Introduction to ALICE data analysis

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also with the help of
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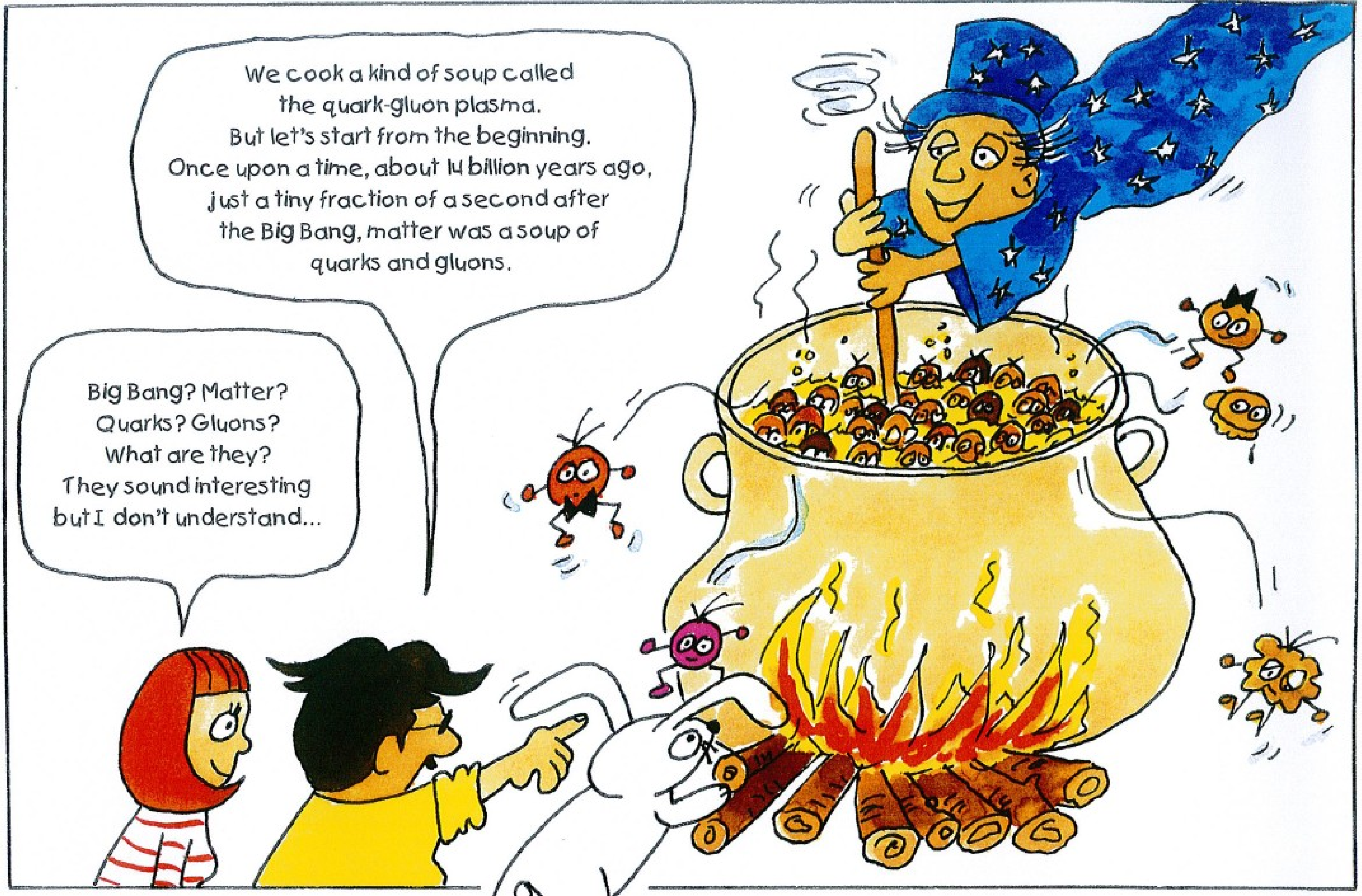
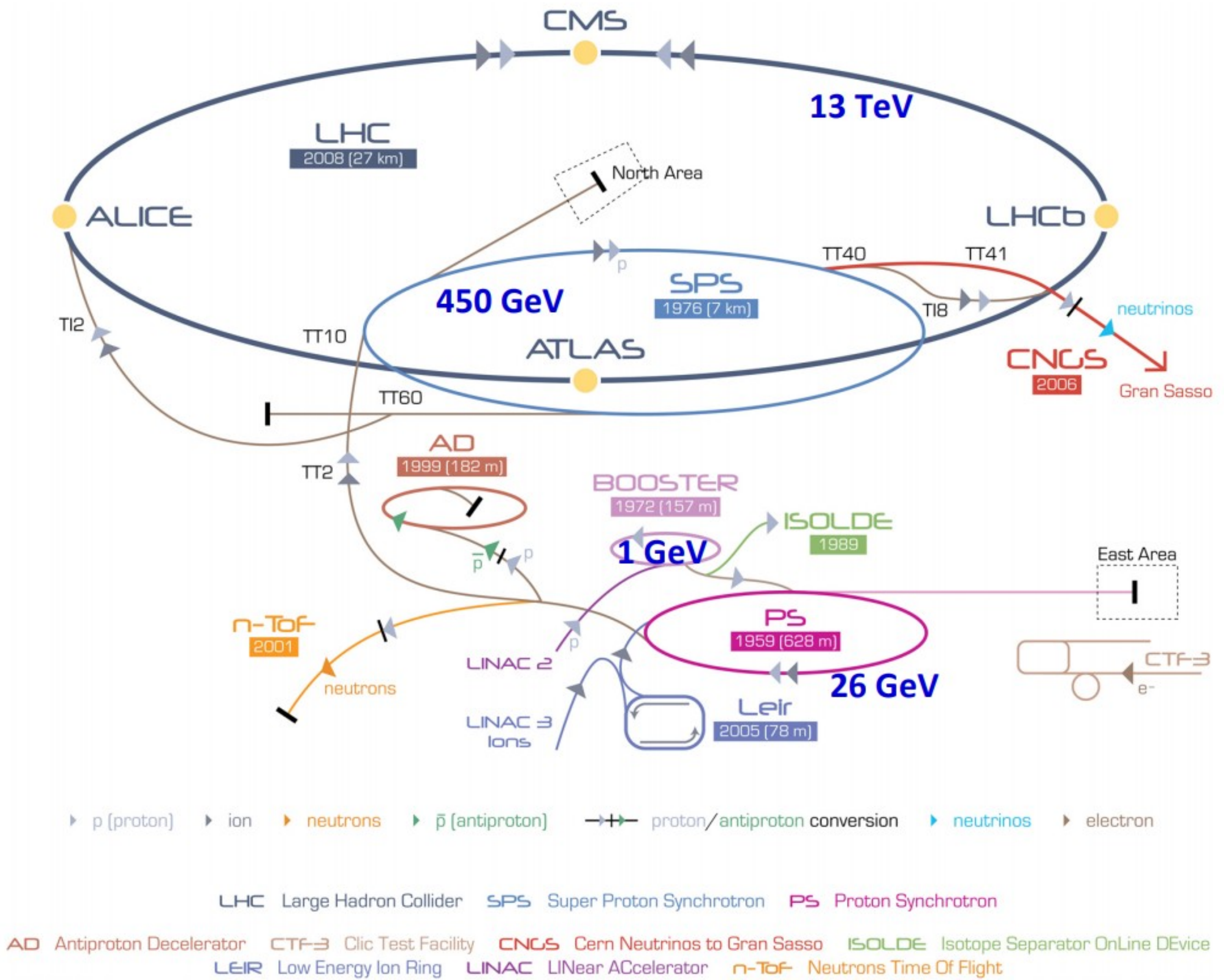
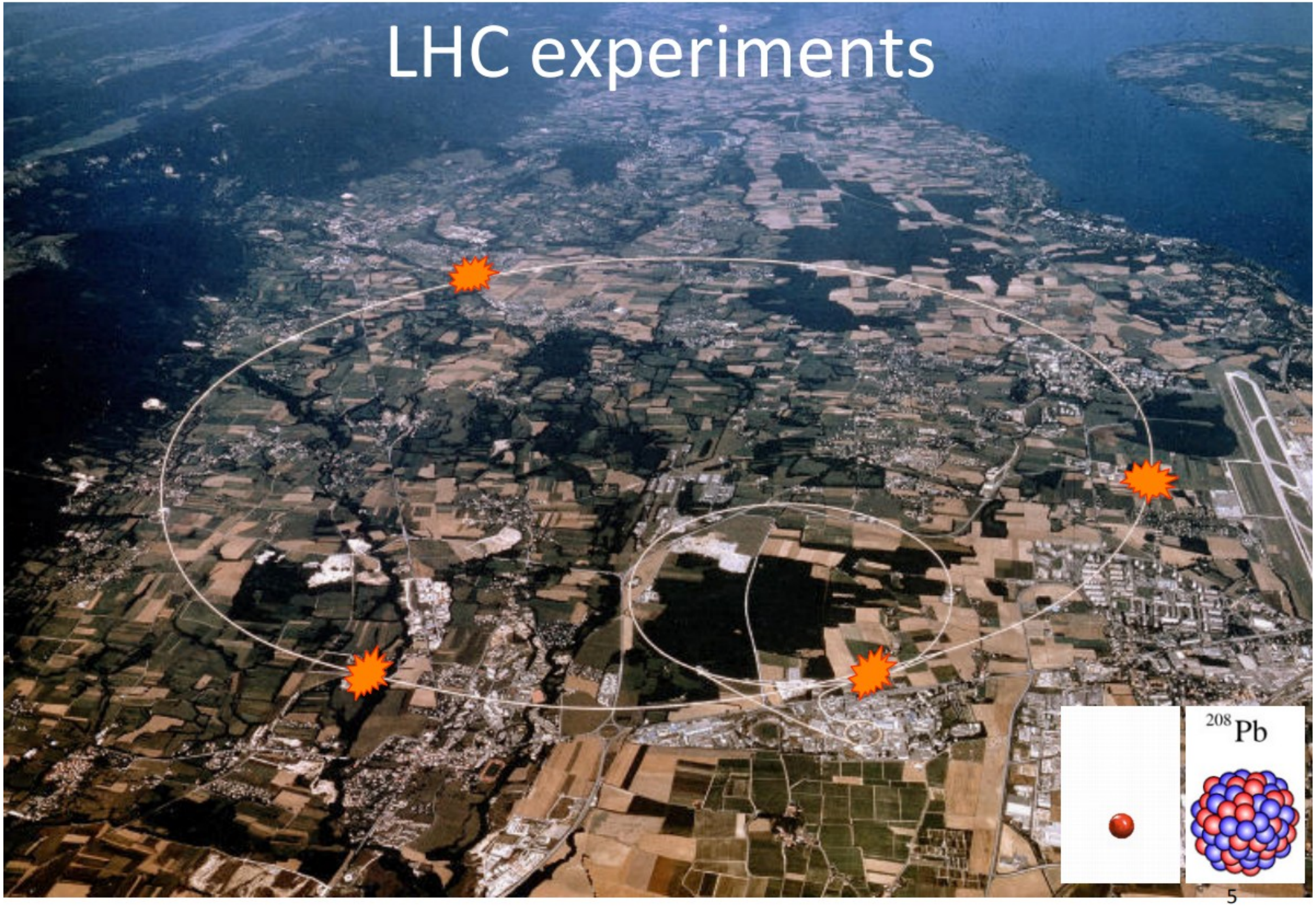
Skeikampen, Norway, 10 january 2020


We cook a kind of soup called the quark-gluon plasma. But let's start from the beginning. Once upon a time, about 14 billion years ago, just a tiny fraction of a second after the Big Bang, matter was a soup of quarks and gluons.
Big Bang? Matter? Quarks? Gluons? What are they? They sound interesting but I don't understand...

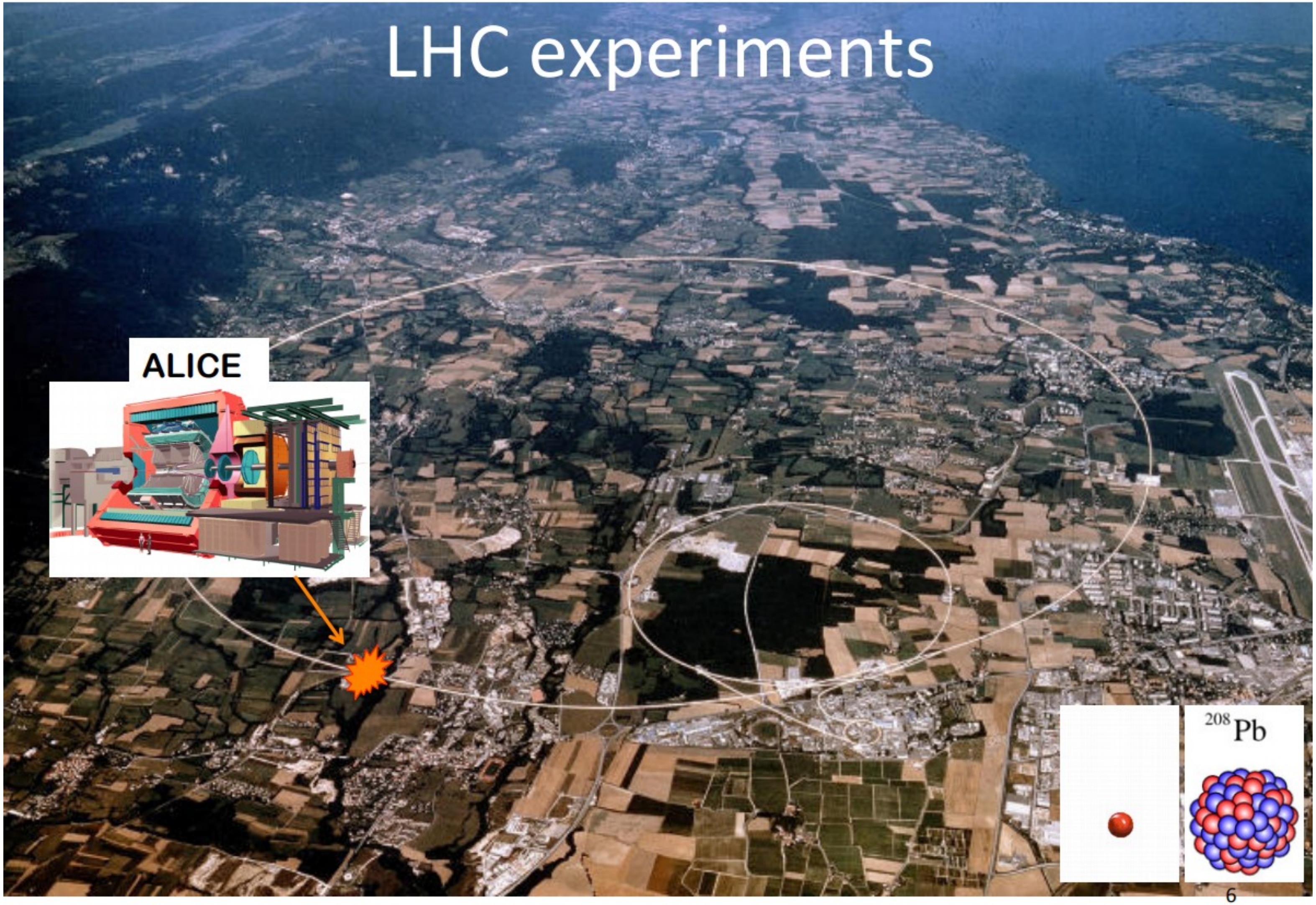
Accelerator complex at CERN



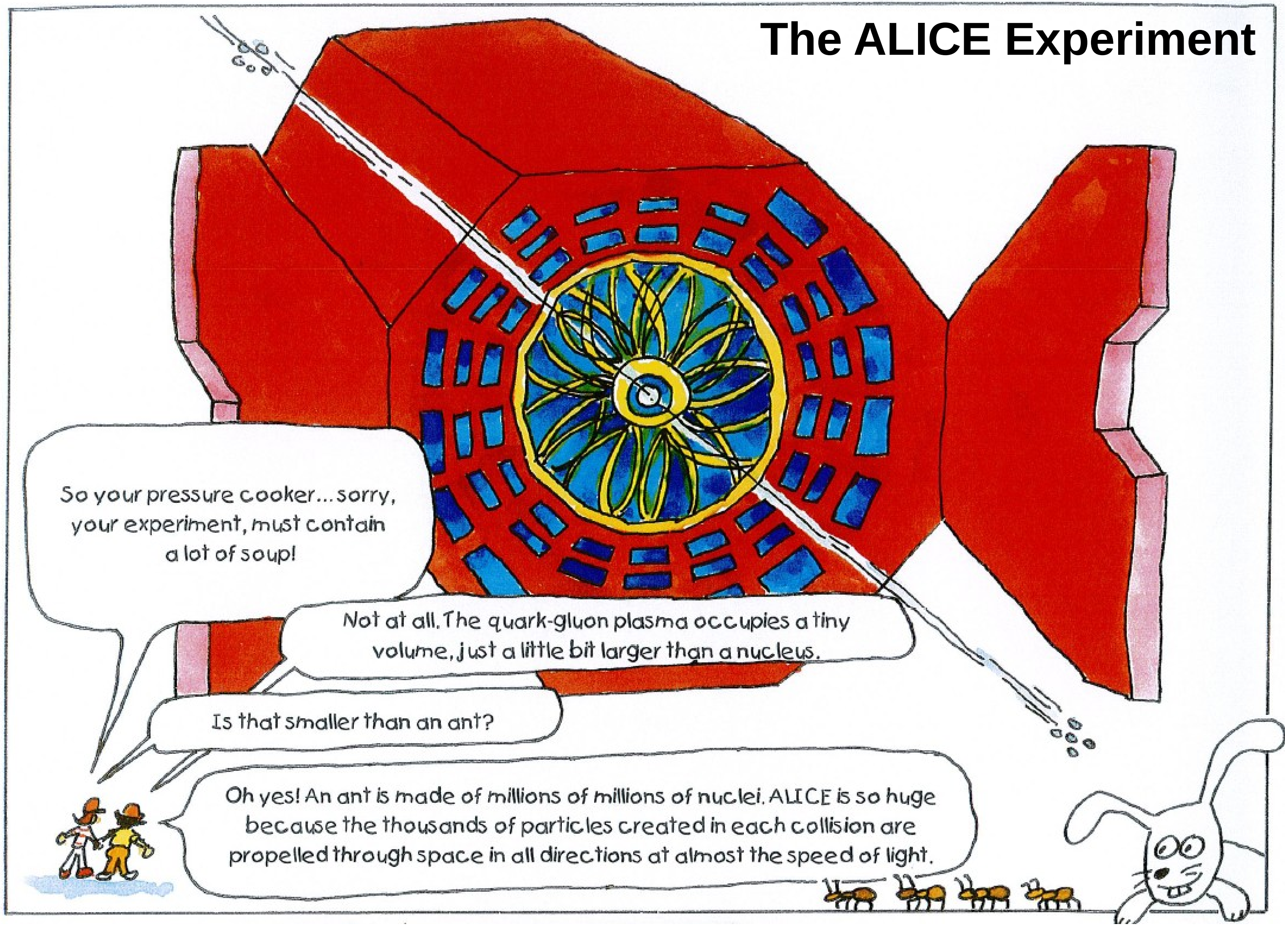
LHC experiments



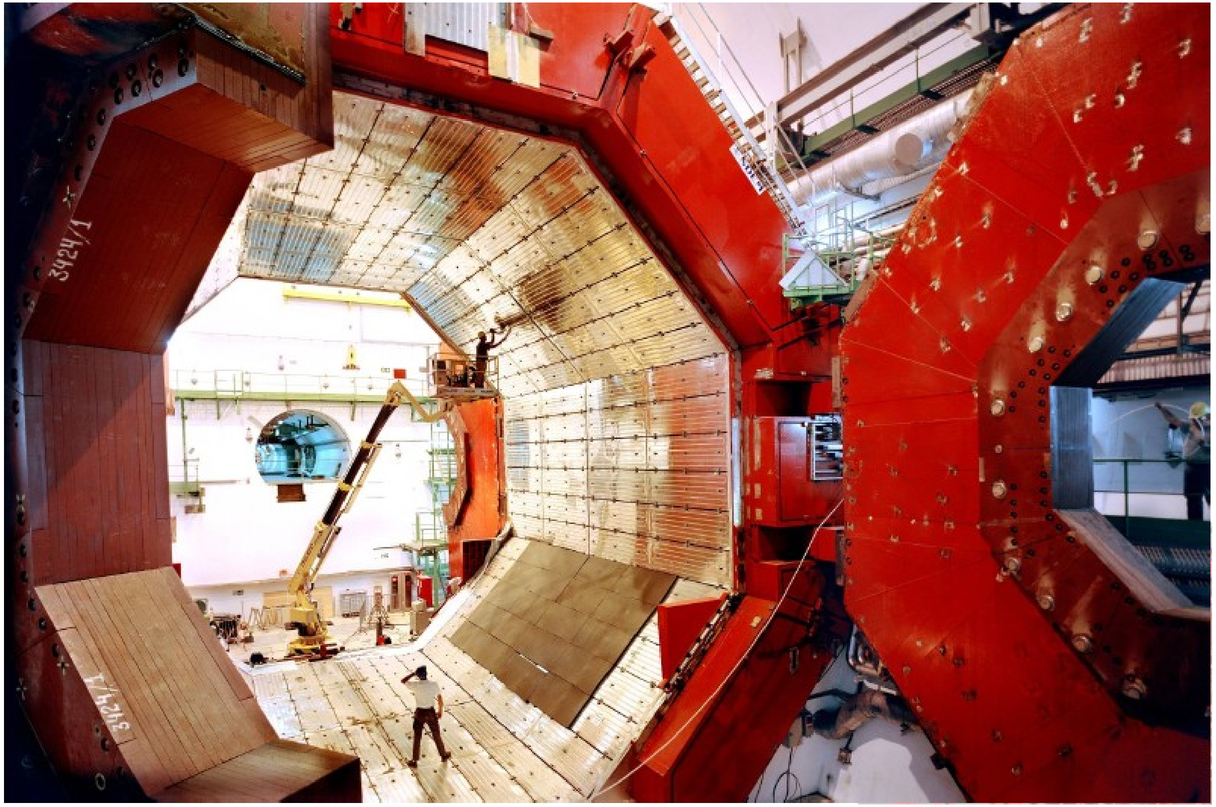
LHC experiments



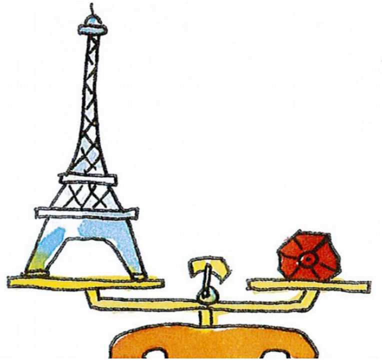
The ALICE Experiment



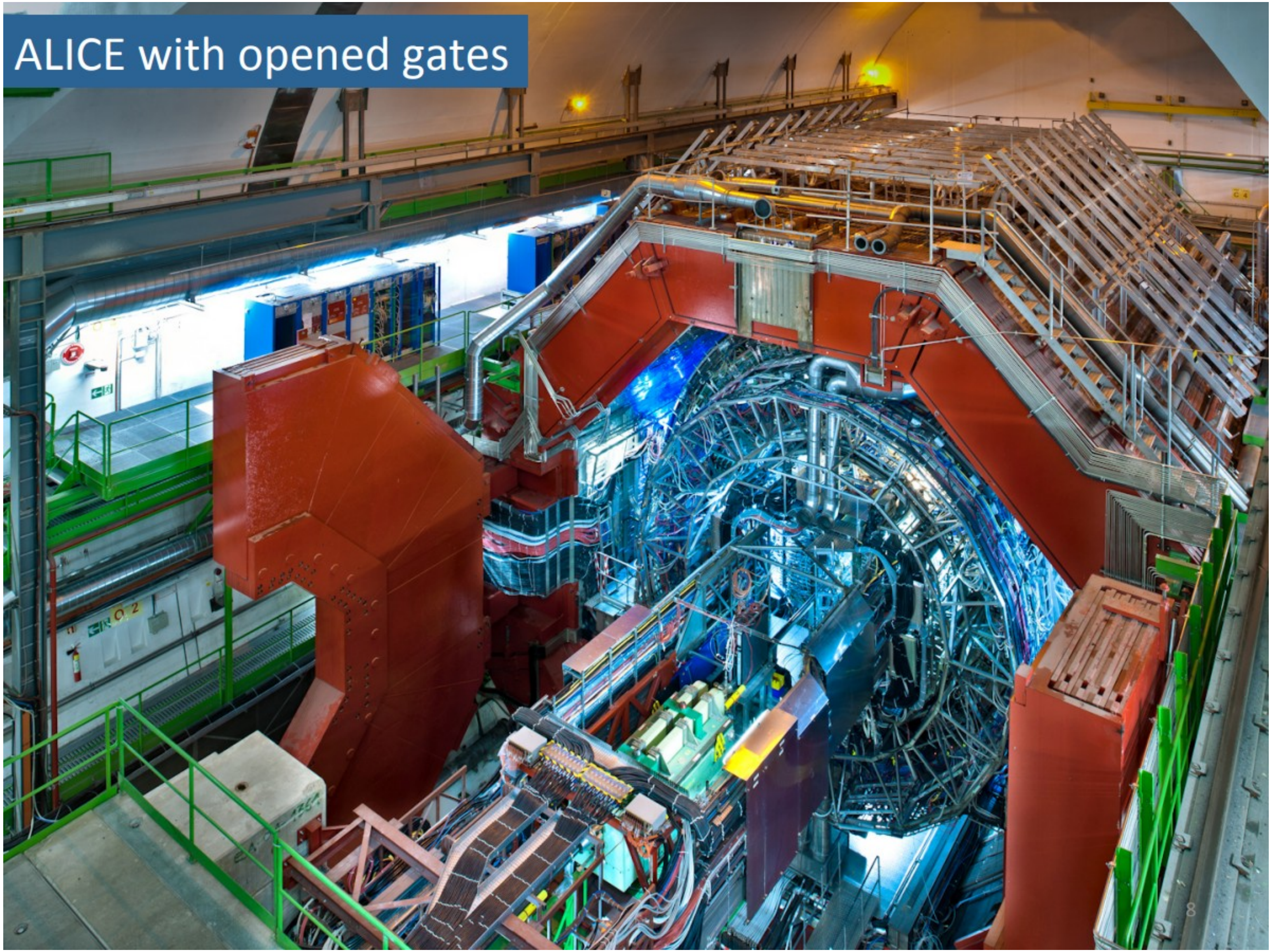
The L3 solenoid magnet



- It creates a uniform 0.5 T magnetic field
- As heavy as the Eiffel tower

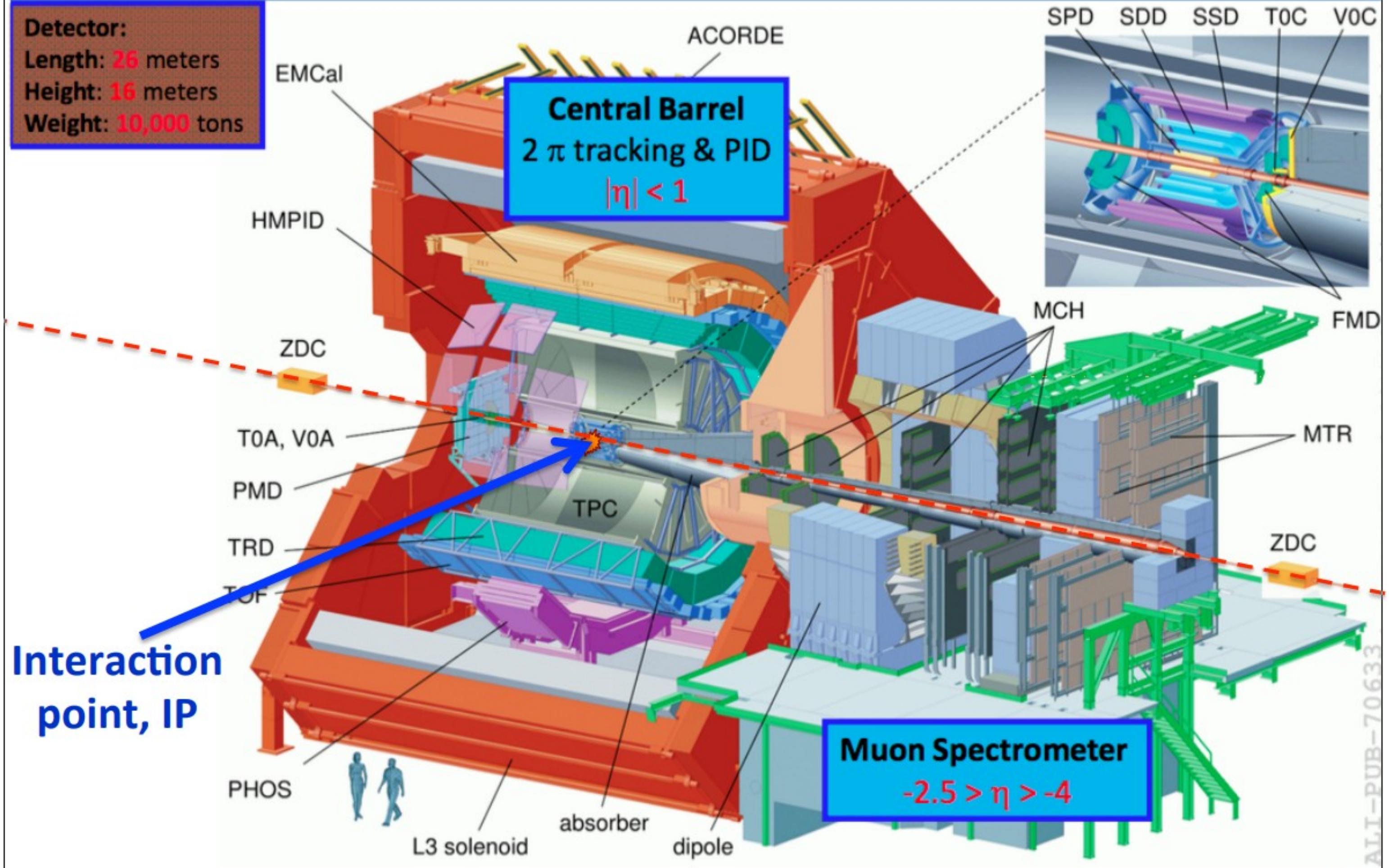


ALICE with opened gates



ALICE experimental setup

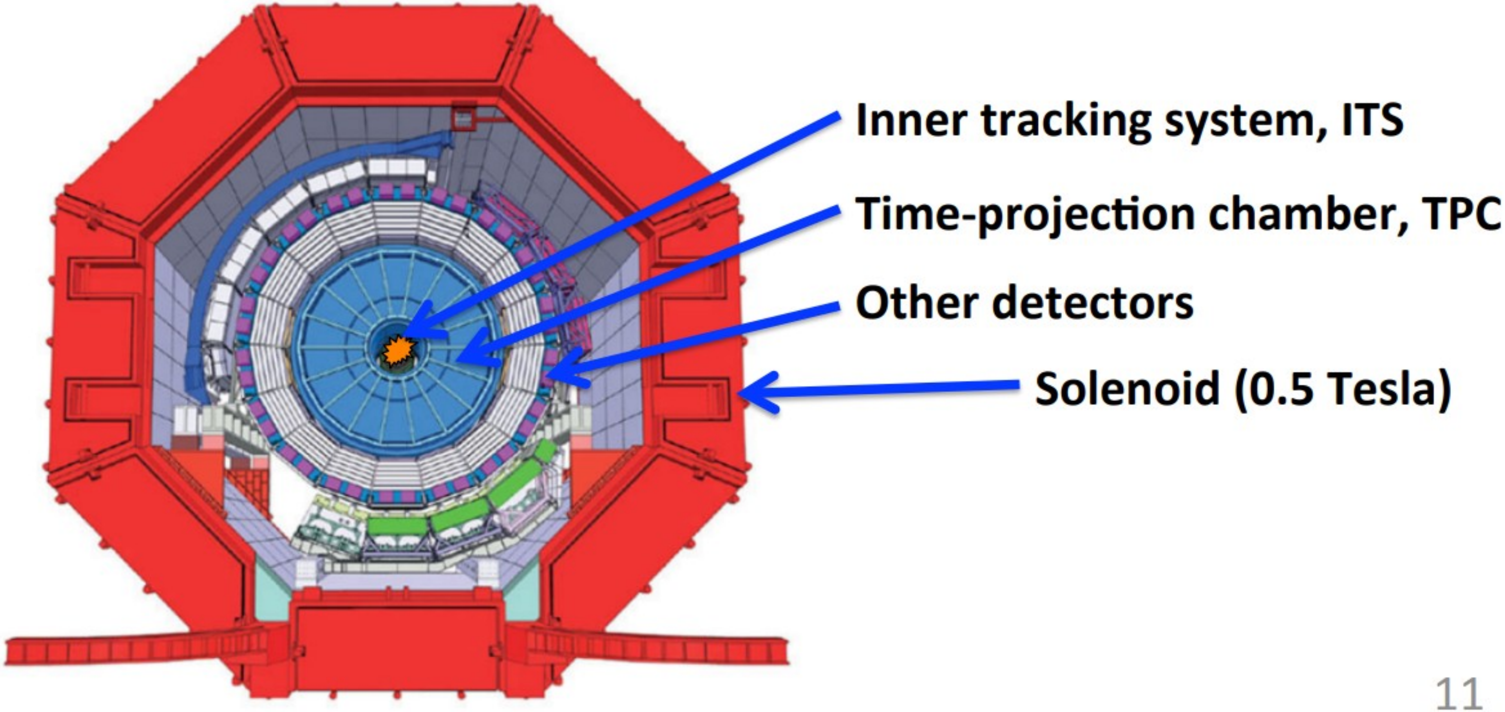
Detector:
Length: 26 meters
Height: 16 meters
Weight: 10,000 tons



from: Evgeny Kryshen, ALICE overvies, QFTHEP 2015

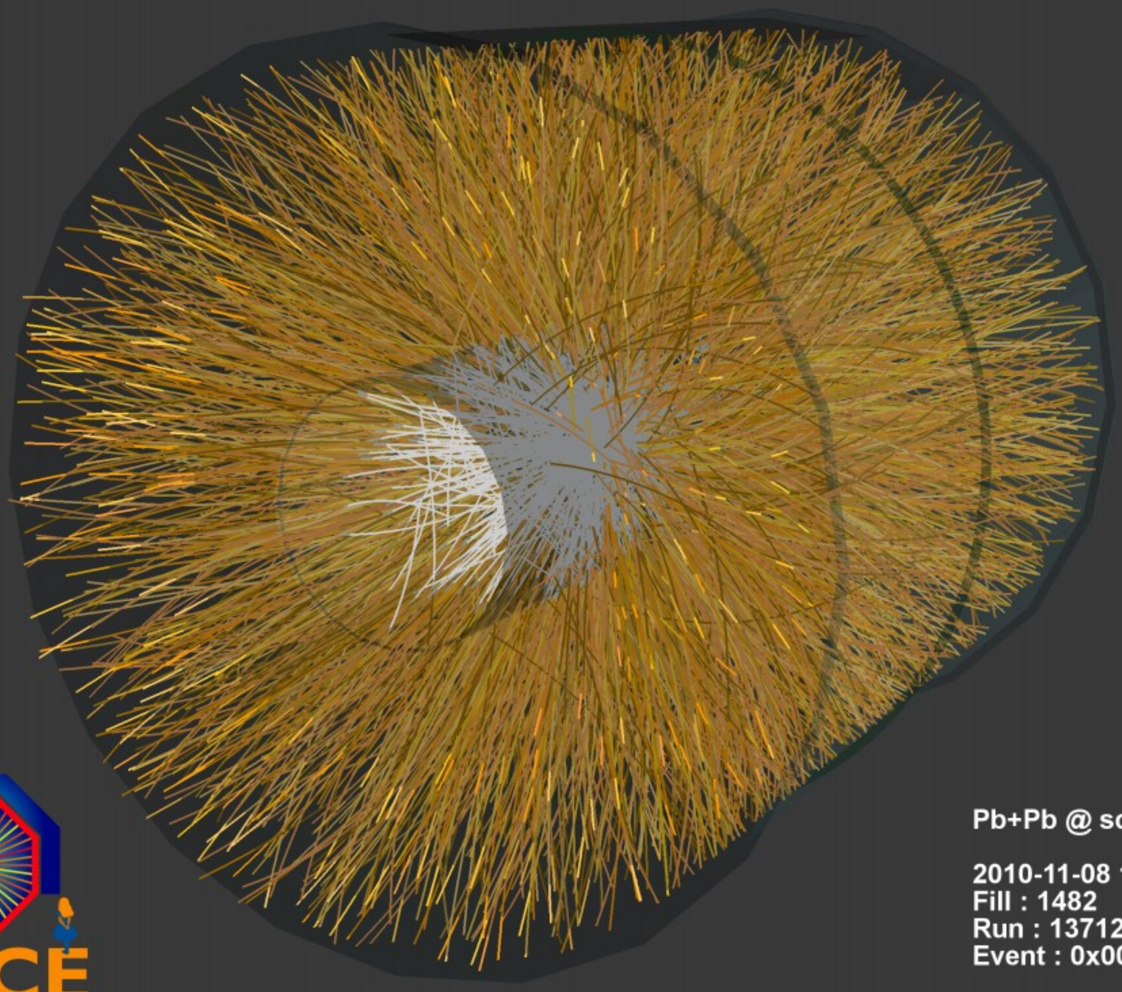
Typical structure of modern HEP experimental setup: **«matryoshka»**

Transverse "slice" of ALICE:



Отобранные события направляются сперва в Вычислительный центр ЦЕРН

Basic concepts in HEP data: event and particle track



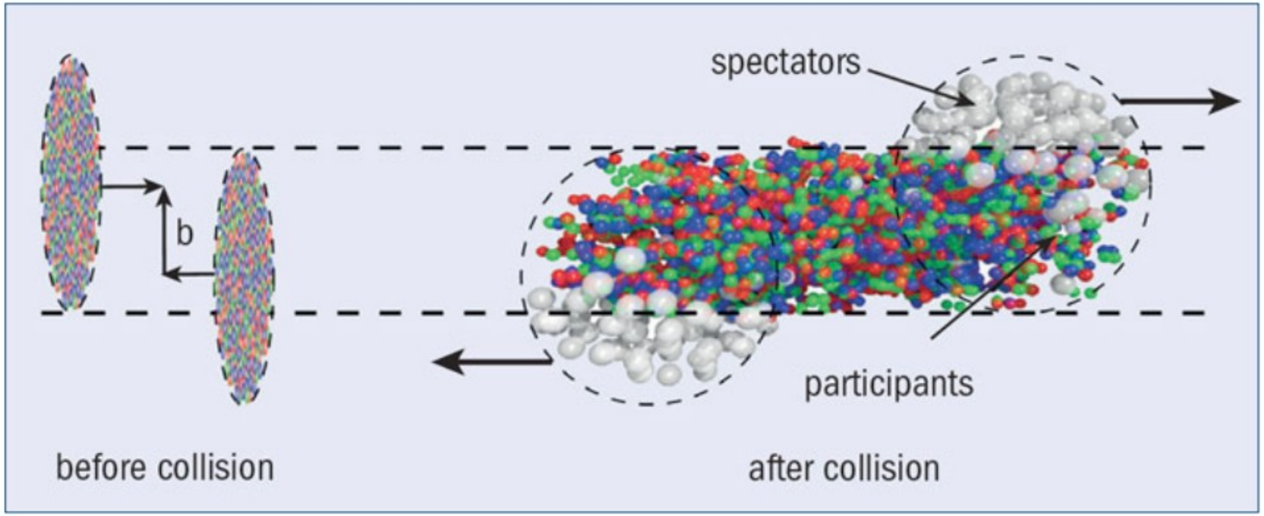
ALICE

Pb+Pb @ sqrt(s) = 2.76 ATeV

2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x00000000D3BBE693

The collision centrality

The centrality is a key parameter in the study QCD matter at extreme energy densities, because it is directly related to the initial overlap region of the colliding nuclei.



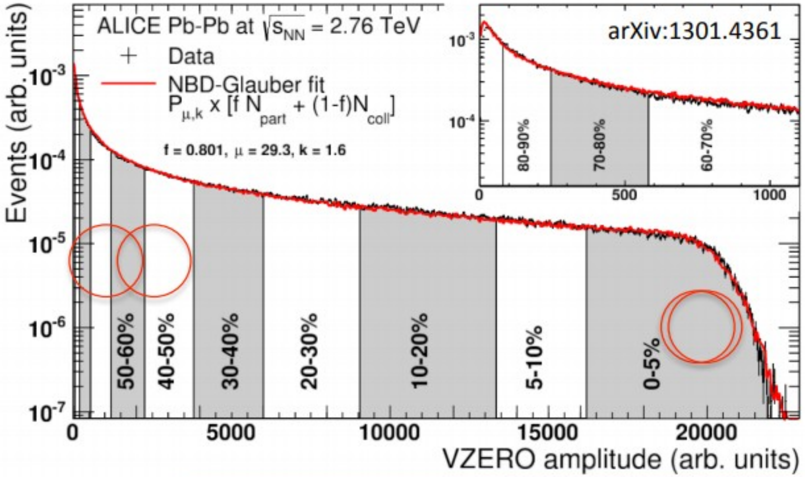
The *impact parameter (b)* is the distance between the centers of the colliding nuclei.

Centrality determination in experiment

Usual receipt:
- use distribution of a signal in some detector
- fit with some geometry-based model
- split into *centrality classes* (0-100%)

In ALICE for Pb-Pb:
use *multiplicity distribution* in (semi-central) **VZERO detector** + Glauber fit

(-3.7<η<-1.7 and 2.8<η<5.1)



close to 0% → most **central** events
closer to 100% → **peripheral** events

→ b_{impact}, N_{part}, N_{coll}, N_{spec} are not directly measurable and are deduced from the **Glauber model**.

Practical analysis details

- ALICE data format:
  - Event header
  - Track list
  - Outer detector information (ZDC, VZERO, TZERO, etc.)

```
void RunTreeAnalysis(const Char_t* inputfilename, const Char_t* outputFilename, Int_t howMany) {
  //
  // Configure and run an analysis locally on local trees of AliReducedEvent's
  //

  TFile* outFile = new TFile("outputFilename", "RECREATE");
  // define your histograms here
  TH1F* histCentrality = new TH1F("histCentrality", "Event centrality", 100, 0., 100.);
  TH1F* histPt = new TH1F("Pt", "Track p_{T}", 100, 0., 10.);

  // create the tree chain
  Int_t entries=0;
  TChain* chain = CreateChain(inputfilename, entries);
  if(!chain) return;
  // set the event branch address
  AliReducedEventInfo* event = new AliReducedEventInfo();
  chain->SetBranchAddress("Event",&event);
  cout << "Looping over " << TMath::Min(entries, howMany) << " events" << endl;

  // the event loop starts here
  for(Int_t ie=0; ie<TMath::Min(entries, howMany); ++ie) {
     // get one event
    chain->GetEntry(ie);
    // Here apply event-wise selections, calculate event-wise quantities and fill histograms
    histCentrality->Fill(event->CentralityVZERO());
    // select events in the centrality range 30-50%
    if(event->CentralityVZERO()<30.0) continue;
    if(event->CentralityVZERO()>50.0) continue;

    // Loop over the list of tracks in the event
    AliReducedTrackInfo * track = 0x0;
    TClonesArray* trackList = event->GetTracks();      // get the track list
    TIter nextTrack(trackList);                         // make an iterator for faster access

    for(Int_t it=0; it<event->NTracks(); ++it) {
       track = (AliReducedTrackInfo*)nextTrack();
       // Here apply track-wise selections, calculate track-wise quantities, fill histograms, etc.
       if(TMath::Abs(track->Eta())>0.8) continue;      // select just particles in |eta|<0.8
       histPt->Fill(track->Pt());
    }  // end of the track loop
  }  // end of the event loop

  // Here write all your histograms into the output file
  outFile->cd();
  histCentrality->Write();
  histPt->Write();
```

Practical analysis details

How to run:

Method 1

- root > .x LoadDependencies.C
- root > RunTreeAnalysis(“inputFile.txt”,”output.root”,1000)

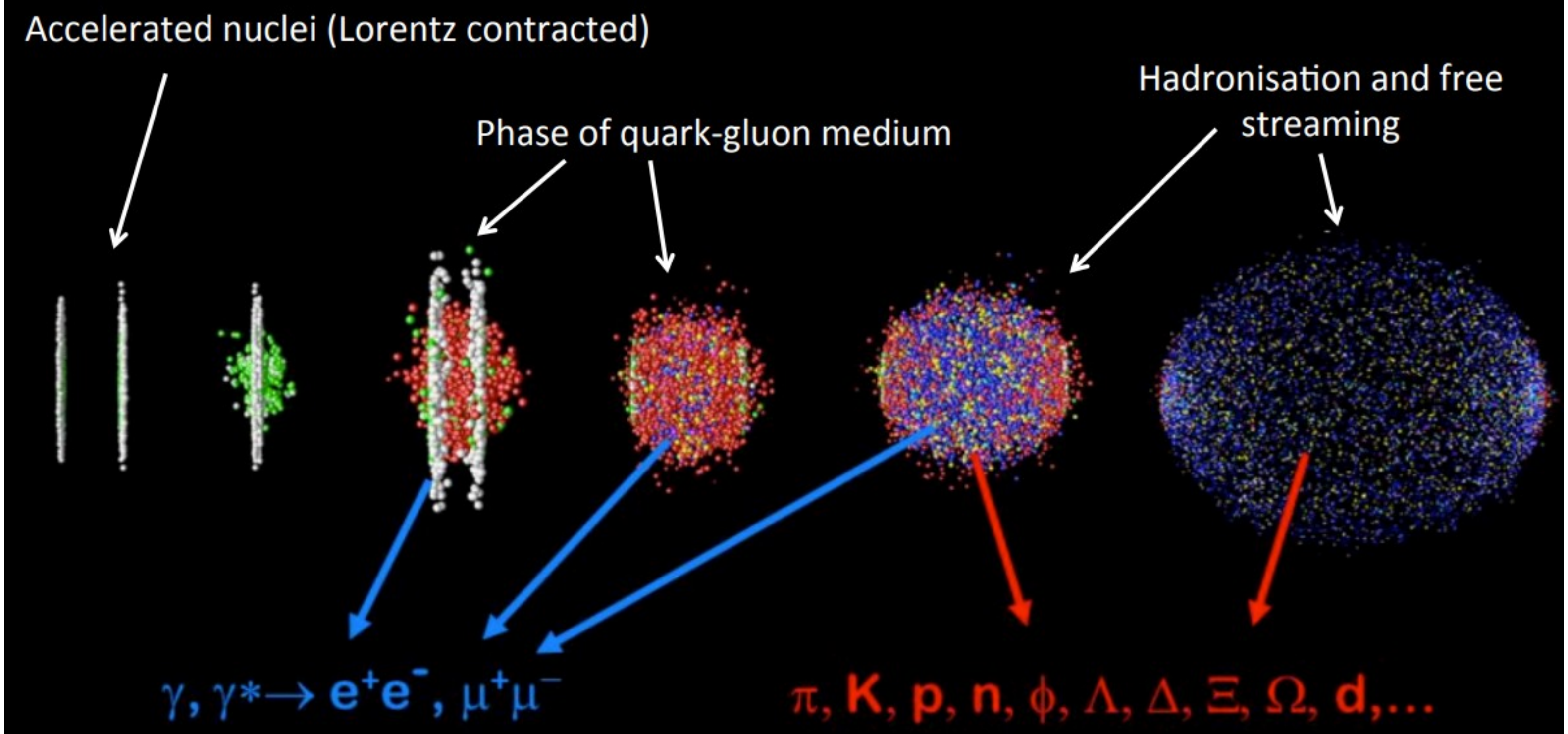
Method 2

- make
- Root > gSystem→Load(“ReducedEvent.so”)
- Root > .L RunTreeAnalysis.C
- Root > RunTreeAnalysis(“inputFile.txt”,”output.root”,1000)

Exercise 1

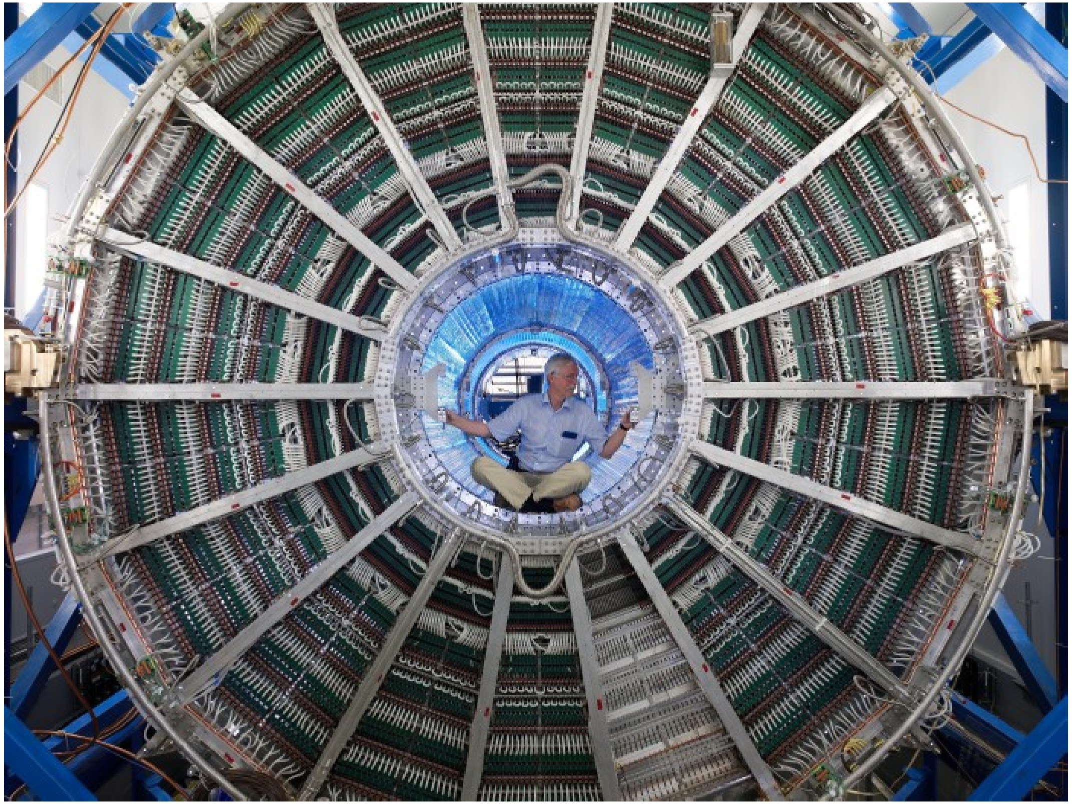
- Use the PbPb_minbias dataset
- Make changes in the RunTreeAnalysis.C macro in order to:
  - Select only events with vertex Z position between -10 and +10 cm
  - Plot histograms for the
    - event Z-vertex distribution *event->Vertex(2)*
    - multiplicity of tracks per event, *count them in the loop*
    - the VZERO multiplicity *event->MultVZERO()*
    - Track multiplicity vs VZERO multiplicity
    - Centrality from VZERO detector *event->CentralityVZERO()*

Collision of two nuclei: evolution with time



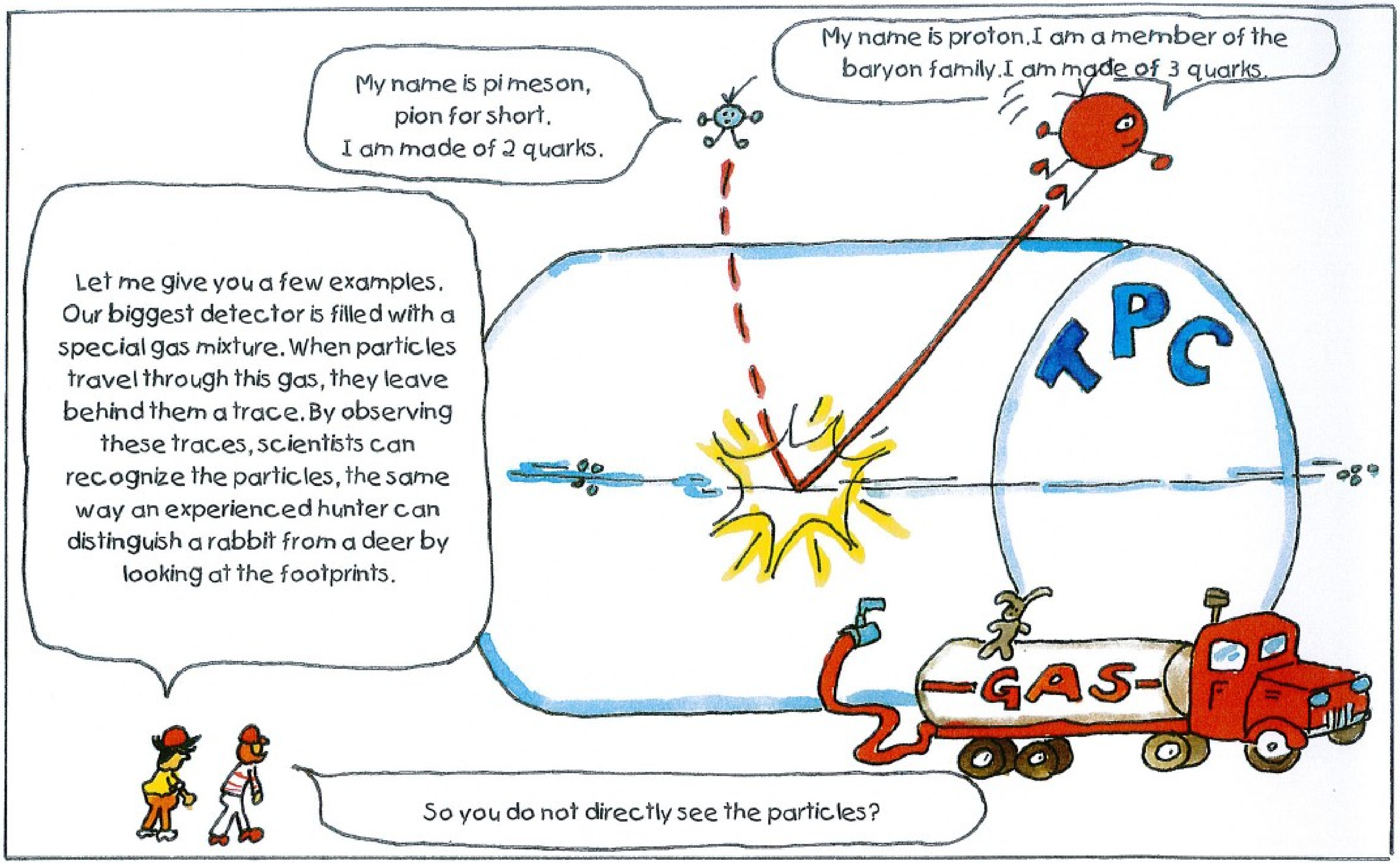
Track and identify directly only particles with long enough lifetime:
e, μ, π, K, p, d, t, ...

The TPC

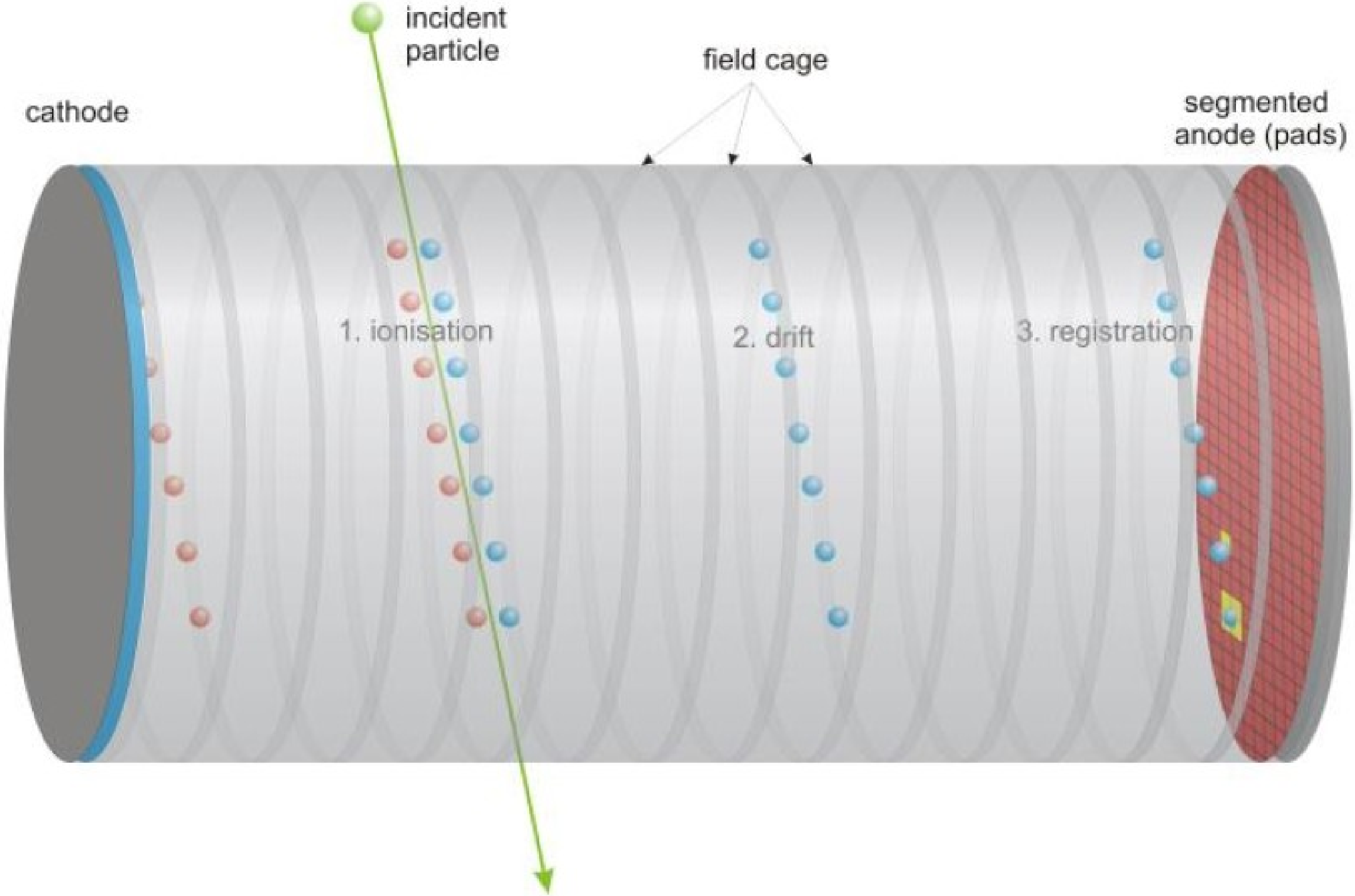


- The Time Projection Chamber is the main ALICE detector
- It is the largest TPC in the world
- 500 Mega-voxel 3D digital camera -> takes ca. 1000 pictures per second
  Currently being upgraded to take up to 50k pictures per second

TPC working principle

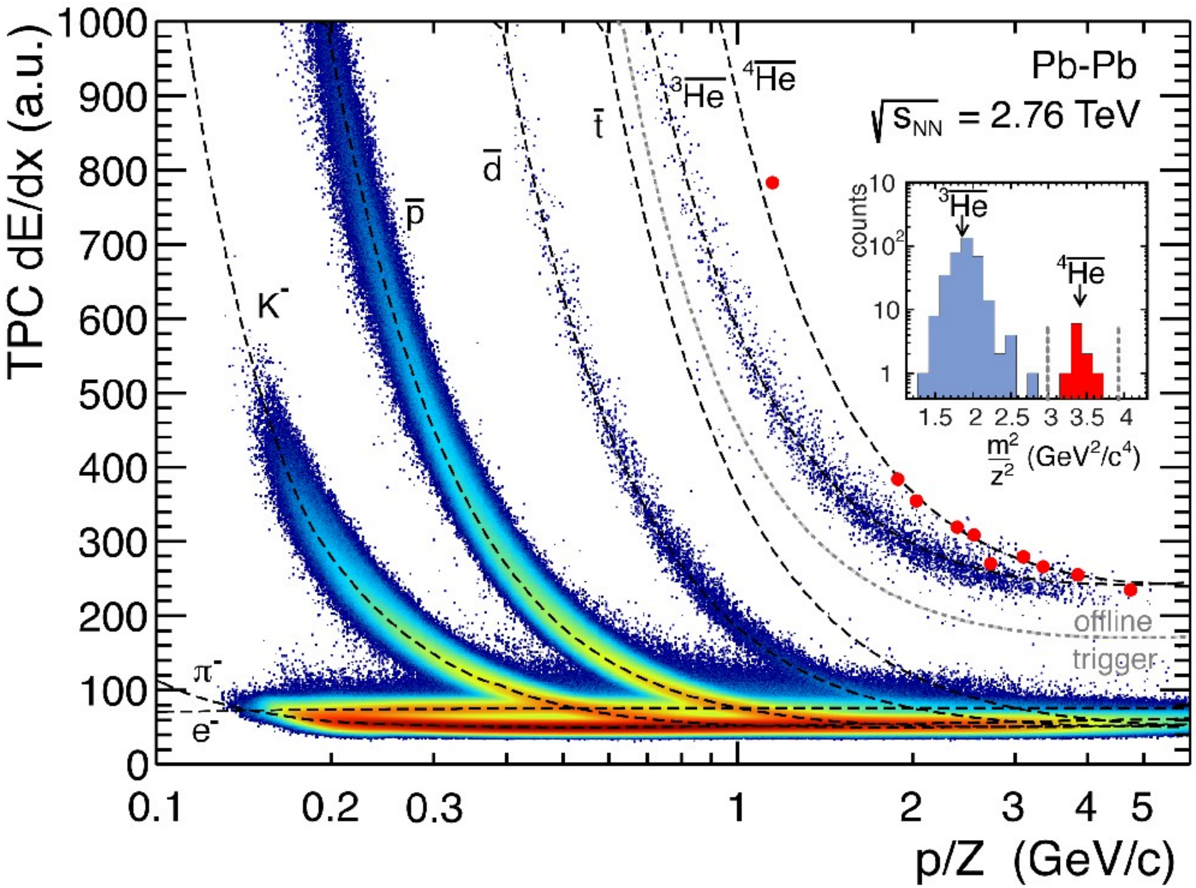


TPC working principle



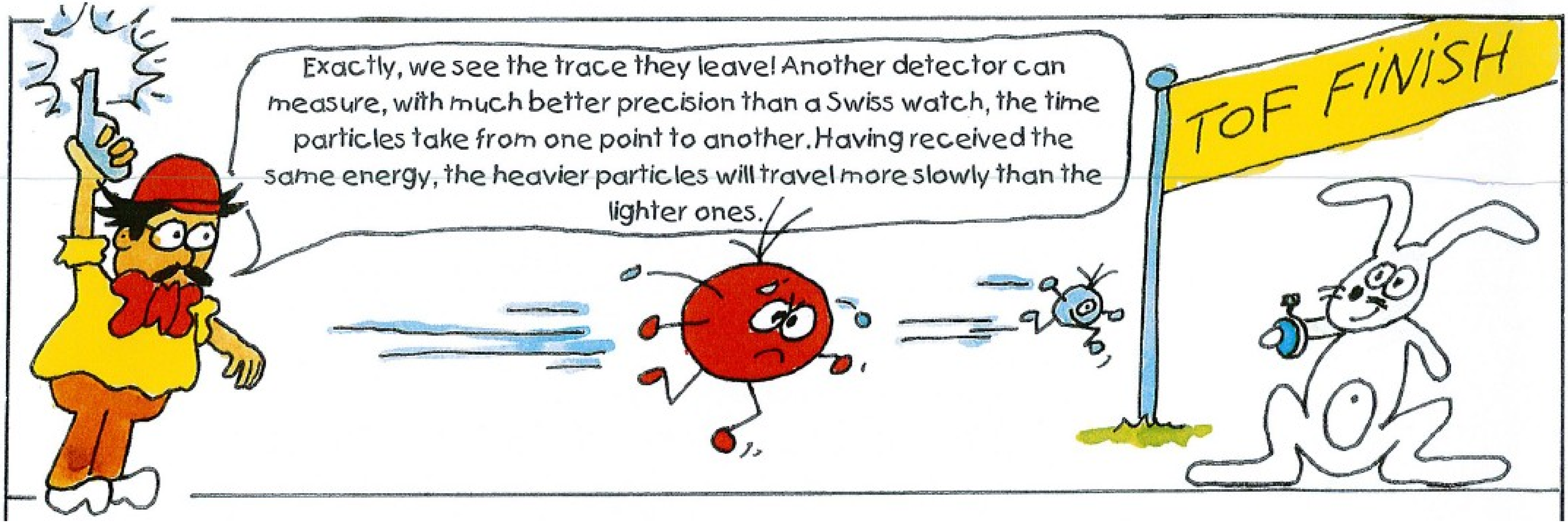
- Momentum measurement: $p_T = qBr$

Particle identification with TPC

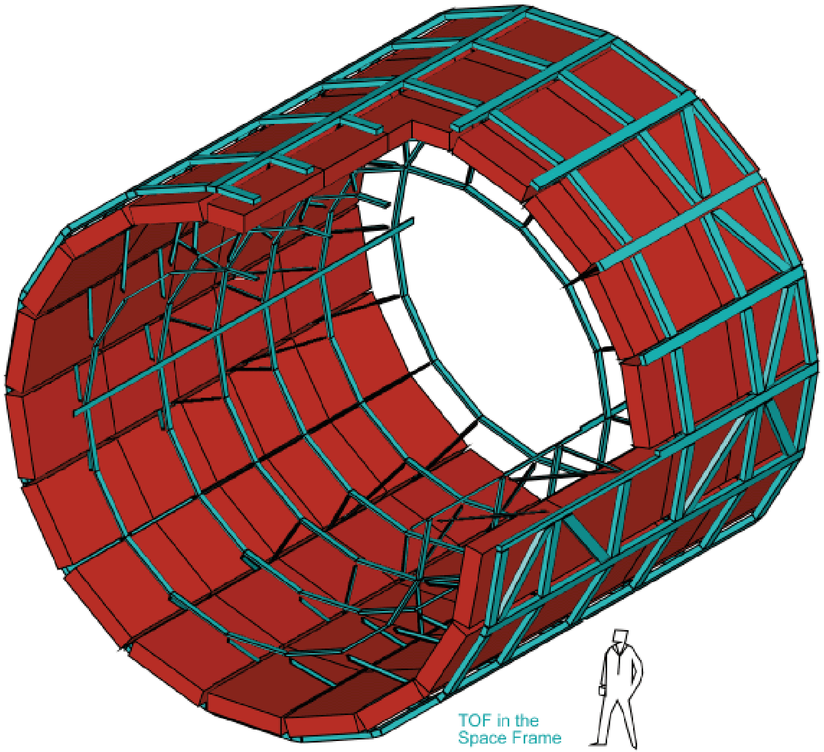


- Particles are identified using their specific energy loss in the TPC gas volume
- Highest mass anti-nuclei observed with the current data sample: anti-^{4}He

The Time-of-Flight detector (TOF)

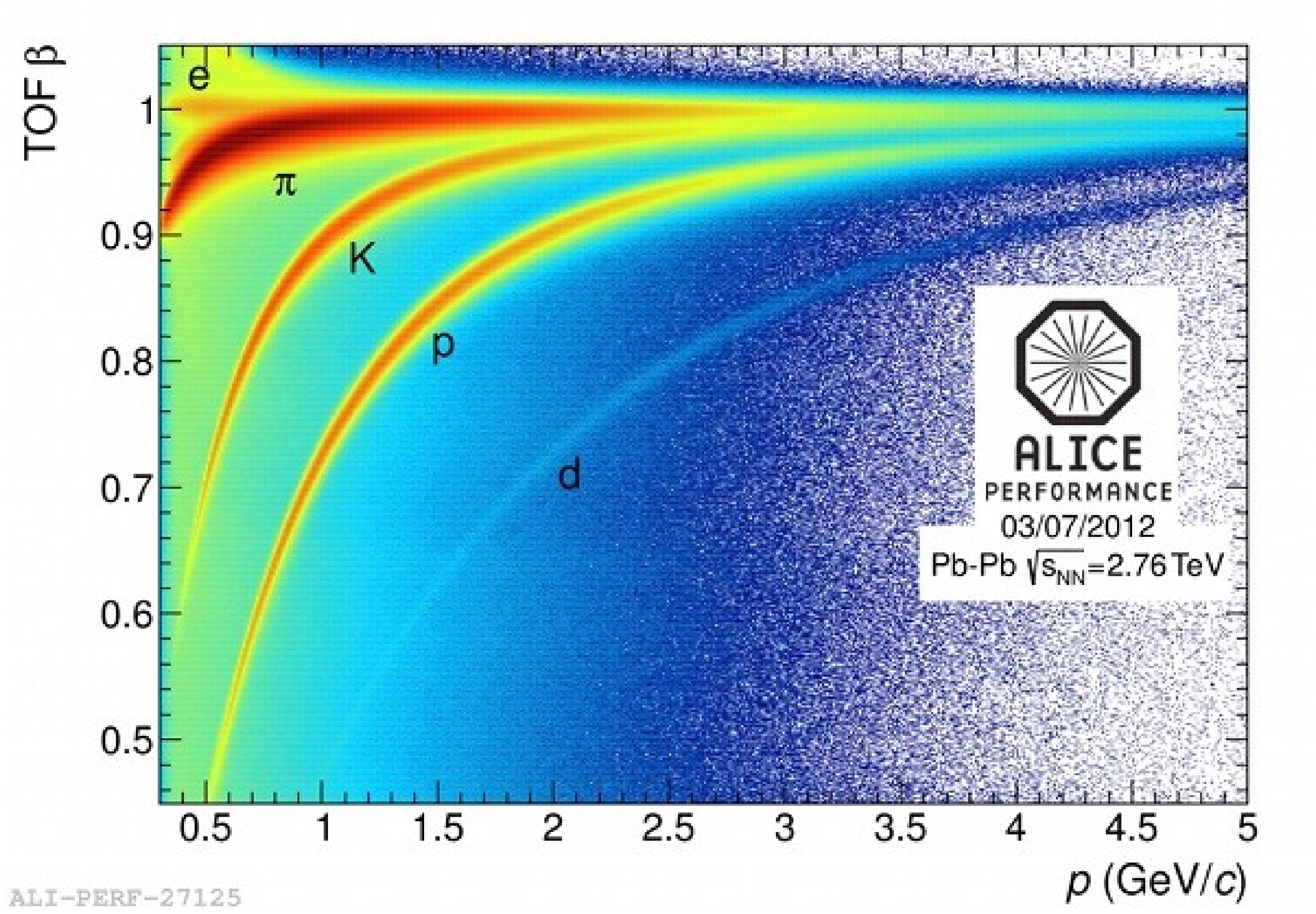


The Time-of-Flight detector (TOF)



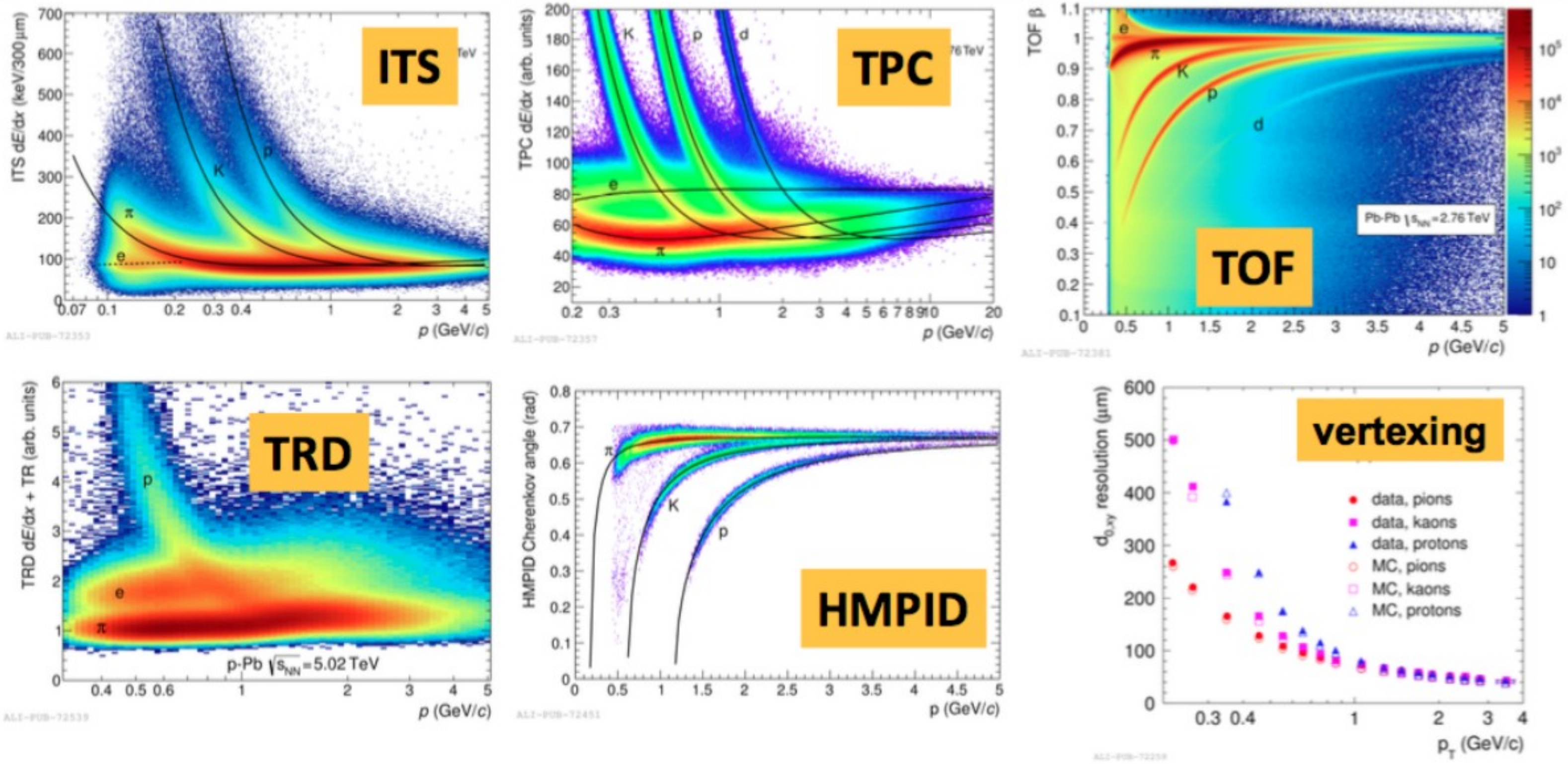
- Measures the time of flight between the collision start and arrival at the detector
- In conjunction with the momentum measurement from tracking -> particle identification
- Time resolution: 100 psec

Particle identification using TOF



- Complements the particle identification of the TPC

PID, vertexing and tracking capabilities



- particle identification (practically all known techniques)
- extremely low-mass tracker ~ 10% of X_0
- excellent vertexing capability
- efficient low-momentum tracking – down to ~ 100 MeV/*c*

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from: Evgeny Kryshen, ALICE overvies, QFTHEP 2015

PID

2. The main variable

in the most general terms:

the signal we observe: calibration is here!

$$\xi = n_\sigma = \frac{x_{PID} - \hat{x}_{PID}(m/z)}{\sigma}$$

what we expect for a given ID (m) hypothesis
→DETECTOR RESPONSE

PID discriminating variable
(in this case "nσ",
for a Gaussian detector response)

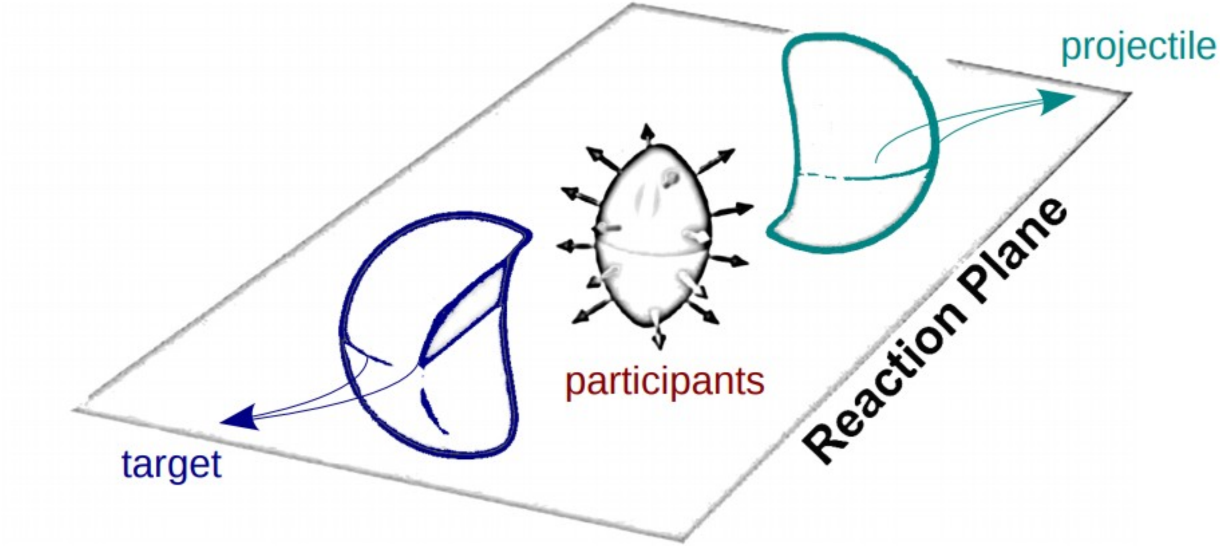
detector resolution
part of detector "response function" (mass dependent)

The typical quantity we defined in the framework is the so called 'nσ' variable.
This is defined (1) for all the detectors included in the framework (see next slides) and (2) for these particle species: e, μ, π, K, p (+ light nuclei: d, t, ^{3}He, ^{4}He)

Exercise 2

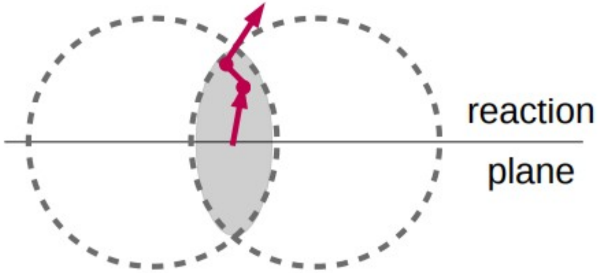
- Use the data set PbPb_cent2030 and plot the following histograms:
- η, φ and pT distributions for all the tracks *track→Eta(), track→Phi(), track->Pt()*
- dE/dx vs p for TPC *track->TPCsignal()*
- β vs p from TOF *track->TOFbeta()*
- n_σ(K) vs p from TPC and from TOF *track→TPCnSig(2), track->TOFnSig(2)*
- n_σ(K) from TPC vs n_σ(K) from TOF

Reaction plane



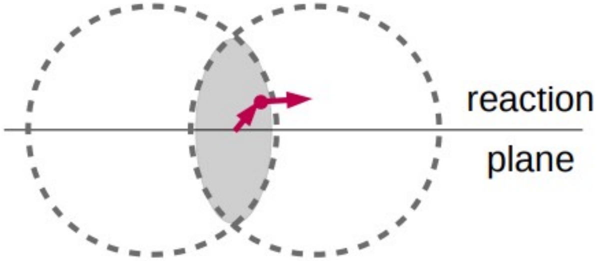
Spatial and momentum space asymmetries

out-of-plane



Multiple interactions with medium

in-plane



Less interaction - small modification

Initial spatial asymmetry converts into
azimuthal anisotropy in the momentum space

Quantified with the Fourier coefficients:

$$\frac{dN}{d(\phi_i-\Psi_n)} \sim 1 + 2 \sum_{n=1} v_n \cos[n(\phi_i-\Psi_n)]$$

v_1 - directed, v_2 - elliptic, and v_3 - triangular flow

Anisotropic flow measurement techniques

$$\frac{dN}{d(\phi_i - \Psi_n)} \sim 1 + 2 \sum_{n=1} v_n \cos[n(\phi_i - \Psi_n)]$$

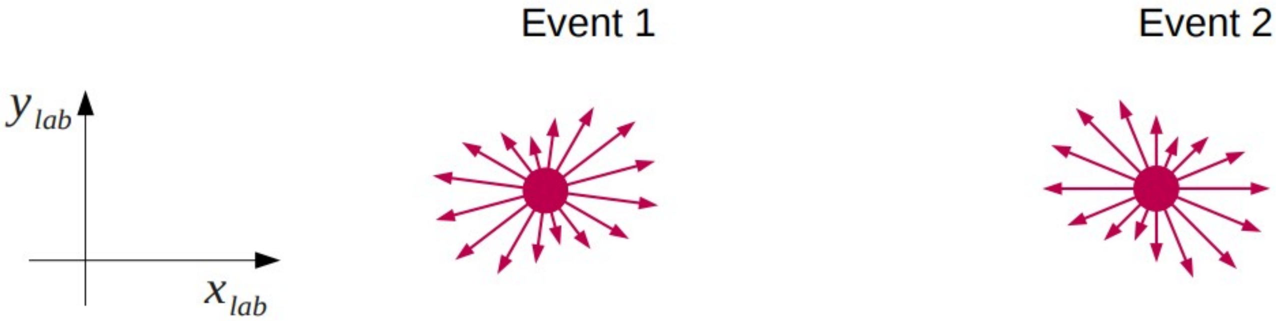
If orientation of the collision symmetry plane is known

$$v_n = \langle \cos[n(\phi_i - \Psi_n)] \rangle$$

BUT: experimentally the collision symmetry plane orientation is unknown

Estimating the reaction plane angle

Reaction plane is not known experimentally
Orientating wrt. to the laboratory frame changes event-by-event

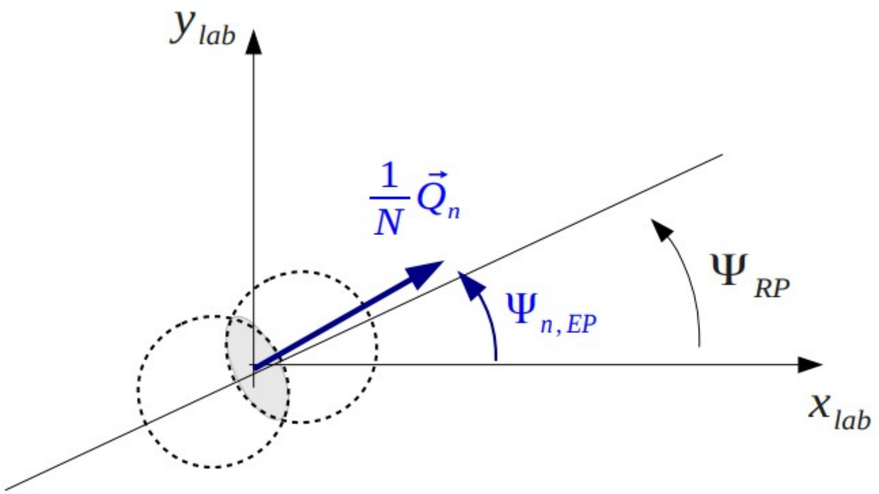


Only measuring particles distribution in the momentum space

If the momentum distribution is azimuthally asymmetric due to flow,
then this asymmetry should be correlated
with the impact parameter direction (reaction plane orientation)

Use particle azimuthal distribution in the event
to estimate the reaction plane angle – event plane vector

Event plane (flow) vector



Vector sum of all particles direction:

$$Q_{n,x} = \sum_i w_i \cos(n\phi_i) \qquad Q_{n,y} = \sum_i w_i \sin(n\phi_i)$$

Experimental estimate of the reaction plane:

Event plane vector: $$\Psi_{n,EP} = \frac{1}{n}\tan^{-1}\left(\frac{Q_{n,y}}{Q_{n,x}}\right)$$

Measuring flow with the event plane vector

$$\frac{dN}{d(\phi - \Psi_{RP})} \sim 1 + 2\sum_{i=1} v_n(p_t, \eta) \cos[n(\phi - \Psi_{RP})]$$

Want to measure:

$$v_n = \langle \cos[n(\phi - \Psi_{RP})] \rangle$$

$\longrightarrow$

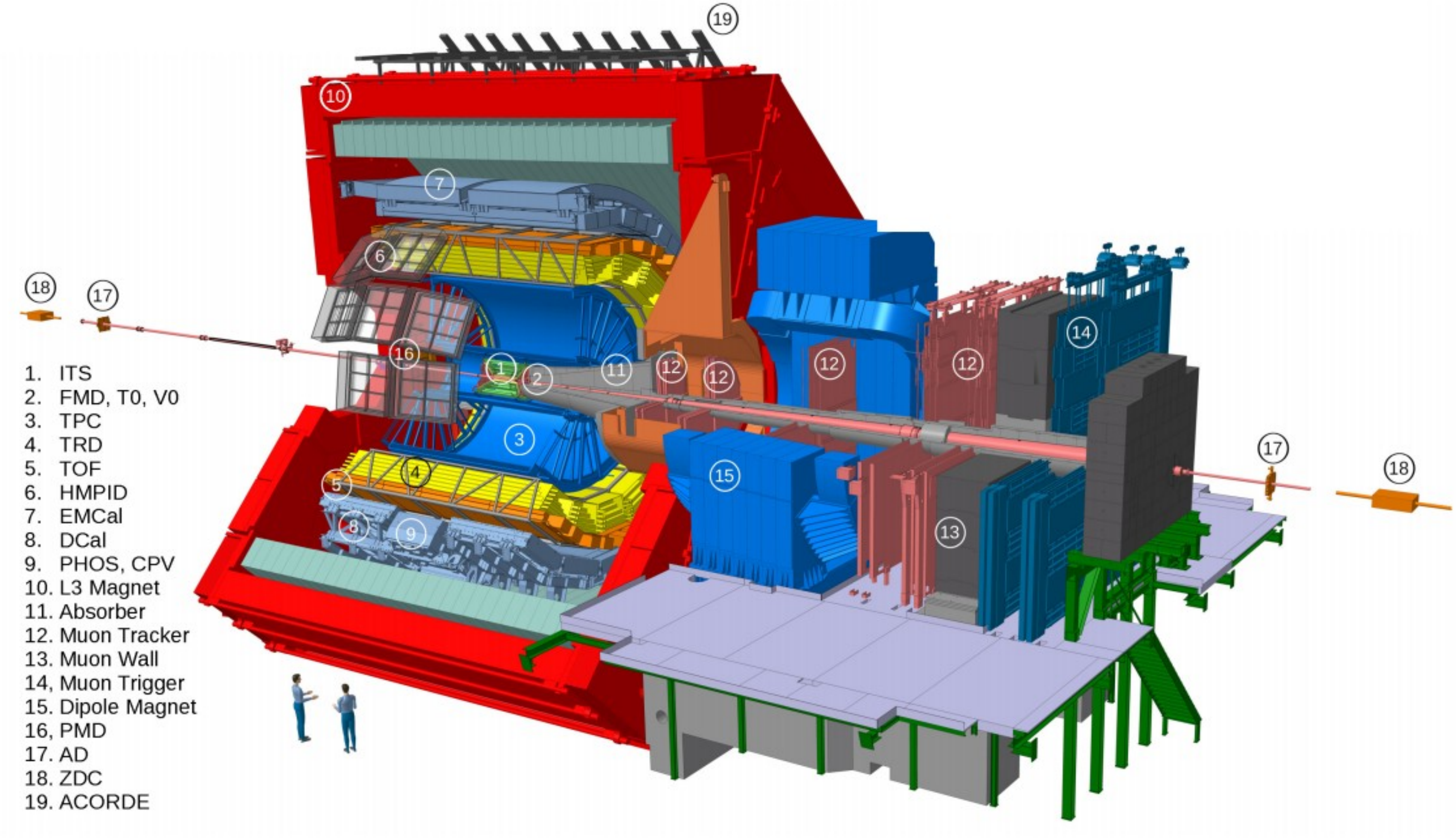
Measured:

$$v_n^{obs} = \langle \cos[n(\phi - \Psi_{n,EP})] \rangle$$

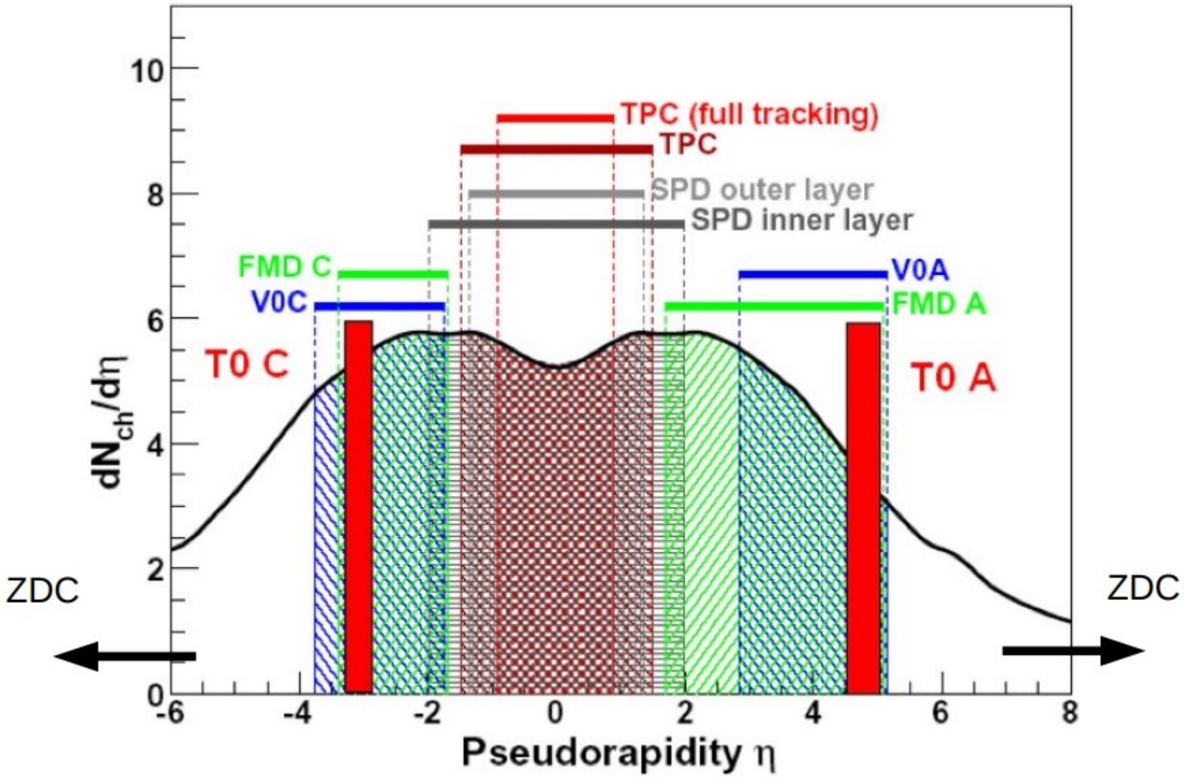
Event plane vector and the reaction plane are correlated with finite resolution:

$$v_n = \frac{\langle \cos[n(\phi - \Psi_{n,EP})] \rangle}{\langle \cos[n(\Psi_{n,EP} - \Psi_{RP})] \rangle} = \frac{v_n^{obs}}{R_n}$$

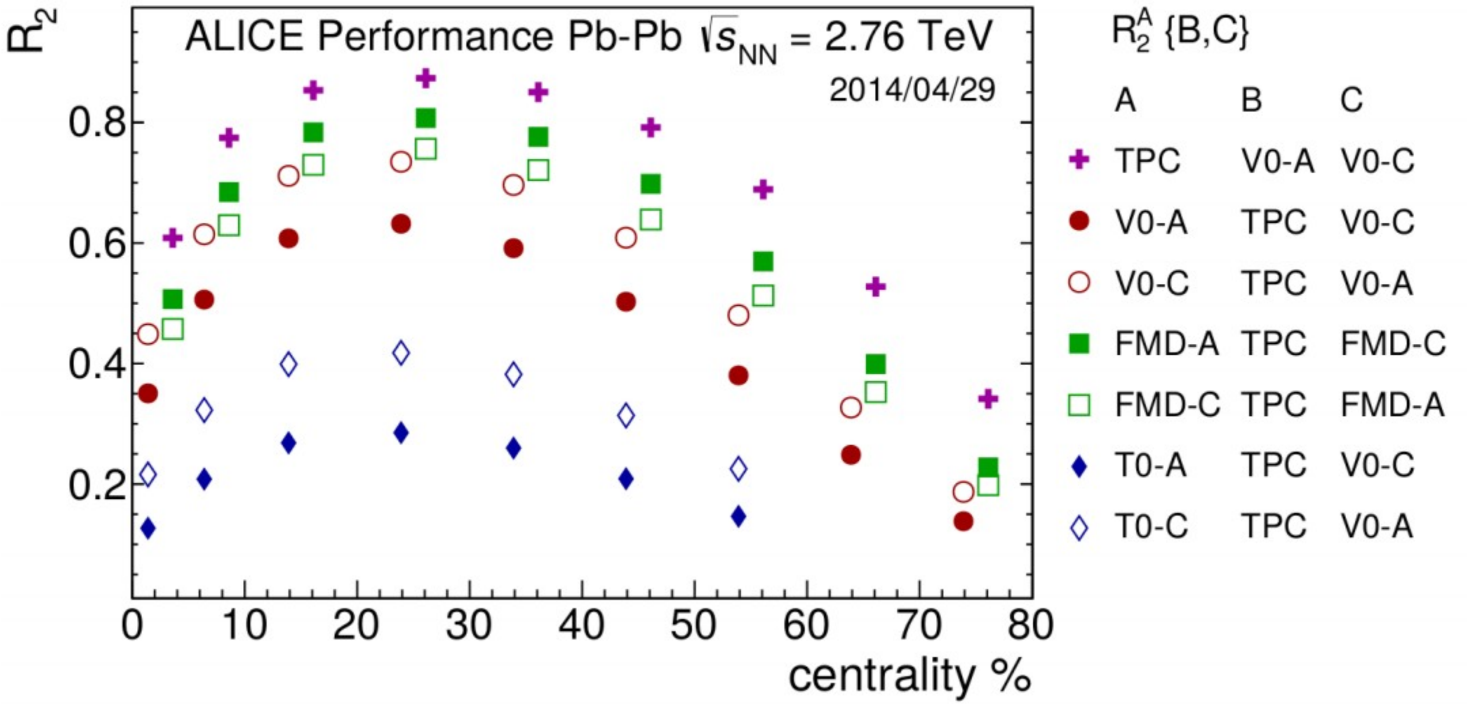
Where we can get an event plane angle in ALICE?



ALICE rapidity coverage



Reaction plane resolution



Exercise 3

- Use the dataset PbPb_cent2030
- Compute and plot the $Q_2\{x,y\}$ vector components using all tracks in the $0.5<\eta<0.8$ interval
- Plot the Ψ_2
- Compute the v_2^{obs} for all charged particles in the interval $-0.8<\eta< -0.5$ and plot it as a function of p_T
- If time allows
  - Use the PbPb_minbias dataset and plot v_2^{obs} as a function of VZERO centrality for charged tracks in $-0.8<\eta< -0.5$ and $1.0<p_T<1.5$ GeV/c

Homework?

- Calculate v_2^{obs} as a function of p_T for identified particles ($\pi^{\pm}$,$K^{\pm}$,p,$\bar{p}$) in the VZERO centrality range 30-40%