THE FERMILAB TEVATRON

RECENT RESULTS AND PLANS FROM DØ AND CDF

Miami 2009, Fort Lauderdale, FL

Chip Brock
Michigan State University
for the CDF and DØ Collaborations

PREDICTION IS HARD, ESPECIALLY...

- "~~640K~~ 1.5 x 10^{31} OUGHT TO BE ENOUGH FOR ANYBODY."

  Bill Gates, 1981

- 1995: USERS WENT "ROGUE"

- ANTICIPATED A "TEV* " UPGRADE:

  ~2 x 10^{32} cm^{-2} s^{-1}

  (or a "TeV33" of 10^{33} cm^{-2} s^{-1})

- EMPHASIS ON $L = \int \mathcal{L} dt$

  1 fb^{-1}

  10 fb^{-1}

  100 fb^{-1}

Future ElectroWeak Physics
at the
Fermilab Tevatron
Report of the *tev_2000* Study Group:
Intermediate Vector Boson Physics

FERMILAB–PUB–96/046

DØ Note 2589 & CDF Note 3177

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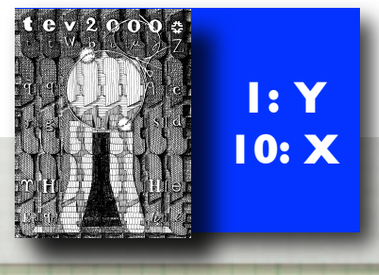
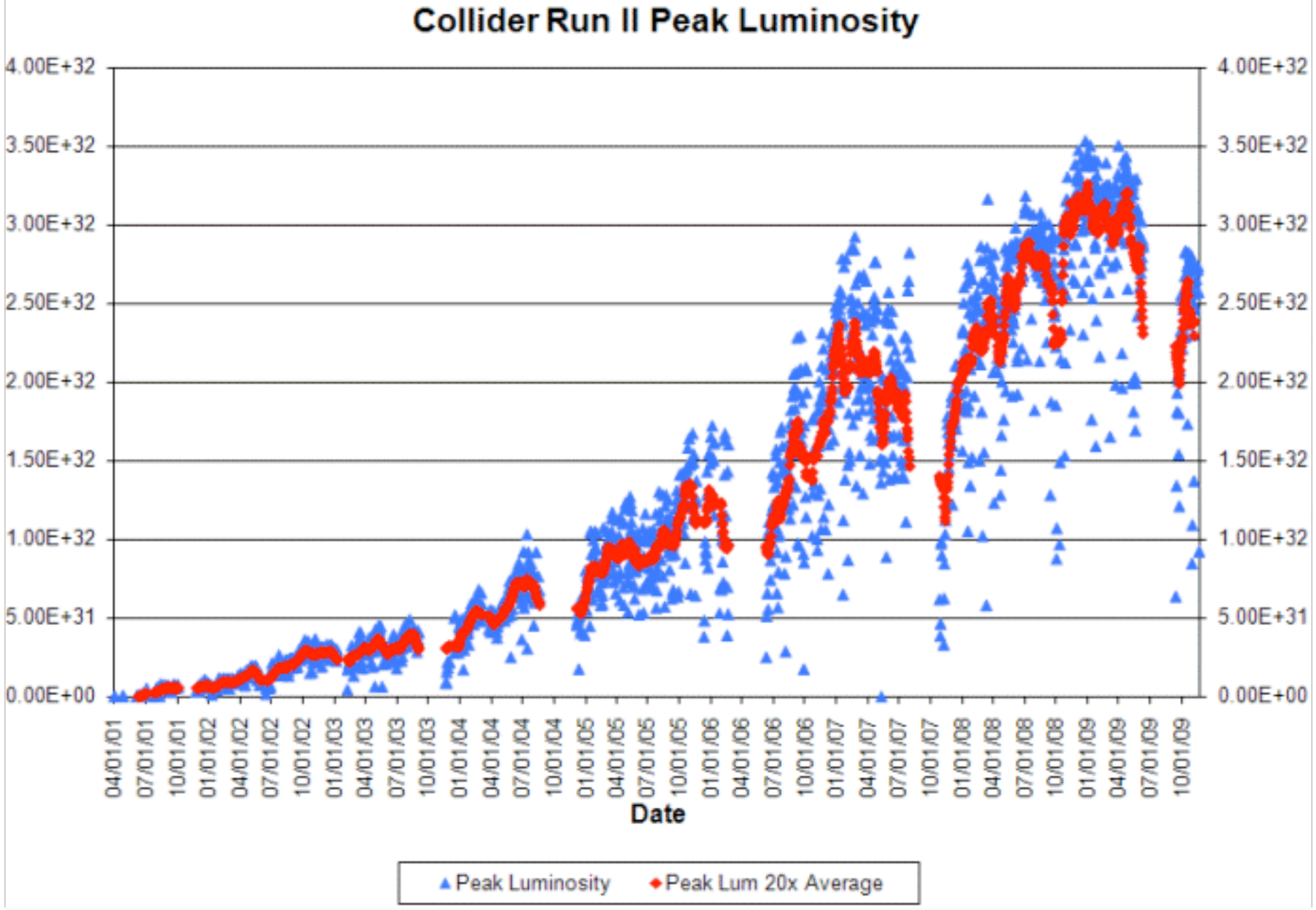
April 1, 1996

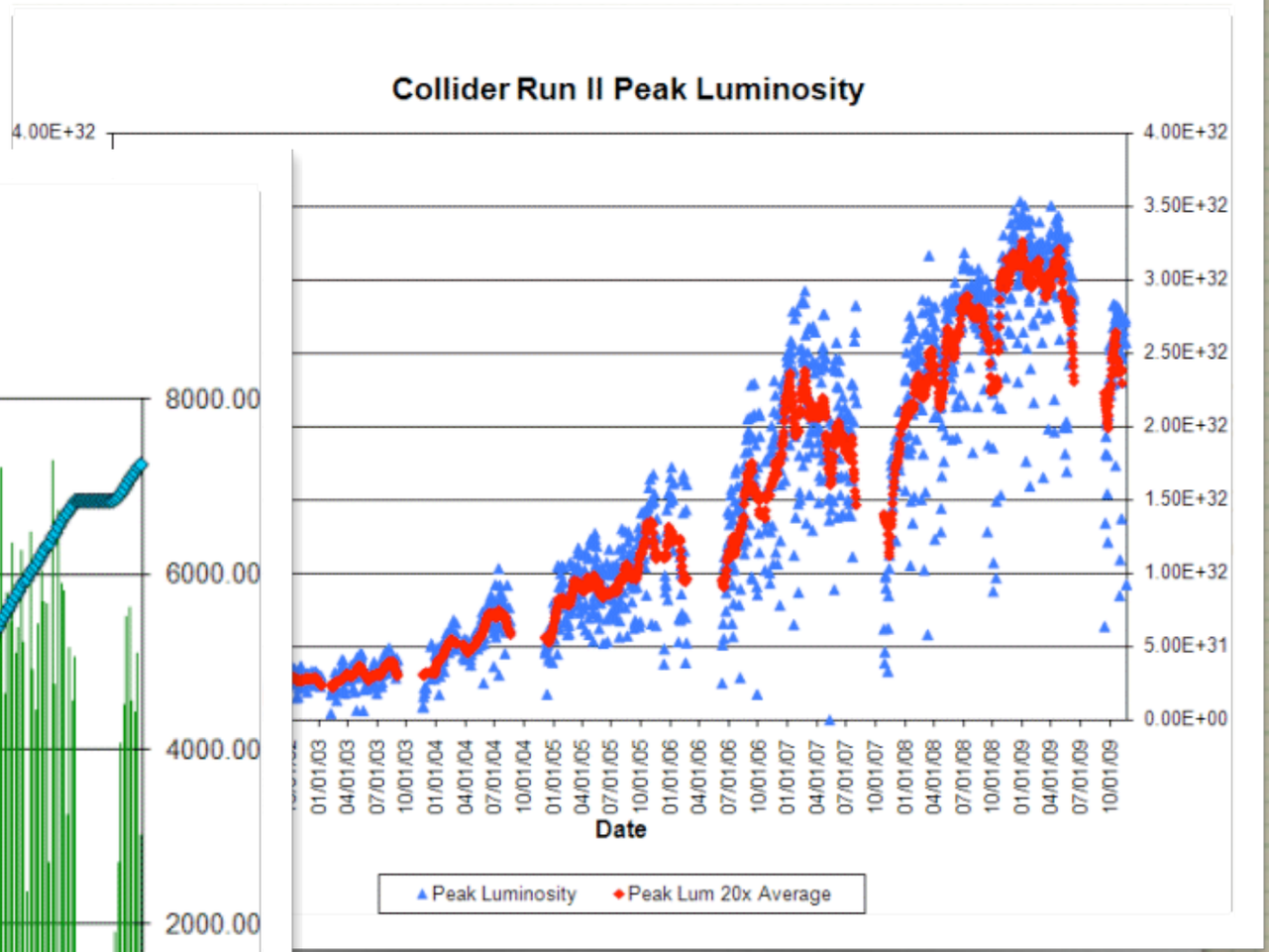


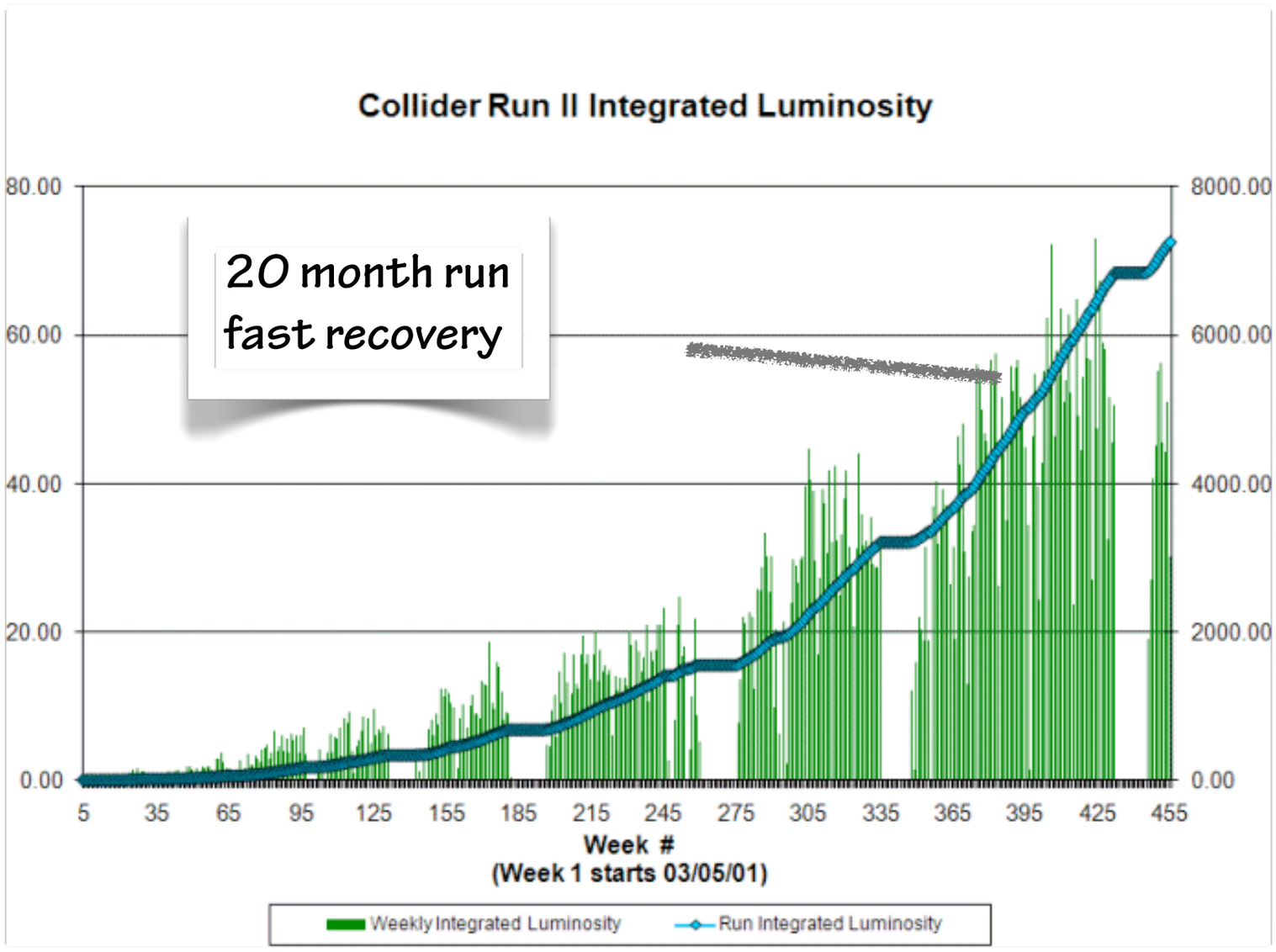


PEAK LUMINOSITY

$3 \times 10^{32}\ cm^{-2}\ s^{-1}$ DURING LAST YEAR

where: <N> ~ 10!

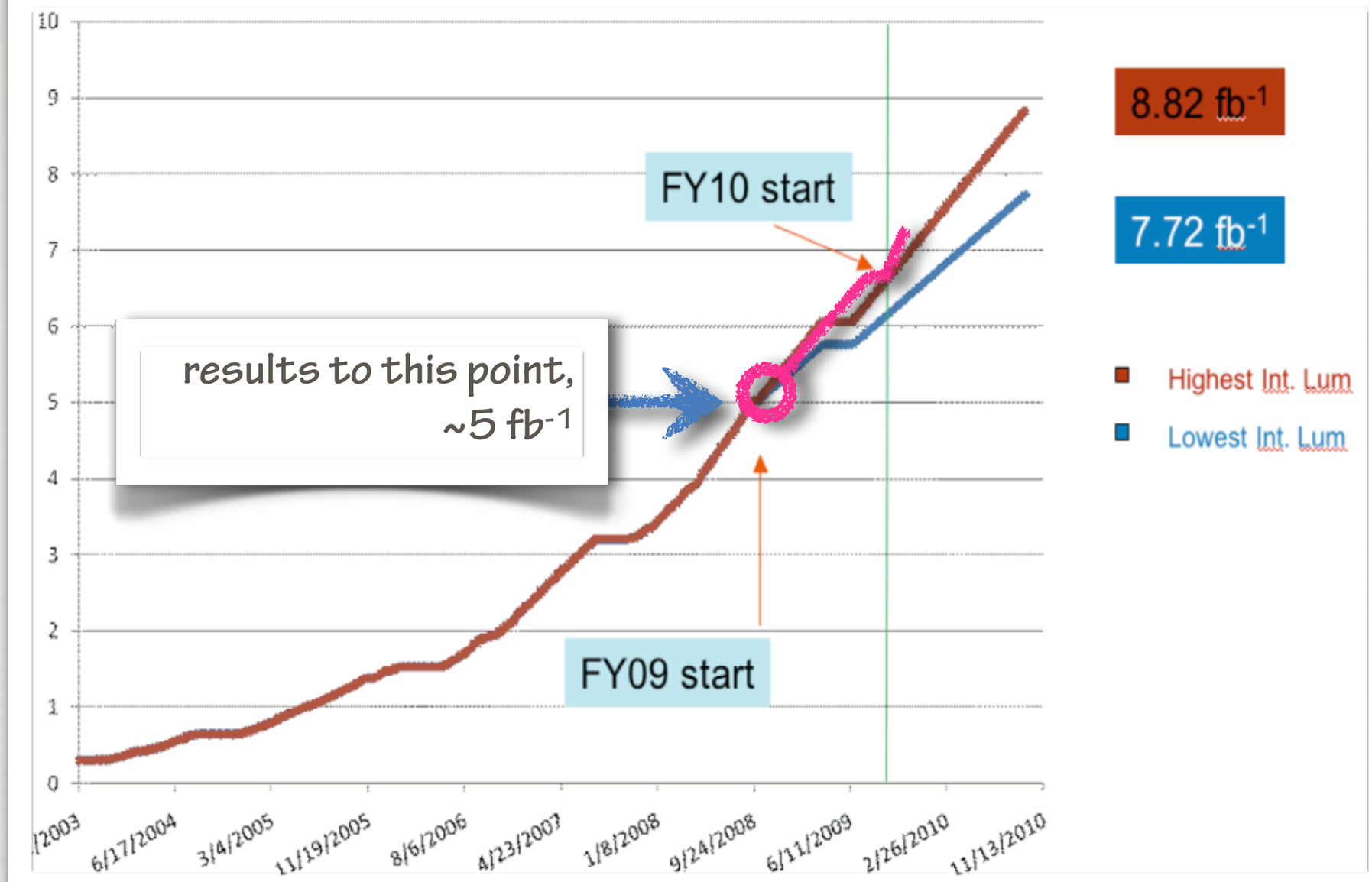




INTEGRATED LUMINOSITY

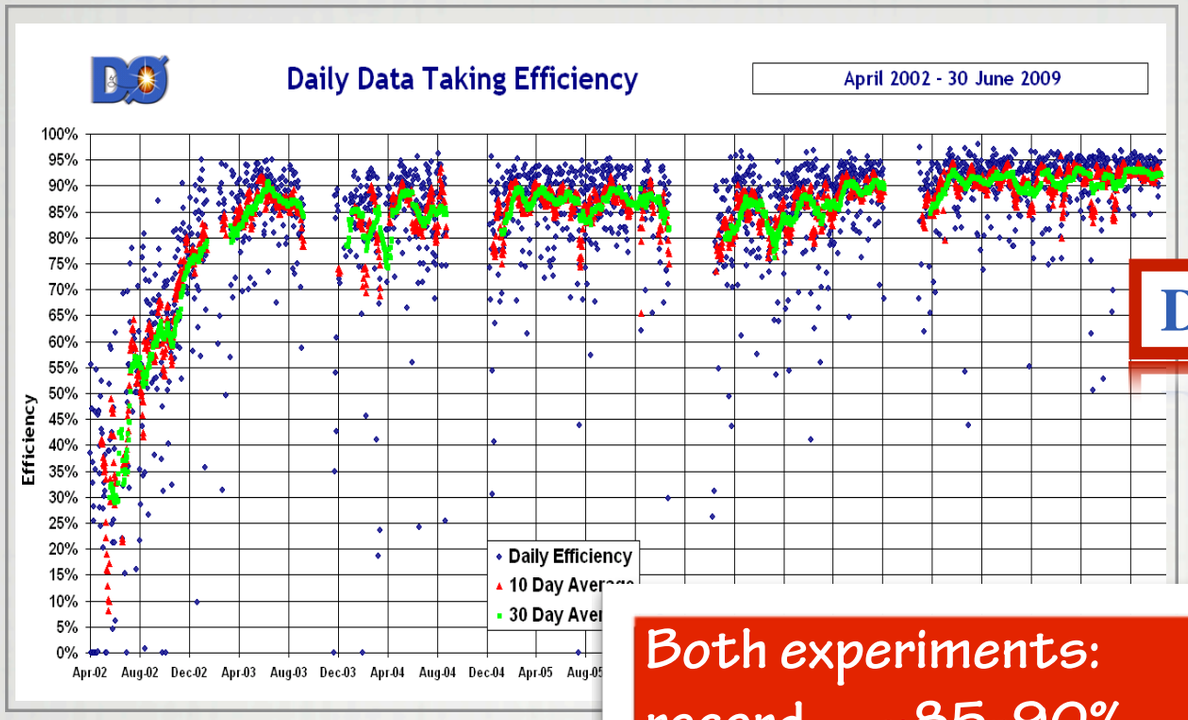
BETTER THAN 200 pb^{-1} PER MONTH

optimizing integrated luminosity is key



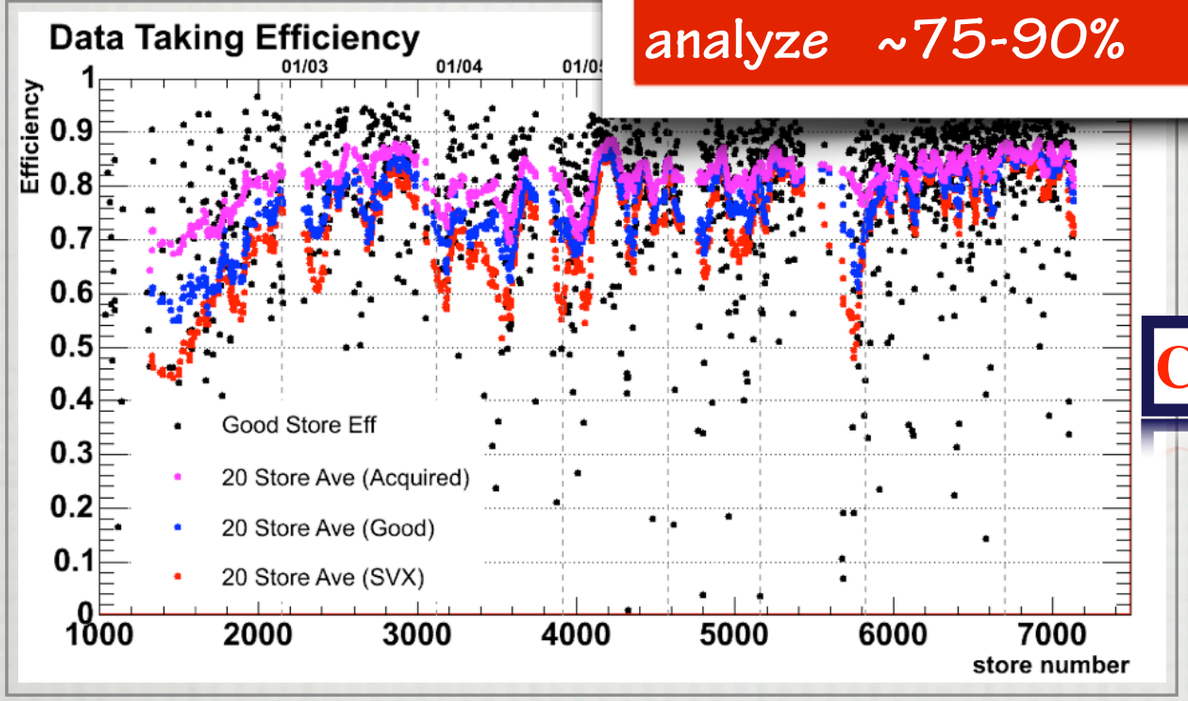
MANAGING EXPECTATIONS

RUN 2 MAY ONLY BE HALF-WAY OVER!



DØ

Both experiments:
record ~85-90%
analyze ~75-90%
of delivered luminosity



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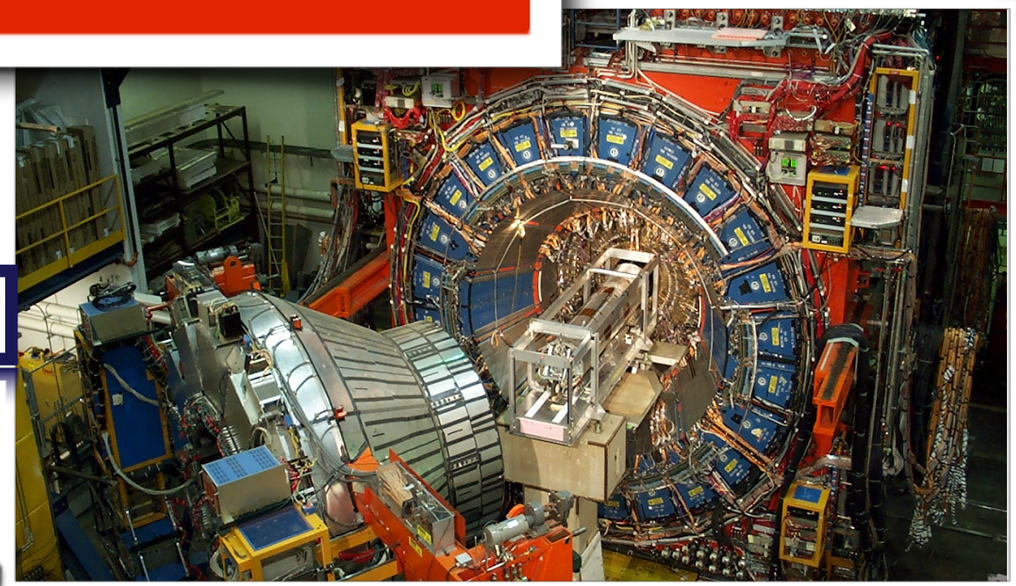


MATURE EXPERIMENTS: COMPETITIVE & COLLABORATIVE

1/2-WAY POINT CONCLUSION 0

THE TEVATRON HADRON COLLIDER IS SURPASSING EXPECTATIONS

A WORD ABOUT TOOLS

- IN 1996 WE BASICALLY HAD TWO TOOLS IN OUR BOX

A WORD ABOUT TOOLS

AD TWO TOOLS IN OUR BOX

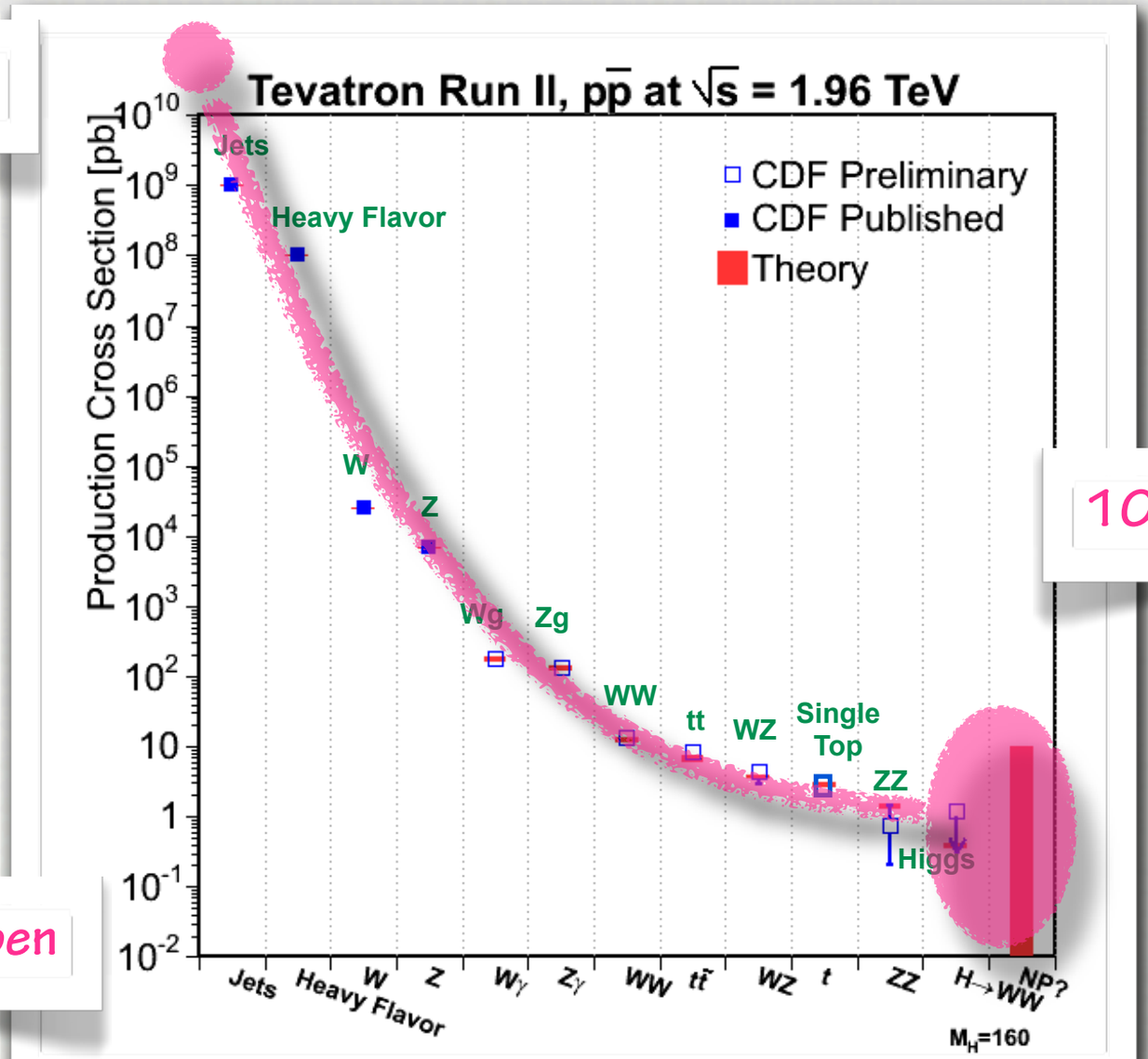
Counting:
signal-background

Templates:
model signal distributions
$\mathcal{L}$ fit to data

Matrix Element:
calculate P for each event
form $\mathcal{L}$ discriminant

NN, BDT:
train a multivariate package
form $\mathcal{L}$ discriminant

something will happen



10 orders of magnitude

and still counting

something might happen

MARCHING WITH THE TEVATRON CROSS SECTION

OUTLINE

- RUNNING CONDITIONS
- NON-HIGGS REVIEW

QCD Physics — high p_T jets, α_s, W/Z + jets

Heavy Flavor Physics — b-baryon discoveries, lifetimes, Bs mixing, CPV,

Electroweak Physics — di-Bosons, M_W, Γ_W

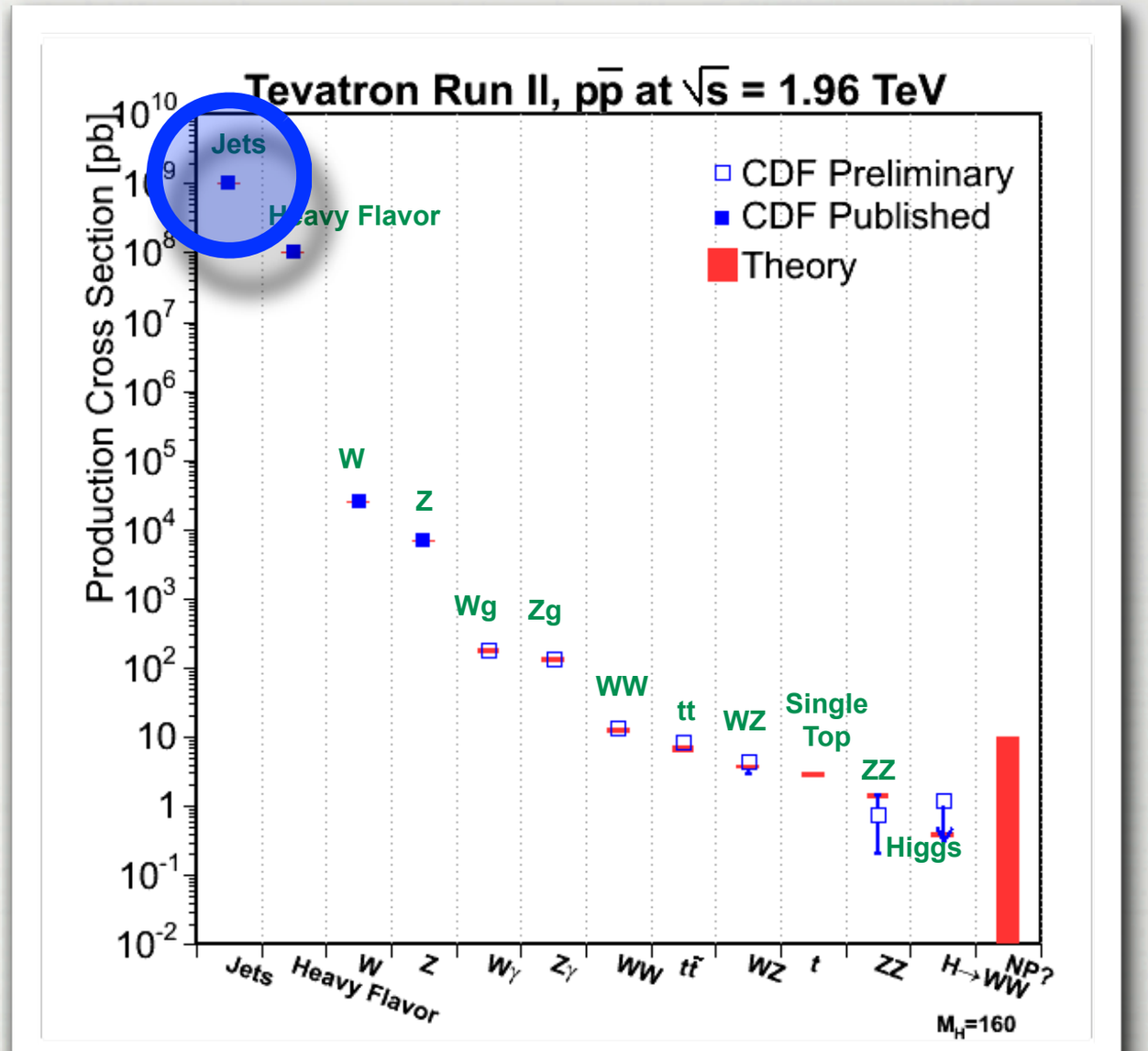
Top Quark Physics — tT: m_t, σ_{tT}, EW; EW t: observation, V_{tb}

Beyond-the -Standard Model Searches — W', Z', SUSY

- CONCENTRATION: ITEMS NEW SINCE MIAMI 2008

QCD PHYSICS

- CLASSIC SEARCH PATH
- PRECISION TEST OF pQCD
- CRUCIAL R&D PLATFORM FOR MODELING

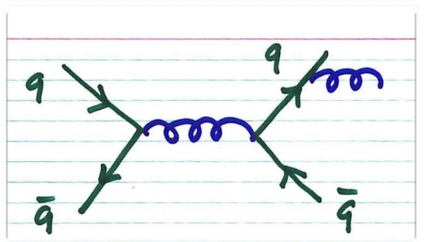


2% of anything happening

QCD

- QCD PROCESSES
  - inclusive jets
  - strong coupling
  - IVBs plus jets
  - IVBs plus b,c
  - dijet angular distns
  - color coherence
  - direct photons
  - double parton scattering
  - k_T studies
  - central, diffractive production
  - UE
  - Drell-Yan
  - Min Bias
  - charge multiplicity

QCD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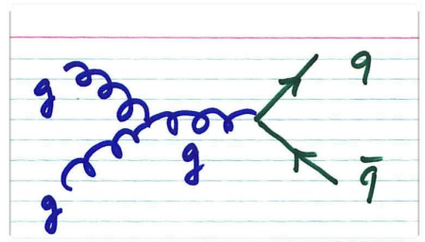
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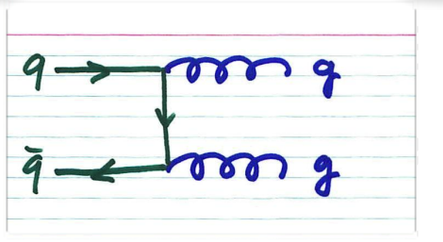
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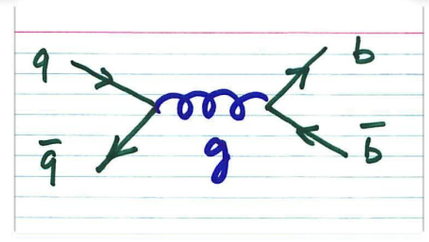
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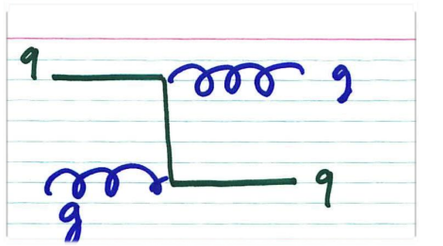
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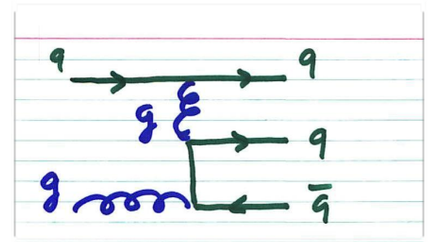
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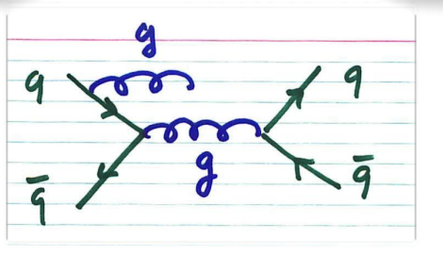
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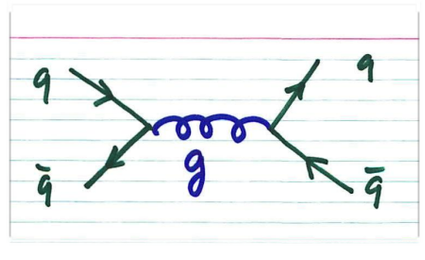
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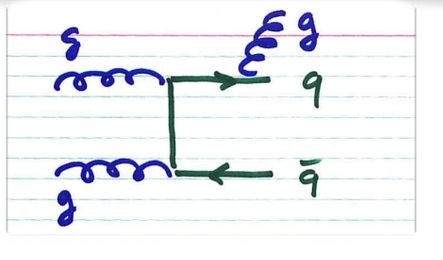
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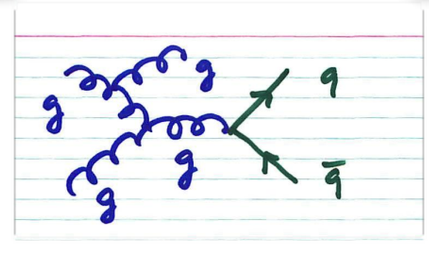
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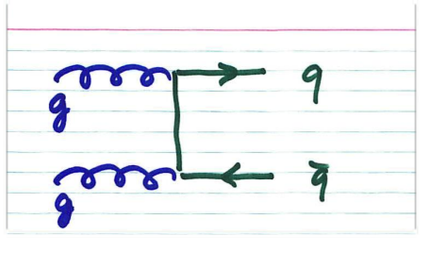
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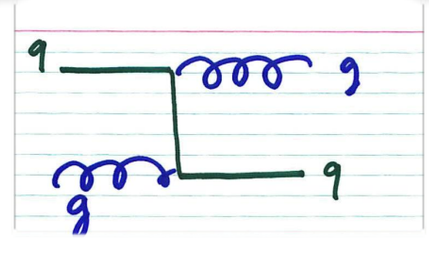
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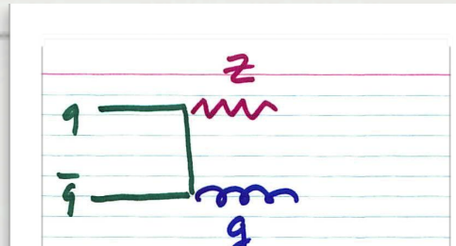
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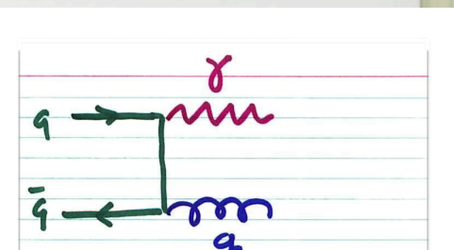
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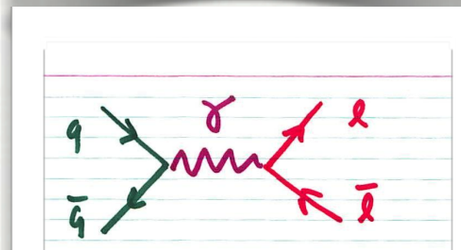
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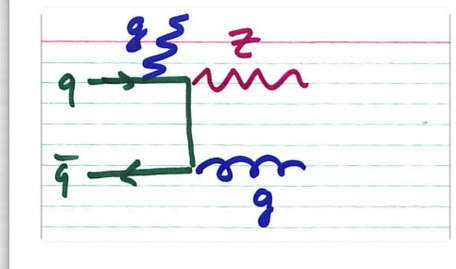
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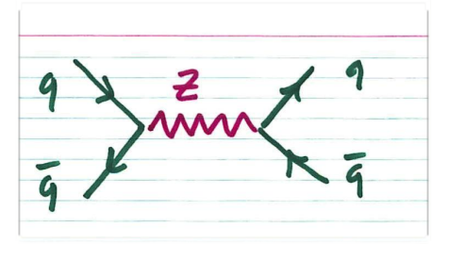
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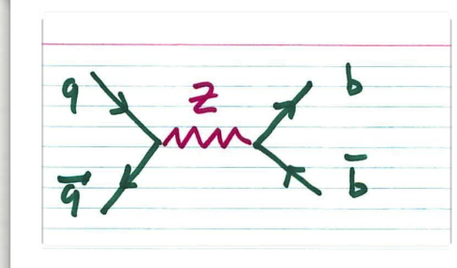
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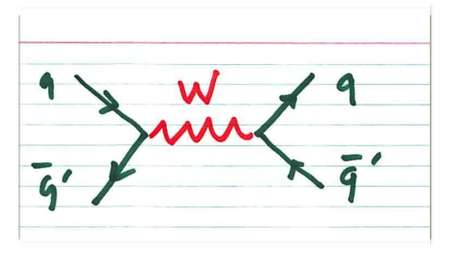
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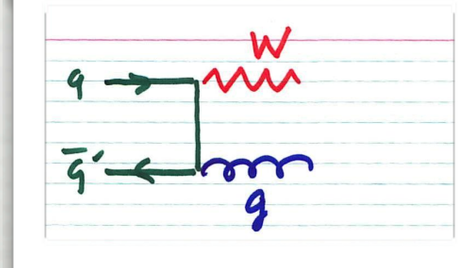
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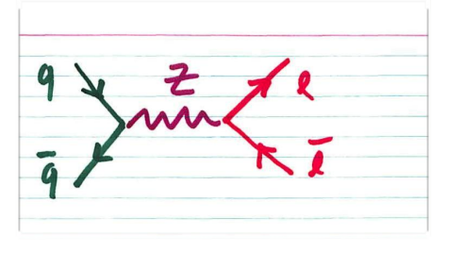
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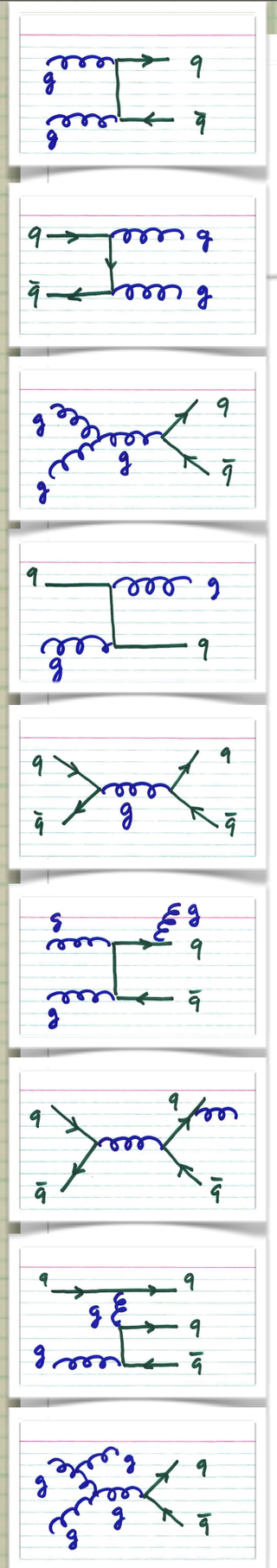
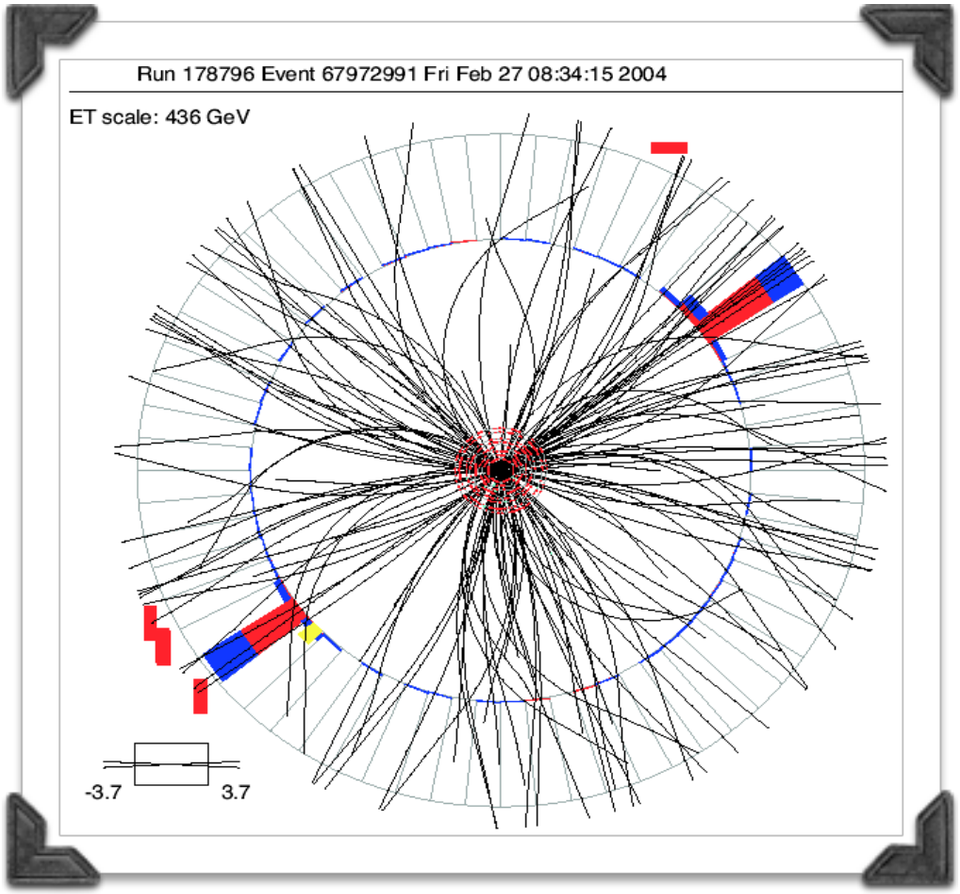


INCLUSIVE JET PRODUCTION



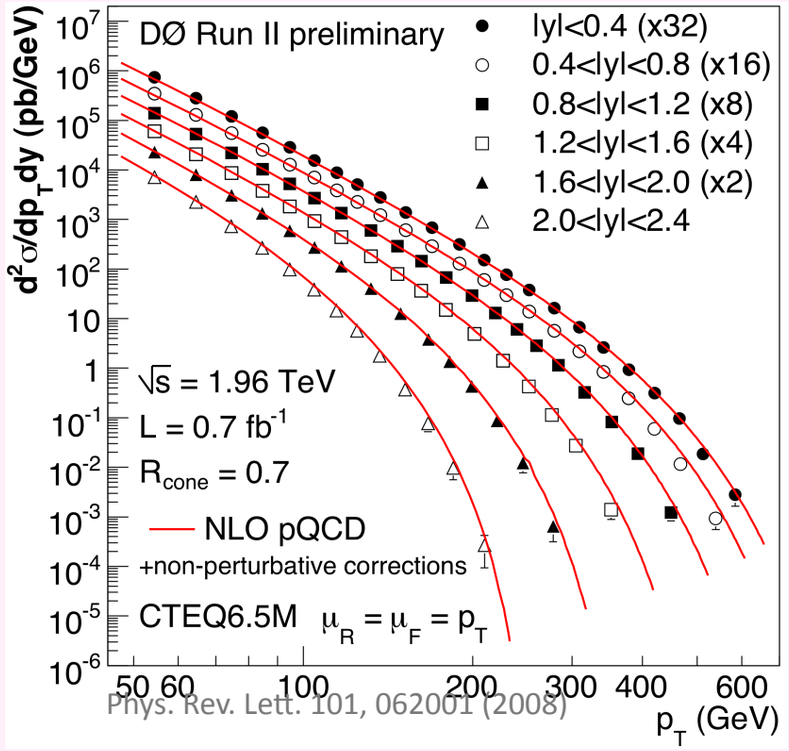
Rutherford Scattering on steroids

$E_T(1) \sim 620$ GeV

$E_T(2) \sim 560$ GeV

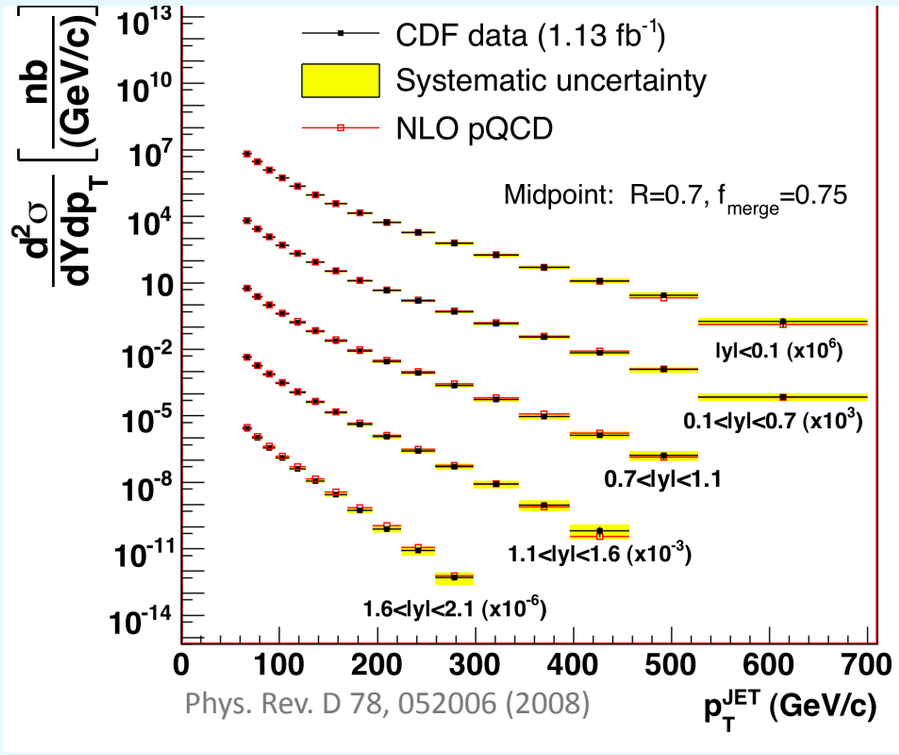
$M_{JJ} \sim 1.2$ TeV

INCLUSIVE JET PRODUCTION



DØ

Phys. Rev. Lett. 101, 062001 (2008)



CDF

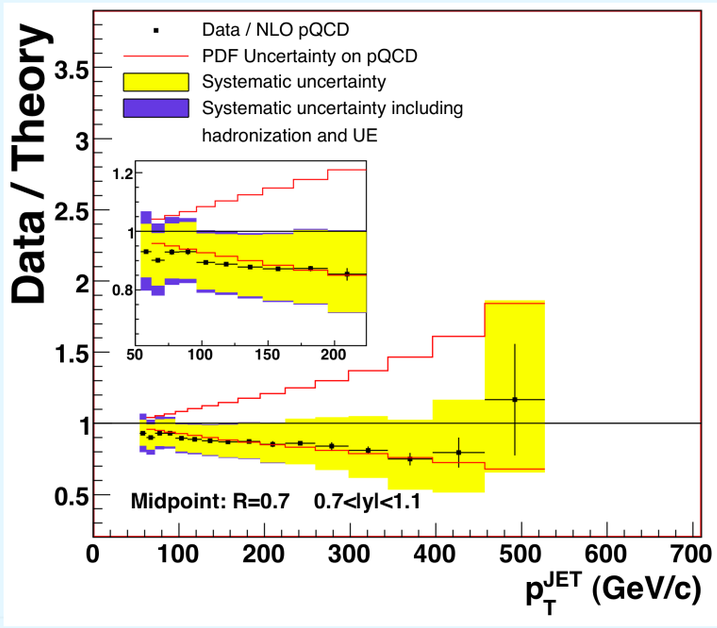
Phys. Rev. D 78, 052006 (2008)

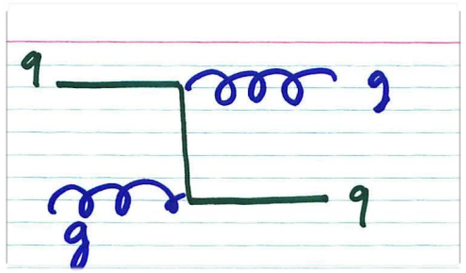
- MULTIPLE ORDERS OF MAGNITUDE

  premium on jet energy scale

  1.2-2% DØ & 2-3% CDF

  ±1% E-scale => ±(5-10)% central

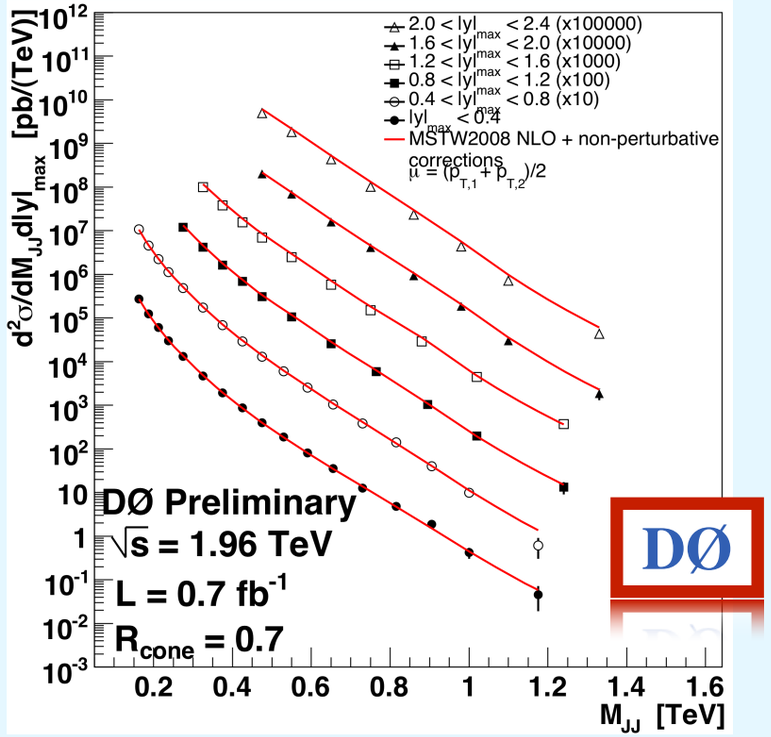




PRECISION QCD: α_S & M_{JJ}

- STRONG COUPLING RUNNING

22/110 inclusive jet s points
50<pT<145 GeV
excluding high-x



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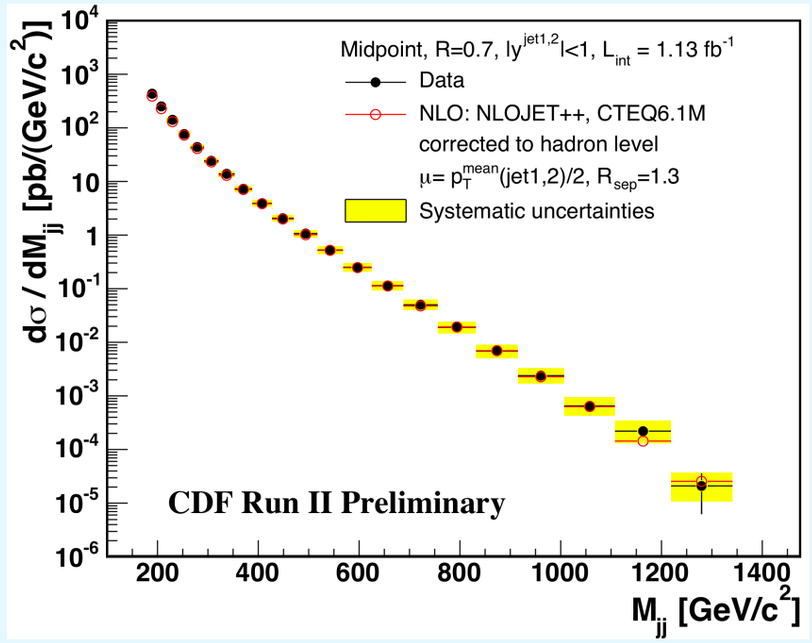

Phys. Rev. D 79, 112002 (2009)

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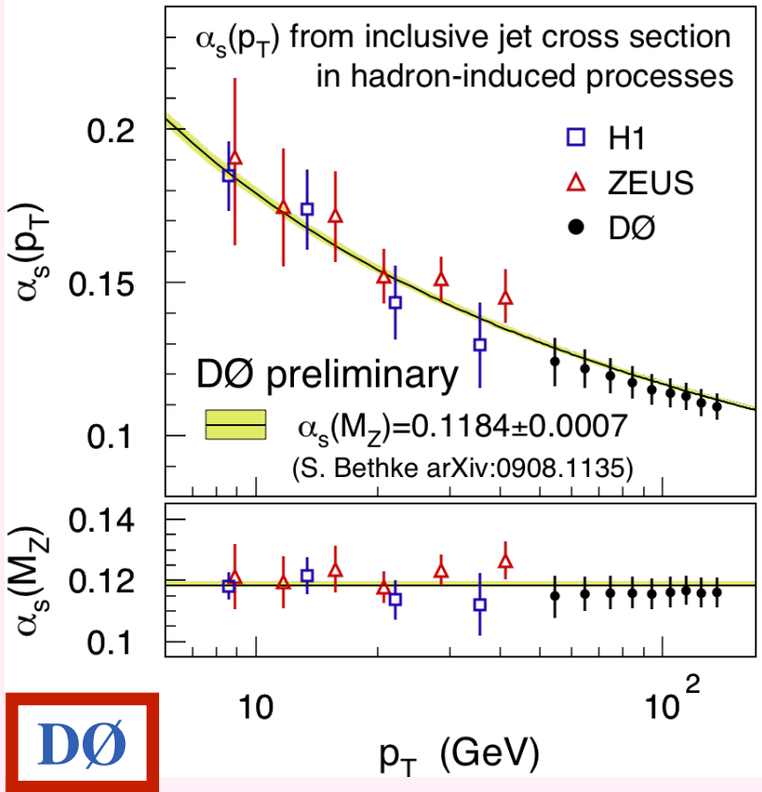
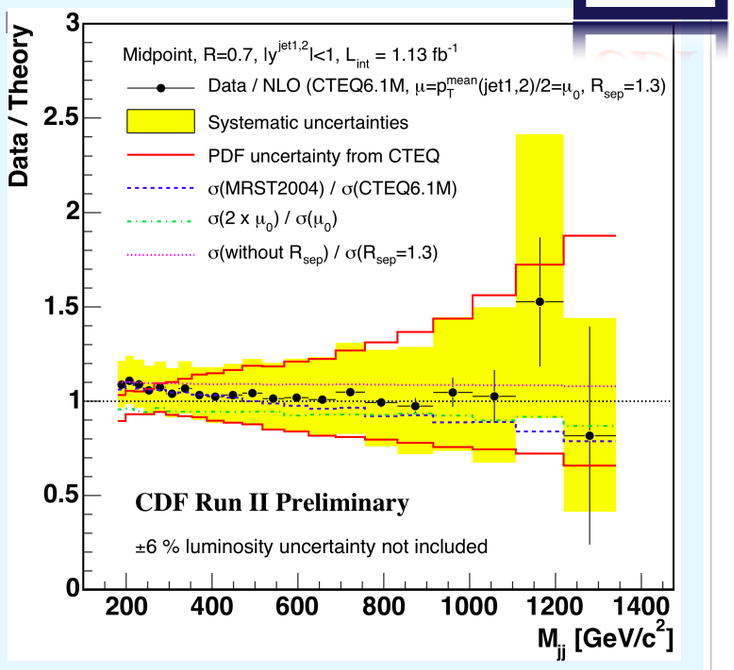
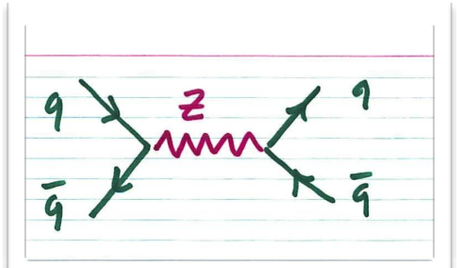


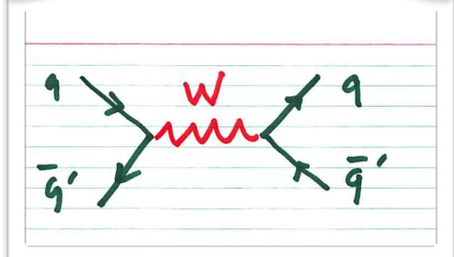
- M_{JJ} NOW STRESSING PDFs
  precision jet physics

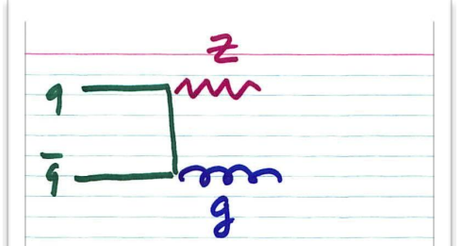


W/Z/γ PLUS JETS PRODUCTION

- A STORIED LABORATORY FOR PQCD STUDIES
  - inherently important
  - crucial backgrounds for discovery channels
  - crucial tune for NL and higher O MC



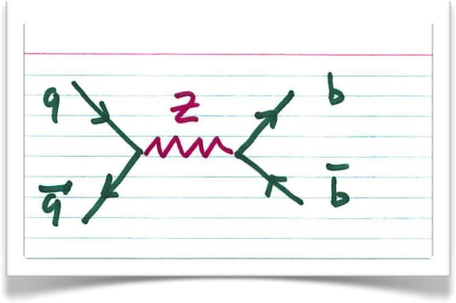


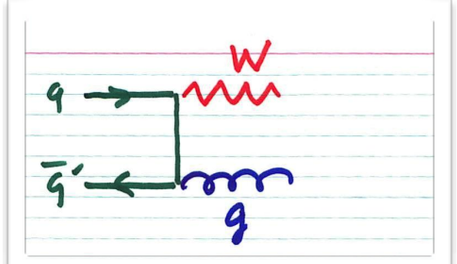


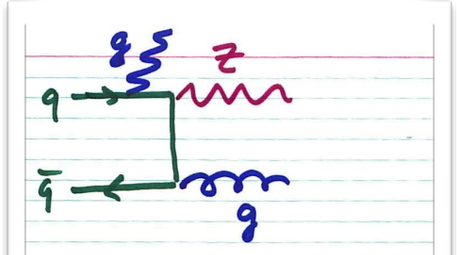
Z/W/γ → inclusive jets, ≥ 1, 2

Z/W/γ → exclusive jets, = 1, 2, 3

Z/W/γ → b, c + jets







W/Z/γ PLUS JETS PRODUCTION

Z + JETS INCLUSIVE

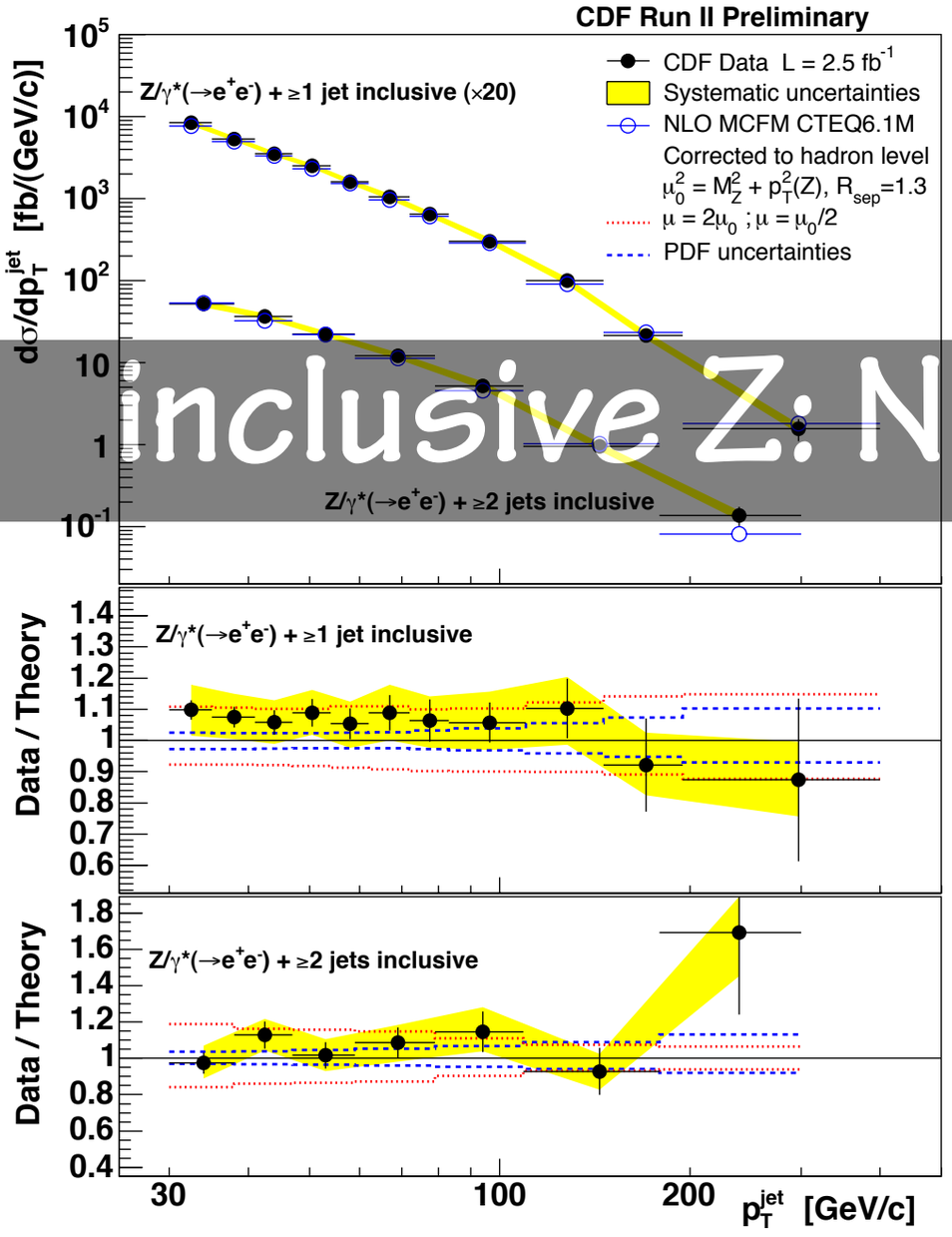
LO 2→ 1, 2, parton shower, Pythia/Herwig

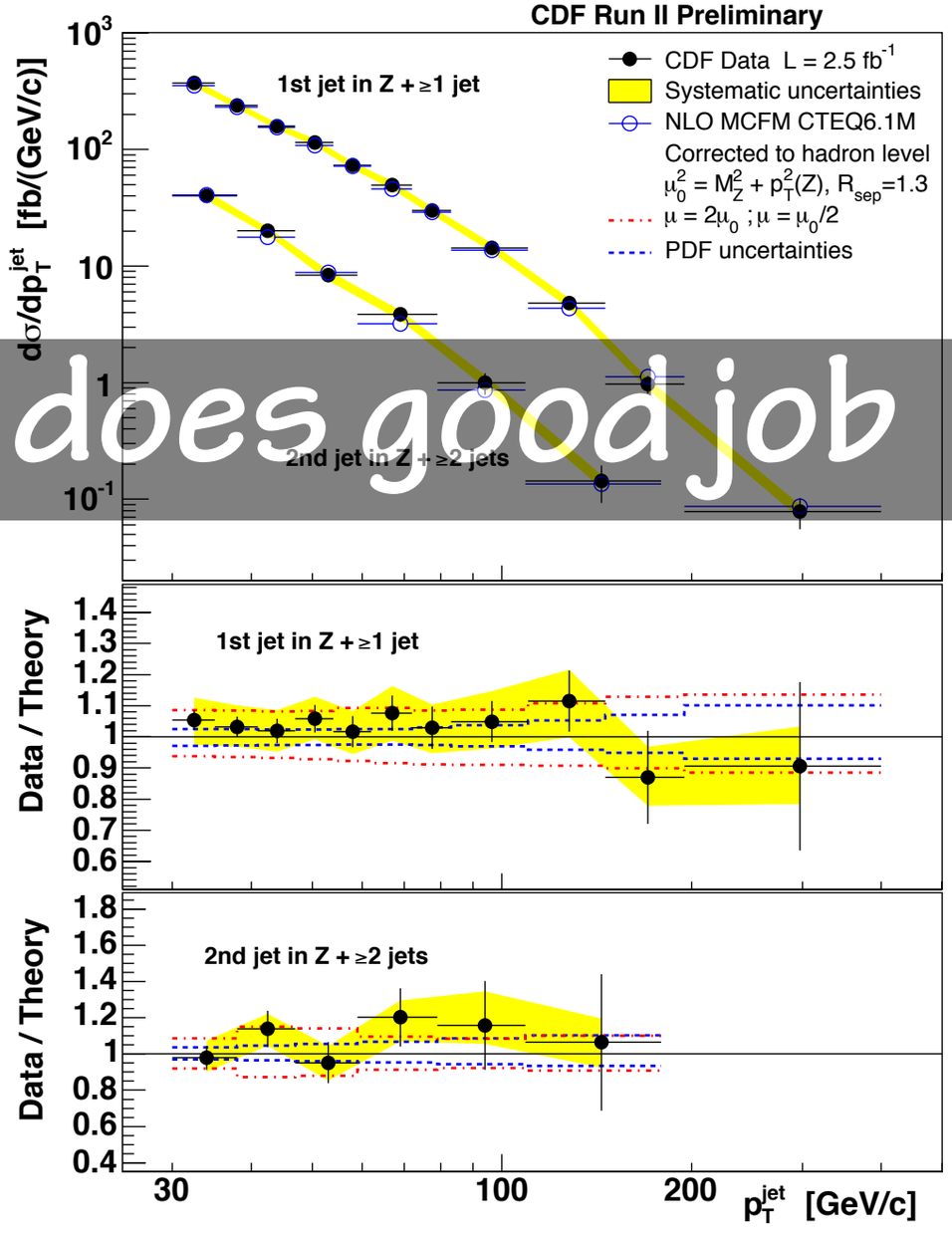
LO 2→ 1-6, ALPGEN, SHERPA

NLO W/Z + 1,2 partons: MCFM; +3 Rocket, Blackhat, SHERPA

clean signature: 12(17)% background, n≥1(3)

systematics ~8-13%



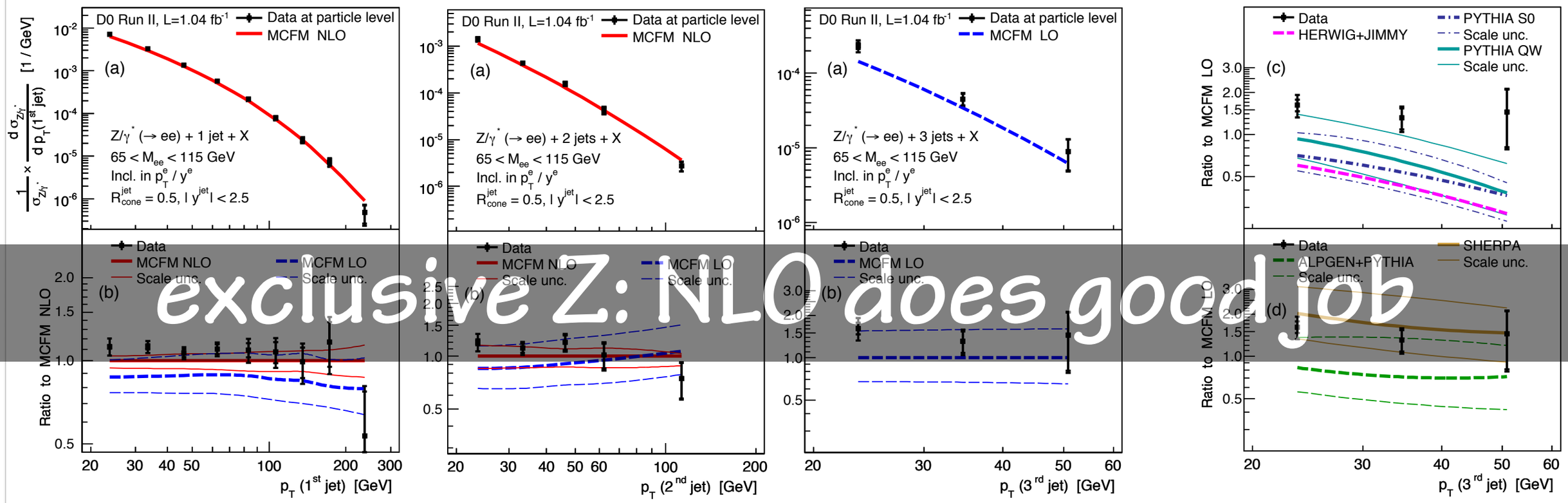


inclusive Z: NLO does good job

PRL 100, 102001 (2008)

W/Z/γ PLUS JETS PRODUCTION

Z PLUS JETS: EXCLUSIVE



= 1 jet = 2 jets = 3 jets

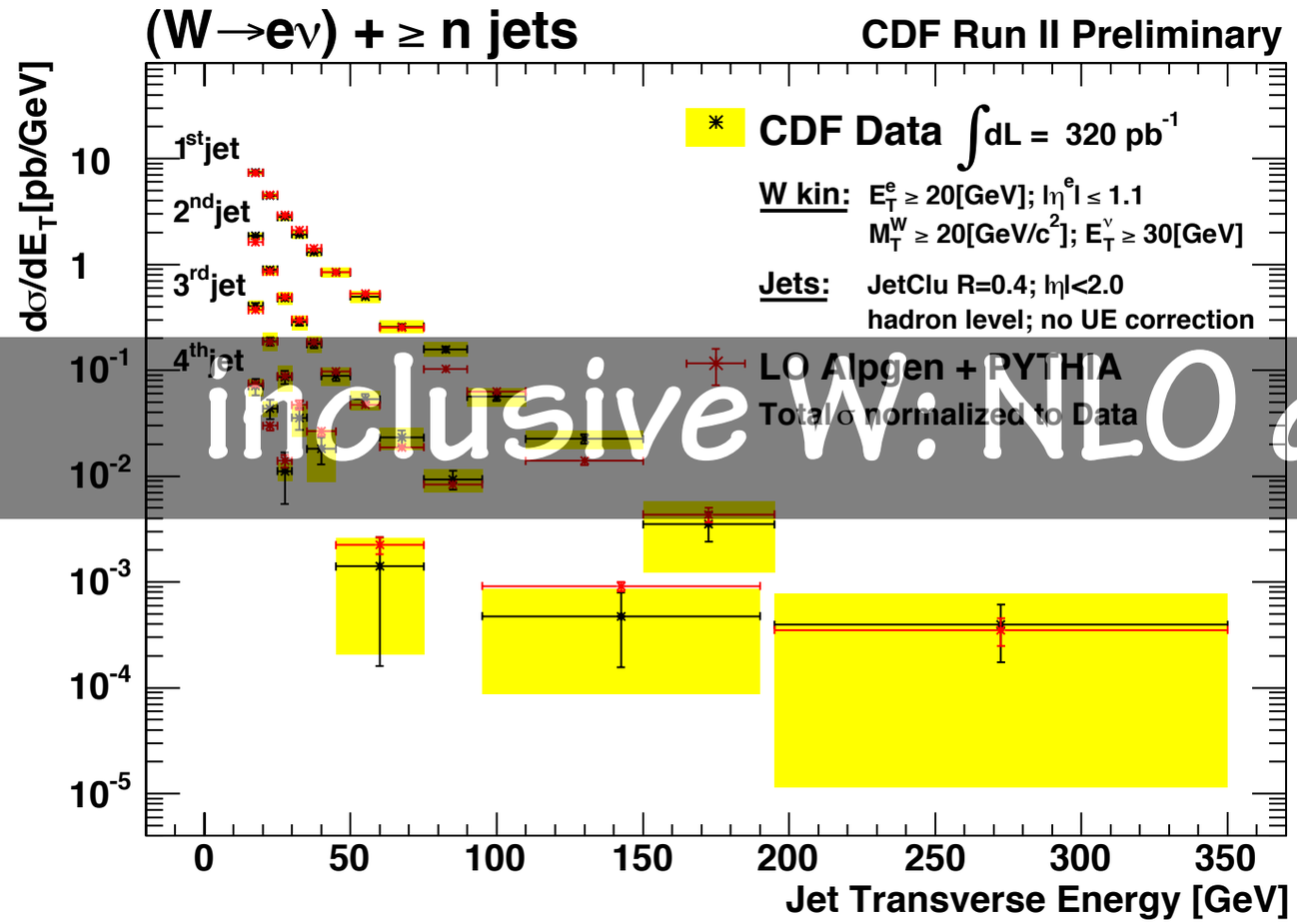
parton shower-based generators disagree in both shape and normalization
Matrix Element plus showering better
(also μμ)

PLB 678, 45 (2009)

exclusive Z: NLO does good job

W/Z/γ PLUS JETS PRODUCTION

W + JETS



systematics: low pT, jet energy scale
high pT, background

a tough measurement by CDF

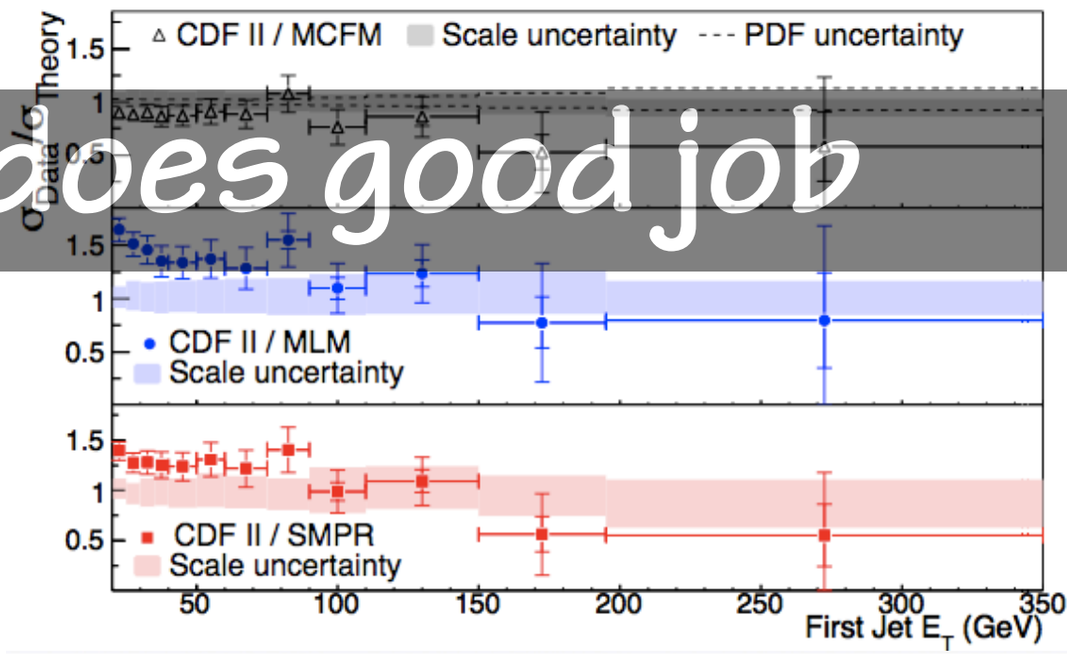
phase space is carefully limited:

$E_T(e) > 20$ GeV

$|\eta(e)| < 1.1$

$E_T(\nu) > 30$ GeV

$m_T(W) > 20$ GeV



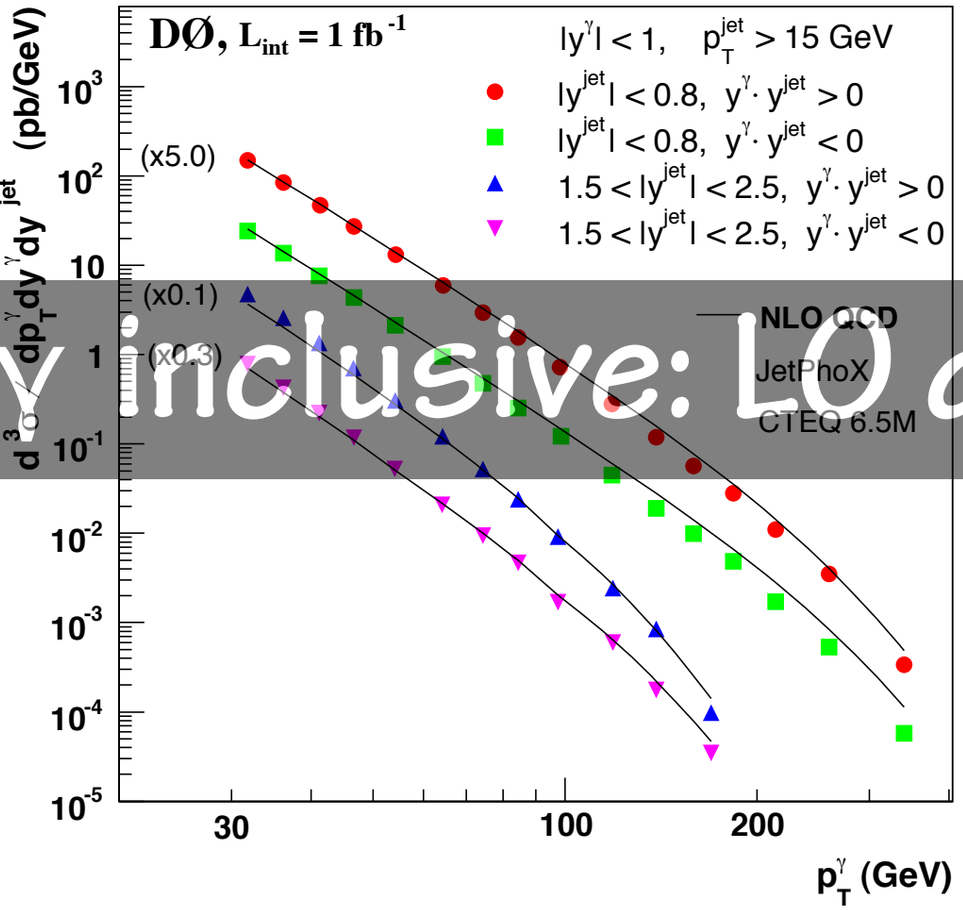
PRD 77, 011108(R) (2008)

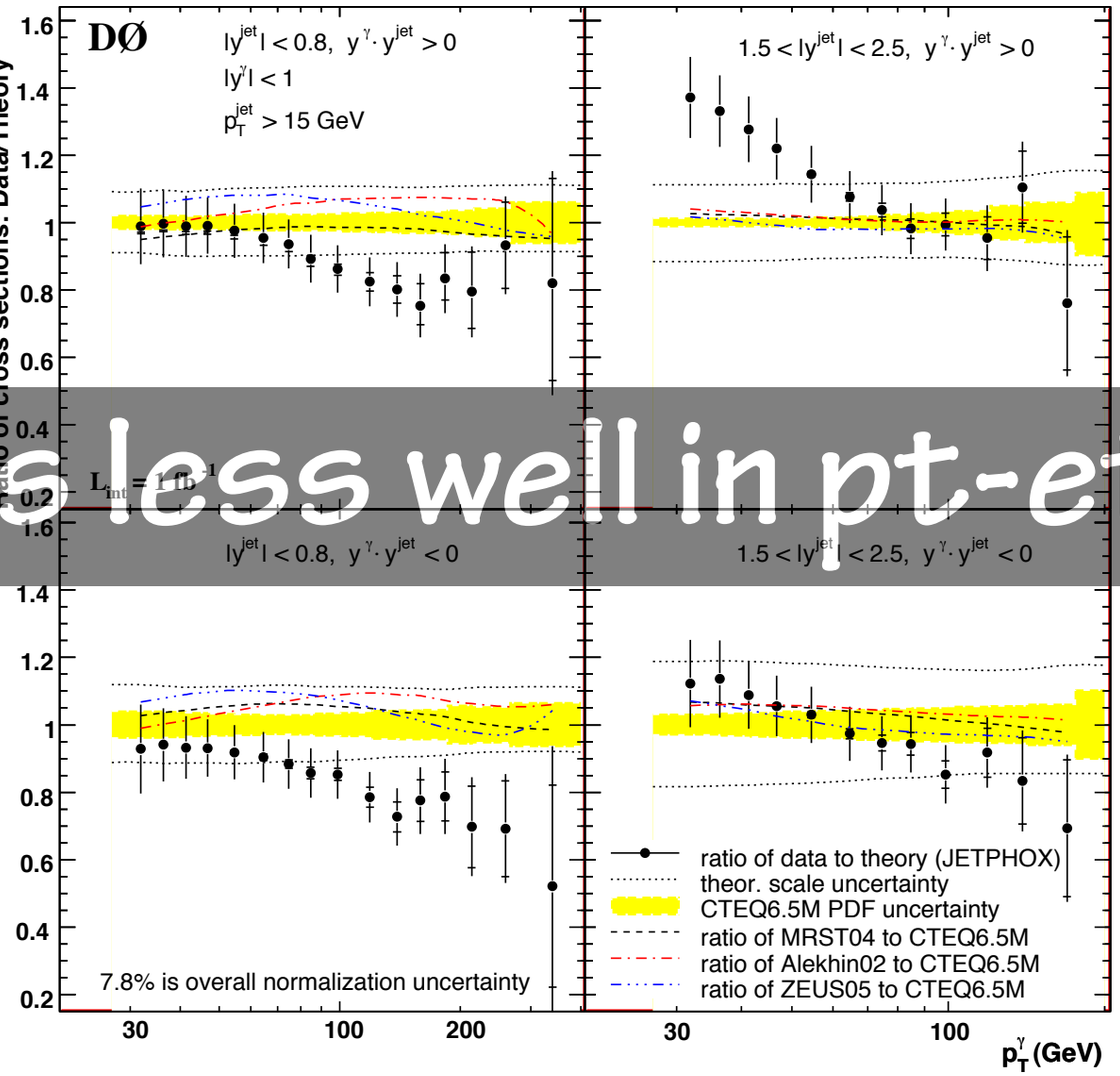
Again, NLO works well.

inclusive W: NLO does good job

W/Z/γ PLUS JETS PRODUCTION

- γ + JETS





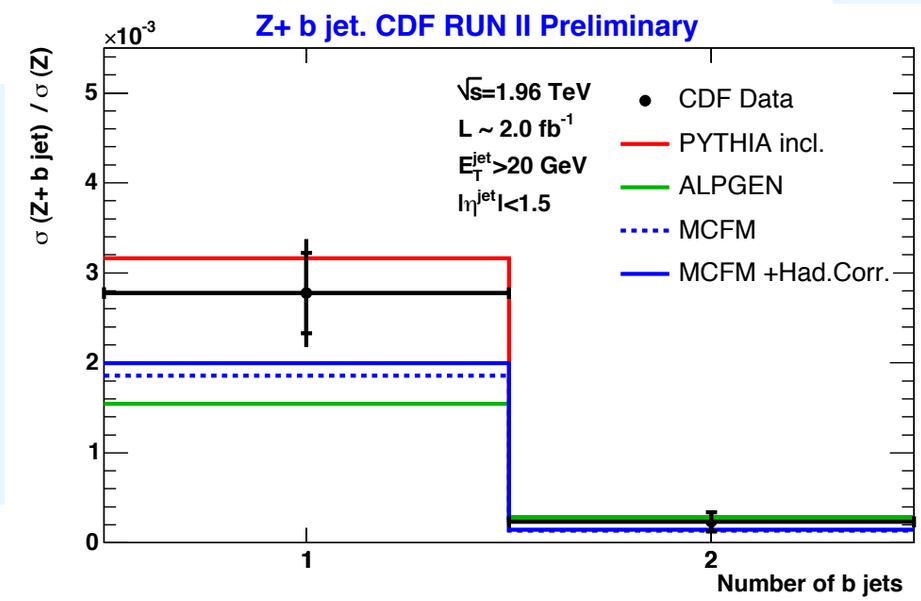
many graphs and significant backgrounds

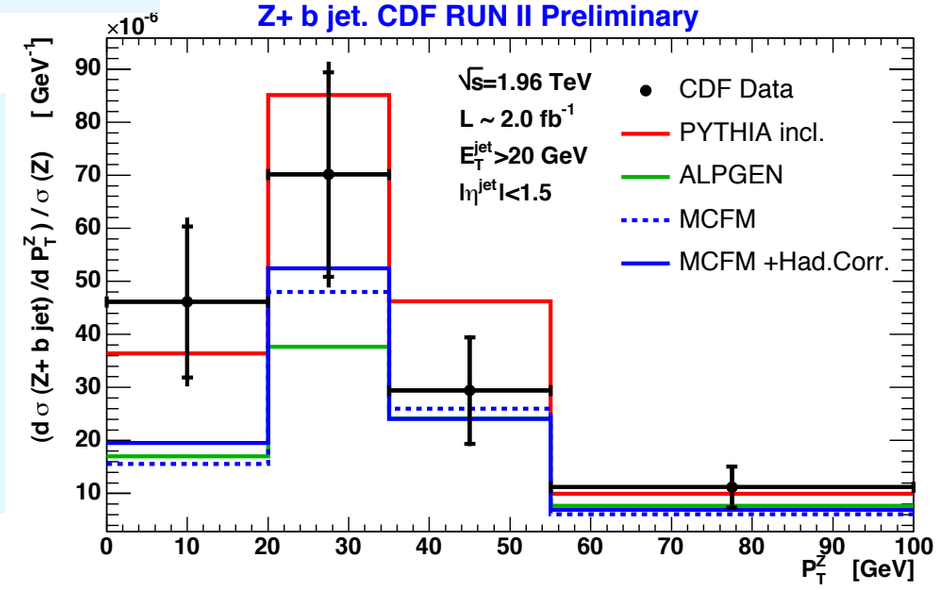
γ inclusive: LO does less well in pt.-eta

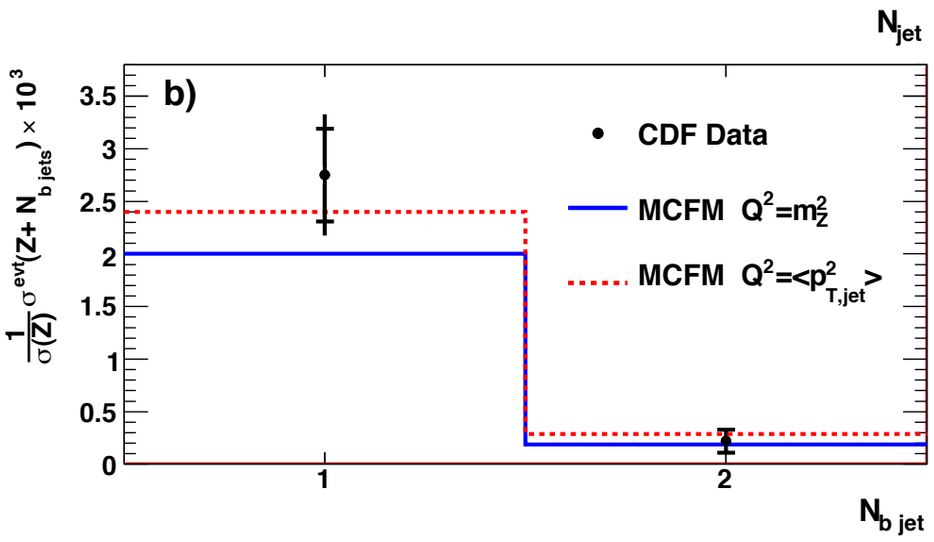
W/Z/γ PLUS JETS PRODUCTION

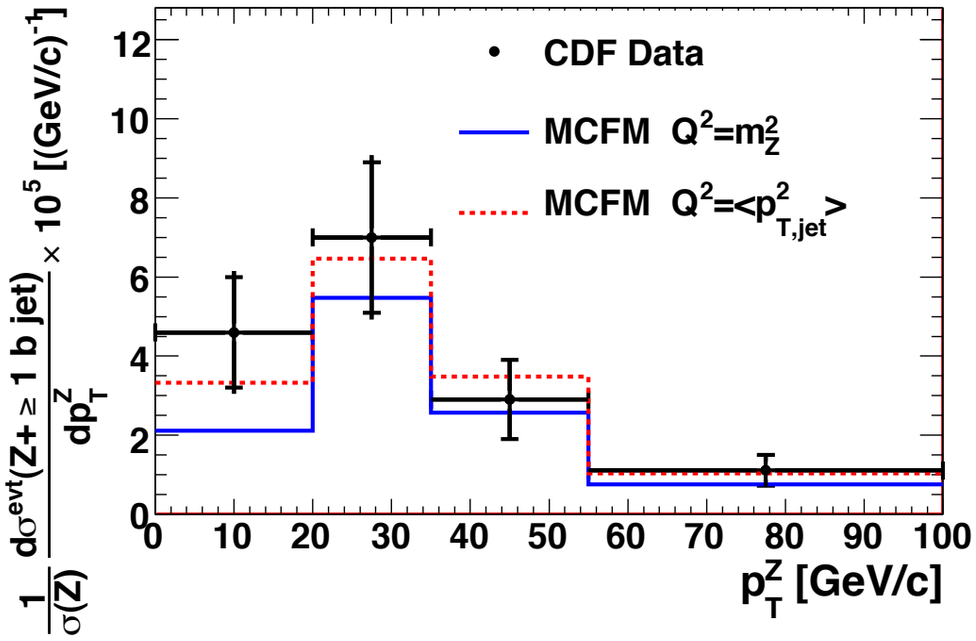
Z/W/γ → b + jets

$$Q^2(MCFM) = M_Z^2 + p_T^2$$









1/2-WAY POINT CONCLUSION 1

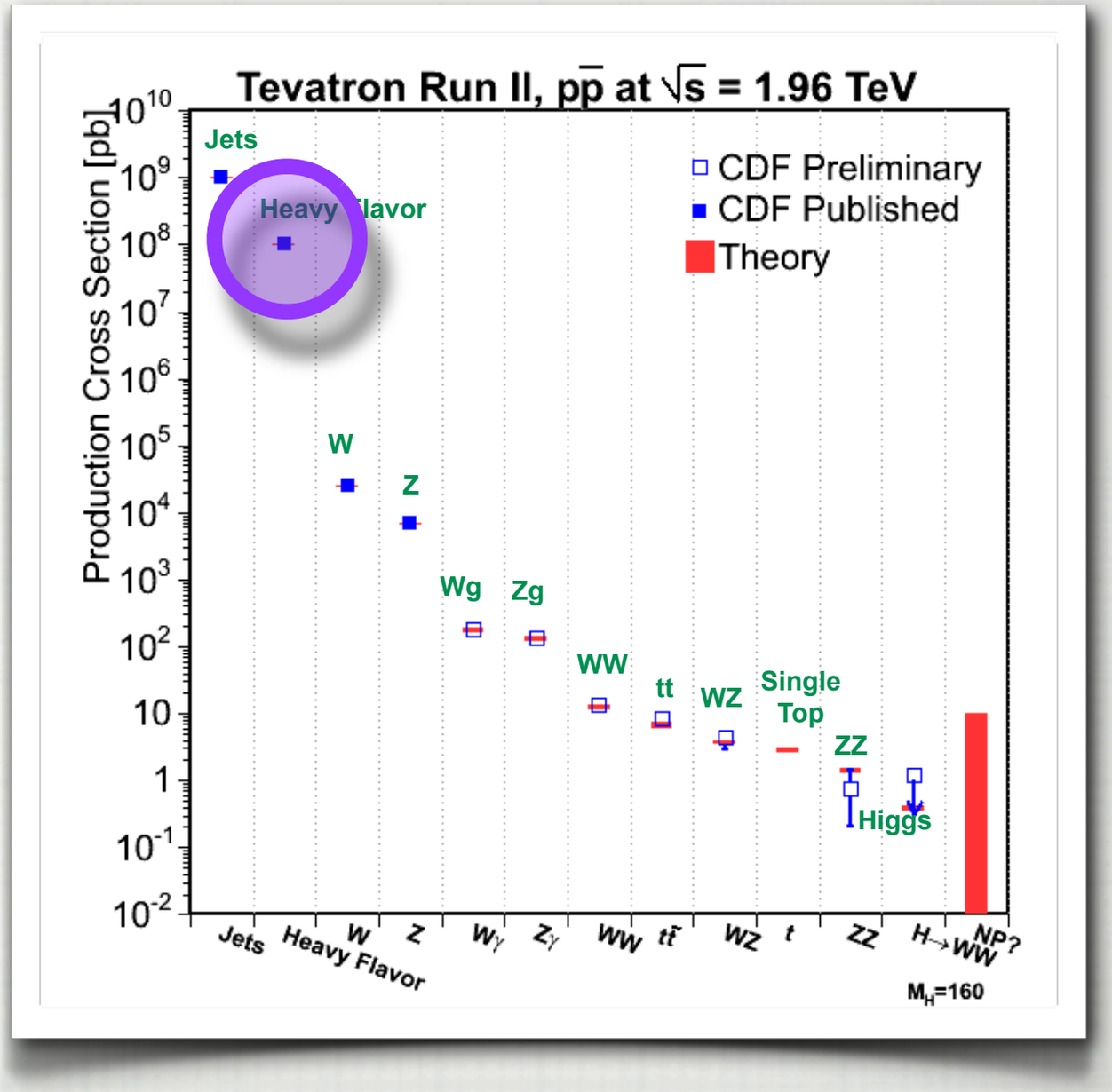
HADRON COLLIDER QCD PHYSICS

IS NOW A PRECISION SCIENCE

HEAVY FLAVOR PHYSICS

EXOTIC B BARYONS
est. 2006

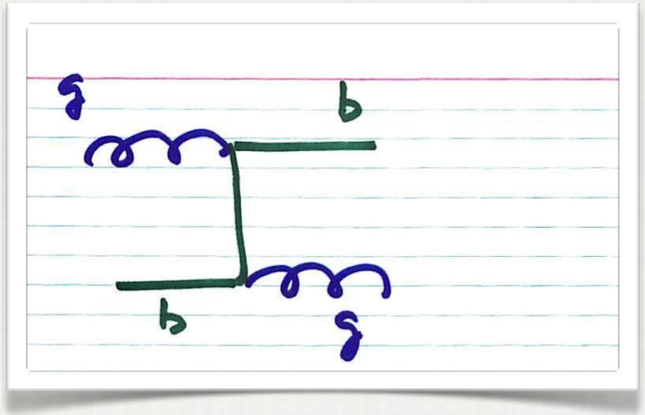
- SEARCHES FOR NEW STATES
- HIGH-STATISTICS TESTS OF CPV
- PRECISION PARAMETERS

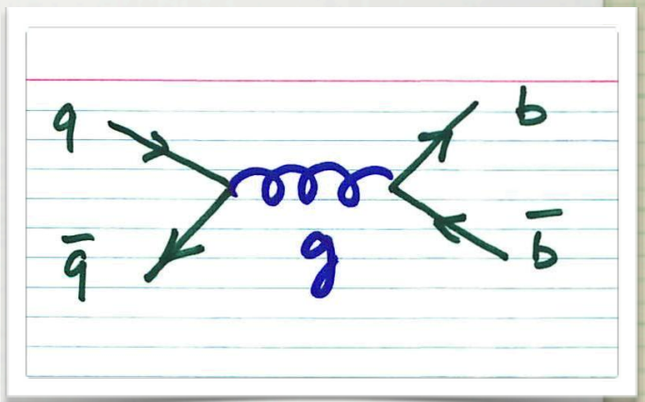


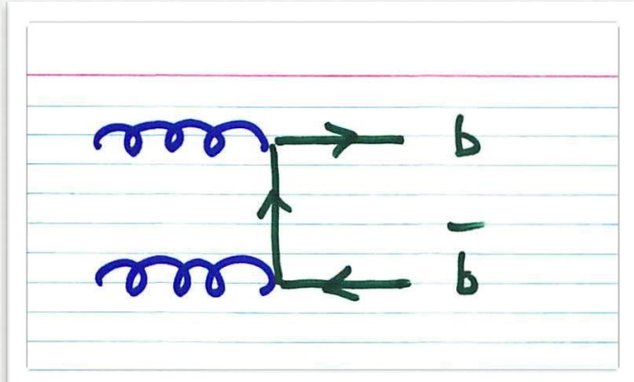
2% of anything happening

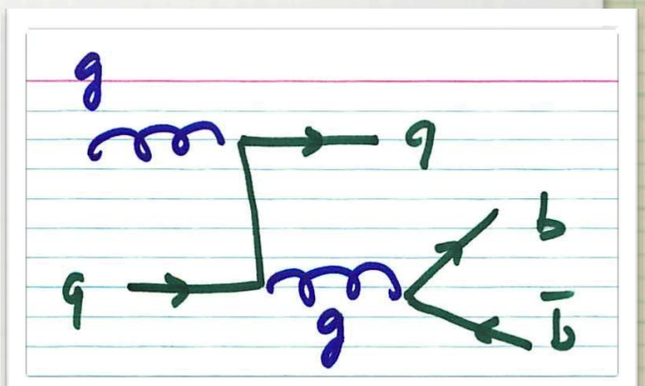
HEAVY FLAVOR

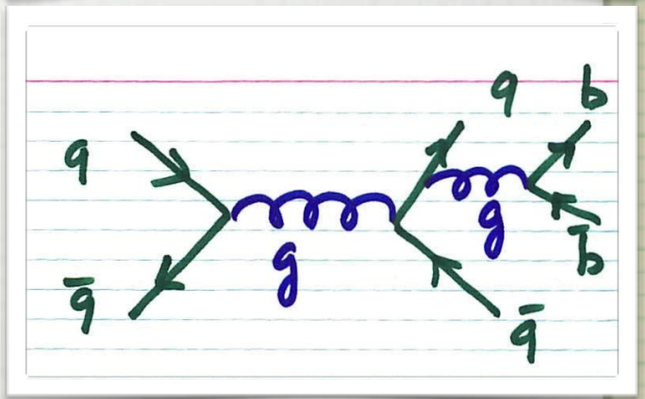
- PROCESSES
  - b-Baryon discoveries
  - b-Baryon lifetimes
  - b-Baryon production rates
  - excited L=1 B mesons
  - charmonium-like states
  - Boxes and Penguins!
  - FCNC
  - CPV







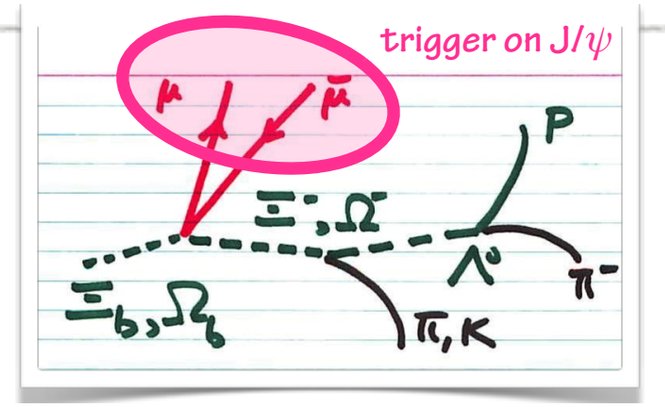




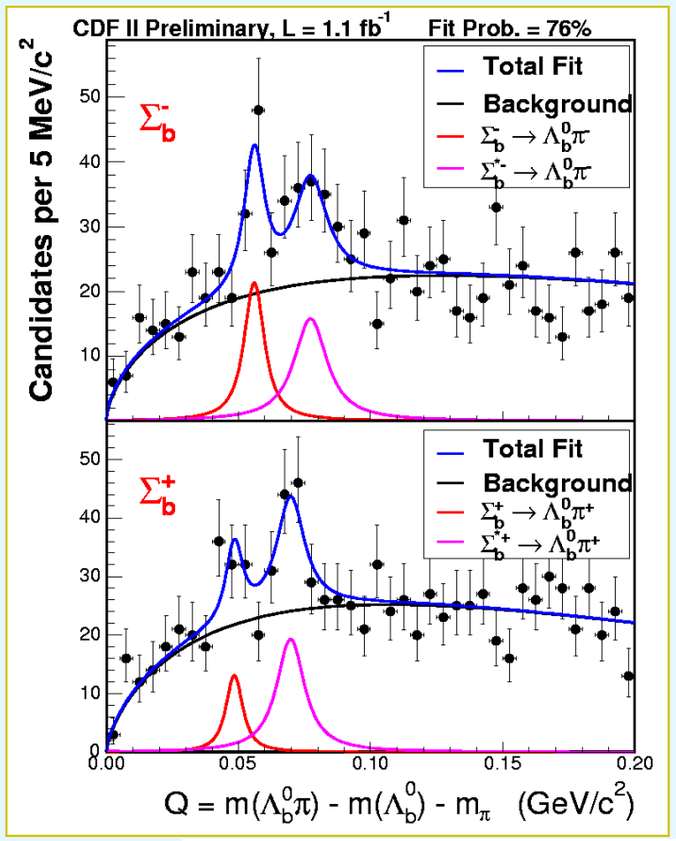
B-BARYONS

- STRICTLY A FERMILAB TARGET

$$\Sigma_b^{(*)\pm} \rightarrow \Lambda_b \pi^{\pm},$$
$$\Lambda_b \rightarrow \Lambda_c \pi^{\pm}, \Lambda_c \rightarrow p K \pi$$



CDF

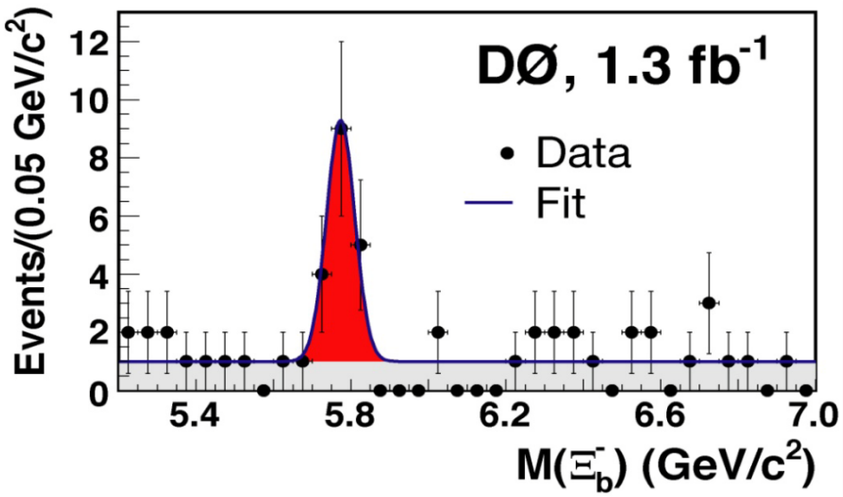


Σ_b (bdd,u)

State	Yield	Q or $\Delta_{\Sigma_b^*}$ (MeV/c^2)	Mass (MeV/c^2)
Σ_b^+	32^{+13+5}_{-12-3}	$Q_{\Sigma_b^+} = 48.5^{+2.0+0.2}_{-2.2-0.3}$	$5807.8^{+2.0}_{-2.2} \pm 1.7$
Σ_b^-	59^{+15+9}_{-14-4}	$Q_{\Sigma_b^-} = 55.9 \pm 1.0 \pm 0.2$	$5815.2 \pm 1.0 \pm 1.7$
Σ_b^{*+}	77^{+17+10}_{-16-6}	$\Delta_{\Sigma_b^*} = 21.2^{+2.0+0.4}_{-1.9-0.3}$	$5829.0^{+1.6+1.7}_{-1.8-1.8}$
Σ_b^{*-}	69^{+18+16}_{-17-5}		$5836.4 \pm 2.0^{+1.8}_{-1.7}$

Ξ_b (bsd,s)

DØ

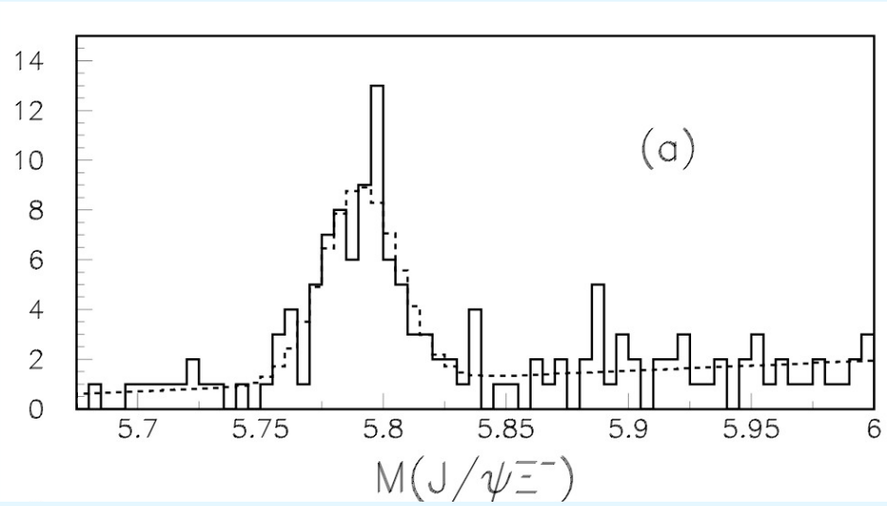


Mass: 5774 ± 11(stat) MeV/c^2

both significance > 5σ

Mass: $5790.9 \pm 2.6 \pm 0.8$ MeV/c^2

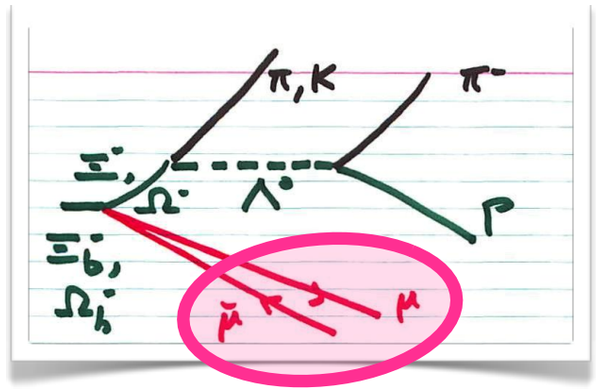
CDF



B-BARYONS

- STRICTLY A FERMILAB TARGET

Ω_b (bss)

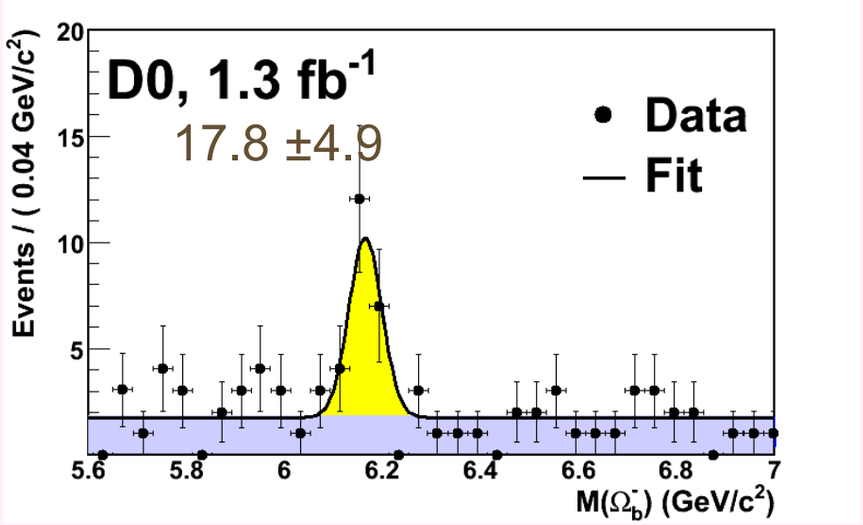


trigger on J/ψ

These results differ by 6σ

M(Ξ_b): DØ > CDF

M(Ω_b): DØ < CDF



DØ

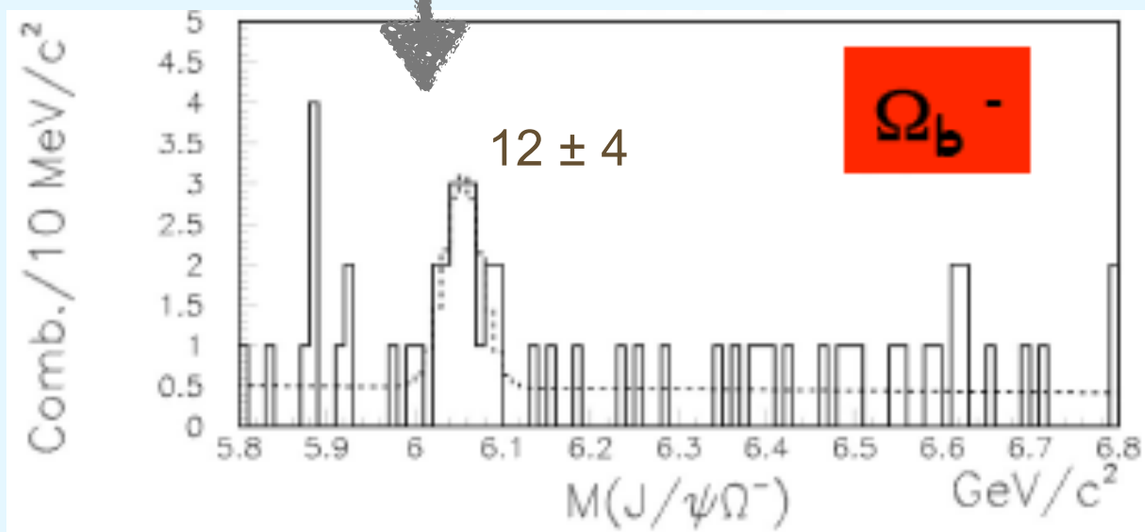
Mass: 6165 ±10 ±11 MeV/c^2

unbinned max likelihood fit

significance 5.05 σ

DØ increasing data set

PRL 101, 232002 (2008)



CDF

Mass: 6054.4 ± 6.8 ± 0 .9 MeV/c^2

Mass fit : significance 4.9 σ

Combined mass and lifetime fit:

significance 5.5 σ

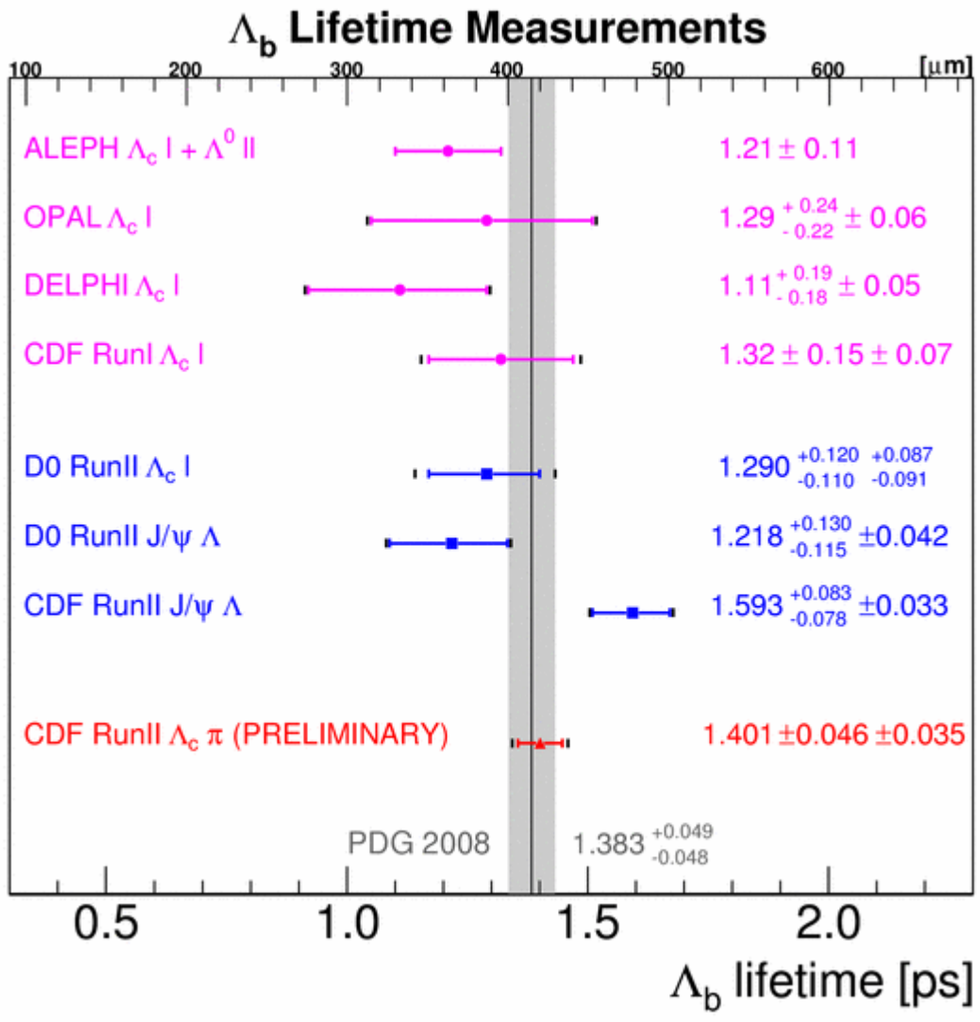
Phys Rev D80, 072003 (2009)

B BARYONS

LIFETIMES

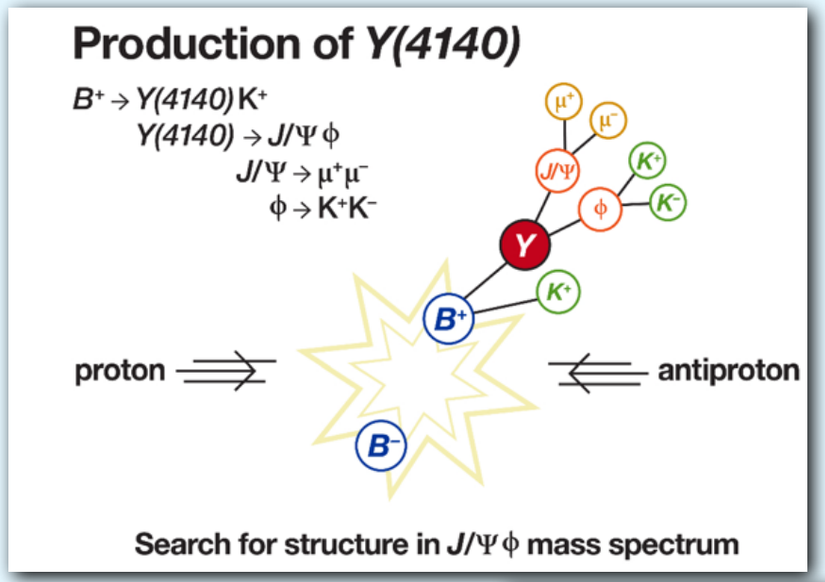
universal to the heavy quark

differences due to spectators



SOMETHING NEW?

unknown composition



the Y(3930) prompted a search for others

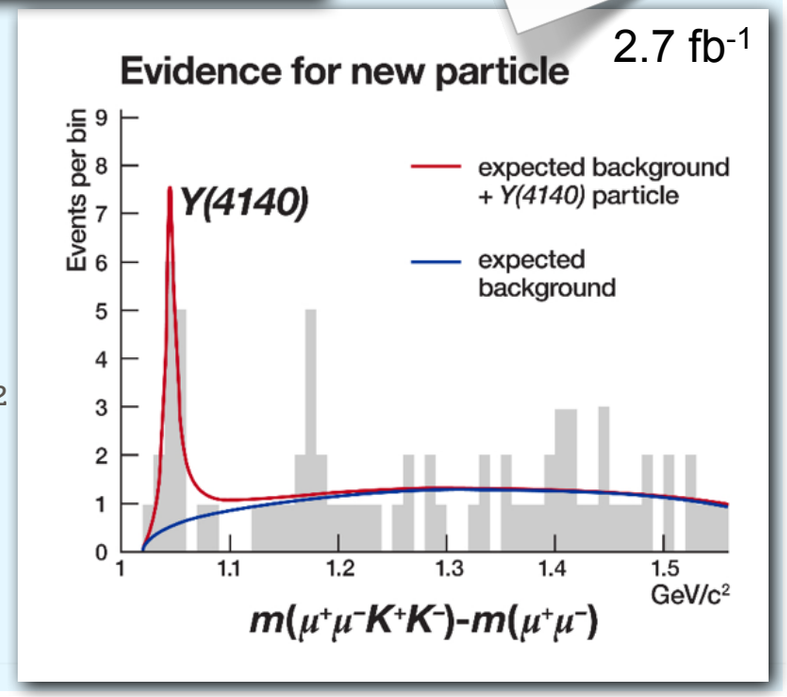
CDF

preliminary

14 ± 5 signal events

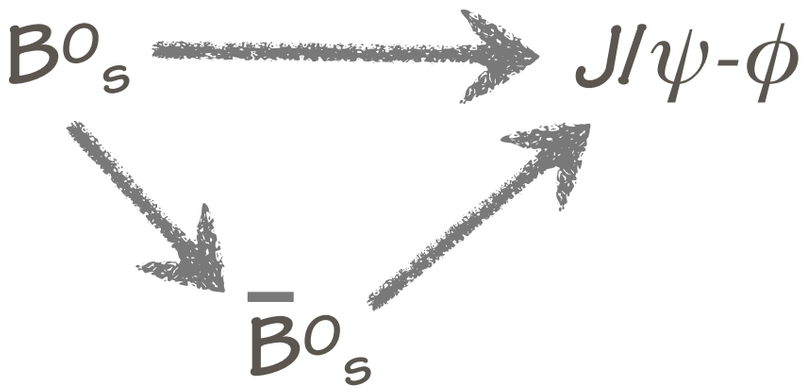
m = 4143 ± 2.9 ± 1.2 MeV/c^2

Γ = 11.7 +8.3 - 5.0 ± 3.7 MeV/c^2



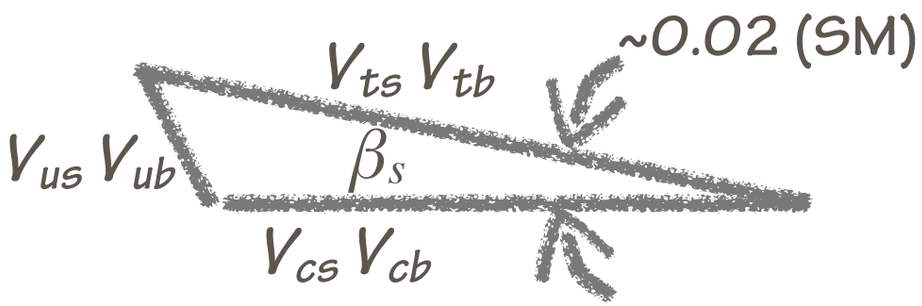
CPV IN B_S SYSTEM

- SEARCHING FOR TINY CPV EFFECTS IN B_S SYSTEM

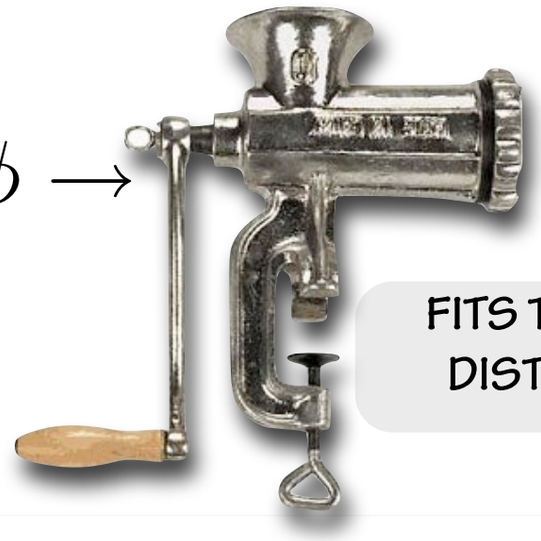


$$i\frac{d}{dt}\begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i\Gamma}{2} & M_{12} - \frac{i\Gamma_{12}}{2} \\ M_{12}^* - \frac{i\Gamma_{12}^*}{2} & M - \frac{i\Gamma}{2} \end{pmatrix} \begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix}$$

$$\begin{aligned} |B_s^H> &= a|B_s^0> + b|\bar{B}_s^0> \\ |B_s^L> &= a|B_s^0> - b|\bar{B}_s^0> \\ \Delta M_s &= M_H - M_L \sim 2M_{12} \\ \Delta\Gamma_s &= \Gamma_L - \Gamma_H \sim 2|\Gamma_{12}|cos\phi \end{aligned}$$



$$B_s^0 \to J/\psi + \phi \to$$



CP-even (Γ_L)

CP-odd (Γ_H)

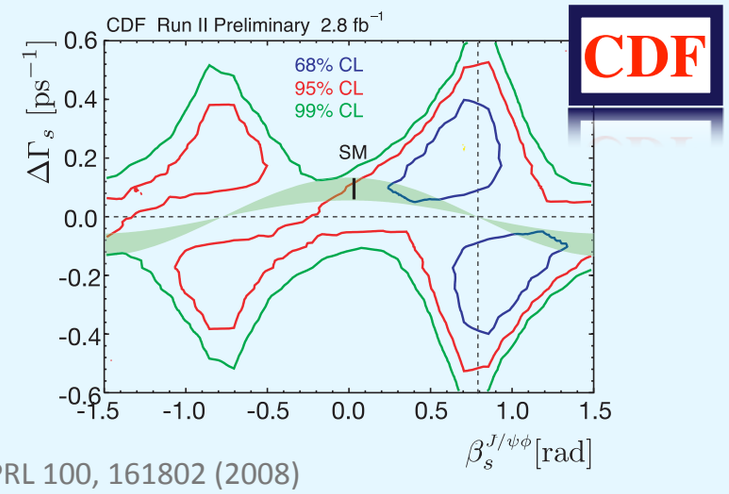
FITS TO ANGULAR DISTRIBUTIONS

CPV IN B_S SYSTEM

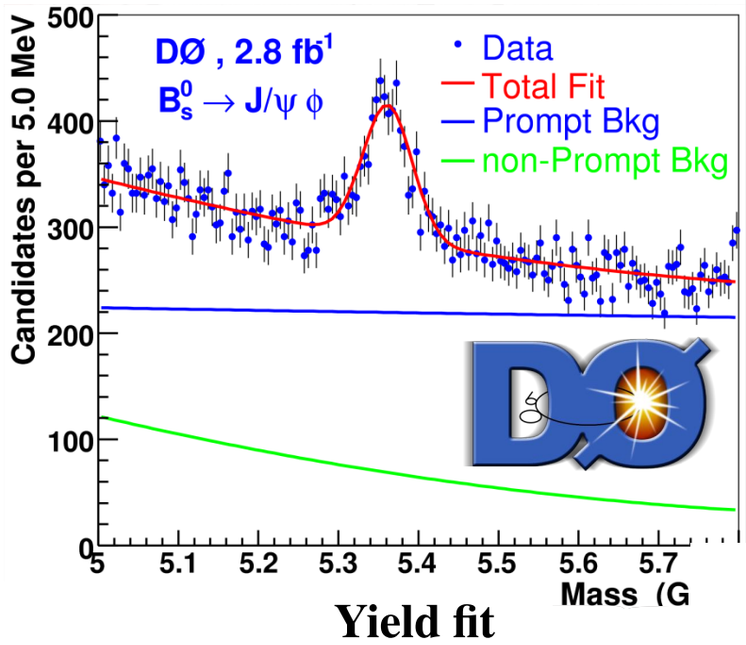
- RESULT IS COMPLICATED EMBEDDING OF Γ_s WITH β_S

SM p-value = 7% =>

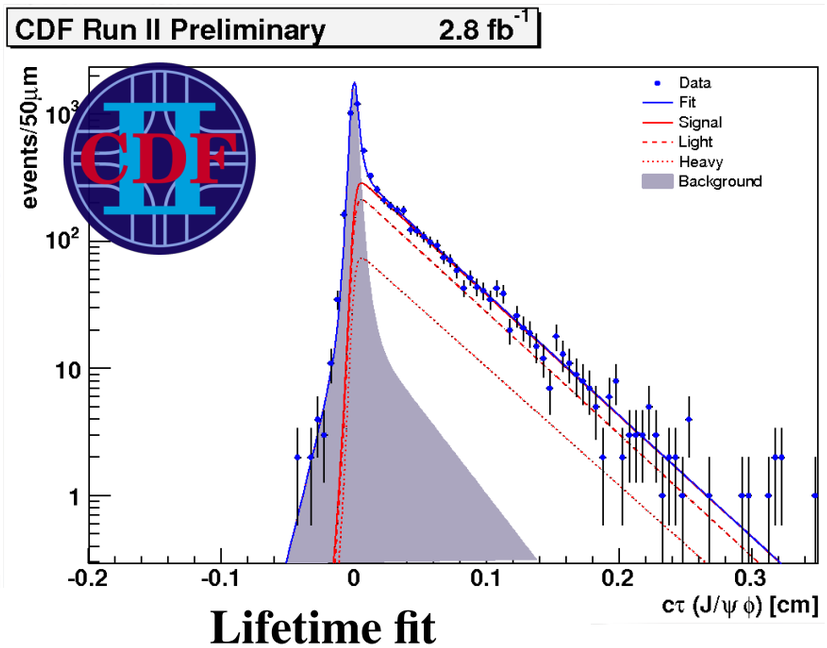
deviation from SM β of 1.8σ



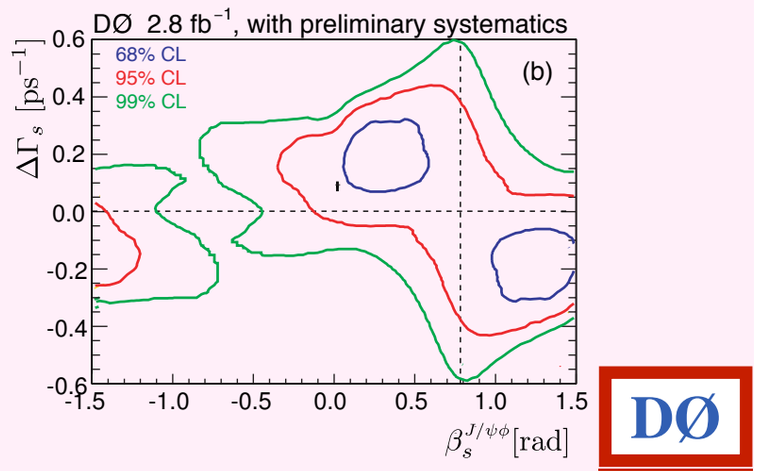
PRL 100, 161802 (2008)



Yield fit



Lifetime fit



SM p-value = 24%

$$\tau(B_s^0) = 1.53 \pm 0.04 \pm 0.01 \text{ ps}$$
$$\Gamma = 0.02 \pm 0.05 \pm 0.01 \text{ ps}^{-1}$$

CDF

$$\tau(B_s^0) = 1.487 \pm 0.060 \pm 0.028 \text{ ps}$$
$$\Delta\Gamma = 0.02^{+0.072}_{-0.078} \pm 0.006 \text{ ps}^{-1}$$

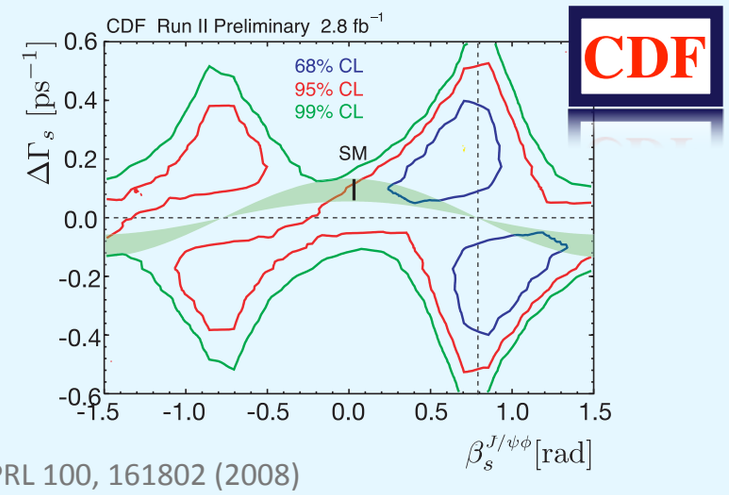
DØ

CPV IN B_S SYSTEM

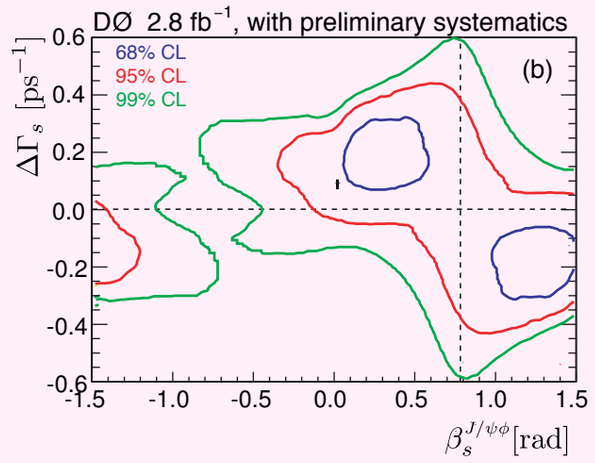
- RESULT IS COMPLICATED EMBEDDING OF Γ_s WITH β_S

SM p-value = 7% =>

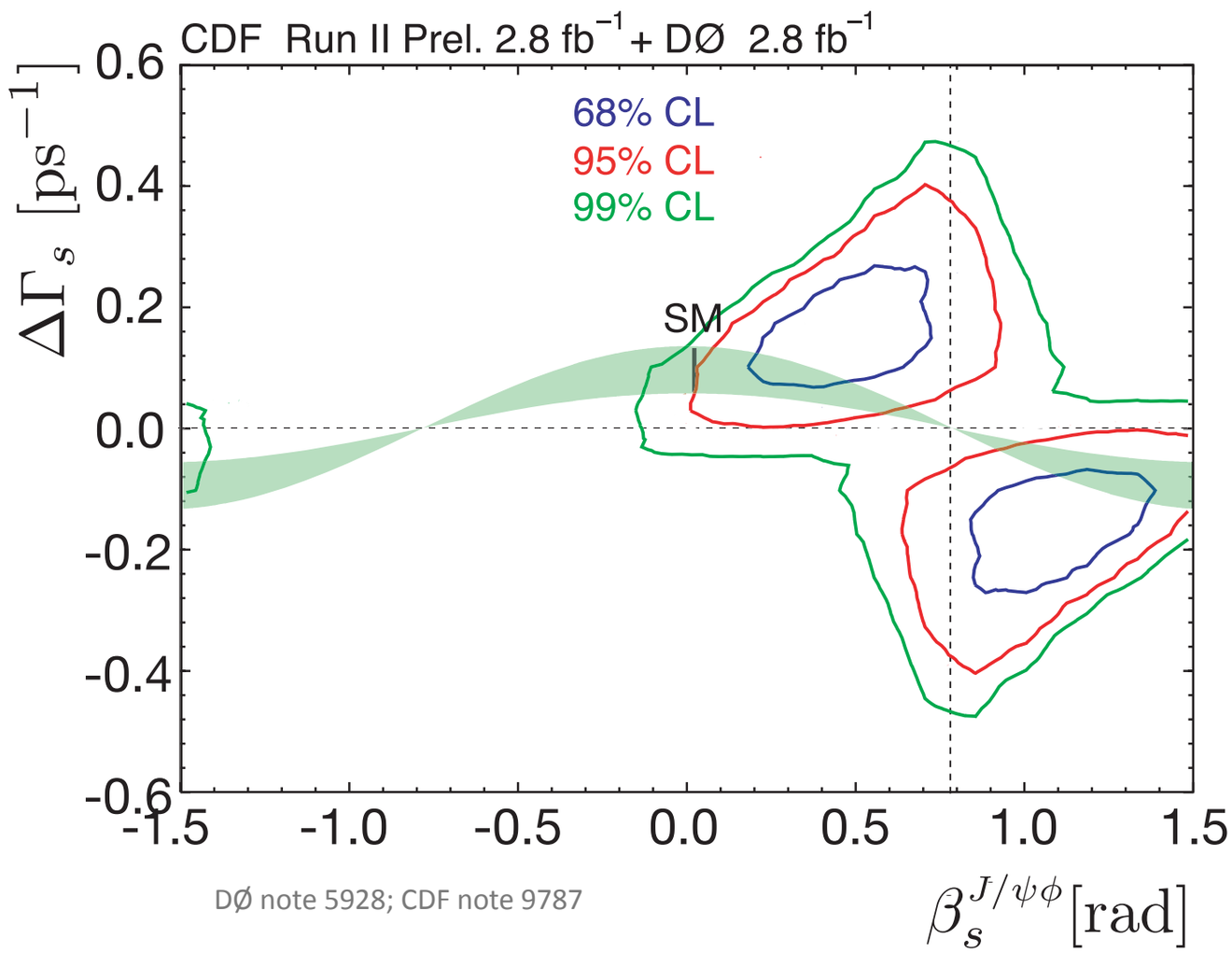
deviation from SM β of 1.8σ



PRL 100, 161802 (2008)



SM p-value = 24%



DØ note 5928; CDF note 9787

combination deviation from SM β of 2.1σ

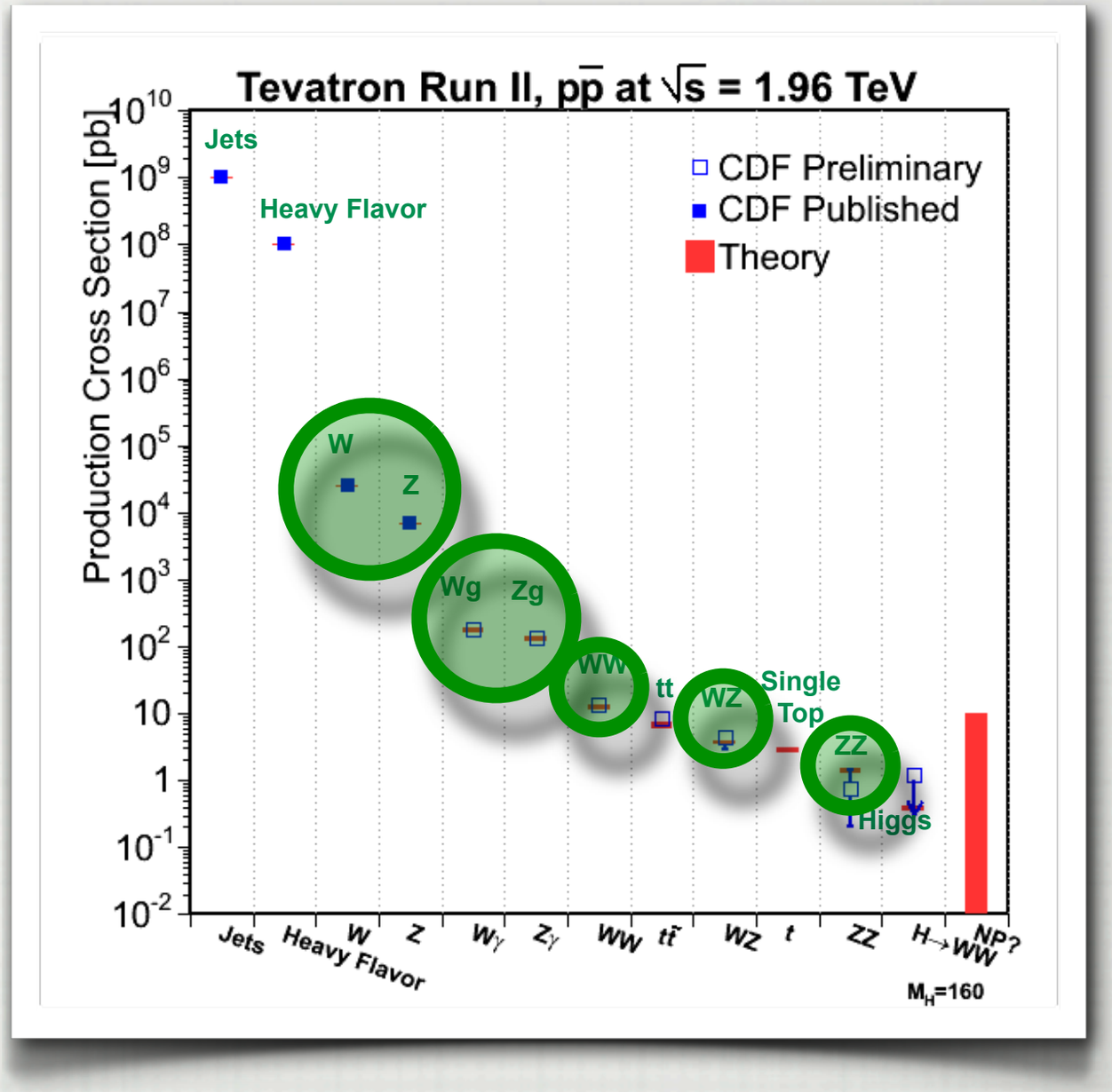
1/2-WAY POINT CONCLUSION 2

HADRON COLLIDER B-QUARK PHYSICS

IS NOW A PRECISION SCIENCE

ELECTROWEAK PHYSICS

- PRECISION PHYSICS OF INTERMEDIATE VECTOR BOSONS
- SEARCHES FOR NEW PHYSICS
- NARROWING THE SM WINDOW FOR HIGGS

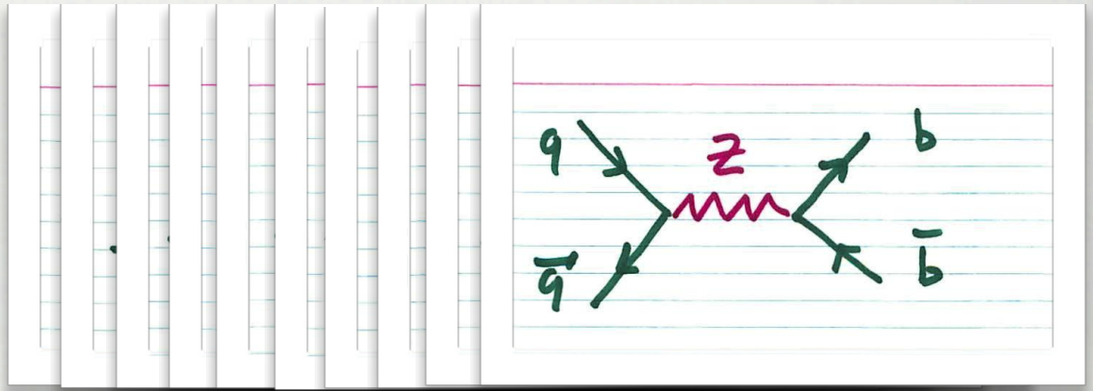


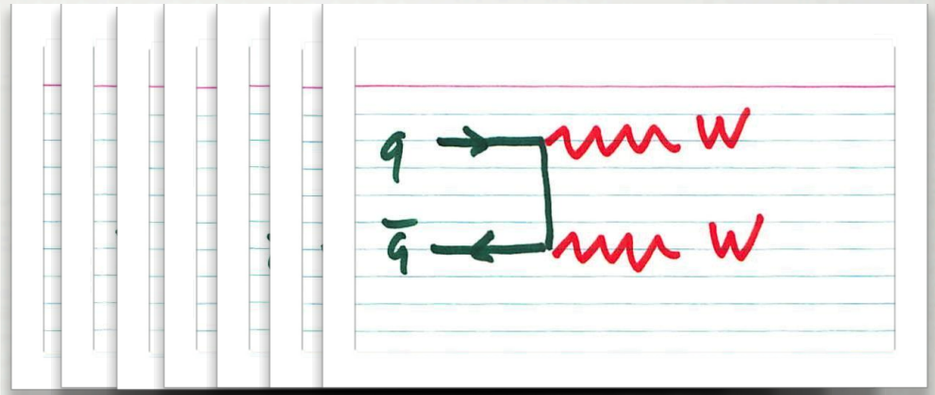
(0.0002 - 0.00000002)% of anything happening

ELECTROWEAK PHYSICS

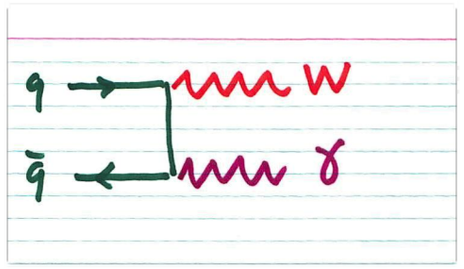
- EW PROCESSES

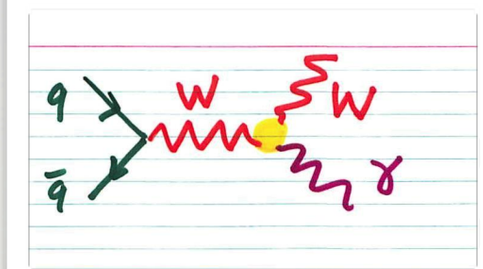
M_W:	1 fb^{-1} (DO & CDF)
Γ_W:	1 fb^{-1} (DO & CDF)
W A_{FB}	4.1 fb^{-1} (CDF)
lepton chg A	0.7 fb^{-1} (e, DØ)
	4.9 fb^{-1} (μ, DØ)
W chg A	1 fb^{-1} (CDF)
Z rapidity	2.1 fb^{-1} (CDF)
$W \to \pi\gamma$	4.3 fb^{-1} (CDF)
$W\gamma \to l\nu\gamma$	~1 fb-1 (DØ)
$Z\gamma \to ll\gamma$	~1 fb-1 (e) 2 fb-(μ) (CDF)
$WW \to l\nu l\nu$	1-3.6 fb-1 (DØ & CDF)
$WZ \to l\nu ll$	1-1.9 fb-1 (DØ & CDF)
$ZZ \to 4l$	4.8 fb-1 (CDF)
$Z\gamma$	~1 fb-1 (e) 2 fb-(μ) (CDF)
$WW+WZ \to l\nu+jj$	1.1 fb-1 (DØ & CDF)
$VV \to$ MET+jj	3.5 fb-1 (CDF)
$Z\gamma\gamma$ & $ZZ\gamma$	~2-3.6 fb-1 (DØ & CDF)
WW & $WW\gamma$	3.6 fb-1 (DØ & CDF)
$ZWW + \gamma WW$	0.7-1.1 fb-1 (DØ)

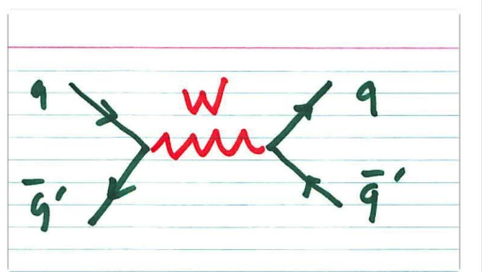


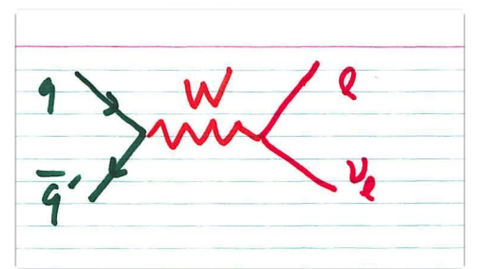


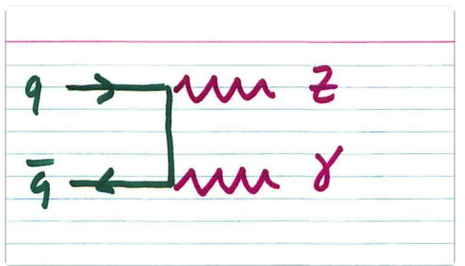
ELECTROWEAK PHYSICS

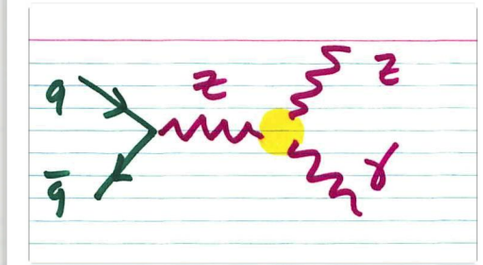


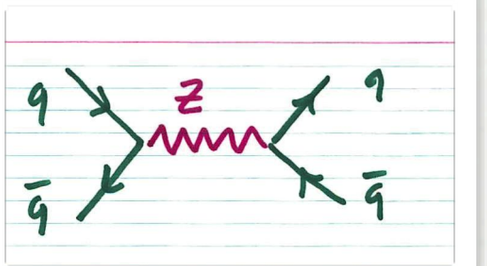


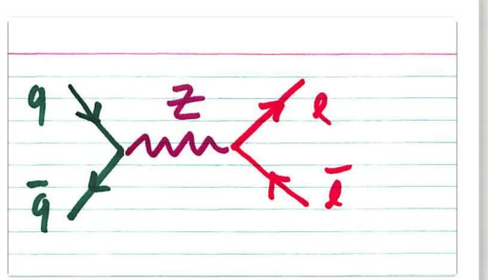


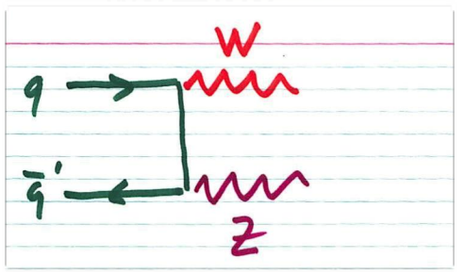


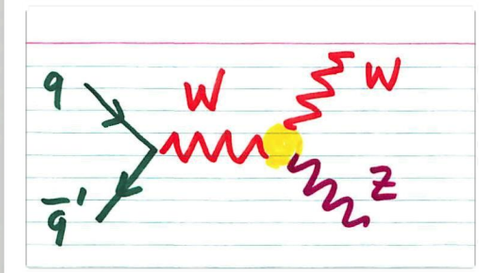


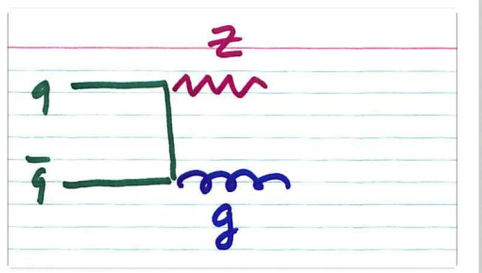


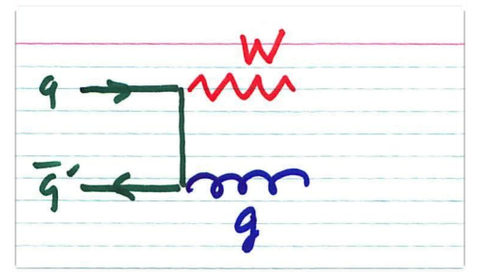


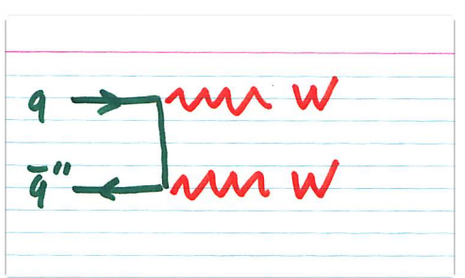


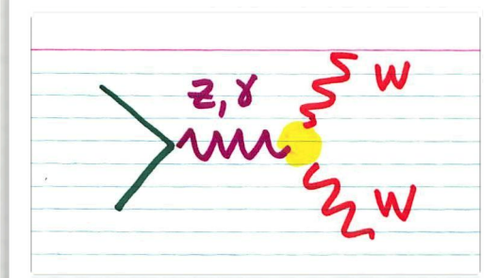


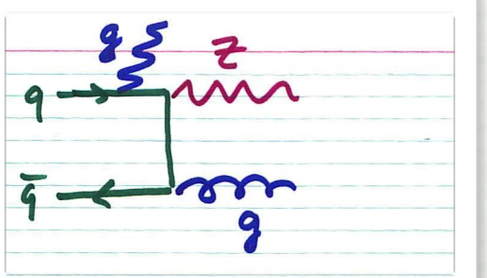










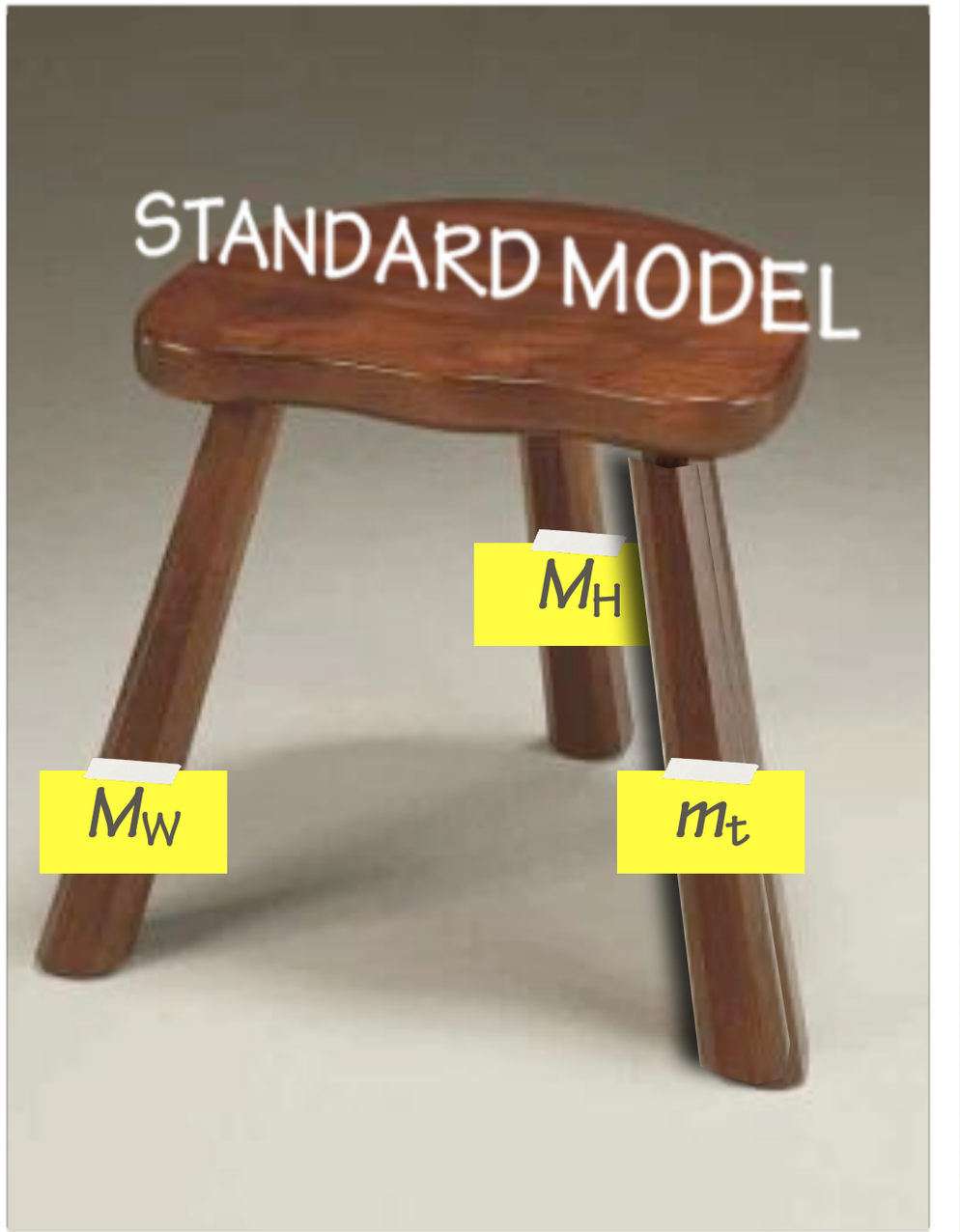


W/Z ARE THE STANDARD MODEL

- SM STABLE ONLY ON 3 ELECTROWEAK LEGS

  and 2 or 3? of them

  are Fermilab objects



http://www.summerofsoftware.org/SoSE2007/index.html

CDF preliminary

Mw

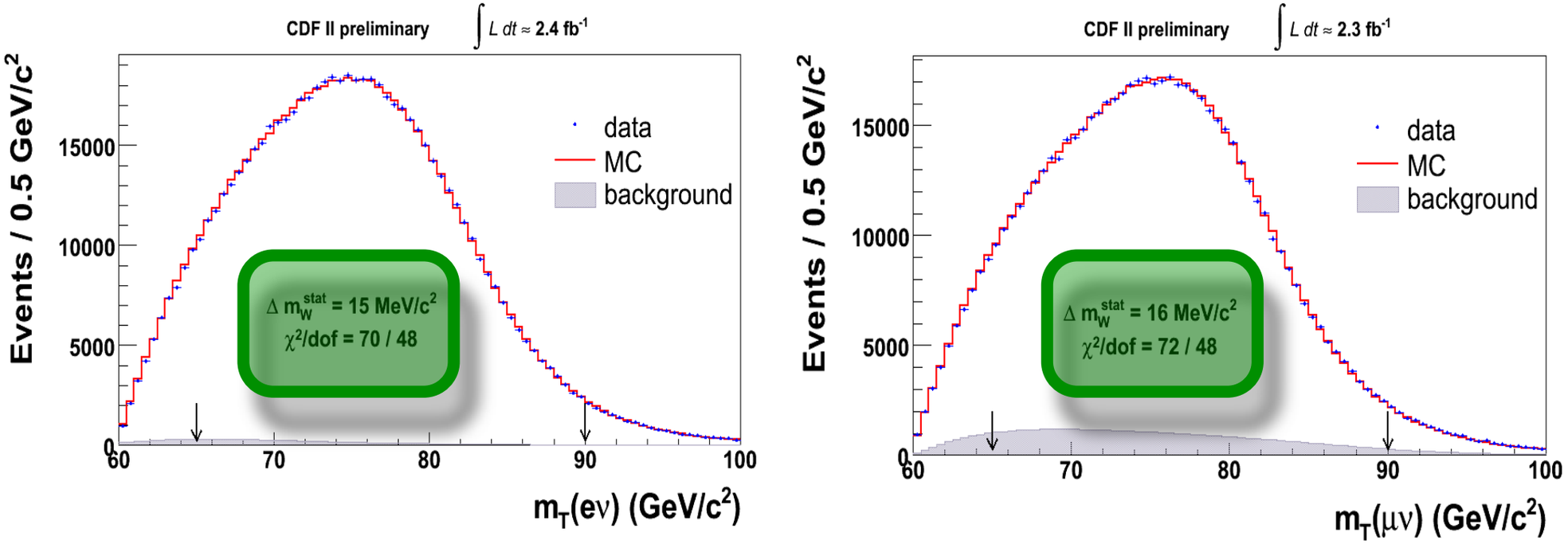
- AMONG THE MOST CHALLENGING MEASUREMENTS AT A COLLIDER

  controlled by the electron energy accuracy and precision

  DØ scales by MZ, canceling many systematics

  CDF e: uses E/p + μ measurement

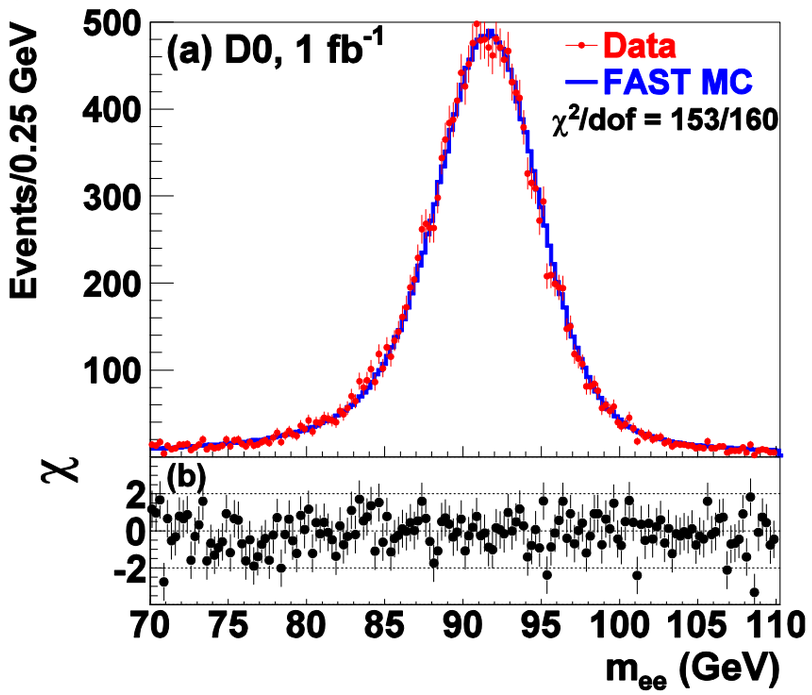
template

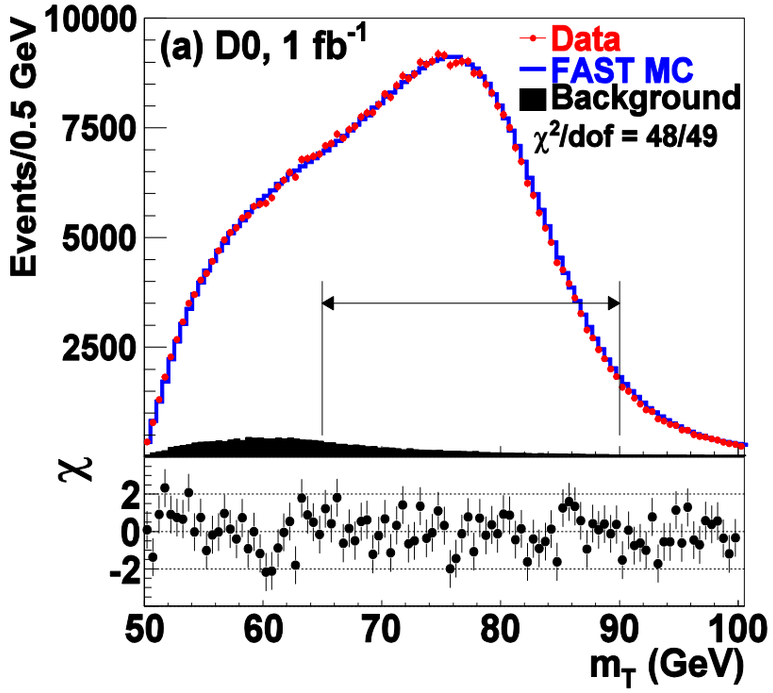


original Run II result (200 pb-1)

M(W) = 80413 ± 34 (stat.) ± 34 (syst.) MeV = 80413 ± 48 MeV

Mw





m(Z) = 91.185 ± 0.033 GeV (stat)

m(W) = 80.401 ± 0.023 GeV (stat)

$\delta M_W(m_T) = 23 \pm 35 \pm 12 = 37\ MeV/c^2$

$M_W = 80.401 \pm 0.021(stat.) \pm 0.038(syst.)\ GeV$
$= 80.401 \pm 0.043\ GeV$

plus comparable measurements in $p_T(e)$ and MET

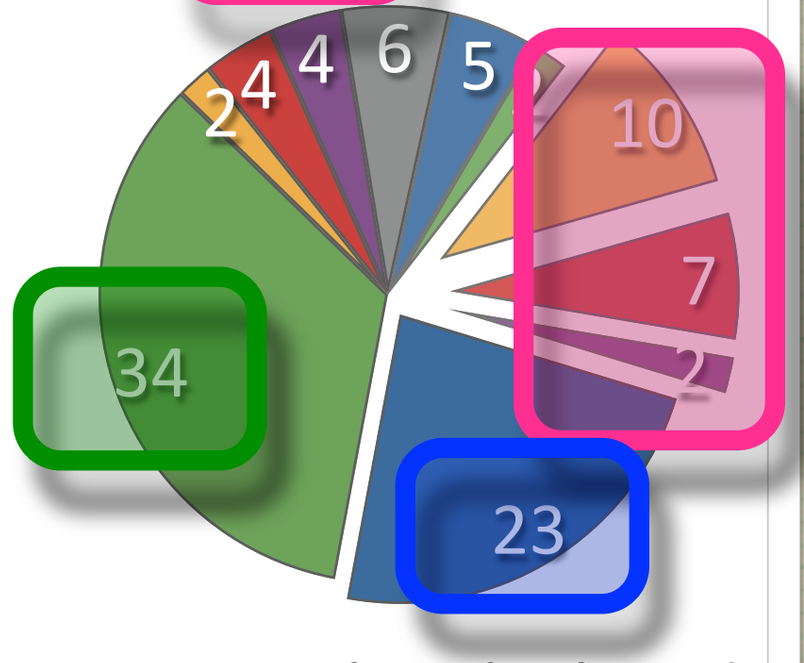
plus width:

$\Gamma(W) = 2.028 \pm 0.038\ (stat) \pm 0.061\ (syst)\ GeV$
$= 2.028 \pm 0.072\ GeV$

(SM $\Gamma_W = 2.093 \pm 0.002\ GeV$)

(LEP $\Gamma_W = 2.196 \pm 0.083\ GeV$)

- statistical
- electron response
- electron resolution
- electron non-lin
- electron E loss diff
- recoil model
- efficiences
- backgrounds
- pdf
- QED
- W pt



Tevatron combined value w/o DØ Run II:

$\Gamma_W = 2.050 \pm 0.058\ GeV$

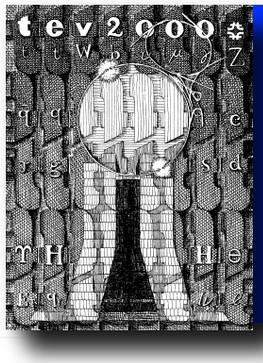
M_W: SUMMARY

- W & Z MEASUREMENTS CONSTITUTE PREMIER, PRECISION PHYSICS

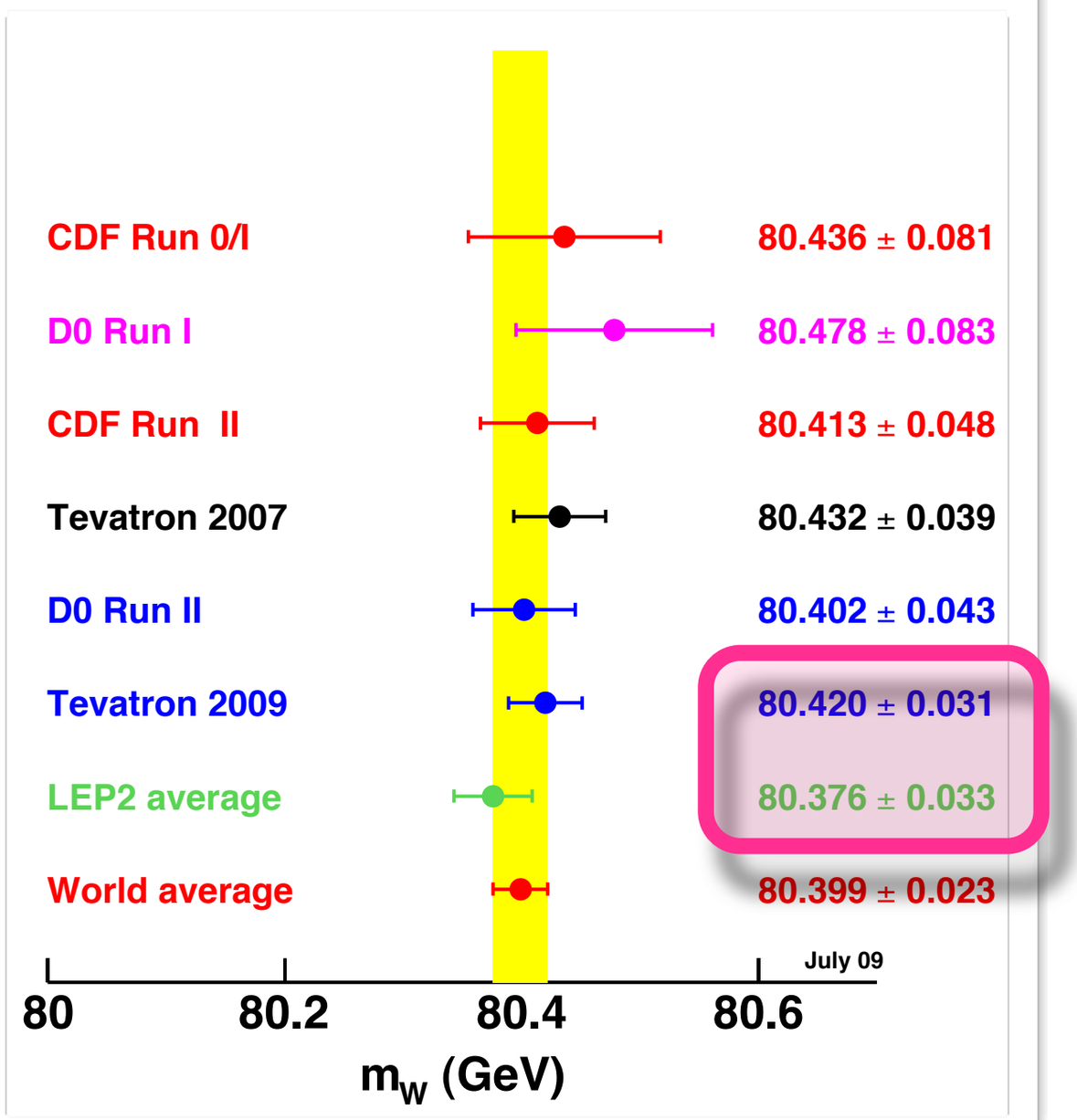
  CDF and DØ errors are correlated

- GOAL IS ΔM_W ±25 MEV/C^2 PER EXPERIMENT

  tough to beat that at LHC for quite a while



1 fb^{-1}: δM_W < 51 MeV/c^2
10 fb^{-1}: δM_W < 29 MeV/c^2

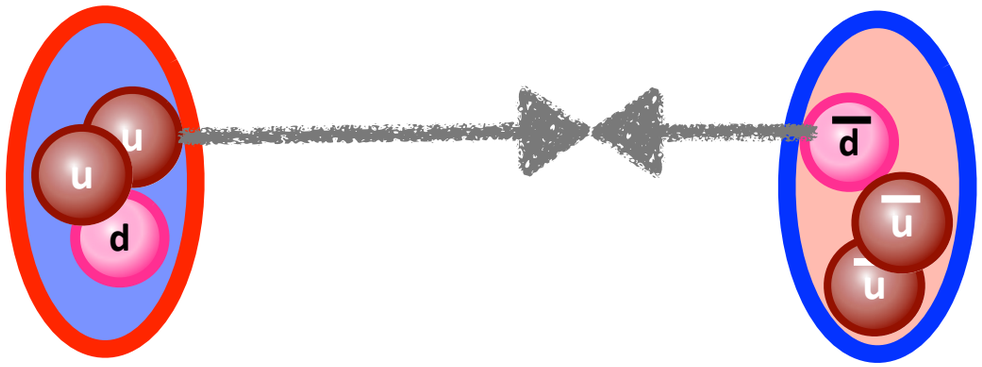


Tevatron ElectroWeak Working Group http://tevewwg.fnal.gov

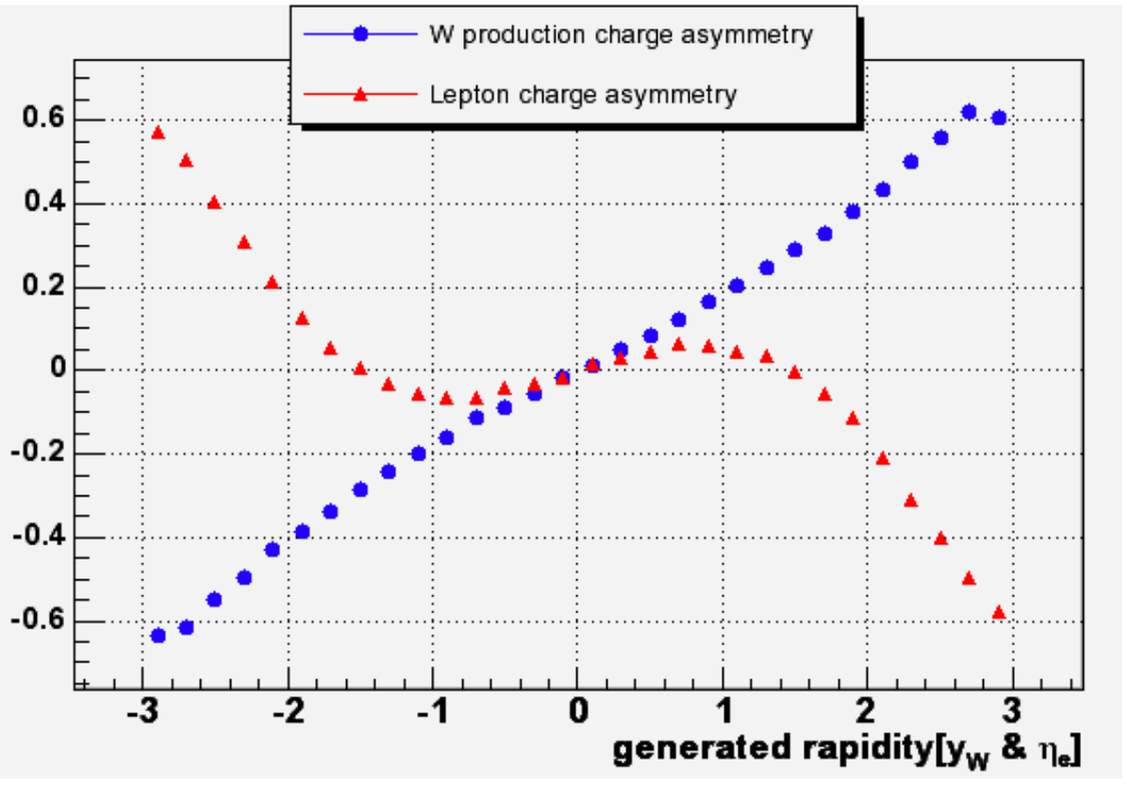
PRODUCTION ASYMMETRIES

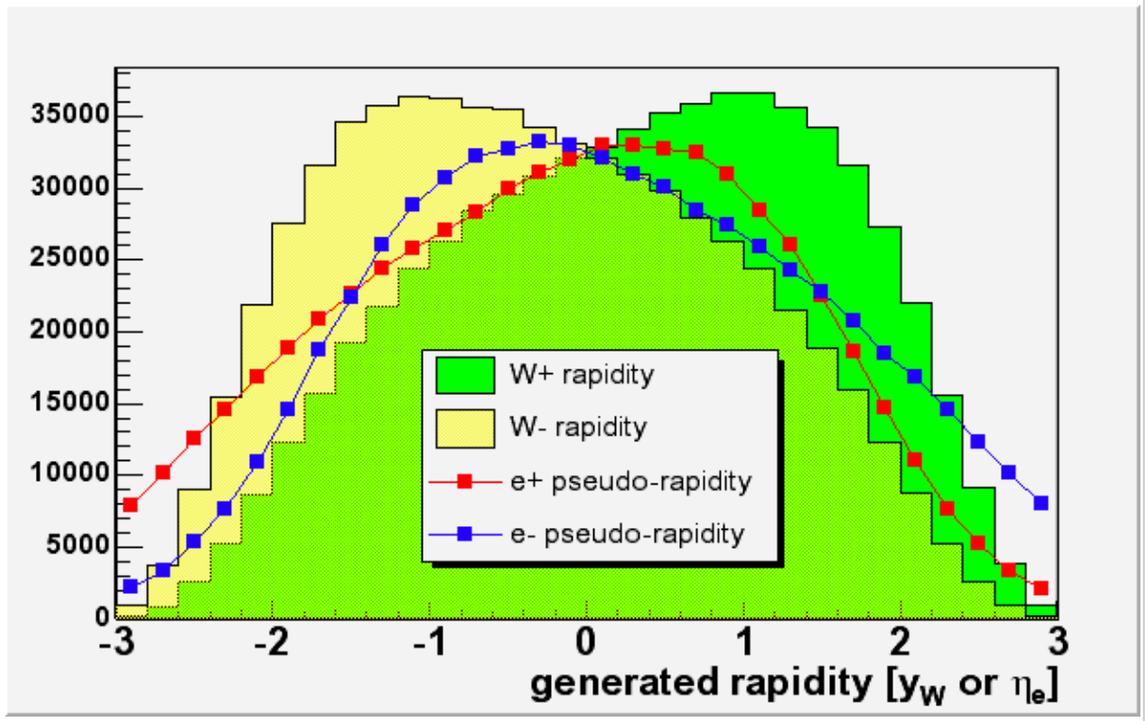
- A BASIC SM WEAK INTERACTION PREDICTION

  important for constraining pdfs



$$A(y_W) = \frac{d\sigma(W^+)/dy_W - d\sigma(W^-)/dy_W}{d\sigma(W^+)/dy_W + d\sigma(W^-)/dy_W}$$





E.L. Berger, F. Halzen, C.S. Kim and S. Willenbrock; Phys. Rev. D40 (1989) 83

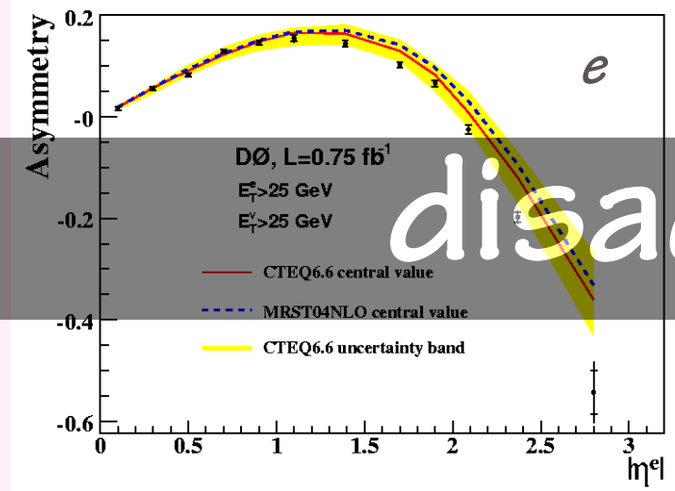
$$y_W = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$$

PRODUCTION ASYMMETRIES: W

- EACH EXPERIMENT TAKES A DIFFERENT APPROACH

DØ: lepton asymmetry $A(\eta_W) \otimes [V\text{-}A]$

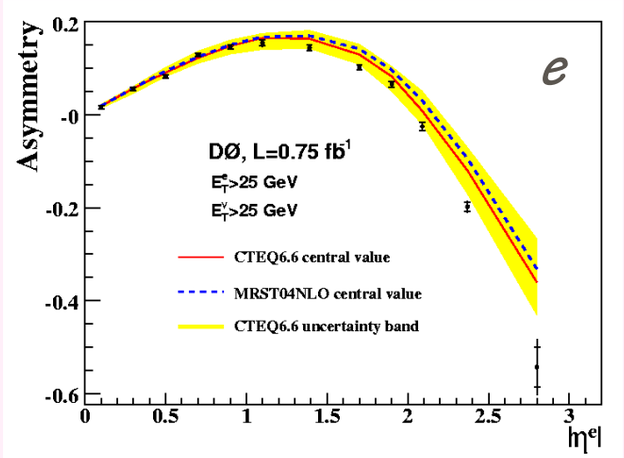
CDF: W boson asymmetry directly

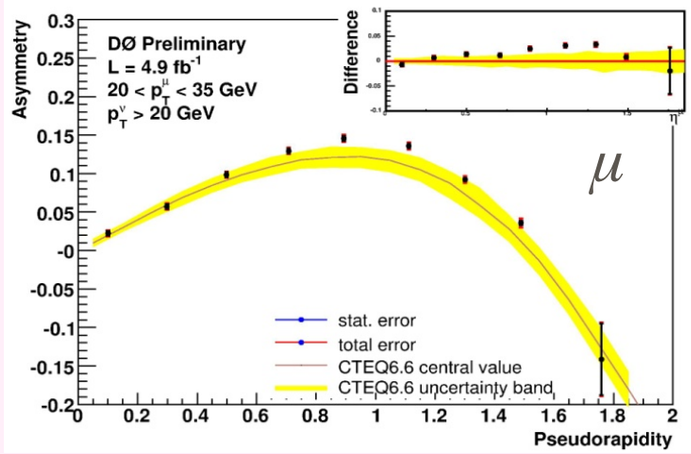


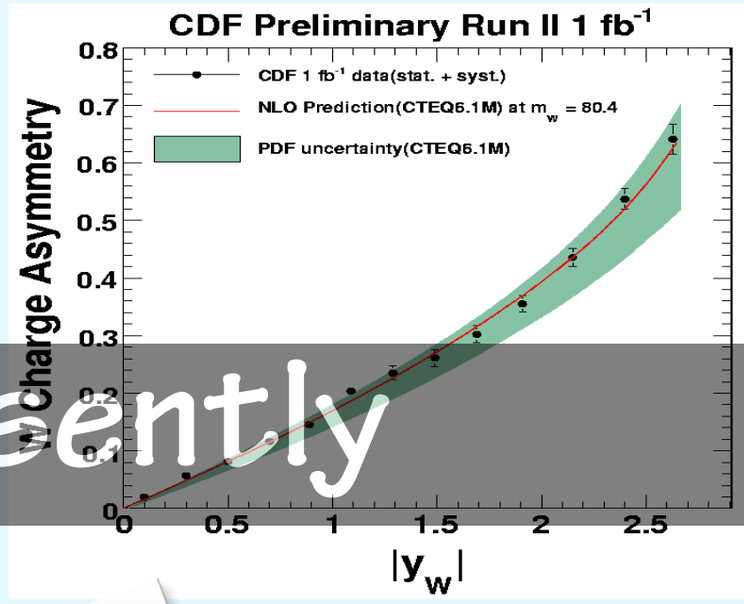
DØ preliminary

bins in small E_T slices

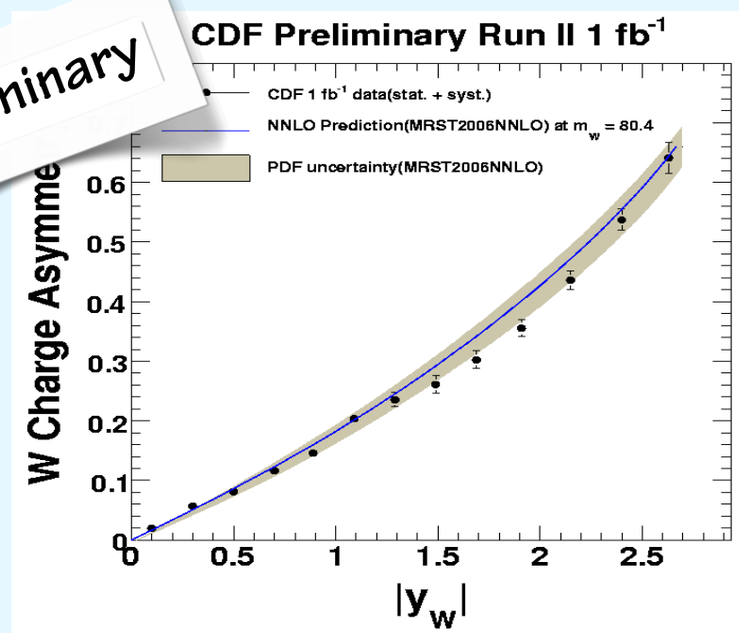
experimental uncertainties small





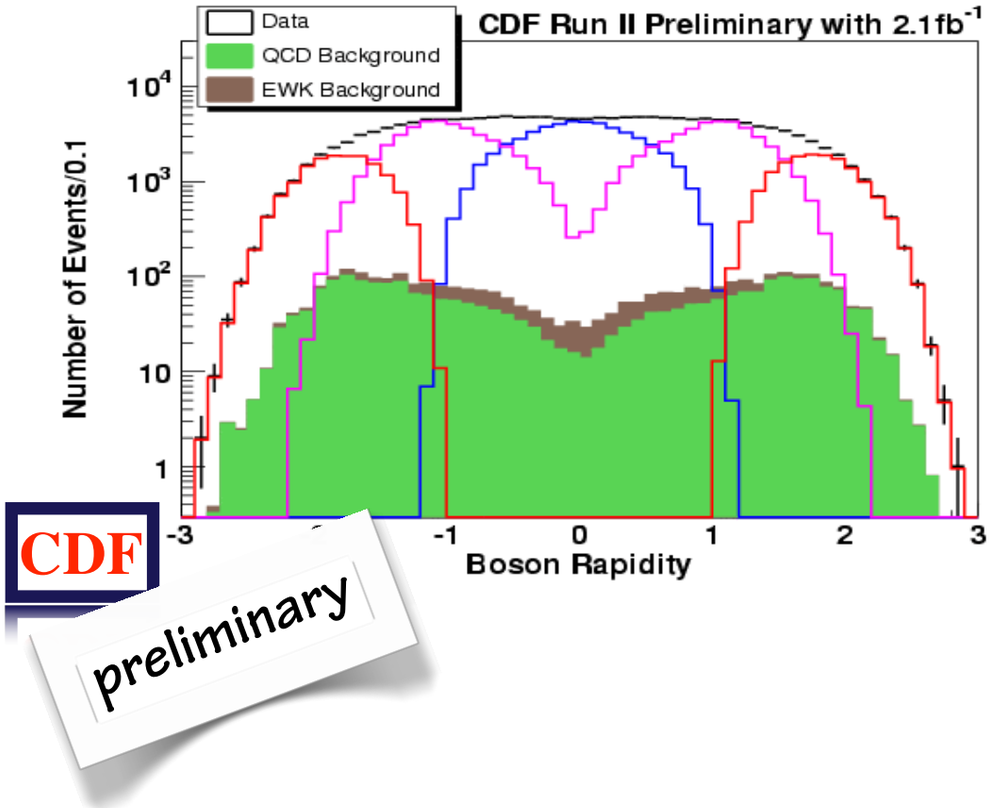


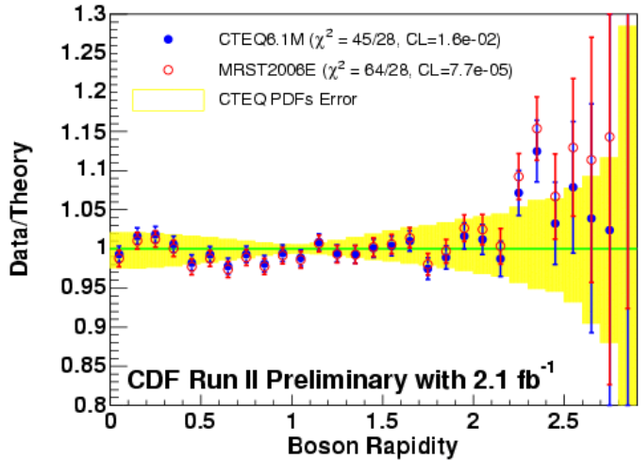
CDF preliminary

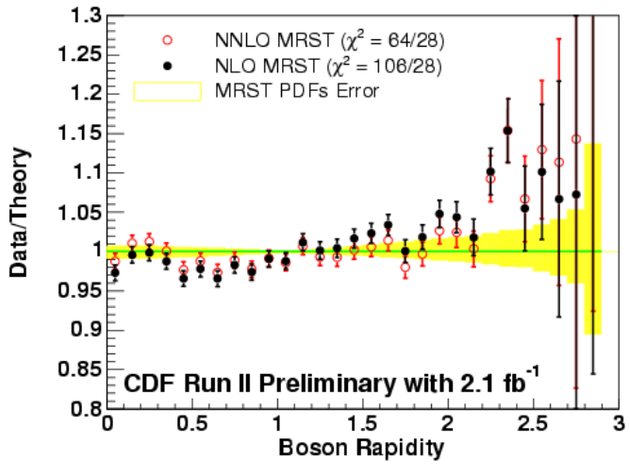


PRODUCTION ASYMMETRIES: Z

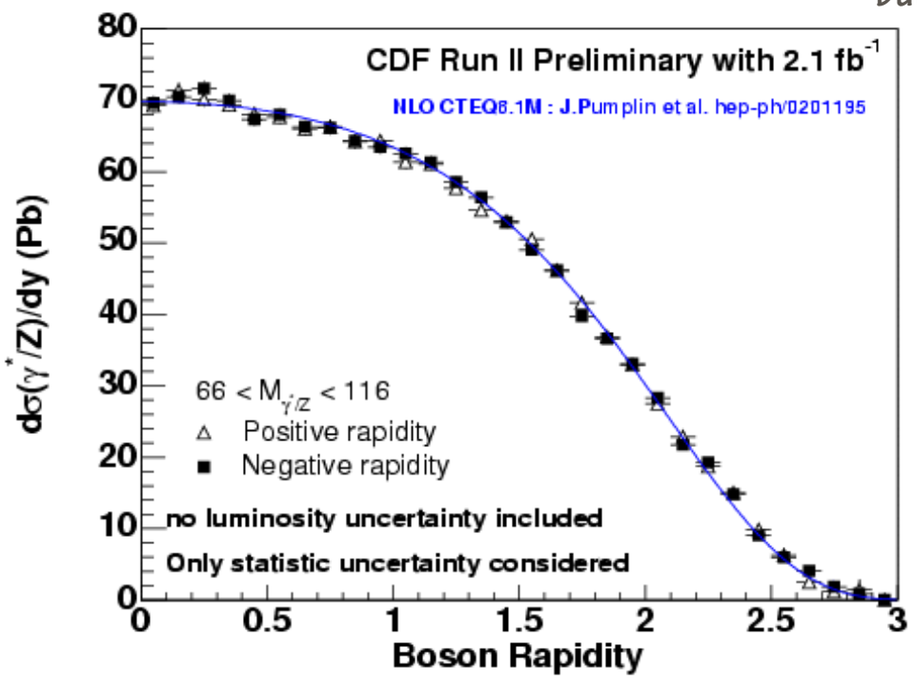
Z RAPIDITY MEASUREMENT







NLO CTEQ6.1M preferred but, story not over...



DIBOSON PHYSICS

- A HIGHLY-CONSTRAINED SET OF INTERACTIONS

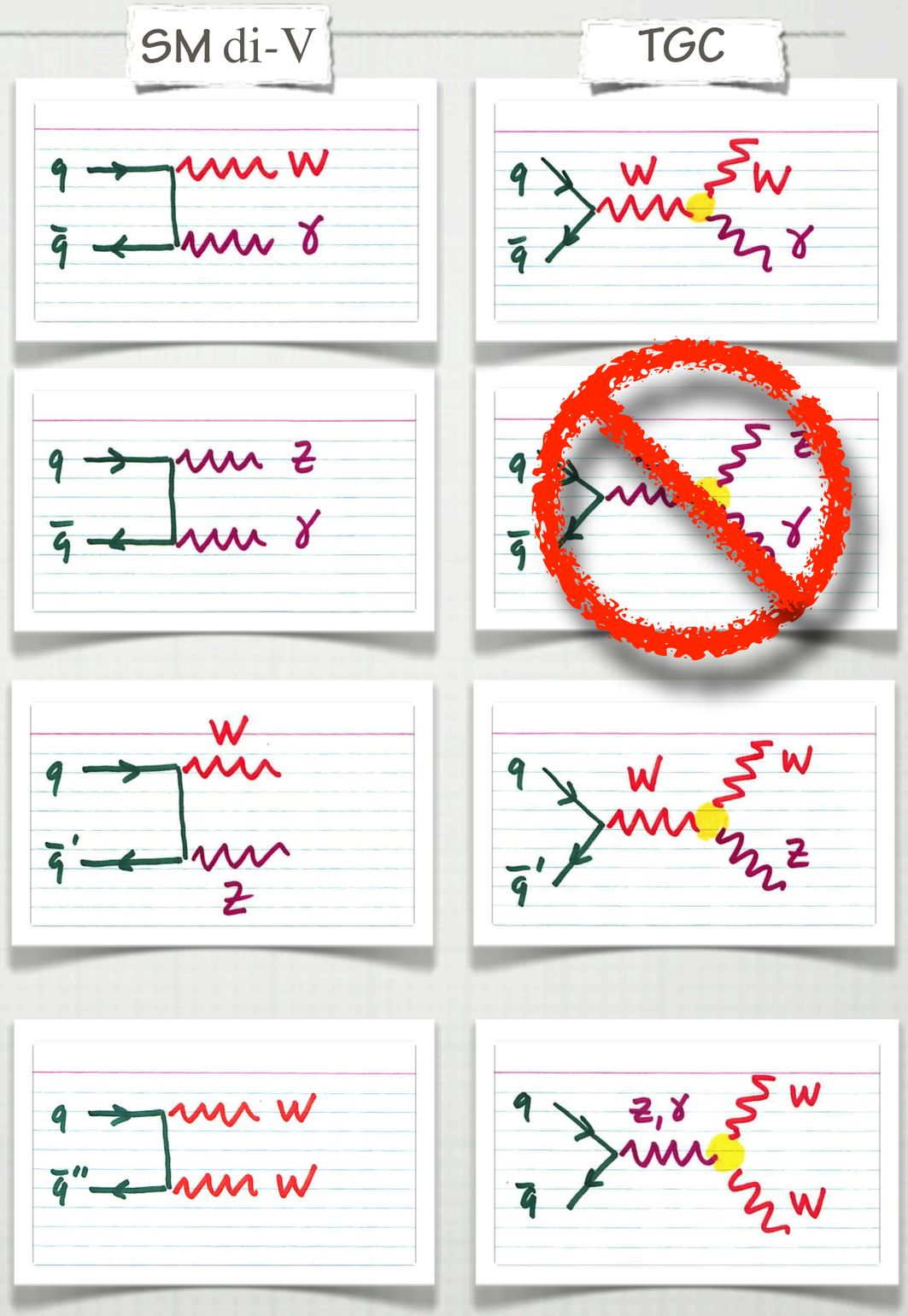
  SM is highly predictive

  Tevatron experiments have been tenaciously pursuing

- LIKE MANY EW AND QCD FINAL STATES

  important precision tests

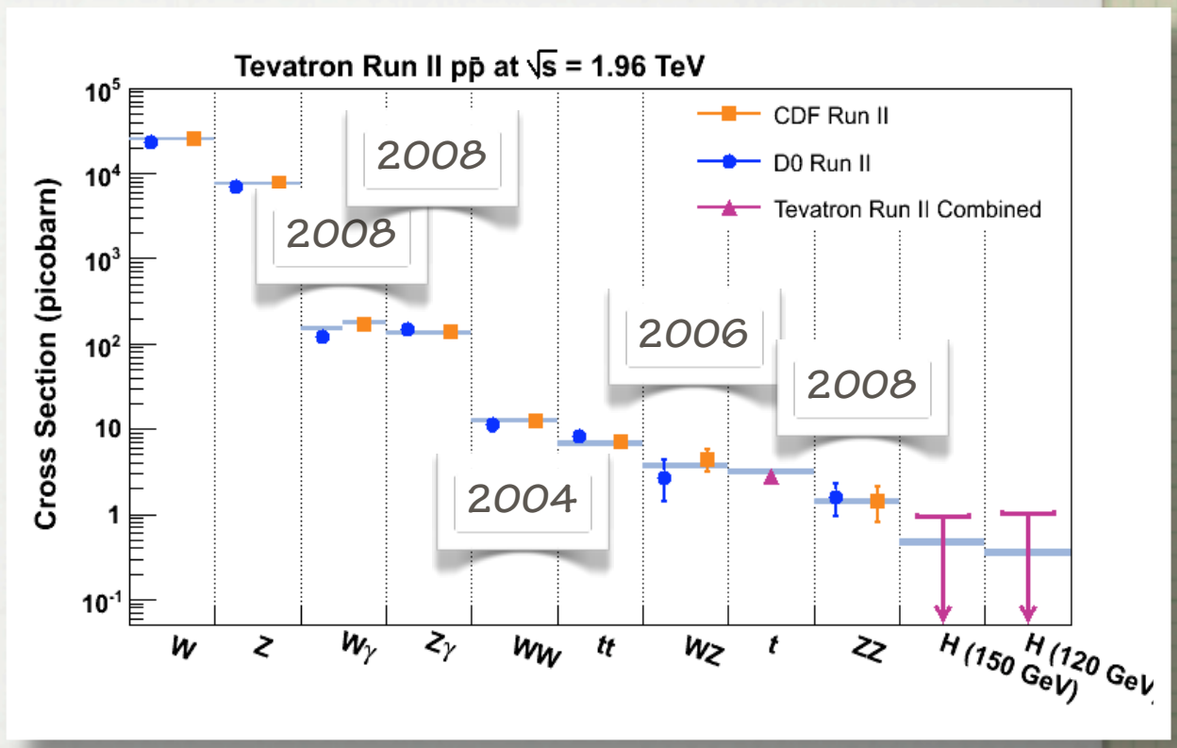
  crucial Higgs backgrounds

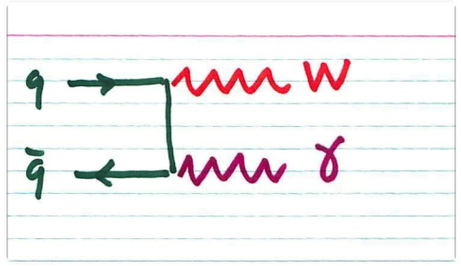


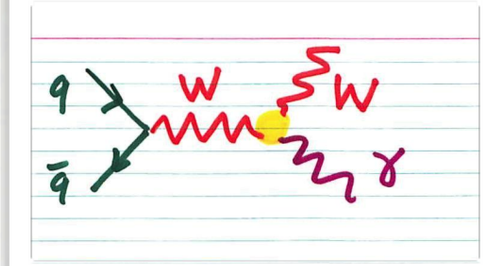
DIBOSON PHYSICS

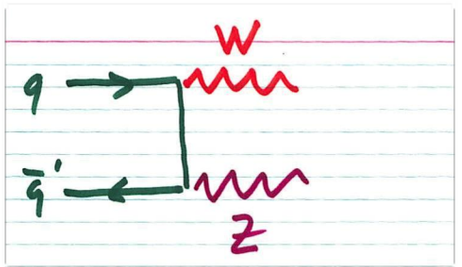
- MANY CHANNELS:

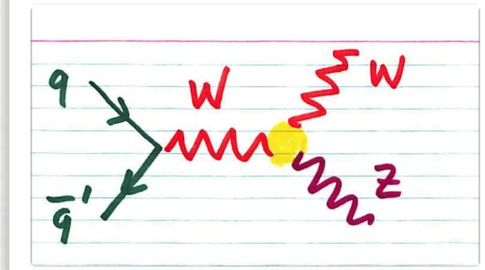
$W\gamma \rightarrow \ell\nu\gamma$	~1 fb^{-1} (DØ)
$Z\gamma \rightarrow \ell\ell\gamma$	~1 fb^{-1} (e) 2 fb^{-}(μ) (CDF)
$WW \rightarrow \ell\nu\ell\nu$	1-3.6 fb^{-1} (DØ & CDF)
$WZ \rightarrow \ell\nu\ell\ell$	1-1.9 fb^{-1} (DØ & CDF)
$ZZ \rightarrow 4\ell$	4.8 fb^{-1} (CDF)
$Z\gamma$	~1 fb^{-1} (e) 2 fb^{-}(μ) (CDF)
$WW+WZ \rightarrow \ell\nu+jj$	1.1 fb^{-1} (DØ & CDF)
$VV \rightarrow$ MET+jj	3.5 fb^{-1} (CDF)
$Z\gamma\gamma$ & $ZZ\gamma$	~2-3.6 fb^{-1} (DØ & CDF)
WW & $WW\gamma$	3.6 fb^{-1} (DØ & CDF)
$ZWW + \gamma WW$	0.7-1.1 fb^{-1} (DØ)

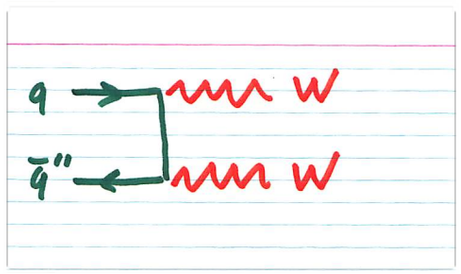


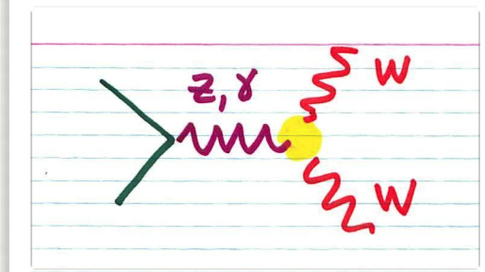








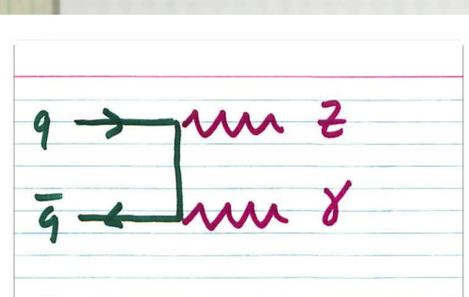


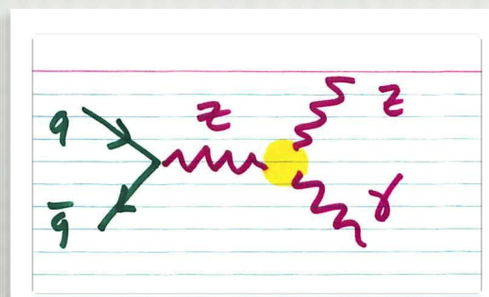


$$\frac{\mathcal{L}_{WWV}}{g_{WWV}} = ig_1^V(W^\dagger_{\mu\nu}W\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + i\kappa_V W_m u^\dagger W_\nu V^{\mu\nu} + i\frac{\lambda_V}{M_W^2}W^\dagger_{\lambda\mu}W^\mu_\nu V^{\nu\lambda}$$

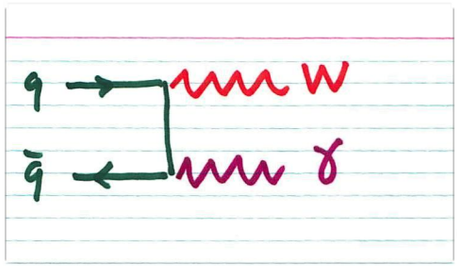
$$\text{SM: } g_1^Z = \kappa_V = 1, \lambda_V = h^V_{3,4} = 0$$

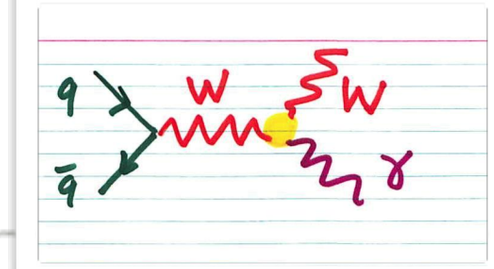
$$\text{SM deviations: } \Delta g_1^Z = g_1^Z - 1, \Delta\kappa_V = \kappa_V - 1, \Delta\lambda_V = \lambda_V - 0, \Delta h^V_{3,4} = h^V_{3,4} - 0$$





$$\mathcal{L}_{Z,\gamma} = -ie[(h_1^V F^{\mu\nu} + h_3^V \tilde{F}^{\mu\nu})Z_\mu \frac{(\partial^\rho\partial_\rho + M_W^2)}{M_Z^2}V_\nu + (h_2^V F^{\mu\nu} + h_4^V \tilde{F}^{\mu\nu})Z^\alpha \frac{(\partial^\rho\partial_\rho + M_V^2)}{M_Z^4}\partial_\alpha\partial\mu V_\nu]$$

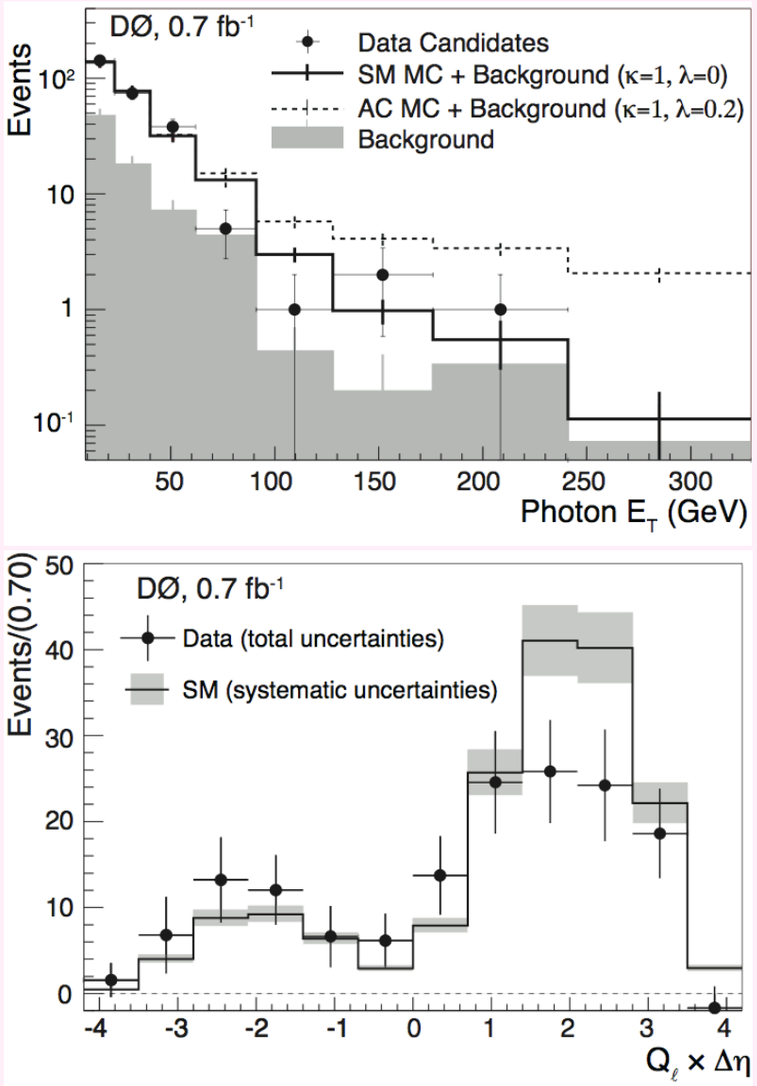




DI-BOSONS: Wγ, Zγ

Wγ PRODUCTION

radiation zero studied by DØ 2008



DØ

σ=14.8±1.6 (stat)±1.0 (syst)±1.0 (lum) pb

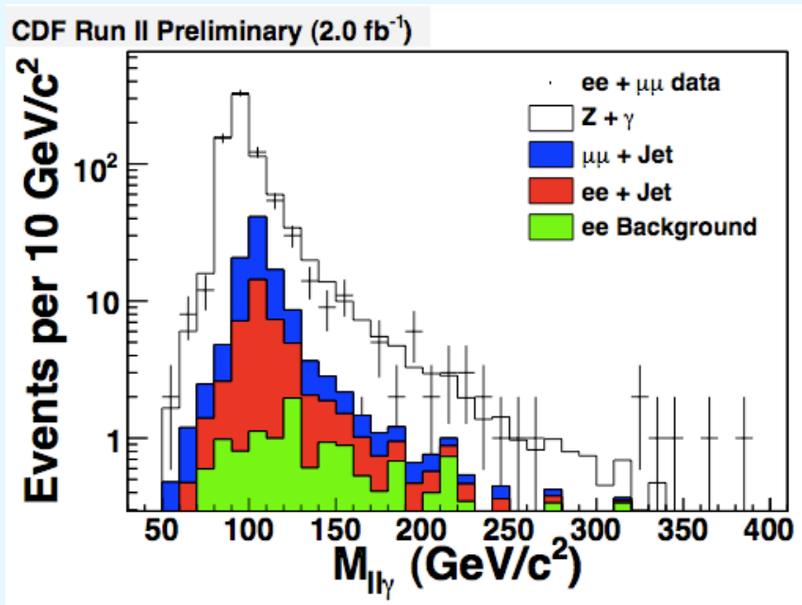
For $E_T(\gamma)>8$ GeV, $\Delta R(\gamma\text{-}l)>0.7$

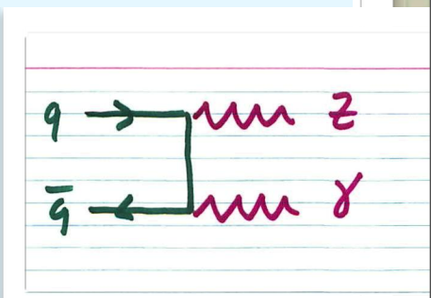
NLO theory: 16.0±0.4 pb

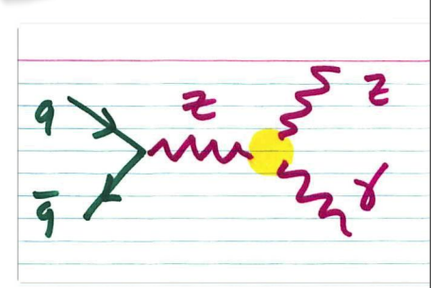
PRL 100, 241805 (2008)

Zγ PRODUCTION

fit for anomalous, neutral TGC







CDF preliminary

$Z \to ee$ (1 fb^{-1}) $\mu\mu$ (2 fb^{-1})

E_T(lep) > 20 GeV

M_{ll} > 40 GeV

CDF: 4.6 ± 0.2 (stat) ± 0.3 (syst) ± 0.3 (lum) pb

CDF ISR region ($M_{ll\gamma}$>100 GeV/c^2): 1.2 ± 0.1 (stat) ± 0.2 (syst) ± 0.1 (lum)

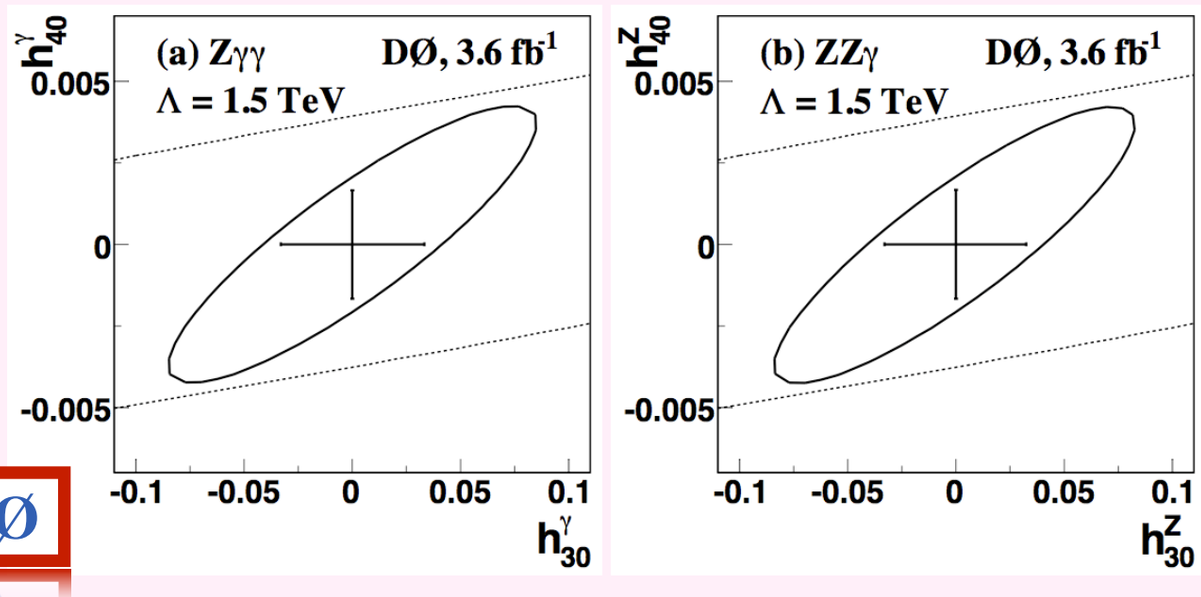
NLO theory: 4.5 ± 0.4 pb

NLO theory ISR region: 1.21 ± 0.10 pb

ANOMALOUS Zγ, Zγγ

DI-LEPTONS (CDF) AND DI-NEUTRINOS (CDF,DØ)

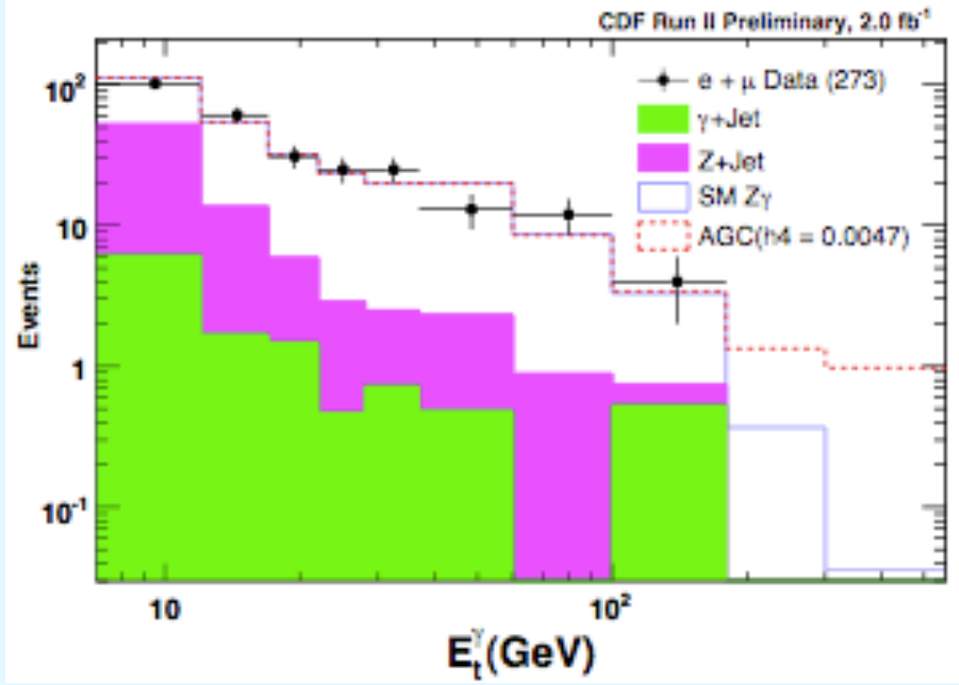
PRL 102, 201802 (2009)



DØ

Z(νν)+γ data

3.6 fb^{-1}, $E_T(\gamma)$>90 GeV; MET>70 GeV, jet & track veto



CDF

Z(*ll*)+γ and Z(νν)+γ data

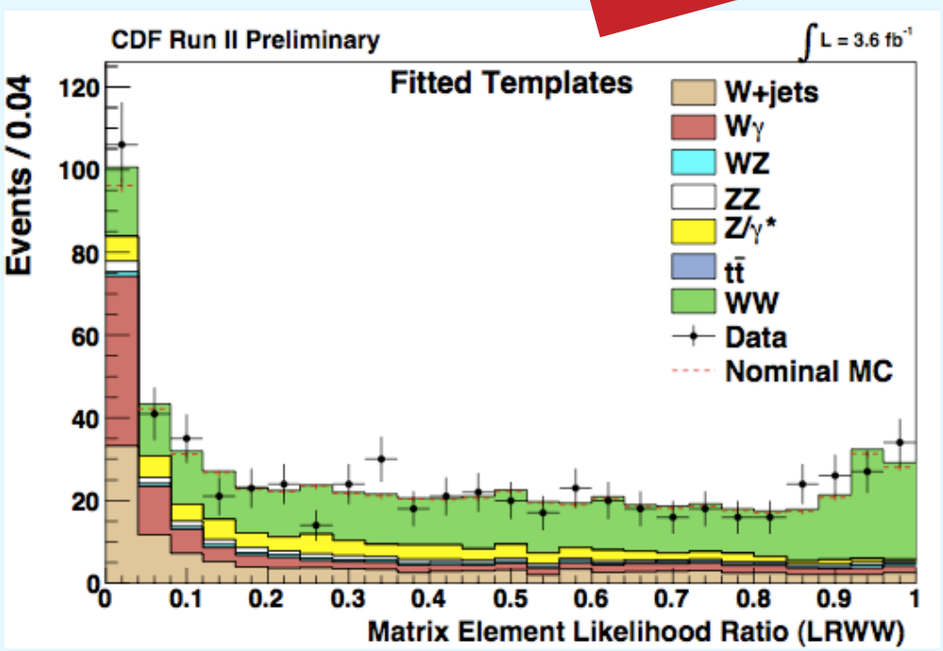
Z(νν)+γ : 2 fb^{-1}, $E_T(\gamma)$>90 GeV; MET>50 GeV,

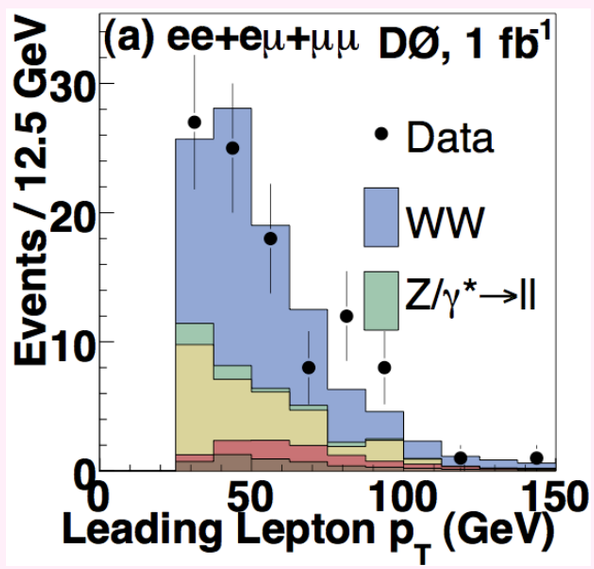
jet & track veto

	CDF	D0	LEP-II
$\|h^Z_3\|$	<0.050	<0.033	-0.2 : 0.07
$\|h^Z_4\|$	<0.0034	<0.0017	-0.05 : 0.12
$\|h^\gamma_3\|$	<0.051	<0.033	-0.049 : 0.008
$\|h^\gamma_4\|$	<0.0034	<0.0017	-0.02 : 0.034

WW AND WZ

☐ WW→ℓνℓν

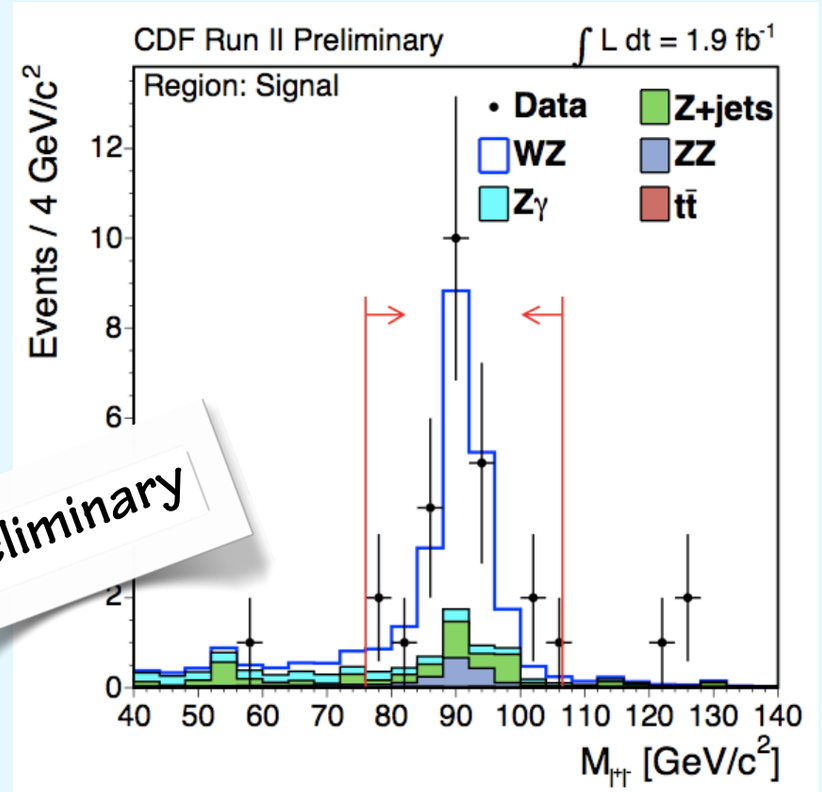




DØ

PRL 103, 191801 (2009)

☐ WZ→Z(ℓℓ)ℓ MET



CDF preliminary

CDF preliminary

CDF: 4.3 +1.3-1.0(stat) ± 0.2(syst) ± 0.3(lum) pb
NLO theory: 3.7 ± 0.3 pb

CDF 1.1 fb-1: PRL 98,161801
D0 1.0 fb-1: PRD 76, 111104

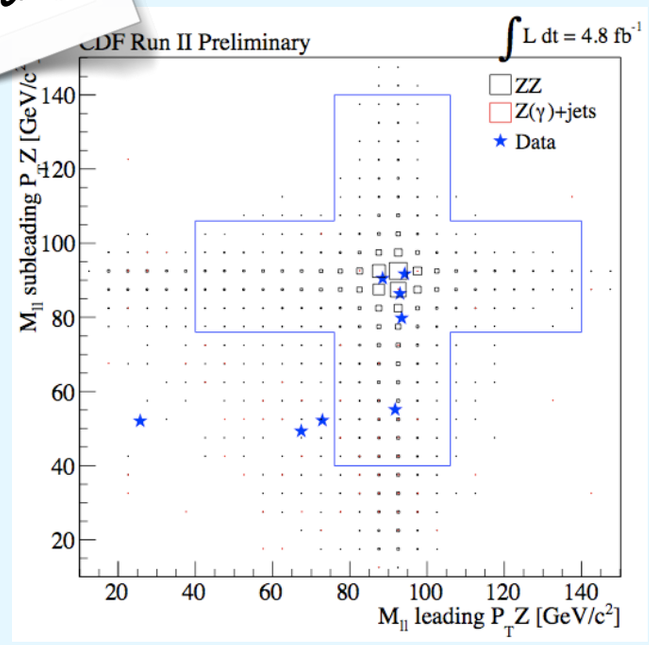
CDF: 12.1 ± 0.9 (stat) +1.6 -1.4 (syst) pb
DØ: 11.5 ± 2.1 (stat+syst) ± 0.7 (lum) pb

NLO theory: 11.66 ± 0.70 pb

FIRST OBSERVATIONS

- $ZZ \to 4\ell$ smallest σ

CDF preliminary



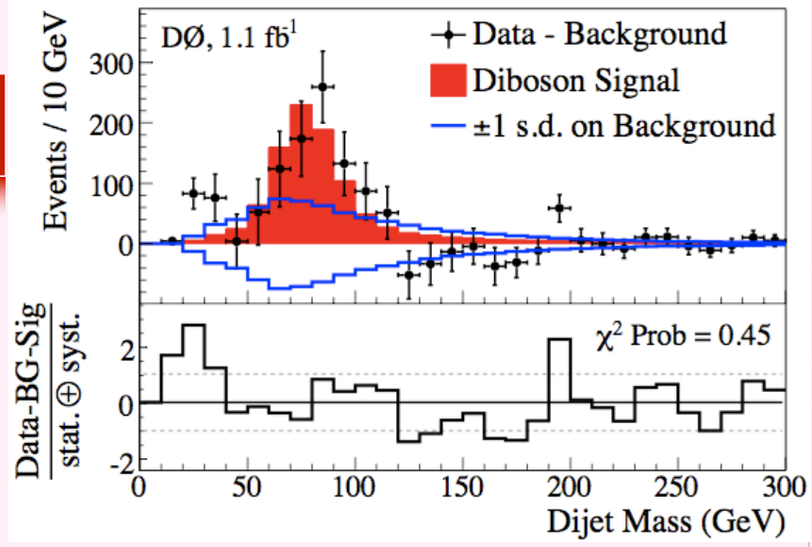
Events in $\mathcal{L} = 4.8\ fb^{-1}$	
Signal	$4.68 \pm 0.02(stat.) \pm 0.76(syst.)$
$Z(\gamma)$+jets	$0.041 \pm 0.016(stat.) \pm 0.029(syst.)$
Total expected	$4.72 \pm 0.03(stat.) \pm 0.76(syst.)$
Observed	**5**

$$\sigma_{p\bar{p}\to ZZ} = 1.56^{+0.80}_{-0.63}(stat.) \pm 0.25(syst.)\ \ pb$$

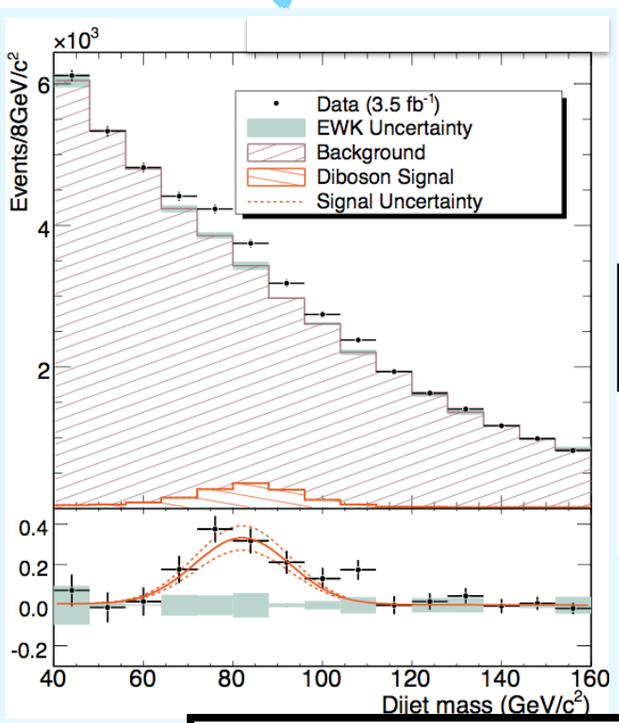
$$\sigma_{p\bar{p}\to ZZ-Th} = 1.4 \pm 0.1(stat. + syst.)\ \ pb$$

- $VV \to MET + jj$
- $WW+WZ \to \ell\nu + jj$

DØ



20.2±2.5(stat)±3.6(syst)±1.2(lum) pb
NLO theory: 16.1±0.9 pb

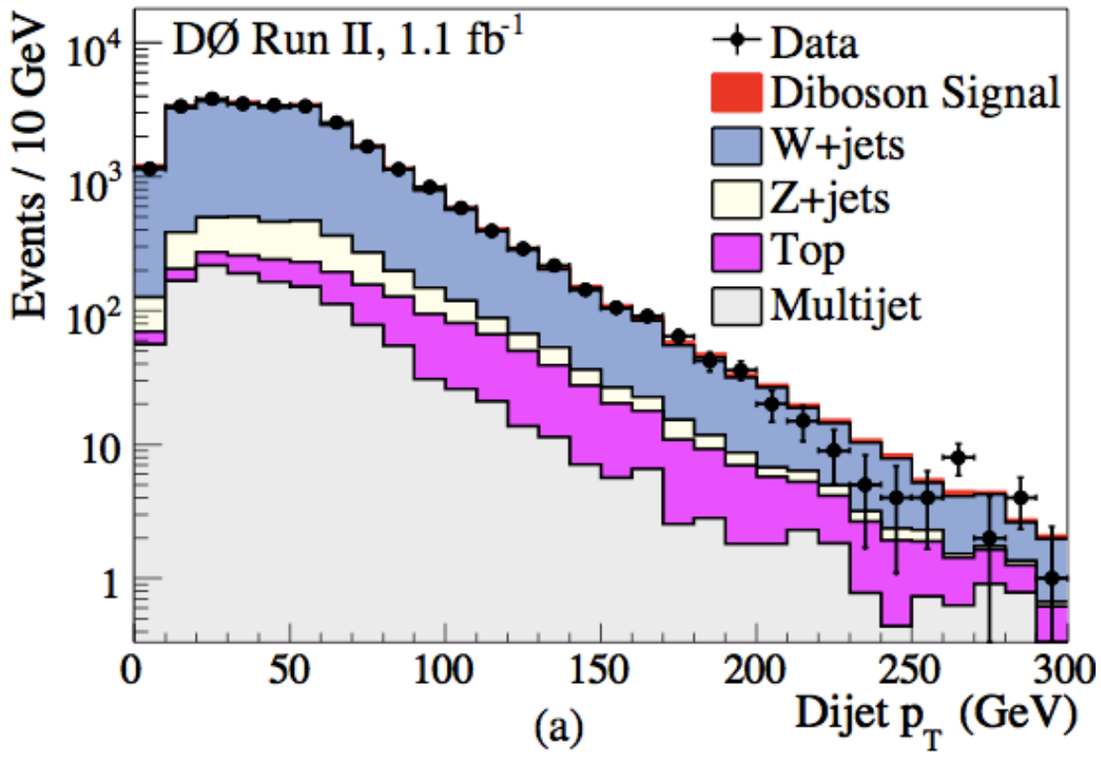


CDF

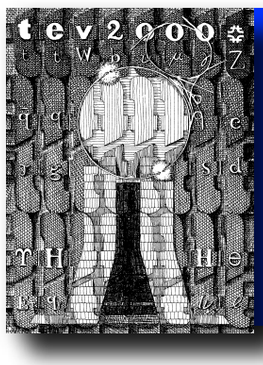
18.0 ± 2.8(stat) ± 2.4(syst) ± 1.1(lum) pb
NLO theory: 16.8±0.5 pb

COMBINED LIMITS with W

- COMBINATION OF 4 CHANNELS:
  - WW+WZ→ℓν+jj (1.1 fb^{-1})
  - WW→ℓνℓν (1 fb^{-1})
  - WZ→ℓνℓℓ (1 fb^{-1})
  - Wγ→ℓνγ (0.7 fb^{-1})
- MOST STRINGENT
  - TGC results
  - μ_W and Q^e_W moments
  - LEP-level precision



PRD 80, 053012



1fb^{-1}: δ Δkγ ± 0.4
10fb^{-1}: δ Δkγ ± 0.3
1fb^{-1}: δ Δ λ ± 0.2
10fb^{-1}: δ Δ λ ± 0.1

	"LEP parameterization	ZWW = γWW
Δk_γ	$0.07\ ^{+0.26}_{-.029}$	(= k_Z) 0.04 ± 0.11
$\lambda = \lambda_\gamma = \lambda_Z$	0.00 ± 0.06	0.00 ± 0.06
Δg_1^Z	0.04 ± 0.09	NA
μ_W	$2.02\ ^{+0.08}_{-.009}$	
Q^e_W	1.00 ± 0.09	

1/2-WAY POINT CONCLUSION 3

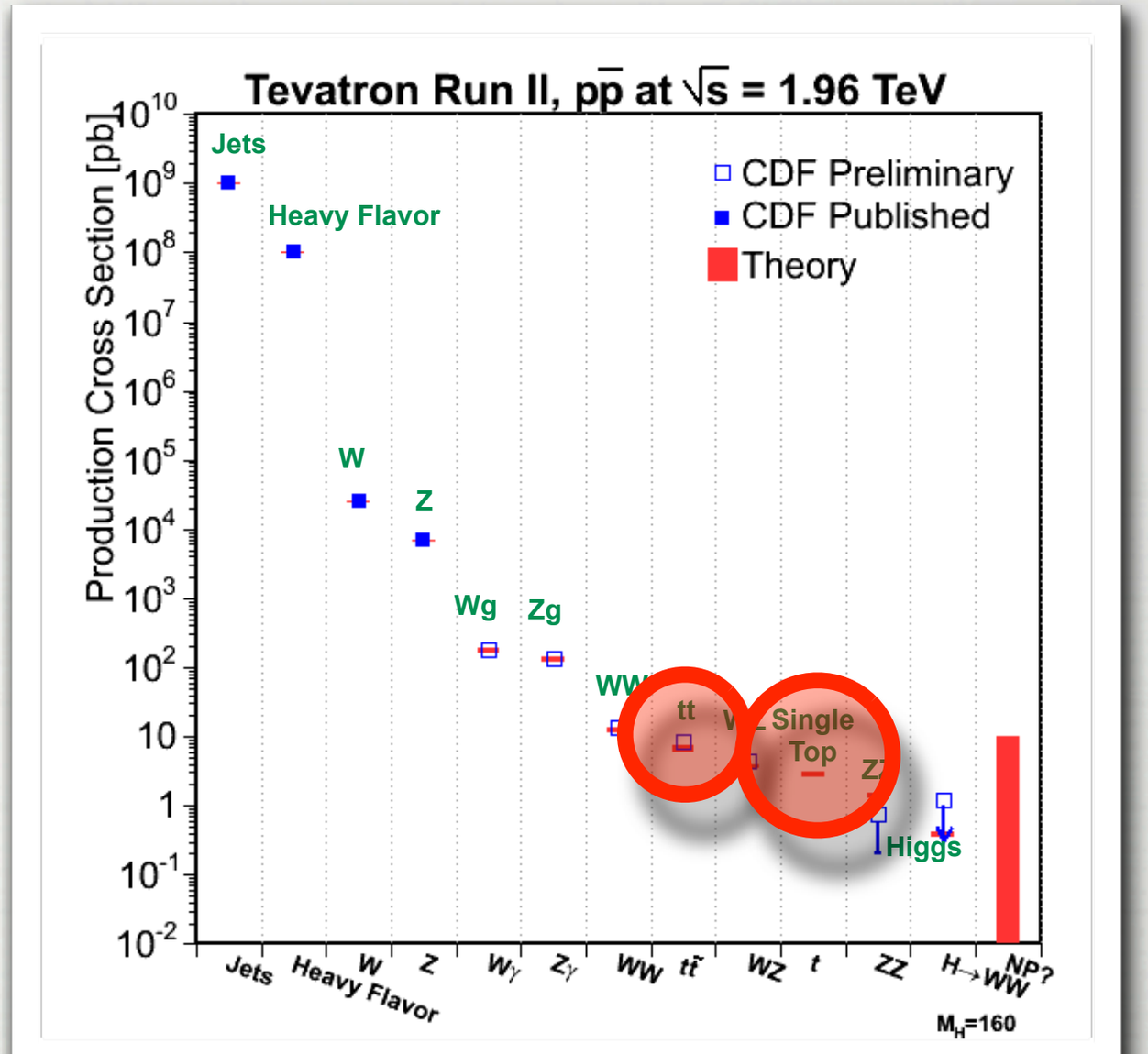
HADRON COLLIDER PHYSICS OF IVBs

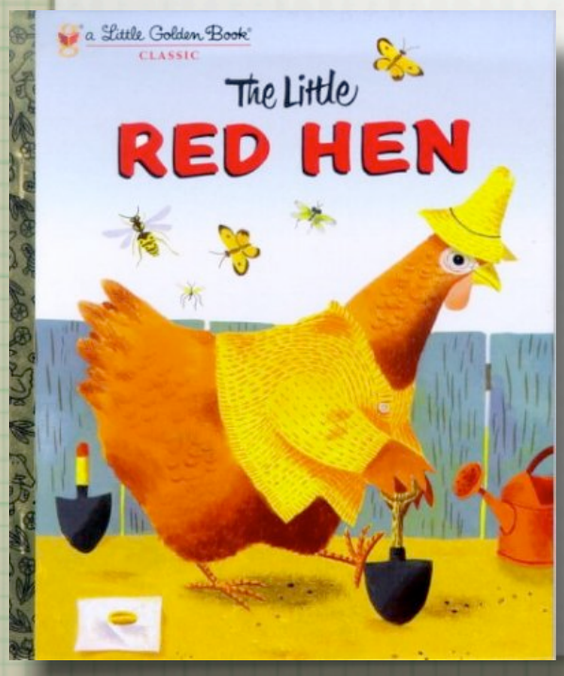
IS NOW AN ULTRA-PRECISION SCIENCE

TOP QUARK PHYSICS

LABOR OF LOVE
since
1995

- ☐ PRECISION PHYSICS!
- ☐ NON-SM BEHAVIOR
- ☐ NARROWING THE SM WINDOW FOR HIGGS





0.00000002% of anything happening

FNAL planted the seeds
and is currently eating it all by itself

TOP QUARK PHYSICS

- QCD PROCESSES

top mass, all channels

top cross sections, all channels

top width

Vtb - top pairs

helicity correlations

BR to W b

di-top mass distributions

CP checks

top charge

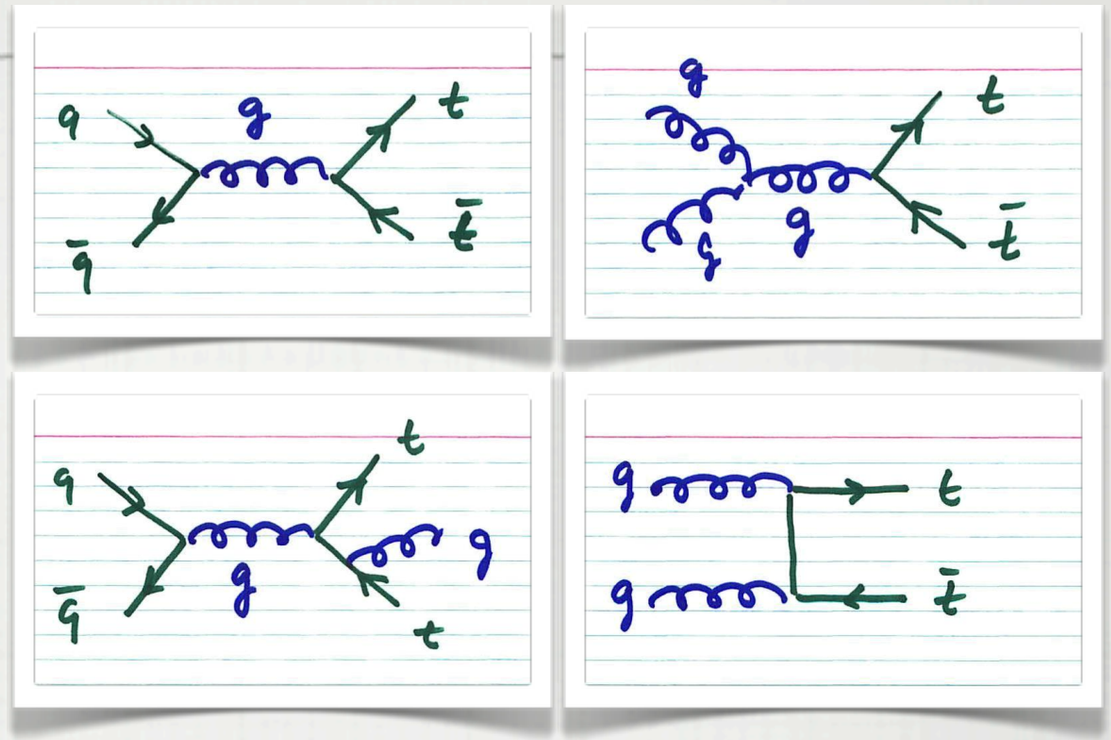
spin decay correlations

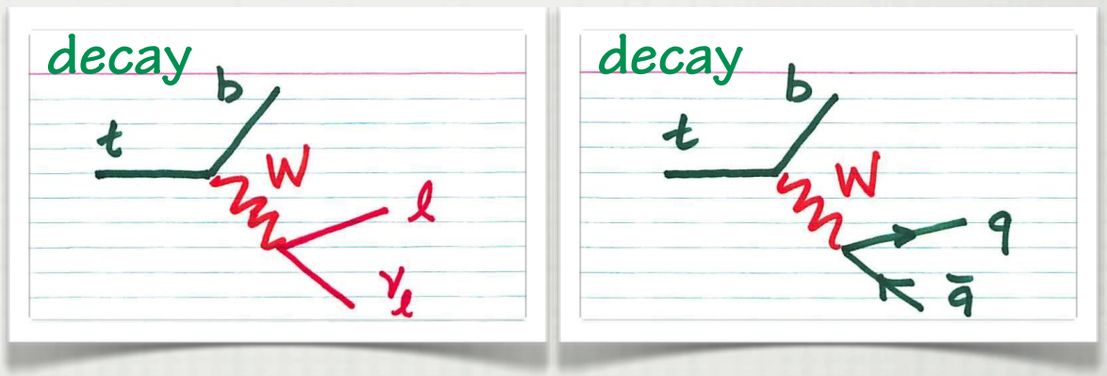
charge asymmetry

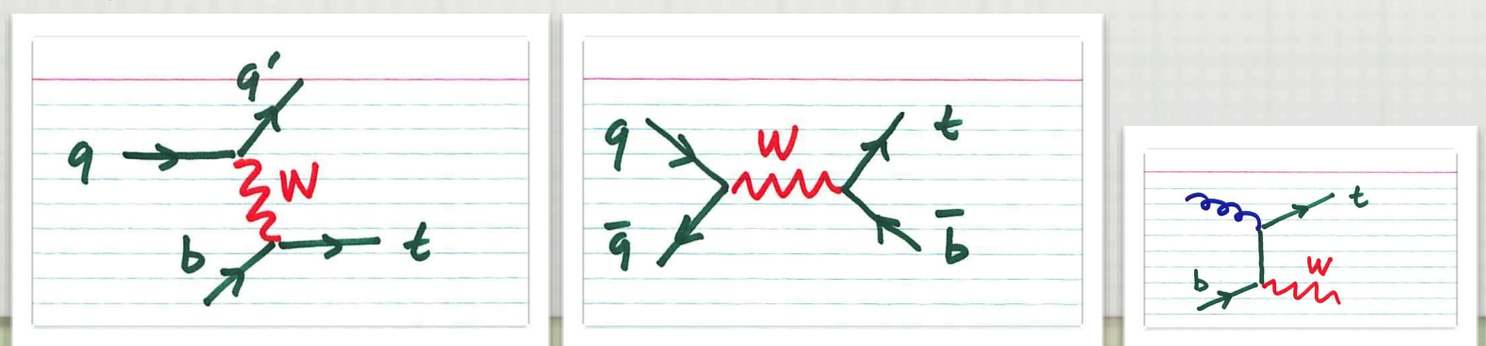
Electroweak top quark production

single top cross sections, both channels

Vtb







TOP QUARK PAIRS

- JOB 1:
  CHARACTERIZATION
  OF THE TOP QUARK

  production

  static properties

- QUANTIFYING THE
  EXPECTED &
  SEARCHING FOR
  SURPRISES

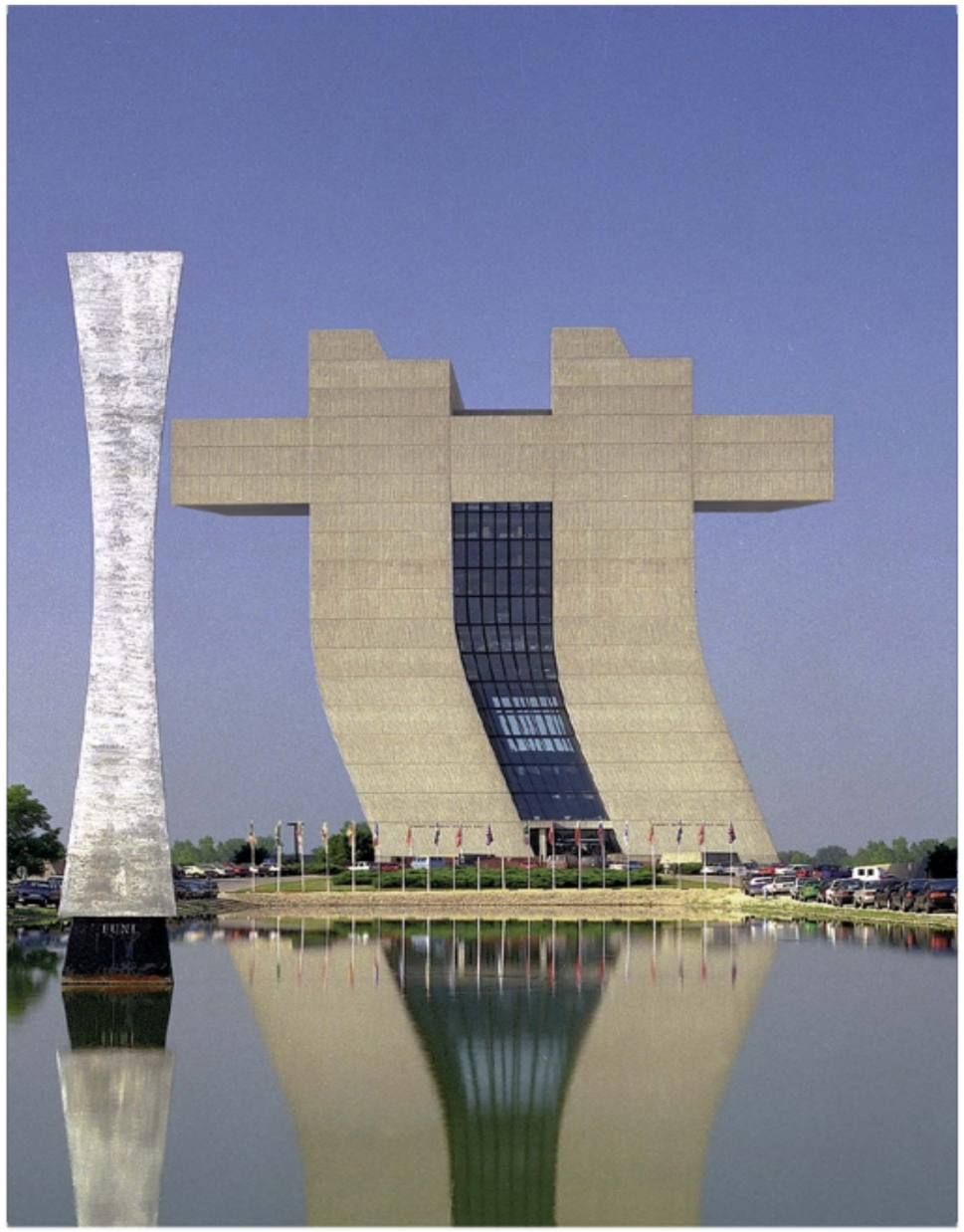


Photo by Reidar Hahn
Artwork by Jan Lueck

tT PRODUCTION

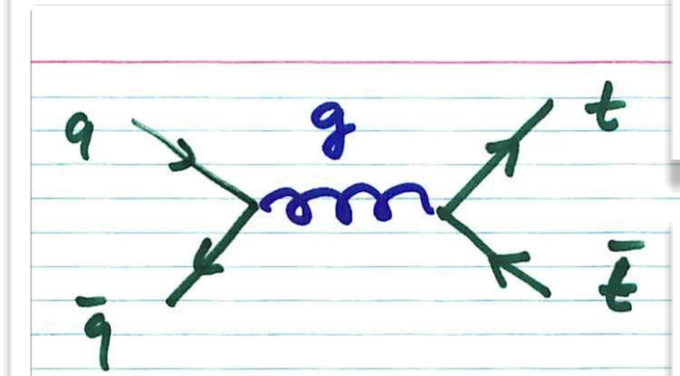
- CROSS SECTION INTO VARIOUS CHANNELS

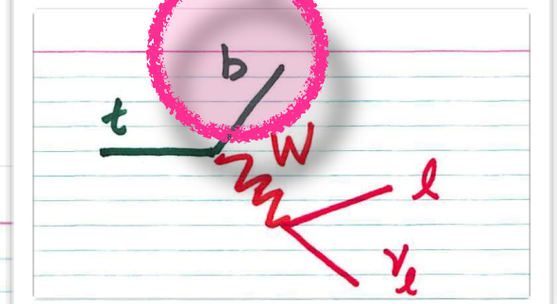
  "counting experiments"

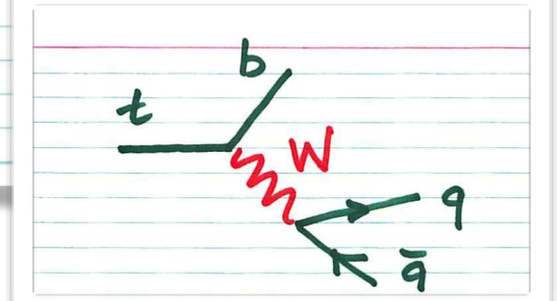
  multivariate analyses

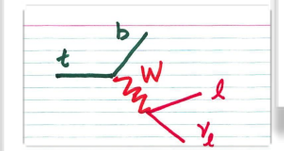
$c\tau$ ~ 450 μm: secondary vertex tagging, 1,2

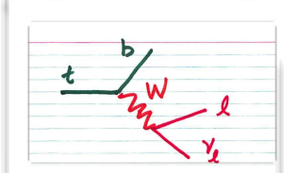
semileptonic B decay: soft lepton in jet

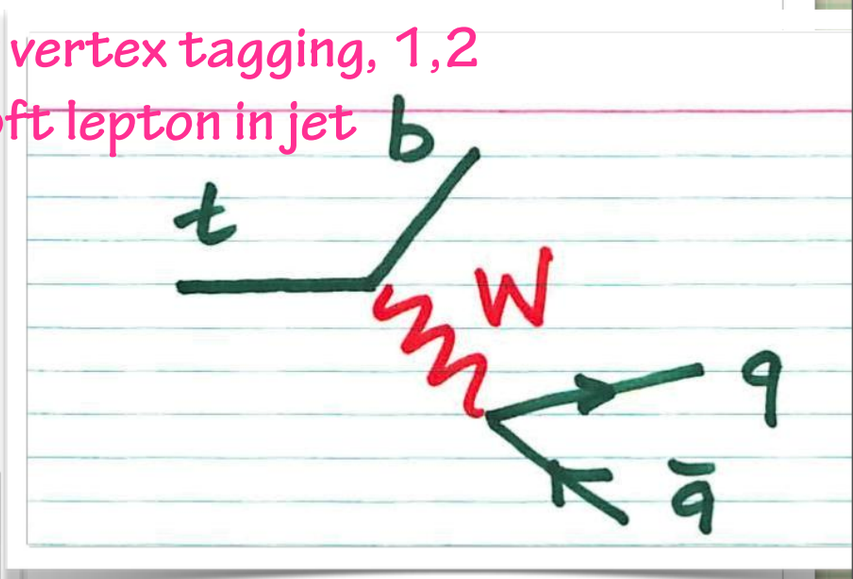


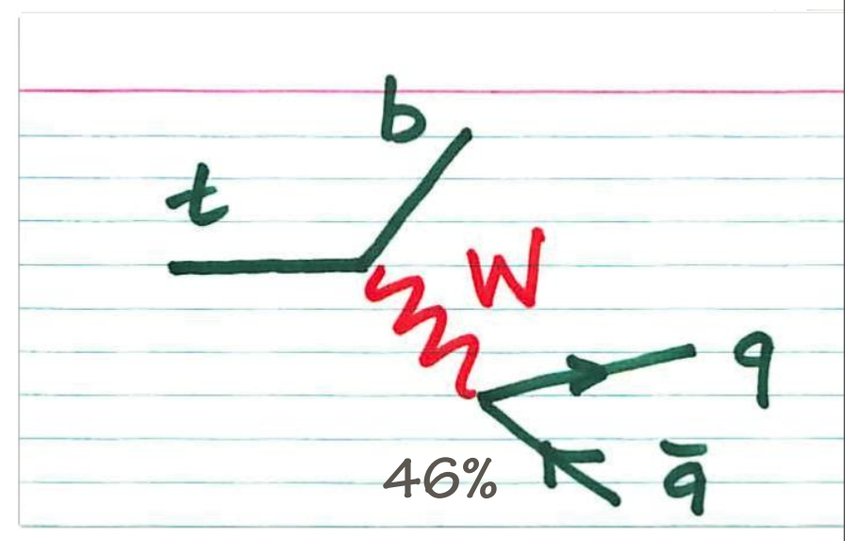












34% lepton+jets

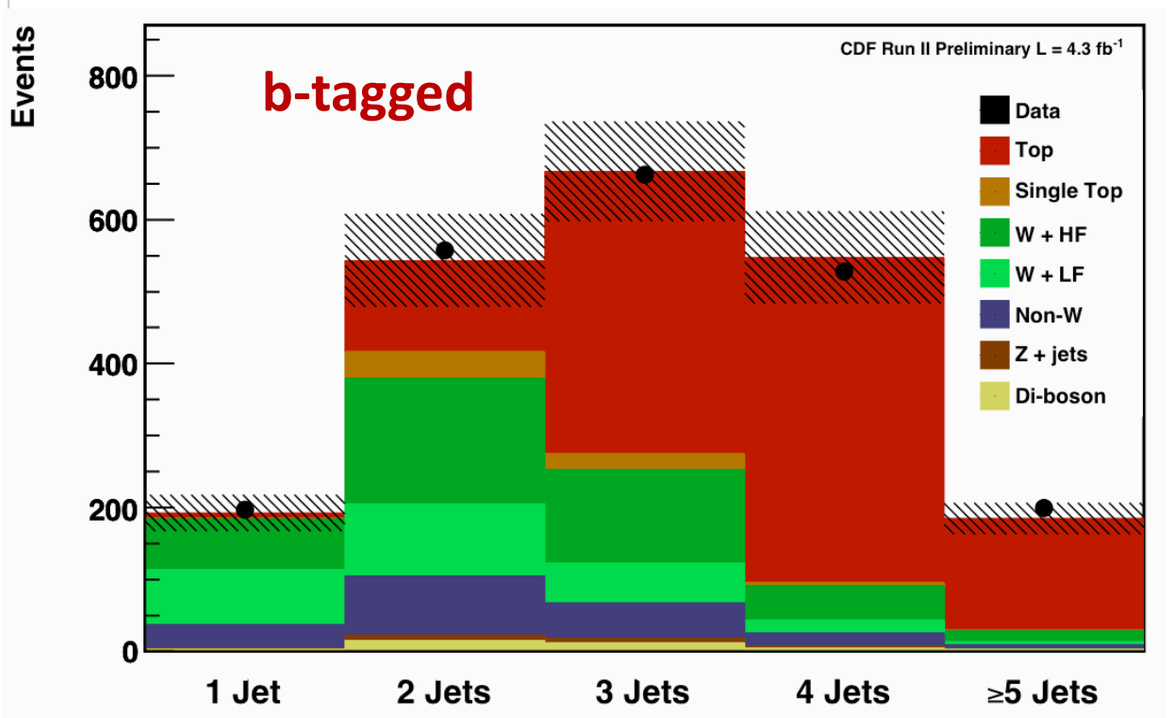
6% dileptons (including t channels)

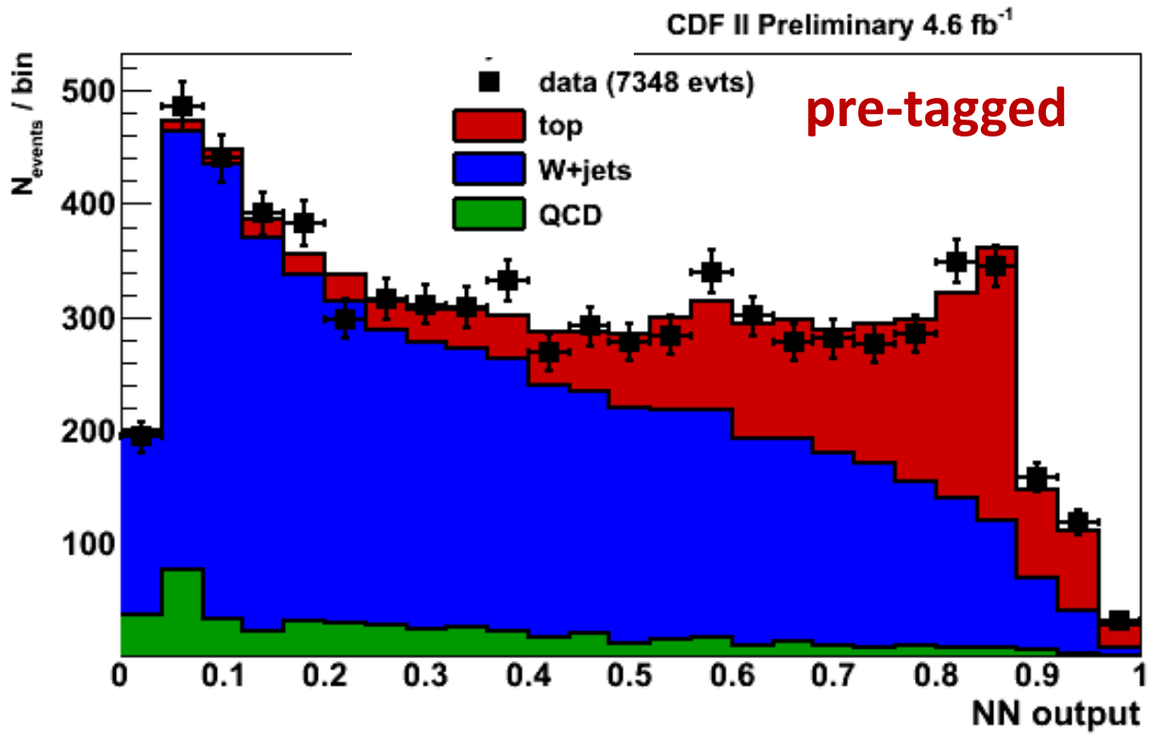
46% all jets

tT PRODUCTION

- CDF LEPTON + JETS, TWO COMPLEMENTARY ANALYSES
  different S/B and systematics

  luminosity *dominates uncertainties–*<u>*normalize to* σ (Z theory)/σ (meas Z)</u>





CDF (4.3 fb^{-1}, m_t= 172.5 GeV), b-tagged:
σ_{tt} = 7.1 ± 0.3(stat) ± 0.6(syst) ± 0.1(Z theory) pb

displaced vertex b-tag
conventional counting analysis

CDF (4.6 fb^{-1}, m_t= 172.5 GeV), pre-tagged:
σ_{tt} = 7.6 ± 0.4(stat) ± 0.4(syst) ± 0.1(Z theory) pb

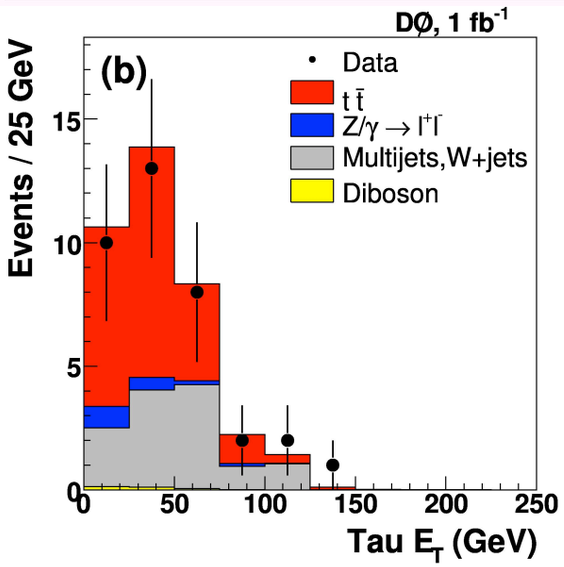
before b-tagging
neural net analysis

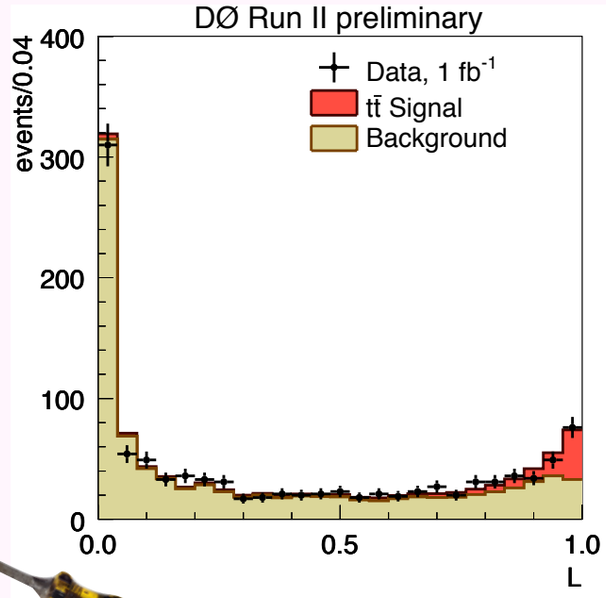
tT PRODUCTION

TAUS & ALL HADRONIC

Tau

σ_{tt}= 7.3 ± 1.3(stat) ± 1.2(syst) ± 0.5(lumi) pb





DØ m_t = 175 GeV

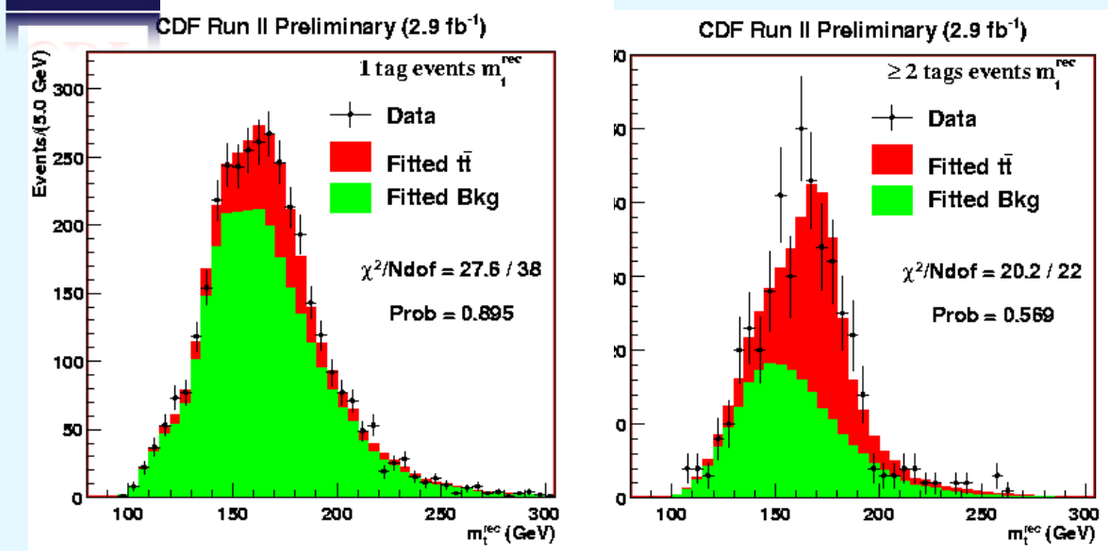
NN, BDT

all Jets

σ_{tt} = 6.9 ± 1.3(stat) ± 1.4(sys) ± 0.4(lumi) pb

CDF m_t = 172.5 GeV

NN, BDT



CDF preliminary, L = 2.9 fb^{-1}			
	Symbol	1 tag	≥ 2 tags
Top mass (GeV/c^2)	M_{top}	$174.8 \pm 2.4^{+1.2}_{-1.0}$	
JES displacement	ΔJES	$-0.3 \pm 0.47^{+0.34}_{-0.37}$	
Observed candidates	n_{obs}	3452	441
Expected background	$n_{(b,exp)}$	2785 ± 83	201 ± 29
Fitted background	$n_{(b,fit)}$	2802 ± 70	220 ± 21
Signal from fit	$n_{(s,fit)}$	643 ± 80	216 ± 25

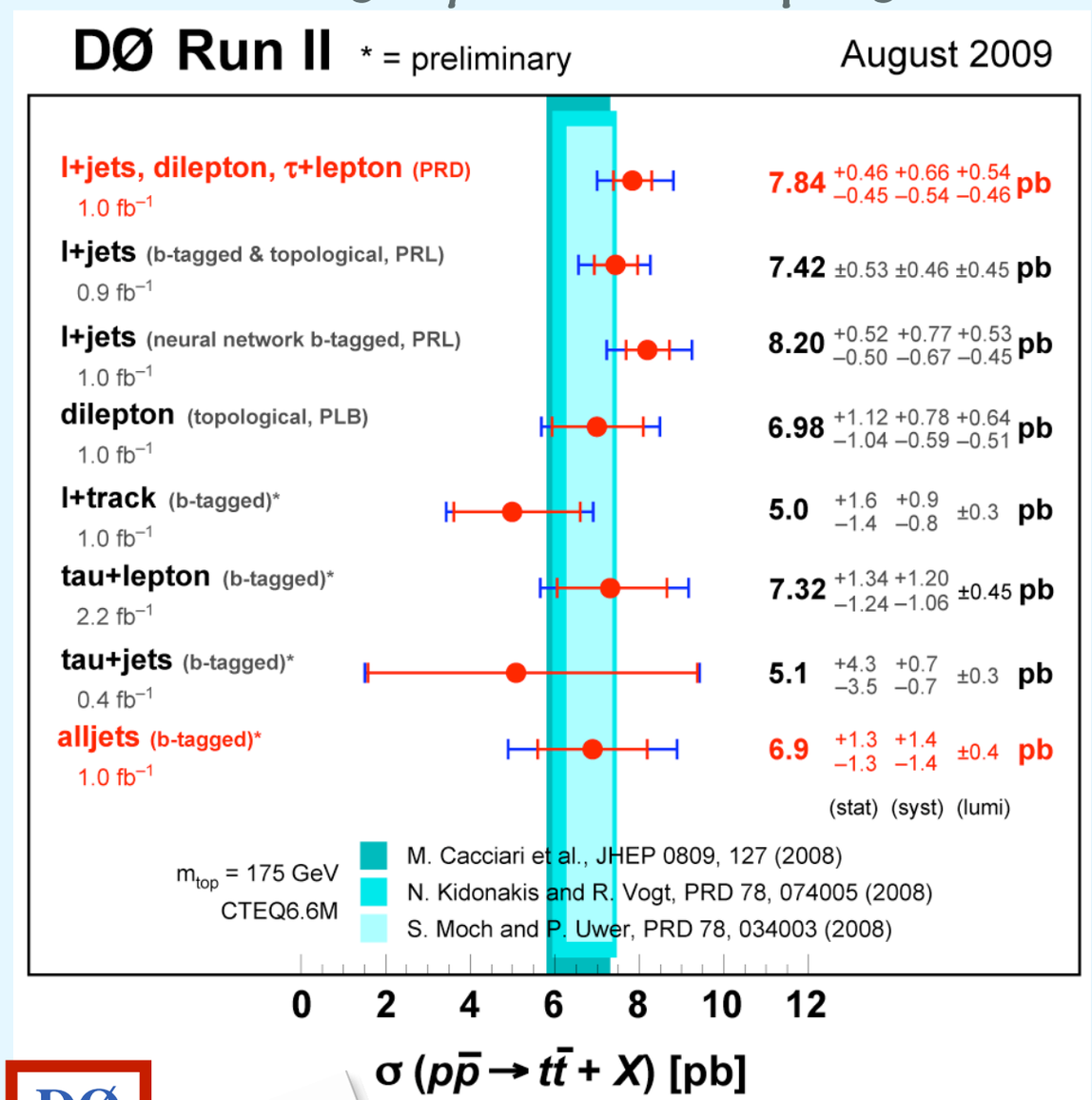
all Jets

σ_{tt} = 7.2 ± 0.5(stat) ± 1.5(syst) ± 0.4(lumi) pb

tT PRODUCTION

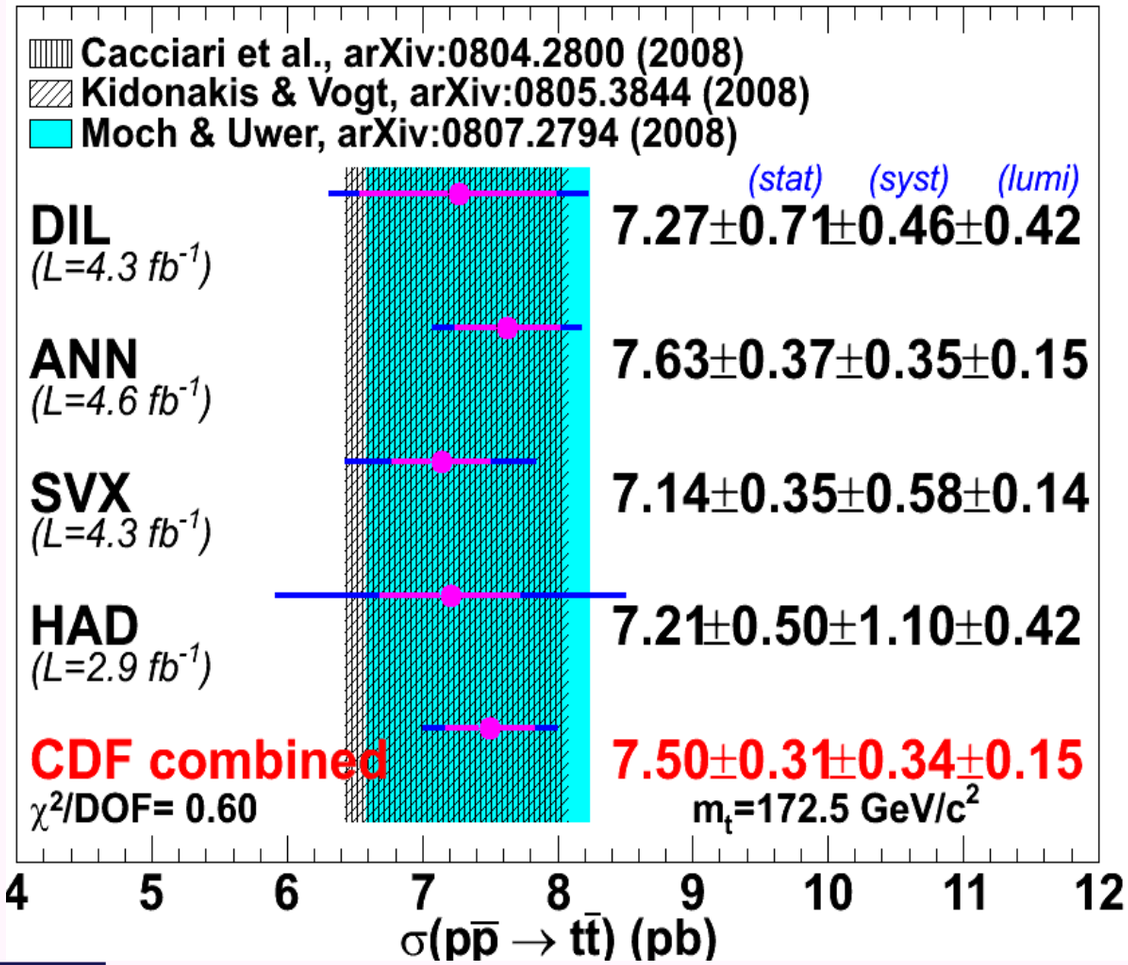
- CHANNELS COMBINED

combining experiments in progress



DØ

preliminary



CDF

top

bottom

charm

strange

down

up

quarks

^{172}YB

electron

neutrinos

leptons

W

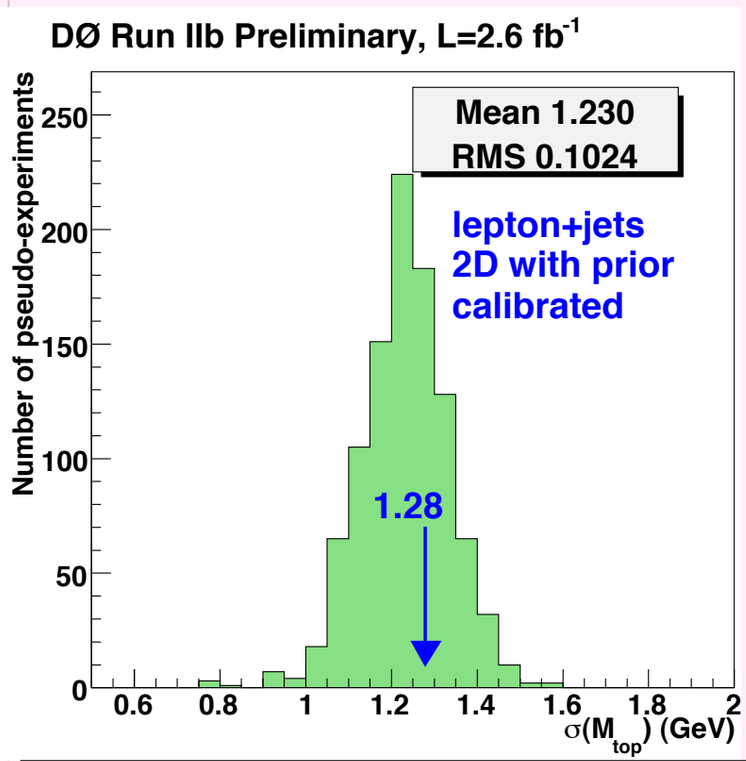
g

γ

Bosons

TOP QUARK MASS

☐ lepton + jets



ME for S & B

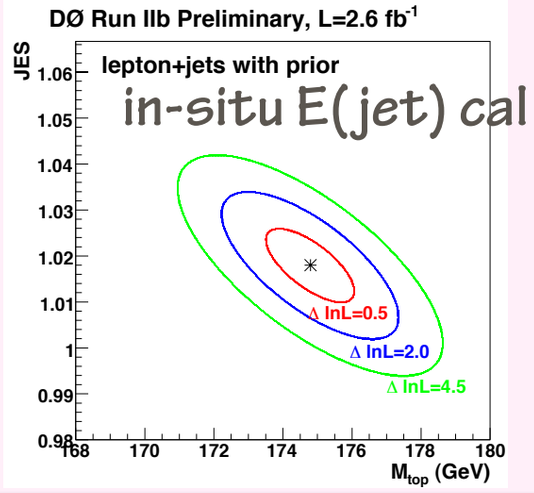
m = 173.7 ± 0.8 (stat) ± 1.6(syst) GeV

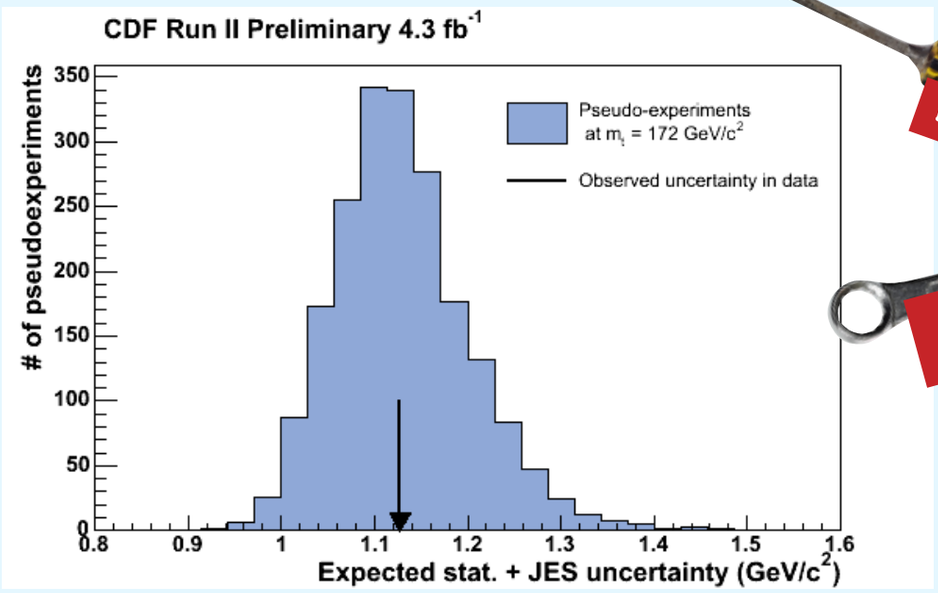
p_T(lep) > 20 GeV, $|\eta|$<1.1(2) e (μ)

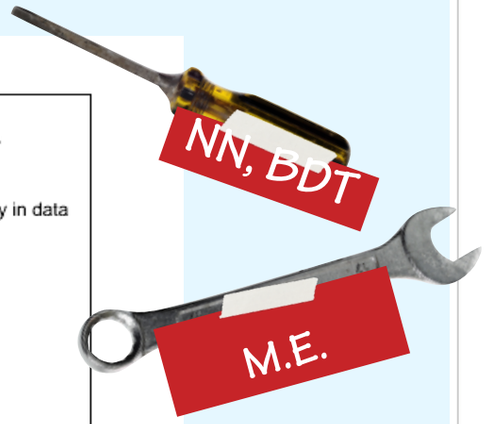
N_J = 4, p_T(jet) > 20 GeV $|\eta|$<2,5

at least 1 jet p_T(jet) > 40 GeV

MET > 20 (25) GeV e (μ)







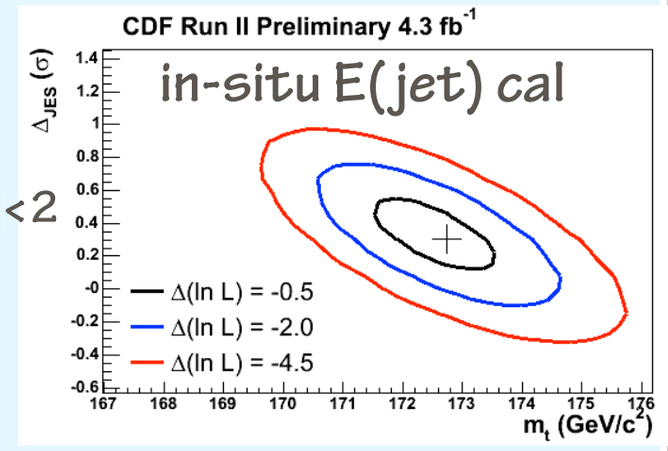
ME for S
NN for B

m = 172.6 ± 0.9 (stat) ± 1.3(syst) GeV

p_T(lep) > 20 GeV, $|\eta|$<1

N_J = 4, p_T(jet) > 20 GeV $|\eta|$<2

MET > 20 GeV



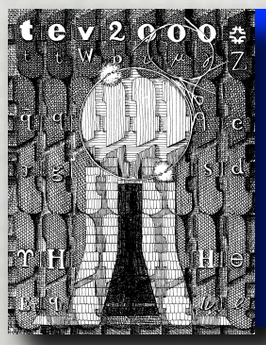
TOP QUARK MASS

- THEY SAID IT COULDN'T BE DONE

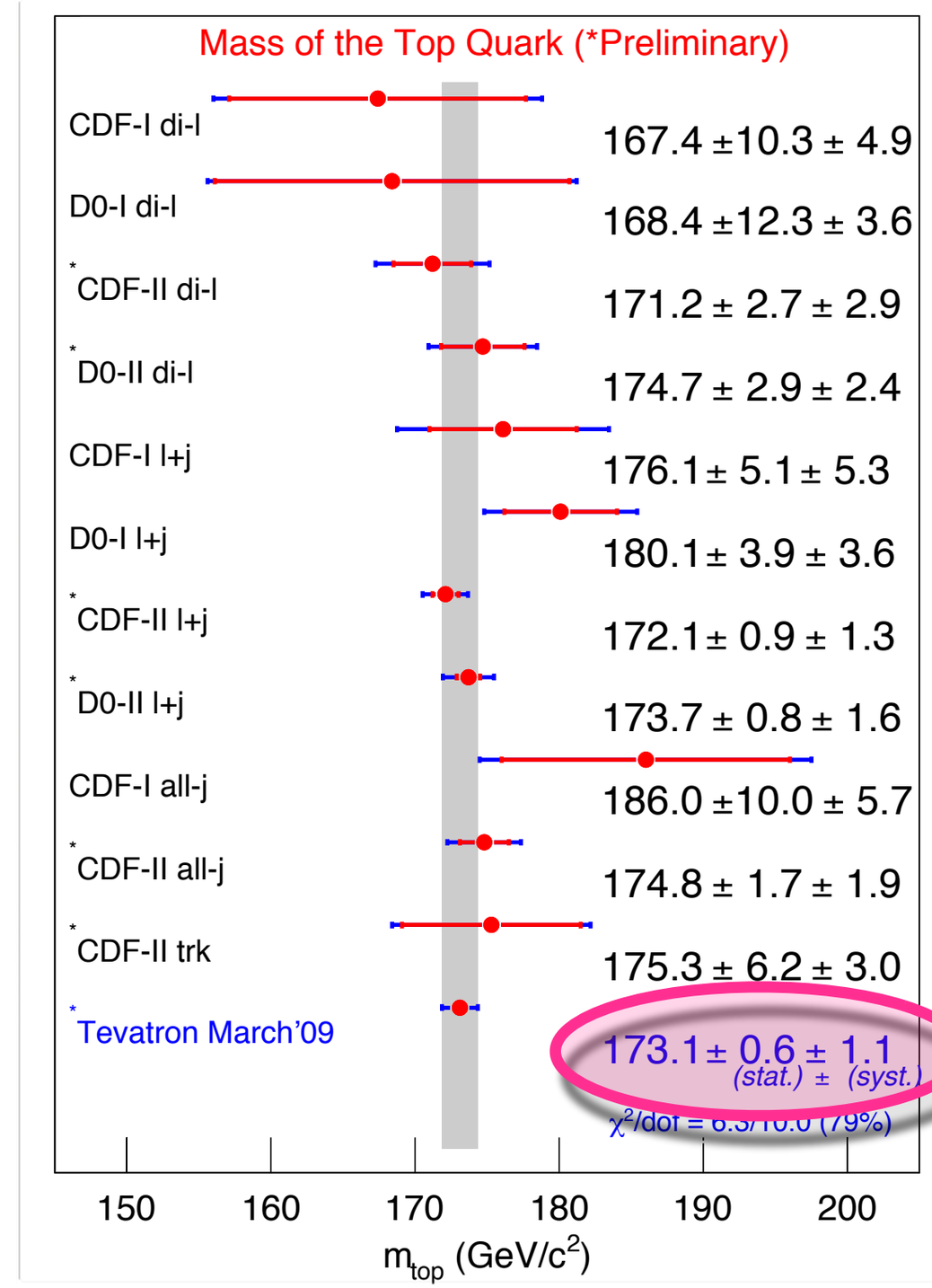
  ultimate FNAL top quark mass precision may be hard to beat-ever

- FUTURE PRECISION

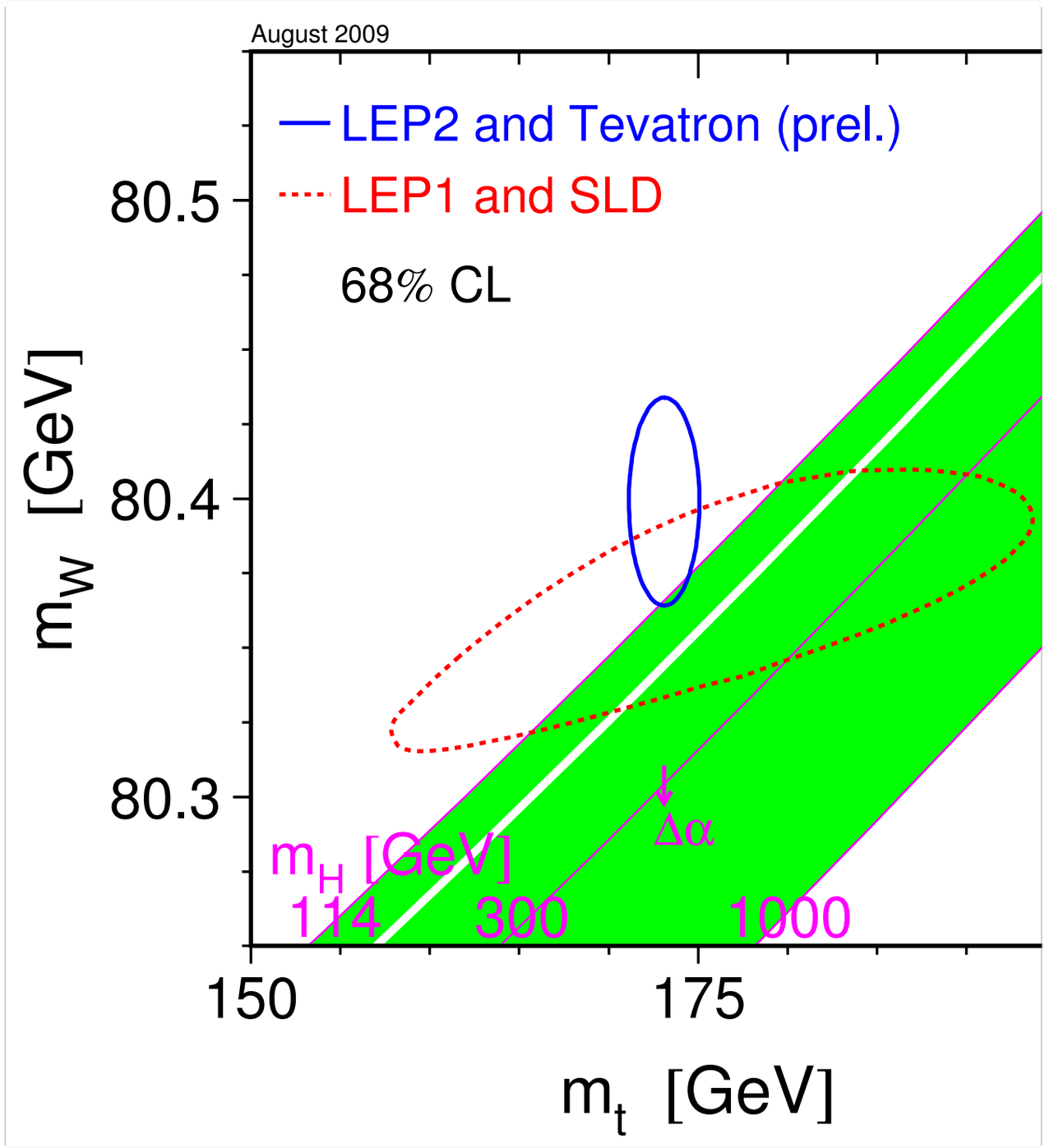
  ± 1 GeV/c^2 per experiment before systematically bottoming out

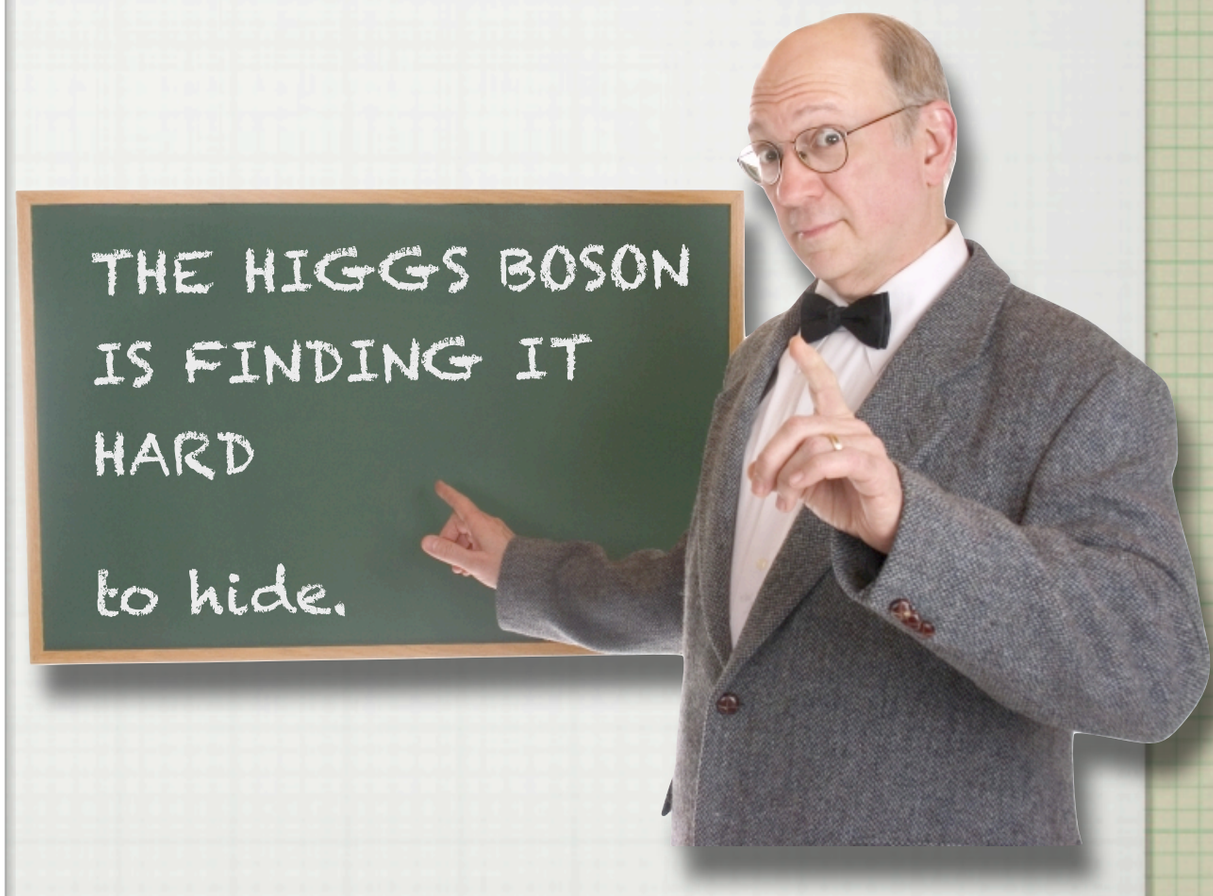


1fb^{-1}: $\delta m_t \sim \pm 4$ GeV/c^2
10fb^{-1}: $\delta m_t \sim \pm 1.3$ GeV/c^2



TOP QUARK: SUMMARY, I

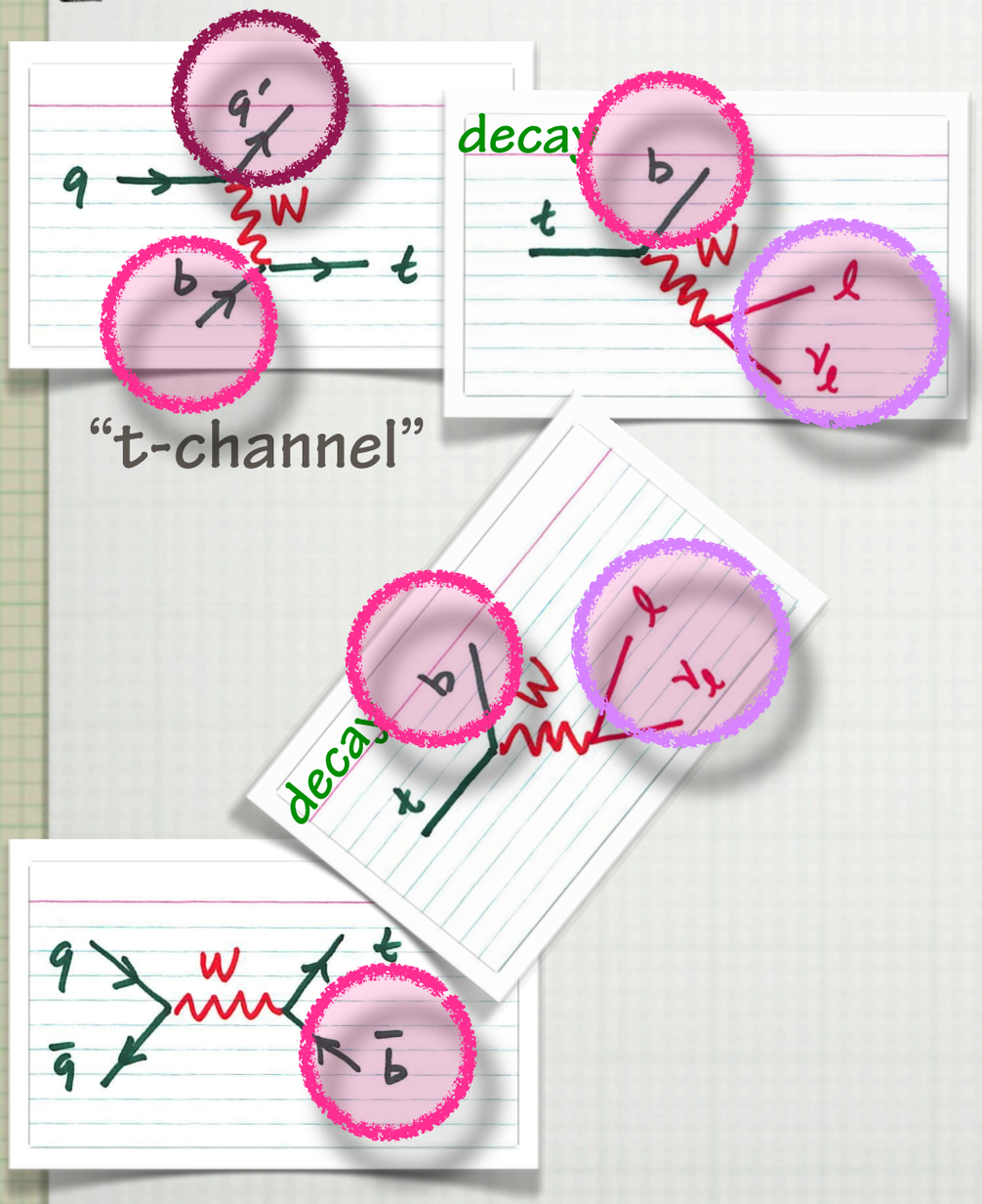




EW TOP QUARK PRODUCTION

AKA "Single Top"

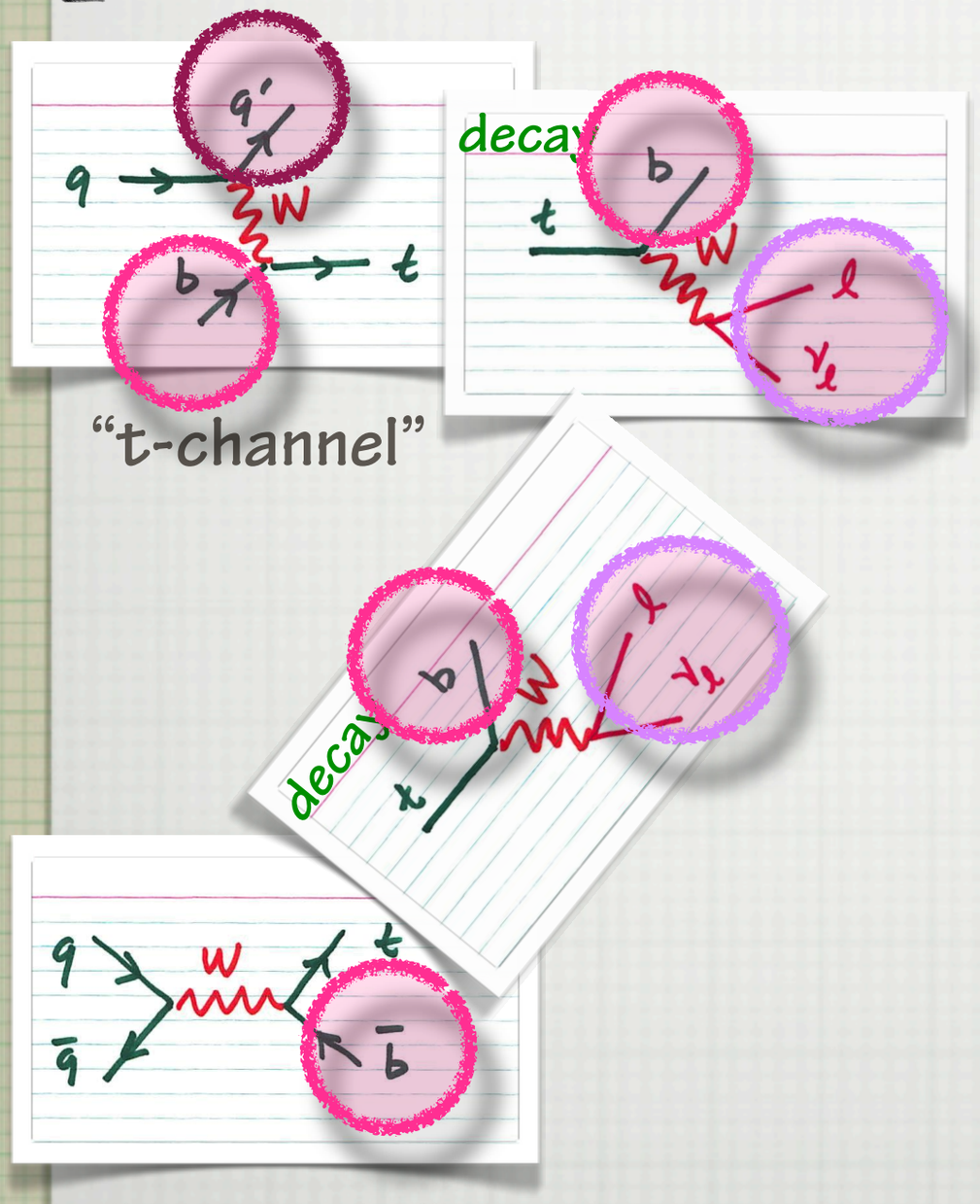
- ANTICIPATED FOR DECADES

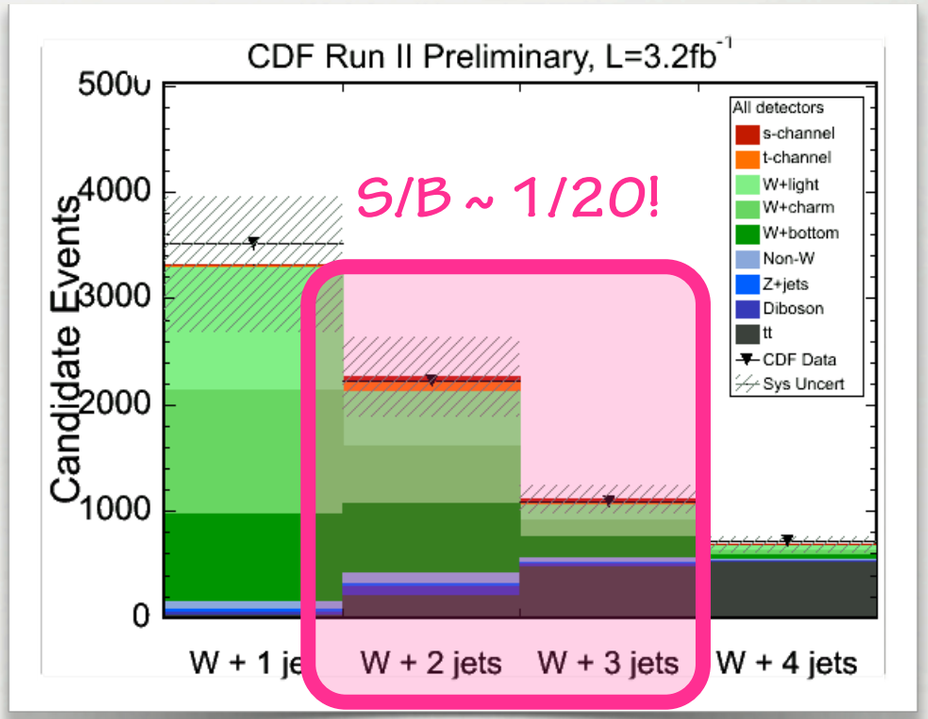


EW TOP QUARK PRODUCTION

AKA "Single Top"

- ANTICIPATED FOR DECADES

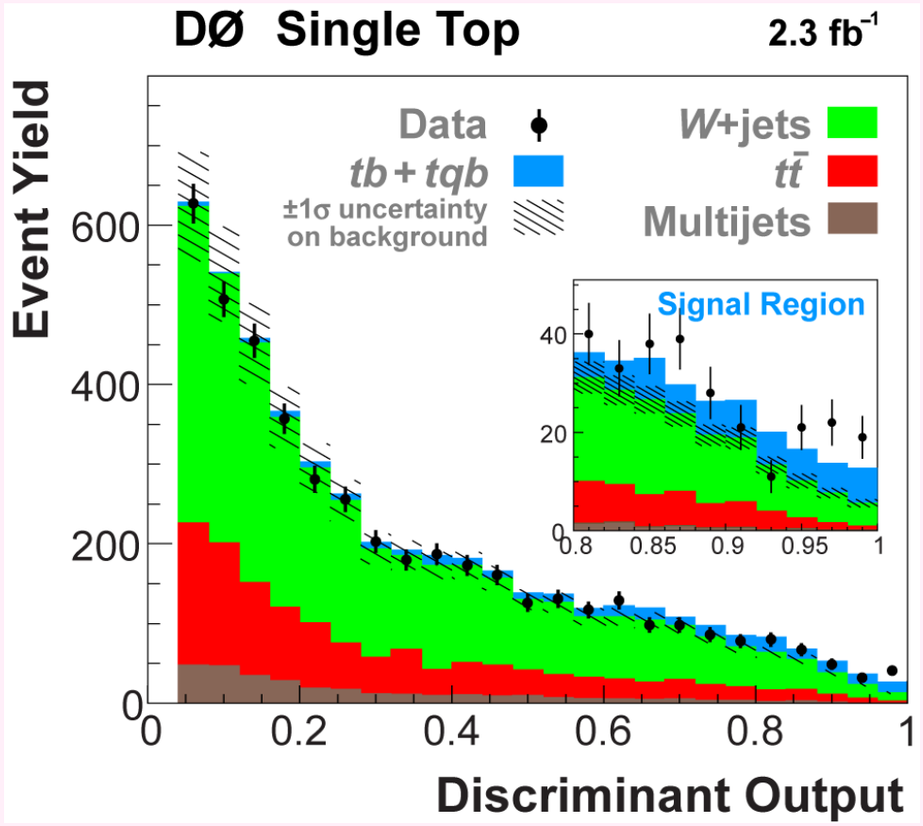




$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

EW TOP QUARK PRODUCTION

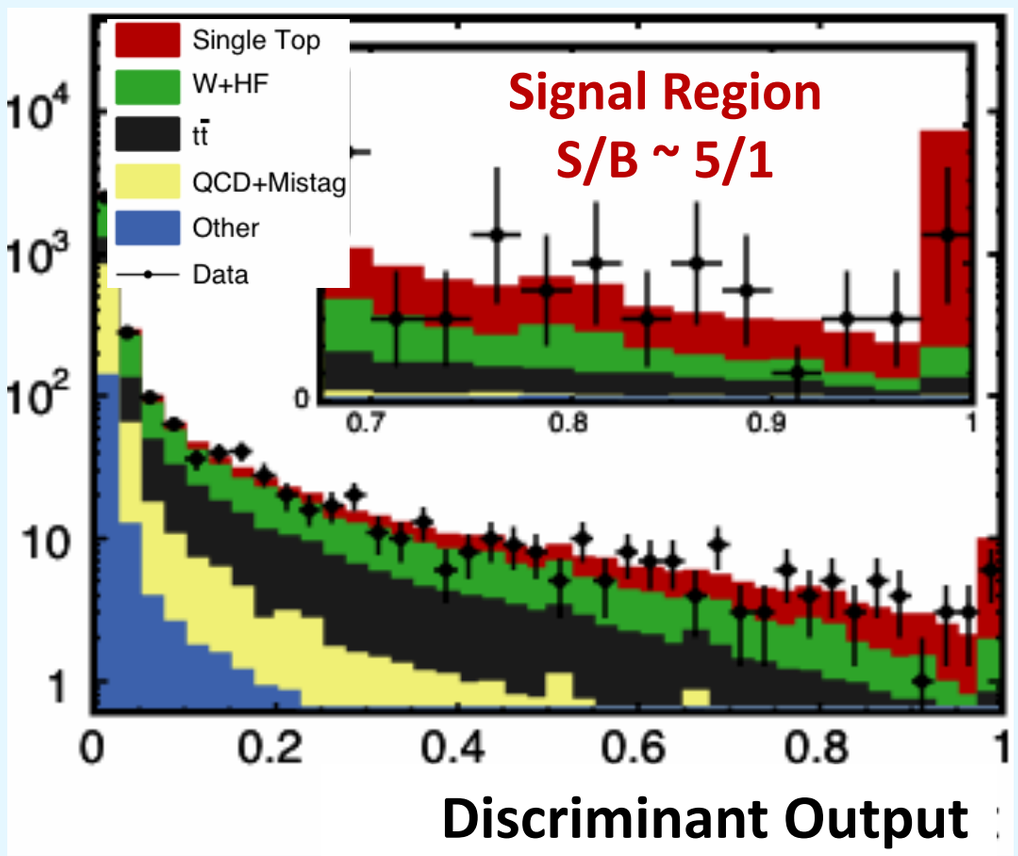
- BOTH EXPERIMENTS HAVE PUBLISHED 5σ "OBSERVATION"



Expected sensitivity: 4.5σ

Observed p-value: 2.5×10^{-7} : 5.0σ

PRL 103, 092001 (2009)



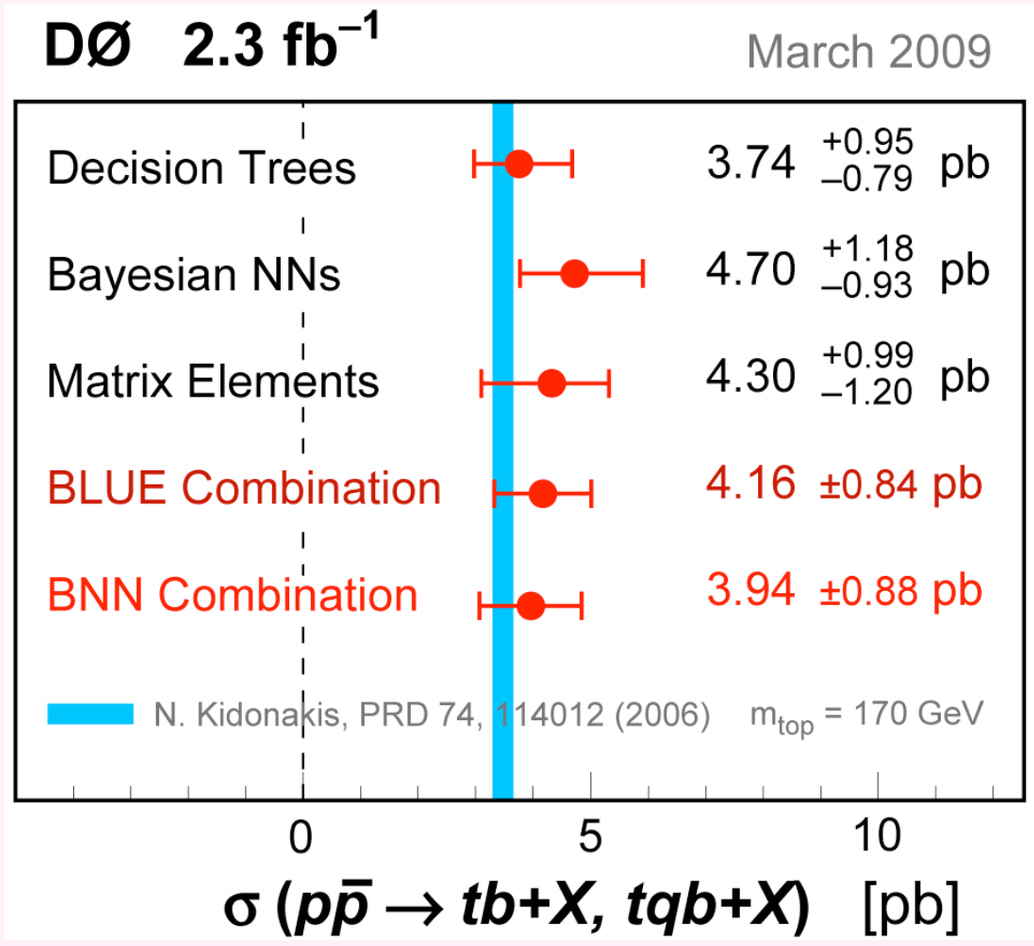
Expected sensitivity: >5.9σ

Observed p-value: 3.1×10^{-7} : 5.0σ

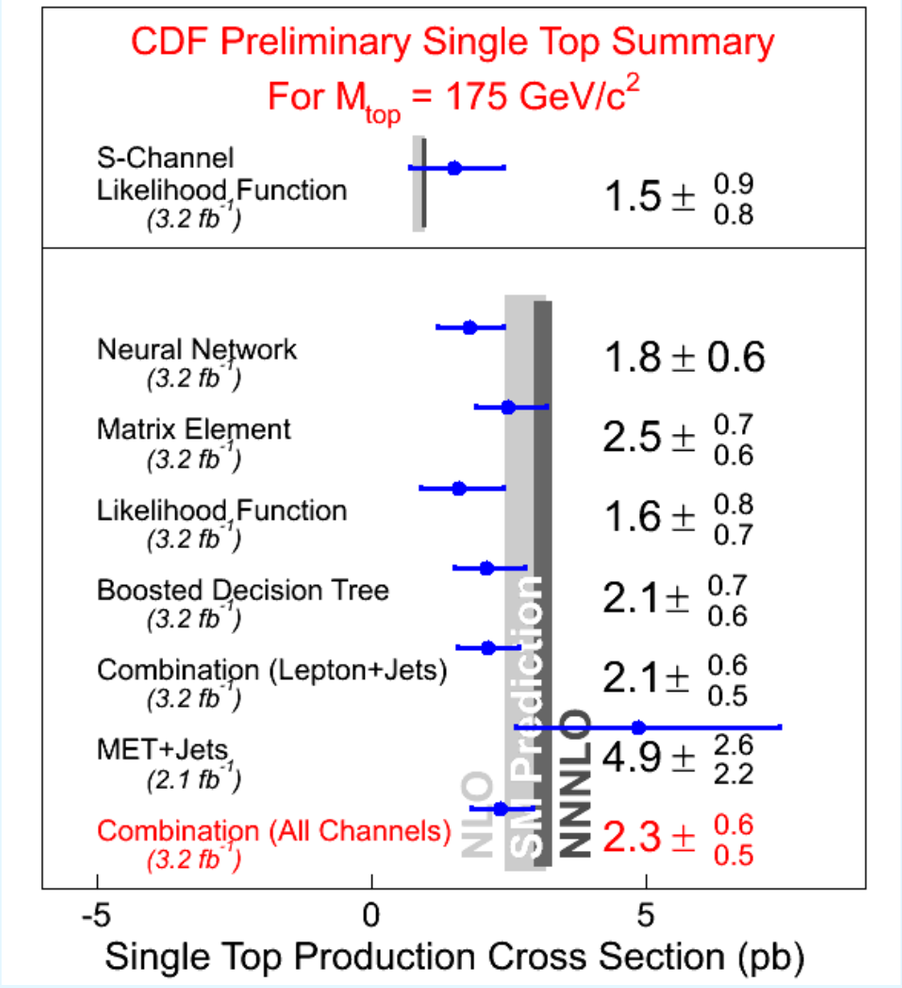
PRL 103, 092002 (2009)

EW TOP QUARK PRODUCTION

CROSS SECTIONS



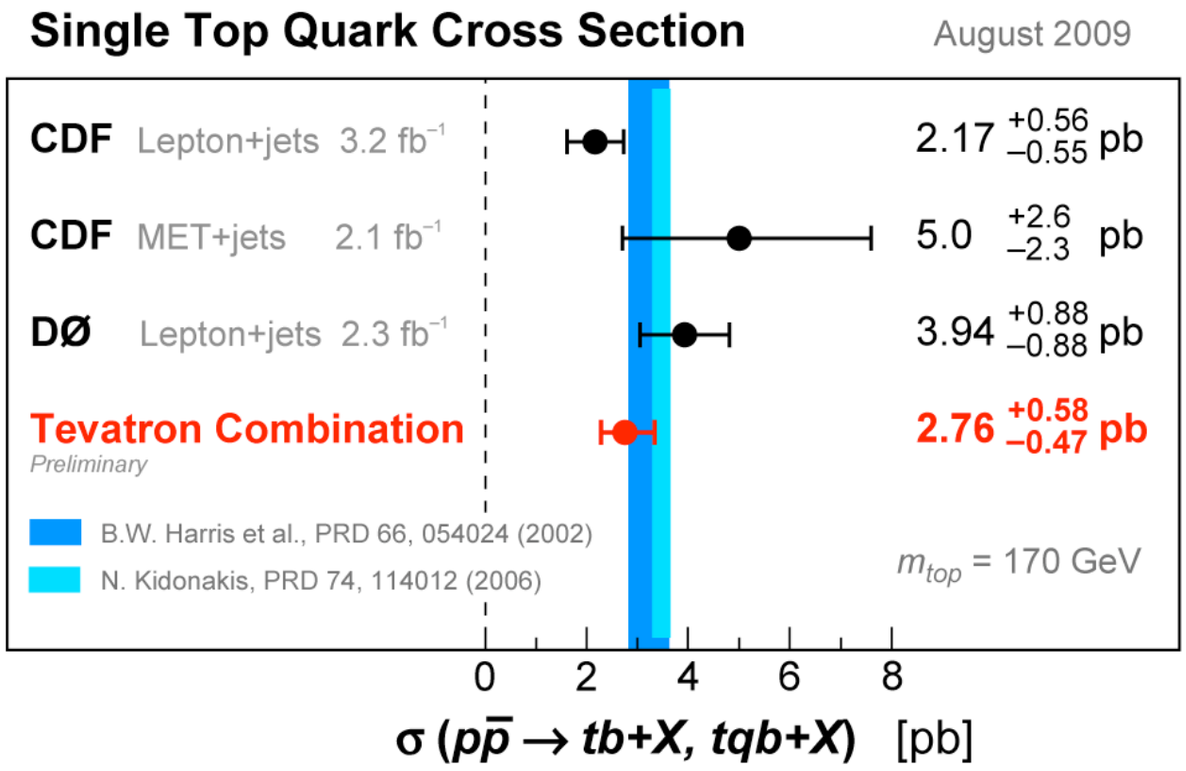
DØ

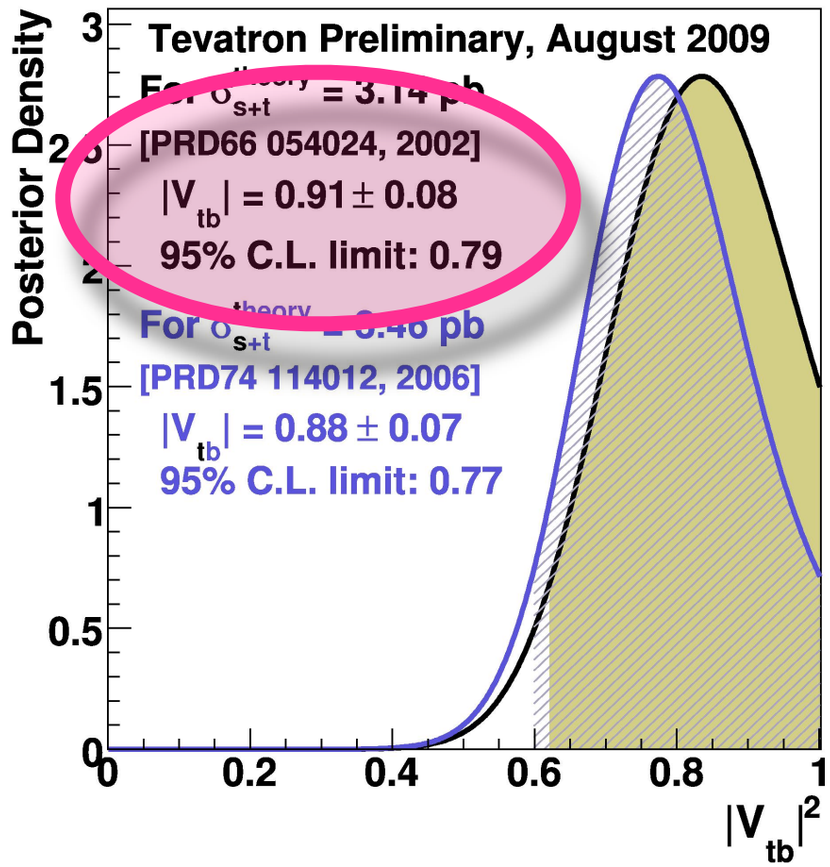


CDF

EW TOP QUARK PRODUCTION

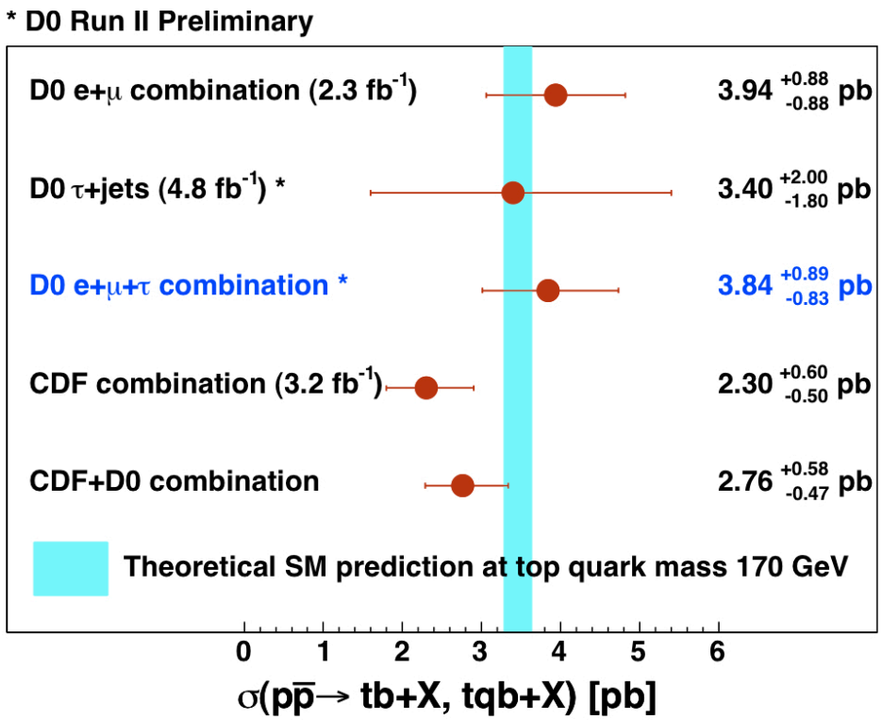
- COMBINED CROSS SECTIONS AND FIRST V_{tb} DETERMINATIONS





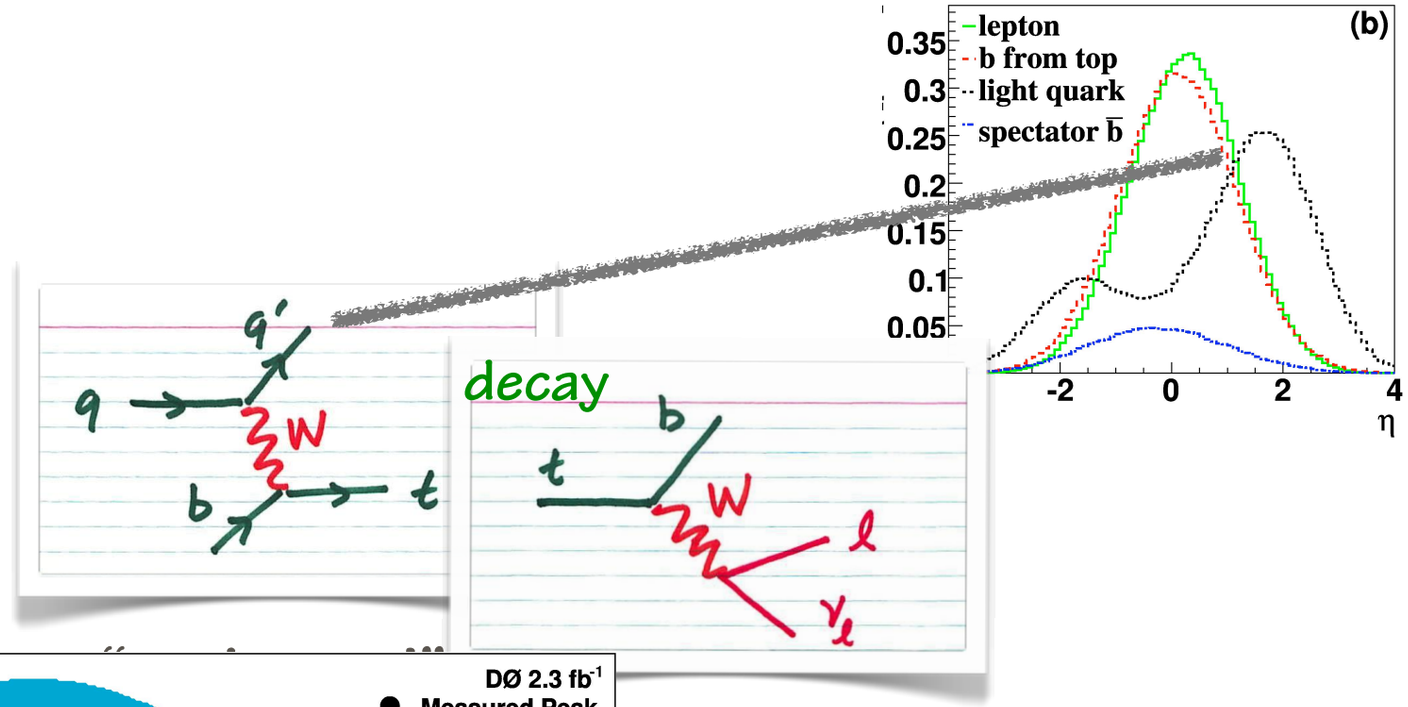
EW TOP QUARK PRODUCTION

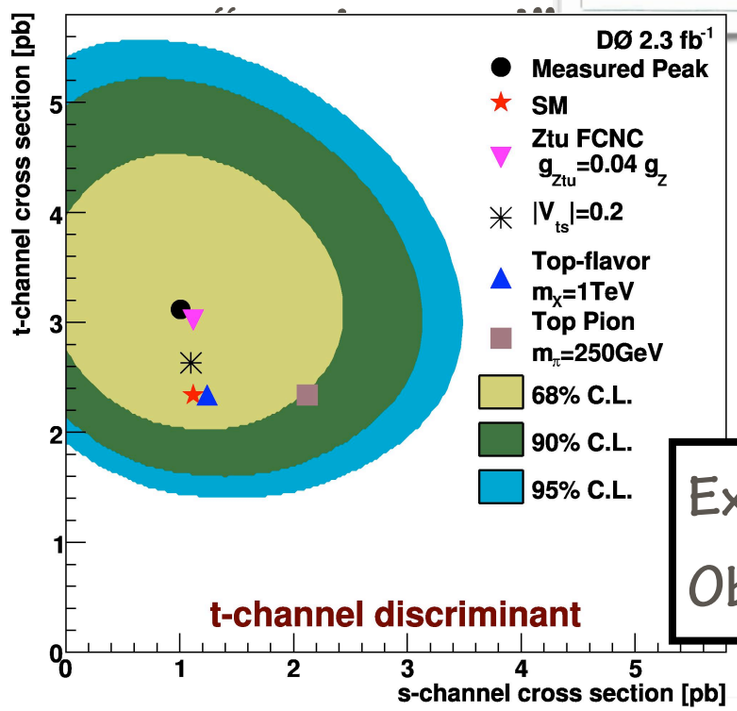
TAU CROSS SECTION



$$\sigma_{s+t} = 3.4\,^{+2.0}_{-1.8}\,(\text{stat+syst})\ \text{pb}$$

T-CHANNEL CROSS SECTION





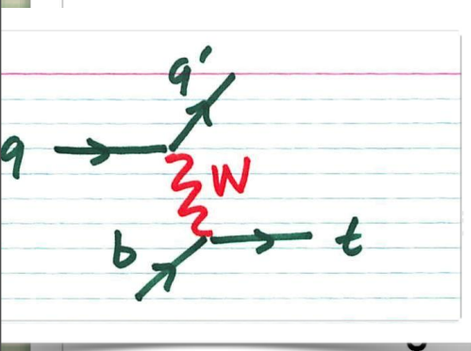
Expected sensitivity: 3.7σ

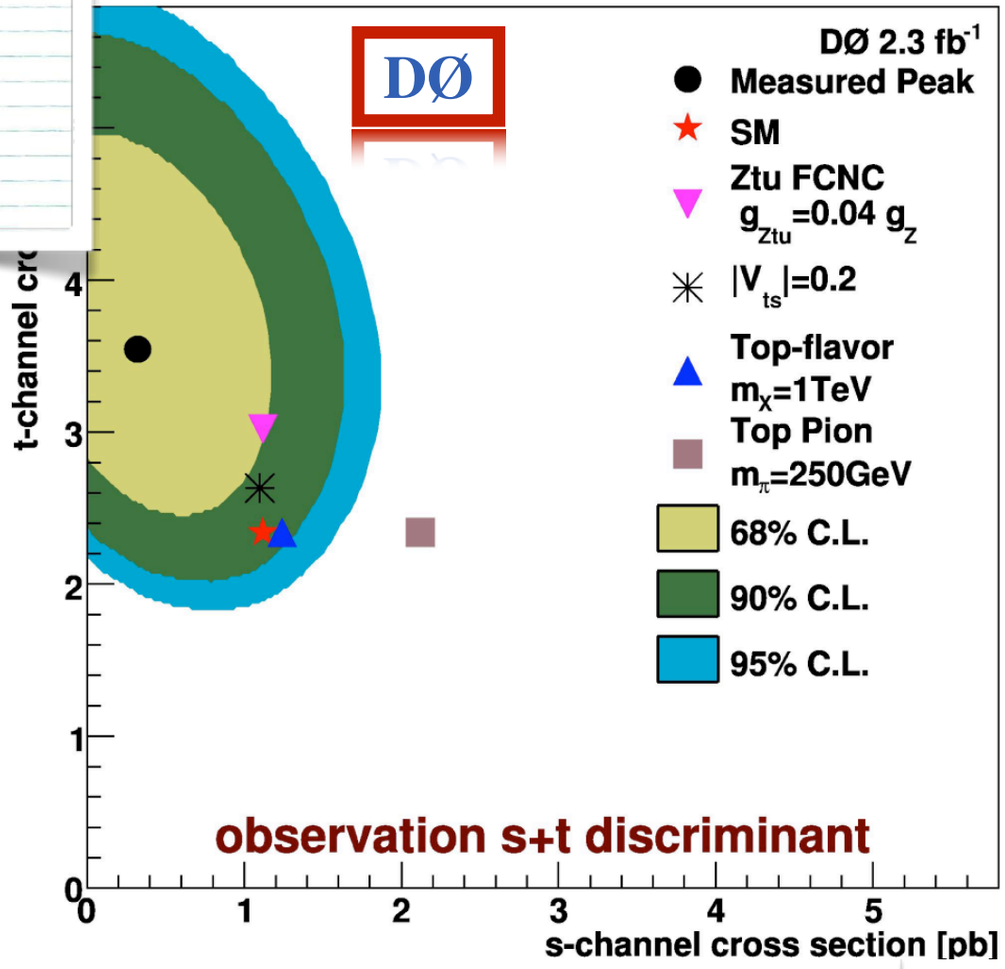
Observed p-value: 8.0×10^{-7} : 4.8σ

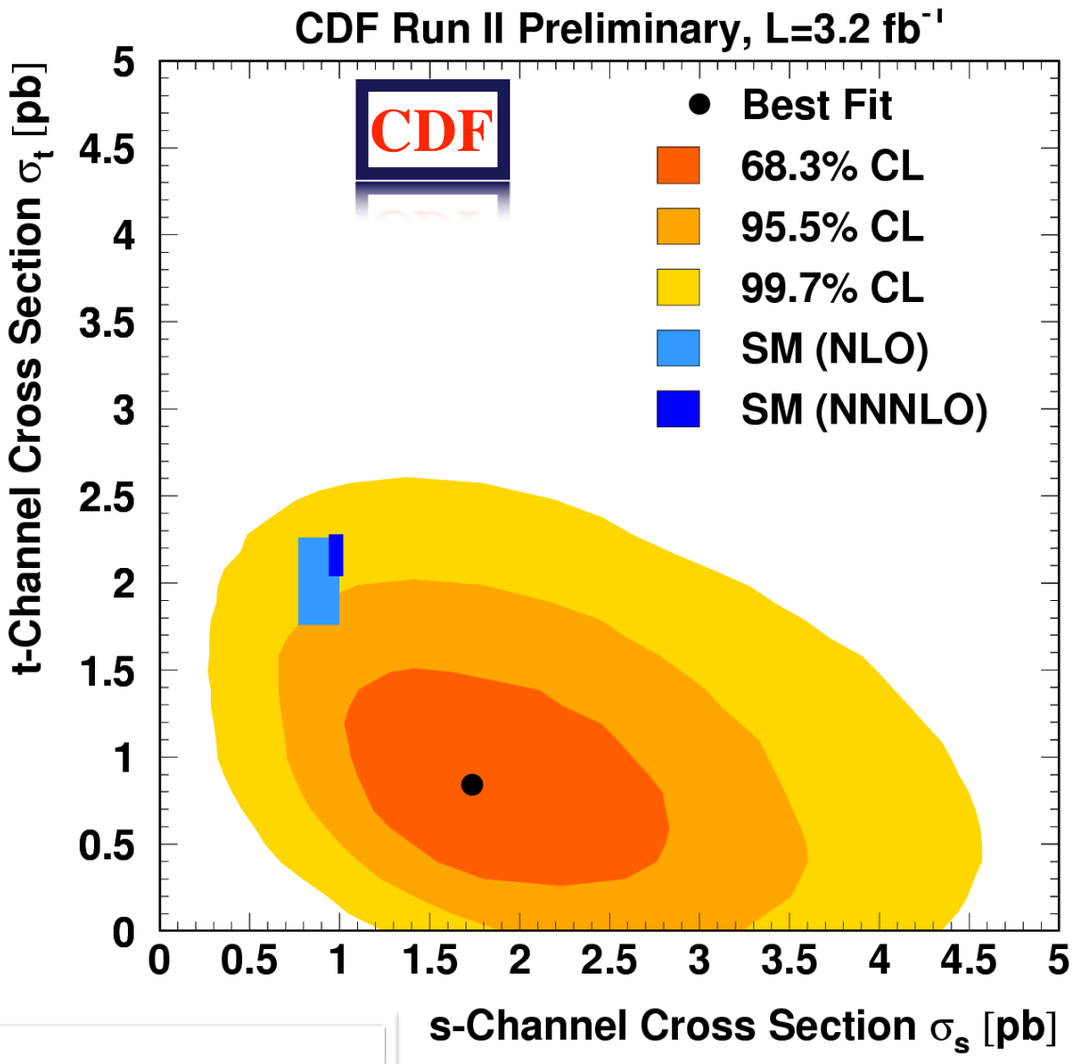
EW TOP QUARK PRODUCTION

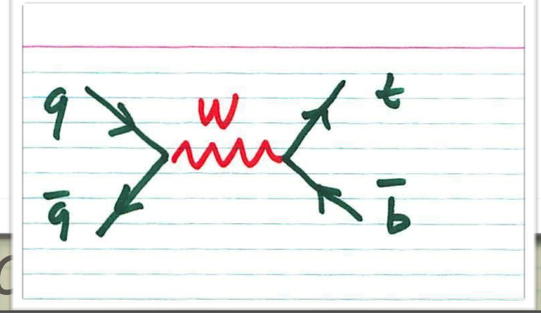
- CHANNEL SEPARATIONS

  t vs s channels









1/2-WAY POINT CONCLUSION 4

HADRON COLLIDER TOP QUARK PHYSICS

IS NOW A PRECISION SCIENCE

TOP QUARK: SUMMARY, 2

Florencia Canelli, LP

Property	Run II Measurement	SM prediction	Luminosity (fb^{-1})
m_t	CDF: 172.6 ± 0.9(stat) ± 1.2(syst) GeV D0: 174.2 ± 0.9(stat) ± 1.5(syst) GeV		4.3 3.6
σ_{ttbar} (@m_t=172.5 GeV) σ_{ttbar} (@m_t=170 GeV)	CDF: 7.50 ± 0.31 (stat) ± 0.34 (syst) ± 0.15 (lumi) pb D0: 7.84 $^{+0.46}_{-0.45}$ (stat) $^{+0.66}_{-0.54}$ (syst) $^{+0.54}_{-0.46}$ (lumi) pb	7.4 ± 0.6 pb 8.06 +0.6 pb	4.5 1
$\sigma_{singletop}$ (@m_t=170 GeV)	Tevatron: 2.76 $^{+0.58}_{-0.47}$ (stat+syst)	2.86±0.8 pb	3.2-2.3
$\|V_{tb}\|$	Tevatron: 0.91 ± 0.08 (stat+syst)	1	3.2-2.3
σ(gg->ttbar)/σ(qq->ttbar)	D0: 0.07+0.15-0.07(stat+sys)	0.18	1
m_t - m_{tbar}	D0: 3.8 ± 3.7 GeV	0	1
σ(tt→ll)/σ(tt→l+jets)	D0: 0.86 $^{+0.19}_{-0.17}$ (stat+syst)	1	1
σ(tt→τl)/σ(tt→ll + l+jets)	D0: 0.97 $^{+0.32}_{-0.29}$ (stat+syst)	1	1
$\sigma_{ttbar+jets}$ (@m_t=172.5 GeV)	CDF: 1.6 ± 0.2 (stat) ± 0.5 (syst)	1.79+0.16 -0.31 pb	4.1
cTtop	CDF: 52.5μm @ 95%C.L.	10^{-10} μm	0.3
Ttop	CDF: <13.1 GeV @ 95%C.L.	1.5 GeV	1
BR(t->Wb)/BR(t->Wq)	CDF: >0.61 @ 95% C.L. D0: 0.97 $^{+0.09}_{-0.08}$ (stat+syst)	1	0.2 0.9
F_0	CDF: 0.62 ± 0.11 D0: 0.490 ±0.106 (stat) ±0.085 (syst)	0.7	2 2.7
F_+	CDF: -0.04 ± 0.05 D0: 0.110 ±0.059 (stat) ±0.052 (syst)	0.0	2 2.7
Charge	CDF: - 4/3 excluded with 87% C.L. D0: 4e/3 excluded at 92% C.L.	2/3	1.5 0.37
Spin correlations	CDF: $\varkappa$ = 0.32 + 0.55 - 0.78, -0.46 < K < 0.87 @ 68%C.L. D0: $\varkappa$ = –0.17 $^{+0.65}_{-0.53}$ (stat + syst)	0.78 $^{+0.027}_{-0.022}$	2.8 4.2
Charge asymmetry	CDF: 0.19 ± 0.07(stat) ± 0.02(syst) % D0: 12 ± 8 (stat) ± 1 (syst) %	0.05 +- 0.015	3.2 0.9

BEYOND THE SM PHYSICS

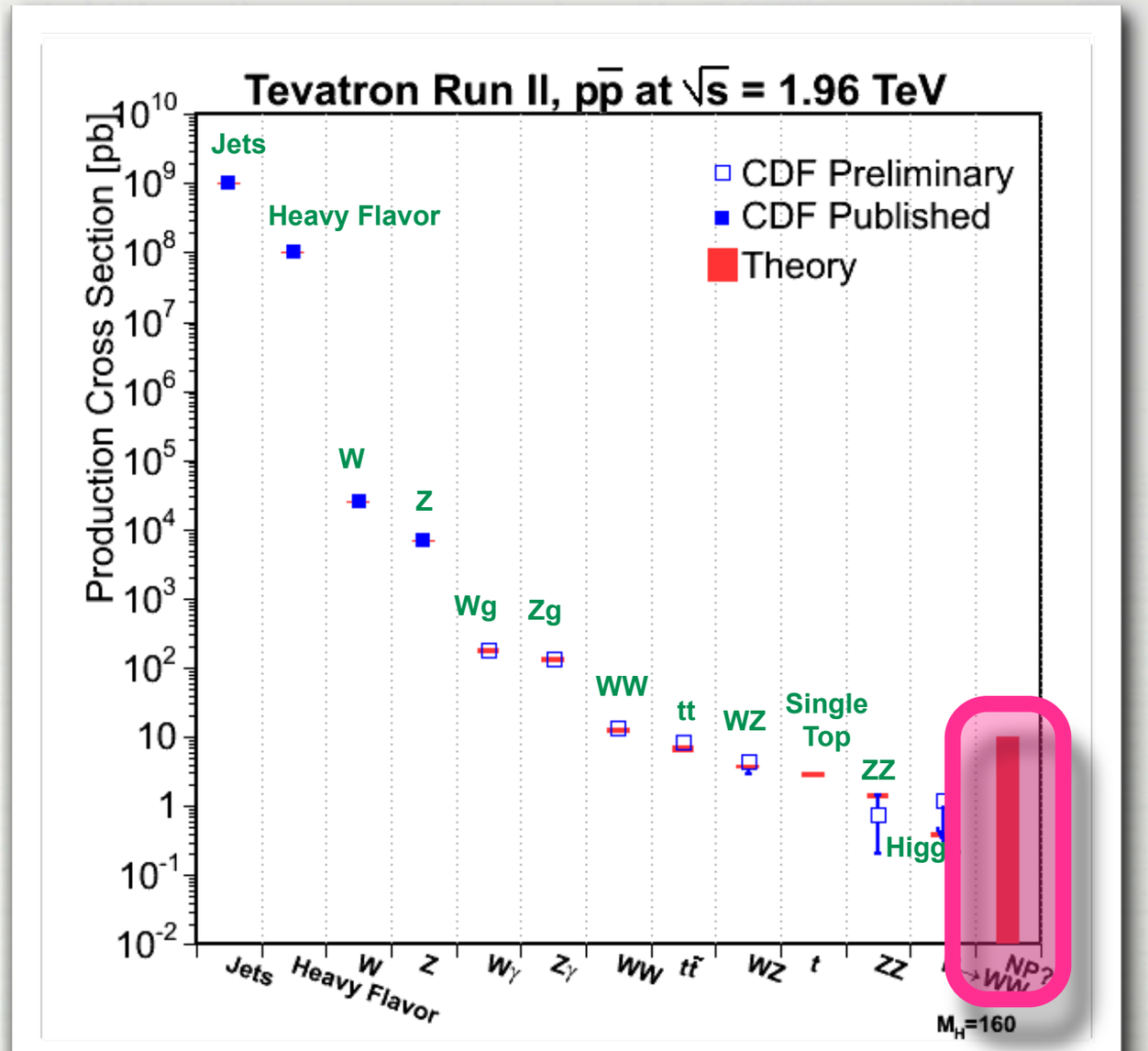
- WELL...EVERYTHING NON-STANDARD

  SUSY-inspired searches

  U(1)' or SU(2)' inspired searches

- THIS SPACE IS HUGE

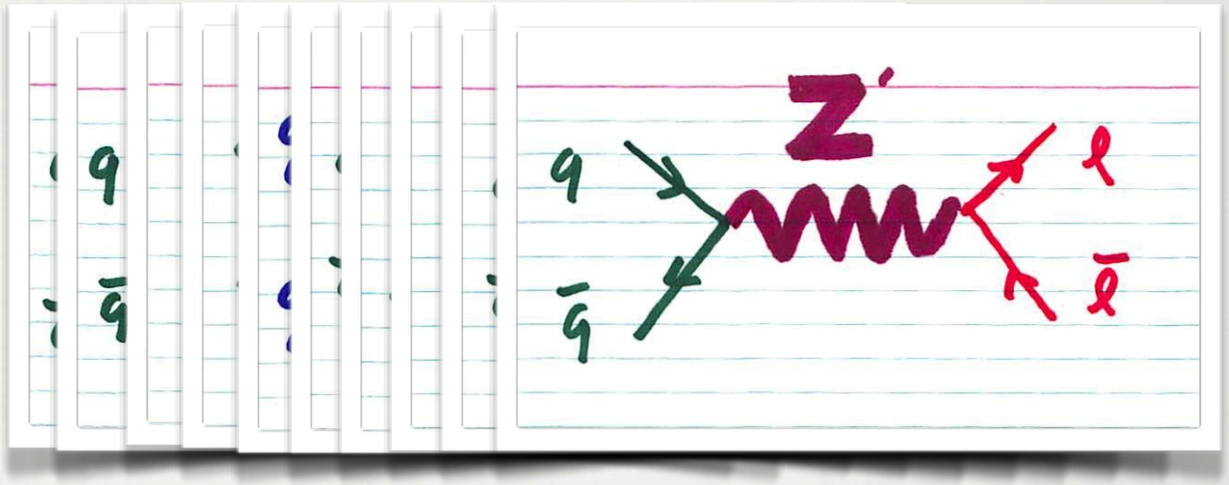
  just a few results

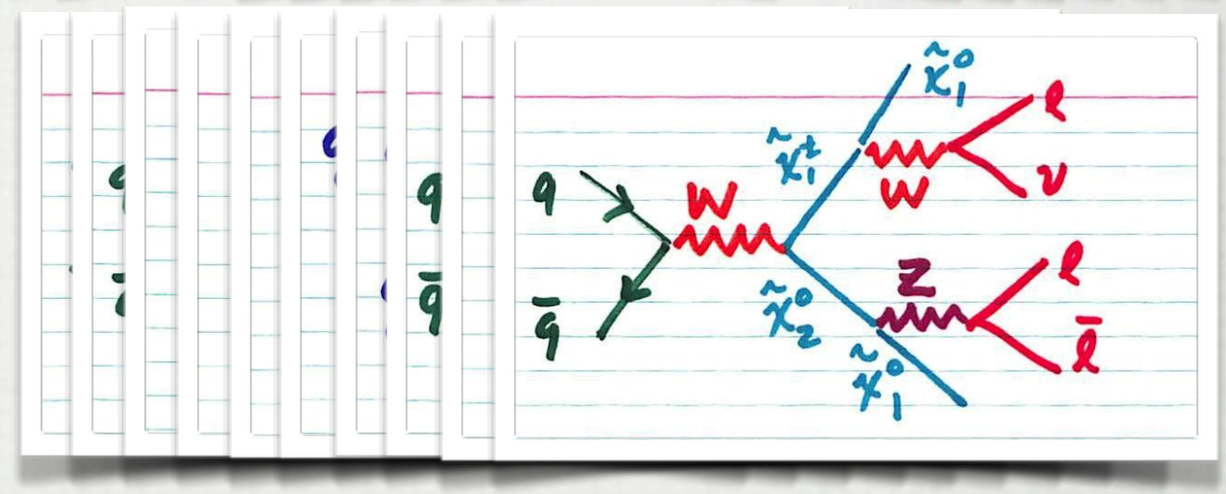


< 0.00000002% of anything happening

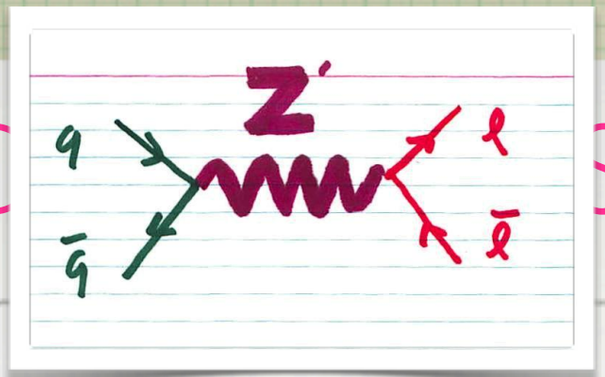
BEYOND THE STANDARD MODEL

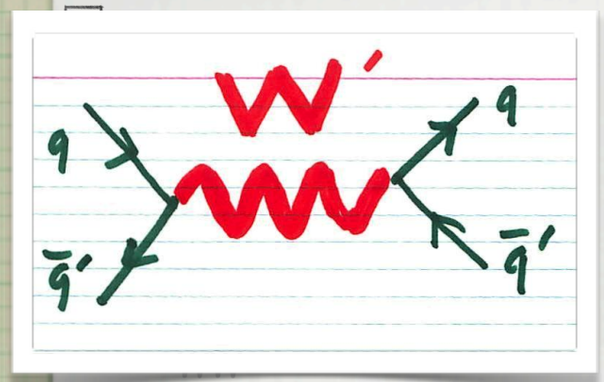
- BSM PROCESSES
  - Z'
  - W'
  - WW
  - WZ
  - chargino-neutralino production
  - trilepton mode
  - heavy/light
  - heavy gaugino searches
  - squark/gluino searches
  - squark production into taus
  - stop searches
  - sneutrino searches
  - GMSB limits
  - "hidden valley"
  - "dark photons"
  - compositeness

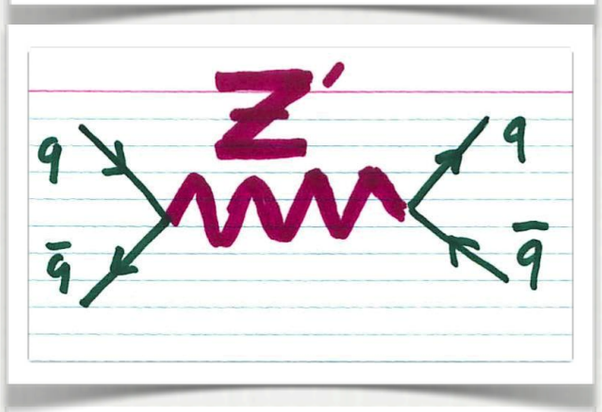


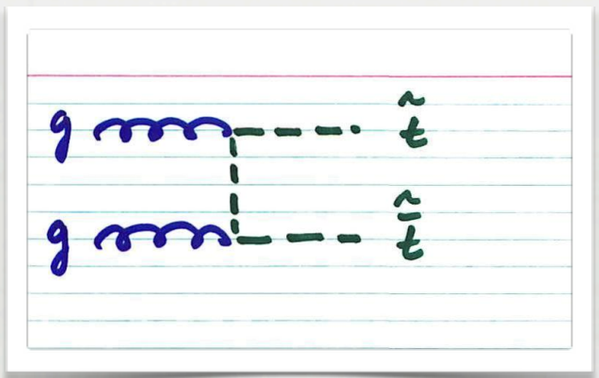


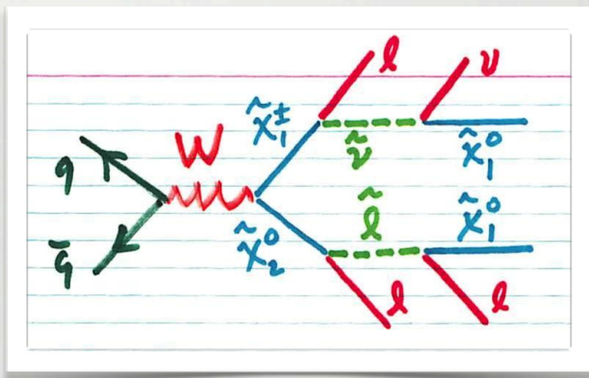
BEYO STANDARD MODEL

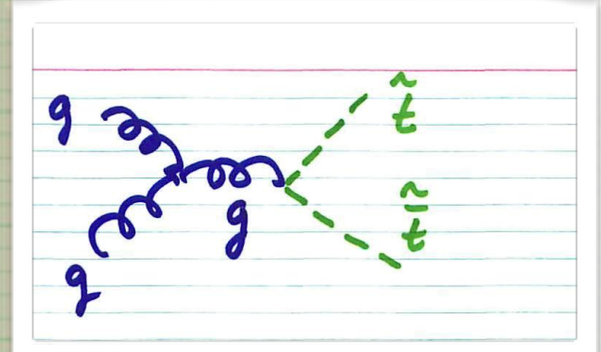


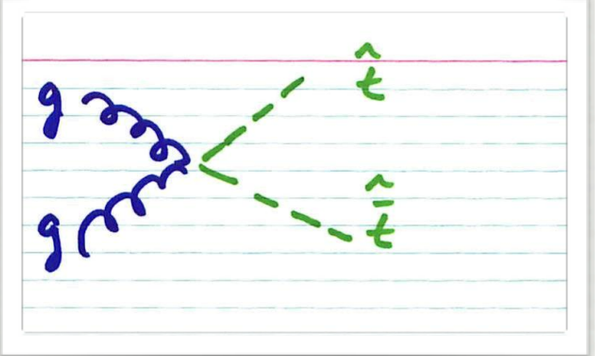


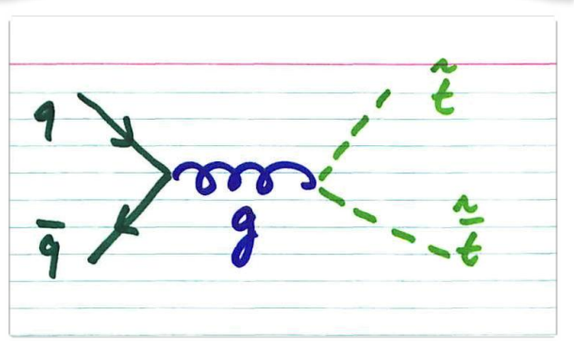


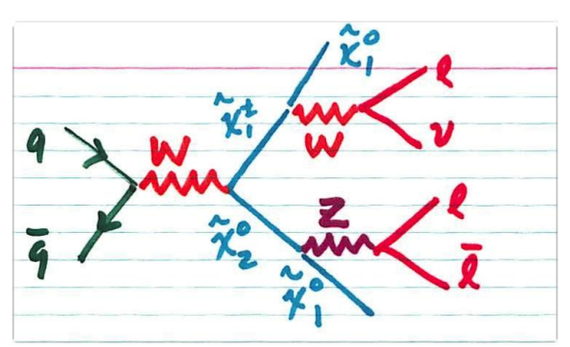




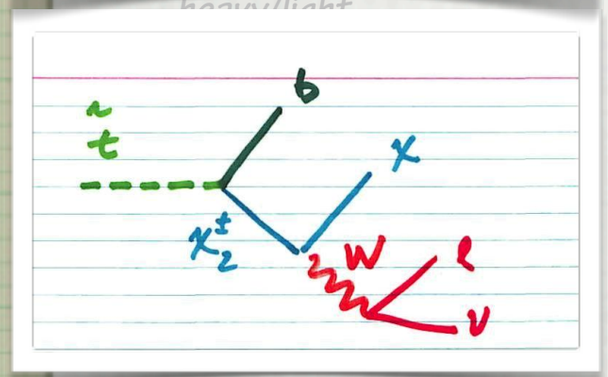


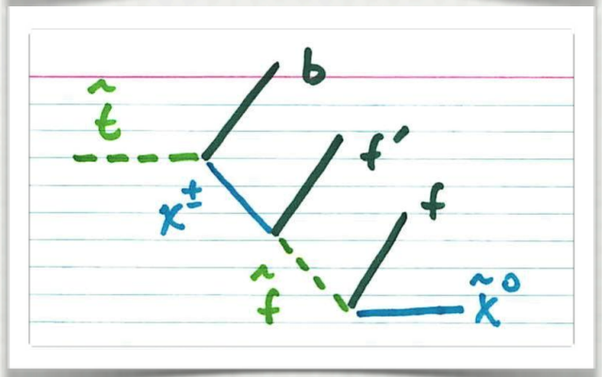


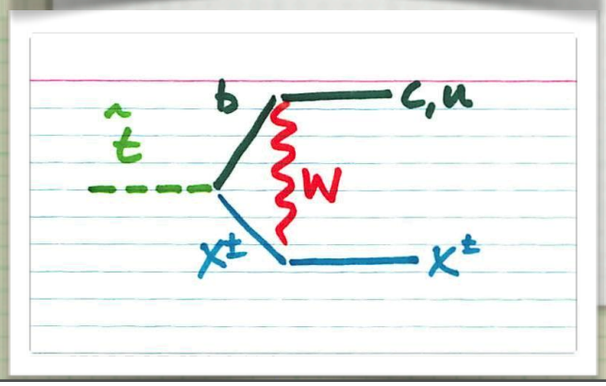


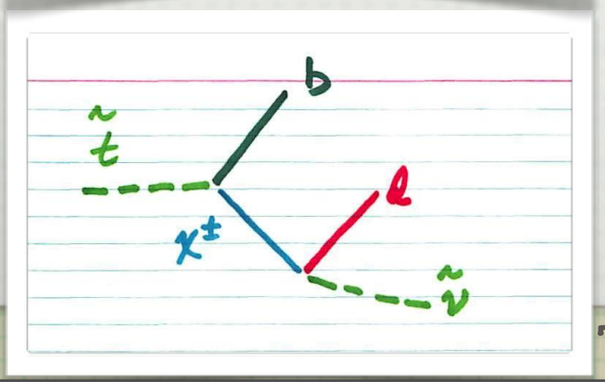


heavy/light

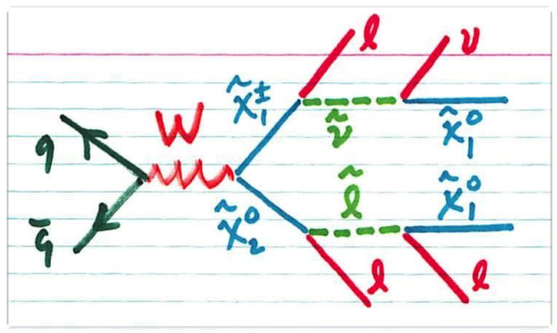








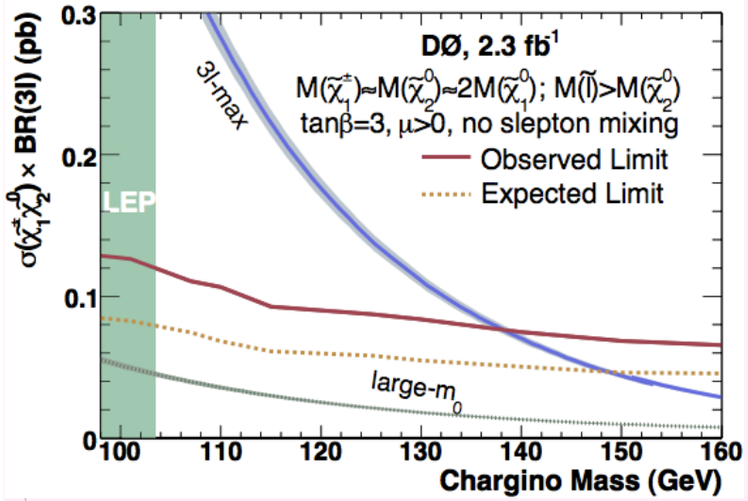
WAKEUP LITTLE SUSY, WAKE UP



- MANY WAYS: HERE, THE CLASSICAL ANALYSIS

  R-parity-conserving, MSSM chargino-neutralino search

CDF

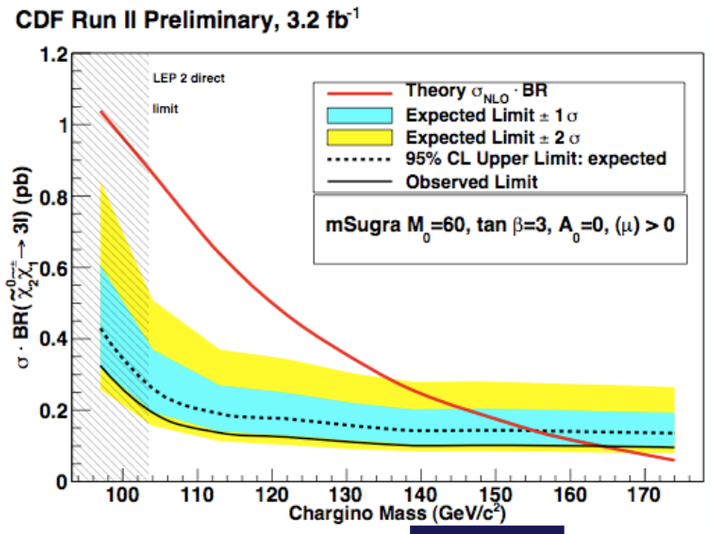


DO (2.3 fb-1)

M(χ±)>138 GeV/c2

Submitted to PLB
Hep-ex/0901.0646

DØ

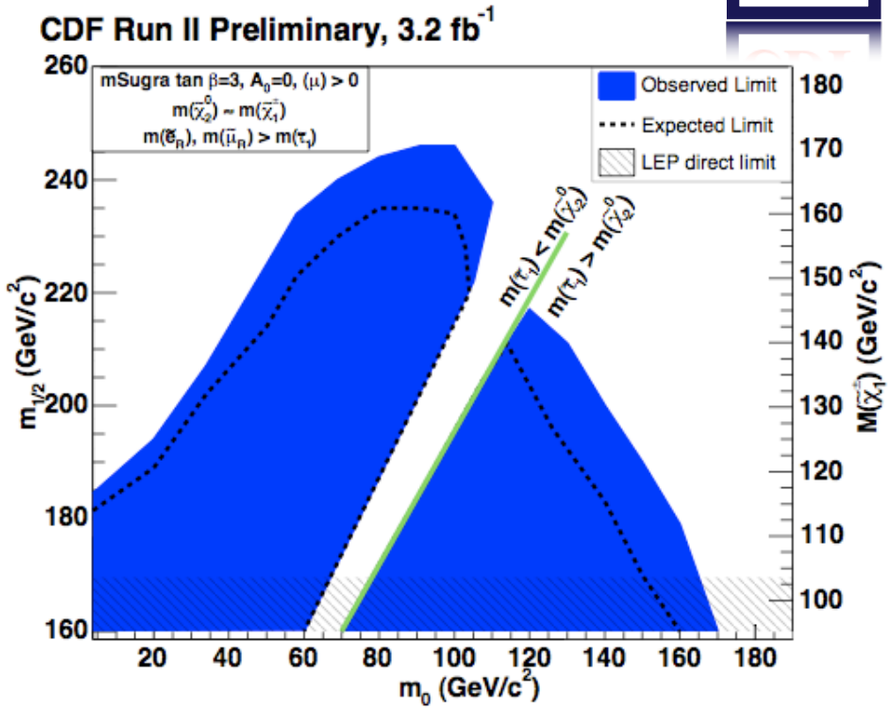


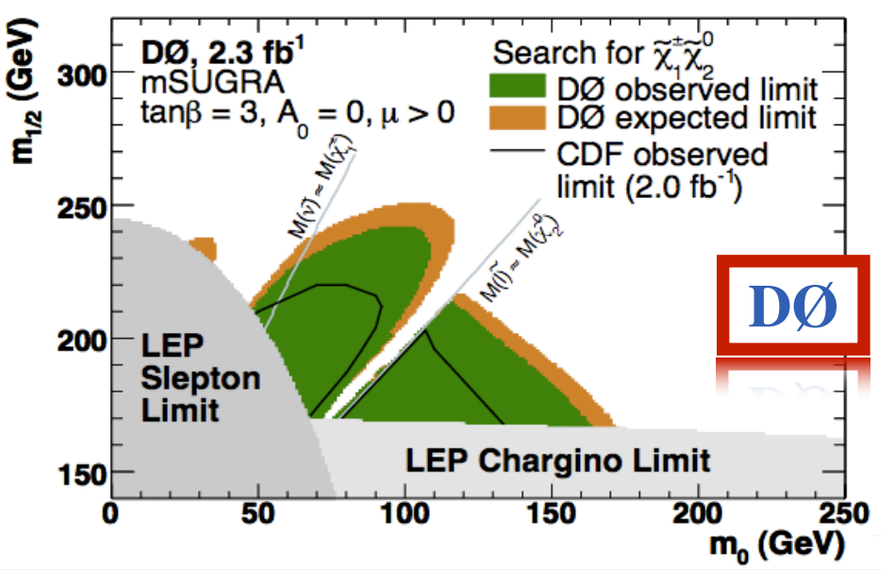
CDF (3.2 fb^{-1})

M(χ±)>164 GeV/c2

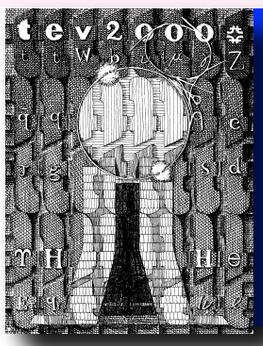
CDF

preliminary

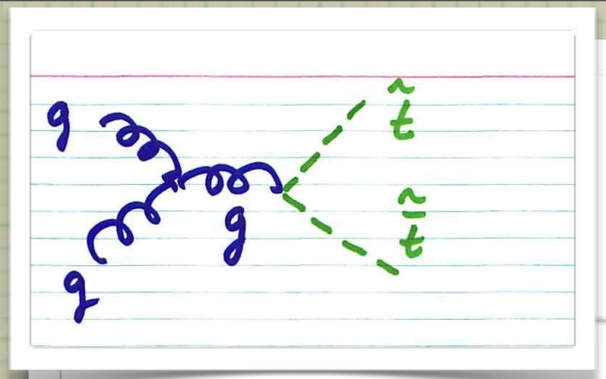




DØ



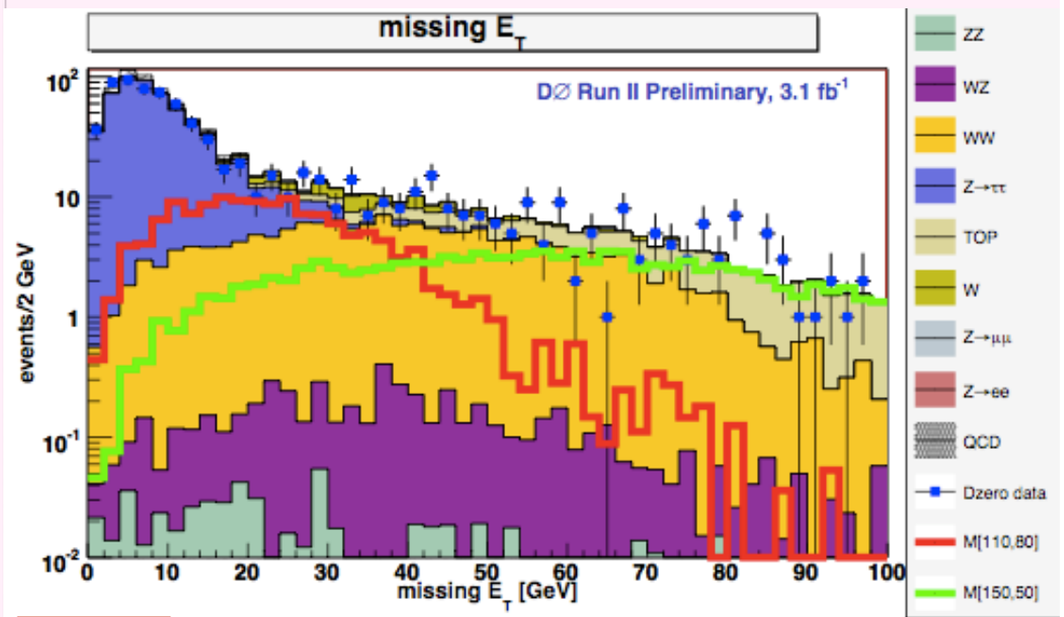
2fb^{-1}: δm(χ±) > 200 Gev/c^2

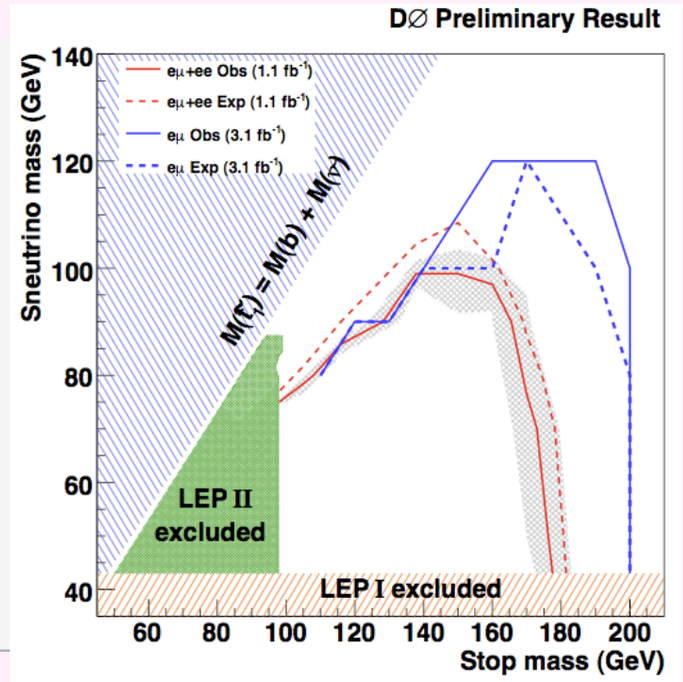


STOP IN THE NAME OF LOVE

A SQUARK SEARCH: A FERMILAB TARGET

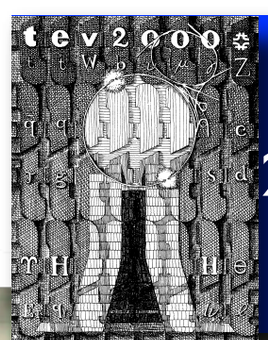
light stop squark ($m_{stop} < m_{top}$) & heavier stop



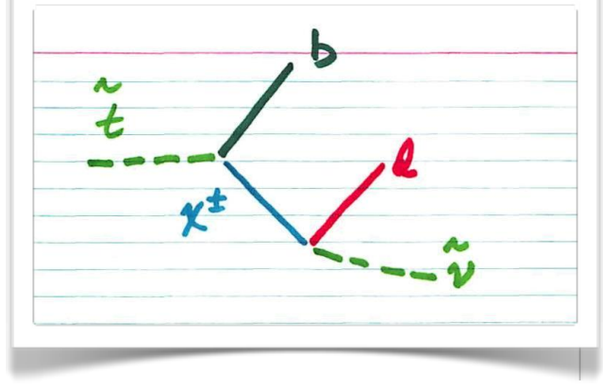


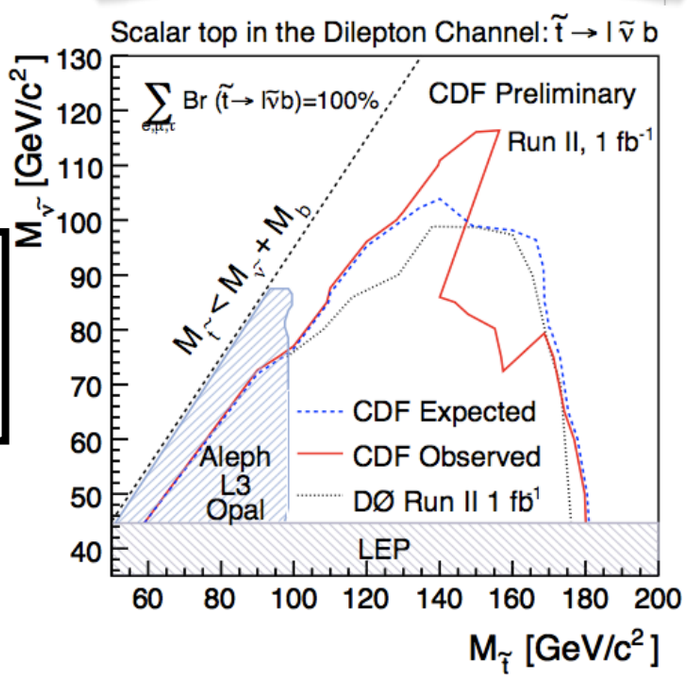
DØ

Results at large Δm=m(stop)-m(sneutrino)
DO (3.1 fb^{-1}): m(stop)>200 GeV
CDF (1 fb^{-1}): m(stop)>180 GeV

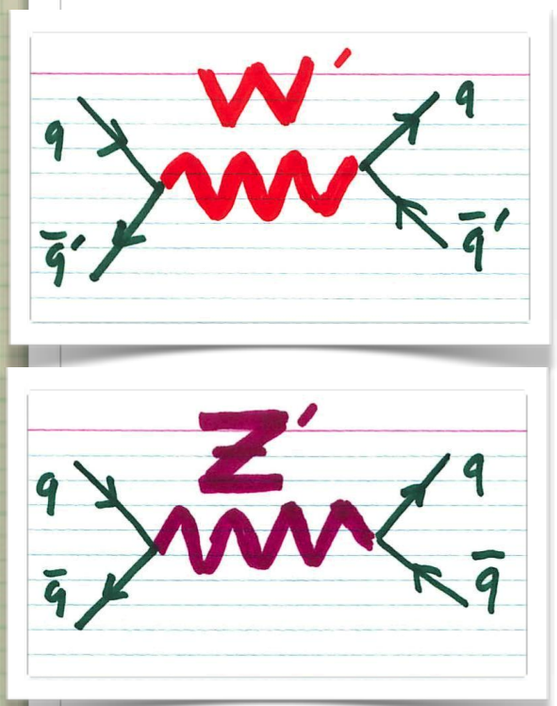


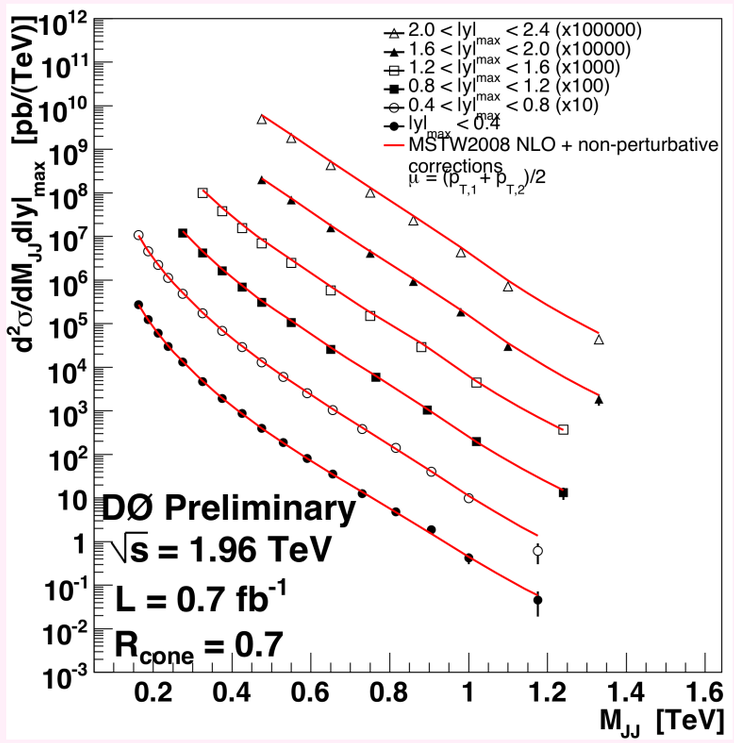
2fb^{-1}: δm(stop) > 130 Gev/c^2



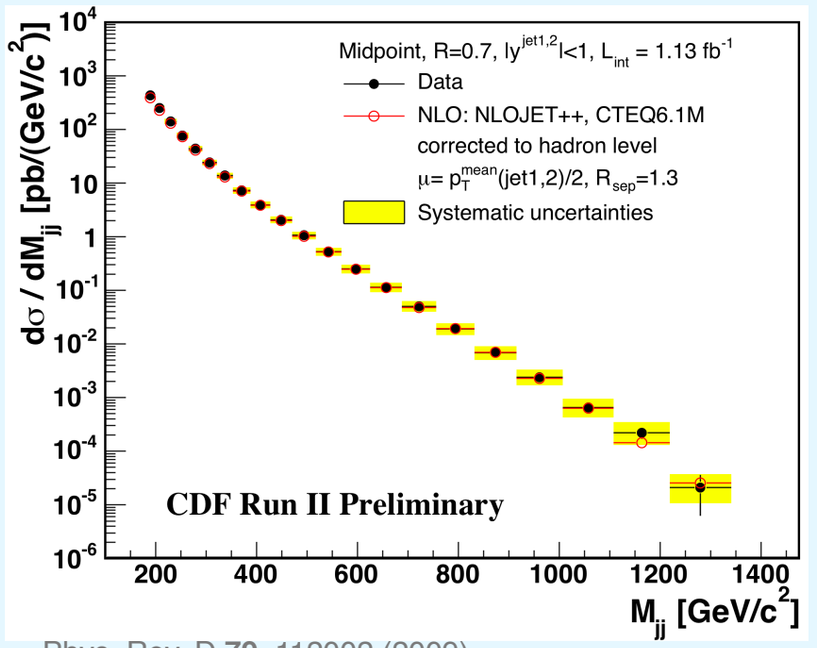


LEAVING ON A JET(S) PLANE?





http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/QCD/Q14/



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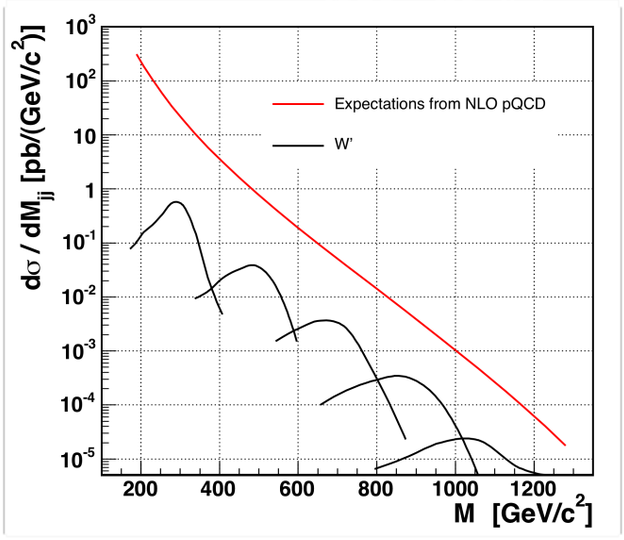
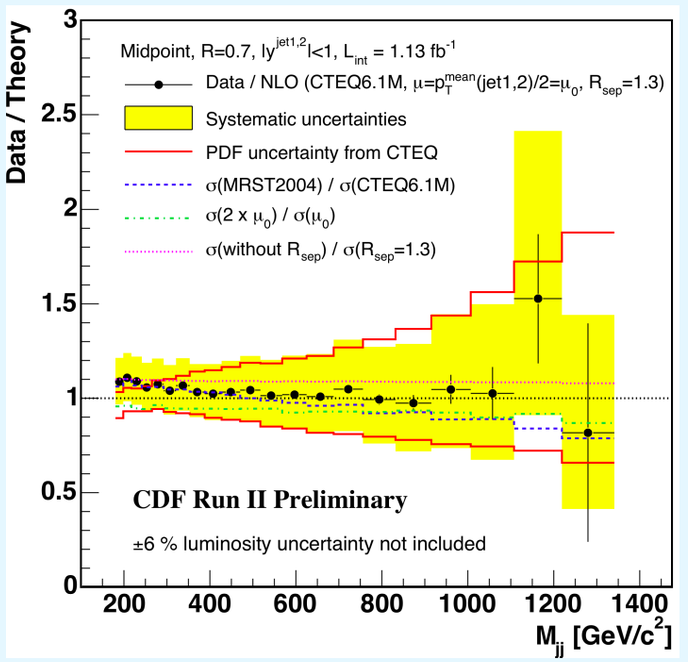
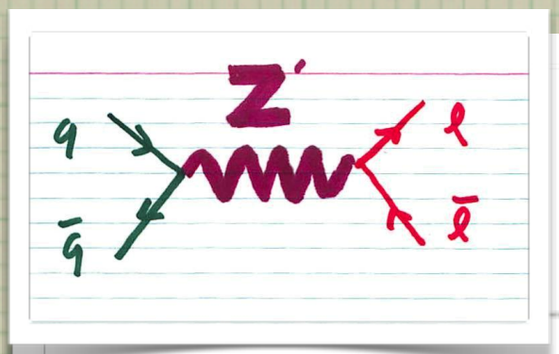
- NO HINTS
  of anything new

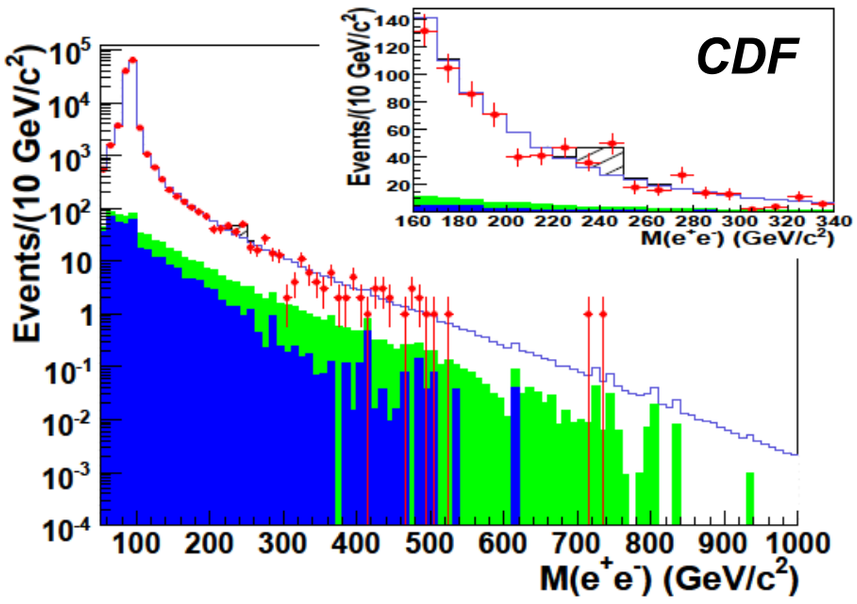


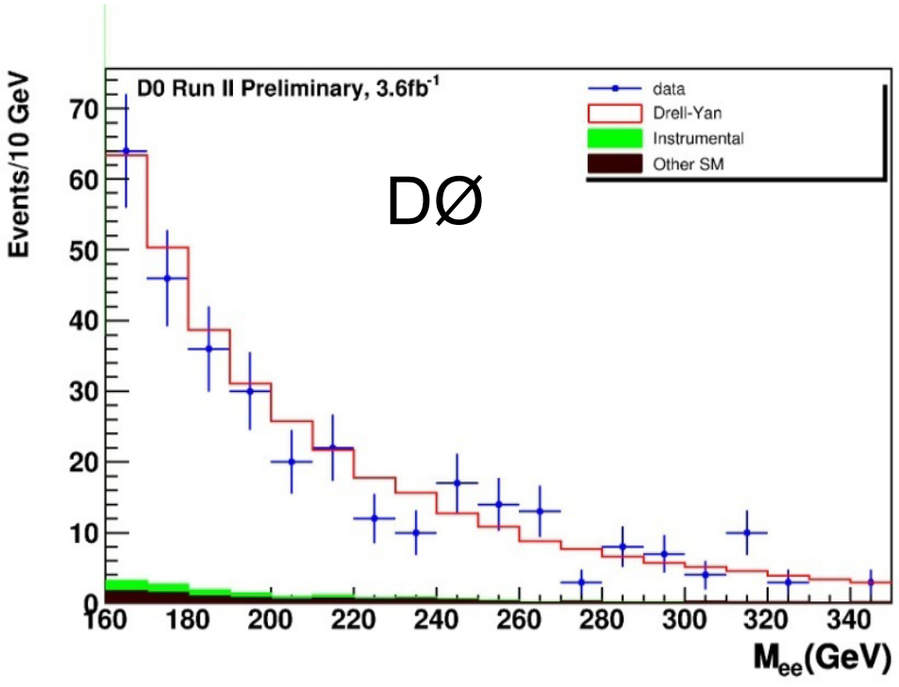


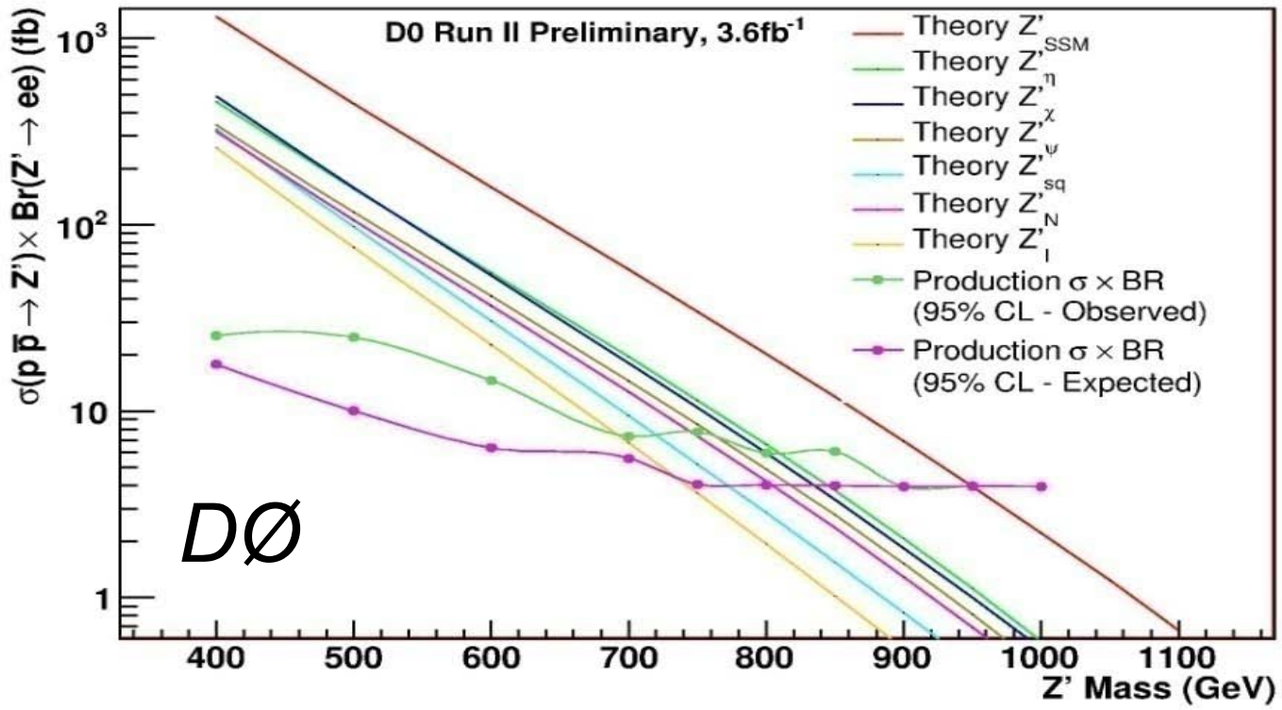


EVERYBODY GET TOGETHER

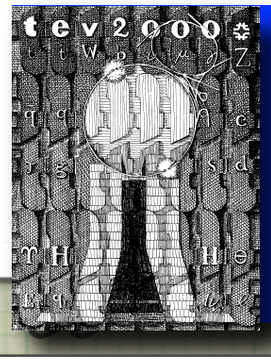
- EXPANDING THE U(1) SECTOR-BUMP-HUNTING





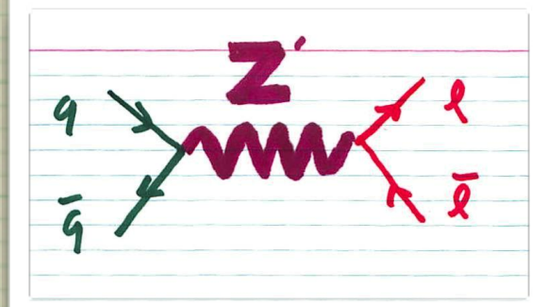


	Obs. 95% C.L lower limits on Z' masses (GeV)						
Z' model	Z'_{SM}	Z'_{Ψ}	Z'_{χ}	Z'_{η}	Z'_{I}	$Z'_{seq.}$	Z'_{N}
CDF	963	851	862	930	735	792	837
D0	950	763	800	810	692	719	744



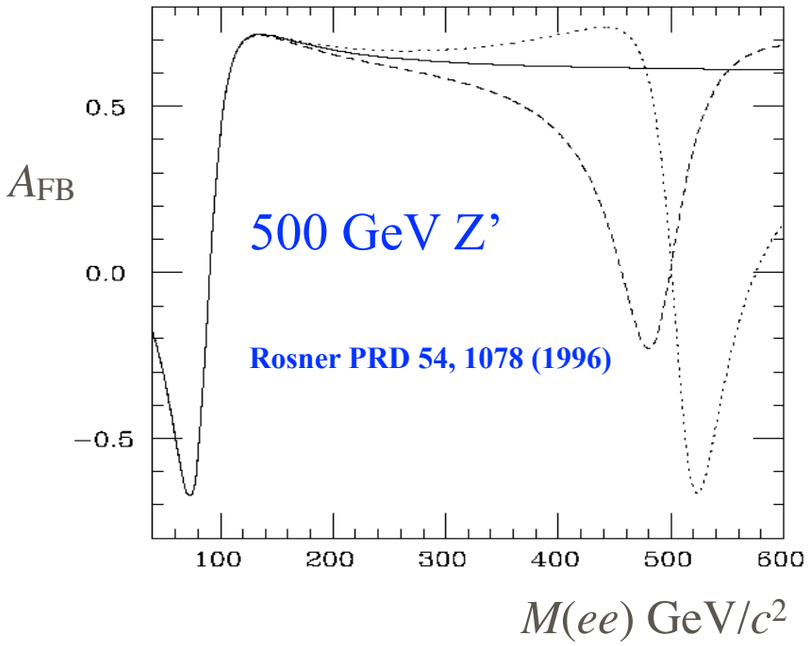
$2fb^{-1}$: $\delta m(Z') > 900$ Gev/c^2

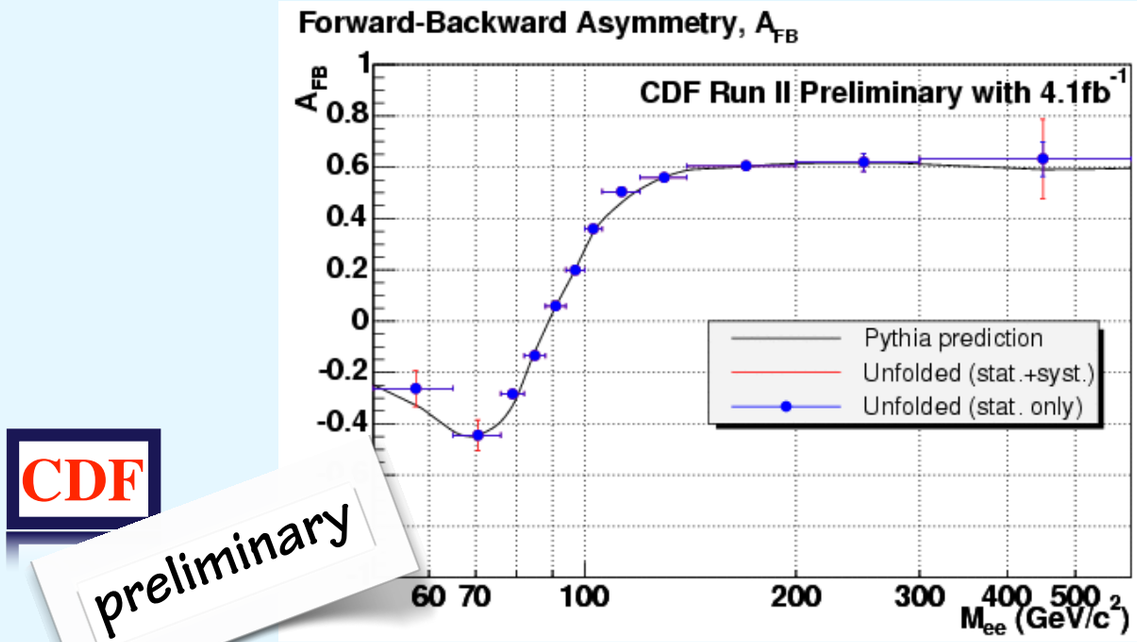
$10fb^{-1}$: $\delta m(Z') > 1200$ Gev/c^2

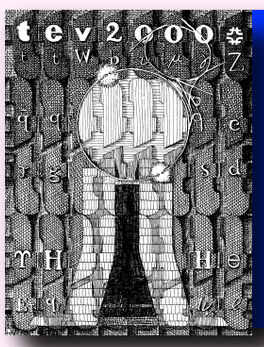


EVERYBODY GET TOGETHER

☐ EXPANDING THE U(1) SECTOR-ASYMMETRIES





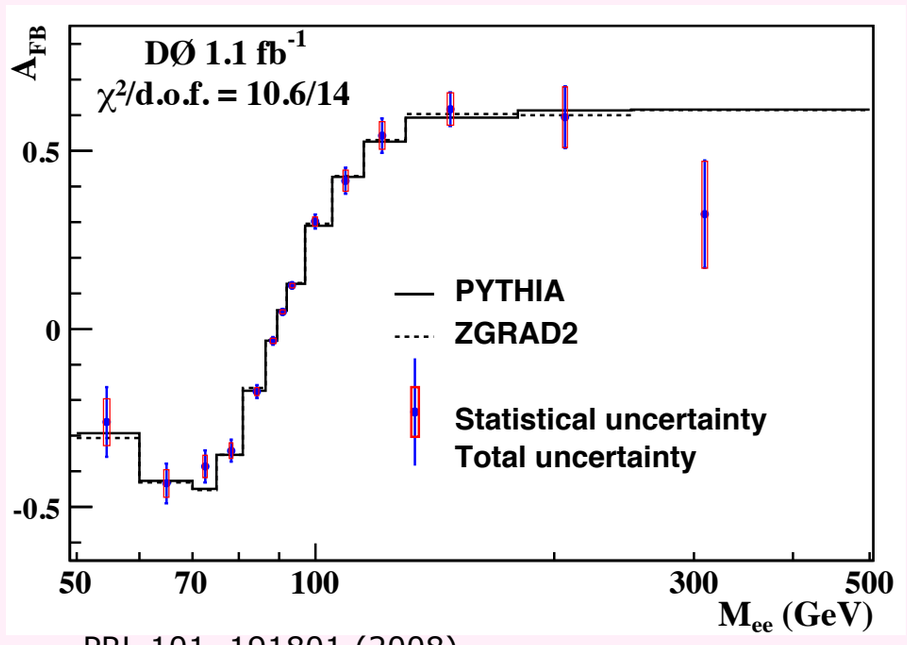


1fb^{-1}: $\delta \sin^2\theta_W \sim 0.001$

10fb^{-1}: $\delta \sin^2\theta_W \sim 0.00032$

$\sin^2\theta_W = 0.2321 \pm 0.0018 \pm 0.0006$

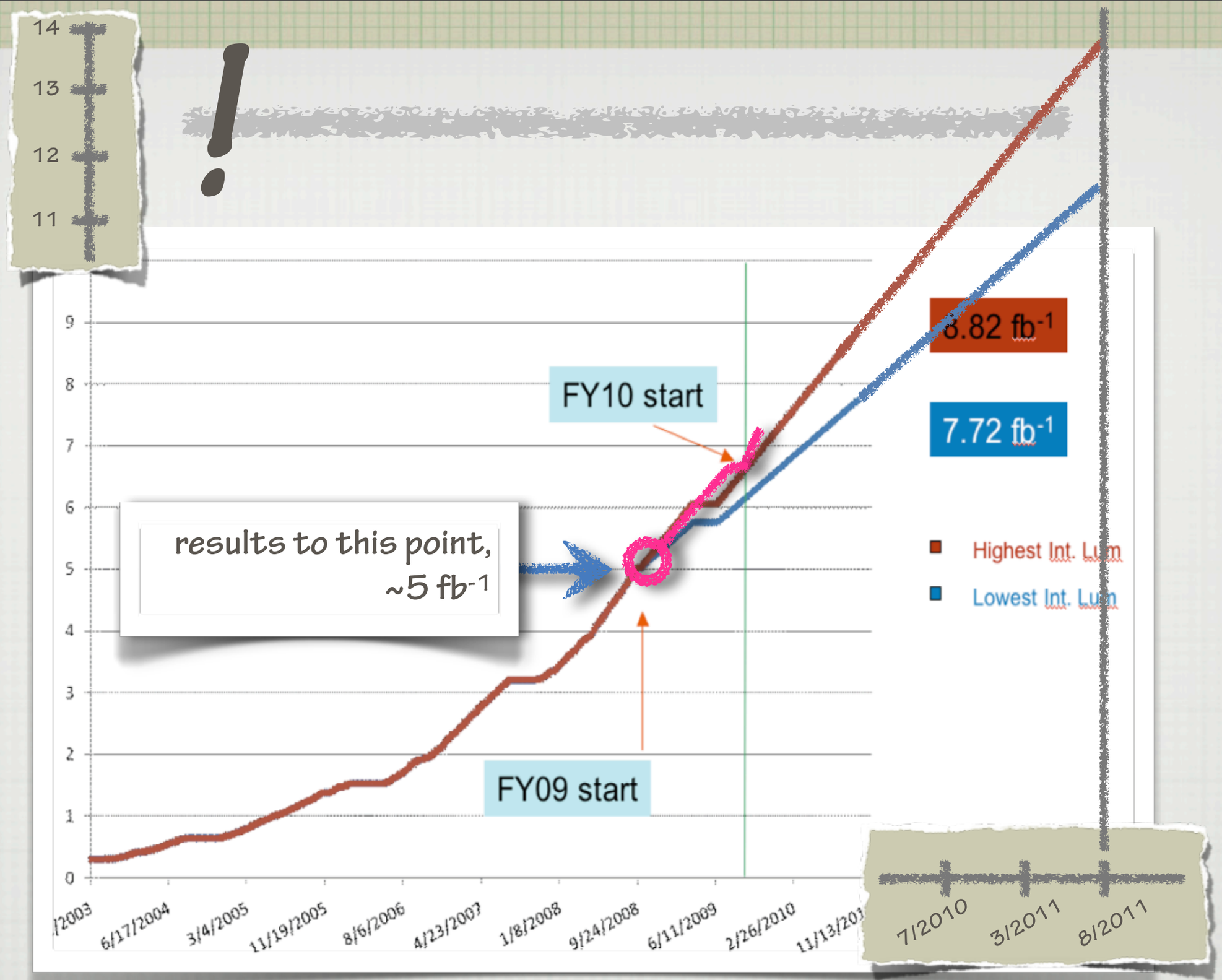
pdfs: 0.0005, E(e) scale: 0.0003



PRL 101, 191801 (2008)

1/2-WAY POINT CONCLUSION 5

THE HADRON COLLIDER ZOO BECOMES MORE AND MORE CONSTRAINED



RUN 2 MAY ONLY BE HALF-WAY OVER!

Draft 2010-13 Fermilab Accelerator Experiments' Run Schedule

Typically Revised Annually - This Version from October, 2009

Calendar Year		2010	2011	2012	2013
Tevatron Collider		CDF & DZero	CDF & DZero	OPEN	OPEN
Neutrino Program	B	MiniBooNE	MiniBooNE		OPEN
		OPEN	OPEN		MicroBooNE
	MI	MINOS	MINOS		OPEN
		MINERvA	MINERvA		MINERvA
		ArgoNeuT			
			NOvA		NOvA
SY 120	MT	Test Beam	Test Beam		Test Beam
	MC	OPEN	OPEN		OPEN
	NM4	E-906/Drell-Yan	E-906/Drell-Yan		E-906/Drell-Yan

This draft schedule is meant to show the general outline of the Fermilab accelerator experiments schedule, including unscheduled periods.

Major components of the schedule include shutdowns:
In Calendar 2010, a 4-6 week shutdown for maintenance is shown.
In Calendar 2011, no shutdown for maintenance is shown.
A 2012-3 11-month shutdown is shown to upgrade the proton source and change the NuMI beam to the Medium Energy (ME) config.

RUN/DATA
STARTUP/COMMISSIONING
INSTALLATION
M&D (SHUTDOWN)

19-Oct-09

Tevatron Collider Program: Young-Kee Kim, HEPAP Meeting, Oct. 22, 2009 Fern

CDF and DØ:

continue to monitor and extrapolate Si trackers:

Both find that inner layers show few % failure, but recover
Both extrapolate acceptable tracking efficiencies to 12 fb-1

Physicist-power:

Seeing ~10%/year attrition

Computing:

available for 5 years after close of Tevatron operations

THE FUTURE CONTINUES... TO HAPPEN!

TEVATRON 1/2-WAY POINT CONCLUSIONS

THE TEVATRON COLLIDER IS A JEWEL

1. *Never* bet against a laboratory's accelerator division
2. Lots of data always make you smarter.

- I'VE BENEFITED FROM RECENT HCP, LP, AND DPF TALKS BY:

Sunil Somalwar
Alex Melnitchouk
Michael Wang
Sasha Pranko
Sabine Lammers
Andreas Warburton
Penny Kasper
Kirsten Tollefson
Stefan Söldner-Rembold
Jacobo Konigsberg
Don Lincoln
Hideki Miyake
Ignacio Redondo
Florencia Canelli
Oscar Gonzalez
David Hitlin
Leo Bellantoni
Heidi Schellman
Markus Wobisch

thanks

Saturday, December 19, 2009