Prospects for ElectroWeak Physics at LHC

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on behalf of ATLAS and CMS Collaborations

INFN Pavia and CERN

Aspen Particle Physics Conference

Aspen Center for Physics

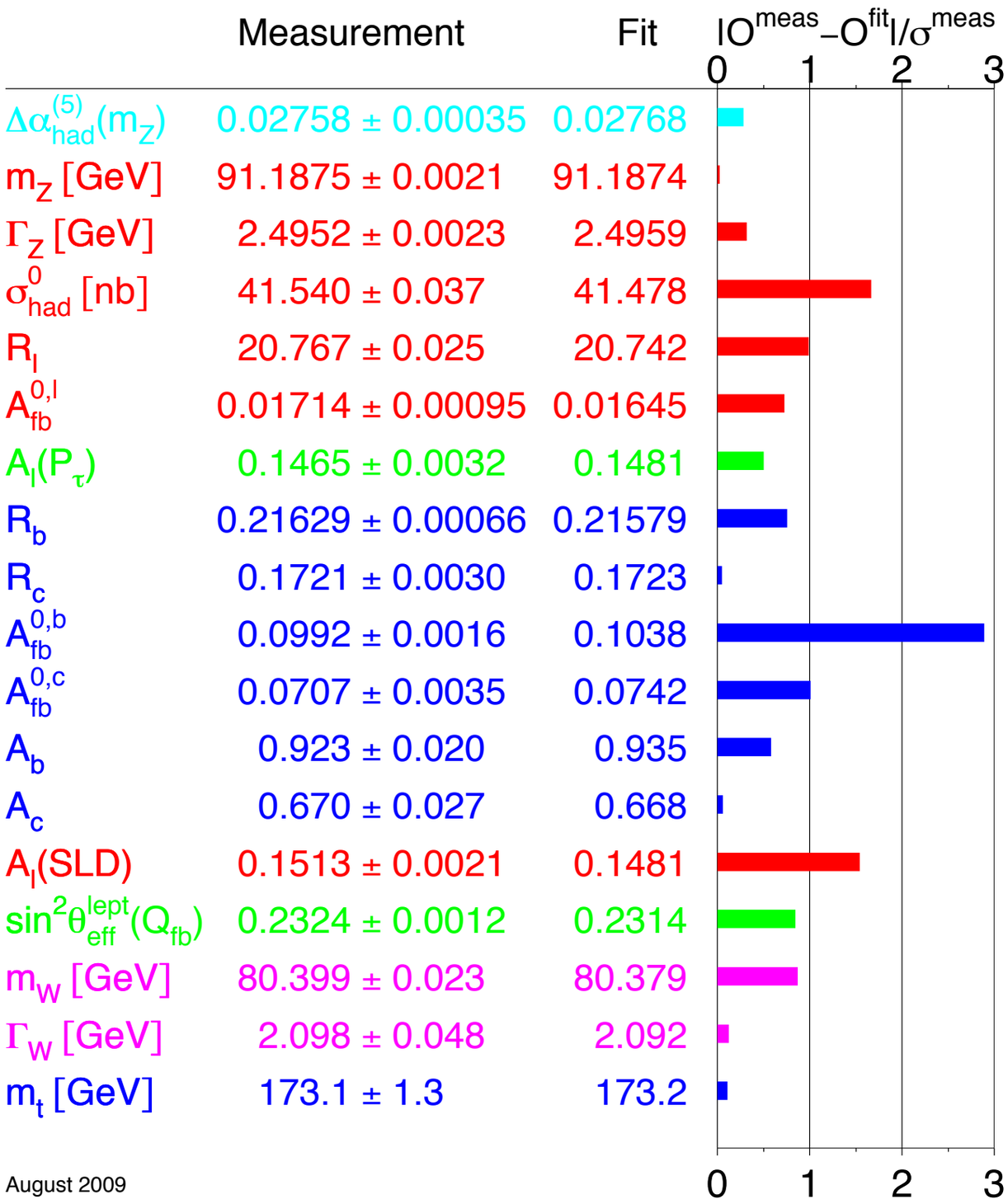
January 17-23, 2010

Outline

- **LHC and experiments**
- **Preliminaries for precision physics**
  - ★ LHC 900 GeV collisions
  - ★ Standard Model as Standard Candle
- **EW Physics measurements**

  focus on 2010 data and

  prospects for high luminosity measurements
  - ★ W and Z cross sections
  - ★ Drell-Yan differential shapes
  - ★ W mass
  - ★ Di-boson studies
  - ★ Z forward-backward asymmetry
- **Outlook**

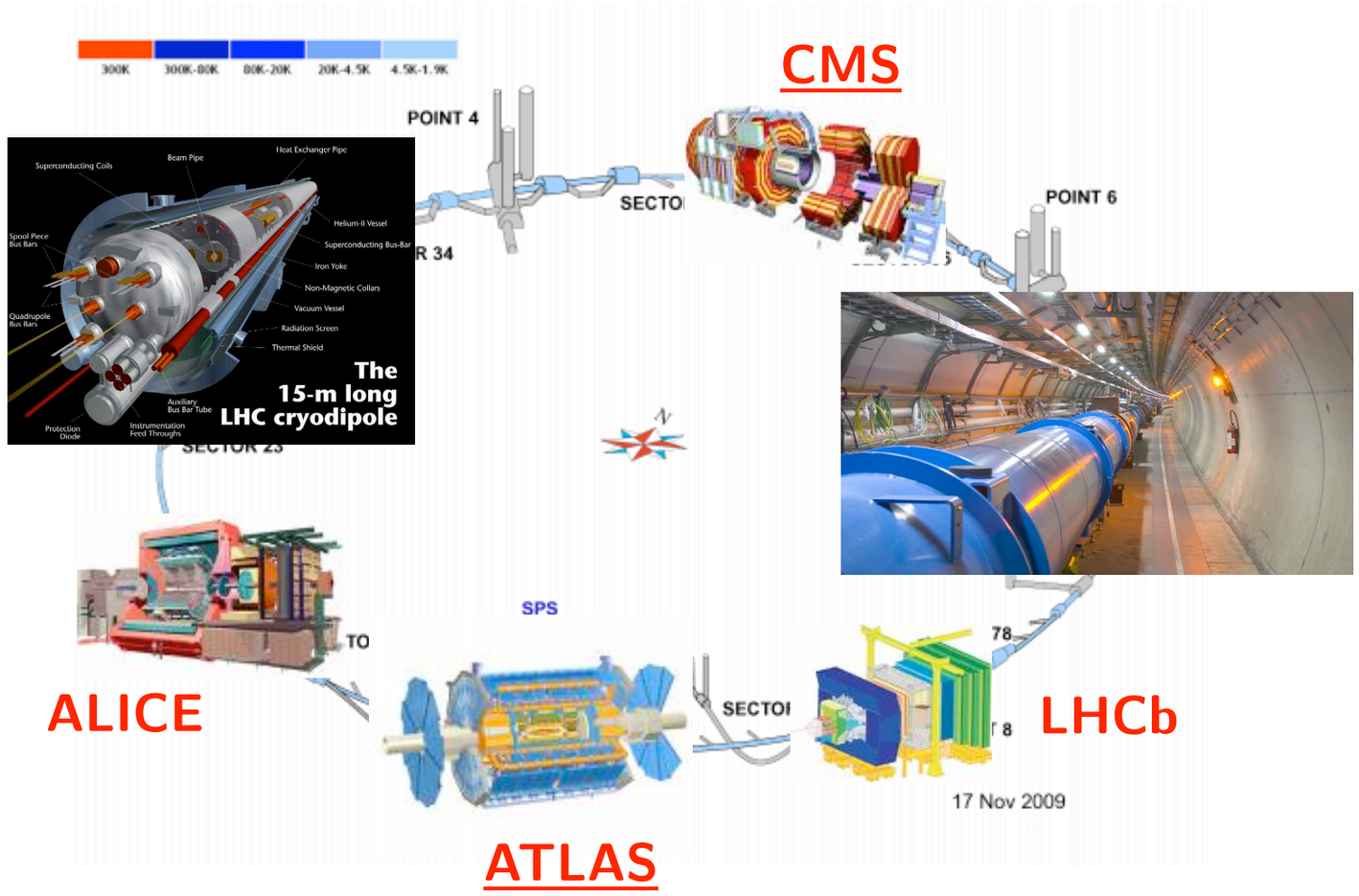


CERN-PH-EP/2009-023

Updated for 2010 winter conferences, 11/01/10, http://www.cern.ch/LEPEWWG

Large Hadron Collider (LHC)

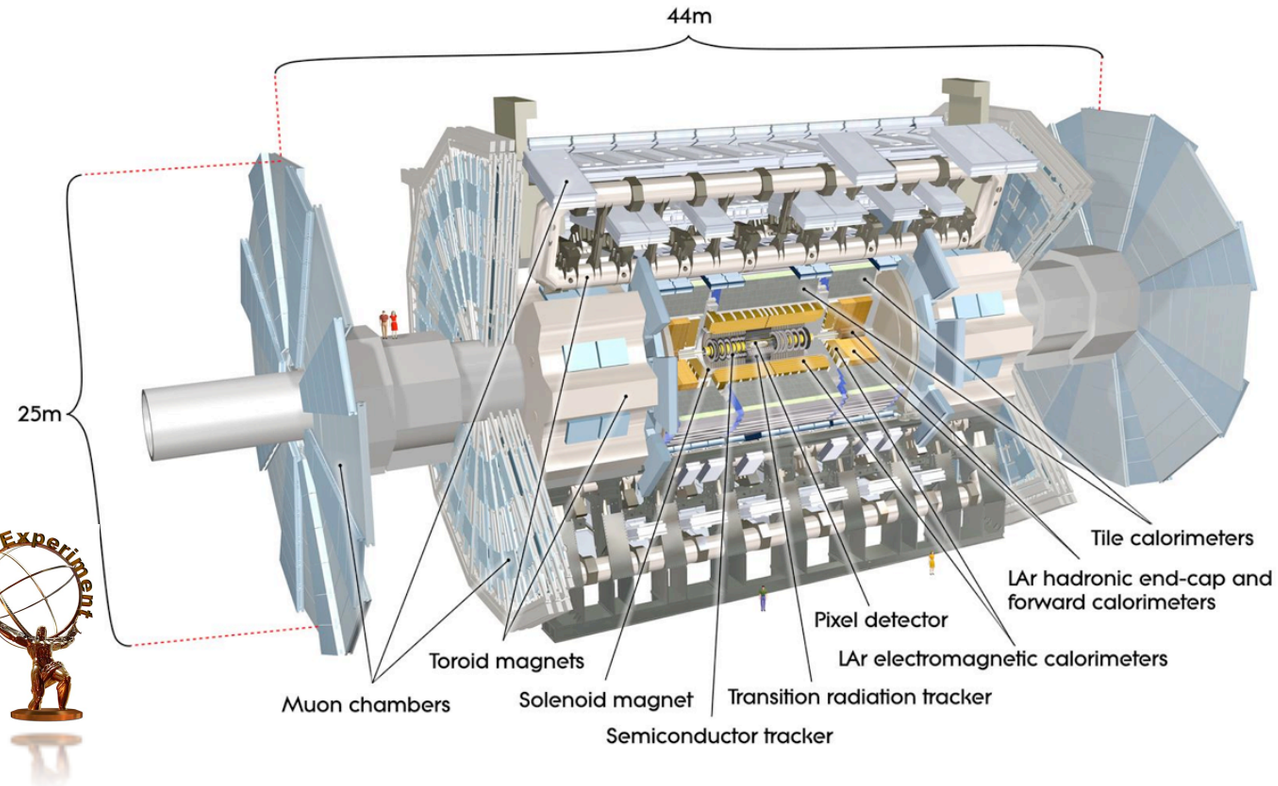
- **LHC key parameters**
  - ★ p-p collisions at **14 TeV** (x7 wrt Tevatron)
  - ★ design luminosity of **10^{34} cm^{-2}s^{-1}** (x100 wrt Tevatron)
  - ★ bunch crossing of 40 MHz, **1GHz pp collisions**
  - ★ Heavy particles production rates $10^{+3...-6}$ Hz (W,Z,top,H,SUSY,..) with **high sensitivity to New Physics**

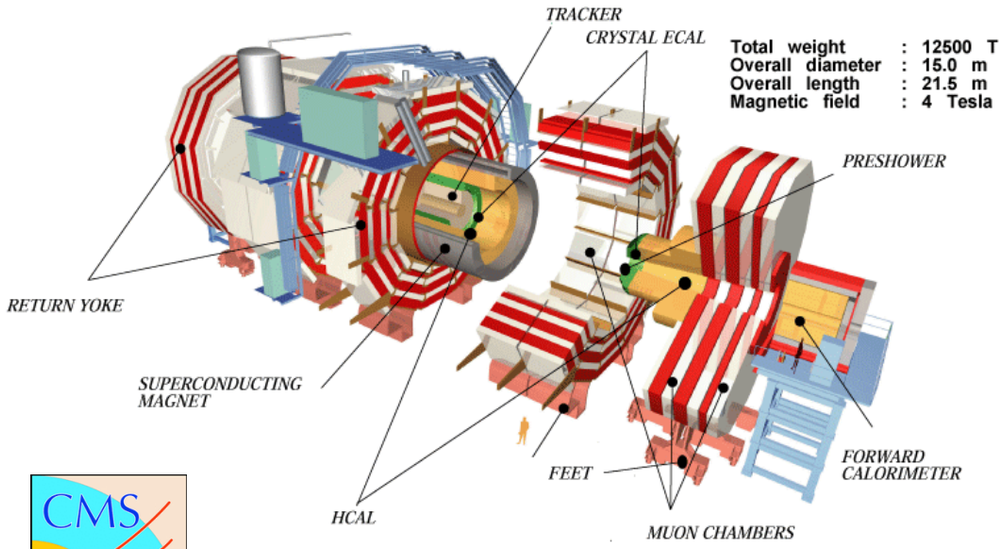


- At regime: ~6x10^6s of pp collision physics running per year
  - ★ ~0.6 fb^{-1}/year if L=10^{32} cm^{-2}s^{-1}
  - ★ ~6 fb^{-1}/year if L=10^{33} cm^{-2}s^{-1}
- **Physics run 2010 starting mid February**
  - ★ 3.5(5) TeV beam energy with the goal to integrate 100-200 pb^{-1} ⇒ **Standard Model re-discovering !**

Channels ($\sqrt{s}$ = 14 TeV)	Events 100 pb^{-1}	Total statistics
W → μν	10^6	10^4 LEP, 10^{6-7} TeVatron
Z → μμ	10^5	10^6 LEP, 10^{5-6} TeVatron
tt → WbWb → μν + X	10^4	10^{3-4} TeVatron
QCD jets p_T > 1 TeV	>10^3	-

ATLAS & CMS detectors

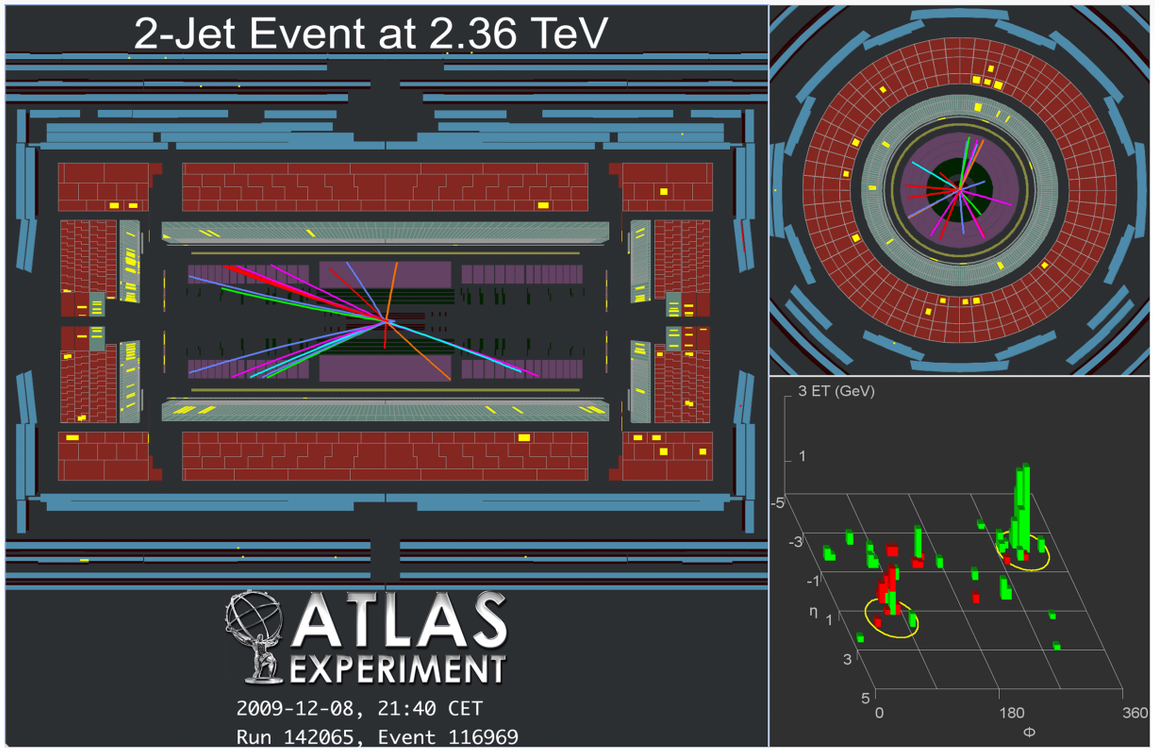


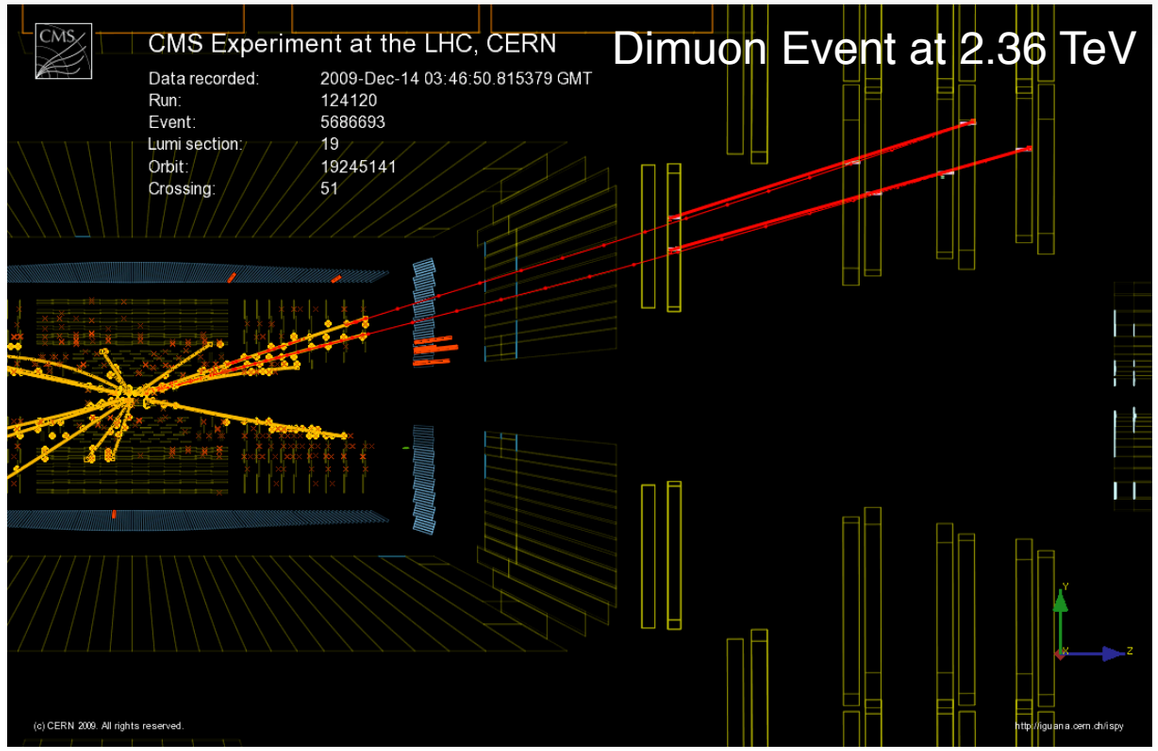


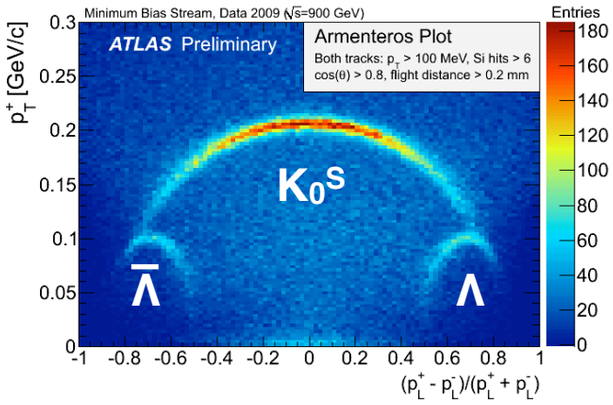
	ATLAS	CMS
Magnetic field	2 T solenoid + toroid (0.5 T barrel 1 T end-cap)	4 T solenoid + return yoke
Tracker	Si pixels, strips + TRT $\sigma/p_T \approx 5\times10^{-4} p_T + 0.01$	Si pixels, strips $\sigma/p_T \approx 1.5\times10^{-4} p_T + 0.005$
EM Calorimeter	Pb+LAr $\sigma/E \approx 10\%/\sqrt{E} + 0.007$	PbWO4 crystals $\sigma/E \approx 2\text{-}5\%/\sqrt{E} + 0.005$
Hadronic Calorimeter	Fe+scint. / Cu+LAr (10λ) $\sigma/E \approx 50\%/\sqrt{E} + 0.03$ GeV	Cu+scintillator (5.8λ + catcher) $\sigma/E \approx 100\%/\sqrt{E} + 0.05$ GeV
Muon	$\sigma/p_T \approx 2\%$ @ 50GeV to 10% @ 1TeV (ID+MS)	$\sigma/p_T \approx 1\%$ @ 50GeV to 5% @ 1TeV (ID+MS)
Trigger	L1 + RoI-based HLT (L2+EF)	L1+HLT (L2 + L3)

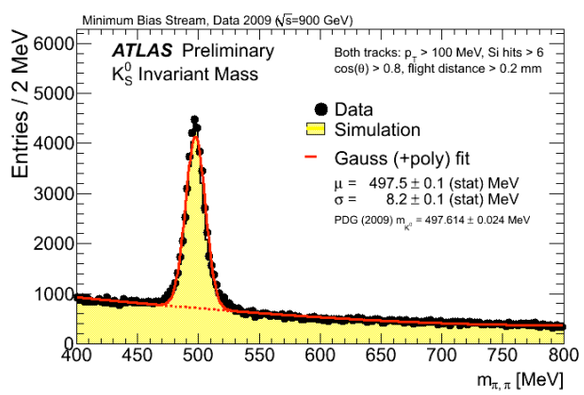
- General purpose detectors with complementary concepts
- For details see
  - ★ G. Aad et al (ATLAS Collaboration) J. Instrum. 3. s08003 (2008)
  - ★ S.Chatrchysn (CMS Collaboration) J. Instrum. 3. s08004 (2008)

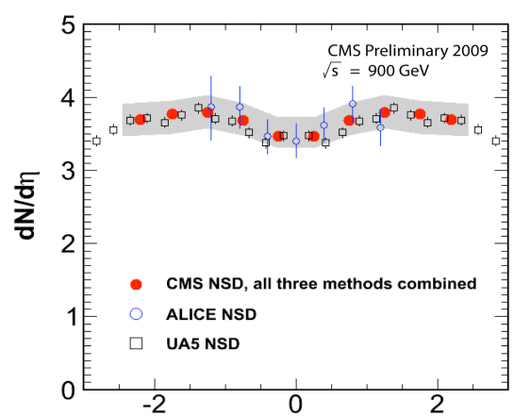
First LHC data at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 2.36$ TeV

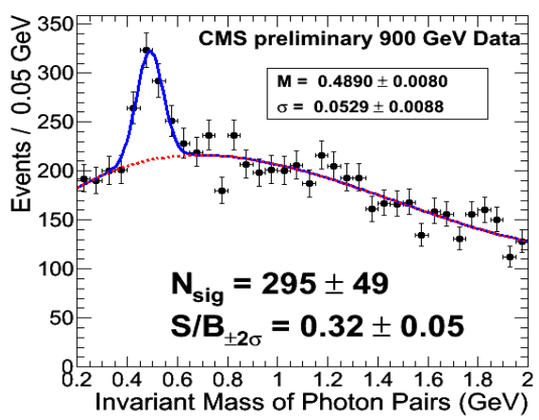


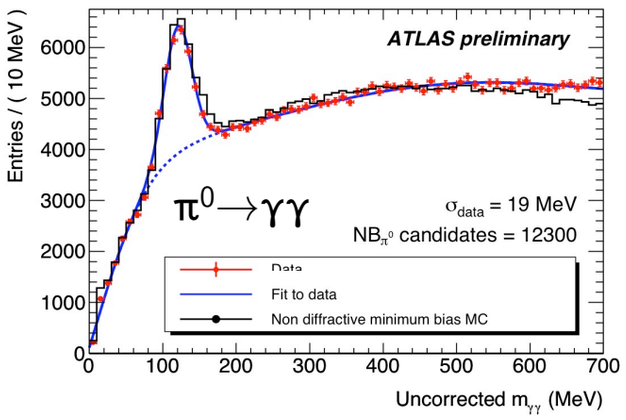


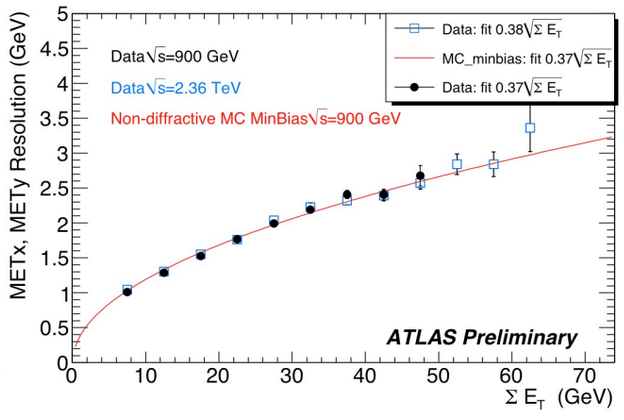


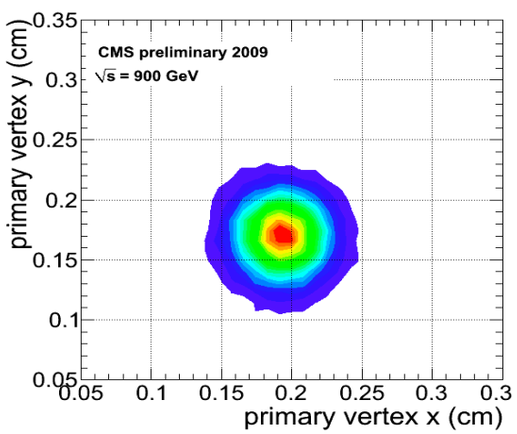


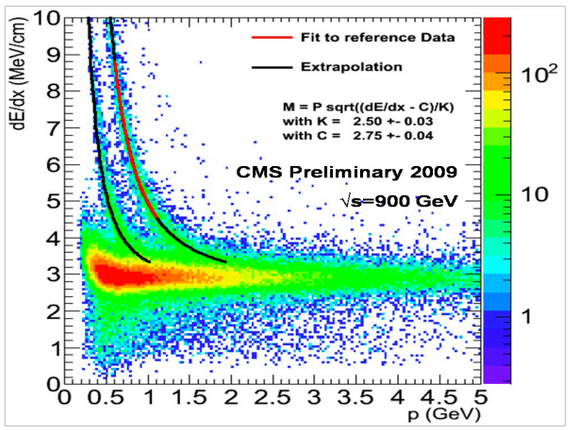












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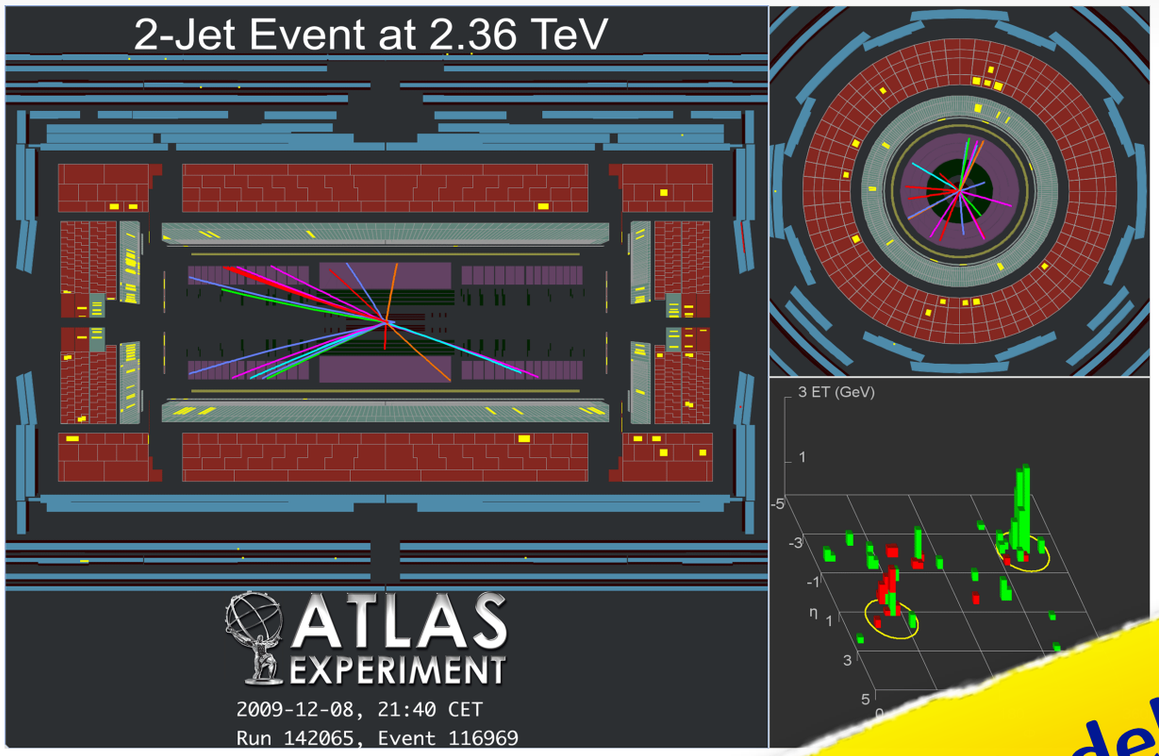
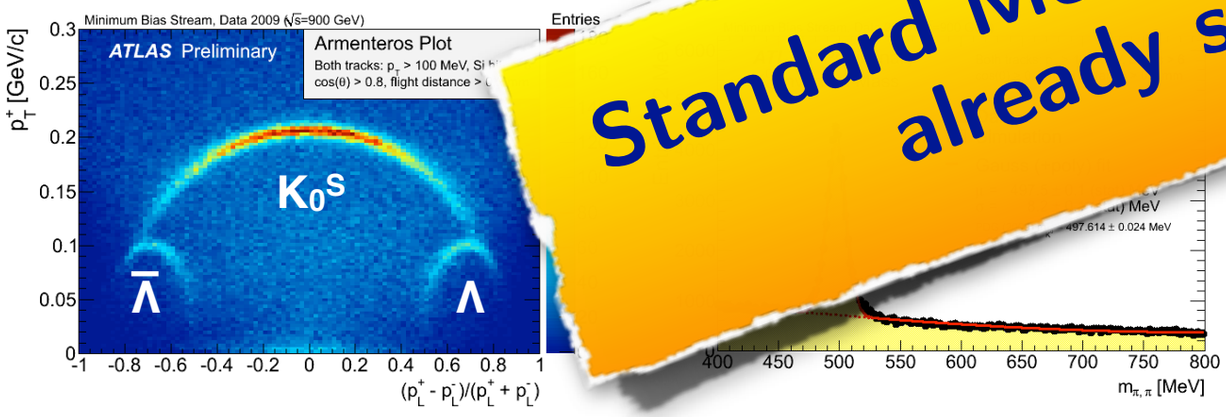
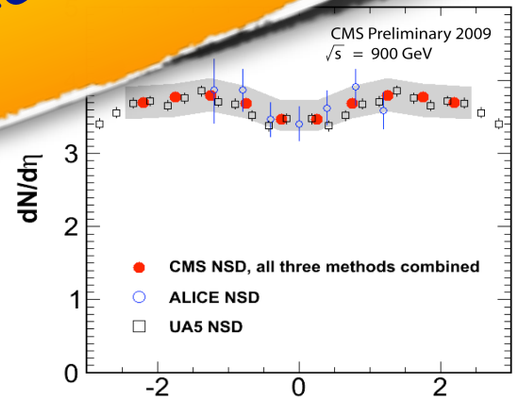
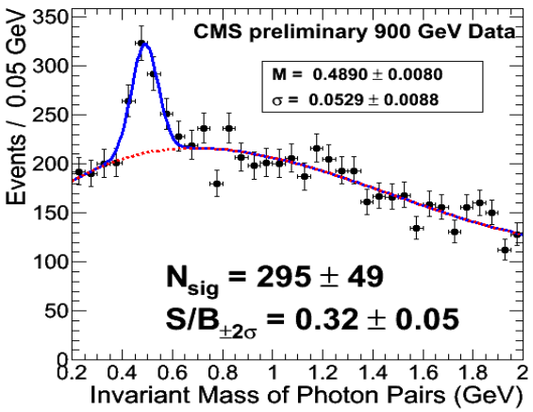
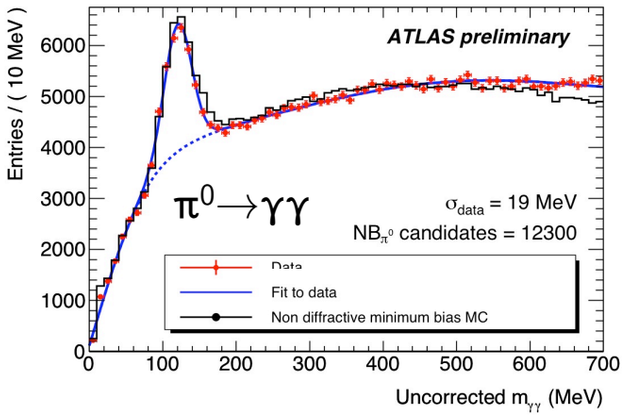


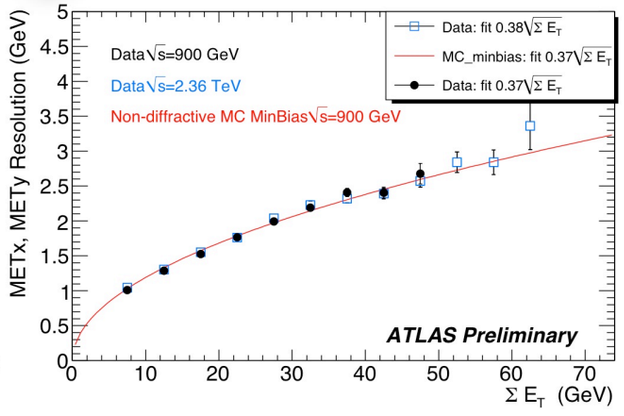
Standard Model re-discovering already started !

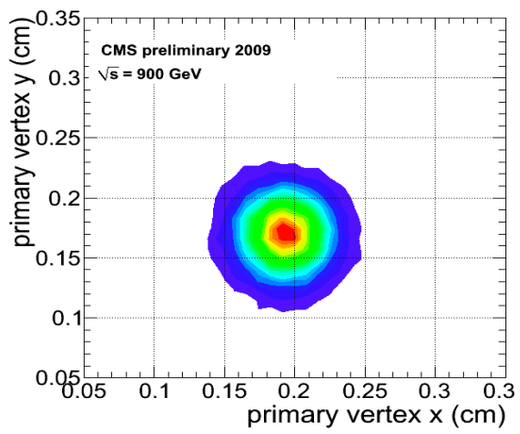


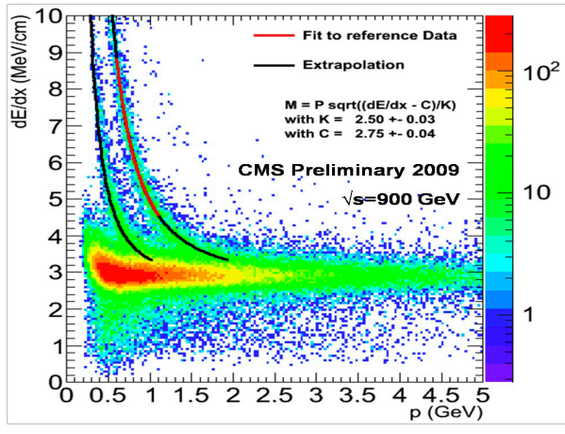






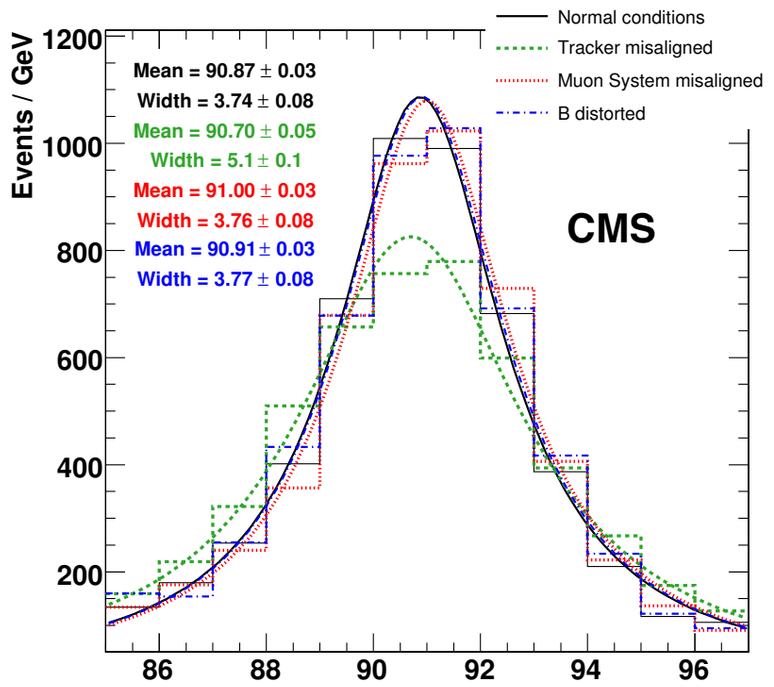




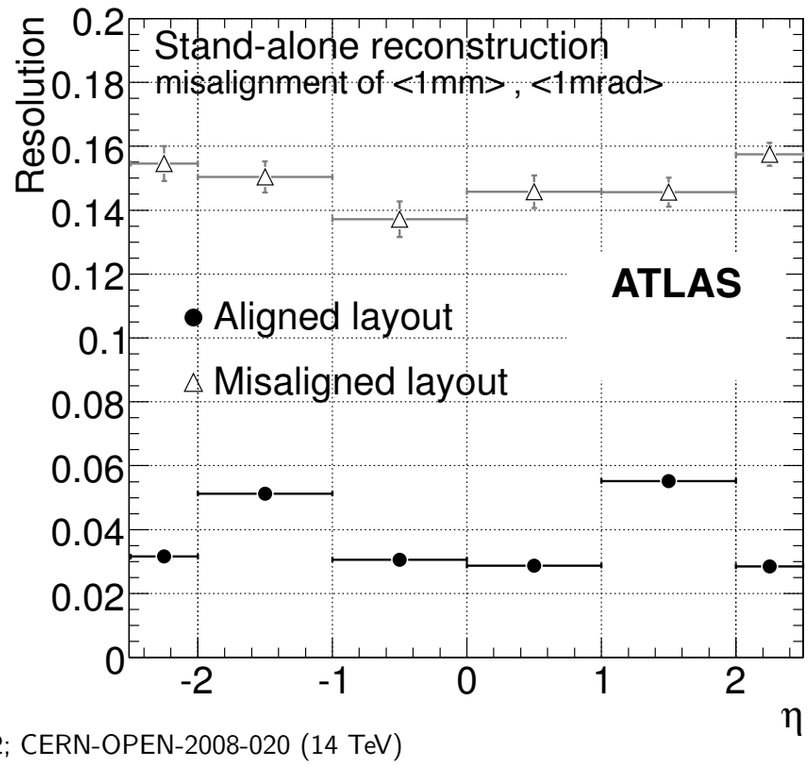


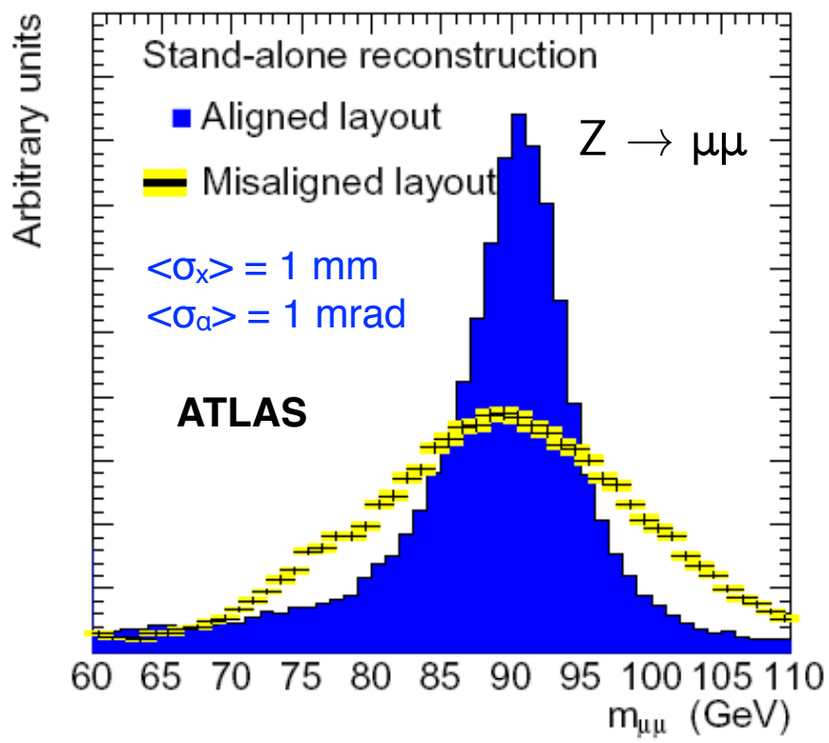
Alignment with $Z \rightarrow \mu^+\mu^-$

- Effect of misaligned detectors on muon reconstruction
  - ★ high reconstruction efficiency
  - ★ major impact on momentum resolution
- Use Z boson mass constraint to derive misalignments parameters from data
  - ★ broader invariant mass spectrum with scale quite unaffected due to first order compensation of opposite charge effects
  - ★ percent precision already after **1 day at 10^{33} cm^{-2}s^{-1}**



CMS PAS 2007/002 (14 TeV)



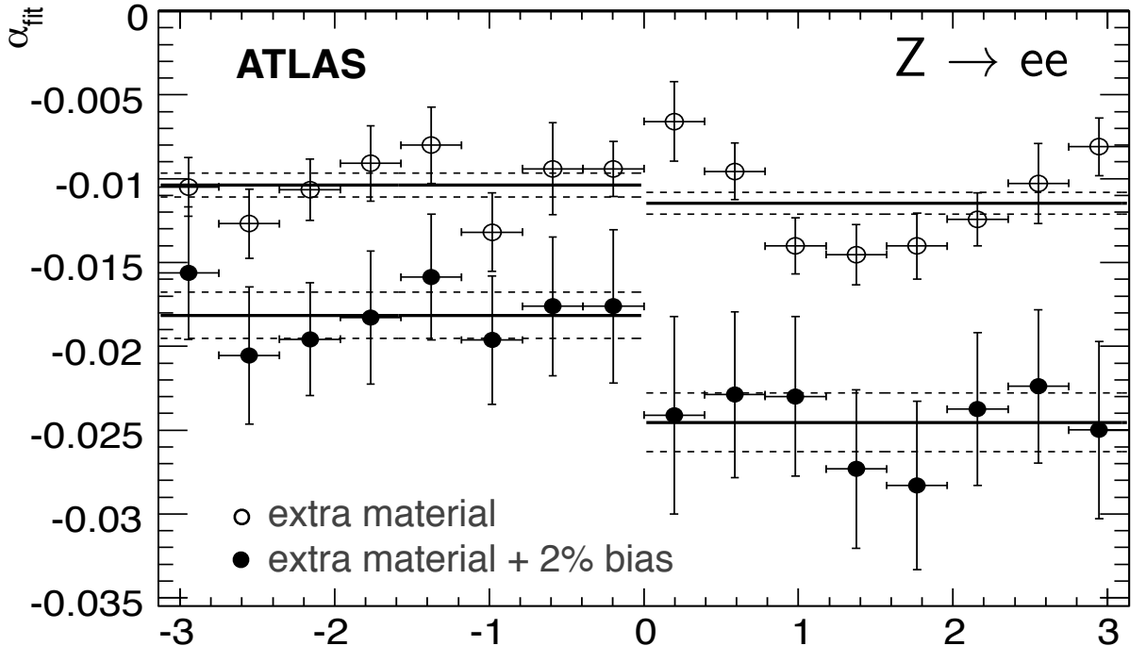


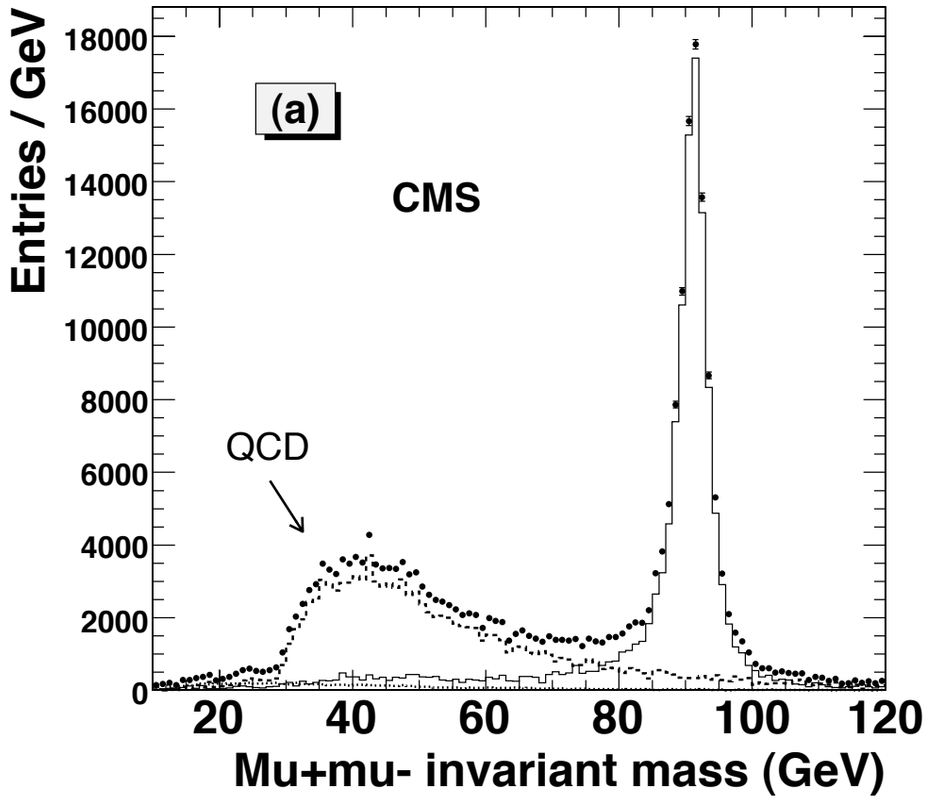
arXiv:0901.0512; CERN-OPEN-2008-020 (14 TeV)

Momentum/energy calibration from $Z \to ll$ (l=e,μ)

- Determination of **momentum resolution/scale** for muons
- **Calorimeter inter-calibration** and **energy scale** for electrons
  - ★ fitting Z boson lineshape
    - Energy range about 20-80 GeV
    - Use peak **position** and **width** to get **scale** and **resolution** parameters
- Fitting the **invariant mass lineshape** after **background subtraction**
  - ★ selection based on high-p_T tracks
  - ★ few days of data taking at 10^{33} $cm^{-2}s^{-1}$
    - **Muon scale** can be estimated to about **1%**
    - **Electromagnetic scale** known at **0.2%** and **resolution constant term** at about **0.7%**

arXiv:0901.0512; CERN-OPEN-2008-020 (14 TeV)

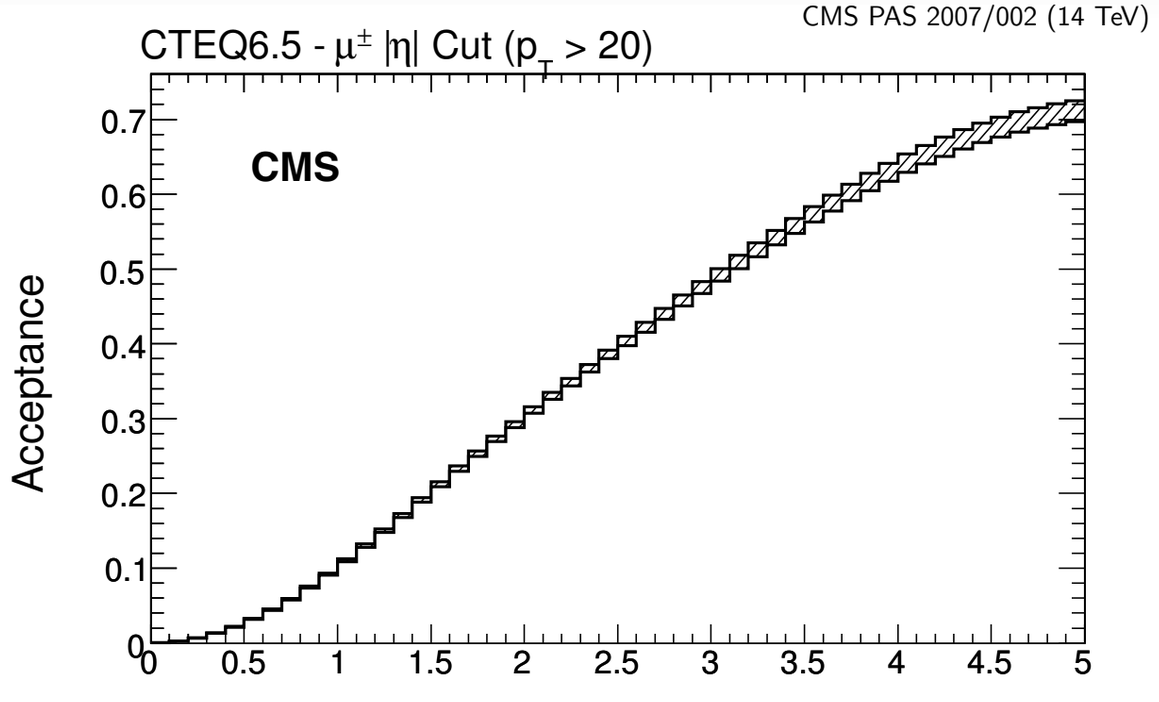


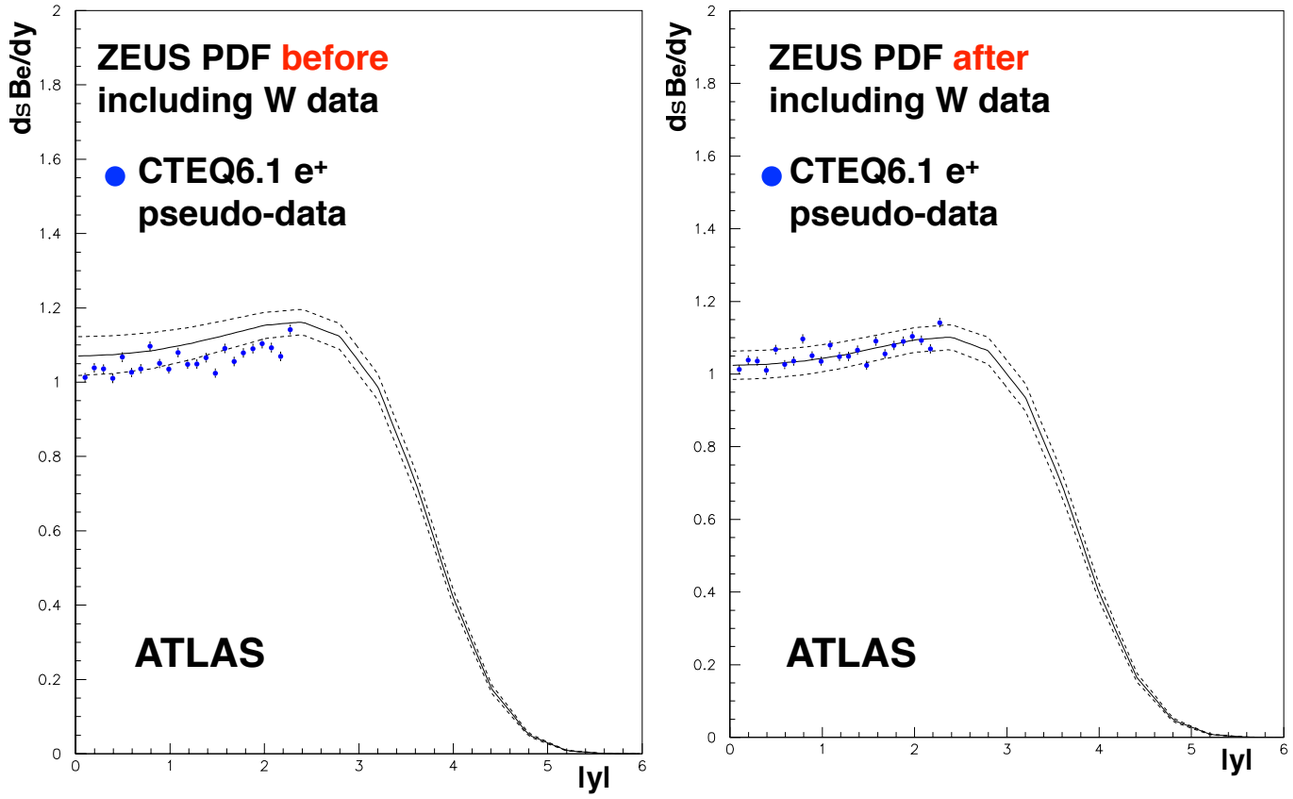


CERN-LHCC-2006-001 (14 TeV)

W,Z to leptons cross sections

- **Acceptance and PDFs uncertainties**
  - ★ **EW and QCD NLO** modelling to get experimental acceptance (**effects at 7-10%**)
  - ★ At the EW scale LHC will explore low-x partons
    - $10^{-4}<x<0.1$ over measurable range ($|y|<2.5$)
  - ★ Scattering between sea quarks: **gluon dominated**



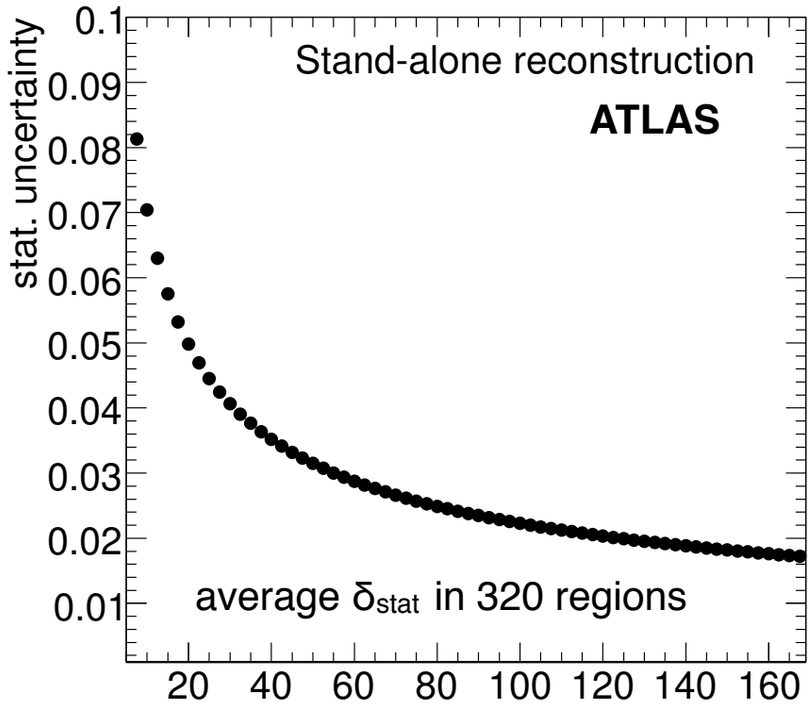


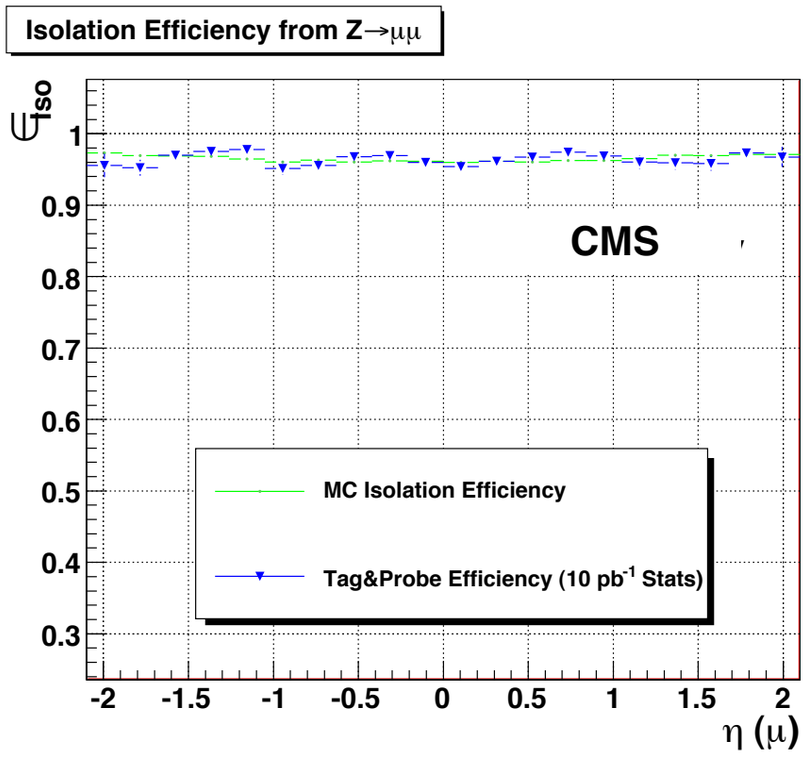
HERA and the LHC - A workshop on the implications of HERA for LHC physics
CERN-2005-014, DESY-PROC-2005-001 arXiv:hep-ph/0601012v3 (14 TeV)

- PDFs constraints from LHC
  - ★ caveat on PDF assumptions
    - s-sbar violations changes W/Z ratio
      ⇒ need $W^{\pm}$,Z differential shapes and ratios
- low-x gluon distribution determined by shape parameter λ ($xg(x)\sim x^{-\lambda}$)
  - ★ BEFORE $\lambda = -0.199 \pm 0.046$
  - ★ AFTER $\lambda = -0.186 \pm 0.027$
- **41% error reduction with 100 pb^{-1}**

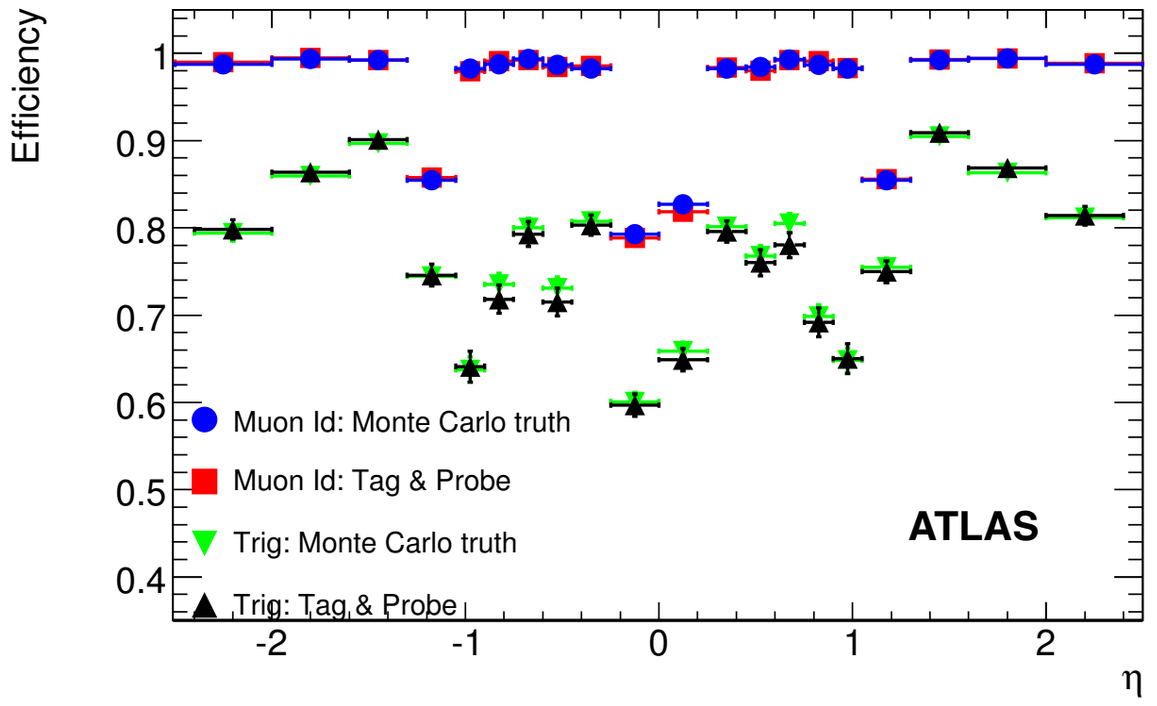
W,Z to leptons cross sections

- **Efficiencies measurements in data**
  - ★ **Tag&Probe** method on **$Z \to ll$**
  - ★ Trigger and offline reconstruction, isolation **efficiencies controlled in data**
    - **Systematics** of the method at **% level**
    - Local **statistical uncertainty** about **7(3)% with 10(50) pb^{-1}**





CMS PAS 2007/002 (14 TeV)

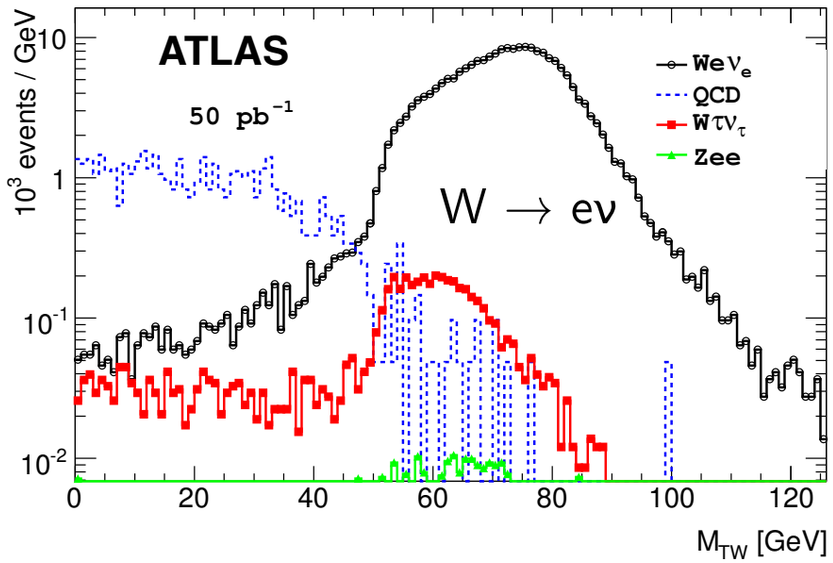


arXiv:0901.0512; CERN-OPEN-2008-020 (14 TeV)

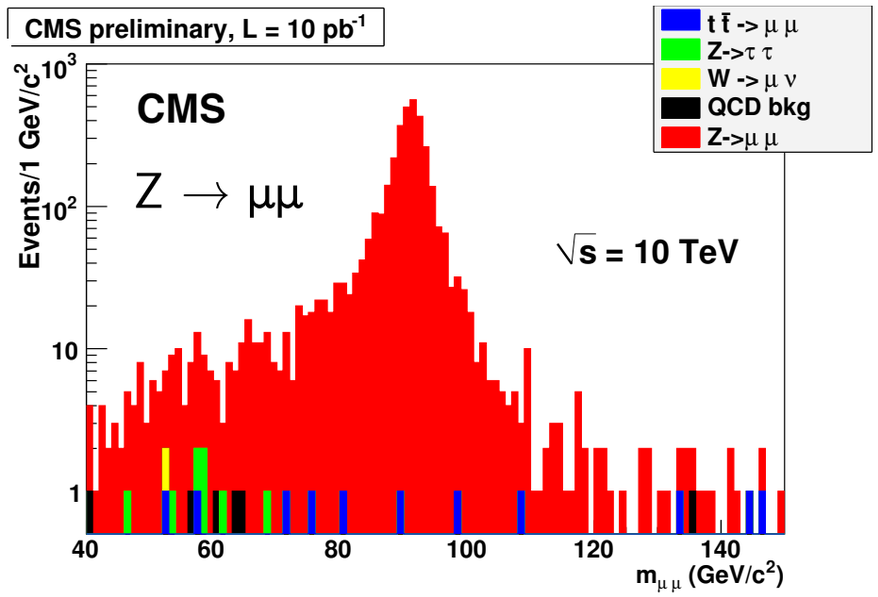
W,Z to leptons cross sections

- **Signal selections**
  - ★ high-p_T leptons (>15-20 GeV) (+ missing energy for W)
  - ★ Tracking (and Calorimeter) isolation
  - ★ (QCD) **background** shapes and normalizations **from data**
    - like-signs and/or isolation rejected selections to get QCD enriched samples
    - e-μ selections to get ttbar and Z→ττ Z background estimates
  - ★ **Uncertainties at level of 5% in early data (about 50 pb^{-1})** (luminosity excluded)
- **W/Z ratio to measure indirectly W width**

arXiv:0901.0512; CERN-OPEN-2008-020 (14 TeV)



CMS PAS EWK-09-001



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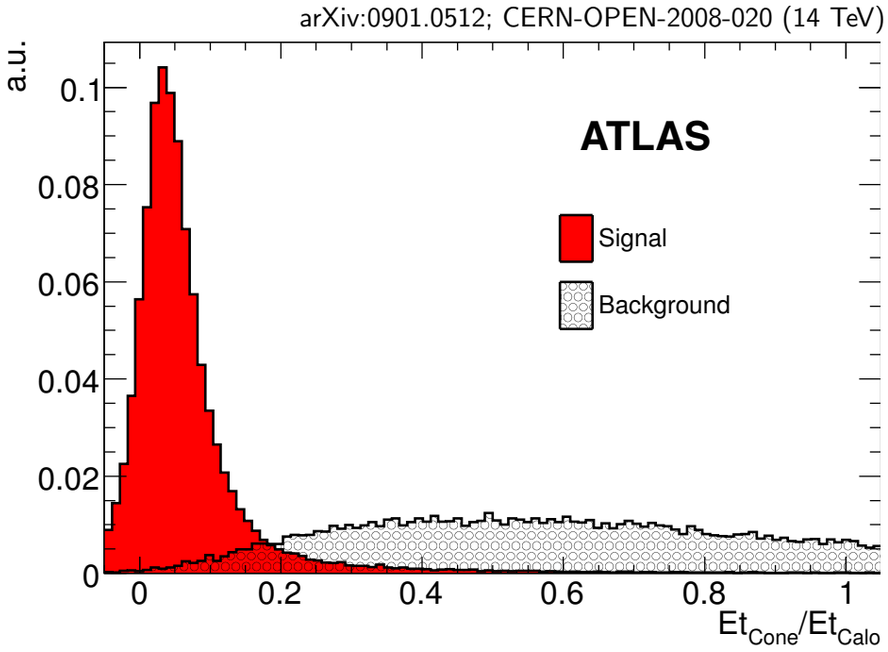

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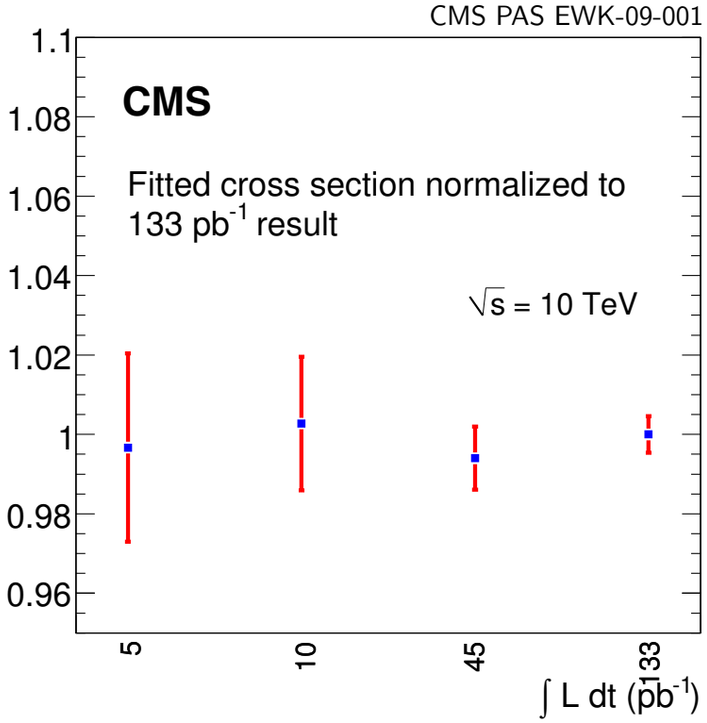
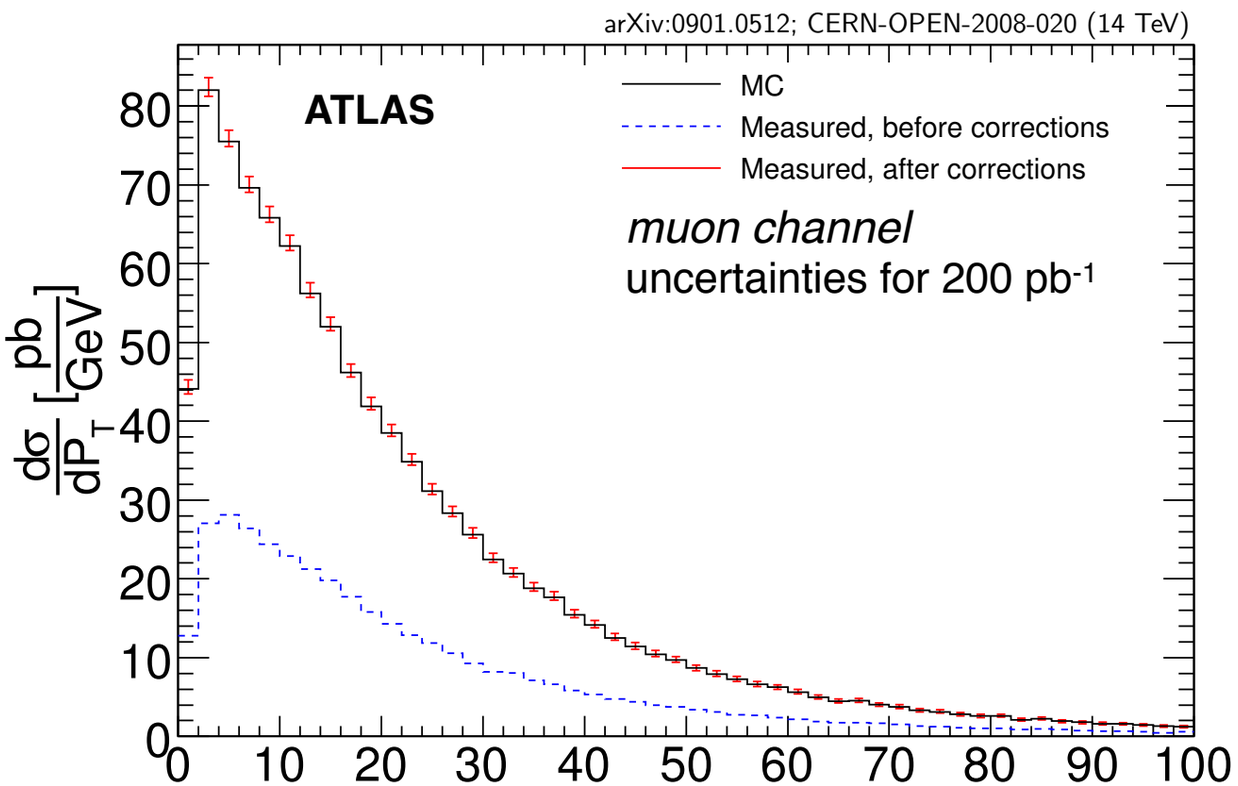
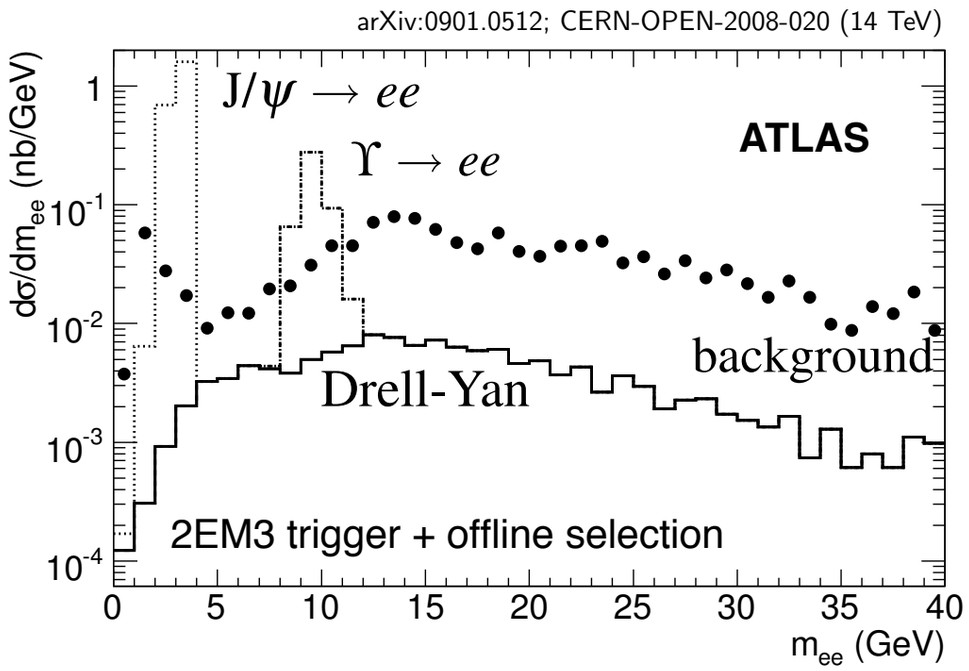
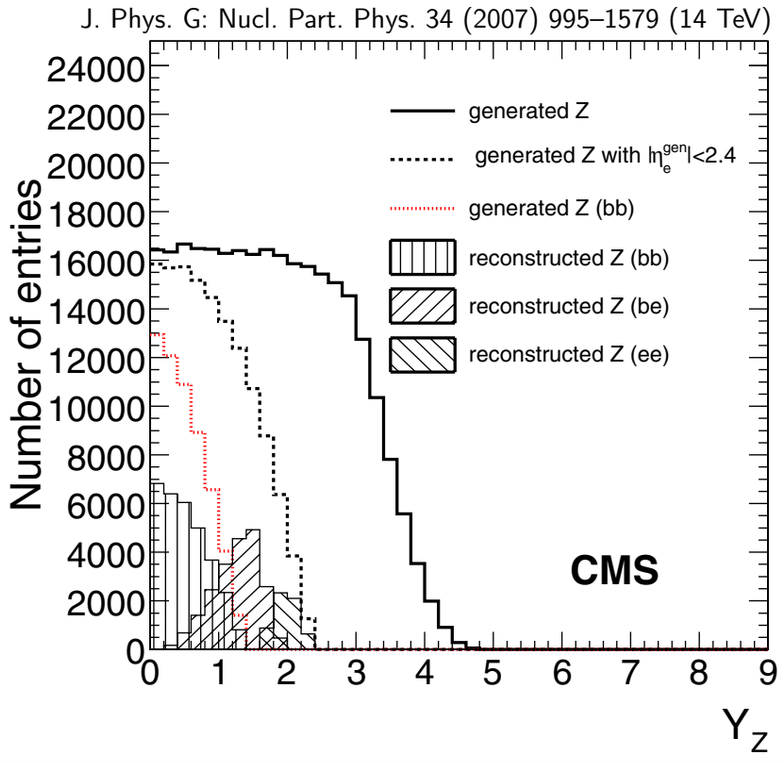


Drell-Yan differential cross sections

- **Differential shapes measurement**
  - ★ to **constrain uncertainties** on **PDF (7%)** and **non perturbative effects**
  - ★ bin-by-bin corrections to account for reconstruction efficiencies and acceptances
- **Low-mass Drell-Yan** production
  - ★ **statistical uncertainty** on integrated cross section of **4(1)% with 50 pb^{-1}(1 fb^{-1})**
  - ★ need to exploit **full e-identification**
- **Z production** in **muon** and **electron** channels
  - ★ cross section as a function of boson p_T and rapidity
- **Dominant background** from **QCD** events
  - ★ to be **checked in data**







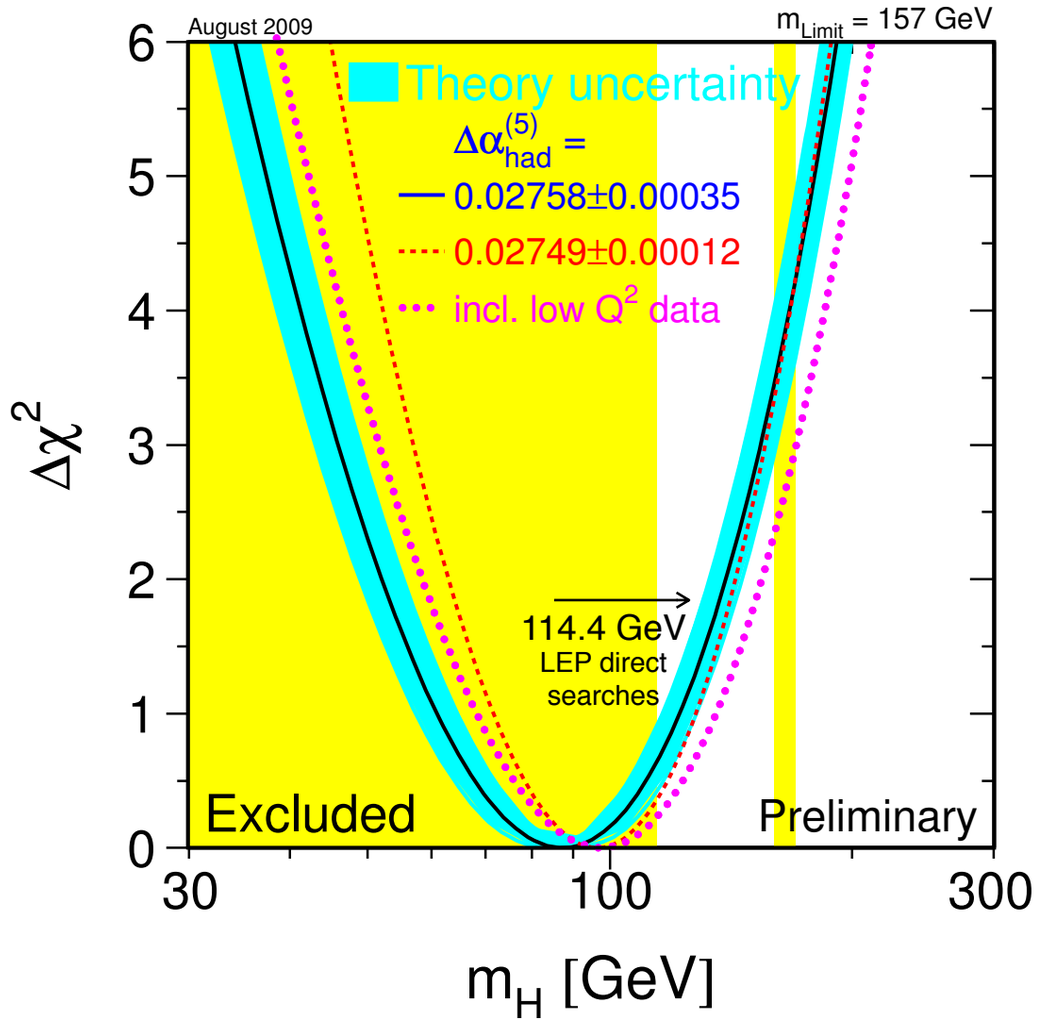
W mass measurement

- SM **masses** of top quark, W and Higgs bosons are related through **radiative corrections**
- Precise measurements of M_{top} and M_W allow
  - ★ consistency check of SM
  - ★ give hints of new physics
  - ★ constrain the mass of SM Higgs boson
- Up to date values[1]
  - ★ $M_{top} = 173.1 \pm 0.6$ (stat) $\pm$ 1.1 (syst) GeV
  - ★ $M_W = 80.399 \pm 0.023$ GeV
  - ★ $M_H = 87^{+35}_{-26}$ GeV (68% CL)
    $M_H < 157$ (186) GeV (95% CL)[2]
- LHC 1 year at 10^{33} cm^{-2}s^{-1} $\Rightarrow$ 6 fb^{-1}
  - ★ about $2 \cdot 10^7$ W events selected per lepton decay with **combined statistical sensitivity at 2 MeV**
  - ★ **challenge is on systematic uncertainties**

[1] 186 GeV limit when including the LEP-2 direct search limit of 114 GeV shown in yellow

$$M_W = 4\sqrt{\frac{\pi^2\alpha^2}{2G_F^2}\frac{1}{sin\theta_W(1-\Delta R)}}$$

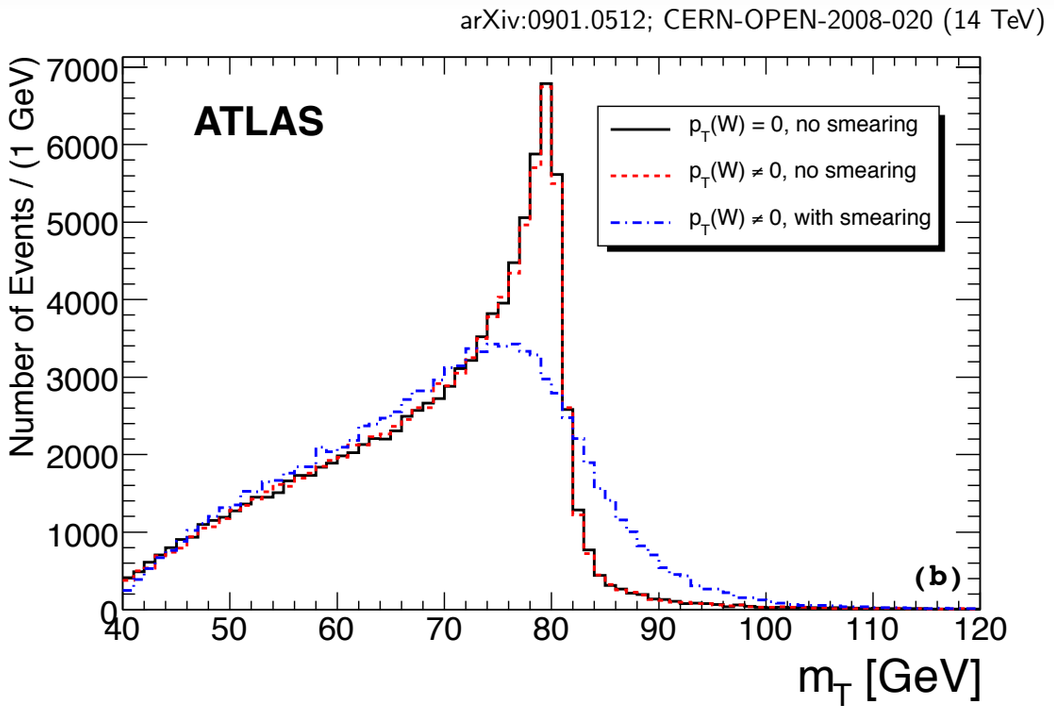
$$\Delta R \sim M_{top}^2,\ logM_H$$

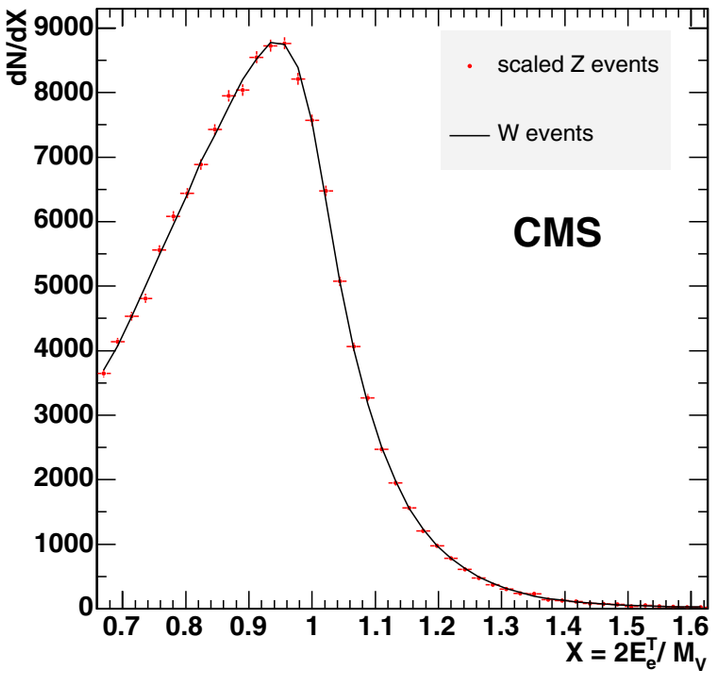


[1] CERN-PH-EP/2009-023
Updated for 2010 winter conferences, 11/01/10, http://www.cern.ch/LEPEWWG

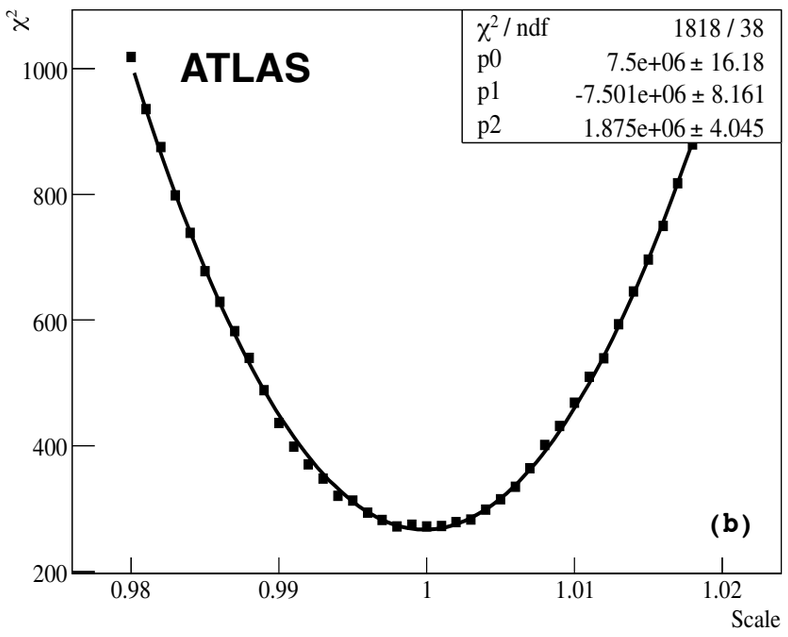
W mass measurement

- Early data analysis focus on **10-20 pb^{-1}** with expected **statistical precision of 120 MeV**
  - ★ W transverse mass
  - ★ lepton transverse momentum or energy
- Non trivial effects from det. smearing and pQCD
  - ★ No analytic approach is possible
    ⇒ numerical methods and **template fits** are used





J. Phys. G: Nucl. Part. Phys. 34 (2007) 995–1579 (14 TeV)



arXiv:0901.0512; CERN-OPEN-2008-020 (14 TeV)

- Scaling observables from Z kinematics and **correcting for detector effects**
- **In-situ calibration** from Z events
  - ★ scale, resolution and efficiencies

W mass measurement

- Summary of **estimated uncertainties in early data** and **prospects for higher luminosities**

Contribution δm_W in MeV	ATLAS p_T e(μ)	ATLAS M_T e(μ)	ATLAS p_T e(μ)	ATLAS M_T e(μ)	CMS e(μ)	CMS e(μ)
Int. Luminosity (fb^{-1})	0.015		10		1	10
Statistics	**120 (106)**	**61 (57)**	**2**		**40***	**15***
Electromagnetic scale	110	110	4	4	10 (14)	2 (<10)
Hadron recoil, MET scale	-	200	-	5**	15 (38)	<10 (<20)
Resolution (efficiency)	5	5	1 (4.5 e, <1 μ)	1 (4.5 e, <1 μ)	5 (30)	2 (<10)
Backgrounds	3	3	2	2	10 (4)	2 (-)
Total experimental	**114**	**230**	**6.5 (5)**	**7.5 (6.5)**	**40 (64)**	**<20 (<30)**
PDFs (QCD, QED corr.)	25	25	3	2	20	<10
Total	**167 (158)**	**239 (238)**	**7 (6)**	**8 (7)**	**25**	**<20**

* scaled to Z statistics, ** extrapolated from Tevatron

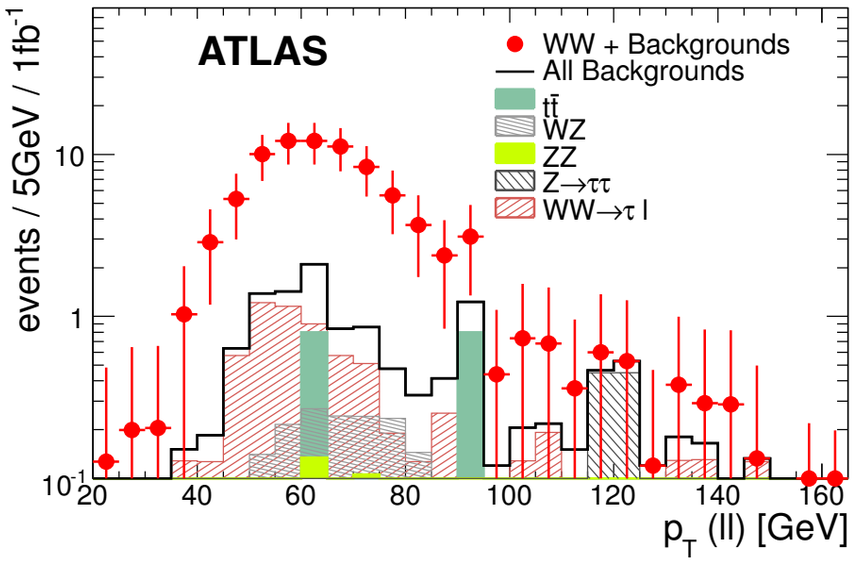
ATLAS arXiv:0805.2093v2 [hep-ex] 13 Jun 2008
arXiv:0901.0512; CERN-OPEN-2008-020
CMS J. Phys. G: Nucl. Part. Phys. 34 (2007) 995–1579

- Systematic uncertainties in **early data** (15 pb^{-1}) dominated by
  - ★ **energy scale** for electron channel (p_T based analysis)
  - ★ **recoil calibration** for muon channel (M_T based analysis)
- Prospects for **higher luminosities** (1 to 10 fb^{-1})
  - ★ improved constraints from Z analysis, better PDFs knowledge from LHC
  - ★ combining information from both channels can give systematic uncertainties < 20 MeV
  - ★ clearly an ultimate fight against systematics to exploit as much as possible statistical power of LHC

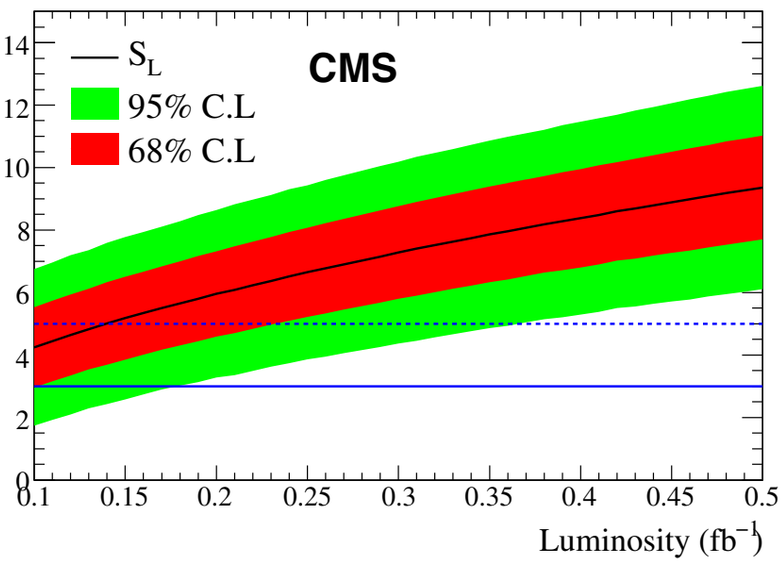
Di-Boson production

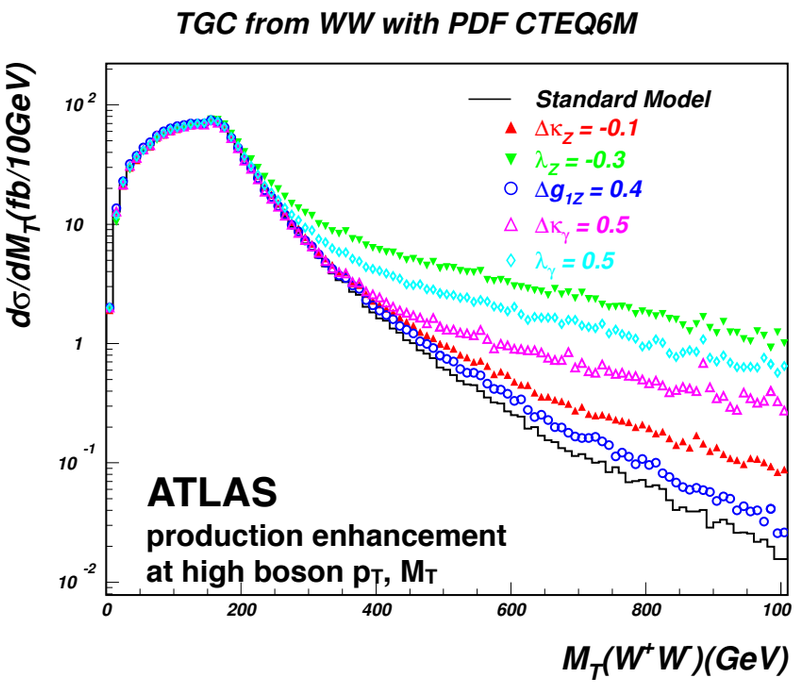
- Studies of WW,WZ,ZZ,Wγ,Zγ productions in lepton/photon final states ($rate_{LHC} \approx 100 \cdot rate_{Tevatron}$)
  - ★ test **beyond Standard Model physics**, **TGC anomalous couplings**, **backgrounds** for Higgs/SUSY searches
- **Production cross sections**
  - ★ Cut-based and multivariate analysis on e-μ-γ ID, isolation, missing energy
  - ★ SM signals **5σ significance** w/ **0.1-0.3 fb^{-1}** (1 fb^{-1} ZZ$\rightarrow$4l) with about 20% syst.

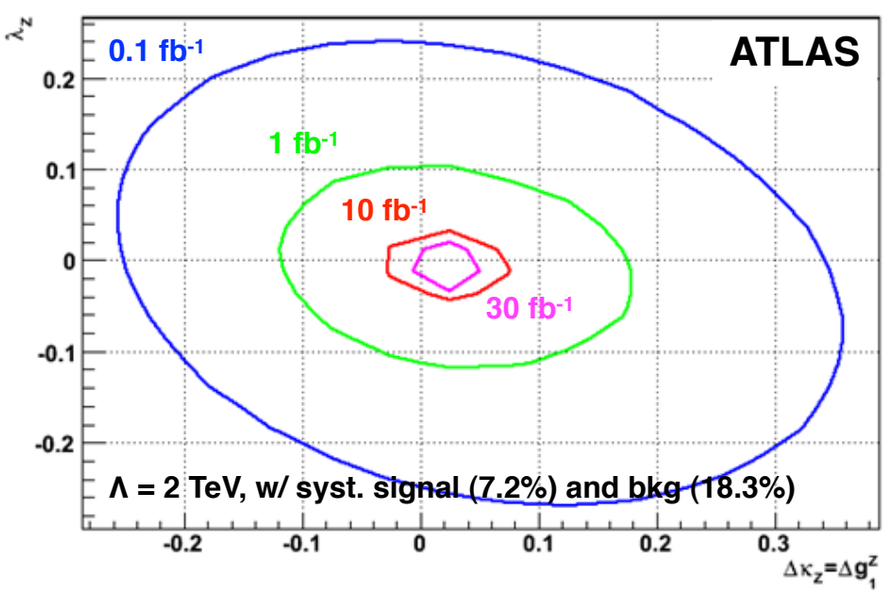
arXiv:0901.0512; CERN-OPEN-2008-020 (14 TeV)



CMS PAS EWK-08-003 (14 TeV)





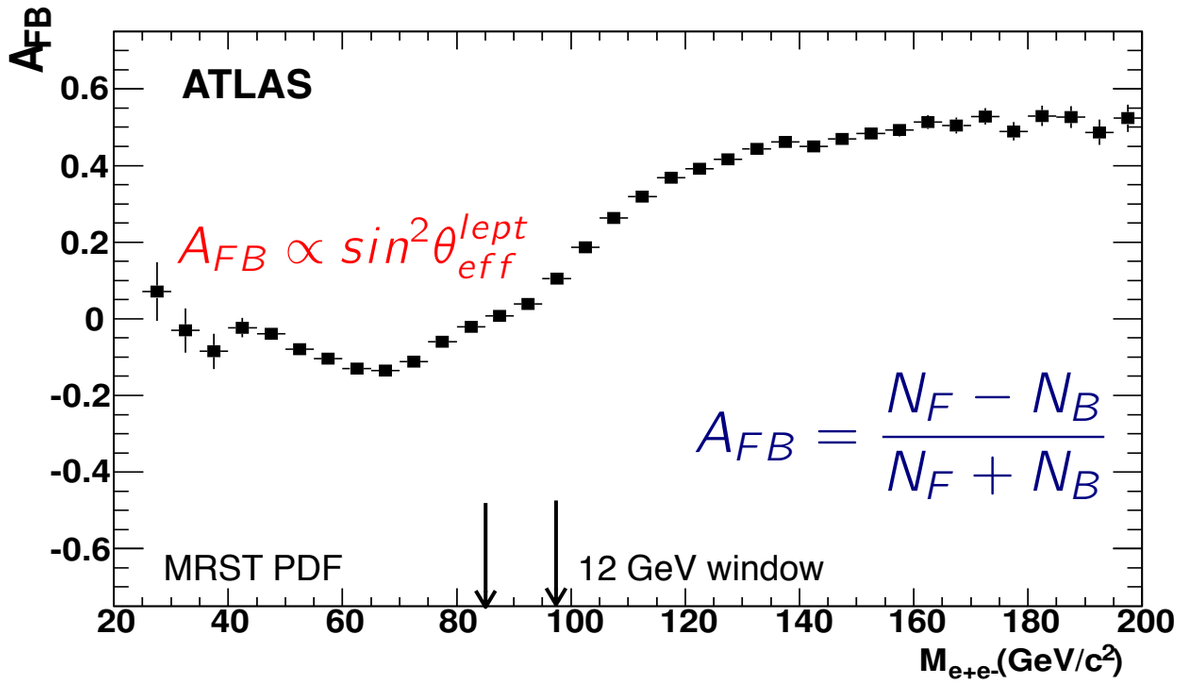


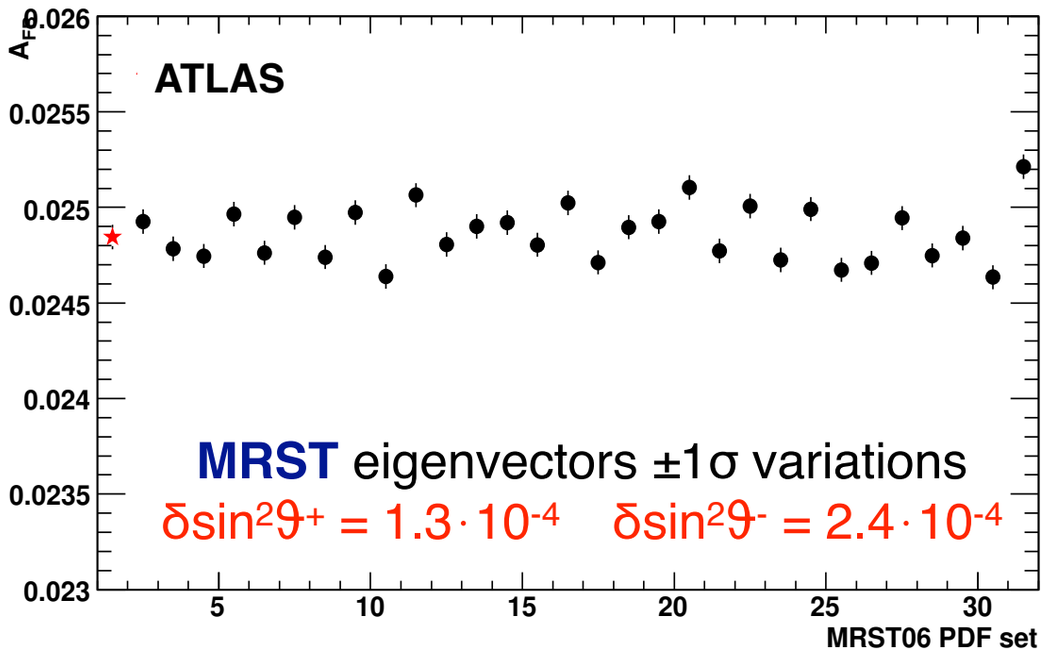
arXiv:0901.0512; CERN-OPEN-2008-020 (14 TeV)

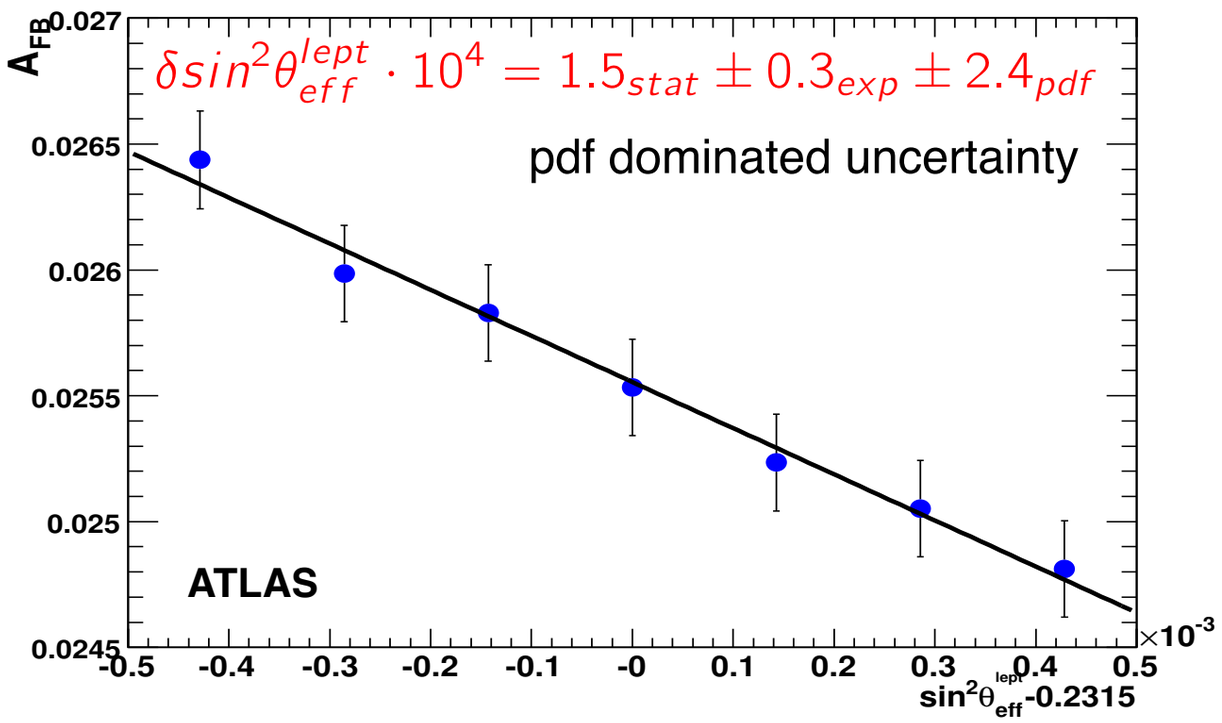
- **TGC anomalous couplings**
  - ★ 95% CL intervals for WWZ couplings
    - systematics relevant only for 30 fb^{-1}

Forward-backward asymmetry in $Z \rightarrow e^+e^-$

- A **precision measurements of $\sin^2\theta_{eff}$**
  - ★ consistency of SM, indirect constraint on H mass and effects of new physics
- **High statistics** needed to be competitive with $\delta\sin^2\theta_{eff} \approx 1.6 \times 10^{-4}$ (world-average)
  - ★ studies for **100 fb^{-1}** with forward electrons preferred over muons due to calorimeter coverage
  - ★ backgrounds from di-jets, ttbar, W+X (γ-jet mis-id)
  - ★ high-p_T electrons tracks + shower shapes (calo only in forward regions) + $|y(e^+e^-)|>1$ (valence-sea quarks)







arXiv:0901.0512; CERN-OPEN-2008-020 (14 TeV)

Outlook

LHC physics already started in 2009, looking forward for an exciting 2010 !

- First data will be fundamental to **calibrate/understand** ATLAS & CMS detectors
  - ★ 900 GeV data confirms an already very good detector simulation
  - ★ W/Z production with lepton decays as "standard candles"
- **"Re-discover" Standard Model** electroweak physics measuring at $\sqrt{s} = 7(10)$ TeV
  - ★ Inclusive and differential cross section measurements
  - ★ More sophisticated measurements as W mass, di-bosons studies and Z forward-backward asymmetry will follow as statistic will increase (some preliminary measurements already w/ order 100 pb^{-1})
  - ★ SM processes as backgrounds for New Physics ⇒ preparing the road to discoveries
- **Theoretical predictions** very often are **limited** by the **PDF uncertainties**
  - ★ At LHC gluon/sea interaction are dominant at low-x: explore new kinematical regions
  - ★ Current uncertainties (~4% on $\sigma_{W,Z}$ - different sets agree within 7%, 1% on asymmetries) could be reduced using first LHC data