Parton Density Functions after HERA, prospect of measurement at LHC

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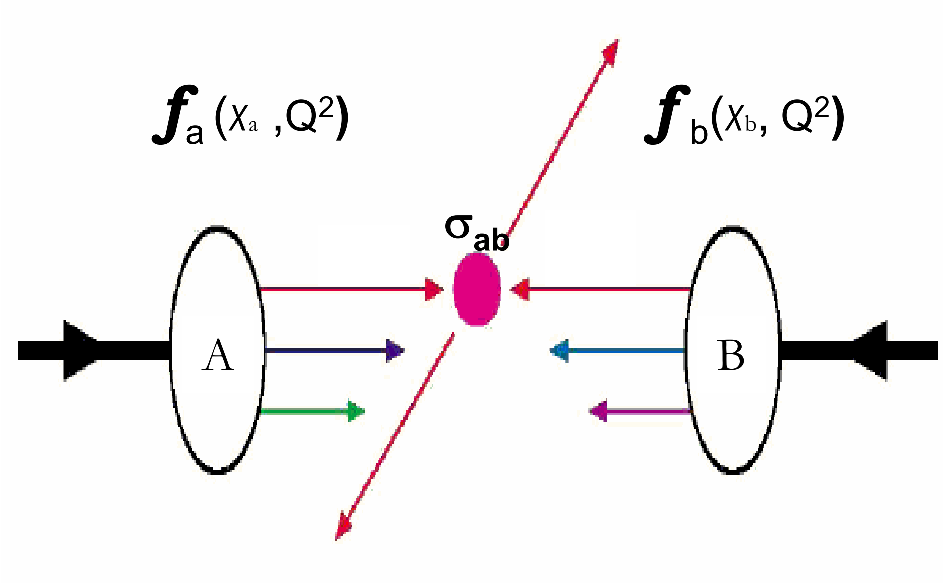
Summary

- Introduction to Parton Distribution Function
- Status of PDFs after HERA
- Impact of PDFs uncertainties on Z and W measurements
- How can the LHC contribute to provide input for the PDFs ?
  - Hard scattering process
    - W,Z production/asymmetries
    - High mass Drell Yan production
    - Dijet production
    - Prompt photon production
    - B and other heavy flavour cross sections

Subject of this presentation

- Example: Impact of PDFs uncertainties on W mass measurement

Parton-Parton interactions



hadron collision =
interaction between the partons
which constitute the proton:

- not well defined parton energy but energy distribution
- parton density rises towards low momentum fractions x
- partonic structure investigable at high momentum transfer

PDFs are parameterizations of the partonic content of the proton
at Hadron Colliders every cross-section calculation is a convolution of the cross-section at parton level and PDFs:

$$\sigma_X = \boxed{\sum_{a,b}} \int_0^1 dx_a dx_b \boxed{f(x_a, flav_a, Q^2) f(x_b, flav_b, Q^2)} \cdot \boxed{\sigma_{ab \to X}(x_a, x_b, Q^2)}.$$

Sum over initial partonic states a,b

Parton Density Function

hard scattering cross-section

Parton distribution functions (PDFs)

$f_i(x,Q^2)$ $\begin{cases} i = u_v, d_v, g \text{ and sea} \\ x = p_{parton} / E_{beam} \text{ parton momentum fraction} \\ Q^2 = \text{momentum transfer} \end{cases}$

How are PDF's determined from global fits?

- QCD predicts the scale dependence of $f_i(x,Q^2)$ through DGLAP evolution equations BUT does not accurately predict the x-dependence which has non perturbative origin
- the x-dependence is parameterised at a fixed scale $Q_0^2 \sim$ 1-2 GeV^2 :
  - **valence quarks**: $f \sim x^{\lambda} (1-x)^{\eta} P(x)$
  - **sea/gluon:** $f \sim x^{-\lambda} (1-x)^{\eta} P(x)$

different parameterisations and no.of free parameters used

- $f_i(x,Q^2)$ is evolved from Q_0^2 to any other Q^2 by numerically solving the DGLAP equations to various orders (LO,NLO, NNLO)
- the free parameters are determined by fit to data from exp. observables

PDF uncertainties:

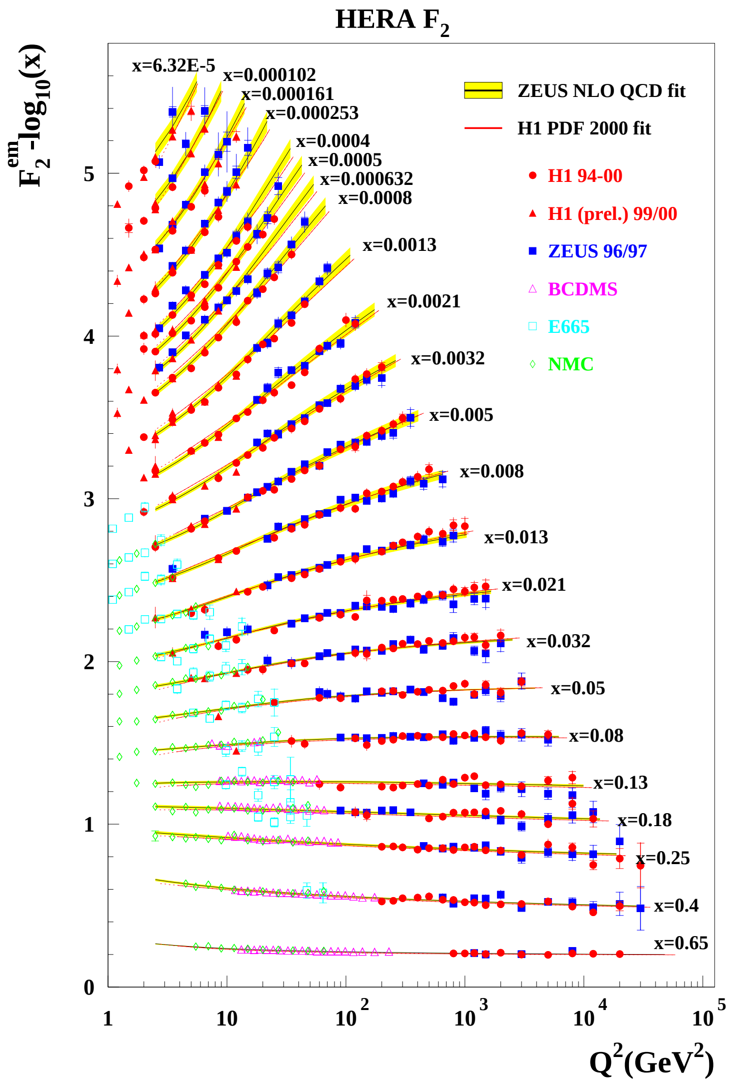
Th: perturbative calculations (i.e DGLAP approx., higher order truncation…)
Th: non-perturbative parameterisations (x-dependence)
Exp: statistical and systematic uncertainties on experimental data inputs
Exp: correlated systematic uncertainties on data points

PDFs sets

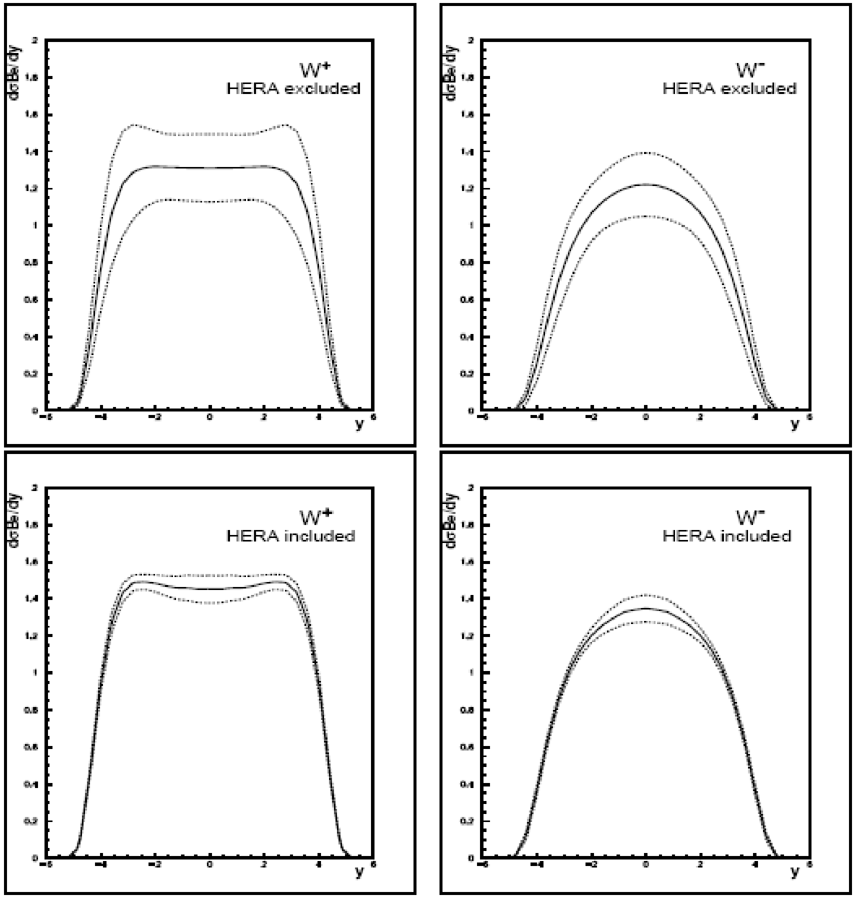
- Pdf's are determined by global analyses of data from
  - **HERA experiments H1, ZEUS**
  - **fixed target DIS experiments**
  - **CDF, D0**

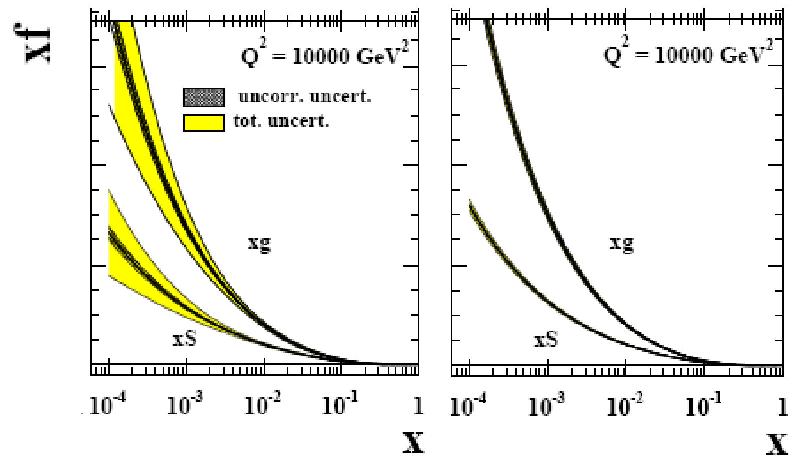
- Three major groups provide semi-regular updates to parton distributions when new data/theory become available:
  1. **MRST (global fits)**
  2. **CTEQ (global fits)**
  3. **HERA collaboration H1, ZEUS (HERA data + fixed target DIS data)**

All of the above groups provide ways to estimate the error on the central pdf



PDFs pre and after HERA

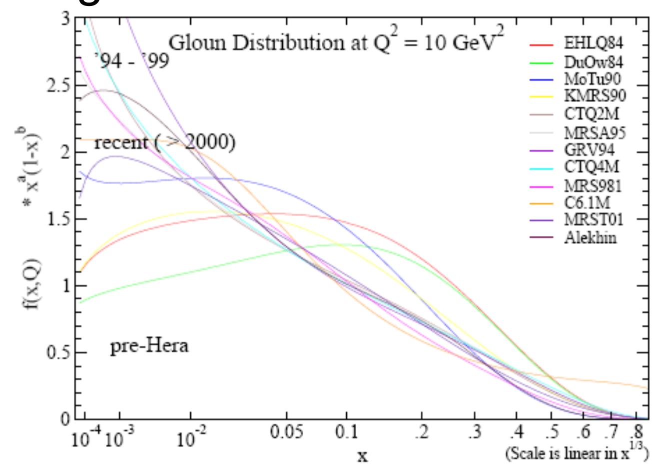




Pre-HERA

Post-HERA

Danger of extrapolating beyond the region where one has fit data



Analytic calculations CTEQ6.1M :

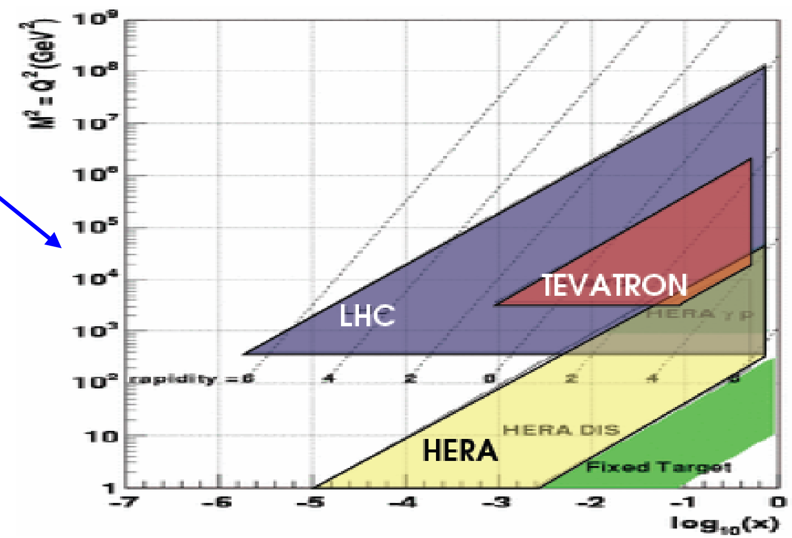
Error bands are the full PDF Uncertainties

Pre-HERA ~ ± 15% uncertainties

Post-HERA ~ ± 5% uncertainties

The LHC region

Kinematic regime for LHC much broader than currently explored



Test of QCD:

- test DGLAP evolution at small x:

is NLO DGLAP evolution sufficient at so small x ?

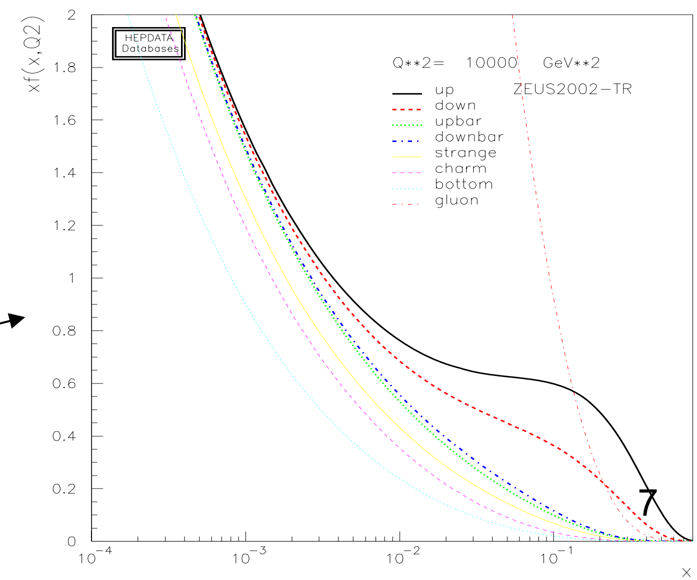
- improve info on high x gluon distribution

At the TeV scale (New Physics!)
cross section predictions for LHC
are dominated by **high-x gluon** uncertainty
(not sufficiently well constrained by PDFs fits)

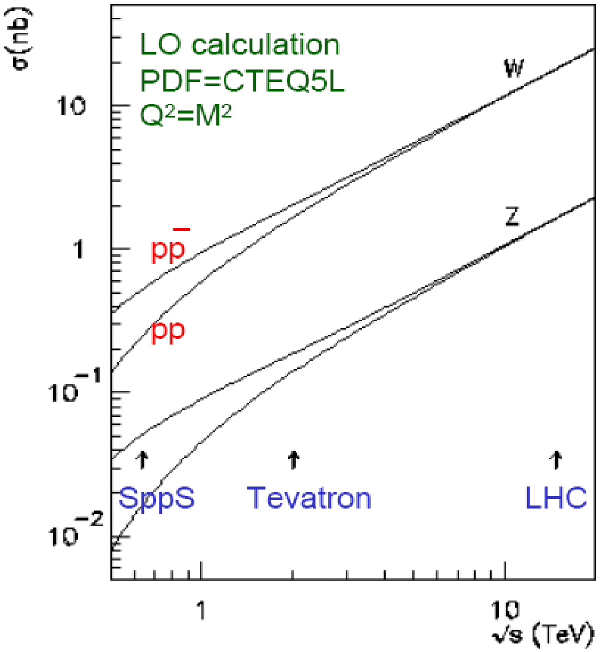
At the EW scale:

- cross section predictions for LHC are dominated by sea and/or gluon interactions at low-x
- at $Q^2 \sim M^2_{W/Z}$ the sea is driven by the **gluon** (via gluon splitting) which is far less precisely determined for all x values

low-x gluon uncertainty dominates



Precision benchmarks: W and Z physics



W production: (main contributions) $\begin{cases} u\bar{d} \to W^+ \\ d\bar{u} \to W^- \end{cases}$

Z production: (main contributions) $\begin{cases} u\bar{u} \to Z \\ d\bar{d} \to Z \end{cases}$

W/Z production have been considered as good standard candle processes with small theoretical uncertainty:

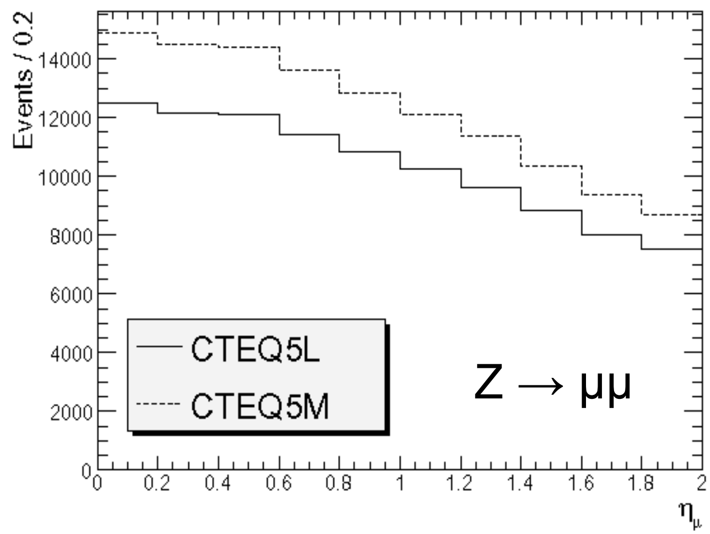
- **both experimental and theoretical errors are under control**
- **NNLO corrections are small and mostly a K-factor**
- **NLO predictions adequate for most predictions at the LHC**
- **could serve as luminosity normalization benchmarks**

PDFs uncertainty dominant contribution. Most PDFs groups quote uncertainties <~5%

PDF Set	$\sigma(W^+).B(W^+ \to l^+\nu_l)$	$\sigma(W^-).B(W^- \to l^-\bar{\nu}_l)$	$\sigma(Z).B(Z \to l^+l^-)$
ZEUS-S no HERA	10.63 ± 1.73 nb	7.80 ± 1.18 nb	1.69 ± 0.23 nb
ZEUS-S	12.07 ± 0.41 nb	8.76 ± 0.30 nb	1.89 ± 0.06 nb
CTEQ6.1	11.66 ± 0.56 nb	8.58 ± 0.43 nb	1.92 ± 0.08 nb
MRST01	11.72 ± 0.23 nb	8.72 ± 0.16 nb	1.96 ± 0.03 nb

Impact of PDFs on x-sec

$Z \rightarrow \mu\mu$	Cross section (pb)		
	σ	$\Delta\sigma_+$	$\Delta\sigma_-$
CTEQ6.5	703.6	21.6	26.7
MRST2006	712.6	13.6	16.0
CTEQ6.1M	652.1	30.2	29.5
MRST2004 (NLLO)	662.8	12.6	17.8
MRST2004 (NLO)	672.4	12.7	18.1



acceptance region (full simulation) :

- $|\eta_\mu| < 2.0$,
- $p_T^\mu > 20$ GeV/c,
- $|M_{\mu\mu^-} - m_Z| < 3\Gamma_Z$

Similar conclusions for W

- **LO-NLO** (es: CTEQ5L - CTEQ5M) : estimate of the differences between LO and NLO treatments ~18% : Systematic variations in the rate can be interpreted in terms of a global normalization factor and shape variations are not very relevant
- **Central value - PDFs errors** (es: CTEQ6.5(0) – CTEQ6.5(1:40)): estimate of the uncertainties involved in the determination of PDFs ~2-3%
- **Different PDFs sets** (es: CTEQ6.5 – CTEQ6.1): estimate of possible systematic uncertainties involved in the theoretical treatment of PDF experimental inputs ~ 7-8%

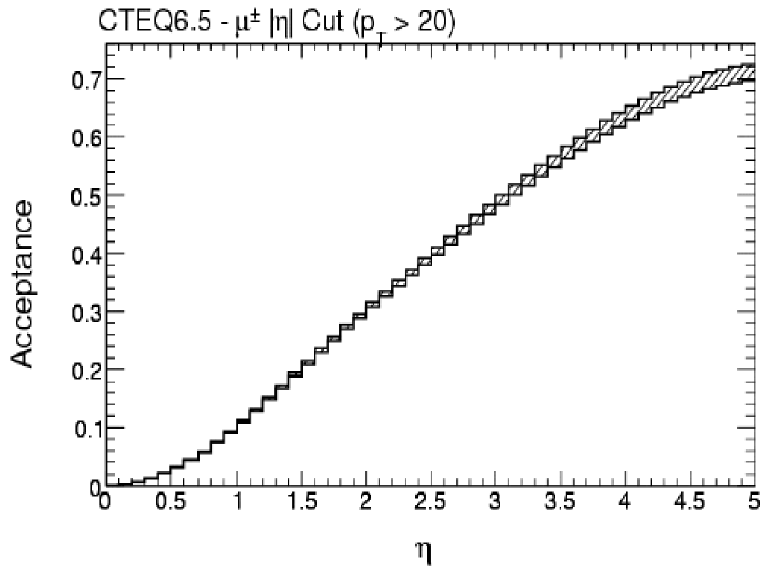
CMS NOTE 2006/082 ,CMS AN 2007- 031 , CMS AN 2007- 026

Impact of PDFs on acceptance

$Z \rightarrow \mu\mu$	acceptance		
	a	Δa_+	Δa_-
CTEQ6.5	0.302	0.004	0.004
MRST2006	0.305	0.004	0.004
CTEQ6.1M	0.303	0.003	0.007
MRST2004 (NLLO)	0.302	0.004	0.004
MRST2004 (NLO)	0.302	0.004	0.004

(full simulation):
$|\eta_\mu| < 2.0$, $p_T^\mu > 20$ GeV/c, $M_{\mu\mu} > 40$ GeV/c^2

CMS AN 2007- 031
CMS AN 2007- 026



- relative error on acceptance: ~ 1%
- the relative uncertainty on acceptance as a function of the kinematic cut on the muon pseudorapidity cut is very flat until the region of extreme cuts is reached.

How to constrain PDFs at LHC: Ratio and Asymmetry distributions

In the *Ratios* there is a partial cancellation of the experimental and from gluon/sea PDFs uncertainties

- the PDFs uncertainty on the A_{ZW} ratio is ~1% and there is agreement between PDFs sets

- the PDFs uncertainty on A_W and A_l is reduced compared to that on the W rapidity spectra within any one PDFs set

ZW Ratio

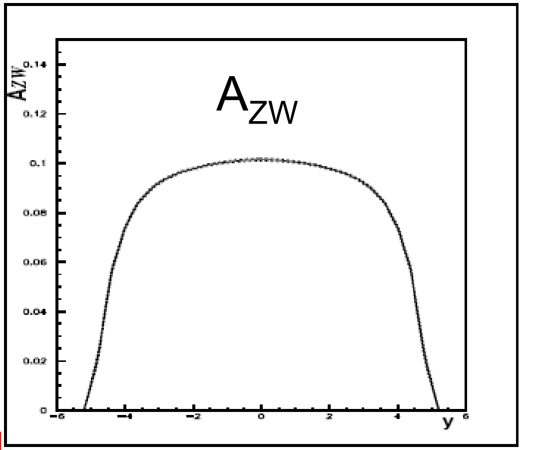
$$A_{ZW} = Z/(W^+ + W^-)$$

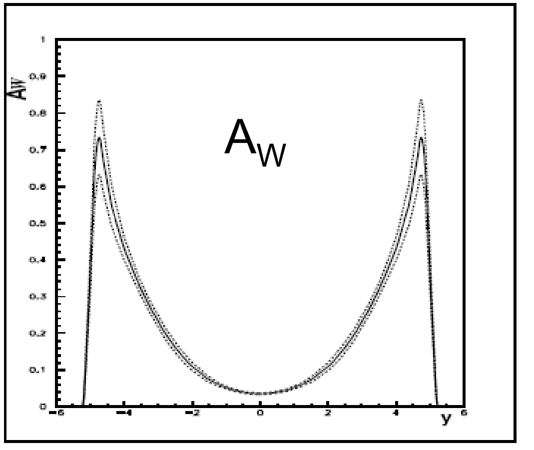
W Ratio

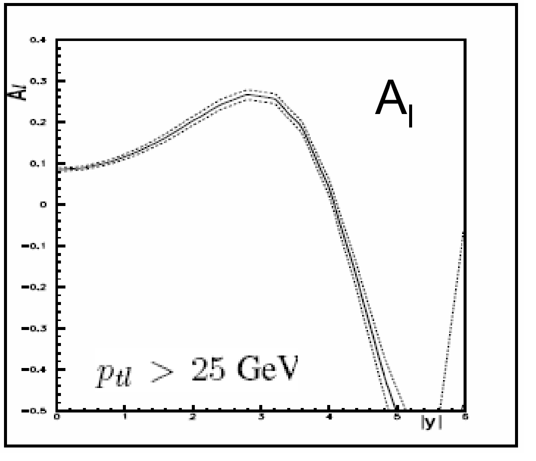
$$A_w = (W^+ - W^-)/(W^+ + W^-)$$

Lepton asymmetry

$$A_l = (l^+ - l^-)/(l^+ + l^-)$$





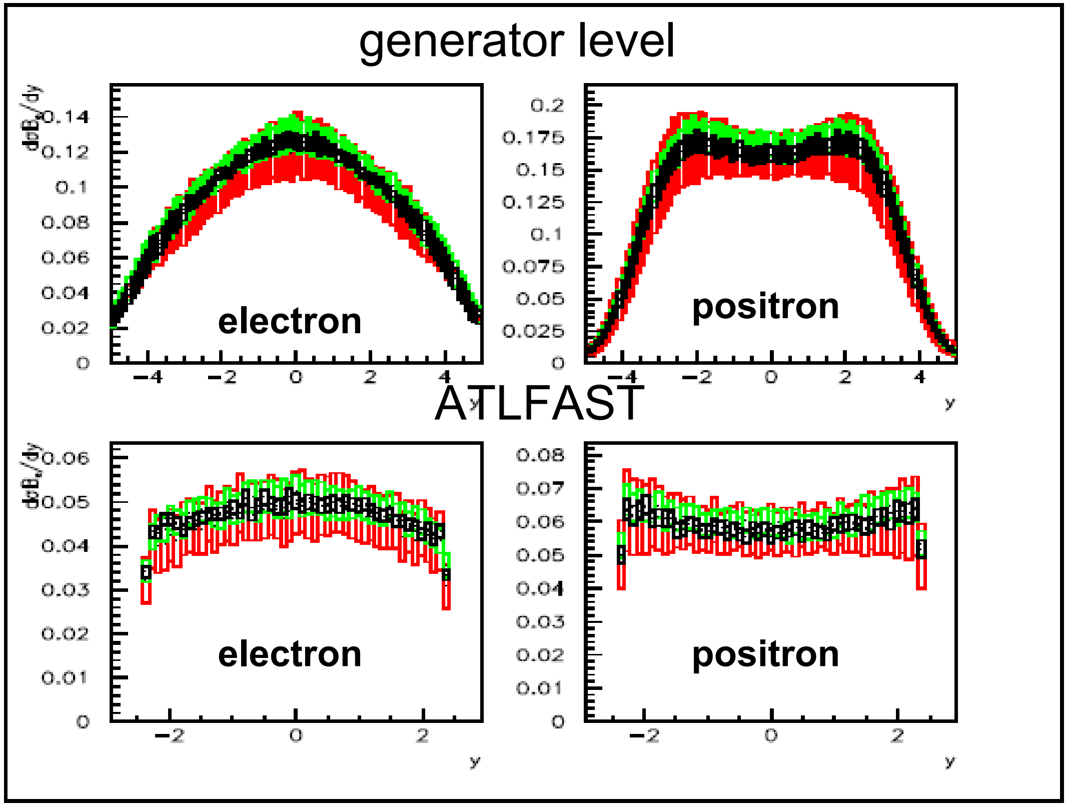


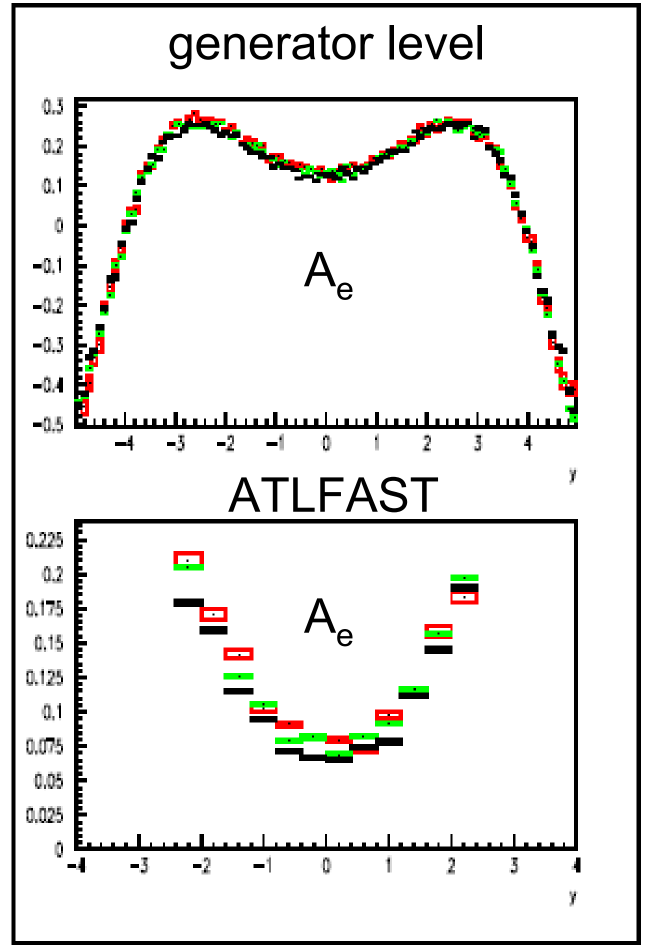
<u>BUT</u> there is not good agreement between PDF sets: a difference in valence PDFs is revealed

↓

MRST predicts Asymmetry ~15% lower than the other PDF sets

Impact of PDFs uncertainties on distributions





Generate with **HERWIG+k-factors** (checked against MC@NLO) using **CTEQ6.1M** , **ZEUS-S**, **MRST2001** PDFs with full uncertainties (from LHAPDF eigenvectors)

At y=0 the total uncertainty is

~ ±6% from ZEUS-S

~ ±4% from MRST01

~ ±8% from CTEQ6.1

hep-ex/0509002
hep-ex/0511020

For the first time with the LHC we will have **valence PDFs discrimination** measuring valence distributions at x~0.005 on proton targets

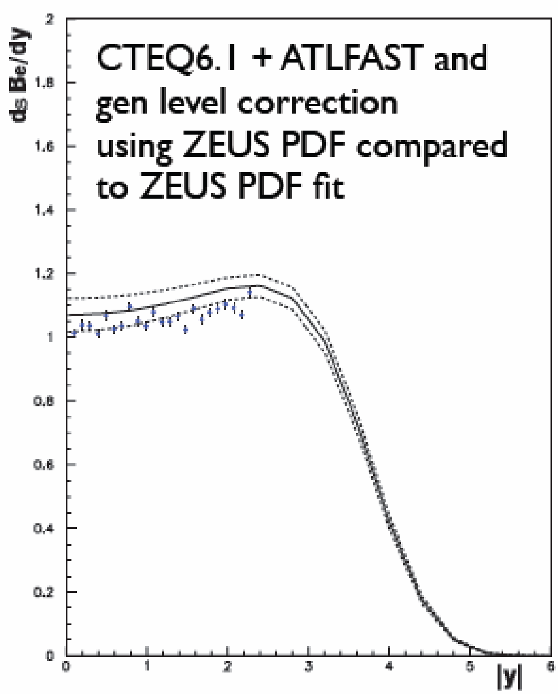
PDFs constraining potential

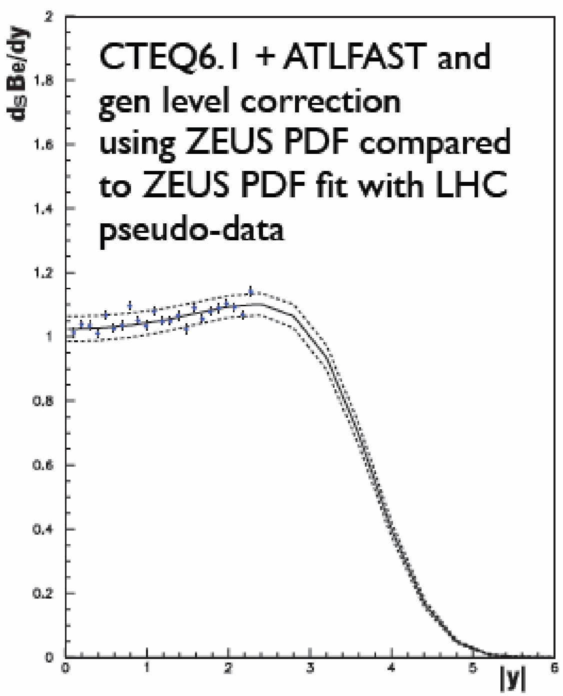
How much can we reduce the PDF errors when LHC is up and running?

Simulate real experimental conditions:
ATLFAST simulated W Rapidity pseudo data included in the global ZEUS PDF fit

Central value of ZEUS-PDF prediction shifts and uncertainty is reduced:
low-x gluon shape parameter λ,
$xg(x) \sim x^{-\lambda}$

BEFORE λ = -0.199 ± 0.046
AFTER λ = -0.181 ± 0.030
→ 35% improvement





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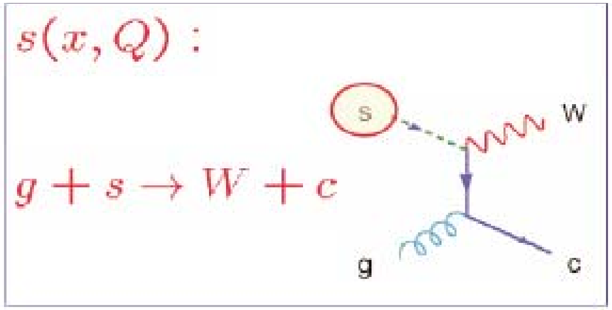
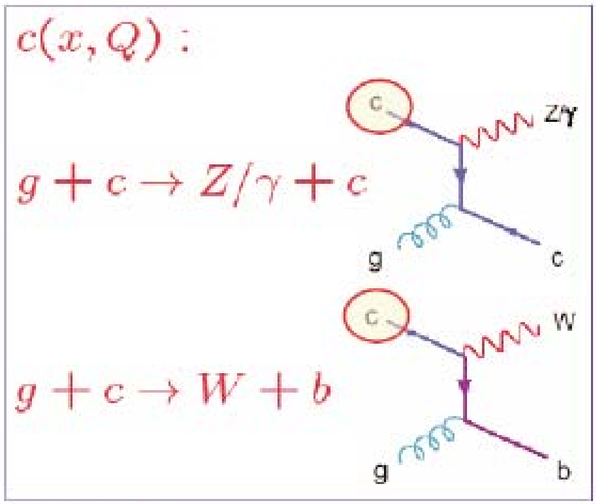
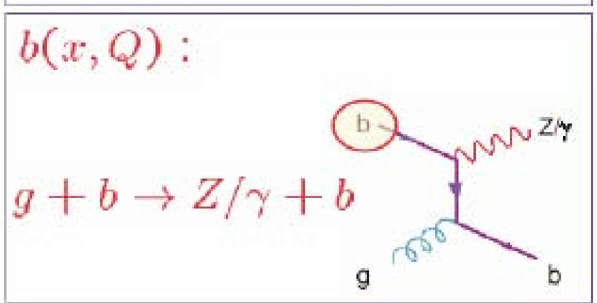
Measuring heavy quark PDFs







Measurement of the Q-quark PDF (Q=s,c,b)

→ Process sensitive to Q content of the proton

Cuts on b jets:

pt > 20 GeV

|η|< 2.5

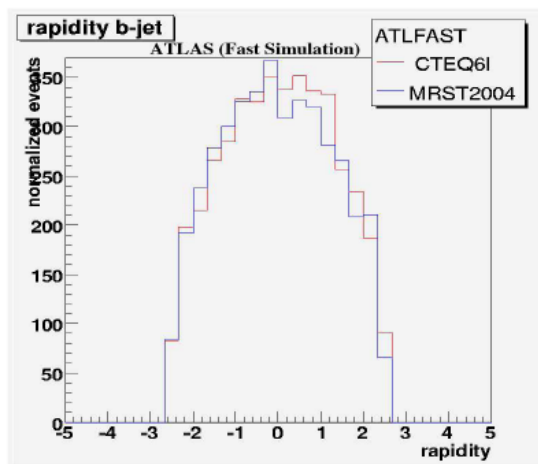
Event selection

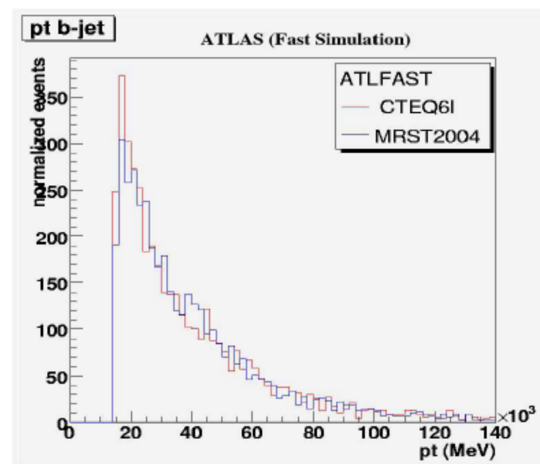
(only Z→μμ)

$|\eta_\mu| < 2.4$,

$p_T^\mu > 20$ GeV/c,

$70 < M_{\mu\mu} < 110$ GeV

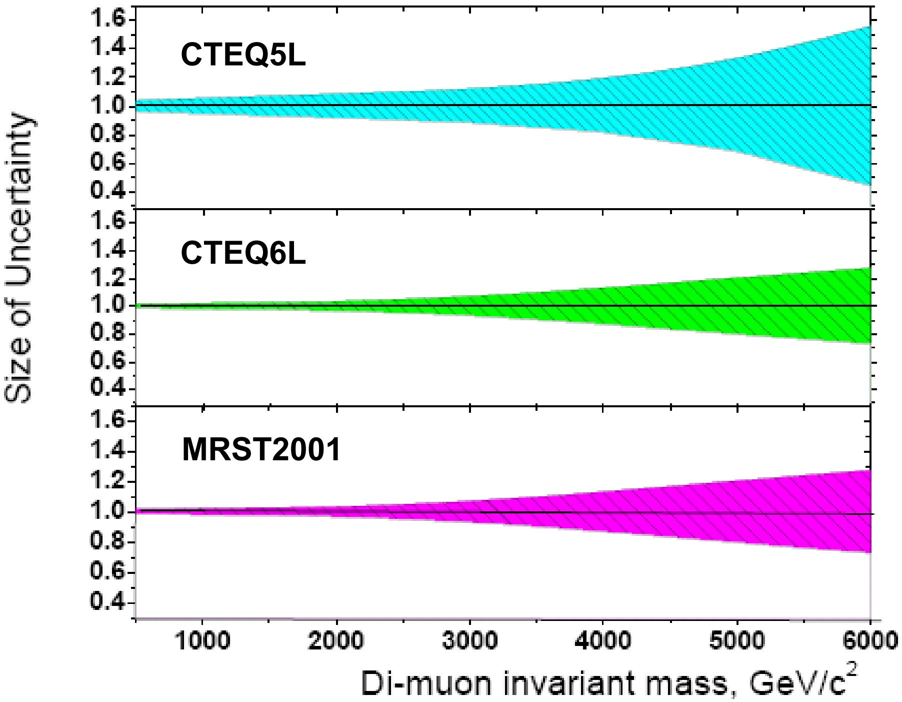




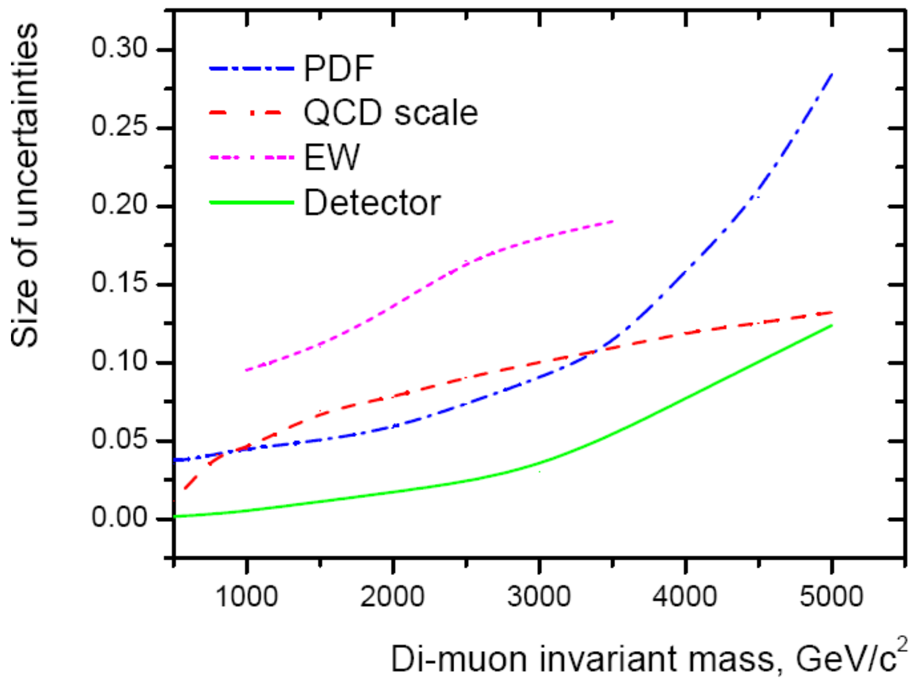
PRELIMINARY

arXiv:0710.4461v1[hep-ex]

High invariant mass region



Drell Yan dimuon production studies (full simulation) :
estimate of cross sections using different PDF sets varies within ±7% for M_{ll}>1 TeV/c^2

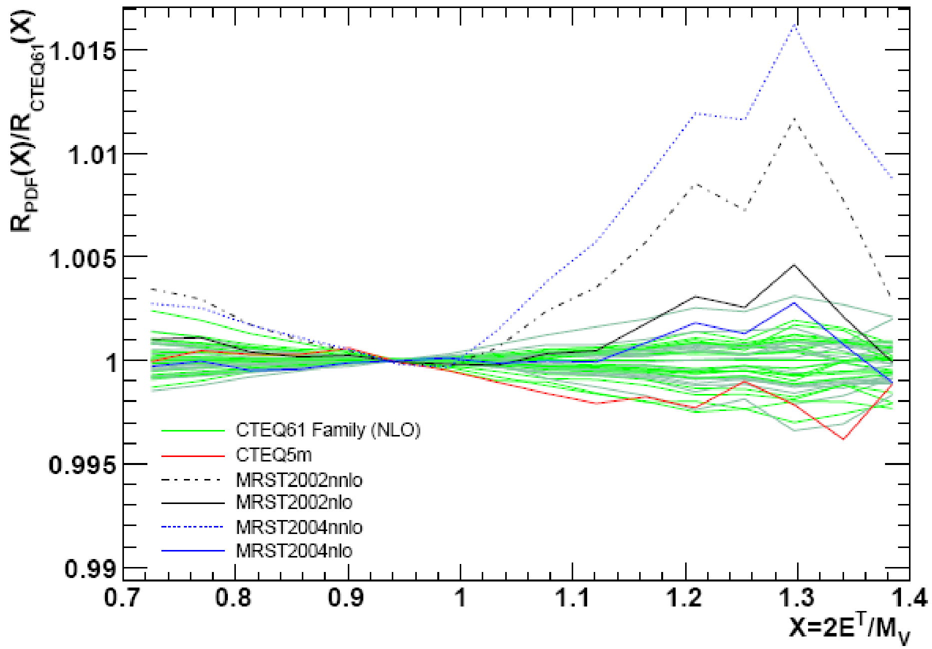


Internal uncertainty on cross section:

* M_{ll} < 1 TeV/c^2:
  same order of the theoretical one, <~ 6%
* M_{ll} >~ 2.5 TeV/c^2:
  the error coming from PDF's is of the order of the statistical one expected for integrated luminosity of 300 fb^{-1}

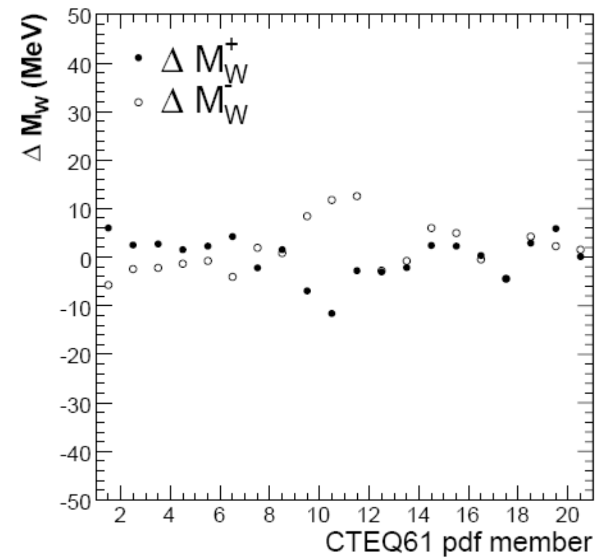
CMS NOTE 2006-123

Impact of the PDFs on the W mass



W mass studied mimic W with Z to control systematics:

$R(X) = (d\sigma_W/dX_W)/ (d\sigma_Z/dX_Z)$
being X the scaled variable $X^V = O^V/M^V$



$$\Delta M_W^+ = \sqrt{\sum_{i=1}^{20} \left[\max\left(M_W(s_i^+) - M_W(0), M_W(s_i^-) - M_W(0), 0\right)\right]^2}$$

$$\Delta M_W^- = \sqrt{\sum_{i=1}^{20} \left[\max\left(M_W(0) - M_W(s_i^+), M_W(0) - M_W(s_i^-), 0\right)\right]^2}$$

CTEQ – MRST results consistent within 10 MeV

Reduction on uncertainties on PDFs needed to control systematics on W mass

Maximal variations of the physical observable from the fit of the electron scaled transverse energy:

$\Delta M^+_W = 23$ MeV
$\Delta M^-_W = 17$ MeV

CMS NOTE 2006/061

Ongoing work …

A lot of work is ongoing to estabilish the LHC power to constrain PDF’s.

Measuring PDF’s at CMS:

- Z+jets, γ+jets, W/Z + X processes to improve the knowledge on gluon and quark functions
- W studies to study the low-x region

  (ie. relax of the u=ubar, d=dbar assumptions)
- High p_T jets studies

Measuring PDF’s at ATLAS:

- Z+jets, γ+jets, W/Z + X processes to improve the knowledge on gluon and quark functions
- PDF uncertainties on W+Jets
- Studies of systematic uncertainties on W/Z acceptances due to PDFs

Conclusions

- HERA data largely improved our knowledge of PDFs
- At LHC we are dominated by gluon/sea interaction at low-x: regions never accessed before will be covered

- Current PDFs uncertainties on W/Z:
  - cross sections: <~ 5% - different sets agree within 8%
  - Ratio and asymmetries: <~ 1%
  - rapidity spectra: <~ 8% - different sets agree within ~5%

- PDFs uncertainties have a large impact on precision studies,

e.g. W mass determination

- Many studies are ongoing to understand how LHC can improve the precision in the PDFs determination

Bibliography

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- Joey Huston (*Eurogdr Supersymmetry Workshop on SM Backgrounds*)
- Joey Huston (Epiphany Workshop Krakow Jan. 2007)
- J.F. Owens (2007 CTEQ Summer School)
- A M Cooper-Sarkar (HERA-LHC workshop 2007)
- A.Tricoli (Workshop sui Monte Carlo, la Fisica e le Simulazioni ad LHC - Frascati, 23 Maggio 2006)
- Albert De Roeck (CTEQ LHC workshop 05/14/07)
- Craig Buttar (CTEQ LHC workshop 05/14/07)
- Roberto Tenchini(CTEQ LHC workshop 05/14/07)

backup

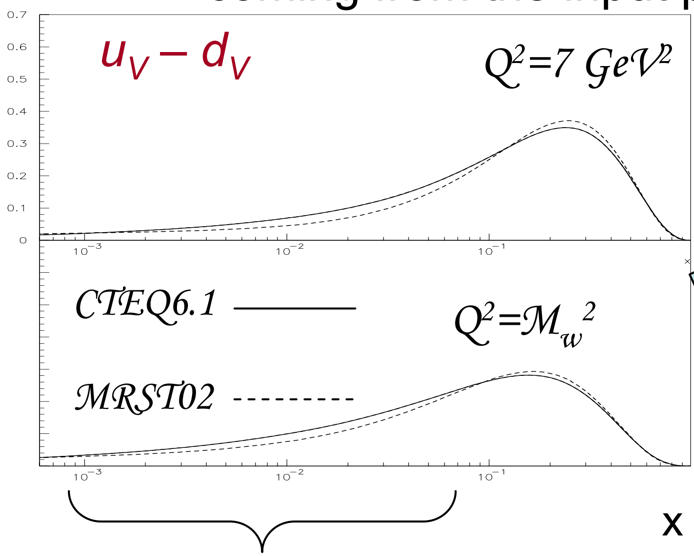
W Charge Asymmetry measurement

A. Cooper-Sarkar

- At LO the Asymmetry is dominated by $u_v - d_v$ parameter :

$$A(y) \equiv \frac{u\bar{d} - d\bar{u}}{u\bar{d} + d\bar{u}} \xrightarrow[\text{At small-x}]{\bar{u} \cong \bar{d} \cong \bar{q}} A(y) \equiv \frac{u_V - d_V}{u_V + d_V + 2\bar{q}}$$

- $u_v - d_v$ parameter is not well constrained by data at very low-x
  - current PDFs simply have prejudices as to the low-x valence distributions coming from the input parameterisations.



x- range affecting W asymmetry in the measurable rapidity range

The small PDF uncertainties at low x do NOT actually reflect the real uncertainty.

at $Q^2=M_W^2$ and x~0.006 (correspongіng to y~0 at LHC): MRST $u_V - d_V$ is 15% lower than other PDF sets which reflects on A(y) measurement.

For the first time with the LHC we will have valence PDF discrimination measuring valence distributions at x~0.005 on proton targets

From A. Tricoli

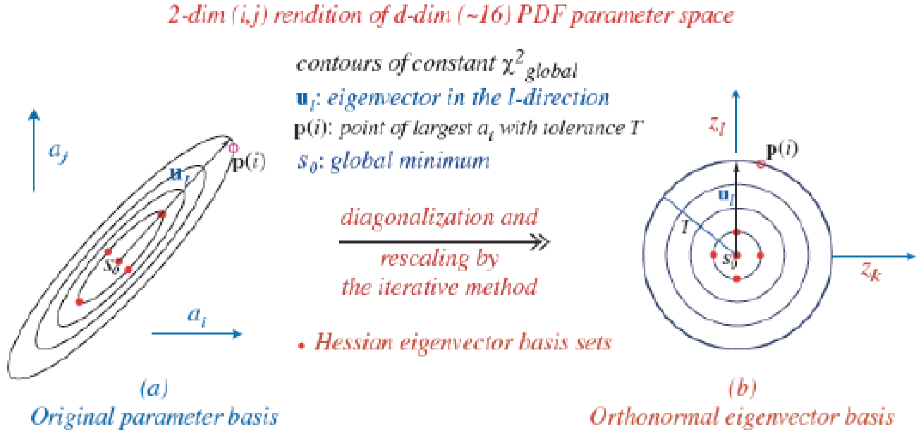
PDFs sets

- Pdf's are determined by global analyses of data from
  - **HERA experiments H1, ZEUS**
  - **fixed target DIS experiments**
  - **CDF, D0 (inclusive jet cross section measurements)**

- Three major groups that provide semi-regular updates to parton distributions when new data/theory becomes available:
  1. **MRST (global fits)**
  2. **CTEQ (global fits)**
  3. **HERA collaboration H1, ZEUS (HERA data + fixed target DIS data)**
  4. Alekhin (DIS data only)

All of the above groups provide ways to estimate the error on the central pdf

- Hessian methodology enables full characterization of parton parametrization space in neighborhood of global minimum



- CTEQ6.1 has 20 free parameters so 20 directions in eigenvector space

40 error pdfs

$$\Delta X^{+}_{\max} = \sqrt{\sum_{i=1}^{N} [\max(X_i^{+} - X_0, X_i^{-} - X_0, 0)]^2},$$

$$\Delta X^{-}_{\max} = \sqrt{\sum_{i=1}^{N} [\max(X_0 - X_i^{+}, X_0 - X_i^{-}, 0)]^2}.$$

Joey Huston

Differences between PDF sets

- different **data sets** in fit
  - different sub-selection of data
  - different treatment of exp. sys. errors
- different **choices** of
  - tolerance to define $\pm\delta f_i$ (CTEQ: $\Delta\chi^2$=100, MRST: $\Delta\chi^2$=50 Alekhin: $\Delta\chi^2$=1)
  - parametric form $Ax^a(1-x)^b[..]$ etc
  - theoretical assumptions about sea flavour symmetry
  - factorisation/renormalisation scheme/scale
  - Q_0^2
  - α_s
  - treatment of heavy flavours

From A. Tricoli

PDF uncertainties

- **Theoretical Uncertainties**
  - **Theoretical Formalism: perturbative calculations,**
    i.e DGLAP approx., higher order truncation, etc.
  - **Model Assumptions: non-perturbative parameterisations (x-depedence)**
    i.e. assumptions to limit the no. of free parameters
- **Experimental Uncertainties**
  - **Statistical and Systematic Uncertainties on experimental data inputs**
  - ***Correlated Systematic* Uncertainties on data points:**

The theoretical uncertainties are estimated varying the theoretical assumptions,
But only recently the correlated syst. on data points are properly considered:
PDF sets after year 2000 provide UNCERTAINTIES: $f_i(x,Q^2) \pm \delta f_i(x,Q^2)$:

use a modified $\chi^2 \to \tilde{\chi}^2 + \Delta T^2$ to consider non-gaussian syst. errors and their correlations. T= tolerance

- **Offset Method**: the correlated syst. errors affect only the determination of the PDF uncertainty, NOT the best fit (centre value) e.g. ZEUS-S $\Delta T^2 \sim 49$
- **Hessian method:** the collective effect of the correlated syst. errors can also modify the values of the best fit e.g. CTEQ6 $\Delta T^2=100$, MRST01: $\Delta T^2=50$

Relative systematics uncertainties on the acceptance for Z→μμ and in W→μν

(CMS, for L ~ 1 fb-1)

Z →μμ

Source	Uncertainty (%)
Tracker efficiency	1
Magnetic field knowledge	0.03
Tracker alignment	0.14
Trigger efficiency	0.2
Jet energy scale uncertainties	0.35
Pile-up effects	0.30
Underlying event	0.21
Total exp.	1.1
PDF choice (CTEQ61 sets)	0.7
ISR treatment	0.18
p_T effects (LO to NLO)	1.83
Total PDF/ISR/NLO	2.0
Total	2.3

W →μν

Source	Uncertainty (%)
Tracker efficiency	0.5
Muon efficiency	1
Magnetic field knowledge	0.05
Tracker alignment	0.84
Trigger efficiency	1.0
Transverse missing energy	1.33
Pile-up effects	0.32
Underlying event	0.24
Total exp.	2.2
PDF choice (CTEQ61 sets)	0.9
ISR treatment	0.24
p_T effects (LO to NLO)	2.29
Total PDF/ISR/NLO	2.5
Total	3.3

- 600 events recorded/pb: size of statistical uncertainties ~ systematic uncertainties at L ~ 3 pb^{-1}.
- Most of the sources assume a detector understood with L=1 fb^{-1} => systematics will be a bit larger at start-up, and decrease with time
- Theory uncertainties are an interesting field of study by themselves

CMS NOTE 2006/082

High invariant mass region (uncertainties)

Table 3: x_1 and x_2 for different masses and rapidities.

y	0	2	4
M = 91.2 GeV/c^2			
x_1	0.0065	0.0481	0.3557
x_2	0.0065	0.0009	0.0001
M = 200 GeV/c^2			
x_1	0.0143	0.1056	0.7800
x_2	0.0143	0.0019	0.0003
M = 1000 GeV/c^2			
x_1	0.0714	0.5278	-
x_2	0.0714	0.0097	-

Table 2: Relative errors of the Drell-Yan muon pairs cross section measurements.

$M_{\mu^+\mu^-}$	Cross section fb	Detector smearing	Statistical 1 fb^{-1}	Statistical 10 fb^{-1}	Statistical 100 fb^{-1}
$\geq$ 200 GeV/c^2	$2.76 \cdot 10^3$	$8 \cdot 10^{-4}$	0.025	0.008	0.0026
$\geq$ 500 GeV/c^2	$1.07 \cdot 10^2$	0.0014	0.11	0.035	0.011
$\geq$ 1000 GeV/c^2	6.61	0.0049	0.37	0.11	0.037
$\geq$ 2000 GeV/c^2	$2.4 \cdot 10^{-1}$	0.017		0.56	0.18
$\geq$ 3000 GeV/c^2	$1.9 \cdot 10^{-2}$	0.029			0.64

CMS Note-2006/123

Background: The backgrounds considered are vector boson pair production ZZ, WZ, WW, $t\bar{t}$ production etc. The simulation and preselection of background events is done using CMKIN [11] with the same cuts as for the signal above. In the SM the expected leading-order cross section of these events is negligible in comparison with the Drell-Yan one (Table 4).

Table 4: Leading-order cross sections of pre-selected di-bosons (ZZ, ZW, WW) and $t\bar{t}$ events in fb for different cut-off values on the dimuon mass. The CTEQ5L parton distributions are used.

$M_{\mu^+\mu^-}$, TeV/c^2	≥ 1.0	≥ 1.5	≥ 2.0	≥ 2.5	≥ 3.0	≥ 4.0
Di-bosons, fb	$2.59 \cdot 10^{-4}$	$1.51 \cdot 10^{-4}$	$5.6 \cdot 10^{-5}$	$2.26 \cdot 10^{-5}$	$9.06 \cdot 10^{-6}$	$1.66 \cdot 10^{-6}$
$t\bar{t}$, fb	$2.88 \cdot 10^{-4}$	$2.58 \cdot 10^{-4}$	$1.55 \cdot 10^{-4}$	$7.02 \cdot 10^{-5}$	$2.93 \cdot 10^{-5}$	$3.65 \cdot 10^{-6}$

Measuring the W mass (uncertainties)

Source of uncertainty	electron channel				muon channel			
	with 1 fb^{-1}		with 10 fb^{-1}		with 1 fb^{-1}		with 10 fb^{-1}	
	assumed uncertainty	ΔM_W	assumed uncertainty	ΔM_W	assumed uncertainty	ΔM_W	assumed uncertainty	ΔM_W
statistics		**40 MeV**		**15 MeV**		**40 MeV**		**15 MeV**
background	10%	10 MeV	2%	2 MeV	10%	4 MeV	2%	negligible
lepton								
energy/momentum scale	0.25%	10 MeV	0.05%	2 MeV	0.1%	14 MeV	$<$0.1%	$<$10 MeV
energy/momentum linearity	6×10^{-5} GeV^{-1}	30 MeV	$<2\times10^{-5}$ GeV^{-1}	$<$10 MeV	expected to be negligible	negligible	expected to be negligible	negligible
energy/momentum resolution	8%	5 MeV	3%	2 MeV	10%	30 MeV	$<$3%	$<$10 MeV
acceptance	resolution in η	2 MeV	resolution in η	2 MeV	resolution in η	19 MeV	$<\sigma_\eta$	$<$10 MeV
detector alignment						12 MeV		negligible
MET scale	2%	15 MeV	$<$1.5%	$<$10 MeV	2%	38 MeV	$\leq$1%	$<$ 20 MeV
MET resolution	5%	9 MeV	$<$2.5%	$<$ 5 MeV	5%	30 MeV	$<$3%	$<$18 MeV
recoil system	2%	15 MeV	$<$1.5%	$<$10 MeV				
total instrumental		**40 MeV**		**$<$20 MeV**		**64 MeV**		**$<$30 MeV**
PDF uncertainties		20 MeV		$<$10 MeV		$\sim$20 MeV		$<$10 MeV
Γ_W		15 MeV		$<$15		10 MeV		$<$ 10 MeV
$p^T(W)$		30 MeV		30 MeV (or NNLO)				
other theory errors	not yet evaluated for this experimental study				not yet evaluated for this experimental study			

Table 7: Expected systematic errors on M_W for the scaled E^T-lepton method with electrons and for the morphing method with muons. The first column lists the systematic effect considered. Columns 2-5 (electron channel) show the assumed detector uncertainty for an initial integrated luminosity of 1 fb^{-1}, the resulting uncertainty on M_W and the extrapolation to an integrated luminosity of 10 fb^{-1} when the detector understanding is assumed to have significantly improved. The last four columns show the expected uncertainties with 1 fb^{-1} and the extrapolation to 10 fb^{-1} for the M_W measurement in the muon channel.

CMS Note-2006/061

• Inelastic pp reactions:		70 mb
• bb pairs • tt pairs	10^5 events/s 0.8 events/s	100 μb 600 pb
• W $\rightarrow$ e ν • Z $\rightarrow$ e e	15 events/s 1.5 events/s	10 nb 1 nb
• Higgs (500 GeV) • Gluino, Squarks (1 TeV)		1 pb 1 pb

Z and W production

- Expected large production :
  - systematics are rapidly a potential limitation
- Production Mode
  - small x
  - gluon PDF : the least known
  - NNLO / DGLAP extrapolation at small X

Cross section Z+b with Z→μμ

PYTHIA	σ_{CTEQ}(pb)	σ_{MRST}(pb)
Z+b	726	764

Pt(μ) > 20 GeV |η(μ)|< 2.5 & pt(b) > 15 GeV |η(b)|< 2.5

~ 16 pb

Including ~ 30% b-tagging efficiency we expect ~ 5 ev/1h (low luminosity)

Di lepton (electron) spectrum

Mass (TeV)	Nevt (1fb-1)	10 evts
1	~160	~70 pb-1
1.5	~30	~300 pb-1
2	~7	1.5 fb-1

Conclusions : The Ground to New Physics

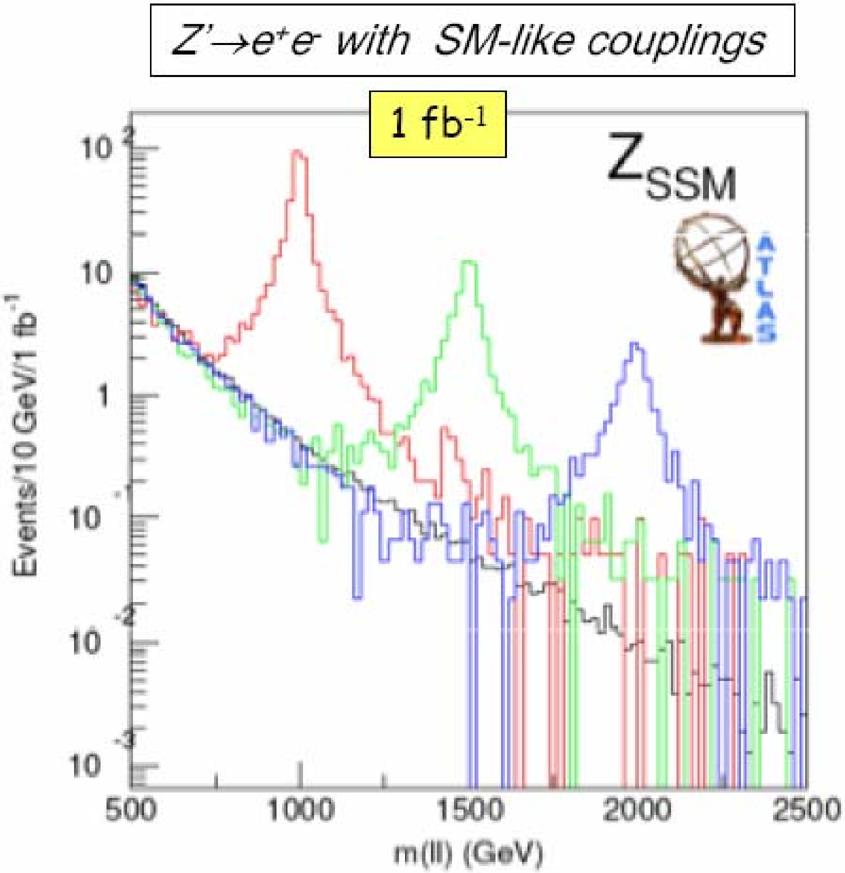
O(10pb-1)	W/Z	Calibration /Alignment Lepton ID Missing Et Isolation	2008
O(100pb-1)	W/Z + jets Top physics	PDfs B tagging , missing Et "Multi Variables" analysis	
O(1fb-1)	Precision Top Physics TGC	In Situ Final Jets Calibration Full detector understanding	2009
	Solid Grounds for New Physics Should be Established		
O(100fb-1) and more	$\sin^2(\vartheta)$ M_W		

Corinne Goy (CNRS/IN2P3)

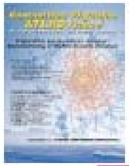
Unless !

Di lepton (electron) spectrum

Mass (TeV)	Nevt (1fb-1)	10 evts
1	~160	~70 pb-1
1.5	~30	~300 pb-1
2	~7	1.5 fb-1

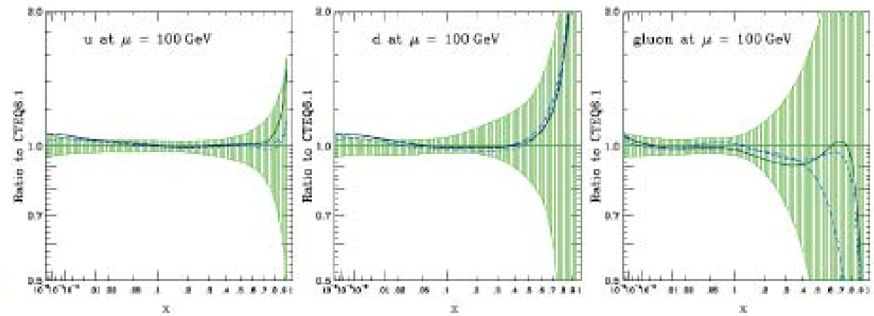


Corinne Goy (CNRS/IN2P3)



Heavy quark mass effects in global fits

- CTEQ6.1 (and previous generations of global fits) used zero-mass VFNS scheme
- With new sets of pdf's (CTEQ6.5/6.6), heavy quark mass effects consistently taken into account in global fitting cross sections and in pdf evolution
- In most cases, resulting pdf's are within CTEQ6.1 pdf error bands
- But not at low x (in range of W and Z production at LHC)
- Heavy quark mass effects only appreciable near threshold
  - ex: prediction for F_2 at low x,Q at HERA smaller if mass of c,b quarks taken into account
  - thus, quark pdf's have to be bigger in this region to have an equivalent fit to the HERA data



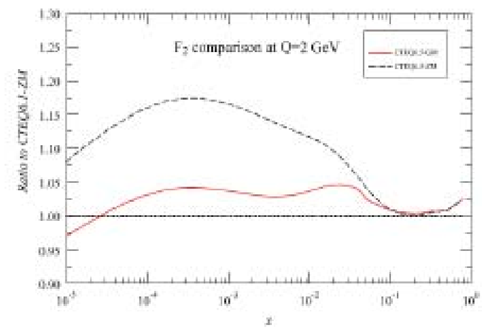
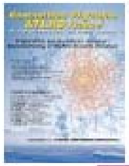


Figure 6: Comparison of theoretical calculations of F_2 using CTEQ6.1M in the ZM formalism (horizontal line of 1.00), CTEQ6.5M in the GM formalism (solid curve), and CTEQ6.5M in the ZM formalism (dashed curve).

→ implications for LHC phenomenology

From Joey Huston



PDF uncertainties at the LHC

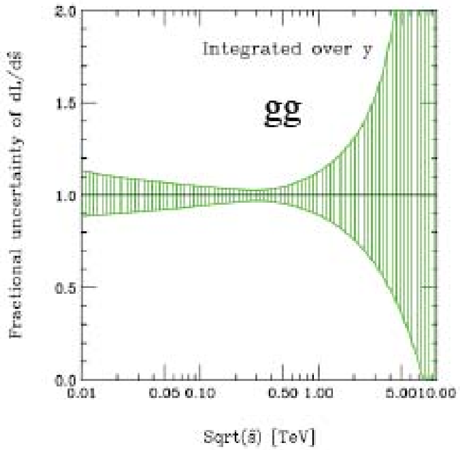


Fig. 4: Fractional uncertainty of gg luminosity integrated over y.

Note that for much of the SM/discovery range, the pdf luminosity uncertainty is small

Need similar level of precision in theory calculations

It will be a while, i.e. not in the first fb^{-1}, before the LHC data starts to constrain pdf's

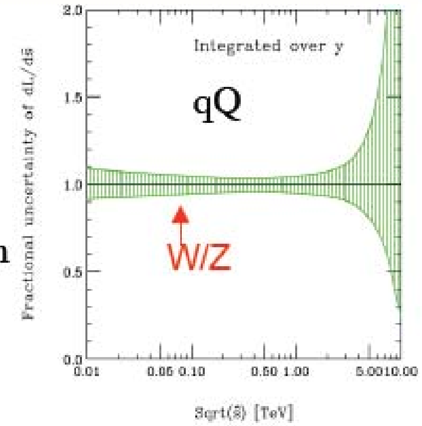


Fig. 7: Fractional uncertainty for Luminosity integrated over y for $d\bar{d}+u\bar{u}+s\bar{s}+c\bar{c}+b\bar{b}+\bar{d}d+\bar{u}u+\bar{s}s+\bar{c}c+\bar{b}b$.

great deal of recent work in ATLAS on storing error pdf information when generating MC events with central pdf; by now, standard practice in CDF/D0

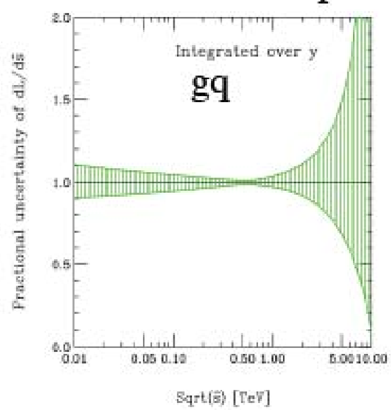
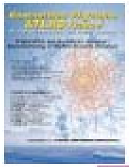


Fig. 6: Fractional uncertainty for Luminosity integrated over y for $g(d+u+s+c+b)+g(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})+(d+u+s+c+b)g+(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})g$.

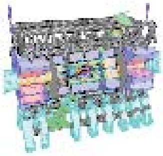
NB I: the errors are determined using the Hessian method for a $\Delta\chi^2$ of 100 using only experimental uncertainties,i.e. no theory uncertainties

NB II: the pdf uncertainties for W/Z cross sections are not the smallest

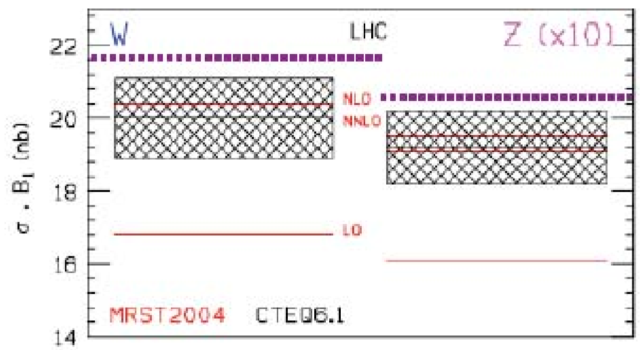
From Joey Huston



CTEQ6.5(6)

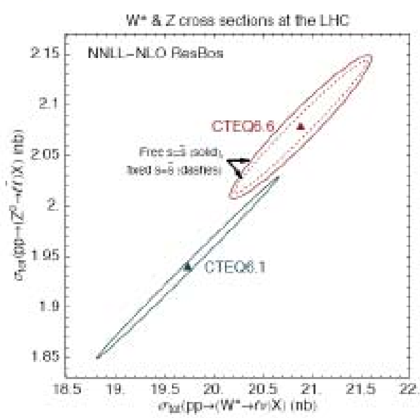


- Inclusion of heavy quark mass effects affects DIS data in x range appropriate for W/Z production at the LHC
- Cross sections for W/Z increase by 7-8%
  - now CTEQ and MRST2004 in disagreement
- And relative uncertainties of W/Z increase
  - although individual uncertainties of W and Z decrease
- Joe now has to use 45 pdf's to keep me happy



CTEQ6.5(6)

Figure 80. Predicted cross sections for W and Z production at the LHC using MRST2004 and CTEQ6.1 pdfs. The overall pdf uncertainty of the NLO CTEQ6.1 prediction is approximately 5%, consistent with figure 77.

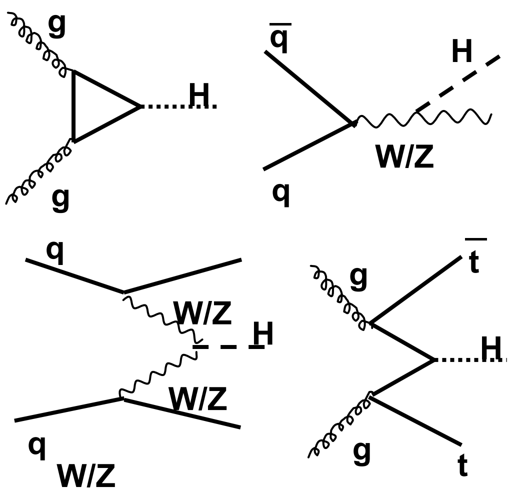


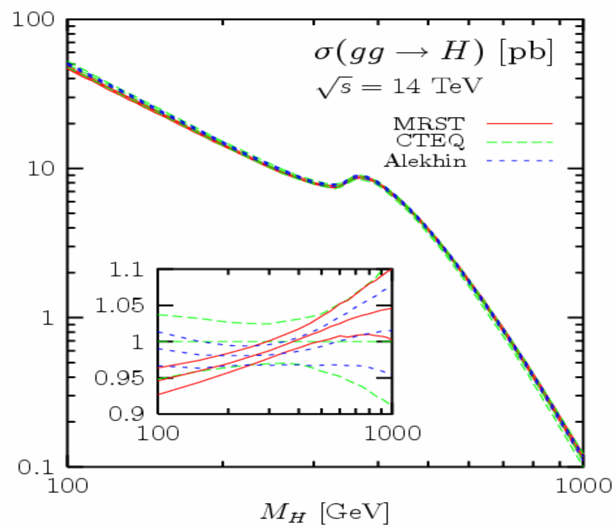
Note importance of strange quark uncertainty for ratio

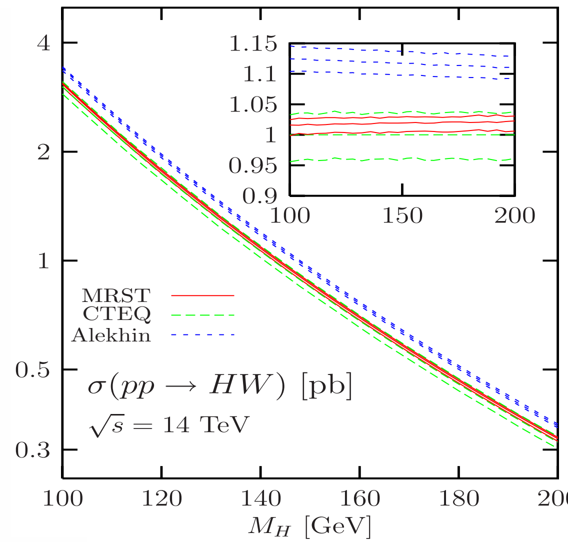
Figure 8: W & Z correlation ellipses at the LHC obtained in the fits with free and fixed strangeness.

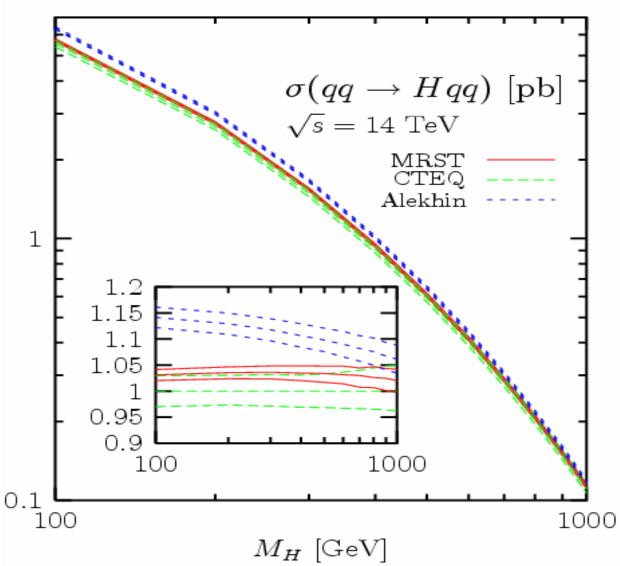
From Joey Huston

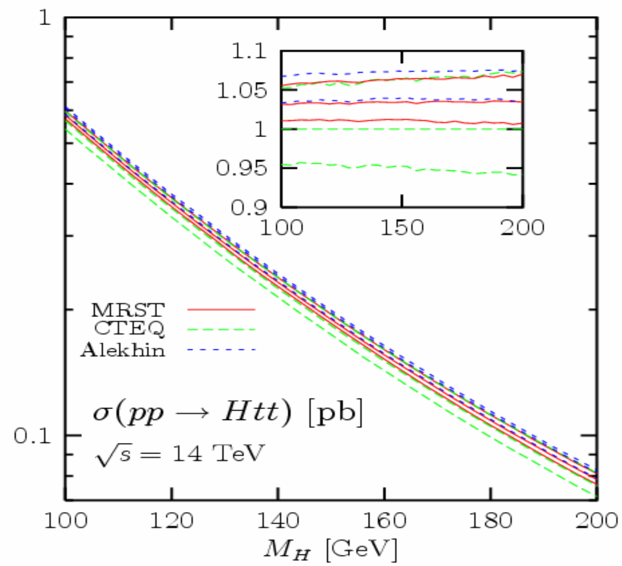
Impact of PDF uncertainty on New Physics: Higgs











PDF uncertainties (CTEQ6M, MRST01E, Alekhin02) on Higgs cross-sections: Up to 10% (15%)

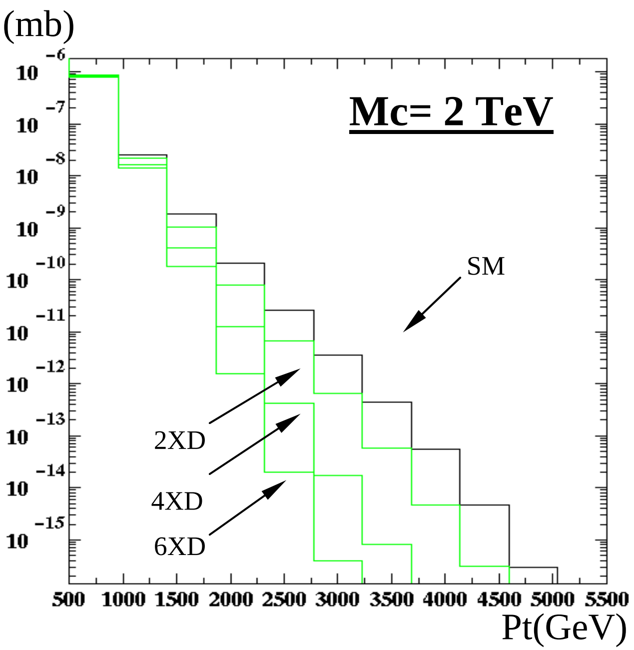
Djouadi & Ferrag,
Phys. Lett. B 586 345:352 (2004)

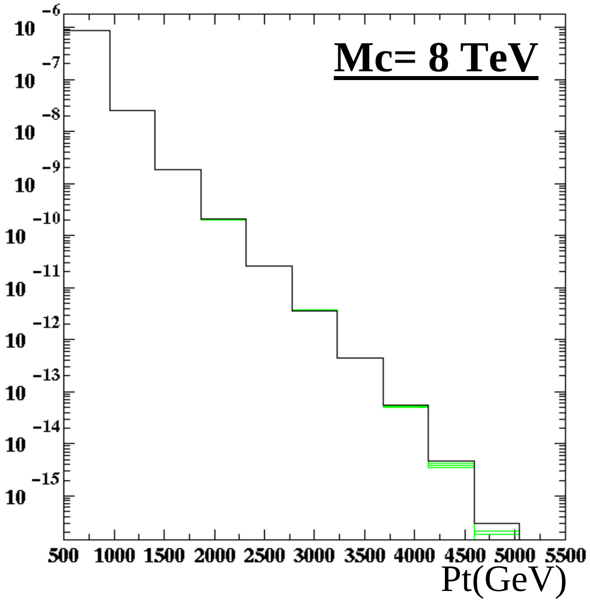
From A. Tricoli

Impact of PDF uncertainty on New Physics:

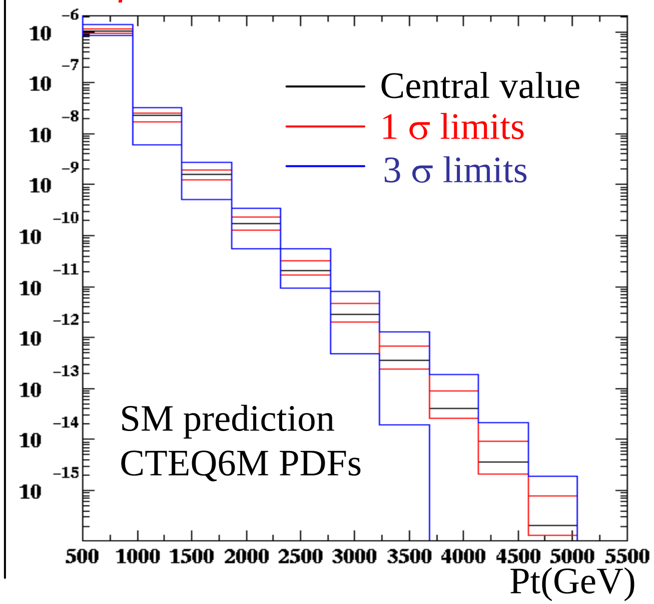
Extra Dimensions *Ferrag, hep-ph/0407303 (2004)*

An E.D. Model: *di-jets cross section in the E.D. regime is a continuity of the Standard Model one with new α_s running:* $\frac{d\sigma^{XD}}{dM_{JJ}} = \frac{d\sigma}{dM_{JJ}}\left(\alpha_S^{XD}\right)$





Standard Model prediction zone: where every measured cross section can be explained by a PDF fit, and *every power of discovering new physics is killed and absorbed by the PDF fit*



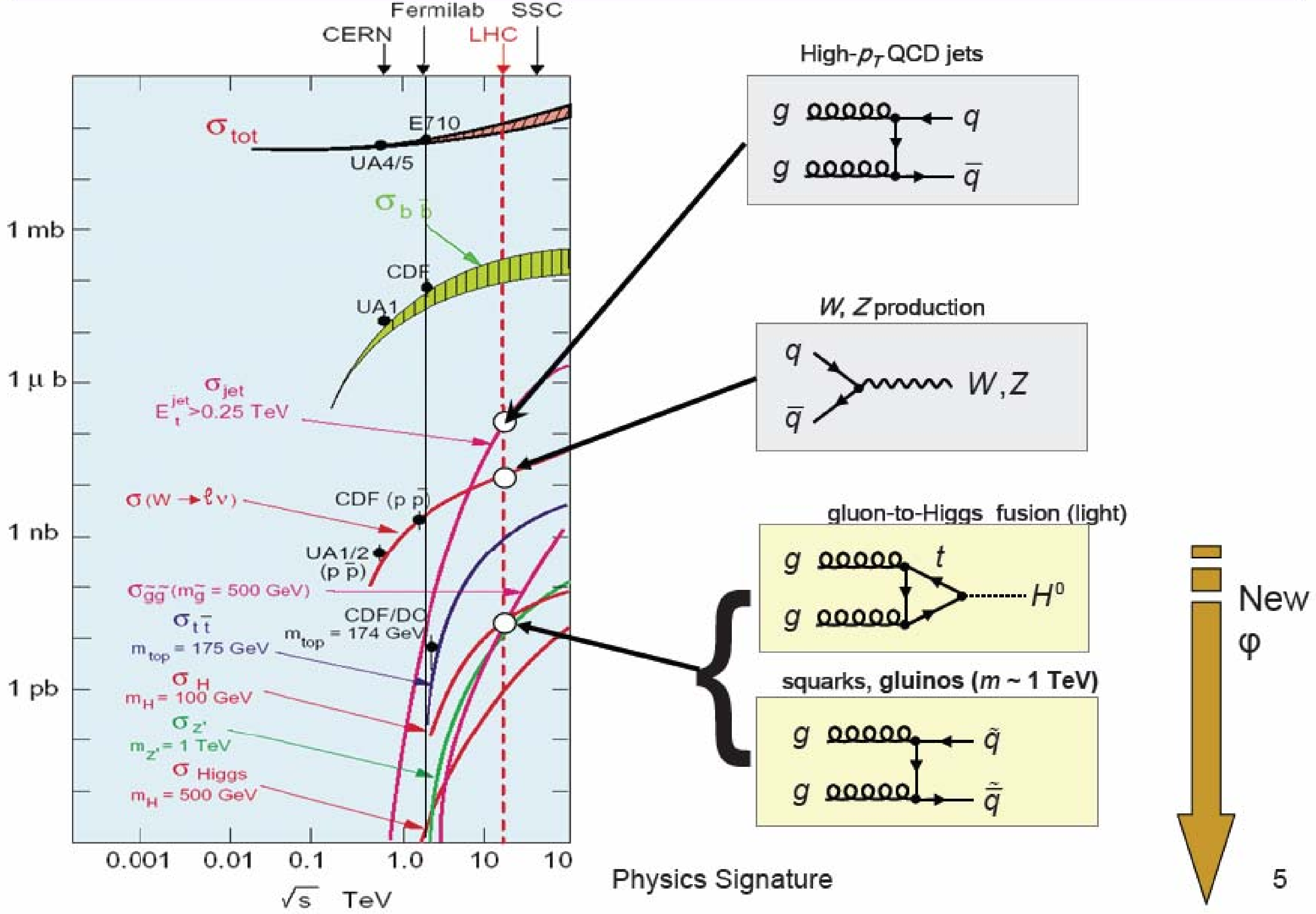
E.D. are masked by PDF uncertainties:

High-x gluon is responsible of the big PDF uncertainties

PDF uncertainties decrease discovery reach for E.D. from M_C 5 (10) TeV to < 2 (3)TeV

From A. Tricoli

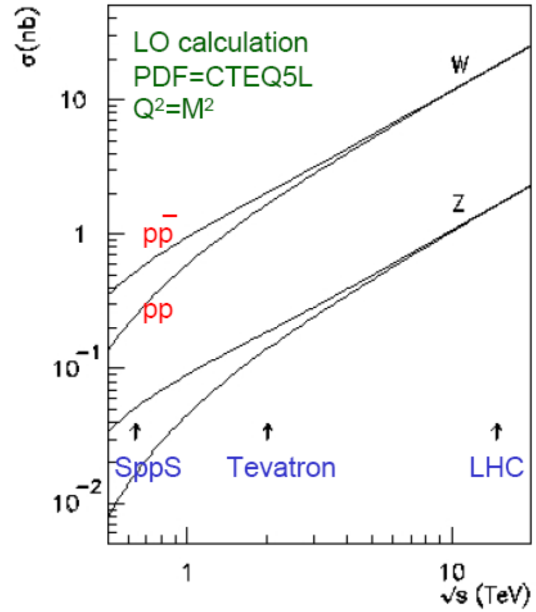
First & Ultimate Background for New Physics

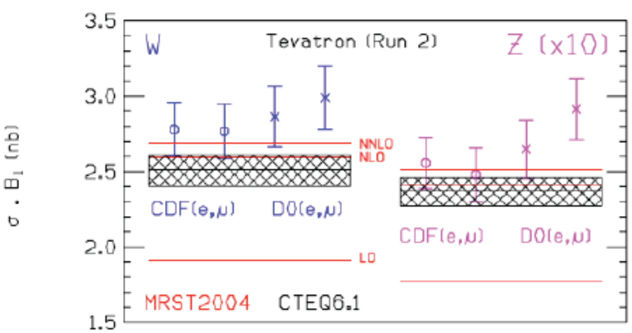


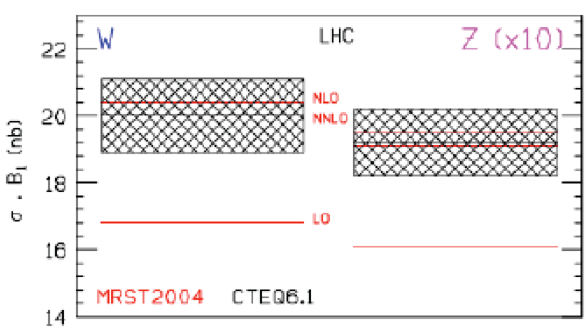
Physics Signature

W and Z cross sections

- W/Z cross sections serve as precision physics monitors
- All cross sections at Tevatron/LHC could be normalized to W/Z
- Both experimental and theoretical errors are under control
- CTEQ and MRST NLO predictions in good agreement with each other
- NNLO corrections are small
- NNLO mostly a K-factor; NLO predictions adequate for most predictions at the LHC







$\sigma(W^+) > \sigma(W^-)$ for pp

$$\frac{\sigma(W^+)}{\sigma(W^-)} \approx \frac{u\bar{d}+\ldots}{\bar{u}d+\ldots} \approx \frac{u}{d} > 1$$

$\sigma(p\bar{p}) > \sigma(pp)$ but
$\sigma(p\bar{p}) \approx \sigma(pp)$ at large s

$$\frac{\sigma_Z(p\bar{p})}{\sigma_Z(pp)} \approx \frac{uu+dd+\ldots}{u\bar{u}+d\bar{d}+\ldots} \approx \frac{u}{\bar{u}} > 1$$

R = $\sigma(W) / \sigma(Z) \sim 10$

$$\frac{\sigma(W)}{\sigma(Z)} \sim \frac{|V_{ab}|^2}{v^2+a^2}\,\frac{BR(W\to l\nu)}{BR(Z\to l^+l^-)} \sim \frac{1}{0.3}3 \sim 10$$

Parton distribution functions (PDF's)

Evolve partons upwards using NLO (or NNLO) DGLAP equations. Fit data for scales above $2-5\mathrm{GeV}^2$. Need many different types of experiment for full determination.

H1 $F_2^{e^+p}(x,Q^2)$ 1996-97 moderate Q^2 and 1996-97 high Q^2, and $F_2^{e^-p}(x,Q^2)$ 1998-99 high Q^2 small x. ZEUS $F_2^{e^+p}(x,Q^2)$ 1996-97 small x wide range of Q^2. 1999-2000 high Q^2. H1 and ZEUS $F_2^{c,b}(x,Q^2)$.

NMC $F_2^{\mu p}(x,Q^2), F_2^{\mu d}(x,Q^2), (F_2^{\mu n}(x,Q^2)/F_2^{\mu p}(x,Q^2))$, E665 $F_2^{\mu p}(x,Q^2), F_2^{\mu d}(x,Q^2)$ medium x.

BCDMS $F_2^{\mu p}(x,Q^2), F_2^{\mu d}(x,Q^2)$, SLAC $F_2^{\mu p}(x,Q^2), F_2^{\mu d}(x,Q^2)$ large x.

CCFR $F_2^{\nu(\bar\nu)p}(x,Q^2), F_3^{\nu(\bar\nu)p}(x,Q^2)$ large x , singlet, valence.

E605, E866 $pN \rightarrow \mu\bar\mu + X$ large x sea.

E866 Drell-Yan asymmetry $\bar u, \bar d$ $\bar d - \bar u$.

CDF W-asymmetry u/d ratio at high x.

CDF D0 Inclusive jet data high x gluon.

DESY 07

Parton distribution functions (PDF's)

New data included.

NuTeV and CHORUS data on $F_2^{\nu,\bar{\nu}}(x,Q^2)$ and $F_3^{\nu,\bar{\nu}}(x,Q^2)$ replacing CCFR.

NuTeV and CCFR dimuon data included directly. Leads to a direct constraint on $s(x,Q^2)+\bar{s}(x,Q^2)$ and on $s(x,Q^2)-\bar{s}(x,Q^2)$. Affects other partons.

CDFII lepton asymmetry data in two different E_T bins – $25\mathrm{GeV} < E_T < 35\mathrm{GeV}$ and $35\mathrm{GeV} < E_T < 45\mathrm{GeV}$. D0II data for $E_T > 20\mathrm{GeV}$.

CDFII (prel) and D0II data on $d\,\sigma(Z)/d\,y$ for $0 < y < 2.5$.

HERA inclusive jet data (in DIS).

New CDFII high-E_T jet data.

DESY 07

Direct high-x data on $F_L(x,Q^2)$.

Update to include all recent charm structure function data.

Would like averaged HERA structure function data.