# Measurements of the Lorentz Angle in the CMS Barrel Pixel Detector with Collisions and Cosmic Data (*preliminary*)

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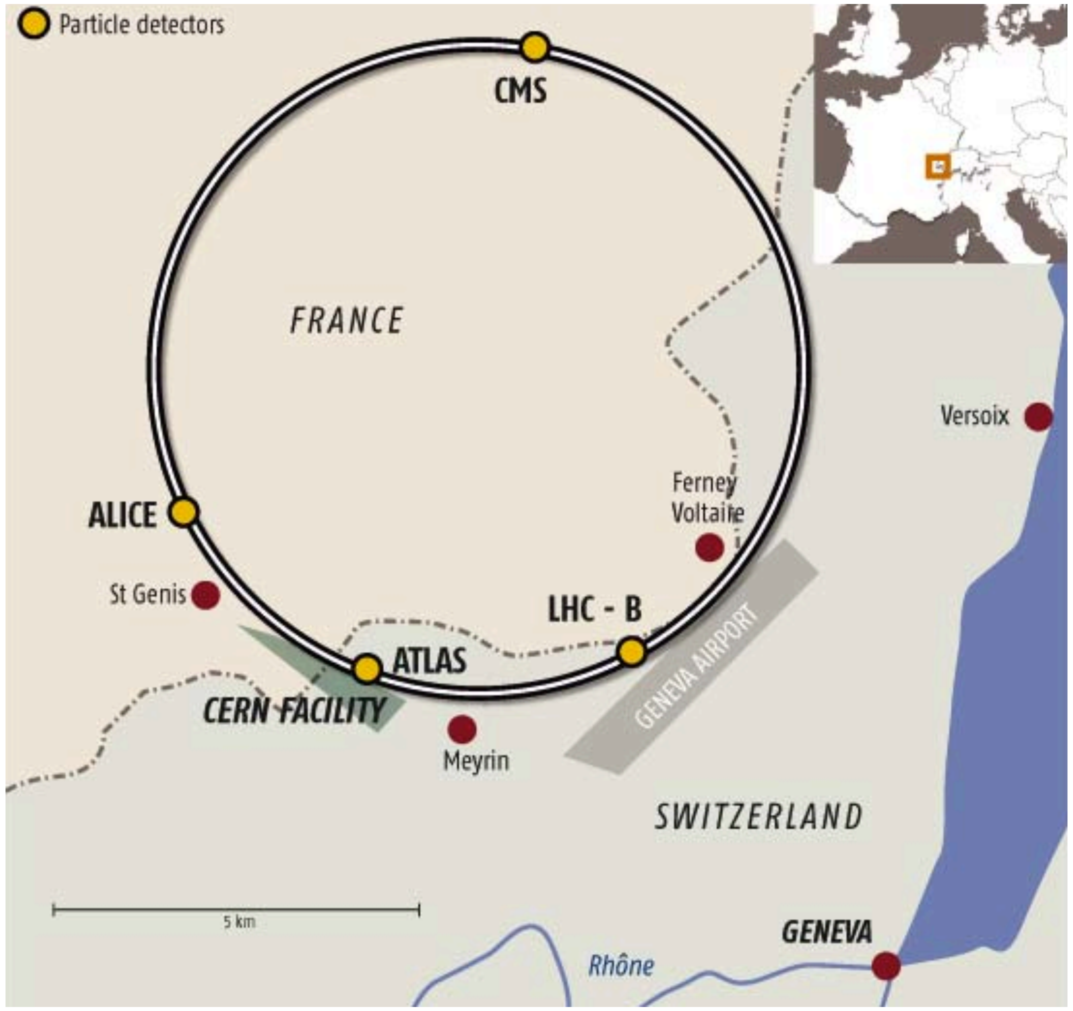
# Outline

- ★ The Large Hadron Collider at CERN and the CMS experiment
- ★ The silicon pixel detector of CMS
- ★ Lorentz angle in the CMS barrel pixel detector
- ★ Measurements of the Lorentz angle with the first collision data from LHC
- ★ Measurements of the Lorentz angle with cosmic data
- ★ Summary

# The Large Hadron Collider

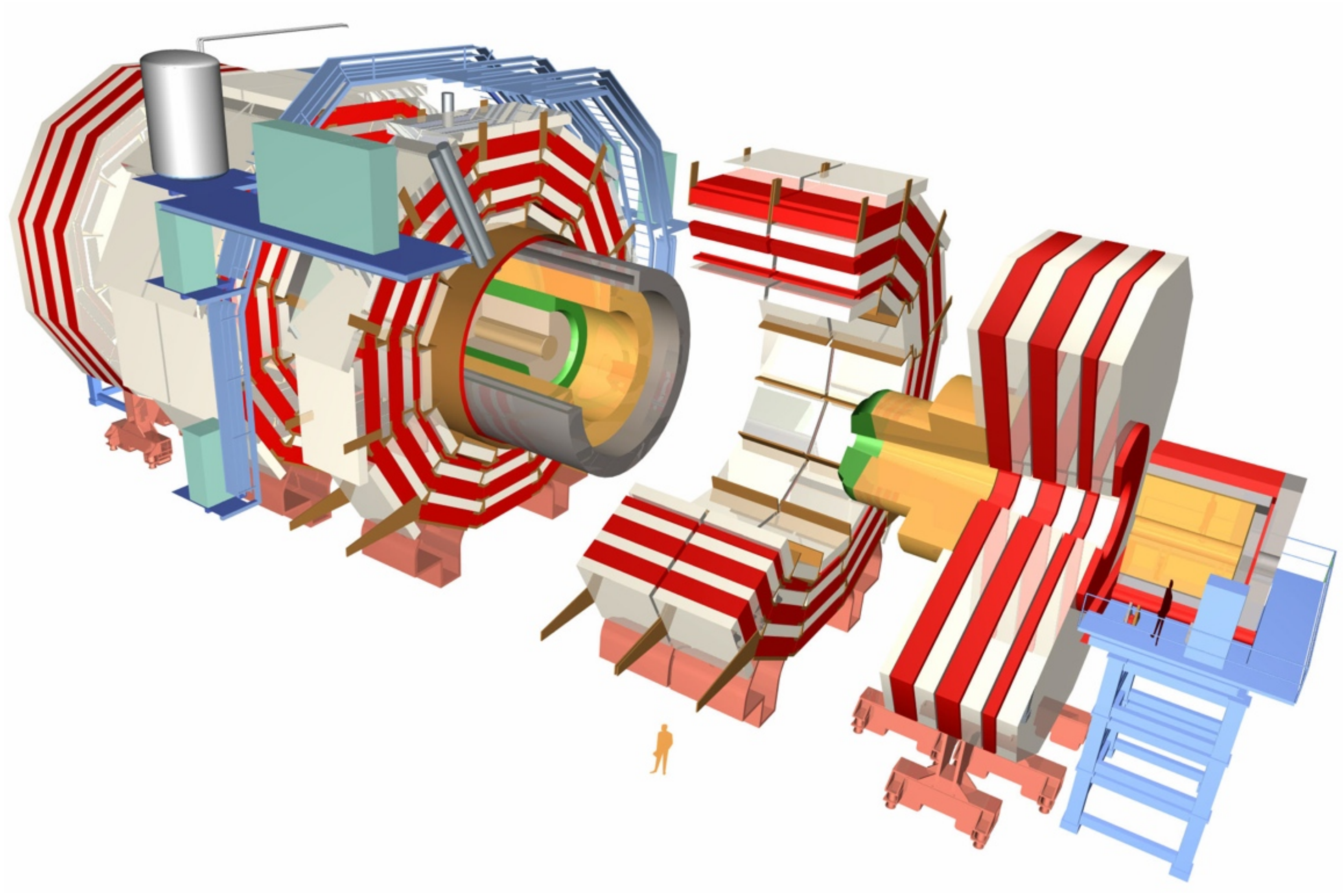



- 27 km in circumference; 50 to 175 m underground
- *pp* collisions, √s = 14 TeV,
  lead nuclei collisions, √s = 574 TeV per nucleus
- superconducting magnets
  - operating temperature 1.9 K (-271.3 °C)
  - peak magnetic field 8.3 T
- ultrahigh vacuum ($10^{-10}$ Torr or ~3 million molecules/$cm^3$)
- collisions rate 25 ns

Four major experiments:
- A Toroidal LHC ApparatuS (**ATLAS**)
and the Compact Muon Solenoid (**CMS**):
  Higgs boson, SUSY, ...
- A Large Ion Collider Experiment (**ALICE**):
  quark-gluon plasma
- **LHCb**:
  b(eauty)-physics

In December 2009, LHC provided for the first time *pp* collisions at energy √s = 2.36 TeV, setting world record for beam and collisions energy

# The Compact Muon Solenoid



Design:
- Silicon inner tracker
  - tracks and secondary vertices reconstruction
- Electromagnetic calorimeter
  - energies of electrons and photons
- Hadronic calorimeter
  - energies of hadrons and ID of events with missing energy
- Magnet
  - 3.8 T superconducting solenoid bending the trajectories of charged particles
- Muon system and return yoke
  - ID and momenta measurements of muons

| | |
|---|---|
| Total weight: | 12 500 T |
| Overall diameter: | 15.0 m |
| Overall length: | 21.5 m |
| Magnetic field: | 3.8 Tesla |

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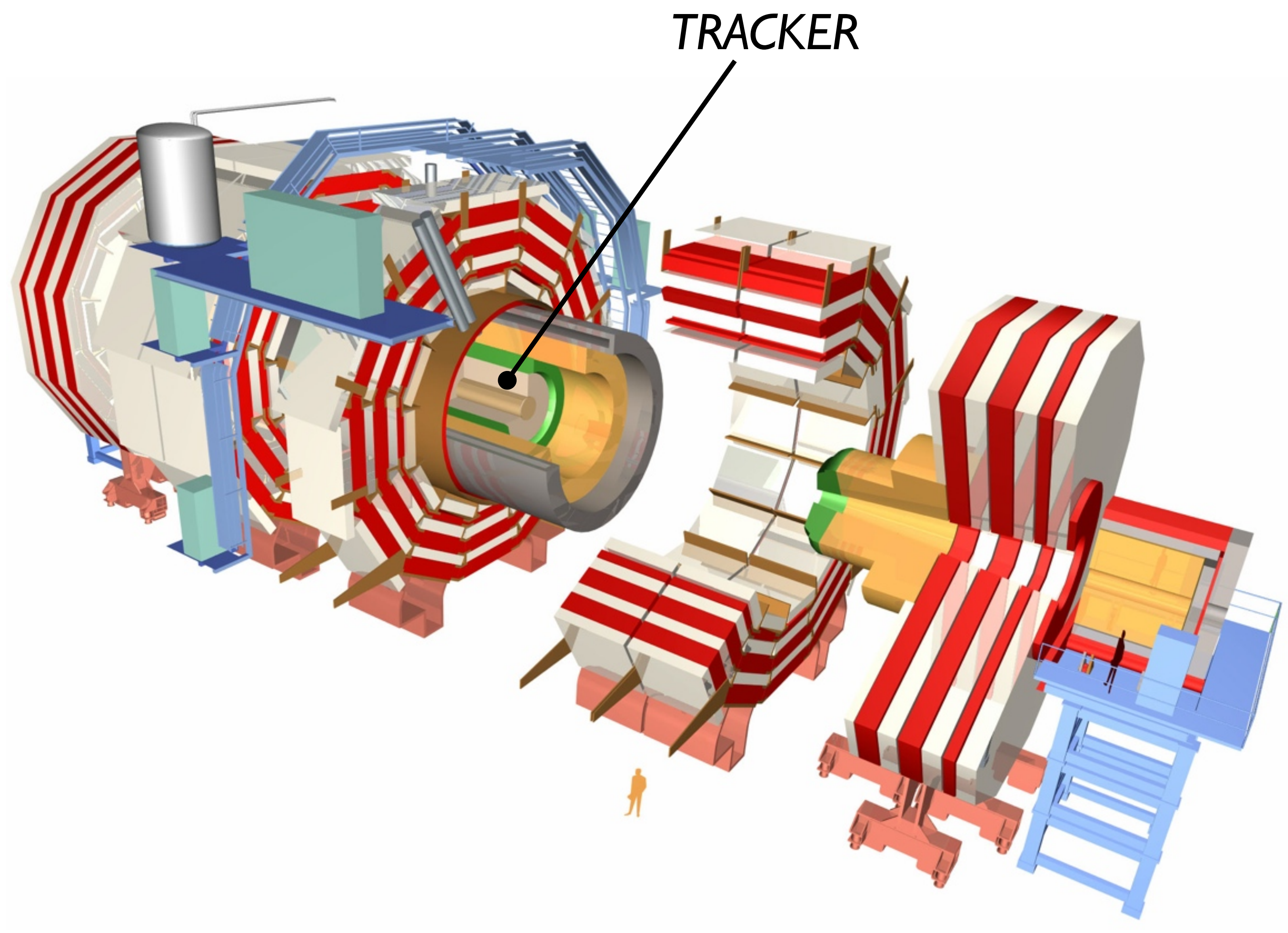


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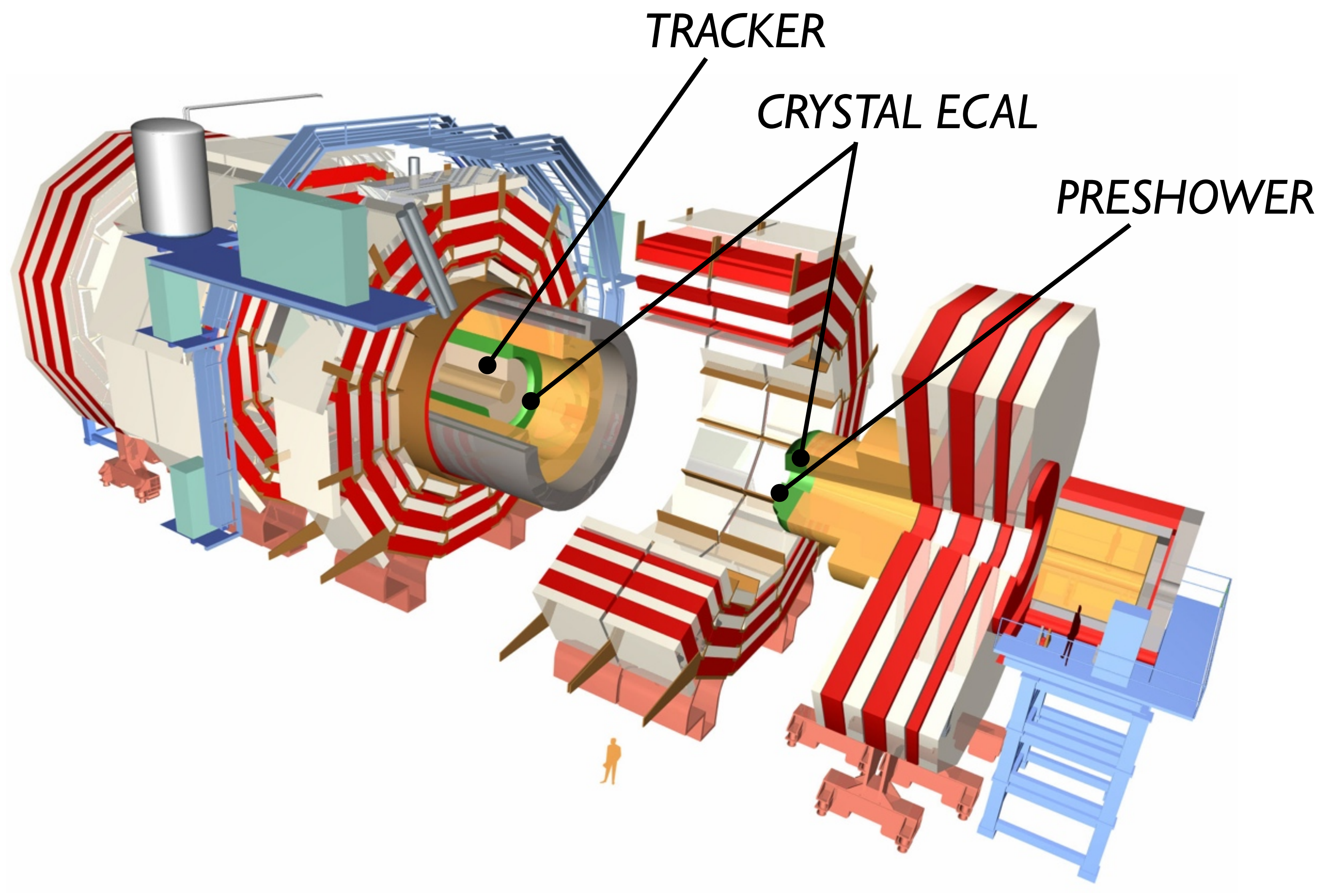


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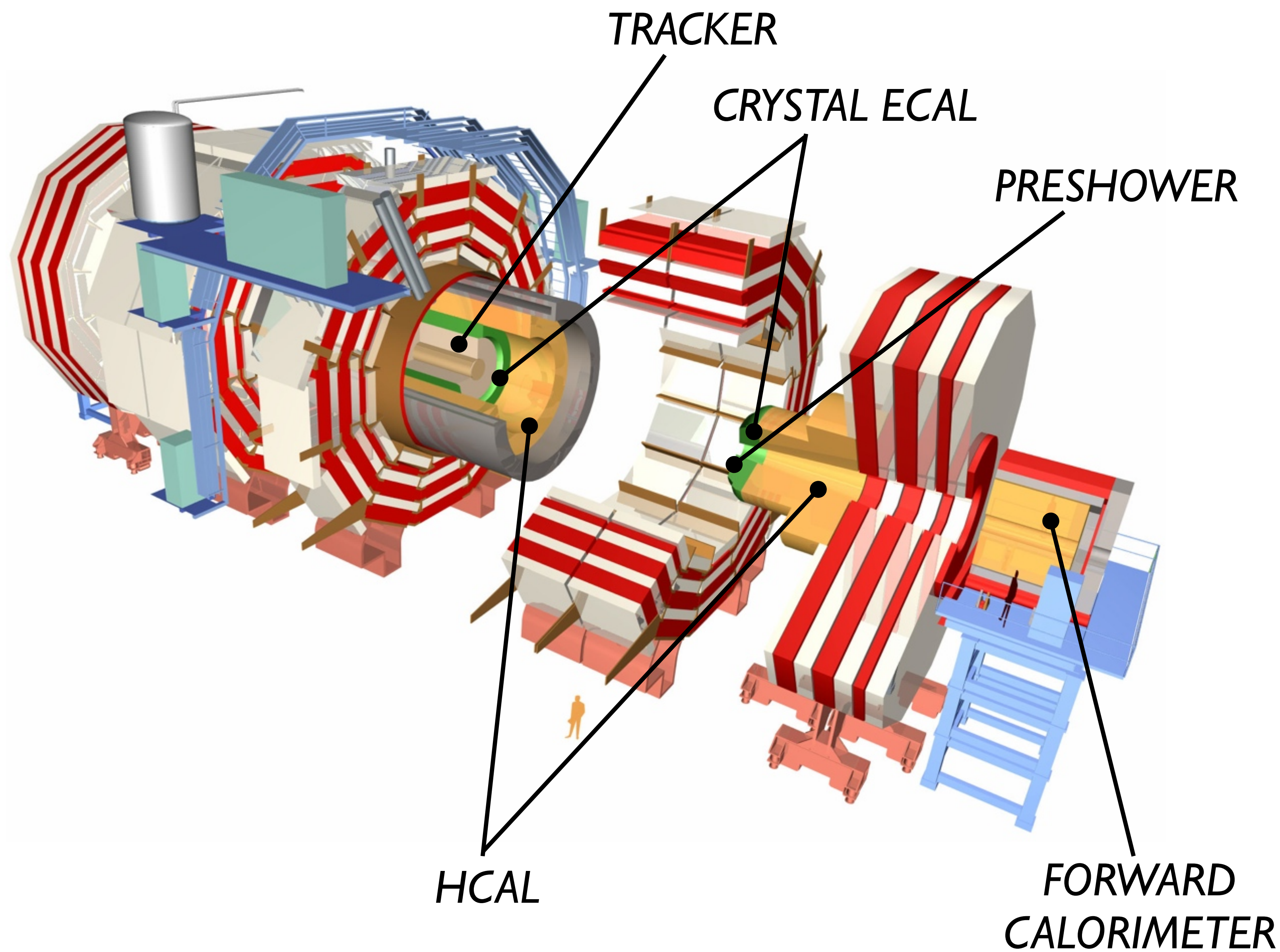


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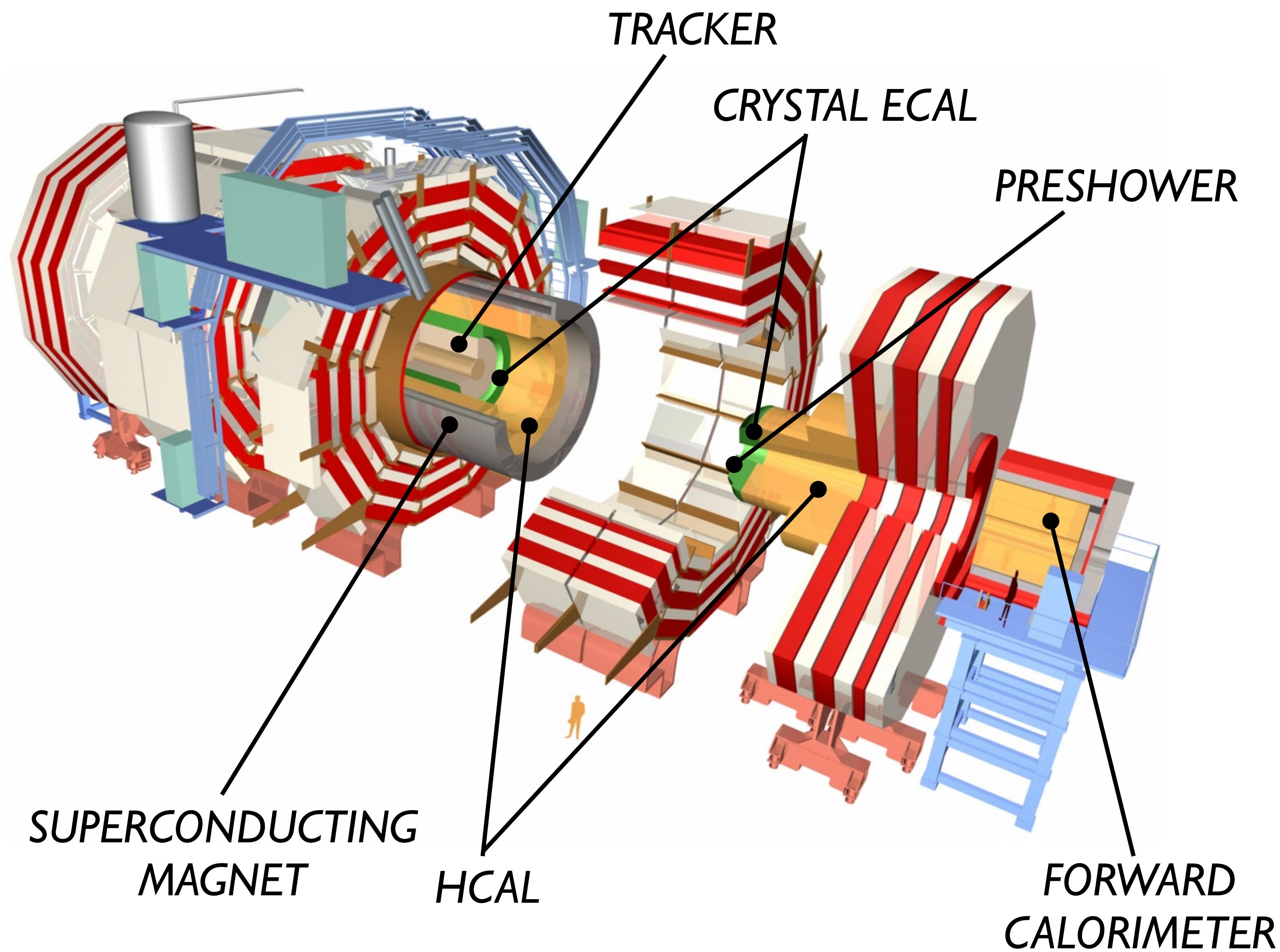


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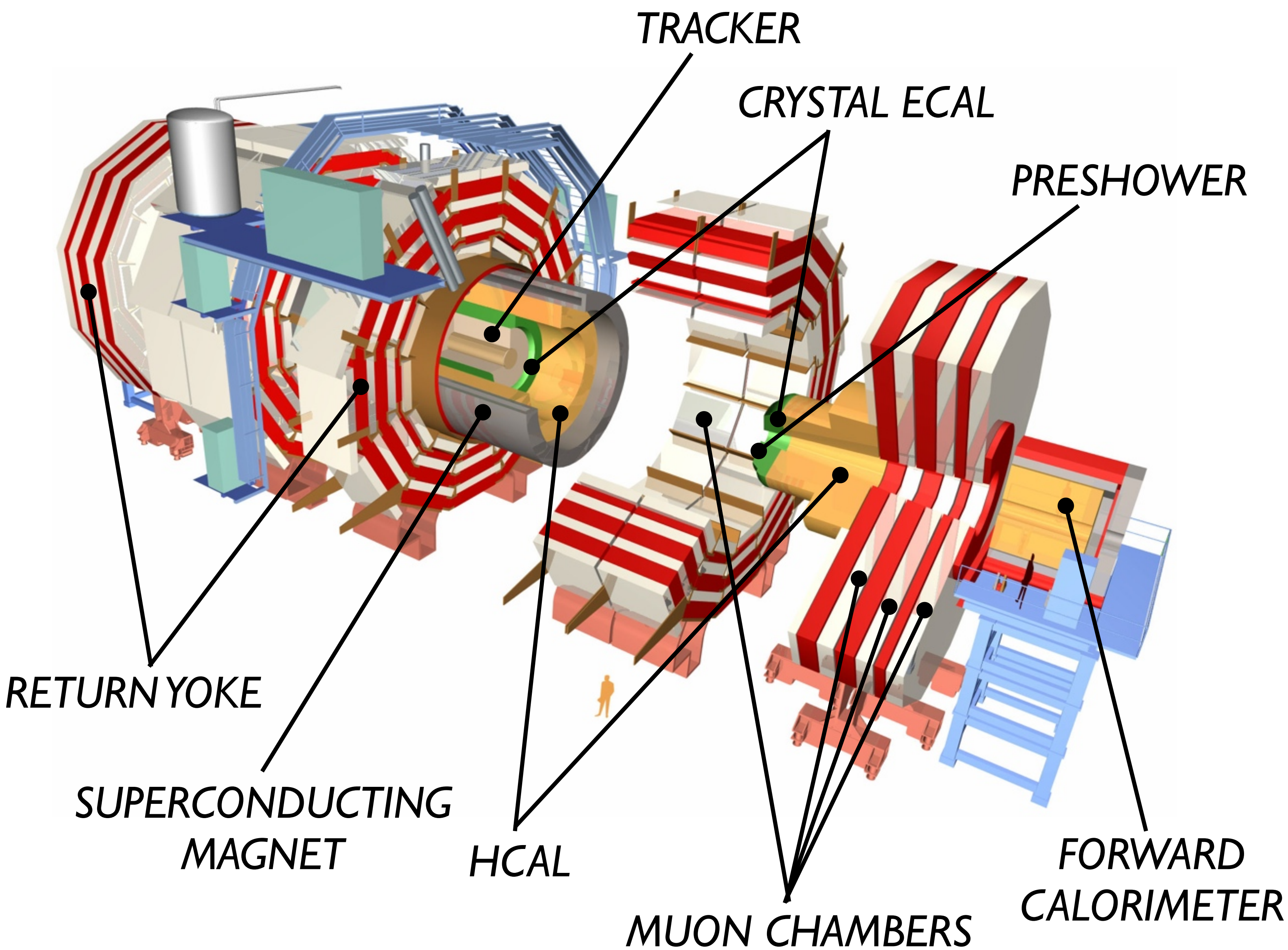


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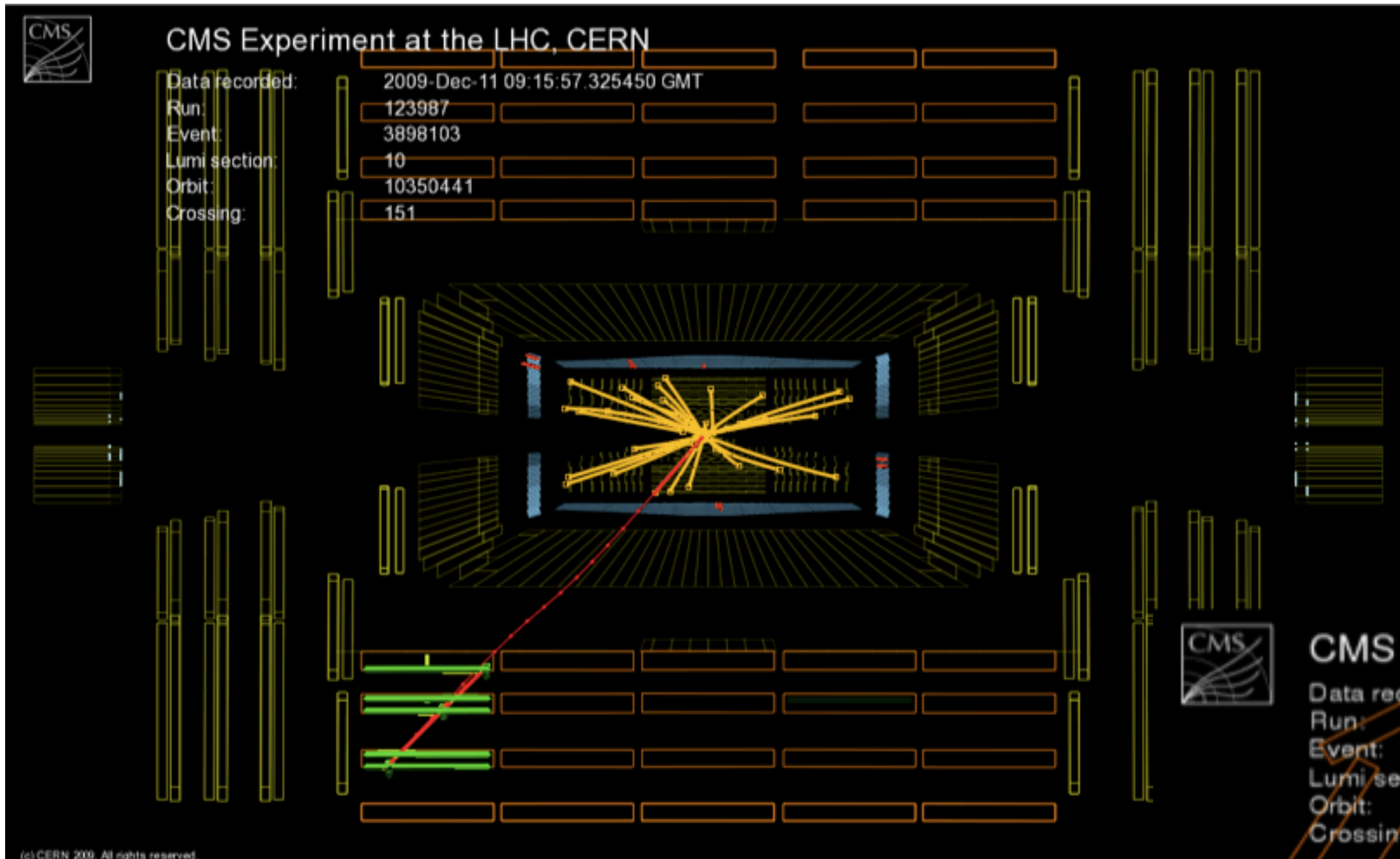
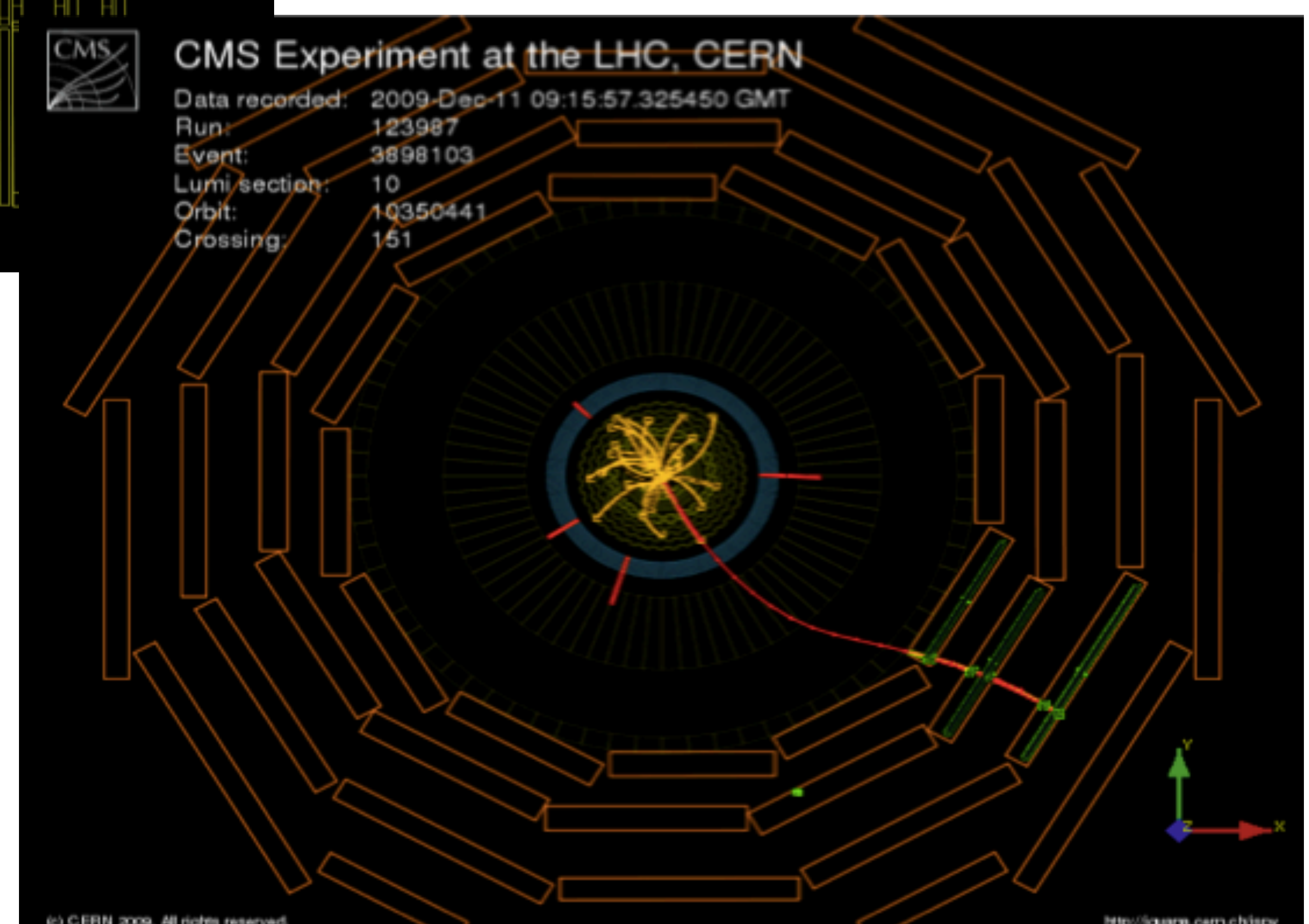
# Event display: muon candidate in CMS at 900 GeV

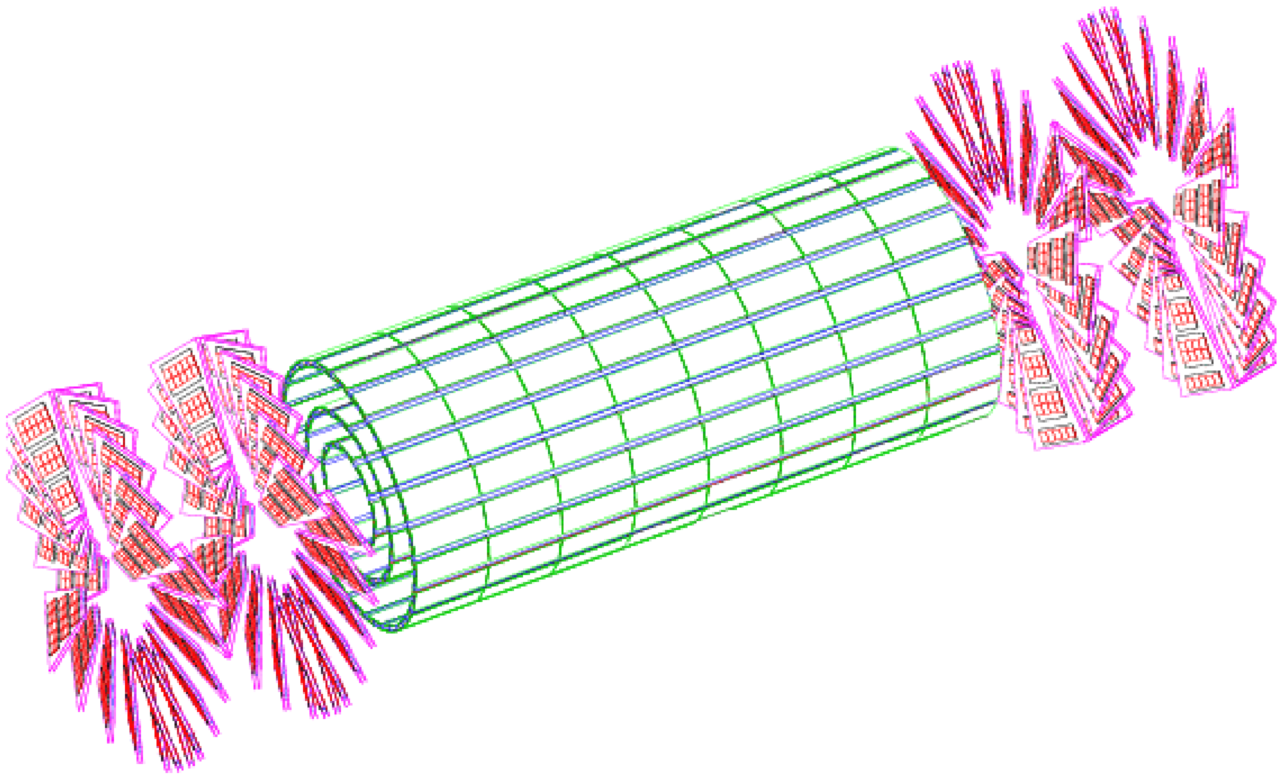


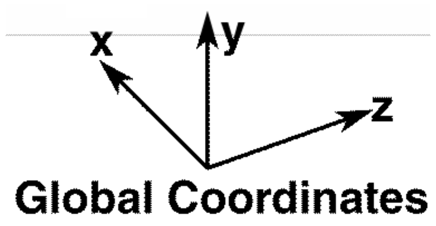

**longitudinal view**

**transverse view**



# The CMS silicon pixel detector






Performance challenge:
- ~ charged 1000 particles every 25 ns
- secondary vertices (b-, τ- tagging)
- radiation hardness

Design:

**barrel pixel detector**:
- three layers (at 4.3cm, 7.2cm and 10.2cm), 53 cm in length
- modules
- silicon pixel sensors (100 μm by 150 μm; 285 μm thick)

**forward pixel detector (endcaps)**:
- two disks at both ends

Spatial resolution: 15-20 μm

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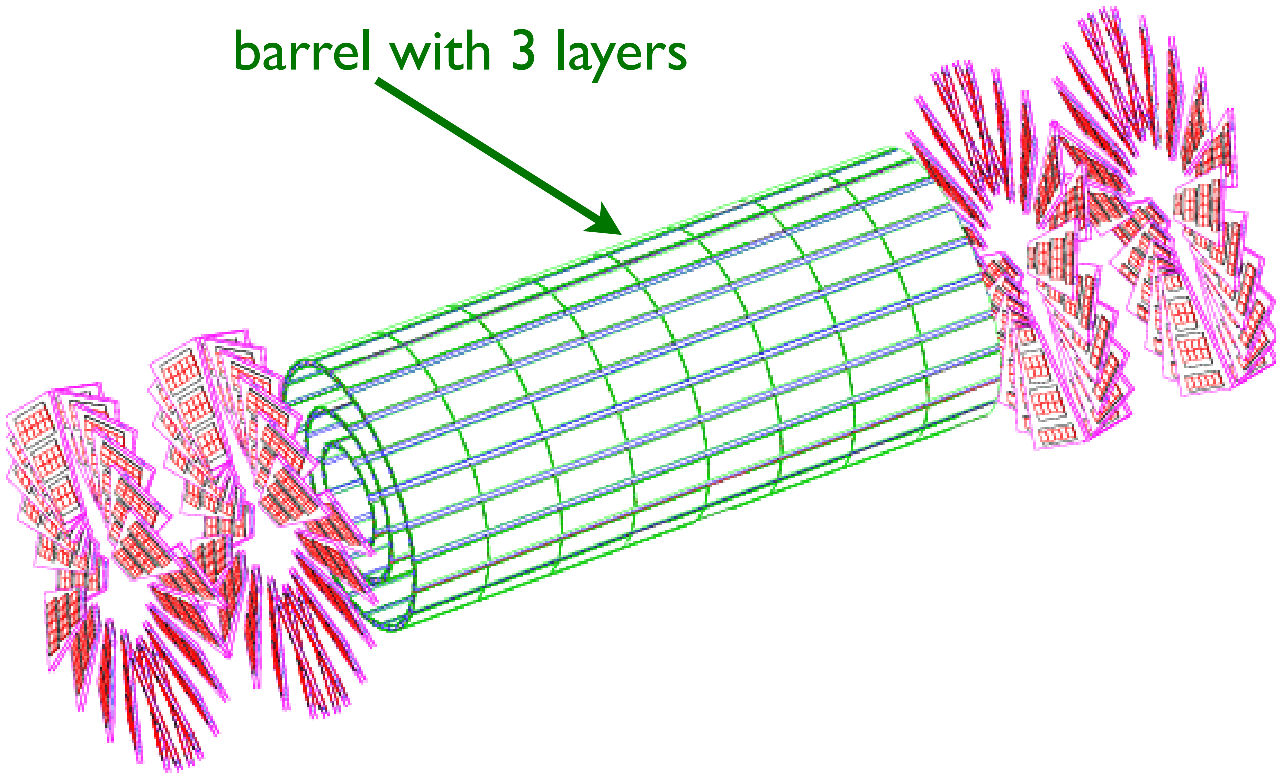


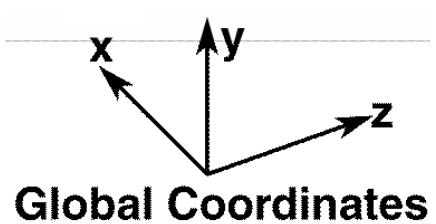


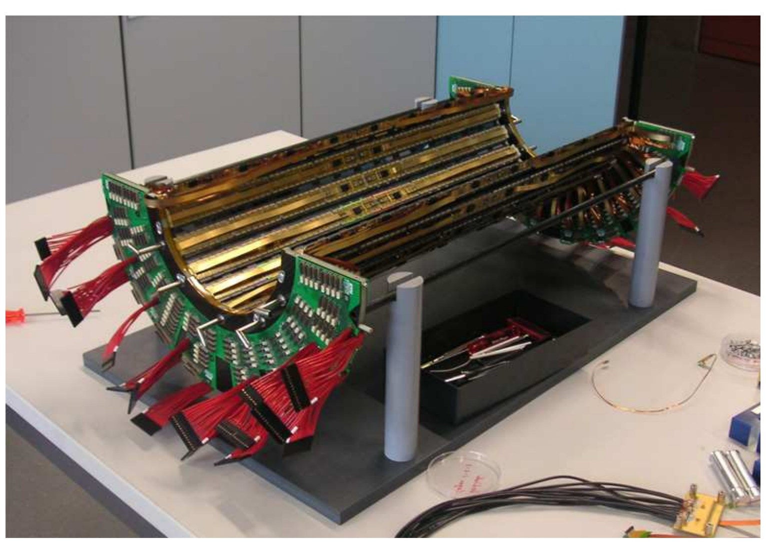

the third layer in the lab

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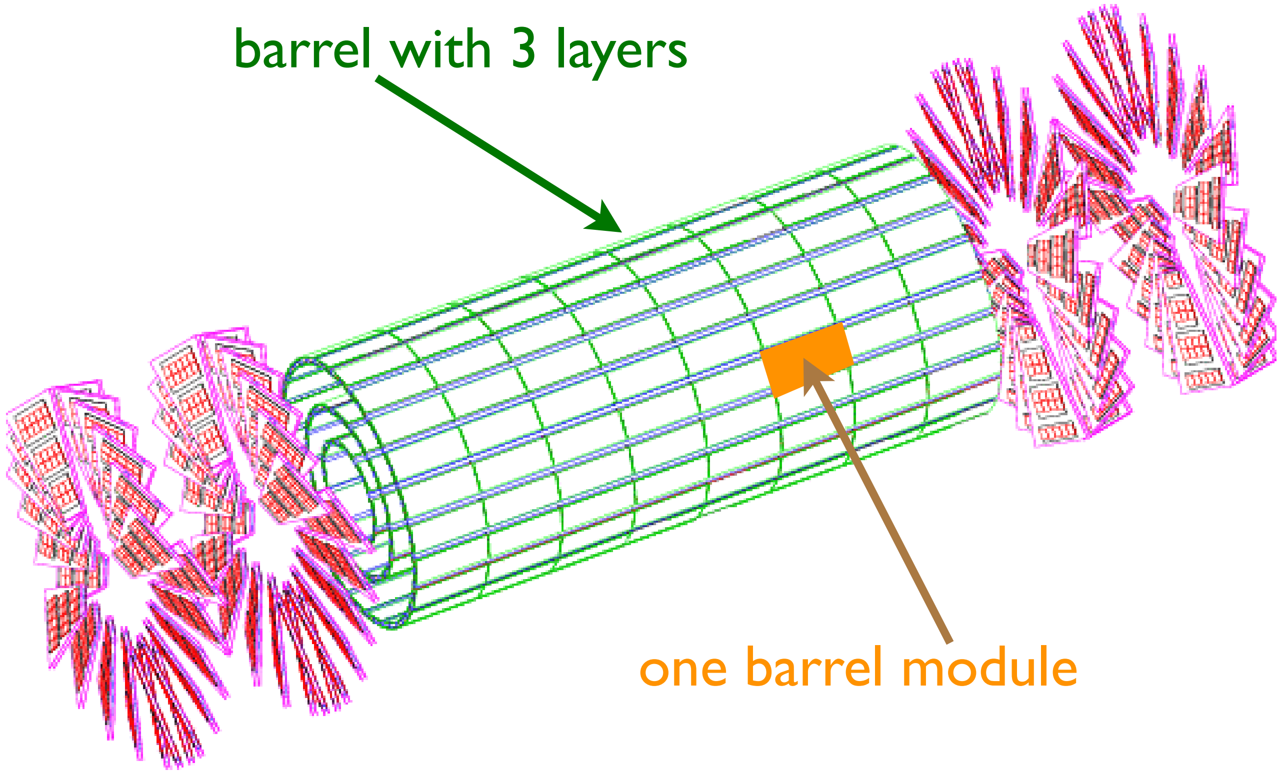


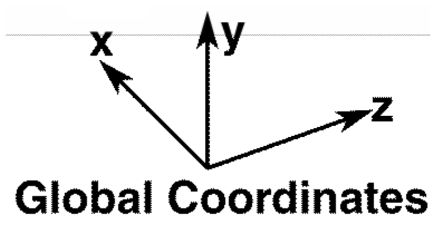


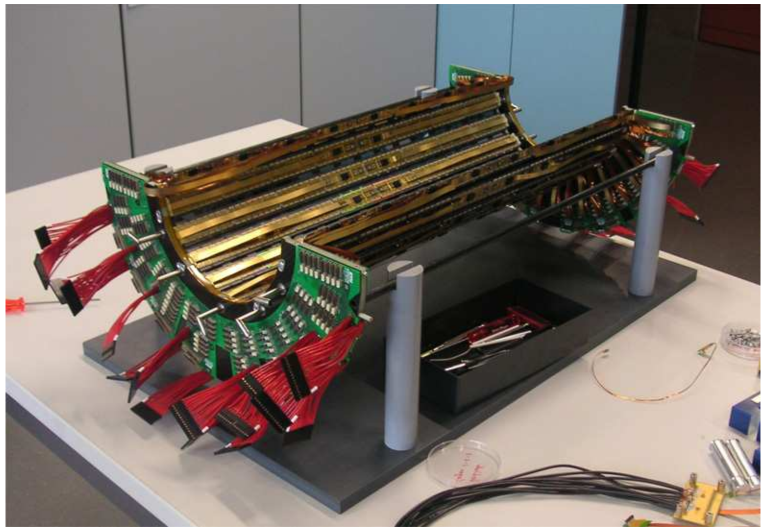

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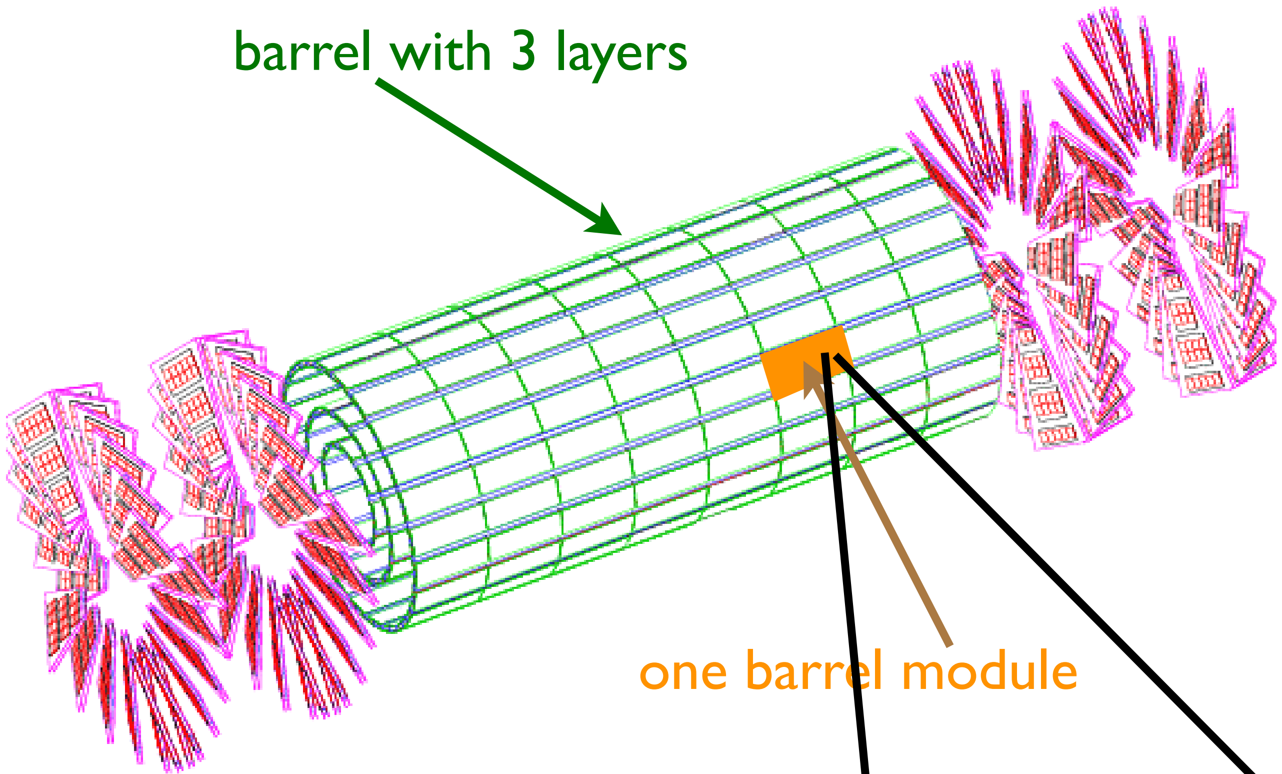


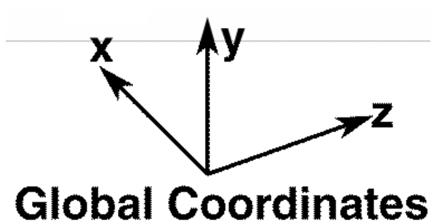


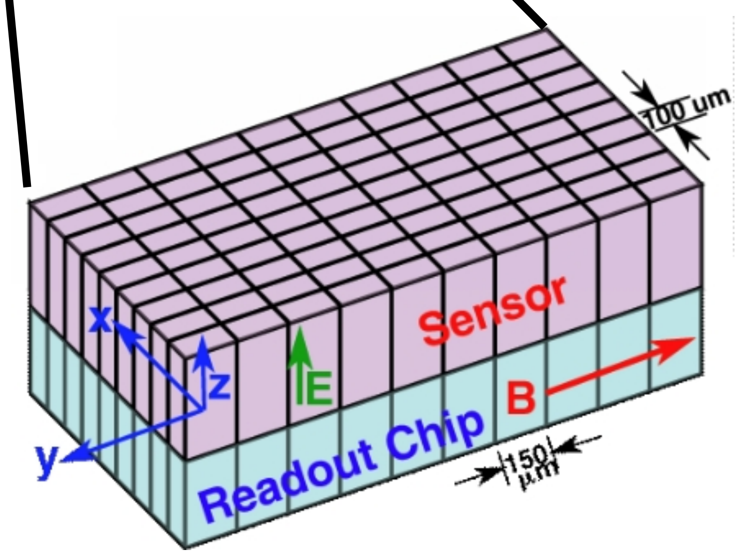


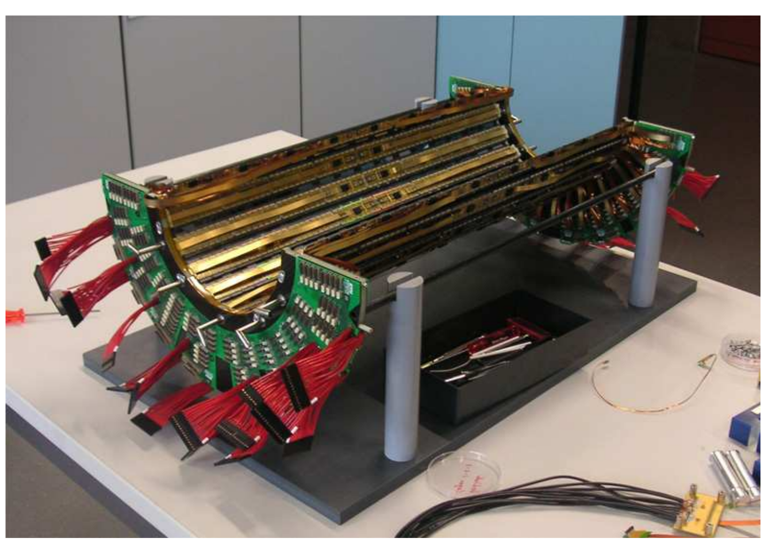

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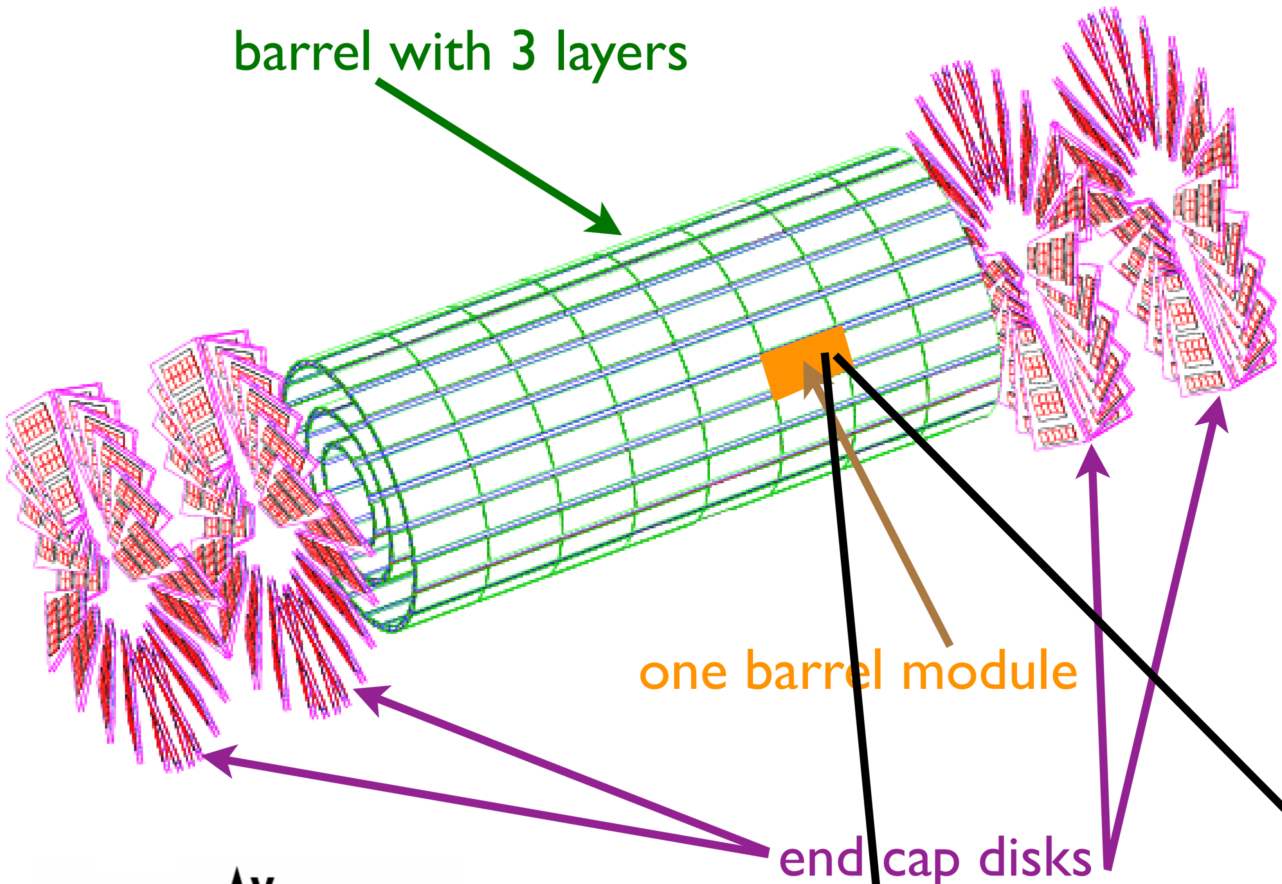


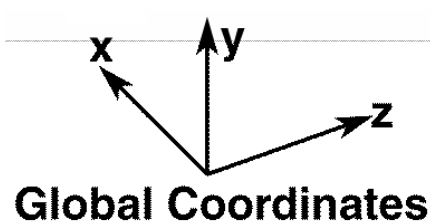


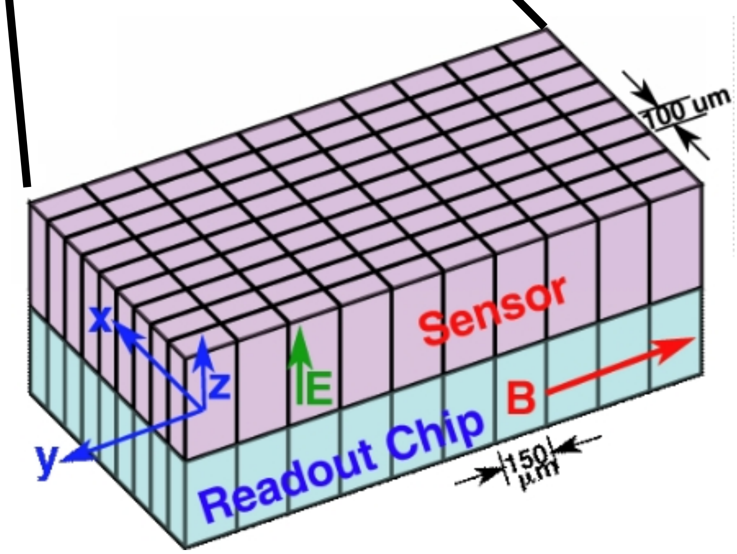


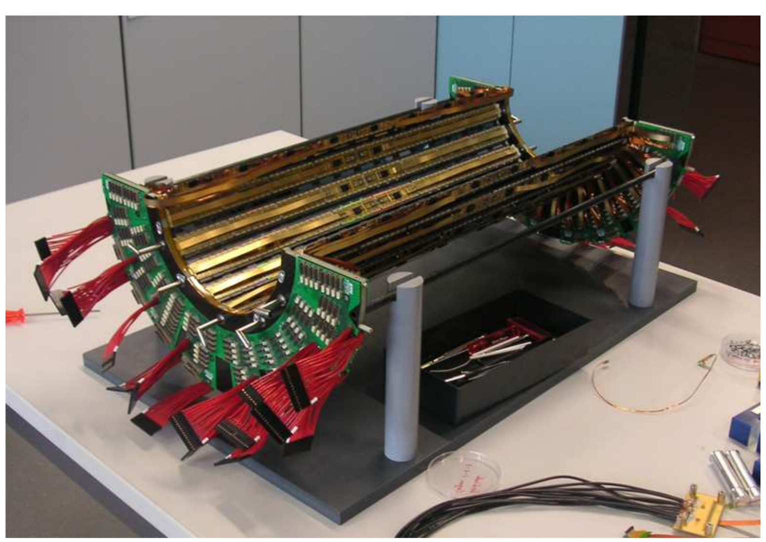

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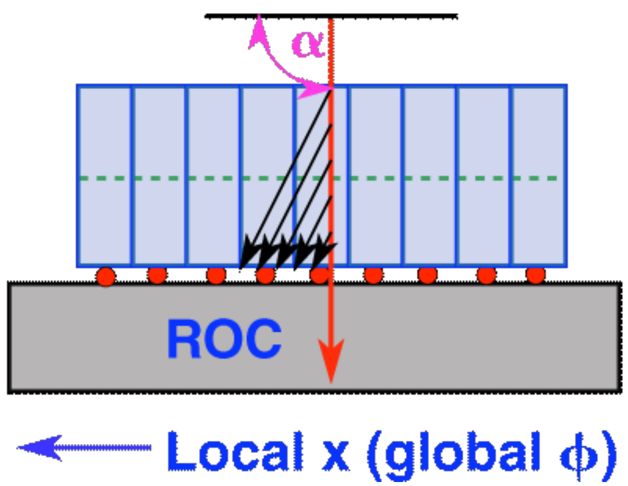
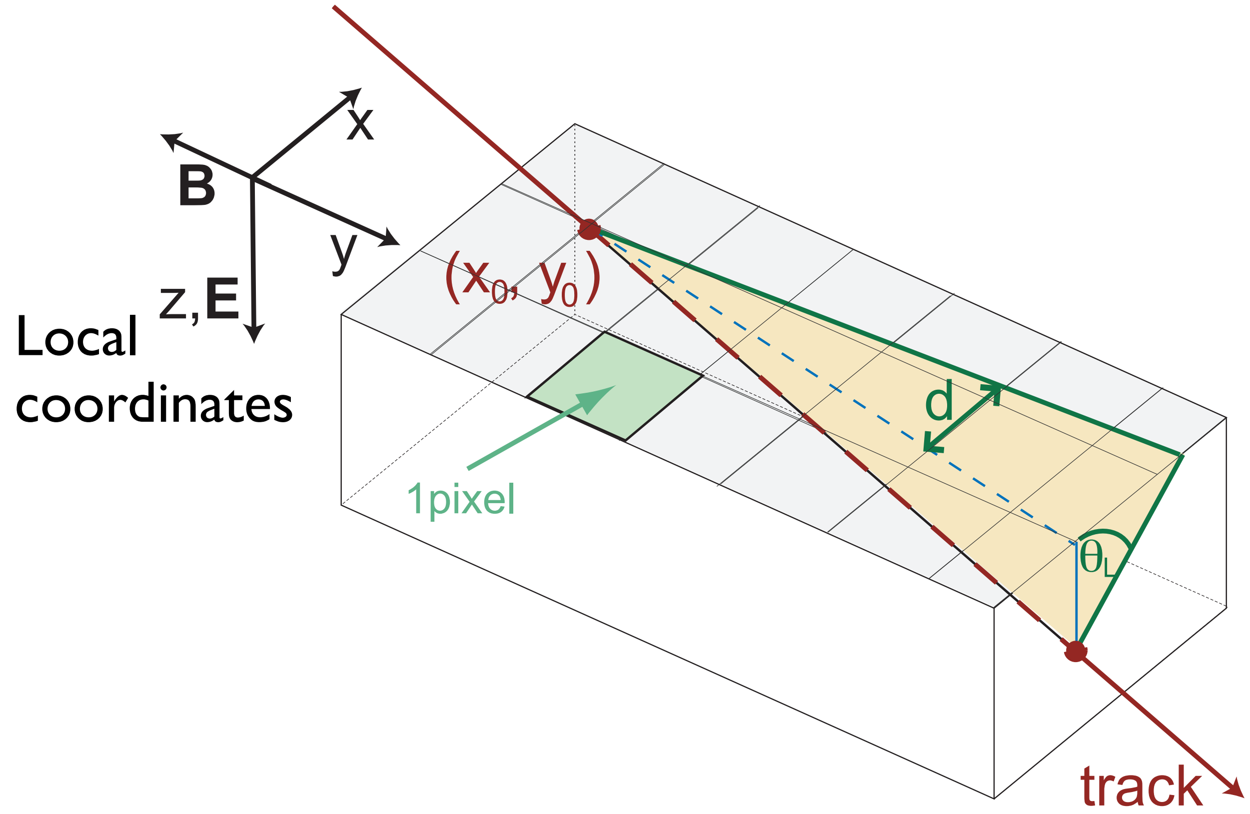
# Lorentz drift in the barrel pixel detector

<u>Origin:</u>
- electron-hole pairs in the pixel sensors
- ***B*** ⊥ ***E***

=> Lorentz force along *x* direction on the ejected electrons




<u>The Lorentz drift results in:</u>
- widened clusters in *x* direction
- charge sharing between pixels

↓

**affects position resolution**

←

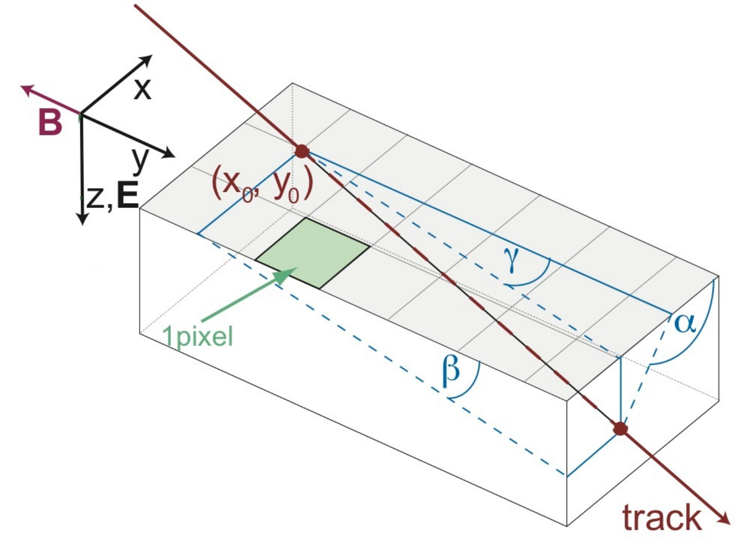
- the Lorentz angle depends on ***E*** and ***B***
- bias voltage increased with time due to irradiation

↓

**the Lorentz angle changes with time**

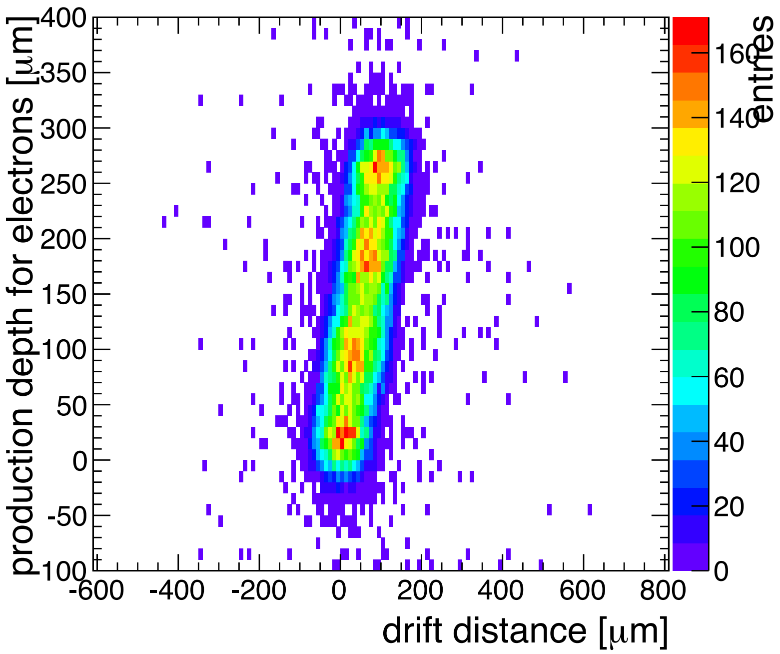
<u>Two methods</u> used to extract the Lorentz angle:
- "grazing angle" method for collision data
- "minimal cluster size" method for cosmic data

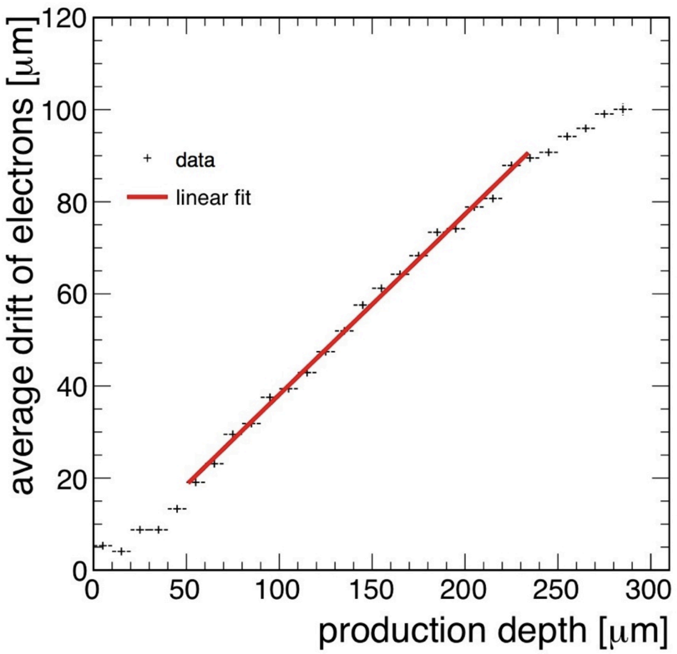
# Lorentz angle extraction from collision data




Idea of the "grazing angle" method

- use of well reconstructed tracks so that the path through the detector is known



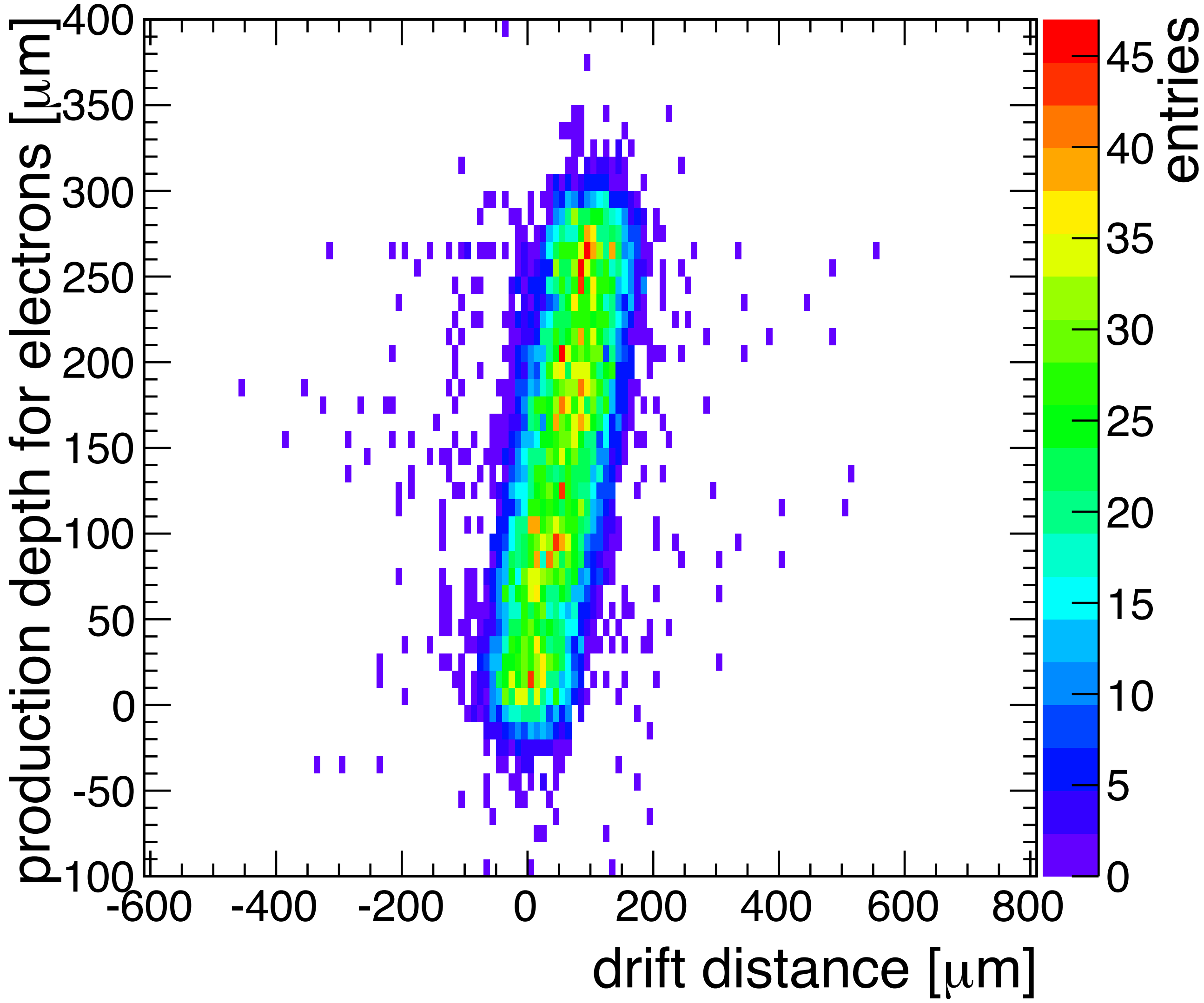




- obtain the drift distance of the electrons created at a certain depth

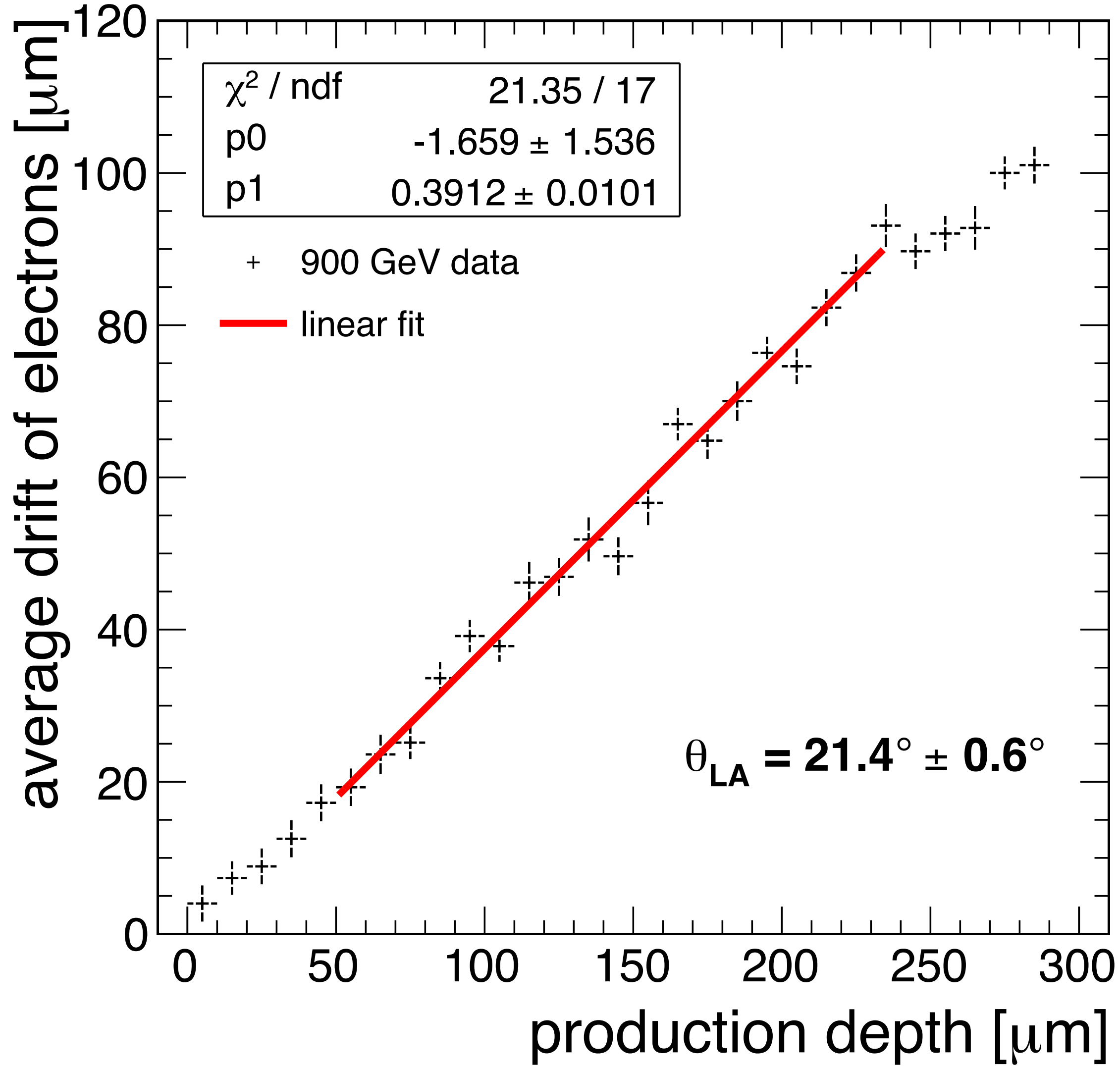
- averaged over many tracks: drift distance vs production depth
- fit over the depth of the detector

Tracks with shallow impact ("grazing") angle w.r.t local *y* axis are used (long clusters in *y* are required)

# 900 GeV collisions, B = 3.8 T



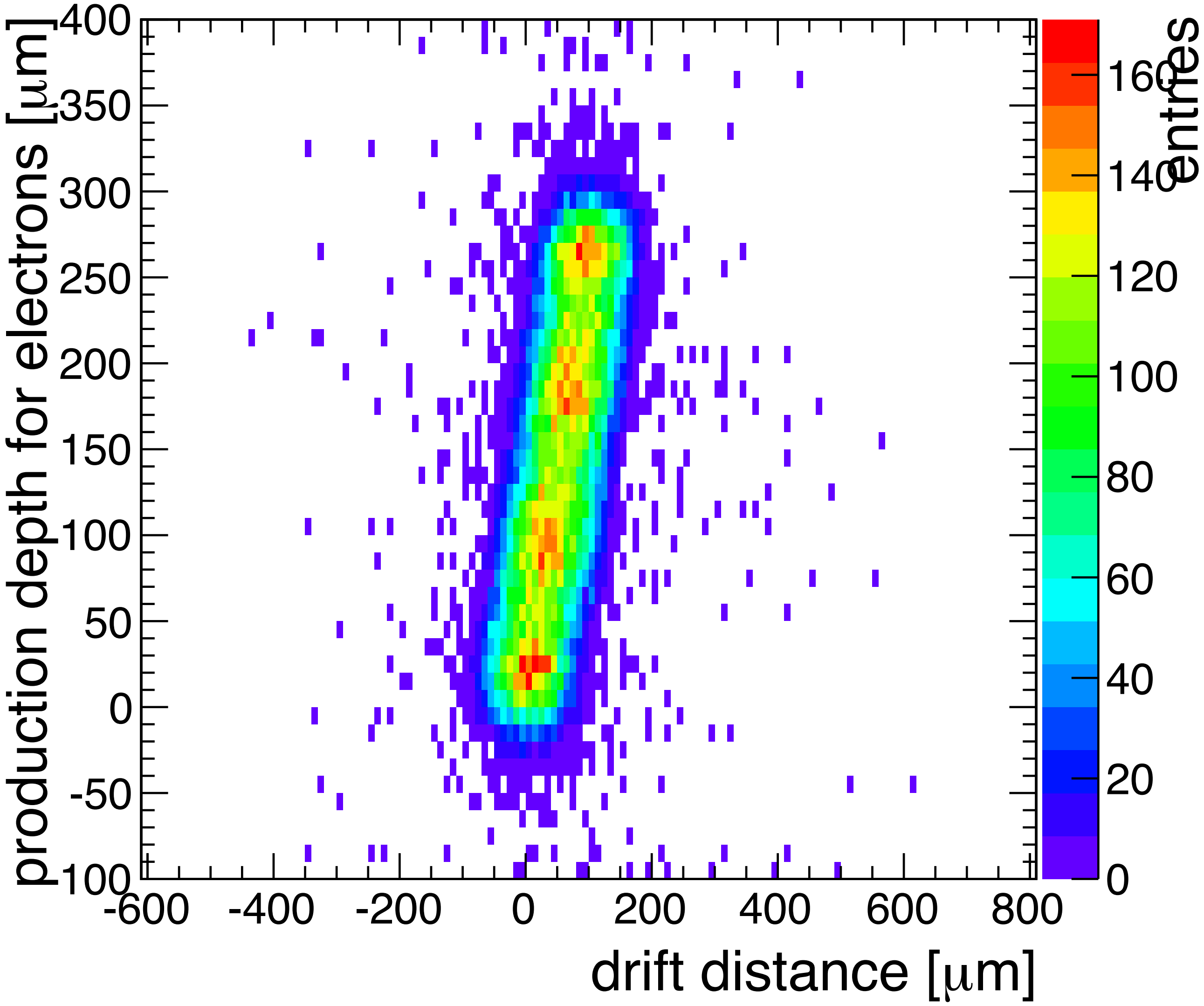

Depth at which the electrons are produced vs their drift distance

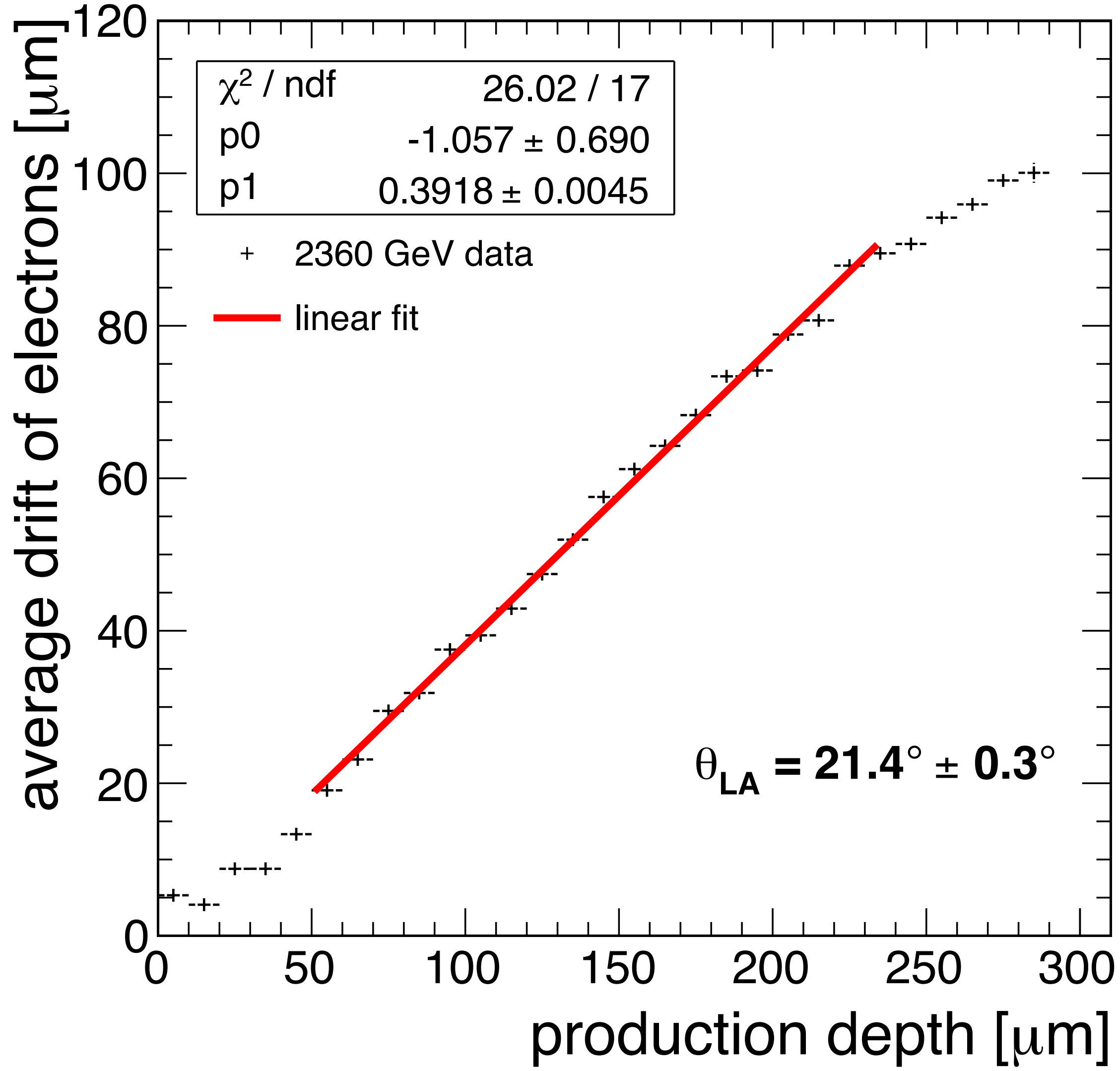



Linear fit to obtain the slope $p1 = \tan(\theta_{LA})$

$$\theta_{LA} = 21.4° \pm 0.6°(\text{stat})$$

# 2360 GeV collisions, B = 3.8 T

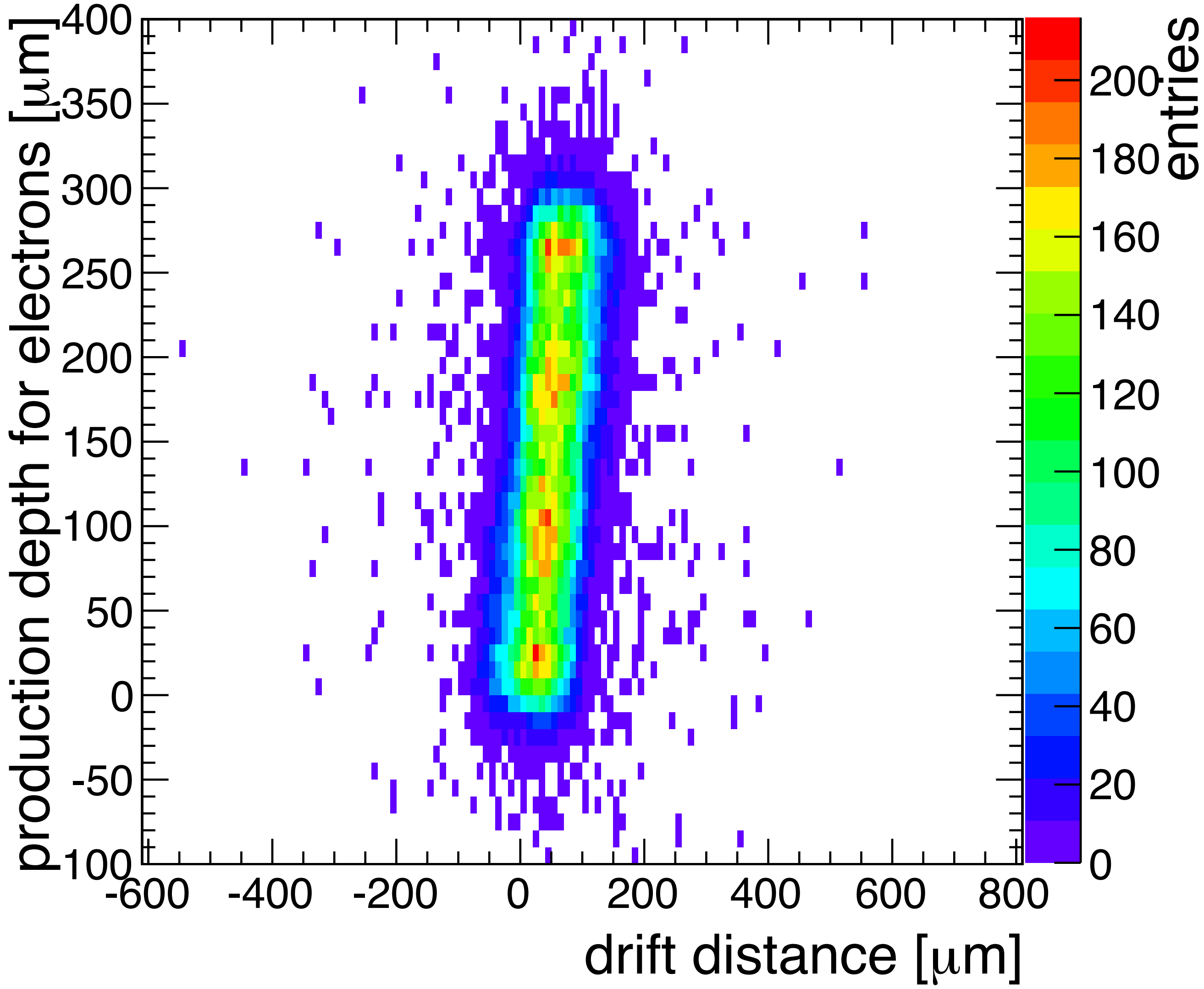


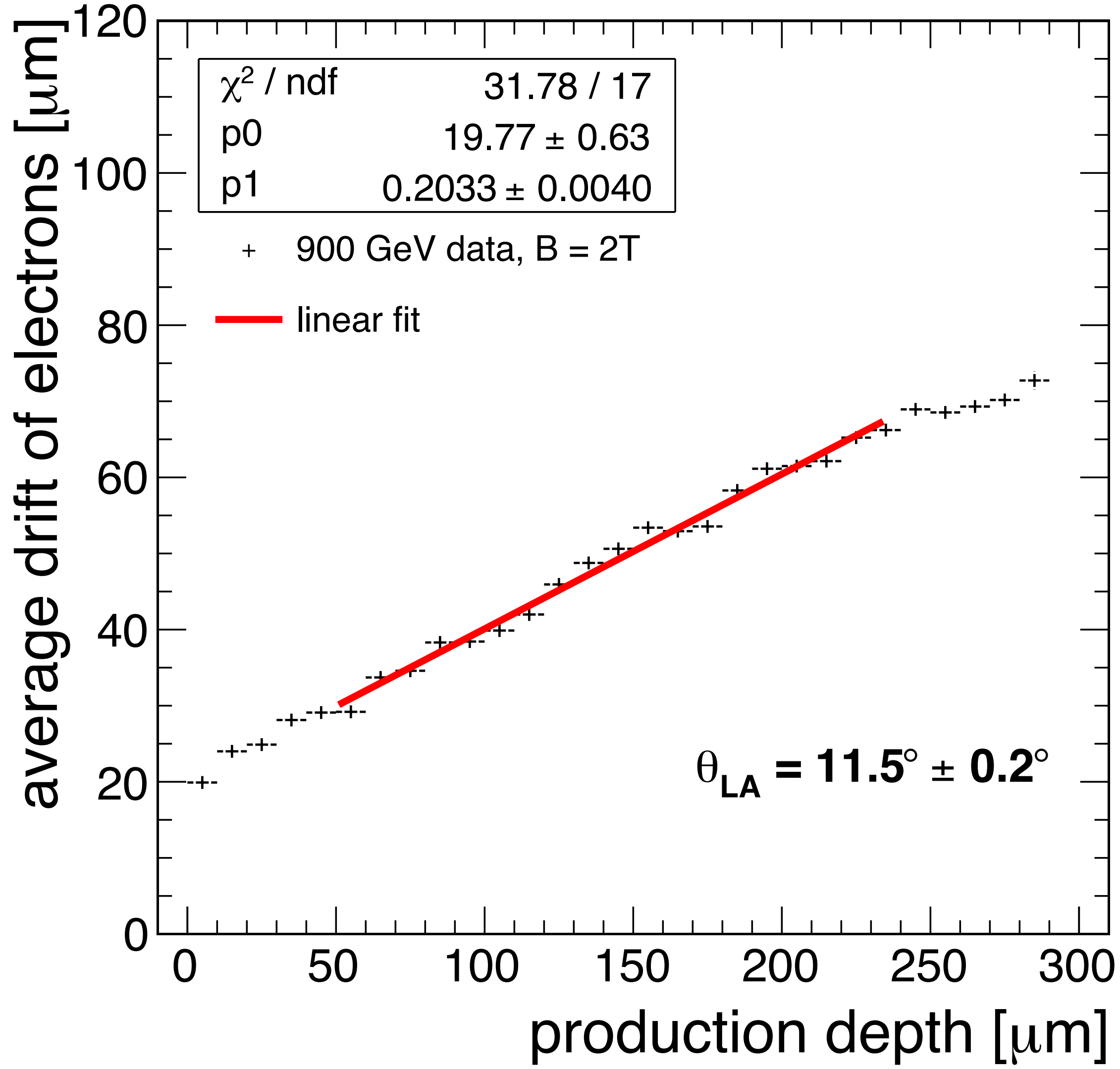




In theory, the Lorentz angle does not depend on the energy.
The results at different energies agree

$$\theta_{LA} = 21.4° \pm 0.3°(stat)$$

# 900 GeV collisions, B = 2 T



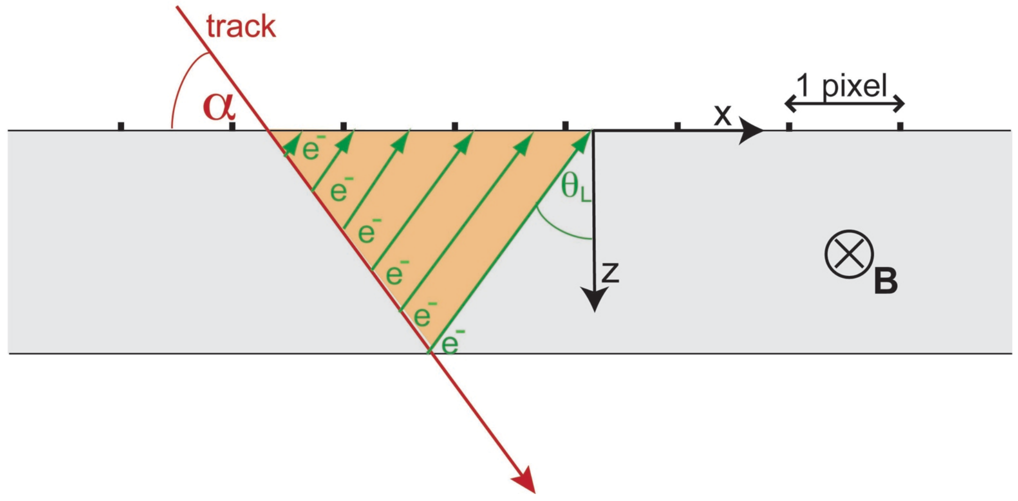




The Lorentz angle is expected to decrease at lower magnetic fields

$$\theta_{LA} = 11.5° \pm 0.2°(\text{stat})$$

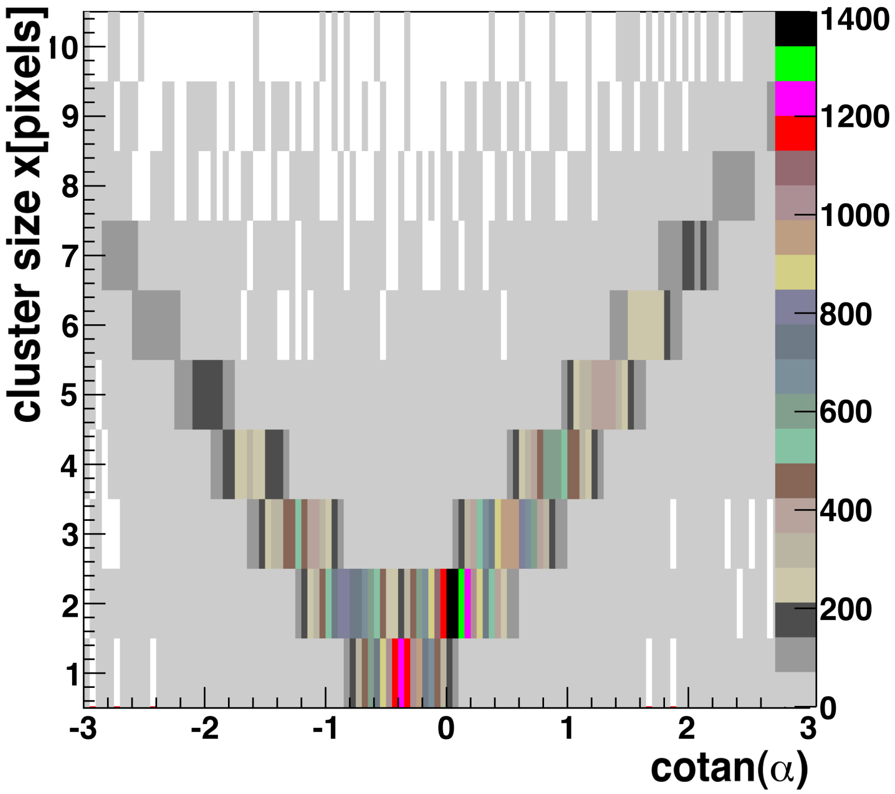
# Lorentz angle extraction from cosmic data

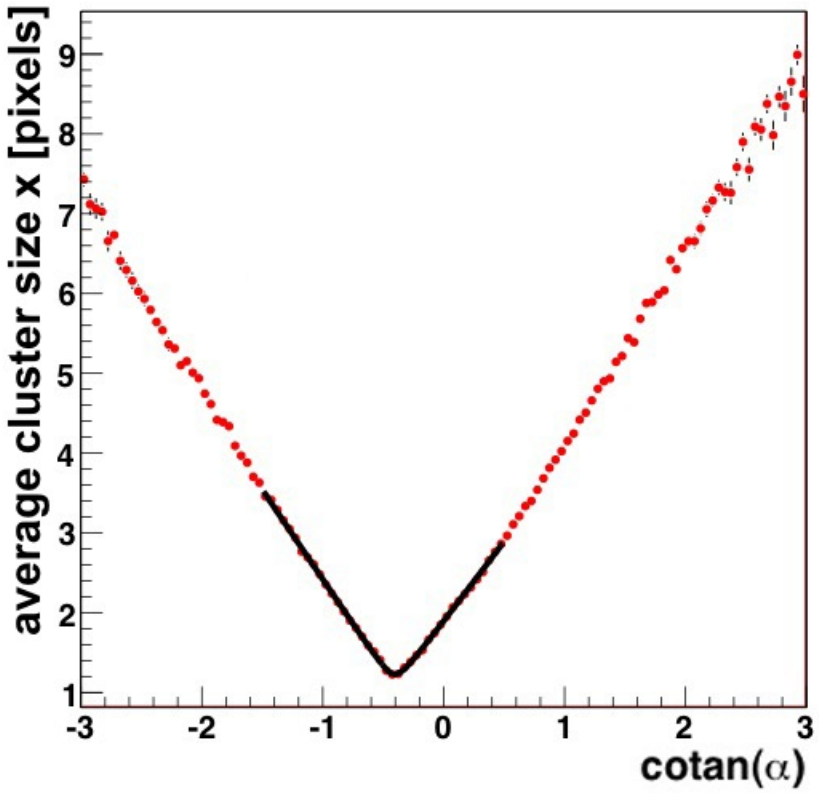
<u>Idea of the "minimal cluster size" method</u>




- The spread of the drifting charge distribution over neighbouring pixels depends on the particle's incidence angle $\alpha$ and is minimum for an angle equal to the Lorentz angle $\Theta_{LA}$

- The Lorentz angle is extracted by finding the minimum of the mean cluster size distribution measured as a function of the track incidence angle



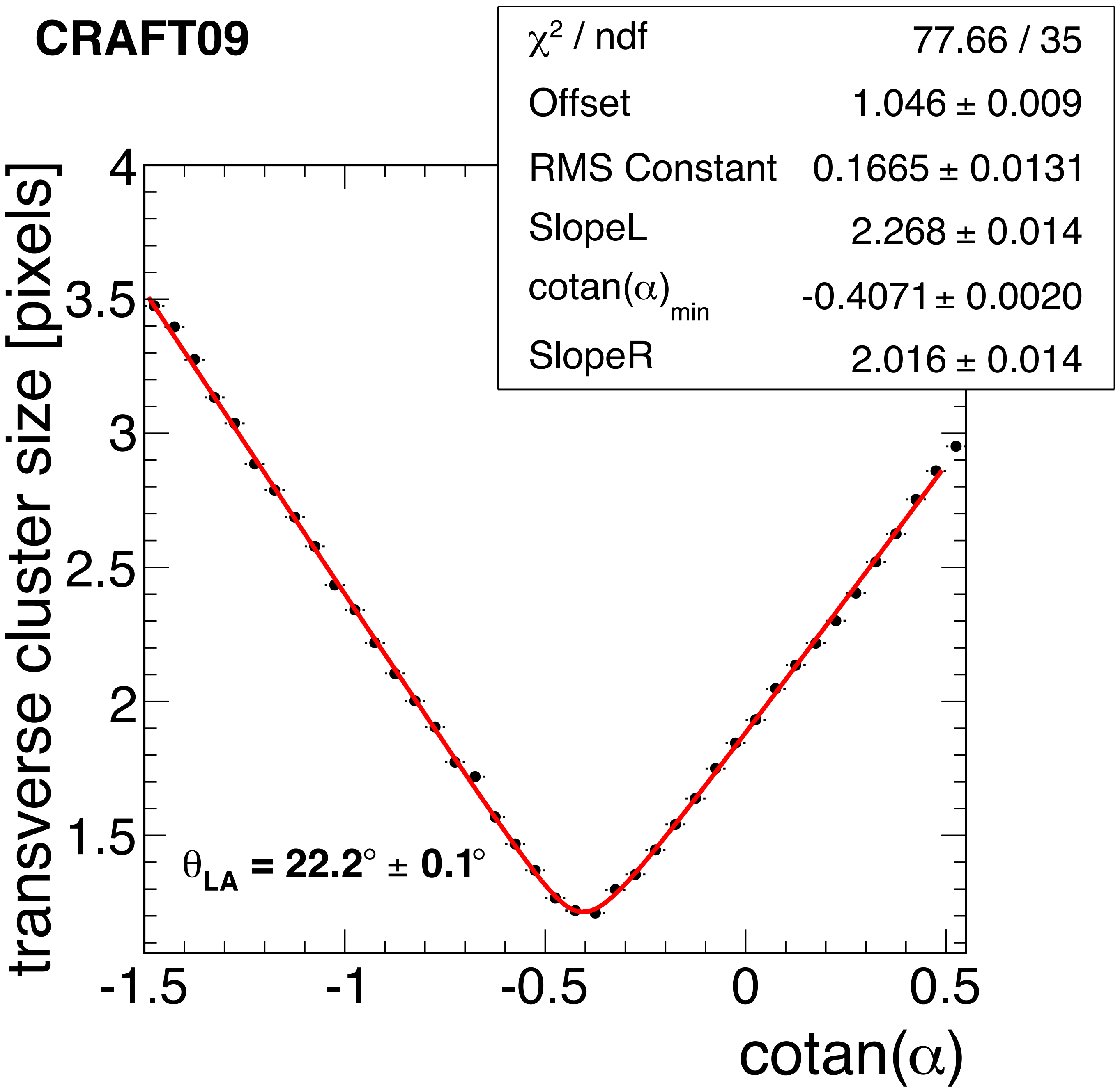

minimal cluster size in $x$, using $\tan(\Theta) = \cot(\alpha)$

=> $\tan(\Theta_{LA}) = \cot(\alpha)_{min}$

<u>this method is not suitable for collision data</u>

because in collision data $80° < \alpha < 100°$

# Result from cosmic data (CRAFT09)




$\theta_{LA} = 22.2° \pm 0.1°$**(stat)**

Opportunity for cross-check with a different and independent method and data

Cosmic data taken during summer '09

**The results from collision data and cosmic data agree**

# Summary of the results

| data type | Lorentz angle |
|---|---|
| 900 GeV, 3.8 T | 21.4° ± 0.6° |
| 2360 GeV, 3.8 T | 21.4° ± 0.3° |
| 900 GeV, 2 T | 11.5° ± 0.2° |
| cosmics, 3.8 T | 22.2° ± 0.1° |

Errors are statistical errors only!

# Summary

- ★ Calibration of the Lorentz angle in the CMS silicon pixel detector needed in order to correct hit position
- ★ The Lorentz angle for the CMS barrel pixel detector measured from LHC first collision data and from cosmic data
- ★ Agreement between collision data and cosmic data results

Thank you for your attention! ☺