HERA-LHC Workshop
CERN, March 26-27, 2004

The Forward Neutron Calorimeters at HERA

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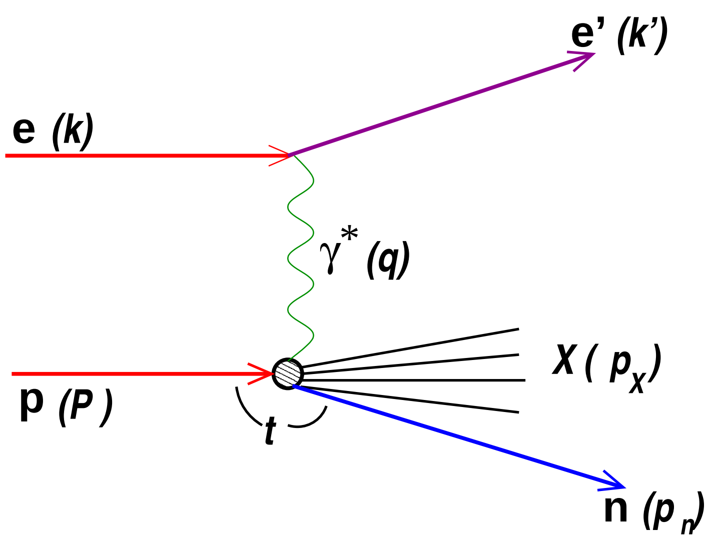
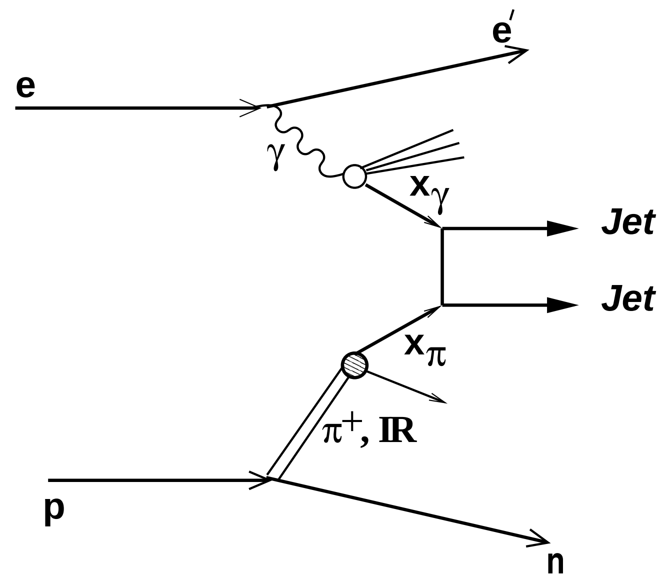
- Introduction and physics case
- Design specifications
- Construction:
  - ZEUS-FNC
  - H1-FNC
- Calibration
- Performance (Resolution, linearity)
- Summary

Introduction

- ▷ The Forward Neutron Calorimeters (FNC) have been installed by both H1 and ZEUS experiments in 1995-1996
- ▷ The purpose is to measure the energy and angles of fast neutrons from reaction $ep \longrightarrow enX$
- ▷ At high E_n the production mechanism is predominantly the pion exchange

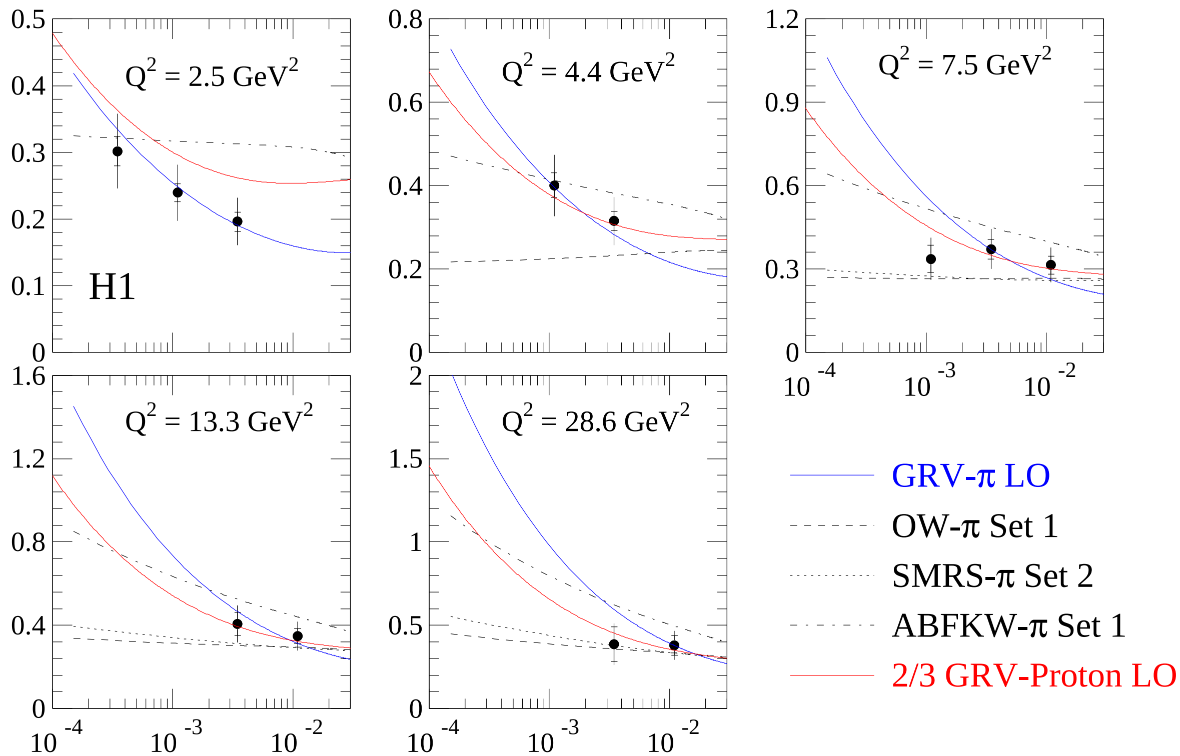




- ▷ Many interesting measurments can be done using the FNC, e.g. measurements of pion structure functions and total pion-photon cross sections, jet and heavy flavour production, studying the correlations between the hadrons produce at central rapidities and the neutrons,...

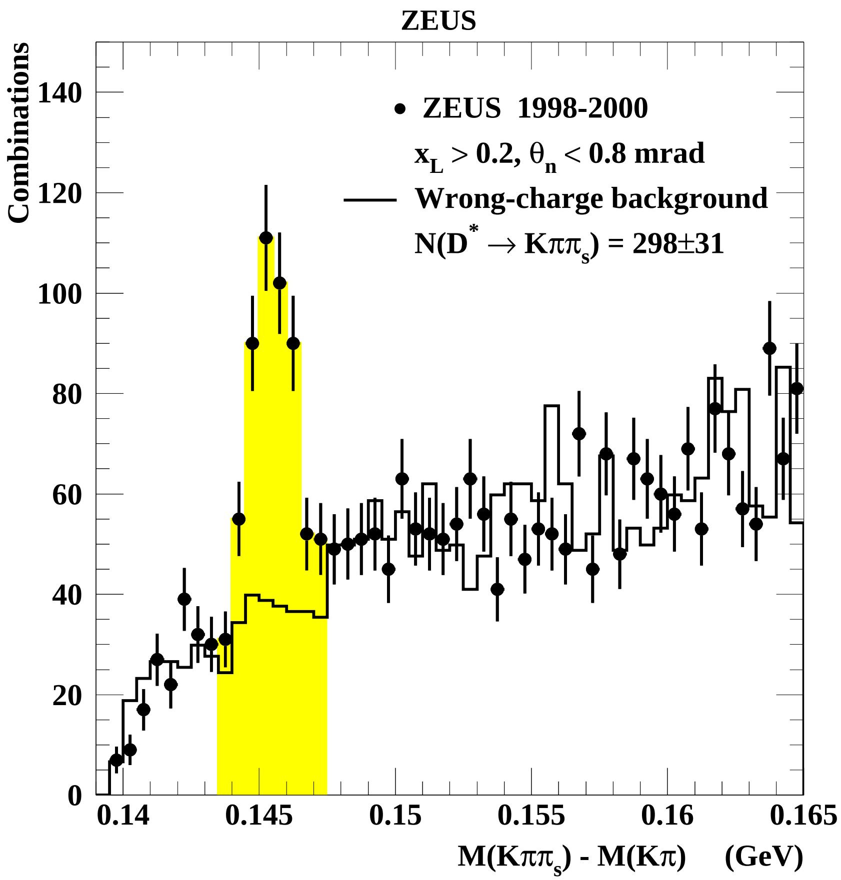
- **First estimate for F_2^π in low x region in the DIS at HERA**
  H1 Collab., *Eur.Phys.J.* C6 (1999) 587; ZEUS Collab., *Nucl.Phys.B* 637 (2002) 3;
- **Data show sensitivity to the parametrizations of the pion structure function (constrained for $x \gtrsim 0.1$ from the fixed target experiments).**

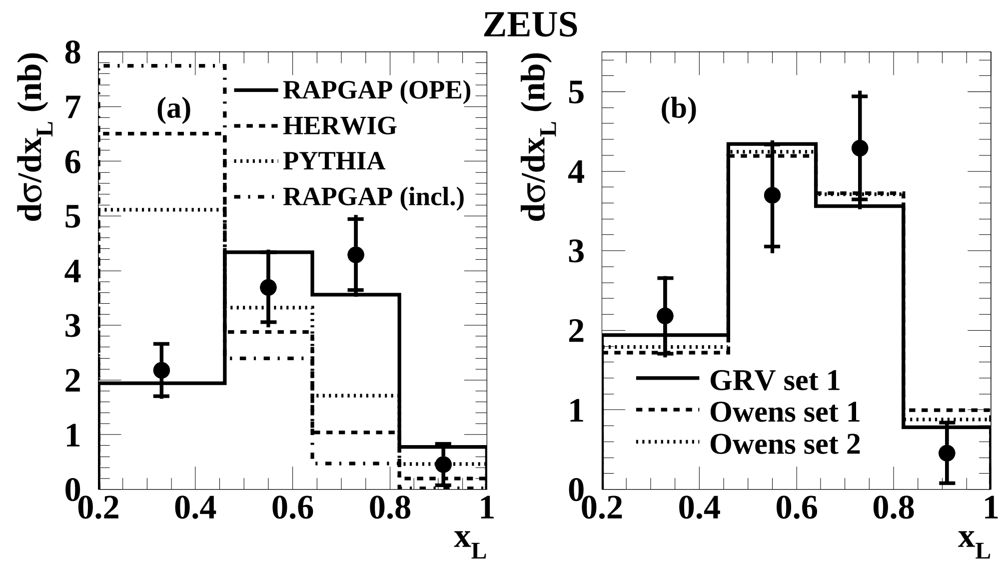
$$\frac{F_2^{LN(3)}(z=0.7)}{\Gamma_\pi}$$



$$\beta = \frac{x}{1-z}$$

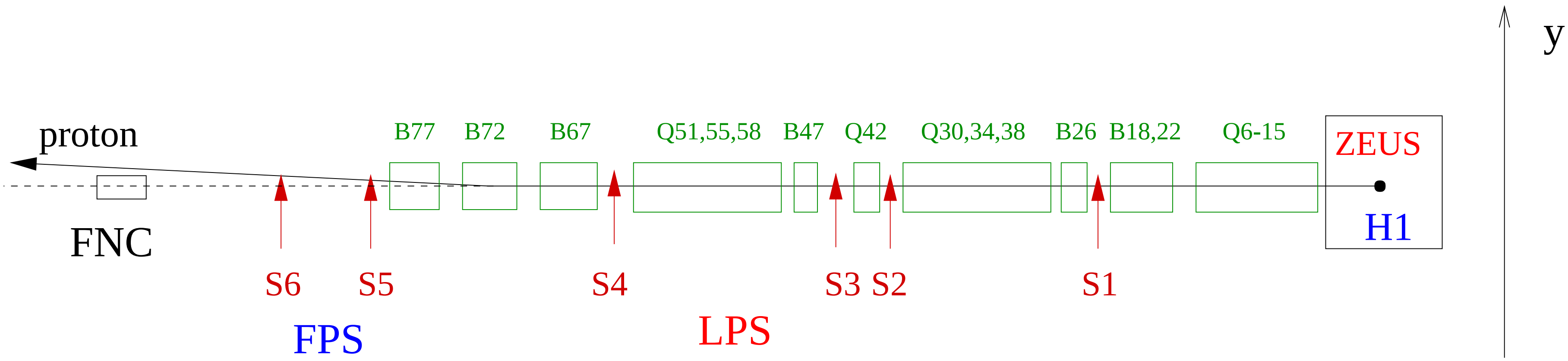
- **Measurement of D^*−mesons in events with leading neutrons**
  ZEUS Collab., DESY-03-221





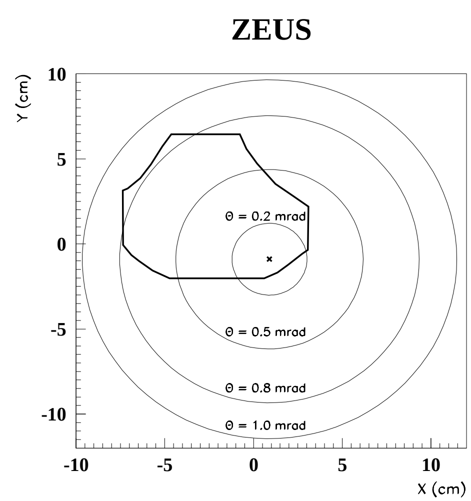
$$x_L = E_n/E_p$$

Design specifications

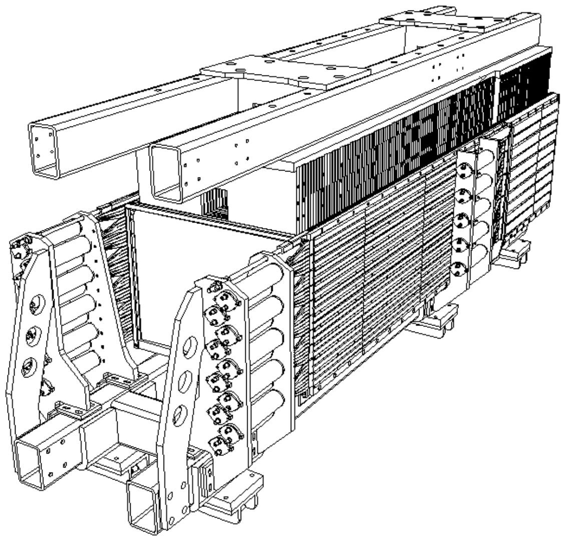


The size and weight of the calorimeter is defined by the space available in HERA tunnel:

- **Position - 105m from the interaction point**
- **Size (x-y-z) $\sim$ 70 $\times$ 70 $\times$ 200 cm^3**
- **Weight $\lesssim$ 10t**
- **Geometrical acceptance is limited by beam-line elements: $\lesssim$ 0.8mrad.**
- **Should work in high radiation environmenet**



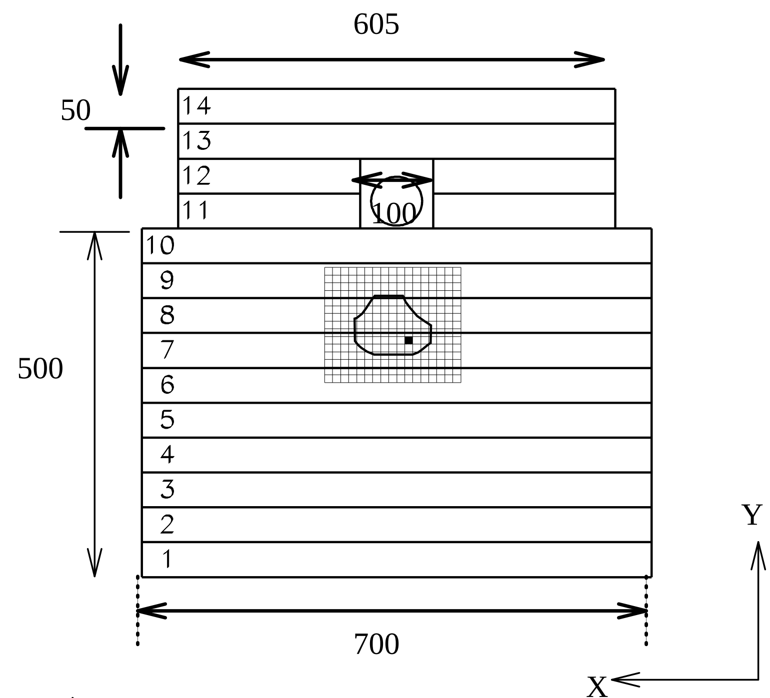
The General view of ZEUS-FNC detector

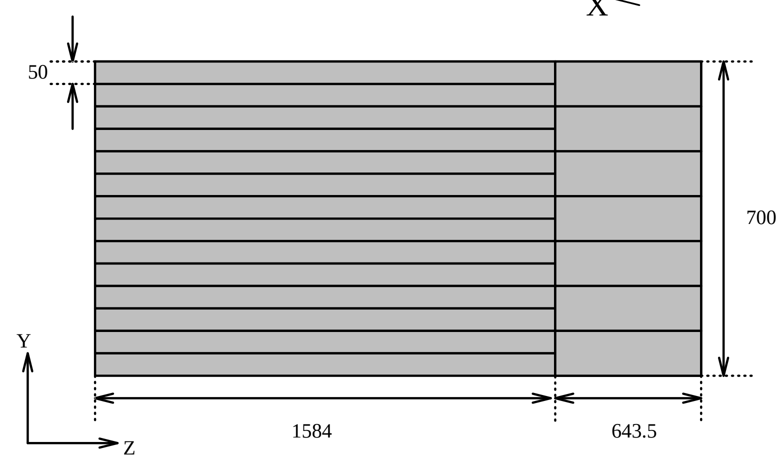


- **S.Bhadra et al.**, *NIM A394 (1997) 121*
- **sampling calorimeter, $e/h \sim 0.96$**
- **134 layers 1.25cm Pb and 0.26cm scintillator, readout by WLS from both sides,**
- **front section (7λ) -14 towers, rear section 3λ,**
- **e/h separation using transverse width of shower**
- $\sigma_E/E = 0.65\%/\sqrt{E\ [GeV]}$

–**Forward Neutron Tracker (since 1998)**

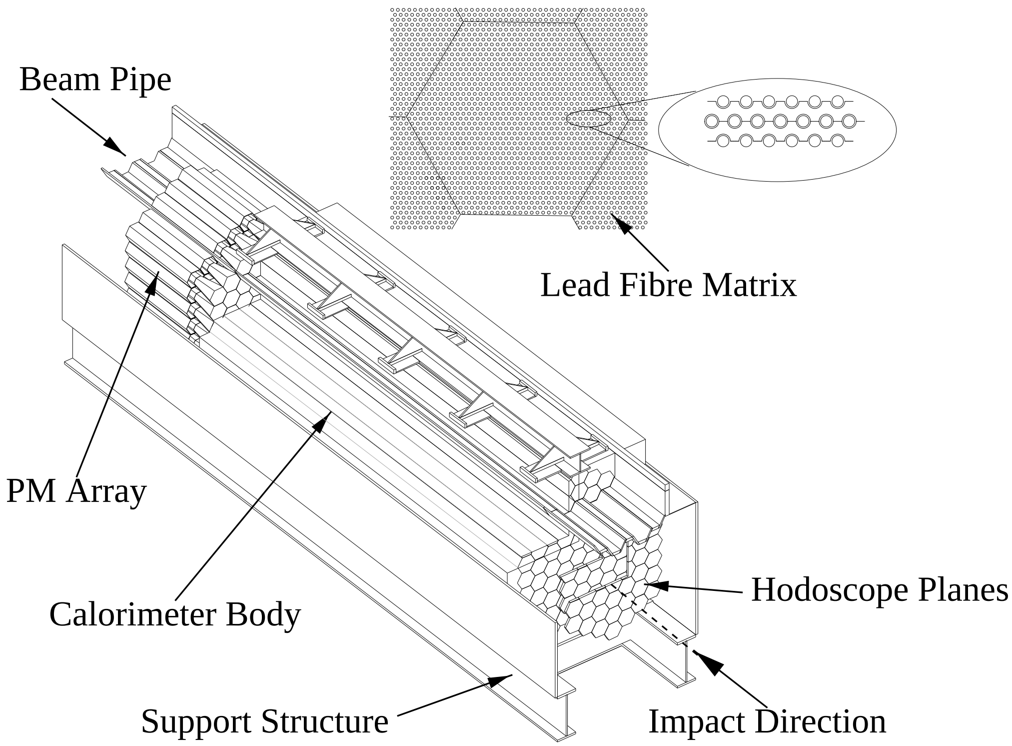
17×15 X-Y strips, 1.2cm each,
installed 1λ inside the calorimeter
position resolution 0.23cm





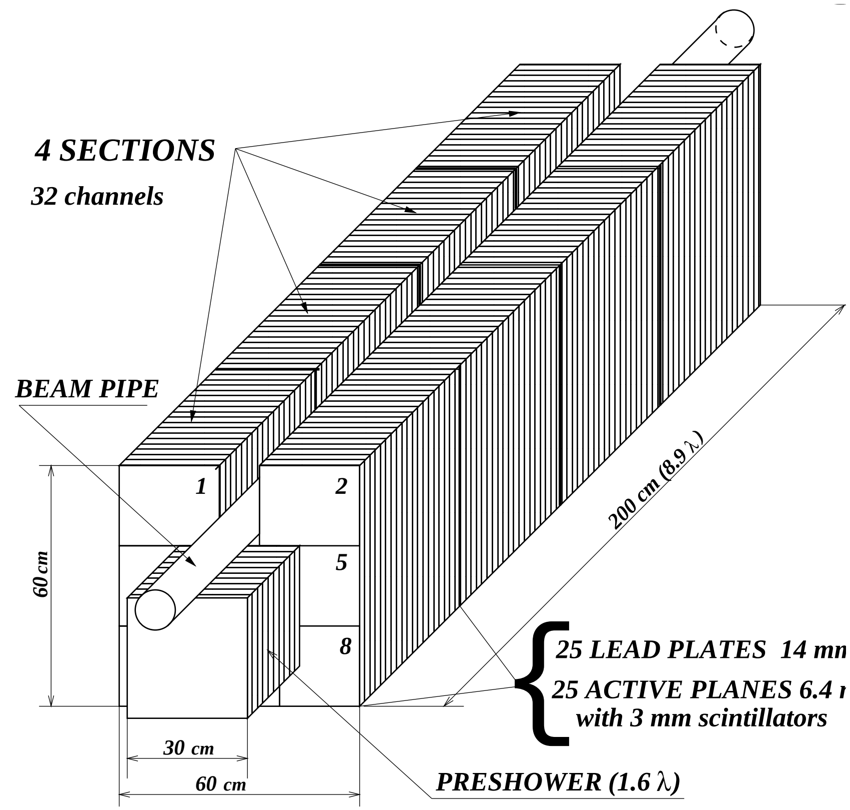
The General view of H1-FNC detector

HERA-1 (1996-2000)



- Spaghetti calorimeter
- 75 modules (1141 fibers in each)
- previously was used in WA89 experiment
- $\sigma_E/E \sim 20\%$ at high E,
- $\sigma_{XY} = 5.13/\sqrt{E[GeV]} \oplus 0.22\ cm$
- In 1998 was upgraded by ‘Preshower’
- H1 Collab., *Eur.Phys.J.* C6 (1999) 587.

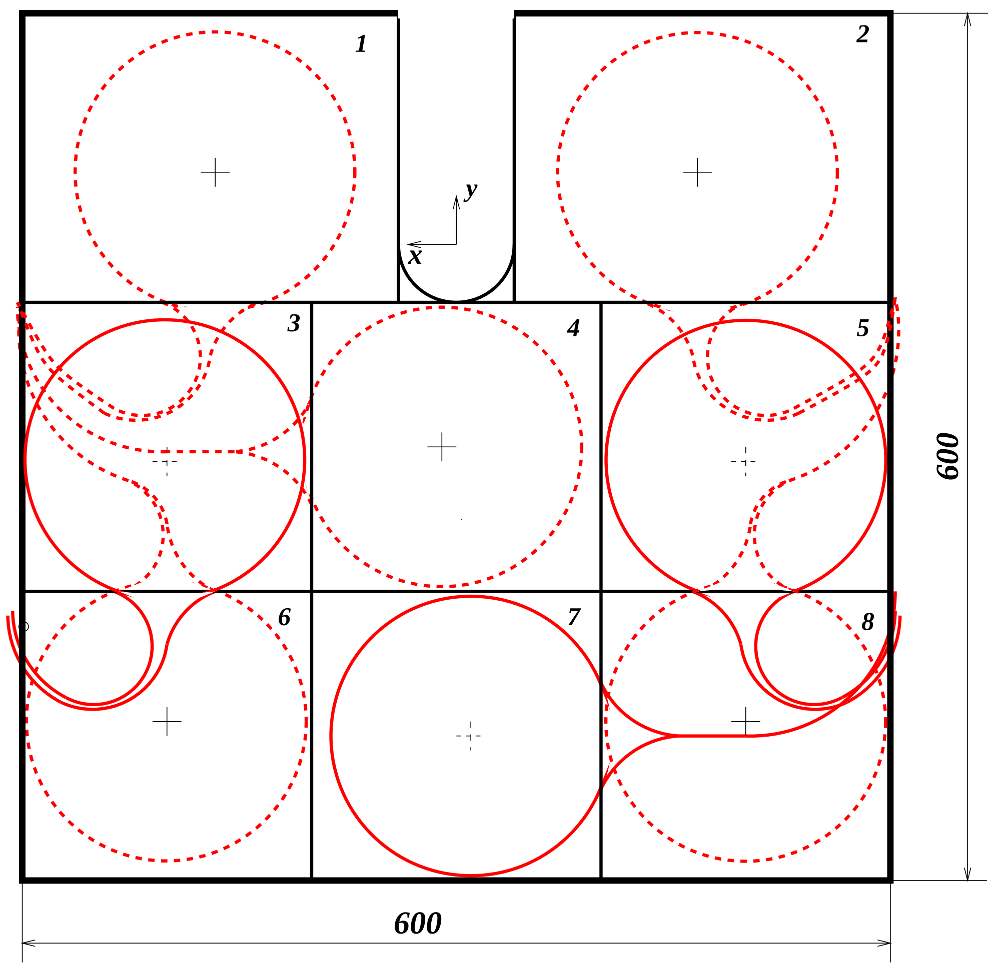
HERA-2 (2002-...)



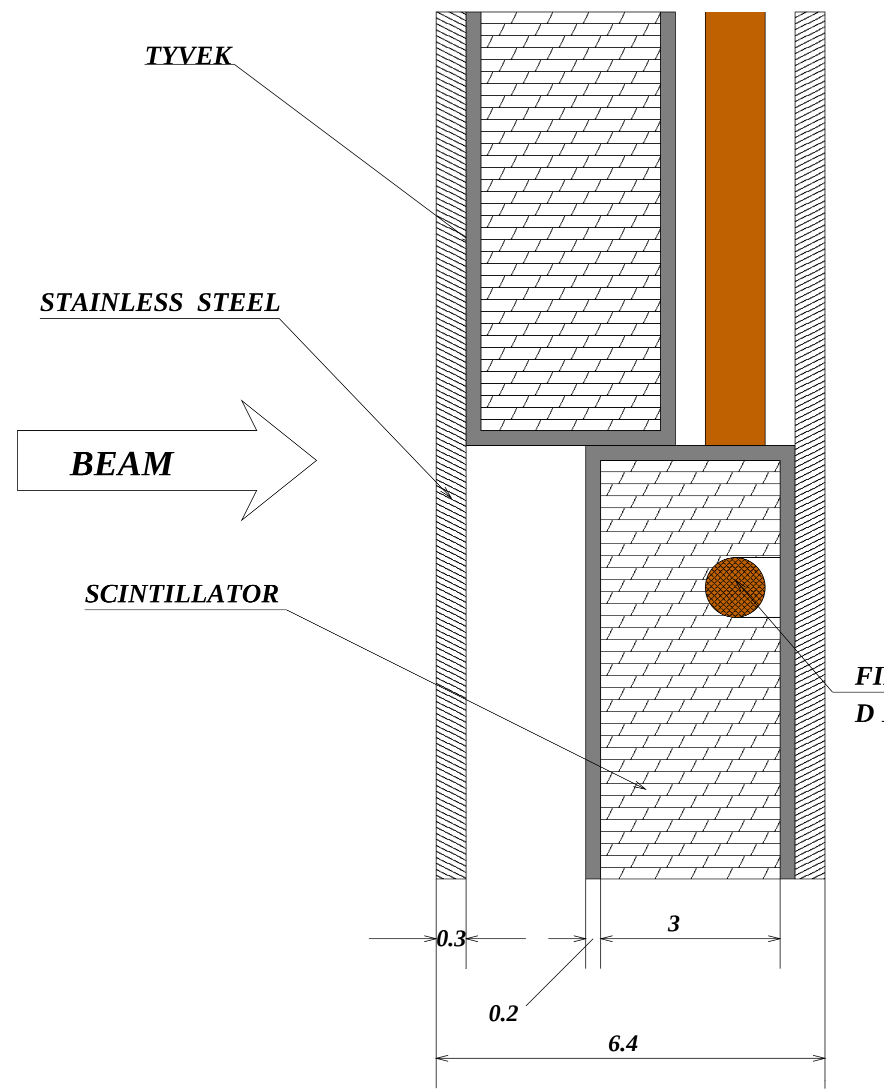
- Preshower + 4 Sections
- each Section consists of 8 Towers
- each Tower is 25 Scintillator tiles

–www-h1.desy.de/h1/www/h1det/calo/fnc/psfiles/fnc_note2002.ps.gz

Active Board– layout of scintillators and fibers



- Scintillator (Kuraray, SCSN-81)
- WLS (Y11-200M, 1mm)
- Transparent fiber (PSM, 1mm)



Structure of H1-FNC

The structure of the main FNC calorimeter

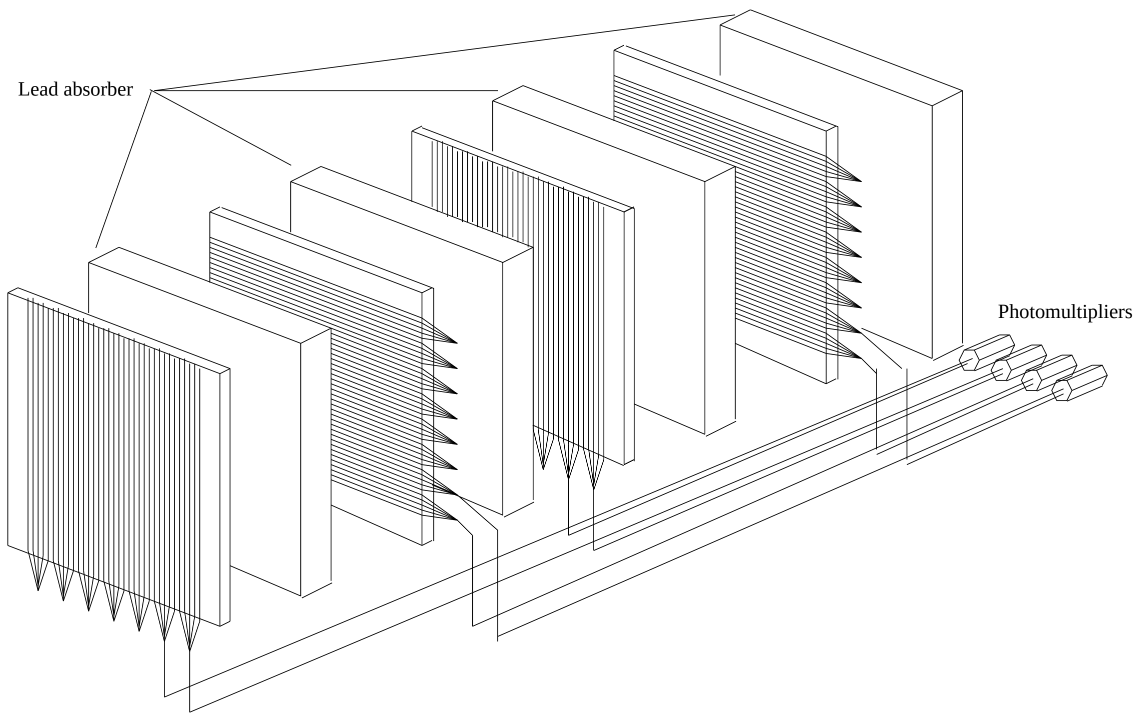
Material	Depth (mm)	Nuclear interaction lengths λ_I
PbSb4	14 $\times$ 100	8.20
scintillator	3.0 $\times$ 100	0.34
Tyvek paper	0.3 $\times$ 100	0.00
steel	0.6 $\times$ 100	0.36
air	2.0 $\times$ 100	0.00
total	2000	8.9

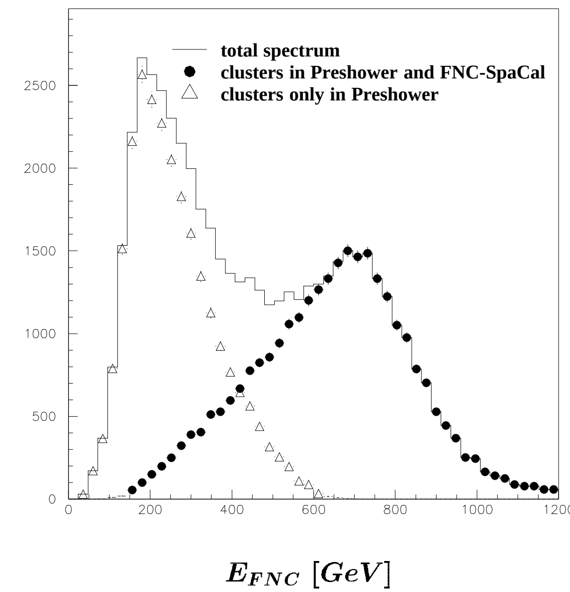
The structure of the Preshower

Material	Depth (mm)	Nuclear interaction lengths λ_I
e/m part		
PbSb4	7.5 $\times$ 12	0.52
scintillator	2.6 $\times$ 13	0.04
Tyvek paper	0.3 $\times$ 12	0.00
air	1.2 $\times$ 12	0.00
total e/m part	142	0.56
hadron part		
PbSb4	14. $\times$ 12	0.98
scintillator	5.2 $\times$ 12	0.07
Tyvek paper	0.3 $\times$ 12	0.00
air	0.6 $\times$ 12	0.00
total hadr.part	251	1.05
total	393	1.6

- 26 $\times$ 26 $\times$ 38.6 cm^3 (1.6λ)
- 12 X-layers, 12 Y-layers, each layer has 9 X (Y) strips

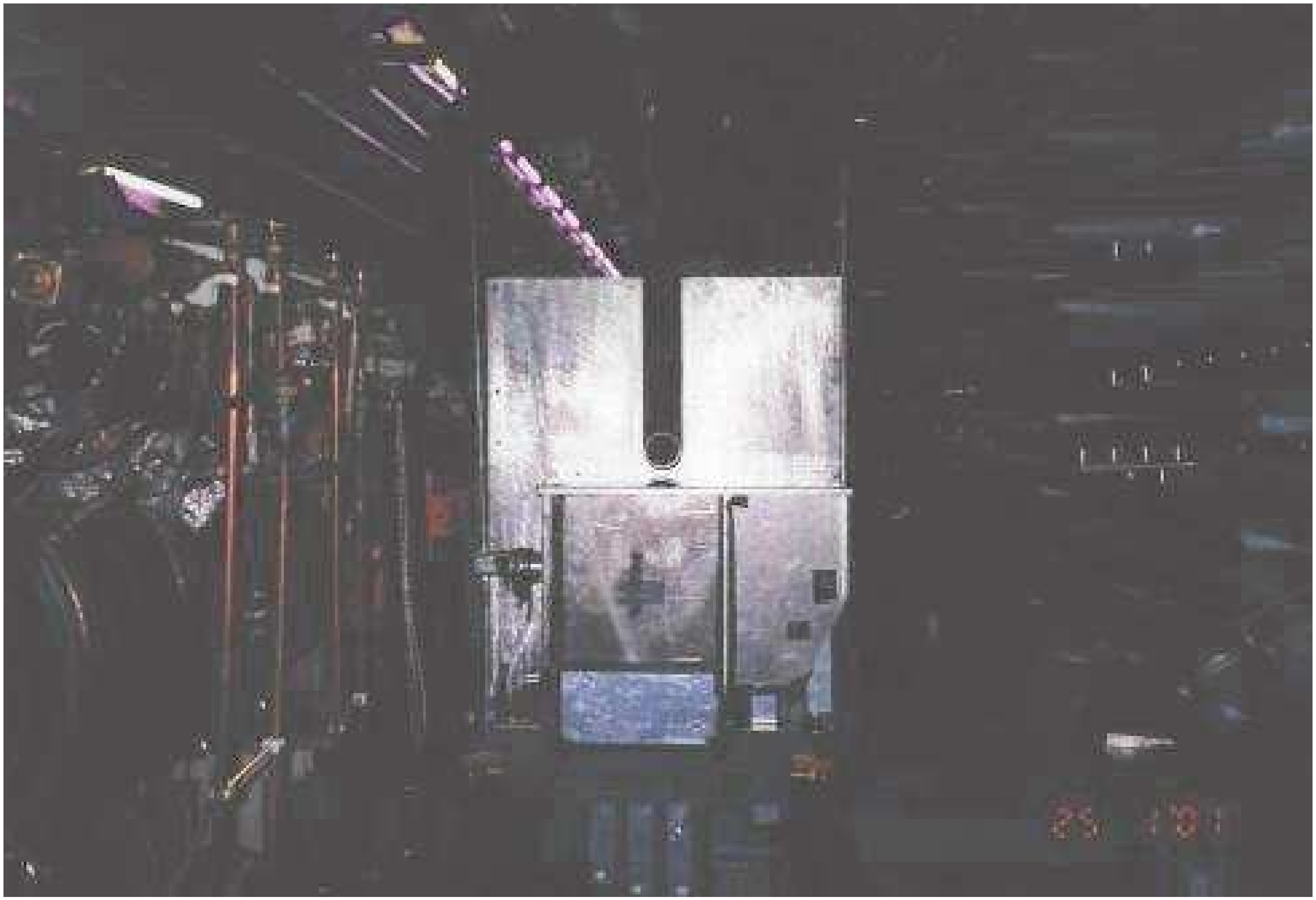
Preshower (H1-FNC)





- $\sim 40\%$ energy of hadronic shower is deposited in Preshower
- improves the energy and position resolutions (better than 3mm) and allows separation of e/m from hadronic showers

H1-FNC



Readout

- **Light signals from 4×8 towers and 2×9 strips are fed into 50 Philips XP2282/B 8-stage photomultiplyers.**
- **Signals from ADCs are readout by CDAQ and by local slow control computer**
- **Signals are digitized by SIS3300 ADCs (8 channels, 100Mhz, 12 bit).**
- **HV supply- LeCroy 1440 HV system**

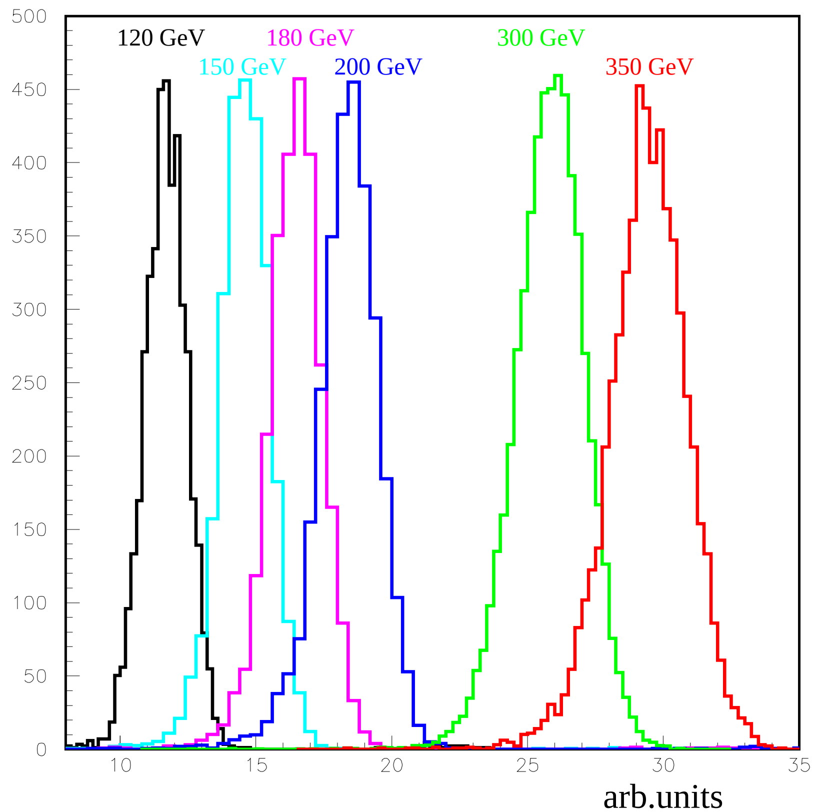
Calibration and Monitoring

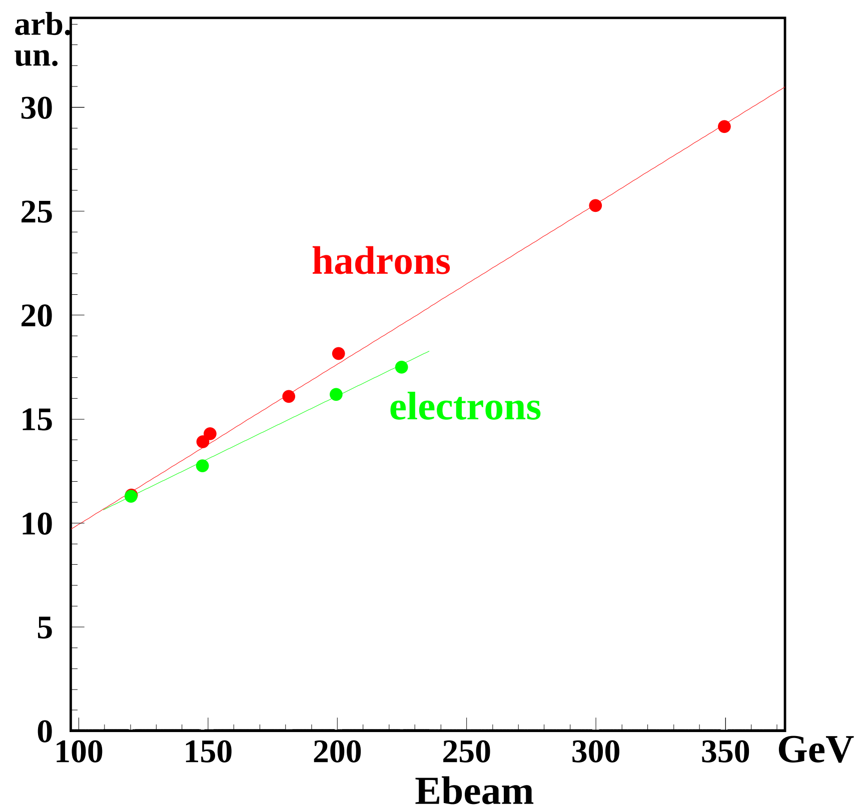
▷ **Initial calibration was done in Juni-July 2000 at CERN SPS beams (H4 and H6) with 120-350 GeV hadrons and 120-225 GeV electrons.**

The H1-FNC energy response

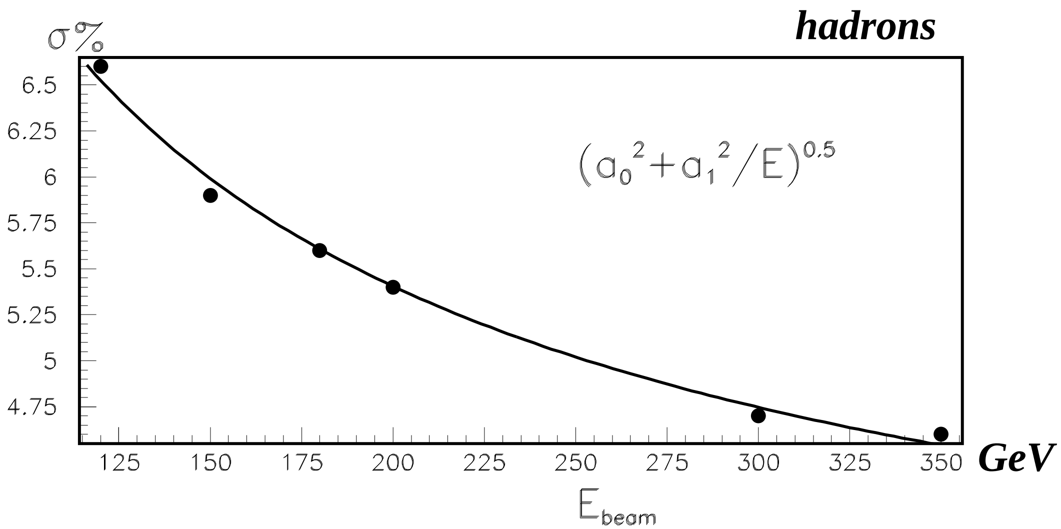
June-July 2000 – CERN hadron beam tests at SPS (H4 and H6 beams)

E_{beam}=120-350 GeV





The H1-FNC energy resolution



from CERN test-beam measurements ($E_{hadron} = 120 - 350\ GeV$)

$$\frac{\sigma_E}{E} = \frac{63.4 \pm 4.7}{\sqrt{E[GeV]}} \oplus (3.0 \pm 0.4)\%$$

(Monte-Carlo estimate was $\sim$ 50%).

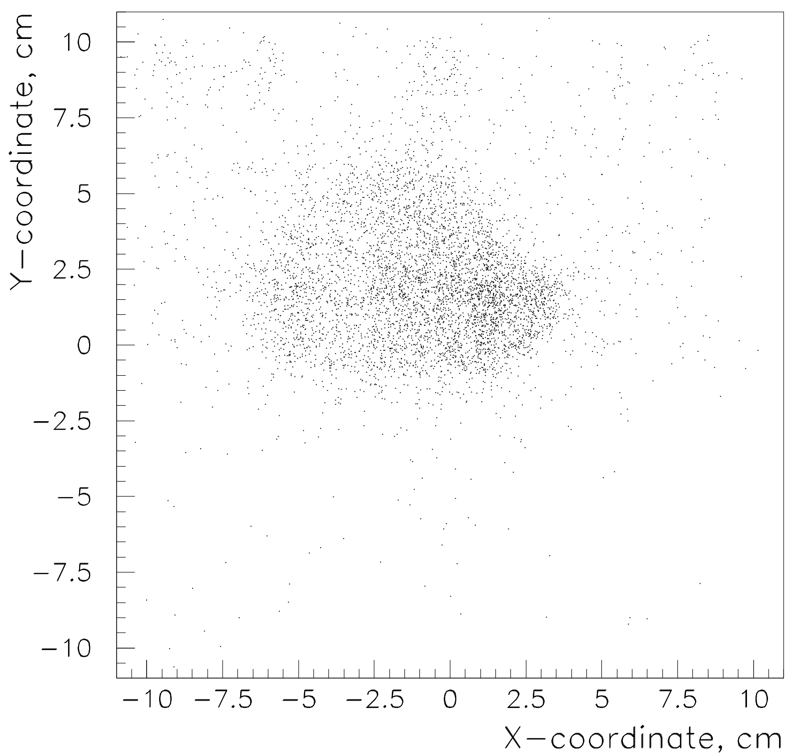
The results for the electrons ($E_{beam} = 120 - 225\ GeV$) are

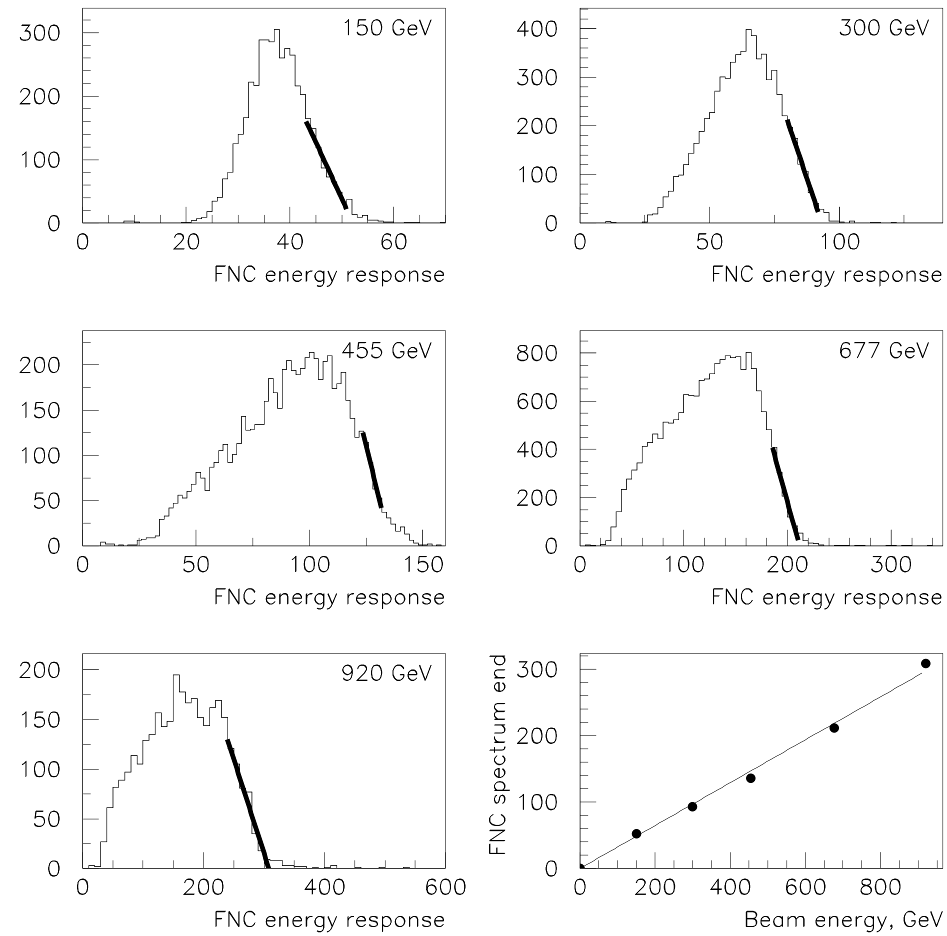
$$\frac{\sigma_E}{E} = \frac{30\%}{\sqrt{E[GeV]}} \oplus 2\%$$

Calibration and Monitoring

- ▷ Initial calibration was done in Juni-July 2000 at CERN SPS beams (H4 and H6) with 120-350 GeV hadrons and 120-225 GeV electrons.
- ▷ The gain variation of PMs and the light yield of the scintillators and WLS is monitored online by two independent blue LED systems:
  1. Light pulses are transferred to all PMTs at 0.5Hz
  2. Light pulses from LEDs are injected into 20% of all scintillators at 0.5Hz
  3. LED stability is monitored by comparing signals from LED and from the radioactive source
- ▷ Changing in gain during data taking are monitored using energy deposits from interaction of proton beam with residual gas in the beampipe. The absolute energy scale is defined by comparing the peak position and the high energy part of energy distribution with the expectation from pion exchange.

Performance and Linearity test with HERA proton beam





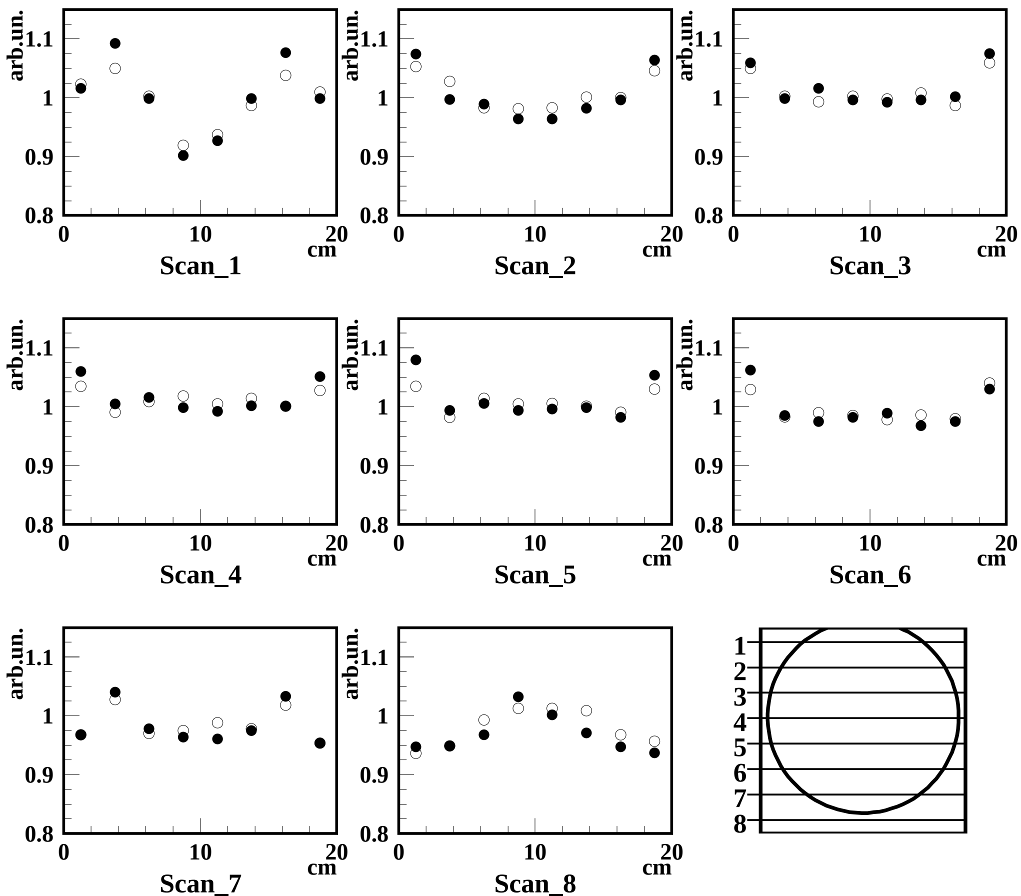
- **Rate and performance are sensitive to the beam conditions**
- **FNC acceptance is very sensitive to the small inclanations of the beams (beam tilt).**

Summary

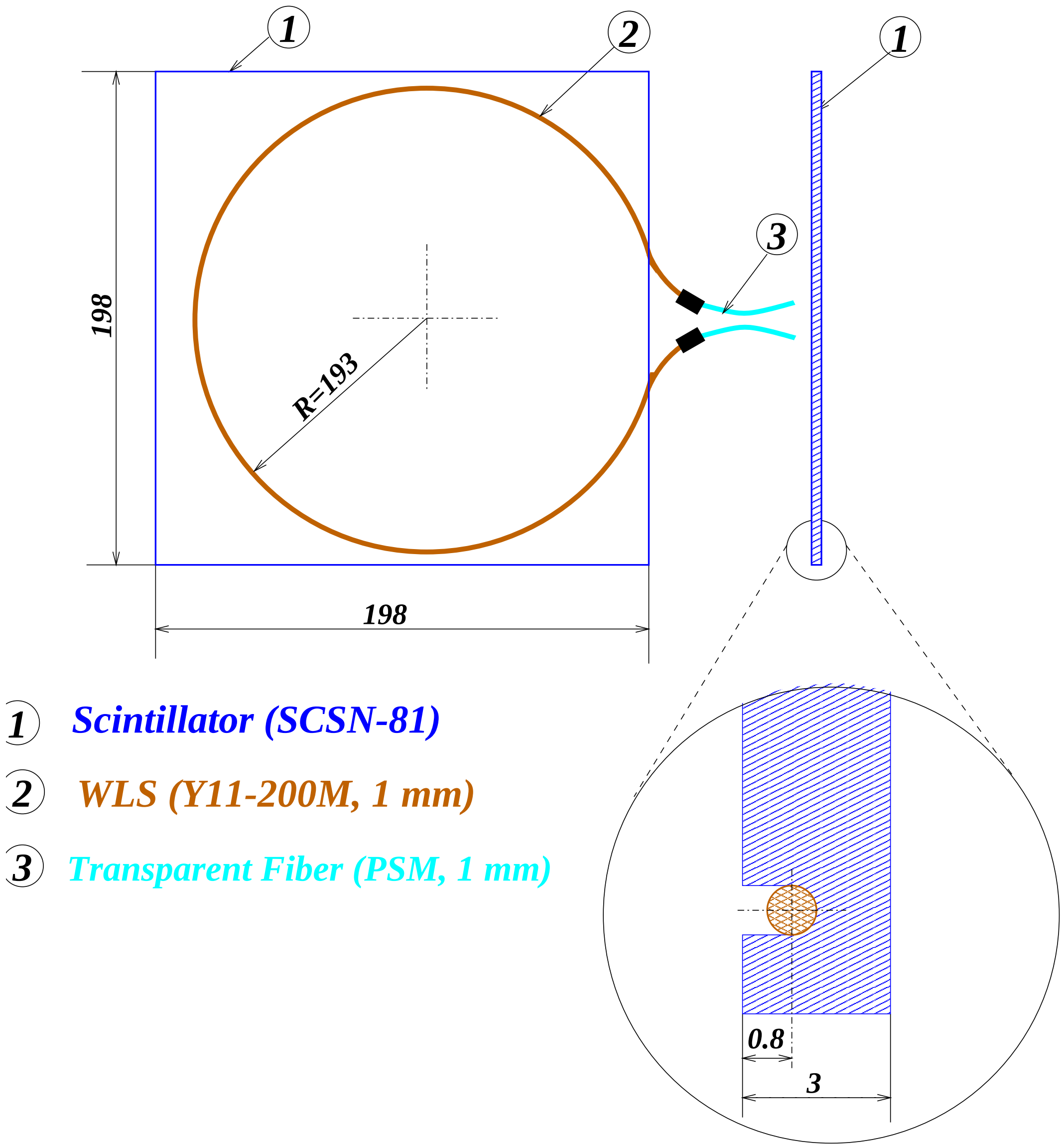
- **The Forward Neutron Calorimeters are valuable additions to both HERA experiments. They provided and will provide in the future many useful, interesting and unique data for physics analysis.**
- **The technique chosen for construction of neutron calorimeters, design parameters and performance satisfy all requirements defined by physics program.**

Horizontal scan of scintillator with 25mm step

Comparison of radioactive source scan (black circle) and Monte-Carlo simulation (open sircle)



Scintillators



H1-FNC DAQ scheme