W+Z Physics with ATLAS and CMS

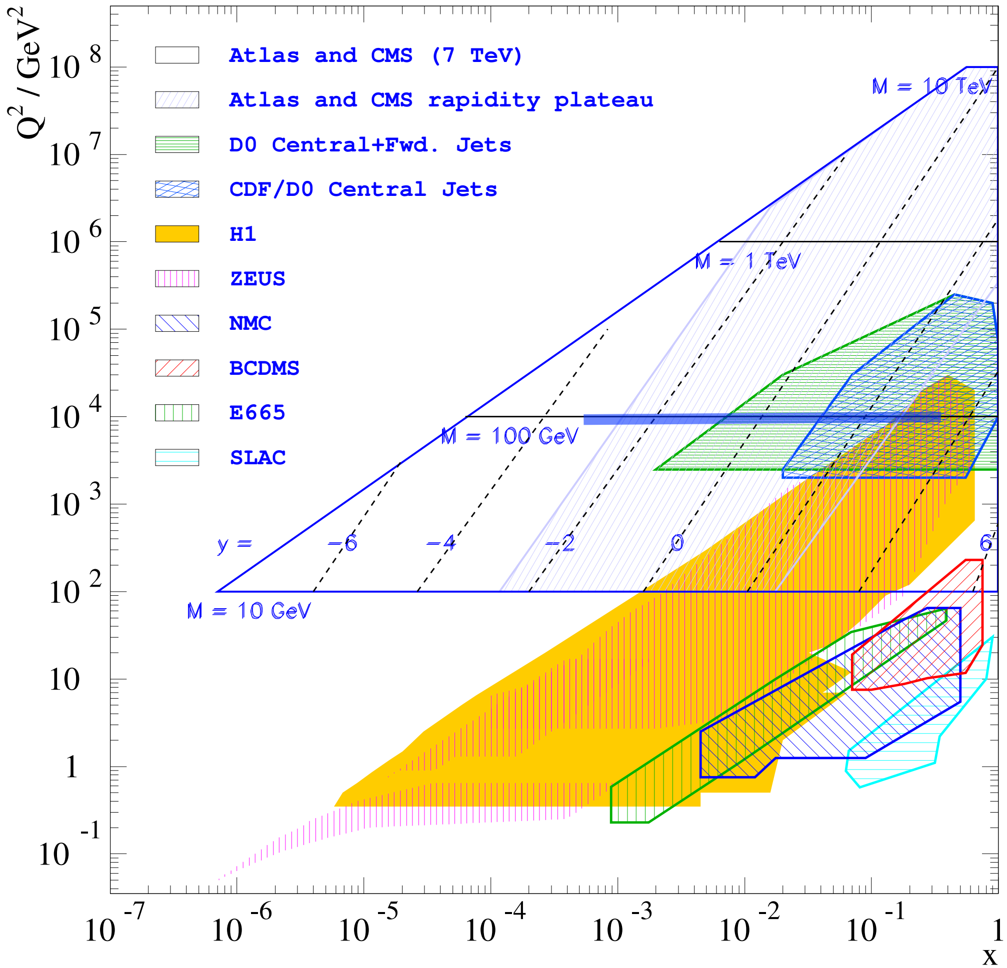
Recent PDF Related Results

Max Klein

UNIVERSITY OF LIVERPOOL

Workshop on PDF and Standard Candles at the LHC - Karlsruhe, 19.3.2012

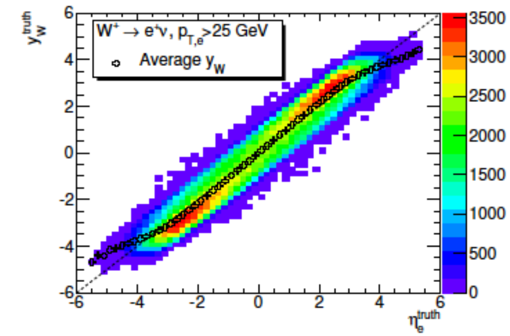
Drell-Yan and Deep Inelastic Scattering



$$Q^2 = M^2$$

$$x_{1,2} = \frac{M}{2E_p} e^{\pm y}$$

for W use pseudorapidity
η_1=-ln tan $\theta_1/2$



$$\frac{d^2\sigma}{dMdy} = \frac{4\pi\alpha^2(M)}{9} \cdot 2M \cdot P(M) \cdot \Phi(x_1,x_2,M^2)$$

P:propagator

Z (NC) channel $\Phi_Z = \sum_q (v_q^2 + a_q^2) F_{q\bar{q}}$

$$F_{q\bar{q}} = x_1 x_2 \cdot [q(x_1,M^2)\bar{q}(x_2,M^2) + \bar{q}(x_1,M^2)q(x_2,M^2)]$$

W$^\pm$ (CC) channel

$$\Phi_{W^+} = x_1x_2[U_{ud}^2(u_1\bar{d}_2 + u_2\bar{d}_1) + U_{cs}^2(c_1\bar{s}_2 + c_2\bar{s}_1) + U_{us}^2(u_1\bar{s}_2 + u_2\bar{s}_1) + U_{cd}^2(c_1\bar{d}_2 + c_2\bar{d}_1)]$$
$$\Phi_{W^-} = x_1x_2[U_{ud}^2(\bar{u}_1d_2 + \bar{u}_2d_1) + U_{cs}^2(\bar{c}_1s_2 + \bar{c}_2s_1) + U_{us}^2(\bar{u}_1s_2 + \bar{u}_2s_1) + U_{cd}^2(\bar{c}_1d_2 + \bar{c}_2d_1)],$$

New constraints to PDFs
lo/hi mass to access lo/hi x
No nuclear corrections in pp

why W+Z at the LHC?

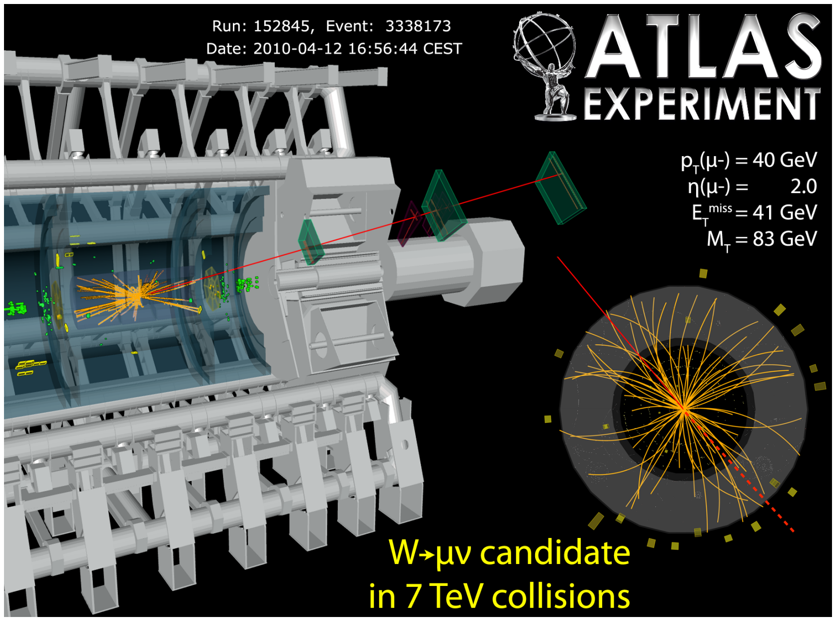
1. Energy Calibration and Lepton Identification [~1% reached]
2. Constrain Parton Densities [dσ/dy, η,W,Z+c,b]
3. Explore QCD in new kinematic domain [p_T(W,Z), W,Z+jets]
4. Perform precision electroweak measurements [Pol(W),$\sin^2\Theta$,TGC]
5. Relation to Higgs: H → WW and H→ ZZ→ 4l and H → $\tau\tau$ as Z → $\tau\tau$

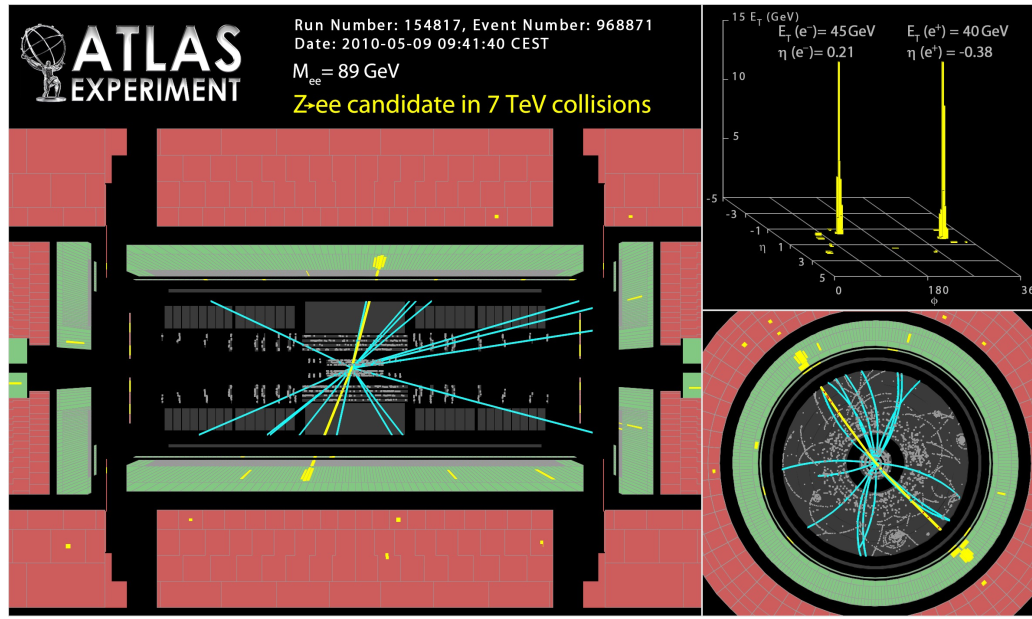
Recent overview on ATLAS and CMS electroweak results:
J.Kretzschmar Moriond Electroweak and further talks at La Thuile and Moriond QCD

W and Z events in ATLAS

$W \rightarrow \mu\ \nu$

$Z \rightarrow ee$





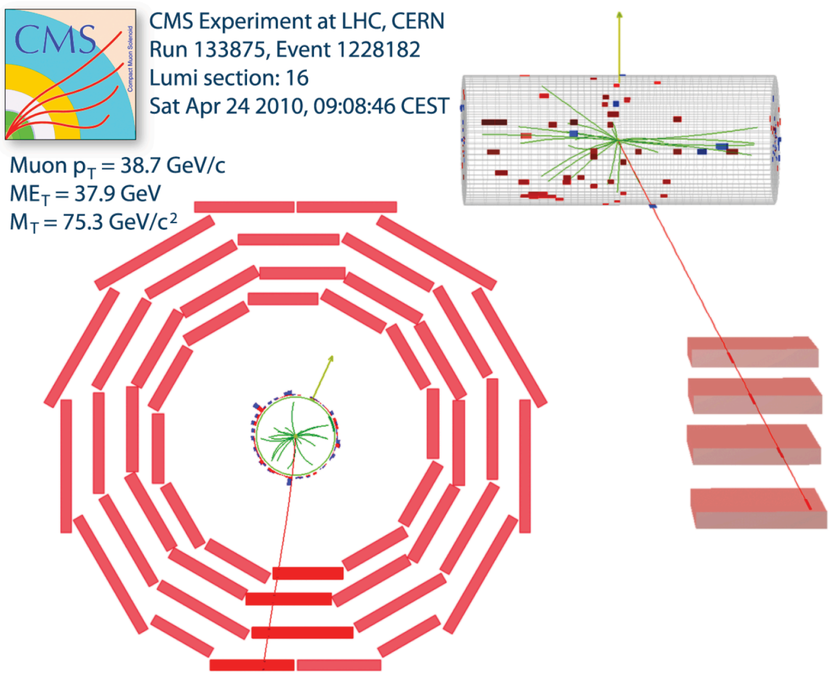
Clear signature, copious: about 10M $W^{\pm}$ and 1M Z in e+ μ per $1fb^{-1}$ luminosity

p_T^l > 20 GeV, p_T^{ν} >25 GeV, m_T>40 GeV | p_T^l > 20 GeV, 66< M_{ll}< 116 GeV $|\eta_l|$<2.5 (**$|\eta_e|$<4.9**)

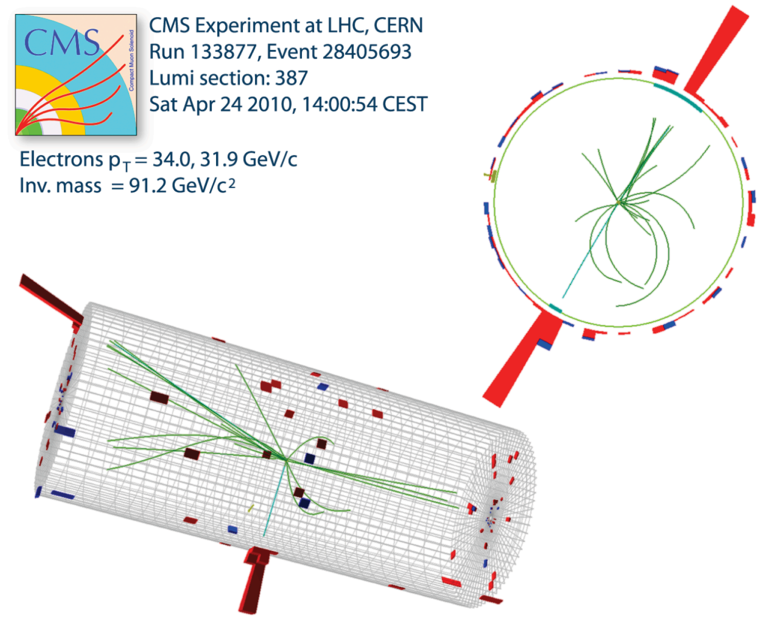
M.Klein, Karlsruhe 19.3.12

W and Z events in CMS

$W \rightarrow \mu \nu$



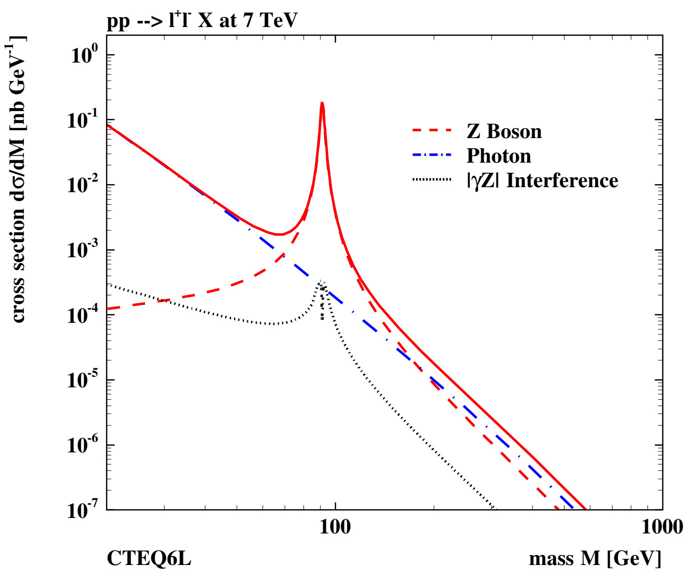
$Z \rightarrow ee$

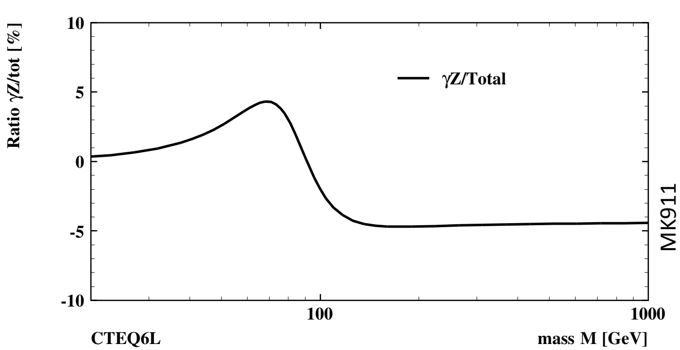


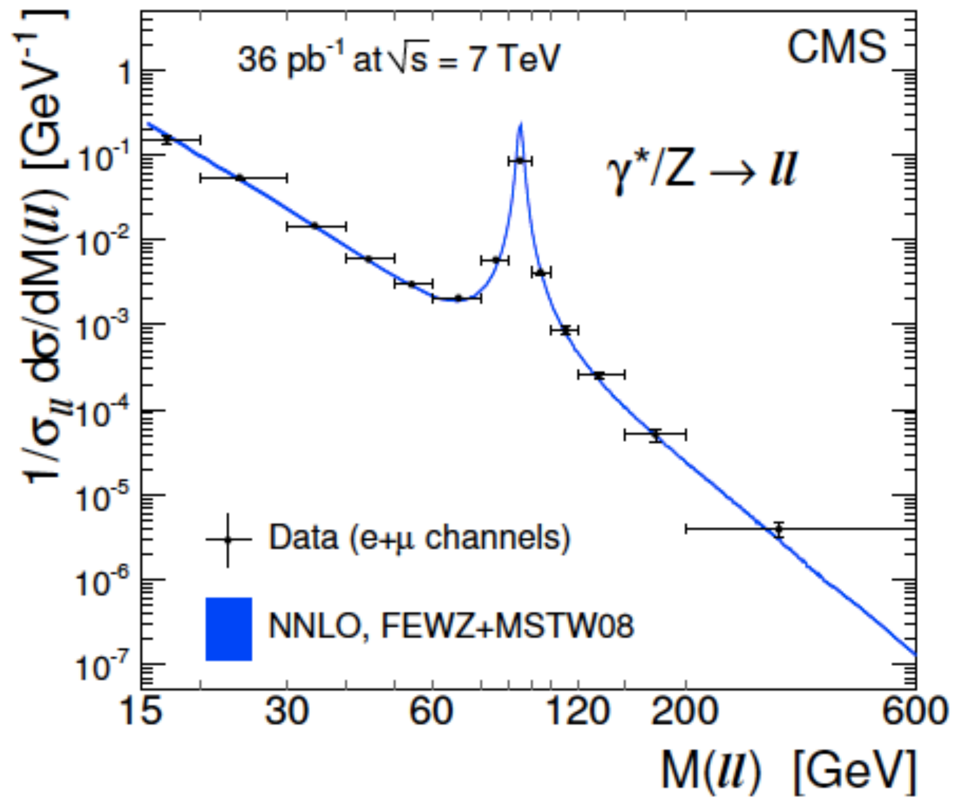
Clear signature and as copious as in ATLAS [even a bit more?]..

$p_T^l > 25$ GeV, $p_T^\nu > 25$ GeV, $|\eta_1| < 2.1$, $m_T > 40$ GeV | $p_T^l > 25$ GeV, $60 < M_{ll} < 120$ GeV, $|\eta_1| < 2.1$

Drell-Yan Spectrum in Neutral Currents







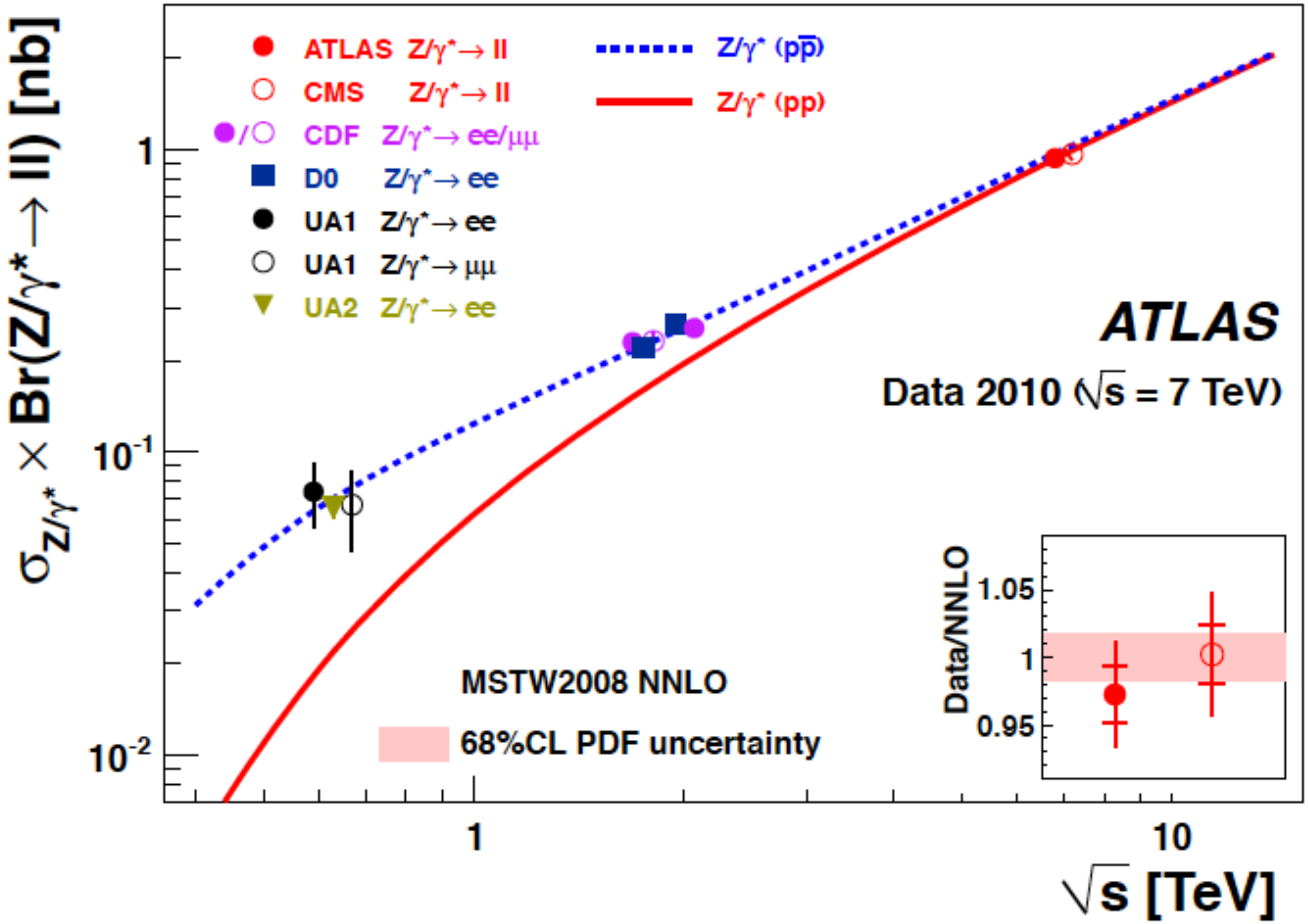
CMS: arXiv:1108.0566 (August 2011) JHEP P10 (2011) 007

Normalised DY spectrum measured with 2010 data to 6% (~20GeV), 3% (Z peak) and 20% at highest M

Low and high mass dominated by Z production
γ Z interference +- 5% left and right from Z peak

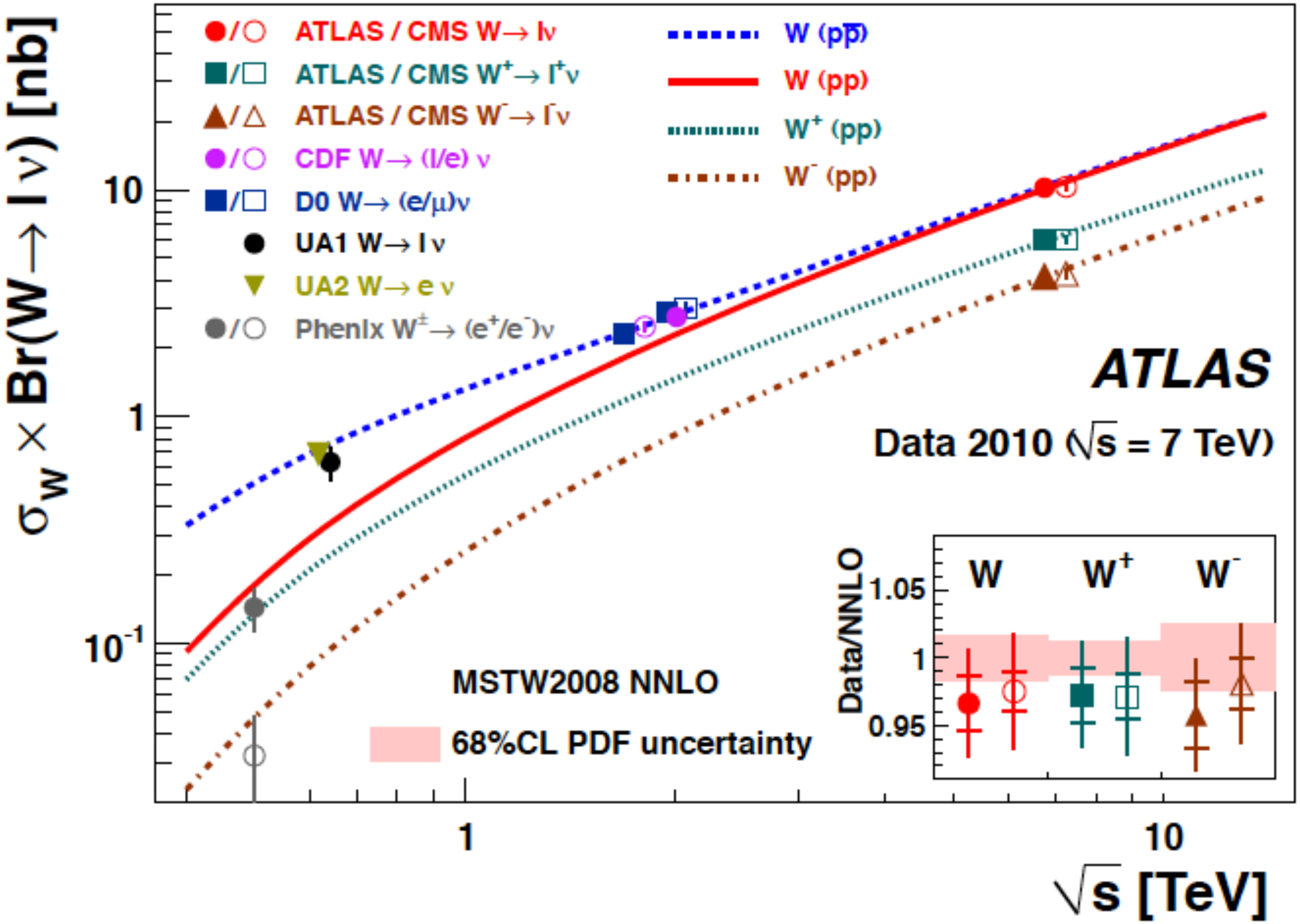
$M_{Z'}$ > 2.21 TeV (ATLAS), 1.94 TeV (CMS)
ATLAS-CONF-2012-007 CMS-EXO-11-019

Total Z→ll Cross Sections vs $\sqrt{s}=2E_p$



Good agreement between ATLAS and CMS within few % measurement precision.

Total W→lν Cross Sections vs $\sqrt{s}=2E_p$



Good agreement between ATLAS and CMS within few % measurement precision.

Integrated Cross Section Uncertainties

1-2% precise fiducial cross sections + 3.4% from luminosity. ATLAS

Data averaged with account for correlations.

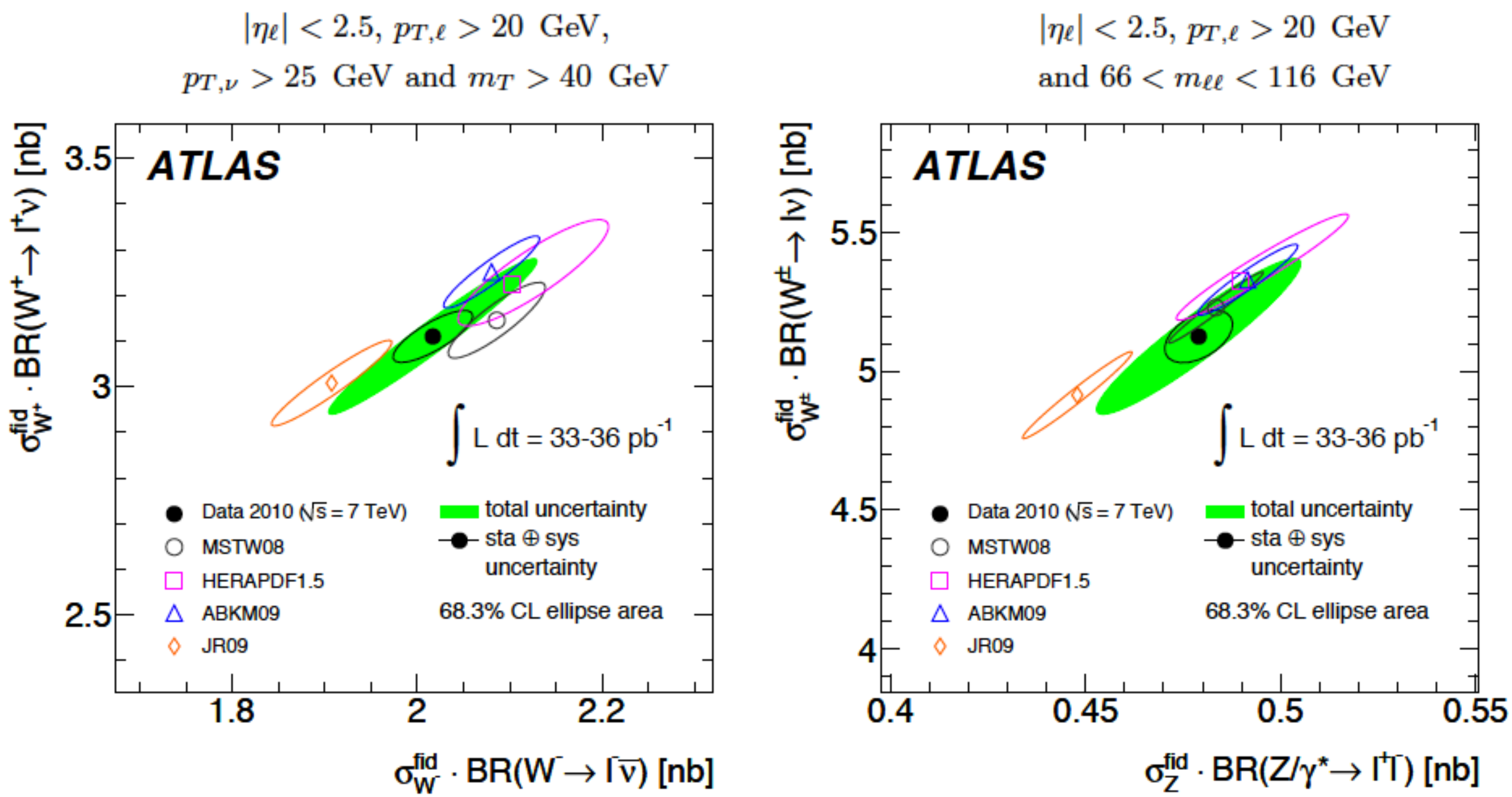
	$\delta\sigma_{W^\pm}$	$\delta\sigma_{W^+}$	$\delta\sigma_{W^-}$	$\delta\sigma_Z$
Trigger	0.4	0.4	0.4	<0.1
Electron reconstruction	0.8	0.8	0.8	1.6
Electron identification	0.9	0.8	1.1	1.8
Electron isolation	0.3	0.3	0.3	—
Electron energy scale and resolution	0.5	0.5	0.5	0.2
Non-operational LAr channels	0.4	0.4	0.4	0.8
Charge misidentification	0.0	0.1	0.1	0.6
QCD background	0.4	0.4	0.4	0.7
Electroweak+$t\bar{t}$ background	0.2	0.2	0.2	<0.1
E_T^{miss} scale and resolution	0.8	0.7	1.0	—
Pile-up modeling	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
$C_{W/Z}$ theoretical uncertainty	0.6	0.6	0.6	0.3
Total experimental uncertainty	1.8	1.8	2.0	2.7
$A_{W/Z}$ theoretical uncertainty	1.5	1.7	2.0	2.0
Total excluding luminosity	2.3	2.4	2.8	3.3
Luminosity		3.4		

TABLE VI. *Summary of relative systematic uncertainties on the measured integrated cross sections in the electron channels in per cent. The theoretical uncertainty of $A_{W/Z}$ applies only to the total cross section.*

	$\delta\sigma_{W^\pm}$	$\delta\sigma_{W^+}$	$\delta\sigma_{W^-}$	$\delta\sigma_Z$
Trigger	0.5	0.5	0.5	0.1
Muon reconstruction	0.3	0.3	0.3	0.6
Muon isolation	0.2	0.2	0.2	0.3
Muon p_T resolution	0.04	0.03	0.05	0.02
Muon p_T scale	0.4	0.6	0.6	0.2
QCD background	0.6	0.5	0.8	0.3
Electroweak+$t\bar{t}$ background	0.4	0.3	0.4	0.02
E_T^{miss} resolution and scale	0.5	0.4	0.6	-
Pile-up modeling	0.3	0.3	0.3	0.3
Vertex position	0.1	0.1	0.1	0.1
$C_{W/Z}$ theoretical uncertainty	0.8	0.8	0.7	0.3
Total experimental uncertainty	1.6	1.7	1.7	0.9
$A_{W/Z}$ theoretical uncertainty	1.5	1.6	2.1	2.0
Total excluding luminosity	2.1	2.3	2.6	2.2
Luminosity		3.4		

TABLE IX. *Summary of relative systematic uncertainties on the measured integrated cross sections in the muon channels in per cent. The efficiency systematic uncertainties are partially correlated between the trigger, reconstruction and isolation terms. This is taken into account in the computation of the total uncertainty quoted in the table. The theoretical uncertainty on $A_{W/Z}$ applies only to the total cross section.*

Integrated W-Z Cross Sections (in fiducial regions)

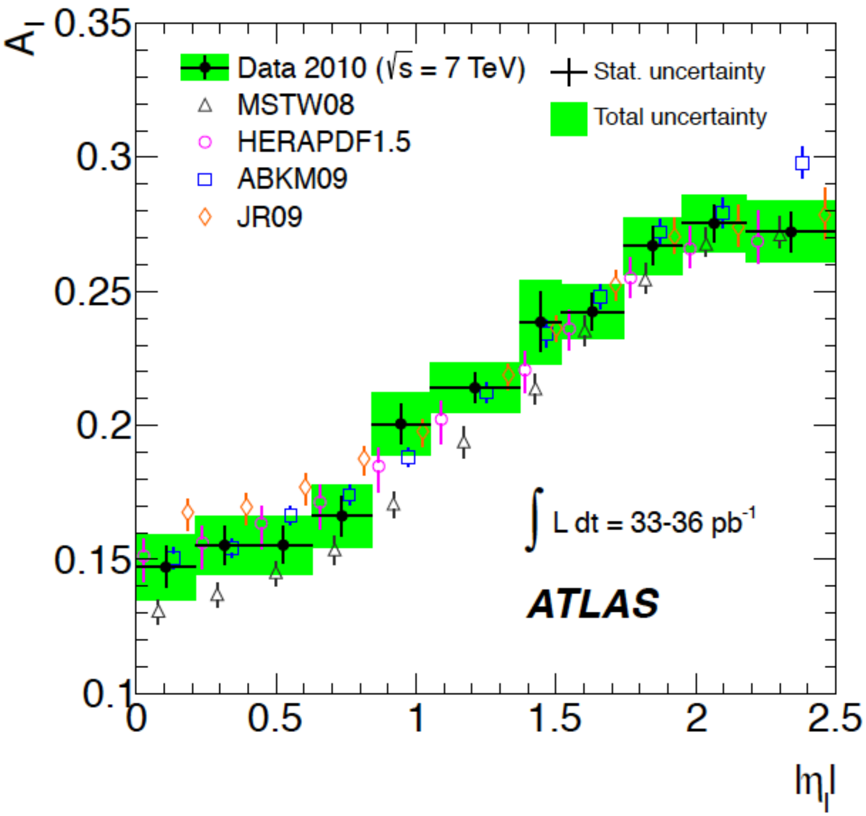


Measurement uncertainty vs σ^{tot} reduced as acc (thy) error becomes negligible. Theory errors taken as 68% for ellipse. PDF uncertainties only, which are defined differently by fit groups. Comparison to NNLO appropriate (and possible with PDFs and FEWZ+DYNNLO). Reduces scale uncertainty effect.

arXiv:1109:5141 → PRD to appear

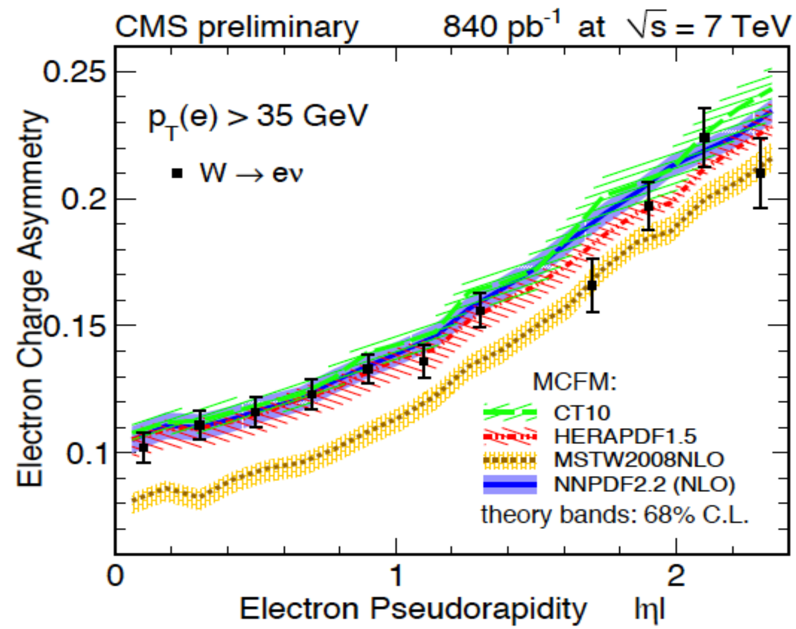
Cf also NNPDF NNLO paper (arXiv:1107.2652)

W Charge Asymmetry



$$\mathcal{A}(\eta) = \frac{d\sigma/d\eta(W^+ \to \ell^+\nu) - d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \to \ell^+\nu) + d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}$$

CMS: New result 2011 (electron) data



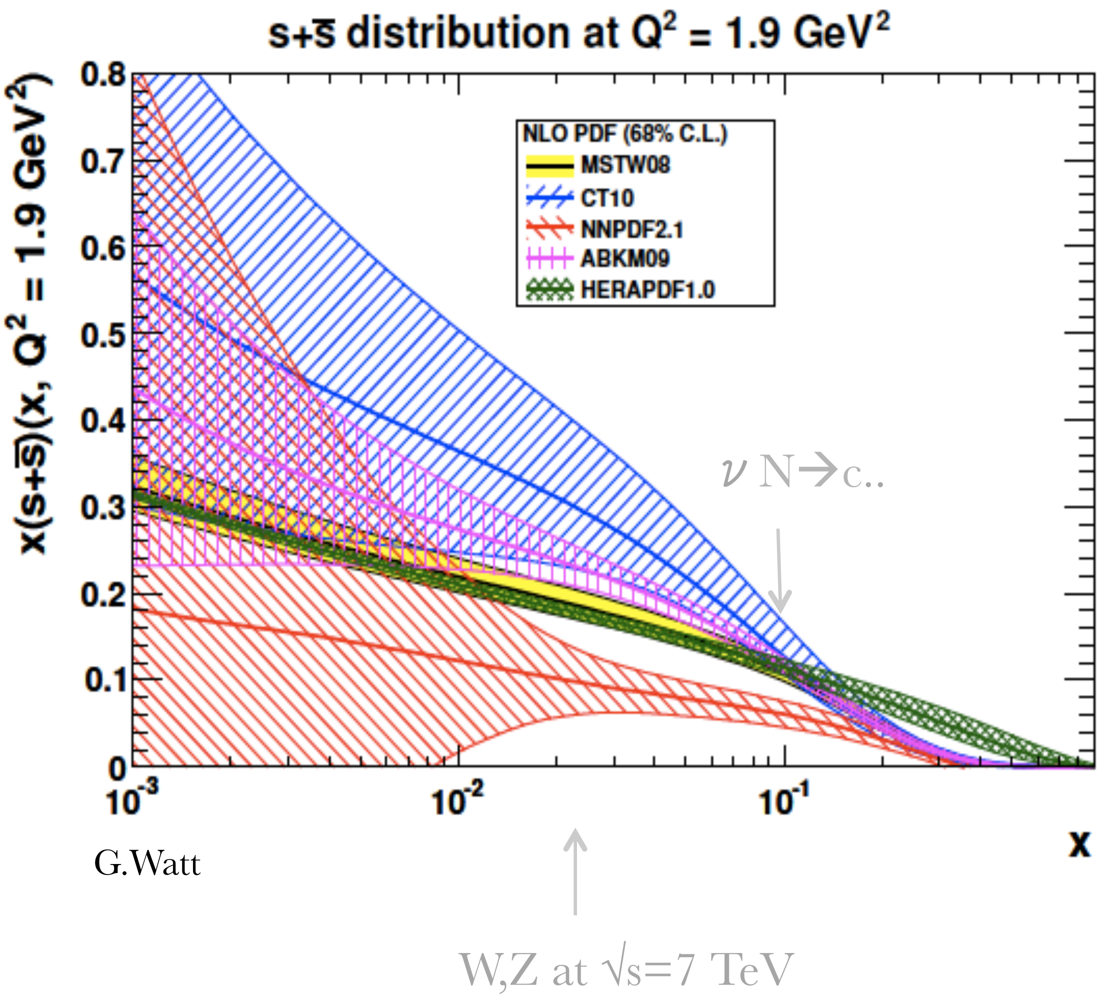
Electron and muon information combined
Less information than in separate cross sections and their correlations. Theory calculated to NNLO.

MSTW08 has too many negative Ws.
Common trend in ATLAS + CMS

CMS PAS SMP-12-001 [7.3.2012]

arXiv:1109:5141 → PRD

Strange Quark Density



G.Watt

SU_3 Flavour: s = u = d ?

M_p >> M_s >> $M_{u,d}$

NuTeV di-muon data:
small s, nuclear corrections

HERMES: N(K): s large

H1,ZEUS: weak sensitivity
through Charged Currents

Important for Sea Composition,
W Boson Mass, QCD..

Determination of the strange quark density of the proton from ATLAS measurements of the $W \to \ell\nu$ and $Z \to \ell\ell$ cross sections

The ATLAS Collaboration*

Joint QCD Analysis of recent ATLAS W,Z differential cross section data and of HERA I inclusive NC,CC DIS data.

HERAPDF1.0 Ansatz [S.Glazov's talk]
NNLO. K-factors, HERAFITTER
RT VFNS Scheme. 13 parameters
After χ^2 minimization. Fixed strange:

$$x\bar{s} = f_s x\bar{D} = f_s x(\bar{d} + \bar{s})$$

$$r_s = \frac{s + \bar{s}}{2\bar{d}}$$

$$x\bar{s}(x) = xs(x)$$

$$f_s = 0.31 \to r_s = \frac{f_s}{1 - f_s} = 0.45$$

epWZ fixed s (r_s=0.5):
χ^2 =546.1/567 (HERA)
χ^2=44.5/30 (ATLAS)

Free strange quark distribution:

$xs(x)=A_s x^{Bs} (1-x)^{Cs}$

fix $B_s = B_{dbar}$

15 parameters:

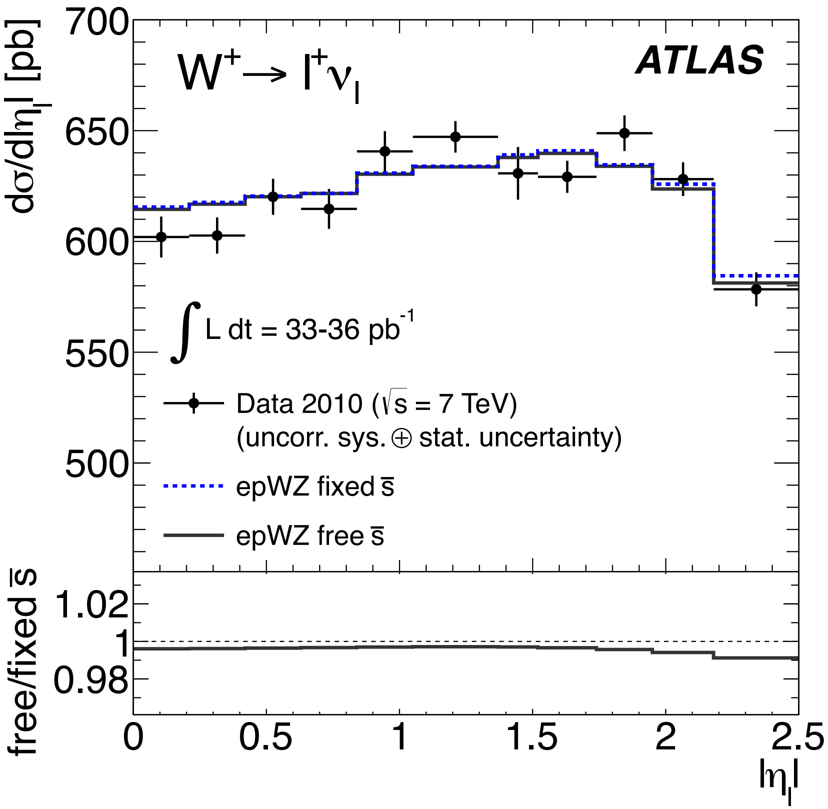
epWZ free s
χ^2 =538.4/565 (HERA)
χ^2=33.9/30 (ATLAS)

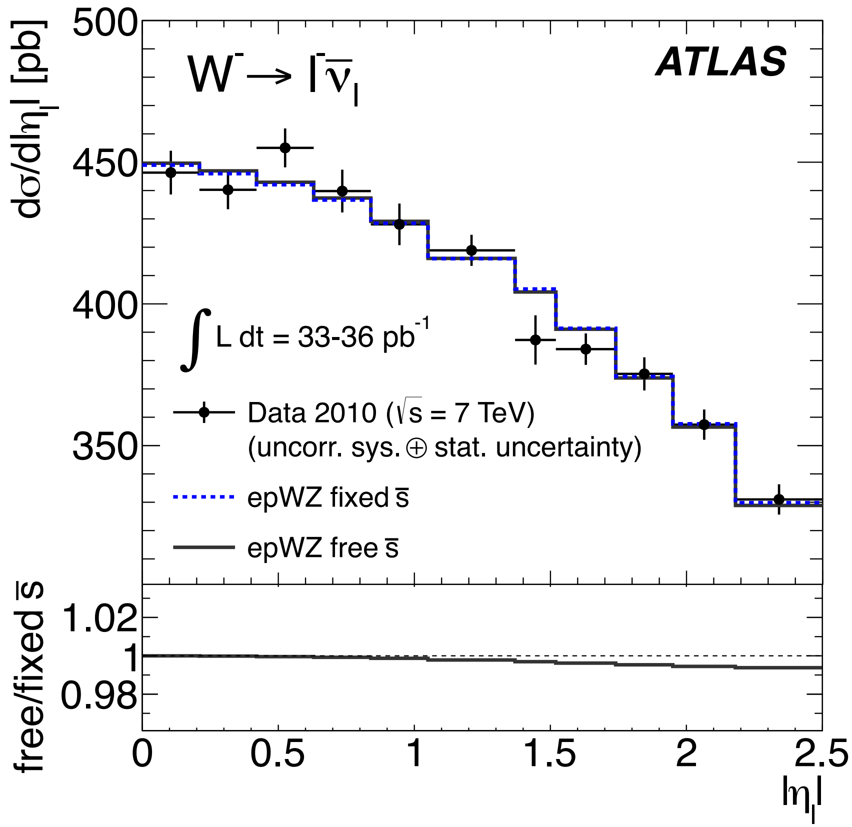
$$r_s = 1.00 \pm 0.20_{\rm exp} \pm 0.07_{\rm mod}\,{}^{+0.10}_{-0.15}{}_{\rm par}\,{}^{+0.06}_{-0.07}{}_{\alpha_S} \pm 0.08_{\rm th}$$

$Q^2=Q_0^2=1.9$ GeV^2, x=0.023

*) submitted to arXiv today

$W^{\pm}$ Pseudorapidity Cross Sections

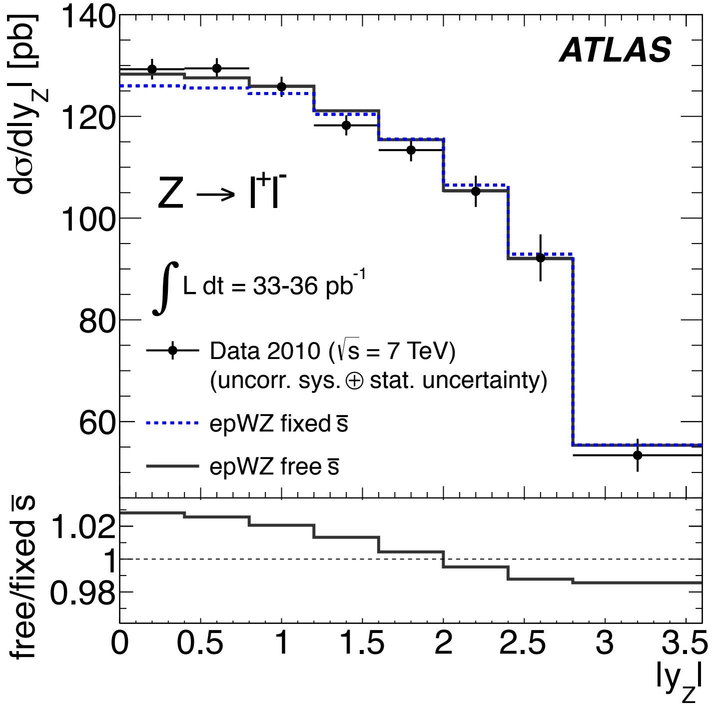




W distributions remain unaltered, small effect at large pseudorapidities.

Data from ATLAS W,Z inclusive cross section paper arXiv:1109.5141, PRD to appear

Z Rapidity Cross Section and r_s

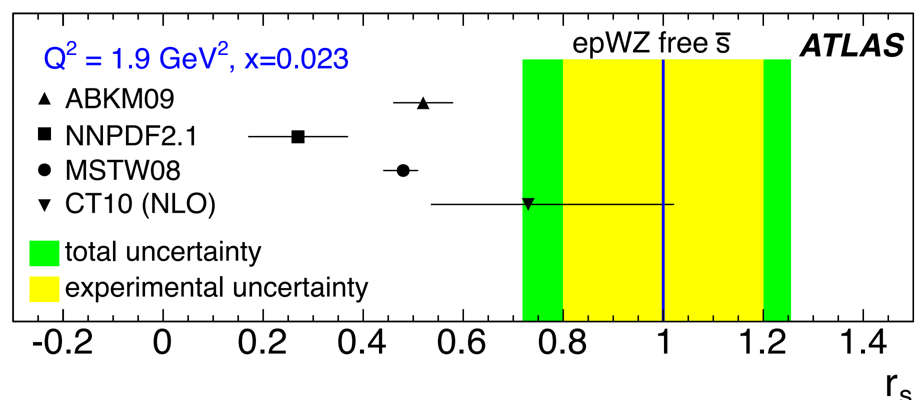


Small but notable change of y_Z distribution related to changing r_s from 0.5 (fixed) to 1 (from fit).

Cross Checks of Observation: 1.00±0.20 (exp)

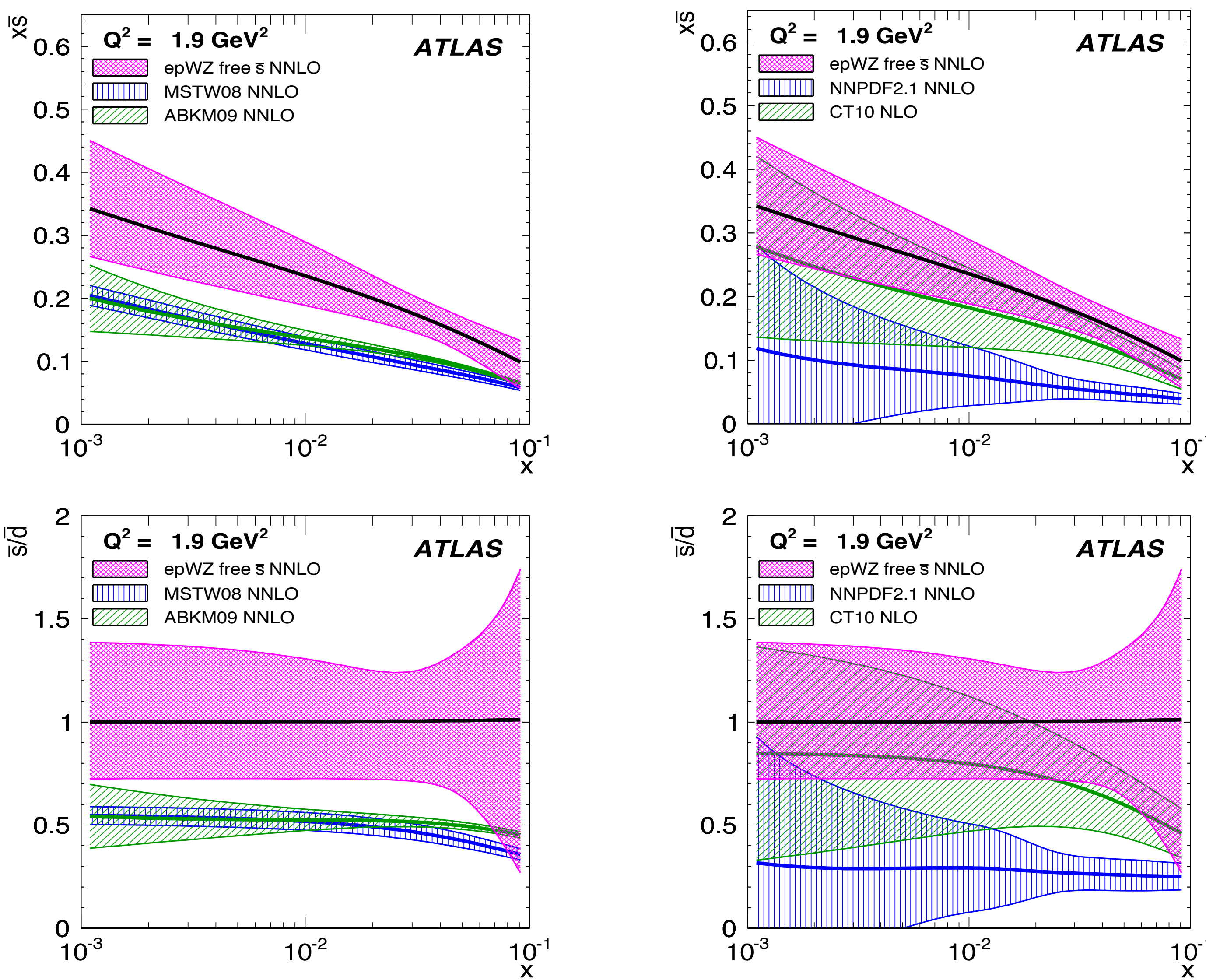
- 0.97 ± 0.26 if systematic errors cannot float
- 1.03 ± 0.19 in NLO analysis
- 1.05 ± 0.19 if c,b are treated as massless
- 0.96 ± 0.25 if ubar.ne.dbar
- 0.92 ± 0.31 using σ(Z) and A_W
- 0.66 ± 0.29 using σ(Z) and A_W from CDF

Consistent result: r_s=1.00 +0.26 -0.28



Strange Distribution and $\bar{s}/\bar{d}$ Ratio (x)

The ATLAS analysis determines xs = A x^B $(1\text{-}x)^C$, linking B to the anti-down density.



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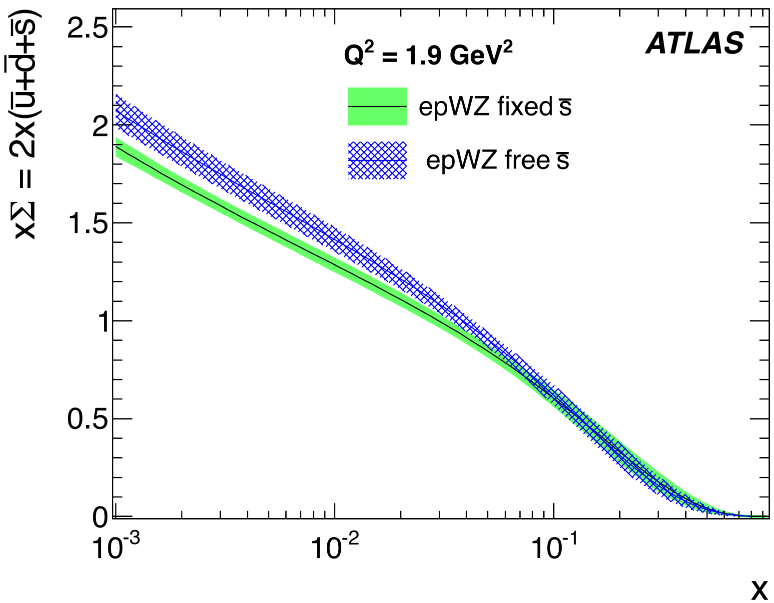
Karlsruhe
19.3.12

Light Quark Sea and $W^{\pm}/Z$ Ratio

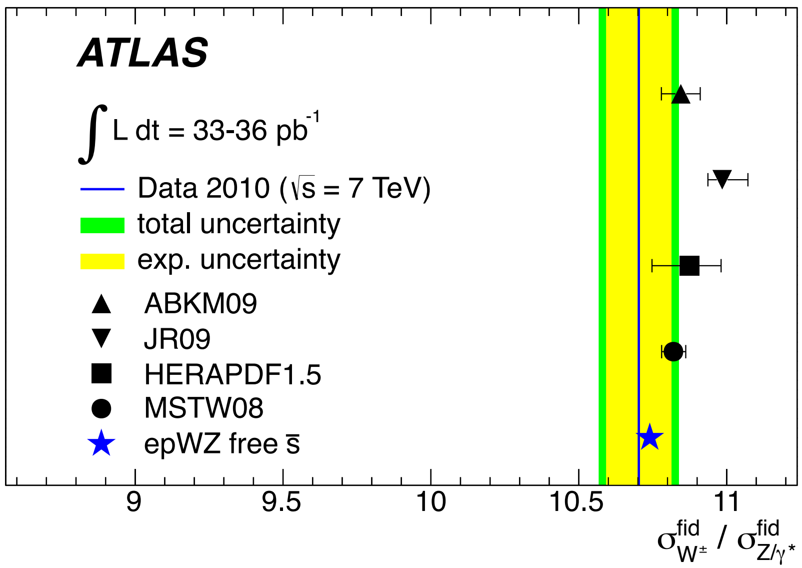


HERA has not measured the light quark sea but F_2: A change of the strange density with fixed F_2 must affect the light sea $x\Sigma$.

The present result enhances $x\Sigma$ at $x=10^{-3}$ and $Q^2=Q_0^2$ by about 8%

Obtain: $\bar{s}/s=0.93 \pm 0.15$ (exp) in W charge dependent determinations.

The NNLO analysis of the HERA and ATLAS data reproduces the $(W^+ + W^-)/Z\gamma^*$ ratio very well:



The r_s sensitivity is related to absolute cross section measurements and to very high precision on data [HERA 2, LHC 2011] and the elw. theory control.

Associated W,Z + c,b Production

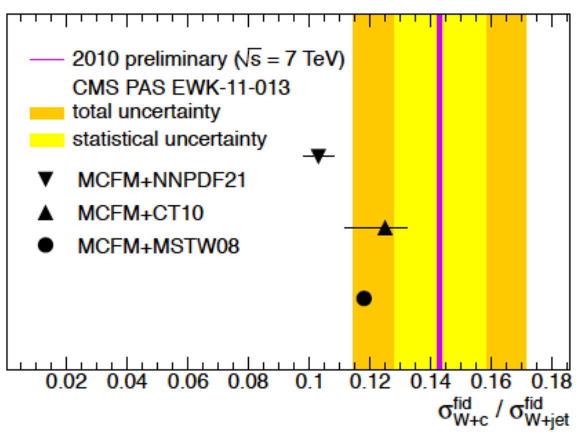
Direct access to strange quark content by selecting Cabibbo-favoured processes $\bar{s}g \rightarrow W^{+}\bar{c}$ and $sg \rightarrow W^{-}c$

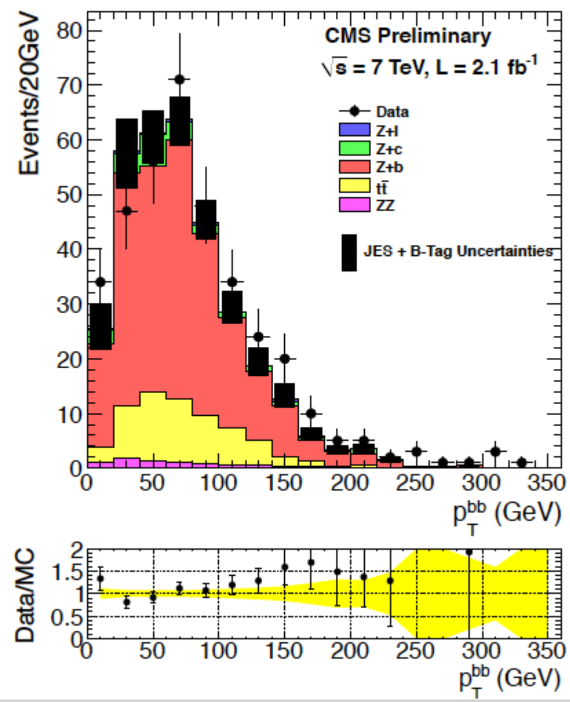
First ratio measurements by CMS using W + secondary vertex tagged jets to $\sim 20\%$ precision; $R_c = \sigma(Wc)/\sigma(W + \mathrm{jet})$ indicates large s

$W + b$ jet (ATLAS) and $Z + b(\bar{b})$ (ATLAS+CMS) were measured

Latest CMS result: $Z + \geq 1b$ and $Z + 2b$ measured to 9% and 20% → YSF talk T.d.P.

$Z + 2b$ cross section agrees with MadGraph+Pythia expectation

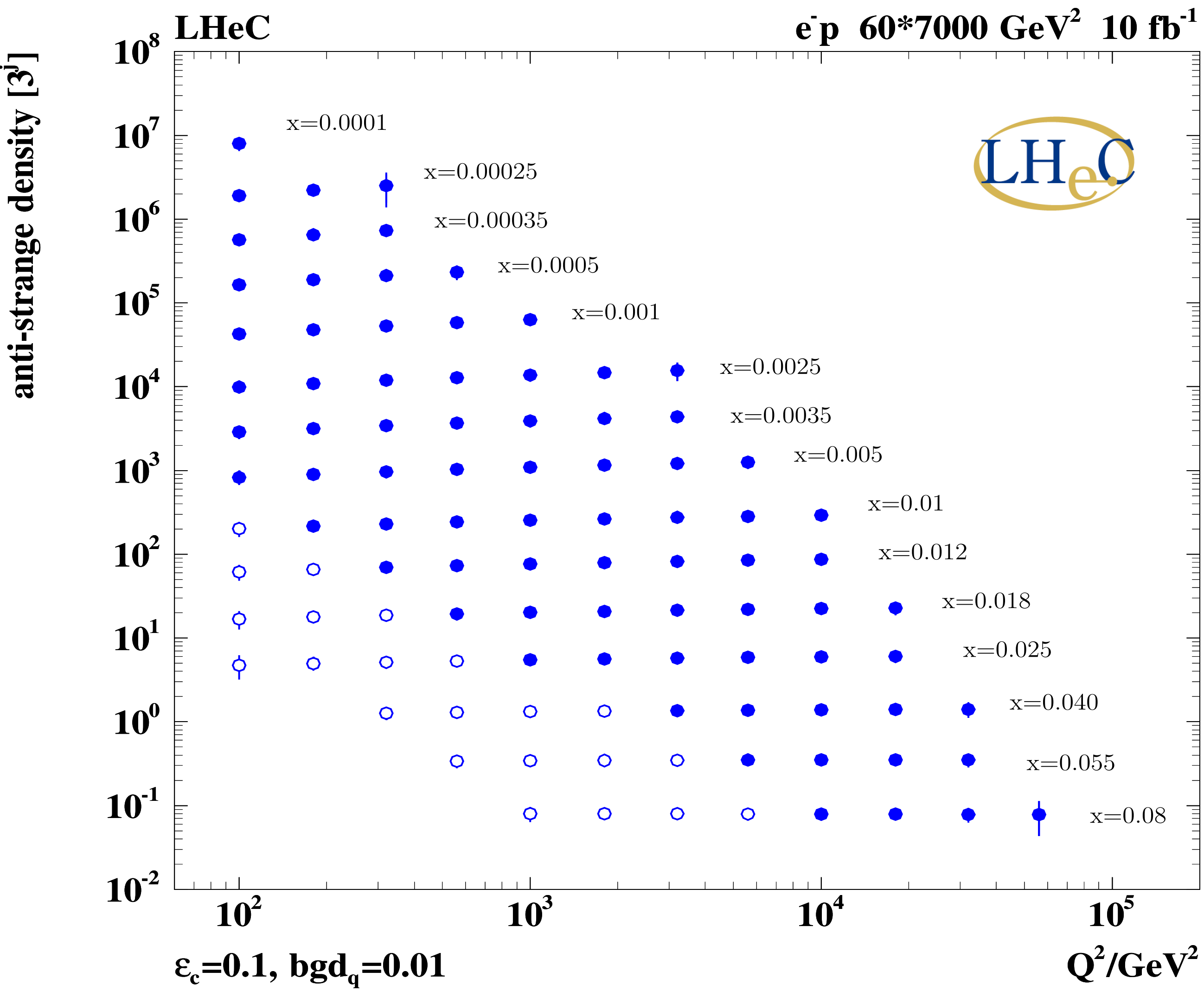




From J.Kretzschmar Moriond Eweak 7.3.12

PLB 707 (2012) 418-437; PLB 706 (2012) 295-313; CMS-PAS-EWK-10-015; CMS-PAS-EWK-11-013

Strange Quark Density from Ws→c in ep → νcX



Tag charm in CC
(10% efficiency)
Light quark bgd: 1%

e^- - anti-strange
e^+ - strange xs(x,Q^2)

Beam spot ≈10x30 μ m²
Systematic error ~5%

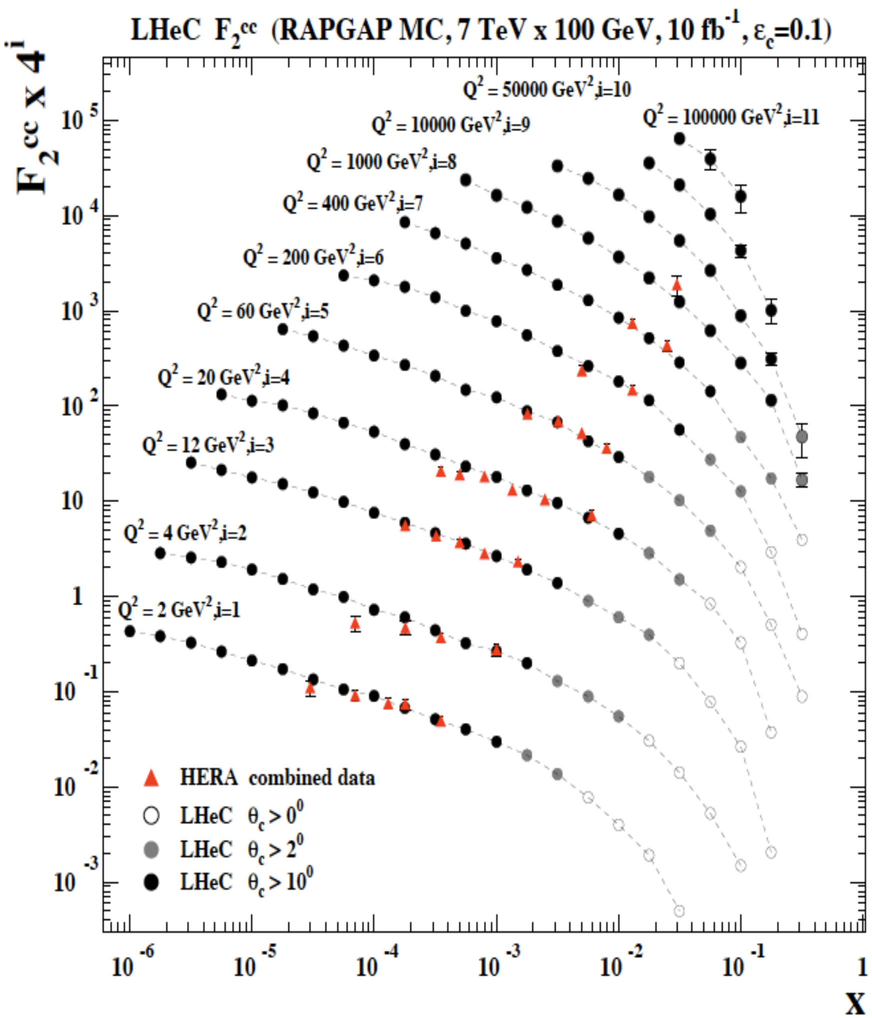
LHeC:
ep, eD, eA with 60 GeV.
100 times HERA Lumi.
Design report being
updated and refereed.
Synchronous LHeC
and HL-LHC operation
→ *Upgrade of the LHC*

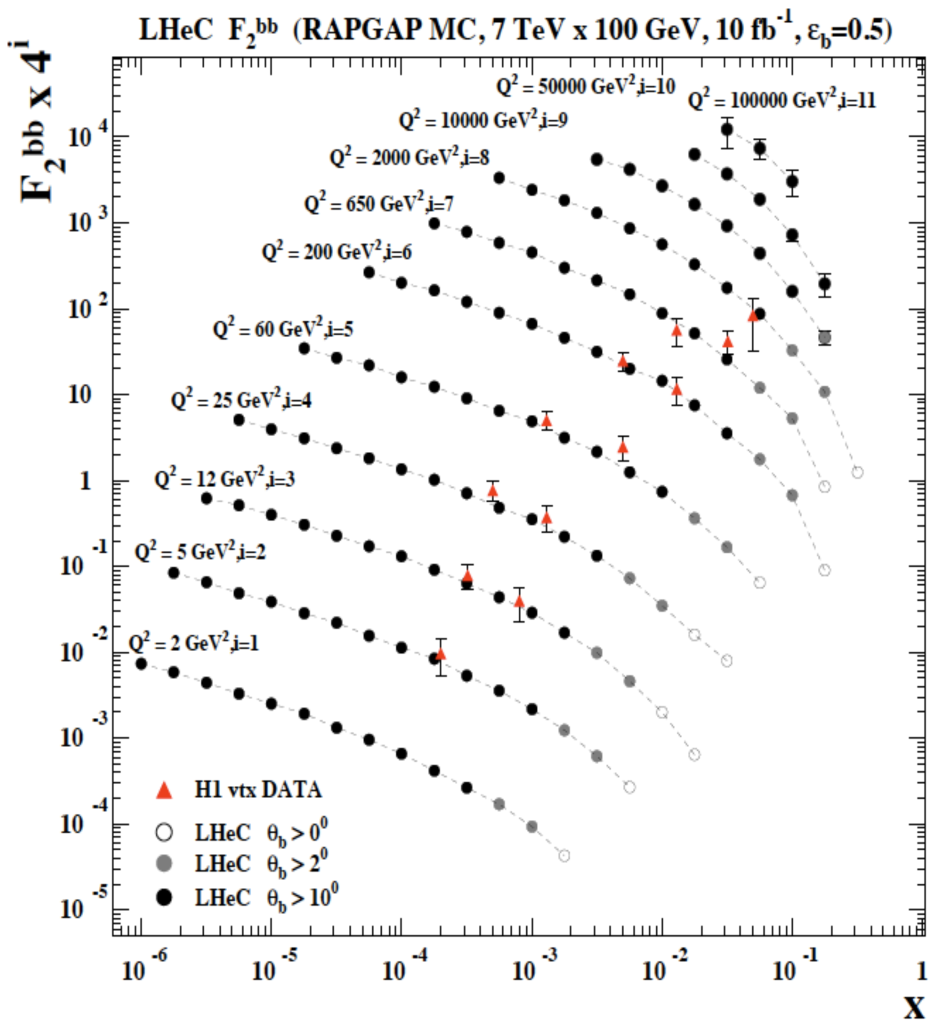
http://cern.ch/lhec
DIS12 at Bonn
Workshop 14/15.6.12

M.Klein, Karlsruhe 19.3.12

$Q^2 \approx 100 - 5\ 10^4$ GeV² x ≈ 0.0001 – 0.1

F_2^{charm} and F_2^{beauty} from LHeC



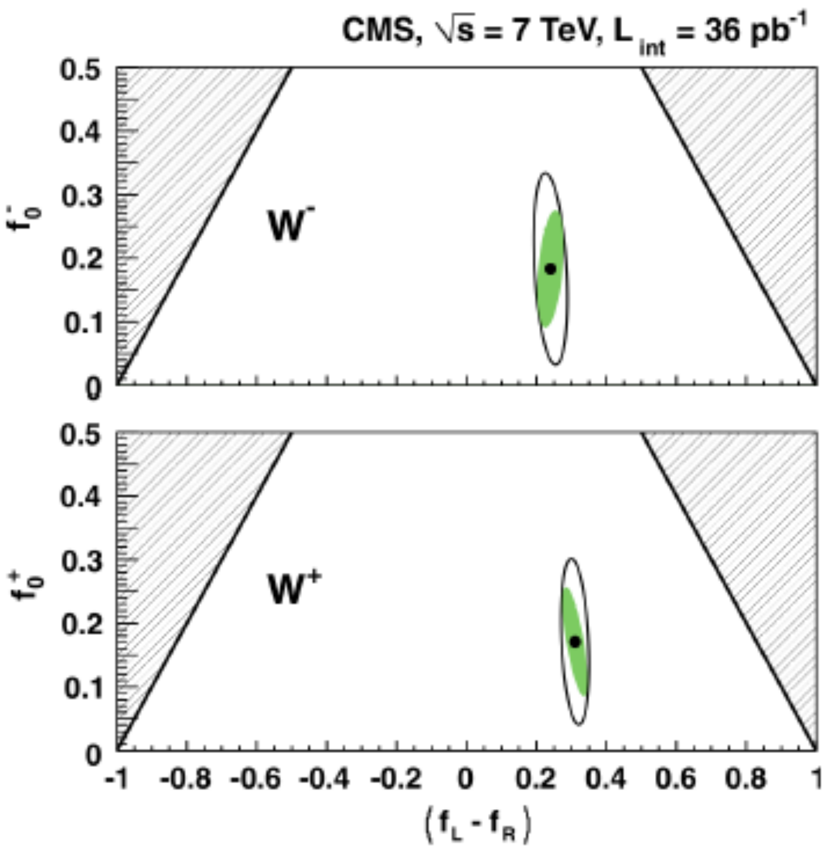


Hugely extended range and much improved precision will pin down heavy quark behaviour at and away from thresholds

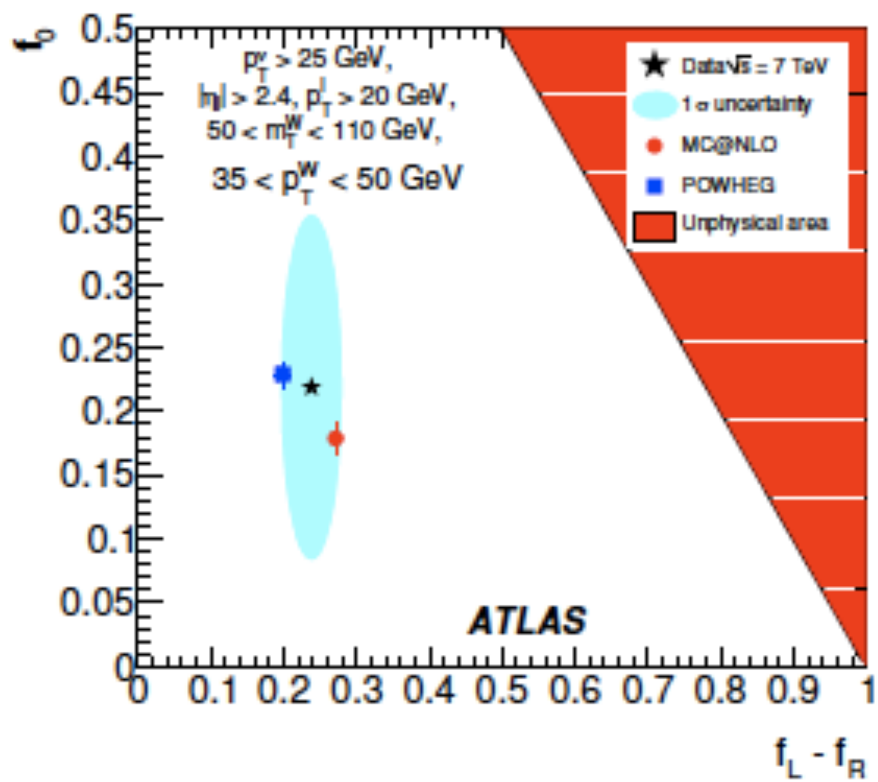
LHeC CDR 1.0 (2011)

W polarisation

New measurements by CMS and ATLAS on the polarisation of W's. Production in L, R or 0 state. At large rapidities predominantly L following influence of valence quarks. Three coefficients $f_L+f_R+f_0=1$. Measure angular distribution as with $L_P = \vec{p}_T^{\,\ell} \cdot \vec{p}_T^{\,W} / |\vec{p}_T^{\,W}|^2 \approx cos\theta$ L: L_p~0, R: L_p~1, 0: flat

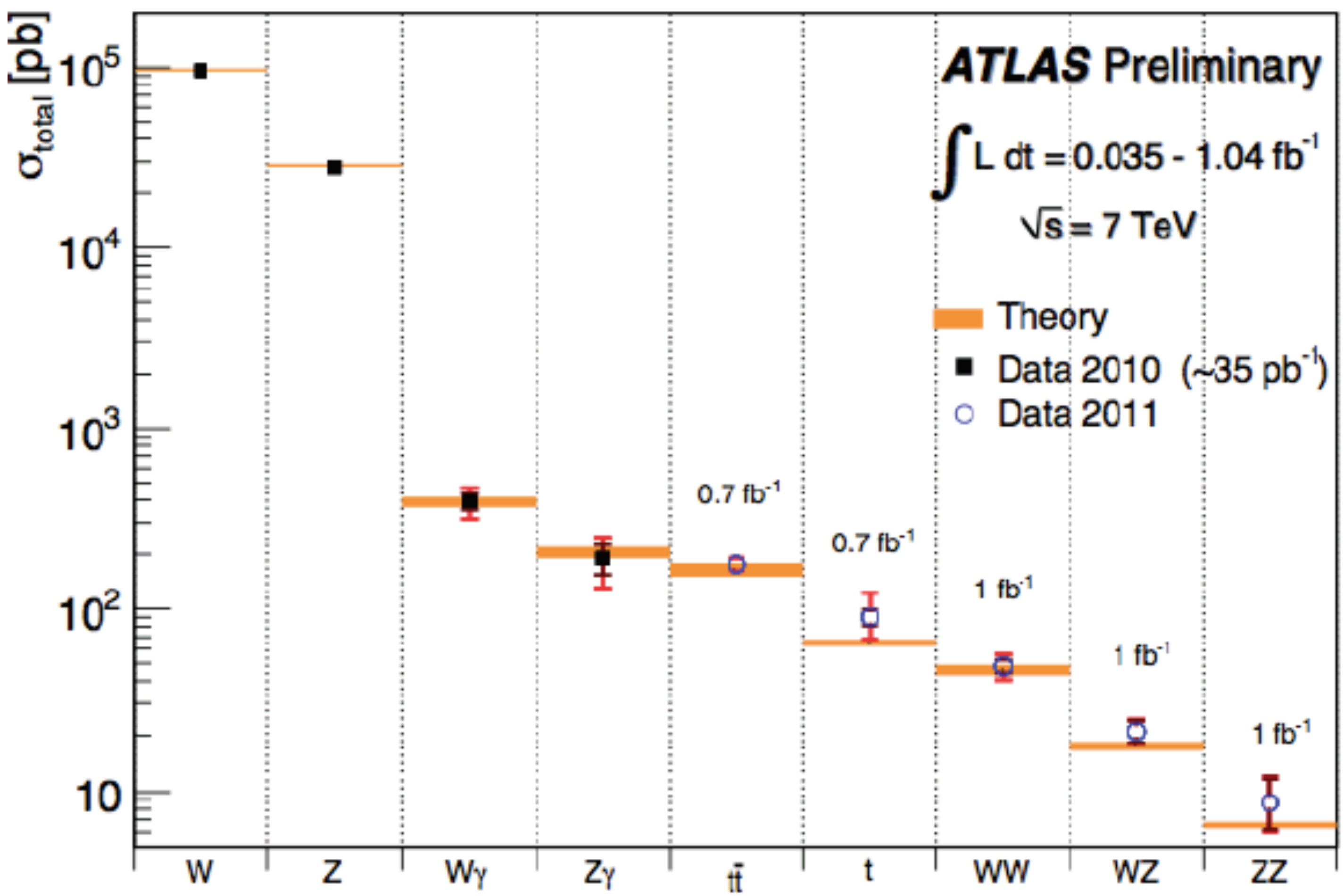


PRL 107, 021802 (2011)

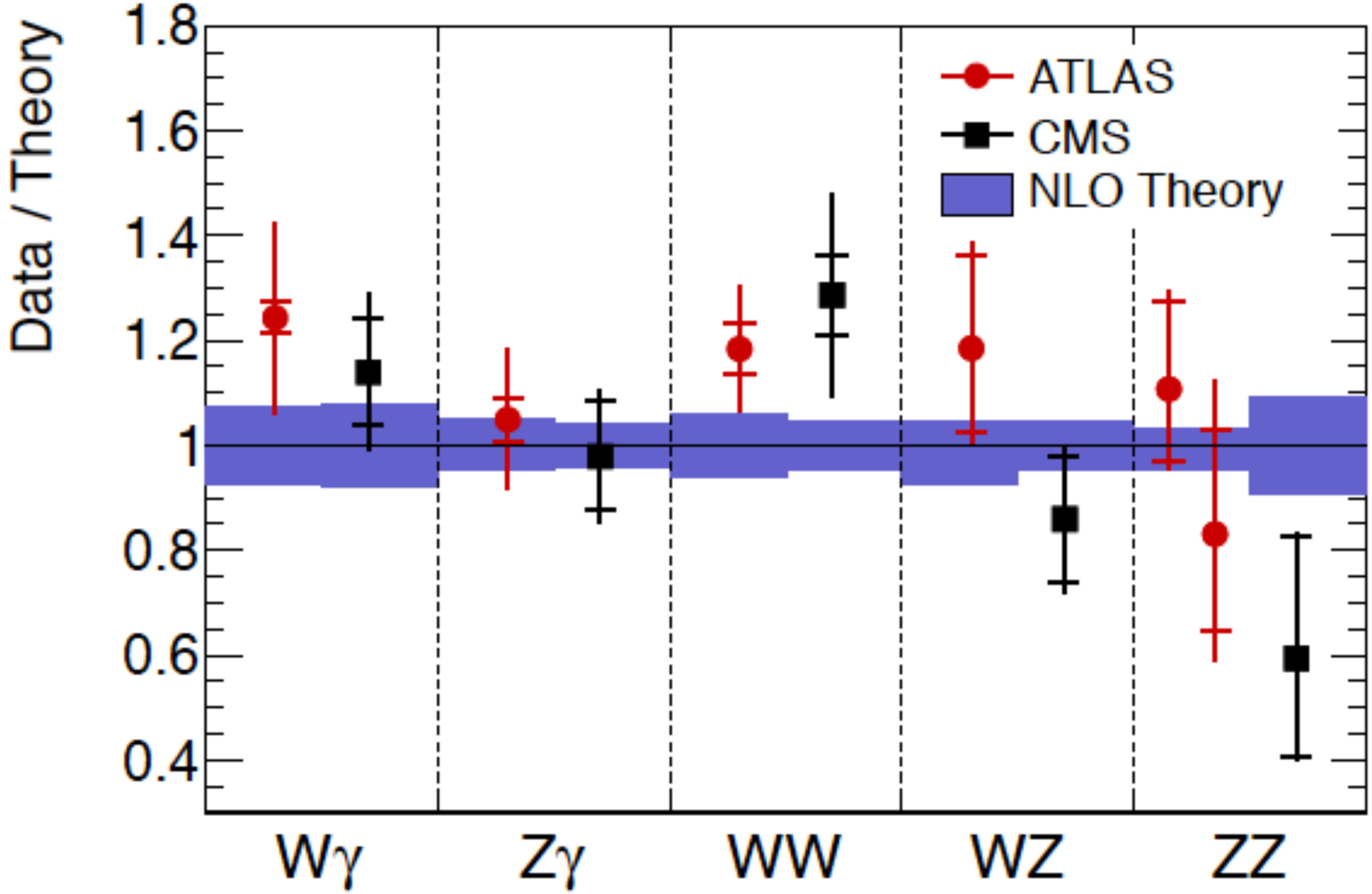


arXiv:1203.2165 → EPJ

Smaller Cross Sections



Di-Bosons

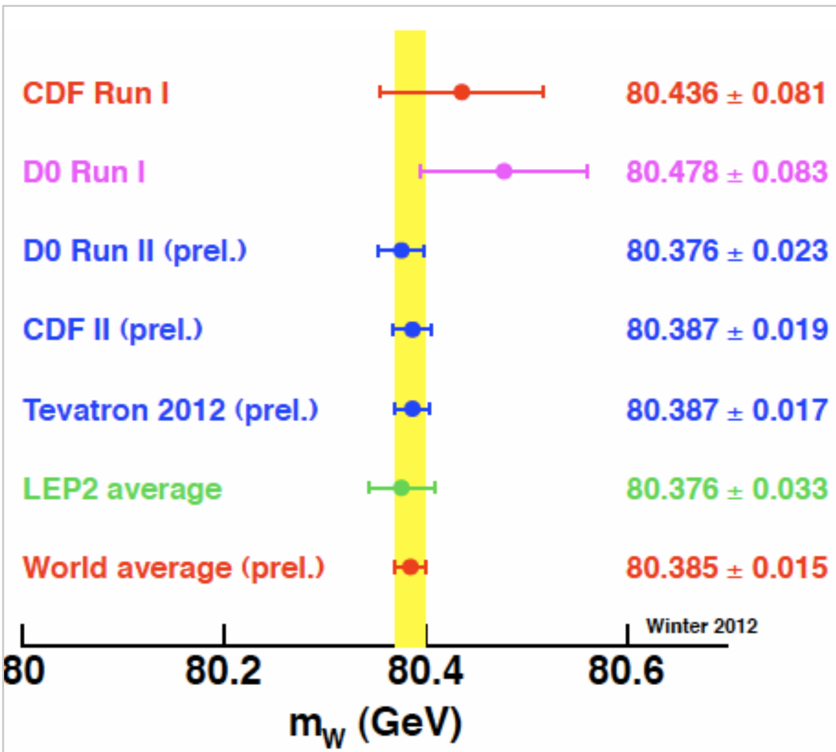


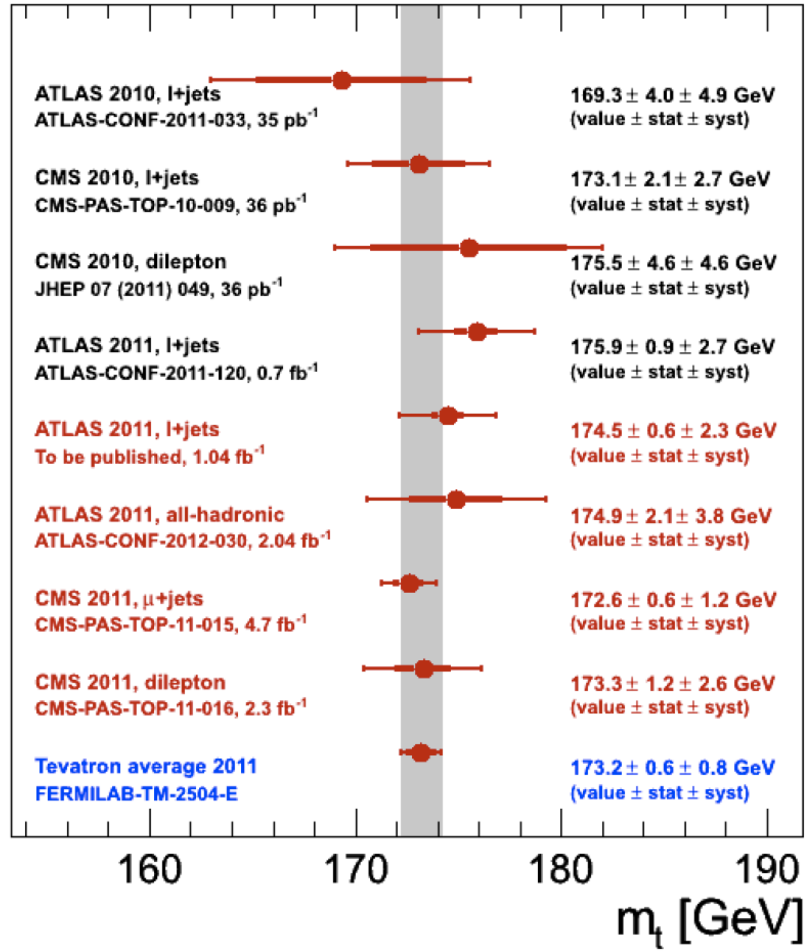
Cf J.Kretzschmar Moriond Electroweak 2012

The di-boson ATLAS and CMS cross section measurements are in good agreement with each other, and with theory.

W and top Masses

Moriond: D0 and CDF: 23, 19 MeV error

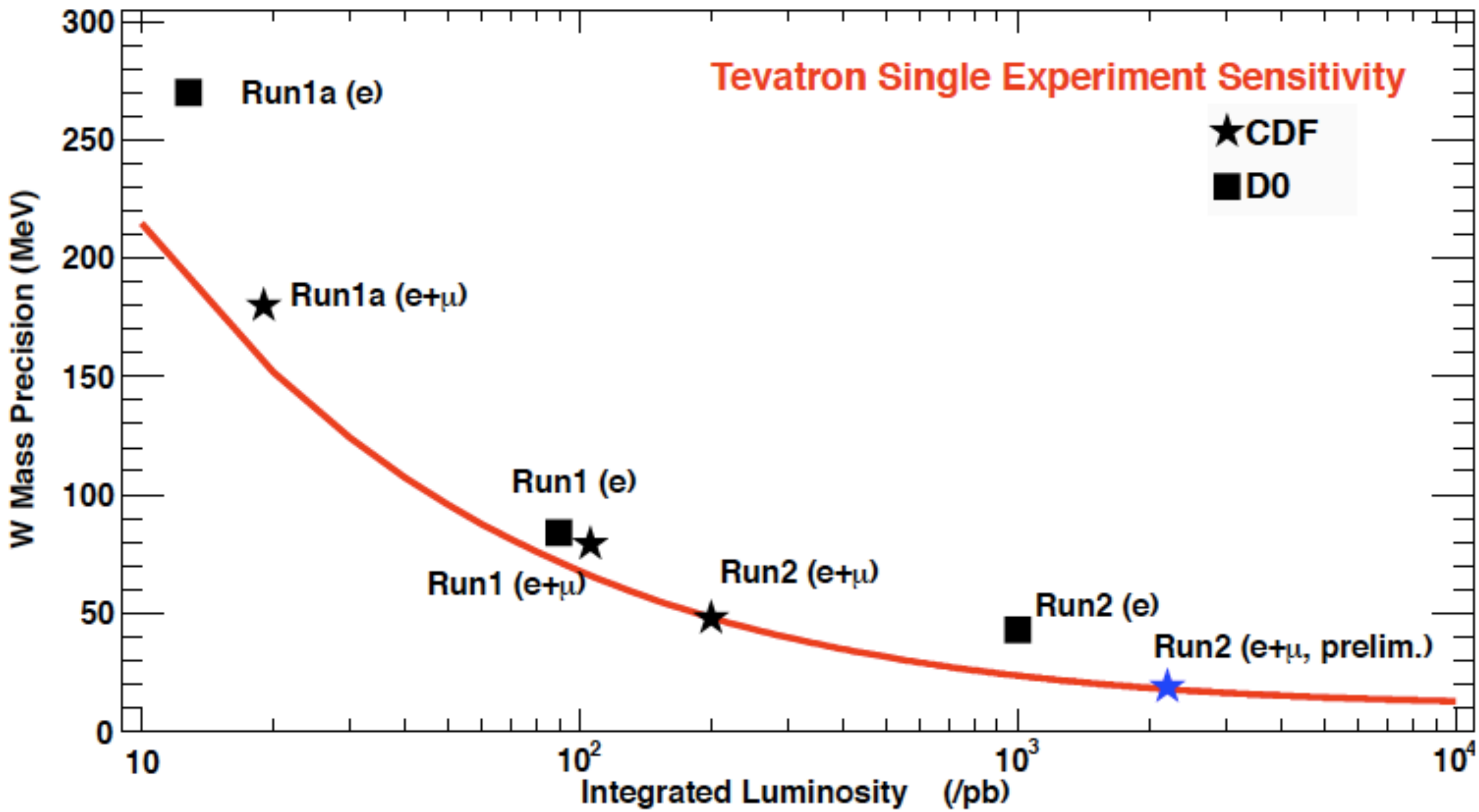




CMS and ATLAS with consistent M_t

Interesting measurements of σ_{tt}

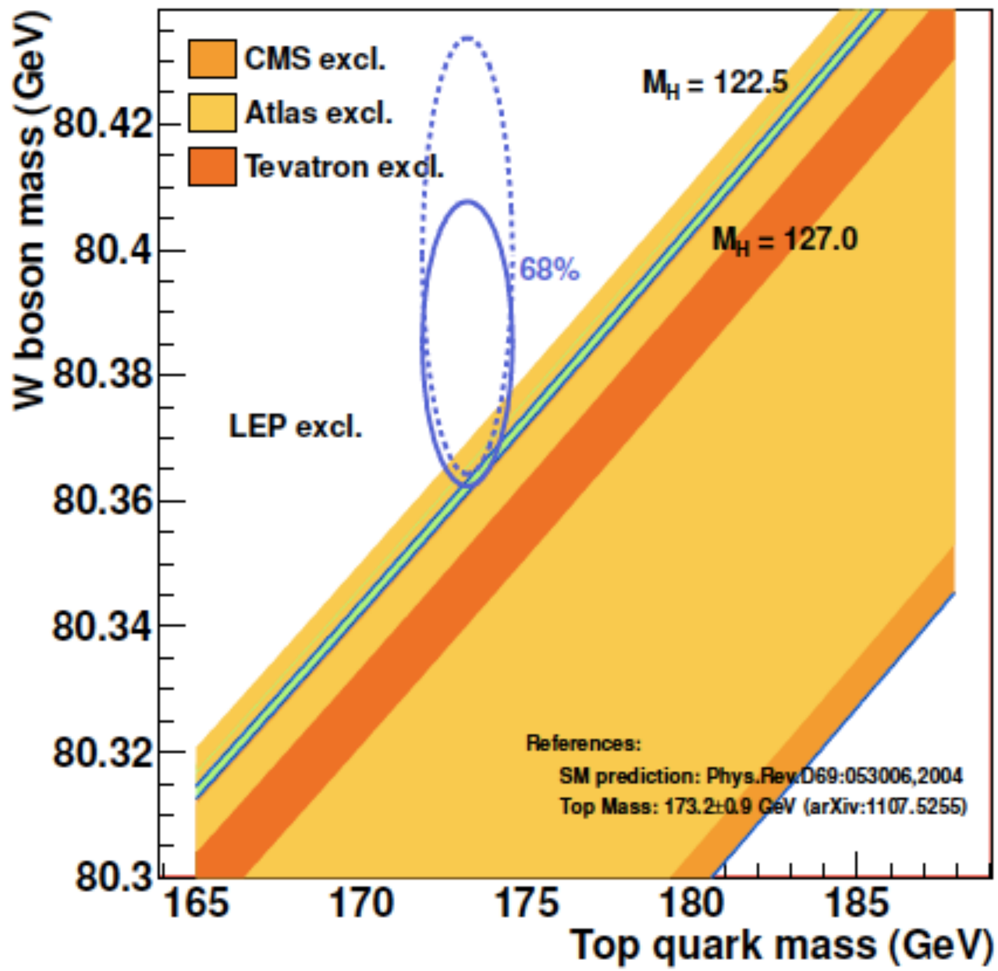
Precision vs Time/Luminosity



Bo Jayatilaka, Moriond Ewk

Tevatron W mass measurement may reach 10 MeV uncertainty. A big challenge for LHC.

W and top Masses and the "SM BEH Scalar"



R.Lopes de Sa (Moriond 11.3.12)

$M_H = 94^{+29}_{-24}\,GeV$ (was $M_H = 92^{+34}_{-26}\,GeV$ before)

Summary

The LHC and its experiments have had an extremely successful start into the TeV range.

ATLAS and CMS have made inclusive W,Z measurements of high precision at an absolute luminosity precision significantly better than expected (and prospects to ~2%).
A novel W charge asymmetry result from CMS, based on ~1fb^{-1}, underlines PDF sensitivity.

The first differential $W^{\pm}$, Z cross section data of ATLAS, jointly analysed with $e^{\pm}p$ cross sections from HERA, suggest that the light quark sea is flavour symmetric and increased by ~8%.
This result is consistent with the large W+c/W+jet ratio as measured by CMS.

The strange quark density is an example for a symbiosis of precision pp and ep measurements, which may be established when the HL-LHC and the LHeC ran synchronously in the 20ies.

A wealth of more analyses, as of all di-boson channels, has been performed and good agreement with pQCD been observed. Not covered here are p_T(Z,W) measurements as are important for approaching an M_W mass measurement precision of interest.

The top mass measurements of CMS and ATLAS approach the Tevatron precision.
The new CDF and D0 W mass measurements have 20 MeV precision. This predicts the SM 'Higgs' particle to be lighter but just consistent with a possible 125GeV mass.

The ATLAS and CMS results presented here are initial observations
… more is to come, and the W polarisation a good example.