Contributo della sezione INFN di Torino alla realizzazione di ALICE

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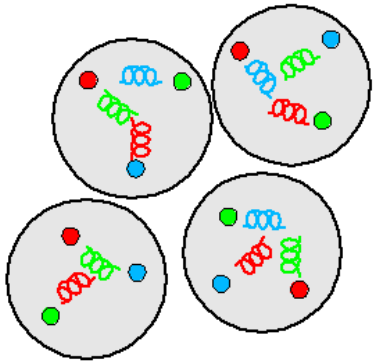
Congressino di Sezione, Torino, 27 Febbraio 2006

High energy nuclear physics

- *GOAL*: study of nuclear matter under extreme temperature and density conditions
  - Study the properties of Quark Gluon Plasma

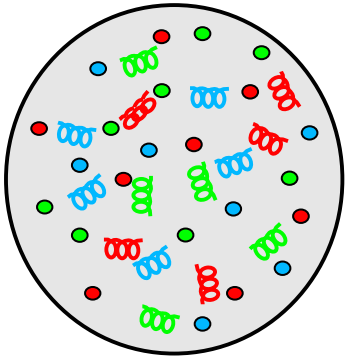
Ordinary nuclear matter



Quarks and gluons ***confined*** *inside hadrons*

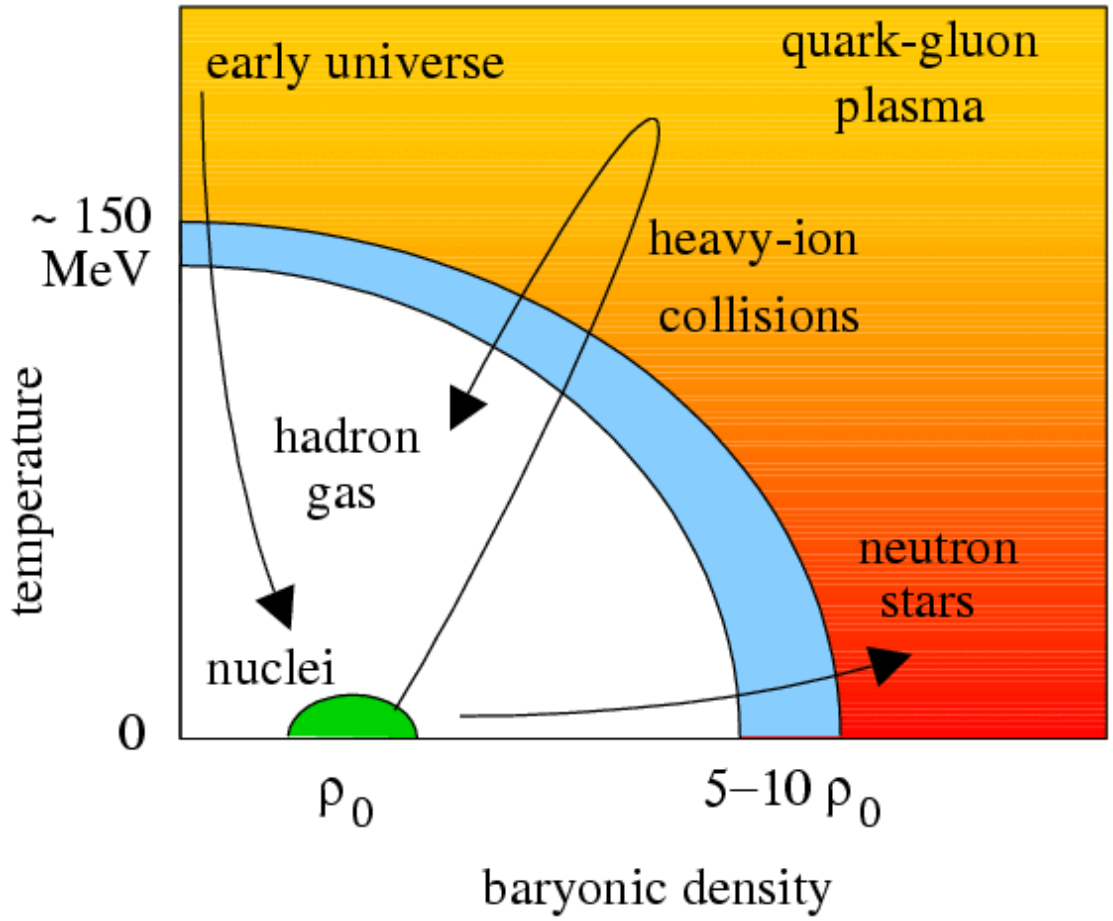
QCD PHASE TRANSITION ($T \sim 2\ 10^{12}$ K $\sim 10^5 \times T^{sun\ core}$)

Quark Gluon Plasma (QGP)



Quarks and gluons ***deconfined*** *= free to move over larger space volumes*

Phase diagram of nuclear matter



- QGP present in the core of neutron stars?

$$\rho_{n.s.} \approx \frac{2 \cdot 10^{30} kg}{4/3\pi \cdot R^3} \approx 10^{15} g/cm^3 \approx 0.5 GeV/fm^3$$

$$\rho_{nucl} \approx 0.14 GeV/fm^3$$

- Was QGP the phase of matter in the early stages of the evolution of the universe (≃10 $^{-6}$ s after the big bang)?

$$T_{bigbang} \approx 10^{19} GeV \approx 10^{32} K$$

$$T_{crit} \approx 150 MeV \approx 10^{12} K$$

Experimental tool: heavy ion collisions

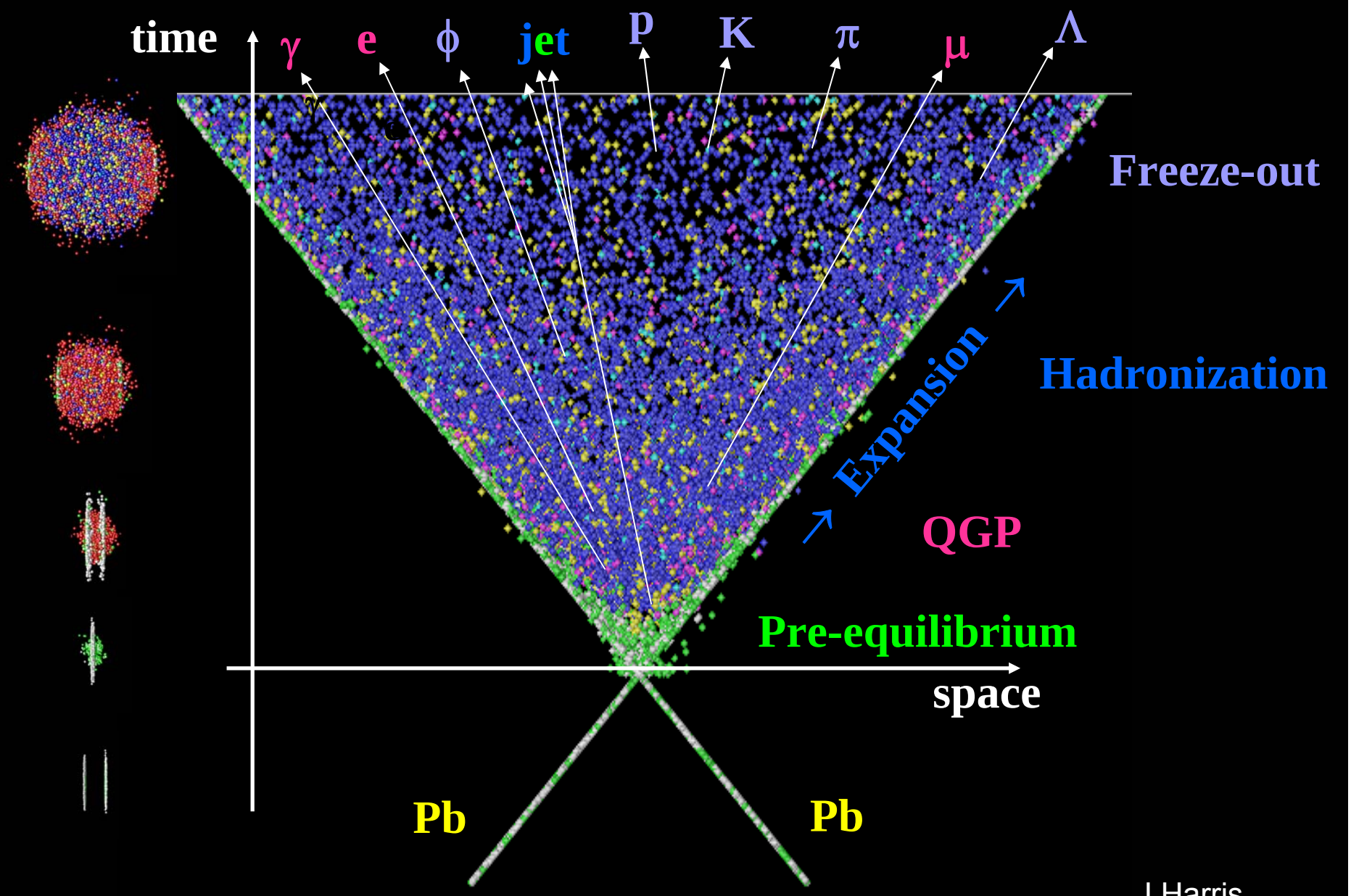
- To use macroscopic variables
  - Big systems (dimensions >> 1 fm)
  - Many produced particles (N >> 1)
- To use thermodynamics
  - System in equilibrium
    - Long lived systems
      - lifetime > relaxation time > 1 fm/c
    - Many collisions per particle
      - Mean free path << system size
- To produce QGP:
  - Large temperature / energy density

Central collisions	SPS	RHIC	LHC
$S^{1/2}$ (GeV)	17	200	5500
dN_{ch}/dy	500	650	<~6000
ε (GeV/fm^3)	2.5	3.5	15-40
t_{QGP}(fm/c)	<1	1.5-4.	4-10
V(fm^3)	1000	7000	20000

$$\varepsilon_{crit} \approx 1.5-3\, GeV/fm^3 \approx (10-20)\times \varepsilon_{nucl}$$

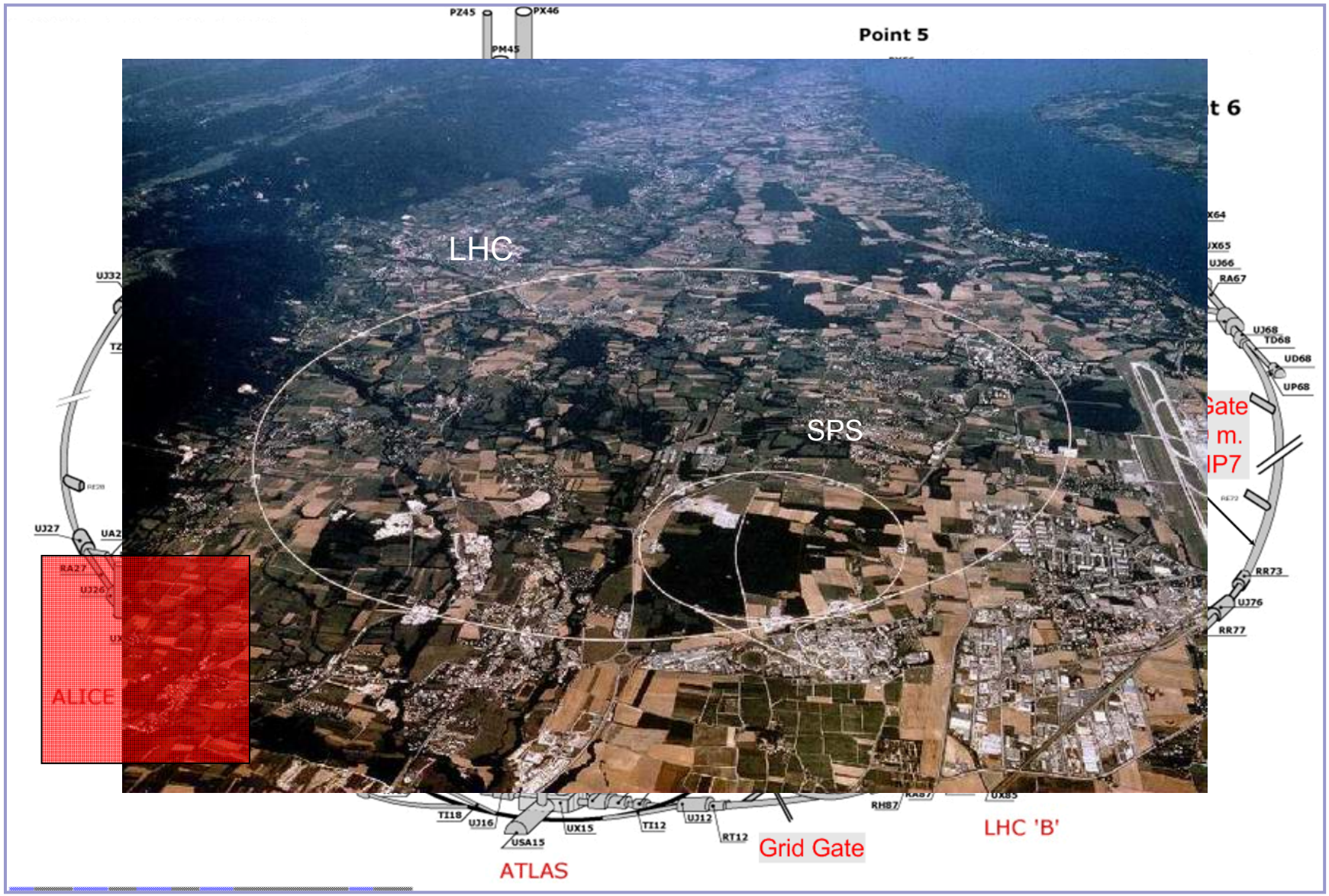
$$\varepsilon_{nucl} = \frac{A\cdot 940 MeV}{\frac{4}{3}\pi R_0^3 \cdot A} \approx 130 MeV/fm^3$$

Space-time evolution



J.Harris

ALICE @ the LHC



Running scenario

- Pb–Pb collisions
  - p-p, p-A,lighter ions also needed as a reference

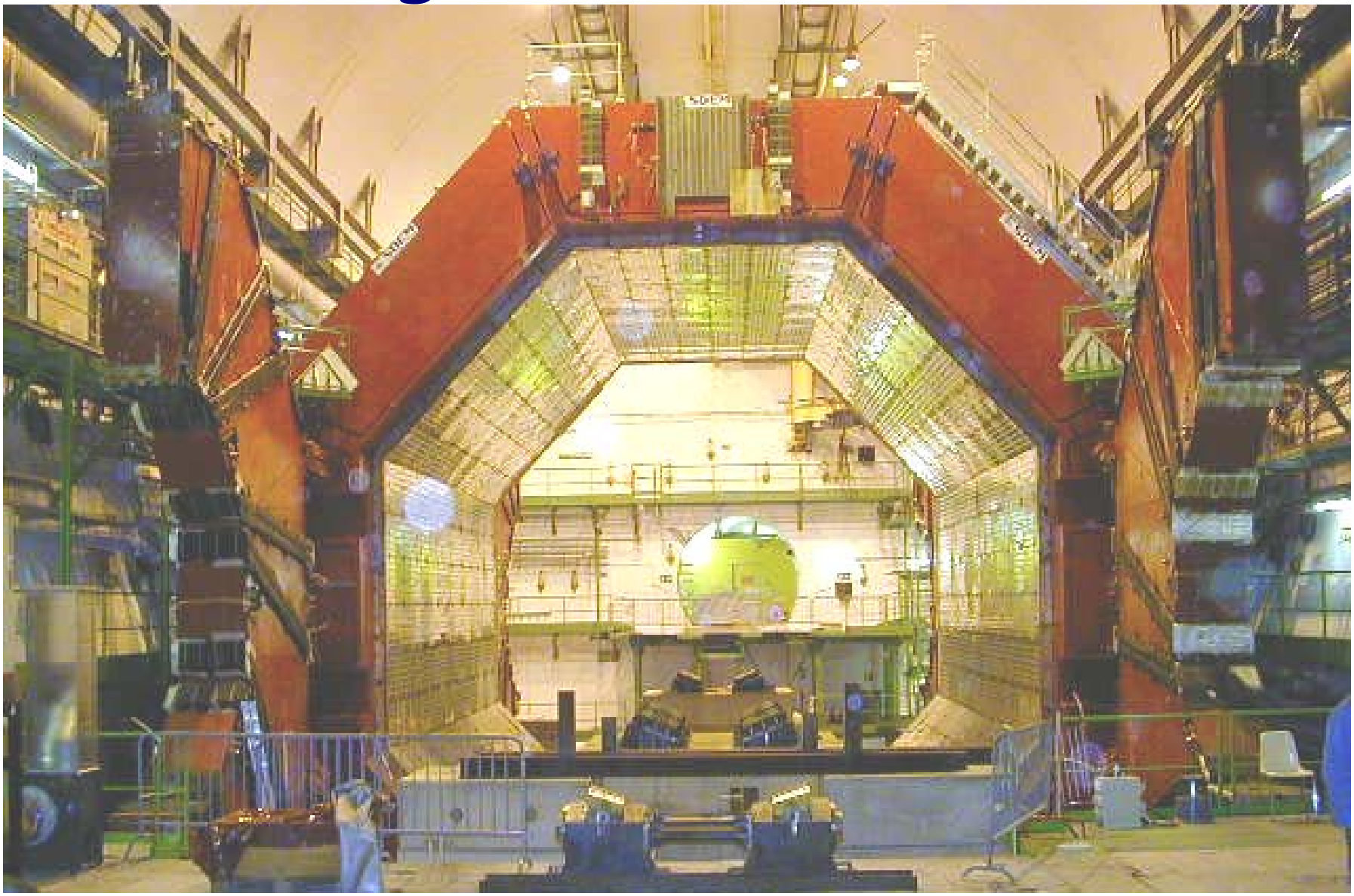
Luminosity:

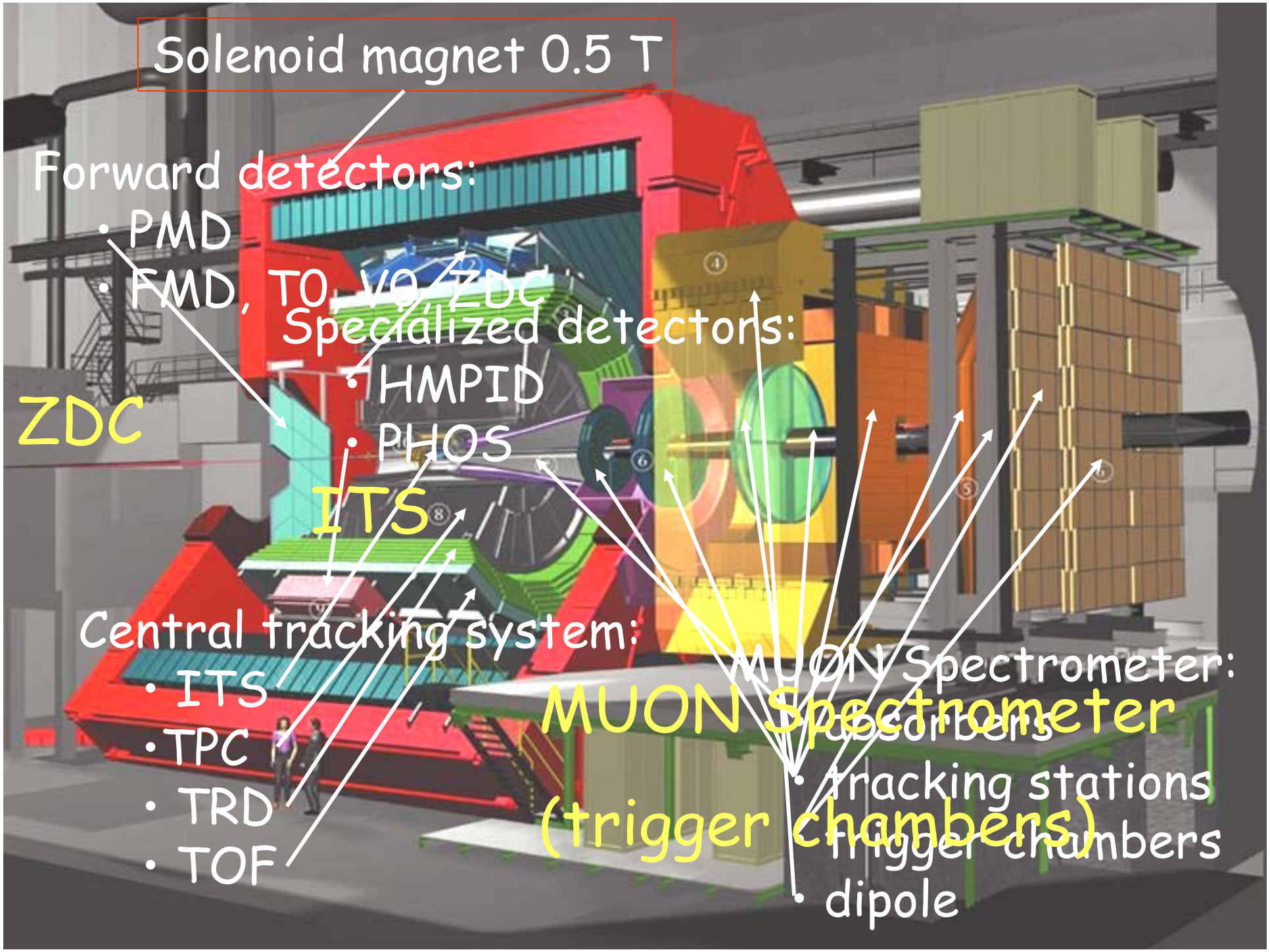
	$\sqrt{s_{NN}}$ (TeV)	$\mathcal{L}_0$ ($cm^{-2}s^{-1}$)	Run time (s/year)
p–p	14.0	10^{34*}	10^7
Pb–Pb	5.5	10^{26}	10^{6**}

$^*\mathcal{L}_{max}$(ALICE) = 10^{31} $^{**}\mathcal{L}_{int}$(ALICE) ~ 0.7 nb^{-1}/year

+ other collision systems: pA, lighter ions (Sn, Kr, Ar, O) & energies (pp @ 5.5 TeV).

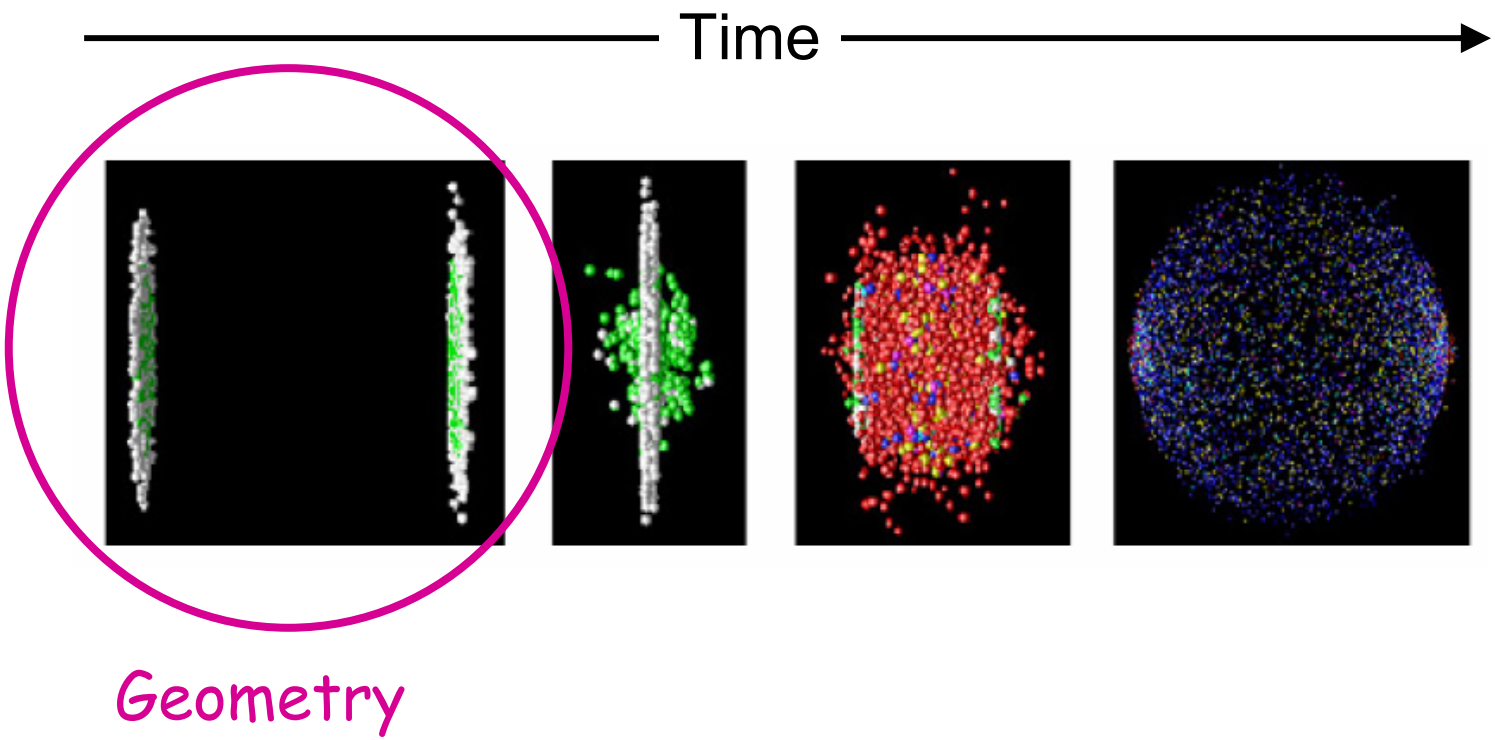
Alice Magnet




Solenoid magnet 0.5 T
Forward detectors:
• PMD
• FMD, T0, V0, ZDC
ZDC
Specialized detectors:
• HMPID
• PHOS
ITS
Central tracking system:
• ITS
• TPC
• TRD
• TOF
MUON Spectrometer:
• absorbers
• tracking stations
• trigger chambers
• dipole
MUON Spectrometer
(trigger chambers)

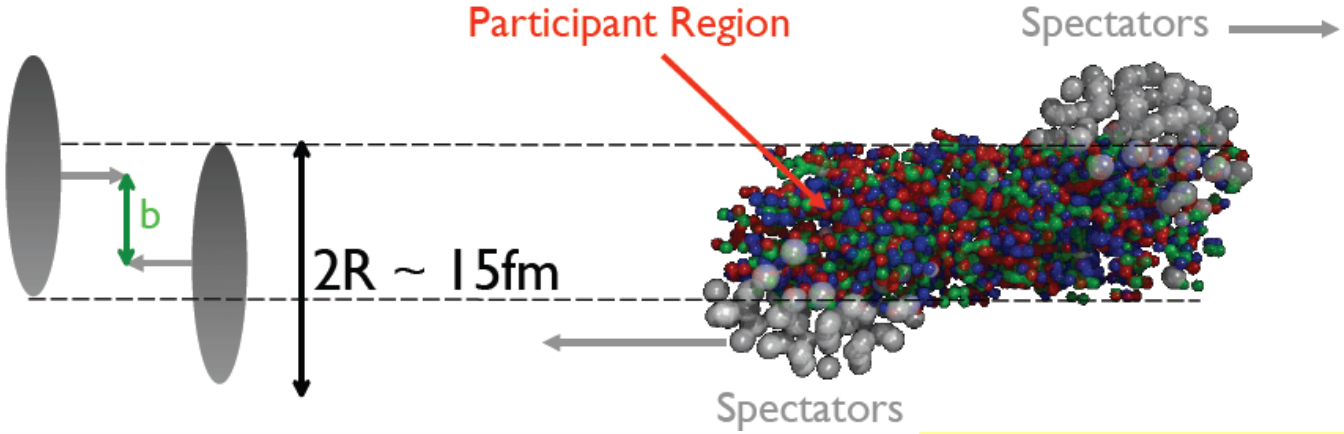
Contribution of Torino

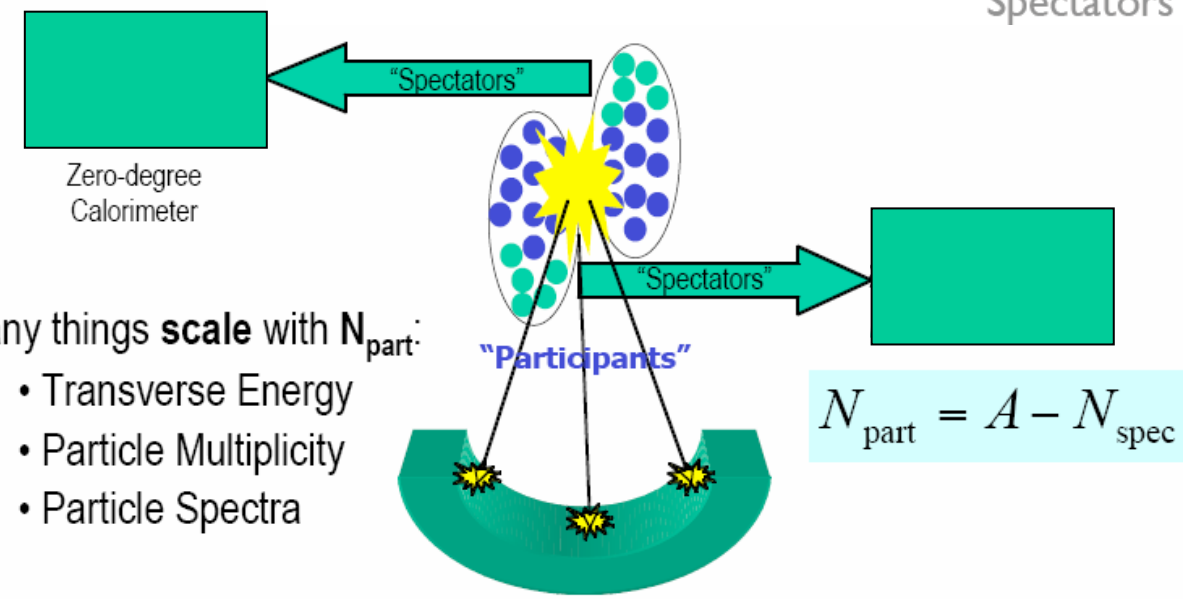
- INFN-Torino
  - Largest italian group in Alice
  - Many important responsibilities in the Collaboration
    - deputy spokesman (P. Giubellino)
    - chairman Coll. board (L. Riccati)
    - responsibility of ITS (Riccati); Silicon Drift Detectors (Tosello); offline ITS (Masera)
    - responsibility of ZDC (Gallio, Scomparin - offline)
    - MUON arm (deputy: E. Vercellin)
    - Soft Physics working group (convenor: Ramello)
    - responsibility of Grid activities (P. Cerello) and LCG interface (S. Bagnasco)


Time
Geometry

Event geometry (I)

- The *impact parameter* (b) detemines the number of nucleons that participate in the collision (N_{part})





Many things **scale** with N_{part}:

- Transverse Energy
- Particle Multiplicity
- Particle Spectra

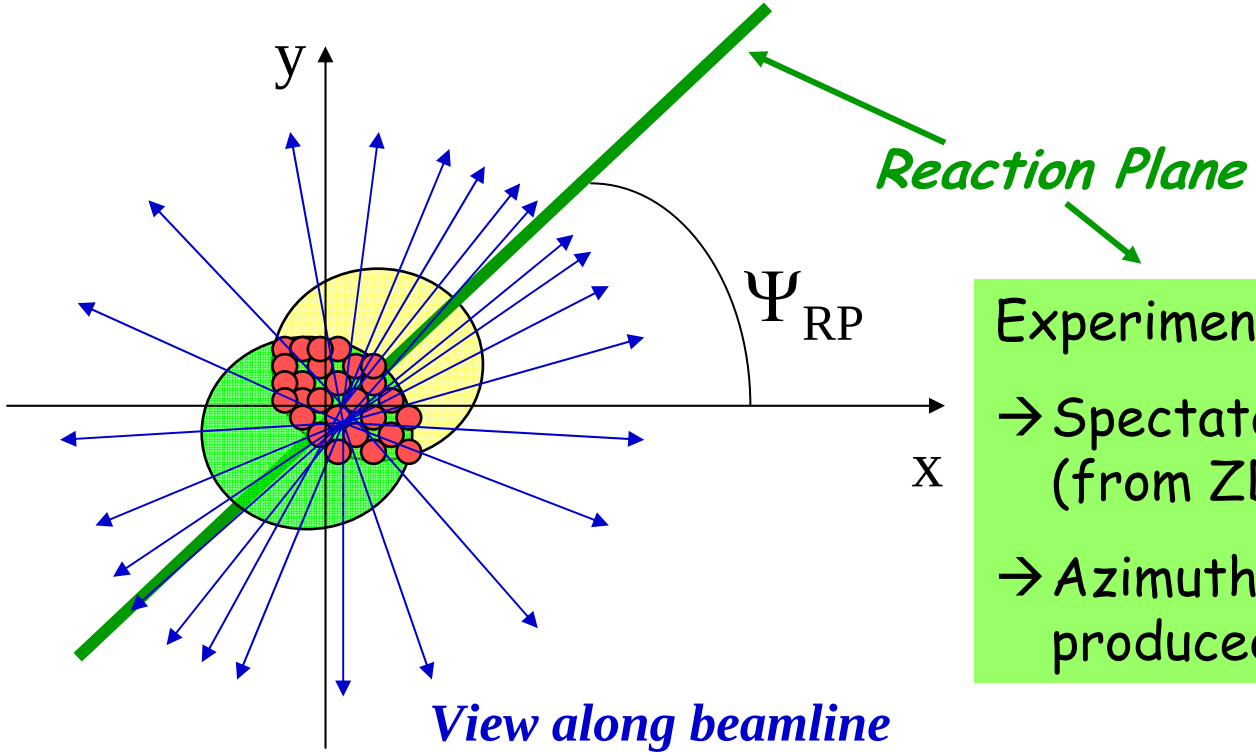
$$N_{part} = A - N_{spec}$$

Small impact parameter
→Many participant nucleons
→Big System
→Many produced particles

Large impact parameter
→Few participant nucleons
→Small System
→Few produced particles

Event geometry (II)

- The *reaction plane* (= plane defined by beam direction and impact parameter) determines the azimuthal anisotropy of the system
  - In the transverse plane (orthogonal to the beam) it is defined by the azimuthal angle Ψ_{RP} of the impact parameter



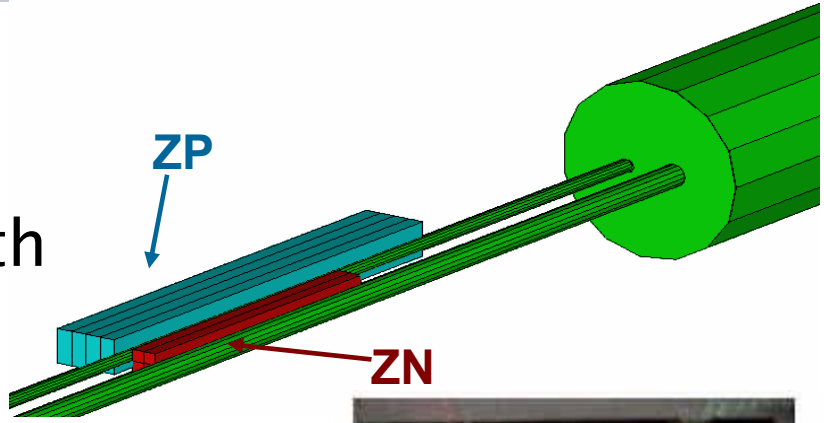
Experimentally estimated from:

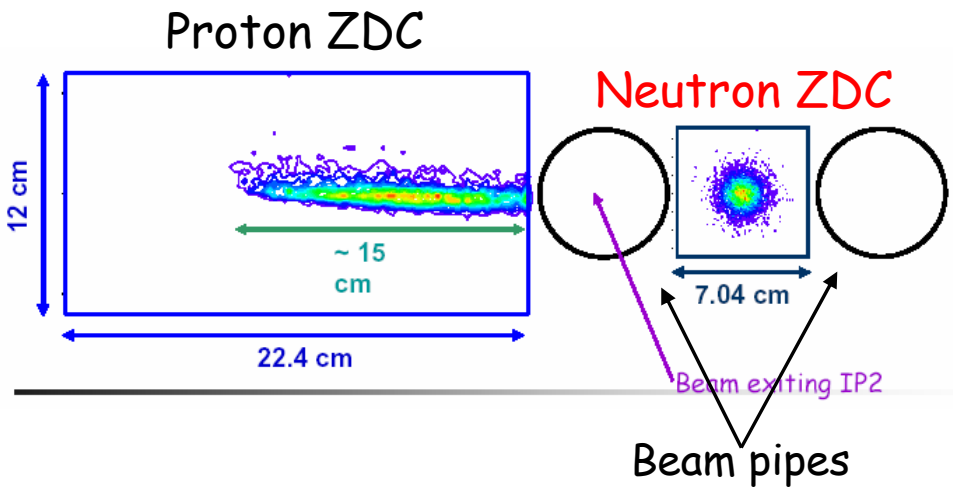
→ Spectator nucleons bounce-off (from ZDC)

→ Azimuthal anisotropy of produced particles (from tracks)

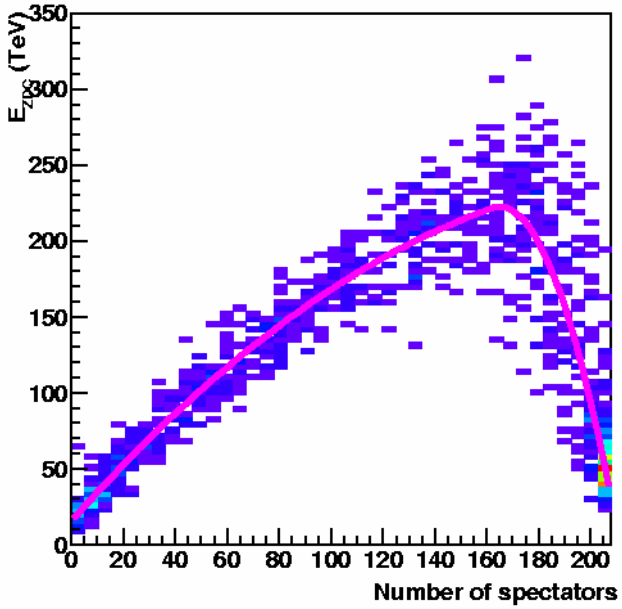
ZDC detectors

- Two sets of calorimeters on both sides of the interaction point
  - made in Torino and Cagliari
- Each set composed by:
  - 2 hadronic "spaghetti calorimeters"
    - 1 for spectator neutrons, 1 for spectator protons
    - Placed at 116 m from the interaction point
  - 1 forward electromagnetic calorimeter (ZEM)
    - Placed at 7 m from the interaction point



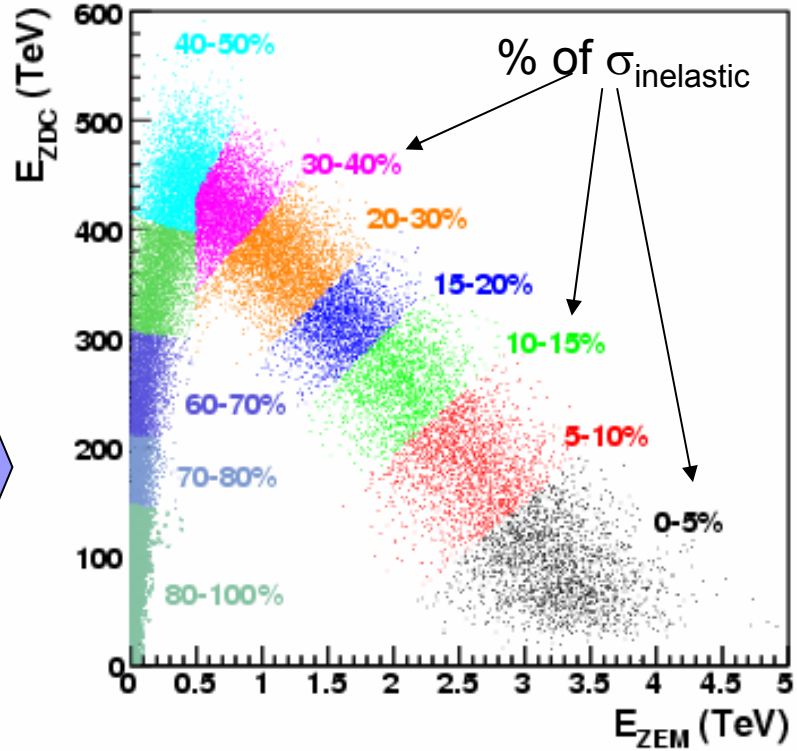


ZDC and centrality determination



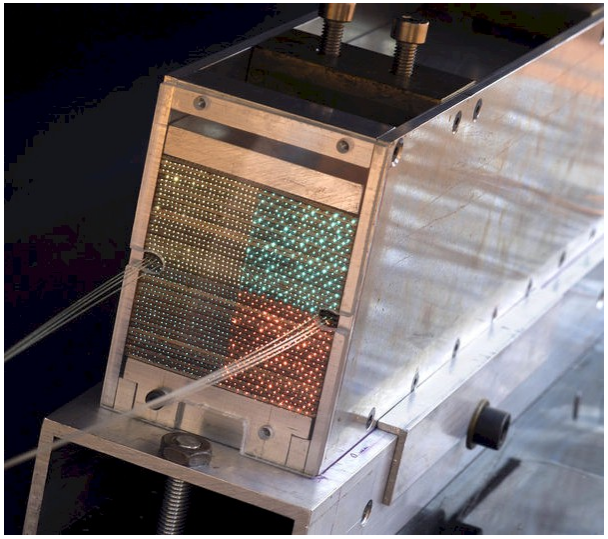
- E_{ZDC} correlated with number of spectators BUT two branches in the correlation
  - Break-up of correlation due to production of fragments (mainly in peripheral collisions)

- ZEM needed to solve the ambiguity
  - Signal with relatively low resolution, but whose amplitude increases monotonically with centrality



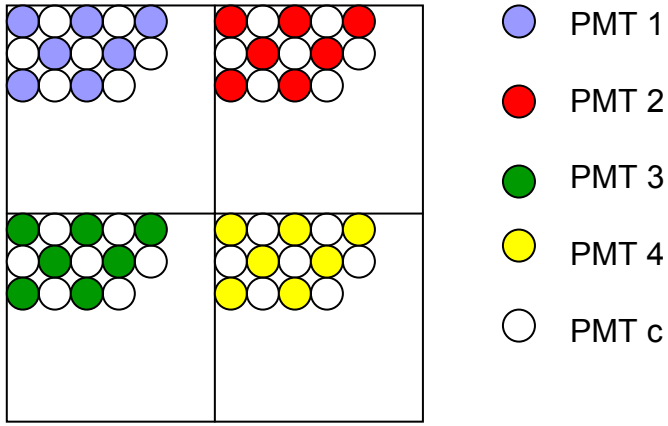
The neutron ZDC (ZN)

Each ZN is made by 44 grooved W-alloy slabs, each of them 1.6 mm thick, stacked to form a parallelepiped of 7.2 x 7.2 x 100 cm^3.



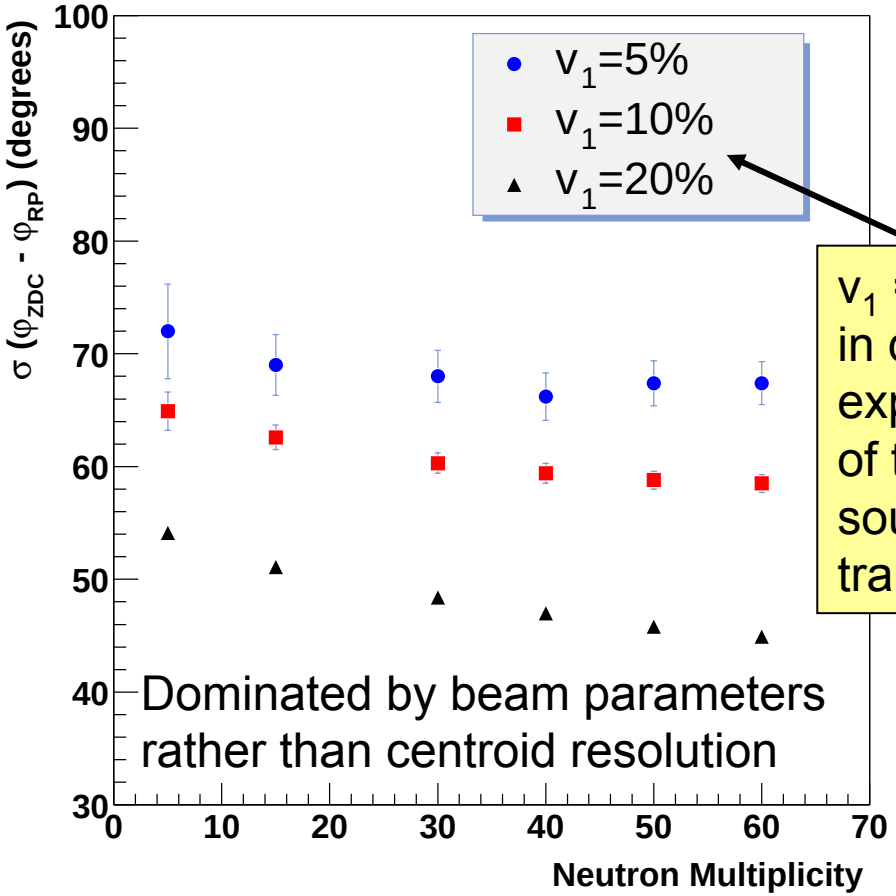
The active part is made of 1936 quartz fibers, embedded in the absorber with a pitch of 1.6 mm. The fibers, hosted in the slab grooves, are placed at 0^0 with respect to the incident particle direction.

Fibers come out from the rear face of the calorimeter, directly bringing the light to 5 photomultipliers (one for each of the 4 towers + 1 for the total energy).

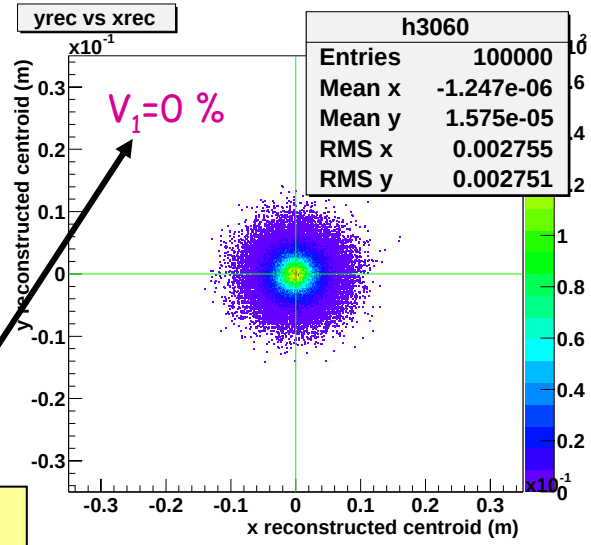


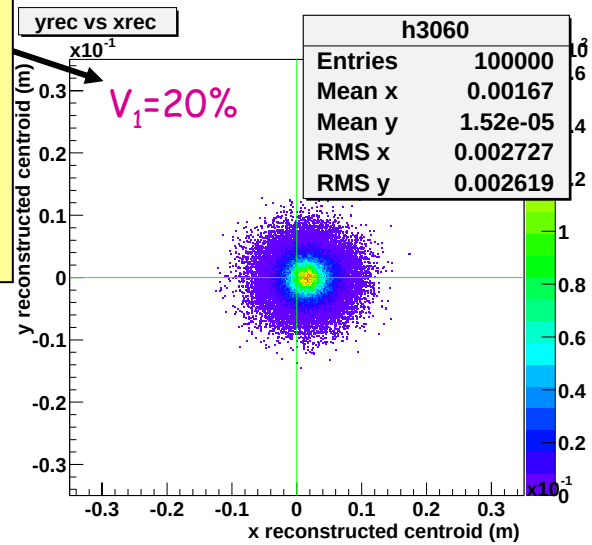
ZN and the reaction plane

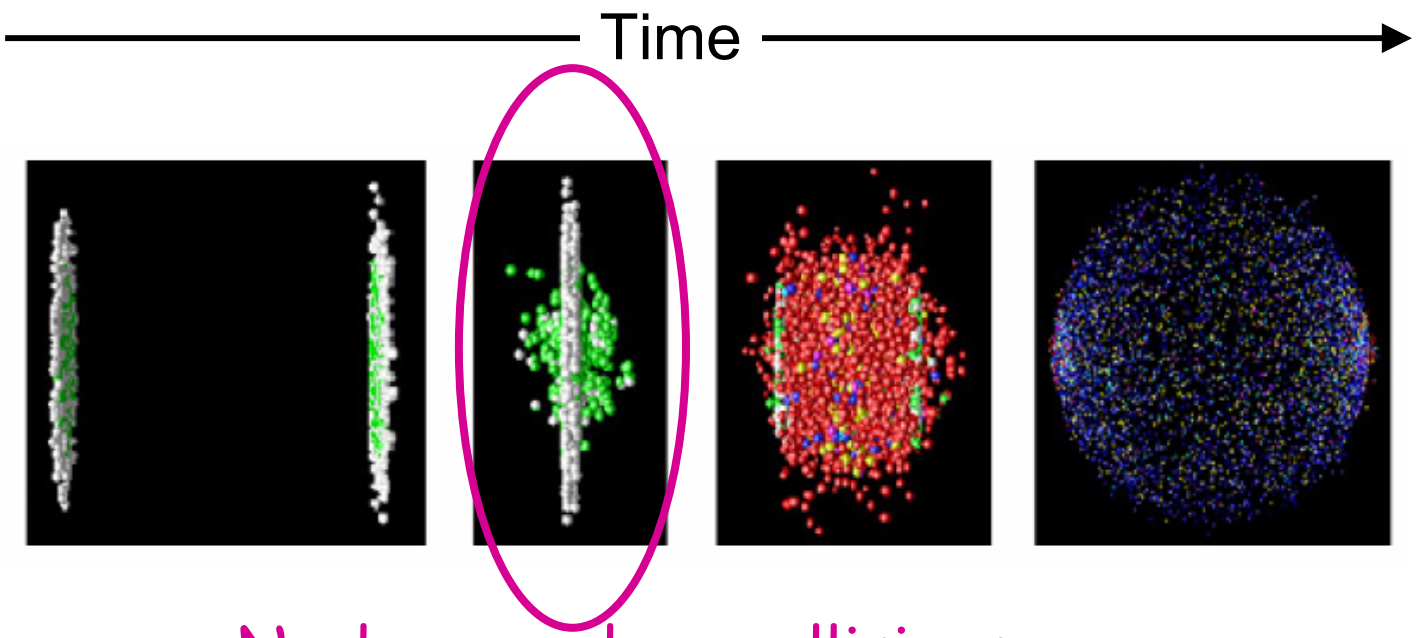
The segmentation in 4 towers gives a rough localization of the spectator neutron's spot on the front face of the calorimeter allowing the experimental estimation of the reaction plane.



v_1 = first harmonic in dN/dφ Fourier expansion = shift of the particle source in the transverse plane

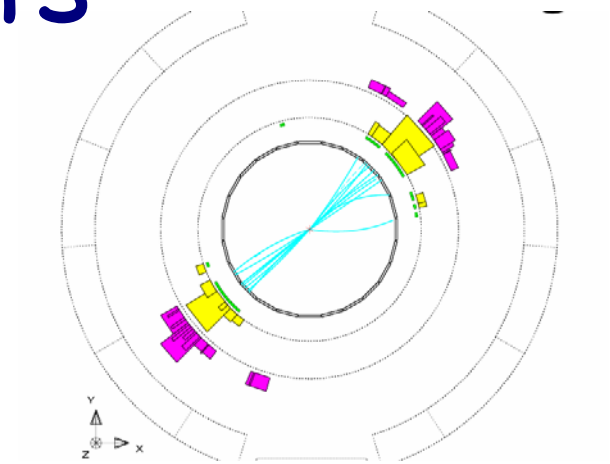


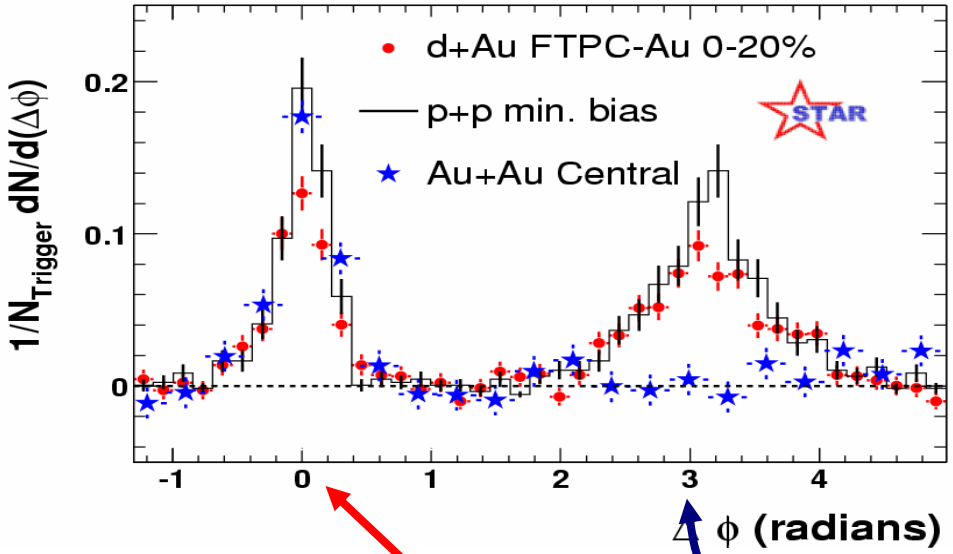




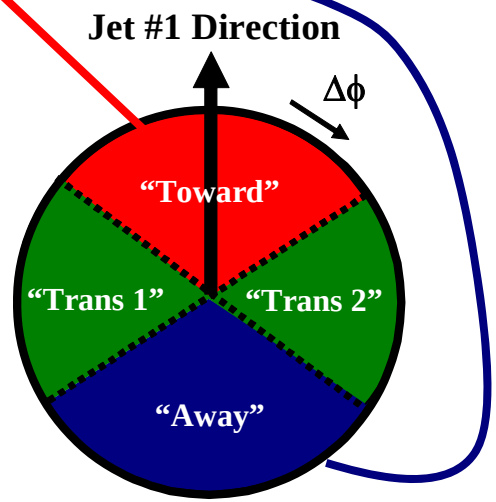
Nucleon-nucleon collisions
→ Energy deposition
Interactions at partonic level
(short time-scale large momentum transfer)
→ Hard probes

Jets



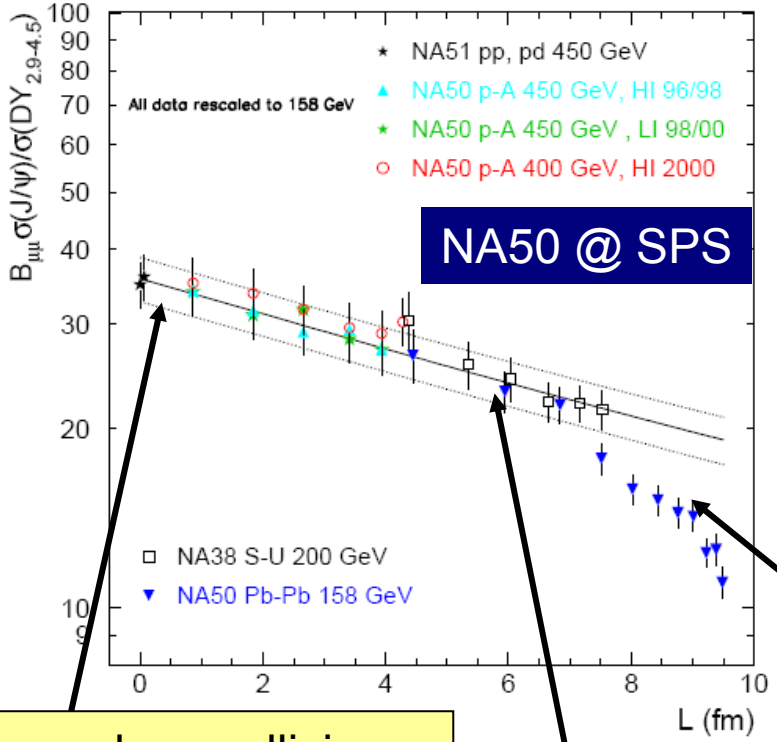


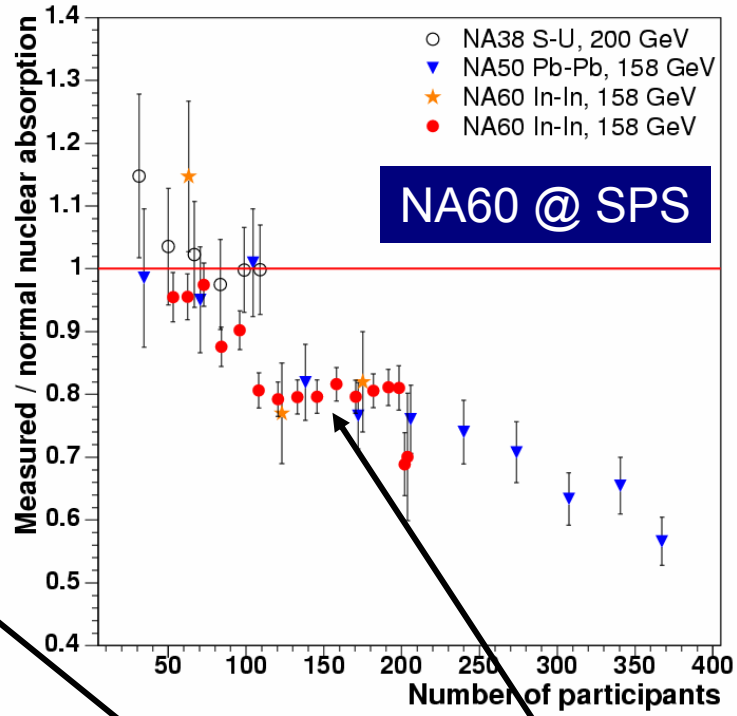
- In p–p collisions
  - Two jets back-to-back (180°)
- d+Au looks like p–p
- In central Au+Au collisions:
  - Disappearance of the away-side jet
  - Jet quenching in the dense medium



J/Ψ production and suppression

- Quarkonia suppression due to colour charge screening predicted as signature of deconfinement (Satz 1986)





Proton-nucleus collisions: Absorption in a length L of nuclear matter (σ_{abs}= 4.18±0.35 mb)

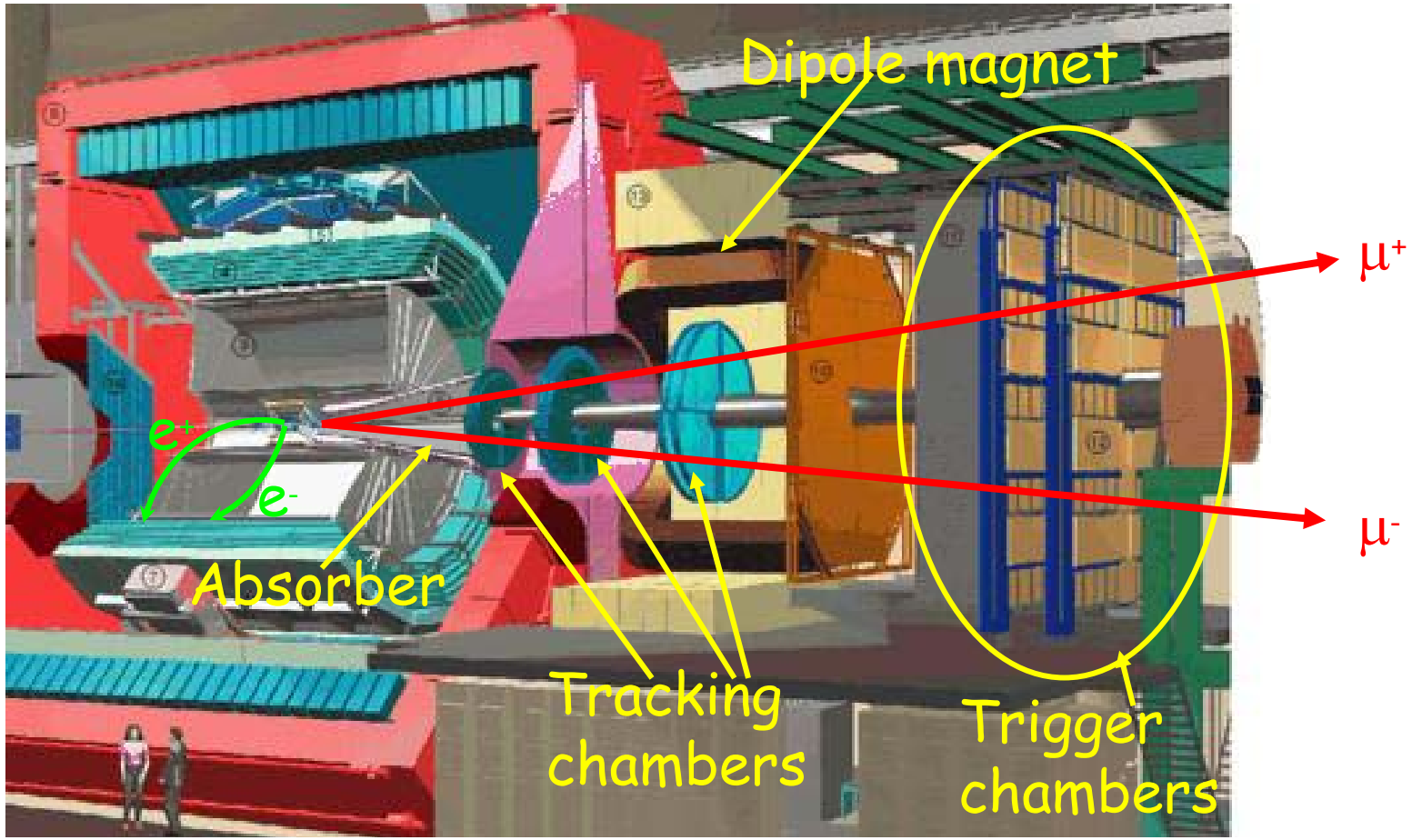
Light-Ion and peripheral Pb-Pb compatible with p-A trend

Anomalous suppression in central Pb-Pb

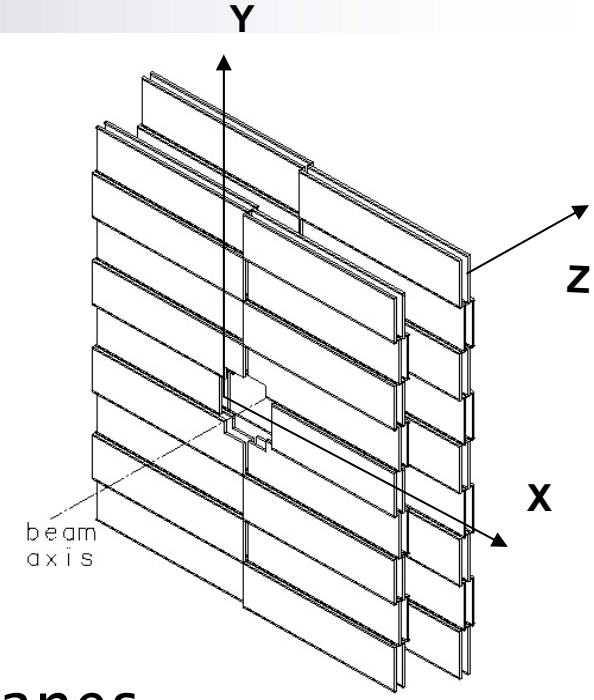
Anomalous suppression also in In-In

Detecting quarkonia in ALICE

- e^+e^- in the central barrel
- $\mu^+\mu^-$ in the forward muon spectrometer

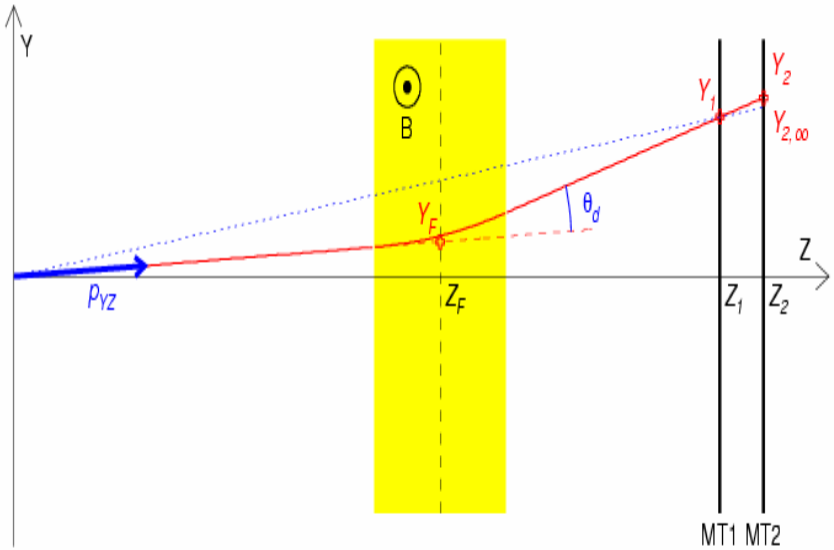


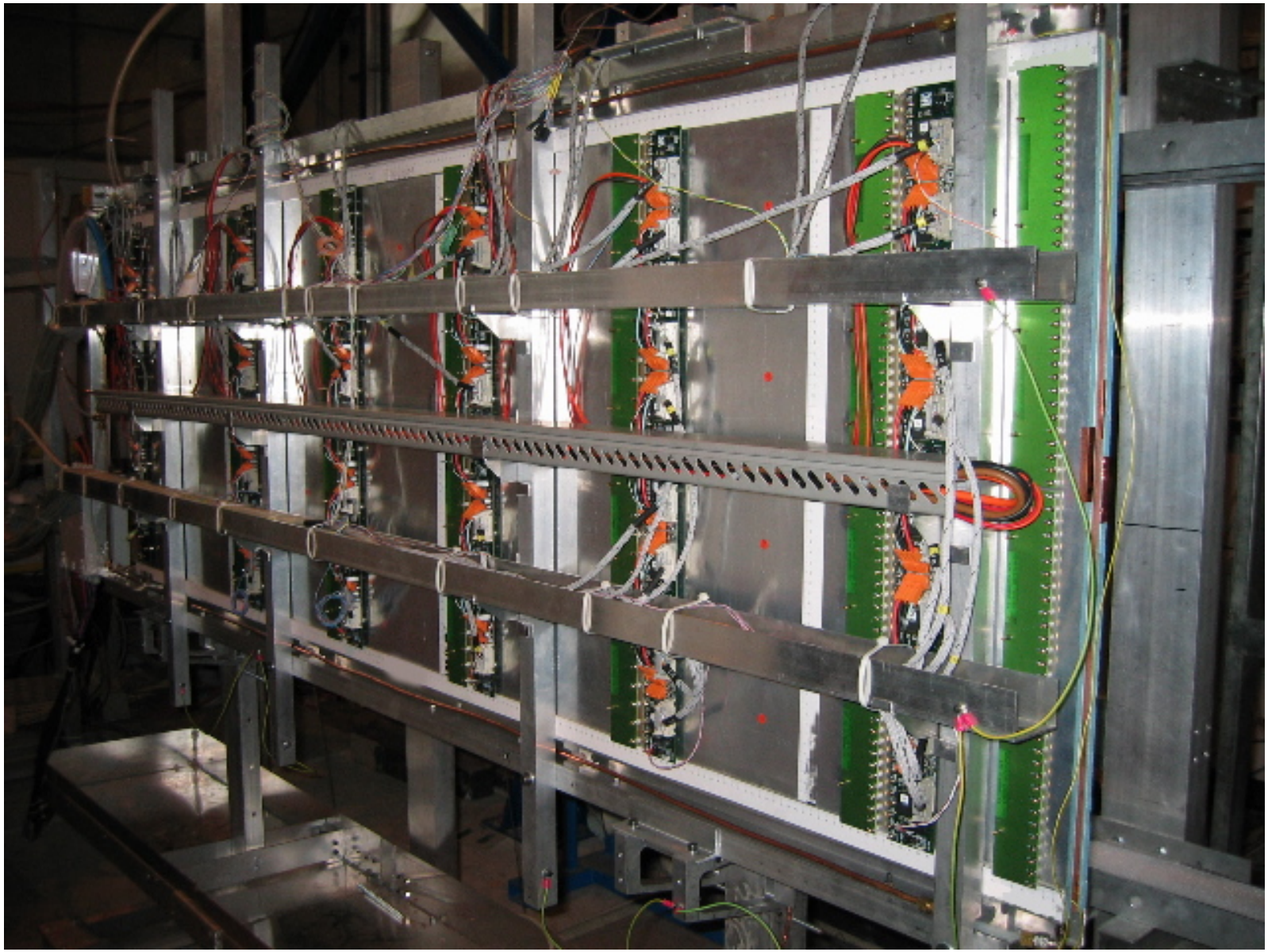
Muon trigger system



- Two stations of two planes each
  - 72 Resistive Plate Chambers (RPC) (≈ 144 m^2)
  - 20992 electronic channels
  - Low resistivity bakelite (≈10^9 Ω cm)
  - High voltage (≈ 8 kV)
  - Gas gap of 2 mm (51% Ar + 7% iC_4H_{10} + 41% $C_2H_2F_4$ + 1% SF_6)
- Chambers read-out by means of two planes of orthogonal strips oriented along X and Y

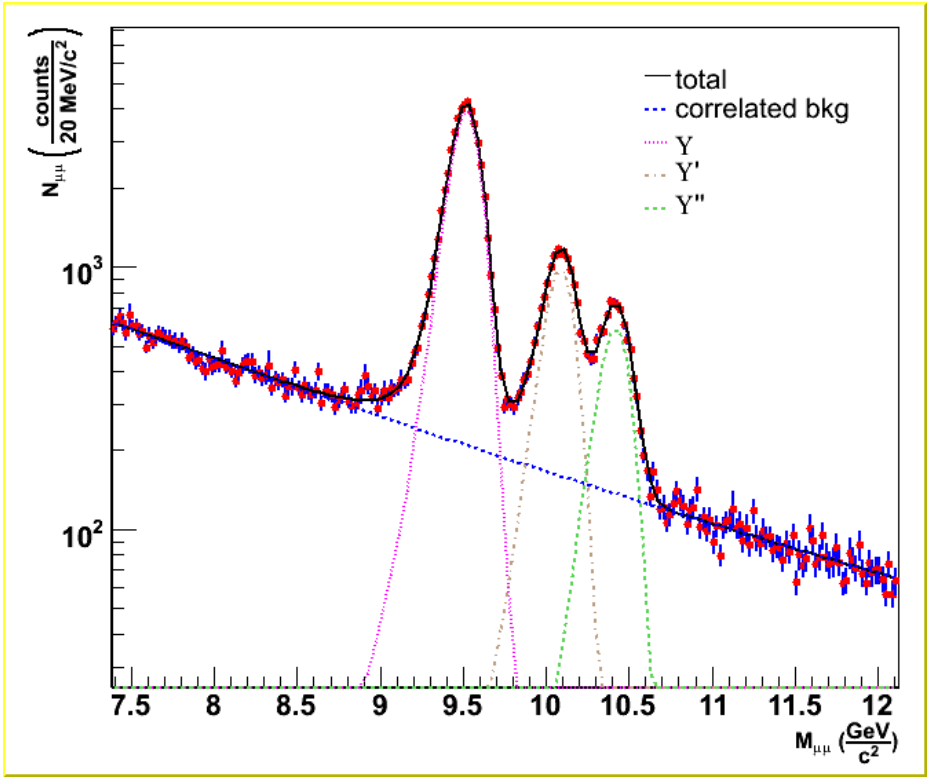
- Cut on muon p_t at the trigger level
  - Magnetic bending ($\theta_d \propto 1/p \propto 1/p_t$)
  - $p_{t,cut}$ (J/ψ)=1 GeV/c
  - $p_{t,cut}$ (ϒ)=2 GeV/c



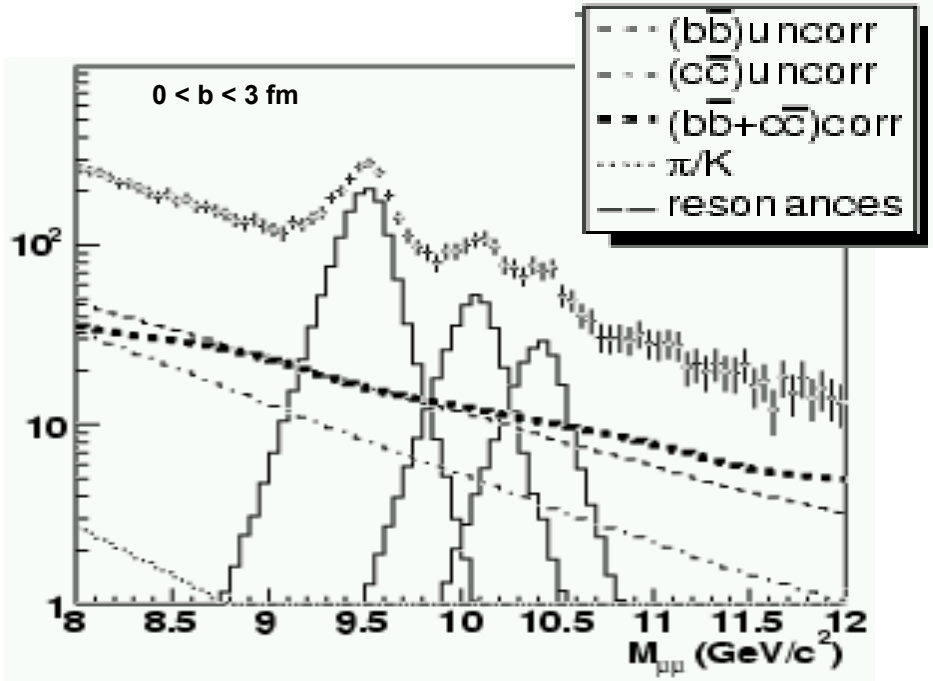


ϒ reconstruction in the muon arm

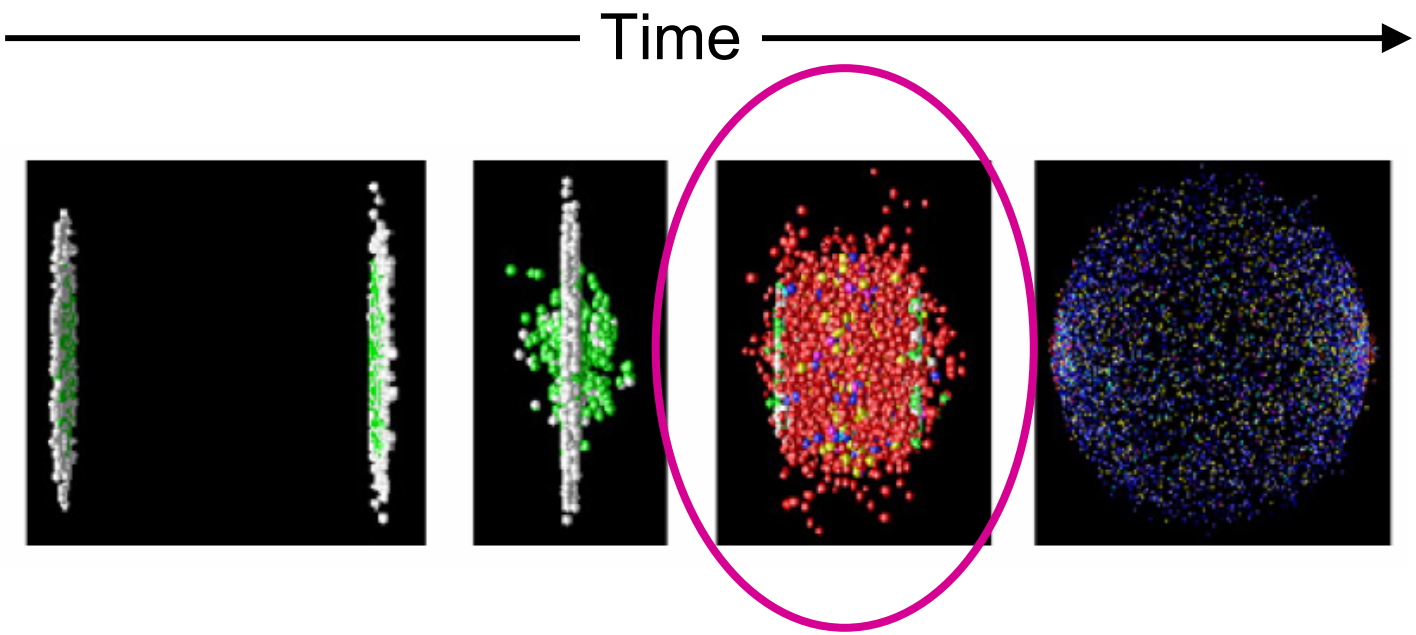
p-p @ 14 TeV



Pb-Pb @ 5.5 TeV

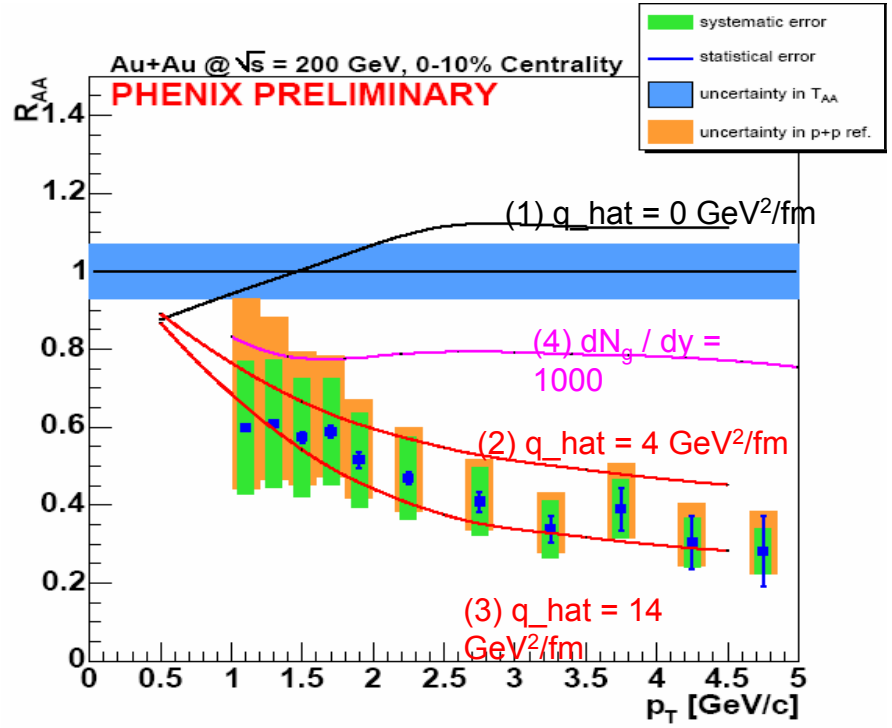


ϒ, ϒ′, ϒ″ can be distinguished



Formation of "the medium"
→ dense, strongly interacting,
→ possibly deconfined

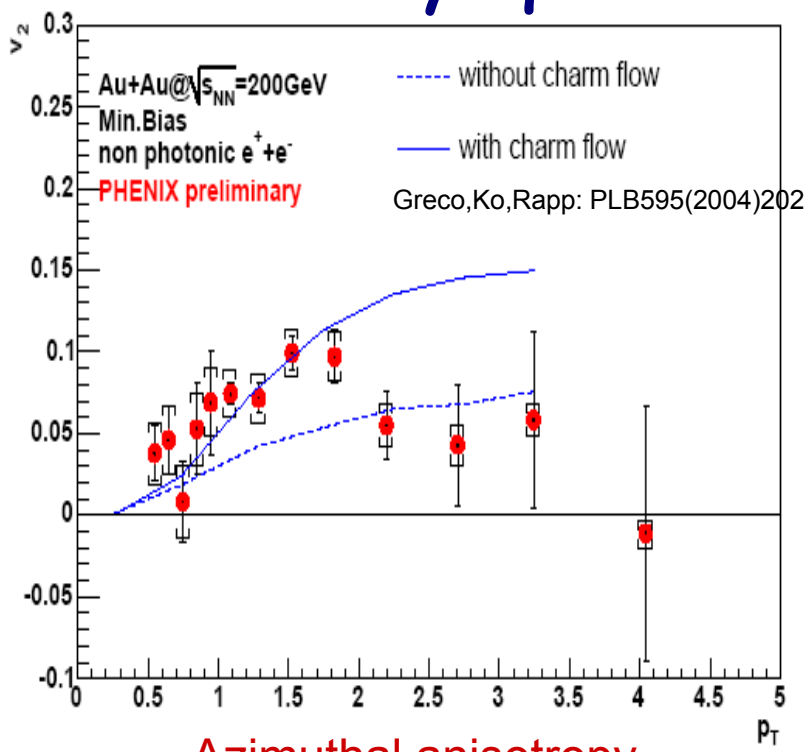
Probe the medium with heavy quarks



Nuclear modification factor

$$R_{AA}(p_T) = \frac{yield_{AA}}{yield_{pp} \times N_{bin}^{coll}}$$

The medium is so dense that c quarks lose energy (by gluon radiation)



Azimuthal anisotropy

$$v_2 = \langle \cos[2(\varphi - \Psi_{RP})] \rangle$$

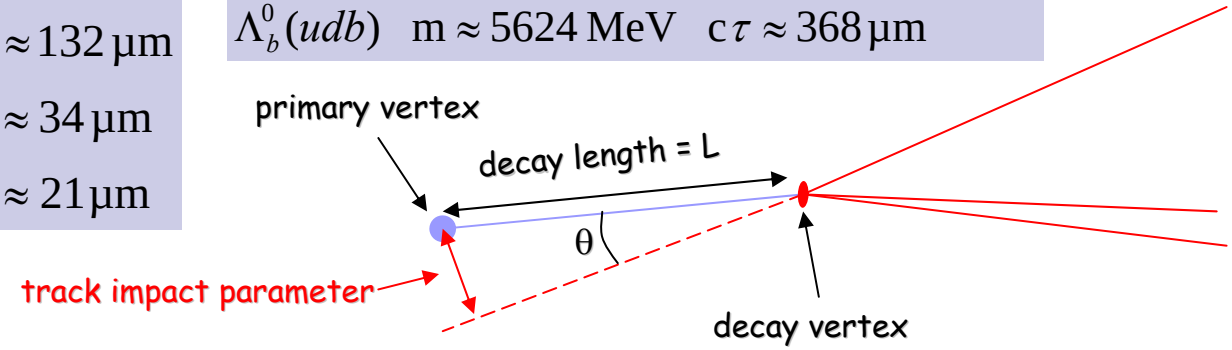
The medium is so strongly interacting that c quarks suffer significant rescattering and develop azimuthal anisotropy

Heavy flavour reconstruction in ALICE

- Weakly decaying beauty and charm states

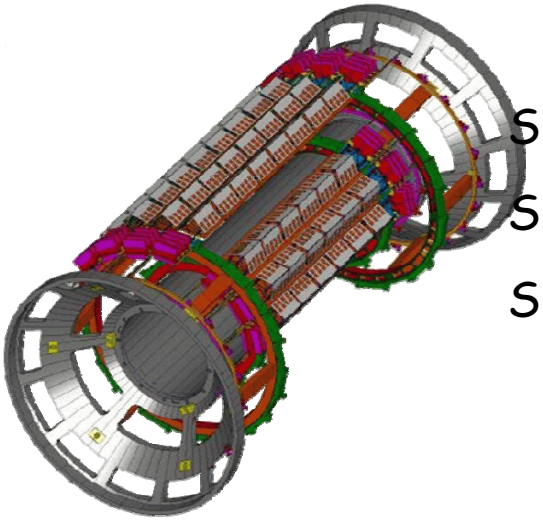
$D^+(c\bar{d})$	$m \approx 1869$ MeV	$c\tau \approx 312\,\mu m$
$D^0(c\bar{u})$	$m \approx 1865$ MeV	$c\tau \approx 123\,\mu m$
$D_s^+(c\bar{s})$	$m \approx 1968$ MeV	$c\tau \approx 147\,\mu m$
$\Lambda_c^+(udc)$	$m \approx 2285$ MeV	$c\tau \approx 60\,\mu m$
$\Xi_c^+(usc)$	$m \approx 2466$ MeV	$c\tau \approx 132\,\mu m$
$\Xi_c^0(dsc)$	$m \approx 2472$ MeV	$c\tau \approx 34\,\mu m$
$\Omega_c^0(ssc)$	$m \approx 2698$ MeV	$c\tau \approx 21\,\mu m$

$B^+(u\bar{b})$	$m \approx 5279$ MeV	$c\tau \approx 501\,\mu m$
$B^0(d\bar{b})$	$m \approx 5279$ MeV	$c\tau \approx 460\,\mu m$
$B_s^0(s\bar{b})$	$m \approx 5370$ MeV	$c\tau \approx 438\,\mu m$
$B_c^+(c\bar{b})$	$m \approx 6.4$ GeV	$c\tau \approx 100-200\,\mu m$
$\Lambda_b^0(udb)$	$m \approx 5624$ MeV	$c\tau \approx 368\,\mu m$



- Need for high precision vertex detector
  - tracks from heavy flavour weak decays are typically displaced from primary vertex by ~ 100's μm
  - resolutions of typical heavy flavour apparatus ~ 10's μm
- Inner Tracking System: ALICE silicon tracker

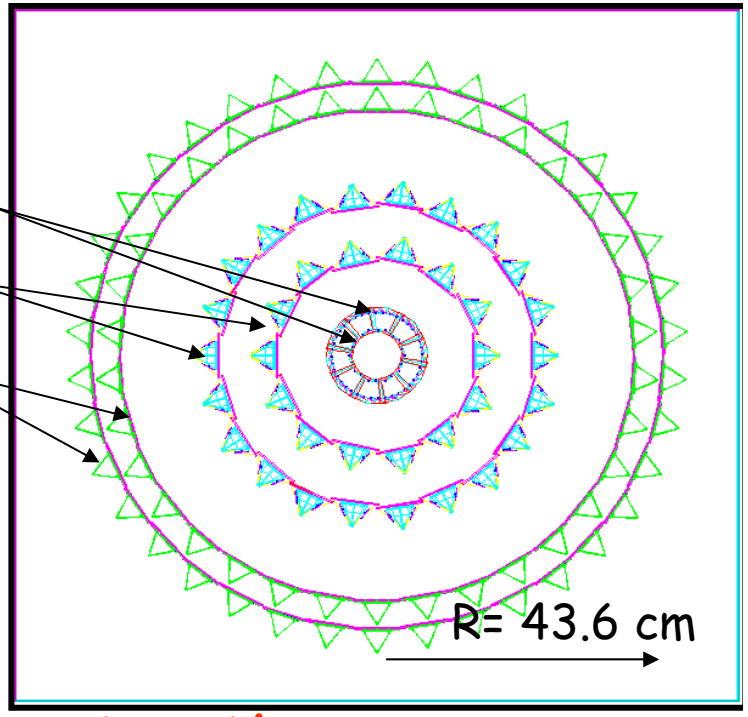
ITS

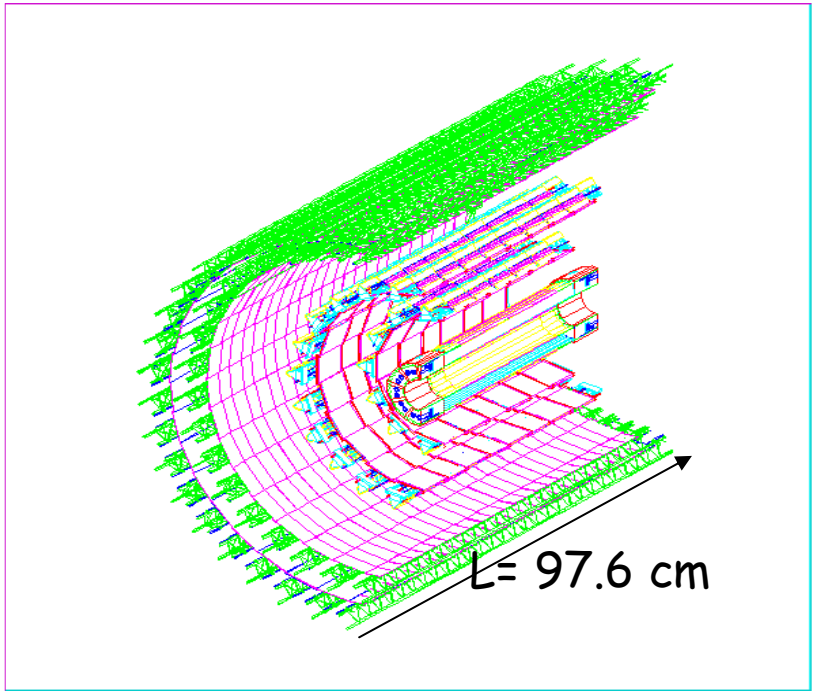


Silicon Pixel Detectors (2D)

Silicon Drift Detectors (2D)

Silicon Strip Detectors (1D)

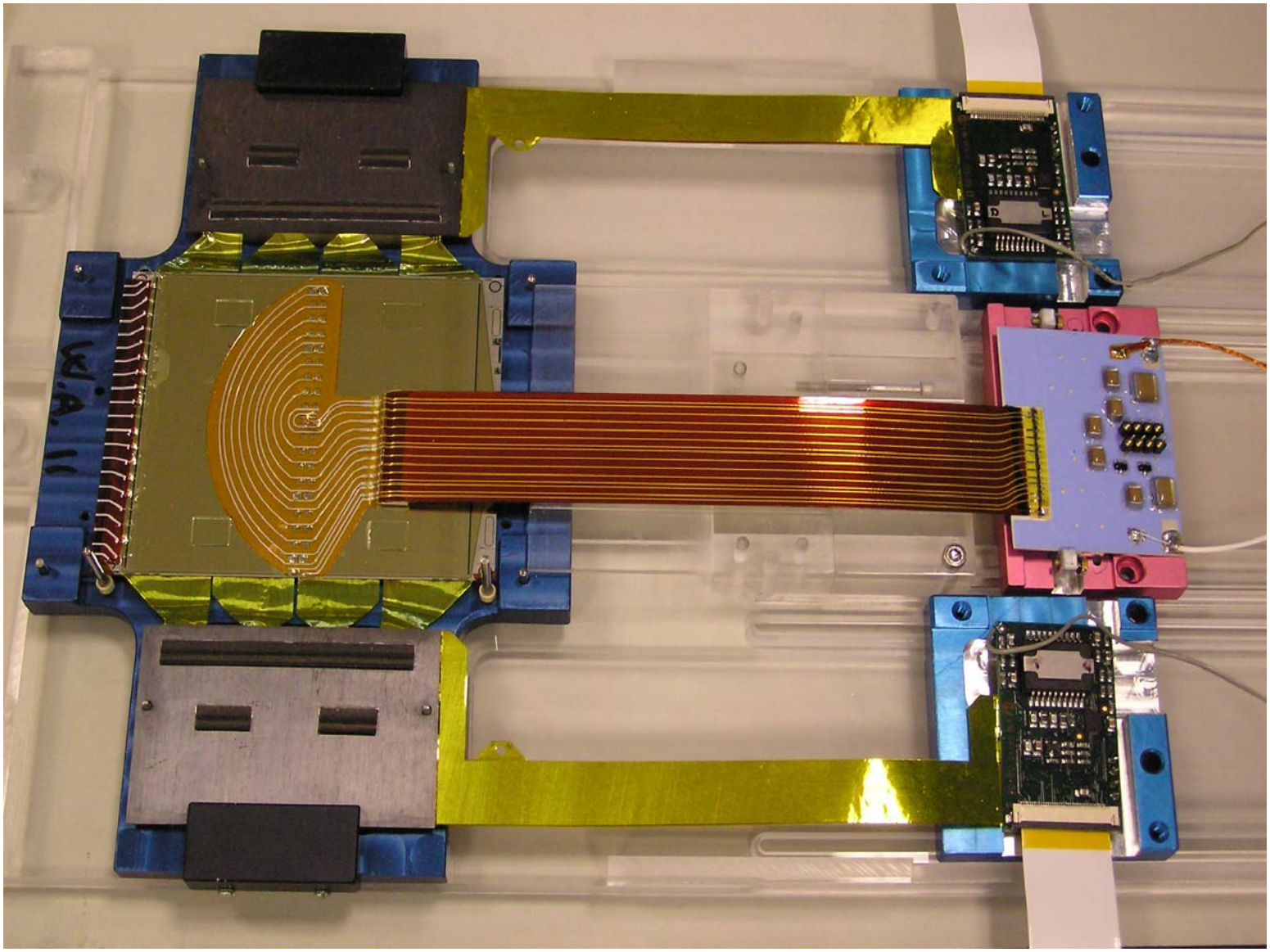


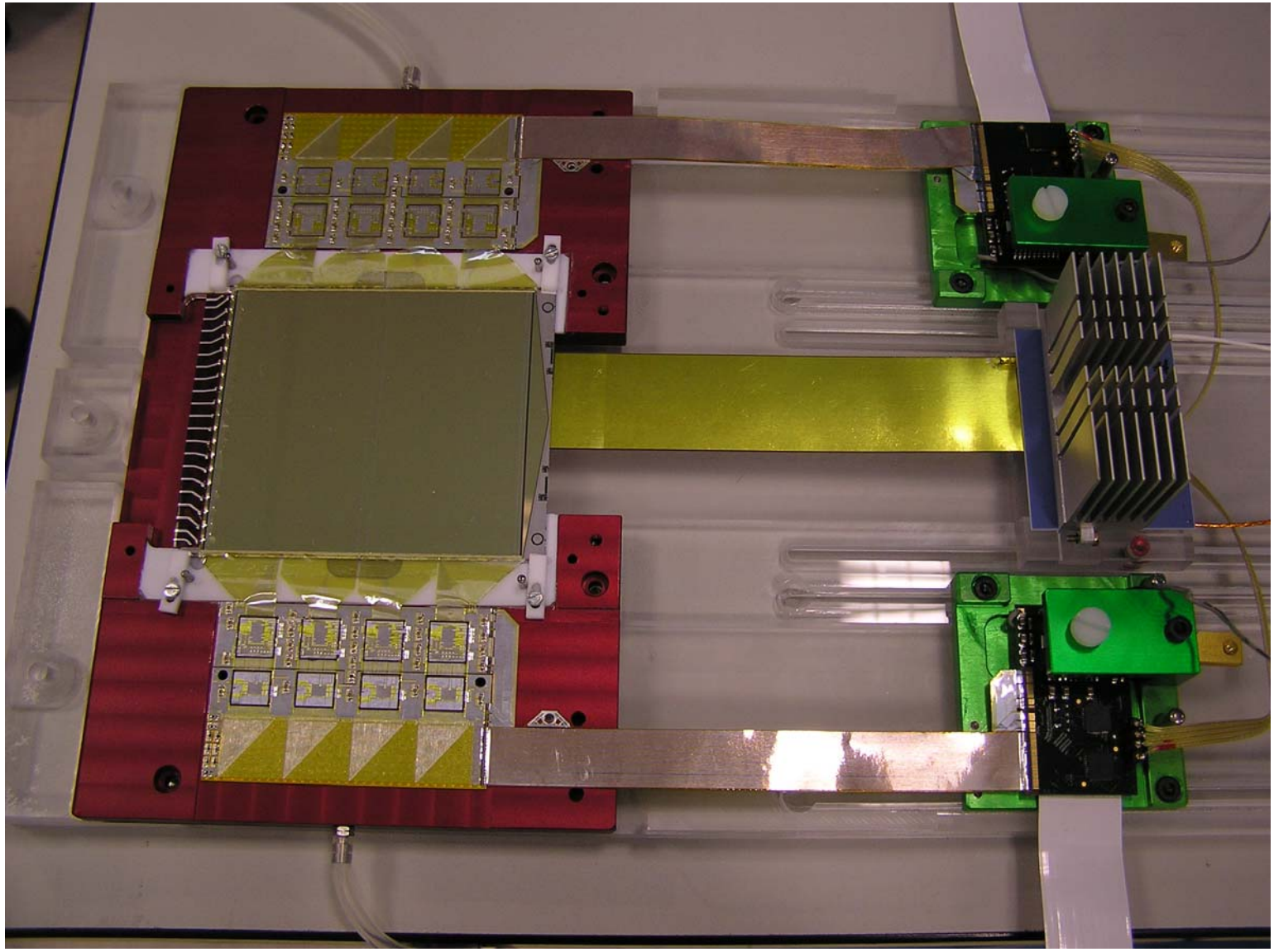


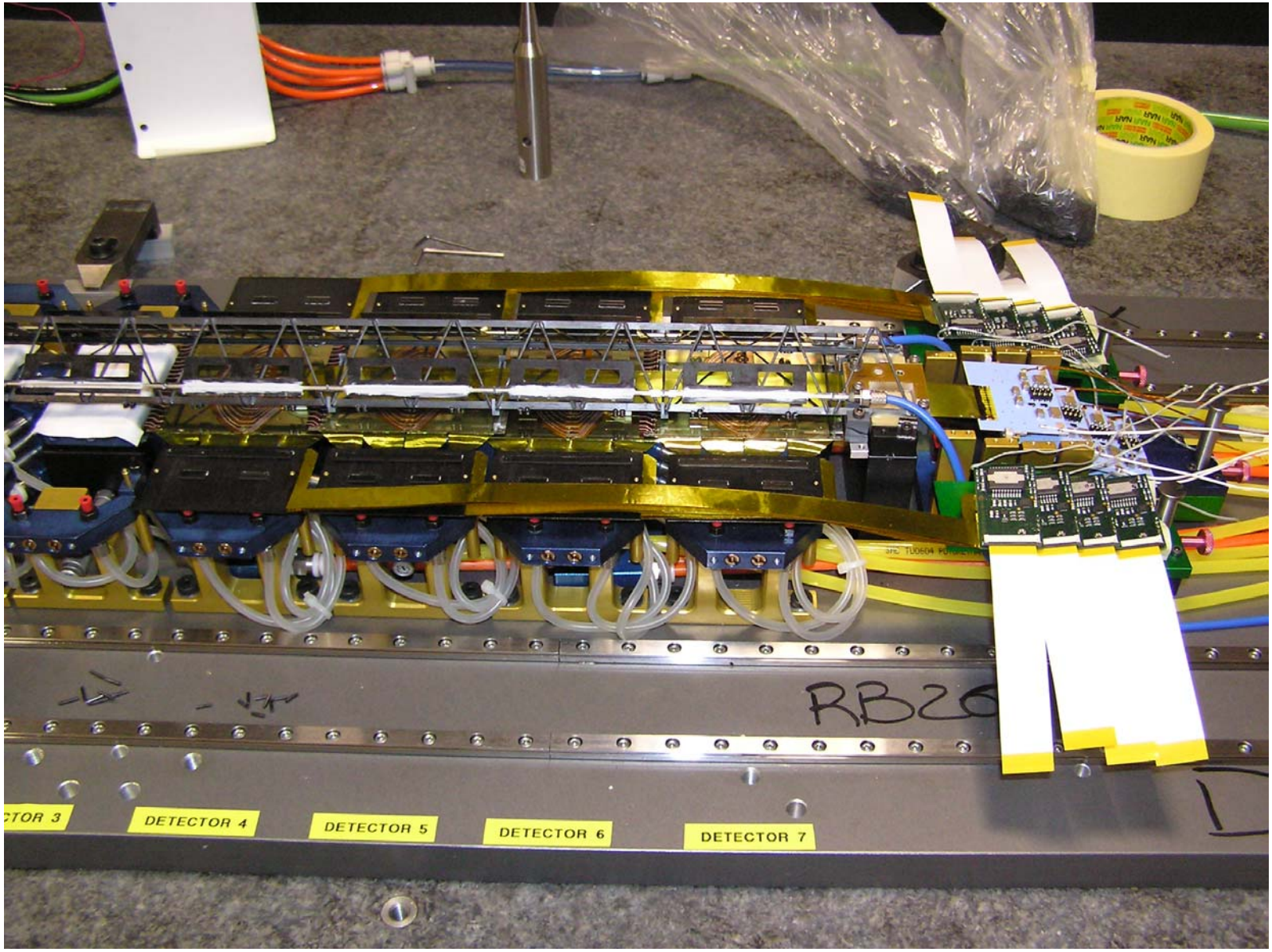
Vertex reconstruction (primary, secondary) resolution <100 μm

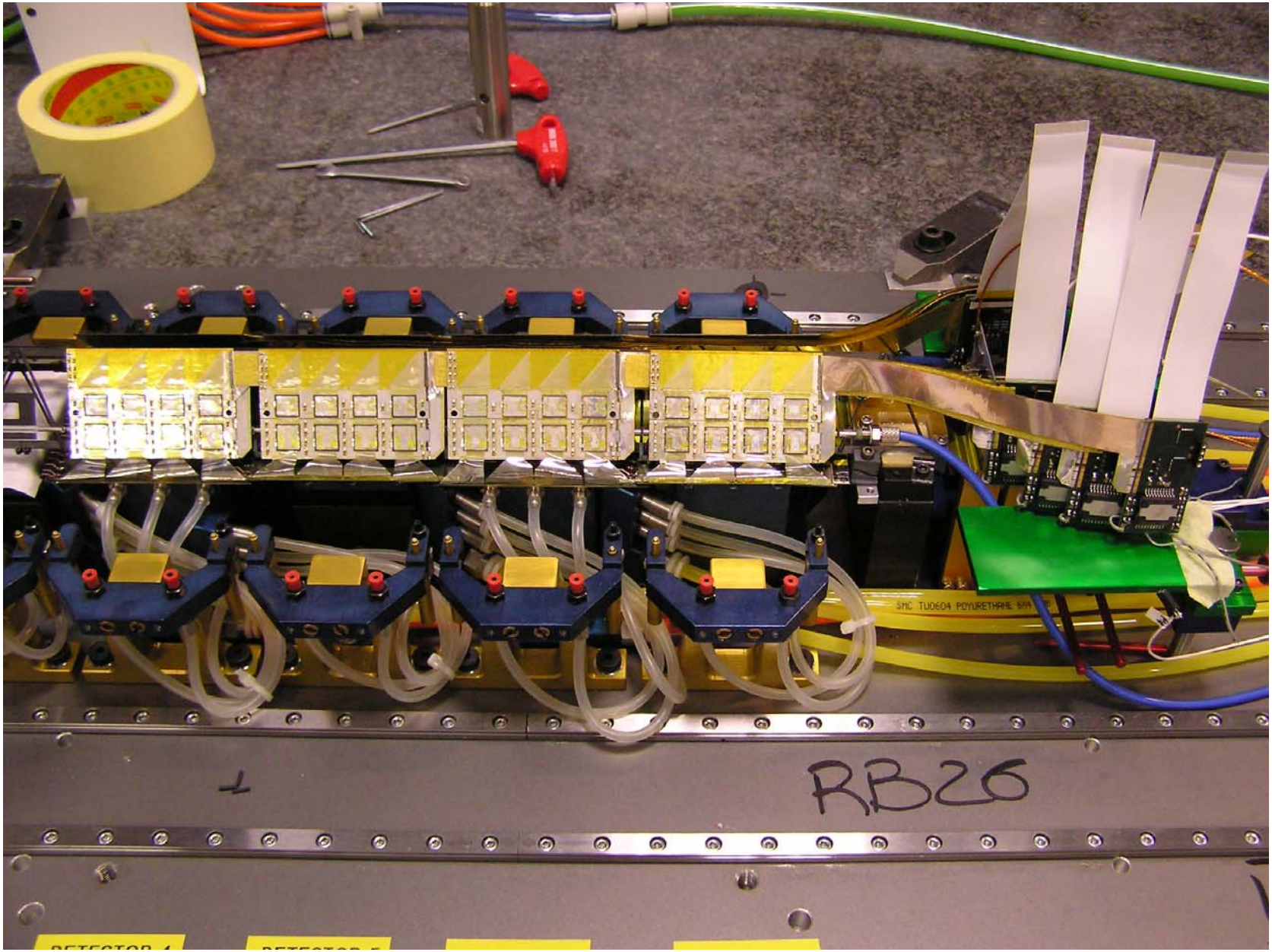
Measurement of dE/dx (Drift, Strip)- PID

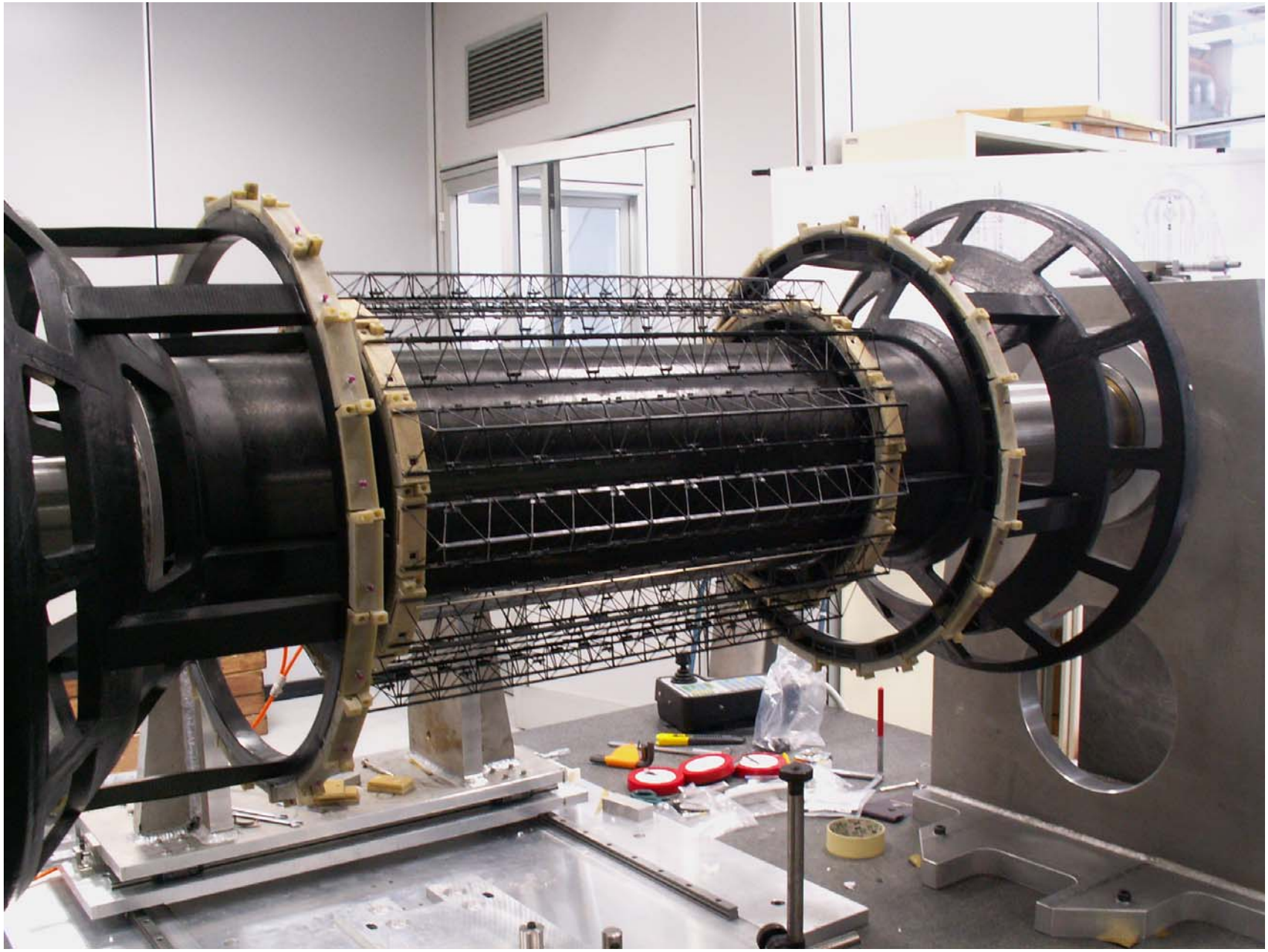
Production of SDD layers

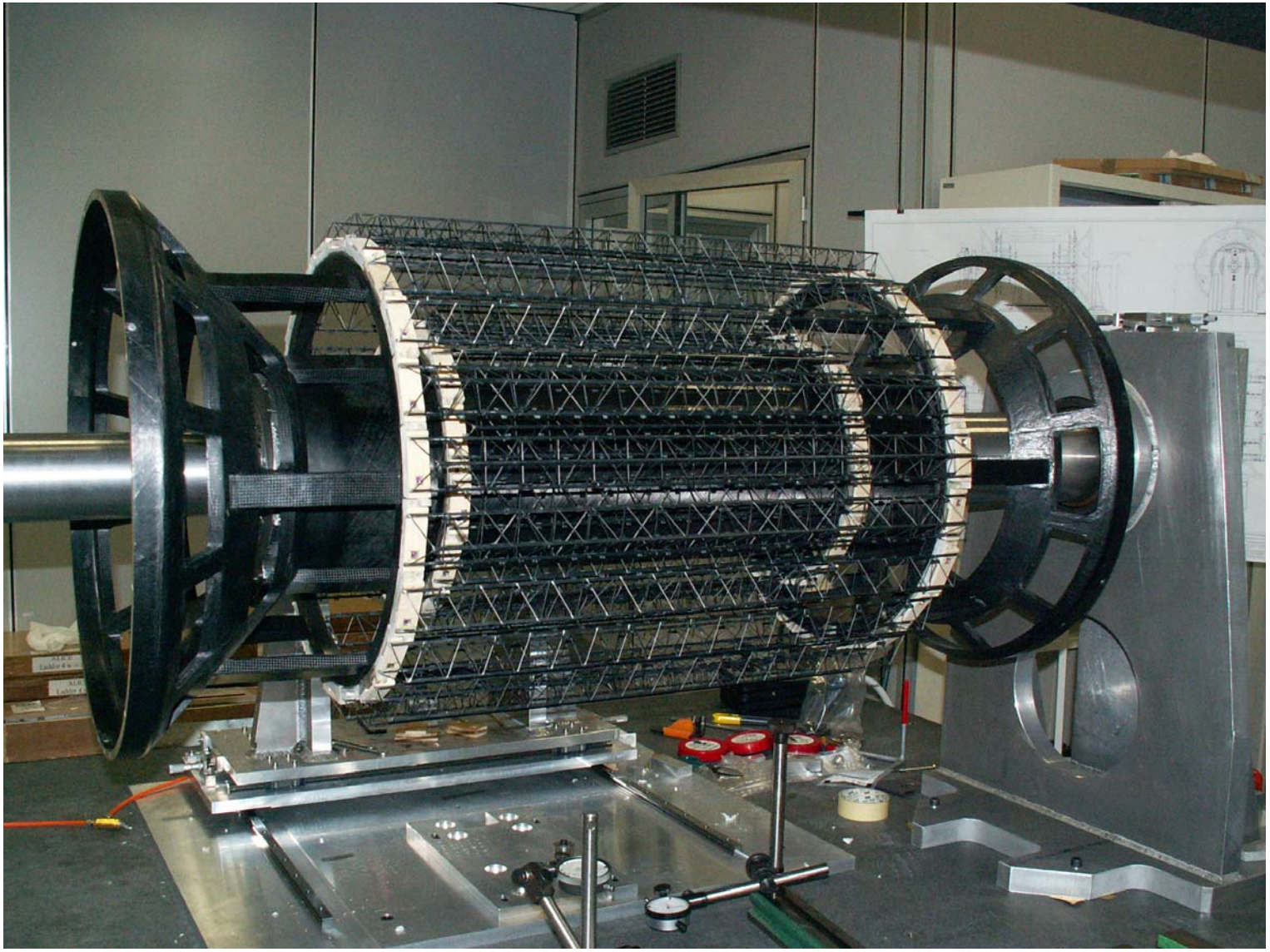


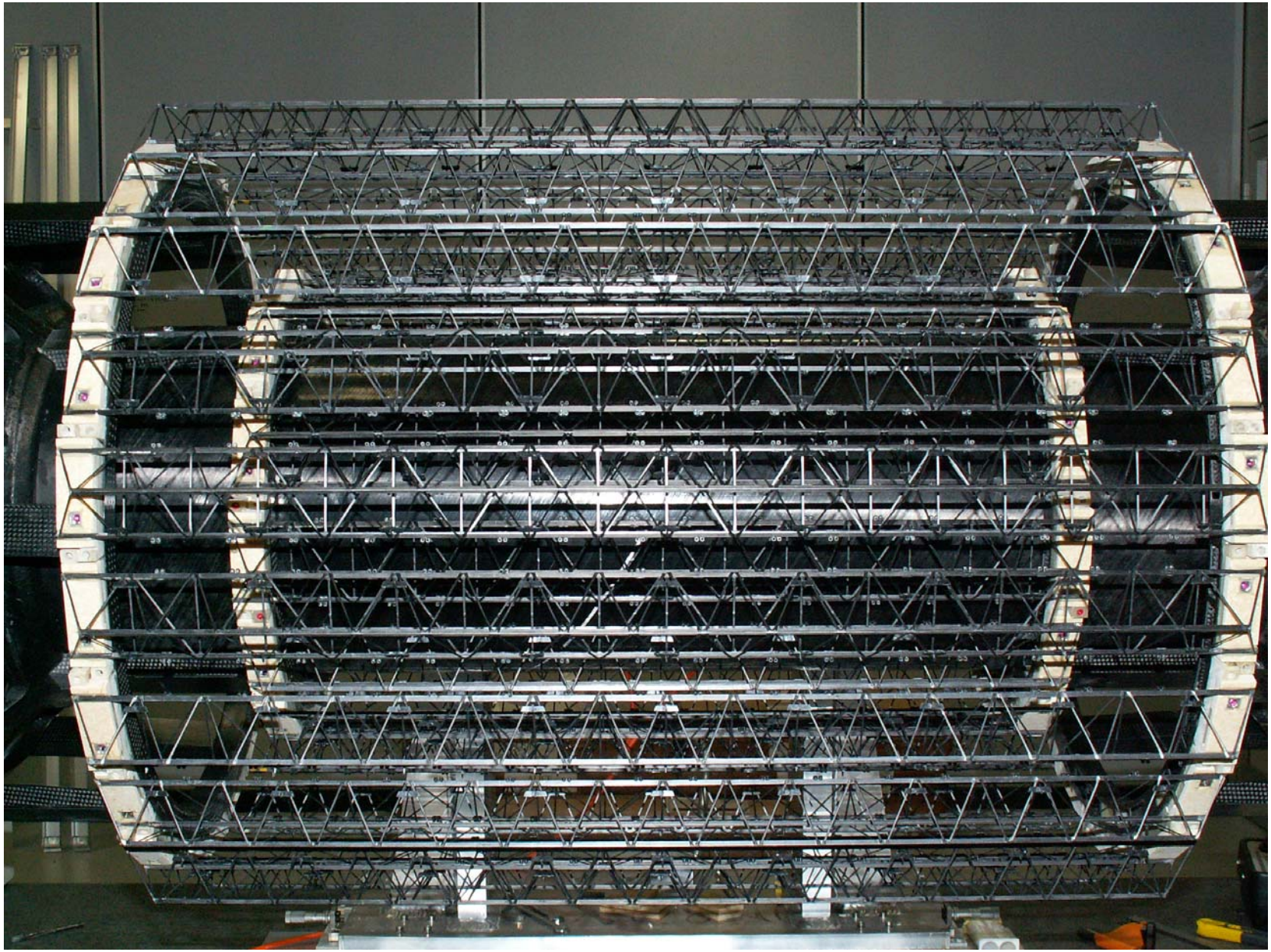



DETECTOR 4
DETECTOR 5
DETECTOR 6
DETECTOR 7


RB26

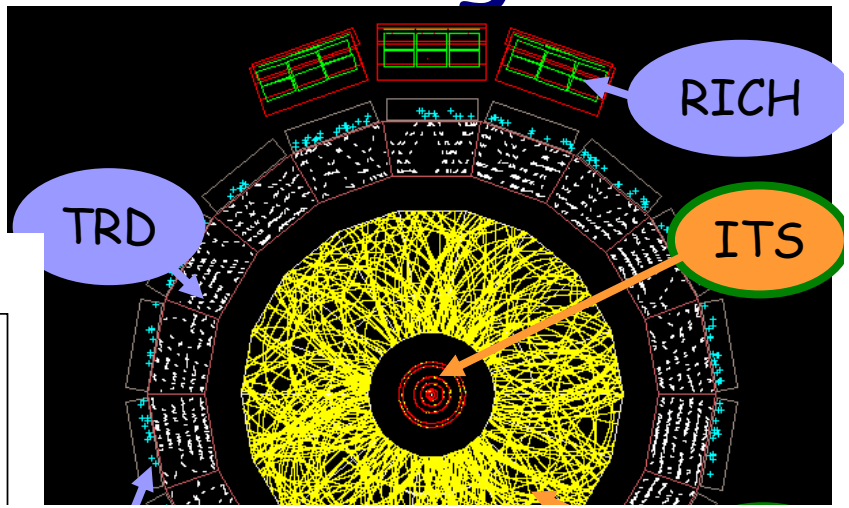


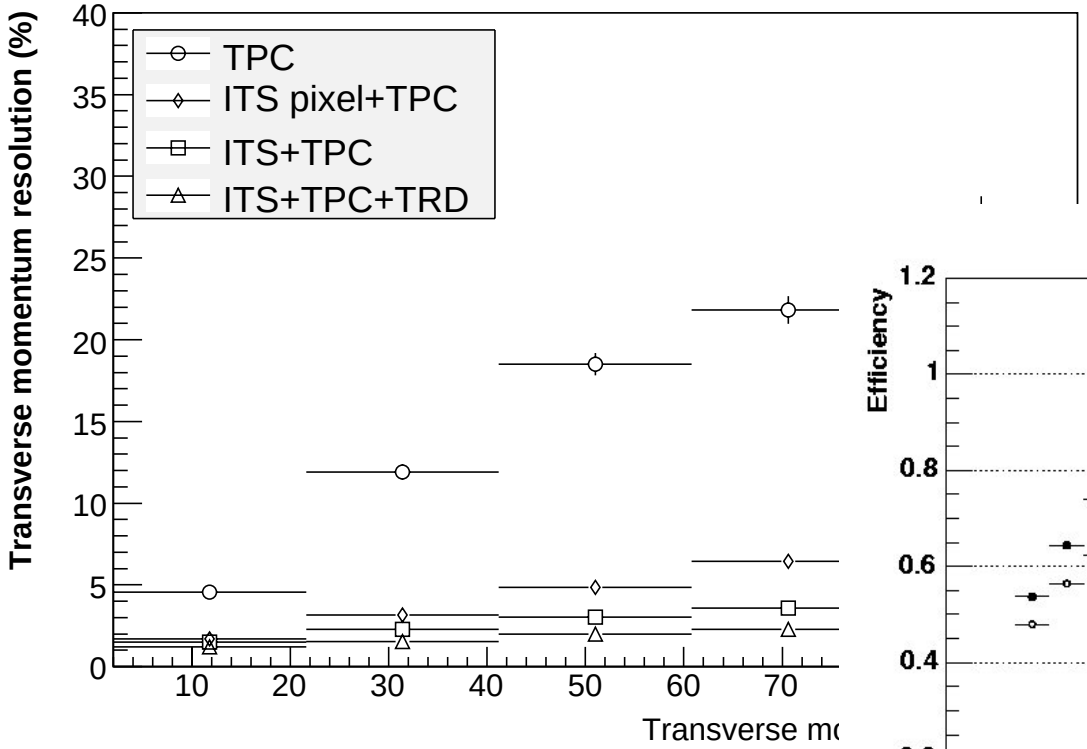


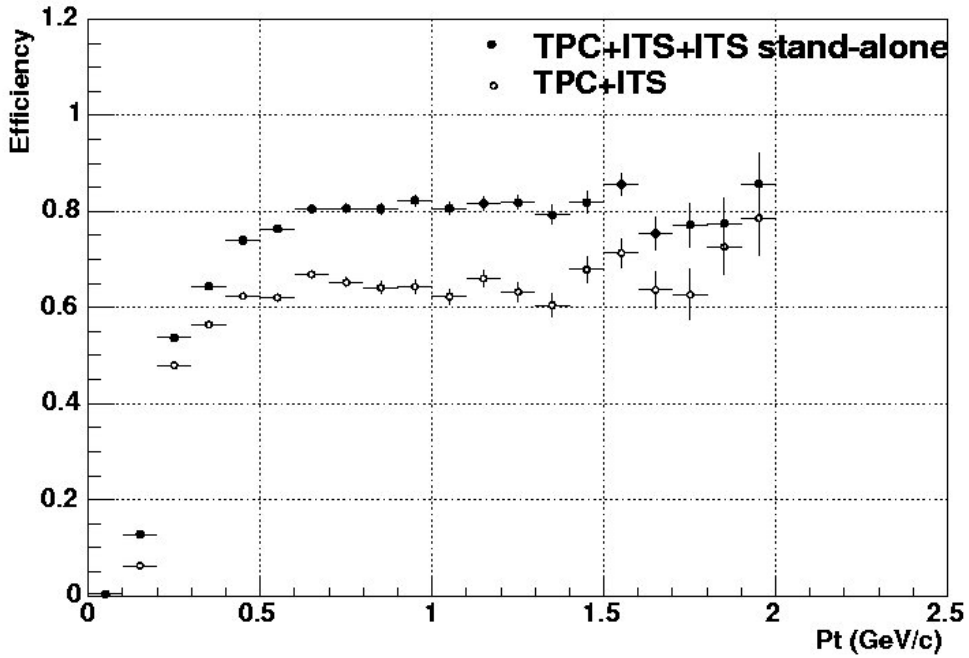


ITS performance: tracking

Tracking is the major challenge in ALICE: ~12000 tracks in a central event in the ITS + TPC acceptance

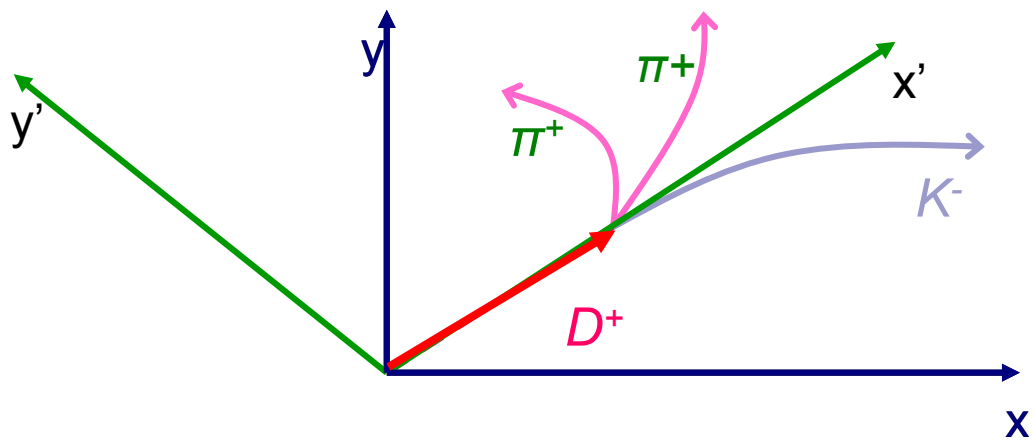


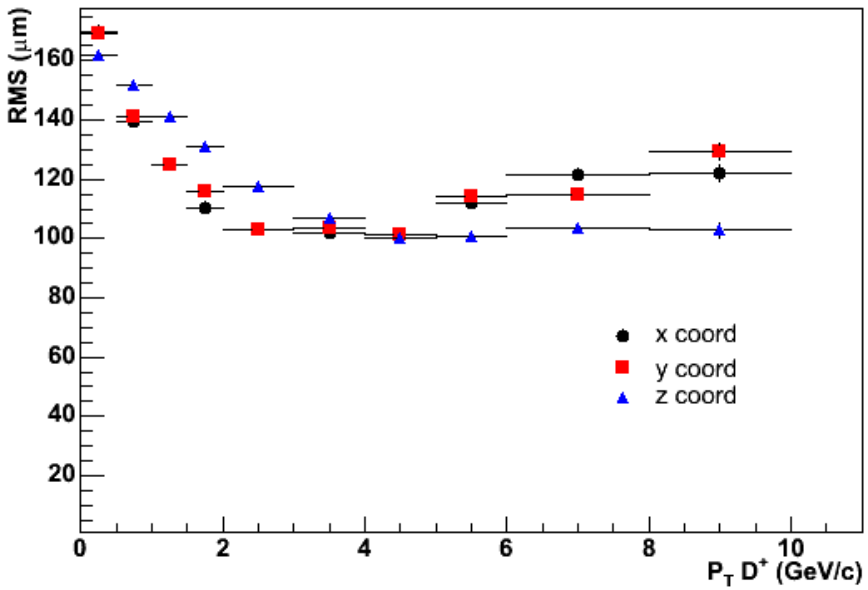


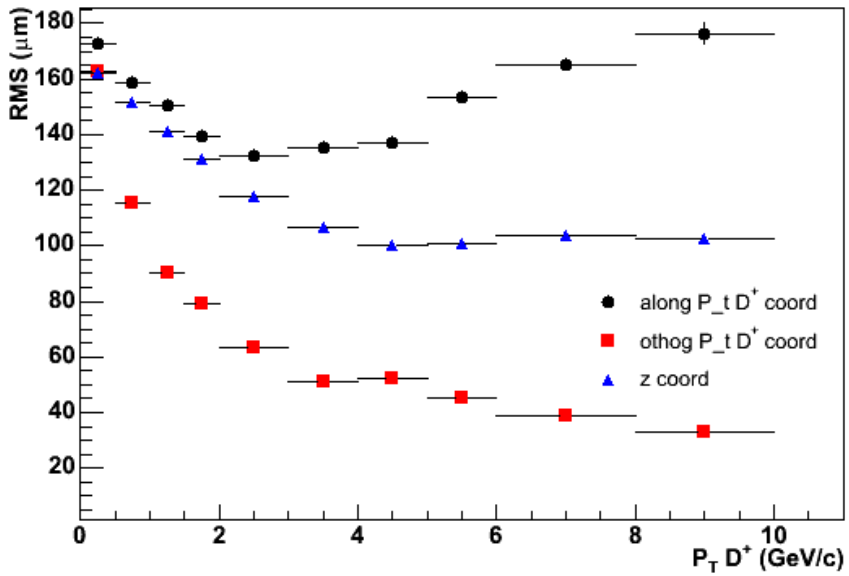


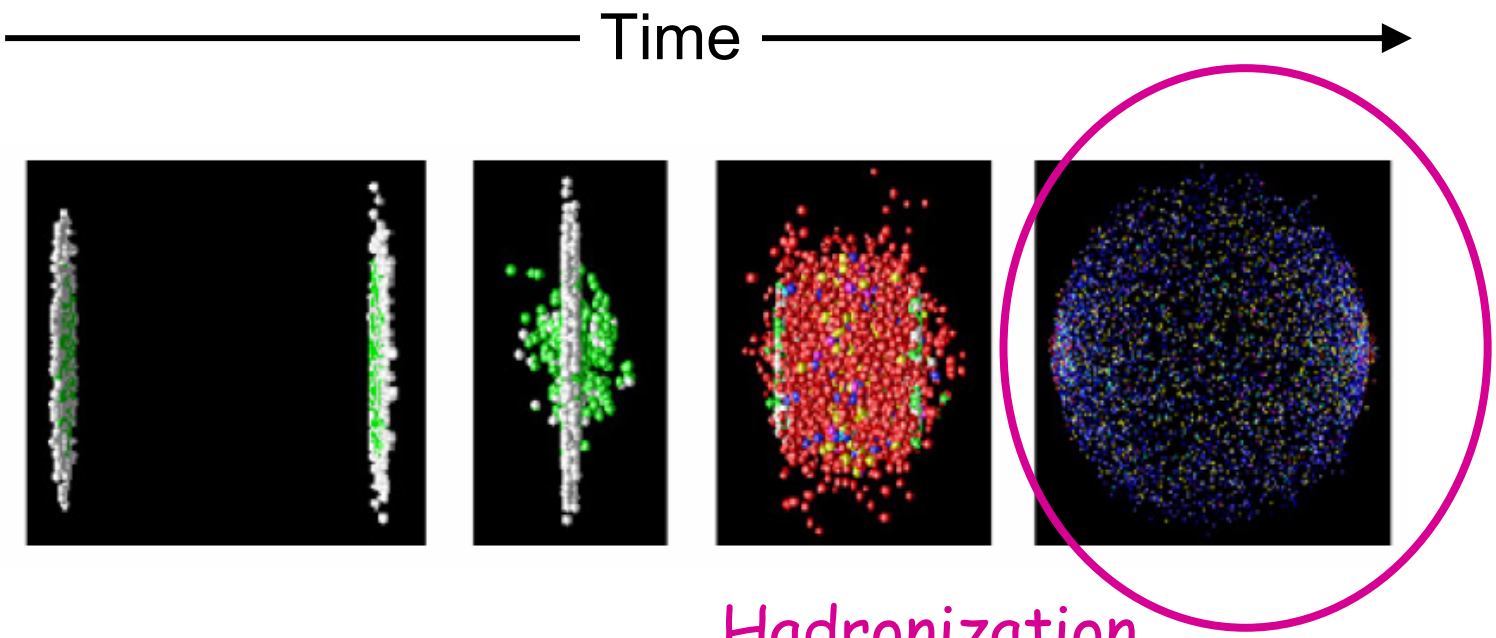
ITS performance: vertexing

- SPD used for primary vertex reconstruction
- ITS improves secondary vertex resolution
  - Example: $D^+ \rightarrow K\pi\pi$







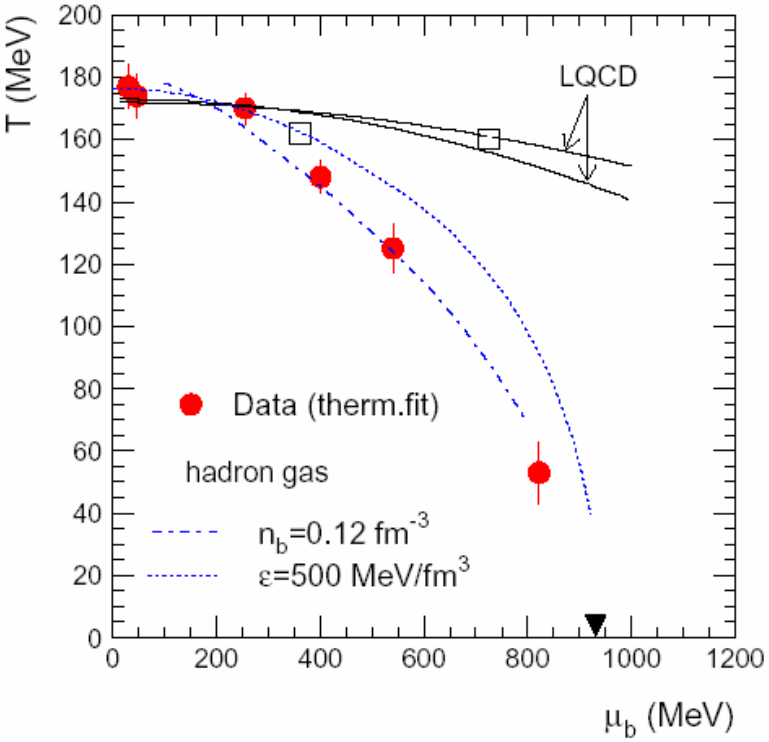


Hadronization
Chemical freeze-out
→ Stop inelastic scatterings
→ Fix particle abundances
Thermal freeze-out
→ Stop elastic processes

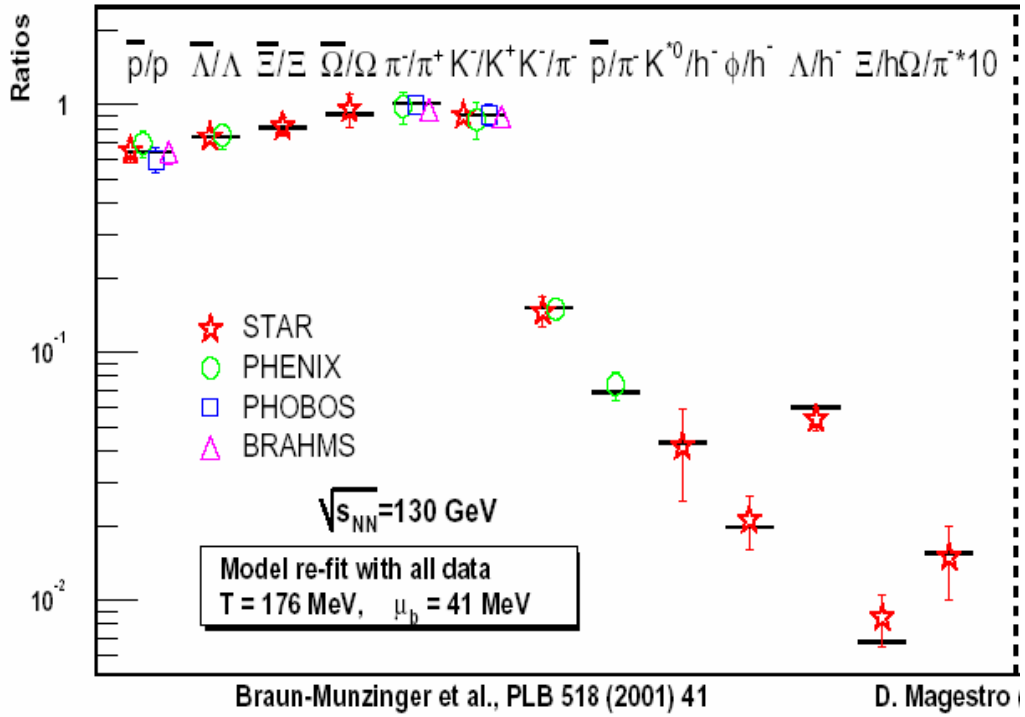
Chemical freeze-out

Thermal model : fit to particle ratios with **2 free parameters**: **T, μ_B**

Points on the phase diagram



Thermal model fit to RHIC data @ $\sqrt{s}$=130 GeV

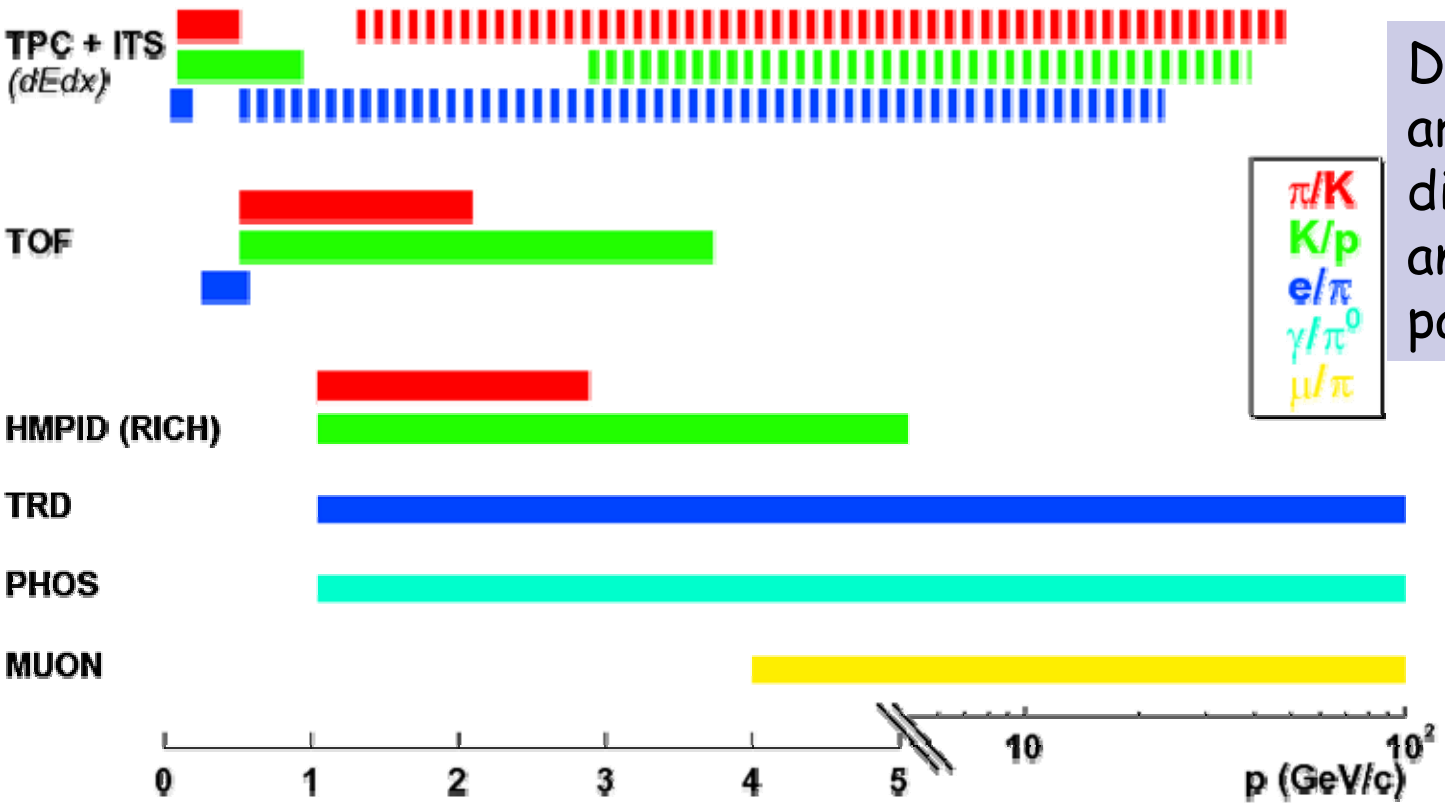


→ Need for:

1) efficient PID for p, K and π
2) Strange particle reconstruction

PID in ALICE

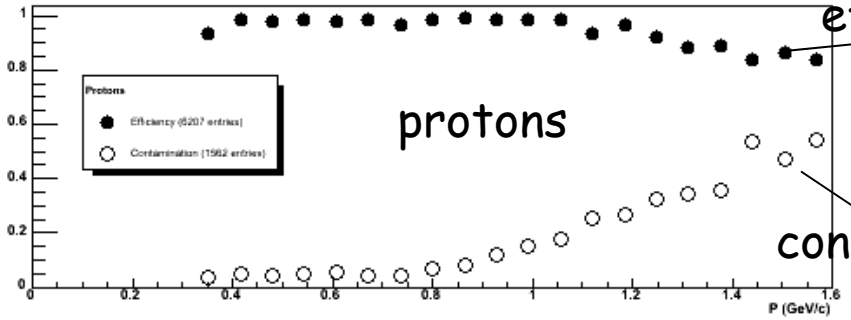
- Particle identification based on:
  - Momentum from track parameters
  - Velocity related information (dE/dx, time of flight, Čerenkov light...) specific for each detector

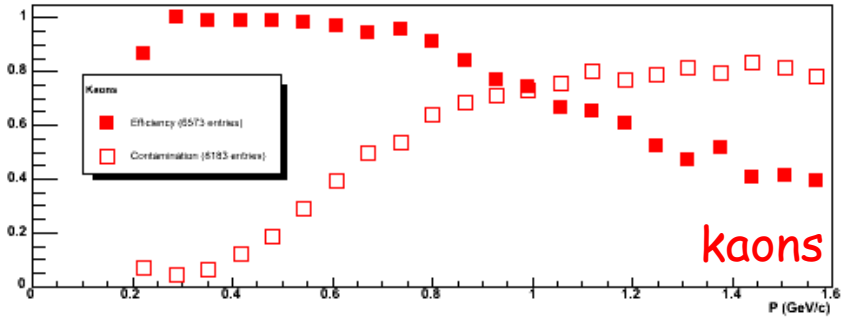


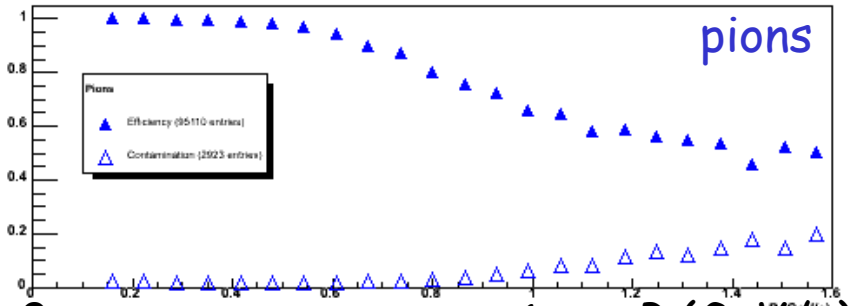
Different systems are efficient in different p ranges and for different particles

ITS contribution to PID

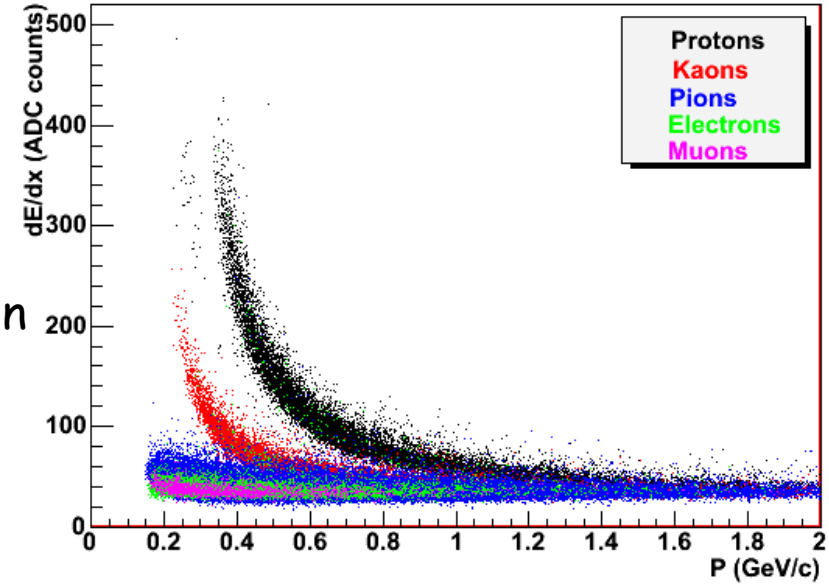
- Combined PID with the information from 4 layers (dE/dx from SDD and SSD layers)

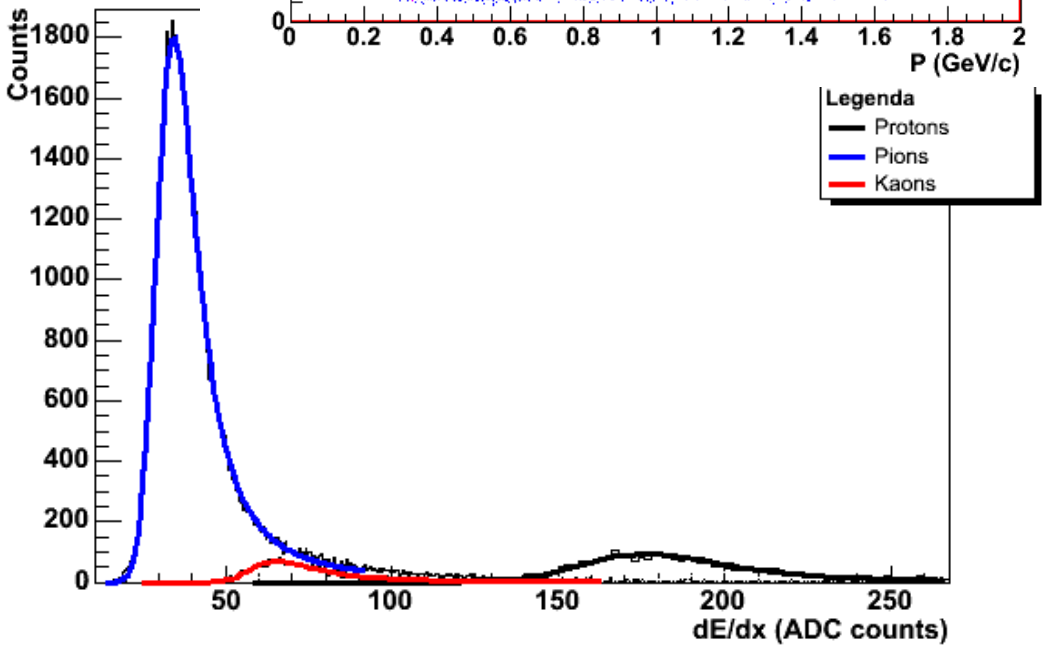






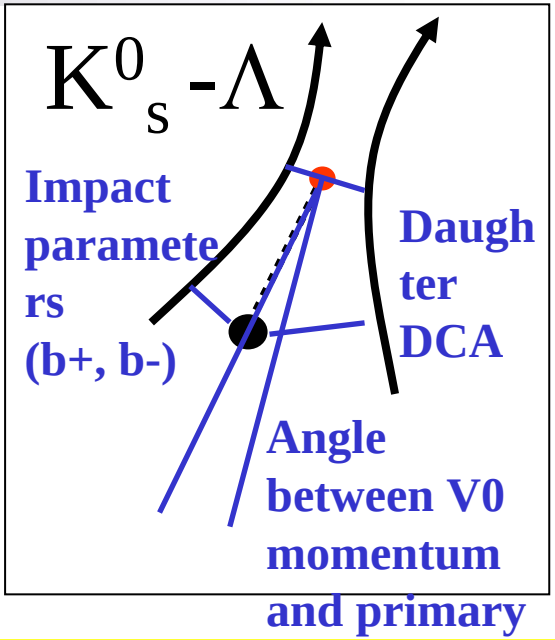
0 1 P (GeV/c)

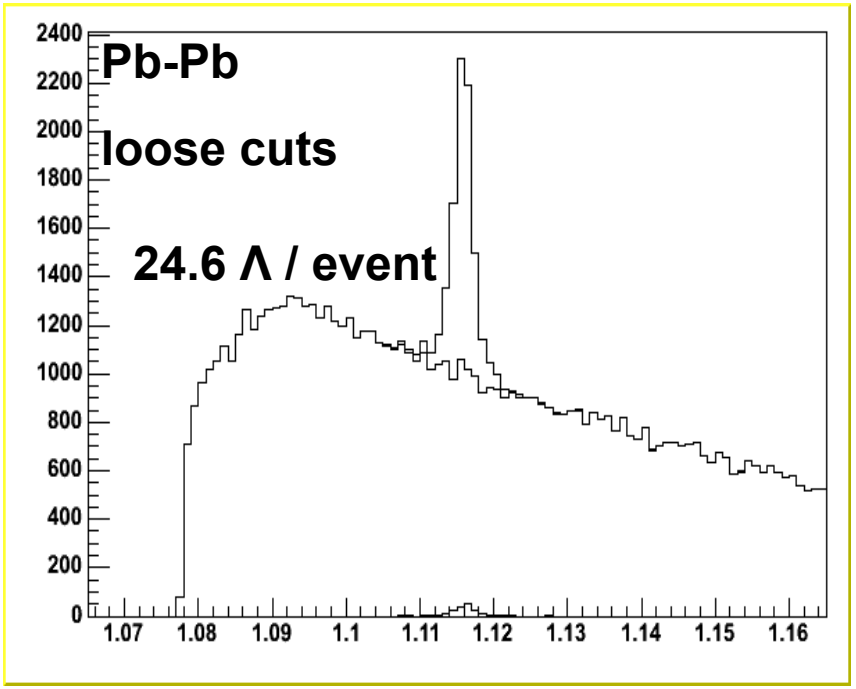


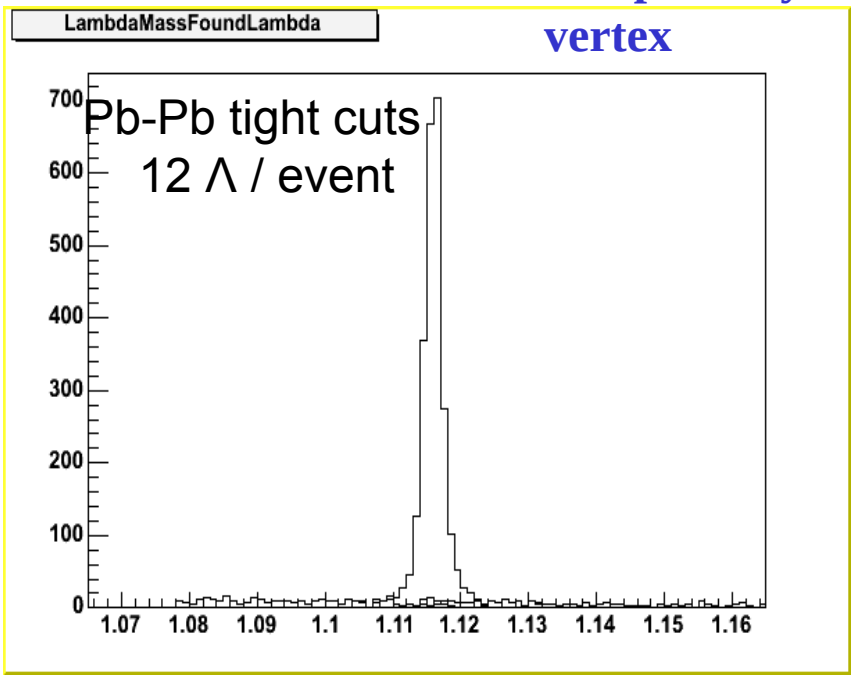


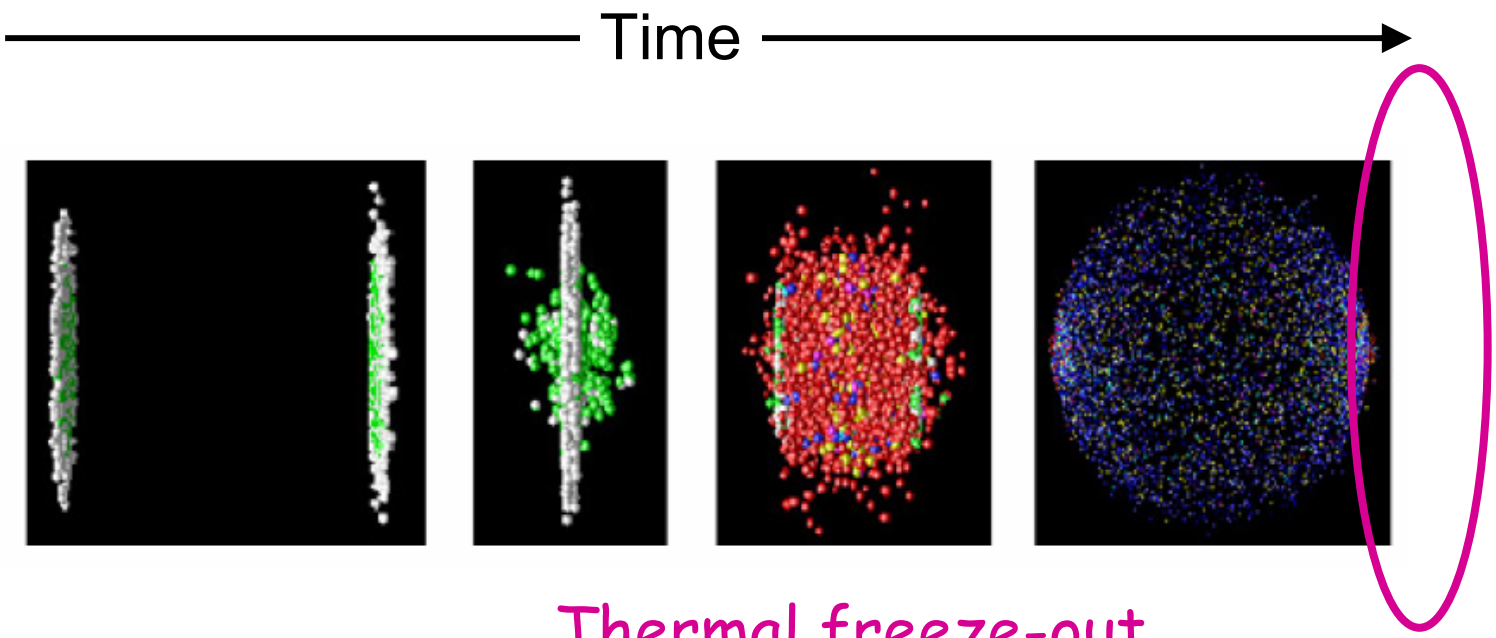
Λ reconstruction

- Need for:
  - Efficient PID for p,π
  - High precision track parameters close to the decay vertex

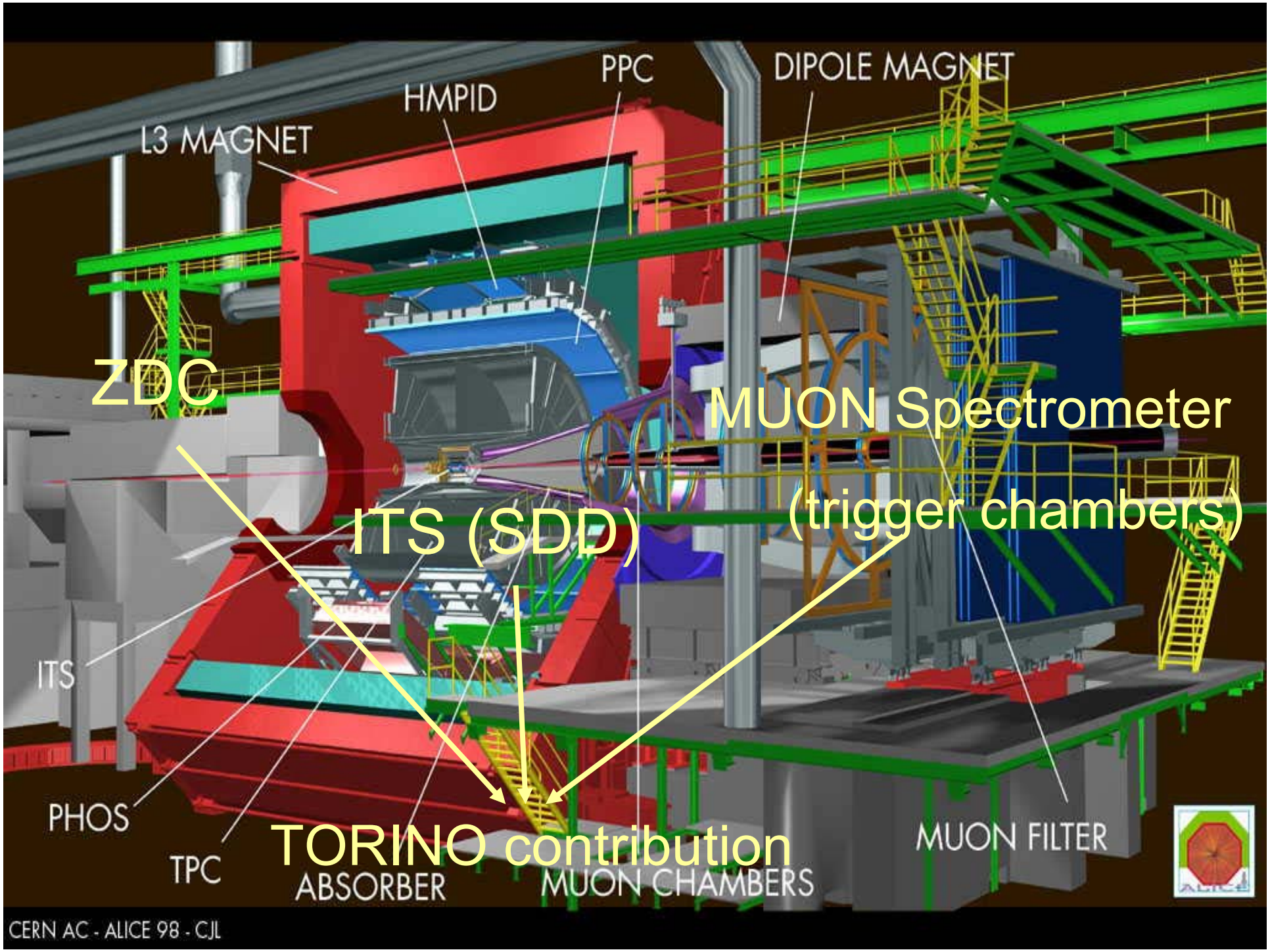








Thermal freeze-out
→ Stop elastic processes
→ Particles fly to ALICE detector


L3 MAGNET
HMPID
PPC
DIPOLE MAGNET
ZDC
MUON Spectrometer
(trigger chambers)
ITS (SDD)
ITS
PHOS
TPC
TORINO contribution
ABSORBER
MUON CHAMBERS
MUON FILTER
CERN AC - ALICE 98 - CJL

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