GEANT 4 and UCL Fast Simulation Comparison for CDF Run IIb W Mass Measurement

1st Year PhD Talk
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Testing GEANT 4 simulations against UCL Fast Simulation's detector model for electrons/gammas passing through the silicon vertex detector, using a virtual test beam

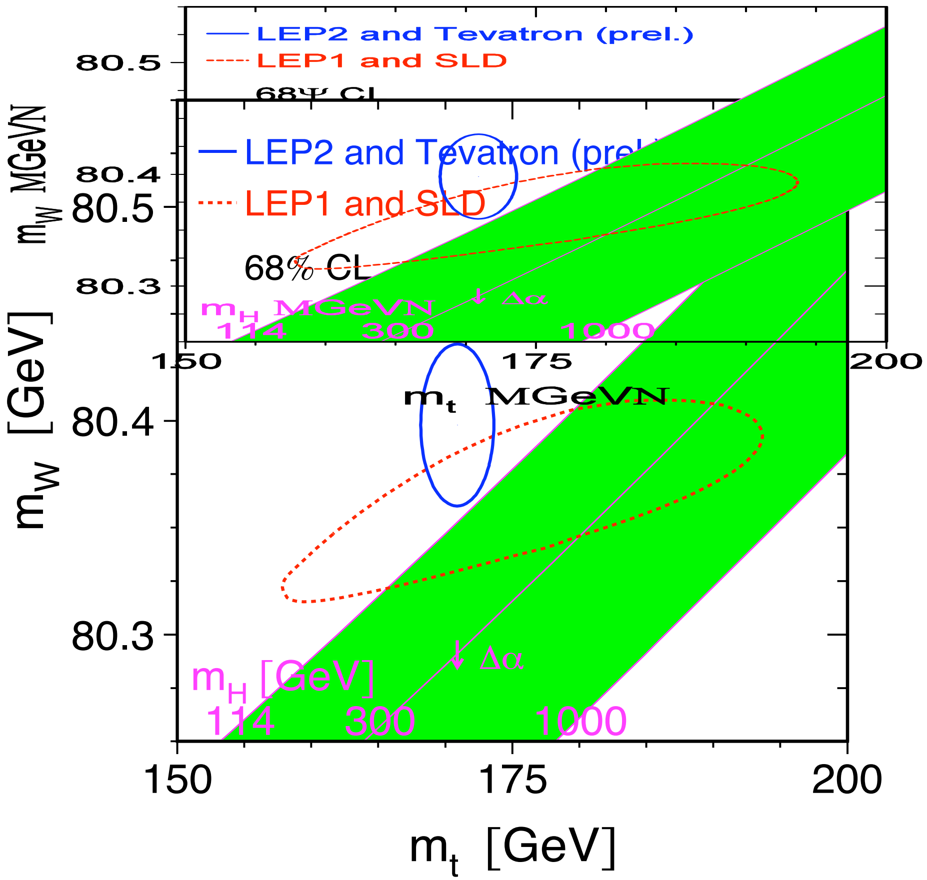
Why Measure W Mass?

- Test of Standard Model

- Can combine W mass and top mass to make an prediction of Higgs mass

  → W mass inaccuracy is main limit on accuracy of this

- If the LHC finds the Higgs, then we can compare direct and indirect Higgs mass estimates, any difference might indicate physics beyond the Standard Model



W Mass Measurement at CDF II

- Aims to be most accurate W mass measurement to date
- Aims to achieve total error on W mass of about 25 MeV

  → Same error on a single measurement as current world average!

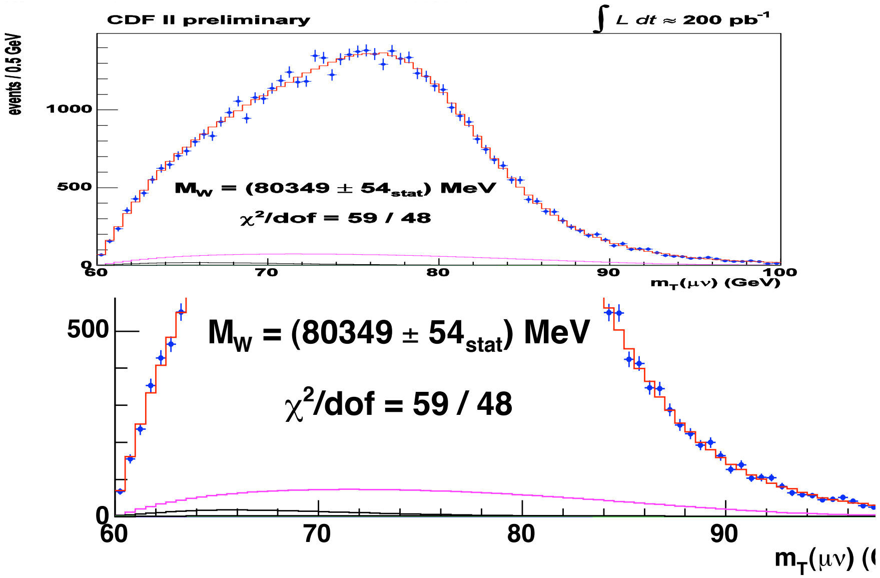
  → ATLAS may not be able to surpass this for a decade or more!
- Considers $W \to e\nu$ and $W \to \mu\nu$
- Uses about 2.3 /fb of data taken in CDF Run IIb

  → 10 times data of first measurement at CDF II

Template Likelihood Fits

- Use template likelihood fits of transverse mass

$$m_T = \sqrt{2 p_T^l \not{p}_T (1 - \cos\Delta\phi)}$$



- Generate templates for range of W masses

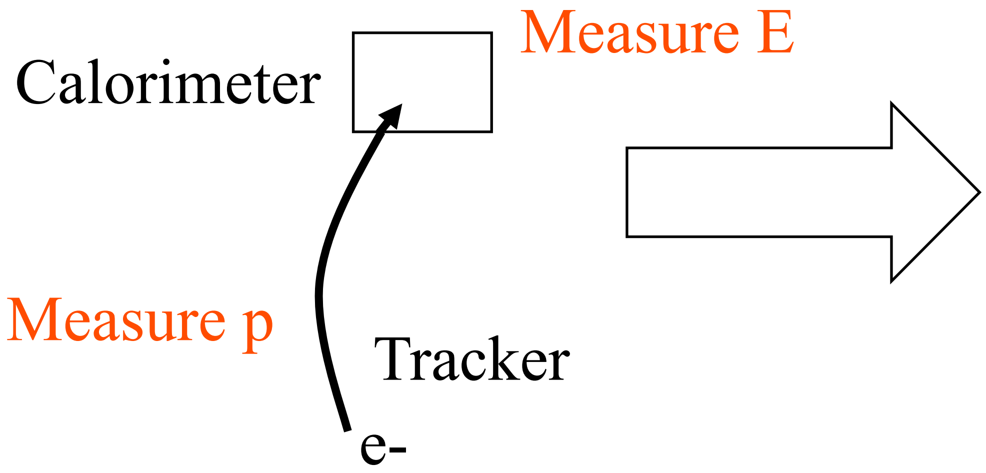
- Blue is data

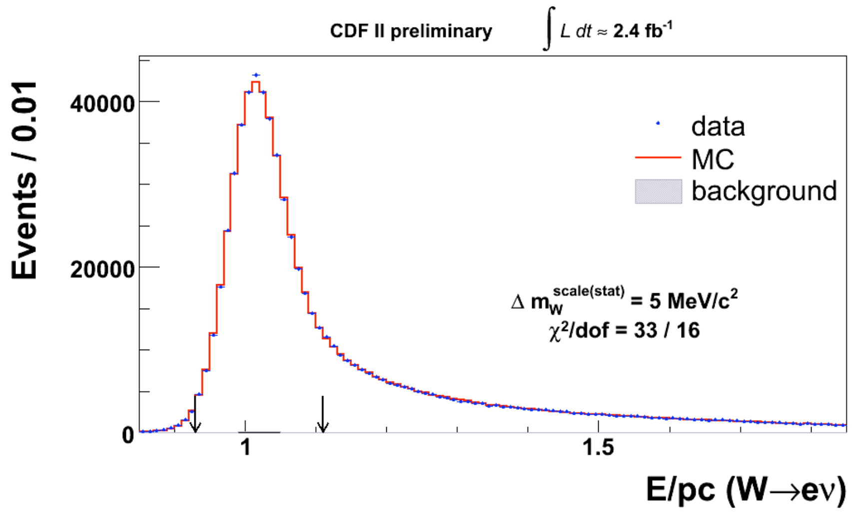
- Red is best fit Monte-Carlo template

  → This is our value of W mass

E/p Calibration

- Use E/p fit to transfer precise tracker calibration to calorimeter
  - → Want to determine the energy scale, S
  - → Simulate E/p distributions for a range of S values
  - → Best fit template gives us are value of S





- Then validate/calibrate energy scale using fit to Z mass

UCL Fast Simulation

- Templates generated using the UCL Fast Simulation
- Advantages over GEANT-based CDF Simulation

  → Faster → Many orders of magnitude more events/second

  → More Flexible → Easier to tinker with parameters of the model
- Disadvantages

  → Not as well tested

  → Less sophisticated detector level physics models

Testing of Physics Model for Silicon Vertex Detector

- Electrons passing through silicon vertex detector can undergo

  → Bremsstrahlung

  → Ionization

- Photons can undergo

  → Pair Production

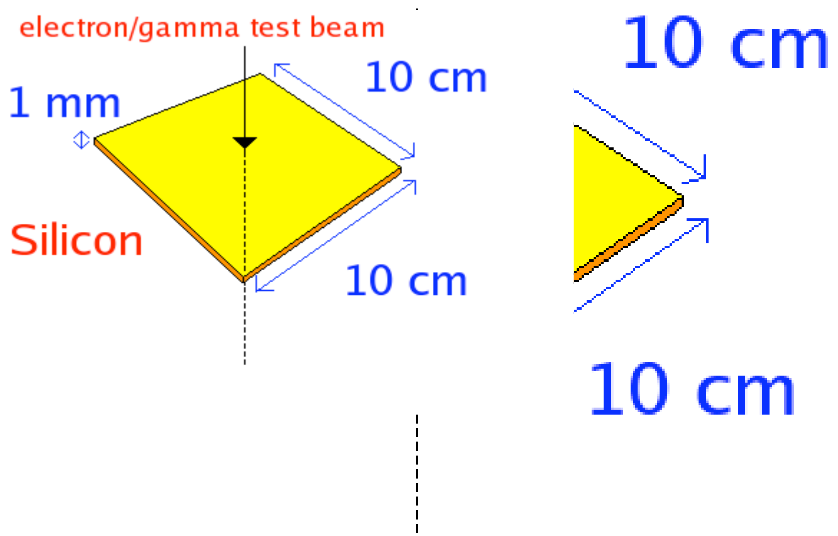
  → Compton Scattering

- Plan to validate UCL Fast Simulation of these against GEANT4

- Then make any necessary improvements to the simulation

Virtual Test Beam Set-up

- Easier to test each process individually using a virtual test beam
- We set-up a virtual test beam experiment in GEANT 4 with electrons incident on a 1 mm thick silicon plate
- A similar set-up was used in UCL Fast Simulation



Electron Bremsstrahlung

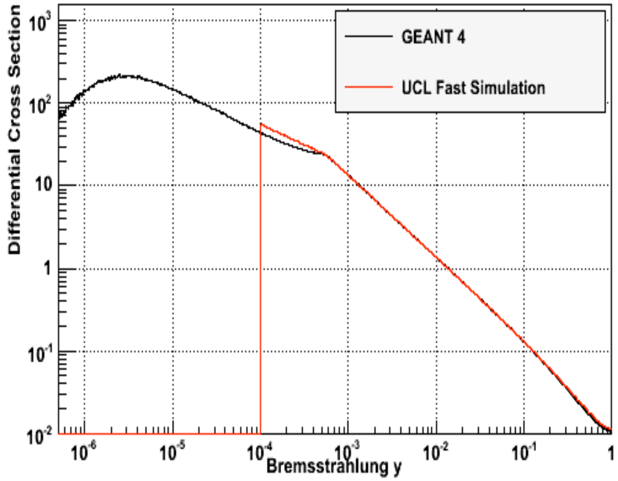
- Most important process is Bremsstrahlung

  → Affects simulated E/p distribution, hence fitted energy scale

- Key quantity is y, the fraction of the electron's energy transferred to the radiated photons

- Compare differential cross section vs. y

- GEANT 4 and UCL Fast Simulation with only Bremsstrahlung process active.

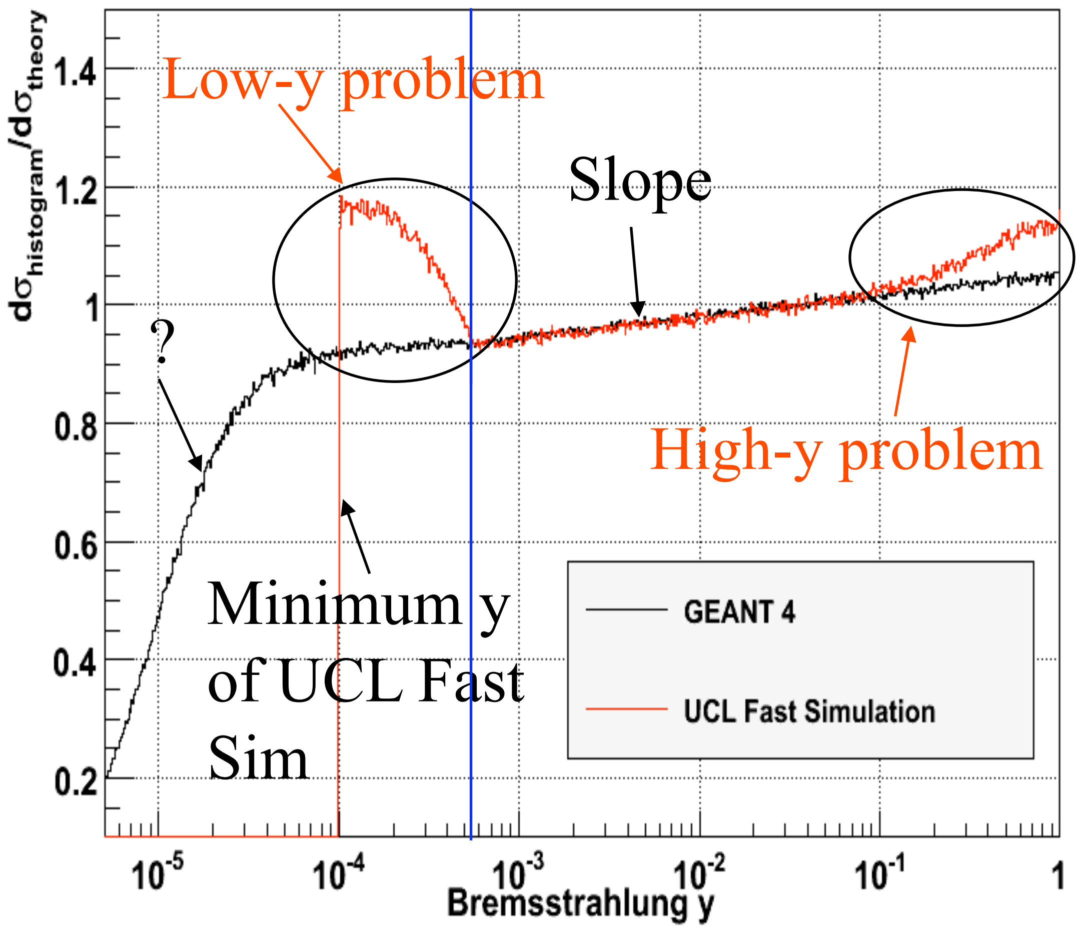


- Difficult to interpret this plot...
- So plot

$$R = \frac{Histogram}{Theory}$$

- Which Theory?
  - Could use basic from PDG review $\frac{d\sigma}{dy} \propto \frac{1}{y}\left(\frac{4}{3} - \frac{4}{3} \cdot y + y^2\right)$
  - Instead use the “theory implemented in GEANT”

First Ratio Plot



- UCL Fast Simulation just uses basic y spectrum given in PDG review, as seen on page 10, along with LPM suppression at low y
- This doesn't account for incomplete screening at high y
- This doesn't account for dielectric suppression at low y
- Blue line is LPM cut-off

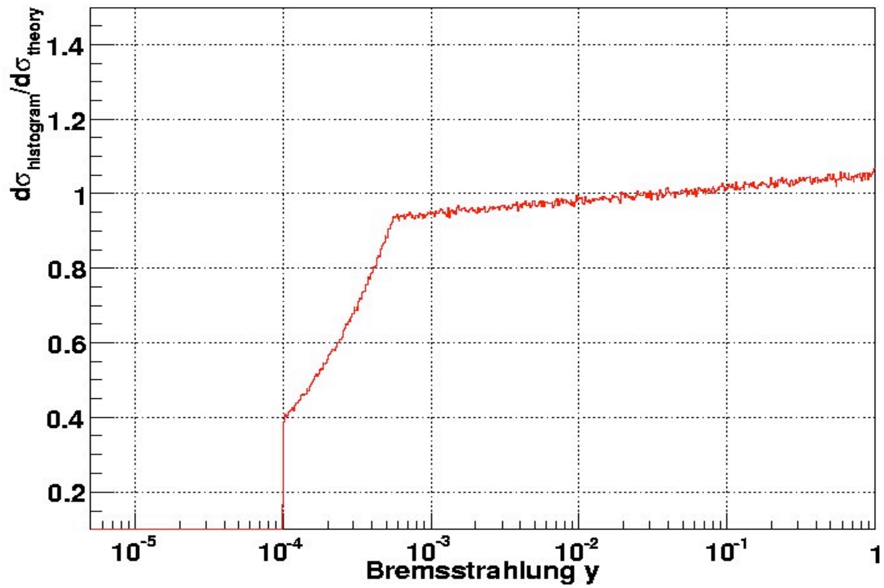
GEANT vs. Theory

- Note even GEANT histogram isn't flat

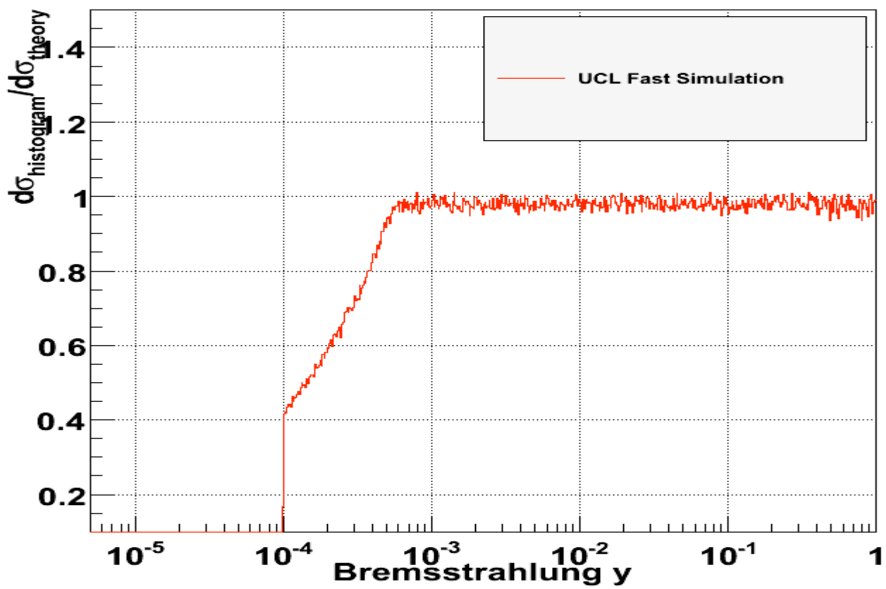
  → Discrepancy at very low-y

  → Slope is due to the possibility of the emission of multiple photons

- Can see that this last point is true by plotting the ratio of UCL Fast Simulation to the basic theory curve from the PDG review that it follows…

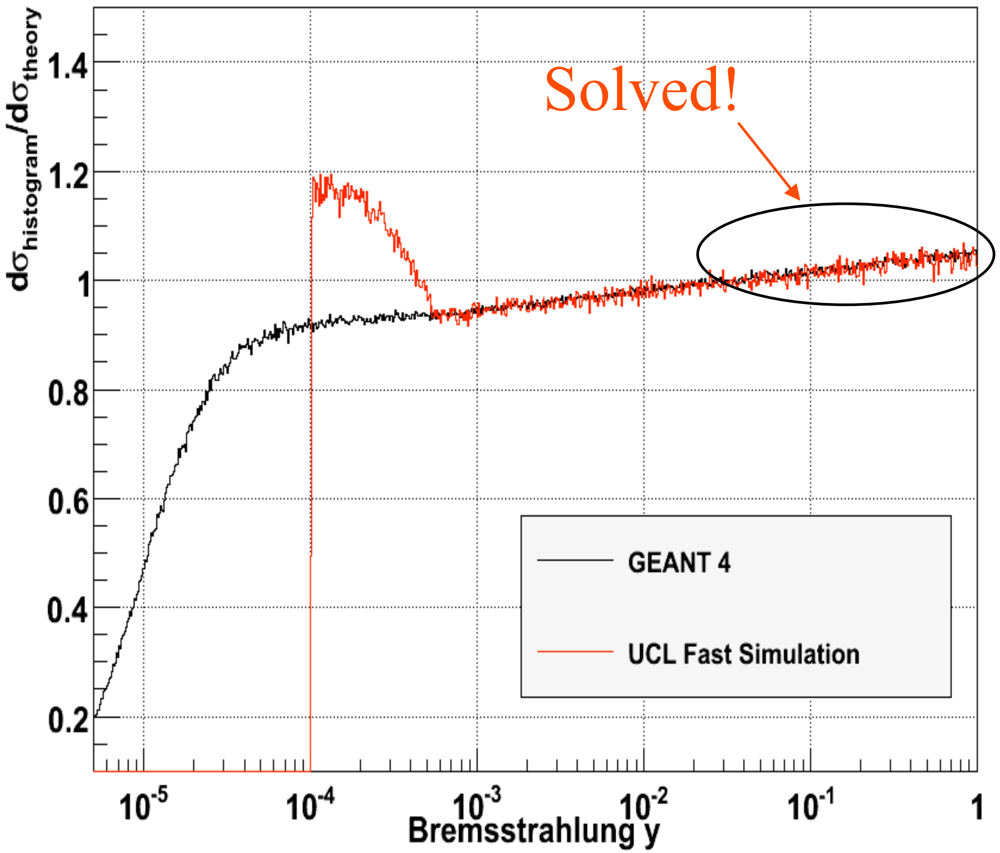


… with multiple photon emission, i.e. normal case



… without multiple photon emission

Second Ratio Plot

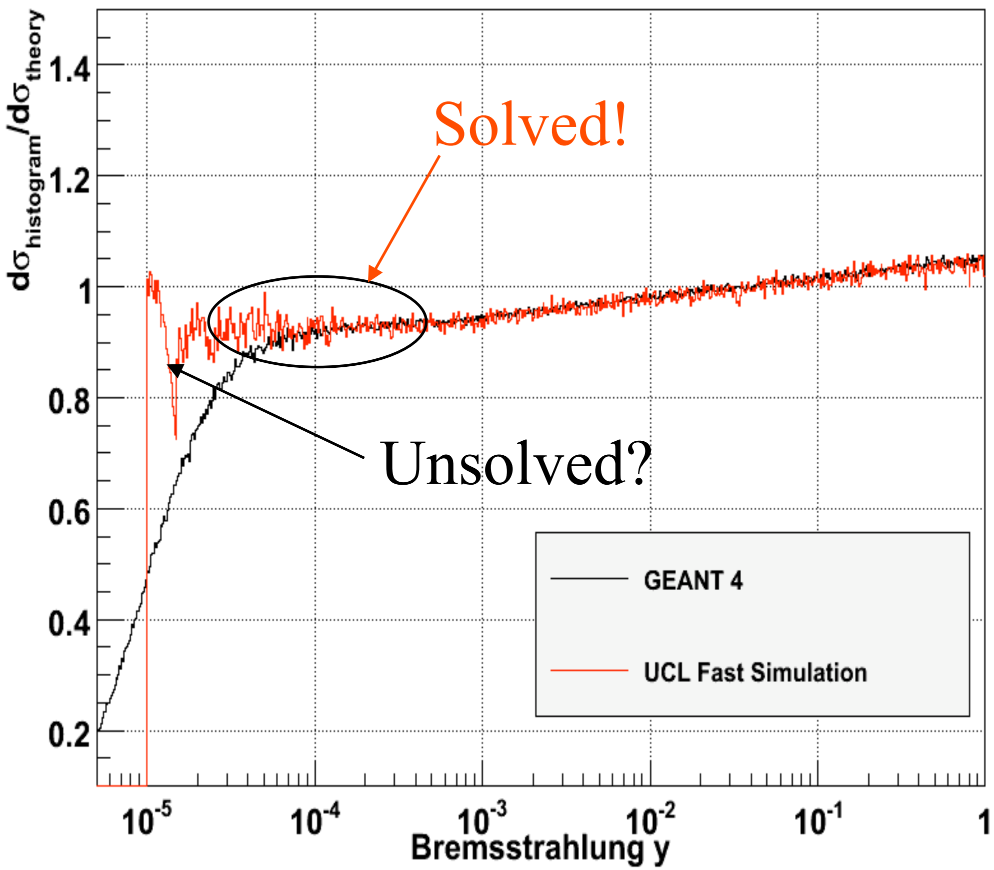


- Try using "GEANT 4 theory" in UCL Fast Simulation
- $$\frac{d\sigma}{dy} \propto \frac{1}{y} \cdot \left(\left(1 - a \cdot y\right) \cdot F_1\left(y\right) + b \cdot y^2 \cdot F_2\left(y\right)\right)$$
- This solves the problem at high-y
- Still need to deal with low-y

Solving the Discrepancy at Low-y

- UCL Fast Simulation implements LPM suppression at low y
- GEANT 4 has both LPM suppression and dielectric suppression at low y, combining of these effects in a non-trivial manner
- Try implementing GEANT's parameterisation of dielectric suppression in UCL Fast Simulation
- i.e. for $y < \dfrac{E}{E_{LPM}}$ we suppress the cross section by S/S_P
- S is a complicated function of $S_P = \dfrac{k^2}{k^2 + C_p \cdot E^2}$
- …And $S_{LPM} = \sqrt{\dfrac{kE_{LPM}}{E^2}}$

Third Ratio Plot



- This correct discrepancy at low-y down to y = 5.5*10E-5
- So model is accurate down to about 2 MeV
- Don't know why we get deviation below this

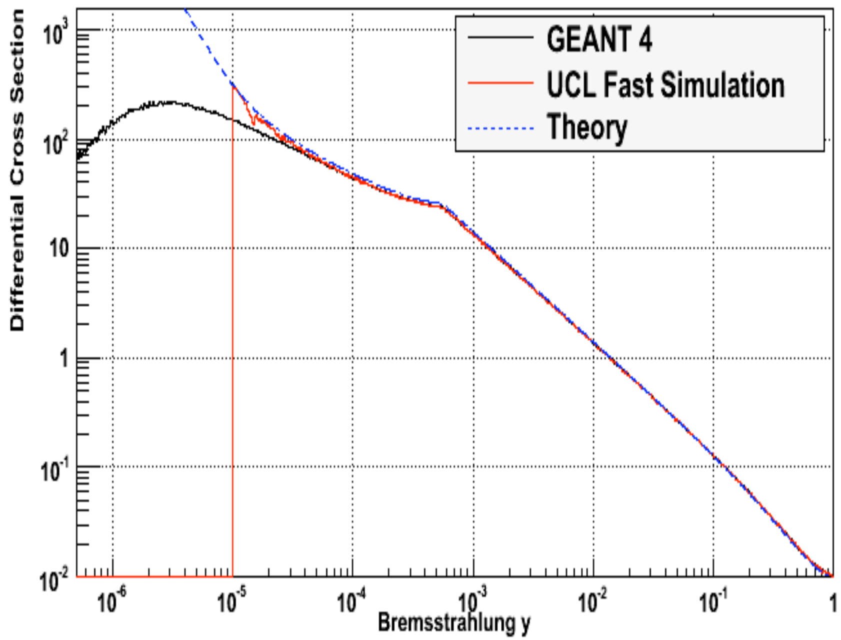
Is this good enough?

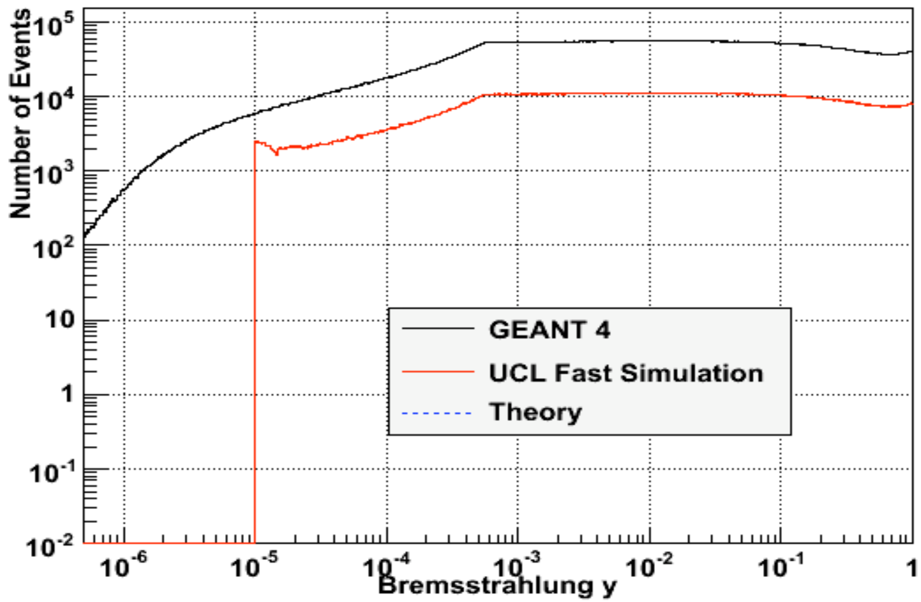
- Hopefully yes …
- Ultimately all that matters is if mismodelling of Bremsstrahlung will affect the measured W-mass
- Can perform fit templates to pseudo-data generate by slightly varied model to test this

  → Haven't got high enough statistics for this yet, work is in progress

  → Initial calculations put the error from this on W mass at about 100 KeV
- Also think about this in terms of physics…

How many events are at very low-y?





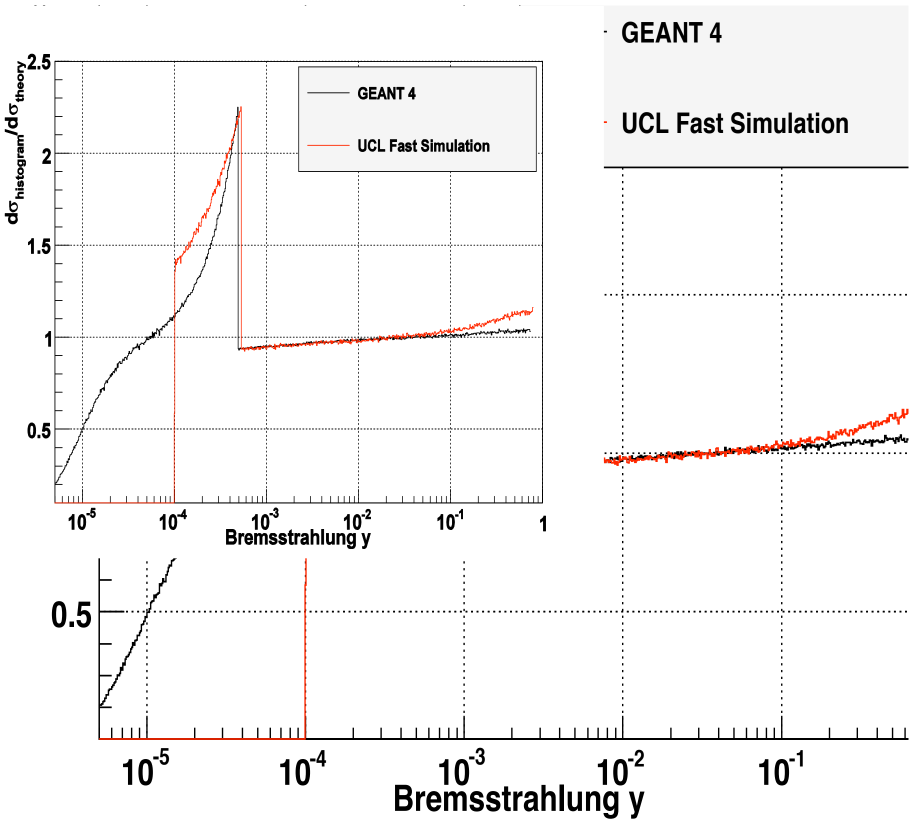
- Although differential cross section at small y is large
- Actual number of events at very low y is small
- Hence a 2 MeV effect can give a 100 KeV error on the measured W mass

Conclusions and Future Plans

- Bremsstrahlung spectrum in now in very good agreement with GEANT 4 down to 2 MeV
- Still not perfect below 2 MeV
- However an initial calculation shows this only produces order of 100 KeV error on W – mass measurement

  → Negligible! Problem Solved!
- New implementation of Bremsstrahlung doesn't slow down UCL Fast Simulation
- Plan to conduct a more through Bremsstrahlung error analysis
- Then to proceed to validate pair production, ionisation and Compton scattering

Back-Up Slide 1



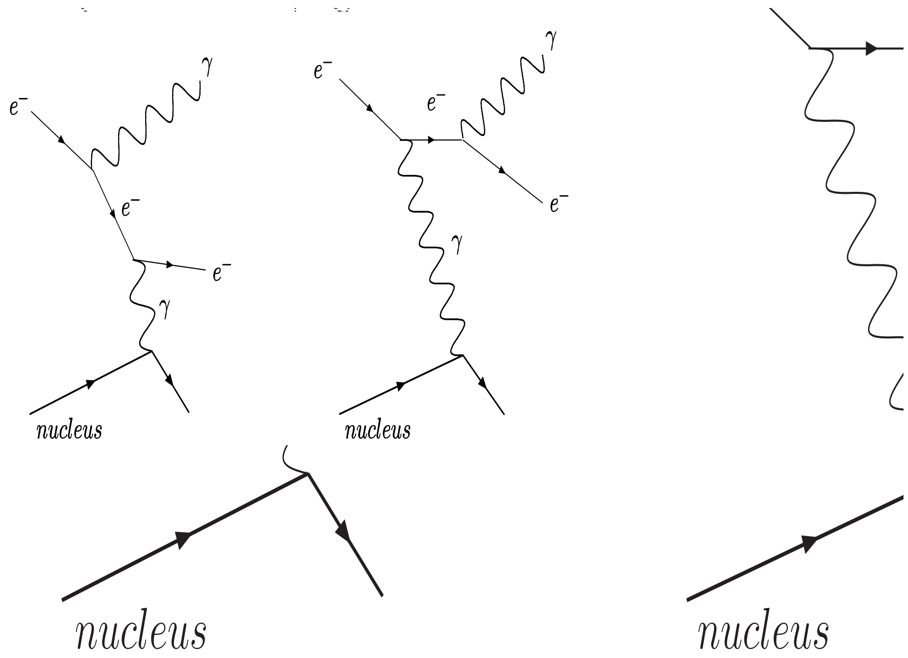


Figure 6

Back-Up Slide 2

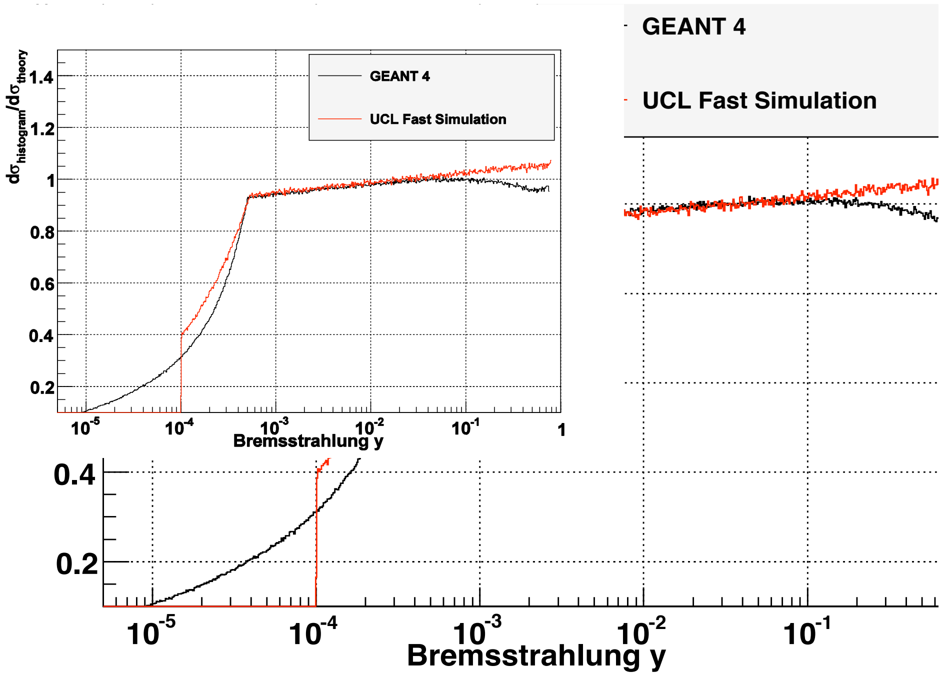


Figure 12

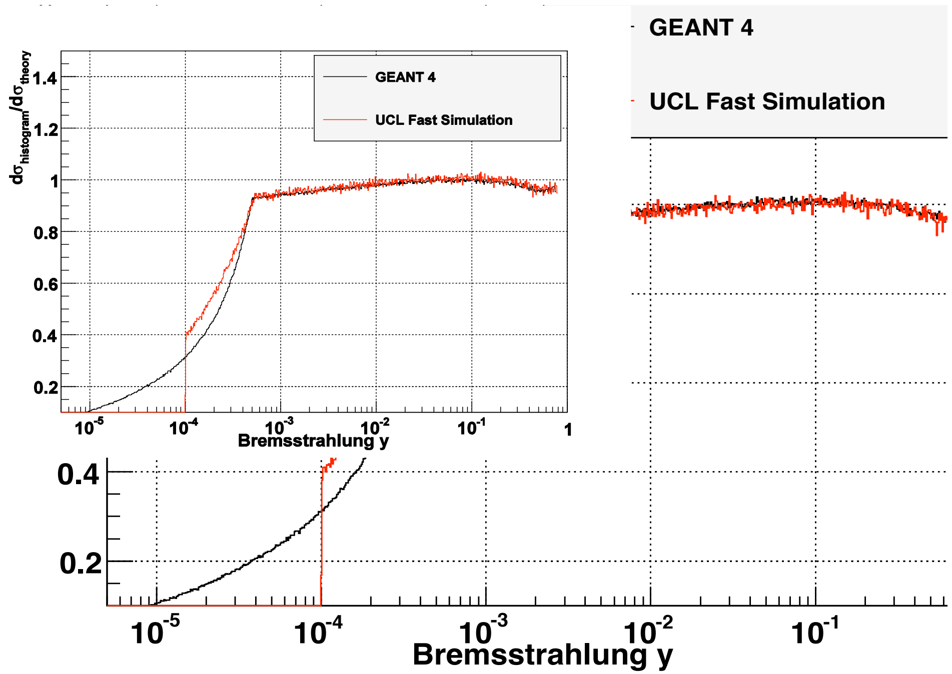


Figure 13

Back-Up Slide 3

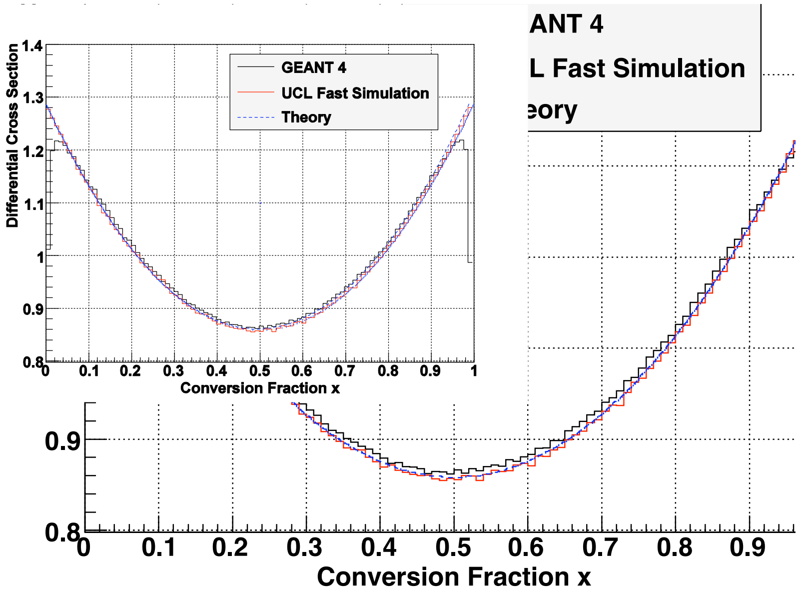


Figure 18

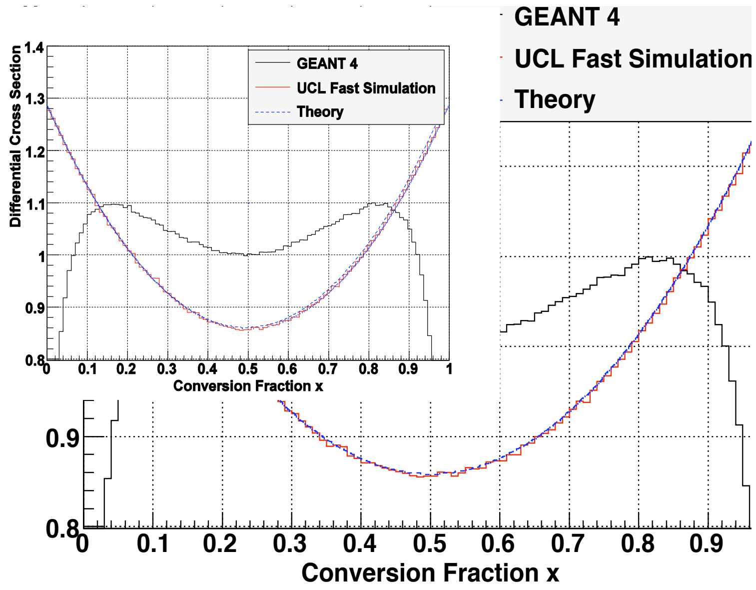


Figure 19

Back-Up Slide 4

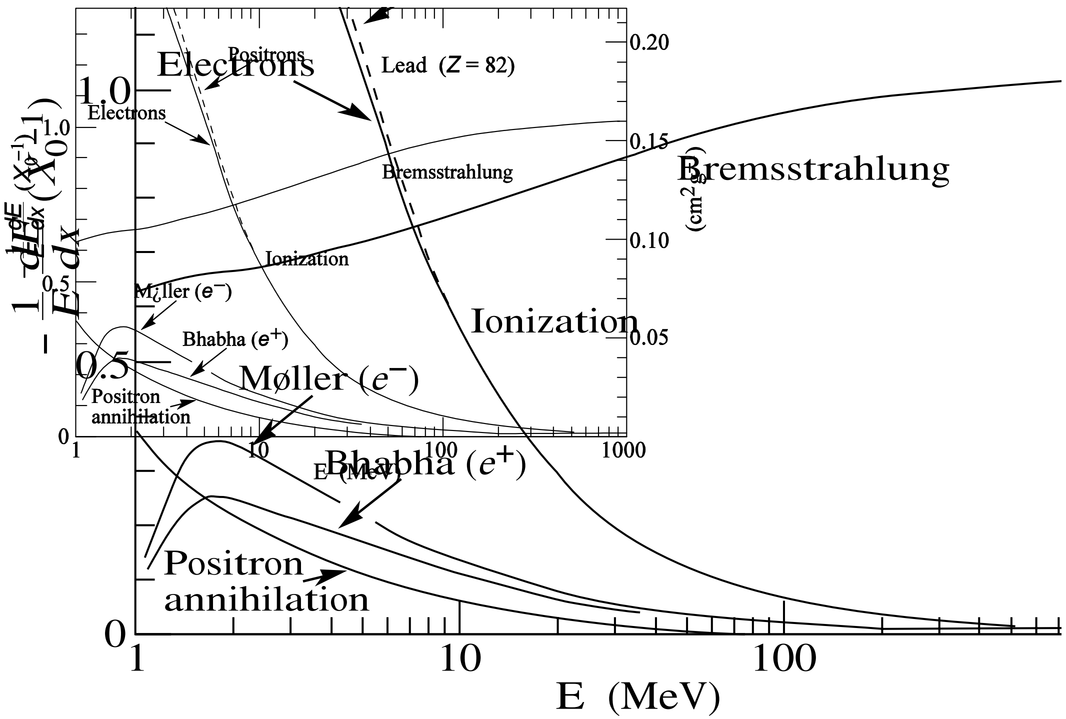


Figure 7