QCD Issues For Mw Measurement (CDF)

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Three Ways to Implement QCD with EW/QED

1. Take a (N)NLO QCD generator and add QED e.g. via PHOTOS or sampling QED MC (e.g. WGRAD) histograms.

2. Take a NLO QED MC and add QCD by sampling NLO QCD (e.g. RESBOS) histograms (and boosting).

3. Combine NLO QED MC (e.g. HORACE) with NLO QCD+PS+intrinsic kT QCD MC (e.g. PYTHIA/HERWIG..)

So far CDF/D0 have only tried (1) and (2) and we probably need to pursue both to ensure so we can probe both QED & QCD assumptions.

(3) – will require further work to get the pT(Z) [& hence PT(W)] shape to match the data with the precision we require for Mw.

The Four QCD Issues at present

1. No estimate as yet even attempted of impact of NNLO QCD/r.scale

{We ignored this in previous Mw measurements and "guessed" it for Γ_W measurement}

- RESBOS is NLO
- QCD matrix element in the NLO QED+sampled NLO QCD **is Born**…

2. The QCD sampling method is somewhat ad-hoc (is it good enough?)

- NLO corrections to W polarisation put in as weights (as $f(\cos\theta_{CS})$)
- s-hat, rapidity & Mz to Mw transition in as weights
- $p_T(W)$ boost – some ambiguity about ISR QED

3. Is REBOS – NLO+resummed BNLY good enough for 2-4fb^{-1} precision ?

- tweaks to functional form…
- Z to W (x_1x_2) dependence…
- "non-RESBOS" O(1%) contributions to $p_T(W)$ – diffr. Ws, QED ISR…

4. The PDF uncertainty…

What do we care about

1. $p_T(W)/p_T(Z)$ and ability to tune $p_T(Z)$ to data with high precision.

- $p_T(W)$ shape is the most important thing to get right; so NNLO is great but still need low p_T description (non-perturb/resummation)

  - enters via cuts $|U| < 15$ GeV and MET model is a function of $p_T(W)$. Any bias in $p_T(W)$ distorts this model and will bias Mw even in m_T fits (ν & e^- don't share $p_T(W)$ equally due to detector response). A bias in $p_T(W)$ affects electron p_T fit (Mw) linearly.

- we need the $p_T(W)$ shape to be good (mean, RMS) to < 10 MeV !!!

2. Rapidity of lepton (PDFs) - enters via cuts $[|Y_{lep}| < 1]$

There is a 2nd order coupling between the PDFs and $p_T(W)$

$p_T(Z)/p_T(W)$

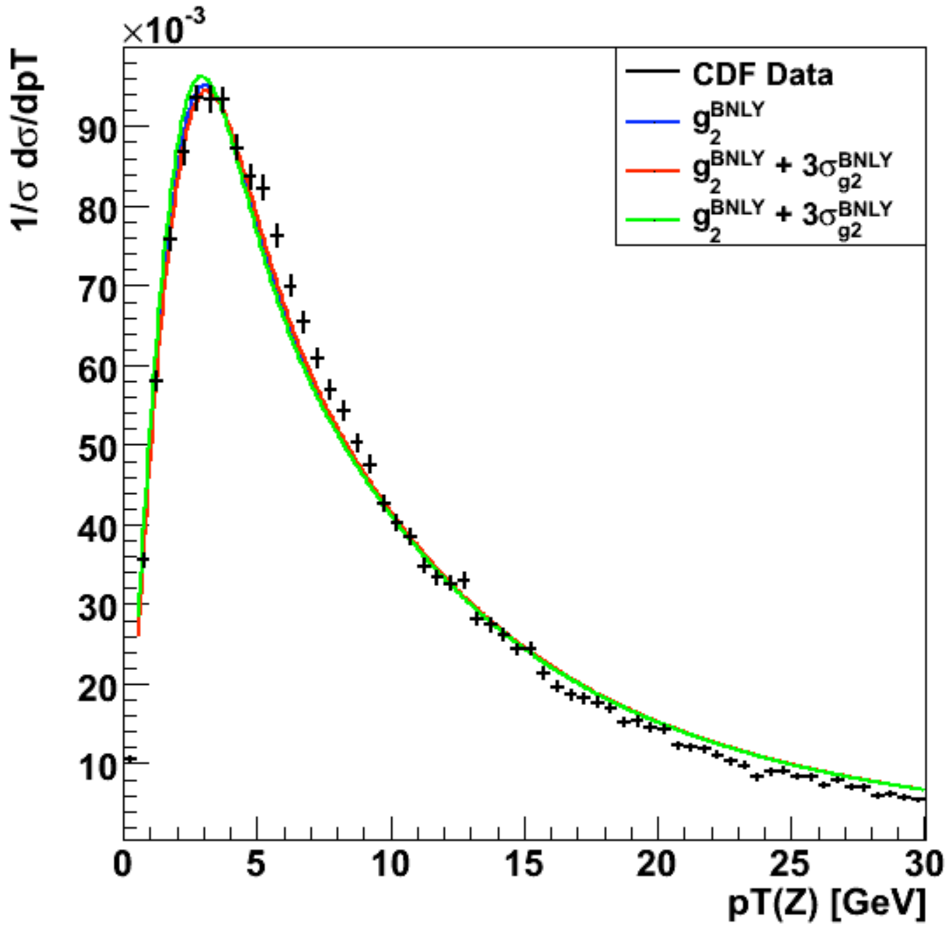
Two approaches – pragmatism vs idealism

1. Fit "theory" parameters e.g. $g_1, g_2, g_3, b_{MAX,} Q_o$ (RESBOS) to Z data & assume same parameters (with same PDF) describe W data.

2. Create ad-hoc function (4-5 parameters) to fit Z data and take Z/W p_T ratio as a function of s-hat, rapidity and p_T from "best" theory.

p_T(Z,W) in RESBOS

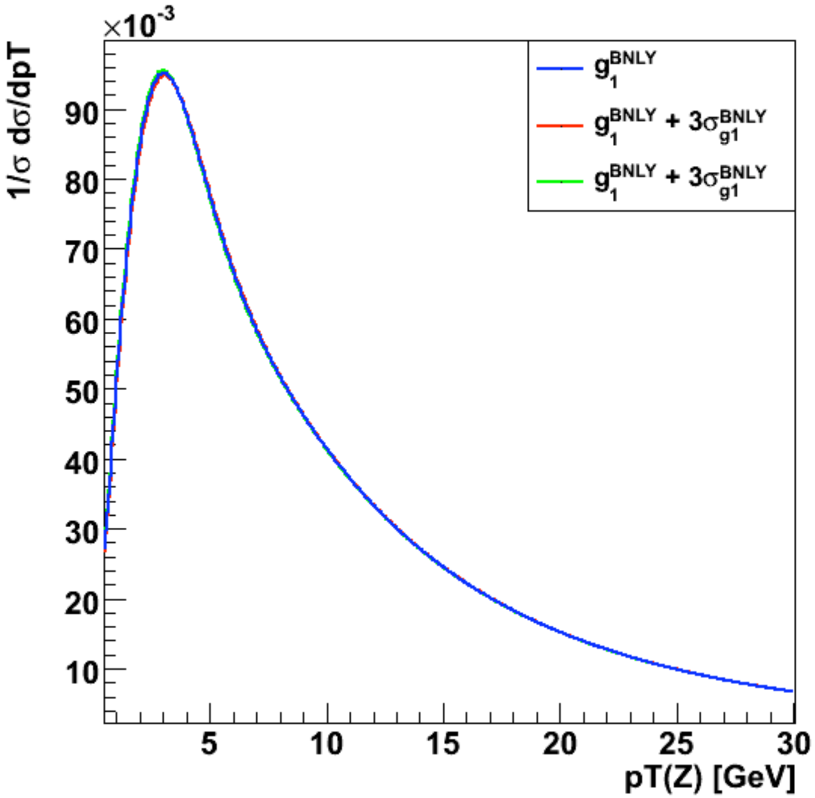
Described by 5 parameters – realistically we can only constrain one (g_2) from Tevatron data.

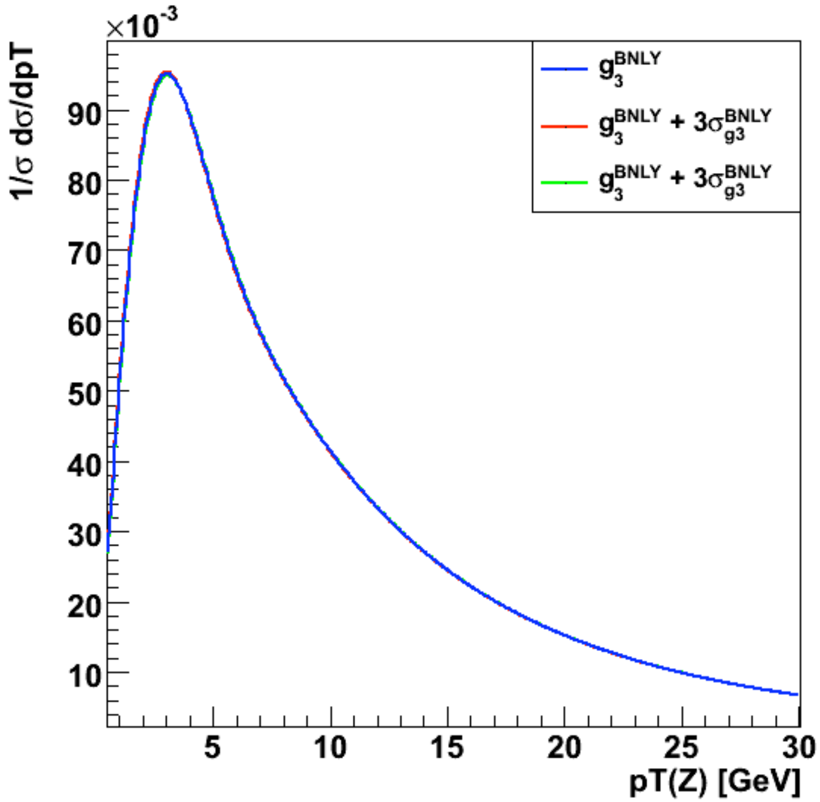


Ideally we'd do these fits in conjunction with low energy data as a function of PDF.

$p_T(Z,W)$ in RESBOS

g_1 and g_3 variance at Tevatron….

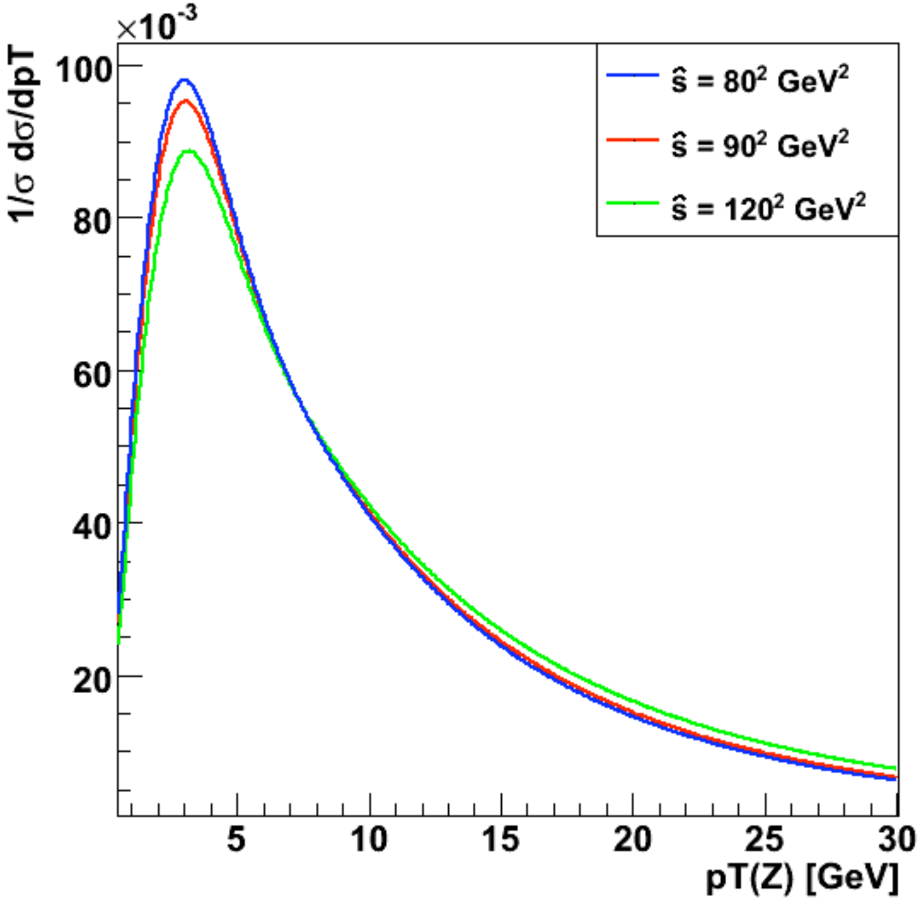




We effectively do a one parameter fit (g_2)…. is this accurate enough and is their sufficient flexibility for the precision of 2-4 fb^{-1} measurements ?

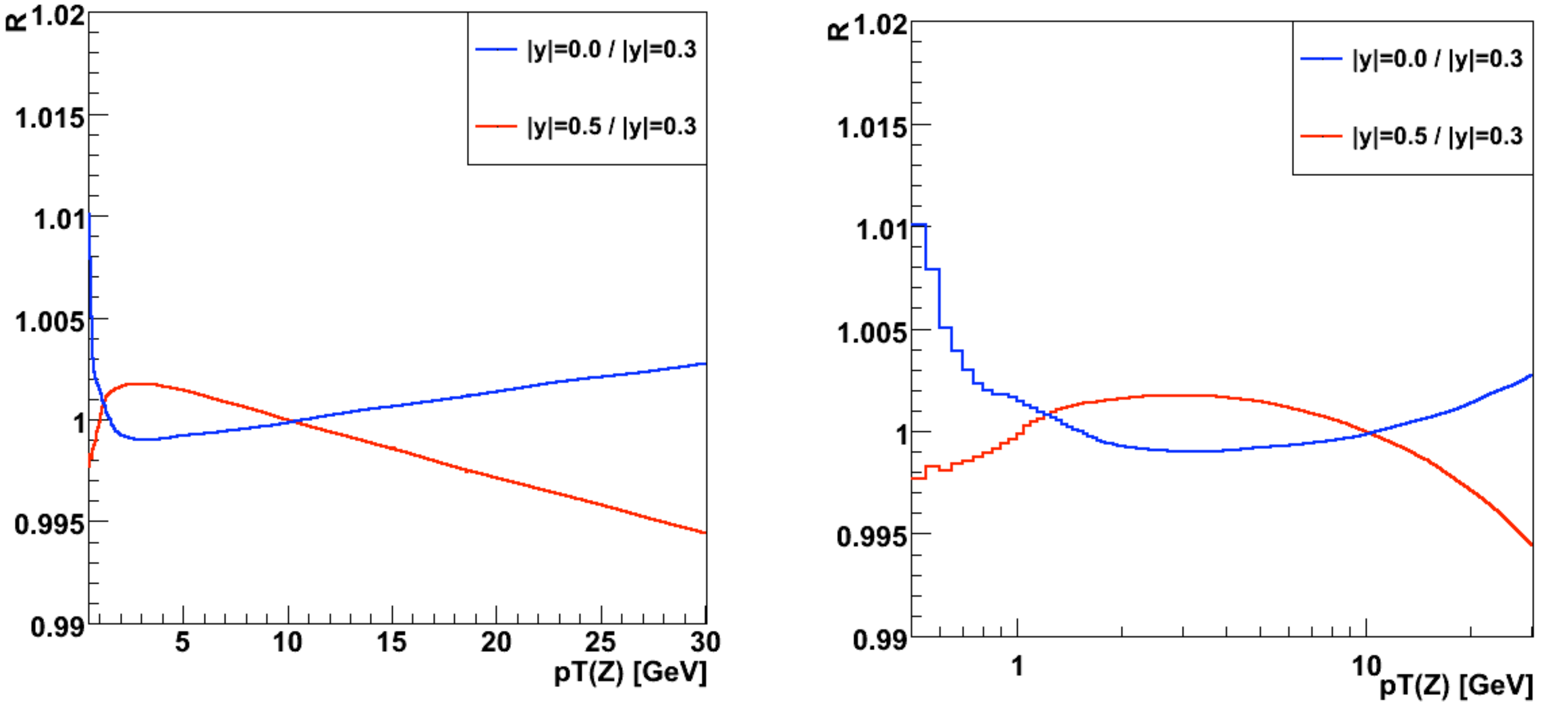
How reliable is the $p_T(W)/p_T(Z)$ Ratio ?

Need to take into account different s-hat (particularly for Γ_W) and rapidity distributions



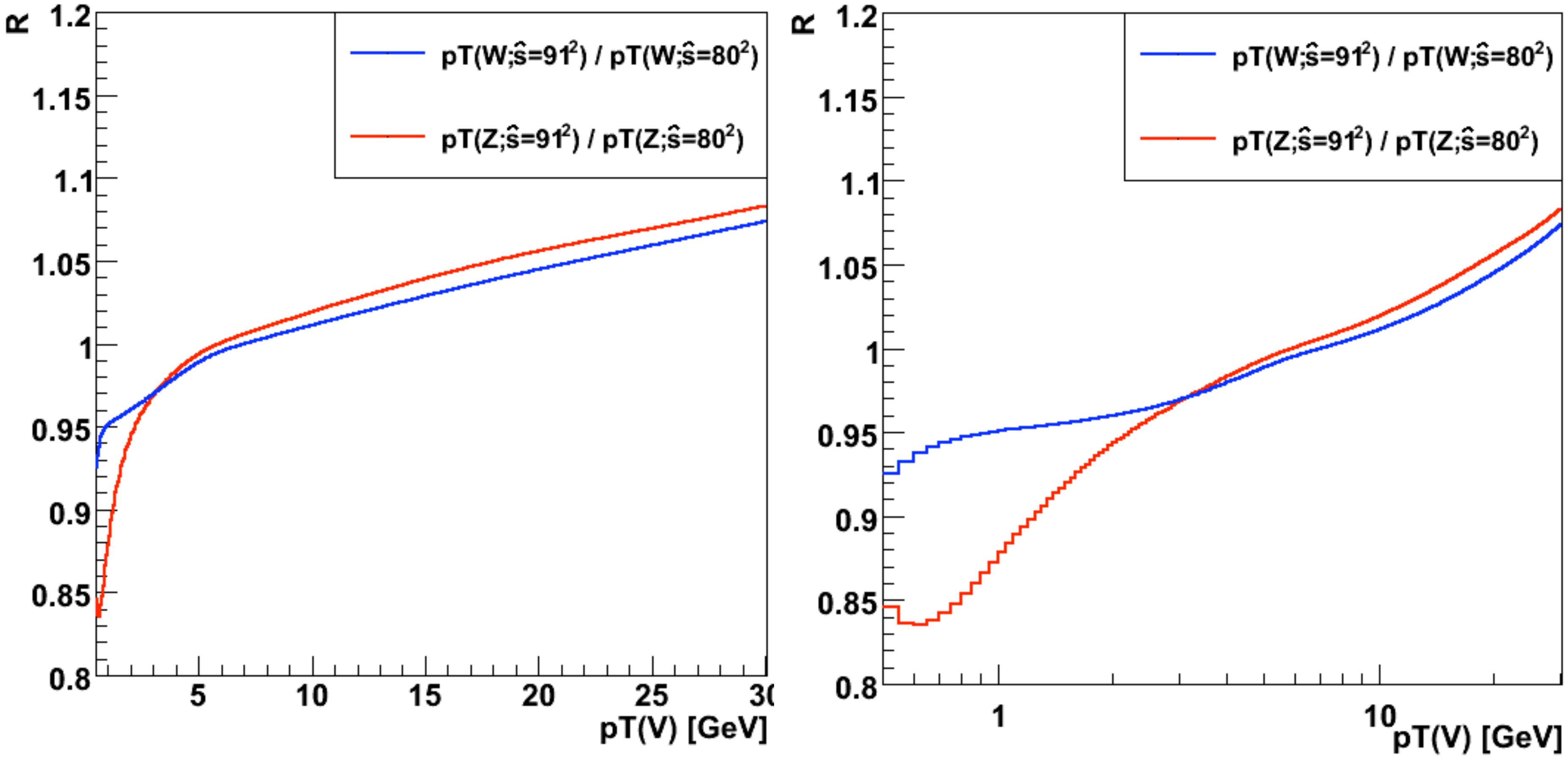
Rapidity Re-weighting..

"R" is ratio of Z/W p_T

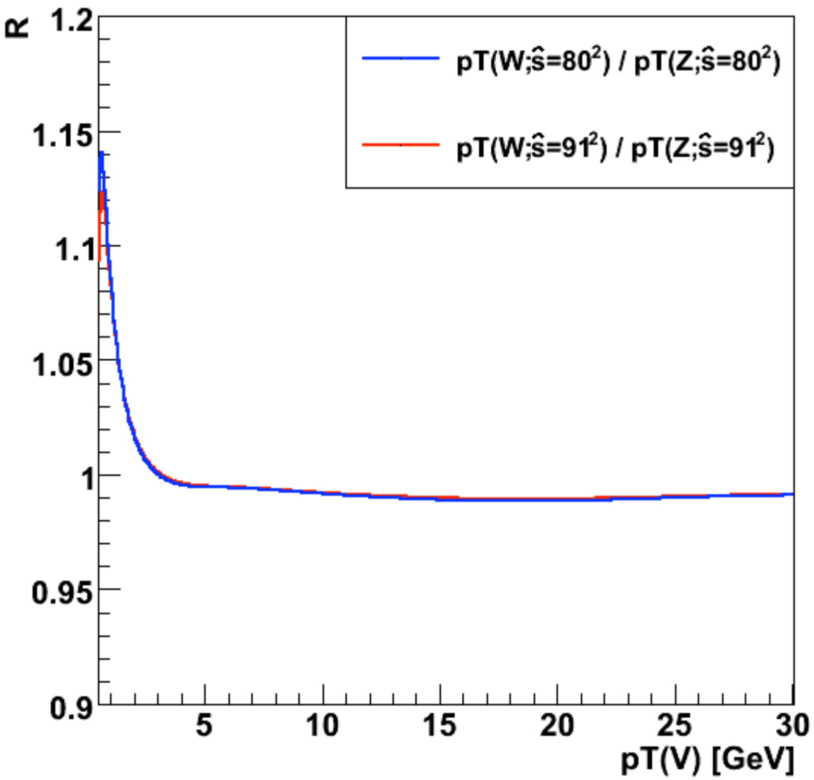


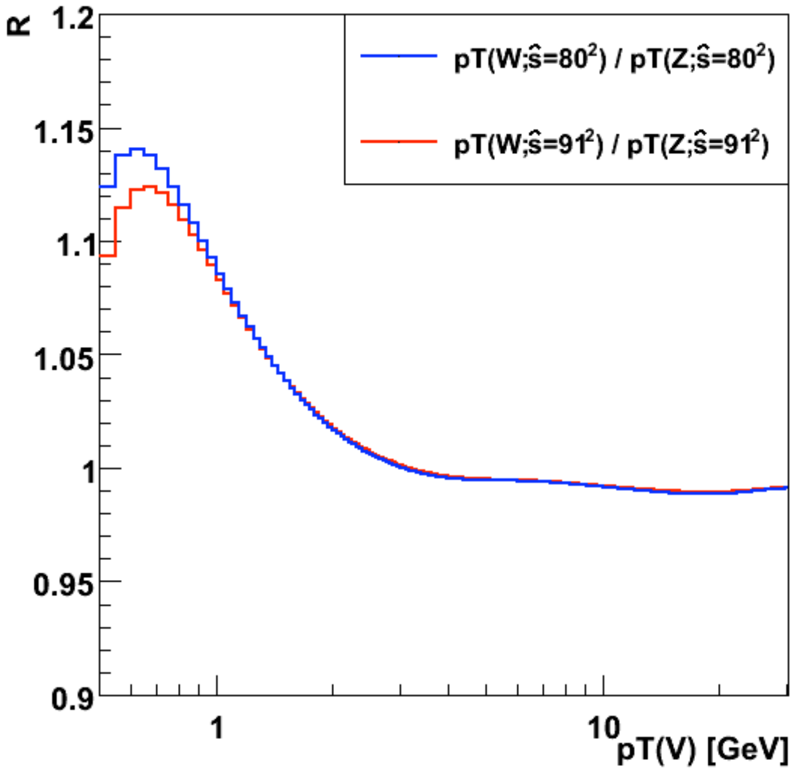
s-hat Re-weighting..

Depends e.g on x_1x_2 dependence in NP (RESBOS) functional form



Having corrected to same Y and s-hat



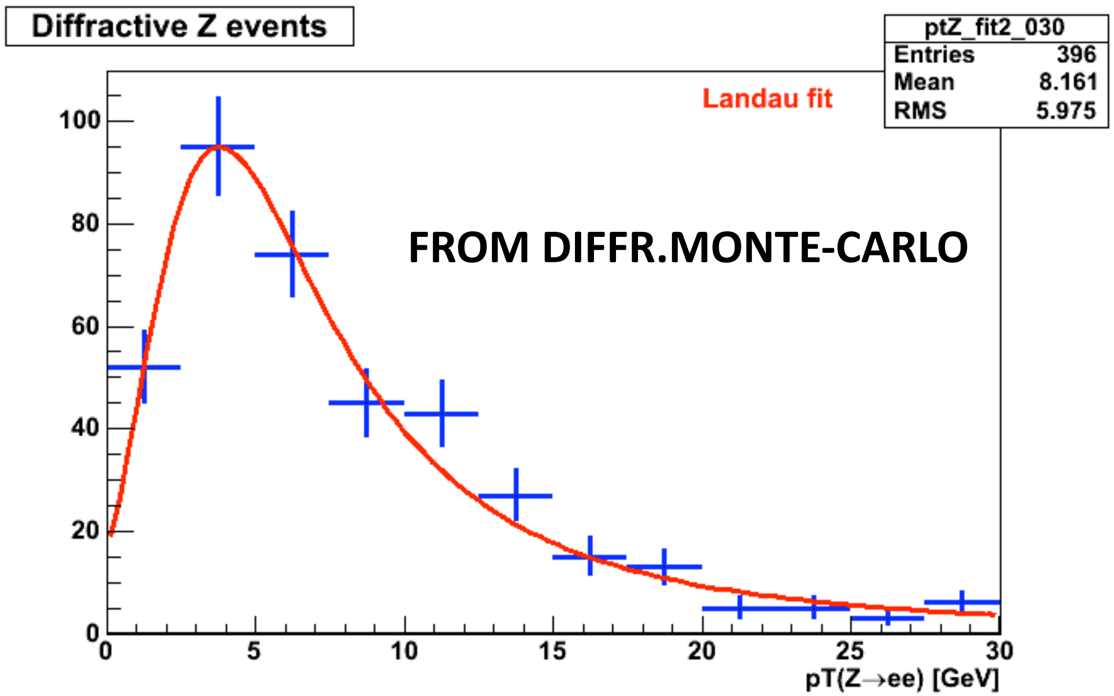


How reliable is this as p_T(W) goes to 0 ???

Other contributions to initial state pT

What about other effects that boost (in p_T) the final state not in RESBOS
- QED ISR
- Diffractive Zs and Ws

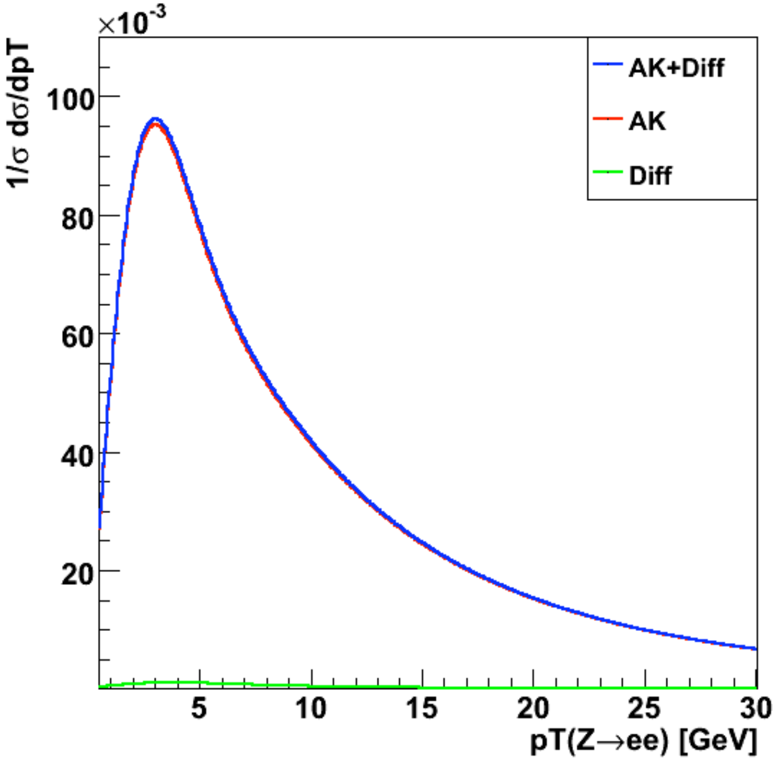
These may bias our $p_T(Z)$ shape at low p_T which we aren't modelling…

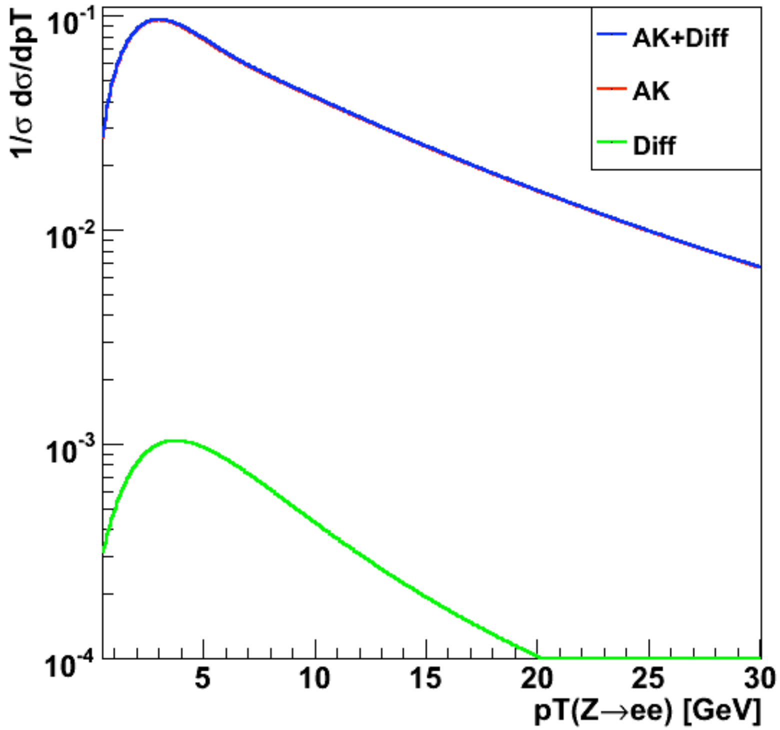


Narrower and at lower pT

1% effect but adding it improves the chisq of our Z p_T fit.

Diffractive W/Z

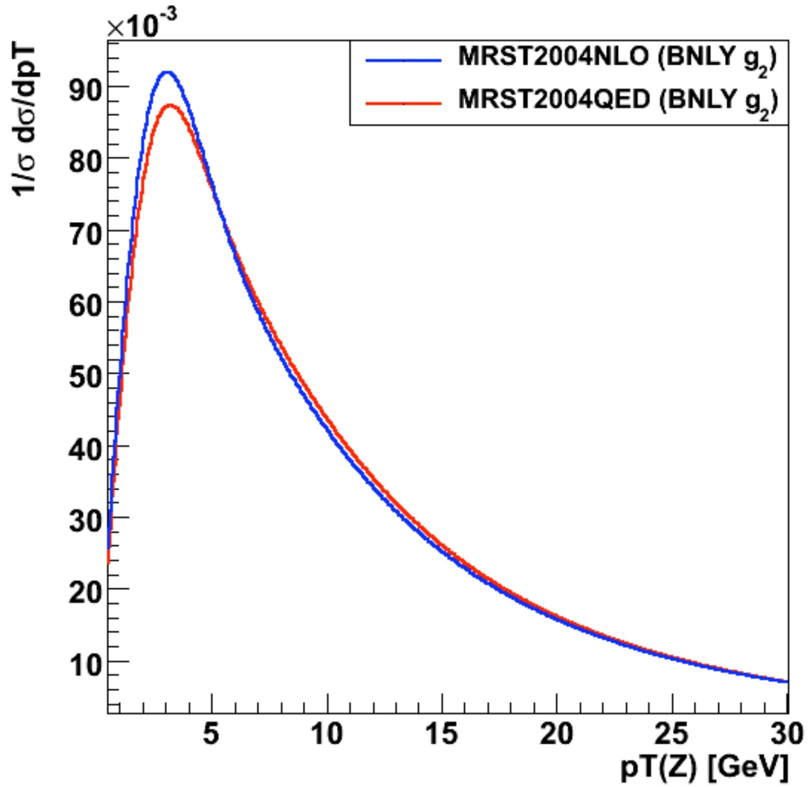




QED ISR

Two issues:

- should use QED evolved PDFs to regulate calculation - but only have one set with no errors and $p_T(W)$ shape is slightly off for this set
- it adds to the boost ($P_T(W)$) and could bias $p_T(Z)$ fit … – how do we account for this

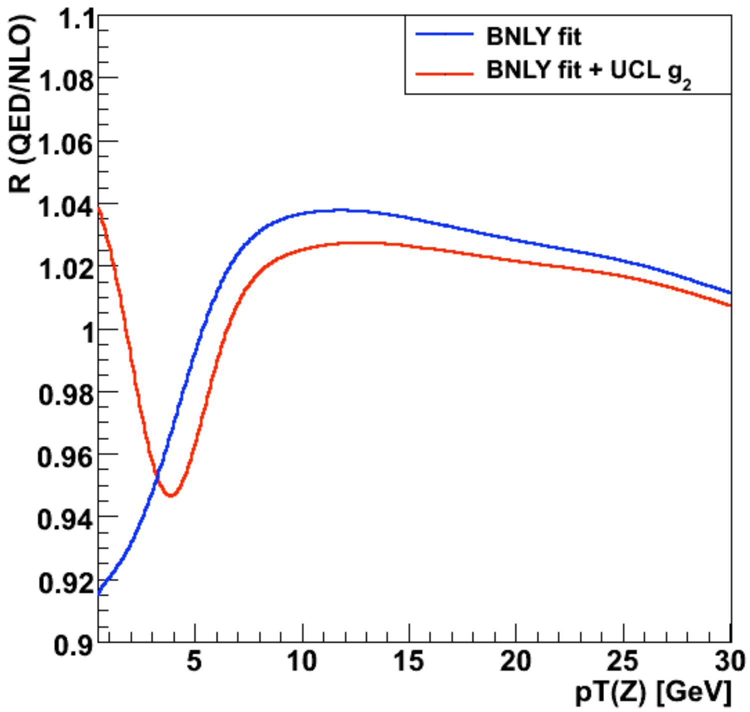


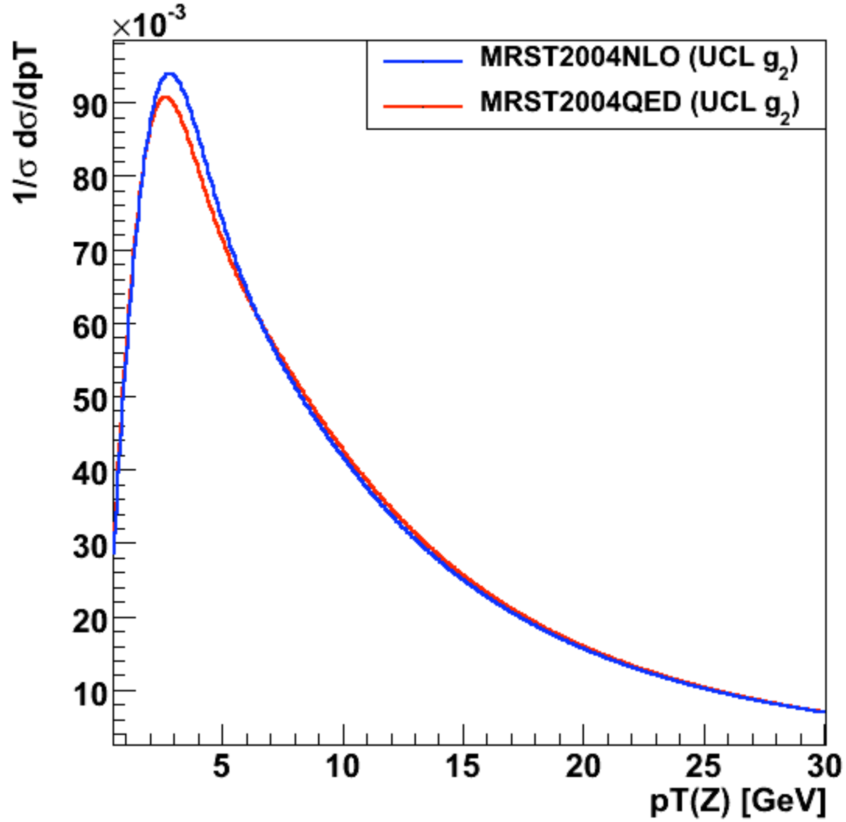
Same g_2 only difference is QED / not QED PDF

Need a different g_2 tune

QED Evolved PDF PT vs non-QED evolved

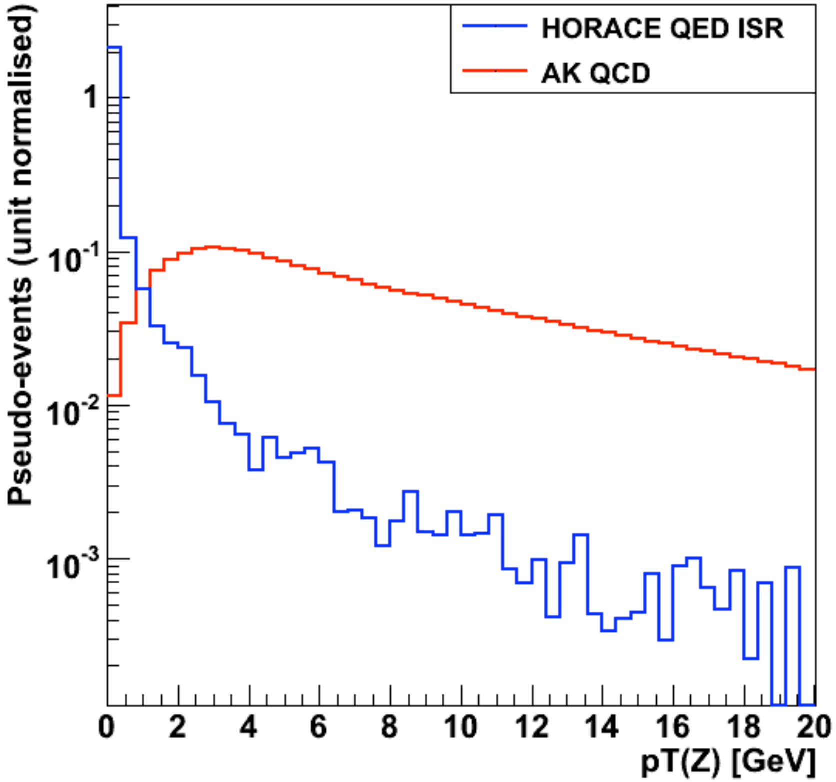
After re-tuning g_2 still significant difference in shape and QED evolved PDFs give poor $p_T(W)$ description…..

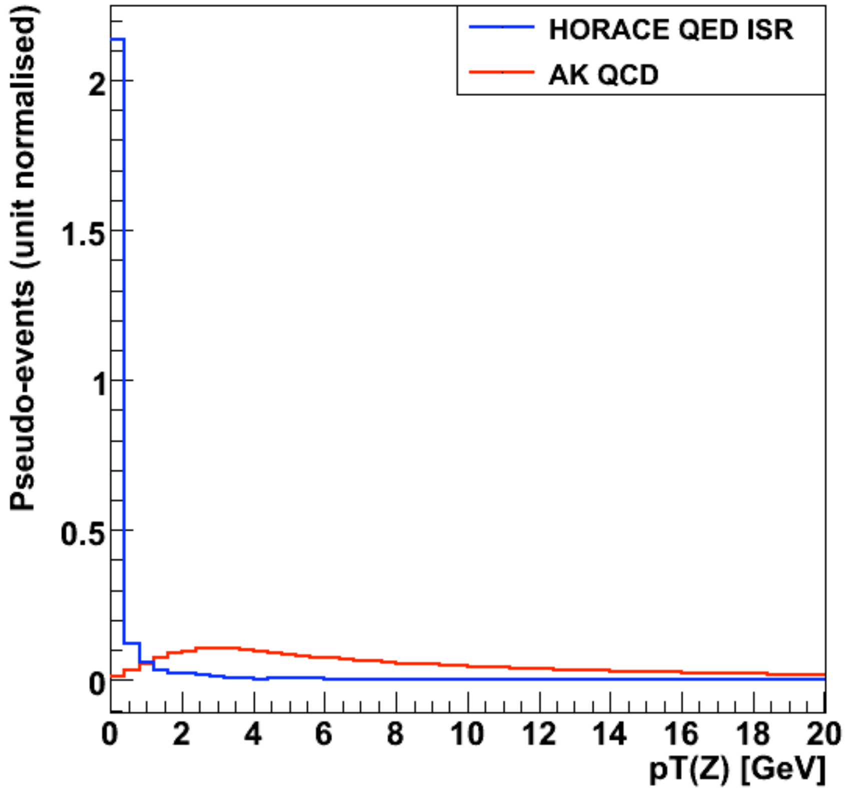




QED ISR Contribution to $p_T(W)$ Boost

Guestimate QED ISR by looking at photon angle to quark,lepton direction





Again this contribution does affect the quality of the $p_T(Z)$ fits

$p_T(W)$ Boosting

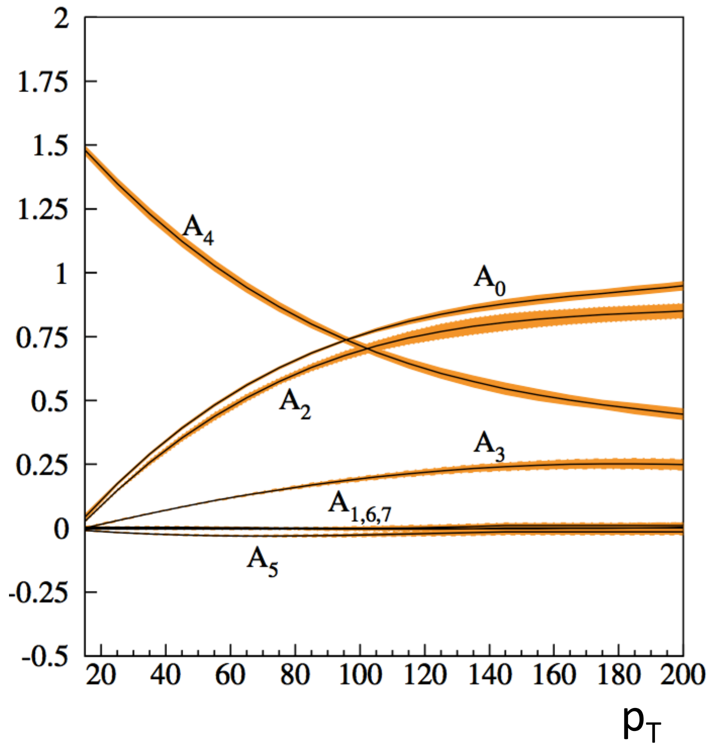
- How this done determined by internal structure of generator eg whether fix Y or Pz and reweight x_1x_2 etc

- QCD and QED $p_T(W)$ boosts not simply additive…

- Whether this makes any difference remains to be seen….

W Polarisation / Decay

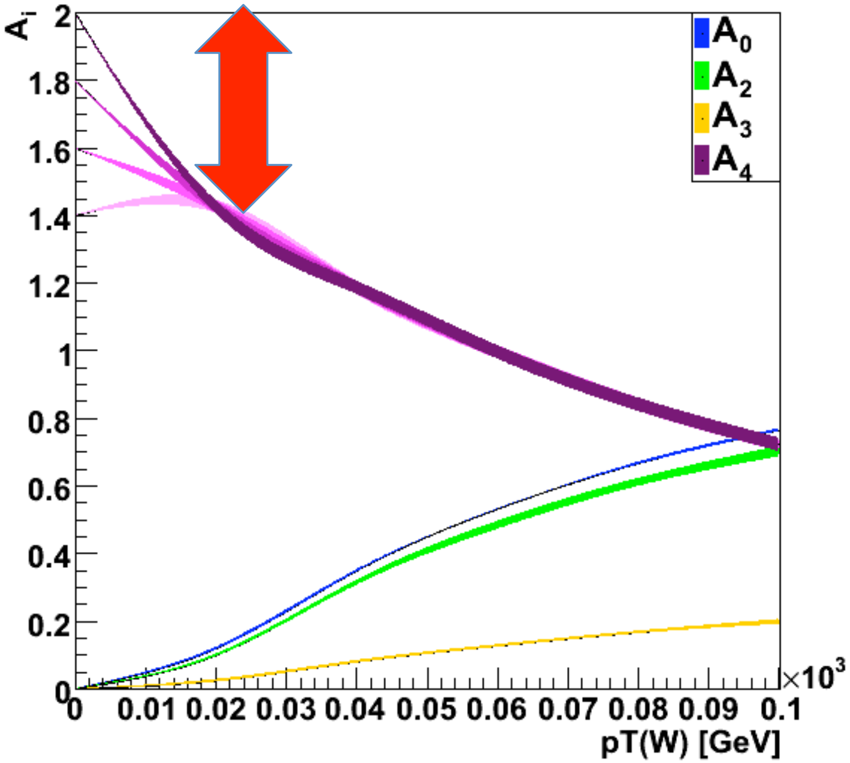
$$\frac{d^4\sigma}{dQ_T^2 dy d\phi d(\cos\theta)} = \frac{3}{16\pi}\frac{d^2\sigma}{dQ_T^2 dy} \times \Big[(1+\cos^2\theta) + \frac{A_0}{2}(1-3\cos^2\theta) + A_1 \sin 2\theta\cos\phi + \frac{A_2}{2}\sin^2\theta\cos 2\phi + A_3\sin\theta\cos\phi + A_4\cos\theta + A_5\sin^2\theta\sin 2\phi + A_6\sin 2\theta\sin\phi + A_7\sin\theta\sin\phi\Big]$$



These "A" only "well-defined" in high p_T region but our measurement is at low p_T and they depend on PDFs (sea/valence mix)

W Polarisation / Decay

This is 40 MeV in Mw

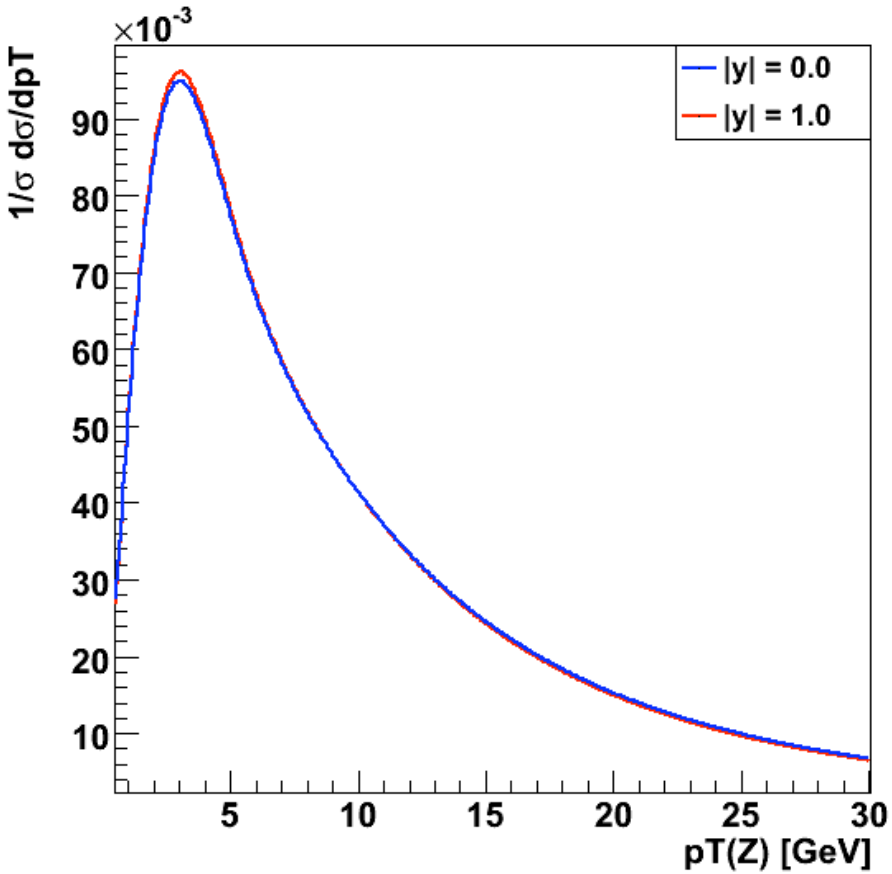


A prescription on what is a reasonable change in A would be appreciated…

Reasonable variation could still be 5 MeV in Mw …

PDF to $p_T(W)$ Coupling

$P_T(Z)/P_T(W)$ and shape of $P_T(Z)$ have weak Y (hence PDF) dependence and we also have an “acceptance” bias from cutting at Y=1.0.



In general we assign a “$P_T(W)$ error” AND an independent PDF error. There is probably some double counting here… a more careful prescription could potentially alter this total error.

Pavel’s talk…

PDF to $p_T(W)$ Coupling

Each PDF needs its own $p_T(W)$ non-perturbative tuning

PDF	g2 fit
CTEQ6M	0.68
CTEQ61	0.68
CTEQ65	0.70
CTEQ66	0.69
MRST2004NLO	0.62
MSTW2008NLO	0.64

Questions / Issues

1. Is it worth a joint P_T(W)-PDF error evaluation ?

2. Is RESBOS/BNLY functional form good enough – how reliable is the Z/W p_T ratio particularly as p_T -> 0 ?

3. Should we care/bother with diffractive contribution to P_T(W)

4. What do we do about QED ISR
   – QED PDFs don't give good P_T(Z) !
   - some ambiguity in how to handle boost.

5. Factorisation scale uncertainty – changes in P_T(W) are huge but then can be absorbed by retuning the NP function ….

6. W polarisation (Ai) uncertainty ?

Questions / Issues

7. What is uncertainty from neglecting NNLO terms and how do we evaluate this (using LO QED + sampled NLO QCD isn't very rigorous). Compare m_T NLO (+ tuned pT(W)) + m_T NNLO (+tuned pT(W)) - crucial in all of these to have PT(W) accurate to 5-10 MeV.

8. Should we throw in an α_S uncertainty or does PDF error cover this ?

9. **Perennial question** – is comparing QCD+QED sampling with QED+QCD sampling good enough to get a feeling for QCD-QED coupling - so far no one has really used RESBOS-A….