# A Large Ion Collider Experiment (ALICE)

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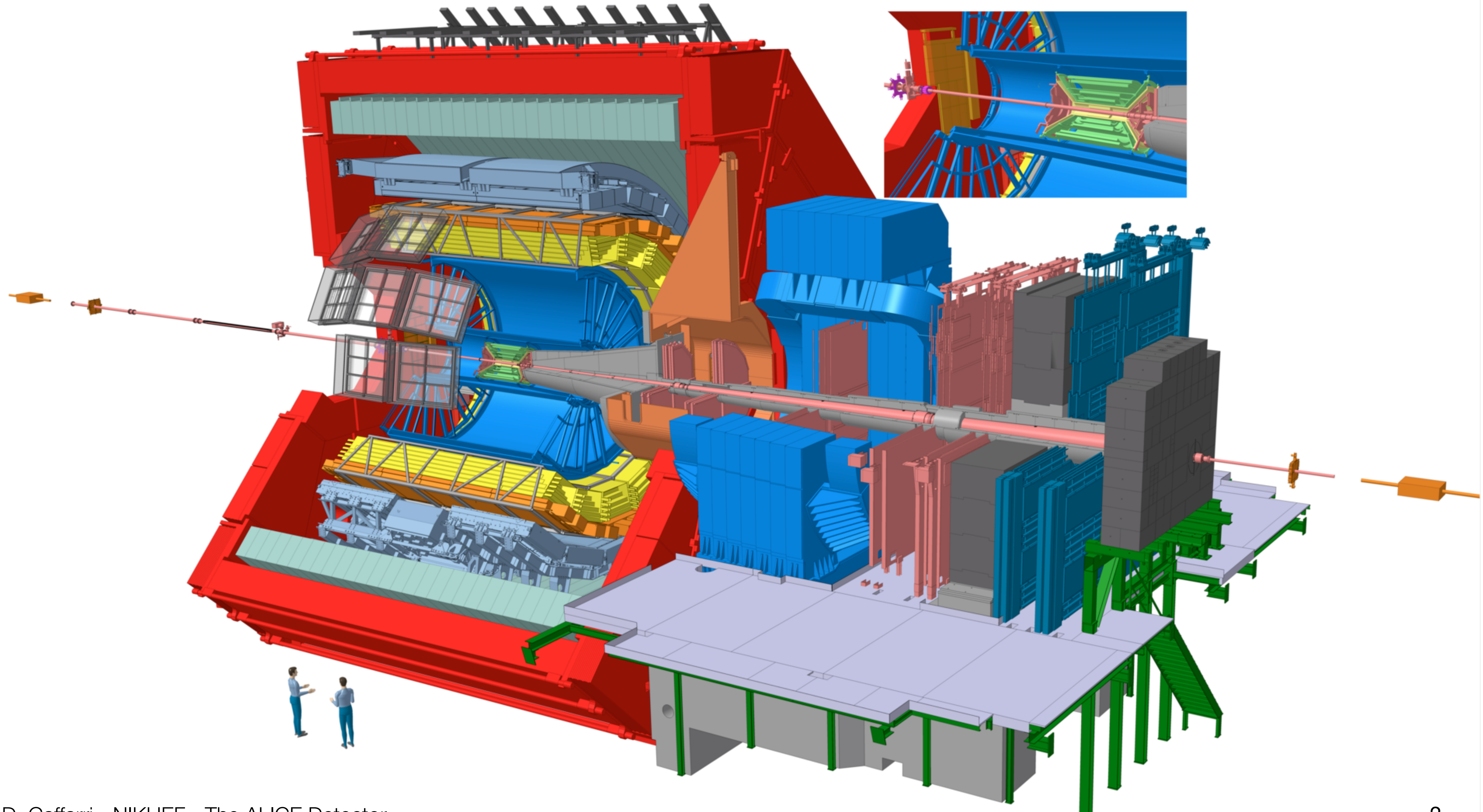

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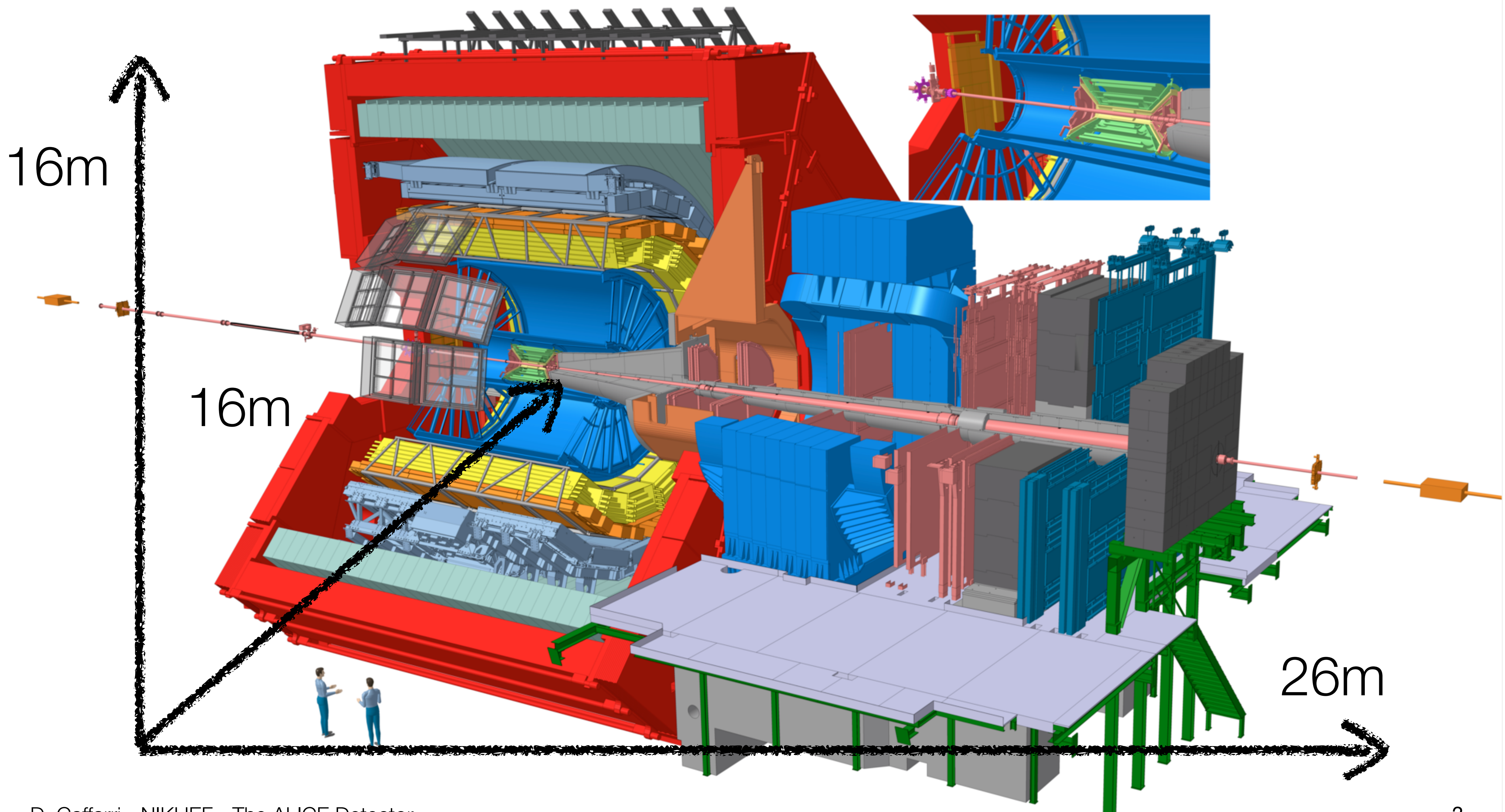

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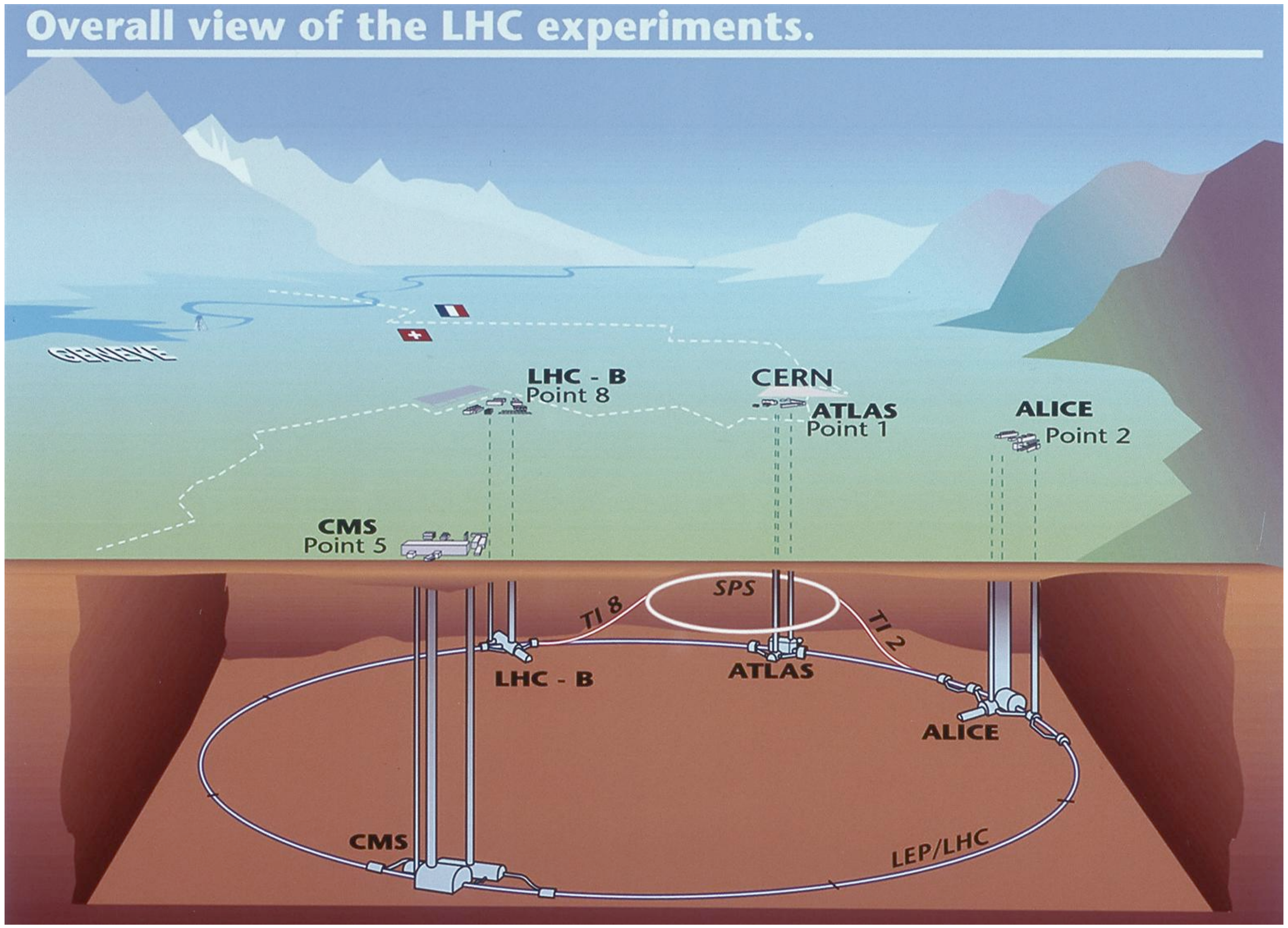
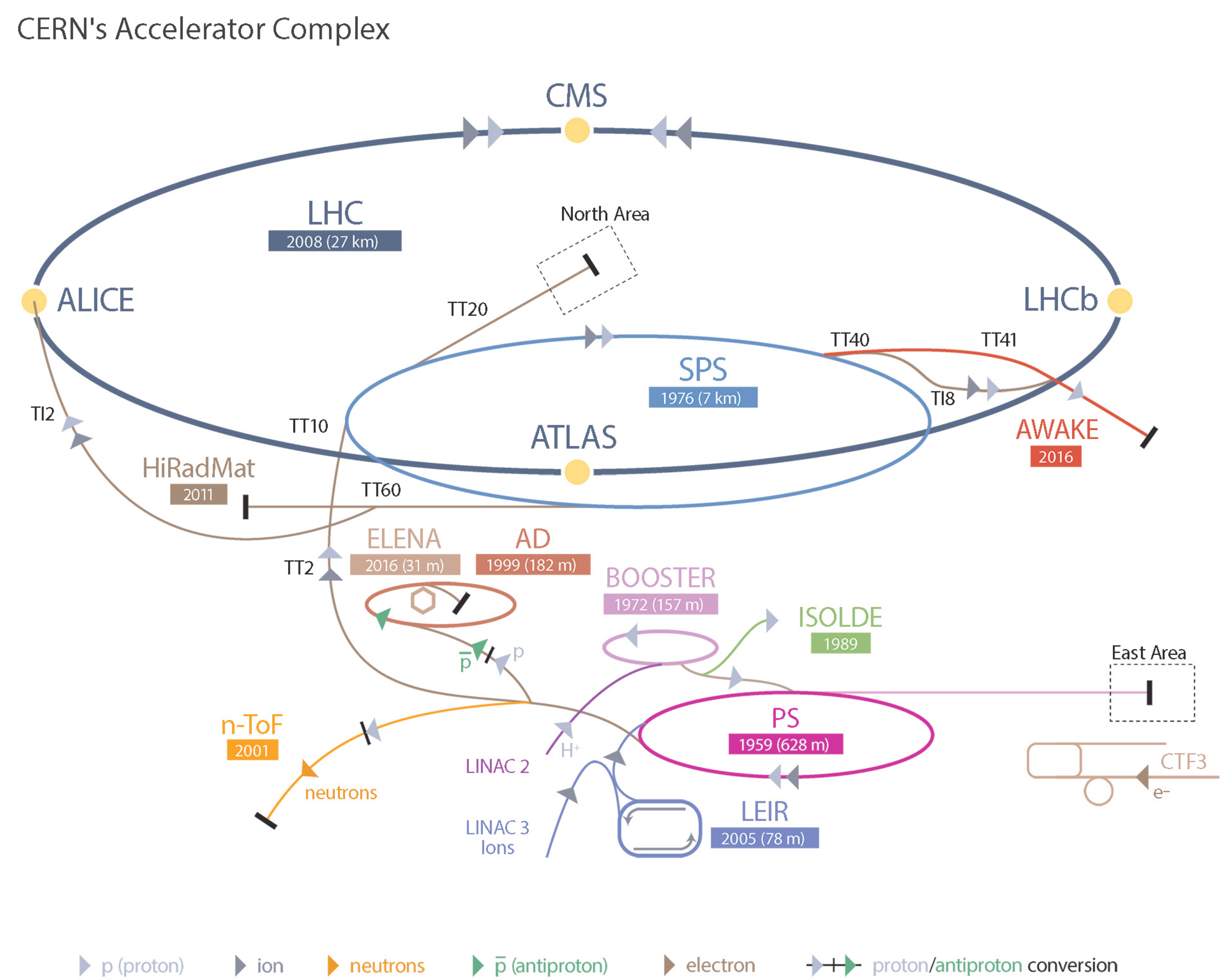



**Large Hadron Collider**

- 27 km accelerator at CERN

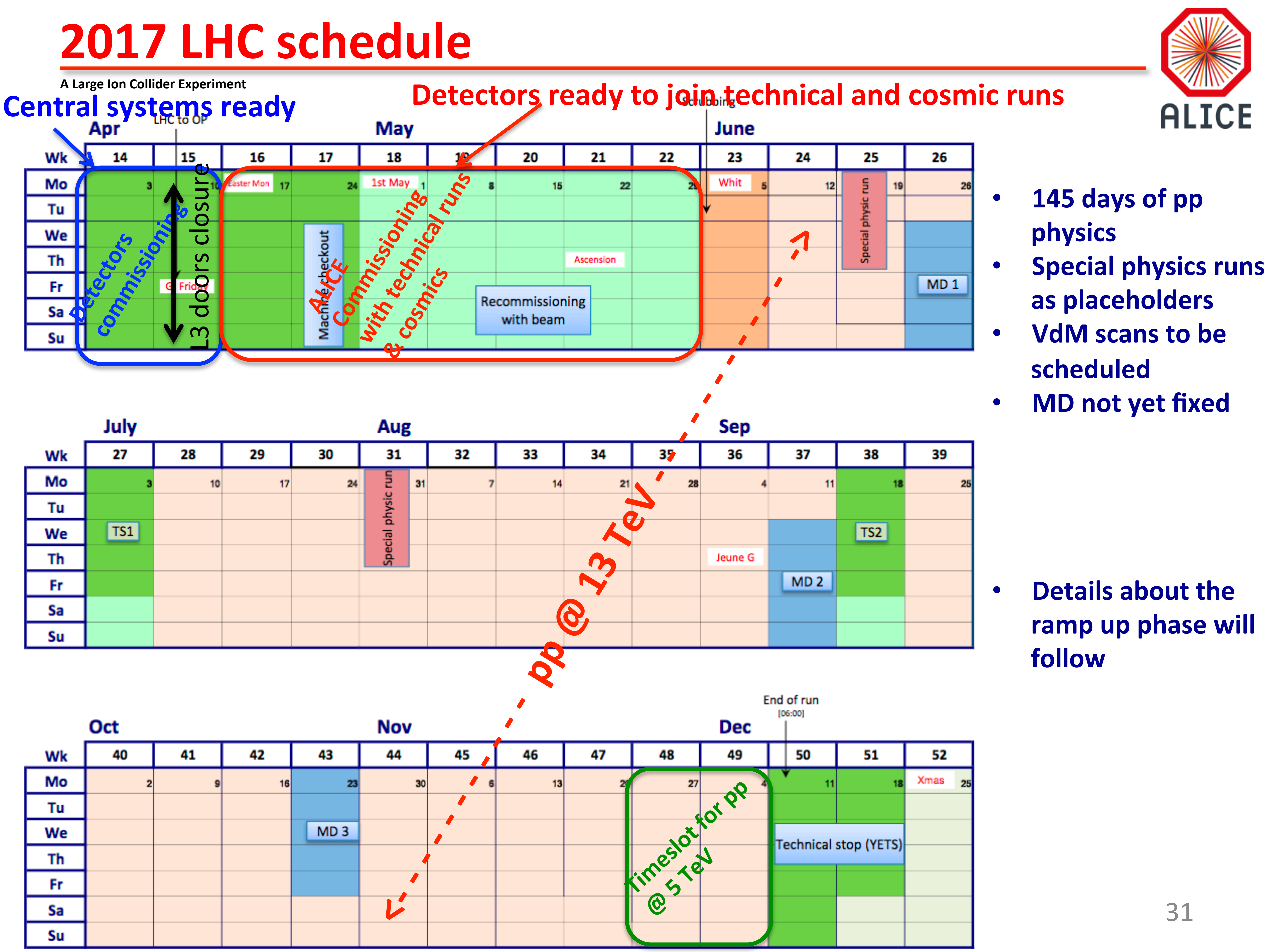
# Large Hadron Collider (LHC)




**Large Hadron Collider**

- 27 km accelerator at CERN
- last step of a complex systems of accelerators
  - peculiar in the world
  - build step by step in the last 60 years
  - important know-how and R&D program
- lot of other physics program in parallel to LHC, exploiting the injection lines

# Large Hadron Collider (LHC)




- ✳ LHC runs from March to beginning of December, 24h / 7 days
- ✳ 7/8 months of pp collisions, 3 weeks of Heavy ions physics runs (p-Pb, Pb-Pb, special pp collisions)

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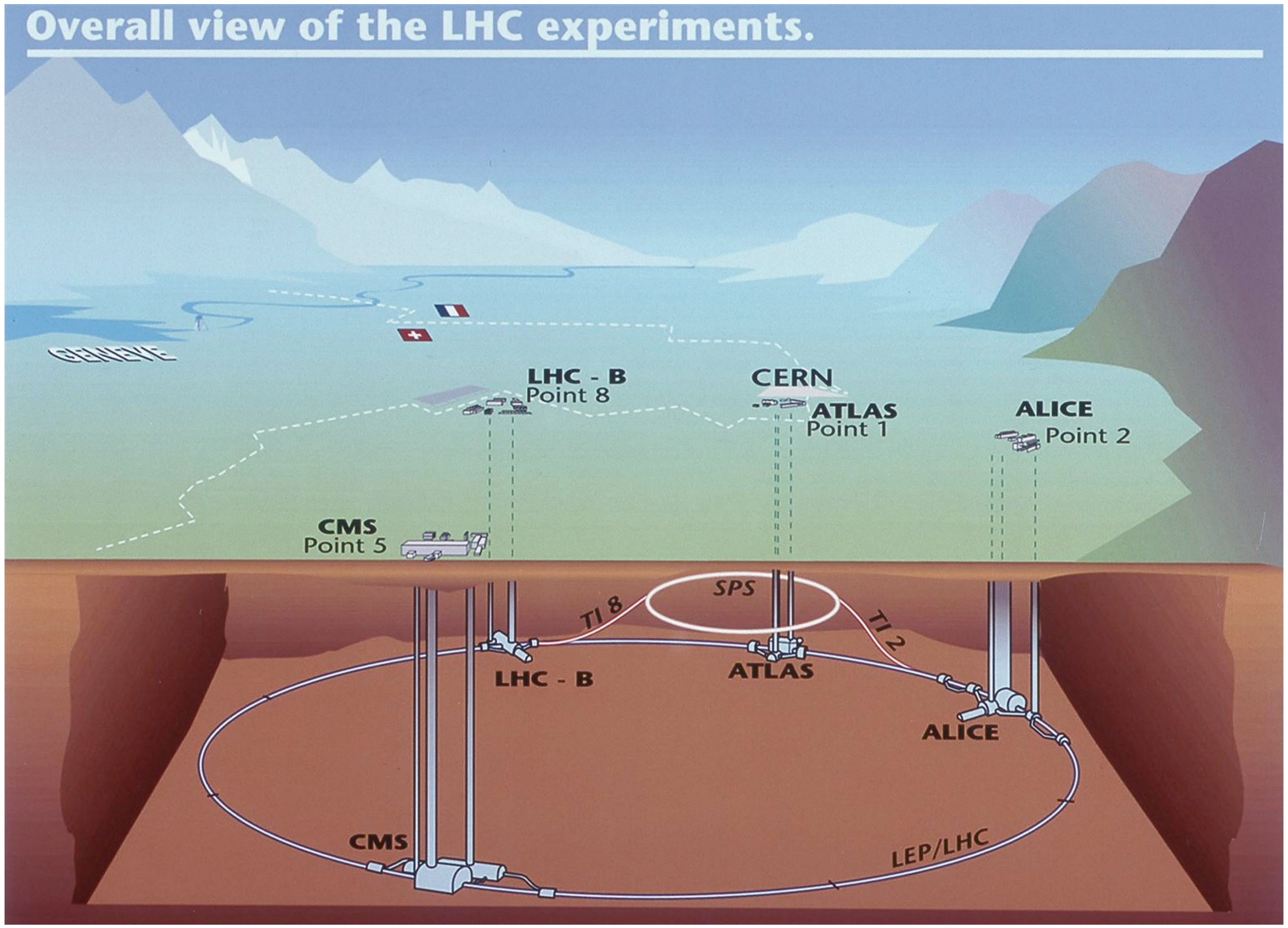
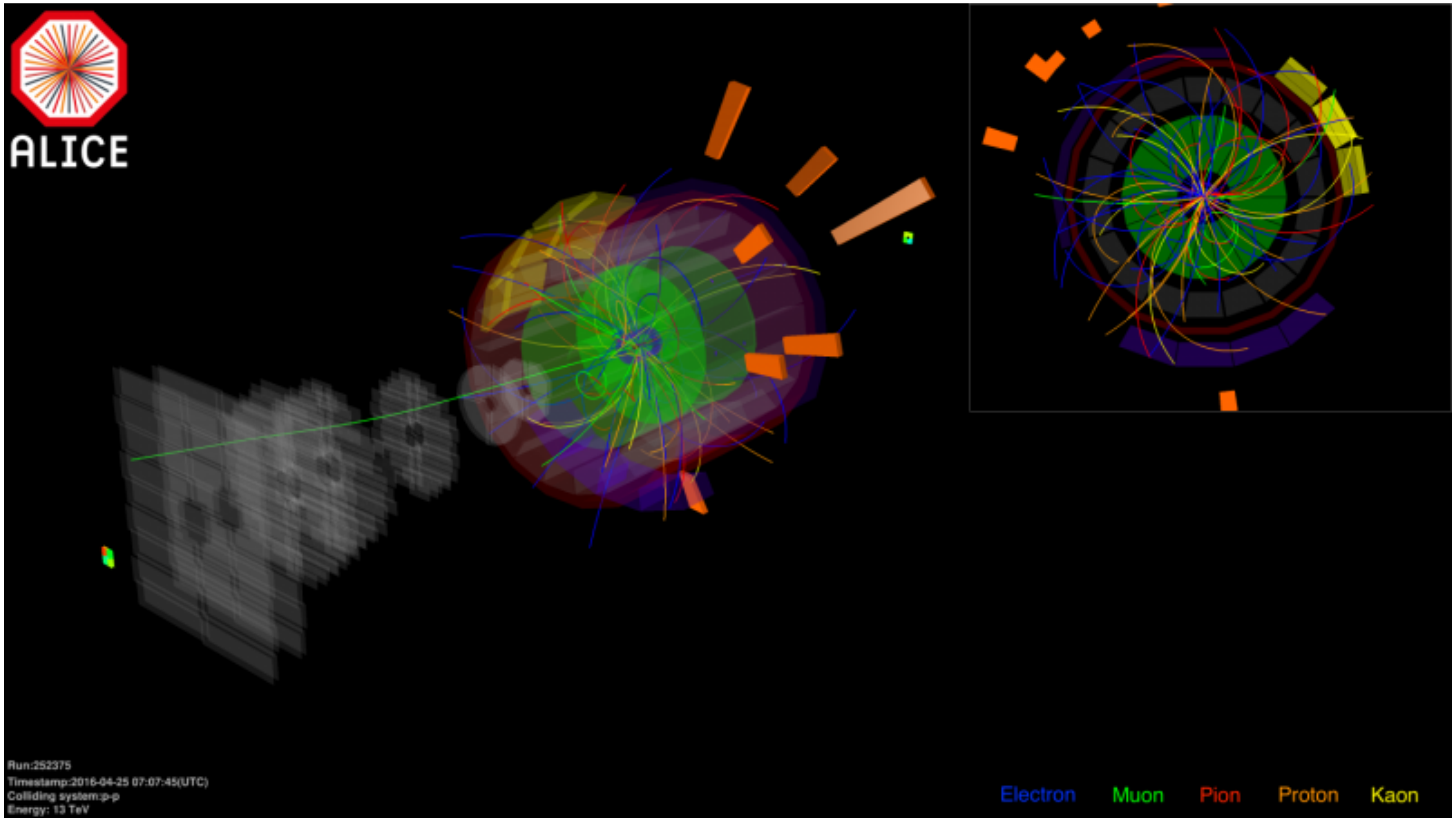



**Large Hadron Collider**

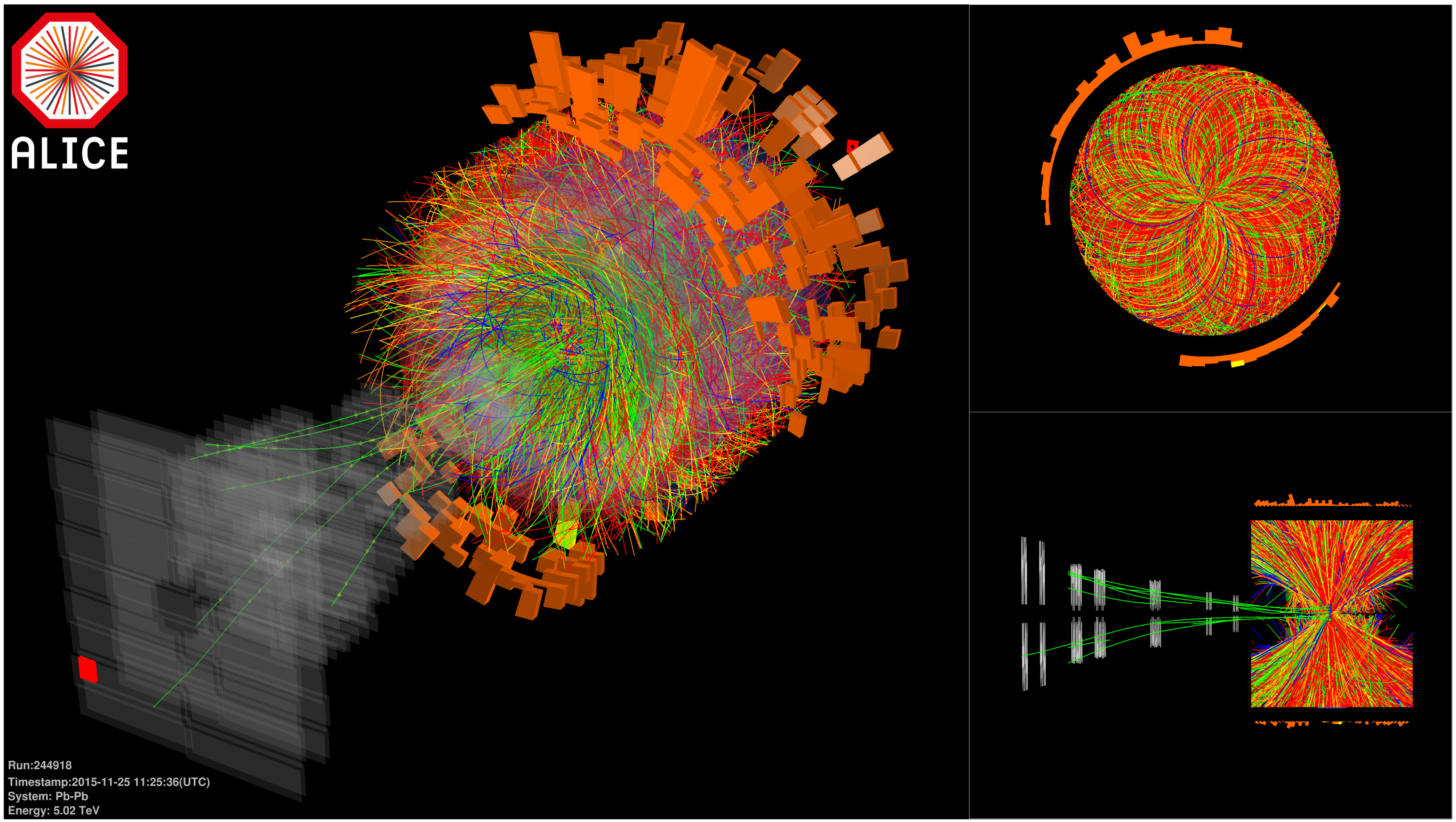
- 27 km accelerator at CERN
- 7/8 months per year of pp collisions
- ~1 month of Pb-Pb collisions
- 4 main experiments on the LHC
  - ALICE
  - ATLAS
  - CMS
  - LHCb
- 3 more "specialized" experiments

# Peculiarity of Pb-Pb collisions wrt to pp?




~ 6/7 particles produced on average per pp collision

# Peculiarity of Pb-Pb collisions wrt to pp?




~ 1600 particles produced on average per Pb-Pb collision (~17 particles for p-Pb collision)

# Peculiarity of Pb-Pb collisions wrt pp?

- Precise characterization of a state of matter that lasts less than a fm/c (1 fm/c ~ 3 x $10^{-24}$ seconds)
- This state of matter is partonic (made of quark and gluons), what we measure in the detector are hadrons.

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- **Main goal of HIC**: connect hadronic measurements of each event in their "ensable" to intrinsic properties of this state of matter (density, temperature, viscosity, …)
- different from pp where we mainly have searches (Higgs, exotica) or SM high-precisions measurements.

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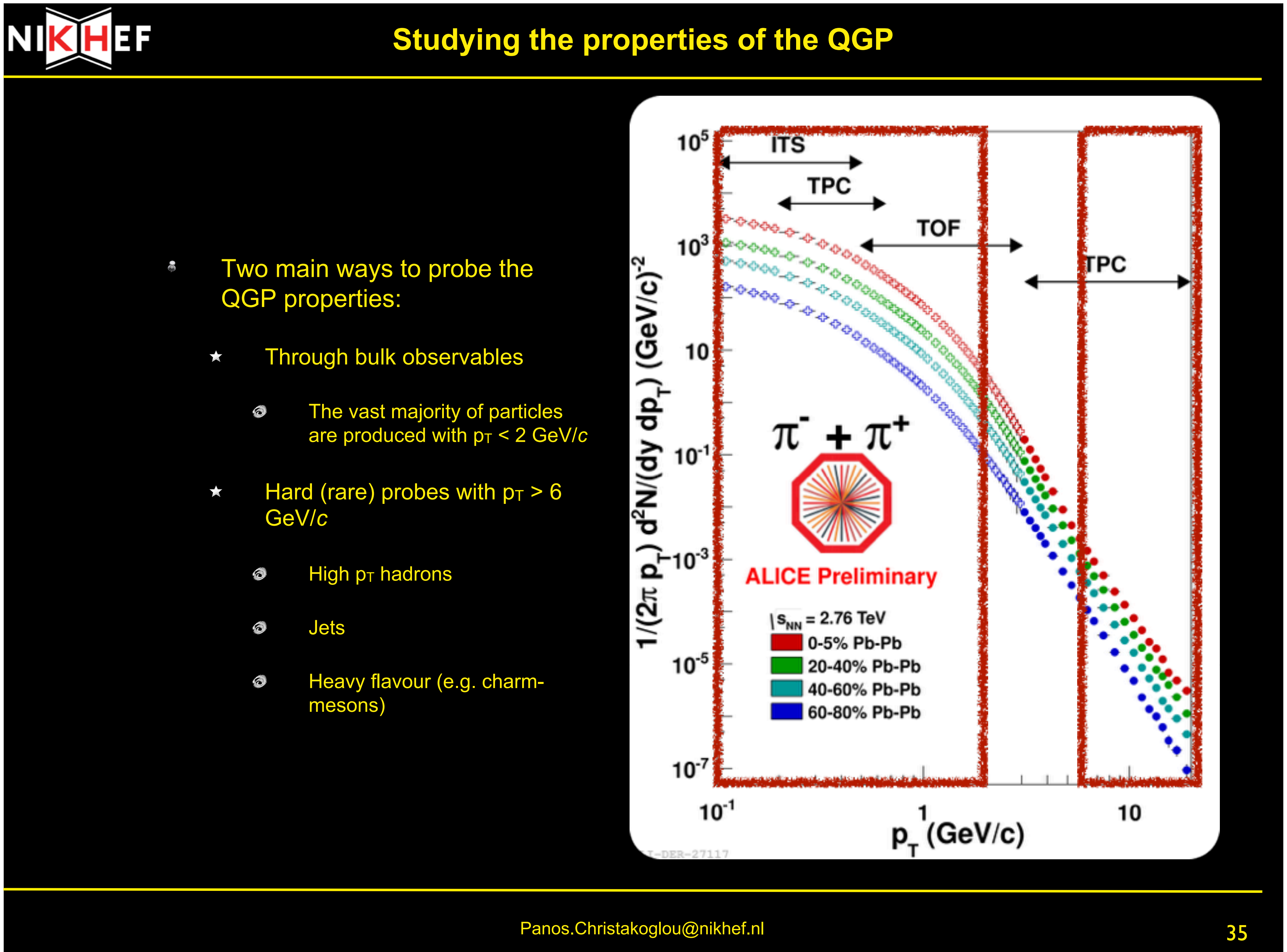
- Broaden set of measurements to access different properties and build a detailed general picture of the medium:
  - Flow measurements
  - Jet quenching
  - Strangeness enhancement
  - Quarkonia suppression
  - …

Goran's talk

# Peculiarity of Pb-Pb collisions wrt pp?




- Low-momentum particles
  - down to 150 MeV
  - vast majority of particles produced
- Particle Identification
  - look for different behaviors for different particle species.

- Need to reconstruct particles down to very low momentum.
- Particle Identification information needed to “recognize” different types of particles

# A Large Ion Collider **Experiment** (ALICE)

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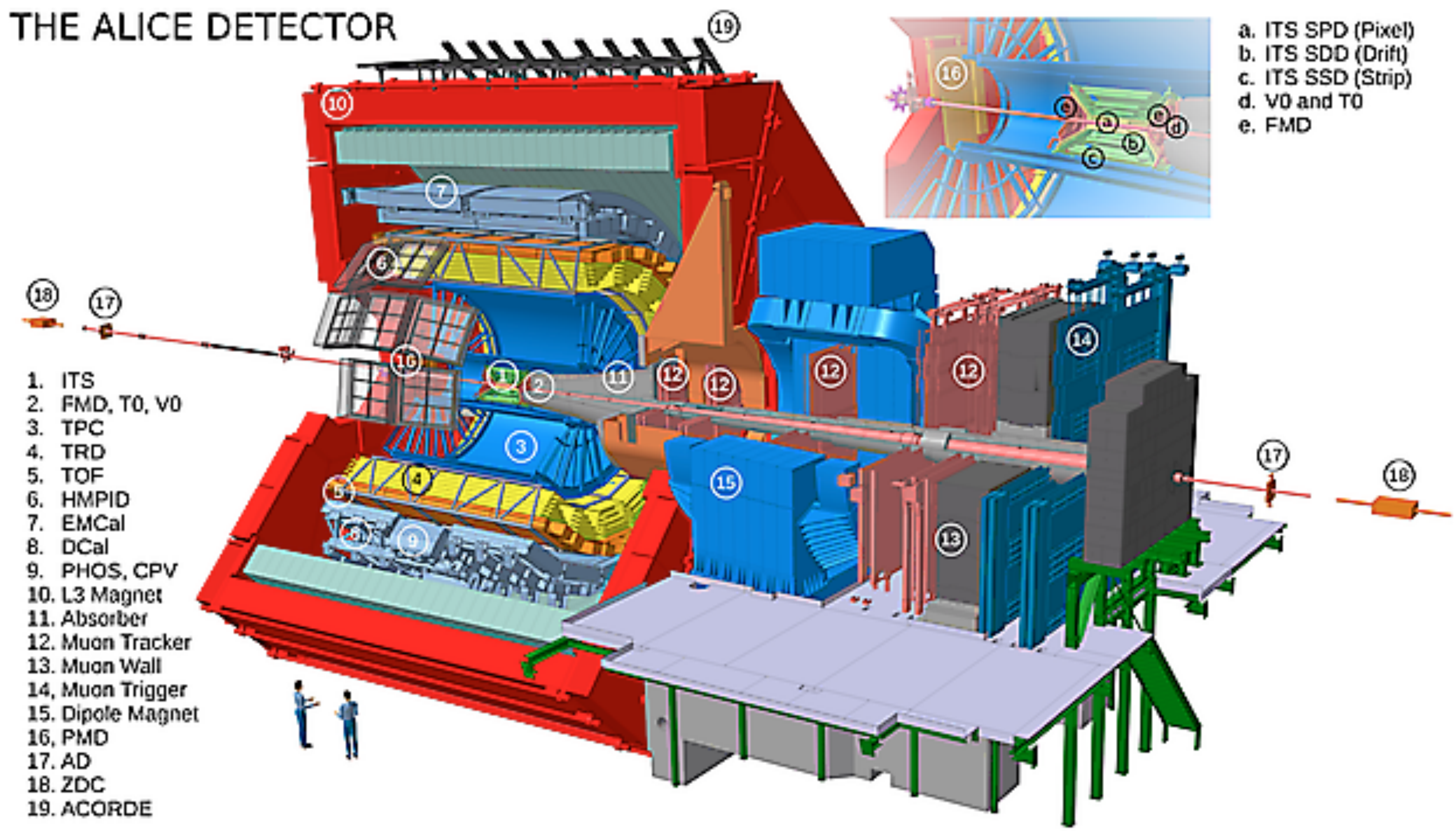
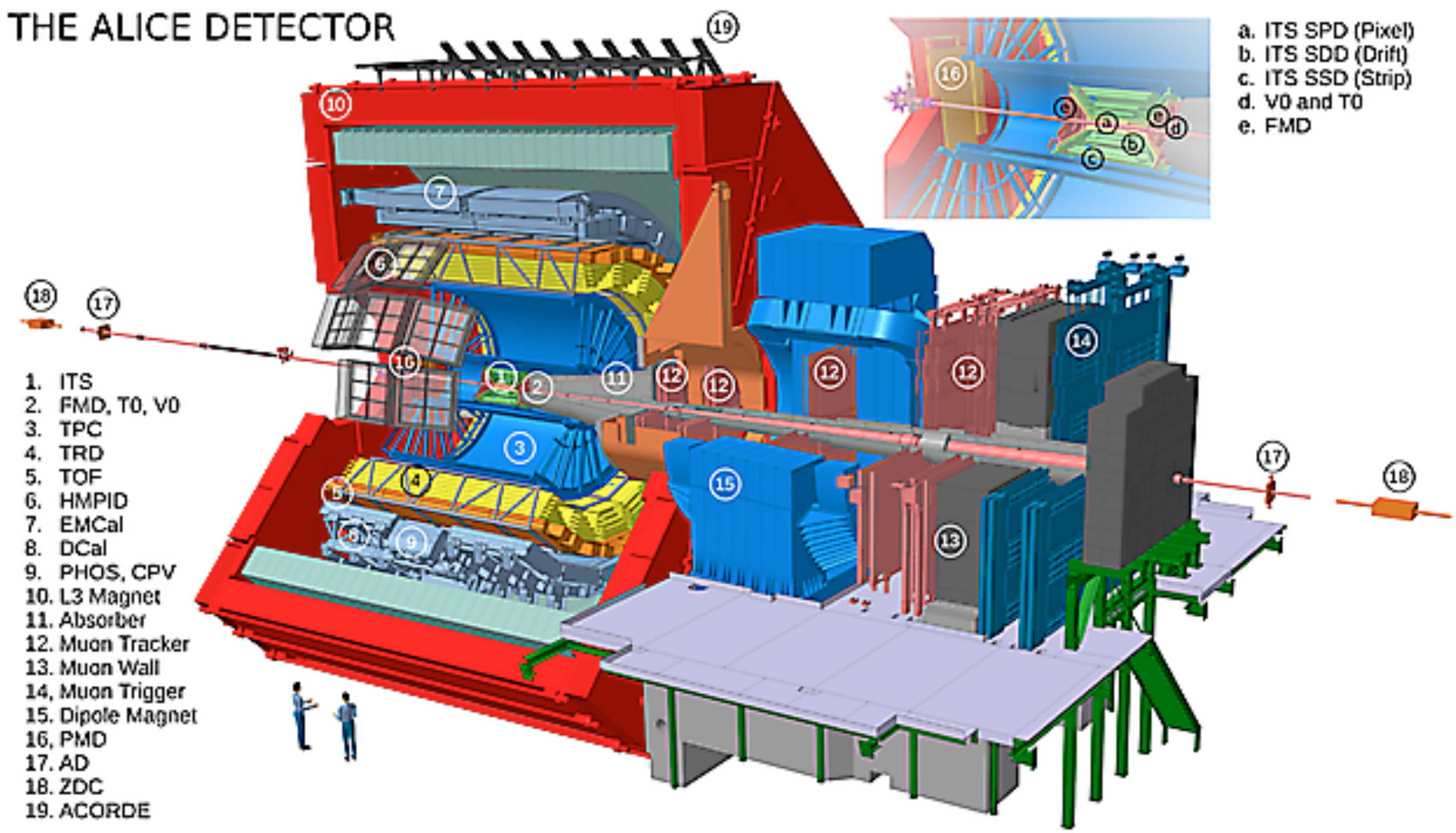


# A Large Ion Collider **Experiment** (ALICE)

- ✳ Need to reconstruct particles down to very low momentum.
- ✳ Particle Identification information needed to “recognize” different types of particles

- ✳ Complex detector formed of 19 sub-detectors.

- ✳ **Cutting edge technologies** and trigger algorithms have been (or are being) developed.



# Tracking and Particle IDentification

- **“Track” a particle** passing trough the detector means:
  - measure its **trajectory** → track length, momentum
  - try to define its **vertex** (where the particle was “born”)
    - close to the interaction point → **primary** particles
    - product of a decay or interaction with the material → **secondary** particles

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- **Identify a track** = try to understand which particle was produced.
  - How? Using effects that are different for **different mass** of the particles:
    - **velocity** (Time of flight method)
    - different **energy loss** while passing trough the detector
    - different **radiation emitted** interacting with a specific detector (transition radiation)

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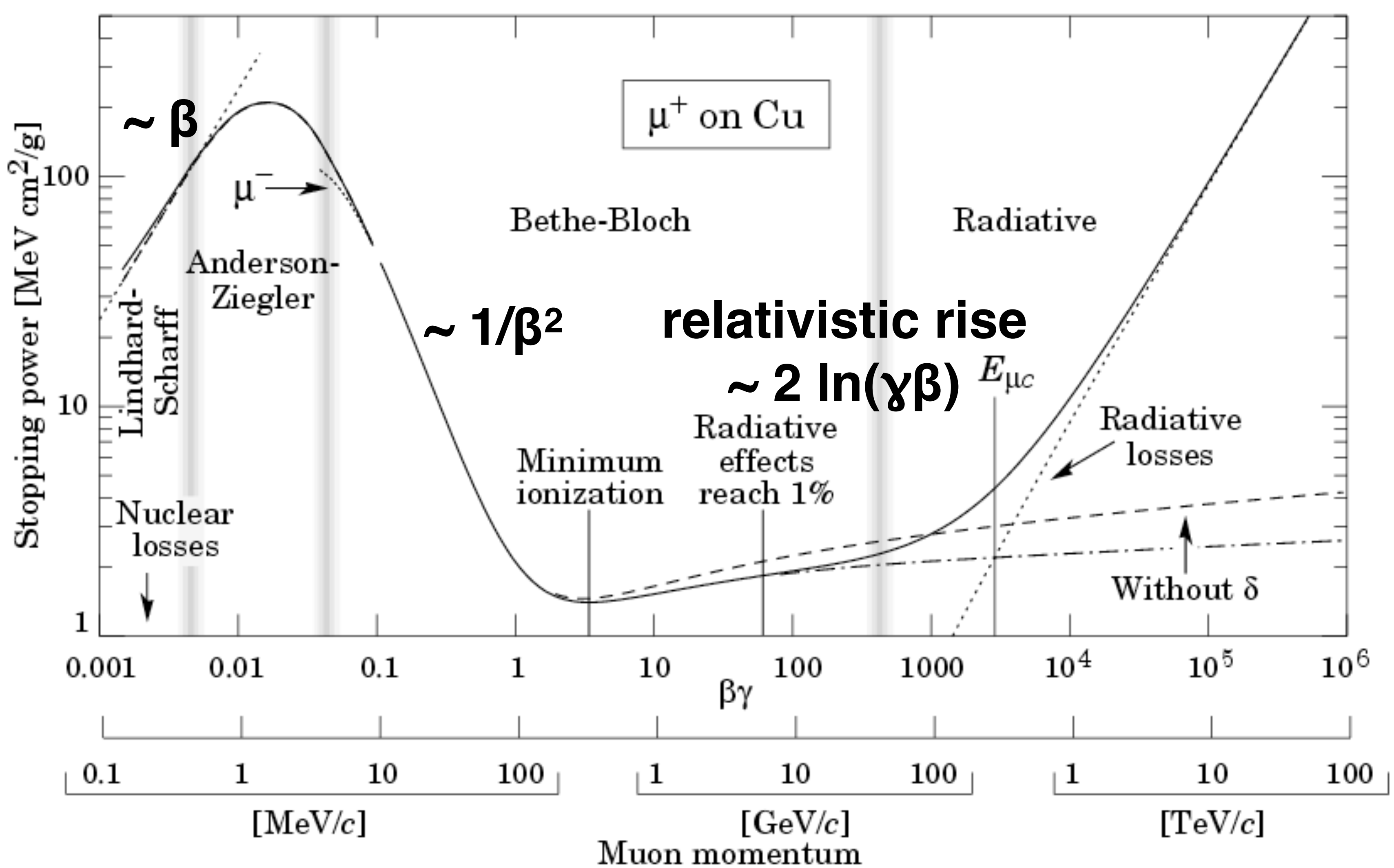
# Bethe-Bloch equation

$$-\left\langle \frac{dE}{dx} \right\rangle = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[ \frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$



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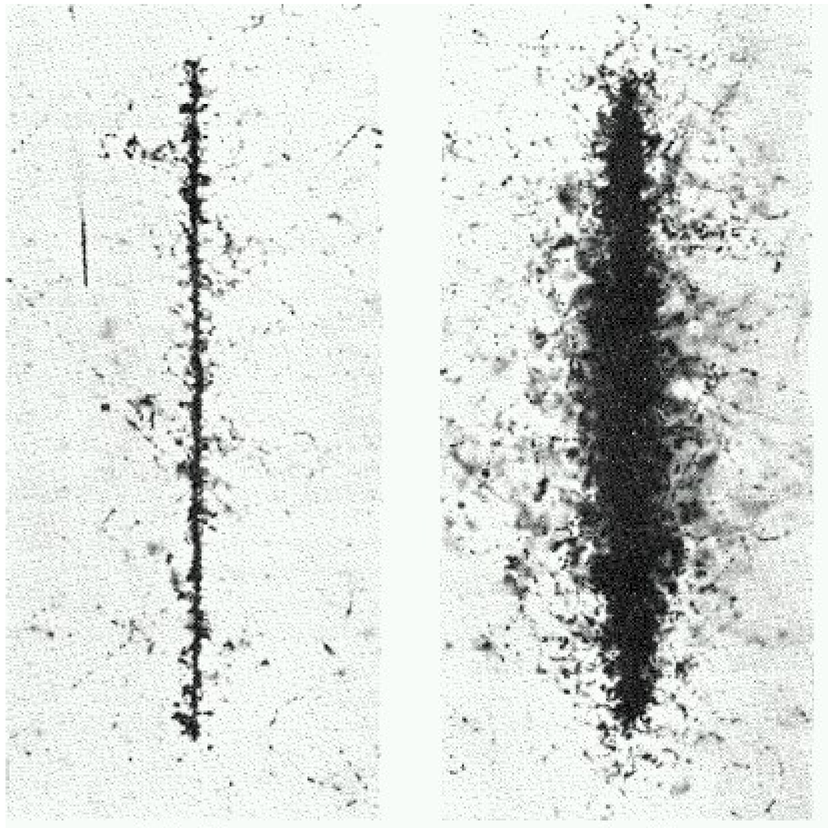
* charge of the particles traversing the chamber

Tracks of ions in emulsion

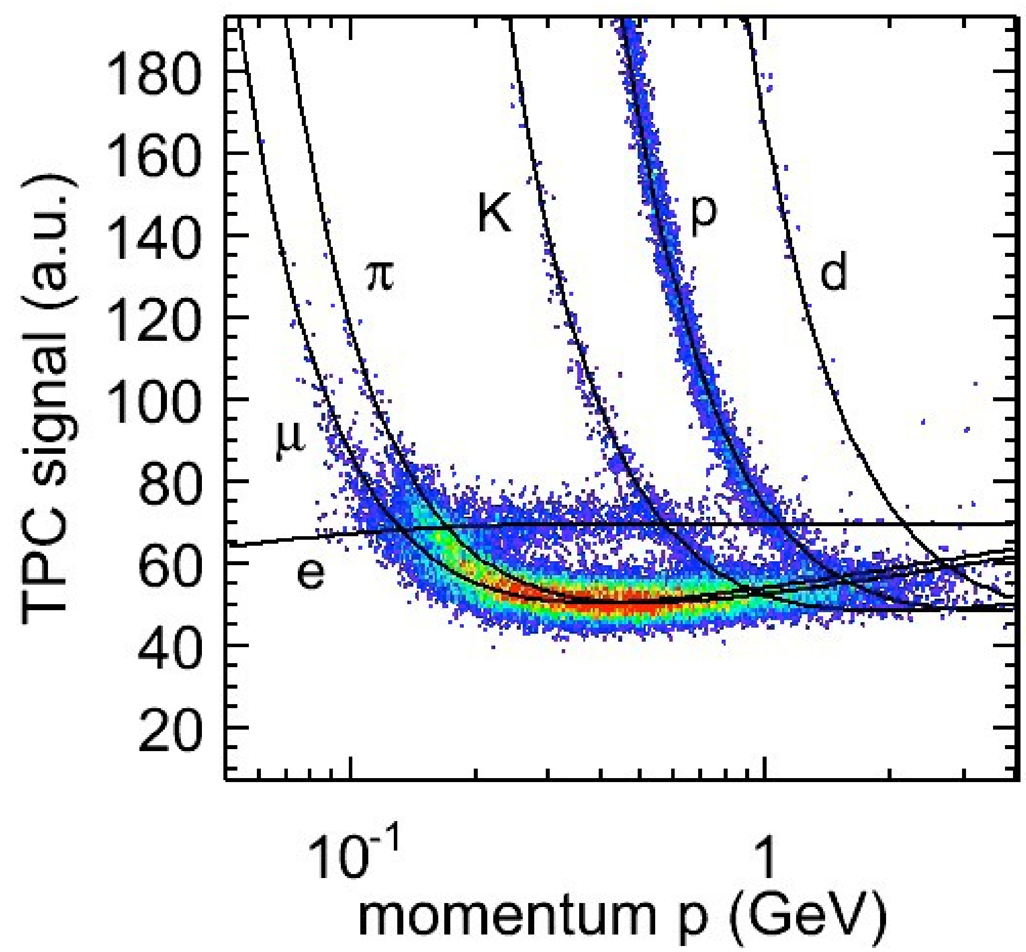


Iron  Z = 26  Thorium  Z = 90

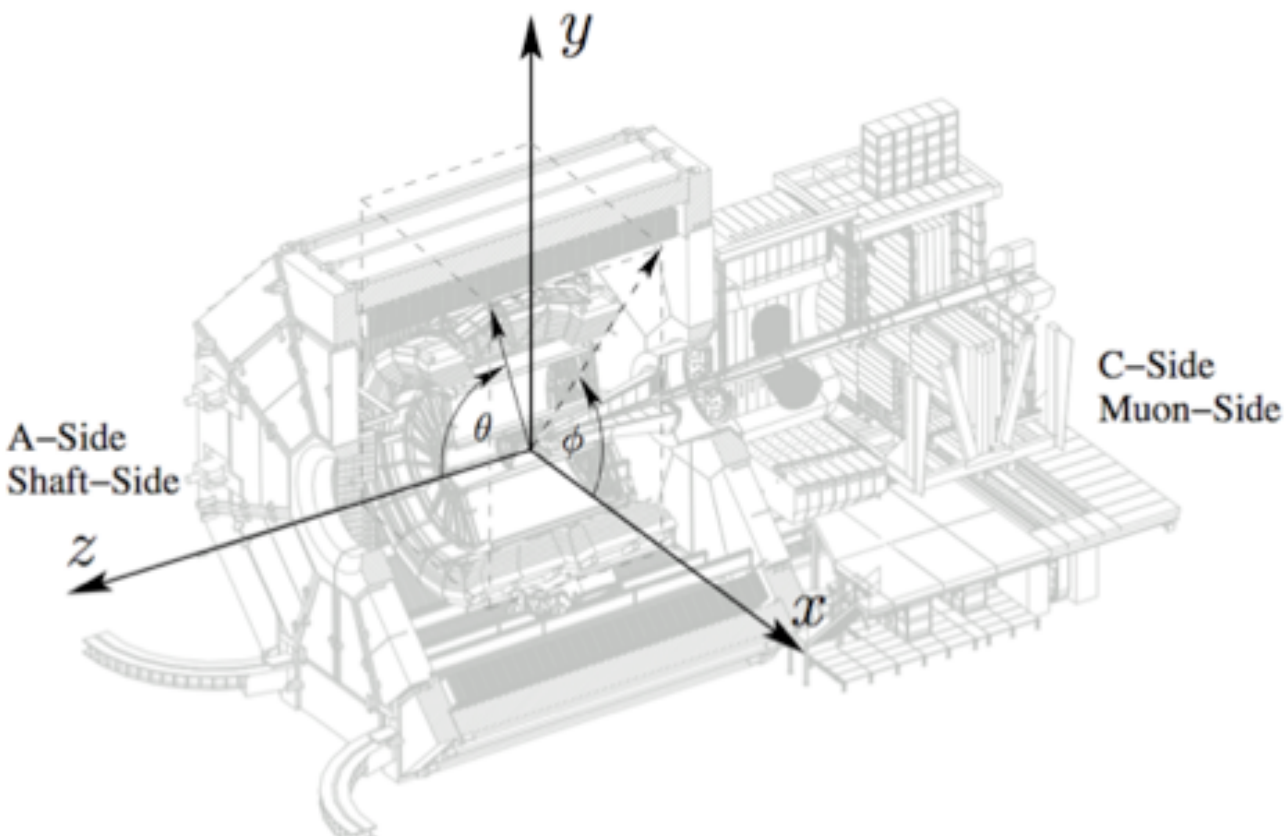
# Bethe-Bloch equation

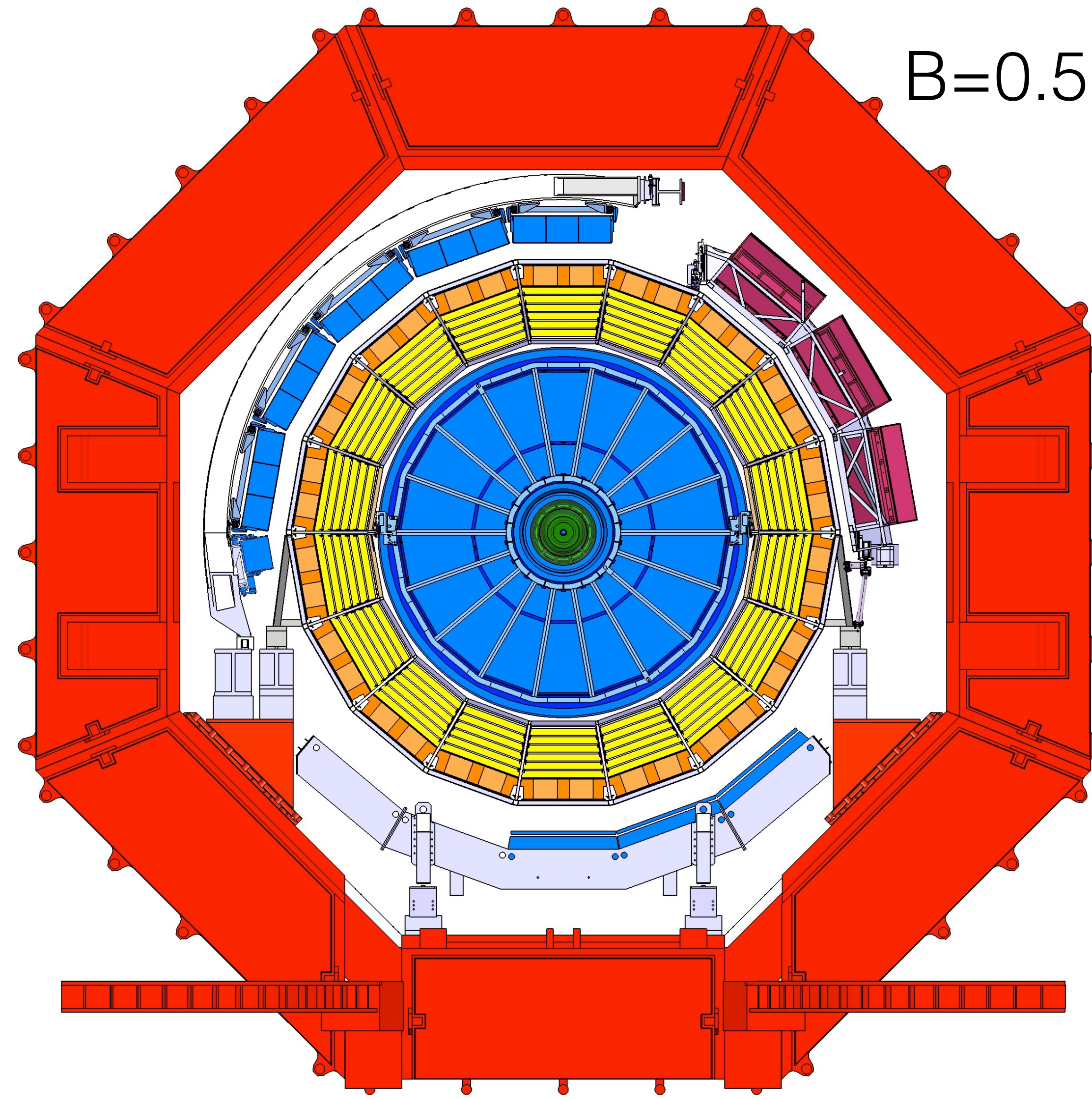
$$-\left\langle \frac{dE}{dx} \right\rangle = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[ \frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

- charge of the particles traversing the chamber
- in the $1/\beta^2$ regime, <dE/dx> vs p is different for different particle species



# Kinematic variables




transverse momentum $p_{\mathrm{T}} = p\sin(\theta_{\mathrm{CM}})$

rapidity relative to the beam axis i.e. longitudinal angle of emerging particle

$$y = \frac{1}{2}\ln\frac{E + p_z c}{E - p_z c}$$

if $m \ll p \Rightarrow E \approx p \Rightarrow \eta \approx y$

$$\eta = -\ln\left[\tan\left(\frac{\theta_{\mathrm{CM}}}{2}\right)\right]$$

Δη is Lorentz invariant under boost along longitudinal axis

# About particle reconstruction

- Today I will discuss only detector used to reconstruct **charged** particles.
  - in particular in ALICE we mainly look at **hadrons**: $\pi$, K, p
- Neutral and decay particles are usually reconstructed with ad hoc analysis techniques.

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- Two main classes of detector:
  - **Silicon detectors**:
    - ionizing radiation (charged particles) produces free electrons / holes in semiconductor materials.
    - very precise (~10-100μm )
    - quite expensive

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- Two main classes of detector:
  - **Silicon detectors**:
    - ionizing radiation (charged particles) produces free electrons / holes in semiconductor materials.
    - very precise (~10-100μm )
    - quite expensive

  - **Gas detectors**:
    - ionizing radiation (charged particles) produces electrons / ions pairs
    - different “regime” at which they can be operated —> different goals
    - can be used for large scale detector
    - different cons to be taken into account depending on the regime they are operated (slow, ion back flow, …)

# Tracking Devices. Inner Tracking System

6 layers of Silicon detectors:
- 2 layers of pixels (SPD)
- 2 layers of drift (SDD)
- 2 layers of strips (SSD)

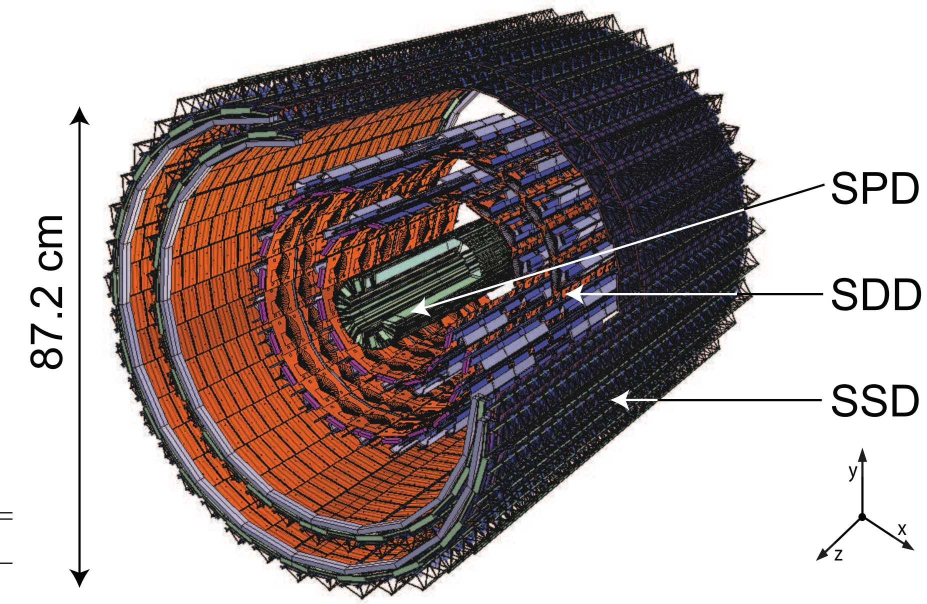


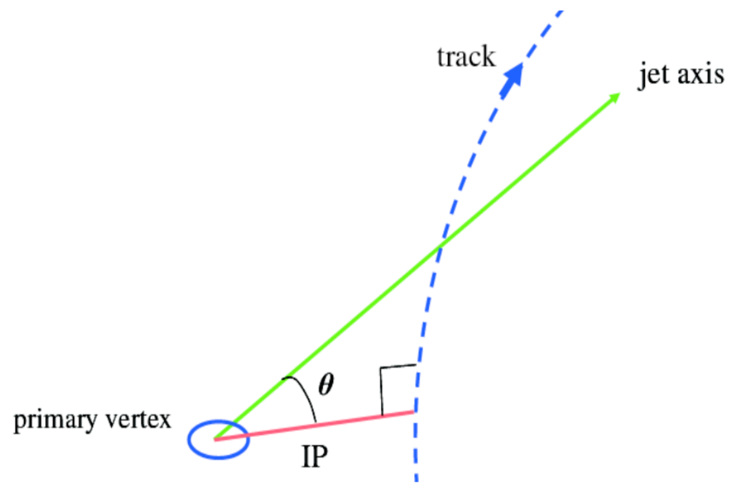

Table 3.2: Characteristics of the six ITS layers.

| Layer | Type | $r$ (cm) | $\pm z$ (cm) | Modules | Active Area per module | Material Budget ($X/X_0$) |
|---|---|---|---|---|---|---|
| 1 | pixel | 3.9 | 14.1 | 80 | $12.8 \times 70.7$ mm$^2$ | 1.14 |
| 2 | pixel | 7.6 | 14.1 | 160 | $12.8 \times 70.7$ mm$^2$ | 1.14 |
| 3 | drift | 15.0 | 22.2 | 84 | $70.17 \times 75.26$ mm$^2$ | 1.13 |
| 4 | drift | 23.9 | 29.7 | 176 | $70.17 \times 75.26$ mm$^2$ | 1.26 |
| 5 | strip | 38.0 | 43.1 | 748 | $73 \times 40$ mm$^2$ | 0.83 |
| 6 | strip | 43.0 | 48.9 | 950 | $73 \times 40$ mm$^2$ | 0.86 |

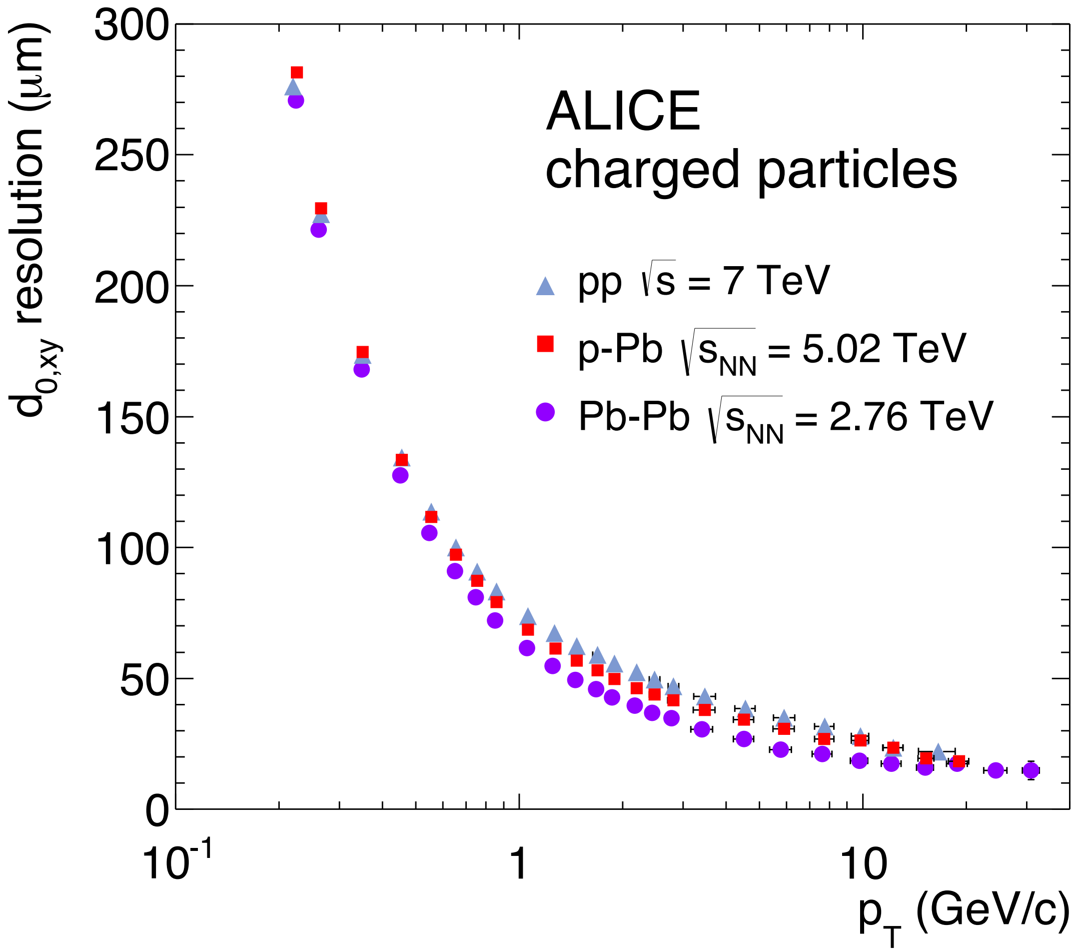
- High **segmentation** → efficient track finding in high multiplicity environment.
- Low **material budget** → tracking down to low-pT, limit multiple scattering.
- High track **impact parameter resolution**.

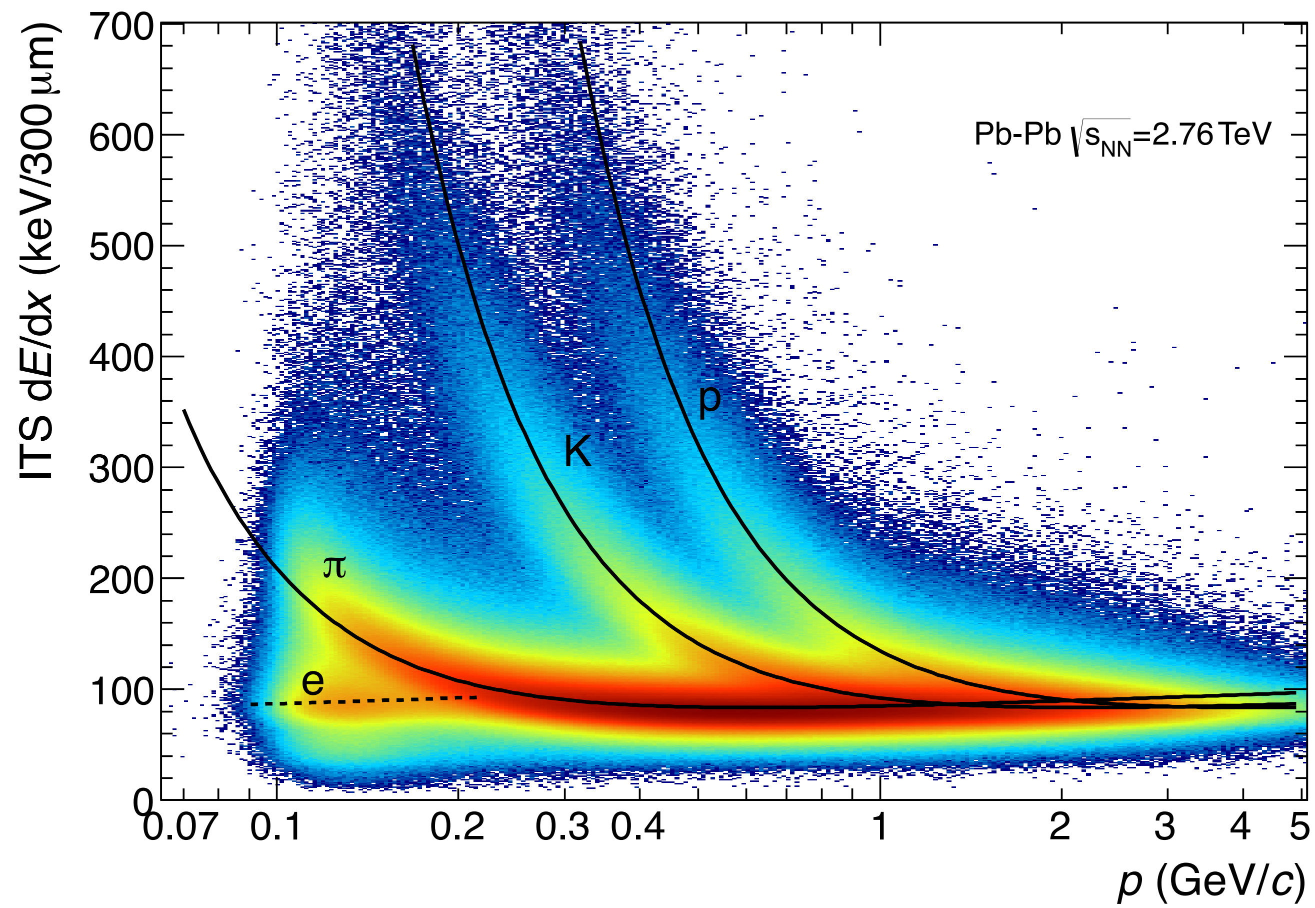
- Due to the technologies chosen, ITS allow also PID at low-pT

# Tracking Devices. Inner Tracking System



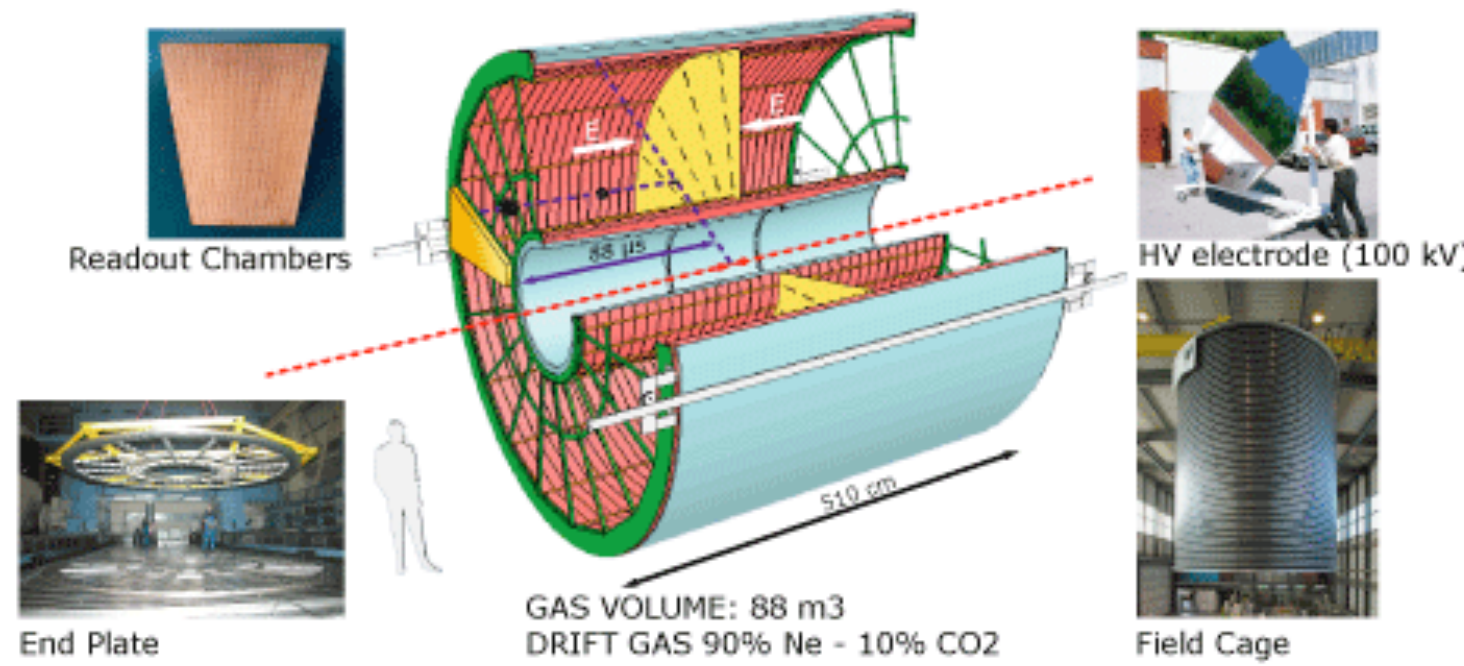

- Separation of particle species from 100 MeV to 500 MeV
- Impact parameter resolution of 60 μm for particles of 1 GeV/c

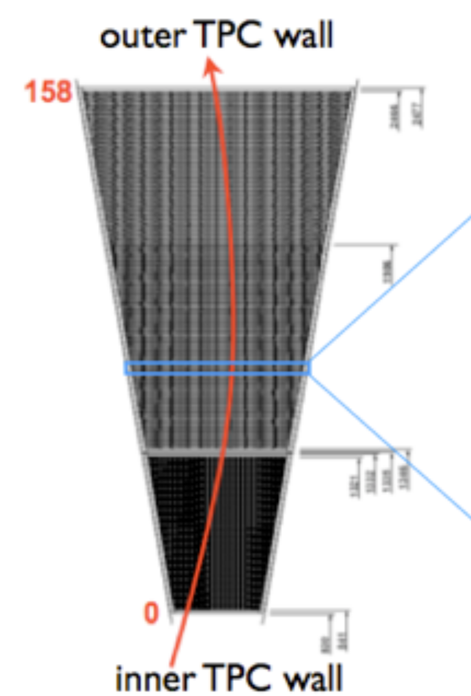


# Tracking Devices. Time Projection Chamber

- Main ALICE tracking device:
  - inner radius 80 cm
  - outer radius 250 cm
  - length 510 cm
  - $|\eta| < 0.9$



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  - inner radius 80 cm
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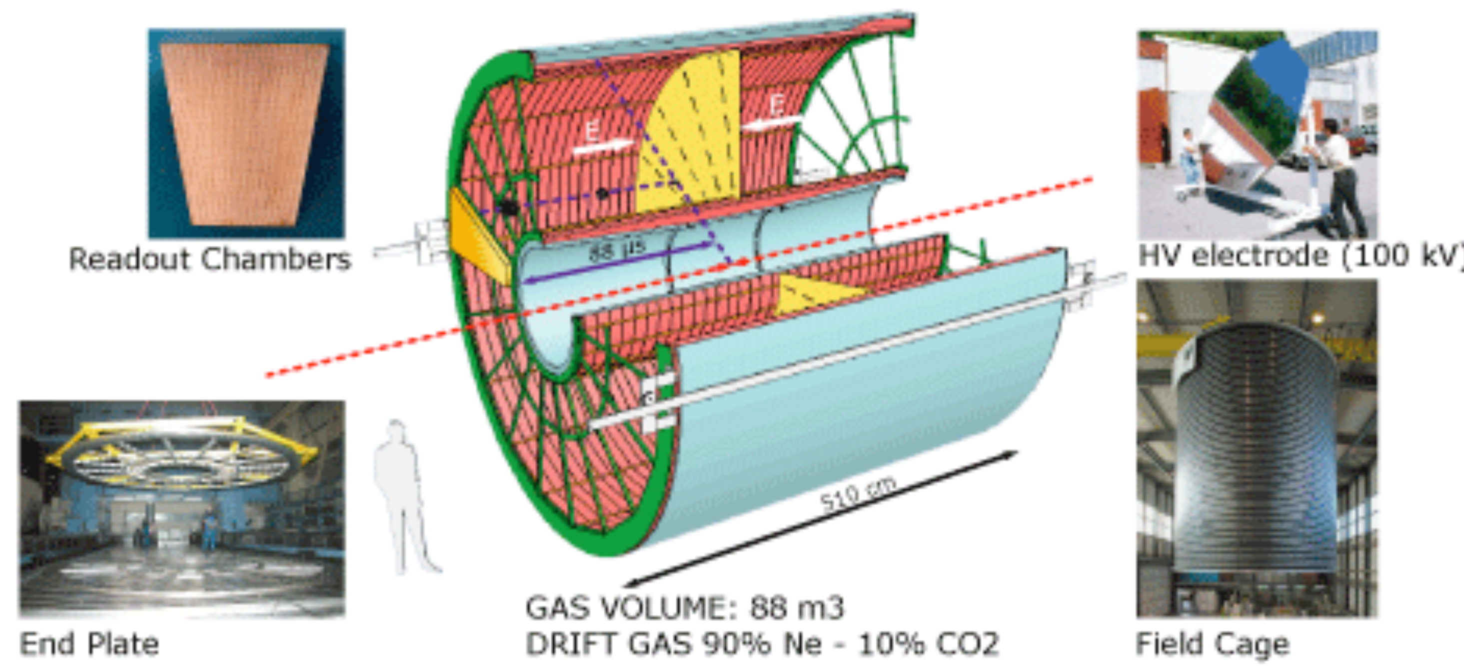
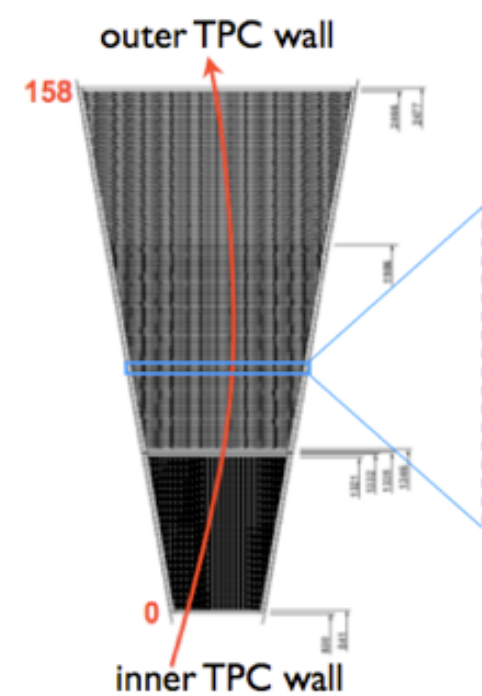
  - $|\eta| < 0.9$
  - $Ne/CO_2/N_2$ gas admixture
    - drift velocity 2.7cm/μs
    - low electron diffusion
    - low radiation length



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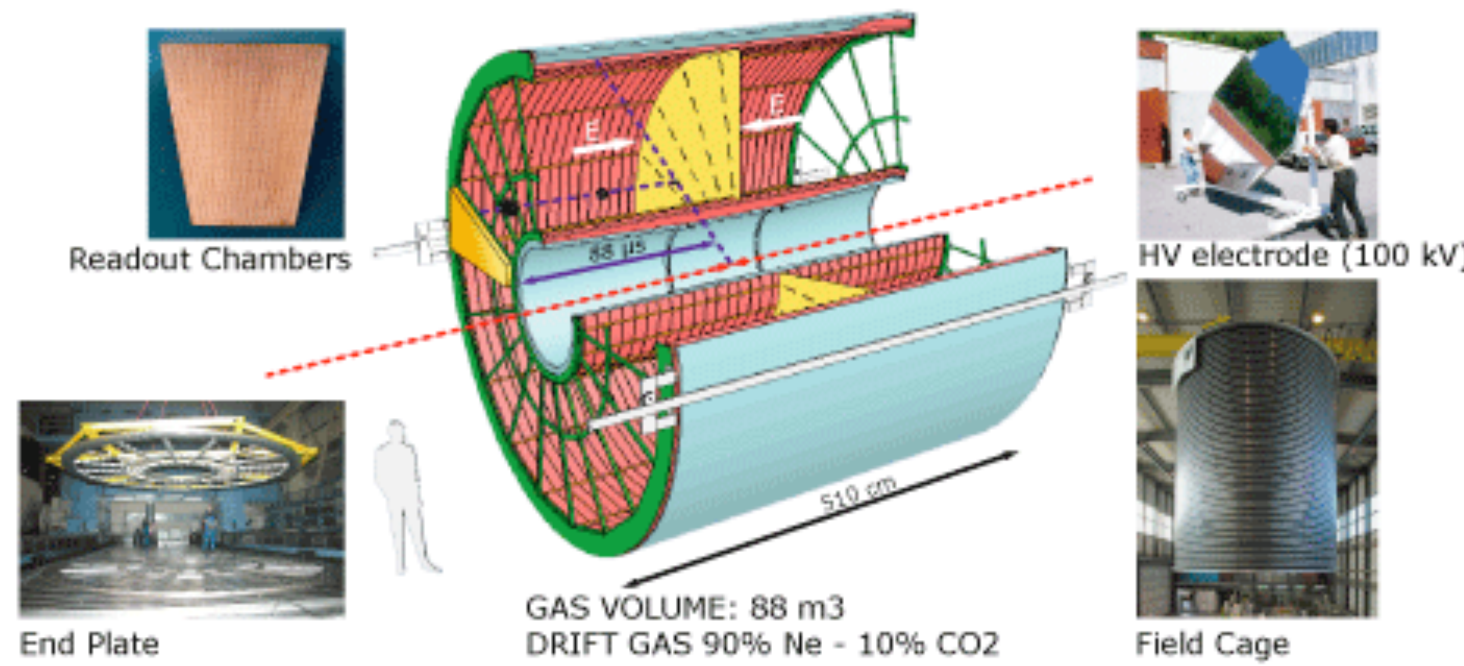
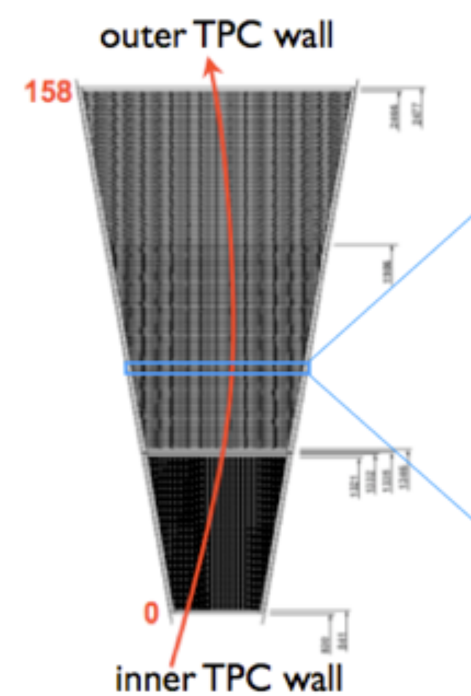
  - $Ne/CO_2/N_2$ gas admixture
    - drift velocity 2.7cm/μs
    - low electron diffusion
    - low radiation length
- Read out planes: MWPC
  - 18 sectors ~ 20° angle
  - up to 159 space points to reconstruct a particle
  - collected charge ≈ mass of the particle



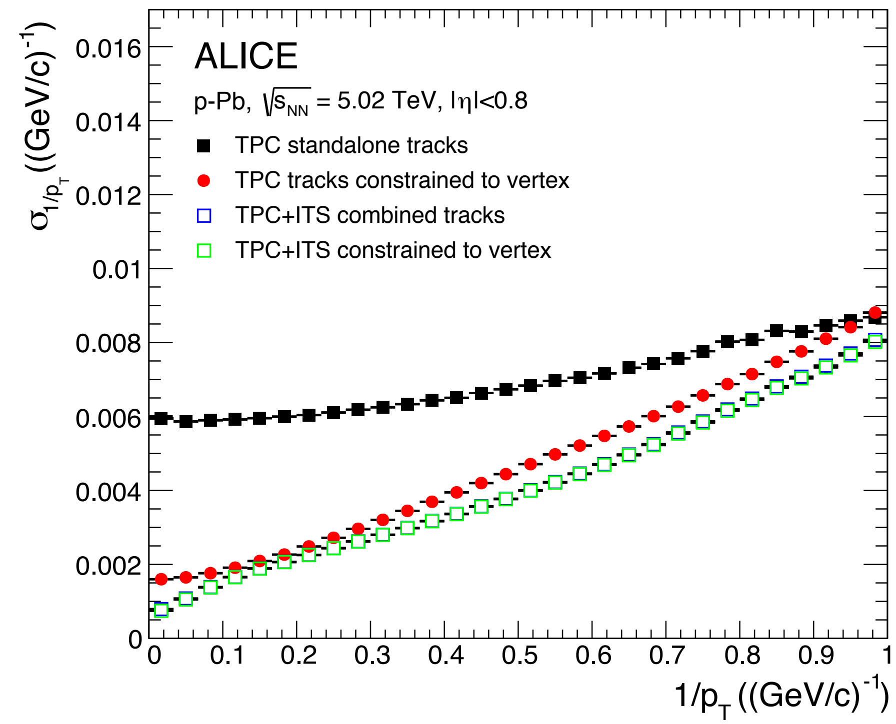



# Tracking Devices. Time Projection Chamber

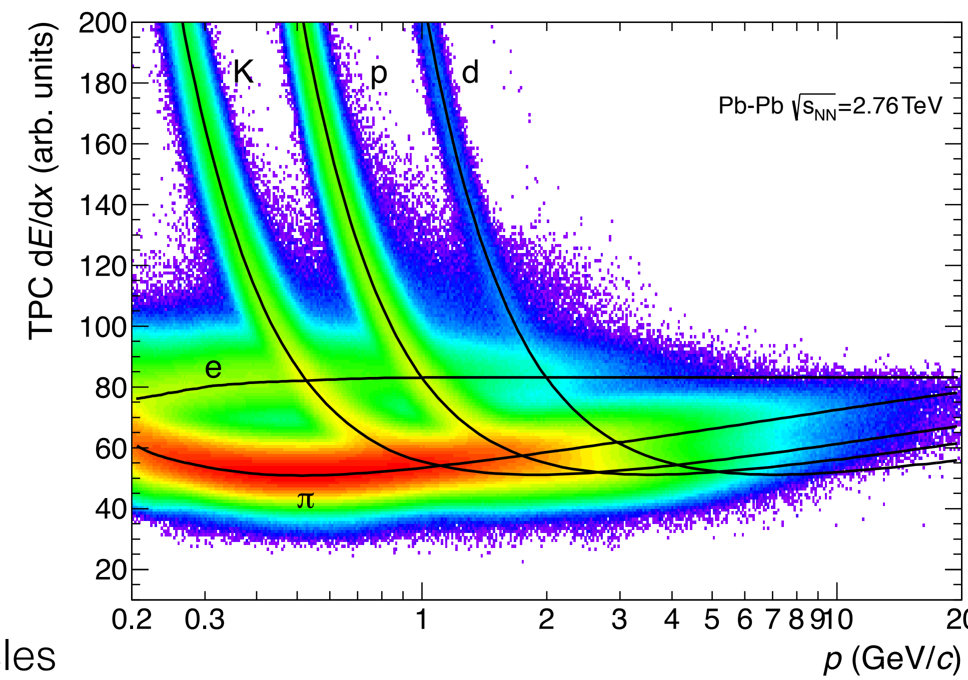
- Main device to measure trajectory and momentum of particles

$$\frac{\sigma_{p_T}}{p_T} = p_T\, \sigma_{1/p_T}$$

  - 0.8% precision on the momentum determination for tracks with pT ~1 GeV
  - 1.8% for tracks with pT ~10 GeV




- Energy deposited by particles while traversing the TPC is different for different particle masses
- Good separation of particles*:
  - π/K up to 0.7 GeV/c
  - K/p out to 1.1 GeV/c



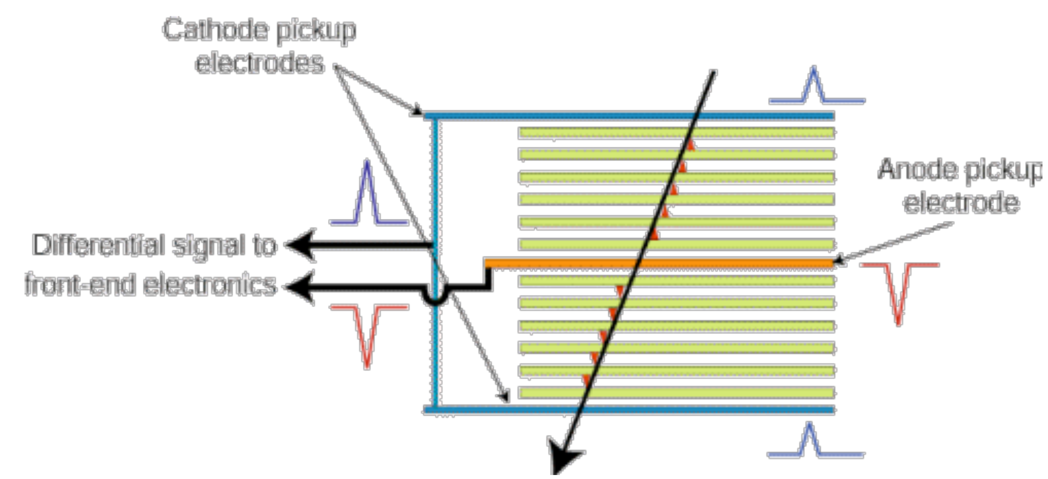

(*) can be use with other ad hoc techniques for high momentum particles

# PID detectors: Time of Flight

- **Velocity measurement**, that associated to the momentum one, allows to measure the mass of the particle.

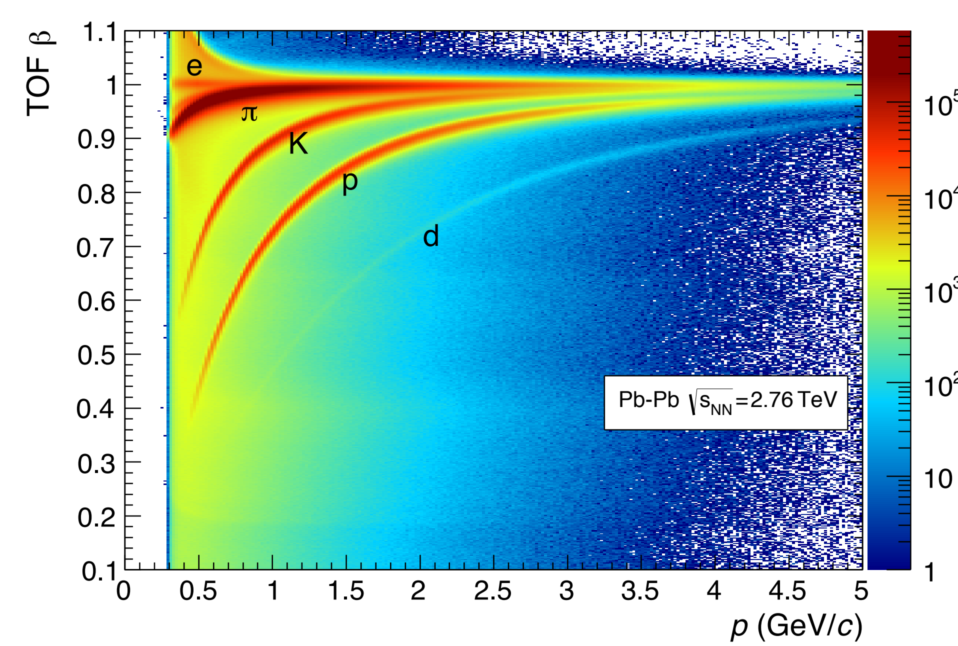
$$m^2 = \frac{p^2}{c^2}\left(\frac{c^2t^2}{L^2} - 1\right).$$

- Gas detector based on **Multigap Resistive Place Chambers** to measure the exact time the particle pass through it.




- **Time Of Flight resolution about 85-100 ps**

- Good separation of different particles:
  - π/K up to 1.5 GeV/c
  - K/p up to 4 GeV/c



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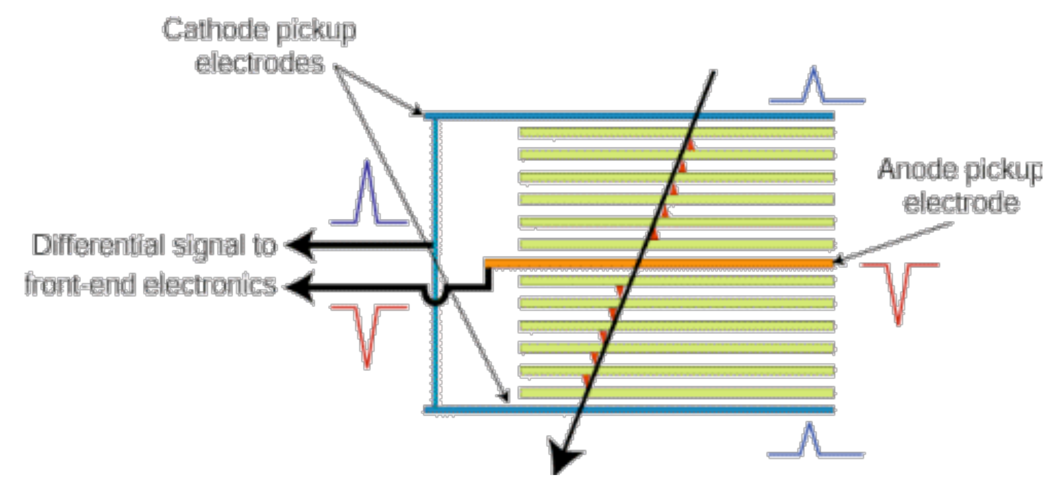
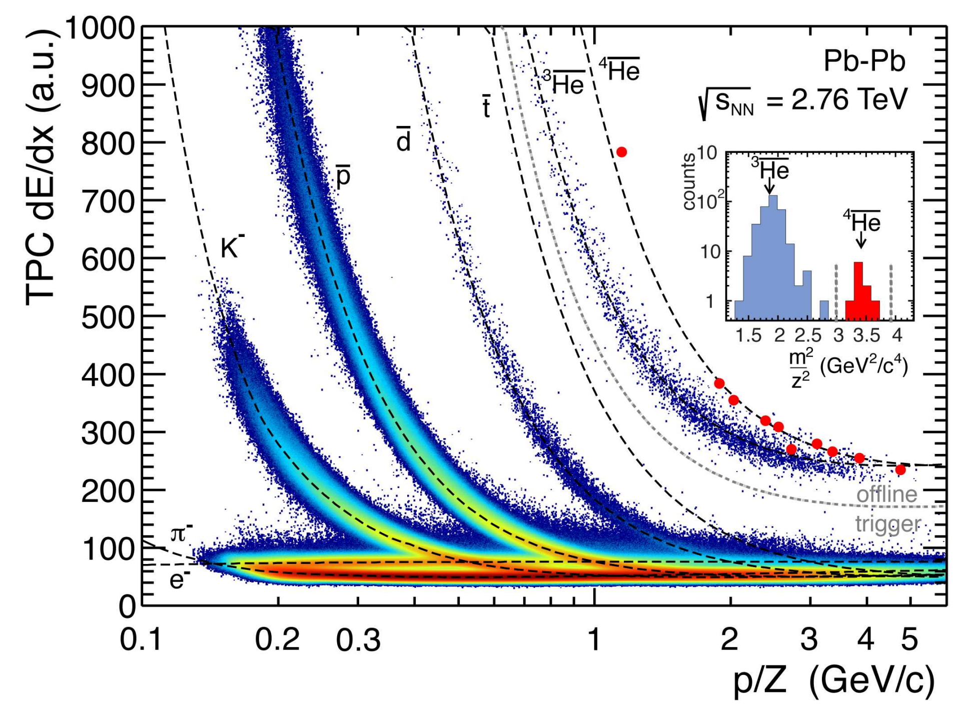


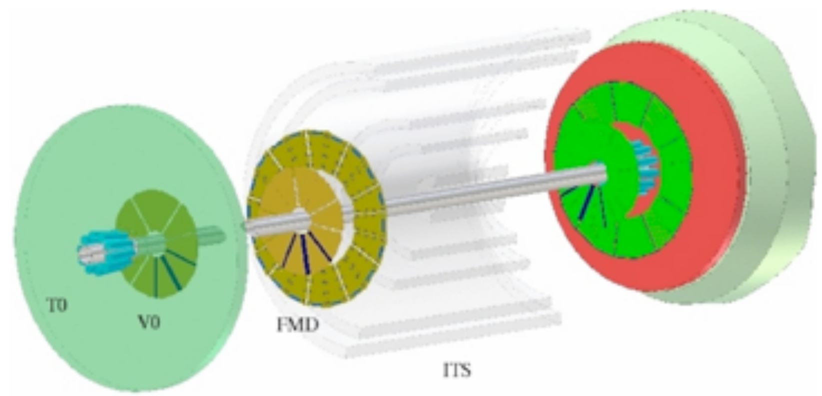

- **Time Of Flight resolution about 85-100 ps**

- Good separation of different particles:
  - π/K up to 1.5 GeV/c
  - K/p up to 4 GeV/c
  - measurement of d, t, … also possible

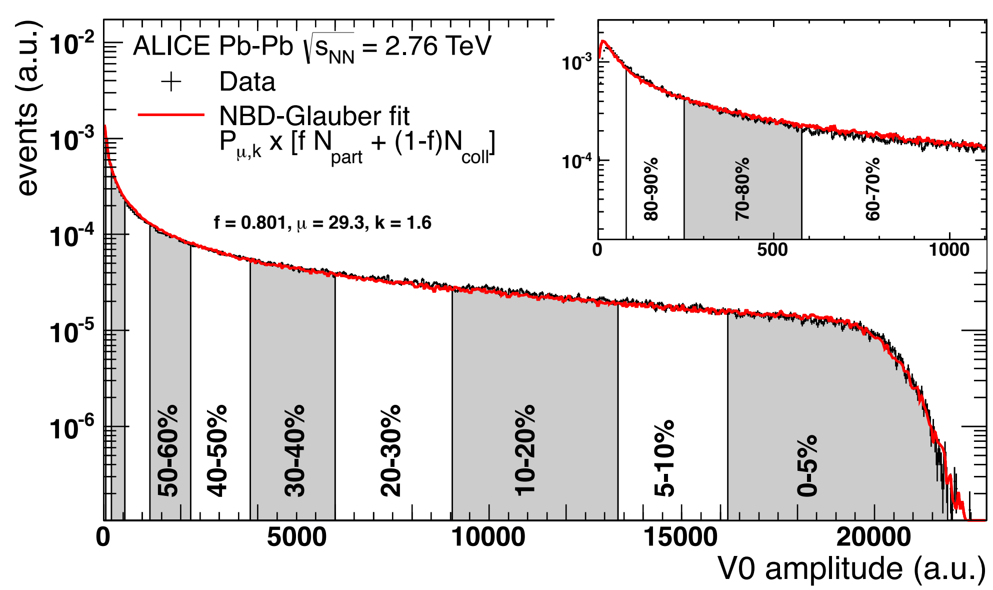


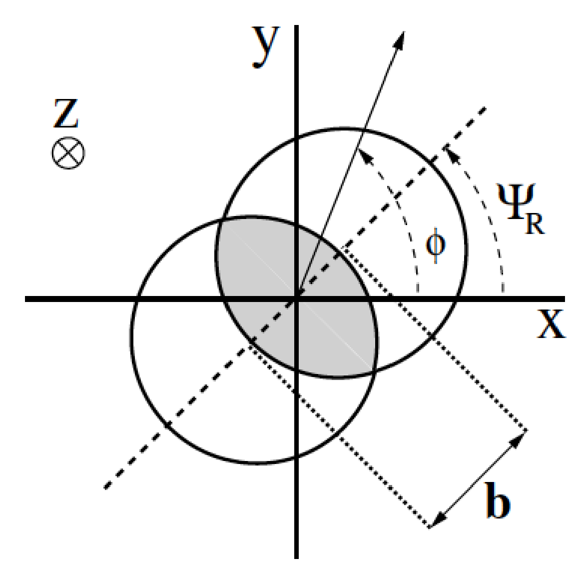
# Trigger and centrality detectors

- **V0 detector**
  - Two arrays of plastic scintillators
  - located at z ~340 cm (V0A) and -90 cm (V0C)
    - $2.8 < \eta < 5.1$ (V0A) $-3.7 < \eta < -1.7$ (V0C)
  - segmented in four rings and eight sectors each




- Fast detector used for:
  - triggers (i.e. selecting online “interesting” events)
  - centrality and event plane determination

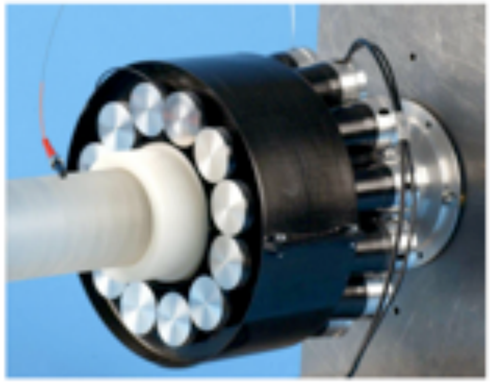


# Trigger and centrality detectors

- **T0 detector**
  - Two arrays of Cherenkov counters
  - located at z ~350 cm (T0A) and -70 cm (T0C)

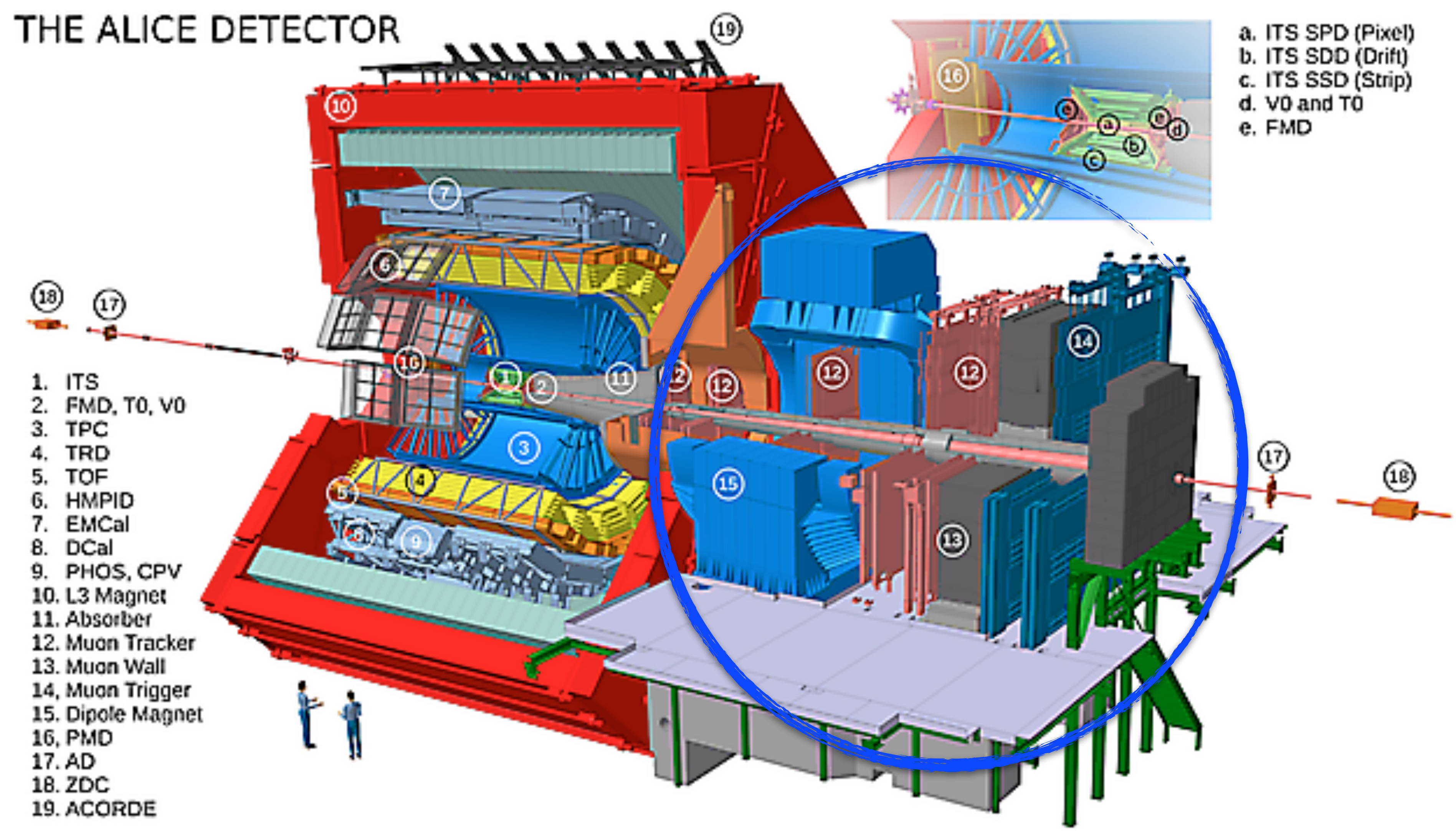
  - Detector used for:
    - triggers (i.e. selecting online “interesting” events)
    - measurement of the particle arrival time at T0A, T0C.
      - important to measure interaction time (for TOF!)



T0 prototype.

# Others: Muons and Electrons

- **Muons**
  - in ALICE only in the forward rapidity with an ad hoc spectrometer



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    - $-4 < \eta < -2.5$
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  - 1 dipole magnet 3Tm
  - 5 tracking chambers
  - 2 trigger chambers
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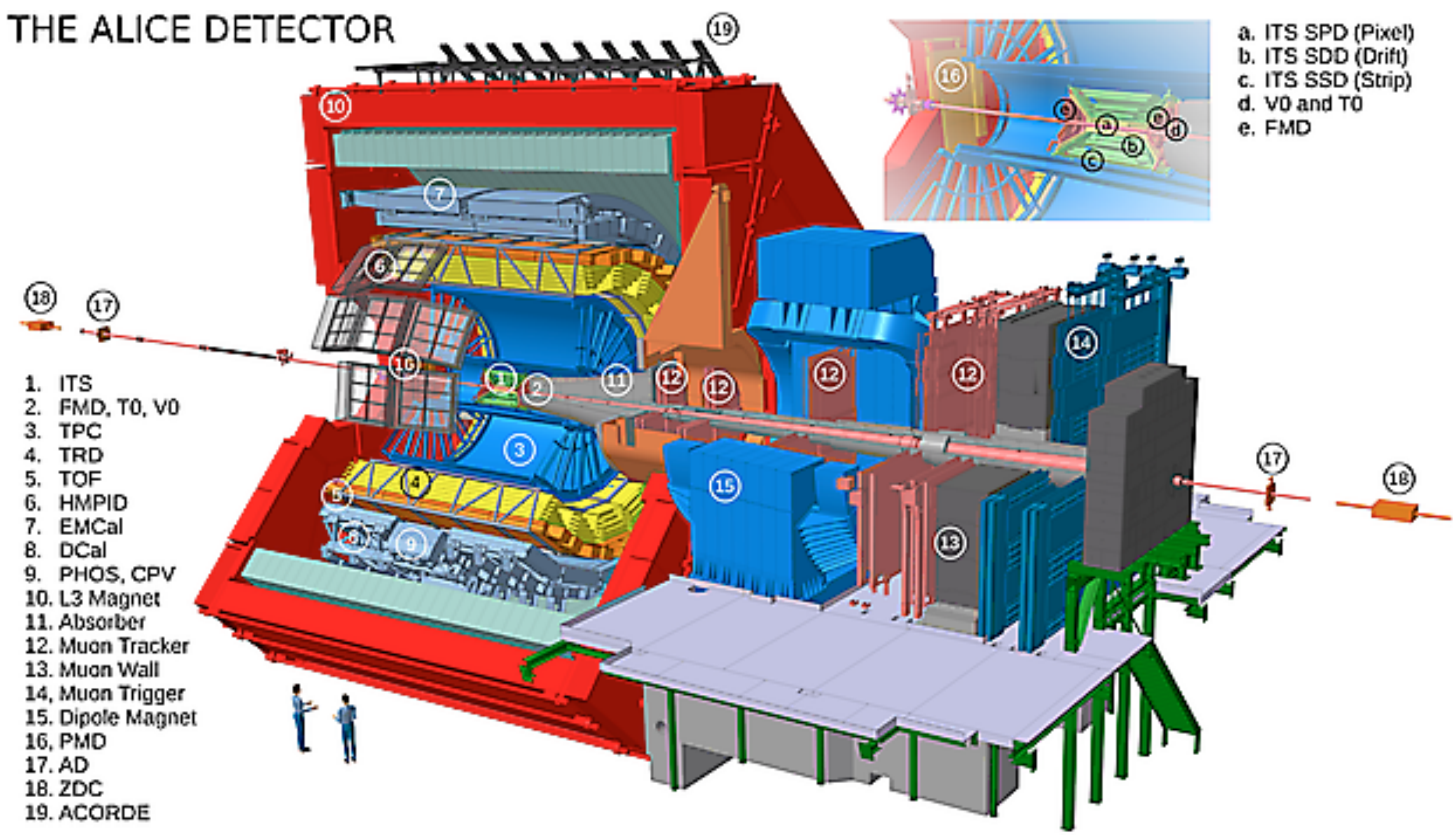
- **Electrons**
  - like all other hadrons, reconstructed only in the central barrel $|\eta| < 0.9$
  - Transition Radiation Detector (separate e from $\pi$, intermediate pT)
  - Electro Magnetic CALoremeter  (electrons deposit their entire energy in the calorimeter)

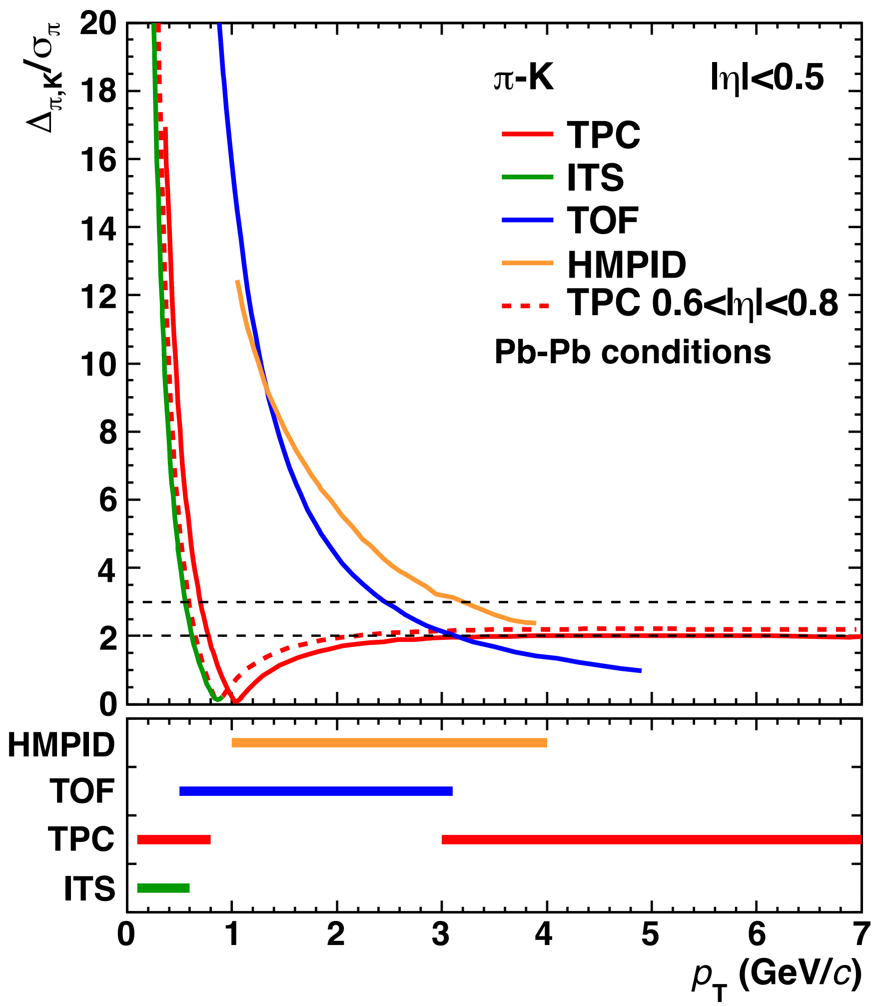
# Summary

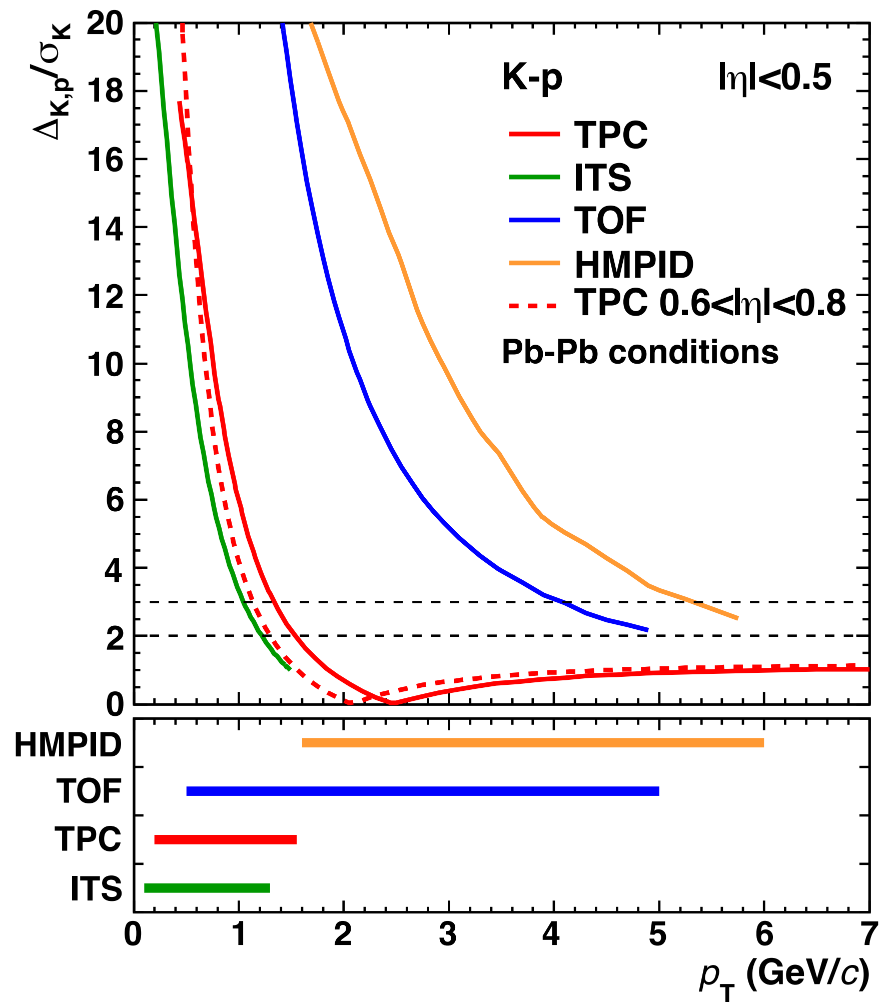
- ALICE is the dedicated heavy ions experiment at CERN
- Mainly designed for low-pT particles and Particle Identification
- 19 sub-detectors with different scopes constitute the full experiment.

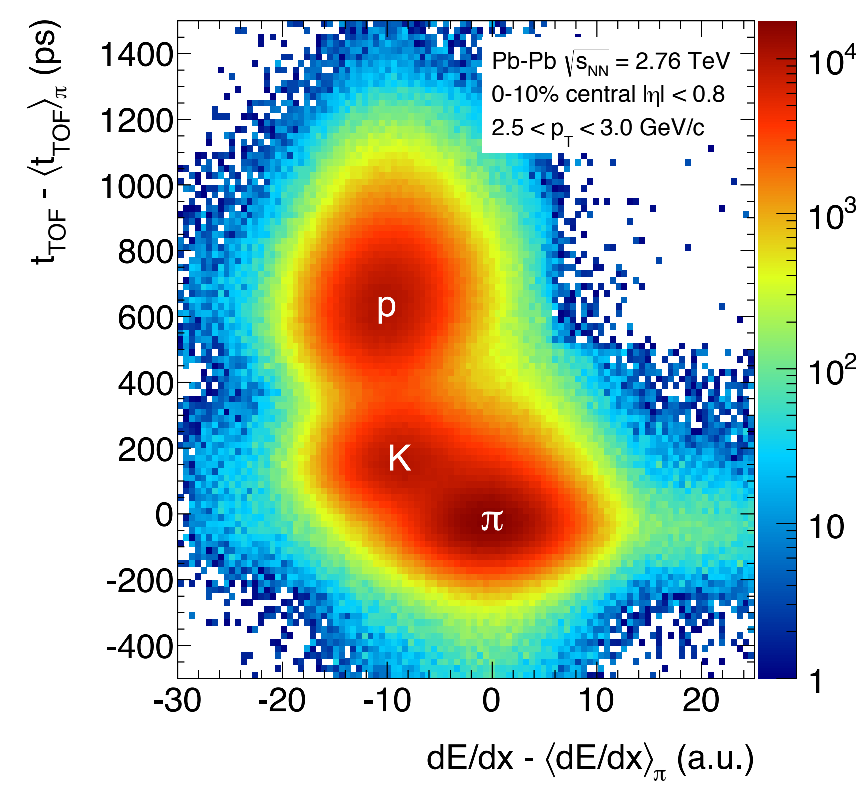


# Back up slides

# ALICE combined hadronic PID

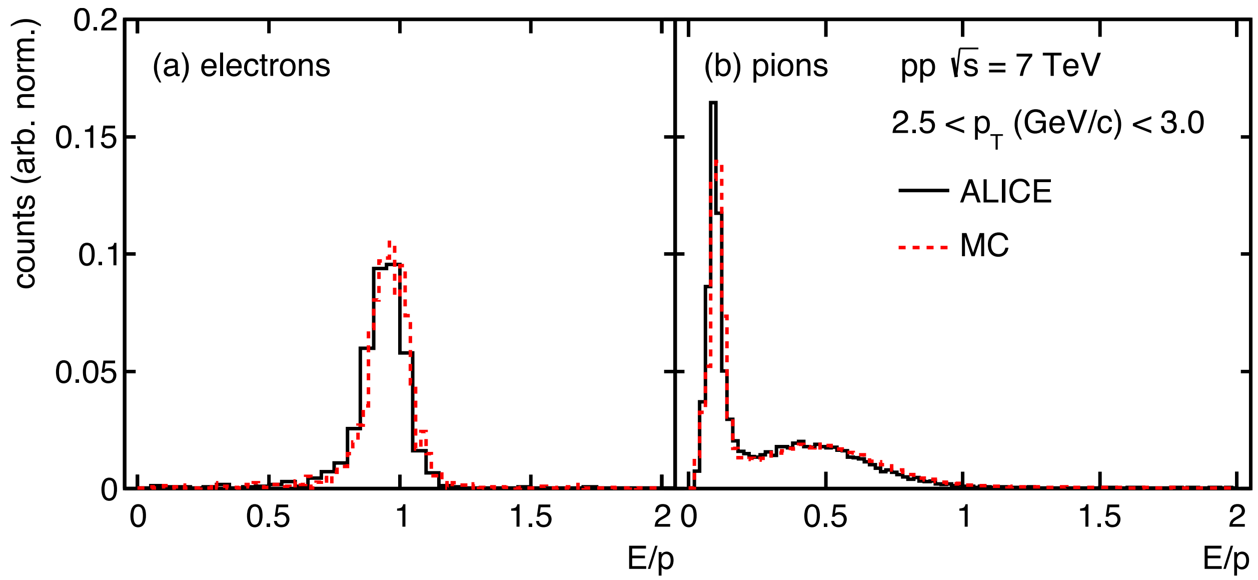


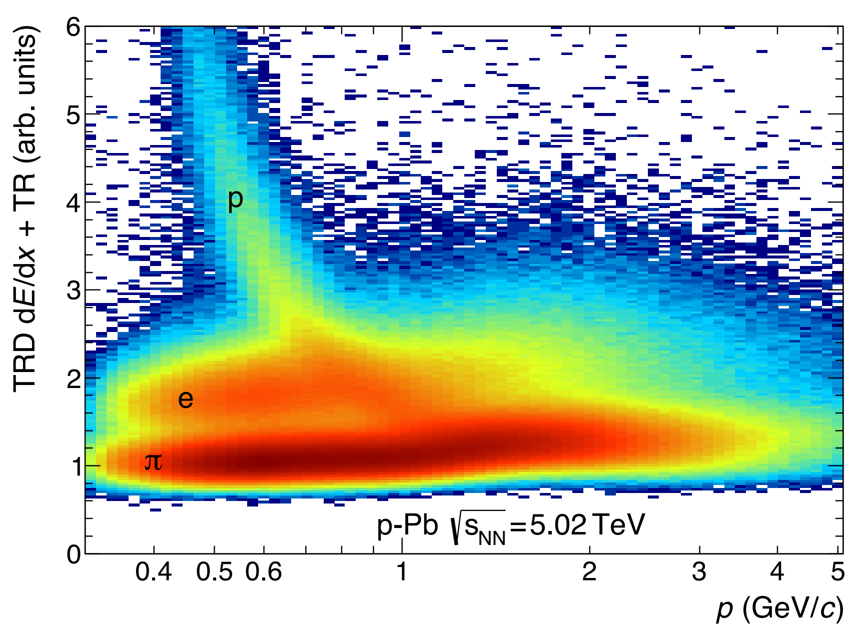
# Electron ID

## EMCAL E/p measurement




EMCAL: Pb scintillator sampling calorimeter
$|\eta| < 0.7$, $1.4 < \phi < \pi$
$\Delta\eta = \Delta\phi \approx 0.014$
Cluster $E_T > 300$ MeV

## TRD



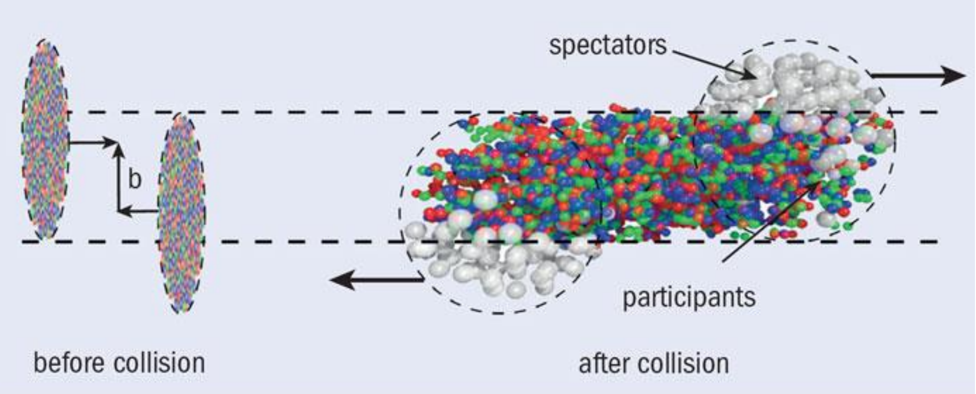

TRD: six layers of radiator and drift chamber.

TR produced when particles ($\gamma > 10^3$) traverse many interfaces of two media of different dielectric constants composing the radiator.

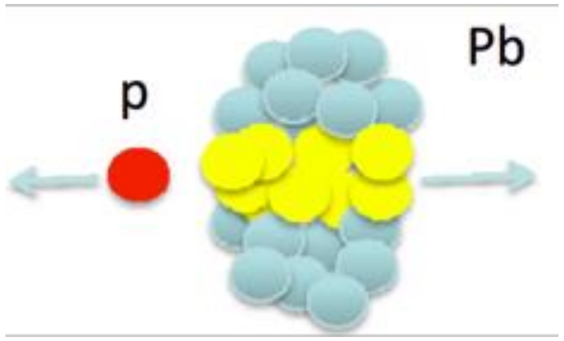
On average, for each electron with a momentum above 1 GeV/c, one TR photon (energy range: 1–30 keV) is absorbed and converted in the high-Z gas mixture (Xe-$CO_2$) in each layer of the detector.

# Centrality Measurement

- The collisions geometry (i.e. the impact parameter b) determines the number of nucleons that participate in the collisions ($N_{part}$)




- Each nucleon can interact with many different nucleons and have multiple collisions ($N_{coll}$)




- Ex - pPb collisions:
  the proton hits on average 6.9 nucleons of the Pb nucleus

→ $\langle N_{coll} \rangle$ = 6.9 +/- 0.6

- How determine $N_{part}$ and $N_{coll}$ ? **Glauber model**
  - Nucleons travel in straight lines
  - Collisions don't alter the nucleons trajectory, only energy
  - No quantum-mechanical interference
  - Interaction probability for two nucleons is given by the nucleon - nucleon (pp) cross section.

# Centrality Measurement

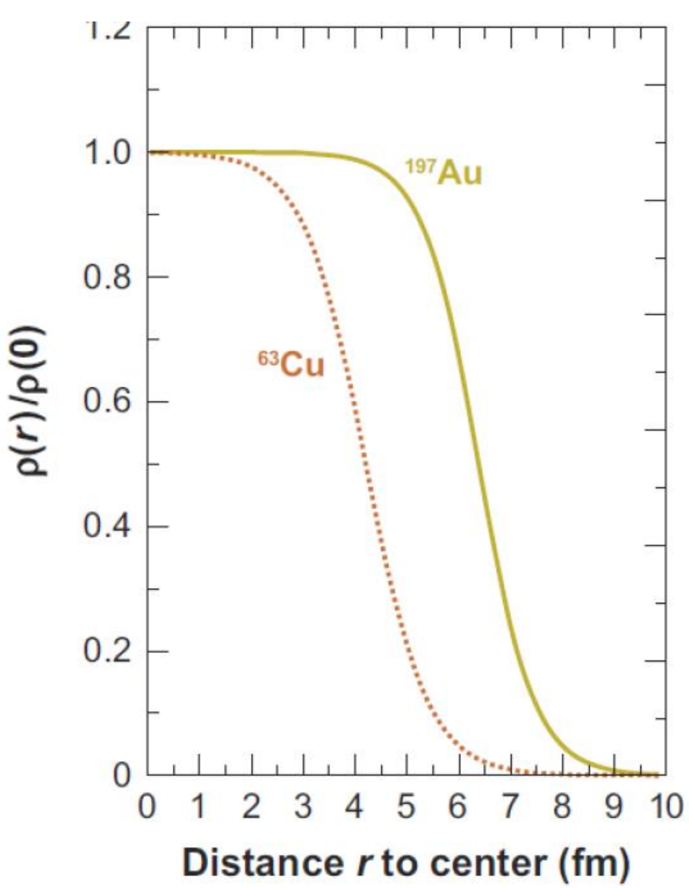
- **Inputs** to the Glauber model:
  - **Distribution of the nucleons in the nuclei:**
    - measured by e-ion scatterings experiments
    - parametrized by Woods-Saxon distribution

$$\rho(r) = \rho_0 \frac{1}{1+\exp\left(\frac{r-R}{a}\right)}$$

**Nuclear radius R**

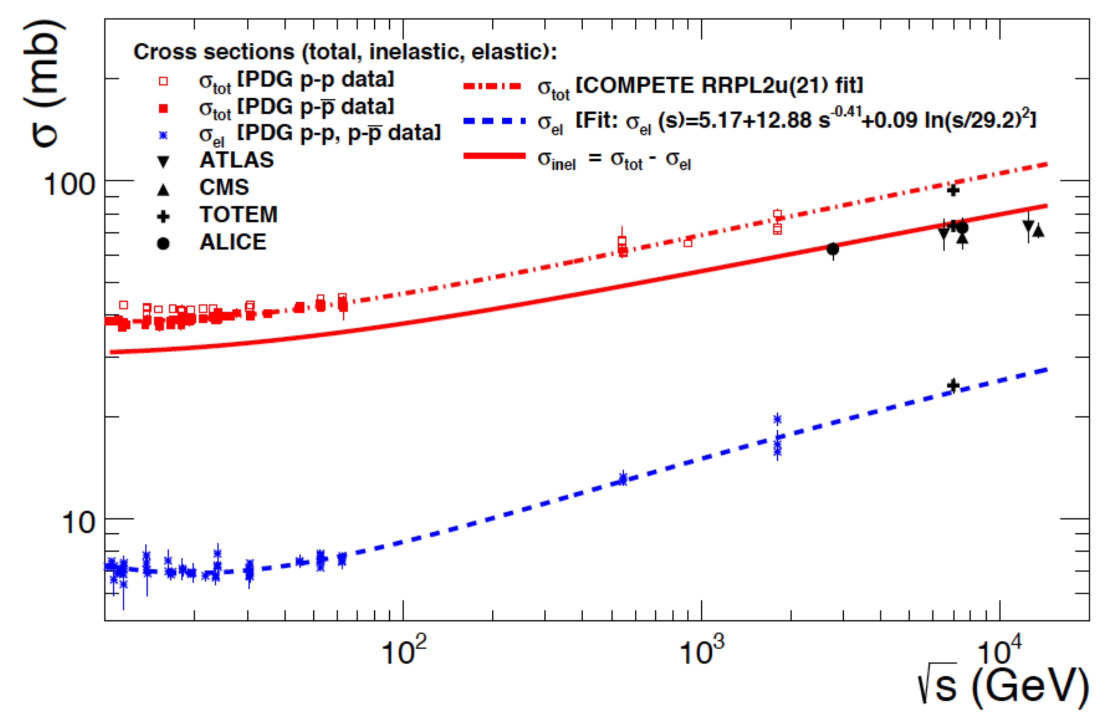
**Density in the center**

**Skin depth a**



# Centrality Measurement

- **Inputs** to the Glauber model:
  - Distribution of the nucleons in the nuclei:
    - measured by e-ion scatterings experiments
    - parametrized by Woods-Saxon distribution
  - **Nucleon-nucleon cross-section**
    - measured in pp collisions or from extrapolation

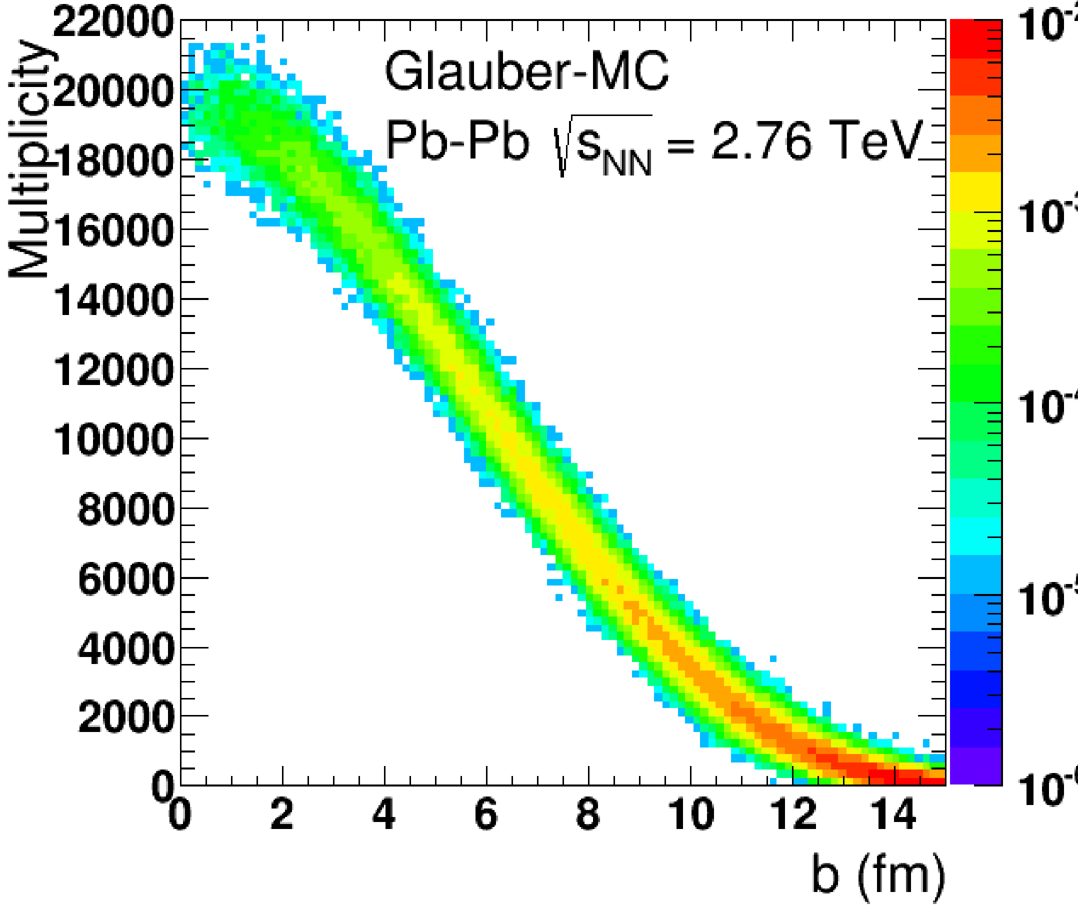



[arXiv:1603.07375v3]

# Centrality Measurement

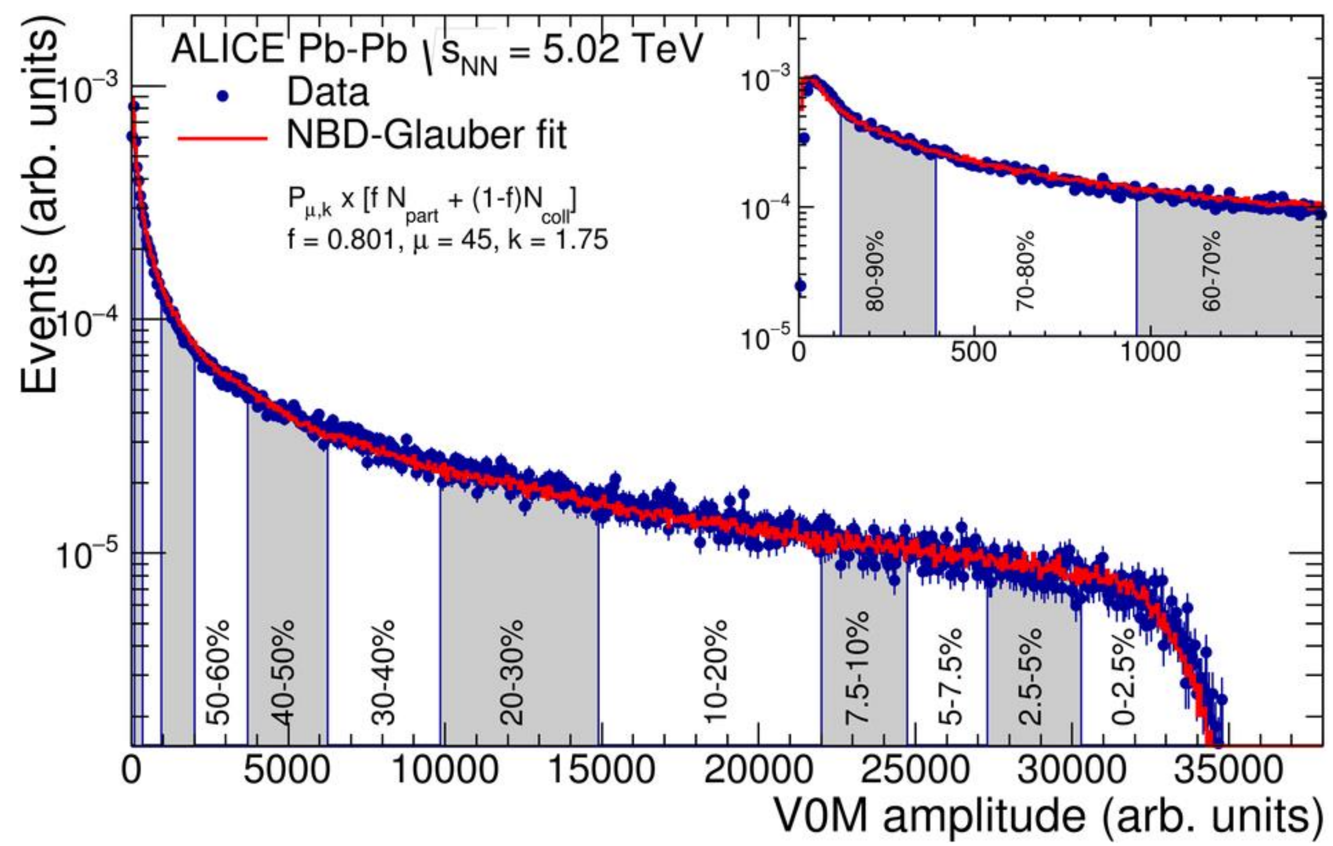
- Inputs to the Glauber model:
  - Distribution of the nucleons in the nuclei:
    - measured by e-ion scatterings experiments
    - parametrized by Woods-Saxon distribution
  - Nucleon-nucleon cross-section
    - measured in pp collisions or from extrapolation
- **Output** of the Glauber model:
  - **multiplicity is inversely proportional to the impact paramete**r
  - knowing the multiplicity of the event we know the impact parameter ( and $N_{part}$, $N_{coll}$)

Plot: A. Toia



# Centrality Measurement

- **Multiplicity distribution:**
  - peak: most peripheral, background contamination
  - Plateau: mid-central
  - Edge: most-central, shape is a product of intrinsic fluctuations and detector acceptance/ resolution




~ # charged particles

- **Fit of the multiplicity distribution:**
  - Number of ancestor $fN_{part}$ + (1-f) $N_{coll}$
  - Each ancestor emits particles according to negative binomial distribution ($P_{\mu,k}$)

- **Slice in % of the hadronic cross section**
  - for each class, possible to extract <$N_{part}$> and <$N_{coll}$> form the fit