Introduction to ALICE and Heavy-Ion Physics

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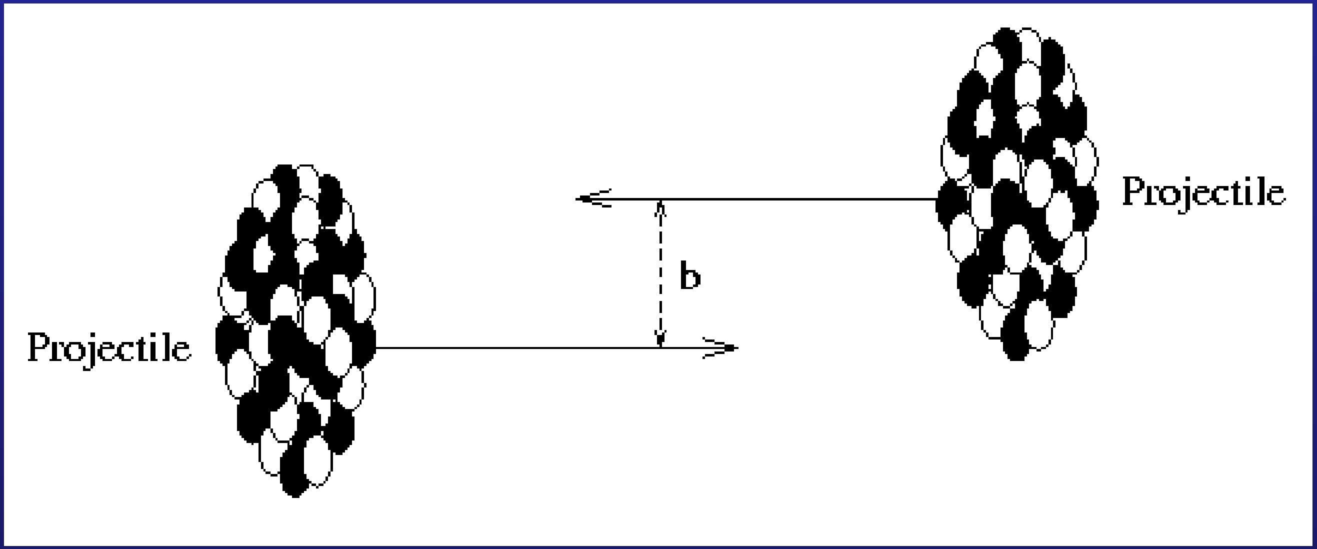
Outline

- Heavy Ion Collisions at Colliders: RHIC and the LHC.
- Why heavy-ion collisions? Some interesting observables.
- The ALICE Experiment
- Norwegian contributions to ALICE

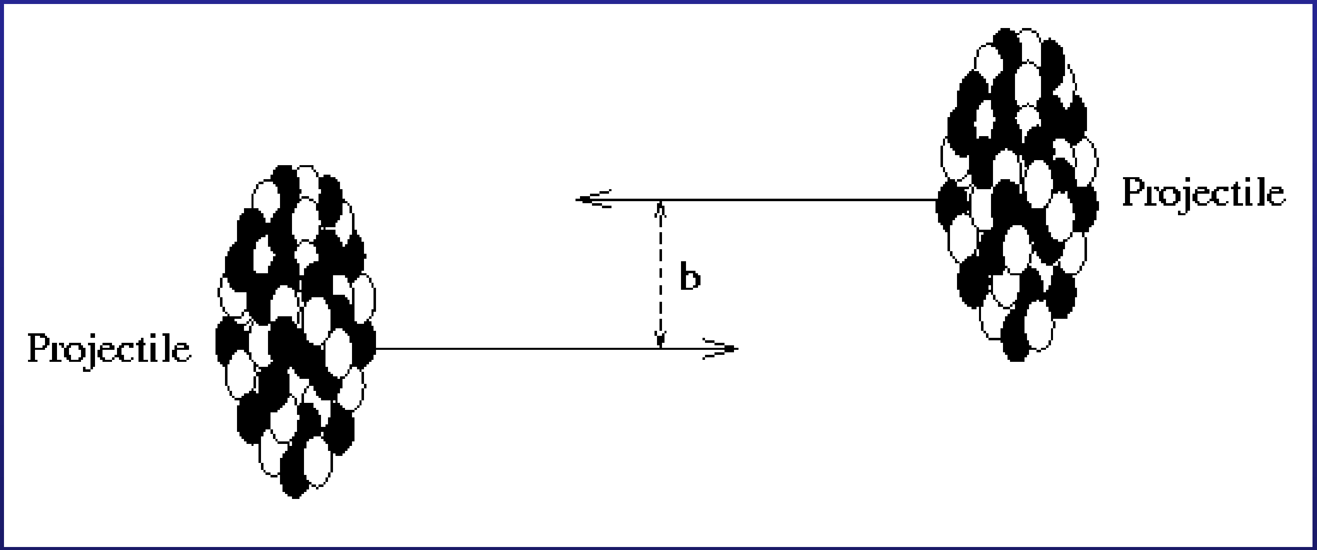
What is a ”heavy ion”?

Accelerator terminology: Any ion with A>4,
$\Rightarrow$ Anything heavier than α-particle

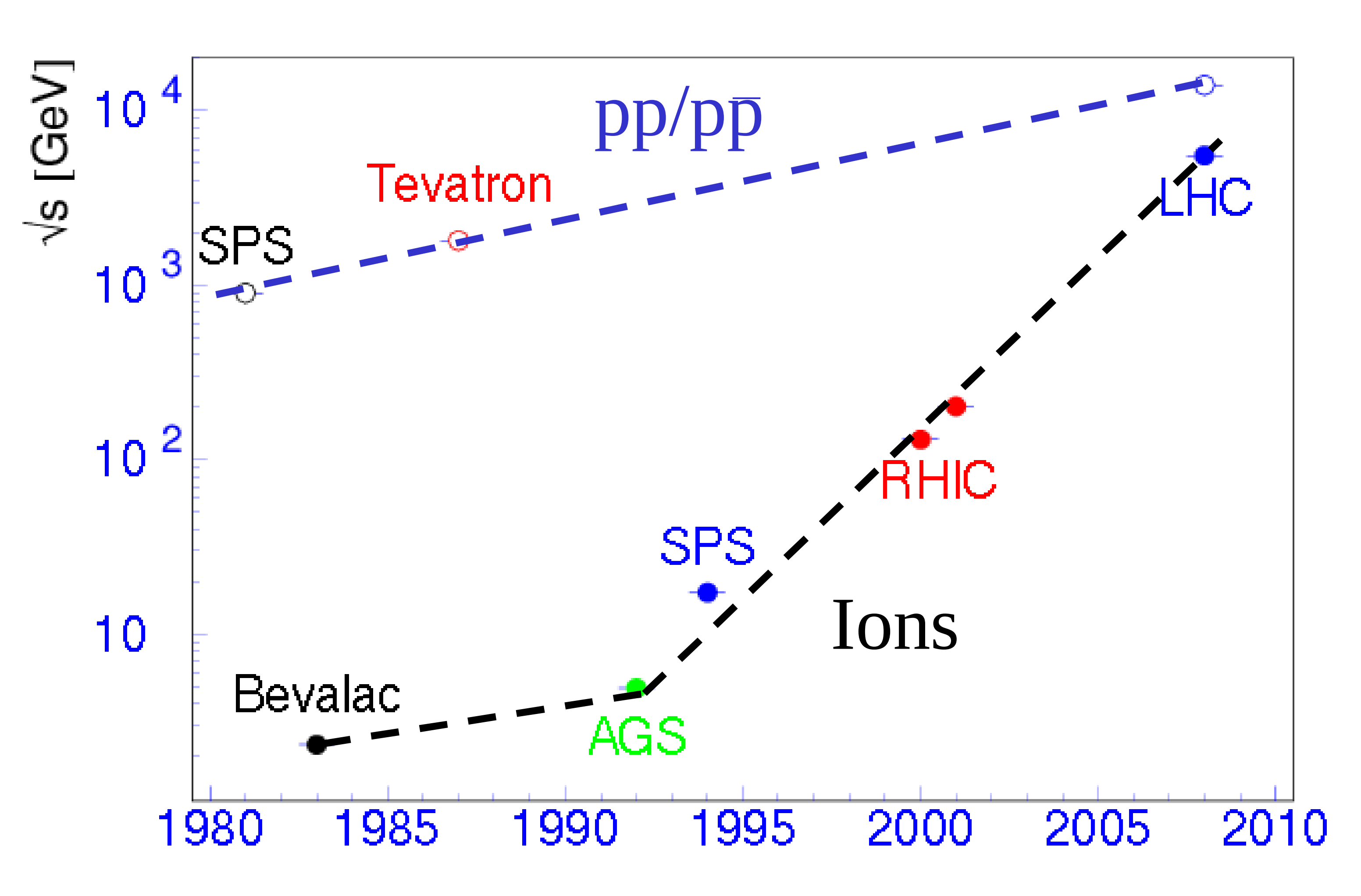
This talk: *truly heavy ions* –
ions with A≈200 (^{197}Au, ^{208}Pb)



Measure of collision energy:
center-of-mass energy per nucleon-nucleon collision, $\sqrt{s_{nn}}$.



The maximum $\sqrt{s_{nn}}$ of truly heavy ions has increased dramatically during the last 25 years:

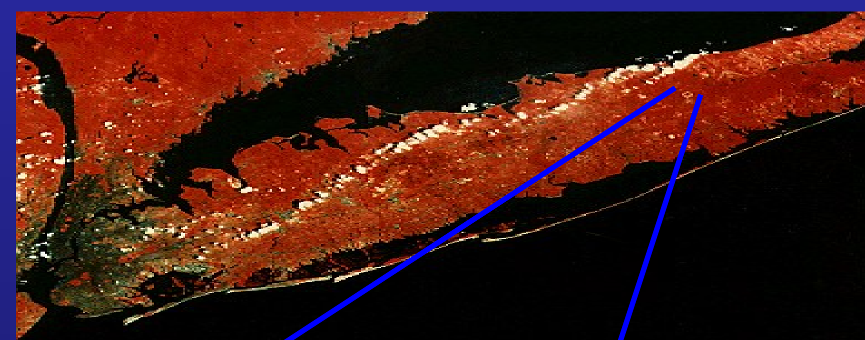


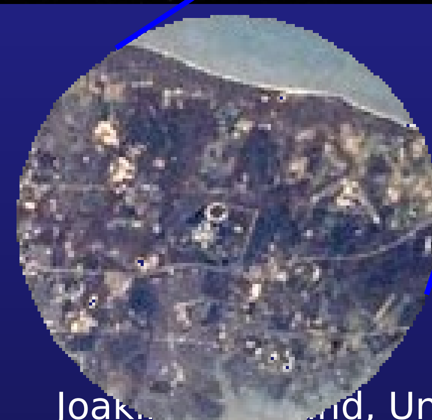
The Relativistic Heavy Ion Collider (RHIC)

Collider for heavy nuclei and (polarized) protons at Brookhaven National Laboratory.

Au+Au @ $\sqrt{s}$ = 200 A GeV

p+p @ $\sqrt{s}$ = 500 A GeV (200 GeV so far)

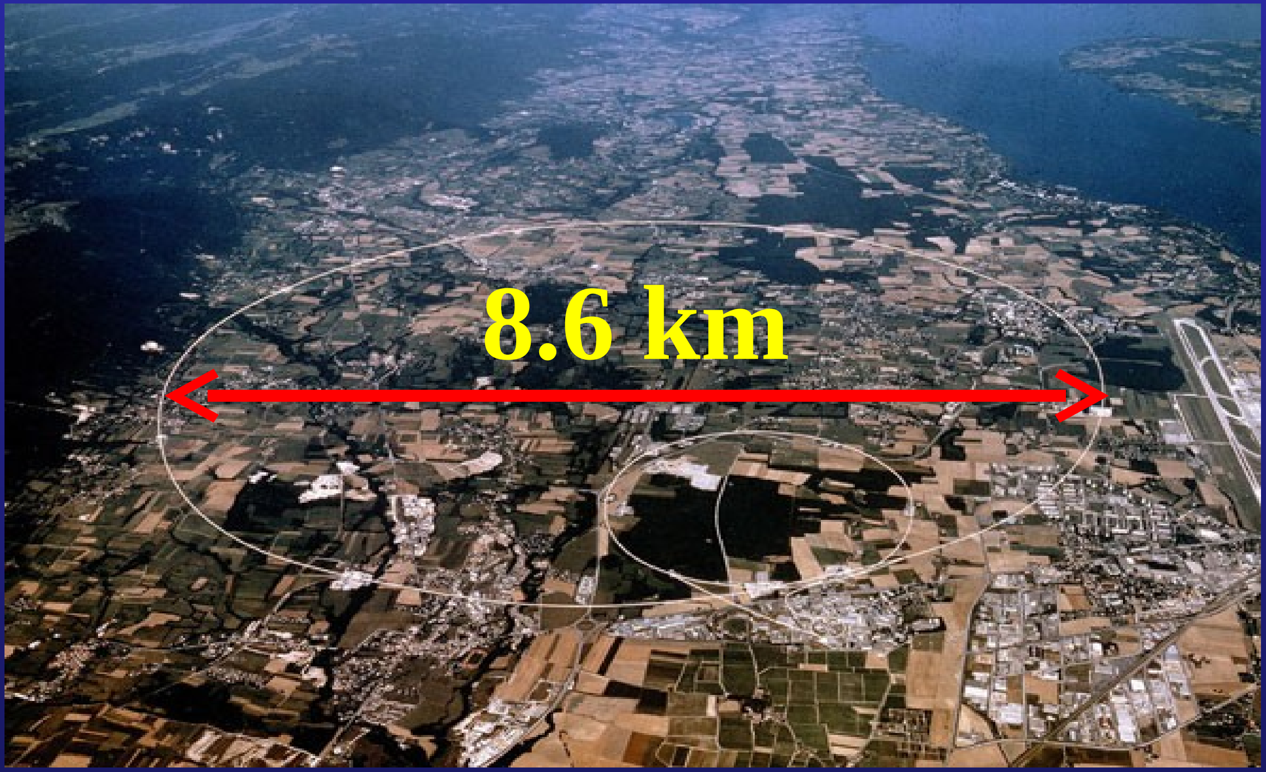




The Large Hadron Collider (LHC)

Collider for protons and heavy nuclei at CERN.

p+p @ $\sqrt{s}$ = 14 TeV (7 TeV initially)
Pb+Pb @ $\sqrt{s}$ = 5.5 A GeV



But why heavy-ions?

Why not just collide protons?
They are also made of quarks and held together by the strong interaction.

Why do we want to collide the heaviest nuclei we can find?

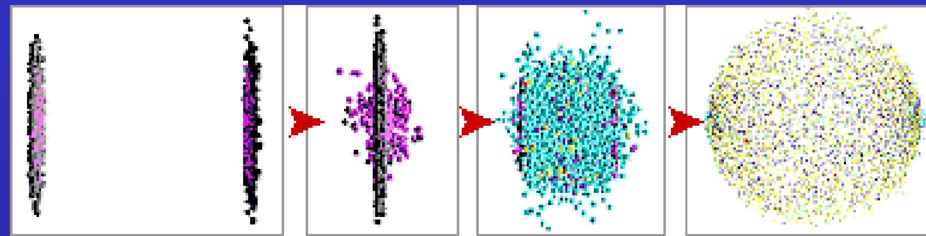
We want to study *nuclear matter*.

Quantum Chromodynamics (QCD) works fine if you treat one particle at a time and when the ”scale” is high enough (above several GeV/c).

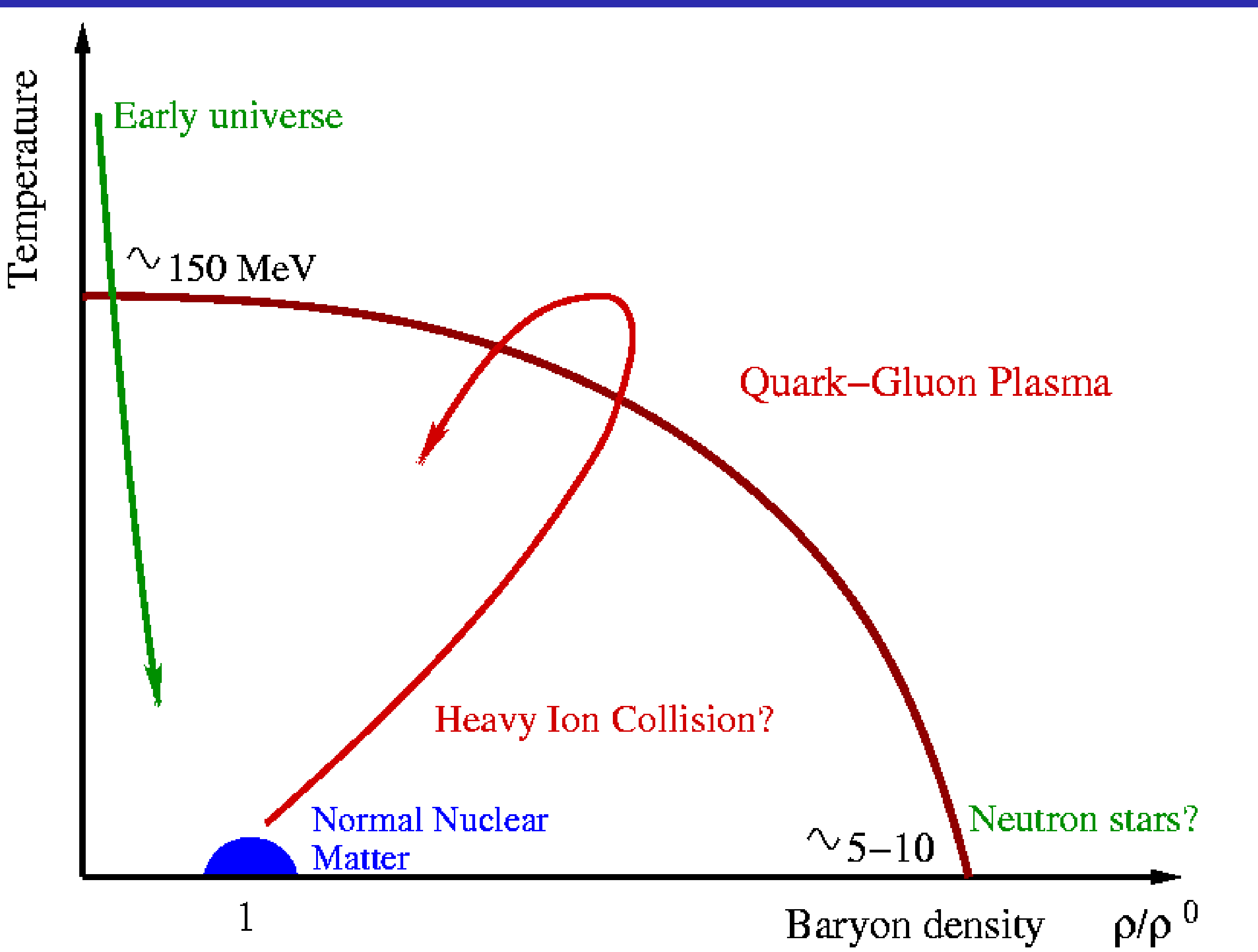
We want to understand how QCD works for large systems, systems containing 1000’s of particles occupying ”large” volumes.

We want to understand how (nuclear) matter behave under extreme conditions, under extreme temperatures and densities.

The goal of relativistic heavy-ion collisions is to study hot and dense nuclear matter



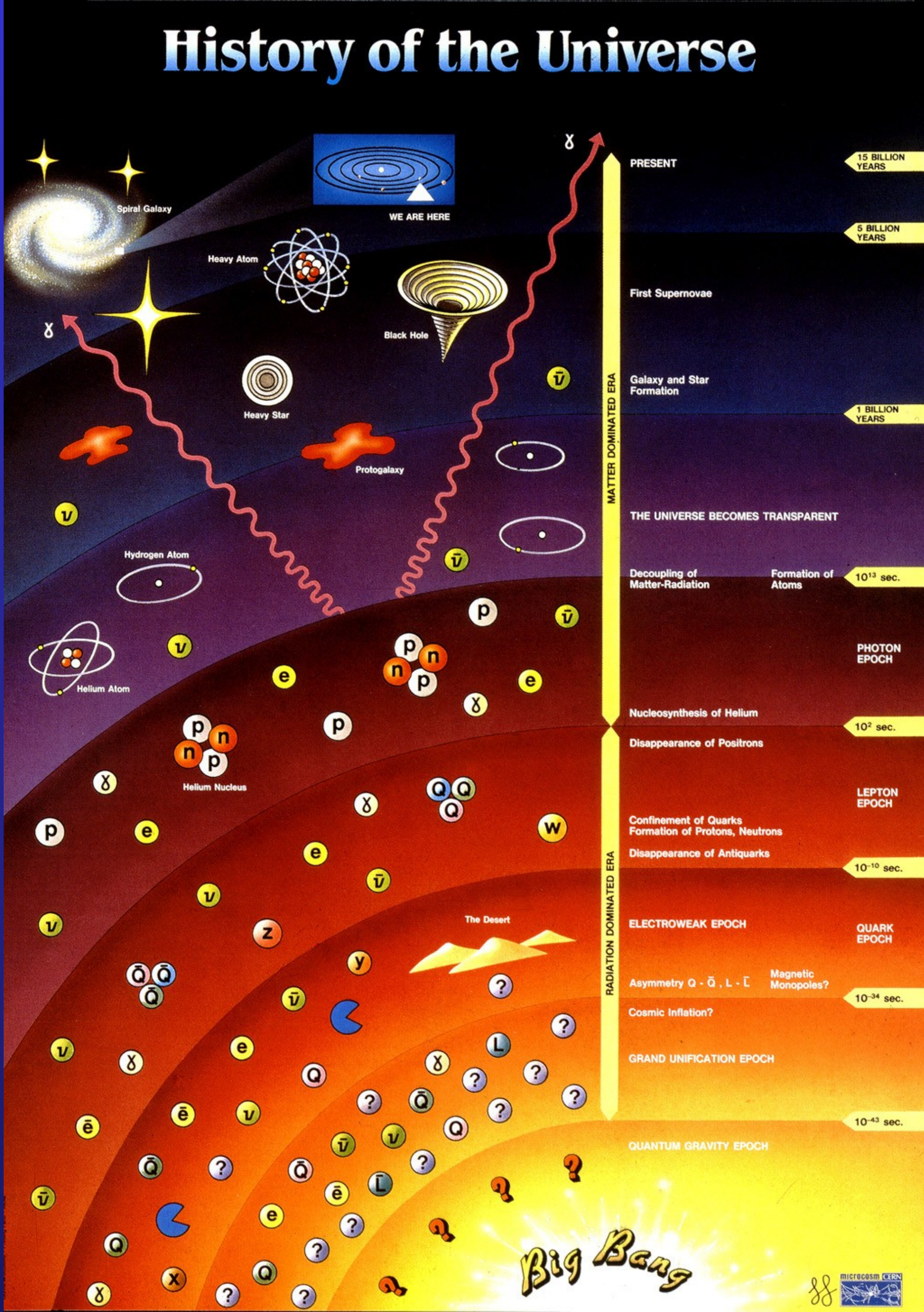
The nuclear phase diagram



The age and temperature of the universe today, $13.7 \cdot 10^9$ years and 2.7 K, respectively. ⇒

T = 150 MeV ≈100μs after Big Bang.

One goal of heavy-ion interactions is to understand what happened in the early universe.

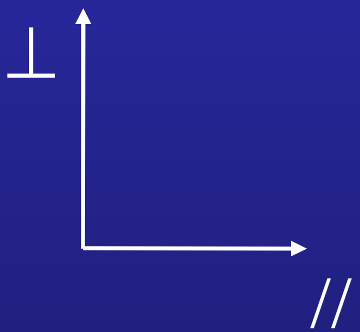


Probing the medium with high-p_T particles

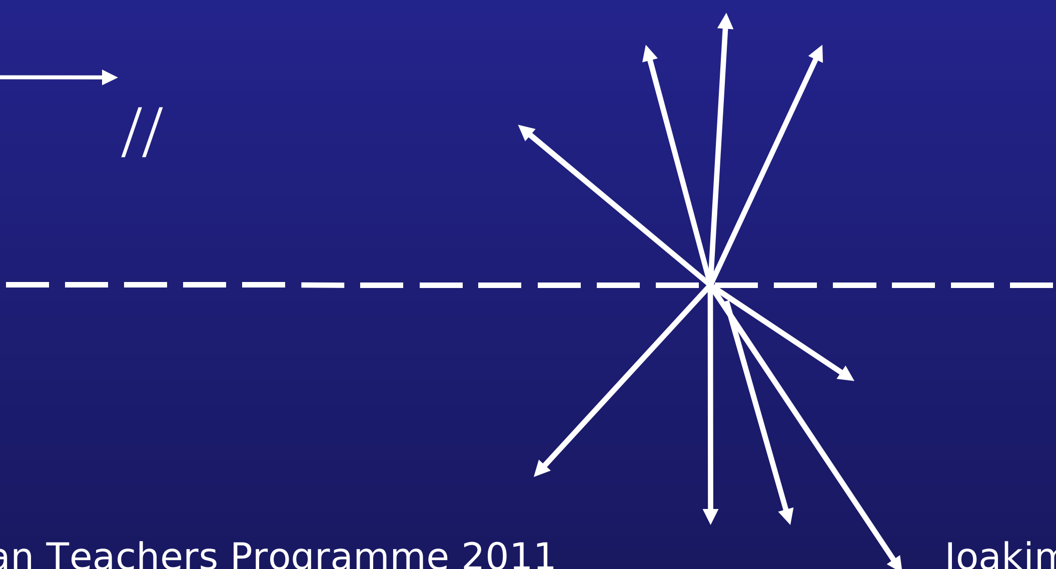
p_T or $p_\perp$: Transverse momentum

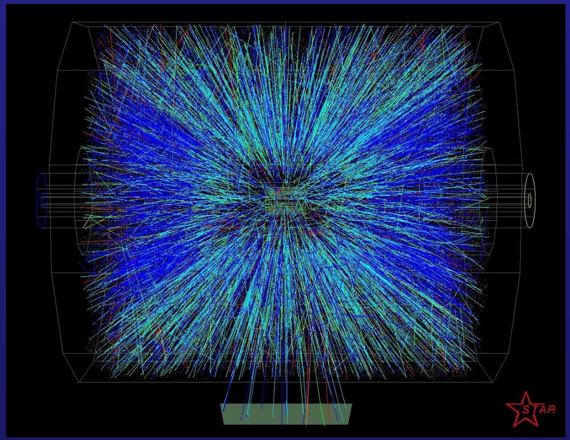
Before:

$p_{//} = +2.75$ TeV/c, $p_\perp = 0$ $p_{//} = –2.75$ GeV/c, $p_\perp = 0$



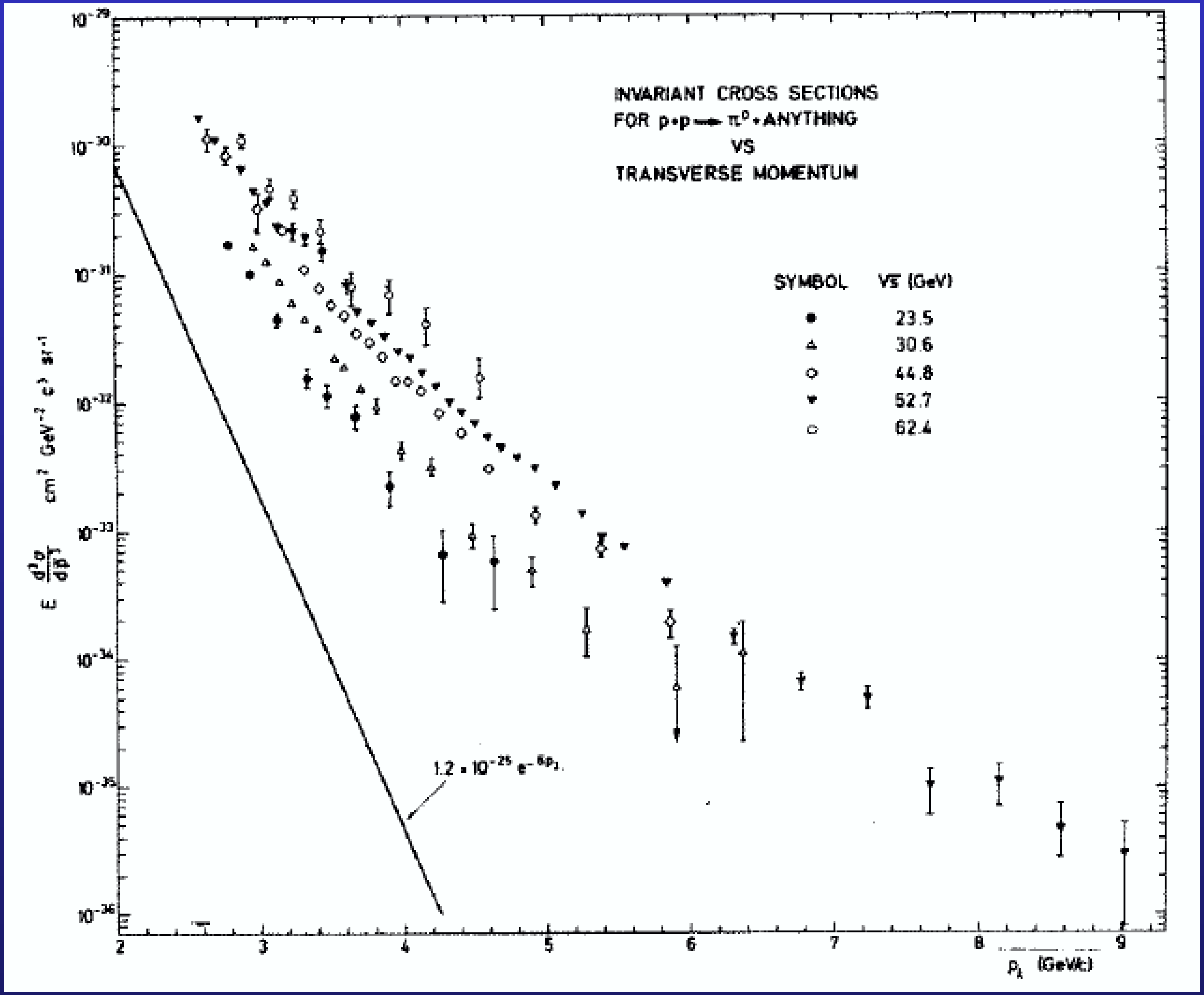
After:





p_T distribution in p+p collisions

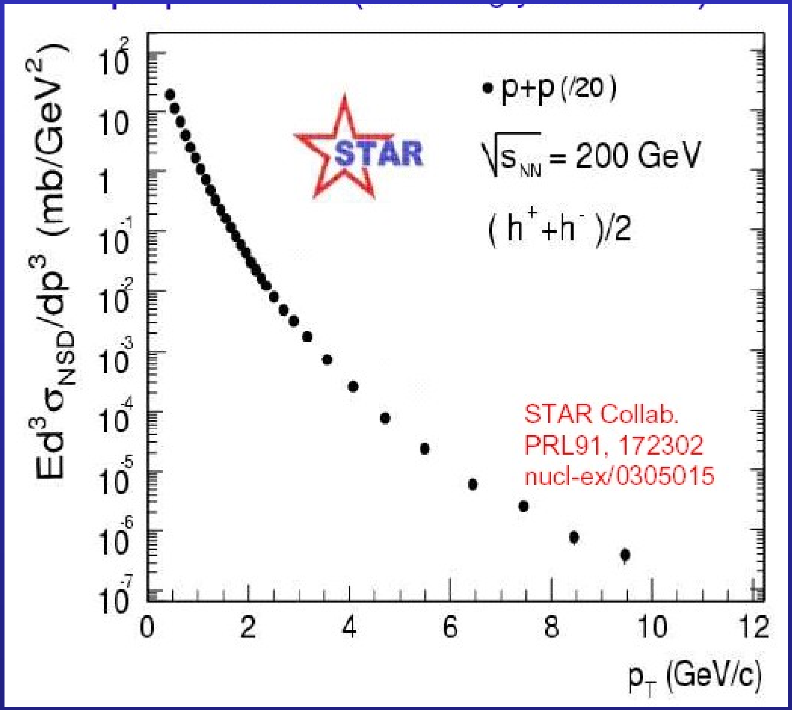
Intersecting Storage Ring (ISR), CERN ~1973, √s = 23-62 GeV



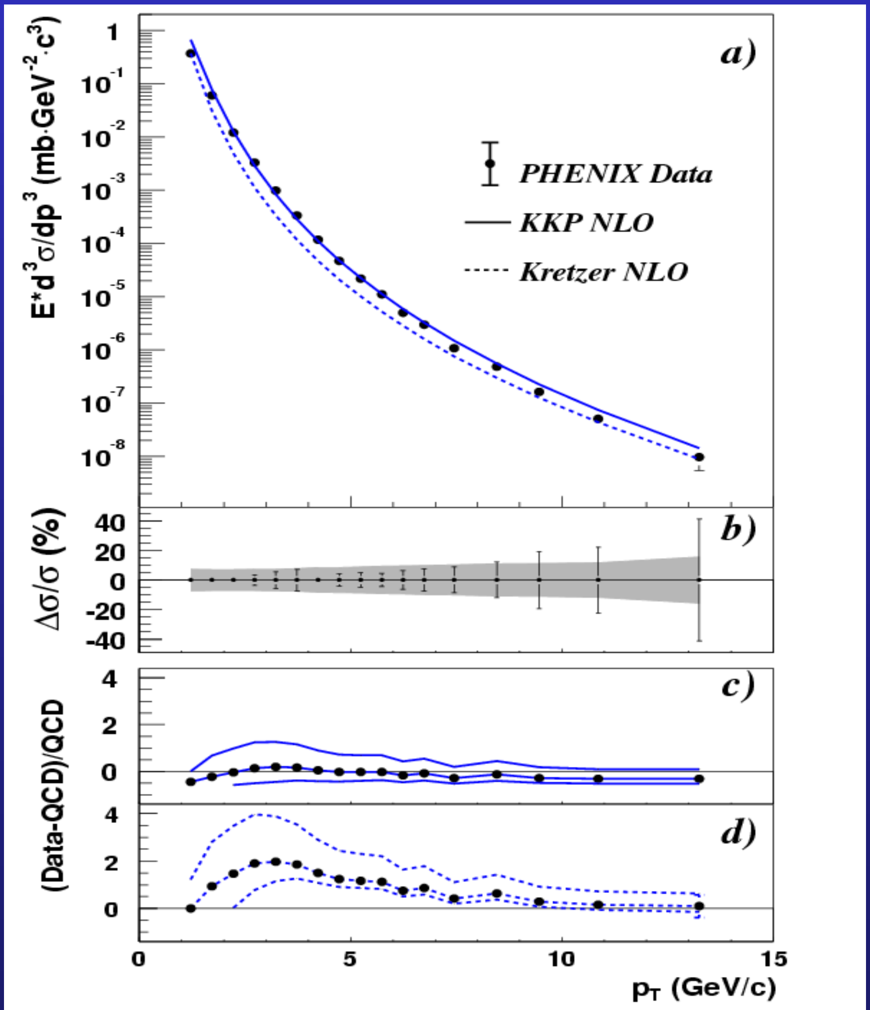
p+p →
π^0 + anything

p_T distribution in p+p collisions at RHIC

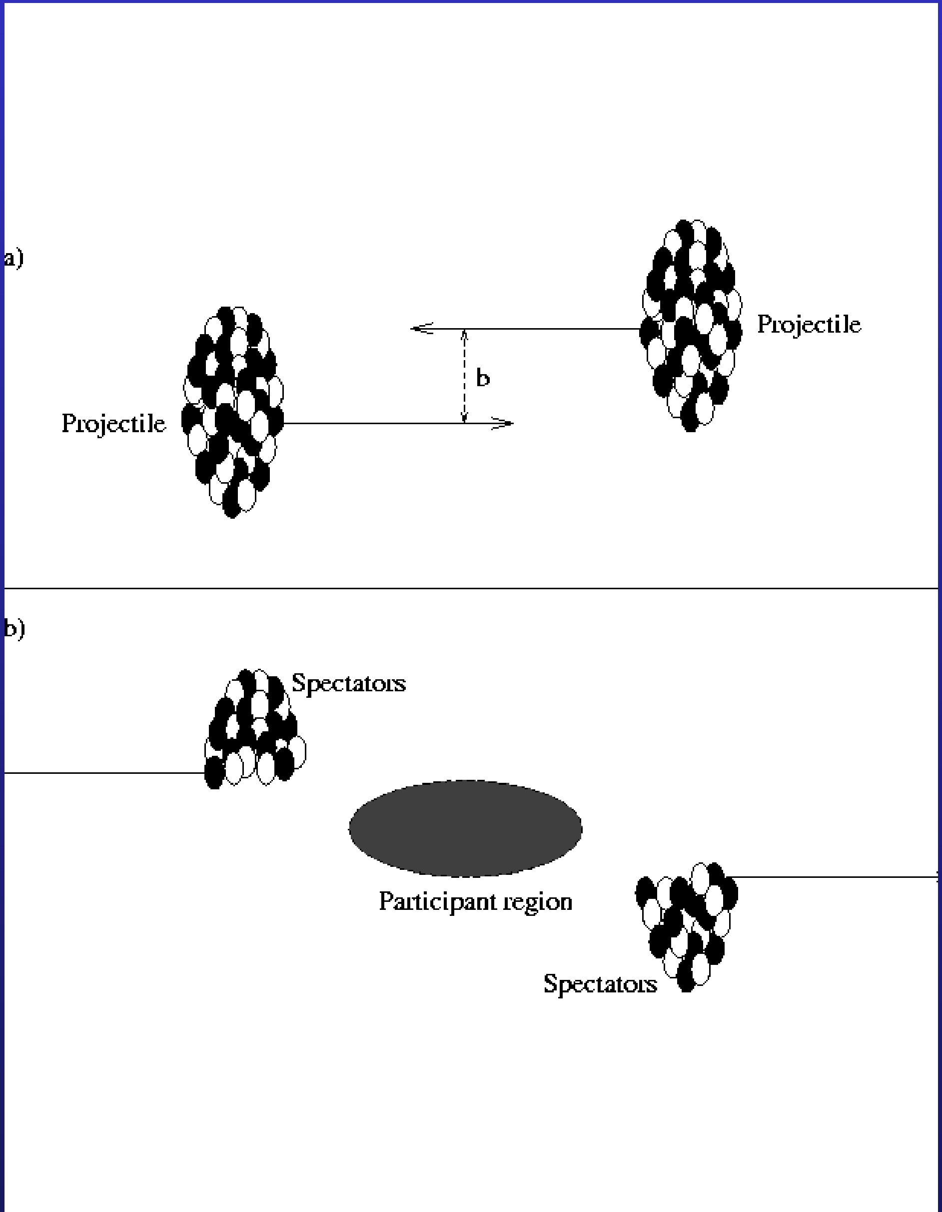
STAR p+p → $h^{+/-}$ + X



PHENIX p+p → π^0 + X



How can we relate this to whar we measure in nucleus-nucleus collisions?



The collisions are characterized by their centrality or impact parameter.

Two measures:

Np : Number of participating nucleons

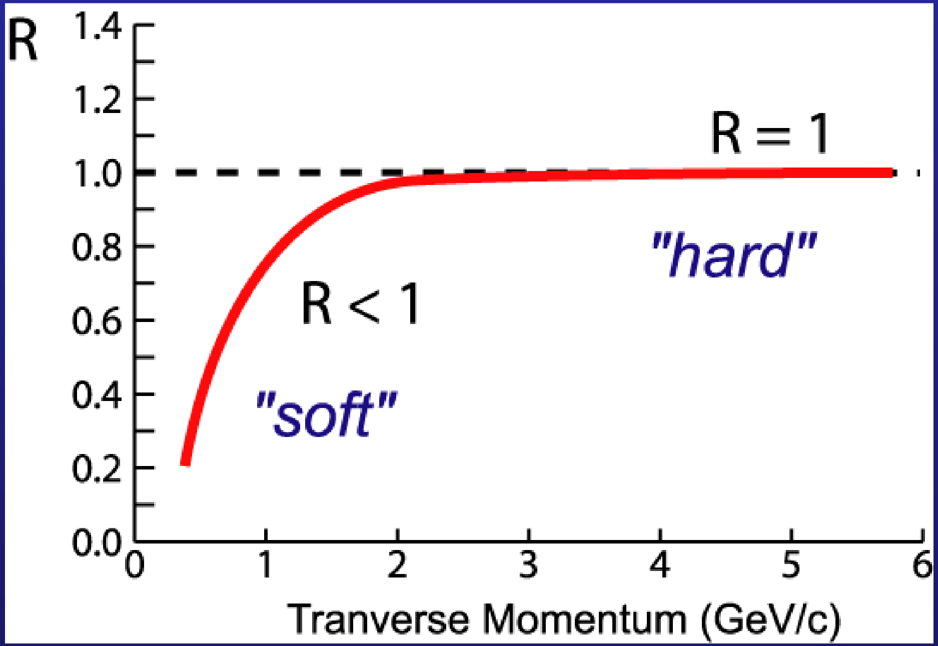
N_{coll} : Number of binary (nucleon-nucleon) collisions

How can we relate this to whar we measure in nucleus-nucleus collisions?

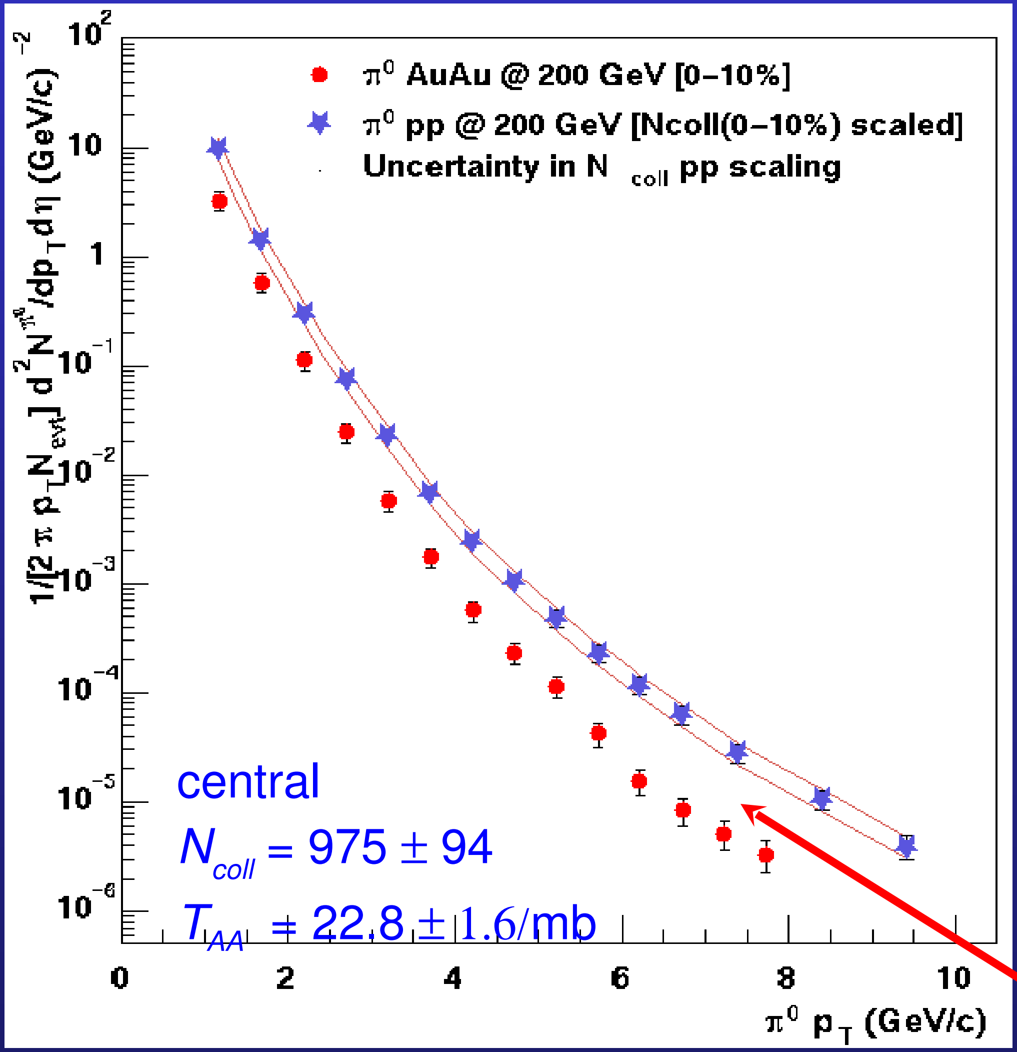
Quantify the suppression using the R_{AA} measure:

$$R_{AA}(p_T) = \frac{(1/N_{EVT})d^2N_{AA}^{\pi 0}/dp_T dy}{<T_{AB}(b)> \times d^2\sigma_{pp}^{\pi 0}/dp_T dy}$$

Expectation in absence of medium effects



p_T distribution in Au+Au collisions at RHIC



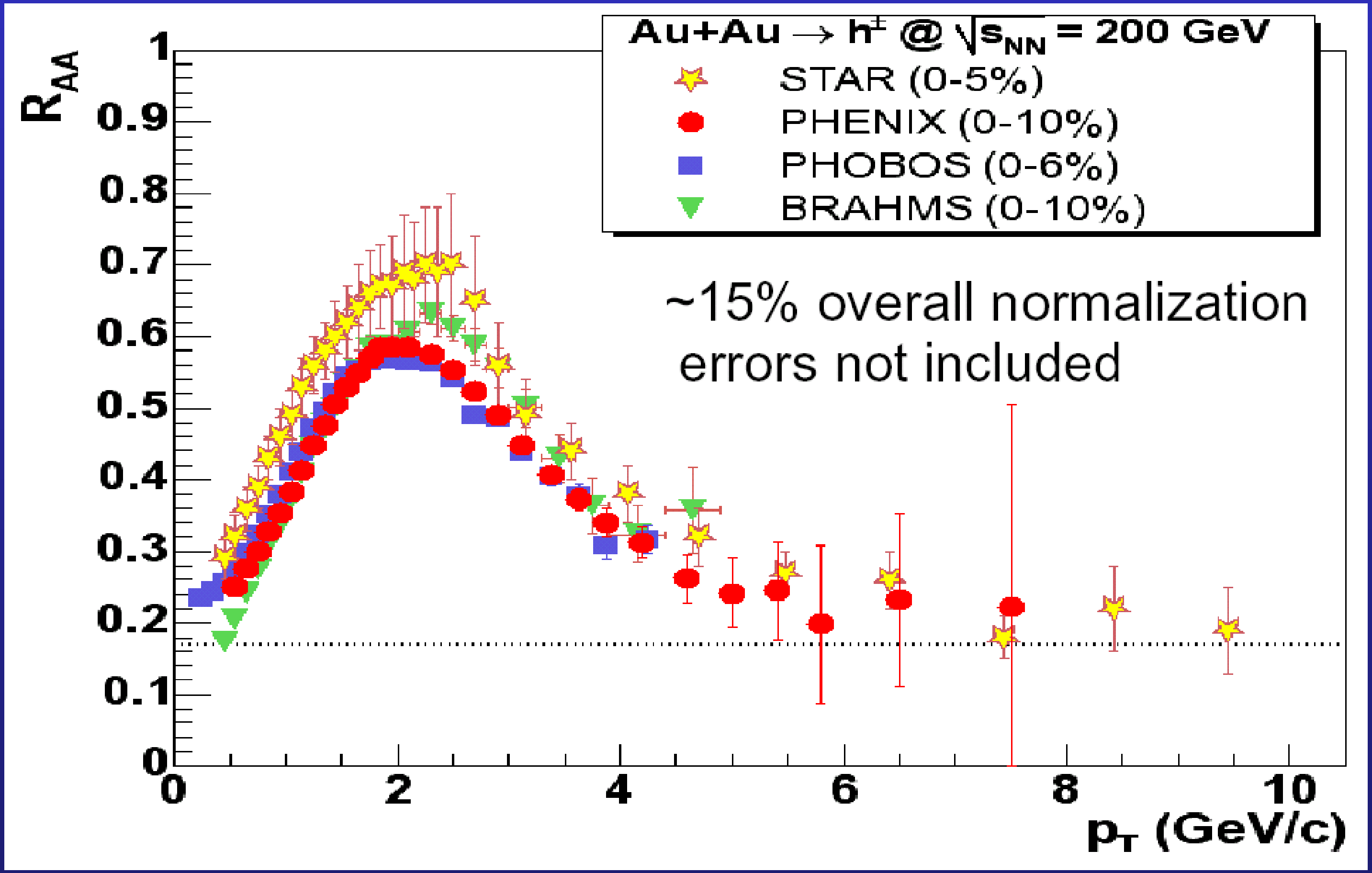
Au+Au $\rightarrow \pi^0$ + X compared with scaled p+p $\rightarrow \pi^0$ + X

Scaled with N_{coll} from nuclear geometry, "Glauber Model".

Expects yield to be proportional to number of NN collisions

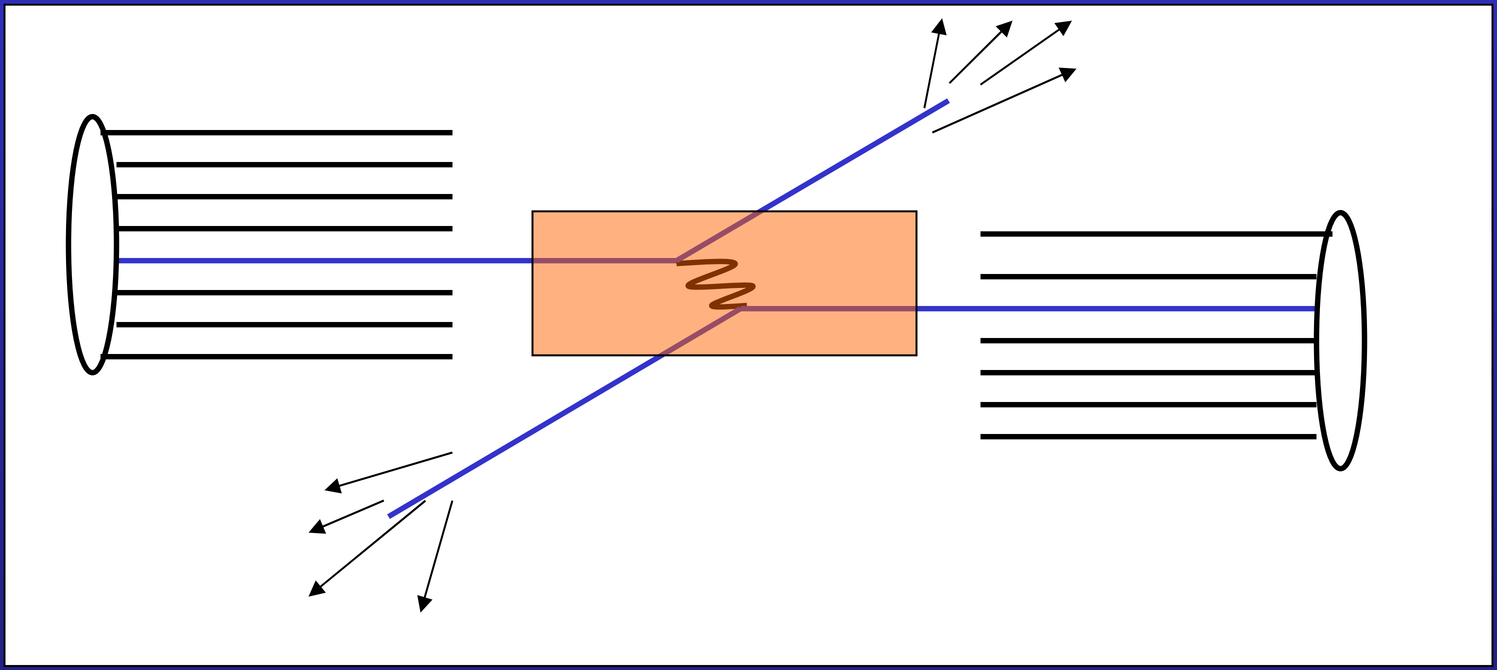
High-pT suppression

The experimental result:



Charged hadrons (not identified)

Can A+A collisions be understood from parton+parton or nucleon-nucleon interactions?

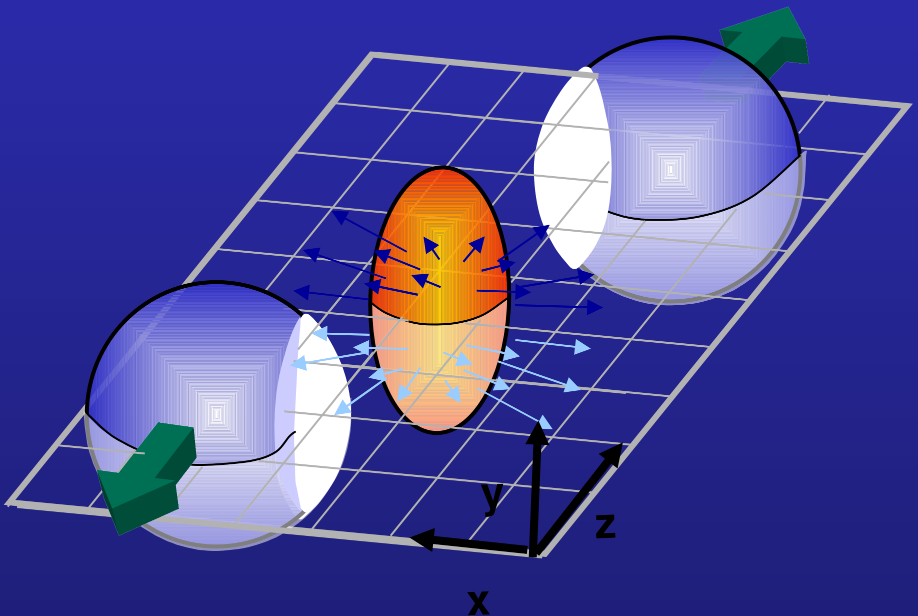


Not entirely, a dense medium is created in the collisions. The produced particle lose energy (gluon bremsstrahlung) as they traverse it.

Prediction: Bjorken (1982), Gyulassy & Wang (1992), ...

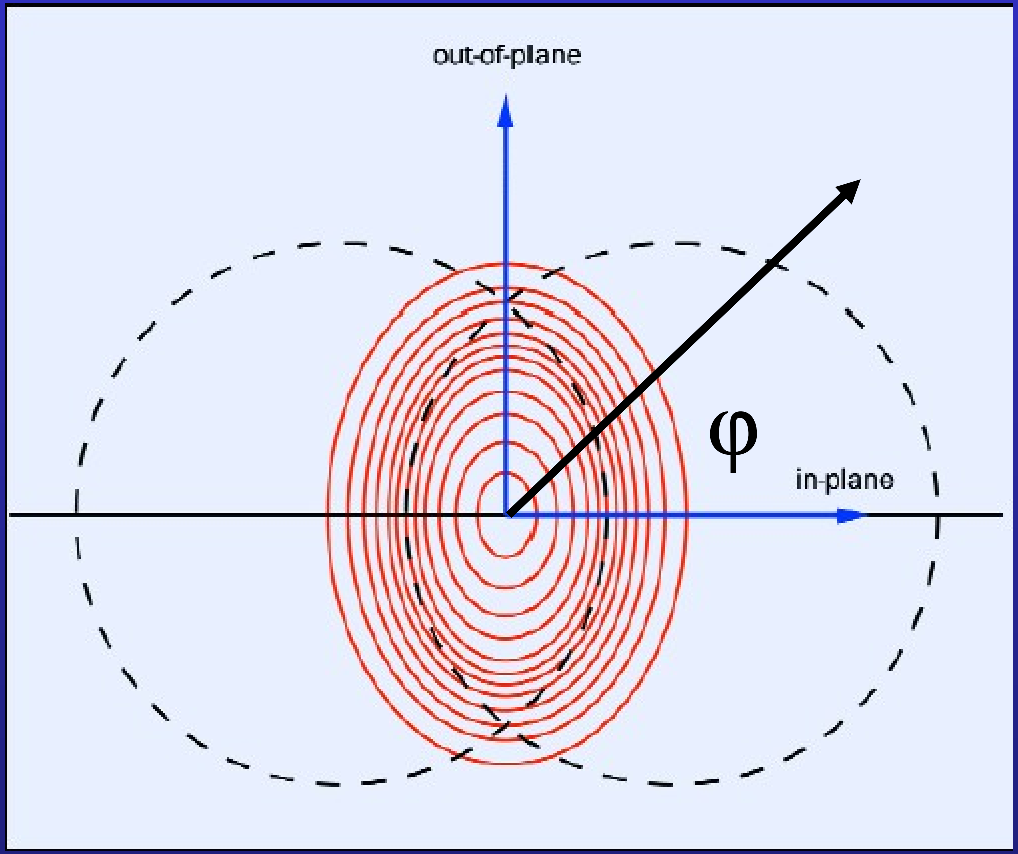
Collective effects

A Nucleus-Nucleus Collision at intermediate impact parameter:



Reaction Plane:
Plane defined by beam axis and
b (impact parameter, 2-D vector)

How are particles distributed in the transverse plane?

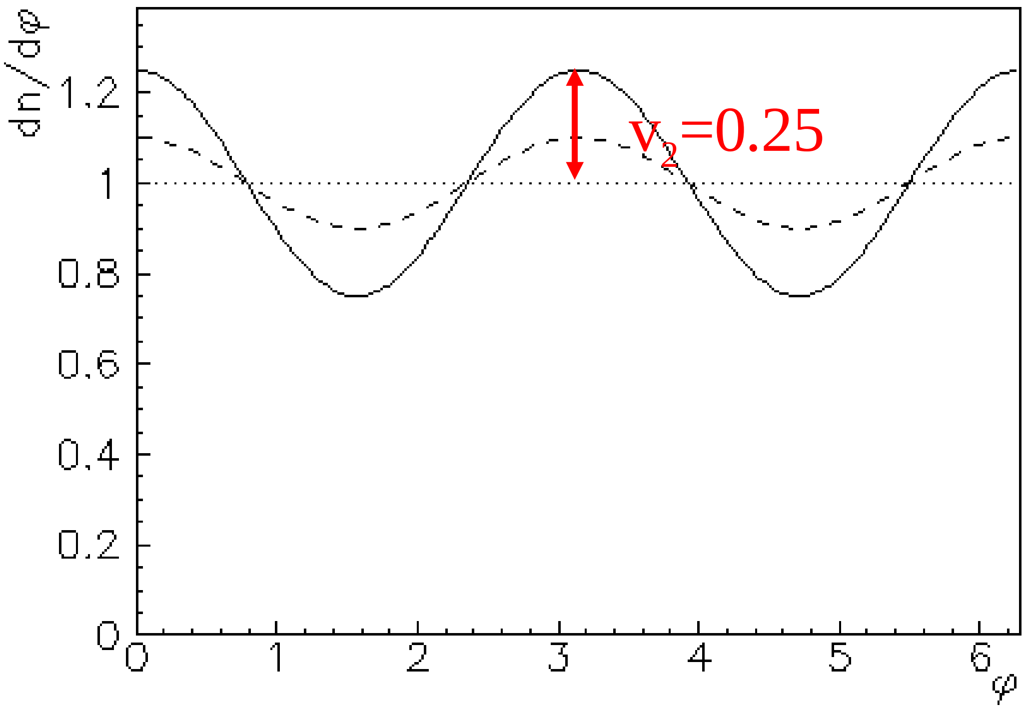


No collective effects ⇒ flat distribution in φ

Definition of v_2

For 180° symmetry

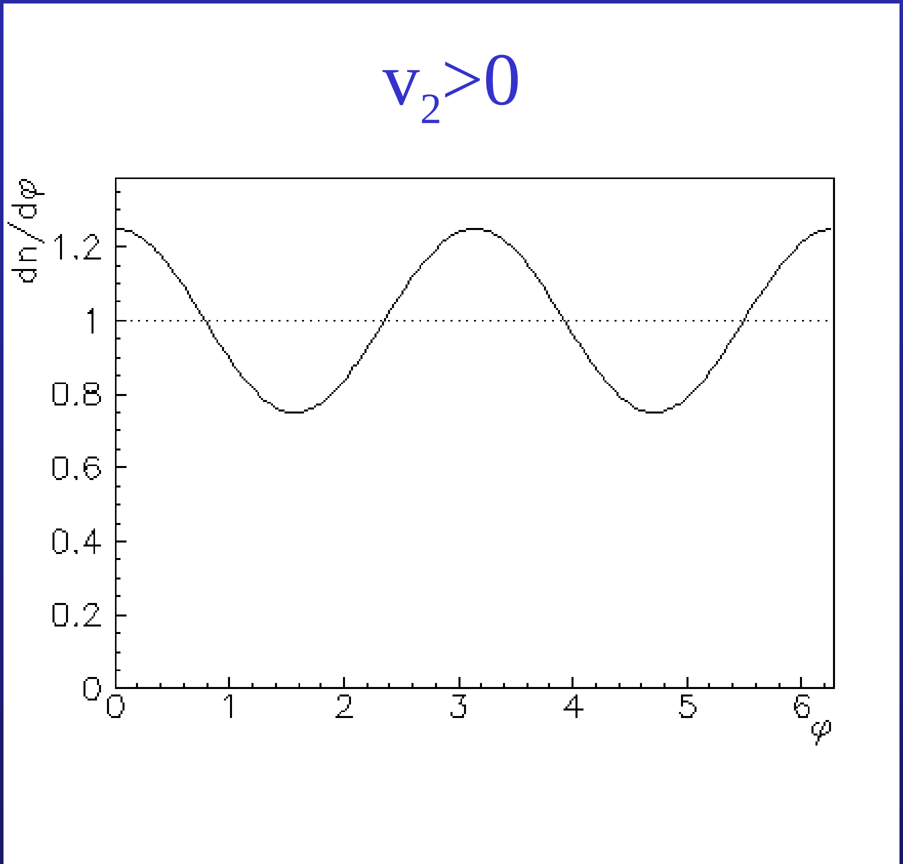
$$\frac{dN}{d\varphi} = 1 + v_2 \cos(2\varphi)$$

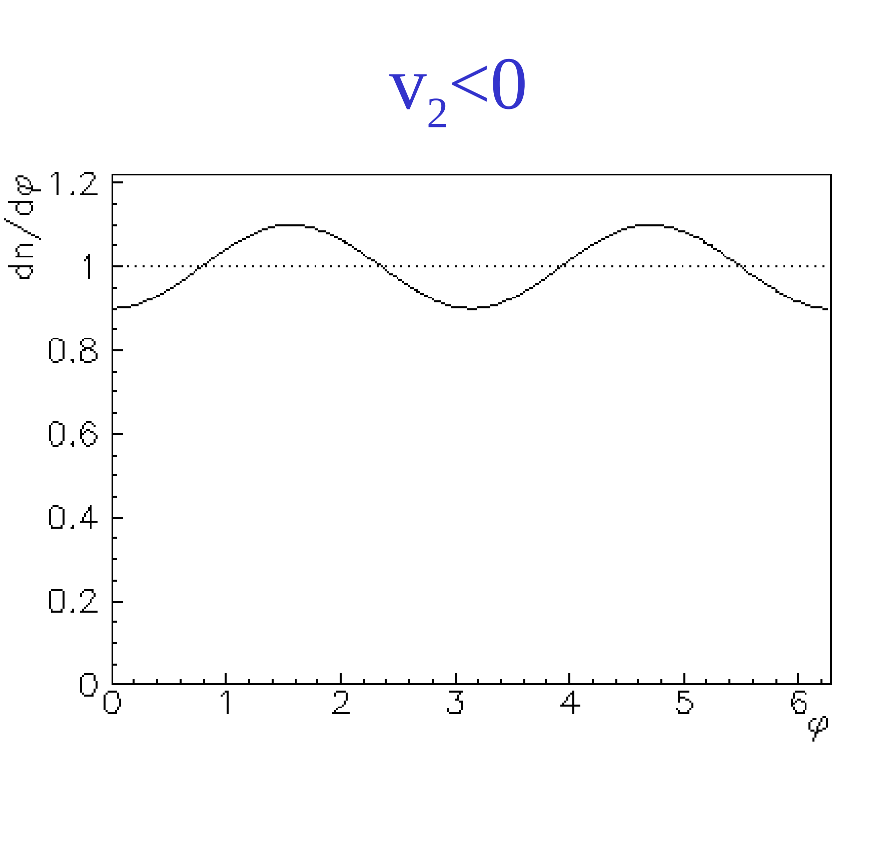


v_2 measures the strength of the flow

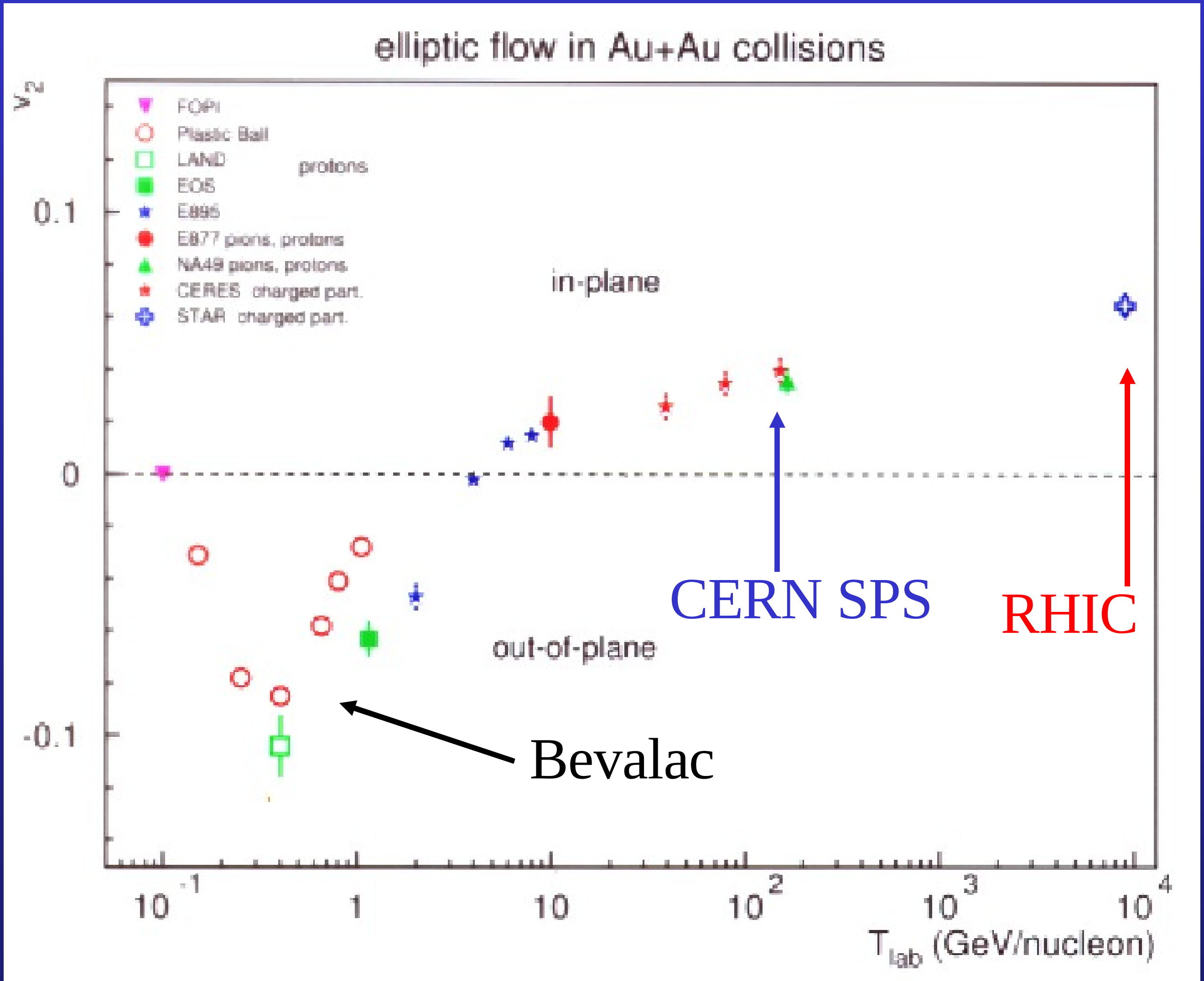
$v_2 > 0$: Flow in the reaction plane

$v_2 < 0$: Flow out of the reaction plane





v_2 vs collision energy

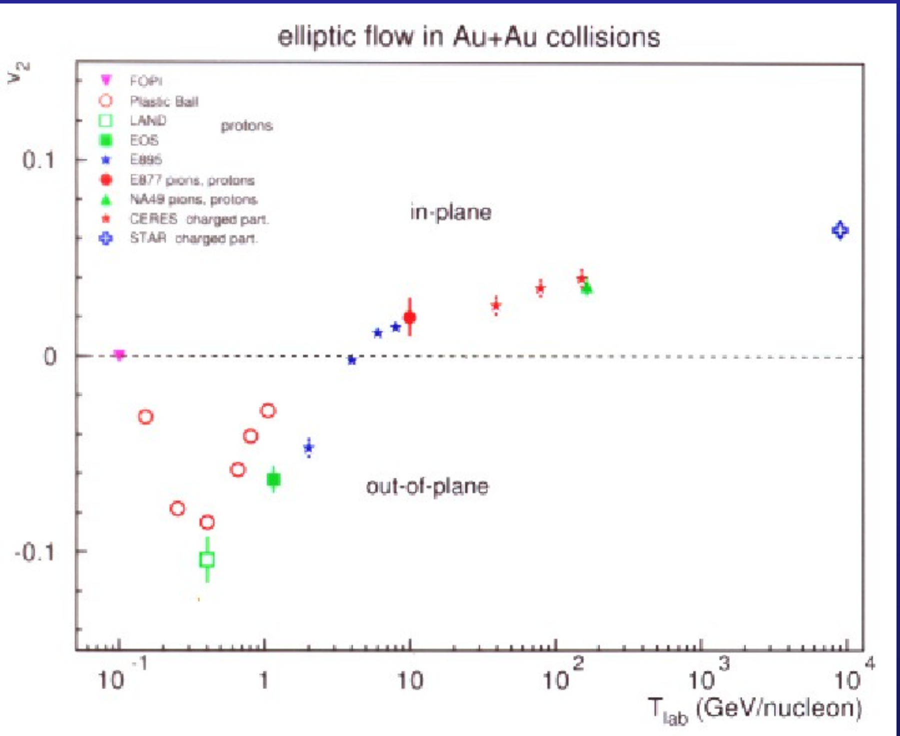


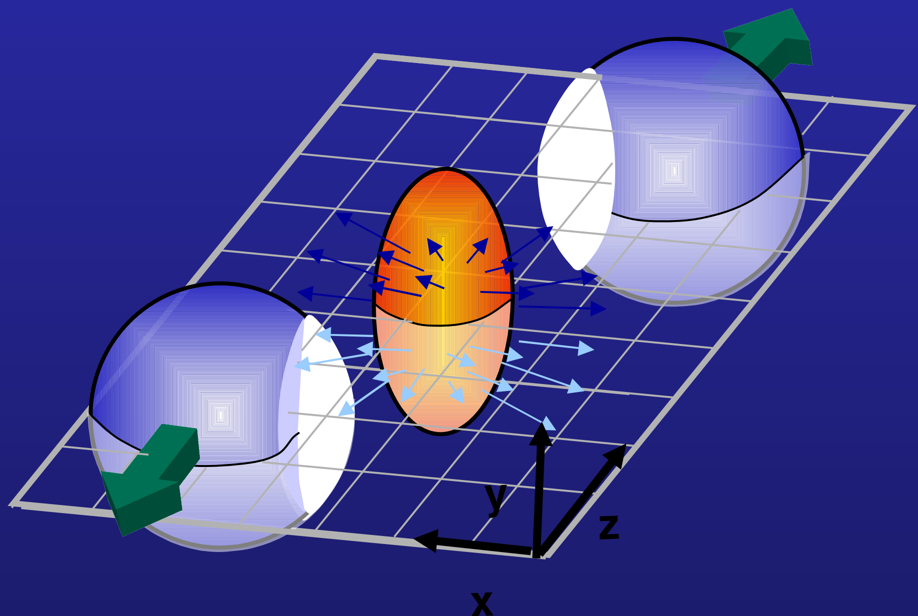
beam kinetic energy in lab frame

v_2 vs collision energy

Low Energy: The spectators block flow in reaction plane,
”squeeze-out”.

High Energy: Hydrodynamic pressure leads to flow of
particles in the reaction plane.



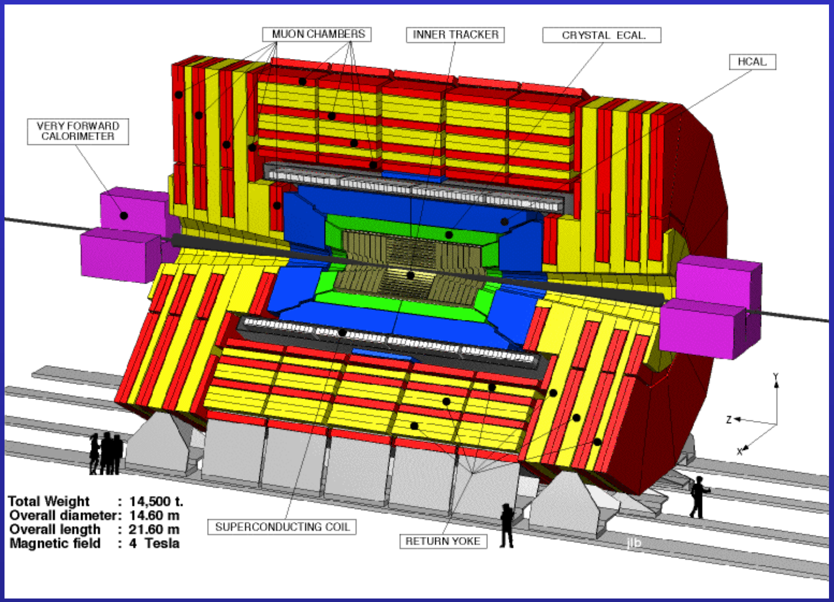


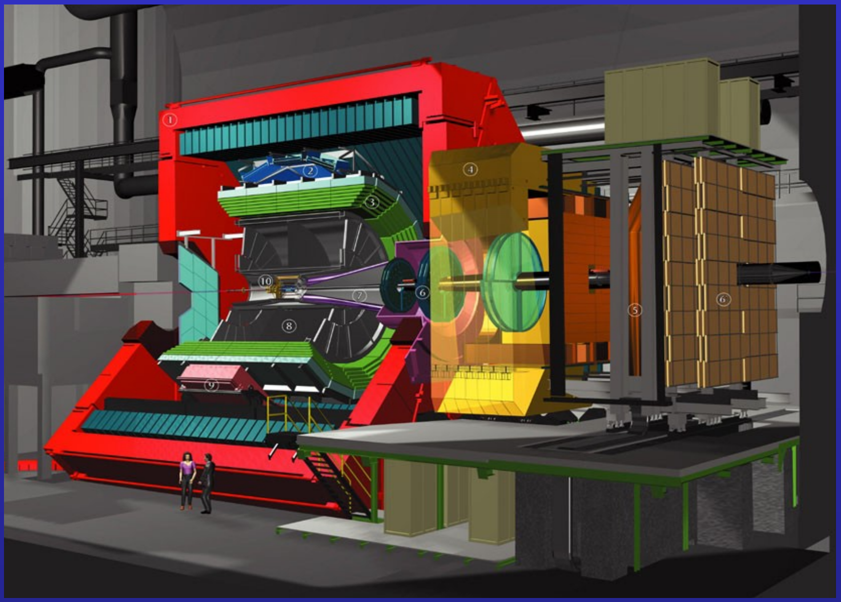
How can we study Heavy-Ion Interactions at the LHC?

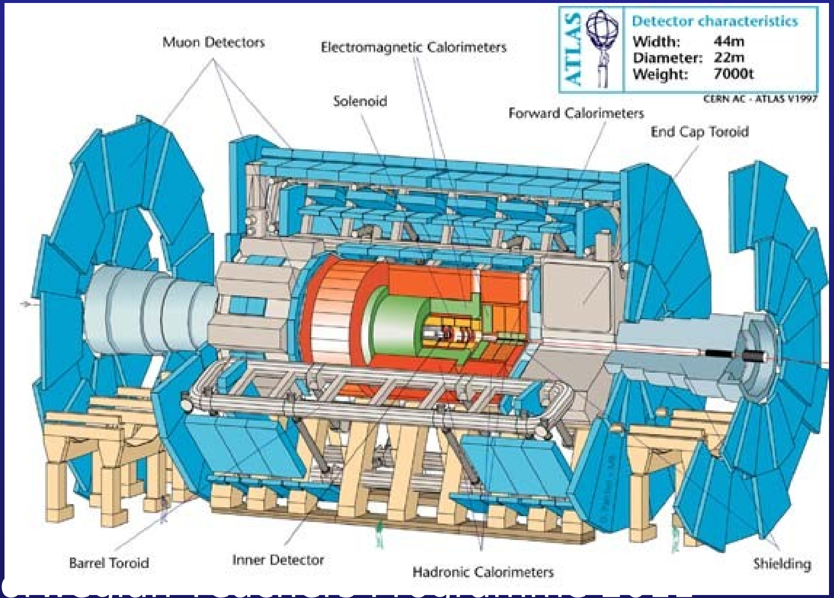
4 experiments at the LHC:

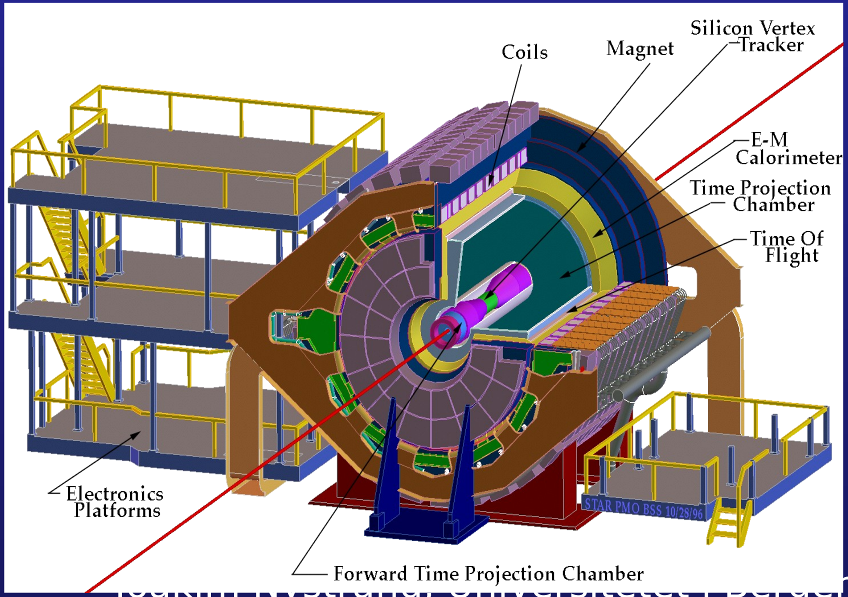
- 2 large, general purpose particle physics experiments
  - ATLAS, CMS
- 1 experiment designed for studying b-quarks
  - LHCb
- 1 experiment dedicated to Heavy-Ion Collisions
  - ALICE

Some High Energy Physics Detectors

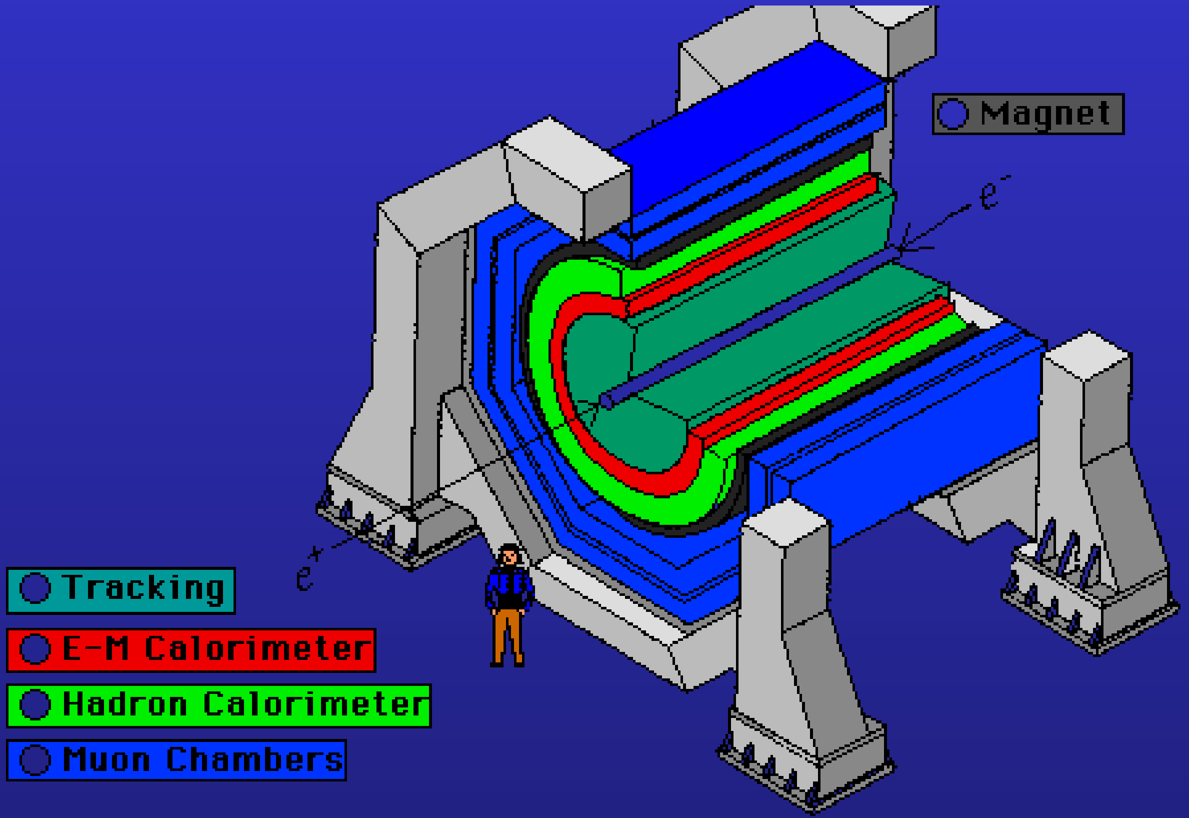








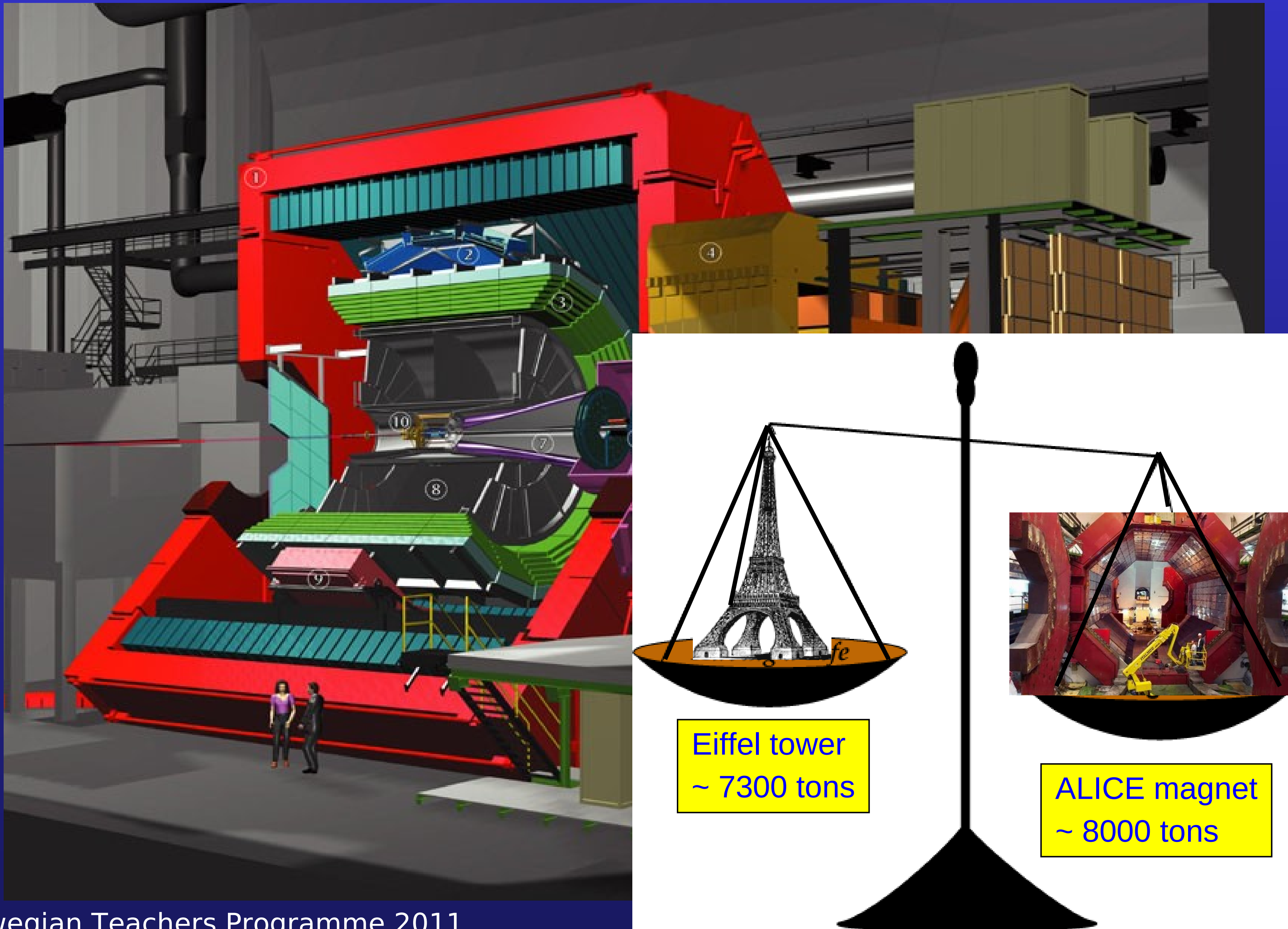
There is a common structure or ordering of the subdetectors



- Most detectors in the central barrel of ALICE are there to track and identify charged particles.
- There will be an ElectroMagnetic Calorimeter covering about 2/3 in φ.
- Muons will be identified in a separate muon arm.

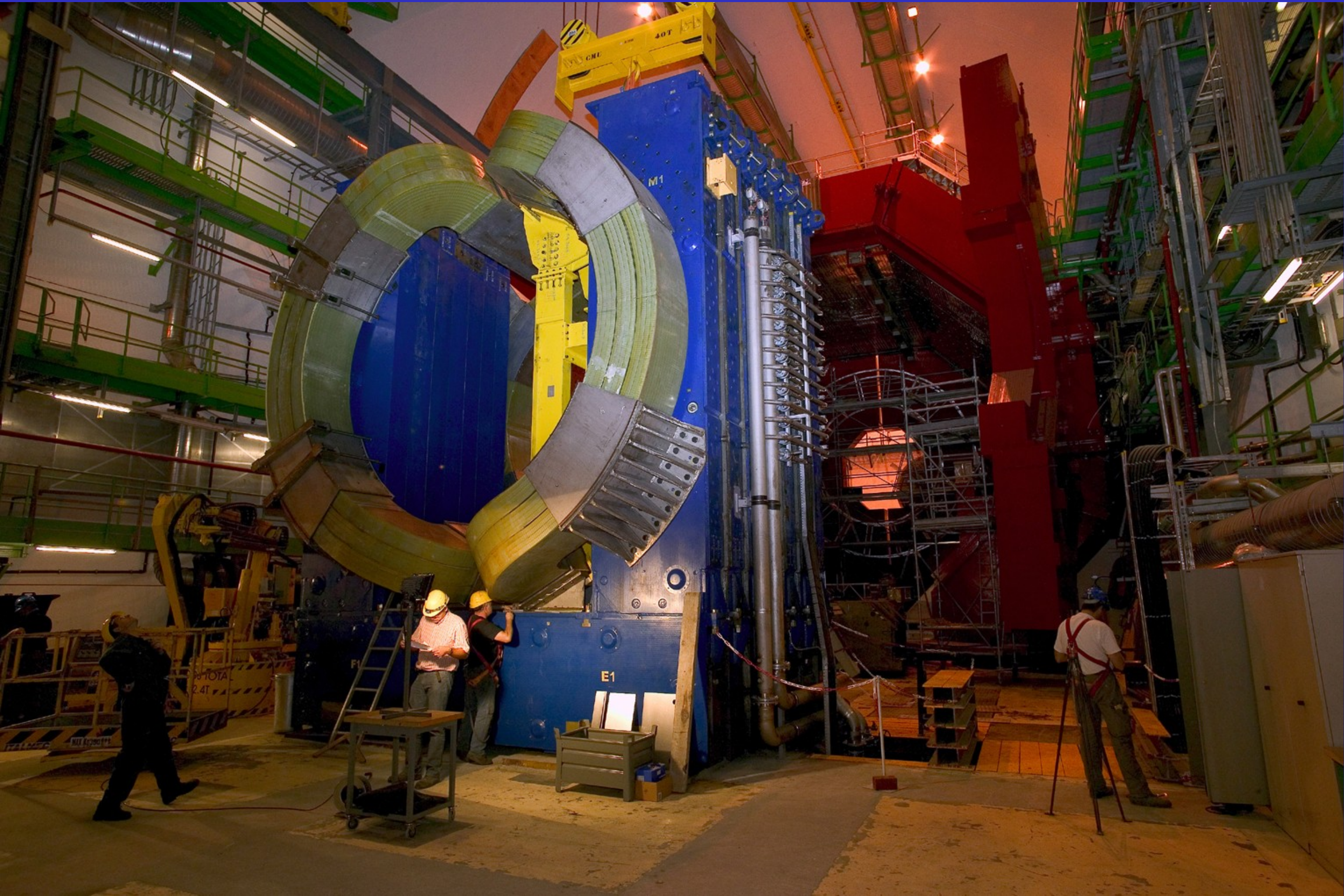
The ALICE Experiment

The ALICE Experiment

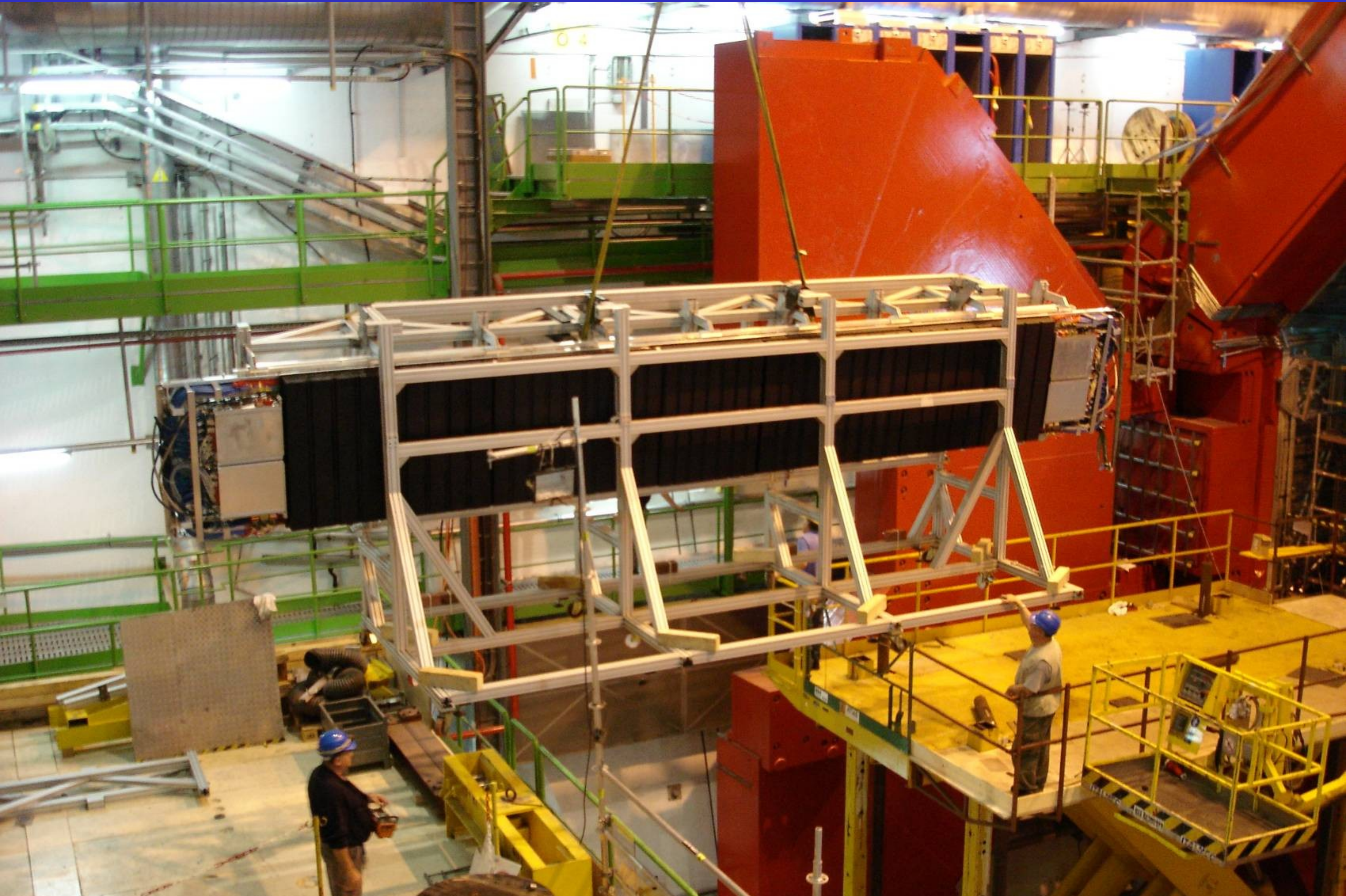


In the beginning...

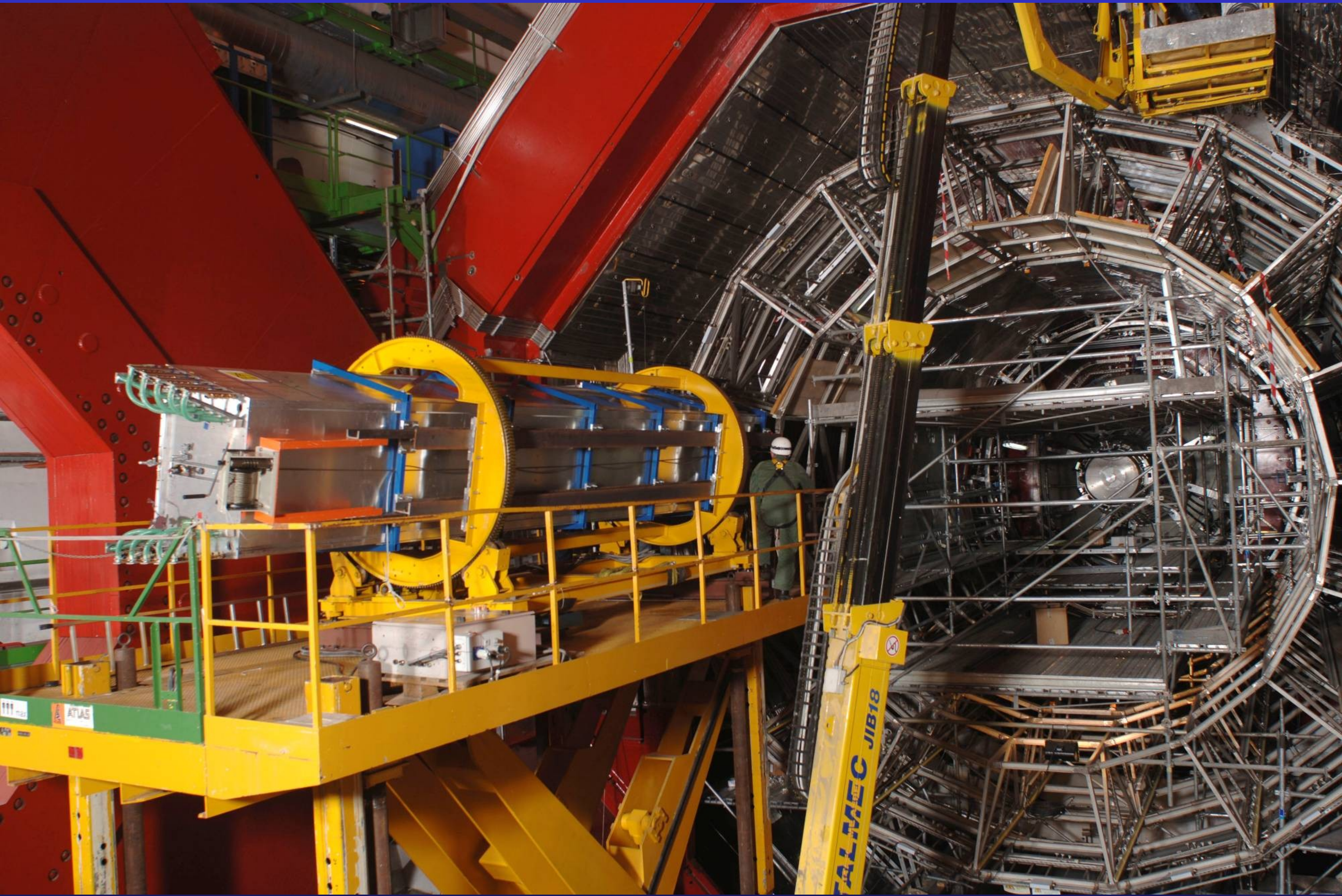
January 2005 (Muon magnet)



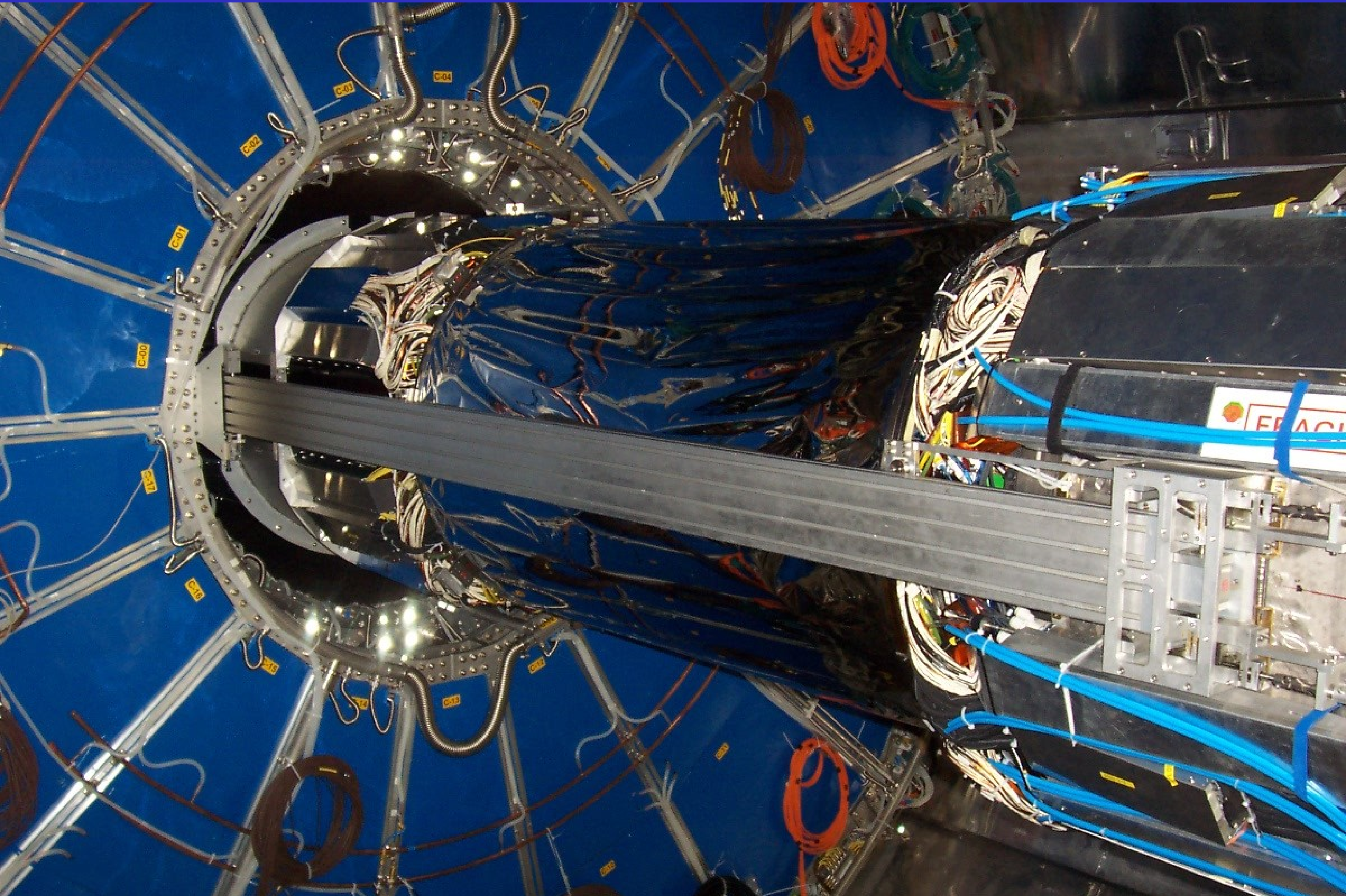
October 2006 (TOF Module)



October 2006 (TRD Module)

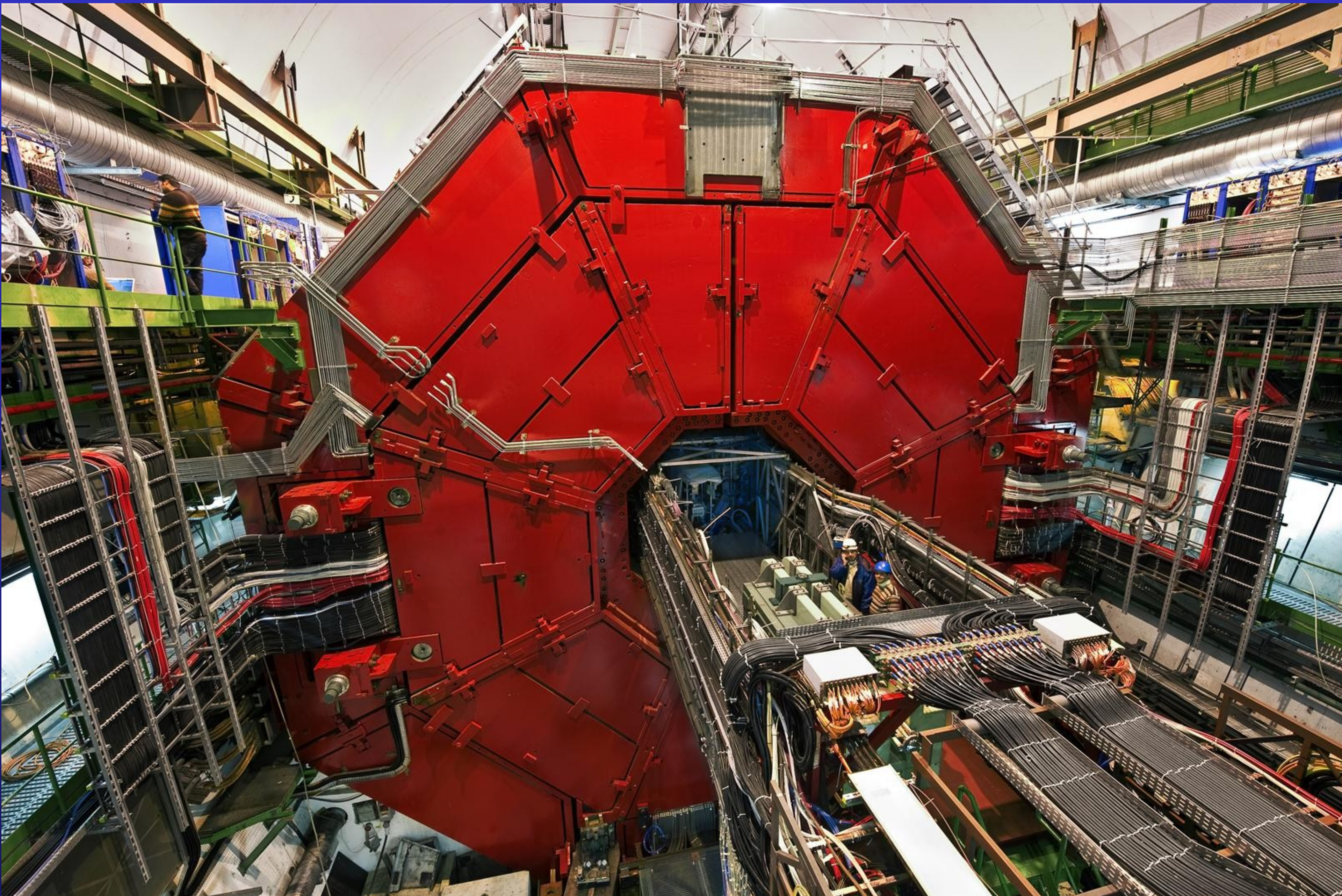


September 2007 (ITS/TPC)



April 2008 (PHOS Module)

Magnet doors closed



September 2008

Beams were circulating in both directions...

Collisions were expected any day or hour...

but ...

September 2008

Beams were circulating in both directions...

Collisions were expected any day or hour...

but ...

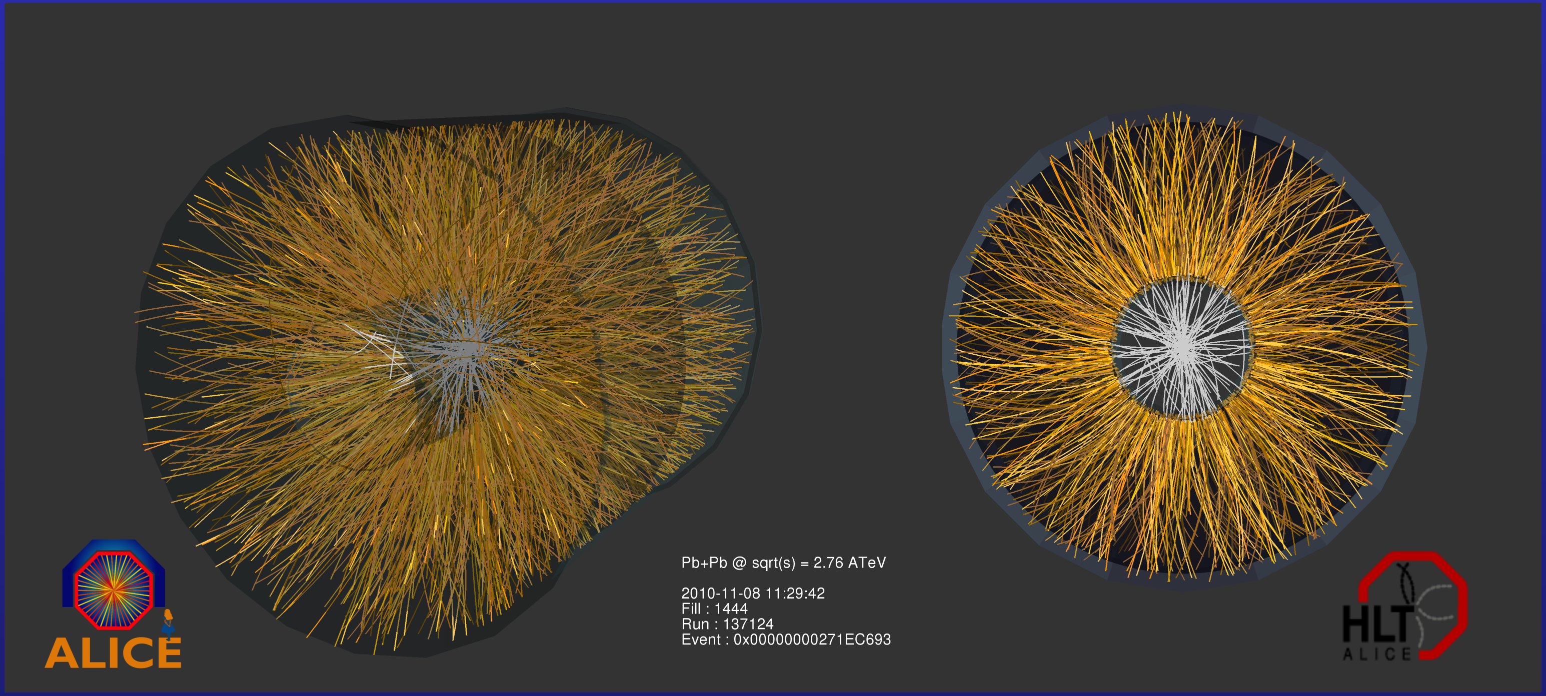
A massive quench in one of the magnets on 19 September 2008!

It took a little bit more than a year to recover

First collisions at LHC: 23 November 2009

And almost one more year to get to heavy ions

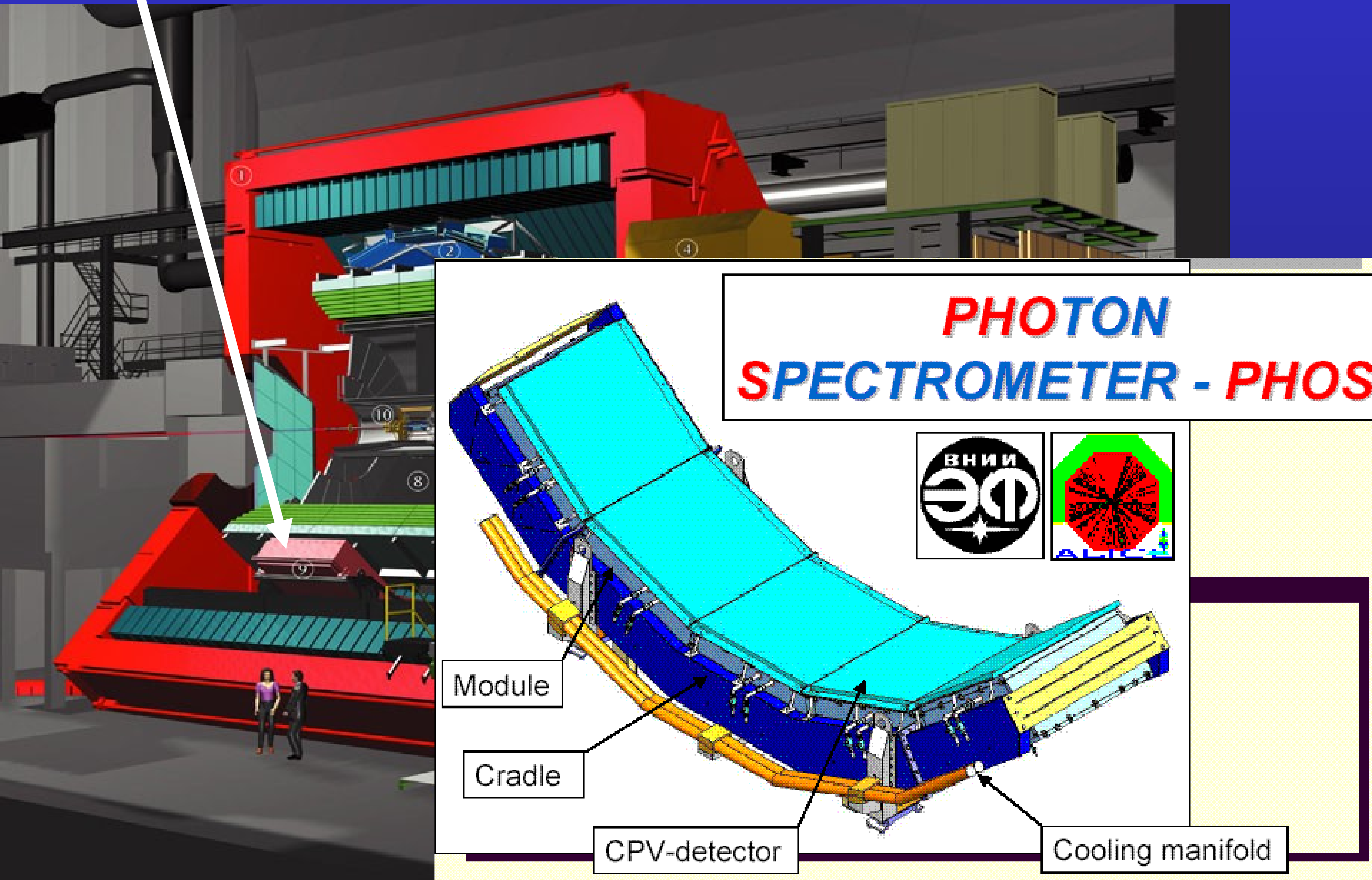
First heavy ion collisions (Pb+Pb) at LHC:
8 November 2010



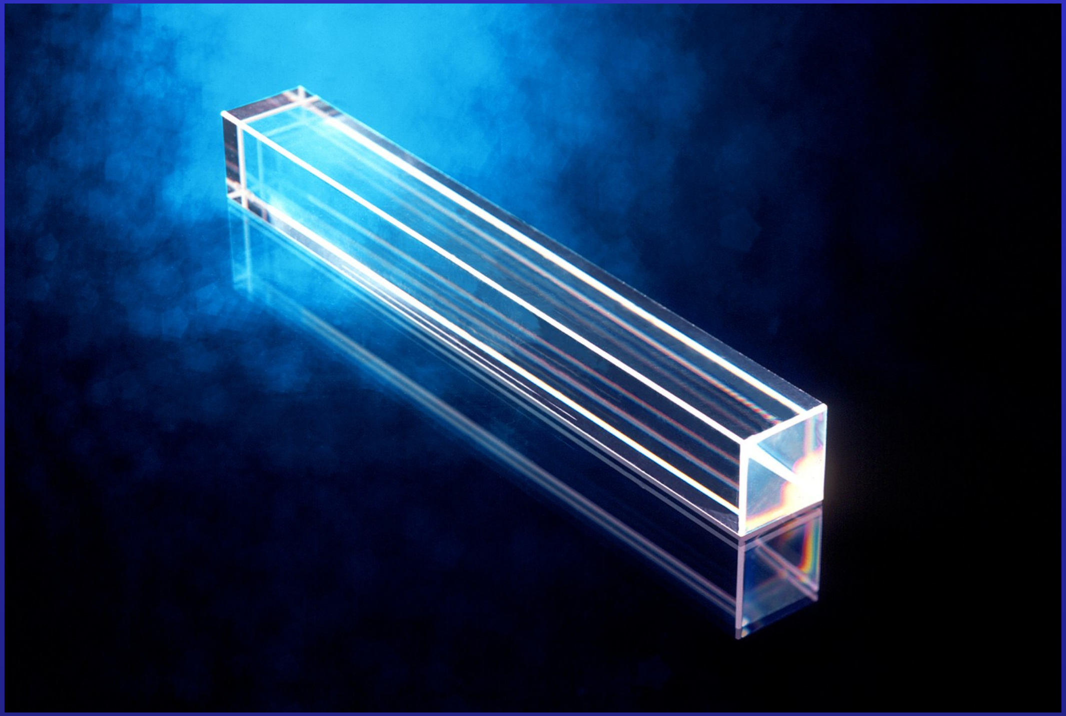
Norwegian Contributions to ALICE

- PHOS = Photon Spectrometer
- High-Level Trigger

PHOS


PHOTON
SPECTROMETER - PHOS
Module
Cradle
CPV-detector
Cooling manifold

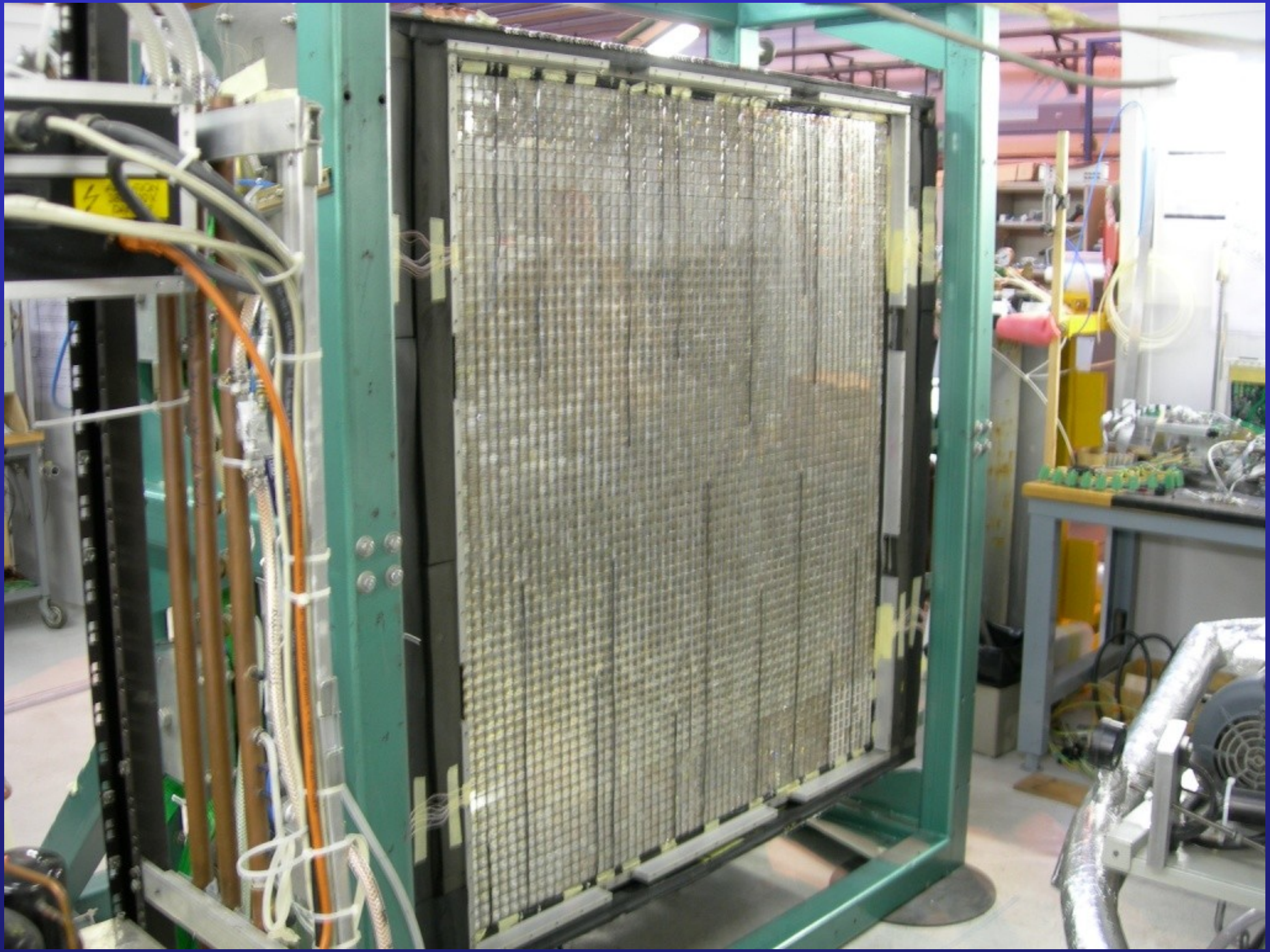
The detector elements are lead-glass crystals.



Dimensions:
$2\times2\times18\ \text{cm}^3$

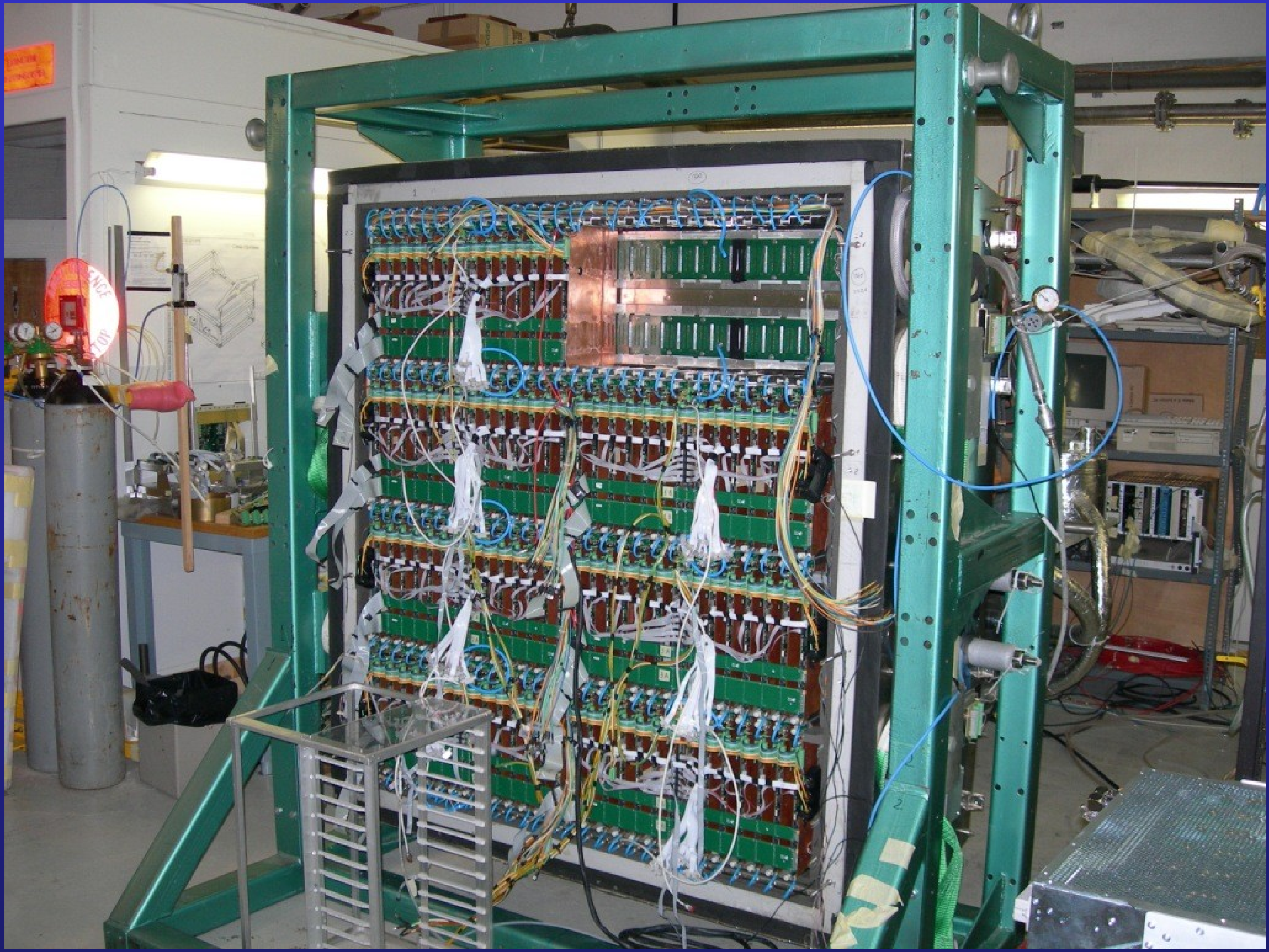
The signal from a crystal is read out by Avalanche Photo Diodes (APDs).

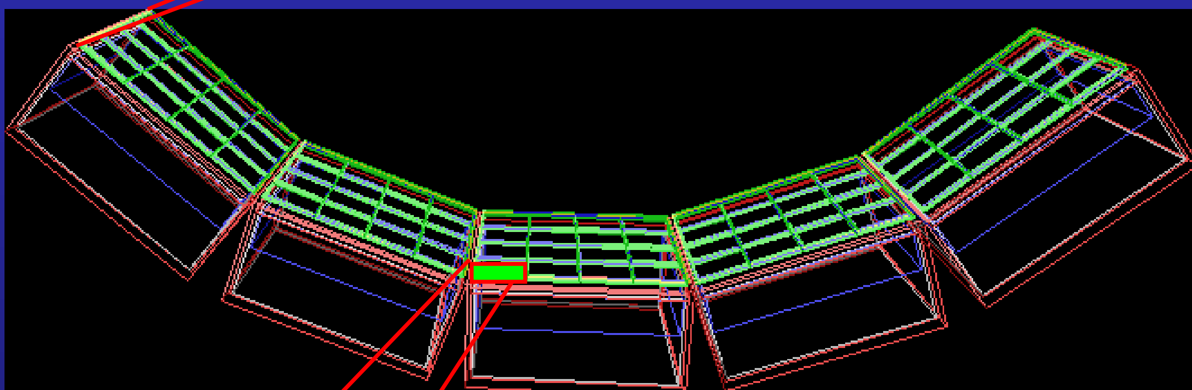
One PHOS Module: 3584 Crystals



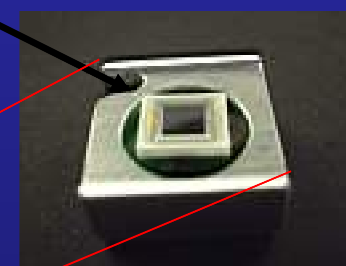
Weight: 2.6 tons

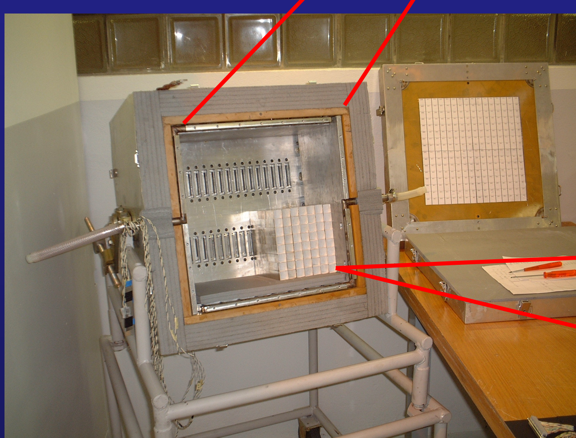
One PHOS Module w/ Front-End Electronics

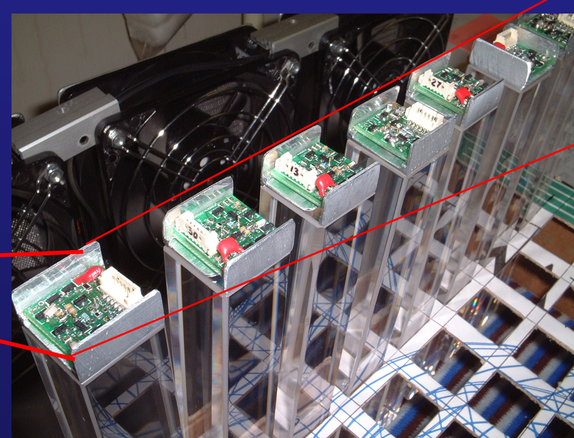




Avalanche Photo Diode





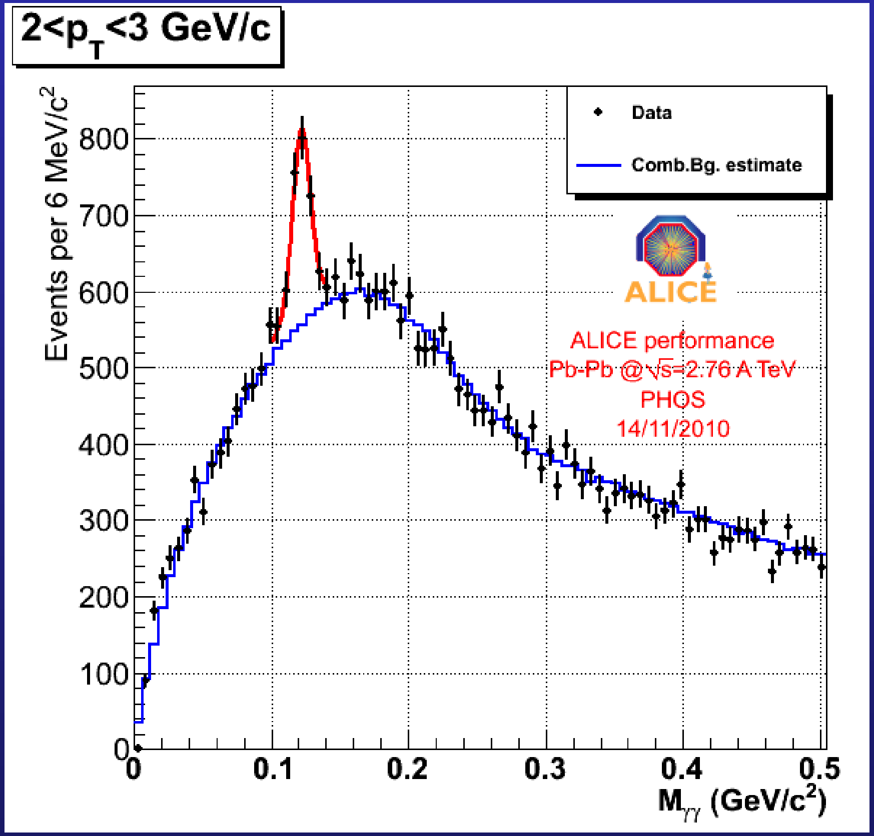


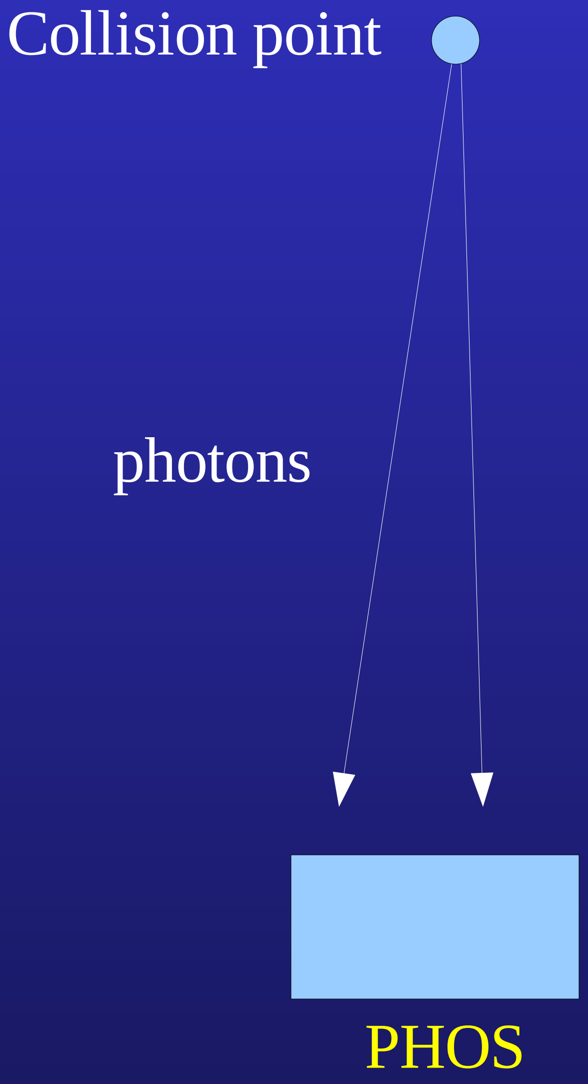
In total 17,920 crystals

Results from heavy-ion run last year

π^0 mesons decay into two photons, $\pi^0 \rightarrow \gamma\gamma$

By measuring the energies and emission angles of the photons, the π^0 can be reconstructed.





The High-Level Trigger

Central (head-on) collisions of Pb+Pb ions produce a data flow of ≈16 GByte/second.

This is too large a rate to write to tape or disk.

It has to be reduced to < 1 GByte/sec.

But we don't know beforehand which events are the most interesting, so it's not good enough to just scale down the rate.

The High-Level Trigger

Send the ≈16 GByte/second of data to a farm of 500-700 PCs with two Dualcore or Quadcore processors each (≈4000 CPUs in total), where the events are reconstructed on-line.

The HLT Computing Farm at Night

Summary

• Heavy Ion Collisions contribute to the rich program of particle and nuclear physics at the LHC.

• The first results (3 months after the first run) confirm and amplify the results from lower energy (RHIC).

• Similar but stronger indications for a hot and dense medium being produced in the collisions.