

Prospects for ElectroWeak Physics at LHC



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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**



August 2009

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

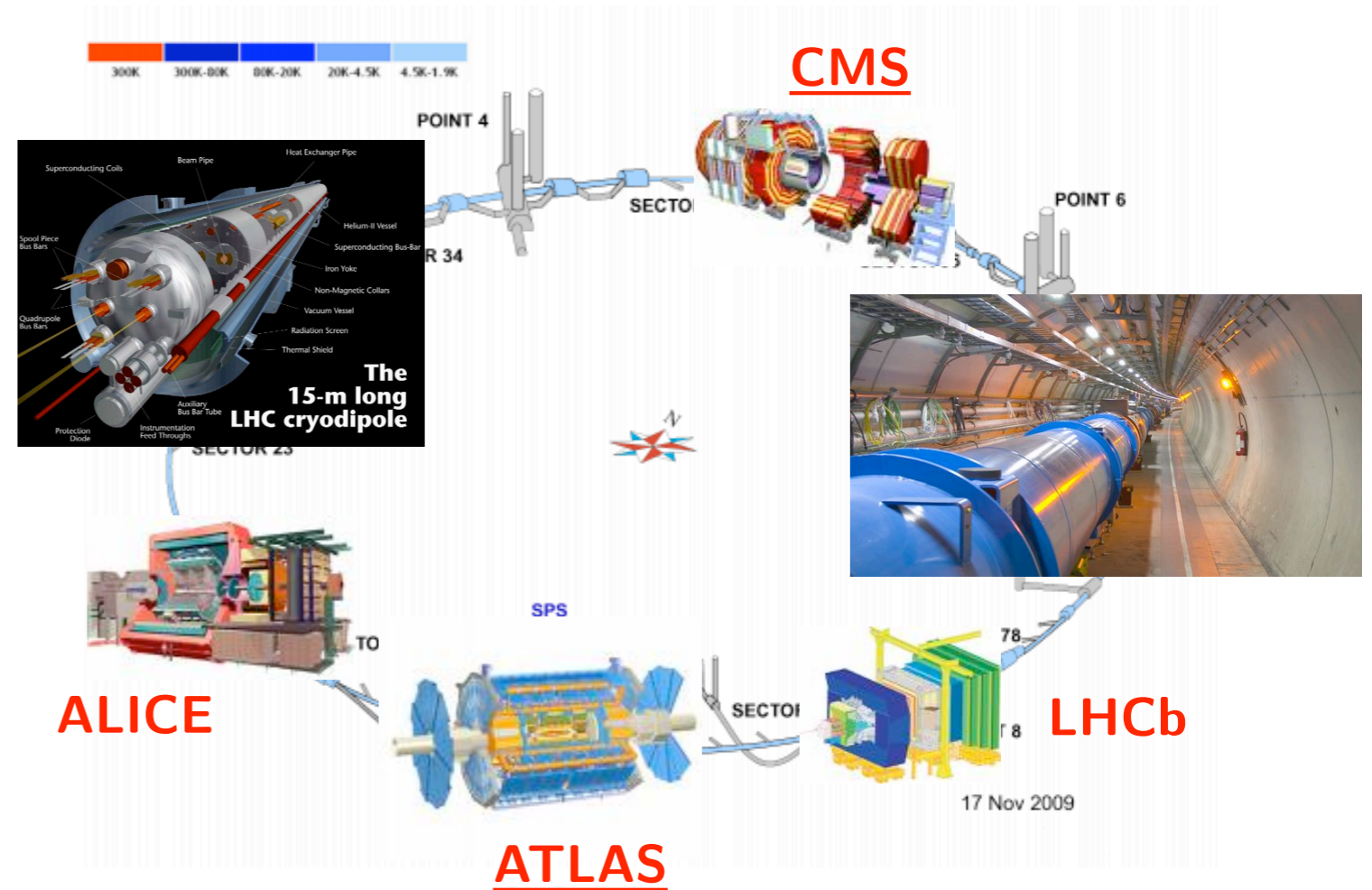
- ★ p-p collisions at **14 TeV**
(x7 wrt Tevatron)
- ★ design luminosity of **$10^{34} \text{ cm}^{-2}\text{s}^{-1}$**
(x100 wrt Tevatron)
- ★ bunch crossing of 40 MHz,
1GHz pp collisions
- ★ Heavy particles production rates
 $10^{+3...-6} \text{ Hz}$ (W,Z,top,H,SUSY,..)
with **high sensitivity to New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

- At regime: $\sim 6 \times 10^6$ s of pp collision physics running per year

- ★ $\sim 0.6 \text{ fb}^{-1}/\text{year}$ if $L=10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- ★ $\sim 6 \text{ fb}^{-1}/\text{year}$ if $L=10^{33} \text{ cm}^{-2}\text{s}^{-1}$

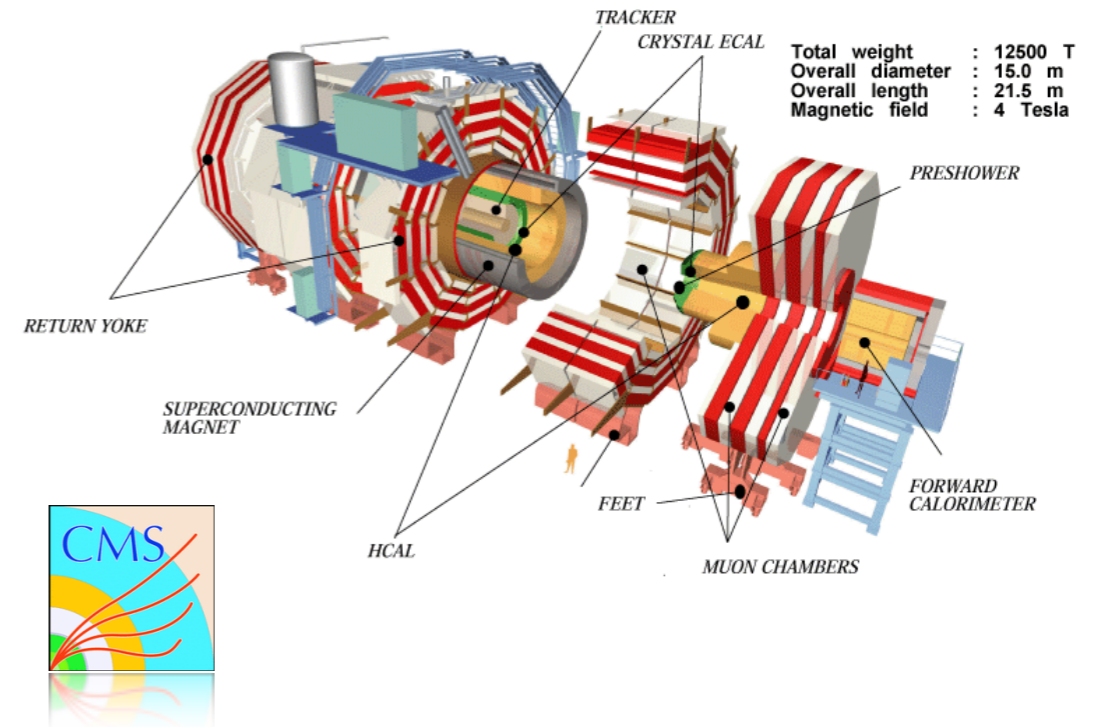
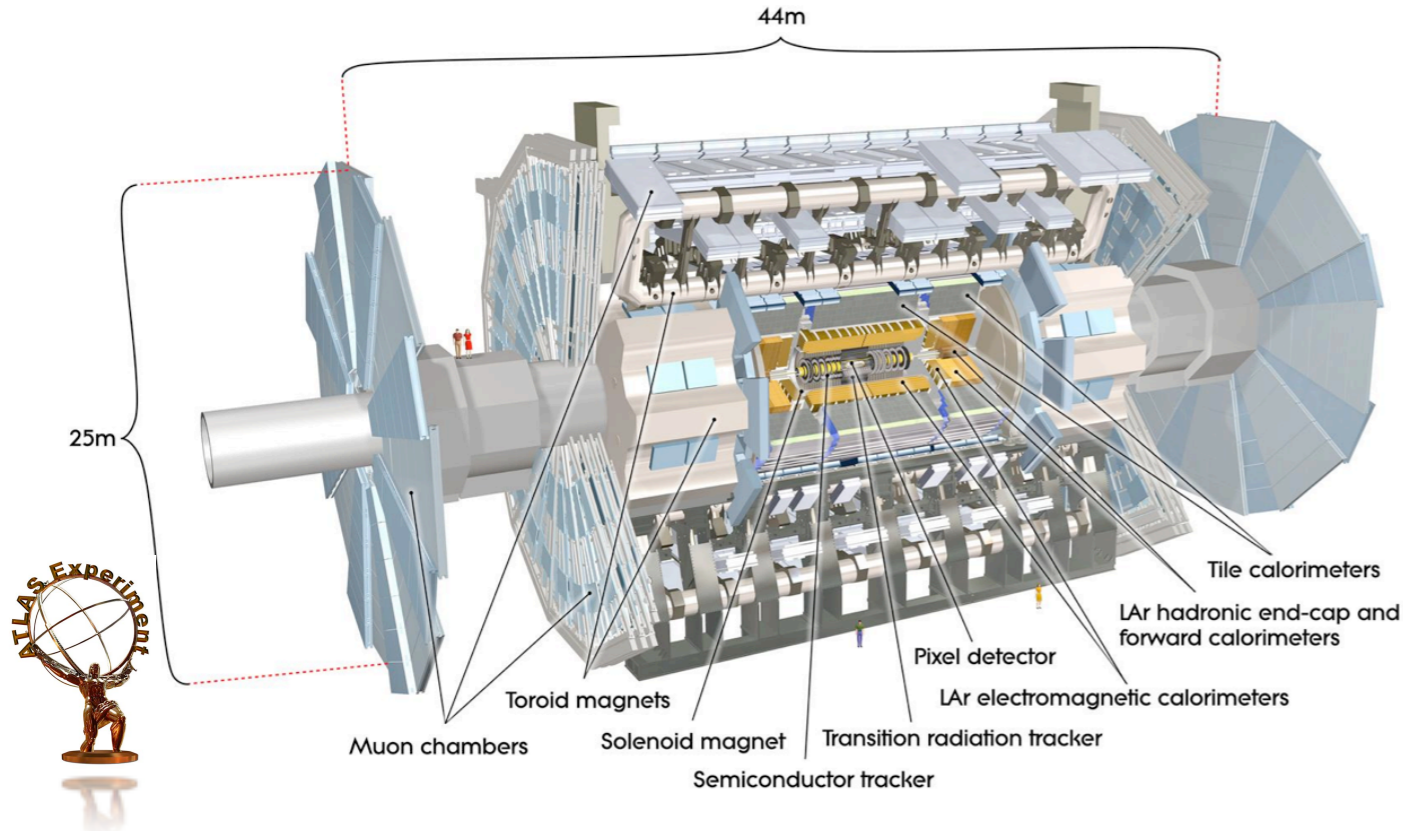
● Physics run 2010 starting mid February

- ★ 3.5(5) TeV beam energy with the goal to integrate 100-200 $\text{pb}^{-1} \Rightarrow$ **Standard Model re-discovering !**



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

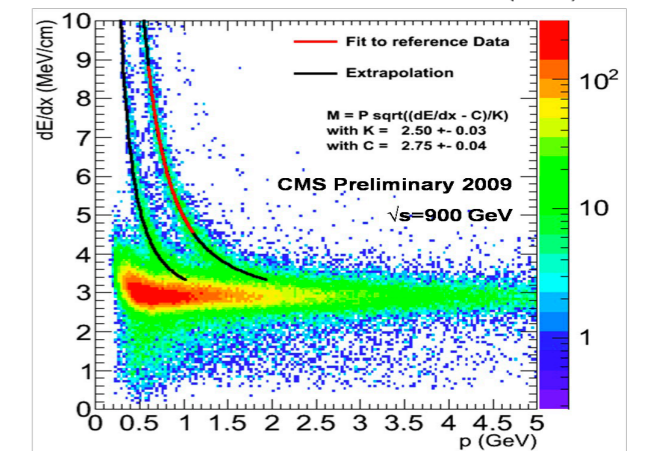
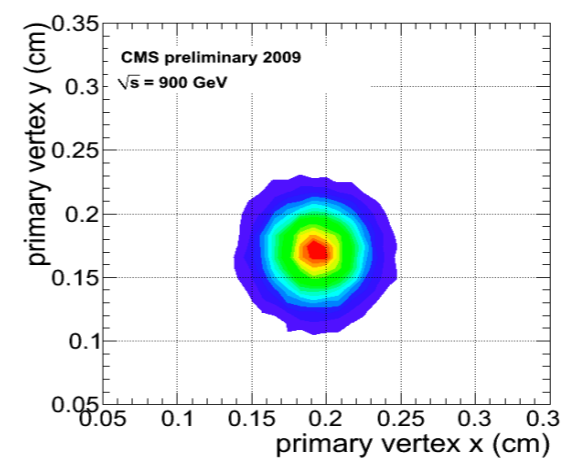
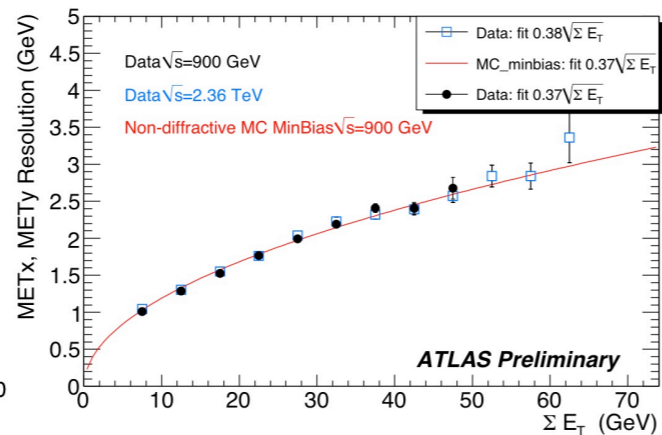
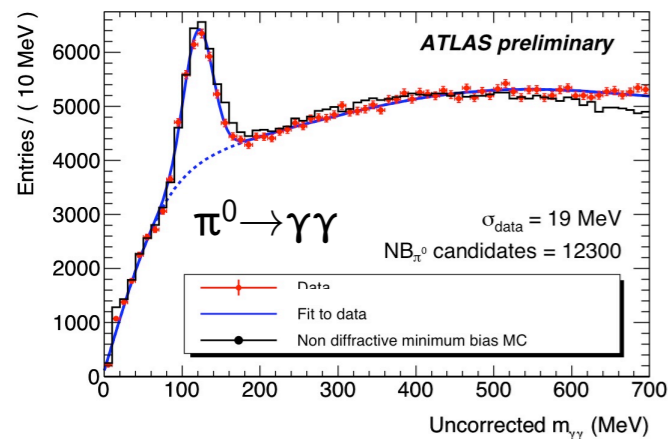
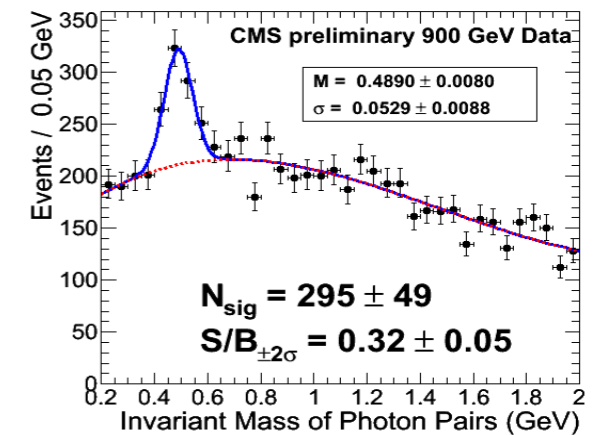
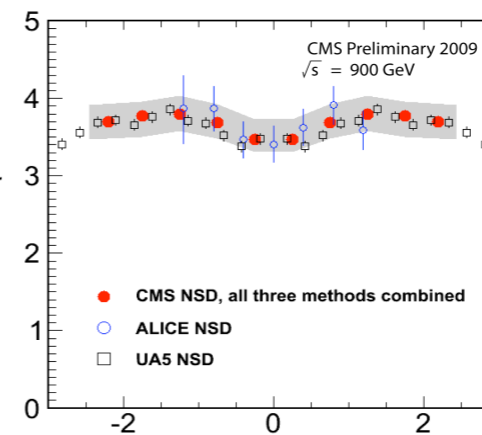
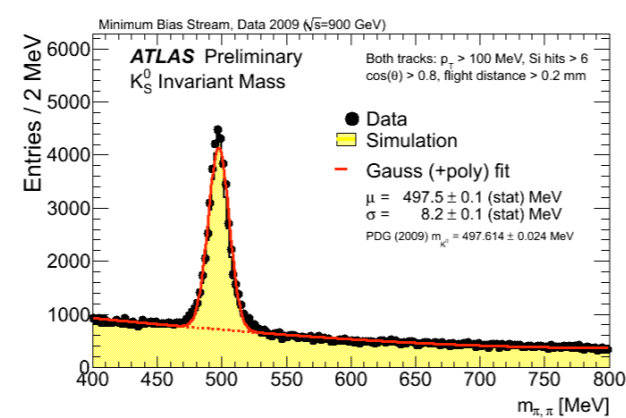
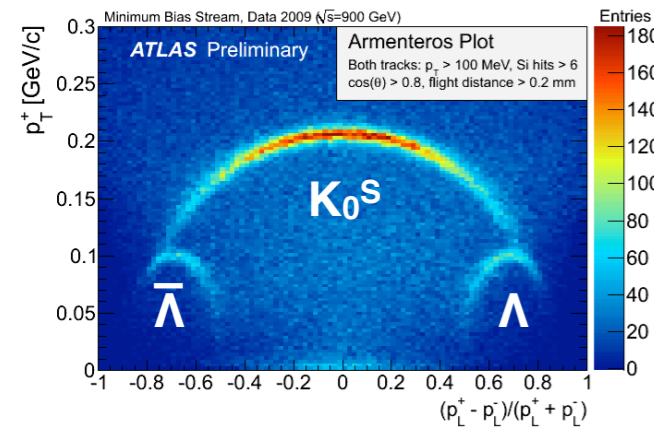
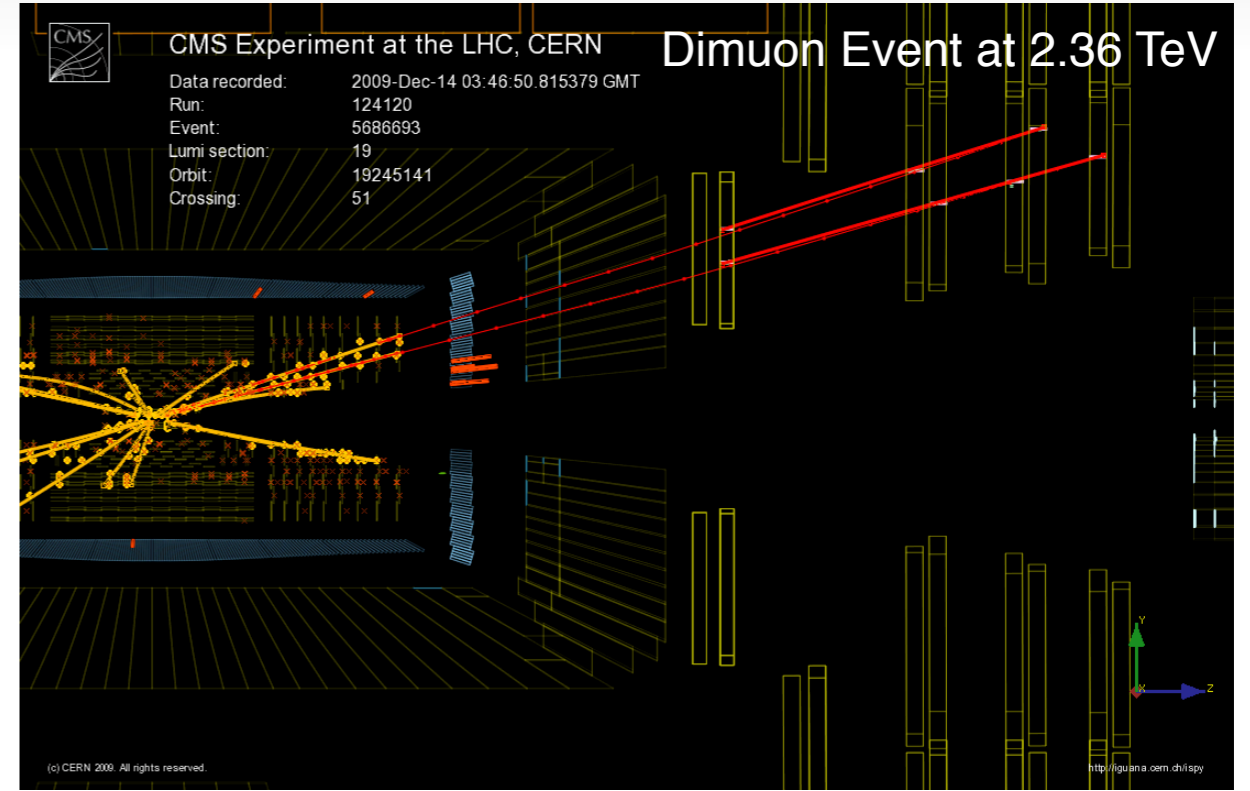
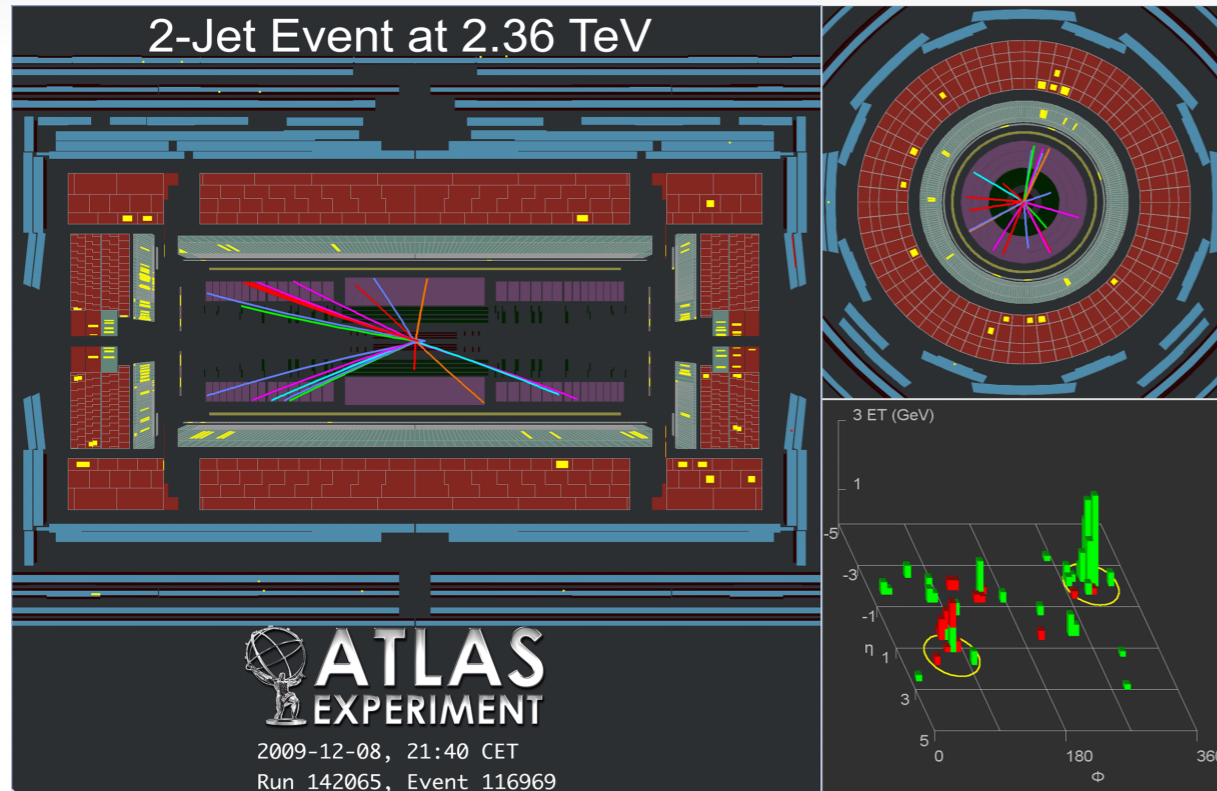
ATLAS & CMS detectors



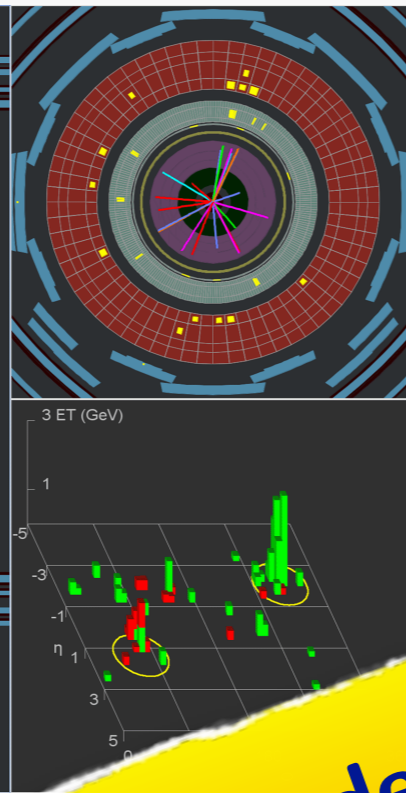
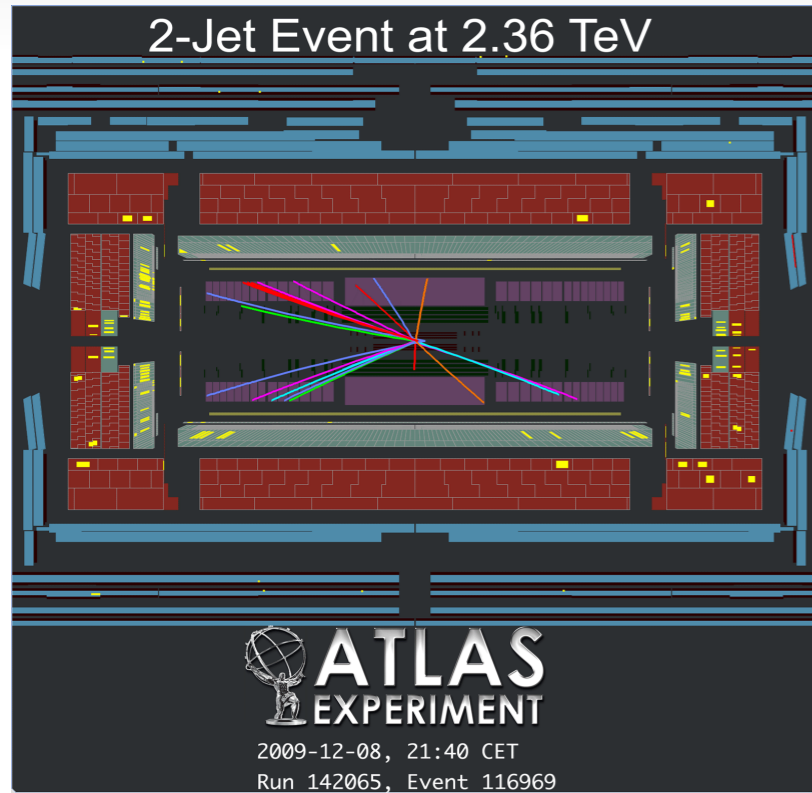
	ATLAS	CMS
Magnetic field	2 T solenoid + toroid (0.5 T barrel 1 T end-cap)	4 T solenoid + return yoke
Tracker	Si pixels, strips + TRT $\sigma/p_T \approx 5 \times 10^{-4} p_T + 0.01$	Si pixels, strips $\sigma/p_T \approx 1.5 \times 10^{-4} p_T + 0.005$
EM Calorimeter	Pb+LAr $\sigma/E \approx 10\%/VE + 0.007$	PbWO4 crystals $\sigma/E \approx 2-5\%/VE + 0.005$
Hadronic Calorimeter	Fe+scint. / Cu+LAr (10 λ) $\sigma/E \approx 50\%/VE + 0.03$ GeV	Cu+scintillator (5.8 λ + catcher) $\sigma/E \approx 100\%/VE + 0.05$ 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)

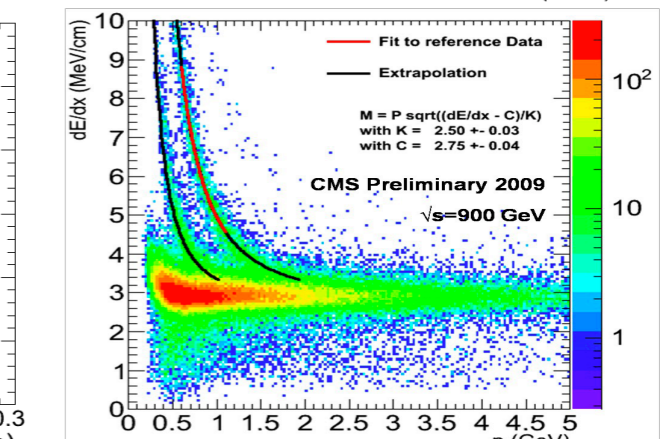
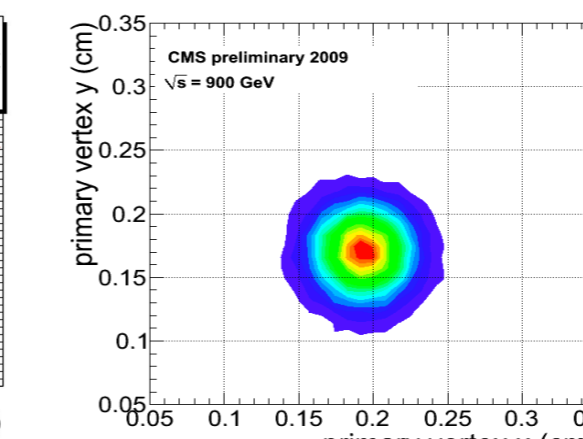
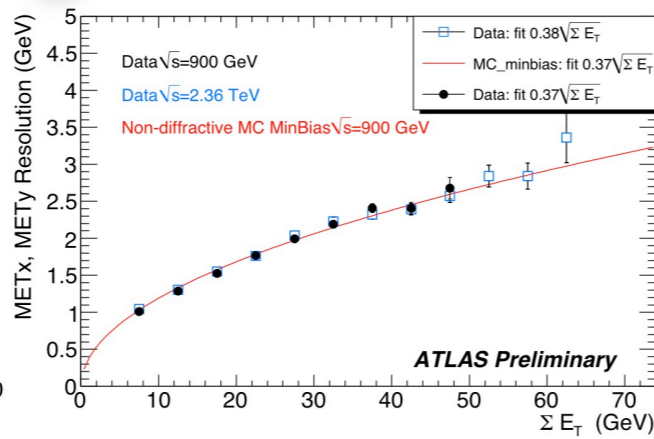
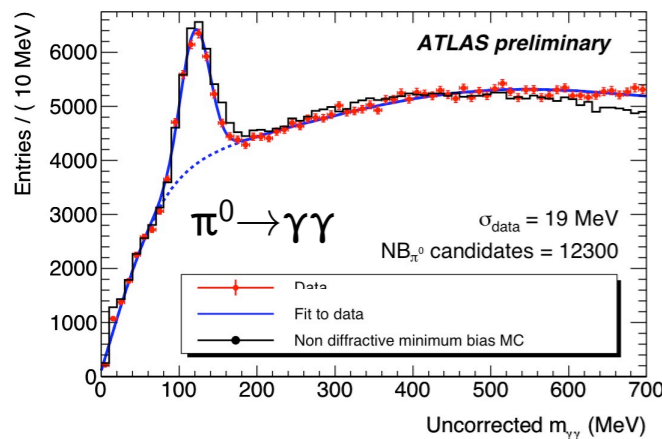
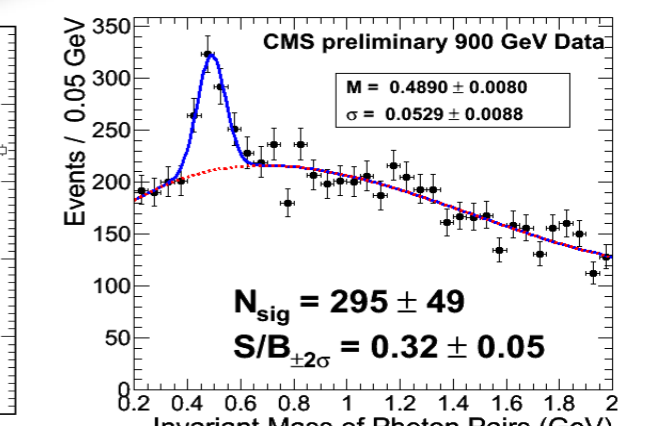
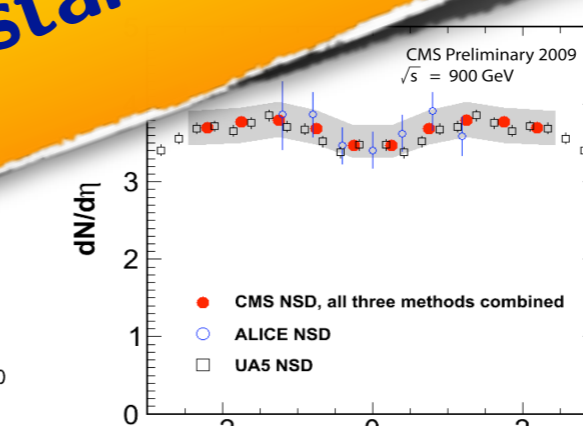
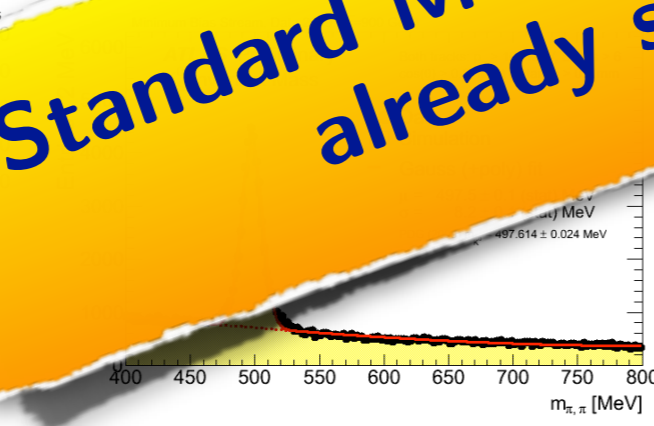
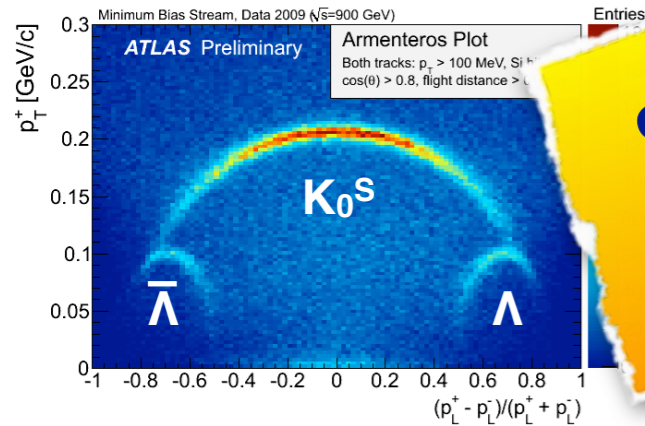
First LHC data at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 2.36$ TeV



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

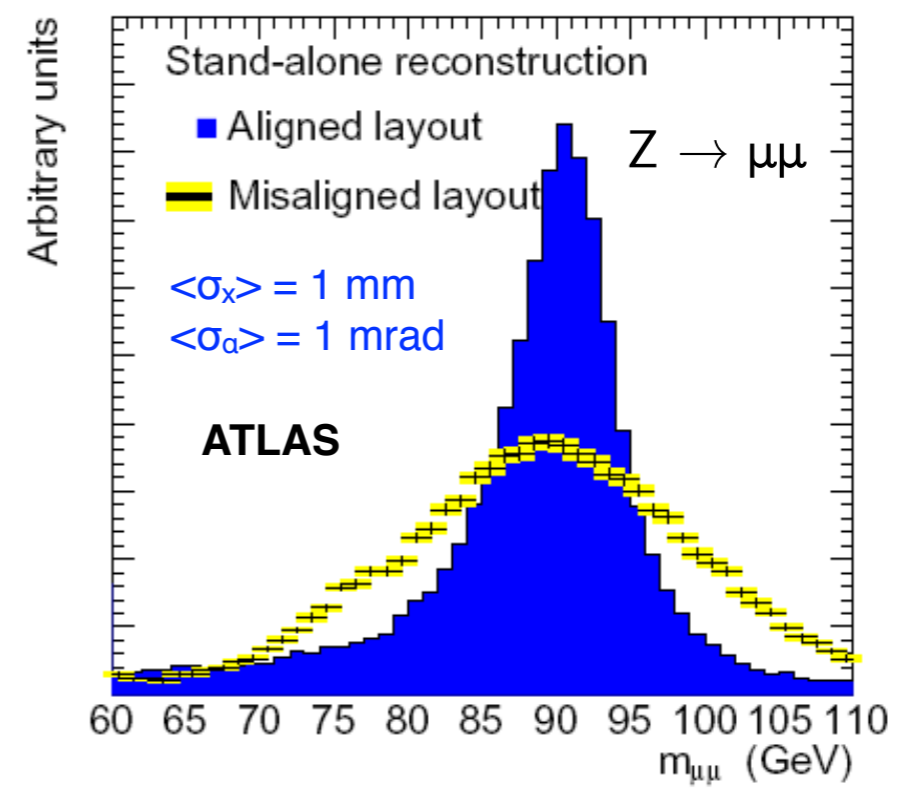
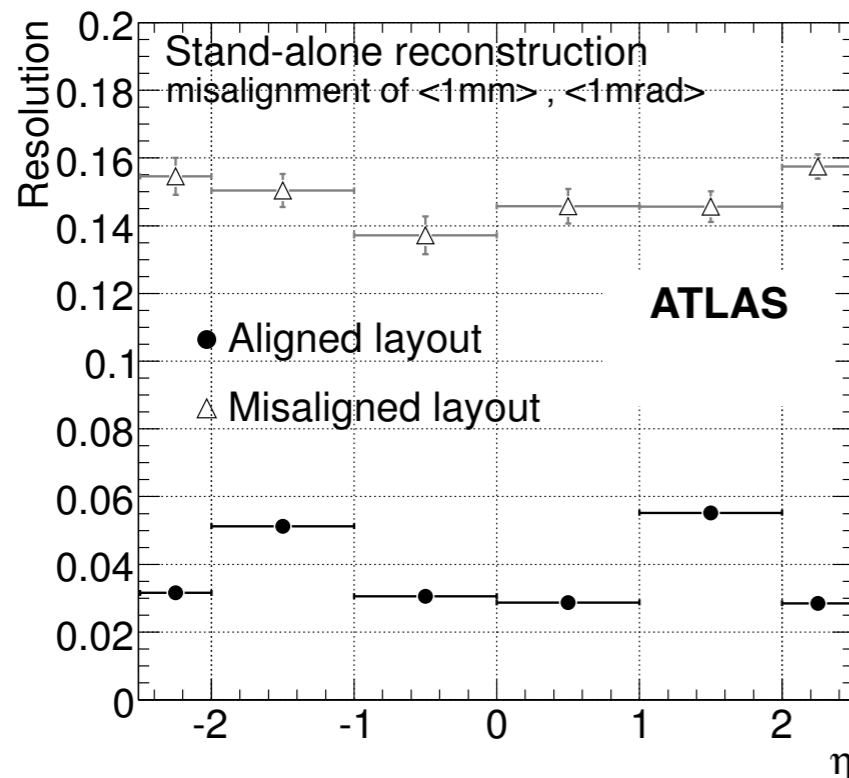
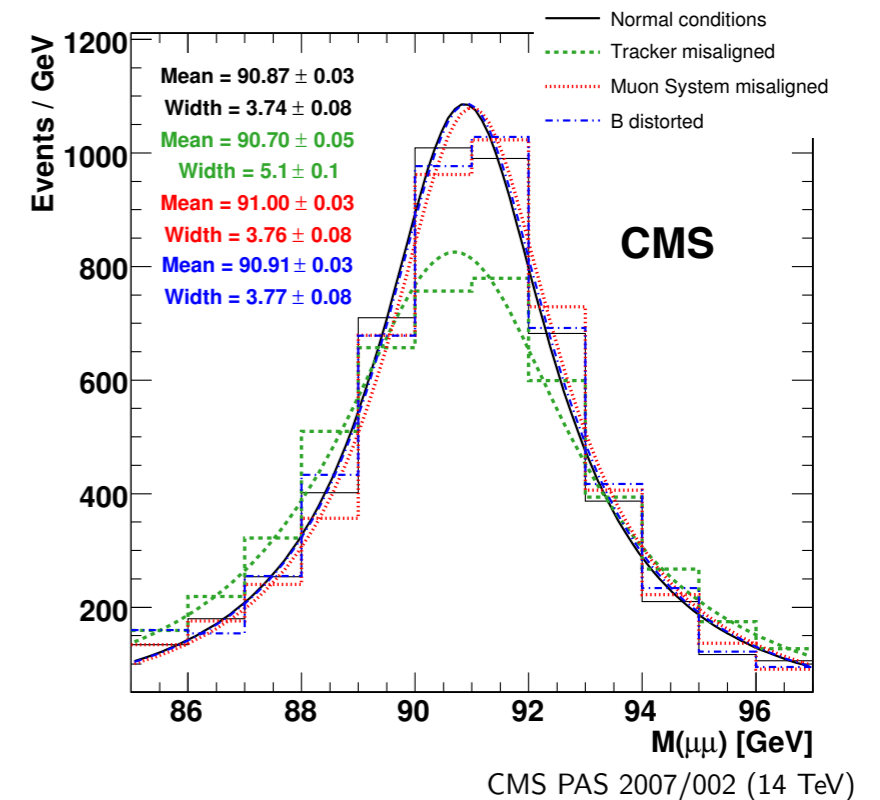


Standard Model re-discovering already started !



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 $10^{33} \text{ cm}^{-2}\text{s}^{-1}$**

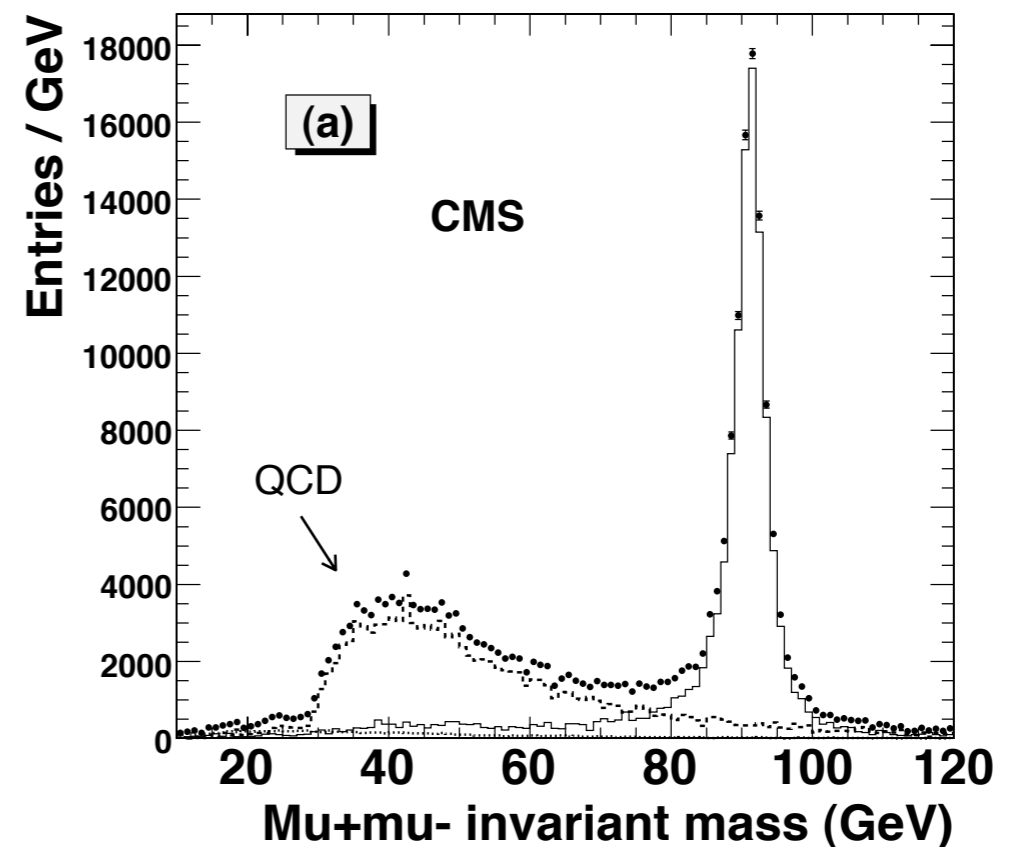
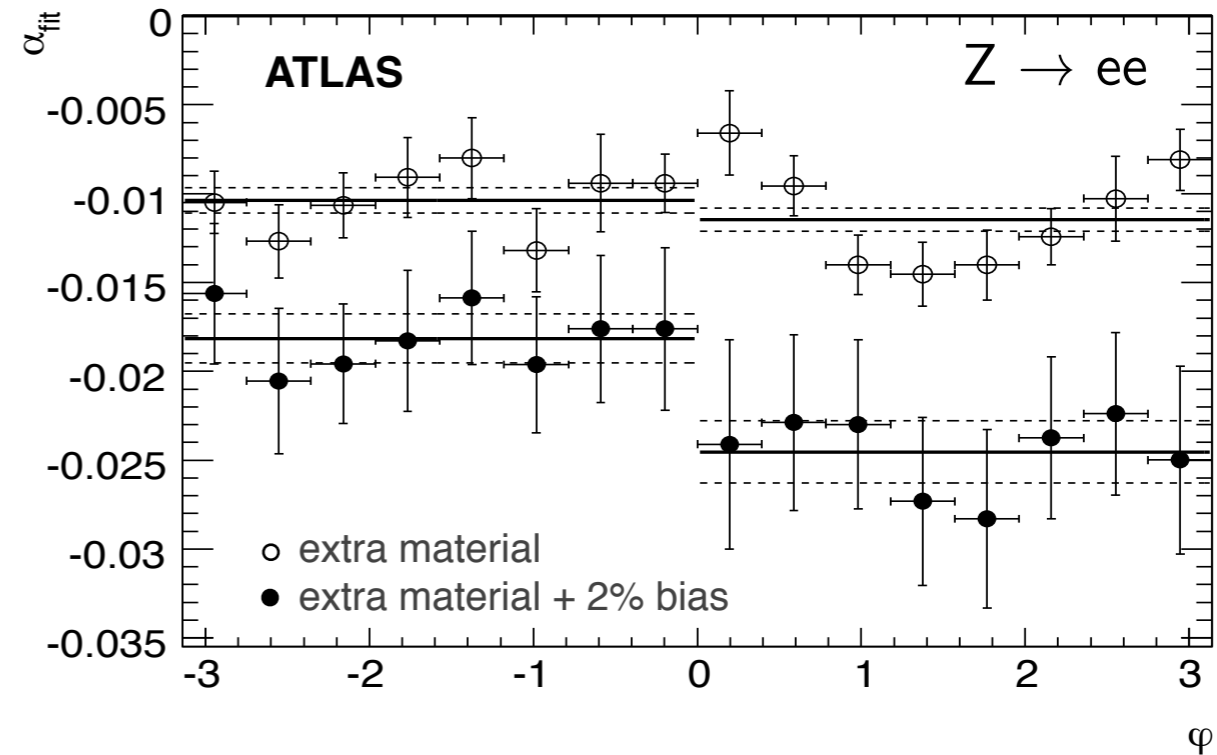


arXiv:0901.0512; CERN-OPEN-2008-020 (14 TeV)

Momentum/energy calibration from $Z \rightarrow ll$ ($l=e,\mu$)

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

- 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 $10^{33} \text{ cm}^{-2}\text{s}^{-1}$
 - **Muon scale** can be estimated to about **1%**
 - **Electromagnetic scale** known at **0.2%** and **resolution constant term** at about **0.7%**

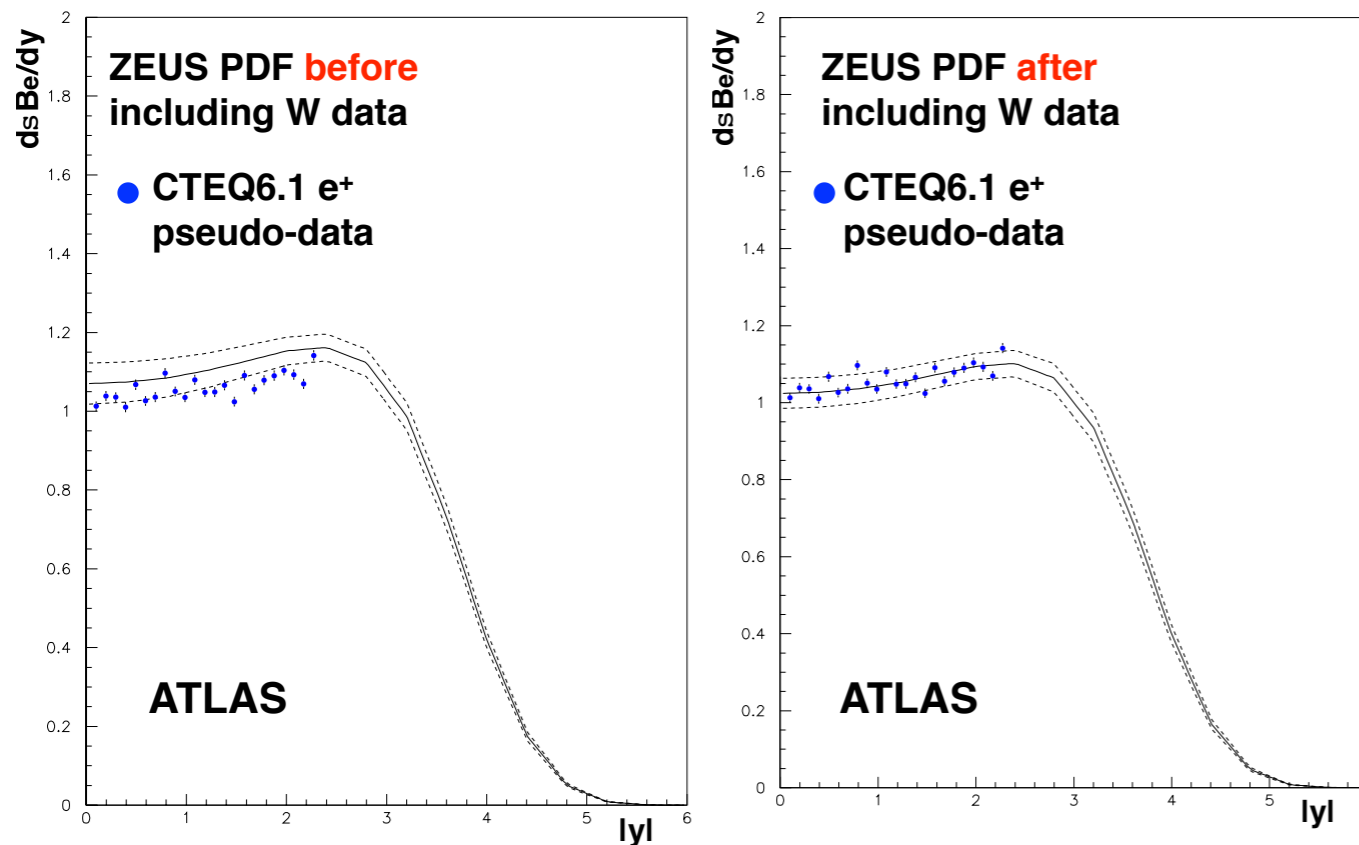


CERN-LHCC-2006-001 (14 TeV)

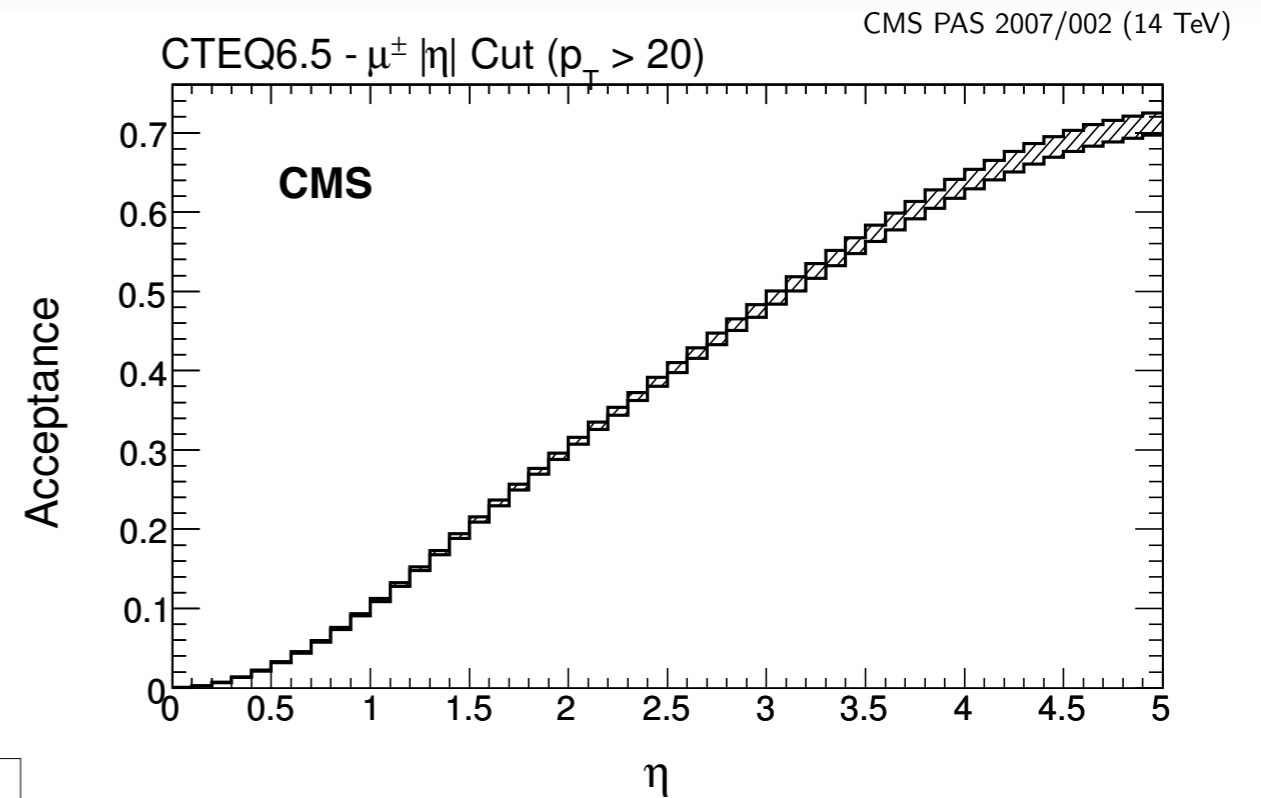
W,Z to leptons cross sections

- **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 ($xg(x) \sim x^{-\lambda}$)

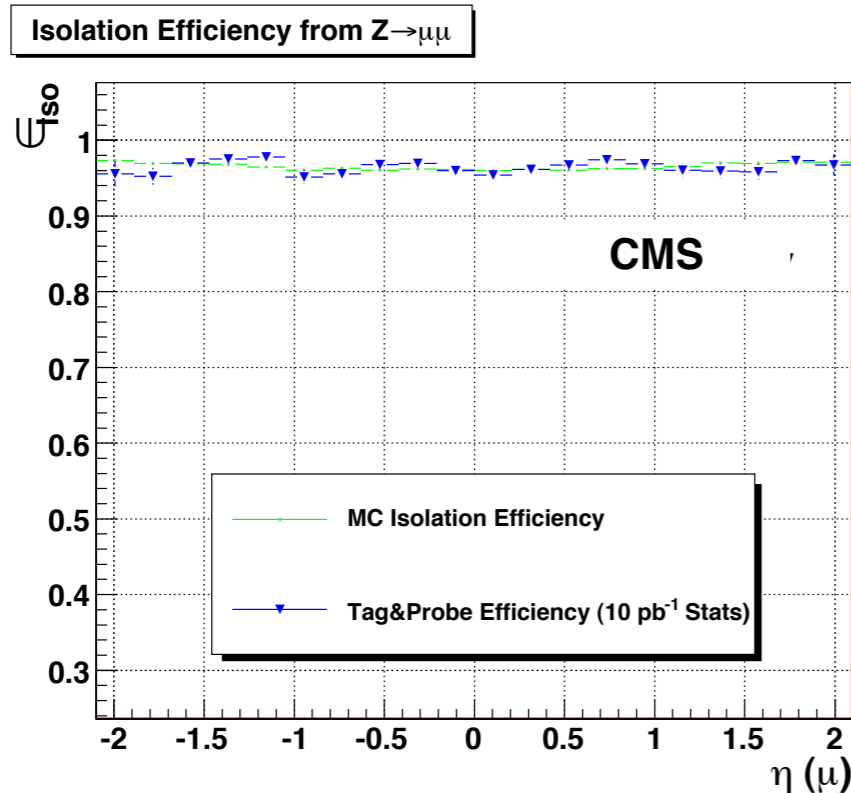
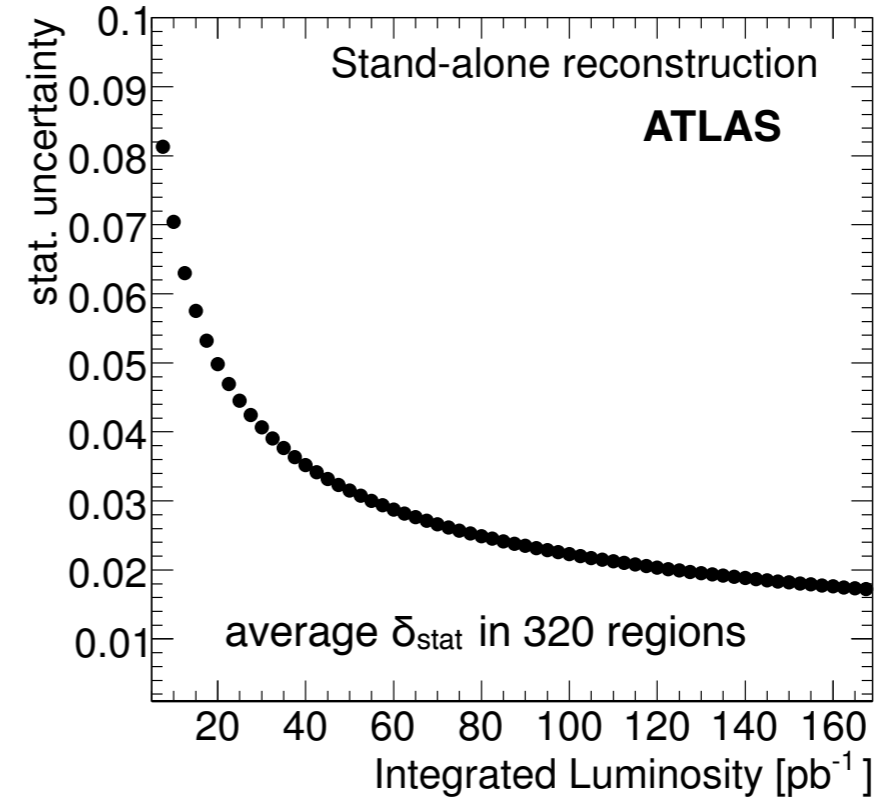
- ★ BEFORE $\lambda = -0.199 \pm 0.046$
- ★ AFTER $\lambda = -0.186 \pm 0.027$

- **41% error reduction with 100 pb⁻¹**

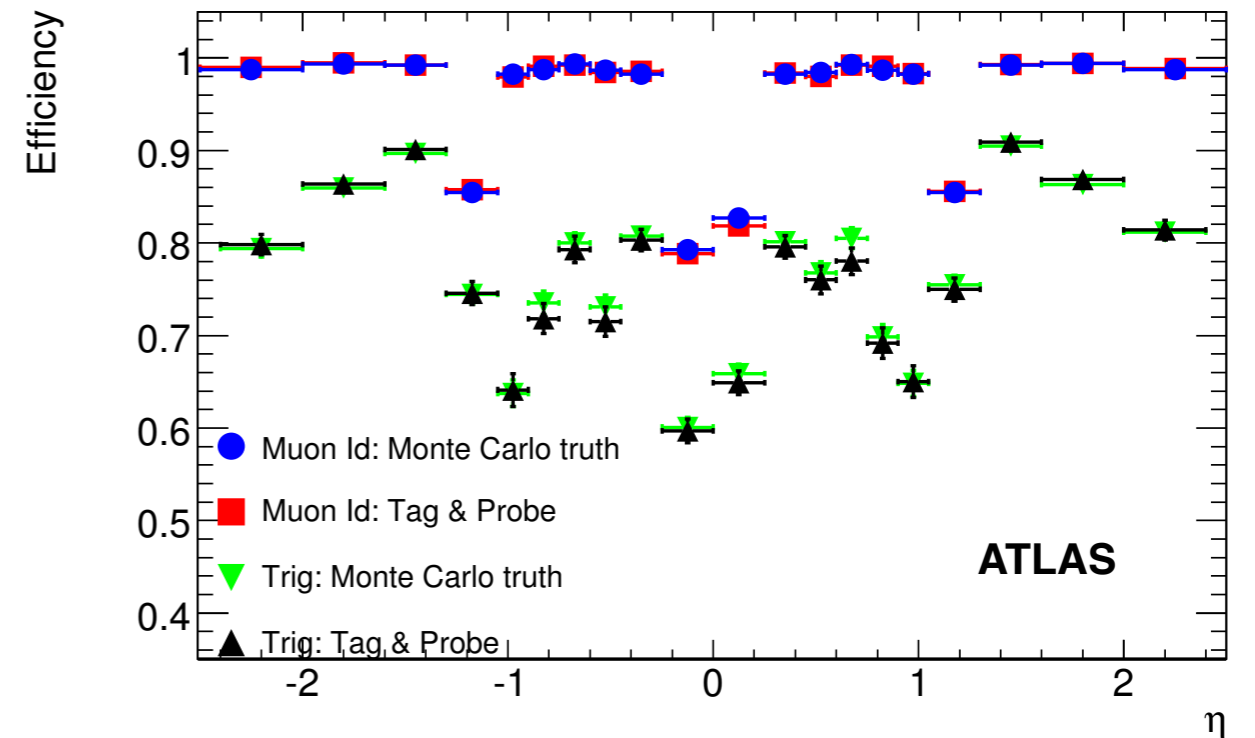
W,Z to leptons cross sections

● Efficiencies measurements in data

- ★ **Tag&Probe** method on $Z \rightarrow \ell\ell$
- ★ 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)



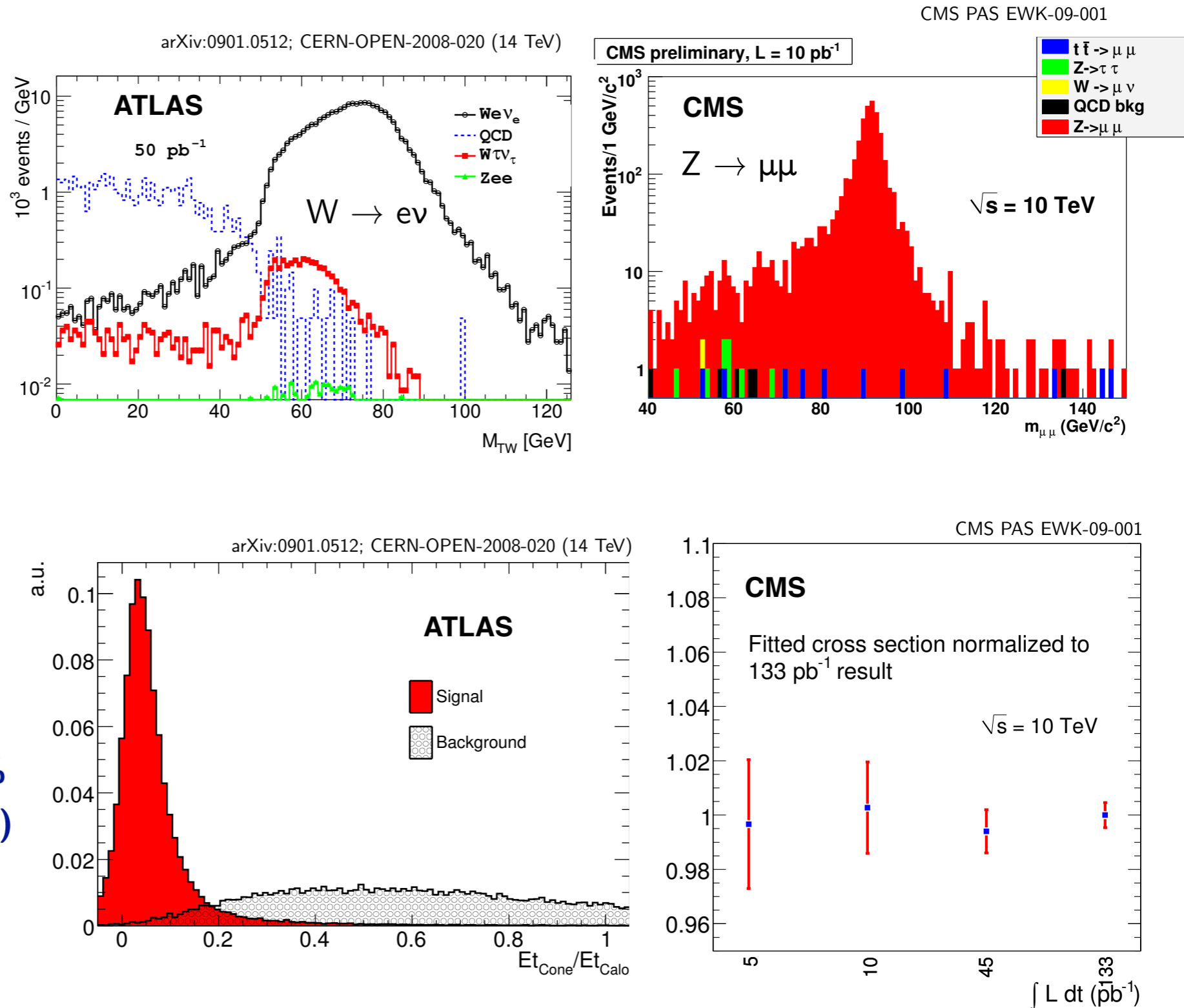
arXiv:0901.0512; CERN-OPEN-2008-020 (14 TeV)

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 $t\bar{t}$ and $Z \rightarrow \tau\tau$ 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



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)**

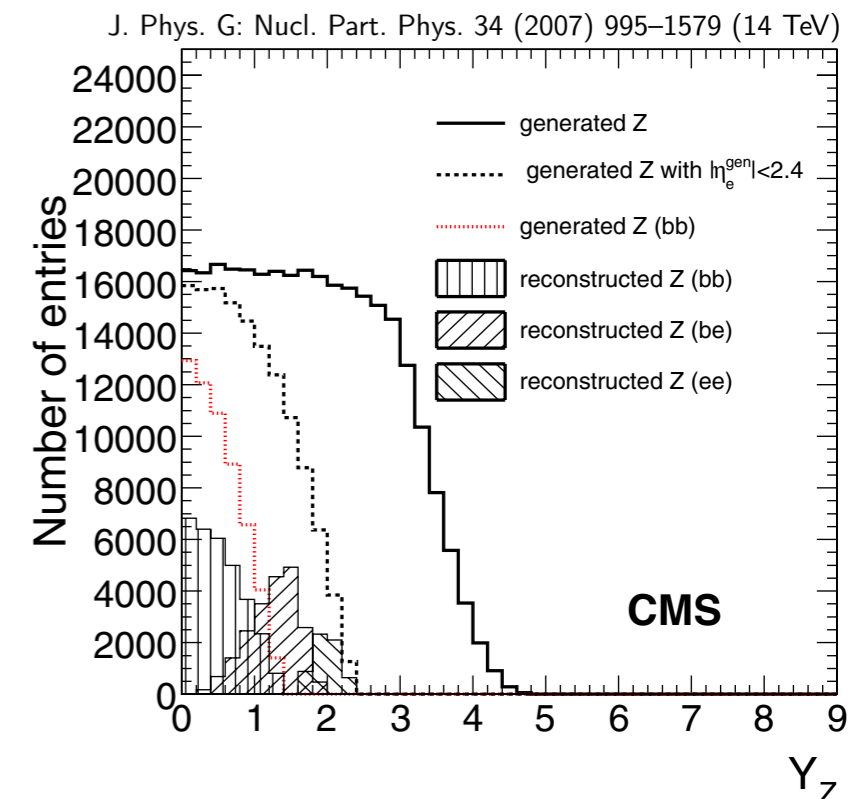
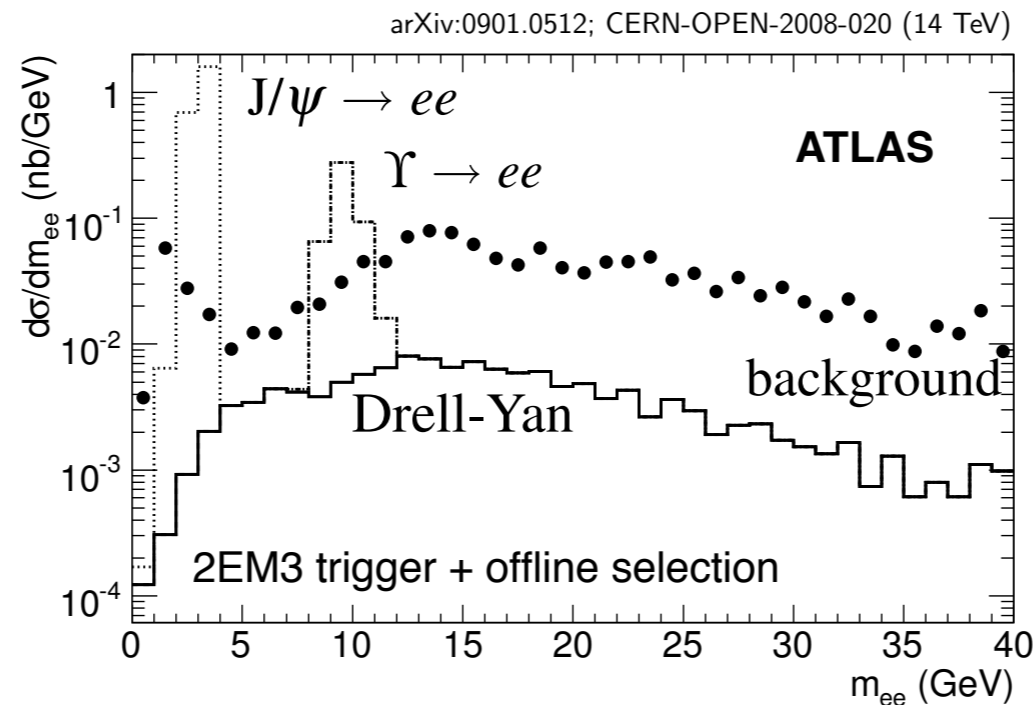
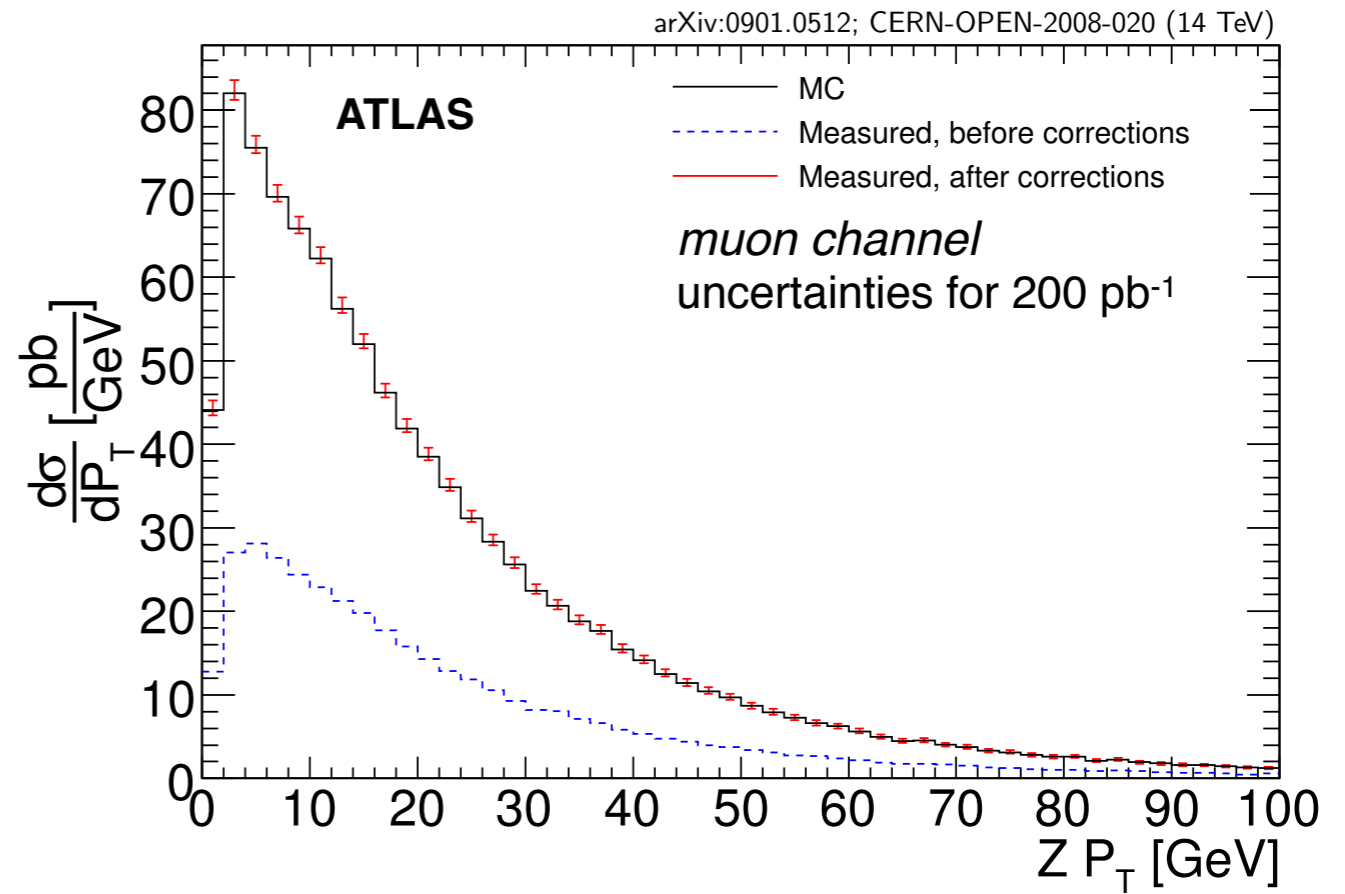
- ★ need to exploit **full e-identification**

- **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 values¹

- ★ $M_{\text{top}} = 173.1 \pm 0.6$ (stat) ± 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

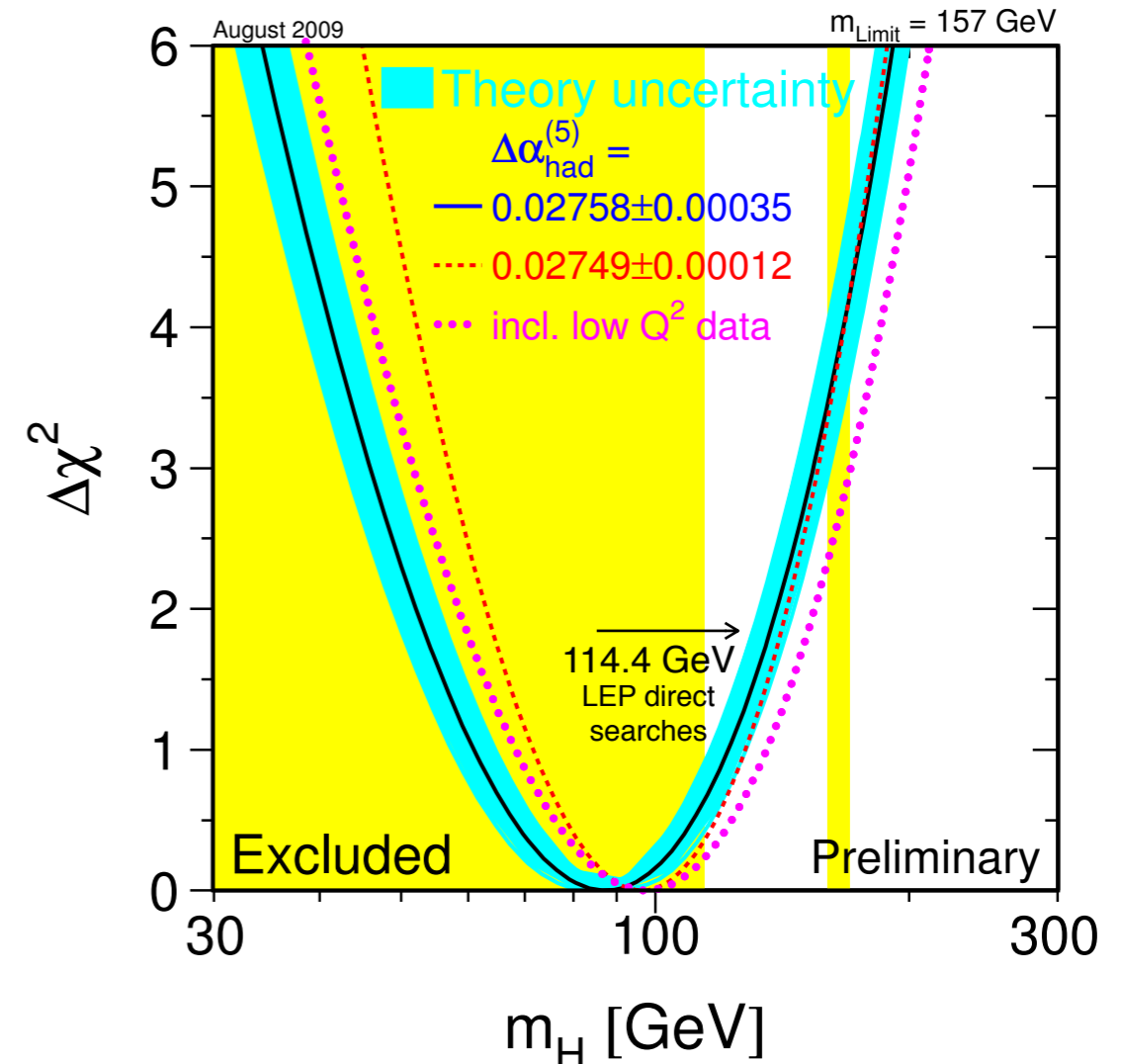
- LHC 1 year at $10^{33} \text{ cm}^{-2}\text{s}^{-1} \Rightarrow 6 \text{ fb}^{-1}$

- ★ about $2 \cdot 10^7$ W events selected per lepton decay with **combined statistical sensitivity at 2 MeV**

- ★ **challenge is on systematic uncertainties**

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

$$\Delta R \sim M_{\text{top}}^2, \log M_H$$



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

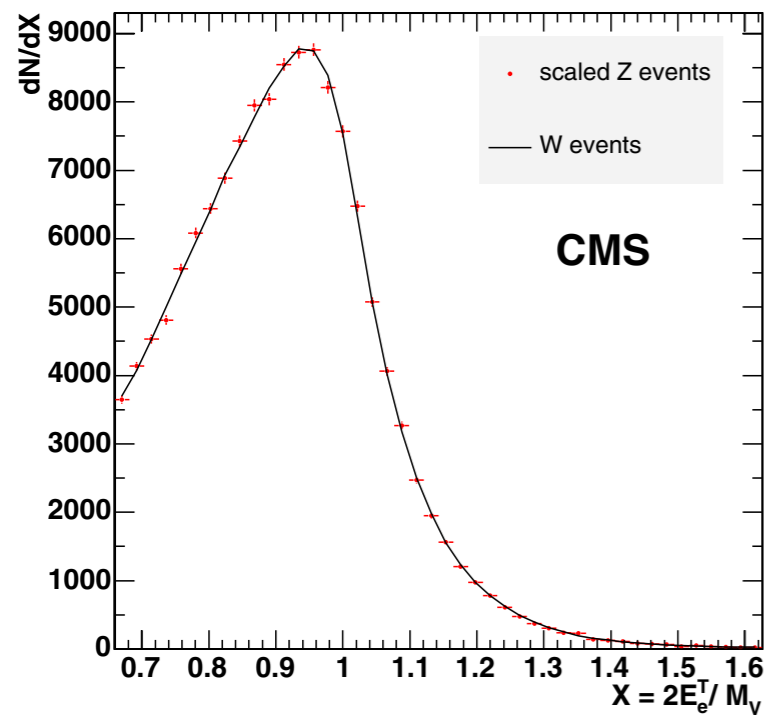
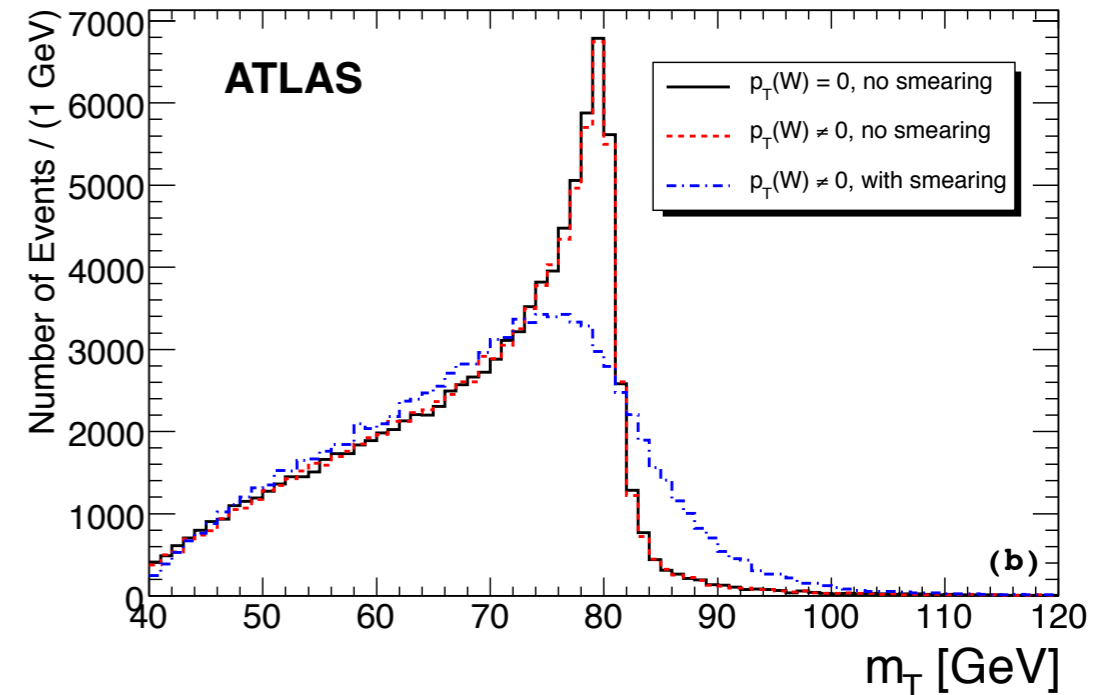
² CERN-PH-EP/2009-023

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

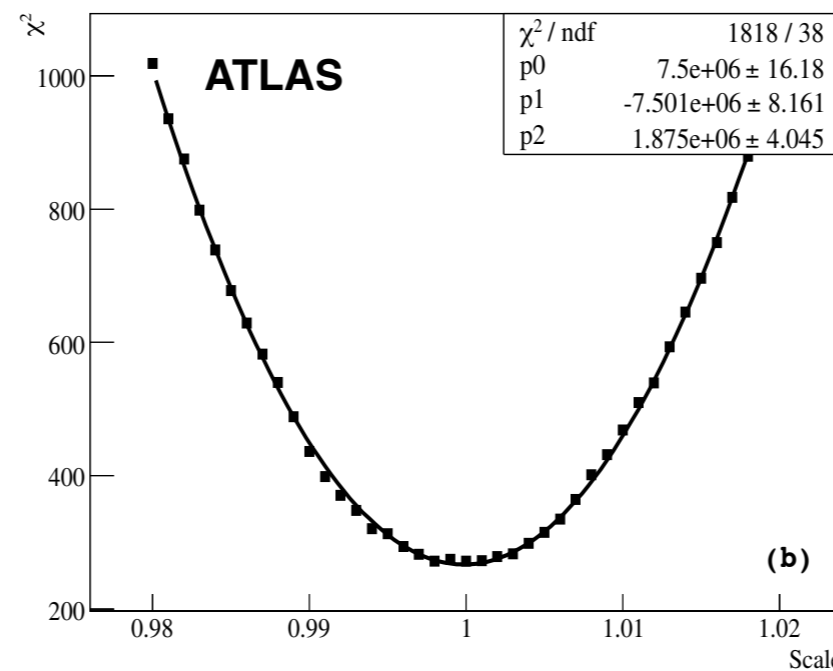
W mass measurement

- 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

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



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 $p_T e(\mu)$	ATLAS $M_T e(\mu)$	ATLAS $p_T e(\mu)$	ATLAS $M_T e(\mu)$	CMS $e(\mu)$	CMS $e(\mu)$
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

- 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 $< 20 \text{ MeV}$
- ★ clearly an ultimate fight against systematics to exploit as much as possible statistical power of LHC

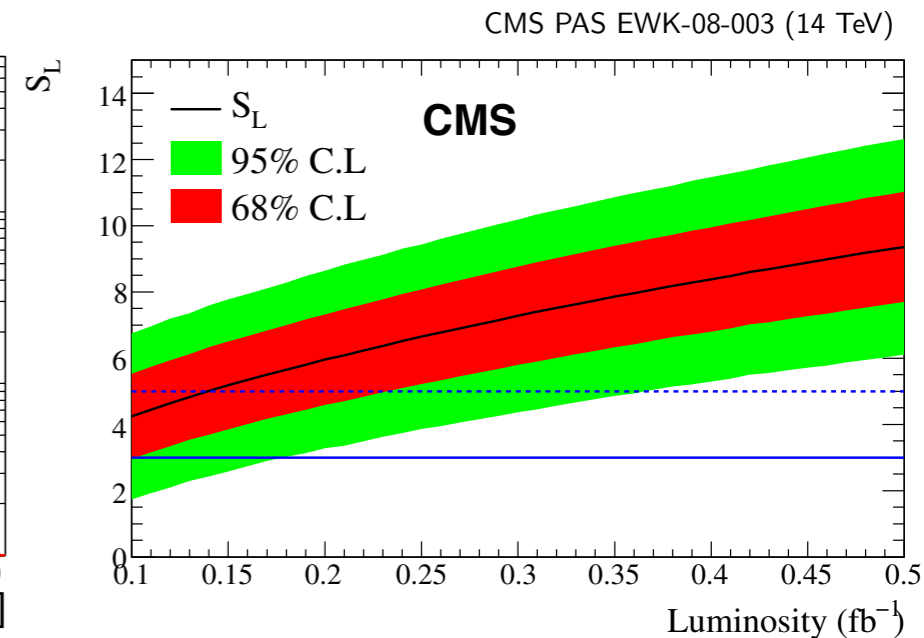
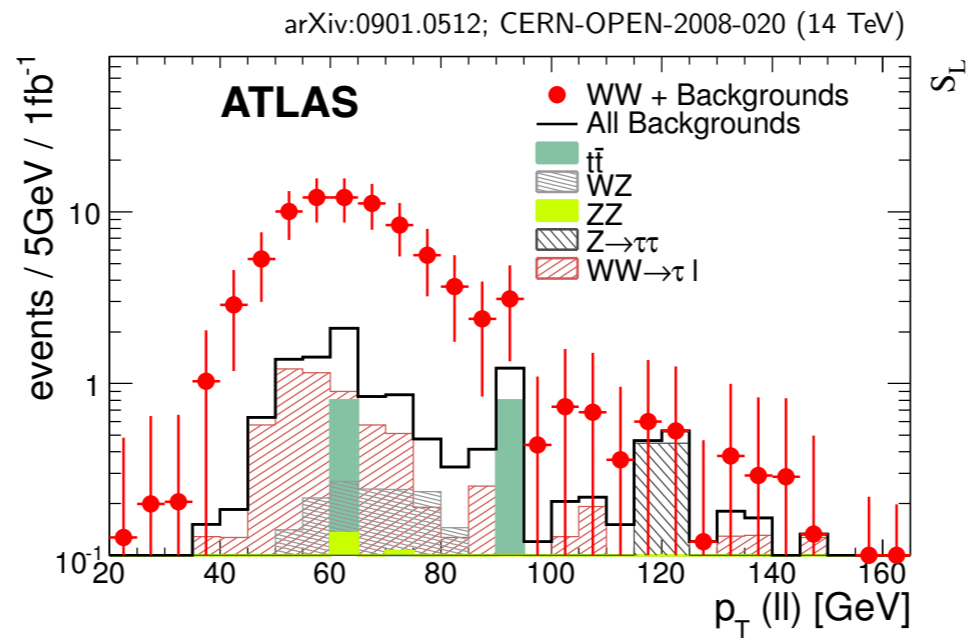
ATLAS arXiv:0805.2093v2 [hep-ex] 13 Jun 2008
 arXiv:0901.0512; CERN-OPEN-2008-020
 CMS J. Phys. G: Nucl. Part. Phys. 34 (2007) 995–1579

Di-Boson production

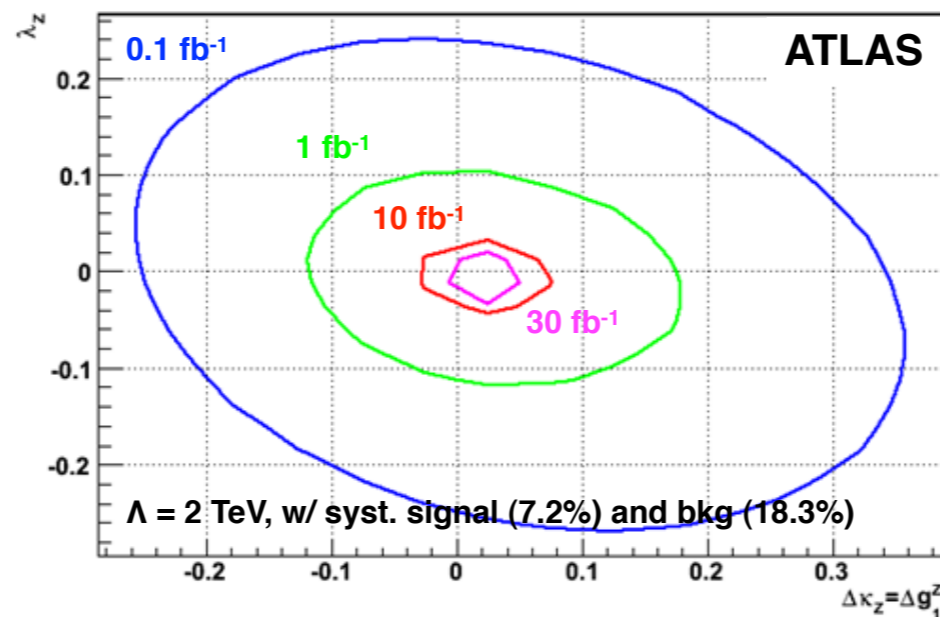
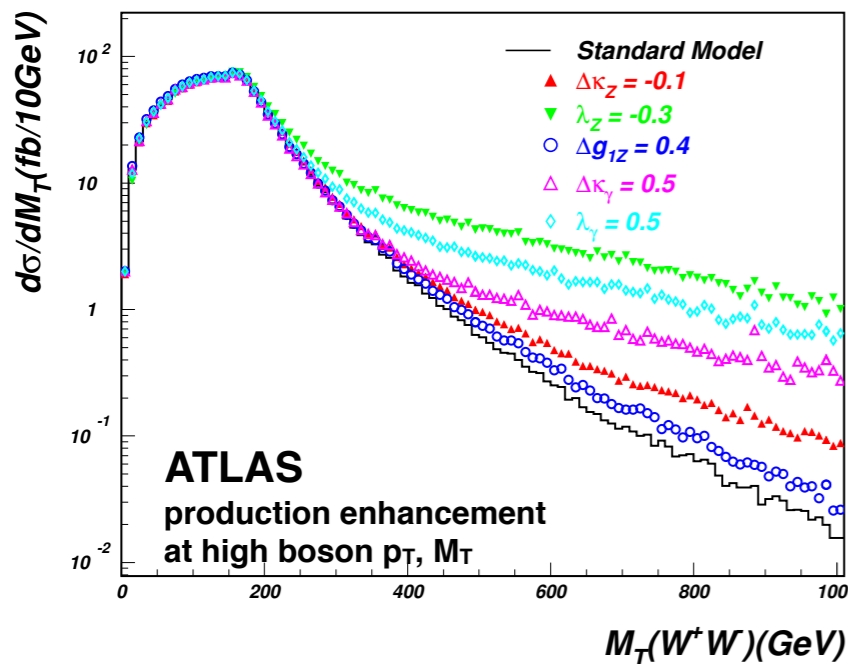
- Studies of $WW, WZ, ZZ, W\gamma, Z\gamma$ productions in lepton/photon final states ($\text{rate}_{\text{LHC}} \approx 100 \cdot \text{rate}_{\text{TeVatron}}$)
 - ★ test **beyond Standard Model physics, TGC anomalous couplings, backgrounds** for Higgs/SUSY searches

• Production cross sections

- ★ Cut-based and multivariate analysis on $e\text{-}\mu\text{-}\gamma$ ID, isolation, missing energy
- ★ SM signals **5σ significance** w/ **$0.1\text{-}0.3 \text{ fb}^{-1}$** ($1 \text{ fb}^{-1} ZZ \rightarrow 4l$) with about 20% syst.



TGC from WW with PDF CTEQ6M



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 $\sin^2\theta_{\text{eff}}$

- ★ consistency of SM, indirect constraint on H mass and effects of new physics

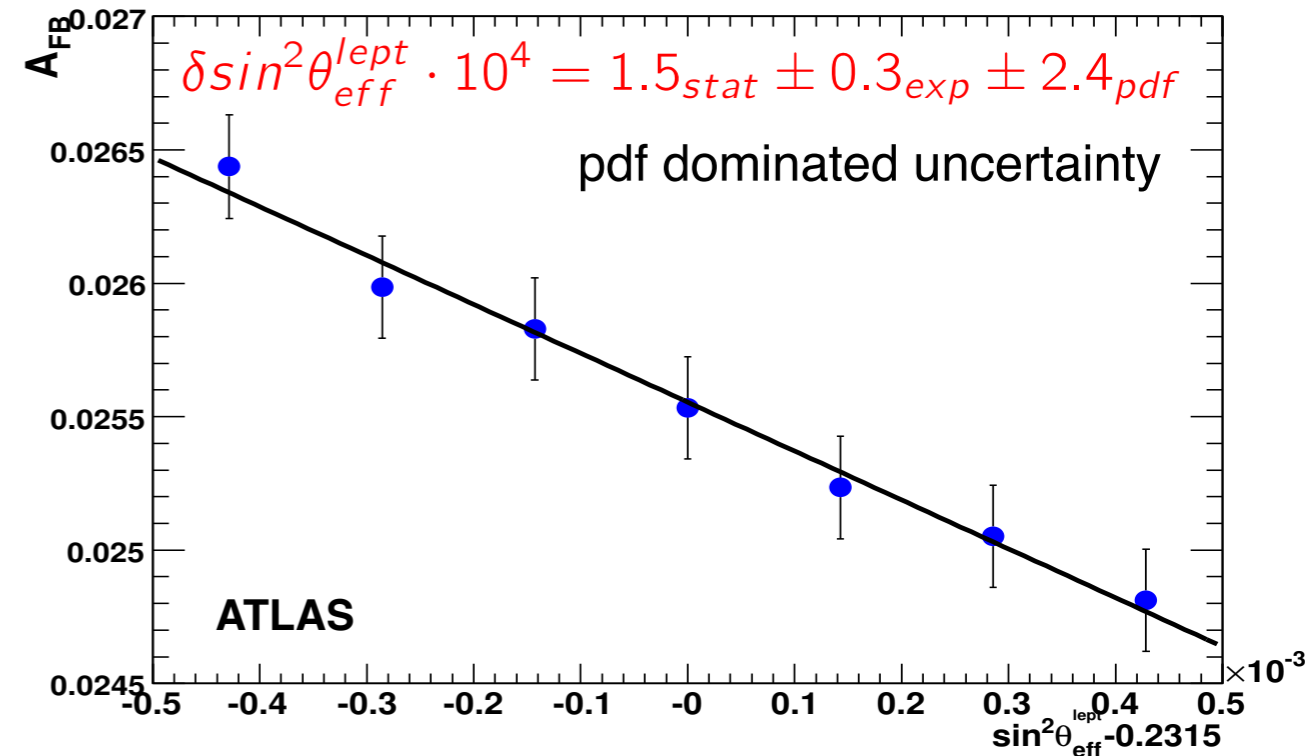
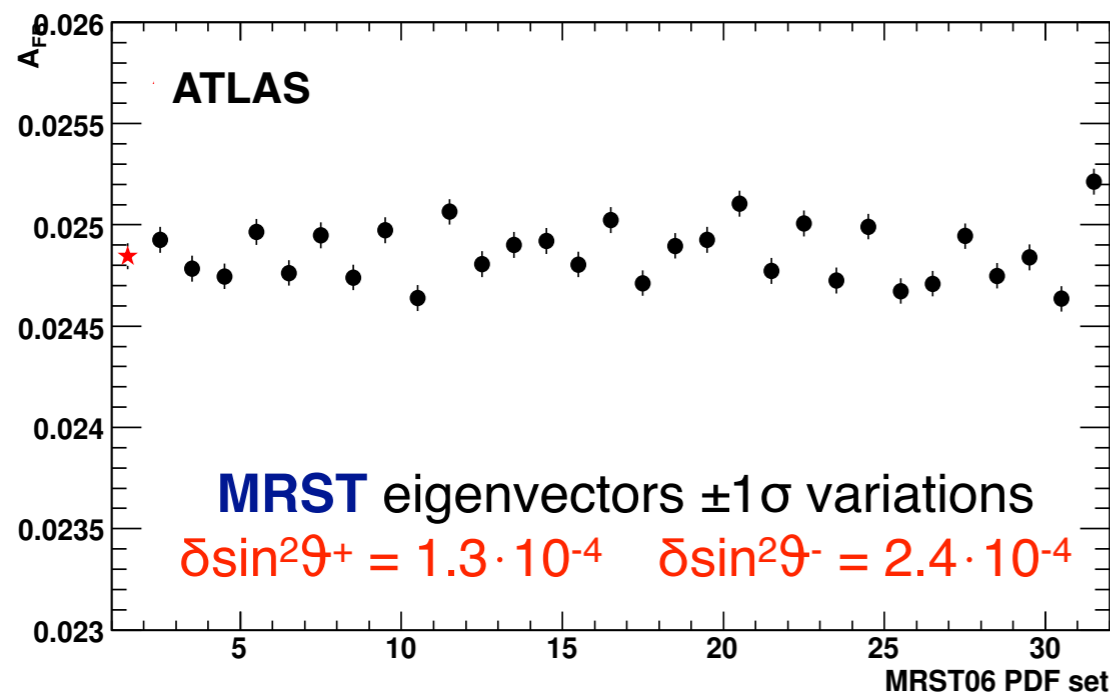
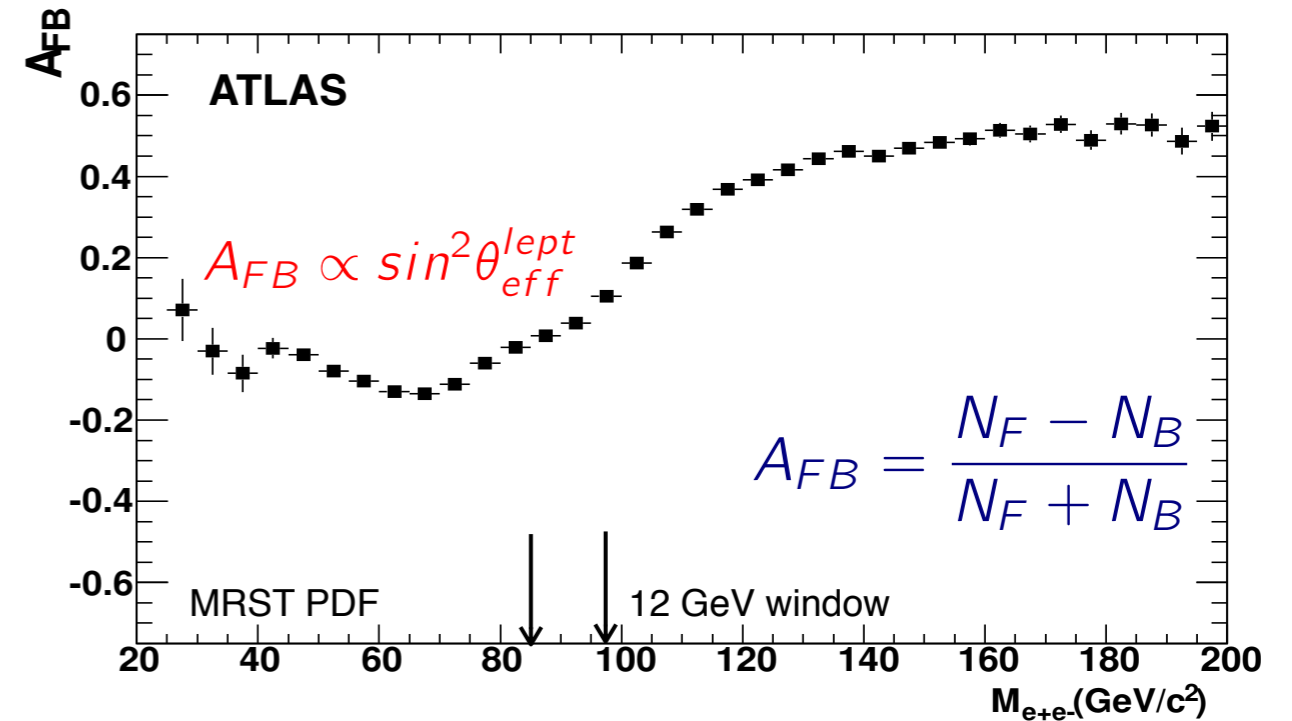
- High statistics needed to be competitive

with $\delta\sin^2\theta_{\text{eff}} \approx 1.6 \times 10^{-4}$ (world-average)

- ★ studies for 100 fb^{-1} with forward electrons preferred over muons due to calorimeter coverage

- ★ backgrounds from di-jets, $t\bar{t}$, $W+X$ (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 \Rightarrow 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 ($\sim 4\%$ on $\sigma_{W,Z}$ - different sets agree within 7%, 1% on asymmetries) could be reduced using first LHC data