Test Beam Results of a Tungsten/Quartz-Fibre Calorimeter for the Luminosity Measurement in H1

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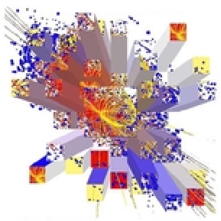
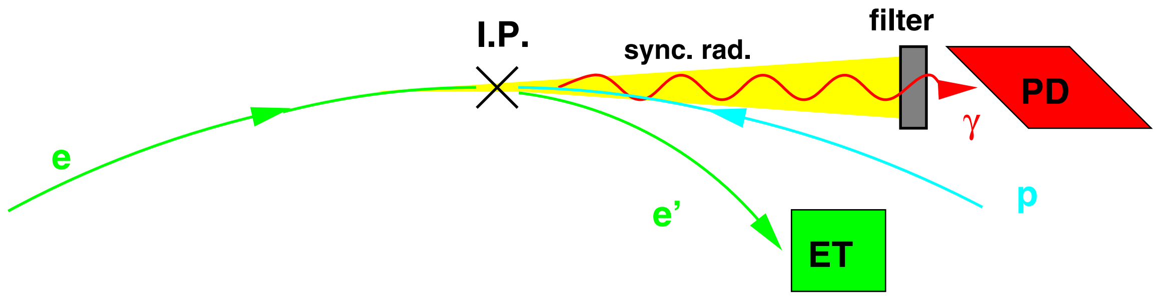


- **The Calorimeter:** Functionality, Requirements, Solutions
- **Energy Response:** Intercalibration, Linearity, Resolution
- **Spatial Response:** Uniformity, Shower Profile, Position Reconstruction

Luminosity Measurement in H1 after the HERA2000 upgrade

Principle: bremsstrahlung process $\quad e\,p \rightarrow e'\,p\,\gamma$

$\Rightarrow \gamma$ counting & Bethe-Heitler (BH) cross section σ_{BH}



HERA 2000 UPGRADE: $\mathcal{L} \times 4$ & $E_e = 30\ \ \mathrm{GeV}$

Main Consequences for the H1 Luminosity Measurement

- stronger synchrotron radiation:

$$\left.\begin{array}{l} P = 400\,\mathrm{W} \nearrow P = 2000\,\mathrm{W} \\ E_C = 35\ \mathrm{keV} \nearrow E_C = 160\ \mathrm{keV} \end{array}\right\} \Rightarrow \text{Dose} = \mathcal{O}(\text{ Trad/a})$$

- higher event rate $\Rightarrow$ pile-up (HERA bunch spacing: 96 ns)

Requirements for the New Photon Detector

- efficient synchrotron radiation filter
  $\longrightarrow 2X_0$ of Beryllium reduce the dose by a factor of $\approx 10^4$
- fast response $\longrightarrow$ Čerenkov calorimetry
- radiation resistance $\longrightarrow$ quartz fibres
- good energy resolution $\longrightarrow$ maximal light yield + fine sampling
- compactness $\longrightarrow$ high density material for radiator
- position measurement of γ-beam $\longrightarrow$ fine granularity in x and y

The W/Quartz-Fibre Calorimeter (1)

Sampling Calorimeter with Twodimensional Strip Geometry

Fibres

- 15422 uncoated quartz fibres (total length $\approx$ 11 km)
- core: pure fused SiO_2 (low OH content), diameter 0.6 mm
- cladding: "hard polymer" (PMMA), numerical aperture: 0.37
- radiation resistance: measured induced attenuation of ≈ 1 dB/ cm for D$= 200 - 400$ Mrad (at very high dose rates)

Fibre Readout

- fused silica light mixers (truncated square pyramids)
- quartz window $1\,1/8''$ PMTs (PHOTONIS XP2978)

Radiators

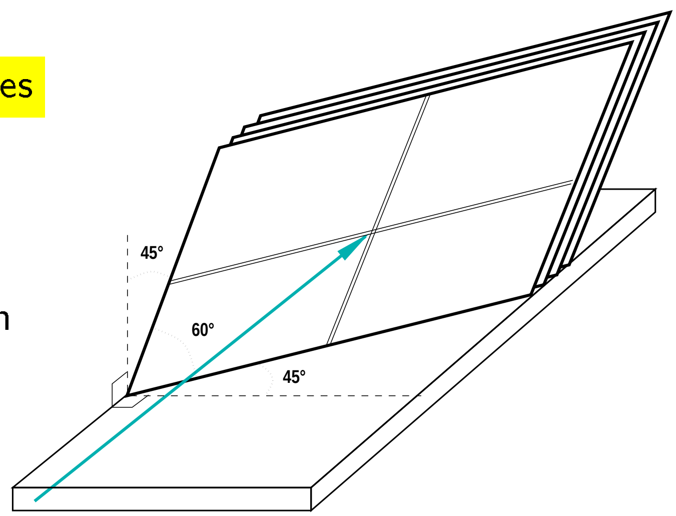
- 69 lozenge-shaped tungsten plates
- thickness 0.7 mm

Geometry

- fibre angle: 45° w.r.t γ-beam
- active volume:

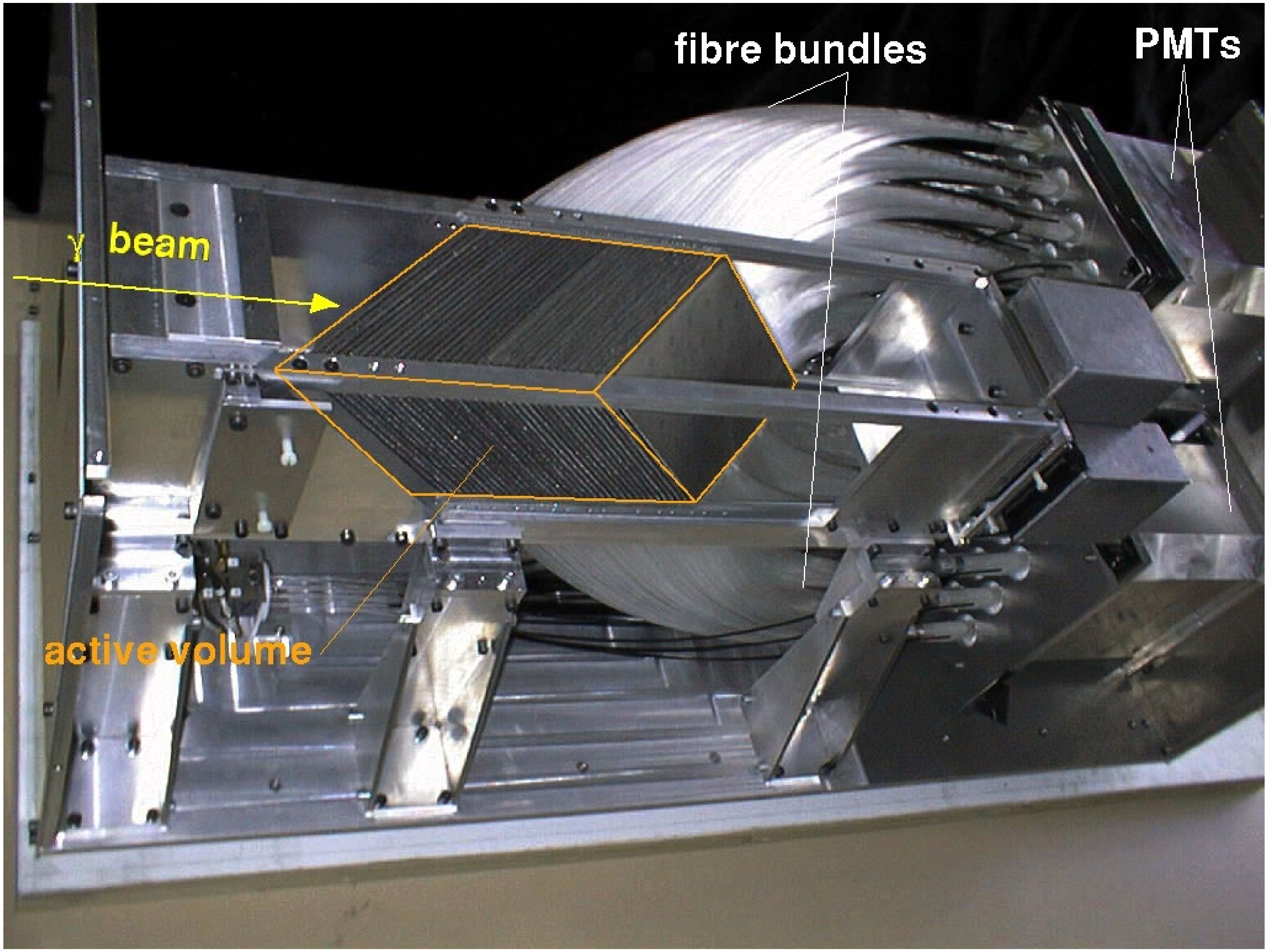
  oblique parallelepipede

  $\sqrt{2}\cdot 12 \times \sqrt{2}\cdot 12 \times 17\ \text{cm}^3$



- layers of horizontally and vertically oriented fibres alternate
- fibre staggering by half a fibre diameter in successive layers
- 12 strips in each direction x and y, effective width 10 mm

The Tungsten/Quartz-Fibre Čerenkov Calorimeter (2)



Key Parameters

tungsten/fibre volume ratio:	1.68
total depth:	25 X_0
sampling freq.:	0.36
average X0:	7.8 mm
Moliere radius:	17 mm

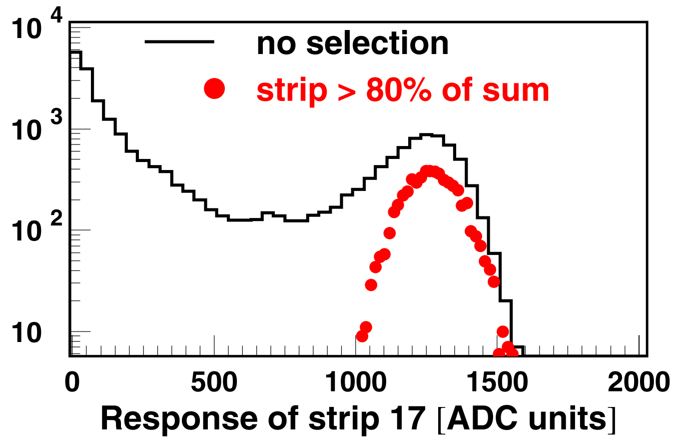
Design Performance

stoch. term:	**19.8%**
sampling:	16.4%
photostat.:	11.1%

[following M. Lundin et al., NIM A372 (1996)]

ENERGY RESPONSE(1): Strip Intercalibration

determine calibration coefficients by iterative method using strip response spectra



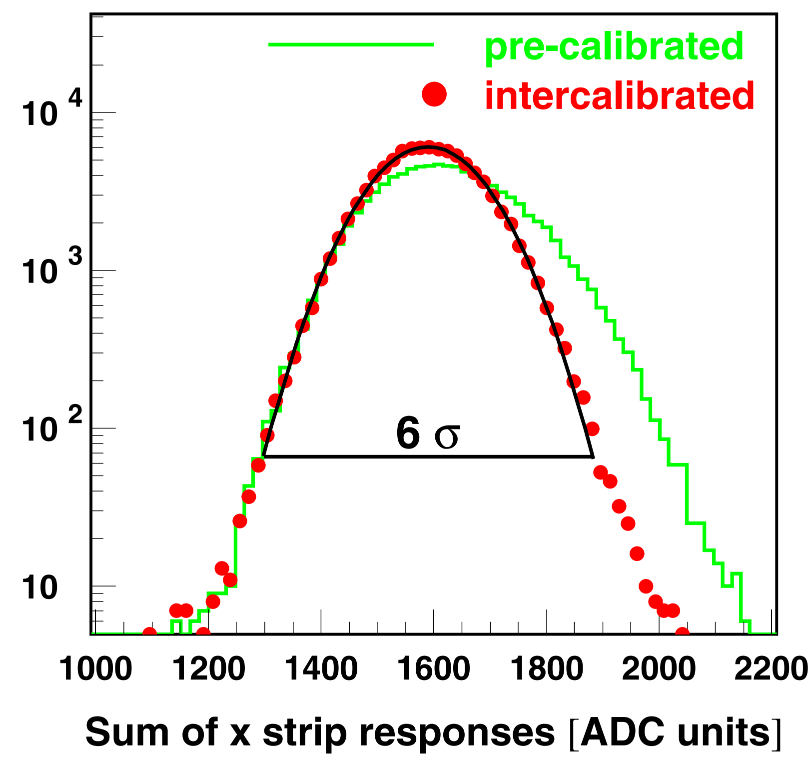
Calibration Procedure

- START with coefficients c_i equal to unity
- REQUIRE $c_i \cdot R_i > 80\% \sum_{xory} c_j \cdot R_j$

  (selects narrow showers hitting strip center)
- FIT GAUSSIAN $\longrightarrow$ mean peak response
- CALCULATE CALIBRATION COEFF'S

  to have identical mean peak response
- REPEAT (convergence after 3 iterations)

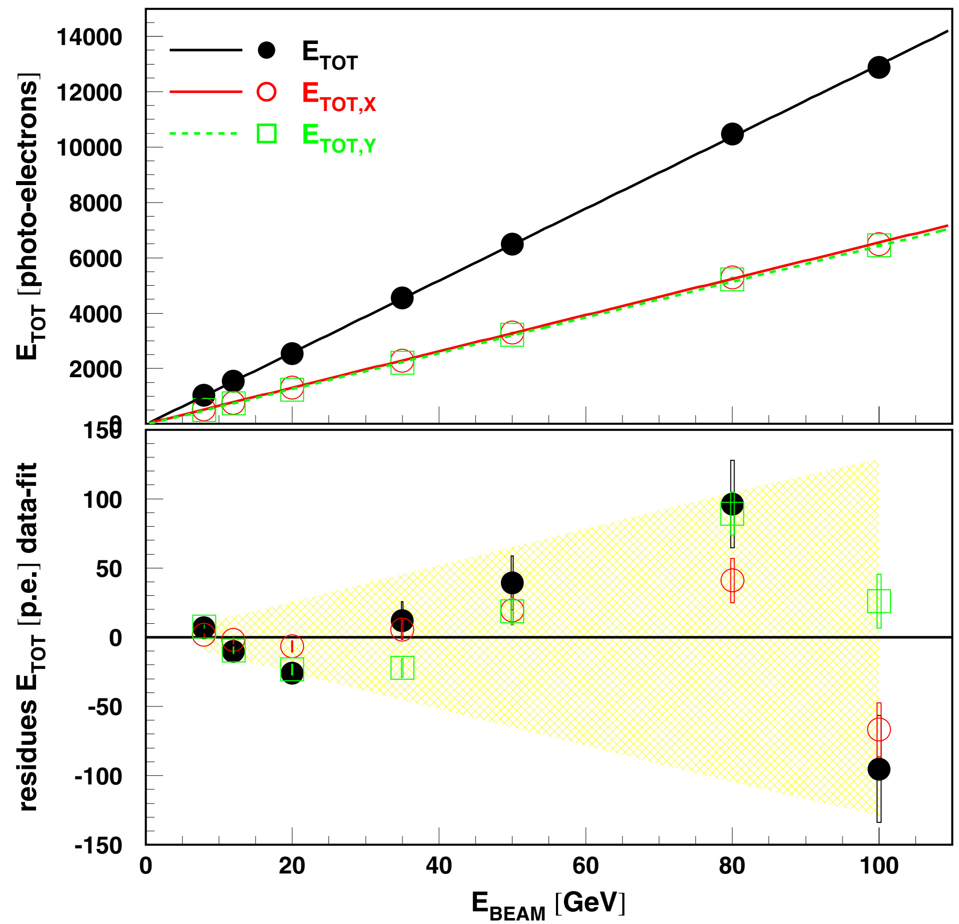
RESULT: Gaussian Peak for E-sum



$\longrightarrow$additional check: response uniformity

ENERGY RESPONSE (2): Response Linearity

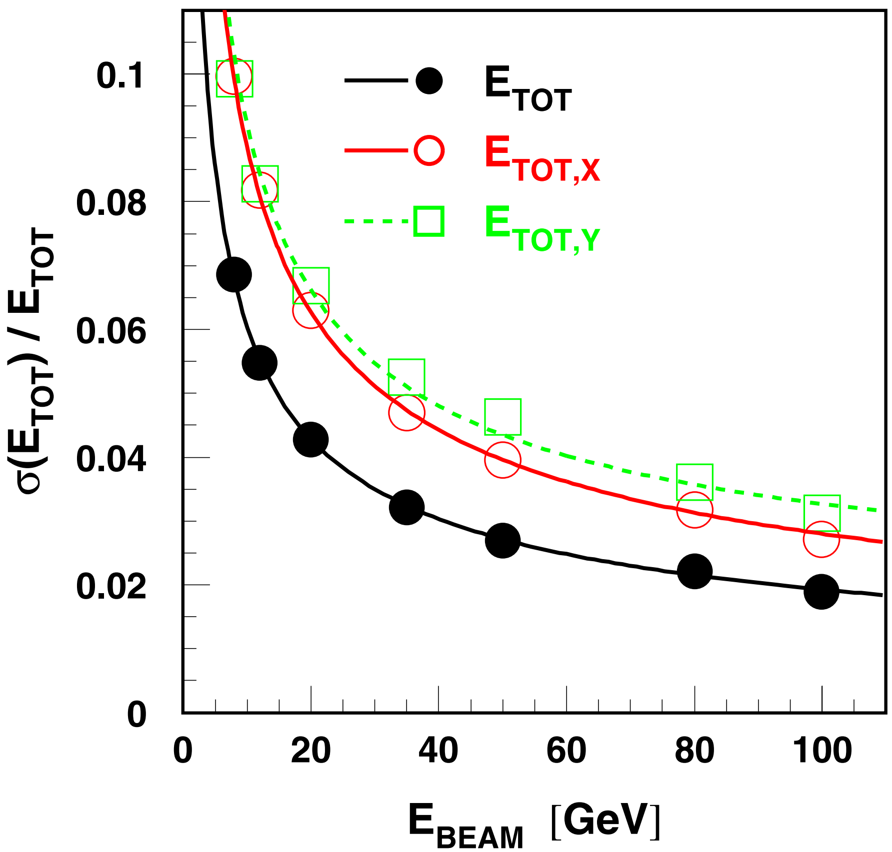
- energy scan at calorimeter center
  energy range 8–100 GeV
- linear fit of calibrated mean peak response v/s beam energy
  Response linear within 1%
- third order non-linearity, possible causes:
  - ADC non-linearity
  - calibration procedure
  - shower leakage
  - error on beam energy



ENERGY RESPONSE (3): Energy Resolution

$$\frac{\sigma(E_i)}{E_i} = \frac{A}{\sqrt{E_{\mathrm{B}}[\mathrm{GeV}]}} \oplus B$$

E-sum	stochastic term A	constant term B
x-strips	$27.58(47)\%$	$0.1(3.5)\%$
y-strips	$27.37(26)\%$	$0.65(23)\%$
all strips	**$19.24(12)\%$**	**$0.52(10)\%$**



- E resolution compatible with design value
- independent sampling by x and y layers

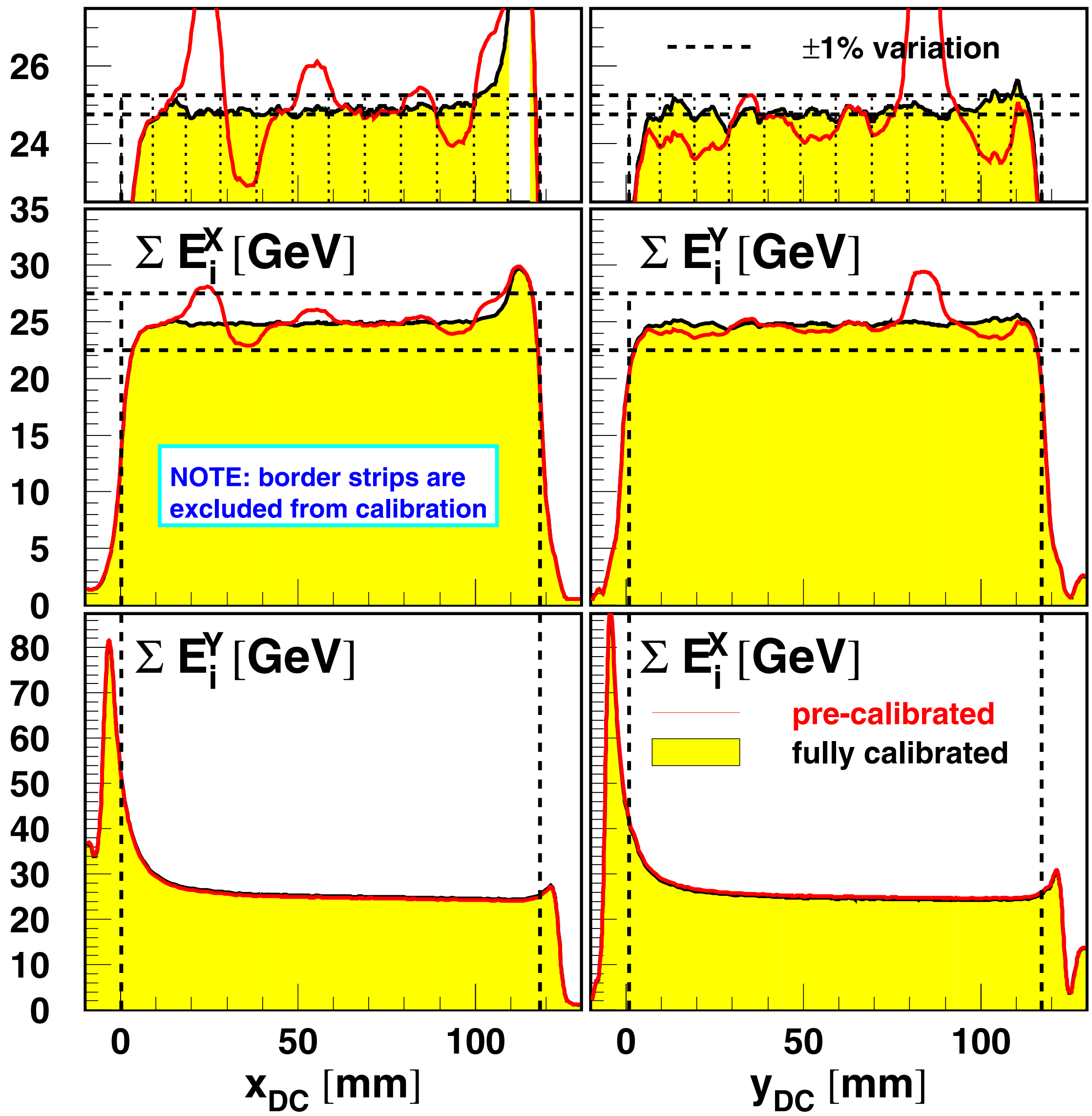
Measurement of photostatistics with LED calibration system:

130 p.e./ GeV $\Rightarrow$ photostatistics contribution to stoch. term: $9\%/\sqrt{E}$

SPATIAL RESPONSE (1): Uniformity

scan of calorimeter center at various E_{BEAM} (50 GeV shown here)

→ additional check of intercalibration



Response uniform to within 1%

Bundle effect: leaking shower particles enhance the signal in the strips closest to the fibre bundles

SPATIAL RESPONSE (2): Shower Profile Parametrization

Čerenkov light yield strongly angle dependent

⇒ **high sensitivity to shower core with fibres oriented at 45°**

- position scans at various beam energies:

  → measure $\sum_{\mathrm{LEFT}} E_i(x_{\mathrm{DC}})$, $\sum_{\mathrm{RIGHT}} E_i(x_{\mathrm{DC}})$, etc.

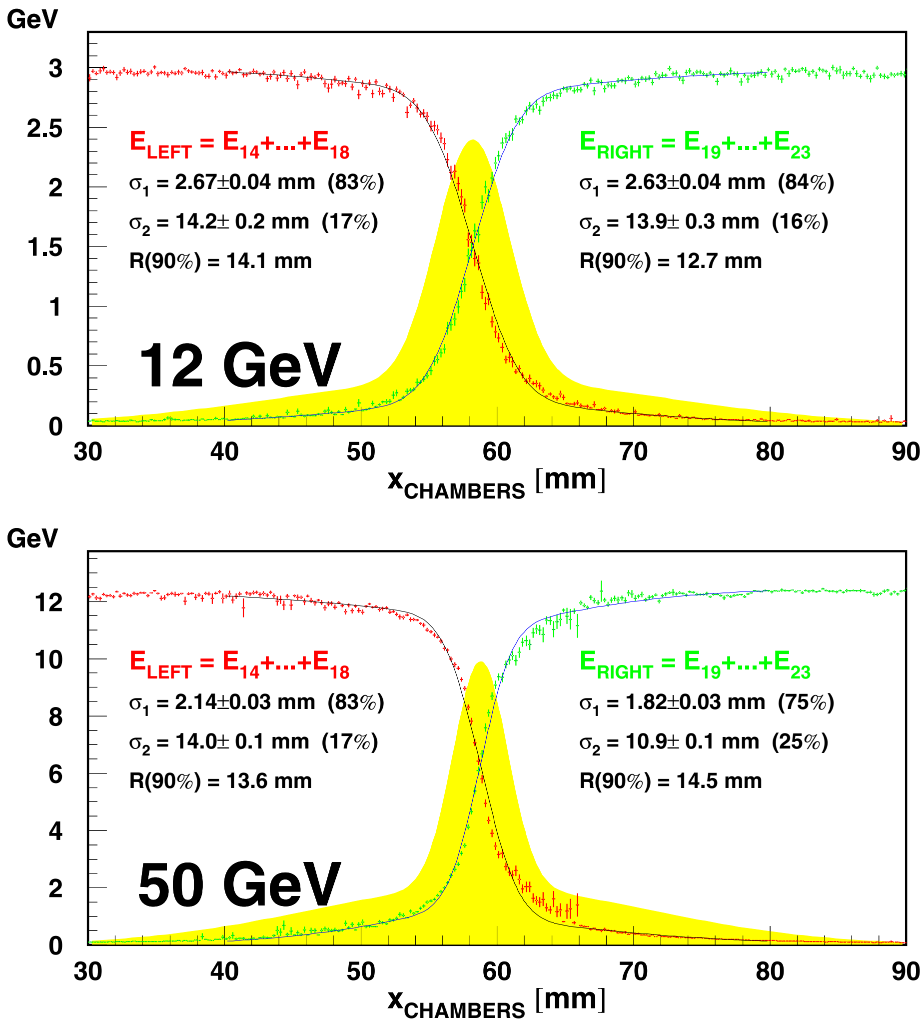
- shower profile parametrization:

  fit sum of two gaussians, e.g.

$$E \cdot \left(\frac{f}{2} \mathrm{Erf}(\frac{x}{\sigma_1} + 1) + \frac{1-f}{2} \mathrm{Erf}(\frac{x}{\sigma_2} + 1) \right)$$

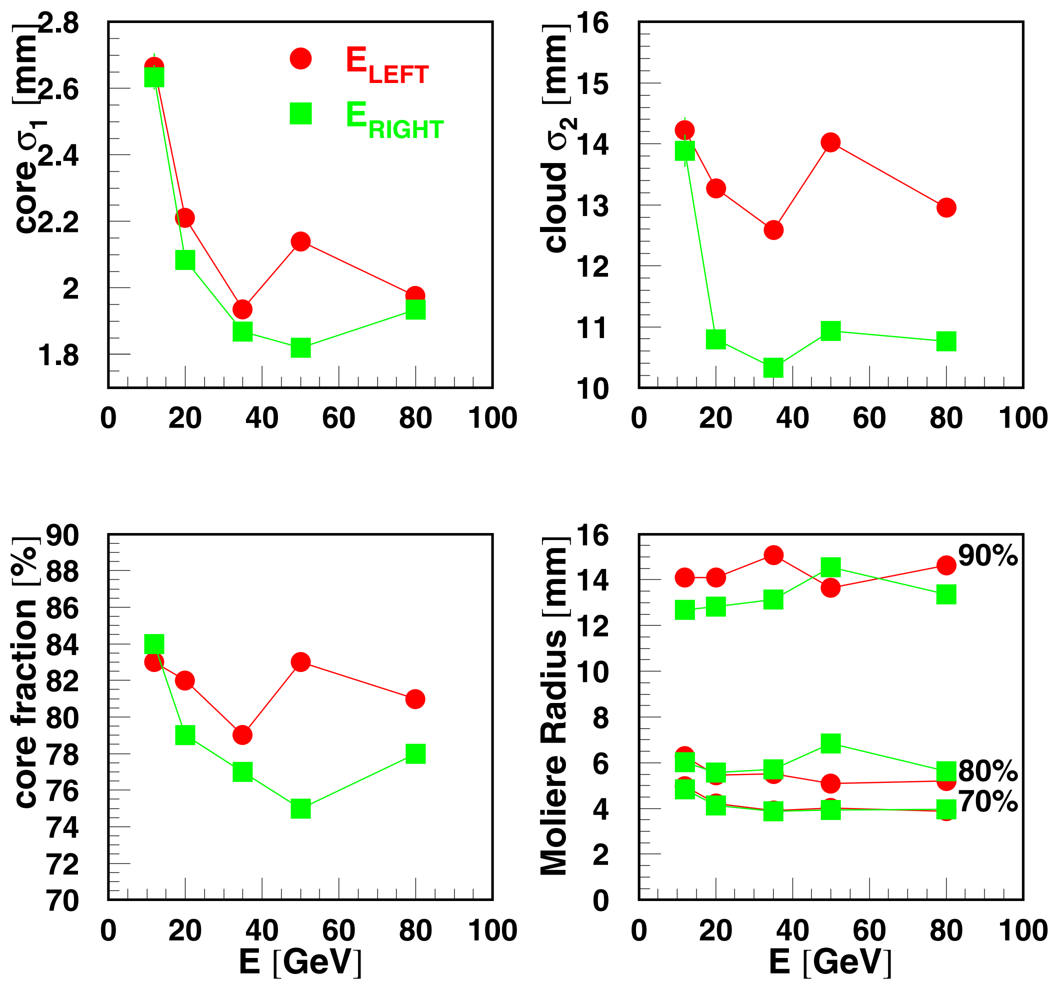
- two shower components:

"pencil" core:	$\sigma_1 \approx 2\,\mathrm{mm}$,	$(\approx 80\%)$
uniform "cloud":	$\sigma_2 \approx 14\,\mathrm{mm}$,	$(\approx 20\%)$



E Dependence of Shower Profile

Variation of core and cloud sizes σ_1 and σ_2, core fraction f, and $n\%$ Moliere radius with energy

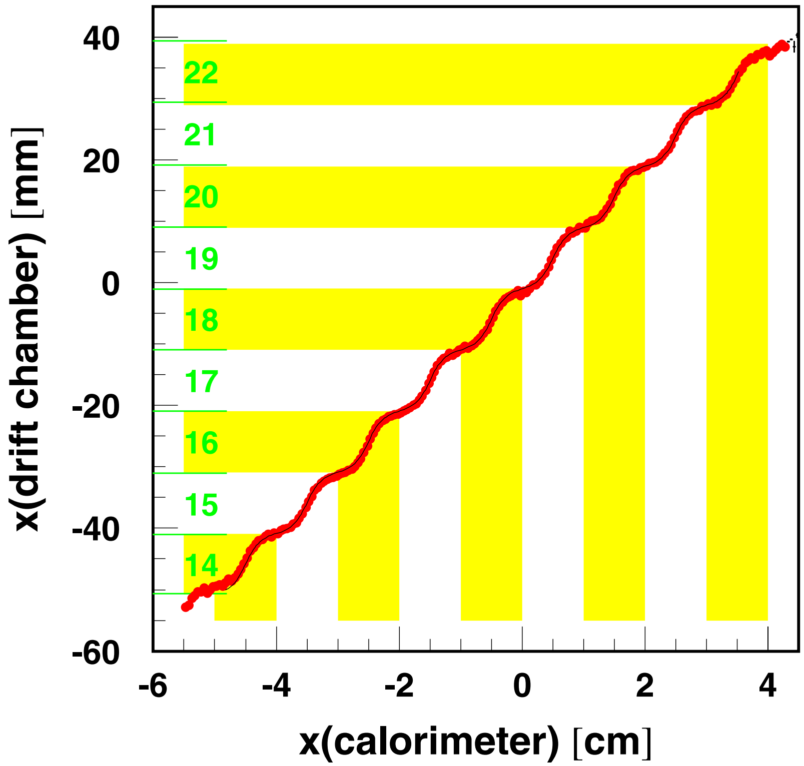


- 80% Molière radius $\approx 6\,\mathrm{mm}$
- 90% Molière radius $\approx 14\,\mathrm{mm}$
- deposited energy 90% Molière radius $\approx 17\,\mathrm{mm}$

With increasing energy, the shower core component decreases slightly and becomes narrower.

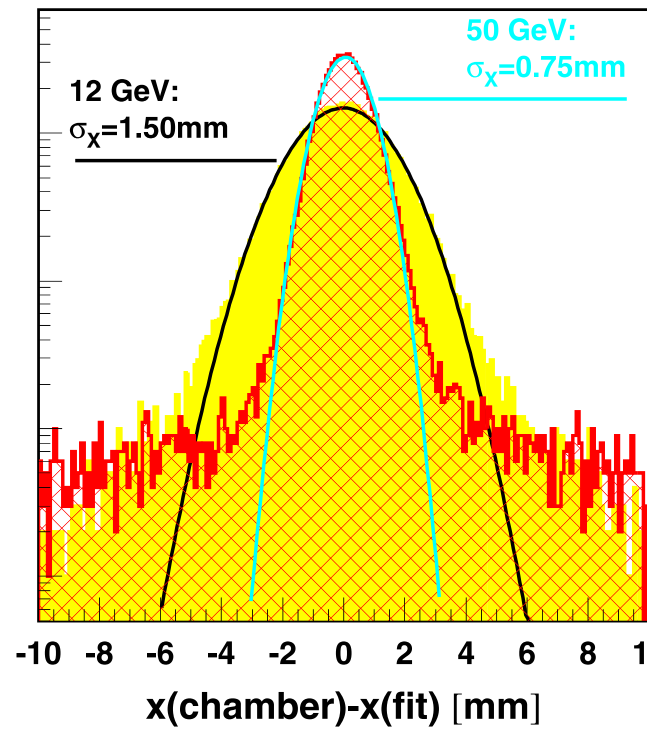
SPATIAL RESPONSE (4): Impact Position Reconstruction

DC impact position v/s E-weighted sum of strip centers



→piecewise $\arctan$ fit (+ track corrections)

fit residues ⇒position resolution



position resolution: $\sigma_x = \frac{5\ \mathrm{mm}}{\sqrt{E[\mathrm{GeV}]}}$

SUMMARY AND CONCLUSION

- new H1 Luminosity Detector designed and built in one year
- first QFCAL with fibres at 45° and granularity in two directions
- tested and calibrated at CERN in SPS-H4 e beam in 1999 and 2000: 6–100 GeV
- good energy resolution ($19\%\sqrt{E}$) due to fine sampling and high fibre content
- E response linear and uniform within one per cent (improvement possible)
- two shower components measured, high sensitivity to shower core (due to fibre angle)
- precise impact position reconstruction demonstrated ($5\,\mathrm{mm}/\sqrt{E[\mathrm{GeV}]}$)
- installation in HERA tunnel in january 2001, luminosity measurement in august 2001