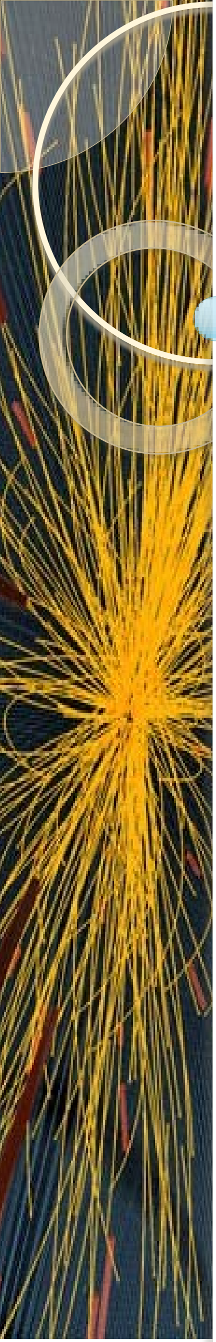
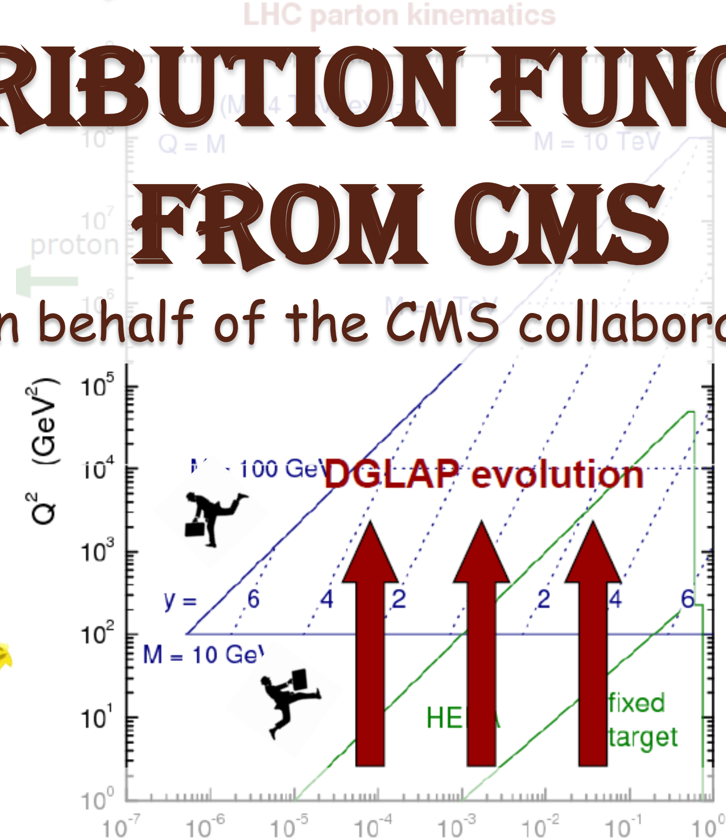


Maxime Gouzevitch

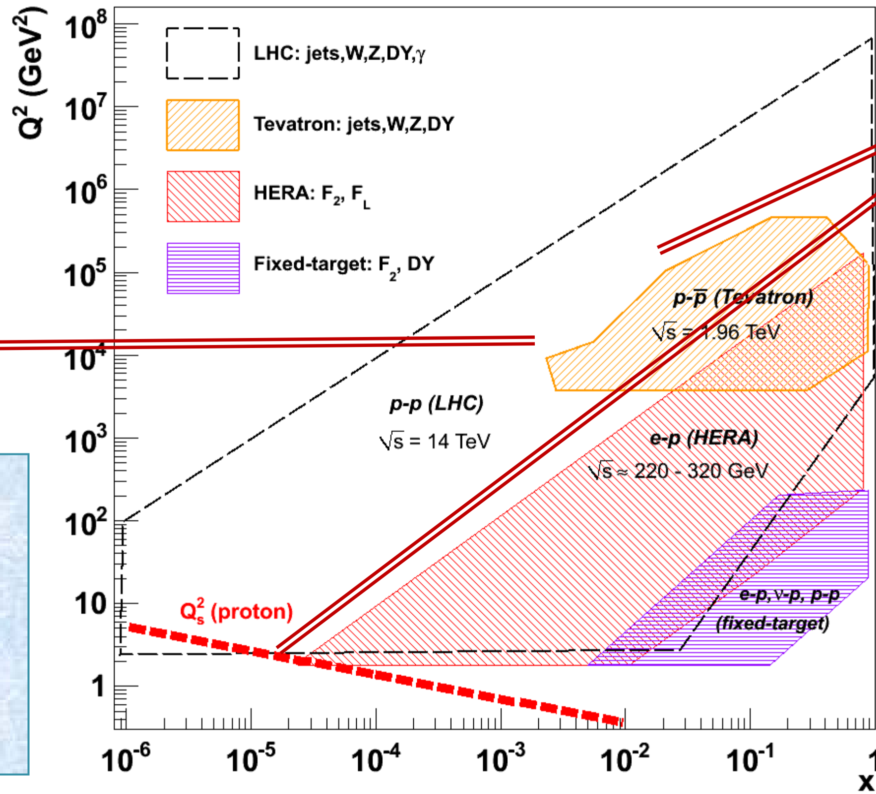
CONSTRAINTS ON PARTON DISTRIBUTION FUNCTIONS FROM CMS

on behalf of the CMS collaboration



Many thanks to: E. Perez, D. d'Enterria, H. Jung, K. Rabbertz, A. Cooper-Sarkar, V. Radescu for expertise.
I took inspiration for some slides from: J. Stirling, R.Rojo.

Scope of the talk



1

Quark PDFs from W,Z and DY production

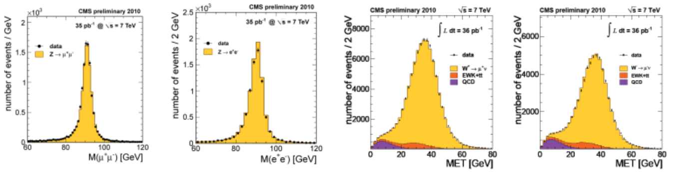
2

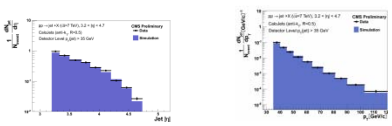
Gluon and α_S from jets

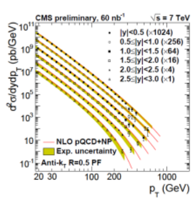
PDF@CMS

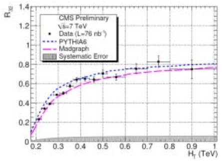
- Why do we need to look for PDFs @ LHC:
  - o Largest Q ever reached (TeV) → we trust DGLAP and RGE to reach it from low Q^2.
  - o Lowest x ever reached (10^{-5}) → we trust *ad hoc* parameterizations constraint by large x data.
  - o Lowest x at perturbative scale : saturation and non linear regime?

- What do we have?
  - o Quarks:
    - W, Z production.
    - DY, prompt photons.
    - Heavy flavors: B-tagged jets, D?
  - o Gluons:
    - Inclusive jets.
    - Dijets.
  - o α_S: Ratio – 3-jets /2-jets. Jet/Event shapes.

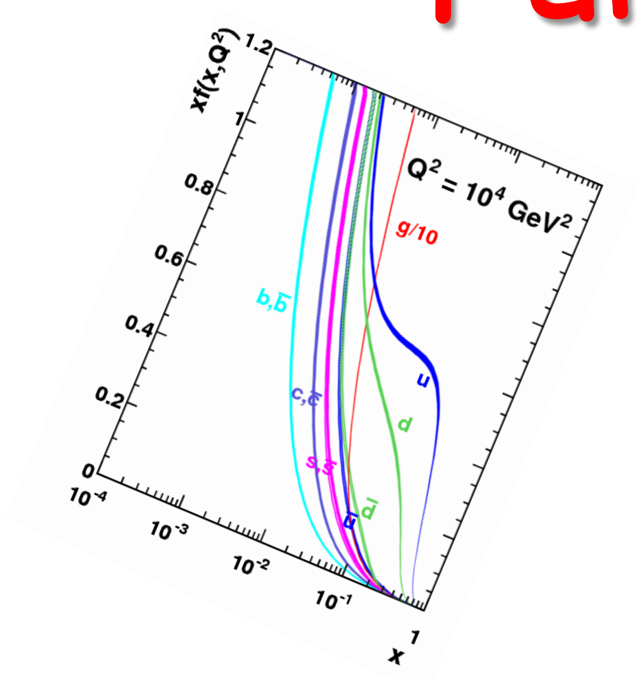




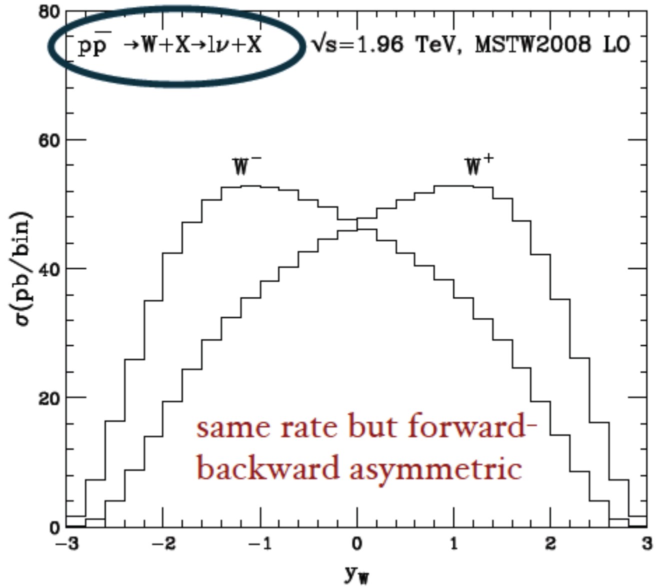


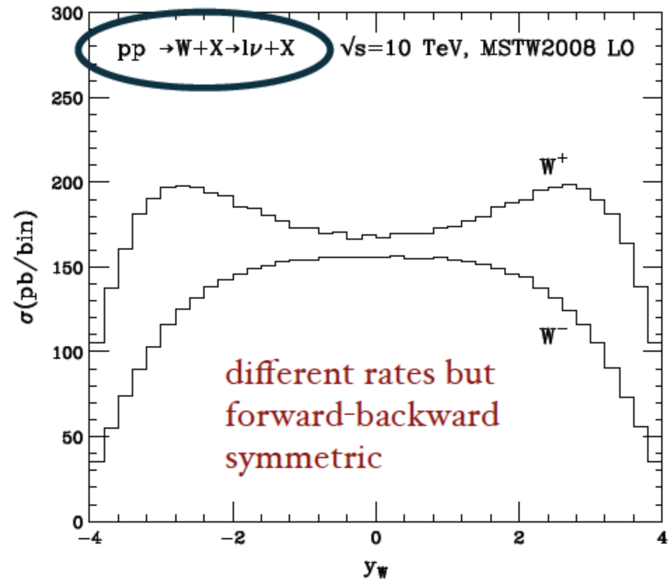


Quark Density Functions

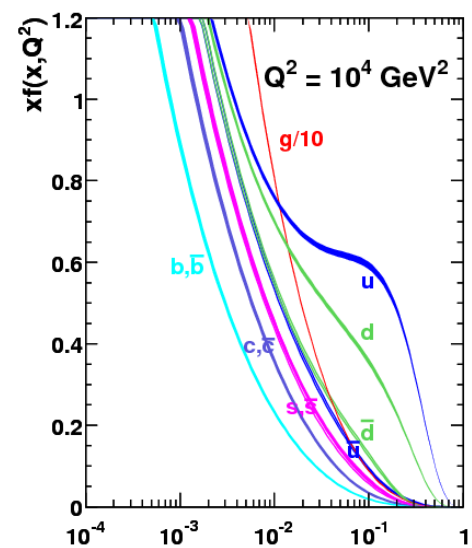


1) Quark densities and vector boson production

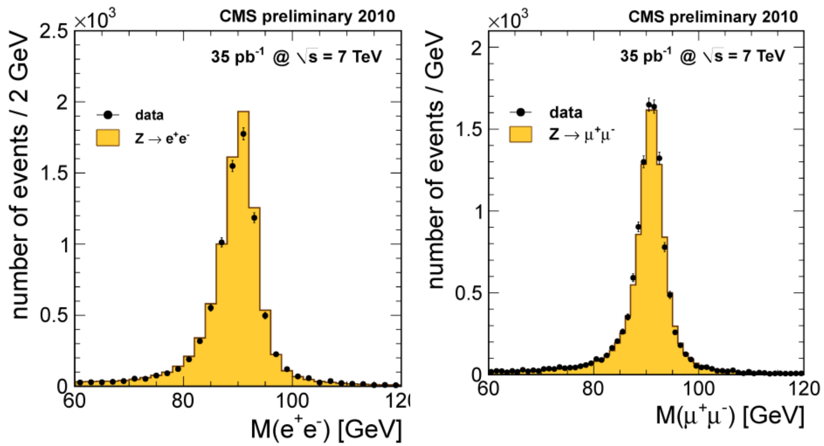




- W, Z production is directly sensitive to the quark densities: valence and sea.
- For example the W+ and W- rates are witness of u and d densities:
  - In average: $x_u > x_d$.
  - In average: $x_{u,d} > x_{anti\text{-}sea}$.



2.1) Inclusive production of W and Z @ CMS

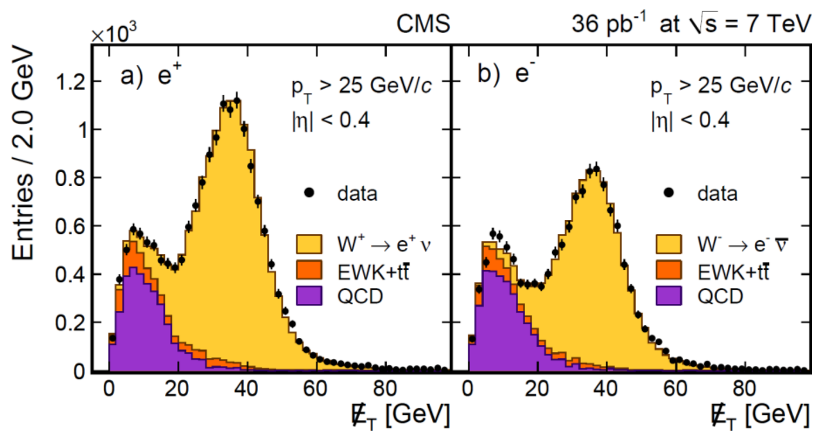


Z→ll

- Yield estimated by template fit from M_{ll}.
- Background estimated to be negligible.

$p_T(e, \mu) > 25$ GeV;

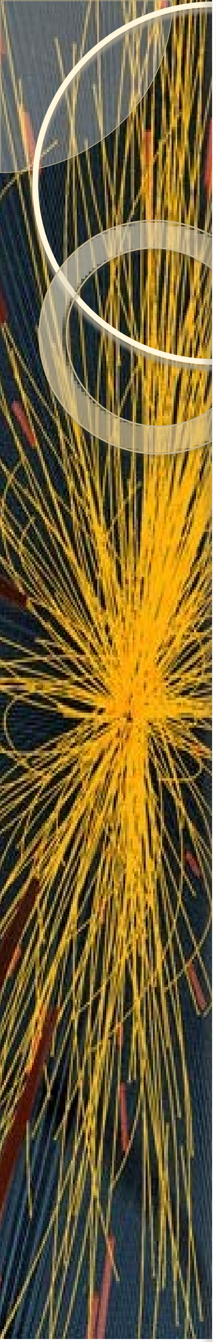
$|\eta_e| < 2.5$* ; $|\eta_\mu| < 2.1$.



$W^\pm \to l\nu$

- Yield estimated by template fit from ME_T.
- Background estimated with data driven methods.

*More precisely: $|\eta_e| < 1.44$ && $1.56 < |\eta_e| < 2.5$ due to ECAL acceptance.

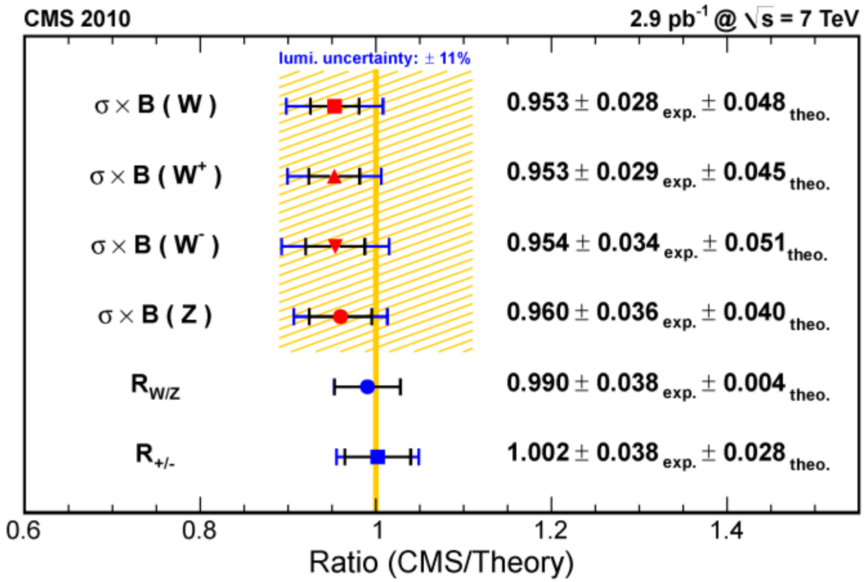


2.2) Inclusive production of W and Z @ CMS

Source	Explanation	Size @2.9pb^{-1}	Prospects for 2011
Lumi	Wan der Meer scans (*PAS-EWK-10-004*). Beam current (5%/beam)	11%	~ 3-5%
Leptons reconstruction	Scales, id …	3-4%	< 1%
Background simulation	Especially for W production	1-2%	< 1%
Acceptance	POWERHEG with different PDFs (CTEQ6.6, MSTW08NLO, NNPDF2.0).	1-2%	1-2%
Total		2-6%⊕ 11%(Lumi)	1-2%⊕ 3-5%(Lumi)

Results about to be public for 35pb^{-1},
The uncertainties are shown for 2.9 pb^{-1} (*arXiv:1012.2466v2*).

2.3) Inclusive production of W and Z @ CMS

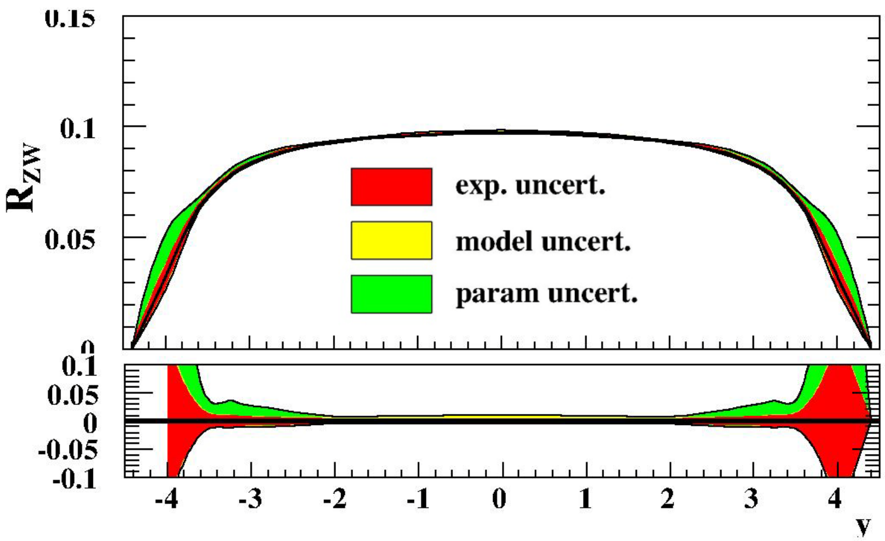


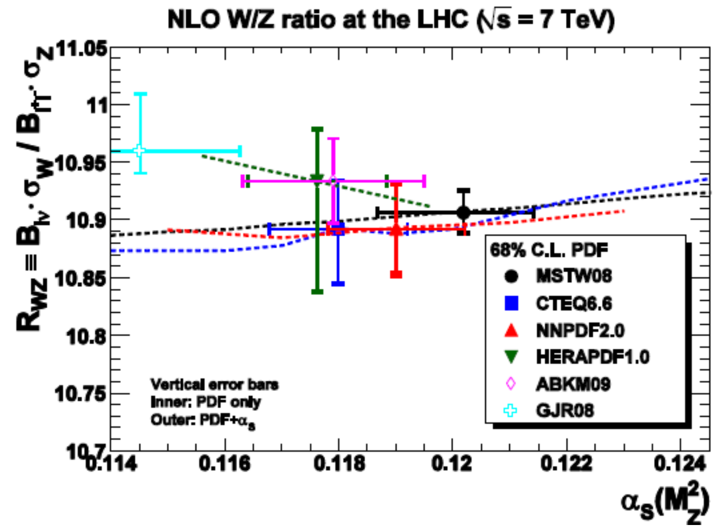
σ(Theory) =
NNLO scales ⊕
MSTW08(68%) ⊕ α_S

PDF uncertainty on W: ~5%.

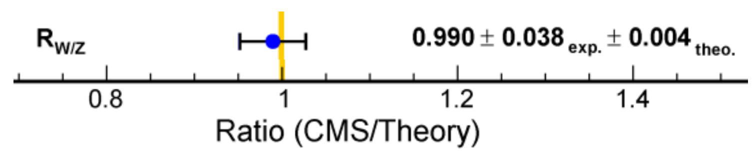
- Absolute cross sections: $\sigma_{exp} < \sigma_{NNLO}$. But σ_{Lumi} might be a limiting factor for the absolute qq luminosity, but not for the shape.
- Asymmetries: $\sigma_{exp} \sim \sigma_{NNLO}$. Extrap. σ_{exp} (2011) ~1% ~ $\sigma_{NNLO}/3$.
  (see Martyn Jarves talk)
- Yields@2.9pb^{-1}: Y(Z) ~ 2K events, Y(W) ~ 50K events.
  - Already in 2010 with 35 pb^{-1} enough data for η binning.
  - In 2011 @ 1fb^{-1}: Y(Z) ~ 0.5M, Y($W^{\pm}$) ~ 1.5M events.

3.1) Impact of W and Z production on PDFs



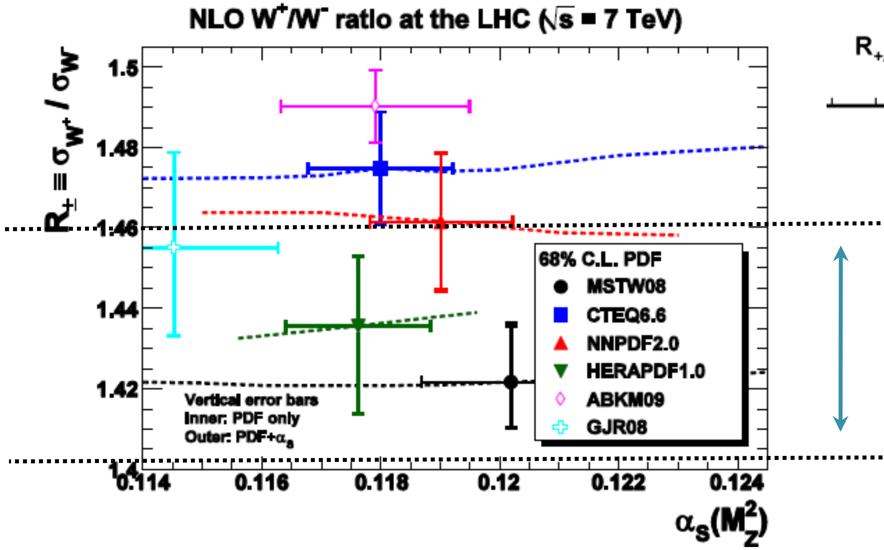


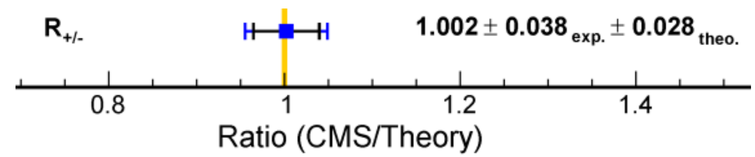
$$R_{ZW}(y) \propto \frac{u\bar{u}+d\bar{d}+...}{u\bar{d}+d\bar{u}+...} \propto \frac{(u+d)\cdot\overline{sea}+...}{(u+d)\cdot\overline{sea}+...} \propto C$$



- Rate flat in the center.
- Low sensitivity to the PDF and α_S, rather to the kinematics.
- Good agreement between PDFs and with CMS results.
- Excellent benchmark to check the quality of CMS measurements.

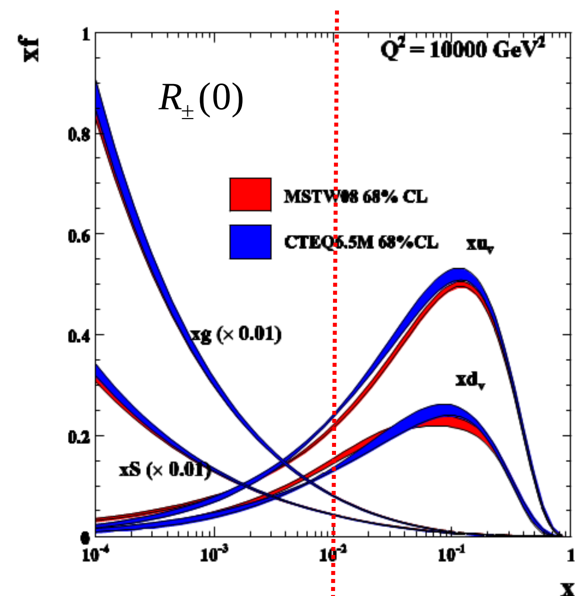
3.2) Impact of W and Z production on PDFs





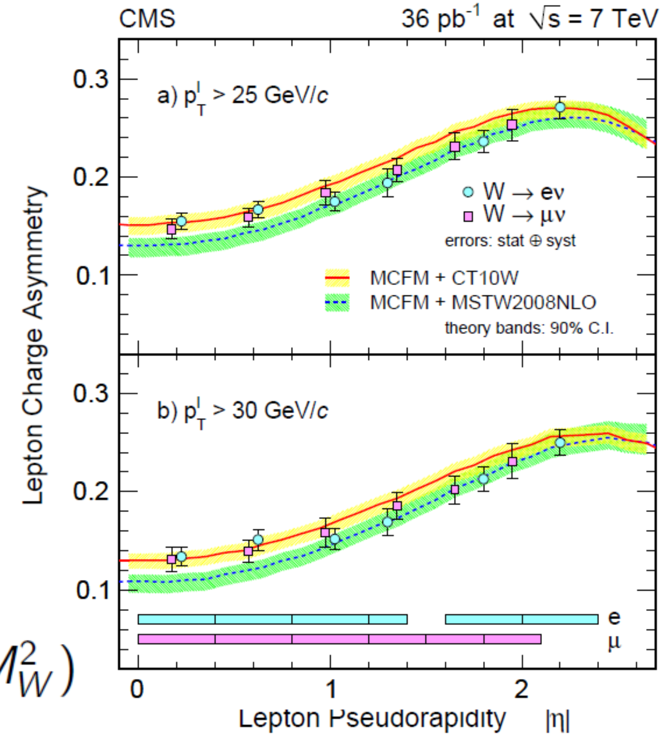
Typical experimental precisionn in 2011.

- Sensitive to the difference in the **u, d** valence. Poorly constrained by HERA data below $x=10^{-2}$: we need large Q with W,Z exchange in DIS to separate **u** from **d**.
- Sensitive to **c** quark (A.Cooper-Sarkar).
- Significant disagreements 4% between PDFs and large uncertainties.
- CMS has the potential to constraint the parameterizations in 2011.



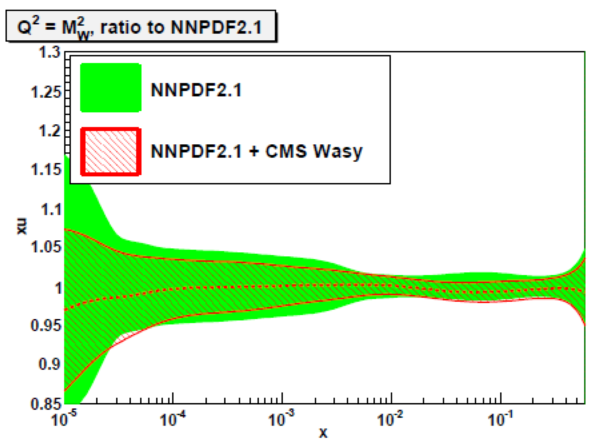
$$R_{\pm}(y) \propto \frac{u\bar{d}+\ldots}{d\bar{u}+\ldots} \propto \frac{u_v\,\overline{sea}+\ldots}{d_v\,\overline{sea}+\ldots}$$

3.3) Impact of W and Z production on PDFs

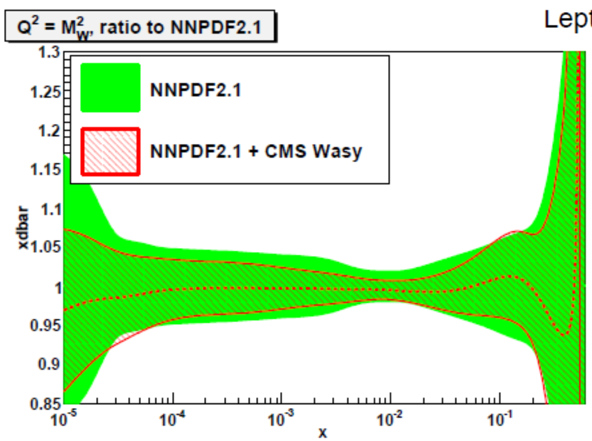


$$A_\ell(y_\ell) = \frac{d\sigma(W^+)/dy_\ell \ - \ d\sigma(W^-)/dy_\ell}{d\sigma(W^+)/dy_\ell \ + \ d\sigma(W^-)/dy_\ell}$$

$xu(x, M_W^2)$



$x\bar{d}(x, M_W^2)$

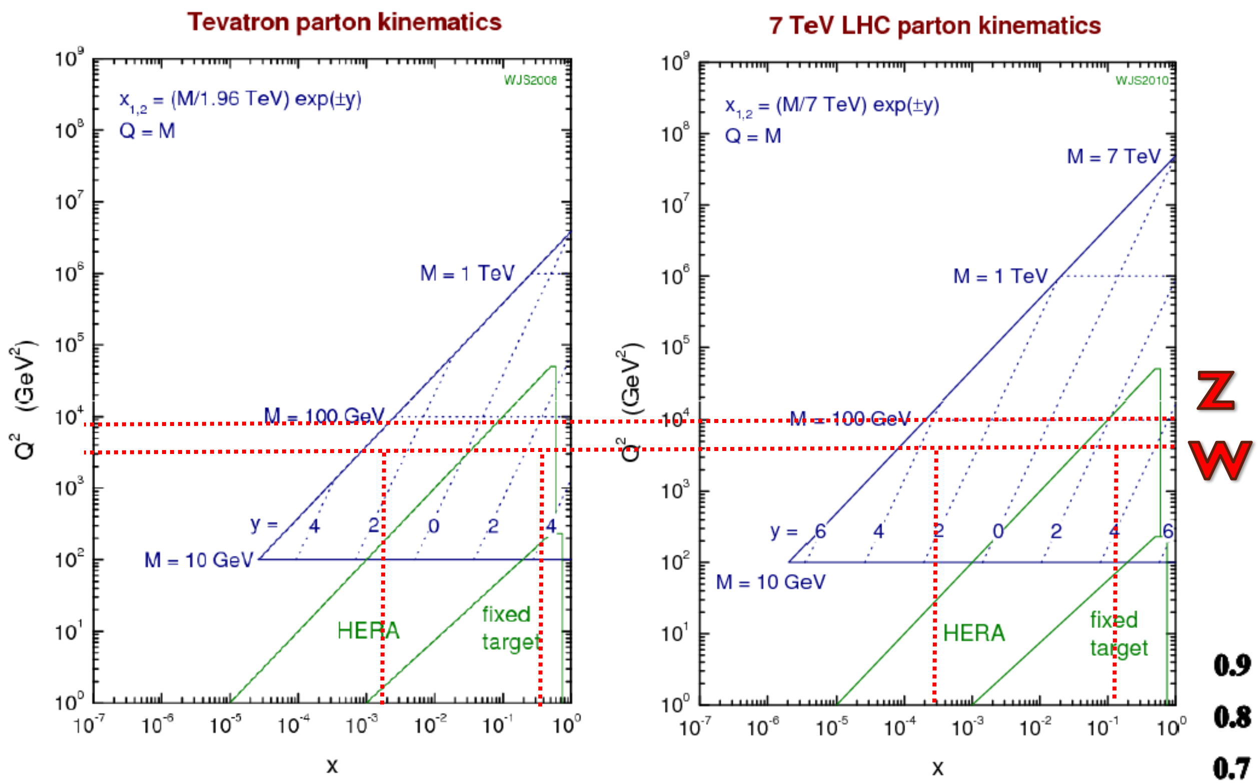


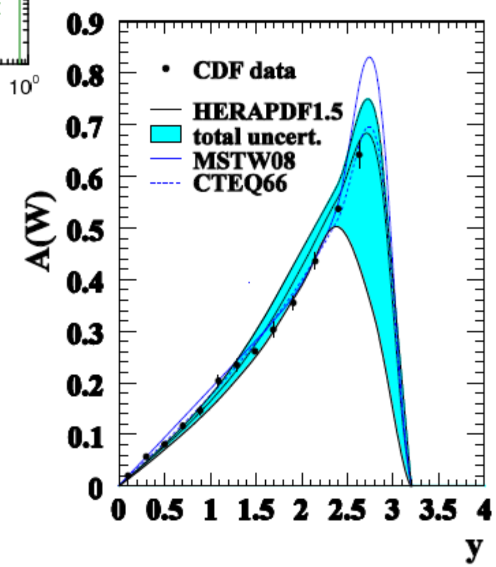
Sea quark PDF uncertainties reduced at medium and small-x

CMS Wasy data: first LHC constrains on PDFs

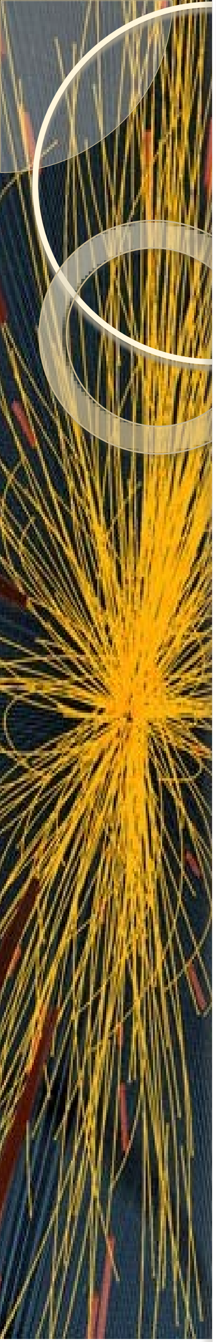
(J. Rojo)

3.4) Impact of W and Z production on PDFs





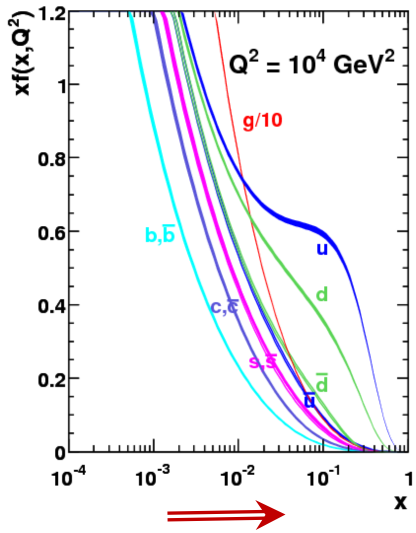
- The precision of W asymmetry in Tevatron already exceeds the PDFs precision. Do we need LHC data?
- But the LHC give a handle to the sea at $x \sim 3 \cdot 10^{-3}$.

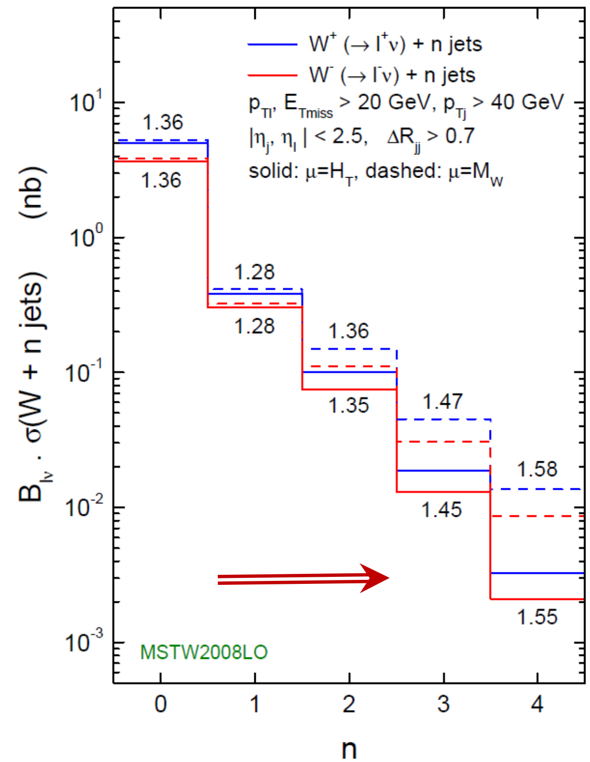


4) Go 1 step further

C.H. Kom, W.J. Stirling arXiv:1004.3404

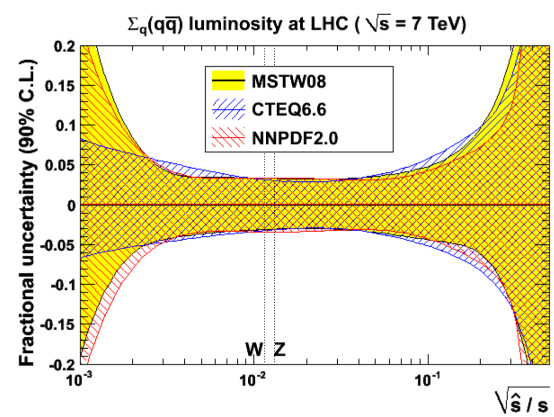
- We can control the values of x by requesting additional jets. Not done at my knowledge at Tevatron.



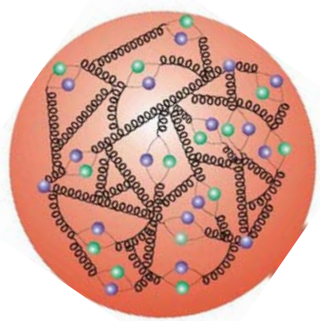


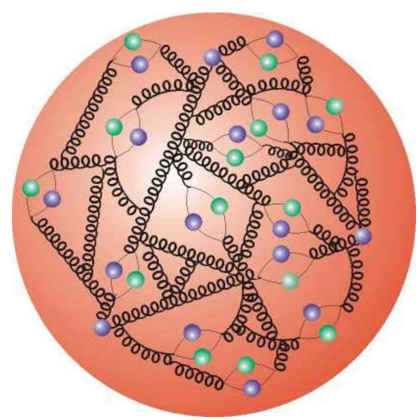
- The DY production via **Z*** or γ* would give access to the full range of masses and x values.

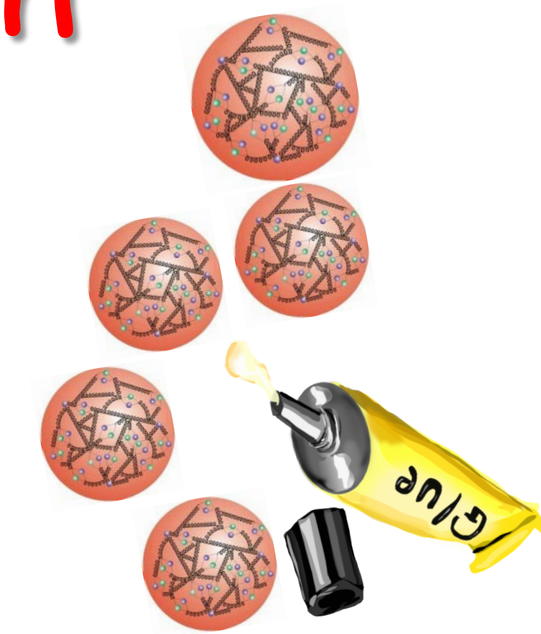
$$\frac{d^2\sigma}{dM_{ll}dy}[pp \to l_1 l_2] \sim \sum_{ij} \left(f_{i/p}(x_1) f_{j/p}(x_2) + (i \leftrightarrow j)\right) \hat{\sigma},$$

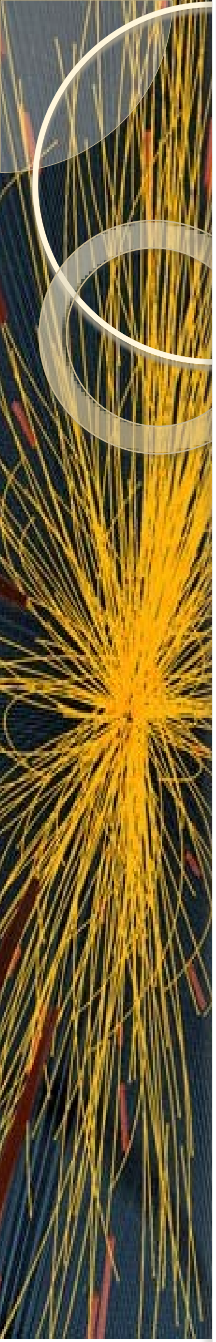


Gluon Density Function

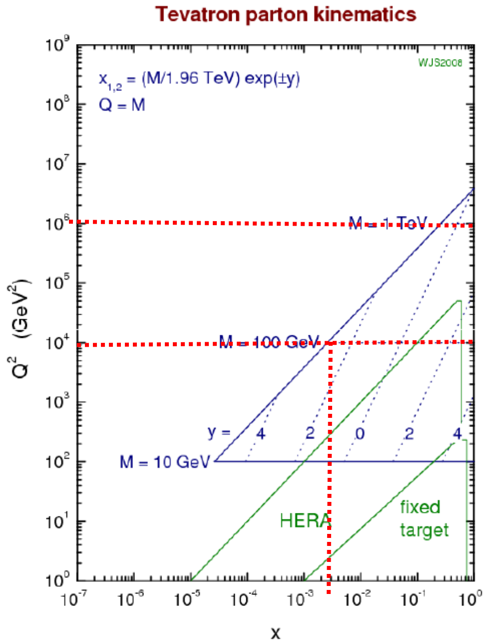


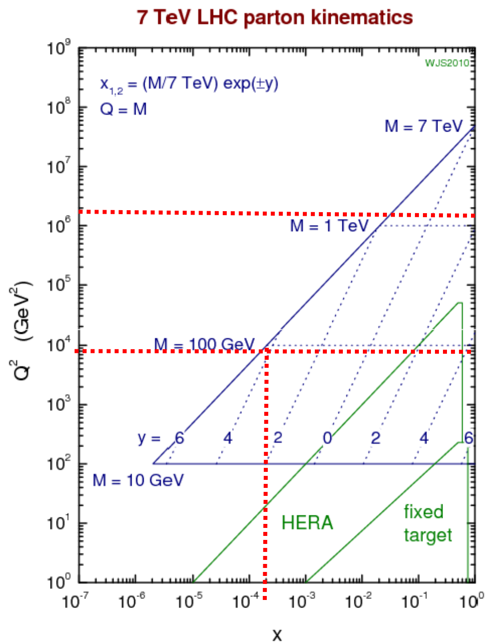


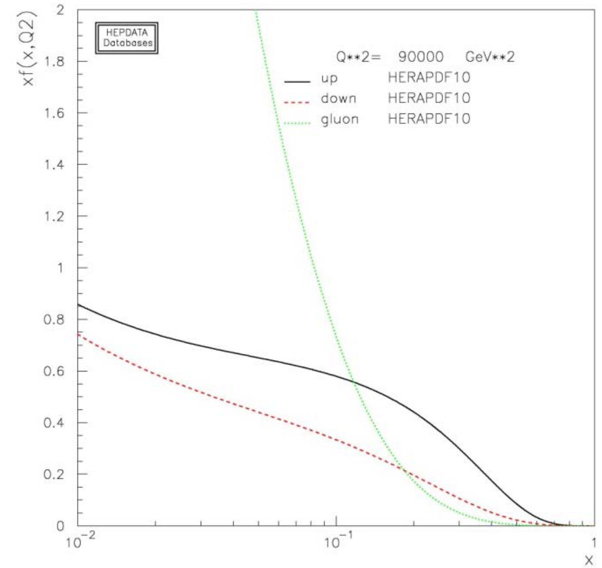




1) Inclusive jets production @LHC







http://hepdata.cedar.ac.uk/pdf/pdf3.html

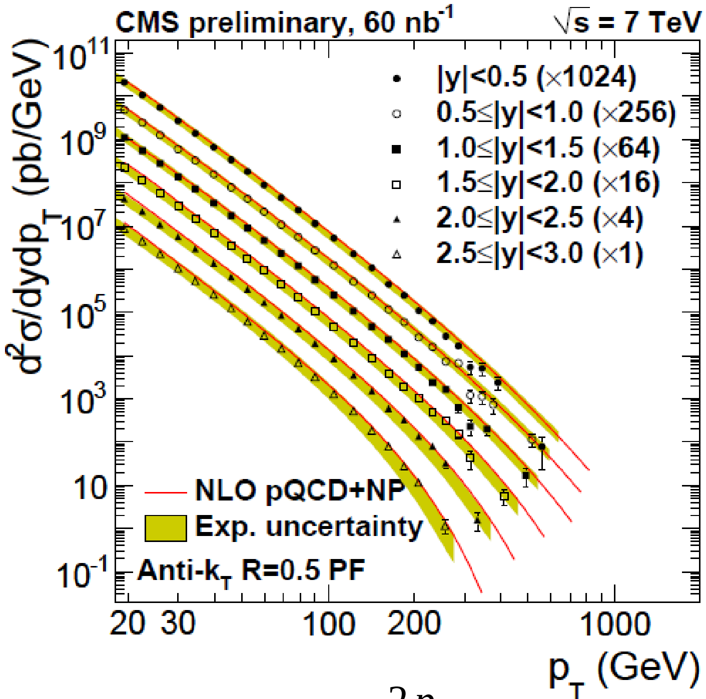
- On the plots is shown the typical region accessible to the inclusive jets measurement.
- @7TeV: we can reach lower x than in Tevatron.
- @7TeV the gluon luminosity dominates up to p_T ~ 300 GeV.

$$x_{1,2} = \frac{p_T}{\sqrt{s}}\left(e^{\pm y_1} + e^{\pm y_2}\right);\ \mathrm{M}{=}2\,p_T\left(1+\cosh(\Delta y)\right)$$

2.1) Inclusive jets in CMS

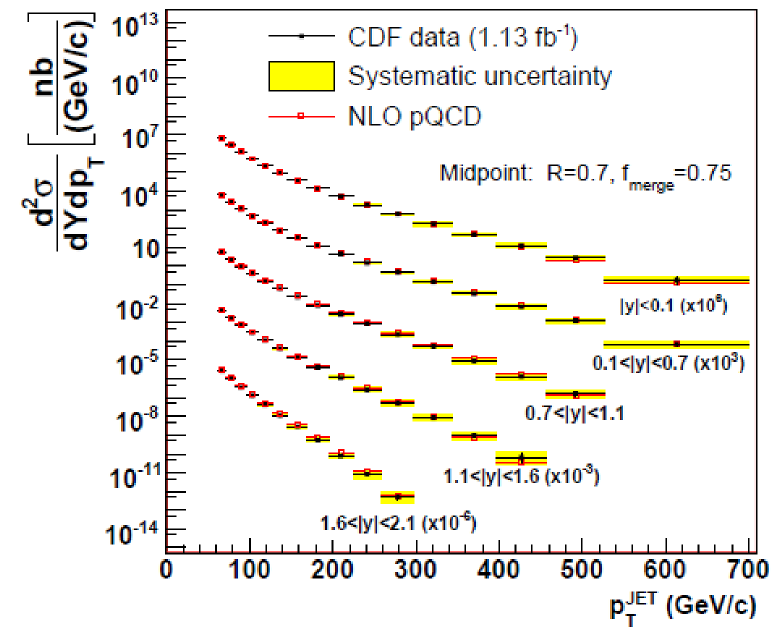
$$x_{1,2} = \frac{p_T}{\sqrt{s}}\left(e^{\pm y_1} + e^{\pm y_2}\right)$$

PAS-QCD-10-011



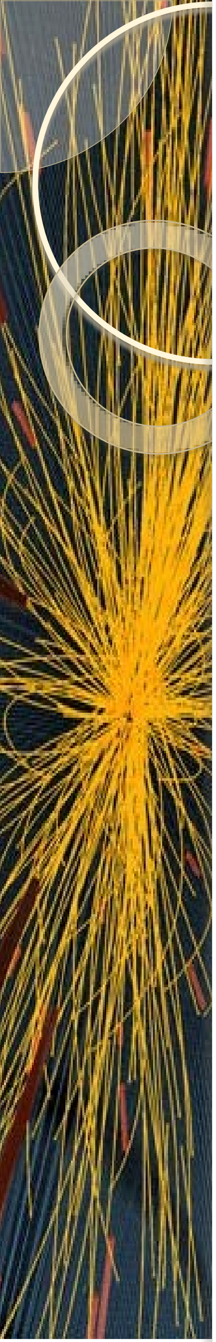
$$5\cdot 10^{-3} < x_{y\sim 0} \sim \frac{2p_T}{\sqrt{s}} < 0.1$$

arXiv:0807.2204



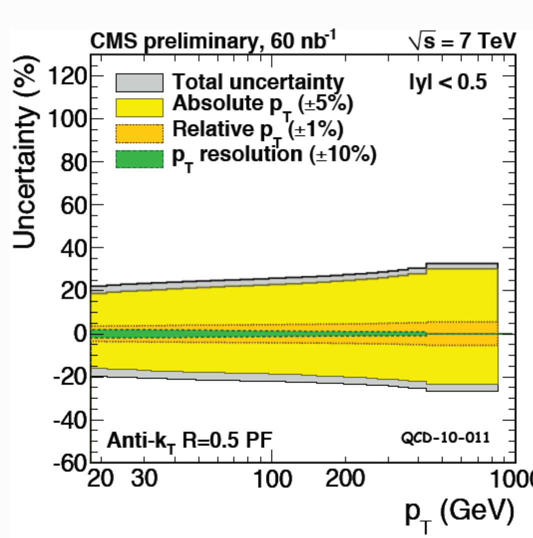
$$0.1 < x_{y\sim 0} \sim \frac{2p_T}{\sqrt{s}} < 0.6$$

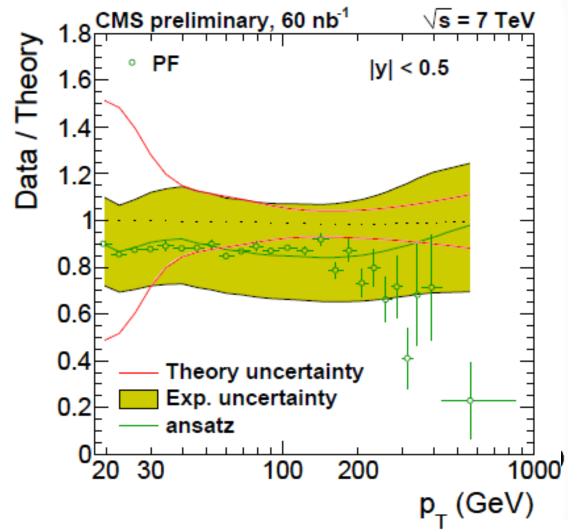
- Low p_T region reached by novel reconstruction method. Dominated by non-peturbative corrections.
- Good description by QCD@NLO.
- 0.2% of 2010 data sample shown. Remaining in the production pipe for Moriond.

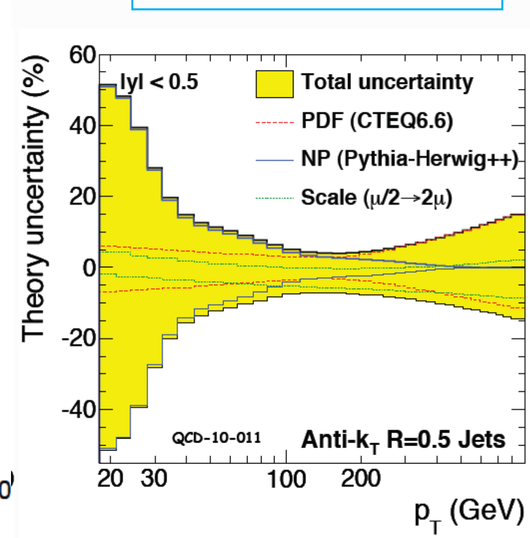


2.2) Inclusive jets in CMS

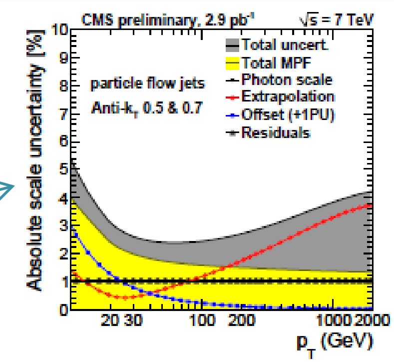
$$x_{1,2} = \frac{p_T}{\sqrt{s}}\left(e^{\pm y_1} + e^{\pm y_2}\right)$$







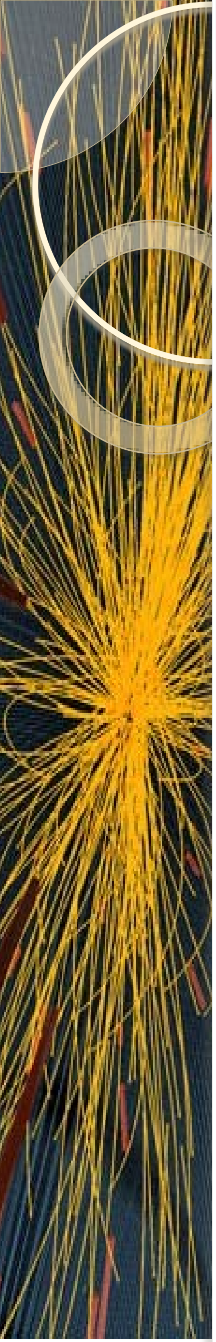
1. Lumi now 11%
   → We expect in 2011: ~ 3-5%.
2. Jet Energy Scale uncertainty 5%
   → We expect in 2011: ~ 2.5%.



3. Statistics would rise by 10^4 in 2011
   and become negligible uncertainty up to p_T = 1 TeV (x~0.3).

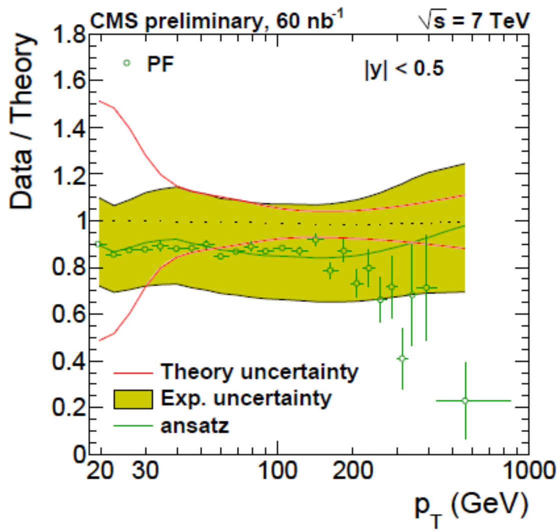
Total @ 1 fb^{-1}: 10% (JES) ⊕ 5% (Lumi) ~ 11% up to p_T = 1 TeV.

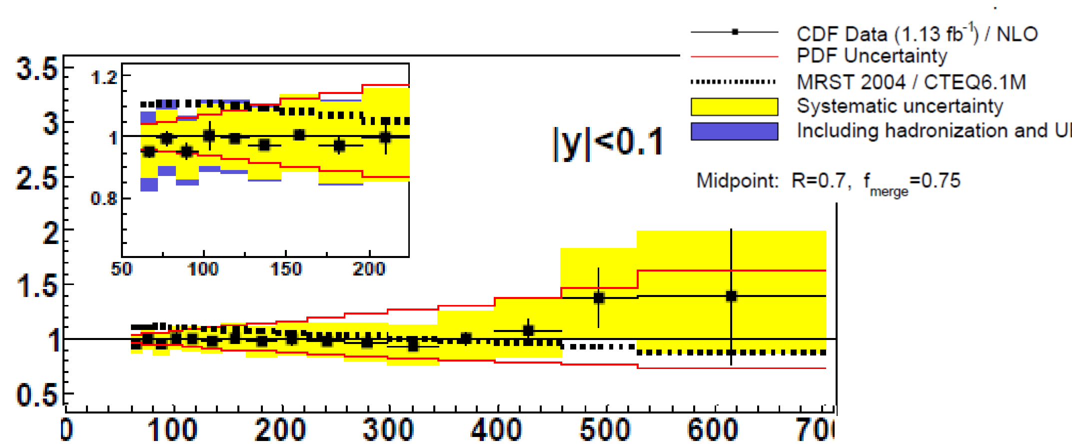
→ Comparable to the PDF dependence (5-10%).



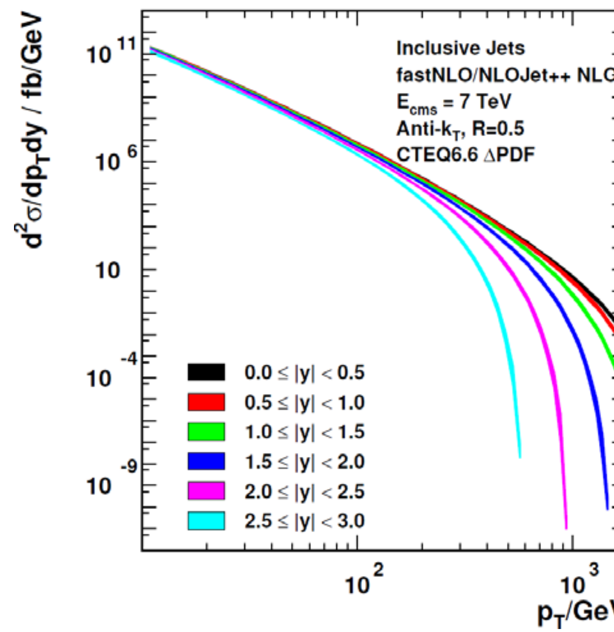
3) Inclusive jets: expected sensitivity

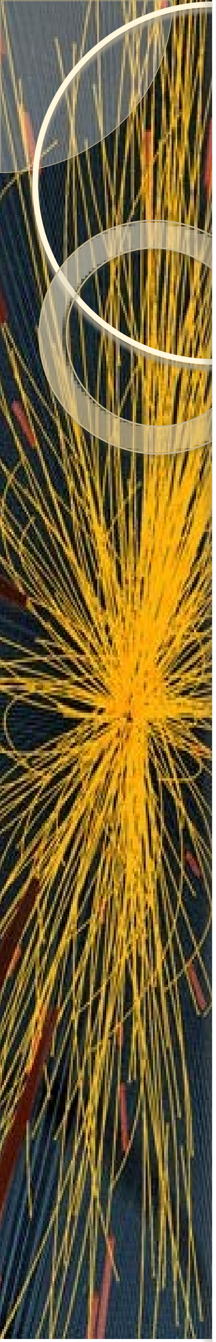
$$x_{1,2} = \frac{p_T}{\sqrt{s}}\left(e^{\pm y_1} + e^{\pm y_2}\right)$$





- Total @ 1 fb^{-1}: 11% up to 1 TeV jets.
- Similar to the Tevatron sensitivity at x~0.3 or p_T ~ 300 GeV.
- But to reach at the LHC the x~0.6 for y ~ 0 (symmetric scattering) we need p_T = 2 TeV and ~100fb^{-1} ☹
- But at y ~ 1 (asymmetric scattering) we have p_T = 1 TeV and ~ 100 events already at 1 fb^{-1} ☺.

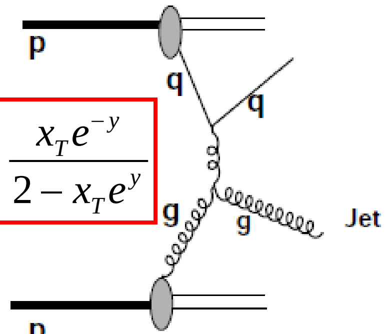


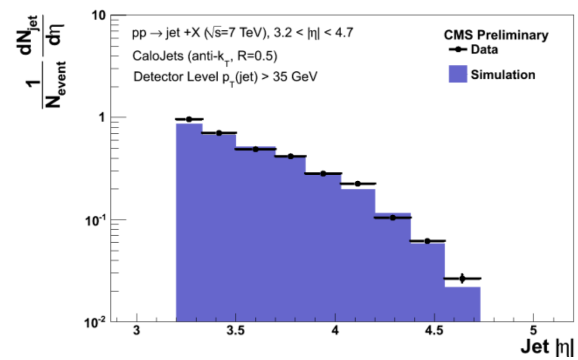


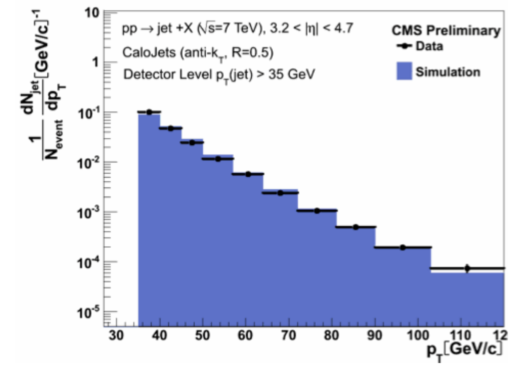
1) Forward jets and low x duality

CMS-DPS-2010/026

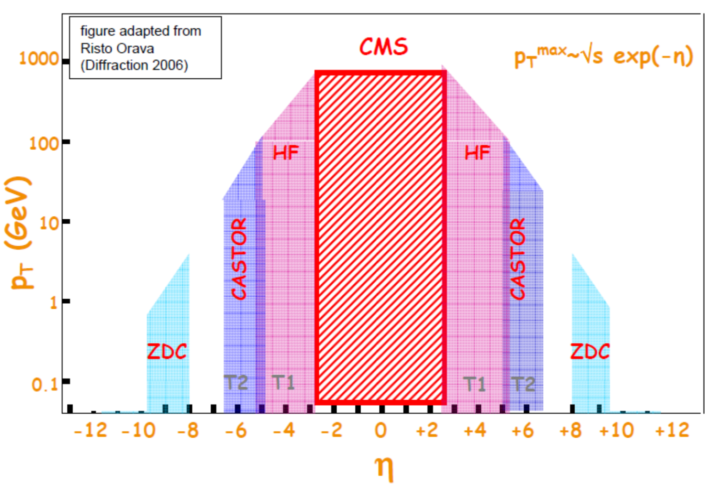
$$x_{\min} = \frac{x_T e^{-y}}{2 - x_T e^{y}}$$

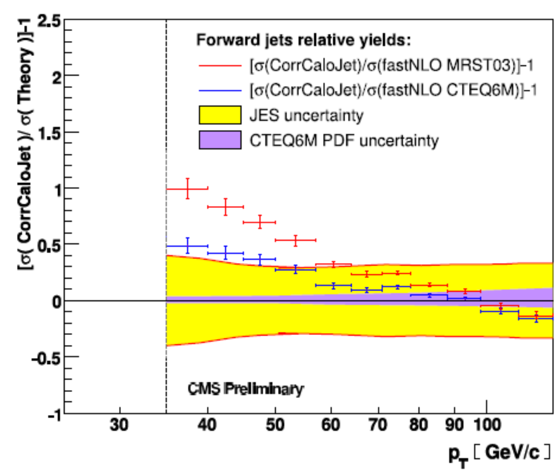






- Forward jets give a e^{-y} lever-arm: x/10 when y+2.
- x_{min} (Hadronic Forward Calo) ~ $2e^{-4}$ and x_{min} (Castor) ~$1e^{-5}$.
- Gluon PDF is only indirectly constrained by Inclusive HERA measurements since HERA jets reach at most x_{min} ~ $5\ e^{-3}$.

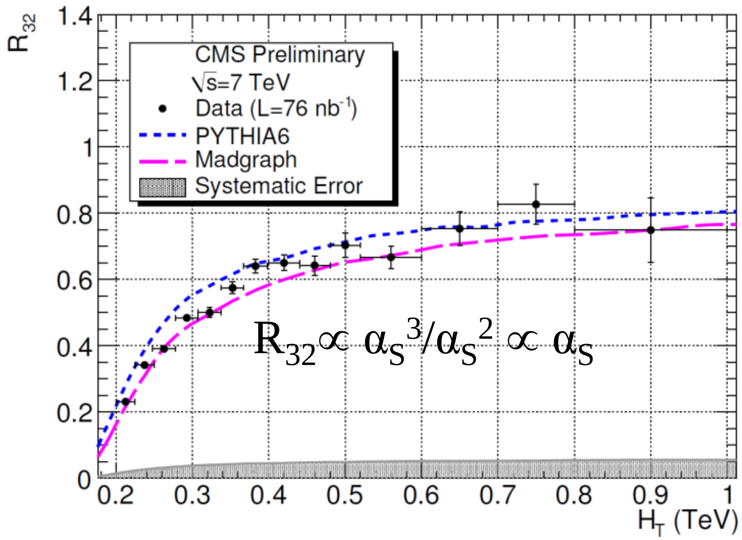




D. d'Enterria, arXiv:0911.1273

4) Test the α_s running @ TeV

- DGLAP equation rely on α_S running to extrapolate from low Q^2 to large Q^2
- We can take $\alpha_S(M_Z)$ from external measurement (LEP) or leave free in the PDF fit. But then we need observables sensitive mainly to α_S running to decorrelate gluon and coupling.
- For example: HERA, Tevatron jets.
- In LHC: Event shapes, Inclusive jets and $R_{32.}$



R_{32} = 3-jet/2-jets = $f(H_T = \sum p_T)$
PAS-QCD-10-012

Source	Size
Experimental	5-10%
PDF	~2%
Missing orders below NLO	~5%
α_S sensitivity	~ 2-5%

- Estimates from K. Rabbertz in α_S workshop in MP Munich (5 days ago).

4) Test the α_S running @ TeV

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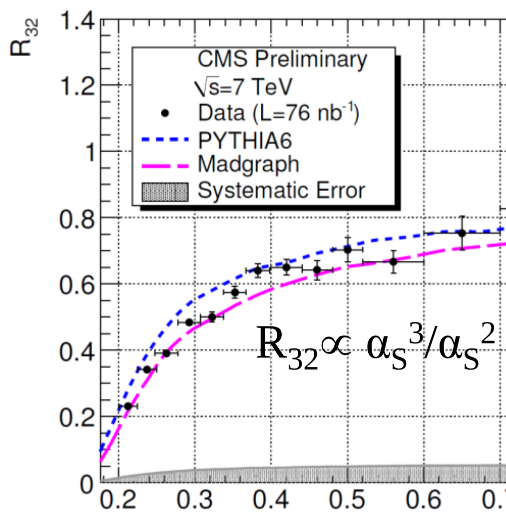


$R_{32} \propto \alpha_S^3/\alpha_S^2$

R_{32} = 3-jet/2-jets = f([redacted]
PAS-QCD-10-012

[redacted]	Size
[redacted]	5-10%
[redacted]	~2%
[redacted]	~5%
[redacted]	~ 2-5%

[redacted] Rabbertz in αS [redacted] Munich (8- [redacted]

- Need more experimental && theory investigation and NNLO calculations.

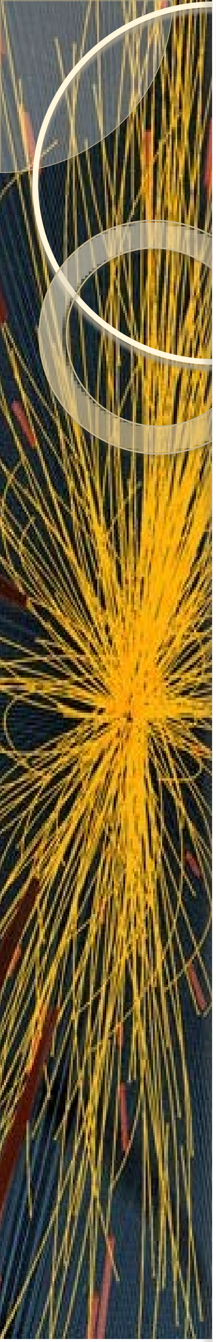
What can we expect from PDFs@LHC

- The PDFs in LHC region are constrained via DGLAP evolution from previous generation experiments.
- Nevertheless uncertainties between 5-20% persist in well constrained regions (typically quark and gluons at $10^{-4} < x < 0.5$).
- In low $x < 10^{-4}$ and large $x > 0.5$ constraints comes mainly from parameterization with large systematic dependencies on fit assumptions (up to 100%).
- LHC have to contribute in those regions to benefit from reliable PDFs.
- LHC may finally access the saturation regime, an exciting non-linear regime that experimentalists are hunting since many years.

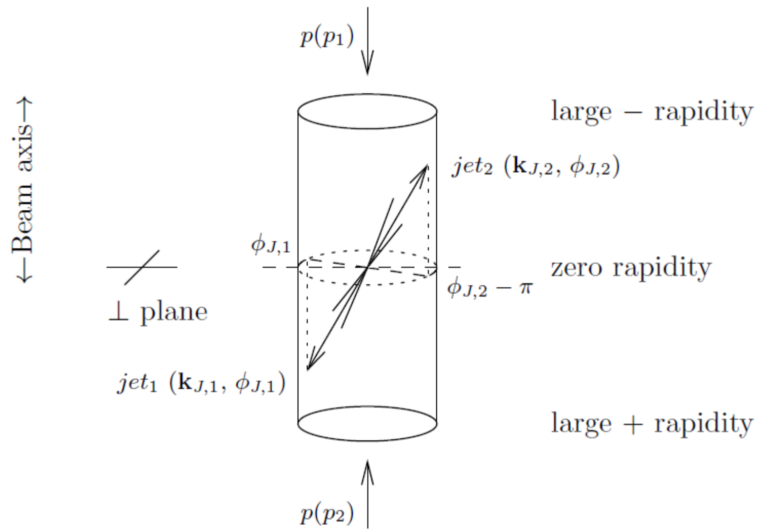
Questions and ideas for the discussion

- Shall the LHC study the sensitivity of it's data in the PDF fits?
- If no: let's wait the global fit collaborations take care of it.
- If yes: there would be few dozen of LHC points. What do we use in addition?
  - Global fits? Does it makes sense to enter the game of global fits, since it is a huge work already performed by 3 collaborations and we don't have man power?
  - Add LHC data to single experiment fits from HERA: already tested as HERA+Tevatron Data. An interesting solution: use tools for HERAPDF (1 tool from H1 and 1 from ZEUS) with HERA data and add LHC points.
  - Then following questions rises:
    - Author right? Which tolls are public, which interanl to the collaborations?
    - Need more toy studies to understand if HERA PDF without fixed target have enough constraints for LHC at large x? For example: if CI was there would they be absorbed by HERA PDF parametrization?
    - Man power? Shall it be done separately in each experiment? In common between experiments? Following the structure of low pT QCD group or Higgs group?
    - Message?

BACKUP



2) BFKL and CCFM

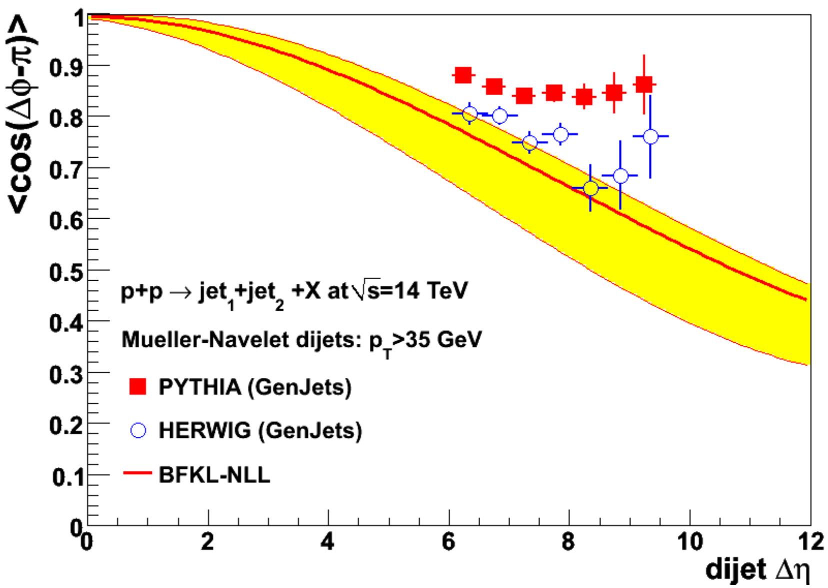


The Mueller-Navelet jets

$|\Delta\eta_{12}|$ large, $p_{T,1} \sim p_{T,2}$

→ No room for DGLAP evolution: $\Delta\varphi_{12} \sim \pi$.

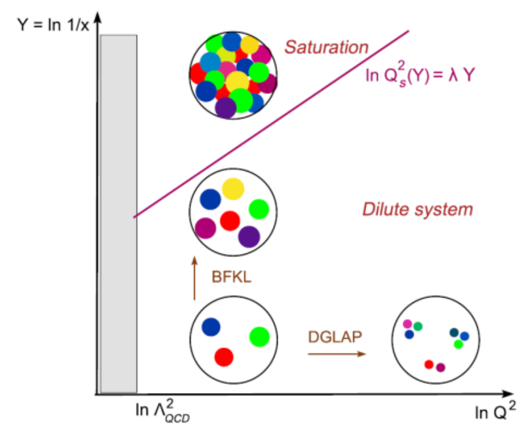
→ Room for soft emissions BFKL (x ordering), CCFM like (θ ordering): $\Delta\varphi_{12} < \pi$



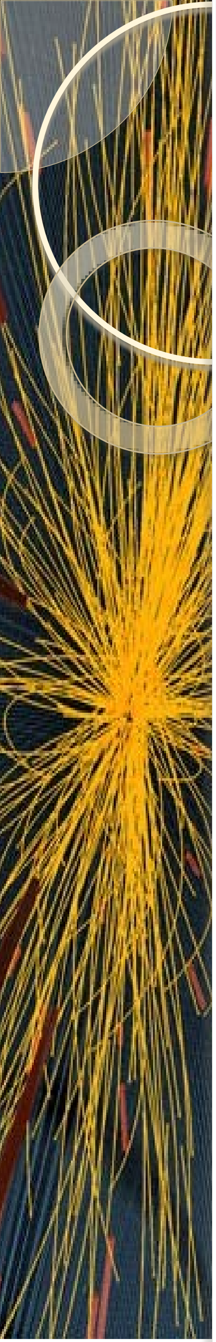
LO ME

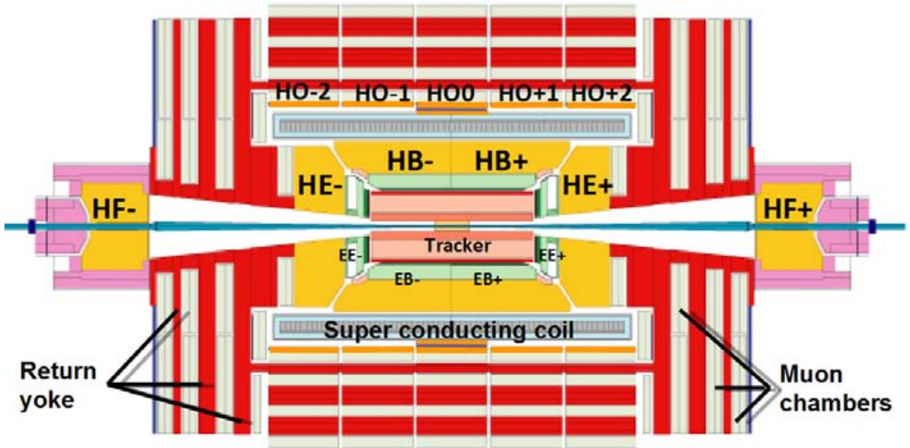
DGLAP

BFKL



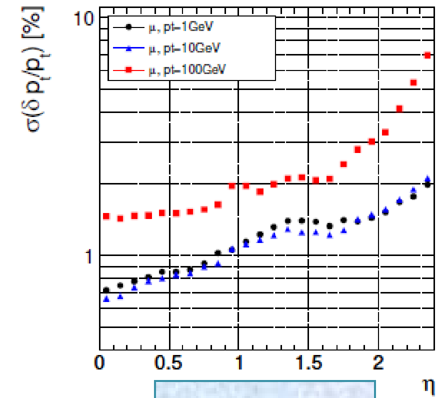
5.1) Particle Flow: global event reconstruction framework



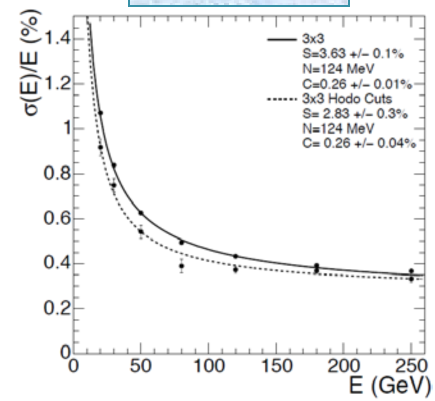


- Using the combination of all available detectors to reconstruct and indentify particles (π, γ, K0, μ, e)
- Low pT π: precision dominated by the tracker.
- High pT π: precision dominated by calorimeters.

Tracker

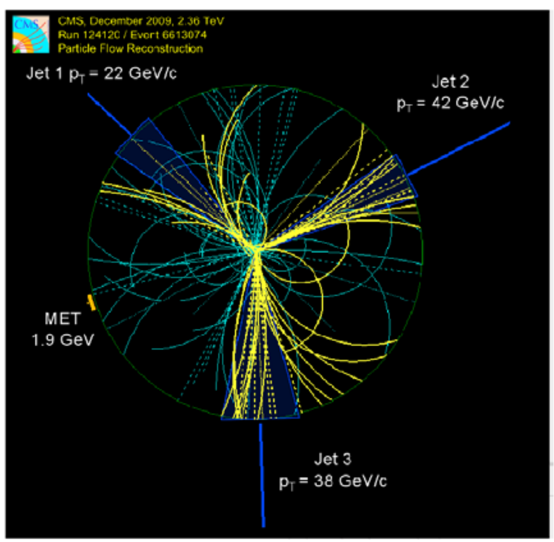


ECAL



HCAL:

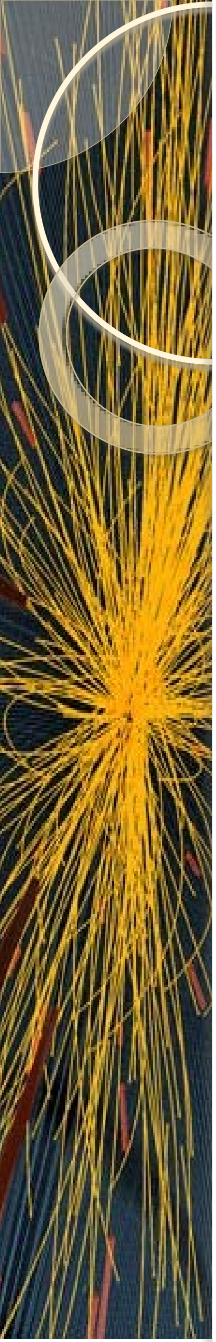
$120\%/\sqrt{E} + 6.9\%$



Transverse view of CMS Tracker (∅ = 2.5 m)

Particles in Jets
Particles out of Jets

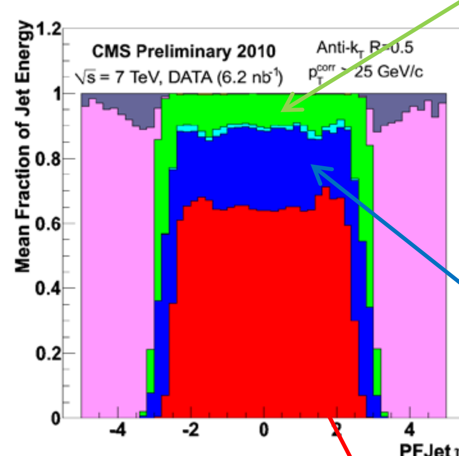
— Charged hadrons
····· Photons
····· Neutral Hadrons



5.1) Particle Flow: global event reconstruction framework

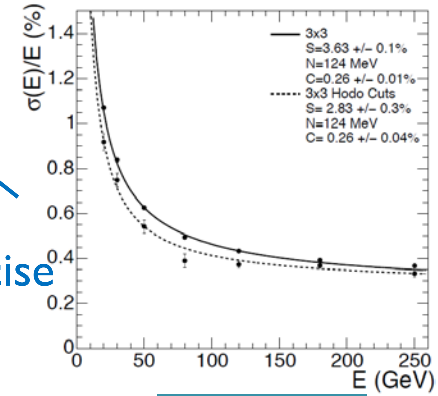
- Using the combination of all available detectors to reconstruct and indentify particles
  (π, γ, K_0, μ, e)
- Low p_T π: precision dominated by the tracker.
- High p_T π: precision dominated by calorimeters.

PAS-PFT-10-003



HCAL:
120%/ √E + 6.9%

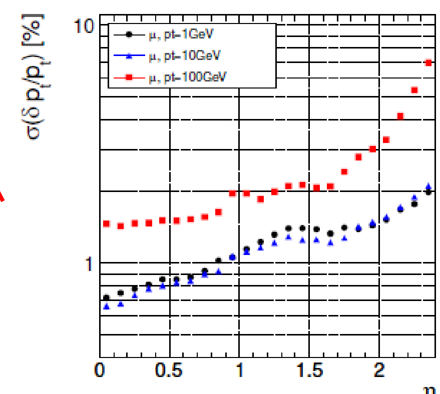
ECAL

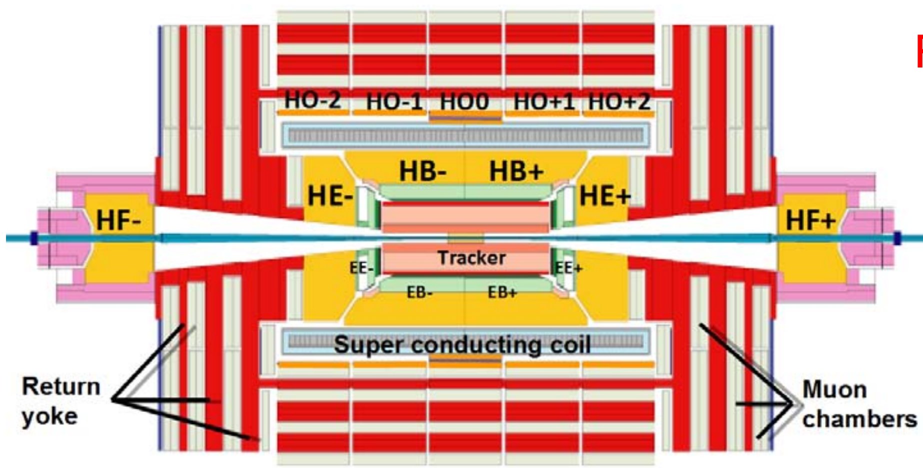


Precise

Precise

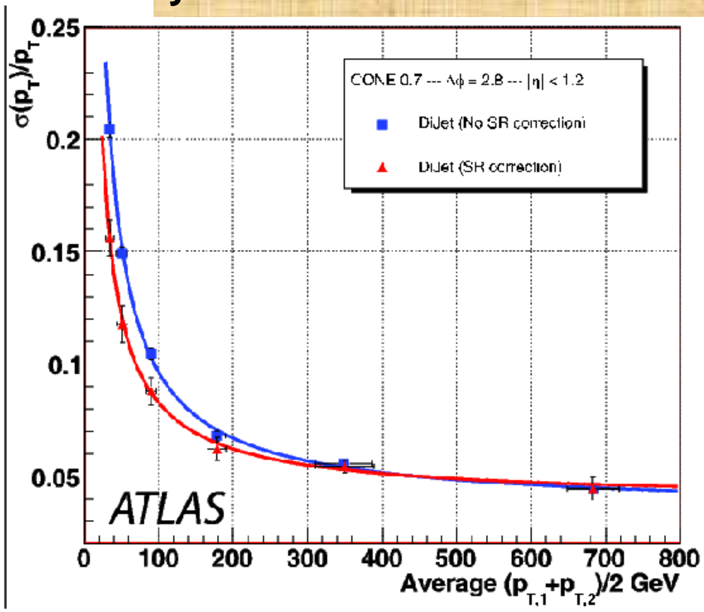
Tracker



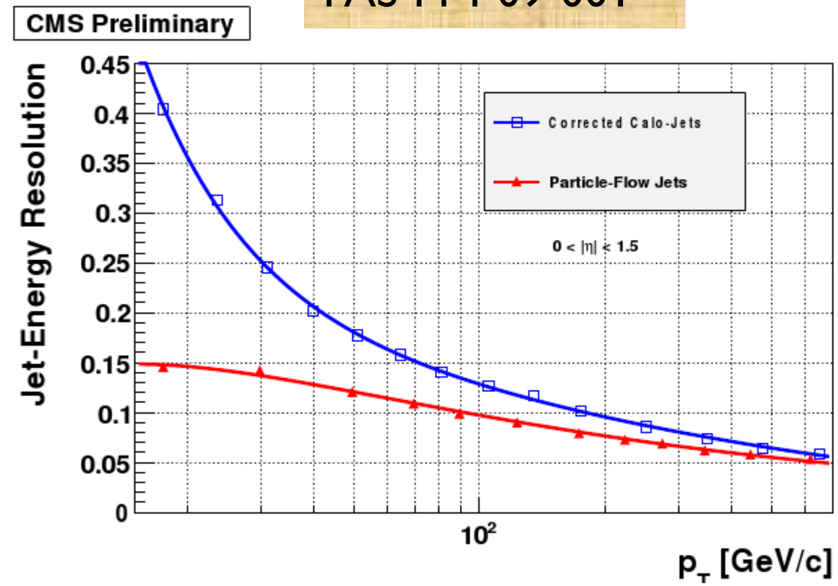


5.2) Particle Flow: global event reconstruction framework

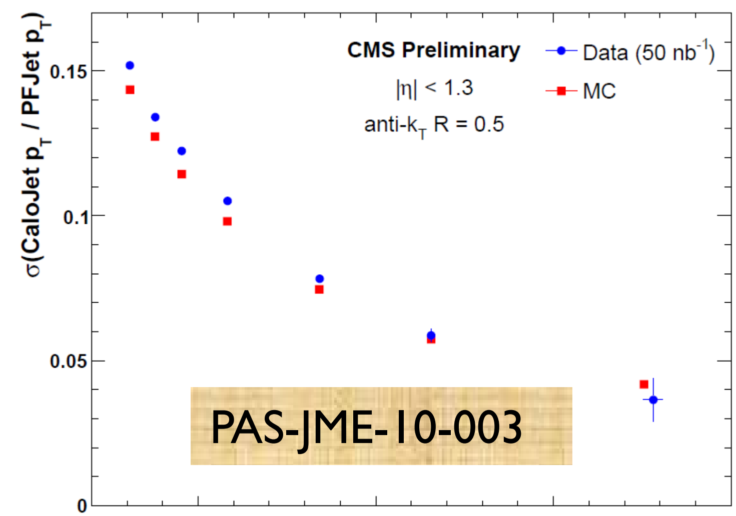
JetEtMissPublicResultsINSI



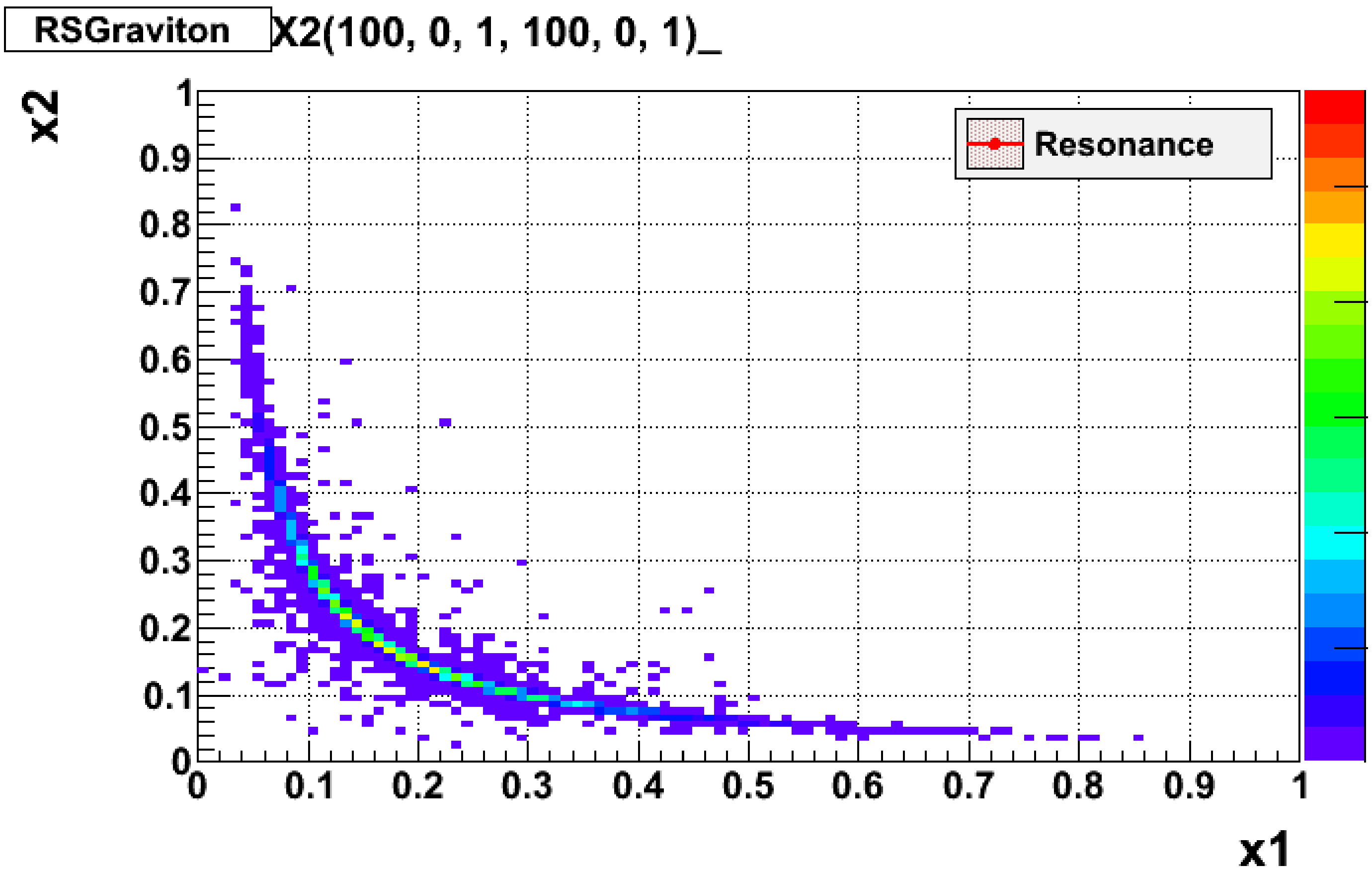
PAS-PFT-09-001



- Particle Flow particles are used to cluster jets or calculate MET.
- Jets response at 100 GeV:
  PF ~ 95%, Calorimeter ~ 70%.
- PF jets resolution is comparable to Atlas Calorimeter jets while CMS Calorimeter jets resolution is significantly worse.
- This expectation is confirmed in-situ with 7 TeV data.

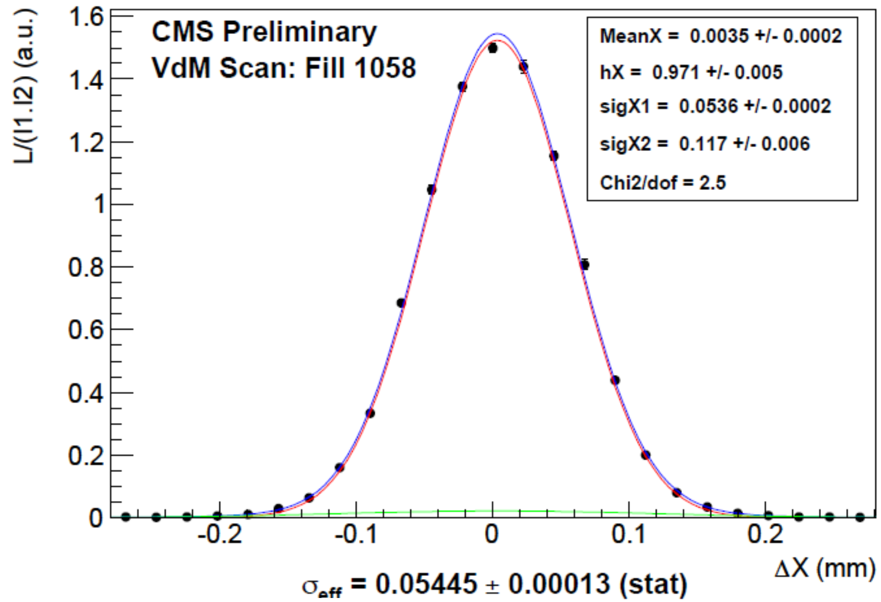


RSG 1200



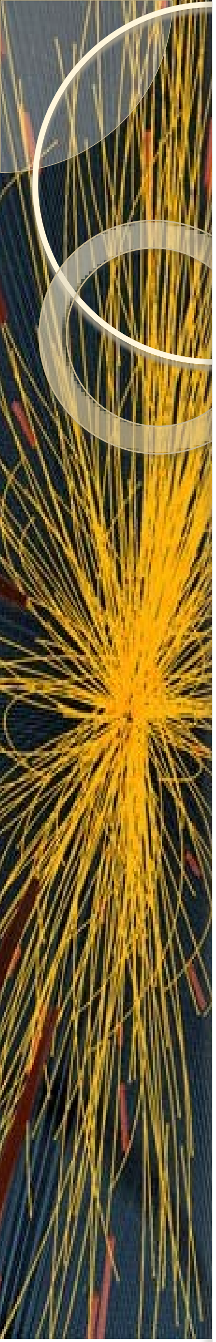
RSGraviton
X2(100, 0, 1, 100, 0, 1)_
x2
x1
Resonance
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

The beam intensities are measured using Fast Beam Current Transformers (FBCT), which measure the current in each 25-ns LHC bunch [6]. The FBCT measurements, which provide accurate bunch-to-bunch values, are normalized to a low-bandwidth measurement of the total circulating current, made by DC current transformers.



Error	Value (%)
Beam Background	0.1
Fit Systematics	1.0
Beam Shape	3.0
Scale Calibration	2.0
Zero Point Uncertainty	2.0
Beam Current Measurement	10.0
Total	11.0

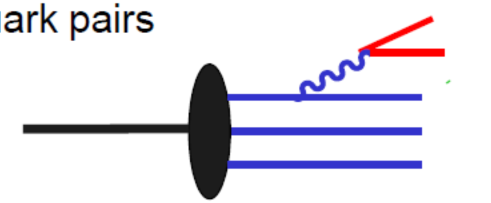
CMS PAS EWK-10-004



James Stirling
Cambridge University

the asymmetric sea

- the sea presumably arises when 'primordial' valence quarks emit gluons which in turn split into quark-antiquark pairs, with suppressed splitting into heavier quark pairs

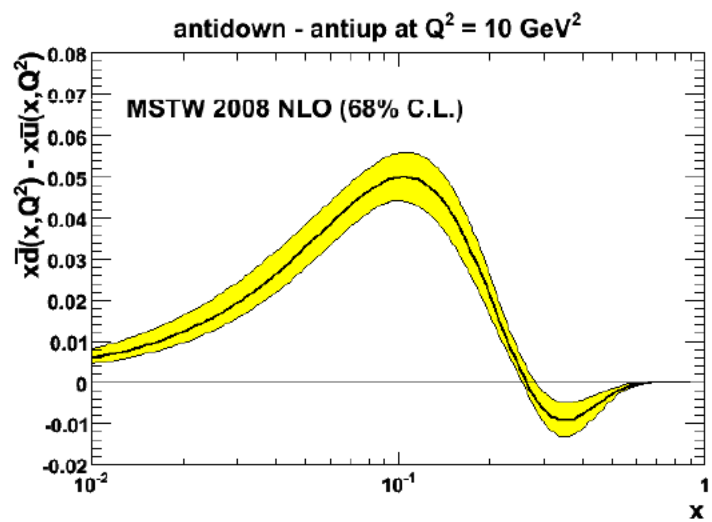


- so we naively expect

$$\bar{u} \approx \bar{d} > \bar{s} > \bar{c} > \ldots$$

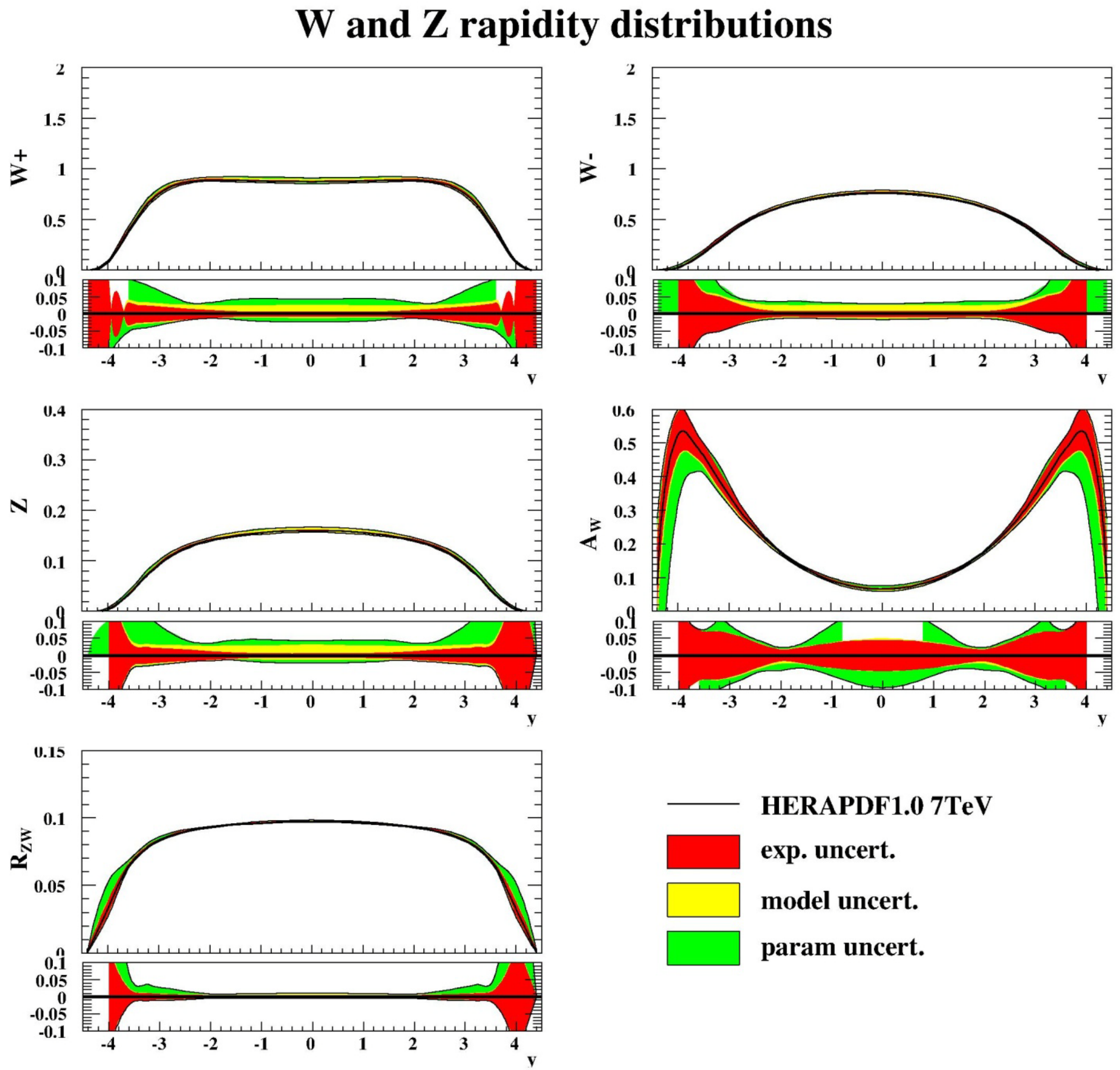
- u_{sea}, d_{sea}, s obtained from fits to data
- c,b from pQCD, $g \rightarrow Q\bar{Q}$

The ratio of Drell-Yan cross sections for $pp, pn \rightarrow \mu^+\mu^- + X$ provides a measure of the difference between the *u* and *d* sea quark distributions

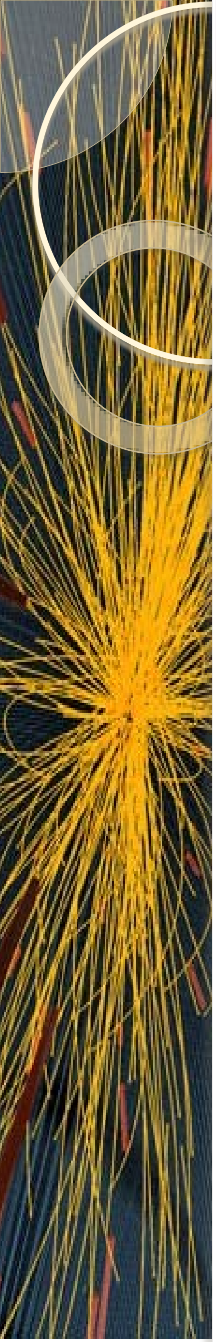


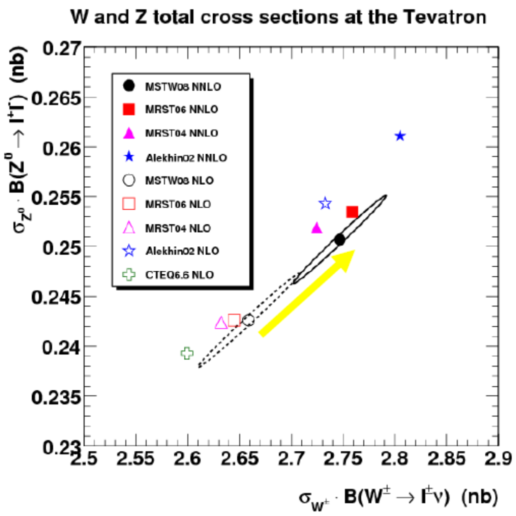
22

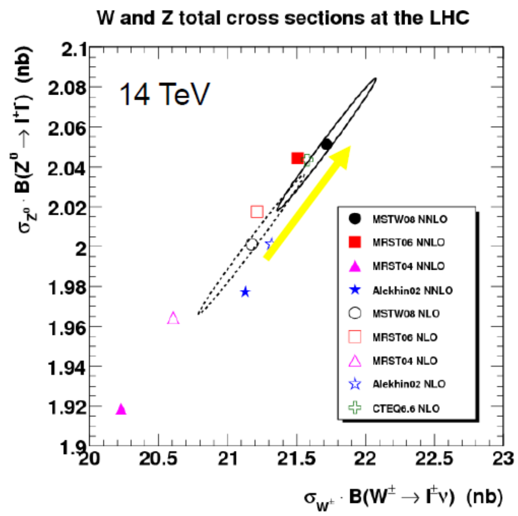
WZ

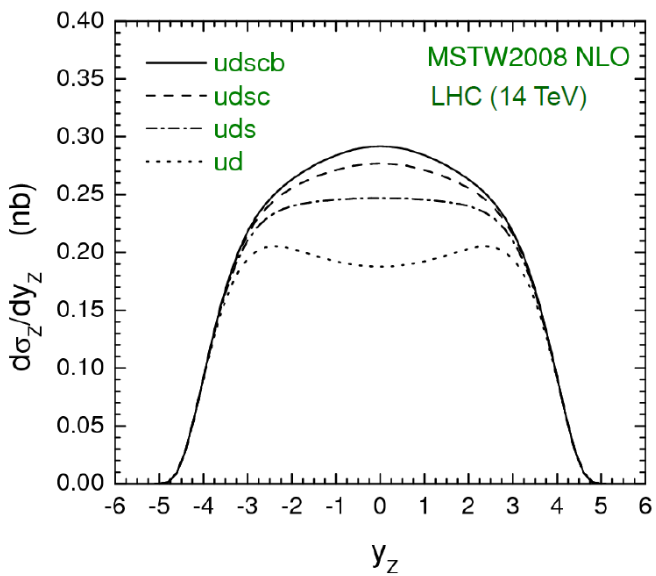

W and Z rapidity distributions
W+
W-
Z
A_W
R_{ZW}
y
HERAPDF1.0 7TeV
exp. uncert.
model uncert.
param uncert.

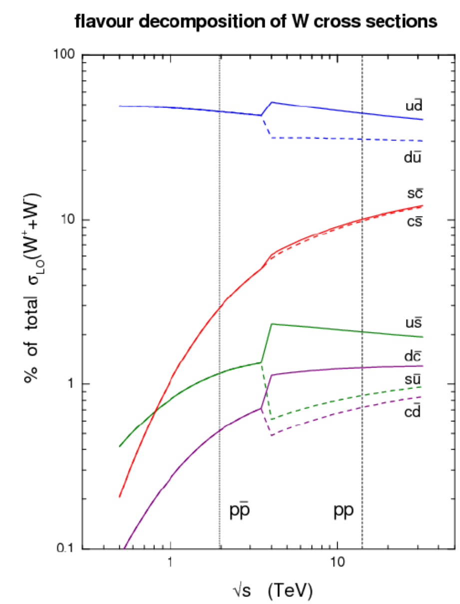
3) Quark densities: Drell-Yann





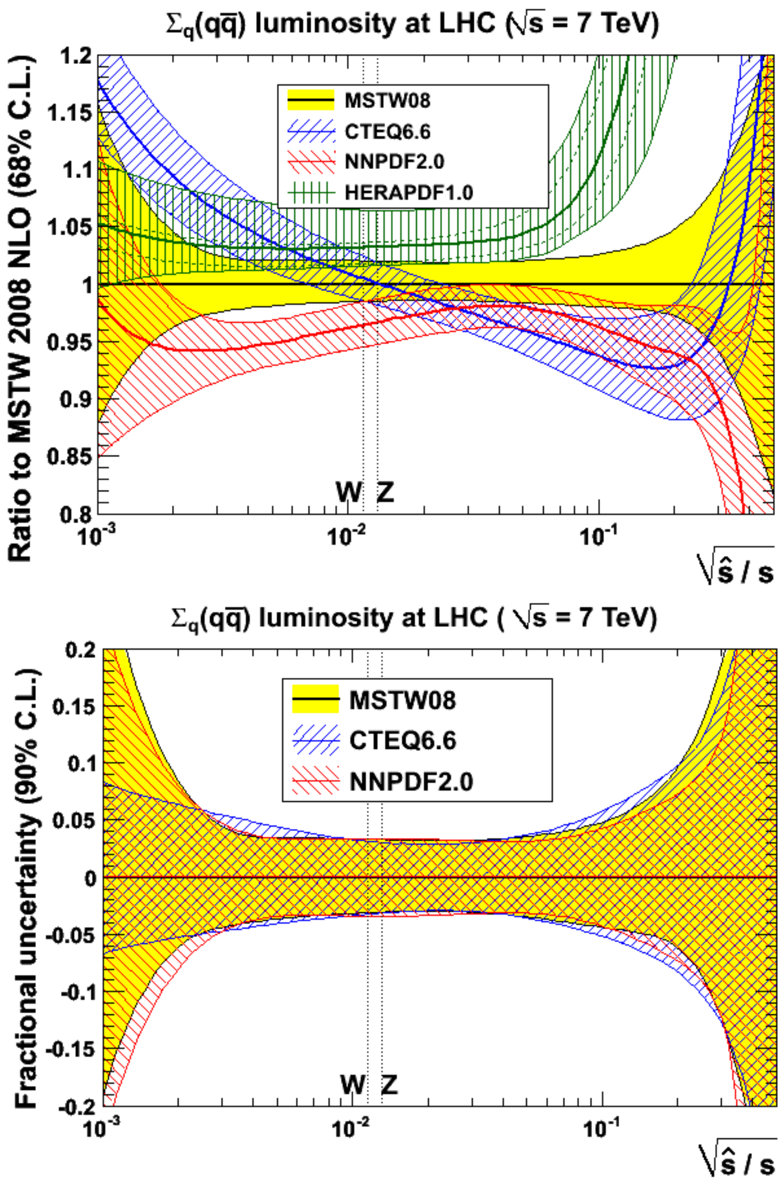






at LHC, ~30% of W and Z total cross sections involves s,c,b quarks

qq scattering



Data set	$N_{\text{pts.}}$
H1 MB 99 e^+p NC	8
H1 MB 97 e^+p NC	64
H1 low Q^2 96–97 e^+p NC	80
H1 high Q^2 98–99 e^-p NC	126
H1 high Q^2 99–00 e^+p NC	147
ZEUS SVX 95 e^+p NC	30
ZEUS 96–97 e^+p NC	144
ZEUS 98–99 e^-p NC	92
ZEUS 99–00 e^+p NC	90
H1 99–00 e^+p CC	28
ZEUS 99–00 e^+p CC	30
H1/ZEUS $e^{\pm}p$ F_2^{charm}	83
H1 99–00 e^+p incl. jets	24
ZEUS 96–97 e^+p incl. jets	30
ZEUS 98–00 $e^{\pm}p$ incl. jets	30
DØ II $p\bar{p}$ incl. jets	110
CDF II $p\bar{p}$ incl. jets	76
CDF II $W \to l\nu$ asym.	22
DØ II $W \to l\nu$ asym.	10
DØ II Z rap.	28
CDF II Z rap.	29

*MSTW2008

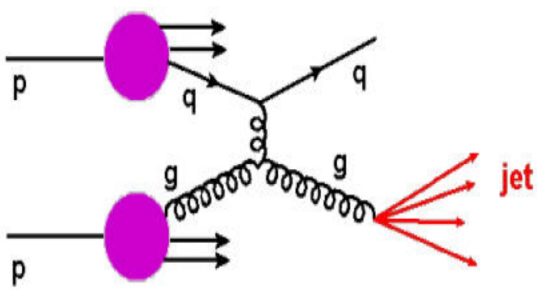
2.2) Inclusive production of W and Z @ CMS

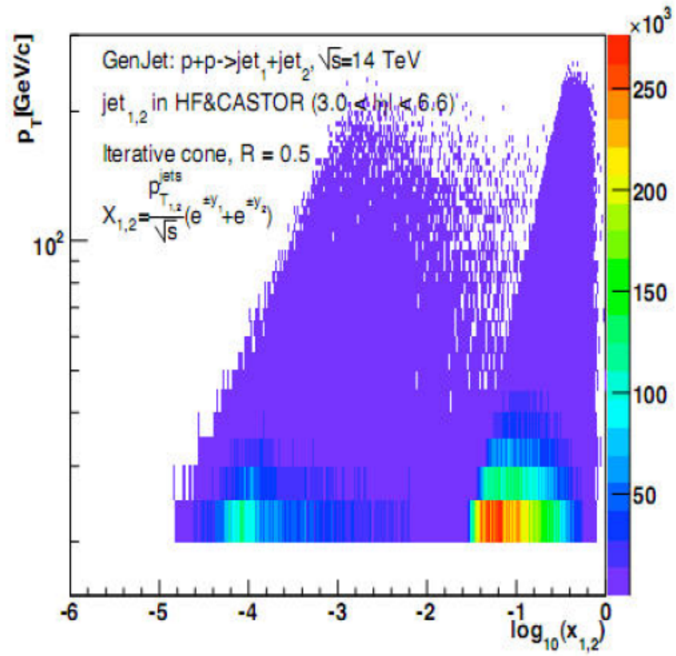
Source	$W \to e\nu_e$	$W \to \mu\nu_\mu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Lepton reconstruction & identification	3.9	1.5	5.9	0.5
Momentum scale & resolution	2.0	0.3	0.6	0.2
$\not{E}_T$ scale & resolution	1.8	0.4	n/a	n/a
Background subtraction/modeling	1.3	2.0	0.1	$0.2 \oplus 1.0$
PDF uncertainty for acceptance	0.8	1.1	1.1	1.2
Other theoretical uncertainties	1.3	1.4	1.3	1.6
Total	5.1	3.1	6.2	2.3

Results not yet public for 35pb-1, so uncertainties shown for 2.9 pb-1

Forward jets: motivation

> Forward jets allow to probe Bjorken-x as low as 10^{-5}: region sensitive to non-linear QCD effects of parton recombination and saturation



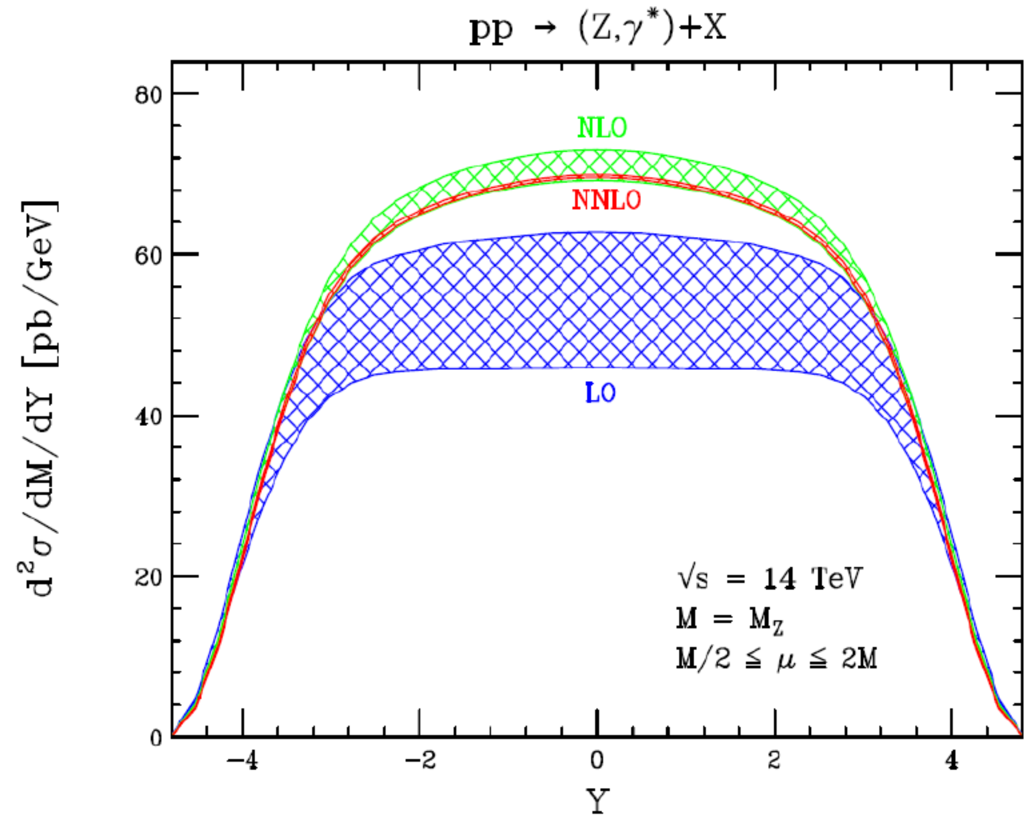


[CMS PAS FWD-08-001 / FWD-10-003]

[CMS and TOTEM Collaborations, CERN/LHCC 2006-039/G-124]

Igor Katkov | Forward Jets and Energy Flow at CMS | Forward Physics at the LHC, Manchester, 12-14 December 2010 | Page 11

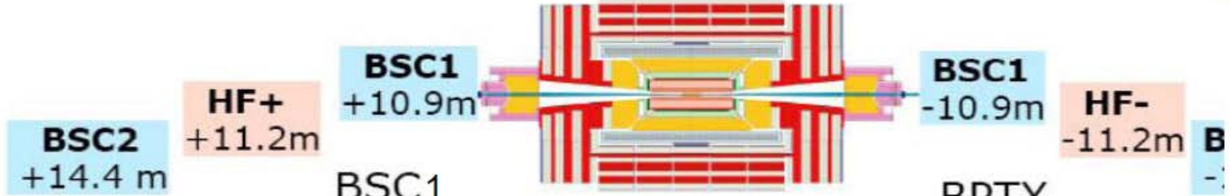
the impact of NNLO: W,Z



Anastasiou, Dixon, Melnikov, Petriello, 2004

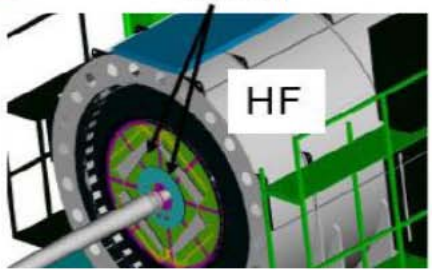
- only scale variation uncertainty shown
- central values calculated for a *fixed* set pdfs with a *fixed* value of $\alpha_S(M_Z^2)$

Trigger System

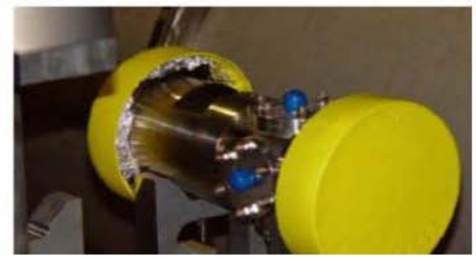


BPTX
+175m

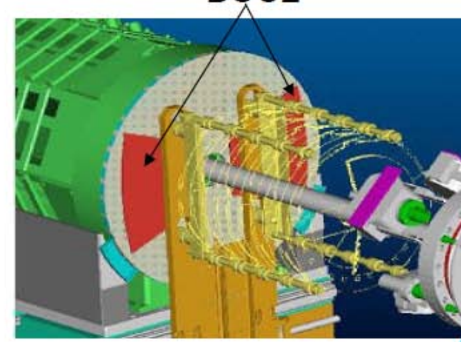
BSC1



BPTX



BSC2



- Beam scintillation counter: info on hits and coincidence signals
- Beam Pick-up Timing for eXperiments: precise info on structure and timing of LHC beams
- BSC + BPTX → minimum bias (beam halo/gas/splash, high multiplicity) triggering / monitoring for pp and HI

Igor Katkov | Forward Jets and Energy Flow at CMS | Forward Physics at the LHC, Manchester, 12-14 December 2010 | Page 4

Inclusive jets cross section

$d\vert y\vert = 2*0.5 = 1$; dpT: 507 - 548 GeV, 967 - 1032 GeV, 1684 - 1784 GeV

$\vert y\vert$ range	<pT>	s/ fb/GeV
$\vert y\vert<0.5$	521.	4.87 E2
	995.	4.14 E0
	1741.	1.09 E-2
$0.5<\vert y\vert<1.0$	521.	4.06 E2
	1002.	2.59 E0
	1714.	2.58 E-3