The Zero Degree Calorimeters for the ALICE experiment

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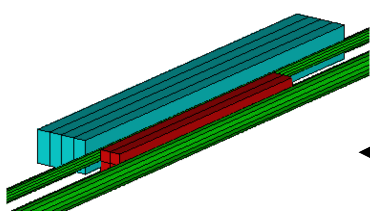
Outline:

- The ALICE experiment and the role of the Zero Degree Calorimeters (ZDC)
- Description of the ZDC detectors
- Results of the beam test performed at the CERN SPS

ALICE: the Heavy Ion experiment at LHC

- Central barrel ($-1<\eta<1$):
  - hadrons
  - photons
  - electrons
- Dimuon arm ($2.5<\eta<4$):
  - muon pairs
- Forward detectors ($\eta>4$):
  - centrality of collisions
    - FMD,T0,V0
    - ZDC ($\eta>8.7$)

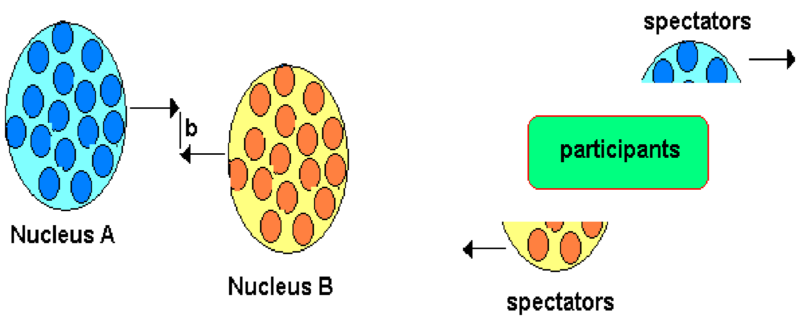


2 sets of ZDC located at 116m from the IP in the machine tunnel

Centrality measurement in H.I. experiment

Many **QGP signatures** depend on **energy density**, estimated through **centrality** of the collision

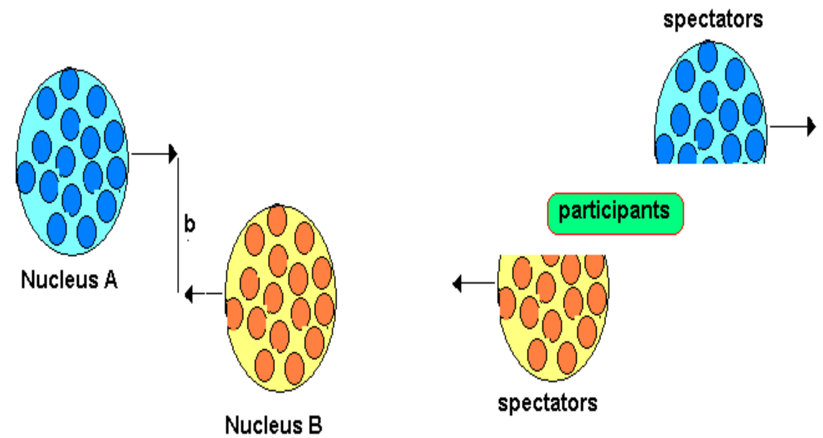
Central collision



Small impact parameter b
Large number of participants
High energy density
Small number of spectators

⇒ **Low energy in the ZDC**

Peripheral collision



Large impact parameter b
Small number of participants
Low energy density
large number of spectators

⇒ **Large energy in the ZDC**

Two identical sets of Zero Degree Calorimeters (ZDC), one on each side relative to the interaction point (I.P.), will measure the centrality of the collision through the detection of zero degree energy.

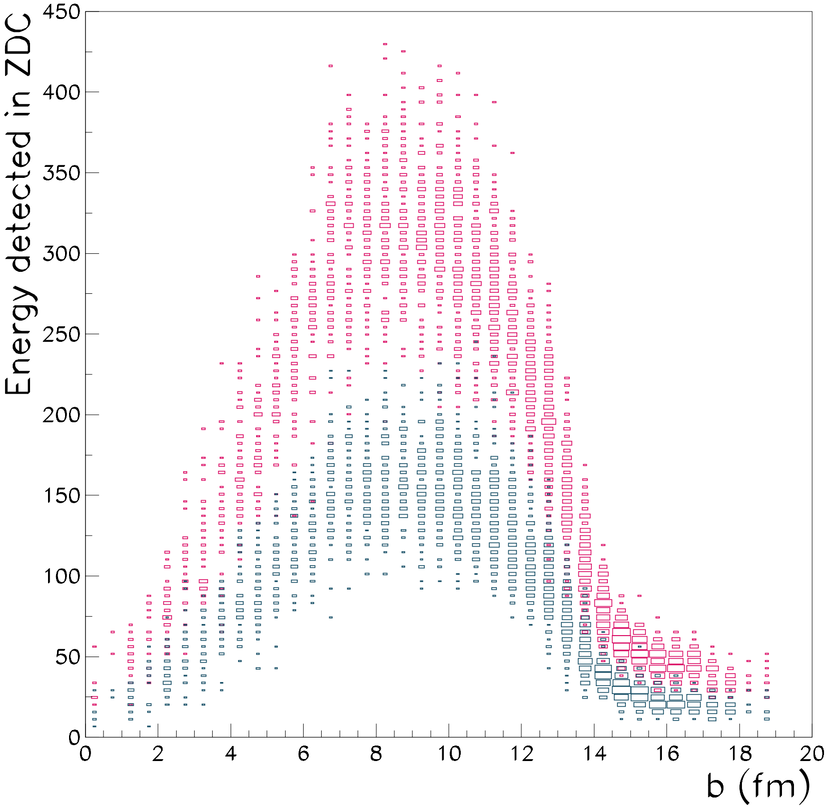
If all the spectator nucleons are detected, then: $\mathbf{N_{spec} = E_{zdc} / E_A \Rightarrow N_{part} = A - N_{spec}}$

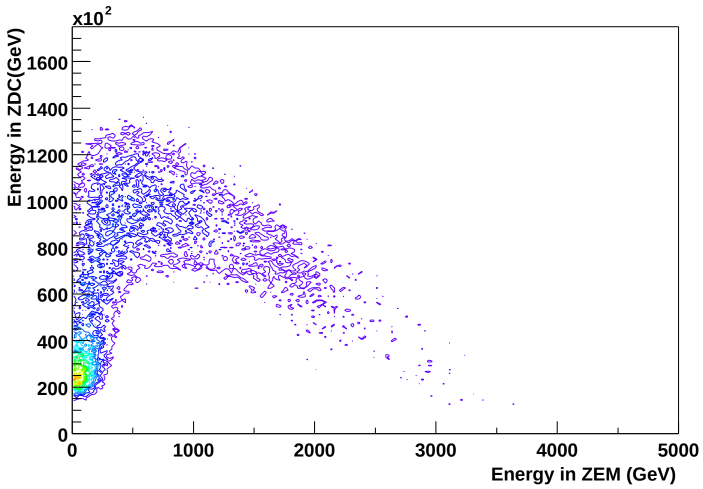
Centrality measurement at colliders

In H.I. collisions nuclear fragments are produced : at colliders they are lost in the beam pipes.

In the ALICE experiment :

- good correlation between E_{zdc} and the impact parameter *b* only for *b* < 11 fm
- full acceptance for spectator neutrons
- small fraction (~ 20%) of spectator protons lost in the beam pipe



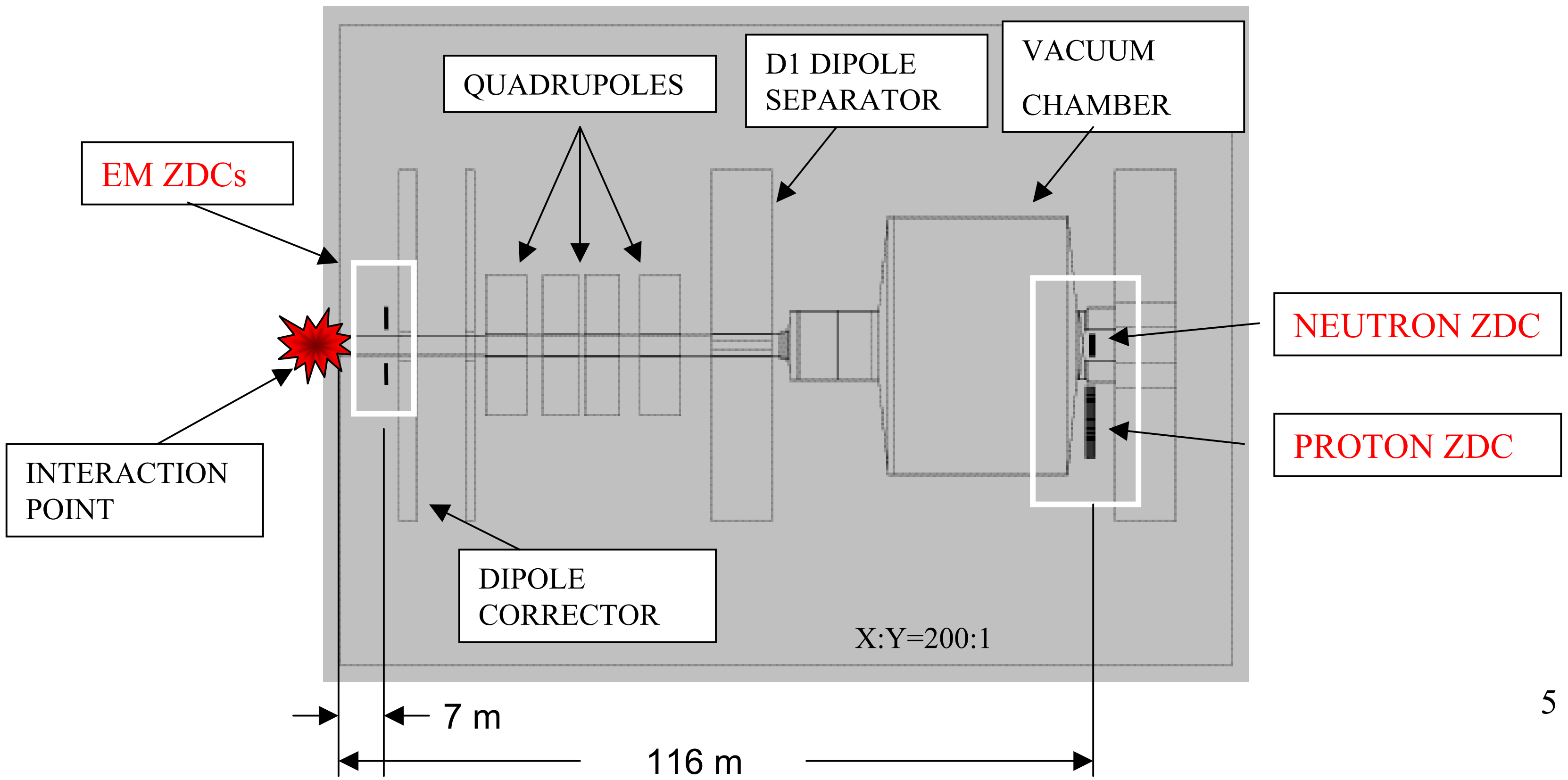


ZDCs completed by two small e.m. calorimeters to identify very peripheral collisions

ZDCs for the ALICE experiment

The ZDC detector is made by

- two identical sets of hadronic "spaghetti" calorimeters, located at opposite sides with respect to the I.P., about 116 m away from it, where the beam pipes are separated. Each set consists of 2 calorimeters, 1 for spectator neutrons (ZN) and 1 for spectator protons (ZP), placed at **0°** with respect to LHC axis.
- two forward EM calorimeters placed at about 7 m from I.P., on the left side, covering the pseudorapidity range $4.8 < \eta < 5.7$.



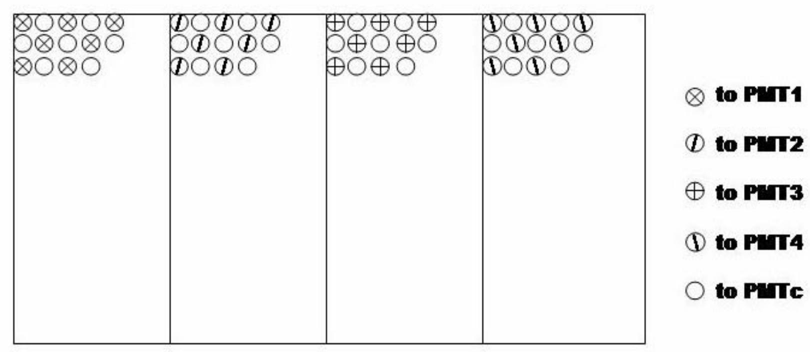
ZP for ALICE: detector description

Passive material : brass

ρ = **9.0 g/cm^3**
30 grooved slabs, each of them 4 mm thick,
stacked to form a parallelepiped 22.8x12x150 cm^3.

Active material : quartz fibers

pure silica core, silica fluorinated cladding, and a hard polymer coat with a diameter of 550, 600, 630 μm respectively. The numerical aperture is 0.22.



The active part of the detector is made of 1680 quartz fibers embedded in the absorber with a pitch of 4 mm. The fibers are placed at 0° with respect to the beam axis and come out from the rear face of the calorimeter.

One every two fibers is sent to a single photodetector (PMTc), while the remaining fibers are connected to four different photodetectors (PMT1 to PMT4), collecting the light from four towers.

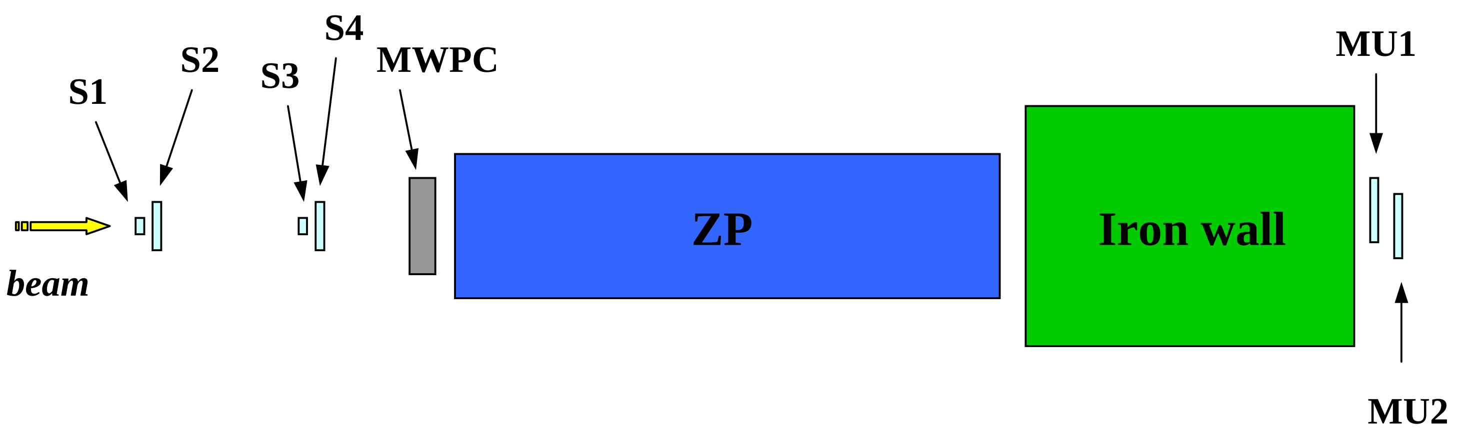
➢ This segmentation allows a rough localisation of the spectator proton's spot .

The 5 bunches of fibers are coupled to 5 PMT **Hamamatsu R329-02** (Quantum Efficiency ~25%).

Beam test at SPS: experimental set-up

ZP1 was tested at H6 beam line in summer 2004 with :

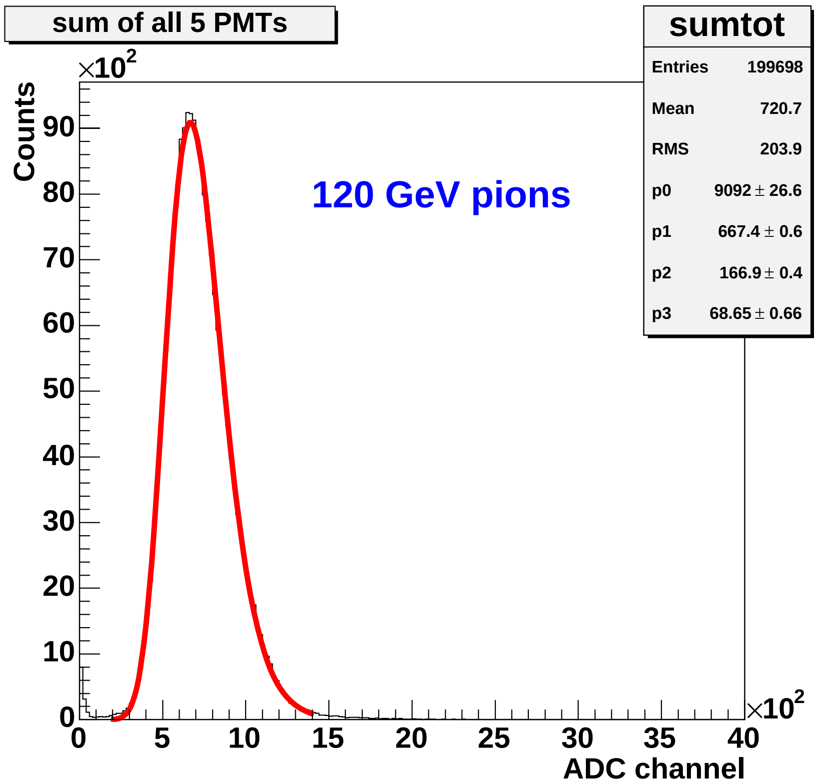
- **hadron beam (E = 50 ÷ 200 GeV)**
- **electron beam (E = 50 ÷ 180 GeV)**



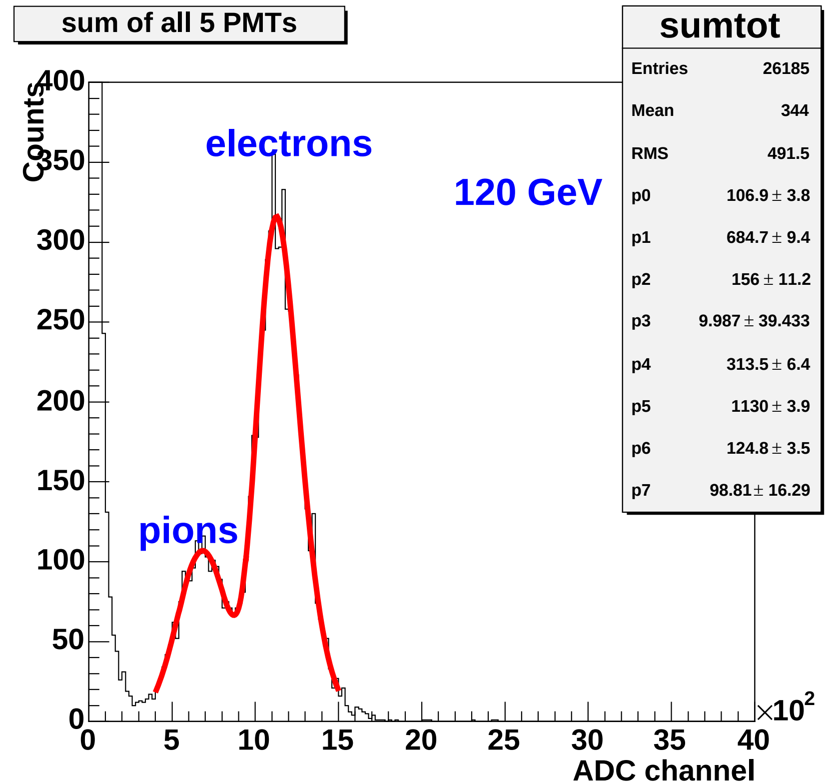
- **S1**, **S2**, **S3**, **S4**: plastic scintillators to provide trigger
- **MWPC**: multiwire proportional chamber to ***define impact point*** on the calorimeter front face
- **MU1**, **MU2**: plastic scintillators to detect muons

ZP1 beam test results:
pions and electrons

ZP1 response to
120 GeV pion beam



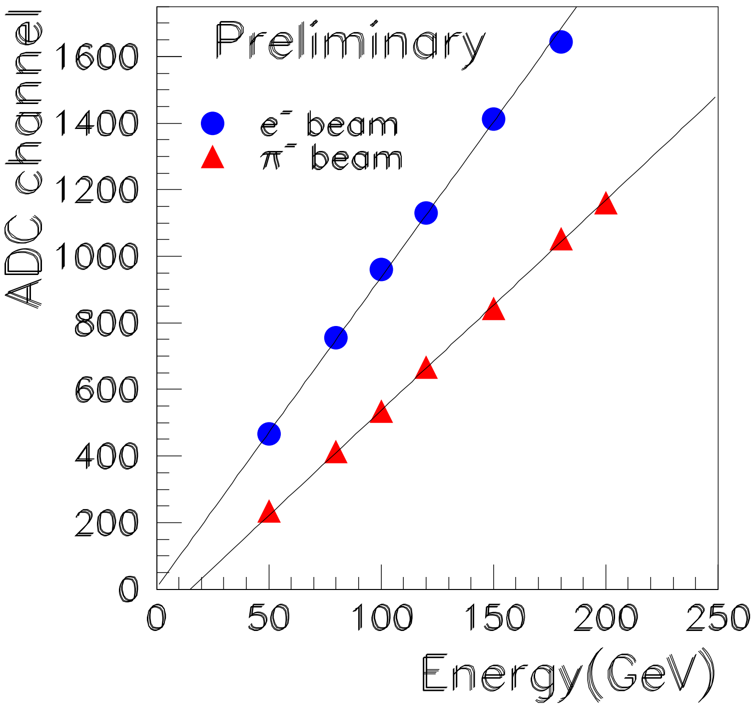
ZP1 response to
120 GeV electron beam



Fit to data: $f(x) = Ne^{-\frac{(x-\mu)^2}{2\sigma(x)^2}}$ where $\sigma(x) = \sigma_0 + \frac{\sigma_1 (x-\mu)}{\mu}$

ZP1 beam test results:
linearity

ZP1 response is proportional to the e^- beam energy in the range from 50 to 200 GeV and shows a threshold for π^-.



ZP1 is highly not compensating :

$$e/\pi \approx 2$$

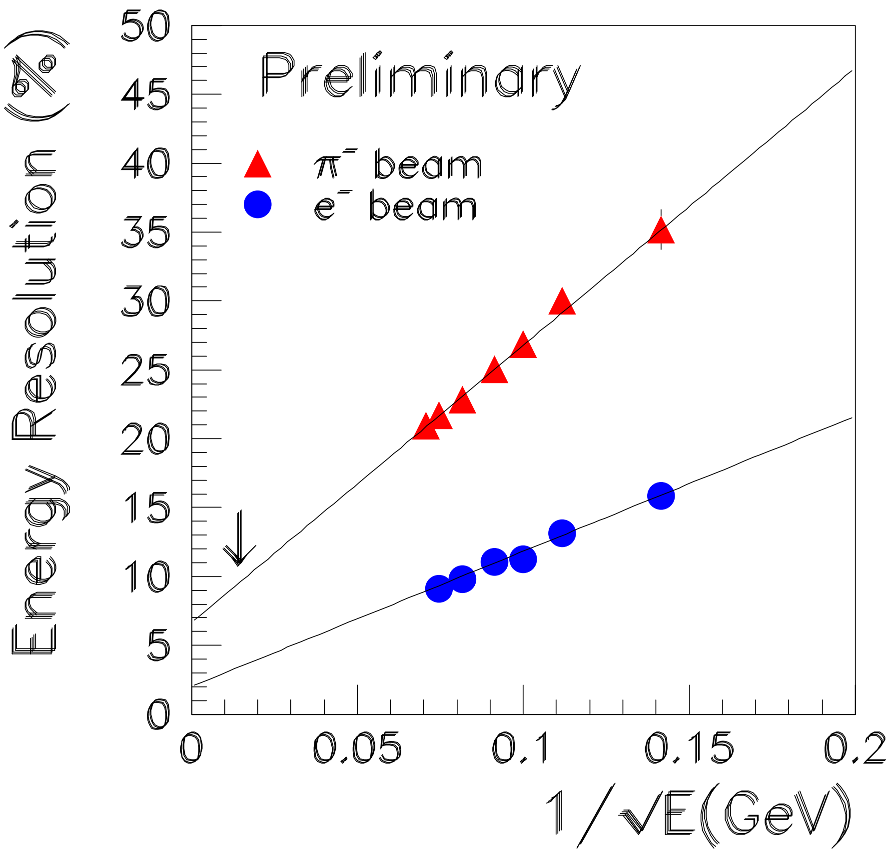
<u>but in ALICE:</u>

1. ZP measures the number of spectator protons, which have the same fixed energy as the beam nucleons.

2. Charged particle produced at IP are bent by D1 separator magnet outside ZP.

3. The energy due to the neutral particles hitting the calorimeter is found to be negligible compared to the energy carried by spectator protons

ZP1 beam test results:
energy resolution



The black solid lines are the results of the fit:

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} + b$$

For pions:

$$a = 201. \pm 2.$$

$$b = 6.6 \pm 0.2$$

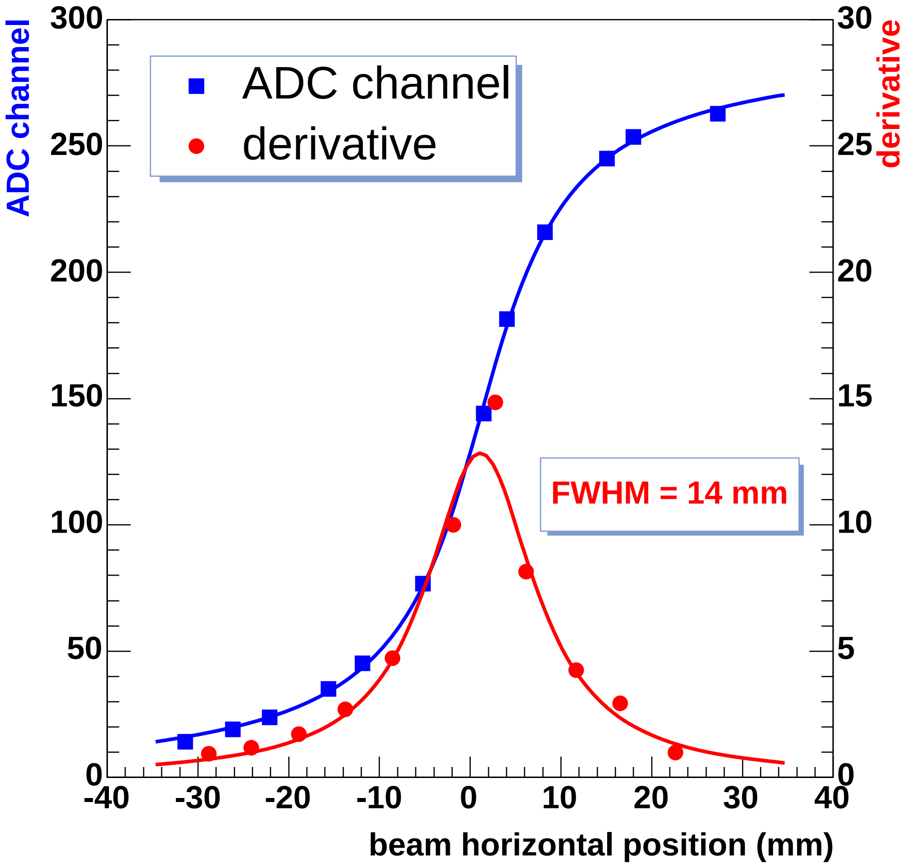
Extrapolation to the ALICE proton spectator energy (**2.7 TeV**):

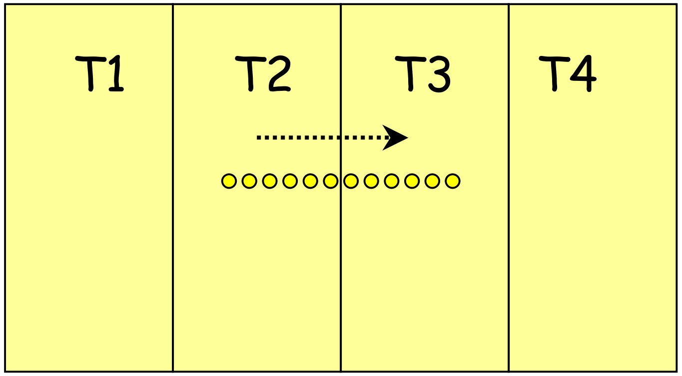
$$\frac{\sigma(E)}{E} \approx 10\%$$

Fulfills the ALICE requirements (TDR)

ZP1 test results:
hadronic shower's transverse profile

Scanning of calorimeter's front face
with a 120 GeV pion beam





- Response of a single ZP1 tower (T3) as a function of the beam impact point on the front face of the calorimeter

Experimental data have been fitted with an arctangent function

- The derivative of the data shows, for the shower's transverse profile, a width of **~14 mm** (FWHM).

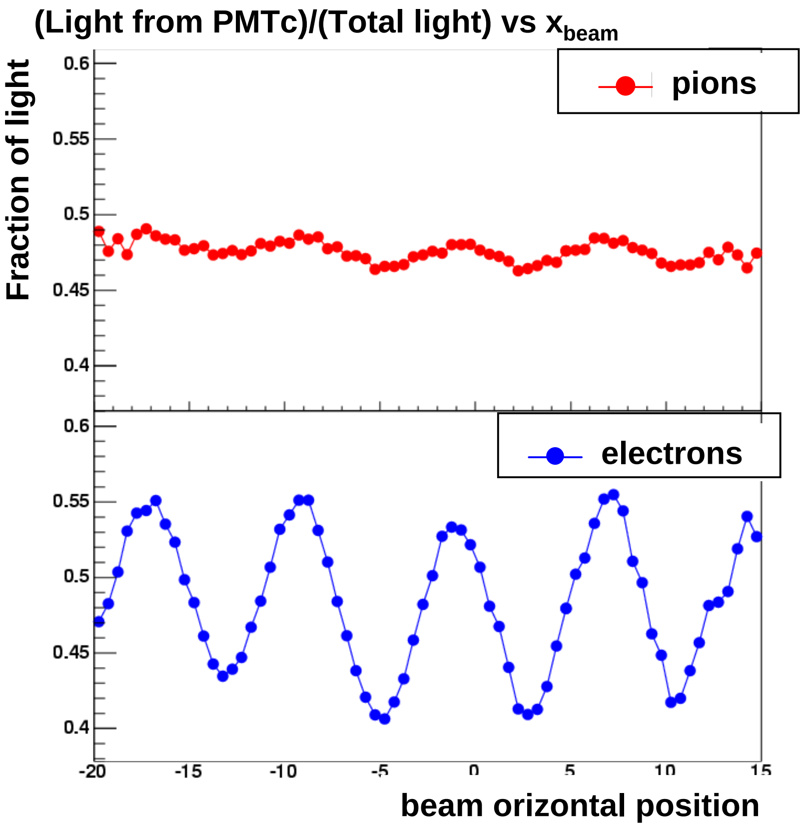
ZP1 test results:
sampling frequency adequate for hadrons

The **uniformity** of the calorimeter's response has been verified with respect to the beam impact point on the front face of the detector.

Negligible oscillations for the pion beam shows that the ZP fiber spacing is adequate for ***hadronic*** calorimetry, as required by **ALICE experiment**

Clear oscillations for the electron beam are due to the size of the shower induced by electrons, narrower than the distance between fibers going to the same PMT (8 mm)

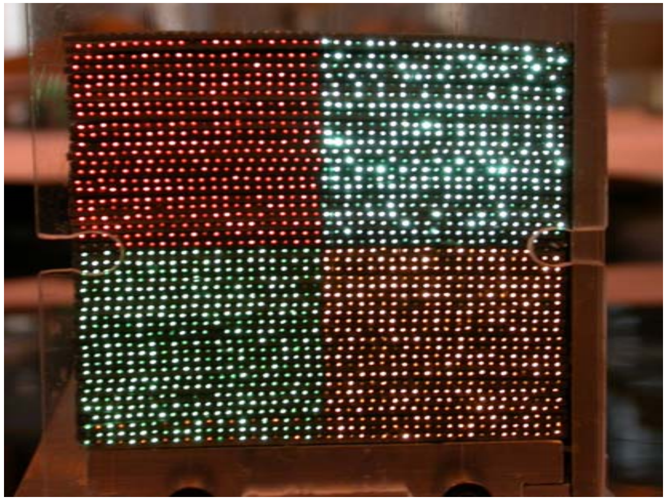
The plot refers to events within a thin window centered on a single fiber plane



ZN for ALICE: detector description

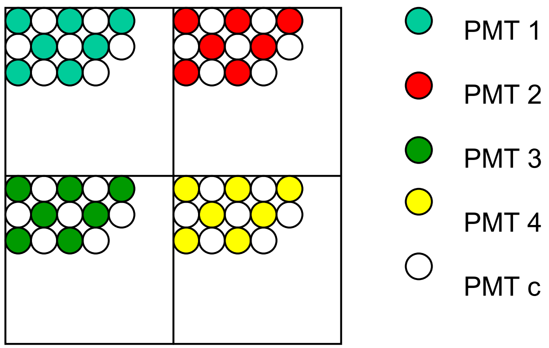
Passive material : W alloy

93.5 % W, 6.5% Ni-Fe, ρ = 17.6 g/cm^3
44 grooved slabs, each of them 1.6 mm thick, stacked to form a parallelepiped 7x7x100 cm^3.



Active material : quartz fibers

pure silica core, silica fluorinated cladding, and a hard polymer coat with a diameter of 365, 400, and 430 μm, respectively. The numerical aperture is 0.22.



The active part of the detector is made of 1936 quartz fibers embedded in the absorber with a pitch of 1.6 mm. The fibers are placed at 0° with respect to the initial particle direction and come out from the rear face of the calorimeter.

One every two fibers is sent to a single photodetector (PMTc), while the remaining fibers are connected to four different photodetectors (PMT1 to PMT4), collecting the light from four towers.

- This segmentation makes ZN a rough **position sensitive device**:
  this **localizing capability** can be used to **monitor the beam crossing angle** and allows the **Reaction Plane estimation**

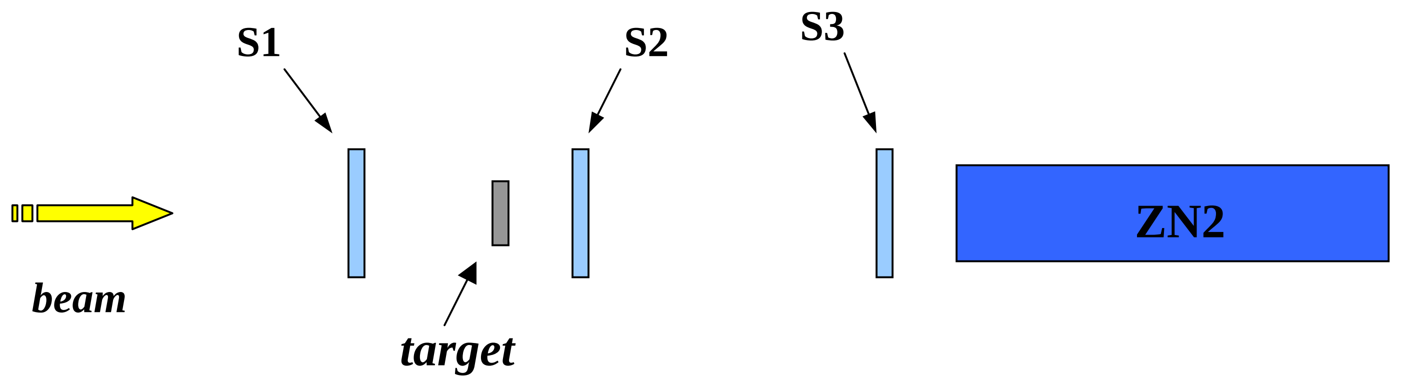
The 5 bunches of fibers are coupled to 5 PMT **Hamamatsu R329-02** (Quantum Efficiency ~25%).

ZN2 test at SPS: ^{115}In beam experimental set-up

The second neutron calorimeter (**ZN2**) was tested at CERN SPS in autumn 2003 with **^{115}In beam (E = 158A GeV) at H8 beam line**

⇓

E ~ 18.2 TeV equivalent to a central collision in ALICE (6÷7 nucleons)



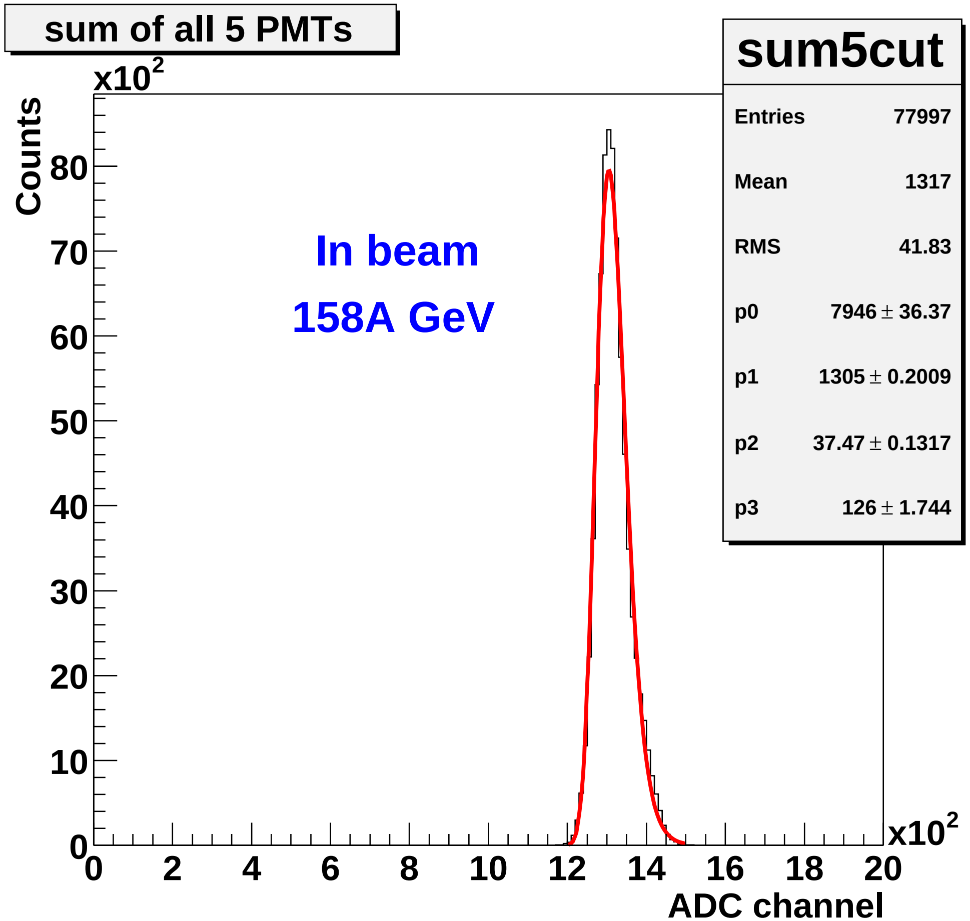
- **S1**, **S2**: plastic scintillators to provide trigger
- **S3**: plastic scintillator to select non-interacting beam
- ^{115}In beam was sent on various **targets**: ^{118}Sn, ^{63}Cu, ^{27}Al, ^{12}C, empty target

ZN2 beam test results:

^{115}In beam

ZN2 response to

158A GeV ^{115}In beam



Energy resolution:

$\sigma_E/E = (2.87 \pm 0.01)\%$

N independent nucleons :

$$\frac{\sigma_E}{E} = \frac{\sqrt{N\sigma_n^2}}{NE_n} = \frac{\sigma_n}{\sqrt{N}E_n} \approx 2\%$$

where $N = 115$ and

$$\left.\frac{\sigma_n}{E_n}\right|_{E=150} = (23.17 \pm 0.06)\%$$

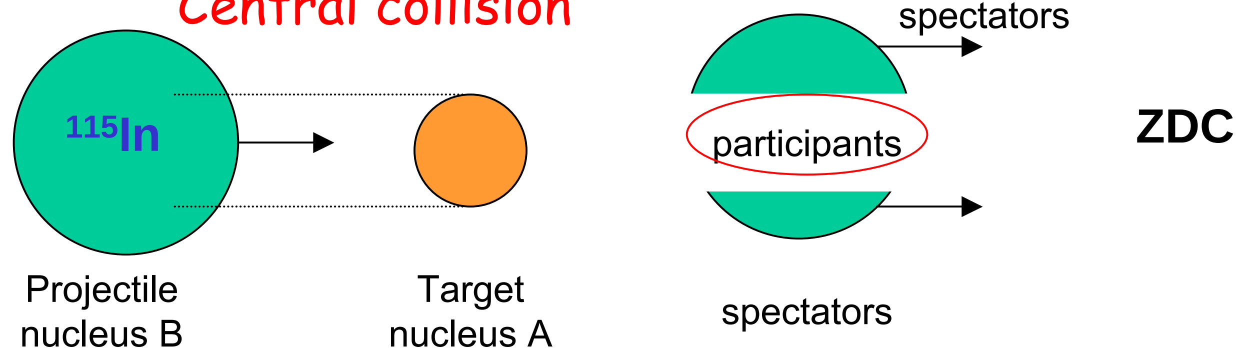
from pion beam test results

ZN2 beam test results:

linearity as function of number of spectators (1)

^{115}In + ^{12}C, ^{27}Al, ^{63}Cu, ^{119}Sn

Central collision



Geometric approximation:
Nucleus = rigid sphere with uniform nucleon distribution

For central collisions:

$$N_{spec} = A \cdot \left[\left(\frac{B}{A} \right)^{\frac{2}{3}} - 1 \right]^{\frac{3}{2}} \Rightarrow$$

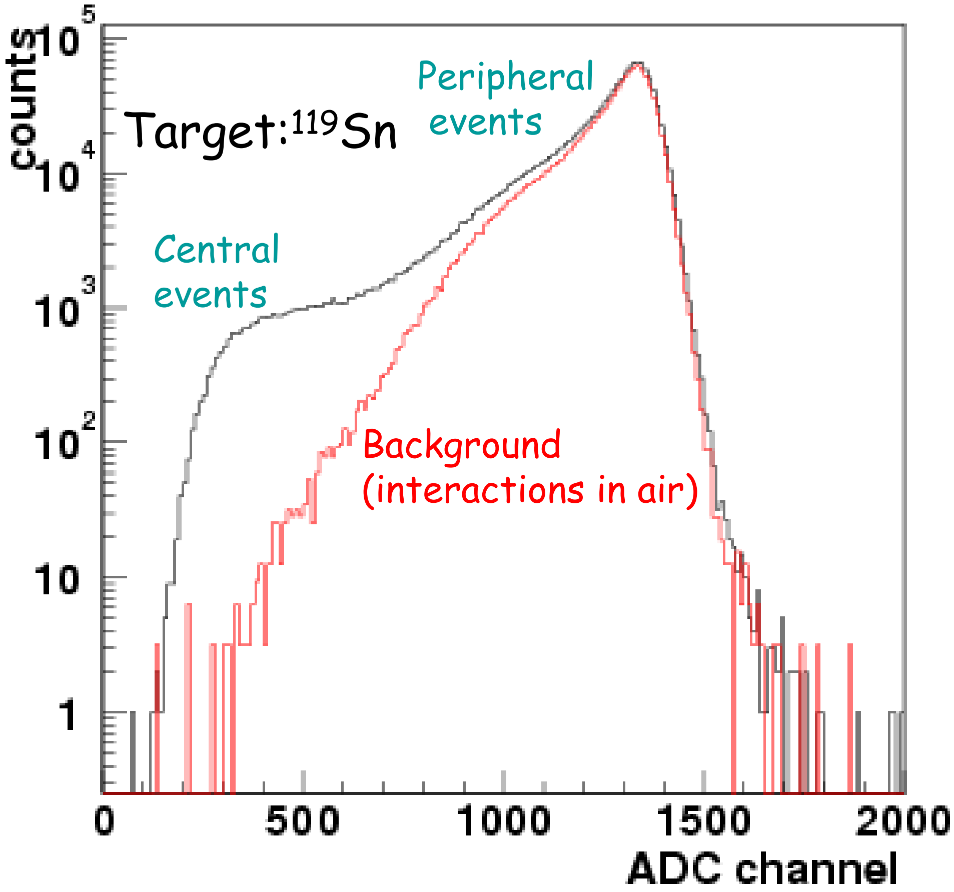
Central collision

Target	Number of spectators
^{118}Sn	0
^{63}Cu	22
^{27}Al	56
^{12}C	79
void	115

ZN2 beam test results:

linearity as function of number of spectators (2)

Spectra after non-interacting beam removal

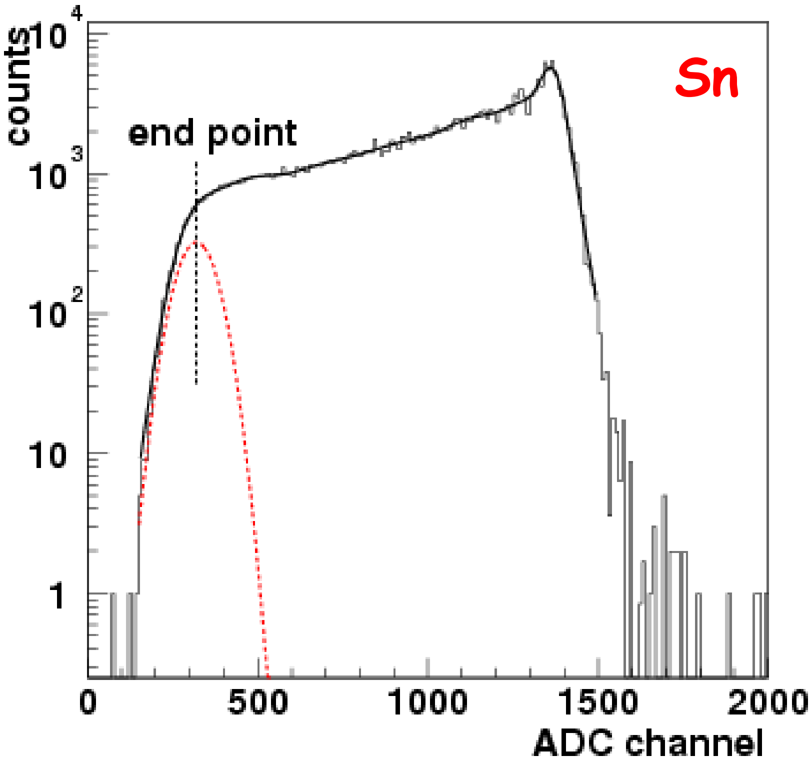


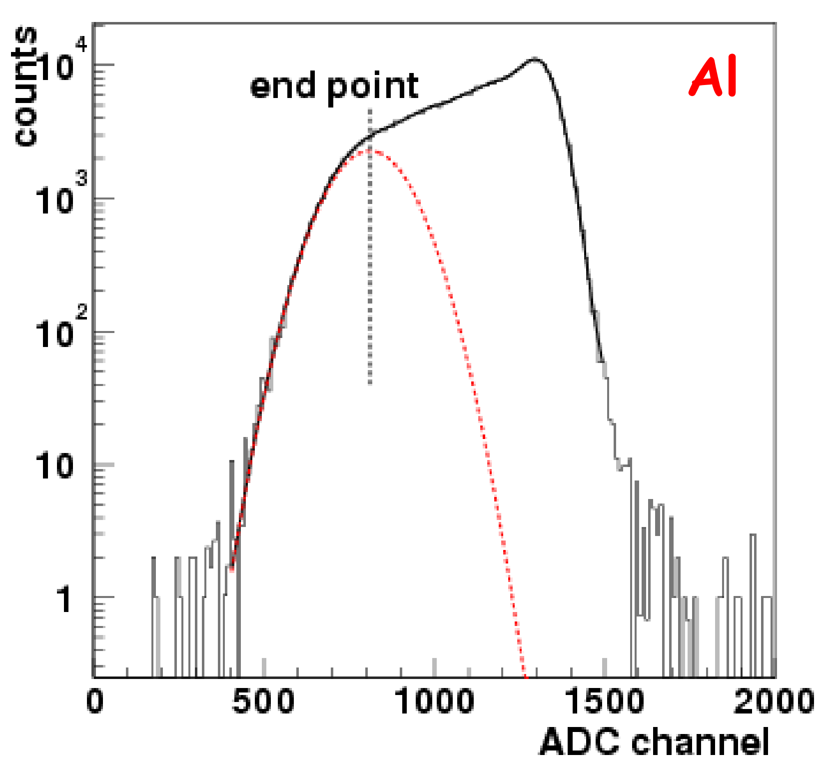
Analysis procedure:

- Removal of non-interacting beam selected by scintillator S3
- Background normalisation and subtraction
- Fit of the spectra with a folding of a finite number of gaussian distributions: the end point of the spectrum has been taken as the mean value of the gaussian at the lowest energy
- Calculation of the energy per participant from the end point of the **Sn** spectrum
- Correction for the participant energy for all the targets

ZN2 beam test results:

linearity as function of number of spectators (3)





for central collisions ^{115}**In** + ^{119}**Sn**

N_{part}=115   and N_{spec}=0

$E_{part} = E_{zdc}(e.p.) / 115$

$E_{spec} = 0$

for central collisions ^{115}**In** + ^{27}**Al**

N_{part}= 59   and N_{spec}= 56

$E_{spec} = E_{ZDC}(e.p.) - N_{part}\, E_{part}$

where E_{part} is found with the Sn target

ZN2 beam test results:
linearity as function of number of spectators (4)

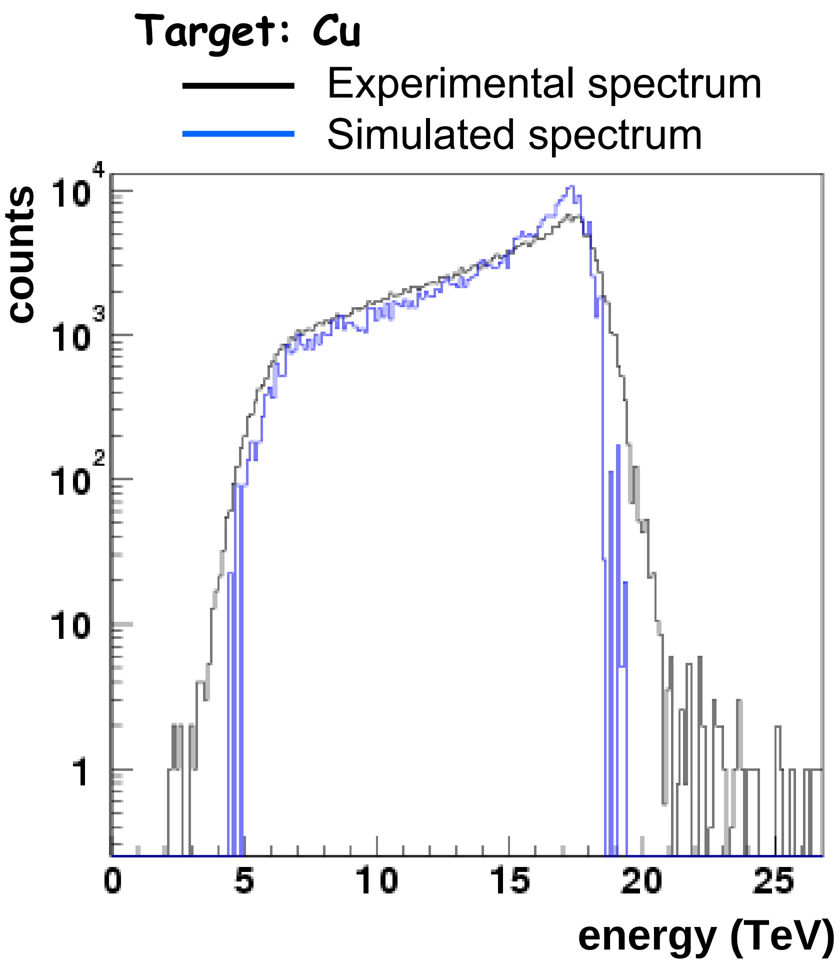
Comparison with simulated data

Monte Carlo simulations of the ZN2 test with ^{115}In beam are performed with **GEANT3.21**:

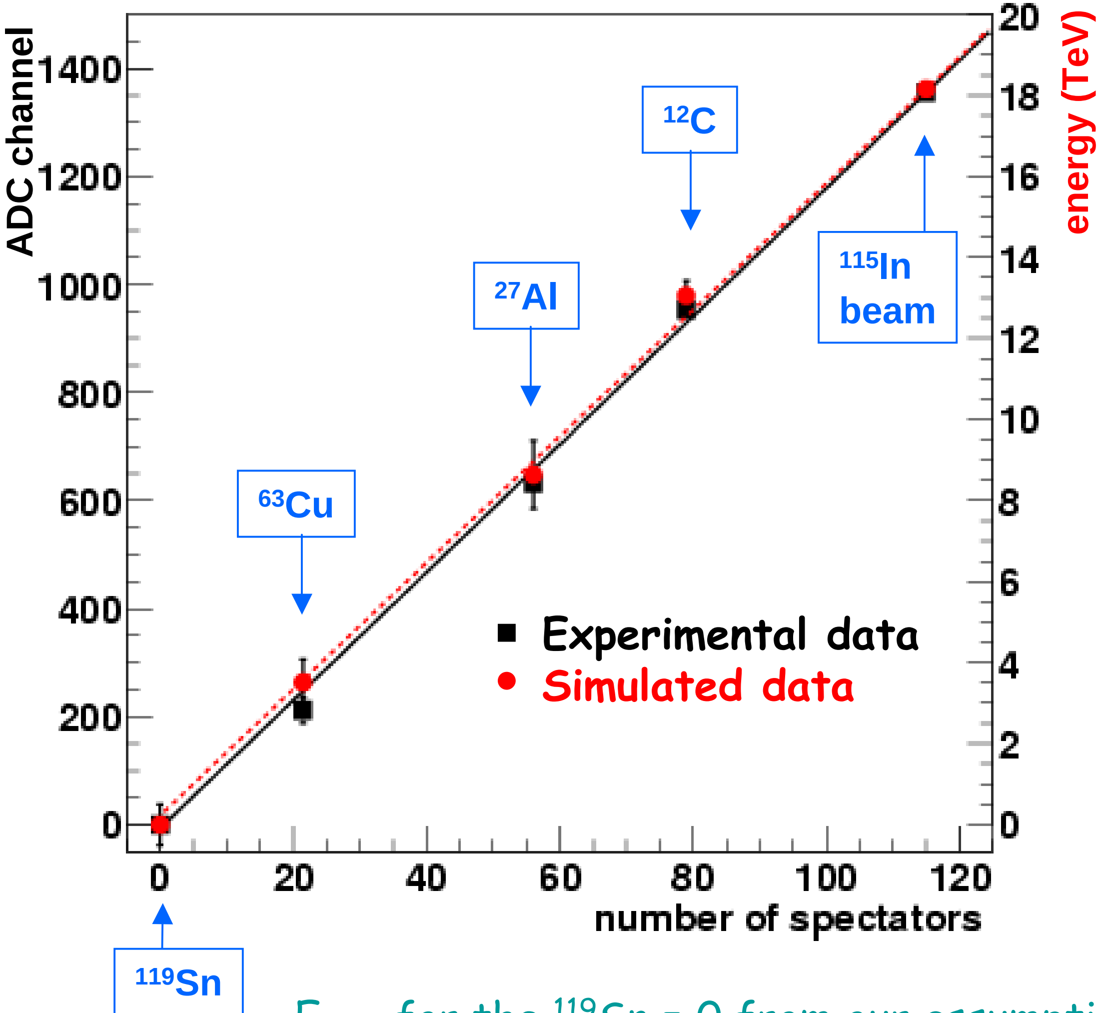
- the nucleus-nucleus interaction is simulated using Fritiof code
- the spectator nucleons are passed to a routine which eventually form nuclear fragments
- the produced particles and nuclear fragments are tracked by GEANT
- experimental resolution has been introduced according to N independent nucleons approximation:

$$\frac{\sigma_E}{E} = \frac{\sqrt{N\sigma_n^2}}{NE_n} = \frac{\sigma_n}{\sqrt{N}E_n}$$

using in this formula, for the single nucleon resolution, the data from test with pions at 150 GeV.



ZN2 beam test results:
linearity as function of number of spectators (5)



E_{spec} for the ^{119}Sn = 0 from our assumptions

$E_{spec} = E_{ZDC}(e.p.) – N_{par}E_{par}$ as a function of number of spectators for all the targets

Data analysis shows a linear behavior of the ZN response as function of the number of incident nucleons.

Approximations:

1. Calculation of N_{spec}
2. Evaluation of E_{part}
3. Determination of end point of E_{zdc} spectrum

Conclusions

Results of the test show:

- For the **Proton Zero Degree Calorimeter**:
  - Signal proportional to the beam energy for electrons
  - Linear behavior as a function of π^- beam energy in the range from 50 to 180 GeV
  - Energy resolution extrapolated to the energy of the **single** spectator nucleon in ALICE (2.7 TeV) is **~ 10%**
  - Sampling frequency adequate for hadronic calorimetry

- For the **Neutron Zero Degree Calorimeter**:
  - Energy resolution for 158A GeV ^{115}In is less than 3% (at energies comparable to central collisions in ALICE)
  - Linear behavior as function of number of incident nucleons

ZDC detectors fulfill the requirements of the ALICE experiment for the determination of event centrality