ALICE@LHC, status, physics prospects, and plans

- Introduction
- pp and AA collisions with ALICE at LHC
- the ALICE experiment
- results of commissioning
- some remarks about physics prospects

pbm, Extreme Matter Institute ***EMMI***, GSI
also at TU Darmstadt and FIAS, Frankfurt

LP09 conference, Hamburg, Aug. 18, 2009

TECHNISCHE UNIVERSITÄT DARMSTADT

General remarks concerning nuclear collisions at LHC

at 30 times increased cm energy
compared to RHIC
the LHC is
the ultimate machine for quark matter studies
with hard probes
and at ultra-high multiplicities

1 Pb-Pb collision at LHC energy
corresponds to 0.18 mJ--macroscopic!

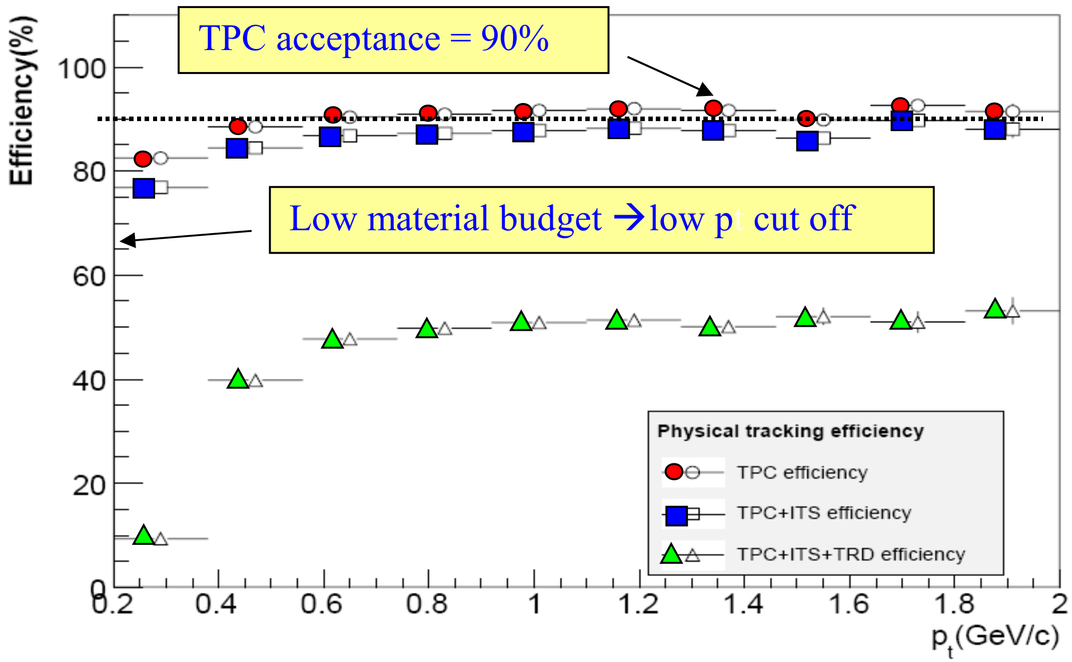
ALICE specific design considerations

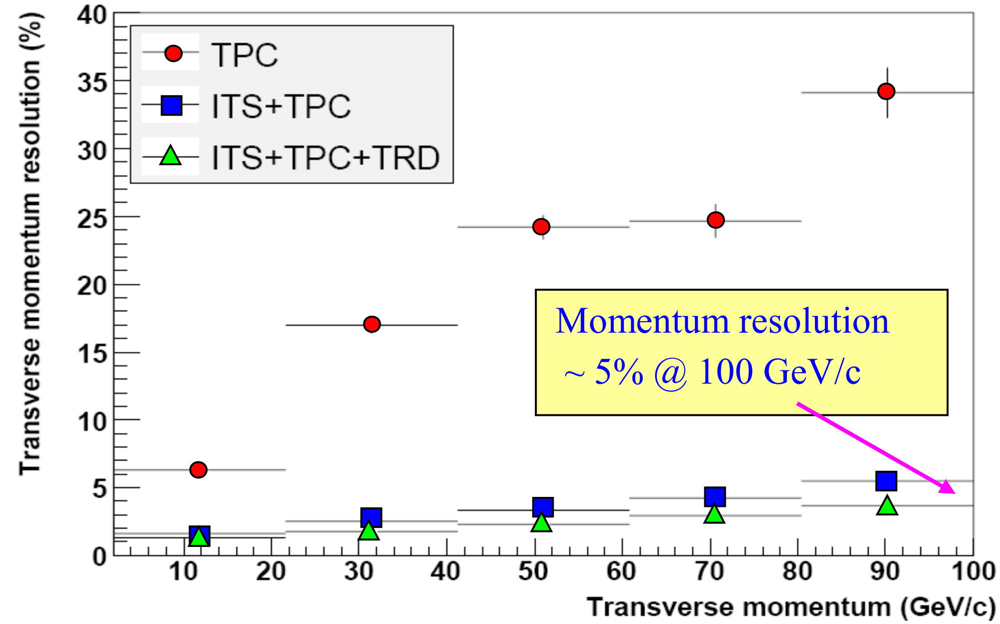
- momentum coverage $0.1 < p <$ a few hundred GeV
- excellent particle identification over a large part of this range in p
- specialized detectors for electrons, muons, and photons
- efficient setup for charm and beauty measurements
- simultaneous characterization of bulk matter (soft) and jets/high pt particles (hard)
- very large data acquisition bandwidth - 1 GByte/s
- efficient on-line tracking even for central Pb-Pb collisions (> 10000 tracks per event)

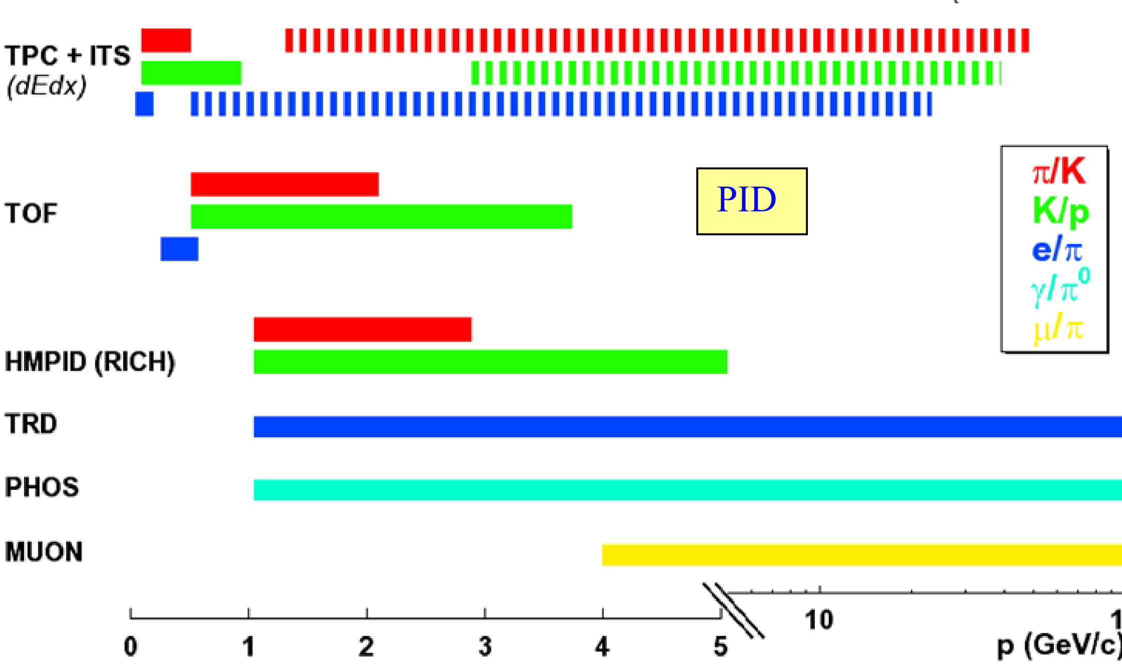
ALICE detector key components

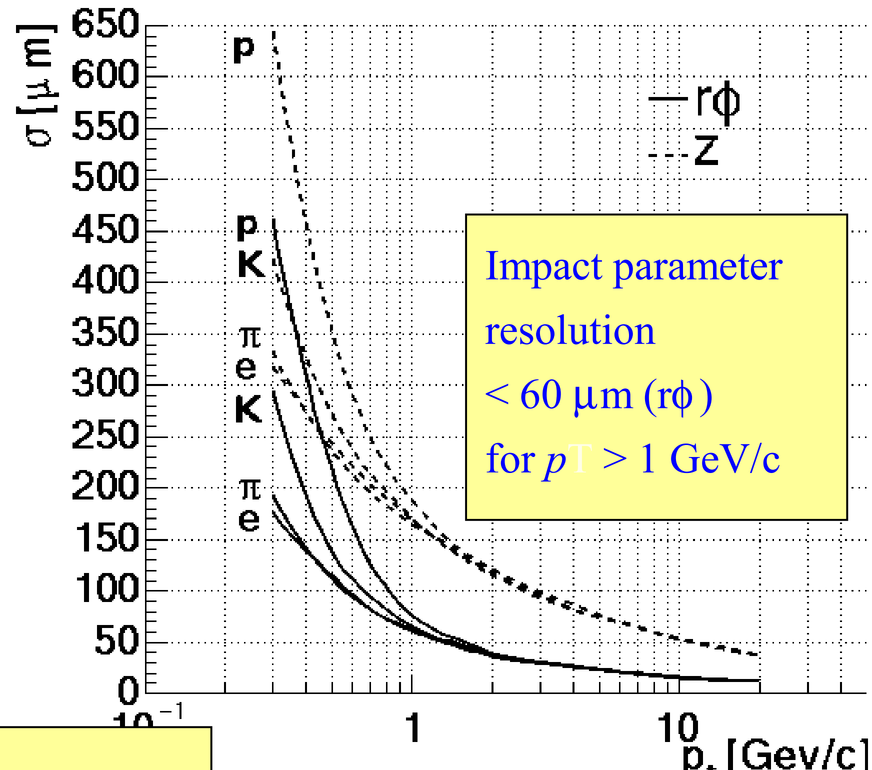
- central tracking and particle ID detector: a large volume TPC
- a 6 layer Si vertex detector for charm and beauty measurements
- a barrel transition radiation detector/tracker (TRD) for electron ID and triggering
- a barrel time-of-flight detector for particle ID
- crystal and sampling calorimeters for electron/photon measurements
- a forward muon detector
- a high level trigger system

ALICE Design Performance









+ decay topologies ((K^0, K^+, K^-, Λ, ϕ, D) K and Λ beyond 10 GeV/c

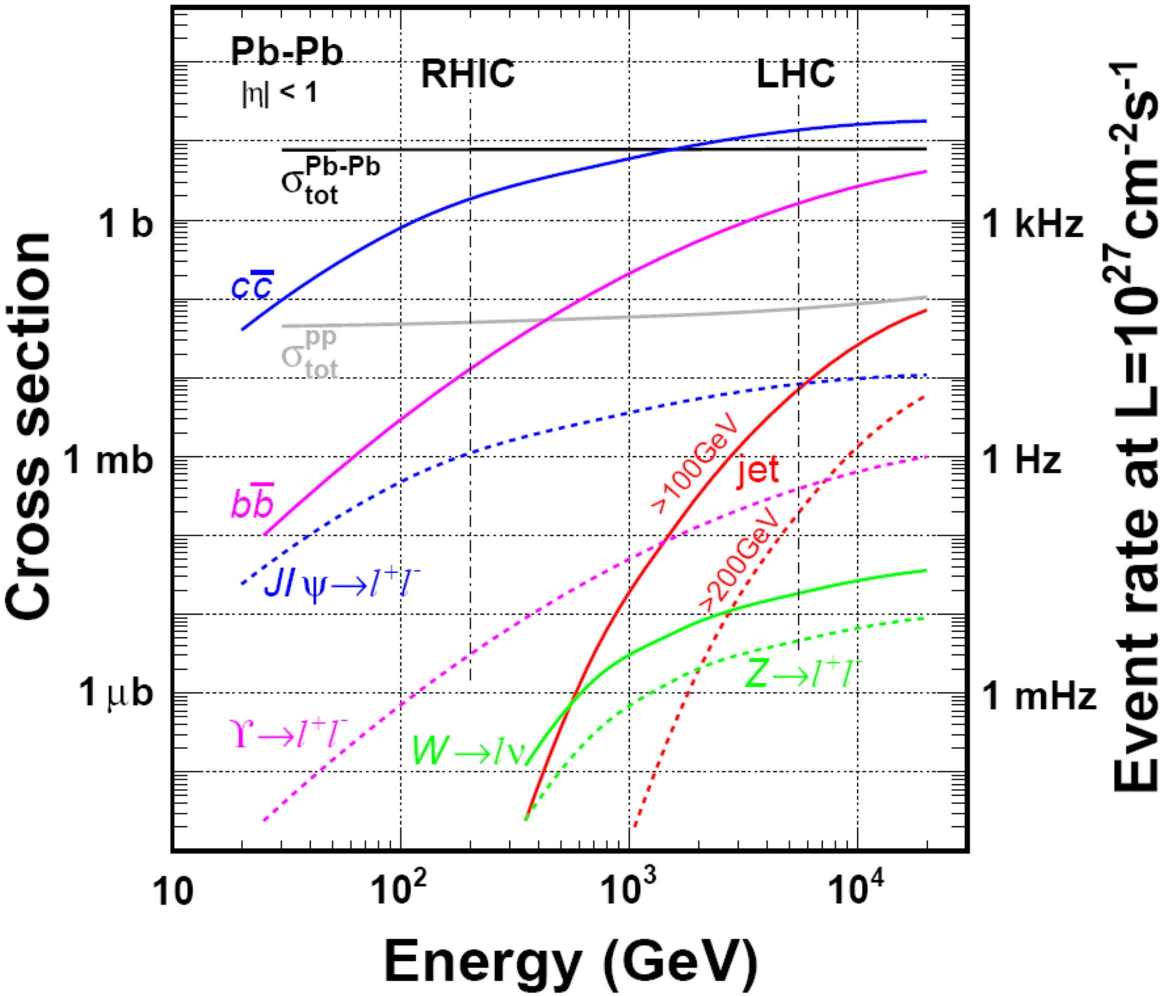
characterizing quark matter at LHC

equation of state
number of degrees of freedom
transport coefficients (viscosity etc)
velocity of sound
parton energy loss and opacity
susceptibilities
deconfinement

studying the condensed matter phases of QCD

and also look for the unexpected

LHC: Cross-sections and Rates



Cross-sections of interesting probes expected to increase by factors of

~ 10 (cc) to

~ 10^2 (bb) to

> 10^5 (very high p_T jets)

relative to RHIC

a new era for heavy quark production studies

up to 100 charm quark pairs in one Pb-Pb collision

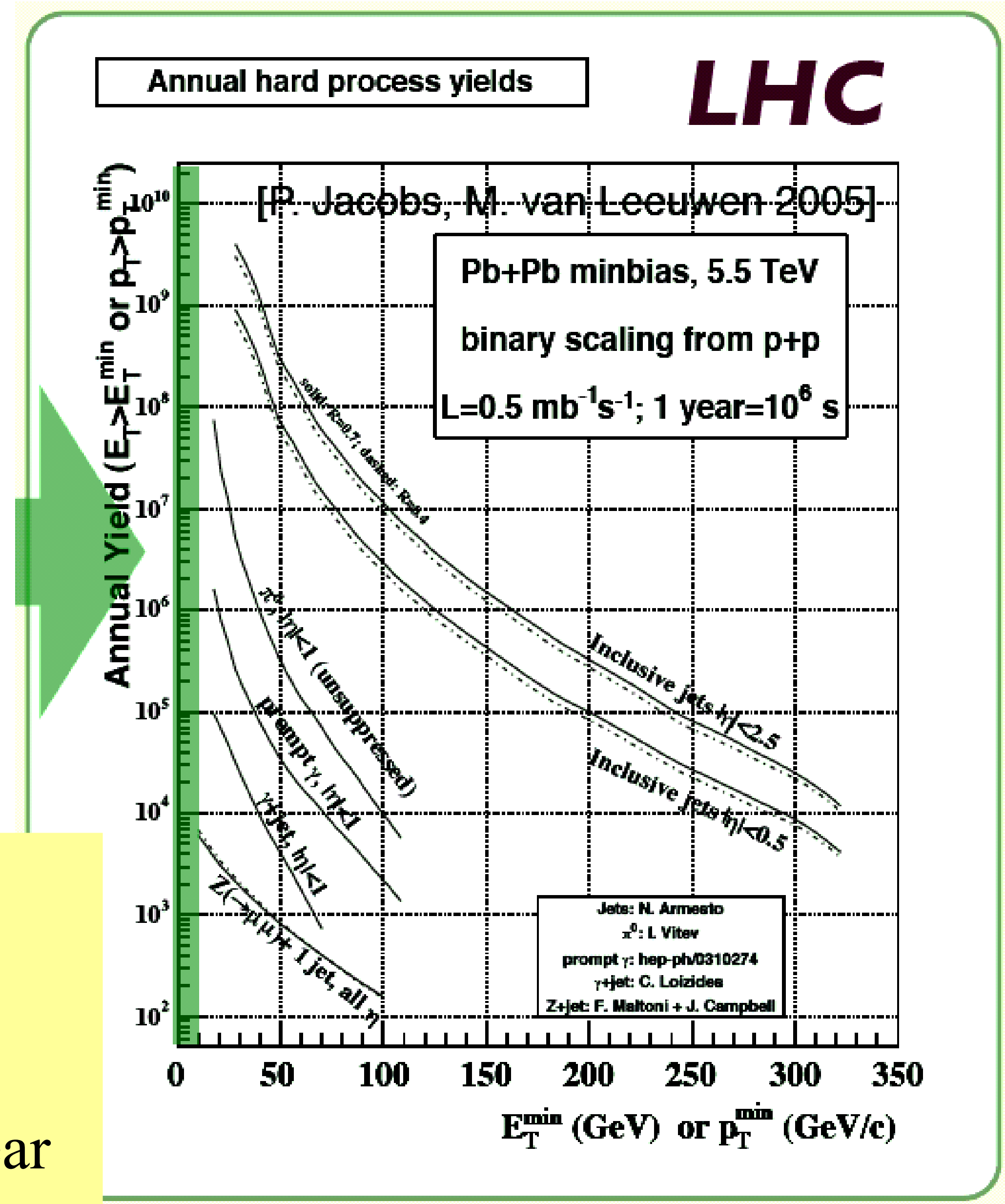
studies of c- and b-quark tagged jets

energy loss of heavy quarks

charmonium and bottomonium studies

the ultimate hard probes machine

covered in detail at RHIC



> 10^4 jets with E_T > 150 GeV in one ALICE year

ALICE physics with proton-proton collisions

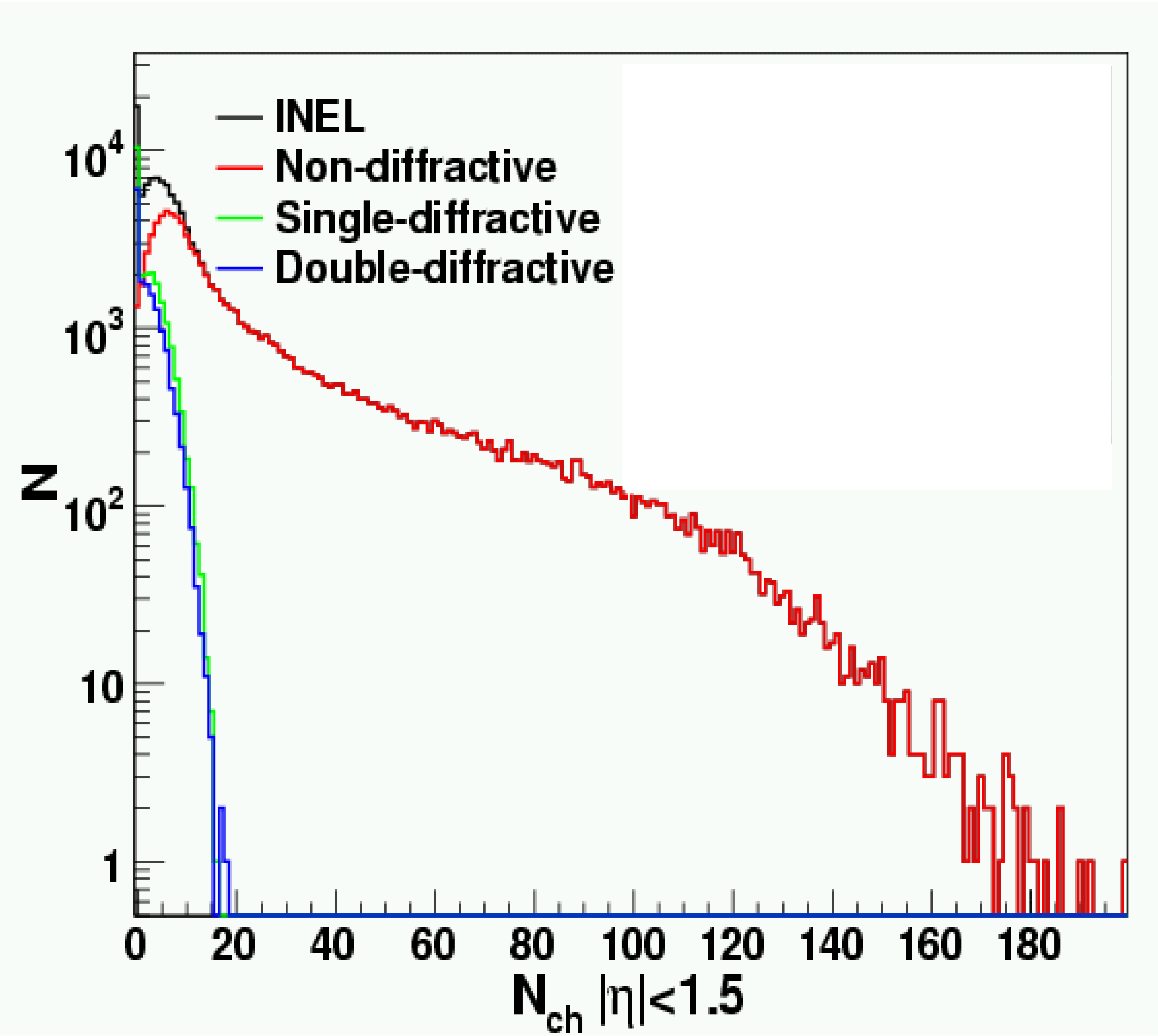
- **start-up**
  - some collisions at 900 GeV
    $\rightarrow$connect to existing systematics
- **pp first high energy run**
  - **ideal beam conditions for ALICE at low luminosity**
  - **collect about 10^9 events in a few months of running**
  - **operate ALICE central barrel at rates up to 1 kHz**

- ALICE detector performs very well in pp
  - very low-momentum cutoff (<100 MeV/c) x_T-regime down to 4×10^{-6}
  - p_t-reach up to 100 GeV/c
  - excellent particle identification
  - efficient minimum-bias trigger
  - excellent vertexing capabilities

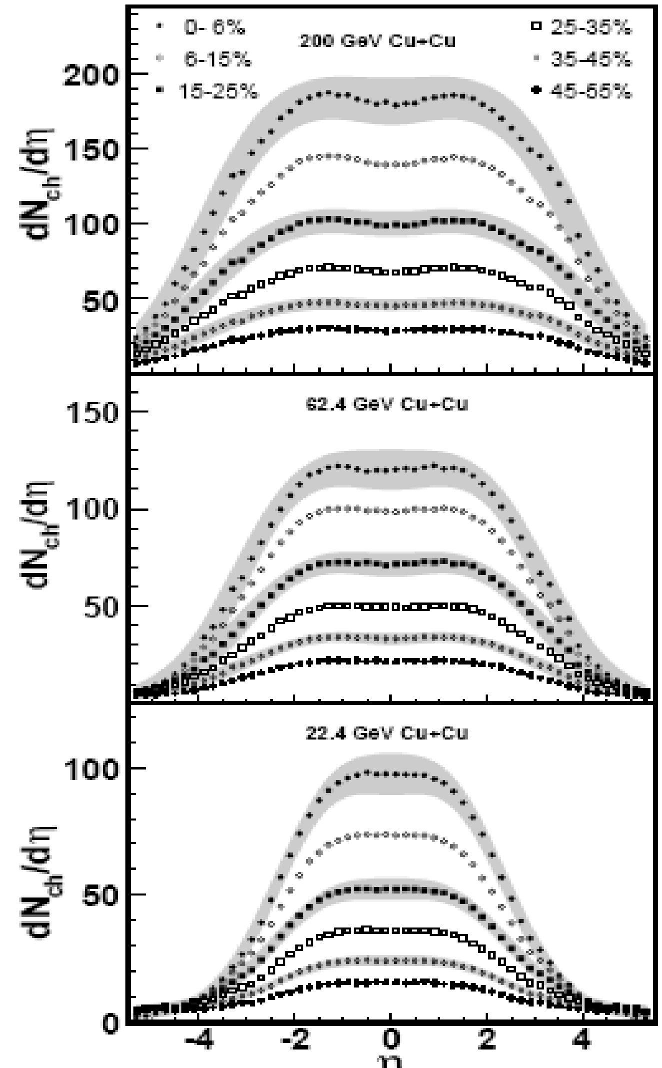
- first physics in ALICE will be pp
  - provides important reference data for heavy-ion programme
  - minimum bias running
- unique pp physics in ALICE e.g.
  - physics at high multiplicities, reachable thanks to the multiplicity trigger from the pixel detectors (7-10 times the mean multiplicity of minimum bias collisions)
    - Same set of measurements and themes of Heavy-Ion collisions (strangeness production, jet-quenching, flow, …)
  - baryon transport
  - measurement of charm and beauty cross sections down to very low transverse momentum (major input to pp QCD physics) both open charm mesons and quarkonia
    - essential is the acceptance in the low-transverse momentum region

ALICE has unique physics potential with pp collisions

multiplicity distribution of pp collisions at LHC energy



high multiplicity
pp at LHC
is similar to
Cu-Cu at RHIC



Phobos coll., PRL 102 (2009) 142301

Nominal LHC Running Conditions for ALICE

Collision system	$\sqrt{s_{NN}}$(TeV)	L_0 ($cm^{-2}s^{-1}$)	Run time (s/year)	σ_{geom} (b)
p + p	14.0	10^{34} *	10^7	0.07
Pb + Pb	5.5	10^{27}	10^6 **	7.7
p + Pb	8.8	10^{29}	10^6	1.9
Ar + Ar	6.3	10^{29}	10^6	2.7

***L_{max} (ALICE) = $10^{30} cm^{-2}s^{-1}$**

**** L_{int} (ALICE) ~ 0.5 nb^{-1}/year**

Actual 2009/2010 energies:

pp collisions: $\sqrt{s_{NN}}$ = 7 - 10 TeV

AA collisions: $\sqrt{s_{NN}}$ =2.8 – 3.9 TeV

initial running at 3.5 + 3.5 TeV

Who is ALICE

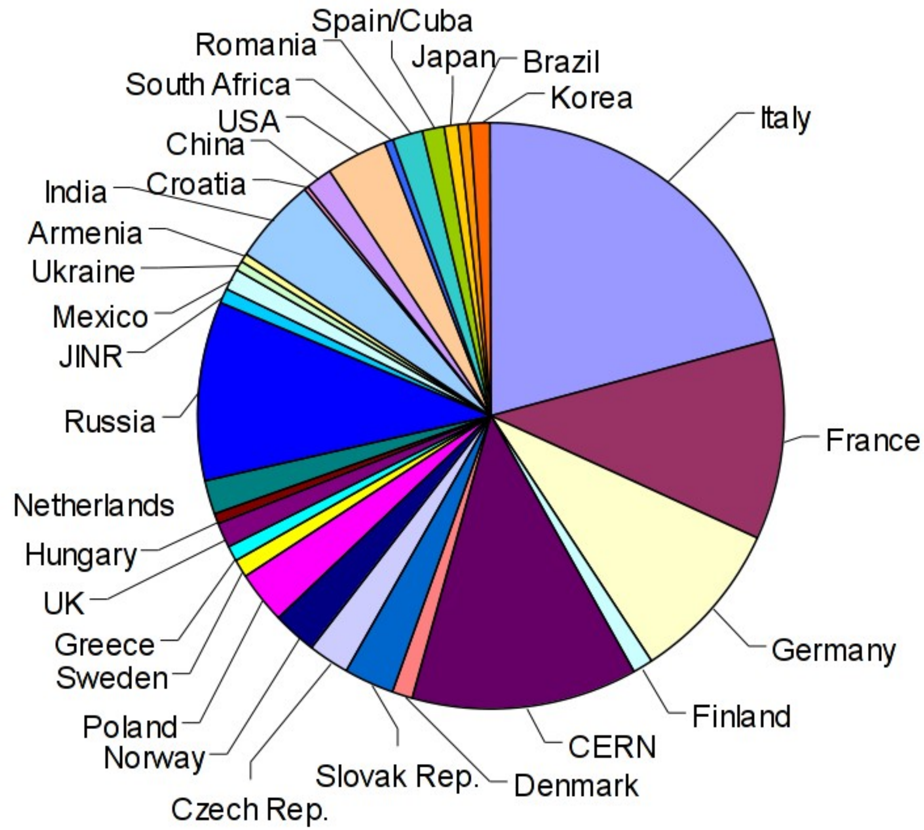
~ 1000 Members from both NP and HEP communities

~30 Countries

~100 Institutes

~ 150 MCHF capital cost

(+ 'free' magnet)



History

1990-1996: Design

1992-2002: R&D

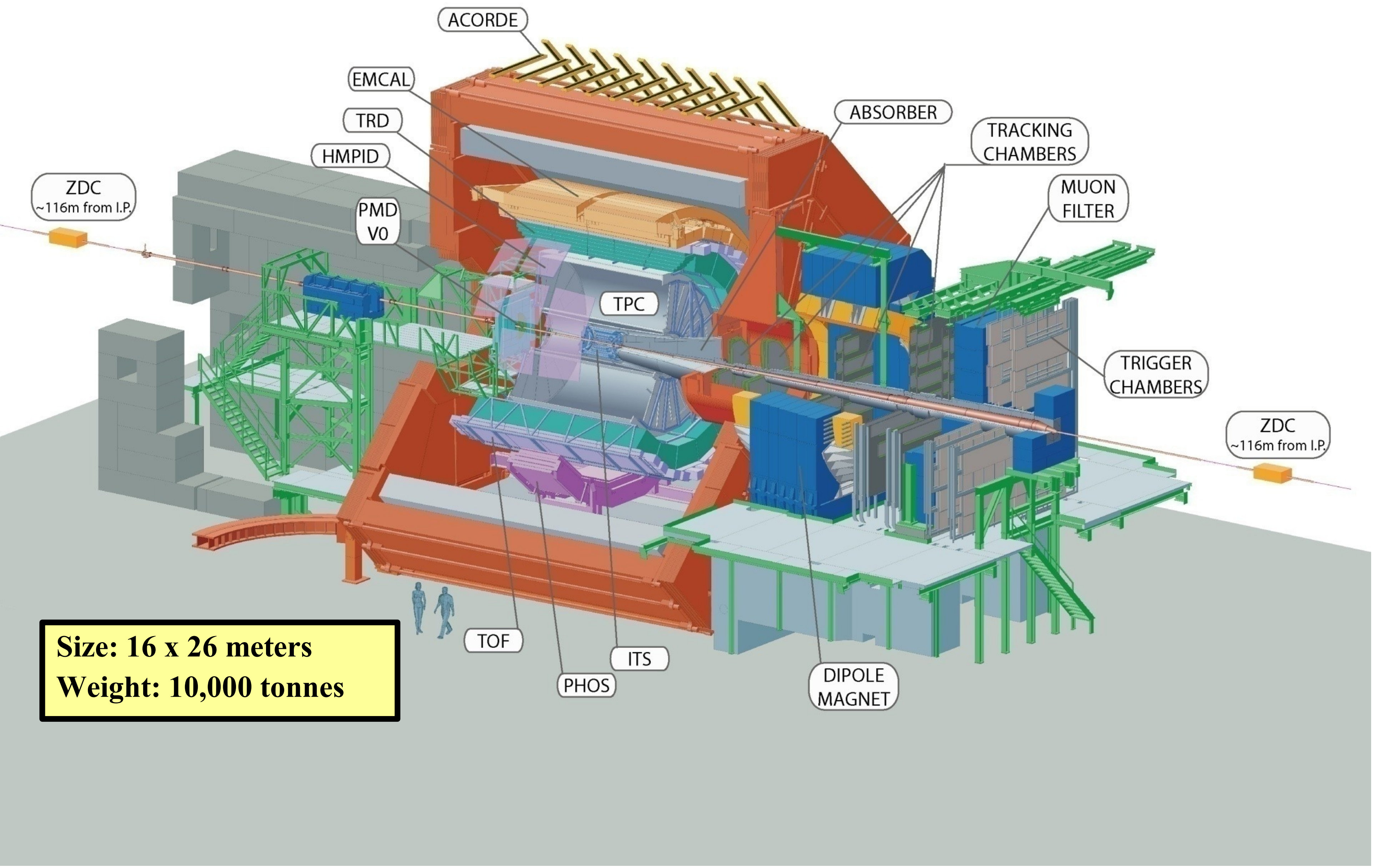
2000-2010: Construction

2002-2007: Installation

2008 -> : Commissioning

3 TP addenda along the way: 1996 : muon spectrometer 1999 : TRD 2006 : EMCAL

ALICE: A Large Ion Collider Experiment at CERN-LHC



Size: 16 x 26 meters
Weight: 10,000 tonnes

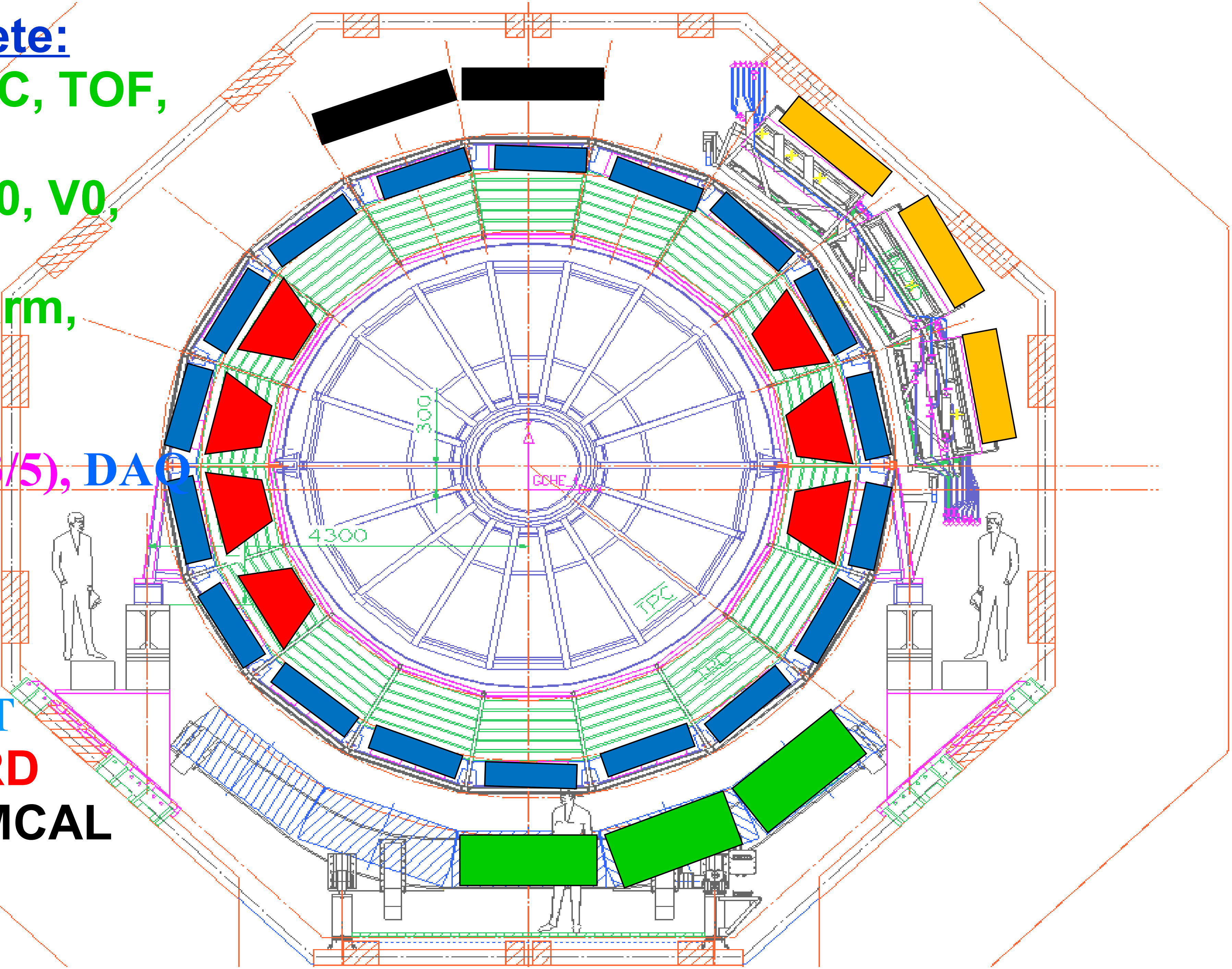
ALICE 2009

Complete:

ITS, TPC, TOF,
HMPID,
FMD, T0, V0,
ZDC,
Muon arm,
Acorde
PMD ,
PHOS(3/5), DAQ

Partial:

2/3 HLT
7/18 TRD
4/12 EMCAL

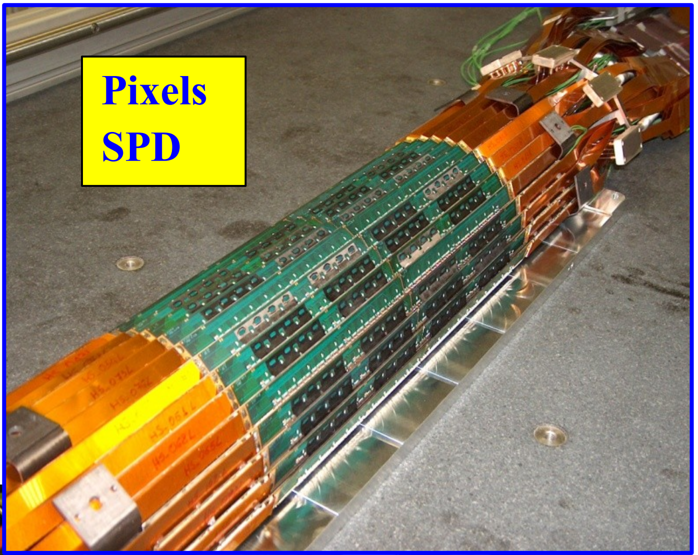


Inner Silicon Tracker

Inner Tracking System

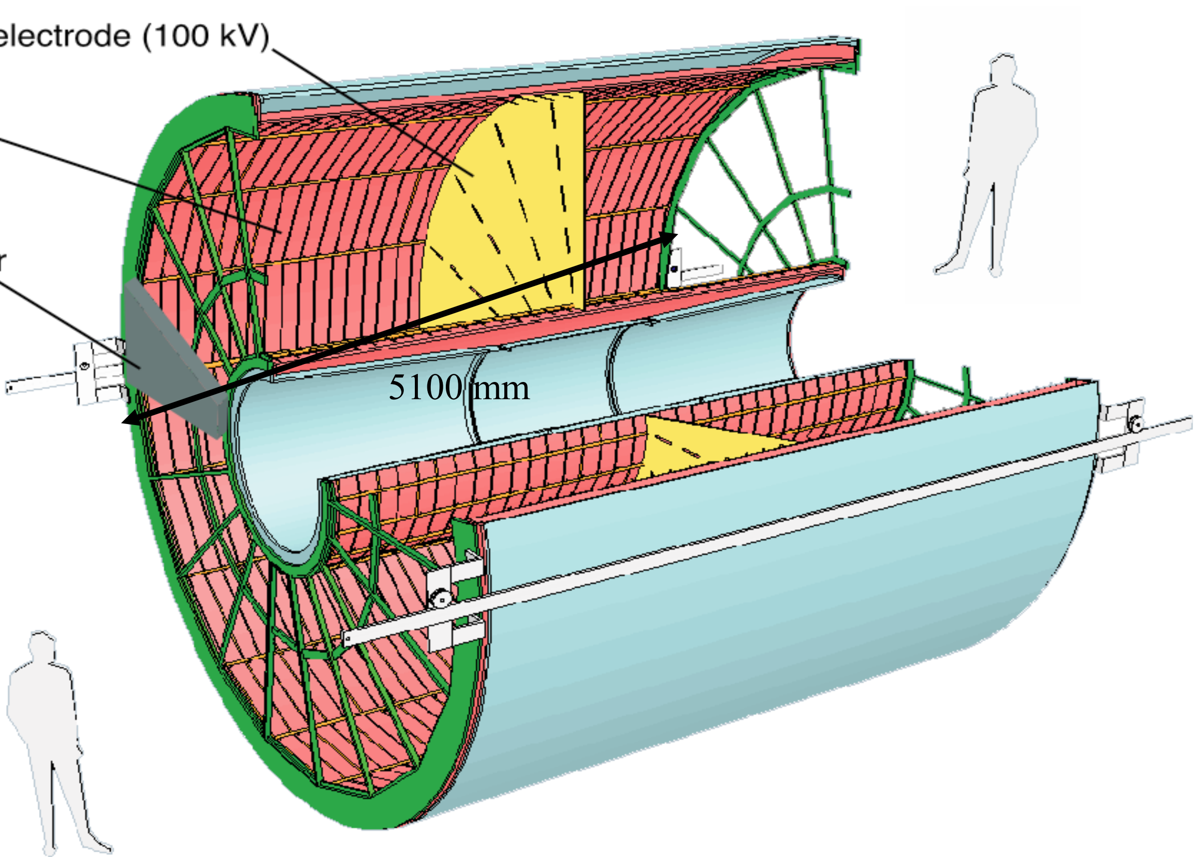
~ 10 m² Si detectors, 6 layers

Pixels, Drift, double sided Strips



The ALICE Time Projection Chamber (TPC)

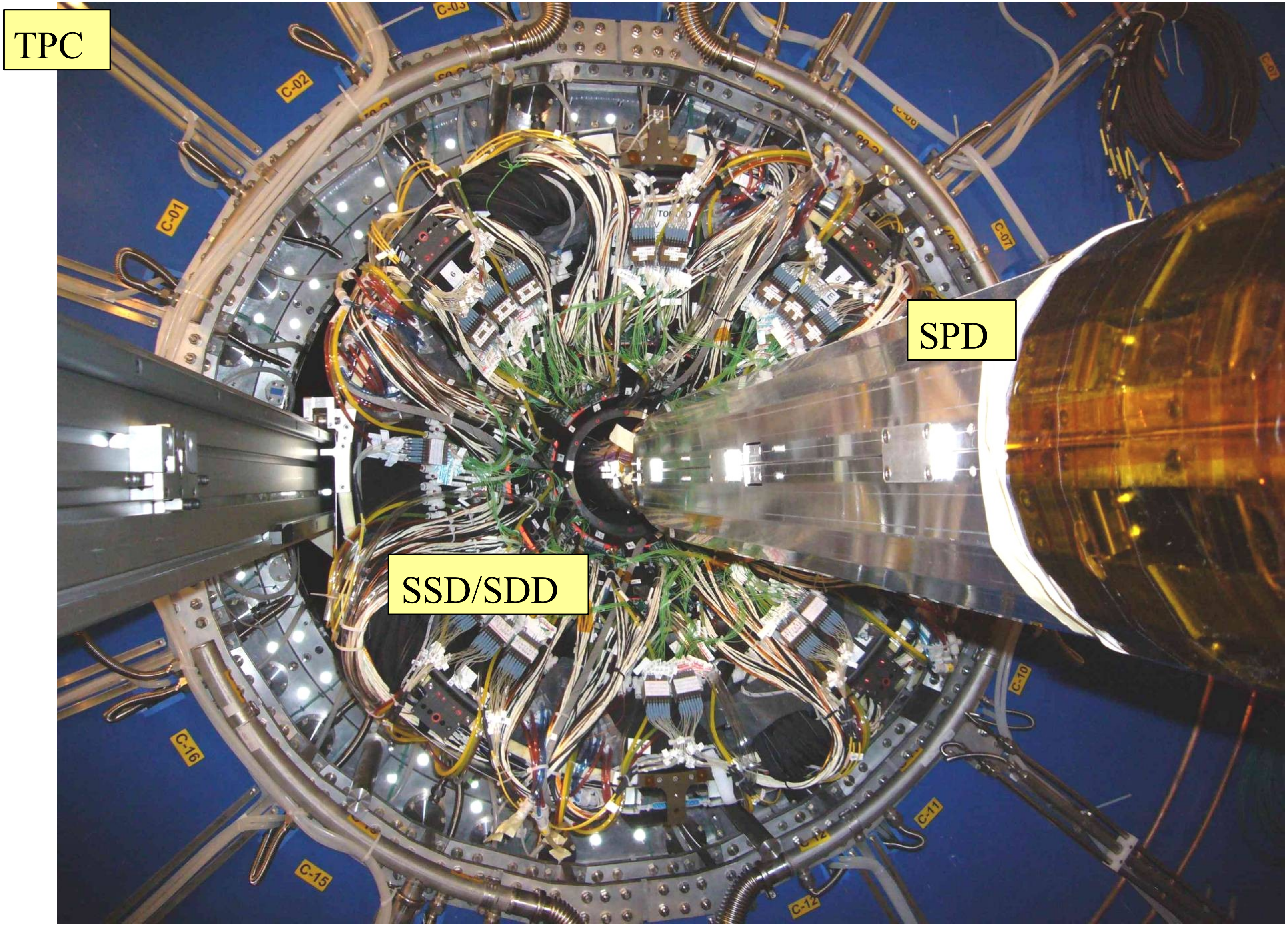
TPC on its way into the ALICE cave



Largest TPC ever built

Radius: 845 - 2466 mm
Drift length: 2 x 2500 mm
Drift time: 92 μs
Drift gas $Ne\text{-}CO_2\text{-}N_2$
Gas volume: 95 m^3
557568 readout pads
Material: (η=0) 3% X_0

Insertion of the Inner Tracking Detector into the TPC



The ALICE Transition Radiation Detector (TRD)

Purpose:

Electron-ID & trigger

Quarkonia $\rightarrow e^+e^-$
Heavy flavour

Some numbers:

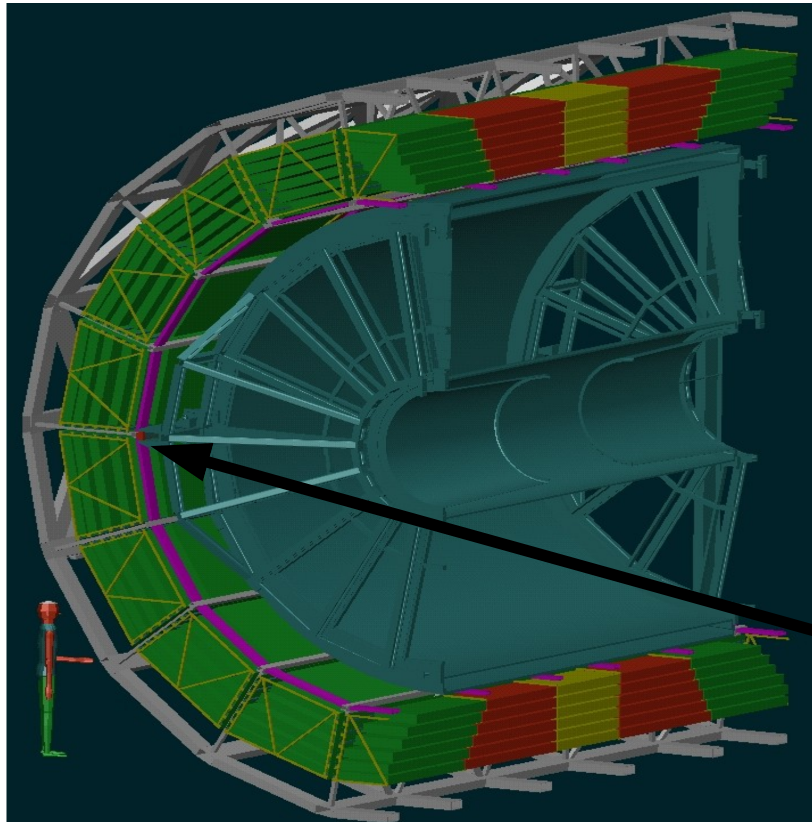
540 chambers

Total area: 736 m^2
(3 tennis courts)

Gas volume: 27.2 m^3

Resolution
($r\varphi$) 400 μm

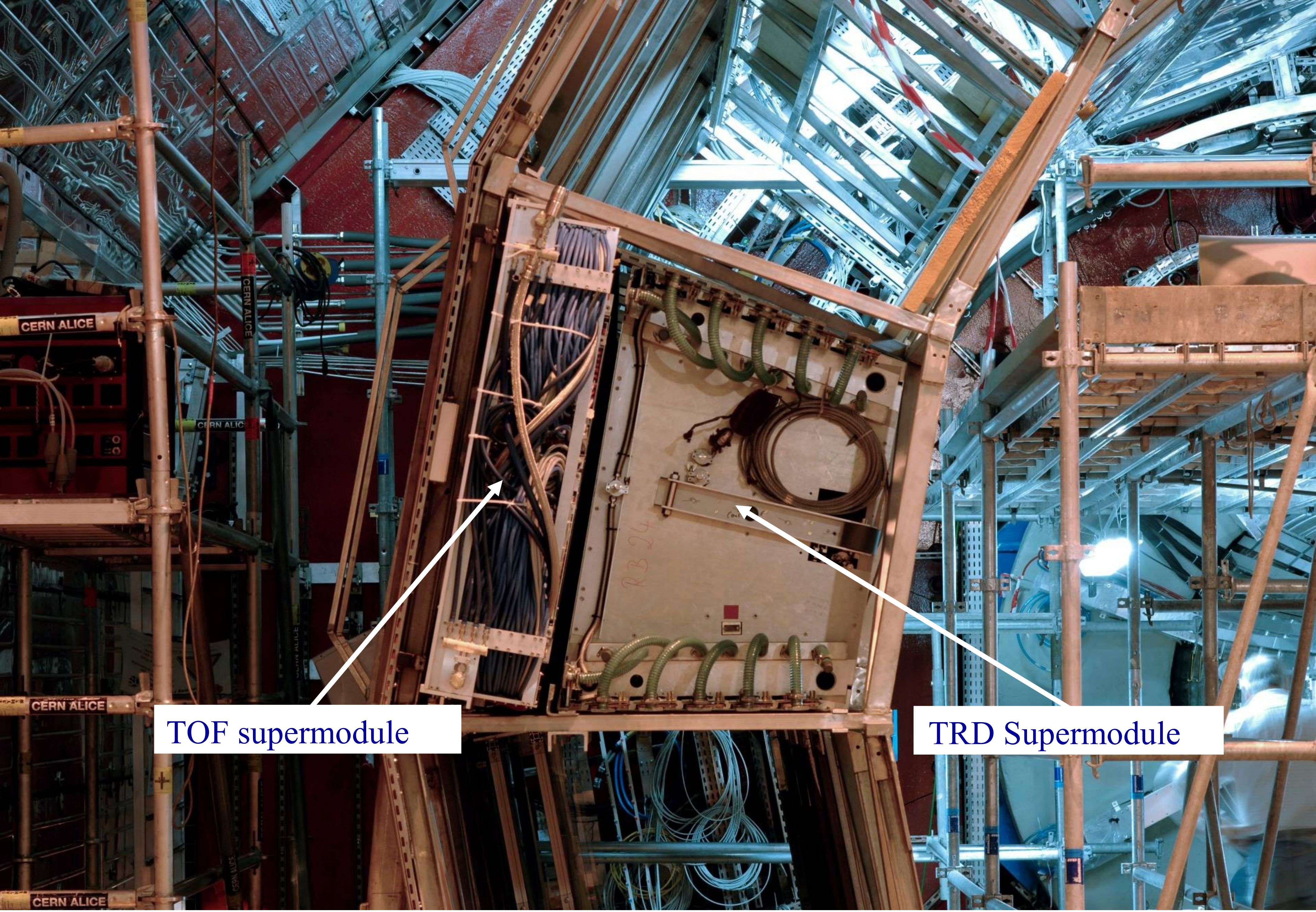
Number of read out channels: 1.2×10^6



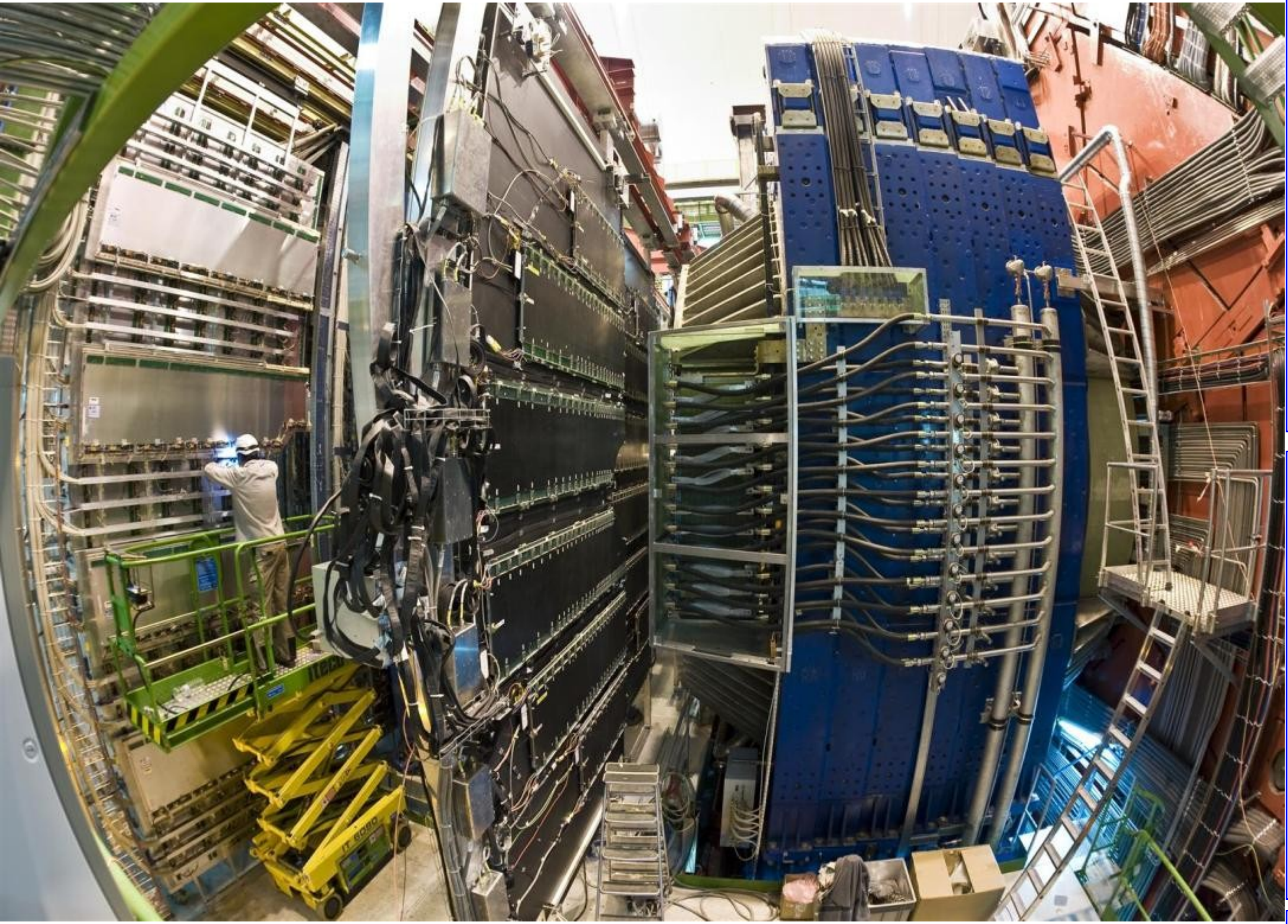
275k custom designed CPUs process 65 Mbytes of raw data for tracking trigger in 6 micro-seconds

lay-out

1 layer of TRD chambers


TOF supermodule
TRD Supermodule
CERN ALICE

ALICE Muon Spectrometer



Tracking system:

Cathode-Pad chambers resolution < 100 um

100 m2, 5 stations

1.1 M channels

St. 1,2 Quadrants

St. 3,4,5 slats

Geometry Monitoring System (GMS)

Trigger system:

Single-gap RPCs

150 m2, 2 stations

20 K FEE chennels

Trigger electronics :

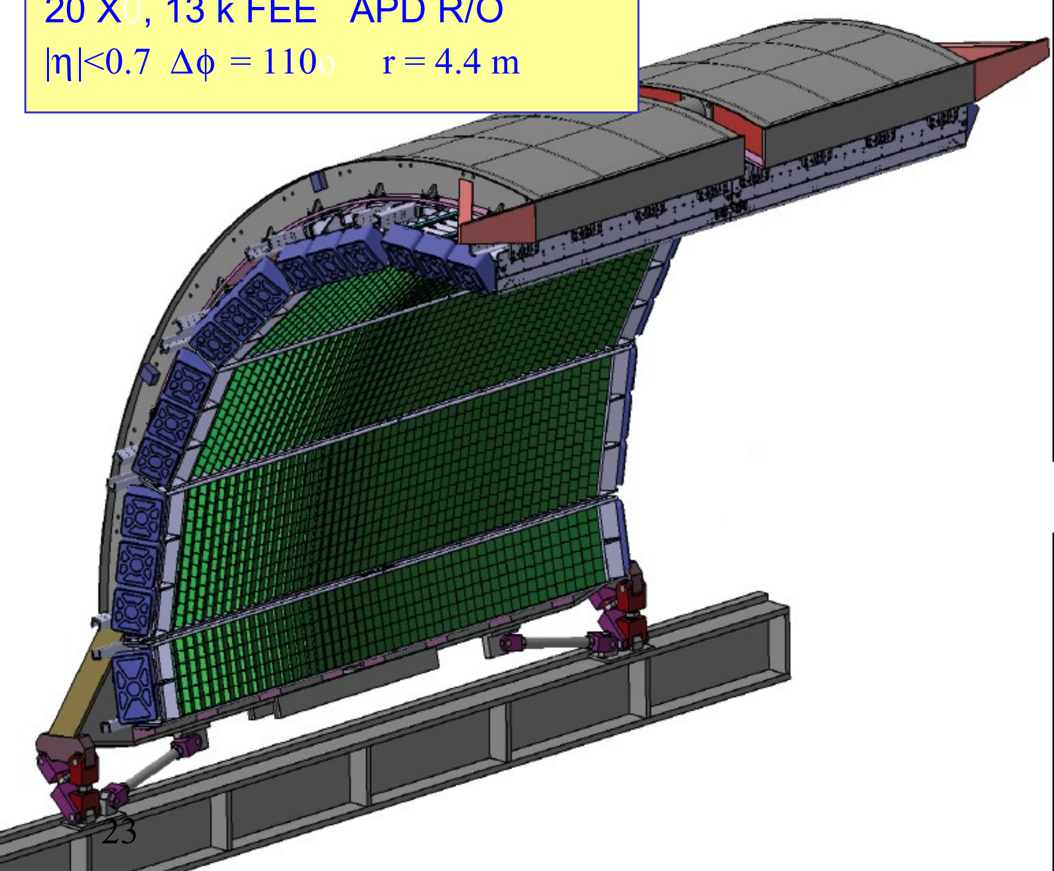
- Local
- Regional
- Global

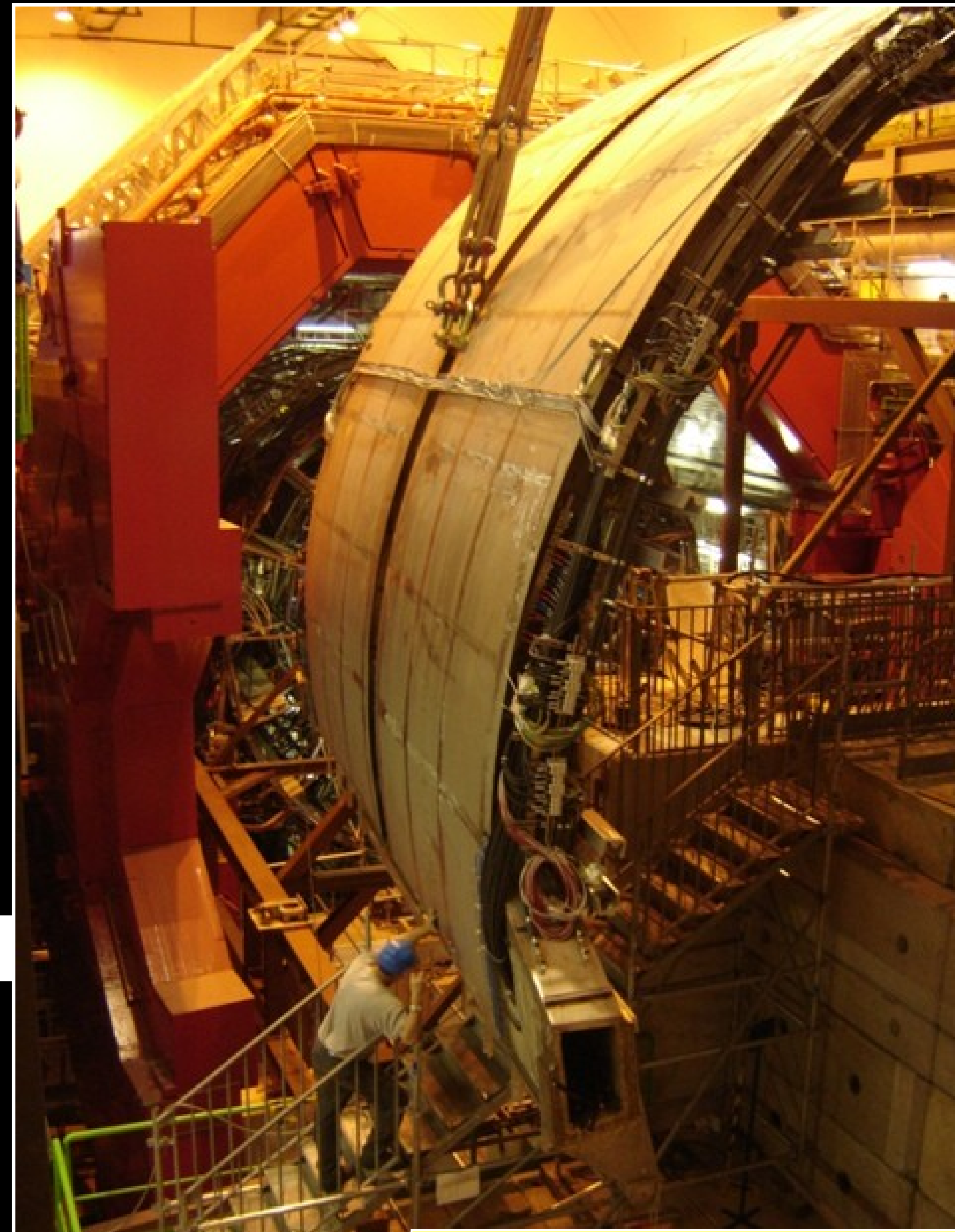
HLT – high level trigger

Electromagnetic Jet Calorimeter

- construction start April 2008
- approved & funded Dec 2008
- US, Italy, France, Finland
- approx. 20% installed
- complete in 2010

44 m^2 Pb-Scint sampling calo,
20 X_0, 13 k FEE APD R/O
$|\eta|<0.7$ $\Delta\phi = 110^o$ $r = 4.4$ m





Nov 2007: EMCAL support

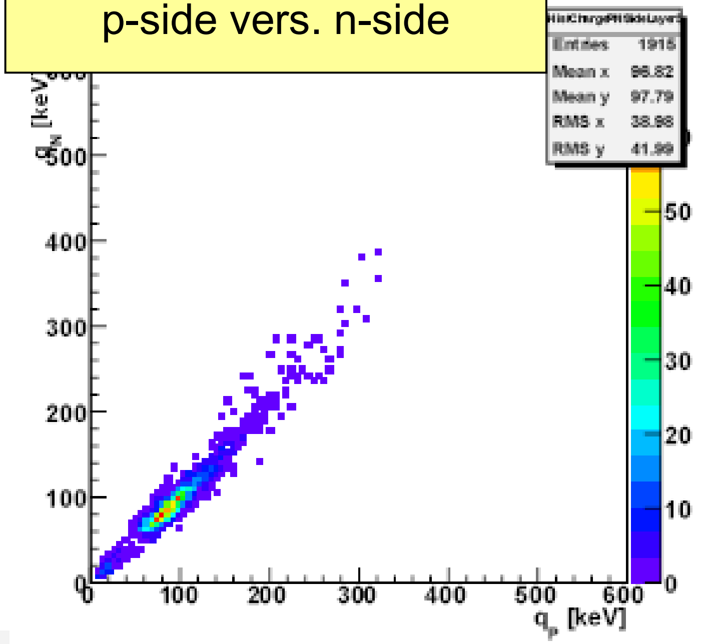
Selected results from ALICE detector commissioning in 2008/2009

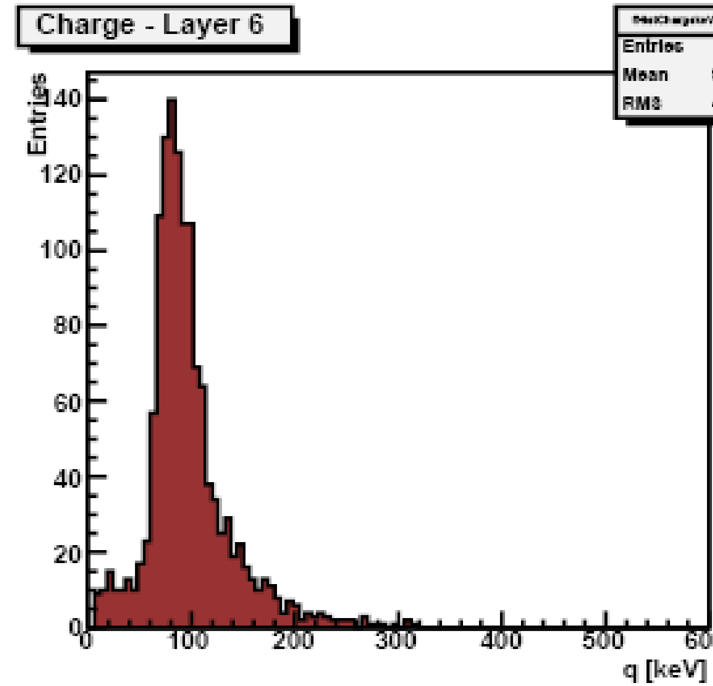
- calibration and alignment of the Si vertex tracker (ITS)
- overall commissioning and calibration of the TPC
- tracking and pion rejection in the TRD
- TOF status and resolution

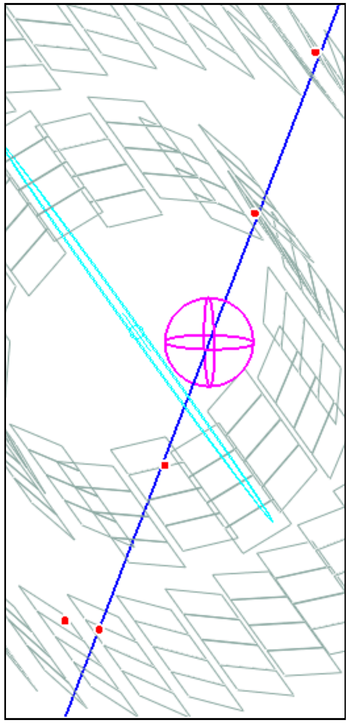
general remarks: all detectors perform at or very close to specifications given in the Technical Design Reports

ITS: detector commissioning results

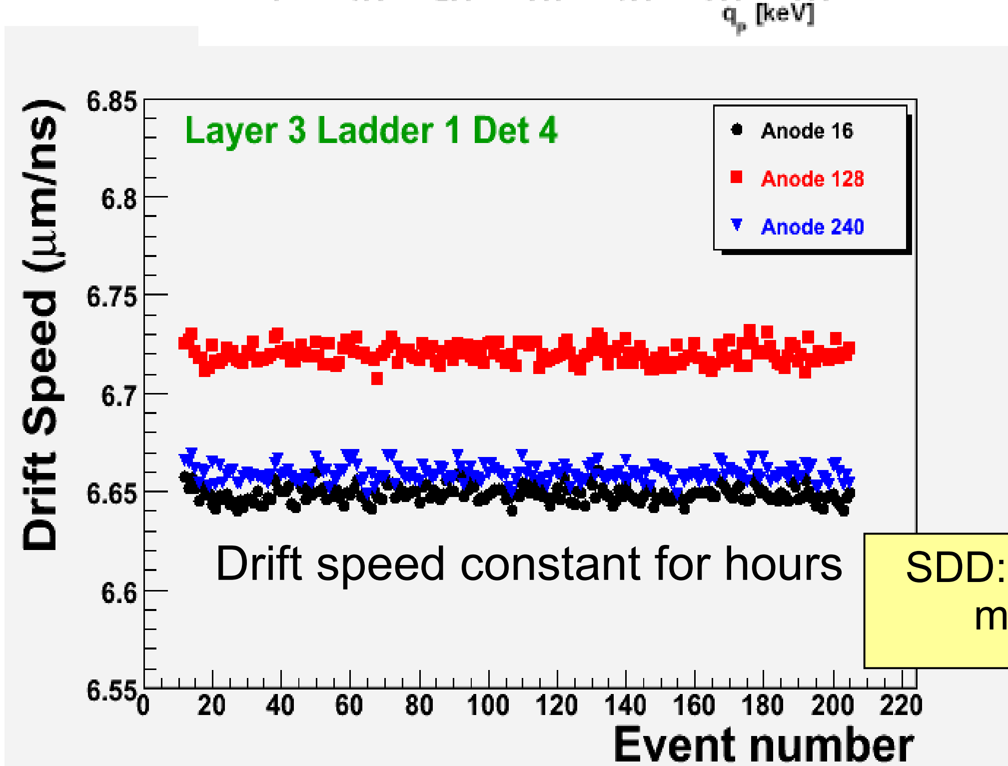
SSD: charge correlation
p-side vers. n-side





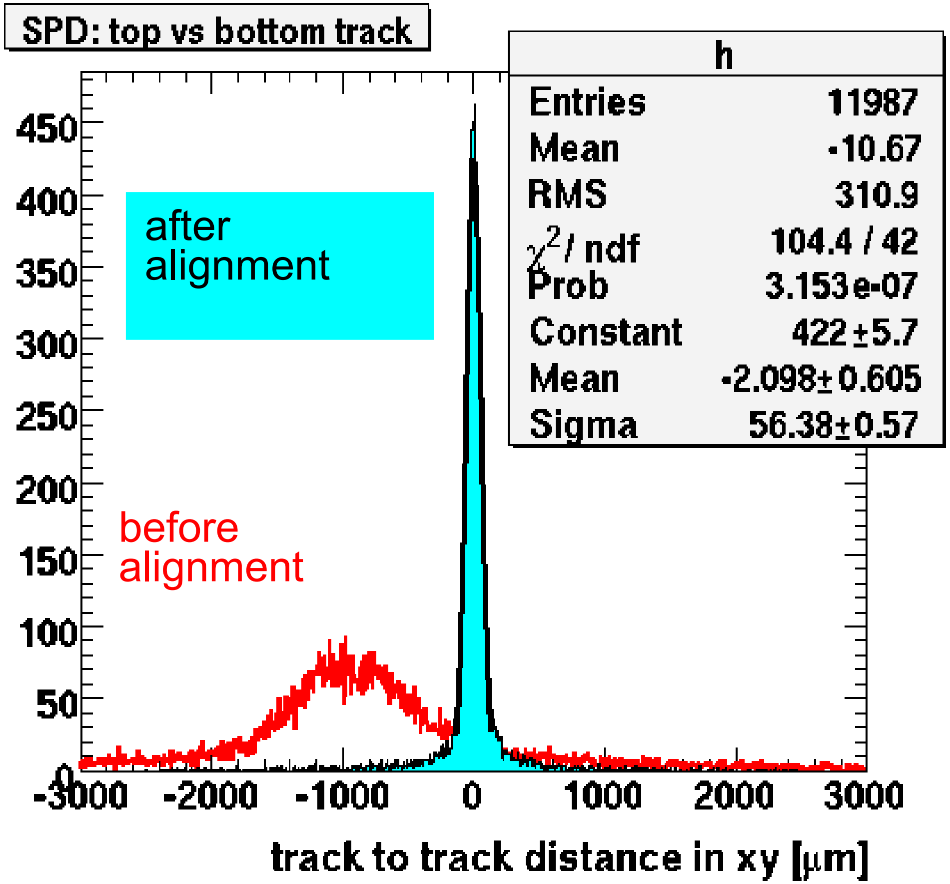


SPD
Top vs bottom



SDD: Drift speed calibration &
monitoring versus time

ITS alignment



SPD: Point resolution (σspatial)

$\sigma\Delta x = \sqrt{2} \times \sigma$spatial

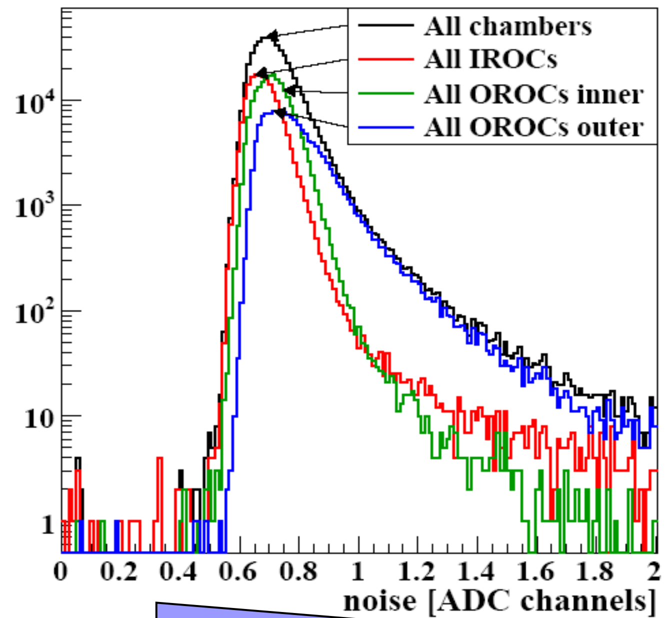
Data: 14 μm

Simulation: 11 μm

ready for data taking

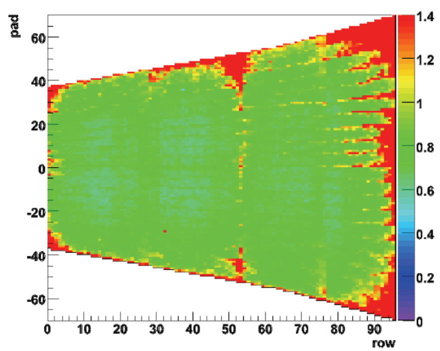
TPC Noise measurements

- Noise level improvement during commissioning
- Mean noise level:
  - Design goal: 1 ADC count (1000 e)
  - **Achieved: 0.7 ADC count (700 e)**
- Data volume:
  - zero suppresed (ZS) events: < 30kB
  - non-ZS: ~ 700MB

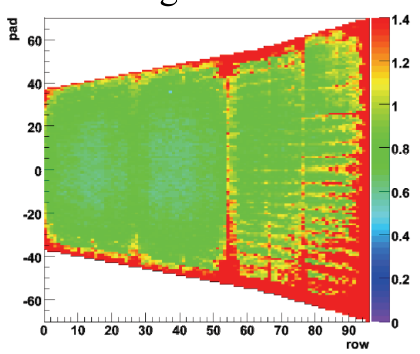


time

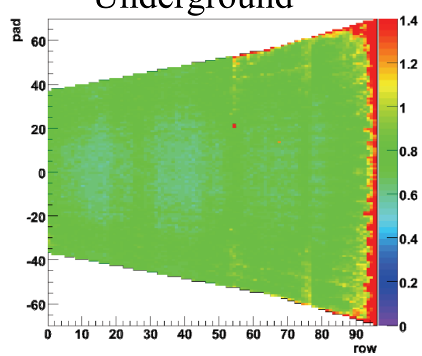
2006 — Clean room

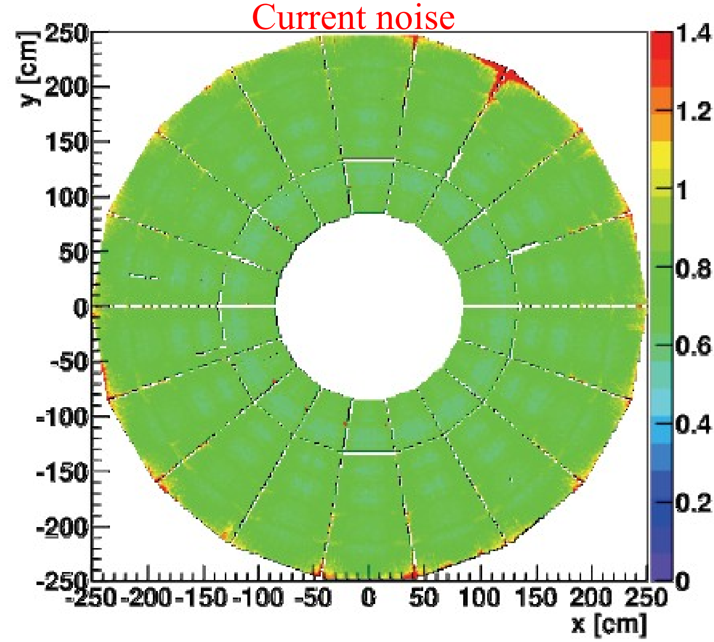


2007 — Underground

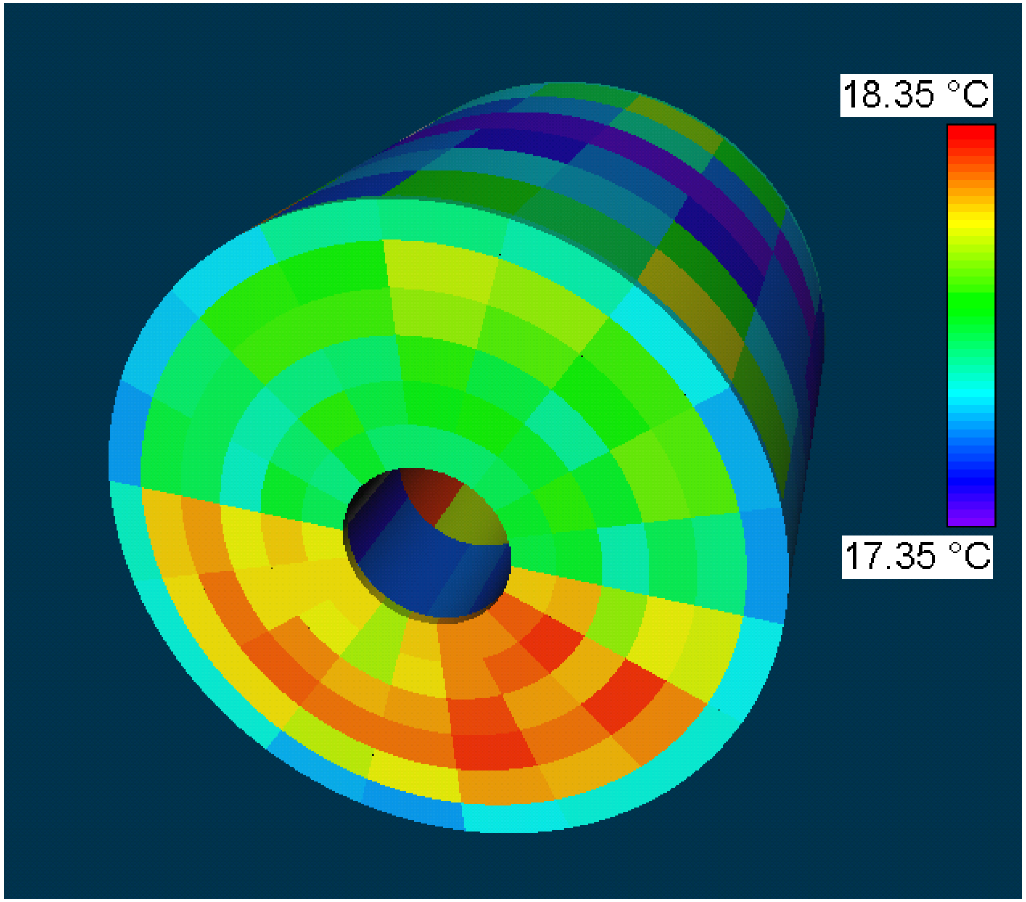


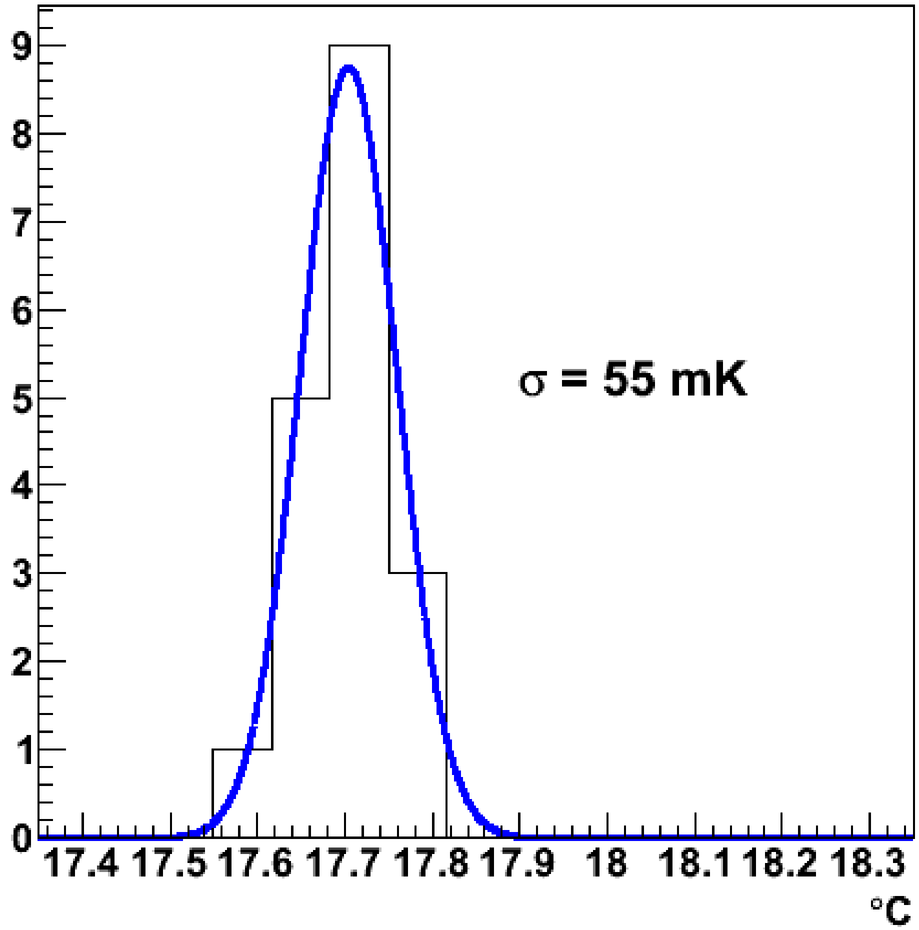
2008 — Underground





Temperature stabilization and monitoring system



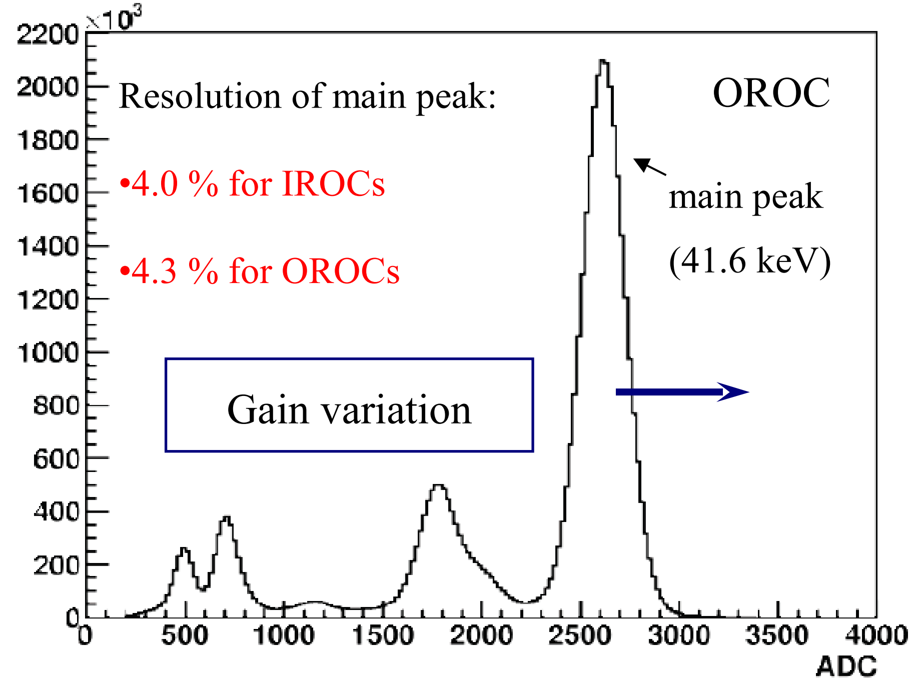


- 57 cooling loops
  - 8 Thermal screens; 4 Chambers
  - 5 Voltage divider
  - 36 Electronics; 4 Power lines
- 500 temperature sensors
  - 36 Sensors inside the TPC close to the readout chambers
- σ: 55 mK; Max-Min= 170 mK

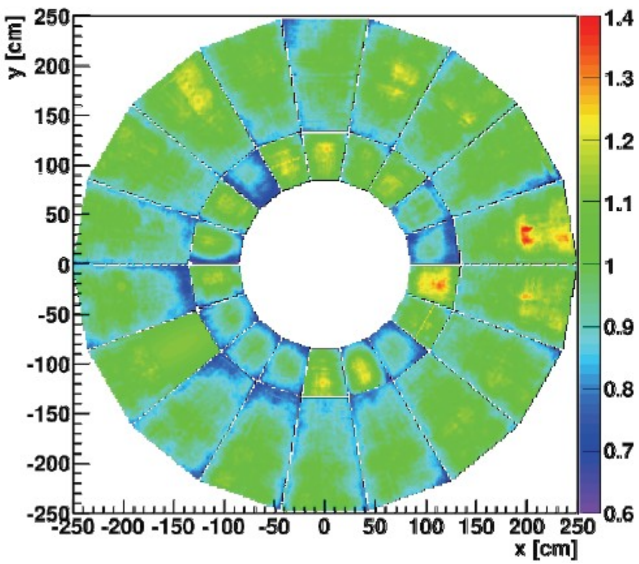
TPC Gain calibration using ^{83}Kr

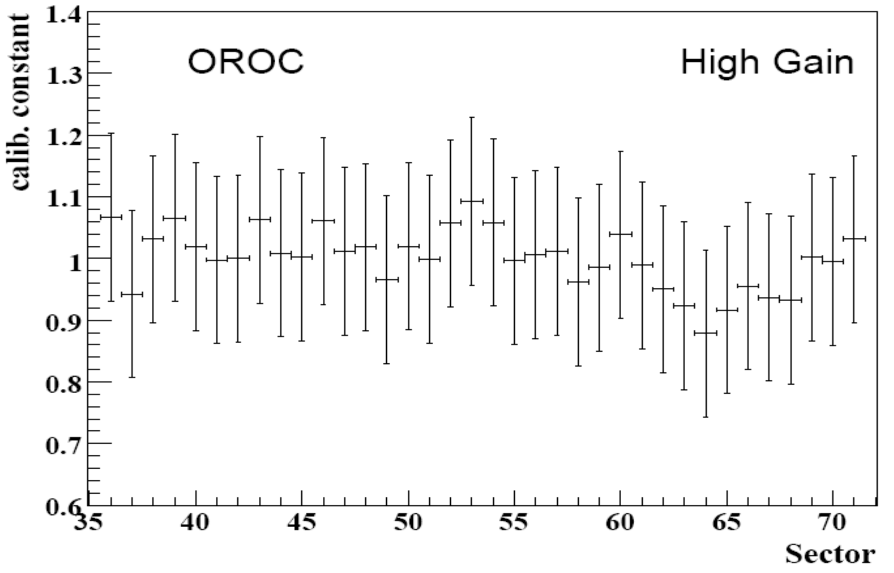
Determine gain for each pad

- Inject radioactive ^{83}Kr
- Fit the main peak (41.6 keV)
- 3 different HV settings (gains)
- High statistics: several 10^8 Kr events
- Repeated after electronic maintenance or every year
- Accuracy of peak position: < 1%   (design: 1.5%)



Relative gain variation C-side



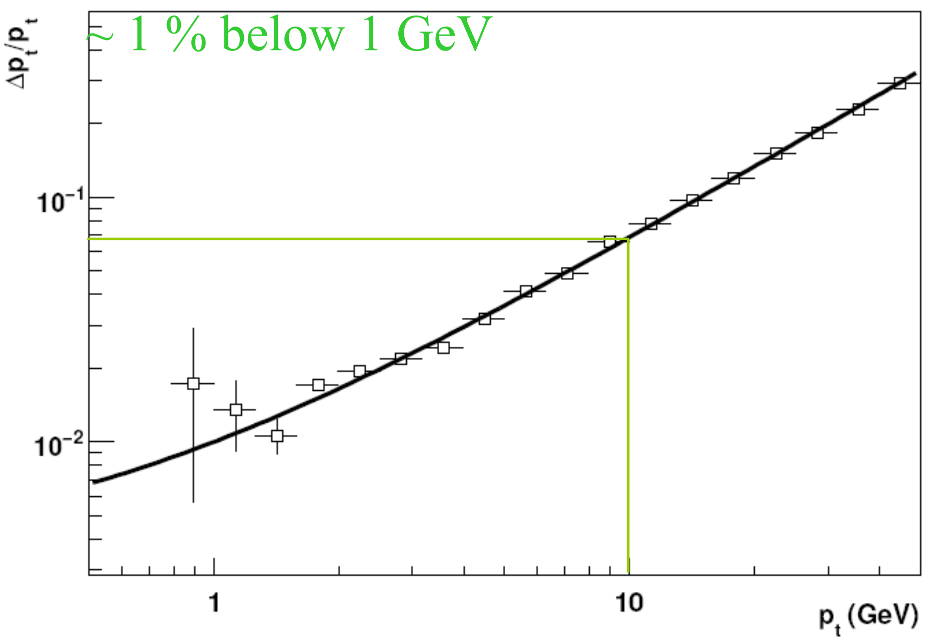


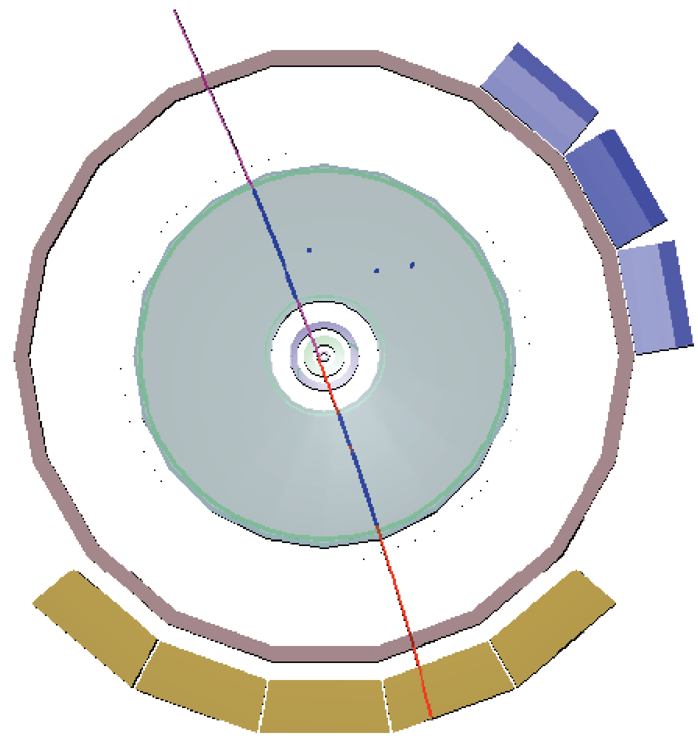
TPC momentum resolution

- Cosmic muon tracks treated independently in two halves of TPC
- Comparison of p_T at vertex gives resolution
- Statistics: $\sim 5 \times 10^6$ events

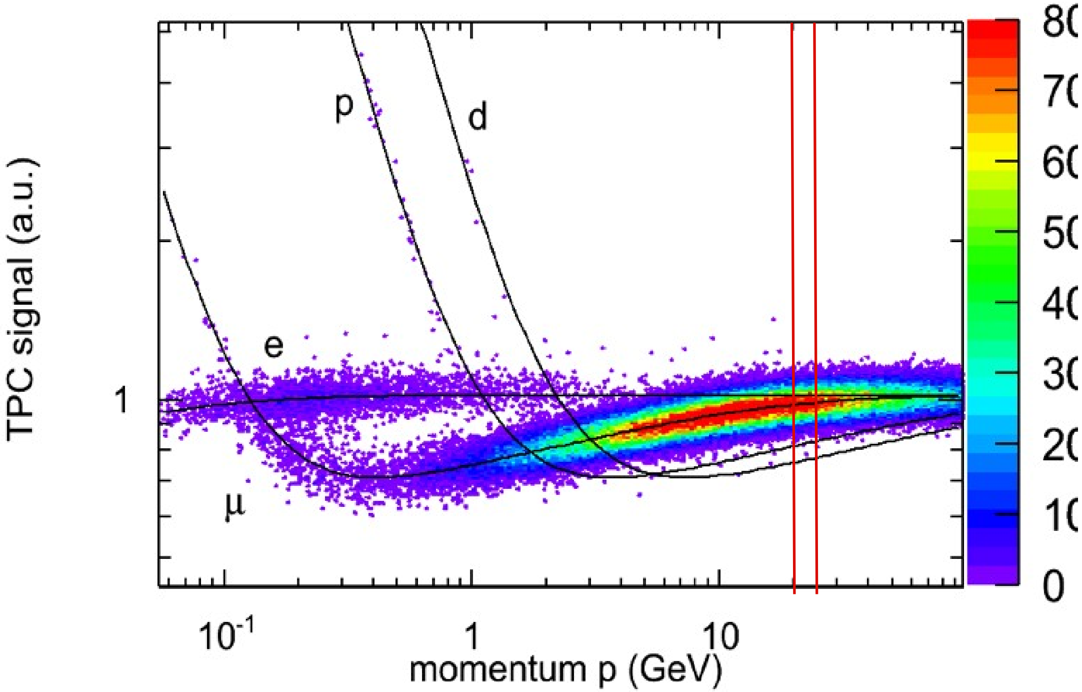
- Design goal: 4.5 % @ 10 GeV
- Achieved: 6.5 % @ 10 GeV

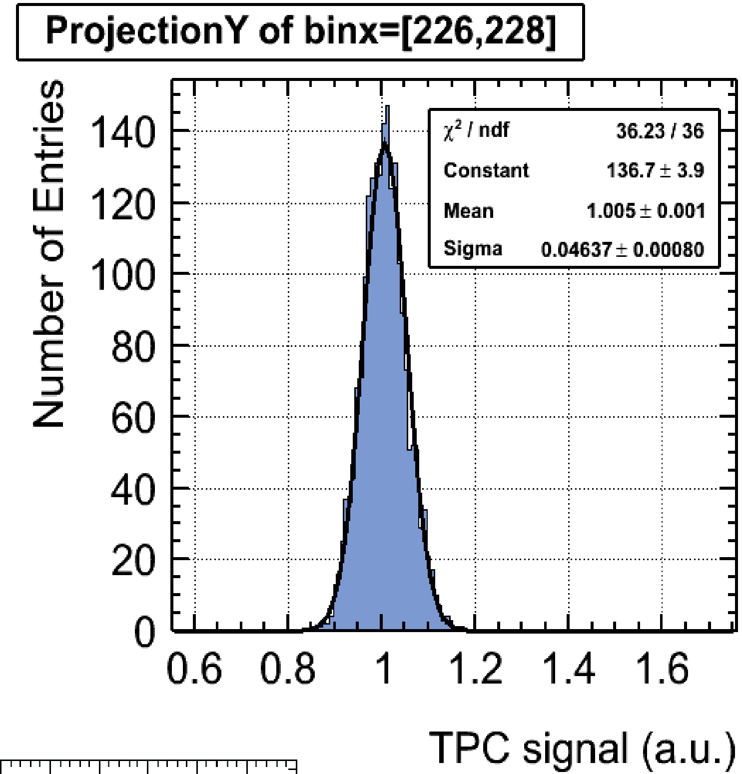
~ 1 % below 1 GeV



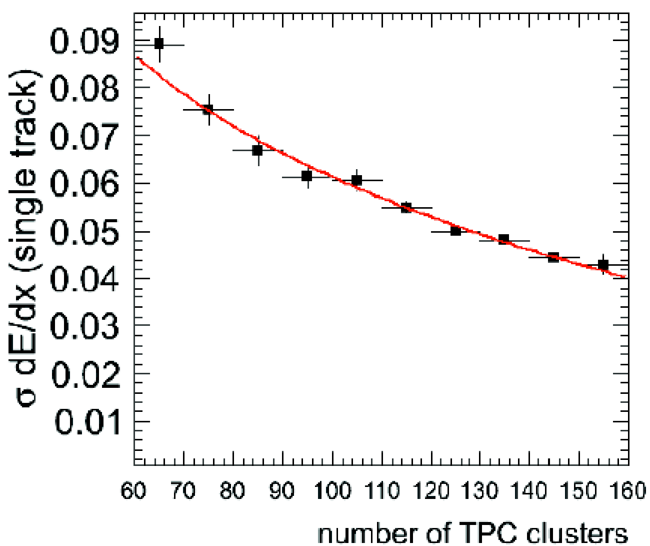


TPC dE/dx Performance



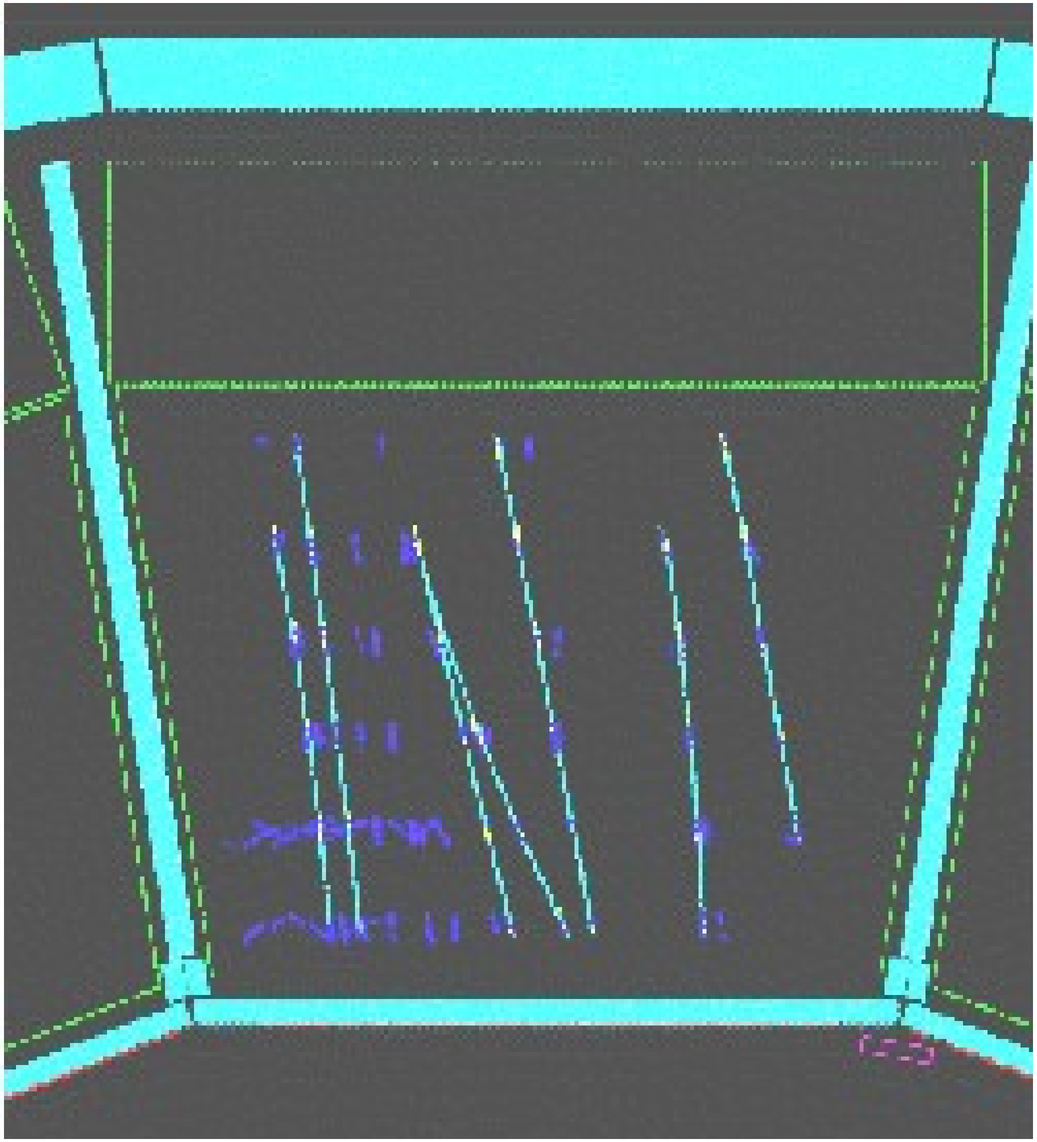


dE/dx resolution <5 %



Tracking of Cosmic Rays in the TRD

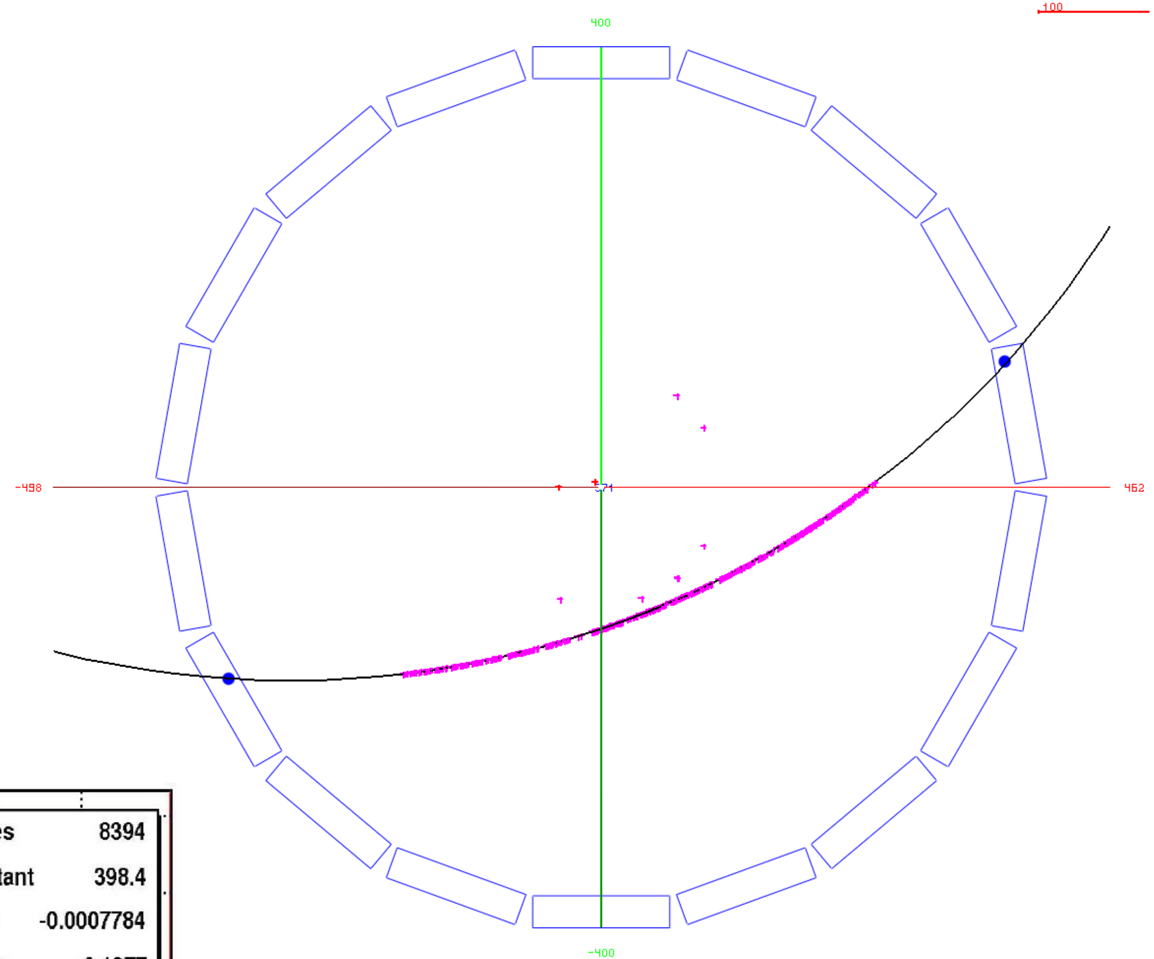
precision tracking
with factor 100
pion suppression



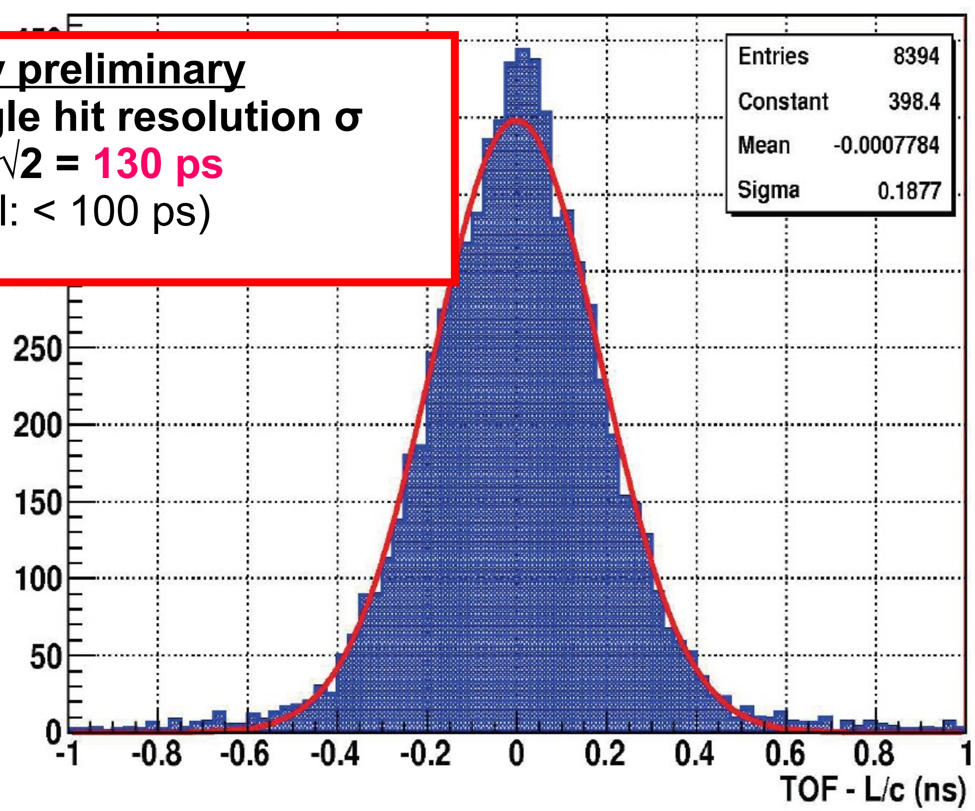
TOF

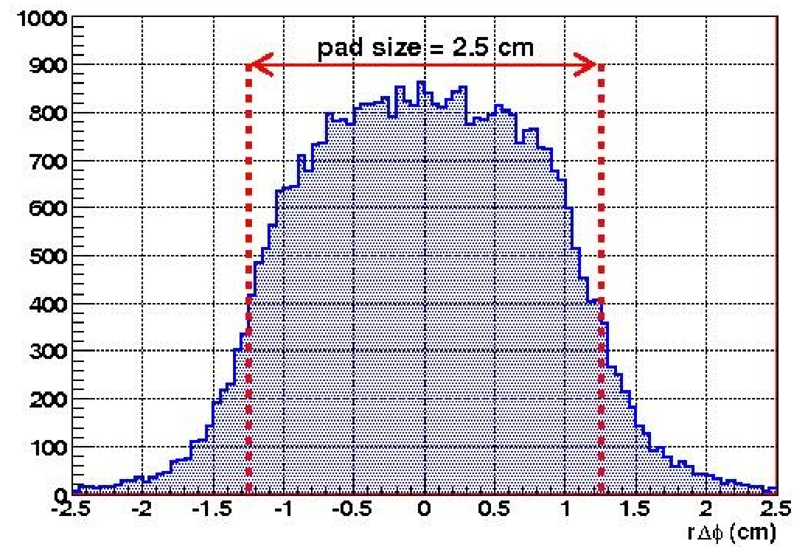
Calibrations with cosmics very promising despite low statistics (10K tracks)
and many 10,000 calibration parameters

Trigger fully functional
Noise rate better than expected



Very preliminary
Single hit resolution σ $190/\sqrt{2}$ = 130 ps
(goal: < 100 ps)

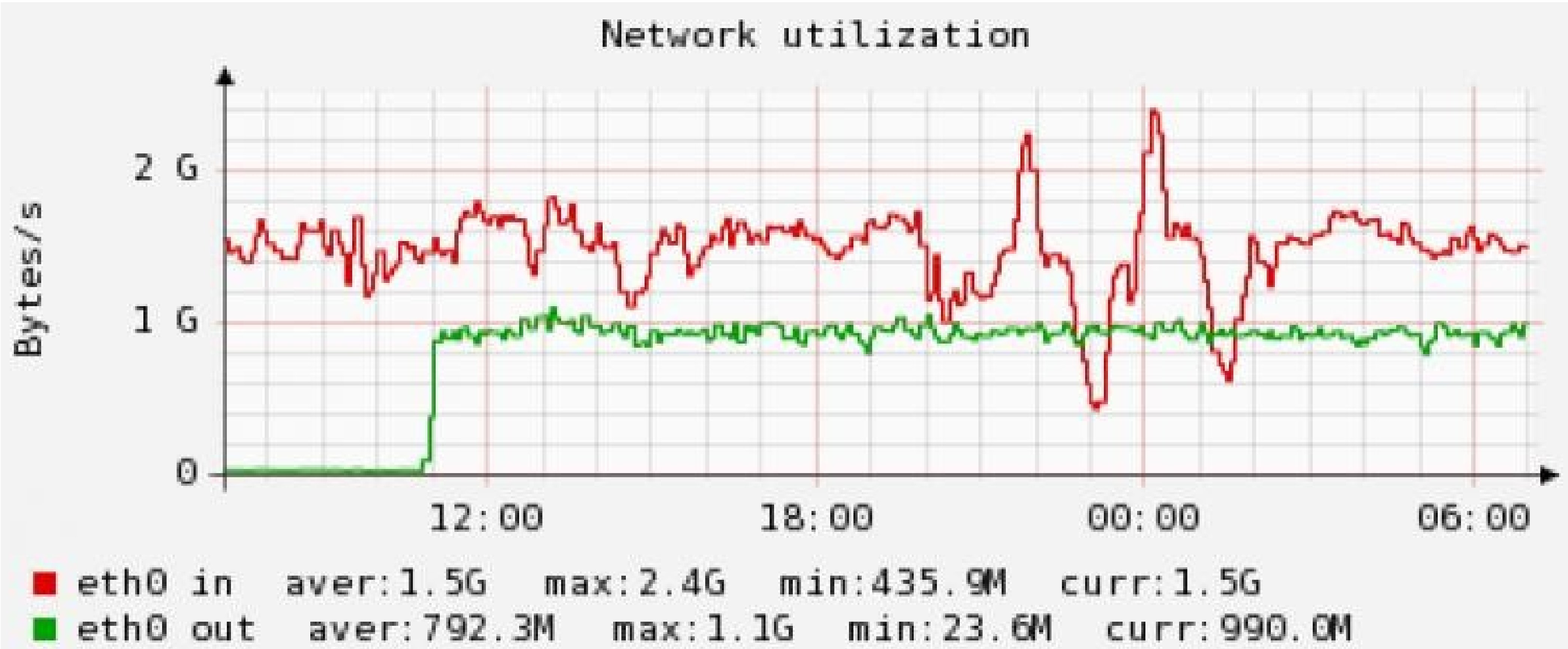




TPC extrapolated tracks – space resolution

ALICE DAQ status

1 Gbytes/s limit reached



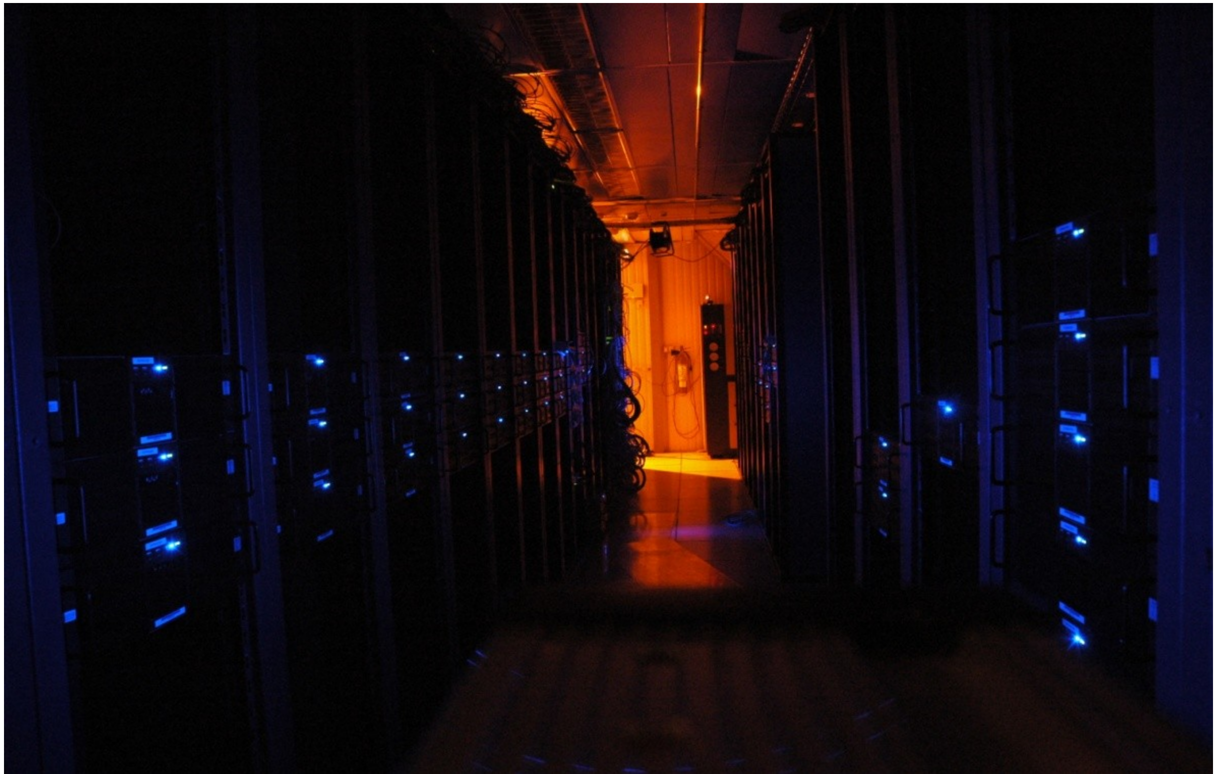
ALICE High Level Trigger

Purpose

- On-line reconstruction for
  - Central Barrel (TPC-ITS, TRD,PHOS, EMCAL,FMD)
  - Muon Arm
- On-line calibration for
  - TPC, PHOS
- On-line monitoring for
  - TPC, PHOS, ITS
- Trigger
  - Trigger framework in place
  - First physics triggers under test

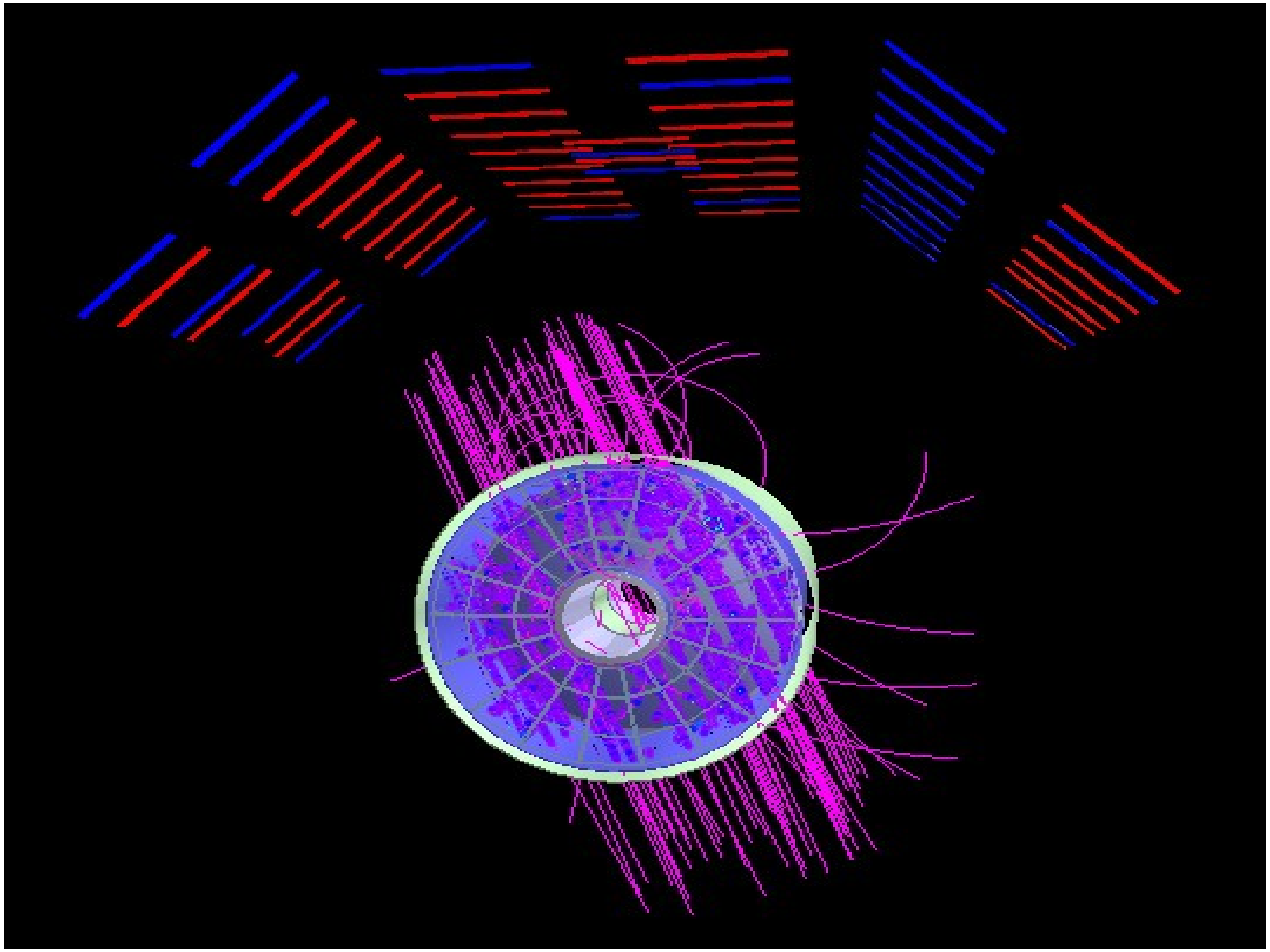
Current hardware:

- 120 Front-End PCs
  - 960 CPU cores
  - 480 DDLs
  - Final setup
- 51 Computing PCs
  - 408 CPU cores
  - pp setup run 2009-10
- Final GigaBit Ethernet setup
- Backbone
  - 72 ports QDR InfiniBand installed
- 20 Infrastructure PCs
  - All Interfaces in place and working



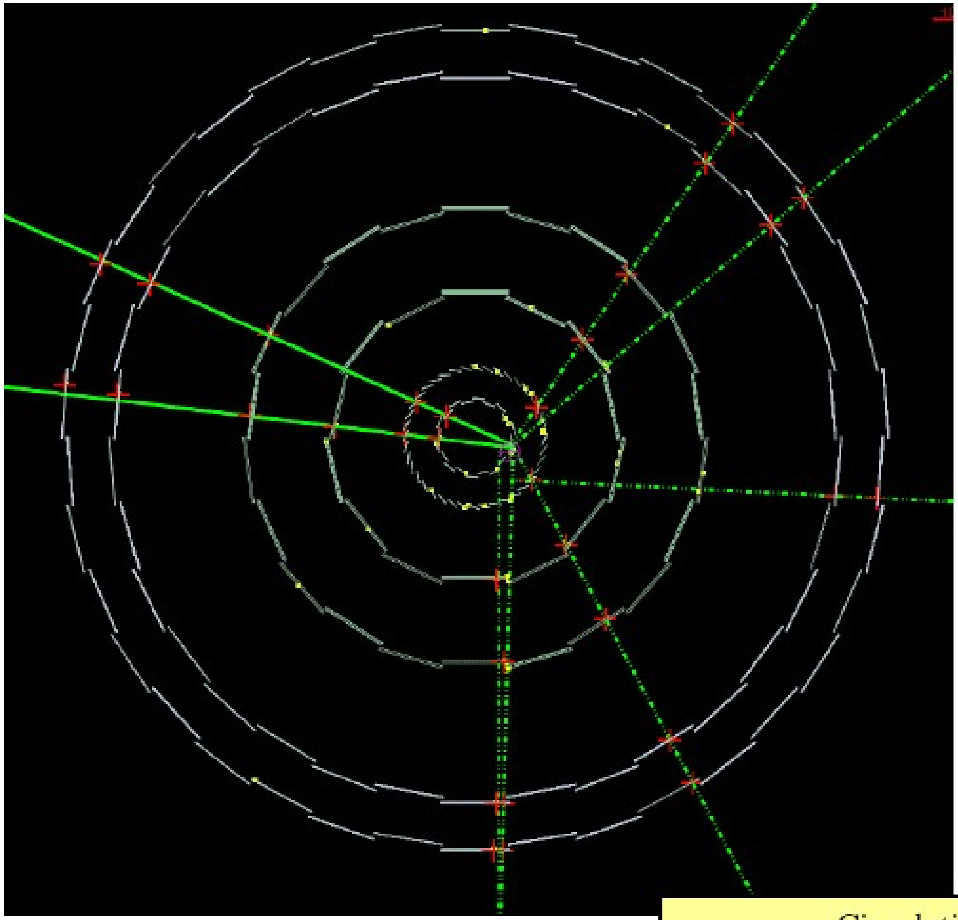
ALICE and the Tera-scale – 52 muons with momenta > 30 GeV in the ALICE TPC

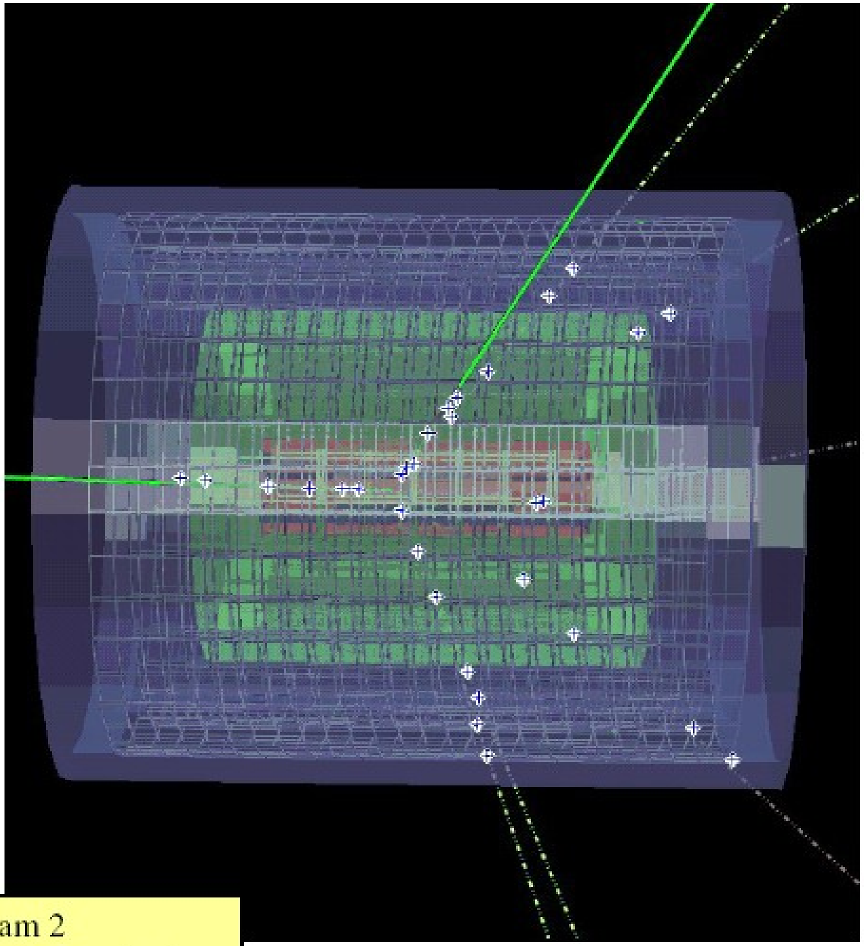
Muon bundle event triggered by ACORDE



Event number: 8560, Number of Tracks: 148, Number of Muons: 52, Number of ACORDE fired Modules:38

First interactions on Sept 12





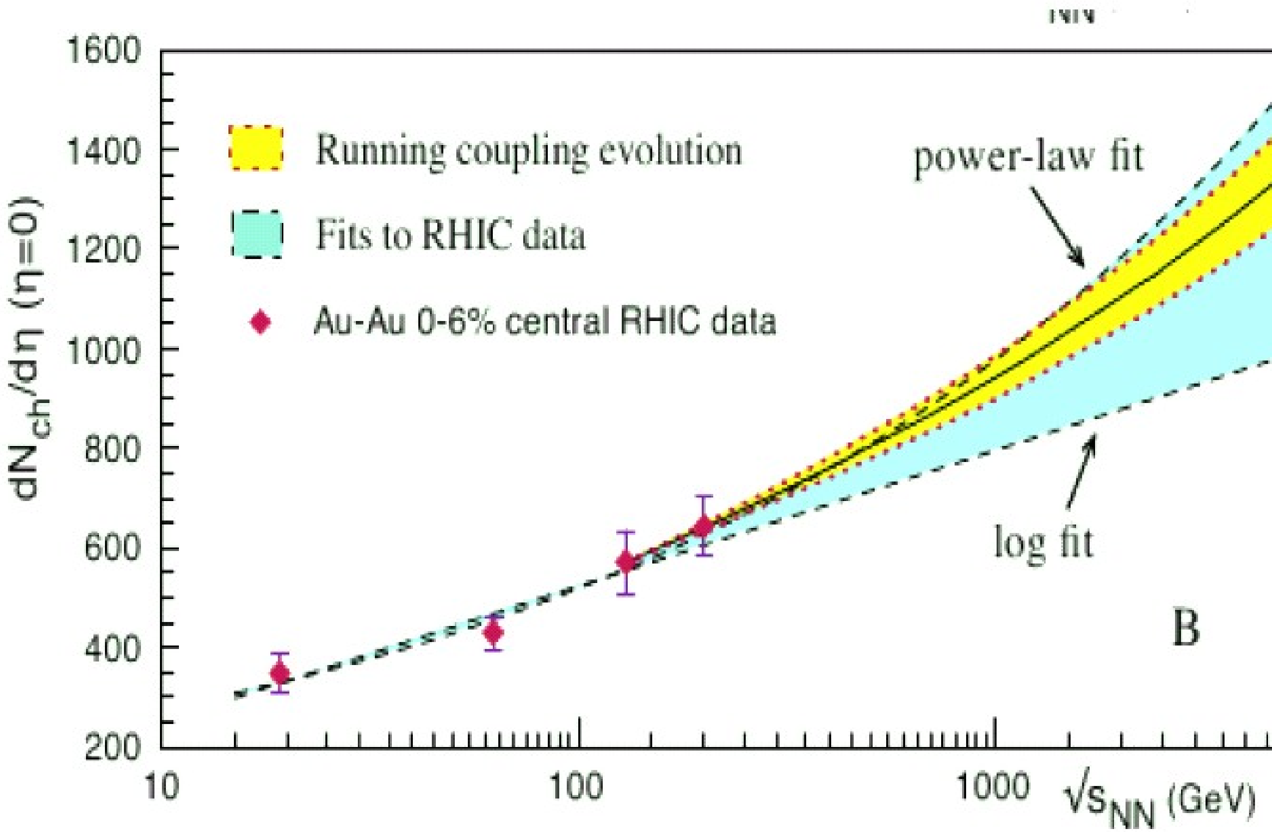
Circulating beam 2
stray particle causing an interaction in the ITS

Pb-Pb 'day 1' physics potential – 3 selected topics

1. multiplicity density and saturation models
2. particle composition and the QCD phase transition temperature
3. elliptic flow and the 'ideal fluid' scenario

Topic 1 - charged particle multiplicity

RHIC energy too low for safe extrapolation, many differing models - strongly sensitive to initial condition at LHC



Summary on particle multiplicity

day 1 results from LHC will define the „particle production landscape“ -> insight into initial conditions and crucial test of different theoretical approaches (color glass cond., saturation, shadowing, ...)

Topic 2 – particle yields and the QCD phase transition temperature

- From AGS energy on, all hadron yields in central PbPb collisions reflect grand-canonical equilibration – **T and mu_b**
- Strangeness suppression observed in elementary collisions is lifted

For a recent review see:

pbm, Stachel, Redlich, QGP3, R. Hwa, editor, Singapore 2004, nucl-th/0304013

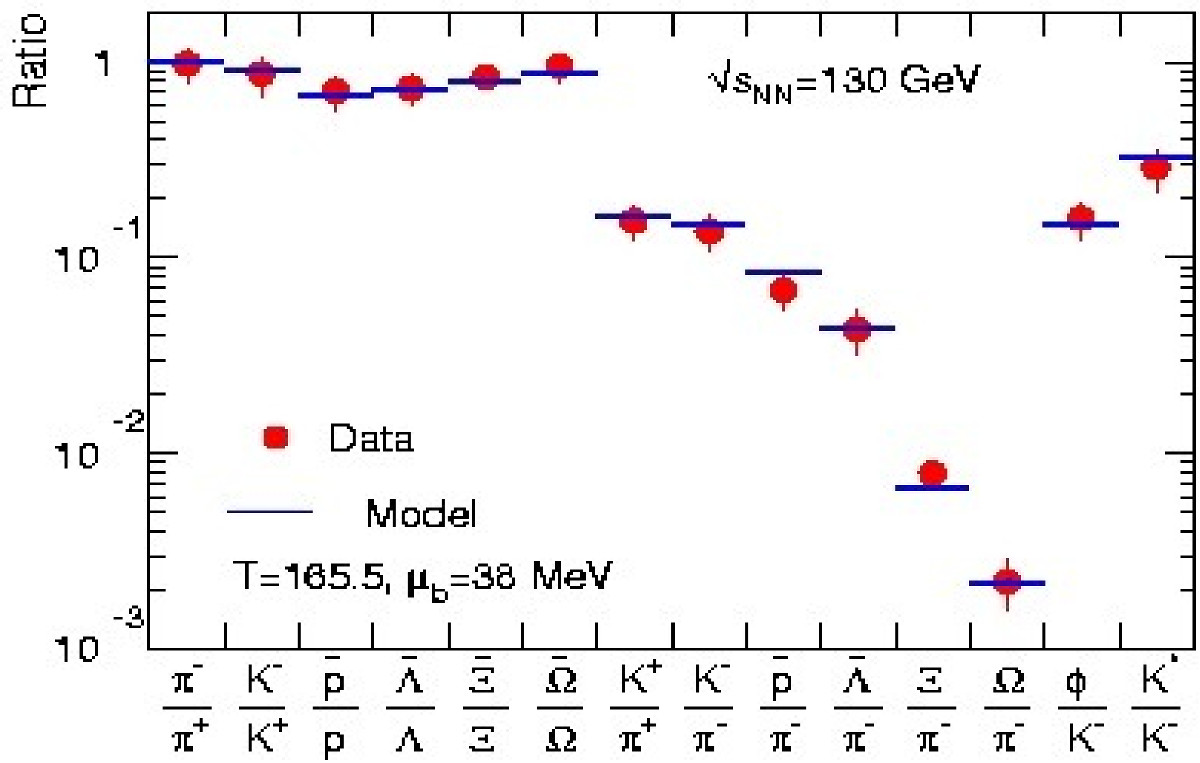
Hadro-chemistry at RHIC

All data in excellent agreement with thermal model predictions

chemical freeze-out at: T = 165 ± 8 MeV

fit uses vacuum masses

most recent analysis: A. Andronic, pbm, J. Stachel, nucl-th/0511071 Nucl. Phys. A772(2006) 167



pbm, Magestro, Stachel, Redlich, Phys. Lett. B518 (2001) 41;
see also Xu et al., Nucl. Phys. A698(2002) 306;
Becattini, J. Phys. G28 (2002) 1553;
Broniowski et al., nucl-th/0212052.

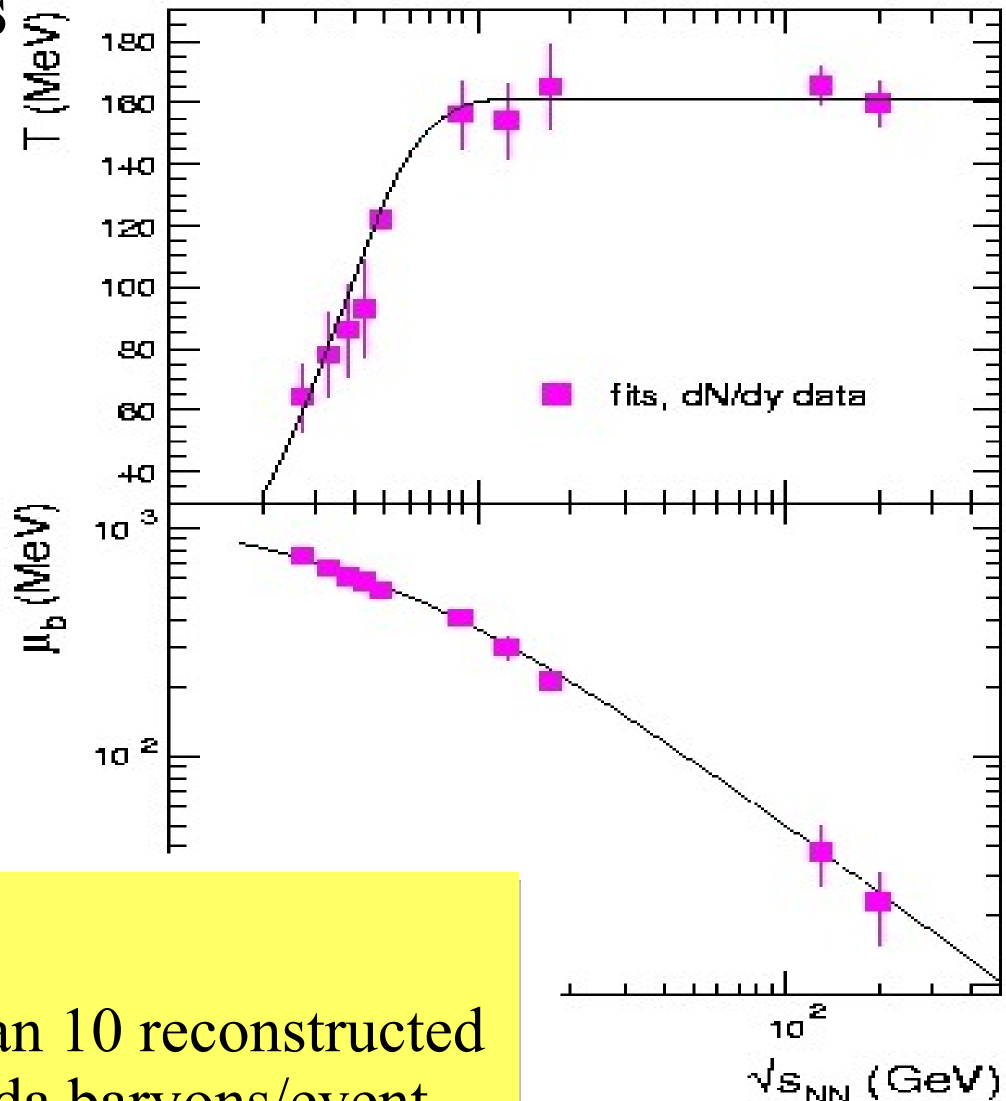
Temperature and chemical potential from particle yields

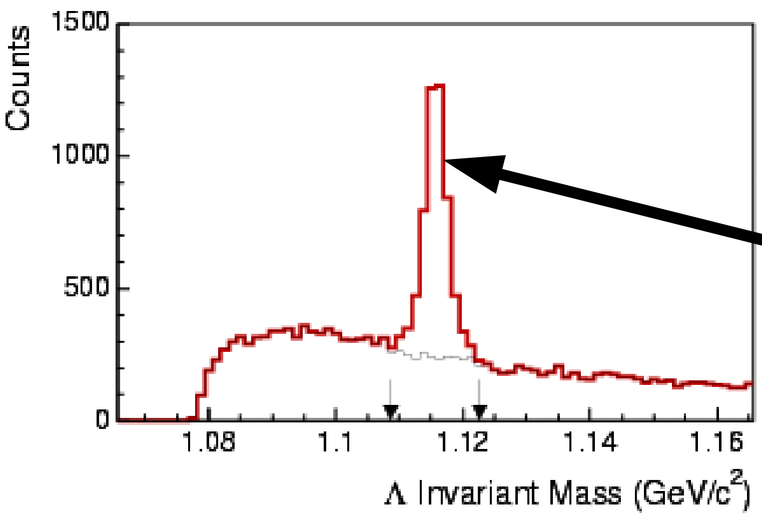
limiting temperature

T_{lim} = 160 MeV

provides connection to QCD phase boundary

will this hold at LHC?



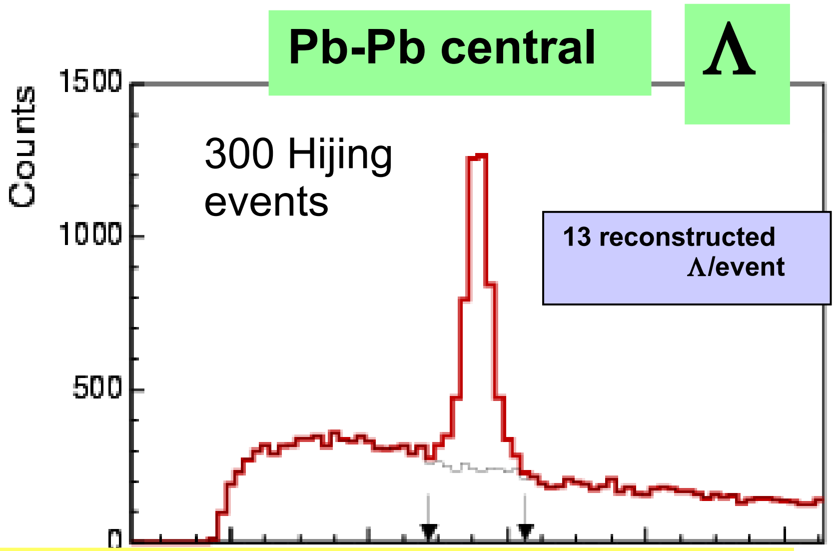


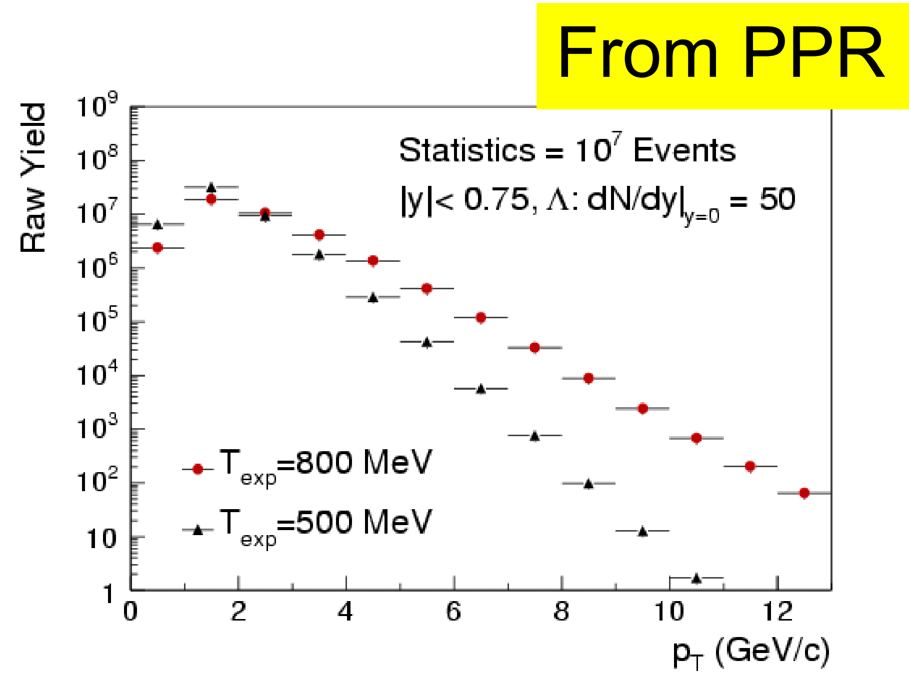
more than 10 reconstructed Lambda baryons/event in central PbPb collisions With ALICE

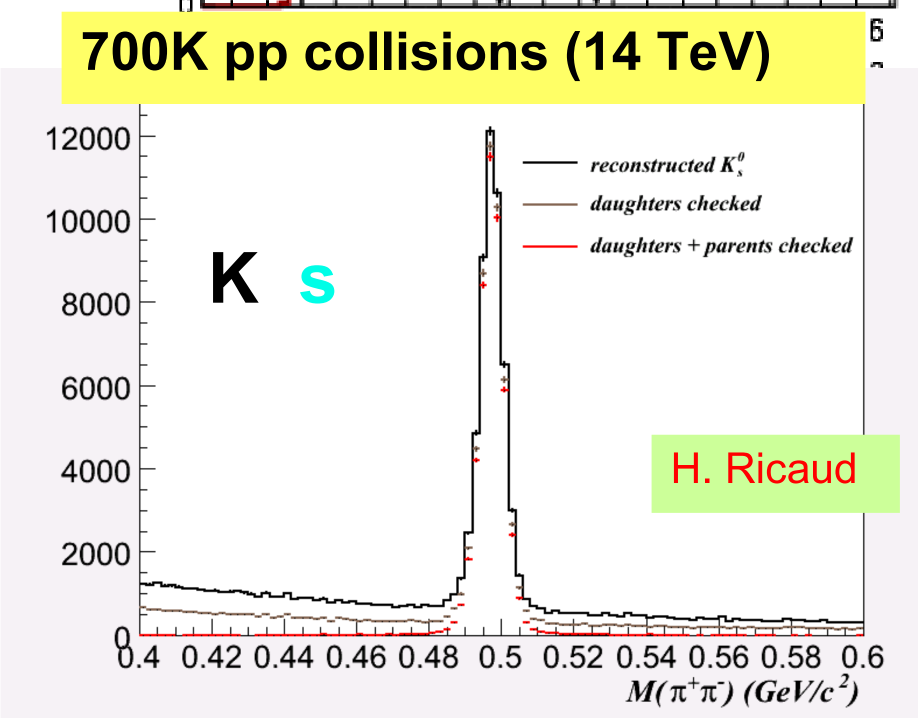
Topological identification of strange hadrons in ALICE

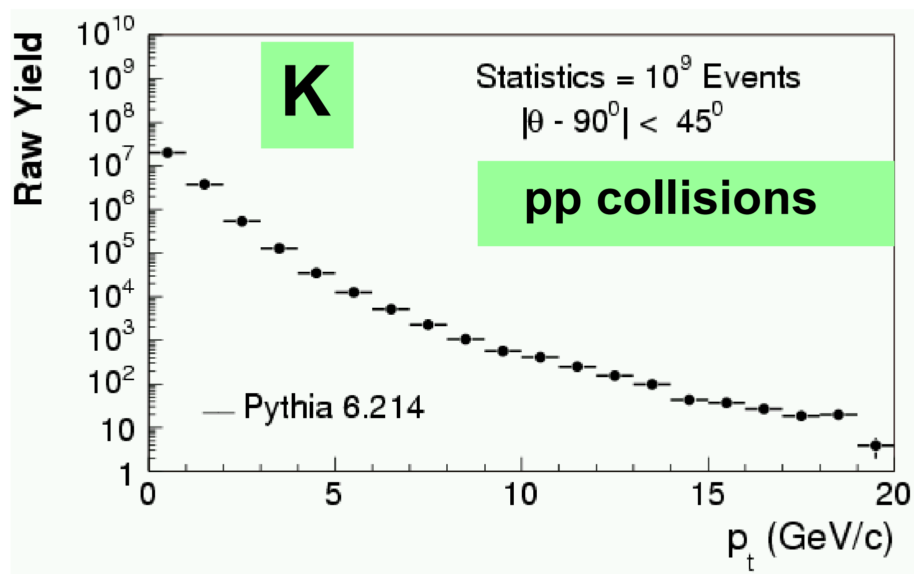
Statistical limit for 1 year: ~ 10 central Pb-Pb, 10 min. bias pp

p_T ~ 13 - 15 GeV for K , K , K_s, Λ p_T ~ 9- 12 GeV for Ξ, Ω









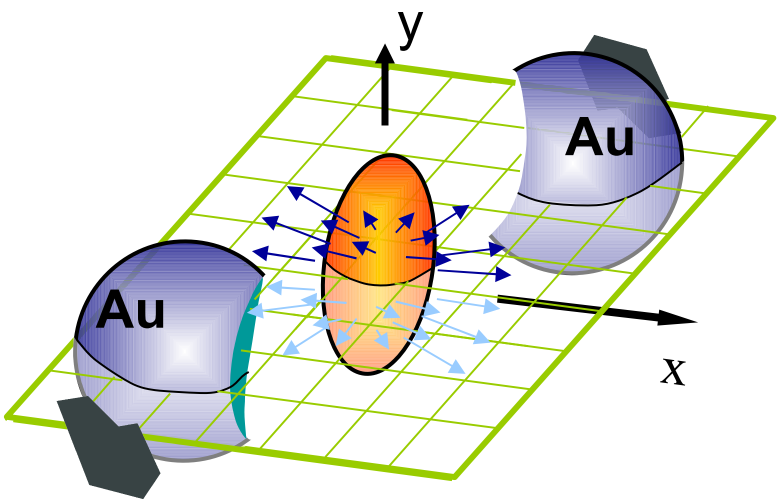
Summary of statistical model interpretation

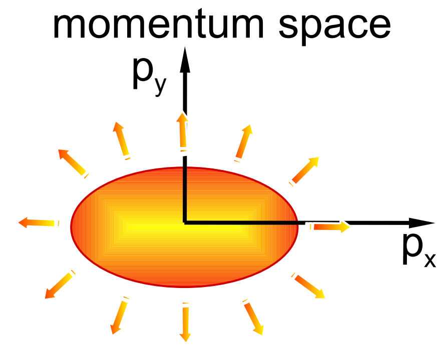
- hadron yields quantitatively described at all energies by 3 parameters: T, mu_b, V
- limiting temperature established
- connection to QCD phase boundary

- first data from LHC will provide a crucial test of this picture: does limiting temperature picture survive a 20 fold increase in cm energy?

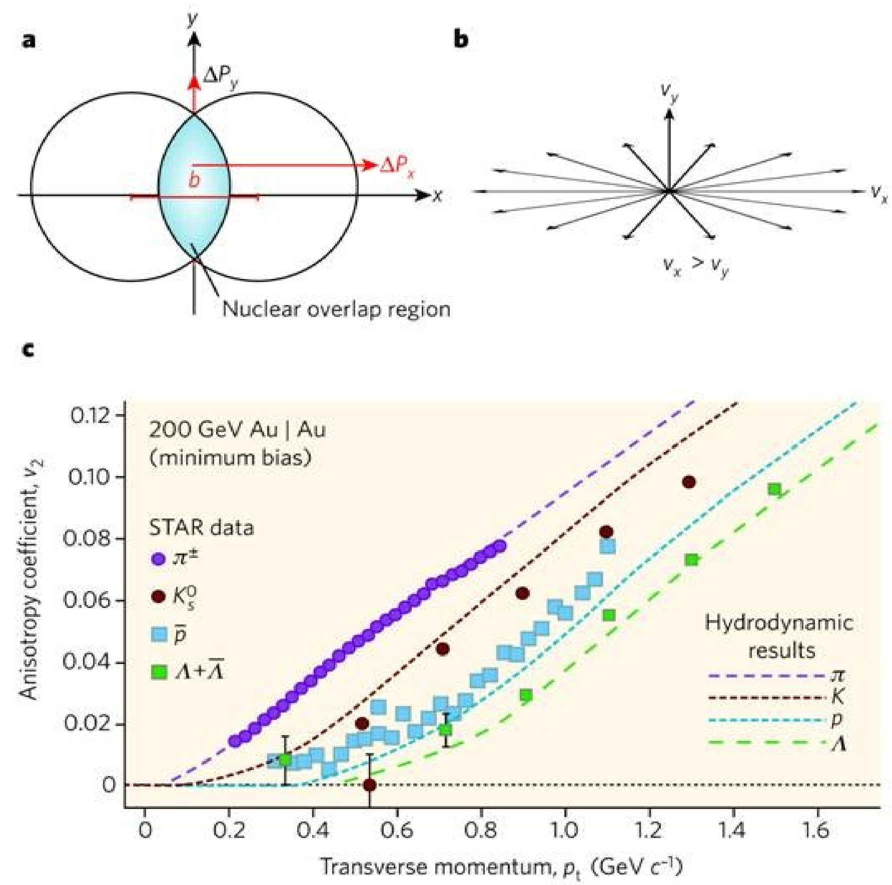
anything else would be a major surprize
already day 1 data from LHC will be decisive

Topic 3- The fireball expands collectively like an ideal fluid





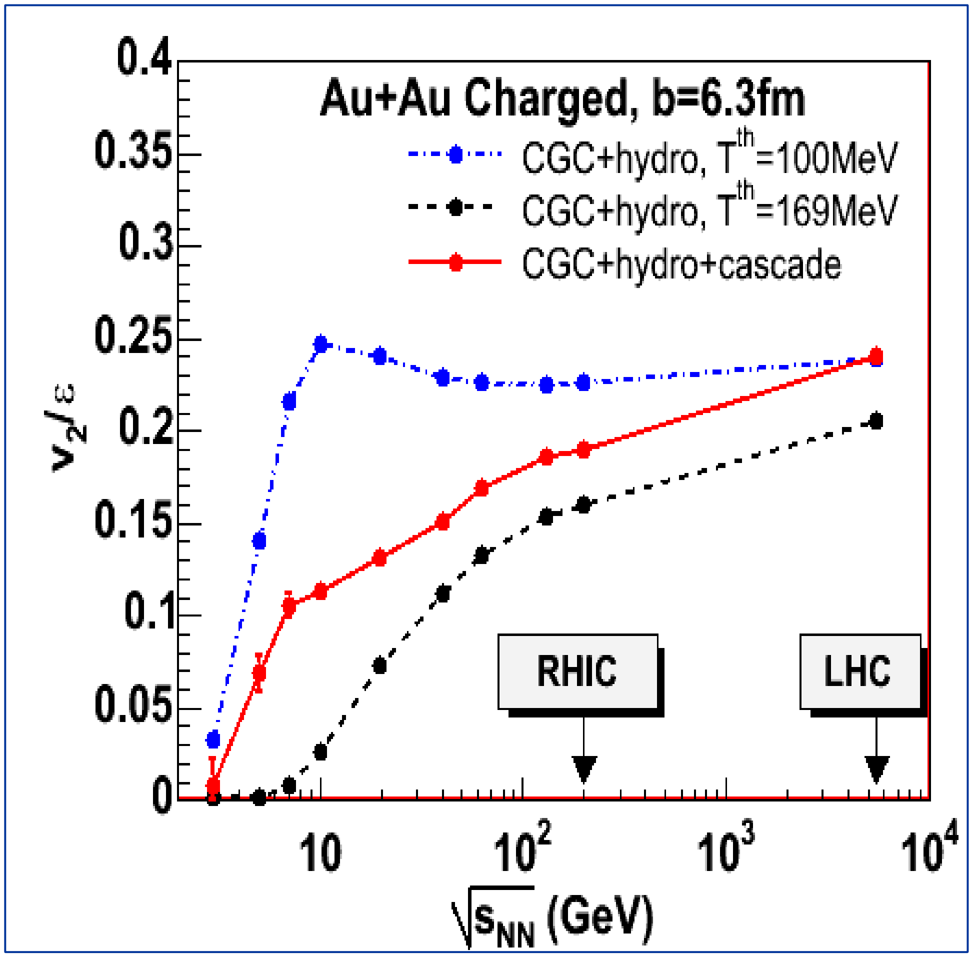
$$dN/d\phi = 1 + 2\,V_2 \cos 2\,(\phi - \psi) + \ldots$$

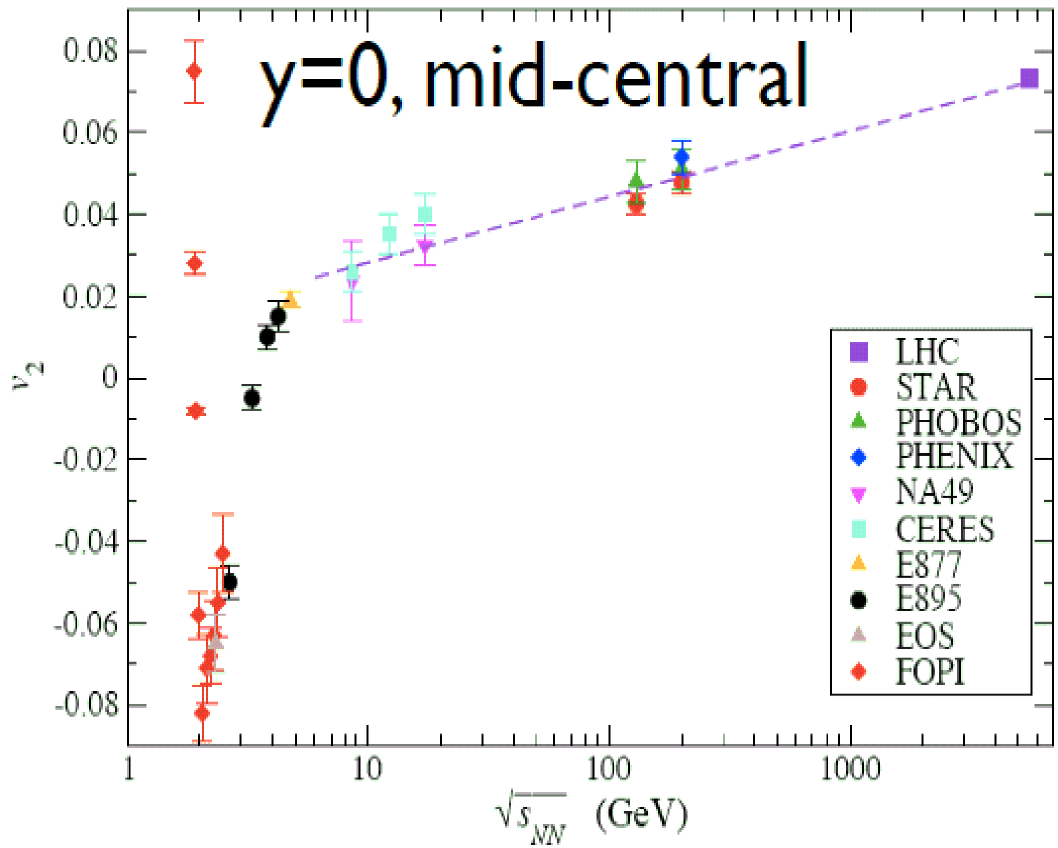


hydrodynamic flow characterized by azimuthal anisotropy coeffient v_2

RHIC results imply that the QGP behaves like an ideal fluid with ultra-low shear viscosity/entropy density ratio will QGP at LHC be similar?

extrapolations to LHC





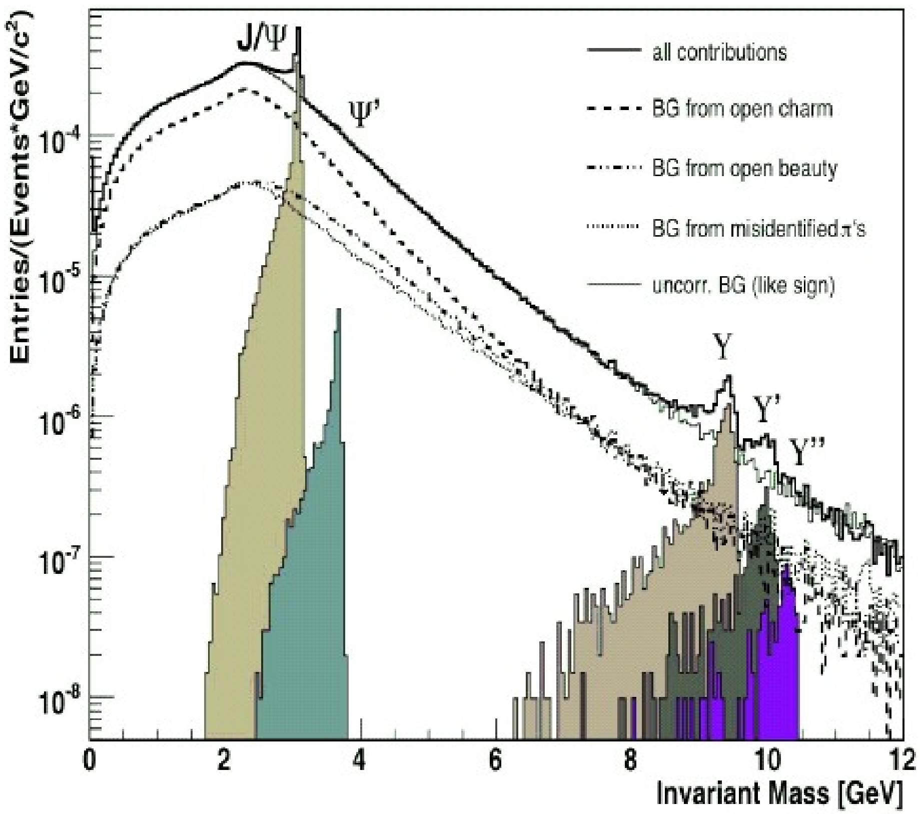
Summary of RHIC Hydro Results

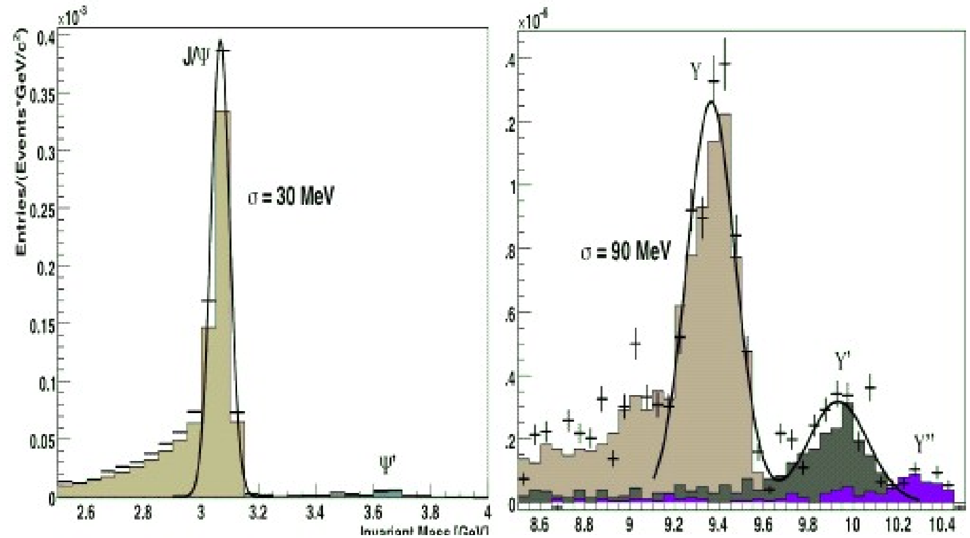
- spectra and flow well explained by ideal hydrodynamics calculations
- viscosity/entropy density close to AdS/CFT limit
- is hydro limit reached at RHIC, will it be „exceeded at LHC“?
- is viscosity only low near phase boundary?
- is quark scaling universal?

day 1 results from LHC will be decisive

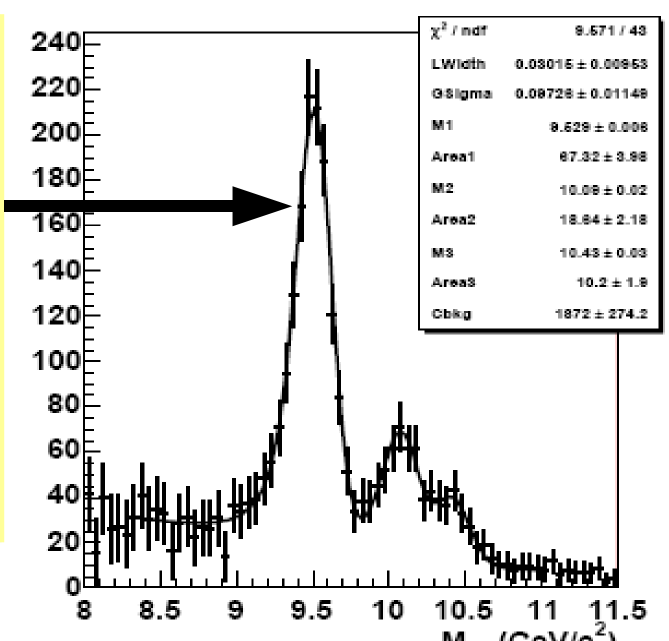
With 1 month of time: quarkonium measurements in PbPb collisions with ALICE

electron identification with TPC and TRD





Υ measurement in the muon arm



Quarkonium as a probe for deconfinement at the LHC

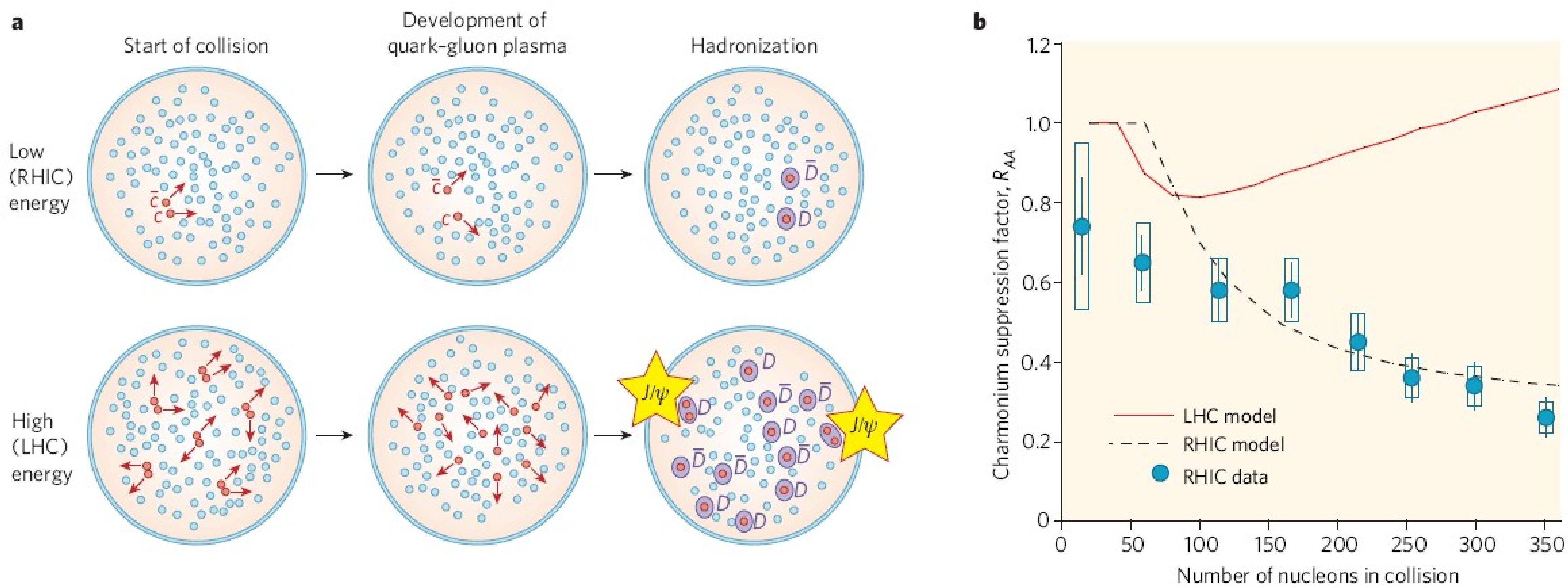
at hadronization of QGP
J/ψ can form again
from deconfined quarks,
in particular if number of
ccbar pairs is large

$N_{J/\psi} \propto N_{cc}^{\ 2}$

(P. Braun-Munzinger and
J.Stachel, PLB490 (2000) 196)

charmonium enhancement as fingerprint of deconfinement at LHC energy

Andronic et al.,
Phys. Lett. B652 (2007) 259



many more very important month-1 observables:

jet production
jet quenching and parton energy loss
heavy quark production

after nearly ten years of construction,
ALICE is ready for beam

we look forward to exciting times