$p_T(Z)$ effect on Γ_W

Effect of NLO QCD corrections to W production on $U_{||}$

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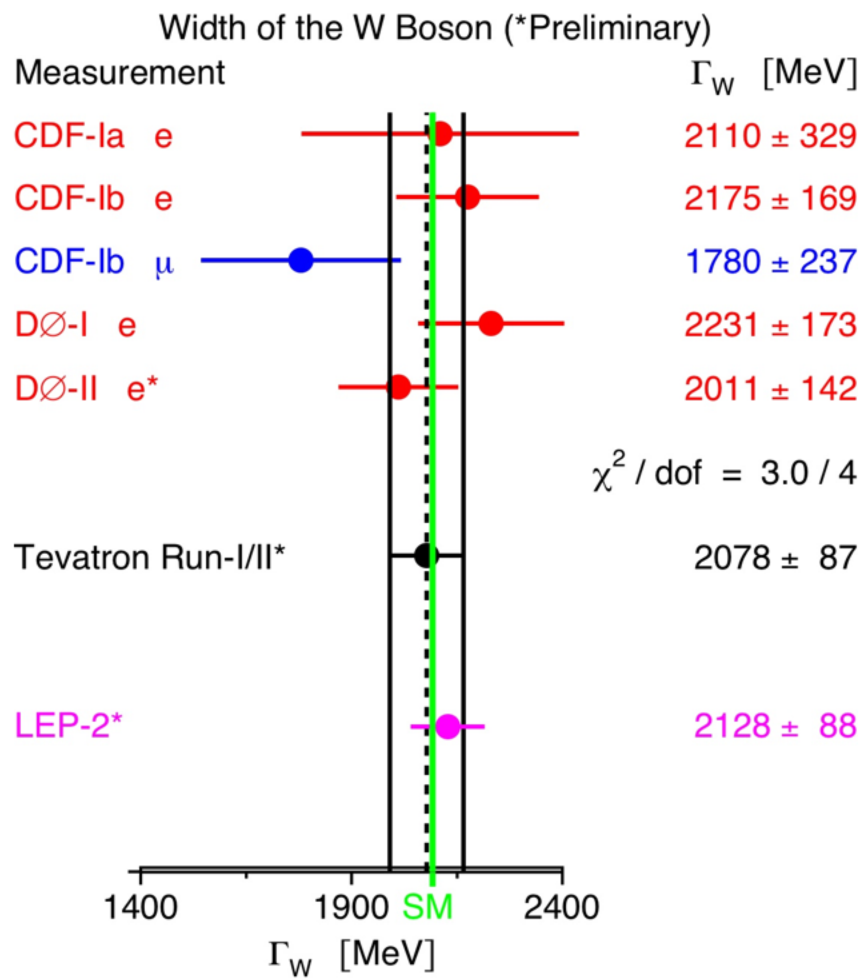
Why measure Γ_W?

- UCL working toward a measurement of W width.
- An anomalous Γ_W would indicate new physics but uncertainty in measurements makes it an inefficient place to search for new physics
- Sets the foundation for a W mass measurement.

- 2005 update from PDG:

$$\Gamma_W(\text{SM}) \approx 2.0936 \pm 0.0022\,\text{GeV}$$
$$\Gamma_W(\text{meas.}) = 2.124 \pm 0.041\,\text{GeV}$$

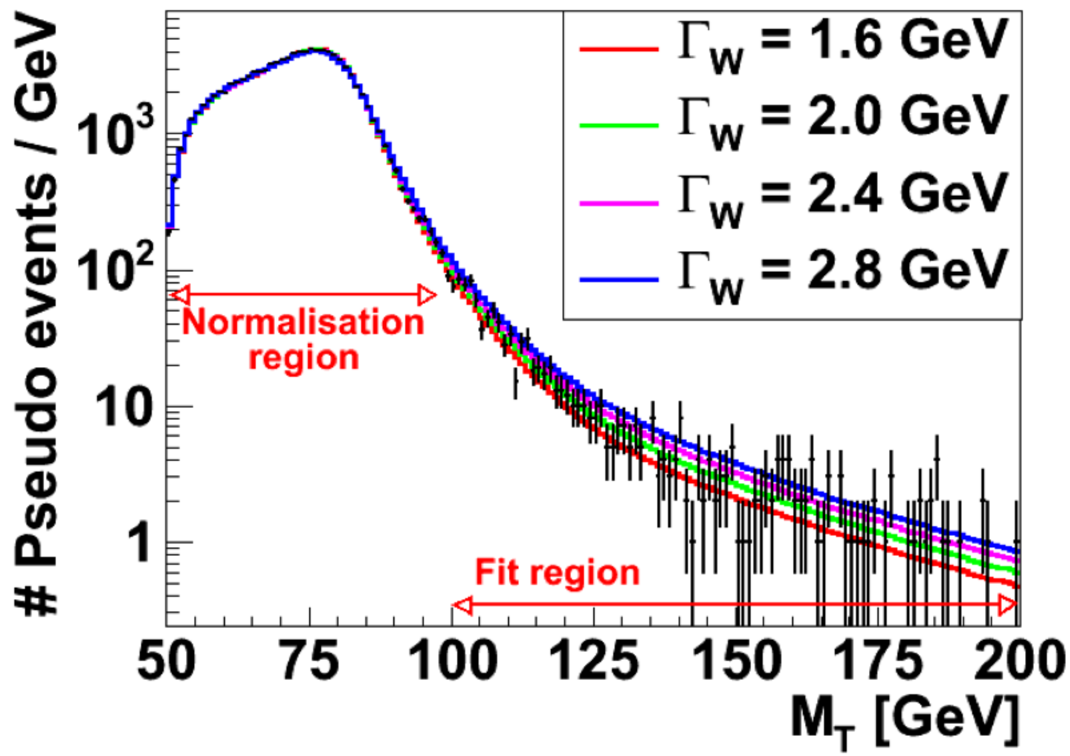


Direct Γ_W measurement

- Model M_T in fast simulation and create templates for different values of Γ_W.
- Line-shapes are normalised to data in the peak region.
- The tail of the M_T distribution is used for fitting.

$$M_T = \sqrt{E_T^2 - P_T^2}$$

100k Events: Simulated Data

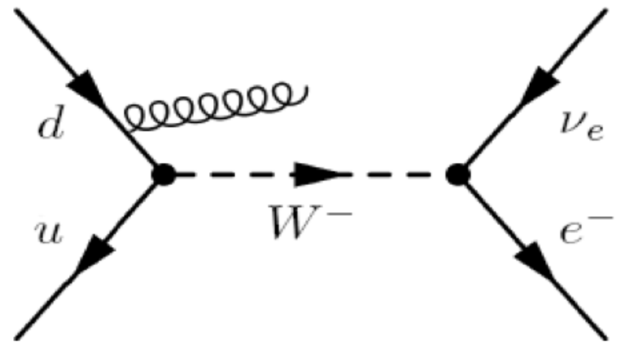


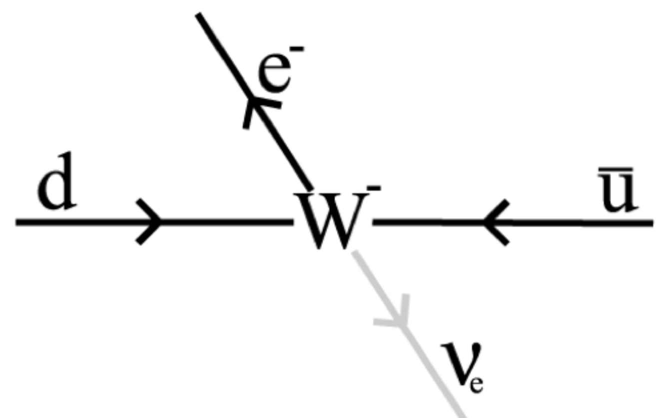
$\Delta\Gamma_W$ from $p_T(Z)$

qqW decay

- QCD emission of gluons prior to interaction is source of non zero $p_T(W)$.
- Neutrino is lost and the information it carries.
- $p_T(W)$ is a vital parameter in the M_T fit and must be known.

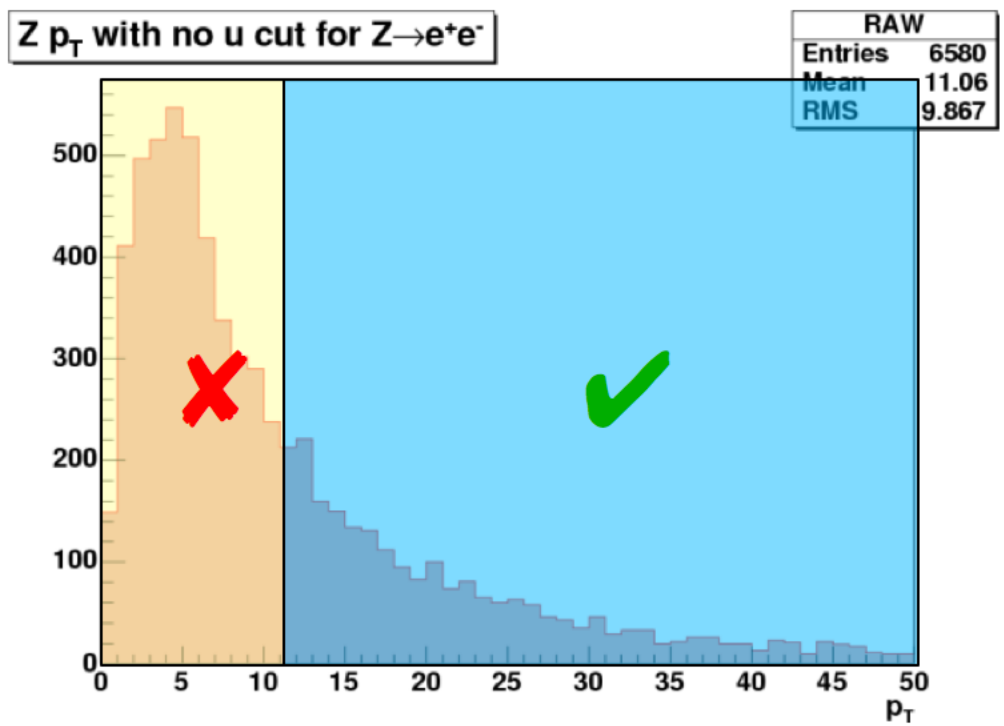
- Calculate pT(W) from QCD?





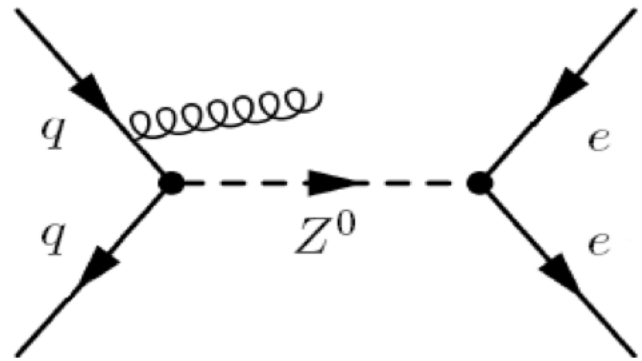
Calculating $p_T(W)$ from QCD

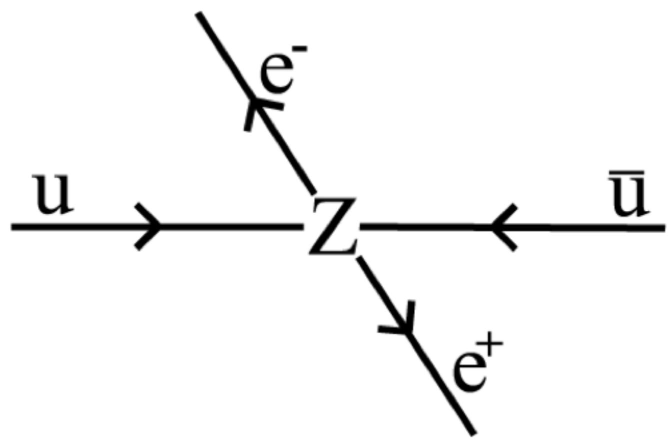
- Perturbative QCD allows good modelling of high energy gluons.
- Low energy gluons can be calculated but these are dependent upon modelling of non-perturbative QCD region.
- Could use a NLO generator such as RESBOS but that uses fits to Run-I data.
- Instead, fit to find pT from Run-II data with higher statistics



qqZ decay

- Z boson have been highly studied from LEP era and is well known.
- No neutrino produced to all information known about the event in transverse plane.
- qqZ to quarks could be used but it would increase the difficulty isolating weak events in the QCD background - only look at Z decaying to leptons.

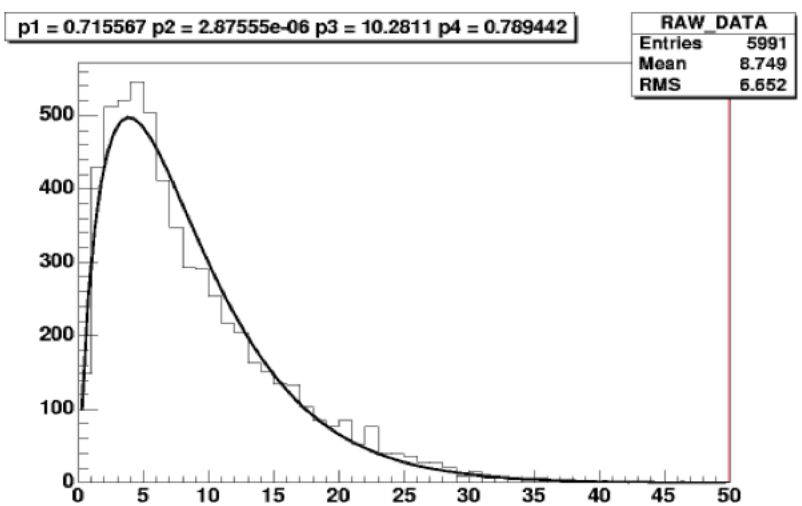




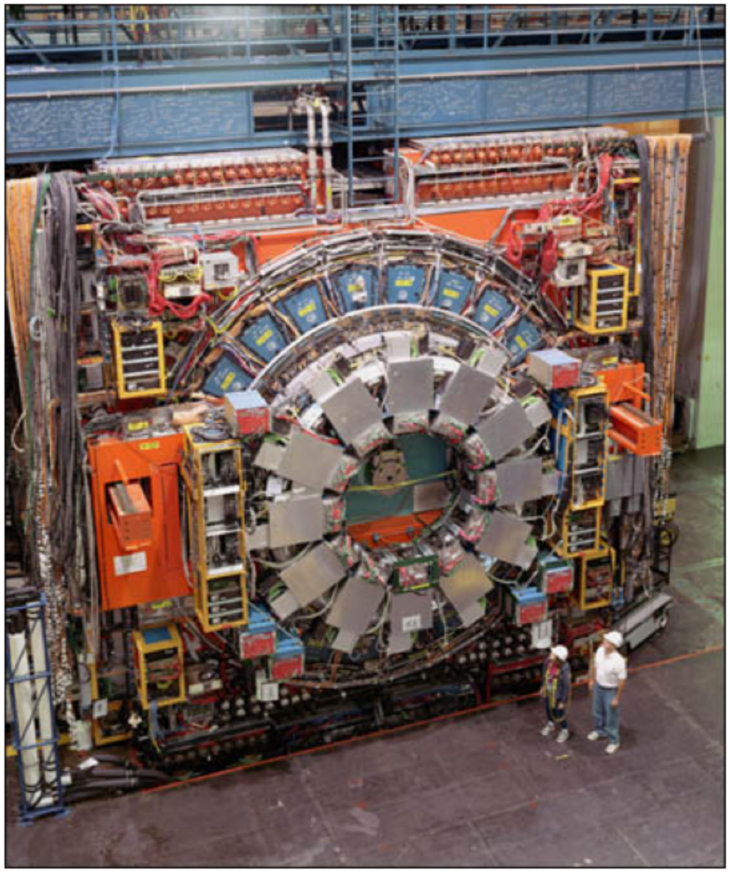
p_T functional form

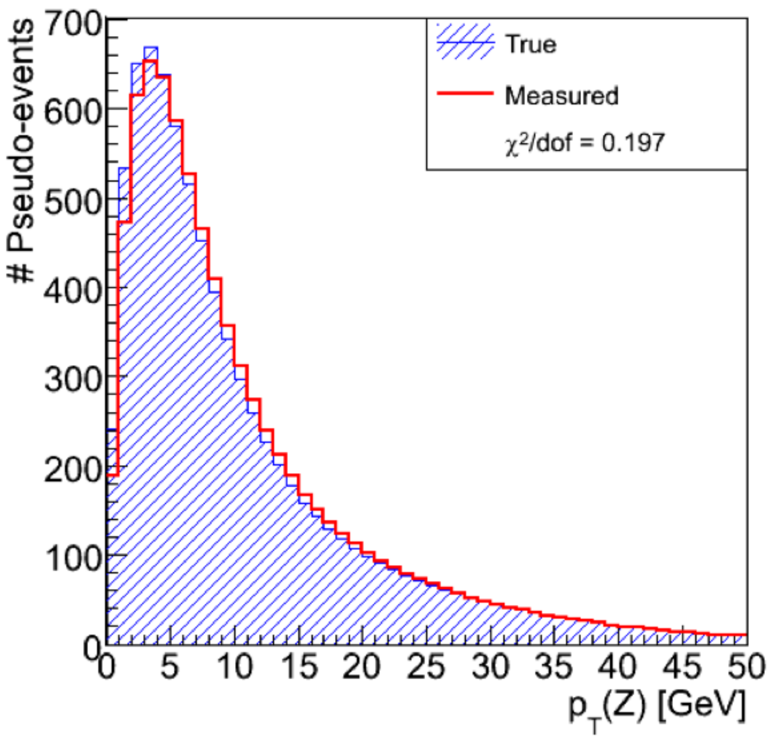
- Used four parameter functional form and parameters from Run-I.

$$\frac{\left(\frac{P_T}{50}\right)^{P_4}}{\Gamma\left(P_4+1\right)}\left[\left(1-P_1\right)P_2^{P_4+1}e^{\frac{-P_2 P_T}{50}}+P_1 P_3^{P_4+1}e^{\frac{-P_3 P_T}{50}}\right]$$



Detector Smearing





Detector Smearing

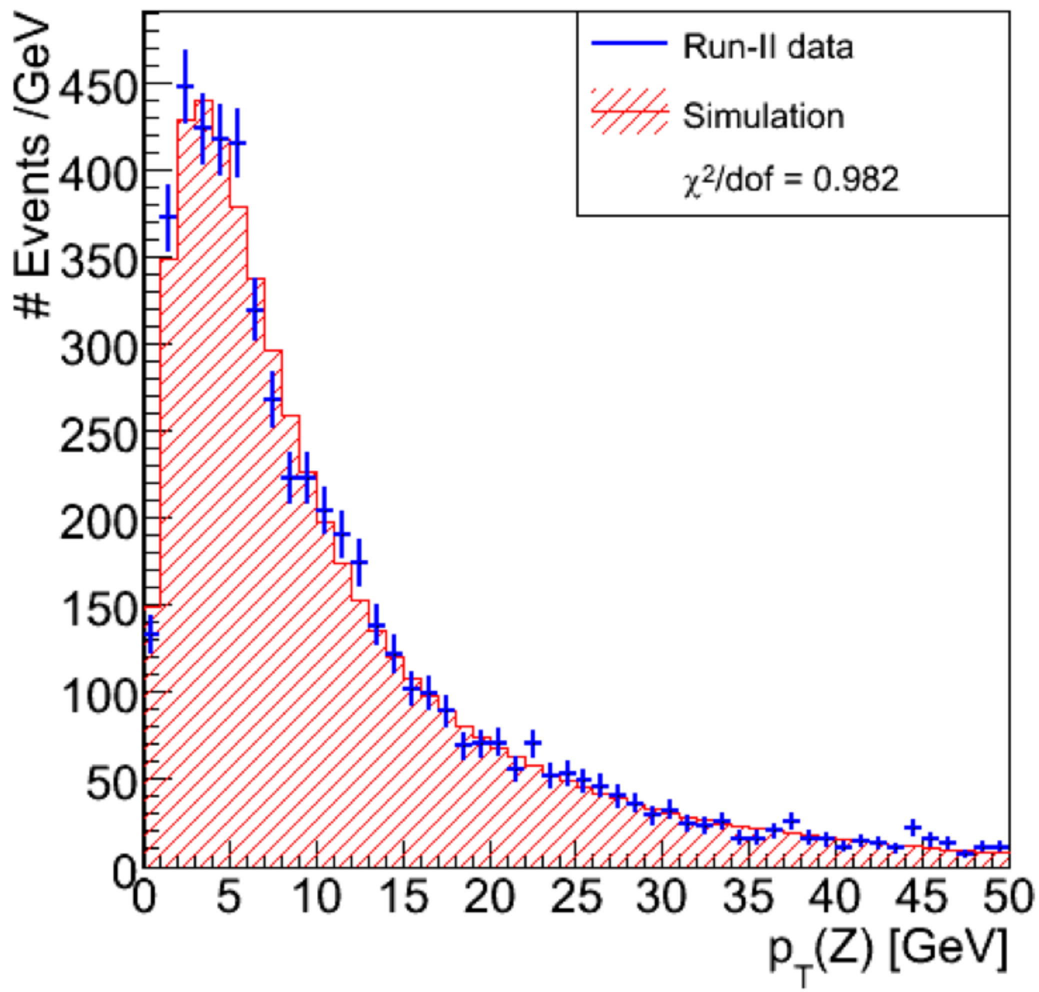
- Monte Carlo was used in conjunction with the simulation to create MC and observed versions of the $p_T(Z)$.
- A reweighting matrix is created by binning the weight of events corresponding to the MC and observed $p_T(Z)$.
- The normalised reweighting matrix is then used to simulate the effects of the detector on any given choice of input parameters.
- The functional form is fitted to data.
- Benefit of the this method is that all four parameters in the functional form can be fitted for at the same time.

Zee Fit

- 150 million simulated events fit to obtain best fit parameters.

P_1	0.623916 ± 0.00326841
P_2	4.38931 ± 0.0432713
P_3	15.2250 ± 1.50293
P_4	0.7590204 ± 0.00918091

- 150 million simulated events generated with new functional form compared with data.

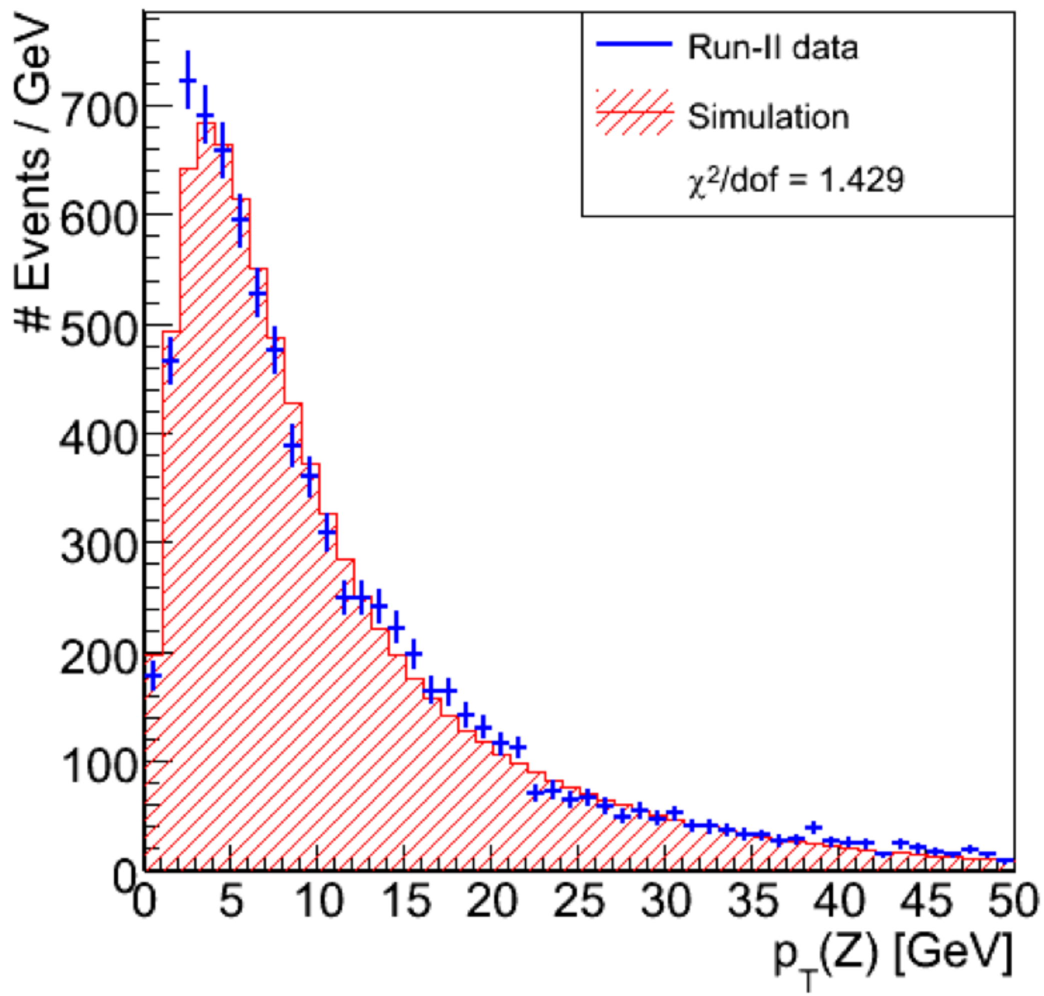


Zμμ Fit

- 150 million simulated events fit to obtain best fit parameters.

P_1	0.586342 ± 0.0012309
P_2	5.18303 ± 0.0200603
P_3	16.4733 ± 0.0896764
P_4	0.973354 ± 0.00721024

- 150 million simulated events generated with new functional form compared with data.

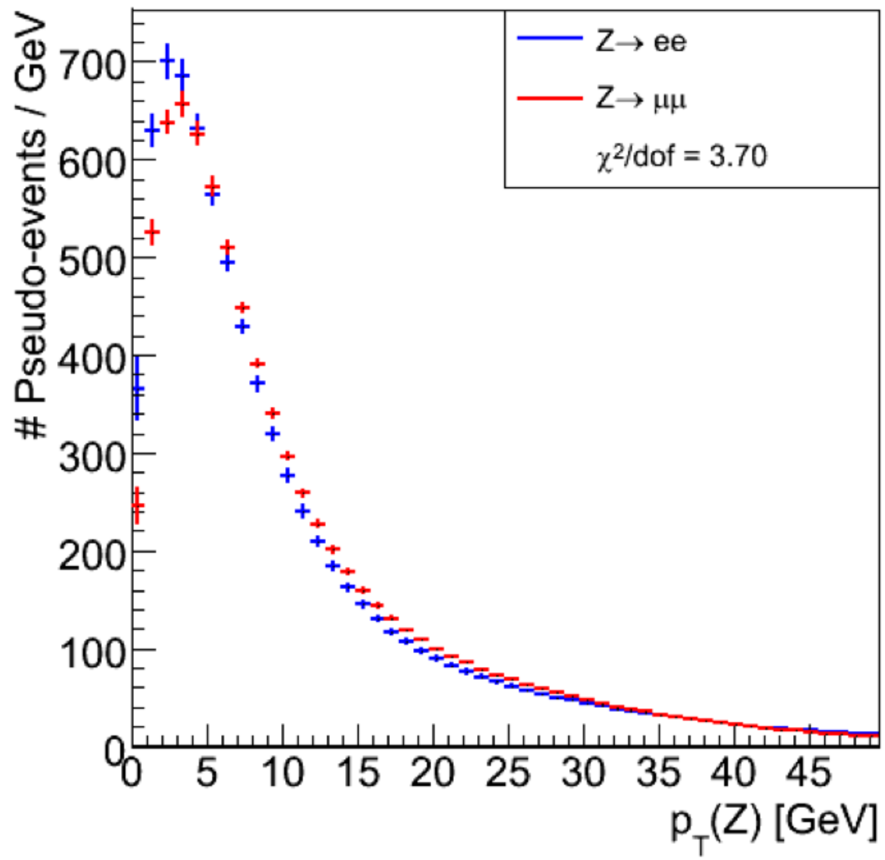


Muon disagreement?

- Run-I fits to electrons and muons gave pT(Z) line-shapes in agreement.

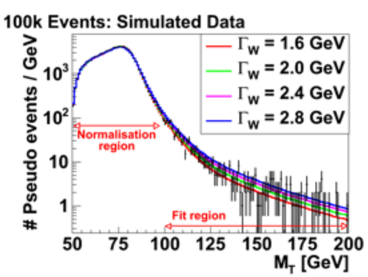
- Why are the Run-II fits inconsistent?
- Poor fit?
- Functional form lacking?
- Backgrounds contaminating the muon sample?

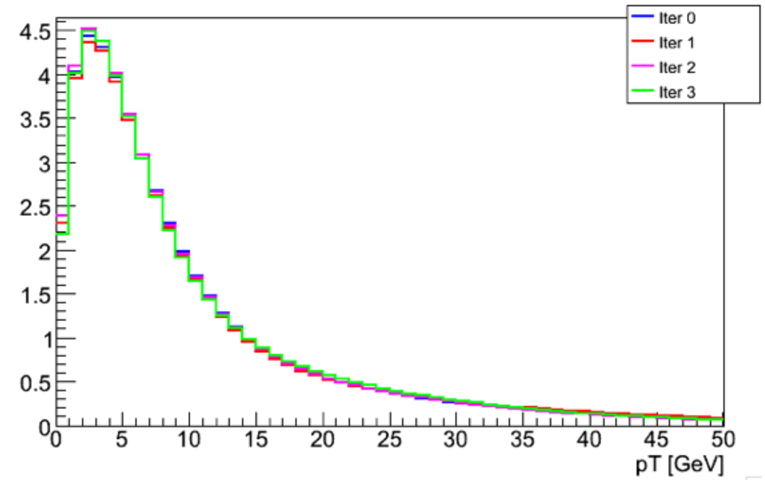
- For the next part of the analysis the Zee and Zμμ simulations used the respective $p_T(Z)$ line-shapes and not an average.

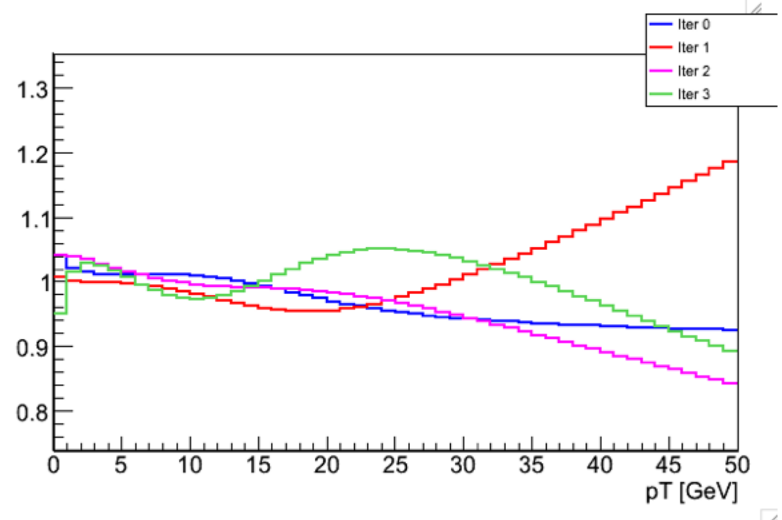


$\Delta\Gamma_W$ from $p_T(Z)$ fits

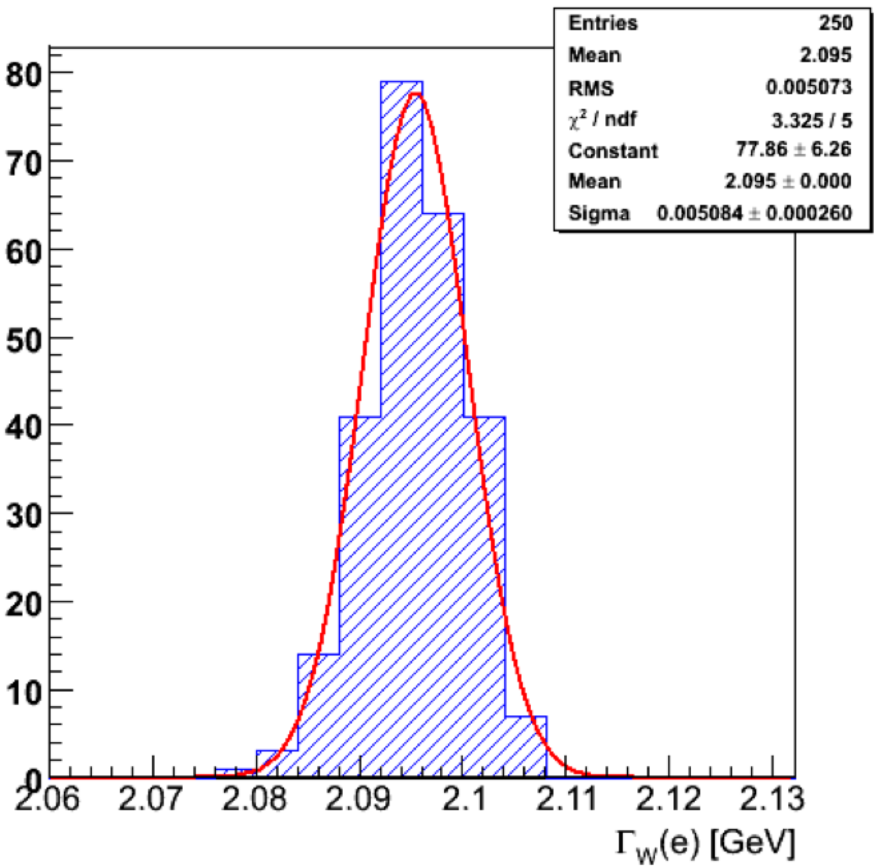
- Covariance matrix of $p_T(Z)$ fits used to generate 250 new p_T line-shapes within 1σ of the best fit
- Each line-shape used to generate a corresponding M_T line-shape array over a Γ_W range.
- A set of unweighted M_T data is also created
- Each array of M_T line-shape fitted to give a value for Γ_W for each time the covariance matrix is sampled.



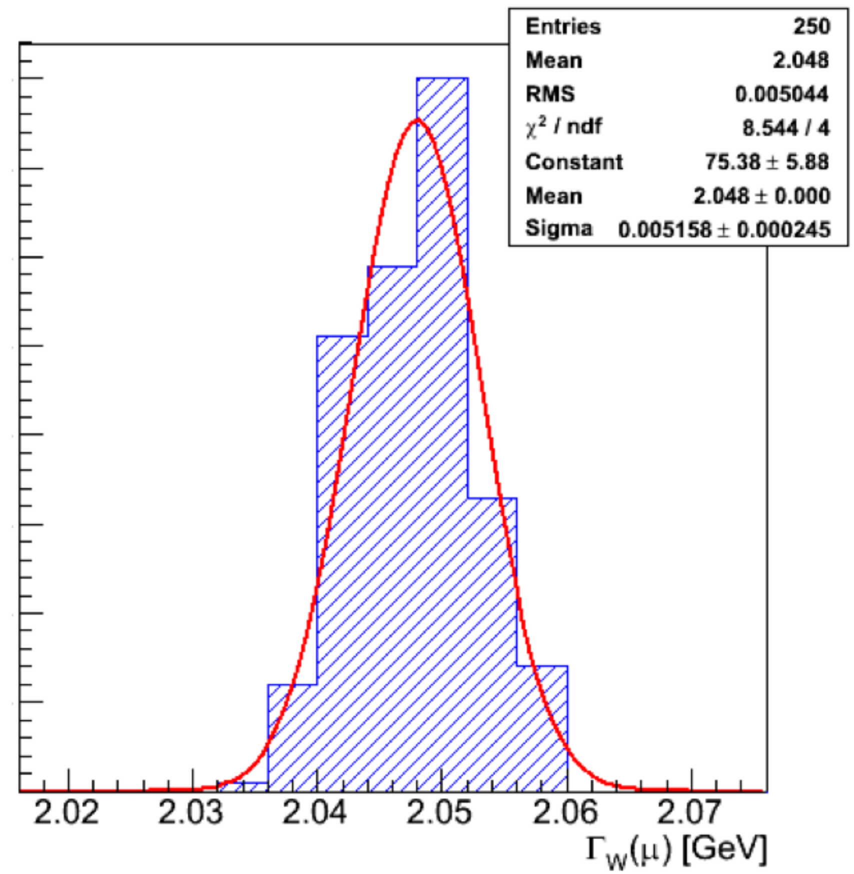




$\Delta\Gamma_W$ from $p_T(Z)$ fits



Wev : $\Delta\Gamma_W$ = 5.084 MeV

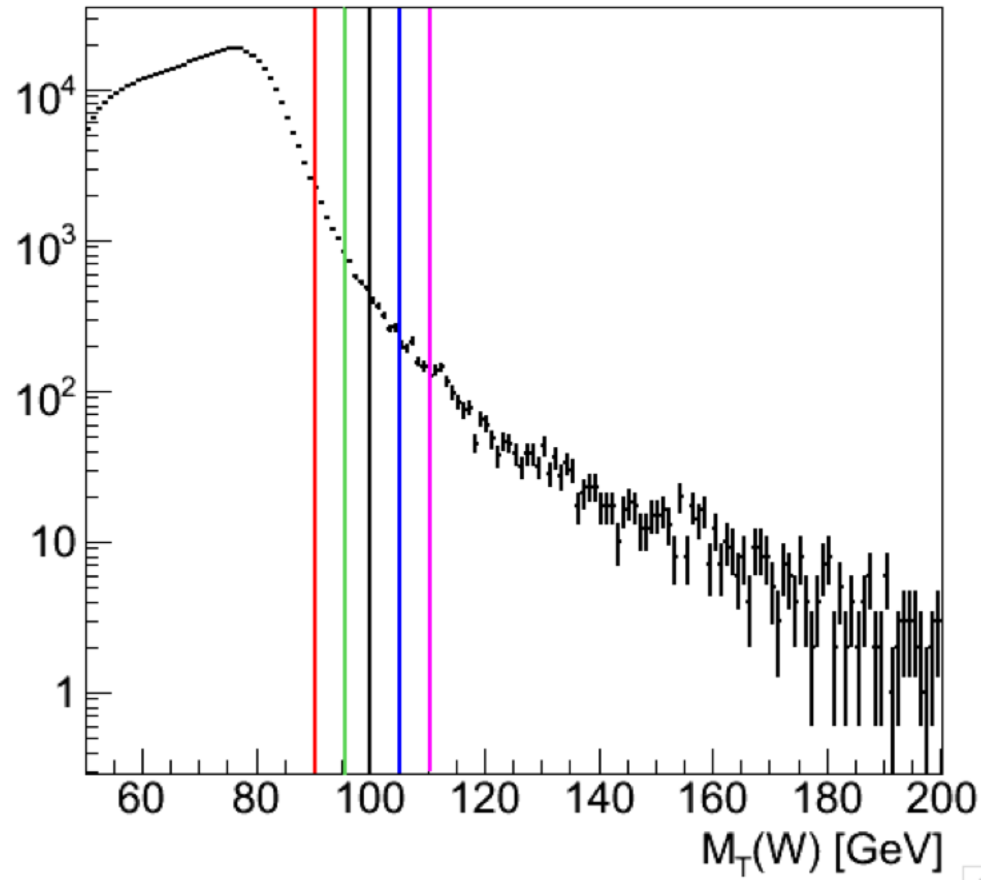


Wμv : $\Delta\Gamma_W$ = 5.158 MeV

Effect of fit range on $\Delta\Gamma_W$

- W $e\nu_e$ (MeV)
- 8.447 ± 0.463
- 7.063 ± 0.306
- 5.084 ± 0.260
- 3.886 ± 0.306
- 2.753 ± 0.127

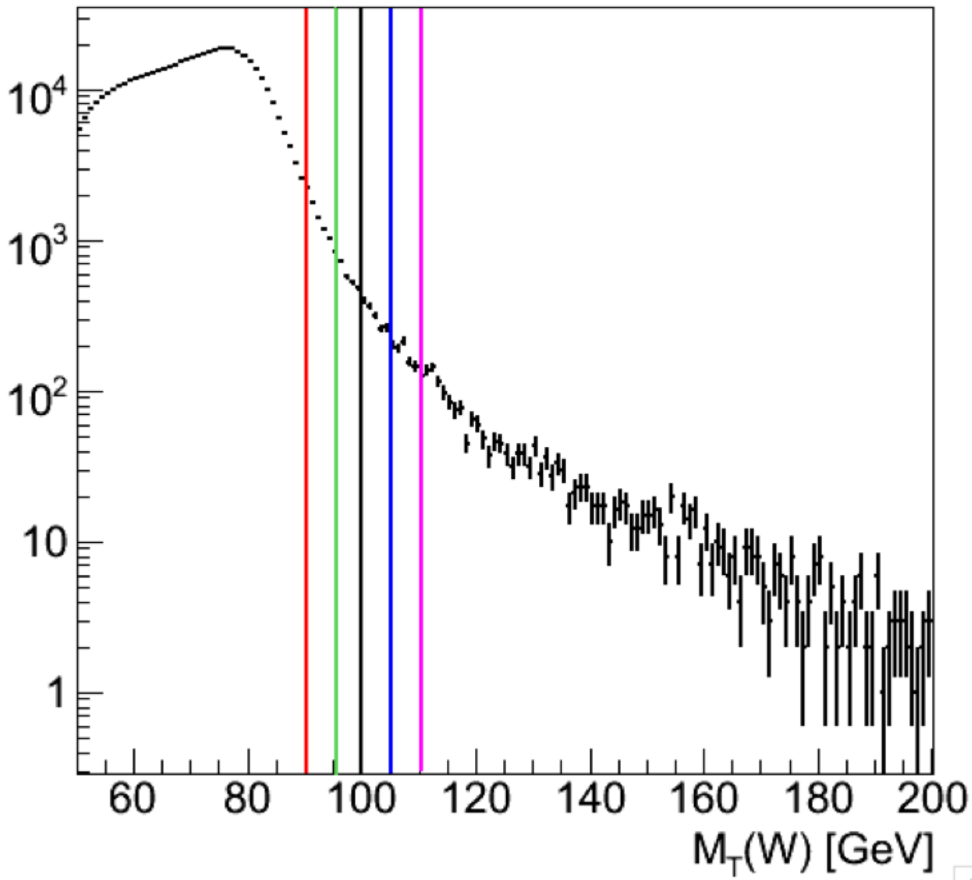
- W $\mu\nu_\mu$ (MeV)
- 8.404 ± 0.387
- 6.841 ± 0.343
- 5.158 ± 0.245
- 3.727 ± 0.173
- 3.031 ± 0.145



Fit mean cross-check

- W $e\nu_e$ (GeV)
- 2.142 ± 0.048 (± 0.0005)
- 2.103 ± 0.049 (± 0.0004)
- 2.095 ± 0.071 (± 0.0003)
- 2.086 ± 0.057 (± 0.0002)
- 2.076 ± 0.104 (± 0.0001)

- W $\mu\nu_\mu$ (GeV)
- 2.064 ± 0.037 (± 0.0005)
- 2.051 ± 0.045 (± 0.0004)
- 2.040 ± 0.058 (± 0.0003)
- 2.058 ± 0.067 (± 0.0002)
- 2.079 ± 0.088 (± 0.0002)



Effect of NLO QCD corrections to W production on $U_{||}$

Boson recoil

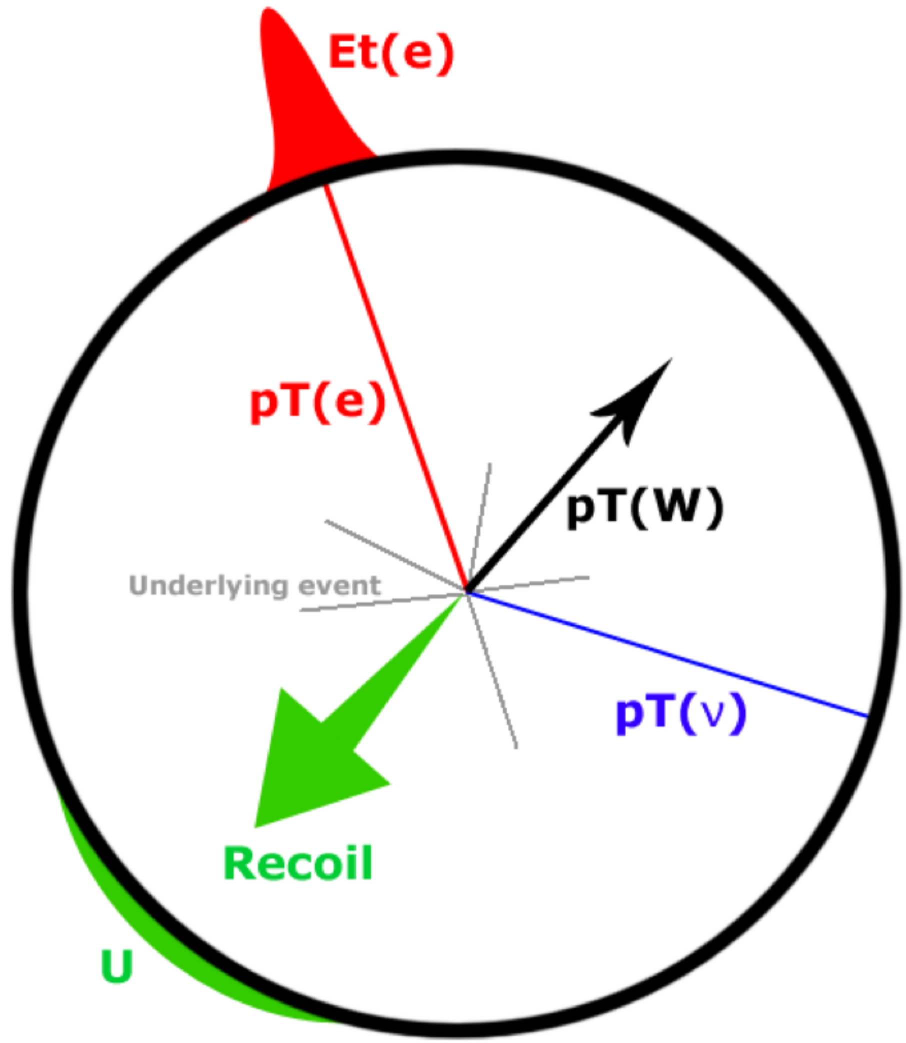
- The boson recoil vector is the sum of all the energies in the the remaining calorimeter towers.

$$\vec{U} = \sum_i (E_i \sin\theta_i)\, \hat{n}_i$$

$$p_T^{\nu} = -\vec{U} - p_T^{l}$$

$$U_{\parallel} = \frac{\vec{U} \cdot \vec{E_T^l}}{|E_T^l|}$$

$$U_{\perp} = \frac{\vec{U} \times \vec{E_T^l}}{|E_T^l|}$$



$U_{||}$ significance

$$M_T = \sqrt{(E_T^W)^2 - (P_T^W)^2} = \sqrt{\left(E_T^l + E_T^\nu\right)^2 - |\vec{E_T^l} + \vec{E_T^\nu}|^2}$$

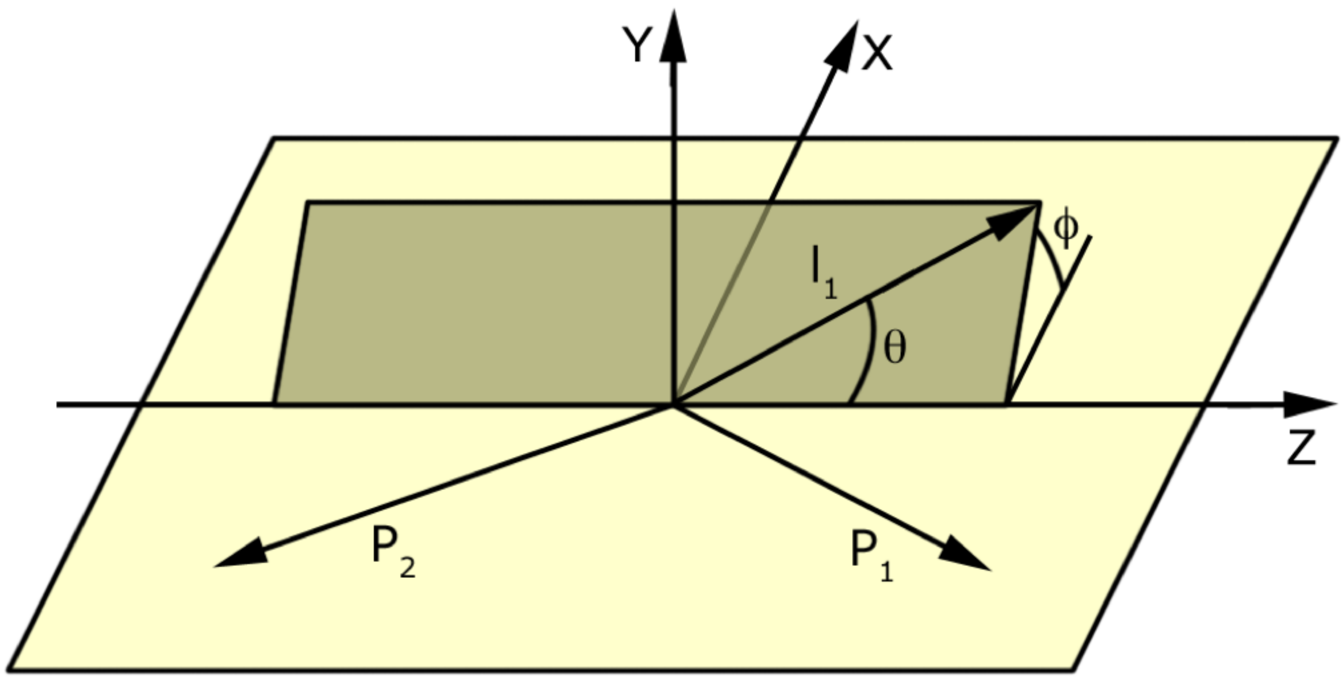
- If you make the substitution for the recoil vector: $\vec{E_T^\nu} = -\vec{U} - \vec{E_T^l}$
- Expanding M_T about P_T^W/E_T^W and assuming the lepton p_T is much larger than the recoil then to first order:

$$M_T \approx 2E_T^l + U_{||}$$

- $U_{||}$ bias will propagate into M_T so $U_{||}$ needs to be understood.

Collins-Soper frame

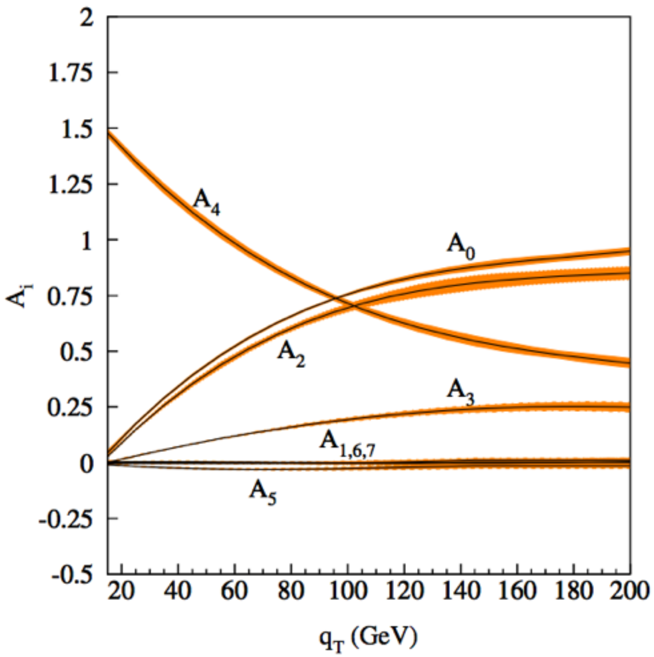
- Defined as the rest frame of the W.
- Set Z perpendicular to $p_T(W)$, boost frame into W rest frame, then rotate xz so that incoming protons lie in the plane.



Angular corrections

- Leading order and next-to-leading order cross section for qqW$^-$ to leptons

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



- If p_T(W) is zero and only valence quarks contribute the interaction is pure V-A and only A_4 remains.

$$\propto (1\pm\cos\theta)^2 = \left(1+\cos^2\theta\right) \pm 2\cos\theta$$

- For W$^+$ A_1, A_4, and A_6 flipped to keep the same CS frame definition.

Angular corrections

- Leading order and next-to-leading order cross section for qqW to leptons

$$\frac{d\sigma}{dq_T^2\,dy\,d\cos\theta\,d\phi} = \frac{3}{16\pi}\frac{d\sigma^\mu}{dq_T^2\,dy}\Big[(1+\cos^2\theta) + \frac{1}{2}A_0\,(1-3\cos^2\theta) + A_1\sin 2\theta\cos\phi$$
$$+\frac{1}{2}A_2\sin^2\theta\cos 2\phi + A_3\sin\theta\cos\phi + A_4\cos\theta$$
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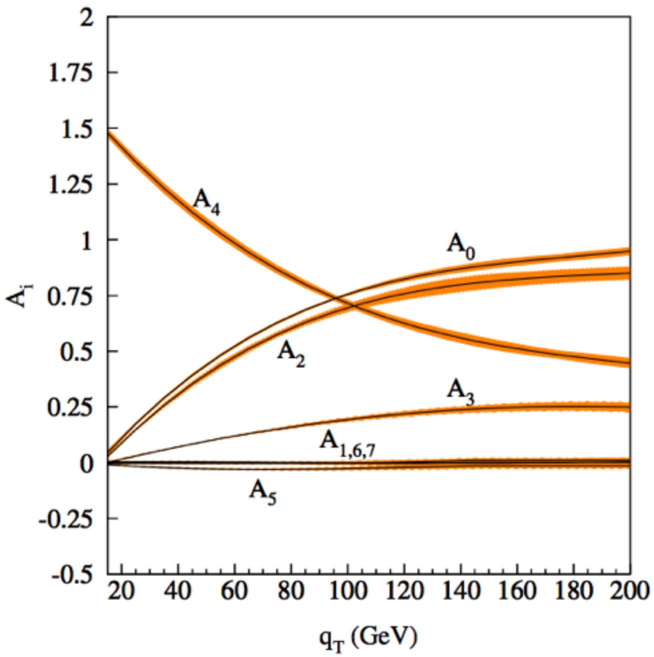
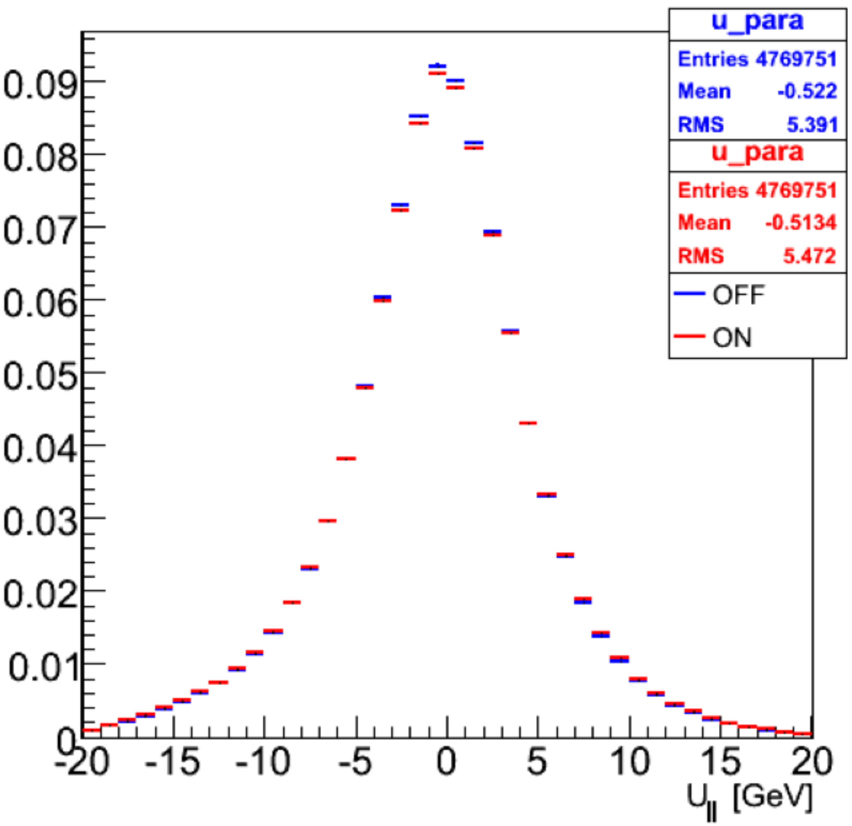


- Assumed A_i to be linear for p_T below 50 GeV

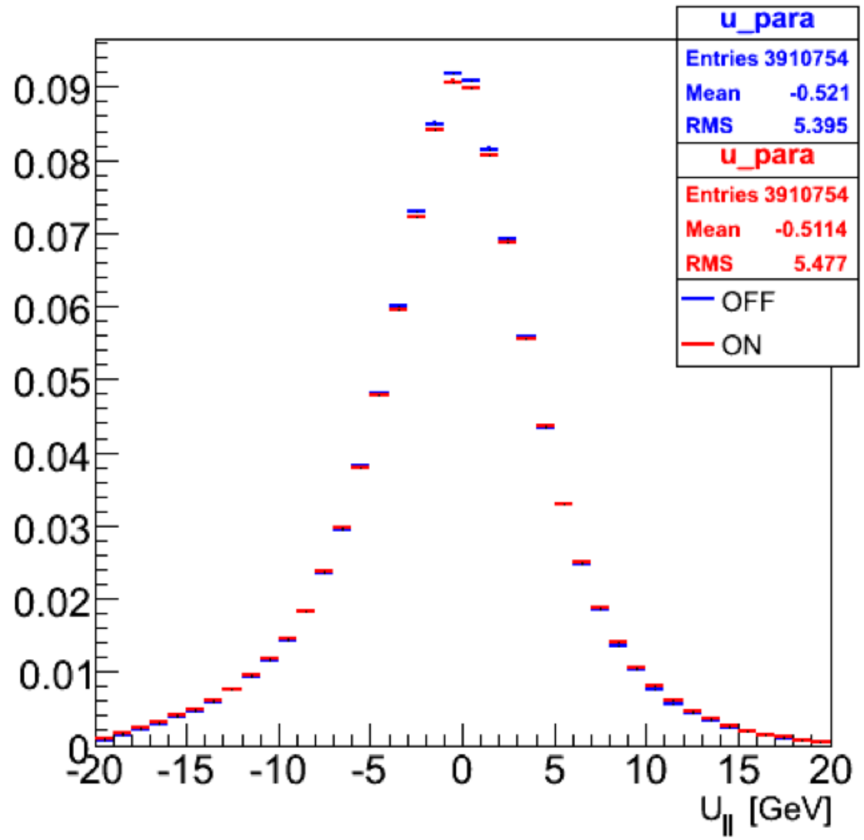
$$\begin{array}{lllllll} A_0 & = & 0.01p_T & & A_1 & = & (0.005-0.00005p_T)\,\beta \\ A_2 & = & A_1 & & A_3 & = & 0.0025p_T \\ A_4 & = & (2-0.01p_T)\,\beta & & A_5 & = & -0.006-0.00048p_T \\ A_6 & = & 0 & & A_7 & = & -0.0002 \end{array}$$

$$\beta = \begin{cases} +1 & W^- \\ -1 & W^+ \end{cases}$$

$U_{||}$ shift

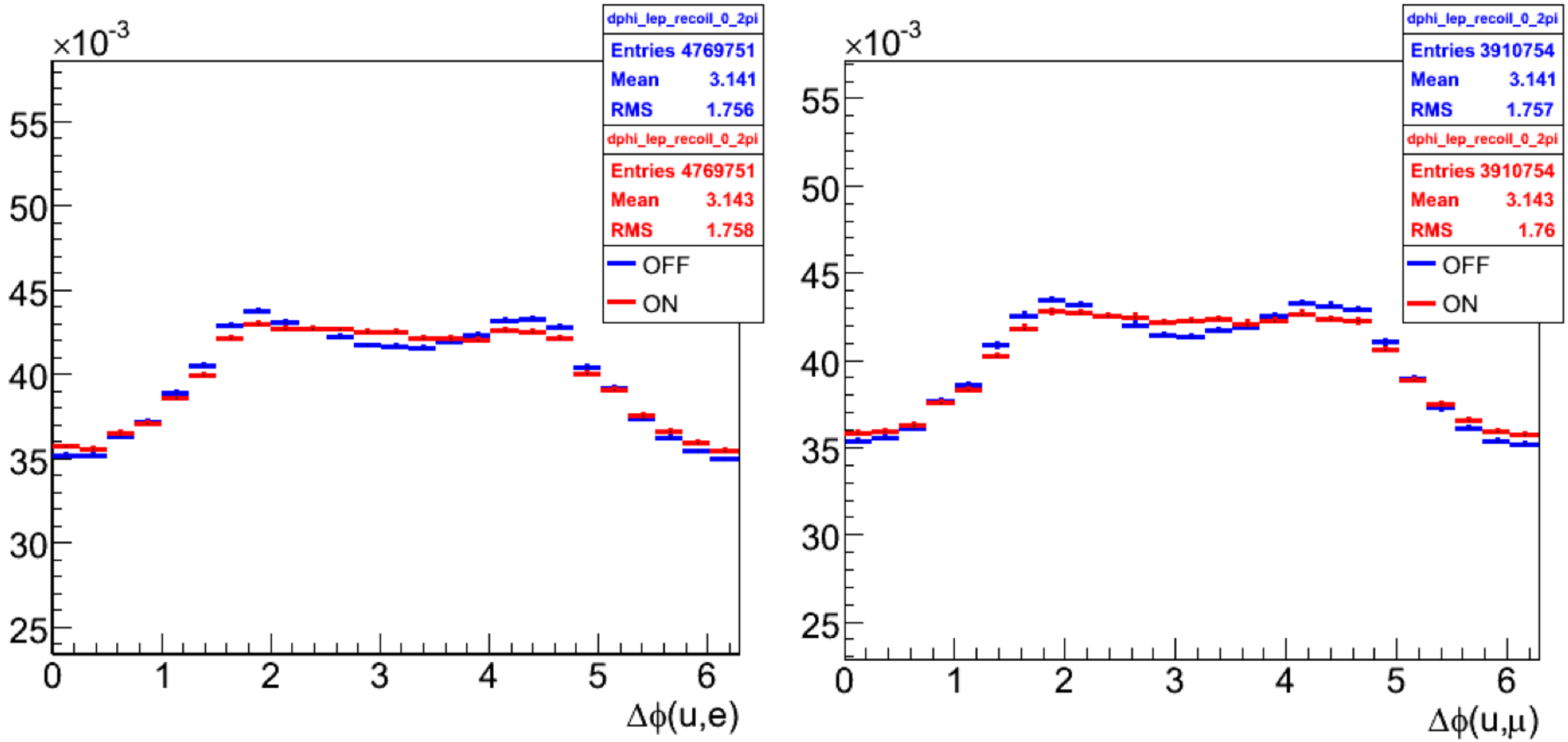


Wev shift: +8.6 MeV



Wμν shift: +9.6 MeV

Effect on Δφ(u,lep)



Summary

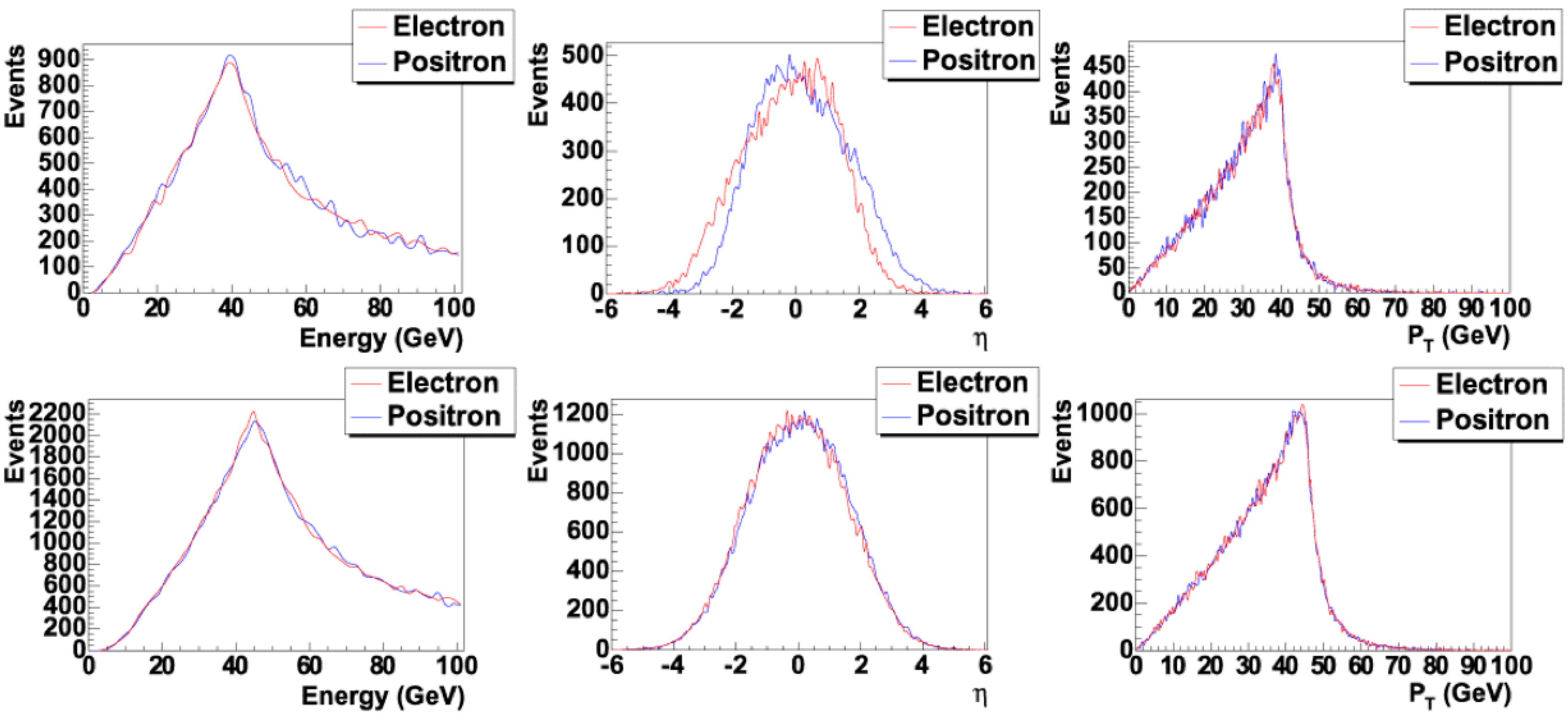
- Can use functional form to model $p_T(Z)$ as a means of modelling $p_T(W)$
- Functional form fitted to the Zee sample well but not so well to the Zμμ sample.
- Electron and muon generator level $p_T(Z)$ are inconsistent - this needs to be understood and corrected if possible.
- Effect of this method of the measurement on Γ_W is to introduce a ~5 MeV systematic from the $p_T(Z)$ fits.

- Next-to-leading order QCD angular corrections built into the simulation but the impact is minor: $U_{||}$ shift of ~ +9 MeV and $\Delta\varphi$ between recoil and lepton is flattened slightly.

- Next work will most probably be working on the recoil model itself.

Backup slides

Z and W comparison



Need to take into account the η difference by re-weighting

Smearing matrix

- Each element corresponds to the likelihood of how a true p_T will be measured.
- Matrix is generated by creating millions of MC Z decays and binning the weight of the event into the correct matrix element.
- Normalise the matrix by insisting that every p_T column (true p_T) adds up to unity; an identity matrix would correspond to a perfect detector.
- Measured p_T histogram created by multiplying a vector of true p_T bins by the matrix.

True pT →

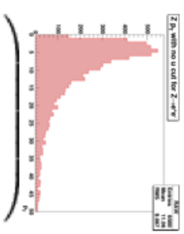
Meas. pT ↓

$$\begin{pmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} & \dots & \alpha_{1n} \\ \alpha_{21} & \alpha_{22} & \alpha_{13} & \dots & \alpha_{2n} \\ \alpha_{31} & \alpha_{32} & \alpha_{13} & \dots & \alpha_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \alpha_{n1} & \alpha_{n2} & \alpha_{n3} & \dots & \alpha_{nn} \end{pmatrix}$$

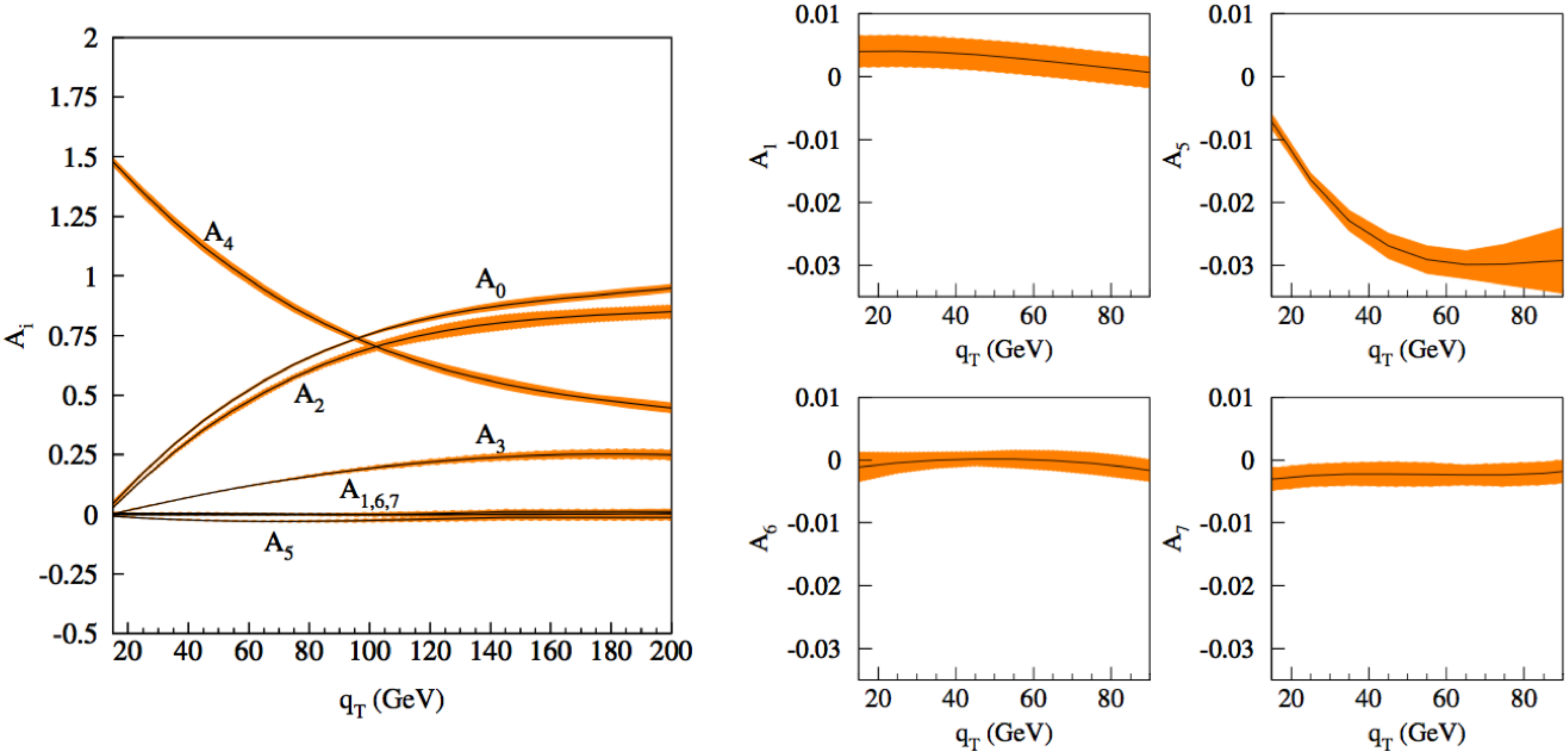
$$\begin{pmatrix} 1 & 1 & 0 & \dots & 0 \\ 6 & 3 & 0 & \dots & 0 \\ 3 & 0 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & 1 \end{pmatrix}$$

$$\begin{pmatrix} 0.1 & 0.25 & 0 & \dots & 0 \\ 0.6 & 0.75 & 0 & \dots & 0 \\ 0.3 & 0 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & 1 \end{pmatrix}$$

$$\begin{pmatrix} m_1 \\ m_2 \\ m_3 \\ \vdots \\ m_n \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & \dots & 0 \\ 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & 1 \end{pmatrix} \begin{pmatrix} t_1 \\ t_2 \\ t_3 \\ \vdots \\ t_n \end{pmatrix}$$



Standard Model angular coefficients



Strogolas and Errede, Phys. Rev. Lett. D 73 (2006)