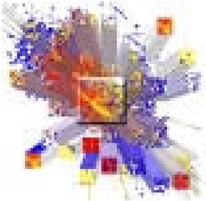
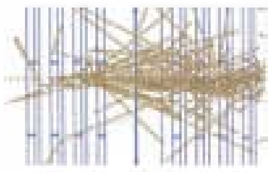


IX International Conference
on Calorimetry in Particle Physics
CALOR2000



Physics with Large Calorimeters at HERA

Julian Phillips

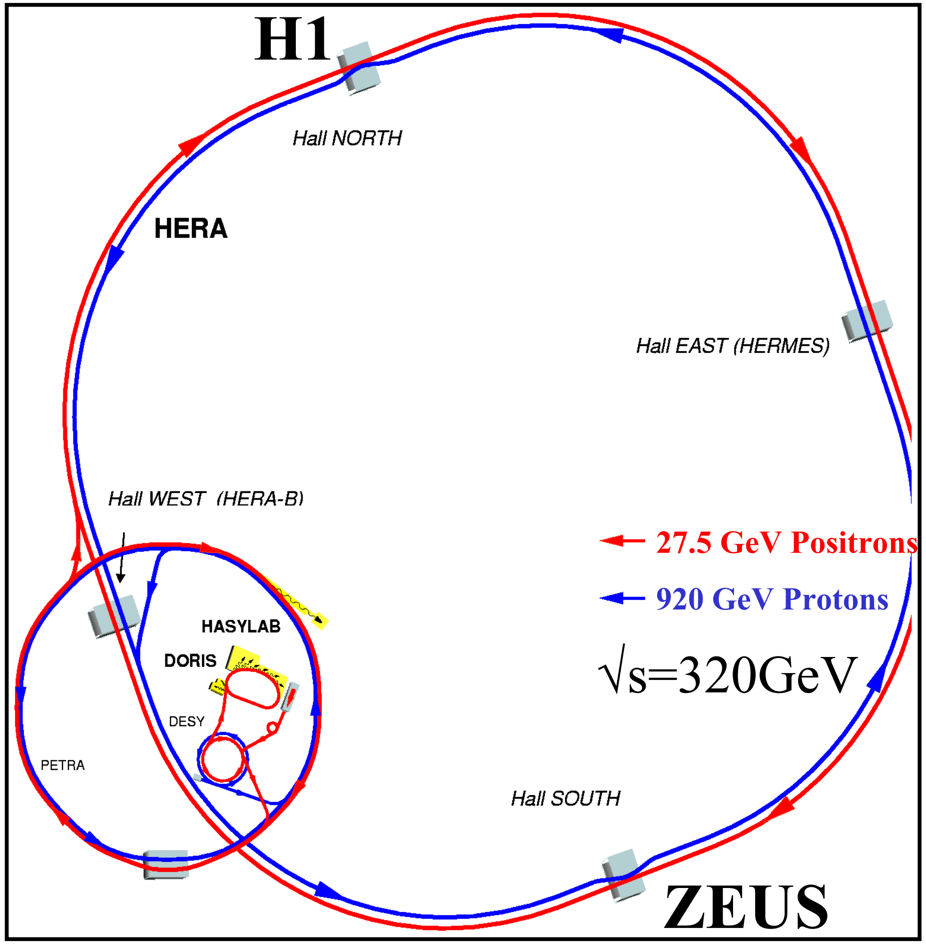
University of Liverpool

For the H1 and ZEUS Collaborations

Outline

- The HERA collider and ep Physics
- The H1 and ZEUS detectors at HERA
- Preview of Results from 4 Talks:
  - The Calibration of the H1 LAr Calorimeter – ***Cigdem Issever***
  - Measurement of Absolute Jet Energies in the H1 LAr Calorimeter – ***Marie Jacquet***
  - Precise Measurement of Jet Energies with the ZEUS Detector – ***Mathew Wing***
  - Optimization of Jet Algorithm Inputs in the ZEUS Detector – ***Steve Magill***
- Summary of Precision Achieved at H1 and ZEUS

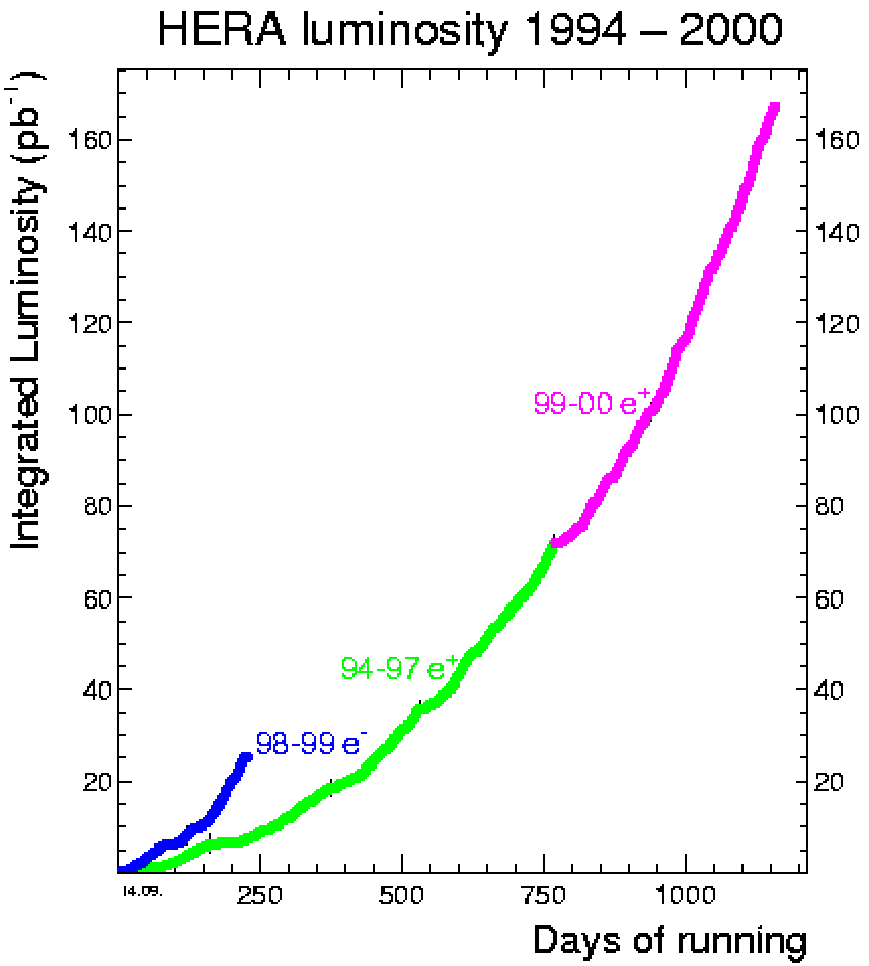
The HERA Collider



27.5 GeV Positrons

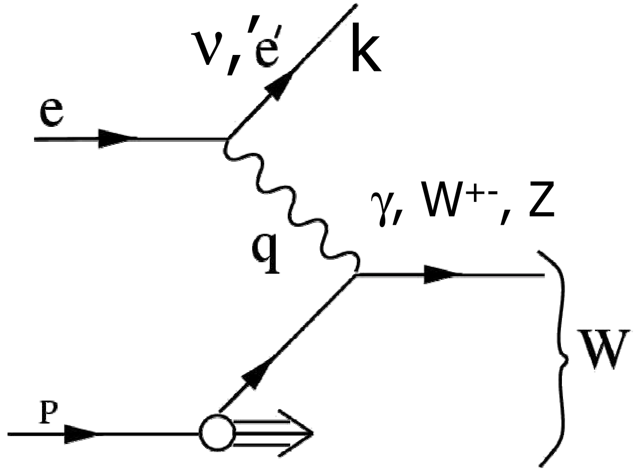
920 GeV Protons

$\sqrt{s}=320\text{GeV}$



HERA Physics

- Probing proton structure at 10^{-18}m with a virtual vector boson:



Kinematics:

$Q^2=-q^2$	resolving power of probe
$W^2=(q+P)^2$	mass of hadronic system
$x = -q^2/2P.q$	fraction of proton momentum
$y = P.q/P.k$	inelasticity parameter

- Neutral Current: ep→eX
  - Structure functions F_2, F_L, xF_3, gluon distribution, BSM searches
- Charged Current: ep→νX
  - Individual parton distributions, electroweak tests
- Final State Measurements
  - Jet rates→Tests of QCD including $\alpha_s(Q^2)$
- BSM searches…

The H1 and ZEUS Detectors

Neutral Current

Energy and angle measurement for electrons and positrons

Charged Current

Precise measurement of inclusive hadronic final state vector (identify missing momentum)

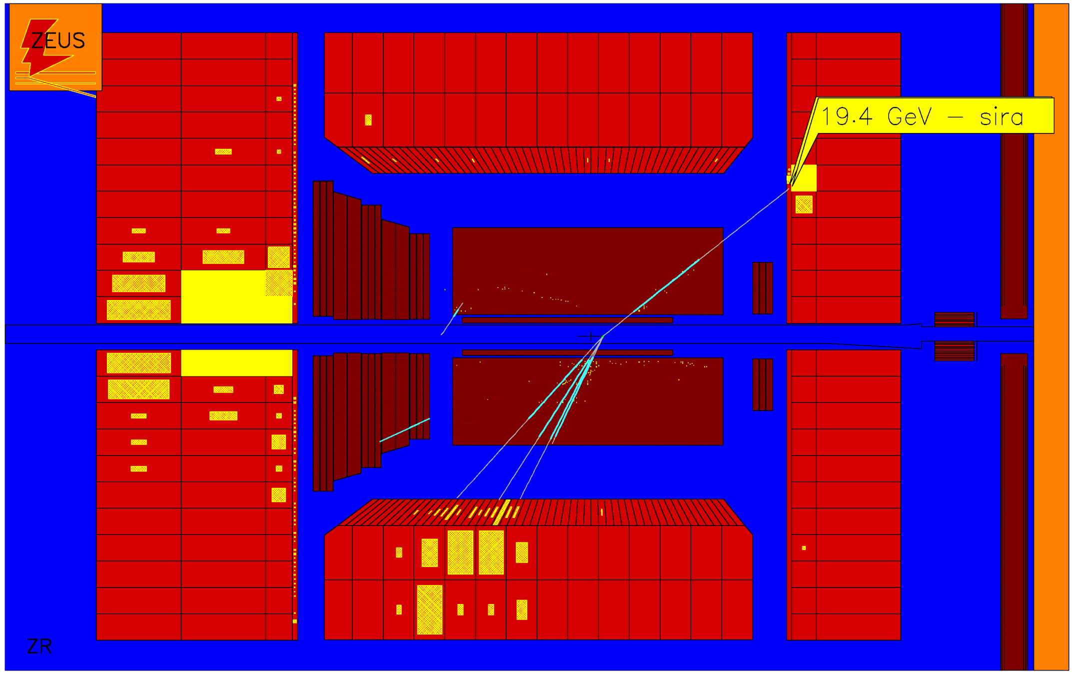
Final State Studies

Maximum coverage of hadronic final state, good spacial resolution, tracking and calorimetry, secondary vertex i.d.

HERA Environment

One lepton beam and one proton beam: challenge of making precision measurements in a high background environment

ZEUS Uranium Scintillator Calorimeter



- Accurate timing ⇒background rejection for first level trigger
- Compensating
- Intrinsic calibration from radiation
- Hadronic resolution:

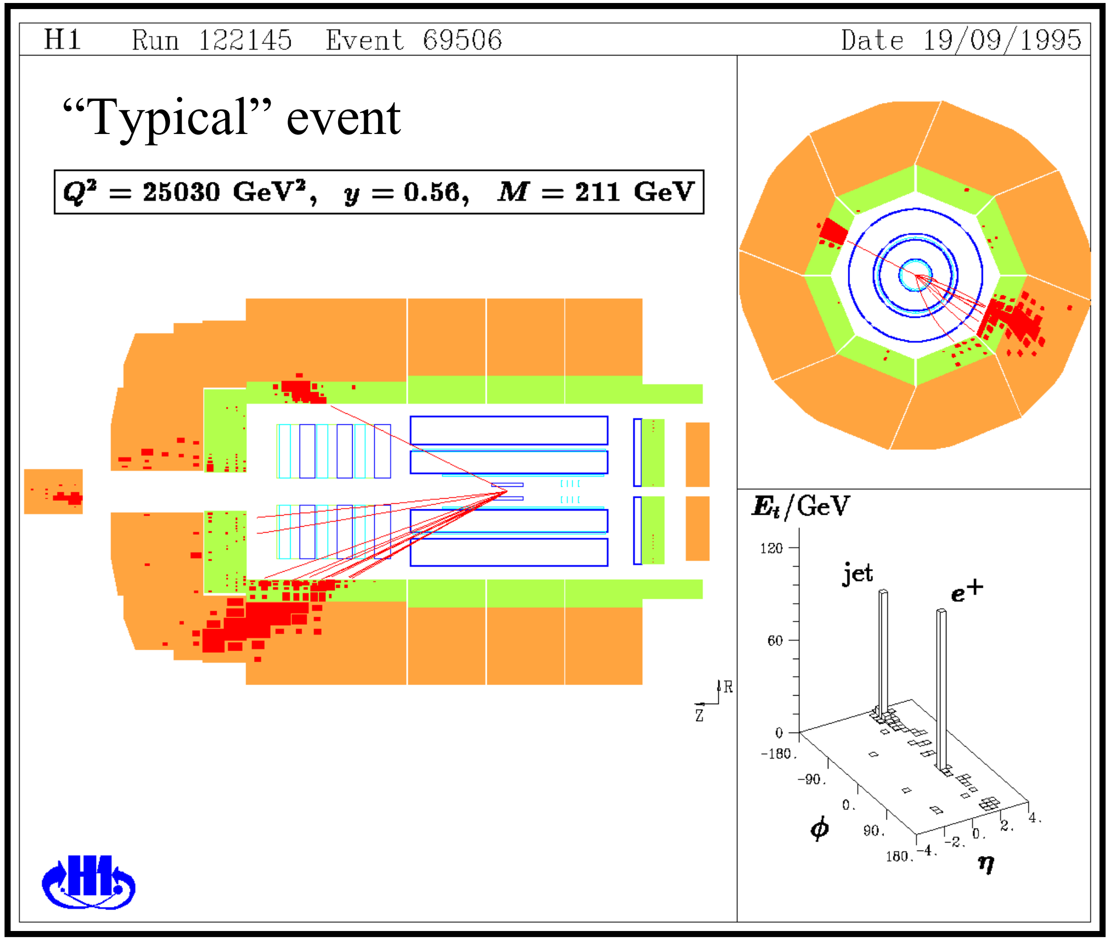
  $\delta E/E = 35\%/\sqrt{E}$

- Electromagnetic Resolution:

  $\delta E/E = 20\%/\sqrt{E}$

- Coarse granularity
- Main Magnet between tracking and calorimeter⇒challenge to understand dead material

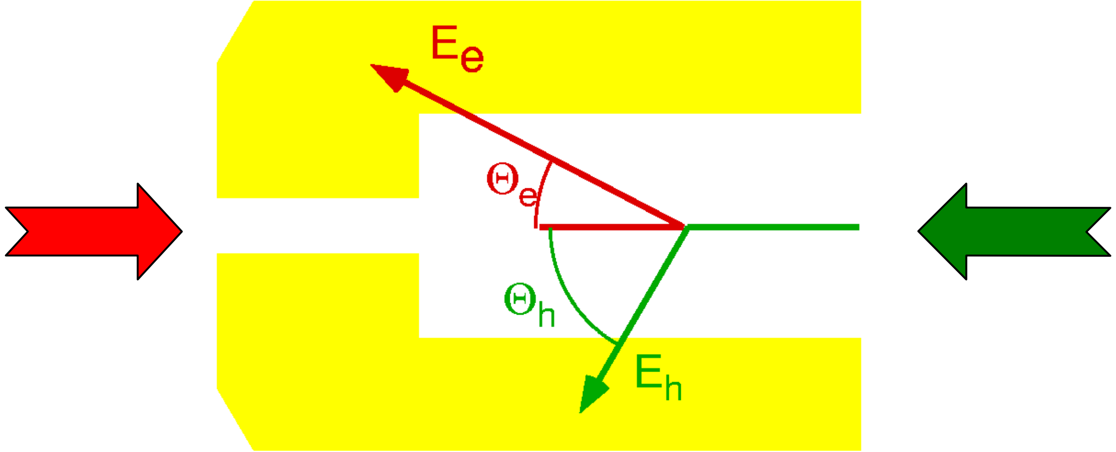
H1 LAr Calorimeter



- LAr Sampling calorimeter:
  - Electromagnetic: Lead 20-30 X_o
  - Hadronic: Steel 5-8λ
- Software Compensation
- Fine grained (45000 channels)
- Very good spacial resolution
- EM resolution:
  $\delta E/E = 12\%/\sqrt{E}$
- HAD resolution:
  $\delta E/E = 50\%/\sqrt{E}$
- Magnet outside calorimeter

HERA Kinematics & Constraints

4 Measurements: energy and angle of scattered lepton and final state



Inclusive hadronic angle

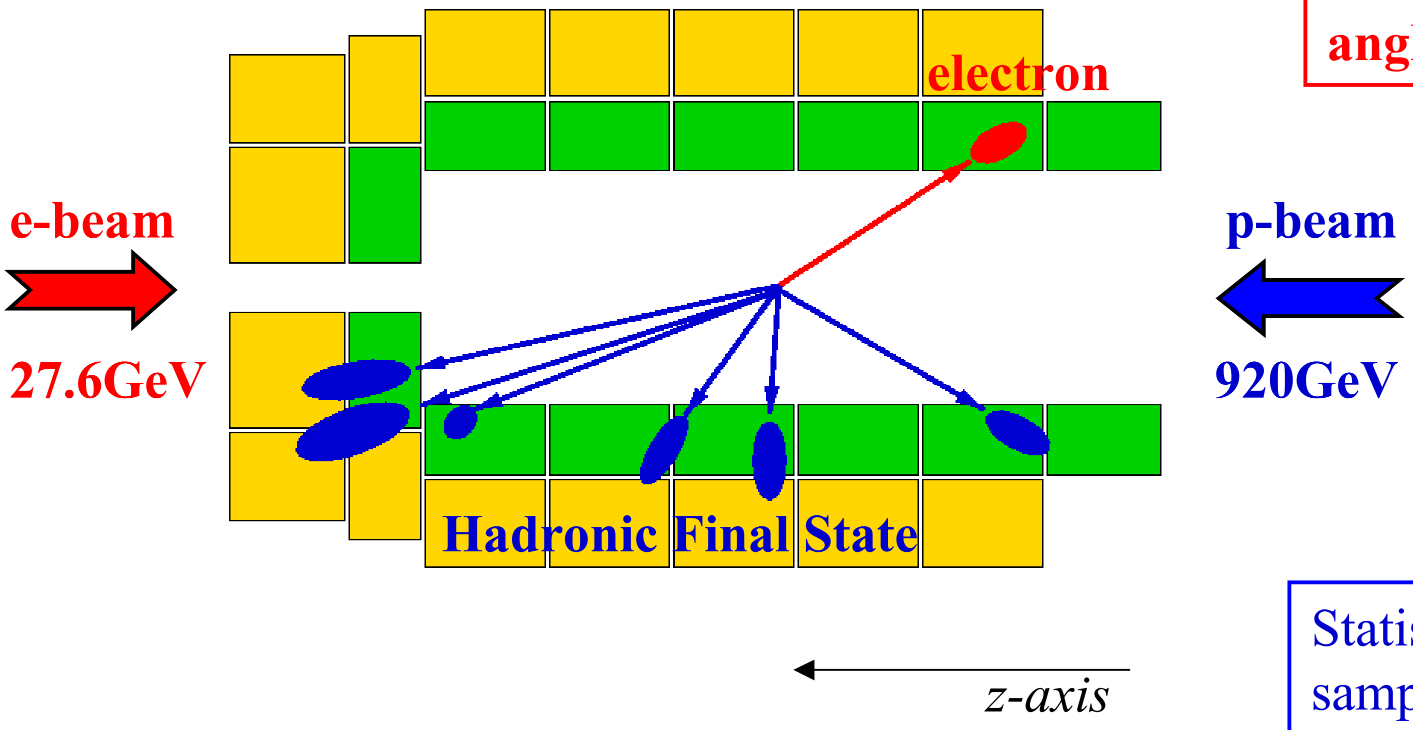
$$\cos\Theta_h = \frac{P_T^2 - (E - P_Z^2)}{P_T^2 + (E - P_Z^2)}_h$$

$E\text{-}P_Z$, P_T summed over all final state particles

Two kinematic d.o.f.: choose 2 from (x,y,Q^2)

- Over constrained system: many possibilities e.g.
  - Transverse Momentum Balance (P_T) balance: $P_t^e = P_T^h$
  - Longitudinal Momentum Balance: $(E-P_z)^e + (E-P_z)^h = 2\,E_e$(beam)
  - "Double Angle Method": predict E_e and E_h from θ_h and θ_e

HERA Calibration Fundamentals



Calibrate electron with double angle energy prediction

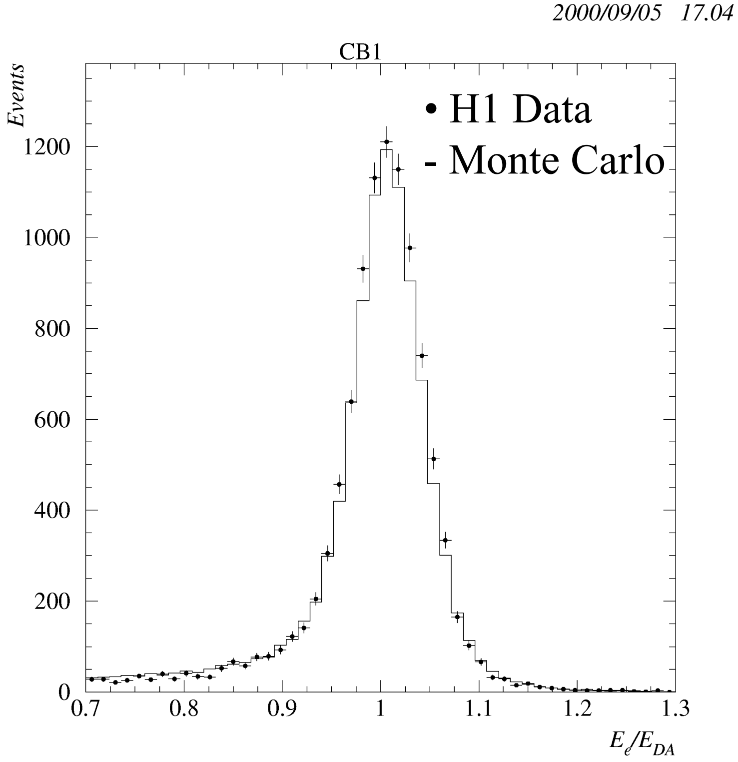
Longitudinal and transverse momentum balance

Statistical techniques on large samples to establish position and energy dependent calibration

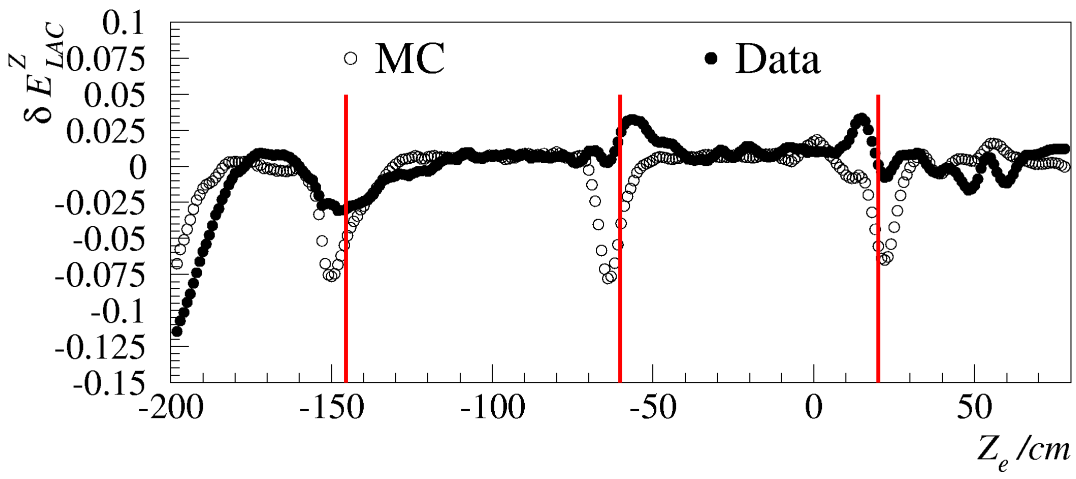
Important to have as many different methods as possible to assess systematic uncertainties

Scattered Lepton Calibration (H1)

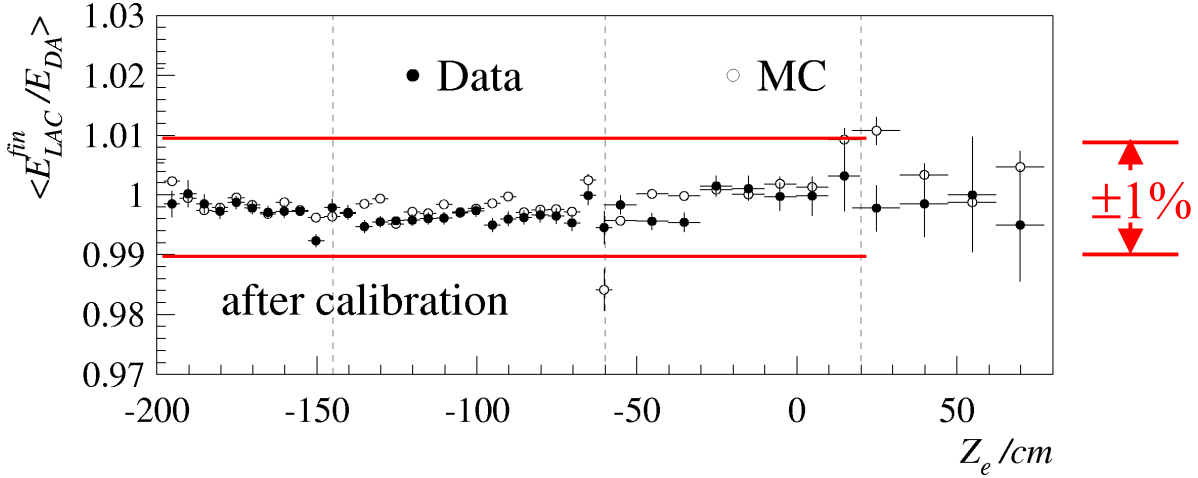
- Double Angle Constraint:
  E_e^{rec} / E_e^{da} vs impact in z



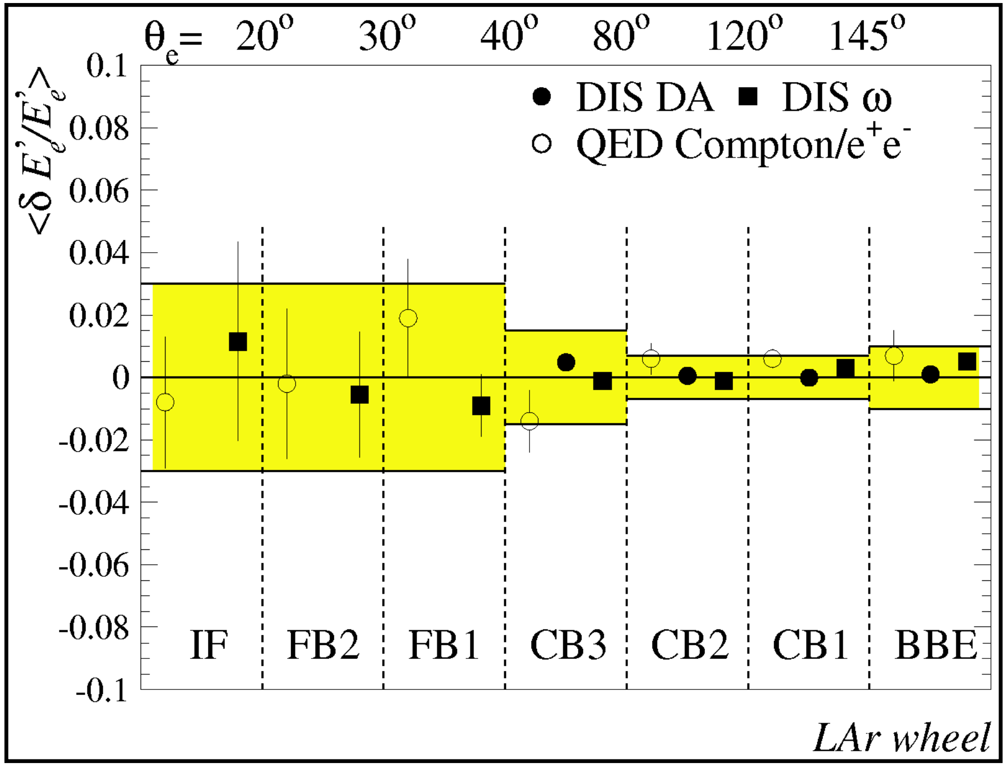
- Calibration correction coefficients:



- Results of applying calibration:



Systematic Uncertainty on Electron Energy (H1)

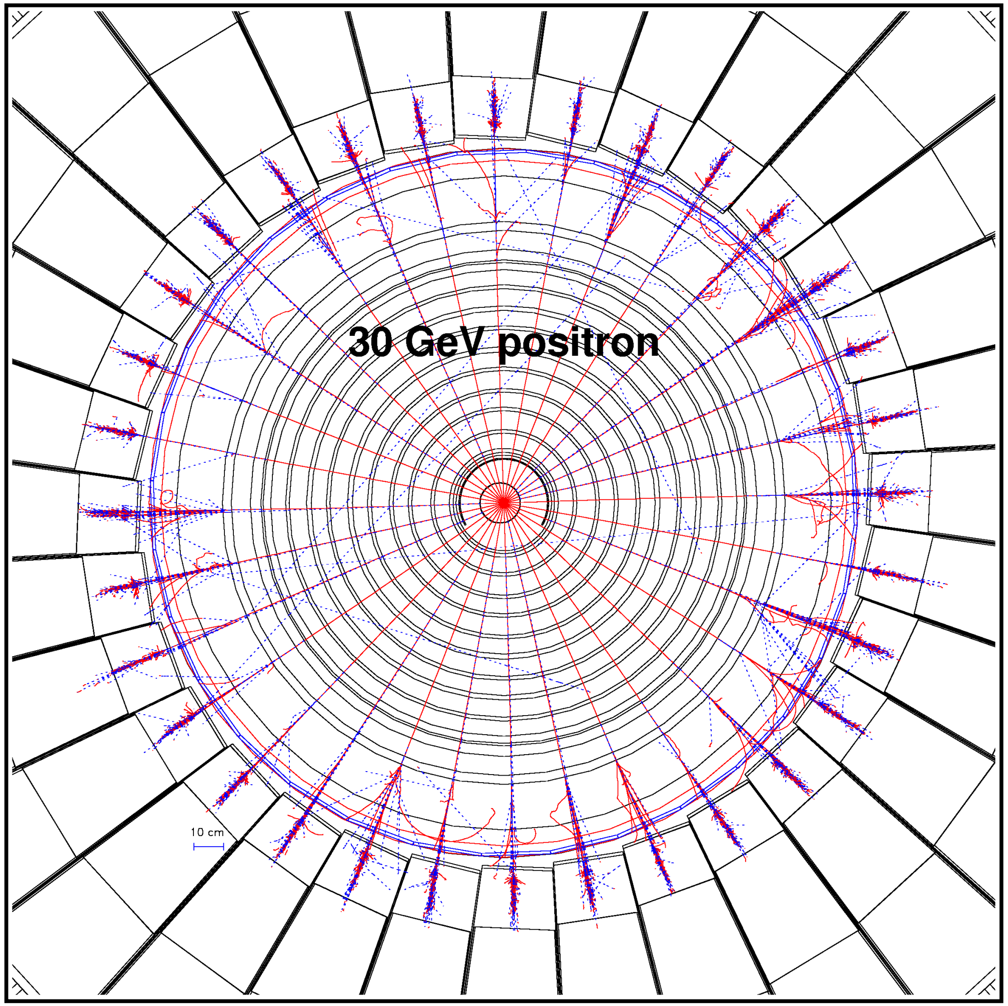


Precision exceeds design goal of 1%

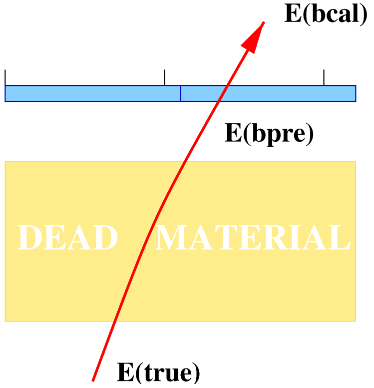
- Compare several different methods for confidence
- Overall uncertainty 0.7% to 3%
- *Correlated* uncertainty only 0.5% (mainly biases of DA method)
- Improvements to $F_2(x,Q^2)$:
  - Low x,Q^2 7% → 4%
  - High x,Q^2 20%→ 15%
- Statistics limited: further improvements possible

Well understood electron permits accurate calibration of hadronic response

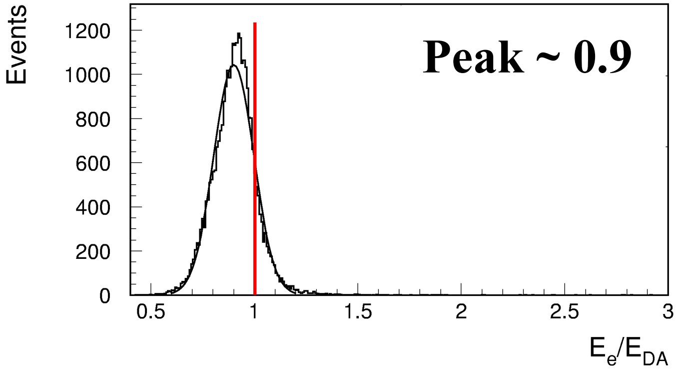
Dead Material Corrections with ZEUS Presampler

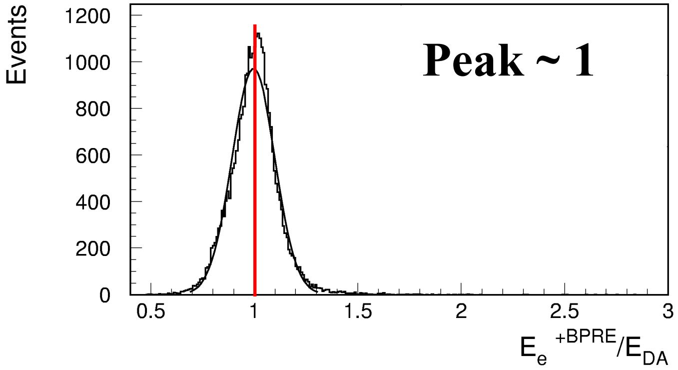


Simulation of 30 GeV positrons



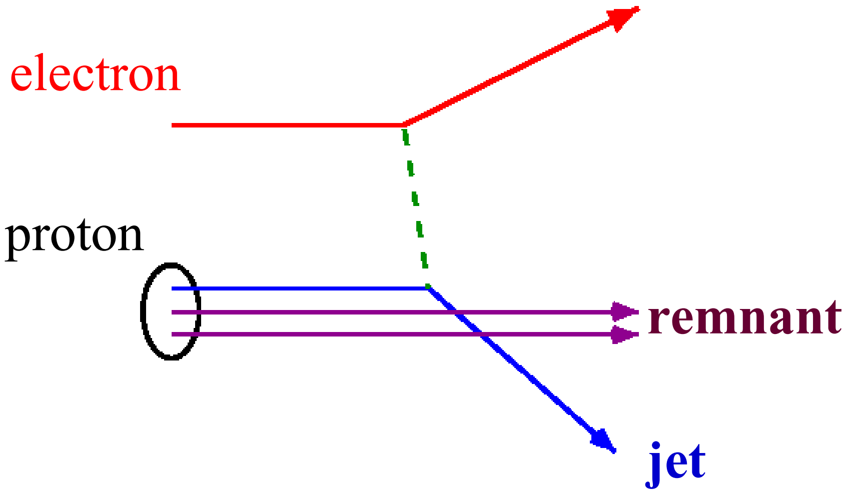
bpre signal proportional to losses in dead material



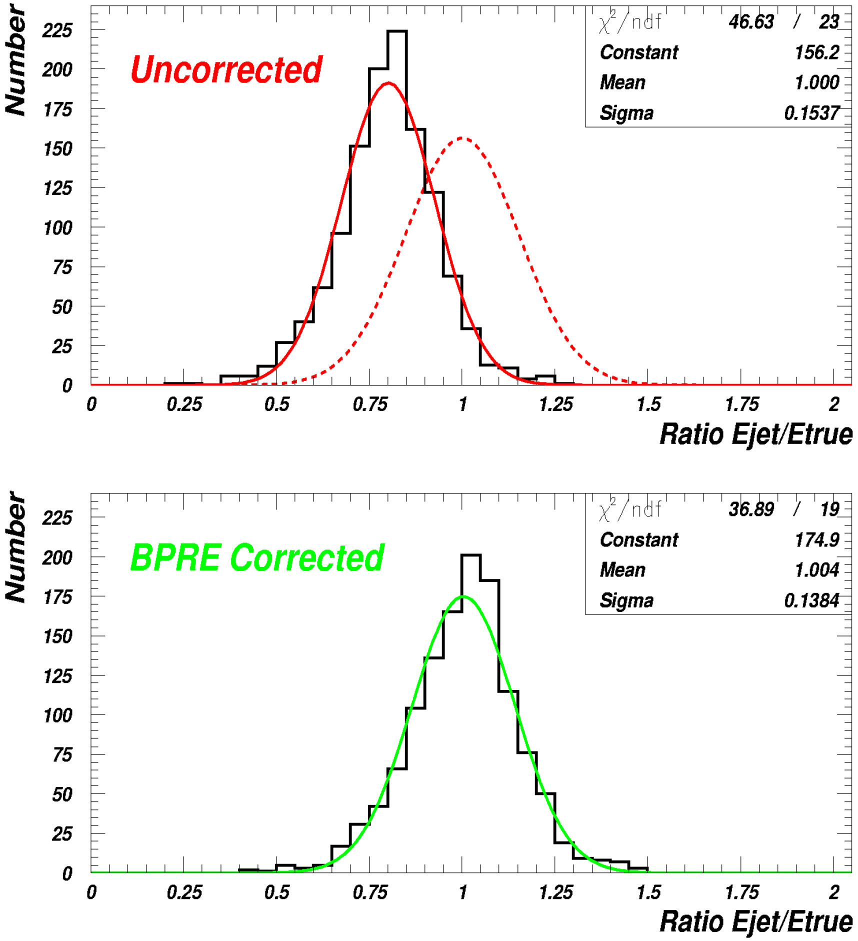


Corrections to Jet Energies with Presampler

- Select 1-jet events (cone) balanced in φ: can calculate “true” jet energy from angle of jet and electron



- Calculate corrections based on activity in presampler in jet cone



Average 12% improvement in resolution

Combining Tracking and Calorimeter Information

- Very low momentum particles never reach the calorimeter (magnetic field)
- Particles loose some energy in material before calorimeter (e.g. ZEUS coil)
  - ⇒ Pre-sampler (ZEUS)
  - ⇒ Trackers recover some of this lost information
- For low momenta the tracker may be more accurate than the calorimeter
- Even for high momenta, directional information may be more accurate from the tracker than from the calorimeter

Can attempt to identify topology of final state (number of charged and neutral particles)

Problems

- Danger of double counting
- Charged and neutral particles may overlap in calorimeter

Several different track-cluster combination algorithms developed in H1 and ZEUS:
⇒See talks of Marie Jacquet and Matthew Wing

ZEUS Hadronic Calibration Method

- Minimise χ^2 defined:

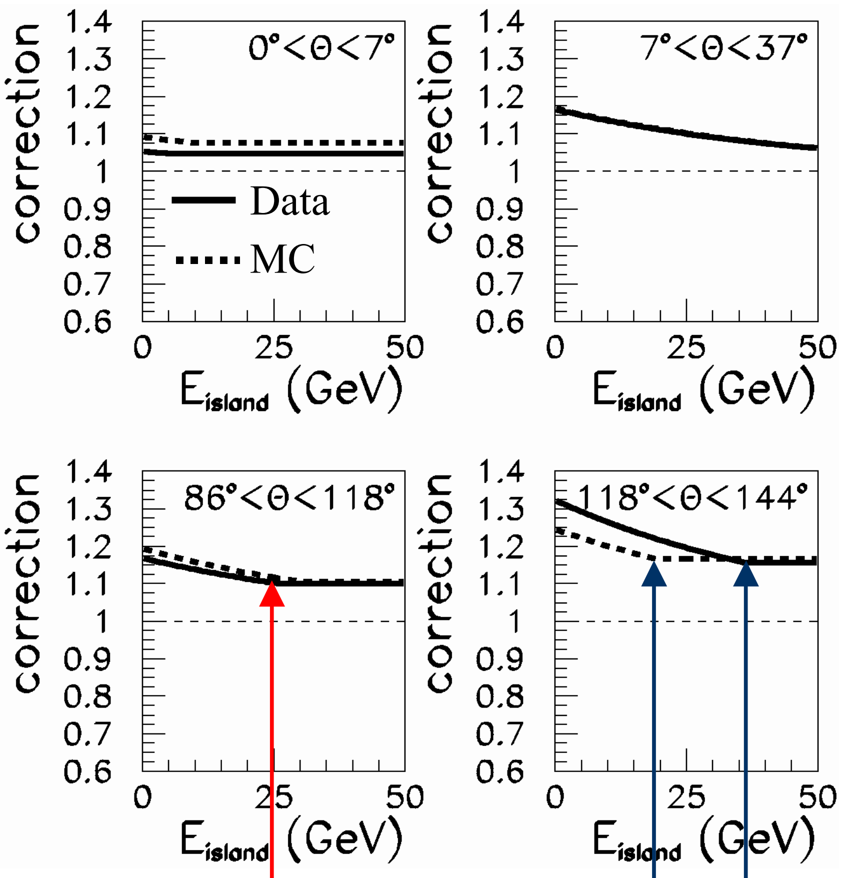
$$\chi^2 = \sum_{Sample1} \min\left\{\left(\frac{P_T^e - P_T^H}{P_T^e}\right)^2, 0.2^2\right\} + \sum_{Sample2} \min\left\{\left(\frac{y^e - y^H}{y^e}\right)^2, 0.2^2\right\}$$

by adjusting "island" correction coefficients:

$$f_{i(\vartheta)}(E) = 1 + \alpha_i \exp\{-0.02\min(E, \beta_i)\}$$

Fit over large sample of events using both transverse and longitudinal momentum balance

Illustration of 4 of 7 angular regions:

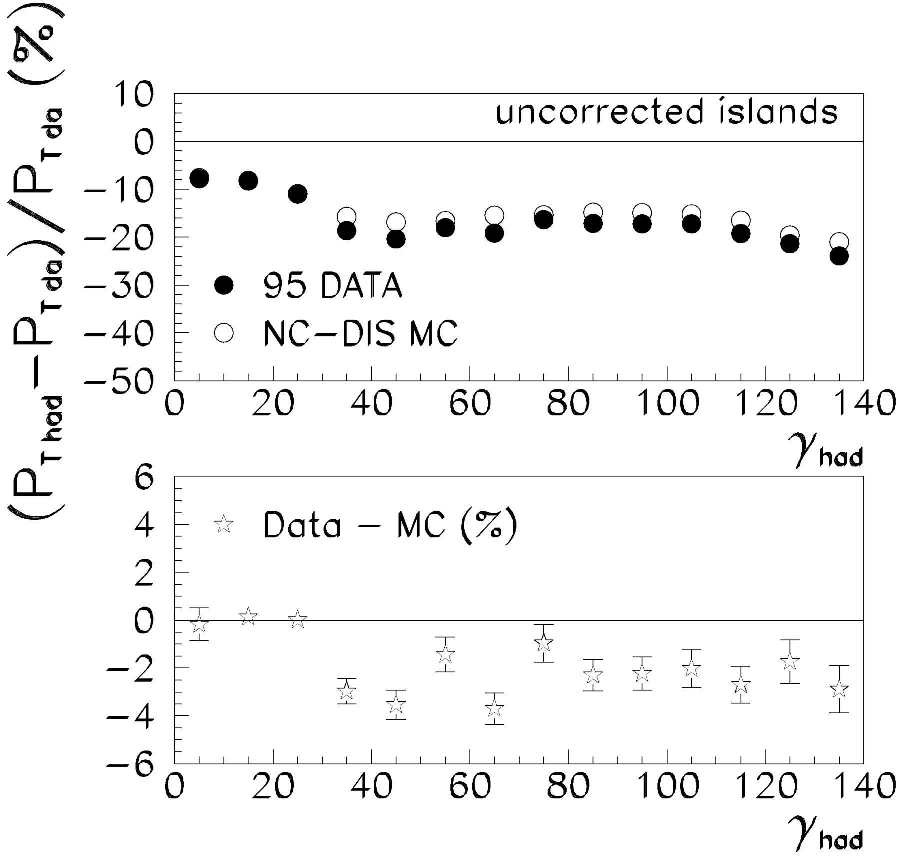


β_i Controls range of energy dependence

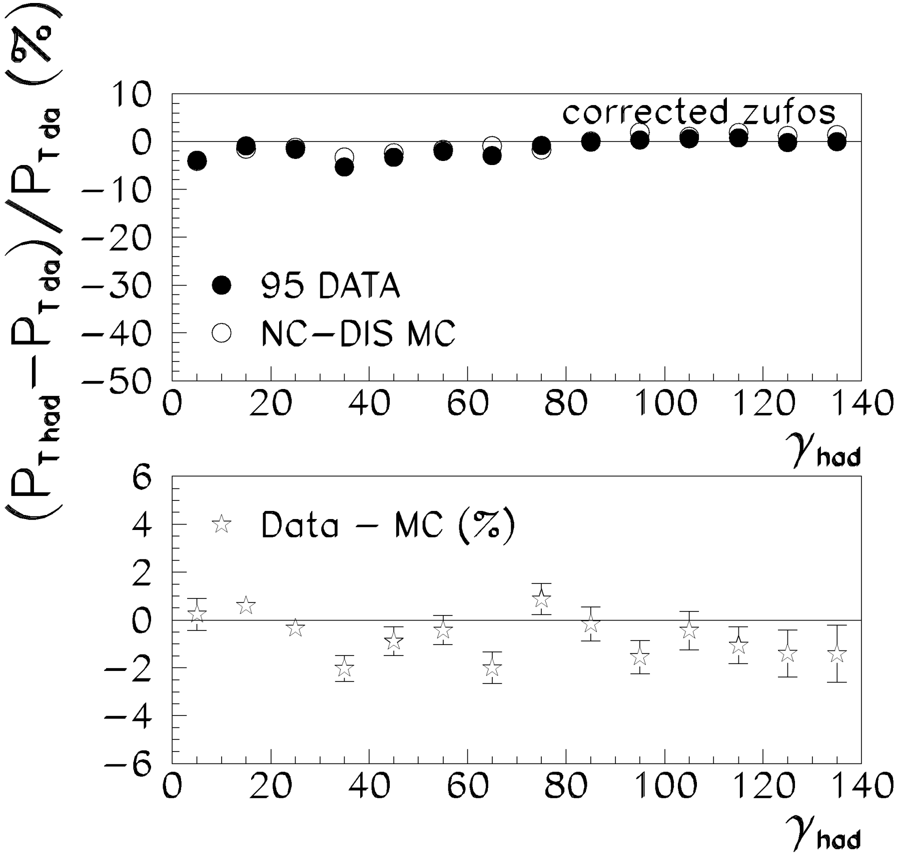
Data and MC different

ZEUS Hadronic Calibration Results

Before Corrections:



After corrections

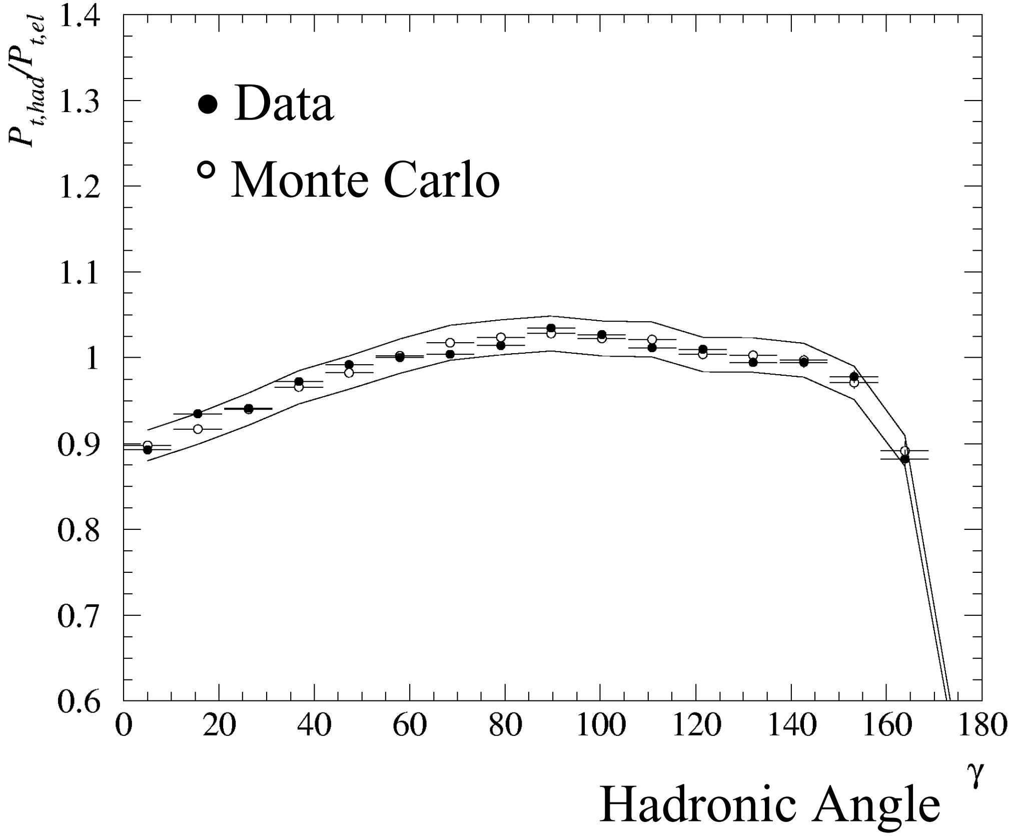


3%(?) Correlated systematic uncertainty

True P_T reconstructed on average

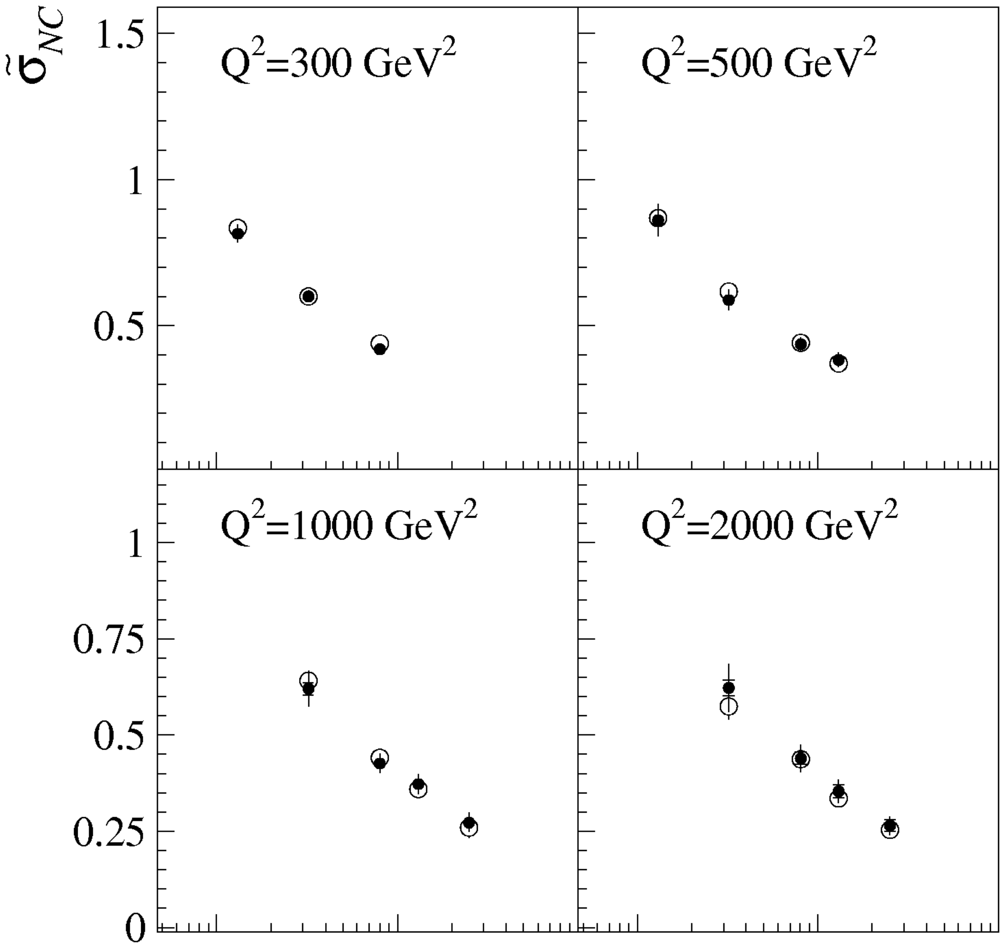
H1 Hadronic Calibration

- Use longitudinal and transverse momentum balance.
- Several different methods*:
  - Angular regions with jets
  - Impact position with jets
  - Octant-wise or wheel-wise calibration with weighting and unfolding techniques
  - Corrections to “true” energy
- 2% Systematic Error
  - 1% Correlated
  - Mostly from electron calibration



Verifying Hadronic Calibration

Measure Neutral Current “reduced” cross section $d^2\sigma/dxdQ^2(ep\rightarrow eX)$



- ● Kinematics from hadrons
- ○ Kinematics from positron

Agreement well within systematic uncertainty

Correlated and Uncorrelated Errors

- Calibration segmented into many physical regions
- Physical regions map onto different kinematic regions
- Some systematic uncertainties are unique to physical regions:
  - Local dead material description
  - Local calibration constants due to drift in gain or efficiency…

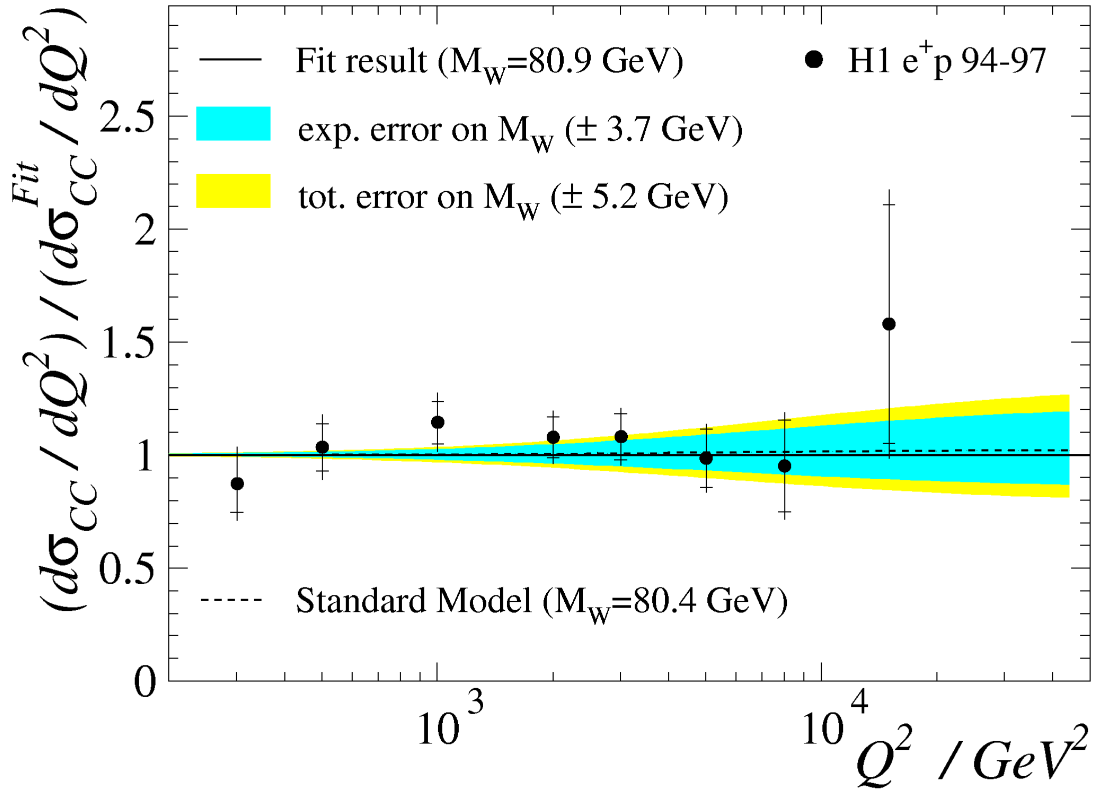
- Some systematic uncertainties are common to all physical regions:
  - Uncertainty in a common reference scale (e.g. DA energy)
  - Potential bias inherent to calibration technique

- Correlated systematics are much more dangerous than uncorrelated

⇒Big potential gain in precision from identifying correlations in errors

Example of Correlations in Systematic Errors

Treatment of correlations in systematic uncertainties only visible when fitting measured cross sections.



<u>Effect of Hadronic Energy Scale</u>

4% correlated:	±1.6GeV
2% correlated:	±0.8GeV
1% correlated, 2% total:	±0.5GeV

Precision Achieved at HERA

H1

- SPACAL (low Q^2, not shown today) 0.3%
- LAr EM: 0.7% of which 0.5% correlated (design 1%)
- Hadronic: 2% of which 1% correlated

ZEUS

- Electromagnetic 1% correlated (check numbers Patrick)
- Hadronic 2% correlated (new numbers here also ?)

Precision still limited by statistics at both experiments: bright future !