

# Advances in Global QCD Analysis and Impact on LHC Phenomenology

HeraLhc07

DESY

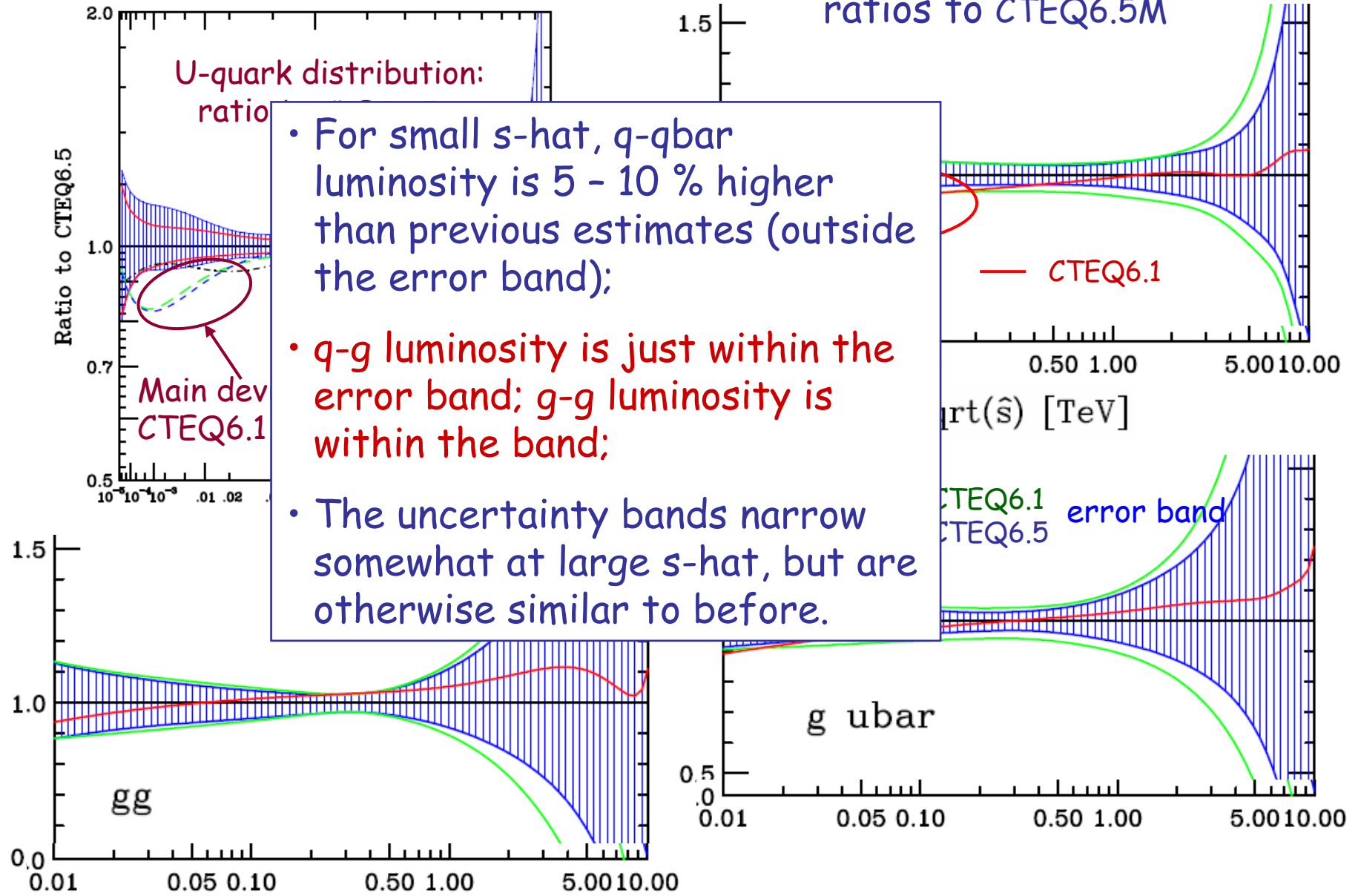
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## Advances in 3 fronts---a briefing

- New PDFs (CTEQ6.5M,S,C) from better treatment of heavy quark mass effects (cf. joint HQ-SF session) → Improved predictions on parton luminosities and SM/BSM phenomenology at the Tevatron & LHC;
  - Emerging *self-consistent* global QCD analysis procedure for determining PDFs and their uncertainties;
  - Combined  $p_T$ -resummation and PDF global QCD analysis for precision W/Z, Top, and Higgs physics at the Tevatron & LHC.
- Collaborators: Lai, Nadolsky, Huston, Pumplin, Stump, Yuan  
(Argonne, Michigan State & U Washington)

Impact of new CTEQ6.5 (M,S,C) PDFs  
on Collider Phenomenology

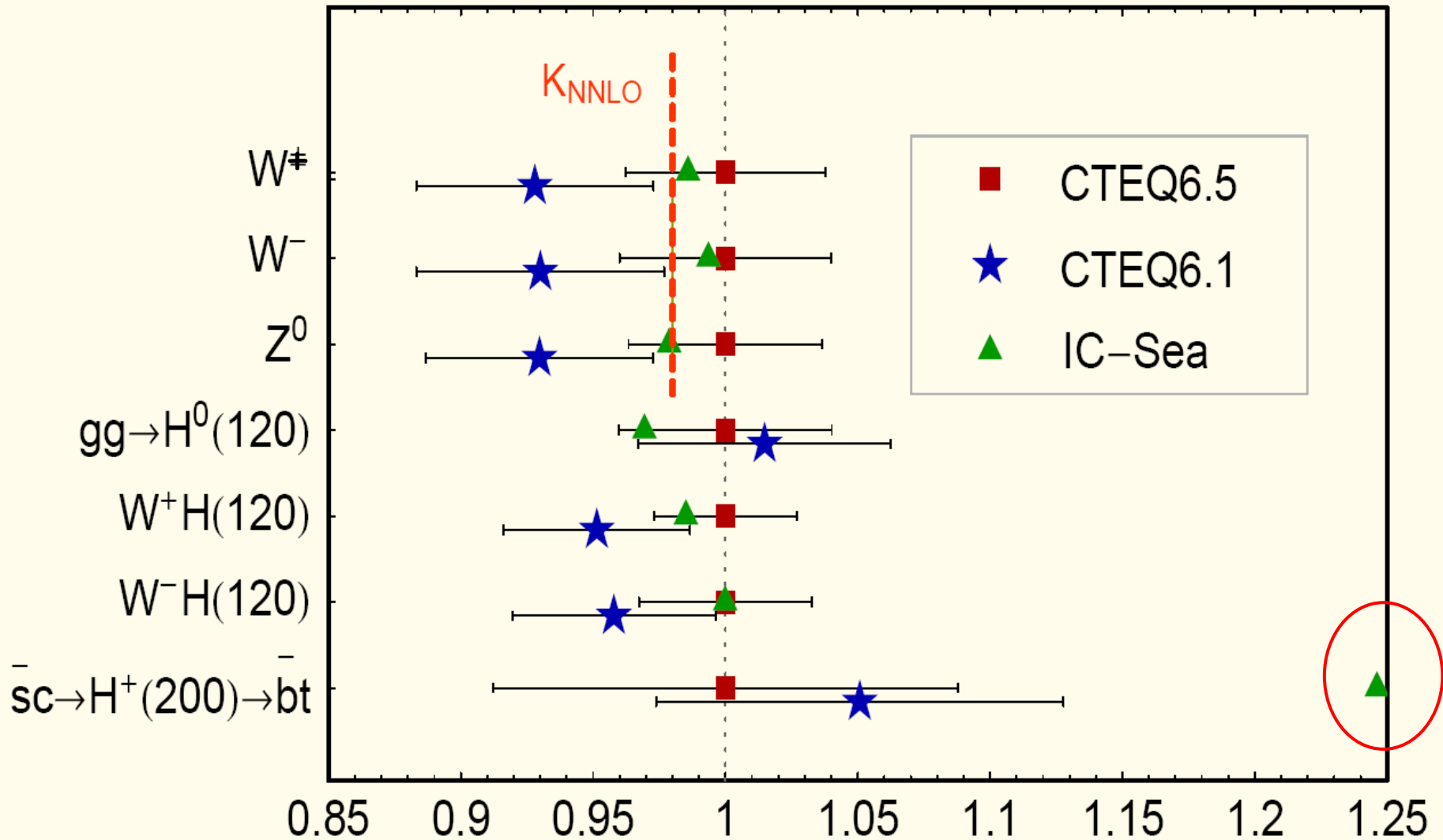
# LHC Luminosities: ratios to CTEQ6.5M



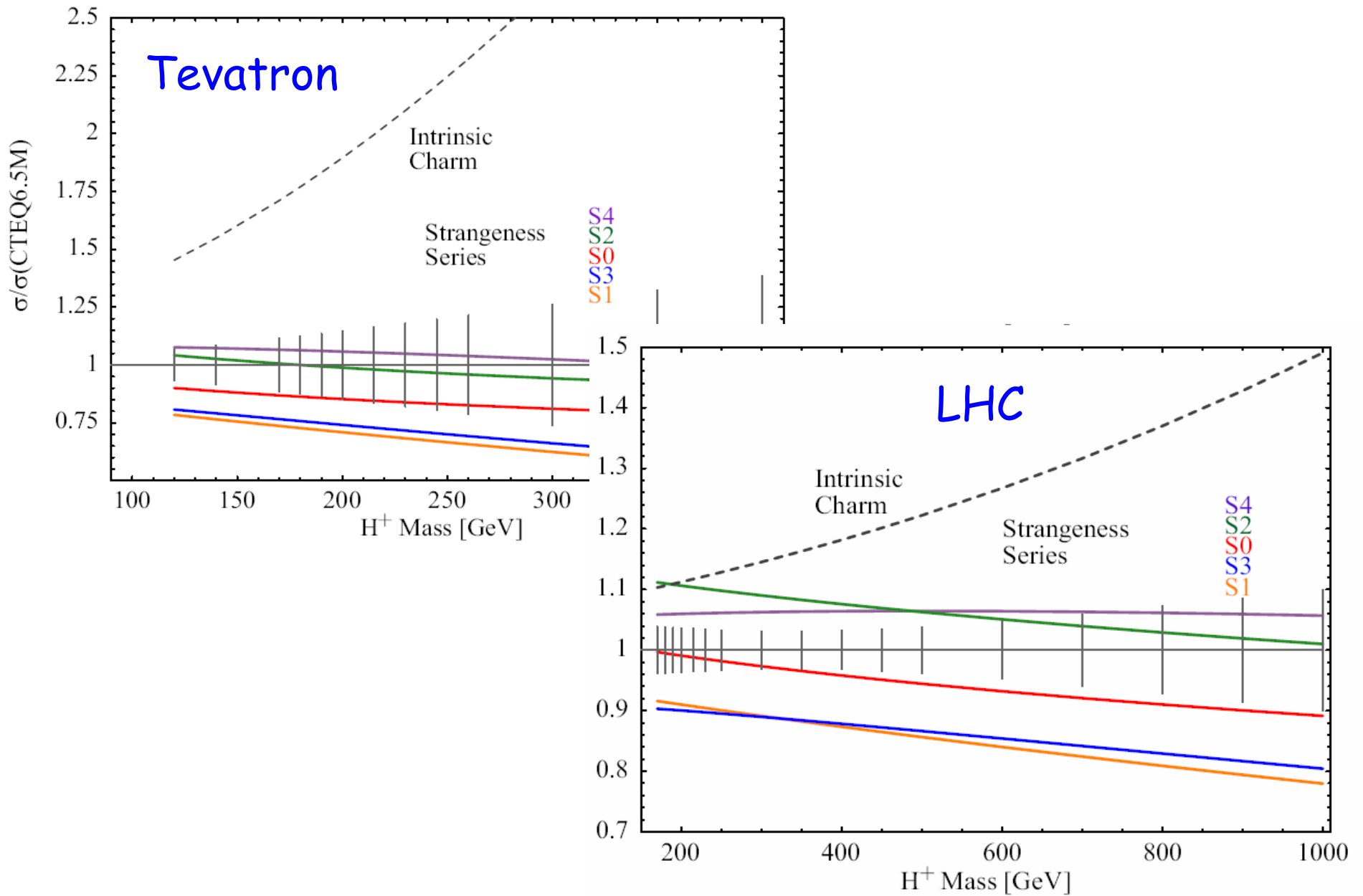
- For small  $\hat{s}$ ,  $q\text{-}q\text{-bar}$  luminosity is 5 - 10 % higher than previous estimates (outside the error band);
- $q\text{-}g$  luminosity is just within the error band;  $g\text{-}g$  luminosity is within the band;
- The uncertainty bands narrow somewhat at large  $\hat{s}$ , but are otherwise similar to before.

# Impact of CTEQ6.5M,S,C PDF's on $\sigma_{\text{tot}}$ 's at LHC

$\sigma \pm \delta\sigma_{\text{PDF}}$  in units of  $\sigma(\text{CTEQ65M})$   
 LHC, NLO, PRELIMINARY



Example: a beyond SM process  $\sigma_{\text{tot}} (c + \bar{s} \rightarrow H^+)$



# Self-consistent Global QCD Analysis

# Self-consistent Global QCD Analysis

- Conventional Global Analyses (Duke-Owens, EHLQ, ... MRST, CTEQ) have made a lot of progress, and have proven to be indispensable for hadron phenomenology in general.
- Methods to estimate uncertainties of PDFs (~2000) have made the approach more quantitative, and greatly enhanced its usefulness.
- However ...  
this approach is also generally regarded as being *lack of statistical basis, subjective, even arbitrary*.

— all true!\*\* (hence the constant search for alternative methods.)

- Can this approach be made *more objective* and better defined?

Yes—by a self-consistent (iterative) procedure that has evolved from our ongoing work.

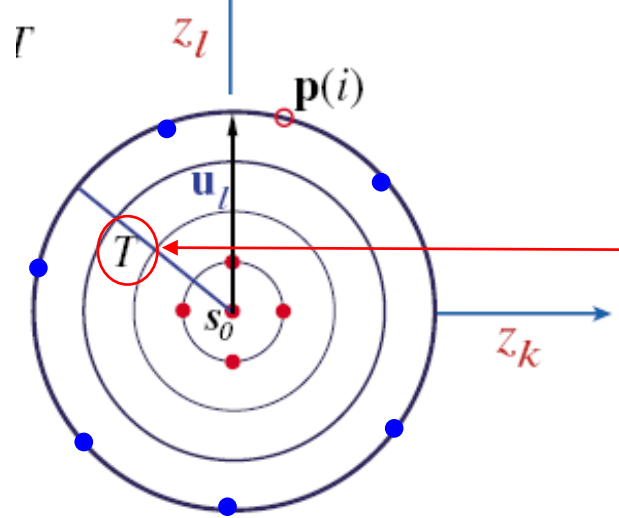
(Lai, Pumplin, Stump, wkt)

\*\* This aspect of the global analysis has been variously characterized as either "art", or "tyranny of the global fitters", and anything in-between.



# The iterative procedure: self-consistent case

Parton parameter space  
(eigenvector basis of Pumplin etal)



$$\chi_{\text{global}}^2(a) = \sum_n w_n \chi_n^2(a)$$

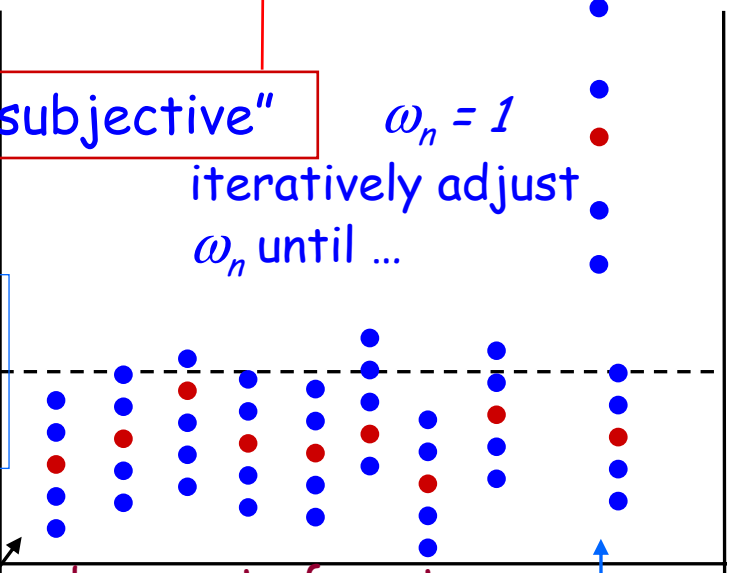
Goodness-of-fit of individual expts.  
(e.g.  $\chi^2/\text{dof}$ , C.L., ... etc.)

"arbitrary", "subjective"

$w_n = 1$

iteratively adjust  $w_n$  until ...

a priori acceptable fit  
(e.g. 90 % CL)



base set of expts  
(e.g. DIS + ...)

new expt. sensitive to new  
parton degrees of freedom

iterations

$w_n$

$\chi_{\text{global}}^2$

T: tolerance for Hessian  
eigenvector sets

## Remarks

- This is a *self-consistent* procedure, since the proper weights and the tolerance for uncertainties in parton parameter space are not chosen a priori, but they are generated iteratively;
- The main goodness-of-fit criterion (e.g. 90% CL), although not unique, is used consistently throughout.
- This procedure is still *not statistically rigorous*, neither is it "*rocket science*". However,
  - It is a great deal *more objective* than before;
  - Because the procedure is *self-consistent (iterative)*, the PDFs and their uncertainties obtained with it is much more *stable* and *robust* than before.

## Failure of self-consistency test:

The iterative process is not guaranteed to yield self-consistent results always!  
Consider ...

Then, the new experiment is shown to be *inconsistent* with the existing sets, according to the adopted criterion of goodness-of-fit.  
(Or, maybe the criterion needs to be reconsidered.)

acceptable fit  
(e.g. 90 % CL)

Examples:

Historical : EMC vs. BCDMS

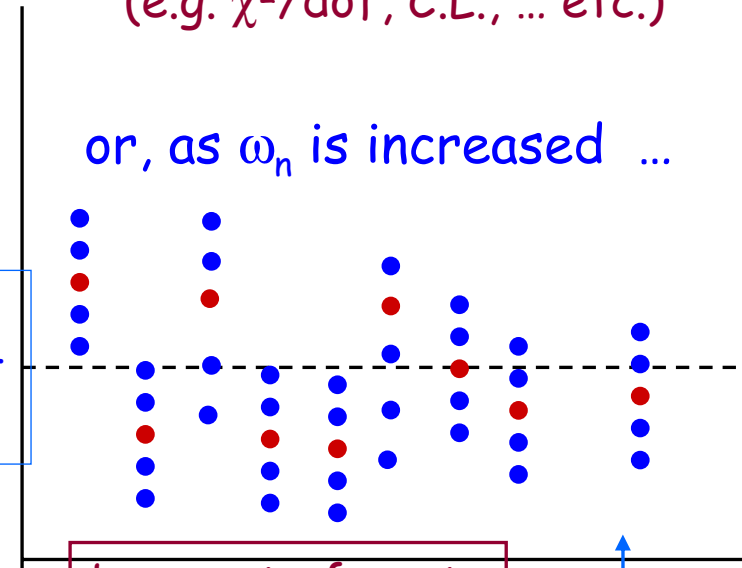
Current : ?? NuTeV (2005) vs. BCDMS

+H1+NMC ?? (Owens et al hep-ph/0702159)

See also Kulagin & Petti hep-ph/0703033

Goodness-of-fit of individual expts.  
(e.g.  $\chi^2/\text{dof}$ , C.L., ... etc.)

or, as  $\omega_n$  is increased ...



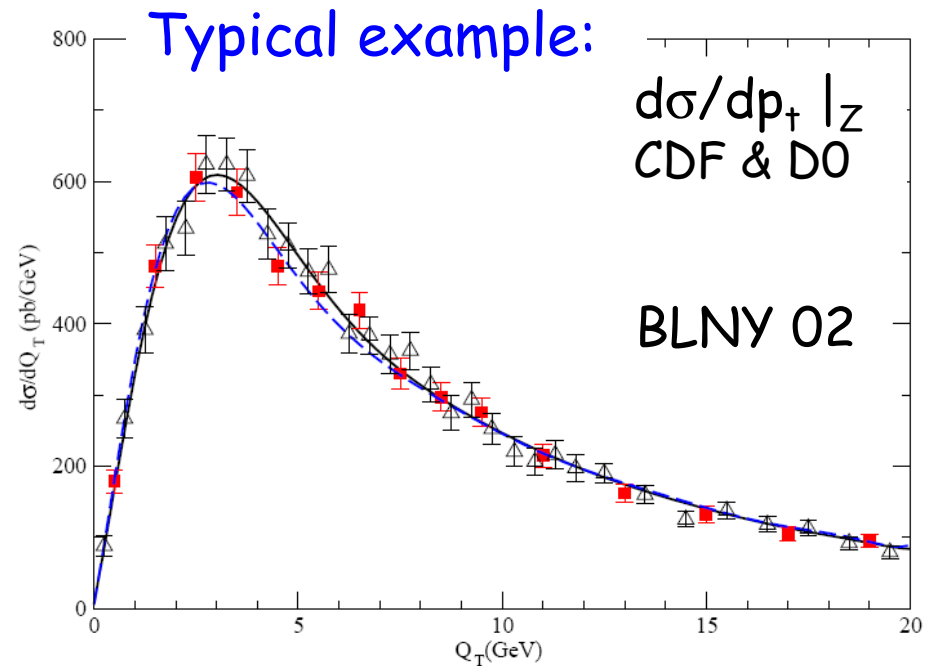
base set of expts  
(e.g. DIS + ...)

new expt. sensitive to new  
parton degrees of freedom

Combined pt resummation ...

- Transverse momentum distribution plays an important role in **precision DY, W/Z, top, and Higgs phenomenology** at hadron colliders, both in SM and BSM.

- In PQCD,  **$p_T$  resummation** is required to describe the transverse momentum distribution in the most important physical region  
 $L_{QCD} < p_T < M_{W/Z/t/H}$ .



- The resummation calculation depends on a small number of **non-perturbative (Sudakov) parameters** that must be determined by fitting DY and W/Z production data.

## Combined $p_T$ resummation and PDF global QCD analysis

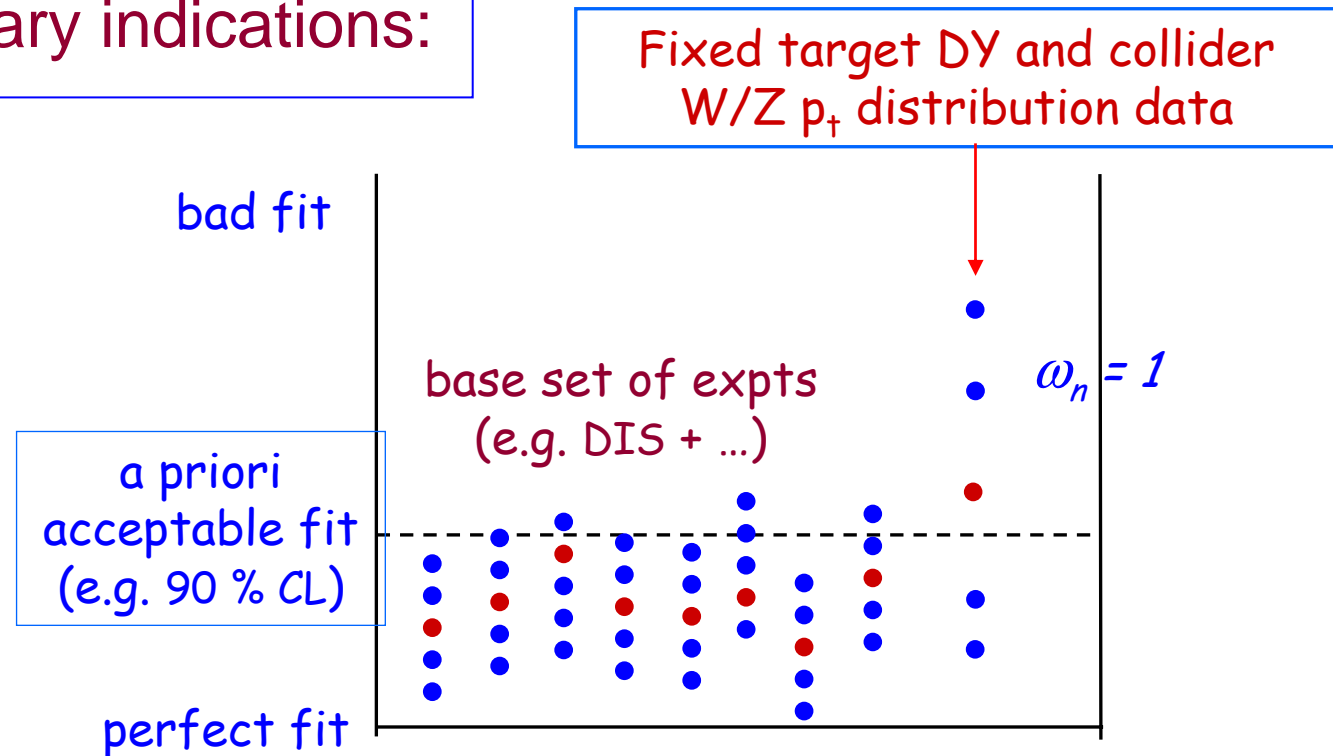
- So far, the studies of  $p_T$  and PDF degrees of freedom are entirely segregated, although physically they are not.
- To achieve high accuracy in precision W/Z, top, and Higgs physics, an integrated approach is imperative; e.g.
  - the reliable estimate of the “PDF uncertainty” in precision  $M_W$  measurement.
  - Higgs discovery, with appropriate  $p_T$ -cut to enhance signal/background ratio.

## Combined $p_T$ resummation and PDF global QCD analysis

- Difficulty in combining  $p_T$  resummation calculation and PDF global QCD analysis: deadly combination of
  - $p_T$  resummation calculation is complicated (multiple convolution integral), hence computationally costly;
  - global QCD analysis typically requires thousands of iterations to optimize PDF, and Sudakov, parameters.
- This (seemingly insurmountable) difficulty has recently been overcome by Hung-liang Lai and Pavel Nadolsky:
  - Combined global analysis involving Sudakov and PDF parameters simultaneously can now be done;
  - An active program of systematic investigation of precision DY, W/Z, top, and Higgs phenomenology has begun (perhaps with first physics results by DIS07).

(Lai, Nadolsky, Yuan, wkt, ...)

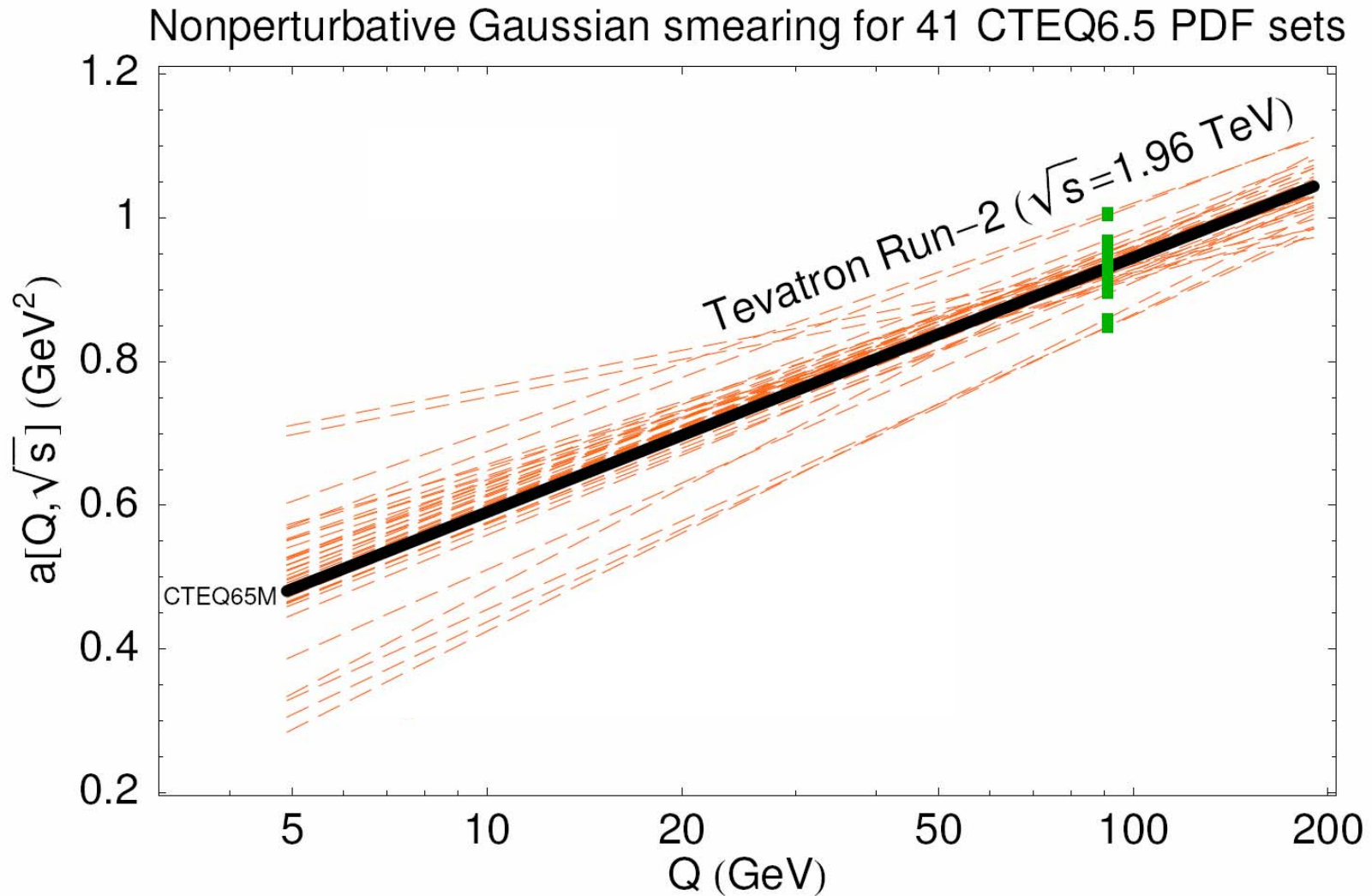
## Preliminary indications:



- By iteratively improving the fit to the combined data sets, the  $p_+$  data will help constrain PDF degrees of freedom not probed before in traditional global analyses.
- The new degrees of freedom so constrained could have important implications for precision measurements, such as  $M_W$  and Higgs production.



Effective Gaussian Smearing Sudakov Exponent from Resummed fits to transverse momentum distribution data



## Outlook

- Frontiers for Global QCD Analysis are continuously been expanded in new directions;
  - Evolutionary, but significant, advances have been made in analysis methodology; while many revolutionary new methods are being proposed and tried;
  - These developments go very well with the demand of ever higher reliability and accuracy of PDFs for the Tevatron RunII and the LHC physics programs.
- There are a lot to look forward to!

# Parton Luminosities at the LHC

