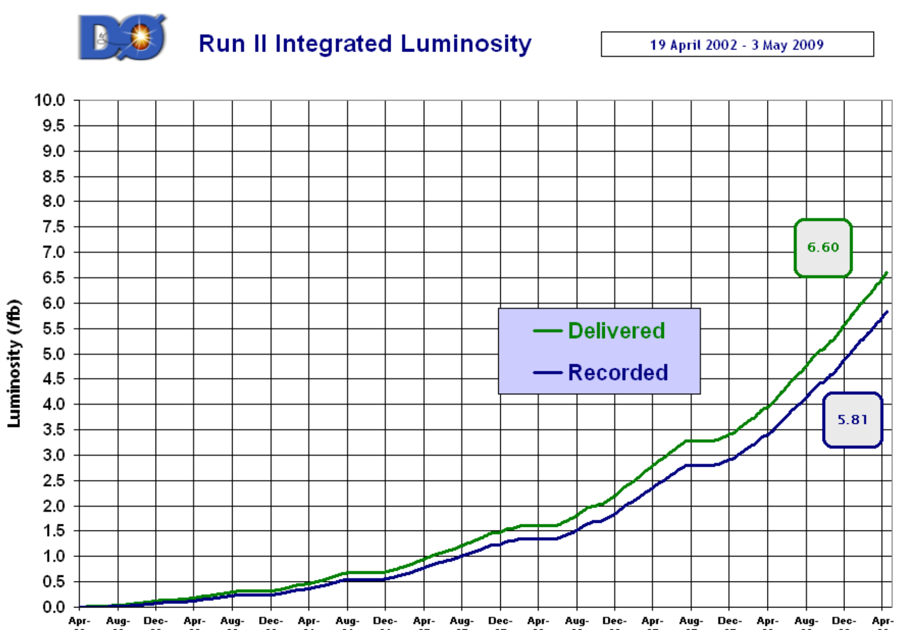
A Study of Low p_T Z Events Using a Novel Technique

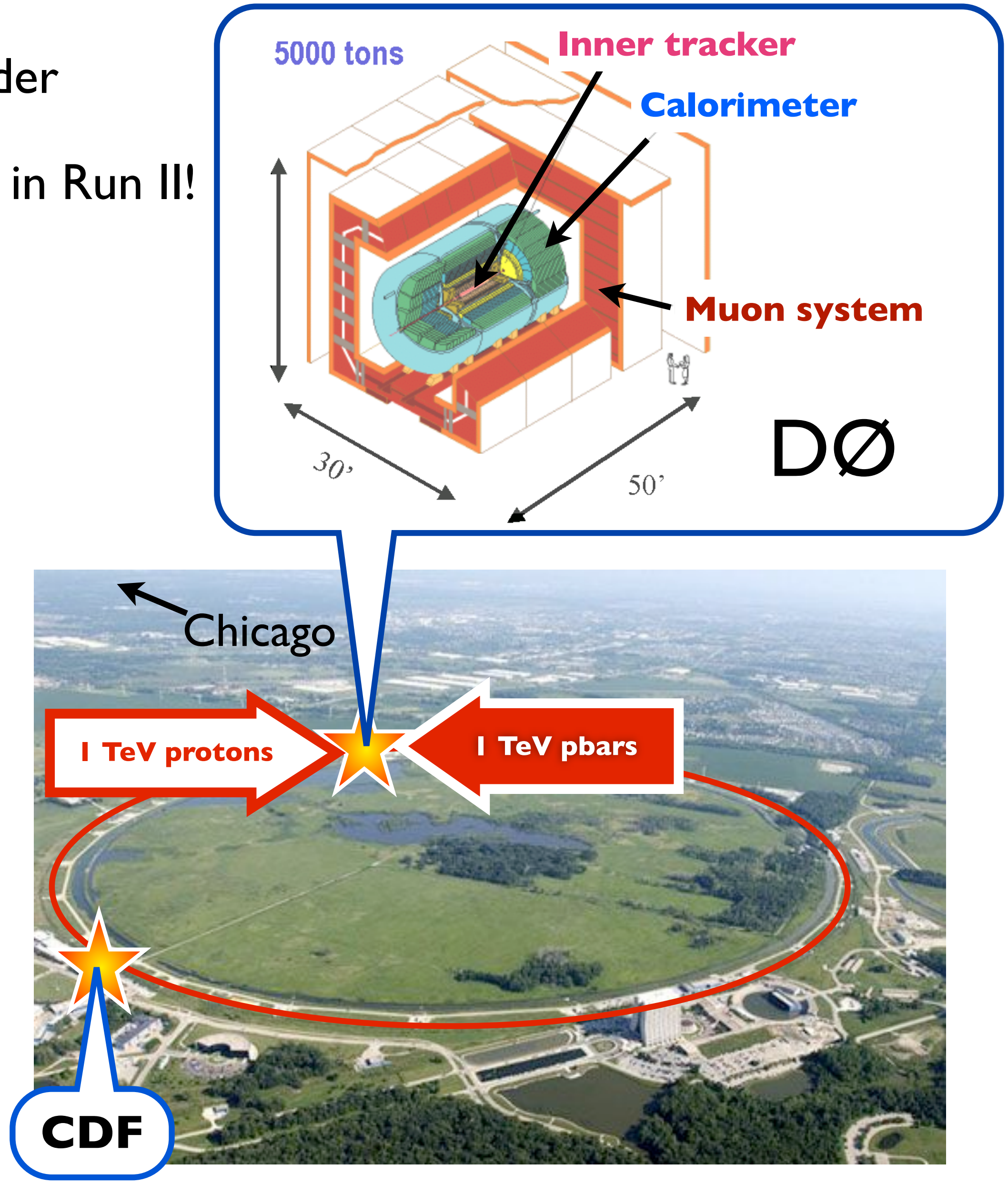
Mika Vesterinen

University of Manchester

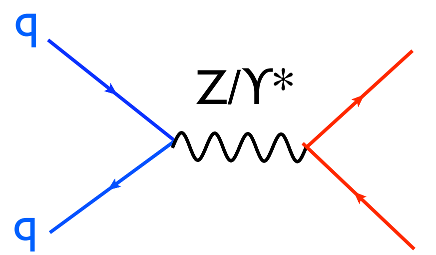
The Tevatron and DØ

- The Tevatron
  - 2 TeV proton anti-proton collider
  - 6.5 fb^{-1} of delivered luminosity in Run II!
- The DØ Experiment
  - General purpose detector
  - At the high energy frontier!

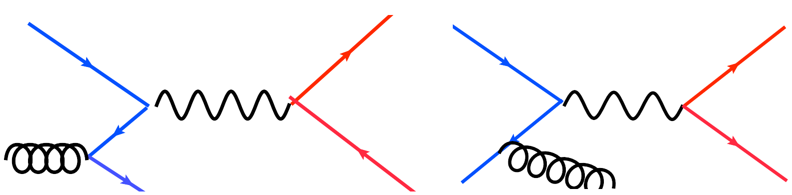




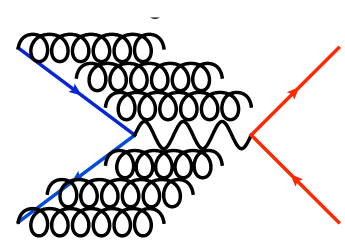
Z Boson Production



- Tevatron is now a "Z factory"
  - ~1 Z produced every 10 seconds!
- Lots of interesting measurements of Z production properties
  - inclusive cross sections, differential cross sections (transverse momentum (p_T), rapidity, A_{FB}....etc).
- The p_T distribution is very interesting
  - High (>30 GeV) p_T tests perturbative QCD
  - Low p_T probes non-perturbative QCD



+ h.o....



Low p_T Z's

- Fixed order pQCD fails at low Z p_T.
  - large logs + non-perturbative (NP) contributions.
- Solution[1]:
  - Resummation of large logs into a Sudakov form factor
  - Absorb NP part into a *universal* form factor.
  - Form factor needs to be measured from data e.g. BLNY[2] form.
  - At the Tevatron, the $\mathbf{g_2}$ parameter determines the p_T distribution.

$$\frac{d\sigma}{dy\,dq_T^2} = \frac{\sigma_0}{S}\int \frac{d^2b}{(2\pi)^2} e^{-i\vec{q_T}\cdot\vec{b}}\tilde{W}^{\mathrm{PERT}} e^{-S^{\mathrm{NP}}b^2} + Y$$

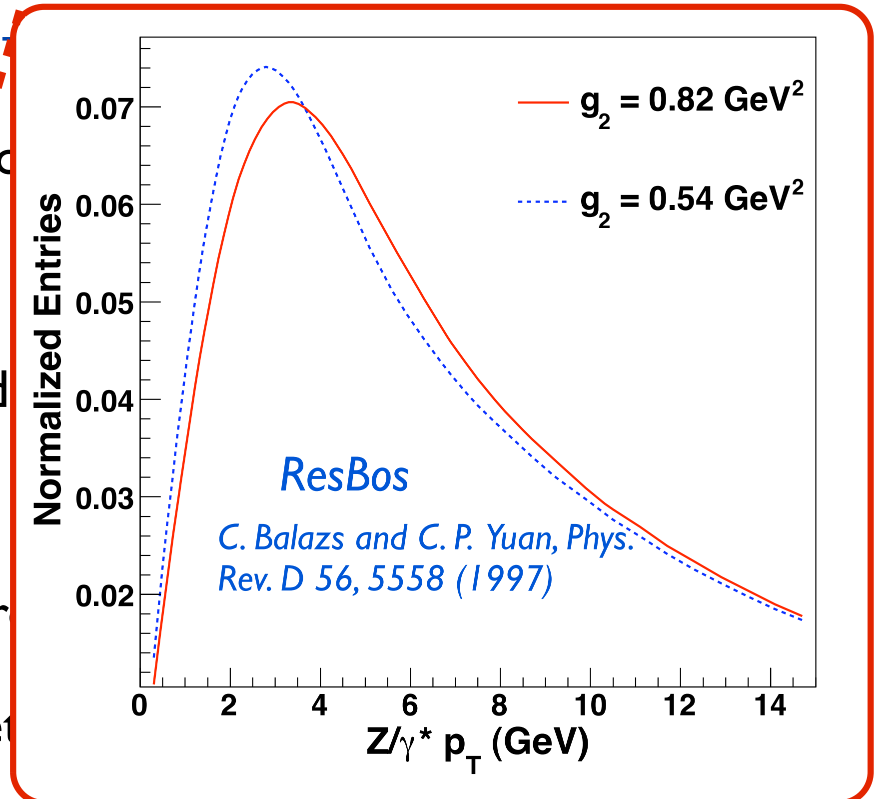
$$S^{\mathrm{NP}}_{\mathrm{BLNY}}(b, Q^2) = -g_1 - g_2 \ln\left(\frac{Q^2}{Q_0}\right) - g_1 g_3 \ln(100 x_A x_B)$$

[1] *J. Collins, D. Soper, G. Sterman, Nucl. Phys. B259 199 (1985)*
[2] *F. Landry, R. Brock, P. Nadolsky, C. P. Yuan. Phys. Rev. D 67, 073016 (2003)*

The University of Manchester

Low p_T Z's

- Fixed order pQCD fails at low Z p
  - large logs + non-perturbative (NP) co
- Solution[1]:
  - Resummation of large logs into a Sud
  - Absorb NP part into a *universal* form
  - Form factor needs to be measured fr
  - At the Tevatron, the $\mathbf{g_2}$ parameter det



$$\frac{d\sigma}{dy\,dq_T^2} = \frac{\sigma_0}{S}\int \frac{d^2b}{(2\pi)^2}\, e^{-i\vec{q}_T\cdot\vec{b}}\,\tilde{W}^{\rm PERT}\, e^{-S^{\rm NP}b^2} + Y$$

$$S^{\rm NP}_{\rm BLNY}(b,Q^2) = -g_1 - g_2\ln\left(\frac{Q^2}{Q_0}\right) - g_1 g_3 \ln(100\, x_A x_B)$$

[1] *J. Collins, D. Soper, G. Sterman, Nucl. Phys. B259 199 (1985)*
[2] *F. Landry, R. Brock, P. Nadolsky, C. P. Yuan. Phys. Rev. D 67, 073016 (2003)*

The University of Manchester

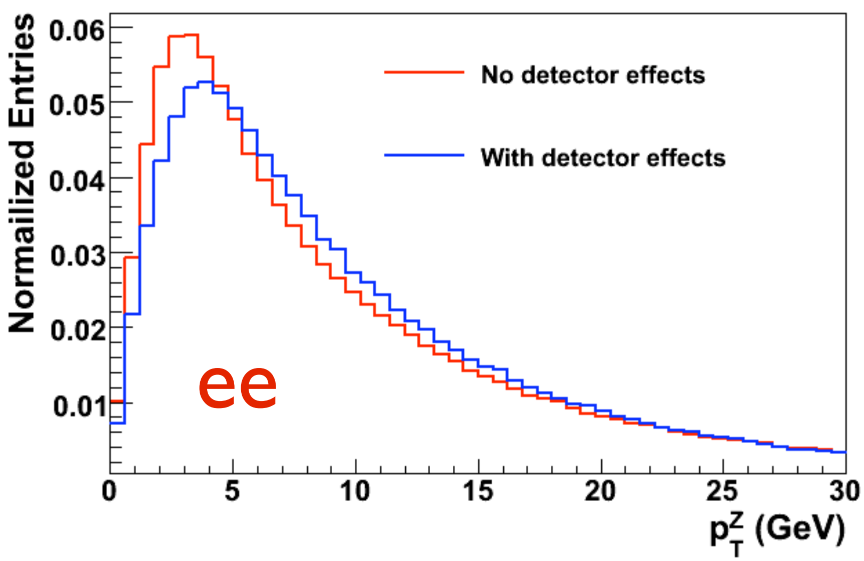
MANCHESTER 1824

Measuring the form factor

- Experiment (Tevatron, LHC exps...) measures the p_T distribution *corrected for detector effects* (unfolding).
  - Combine with low Q^2 Drell-yan data and fit the NP form factor
  - Detector corrections can be very large, and come with large uncertainties!
  - Mainly lepton $p_T(E_T)$ resolution and efficiency dependence on the Z p_T.

Solution

Build a different observable that is sensitive to the Z p_T,
but less affected by detector effects.



The a_T Observable

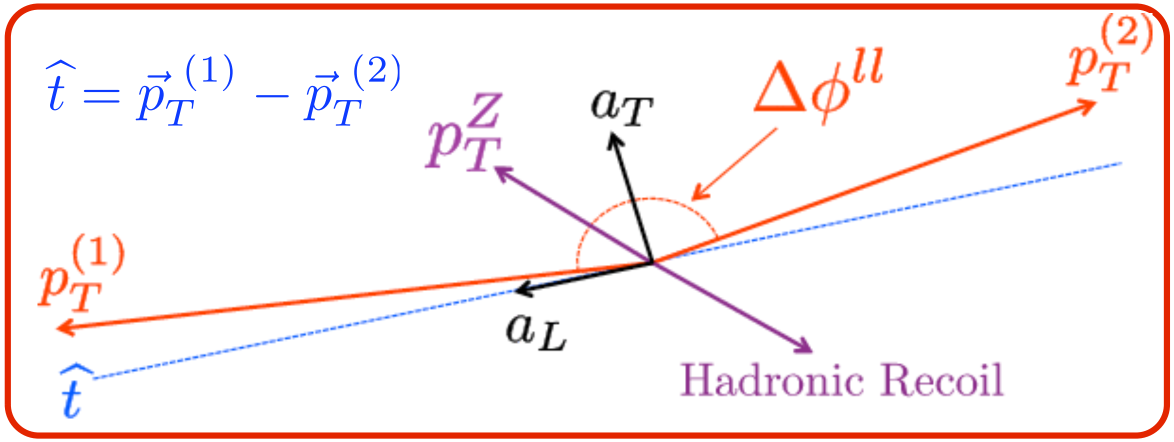
- Split the Z p_T into into a_T and a_L with respect to the event thrust axis.

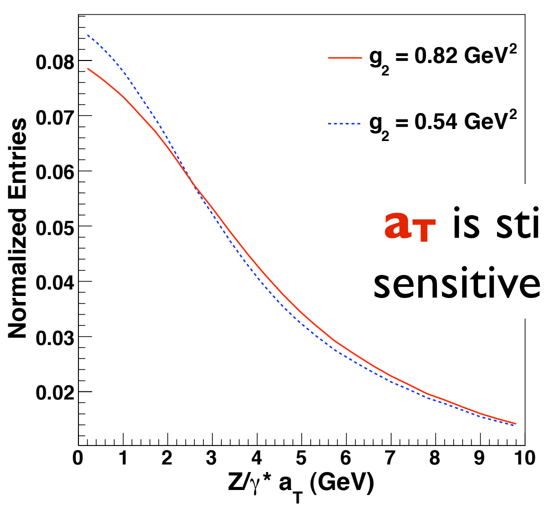
Lepton p_T resolution

At low p_T, $\Delta\phi \sim \pi$, and a_T is much better measured!

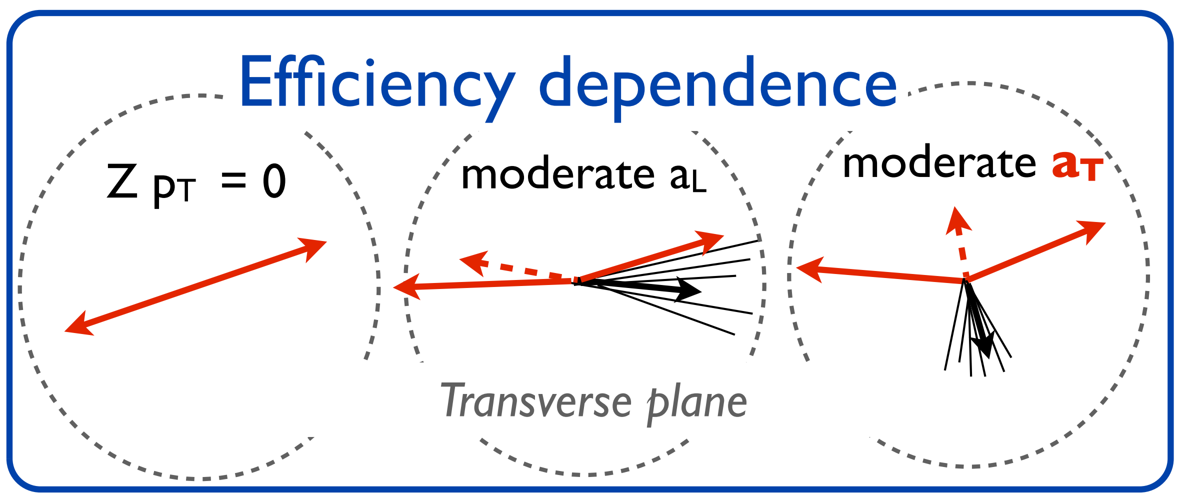
Efficiency dependence

Probability for event to pass cuts on p_T and isolation of the leptons depends on a_L and p_T, but not on a_T.



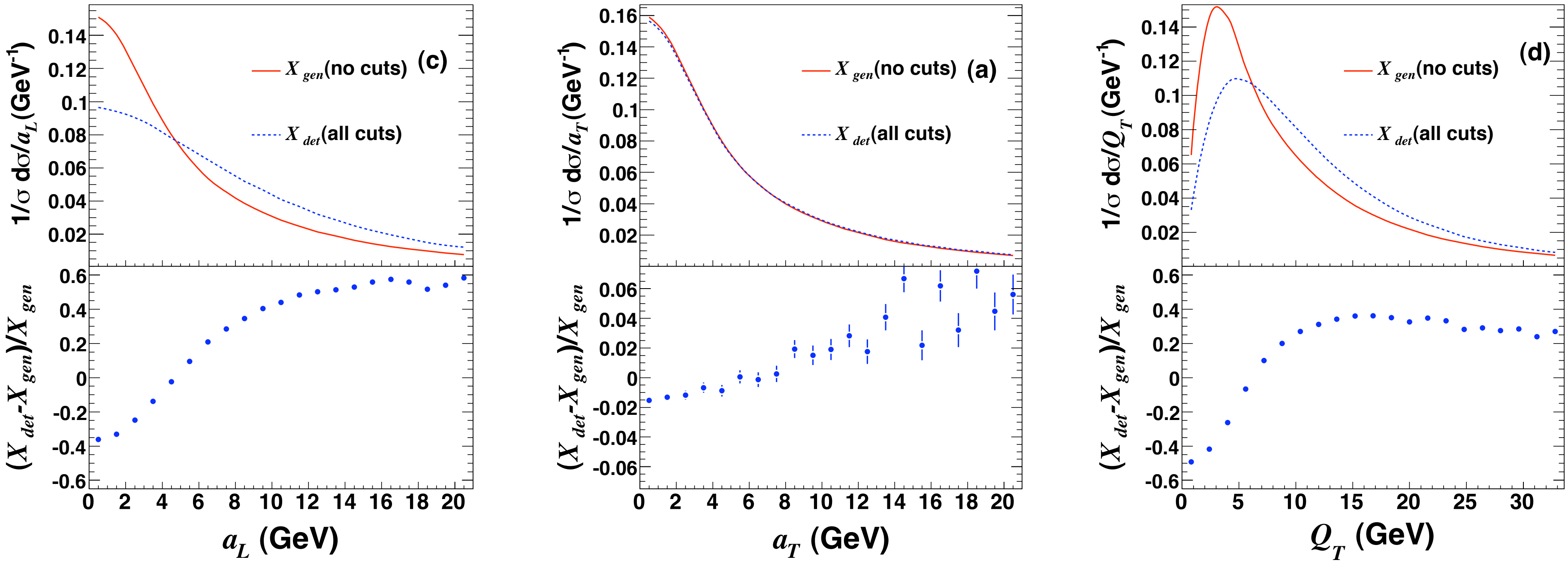


a_T is still very sensitive to g_2!



Performance of a_T MC

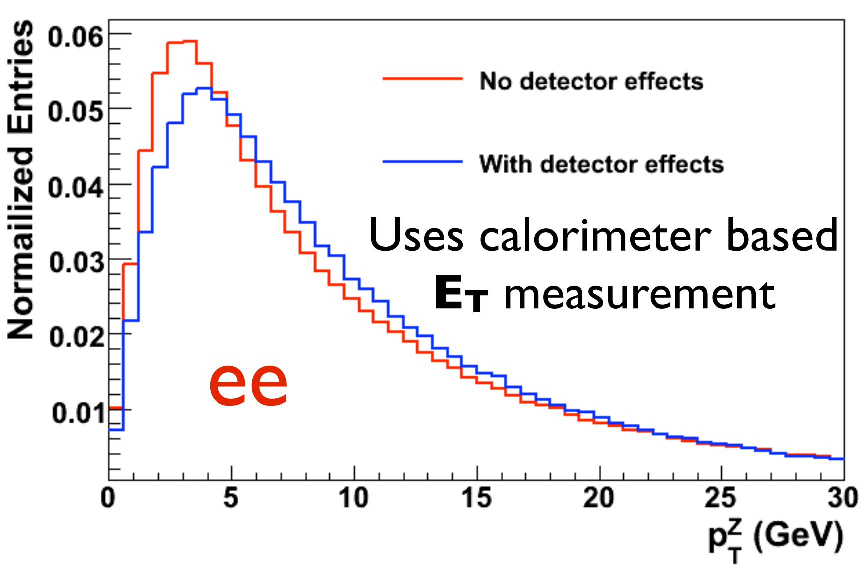
- a_T is far less sensitive to detector effects than a_L (and p_T)[1]!
  - E.g. comparison of **generated** distribution with **detector-level** distribution with selection cuts.
  - Sensitivity to the physics (g_2 parameter) is not degraded by the resolution.

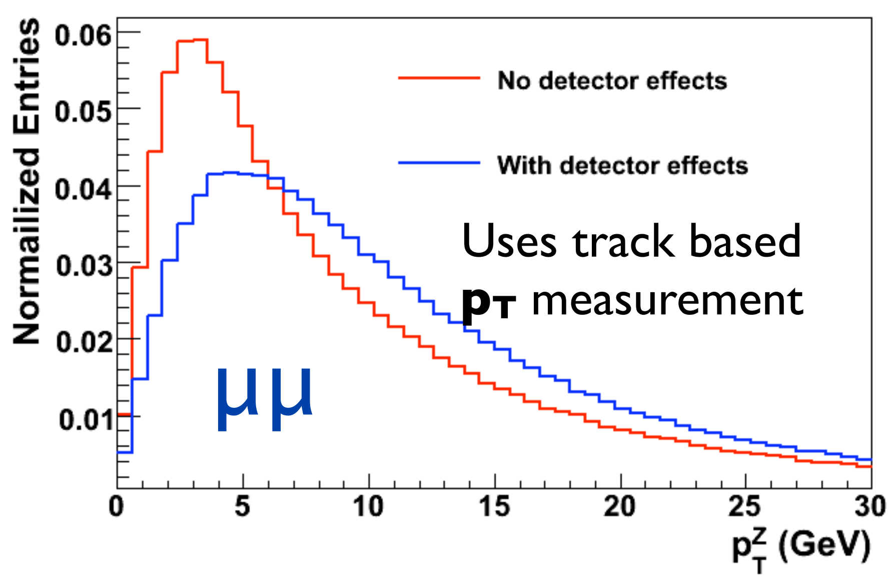


[1] M. Vesterinen, T. R. Wyatt, Nucl. Instr. Meth. in Phys. Res. A 602 (2009); arXiv:0807.4956v1

Measurement of g_2

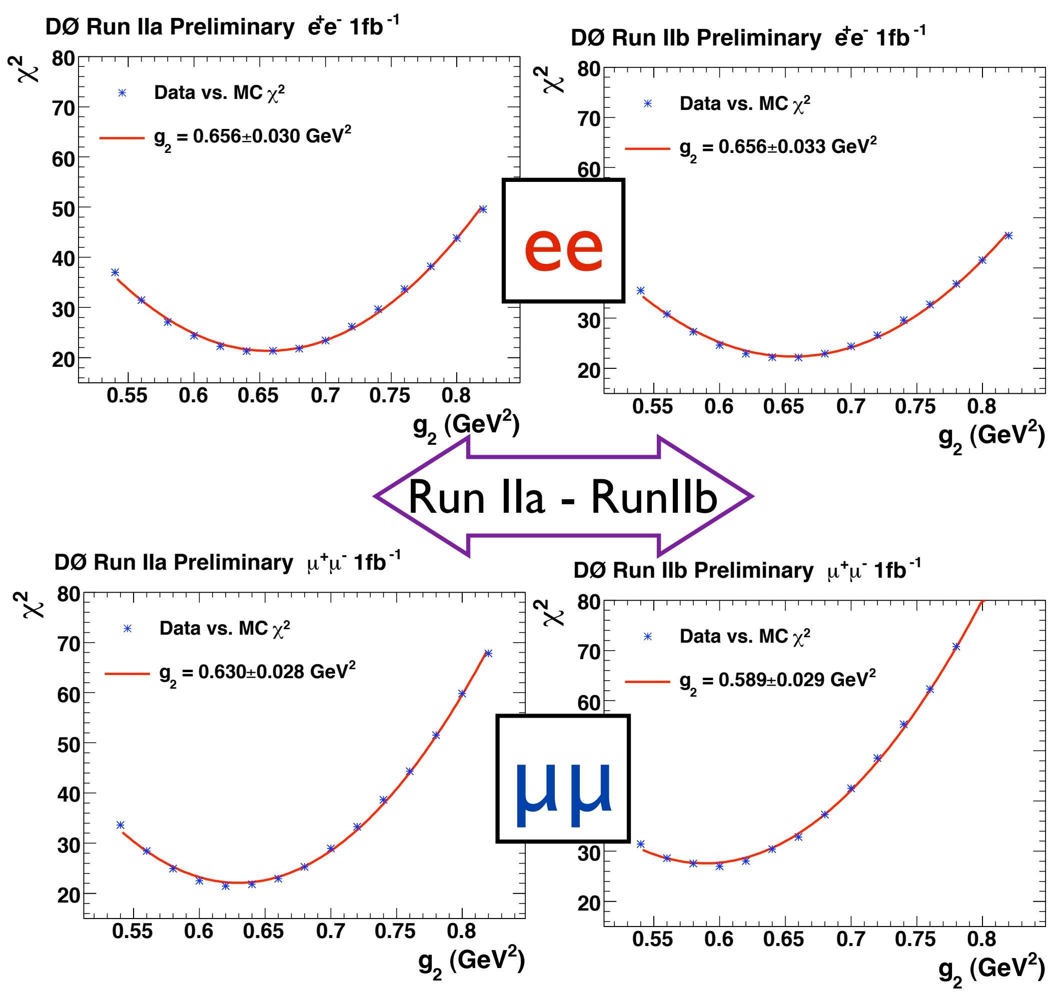
- Our goal is the *detector corrected* **a_T** distribution
- To start with: measure the value of **g_2** *without unfolding the data*
  - Compare the a_T distribution in data with MC "g_2 templates"
  - Using **a_T** allows us to use both **ee** and **μμ** decay channels!

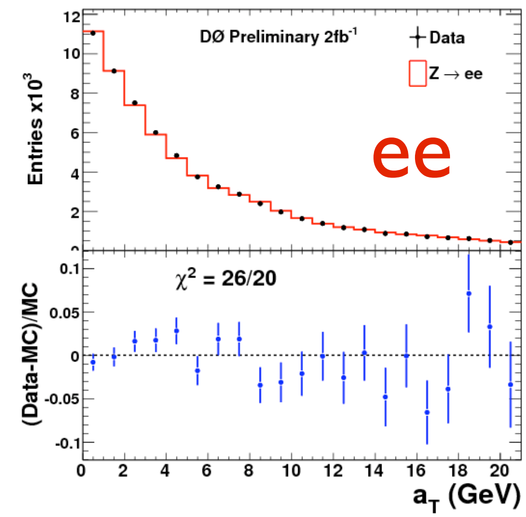


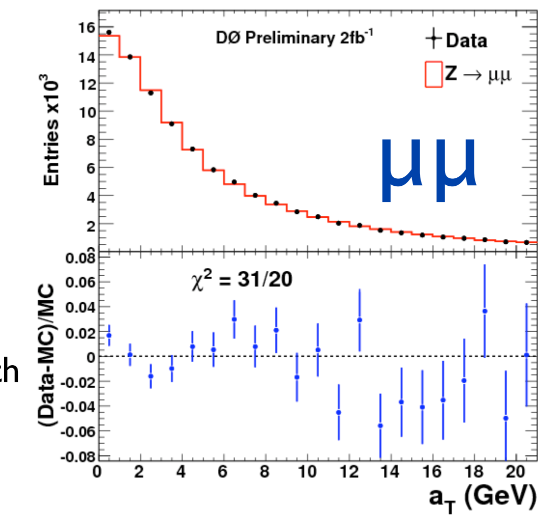


Fitting g_2

- Compare a_T distribution in data with MC "g_2 templates"
  - Find the best fit from the minimum X^2.







a_T data-vs-mc plots with combined ee and μμ measured g_2.

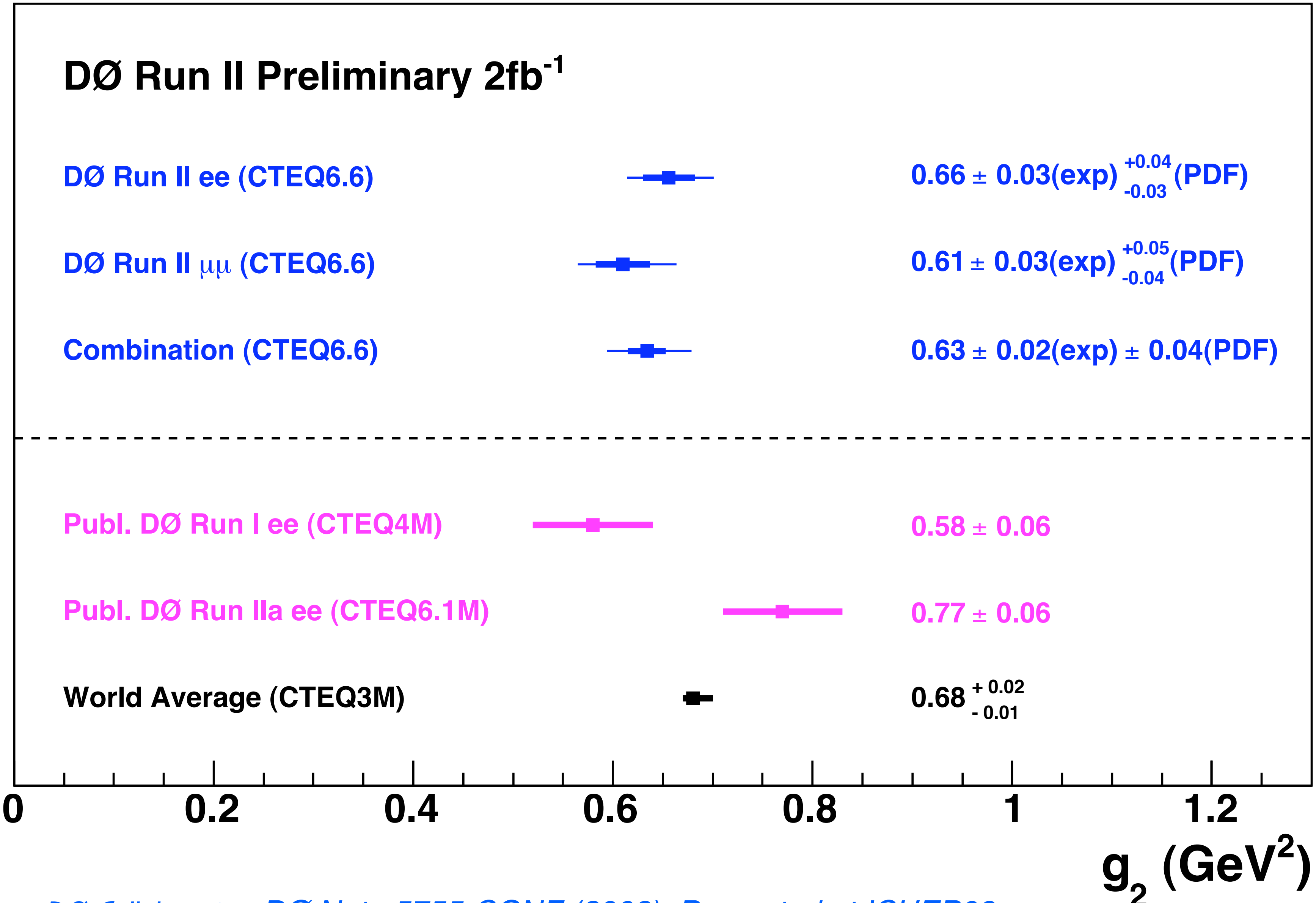
Uncertainties

- Statistical: ~3% (per channel)
- Experimental (simulation)
  - Backgrounds: ~ 1%,
  - Lepton p_T scale: ~ 0.5%,
  - Angular efficiency correlations: ~1%,
  - Efficiency dependencies on p_T and η: ~ 0.5%.
  - Final state radiation: ~ 0.5%.
- Theoretical
  - PDFs: ~ 6-7% !!

MANCHESTER 1824

The University of Manchester

Results



DØ Collaboration, DØ Note 5755-CONF (2008), Presented at ICHEP08.

The University of Manchester

Conclusions

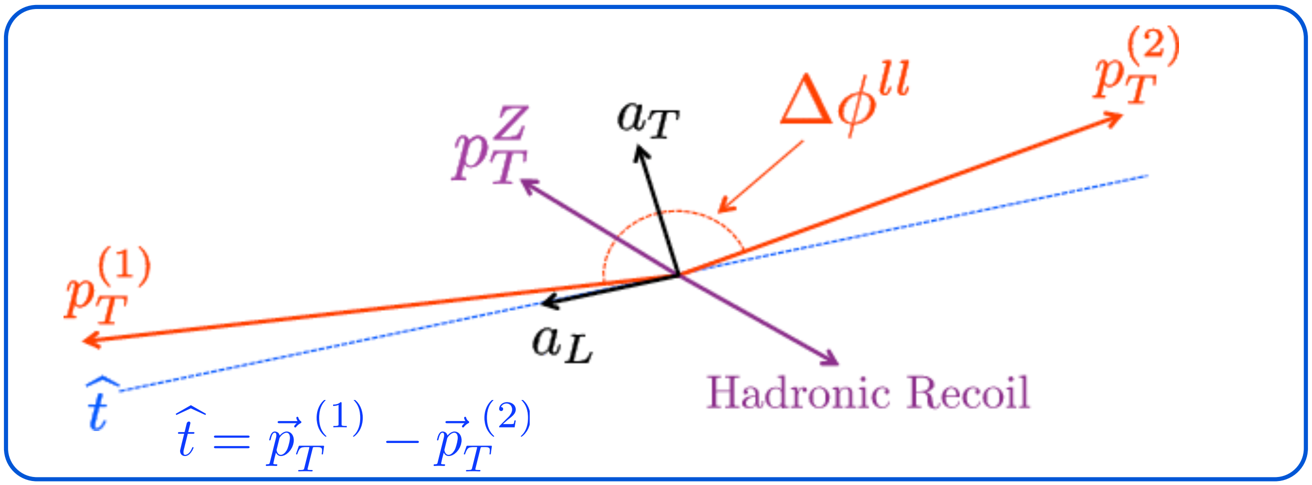
- The Z p_T is an important measurement at the Tevatron.
- Detector effects are large at low p_T.
- Novel observable **a_T** is almost unaffected!
  - *M. Vesterinen, T. R. Wyatt, Nucl. Instr. Meth. in Phys. Res. A 602 (2009); arXiv: 0807.4956v1*
- Measurement of **g_2** parameter
  - $g_2 = 0.63 \pm 0.02^{exp} \pm 0.04^{PDF}$ GeV^2
  - Both **ee** and **$\mu\mu$** channels!
  - Comparable precision to world average!
    - *DØ Collaboration, DØ Note 5755-CONF (2008), Presented at ICHEP08.*
- Detector corrected **a_T** distributions soon.

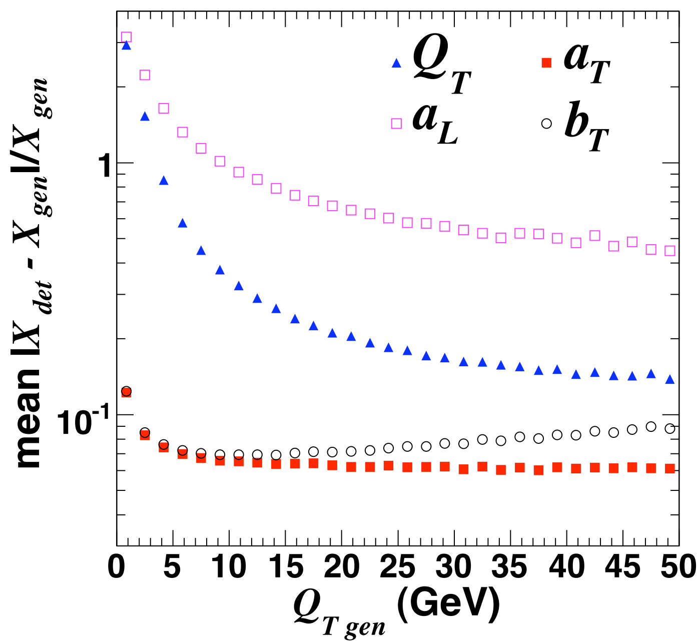
Backup slides

Lepton p_T Resolution

- Compare the resolutions of a_T, a_L and p_T.
  - Event-by-event, look at the (fractional) difference between "generator-level" and "detector-level".
  - Plot the mean of this, vs. generator level Z p_T.

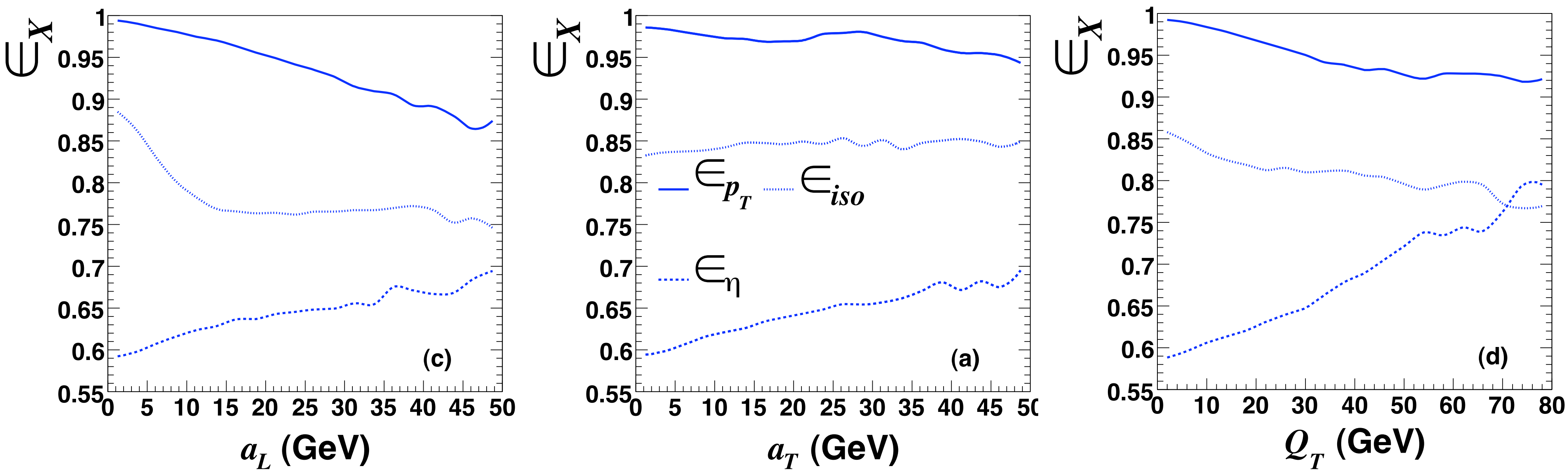
Event-by-event, a_T is much more precisely determined than the Z p_T!





Efficiency

- Apply typical event selection cuts
  - Cut on detector-level lepton p_T, isolation, pseudo-rapidity.



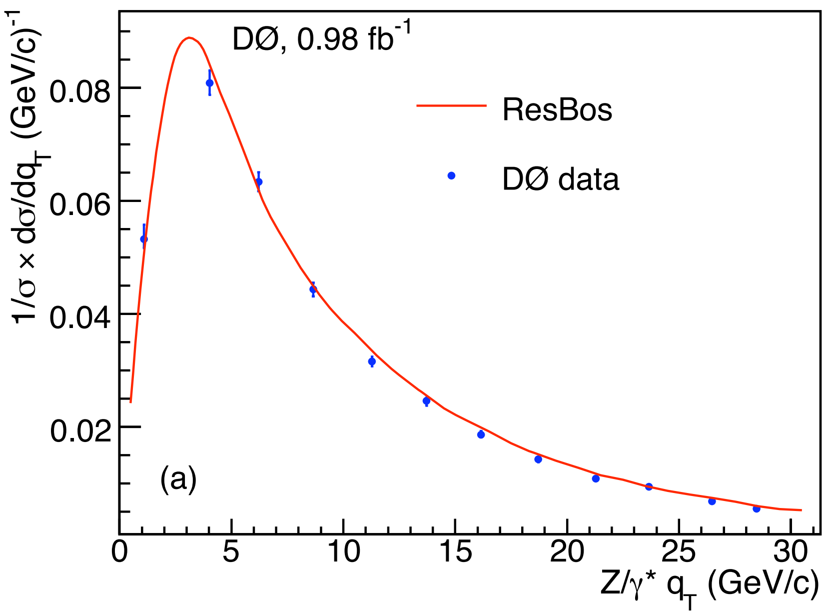
a_T is much less correlated with event selection efficiency than a_L.

MANCHESTER 1824

The University of Manchester

ResBos

- All implemented in the event generator ResBos[1]
  - "The Monte Carlo for Resummed Boson Production and Decay."
  - Matches resummation at low Z p_T to NLO pQCD at large Z p_T.
  - Key part of Tevatron W mass measurements.
- Compared with recent DØ data[2]
  - Good agreement at low p_T.



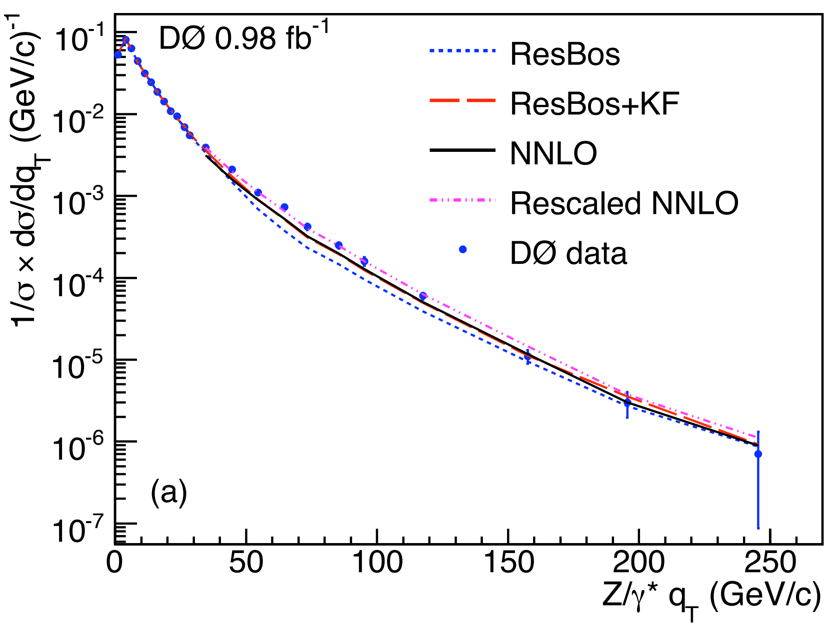
[1] C. Balazs and C. P. Yuan, Phys. Rev. D 56, 5558 (1997)
[2] DØ collaboration, V. M. Abazov et al, Phys. Rev. Lett. 100 102002 (2008)

MANCHESTER 1824

The University of Manchester

ResBos

- All implemented in the event generator ResBos[1]
  - "The Monte Carlo for Resummed Boson Production and Decay."
  - Matches resummation at low Z p_T to NLO pQCD at large Z p_T.
  - Key part of Tevatron W mass measurements.
- Compared with recent DØ data[2]
  - Disagreement at high p_T.



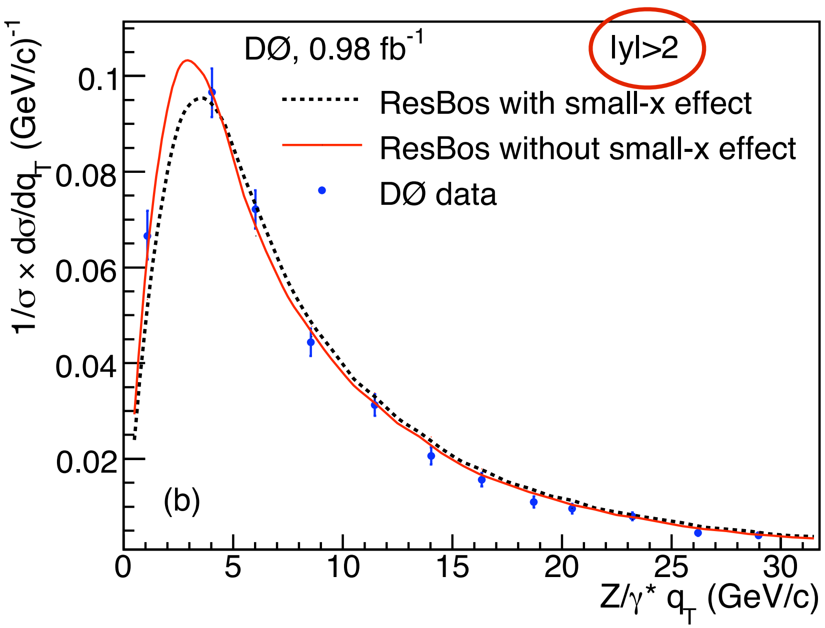
[1] *C. Balazs and C. P. Yuan, Phys. Rev. D 56, 5558 (1997)*

[2] *DØ collaboration, V. M. Abazov et al, Phys. Rev. Lett. 100 102002 (2008)*

The University of Manchester

ResBos

- All implemented in the event generator ResBos[1]
  - "The Monte Carlo for Resummed Boson Production and Decay."
  - Matches resummation at low Z p_T to NLO pQCD at large Z p_T.
  - Key part of Tevatron W mass measurements.
- Compared with recent DØ data[2]
  - Low p_T and large rapidity is very interesting but large uncertainties.

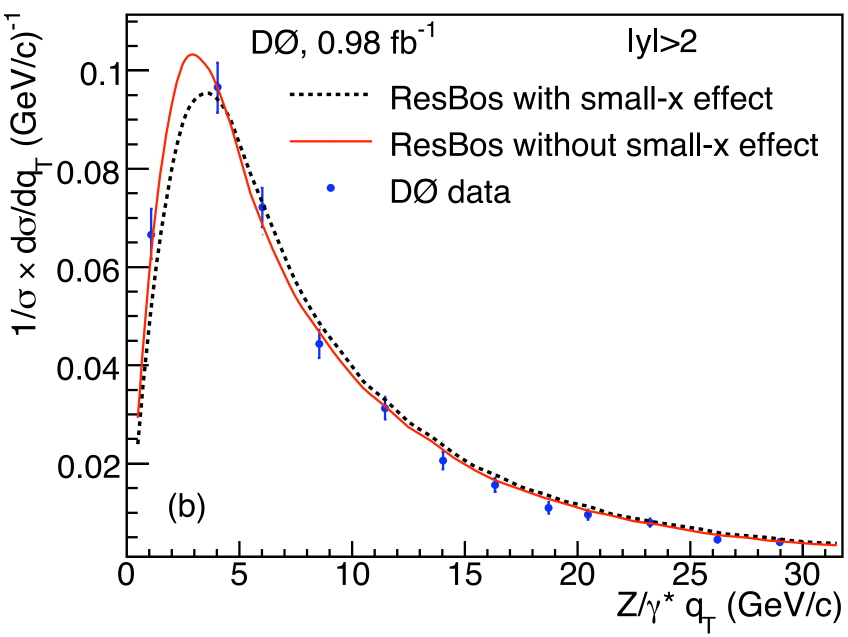


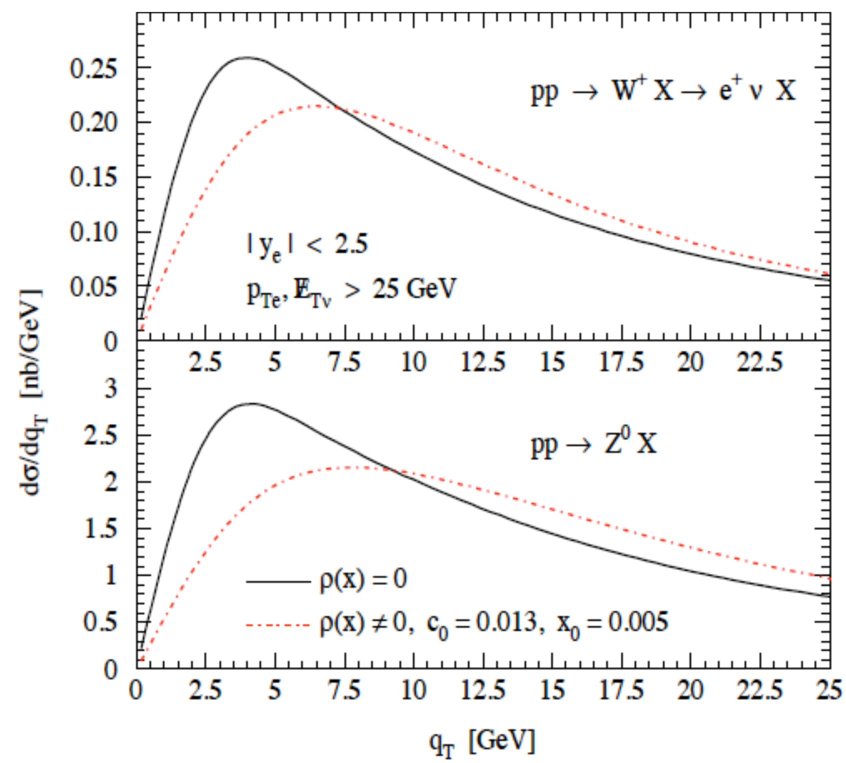
Better agreement without "small-x broadening"[3]

[1] C. Balazs and C. P. Yuan, Phys. Rev. D 56, 5558 (1997)
[2] DØ collaboration, V. M. Abazov et al, Phys. Rev. Lett. 100 102002 (2008)
[3] P. Nadolsky, D.R. Stump, and C.P. Yuan, Phys. Rev. D 64, 114011 (2001).

Small-x Broadening

- Small-x broadening was needed to describe DIS data[1]
- At the Tevatron: harder p_T for large rapdity ($|y| > 2$).
- At the LHC: harder *inclusive* p_T[2].

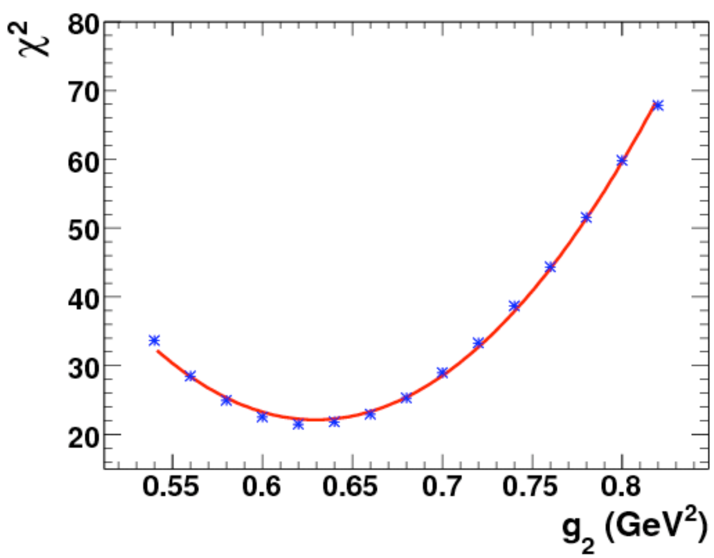




[1] *P. Nadolsky, D.R. Stump, and C.P. Yuan, Phys. Rev. D 64, 114011 (2001).*
[2] *S. Berge, P. Nadolsky, F. Olness, C. P. Yuan, Phys. Rev. D 72, 033015 (2005).*

Sensitivity to the Physics

- Do a "toy" measurement of g_2 in MC
  - Make a set of MC templates corresponding to different g_2.
  - Call a smaller subset (~200k events) of MC with particular g_2,   our "pseudo-data."
  - Fit g_2 using a minimum χ^2.
    - And get the statistical uncertainty on g_2.
    - Repeat for different lepton p_T resolutions



	p_T	a_T	a_L	$d^2\sigma/da_T da_L$
$\delta(1/P_T)$ (1/GeV)	$1\sigma\ \delta g_2$ (%)			
0.000	1.4	2.2	2.4	1.4
0.001	1.8	2.2	3.6	1.6
0.003	3.1	2.3	8.9	2.1

PDF Uncertainty

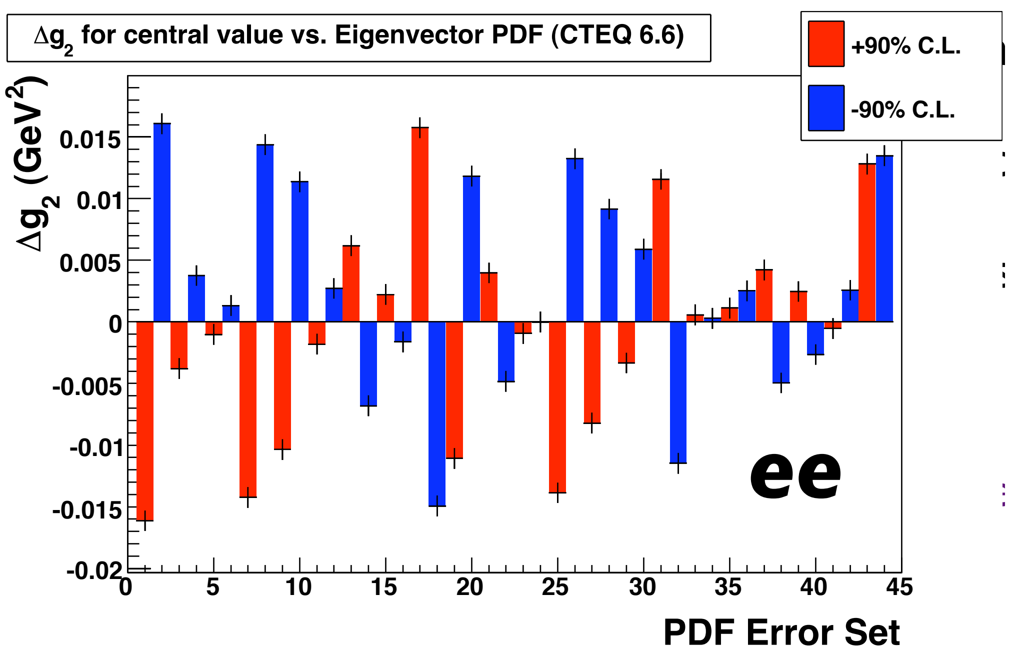
- Purely theoretical
  - Change in the ResBos $d\sigma/dp_T$ *at fixed* g_2.
    - Experimental acceptance uncertainty is negligible.
- Used the CTEQ 6.6 PDFs[1] to generate our ResBos templates
  - 22 approximately orthogonal parameters.
  - Repeat the measurement 44 more times (22x ±90% CL).
  - Basically add in quadrature the shifts in fitted g_2.
  - Some parameters shift g_2 in the same direction for + and -.
    - If this is the case, take the larger and assign a one sided uncertainty.

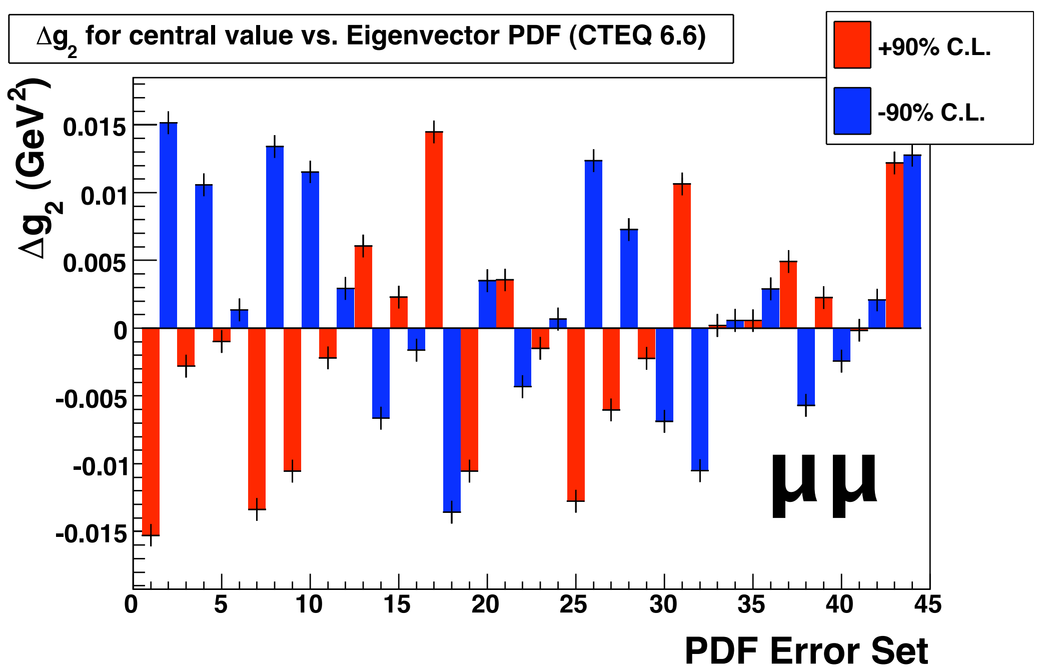
[1] *CTEQ Collaboration, P. Nadolsky et al., hep-ph/0802.0007v3 (2008).*

The University of Manchester

PDF Uncertainty

- Purely theoretical
  - Change in the ResBos $d\sigma/dp_T$ *at fixed* g_2.
    - Experimental acceptance uncertainty is negligible
- Used the CTEQ 6.6 PDFs to generate our ResBos templates

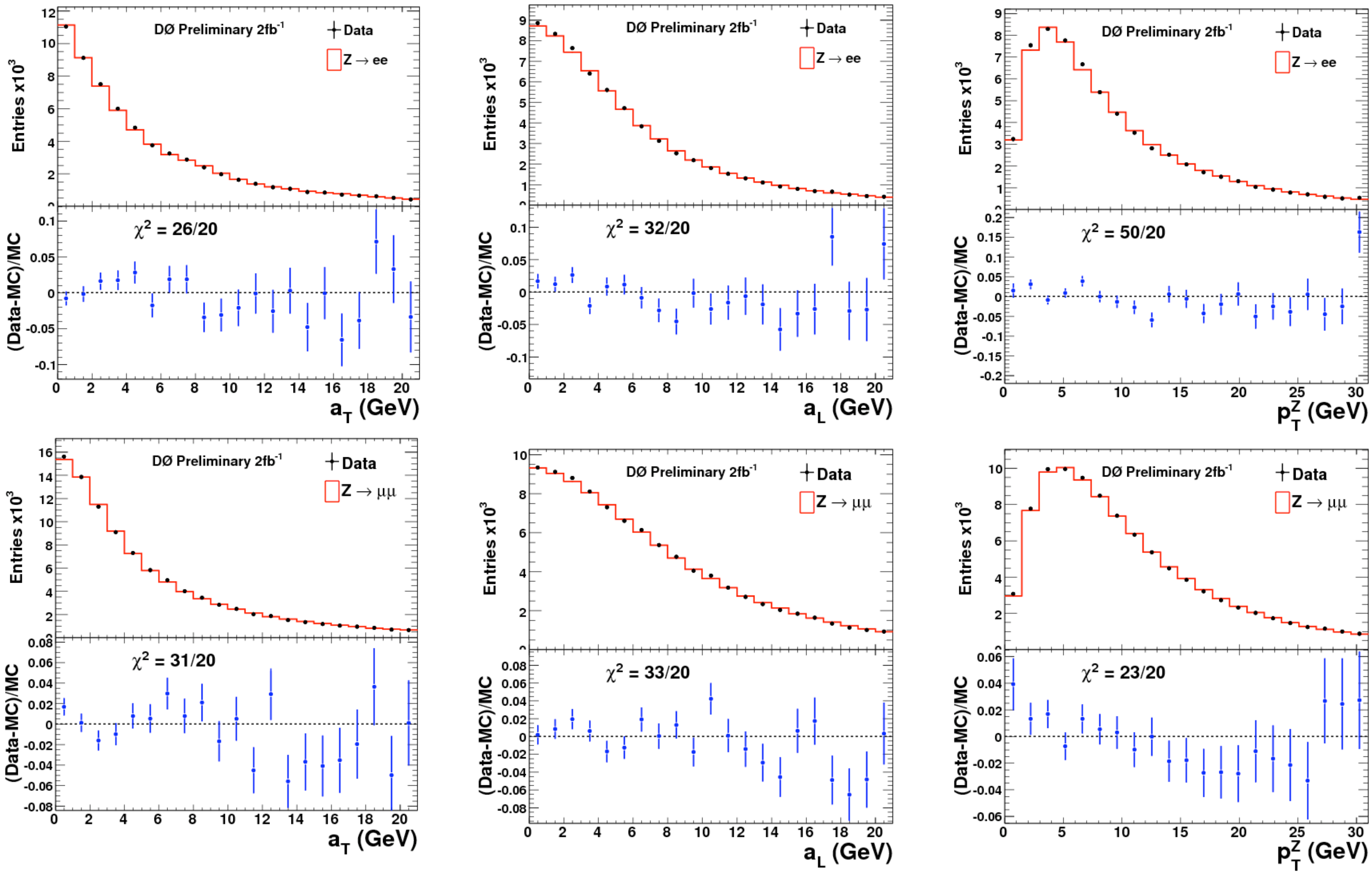




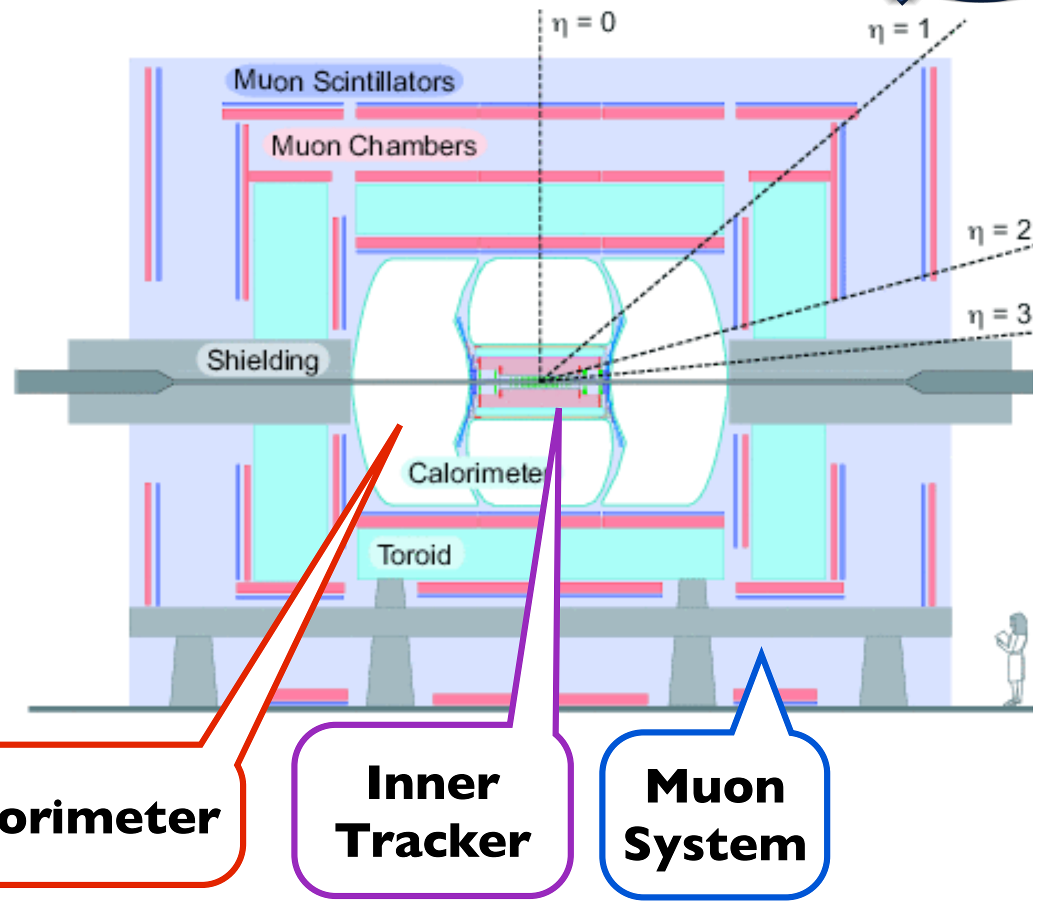
MANCHESTER 1824

The University of Manchester

The “Z pT” distributions: a_T,a_L,p_T



Event Selection



2 fb^{-1} of data

- 2x more than previous analysis

Z→ee selection

- single electron trigger
- Two EM clusters in the calorimeter
- E_T, and shower shape cuts
- Matched to a central track

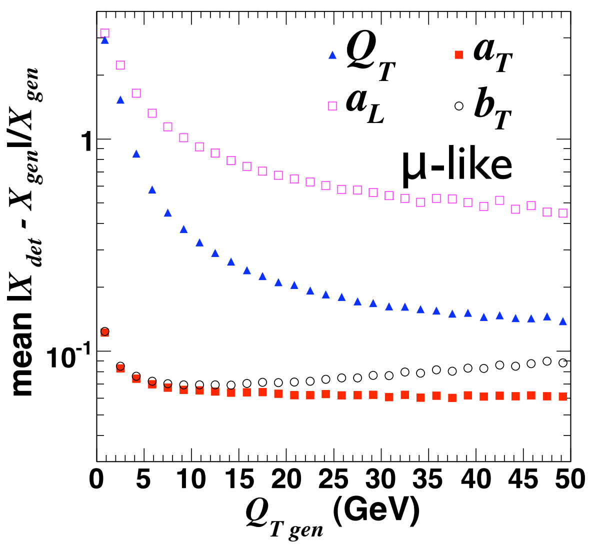
Z→μμ selection

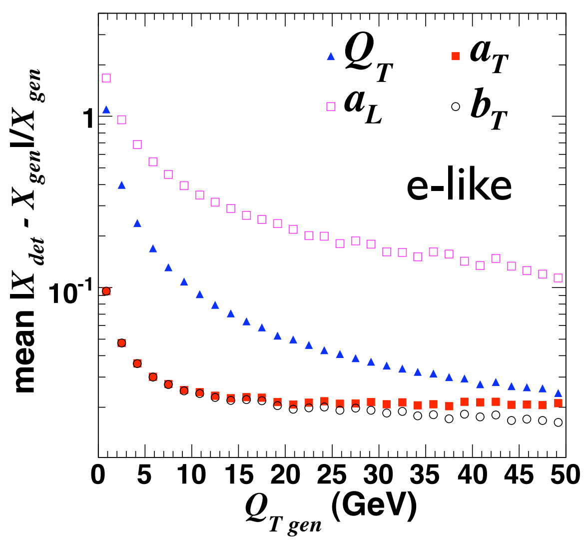
- Single muon trigger
- two muons with central track
- p_T and isolation cuts

MANCHESTER 1824
The University of Manchester

a_T vs b_T

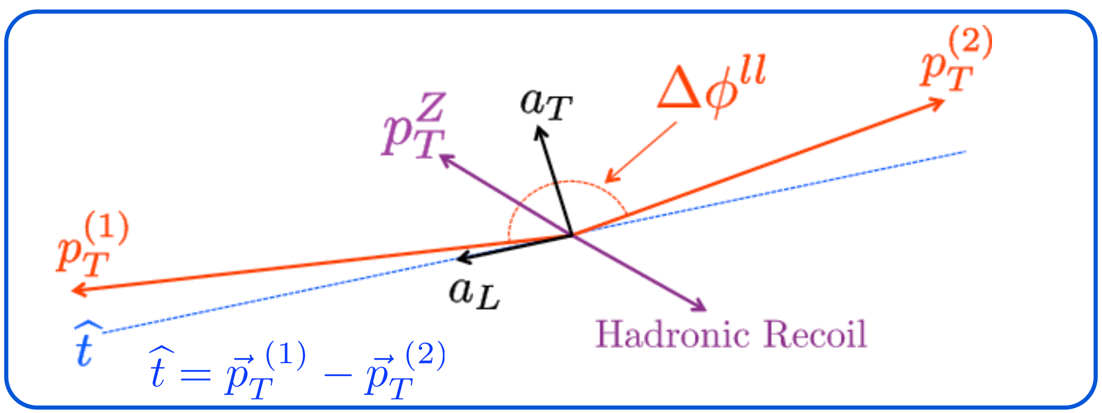
- Electron-like resolution: $\delta E_T \sim E^{1/2}$
- Muon-like resolution: $\delta(1/p_T)$ = const
- a_T is better for e-like, b_T for μ-like, so we prefer to use b_T at DØ.





$$\hat{t} = \vec{p}_T^{\,(1)} - \vec{p}_T^{\,(2)}$$

$$\hat{b} = \vec{p}_T^{\,(1)} - \frac{p_T^{(1)}}{p_T^{(2)}} \vec{p}_T^{\,(2)}$$



b_T is better for e-like, a_T for μ-like, therfore a_T is more suited for DØ.

p_T Resolution

- We originally set out to reduce our sensitivity to p_T resolution uncertainties
- Try a super-conservative variation of the resolution in MC!
  - With Z p_T, g_2 shifts by ~ ± 25%
  - With a_T the shifts in g_2 are around ~ ± 0.3%!