Constraints to PDFs with Inclusive W/Z Production at CMS

Ping Tan

Fermi National Accelerator Laboratory

PDF4LHC Workshop, Aug 6, 2009

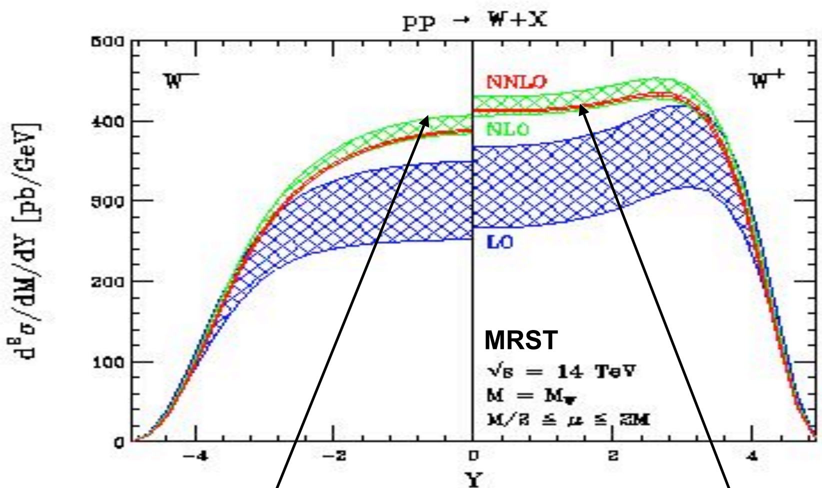
Outline

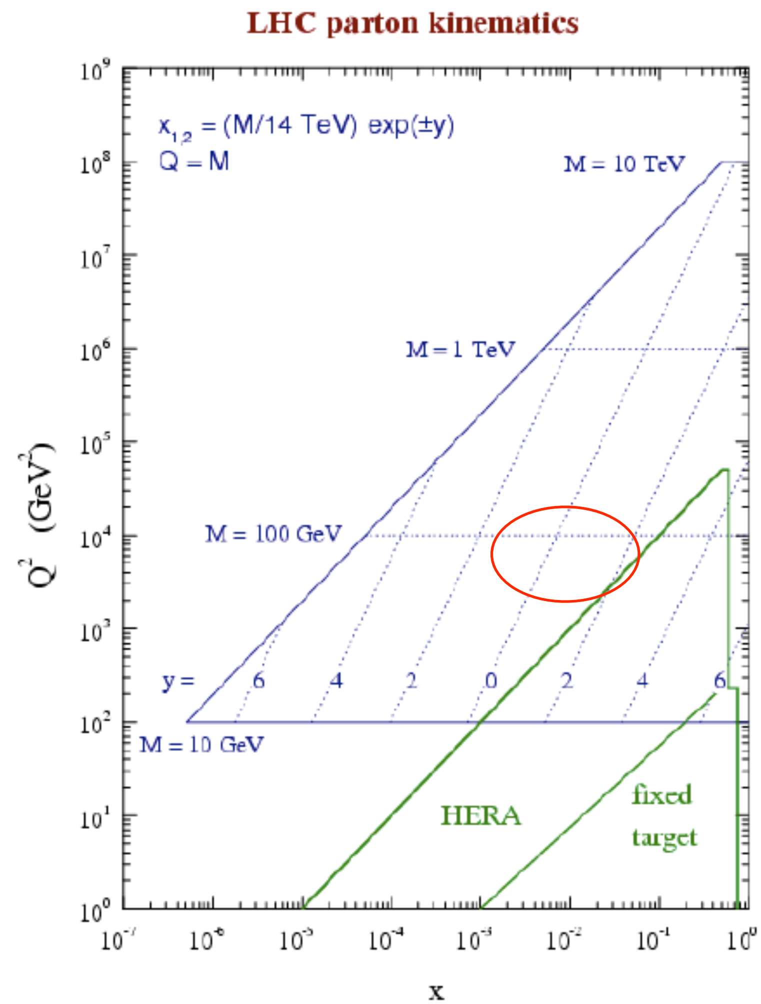
- ✦ Physics motivation
- ✦ Measurement of the Muon Differential Cross Sections and Charge Asymmetry in W(μν)
- ✦ Z boson rapidity shape
- ✦ Summary & Outlook

Probing the PDFs at LHC

$$\frac{d\,\sigma}{d\ \mathrm{variable}}[\mathrm{pp} \to \mathrm{X}] \sim \sum_{\mathrm{ij}} \left(\mathrm{f}_{\mathrm{i/p}}(\mathrm{x}_1)\mathrm{f}_{\mathrm{j/p}}(\mathrm{x}_2) + (\mathrm{i} \leftrightarrow \mathrm{j})\right)\ \hat{\sigma}$$

- W/Z cross sections at LHC are at 10s-100s nb.
- LHC offers unique opportunity to probe Parton Distribution Functions (PDFs), kinematics, sea quarks, etc. $x \in 10^{-2} \sim 10^{-3}$ (central W/Zs)
- Test higher-order theoretical calculations with W/Z rapidity distributions.





Lepton Charge Asymmetry

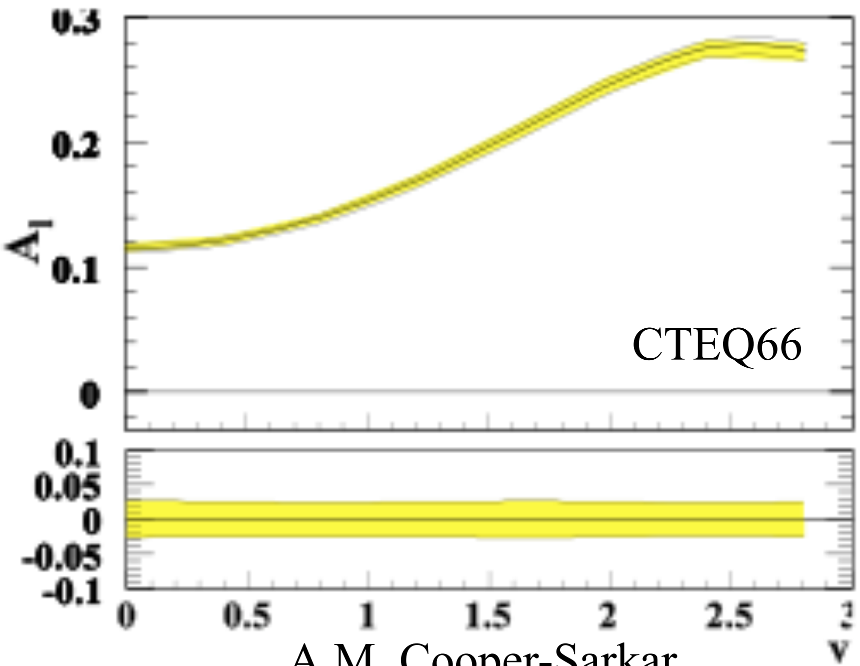
- W boson production can directly probe valence-sea quark ratio at LHC.

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

- However, only the leptons can be accessible directly: ~3.5% precision theoretically (CTEQ66).

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

- W V-A asymmetry dilutes the expected W asymmetry.
- Acceptance can differ from unity by about 10% when experimental cuts on lepton p^T or MET are applied.



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

Trigger & Event Selections

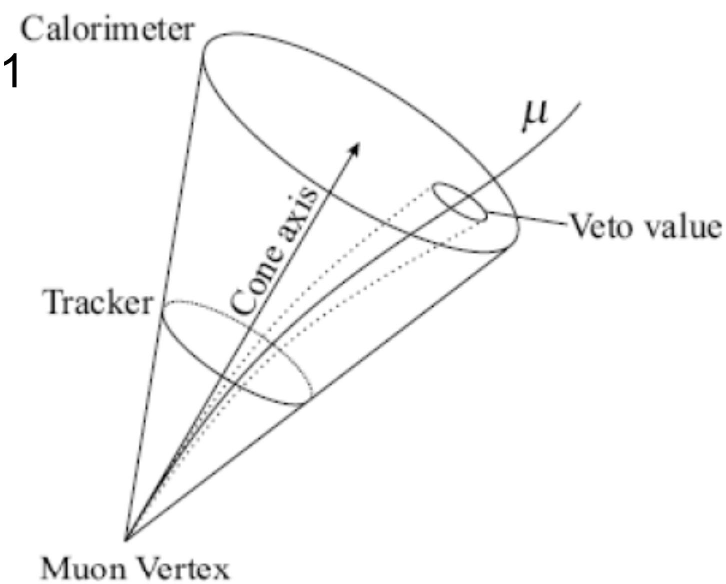
- A single muon trigger with p_T > 15 GeV.
- Exactly one muon candidate within full coverage ($|\eta|<2.4$) per event with
  - Associated silicon track hits >=12
  - Silicon track normalized $\chi^2 < 5$
  - Muon p_T > 10 GeV.

Veto Drell-Yan events!

- Match muon candidate with trigger object, $|\eta| < 2.1$
- Muon p_T + Iso > 25 GeV, $Iso = \sum E_T$
- Isolation z < 0.05 (reduce QCD background)

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

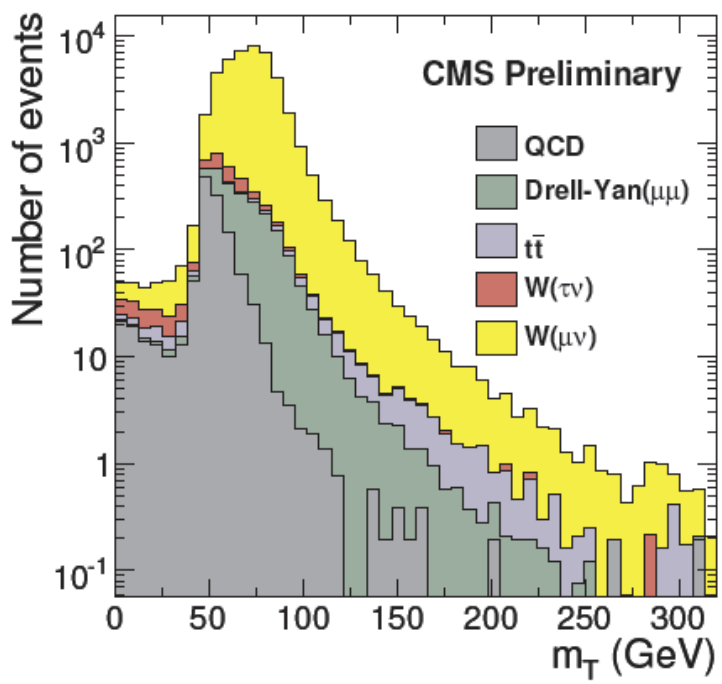
- MET > 20 GeV



Signal efficiency is 53.4% (μ^+) and 60.6%(μ^-) (normalized to generated signal events with $|\eta|<2.1$)

Expected Signal Yields

MC Type	Luminosity (pb^{-1})	$W^+ \to \mu^+\nu$		$W^- \to \mu^-\nu$	
		Events/pb	Relative frac. (%)	Events/pb	Relative frac. (%)
$W \to \mu\nu$	133.1	2294.3±4.2	91.9±0.2	1623.2±3.5	89.8±0.2
$W \to \tau\nu$	91.8	43.1±0.7	1.70±0.03	32.9±0.6	1.80±0.03
$t\bar{t}$	75.4	9.9±0.4	0.40±0.02	10.1±0.4	0.61±0.02
Drell-Yan	666.8	89.4±0.4	3.60±0.02	81.6±0.4	4.50±0.02
QCD	51.6	60±1.0	2.40±0.04	60±1.0	3.30±0.06



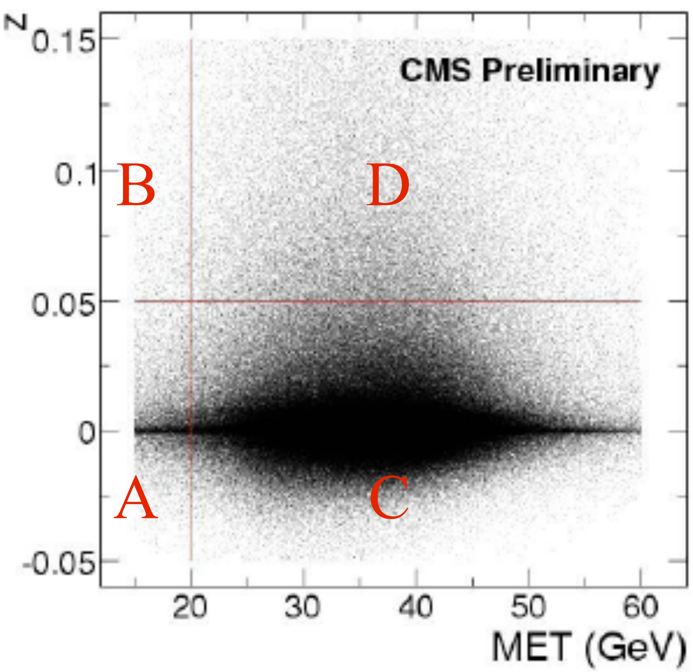
- Drell-Yan background dominates (~4%).
- QCD dijet background is at 2-3% level, large uncertainty in MC predictions.
- Overall S/B ~ 10. (Using LO cross sections)

$$m_T = \sqrt{2 \cdot p_T \cdot MET \cdot (1 - cos(\Delta\phi))}.$$

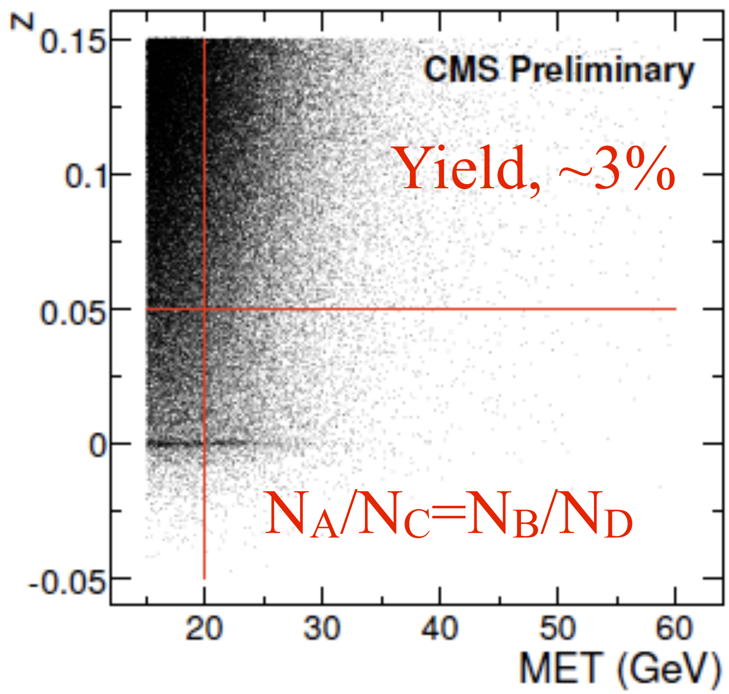
QCD Background Subtraction

- ✦ Relying on MC to estimate electro-weak background (Drell-Yan, W(τν), ttbar). (NLO, NNLO effects)
- ✦ Data-driven method to subtract the rest of the QCD background (reduce systematic error).

W(μν)



QCD

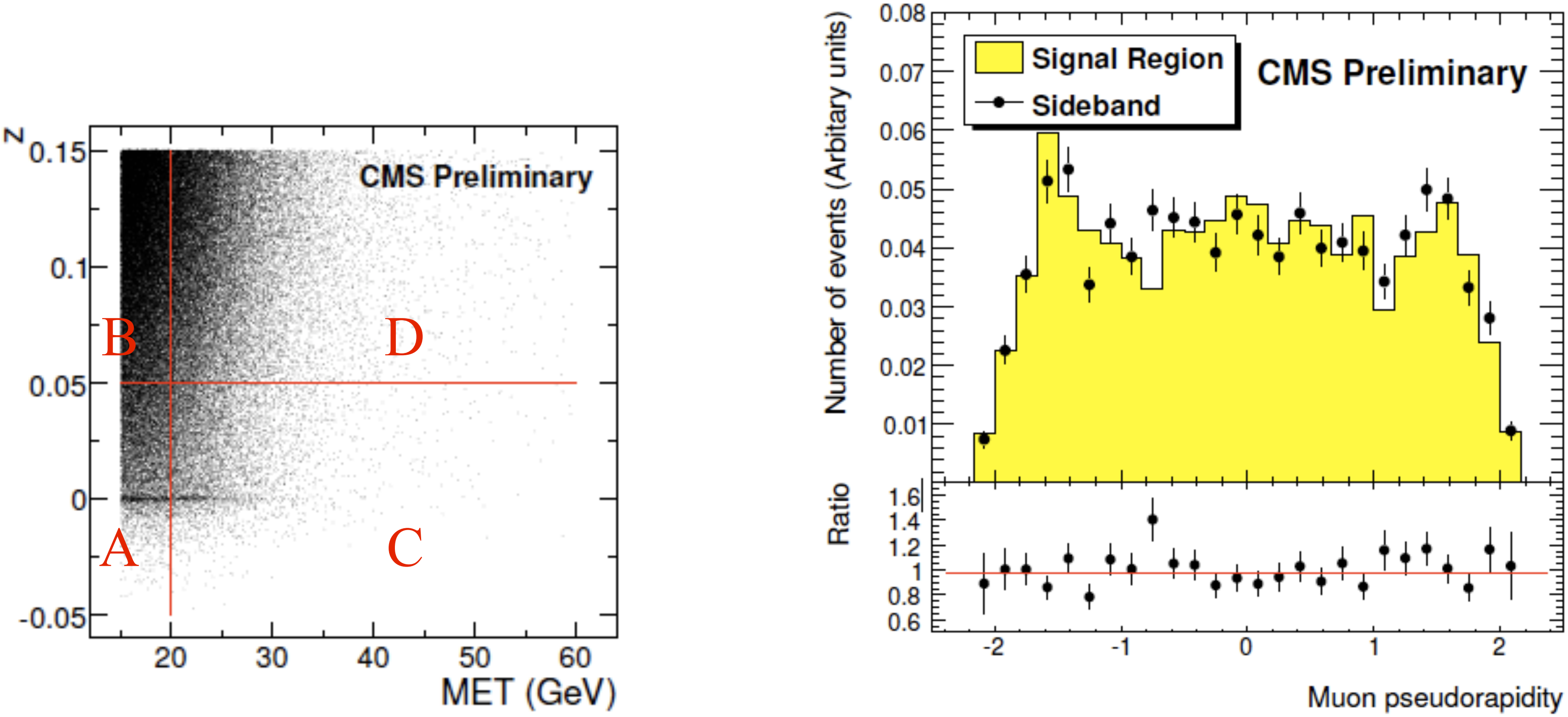


$$z = 1 - \frac{p_T}{p_T + Iso}.$$

~1% systematic uncertainty on signal yield (3% QCD background)

Rapidity Shape of QCD Background

- Use sideband (A) to predict rapidity distribution of QCD background in signal region (C).
- Checked over MC: agreement is within sample statistics.



Differential Cross Sections

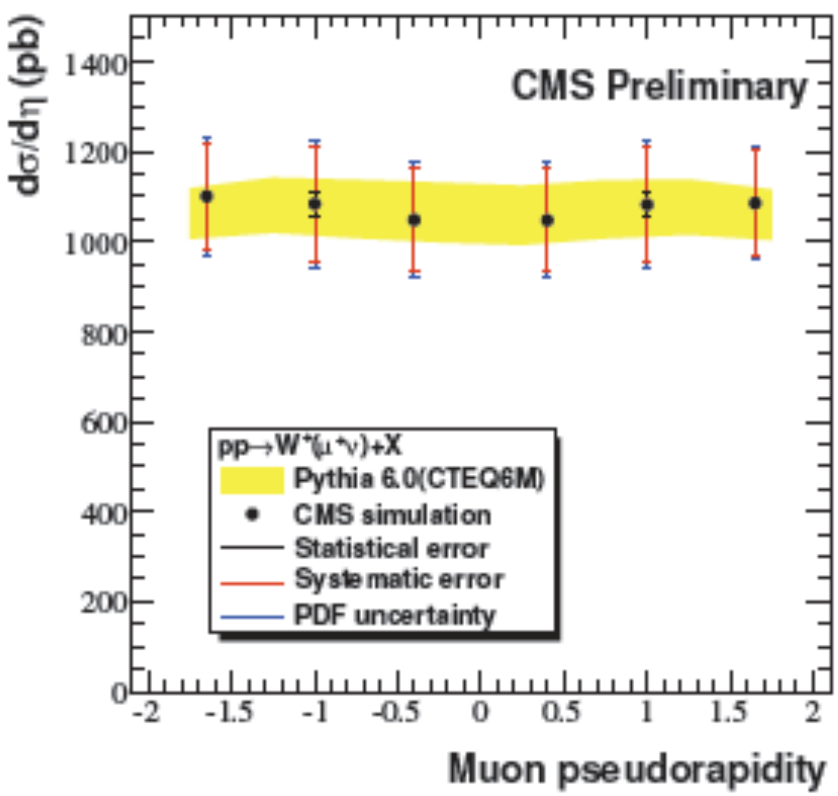
- Related cross sections to observed number of events

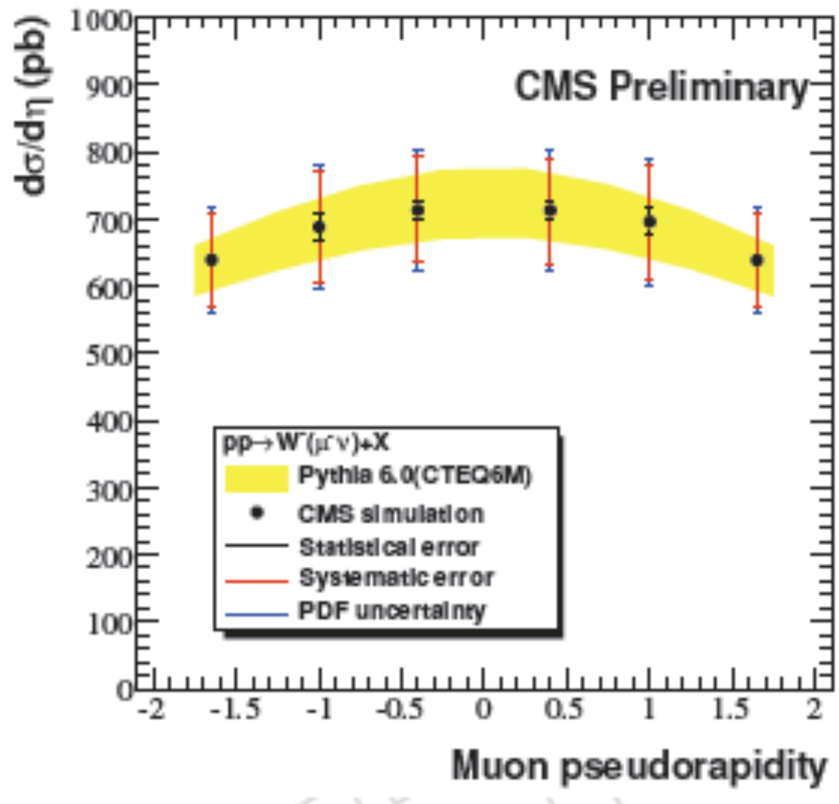
$$\frac{dN}{d\eta} = \mathcal{L} \cdot \frac{d\sigma}{d\eta} \cdot \epsilon_{HLT} \cdot \epsilon_{offline} \cdot \epsilon_{acceptance} \cdot$$

- Expected Systematic errors, 12-13%. (very conservative)
  - Estimated acceptance with CTEQ6M, 4-5%.
  - Efficiency correction, 4-5%. (Assuming efficiencies determined with 10 pb^{-1} of Drell Yan dimuon events).
  - Background subtraction and estimation, 1-2%.
  - Expected luminosity error, 10%.
  - Others, ...

Muon Differential Cross Section at 10 pb^{-1}

- Even at 10 pb-1 of integrated luminosity, results are dominated by systematic errors. (MC generated with CTEQ6L)
- Can reduce luminosity error if comparing shape to higher-order calculation.





Charge Asymmetry at 100 pb^{-1}

- Theoretically preferred charge asymmetry,

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

- Relate experimental observable, number of events, to above asymmetry: experimental inefficiencies, acceptances, etc.

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

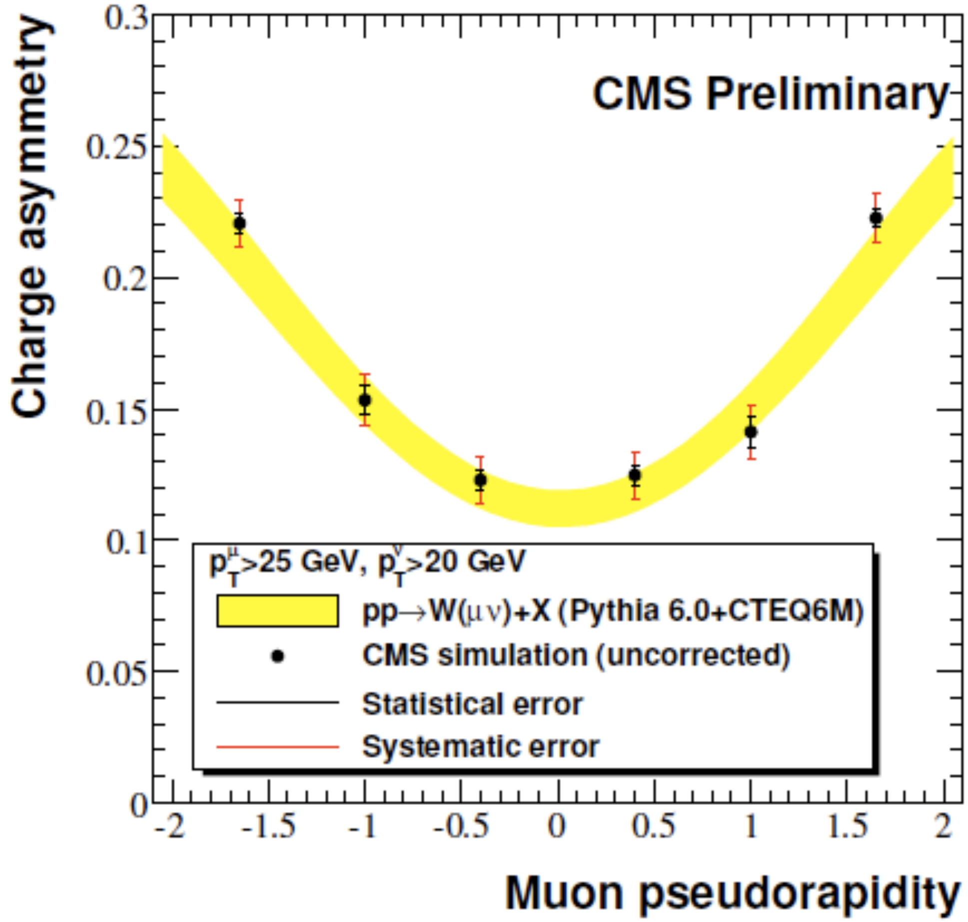
- Symmetric detector: trigger/offline efficiency ratios are 1. Acceptance differs from unit.

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

Experimental observable | Theoretical prediction

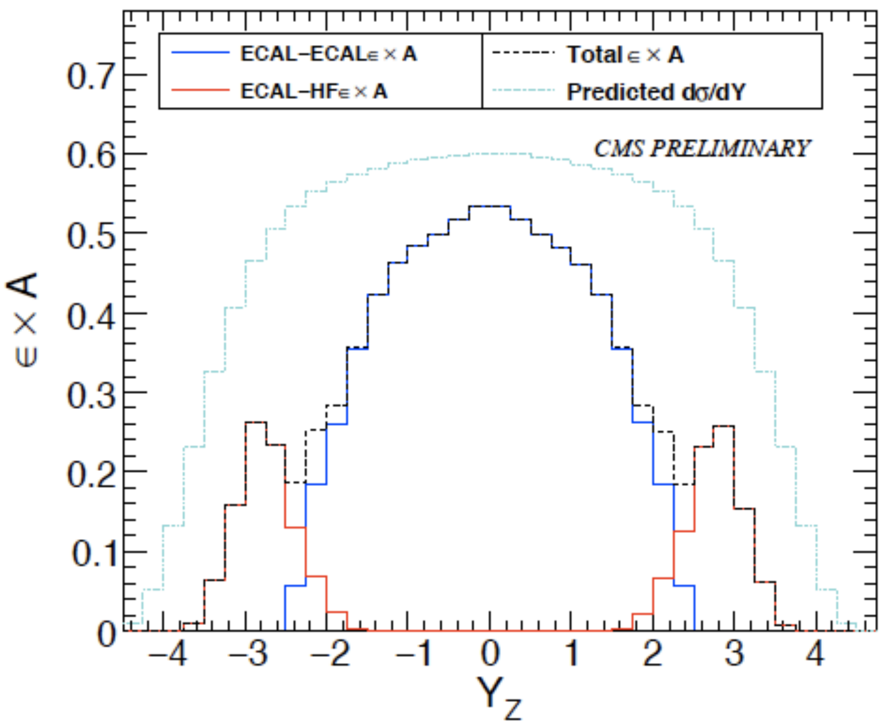
Charge Asymmetry at 100 pb^{-1}(I)

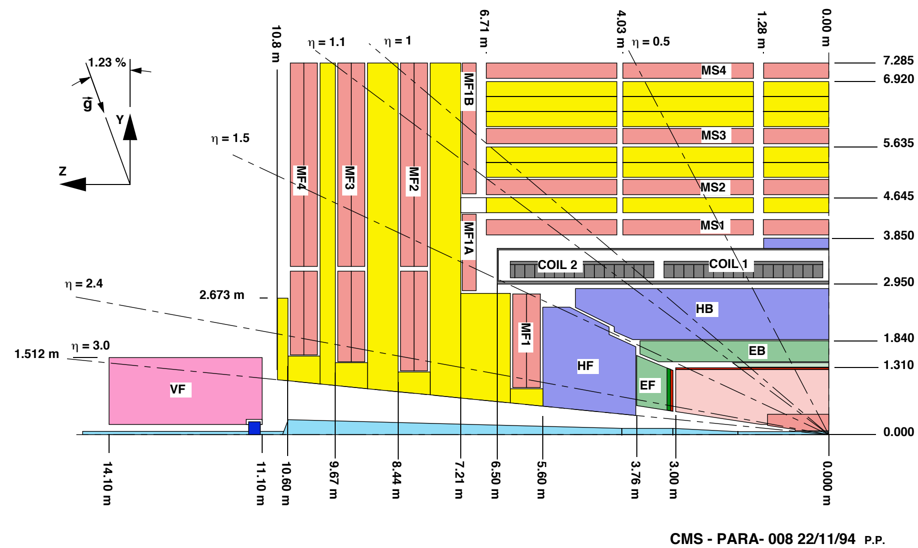
- Statistical errors: 0.004-006.
- Systematic error is dominated by the error on the offline and trigger efficiency ratio between μ^+ and μ^-.
  (assumed to be determined at 1.3% level with 100 pb^{-1} of integrated luminosity)
- Could provide constraints to different PDF models.
- Some minor experimental & theoretical systematic errors are not included, muon p_T resolution, MET resolution, etc.



Z(ee) Rapidity Shape

- ✦ Single isolated electron trigger (E_T>15 GeV).
- ✦ Very little background: W/Z+jets, dijets, photon+jets, etc.
- ✦ Very unique technique: electron reconstruction with the CMS Forward Hadron(HF) detector, longitudinal shower information..



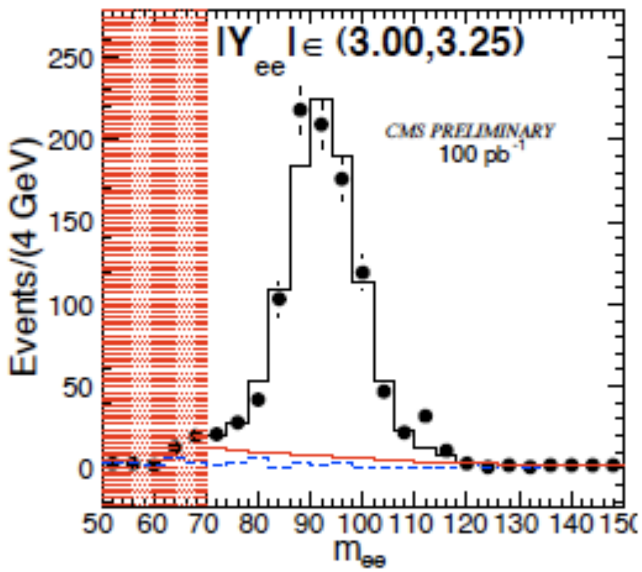


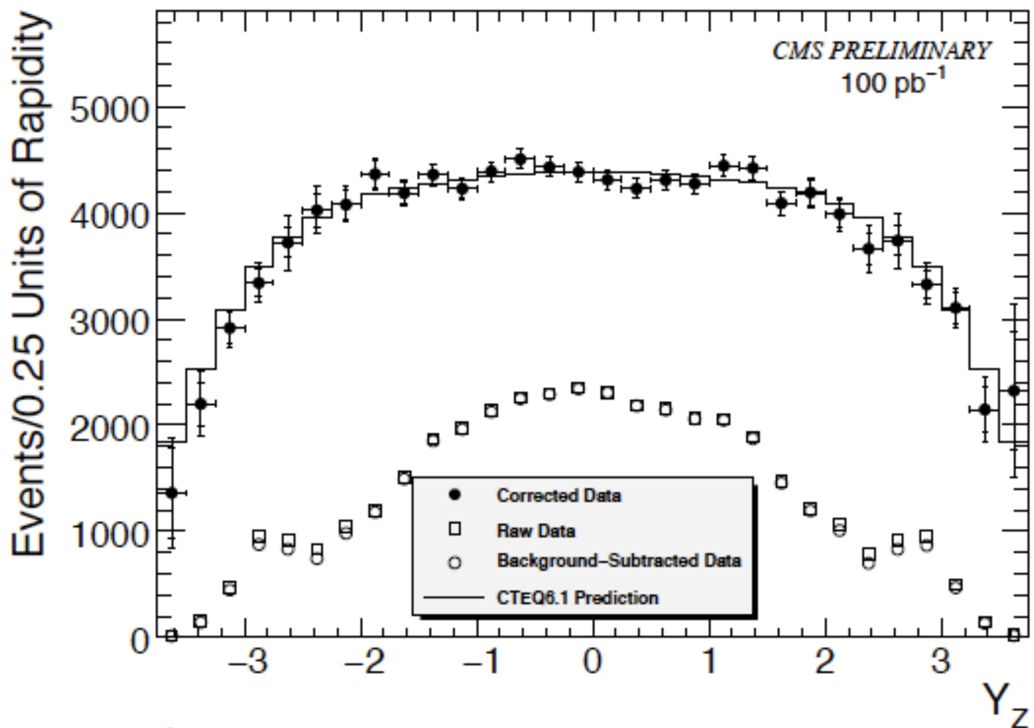
Largely extend the acceptance (rapidity from ~2.5 to ~4.0) →lower x in parton kinematics!

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

- Estimate the expected sensitivities in W(μν) differential cross section and charge asymmetry with early CMS data.
- Differential cross sections will be limited by systematic errors even with 10 pb^{-1} of integrate luminosity.
- Muon charge asymmetry could provide constraints to PDF models with 100 pb^{-1} of integrated luminosity if systematic errors are under control.
- With 100 pb^{-1} of integrated luminosity, Z rapidity shape can provide constraints to PDFs.

Back-up Slides