W Mass Overview and Future Needs

WZ Workshop

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- Scaling of uncertainties in Run 2
- Theoretical uncertainties
  - $p_T(W)$
  - PDFs
  - QED radiative corrections
- Summary

Motivation

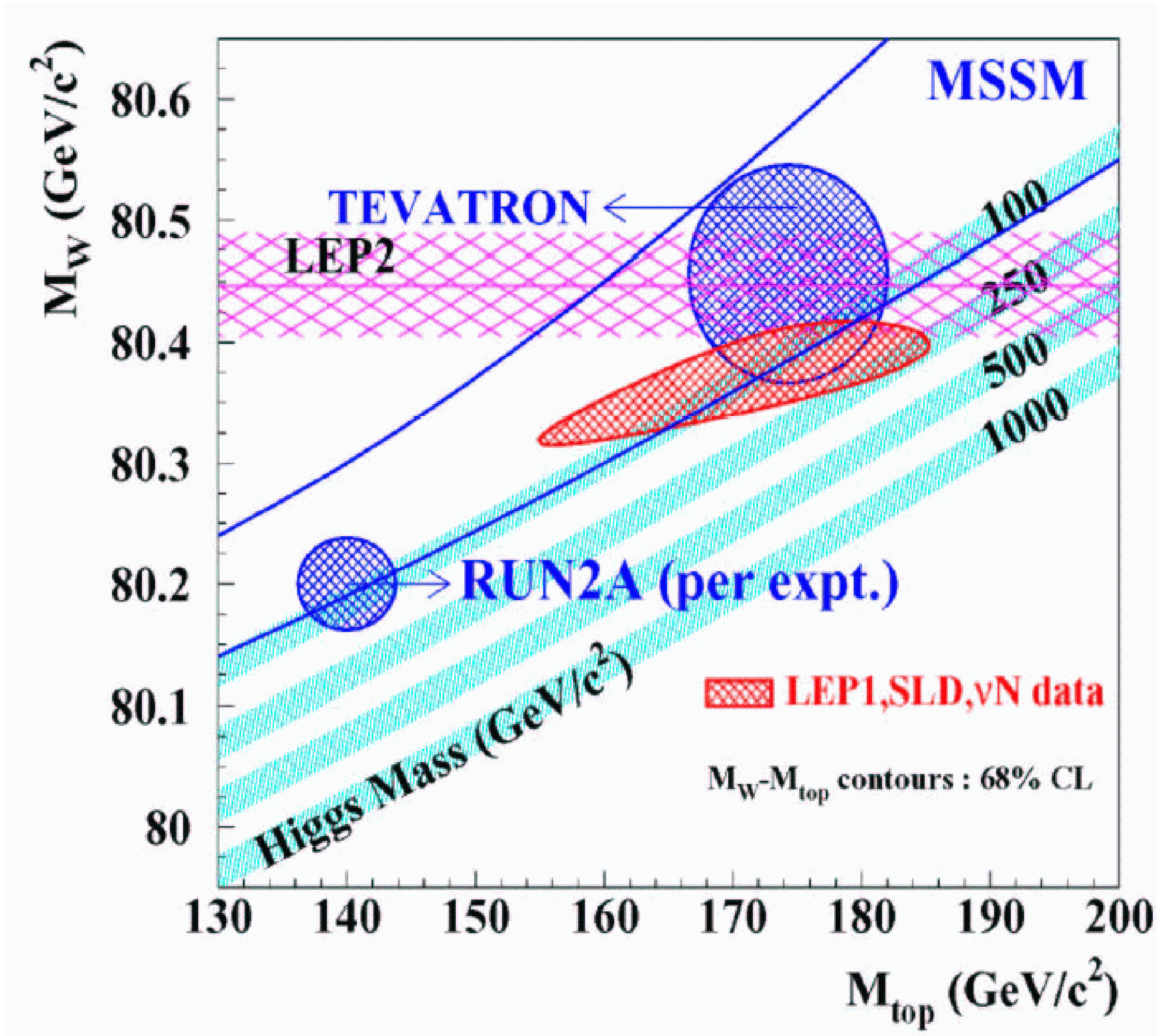
Run 2a (2 fb^{-1}) expectation shown:

$\Delta M_W \sim 40$ MeV

$\Delta m_{top} \sim 2.5$ GeV

per experiment

can we do better?



Run 1 Results

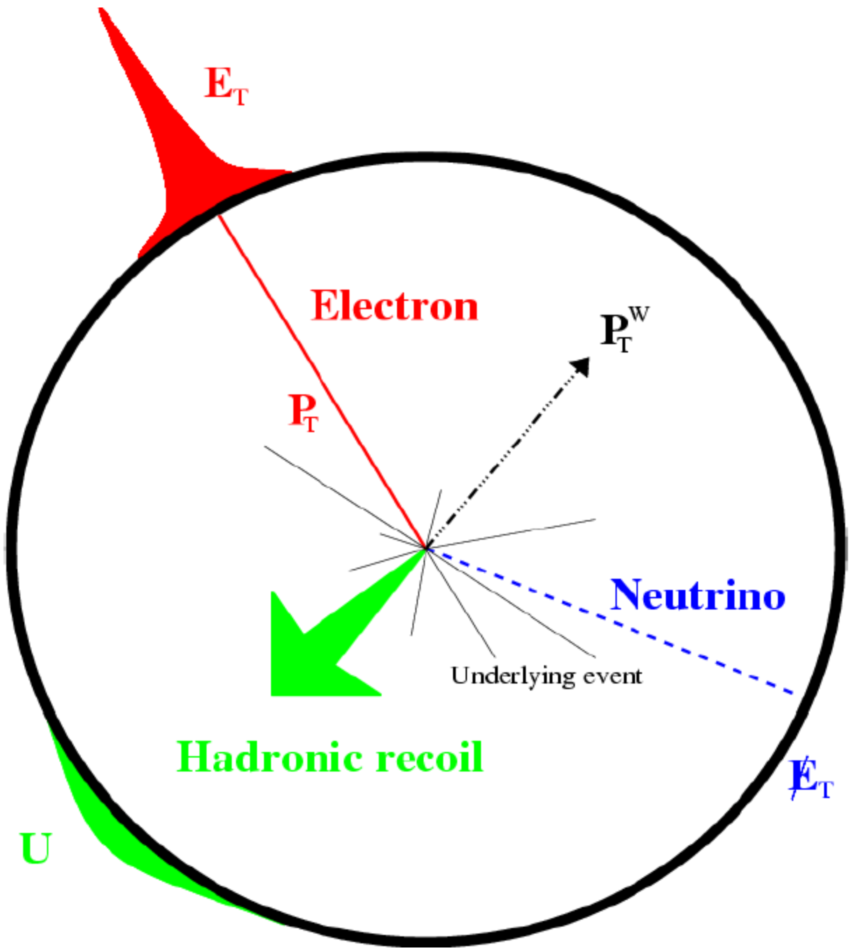
- Tevatron (CDF and D0) Averages:
  - $M_W = 80.456 \pm 0.059$ GeV (19 MeV correlation)
  - $\Gamma_W = 2.115 \pm 0.105$ GeV (26 MeV correlation)
  - Correlated uncertainties due to QED radiative corrections, parton distribution functions, and W mass/width inputs
- Joint $M_W - \Gamma_W$ combination (no external W mass or width information used):
  - $M_W = 80.452 \pm 0.060$ GeV
  - $\Gamma_W = 2.105 \pm 0.106$ GeV
  - Correlation coefficient = -0.17
- Analysis of correlations and Tevatron combined results published (PRD70, 092008, 2004) by CDF, D0 & TeV-EWWG

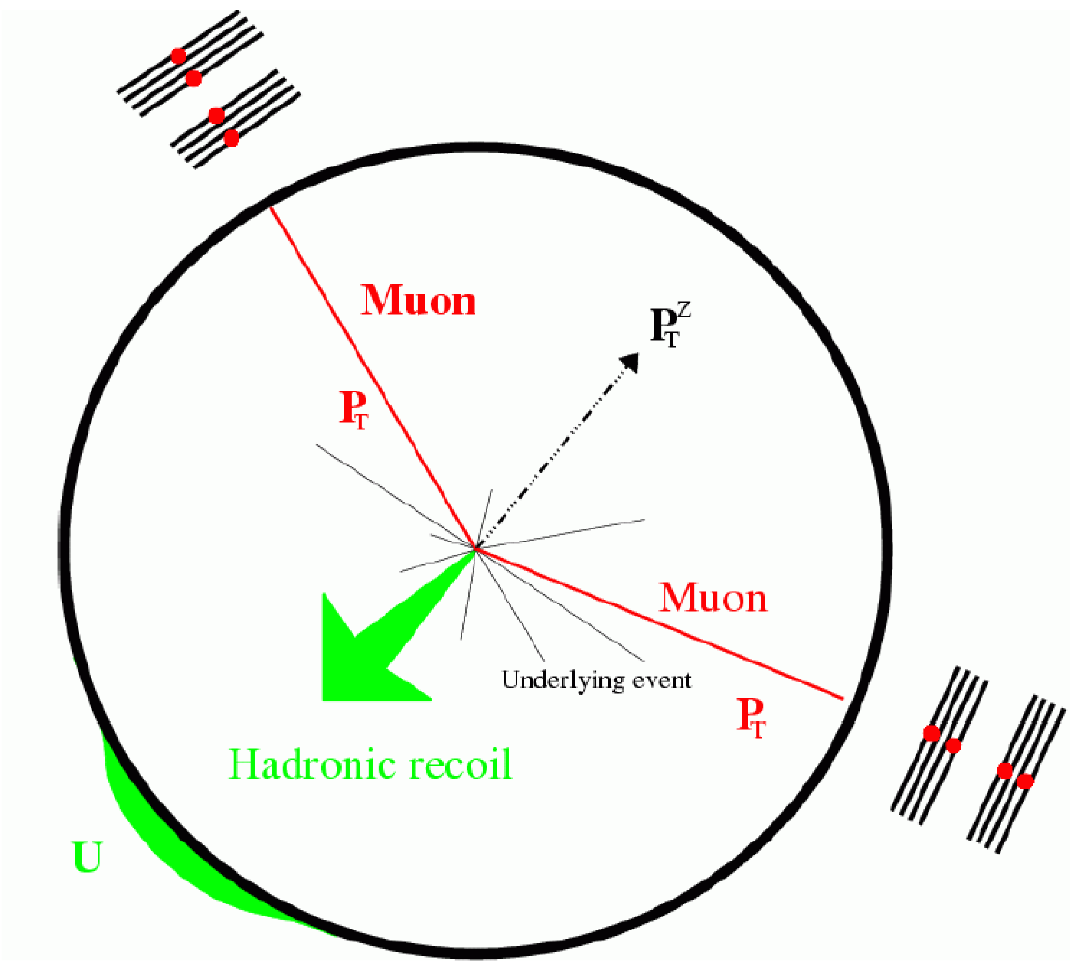
Run 2 Extrapolation

- Scaling of ΔM_W and $\Delta\Gamma_W$ with integrated luminosity:
  - During 1987-1995 running period, integrated luminosity per collider experiment increased from 4 pb^{-1} → 20 pb^{-1} → 110 pb^{-1}
  - ΔM_W reduced correspondingly: ~400 MeV → 150 MeV → 60 MeV, following $L^{-½}$ scaling
- Systematics constrained with collider data
- Continuation of this trend could lead to ΔM_W ~ 15 MeV, $\Delta\Gamma_W$ ~ 25 MeV with 2fb^{-1}

W and Z production at the Tevatron

Isolated, high p_T leptons,
missing transverse momentum in W's





Typically small hadronic (jet) activity

Run 1 W Mass
Systematic Uncertainties (MeV)

	CDF μ	CDF *e*	D0 *e*
W statistics	100	65	60
Lepton energy scale	85	75	56
Lepton resolution	20	25	19
Recoil model	35	37	35
pT(W)	20	15	15
Selection bias	18	-	12
Backgrounds	25	5	9
Parton dist. Functions	15	15	8
QED rad. Corrections	11	11	12
Γ(W)	10	10	10

(Correlated uncertainties)

Calorimeter Recoil Model and $p_T(W)$

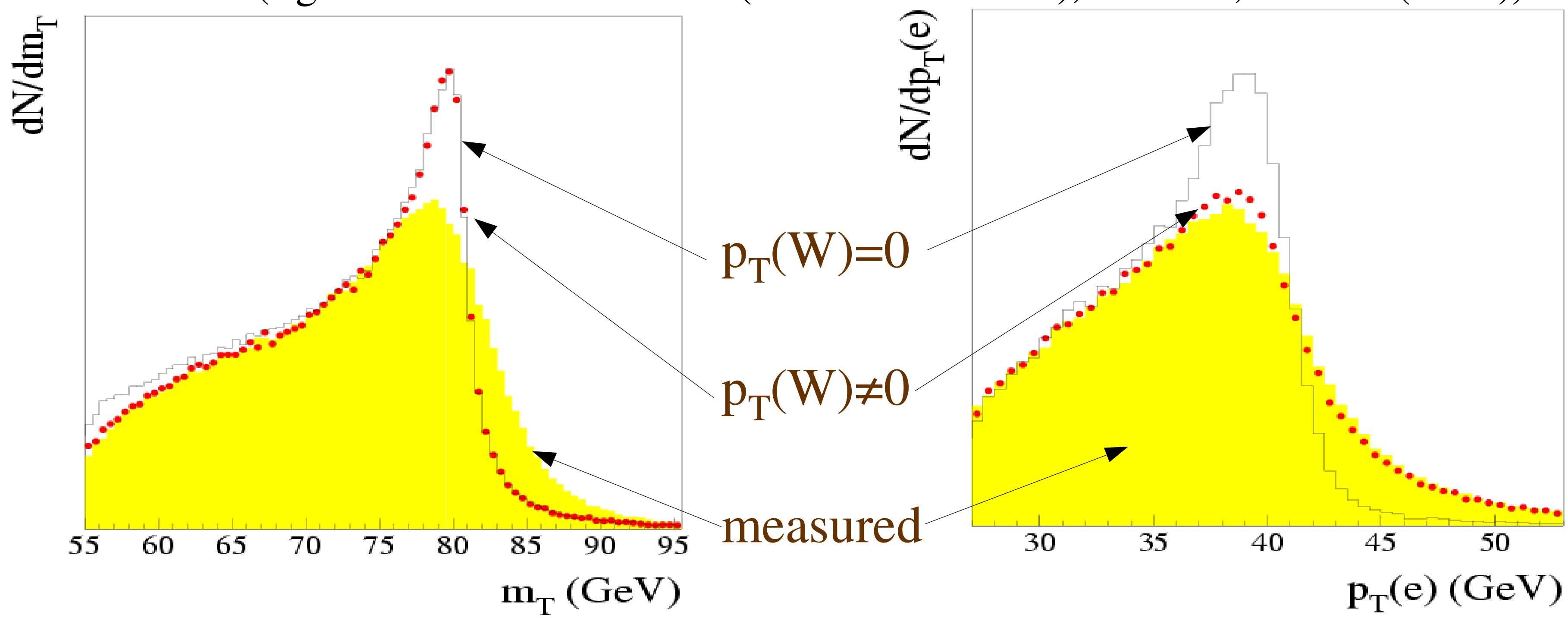
- W mass measured using the location of the Jacobian edge in $p_T(l)$ or m_T distribution:
  - $M_T = \sqrt{(2\, p_T^{\,l}\, p_T^{\,\nu}\, (1 - \cos\phi_{l\nu})}$
  - Insensitive to $p_T(W)$ to first order
  - Reconstruction (by conservation of momentum) of p_T^{ν} sensitive to hadronic response and multiple interactions
- Recoil model tuned using $Z \rightarrow ll$ data
  - Need to understand W vs Z differences, due to
    - Presence of second lepton in Z events
    - Difference in rapidity distributions

Calorimeter Recoil Model and $p_T(W)$

- Advantage of $p_T(l)$: insensitive to hadronic response modelling, but need theoretical model of $p_T(W)$
  - Use precisely measured $p_T(Z \rightarrow ll)$
  - Need to understand W vs Z differences, due to theoretical differences in production (see Pavel's talk)
    - higher Q^2 for Z's
    - different quark PDFs in initial state
      - Non-perturbative QCD effects
      - Different QED ISR photons
    - difference in rapidity distributions and correlation between rapidity and p_T

Calorimeter Recoil Model and $p_T(W)$

(figures from Abbott *et. al.* (D0 Collaboration), PRD 58, 092003 (1998))



- Relevant $p_T(W)$ range ~ 5-10 GeV
  - Large non-perturbative contribution
  - Potential for small difference between $p_T(W)$ and $p_T(Z)$ due to charm-induced production ($sc \rightarrow W$)
    - Explored by Pavel Nadolsky *et al*, expected to be small

Parton Distribution Functions

- P_T^l, m_T not invariant under longitudinal boost given experimental rapidity cuts
- Forward rapidity coverage important to limit uncertainty from PDFs
  - W charge asymmetry measurement constrains *u/d* PDF ratio: statistics-limited
    - CDF measured in Run 1, new forward calorimeters in Run 2
    - D0 has forward coverage, charge measurement in Run 2
  - Use Forward W's in mass analysis
    - D0 did in Run 1, reduced PDF uncertainty (8 MeV vs 15 MeV)
- PDF fitters (MRST, CTEQ) now providing rigorous errors - consensus on "1σ" to emerge

PDFs

From Joey Huston's talk at W Mass Theory Workshop, Nov 2003

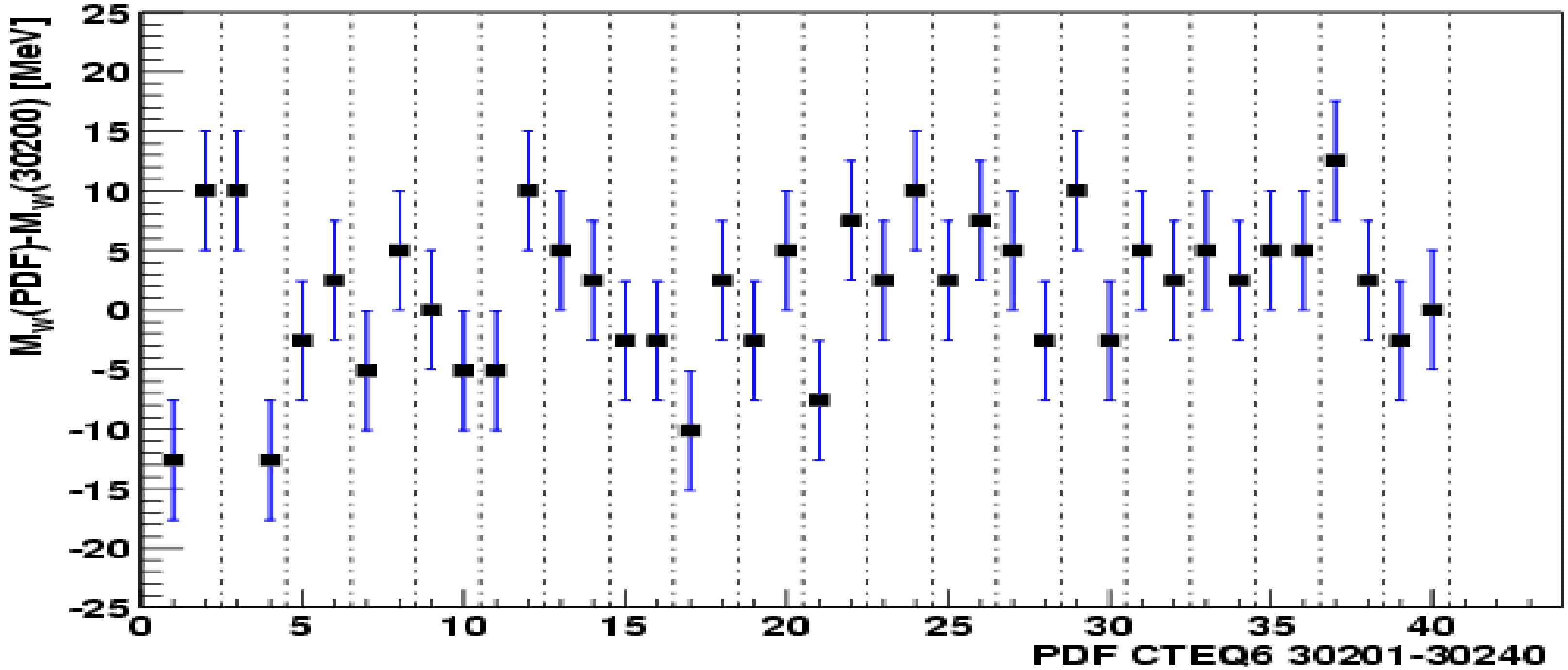
- Experimental errors
  - Hessian/Lagrange multiplier techniques designed to address estimate of these effects
    - question is what $\Delta\chi^2$ change best represents estimate of uncertainty
      - a strict fundamentalist would say $\Delta\chi^2$ of 1 (for 1 σ error)
      - CTEQ uses $\Delta\chi^2$ of 100 (out of 2000) for something like a 90% CL limit
      - MRST uses $\Delta\chi^2$ of 50 for 90% CL limit

More details in Joey's talk – summary is that the 'metric' of this χ^2 is not trivial

but it matters: quoted W mass error is proportional to this metric

PDFs

From Oliver Stelzer-Chilton



Calculate W mass shift due to each of 40 PDF's from CTEQ error ensemble (relative to default PDF)

Useful to see which eigenvectors contribute most uncertainty to W mass.

Can we relate this information to physics? What physical aspect of PDF's is most important?

PDFs

For example: u/d ratio is know to be relevant to W mass analsis

CDF Collaboration,
D. Acosta et al
PRD 71, 051104
(2005)

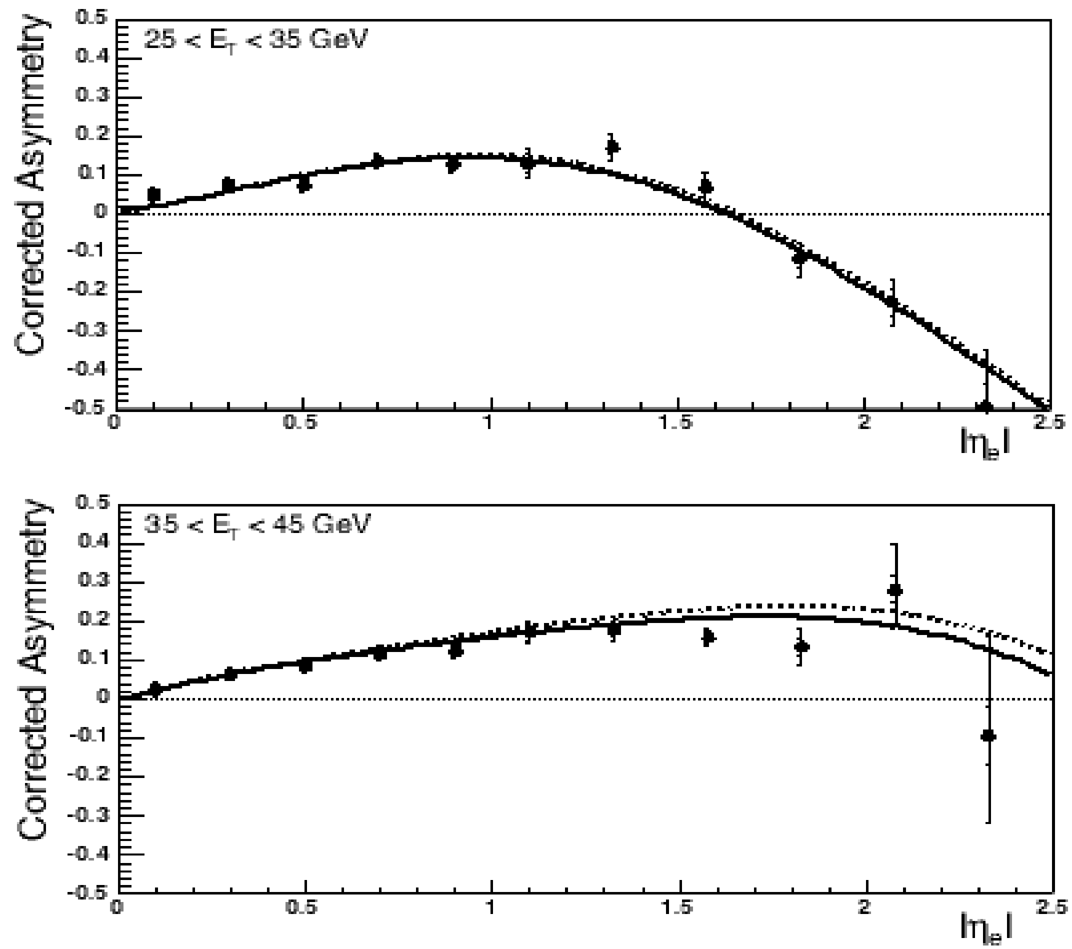


FIG. 5. The measured asymmetry, $A(|\eta_e|)$, is plotted and predictions from the CTEQ6.1M (solid) and MRST02 (dashed) PDFs are compared using a NLO RESBOS calculation. Both statistical and total (statistical + systematic) uncertainties are shown. The upper plot is for $25 < E_T < 35$ GeV. The lower plot is for $35 < E_T < 45$ GeV.

need more W
asymmetry data
to constrain PDF's
further

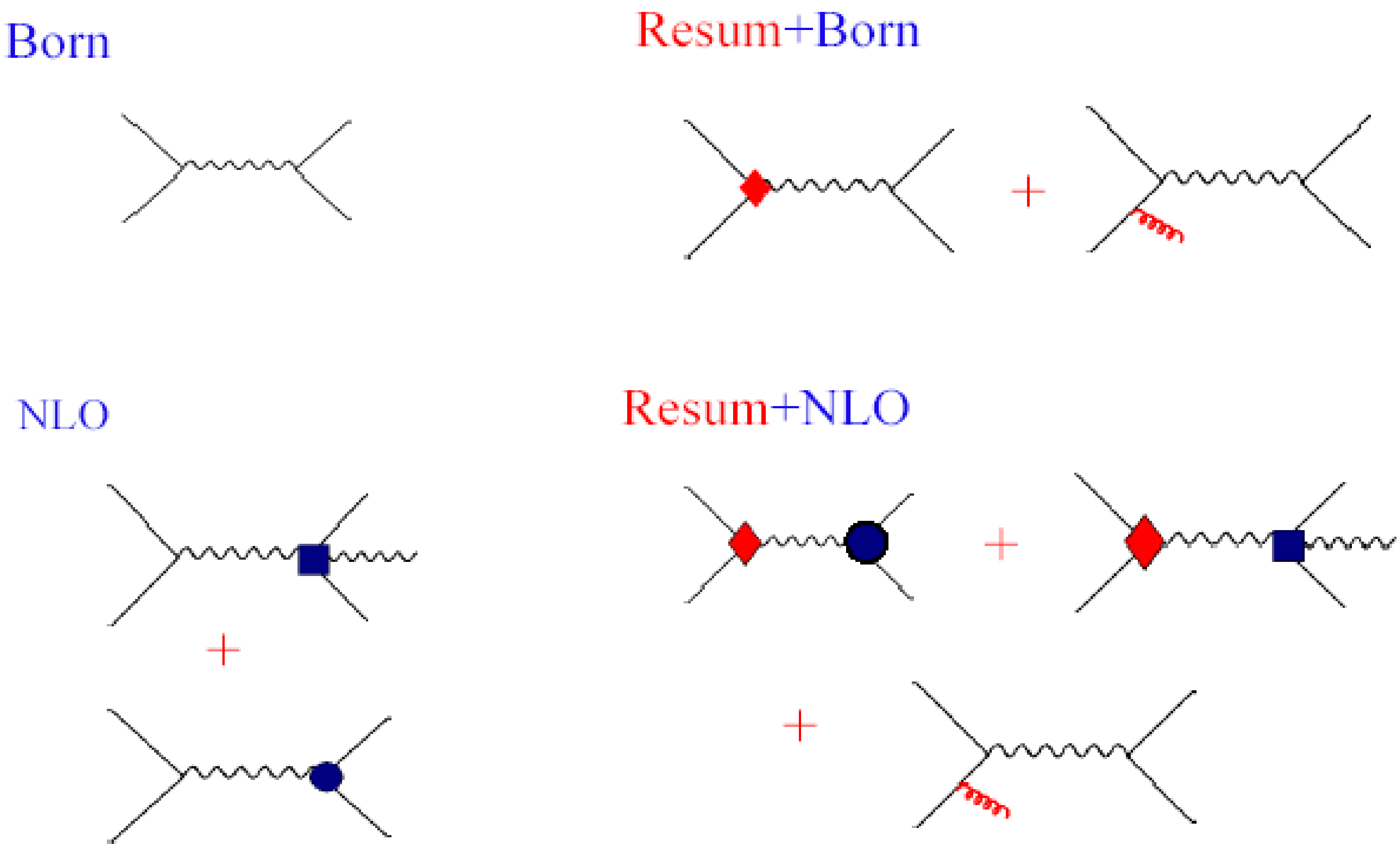
need to think about
how PDF uncertainty
will improve in future

QED Radiative Corrections

- Improvements over Run 1:
  - Complete NLO QED calculations available (U. Baur *et. al.*) for single photon emission
  - 2-photon calculations performed (Carloni Calame *et. al.*, hep-ex/0303102; Placzek & Jadach, hep-ex/0302065), predict 2-8 MeV shift in W mass
  - Combined QCD+QED (FSR γ) generator for W and Z bosons available - RESBOS-A (Cao & Yuan)
- Uncertainty in QED corrections not expected to be a fundamental limitation

RESBOS-A

Cao & Yuan talk from W mass theory workshop, Nov 2003



ISR matters at the 5 MeV level (Ian Vollrath) & is different for W and Z
Radiation off propagator matters at the 5 MeV level & is different for W and Z

Summary & Scaling of Theoretical Uncertainties

- $p_T(W)$ uncertainty will most likely be limited by experimental issues of Z vs W data events
- QED technology continues to improve – we (experimentalists) have to figure out how to incorporate all the details into the analysis
- PDF improvements not easy to come by – what additional global data do we need to collect and analyse in the next few years?
  - How well can we do forward electrons in run 2? forward muons?