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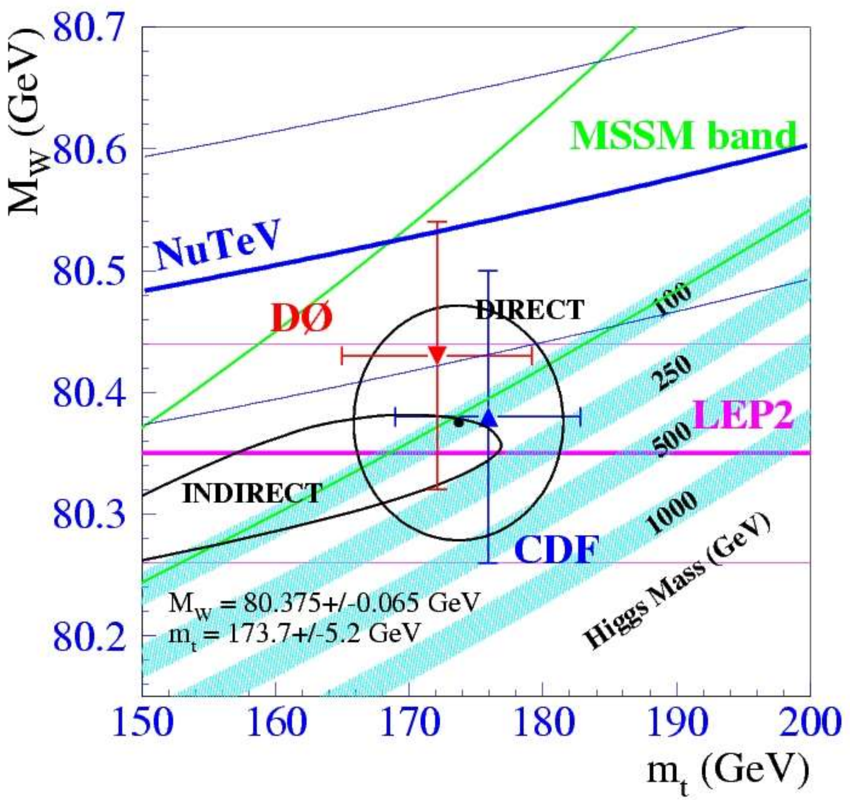
18 March 2004

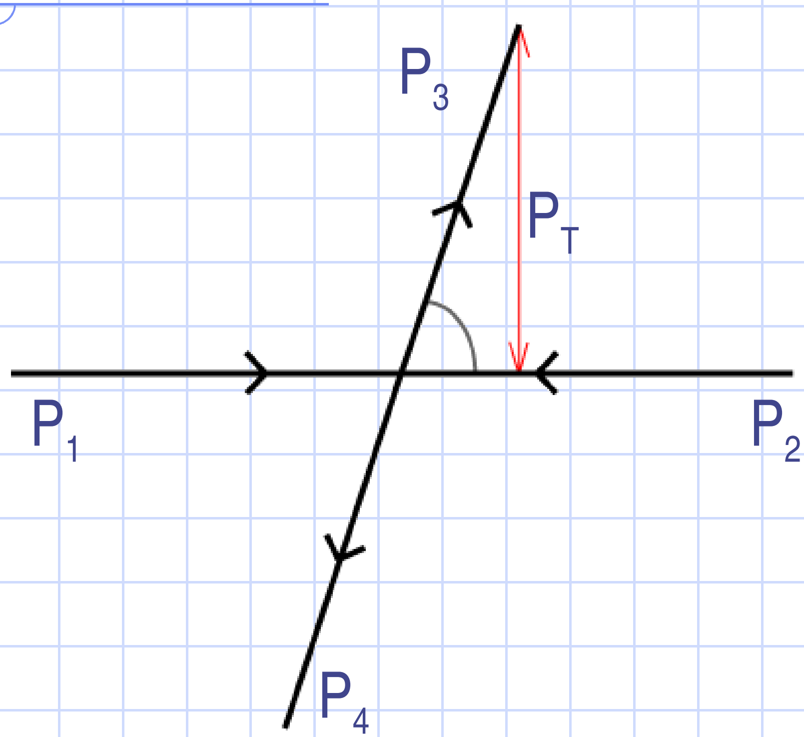
Transverse momentum of Z^0 and associated $W^\pm$ mass uncertainty

Why is the $W^{\pm}$ mass important?



- M_W and m_t are a good tests of the Standard Model.
- We want to know M_W to better than 0.04%
- This precision is difficult to achieve when colliding hadrons.

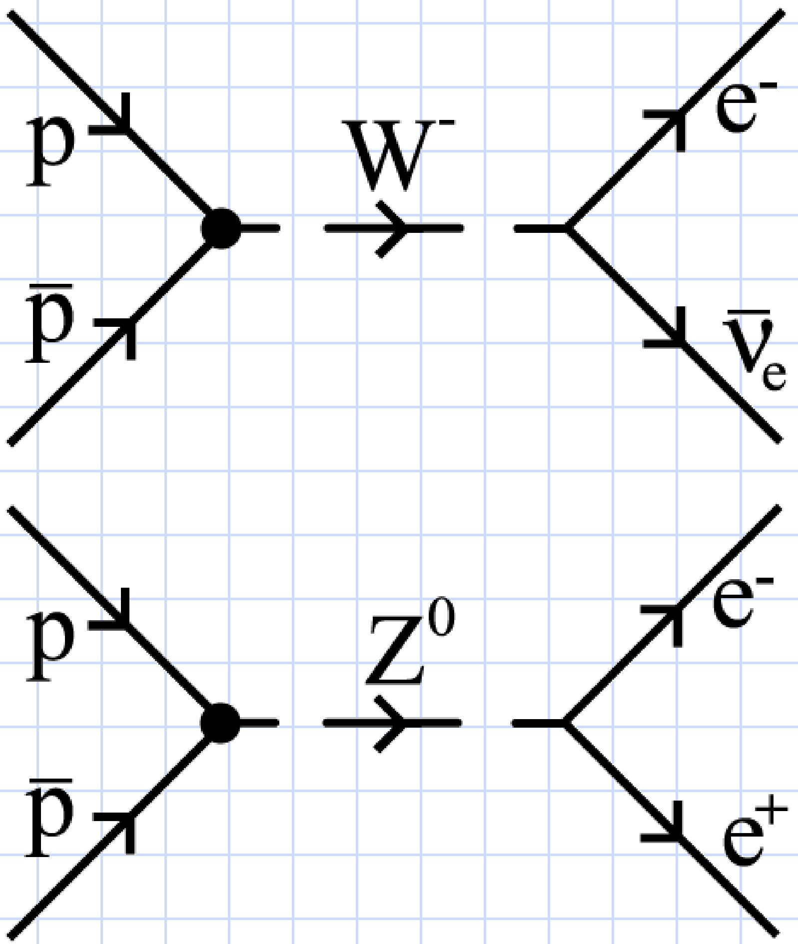
Transverse mass & momentum



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

- We cannot measure the total mass, we lose longitudinal information down the beam pipe.
- But we can measure the mass in the transverse plane, and derive the total via fitting.

Boson Production

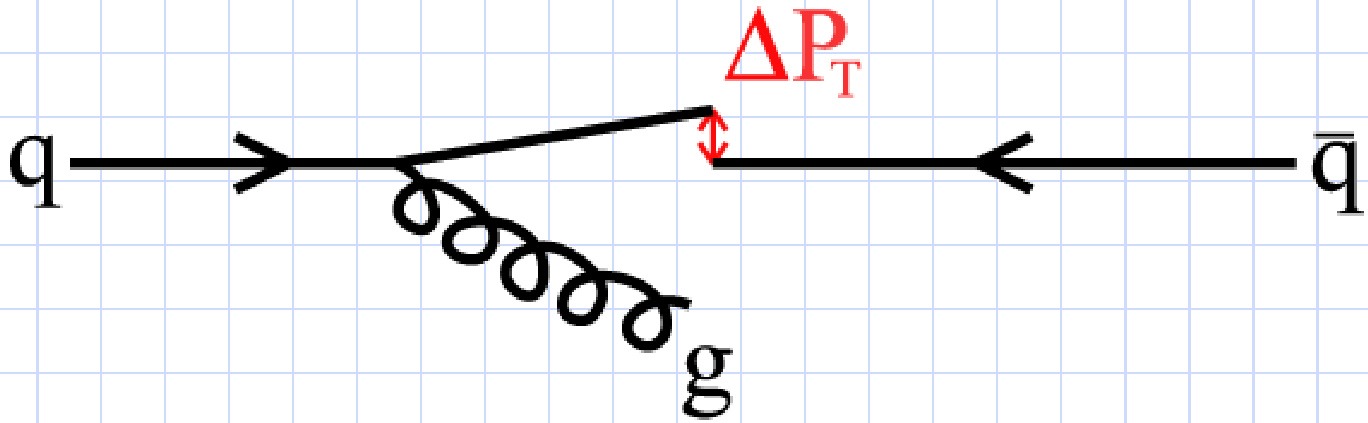


- W and Z bosons can be produced from proton-antiproton collisions in particle accelerators, such as the Tevatron at Fermilab.

Fermilab (FNAL)

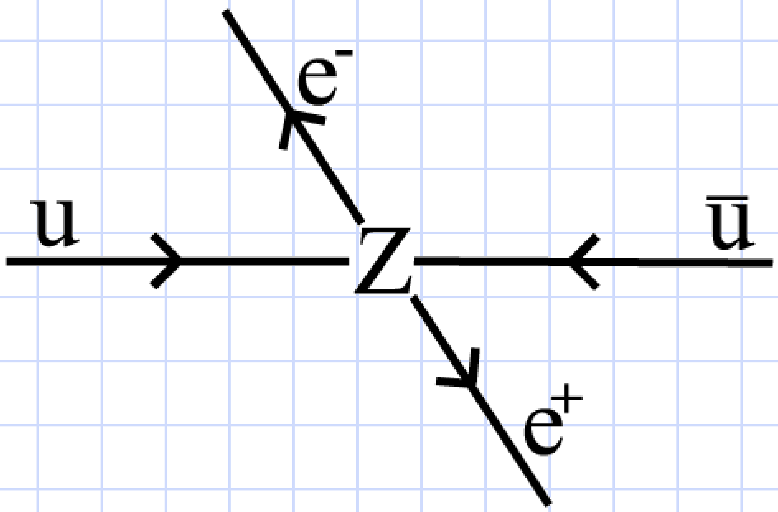
- Located 45 miles from Chicago.
- Tevatron can accelerate protons to 1.8 TeV

QCD Radiation effects



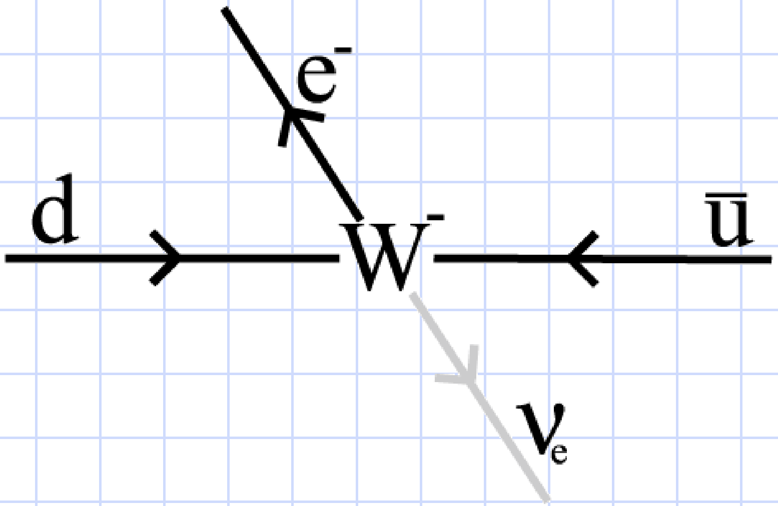
- Highly energetic quarks can emit gluons, carrying a fraction of the momentum – the quark's trajectory changes.
- There is an uncertainty in the P_T of the colliding quarks, therefore an uncertainty in the P_T of the boson is introduced.

QCD Radiation effects

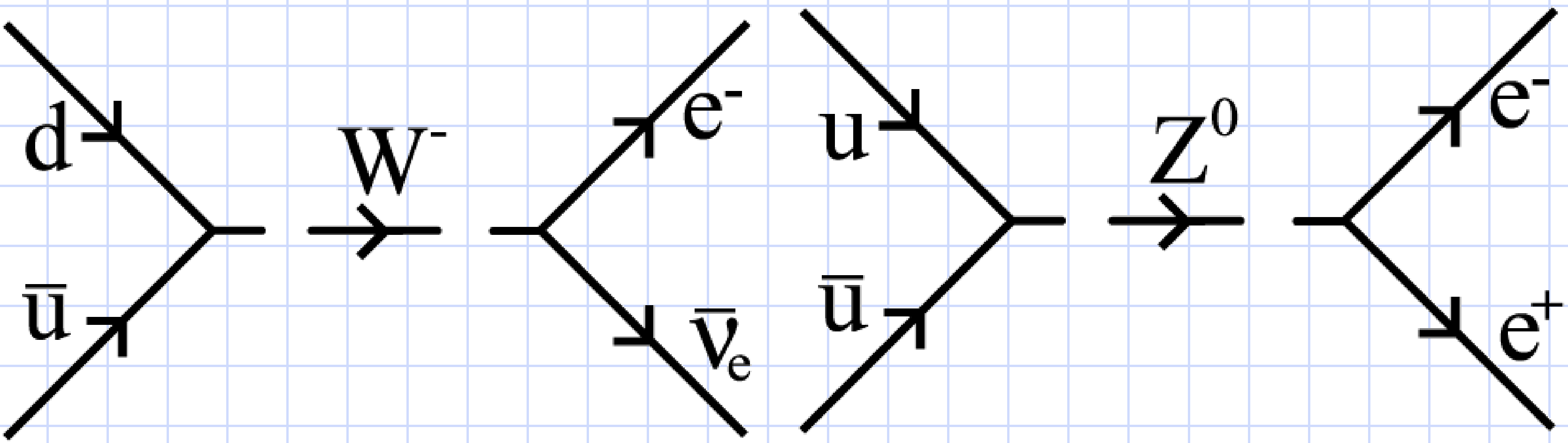


- The uncertainty in the P_T of the Z^0 can be easily observed from the electron and positron.

- The P_T of the W is much harder to determine.

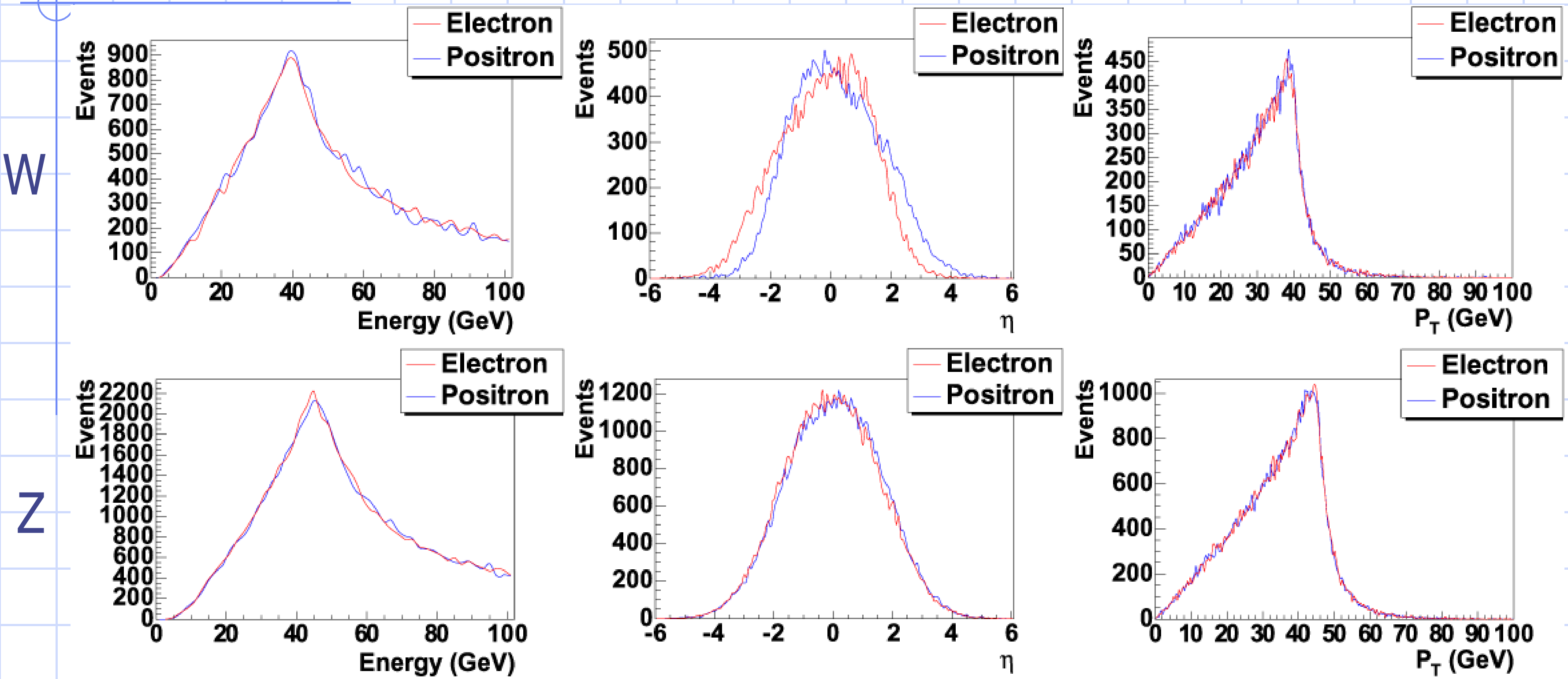


$W^{\pm}$ vs Z^0



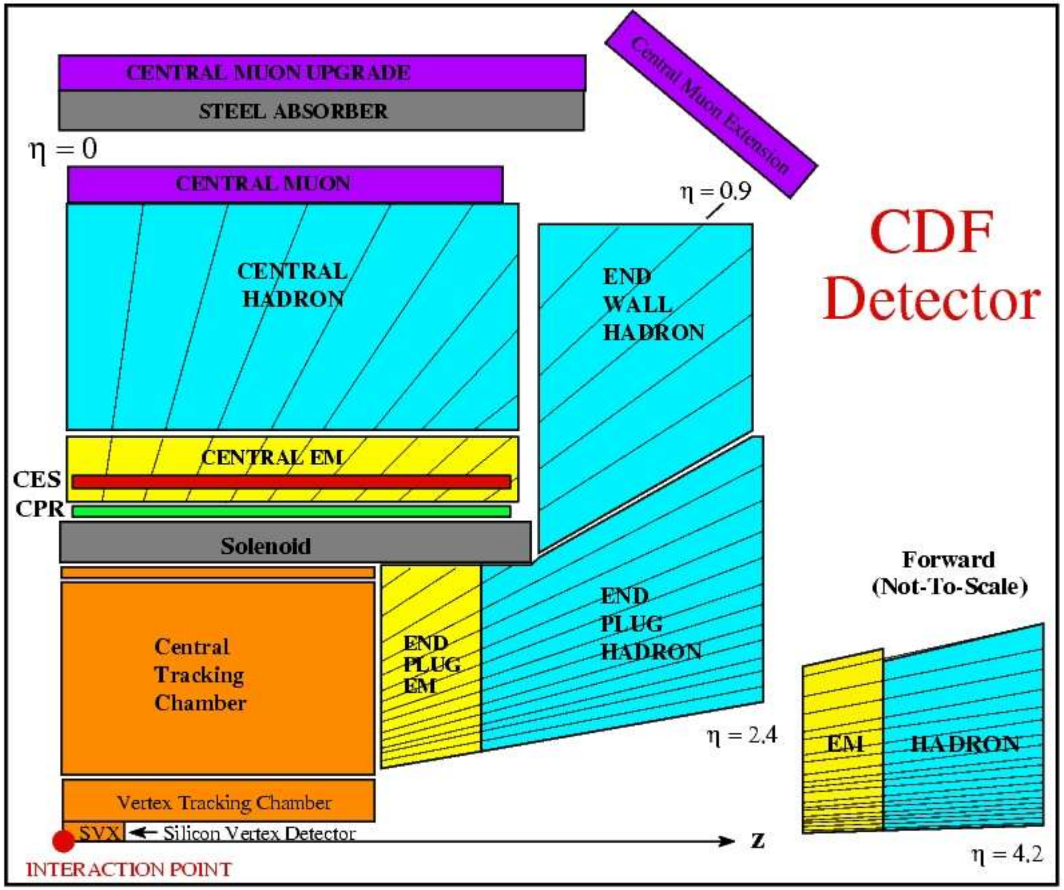
- Both processes have the same weak coupling strength, plus they have similar QCD couplings and propagator terms.

W± vs Z0 (HERWIG)



- The HERWIG simulations show that the processes are very similar.
- The $P_T(W)$ can be modelled from the $P_T(Z)$

Collider Detector (CDF)



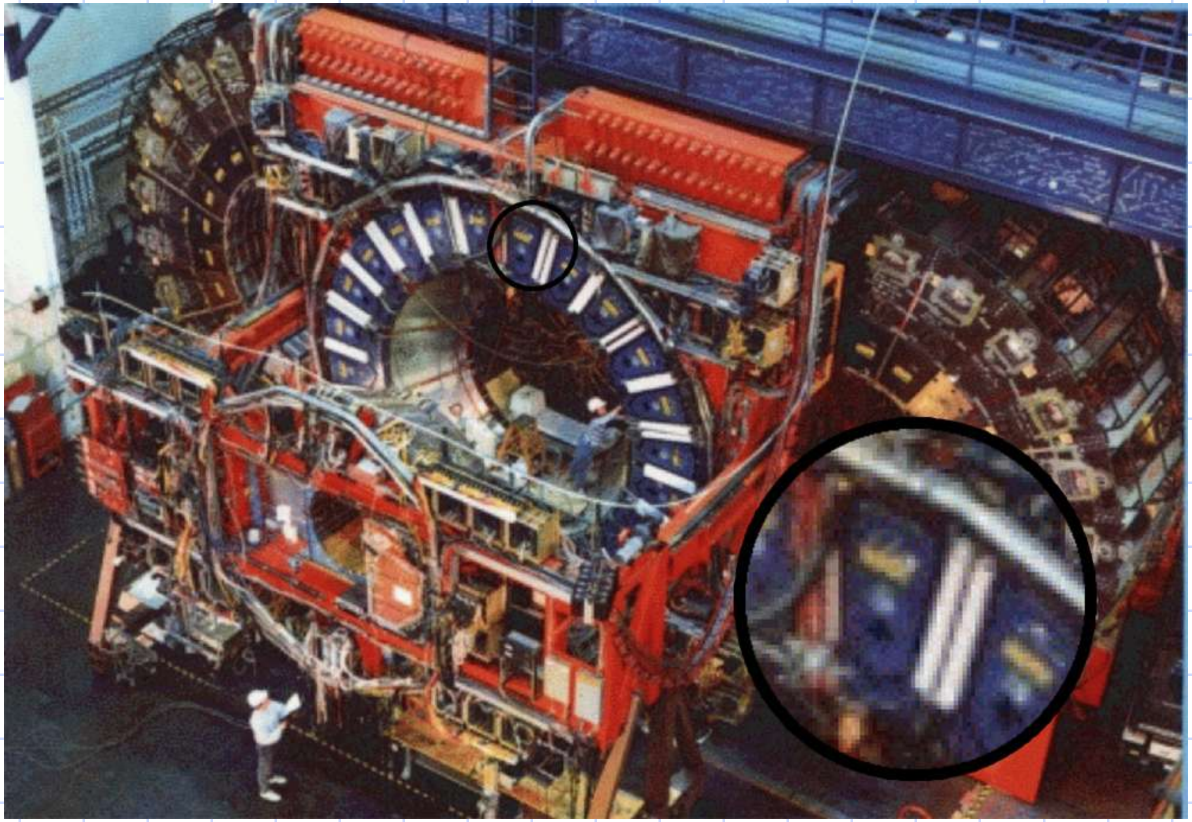
- The CDF detector was to be modelled, so that the predicted $P_T(Z)$ form could be checked against actual data.

Modelling the CEM (I)

- Detectors are not perfect – they have a finite resolution.
- The Central Electromagnetic calorimeter (CEM) was the detector to be simulated.
- The CEM has an energy resolution:

$$\frac{\Delta E}{E} = \frac{0.135}{\sqrt{E_T}}$$

Modelling the CEM (II)



- The CEM is comprised of many “towers”.

Modelling the CEM (III)

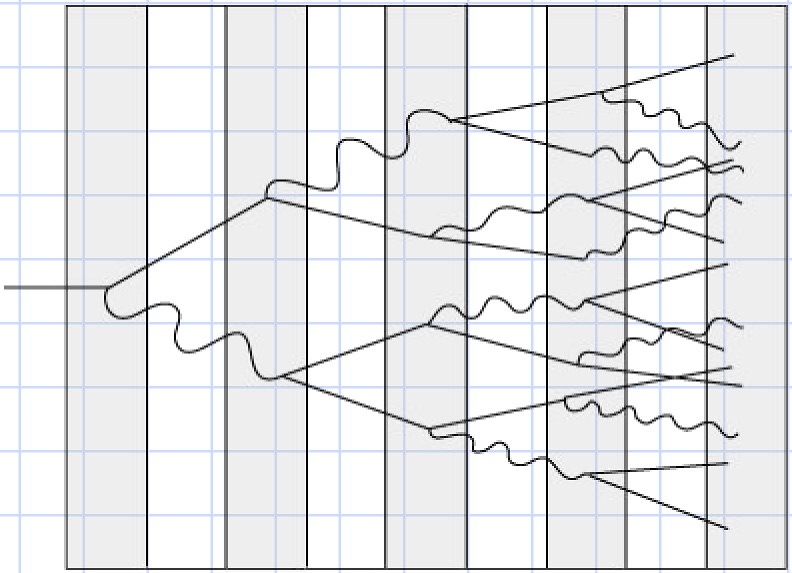
- The modular nature introduces more uncertainty: different electronics in each module, etc.
- One needs to introduce another factor to take this into account:

$$\left(\frac{\Delta E}{E}\right)^2 = \frac{(0.135)^2}{E_T} + \kappa^2$$

- The extra term has the effect of containing all the additional uncertainty as well. As a result, it changes frequently, and must be determined for a data set.

Modelling the CEM (IV)

- Electrons as positrons interact with the absorbing material, producing photons.
- Photons produce electron/positron pairs.



- The electromagnetic shower process will have fluctuations, but these are <u>random</u>.

Modelling the CEM (V)

- Random processes – Gaussian statistics.
- The energy the CEM will measure:

$$E(\kappa) = E\left(1 + \sigma\sqrt{\frac{(0.135)^2}{E_T} + \kappa^2}\right)$$

- Thus, the momentum uncertainty:

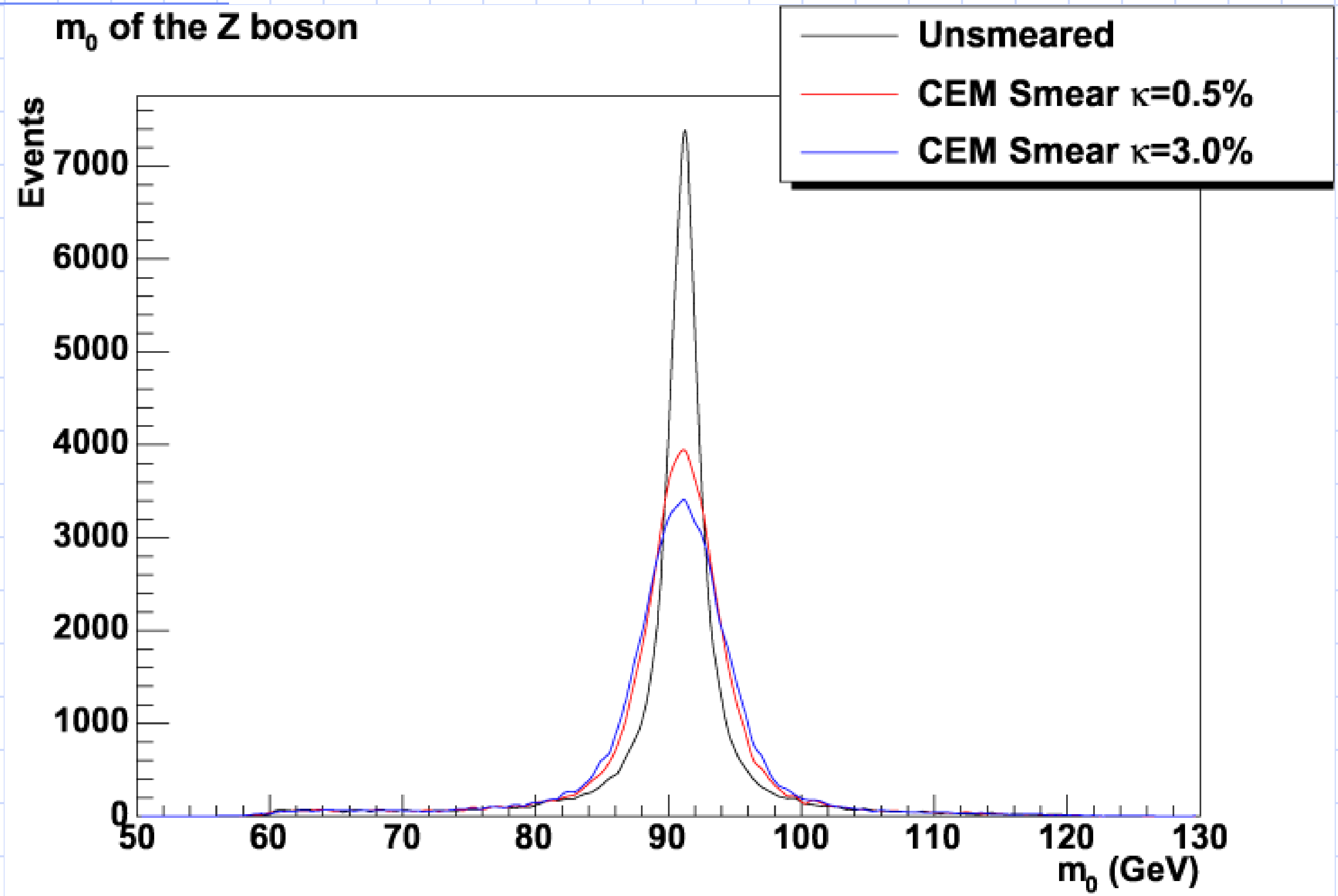
$$P_i(\kappa) = P_i\left(1 + \sigma\frac{E\Delta E}{\sqrt{E^2 - m_0^2}}\right)$$

- What is the significance of the term?

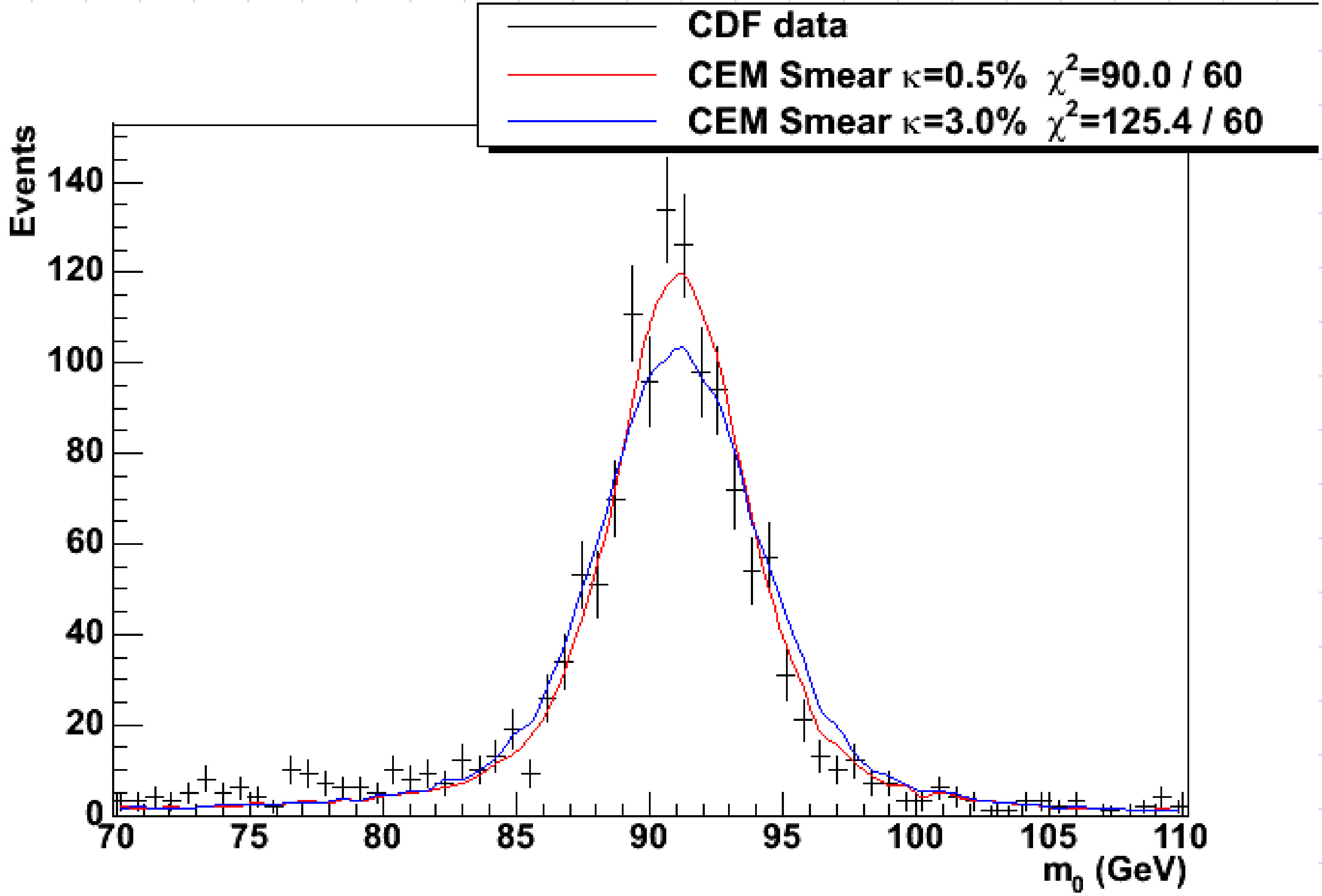
The CEM simulation - Z^0 decay

- For each event, there are a 4-vector momenta for the positron and electron from a HERWIG simulation.
- Each particle has a ‘smeared’ clone created, the particle as seen by the CEM.
- The 4-vectors are combined to construct a ‘smeared’ and ‘unsmeared’ Z boson for the event.
- The properties of the boson are recorded.
- This is repeated for many events - approx. 60,000
- Histograms were created for various values of

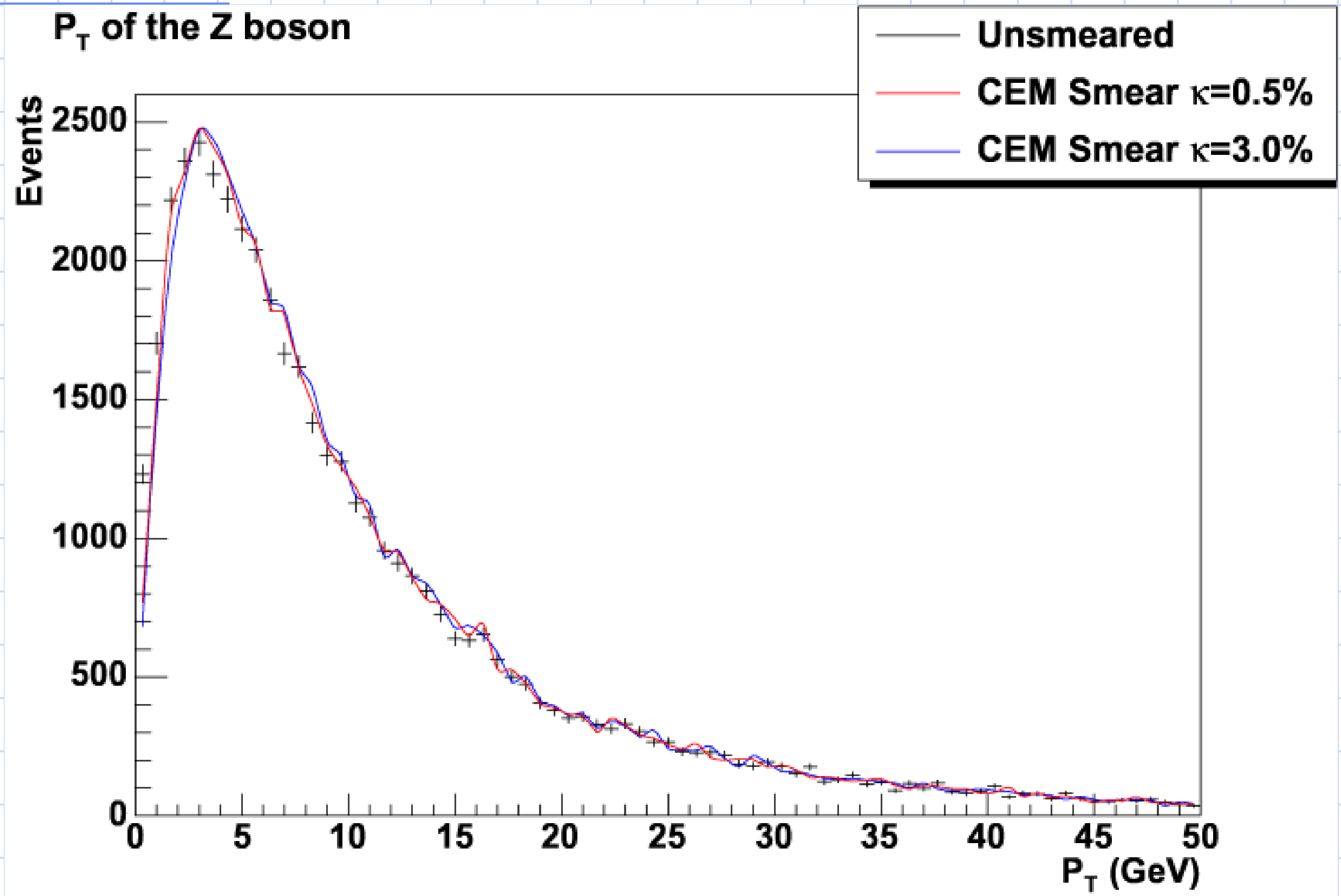
Significance of



Significance of



Significance of



Rest mass fit – Finding

- can be calculated using a two parameter fit:
- Various rest mass distributions with different m_0 and are created and compared with data from the CDF.
- The distribution that has the best chi-squared fit to the data contained .
- was found to be 1.742%

PT Form

- Now a theory can be formed and tested against CDF data using the CEM simulation.
- $P_T(Z)$ was modelled using an ad hoc functional form:

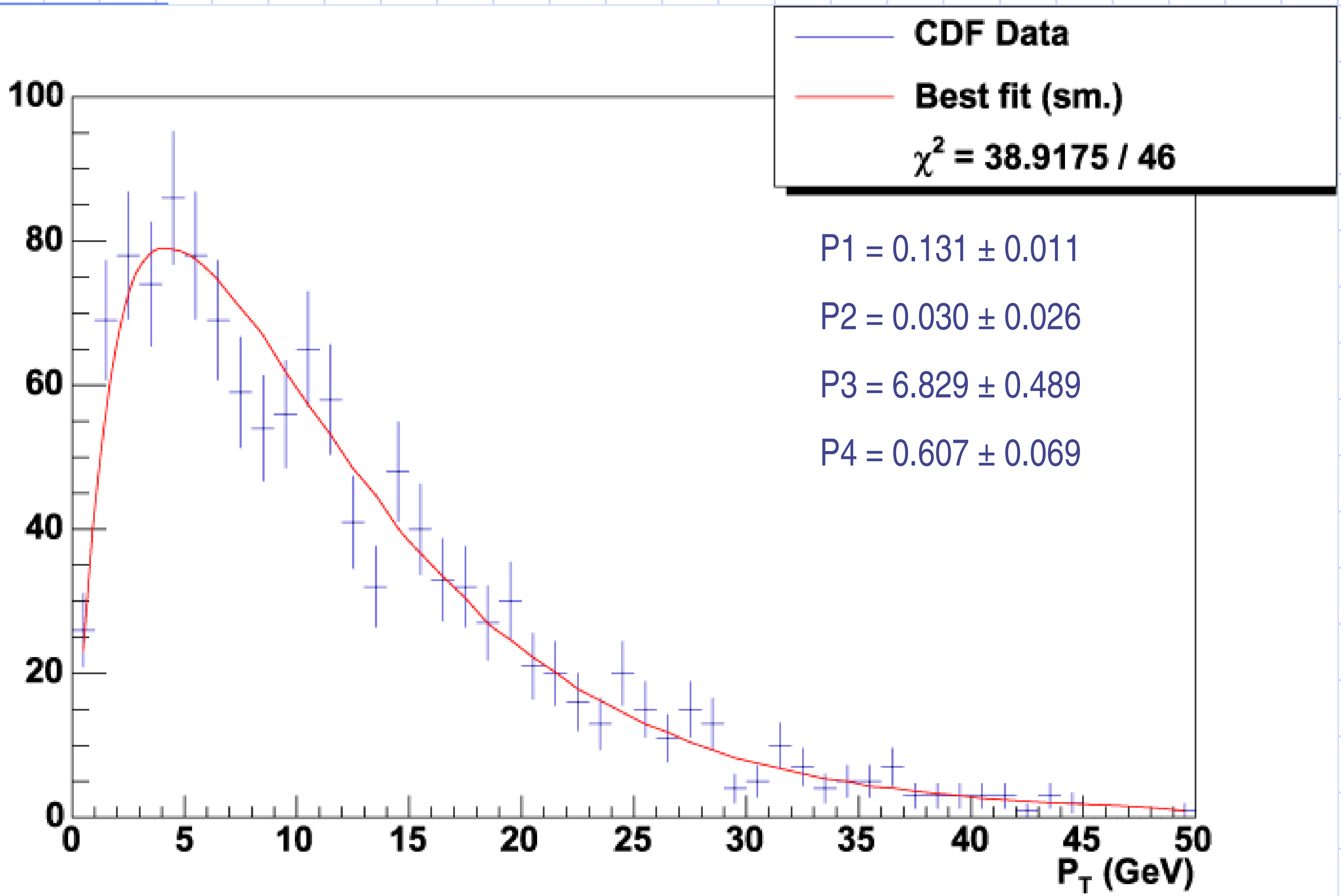
$$\frac{\left(\frac{P_T}{50}\right)^{P_4}}{\Gamma\left(P_4+1\right)}\left[\left(1-P_1\right)P_2^{P_4+1}e^{\frac{-P_2P_T}{50}}+P_1P_3^{P_4+1}e^{\frac{-P_3P_T}{50}}\right]$$

- The form has no physical basis, it is superposition of two exponentials that can describe the shape of the P_T curve.

Z^0 Functional form fit

- 4.6 million HERWIG events were used to create a ‘smeared’ and ‘unsmeared’ $P_T(Z)$ distributions.
- These were normalised and divided to created a weighting index.
- Now, the functional form can be re-weighted so that is described the P_T as measured by the CEM. This process is repeated until the functional form that gives the lowest chi-squared fit to actual CDF P_T data is found.
- The four parameters, and their errors, used to generate the form are retained.

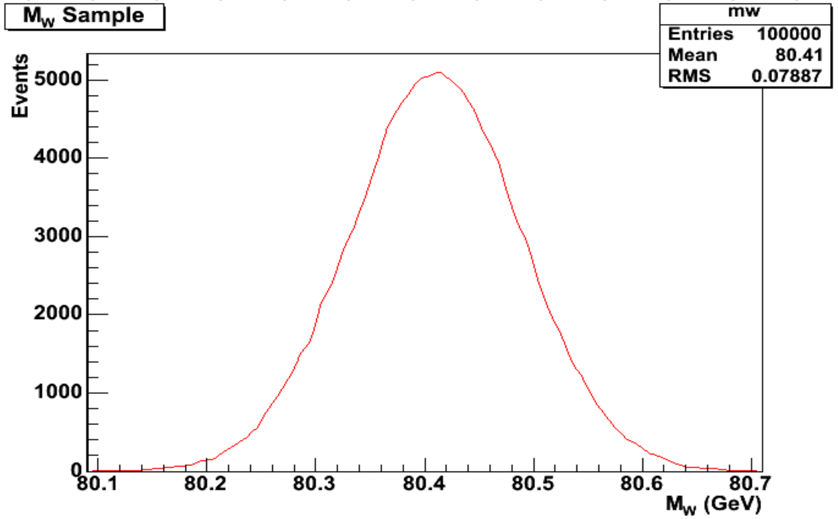
Z^0 transverse momentum



What next?

- Use the $P_T(Z)$ form to generate a M_W plot:
- Four new parameters will be generated from my best fit.
- These will be re-weighted to describe the $P_T(W)$
- A value of the transverse mass of the W can be determined form the P_T form to give a mass for the new parameter set.

- Repeating this process many times will produce a mass graph, from which a mass uncertainty can be estimated.



Summary

- A precise W mass measurement is important.
- We can only measure mass in the transverse plane.
- QCD gluons cause uncertainty in the PT of the bosons, introducing error in the boson mass.
- The QCD effects can be observed accurately for the Z, but not very well for the W. However, we can model the effect on the W from the Z.

Summary (cont.)

- The limit of the detector upon resolution needs to be modelled for.
- A simple simulation of the CEM at the CDF was built.
- A theoretical form for the $P_T(Z)$ was run through the simulator and fitted to fit the data from the CDF.
- The chi-squared fit of the data showed that the form could be used to model the P_T of the Z boson.
- Transforming this into a W mass uncertainty is currently being worked upon.

The End.

CEM Uncertainty