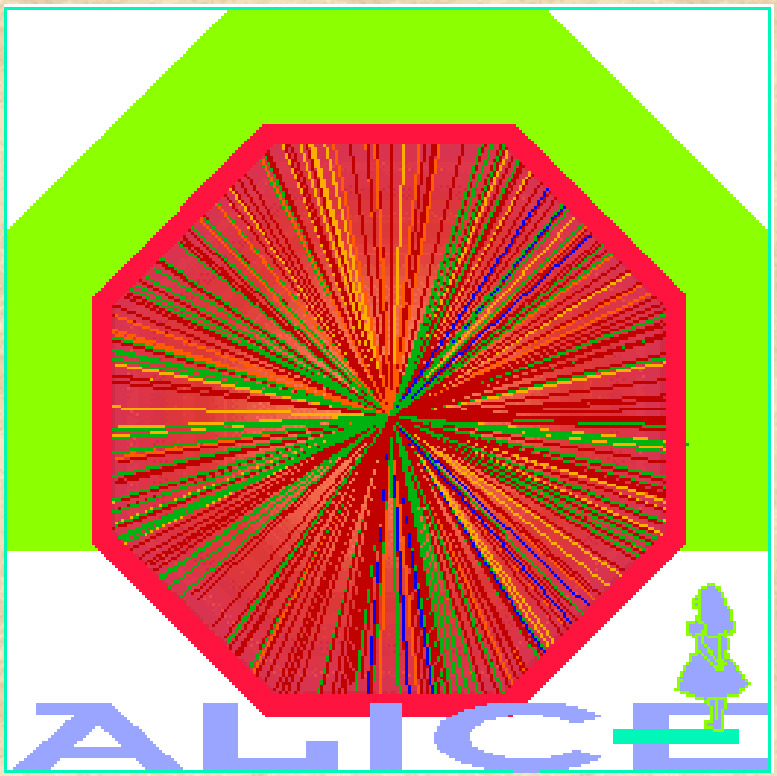
ALICE Experiment

- Physics motivation
- Experimental conditions
- Detector status
- Physics performance



WHY HEAVY IONS AT THE LHC?

.... factor ~30 jump in $\sqrt{s}$ ...

(Corresponds to more than 10^{18} eV in the lab frame – macroscopic energy)

hotter - bigger -longer lived

$\varepsilon_{LHC} > \varepsilon_{RHIC} > \varepsilon_{SPS}$

$V_{f\,LHC} > V_{f\,RHIC} > V_{f\,SPS}$

$\tau_{LHC} > \tau_{RHIC} > \tau_{SPS}$

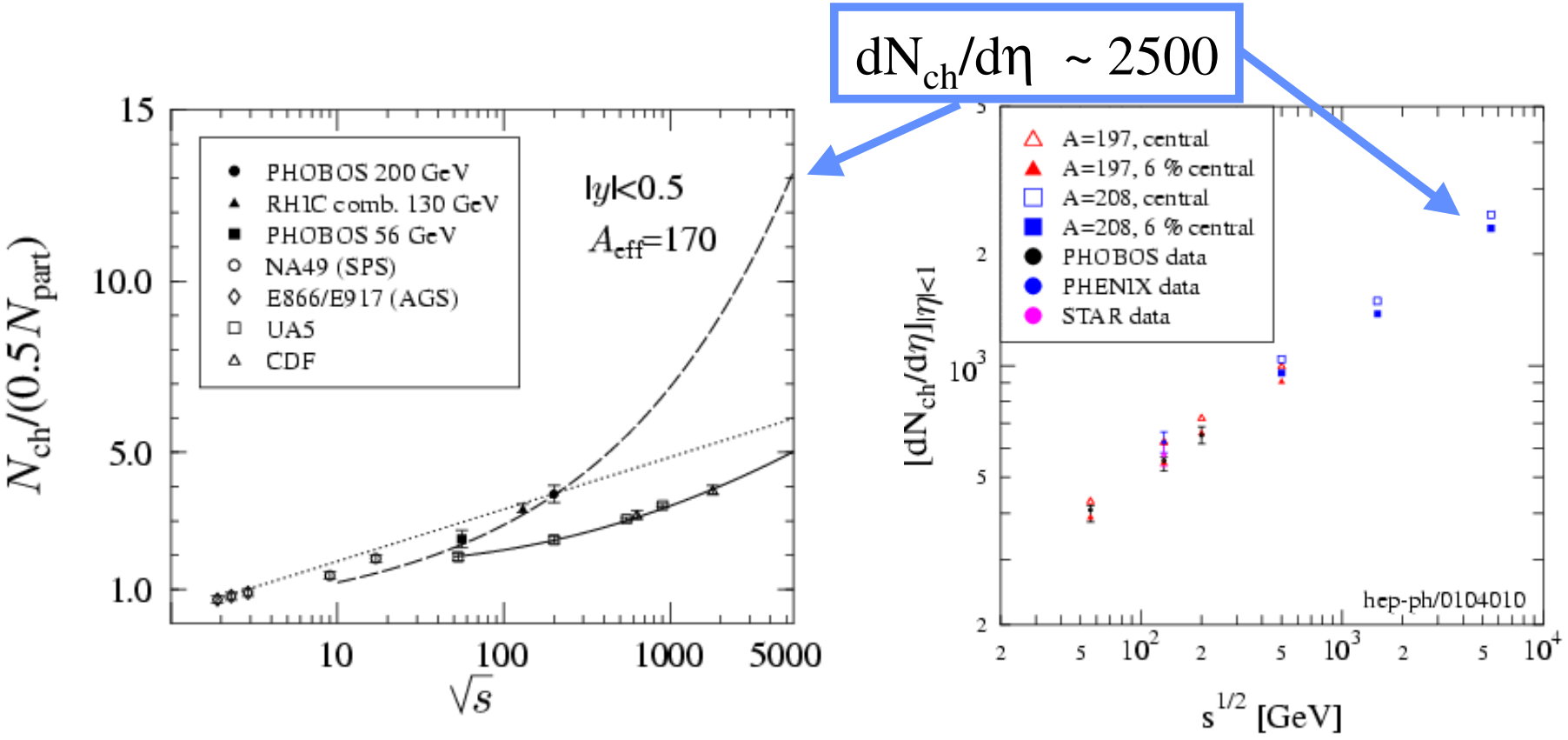
Central collisions	SPS	RHIC	LHC
$s^{1/2}$(GeV)	17	200	5500
dN_{ch}/dy	500	650	3-8 $x10^3$
ε (GeV/fm^3)	2.5	3.5	15-40
V_f(fm^3)	10^3	$7x10^3$	$2x10^4$
τ_{QGP} (fm/c)	<1	1.5-4.0	4-10
τ_0 (fm/c)	~1	~0.5	<0.2

Understanding QCD at high temperature

(Most of the hadronic mass has origin in QCD field, not in Higgs mechanism)

What multiplicity do we expect?

old estimates: dN_{ch}/dy 2000 - 8000, now we can extrapolate from RHIC data

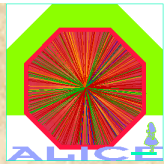


(from K.Kajantie, K.Eskola)

but ...

- **The major uncertainties in the energy dependence are still there**
  - ⇨ **only some improvement with the RHIC data!**
- **Still no safe way to extrapolate**
  - ⇨ **shadowing/saturation (might decrease Nch)**
  - ⇨ **jet quenching (might increase it)**
  - ⇨ **A-scaling (soft vs. hard)**
- **Simple scaling form RHIC (log-log plot) ~2500**
- **-> very safe guess $dN_{ch}/d\eta$ ~ 1500 - 6000**

Experimental conditions @ LHC



- **pp commissioning start April 2007**

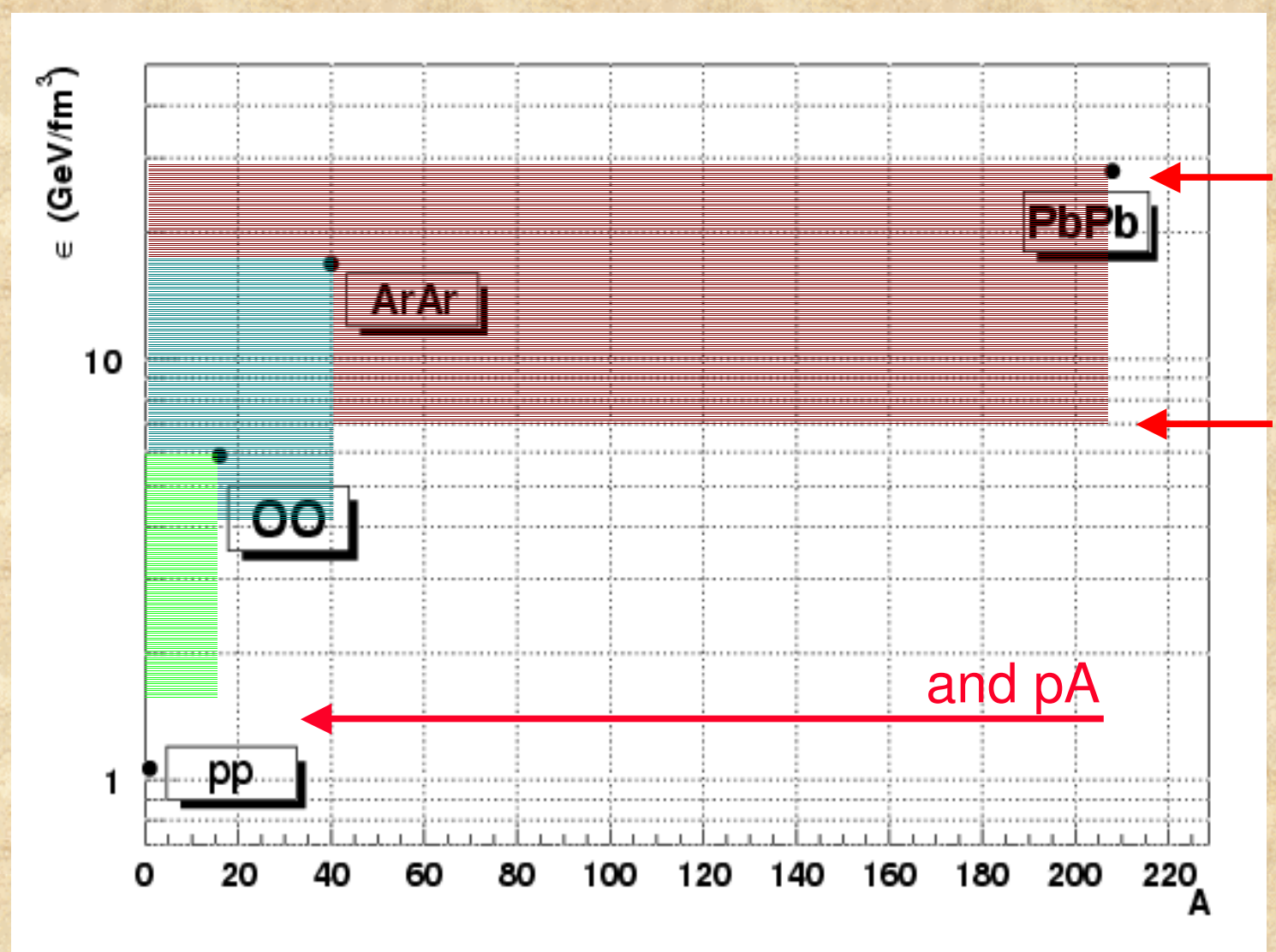
- **A recent workshop (June 2002) re-stated the wish list of the HI community for the LHC**

  - **Initial few years** (1HI 'year' = 10^6 effective s, ~like at SPS)
    - **2 - 3 years Pb-Pb** — **L ~ 10^{27} $cm^{-2}s^{-1}$**
    - **1 year p - Pb 'like'** (**p**, d or α) — **L ~ 10^{29} $cm^{-2}s^{-1}$**
    - **1 year light ions** (eg Ar-Ar) — **L ~ few 10^{27} to 10^{29} $cm^{-2}s^{-1}$**

      plus, for ALICE (limited by pileup in TPC):
    - **reg. pp** run at $\sqrt{s}$ = 14 TeV — **L ~ 10^{29} and < $3x10^{30}$ $cm^{-2}s^{-1}$**
  - **Later: different options depending on Physics results**

- Heavy Ion running part of LHC initial program, early pilot run expected by end of 2007

Use different ion species to vary the energy density



ALICE Physics goals

(has to cover in one experiment what at the SPS was covered by 6-7 experiments, and at RHIC by 4!!)

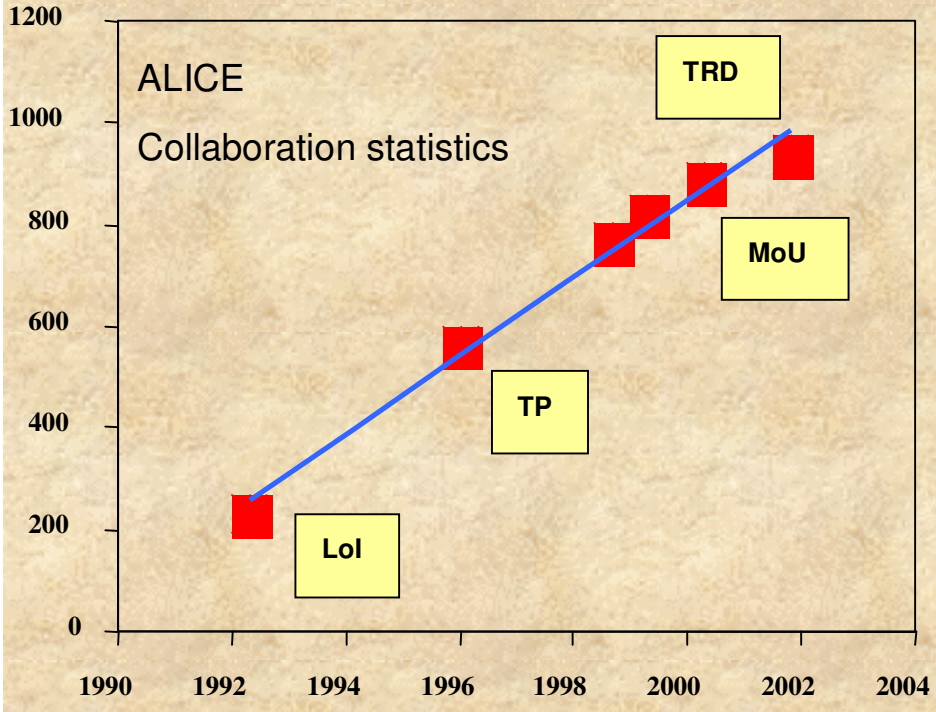
- **Global observables:**
  Multiplicities, η distributions
- **Degrees of freedom as a function of T**
  hadron ratios and spectra, dilepton continuum, direct photons
- **Early state manifestation of collective effects:**
  elliptic flow
- **Energy loss of partons in quark gluon plasma:**
  jet quenching, high pt spectra, open charm and open beauty

- **Deconfinement:**
  charmonium and bottonium spectroscopy
- **Chiral symmetry restoration:**
  neutral to charged ratios, res. decays
- **Fluctuation phenomena - critical behavior:**
  event-by-event particle comp. and spectra
- **Geometry of the emitting source:**
  HBT, impact parameter via zero-degree energy flow
- **pp collisions in a new energy domain**

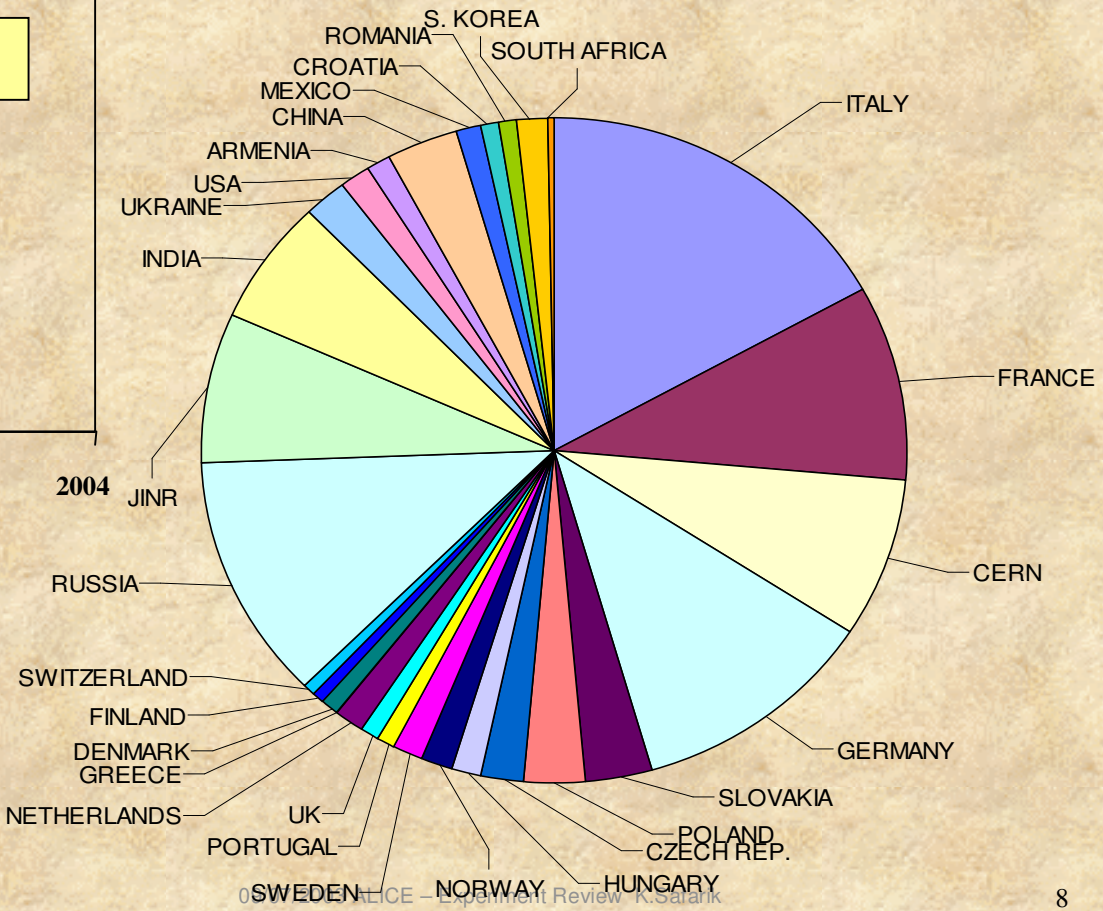
- Large acceptance
- Good tracking capabilities
- Selective triggering
- Excellent granularity
- Wide momentum coverage
- P.I.D. of hadrons and leptons
- Good sec. vertex reconstr.
- Photon Detection

Use a variety of experimental techniques!

Alice Collaboration



After more than 10 years of life, still healthy and growing!

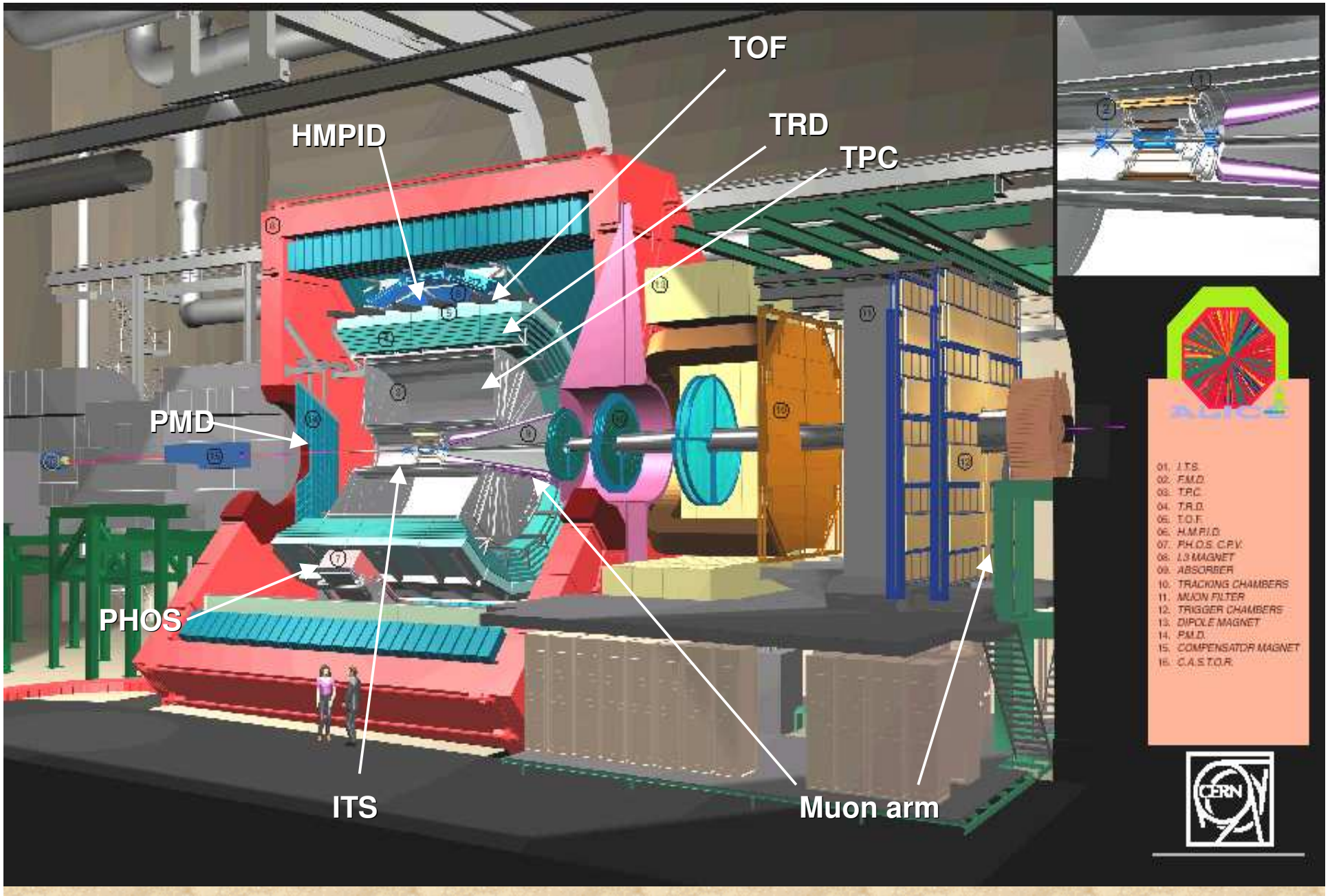


937 members

(63% from CERN MS)

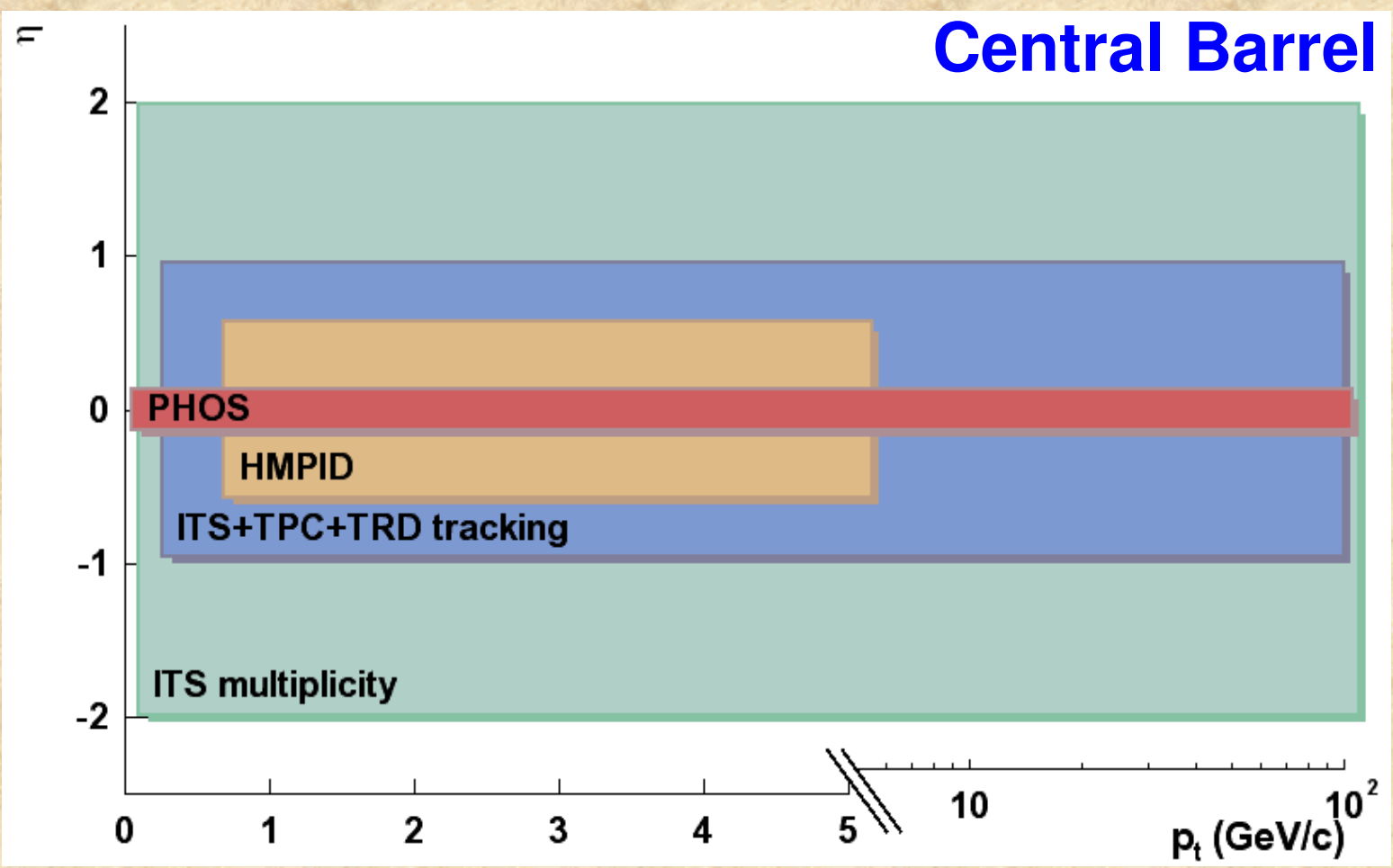
77 Institutions,

29 Countries



ALICE Detector

ALICE DETECTOR ACCEPTANCE



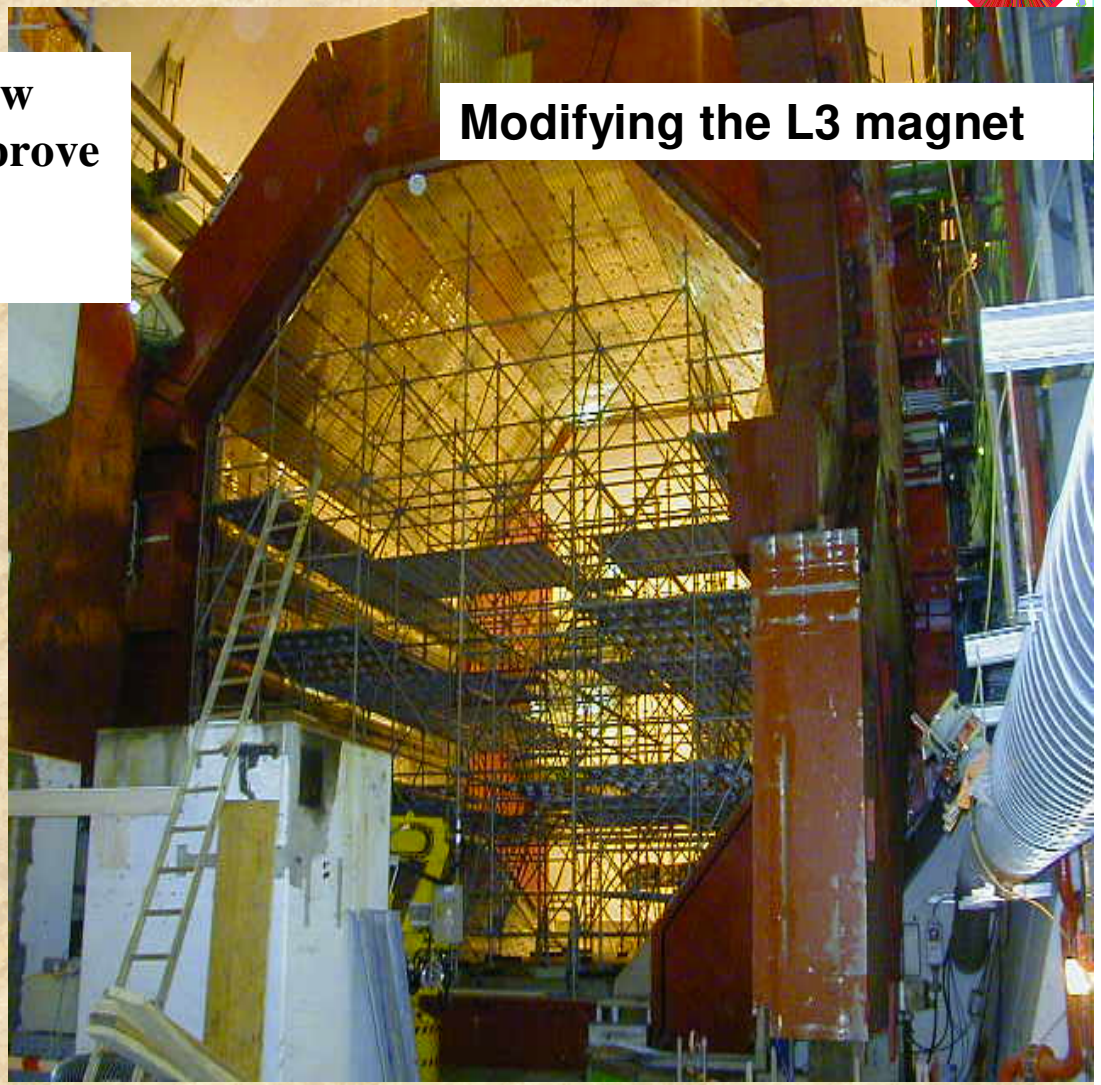
Muon arm: 2.4<η<4

PMD 2.3<η<3.5

FMD: -5.4<η<-1.6, 1.6<η<3

L3 Magnet

Installation of new Iron plugs to improve field quality **finished** (ITEP)



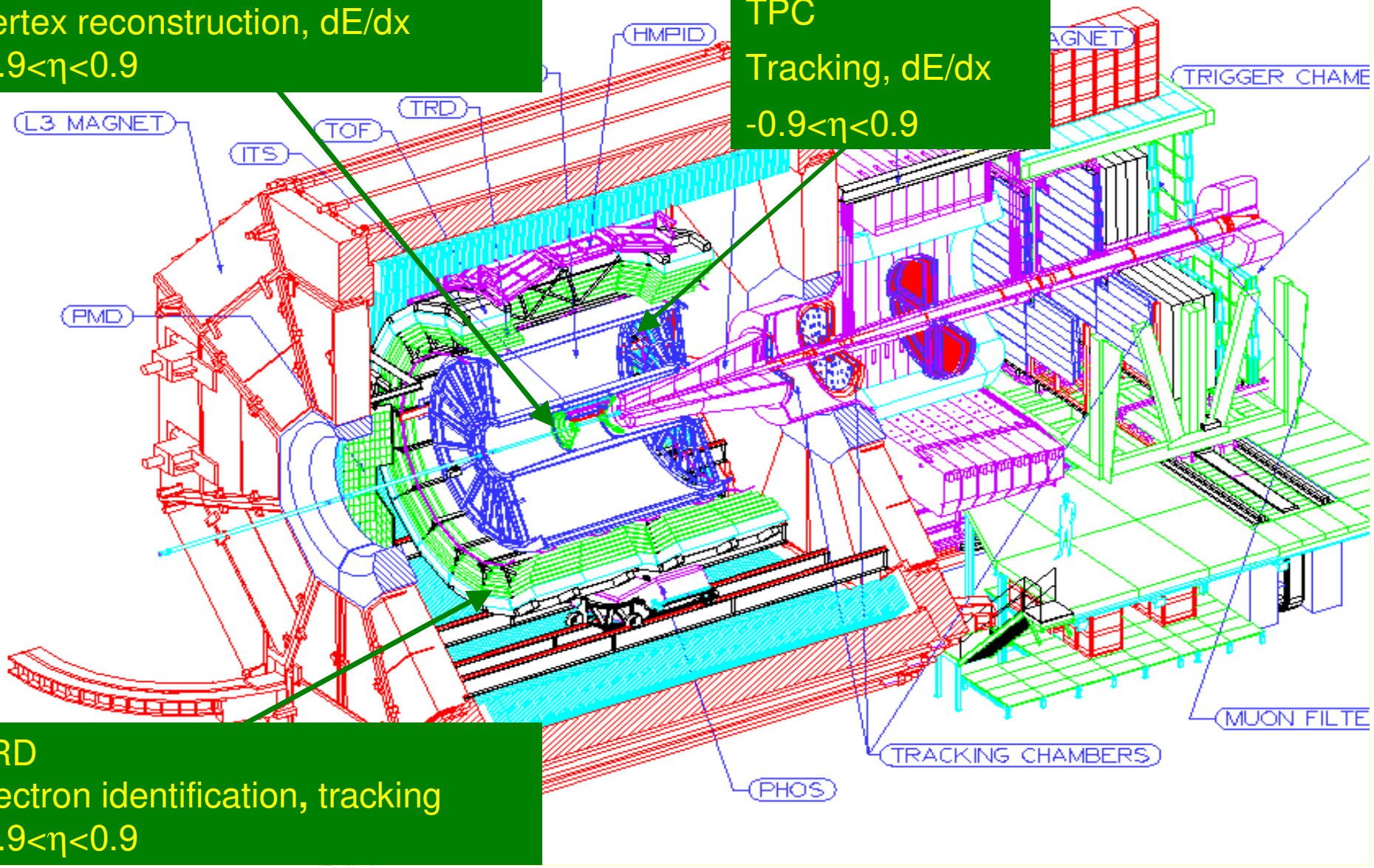
Modifying the L3 magnet

Finished microscopic **inspection** of L3 **cooling**:
Inner parts ok, outer sections need repairs & upgrades (manometers, valves etc..)
Expect to be **able to run** magnet at **nominal field** (0.5 T)

ALICE LAYOUT: TRACKING

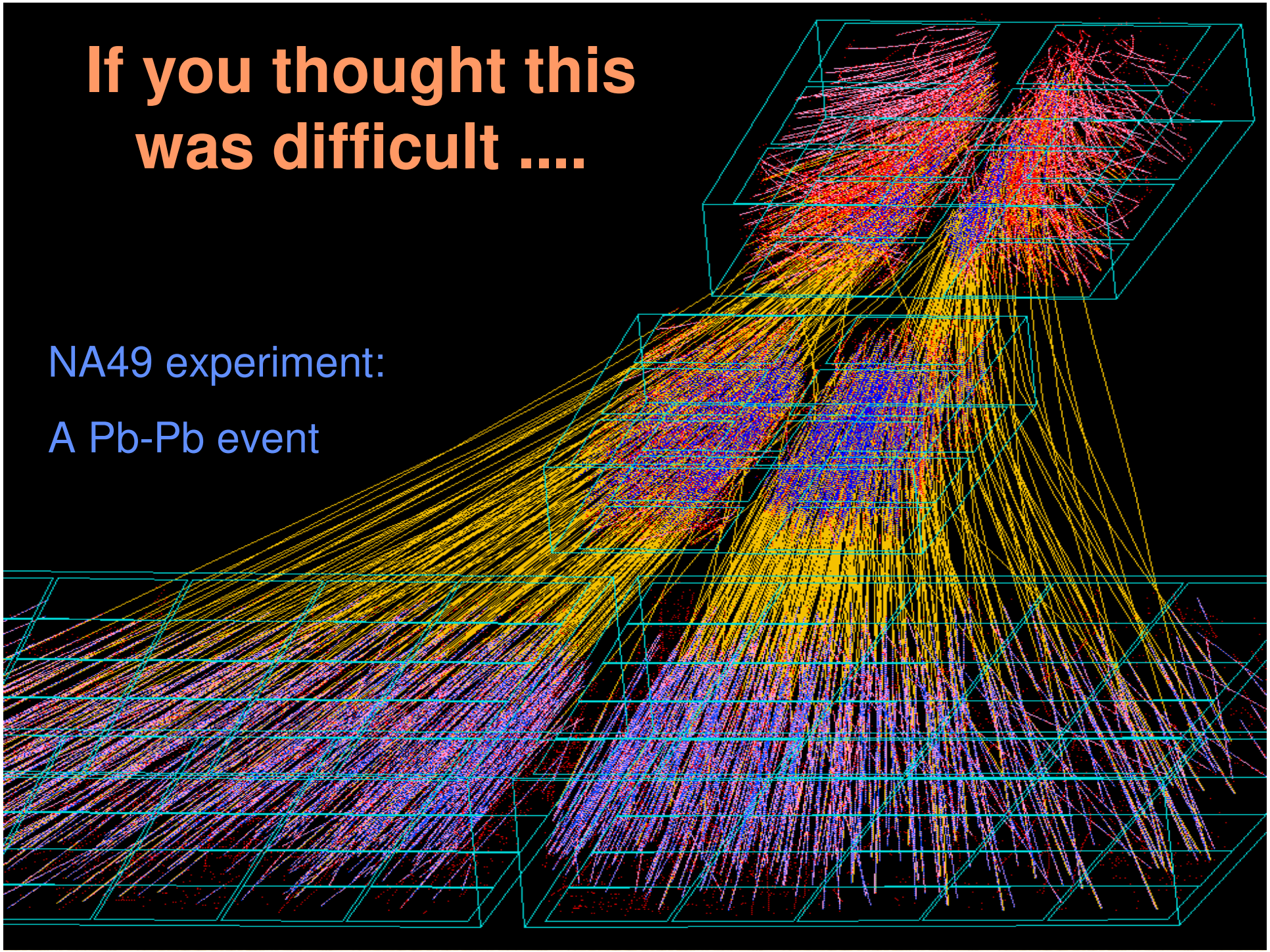
Inner Tracking System (ITS):
6 Si Layers (pixels, drift, strips)
Vertex reconstruction, dE/dx
-0.9<η<0.9

TPC
Tracking, dE/dx
-0.9<η<0.9



TRD
electron identification, tracking
-0.9<η<0.9

If you thought this was difficult ....

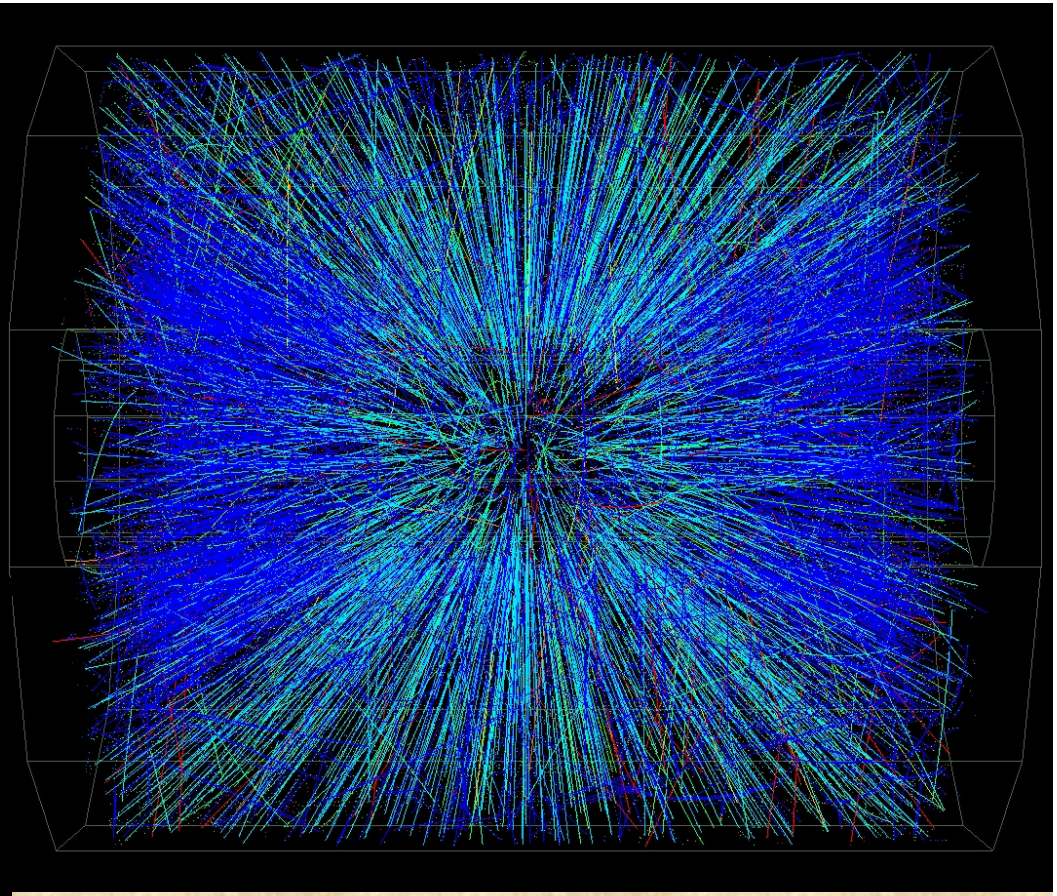


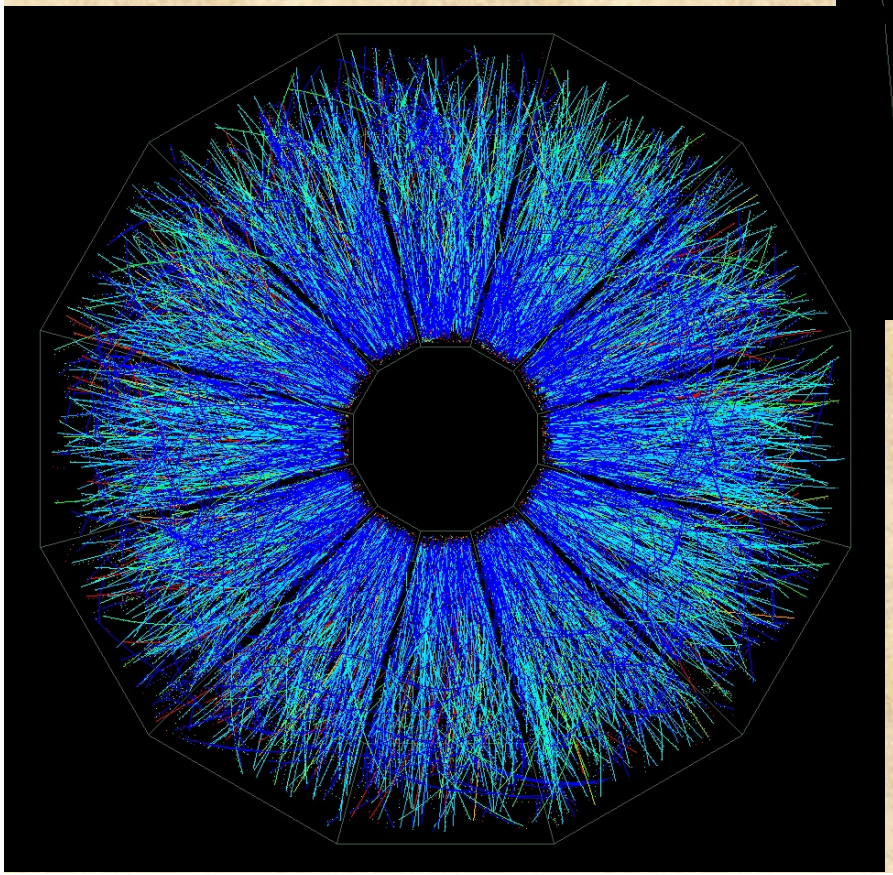
NA49 experiment:

A Pb-Pb event

And

this was almost impossible ...



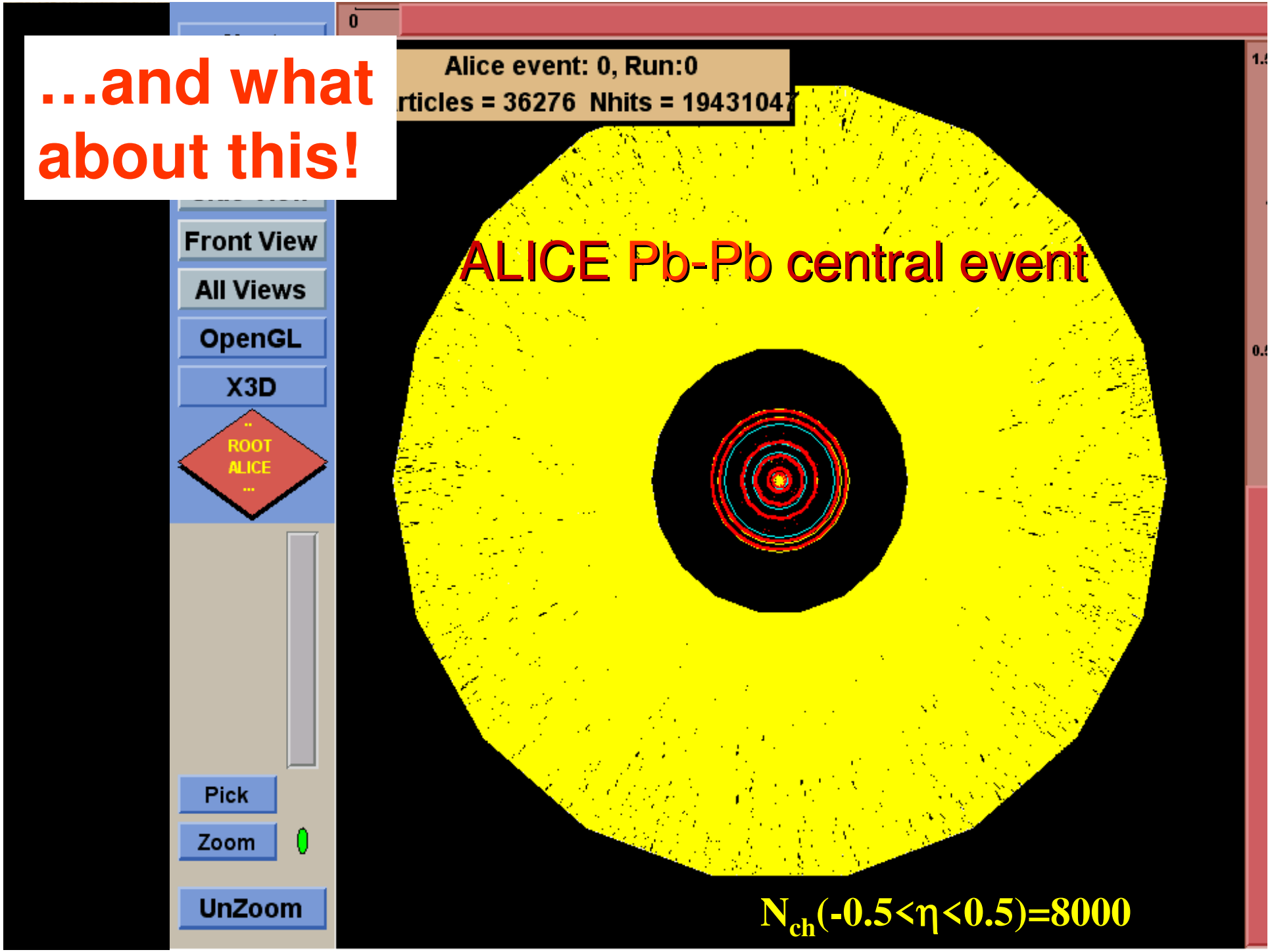


STAR

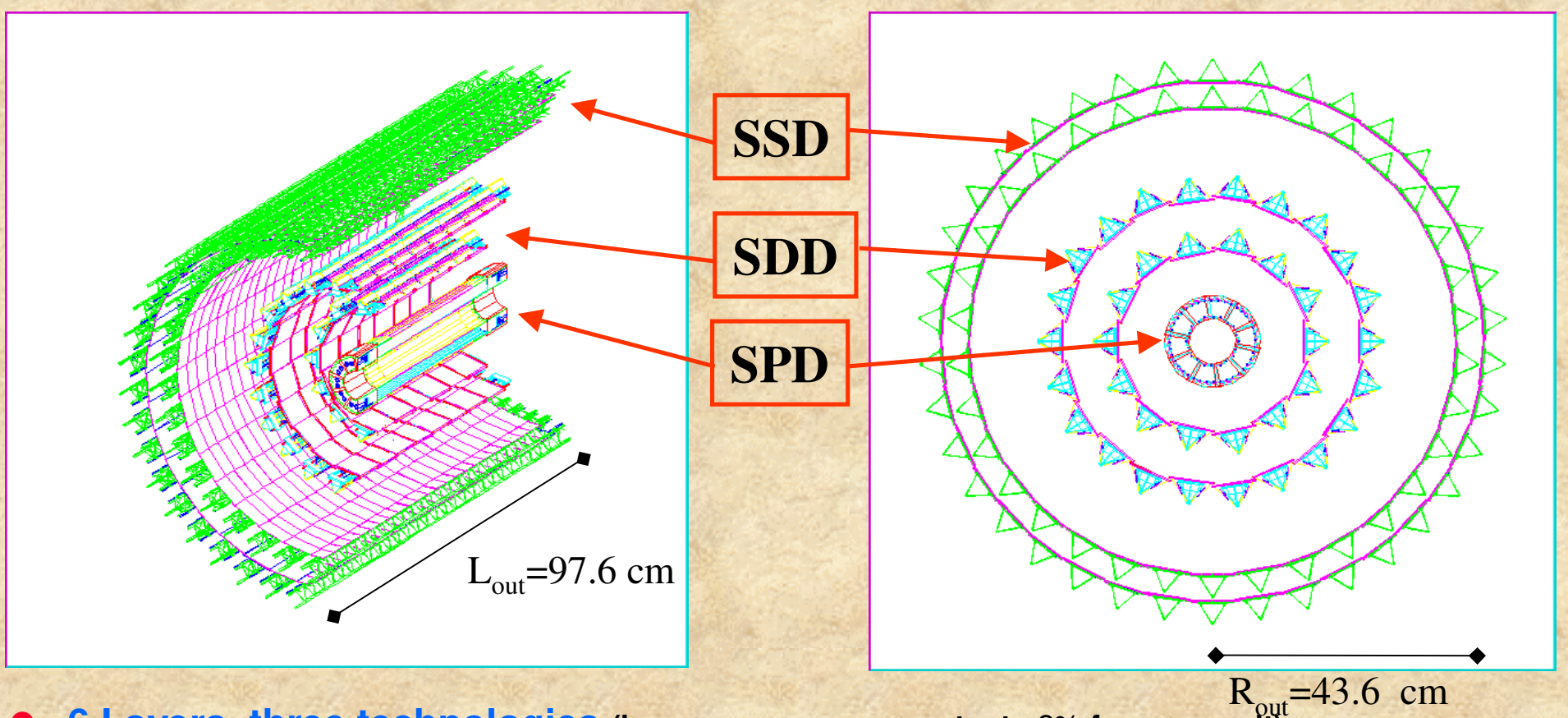
A central Au-Au event

@ ~130 GeV/nucleon

CM energy


…and what about this!
Alice event: 0, Run:0
rticles = 36276 Nhits = 19431047
Front View
All Views
OpenGL
X3D
ROOT
ALICE
Pick
Zoom
UnZoom
ALICE Pb-Pb central event
$N_{ch}(-0.5<\eta<0.5)=8000$

The ALICE Inner Tracking System



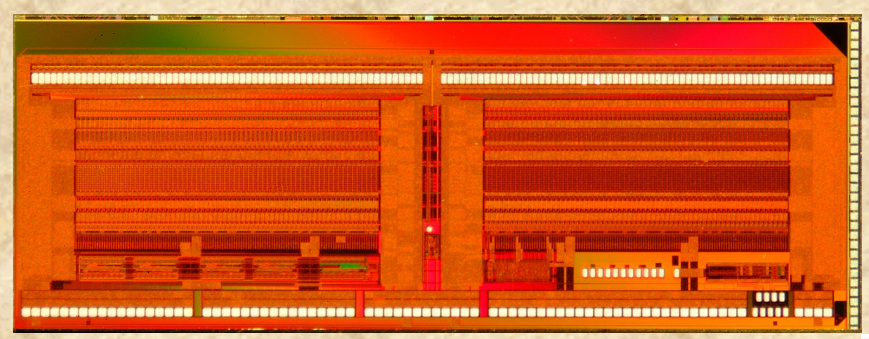
- **6 Layers, three technologies** **(keep occupancy ~constant ~2% for max mult)**
  - ⇨ **Silicon Pixels (0.2 m², 9.8 Mchannels)**
  - ⇨ **Silicon Drift (1.3 m², 133 kchannels)**
  - ⇨ **Double-sided Strip Strip (4.9 m², 2.6 Mchannels)**

Major technological challenge!

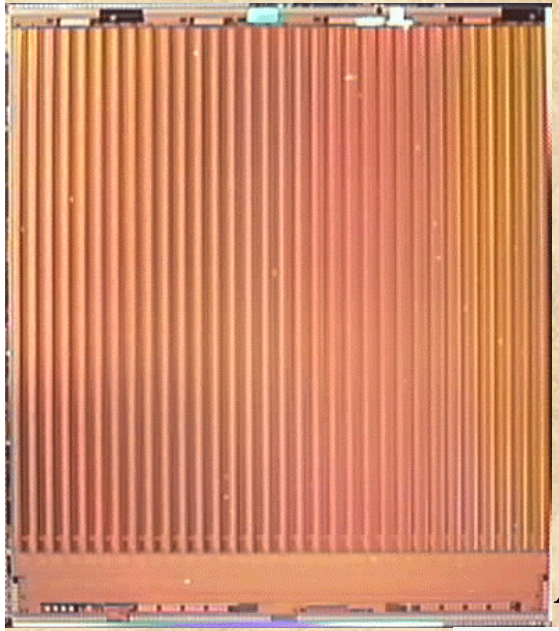
ITS: Many electronics developments

(all full-custom designs in rad. tol., 0.25 μm process)

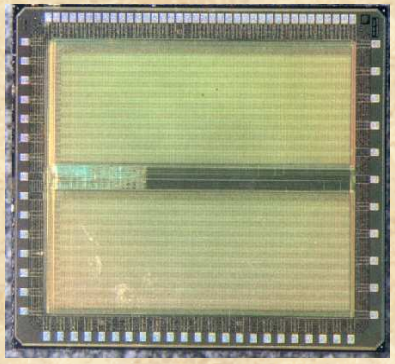
ALICE PIXEL CHIP
50 μm x 425 μm pixels
8192 cells
Area: 12.8 x 13.6 mm^2
13 million transistors
~100 μW/channel

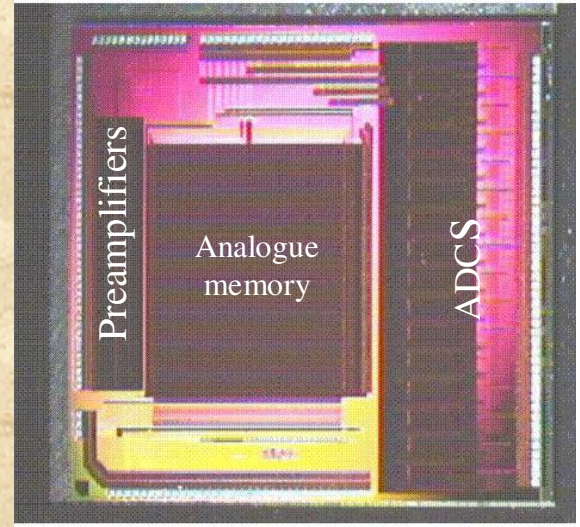


ALICE SSD FEE
HAL25 chip:
128 channels
Preamp+s/h+
serial out



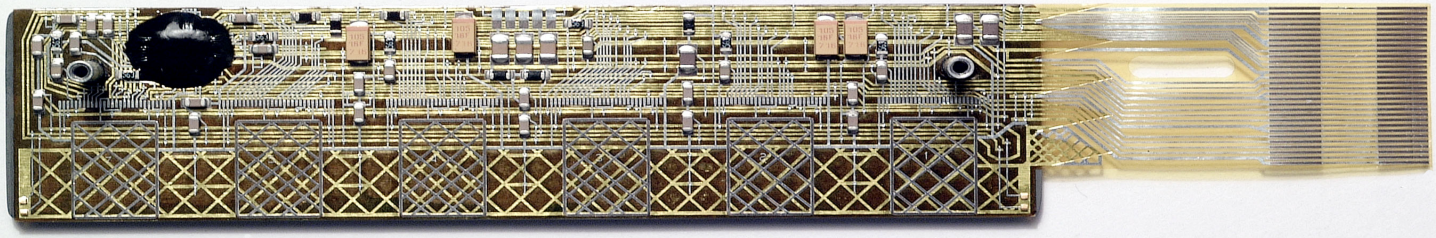
ALICE SDD FEE
Pascal chip:
64 channel preamp+ 256-deep
analogue memory+ ADC
Ambra chip:
64 channel
derandomizer
chip



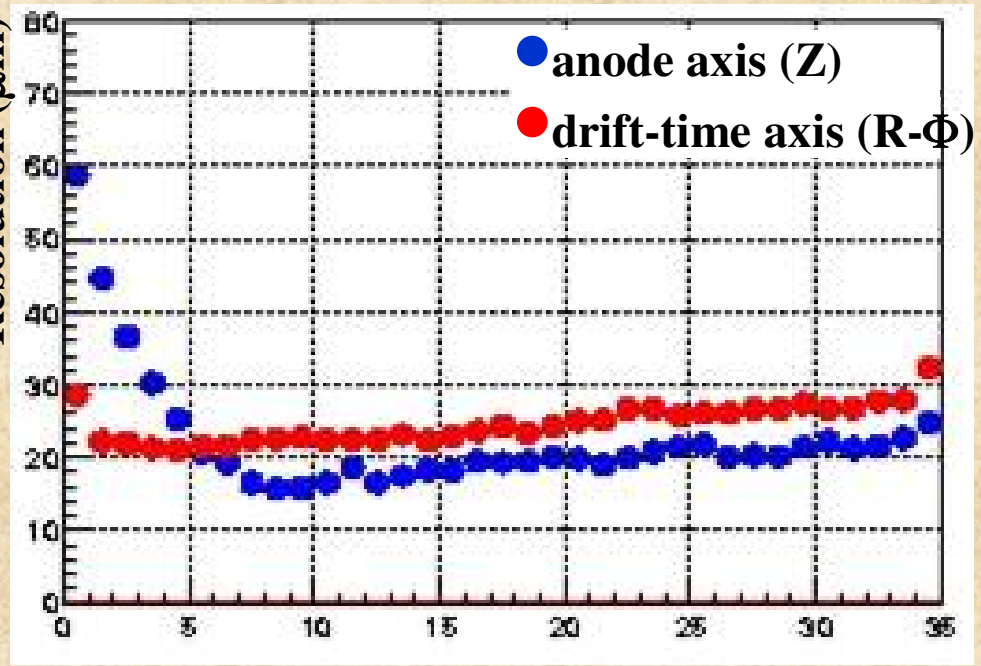


And extreme lightweight interconnection techniques:

SSD tab-bondable
Al hybrids

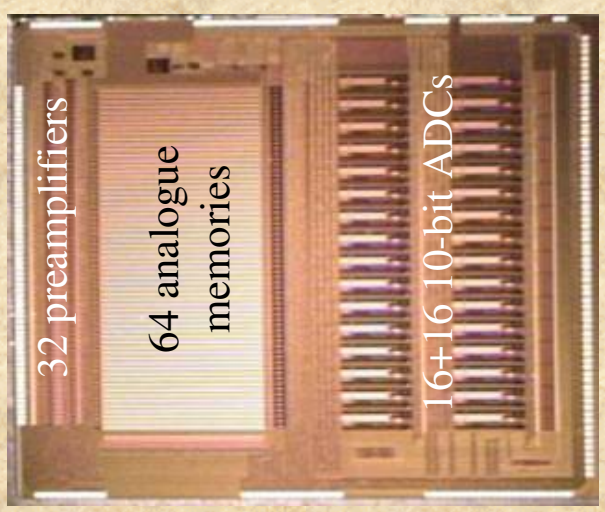


SDD spatial resolution & FEE

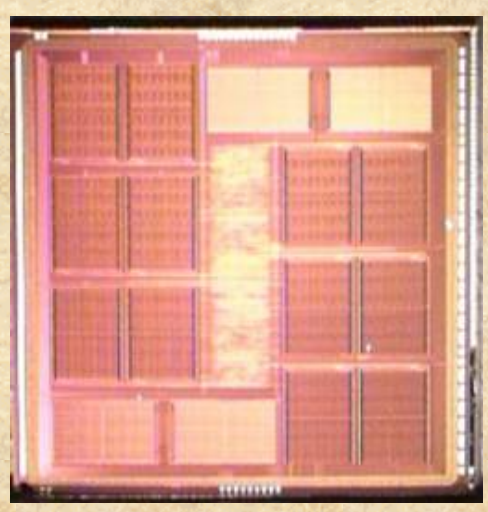


- June 2002 SPS beam test
  - ⇨ Readout with PASCAL-32 + AMBRA-2
- Exceeds design resolution (30 μm)

⇒ PASCAL and AMBRA designs satisfy specs

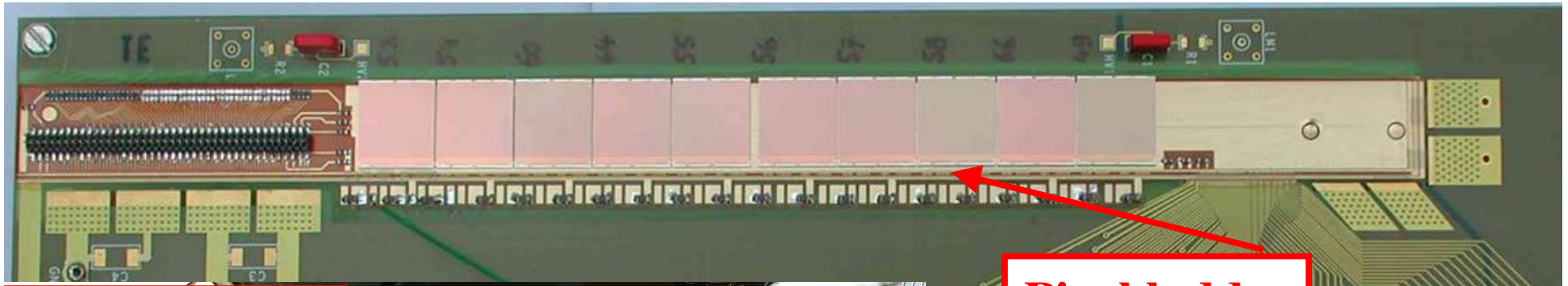


PASCAL-64



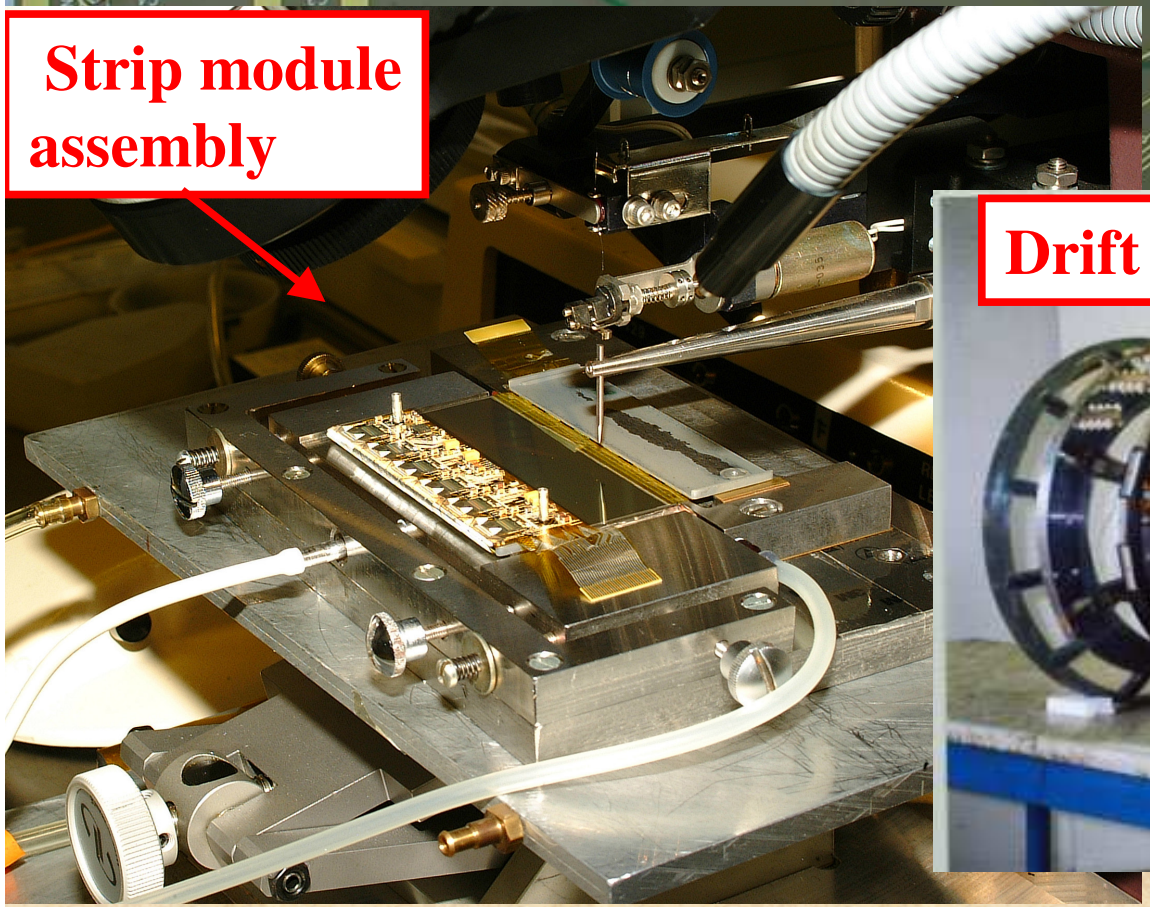
AMBRA-4

- PASCAL-64 (Pre-amp/shaper)
  - ⇨ Full custom, rad-tol, 10*9 mm^2
  - ⇨ 64 channels, differential I/O to/from AMBRA
- AMBRA-4 (digital buffer)
  - ⇨ New rad-tol design, 8*9 mm^2
  - ⇨ 4-level digital buffer (16kB each)
  - ⇨ differential I/O to/from PASCAL & end-ladder

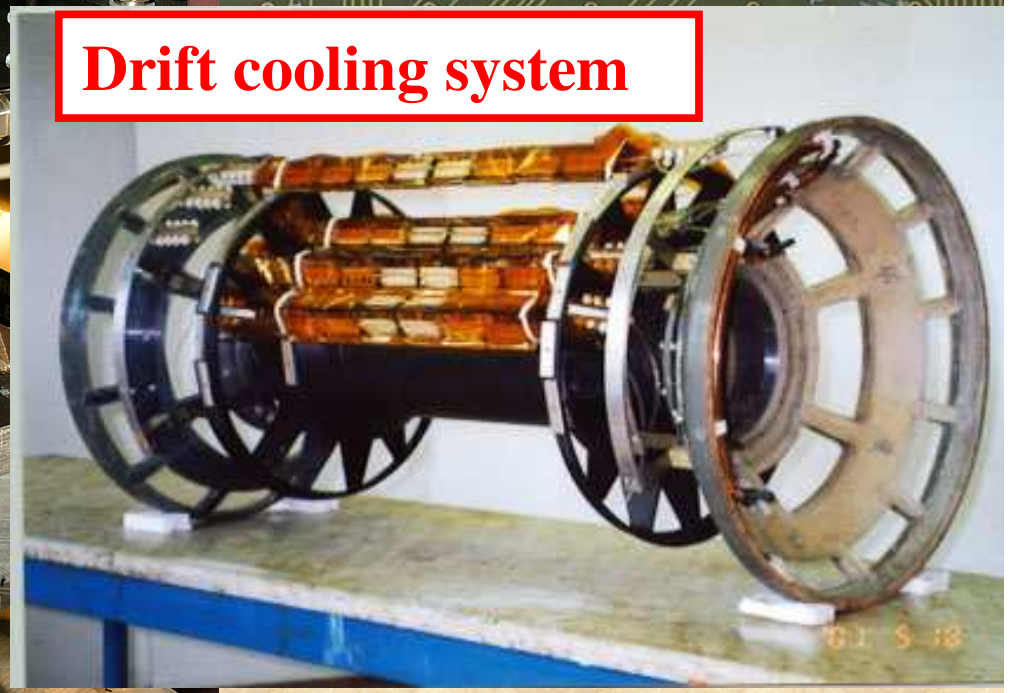


Pixel ladder

Strip module assembly

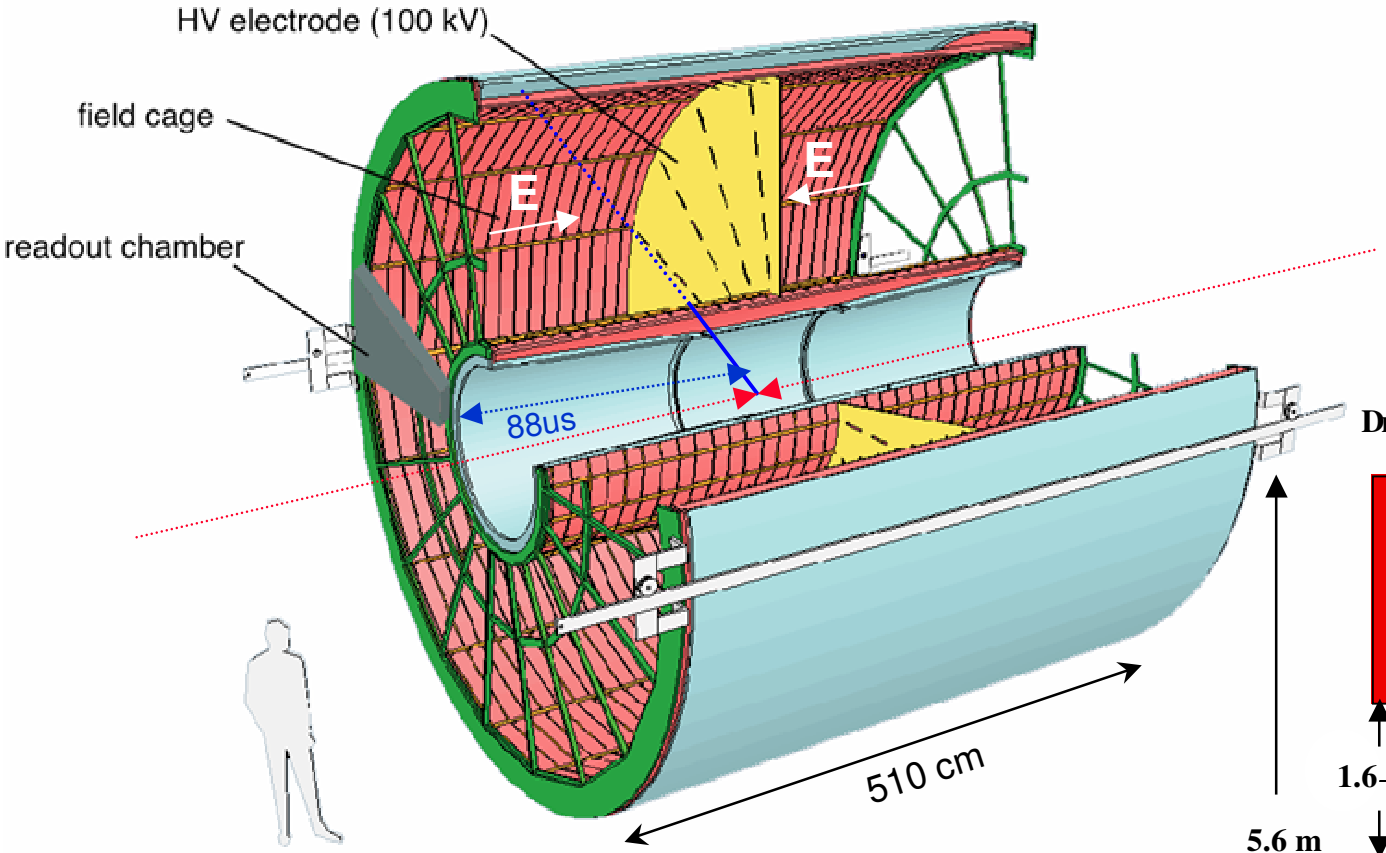


Drift cooling system



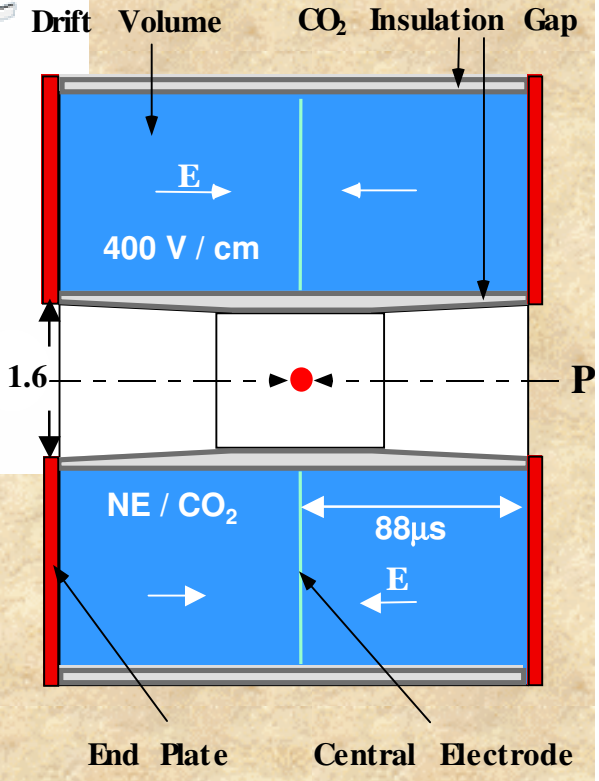
System testing and setting up of series production

TPC layout



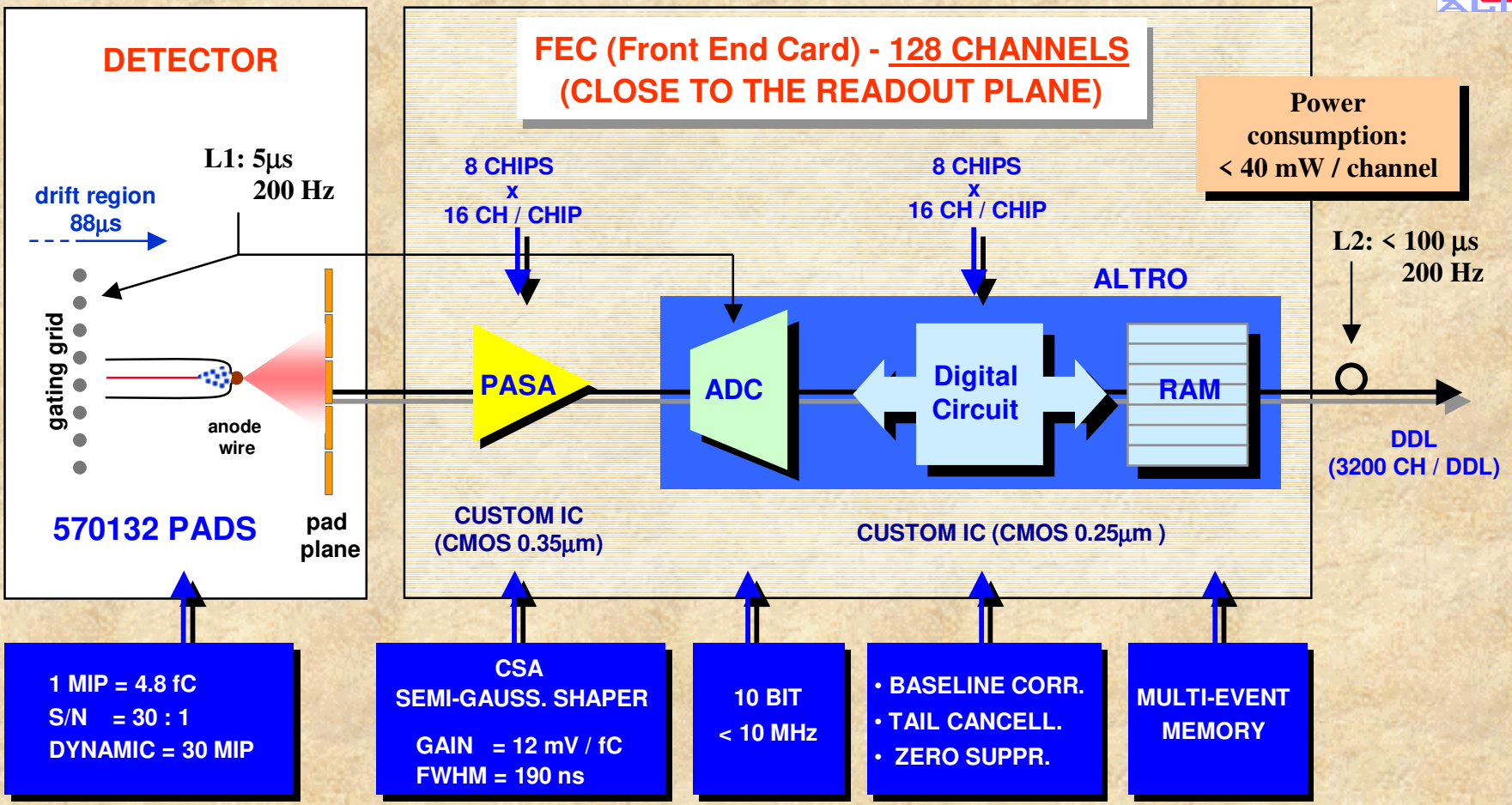
GAS VOLUME
88 m³

DRIFT GAS
90% Ne - 10%CO_2



Readout plane segmentation
18 trapezoidal sectors
each covering 20 degrees in azimuth

Front End Electronics Architecture

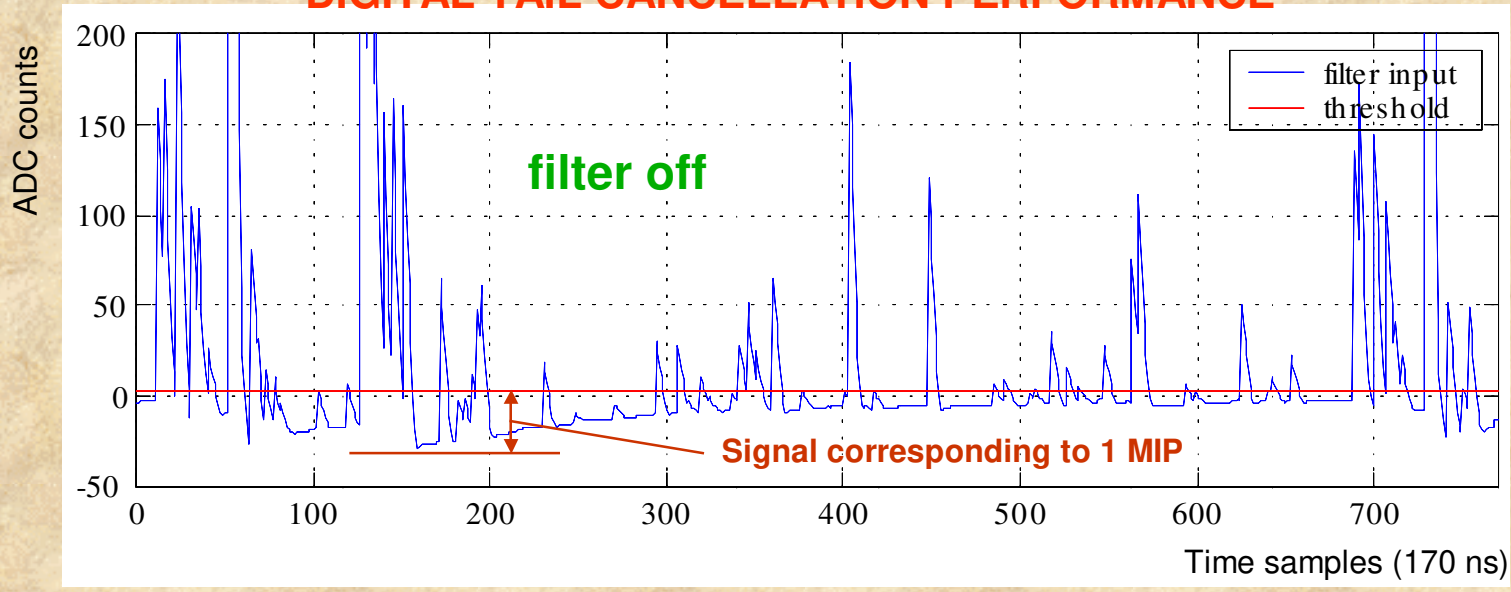


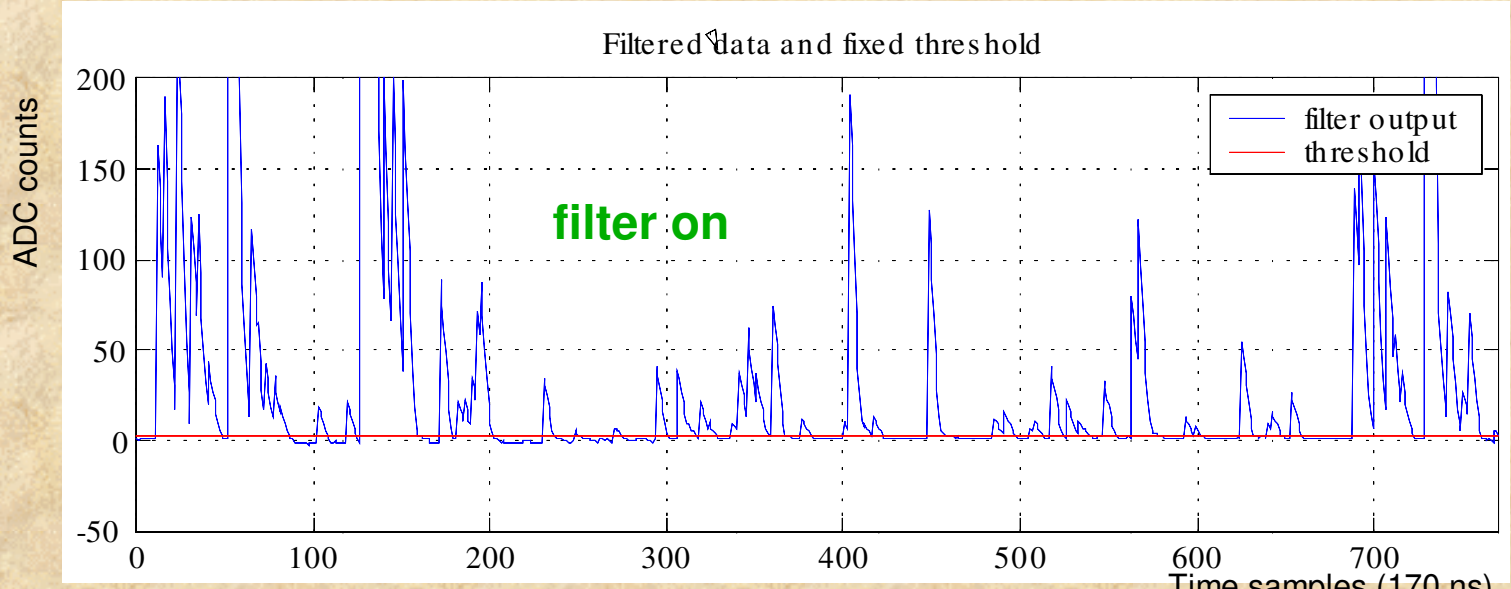
FEE FOR THE NA49 AND STAR TPCs

- analog memory in front of the ADC ⇒ readout time independent of the occupancy
- no zero suppression in the FEE ⇒ high data throughput on the detector data links

The Ion–Tail Problem

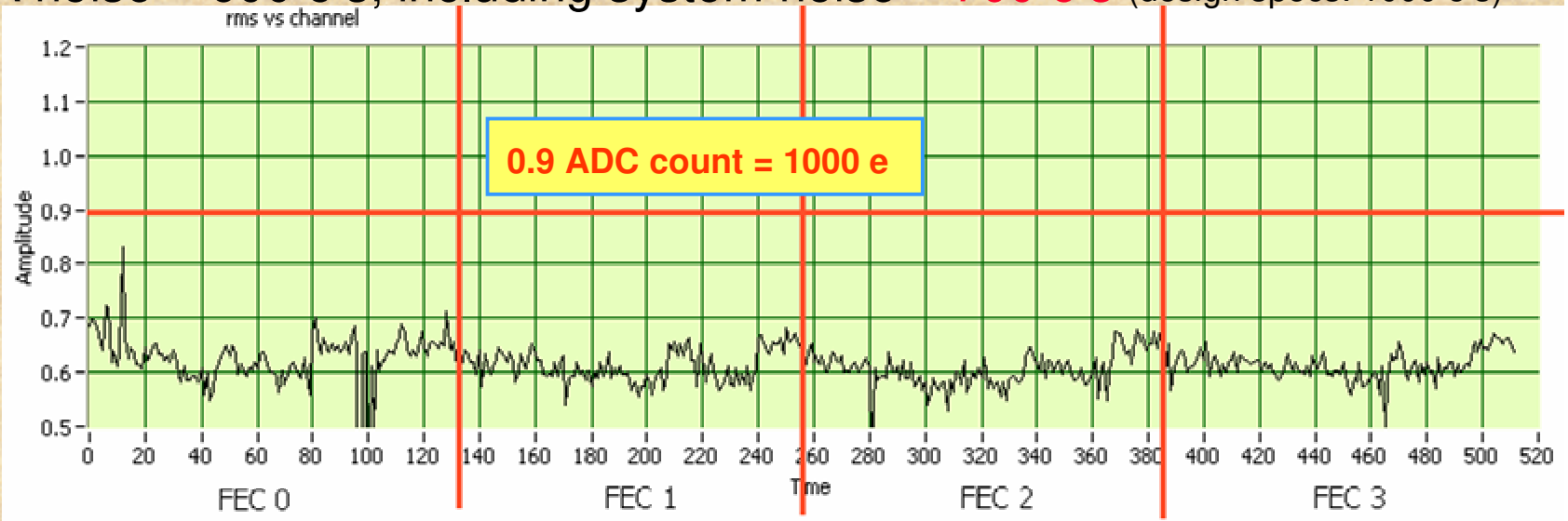
DIGITAL TAIL CANCELLATION PERFORMANCE

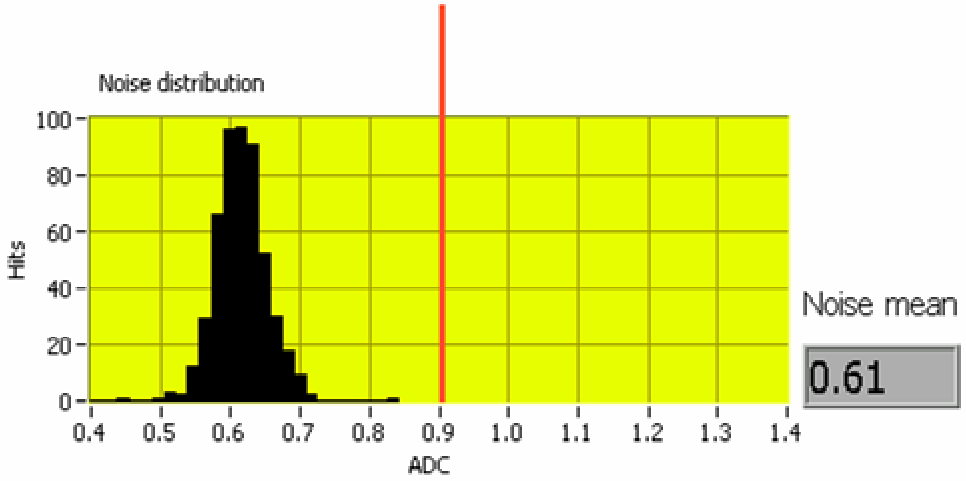


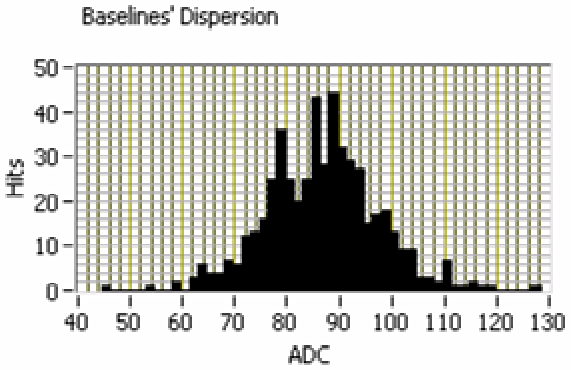


TPC Sector Test

- **TPC prototype FC + 1 production IROC**
  - ⇨ cosmic ray test with ~ final FEE
  - ⇨ PASA noise ~ 600 e's, including system noise ~ 700 e's (design specs: 1000 e's)

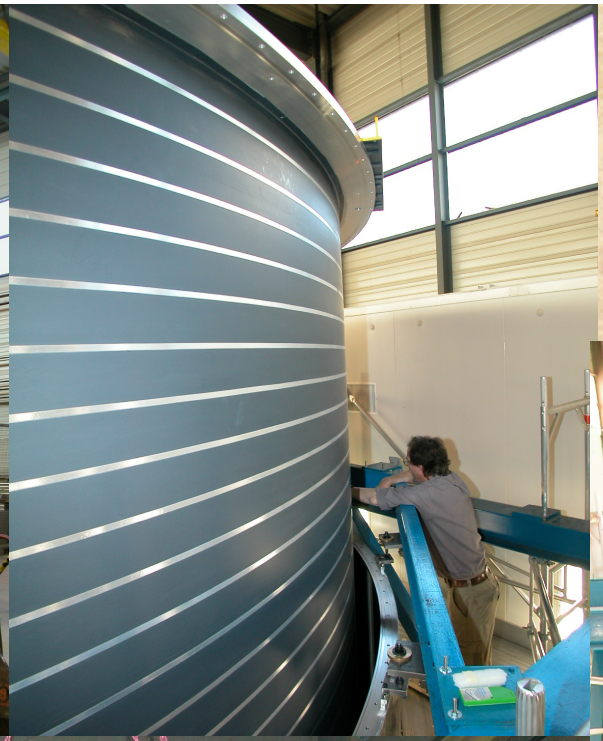


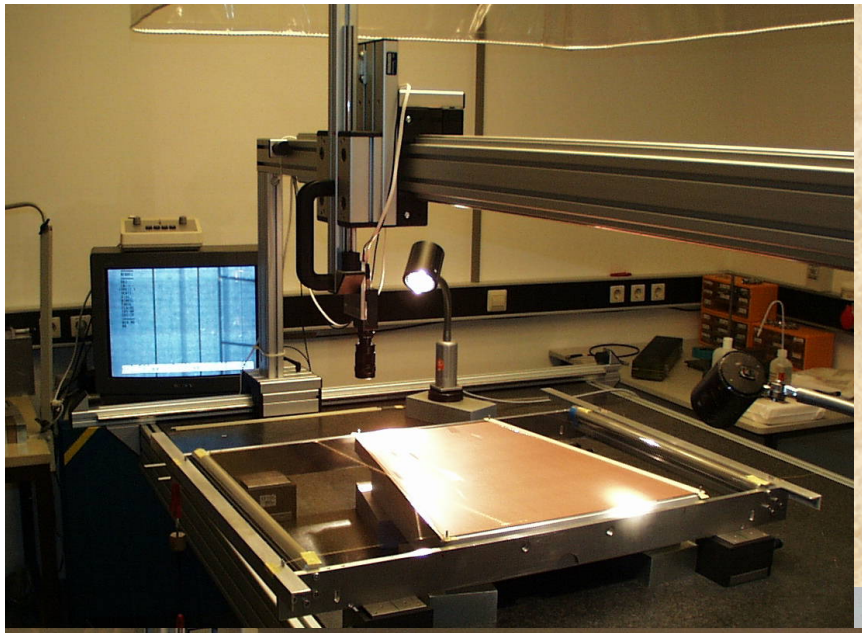




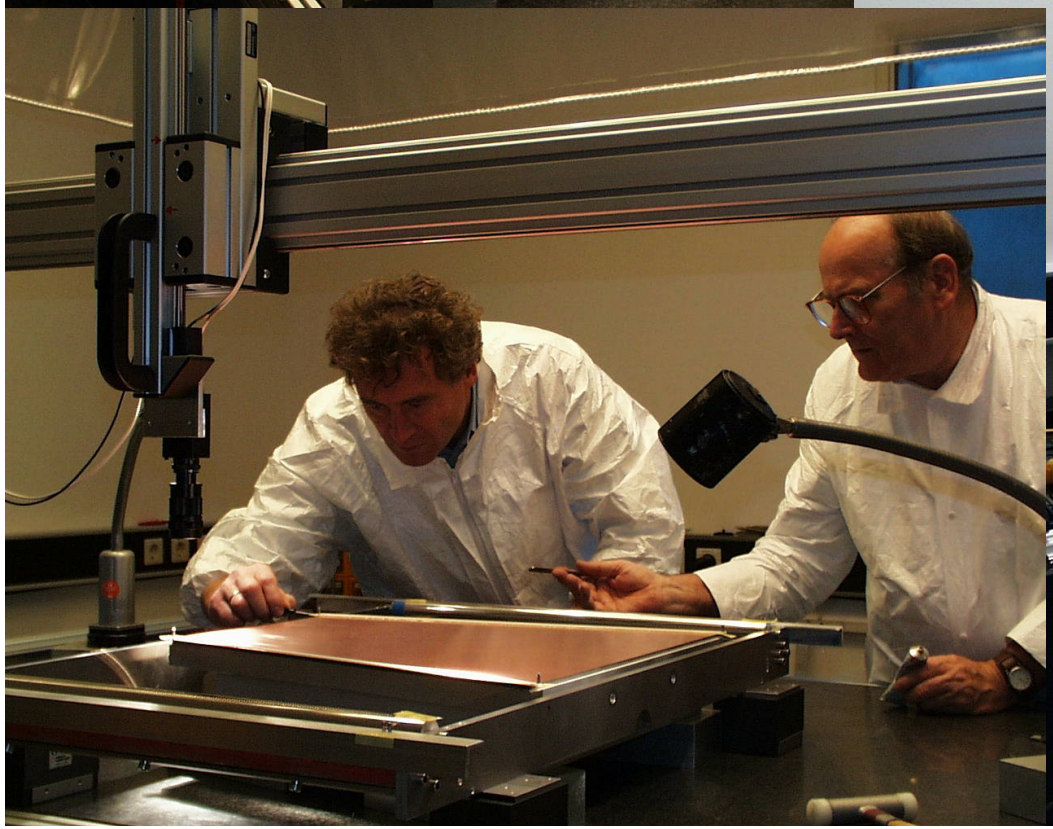
The ALICE TPC becomes real

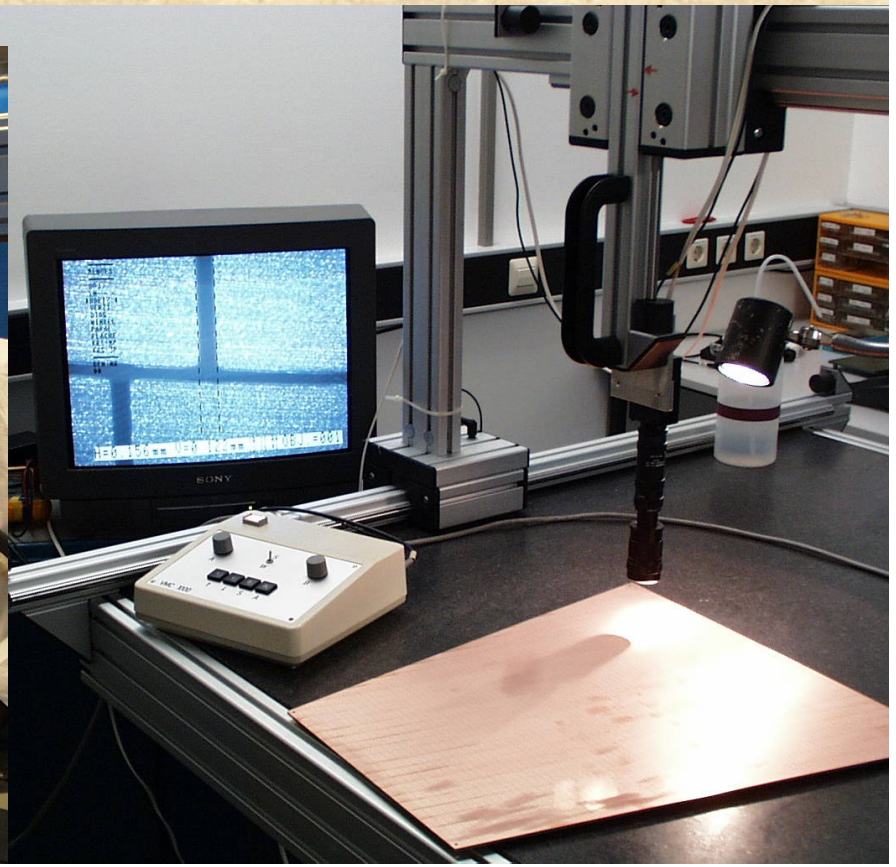
(outer field cage and end plates)



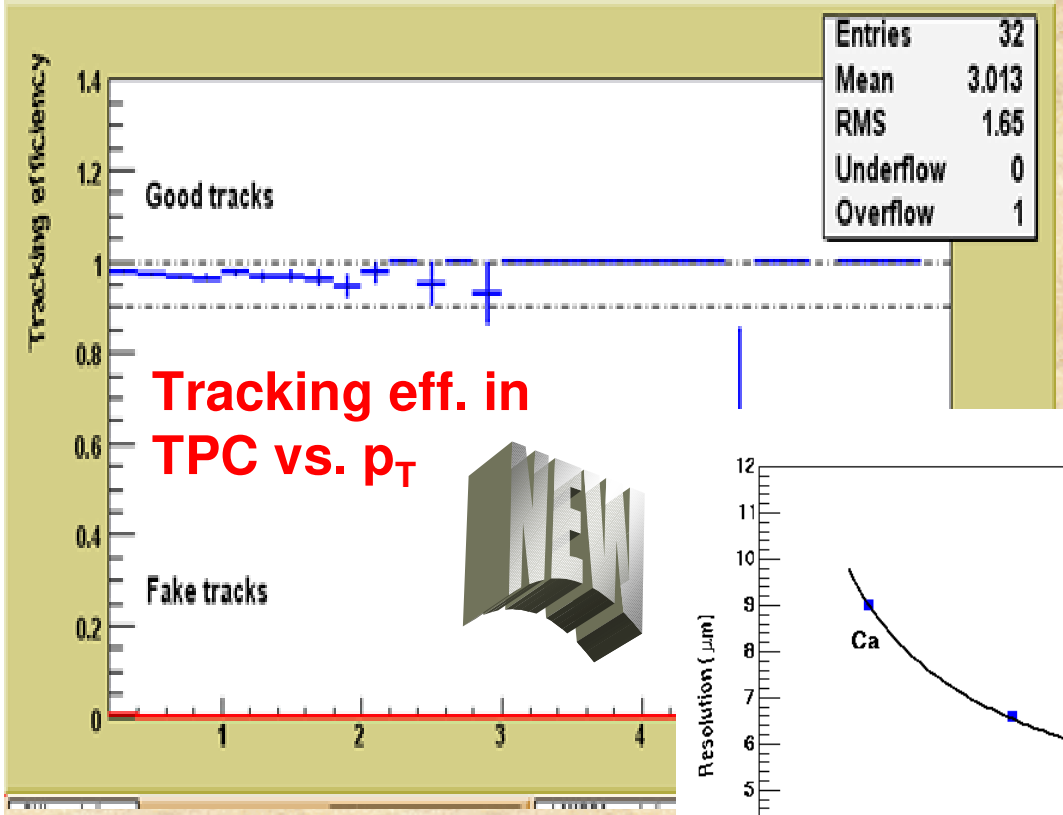


Construction of the TPC readout chambers: more than half of the inner ones already completed!

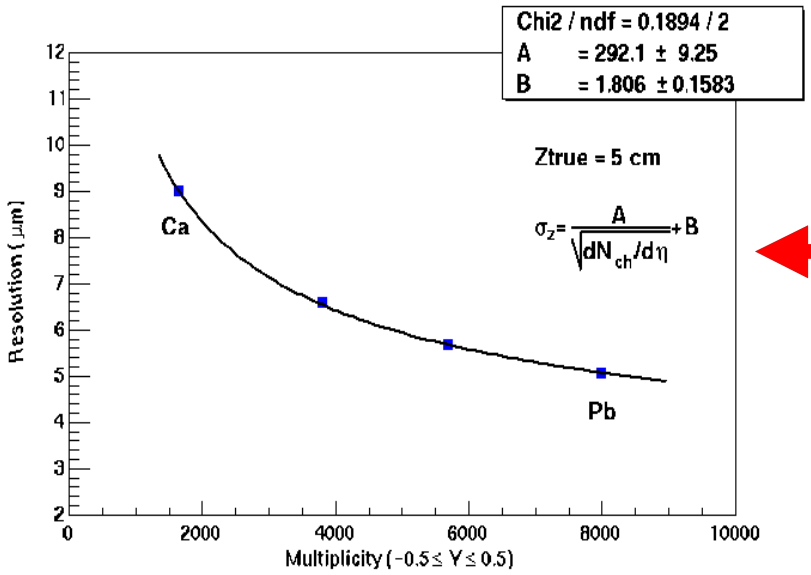




Tracking performance-I



Tracking eff. in TPC vs. p_T



Primary vertex from pixels (combinatorial)

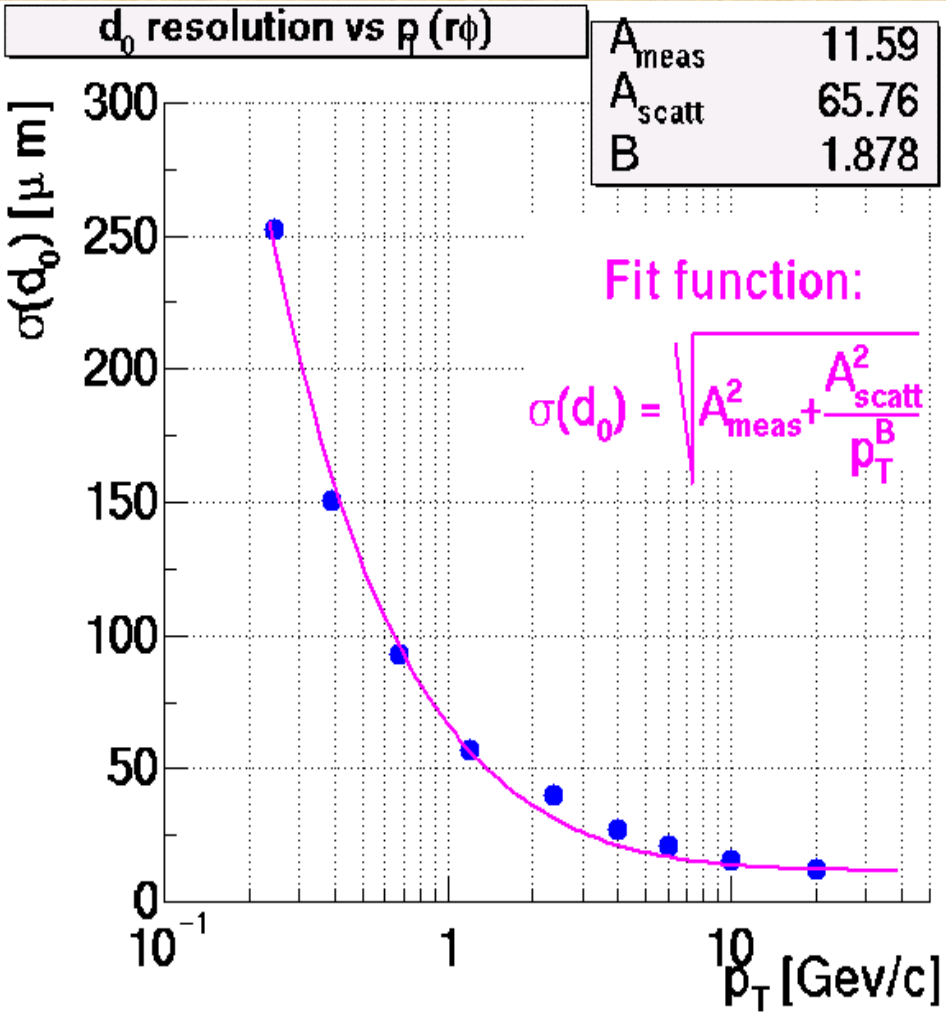
$\sigma_x = 15\ \mu m$

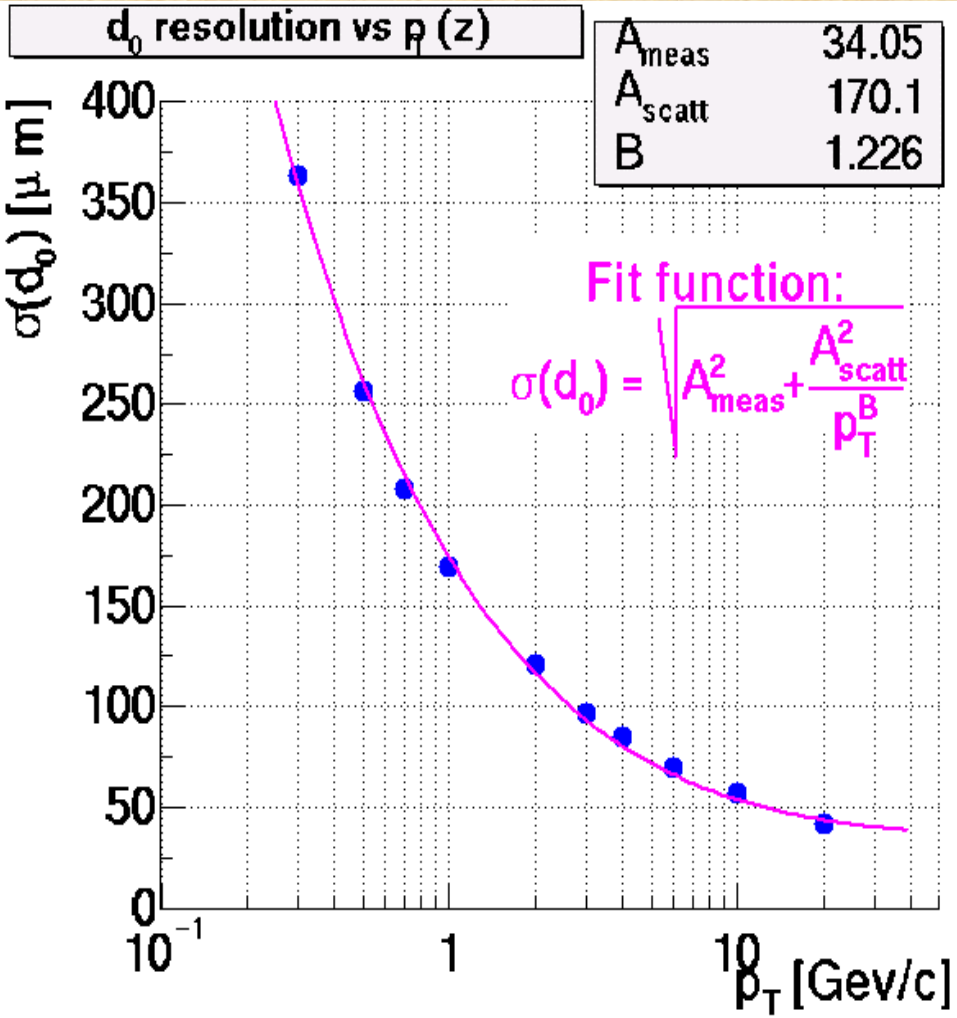
$\sigma_y = 15\ \mu m$

$\sigma_z = 5\ \mu m$

Track reconstruction in TPC-ITS: d_0 measurement

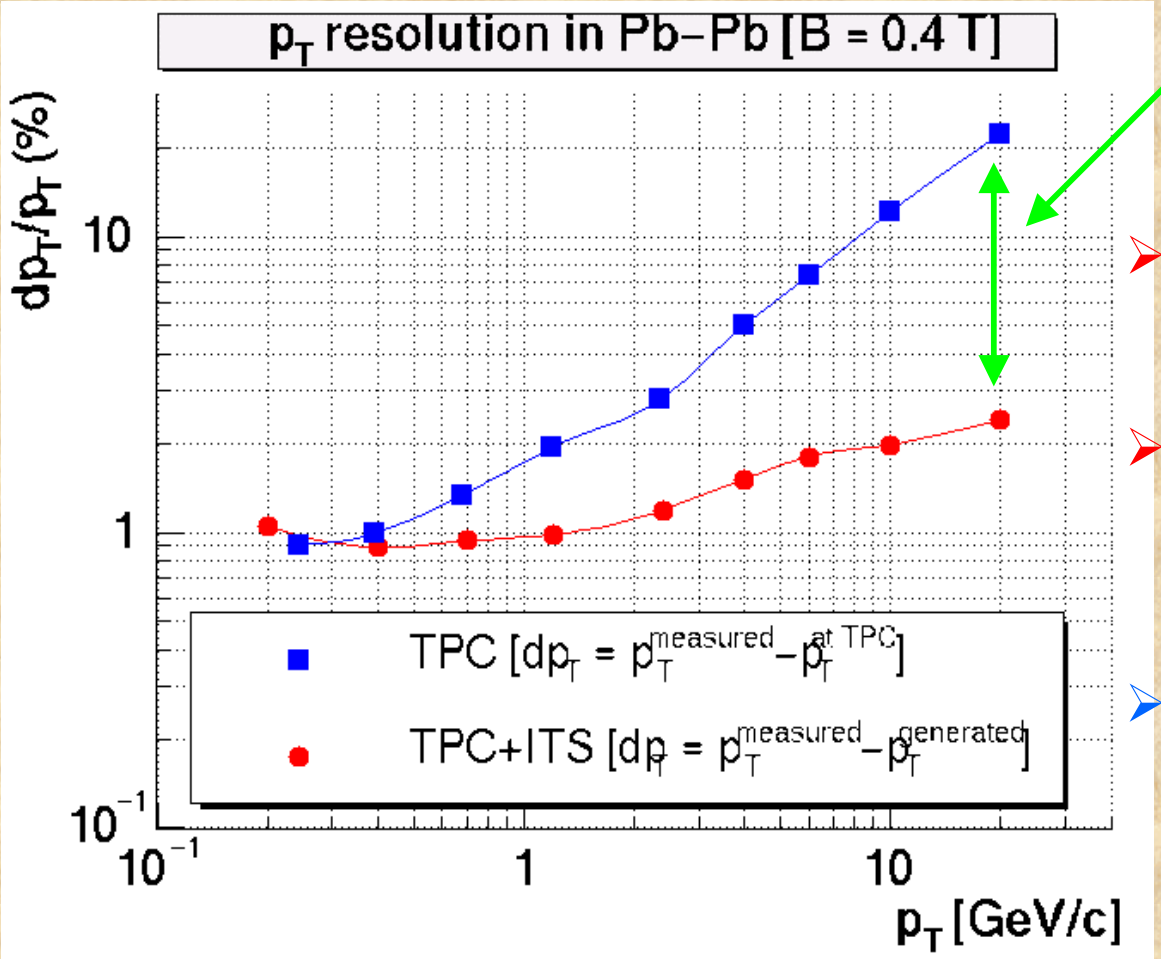
- Measurement of impact parameters is crucial for secondary vertex reconstruction





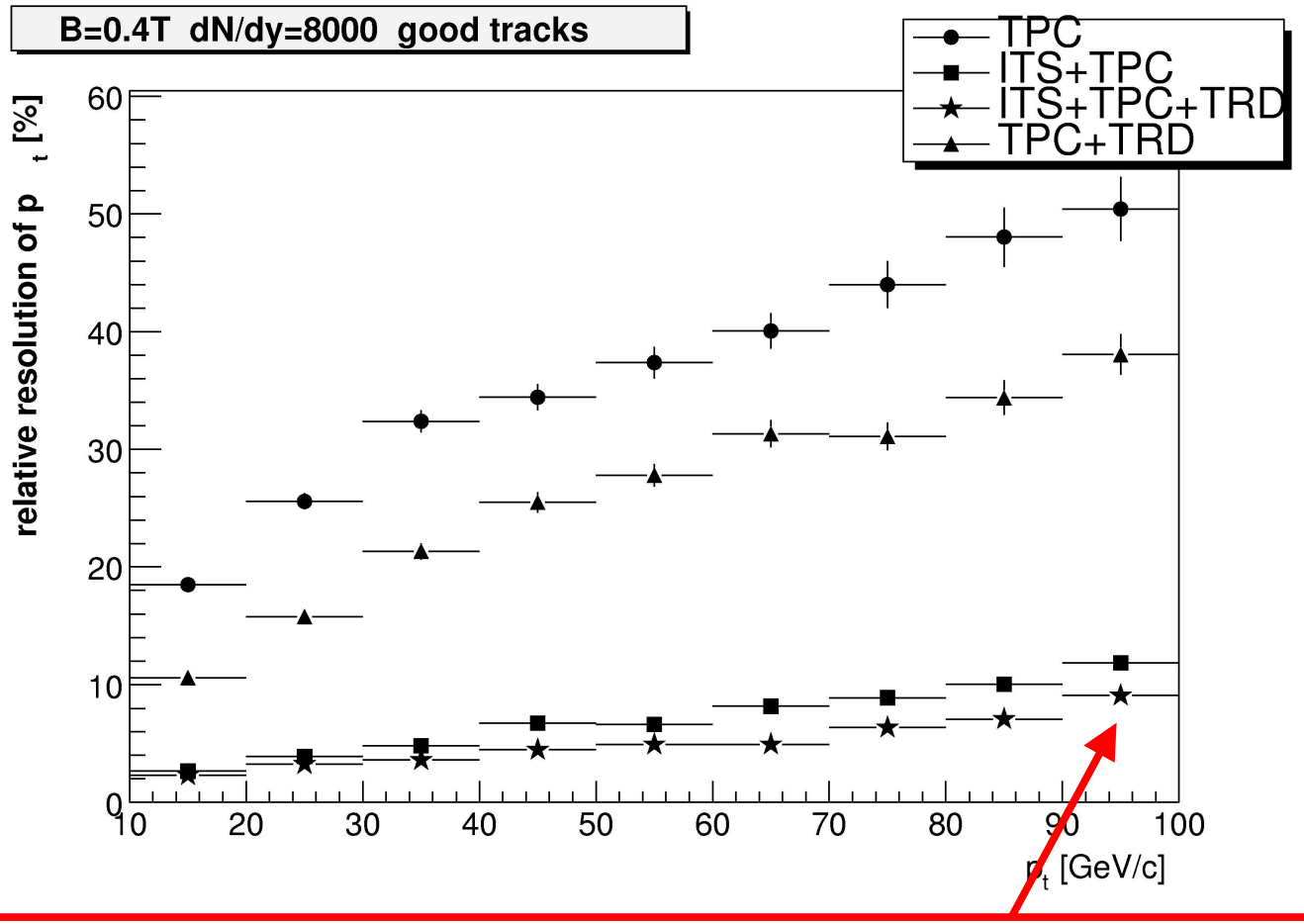
Track reconstruction in TPC-ITS: p_T resolution

- The track momentum is measured (mainly) by the TPC
- With ITS: resolution improves by a factor ~10 for high p_T tracks



- Lever arm larger by 1.5 accounts for a factor ~ 2
- Remaining effect due to high resolution of points measured in ITS
- More improvement comes including the TRD in the tracking

Tracking-II: Momentum resolution

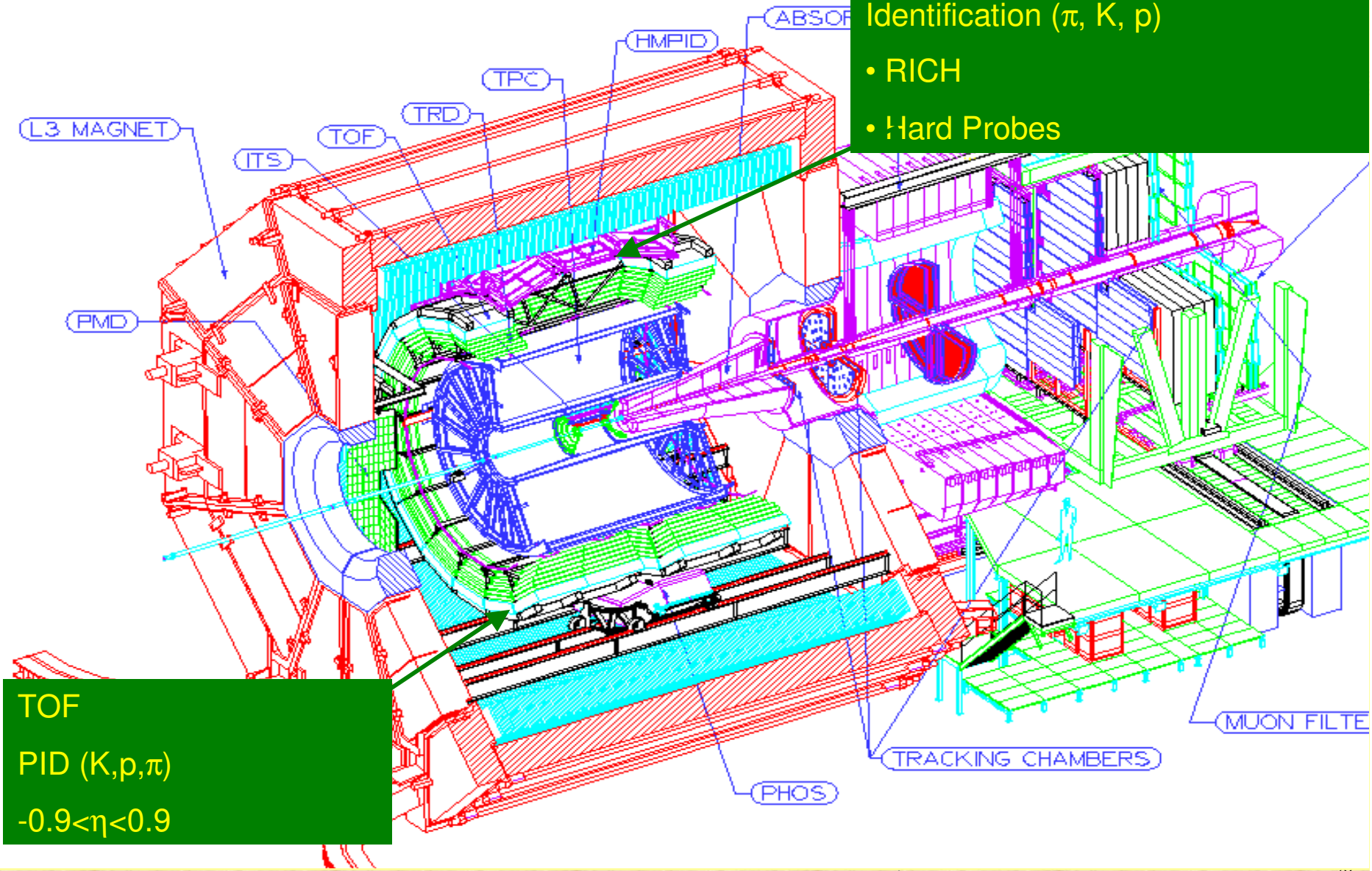


resolution ~ 9% at 100 GeV/c
excellent performance in hard region!

ALICE LAYOUT: PID

HMPID: High Momentum Particle Identification (π, K, p)

- RICH
- Hard Probes



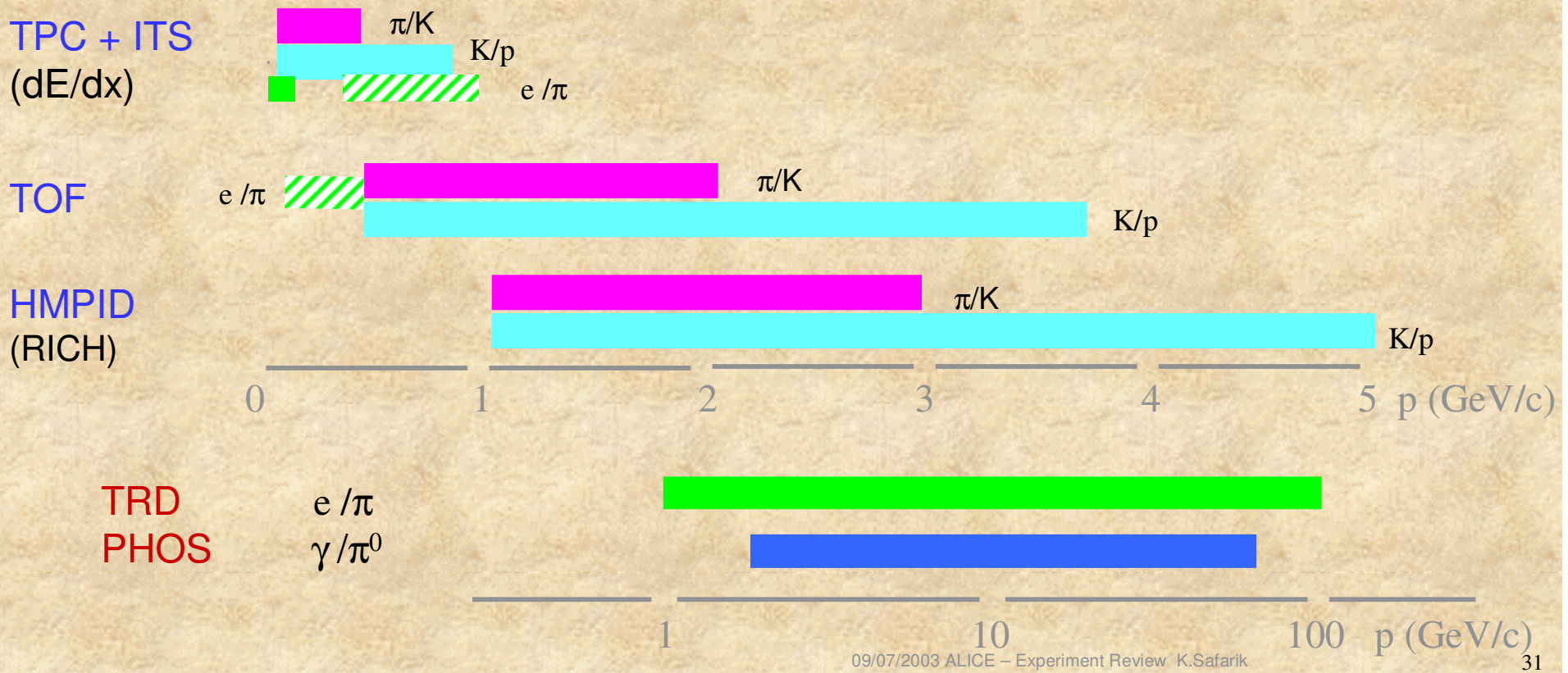
TOF

PID (K,p,π)

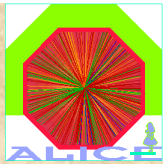
-0.9<η<0.9

ALICE PID - I

- π, K, p identified in large acceptance (2π * 1.8 units η) via a combination of dE/dx in Si and TPC and TOF from ~100 MeV to 2 (p/K) - 3.5 (K/p) GeV/c
- Electrons identified from 100 MeV/c to 100 GeV/c (with varying efficiency) combining Si+TPC+TOF with a dedicated TRD
- In small acceptance HMPID extends PID to ~5 GeV
- Photons measured with high resolution in PHOS, counting in PMD, and in EMC



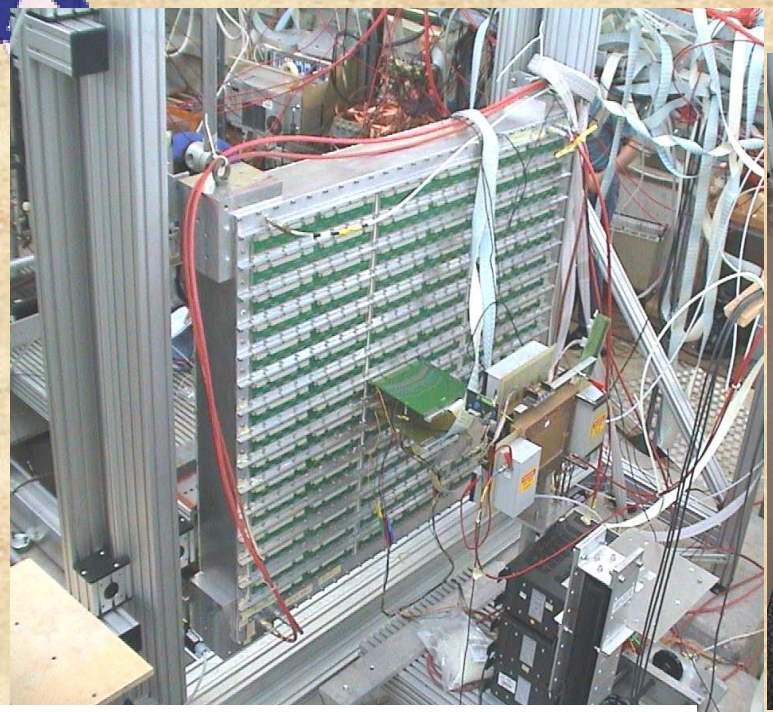
ALICE PID - II

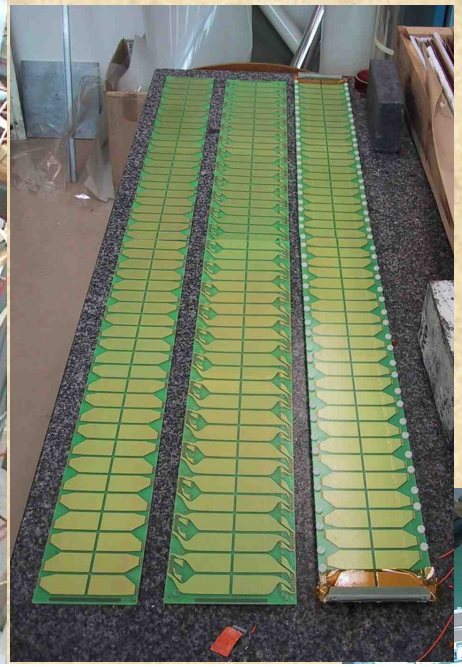


- Λ are identified reconstructing the decay vertex for transverse momenta in the range 500 MeV/c to ~ 15 GeV/c
- Same for K^0 in the range 250 MeV/c to ~ 10 GeV/c
- Identification of K via the detection of the decay vertex (kink): the method is expected to have reasonable efficiency from 300 MeV/c up to ~ 10 GeV/c
- Also under study is the possibility of identification of π, (K, p) in the relativistic rise region using dE/dx in both TPC and TRD

Full size TOF modules under test

Time Of Flight





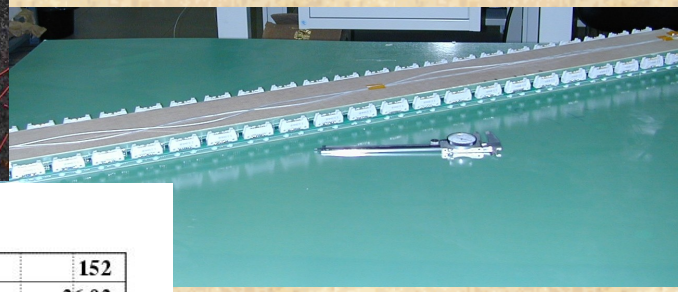
for π, K, p PID

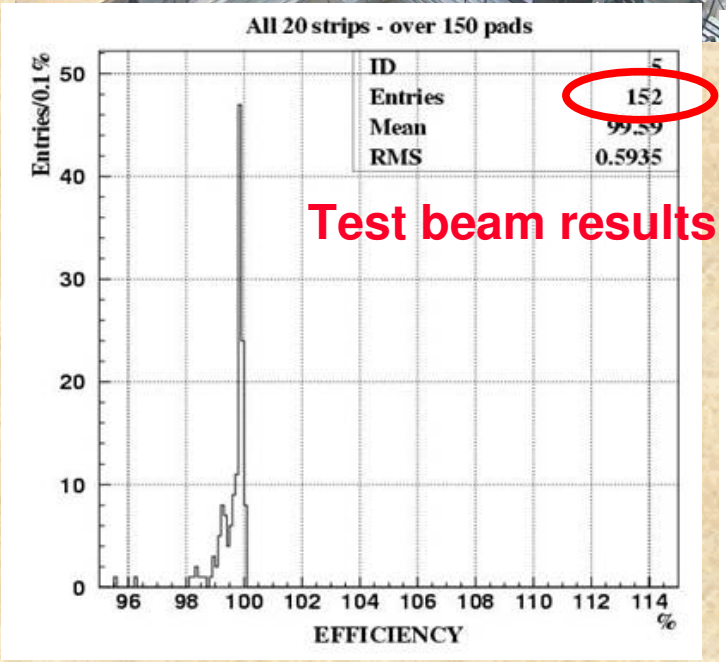
π-K for p <2 GeV/c

K-p for p <4 GeV/c

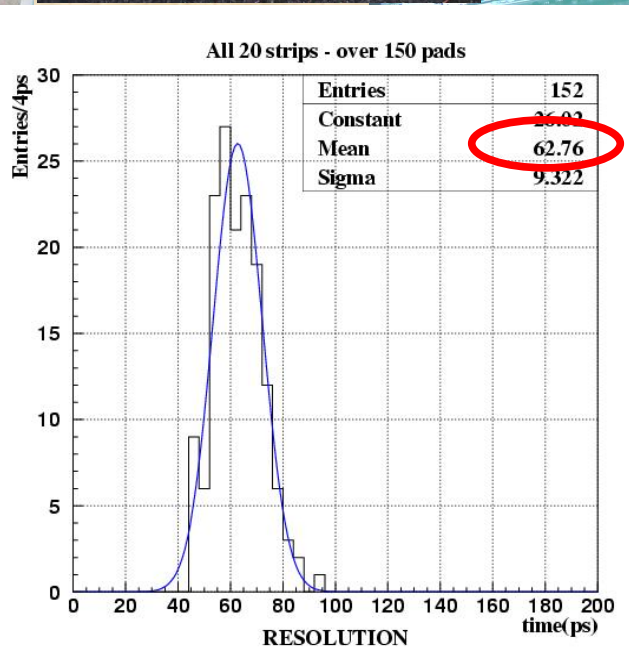
- 0.9 < η < 0.9

full ϕ



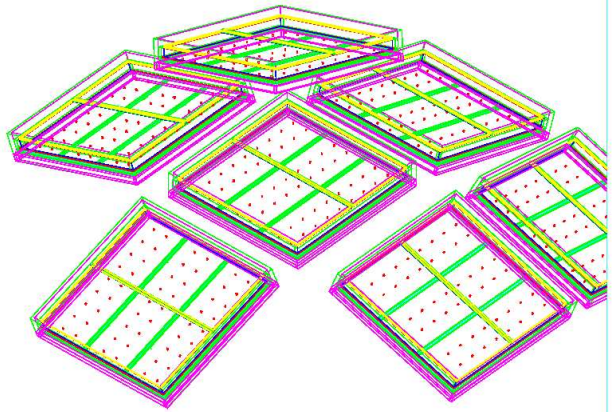


Test beam results

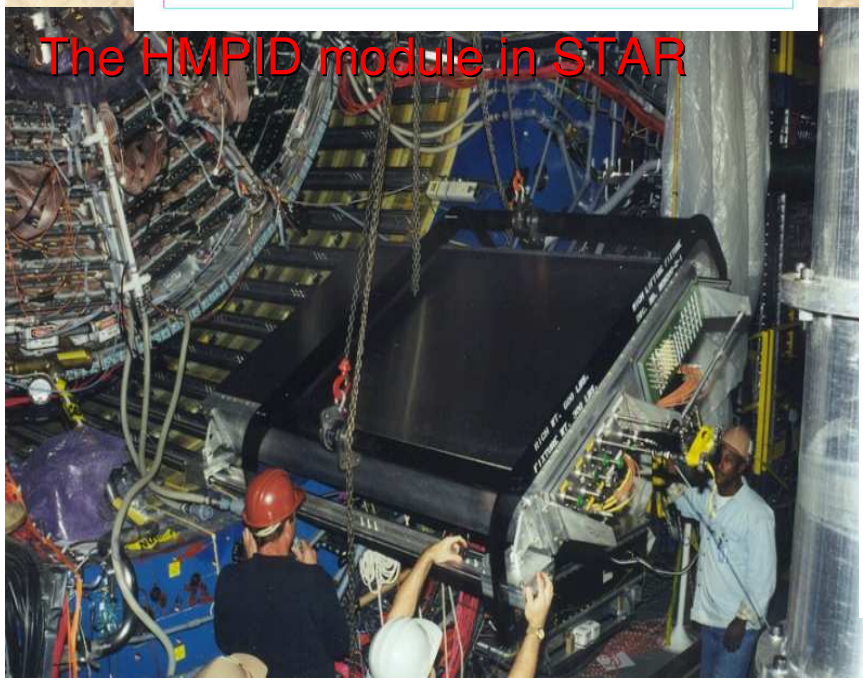


High Momentum Particle Identification

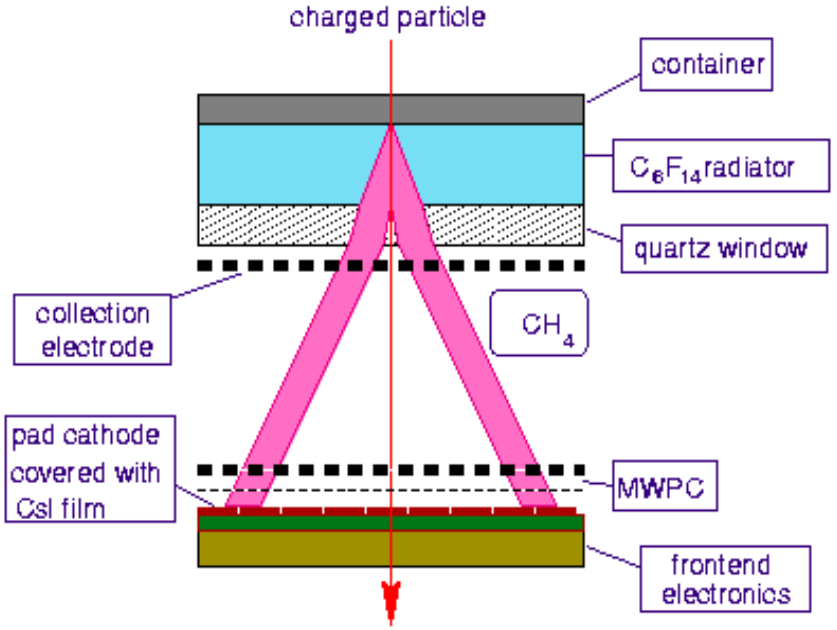
7 modules, each ~1.5 x 1.5 m^2



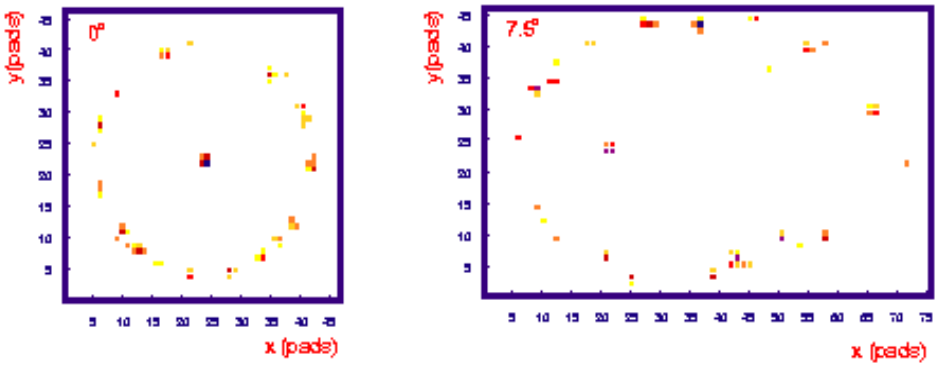
The HMPID module in STAR

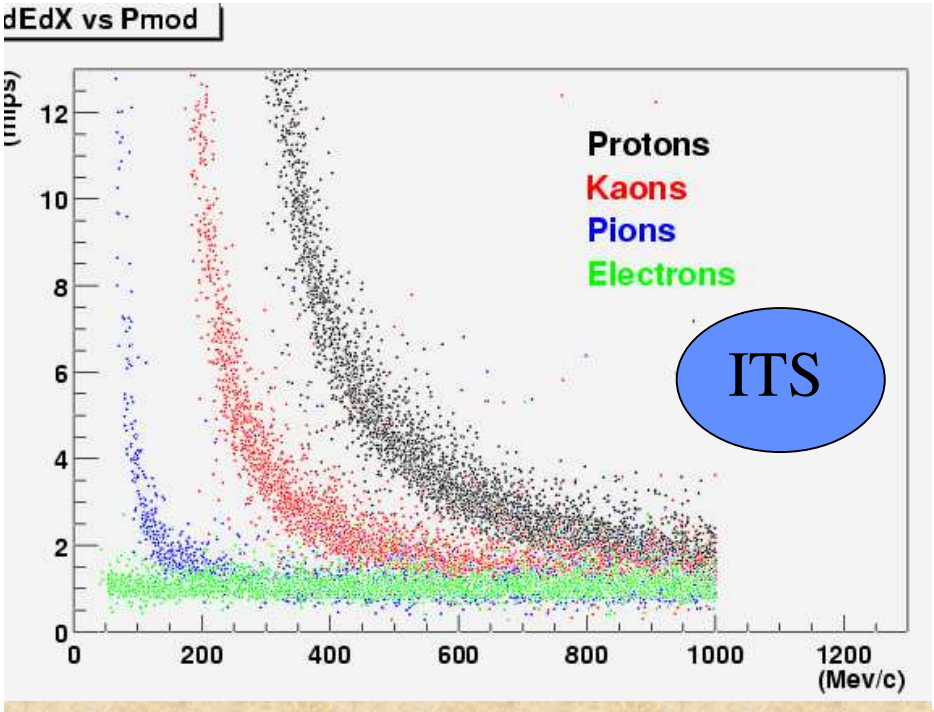


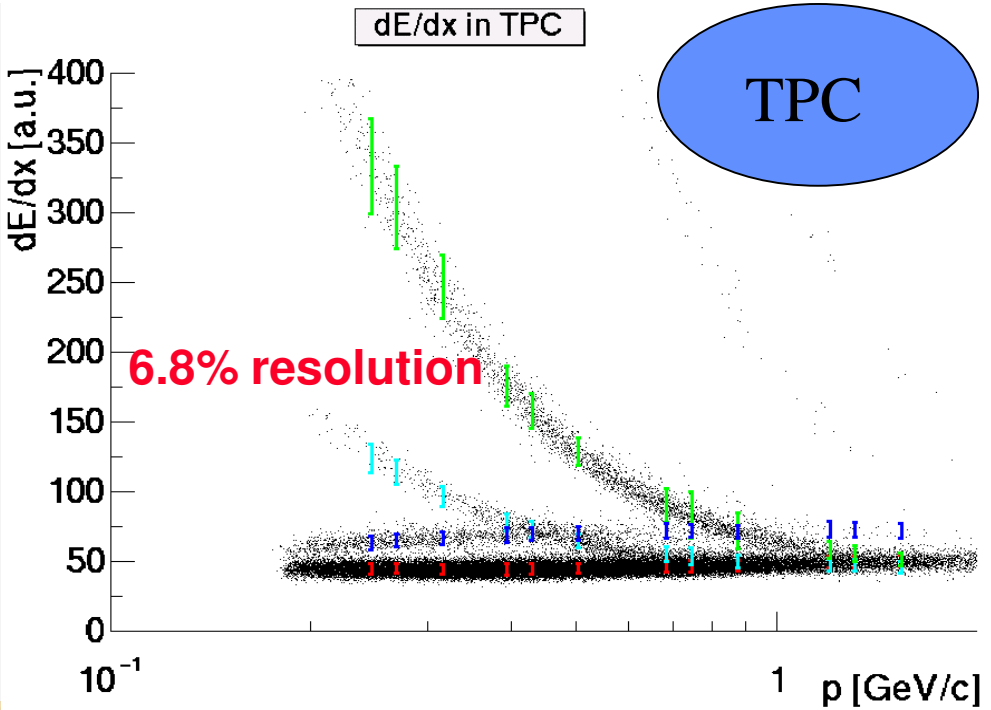
RICH



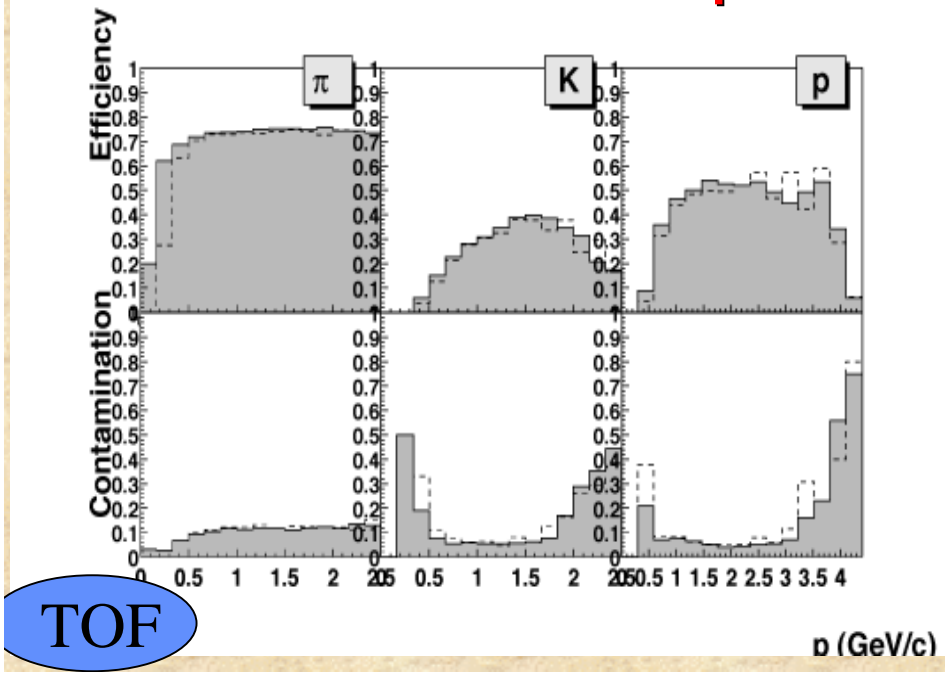
STAR data

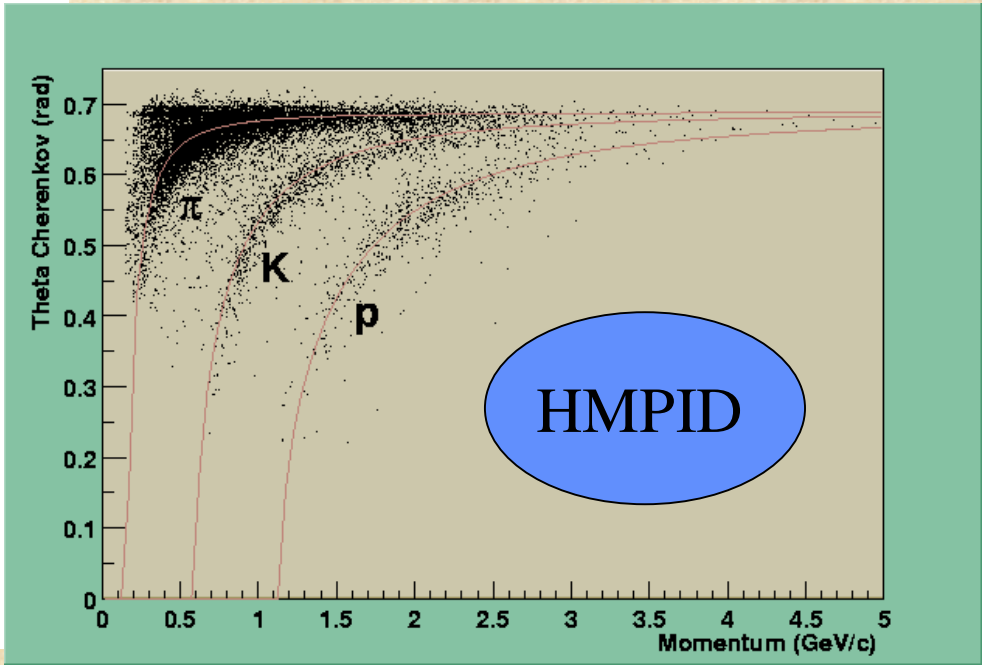






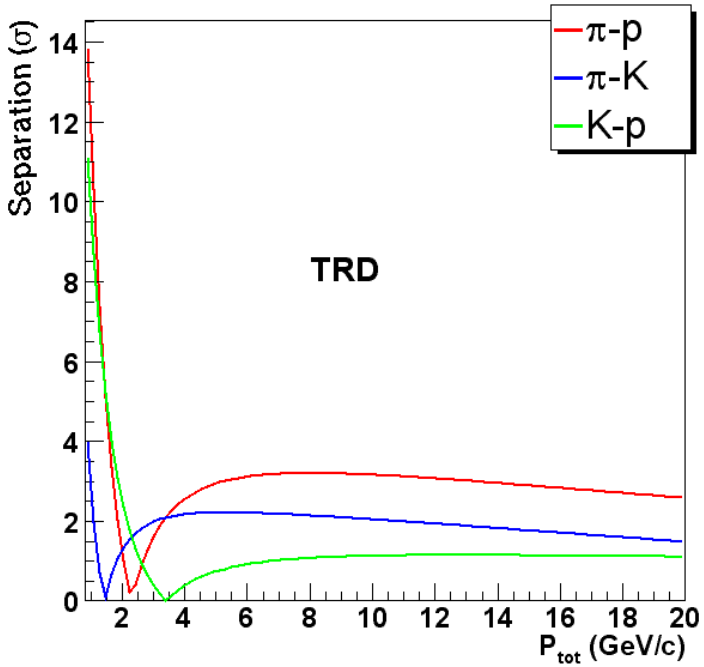
Particle Identification performance

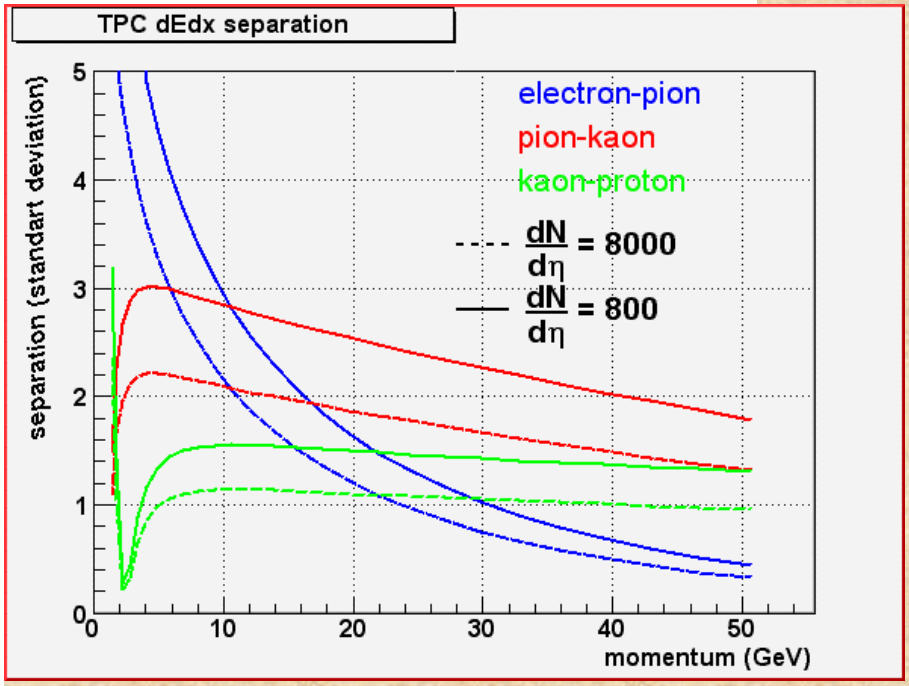


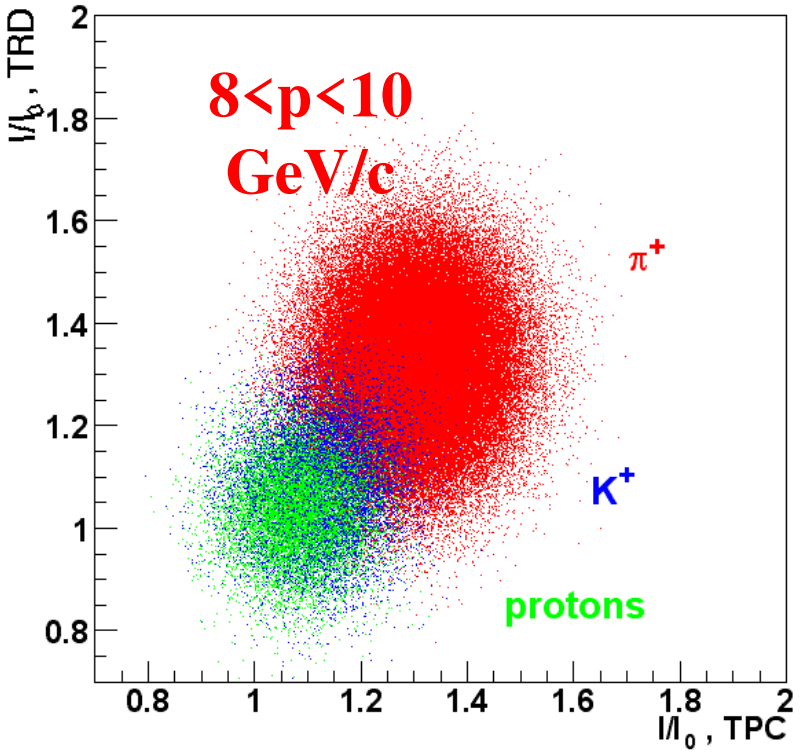


Under study: extension of PID to even higher momenta

- Combine TPC and TRD dE/dx capabilities (similar number of samples/track) to get statistical ID in the relativistic rise region





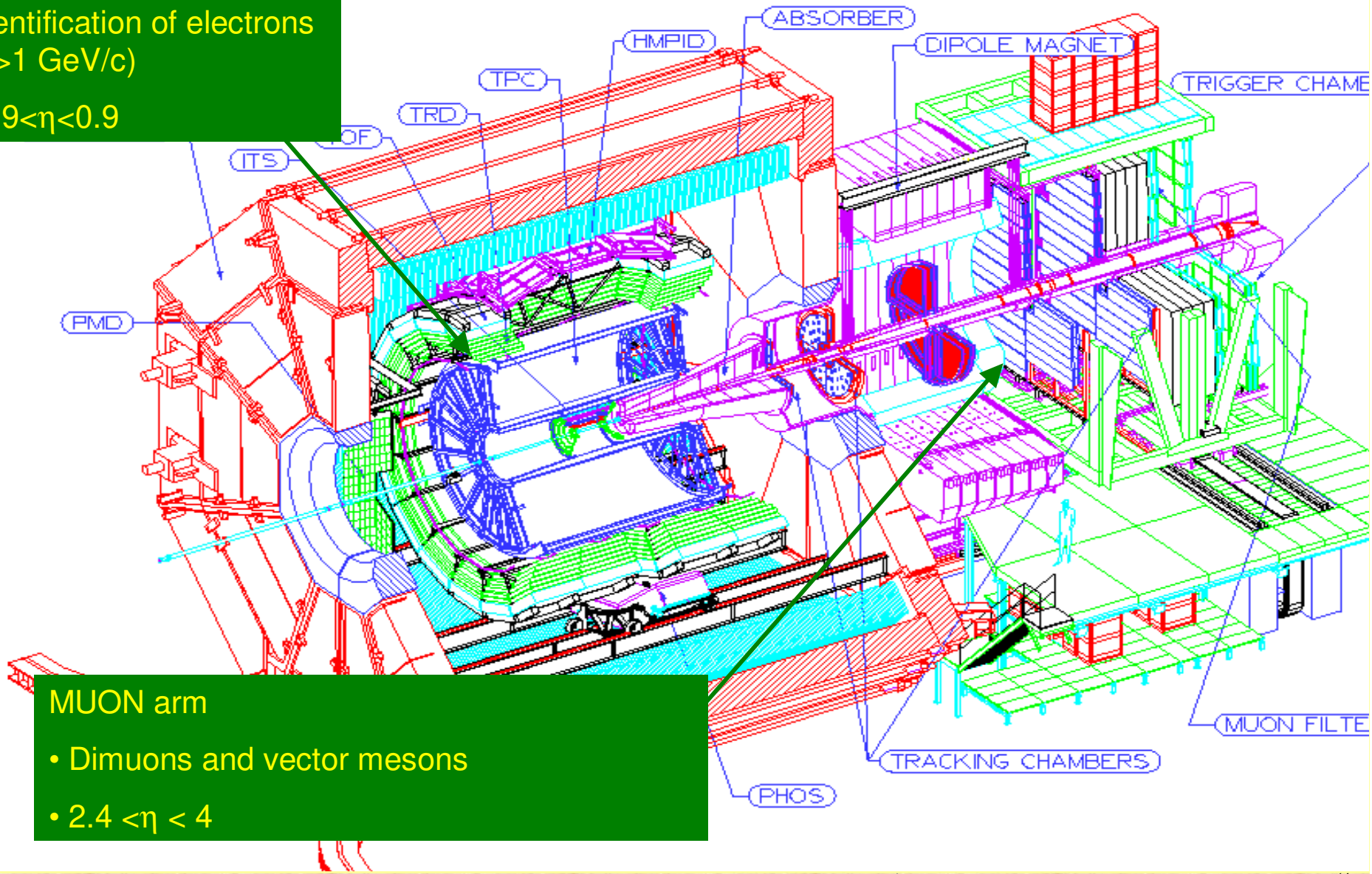


ALICE LAYOUT: lepton detection

TRD

Identification of electrons (p>1 GeV/c)

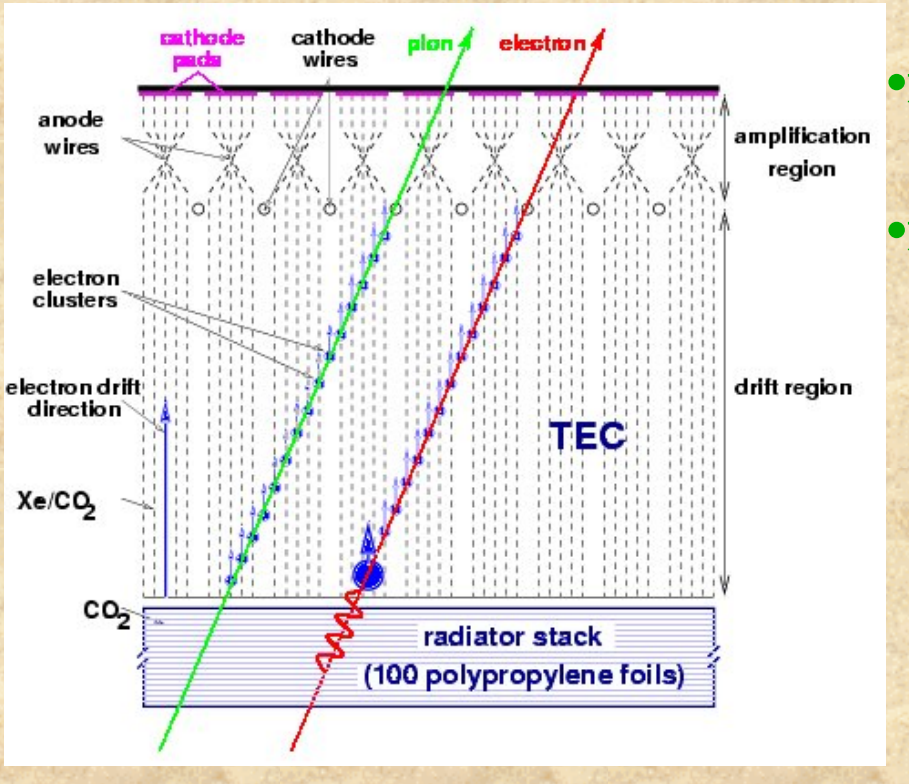
-0.9<η<0.9



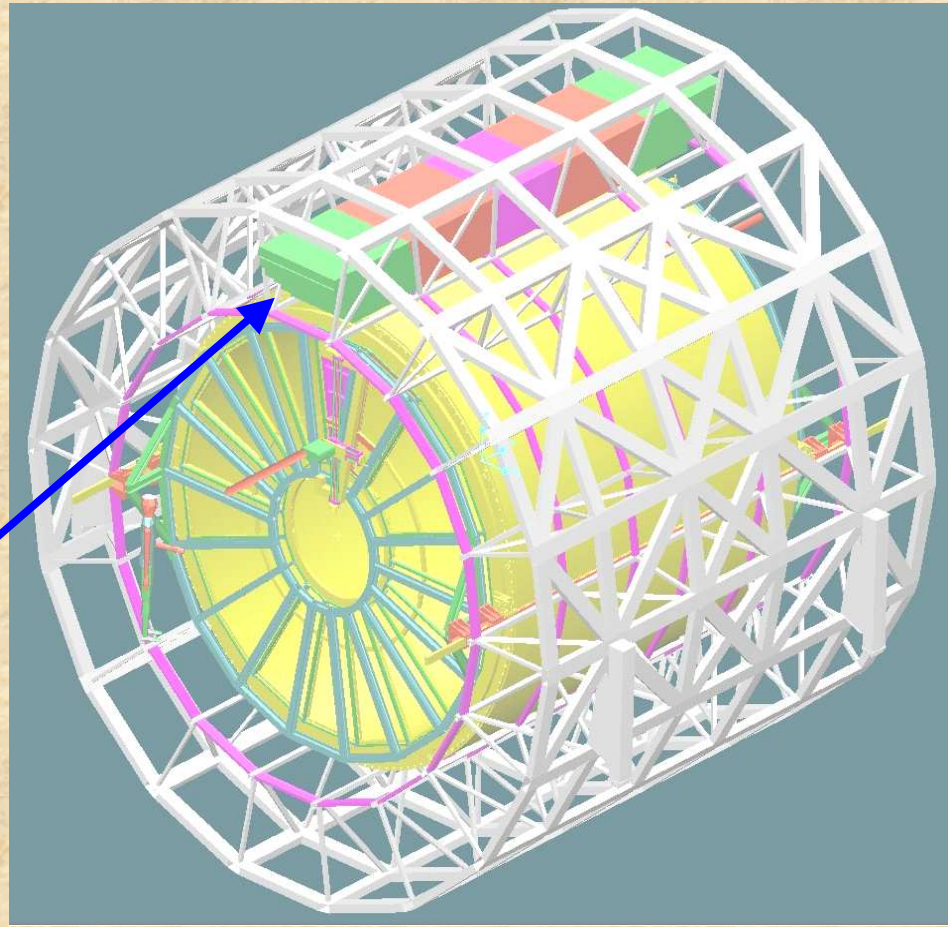
MUON arm

- Dimuons and vector mesons
- 2.4 <η < 4

Transition Radiation Detector



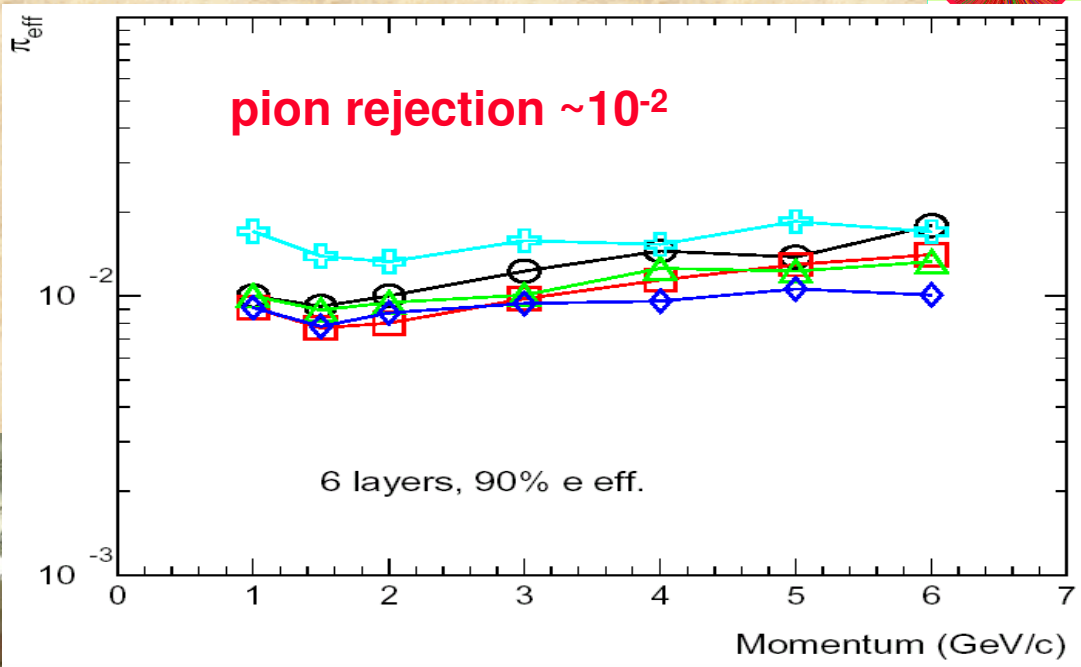
- for e PID, p>1 GeV/c
- for e and high p_t trigger, p>3GeV/c



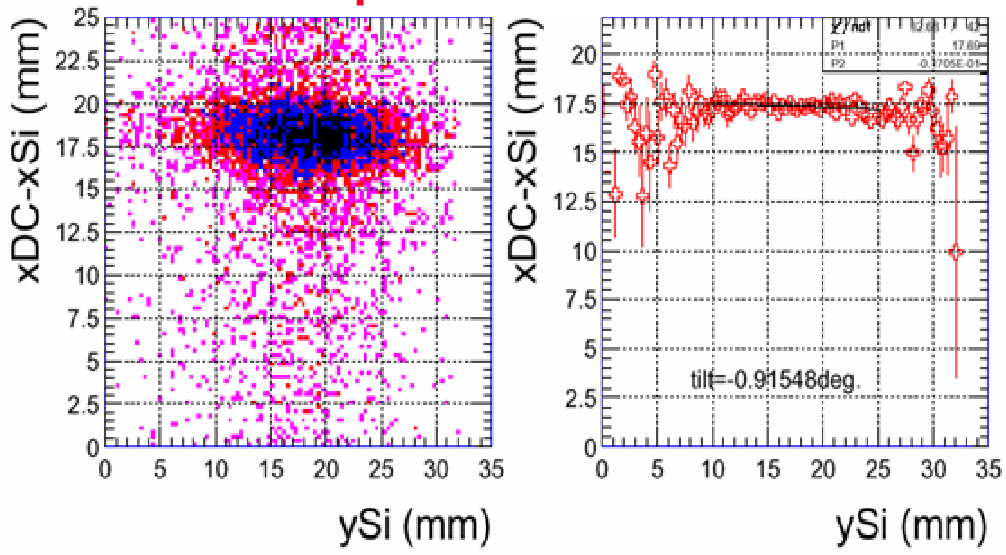
stack of 6 chambers
5 in a row form
a supermodule

TRD beam test

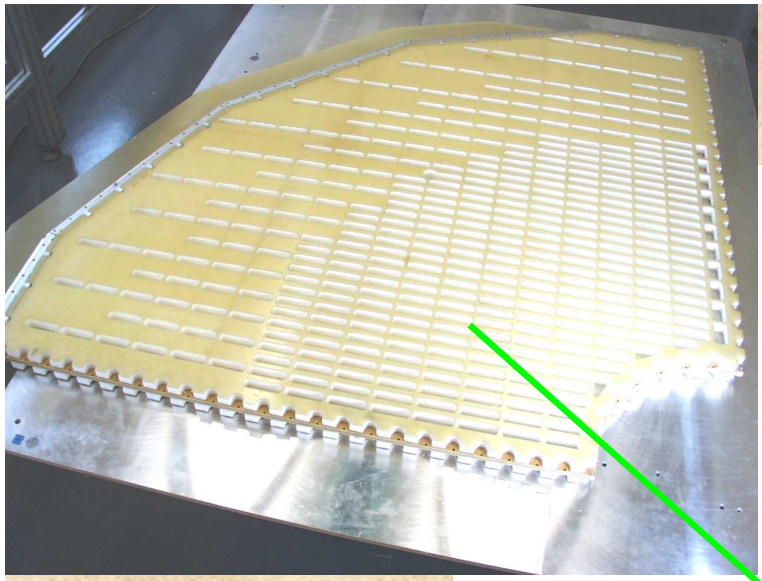
- **PS test October 2002**
  - ⇨ 5 chambers in a row (6 in ALICE)
    - ✪ Module #0 + 5 small prototypes
    - ✪ verify combined π rejection
  - ⇨ online resolution < 400 μm



spatial resolution

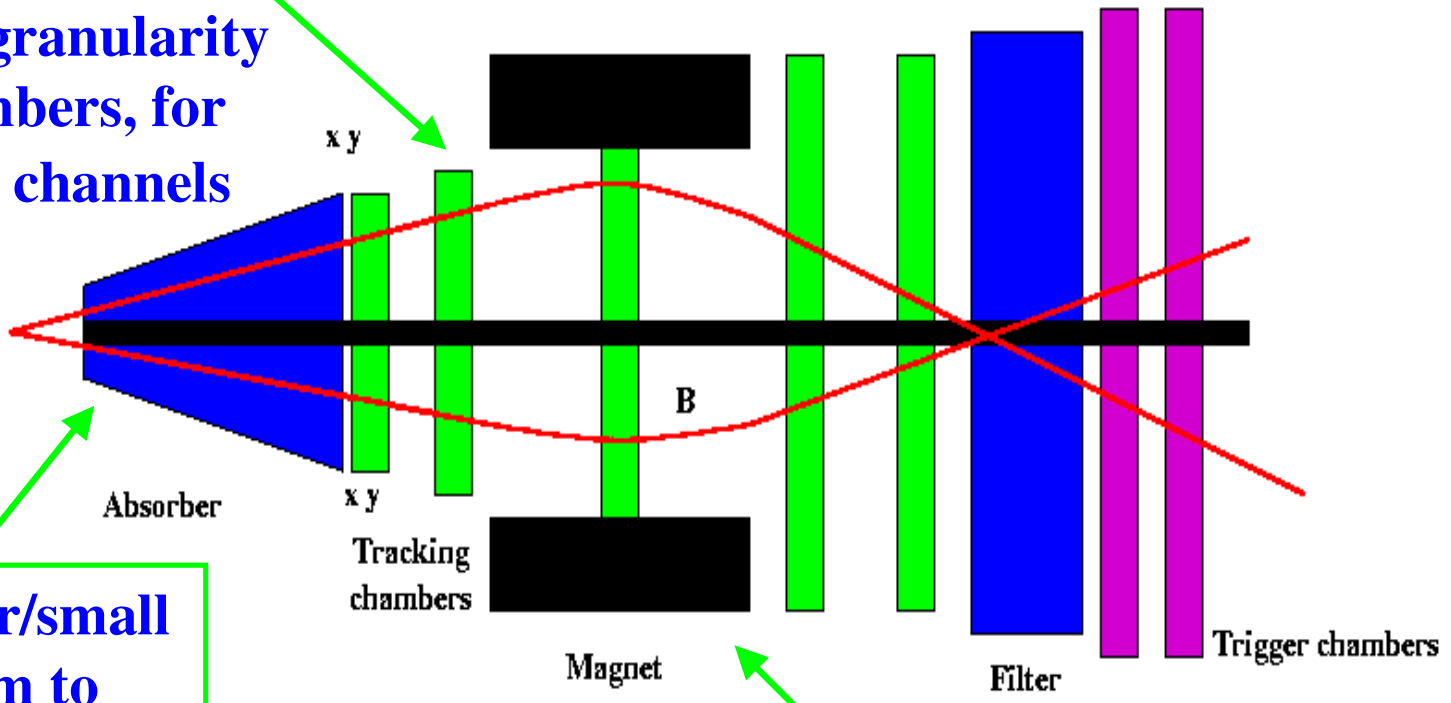


Dimuon Spectrometer



- Study the production of the J/Ψ, Ψ', Υ , Υ ' and Υ '' decaying in 2 muons, $2.4 < \eta < 4$
- Resolution of 70 MeV at the J/Ψ and 100 MeV at the Υ

5 stations of high granularity pad tracking chambers, for over 800k readout channels

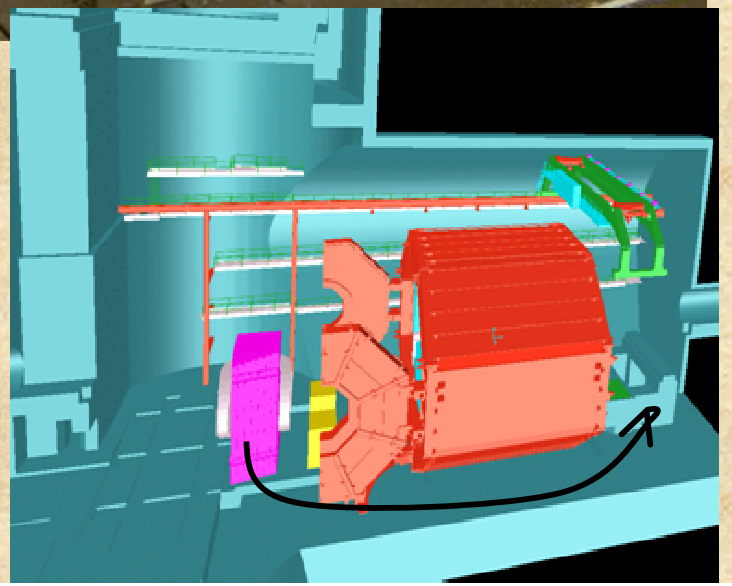


Complex absorber/small angle shield system to minimize background (90 cm from vertex)

Magnet: world largest warm dipole 6.7x5x9m^3, 800 Tons, ~ 4 MW, bending power 3Tm

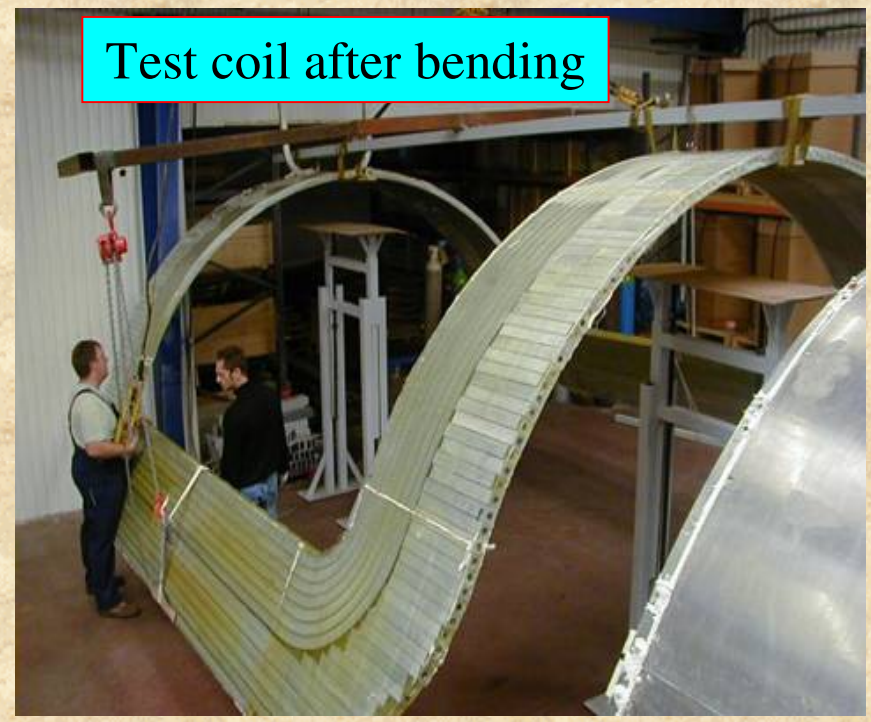
Muon Magnet

Iron yoke horizontal test-assembly



- **Dipole Magnet**
  - ⇨ **0.7 T and 3 Tm**
  - ⇨ **amongst World's largest warm dipoles**
- **Progress:**
  - ⇨ **Yoke finished end 2002 in Russia**

Test coil after bending

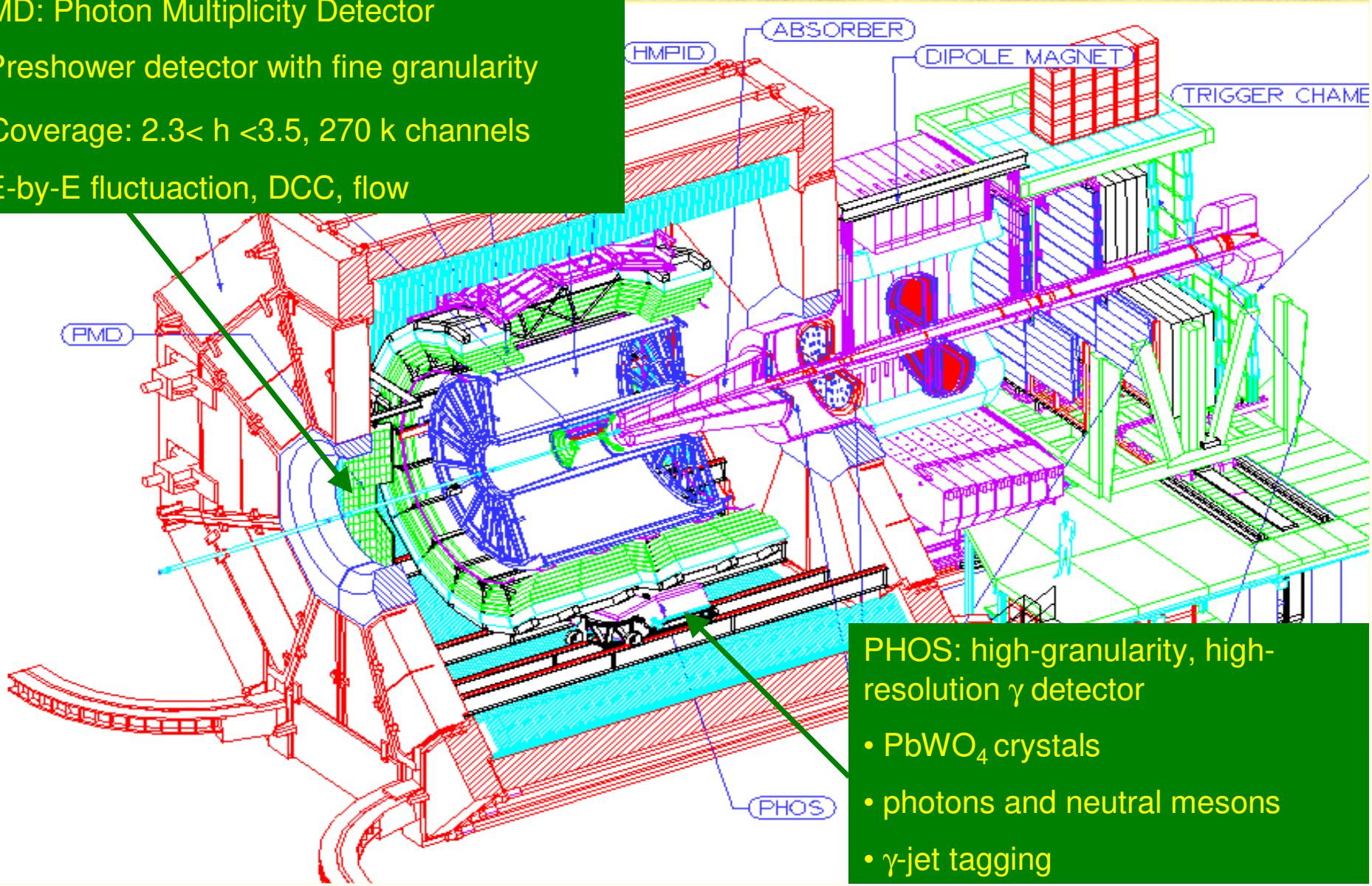


- **vertical pre-assembly**
  - ⇨ **starting spring 2003 at CERN**
  - ⇨ **in temporary position, but close to L3**

ALICE LAYOUT: photons

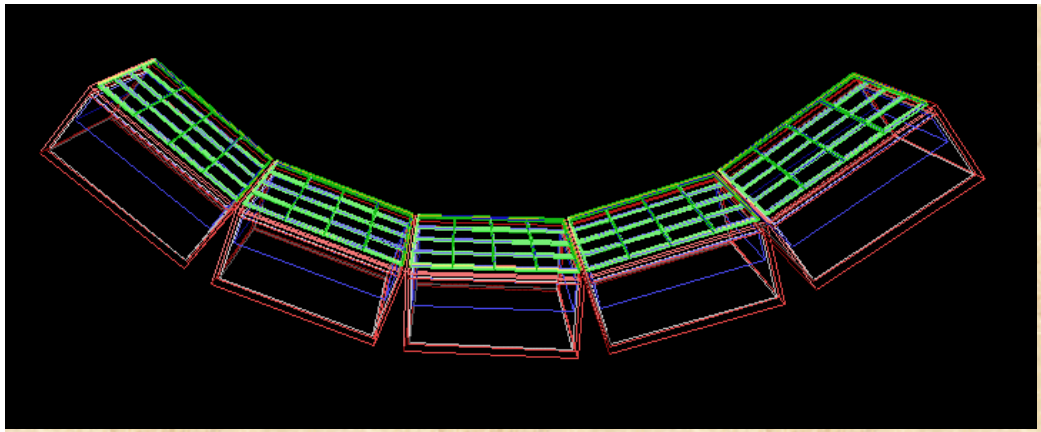
PMD: Photon Multiplicity Detector

- Preshower detector with fine granularity
- Coverage: 2.3< h <3.5, 270 k channels
- E-by-E fluctuaction, DCC, flow



PHOS: high-granularity, high-resolution γ detector

- $PbWO_4$ crystals
- photons and neutral mesons
- γ-jet tagging



Photon Spectrometer

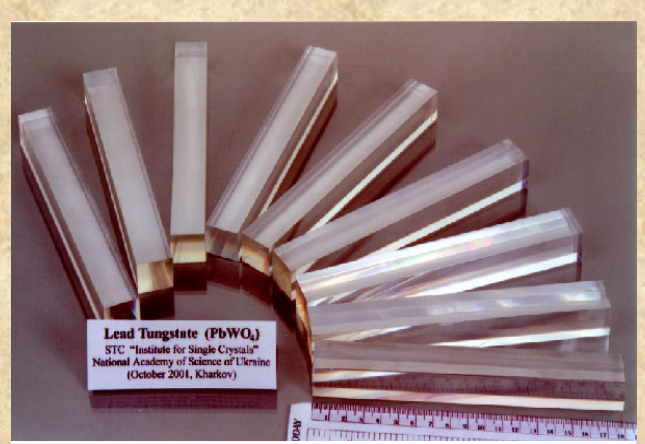
for photons, neutral mesons and γ-jet tagging
small acceptance
$-0.12 < \eta < 0.12$

$PbWO_4$ crystals

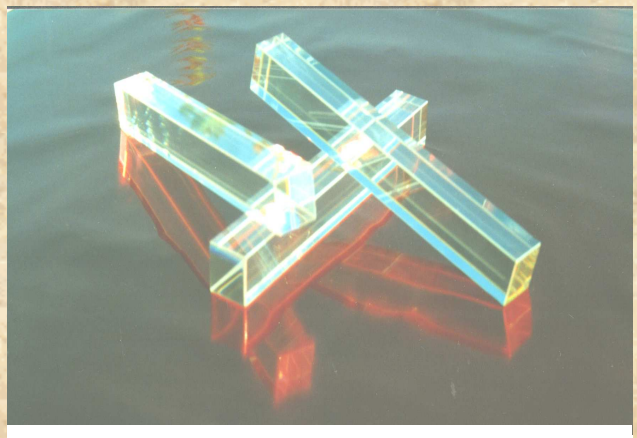
Excellent energy resolution:

stochastic	**$2.7\%/E^{1/2}$**
noise	**$2.5\%/E$**
constant	**1.3%**

Very high granularity (~same cell size as CMS EMcal (2cm) at ~ 3 times larger distance)



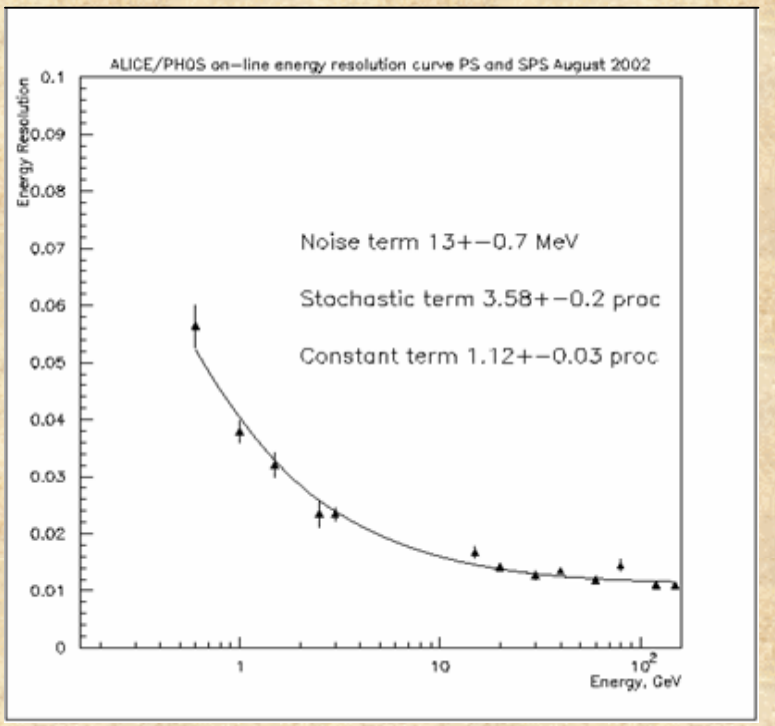
Ukrainian crystals

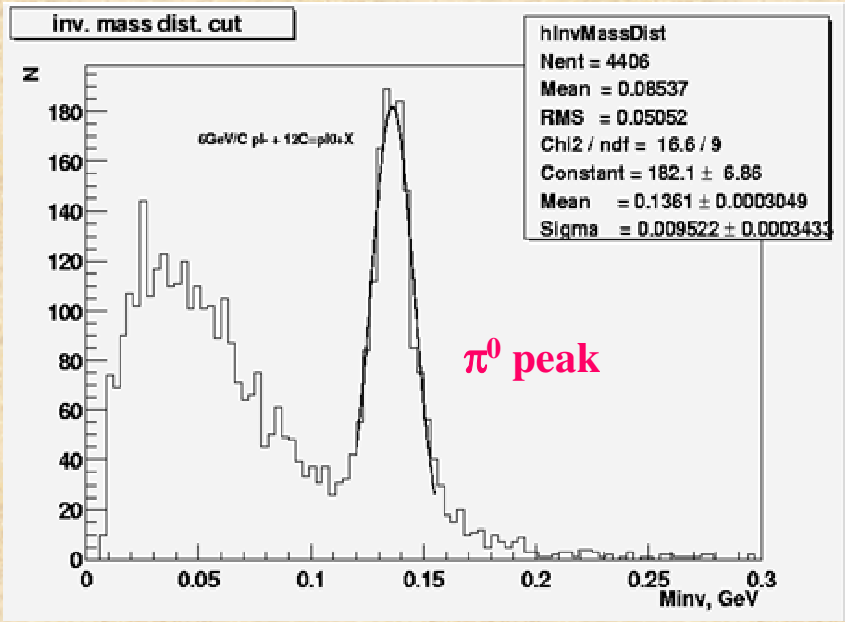


Apatity PWO crystals

PHOS test results

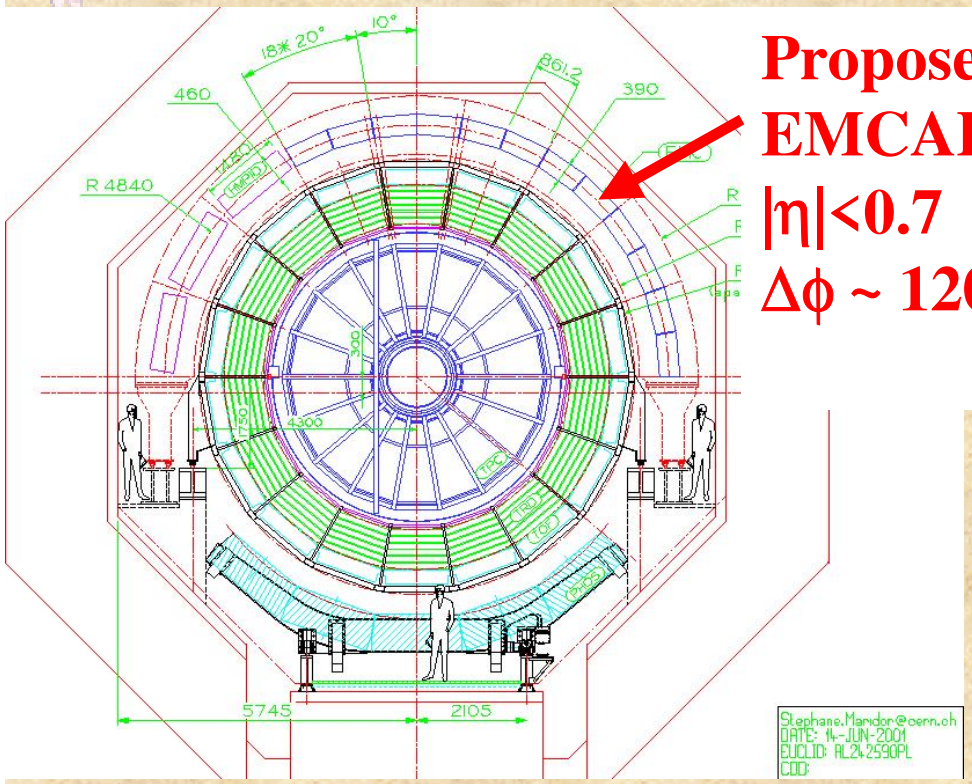
- **A matrix of 8x8 crystals was tested with electron and hadron beams at CERN in a broad energy range.**
  - **APD's were used as photodetectors.**
  - **The matrix was installed in a prototype equipped with a cooling/thermo-stabilization system. The test was performed at a working temperature –25 °C stabilized to a level of 0.1 °C.**





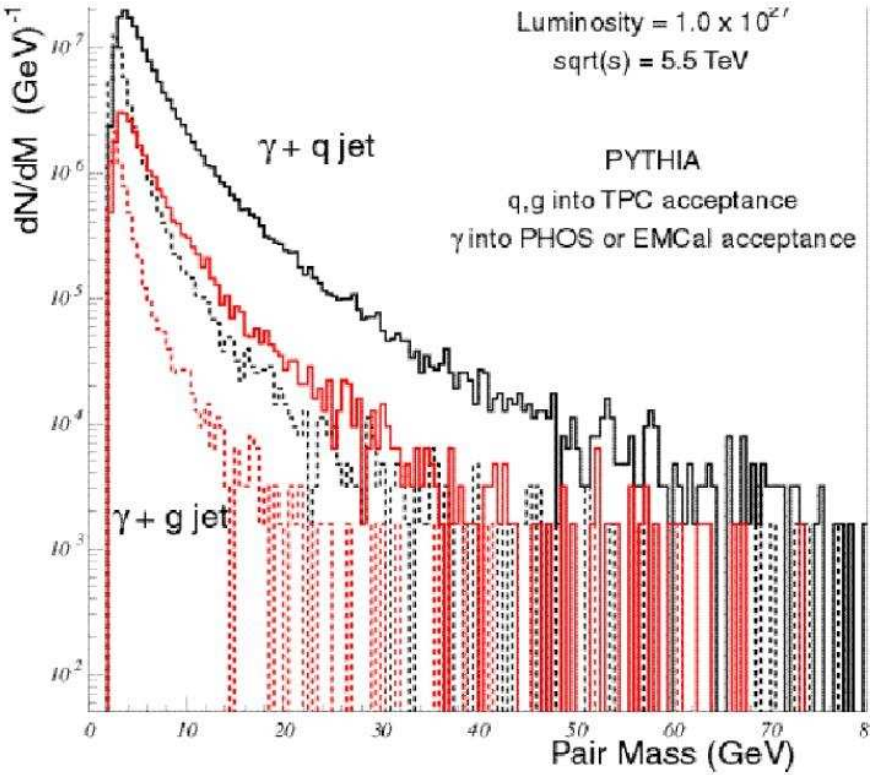
- FEE: some delay because of uncertainty in US participation
  - New, simpler design (using slightly modified TPC electronics & board) by Oct 03
  - Calibration of first module starting 2004

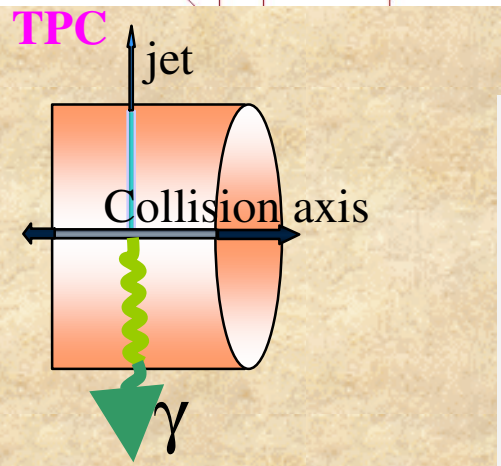
EMCAL => trigger and γ-jet, + improve resolution on E_{jet}

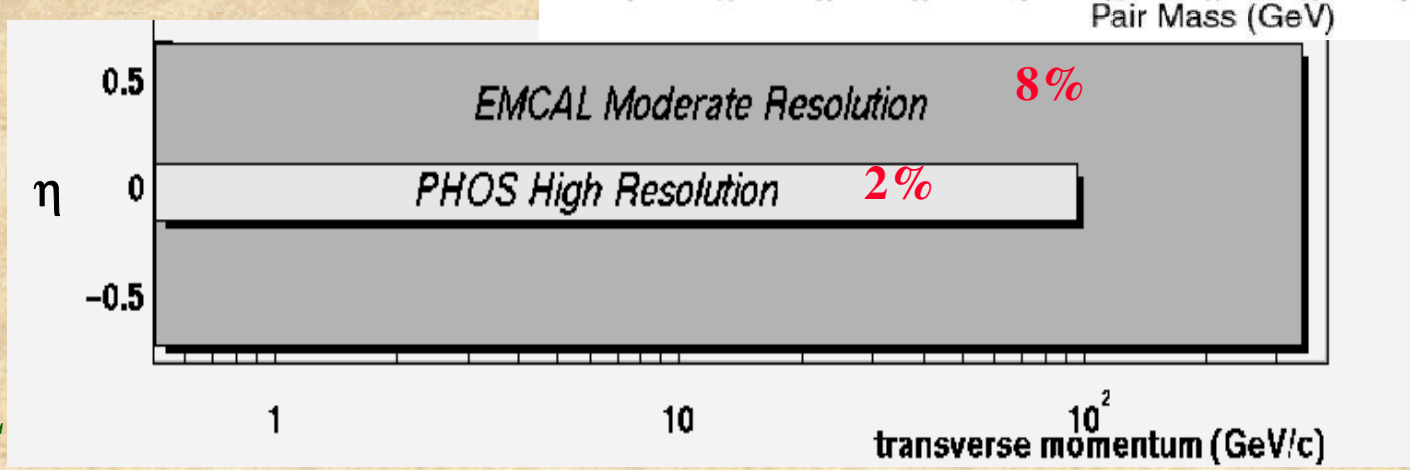


Proposed EMCAL
|η|<0.7
Δφ ~ 120°

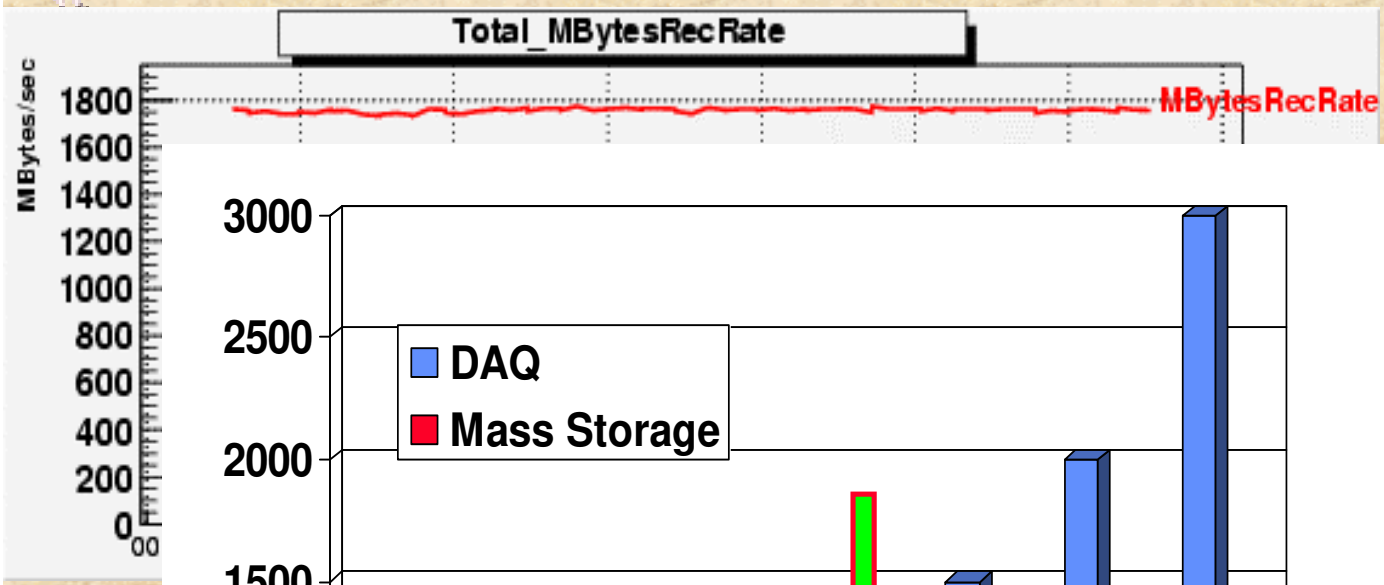
γ-jet with PHOS+EMCAL + TPC

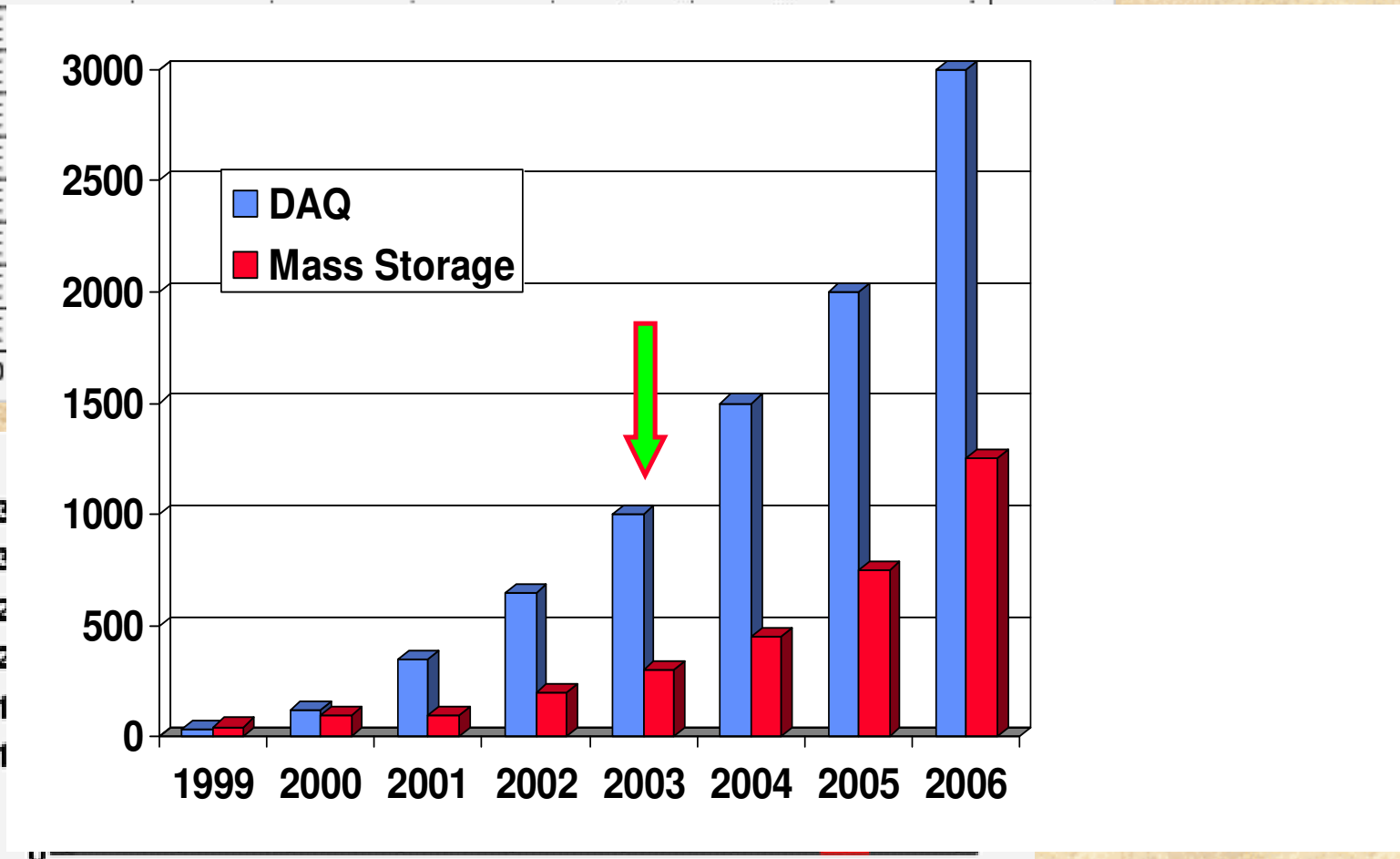


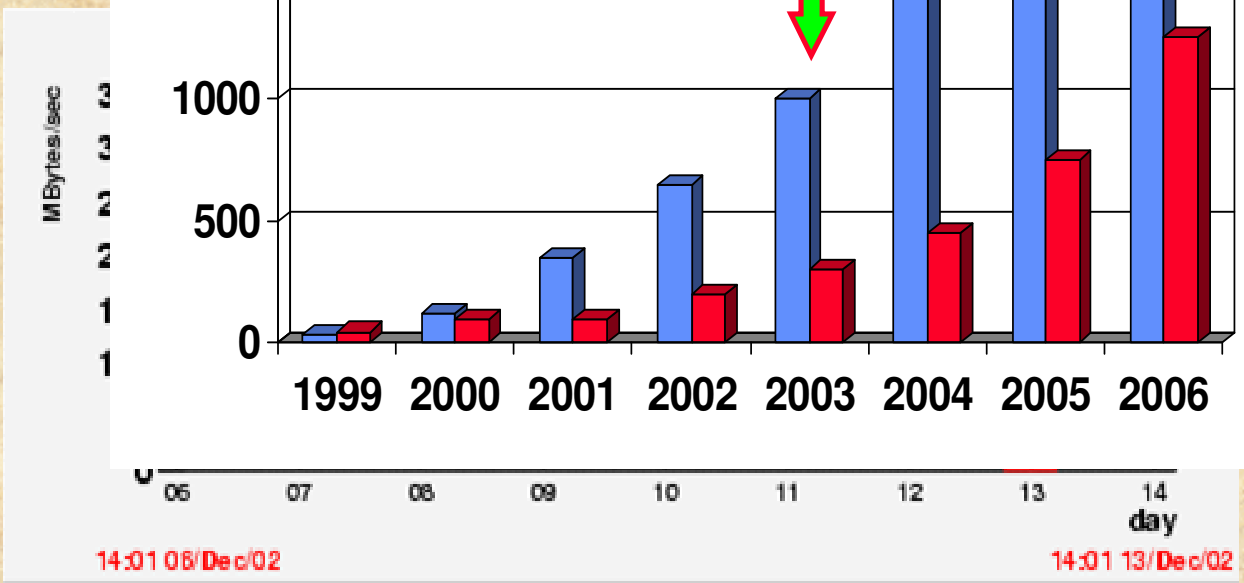




ADC IV performances







DATE event-building

te/s

e

on

-building

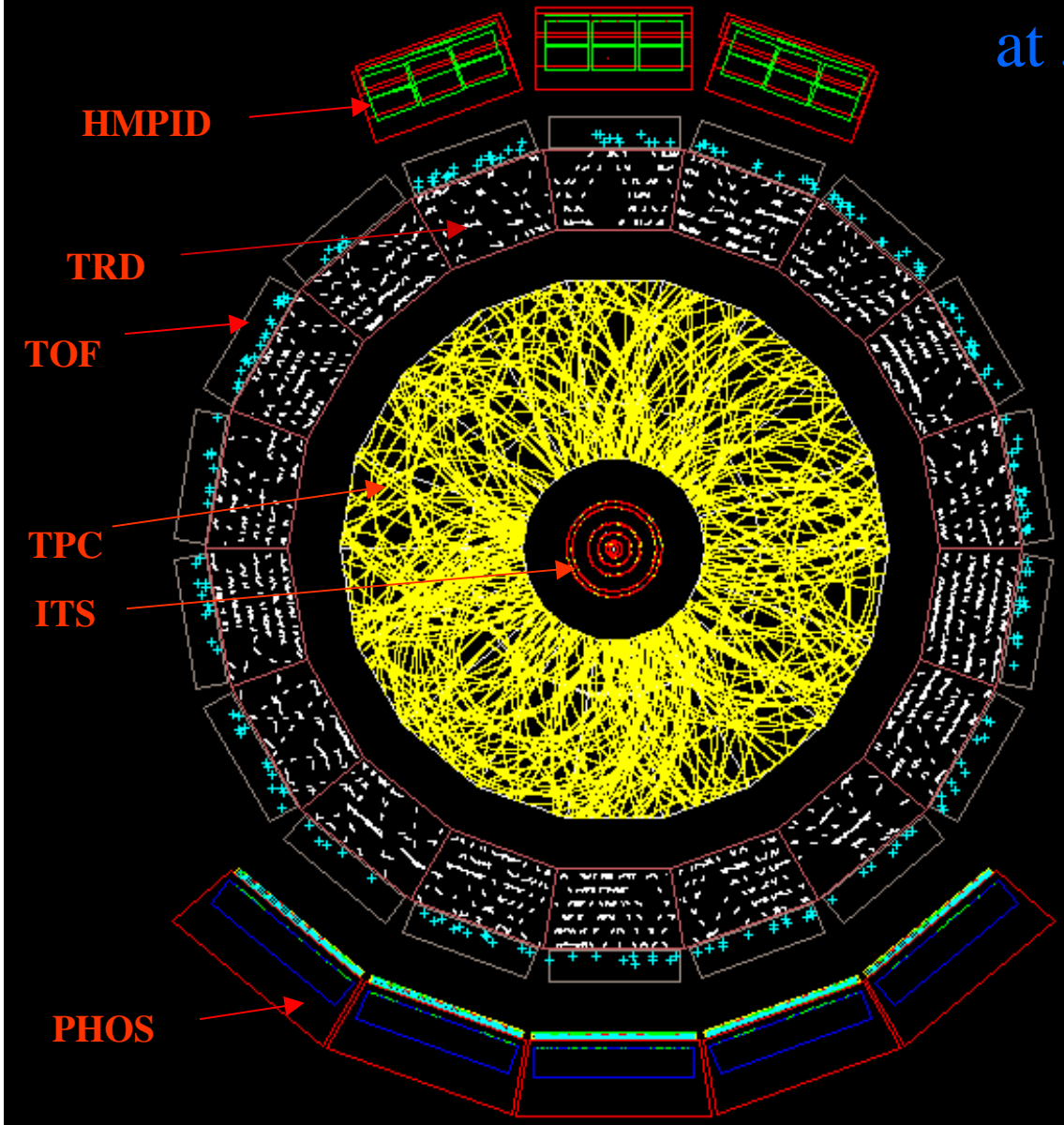
ng to disk

s.

target 300 MBytes/s

Outperforming the plan, with commodity hardware!

Studies of the ALICE Performance



5000 PbPb events
at 5.5 TeV/nucleon pair
were produced
for PPR

In this picture:
dNch/dη ~ 8000
(slice: 2° in θ)
84'210 primary particles

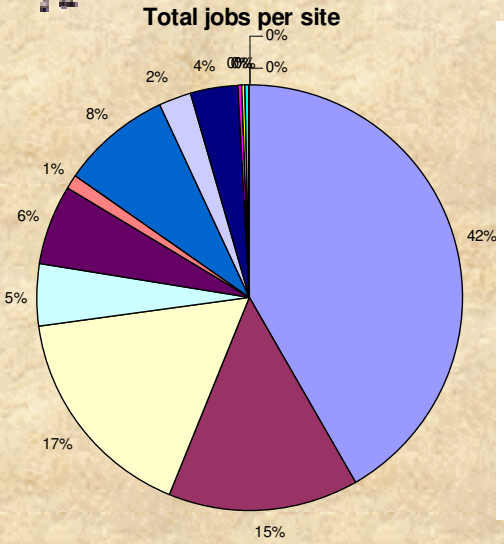
Data size

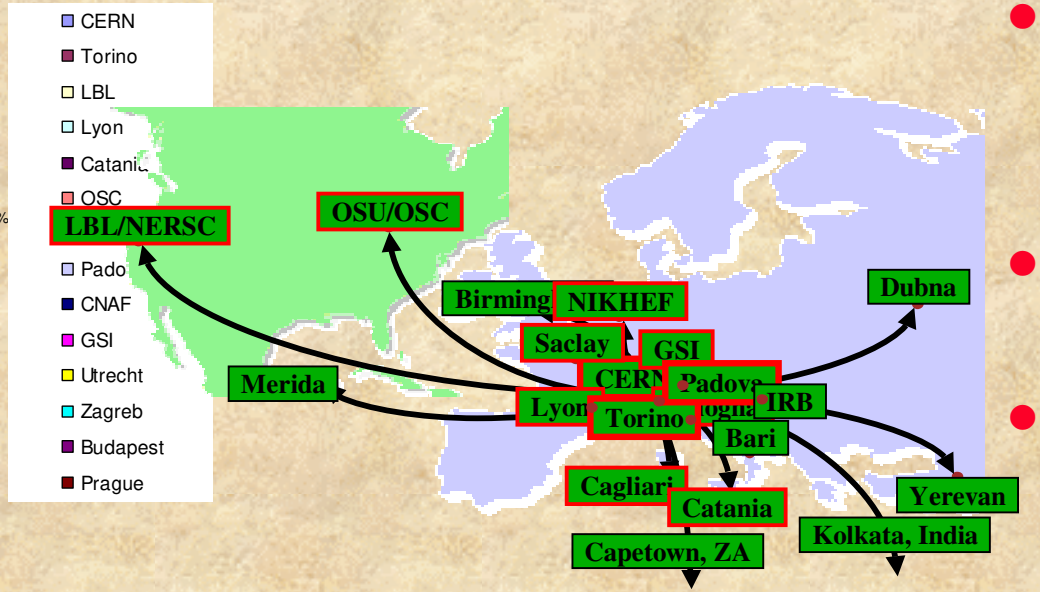
- Hits ~1.4Gb
- Digits ~1.1Gb

CPU time **on 800MHz PIII**

- Hits ~24h
- Digits ~15h

ALICE Grid http://alien.cern.ch





- 35 sites configured, at present ~14 contributing with CPU cycles
- 4 sites providing mass storage capability
- Fully distributed production controlled from one point
- 12 production rounds in past 12 months

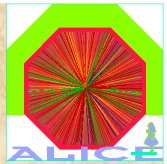
22713 jobs,
~12CPUh/job,
~1GB output/job
up to **450 concurrently running** jobs

Production Edit

ROUND	TAG	COMMENT	STATUS	COMMAND	Statistics
2001-01	V3.05	Test-Round	TESTING	AliRoot	view Chart
2001-02	V3.06	PPR-Production	DONE	AliRoot	view Chart
2002-01	V3.07.03	EMCAL-Production	DONE	AliRoot	view Chart
2002-02	V3.08.03	Proton-proton minimum bias for charm	DONE	AliRoot	view Chart
2002-03	V3.08.Rev.01	PPR production	STARTED	AliRoot	view Chart
2002-04	V3.08.Rev.01	p-p minimum bias	DONE	AliRoot	view Chart

http://alien.cern.ch/Alien/main?task=production

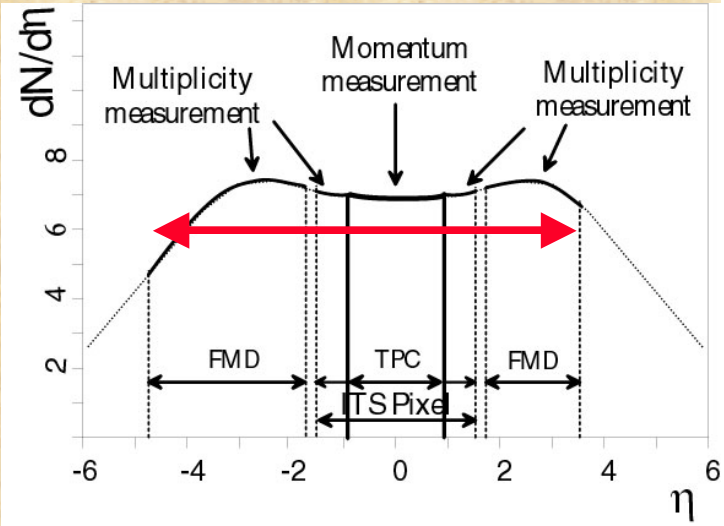
Motivation for pp study



- First insight in pp collisions in new energy domain ($\sqrt{s} = 14$ TeV), study of evolution of soft hadronic physics
  - ⇨ Cosmic ray interactions show `knee' in $10^{15}$–$10^{16}$ eV region and `ankle' in 10^{18}–10^{19} eV region
  - ⇨ $\sqrt{s} = 14$ TeV corresponds to 10^{17} eV in lab frame
- Contribution to knowledge of underlying minimum bias (background) pp events for other LHC physics programmes (Higgs search, B–physics, etc.)
- Provide pp data as a reference for study of other collision systems (p-A, A-A)
- Low multiplicity data to commission and calibrate various components of ALICE

ALICE advantages for pp

- p_t cut-off
- η-coverage



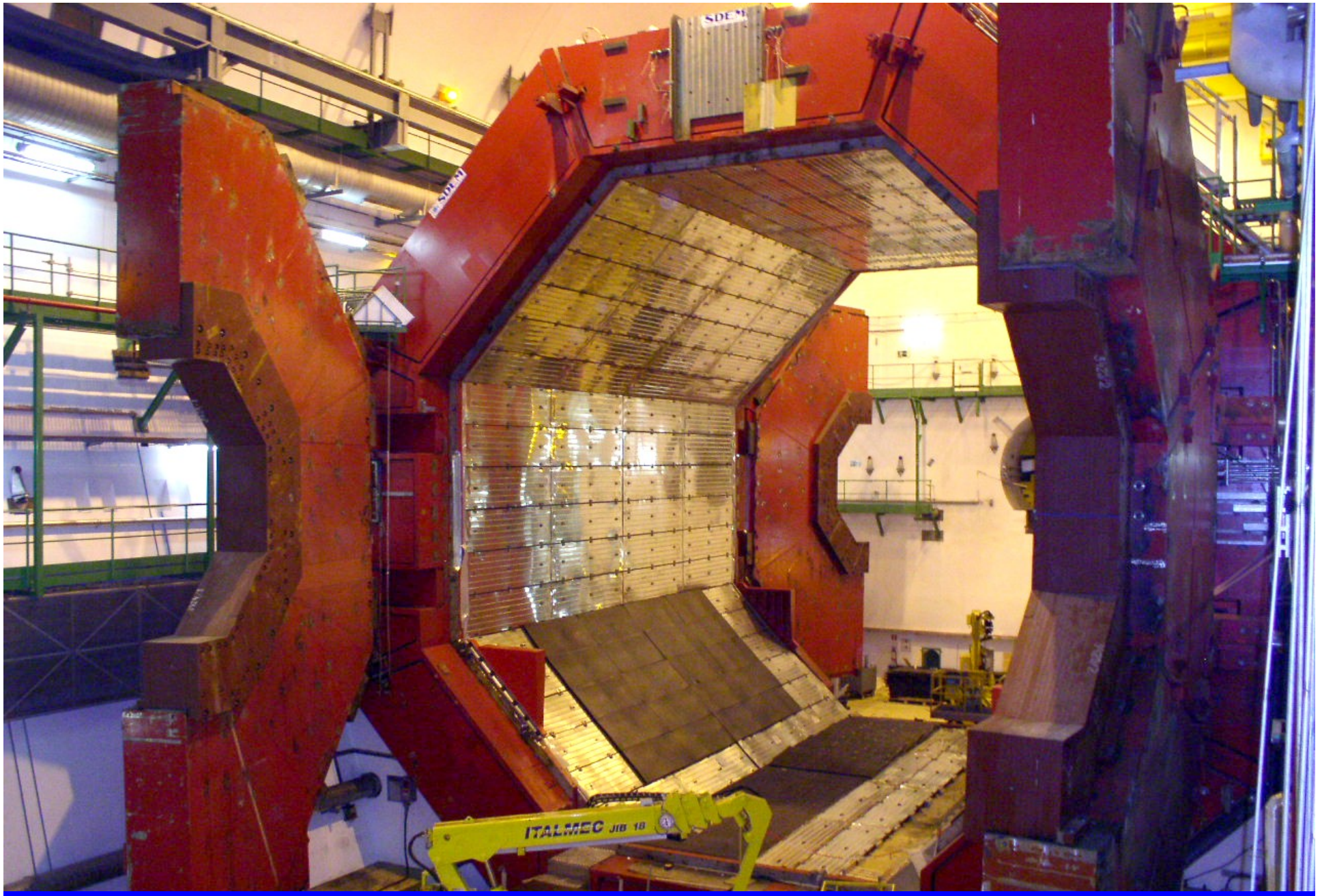
- **Magnetic field (but this could be lowered)**

	Magnetic field (T)
ALICE	0.2 – 0.4
ATLAS	2.0
CMS	4.0

- **Material thickness (hard to change)**

	Material thickness X/X_0 (%)	Minimal pion ($\pi^{\pm}$) momentum (MeV)	Minimal kaon ($K^{\pm}$) momentum (MeV)
ALICE	7	80	200
ATLAS	30	130	305
CMS	20	115	280

- **Particle identification (TOF and HMPID)**
- **ATLAS and CMS have better η-coverage**



Looking forward to fill the empty space