Know-How of Torino's group

The Torino group has experience in the construction and operation of

- Zero Degree Calorimeters (ZDC)
  - → to measure the centrality of the collisions
  - → used in the NA50/NA60/ALICE experiments

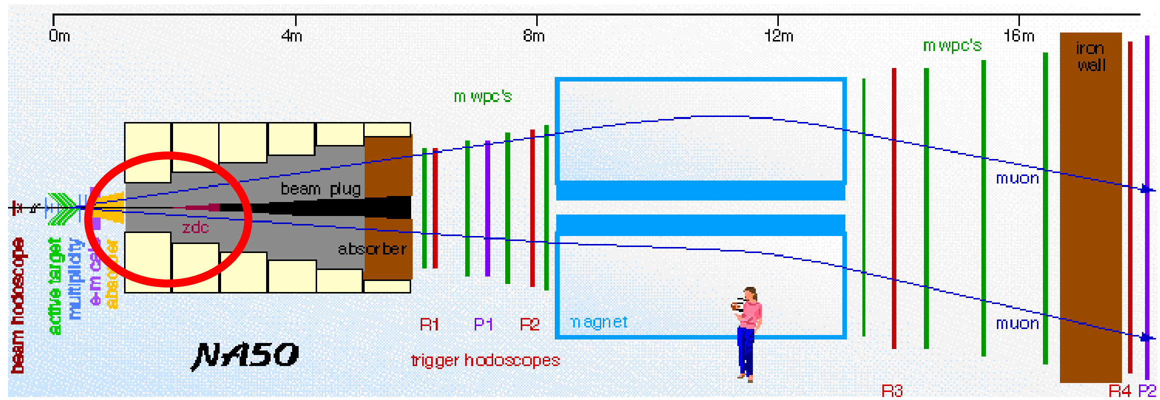
- Resistive Plate Chambers (RPC)
  - → trigger detector for muons
  - → used in the Muon Spectrometer of the ALICE experiment

Zero Degree Calorimeters

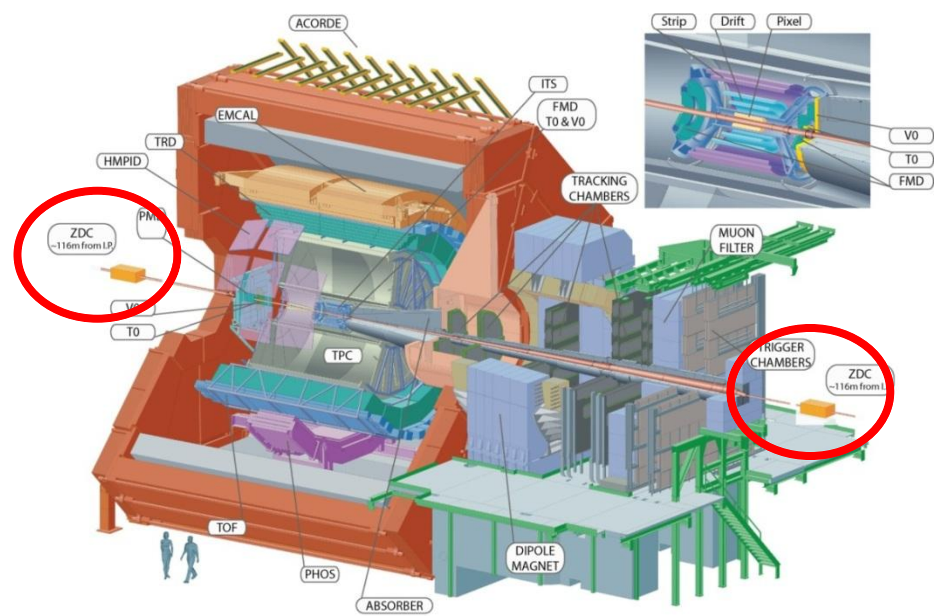
Adopted both at fixed target and at collider experiments to measure the centrality of the collisions

- Fixed target experiments:
  NA50, NA60

Nuclear Instruments and Methods in Physics Research A411 (1998) 1



- Collider experiment:
  ALICE

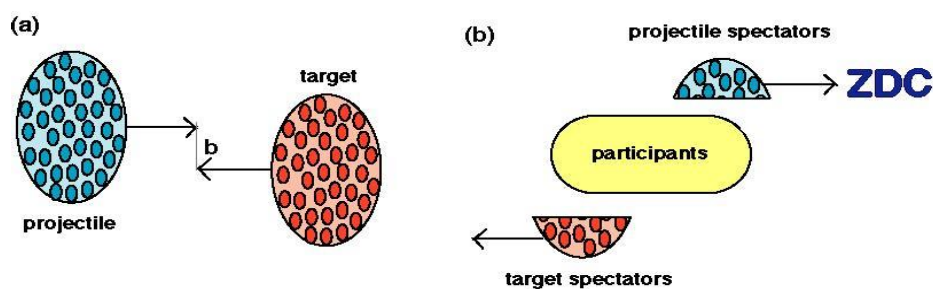


ALICE coll., 2008 JINST 3 S08002

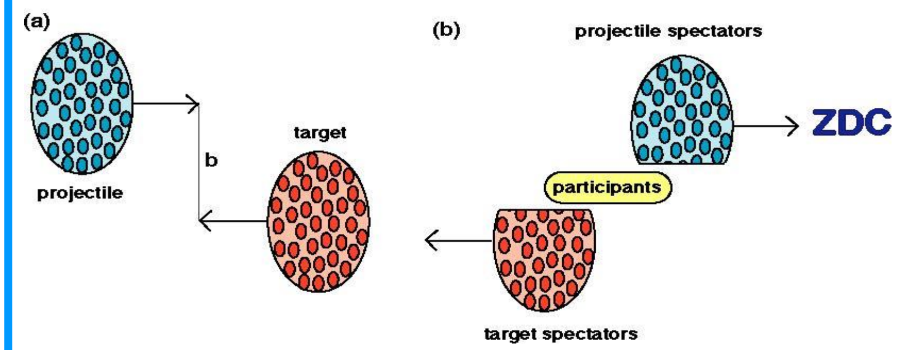
Centrality measurement in HI collisions

Main aim of the ZDCs: centrality measurement in HI collisions, through the detection of the energy carried by spectator nucleons emitted at 0°
→ Observable directly related to the geometry of the collisions

central collisions



peripheral collisions



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

→ Small amount of energy in the ZDC

- Large impact parameter b
- Small number of participants
- Low energy density

→ Large energy in the ZDC

If all the spectator nucleons are detected, E_{ZDC} provides a direct estimate of the number of participants

$$E_{ZDC} \sim E_A \times N_{spec} \quad \Rightarrow \quad N_{part} = A - N_{spec} = A - E_{ZDC}/E_A$$

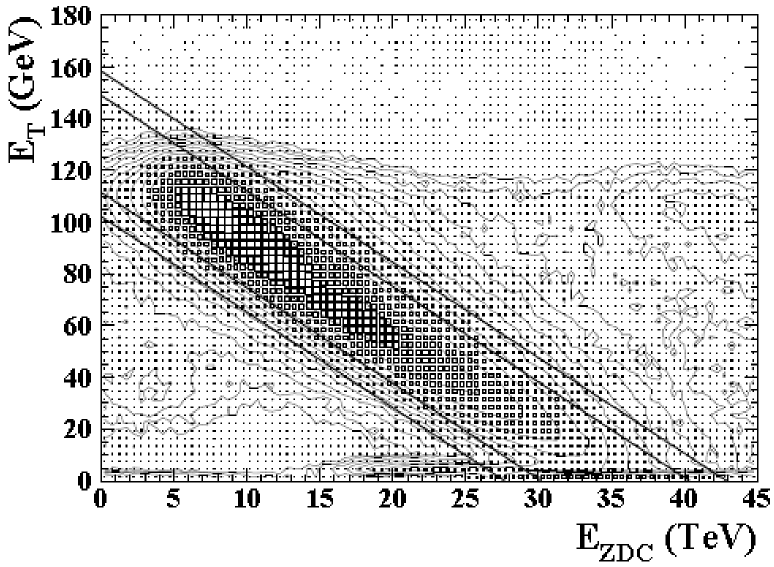
where A is the mass number of the ion and E_A is the beam energy per nucleon

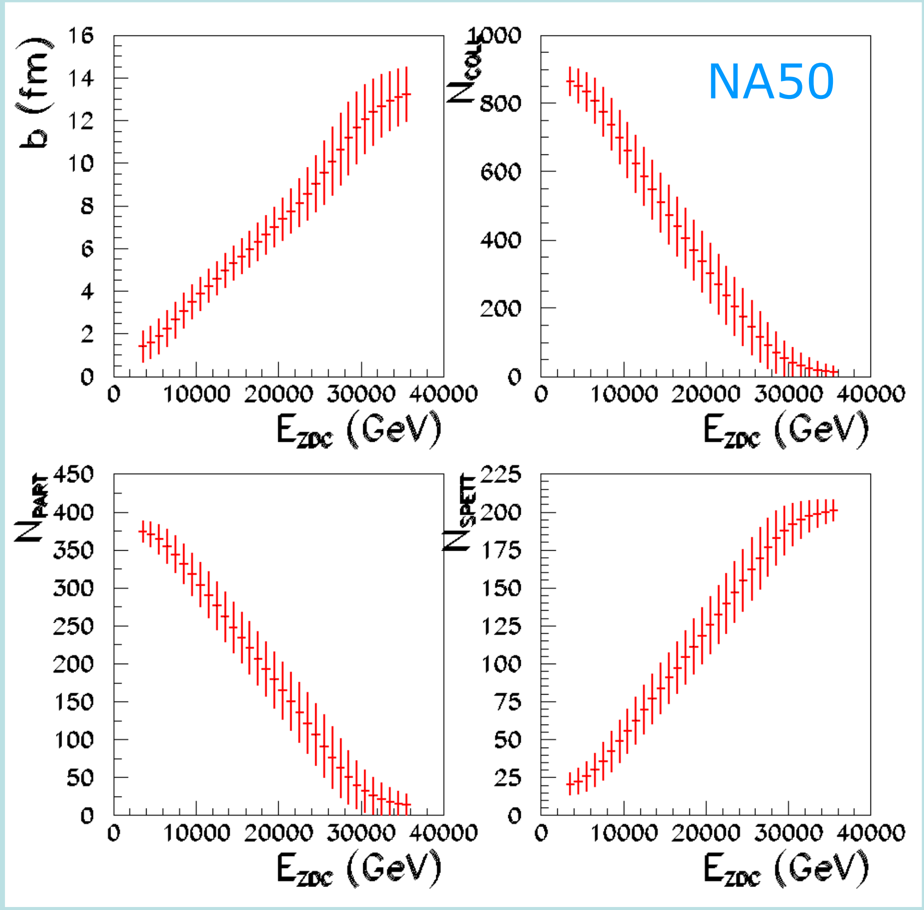
Centrality measurement – fixed target

Fixed target experiments

- Monotonic correlation between E_{ZDC} and the centrality related variables

- Correlation with other centrality detectors used in the analysis to clean the event sample

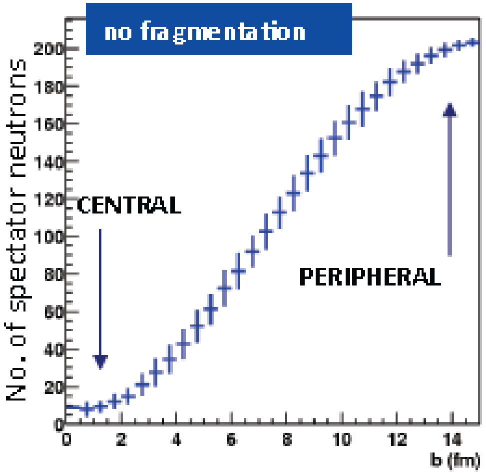


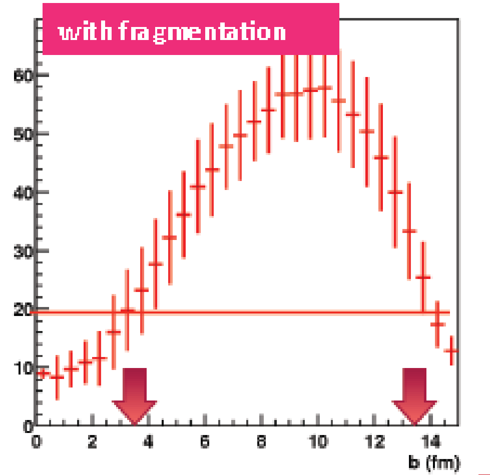


Centrality measurement - colliders

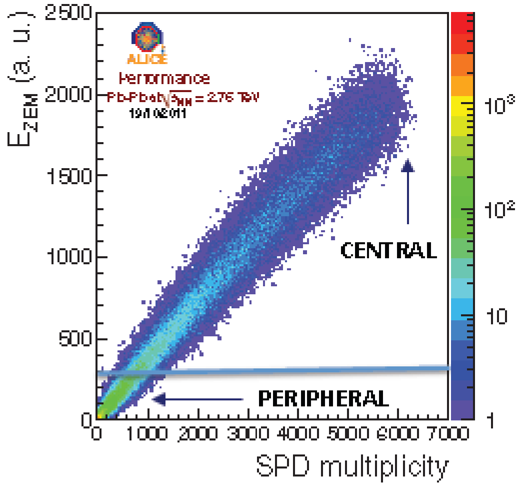
- In HI collisions, nuclear fragments are produced
  → At colliders they remain in the beam pipes, having a Z/A ratio very close to the beam one, and they're not detected by the ZDCs

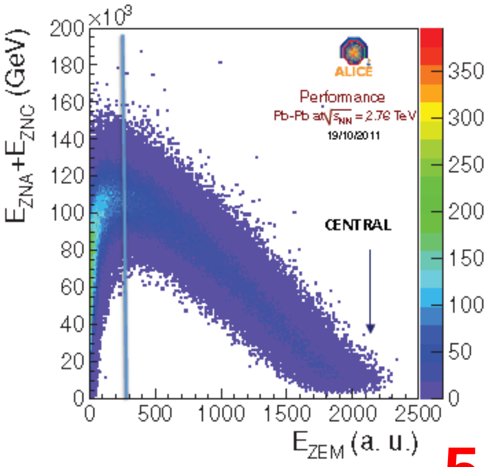
- A very small energy detected in the ZDC may, therefore, correspond to
  → very central collisions
  → peripheral collisions + undetected fragment production





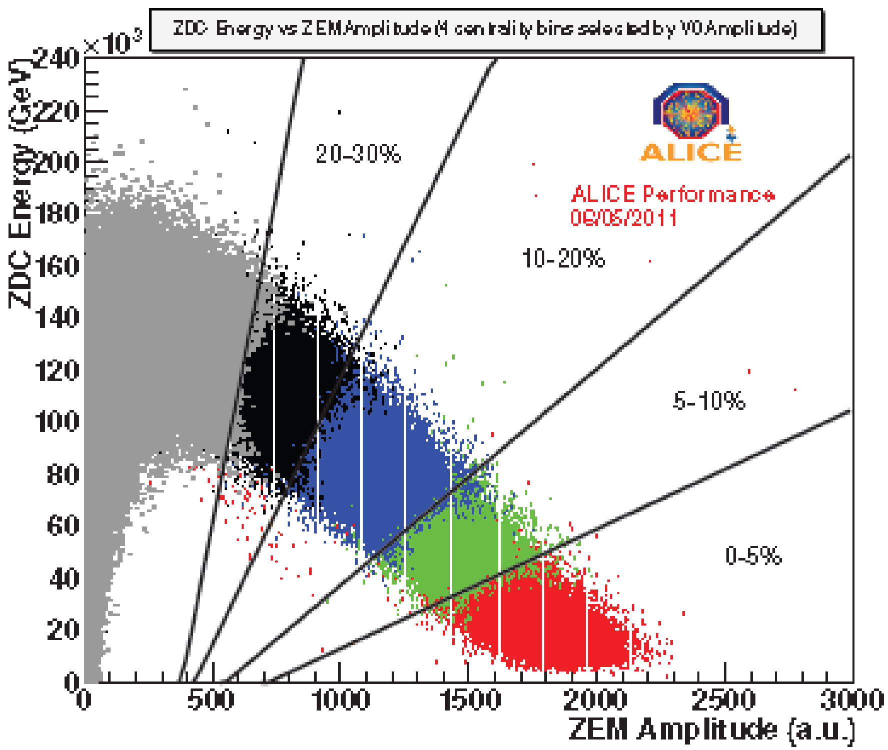
- The information provided by forward electromagnetic calorimeters (ZEM), measuring the forward energy (monotonically increasing with centrality), helps to solve the ambiguity

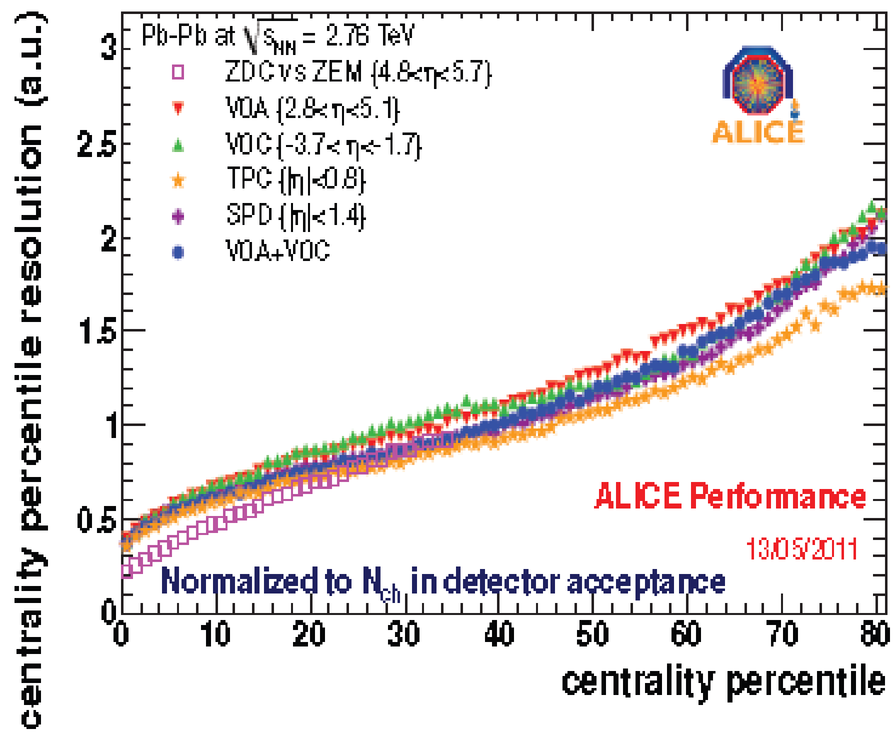




Centrality measurement in ALICE

- In ALICE the centrality can be determined in several independent ways
  - Up to 30-40% centrality percentile, the ZDCs provide a very accurate centrality estimate. Above this value, the uncertainty due to fragment production worsen the resolution



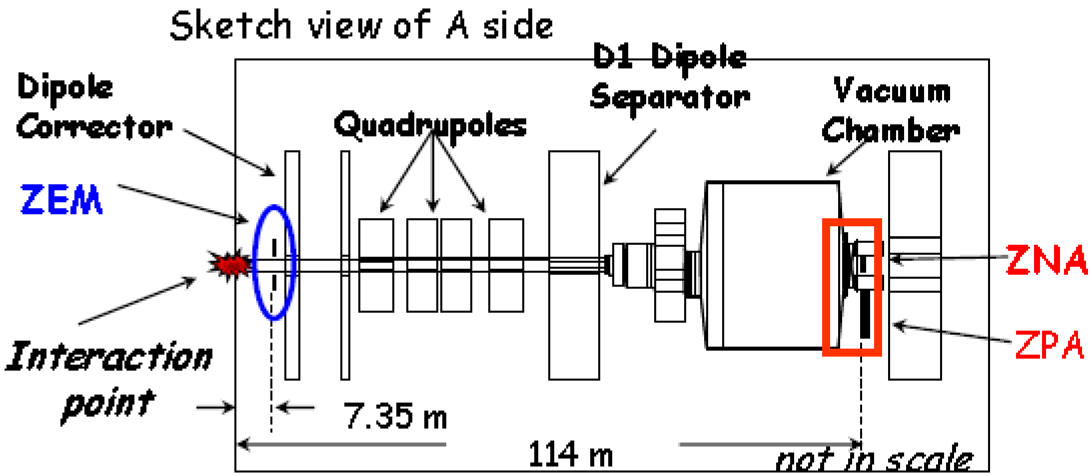


Zero Degree Calorimeters in ALICE

- The ALICE ZDC detector is made of:

- Two sets of hadronic spaghetti calorimeters, located at opposite sides wrt the IP (116m away from it), where the beam pipes are separated Each set consists of 2 calorimeters placed at 0° respect to the LHC axis (protons and neutrons are separated by the magnetic elements of the LHC beam line)
    - 1 for spectator nucleons (ZN)
    - 1 for spectator protons (ZP)

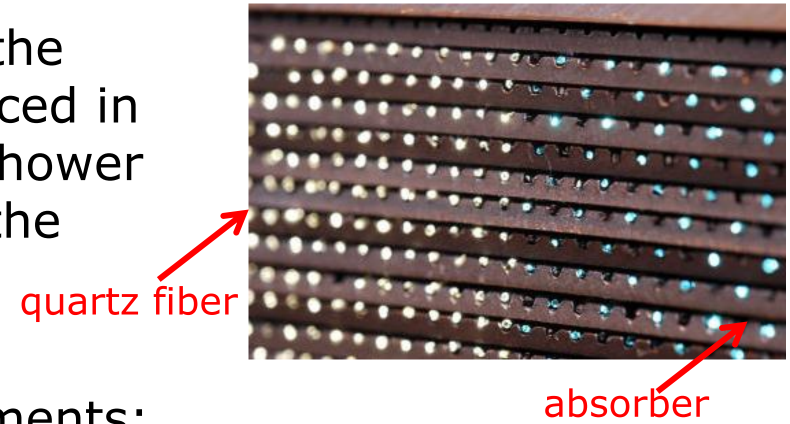
- Two forward EM calorimeters placed ~7m from the I.P., on the left side, covering the range $4.8<\eta<5.7$



Detection technique

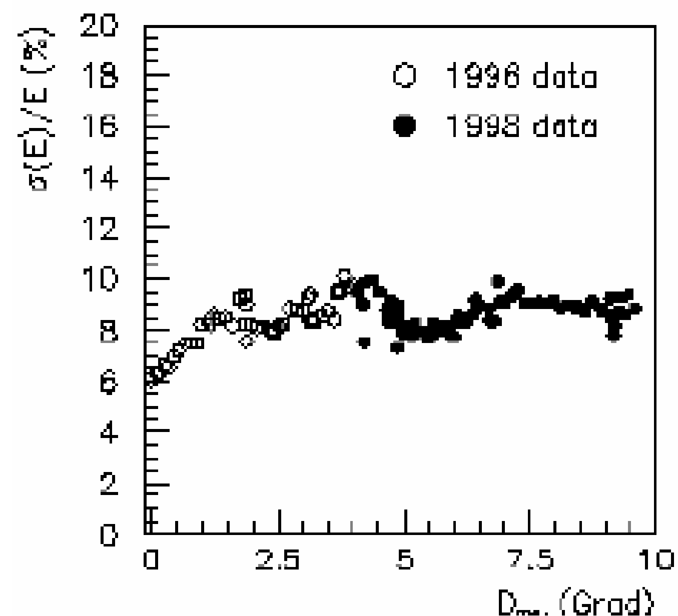
- ZDCs are sampling calorimeters, with silica optical fibers, as active material, embedded in a dense absorber (Quartz fiber calorimetry)

- The principle of operation is based on the detection of the Cherenkov light produced in the fibers by charged particles of the shower induced by spectator nucleons hitting the calorimeter front face



- The technique fulfills the ALICE requirements:

  - Reduced transverse size of the detectable shower → compact detectors
  - Signal width < 10ns → fast response
  - Quartz fibers → high resistance to radiation (good behaviour of the ZDC in the NA50 environment, 10 times harsher than the ALICE one)

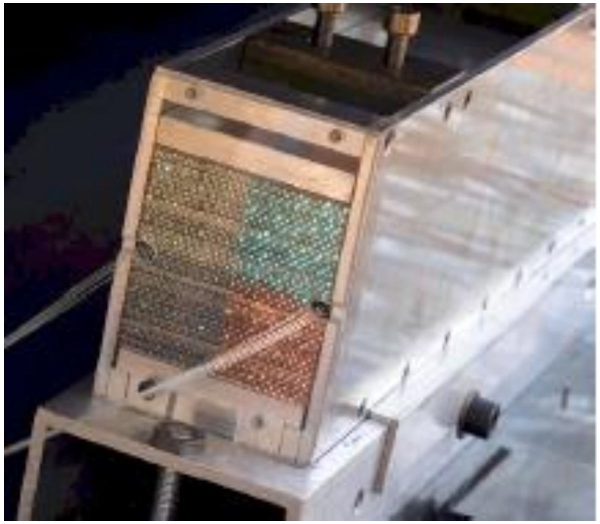


ZDCs for ALICE

The Neutron ZDC (ZN)

- Consists of 44 grooved W-alloy slabs (ρ=17.6 g/cm^3), each of them 1.6 mm thick, stacked to form a parallelepiped (7.2 x 7.2 x 100 cm^3, 8.5 λ_I)

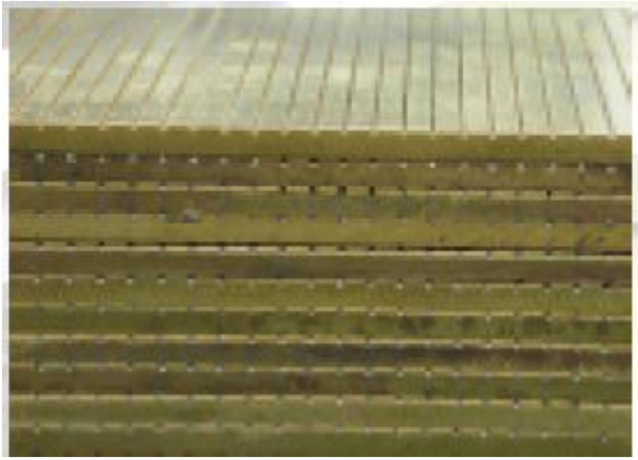
  1936 quartz fibers ($\varnothing$ 365μm), embedded in the absorber with a pitch of 1.6 mm



The Proton ZDC (ZP)

- Consists of 30 grooved brass slabs (ρ=8.48 g/cm^3), each of them 4 mm thick, stacked to form a parallelepiped (22.8 x 12 x 150 cm^3, 8.4 λ_I)

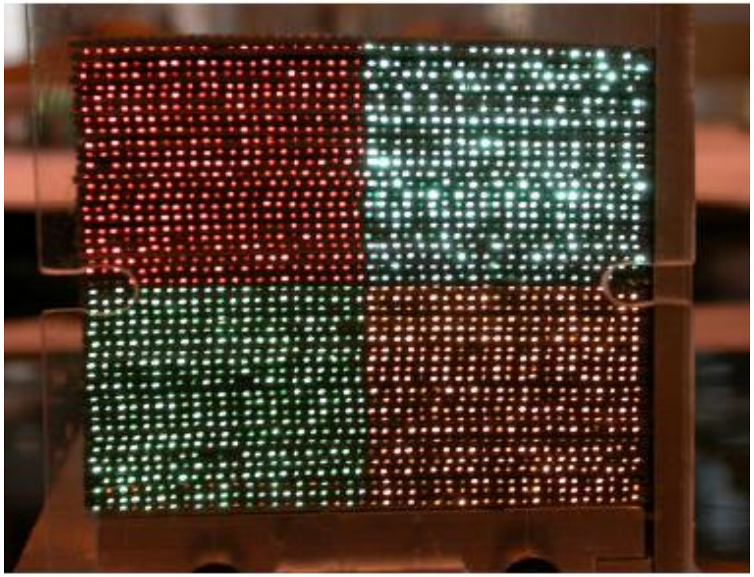
  1680 quartz fibers ($\varnothing$ 550μm), embedded in the absorber with a pitch of 4 mm



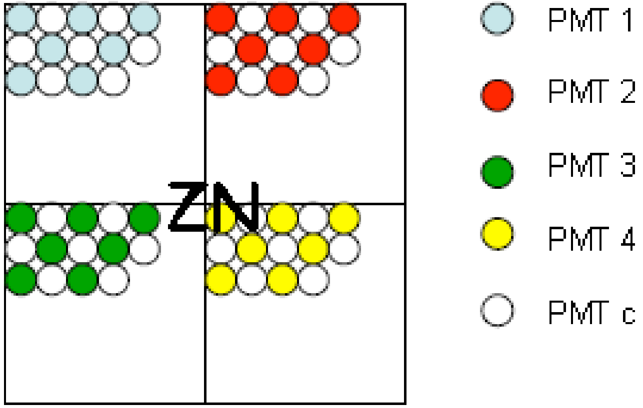
ZDCs readout segmentation

- The fibers are placed at 0° with respect to the beam line, and come out from the rear face of the calorimeter, bringing lights to the PMTs.

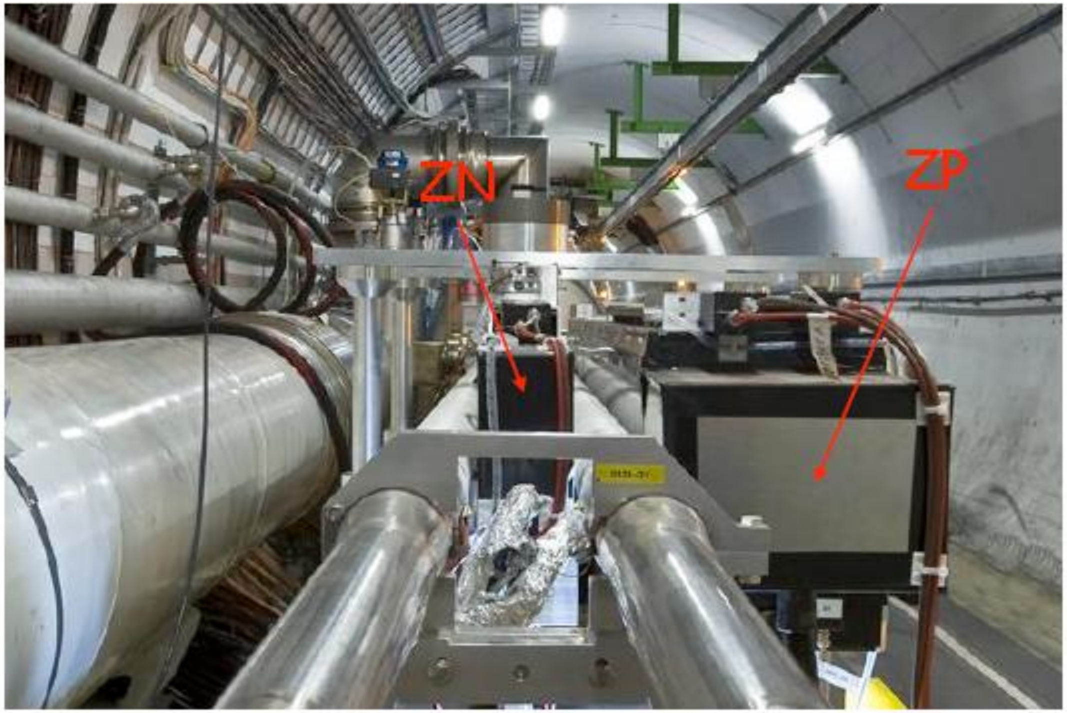
- One out of two fibers is sent to a common photomultiplier, while the remaining fibers are collected in bundles and sent to four different PMTs



Fibers connected to different PMTs are lighted in different colors

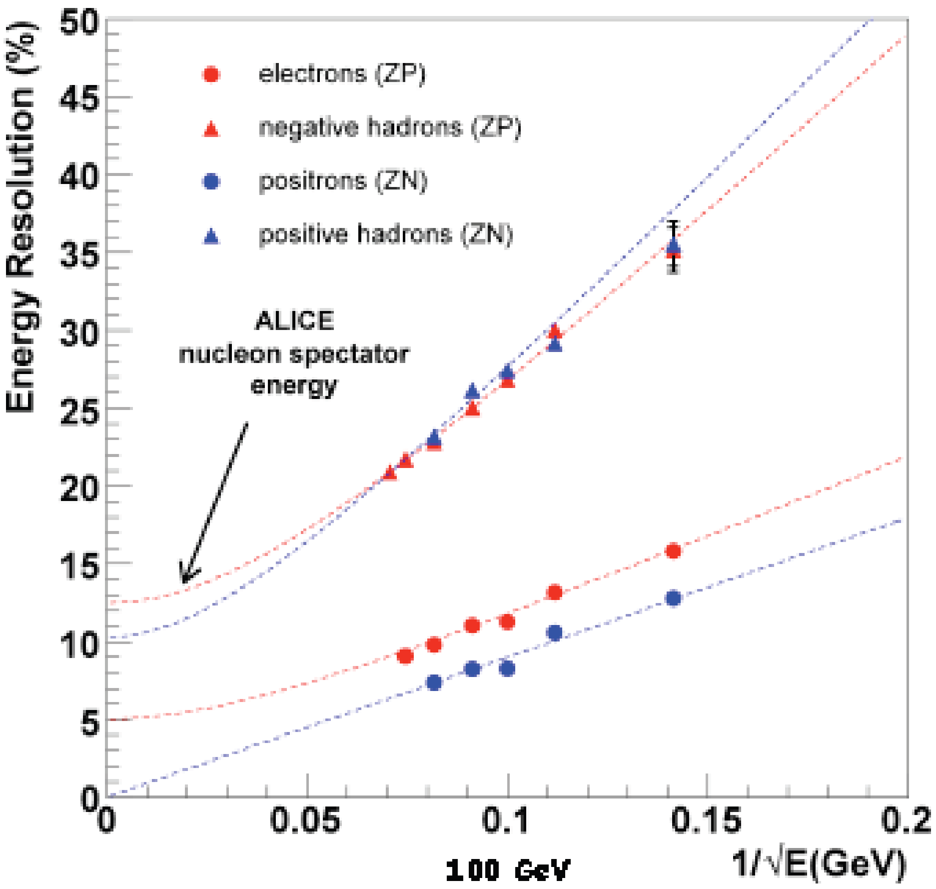


ZDCs installation in the LHC tunnel



ZDCs performances

Energy resolution:
The ZDC physics performances are related to the resolution on the number of spectators nucleons, which depends on the ZDCs energy resolution



From tests done with hadron beams the SPS, the expected resolution at LHC energy is:

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

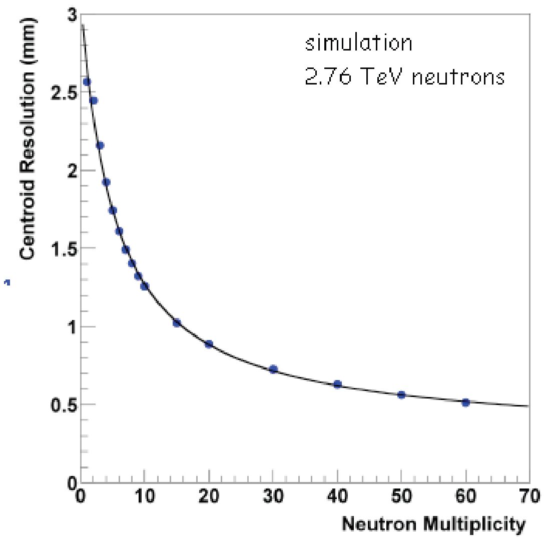
ZN ~ 11.4%
ZP ~13%

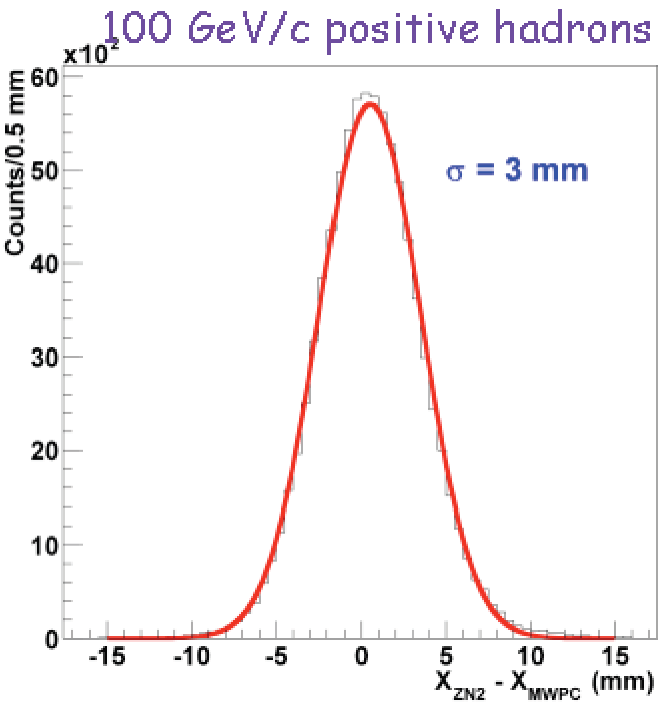
ZDCs performances (2)

Thanks to its segmentation, ZN can also measure the position of the centroid of the incoming spectator nucleons, allowing:

- the monitoring of the beam crossing angle
- the determination of the event plane

The resolution on the impact point is ~3mm (clearly improving with the neutron multiplicity)





ZDCs as luminosity monitor

- ALICE ZDCs provide an independent monitor of the beam luminosity measuring the rate of neutron emission by EMD processes

$$L = R^{EMD} / \sigma^{EMD}$$

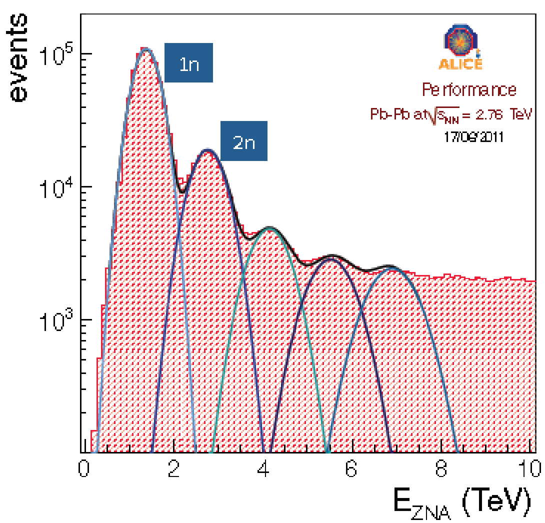
- EM dissociation (EMD) → in ultra-peripheral ($b>2R_{Pb}$) interactions, nuclei interact via long range EM forces

- Cross sections from EM processes at LHC exceeds hadronic σ value by order of magnitude (σ^{had}~8b, σ^{EMD}~226 b)
  → Limit to heavy-ion beam lifetime

- EM interaction can lead to GDR excitation followed by neutron emission
  →dominant channel for heavy nuclei
  →study of EM dissociation with neutron emission

SINGLE EMD: at least 1 nucleus emits at least 1 neutron
MUTUAL EMD: Both nuclei emit at least 1 neutron

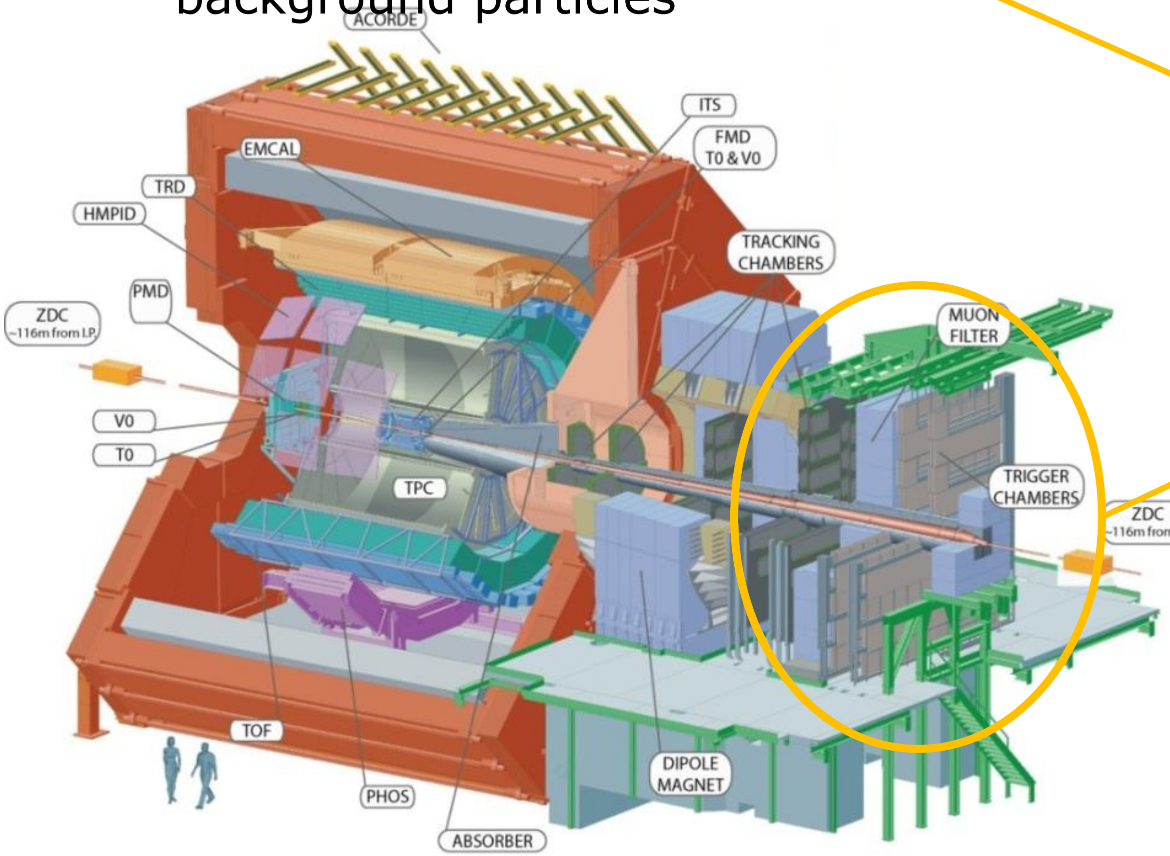
Neutron emitted in EMD process have rapidity close to the beam one
→ detected by the ZNs with 99% acceptance
→ Process can be used to monitor LHC luminosity

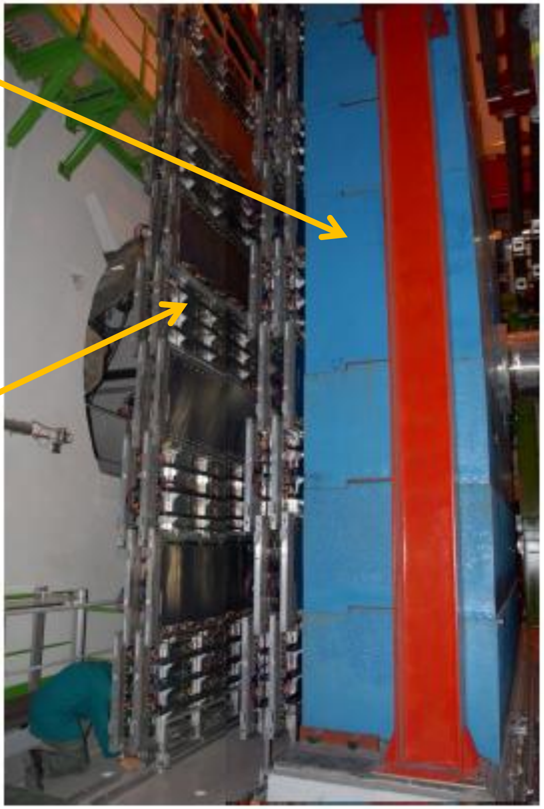


ALICE Muon Trigger System

- The Muon Trigger system of the ALICE experiment is based on Resistive Plate Chambers (RPC)

- Goal: trigger on high p_t muons from heavy flavor and quarkonia decay
- Two stations located after an iron wall to stop low energy background particles





L5

Requirements for ALICE muon trigger

To work in the ALICE environment, the muon trigger detector should fulfill the following requirements:

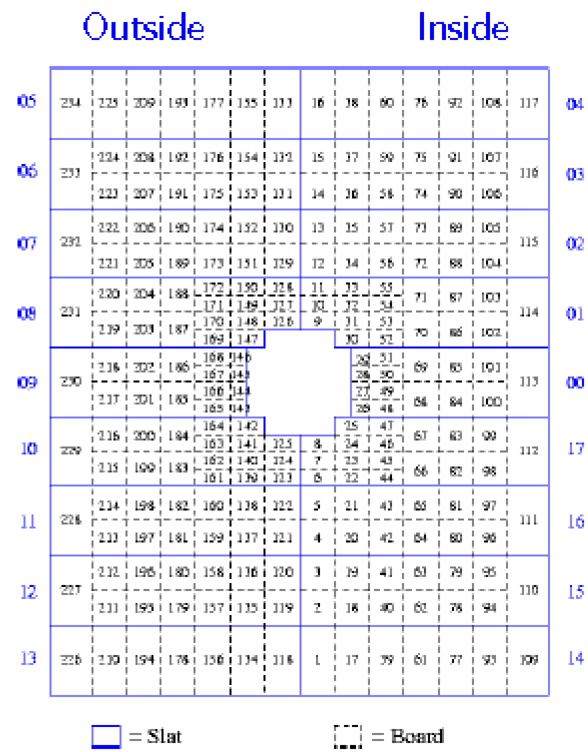
- Muon detection efficiency large on all the detector area (> 95%)
- Rate capability ~ 100 Hz/cm^2
- Fast response ~ 2ns
- Reduced cluster size ~1 (to guarantee trigger selectivity)
- Large area covered
- Ageing resistant

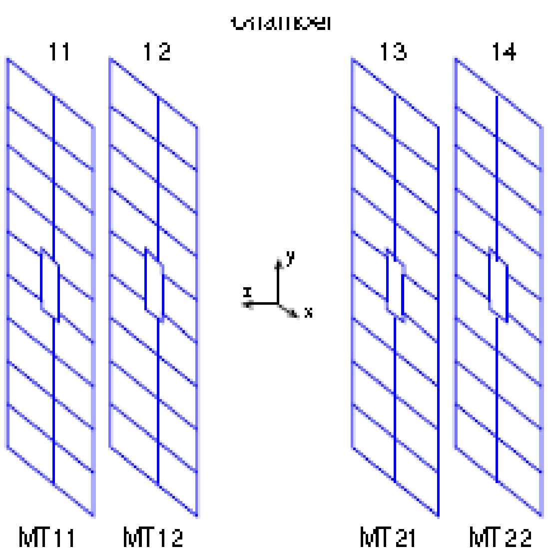
RPCs are well suited for covering large surfaces and offer very good space and time resolutions

ALICE Muon Trigger system

ALICE Muon Trigger system is based on

- 4 planes of detectors arranged in 2 stations of 2 planes each (6x6m^2)
- each plane has 18 RPCs (72 RPCs in total)
- total surface ~140m^2
- stations are located 16-17m away from the interaction point
- 21000 strips (1,2,4 cm pitch) and readout channels



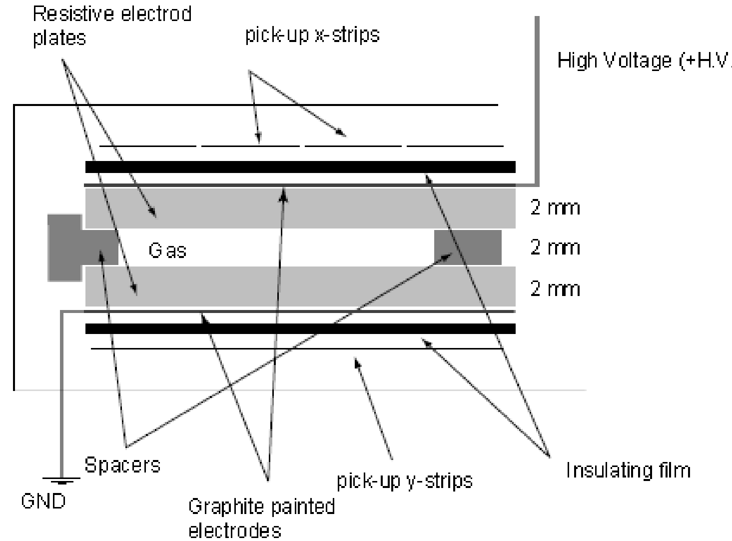


RPC are read on both sides with orthogonal strips:

- Bending plane: measure the y position (⊥ to the magnetic field)
- Non-bending plane: measure the x position (|| to the magnetic field)

The RPC

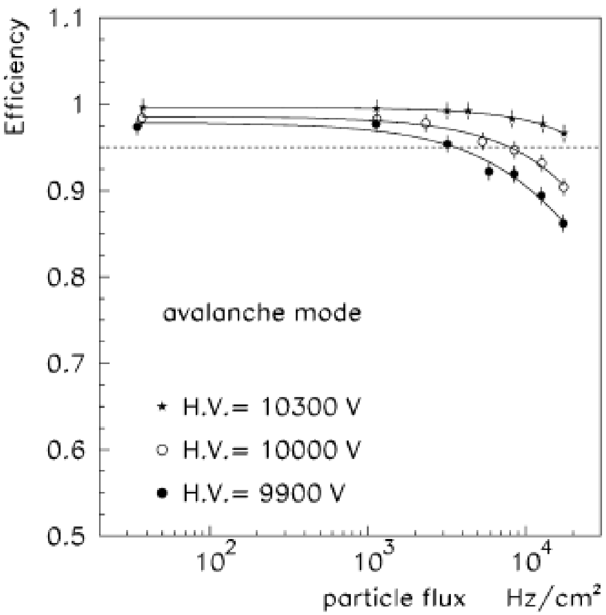
- RPC area: min 72 x 223 cm^2, max 76 x 292 cm^2
- 5 combinations of RPC shape and strip segmentation
- Strip pitch: 1,2,4 cm. Strip length: 17-72 cm
- Single 2mm gap low resistivity bakelite electrodes (ρ~3-9 x 10^9 Ωcm)
- Highly-saturated avalanche mode.
  Gas mixture:
  89.7% $C_2H_2F_4$, 10% i-C_4H_{10}, 0.3% SF_6
  No electronic amplification of the signal
- Operating HV: 10250±100 V

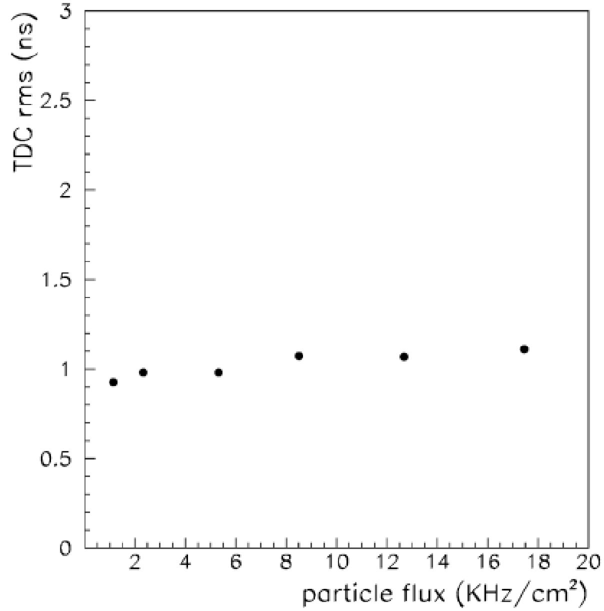


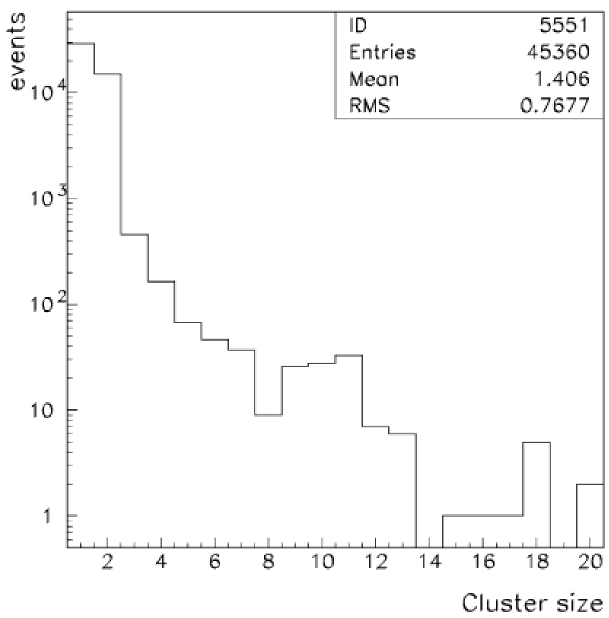
NIM A451(2000) 462,
NIM A533 (2004) 112,
NIM A457)2001)117

R&D RPC performances

RPCs fulfills the required characteristics for the ALICE experiment. From test beam results:







Efficiency: >95% for rate capabilities >1kHz/cm^2

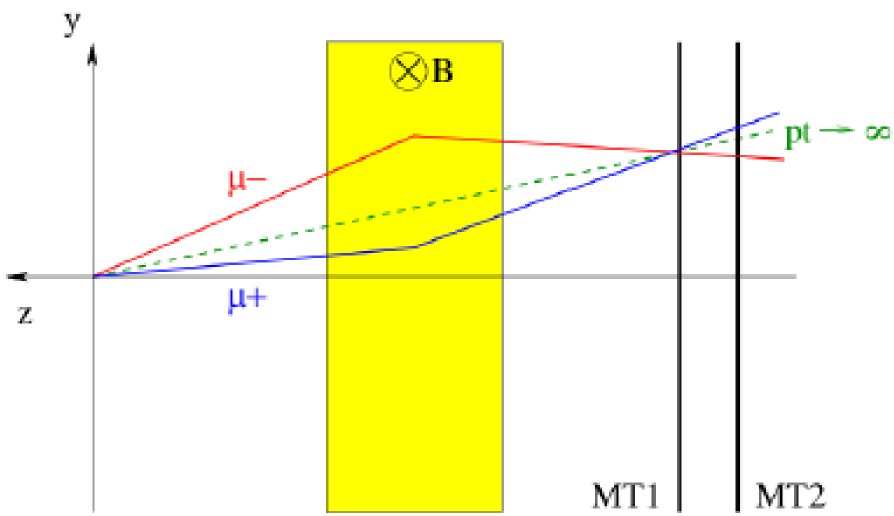
Time resolution: ~1ns up to ~10-20kHz/cm^2

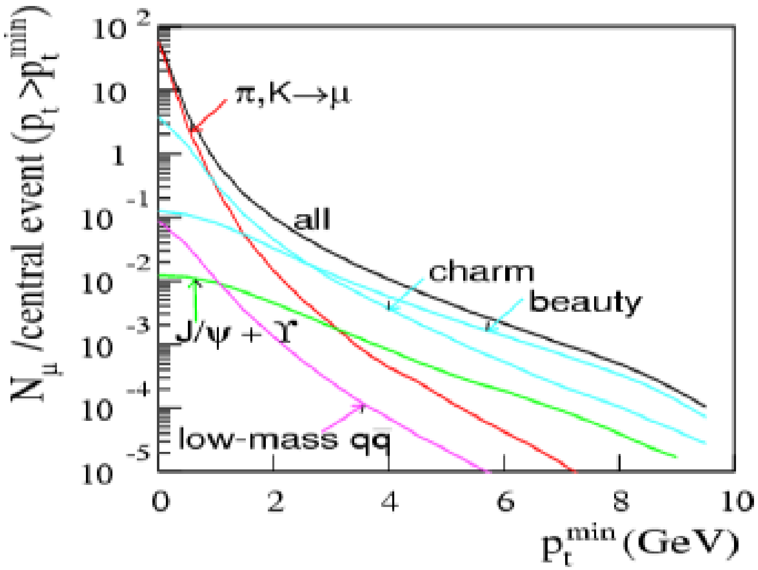
Cluster size: ~1.4

Ageing: test at the CERN GIF have shown that the RPC should "survive" to ~10 years of LHC data taking

Trigger algorithm

A muon p_t cut is needed to reduce the background made of light mesons decay





Trigger algorithm:
Request 3/4 planes hit; the p_t of a track is calculated wrt to an infinite momentum track

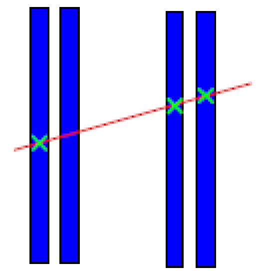
Triggers:

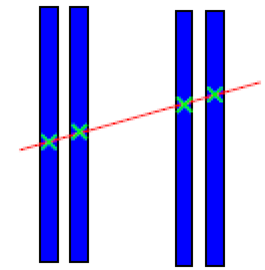
- Two different p_t thresholds can be programmed (e.g. 1 GeV/c and 2 GeV/c)
- Several trigger signals sent to the CTP (Central Trigger Processor): single μ, unlike and like sign dimuons with low and high p_t thresholds

RPC behaviour after 2 years at LHC

Efficiency evaluation:

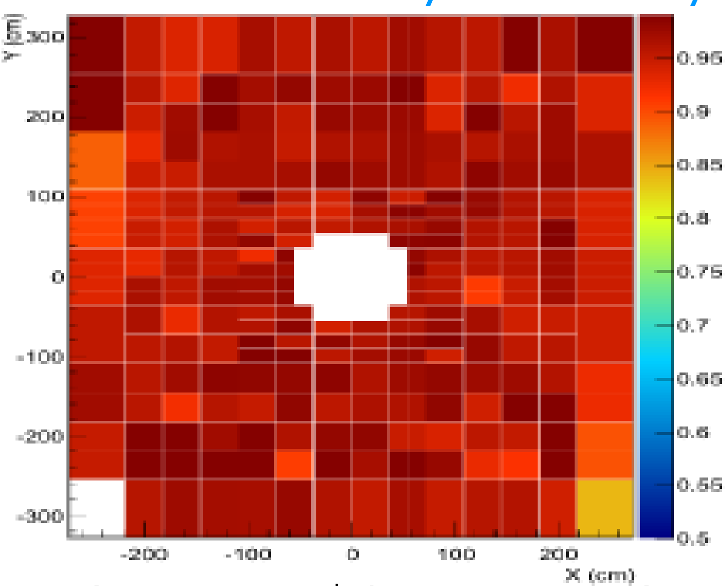
- Based on the redundancy wrt trigger condition (ratio of 4/4 to ¾ coincidences)
- Method allows high granularity efficiency mapping

$N^{12}_{3/3} =$ 

$N_{4/4} =$ 

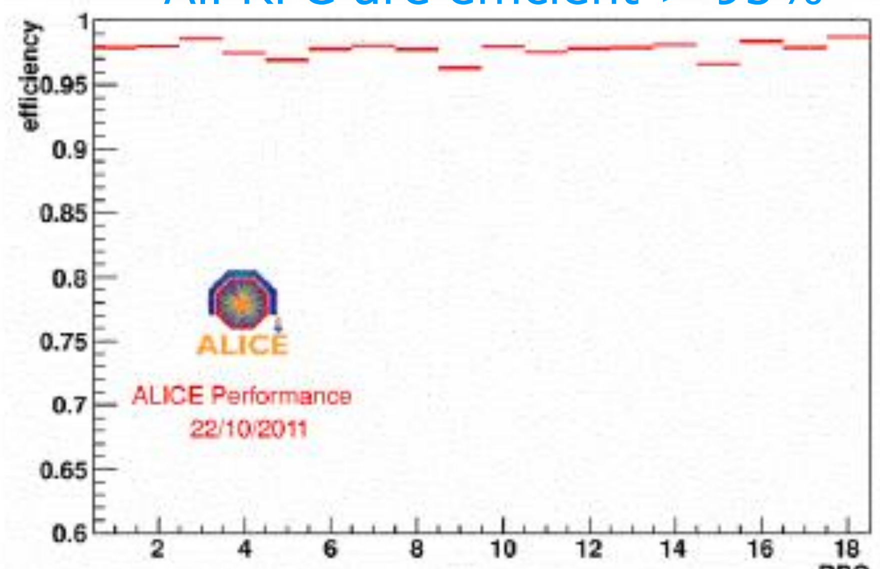
$$\varepsilon_{3} = \frac{N_{4/4}}{N^{3}_{3/3} + N_{4/4}}$$

Good efficiency uniformity



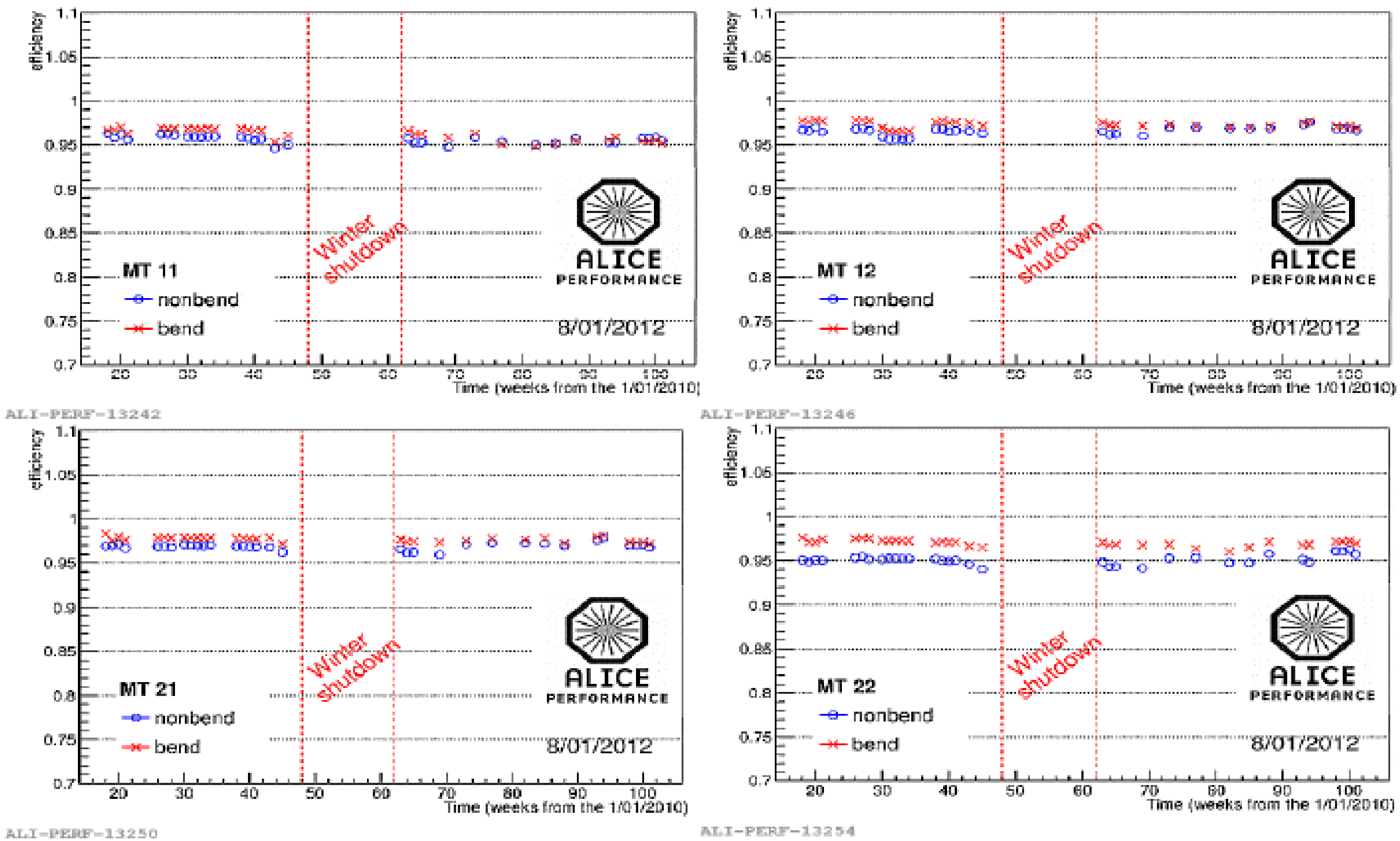
(example: 3rd detection plane)

All RPC are efficient > 95%



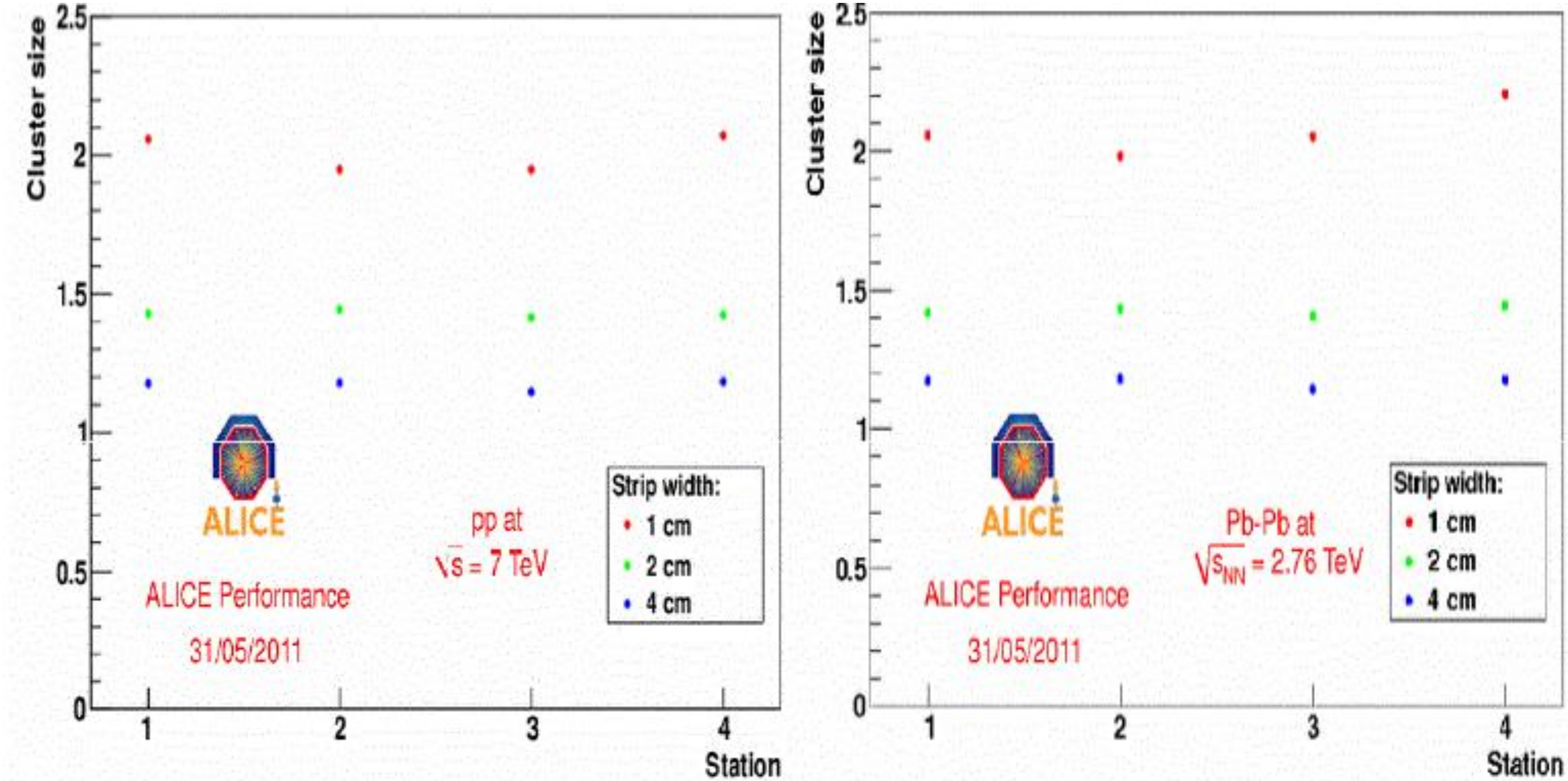
RPC efficiencies: stability in time

Trend of the average efficiencies for the 4 detection planes (18 RPC per plane)



Average efficiency ~95% (stable within ~0.5% after two years of data taking)

Cluster size

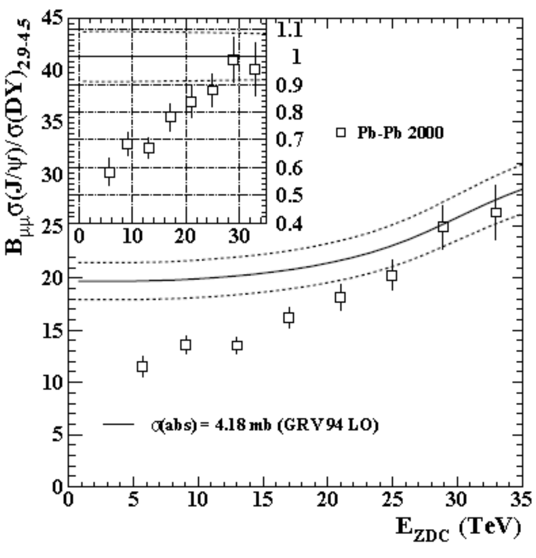


- Average cluster size with 2 cm strips ~ 1.40
- Results from R&D ~1.3
- No difference between pp and PbPb

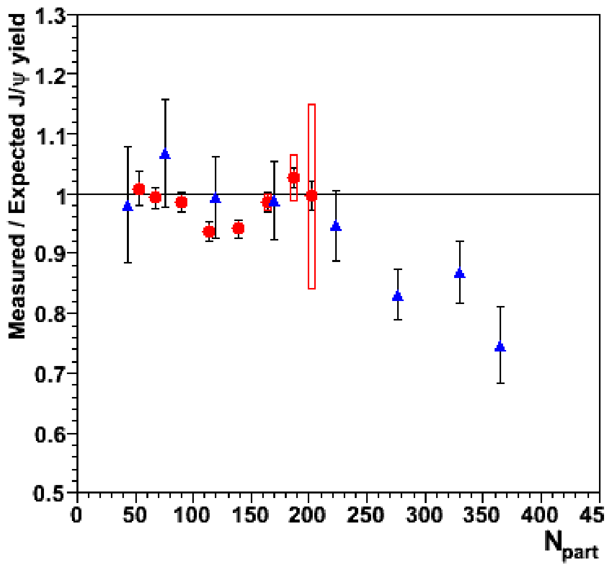
Conclusions

- Both ZDCs and RPCs are playing a crucial role in toward physics results!
  - ALICE results on quarkonium and single muon from heavy flavour strongly rely on the MUON trigger
  - The ZDC has been fundamental as centrality estimator already in NA50 and NA60 and now also in ALICE!

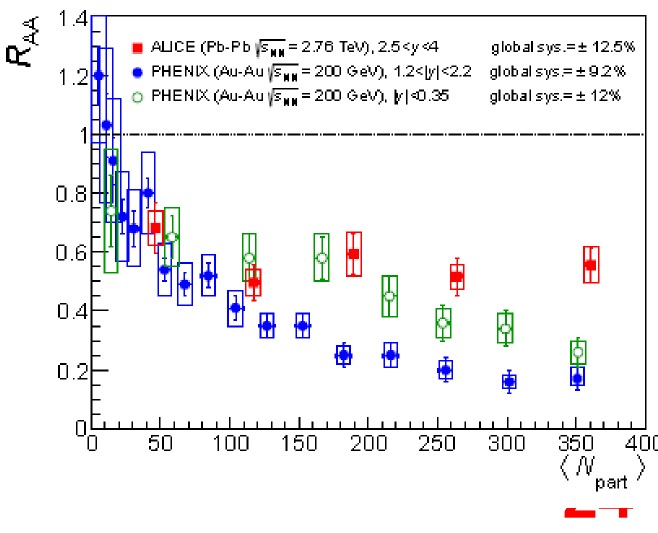
NA50



NA60

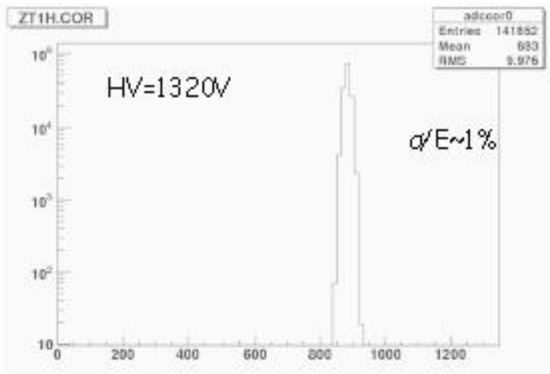


ALICE



Backup

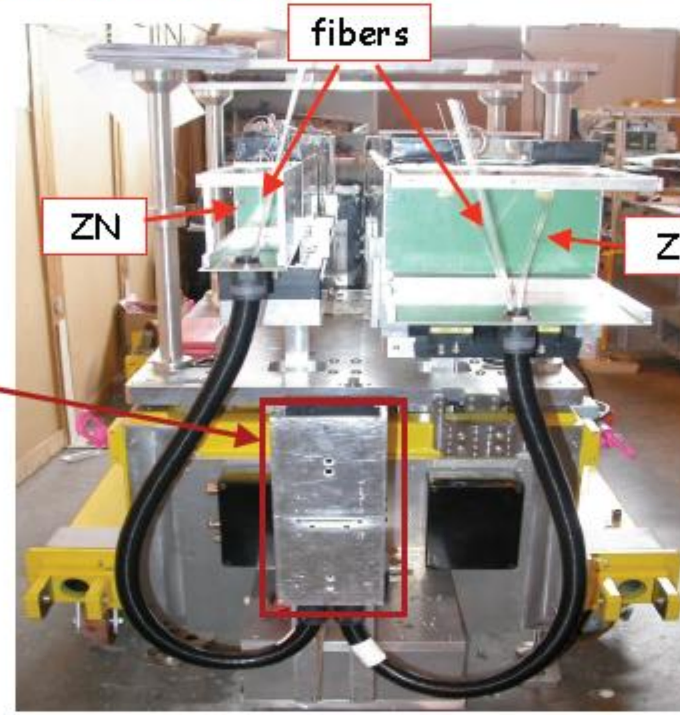
ZDCs Stability Monitoring (1)



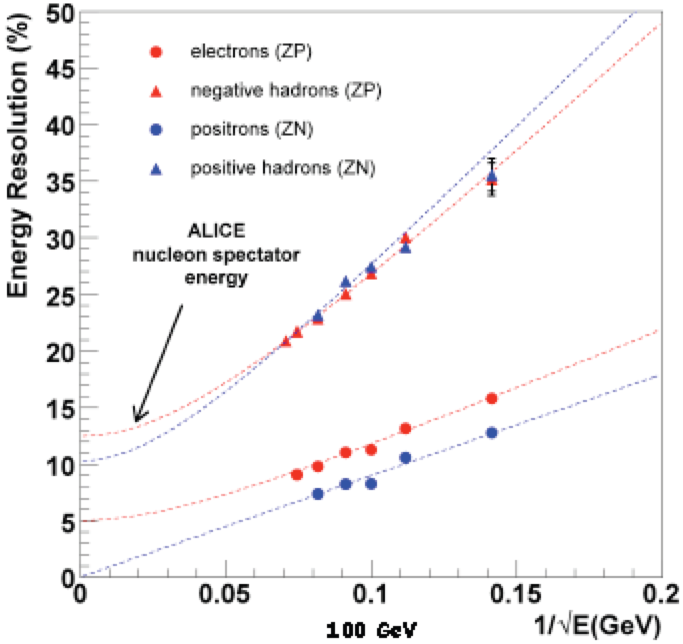
- Pulsed light from a Laser Diode

-> (PMT + fibers) radiation damage monitoring with an accuracy of 1%

Laser Diode (λ=405nm, pulse width=70ps)



Energy resolution



The black line are the results of the fit:

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

For positrons(ZN) /electrons(ZP)

ZN: a = (89.9 ± 0.7) % GeV$^{1/2}$, b = (0.0±2.9) %

ZP: a = (106.8 ± 0.9) % GeV$^{1/2}$, b = (5.±0.3) %

For positive hadrons(ZN) /negative hadrons(ZP)

ZN: a = (256.6 ± 2.9) % GeV$^{1/2}$, b = (10.3±0.6) %

ZP: a = (237.0 ± 2.) % GeV$^{1/2}$, b = (12.5±0.2) %

Extrapolation to 2.7 TeV hadrons

(ALICE spectator nucleon energy in Pb-Pb interactions)

ZN: $\frac{\sigma(E)}{E} \approx 11.4\%$ ZP: $\frac{\sigma(E)}{E} \approx 13\%$

comparable to the spectator energy fluctuations

ZN response to 158A GeV/c ^{115}In beam: $\frac{\sigma(E)}{E} \approx 2.8\%$ to be compared to $\frac{1}{\sqrt{115}} \frac{\sigma(E)}{E}\Big|_{E=150} \approx 2.2\%$

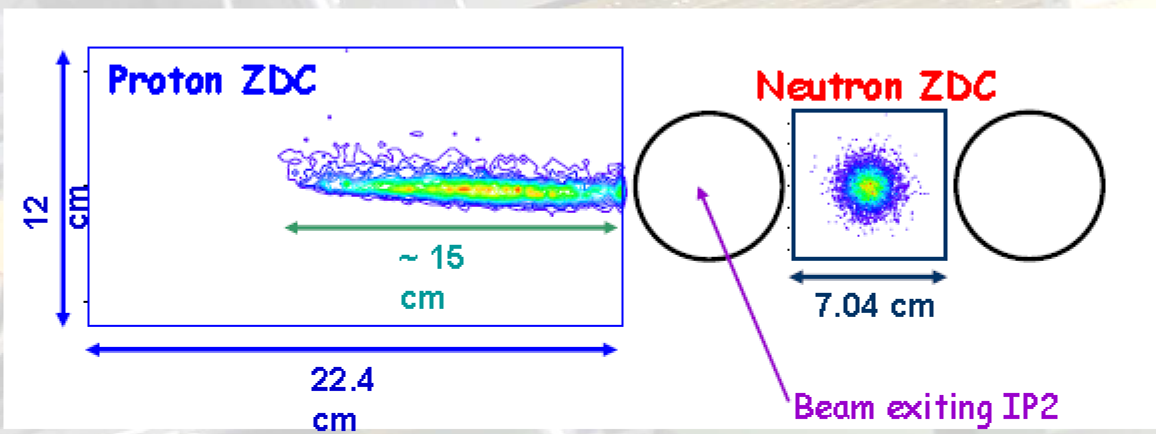
ZDCs' acceptances

Due to Fermi motion boosted by Lorentz transformations, **the spread for the longitudinal momentum of spectators**, is about 500 Gev/c.

The momentum spread of spectator protons results in a large horizontal dispersion after separator dipole D1, and some of them are lost along the beam line.

Spectator protons distribution over ZP front face is enlarged: 90% of detected protons hit a $12.6 \times 2.8\ cm^2$ area.

For the spectator neutrons only the transverse component of the Fermi momentum plays a role in determining the size of the spot at the ZDC location, which is of the order of $0.6 \times 0.6\ cm^2$ at $1\ \sigma$ level. No losses of neutrons are expected along the beam line.



ZDC physics issues

The ZDCs estimate the centrality of the ion-ion collision by measuring the energy carried away by the non-interacting nucleons (spectators). A dipole magnet separates the spectator protons from the ion beams.

during H.I. runs:

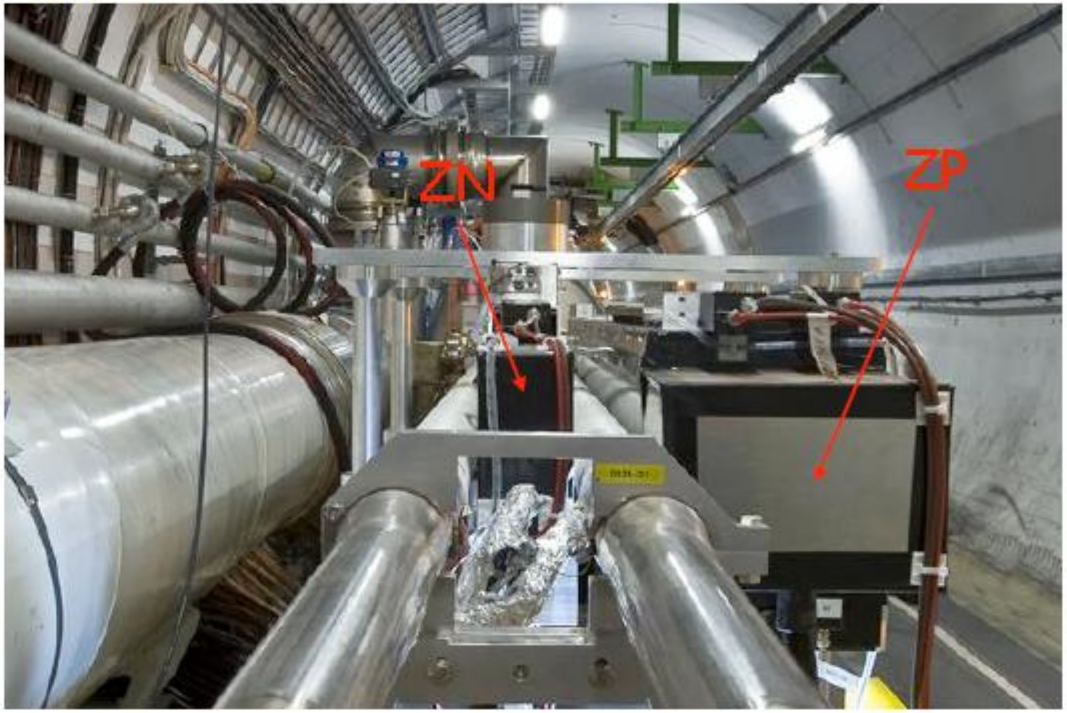
- Centrality of the collision
- Absolute luminosity

during pA runs:

- Centrality of the collision
- Relative luminosity

during pp runs:

- ~15% acceptance for diffractive protons



EM DISSOCIATION (EMD) ➡ in ultra-peripheral ($b \geq 2R_{Pb}$) interactions nuclei interacts via long-range EM forces

Weizsäcker-Williams framework ➧ interaction with equivalent photons (flux αZ^2)

Cross sections for EM processes at LHC energies exceeds hadronic cross section value by orders of magnitude ➧ for Pb-Pb @ 5.54 A TeV: σ^{had}~8 b, σ^{e+e-}~281b, σ^{EMD}~226 b

➧ limit to heavy ion beam lifetime [R. Bruce *et al.*, Phys.Rev. 12 071002 (2009)]

EM interaction can lead to:

- nucleus excitation followed by break-up
- GDR excitation followed by neutron emission ➧ dominant channel for heavy nuclei

➡ Study of EM dissociation with neutron emission

Definitions:

SINGLE EMD ➡ AT LEAST 1 nucleus emits AT LEAST 1 neutron

MUTUAL EMD ➡ BOTH nuclei emit at least 1 neutron

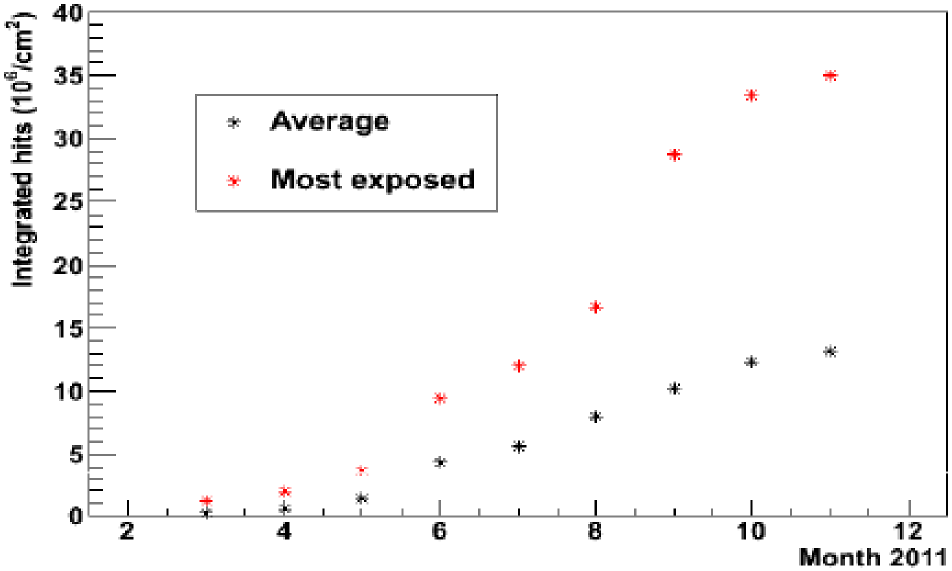
Neutrons emitted in EMD processes have a rapidity close to the beam one

➧ detected by the ZNs with 99% acceptance

➧ the process can be used to monitor LHC luminosity

RPC behaviour after 2 years at LHC

RPC behaviour after two years of data taking in the ALICE experiment



Integrated hits so far:

13 Mhit/cm^2 on average

35 Mhit/cm^2 on the most exposed RPCs

Detectors have been ageing-tested up to 550 Mhit/cm^2