What needs to be done on PDF analysis?

Disclaimer:

any overlap between the content of this presentation and the announced title (conjured by Joey) is purely coincidental.

Open Issues on PDFs of the nucleon.

Challenges for PDF analysis at the Tevatron and the LHC

Action items / projects for this workshop

Confession:

the strong overlap between the content of this presentation and the punch lines of the PDF talk at the 09/04 workshop is entirely intentional.

Wu-Ki Tung, joint meeting of QCD and EW workgroups, Dec. 1, 2004

Mini Summary on current status of PDF Analysis

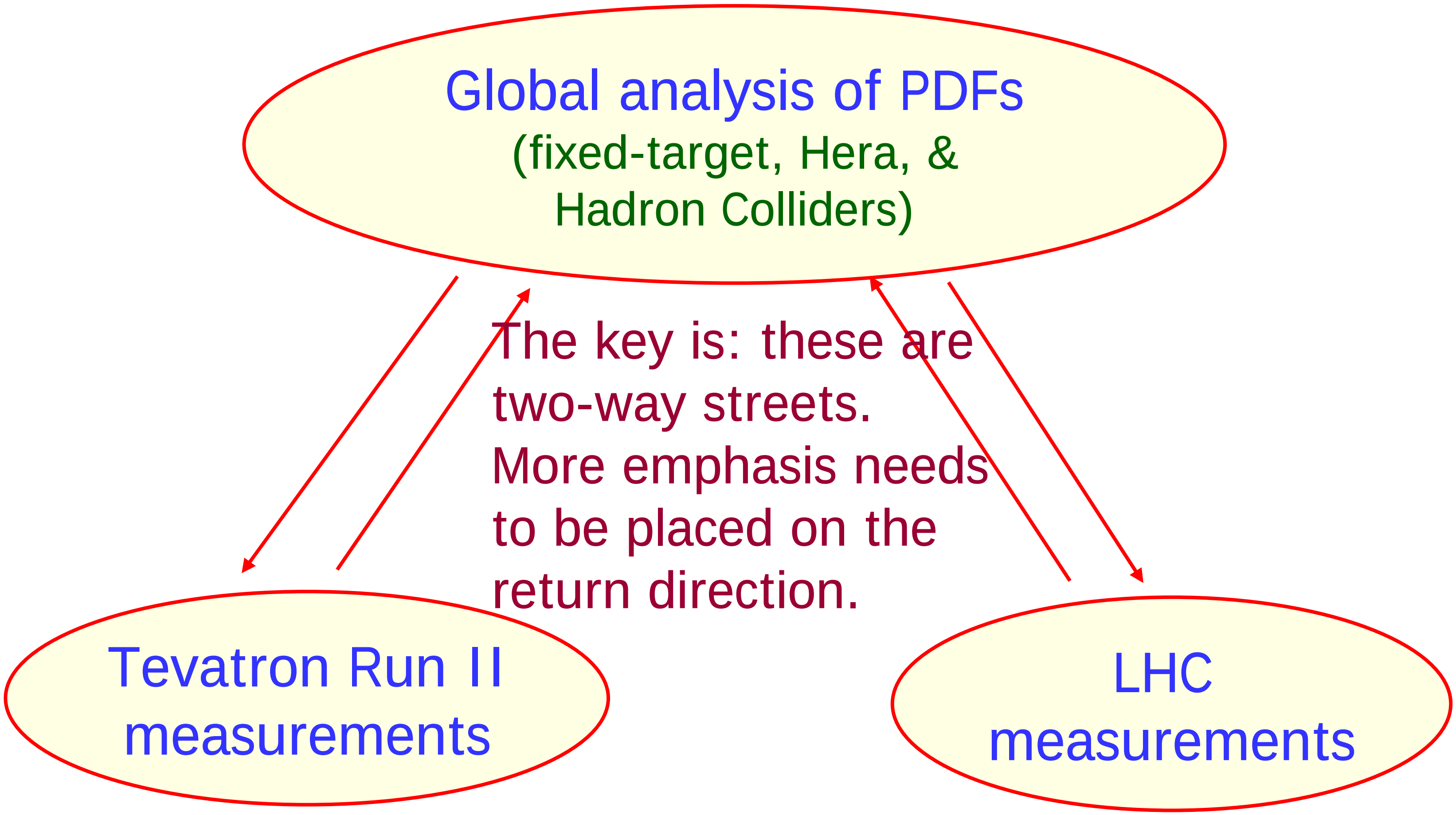
- A great deal of progress has been made since the first LO analyses were make;
- But, many areas of uncertainties and uncharted territories remain.

Open Issues: (before we can really understand the parton structure of nucleon, and are able to make reliable predictions)

- Reliable methods of quantifying uncertainties —experimental (between global data sets) and theoretical (many);
- Gluon distribution at large and small x is very uncertain;
- Isospin asymmetry: *d/u* at large *x*; *(db-ub)/(db+ub)* at large *x*;
- Isospin violation (i.e. d_n .ne. u_p);
- Strangeness s(x); and strangeness asymmetry (s-sb)/(s+sb);
- Heavy quark (c and b) parton distributions.

Collider programs have a lot to contribute to, and to benefit from, further advances in this enterprise!

PDFs, Tevatron and LHC



Crucial for improving PDFs, and narrowing the uncertainties on M_W measurement (underestimated currently).

Collider Physics Issues related to Global QCD Analysis

- Standard Candle Processes:
  W/Z total cross-section predictions;
- Precision PQCD phenomenological analyses (Tevatron):
  Jet and Dir. photon X-secs;
  W/Z, DY rapidity distributions;
  W/Z transverse momentum distributions;
  W/Z + Jet differential cross sections;
  (Complementary to precision DIS phenomenology of the 1990's)
  All have direct impact on how well we can do on
  W-mass measurement and Top physics.

QCD WG

Top-EW WG

- Precision Top and Higgs Phenomenology (LHC):
  predictions and measurement of SM parameters.

Higgs WG

- Predictions on possible New Physics Discoveries:
  SUSY, Technicolor and other strong dynamics, Extra Dimensions ...

Landscape WG

The precision phenomenology issues
are also intimately tied to:

How well do we understand the
uncertainties of PDFs?

Uncertainties due to exptl input to the global analysis:

- Have been the focus of much work by several groups (exptl and theory); (Alekhin, GKK, H1, Zeus, Cteq, Mrst)
- The community needs to understand: the main difficulty is not with the statistical methods; rather it is with developing sensible ways to treat nominally incompatible experimental data sets used in the global analysis. $\Rightarrow$ There are no rigorous answers; some subjective judgment must be involved. $\Rightarrow$ differences in estimated uncertainties among groups.
- Issues are complex; most recent, practical approaches are: (i) an iterative Hessian method (eigenvector solu-tions.); (ii) a Lagrange Multiplier method---developed by Stump, Pumplin etal (MSU/CTEQ), also used by Mrst, Hera groups

These methods can be used by our workgroup to study the sensitivity of various measurements to important physical issues.

Theoretical uncertainties (at small x and low Q):

(No less difficult to quantify. Studied empirically by varying kinematic cuts used in the global analysis.)

These issues were studied in CTEQ1,2 analyses. The stable cuts found then have been left unchanged since.

Recent study by MRST revived the interest on this issue, particularly because of its findings, that the cuts have an important impact on predictions for the PDFs, and their Tevatron Run II and LHC predictions. hep-ph/0308087

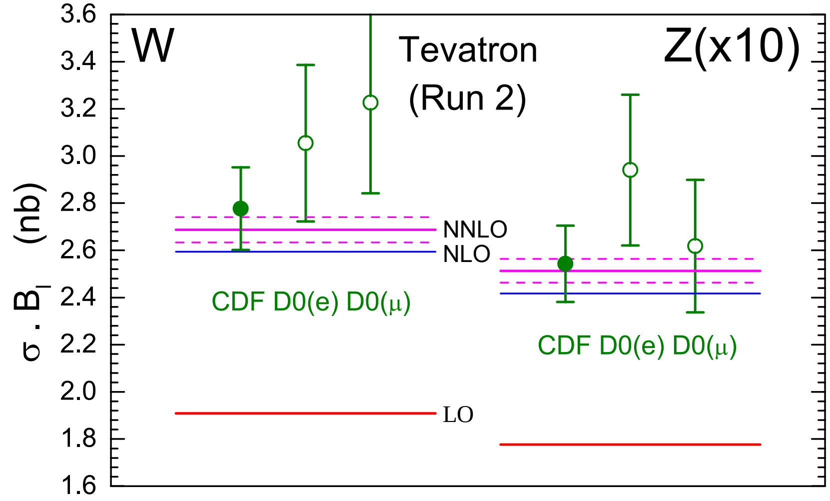
Important for Tevatron II and LHC physics:

Are these indications supported also by current CTEQ analysis?

Good news: We found NLO QCD analysis results on W/Z physics quite stable and robust.

Bad news: much needs to be done to better estimate theoretical uncertainties.

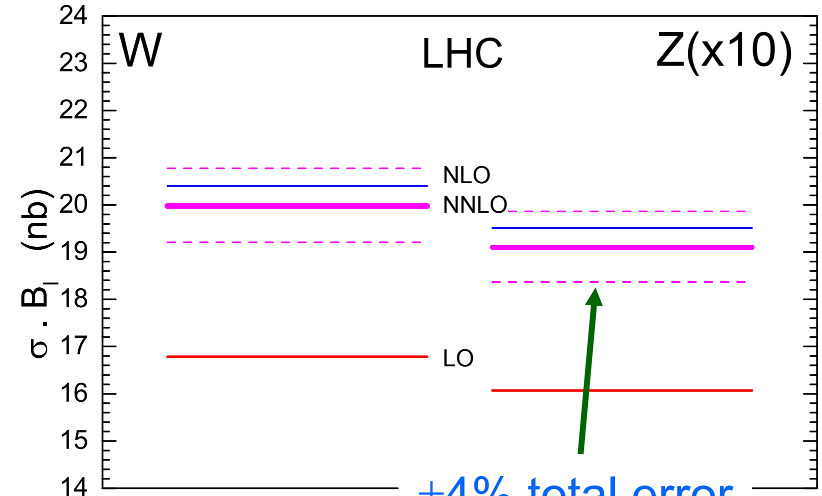
Standard Candle:
σ(W) and σ(Z) : precision predictions and measurements at Tevatron Run 2 and the LHC.



Exptl uncertainties:

LHC	**σ_{NLO}(W) (nb)**
MRST2002	204 ± 4 (expt)
CTEQ6	205 ± 8 (expt)
Alekhin02	215 ± 6 (tot)

should be ignored, since it did not take into account DY input.

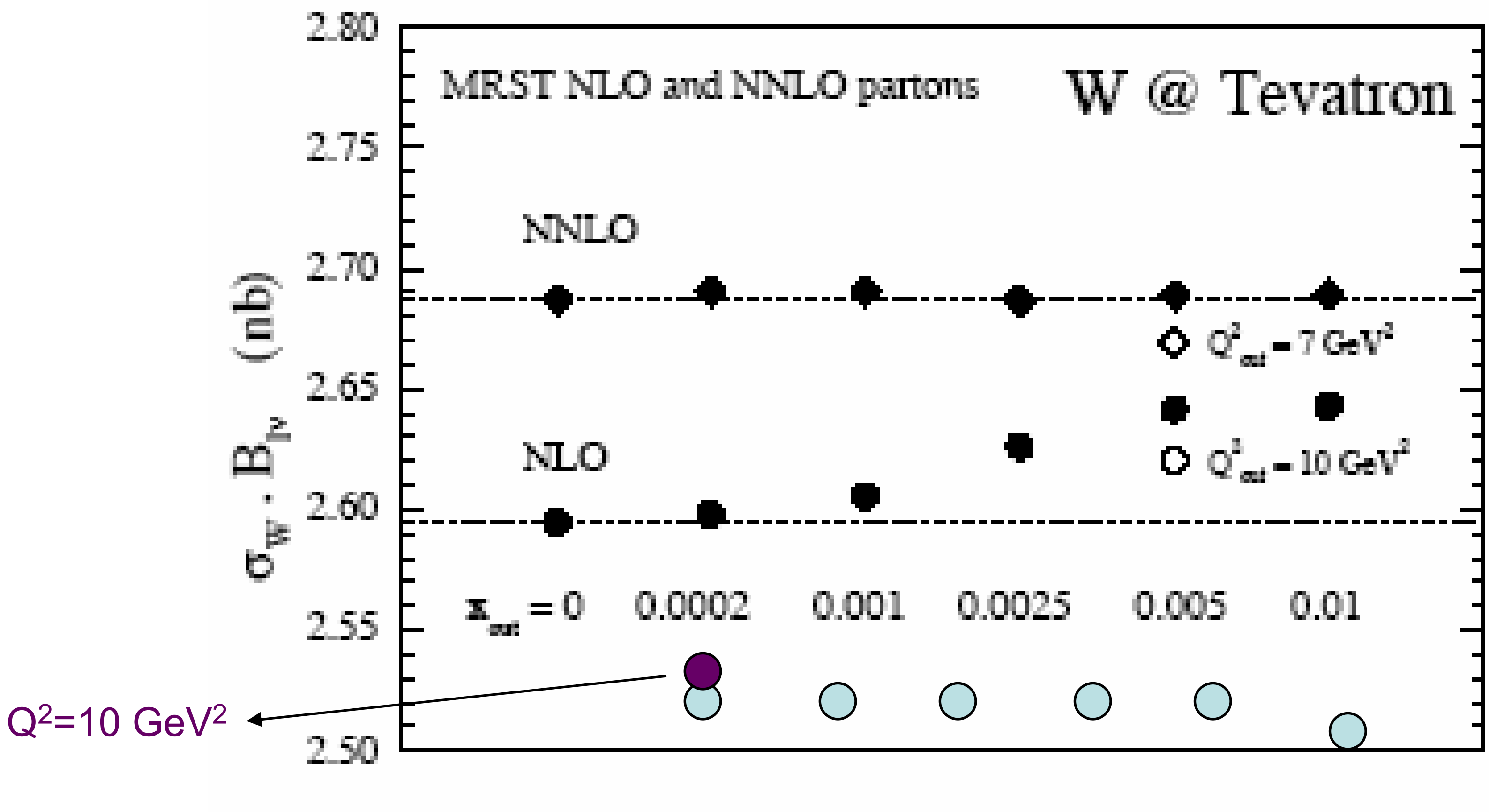


±4% total error
(MRST 2002)

partons: MRST2002
NNLO evolution: van Neerven, Vogt approximation to Vermaseren et al. moments
NNLO W,Z corrections: van Neerven et al. with Harlander, Kilgore corrections

(Stirling, HeraLhc Workshop 2004)

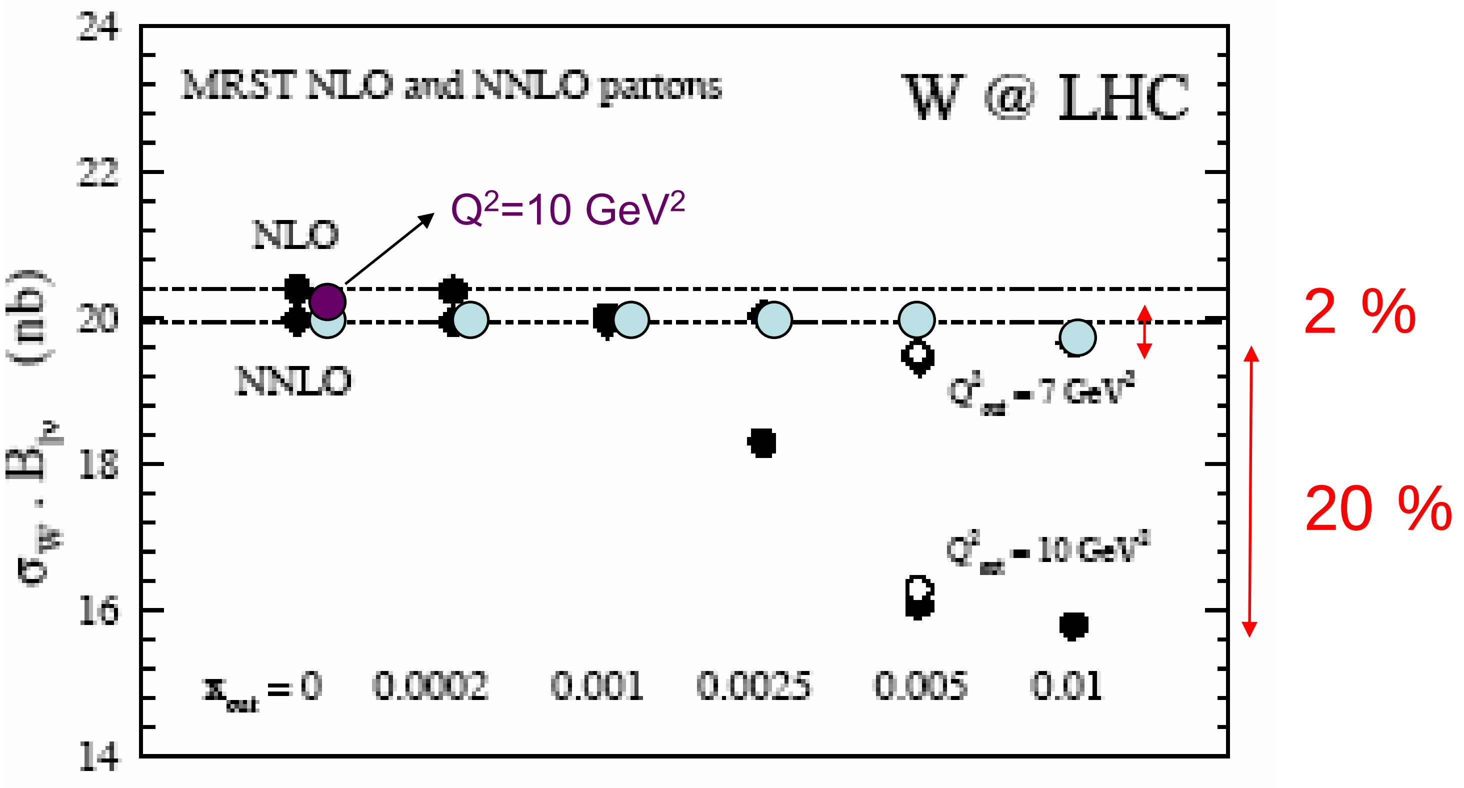
σ_W at the Tevatron



○ shows the results of applying x cuts to the CTEQ6 data set and performing a NLO fit

No significant instability found in the CTEQ NLO analysis. (Huston)

W total cross section at the LHC

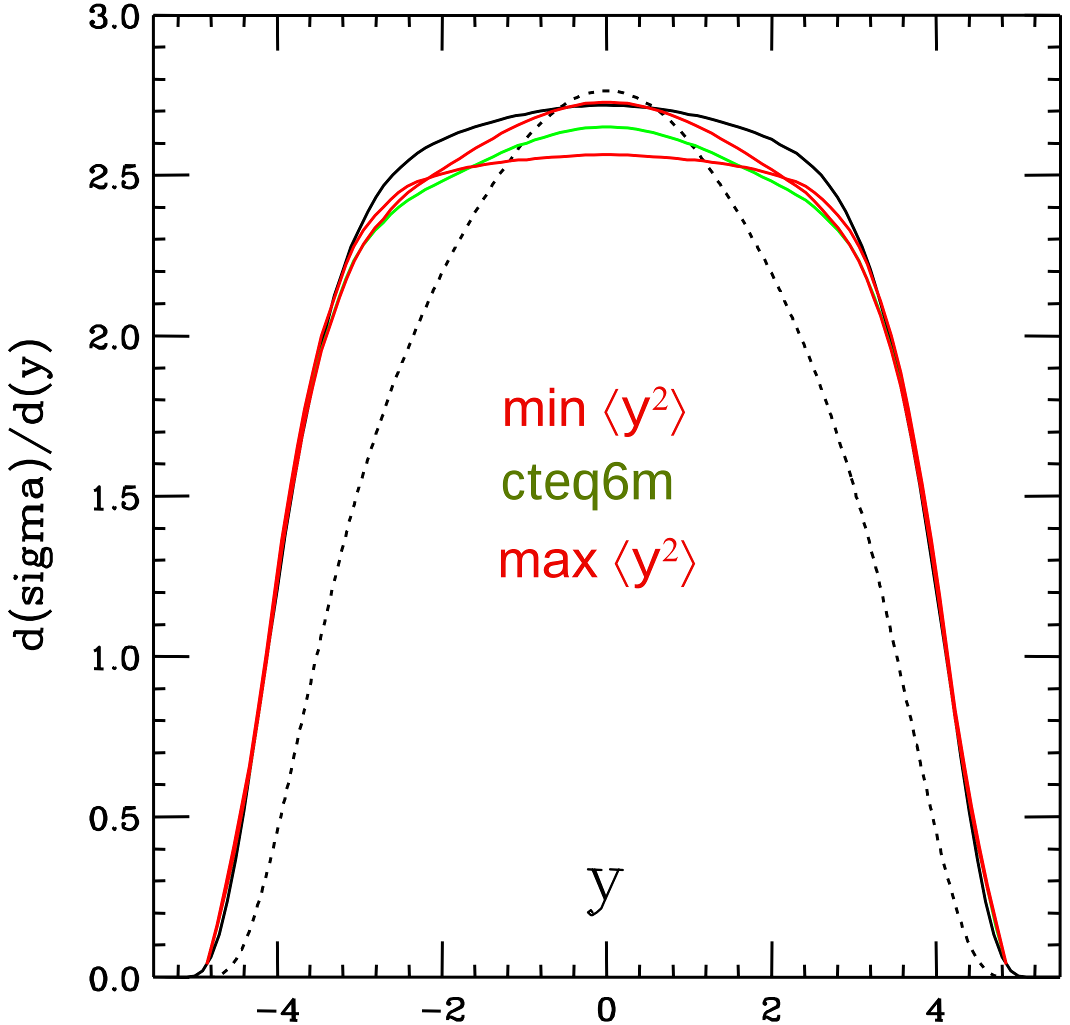


○ shows the results of applying x cuts to the CTEQ6 data set and performing a NLO fit.

We found that NLO σ_W is quite stable w.r.t. "theory uncertainties". Aside from an overall k-fac of ~1.04, NNLO is not needed to lend stability to the calculations.

CTEQ study of the W rapidity distribution at LHC (Pumplin)

- Search in the parton parameter space, using eigenvector solutions in the improved Hessian approach, to probe the extremes in predicted shape–max/min $\langle y^2 \rangle$.



Surely experiment can tell the differences!?

"Yes, within the first 5 minutes at LHC." -- Joey Huston

What can HCP contribute to Global QCD Analysis of PDFs

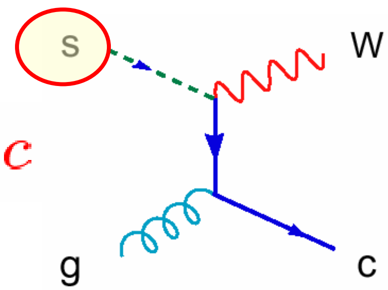
- In general: next generation of colliders are W/Z factories; many processes can provide new information on PDFs.
- More specifically:
  - Many gluon-sensitive processes can help narrow the large uncertainties on $g(x,Q_0)$;
  - W/Z rapidity distributions, $R(W_+/W_-)$, … can provide needed information on SU(2) flavor dependence of partons: u(x), d(x), ub(x), db(x);
  - Systematic study of p_t distribution probes new parton degrees of freedom. ⇐ not yet explored at all!
  - New channels to study s(x) and heavy quark distributions.
- All these can have significant feedback on precision measurement of m_W, and top, Higgs parameters.

Probing the Sea Quark PDFs: s, c, b using tagged final states $W/Z/\gamma + c/b$?

Cf. Campbell et al. hep-ph/0312024

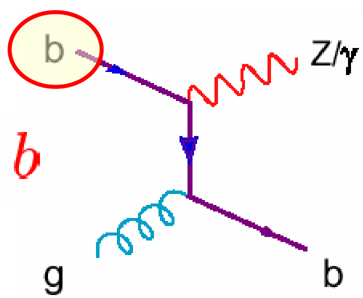
$s(x, Q)$:

$$g + s \rightarrow W + c$$



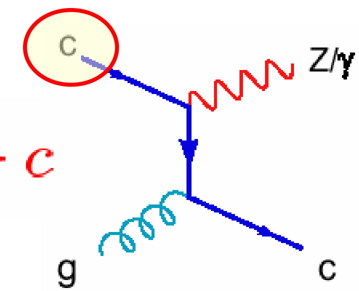
$b(x, Q)$:

$$g + b \rightarrow Z/\gamma + b$$

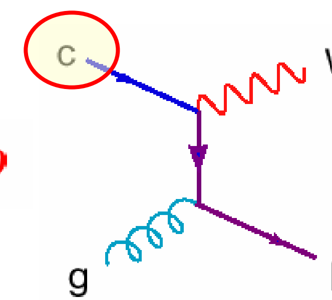


$c(x, Q)$:

$$g + c \rightarrow Z/\gamma + c$$



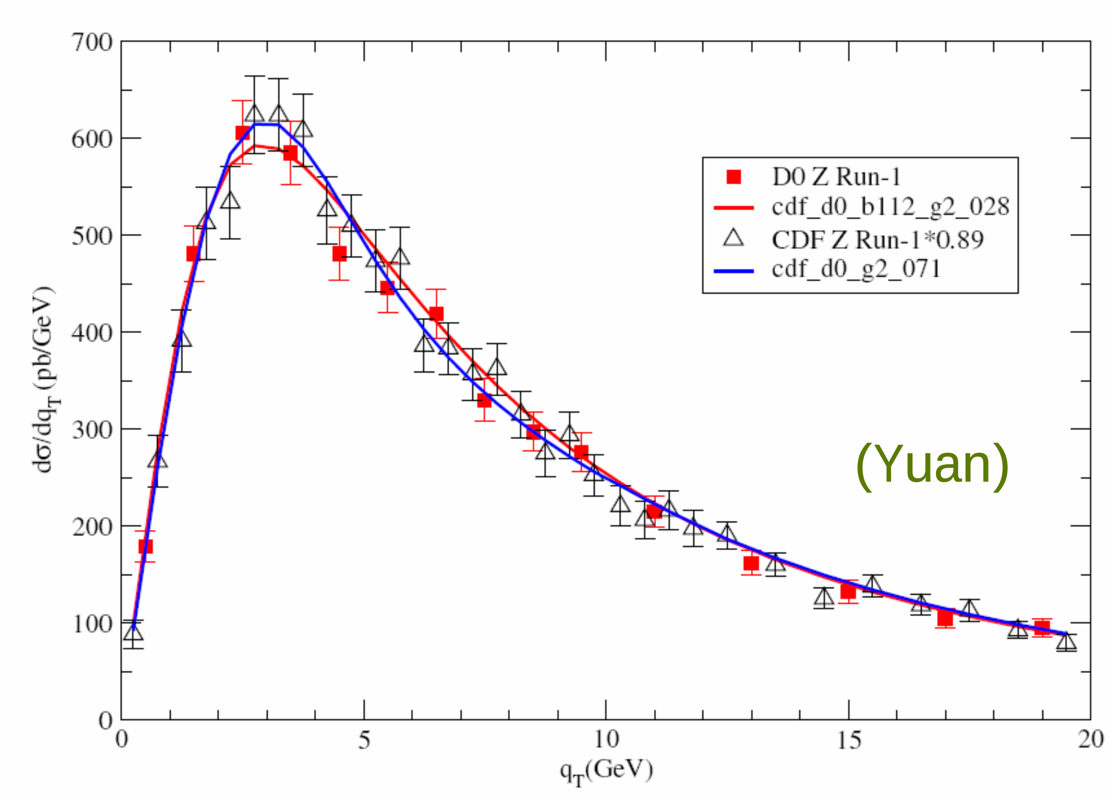
$$g + c \rightarrow W + b$$



In this workshop, we can calculate the range of predicted Xsecs, and estimate their sensitivity to variations of s, sbar, c, and b distributions.

P_T distribution and resumed PQCD

Cf. Nadolsky talk



- Resummation essential — a new frontier in precision PQCD phenomenology;
- Sensitivity to PDFs has not yet been studied in any systematic way;
- Important for pinning down Δm_W due to PDFs —a major source of m_W measurement error.

Non-perturbative parameters in the Sudakov exponent factor can be studied in combined fits to collider W/Z and lower energy DY data.

Systematic study of sensitivities of W/Z p_t distributions to PDF and non-perturbative parameters uncertainties is now underway.

Top Cross section at the Tevatron

M. Cacciari, S. Frixione, M.L. Mangano, P. Nason , G. Ridolfi

CTEQ PDF uncertainties

$\sqrt{S}$	m_{top}	σ_{min}	$\sigma_{ref}(\mathbf{6M})$	σ_{max}
1800	170	5.29	6.10	6.63
1800	175	4.51	5.19	5.64
1800	180	3.85	4.43	4.81
1960	170	6.79	7.83	8.54
1960	175	5.82	6.70	7.30
1960	180	5.00	5.75	6.25

MRST PDF uncertainties

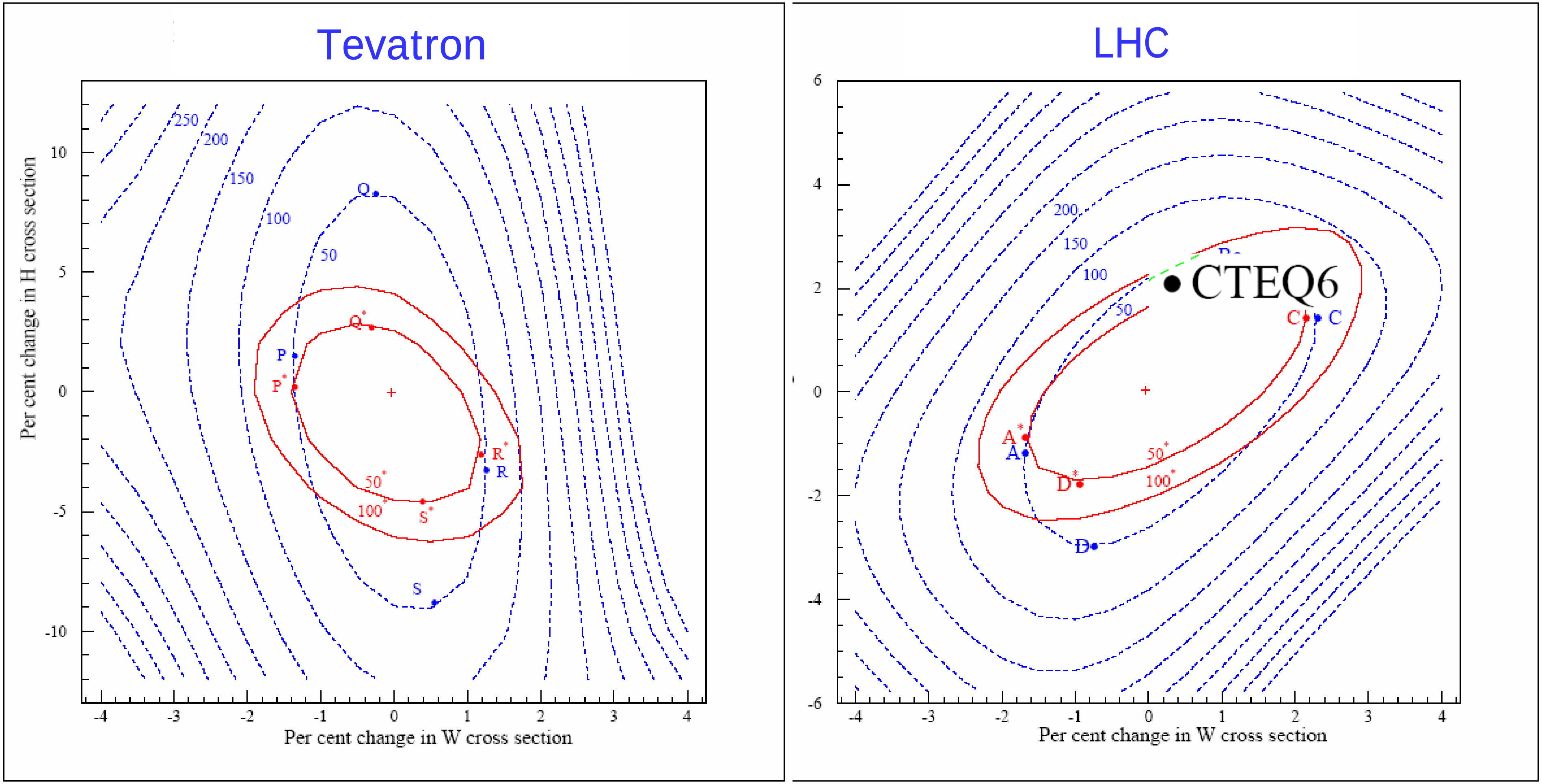
$\sqrt{S}$	m_{top}	σ_{min}	$\sigma_{ref}(\mathbf{0})$	σ_{max}
1800	170	5.52	6.13	6.44
1800	175	4.69	5.21	5.47
1800	180	4.00	4.44	4.67
1960	170	7.11	7.90	8.31
1960	175	6.08	6.76	7.10
1960	180	5.21	5.79	6.08

MRST PDF uncertainties
+ scale dependence

$\sqrt{S}$	m_{top}	$\sigma_{min}\ (r_\mu = 2,\ \mathbf{A01L})$	$\sigma_{ref}(r_\mu = 1,\ \mathbf{0})$	$\sigma_{max}\ (r_\mu = 0.5,\ \mathbf{J01})$
1800	170	5.48	6.13	6.72
1800	175	4.66	5.21	5.71
1800	180	3.98	4.44	4.86
1960	170	7.04	7.90	8.69
1960	175	6.03	6.76	7.41
1960	180	5.17	5.79	6.34

Higgs Physics

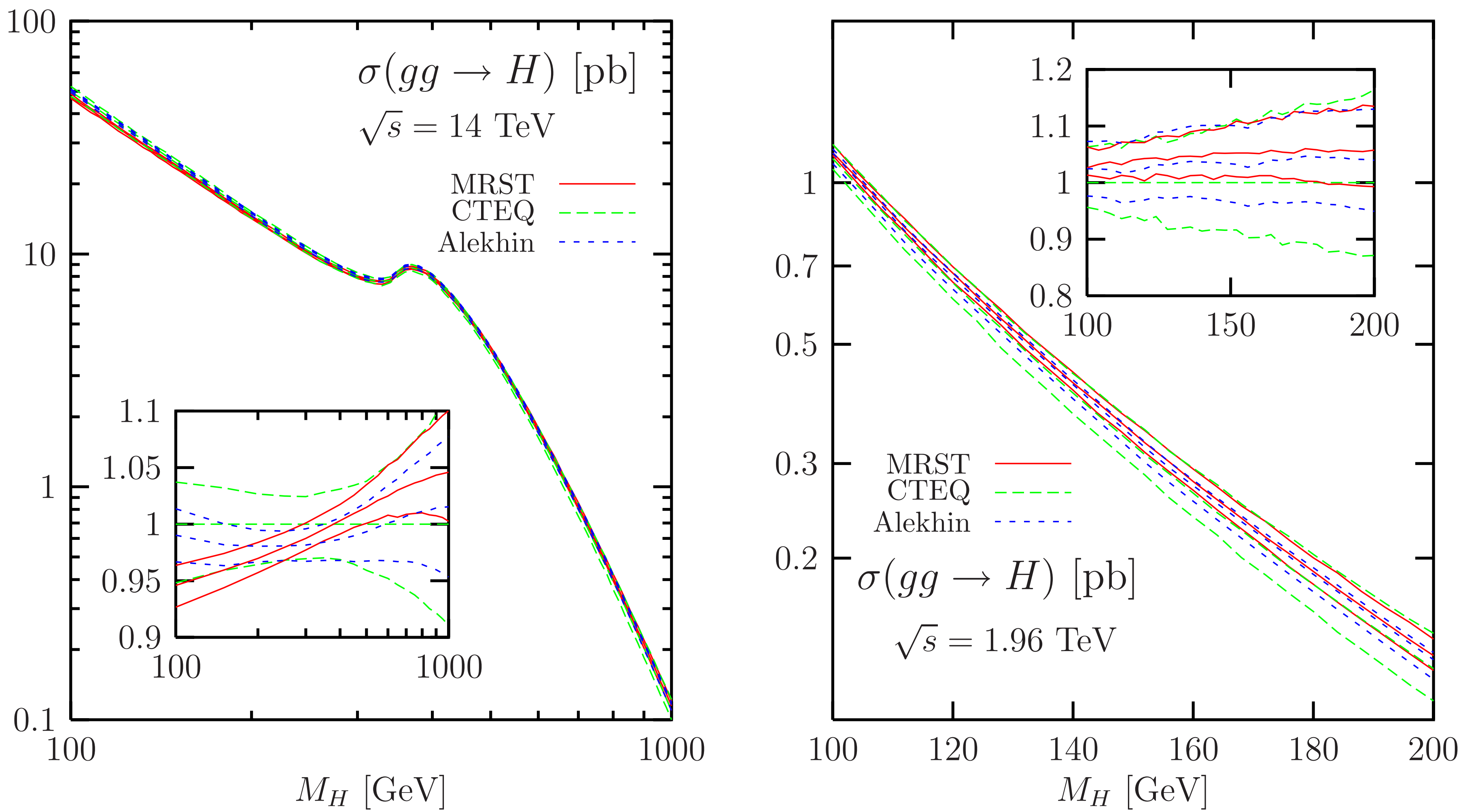
Contour plots of χ^2 in the σ_H-σ_W plane MRST



χ^2-plots for W and Higgs $(120\mathrm{GeV})$ production at the Tevatron and LHC α_S free (blue) and fixed (red) at $\alpha_S = 0.119$.

Higgs Physics at the Tevatron and LHC

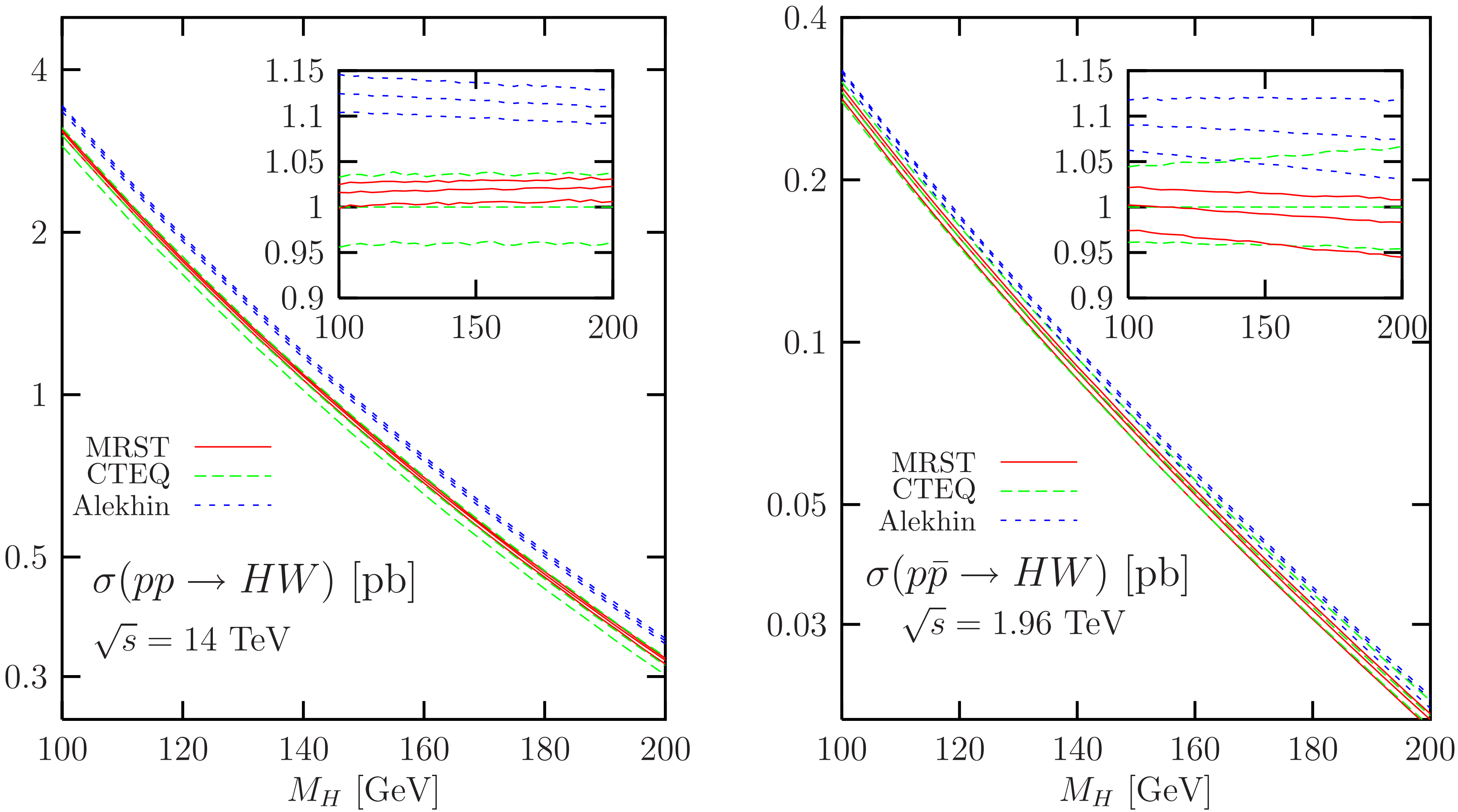
- Uncertainties due to PDFs for $gg \to H$



Djouadi & Ferrag, hep-ph/0310209

Higgs Physics at the Tevatron and LHC

• Uncertainties due to PDFs for *pp → H W*



Djouadi & Ferrag, hep-ph/0310209

Action Items / Projects

- W/Z total cross sections as luminosity monitors; (NNLO)
- W/Z (double/single) differential cross sections and ratios (asymmetries) as new inputs to pin down u/d/ub/db distributions;
- In-depth study of W/Z pt distributions to study the combined effects of PDFs and the non-perturbative Sudakov parameters;
- In-depth study of the PDF uncertainty of M_W measurement;
- Systematic study of W/Z/g + heavy-flavor-jet final states to pin down s/c/b parton distributions;
- Refine the estimates of experimental and theoretical uncertainties of PDFs based on global analysis, including Tevatron data;
- Propagate estimated PDF errors so estimated to LHC physics predictions.

Two FAQs deliberately left out of this discussion:

- Can we calculate "1-σ errors" on our measurement due to PDF uncertainties?
  More specifically, do the CTEQ 40 sets of eigenvector PDFs yield 1-σ errors?

No. (to both questions)

Why? Need another talk to explain.

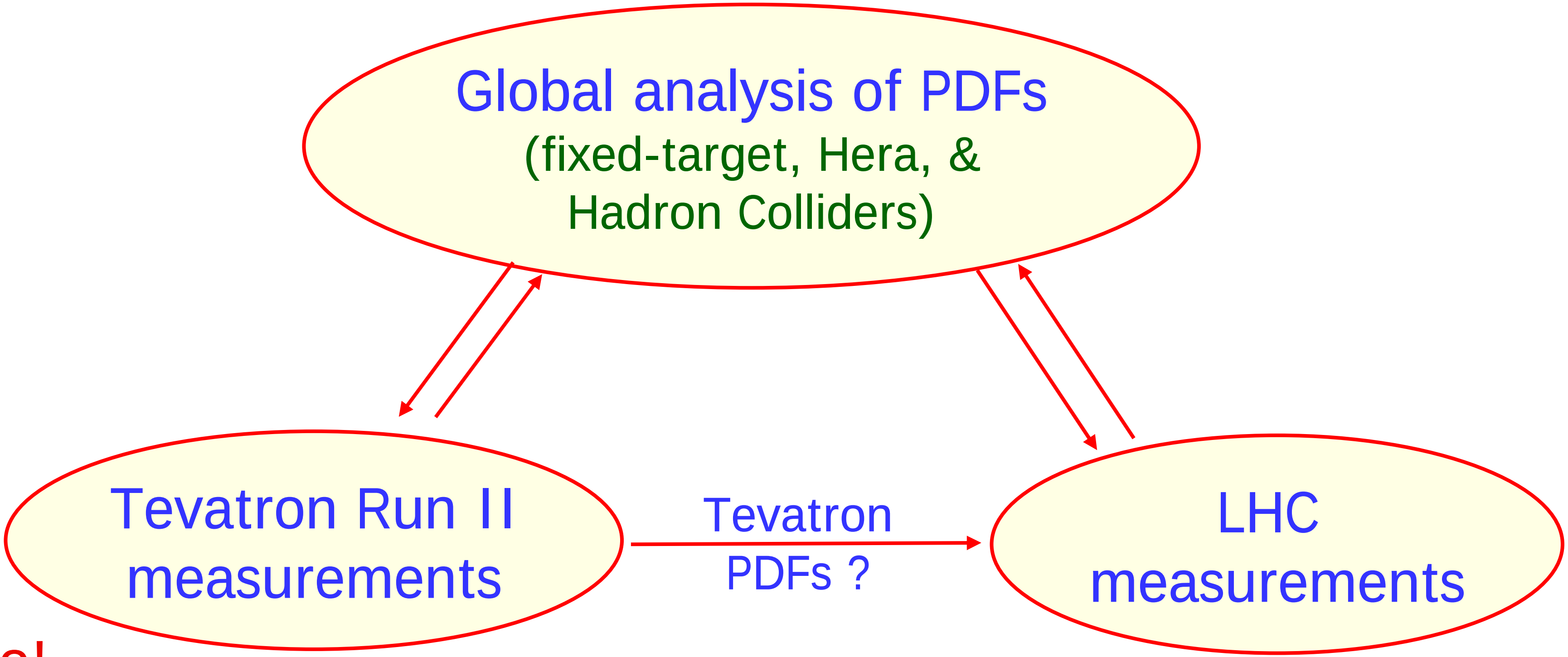
For practical purposes: consider them as 90% CL estimates (at your own risk).

- How do we produce "Tevatron-only" PDFs, to be used at LHC?

What for? To reduce systematic errors ("collider only")?

Question does not make much sense; but ...

Tevatron PDFs for LHC ?



No!

PDFs are *universal*; *true* PDFs must fit data for *all* processes.

However, Correlation between Tevatron and LHC measurements *can* be studied *in the global QCD analysis context*, e.g. by using the CTEQ Hessian and Lagrange Multiplier methods, with suitable emphasis factors.

Examples of such practical tools

- The improved Hessian method: iterative method to diagonalize the Hessian matrix and generate stable, physically meaningful error ranges;
- The Lagrange multiplier method to make robust estimates of uncertainties of individual parameters and predicted physical quantities;
- Alternative Hessian methods to study the compatibility between experiments and answer specific questions such as how many parameters (and which ones) are significantly constrained by a give experimental set or sets.

(Jon Pumplin, Hera-LHC workshop)