Structure functions and parton densities for LHC

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DESY-Zeuthen

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Outline

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  - Clean access to the structure of the proton

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  - NNLO evolution, sets on the market.

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- Parton distributions
  - NNLO evolution, sets on the market.
- PDFs and the LHC
  - influence on important observables,
  - more accurate extraction possible?

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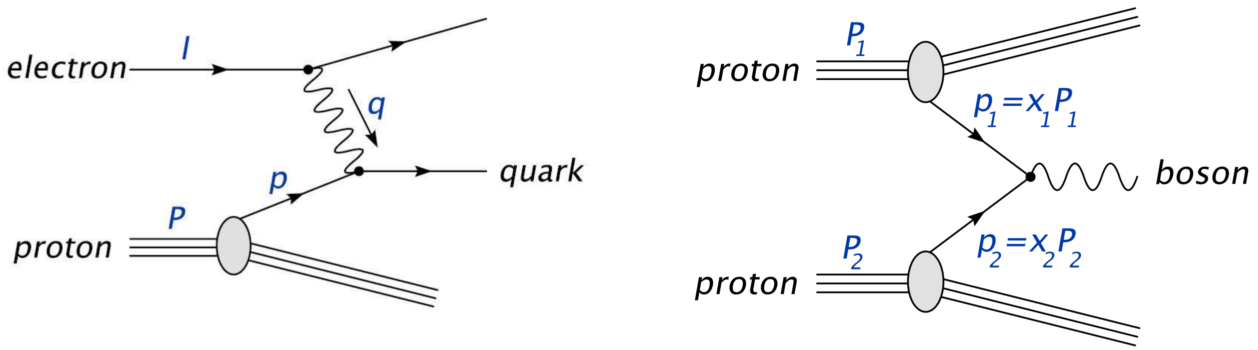

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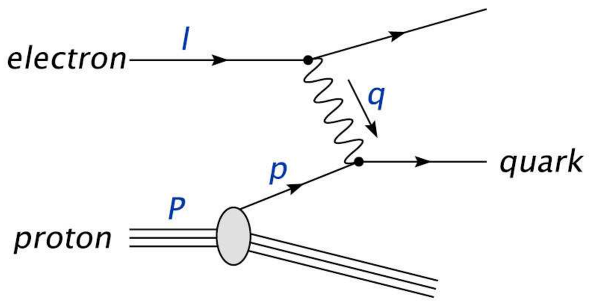

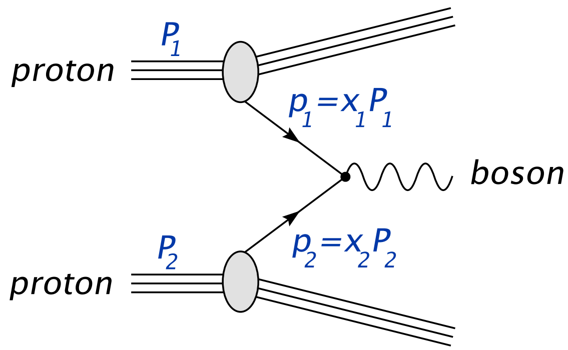

- All the relevant information about the structure of the particular hadron is encoded into the PDFs (details follow).

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  - Non-perturbative objects
  - extracted from experimental data: HERA, Tevatron, etc.
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  - The challenge of the future (i.e. LHC) is different: in important observables the dominant uncertainties are from PDFs (details follow).

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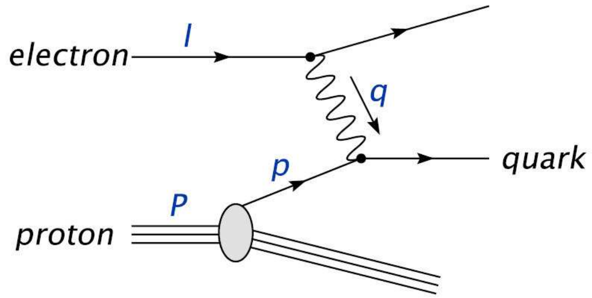
- Factorization Theorem is applied two ways:
  - extract PDFs from data
  - make predictions for other observables

Structure functions

Structure Functions

- Consider DIS in the single photon approximation:



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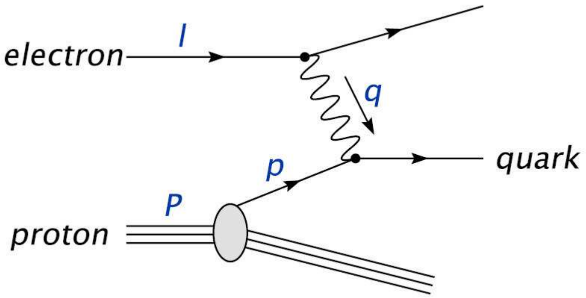

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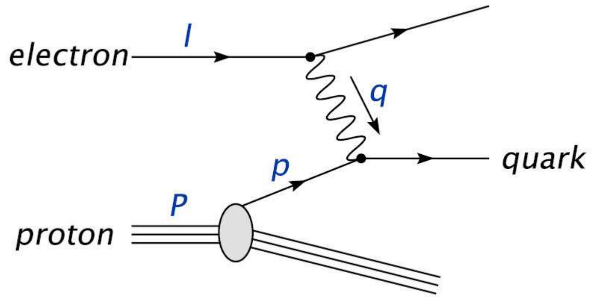

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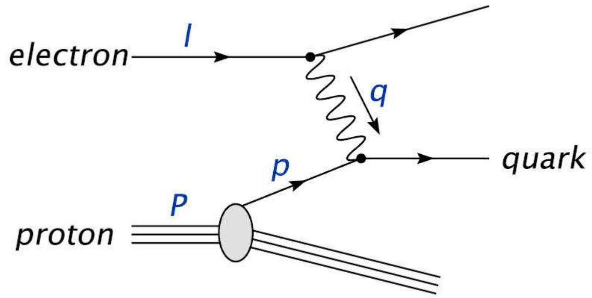

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- In the unpolarized case, neglecting lepton masses parameterize $W_{\mu\nu}$ with three structure functions F_1, F_2, F_3.
- Both for NC and CC the measurable cross-section reads:

$$\frac{d^2\sigma}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2} \left\{ y^2 x F_1 + \left[1 - \left(1 + \frac{x^2 y^2 M^2}{Q^2} \right) \right] F_2 \pm xy \left(1 - \frac{y}{2} \right) F_3 \right\}$$

Structure Functions: measurements

- What can be measured and to what extend?

Courtesy PDG and H1

Process	Main Subprocess	PDFs Probed
$\ell^{\pm}N \to \ell^{\pm}X$	$\gamma^* q \to q$	$g(x \lesssim 0.01), q, \overline{q}$
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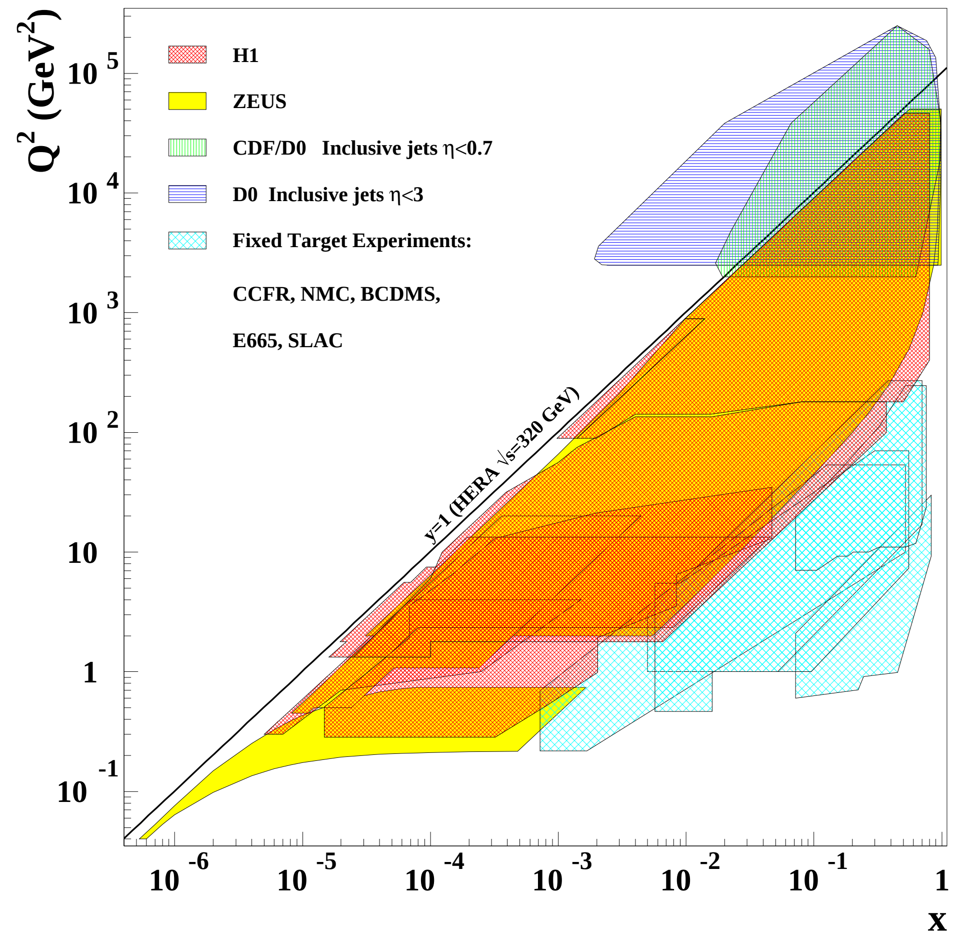
$\nu\ N \to \mu^+\mu^- X$	$W^* s \to c \to \mu^+$	s
$\ell N \to \ell Q X$	$\gamma^* Q \to Q$	$Q = c, b$
	$\gamma^* g \to Q\overline{Q}$	$g(x \lesssim 0.01)$
$pp \to \gamma X$	$qg \to \gamma q$	g
$pN \to \mu^+\mu^- X$	$q\overline{q} \to \gamma^*$	$\overline{q}$
$pp, pn \to \mu^+\mu^- X$	$u\overline{u}, d\overline{d} \to \gamma^*$	$\overline{u} - \overline{d}$
	$u\overline{d}, d\overline{u} \to \gamma^*$	
$ep, en \to e\pi X$	$\gamma^* q \to q$	
$p\overline{p} \to W \to \ell^{\pm}X$	$ud \to W$	$u, d, u/d$
$p\overline{p} \to$ jet $+X$	$gg, qg, qq \to 2j$	$q, g(0.01 \lesssim x \lesssim 0.5)$



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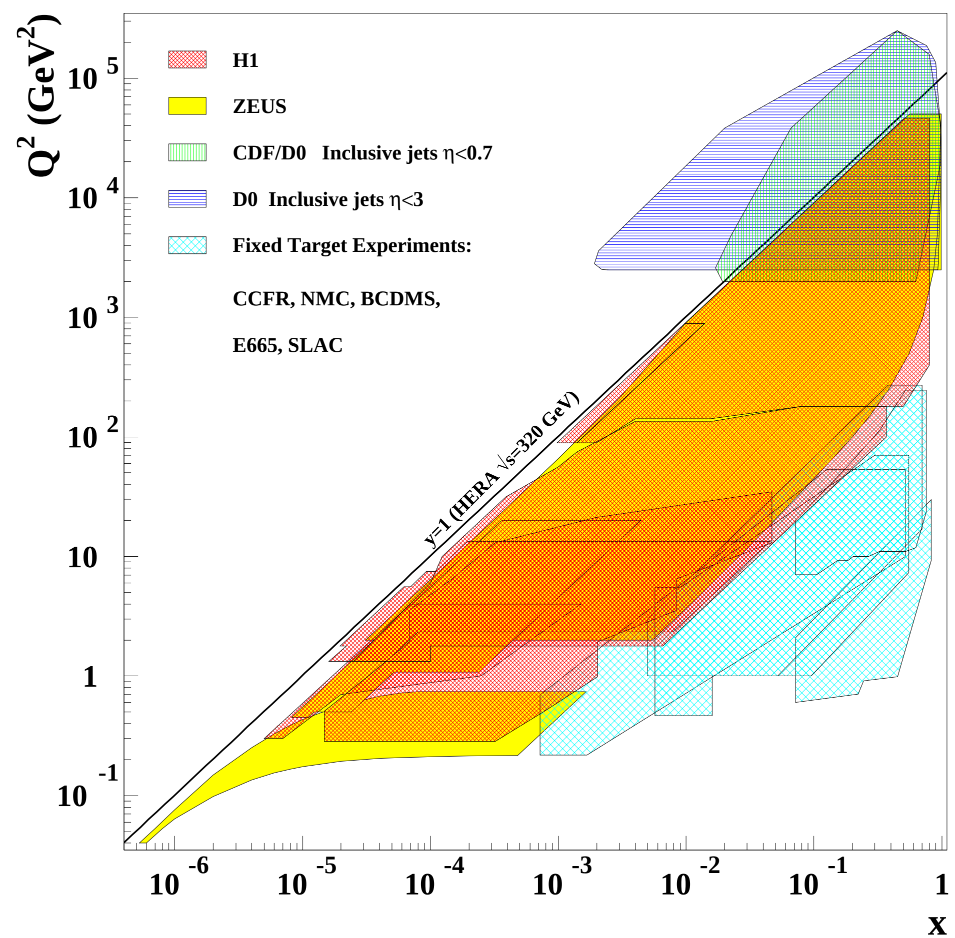


- Possible to test DGLAP evolution across a range of scales and experiments!

Structure Functions: results from HERA

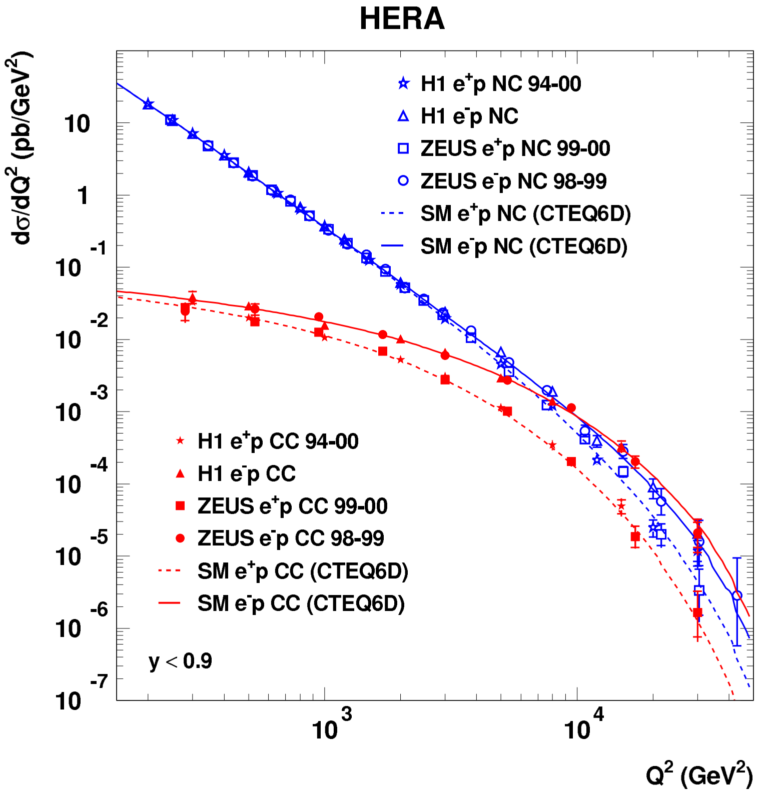
Introduction

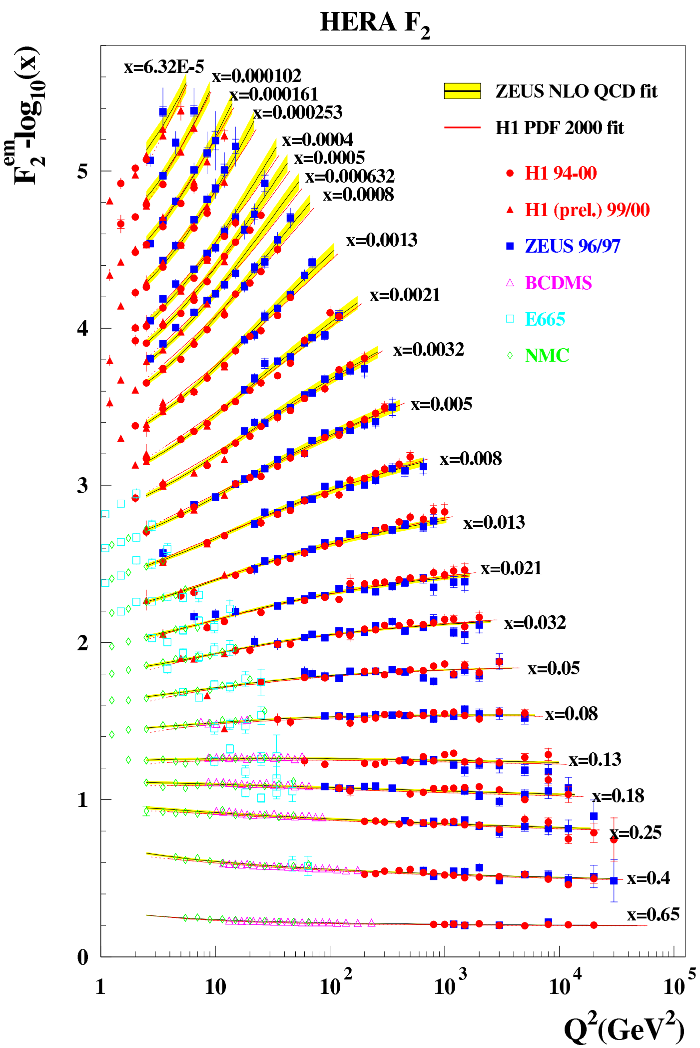
Structure functions
- SFs - definition
- SFs - measurements
- SFs - HERA
- SFs - NuTeV
- SFs - theory
- SFs - theory(2)

Parton Distribution Functions

PDFs and the LHC

- HERA (H1 and ZEUS) provide us with wit a wealth of data on both NC and CC DIS.





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  - strange see asymmetry: $s - \bar{s} \neq 0$

Brodsky, Ma ('96); Catani, de Florian, Rodrigo, Vogelsang ('04)

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Moch, Vermaseren, Vogt ('05)

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    Moch, Vermaseren, Vogt ('05)
  - massless inclusive CC DIS: 2 loop (NNLO)

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Structure Functions: QCD theory (cont.)

- What is currently known in DIS?
  - massless inclusive NC DIS: 3 loop (NNNLO)

    Moch, Vermaseren, Vogt ('05)
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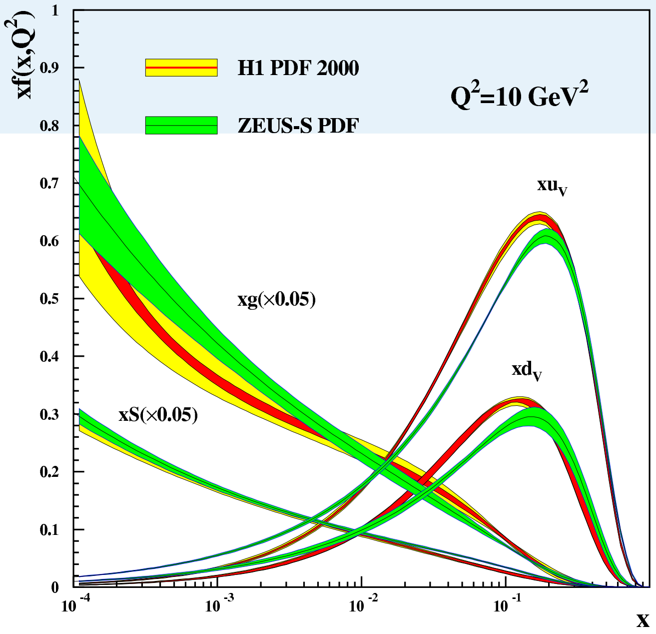
    Glück, Kretzer, Reya ('96); Kretzer, Schienbein ('98)

Parton Distribution Functions

DGLAP equation

- PDFs are purely non-perturbative



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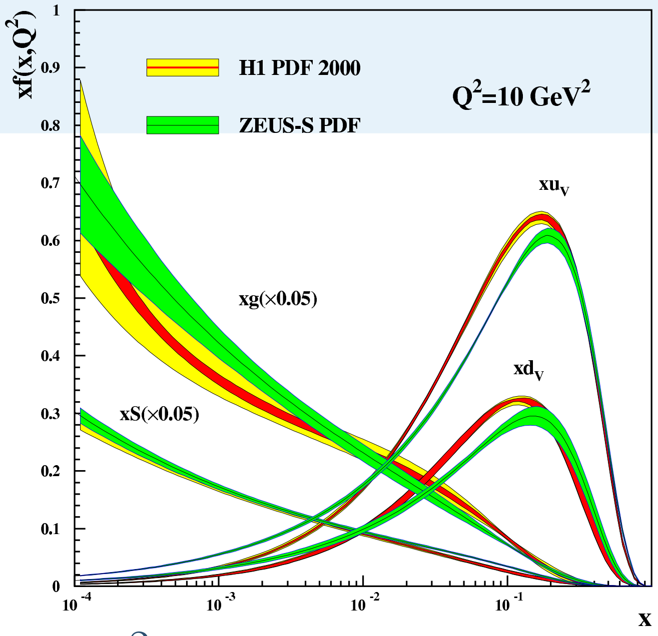

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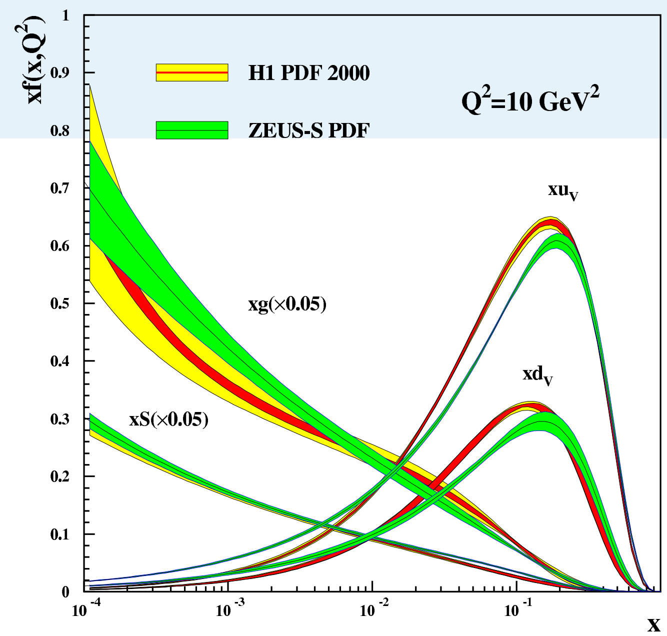

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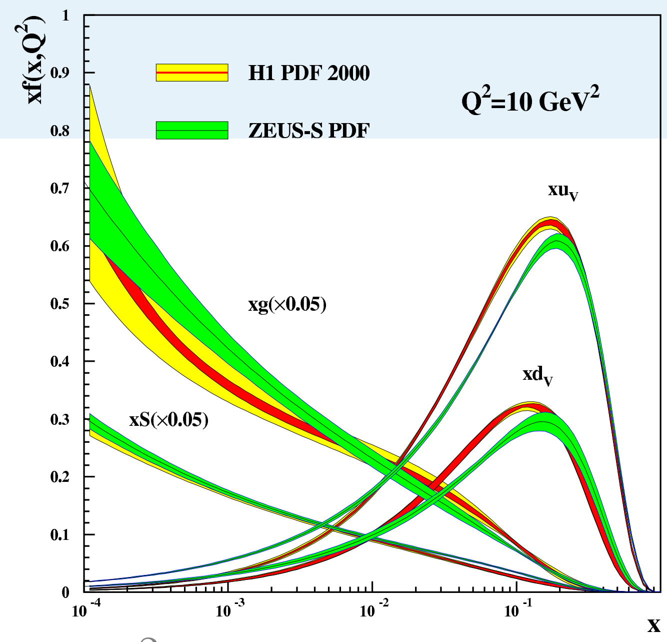

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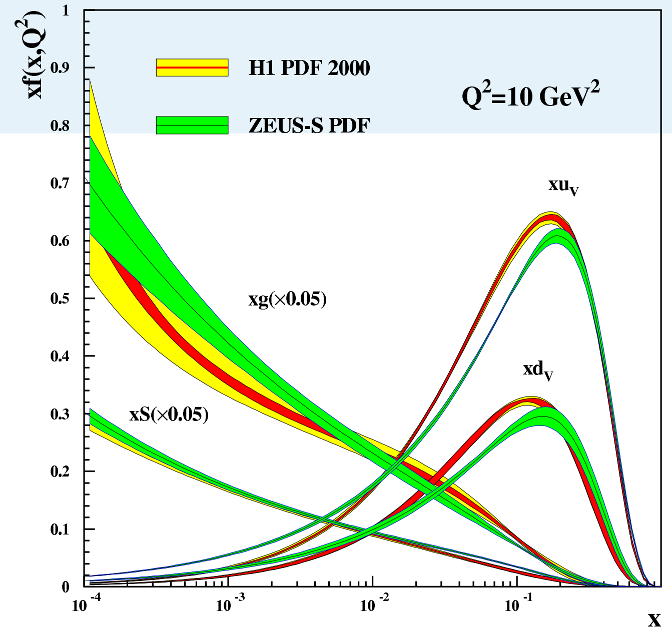

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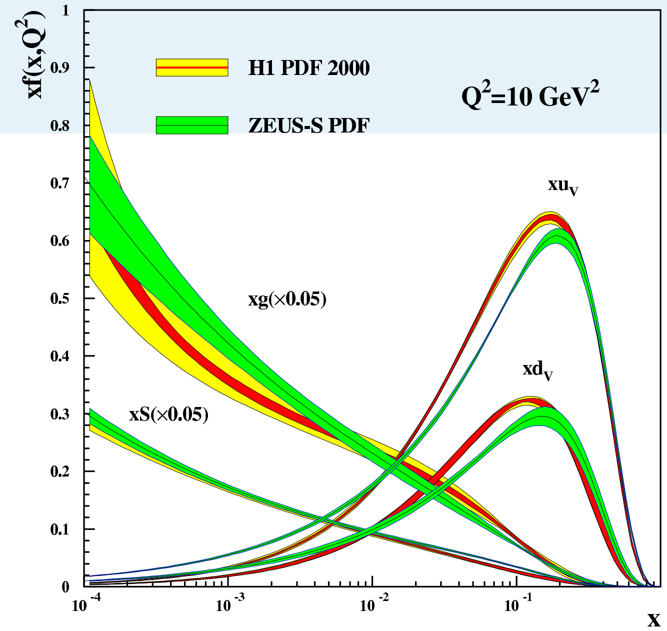

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- Examples:
  - MRST: $\mu_0^2 = 1\mathrm{GeV}^2$
    $xg(x) = c_1 x^a (1-x)^b (1 + c_3 x^{0.5} + c_4 x) - c_5 x^c (1-x)^d$.
  - CTEQ6: $\mu_0^2 = 1.69\mathrm{GeV}^2$
    $xg(x) = c_1 x^a (1-x)^b \mathrm{e}^{cx} (1 + c_2 x)^d$.

Splitting functions of QCD

DGLAP equation is specified by the QCD splitting functions:

$$P_{ij}^{(S,T)}(\alpha_s(\mu^2),x) = \sum_{n=0} \left(\frac{\alpha_s(\mu^2)}{2\pi}\right)^{n+1} P_{ij}^{(n)(S,T)}(x)$$

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- To get the time-like NS functions a relation between the NS time-like and space-like functions was devised.

A.M., Moch, Vogt ('06)

The result can be cast in a very simple form:

Dokshitzer, Marchesini, Salam ('05)

$$P^{(2),T} - P^{(2),S} = \left[\ln(z).\left(P^{(1),T} + P^{(1),S}\right)\right] \otimes P^{(0)} + \left[P^{(1),T} + P^{(1),S}\right] \otimes \left[\ln(z).P^{(0)}\right]$$

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Sets of PDFs (cont.)

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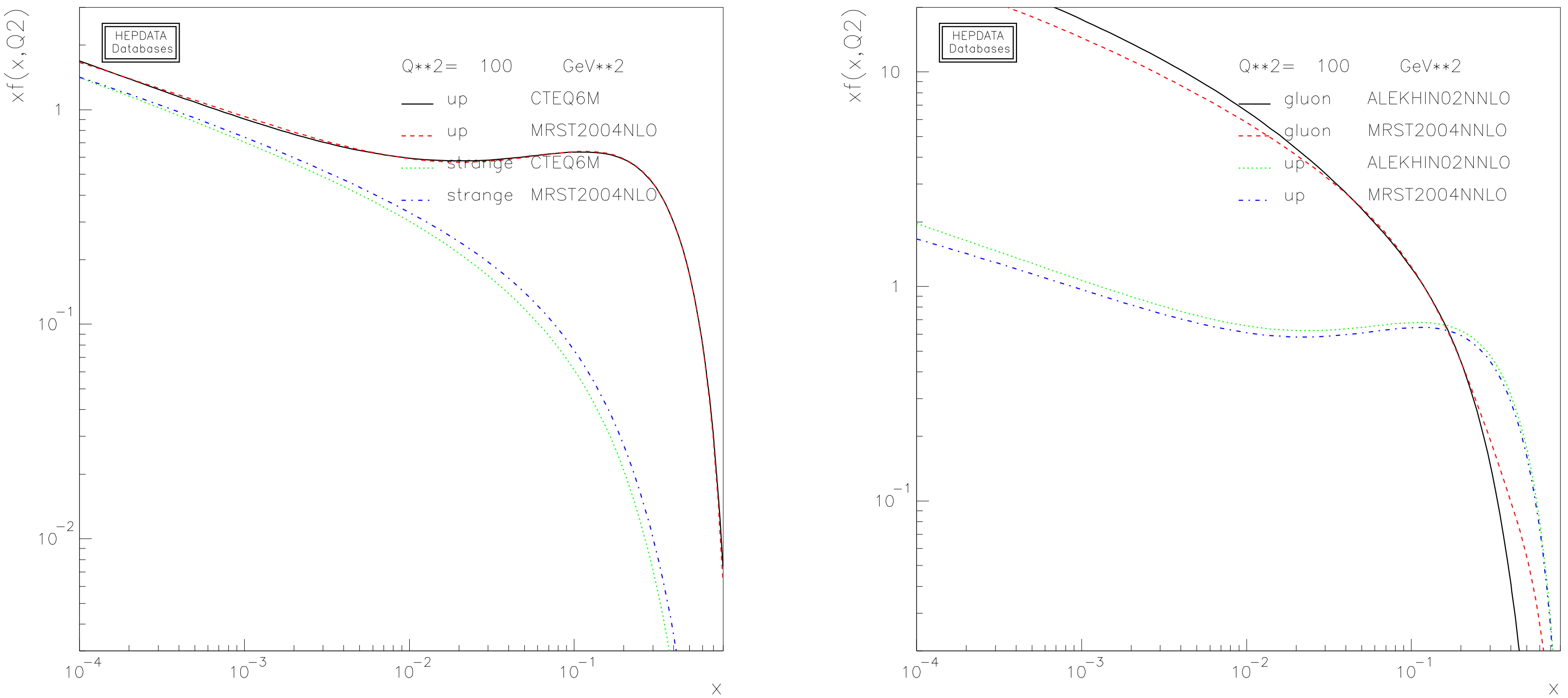

Sets of PDFs: comparisons, error bands

Introduction

Structure functions

Parton Distribution Functions

- DGLAP equation
- Solving DGLAP
- QCD splitting functions
- QCD splitting functions (2)
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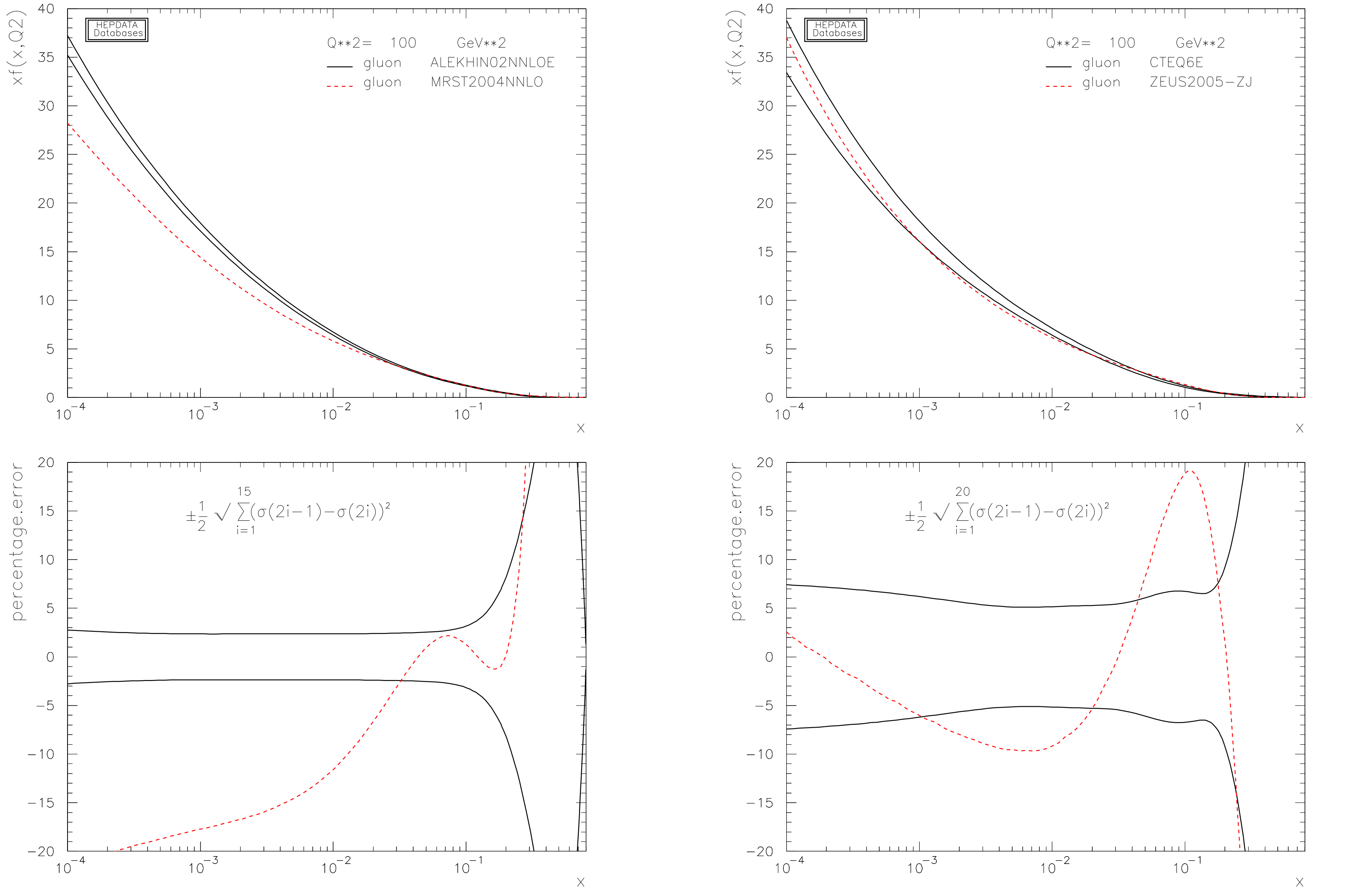
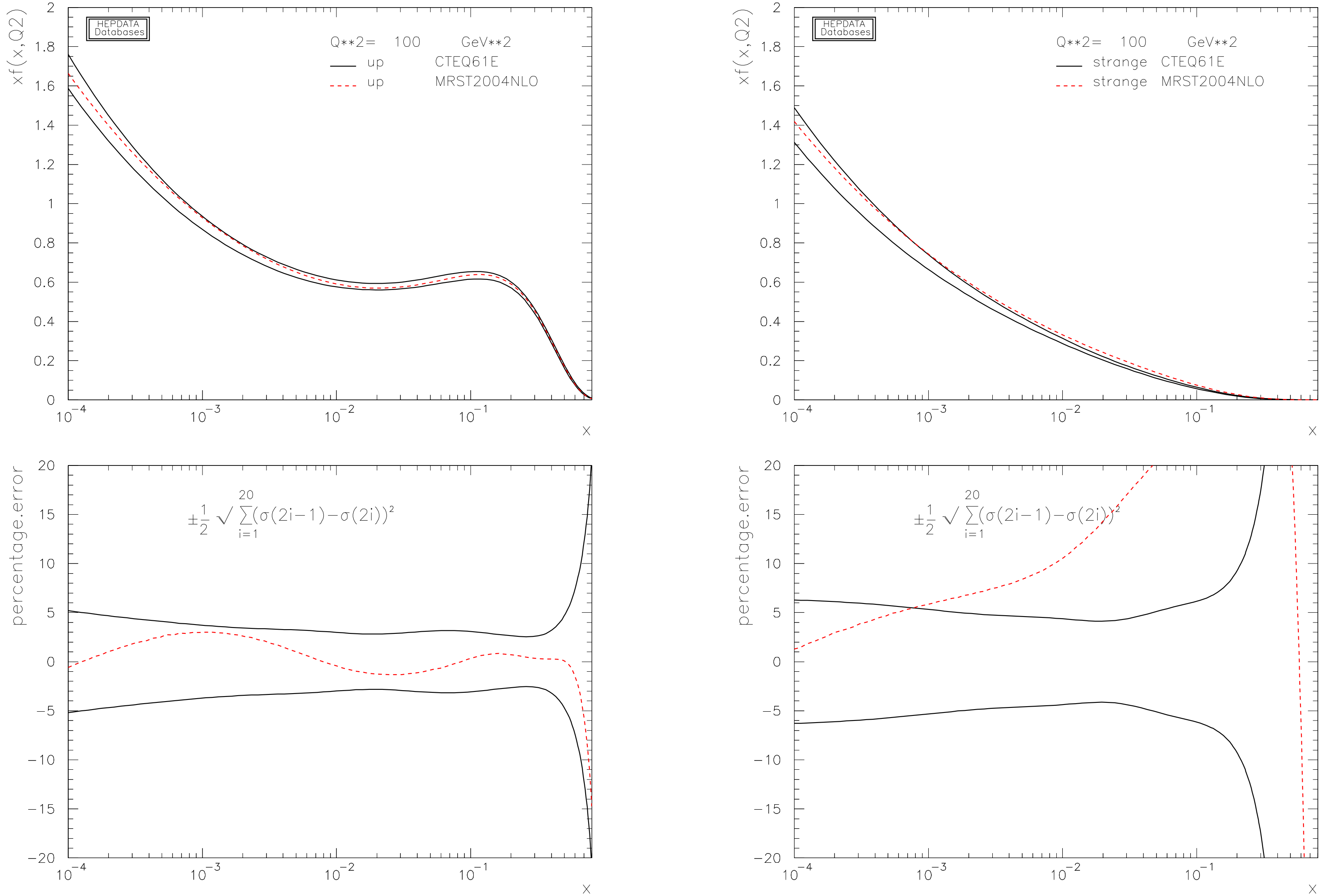
- Sets of PDFs: plots
- Sets of PDFs: plots(2)

PDFs and the LHC



Sets of PDFs: comparisons, errors (cont.)



PDFs and the LHC

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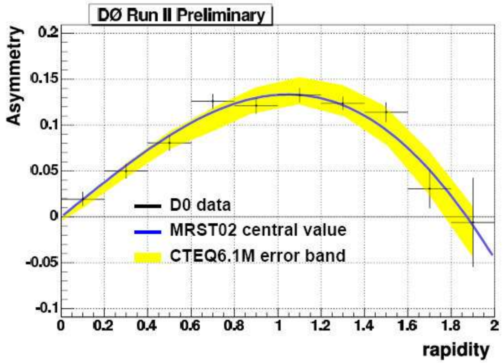

M. Sanders, talk at ICHEP2006

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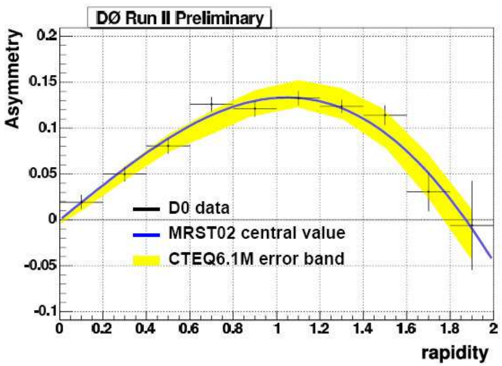

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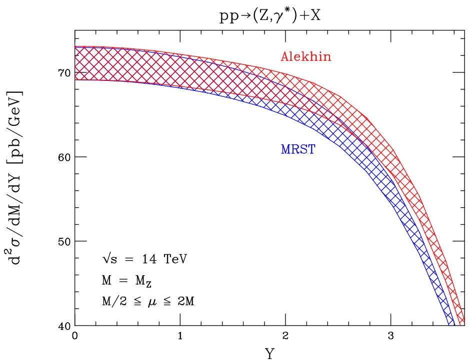

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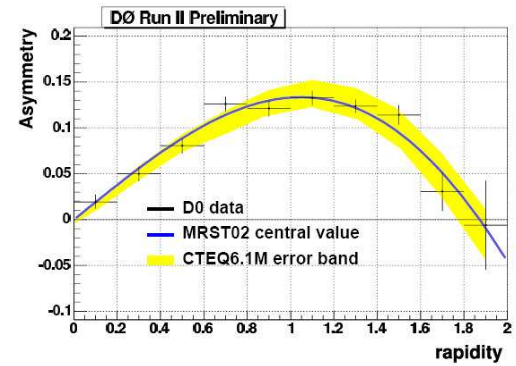

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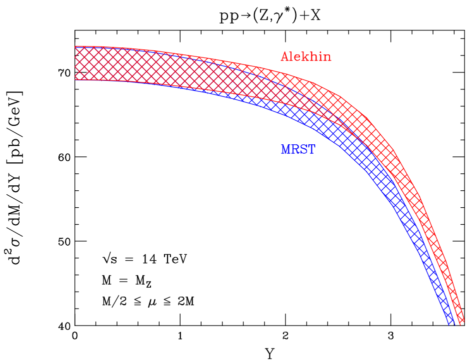

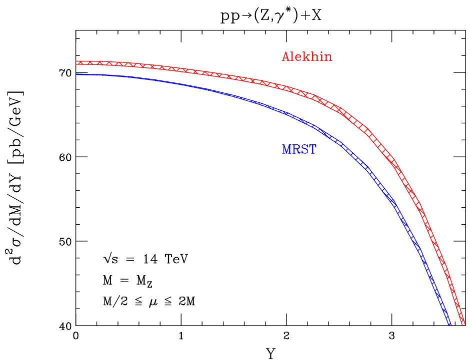

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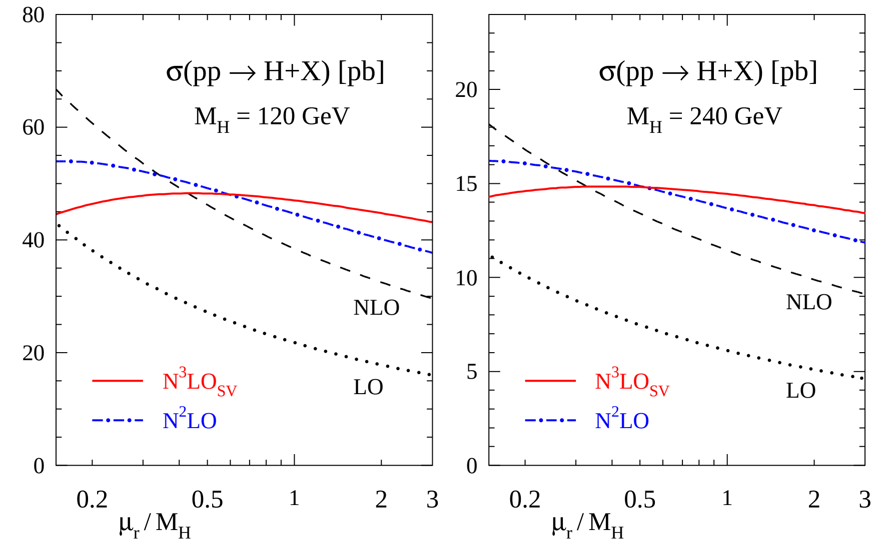

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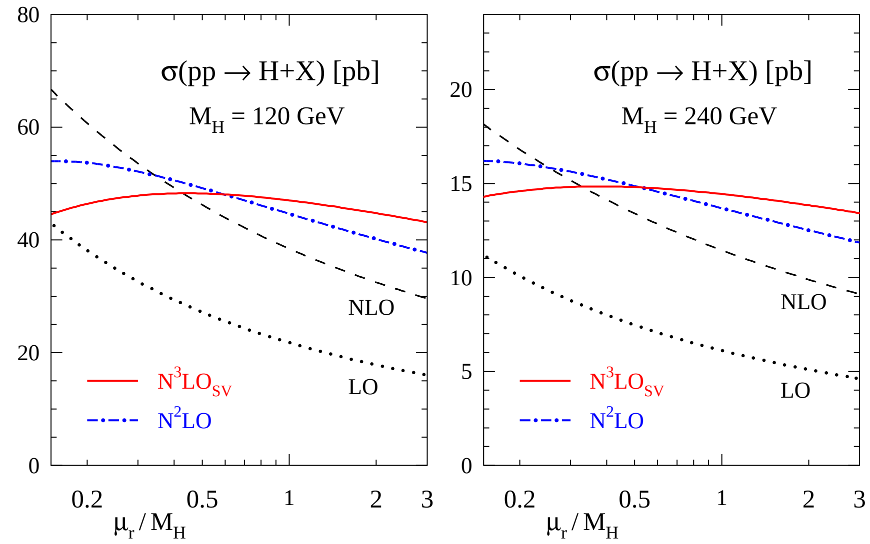

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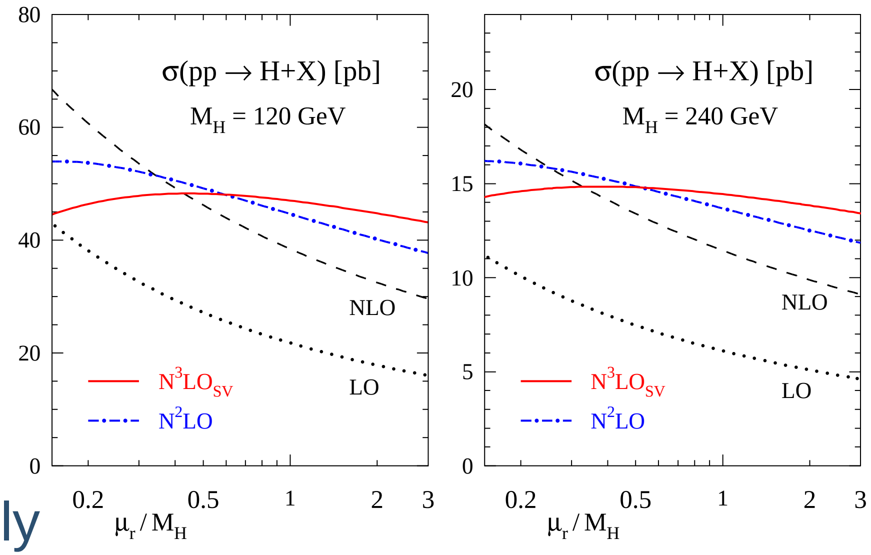

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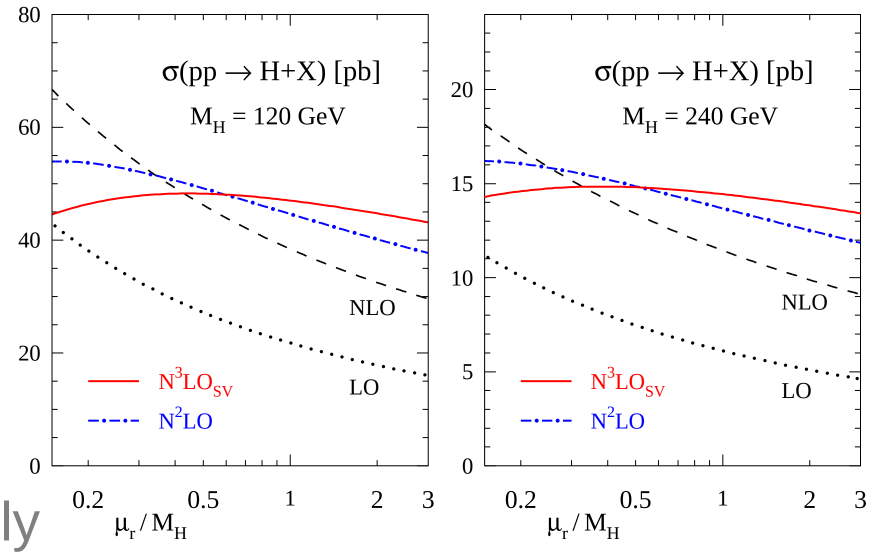

Anastasiou, Melnikov, Petriello ('05)

- Perturbative uncertainty in the $8 - 10\%$. Perhaps even less.

Catani, de Florian, Grazzini, Nason ('03)

PDFs and LHC: Higgs, $t\bar{t}$, jets.

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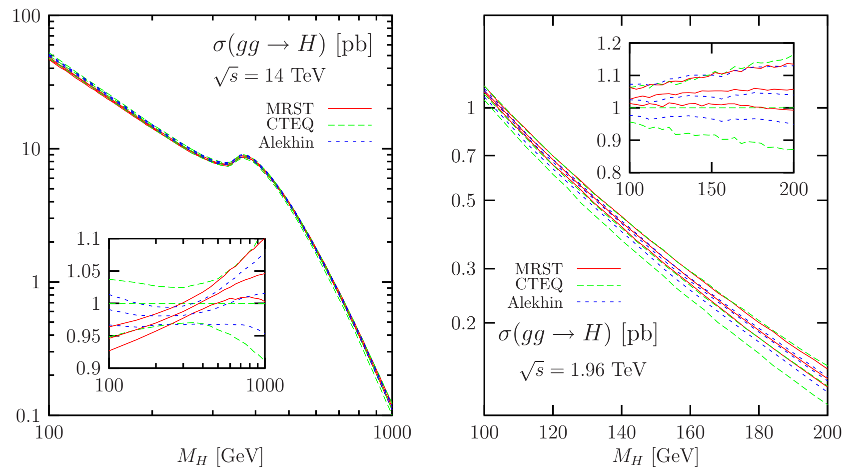

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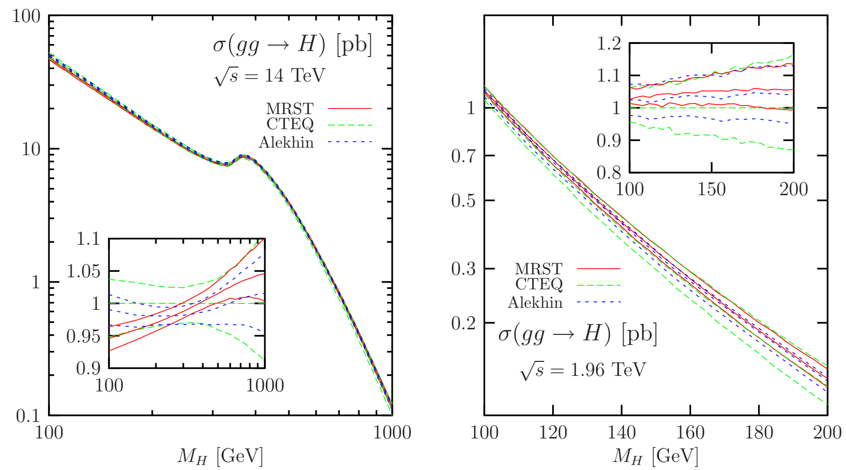

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- The gluon distribution is important for $t\bar{t}$ too.
  - PDF uncertainty $\sim 3-4\%$,
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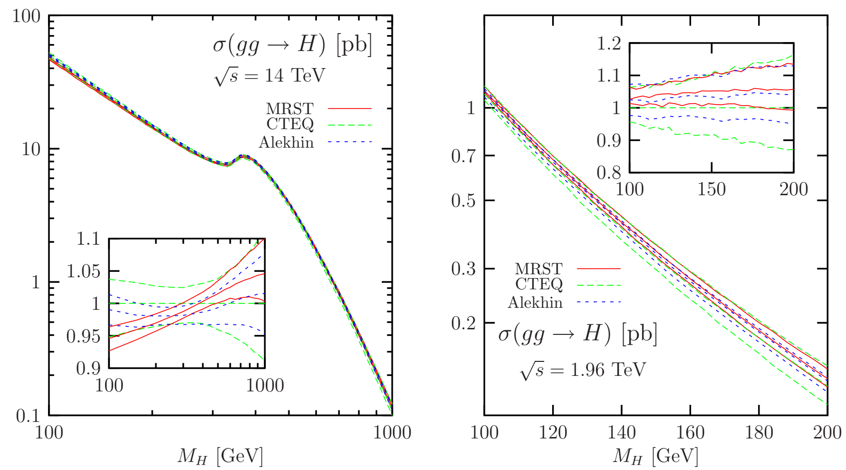
  - total experimental $\lesssim 10\%$.

talk by Peter Uwer

PDFs and LHC: Higgs, $t\bar{t}$, jets.

- Uncertainties from PDF are $3-5\%$. However, set dependent:



Djouadi, Ferrag ('03)

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- jet production at NNLO will be important to constrain it better at large x.

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