Analysis of $Z \rightarrow l^+l^-$ Polarization at CMS

Nhan Tran

Johns Hopkins University

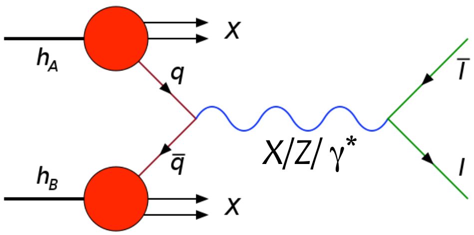
on behalf of the CMS Collaboration

Young Scientist Forum

Rencontres de Moriond, EW

March 15, 2011

Motivation and Methodology



- The process $q\bar{q} \to X \to l^+l^-$ rich with possible beyond the SM physics scenarios: extra-dimensions, new gauge bosons, etc.
- SM $q\bar{q} \to Z/\gamma^* \to l^+l^-$ provides valuable testing ground
- Consider the Drell-Yan differential cross-section:

$$d\sigma/(ds \cdot d\cos\theta \cdot dY)$$

  - $d\cos\theta$: sensitive to $Z \to f\bar{f}$ couplings and weak mixing angle, $\sin^2\theta_W$
  - Relative contributions of Z/γ^* in mass dependence
- Perform a multivariate analysis to increase sensitivity

By studying the differential cross-section of the DY process, we can make precision measurements of SM parameters; deviations may come from new physics in $X/Z/\gamma^*$.

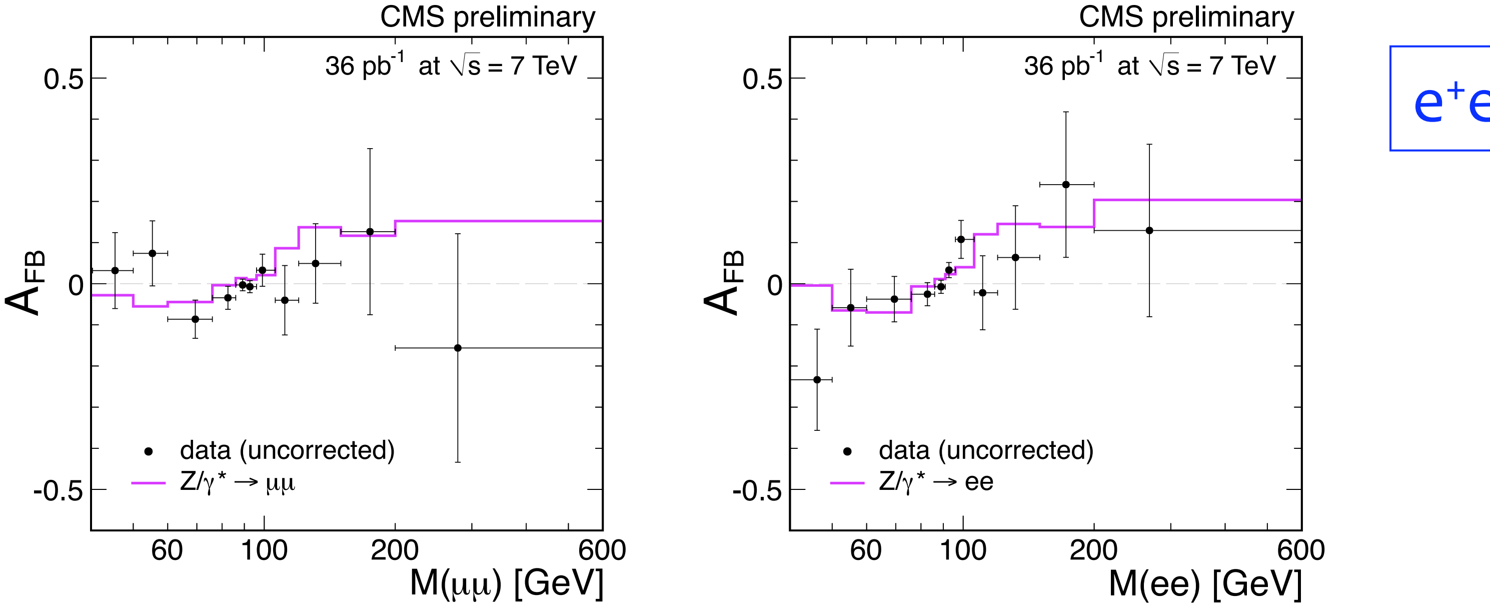
Forward-backward asymmetry

- Forward-backward asymmetry, A_{FB}: simple analysis of Drell-Yan angular distribution with 36 pb^{-1}
  - Sensitive to broad high-mass resonance; slope sensitive to couplings
- Idea: measure cosθ asymmetry in bins of mass:

$$A_{FB} = (N_F - N_B)/(N_F + N_B)$$

- A_{FB} in good agreement with the Powheg and CMS simulation

$\mu^+\mu^-$



e^+e^-

Methodology

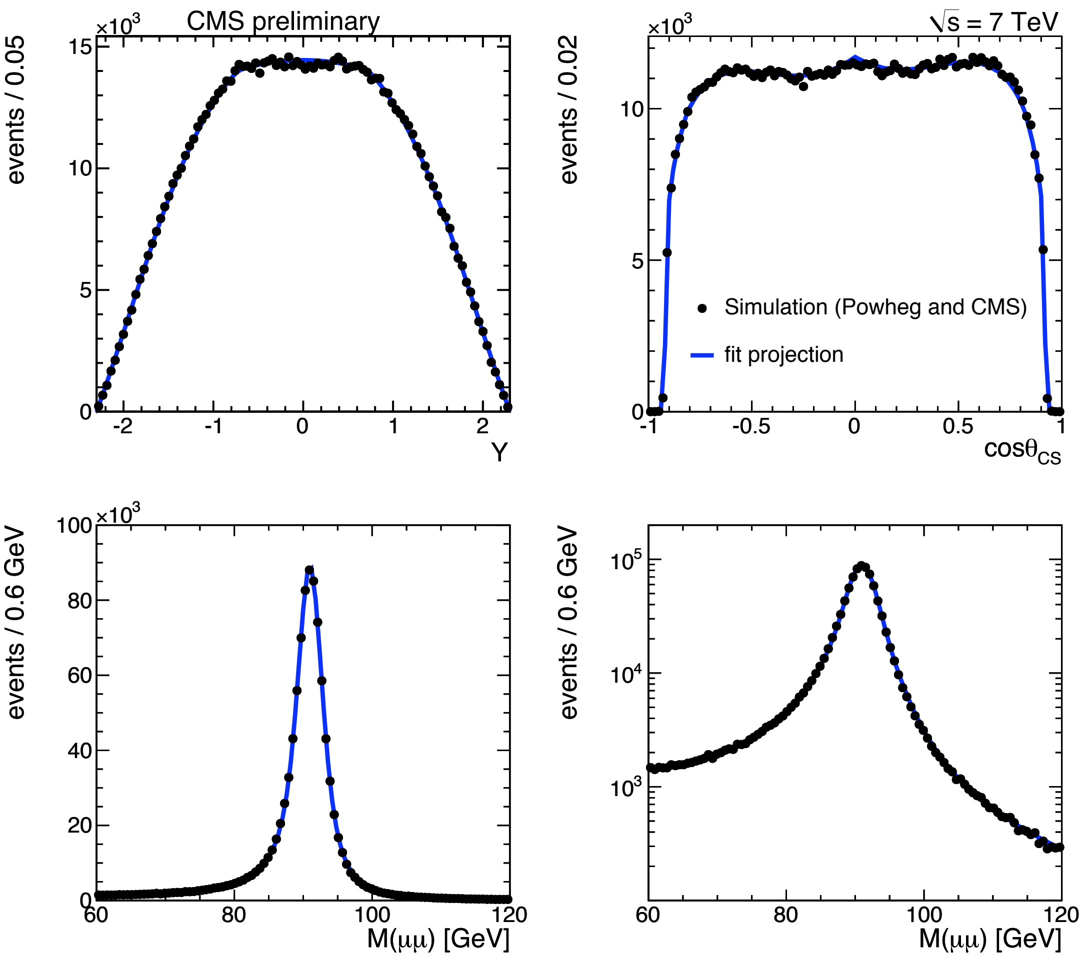
- Idea: per event multivariate likelihood function to extract maximal information from the event
  - requires contributions from signal and background model probability distribution functions
- Prob. dist. func. in observables of mass, angle, rapidity:

$$\mathcal{P}_{sig}(m,Y,\cos\theta;\sin^2\theta_W) = [\mathcal{P}_{ideal}(m,Y,\cos\theta) \otimes \mathcal{R}(m)] \times \mathcal{G}_{acc}(m,Y,\cos\theta)$$

  - Y-dependence includes description of q-$\bar{q}$ direction ambiguity
  - accounts for detector acceptance and efficiency
  - convolution to account for resolution and FSR
- Assume the SM and PDFs well-established, perform a single parameter likelihood fit for $\sin^2\theta_W$
- Information about $\sin^2\theta_W$ contained in the shape of the multivariate distribution

Likelihood model with simulation

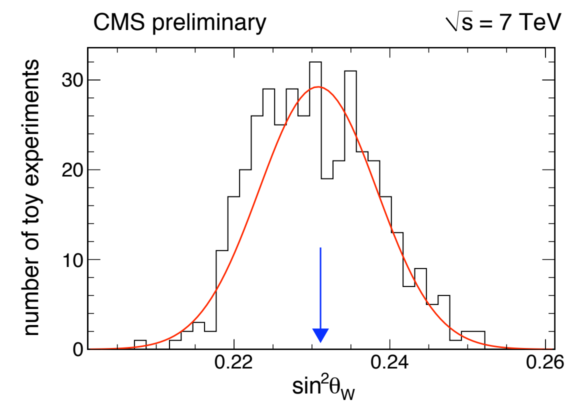
Final likelihood model fit on Powheg and CMS simulation



Result of 400 toy experiments including sig + bkg yields:

$\sin^2\theta_W = 0.2306 \pm 0.0004$

(generated value: 0.2311)



Statistical error:

per toy experiment = 0.0078 ± 0.0003

from data = 0.0077

Goodness-of-fit test:

Ratio of $(-\log \mathscr{L})$ in MC and data is

0.9997 ± 0.0029

Systematic uncertainties

Dominant systematics from FSR and resolution/alignment

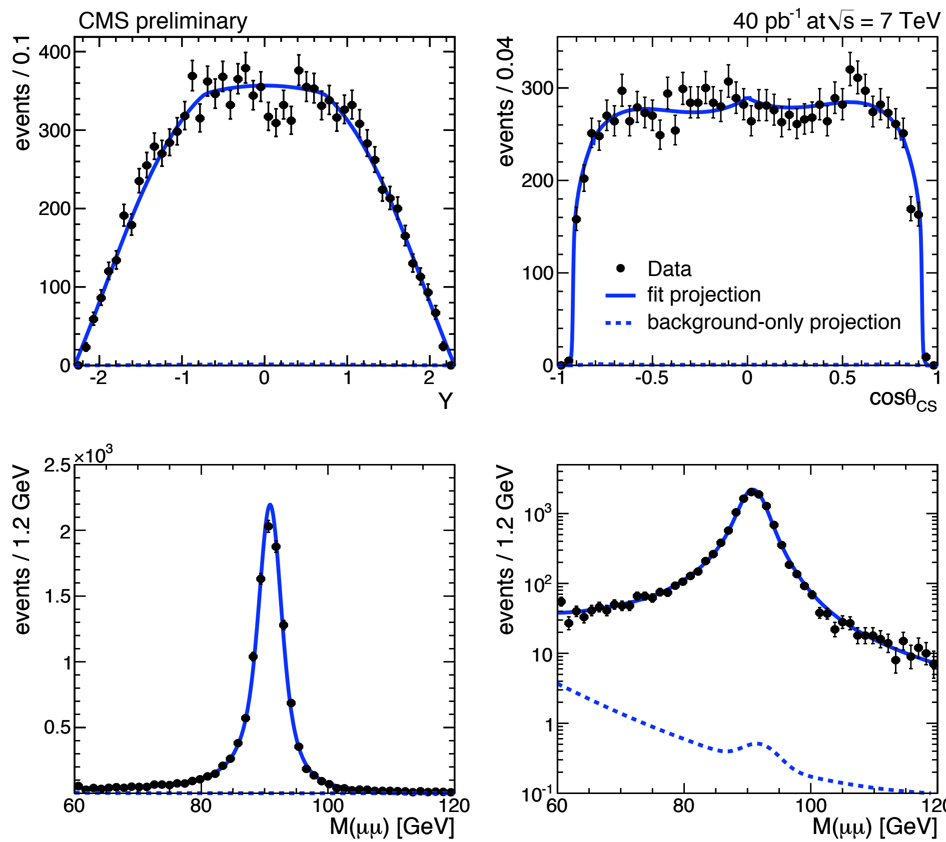
Conservative estimates, some cases statistics limited

source	uncertainty
LO model (ISR)	0.0011
PDFs	0.0015
FSR	0.0018
resolution/alignment	0.0022
fit model	0.0010
background	0.0007
total	0.0036

Total systematic error less than expected statistical error

Results with 40 pb^{-1} of data

Data fit central value kept blind to avoid analysis bias



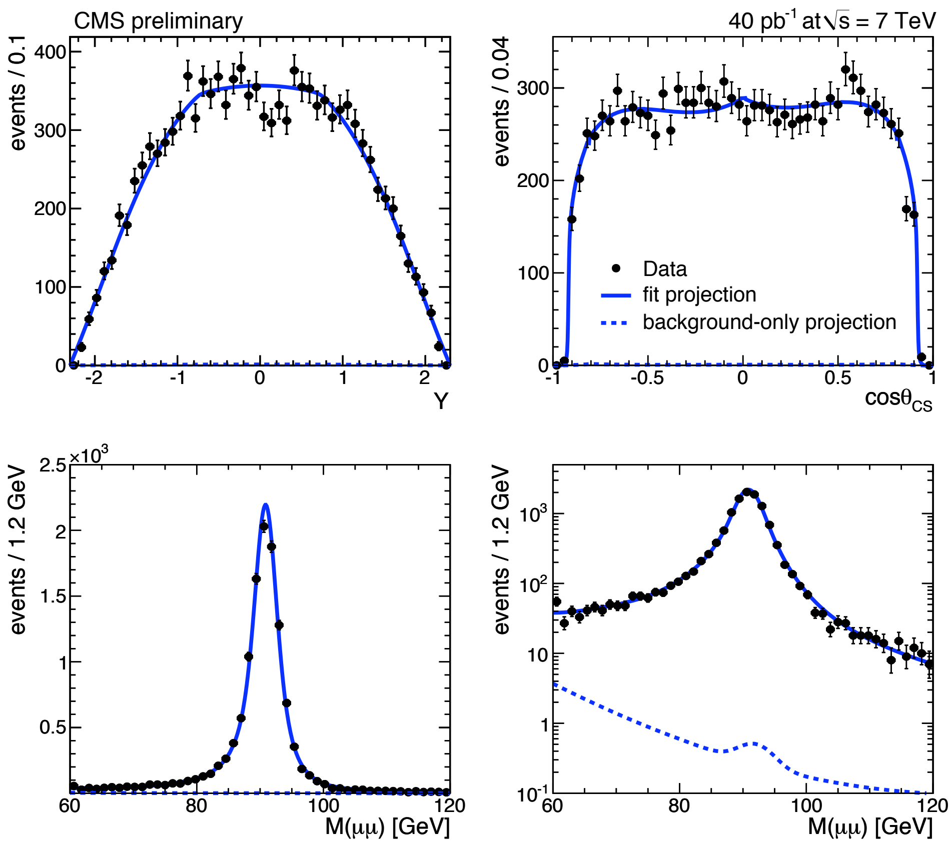
Fit result: $\sin^2\theta_W$ = X.XXXX ± 0.0077 (stat.) ± 0.0036 (sys.)

PDG value: 0.2312

Final cross-check: goodness-of-fit test yields good agreement with MC

Results with 40 pb^{-1} of data

Data fit central value kept blind to avoid analysis bias



Fit result: $\sin^2\theta_W = 0.2287 \pm 0.0077\,(\text{stat.}) \pm 0.0036\,(\text{sys.})$

PDG value: 0.2312

Final cross-check: goodness-of-fit test yields good agreement with MC

Conclusions and Outlook

- We perform angular analysis of $Z \rightarrow l^+l^-$
- The forward-backward asymmetry is measured with 36 pb^{-1} in good agreement with the SM
- A new technique is presented to measure $\sin^2\theta_W$ and a first measurement is made in the $Z \rightarrow \mu^+\mu^-$ channel with 40 pb^{-1}

Fit result: $\sin^2\theta_W = 0.2287 \pm 0.0077$ (stat.) ± 0.0036 (sys.)

- With 2011 statistics and combination with $Z \rightarrow e^+e^-$, a competitive measurement of the Weinberg weak mixing angle can be established in the channel $u\bar{u}$ or $d\bar{d} \rightarrow Z \rightarrow l^+l^-$

Backup

Event selection and background

- Lepton selection
  - isolation and other quality requirements
  - muon selection, A_{FB}
    - $p_T > 20$ GeV and $|\eta| < 2.1$
  - muon selection, likelihood analysis
    - $p_T > 18,7$ GeV; $|\eta| < 2.4$; $p_T(CS) > 18$ GeV; $|\eta|(CS) < 2.3$; $p_T(Z) < 25$ GeV
  - electron selection, A_{FB}
    - ET > 20 GeV (with energy scale corrections); $|\eta| < 2.5$ (excluding $1.4442 < |\eta| < 1.560$)
- Backgrounds
  - leading contributions from $\tau^+\tau^-$, QCD, $t\bar{t}$ with smaller contributions from WW, WZ, W inclusive, ZZ
  - total background per channel < 1%

Likelihood technique vs. counting analysis

- What is the statistical improvement of likelihood method over traditional "template" method?
  - "Template" method: generate templates of AFB for many values of $\sin^2\theta_W$, extract most probable value
- Feasibility test: run toy experiments comparing methods under equivalent conditions with Powheg simulation and CMS "fast resolution smear"
- Expected statistical error from $40pb^{-1}$ sample:
  - Template method: $\sigma(\sin^2\theta_W) = 0.0113$
  - Likelihood method: $\sigma(\sin^2\theta_W) = 0.0080$
- Likelihood technique a factor of 1.4 improvement over template method; equivalent to doubling the statistics!

Acceptance and efficiency model

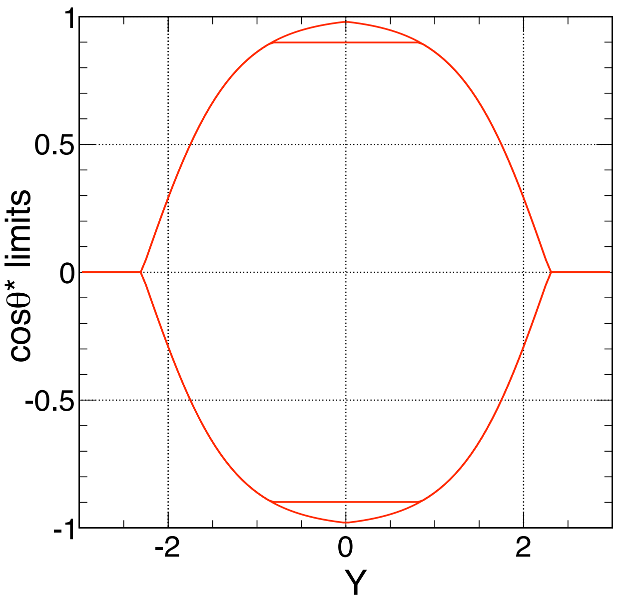
$\mathcal{G}_{acc}(m, Y, \cos\theta)$ further sculpts the cosθ and Y distributions

Lepton cuts: $|\eta| < Y_{max}$; $p_T > p_{T,min}$

Acceptance conditions:

$|\cos\theta| < \tanh(Y_{max} - |Y|)$; $|\cos\theta| < [1-(2p_{T,min}/m)^2]^{1/2}$

2D acceptance function



2D efficiency function