

# ATLAS Highlights and Outlook

## US LHC Users Association

Argonne National Laboratory

November 13, 2014

Chip Brock, for the ATLAS Collaboration

Michigan State University

# ATLAS @work

efficient and productive

~90% usable data efficiency

2010:  $\sqrt{s} = 7$  TeV, 0.05/fb

2011:  $\sqrt{s} = 7$  TeV, 4.6/fb

2012:  $\sqrt{s} = 8$  TeV, 20.3/fb

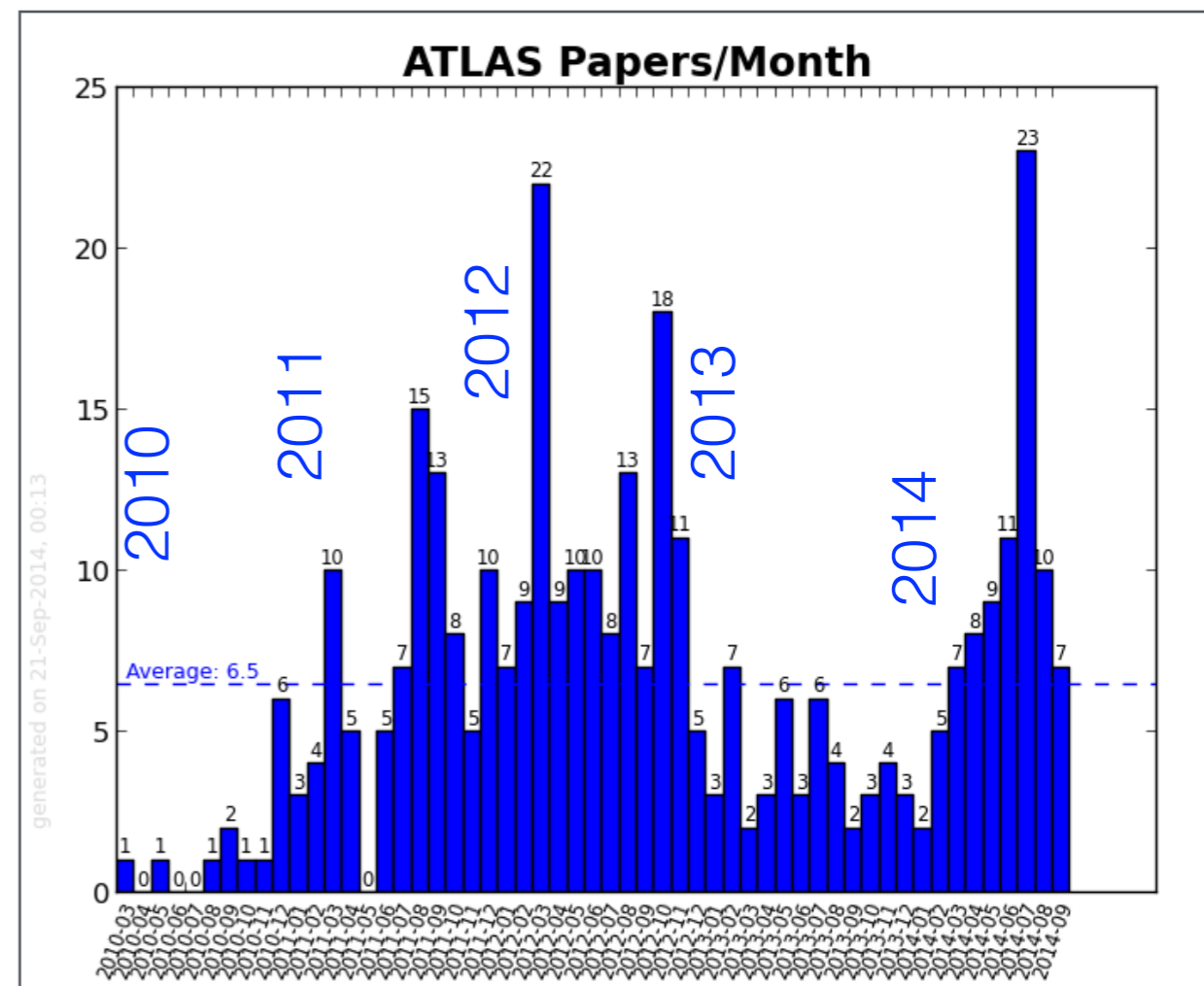
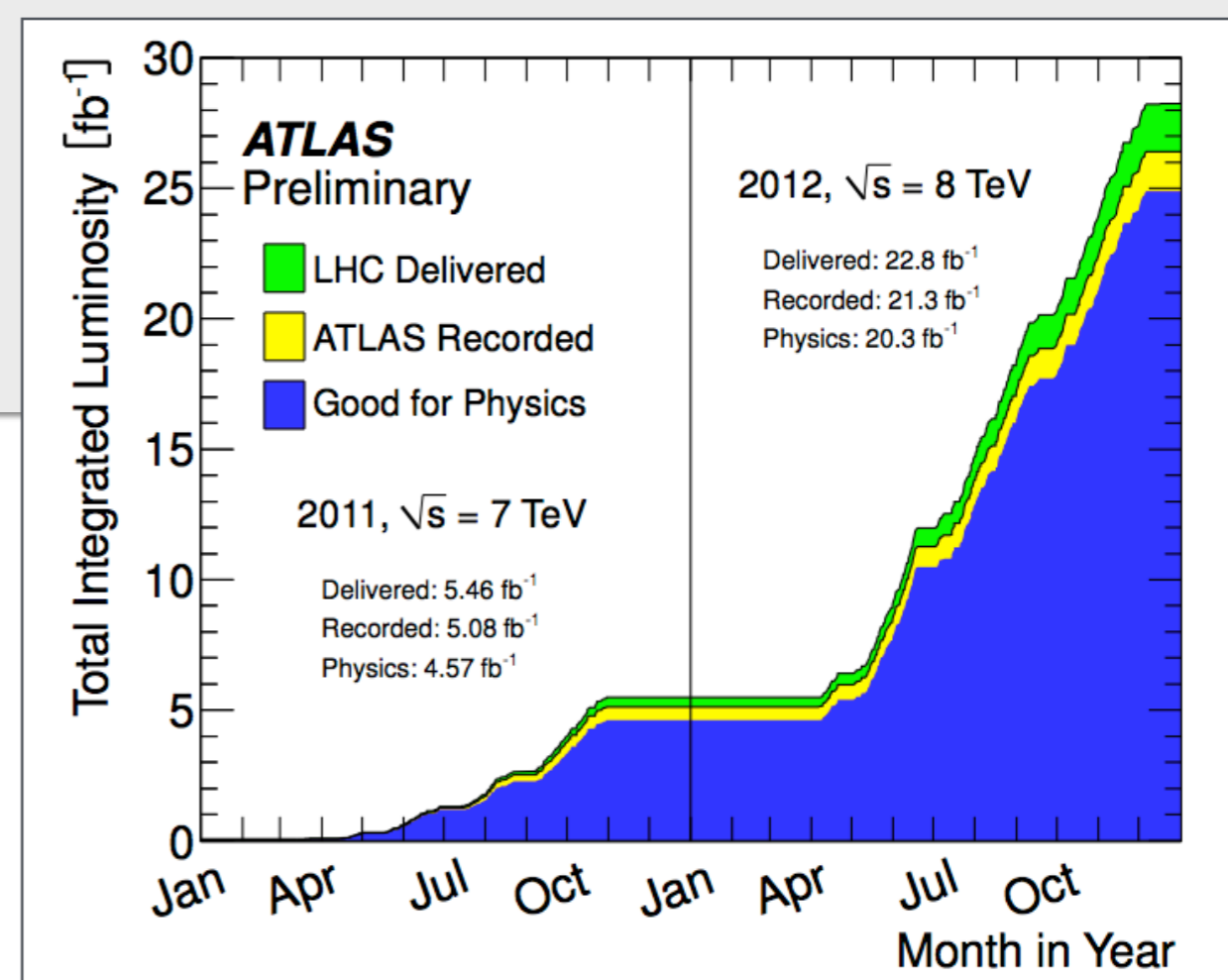
Run I results: a 2014 publication stream

350 publications, ~150 performance

~100 to come

600 CONF notes

660 conference talks



# Snowmass Energy Frontier

Research Program:

---

## **1. Measure properties of the Higgs boson.**

Including: mass, CP properties, and especially couplings

## **2. Measure properties of the: t, W, and Z**

Because they talk “loudly” to the Higgs

## **3. Search for TeV-scale particles**

A scale inspired by naturalness

# Snowmass Energy Frontier

Research Program:

## **1. Measure properties of the Higgs boson.**

Including: mass, CP properties, and especially couplings

## **2. Measure properties of the: t, W, and Z**

Because they talk “loudly” to the Higgs

## **3. Search for TeV-scale particles**

A scale inspired by naturalness

*I'll add:*

## **4. Wrestle the Standard Model to the ground.**

## **5. Search for kinematical anomalies wrt SM (see #4)**

# Is excitement about Run 2...

sort of ...underwhelming?



**Rule of thumb: a x10 increase in  $\mathcal{L}$  is like x2 in  $E_{cm}$**

and visa versa

**Run 2 nearly gives us both leading to:**

**Unprecedented precision**

W 's, tops, Higgs!, flavor, inclusive  $\sigma$  's,

**Significant discovery reach**

surpass the 1 TeV SUSY scale,  $Z'/W'$ , BSM Higgs

1%

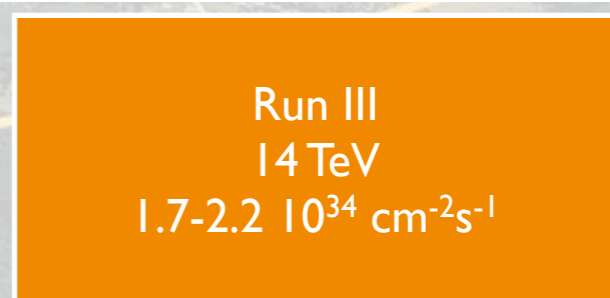
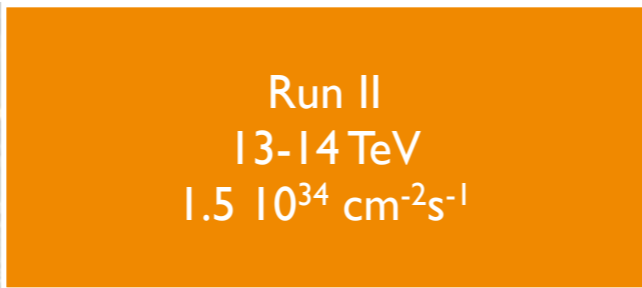
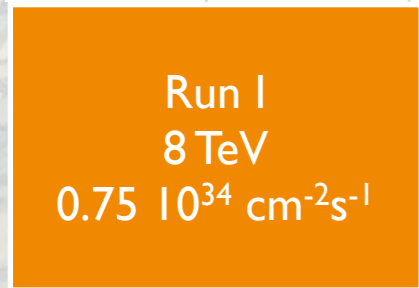
# buckle in

■ The LHC running is just beginning

(Anadi Canepa, today)

“phase 0 upgrades”

“phase 1 upgrades”



$20 \text{ fb}^{-1}$

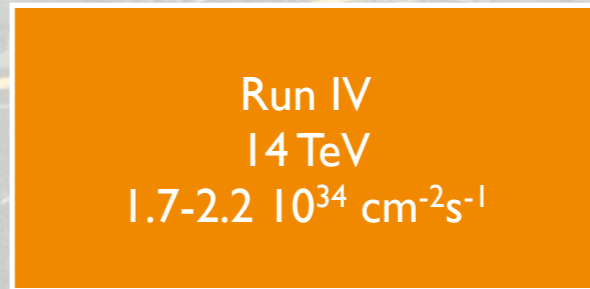
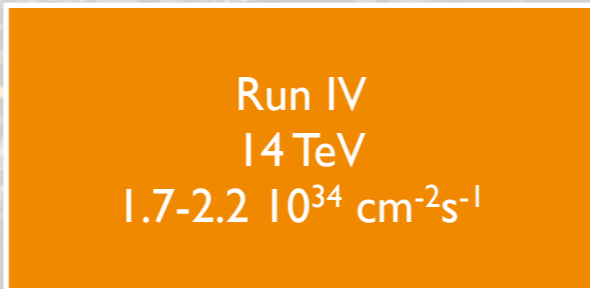
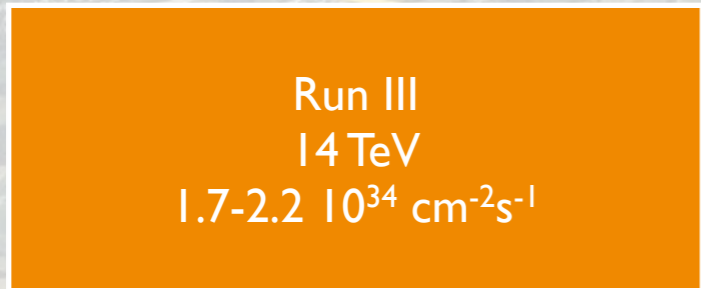
$100 \text{ fb}^{-1}$

$300 \text{ fb}^{-1}$

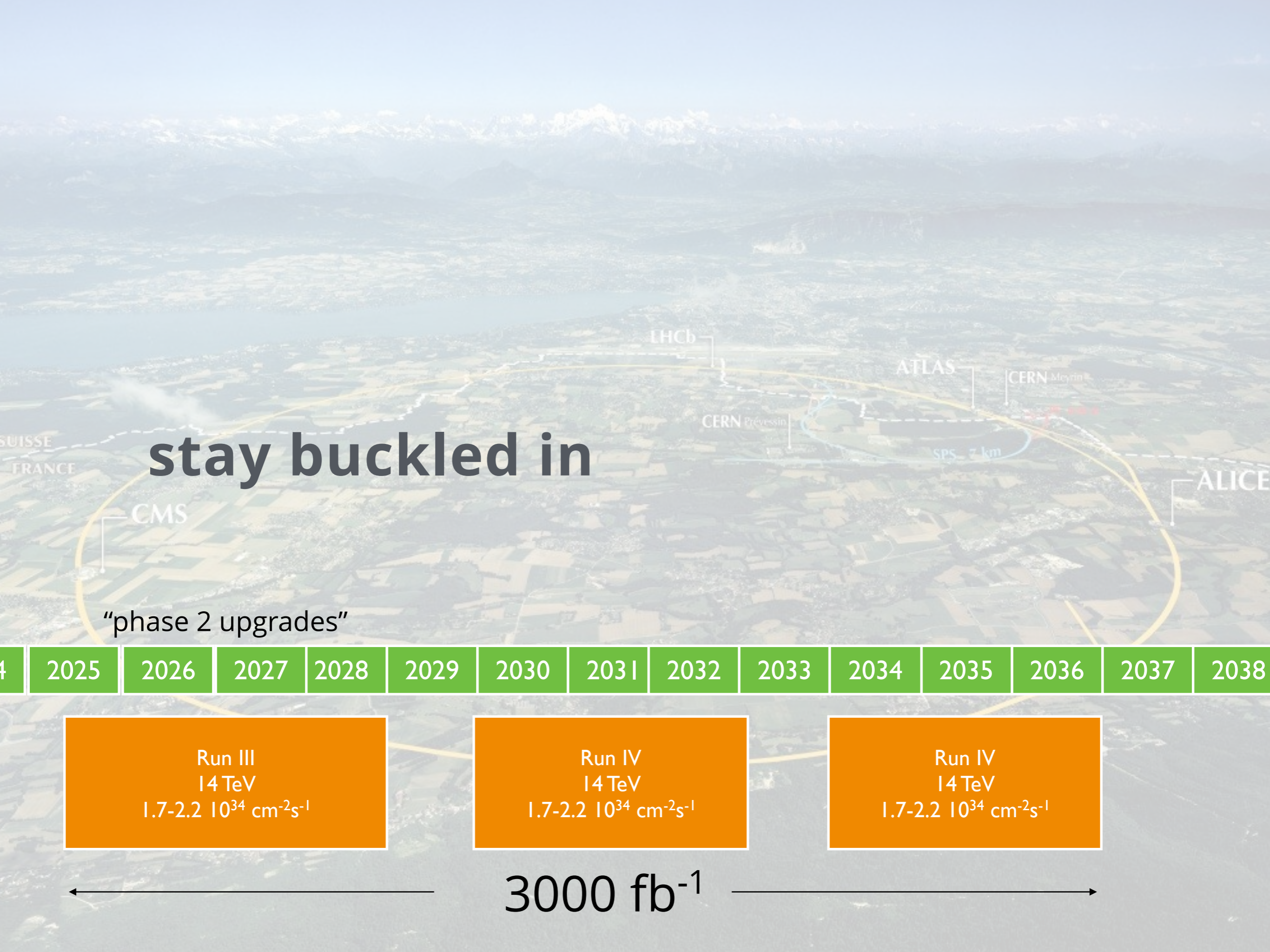
you are here

# stay buckled in

"phase 2 upgrades"



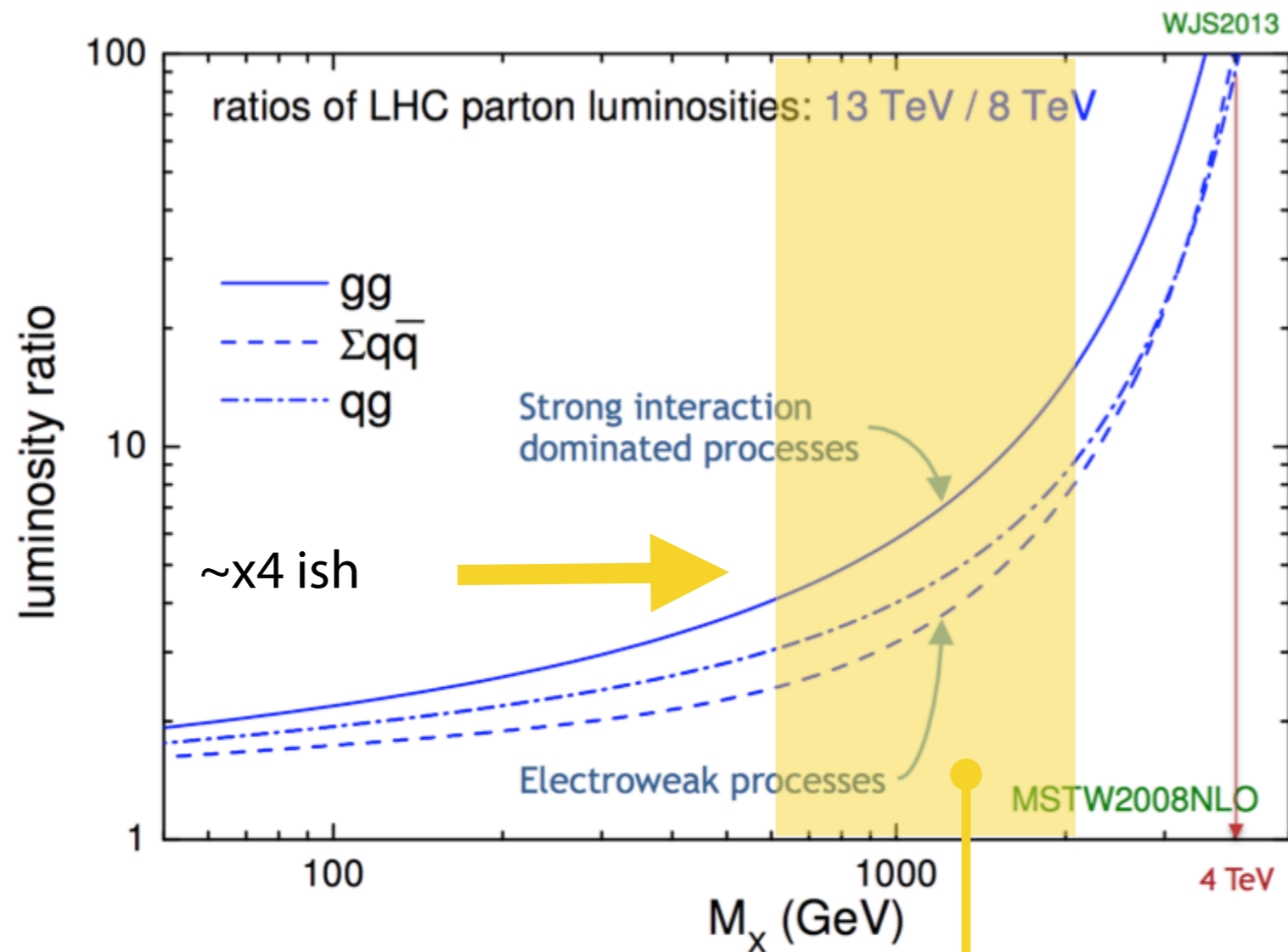
$3000 \text{ fb}^{-1}$





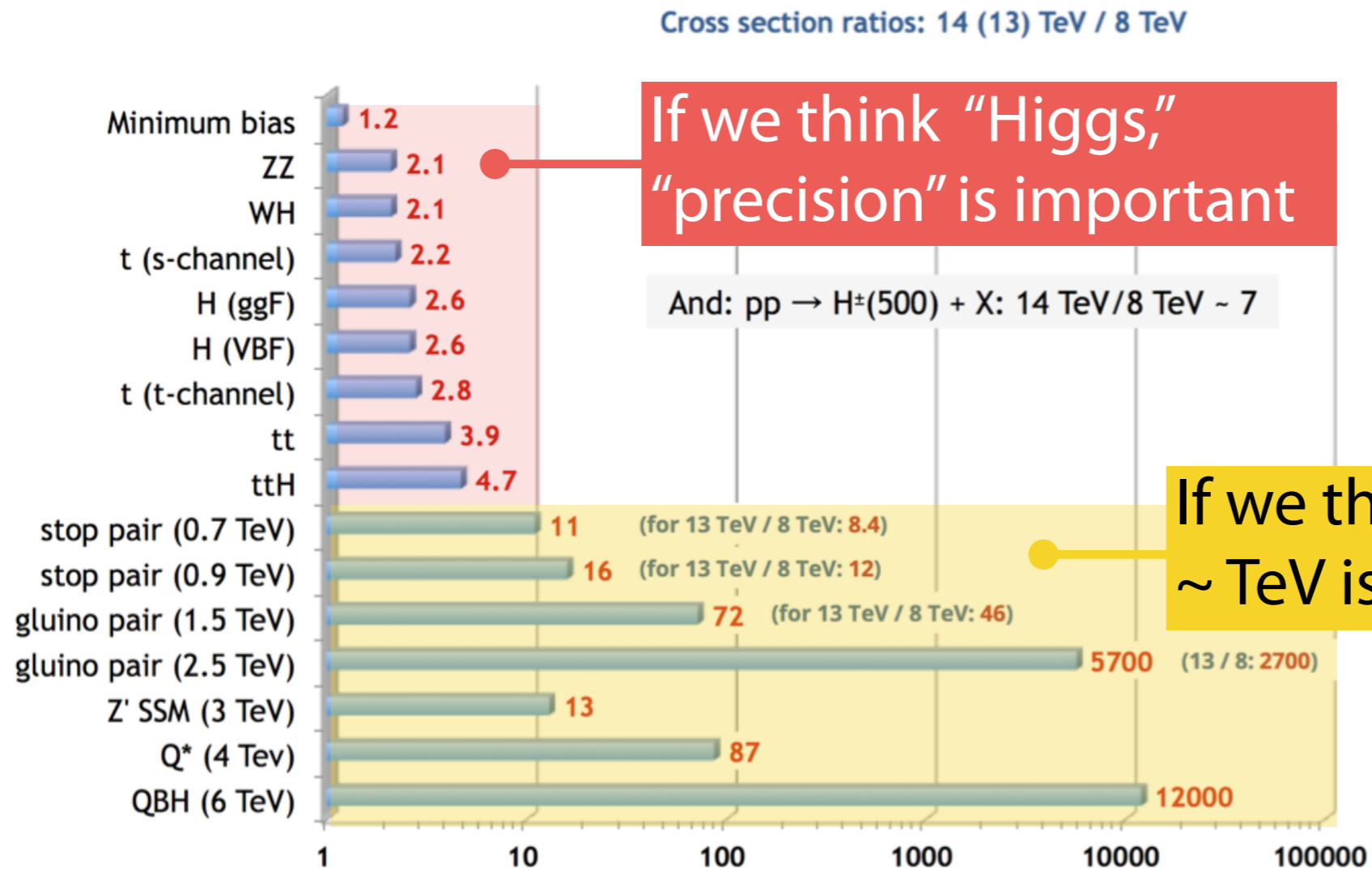
x2

# Higher energy: More parton luminosity



If we think "natural," then  
~ TeV is interesting

# Higher energy: larger cross sections



Run 1 is essentially a wrap

# Higgs Boson Physics

## Notable results

---

### **from Run 1 we anticipated:**

Discovery, first looks

### **from Run 1 we achieved:**

Discovery, indeed. and more:

mass, couplings, important final states, differential distributions

### **in Run 2, we expect:**

Cross sections 13/14 TeV, ttH, high mass BSM searches, combination  
precision couplings, differential distributions

~x10 more statistics

# Higgs Boson mass

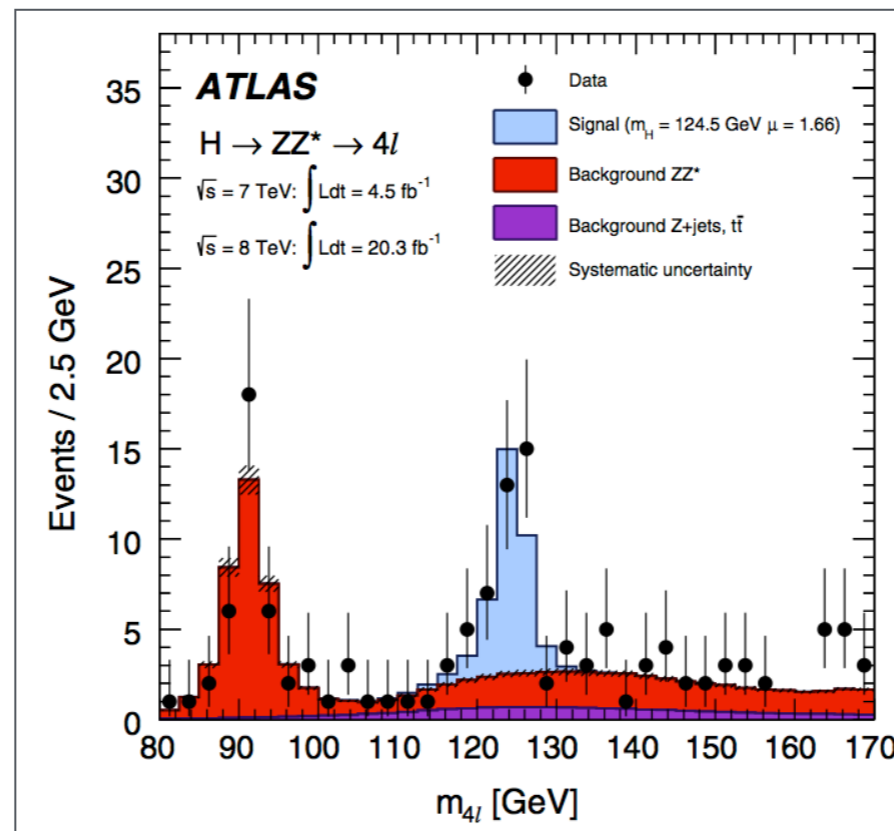
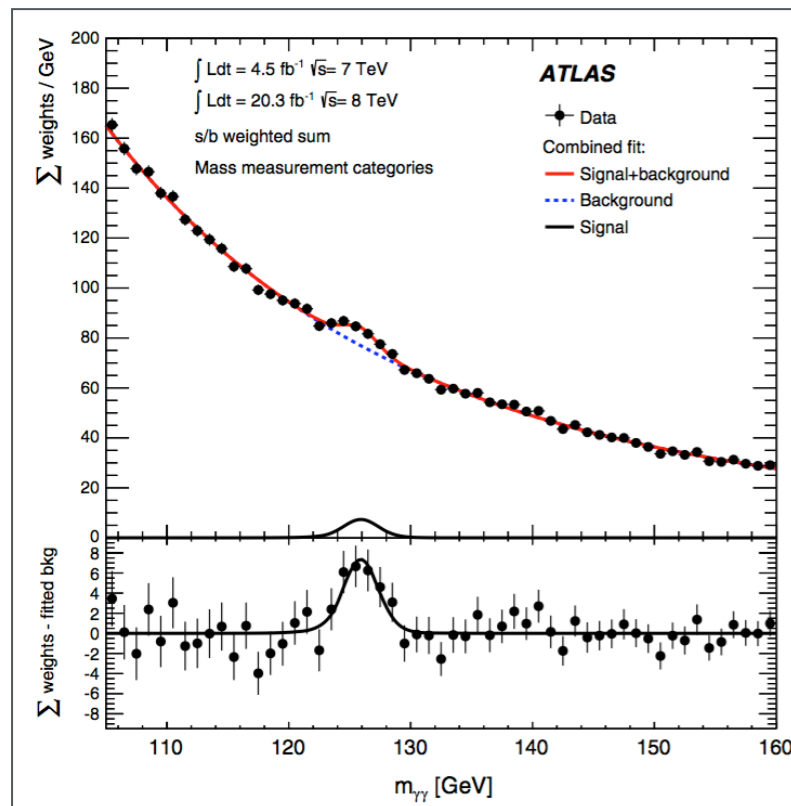
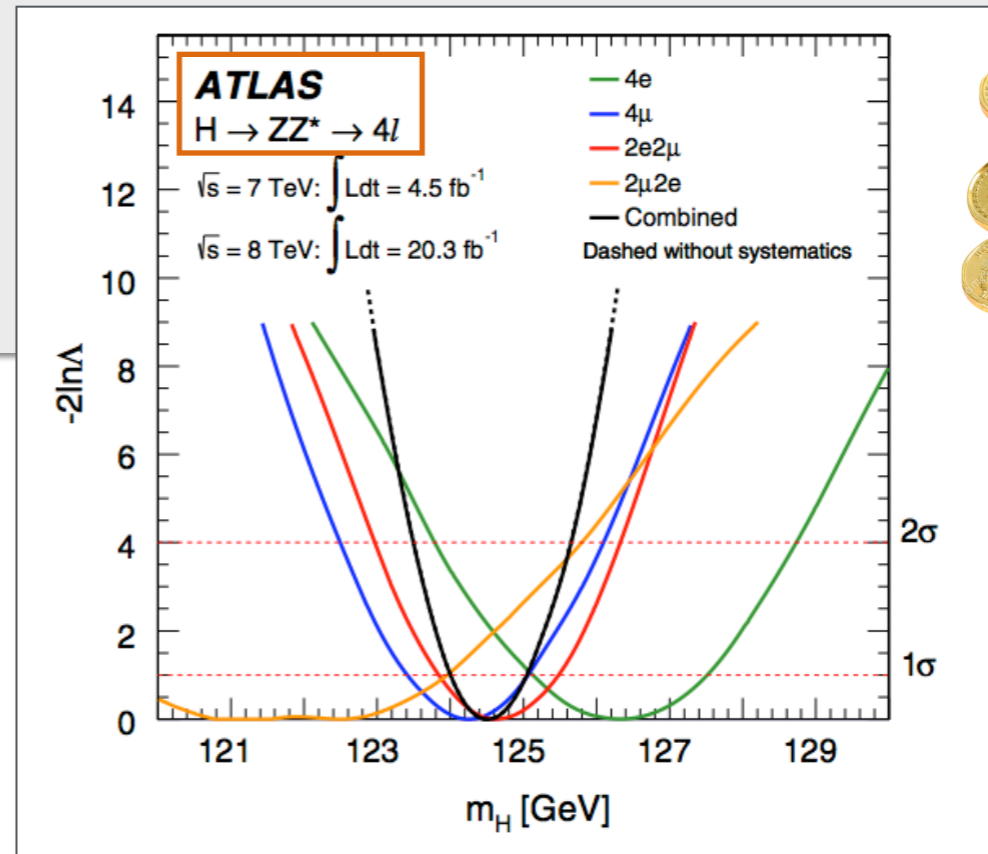
## Agony and Ecstasy

### Agony:

$m_H$  only  $\sim 125$  GeV

### Ecstasy:

$m_H$  precisely =  $125.36 \pm 0.37 \pm 0.18$  GeV  $\gamma\gamma$  and  $Z^*Z$



(Laser Kaplan, Today)

$\sim 40$  signal/channel

Run II: expect 400-500

PHYSICAL REVIEW D 90, 052004 (2014)

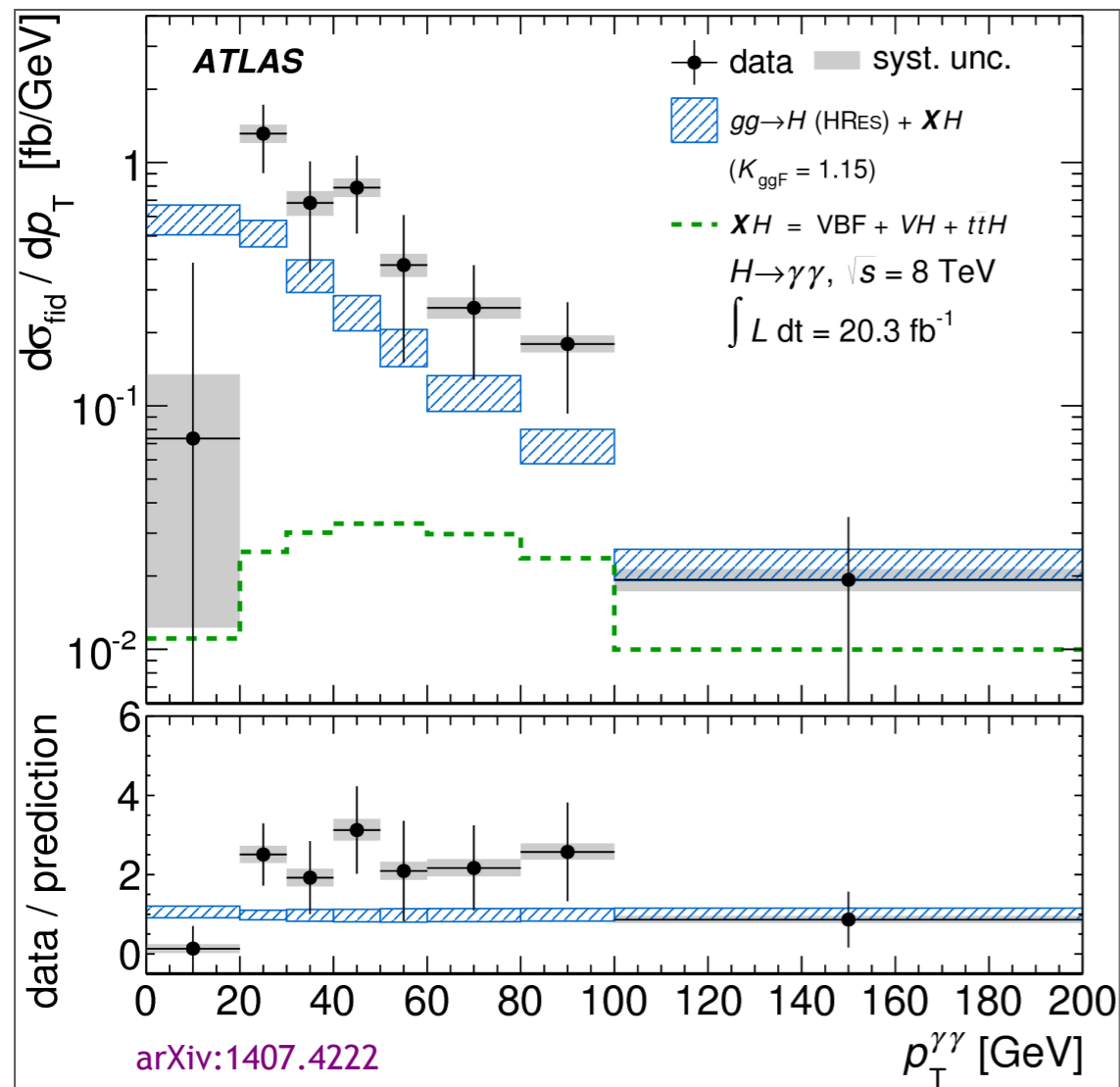
# Higgs in slices

## differential distributions



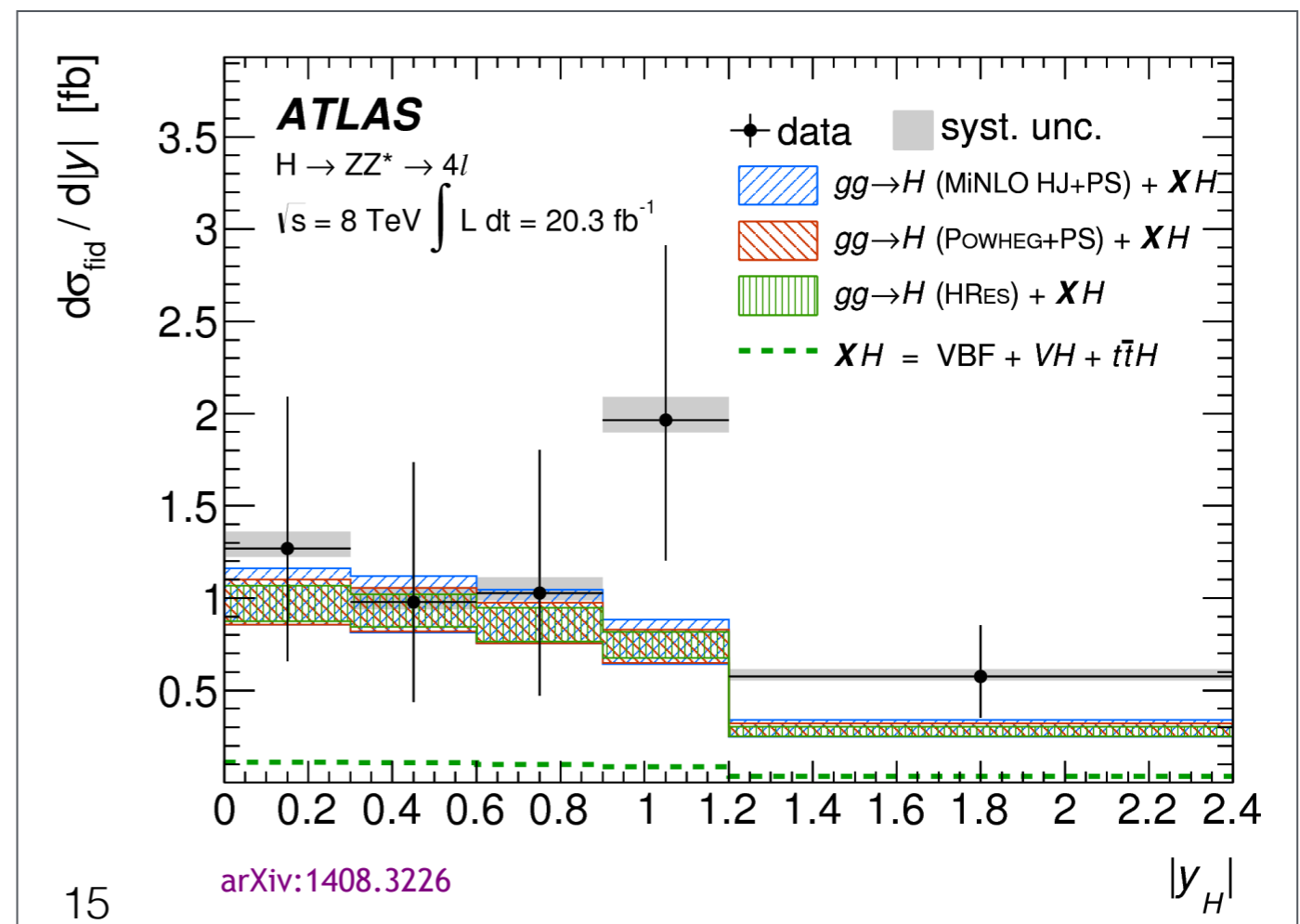
**the details** unfolded to the particle level

$$H \rightarrow \gamma\gamma \quad gg \rightarrow H \text{ HRES}$$



$$H \rightarrow ZZ^* \rightarrow 4\ell$$

$$gg \rightarrow H \text{ MINLO, POWHEG, HRES2}$$



# Higgs couplings, 1

signal strengths, small, vibrant industry

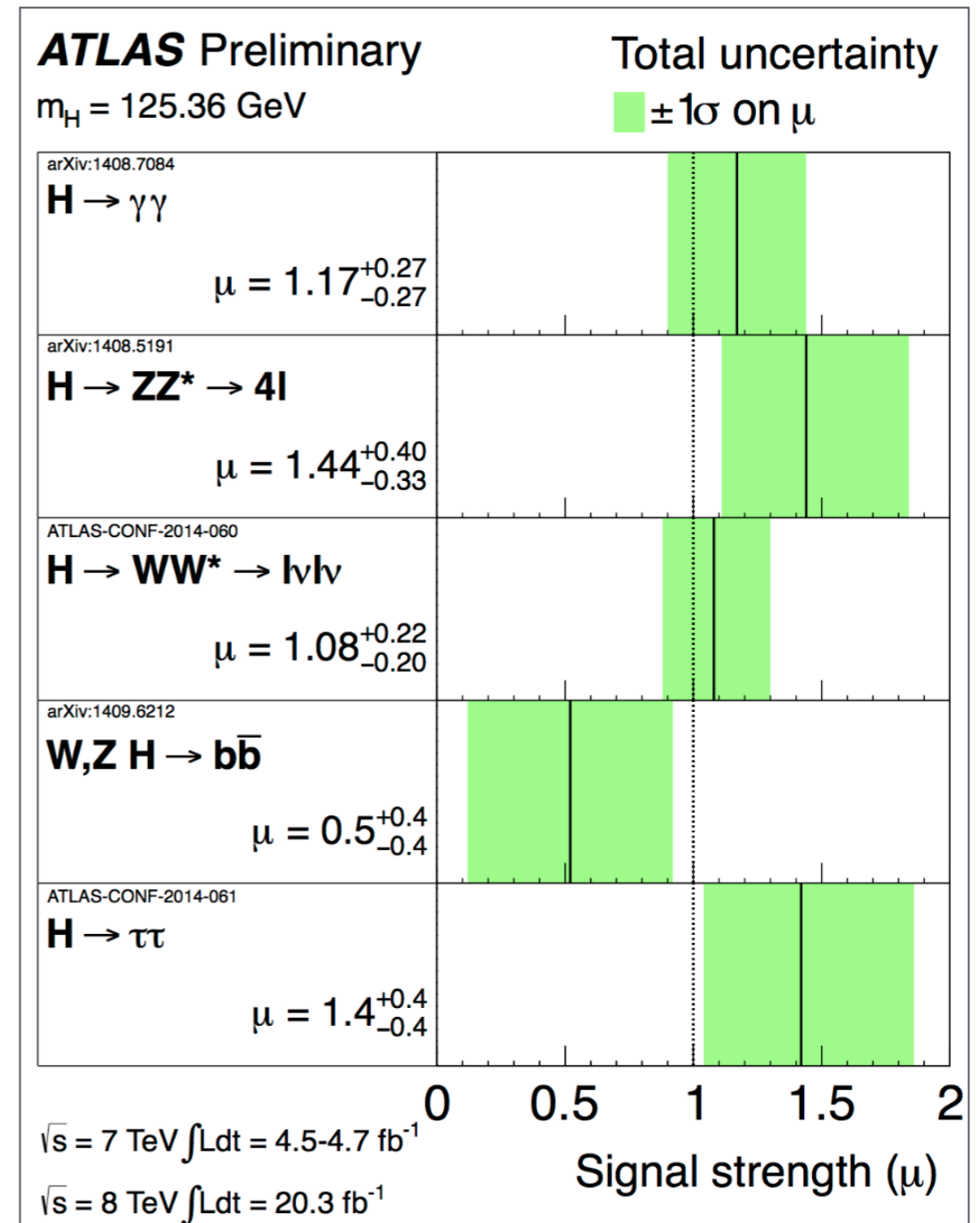
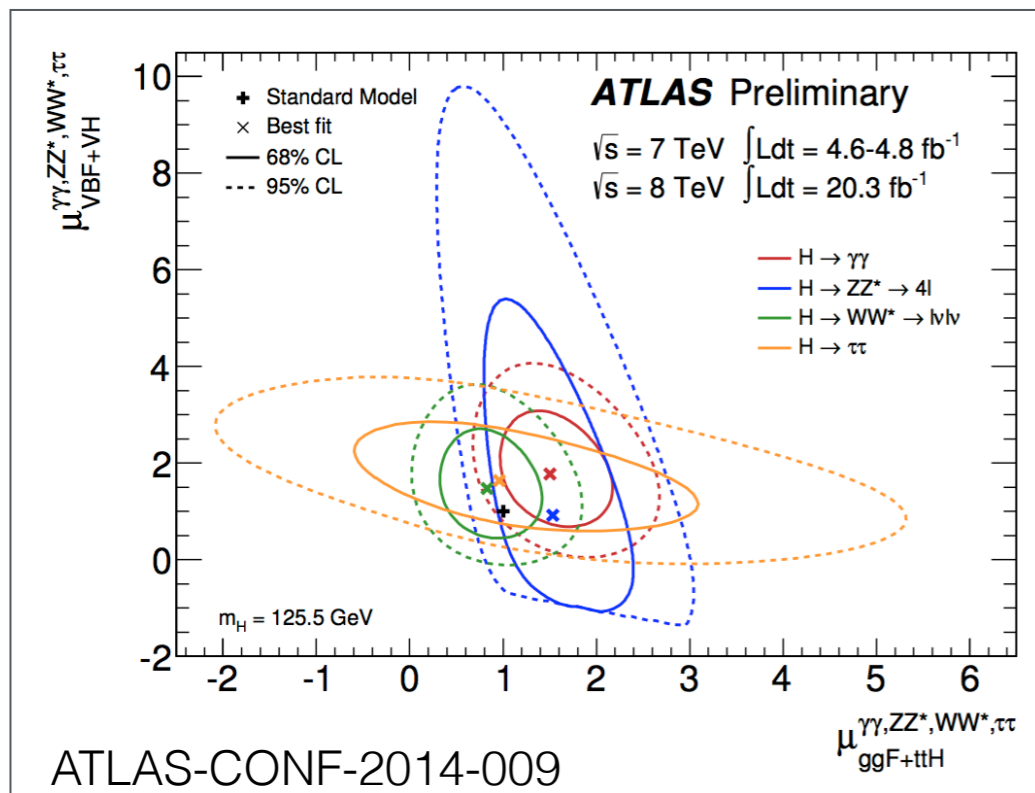


## succession of assumptions

least constrained, signal strength:

## other fits with constraints

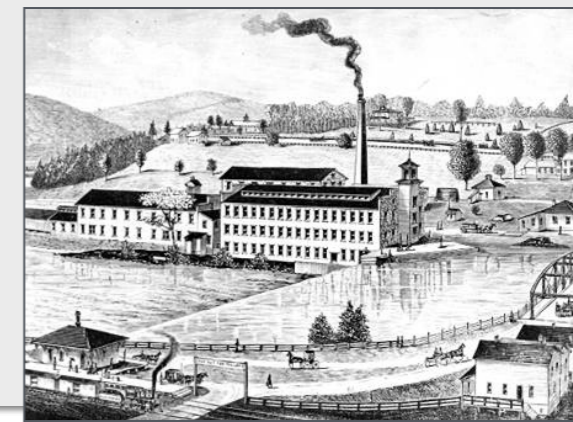
$$\mu_{VBF+VH} = \mu_{VBF} = \mu_{VH} \quad \mu_{ggf+ttH} = \mu_{ggf} = \mu_{t\bar{t}}$$





# Higgs couplings, 2

global fitting, big, growing industry



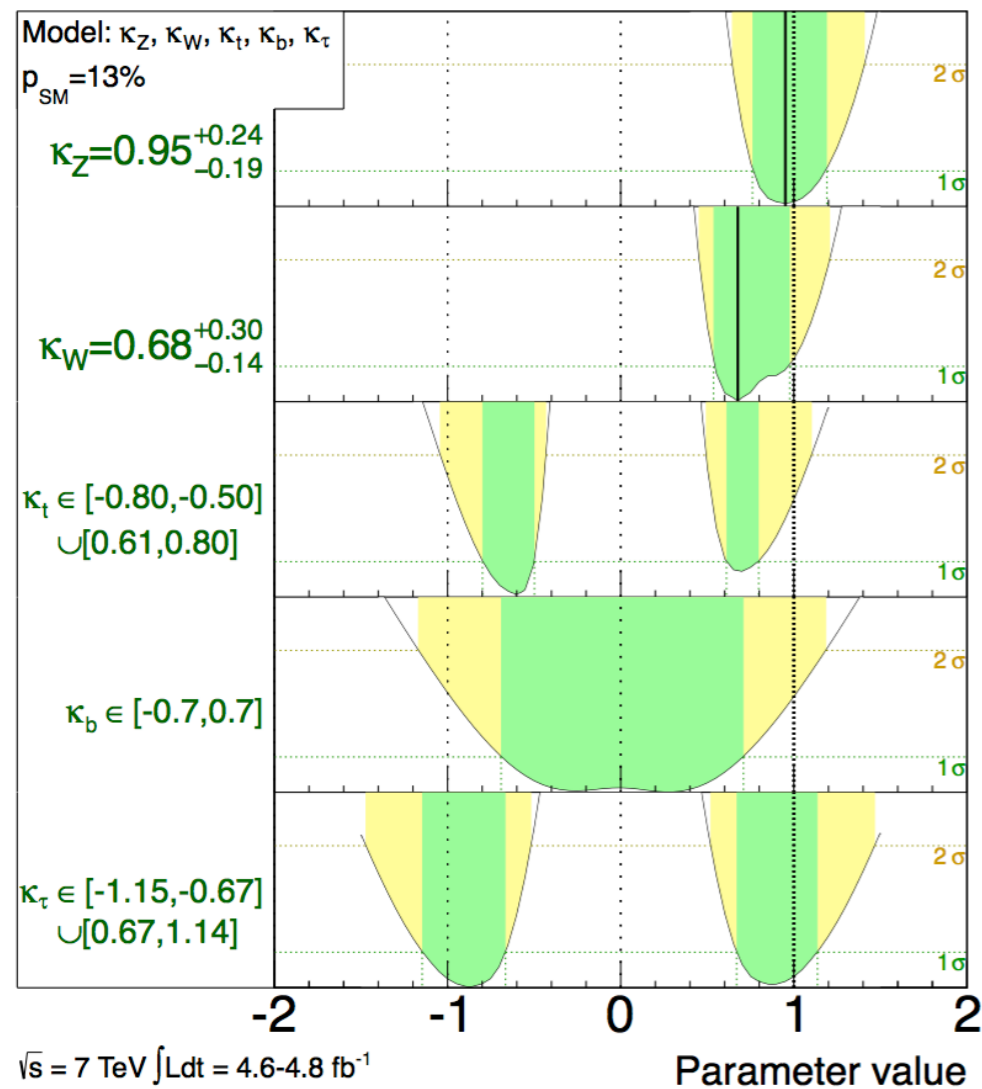
## global fitting

**ATLAS Preliminary**

$m_H = 125.5 \text{ GeV}$

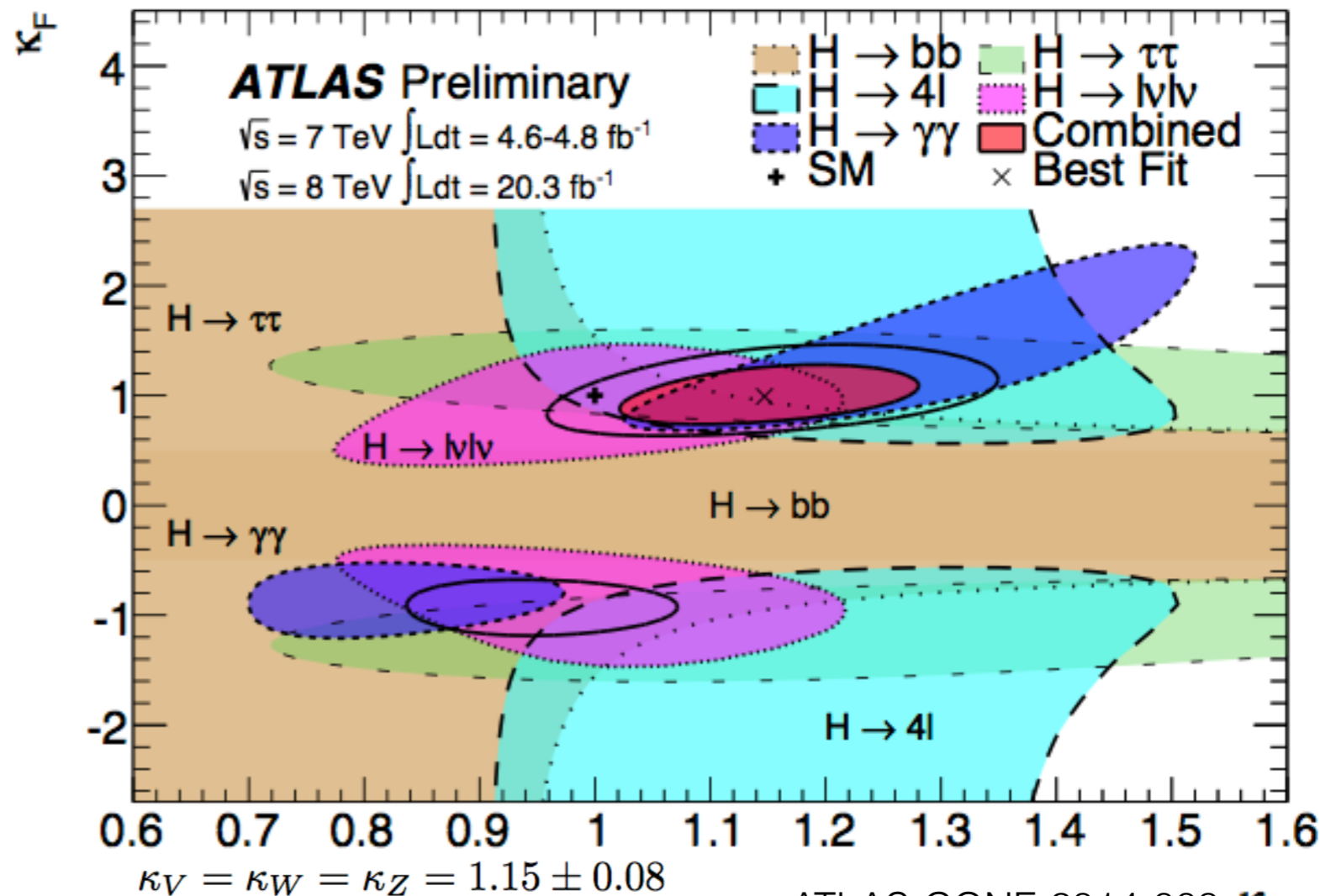
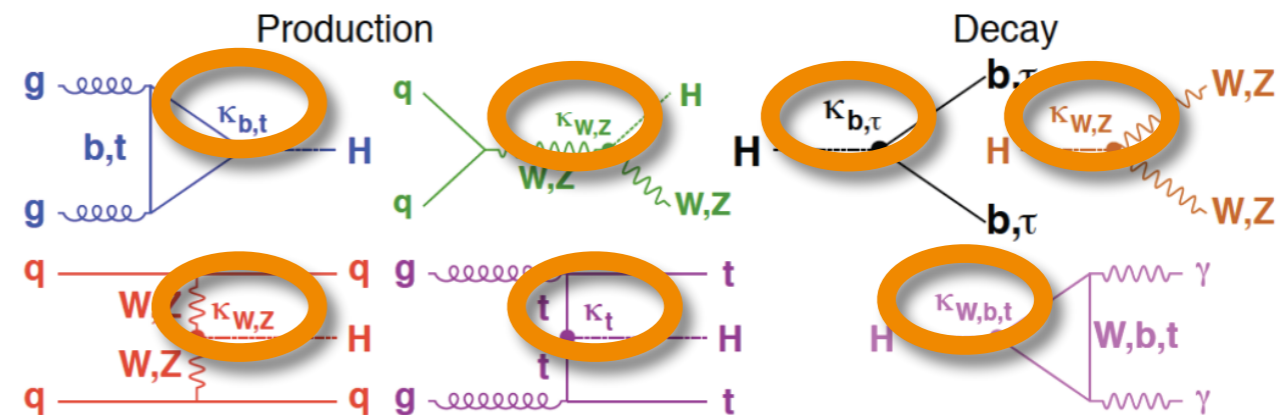
Total uncertainty

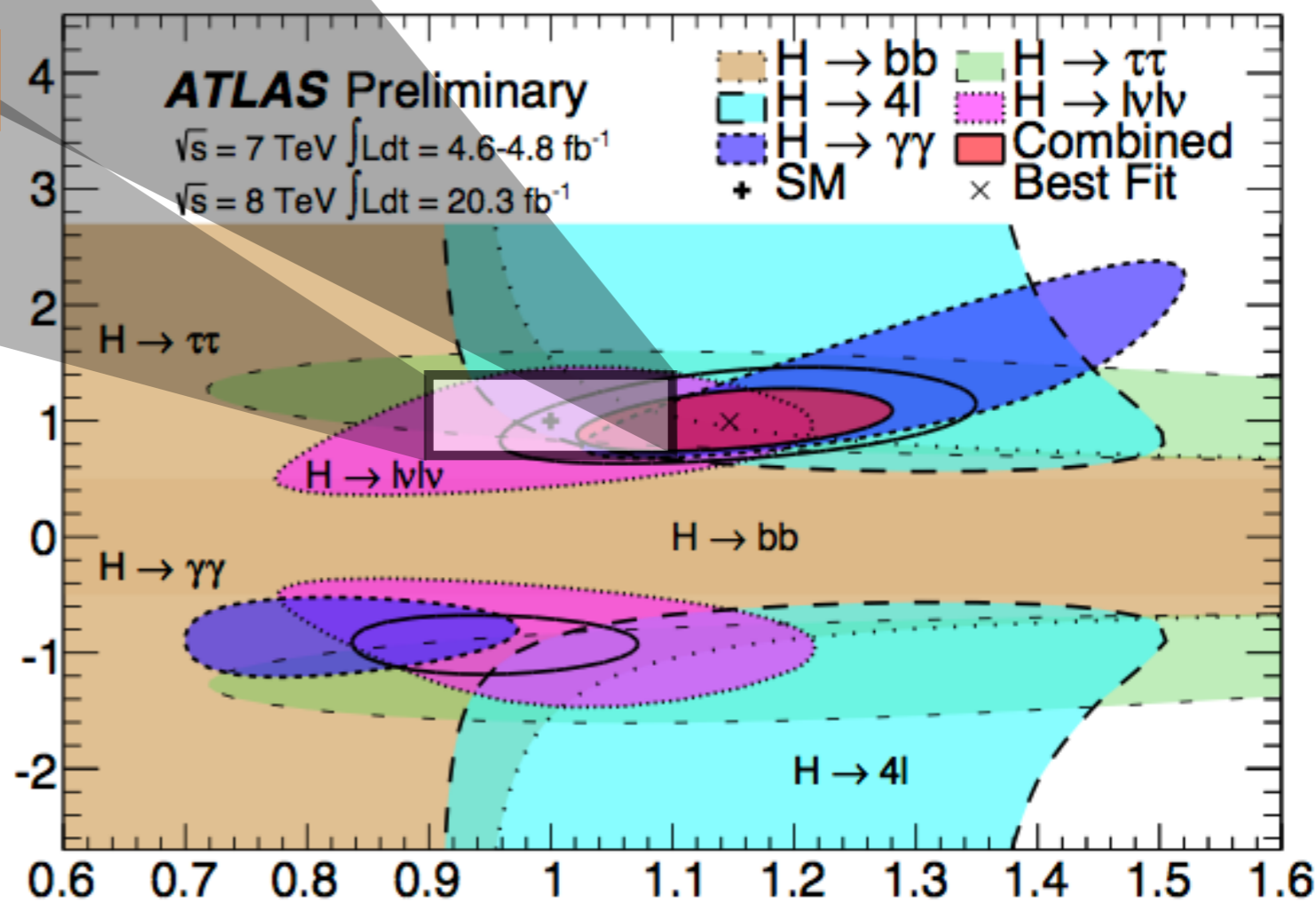
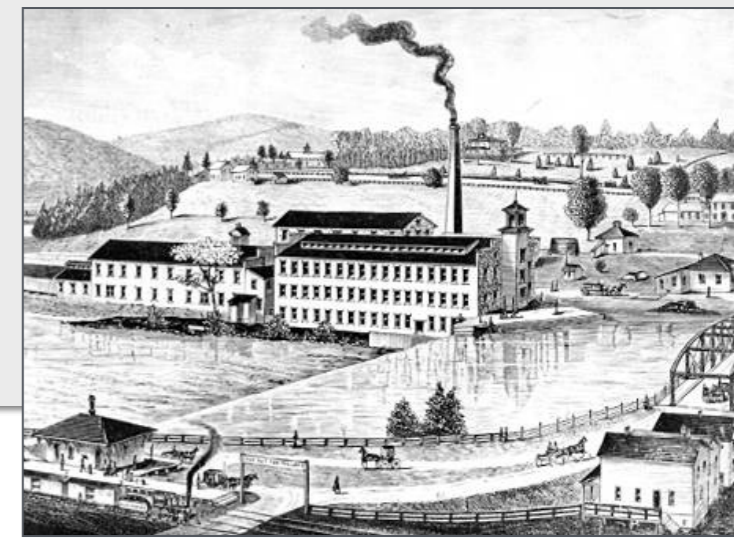
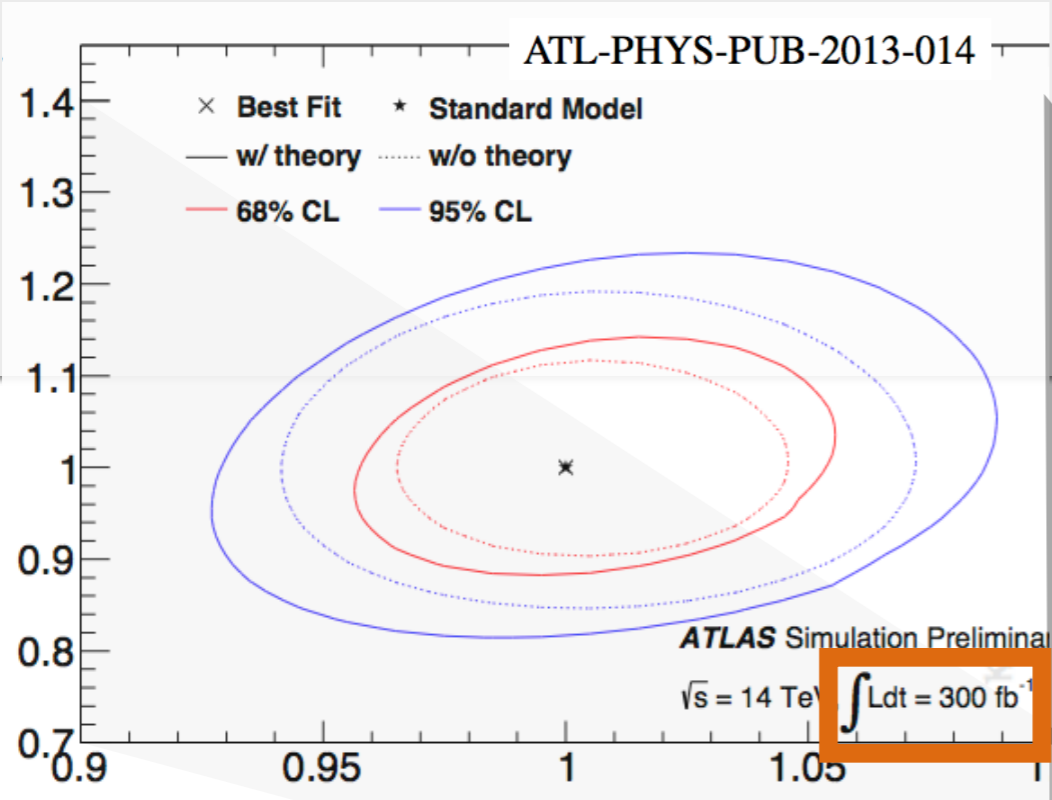
± 1σ ± 2σ



$\sqrt{s} = 7 \text{ TeV} \int L dt = 4.6\text{-}4.8 \text{ fb}^{-1}$

$\sqrt{s} = 8 \text{ TeV} \int L dt = 20.3 \text{ fb}^{-1}$





The precision Higgs Boson era has begun.

$$\kappa_V = \kappa_W = \kappa_Z = 1.15 \pm 0.08$$

$$\kappa_F = \kappa_t = \kappa_b = \kappa_\tau = \kappa_g = 0.99 \pm 0.17$$

*But Wait...*  
**THERE'S  
MORE!**

## SM higgs final state configurations:

WW,  $\tau\tau$ , bb (Puja Saha, Friday)

fiducial and differential cross sections ZZ

tTH  $\rightarrow$  2 gamma, constrain top Yukawa

on-off peak total width measurement

## 125 GeV Higgs Boson characteristics

differential distributions, CP, spin

## BSM Higgs searches

Charged Higgs, LFV final states, Heavy Higgs, NMSSM, Invisible decays,  
Exotic Higgs, scalar diphoton



# Standard Model Physics



Notable results

## from Run 1 we anticipated:

“Rediscovery”...Precision total & inclusive cross sections, VV studies, differential cross sections. Did we expect MW?

## from Run 1 we achieved:

Rediscovery, indeed.

## in Run 2, we expect:

Re-rediscovery...Precision couplings, differential distributions, much pileup study.

First  $M_W$ ?

Attention to WW

5x - 10x more statistics

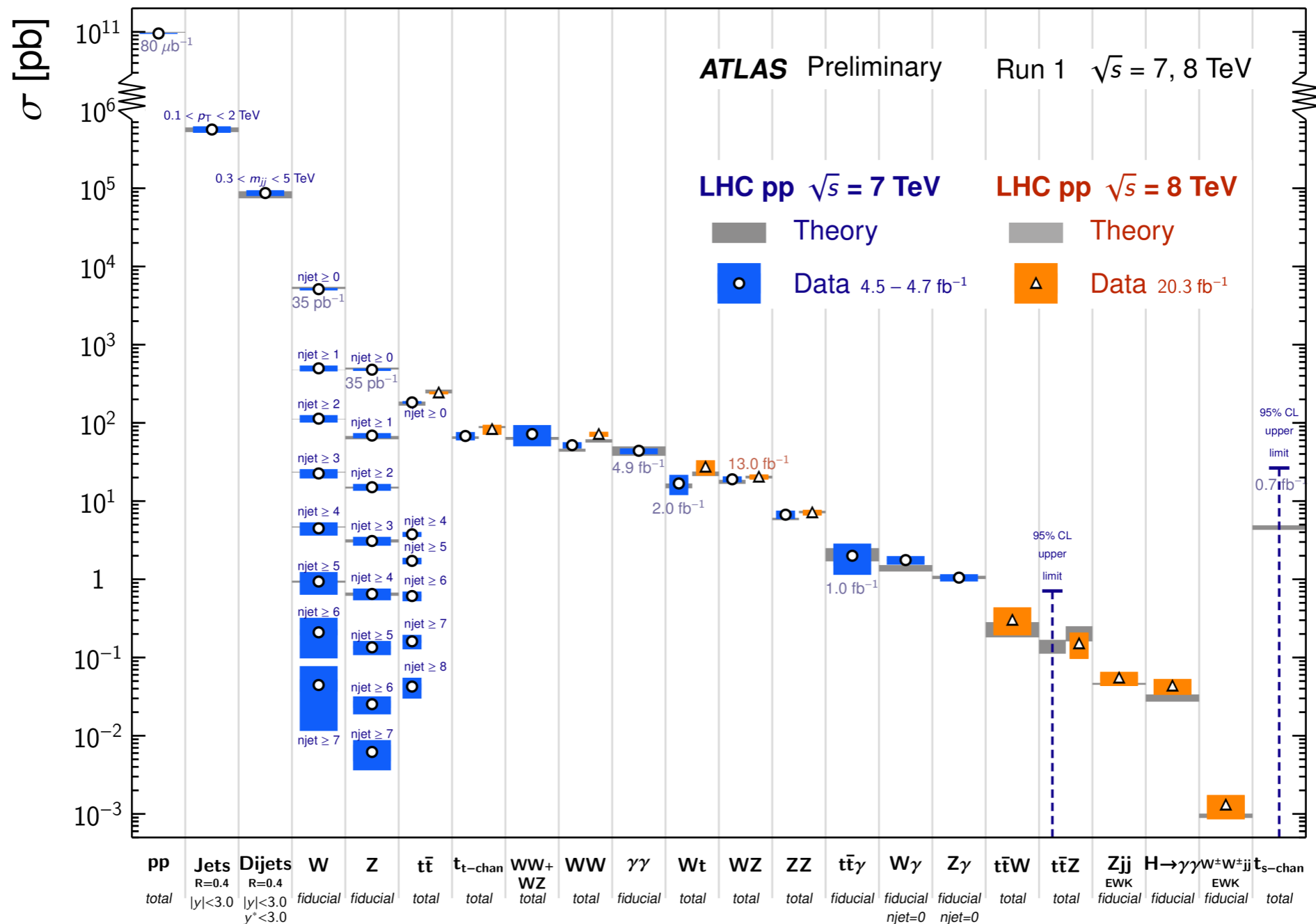
# Standard Model Paleontology

pick your favorite dinosaur



## Standard Model Production Cross Section Measurements

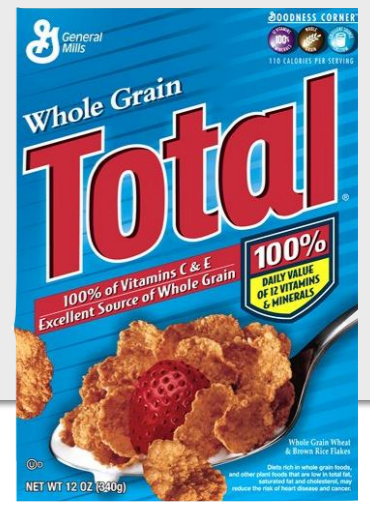
Status: July 2014



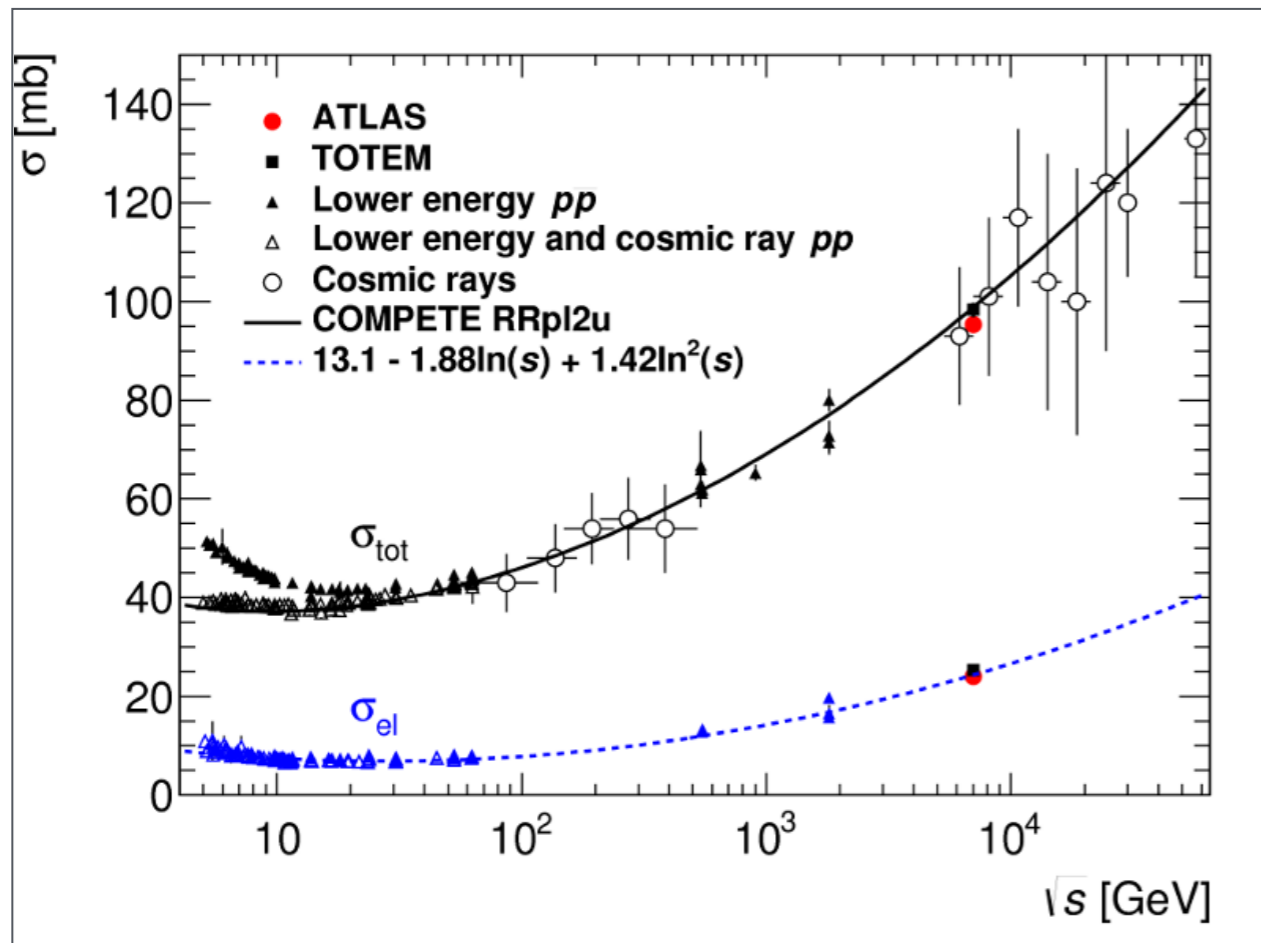


# The basics

## Elastic and total pp cross section

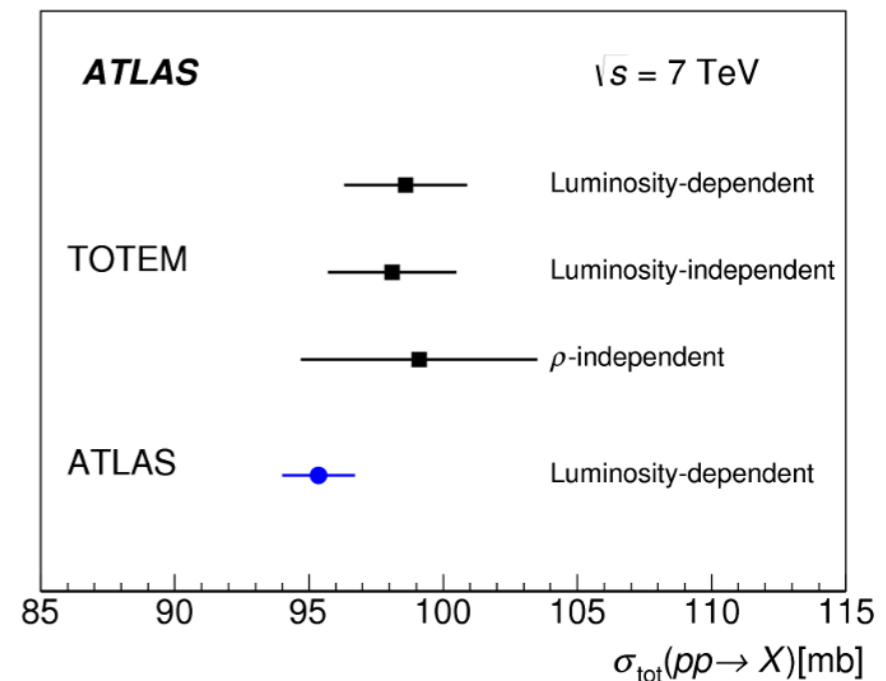
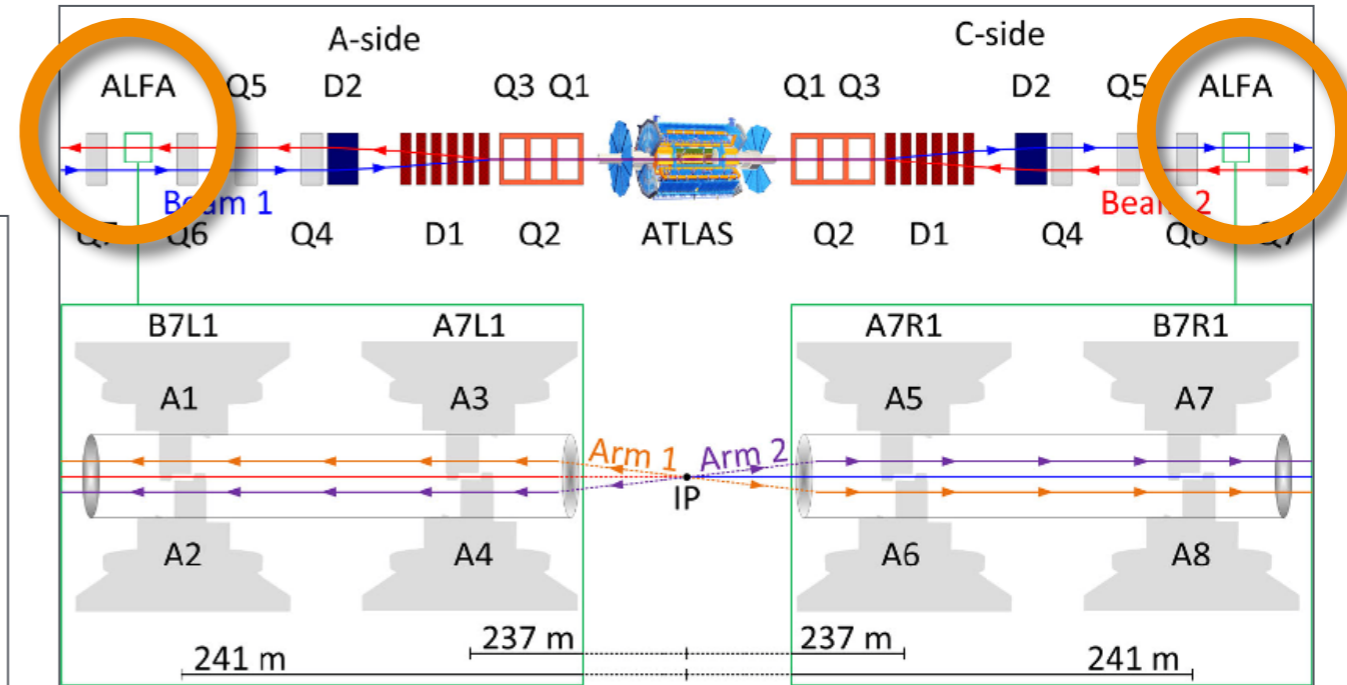


ALFA detectors at  $\pm 240\text{m}$   
special run of  $80/\mu\text{b}$



arXiv:1408.5778

**Result:**  $\sigma_{\text{tot}}(pp \rightarrow X) = 95.35 \pm 0.38 \text{ (stat)} \pm 1.25 \text{ (exp)} \pm 0.37 \text{ (extr)} \text{ mb}$   
and elastic slope  $B = 19.73 \pm 0.14 \text{ (stat)} \pm 0.26 \text{ (syst)} \text{ GeV}^{-2}$



# QCD jet physics

## di-jet observables

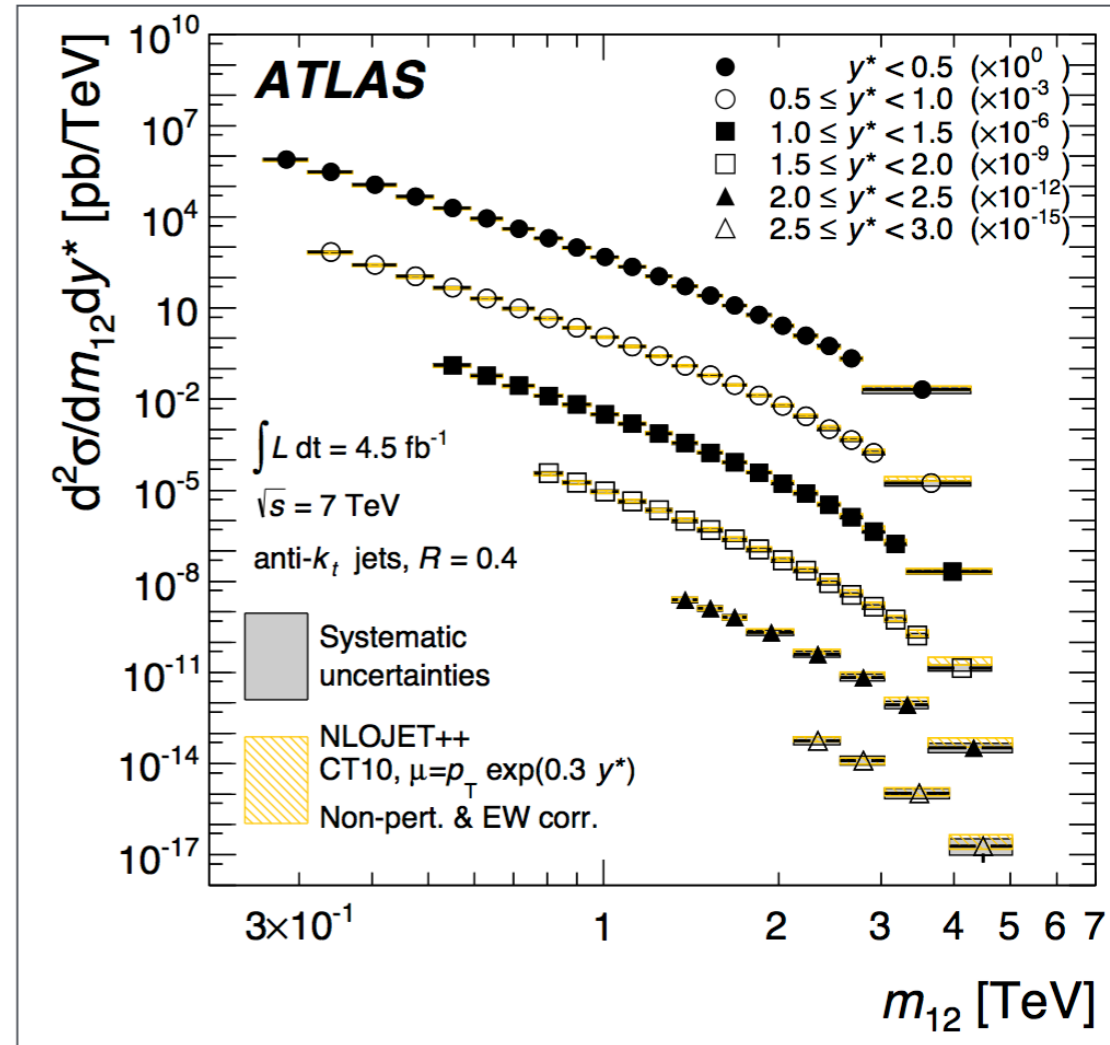


7 TeV running, double differential

Bins of  $m_{12}$  and rapidity

composite scale limit  $\Lambda < 6.9 - 7.7$  TeV

arXiv:1312.3524

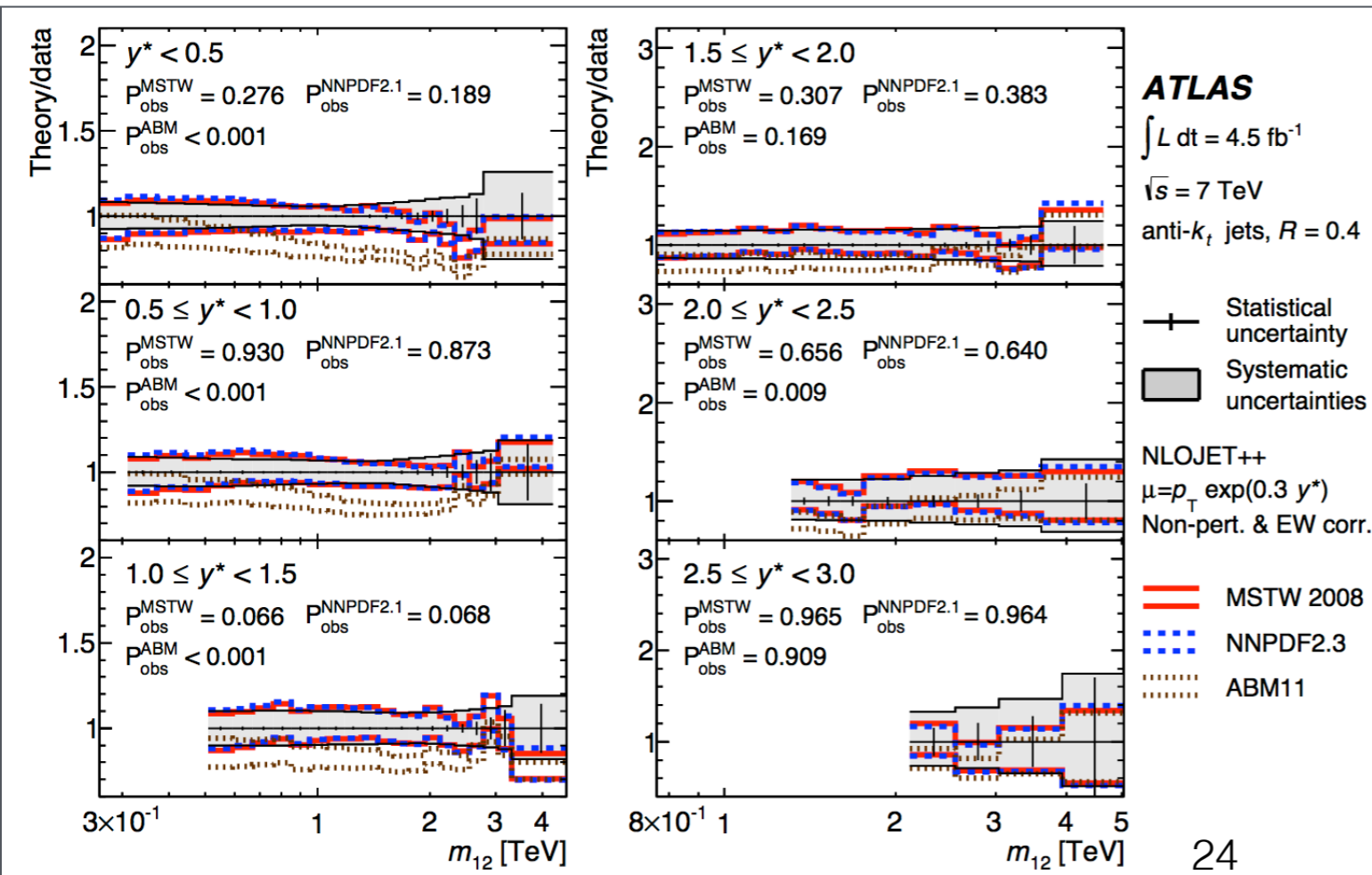


Agreement found:

NLOjet++ predictions using CT10, NNPDF2.1, and MSTW 2008

Disagreement found:

NLOjet++ predictions using ABM11 & HERAPDF1.5





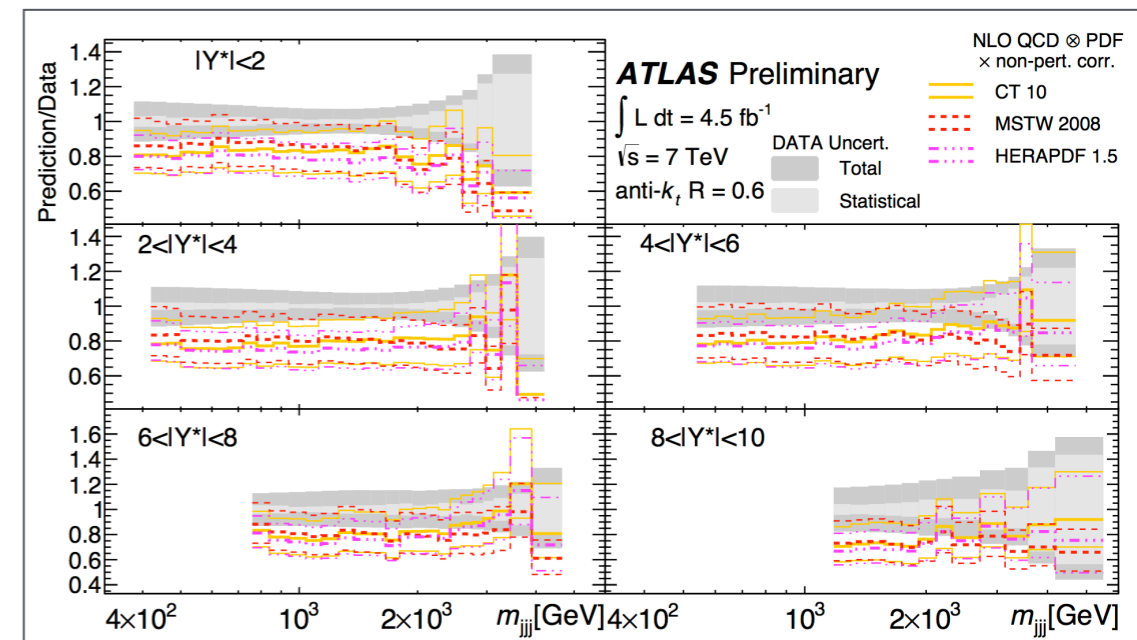
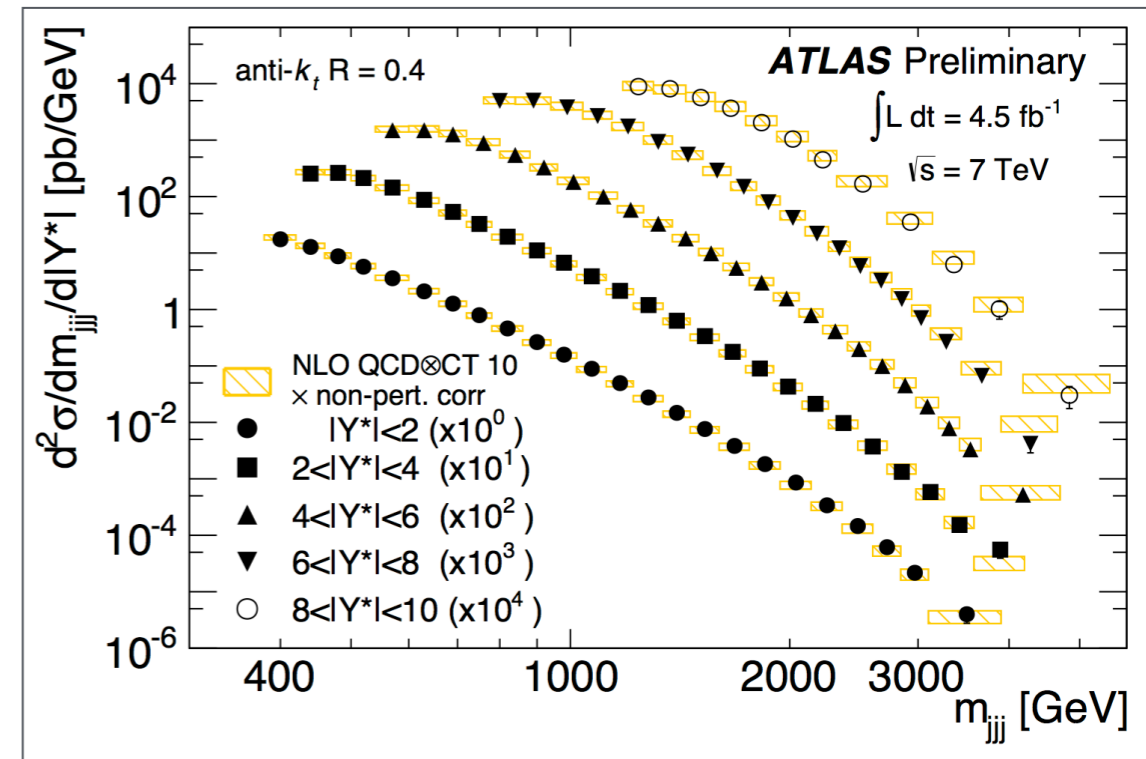
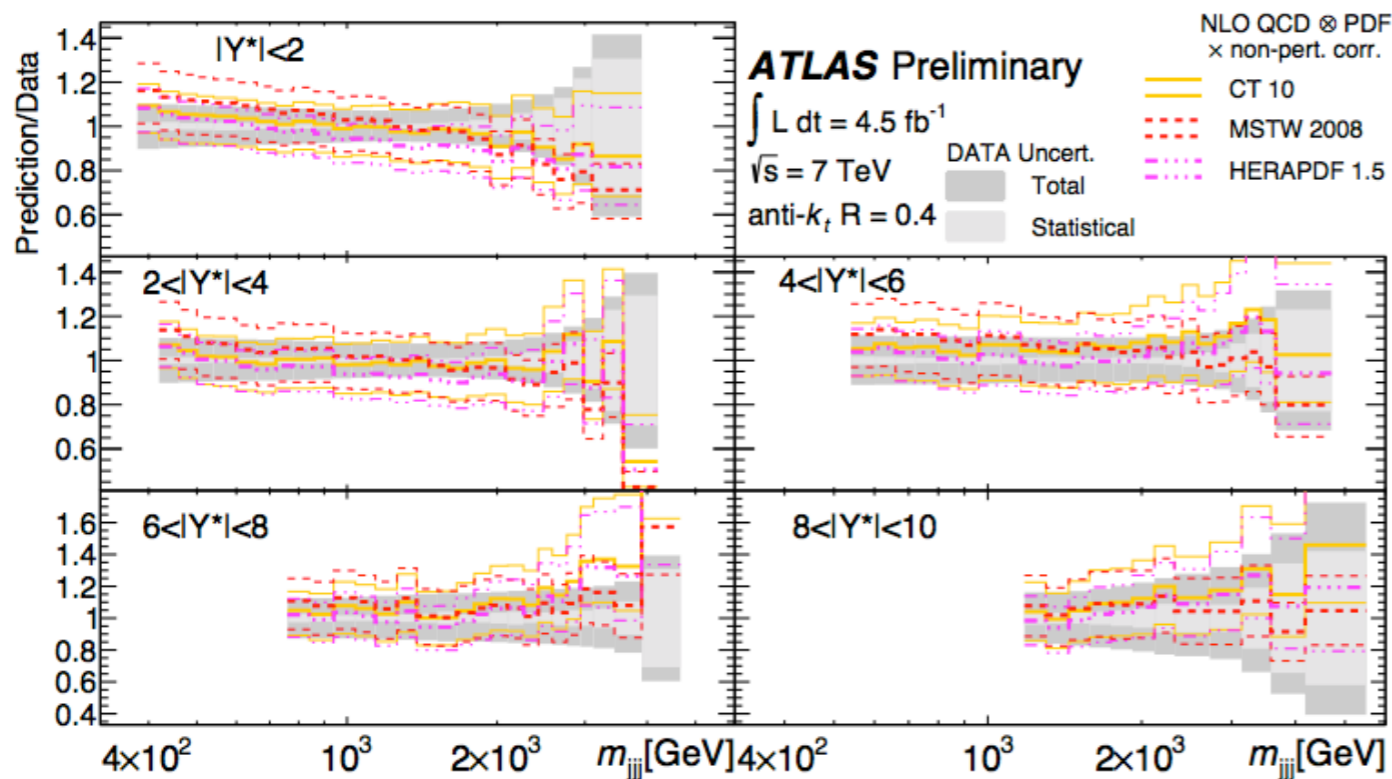
# QCD jet physics

## 3 jet cross sections



7 TeV running, double differential,  $m_{jjj}$

good agreement with most NLO pdf  
for  $R = 0.4$ , less for  $R = 0.6$



# Electroweak physics

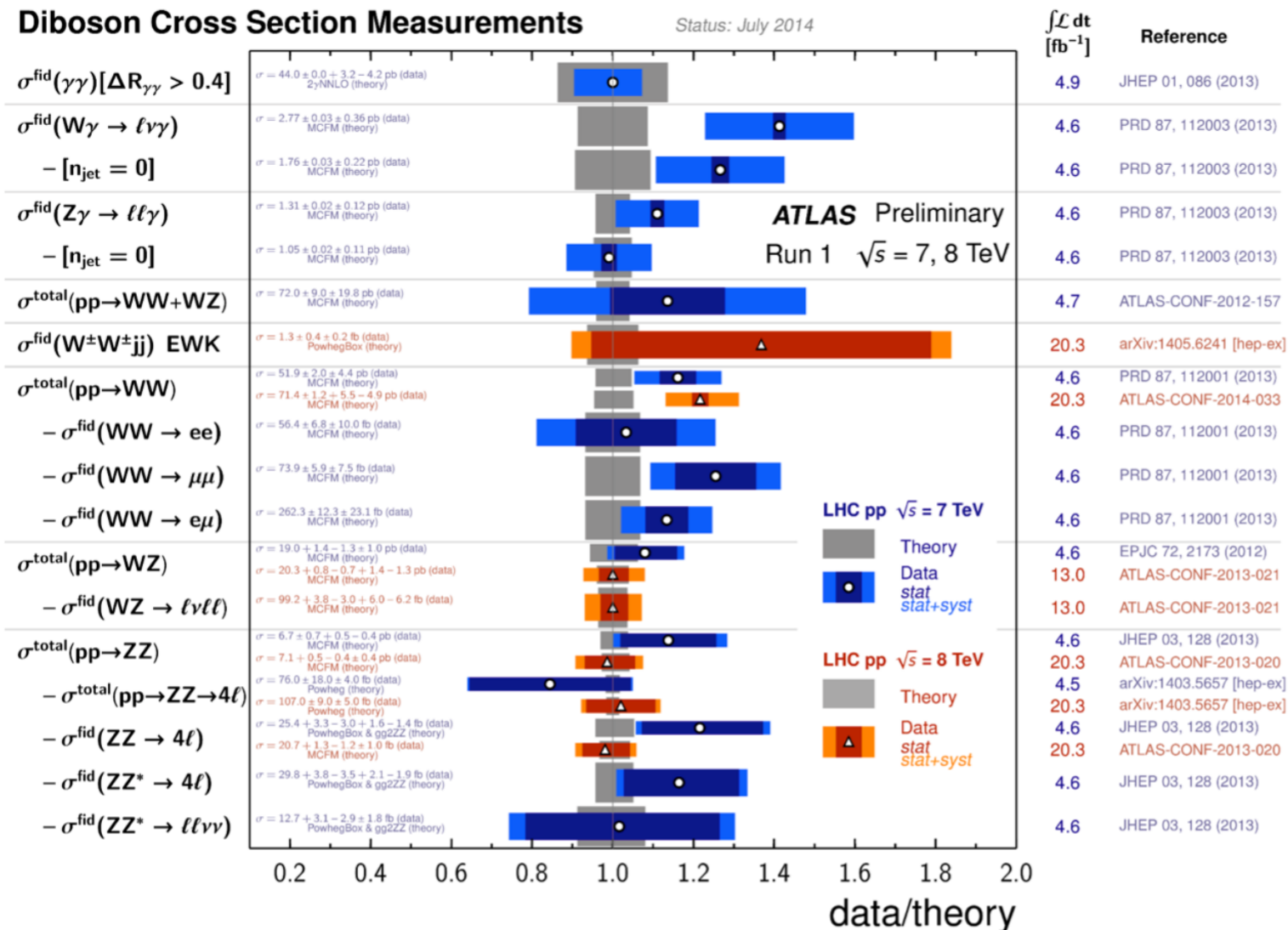
## $W^+W^-$ continues to be interesting



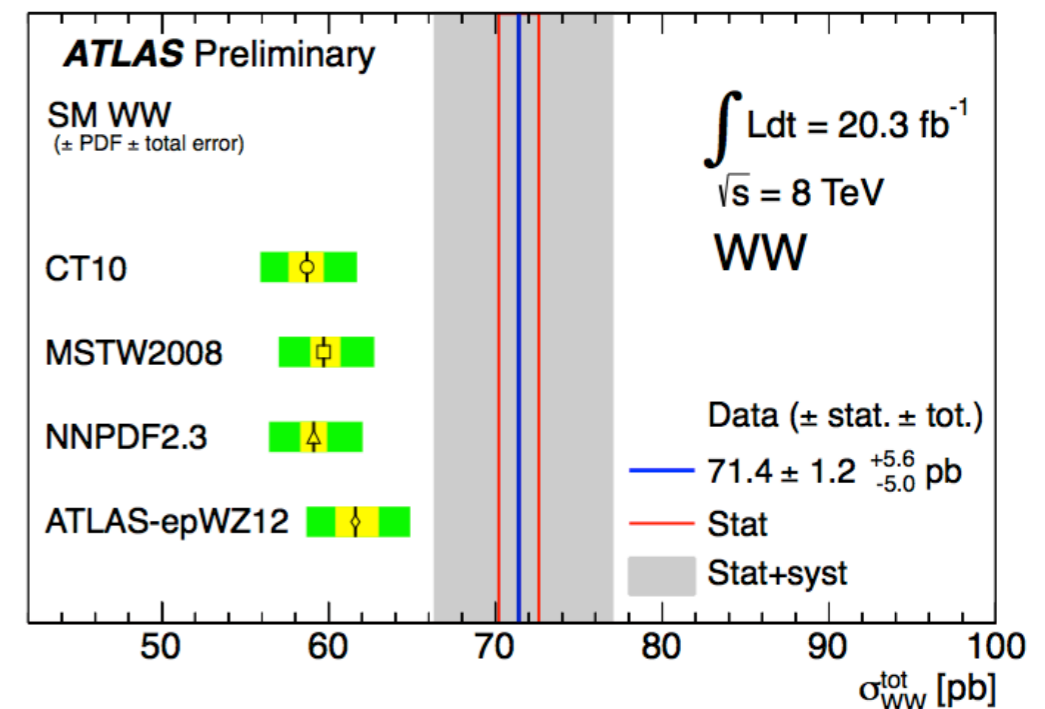
yesterday's background is today's confusion?

### Diboson Cross Section Measurements

Status: July 2014



Comparison with theory is difficult



$t\bar{t}$  and  $t$  backgrounds mandate a jet-veto requirement of  $p_T > 25 \text{ GeV}$

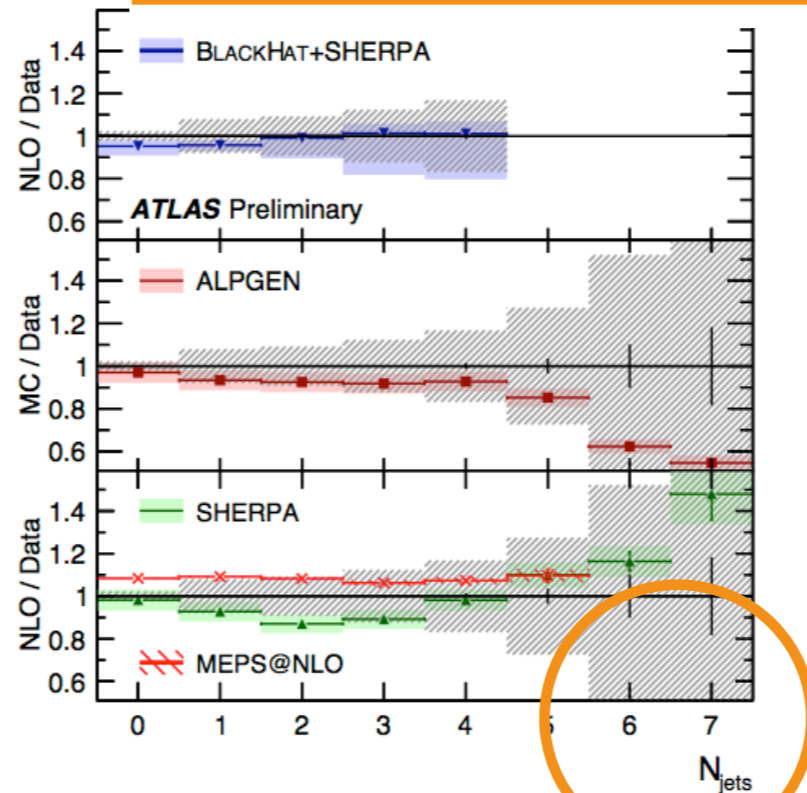
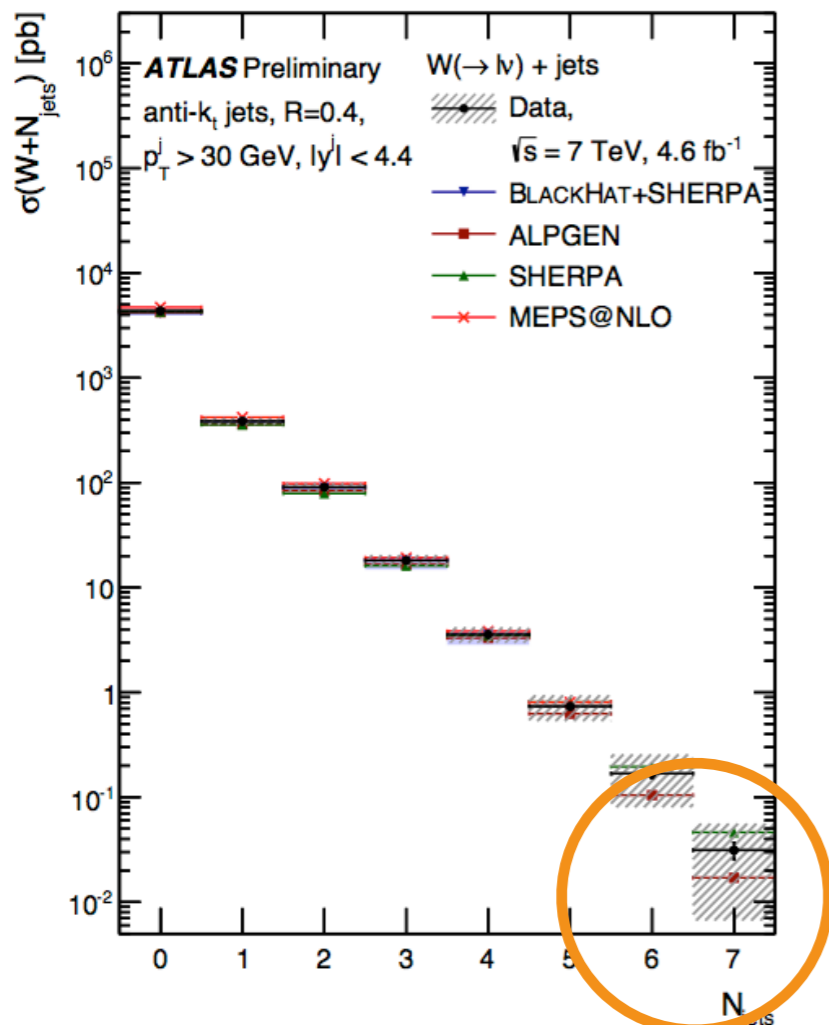
ATLAS-CONF-2014-033

expect x10 or so more statistics

# W+jets up to 8!

7 TeV running, leptonic  
decay modes

BLACKHAT+SHERPA, HEJ, ALPGEN,  
SHERPA AND MEPS@NLO

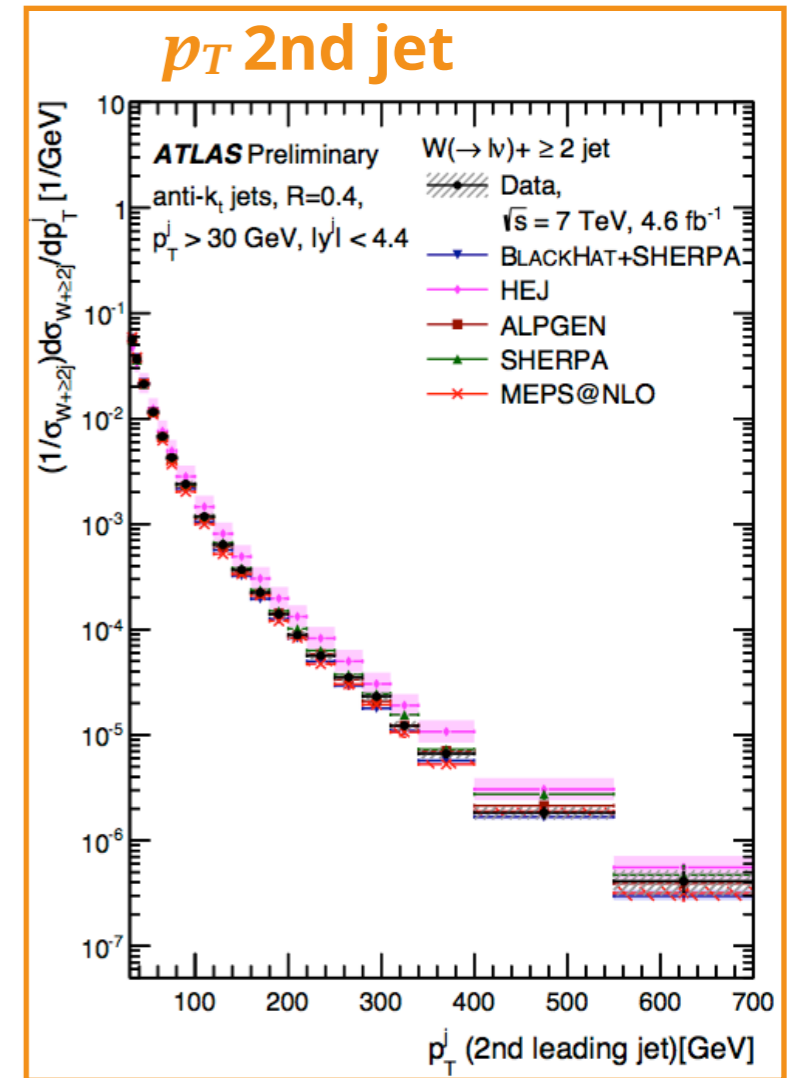
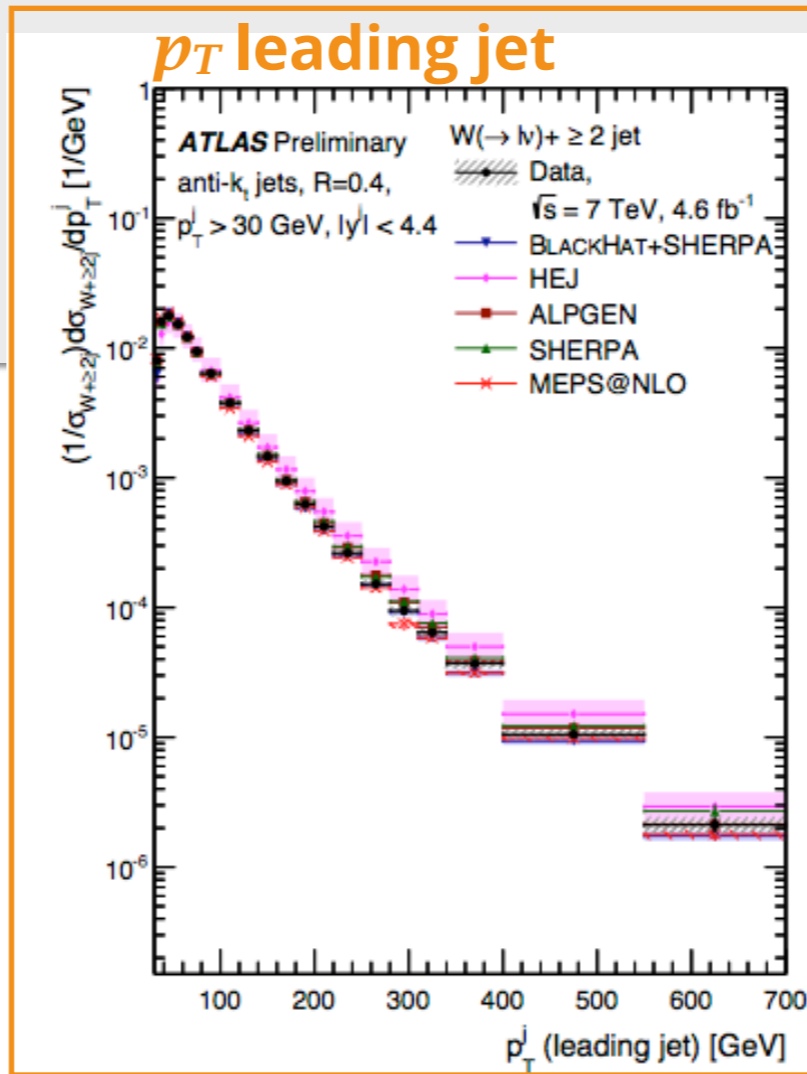


ATLAS-CONF-2014-035

27



e.g.  $\geq 2$  j



generally, good agreement  
but no prediction fits all  
distributions

*But Wait...*  
**THERE'S  
MORE!**

## Z/W production

heavy flavor:  $W + c$  (arXiv:1402.6263) and  $Z \rightarrow b\bar{b}$  (arXiv:1404.7042)

underlying event

$p_T(Z)$

$W\gamma, Z\gamma, ZZ, W^+W^-, W^\pm Z$ , fully leptonic and semileptonic

## jet structure

inclusive jet  $m_{jj}$ , boosted W/Zs, jet gap studies

## Multi-bosons

aQGCs, TCG for  $Z/\gamma - WW$

QGC for  $WWWW$

evidence for electroweak WW fusion (Jessica Metcalfe, Friday),  $Zjj$  production

evidence for  $WW \rightarrow WWjj$  scattering



# Top quark Physics

Notable results



## from Run 1 we anticipated:

precision cross sections, precision mass of 1-3.5 GeV, rediscovery of single top, single top  $Wt$  channel

## from Run 1, we achieved:

precise cross sections, mass, distributions  $t\bar{t}$  and single top

## in Run 2, we expect:

20x more statistics!

# Top quark cross section

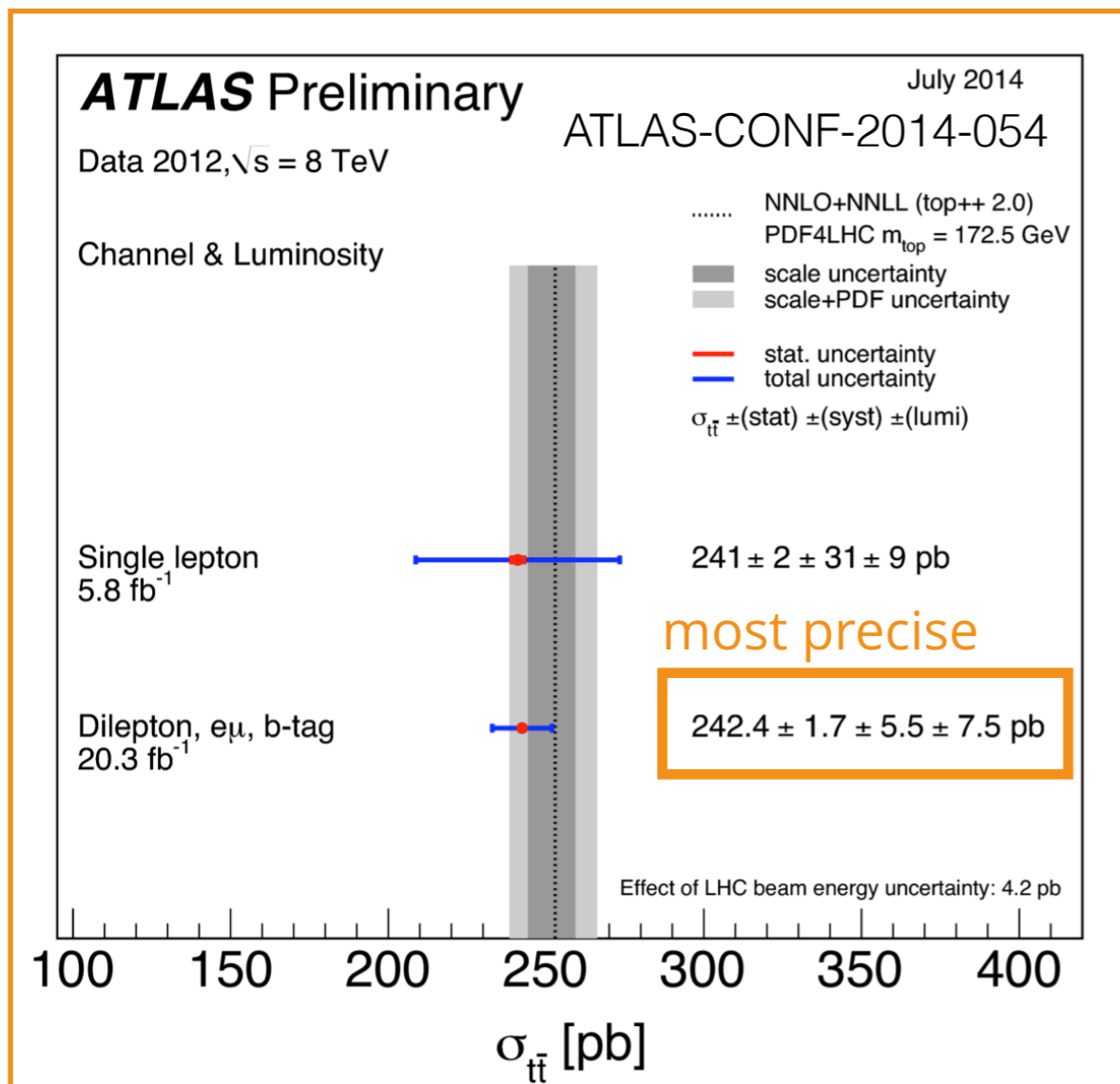
win-win



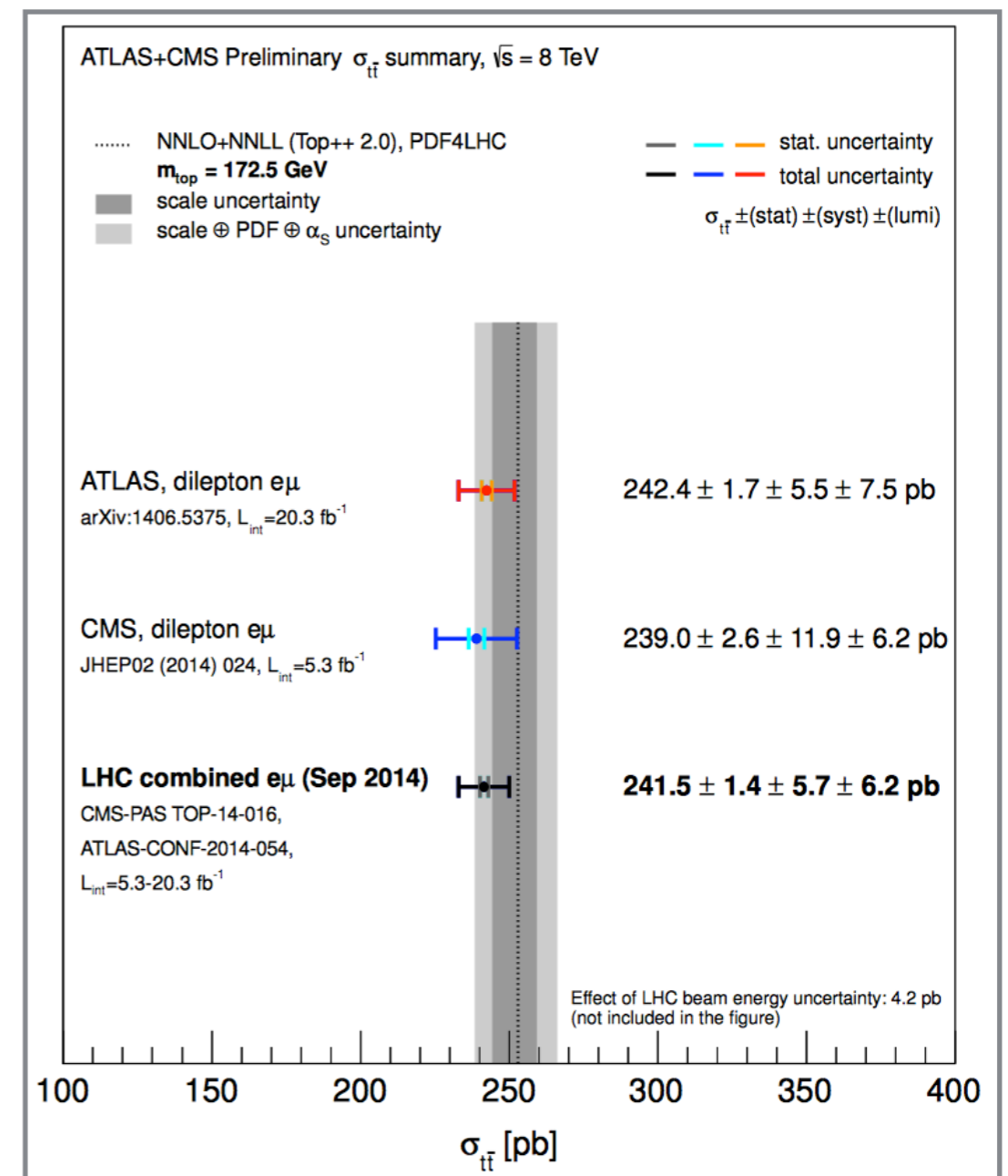
Most precise determinations from single and di-lepton channels

NNLO+NNLL agreement

largest sys: ttbar modeling & pdfs



## Combined ATLAS+CMS eμ



# Single top, $Wt$

win-win

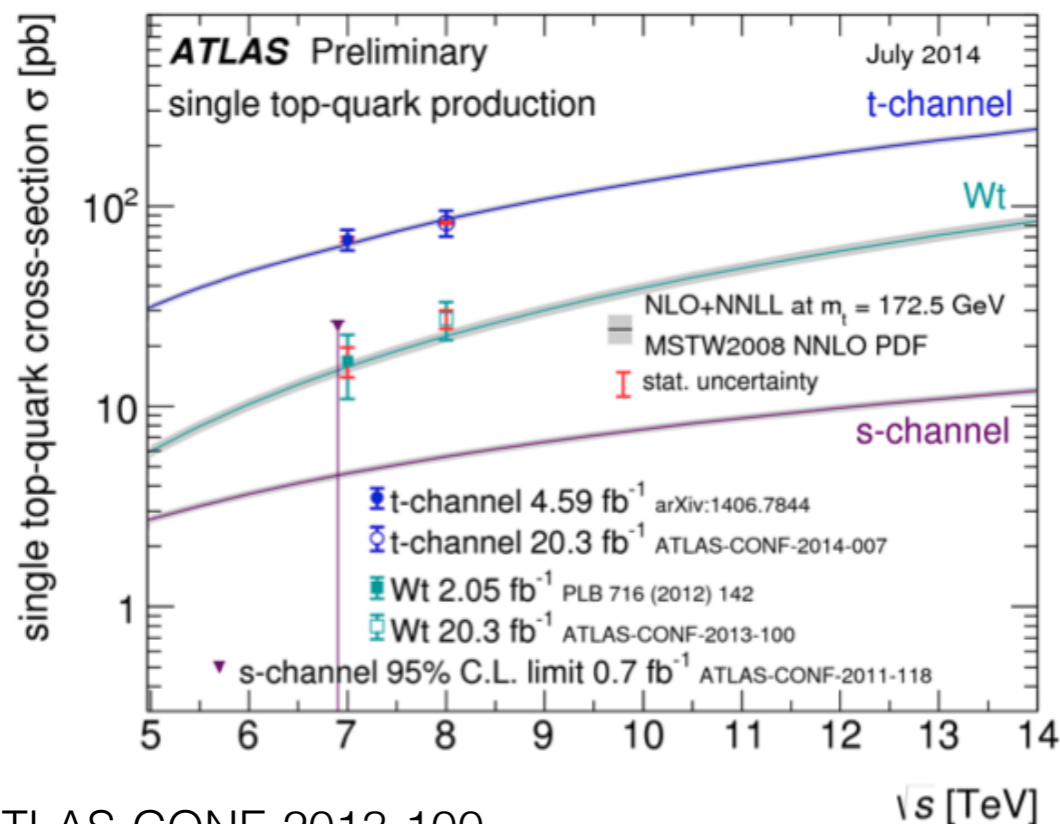


ATLAS evidence at  $4.2\sigma$

then ATLAS + CMS

agreement with NLO+NNLL

## All 3 single top channels:



ATLAS-CONF-2013-100

ATLAS-CONF-2011-118

ATLAS-CONF-2014-007

## Combined ATLAS+CMS $Wt$

ATLAS+CMS Preliminary TOPLHCWG

September 2014

Data 2012,  $\sqrt{s} = 8$  TeV,  $m_t = 172.5$  GeV

..... NLO+NNLL (arXiv:1210.7813)  
 MSTW2008<sub>NNLO</sub>  
 ■ scale uncertainty  
 ■ scale  $\oplus$  PDF uncertainty

— stat. uncertainty  
 — total uncertainty  
 $\sigma_{tW} \pm(\text{stat}) \pm(\text{syst}) \pm(\text{lumi})$

ATLAS,  $L_{\text{int}} = 20.3 \text{ fb}^{-1}$   
 ATLAS-CONF-2013-100

CMS,  $L_{\text{int}} = 12.2 \text{ fb}^{-1}$   
 PRL 112 (2014) 231802

**LHC combined (Sep. 2014)**  
 ATLAS-CONF-2014-052,  
 CMS-PAS-TOP-14-009

$27.2 \pm 1.9 \pm 4.3 \pm 0.8 \text{ pb}$

$23.4 \pm 1.9 \pm 4.6 \pm 0.6 \text{ pb}$

**$25.0 \pm 1.4 \pm 4.4 \pm 0.7 \text{ pb}$**

Effect of LHC beam energy uncertainty:  $0.38 \text{ pb}$   
 (not included in the figure)

ATLAS-CONF-2013-052

$\sigma_{tW}$  [pb]

# Top quark mass

win-win-win

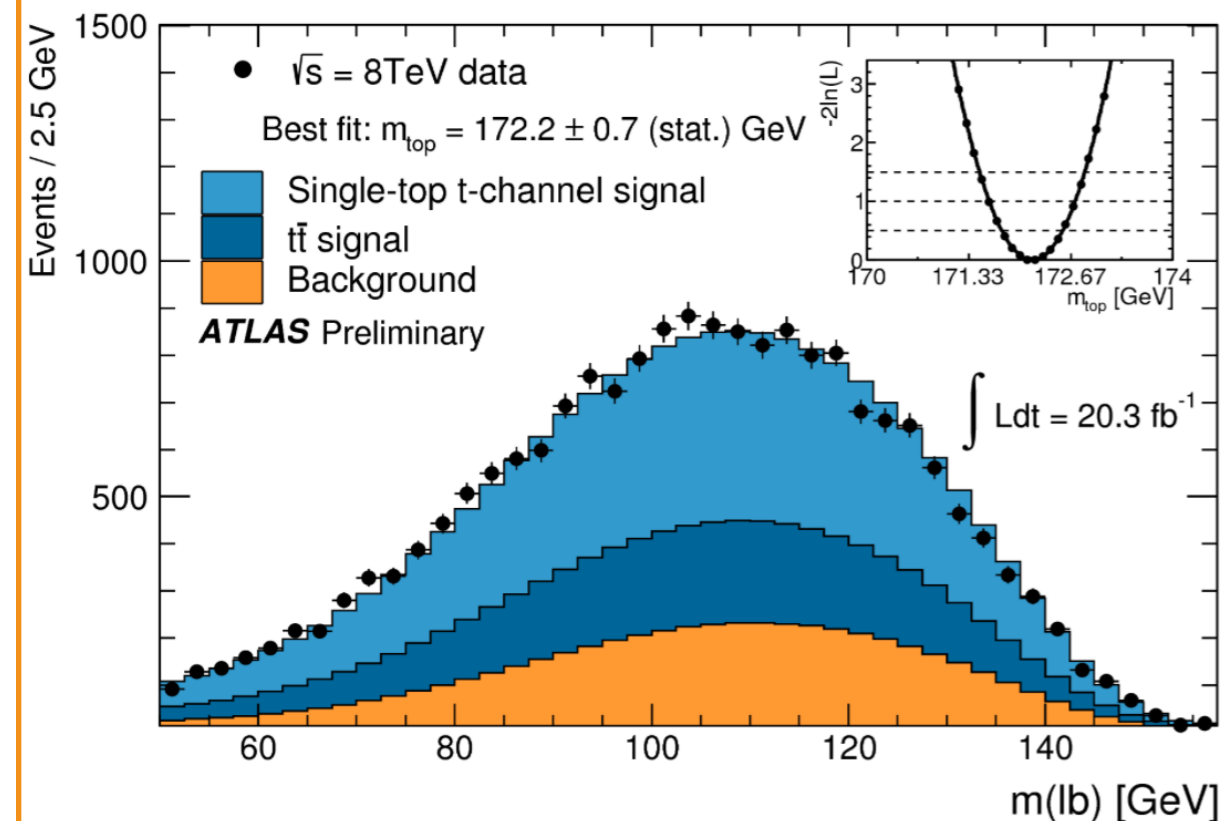


2008 estimates for 1/fb:  $\pm 1-3.5$  GeV in three channels

Run 1 results? Better than predicted.

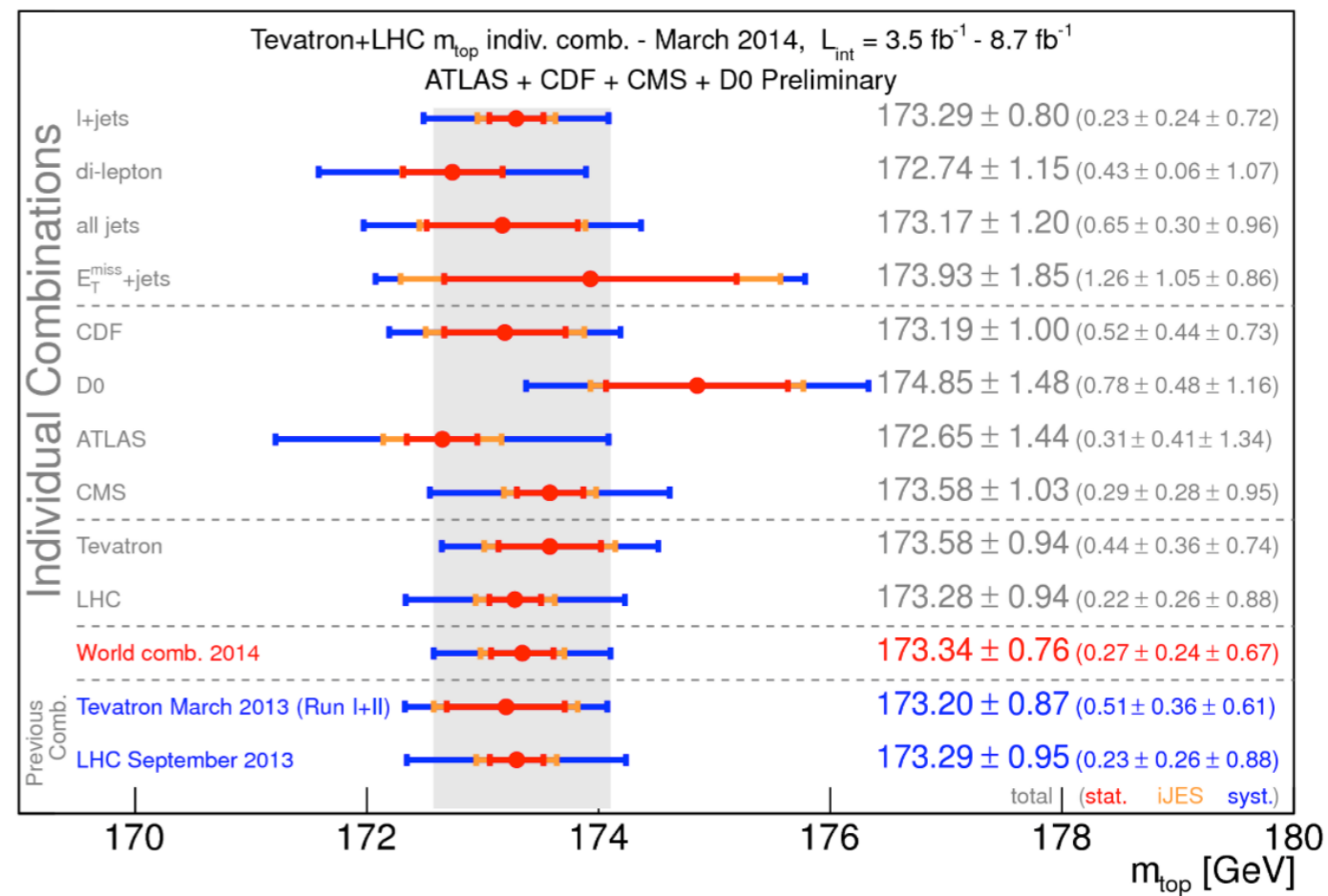
the world:  $< 0.5\%$  uncertainties

## Single top "enhanced"



ATLAS-CONF-2014-055

## Combined ATLAS+CMS + CDF + D0





*But Wait...*  
**THERE'S  
MORE!**



## **top cross sections**

all hadronic final states, tau final states,  $t\bar{t}$ /Z/WW

differential distributions: parton level, boosted  $t\bar{t}$ , associated production with jets and heavy flavor, W/Z, high  $p_t$  boosted

## **single top**

CP violation

## **top mass**

pole mass from cross section tail,  $t$ - $T$  mass difference

## **top properties**

charge, W polarization, FCNC searches, charge asymmetry,  $t$  polarization

# Exotic Physics

## Notable results



### from Run 1 we anticipated:

supersymmetry discovery? no Higgs? Higgs? BSM Higgses (SP?),  
extension of Tevatron IVB' searches by x2 or more,

### from Run 1 we achieved:

supersymmetry limits! one Higgs, BSM Higgs searches, IVB' searches

### in Run 2, we expect:

early concentration on gluino searches, di- $\ell$  & di-jet bump searches

BSM Higgs hints

additional IVB' searches

50x - 1000x more statistics!

# Supersymmetric Physics

## squarks and gluinos

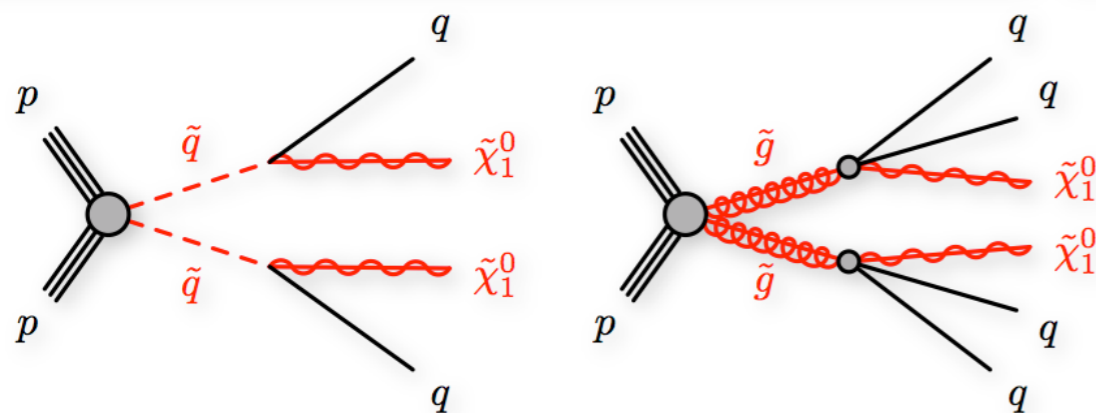
eg inclusive searches:

0 leptons + 2-6 jets + MET

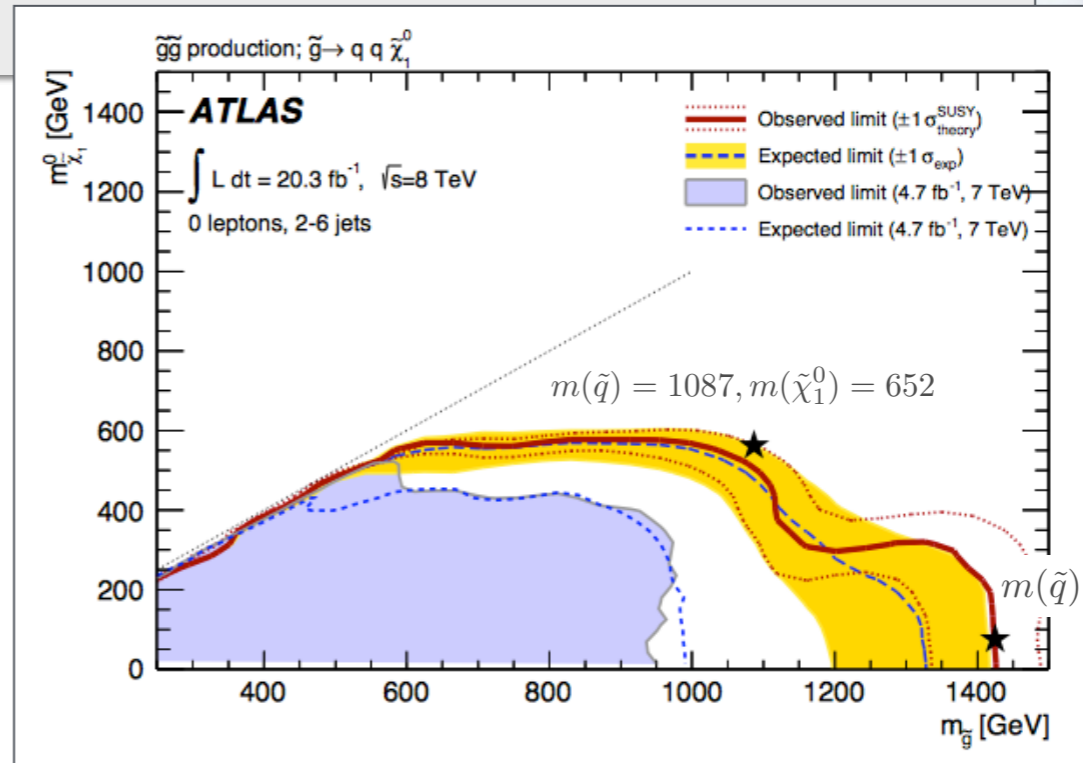
simplified models MSSM  
scenario

strong production of gluinos +  
1st- and 2nd-generation  
squarks

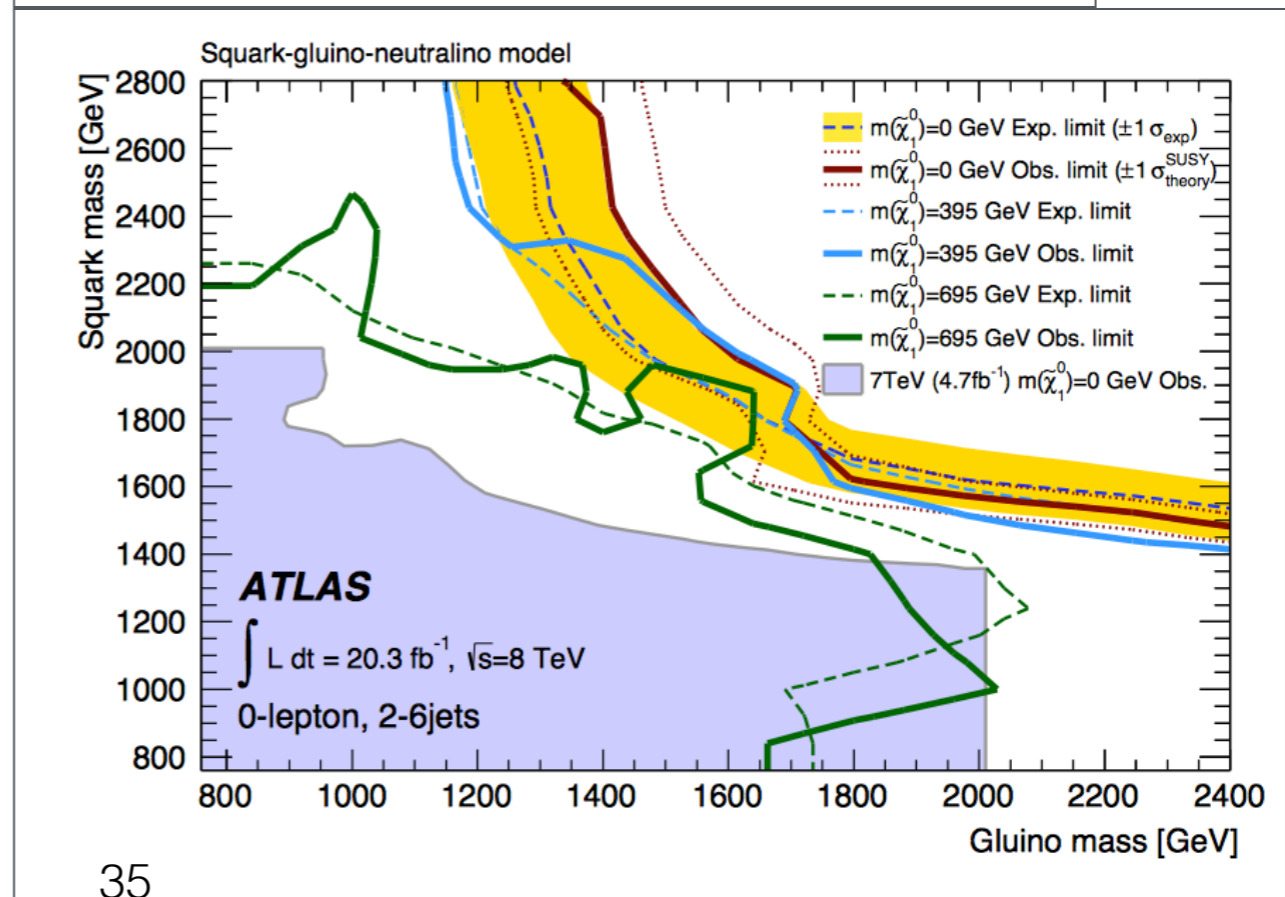
direct decays to quarks and  
lightest neutralinos.



DESPERATELY  
SEEKING SUSAN



arXiv:1405.7875



# stop

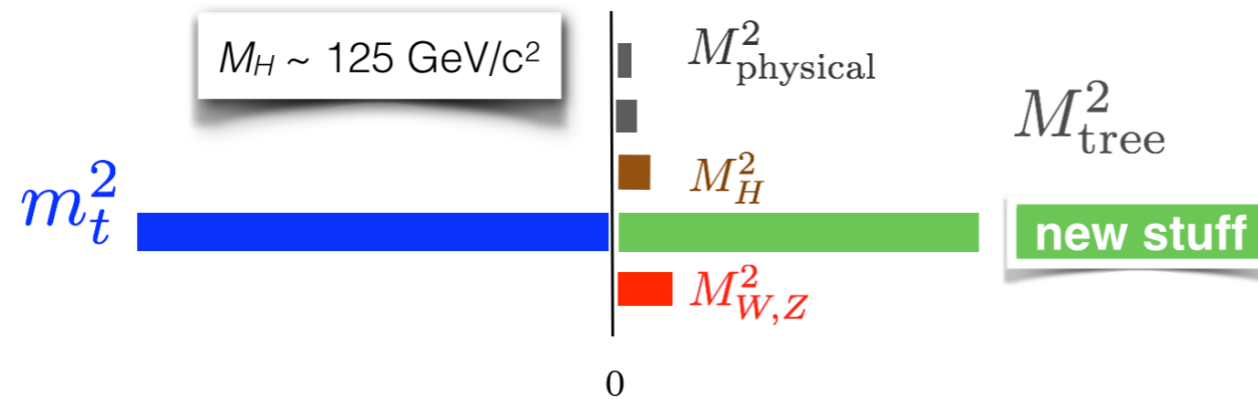
## “Natural” scenarios?

### Tev-ish new particle solution?

STOP! IN THE NAME OF LOVE  
I'M IN LOVE AGAIN



$$M_H^2 = M_{\text{tree}}^2 + \left( \text{Higgs self-energy loop} \right) + \left( \text{top quark loop} \right) + \left( \text{W/Z loop} \right) + \left( \text{BSM} \right)$$



  
**DON'T PANIC  
ACT NATURAL**

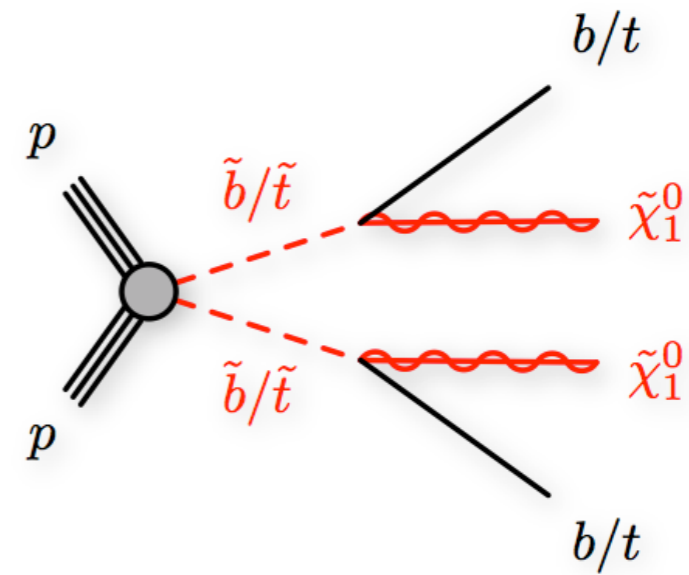
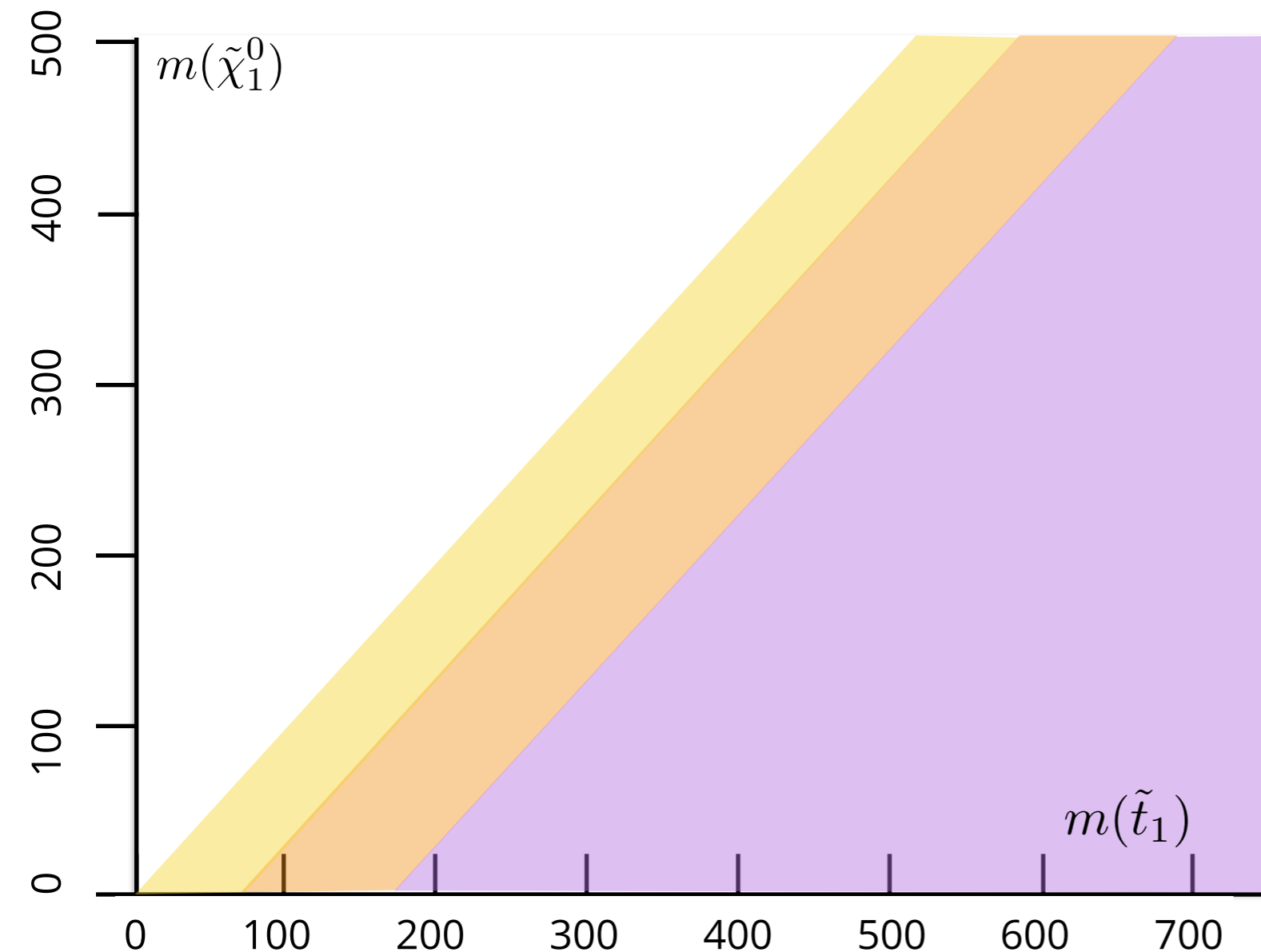
# stop

naturally motivated



## e.g. direct stop/sbottom production

look like conventional tT



Signature-based analyses:

- 0L + 2 bjets + MET
- 0L + 6 (2b) jets + MET
- 1L + 4 (1b) jets + MET
- 2L + jets + MET

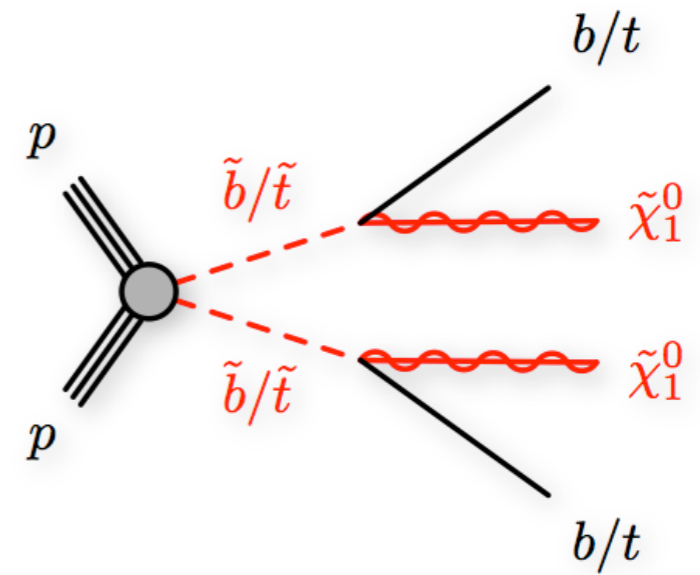
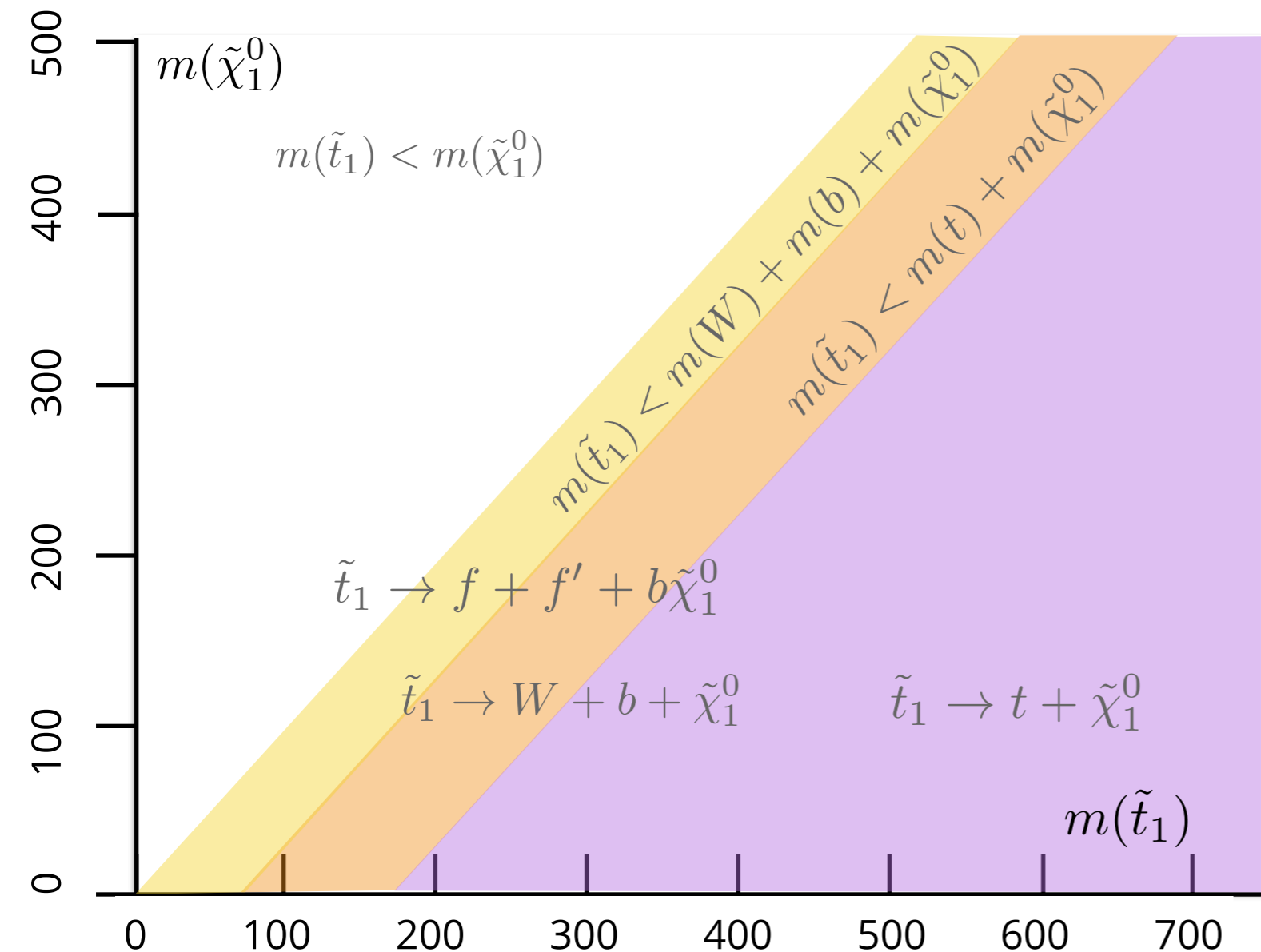
# stop

naturally motivated



## e.g. direct stop/sbottom production

look like conventional tT



Signature-based analyses:

- 0L + 2 bjets + MET
- 0L + 6 (2b) jets + MET
- 1L + 4 (1b) jets + MET
- 2L + jets + MET

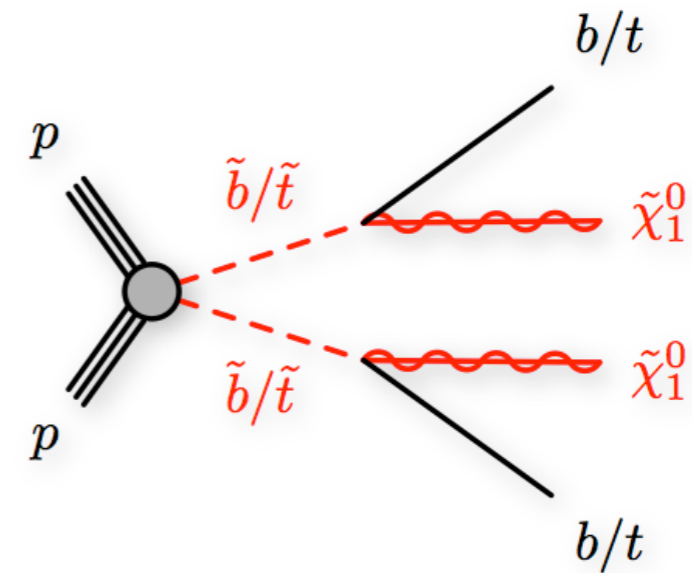
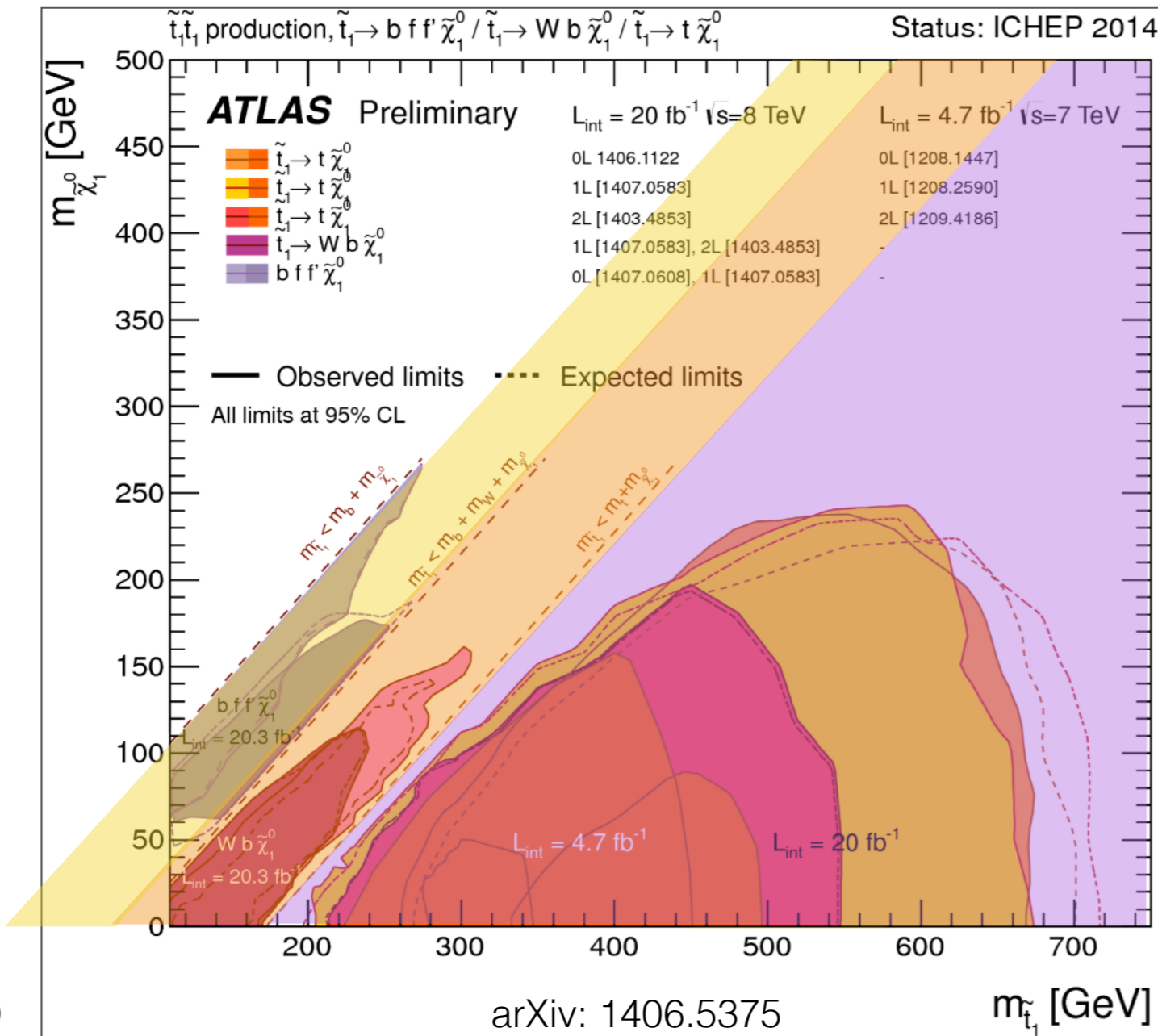
# stop

## naturally motivated



### e.g. direct stop/sbottom production

look like conventional tT



Signature-based analyses:

- 0L + 2 bjets + MET
- 0L + 6 (2b) jets + MET
- 1L + 4 (1b) jets + MET
- 2L + jets + MET

arxiv:1208.1447 (0 lepton 7 TeV)  
 arxiv:1208.2590 (1 lepton 7 TeV)  
 arxiv:1209.4186 (2 leptons 7 TeV)  
 arxiv:1407.0583 (1 lepton 8 TeV, 20/fb)  
 arxiv:1406.1122 (0 lepton + 5/6 jets 8 TeV, 20/fb)  
 arxiv:1403.4853 (2 lepton + jets+ MET 8 TeV, 20/fb)  
 [7] arxiv:1407.0608 (0 lepton + jets (c-jets) + MET 8 TeV, 20/fb)

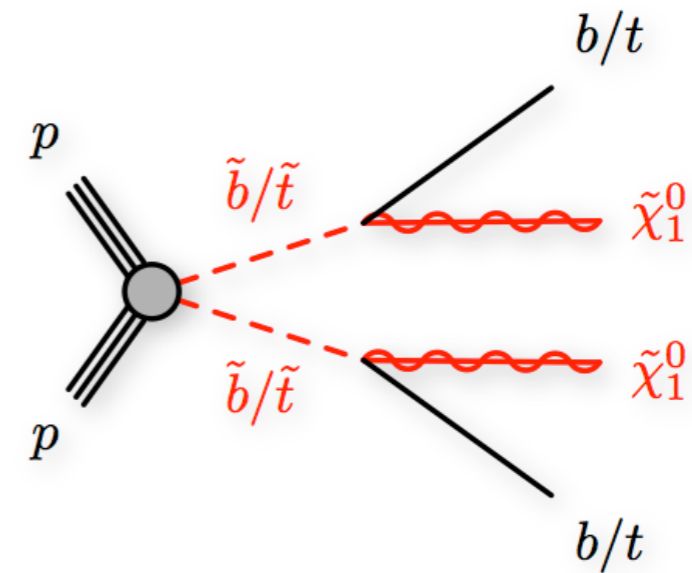
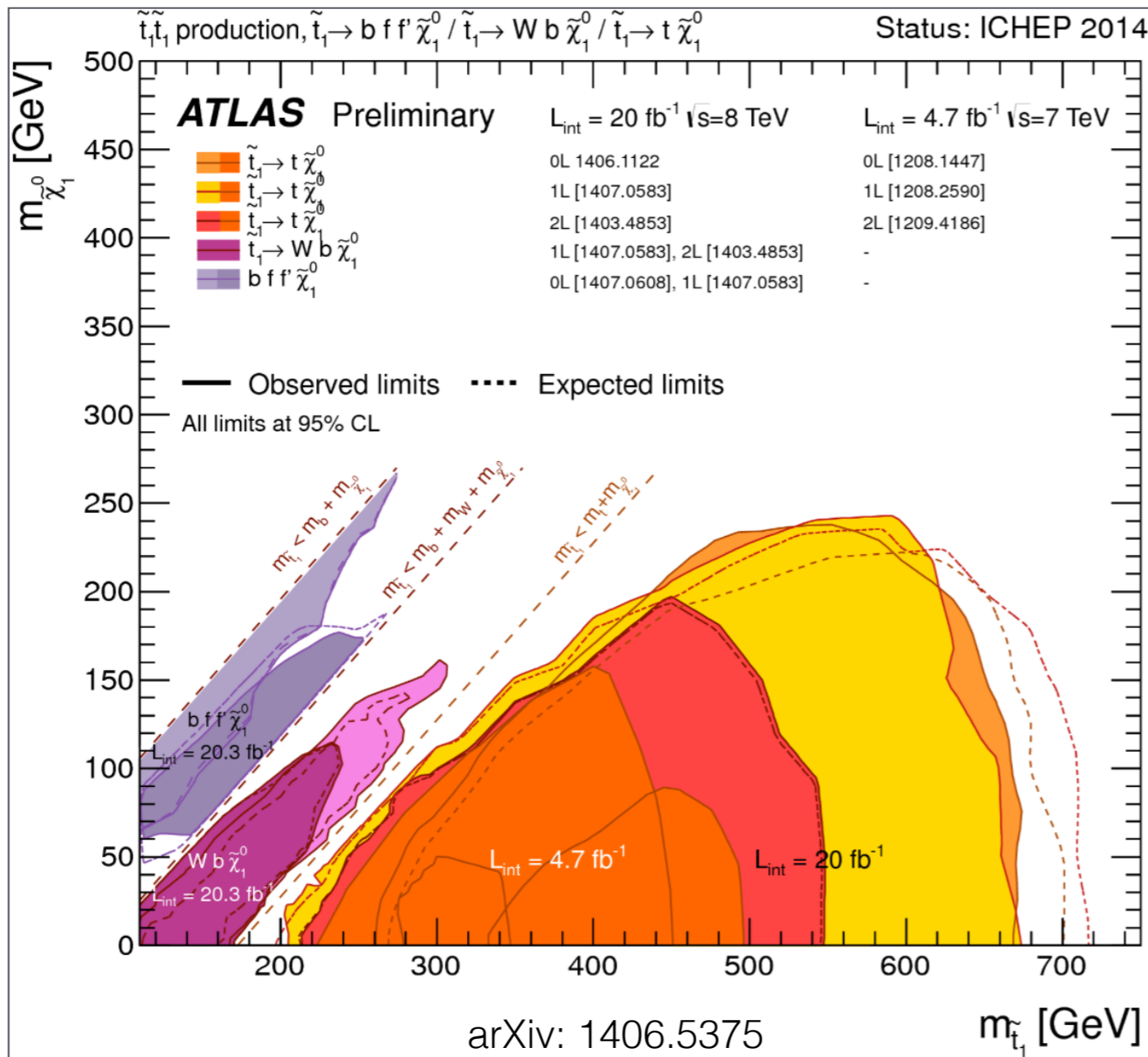
# stop

## naturally motivated



### e.g. direct stop/sbottom production

look like conventional tT



### Signature-based analyses:

- 0L + 2 bjets + MET
- 0L + 6 (2b) jets + MET
- 1L + 4 (1b) jets + MET
- 2L + jets + MET

- arxiv:1208.1447 (0 lepton 7 TeV)
- arxiv:1208.2590 (1 lepton 7 TeV)
- arxiv:1209.4186 (2 leptons 7 TeV)
- arxiv:1407.0583 (1 lepton 8 TeV, 20/fb)
- arxiv:1406.1122 (0 lepton + 5/6 jets 8 TeV, 20/fb)
- arxiv:1403.4853 (2 lepton + jets+ MET 8 TeV, 20/fb)
- [7] arxiv:1407.0608 (0 lepton + jets (c-jets) + MET 8 TeV, 20/fb)

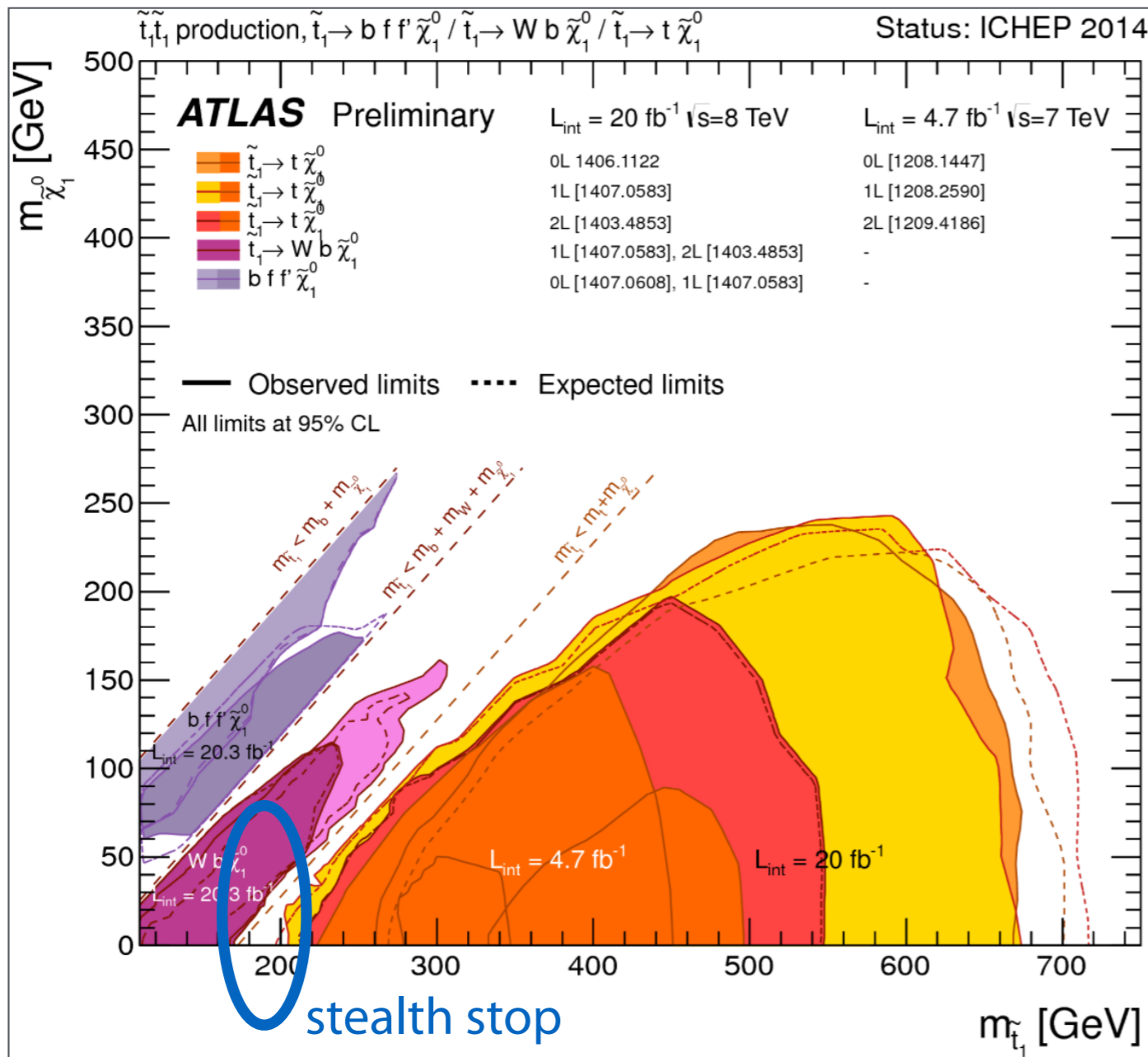


# stealthy stop

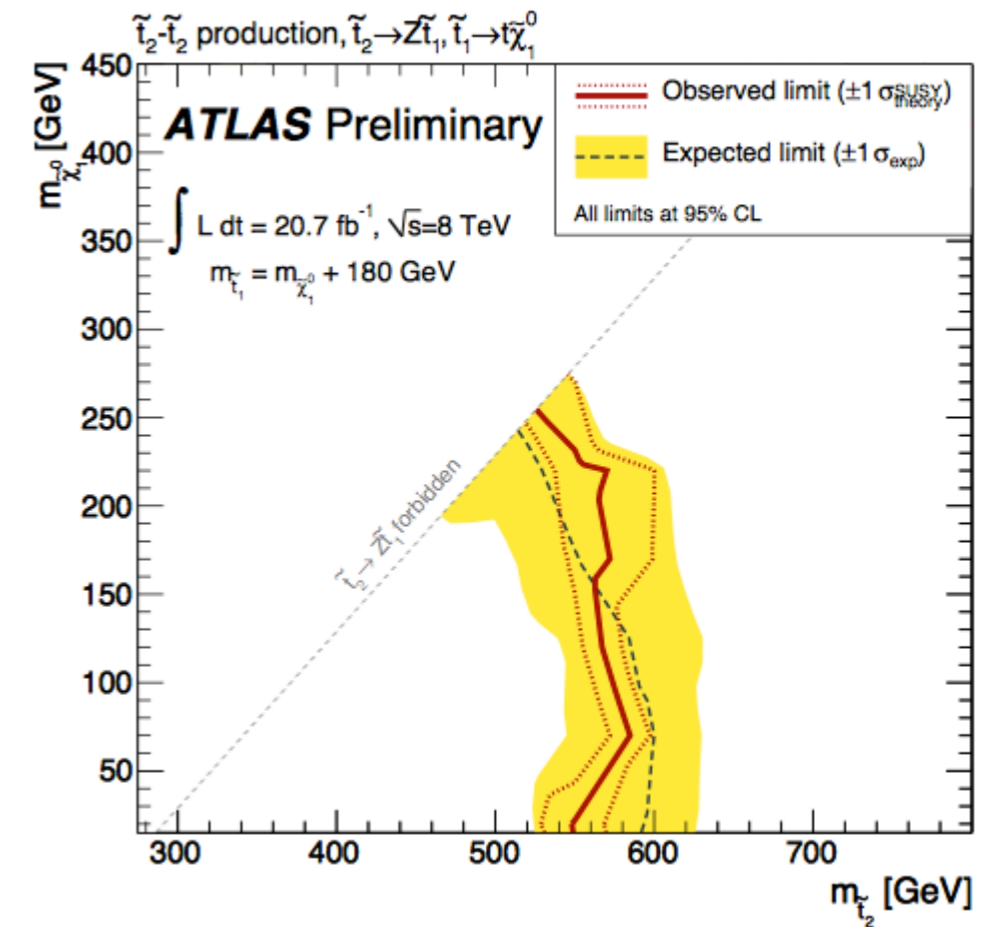
kinematical no-man's land



## second generation



$$\tilde{t}_2 \rightarrow Z + \tilde{t}_1 \rightarrow Z + t + \tilde{\chi}_1^0$$

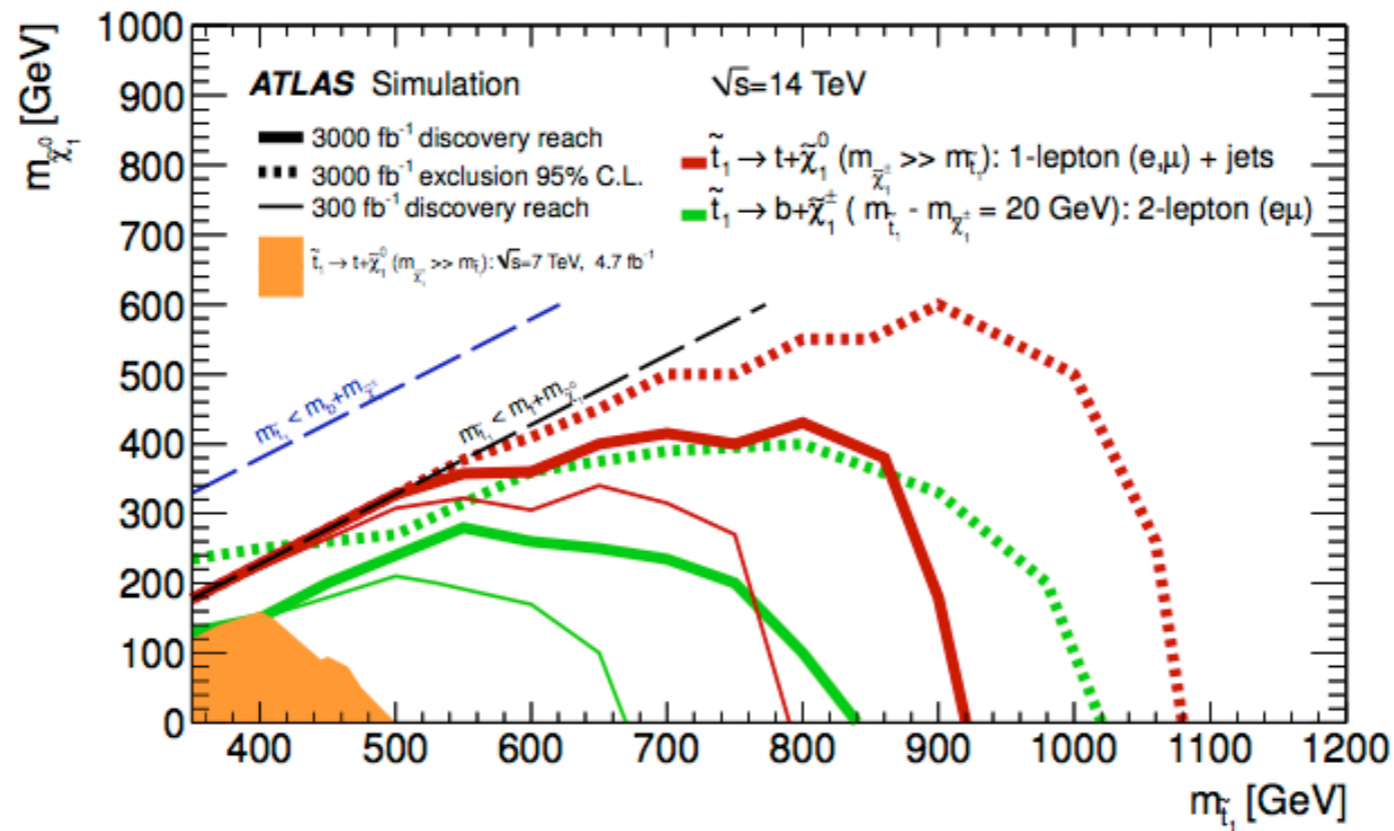


ATLAS-CONF-2013-025

# Run 2

## Center of mass energy directly extends searches

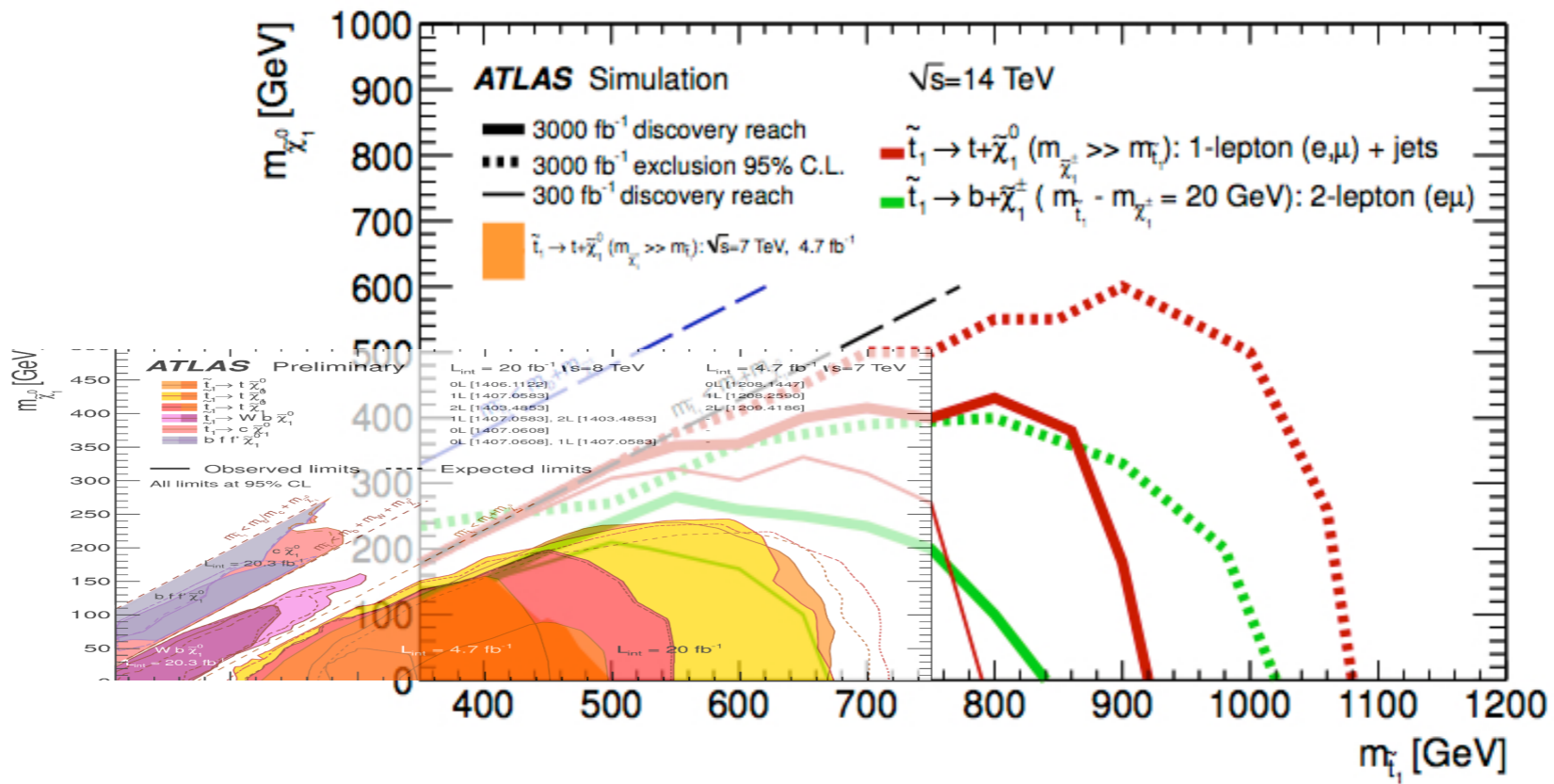
that rule of thumb...



ATL-PHYS-PUB-2012-001

# Run 2

## Center of mass energy directly extends searches



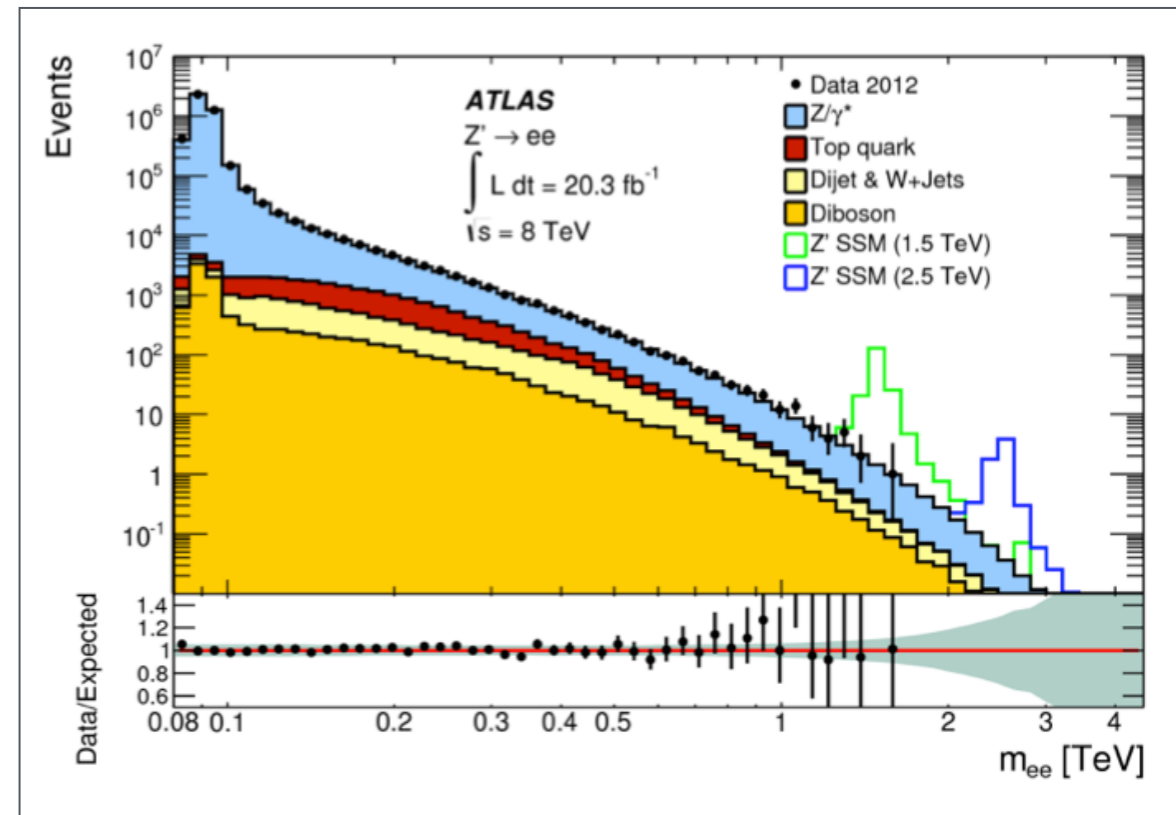
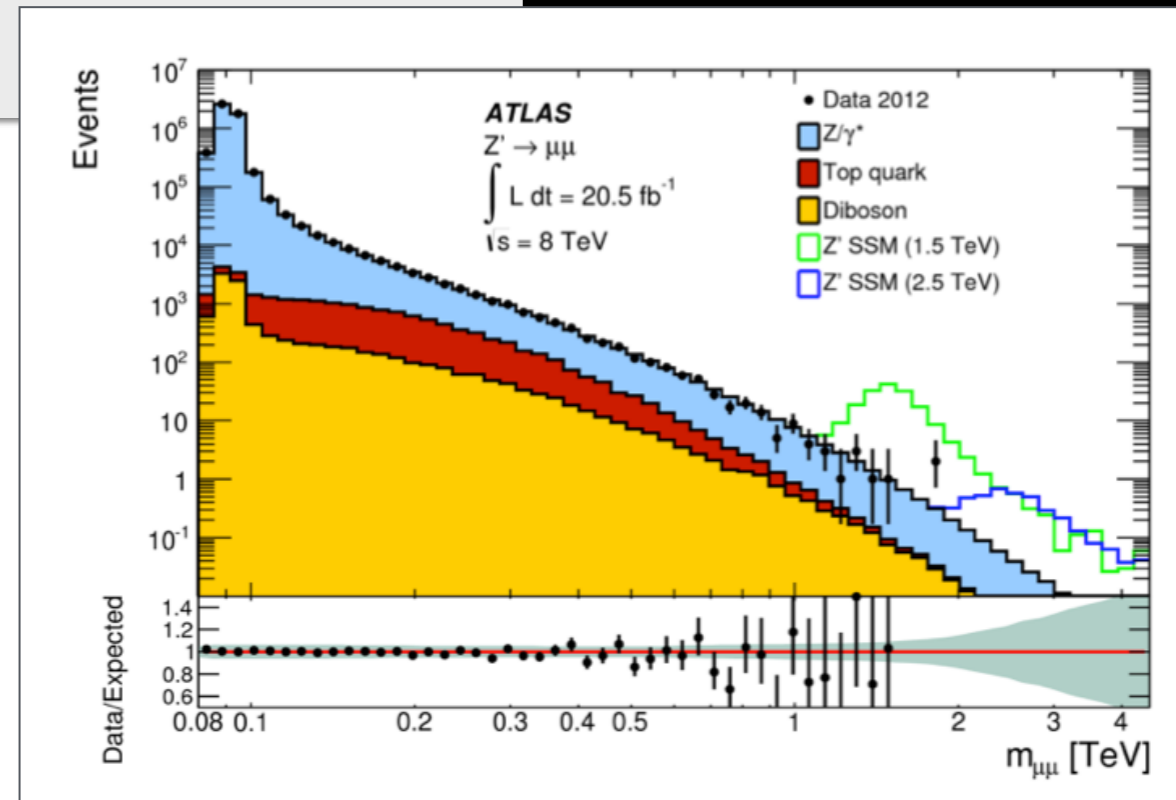
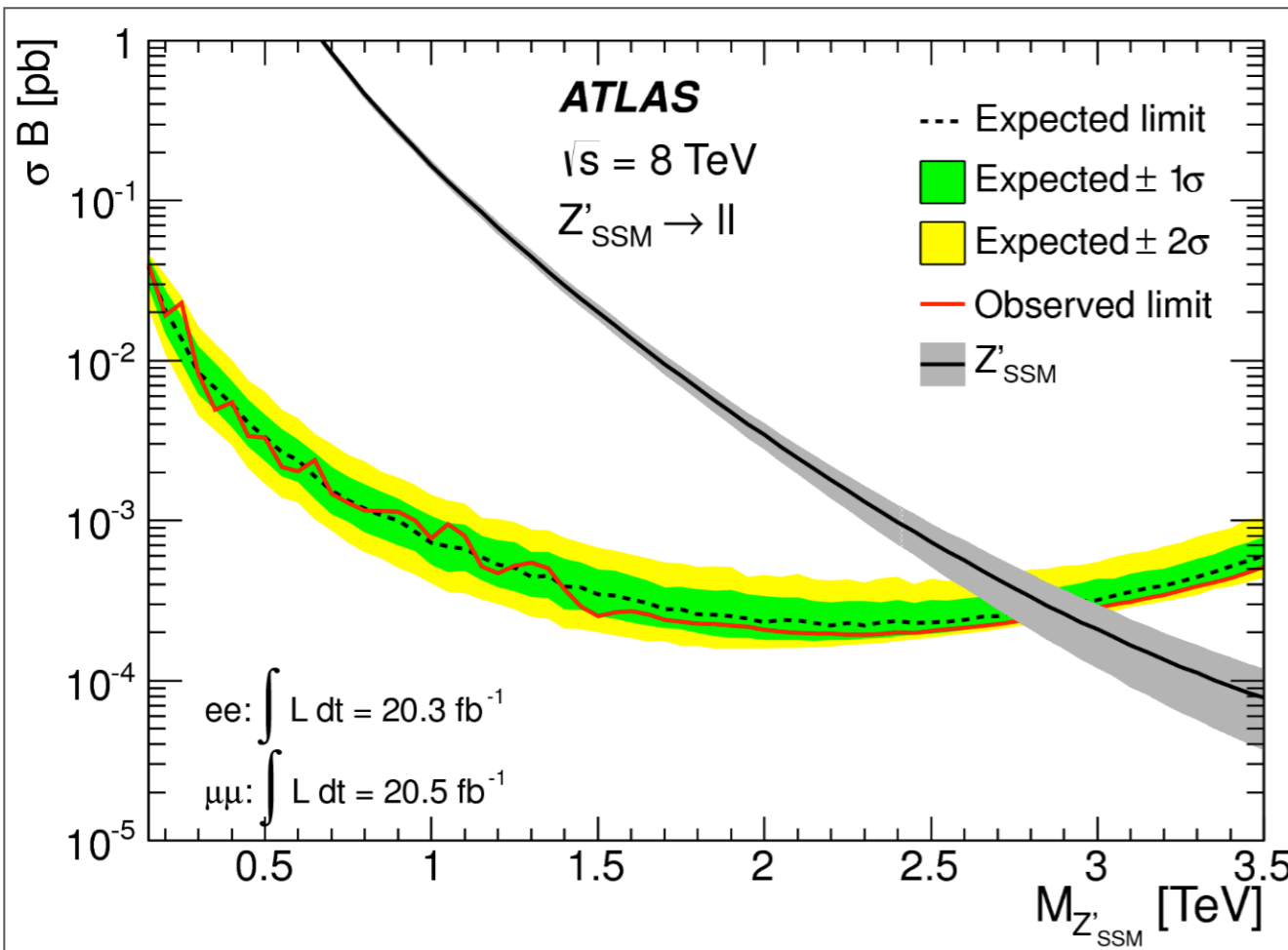
ATL-PHYS-PUB-2012-001

# Z prime

electrons and muons

a standard way to extend the SM

Snowmass suggests  $\sim 4\text{TeV}$  reachable

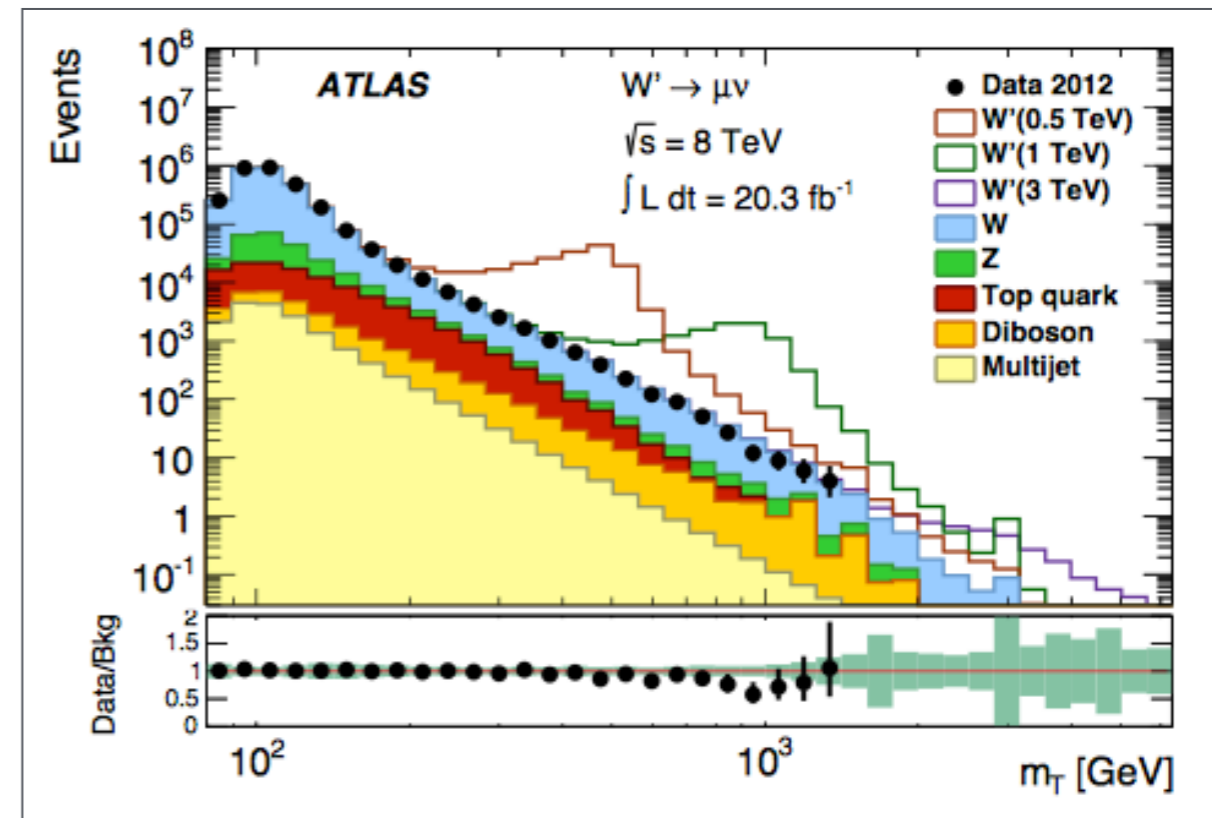
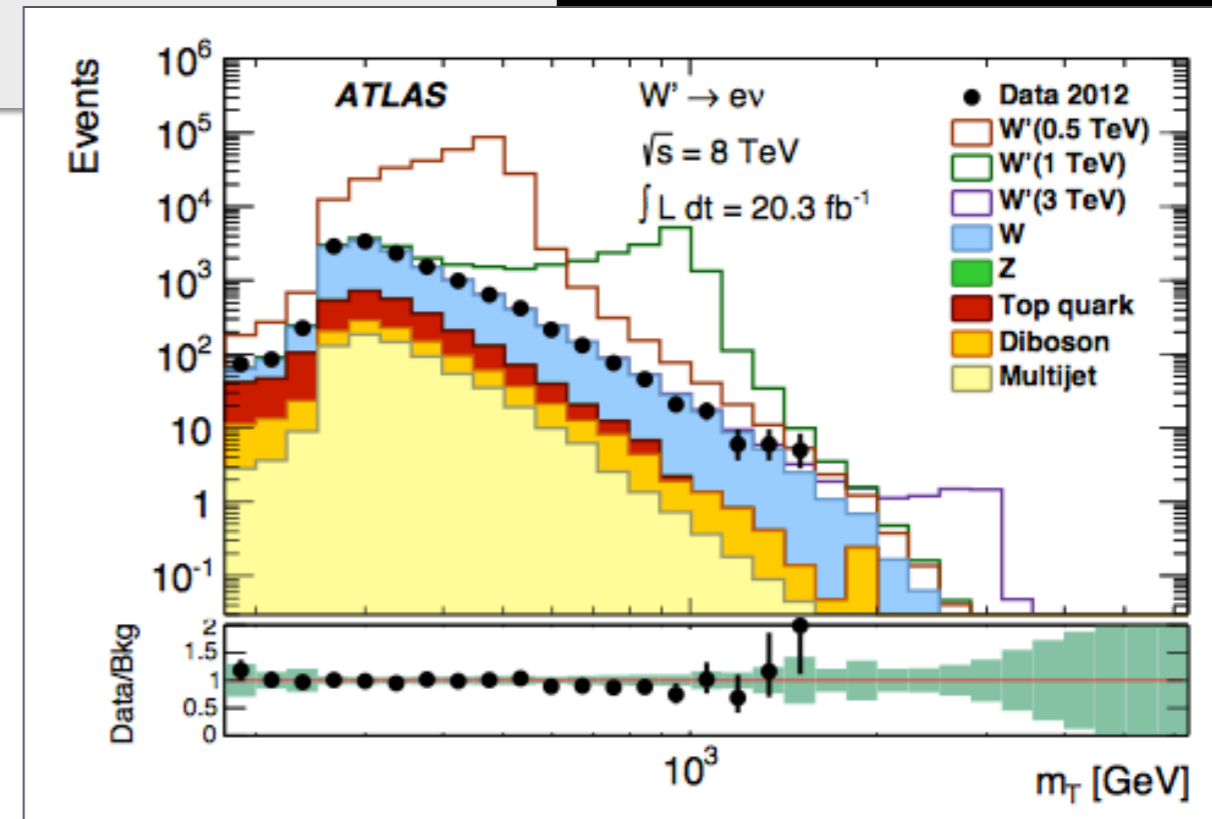
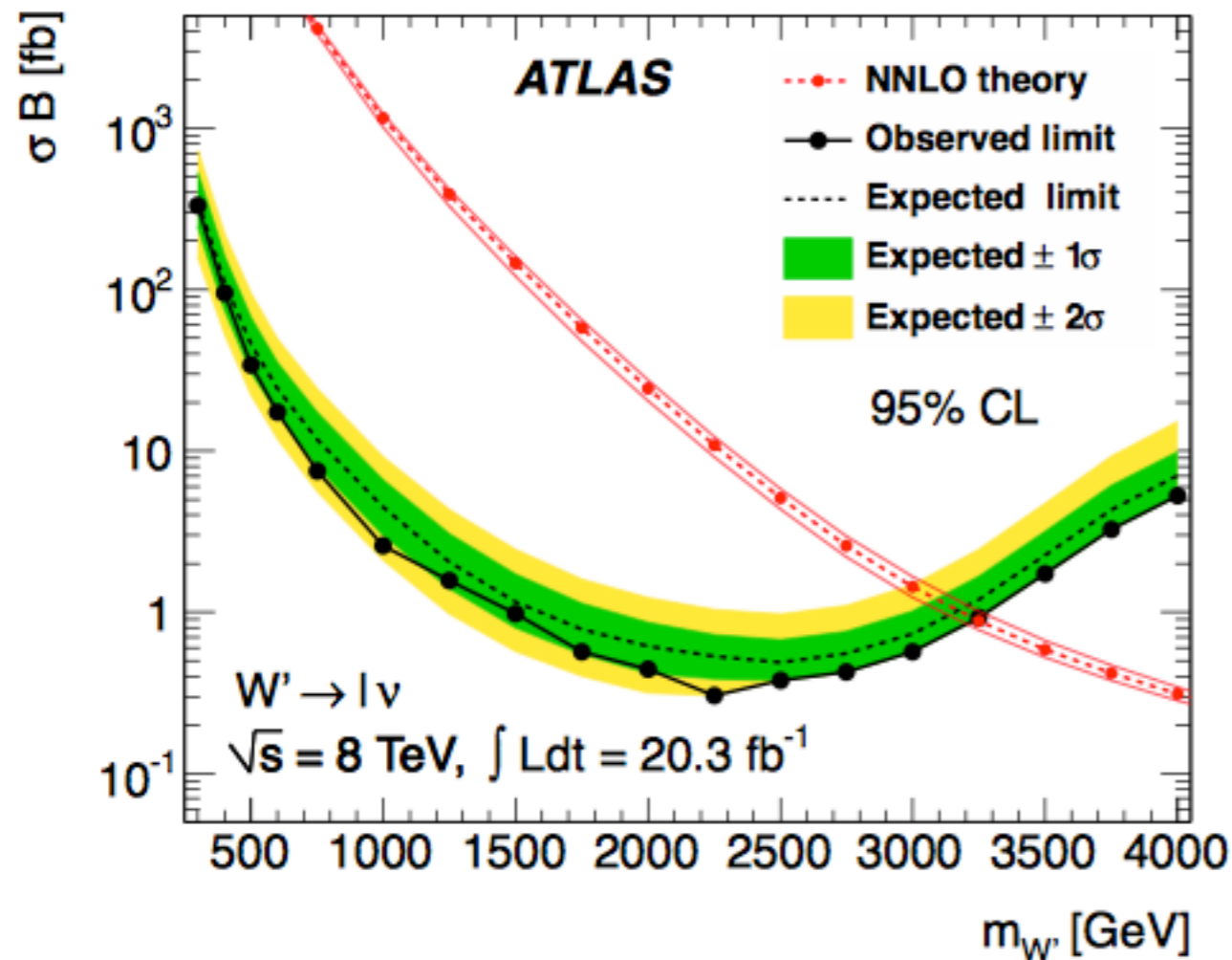


# W prime

electrons and muons

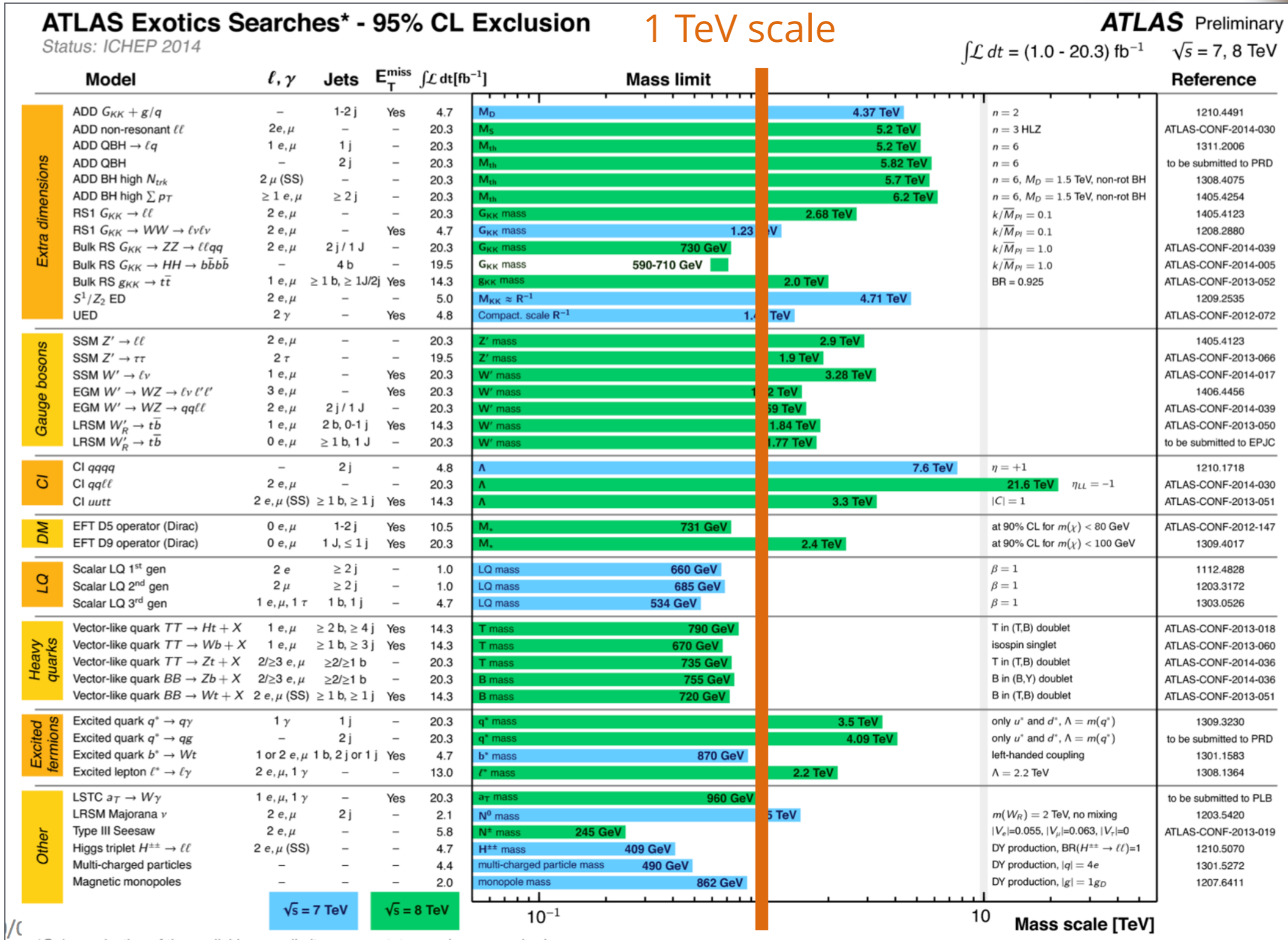
a partner

arXiv:1407.7494v1



# Exotics in a nutshell

a big nutshell



# SUSY in a nutshell



## ATLAS SUSY Searches\* - 95% CL Lower Limits

Status: ICHEP 2014

1 TeV scale

ATLAS Preliminary

$\sqrt{s} = 7, 8 \text{ TeV}$

Model	$e, \mu, \tau, \gamma$	Jets	$E_T^{\text{miss}}$	$\int \mathcal{L} d\mathcal{T} [\text{fb}^{-1}]$	Mass limit	Mass limit	Reference	
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$	1.7 TeV	1405.7875
	MSUGRA/CMSSM	1 $e, \mu$	3-6 jets	Yes	20.3	$\tilde{g}$	1.2 TeV	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	1308.1841
	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	850 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.3 TeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qq\tilde{\chi}_1^0 \rightarrow qqW^\pm\tilde{\chi}_1^0$	1 $e, \mu$	3-6 jets	Yes	20.3	$\tilde{g}$	1.18 TeV	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 $e, \mu$	0-3 jets	-	20.3	$\tilde{g}$	1.12 TeV	ATLAS-CONF-2013-089
	GMSB ( $\tilde{\ell}$ NLSP)	2 $e, \mu$	2-4 jets	Yes	4.7	$\tilde{g}$	1.2 TeV	1208.4688
	GMSB ( $\tilde{\ell}$ NLSP)	1-2 $\tau + 0-1 \ell$	0-2 jets	Yes	20.3	$\tilde{g}$	1.6 TeV	1407.0603
	GGM (bino NLSP)	2 $\gamma$	-	Yes	20.3	$\tilde{g}$	1.2 TeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 $e, \mu + \gamma$	-	Yes	4.8	$\tilde{g}$	619 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	$\gamma$	1 $b$	Yes	4.8	$\tilde{g}$	900 GeV	1211.1167
	GGM (higgsino NLSP)	2 $e, \mu$ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$	690 GeV	ATLAS-CONF-2012-152
Gravitino LSP	0	mono-jet	Yes	10.5	$E_T^{1/2}$ scale	645 GeV	ATLAS-CONF-2012-147	
$3^{\text{rd}}$ gen. $\tilde{g}$ med.	$\tilde{g} \rightarrow b\tilde{b}\tilde{\chi}_1^0$	0	3 $b$	Yes	20.1	$\tilde{g}$	1.2 TeV	1407.0600
	$\tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	1308.1841
	$\tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0-1 $e, \mu$	3 $b$	Yes	20.1	$\tilde{g}$	1.4 TeV	1407.0600
	$\tilde{g} \rightarrow b\tilde{t}\tilde{\chi}_1^0$	0-1 $e, \mu$	3 $b$	Yes	20.1	$\tilde{g}$	1.4 TeV	1407.0600
$3^{\text{rd}}$ gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$	0	2 $b$	Yes	20.1	$\tilde{b}_1$	100-620 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow t\tilde{\chi}_1^0$	2 $e, \mu$ (SS)	0-3 $b$	Yes	20.3	$\tilde{b}_1$	275-440 GeV	1404.2500
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^0$	1-2 $e, \mu$	1-2 $b$	Yes	4.7	$\tilde{t}_1$	110-167 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$	2 $e, \mu$	0-2 jets	Yes	20.3	$\tilde{t}_1$	130-210 GeV	1403.4853
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	2 $e, \mu$	2 jets	Yes	20.3	$\tilde{t}_1$	215-530 GeV	1403.4853
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^0$	0	2 $b$	Yes	20.1	$\tilde{t}_1$	150-580 GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	1 $e, \mu$	1 $b$	Yes	20	$\tilde{t}_1$	210-640 GeV	1407.0583
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	0	2 $b$	Yes	20.1	$\tilde{t}_1$	260-640 GeV	1406.1122
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$	0	mono-jet/ $c$ -tag	Yes	20.3	$\tilde{t}_1$	90-240 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 $e, \mu$ (Z)	1 $b$	Yes	20.3	$\tilde{t}_1$	150-580 GeV	1403.5222
$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 $e, \mu$ (Z)	1 $b$	Yes	20.3	$\tilde{t}_2$	290-600 GeV	1403.5222	
EW direct	$\tilde{\ell}_L\tilde{\ell}_L, \tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$	2 $e, \mu$	0	Yes	20.3	$\tilde{\ell}$	90-325 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \rightarrow \tilde{\ell}\nu(\tilde{\nu})$	2 $e, \mu$	0	Yes	20.3	$\tilde{\chi}_1^\pm$	140-465 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \rightarrow \tilde{\tau}\nu(\tilde{\nu})$	2 $\tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$	100-350 GeV	1407.0350
	$\tilde{\chi}_1^+\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_L\nu\tilde{\ell}_L(\tilde{\nu}\nu), \tilde{\ell}\nu\tilde{\ell}_L(\tilde{\nu}\nu)$	3 $e, \mu$	0	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	700 GeV	1402.7029
	$\tilde{\chi}_1^+\tilde{\chi}_2^0 \rightarrow W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 $e, \mu$	0	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	420 GeV	1403.5294, 1402.7029
	$\tilde{\chi}_1^+\tilde{\chi}_2^0 \rightarrow W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	1 $e, \mu$	2 $b$	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	285 GeV	ATLAS-CONF-2013-093
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0 \rightarrow \tilde{\ell}_R\ell$	4 $e, \mu$	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$	620 GeV	1405.5086
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$	270 GeV	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$	832 GeV	1310.6584
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0 \rightarrow \tilde{\tau}(\tilde{e}, \tilde{\mu}) + \tau(e, \mu)$	1-2 $\mu$	-	-	15.9	$\tilde{\chi}_1^0$	475 GeV	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$ , long-lived $\tilde{\chi}_1^0$	2 $\gamma$	-	Yes	4.7	$\tilde{\chi}_1^0$	230 GeV	1304.6310
RPV	$\tilde{q}\tilde{q}, \tilde{\chi}_1^0 \rightarrow qq\mu$ (RPV)	1 $\mu$ , displ. vtx	-	-	20.3	$\tilde{q}$	1.0 TeV	ATLAS-CONF-2013-092
	LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e + \mu$	2 $e, \mu$	-	-	4.6	$\tilde{\nu}_\tau$	1.61 TeV	1212.1272
	LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e(\mu) + \tau$	1 $e, \mu + \tau$	-	-	4.6	$\tilde{\nu}_\tau$	1.1 TeV	1212.1272
	Bilinear RPV CMSSM	2 $e, \mu$ (SS)	0-3 $b$	Yes	20.3	$\tilde{q}, \tilde{g}$	1.5 TeV	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 $e, \mu$	-	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_1^0$	750 GeV	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow \tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_1^0$	450 GeV	1405.5086
	$\tilde{g} \rightarrow qq\tilde{q}$	0	6-7 jets	-	20.3	$\tilde{g}$	916 GeV	ATLAS-CONF-2013-091
Other	$\tilde{g} \rightarrow \tilde{t}_1 t, \tilde{t}_1 \rightarrow bs$	2 $e, \mu$ (SS)	0-3 $b$	Yes	20.3	$\tilde{g}$	850 GeV	1404.2500
	Scalar gluon pair, sgluon $\rightarrow q\tilde{q}$	0	4 jets	-	4.6	sgluon	100-287 GeV	incl. limit from 1110.2693
	Scalar gluon pair, sgluon $\rightarrow t\tilde{t}$	2 $e, \mu$ (SS)	2 $b$	Yes	14.3	sgluon	350-800 GeV	ATLAS-CONF-2013-051
WIMP interaction (D5, Dirac $\chi$ )	0	mono-jet	Yes	10.5	$M^*$ scale	704 GeV	ATLAS-CONF-2012-147	

$\sqrt{s} = 7 \text{ TeV}$  full data  
 $\sqrt{s} = 8 \text{ TeV}$  partial data  
 $\sqrt{s} = 8 \text{ TeV}$  full data

$10^{-1}$

Mass scale [TeV]

\*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus  $1\sigma$  theoretical signal cross section uncertainty.

*But Wait...*  
**THERE'S  
MORE!**

## SUSY

stop searches (Max Wanotayaroj, Friday)

spin correlations

Electroweak-ino production, many channels and assumptions

GSMB models, delayed and non-pointing photons

out of time events and disappearing tracks

R-parity violating final states

## Additional searches

W' searches to hadronic final states (Ho Ling Li, Friday)

dijet, ZZ, ZW, W\gamma, Z\gamma resonances

Vector like quarks (Brad Schoenrock, Friday)

Dark Matter inspired: Mono jets, tT, b, t

LFV and long-lived neutral particles (Andrew Hard, Friday)

prompt and non-prompt lepton jets (Hari Namasivayam, today)





# Flavor Physics

## Notable results



### from Run 1 we anticipated:

measure:  $bb \rightarrow J/\psi$ ,  $pp \rightarrow J/\psi$ , and  $B^+ \rightarrow J/\psi + K^+$  cross section ratios  
begin to contribute to world averages on B-hadron properties; start to  
set limits on rare decays

### from Run 1 we achieved:

many production studies,  $\chi$ ,  $\psi$  studies, new physics searches, new  $b$   
states

### in Run 2, we expect:

increased statistics, improved performance/triggers, robust against  $\mathcal{L}$

# First excited $B_c^*$

open beauty discovery,  $cb$



S. Godfrey PHYSICAL REVIEW D **70** 054017

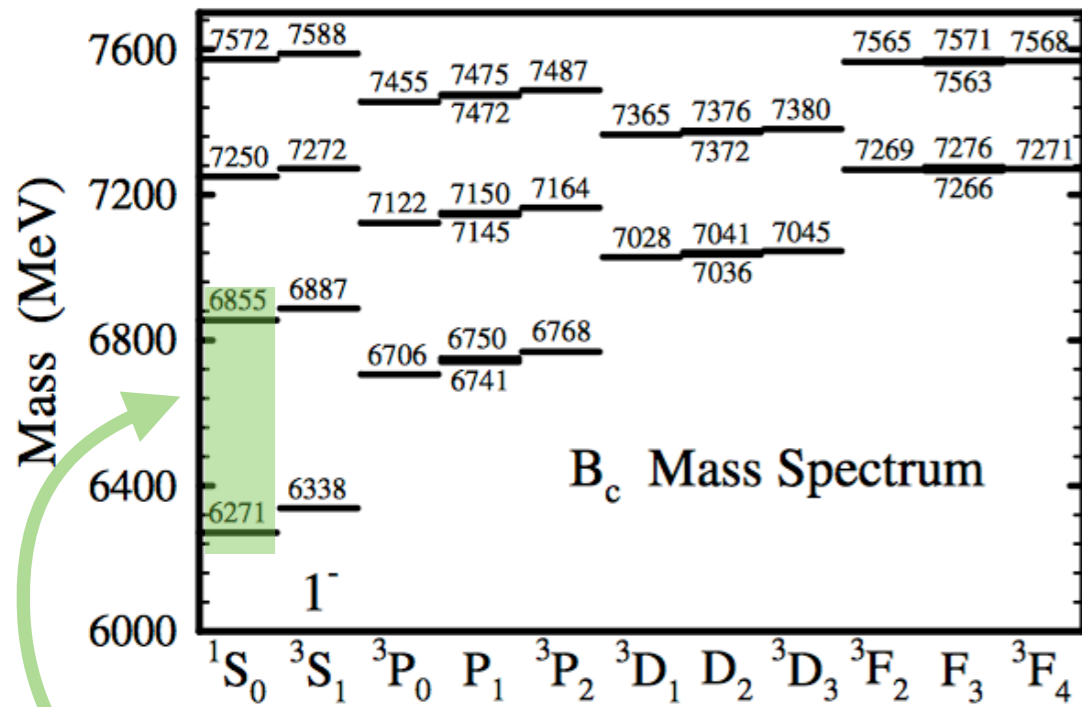
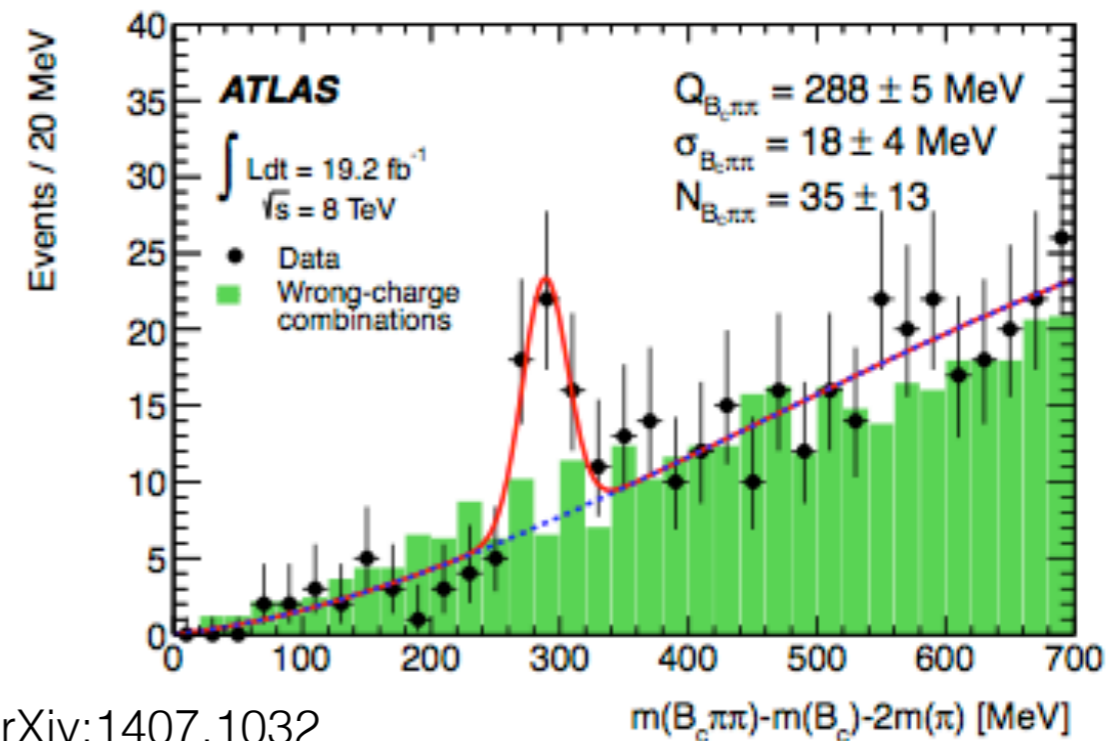
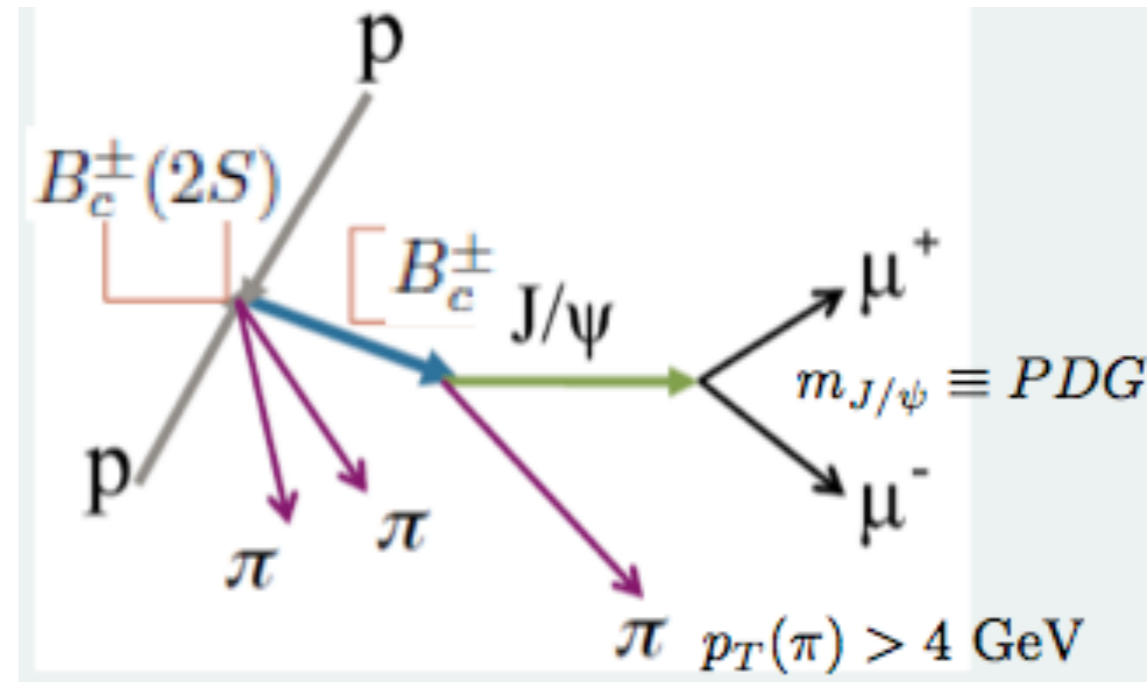


FIG. 1. The  $B_c$  mass spectrum.

$$2^1S_0 \rightarrow 1^1S_0 + 2\pi \quad \text{E1 - E1 transition}$$

Q values consistent with the production and decay of a new state,  $B_c^*$  with a mass of  $6842 \pm 4 \pm 5$  MeV

Significance is  $5.2 \sigma$  with “look-back”



But Wait...  
**THERE'S  
MORE!**



## Production and Decays, incl

$\psi(2s)$  in many distributions, prompt and non-prompt

$W^+$  incl double parton scattering contribution

$\chi_c$  production, prompt?

$\Upsilon(1s, 2s, 3s)$  production

open charm/beauty, in jets, inclusive

## Spectroscopy, incl

$\chi_b(3P)$  discovery,  $\Lambda_b$  mass, lifetime, PV in  $\Lambda_b \rightarrow J/\psi \Lambda^0$ , Rare Decays

## Searches, incl

FCNC search for  $B_{d/s} \rightarrow \mu^+ \mu^-$

# Long Shutdown 1 Projects

# Tracking system

Insertable B Layer, aka IBL

5.1 to 3.3 cm to IP

pixels reduced: 50 x 250  $\mu\text{m}$

new sensors and readout chip

May 7:

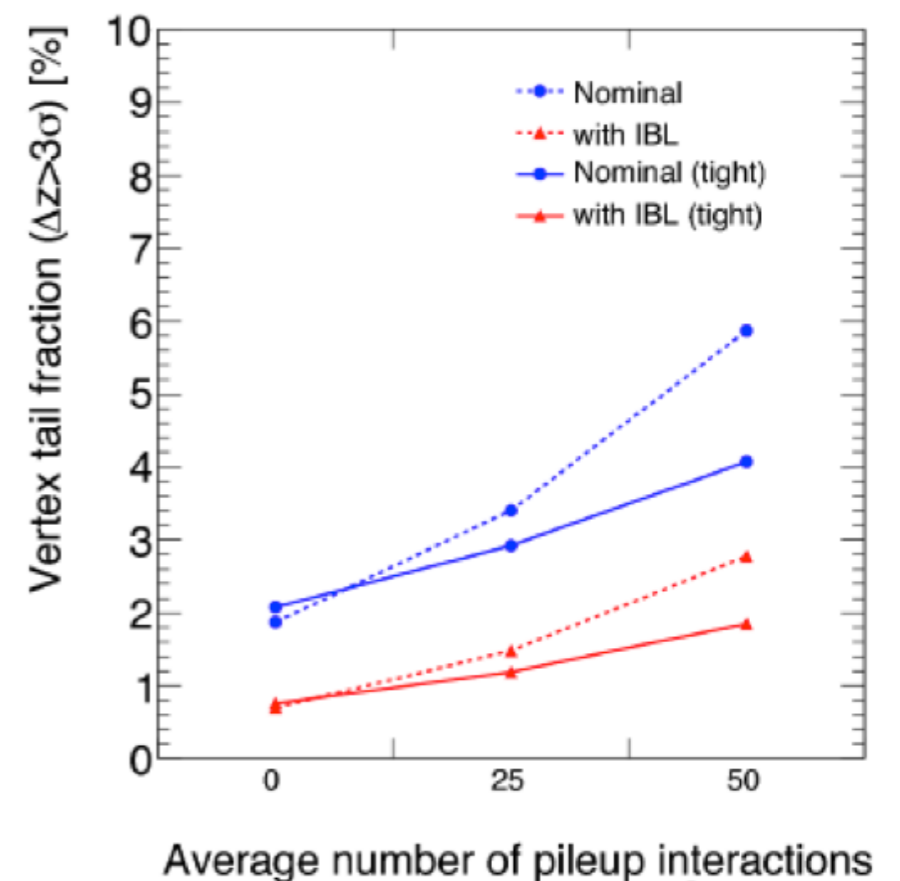
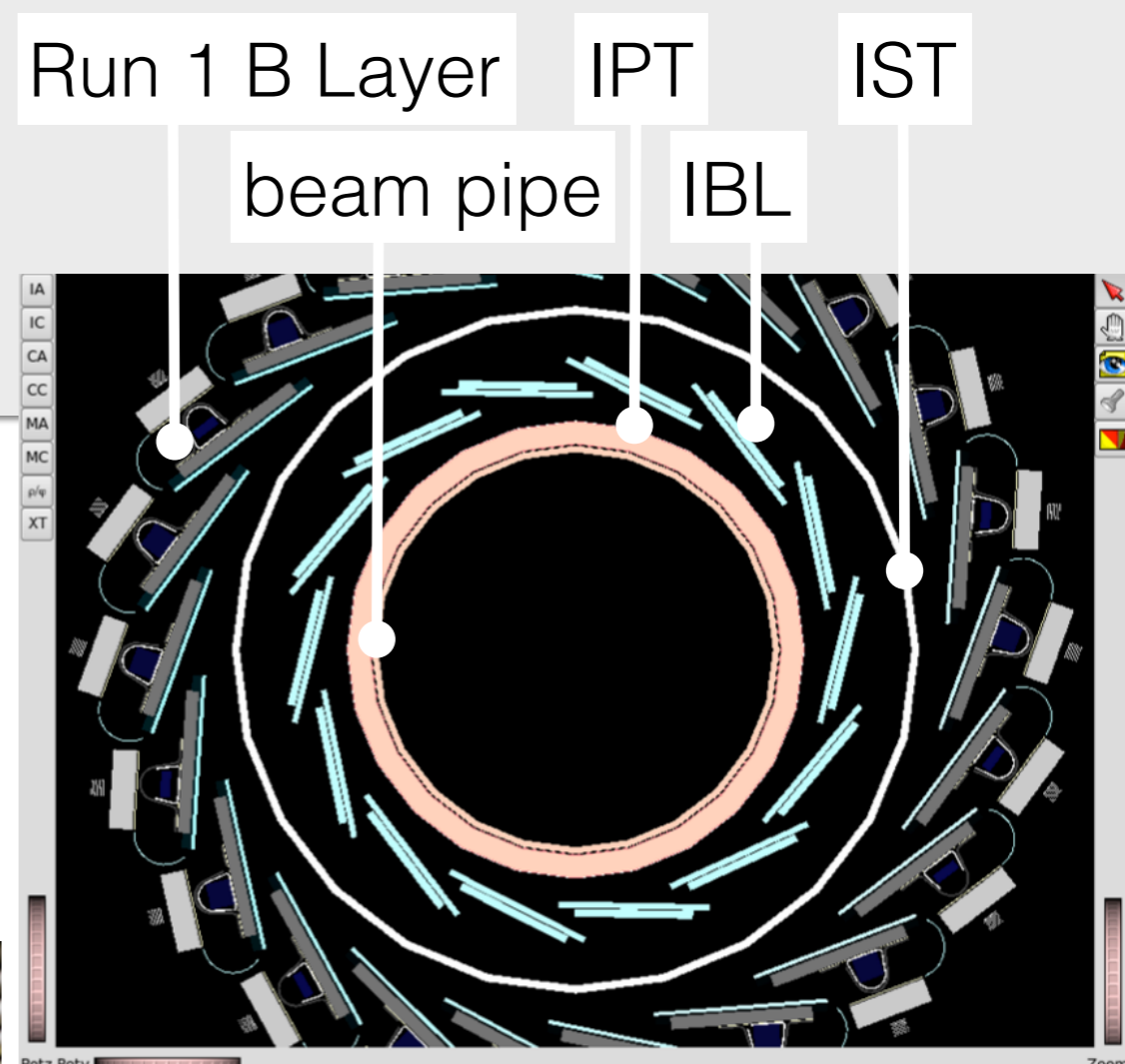
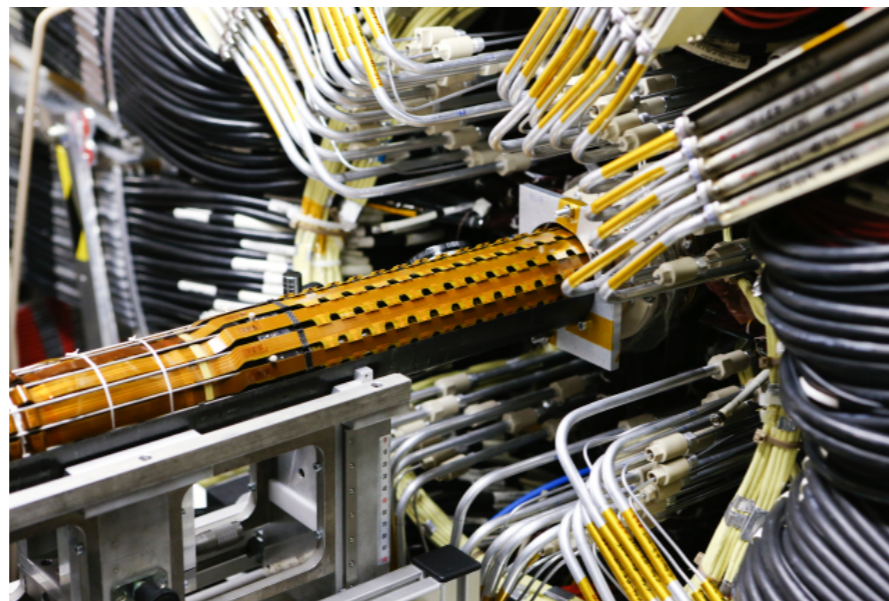
Gains:

impact param

light jet reject

redundancy

Status: live >99.9%



# Tracking and Calorimeter Systems

many projects

## **SCT and TRT readouts enhanced, operational**

new ROD in SCT

90 → 128 S links and compression leading to 100 kHz @  $\mu = 87$

data compression, different gating in TRT leading to 104 kHz with 2% occupancy

## **Pixel Detector brought to surface, reinstalled**

Layer 0: 6.3% → 1.4%; Layer 2: 7% → 1.9%; now 98% functional of 1744

new diamond/Si beam monitors installed

prepared for IBL

## **LAr and Tilecal**

LVPS replaced (LAr) fixed (Tilecal): readouts tested to more than 100 kHz

Phase 1 “demonstrator” installed

Min-bias trigger scintillators

# Muon system

staged from Run 1

## New ROD for CSC system

limited ATLAS L1 trigger rate to 70 kHz...now 100 kHz

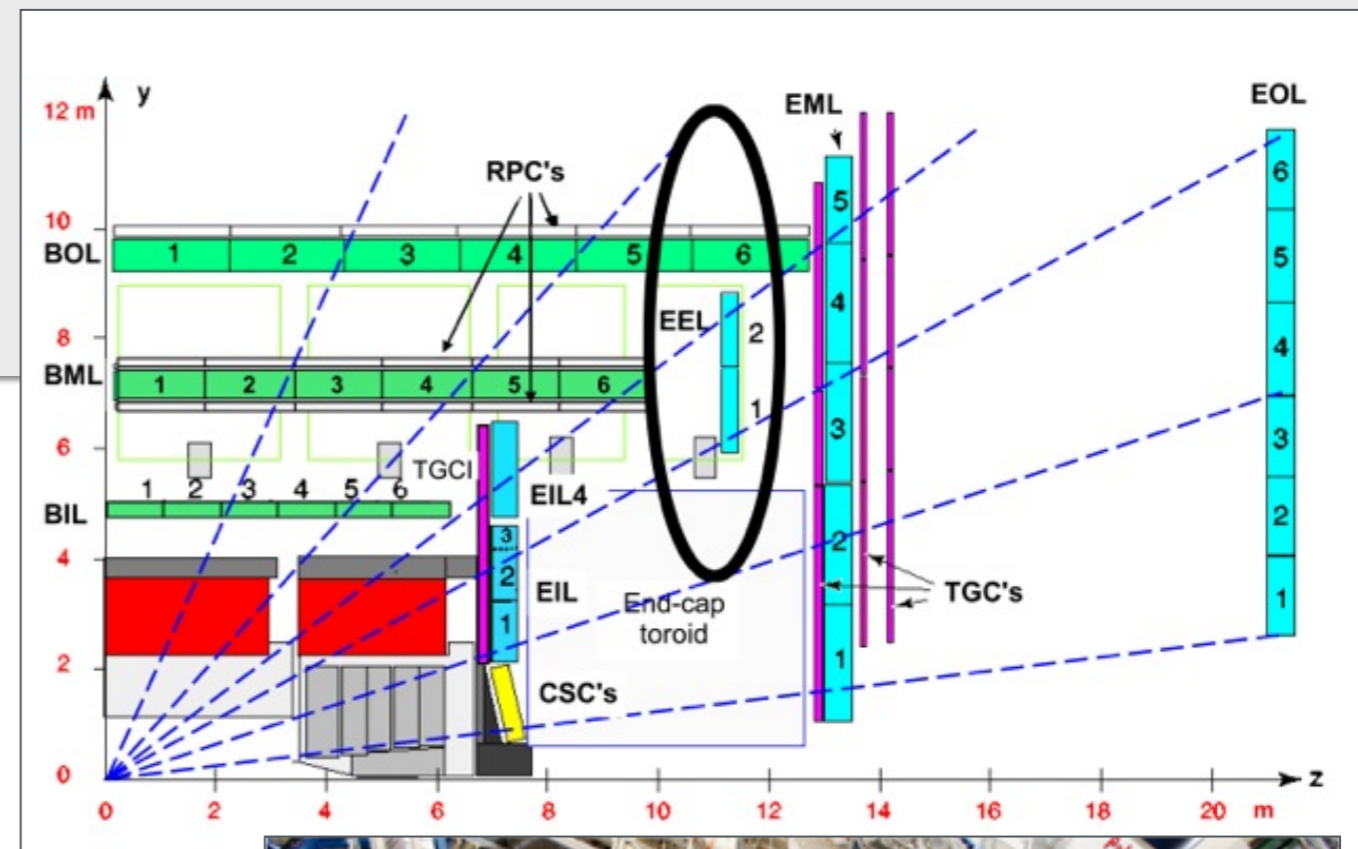
## New EE endcap chambers

## Repairs

Broken CSC chambers, repaired, reinstalled

RPC leak repairs

TGC chamber replacement requires detector to be closed



# Trigger system

considerable enhancements

$E_{CM}$  from 8 to 13 TeV (x2.5) +

$\mathcal{L}_{peak}$  0.8 to  $1.6 \times 10^{34}/\text{cm}^2/\text{s}$

5x trigger rates from Run 1

## Upgrades to:

L1 rate, 70 kHz  $\rightarrow$  100 kHz  
operation, factor 4/3 increase.

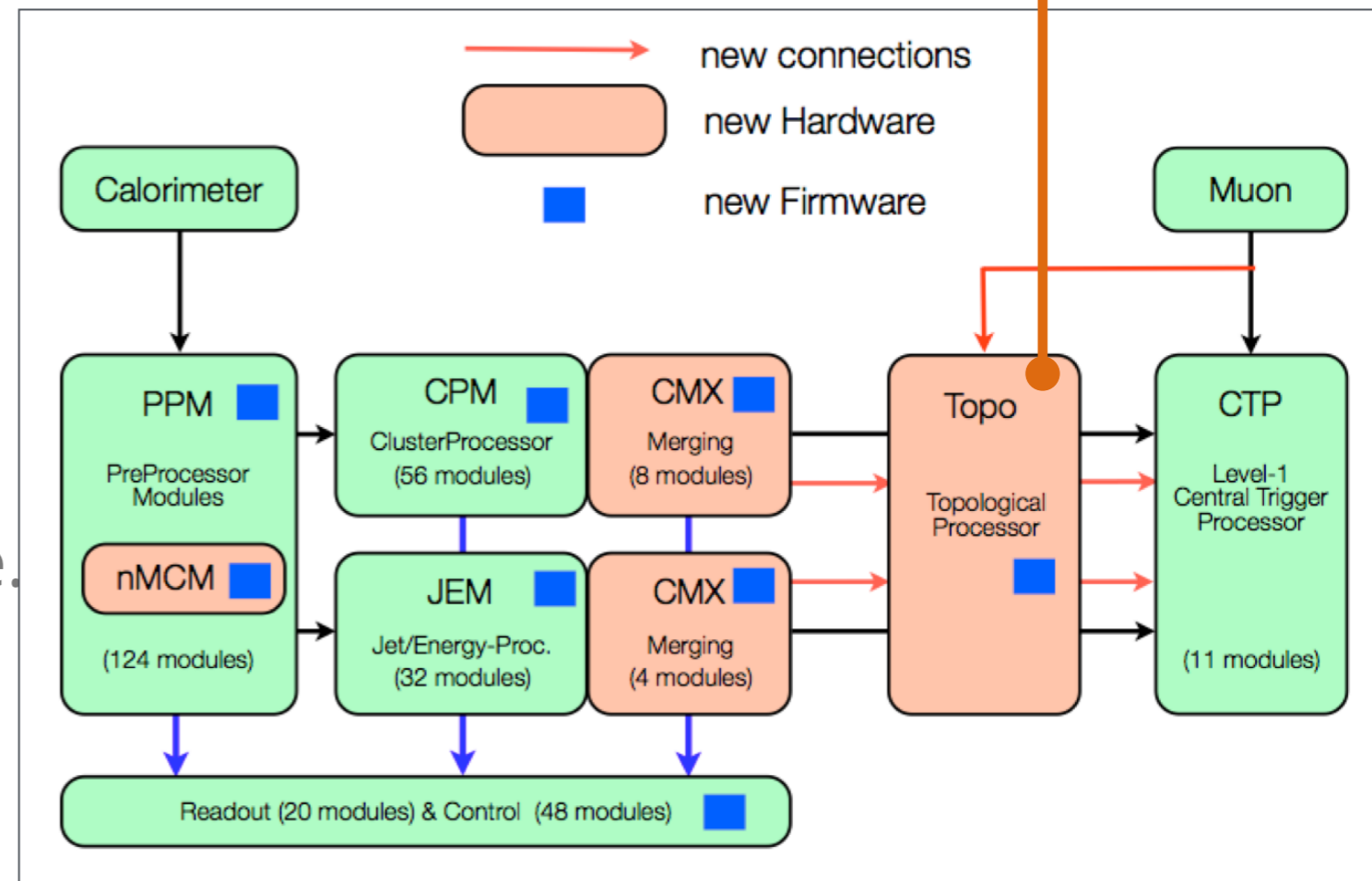
### hardware

HLT rate, 400 Hz  $\rightarrow$   $\sim$ 1 kHz  
operation, factor of  $\sim$ 2 increase.

### algorithms

“L1Topo”: topological object correlations at L1

jet + E<sub>miss</sub> + angle sep & improved E<sub>miss</sub>





# Trigger system hardware

## New preprocessors (nMCM)

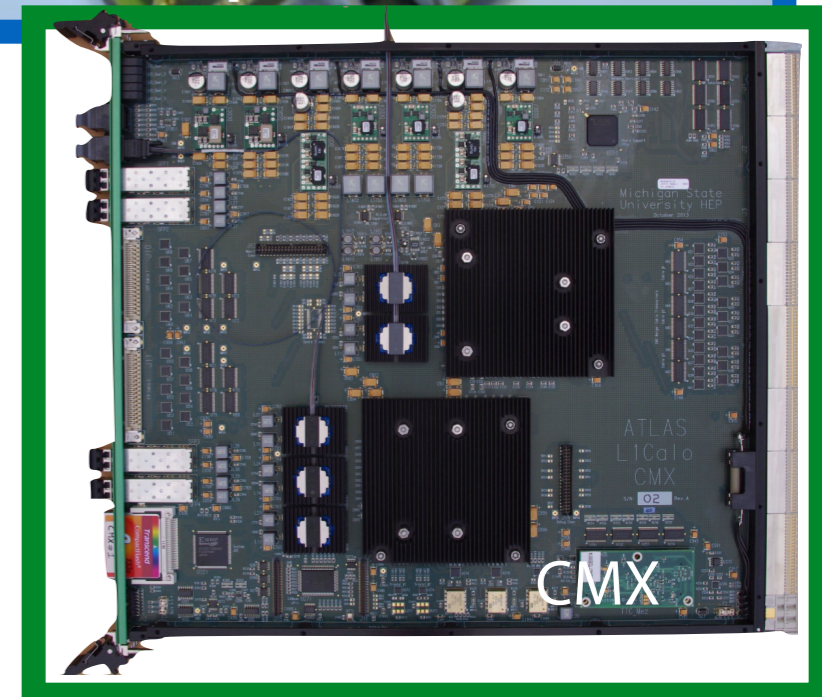
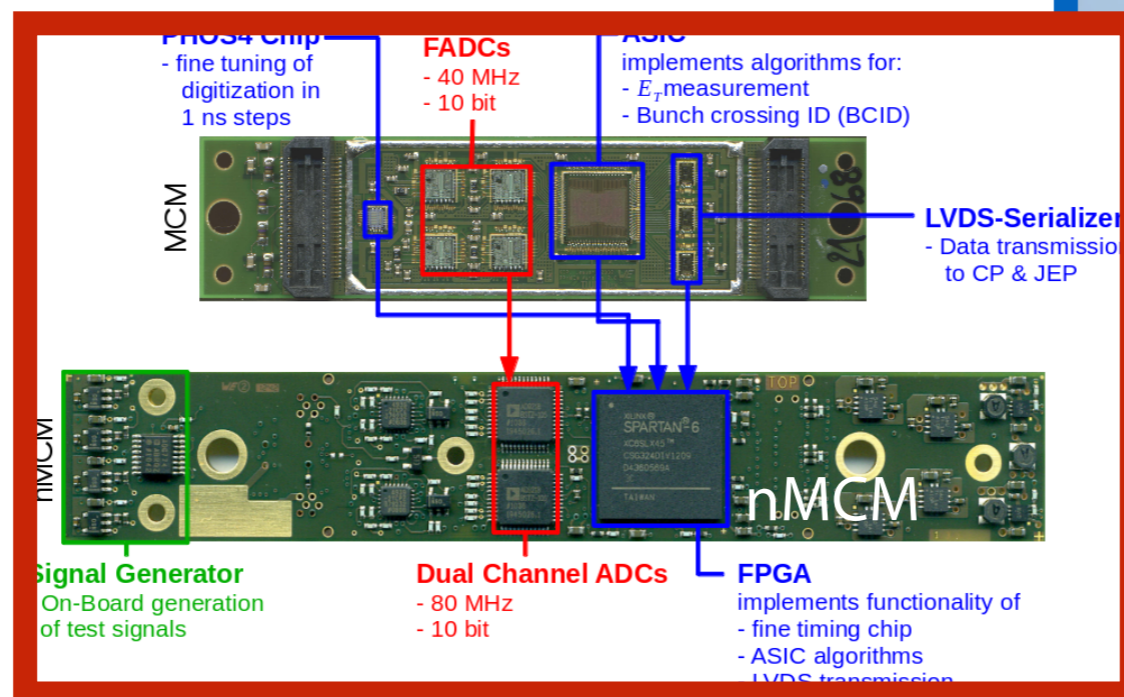
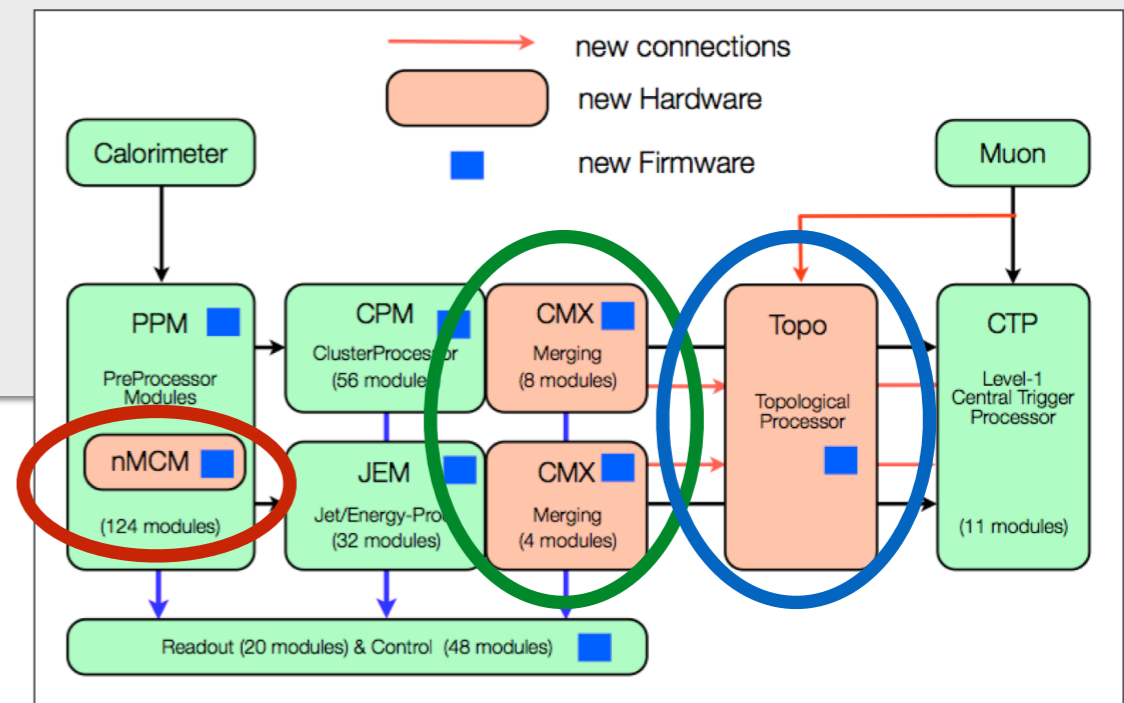
80 MHz digitization, lower noise

## New merger modules (CMX)

x4 speed enhancement over CMM

## L1 Topo processor

trigger on object relations at L1 e.g.  $\Delta\phi(E^{miss}_T, j)$

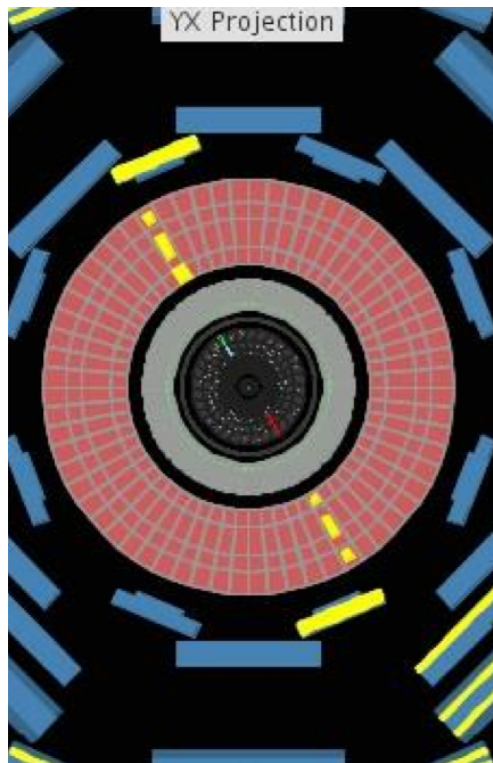


Commissioning underway in-situ

# Commissioning

multiple "Milestone weeks"

24/5! M's cosmic rays HLT & reco'd Tier 0



	M3	M4	M5	M6	M7
	May19- May 23	Jul 7- Jul 11	Sep 8- Sep 12	Oct 13- Oct 17	Nov 24- Dec 08
PIX		X <sup>1</sup> , X <sup>2</sup>	X <sup>2</sup>		
IBL		X <sup>1</sup>	X <sup>2</sup>		
SCT		X	X <sup>2</sup>		
TRT					
LAR		X			
TIL		X			
MBTS		X			
L1Calo		X <sup>2</sup>	X <sup>3</sup>	X <sup>4</sup>	
CSC			X <sup>2</sup>	X <sup>2</sup>	
MDT					
RPC	X <sup>1</sup>				
TGC				X <sup>2</sup>	
BCM					
ALFA			X		
LUCID				X	
Lumi			X		

# Commissioning

multiple "Milestone weeks"

24/5! M's cosmic rays HLT & reco'd Tier 0



	M3	M4	M5	M6	M7
	May19- May 23	Jul 7- Jul 11	Sep 8- Sep 12	Oct 13- Oct 17	Nov 24- Dec 08
PIX		X <sup>1</sup> , X <sup>2</sup>	X <sup>2</sup>		
IBL		X <sup>1</sup>	X <sup>2</sup>		
SCT		X	X <sup>2</sup>		
TRT					
LAR		X			
TIL		X			
MBTS		X			
L1Calo		X <sup>2</sup>		X <sup>4</sup>	
CSC			X <sup>2</sup>	X <sup>2</sup>	
MDT					
RPC	X <sup>1</sup>				
TGC				X <sup>2</sup>	
BCM					
ALFA			X		
LUCID				X	
Lumi			X		

**ATLAS**  
reading out  
since "M5"

# Computing & Software & Analysis

speed/efficiency and pileup

Many algorithmic, mathematical, fitting changes

factor >3 gains

pileup robustness

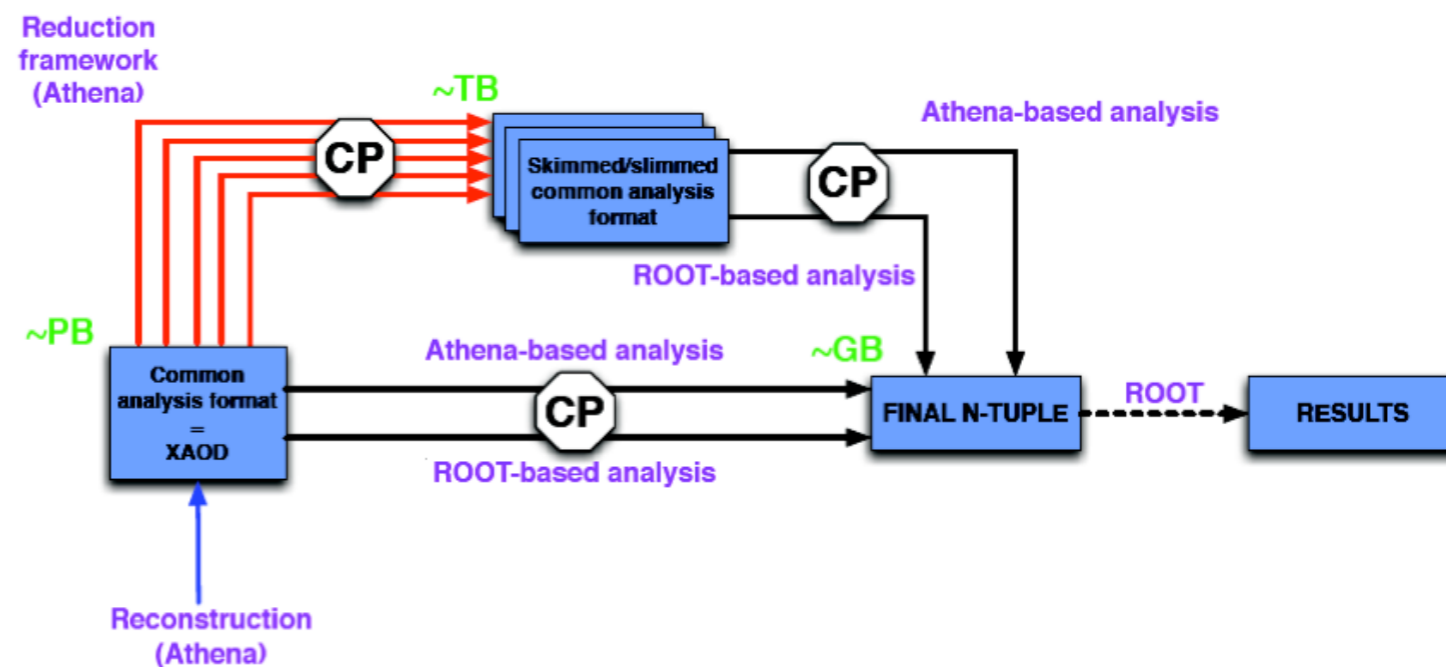
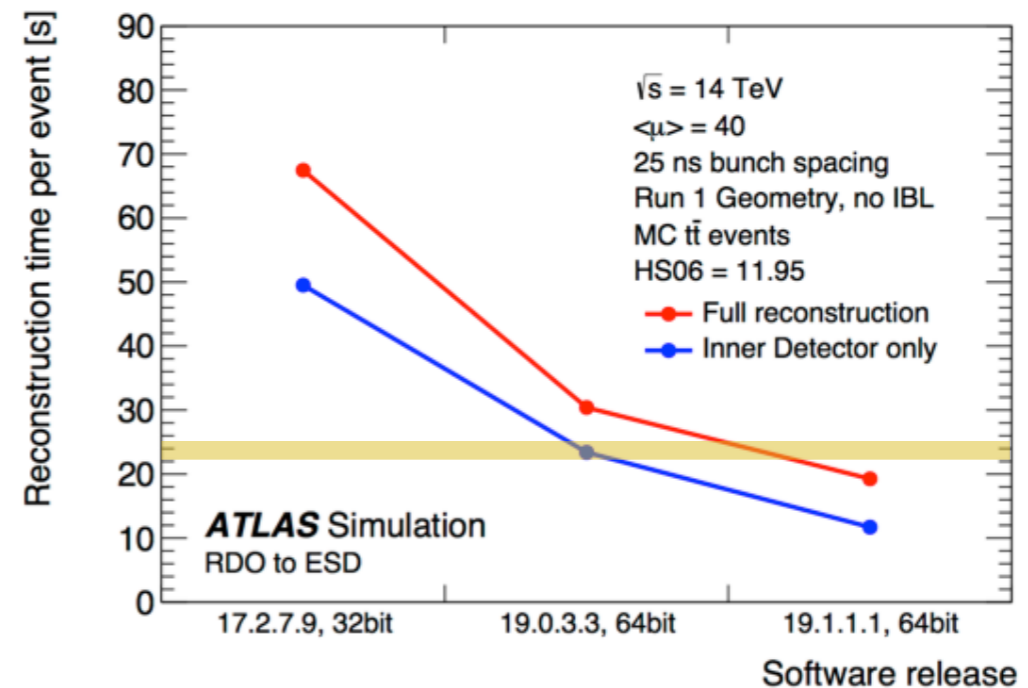
Completely redesigned analysis model

“xAOD” Athena reconstruction is ROOT-readable, tuning.

disk usage tight...working on xAOD sizes

memory usage gymnastics

CP tools mostly migrated



# conclusion

Run 2 is an unusual event for all of us

---

we've seen CM energy increases:

tevatron 2 TeV to LHC 8 TeV

*now* we can anticipate:

14 TeV

# conclusion

Run 2 is an unusual event for all of us

---

we've seen CM energy increases:

tevatron 2 TeV to LHC 8 TeV

*now* we can anticipate:

14 TeV

we've seen instantaneous  $\mathcal{L}$  increases:

tevatron peak of  $4 \times 10^{32}$  /cm<sup>2</sup>/s to LHC peak of  $7 \times 10^{33}$  /cm<sup>2</sup>/s

*now* we can anticipate:

$1.5 \times 10^{34}$  /cm<sup>2</sup>/s

# conclusion

Run 2 is an unusual event for all of us

we've seen CM energy increases:

tevatron 2 TeV to LHC 8 TeV

*now* we can anticipate:

**Orders of magnitude!**

we've seen instantaneous  $\mathcal{L}$  increases

tevatron peak of  $4 \times 10^{32}$  /cm<sup>2</sup>/s to LHC peak of  $7 \times 10^{33}$  /cm<sup>2</sup>/s

*now* we can anticipate:

$1.5 \times 10^{34}$  /cm<sup>2</sup>/s

# Conclusions

