Inclusive W/Z Production at CMS

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on behalf of the CMS Collaboration

Fermilab

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Outline

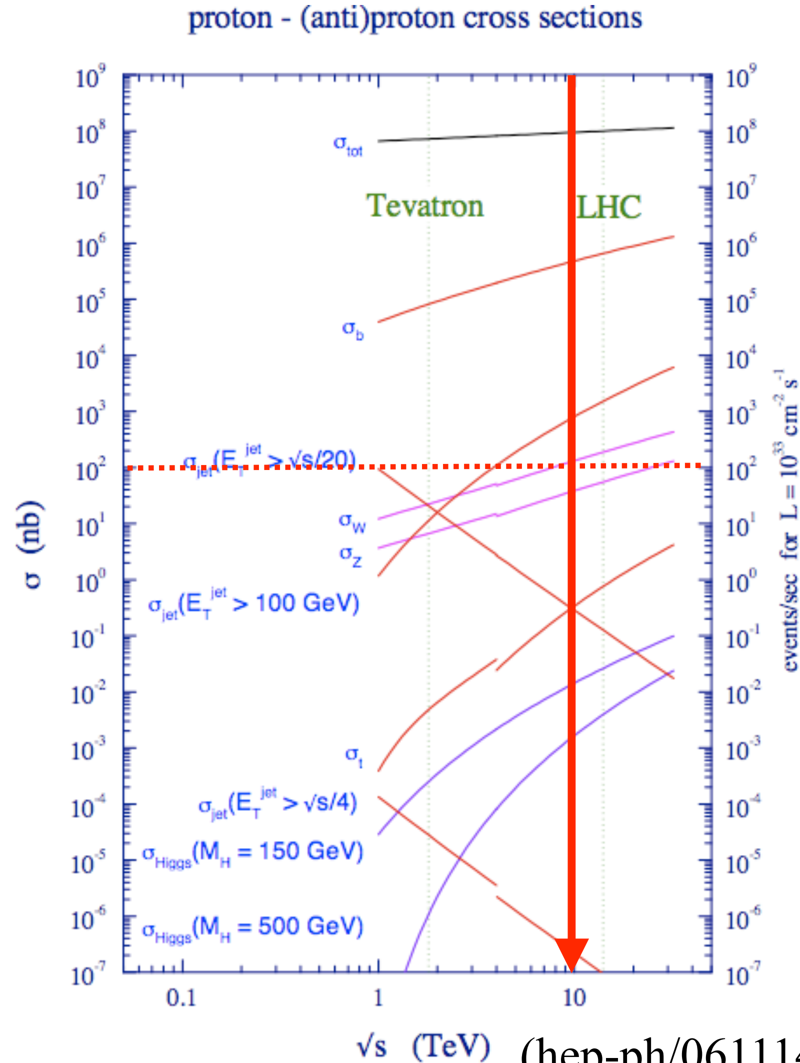
- ✦ Physics motivation
- ✦ The Large Hadron Collider and the CMS experiment
- ✦ Early Electro-Weak physics at CMS
  - ❖ Inclusive W/Z boson cross sections at LHC
  - ❖ Constraints on the Parton Distribution Functions (PDFs), differential cross sections, charge asymmetries, etc.
- ✦ Summary

Disclaimer: this is a very selected coverage of the very rich, exciting electro-weak physics program at CMS

Physics Motivation

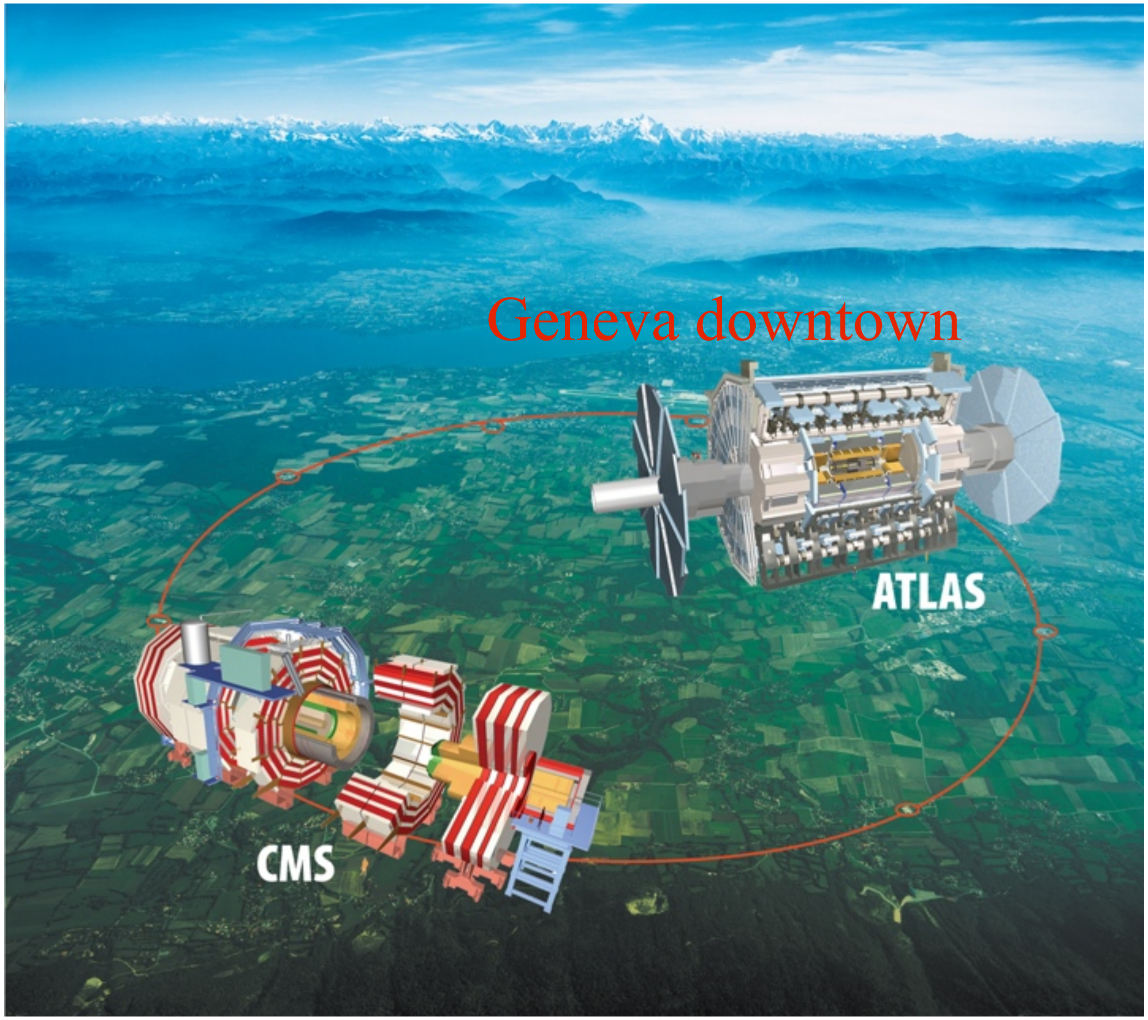
- LHC is a W/Z factory. Has very rich SM physics program, cross sections, p_T spectrum, charge asymmetry, forward-backward asymmetry, mass, width, etc.

- Detector performance: missing transverse energy studies, efficiencies of lepton reconstruction/identification/ trigger, etc.
- Beyond SM: standard candles for W', Z', other exotic gauge boson searches, multi-gauge boson production.



(hep-ph/0611148)

The Large Hadron Collider



- 27 km LEP tunnel.
- Design parameters:
  luminosity: 10^{-34} $cm^{-2}s^{-1}$
  proton-proton collision at 14 TeV
- Beam injection expected in the end of this year.
- First physics run to accumulate a few hundred pb^{-1} of integrated luminosity,
  (at 10 TeV or less).

The CMS Experiment

• CMS collaboration: 183 institutes in 38 counties, ~3000 physicists and engineers.

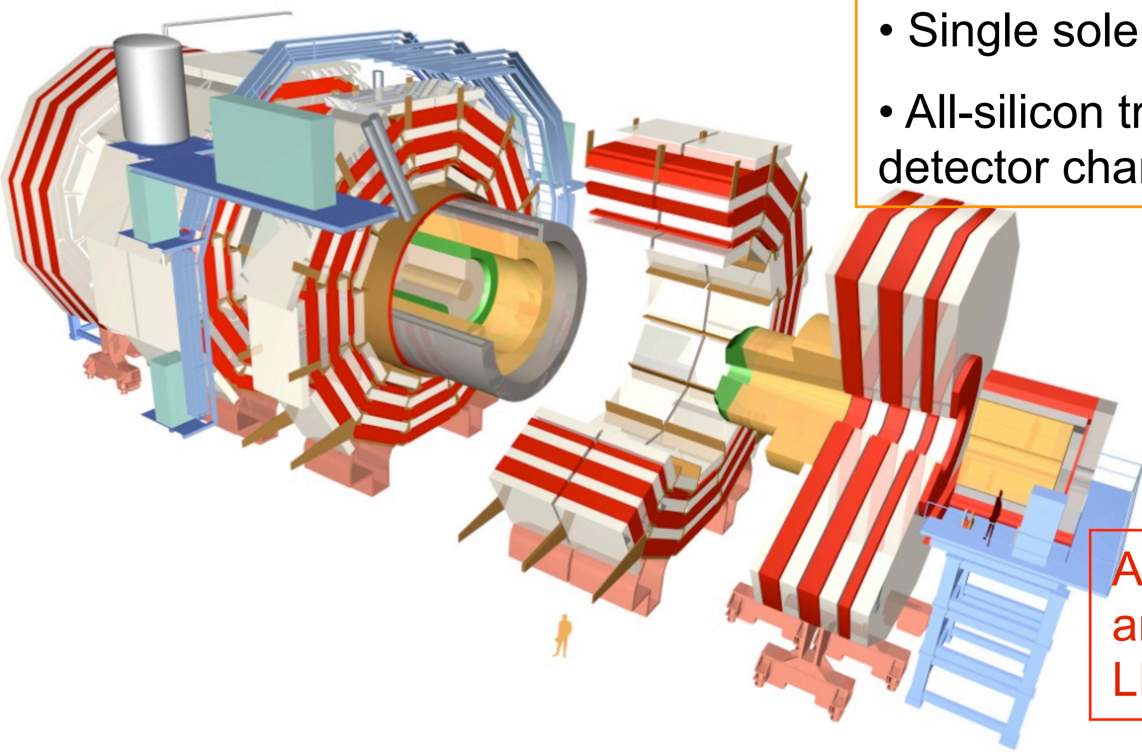
• 4π general-purpose hadron collider detector.

• Dimensions: 21m (L) x 15m (H) x 15 (W)

• Weight: 12,500 T.

• Single solenoidal magnet @3.8 T.

• All-silicon tracking detector, about 100 M detector channels.



Active detector commissioning and will be ready well before LHC beam injection!

Inclusive $W \to l(\mu/e)\nu$ Cross Sections

- Standard candle at LHC: one of the first resonances to be observed at LHC?
- Very precise prediction in cross sections, ~2-3% level.

PDF set	$\sigma_{W+}\ B_{W\to l\nu}$ (nb)	$\sigma_{W-}\ B_{W\to l\nu}$ (nb)	$\sigma_Z\ B_{Z\to ll}$ (nb)
MSTW08	8.55±0.15	6.25±0.12	1.38±0.025
CTEQ66	8.77±0.18	6.22±0.14	1.40±0.027

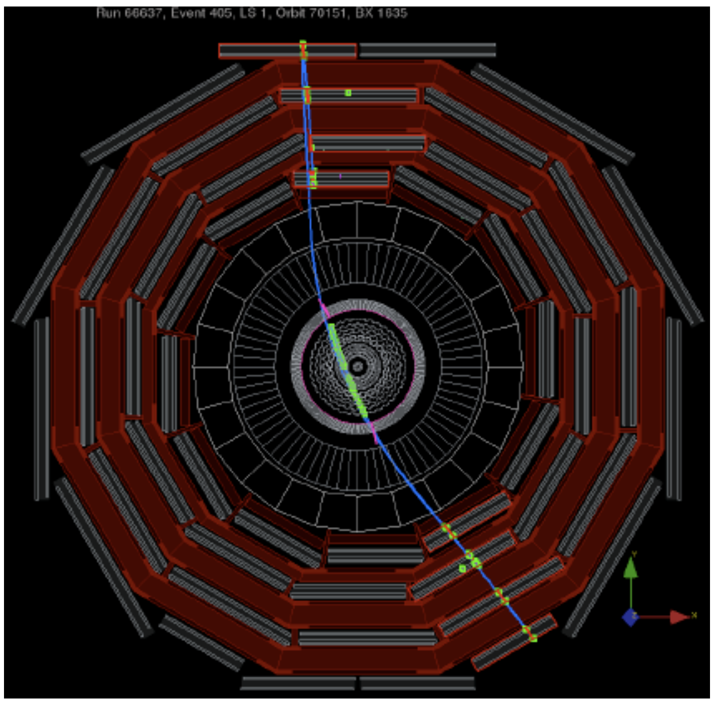
A.M. Cooper-Sarkar, PDF4LHC workshop (2009)

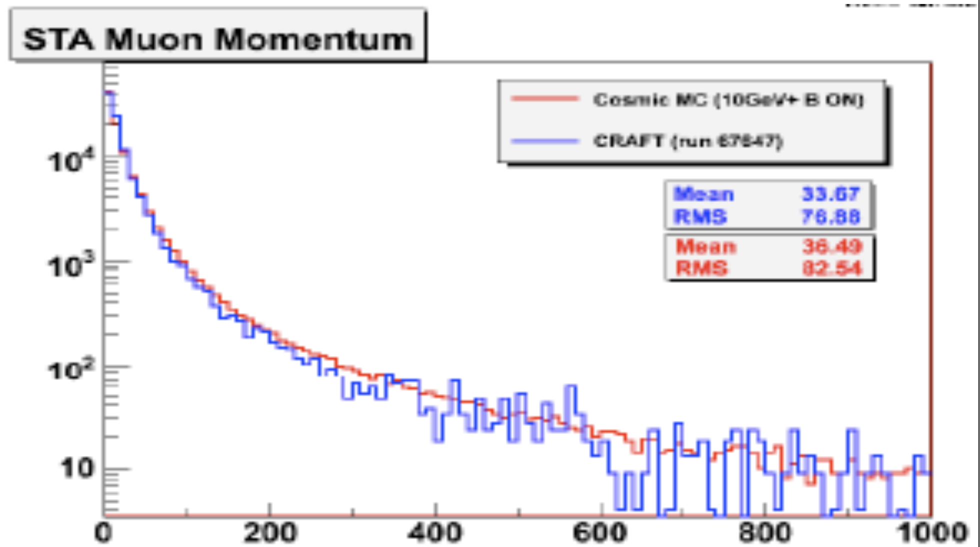
- Experimental signature: single electron/muon + missing transverse energy (MET).
- Trigger: high-efficiency single lepton trigger,
  - ~ 97% efficient for electrons (E_T> 15 GeV, $|\eta|$ < 2.5)
  - ~ 90% efficient for muons (p_T > 15 GeV, $|\eta|$ < 2.1)

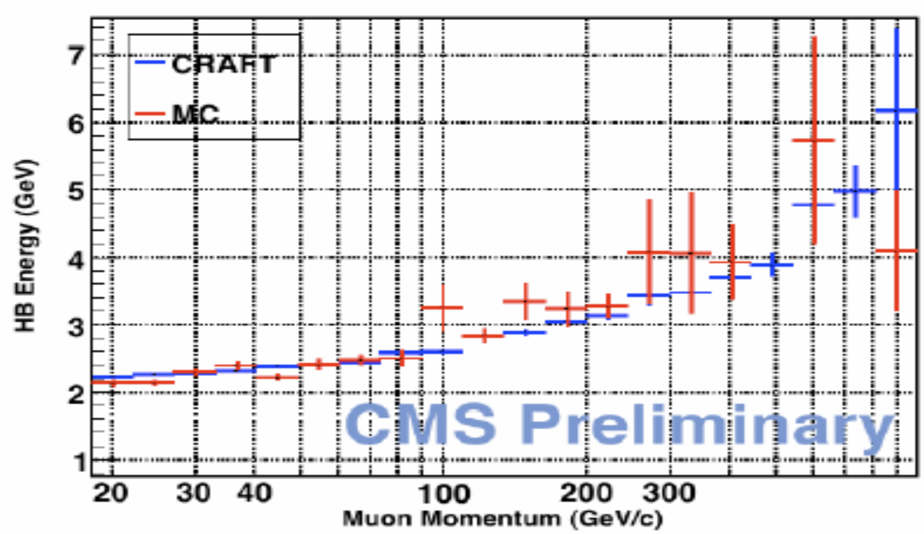
Understanding Detector

✦ Cosmic muon in the CMS detector is well understood: momentum, energy deposit in calorimeter, etc.

✦ Demonstrated capability/performance in muon reconstruction.

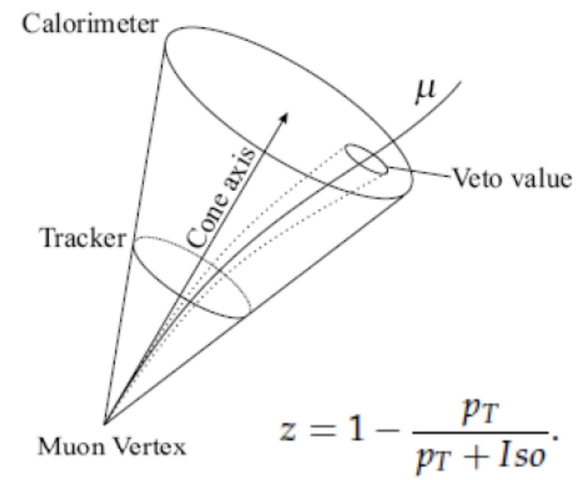




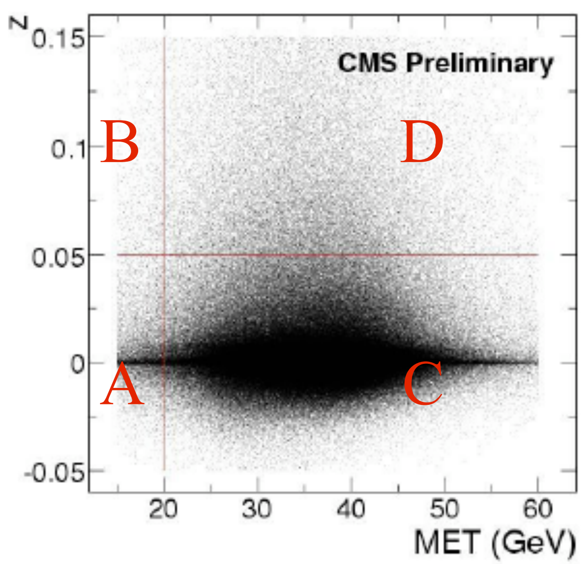


Background Studies

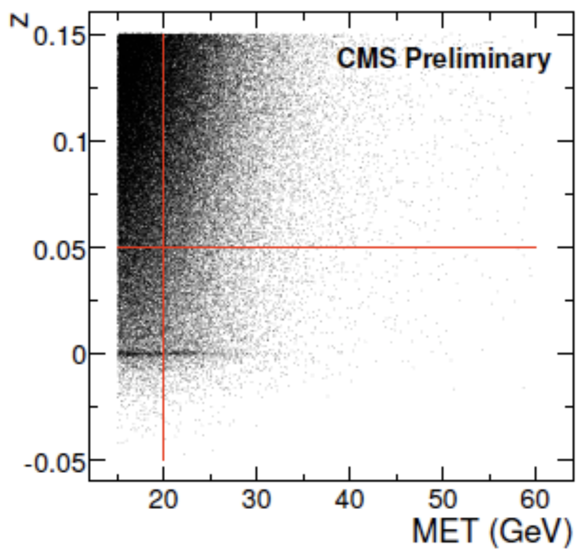
- Backgrounds: QCD dijets, Drell-Yan, ttbar, W(τυ), γ+jet (W(eυ))
- Isolation: track/calorimeter-based, or combined. ~two order of magnitude reduction in QCD dijet background.
- Data-driven method to subtract the rest of the QCD background.



W(μν)



QCD



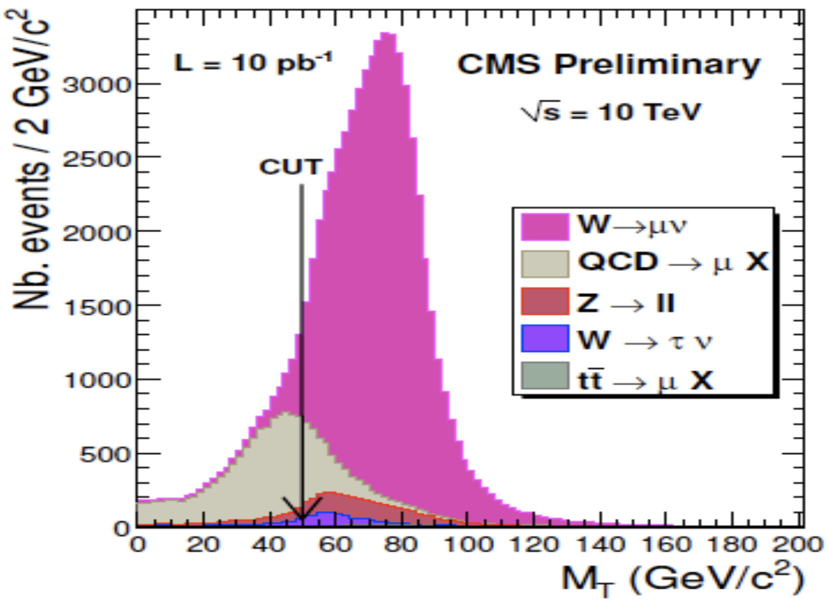
- Two non/weakly-correlated variables:

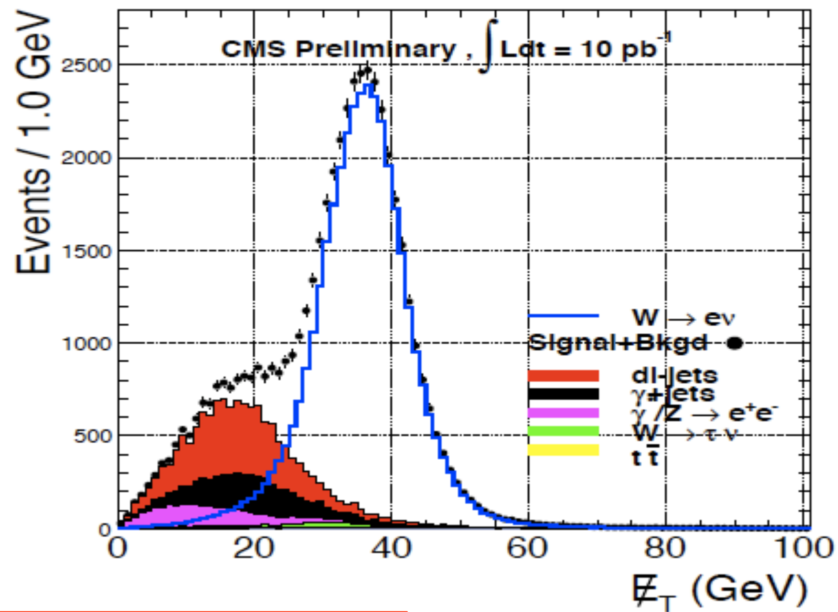
$$N_A/N_C=N_B/N_D$$

- ~1-2% systematic uncertainty (expecting < 10% QCD background)

Expected Results at 10 pb-1

$$m_T = \sqrt{2 p_T \not{E}_T (1 - \cos\Delta\phi_{\ell, \not{E}_T})}$$



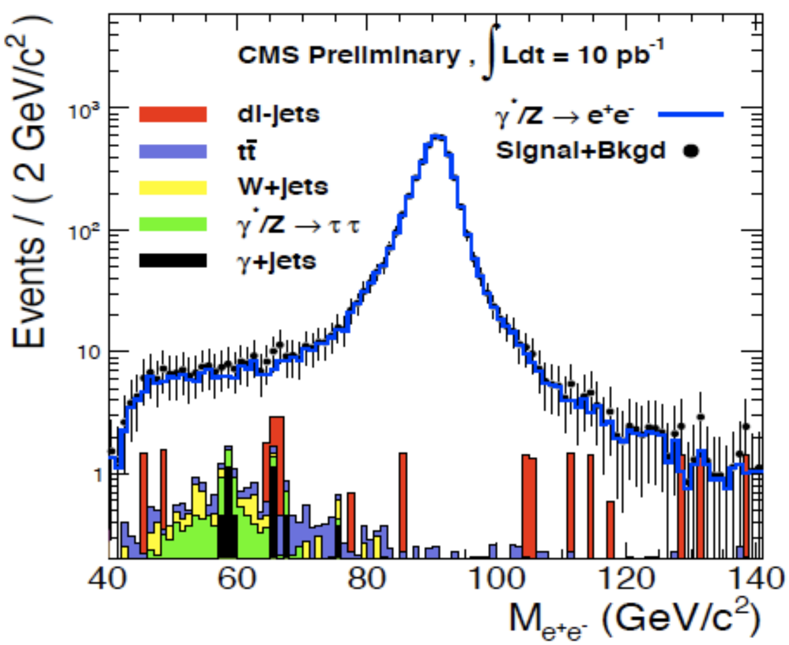


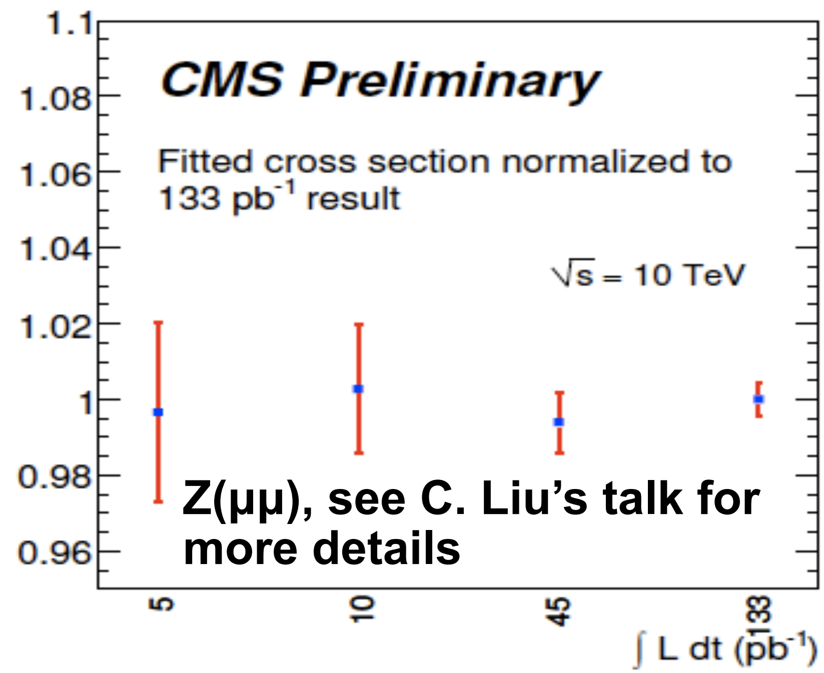
$$\sigma_W \times BR(W \rightarrow e\nu) = \frac{N_W^{pass} - N_W^{bkgd}}{A_W \times \epsilon_W \times \int L dt}$$

- ✦ σ×Br(W→eν)=14200±200(stat.) pb, good agreement with MC truth
- ✦ Expecting few% systematic error + 10% luminosity error. (Luminosity monitoring?)

Inclusive Z→ll(μ/e) Cross Sections

- Another standard candle at LHC,
  $\sigma_Z B_{Z\to ll}$ ~1.40±0.03 (NNLO)
- Experimental signature: two high-p_T isolated leptons.
- Very little background (<1%): QCD dijets, W+jets, ttbar, Z(ττ), etc.
- < 2% statistical precision at 10pb^{-1} with systematic error dominated by 10% luminosity error.

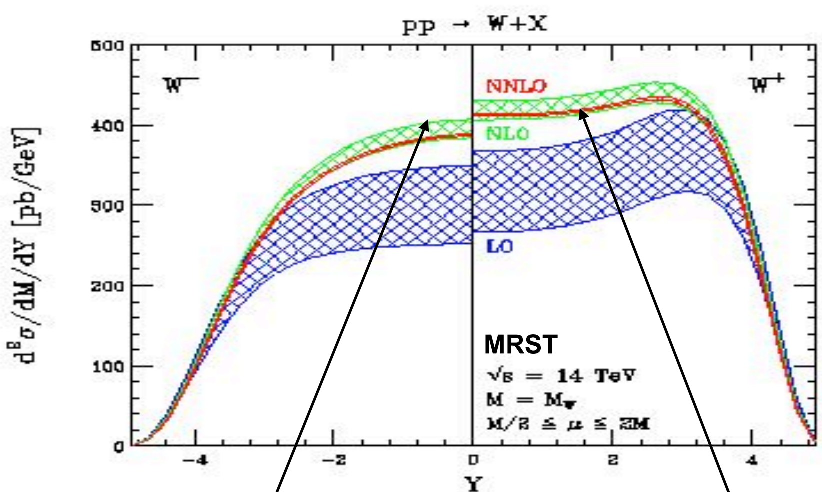




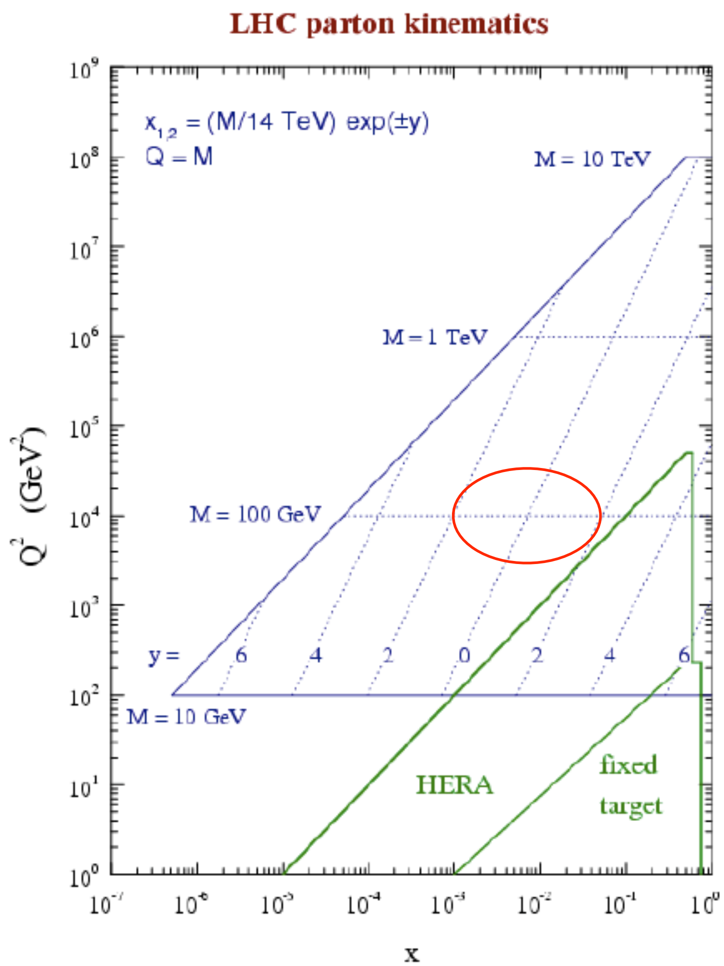
Probing the PDFs at LHC

$$\frac{d\,\sigma}{d\text{ variable}}[pp \to X] \sim \sum_{ij} \left(f_{i/p}(x_1) f_{j/p}(x_2) + (i \leftrightarrow j)\right) \hat{\sigma}$$

- LHC offers unique opportunity to probe Parton Distribution Functions (PDFs), kinematics, sea quarks, etc.
  $8.5 \cdot 10^{-4} < x < 8.5 \cdot 10^{-2}$ (cental W/Zs)
- Test higher-order theoretical calculations with W/Z rapidity distributions.

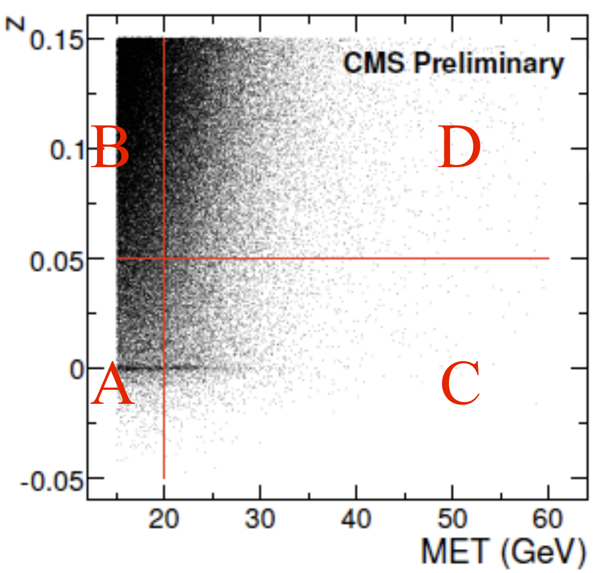


NNLO corrections small ~ few%
NNLO residual scale dependence < 1%

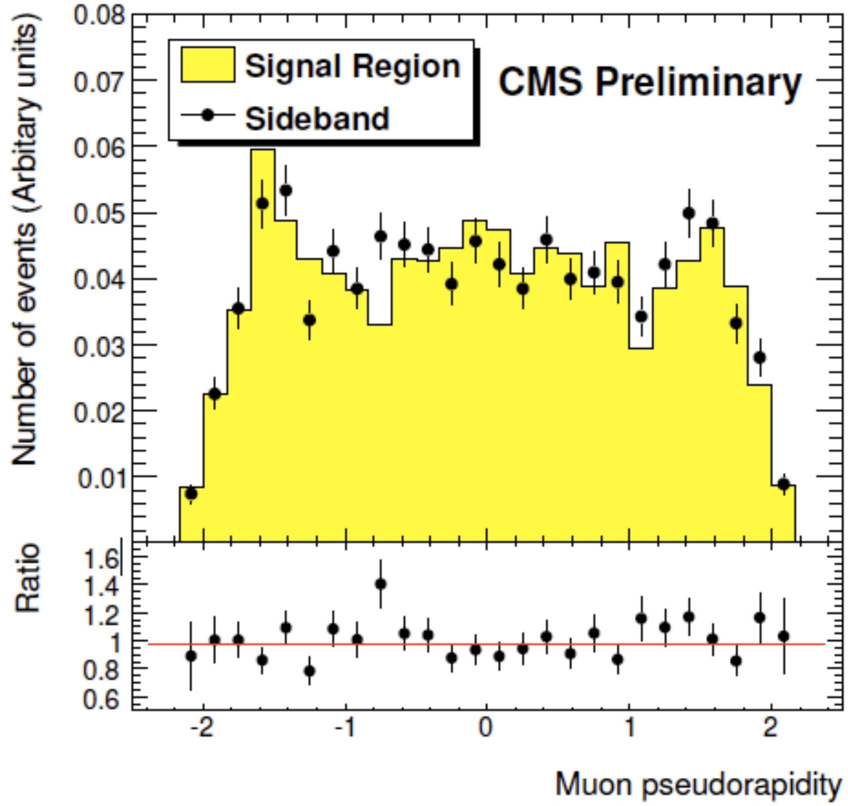


Muon Differential Cross Sections in Inclusive W→μν productions

- Same trigger path, very similar event selections as the inclusive cross section analysis.
- Same QCD background subtraction technique, ABCD matrix method.
- Use sideband (A) to predict rapidity distribution of QCD background in signal region (C).



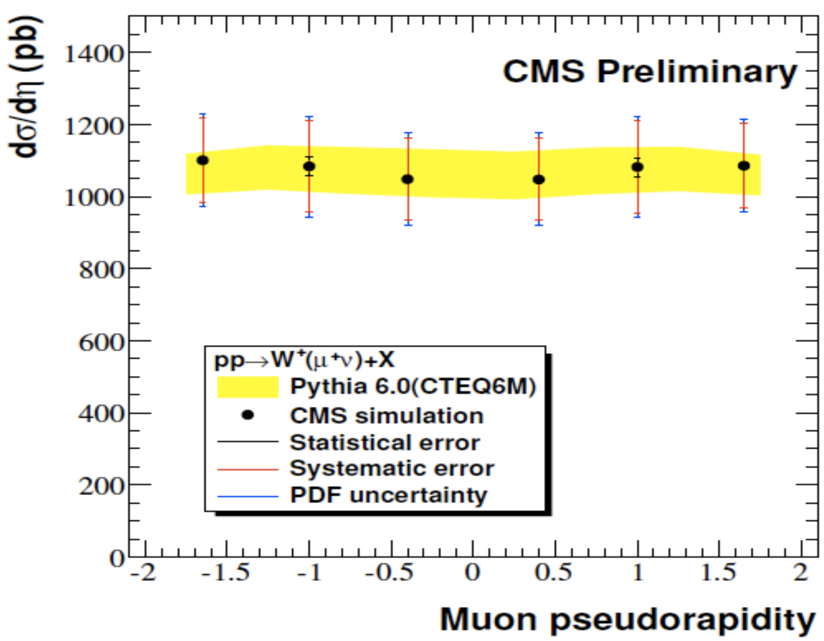
$$z = 1 - \frac{p_T}{p_T + Iso}.$$

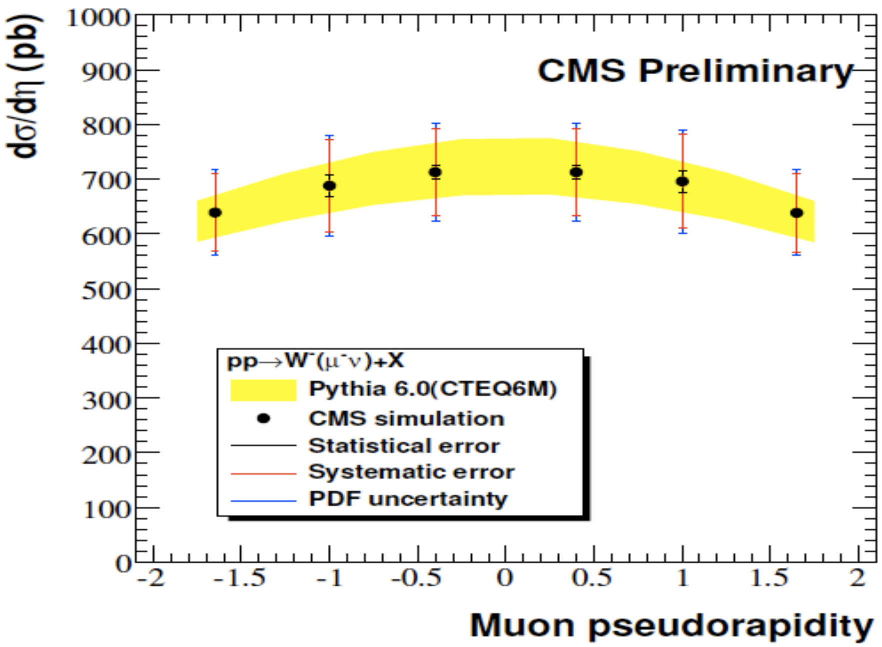


Expected Result at 10 pb-1

$$\frac{dN}{d\eta} = \mathcal{L} \cdot \frac{d\sigma}{d\eta} \cdot \epsilon_{HLT} \cdot \epsilon_{offline} \cdot \epsilon_{acceptance} \cdot$$

- Relate background-subtracted signal events with cross sections: correct for acceptance, offline and trigger efficiencies, etc.
- Systematic error (10% luminosity error) dominates.
- Can reduce luminosity error by comparing shape to higher order calculations.





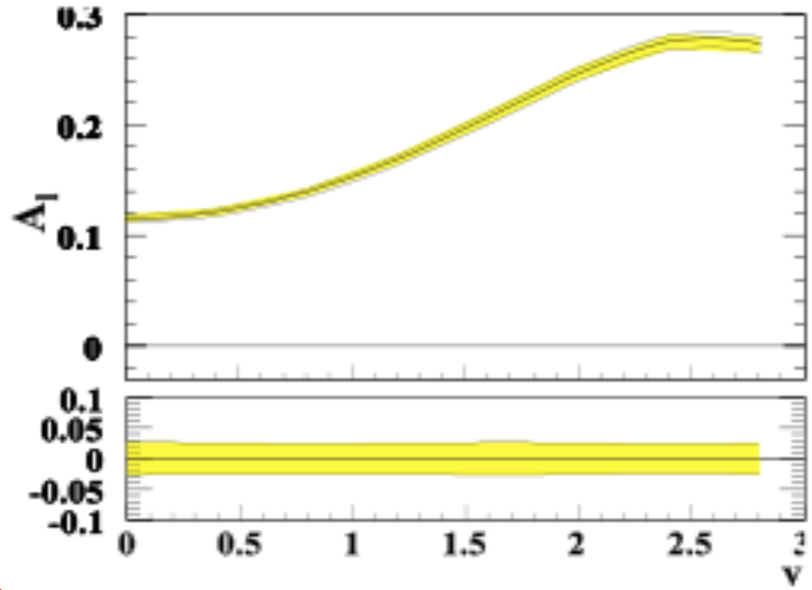
Muon Charge Asymmetry

- W boson production can directly probe valence-sea quark ratio at LHC.

$$A_W \approx \frac{u\bar{d} - \bar{u}d}{u\bar{d} + \bar{u}d} \approx \frac{u_{val} - d_{val}}{u_{val} + d_{val} + 2\bar{q}}$$

- However, only the leptons can be accessible directly, ~3.5% precision (CTEQ66).
- W V-A asymmetry dilutes the expected W asymmetry.

$$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\nu) - \frac{d\sigma}{d\eta}(W^- \to \mu^-\nu)}{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\nu) + \frac{d\sigma}{d\eta}(W^- \to \mu^-\nu)}.$$



A.M. Cooper-Sarkar, PDF4LHC workshop (2009)

- Symmetric detector: efficiencies cancel out experimentally.
- Acceptance can differ from unit by about 10%.

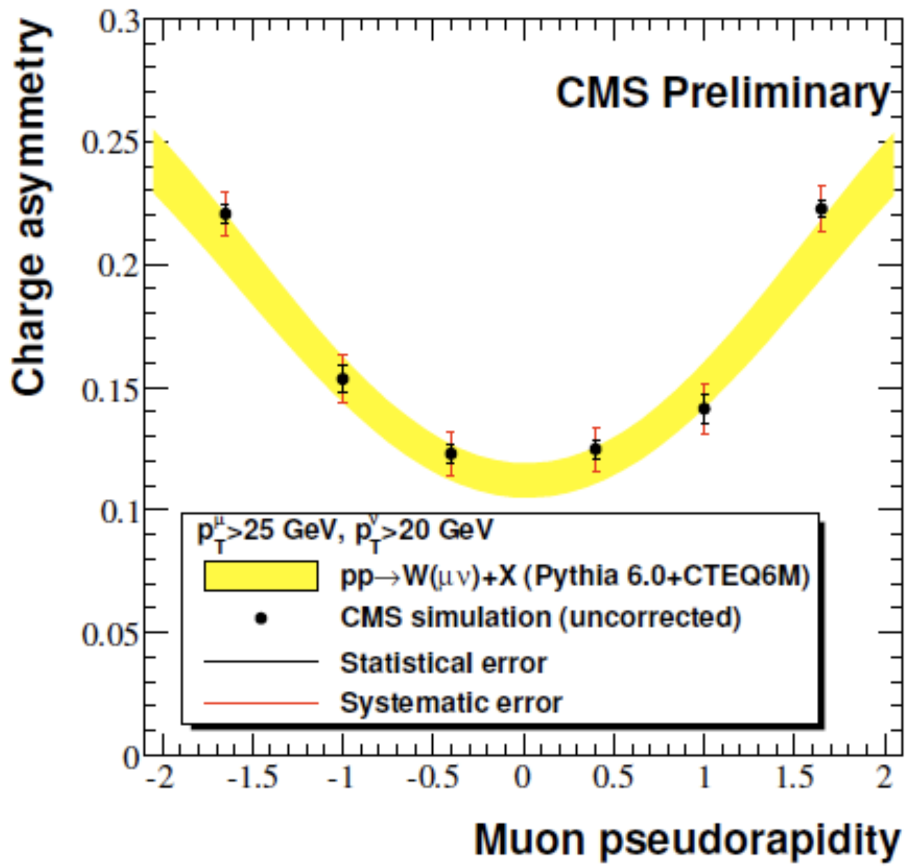
$$A(\eta) = \frac{\frac{dN^+}{d\eta} - \frac{dN^-}{d\eta} \cdot \frac{\epsilon^+_{HLT} \cdot \epsilon^+_{offline} \cdot \epsilon^+_{acceptance}}{\epsilon^-_{HLT} \cdot \epsilon^-_{offline} \cdot \epsilon^-_{acceptance}}}{\frac{dN^+}{d\eta} + \frac{dN^-}{d\eta} \cdot \frac{\epsilon^+_{HLT} \cdot \epsilon^+_{offline} \cdot \epsilon^+_{acceptance}}{\epsilon^-_{HLT} \cdot \epsilon^-_{offline} \cdot \epsilon^-_{acceptance}}}$$

Charge Asymmetry at 100 pb^{-1}

$$A(\eta)_{obs} = \frac{\frac{dN^+}{d\eta} - \frac{dN^-}{d\eta}}{\frac{dN^+}{d\eta} + \frac{dN^-}{d\eta}} = \frac{d\sigma^+/d\eta - \left(\frac{\epsilon^-_{acceptance}}{\epsilon^+_{acceptance}}\right) \cdot d\sigma^-/d\eta}{d\sigma^+/d\eta + \left(\frac{\epsilon^-_{acceptance}}{\epsilon^+_{acceptance}}\right) \cdot d\sigma^-/d\eta}.$$

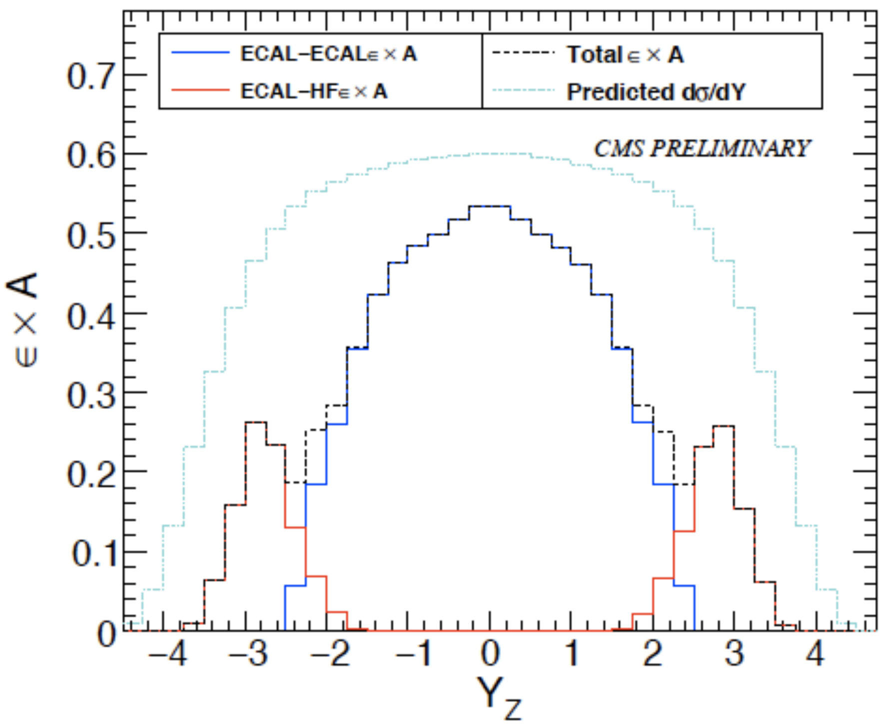
Theoretical prediction

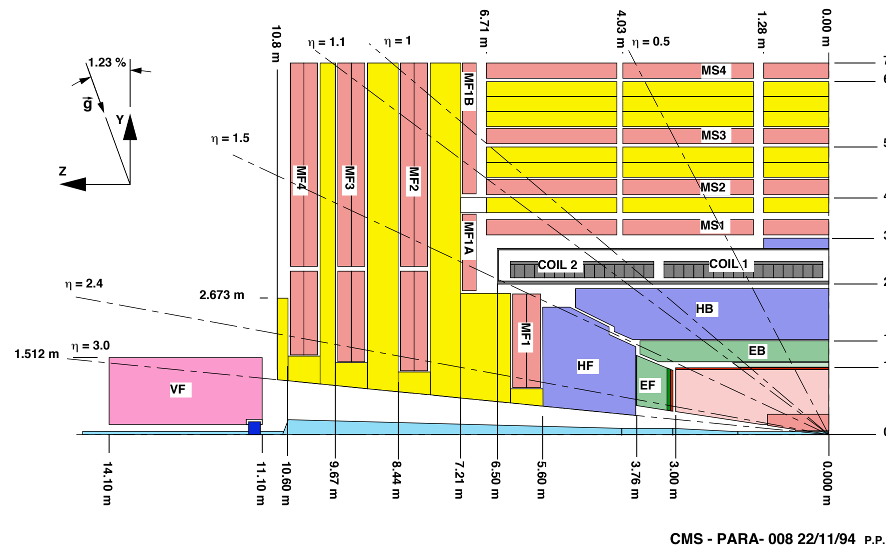
- Calculate charge asymmetry with background-subtracted signal events.
- Leave the acceptance in theoretical predictions to be compared to.
- Statistical errors: 0.004-006.
- CMS is symmetric in muon detection with respect to charge.
- Systematic error is dominated by the error on the offline and trigger efficiency ratio between μ^+ and μ^-. (assumed to be determined at 1.3% level with 100 pb^{-1} of integrated luminosity)
- Could provide constraints to different PDF models.



Z(ee) Rapidity Shape

- Single isolated electron trigger (E_T>15 GeV).
- Similar backgrounds as the inclusive Z(ee) analysis.
- Very unique technique: electron reconstruction with the CMS Forward Hadron(HF) detector, longitudinal shower information..



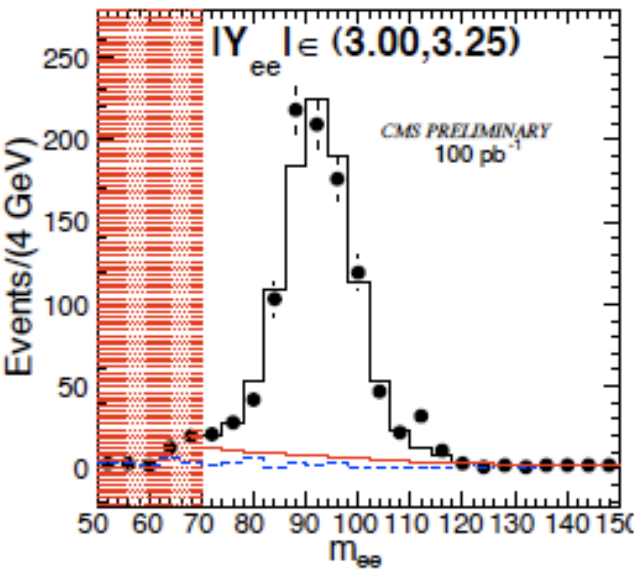


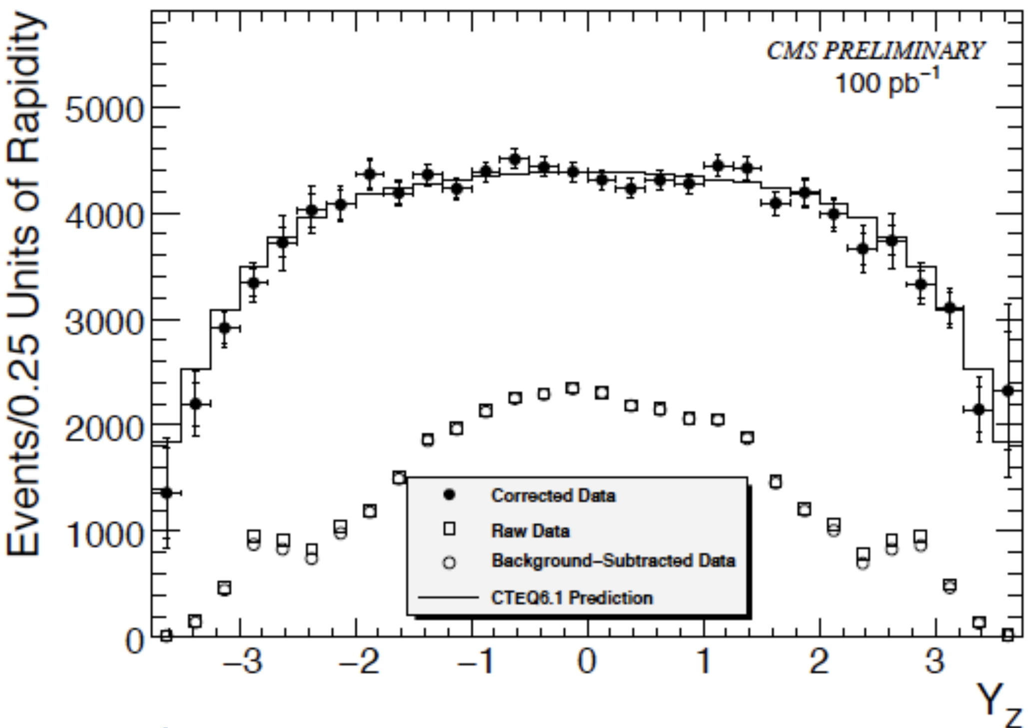
Largely extend the acceptance (rapidity from ~2.5 to ~4.0) →lower x in parton kinematics!

Expected Results at 100 pb^{-1}

$$\frac{1}{\sigma}\frac{d\sigma(Z \rightarrow e^+e^-)}{dY_i} = \frac{(\epsilon \times A)}{N - B} \cdot \frac{N_i - B_i}{\Delta_i(\epsilon \times A)_i}$$

- ✦ Background estimated with a two-component fit method.





- ✦ The background of HF electrons are under control.
- ✦ With 100 pb-1 of integrated luminosity, it can constrain different PDF models.

Summary

- LHC will start beam injection again at the end of this year and will open up a new energy regime.
- CMS is getting ready to collect LHC data.

- There is a very rich electro-weak physics program at CMS.
- With as little as 10 pb^{-1} of integrated luminosity, we will measure the W/Z cross sections with high precision.
  - Establish standard candles for new physics searches
  - Potentially be used for luminosity monitoring
- With about 100 pb^{-1} of integrated luminosity, we will be able to provide insights into the PDFs at LHC,
  - Muon charge asymmetry
  - Z rapidity shape

- There are many other very interesting electro-weak physics aspects using W/Zs, such as W mass/width, Z forward-backward asymmetry.

Back-up Slides

ATLAS/CMS Detector Performance

Magnetic Field		2.4 T Solenoid + 4T Toroid	4 T Solenoid
Inner Tracker	$\sigma(p_T)/p_T$ (100 GeV)	3.8%	1.5%
	$\lvert\eta\rvert$ coverage	2.5	2.5
EM Calorimeter	$\sigma(E)/E$	10%/√E+0.007	2-5%/√E+0.005
	$\lvert\eta\rvert$ coverage	3.2	3.0
HAD Calorimeter	$\sigma(E)/E$	50%/√E+0.03	100%/√E+0.05
	$\lvert\eta\rvert$ coverage	4.9	5.2
Muon Performance	$\sigma(p_T)/p_T$ (1 TeV)	7%	5%
	$\lvert\eta\rvert$ coverage	2.7	2.4

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