Calibration of the ZEUS calorimeter for electrons

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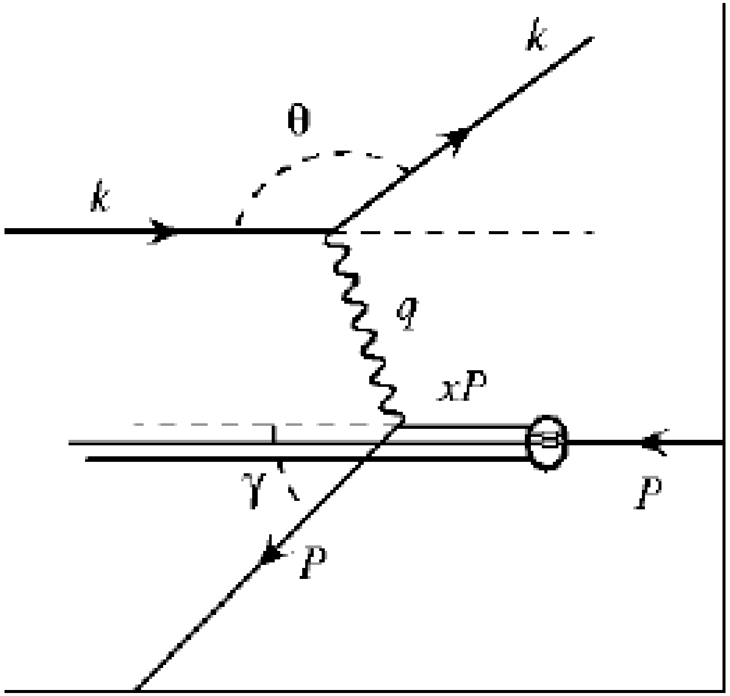
Outline

- HERA physics
- The ZEUS detector
  - Dead material
  - Non-uniformity
- Combining information
  - Presampler detectors
  - Tracking detectors
  - Hadron Electron Separators
- RCAL Calibration
- BCAL Calibration
- Results
- Summary

HERA physics



$Q^2 = -q^2$	resolving power of probe
$x = (q+P)^2$	fraction of proton momentum
$y = \frac{-q^2}{2P\cdot q}$	inelasticity parameter
$W^2 = (q+P)^2$	mass of hadronic system

- Neutral Current DIS exchanged boson γ or Z^0
- Charged Current DIS exchanged boson $W^{\pm}$
- Photoproduction exchanged boson γ with $Q^2 \sim 0$ GeV^2

HERA physics requirements

- Neutral Current
  - Energy and angle measurement for electrons
- Charged Current
  - Measurement of inclusive hadronic final state
  - Measurement of missing momentum
- Jets & tests of QCD
  - Measurement of jet energy and angle
  - Measurement of jet shape

HERA kinematics

- Measure energy and angle of scattered lepton and hadronic final state
- Over constrained system - only two degrees of freedom
  - Transverse momentum balance $P_T^e = P_T^h$
  - Longitudinal momentum $(E-p_z)^e + (E-p_z)^h = 2E_e(\text{beam})$
  - Double angle method (next slide…)
- Use all possible methods to study systematic uncertainties

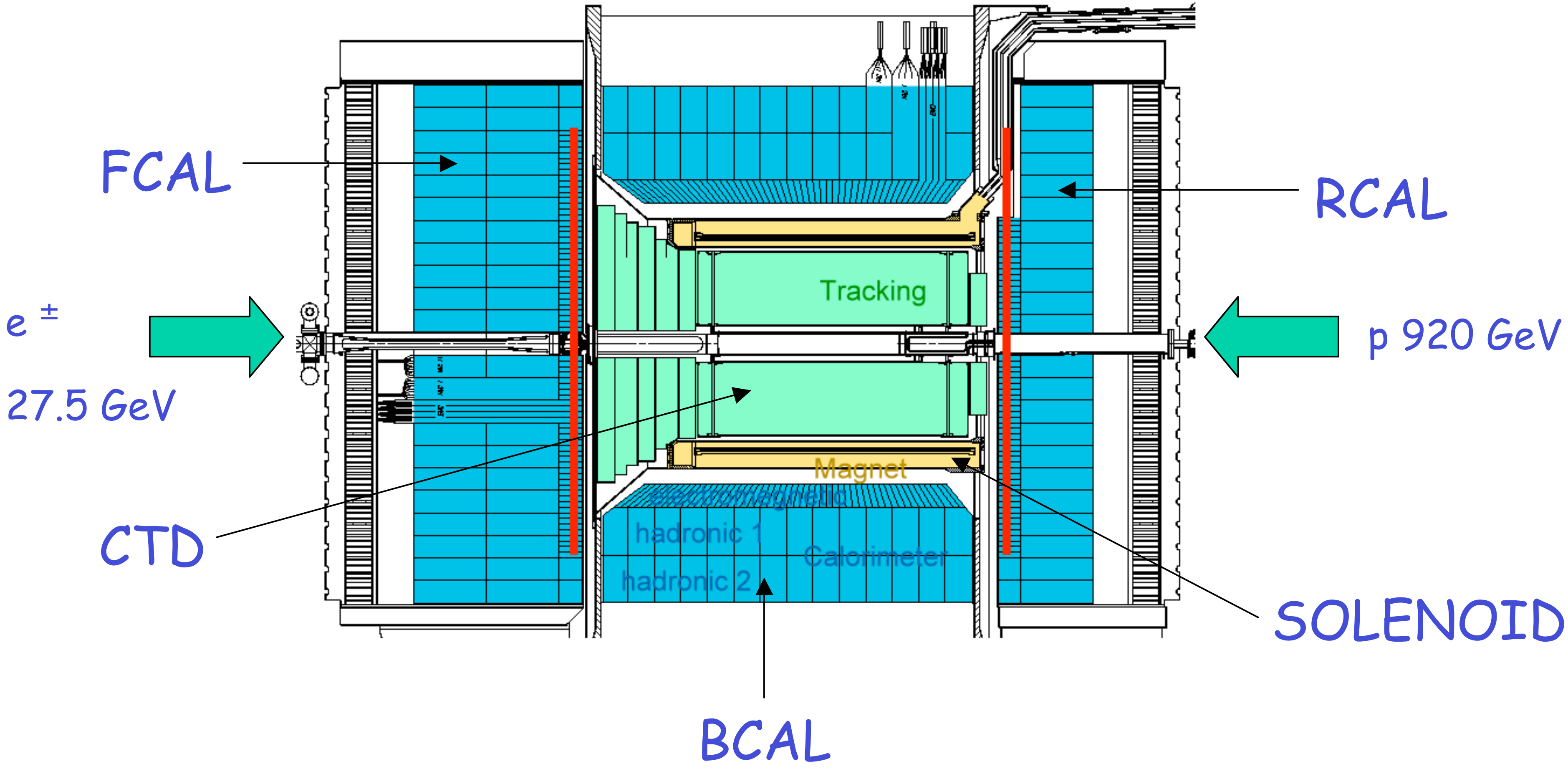
Double Angle Method

- Predict E'_e and E_h from scattering angles γ and θ

$$E'_{DA} = 2 \cdot E_e \frac{\sin\gamma}{\sin\gamma + \sin\theta - \sin(\theta + \gamma)}$$

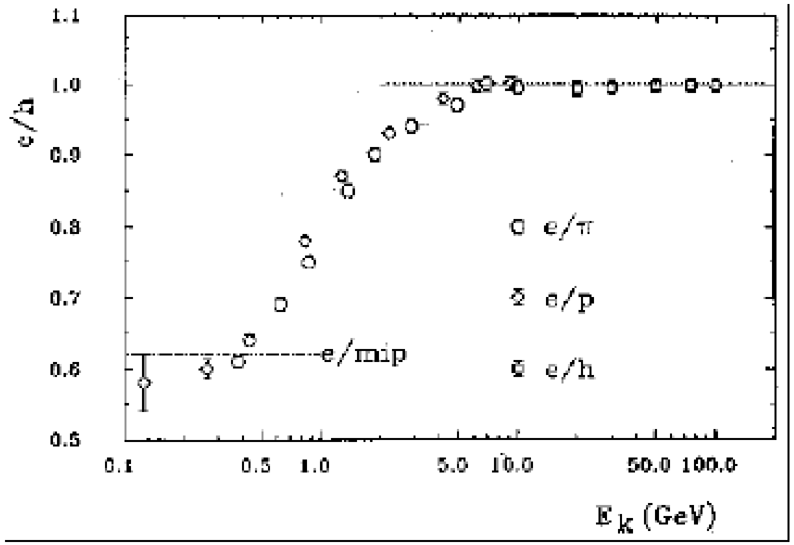
- Insensitive to overall energy scale of the CAL
- Sensitive to ISR
- Relies on good understanding of the hadronic final state and precise position reconstruction
- Angles measured more accurately than energies at ZEUS

The ZEUS detector



The ZEUS calorimeter - test beam

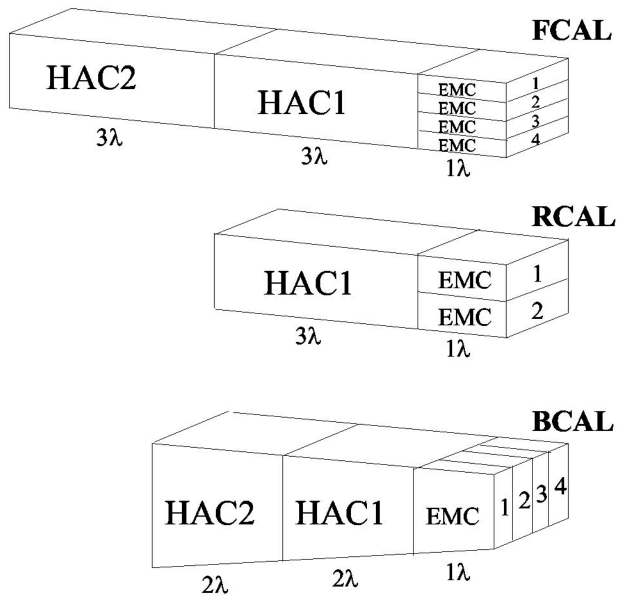
- Uranium-Scintillator
- Compensating (e/h=1)
- Calibration from UNO
- ~6000 cells
- Precise timing information
- Solenoid between tracking and CAL



Electrons $\frac{\sigma(E)}{E} = \frac{18\%}{\sqrt{E(GeV)}}$

Hadrons $\frac{\sigma(E)}{E} = \frac{35\%}{\sqrt{E(GeV)}}$

The ZEUS calorimeter - geometry



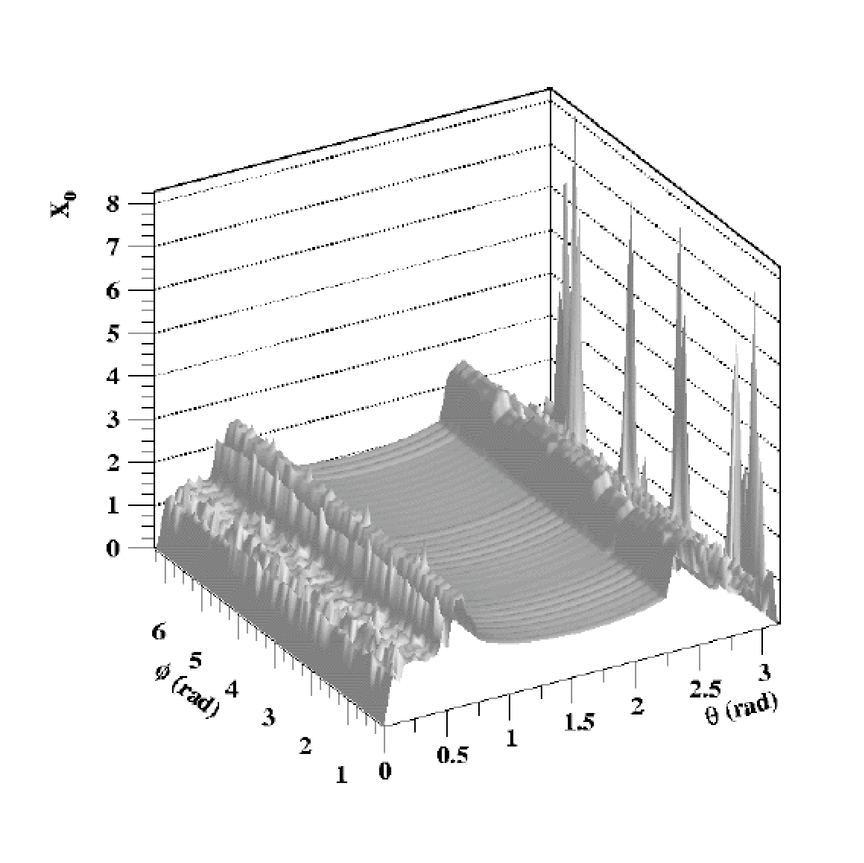
- EMC cells
  - 5x20 cm^2 (10x20 cm^2 in RCAL)
  - 1 interaction length
- HAC cells
  - 20x20 cm^2
  - 3 interaction lengths (2 in BCAL)
- Readout 2 PMTs per cell
- Imbalance gives position

The ZEUS calorimeter - calibration

- Uniform structure throughout the entire calorimeter
- Natural uranium activity provides absolute energy calibration
- Each cell is calibrated back to its test beam result
- Calibration runs taken between physics runs

Dead material

- In barrel region solenoid ~ $1X_0$
- Endplates of CTD
- Support structures for forward tracking detectors
- Cryogenics in rear of detector
- Measuring electron energy precisely is a challenge!



Non-uniformity

- Geometry of CAL leads to non-uniform electron energy response
- Energy lost between CAL cells
- Energy leakage between CAL sections
- Energy leakage around beam pipe holes
- Variation typically between 5-10%

Combining detector information

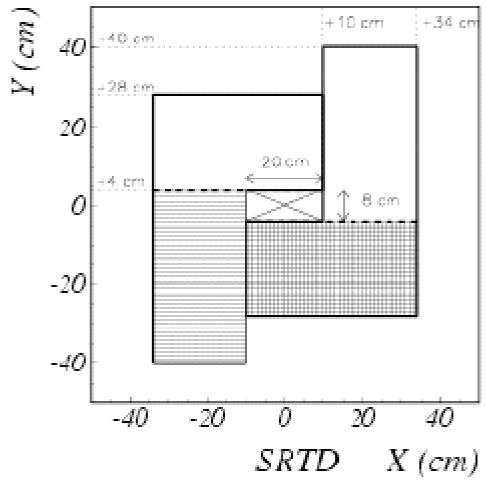
- Presampler detectors
  - Information on dead material
- Tracking detectors
  - Absolute energy calibration at low energy and alignment
- Hadron Electron Separators
  - Distinguish between EM and HAD showers
  - Position information

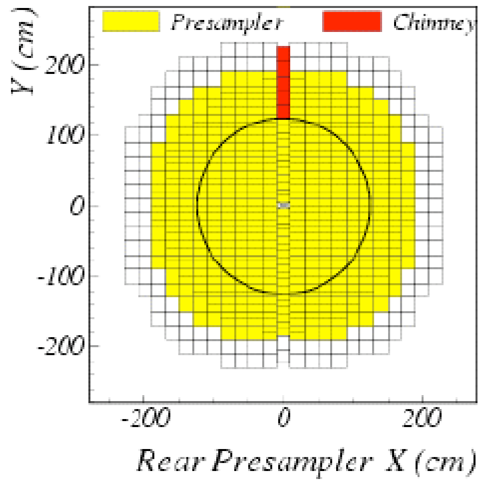
RCAL Electron Calibration

- ✘ Significant dead material between IP and RCAL
- ✘ RCAL has largest EMC cells ($10 \times 20 cm^2$)
- ✘ Cannot rely on tracking
- ✓ High statistics

- Use NN e-finder
- Kinematic Peak events
  - $E'_e \sim 27.5$ GeV
- Double Angle Method
  - $15 < E'_e < 25$ GeV
- QED Compton
  - $5 < E'_e < 20$ GeV

SRTD & Rear presampler

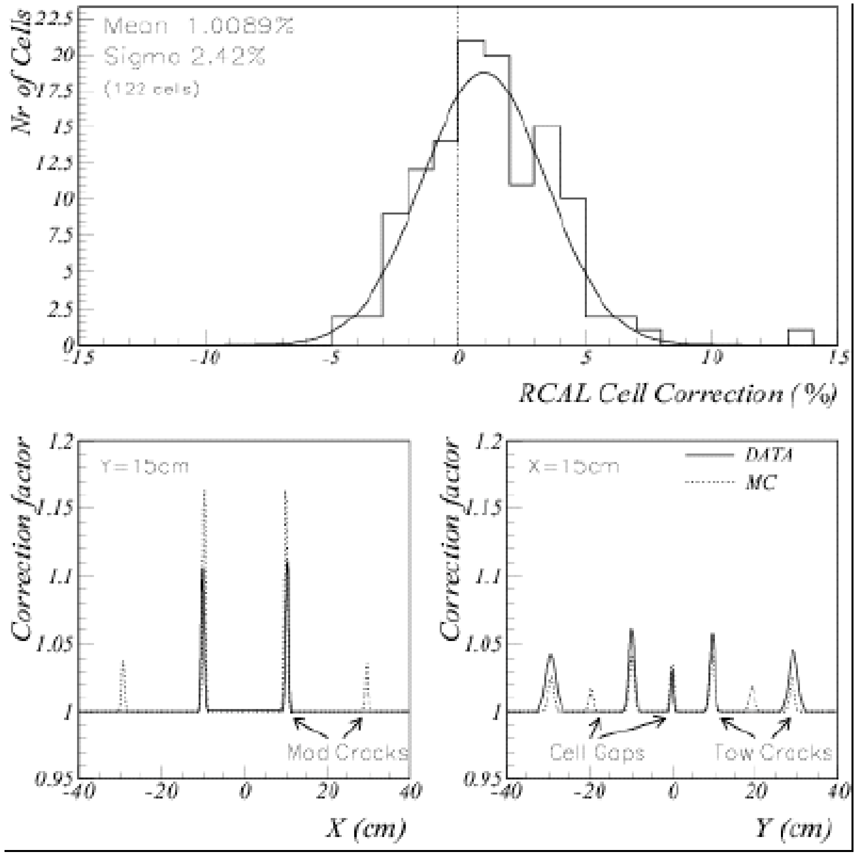




- Scintillator strips
- Precise position measurement
- Use MIPS signal for energy calibration

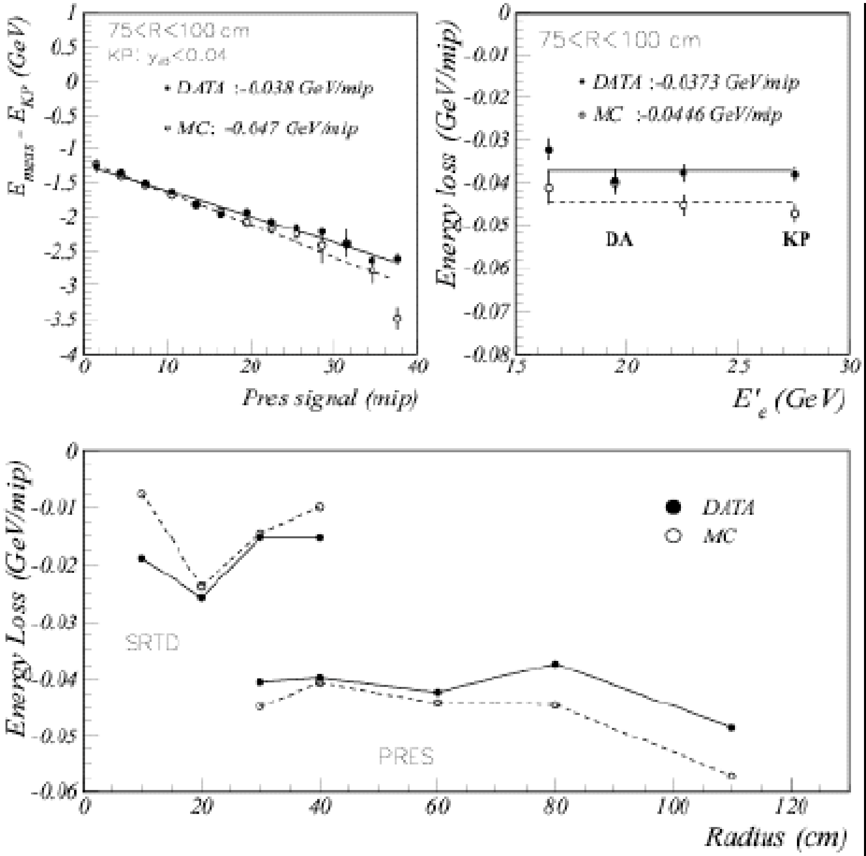
- 20x20 cm^2 tiles
- Mounted on face of RCAL
- Use MIPS signal to calibrate for dead material

Non-uniformity



- Choose events with low MIPS in SRTD and PRES
- Compare position of KP on cell-by-cell basis to correct each cell to uniform response
- Consider E_{CAL}/E_{DA} as a function of position
- Derive corrections for non-uniformity between CAL cells independently for data and MC

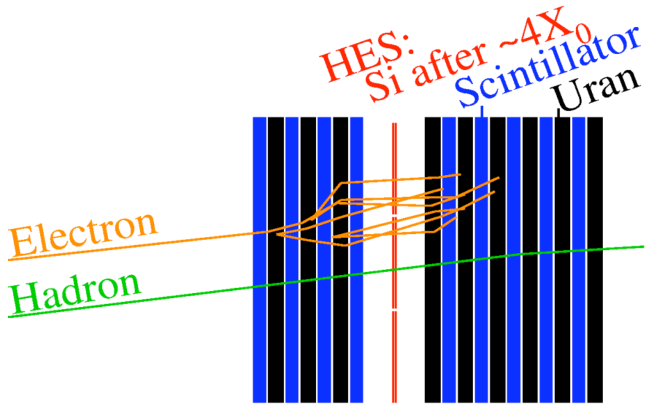
Dead Material

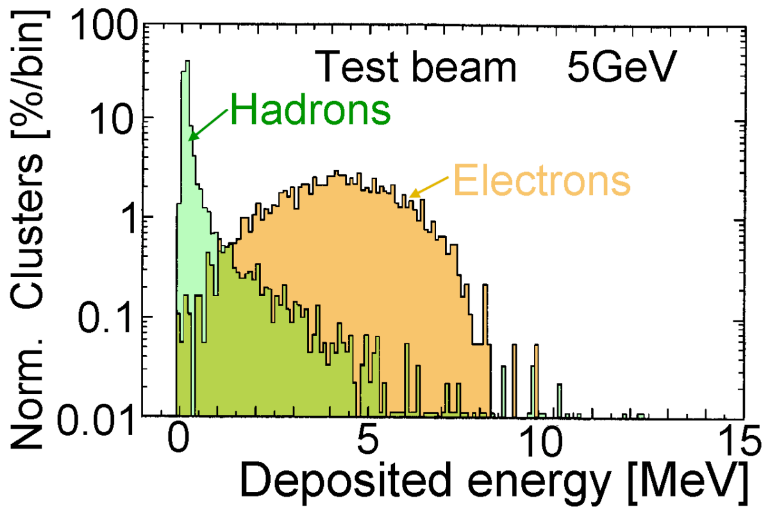


- PRES and SRTD give MIPS signal proportional to energy loss
- Calibrate using KP and DA event samples
- No dependence on electron energy
- Dependence on radius i.e. angle of incidence
  - Also seen in test-beam
- Derive suitable corrections

Hadron Electron Separators

- 20 m^2 of diodes
- 300 μm Si pad detectors
- Located at EM shower max ~$4X_0$ in RCAL and FCAL
- Highly segmented (3x3 cm^2) gives improved position measurement
- Separation of $e^{\pm}$ and γ from hadrons, in particular inside jets
- Input to NN e-finders



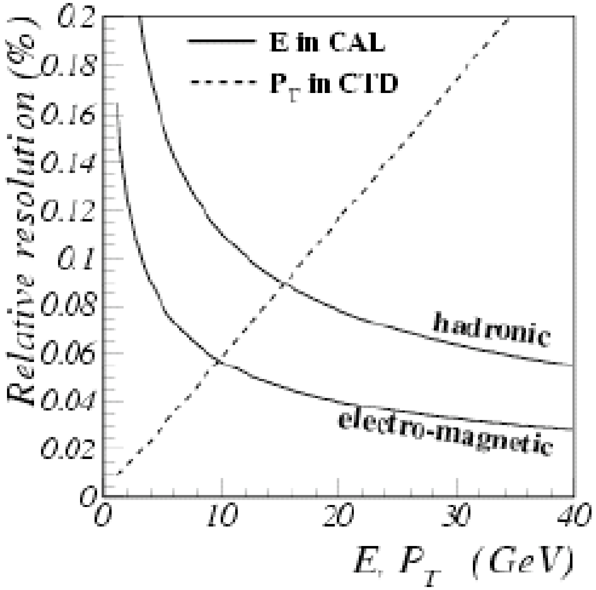


BCAL Electron Calibration

- ✘ Solenoid between IP and BCAL
- ✓ Use CTD track for electron angle – good resolution in DA method
- ✓ Compare CTD track momentum with CAL energy

- Elastic J/ψ events
- QED Compton events
- Double Angle Method

Central Tracking Detector

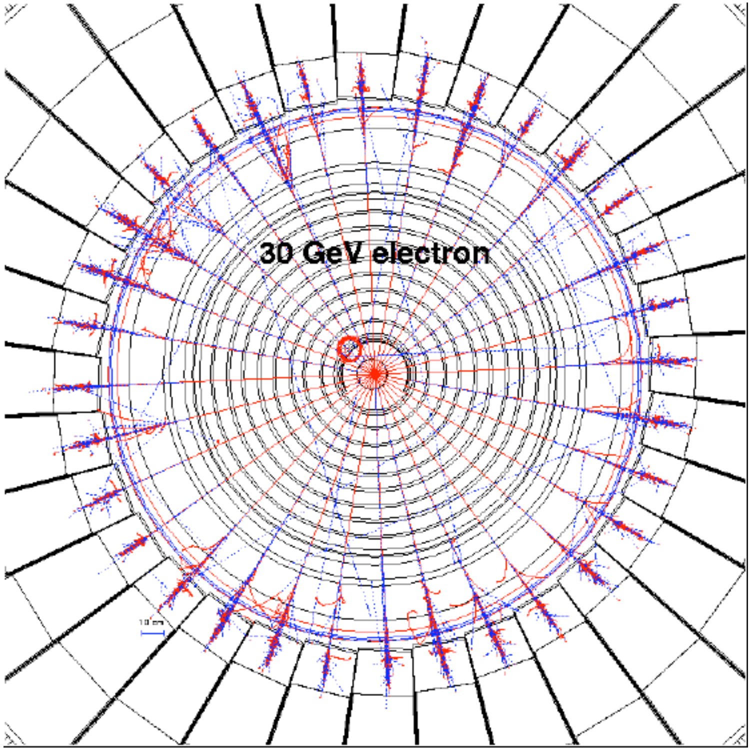


- Drift chamber
- $15^\circ < \theta < 164^\circ$
- ~5K sense wires
- Resolution:

$$\frac{\sigma(p_T)}{p_T} = 0.0058 p_T \oplus 0.0065 \oplus \frac{0.0014}{p_T}$$

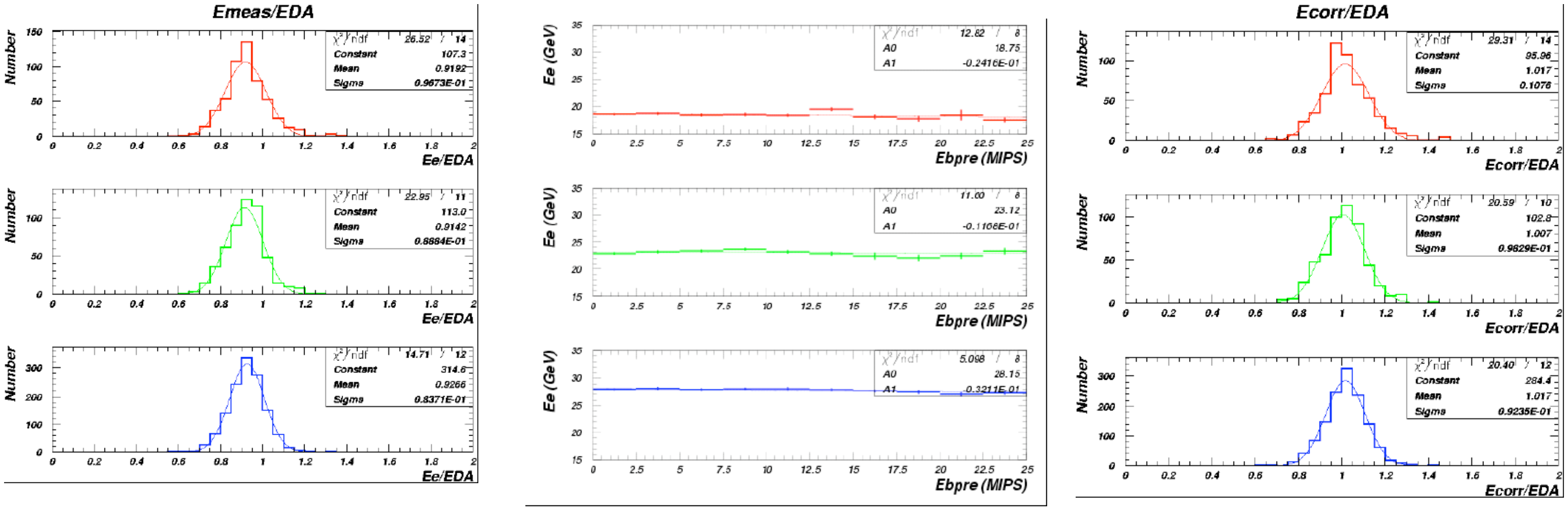
- Use to calibrate CAL at lower energies

Barrel presampler



- Most electrons shower in solenoid before hitting CAL
- BPRES signal proportional to losses in dead material
- Produce dead material "map"
- Correct electron energy
- Can also use for hadrons and γ/π^0 separation….

Barrel presampler



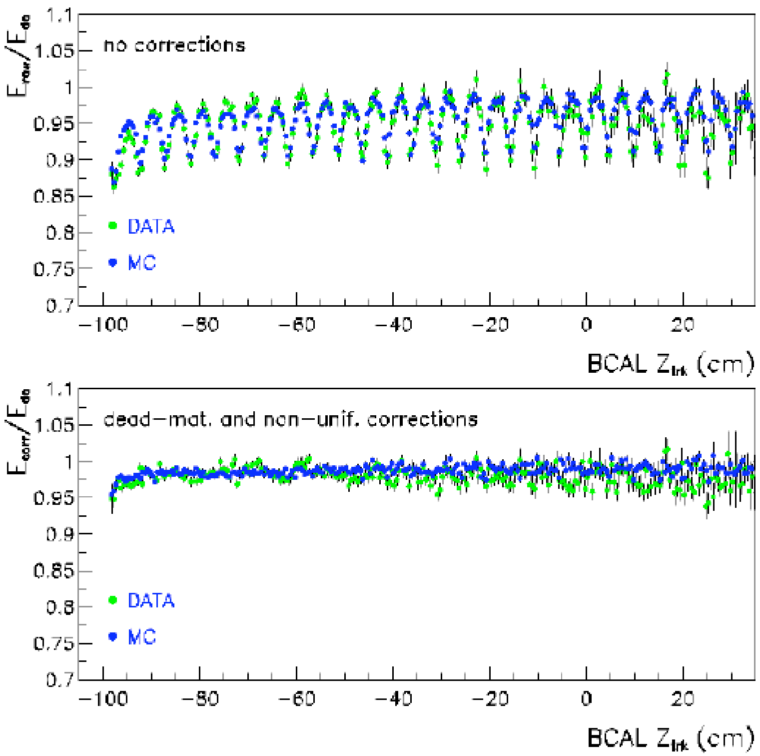
E'_e 20 GeV

E'_e 25 GeV

E'_e 30 GeV

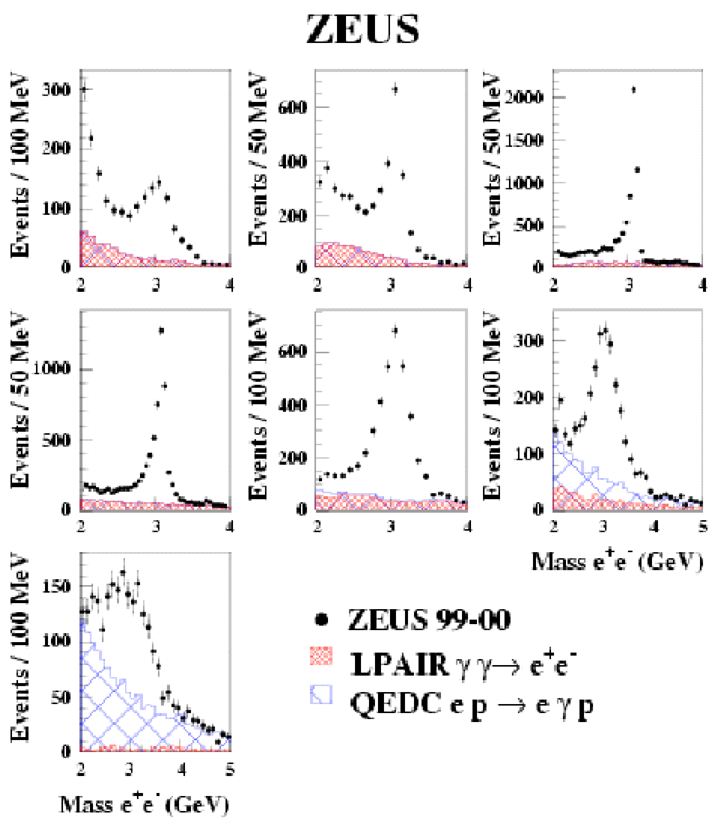
- Fit BPRES MIPS signal to E_{CAL}
- Correction is energy independent

Non-uniformity



- Clearly see the structure of the BCAL cells in uncorrected data and MC
- Consider E_{CAL}/E_{DA} as a function of position
- Use track position to derive corrections in terms of z and φ
- Become limited by statistics in +z

Physics channels - Elastic J/ψ



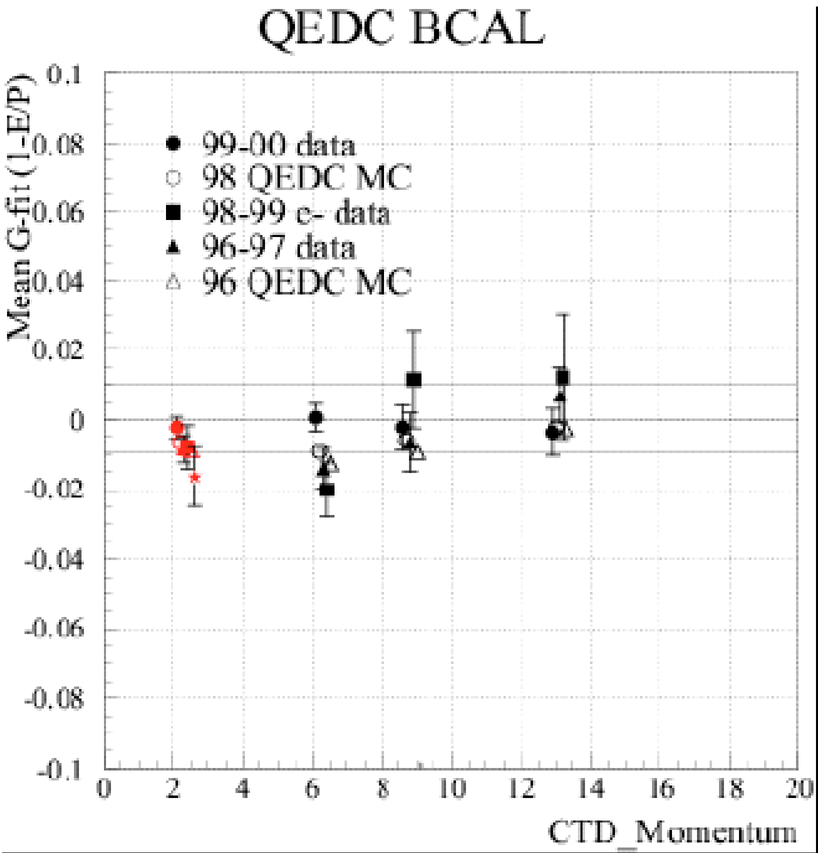
- J/ψ -> e^+e^-
- e+e- in BCAL
- Compare track momentum and CAL energy
- Range 1-3 GeV

✓ Absolute energy calibration

✘ Only low energy

✘ Low stats

Physics channels - Elastic QED
Compton



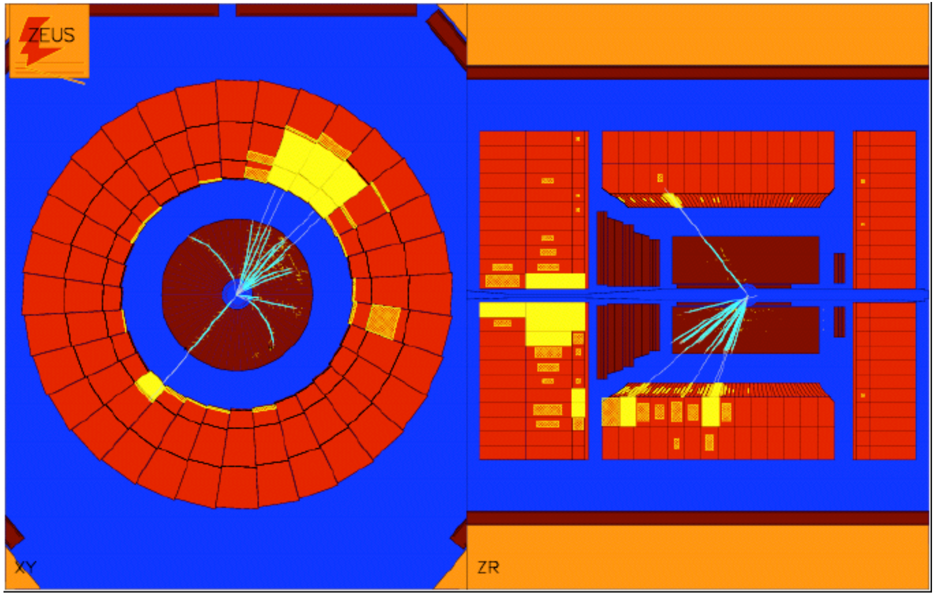
- Clean signal
- e in BCAL
- Compare track momentum and CAL energy
- Range $2 < E'_e < 15$ GeV

✓ Absolute calibration

✓ Bridges gap between high and low energy

✘ Low stats

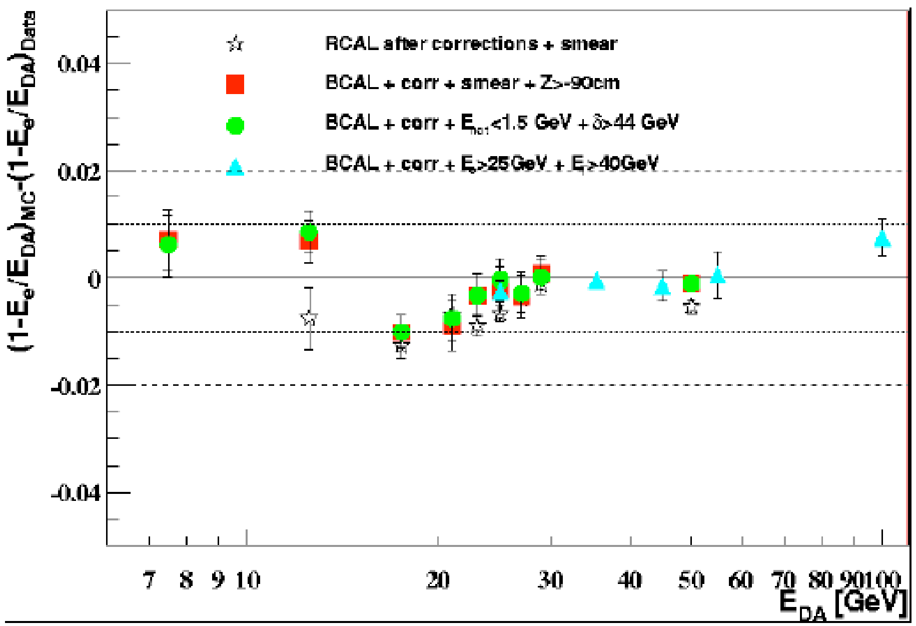
Physics channels - NC DIS



- Use DA method
- ✓ Good position resolution from track
- ✓ Spans all energy ranges
- ✘ Limited by statistics for higher energies
- ✘ Bias in DA reconstruction limits accuracy at lower energies

Results

- Uncertainty in RCAL ± 2% at 8 GeV falling to ±1% for energies of 15 GeV and higher
- Uncertainty ±1% in BCAL
- Insufficient statistics in FCAL
  - Use result of test-beam and assign uncertainty of ±3%



Summary

- Combined information from sub-detectors to improve the CAL electron energy measurement
- Used physics channels with overlapping energy ranges
- Systematic uncertainty of ±1% for most physics analyses