Perspectives of the
ALICE
Experiment

Massimo Masera for the ALICE Collaboration

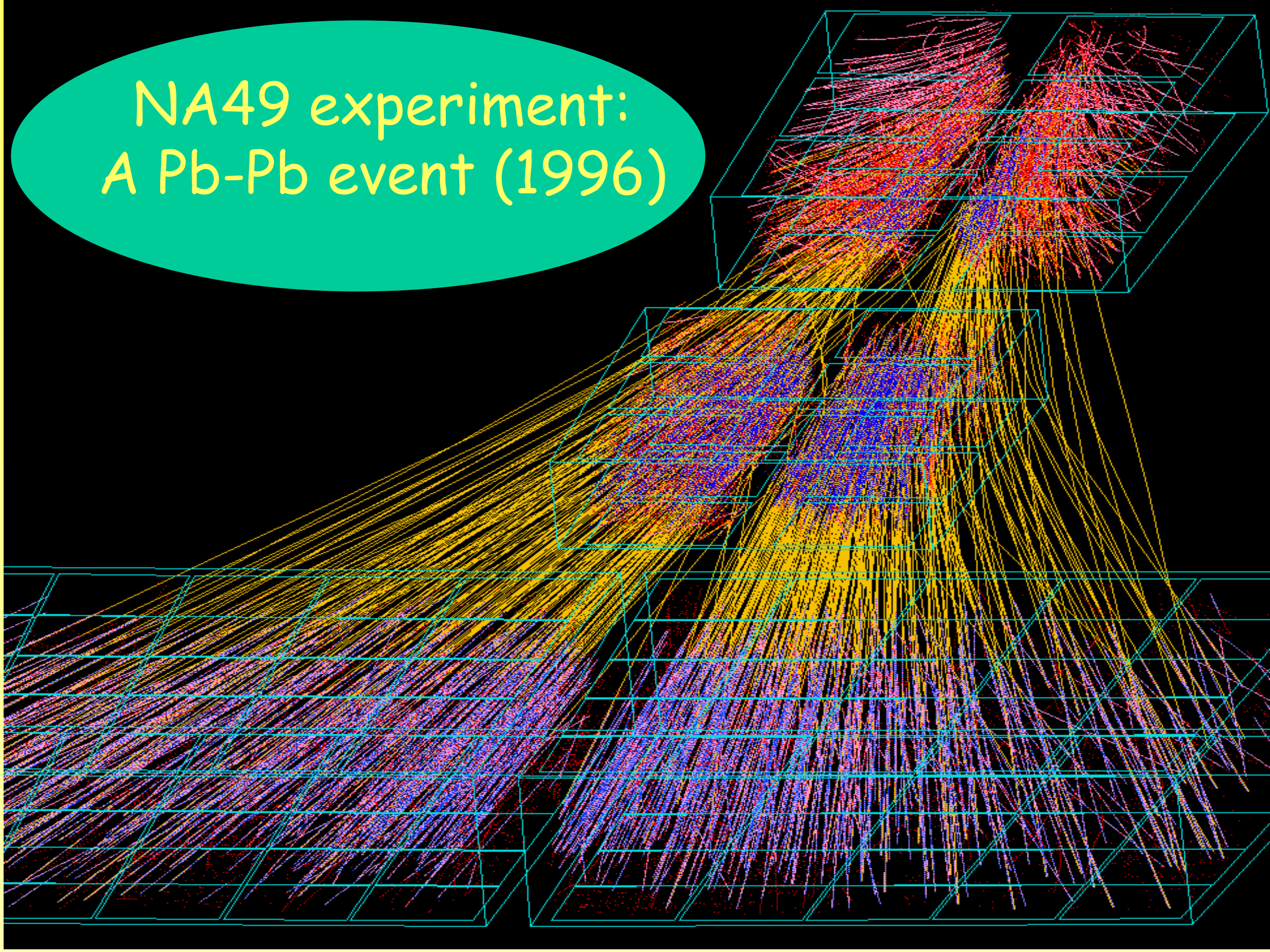
LES RENCONTRES DE PHYSIQUE DE LA VALLEE D'AOSTE

9-15 March, 2003 La Thuile

SPS

Pb ions since 1995 @ 158 Gev/nucleon...

The Heavy Ion programme at the SPS is still active: NA60 will study dimuon at low mass with high mass resolution

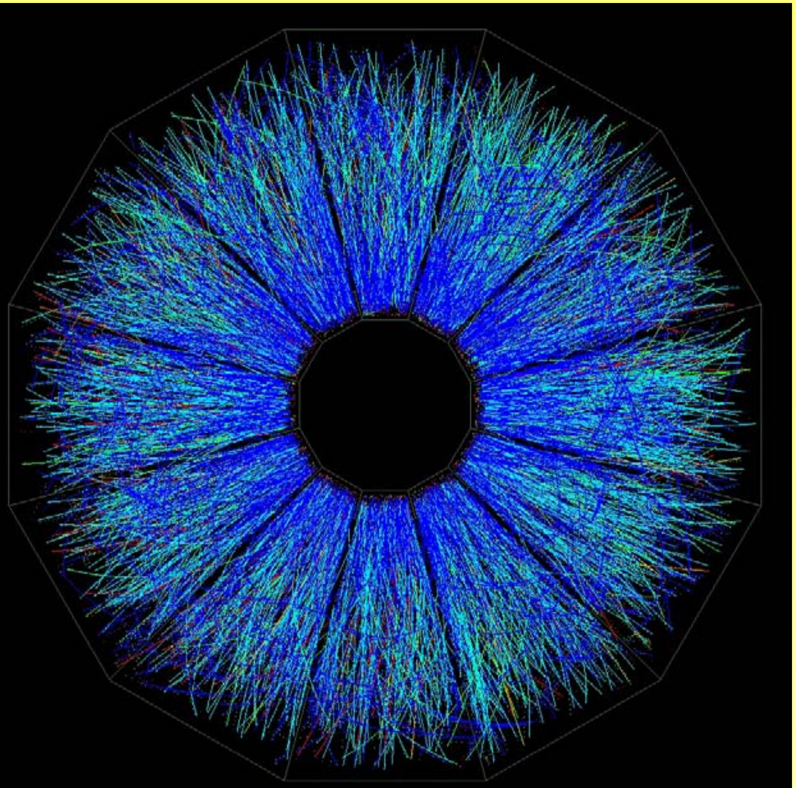


NA49 experiment:
A Pb-Pb event (1996)

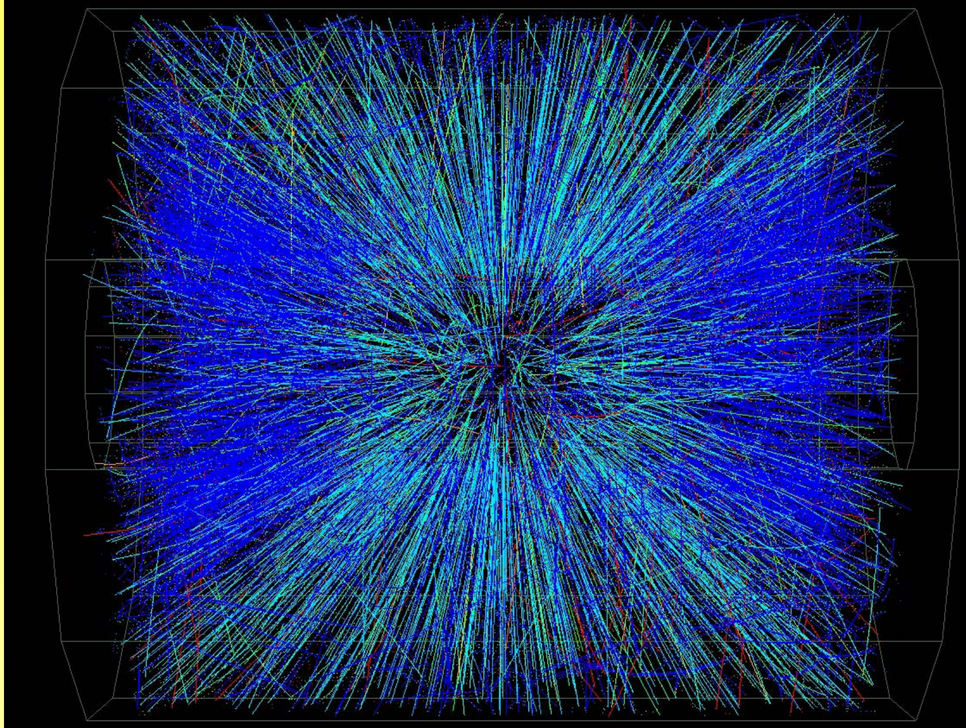
Experiments at SPS, RHIC and LHC share the common purpose of probing and studying the phase transition to QGP

… RHIC at BNL

Started in year 2000



color code ⇒ energy loss

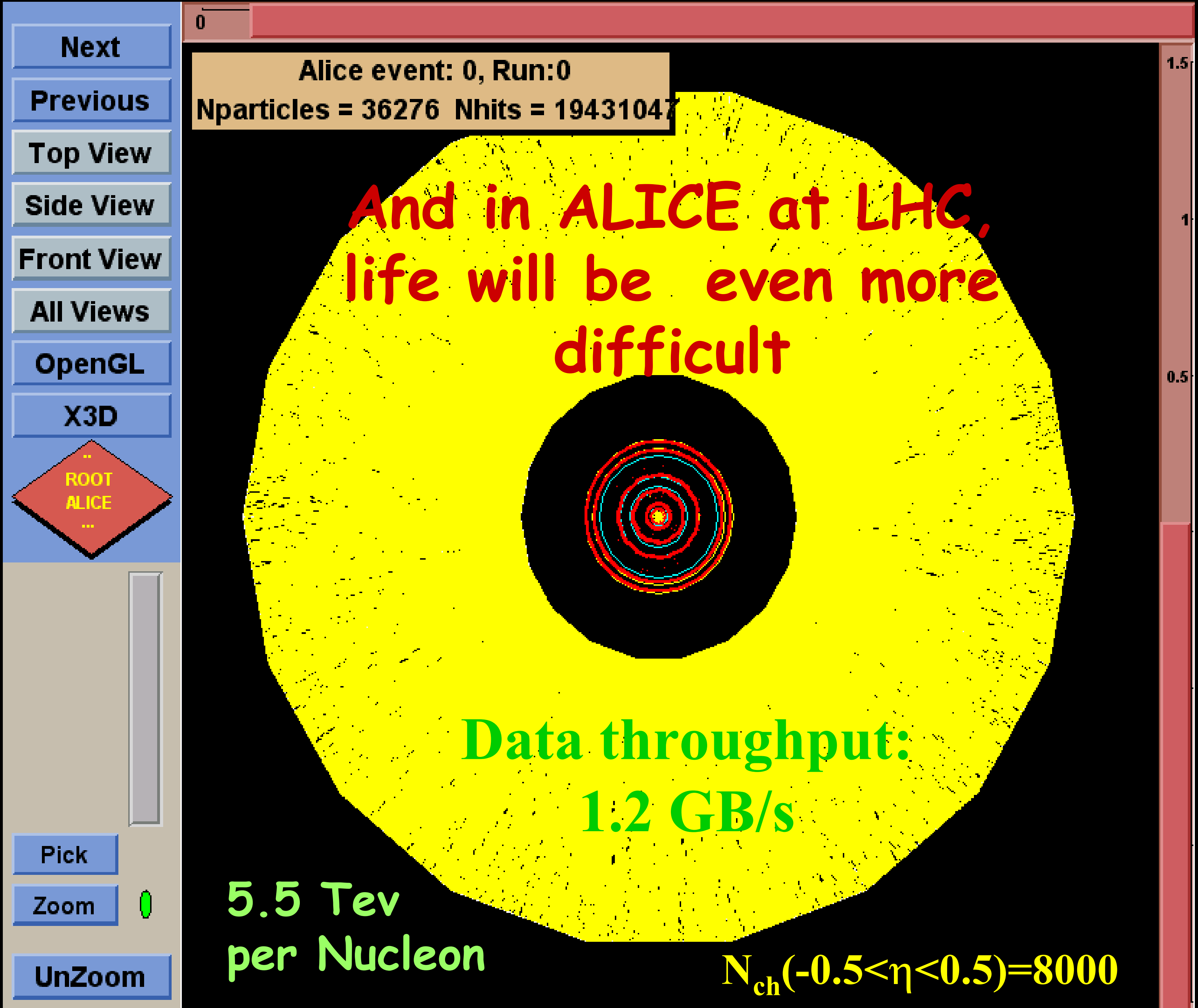


STAR

A central (real!) Au-Au event
@ ~130 GeV/nucleon CM energy

The experimental challenges posed by the currently available Heavy Ion collisions are evident!

Results from RHIC were presented by S.White on Wednesday



Alice event: 0, Run:0
Nparticles = 36276 Nhits = 19431047

And in ALICE at LHC, life will be even more difficult

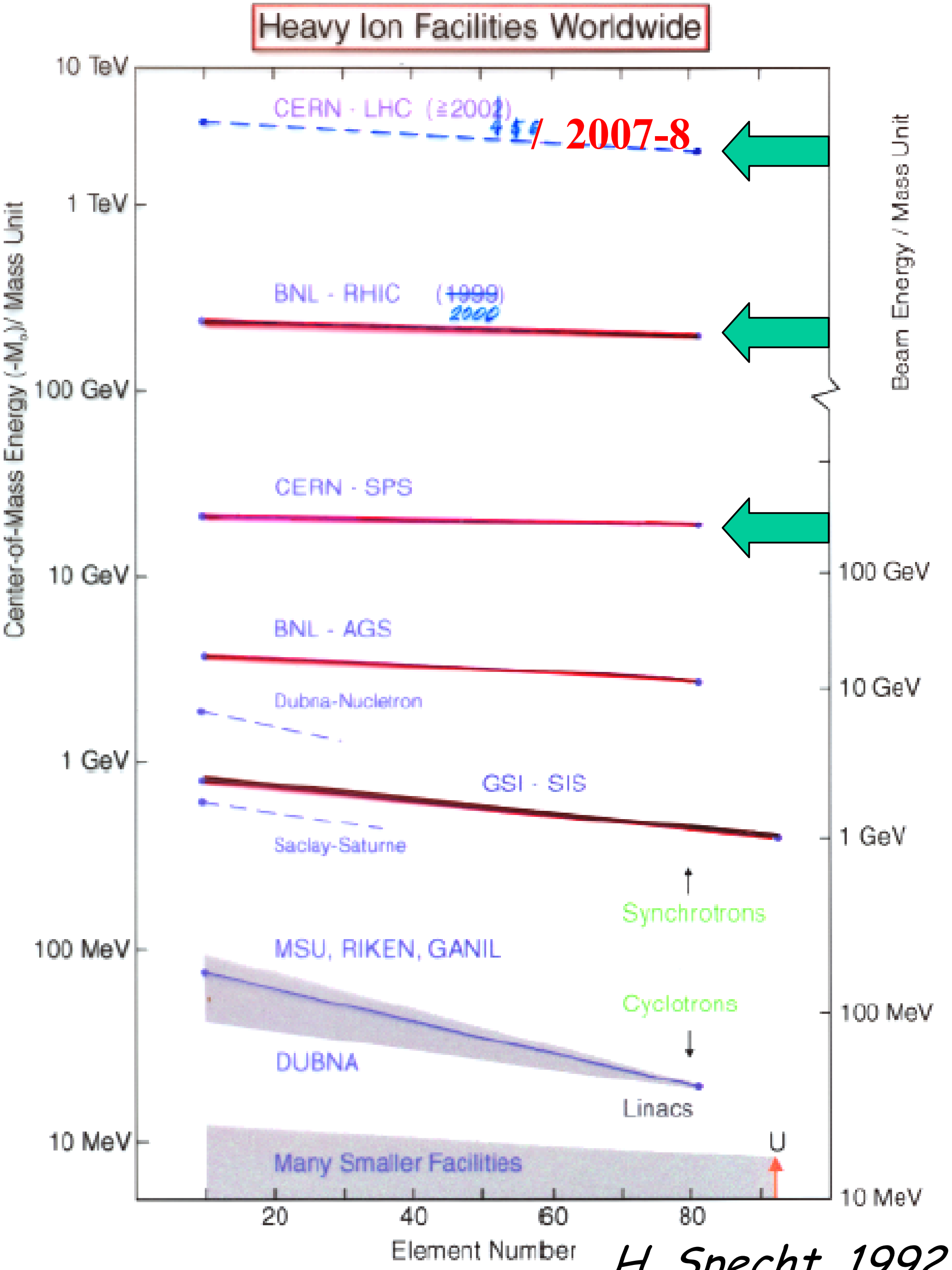
Data throughput: 1.2 GB/s

5.5 Tev
per Nucleon

$N_{ch}(-0.5<\eta<0.5)=8000$

The Large Hadron Collider

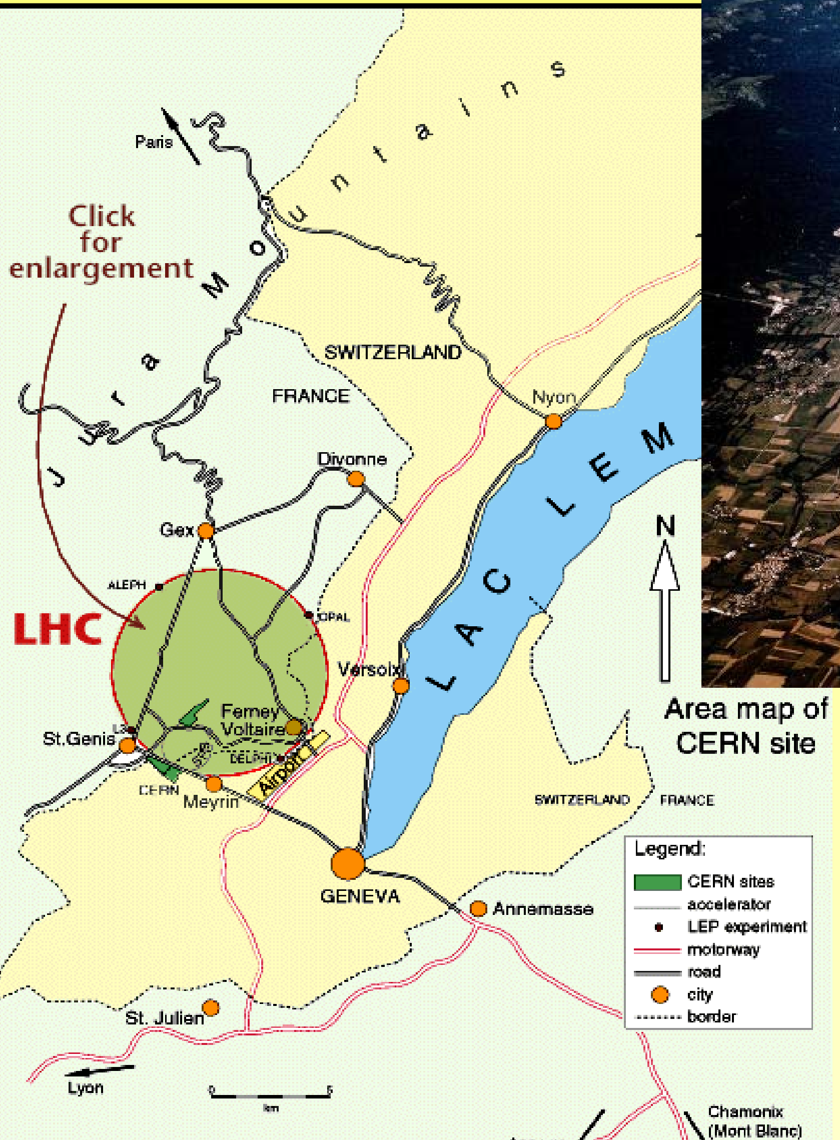
- **The LHC is the latest of a series of successful accelerators**
- Main orders for LHC components are now out, the construction plan seems solid, so now the target date should not change anymore



H. Specht, 1992

The Large Hadron Collider /2

Scheduled start: 2007



$\sqrt{s_{pp}} = 14$ TeV $\sqrt{s_{PbPb}} = 5.5$ TeV $(\Delta\eta \sim 17)$

Note : $\sqrt{s}$ limited by needed bending power.

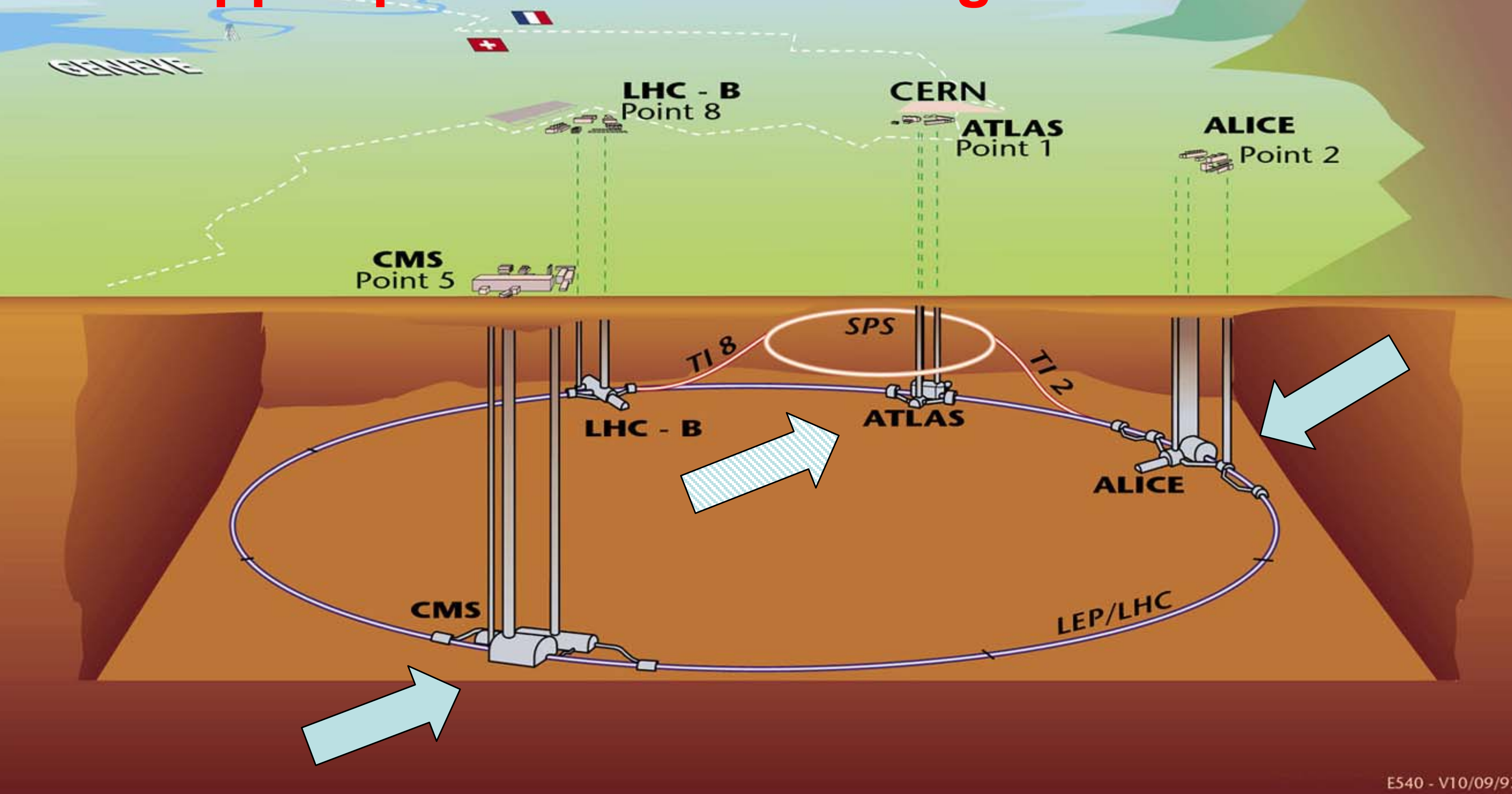
LHC : 1232 superconducting dipoles with B = 8.4 T working at 1.9 Kelvin (the largest cryogenic system in the world)

Overall view of the LHC experiments.

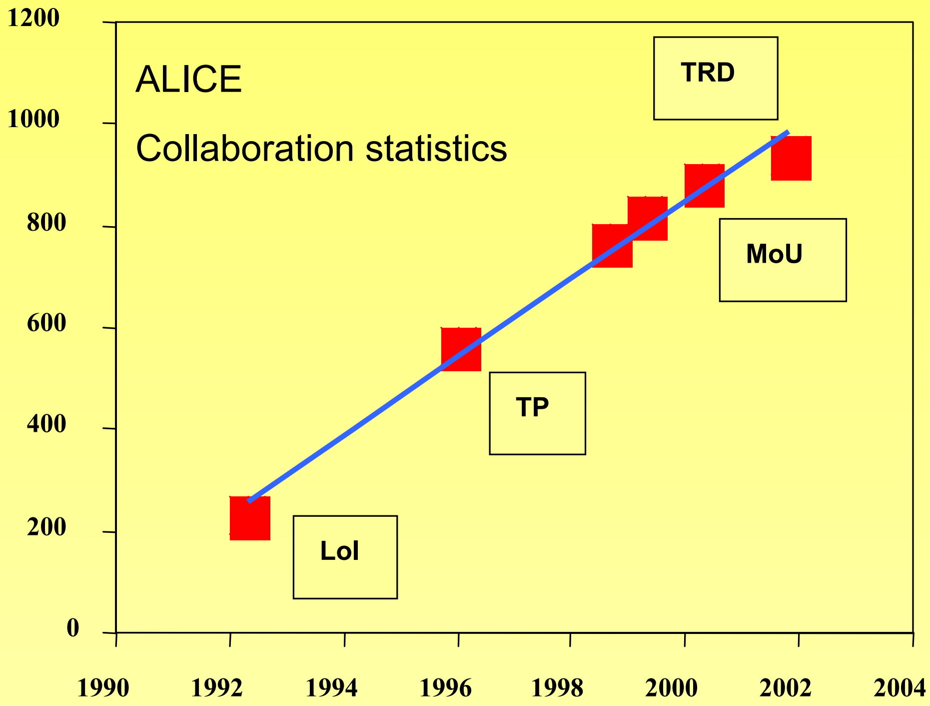
One HI experiment with a pp program: ALICE

One pp experiment with a HI program: CMS

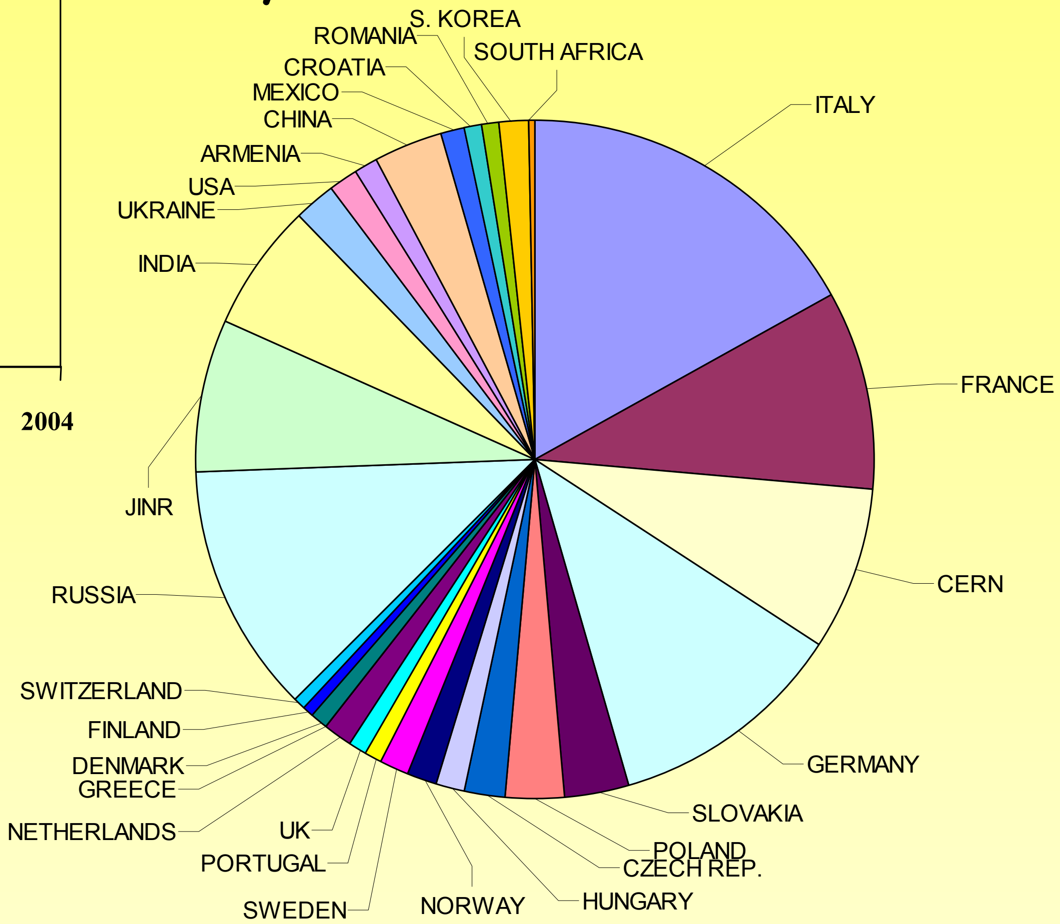
One pp experiment considering HI: ATLAS



Who/what is ALICE ?



After *more than 10 years of life*, ALICE keeps growing! At present, discussions are ongoing with over 20 more institutions from Brazil, Japan, Turkey and USA



937 members

(63% from CERN MS)

77 Institutions,

29 Countries

2007 is far.. However ALICE is already in its installation phase: here the magnet plugs

The ALICE Magnet:

ready for the experiment to move in!

Experimental conditions @ LHC

- pp commissioning: April 2007
- 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 $\mathcal{L} \sim 10^{27}$ $cm^{-2}s^{-1}$
    - 1 year p - Pb 'like' (p, d or α) $\mathcal{L} \sim 10^{29}$ $cm^{-2}s^{-1}$
    - 1 year light ions (eg Ar-Ar) $\mathcal{L}$ ~few 10^{27} to 10^{29} $cm^{2}s^{-1}$
      ALICE is limited by pileup in TPC:
    - reg. pp run at $\sqrt{s}$ = 14 TeV $\mathcal{L} \sim 10^{29}$ and < $3x10^{30}$ $cm^{-2}s^{-1}$
  - Later: different options depending on Physics results
- **Heavy Ion is a part of the LHC initial program, early pilot run expected by end of 2007**

Why Heavy Ion collisions

- Colliding two heavy nuclei at ultrarelativistic energies allows to create in the laboratory a bulk system with huge density, pressure and temperature (T over 100,000 times higher than in the core of the Sun!) and to study its properties
- At such densities, hadrons are so closely packed that they interpenetrate; novel physics phenomena are likely to appear
- QCD predicts that under such conditions a phase transition from a system composed of colorless hadrons to a Quark-Gluon Plasma (QGP) should occur (the QGP should live for a very short time, about 10^{-23}s, or a few fm/c).
- Possible **key to understand Confinement**
- Also path to the region of highest energy collisions in Cosmic Rays (Accelerators start competing with the Universe!)

- A skier (quark?) is confined inside snow patches (hadrons?)

Temperature

- the skier can move further…a new phase develops

.. goes up

- a skier (quark?) can move freely over long distances...

.. this way

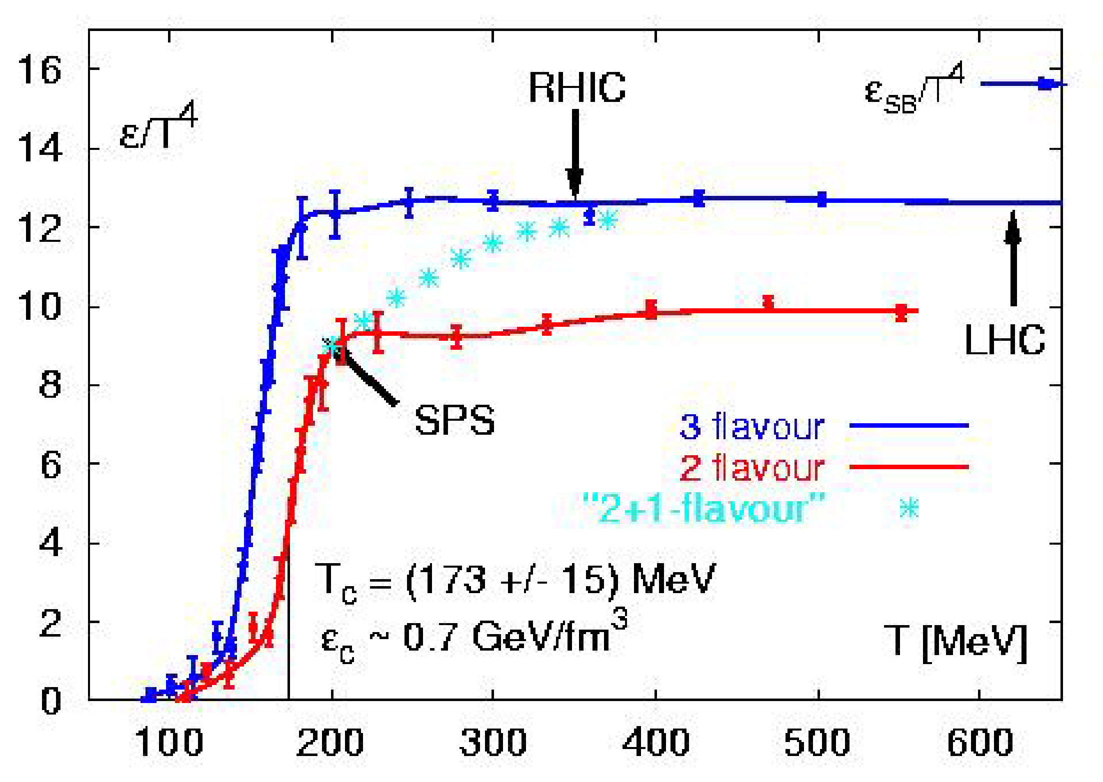
L. Maiani, 2000

Lattice QCD calculations

In lattice QCD, non-perturbative problems are treated by discretization on a space-time lattice.

- $T_c \cong 170$ MeV $\varepsilon_c \cong 0.6$ GeV/fm^3

- The limit of an ideal Stefan Boltzmann gas of quarks and gluons is not reached → non perturbative phenomena are still relevant



La Thuile, 15/3/2003

Why Heavy Ions at the LHC ?

New or more important at the LHC w.r.t. SPS and RHIC:

- Vanishing net baryon density ($\mu_B \rightarrow 0$)
- Closer to lattice QCD assumptions, closer to Early Universe
- High energy density → limit of an “ideal” gas of QCD quanta
- Stronger thermal radiation
- Hard probes:

eavy flavours

ets and jet quenching

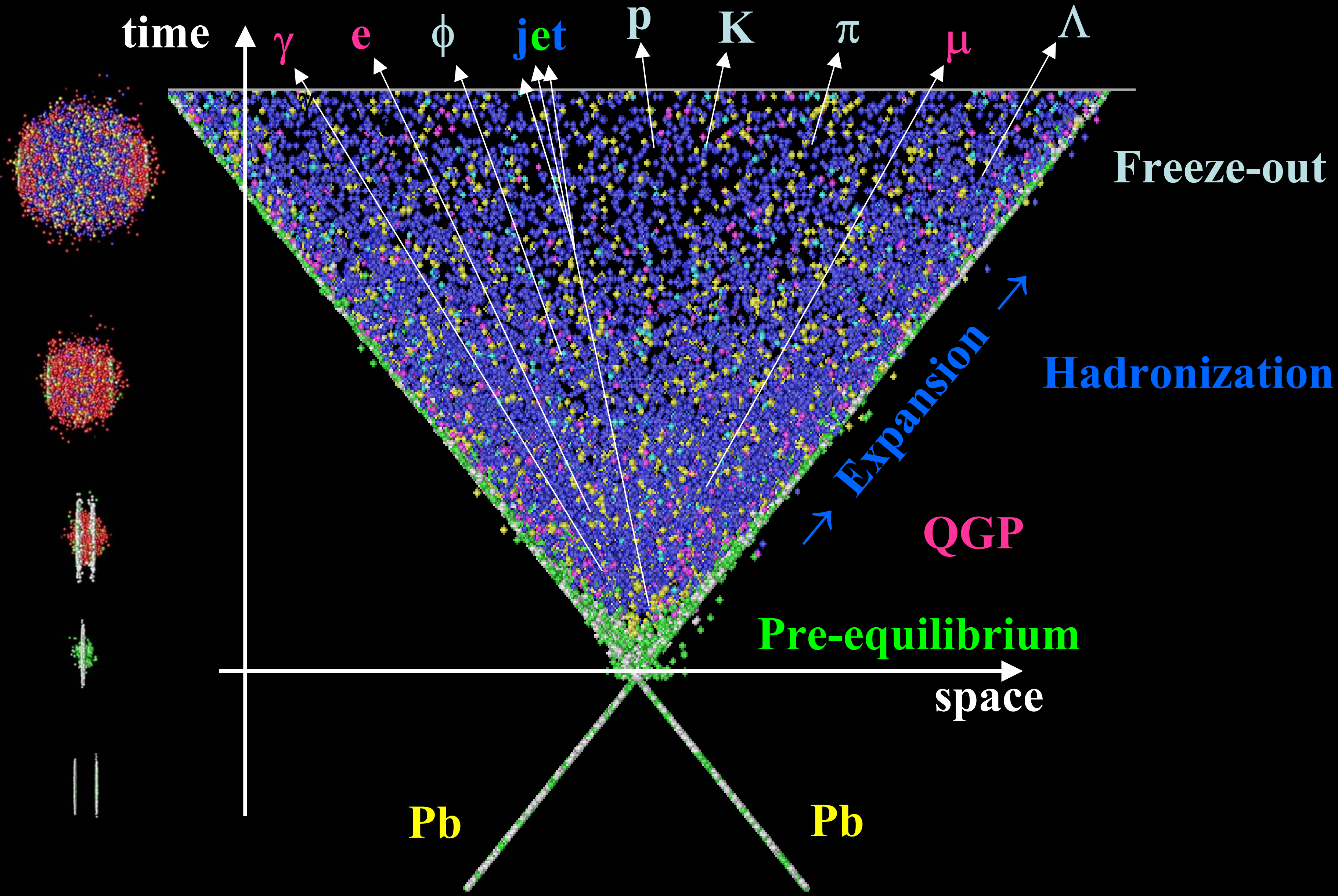
Dominant processes in particle production
SPS: soft
RHIC: soft and semi-hard
LHC: semi-hard and hard

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

1) $\varepsilon_{LHC} > \varepsilon_{RHIC} > \varepsilon_{SPS}$
2) $V_f^{LHC} > V_f^{RHIC} > V_f^{SPS}$
3) $\tau_{LHC} > \tau_{RHIC} > \tau_{SPS}$

- The LHC is the ideal place to study the QGP:
- hotter - bigger -longer lived
- ~ 10^4 particles per event: Event by event physics

Space-time Evolution of Collisions



Diagnostic tools

the experimental challenge: to observe in the final state the signatures of the phase transition

- **Low-p_t "soft" probes**

thermal particle production from QGP

  - single particle spectra
  - two particle correlations
  - particle abundances and ratios
  - flow patterns
  - E_t

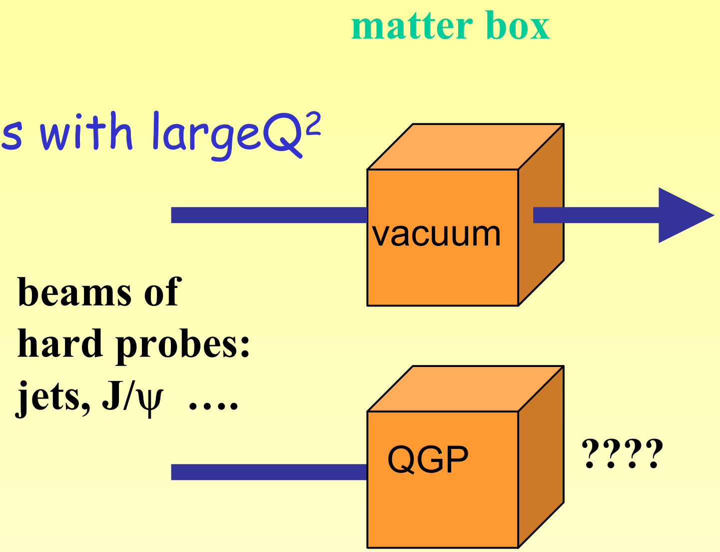
Caveat: pure hadronic effects can mimic expected QGP signaturures

Therefore one needs:

- to establish experimentally a **solid baseline** studying systems where no QGP is expected (e.g. **pp, pA**) and use these data as a reference

- **High-p_t "hard" probes**

during formation phase parton scattering processes with largeQ^2 create high mass or high momentum objects that penetrate hot and dense matter and are sensitive to the nature of the medium



beams of hard probes: jets, J/ψ ….

ALICE Physics goals / 0

- ALICE has to cover in one experiment what at SPS was studied by 6-7 different experiments and at RHC by 4
- ALICE aims to study the most wide spectrum of signals covering in a thorough way the dynamics of the collision

ALICE Physics goals / 1

- **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
- **Study deconfinement:**
  - charmonium and bottonium spectroscopy
- **Study chiral symmetry restoration:**
  - neutral to charged ratios, resonance decays

ALICE Physics goals / 2

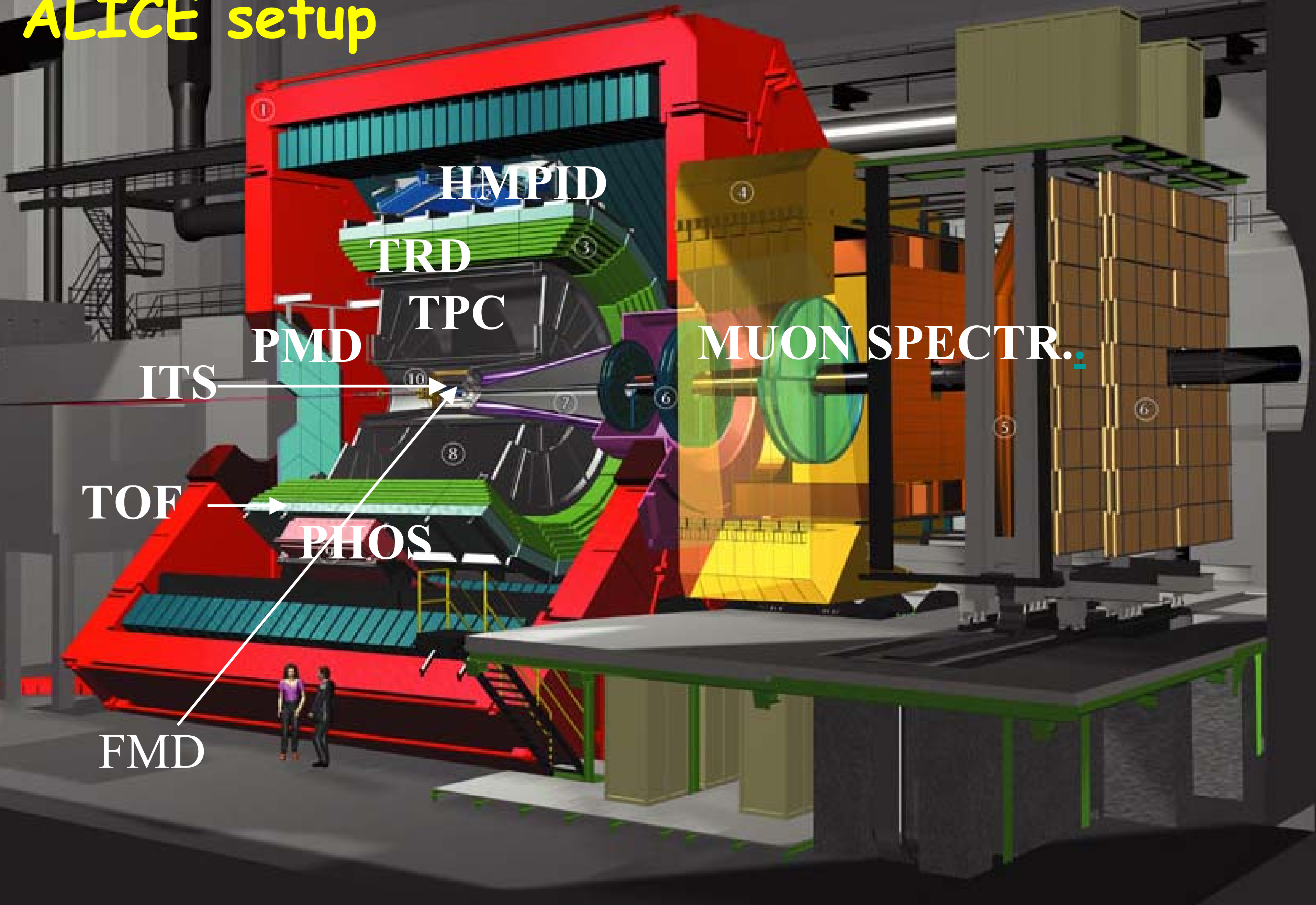
- **Detect fluctuation phenomena - critical behavior:**
  - event-by-event particle composition, spectra
- **Measure the geometry of the emitting source:**
  - HBT, impact parameter via zero-degree energy flow
- **Study pp collisions in the new energy domain (complementary w.r.t ATLAS and CMS)**
- **Search for:** Centauro events, strangelets

NEEDS

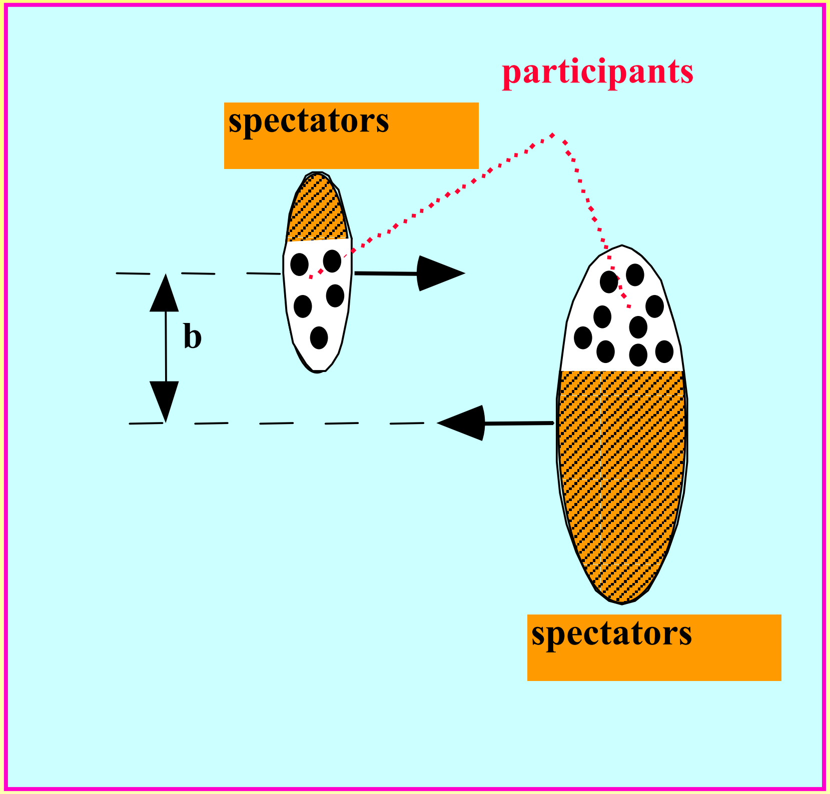
- Large acceptance
- Good tracking capabilities
- Selective triggering
- Excellent granularity
- Wide momentum coverage
- P.I.D. of hadrons and leptons
- Good sec. vertex reconstruction
- Photon Detection

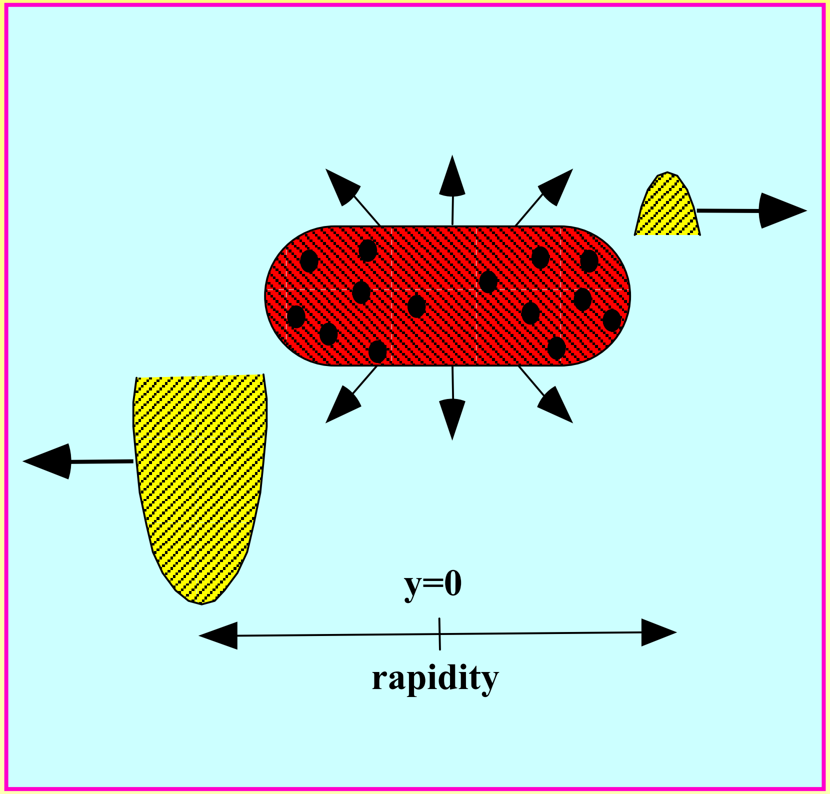
Use a variety of experimental techniques!

ALICE setup



Measure of the event geometry…



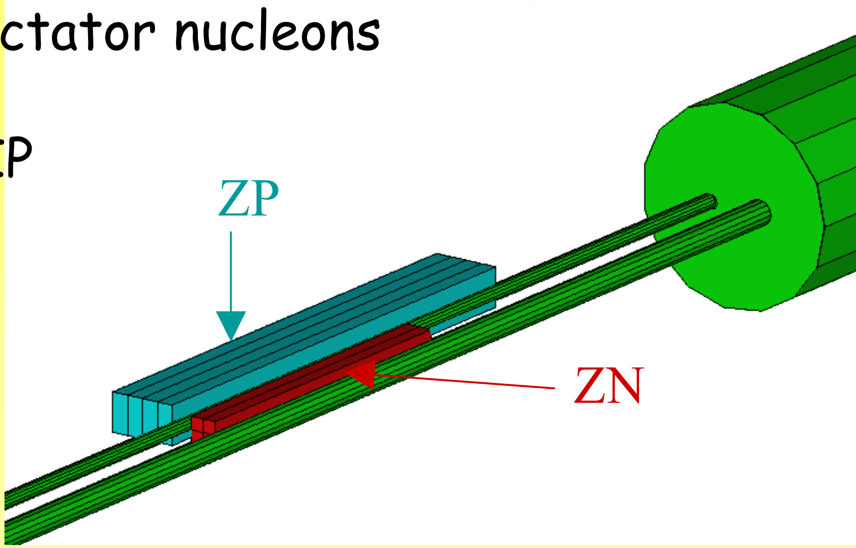


Measure the energy of the spectators, mostly individual neutrons and protons

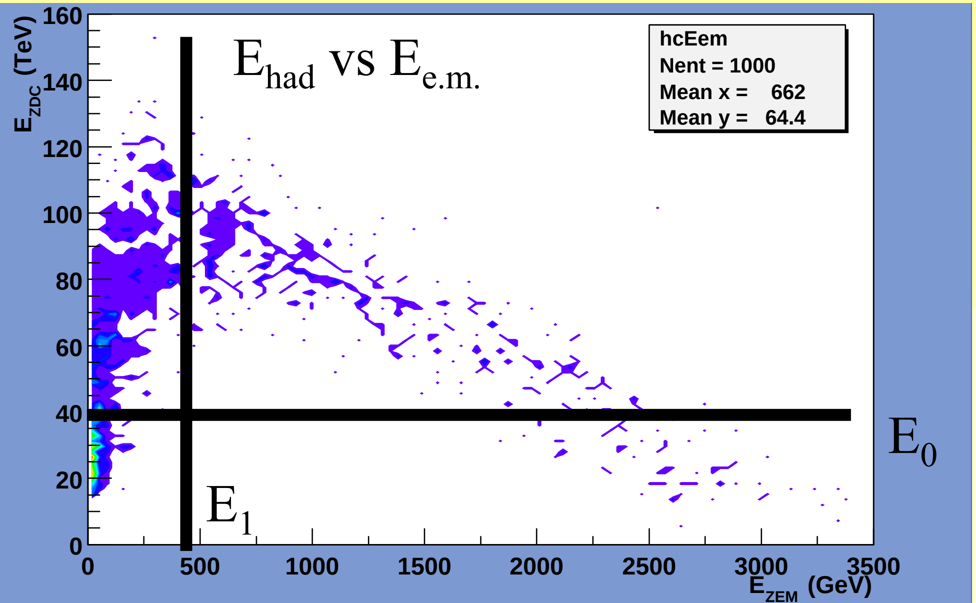
… How? Zero Degree Calorimeters
=> use the machine optics to catch particles at beam rapidity (angle zero)

Aim: determination of the impact parameter of the collision by measuring the energy carried by the spectator nucleons

Where: hadronic cal at ~ 116 m from IP
e.m. calorimeter at ~ 8 m from IP

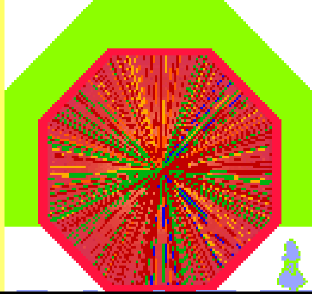


*Central events selected with **both***:
- -Energy in hadronic calorimeters < E_0
- -Energy in e.m. calorimeter >E_1



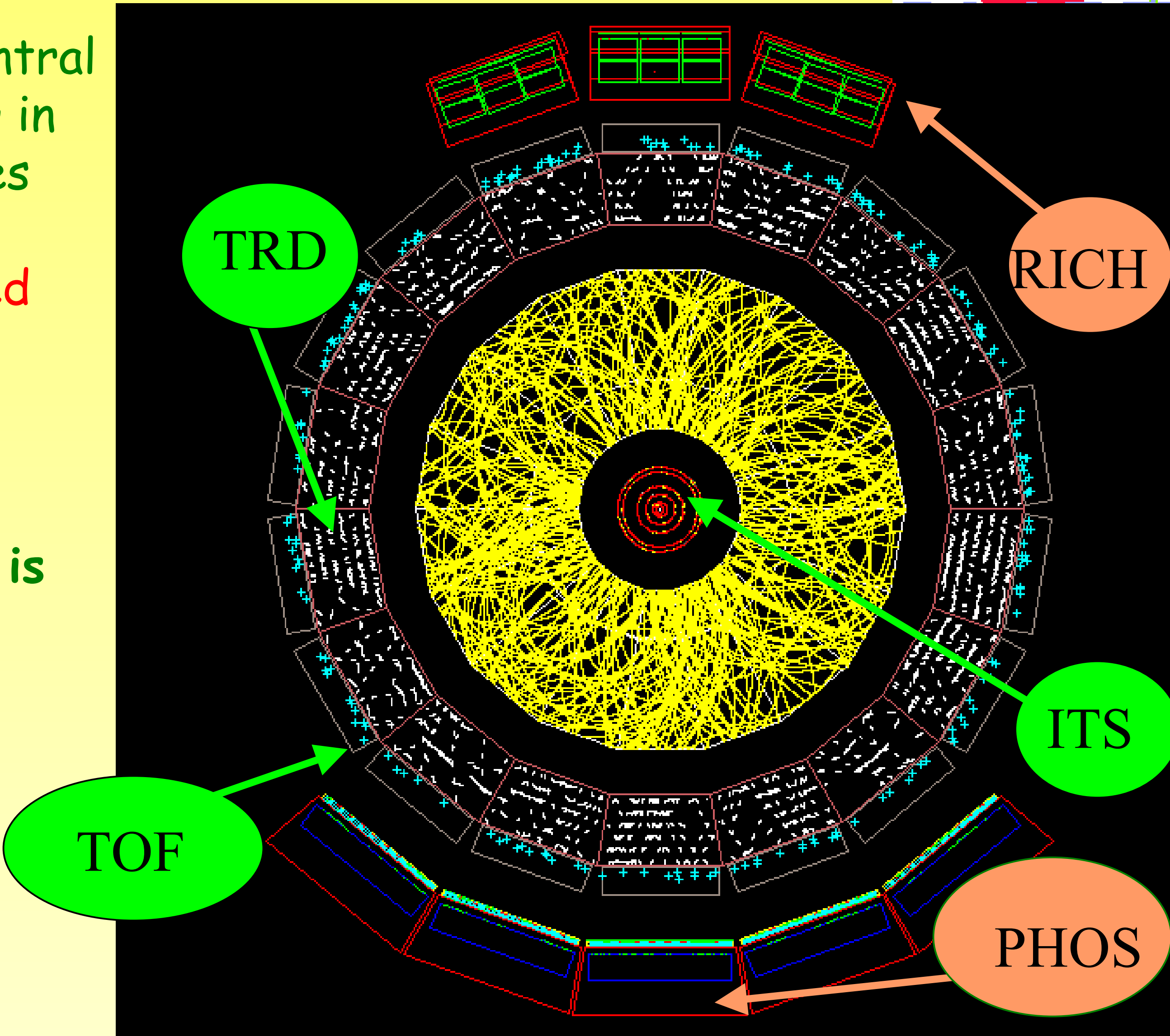
	Proton ZDC (ZP)	Neutron ZDC (ZN)	EM ZDC
Dimensions (cm^3)	12x21x150	7x7x100	7x7x21
Absorber	brass	W-alloy	lead
Fibre angle wrt LHC axis	0^O	0^O	45^O
Fibre ∅ (μm)	550	365	550

Tracking: the major challenge for ALICE



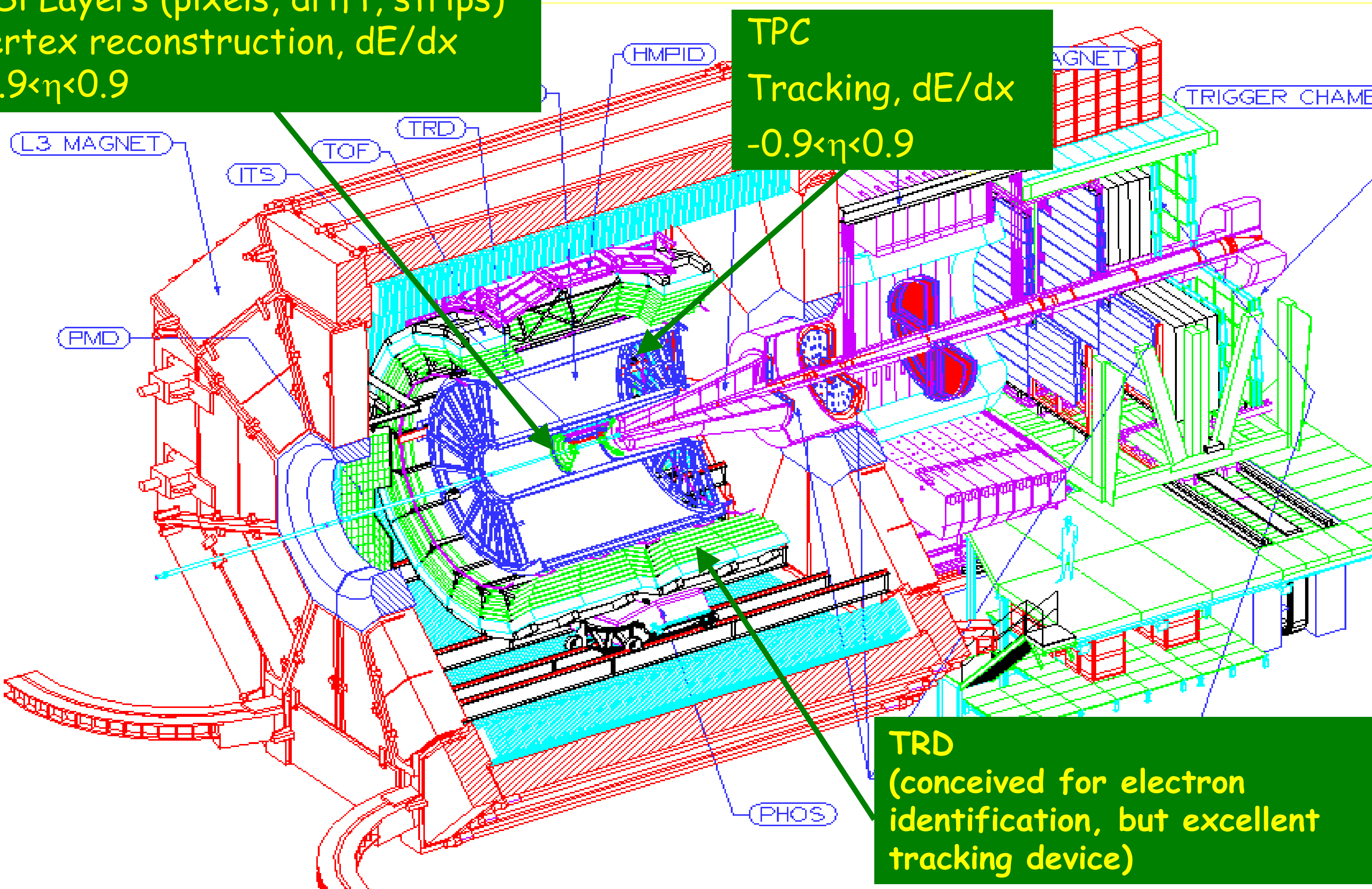
- Event display for a central Pb-Pb collision. Tracking in the central brrel involves TOF, TRD, TPC, ITS.
- Track finding is carried out in the TPC

- $N_{ch}(-0.5<\eta<0.5)=8000$
- **Only a slice of $\Delta\theta=2^o$ is shown**



La Thuile, 15/3/2003

ALICE LAYOUT: TRACKING



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

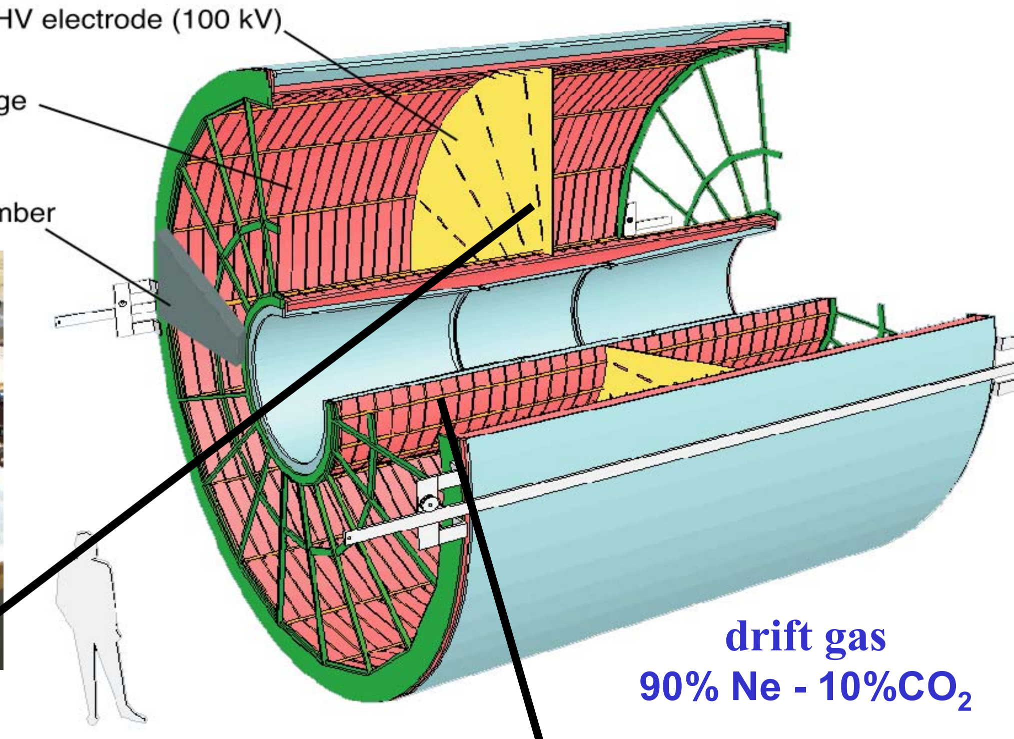
TPC

Tracking, dE/dx

$-0.9<\eta<0.9$

TRD
(conceived for electron identification, but excellent tracking device)

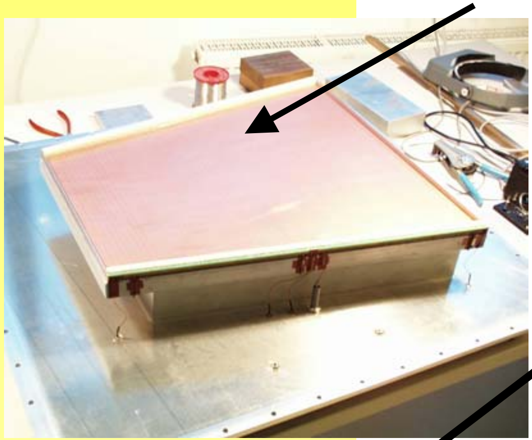
Time Projection Chamber largest ever: 88 m^3, 570 k channels



drift gas
90% Ne - 10%CO$_2$

for tracking and PID via dE/dx

$-0.9 < \eta < 0.9$

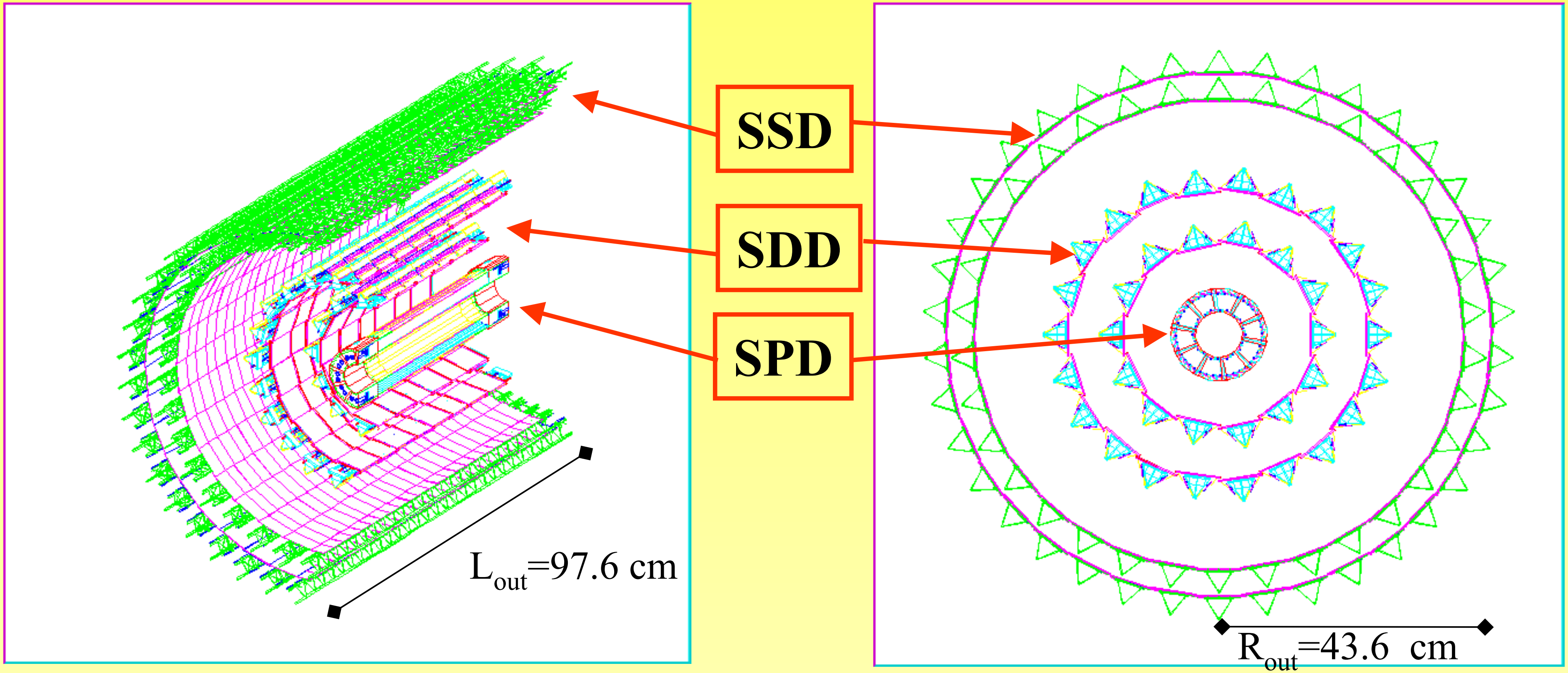


Central Electrode Prototype

25 µm aluminized Mylar on Al frame

Assembly of the TPC outer field cage and end plates

The Inner Tracking System



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

See E. Crescio's talk on SDD tomorrow afternoon

ITS: Many electronics developments

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

ALICE PIXEL CHIP

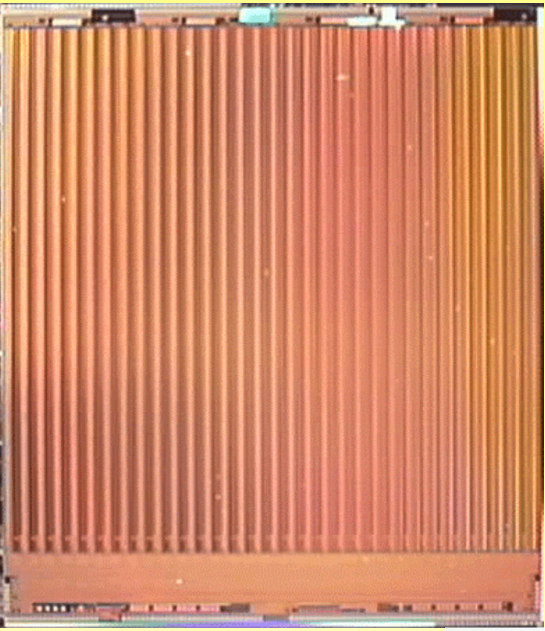
50 μm x 425 μm pixels

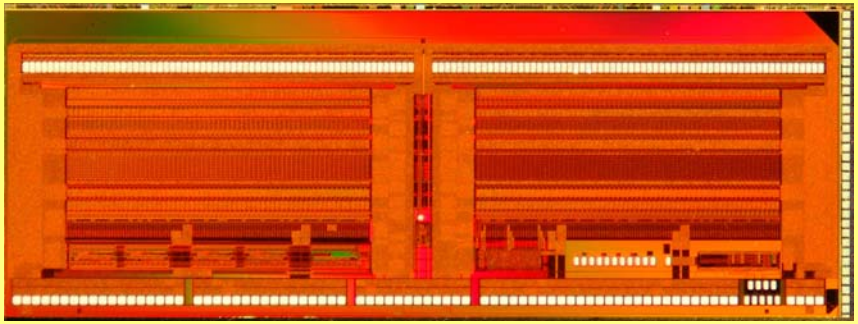
8192 cells

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

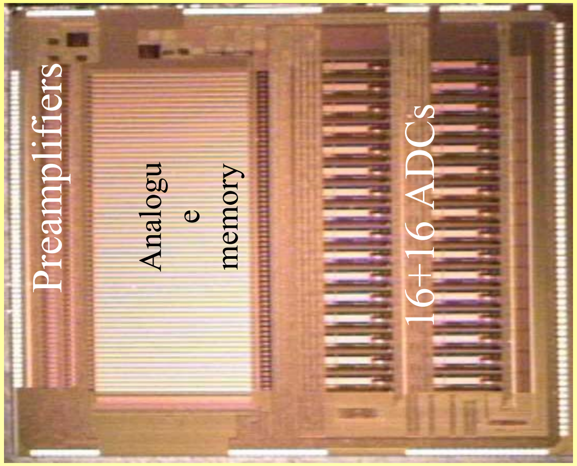
ALICE SDD FEE

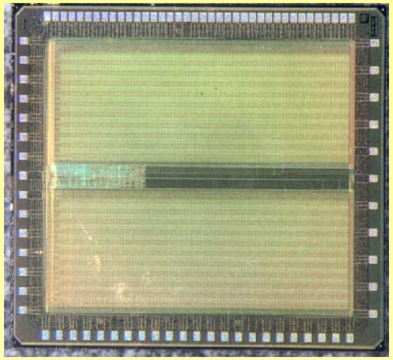
Pascal chip:

64 channel preamp+ 256-deep analogue memory+ ADC

Ambra chip:

64 channel derandomizer chip

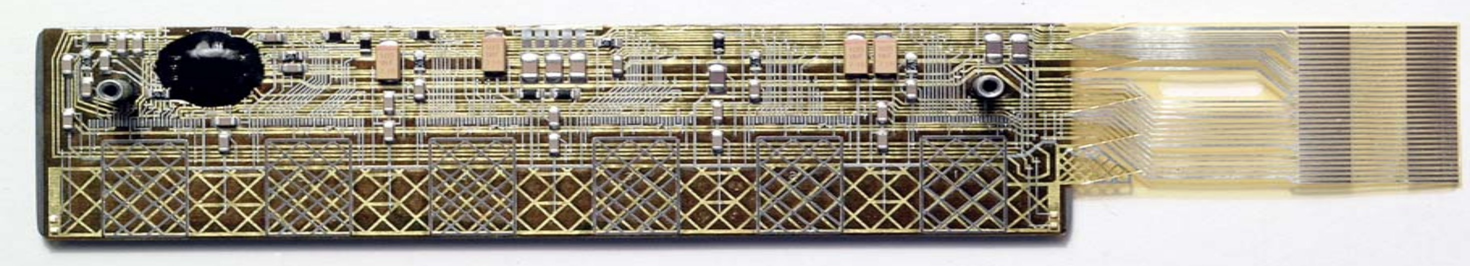


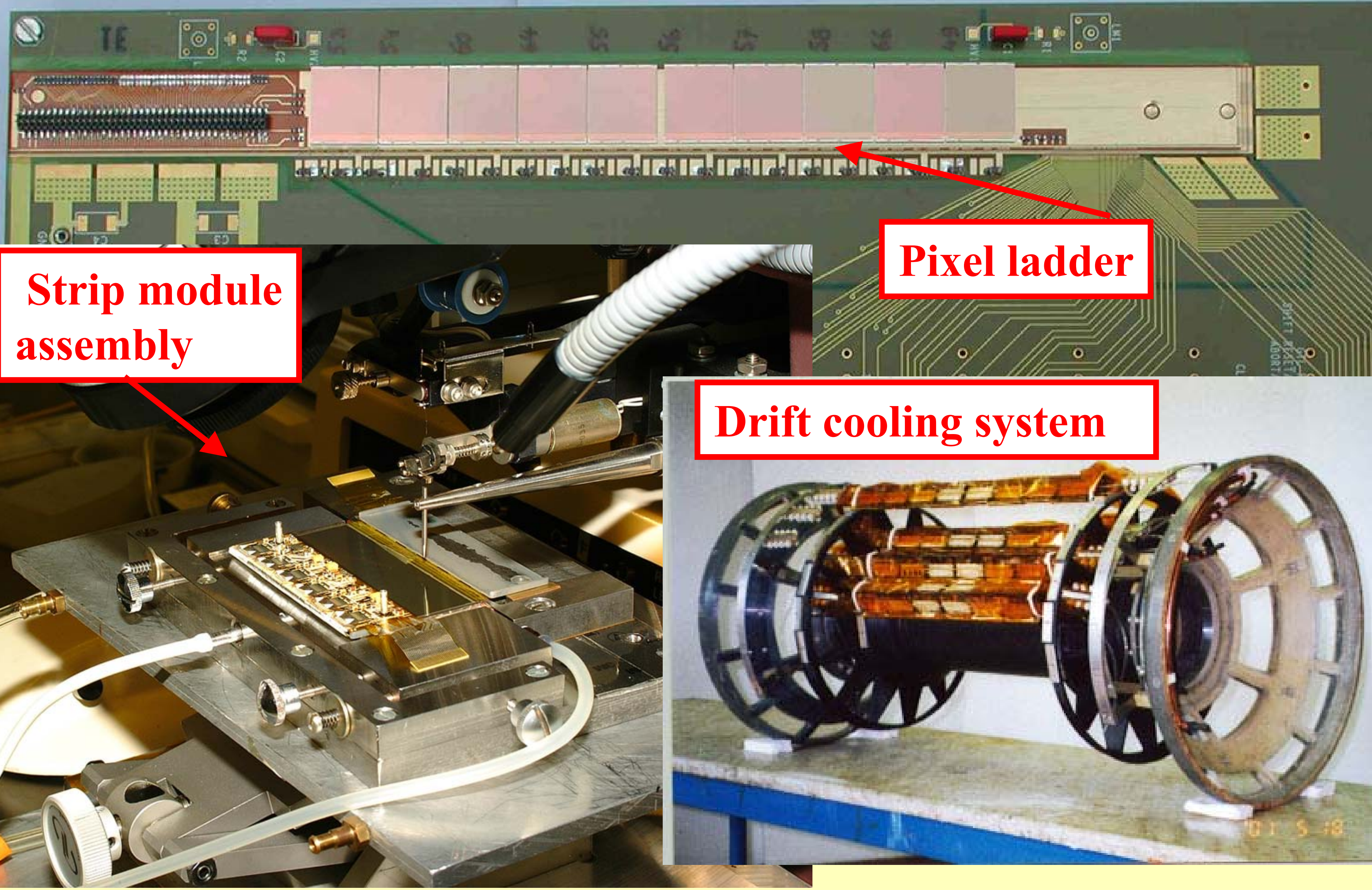


And extreme lightweight interconnection techniques:

SSD tab-bondable

Al hybrids





Pixel ladder

Strip module assembly

Drift cooling system

System testing

Tracking in the central barrel

- $dN/d\eta|_{max}=8000$ → tracking in the central barrel is a great challenge !
- Requirements (TPC+ITS):
  - Good efficiency (> 90%) for $p_T > 0.2$ GeV/c @ 0.4 Tesla magnetic field
  - Momentum resolution (dp/p) ~ 1÷2% at low momenta and few % at 5 GeV/s
  - Good vertexing capabilities: V0, charm
  - Particle identification (dE/dx, kinks)

Tracking solutions

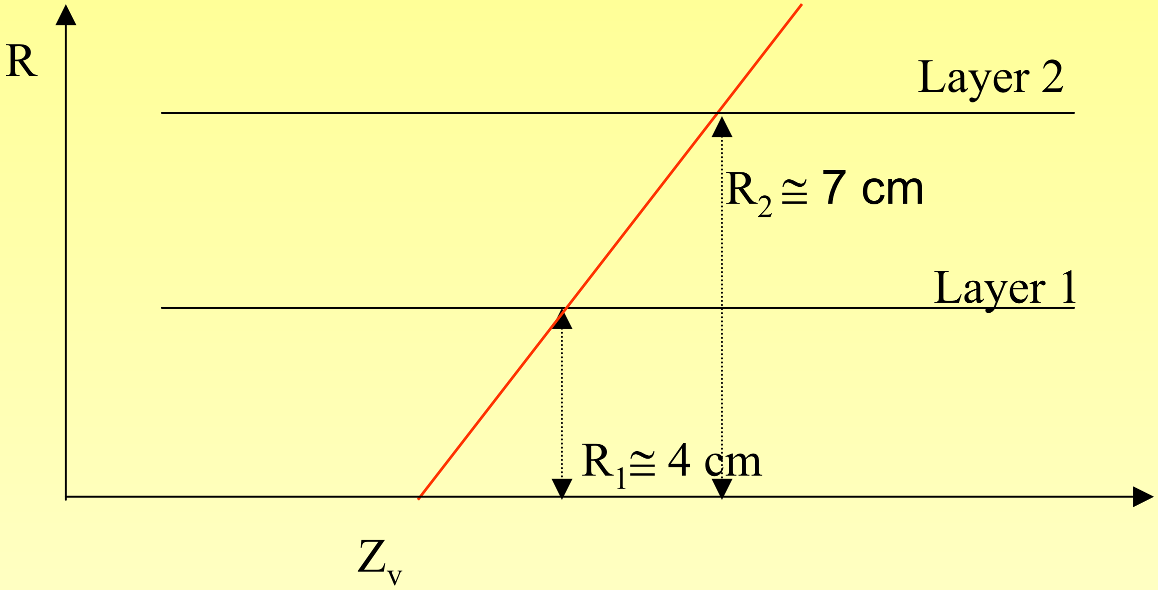
- Tracking finding and fitting: Kalman filtering
- Track seeding: outer TPC (lower track density)
- Tracks prolonged to ITS
- In ITS: Kalman + vertex constraint (σ_z=100 μm)
- From ITS: back propagation to TRD and TOF

Needs

Primary vertex position measurement

Vertex determination

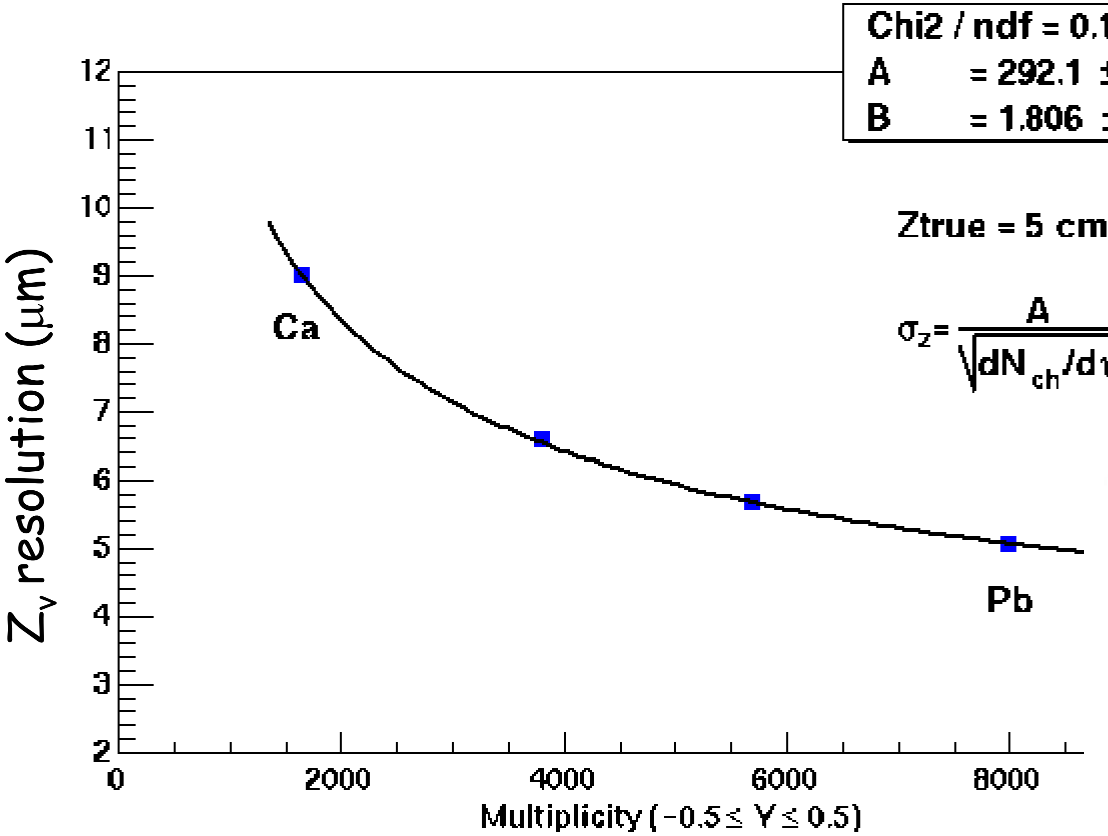
Z_v is estimated starting from a correlation between the first 2 ITS layers (PIXEL) in a narrow azimuthal ($\Delta\phi$) window (here high multiplicity HELPS!)



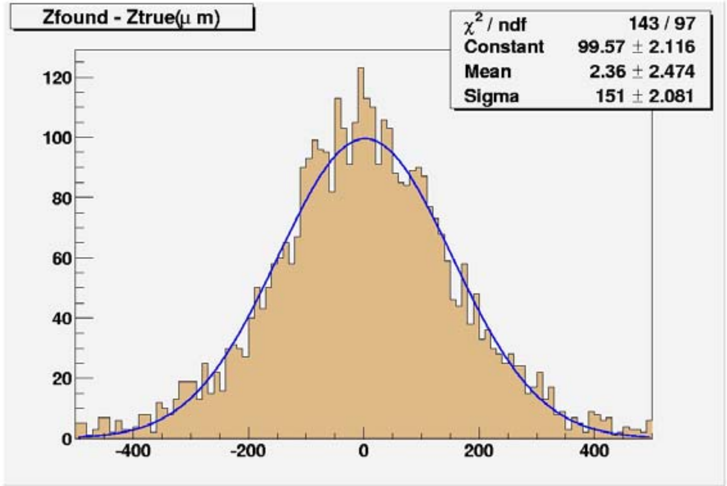
The coordinates in the bending plane are measured in a similar way.

More precise results can be obtained by using the reconstructed tracks

Vertex determination /2



p-p

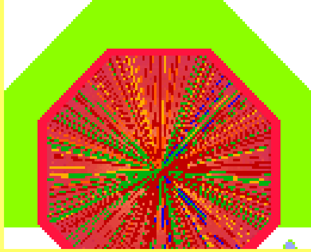


Pb-Pb → $\sigma_z \cong 5 \div 10$ μm ; $\sigma_x = \sigma_y \cong 25$ μm

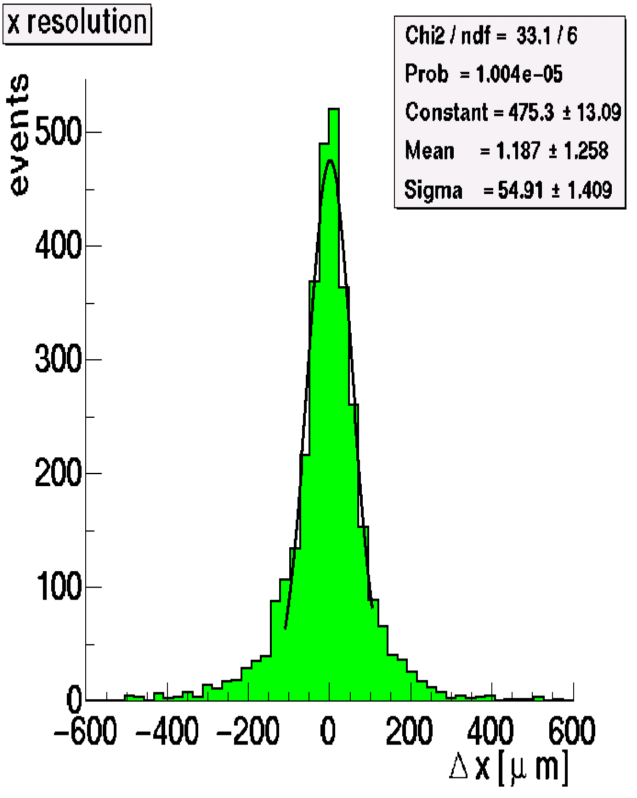
p-p → $\sigma_z \cong 100$ μm; $\sigma_x = \sigma_y \cong 55$ μm with tracks

No dependence on B

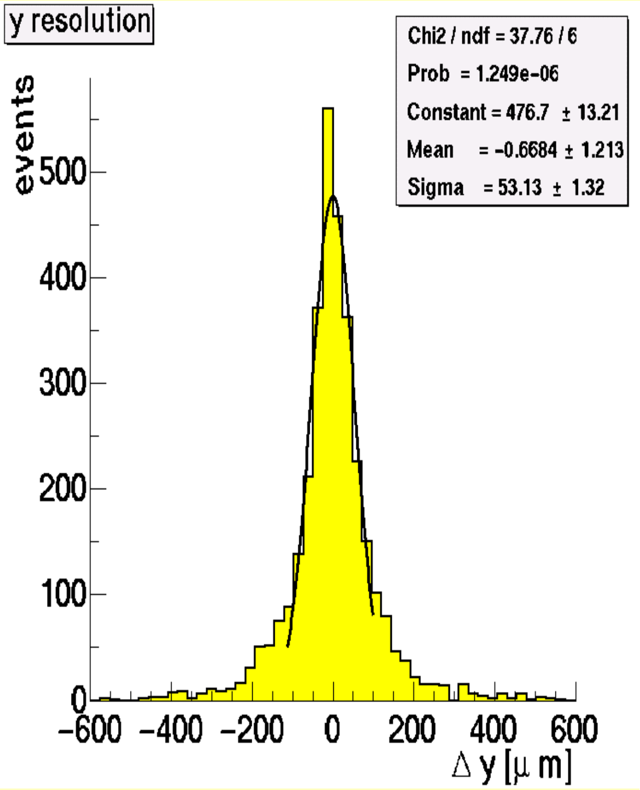
Resolutions for pp with tracks



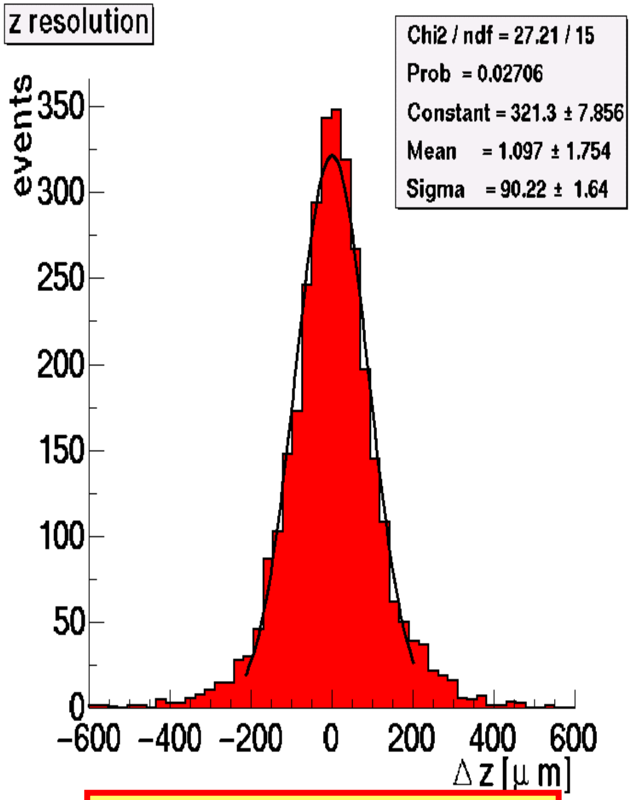
Non diffractive pp collisions generated with Pythia (CTEQ4 LO str. Functions). Steps: Z coord. found with pixels; coordinate finding from the point of closest approach of reconstructed tracks; coordinate fitting → reasonable error estimate



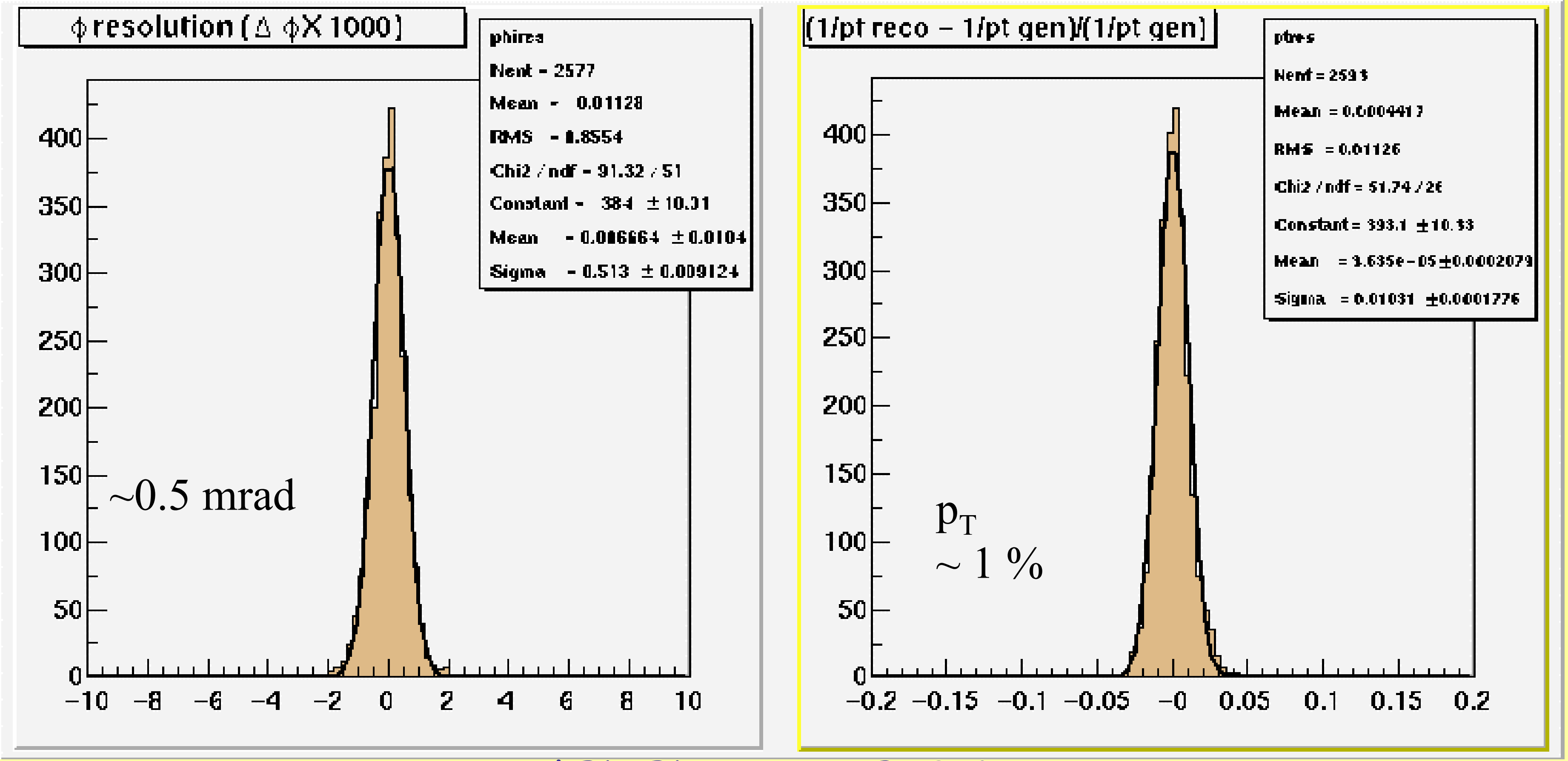
σ(x) = 55 μm



σ(y) = 55 μm



σ(z) = 90 μm

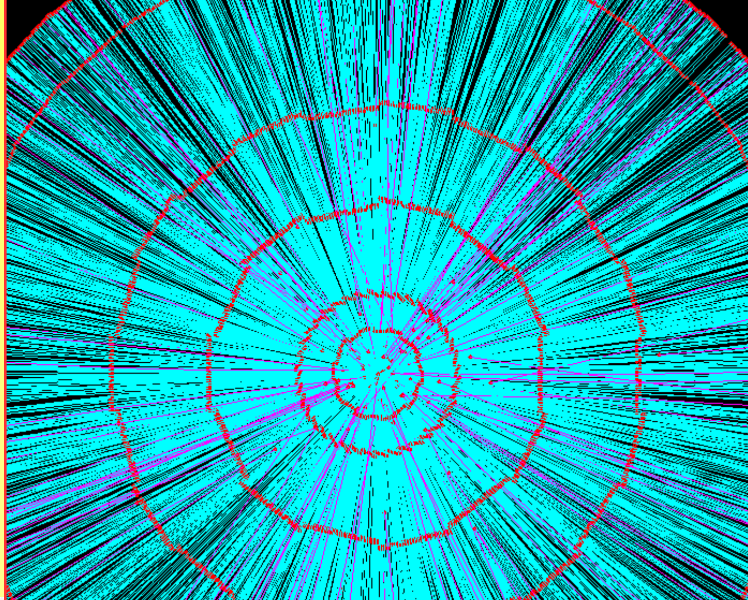


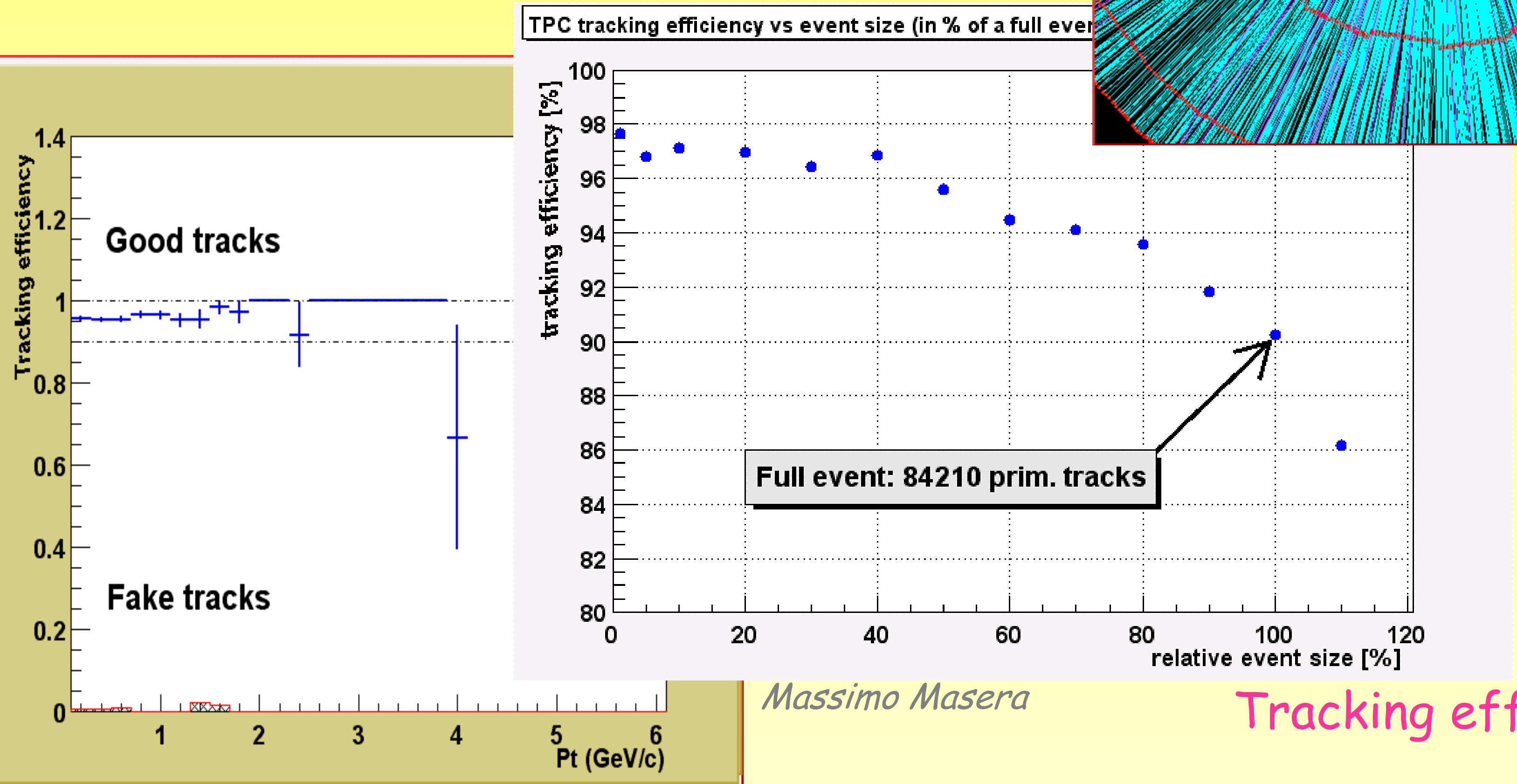
Central Pb-Pb -- B=0.4 T

	all p_T		p_T> 5 GeV/c	
B(T)	0.2	0.5	0.2	0.5
Δp/p TPC (%)	2.4	1.2	8.5	5.8
Δp/p TPC+ITS (%)	1.6	0.7	3.4	1.4

Display of reconstructed tracks in ITS.

- ✓Clusters are red dots
- ✓Cyan lines: primary tracks
- ✓Magenta lines: secondary tracks

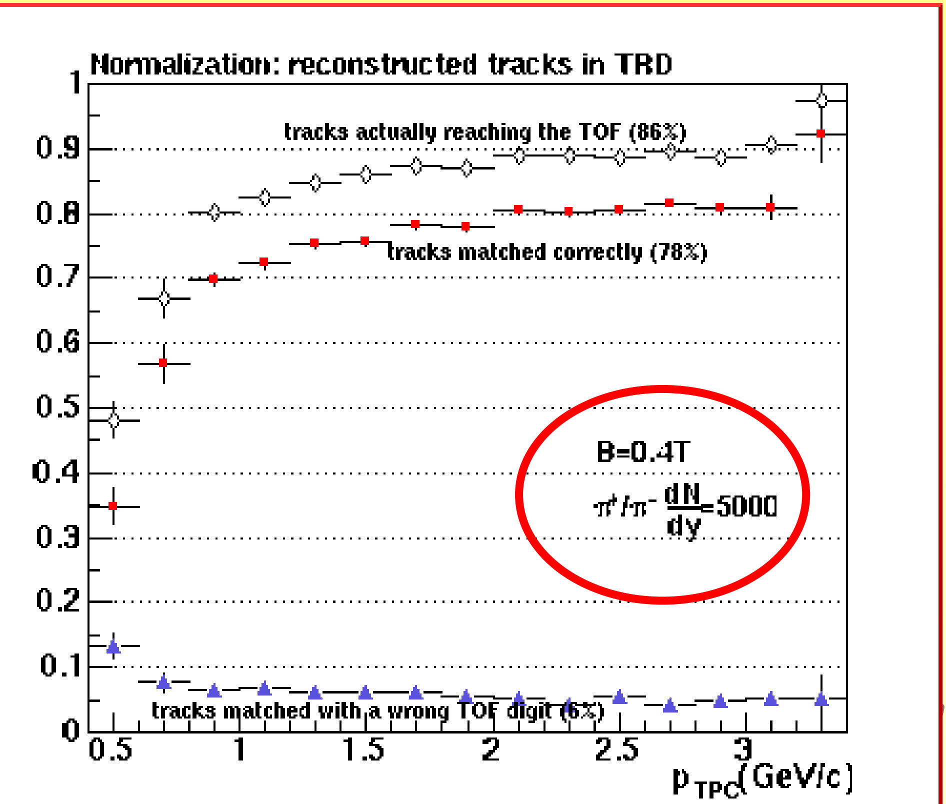


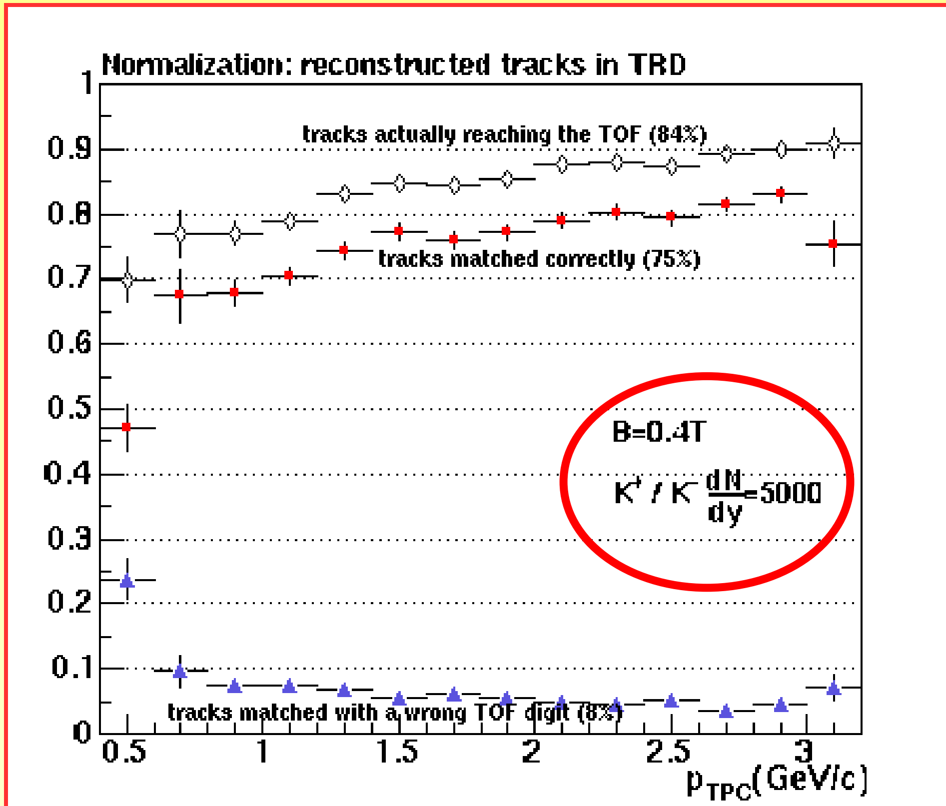


Tracking eff. In TPC

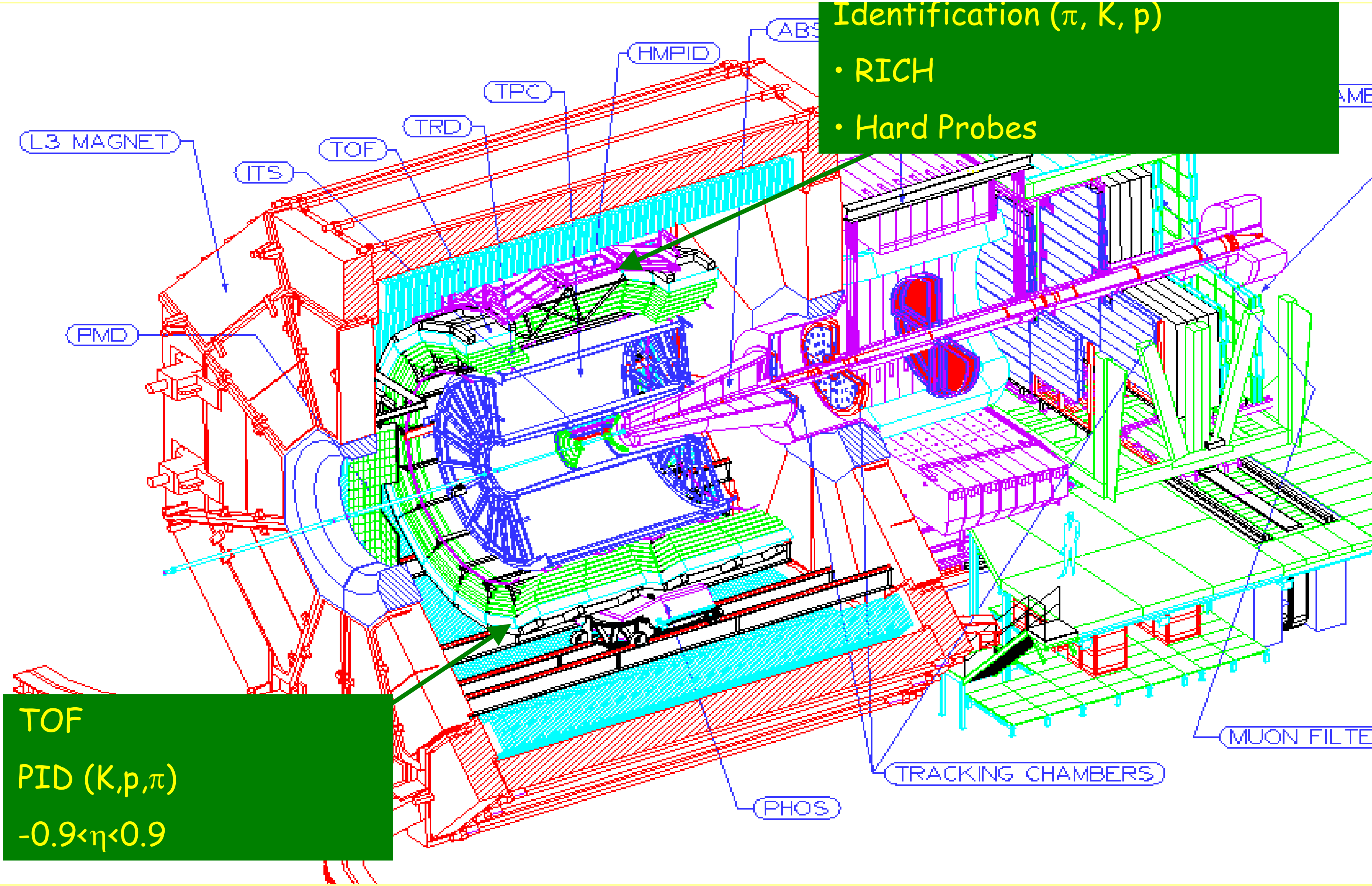
Matching with TRD and TOF

- Tracks are back-propagated to the outer detectors: TRD and TOF
- The fist results on the full chain of reconstrunction have been presented in January 2003
- The matching efficiency TRD-TOF is ~90%





ALICE LAYOUT: PID



Identification (π, K, p)

- RICH
- Hard Probes

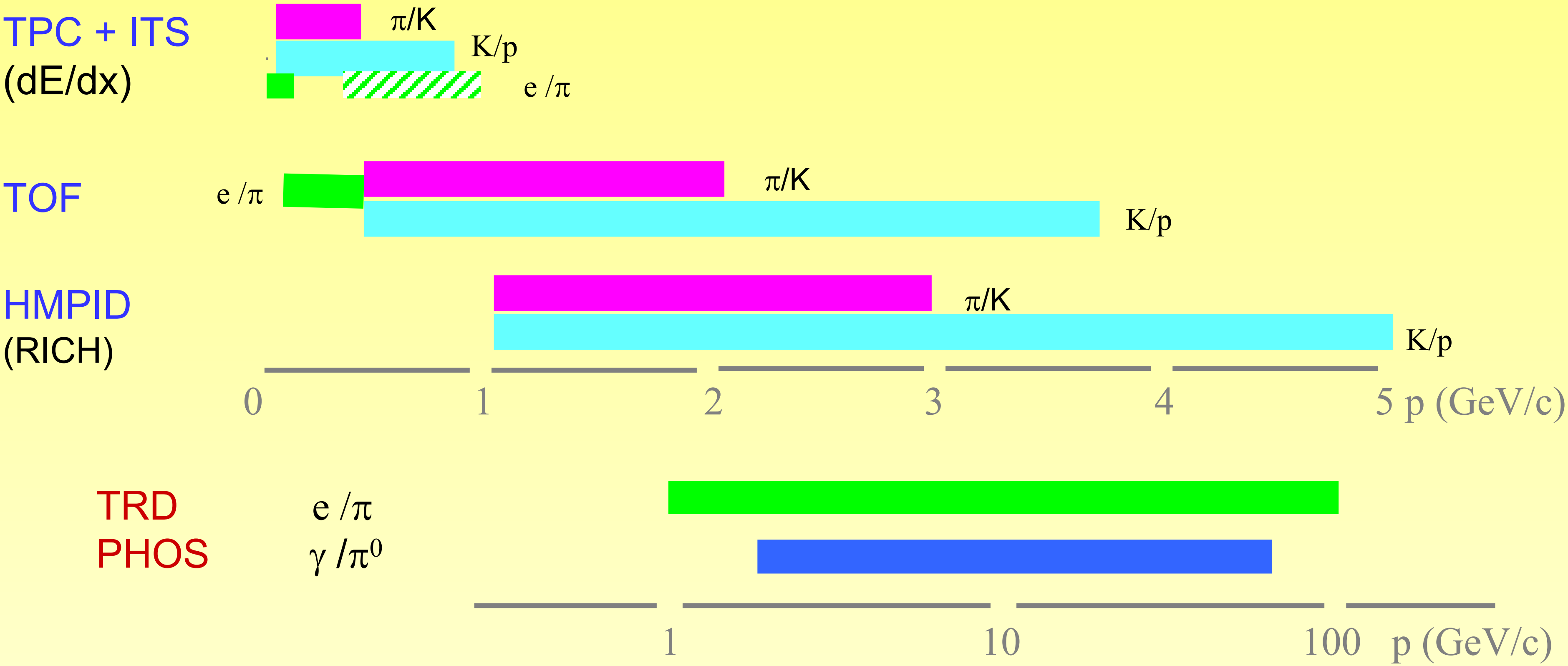
TOF

PID (K,p,π)

$-0.9<\eta<0.9$

Particle Identification / 1

- 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 EM energy flow in EMCAL



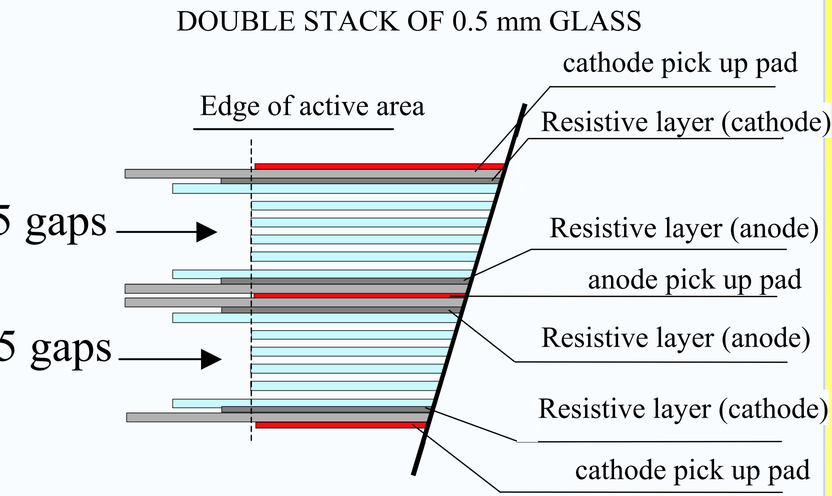
Particle Identification / 1

- Λ are identified reconstructing the decay vertex for transverse momenta in the range 500 MeV/c to ~ 10 GeV/c
- Same for K^0 in the range 250 MeV/c to ~ 10 GeV/c
- Under study is the 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

Time Of Flight

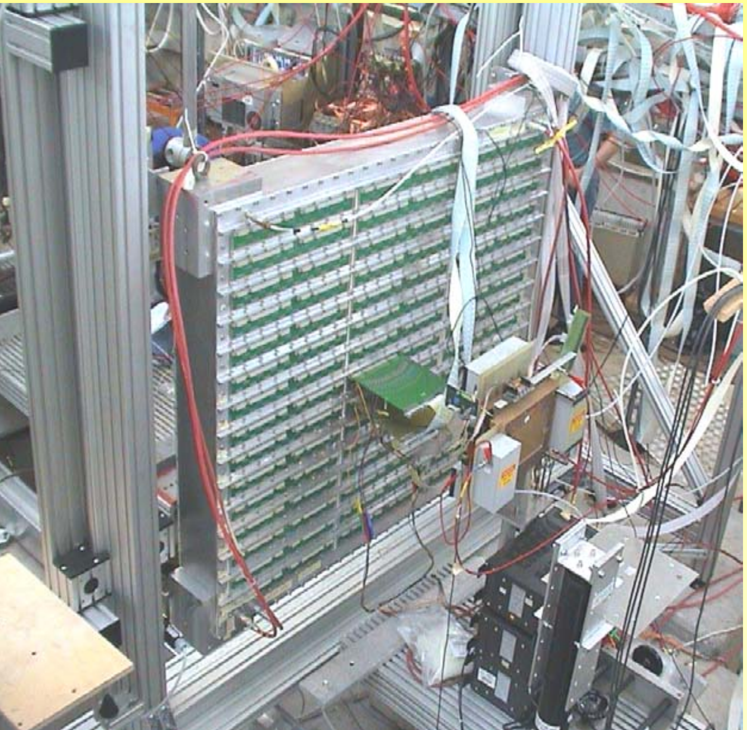
for π, K, p PID
π, K for p <2 GeV/c
p for p <4 GeV/c

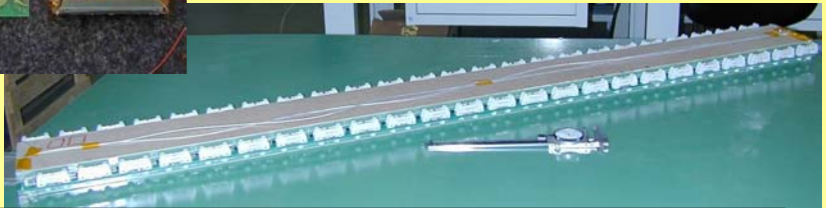
- 0.9 < η < 0.9
full ϕ

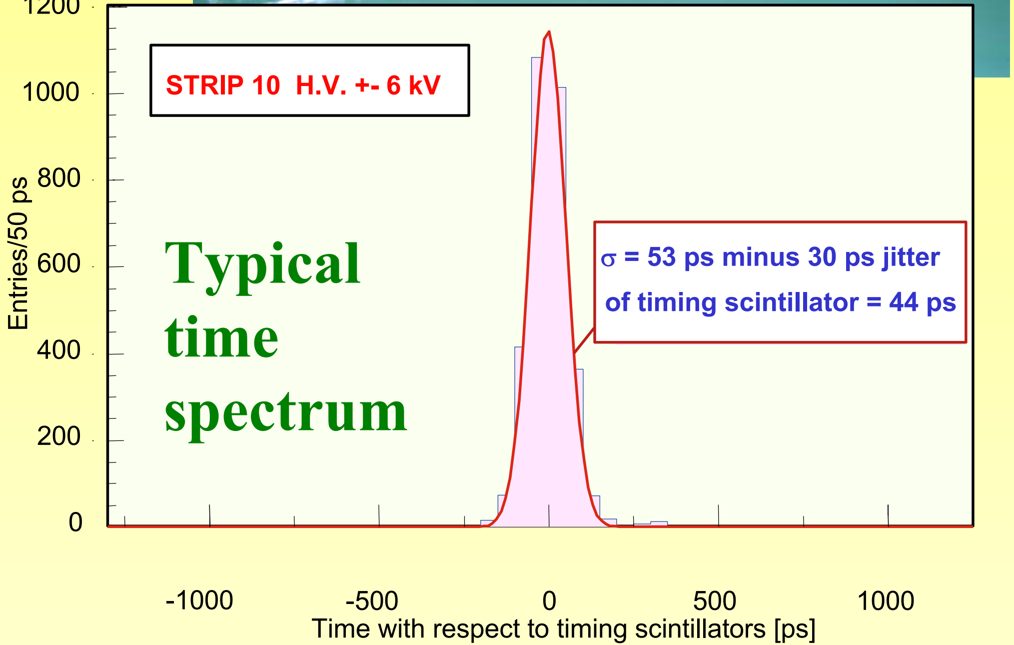


Multigap Resistive Plate Chambers

full size TOF modules under test





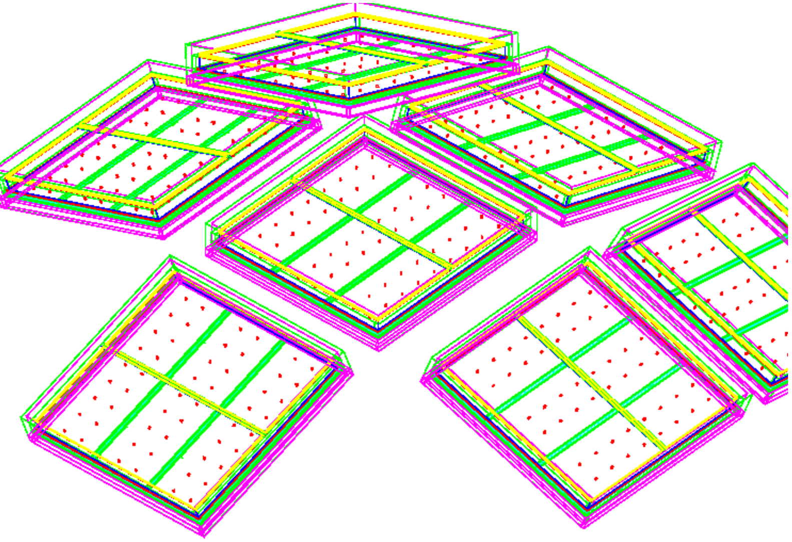


STRIP 10 H.V. +- 6 kV

Typical time spectrum

σ = 53 ps minus 30 ps jitter of timing scintillator = 44 ps

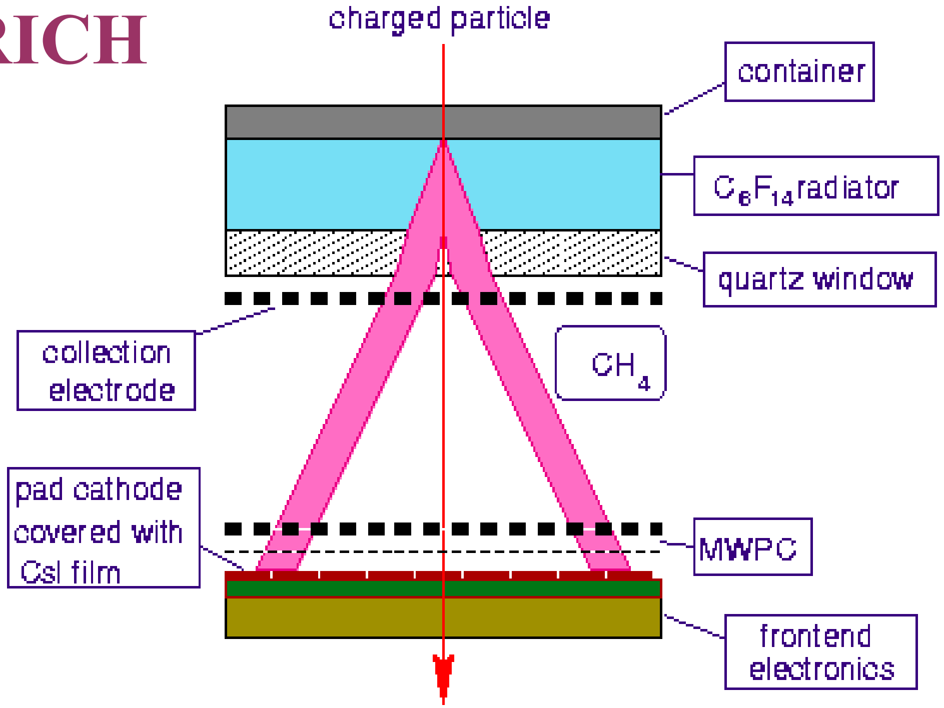
High Momentum Particle Identification



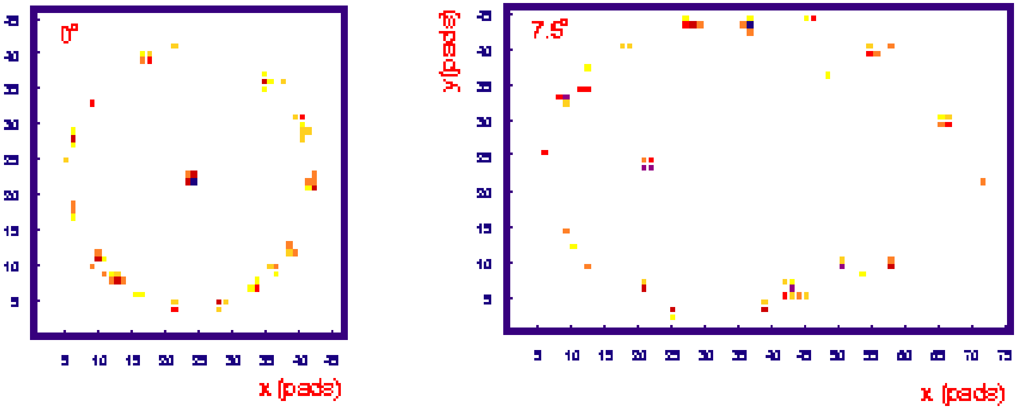
7 modules, each ~1.5 x 1.5 m^2

The HMPID module in STAR

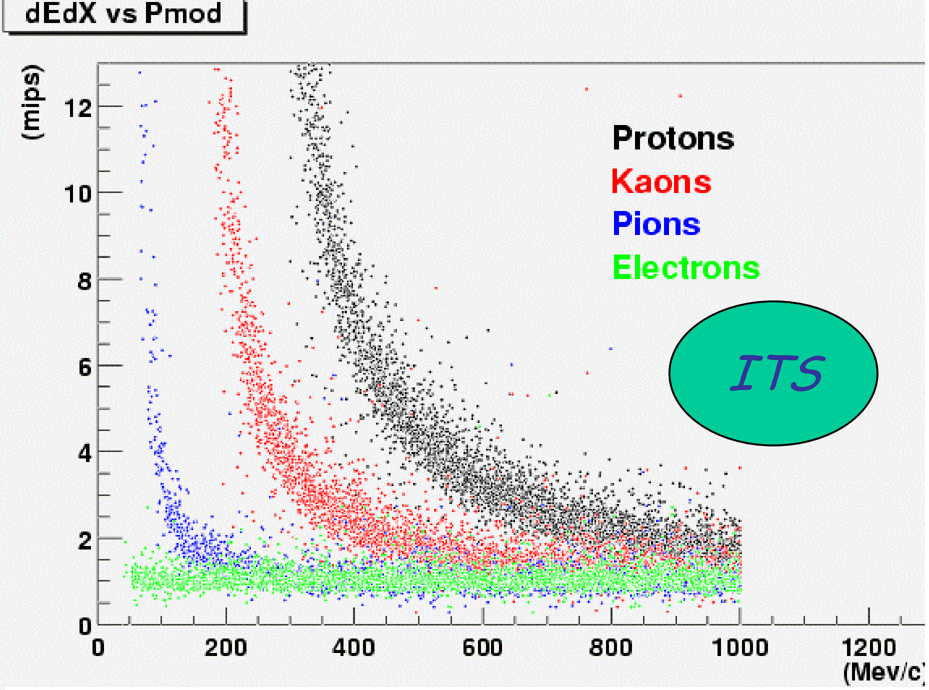
RICH

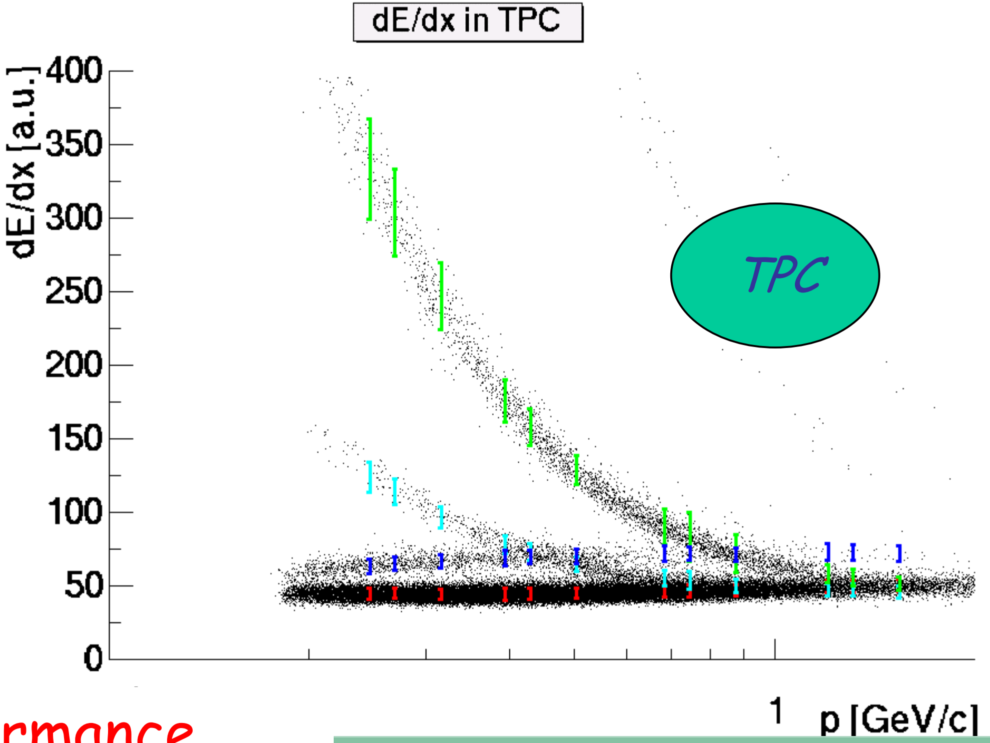


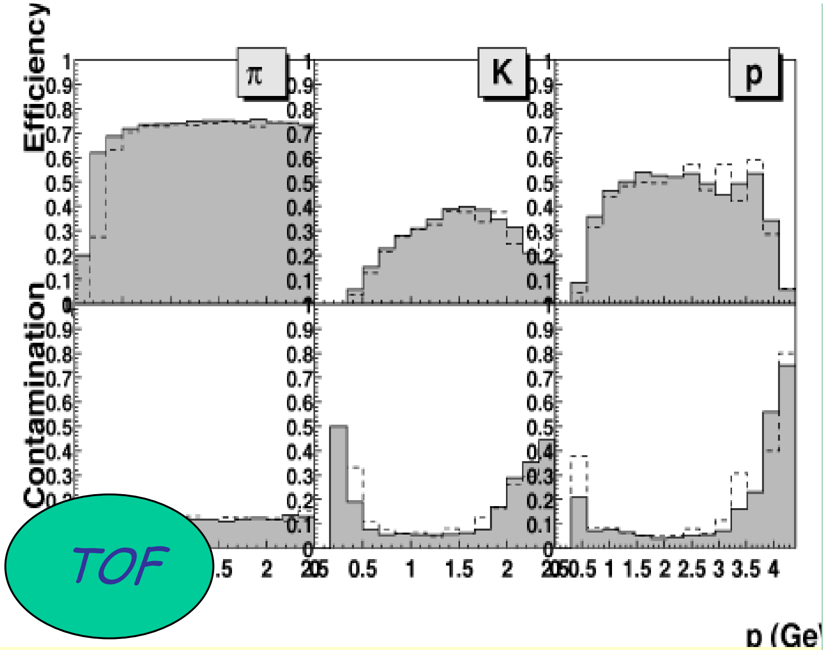
STAR data

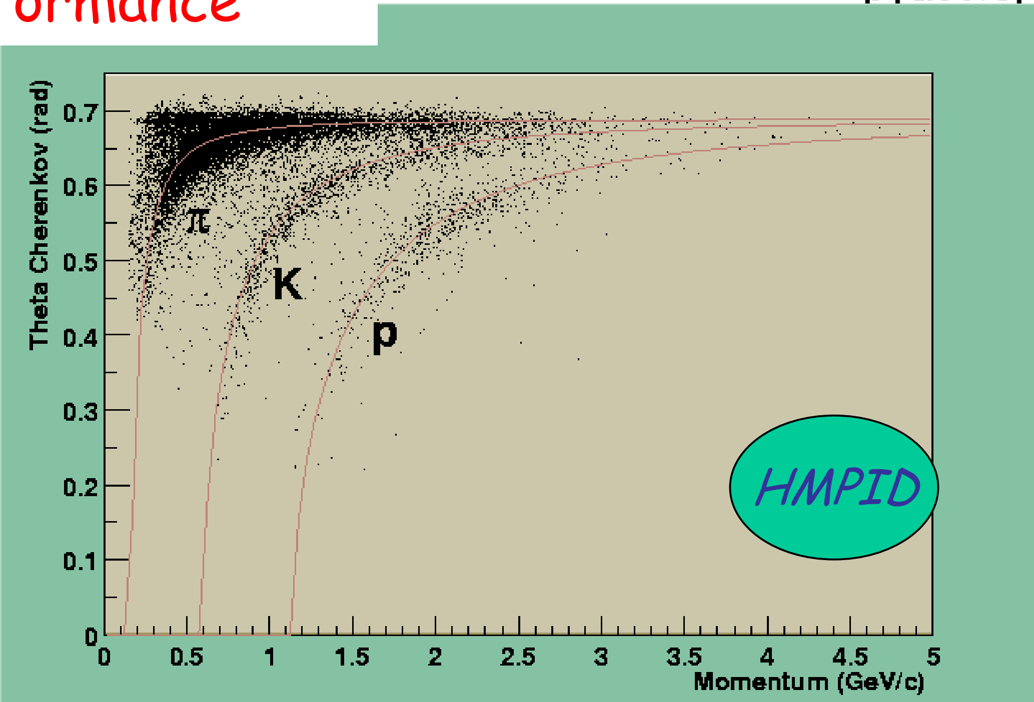


Particle Identification performance



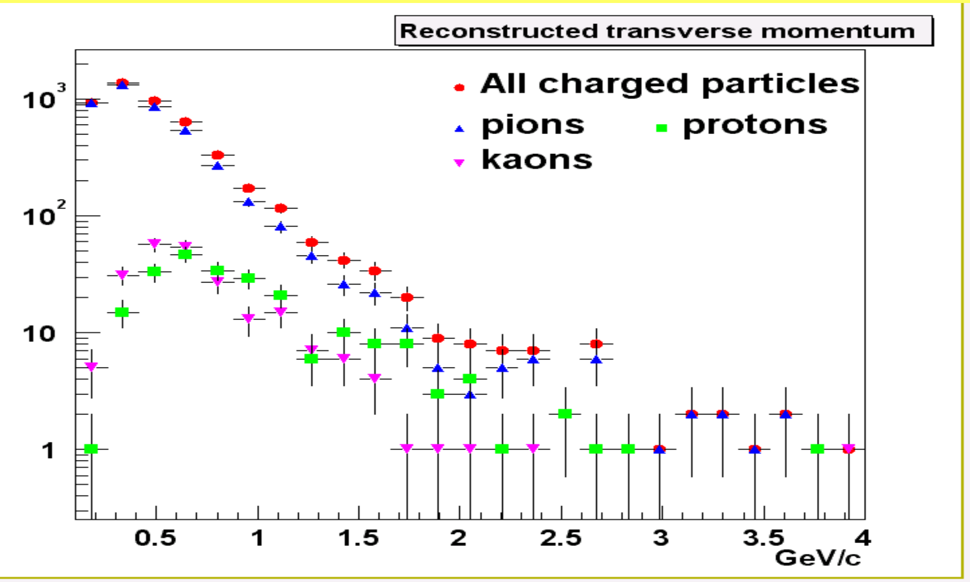




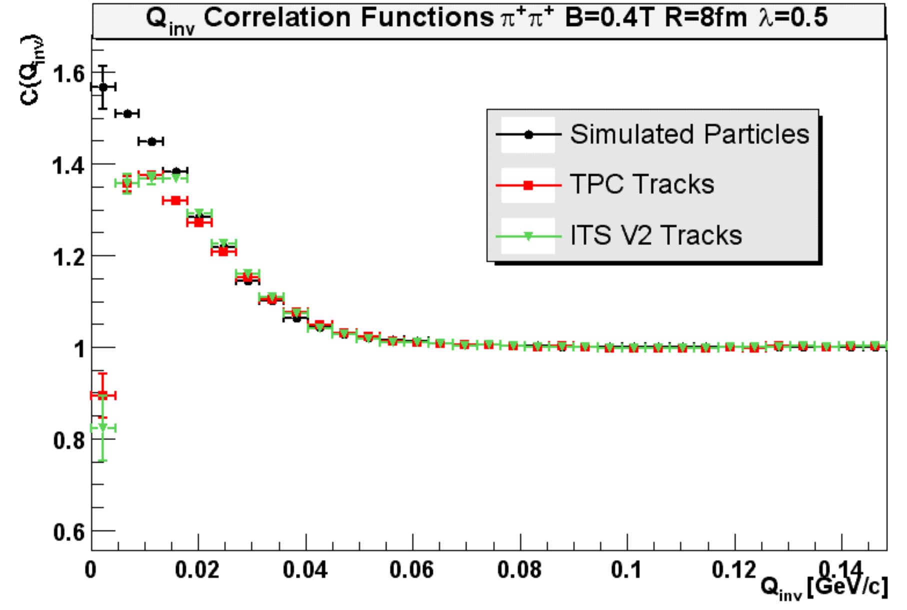


Hadronic Observables - I

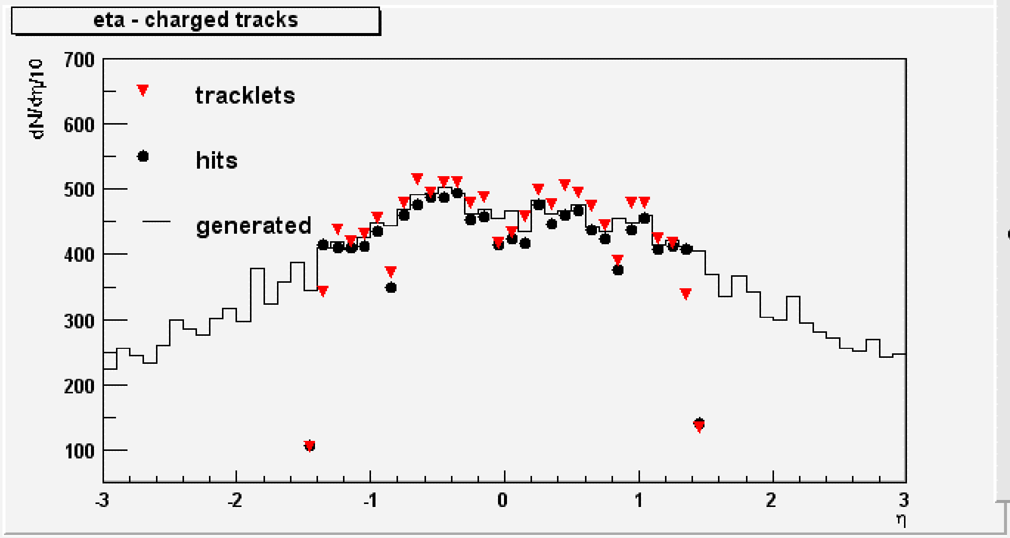
particle spectra (single event)



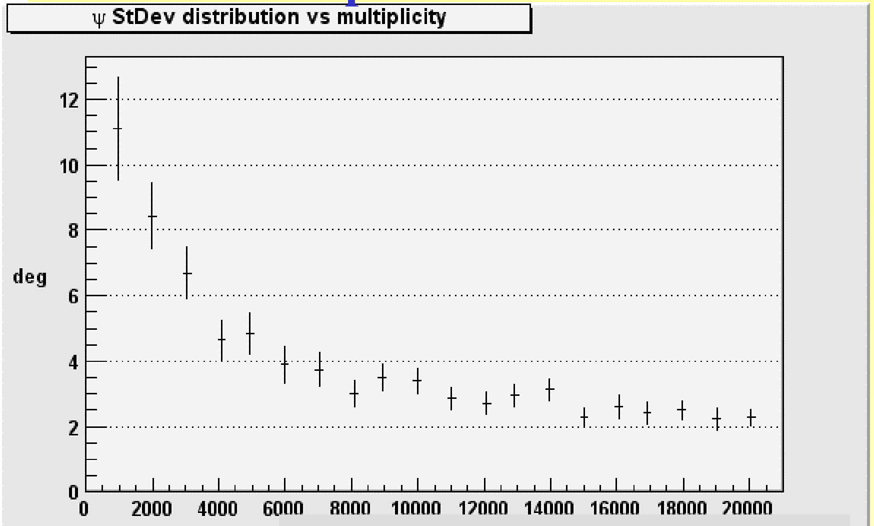
two particle HBT correlations



multiplicity, pseudorapidity reconstruction

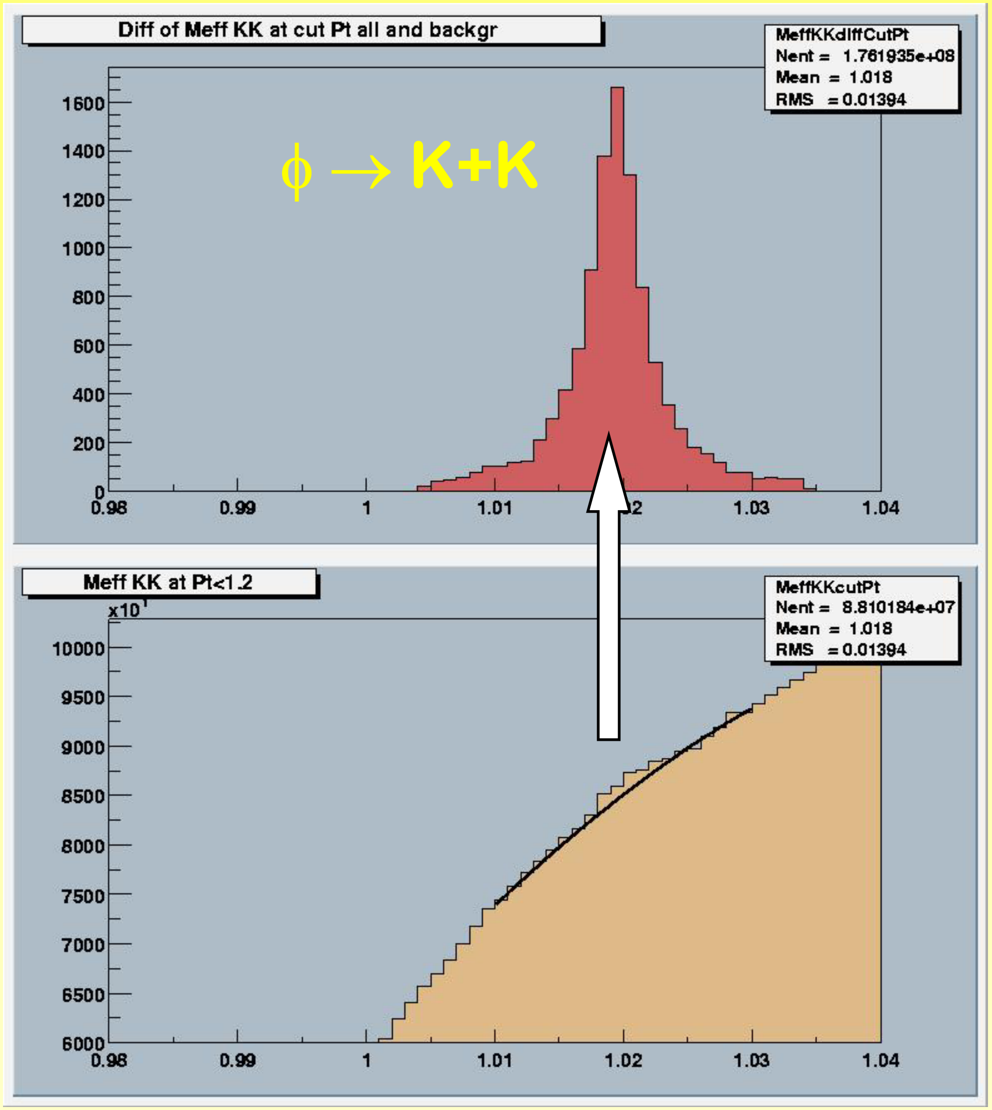


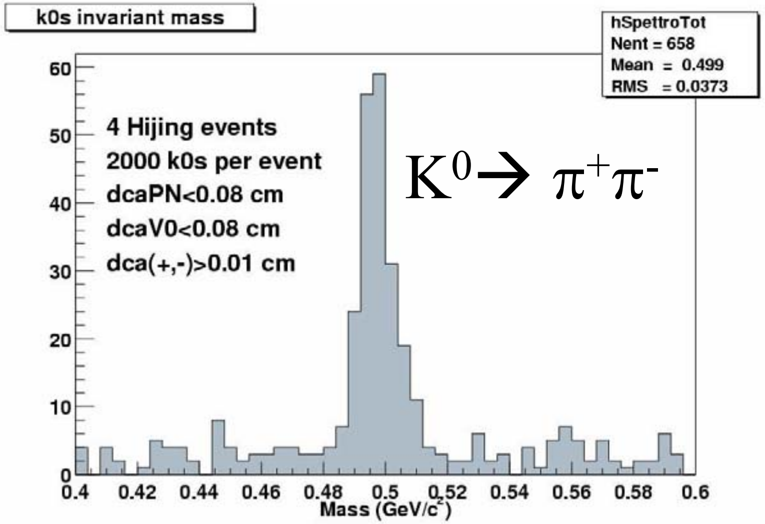
reaction plane resolution

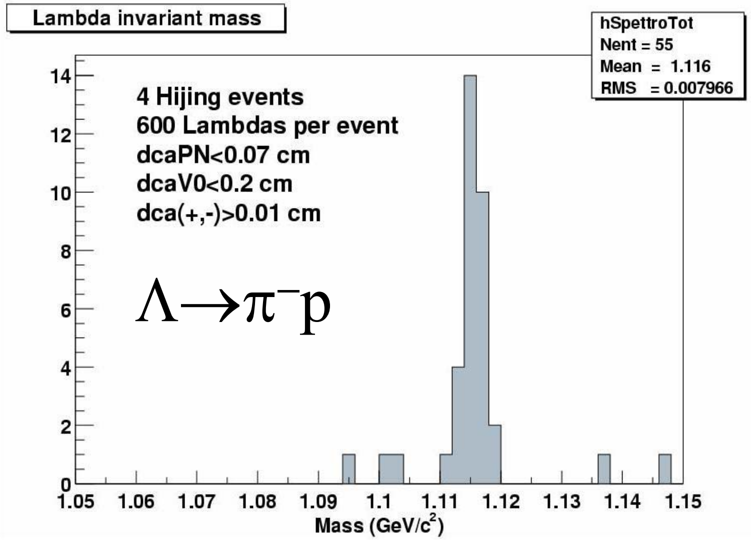


multiplicity in ALICE central detector

Hadronic Observables -II







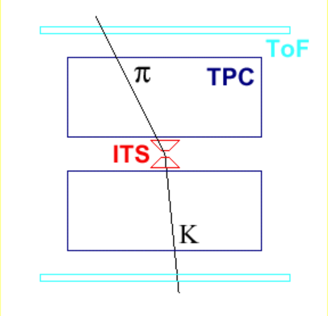
Reconstruct (dN/dy~6k):

~ 30 K^0/central event

~ 3 Λ/central event

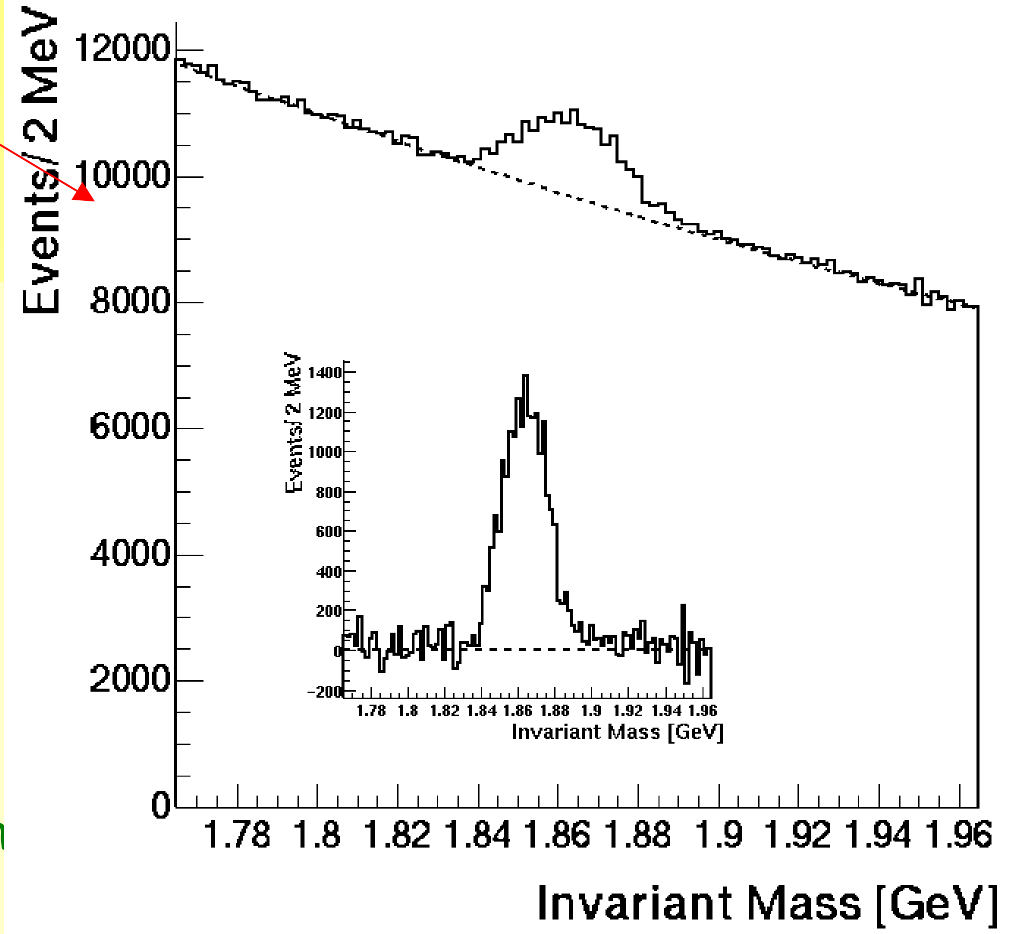
H.O. III -Secondary vertices and hard probes: hadronic charm

Secondary vertex finding capabilities + PID can be exploited to detect processes as $D^0 \rightarrow K^-\pi^+$ and D+ $\rightarrow K^- \pi^+ \pi^+$ (and chg. conjugates)



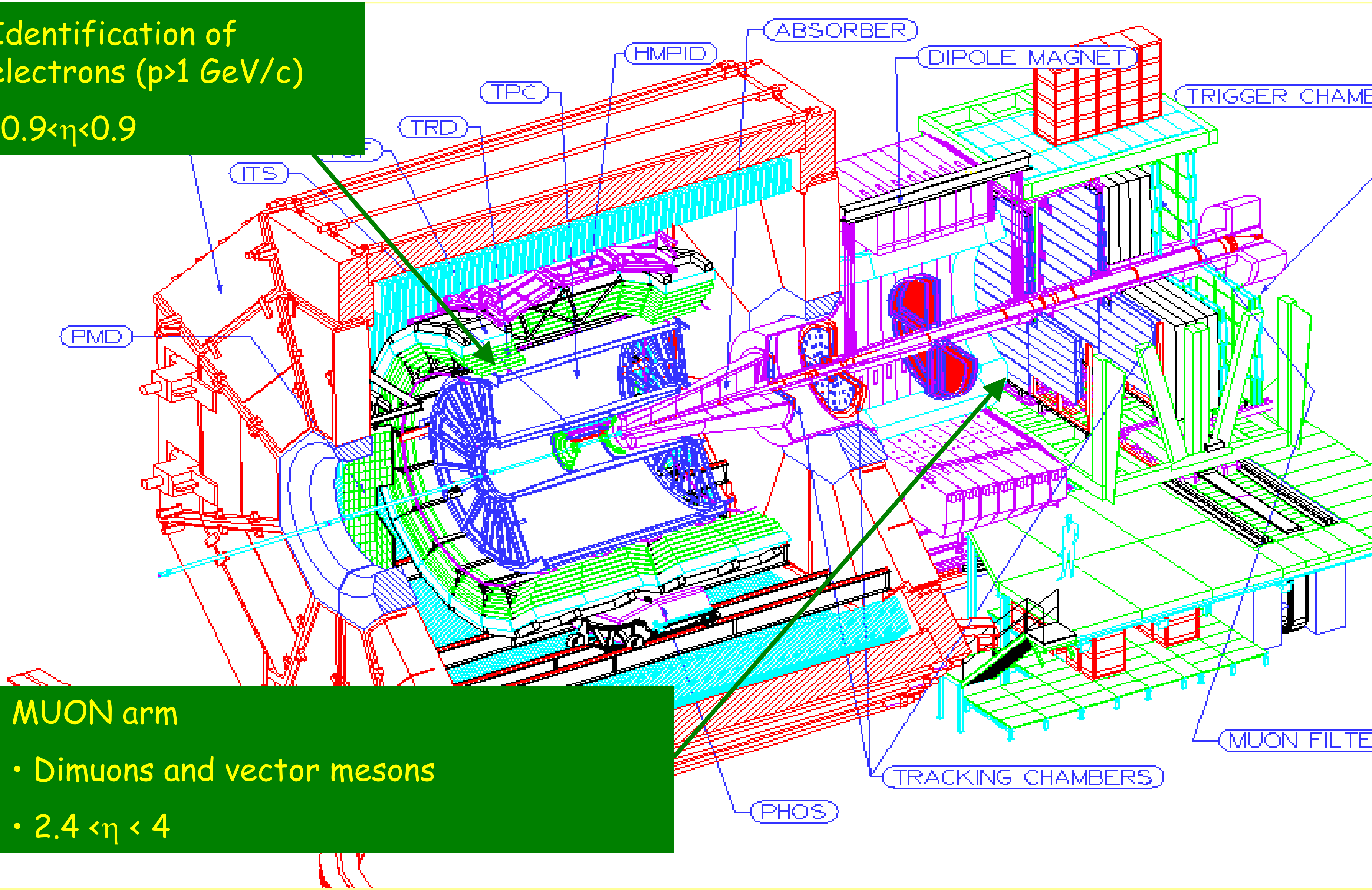
~10^7 Pb-Pb events

S/√(S+B)=37



- ✓ ~140 D^0/ central event
- ✓ $D^0 \rightarrow K^-\pi^+$ has been studied
- ✓ ~0.5 $D^0 \rightarrow K^-\pi^+$ accepted/event
- ✓ Mass 1.864 GeV/c^2 cτ=124 μm
- ✓ Large uncertainties: indirect measurements at SPS (excess A-A w.r.t. p-p)
- ✓ Also important for J/ψ normalisation

ALICE LAYOUT: lepton detection



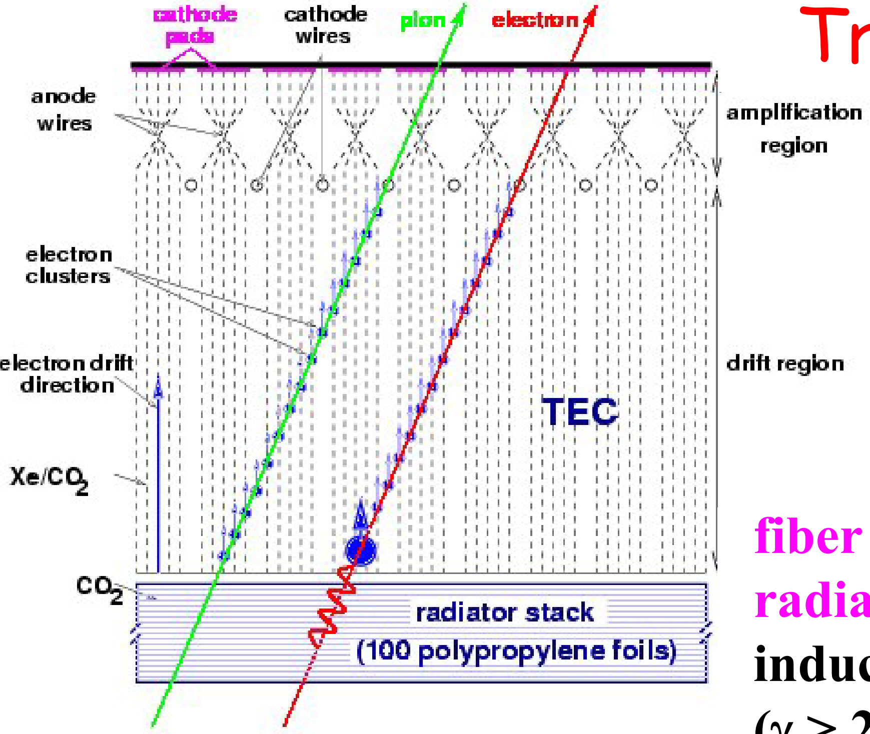
Identification of electrons (p>1 GeV/c)

$-0.9<\eta<0.9$

MUON arm

- Dimuons and vector mesons
- $2.4 < \eta < 4$

Transition Radiation Detector

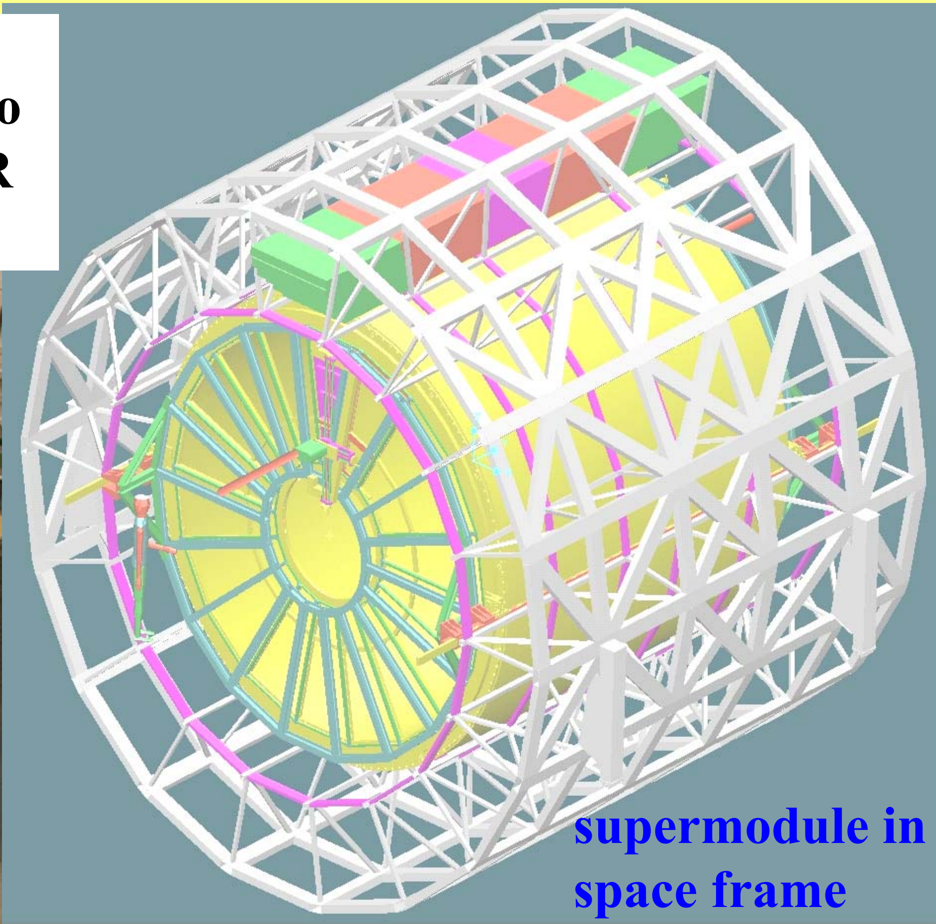


- $0.9<\eta<0.9$
- Large: 800 m2 – high granularity (1.2 M channels)
- El. id. for p>1 GeV/c
- El. Trigger (L1) for p>3 GeV/c

fiber radiator to induce TR ($\gamma > 2000$)

Full scale prototype

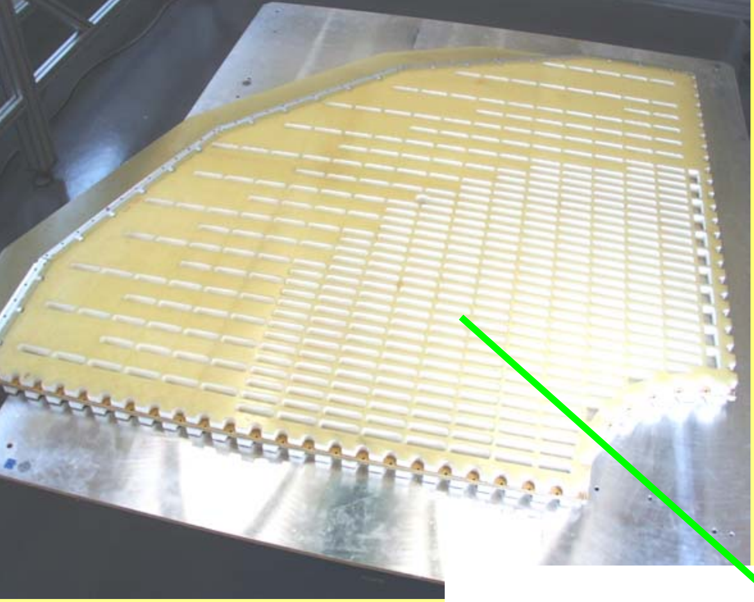
largest chamber: 1200 x 1600 mm



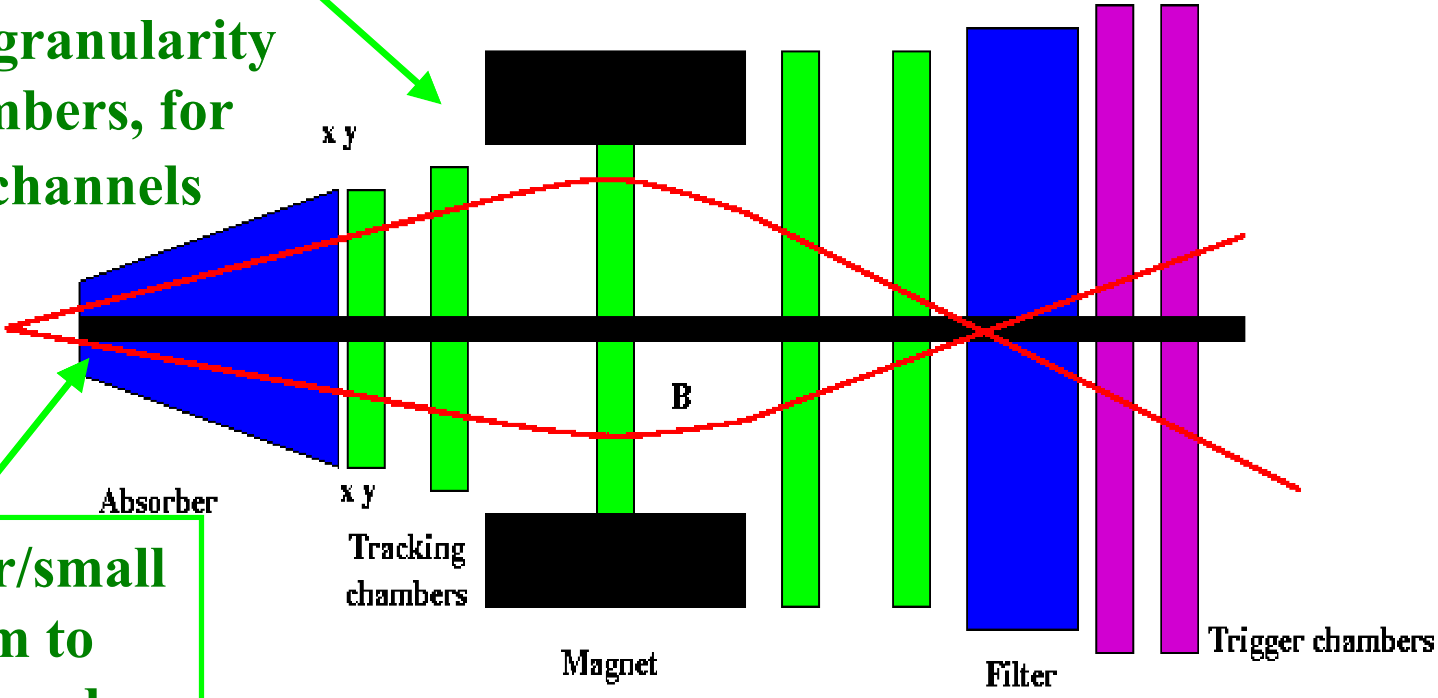
supermodule in space frame

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 1M readout channels



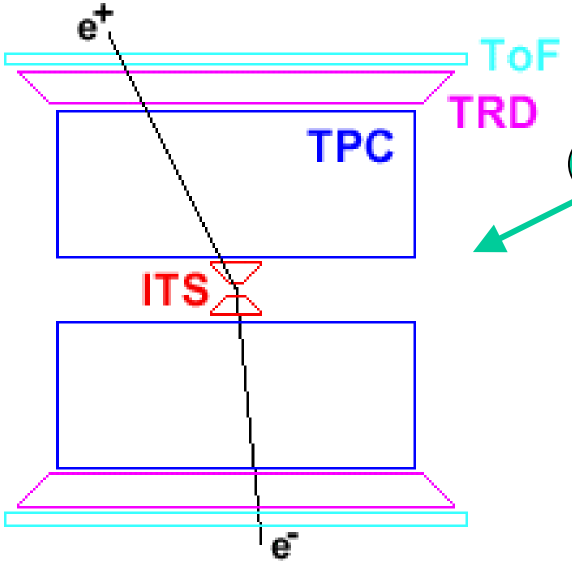
Complex absorber/small angle shield system to minimize background (90 cm from vertex)

Heavy quarkonia in ALICE

- Identification of charmonia and bottonomia states through their dilepton decay channel both in the e^+e^- and in the $\mu^+ \mu^-$ channel

- Large background from open charm & bottom
- ψ produced also via *b* decays
- important to have good mass resolution (~ 1%) to separate the different states => perform detailed spectroscopy

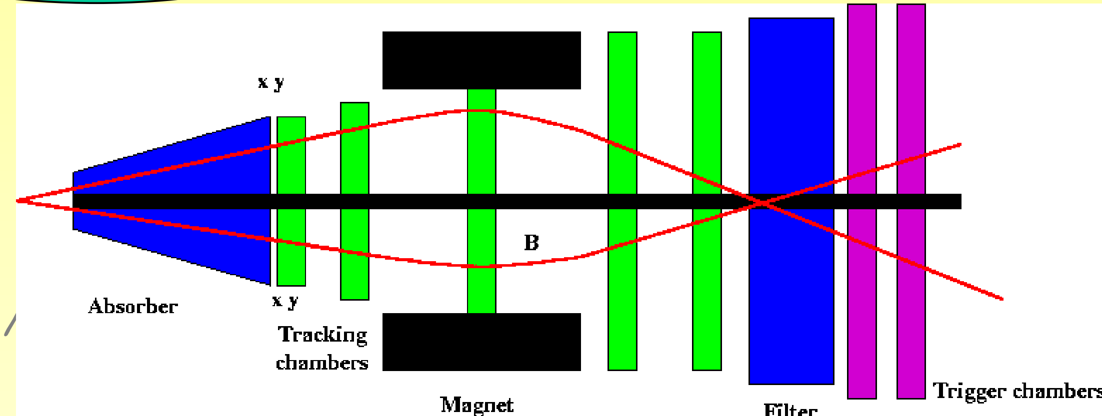
e^+e^- channel (TRD)



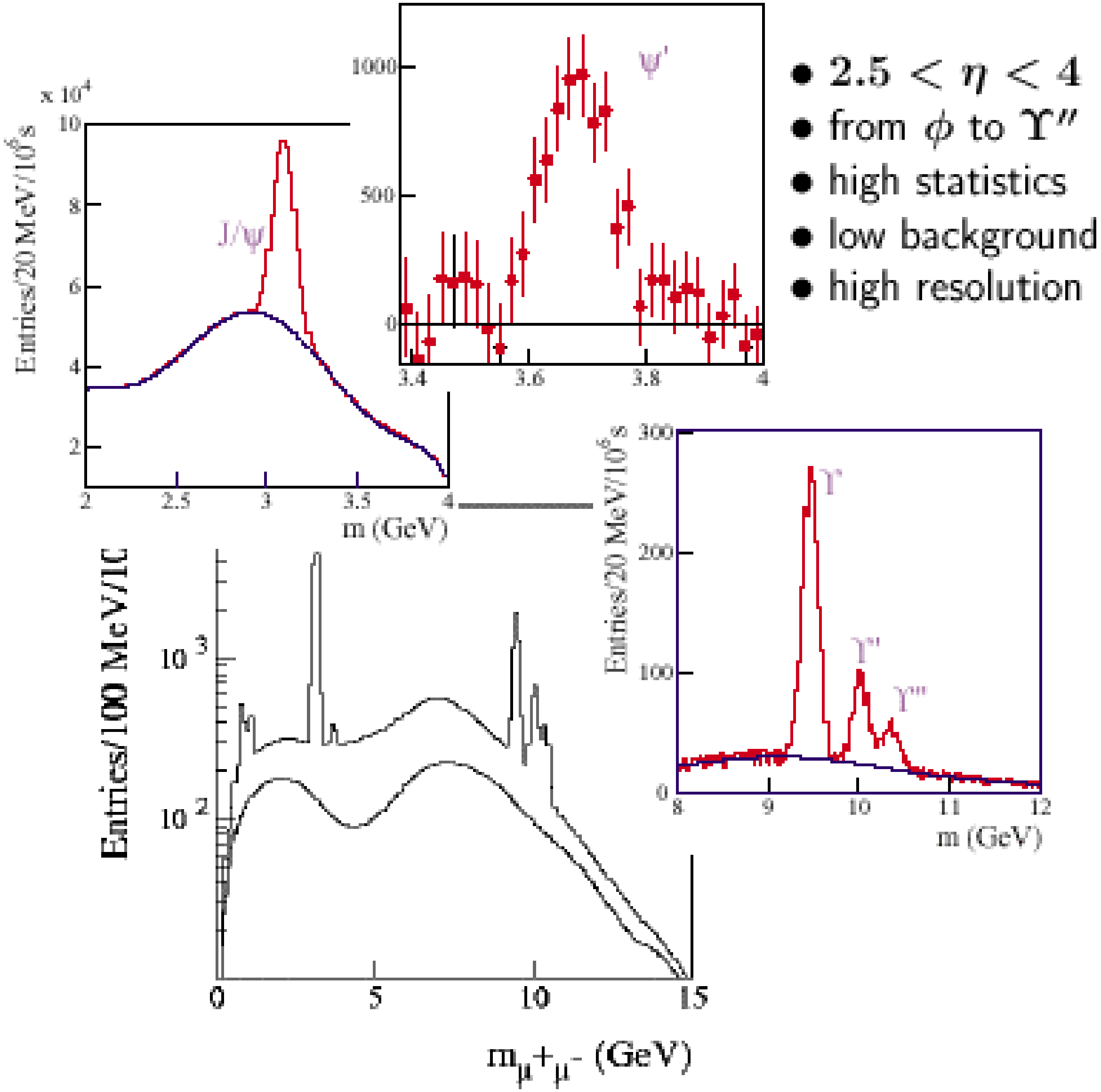
$(-0.9 < \eta < 0.9)$

$\mu^+ \mu^-$ channel (Muon arm)

$(2.5 < \eta < 4)$



$\mu^+ \mu^-$ channel



- $2.5 < \eta < 4$
- from ϕ to Υ''
- high statistics
- low background
- high resolution

- σ_M =94.5 MeV/c^2 at the Υ
- Separation of Υ, Υ', Υ''
- Total efficiency ~ 75%
- Expected statistics (significance – 1 yr):

	central	min. bias
J/ψ	310	574
ψ'	12	23
Υ	39	69
Υ '	19	35
Υ "	12	22

from min. bias events:

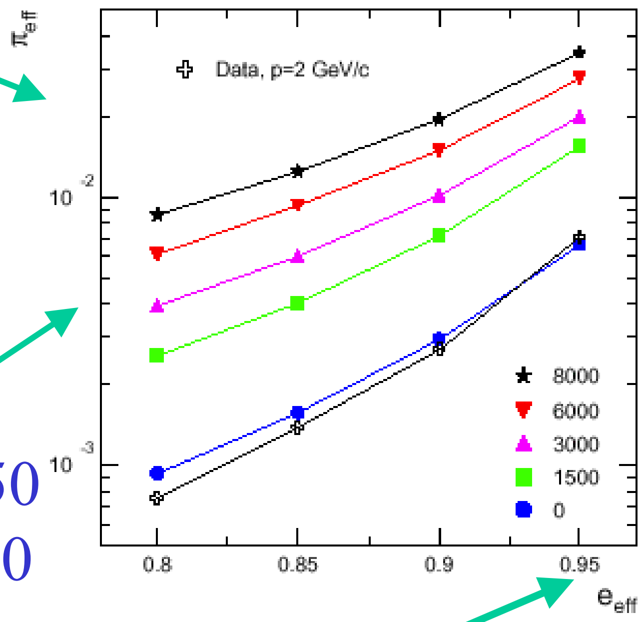
~ 8k Υ and ~700k J/ψ /yr

e^+e^- channel

TPC+TRD → J/ψ and Υ

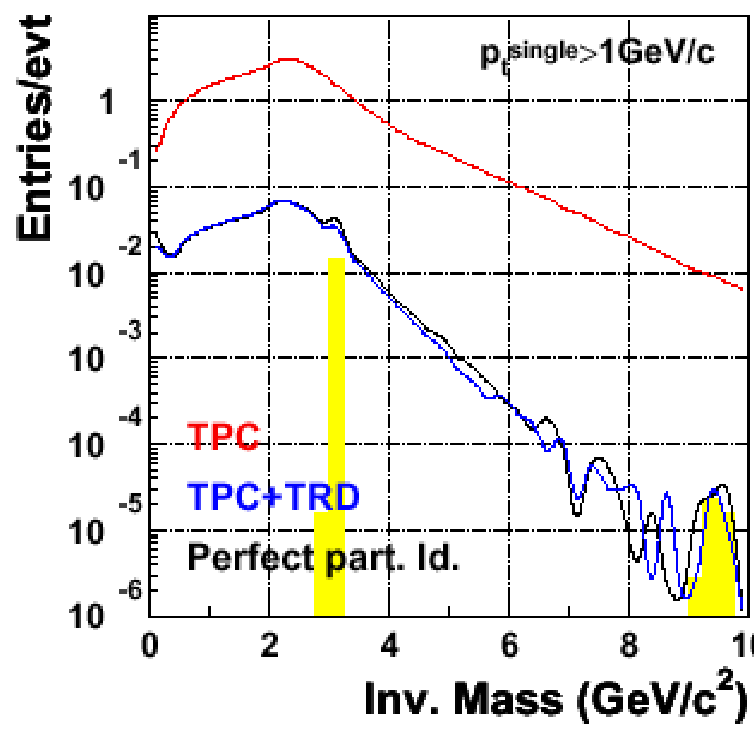
Υ , Υ' and Υ'' separation with B=0.4 T

π efficiency

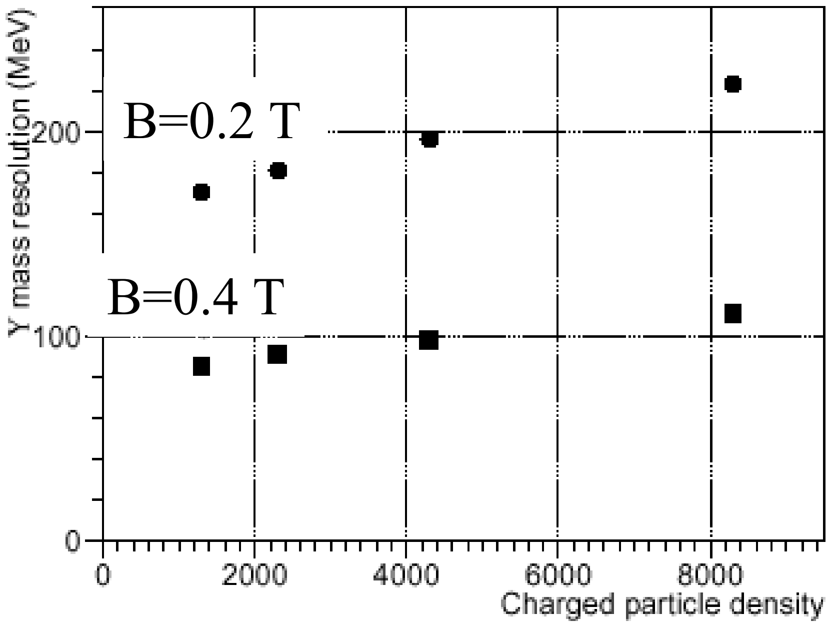


TRD:
π rejection >50
@dN/dy=8000

Electron efficiency



stat. sample,
from min.
bias events:
~ 2.5k Υ/yr



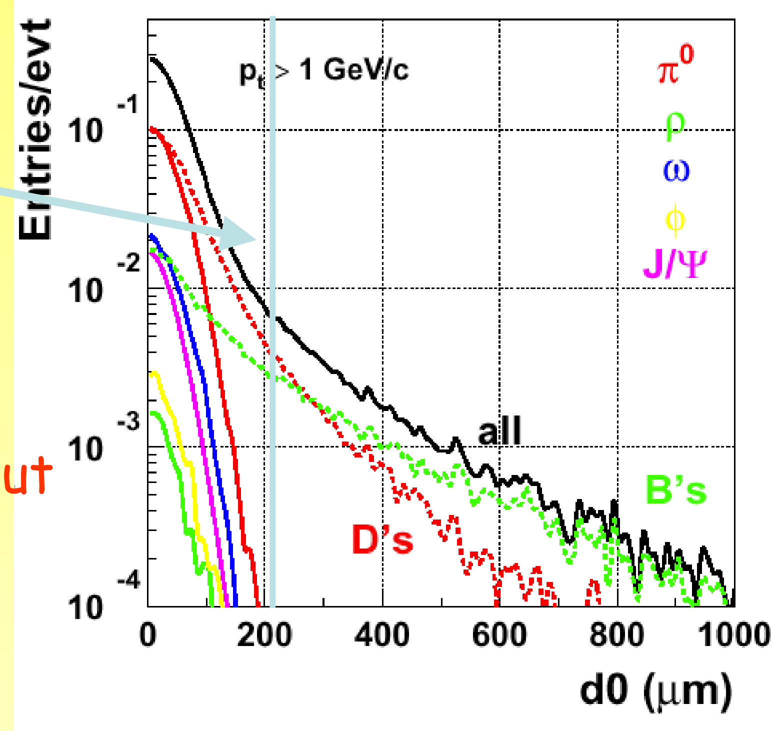
High e^+e^- yield from *b* and *c* quarks:
$240 \cdot 10^3$ evts/yr from *c*
$540 \cdot 10^3$ evts/yr from *b*

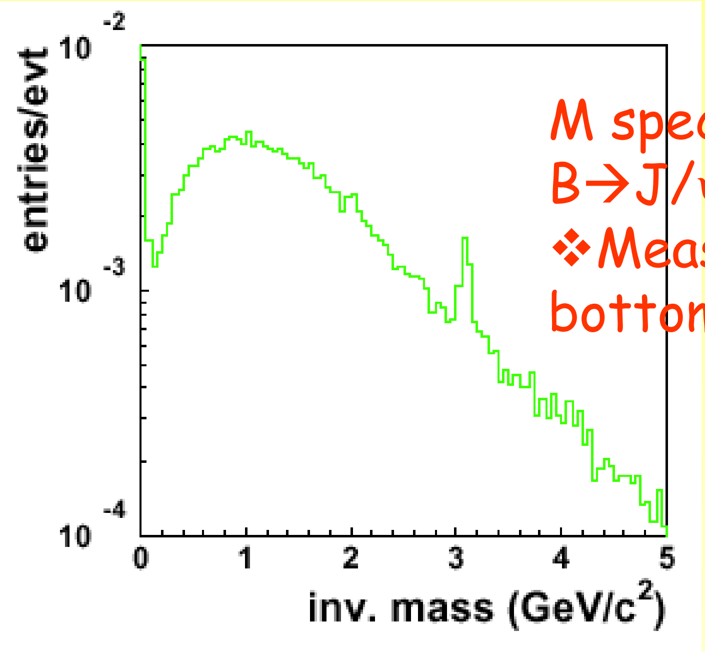
e^+e^- channel: J/ψ from b

$c\tau$ = 300÷400 μm for D and B mesons

B(D) → e + X The d_0 of the electron can be measured with the ITS

d_0 < cut → resonances
d_0 > cut → D,B mesons



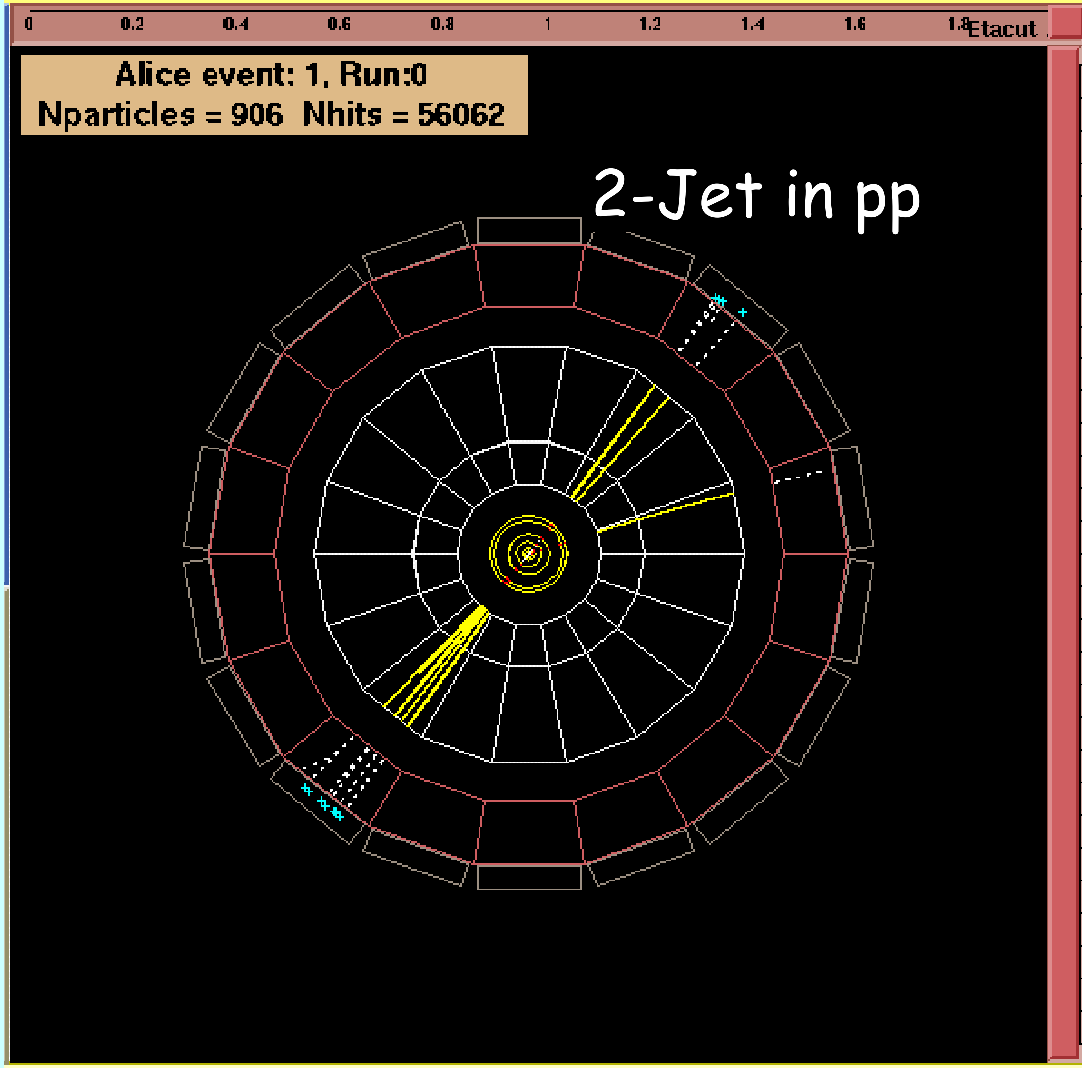


M spectrum for d_0>cut: B→J/ψ signal singled out

❖ Measurement of bottom cross section

Jets via leading particle in TPC

1) Find the leading particle
2) If leading particle has a pt_{max}> 4 GeV use it as a seed for jet.
3) Particles with pt> 2 GeV are associated to the jet if $\Delta R=\sqrt{(\Delta\phi^2+\Delta\eta^2)} < 0.7$
4) Calculate sum of momentum vectors.
5) Mark all used particles.
6) Repeat until no more seeds are found.

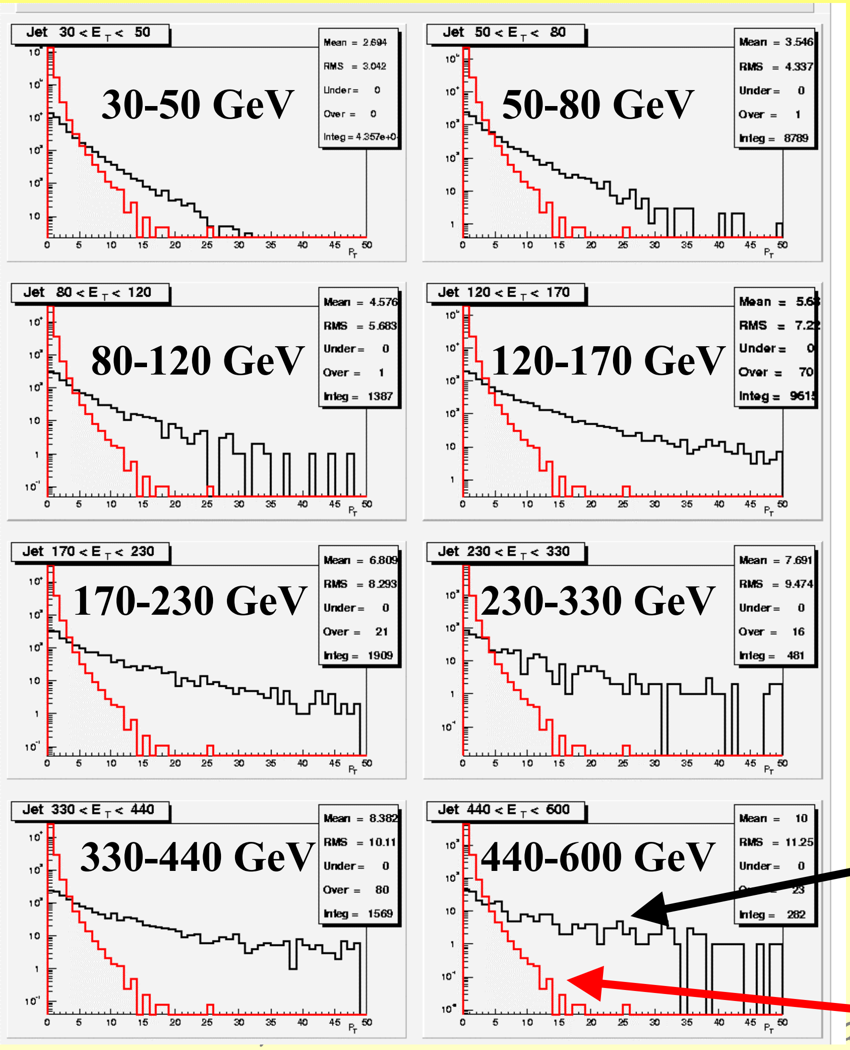


Alice event: 1, Run:0
Nparticles = 906 Nhits = 56062

2-Jet in pp

Jets in ALICE

using all tracking detectors + the TRD triggering capability



$0 < p_T < 50$ GeV/c

Use high-p_T leading particle as seed

Measure: **$p_T > 2$ GeV/c**

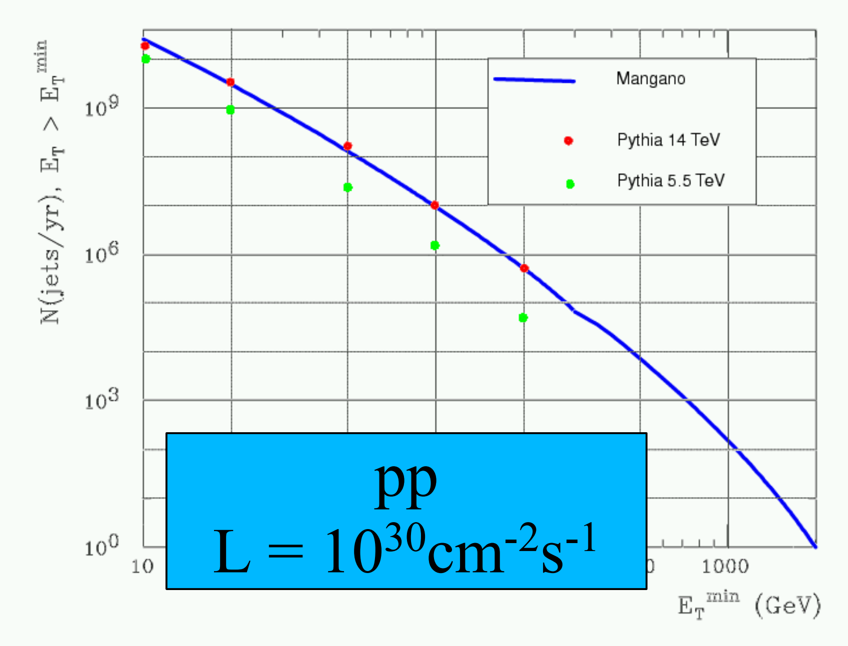
fragmentation p_T distribution, particle composition, p_T- y correlations, multiplicity correlations, …

Example: evolution of hard fragmentation as E_T^{jet} increases

Jet Fragment p_T Distribution in Jet Cone

Normalized background p_T distribution in Jet Cone

Jet Rates in Central ALICE (|η|<.9)



pp

$L = 10^{30} cm^{-2} s^{-1}$

Reasonable rate up to E_T ~200 GeV

Pb Pb rates:

p_t jet > (GeV/c)	jets/event	accepted jets/month
5	$3.5\ 10^{2}$	$4.9\ 10^{10}$
50	$7.7\ 10^{-2}$	$1.5\ 10^{7}$
100	**$3.5\ 10^{-3}$**	**$8.1\ 10^{5}$**
150	$4.8\ 10^{-4}$	$1.2\ 10^{5}$
200	$1.1\ 10^{-4}$	$2.8\ 10^{4}$

with TRD jet trigger

First studies give 1Hz trigger rate for central PbPb collisions and p_t jet > 100 GeV/c

real jets triggers 0.7/s

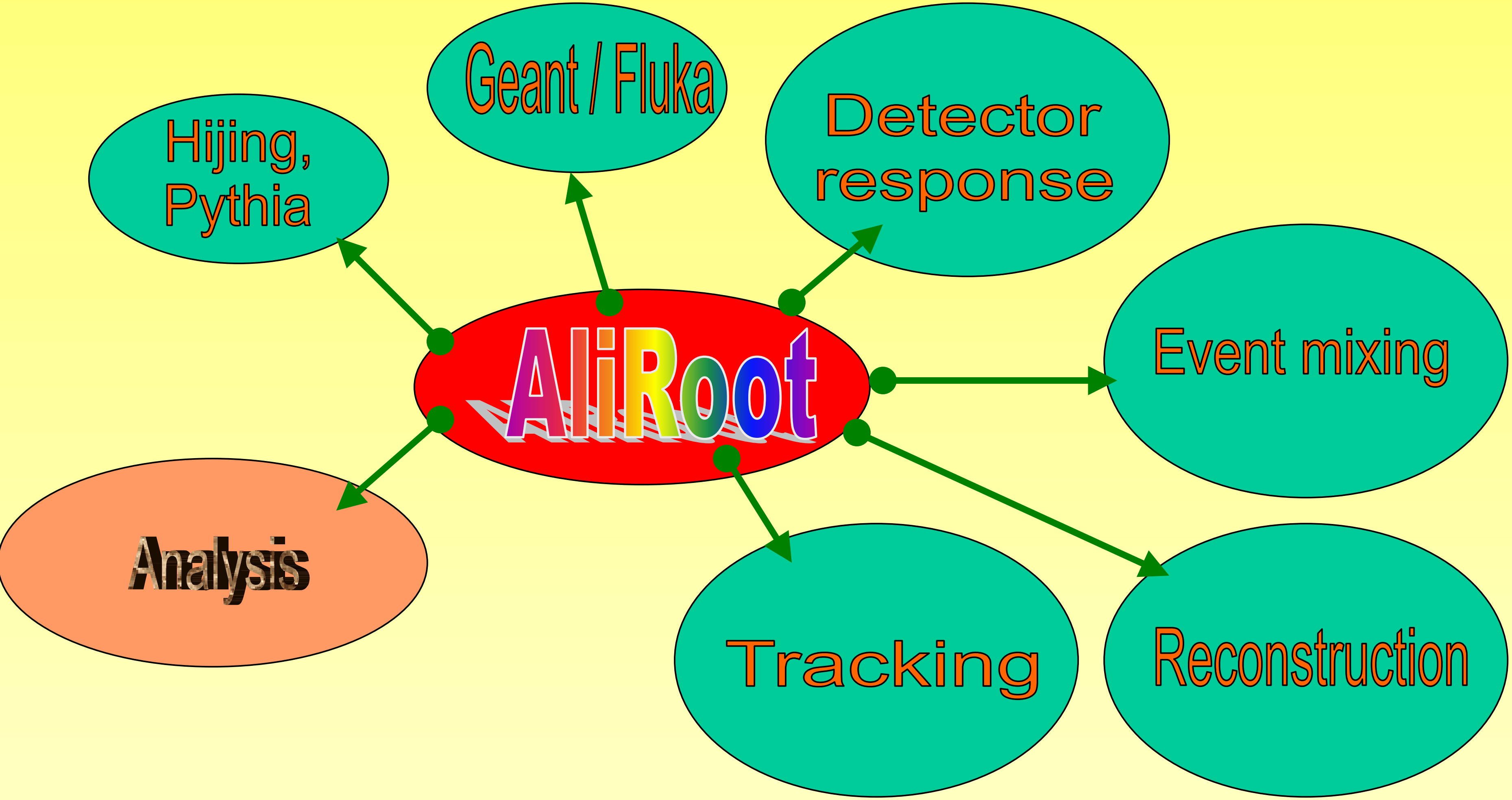
false triggers 0.3/s

Software

- All the simulation resuts shown here have been produced by means of the ALICE computing framework, AliRoot, which is based on ROOT(*) and is entirely written in C++ but is able to use legacy cose ritten in Fortran (Geant 3, event generators)
- The massive production of events is done on a distributed network af big and small computing centers via our GRID interface:AliEn (Alice ENvironment)
- Data challenges are regularly scheduled to be able to cope with the very demending experimental conditions (1.2 GB/s)

(*) http://root.cern.ch

ALIROOT



AliRoot

Hijing, Pythia

Geant / Fluka

Detector response

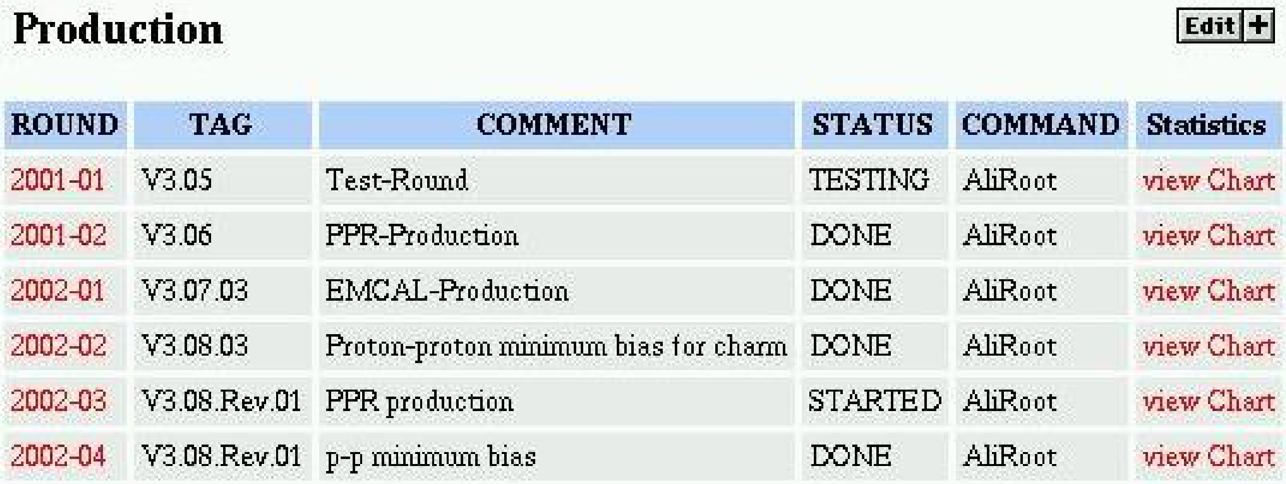
Event mixing

Reconstruction

Tracking

Analysis

ALICE GRID is there: ALIEN



Production

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

- 28 sites configured, at present ~14 contributing with CPU cycles
- 4 sites providing mass storage capability
- Tests carried on in more sites, including Merida, MX
- Several more expressed interest

Summary

✓ Heavy Ions at √s=5.5 TeV: a step forward to the QGP physics

✓ New region of the QCD phase diagram: small μ_B and high T

✓ New observables: Υ and its possible suppression

✓ Availability of direct partonic probes: jets

✓ The accelerator and the apparats are being built

✓ The software tools for the analisys are getting ready

✓**A rich harvest of Physics is ahead of us: the LHC is a great place where to do Heavy Ion Physics!**