Studies of $Z/\gamma^\star$ differential cross sections in $p\bar{p}$ collisions with the DØ detector

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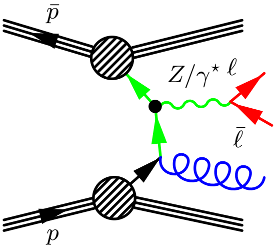
Outline

1. Introduction to the measurements and to the DØ detector
2. Measurement of the Forward-Backward Asymmetry
3. Determination of $\sin^2\theta_W$
4. Determination of the light quark couplings
5. Definition of $\phi^\star_\eta$
6. Measurement of $1/\sigma \; d\sigma/d\phi^\star_\eta$
7. Comparison to theoretical prediction

PART 1 (items 2–4)

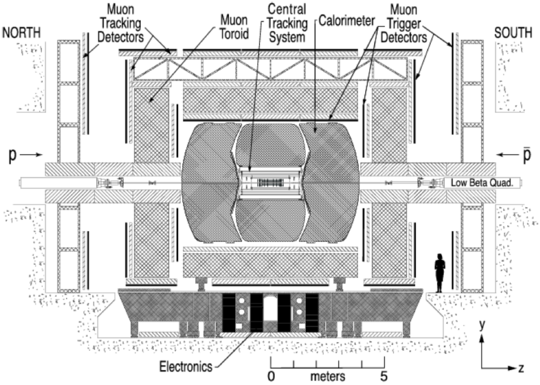
PART 2 (items 5–7)



One of the most studied processes in collider experiments.
Can we still learn something new?

1. Precision EW measurements
   - Study the angular distribution of the decay products as a function of their invariant mass
   - Extract $\sin^2\theta_W$ and Z-light quark couplings
2. Colorless final state is a clean probe for QCD physics in the initial state
   - Study the Q_T^Z distribution at low momenta
   - Compare to predictions from resummed calculation and non-perturbative models

The DØ detector

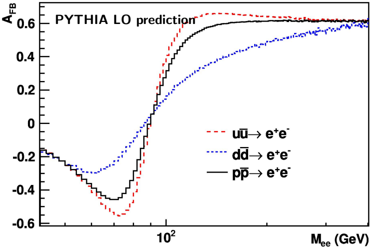


- Central Tracker
  - Silicon Microstrip Detector
  - Central Fiber Tracker
  - $2T$ Solenoid
- Calorimeter
  - Central Calorimeter: $|\eta| \lesssim 1.1$
  - End-Caps: $1.0 \lesssim |\eta| \lesssim 4.0$
- Muon detectors
  - Central Muon Detector: $|\eta| \lesssim 1.0$
  - Forward Muon Detector: $1.0 \lesssim |\eta| \lesssim 2.0$
  - $1.8T$ Toroid

PART 1

Measurement of $\sin^2\theta^{\ell}_{eff}$ and Z-light quark couplings using the forward-backward charge asymmetry in $p\bar{p} \to Z/\gamma^\star \to e^+e^-$ events with $\mathcal{L} = 5.0\, fb^{-1}$ at $\sqrt{s} = 1.96\, TeV$

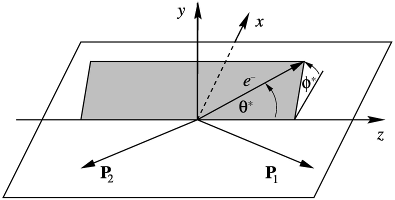
Forward-Backward Asymmetry



$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

$$\sigma_F = \int_0^1 \frac{d\sigma}{d\cos\theta^\star} d(\cos\theta^\star)$$

$$\sigma_B = \int_{-1}^0 \frac{d\sigma}{d\cos\theta^\star} d(\cos\theta^\star)$$



Sensitive to:

- $\sin^2\theta_W$
- Coupling of light quarks to Z

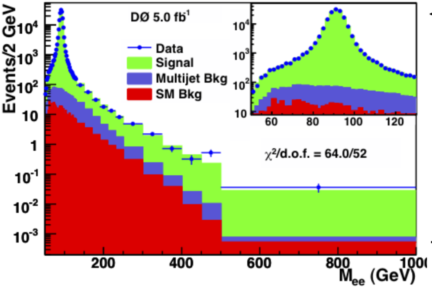
Curious previous EW asymmetry results:

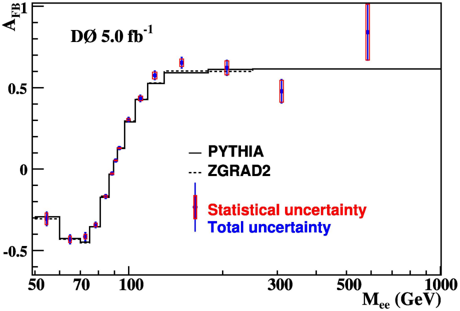
- LEP $A_{FB}^{0,b}$: 2.5σ away from EW fit
- SLD A_ℓ: 2.0σ away from EW fit

[GFitter, arXiv:1107.0975]

Measurement strategy for A_{FB}

- Measure N_F and N_B from e^+e^- events in bins of their invariant mass.
  - $E_T^e > 25\,GeV$, $|\eta^e_{det}| < 1.0$ or $1.5 < |\eta^e_{det}| < 2.5$
- Concentrate in the electron channel due to DØ good acceptance and resolution. $5\,fb^{-1}$ of integrated luminosity analyzed.
- Apply corrections for detector resolution, acceptance, efficiency and charge mis-identification to unfold data and compare to theoretical predictions.

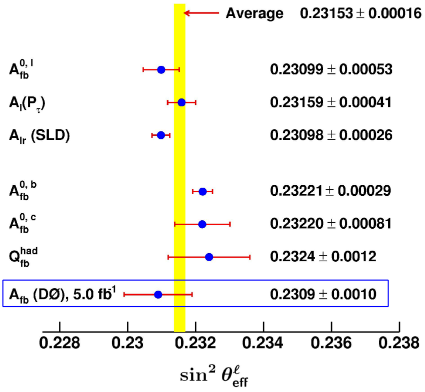




Extraction of $\sin^2\theta_W$

- We extract $\sin^2\theta_W$ from background subtracted raw A_{FB} to avoid introducing uncertainties from the unfolding procedure.
- We compare the data to templates generated with different $\sin^2\theta_W$ and extract the best value and uncertainty minimizing the χ^2.

$$\sin^2\theta^{\ell}_{eff} = 0.2309 \pm 0.0008(\text{stat.}) \pm 0.0006(\text{syst.})$$



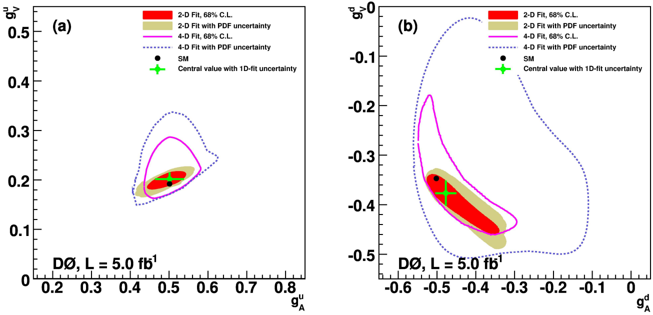
- Dominated by light-quark asymmetry
- All others are either flavor-blind or HQ

Syst. Uncertainties	
PDF	0.00048
EM scale/res	0.00029
MC statistics	0.00020

Extraction of light quark couplings to the Z boson

- Two different strategies:
  - 2-dim template in either (g_A^u, g_V^u) or (g_A^d, g_V^d)
  - 4-dim template in all couplings.
- Due to limited MC statistics with full detector simulation, we use the unfolded A_{FB} distribution.

Z-u quark coupling　　Z-d quark coupling



Results (2D templates)	
g_A^u	0.501 ± 0.061
g_V^u	0.202 ± 0.025
g_A^d	-0.477 ± 0.112
g_V^d	-0.377 ± 0.081

Most precise determination to date!

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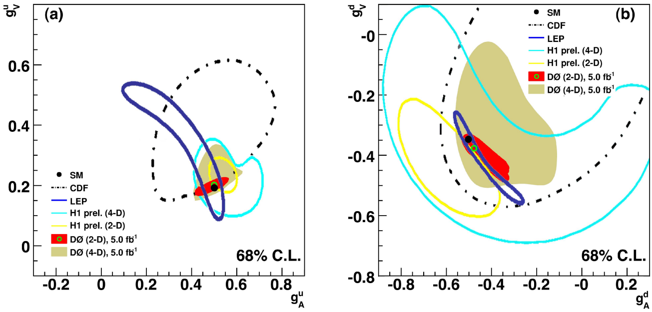

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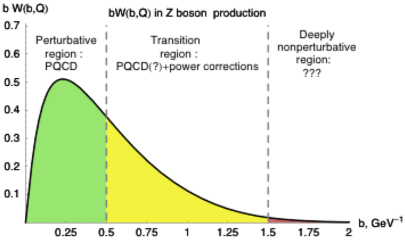
PART 2

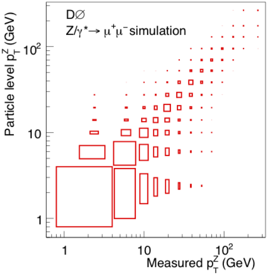
Precise study of the $Z/\gamma^\star$ boson transverse momentum distribution in $p\bar{p}$ collisions using a novel technique

- The distribution at low Q_T can be described by soft gluon resummed calculations with parameterizations of NP phenomena.
  - BNLY (Brock, Landry, Nadolsky, Yuan) parameterization
  - Small-x broadening *Berge et al, hep-ph/0410375*

$$W(b, Q, x_a, x_b) \simeq W_{LP}(b, Q, x_a, x_b) e^{-\mathcal{S}(Q, x_a, x_b) b^2}$$

$$\mathcal{S}^{\text{BNLY}}(Q, x_a x_b) = g_1 + g_2 \ln \frac{Q}{3.2} - g_3 \ln(100 x_a x_b)$$

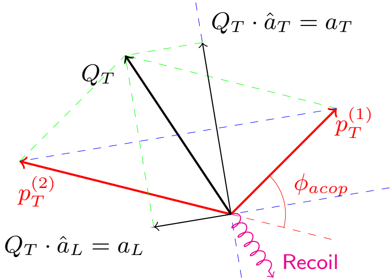




- However, it is difficult to measure directly the boson Q_T as such low scale due to resolution effects.
- The unfolding procedure introduces large uncertainties in the low Q_T region.
- In our previous measurement of $1/\sigma \times d\sigma/dQ_T^Z$ with $1\, fb^{-1}(Z \rightarrow \mu^+\mu^-)$, for $Q_T < 4\, GeV$, we obtained $\sigma_{stat} \approx 1\%$ while $\sigma_{syst} \gtrsim 8\%$.
- Is this the end of the road?

A novel variable to study the Q_T^Z distribution

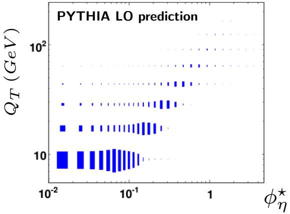
Recently, many new variables that can be measured with better experimental resolution while keeping the sensitivity to the same physics as Q_T^Z have been proposed and studied, both theoretically and experimentally.



$$\phi_\eta^\star = \tan\left(\frac{\phi_{acop}}{2}\right)\sin\left(\theta_\eta^\star\right)$$

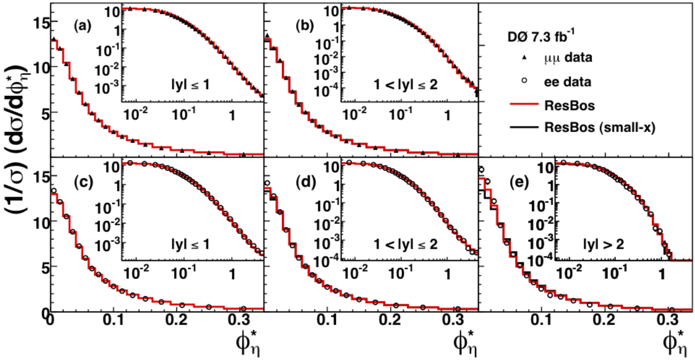
$$\cos\left(\theta_\eta^\star\right) = \tanh\left[(\eta^- - \eta^+)/2\right]$$

- $\phi_\eta^\star$ has been shown to be an optimum variable. It is measured using only the direction of the leptons and thus with greater resolution.
- $\phi_\eta^\star \simeq a_T/M_{\ell\ell}$ and tends to $Q_T/M_{\ell\ell}$ at large Q_T.

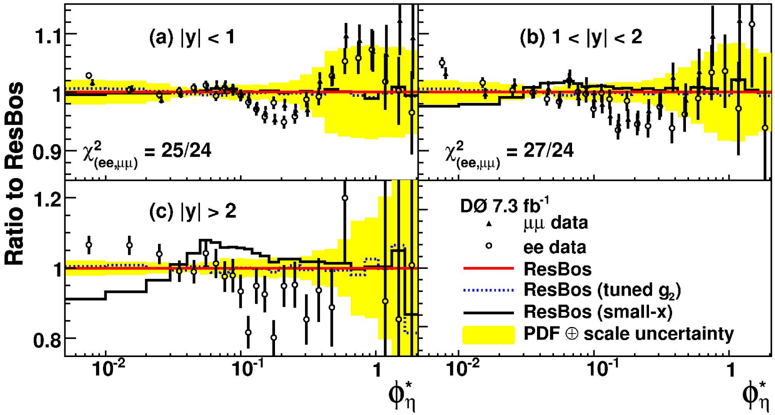


Measurement strategy for $1/\sigma \times d\sigma/d\phi^{\star}_{\eta}$

- Select $e^{+}e^{-}$ and $\mu^{+}\mu^{-}$ final states. $7.3\, fb^{-1}$ in this analysis
  - $E^{e}_{T} > 20\, GeV$, $|\eta^{e}_{det}| < 1.1$ or $1.5 < |\eta^{e}_{det}| < 3.0$
  - Isolated muon with $p^{\mu}_{T} > 15\, GeV$
  - $70 < M_{\ell\ell} < 110\, GeV$
- Unfold to generator-level in three rapidity bins. Since the acceptances and efficiencies are different, we do the unfolding independently for ee and $\mu\mu$.



Comparison to theoretical prediction



BNLY g_2 parameter		
Rapidity range	e^+e^-	$\mu^+\mu^-$
$\lvert y\rvert < 1$	0.644 ± 0.013	0.670 ± 0.012
$1 \leq \lvert y\rvert < 2$	0.619 ± 0.017	0.645 ± 0.019
$\lvert y\rvert \geq 2$	0.550 ± 0.048	-

- Data clearly disfavours small-x broadening.
- For very low $\phi^\star_\eta$, $\sigma_{stat} \simeq 0.5\%$ and $\sigma_{syst} \simeq 0.1\%$

References

Main references:

- Measurement of $sin^2\theta^{\ell}_{eff}$ and Z-light quark couplings using the forward-backward charge asymmetry in $p\bar{p} \rightarrow Z/\gamma^{\star} \rightarrow e^+e^-$ events with $\mathcal{L} = 5.0\, fb^{-1}$ at $\sqrt{s} = 1.96\, TeV$
  arXiv:1104.4590. Phys. Rev. **D84**, 2011
- Precise study of the $Z/\gamma^{\star}$ boson transverse momentum distribution in $p\bar{p}$ collisions using a novel technique
  arXiv:1010.0262. Phys. Rev. Lett. **106**, 2011

Supplementary references:

- Measurement of the Forward-Backward Charge Asymmetry and Extraction of $\sin^2\theta^{eff}_{W}$ in $p\bar{p} \rightarrow Z/\gamma^{\star} + X \rightarrow e^+e^- + X$ Events Produced at $\sqrt{s} = 1.96\, TeV$
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- Measurement of the Normalized $Z/\gamma^{\star} \rightarrow \mu^+\mu^-$ Transverse Momentum Distribution in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96\, TeV$
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  arXiv:0807.4956. Nucl. Instrum. Meth. **A602**, 2009
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