
# *Z* boson production at DØ

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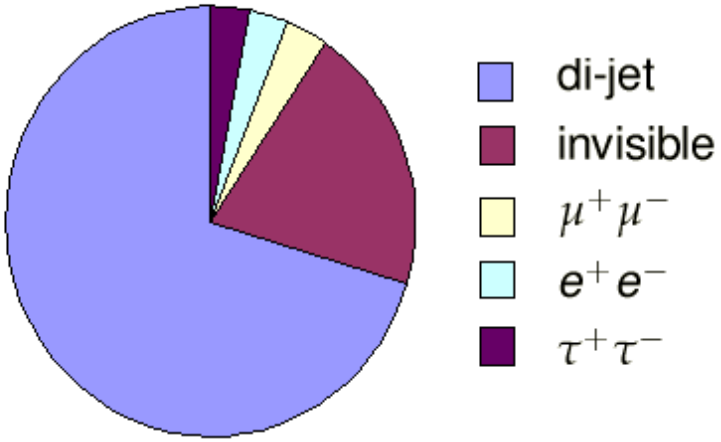
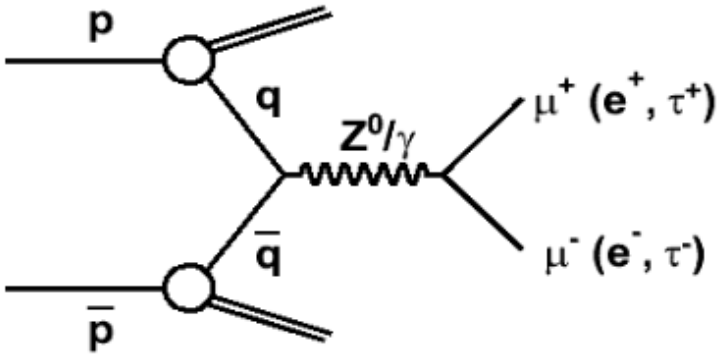
# $Z$ Boson Production at the Tevatron

Branching Fractions of the $Z$ boson




Only di-lepton channels practical




Leading order $q\bar{q} \rightarrow Z \rightarrow \ell\ell$

100,000 $Z \rightarrow e^+e^-(\mu^+\mu^-)$ events per $\mathrm{fb}^{-1}$ with standard cuts

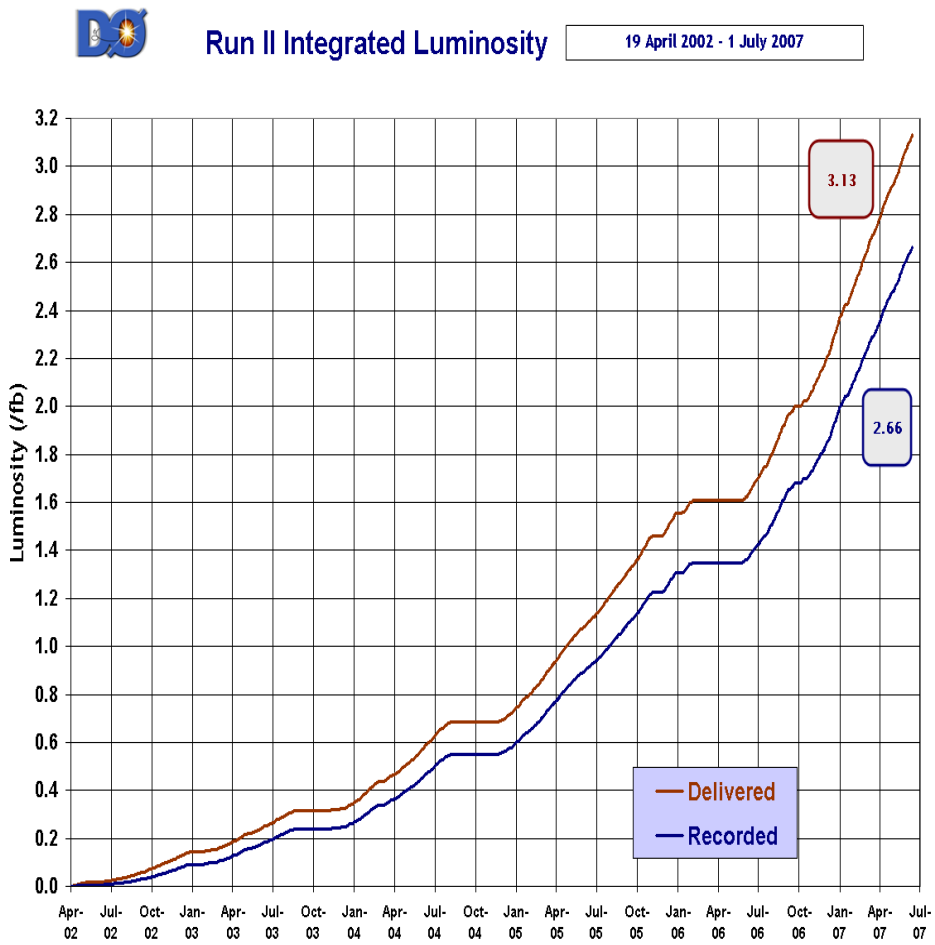
Z bosons analyses can test:

- Parton distribution functions
- QCD at NNLO
- Resummation formalism

## Outline for rest of talk

- Apparatus
- Two Analyses:
  - Rapidity of the Z boson
  - $p_T$ of the Z boson
- Conclusion and Outlook

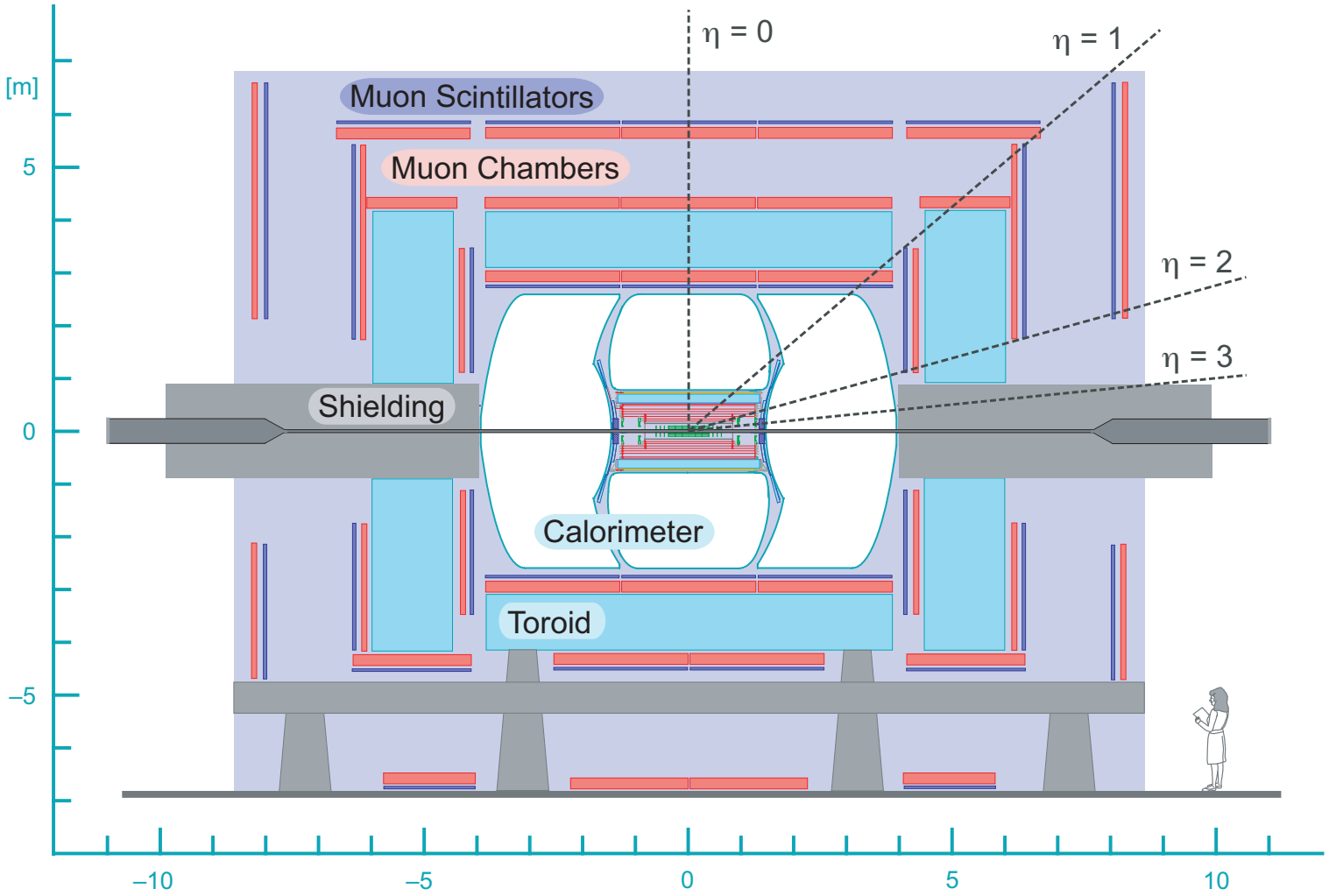
# The Tevatron




- $p\bar{p}$ collider, $\sqrt{s} = 1.96$ TeV
- Highest energy accelerator in the world

- Approximately 3 $\mathrm{fb}^{-1}$ delivered
- Data are still being taken

# The DØ Detector




- Electron coverage for $|\eta| < 1.1$ and $1.5 < |\eta| < 3.2$
- Uniform muon coverage for $|\eta| < 2.0$

# $Z$ Boson Rapidity and Fractional Momentum

The rapidity $y$ of the $Z$ boson is defined as:

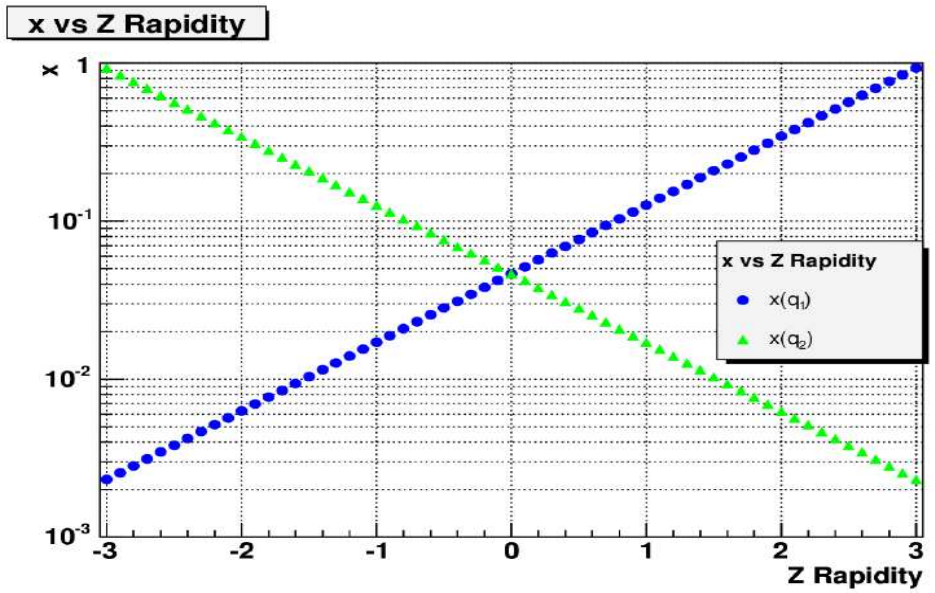
$$y = \frac{1}{2} \ln \frac{E + p_L}{E - p_L}$$

where $E$ is the Energy of the $Z$ boson and $p_L$ is the component of its momentum along the beam direction.

Large values of $|y|$ maximize $|x_1 - x_2|$. This can test the parton distribution functions (PDFs) for large and small values of $x$.

The momentum fractions $x_1$ and $x_2$ carried by the partons which produce a $Z$ boson are related to the $Z$ boson rapidity $y$ by:

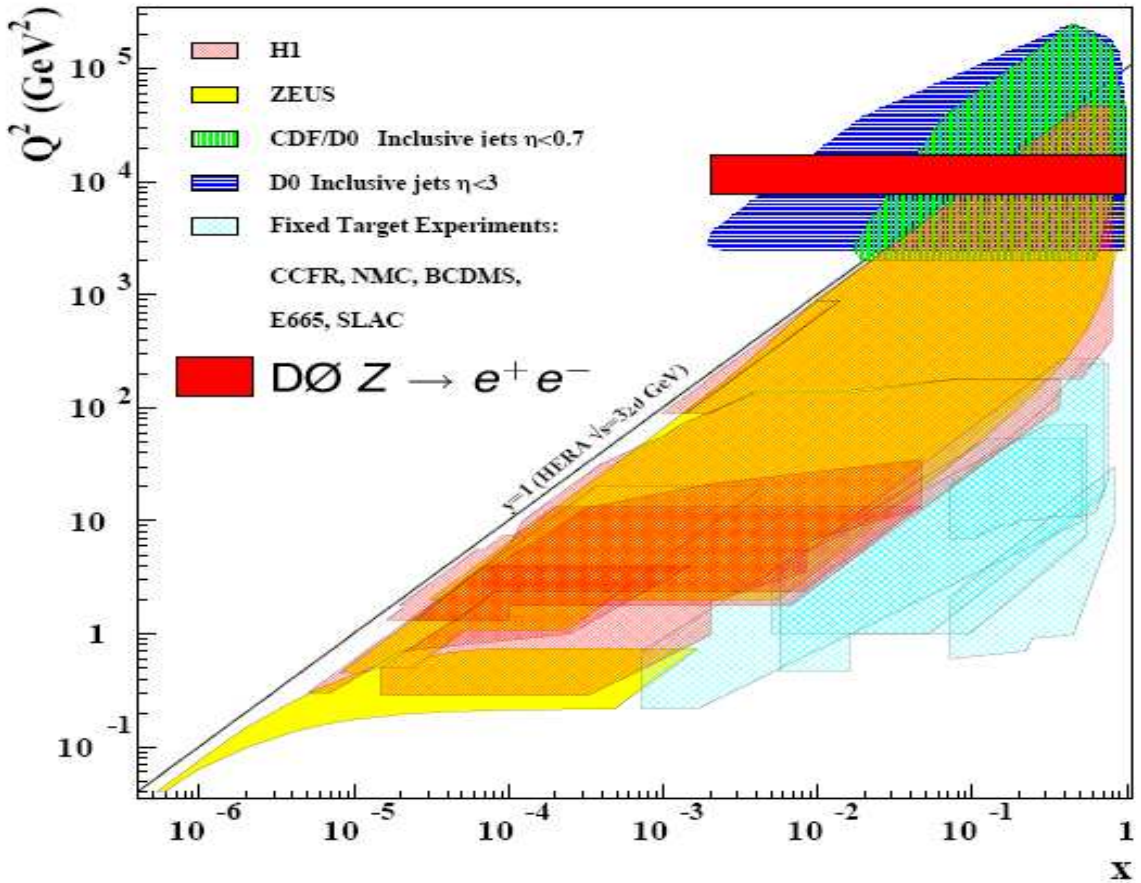
$$x_{1,2} = \frac{M_{Z/\gamma^*}}{\sqrt{s}} e^{\pm y}$$



# Probing the Parton Distribution Functions

The Tevatron can probe the PDFs at large $Q^2$ for $10^{-3} \lesssim x \lesssim 1$

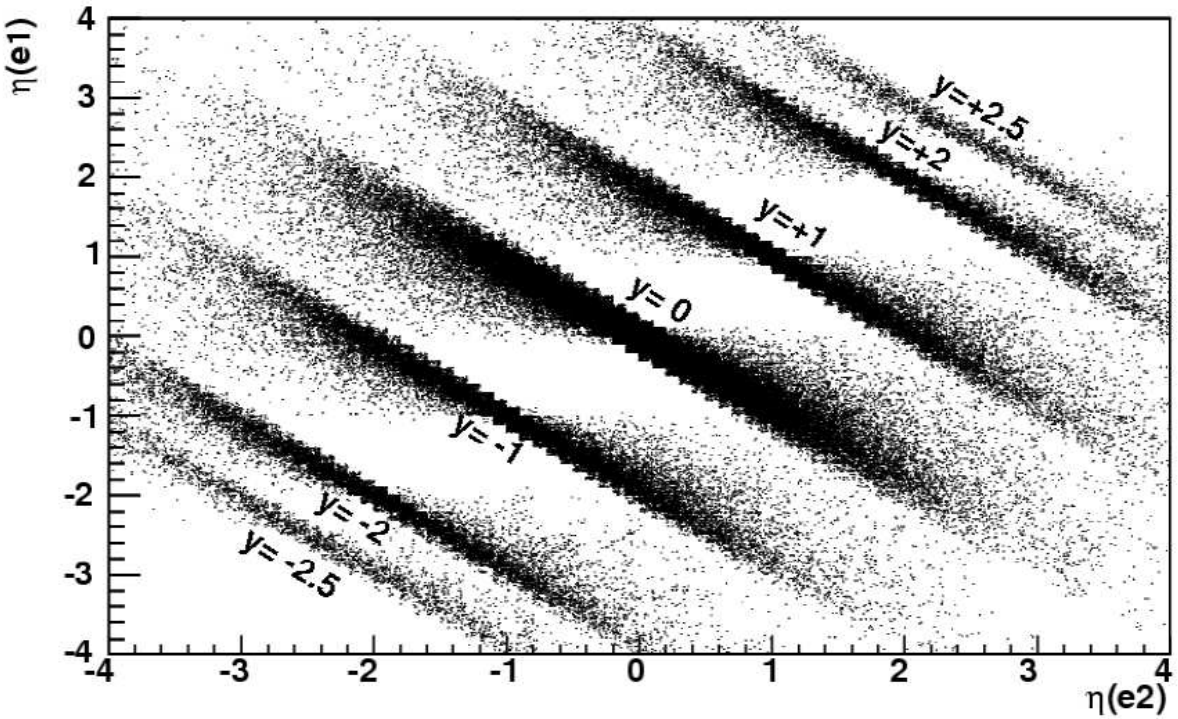
(hep-ex 0411051)




For the $Z \rightarrow e^+e^-$ analysis $Q^2 \approx M_Z^2$

# Boson Rapidity and Electron Pseudorapidity

$y$ is the rapidity of the $Z$ boson, $\eta$ is the pseudorapidity of an electron




- Large values of $|y|$ correspond to large values of lepton $\eta$.
- Forward lepton identification is crucial.

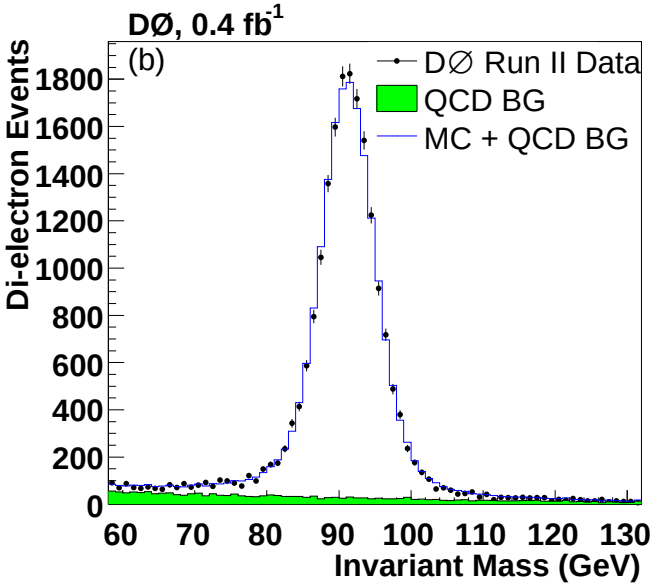
# $Z \rightarrow e^+e^-$ Rapidity Analysis

Event Selection:

- $|\eta| < 3.2$
- $71 < M_{ee} < 111$ GeV
- $p_{T,1(2)} > 25(15)$ GeV

Data set: 400 $\mathrm{pb}^{-1}$

18k $Z/\gamma^*$ events selected



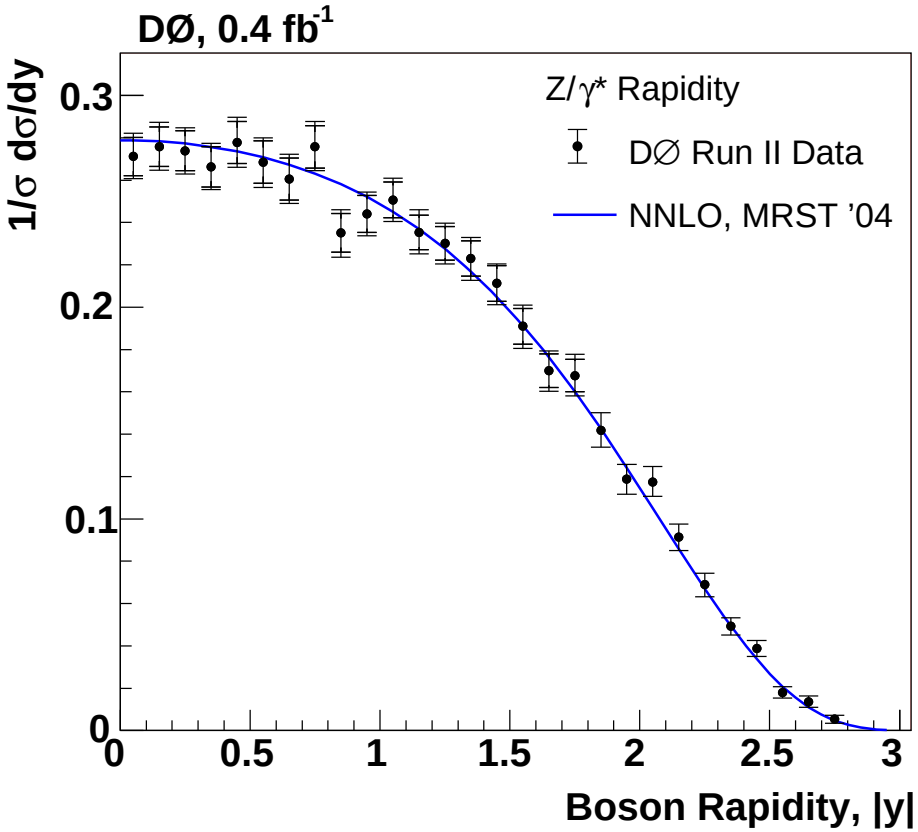

## Goals

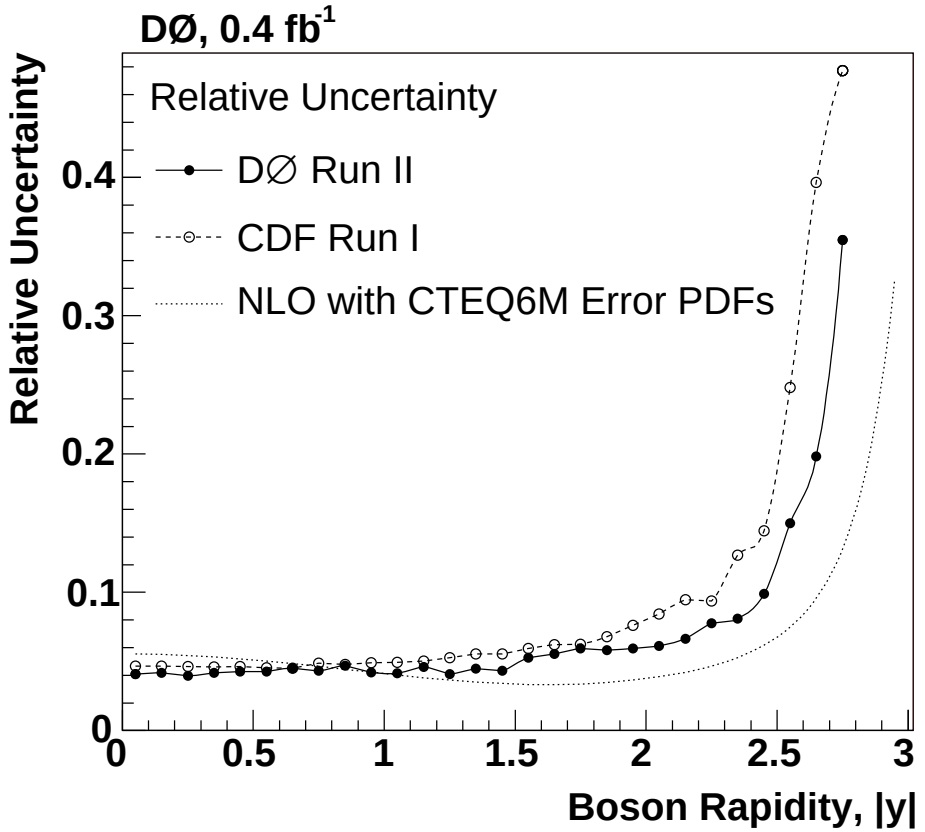
- Determine $d\sigma/dy$
- Compare to NLO + NNLO theory
- Constrain PDFs for new ranges of $(Q^2, x)$

$$\frac{1}{\sigma}\left(\frac{d\sigma}{dy}\right) = \frac{(\epsilon \times A)_{avg}}{N^{obs}_{total} - N^{bkg}_{total}} \frac{N^{obs}_i - N^{bkg}_i}{\Delta_i(\epsilon \times A)_i}$$

- $\epsilon \times A$: Monte Carlo (ResBos+PHOTOS)
- Backgrounds: QCD multi-jet, up to 6%

# *Z* Rapidity Final Results



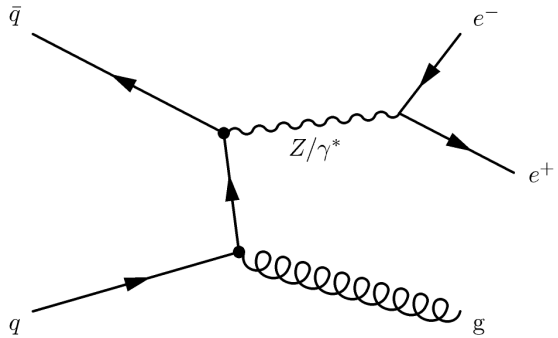



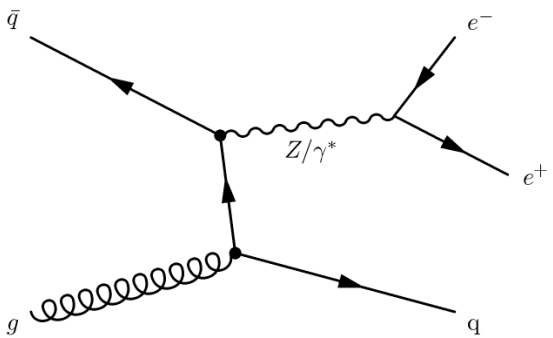

- Most precise *Z* boson rapidity measurement with largest rapidity range. Accepted for publication in PRD (hep-ex 0702025).
- Inner (outer) error bar is the statistical (total) uncertainty
- Statistics limited

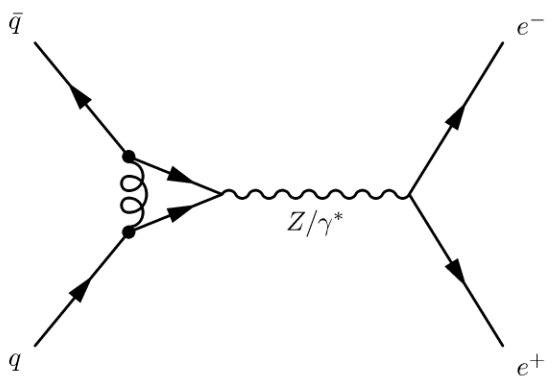
# Transverse Momentum of the $Z$ boson

$Z$ boson $p_T$:

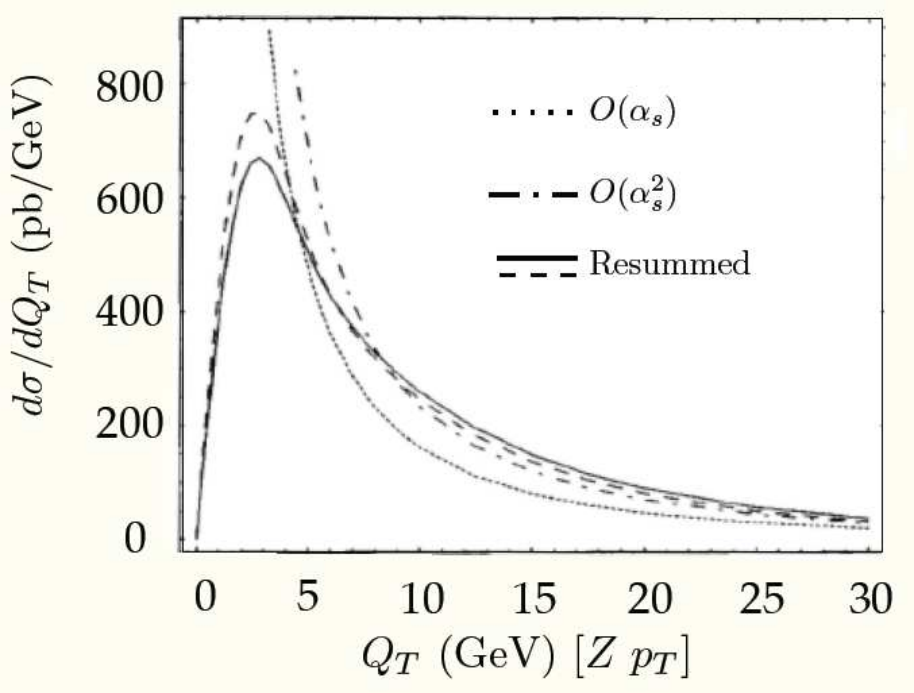
- $p_T$ zero at leading order
- Generated mostly through NLO initial state gluon radiation
- Cross section converges for large $p_T$ using perturbative QCD theory
- Cross section diverges for small $p_T$ using perturbative QCD theory
- Resummation CSS formalism allows the cross section to be calculated including all orders in $\alpha_s$ at low $p_T$

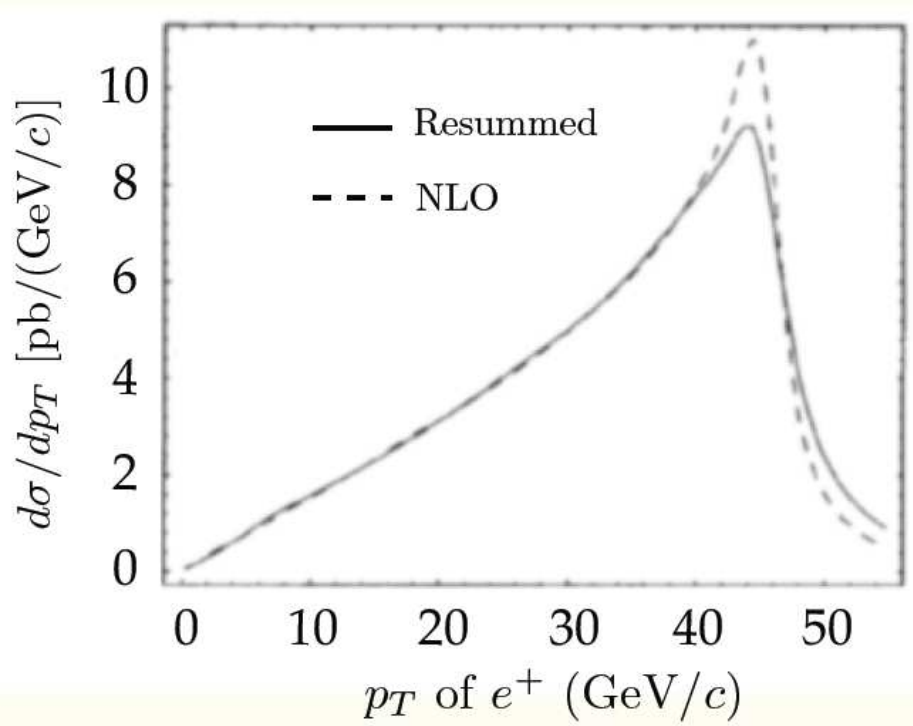


# Resummation Formalism

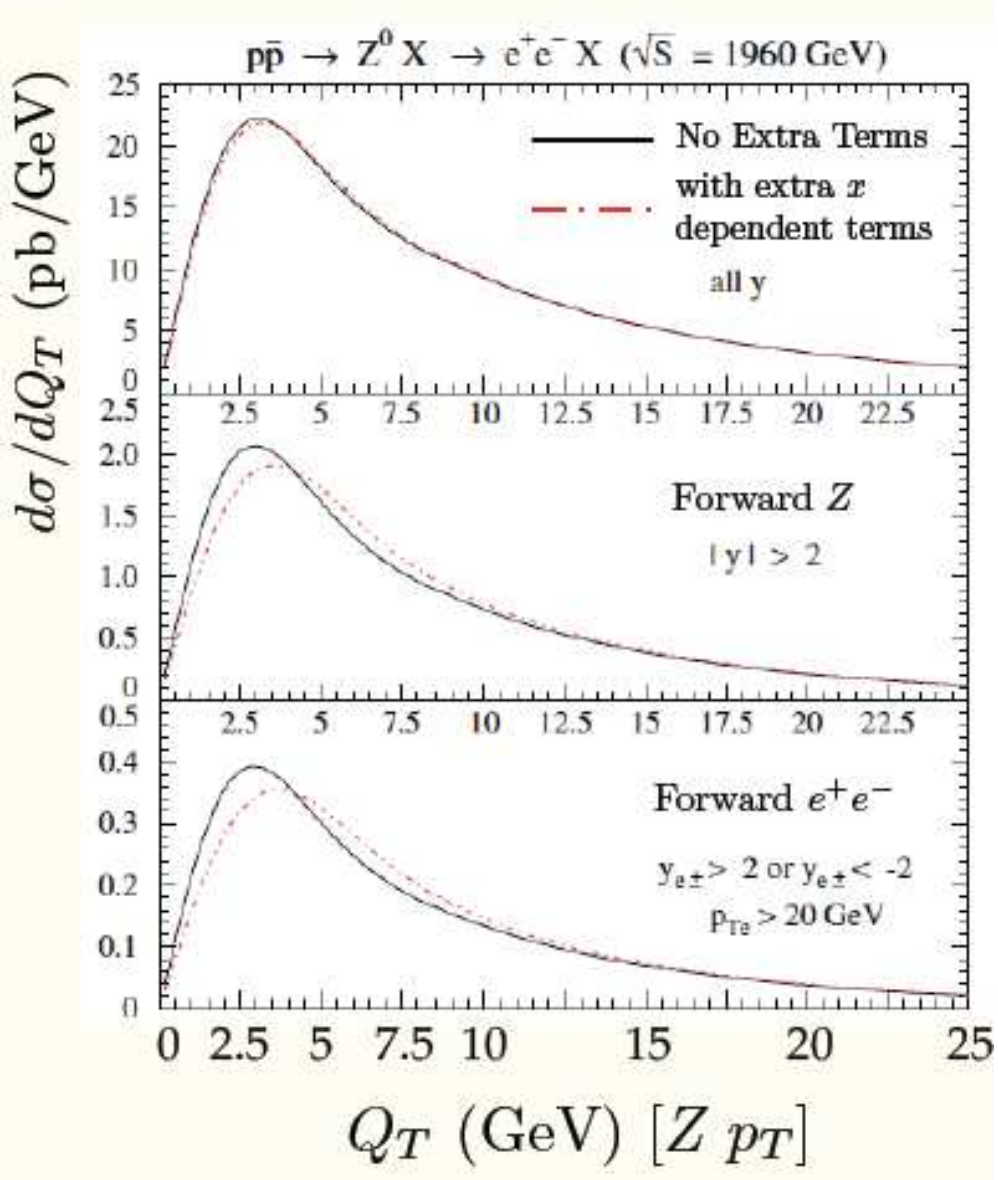



Plots from PRD 56:5558

- Cross section diverges using perturbative QCD for small $p_T$ due to soft gluon radiation
- Fix with the resummation CSS formalism
- Resummation has a parameter $g_2$ which determines the peak of $p_T$ distribution

# $Z$ Boson $p_T$ and Forward Rapidity




- For high rapidity, resummation theory may require extra terms dependent on $x$
- New terms broaden the $p_T$ distribution for $x < 10^{-2}$
- Would affects the $W$ and Higgs bosons
- Could be significant at the LHC

hep-ph 0410375

# $Z \rightarrow e^+e^-$ $p_T$ Analysis

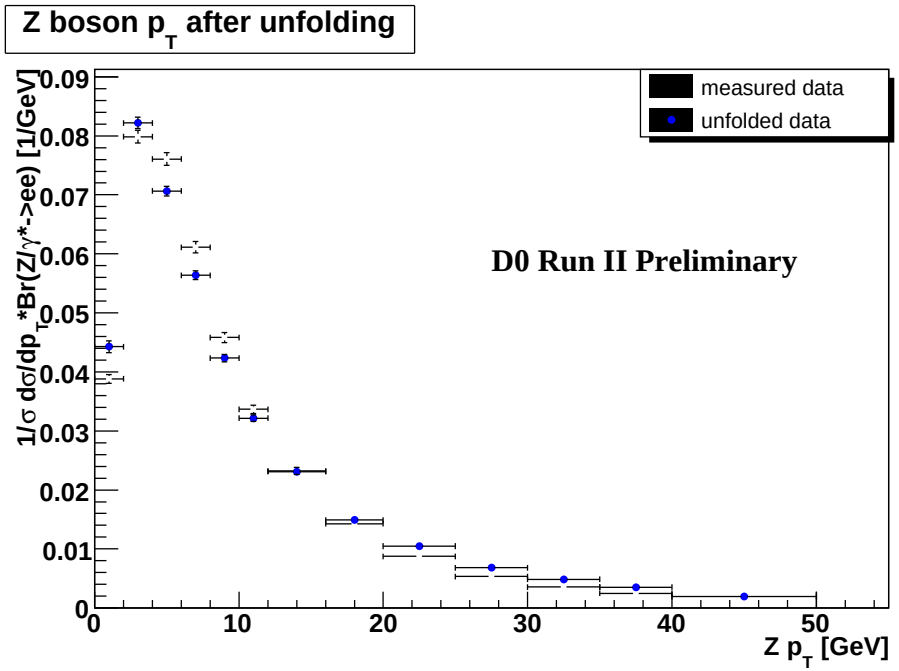
## Goals

- Determine $d\sigma / dp_T$
- Test resummation formalism and NNLO QCD
- Measure $g_2$
- Look for broadening of distribution for $|y| > 2$

- Data: 960 $\mathrm{pb}^{-1}$.
- Similar event selection as rapidity analysis, except:
  - $p_T > 25$ GeV
  - Central calorimeter electrons only
- Acceptance and Efficiency determined by same method as rapidity analysis
- Same backgrounds as Z rapidity analysis

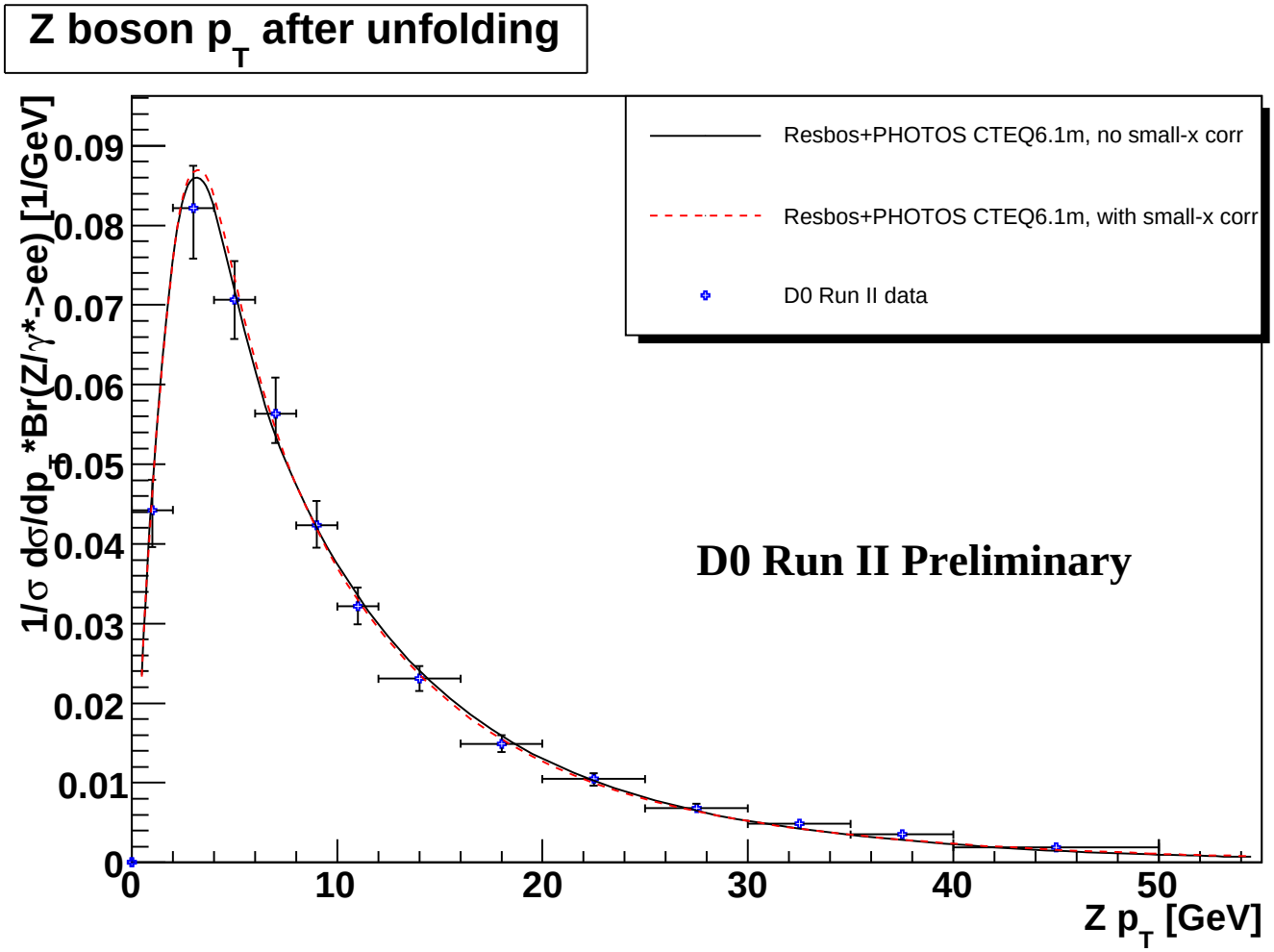
# Unfolding

The detector resolution, kinematic cuts, and lepton efficiencies all affect the observed $p_T$ distribution. The process of going from the observed distribution to the true distribution is denoted as unfolding.




Use RUN program (Regularized Unfolding) by Blobel for unfolding

# The $Z$ boson $p_T$ Distribution




Error bars include statistical and systematic uncertainties.

Data and theory agree well: $\chi^2/\mathrm{ndf} = 16.2/13$.

# Conclusion and Outlook

- $Z$ bosons provide precise test of the PDFs, QCD at NNLO, and the resummation formalism
- 100,000 $Z \rightarrow \ell\ell$ events per $\text{fb}^{-1}$ with standard cuts
- More data to be analyzed, more data being taken

## Available Now

- Shape of the $Z$ boson rapidity distribution - most precise measurement (hep-ex 0702025 accepted for publication in PRD)
- Preliminary measurement of the $Z$ boson $p_T$ distribution to 50 $GeV$

## Coming Soon

- Precise measurement of $g_2$
- Extend $p_T$ measurement to 260 GeV; include forward electrons
- Study $p_T$ broadening