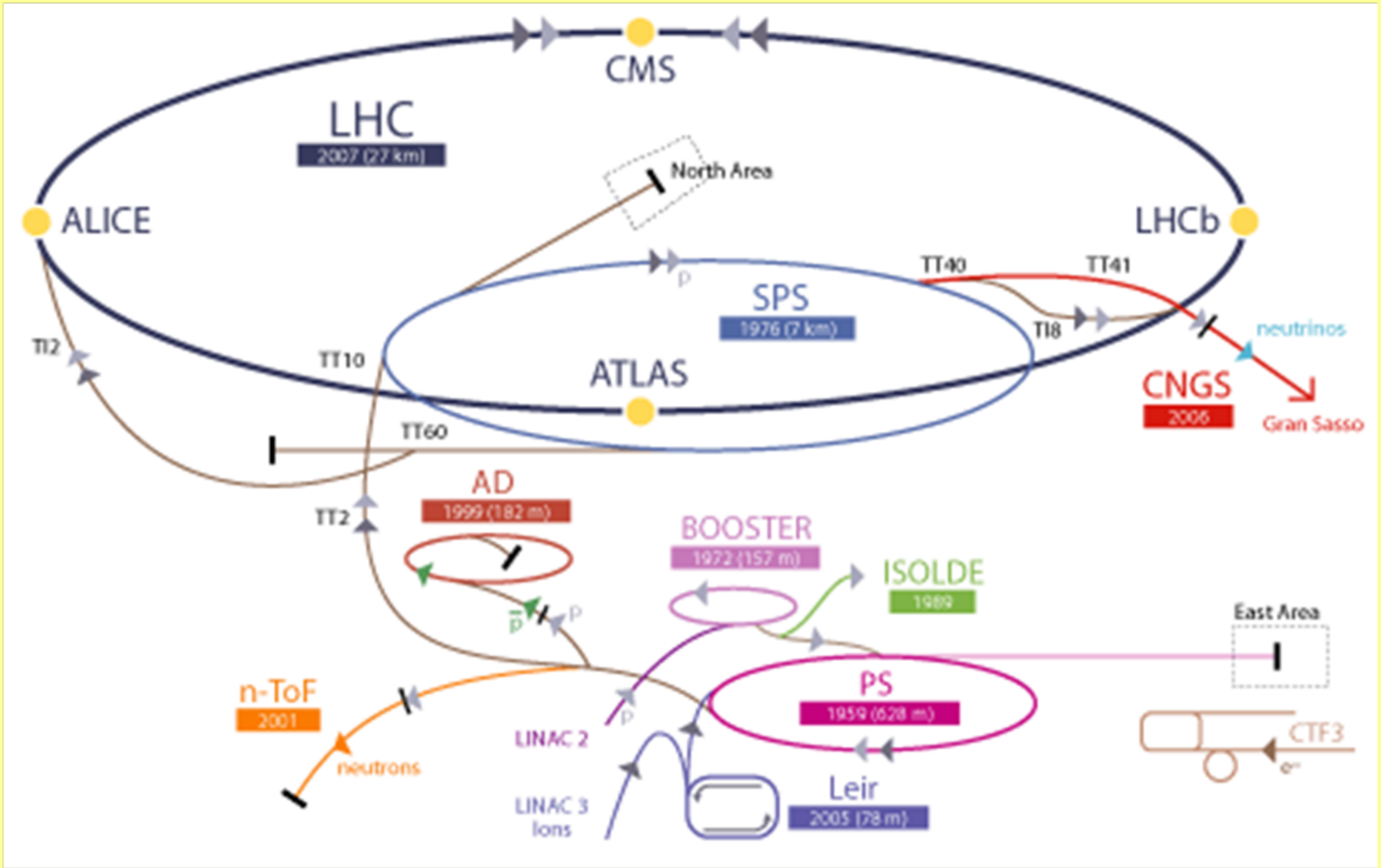
XIX International Baldin Seminar on High Energy Physics Problems "Relativistic Nuclear Physics & Quantum Chromodynamics“

September 29 – October 4, 2008, Dubna, Russia

The ALICE experiment at LHC

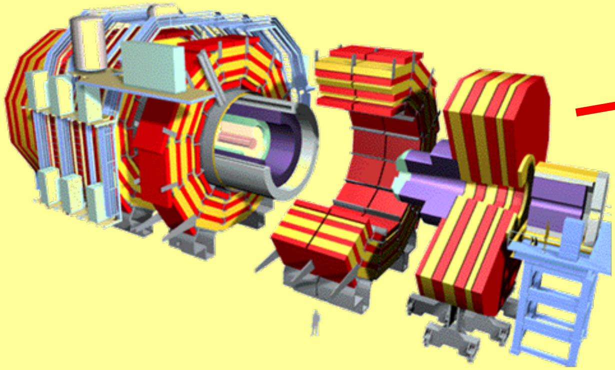
A.S.Vodopyanov (JINR)
for the ALICE collaboration

The CERN accelerator complex

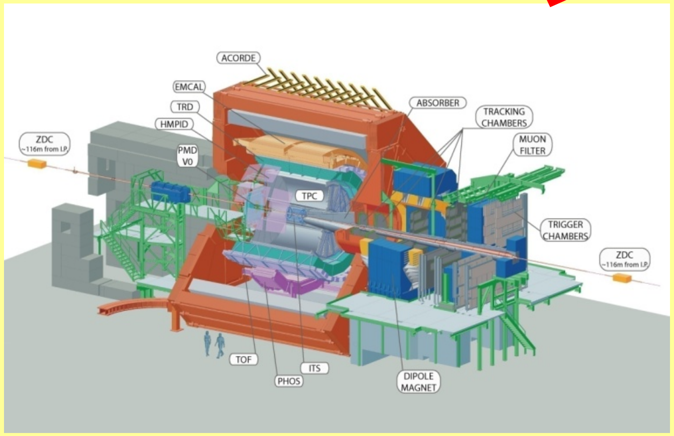


LINAC2- BOOSTER-PS-SPS-LHC

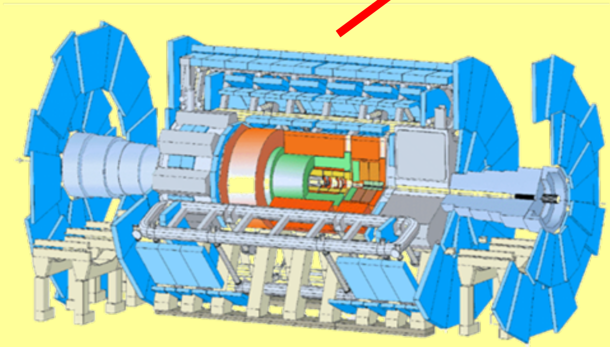
p+p @ 14 TeV
Pb+Pb @ 5.5 A TeV



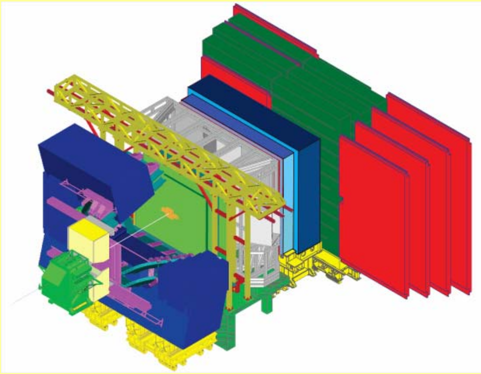
CMS



ALICE



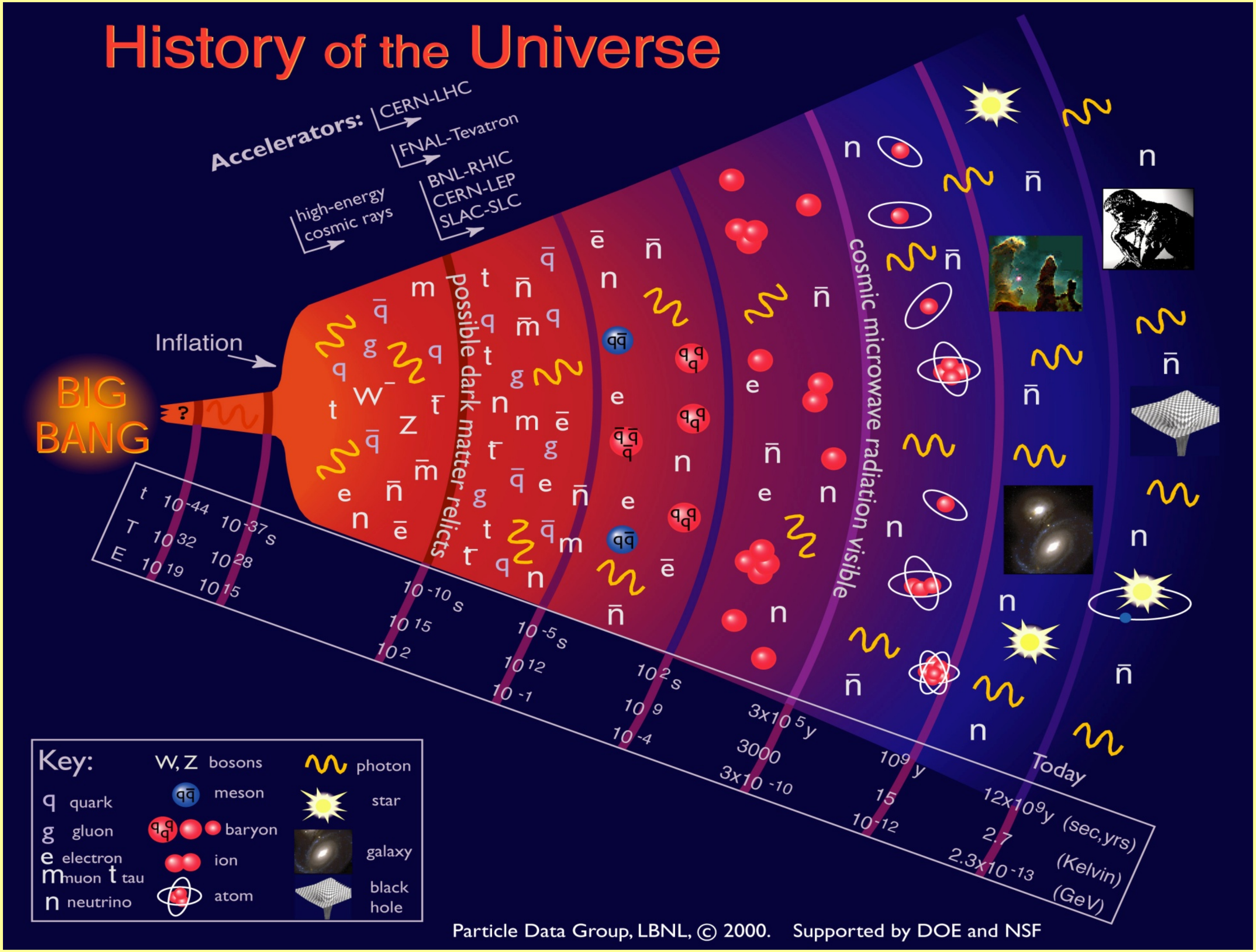
ATLAS



LHCb

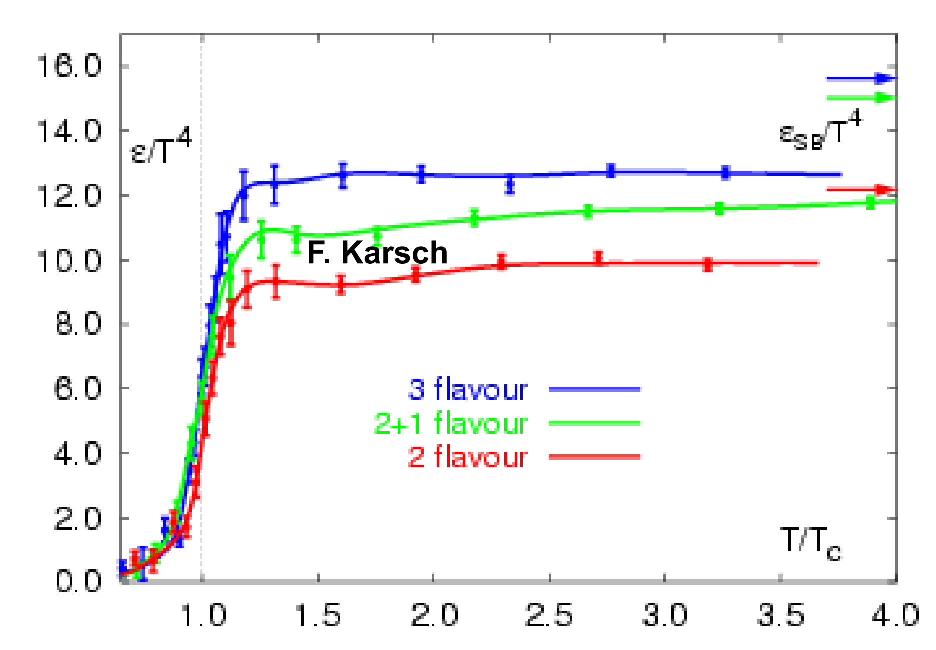
What Physics Questions might be answered at LHC

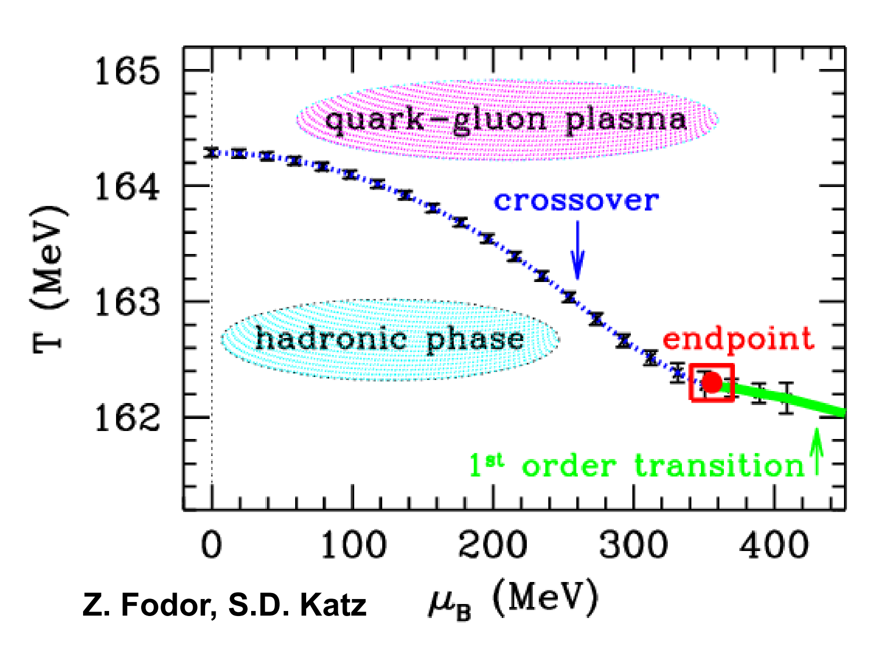
- ***ALICE:***
  - *Chiral Symmetry breaking;*
  - *Origin of mass of hadrons;*
  - *Deconfinement;*
  - *Hadronization;*
- ***ATLAS, CMS, LHCb:***
  - *Higss mechanism;*
  - *Supersymmetry;*
  - *CP violation;*



History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relics
cosmic microwave radiation visible
t 10 -44 10 -37 s
T 10 32 10 28
E 10 19 10 15
10 -10 s
10 15
10 2
10 -5 s
10 12
10 -1
10 2 s
10 9
10 -4
3x10 5 y
3000
3x10 -10
10 9 y
15
10 -12
Today
12x10 9 y (sec,yrs)
2.7 (Kelvin)
2.3x10 -13 (GeV)
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

Quark-Gluon Plasma

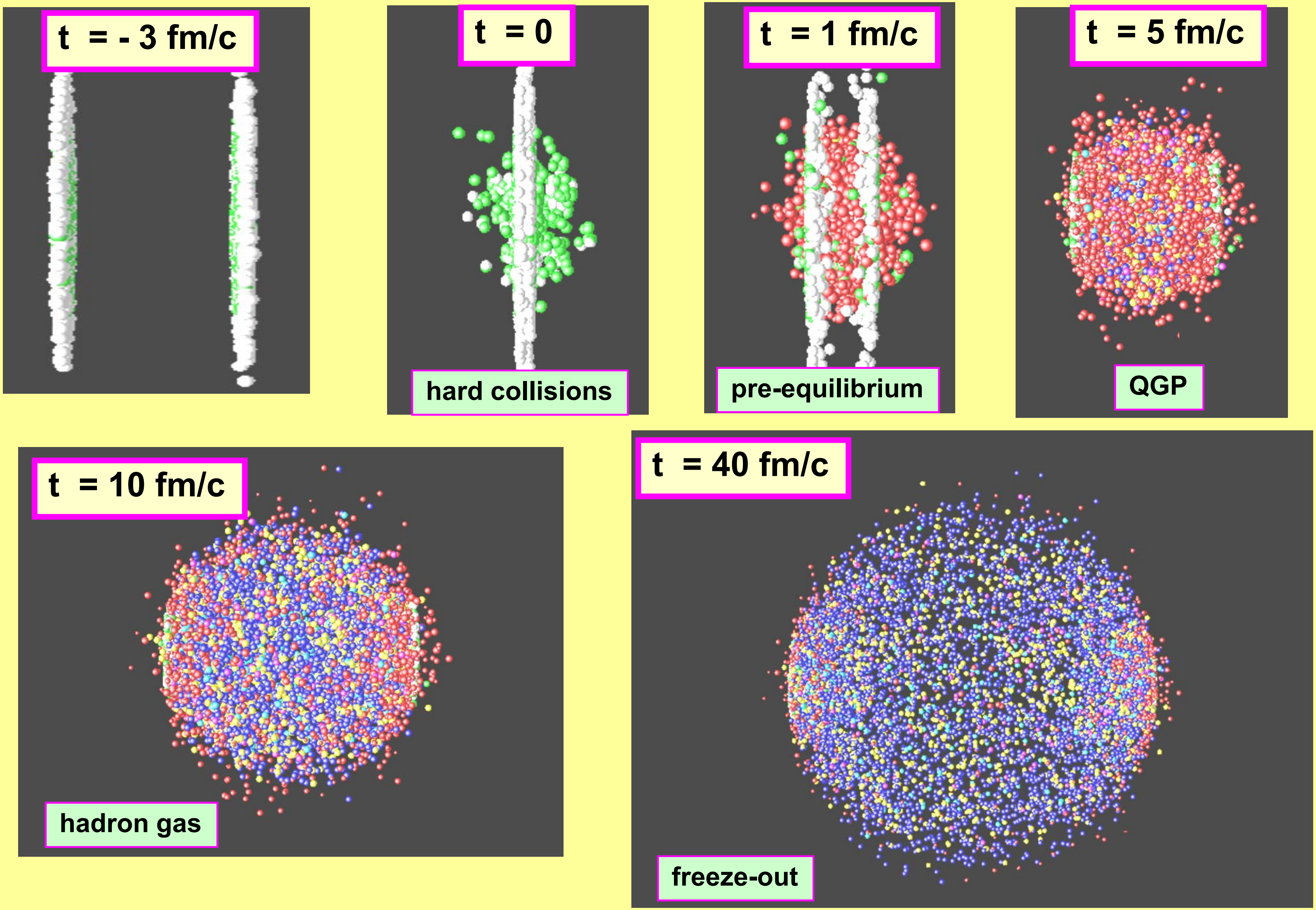




Transition to QGP at T_c= 175 ± 15 MeV; ε_c = 0.7 ± 0.2 GeV/fm^3

"QGP ≡ a (locally) thermally equilibrated state of matter in which quarks and gluons are deconfined from hadrons, so that color degrees of freedom become manifest over nuclear, rather than merely nucleonic, volumes."

Heavy Ion Collision

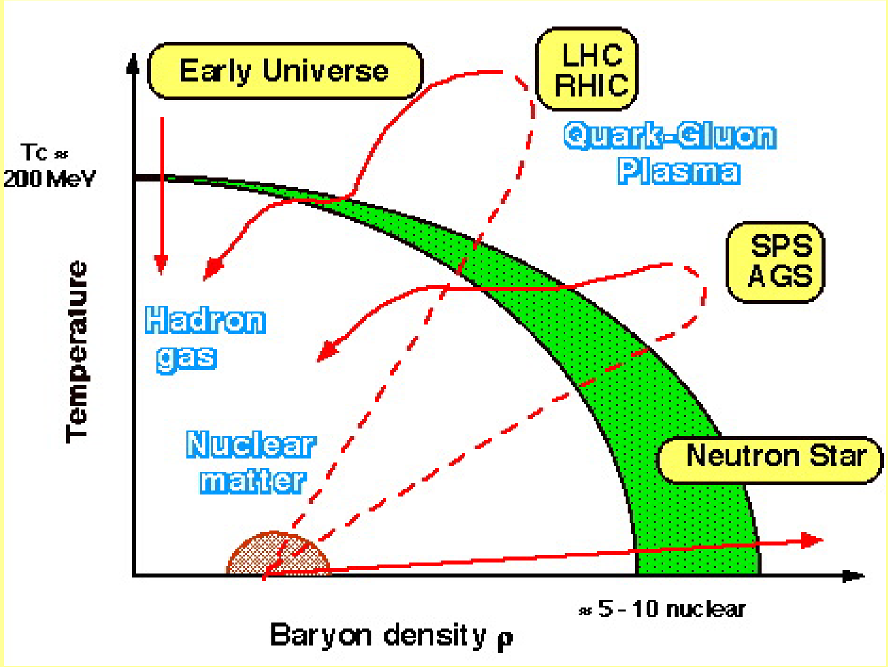


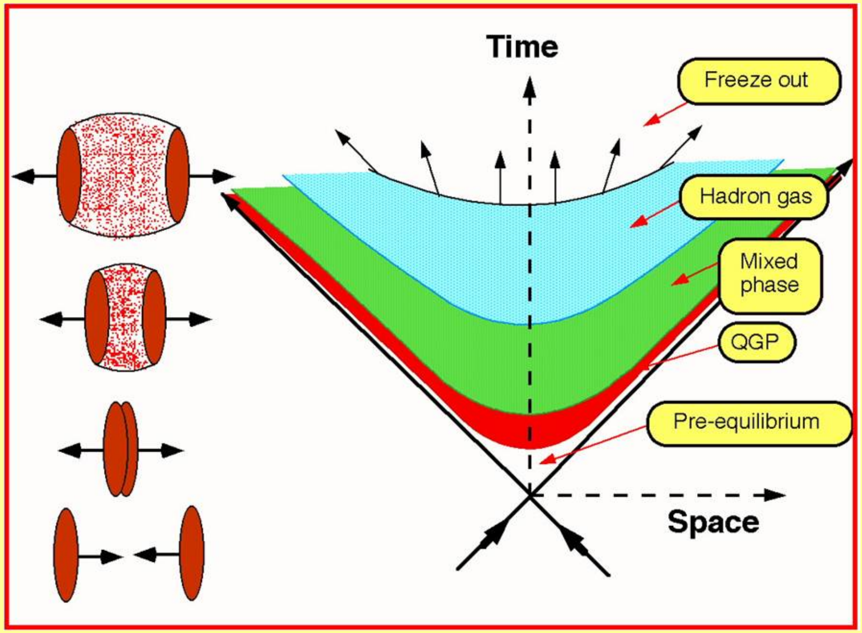
From SPS to RHIC to LHC
'hotter – bigger – longer lived'

Formation time τ_0 3 times shorter than RHIC
Lifetime of QGP τ_{QGP} factor 3 longer than RHIC
Initial energy density ε_0 3 to 10 higher than RHIC

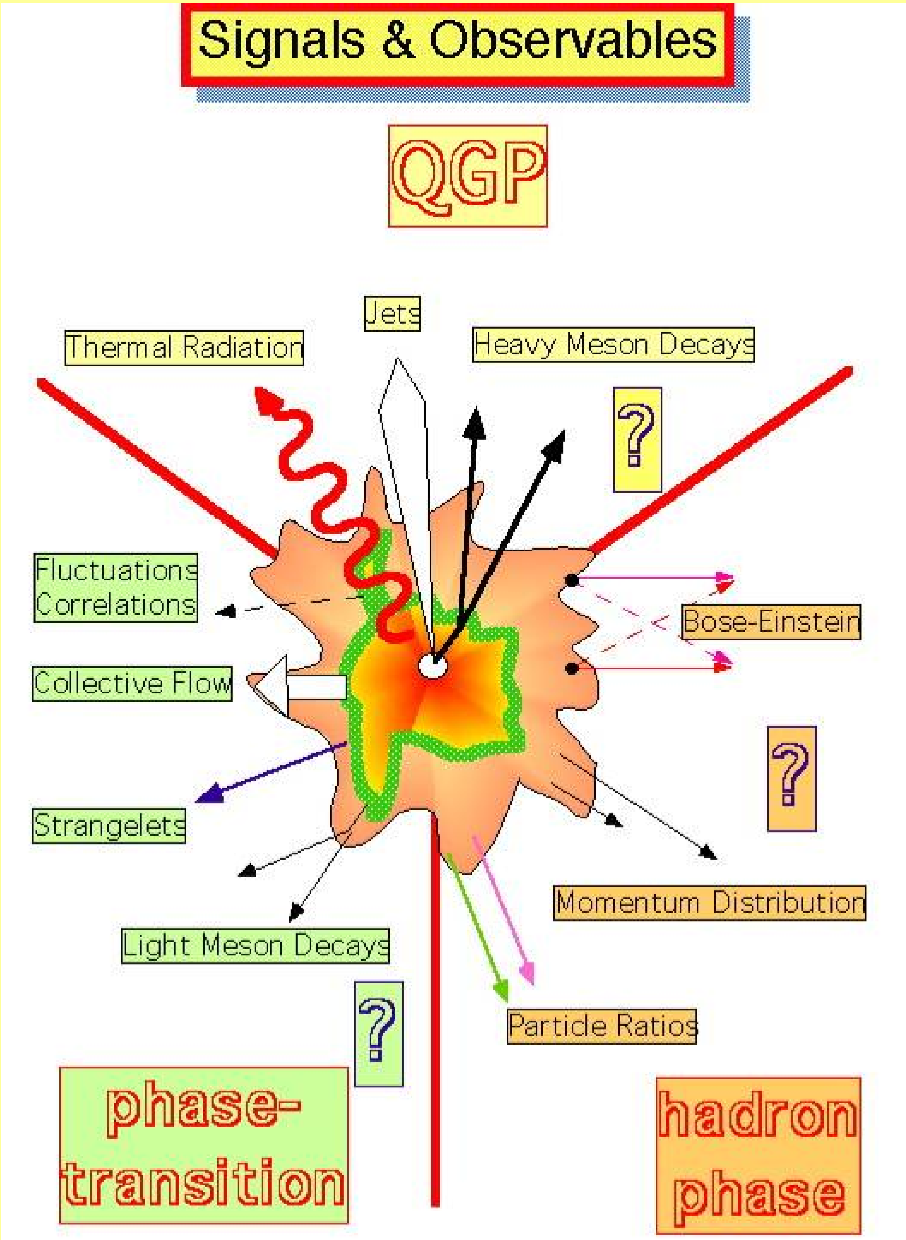
Central collisions	SPS	RHIC	LHC
$s^{1/2}$(GeV)	17	200	5500
dN_{ch}/dy	500	850	2–8 $\times 10^3$
ε (GeV/fm^3)	2.5	4–5	15–40
V_f(fm^3)	10^3	7×10^3	2×10^4
τ_{QGP} (fm/c)	<1	1.5–4.0	4–10
τ_0 (fm/c)	~1	~0.5	<0.2

Phase Diagram of Matter

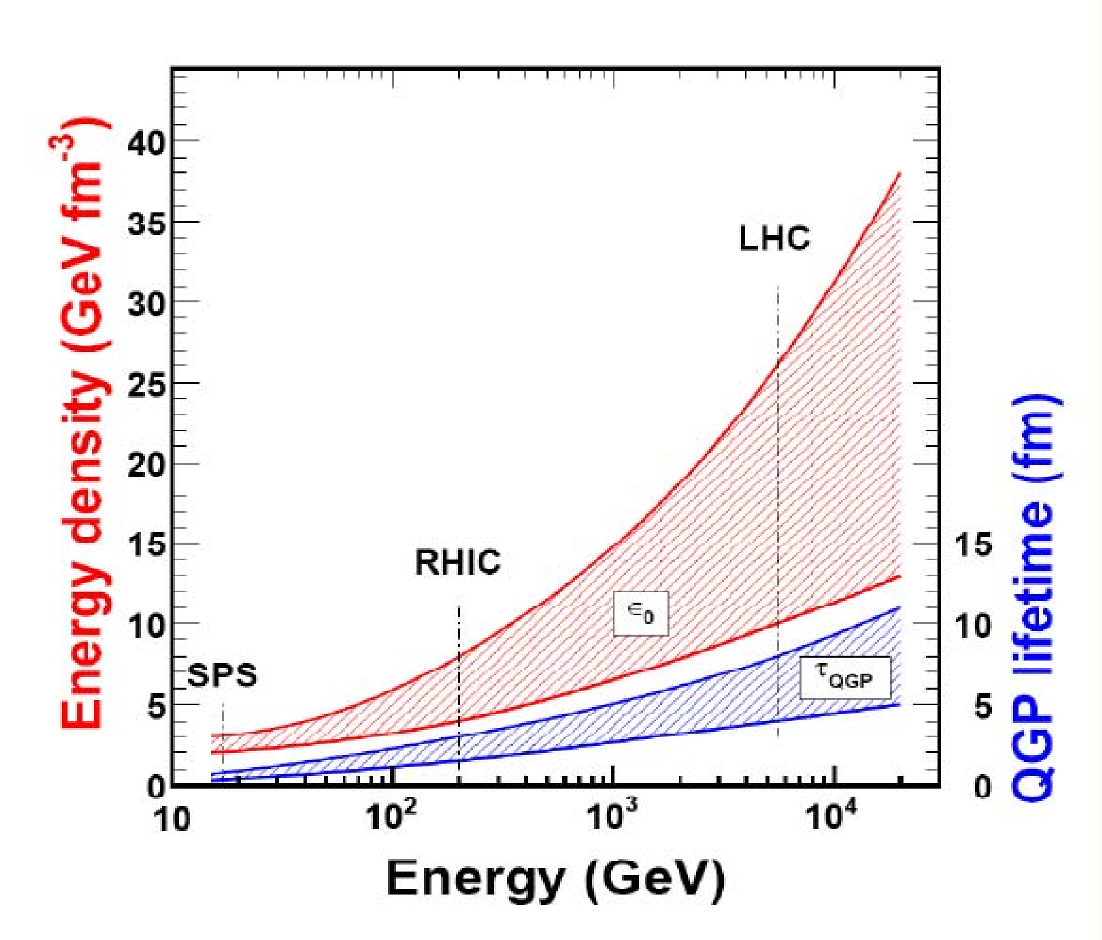




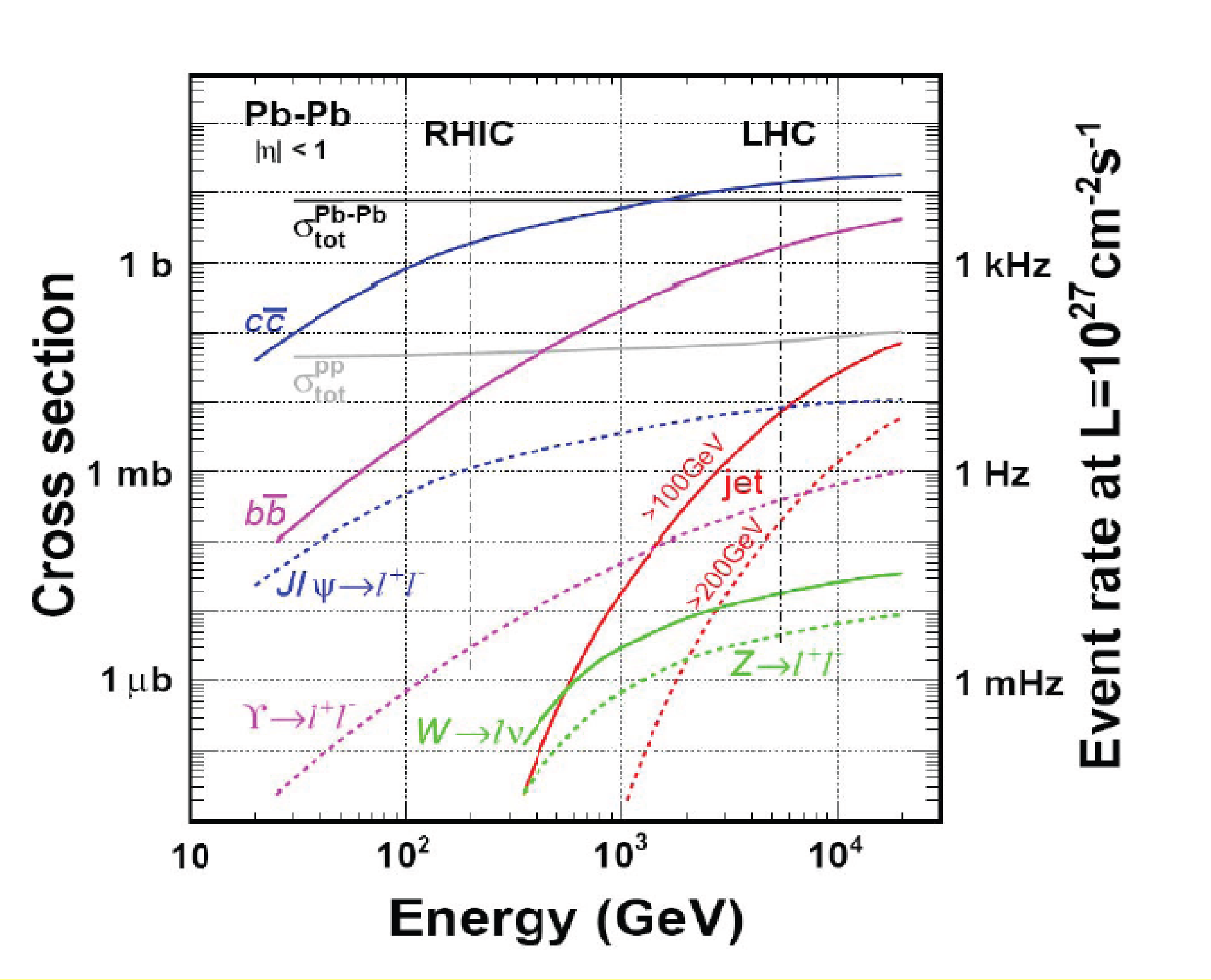
Quark – Gluon Plasma



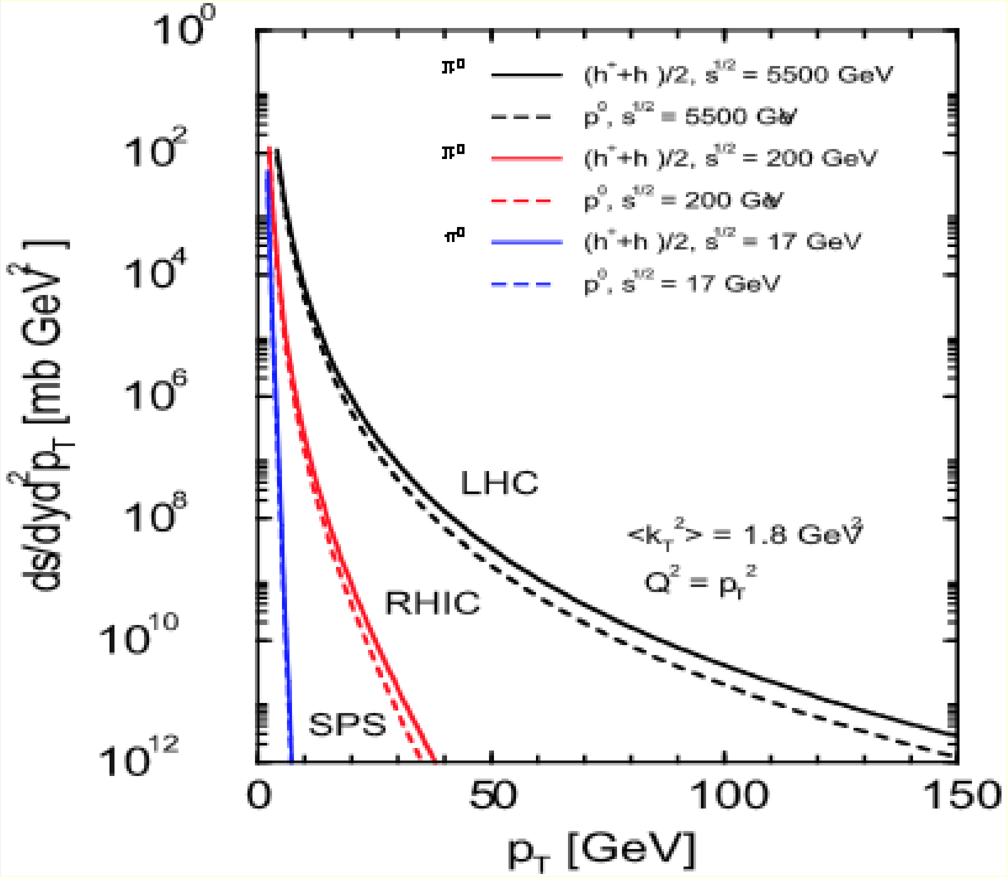
LHC conditions: Energy density



LHC conditions: Cross-sections



LHC conditions: Hard Processes



Significant contribution of hard processes to the total AA cross-section ($\sigma_{hard}/\sigma_{tot}$ = 98%):

Bulk properties dominated by hard processes;

Very hard probes are abundantly produced.

Weakly interacting probes become accessible (g, Z^0, $W^{\pm}$).

ALICE physics tasks

- **Event characterization**
  Multiplicity, centrality

- **Bulk properties of the hot and dense medium (dynamics of hadronization)**
  Hadron ratios, hadronic resonances

- **Chiral symmetry restoration**
  Short lived resonance masses

- **Space-time fireball description and fireball expansion dynamics**
  Momentum correlations (HBT), Radial and anisotropic flow

- **Heavy quark production**
  Charmonium and bottonium (Debye screening, recombination(?))

- **Partonic energy loss in QGP**
  Jet reconstruction, Jet quenching, high pt spectra, inclusive high p_T suppression, open charm (Mass/color dependence of E loss)

- **Fluctuation phenomena**
  Event-by-Event analysis

- **.........................**

LHC as Heavy-Ion Collider

Running parameters

Collision system	$\sqrt{s_{NN}}$(TeV)	$\mathcal{L}_0$ (cm^{-2}s^{-1})	$<\mathcal{L}>/\mathcal{L}_0$(%)	Run time (s/year)	σ_{geom} (b)
pp	14.0	10^{34} *		10^7	0.07
PbPb	5.5	10^{27}	50	10^6 **	7.7
pPb	8.8	10^{29}		10^6	1.9
ArAr	6.3	10^{29}	65	10^6	2.7

*$\mathcal{L}_{max}$(ALICE) = 10^{31}

** $\mathcal{L}_{int}$(ALICE) ~ 0.5 nb^{-1}/year

ALICE Collaboration

~ 1000 Members

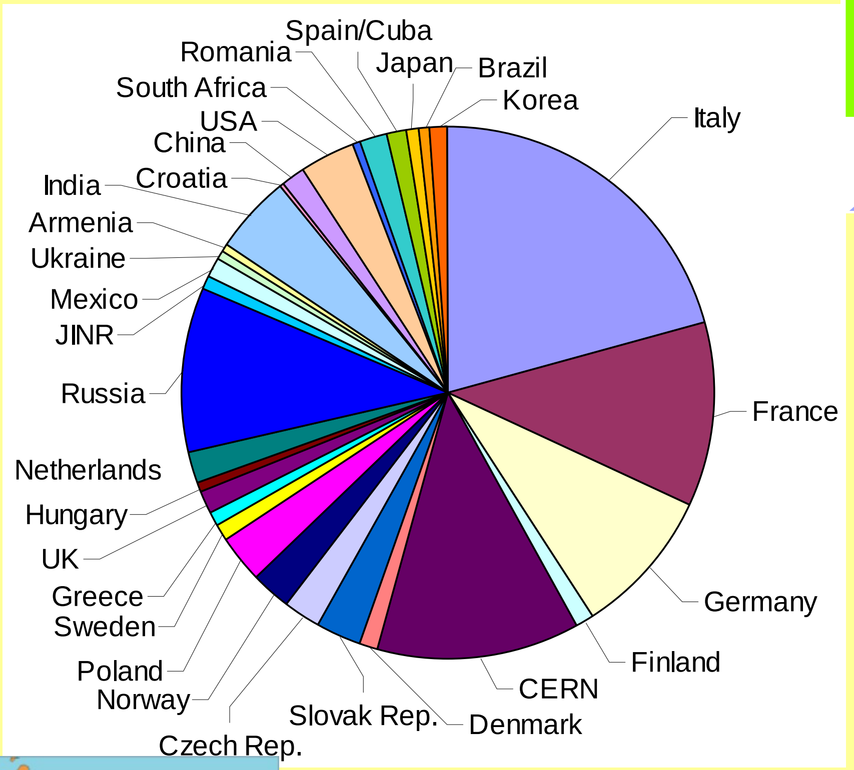
(63% from CERN MS)

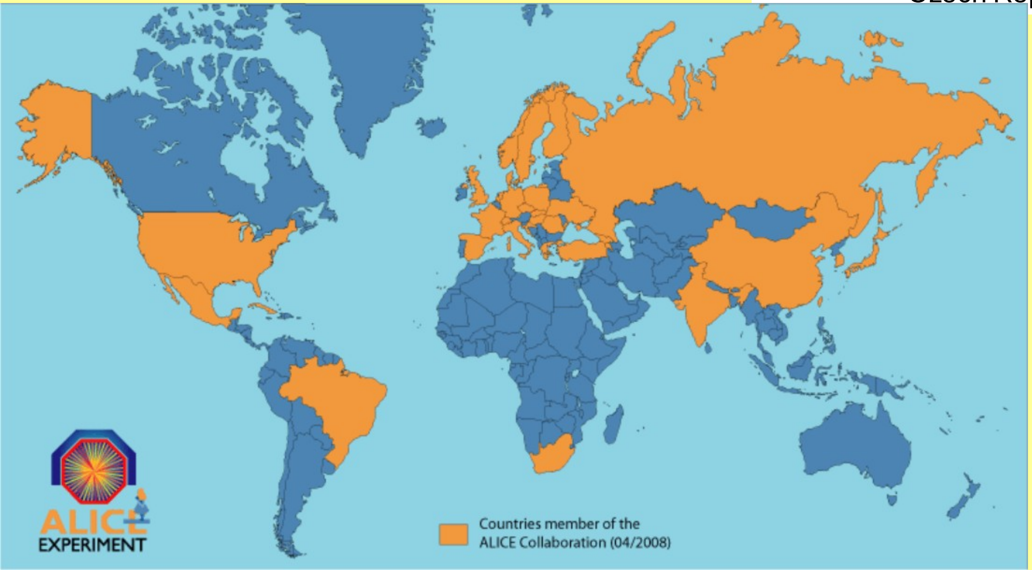
~30 Countries

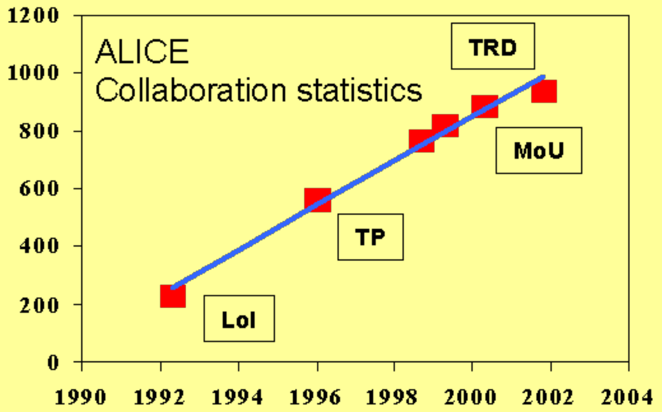
~100 Institutes

~ 150 MCHF capital cost

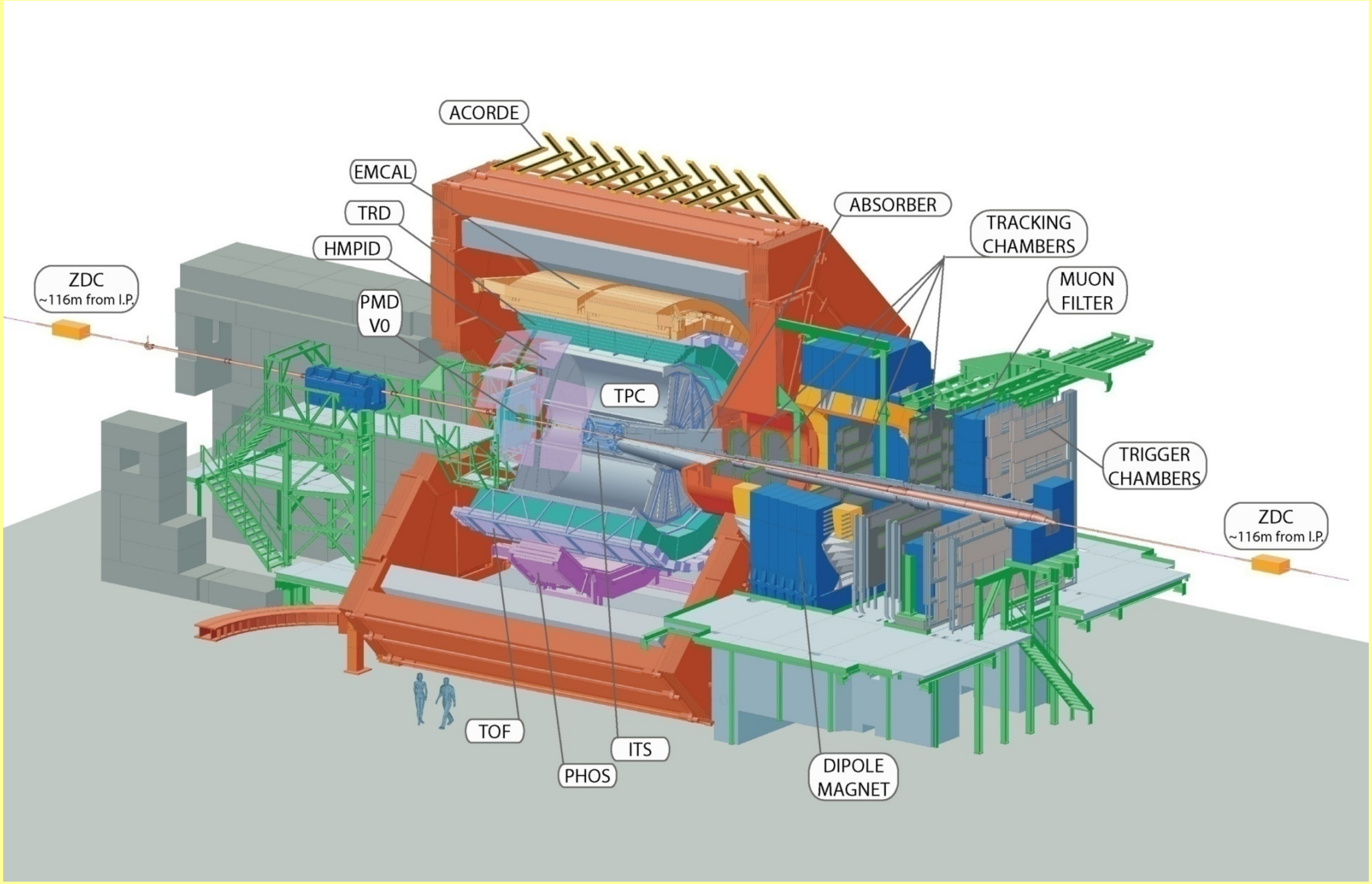
(+ 'free' magnet)







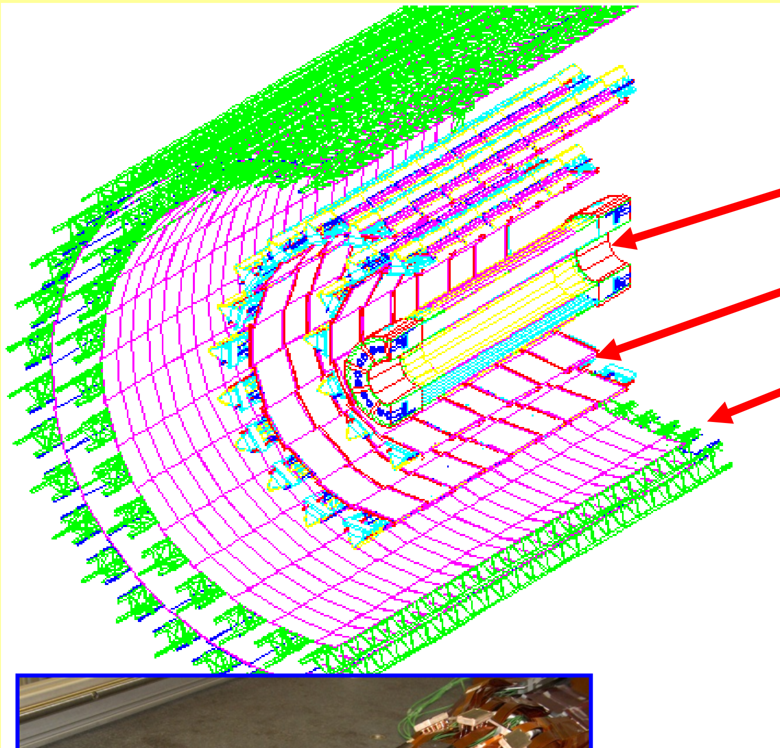
ALICE: A Large Ion Collider Experiment



The Inner Tracking System:

Primary vertex, Secondary vertex, Particle identification, Standalone reconstruction

~ 12.5M channels

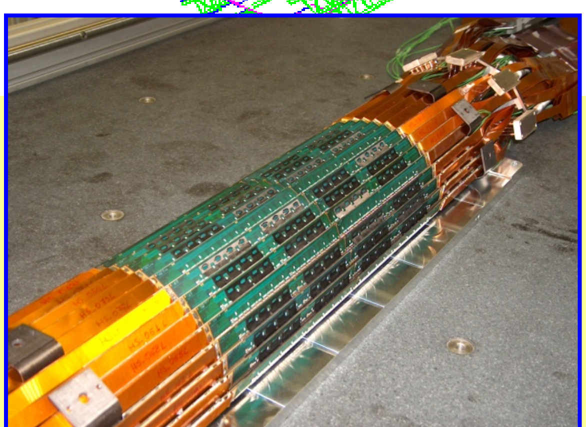


SPD-Silicon Pixel

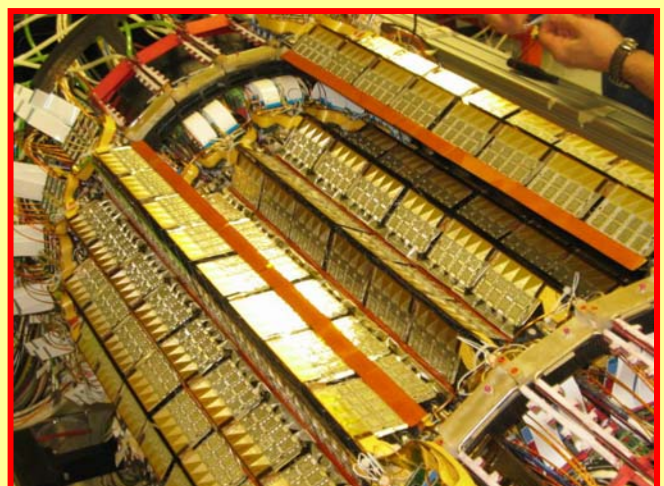
SDD-Silicon drift

SSD –Silicon Strip

Strips



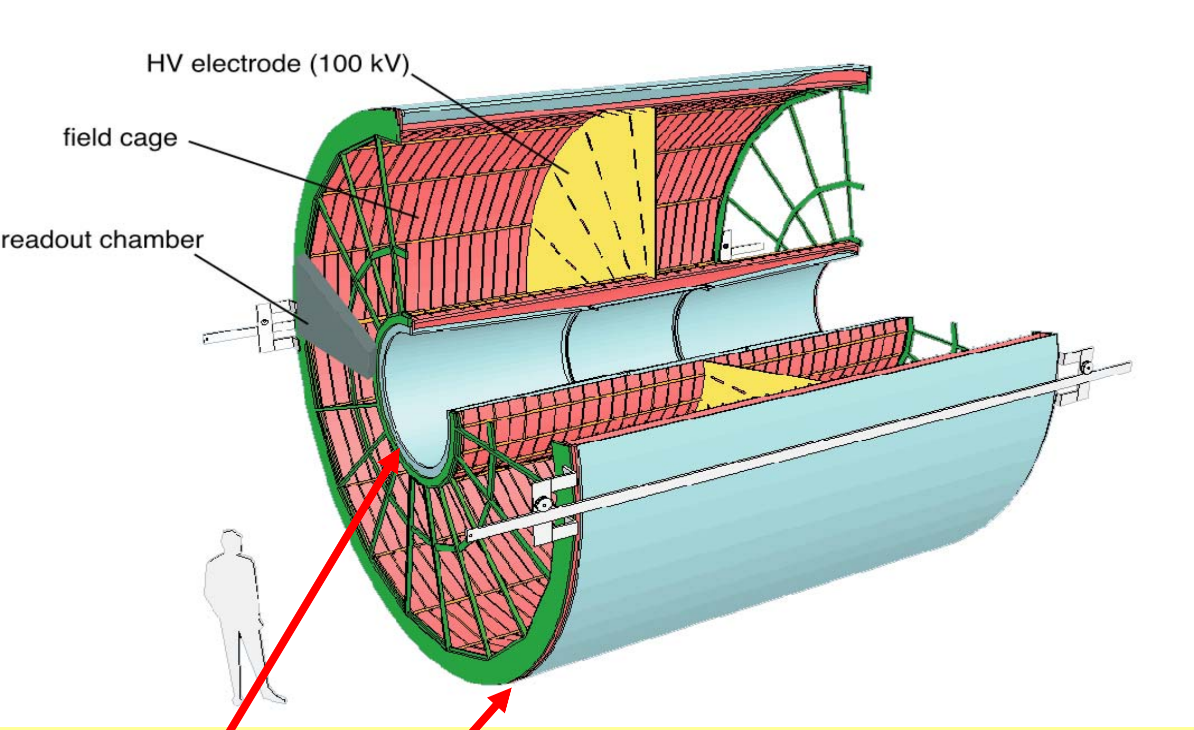
Pixels



Drift

The Time Projection Chamber:

Main tracking detector (charged particles) of the ALICE Central Barrel



845 < r < 2466 mm
Drift length 2 x 2500 mm
Drift gas Ne-CO_2-N_2 (86/9/5)
Gas volume 95 m3
557568 readout pads

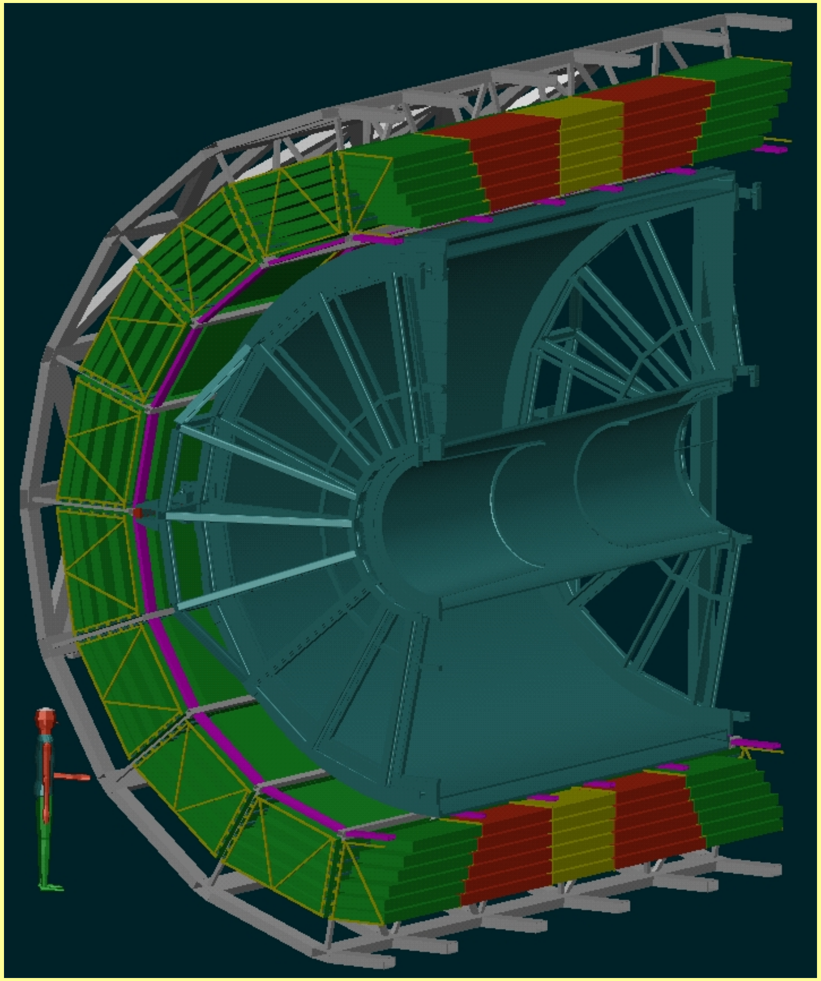
TPC installation

Inner and Outer Vessels

Outer dia. ~5m; L~5m

The Transition Radiation Detector:

e - identification



- 18 supermodules
- 6 radial layers
- 5 longitudinal stacks

540 chambers

750m² active area

28m³ of gas

Each chamber:

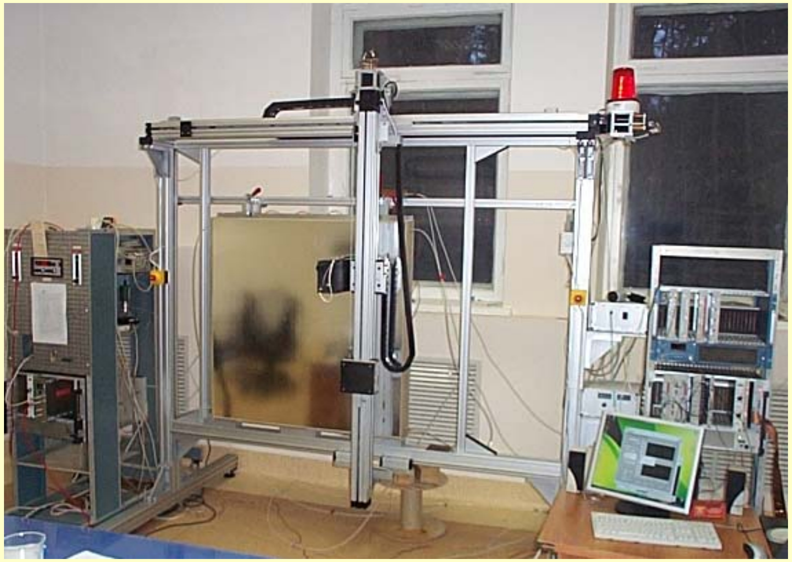
≈ 1.45 x 1.20m²

≈ 12cm thick

(incl.Radiators

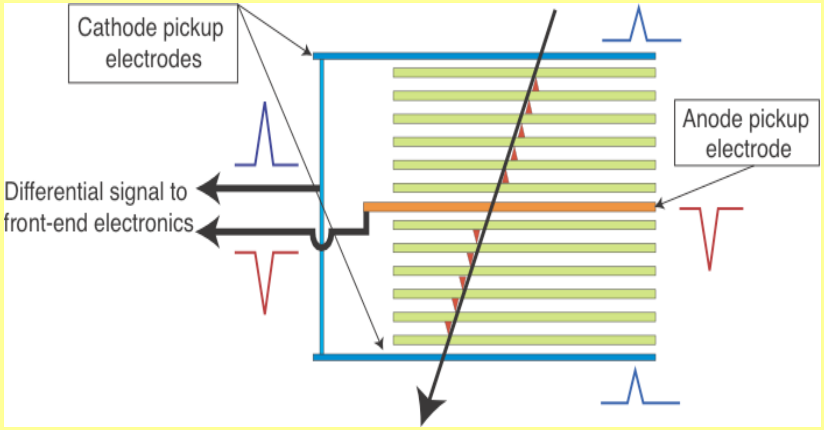
and electronics

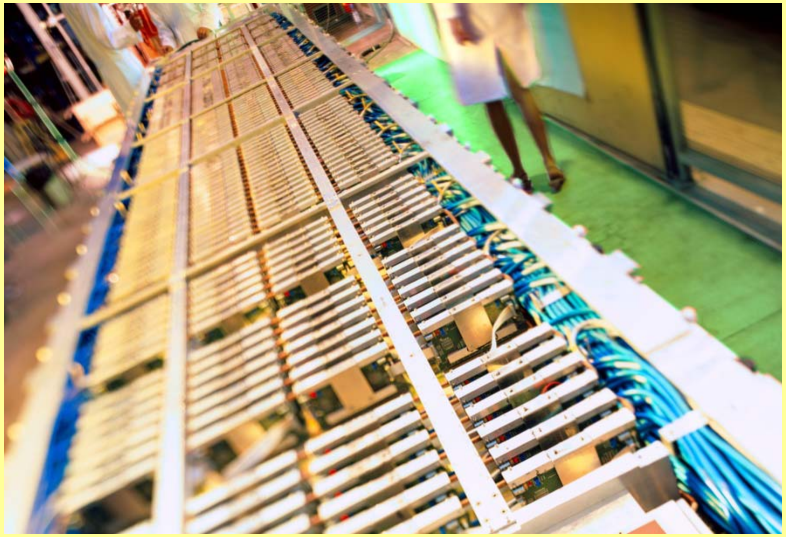
Transition Radiation Detector Drift Chambers Construction

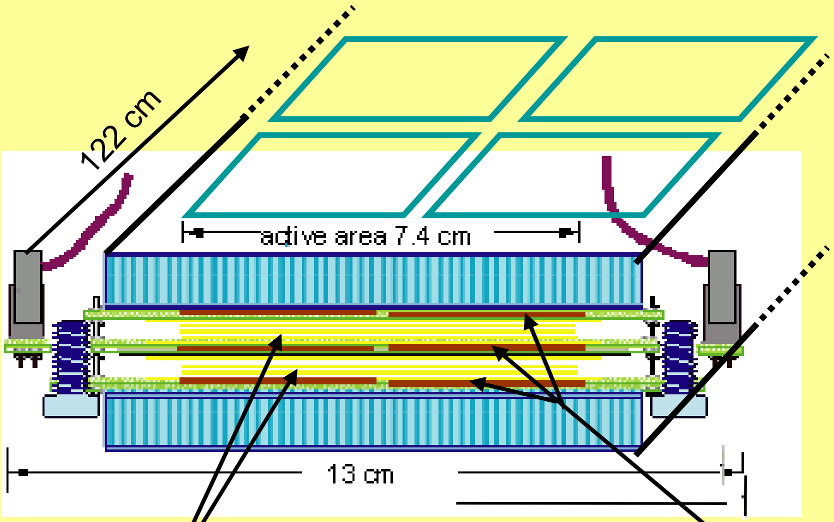


The Time Of Flight System

Principal scheme







10 gas gaps of 250 micron each

Readout pads 3.5 x 2.5 cm^2

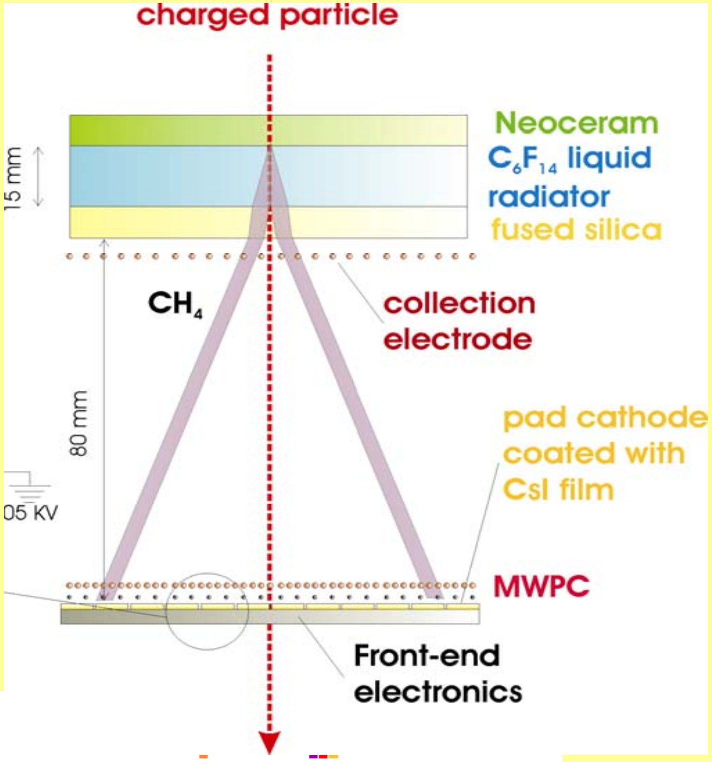
TOF basic element:
double-stack Multigap RPC strip
7.4x120 cm^2 active area
segmented into 96 readout pads

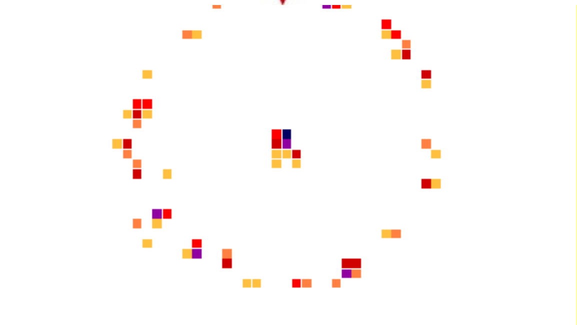
- Time resolution < 100 psec
- Efficiency 99%

The High Momentum Particle Id Detector

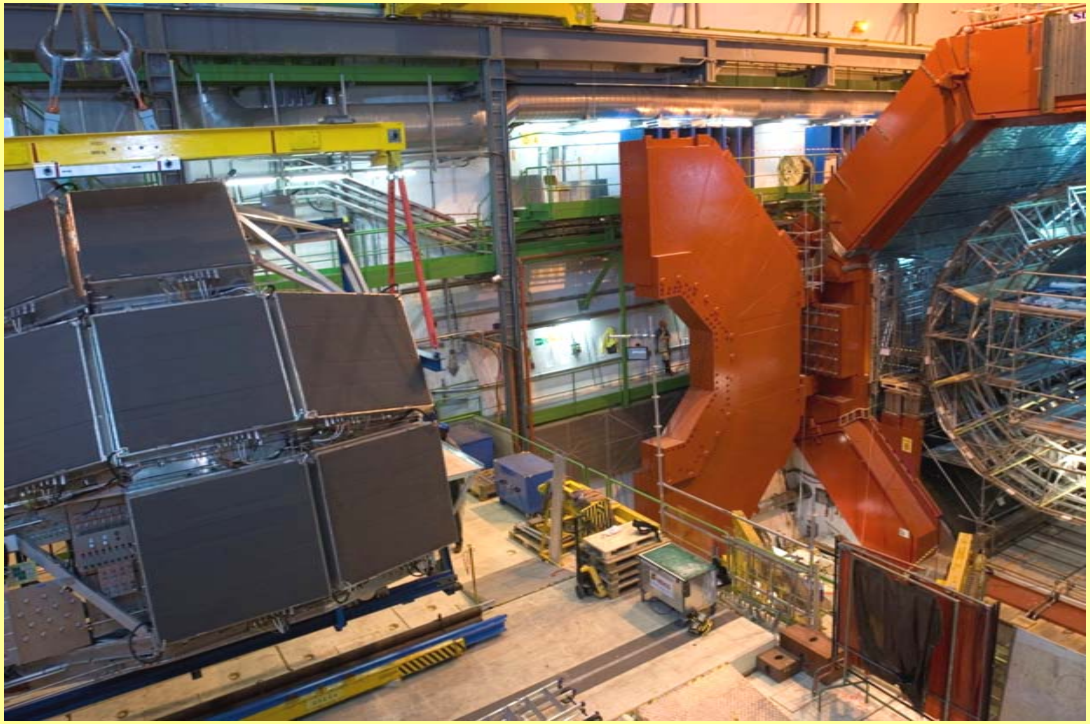
Single-Arm proximity-focus RICH w/ active surface ~ 11 m^2 at R ~ 4.7 m

Principal scheme





Installation of HMPID



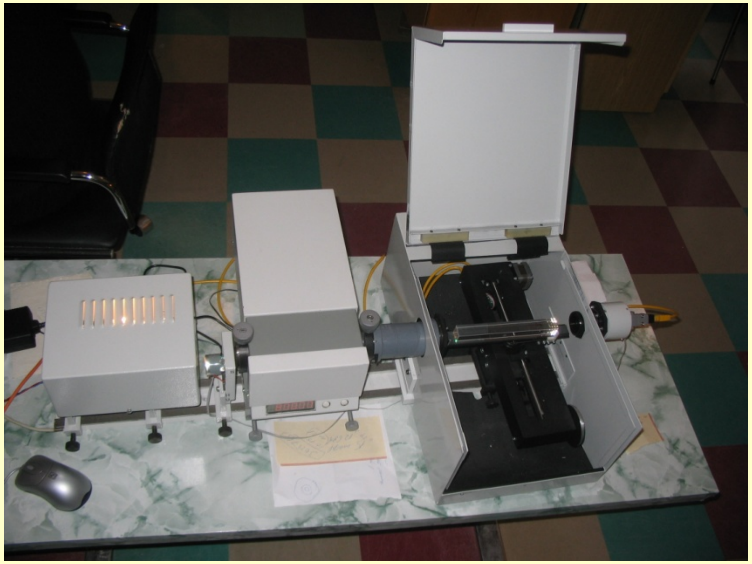
PHOTON + MIP DETECTION

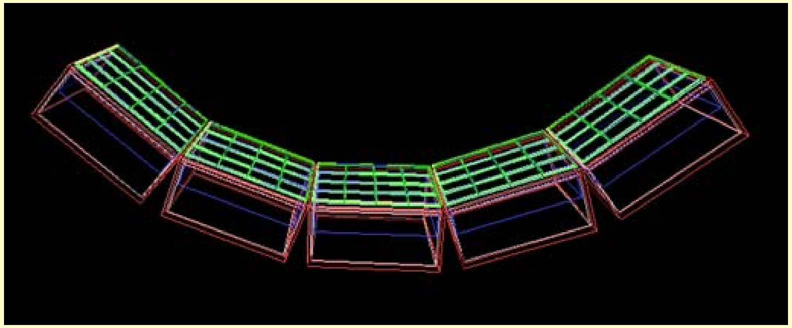
MWPC with CH_4 with analogue pad r/o (~160×10^3 channels), photon conversion on a layer of CsI (Q.E. ≈ 25% @ 175 nm)

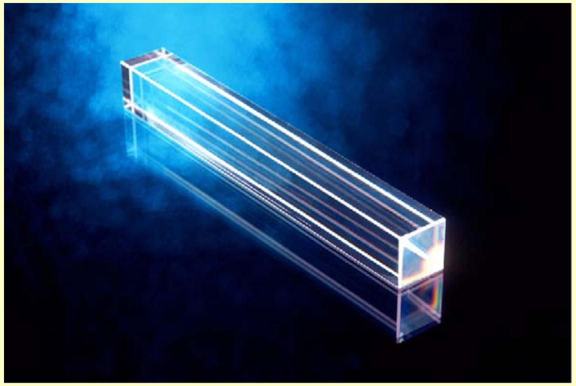
Photon Spectrometer

$PbWO_4$ crystal (17920 cristals in total):

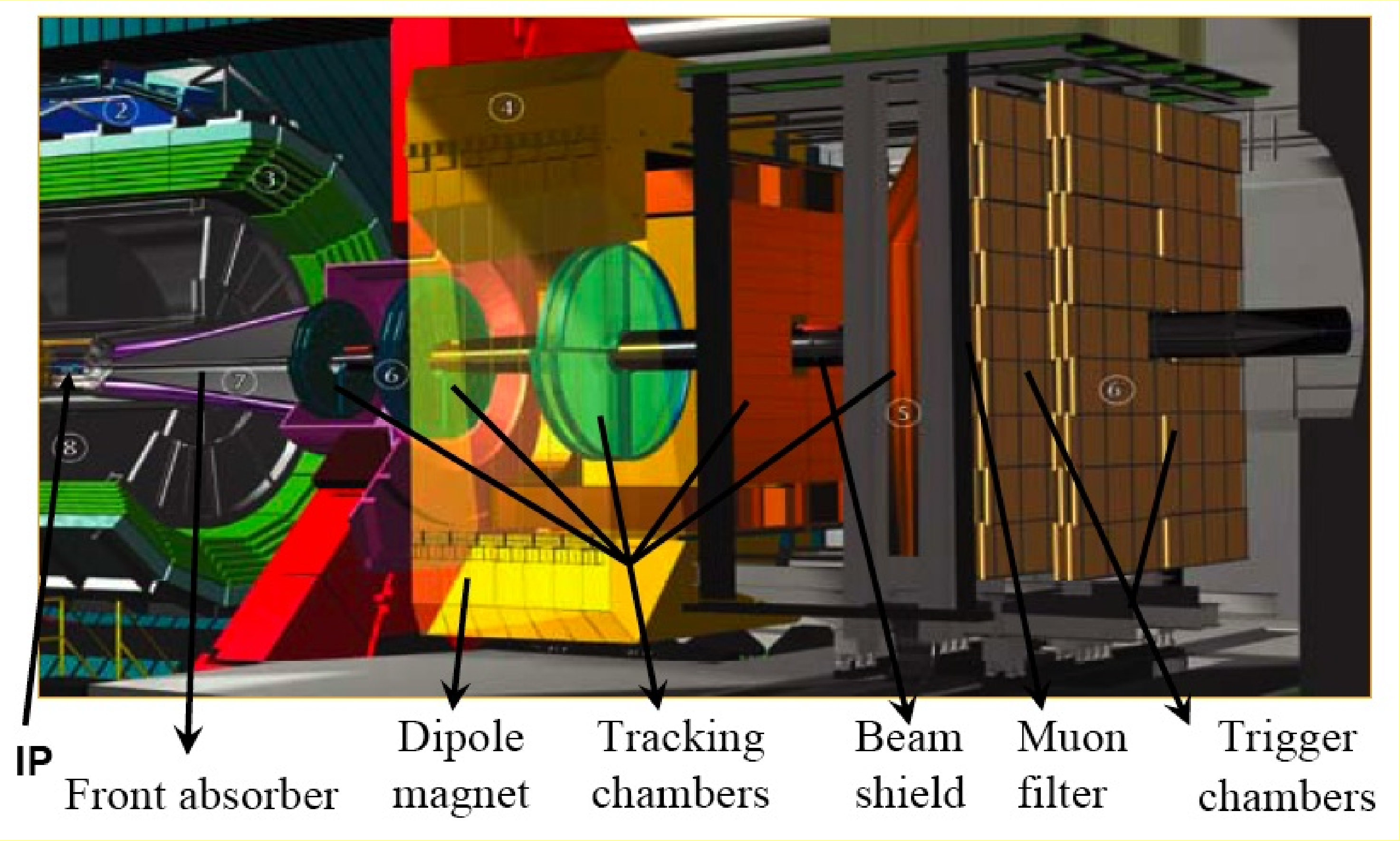
R_M=2.2 cm, X_0=8.9 mm, ρ=8.28 g/cm^3, n=2.16, size: 22×22×180 mm^3







Forward Muon Spectromneter

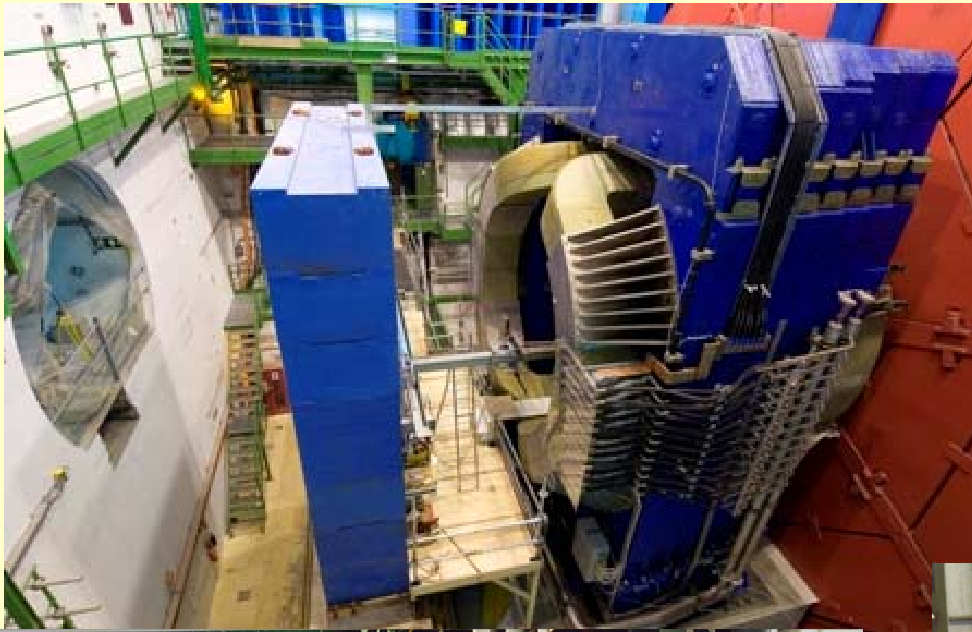


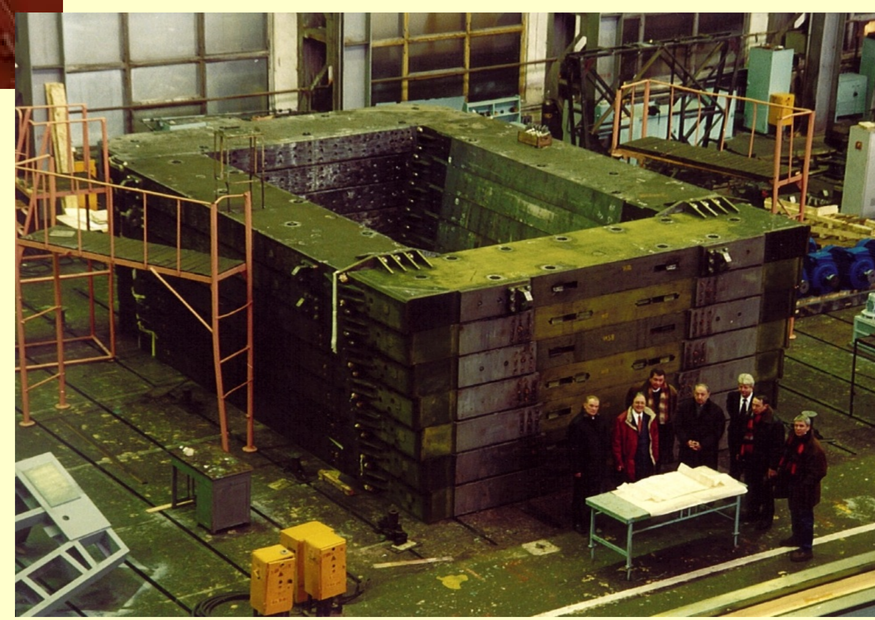
Acceptance on single m:
- p>4 GeV/c
- $-4.0 < \eta < -2.5$

$\Delta M/M \sim 1\%$ at Y- mass

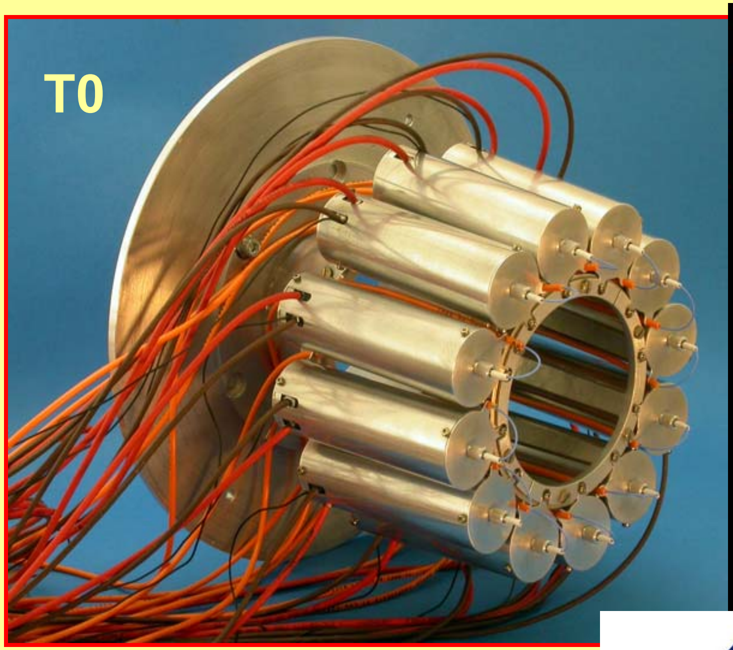
Large Dipole Magnet for Dimuon Spectrometer

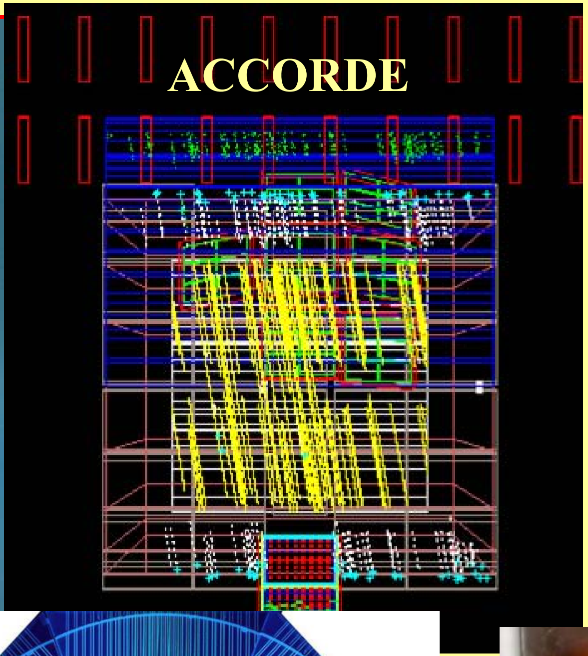
(850 ton, 9 x 7 x 4.5 m)

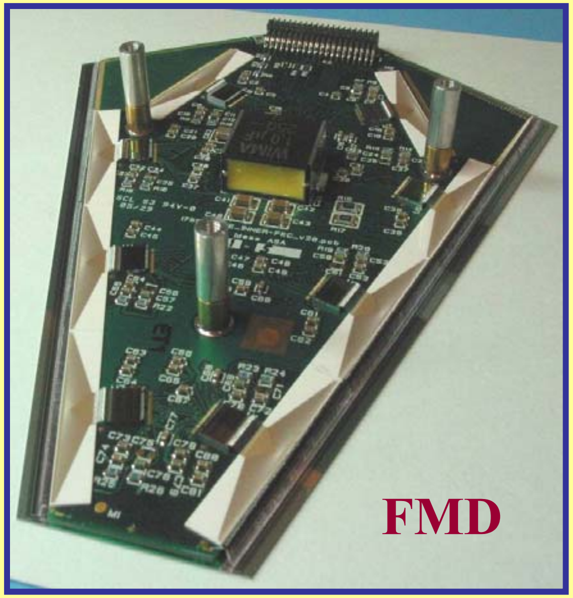


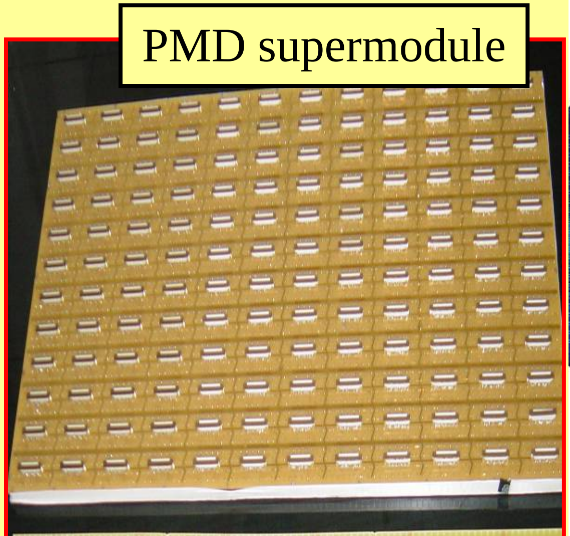


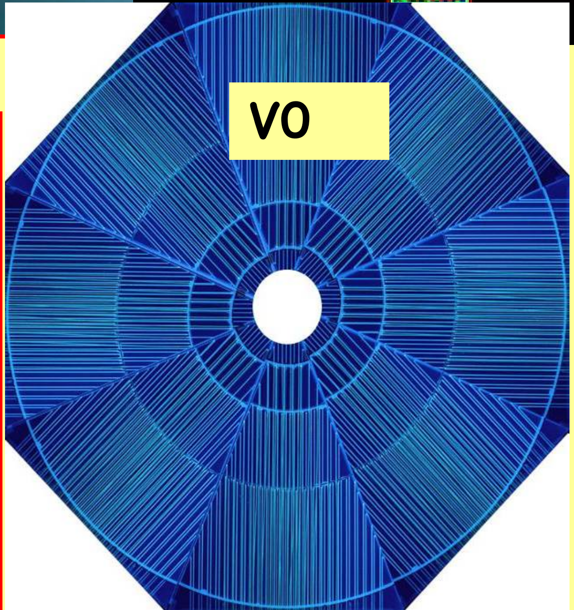
Forward Detectors

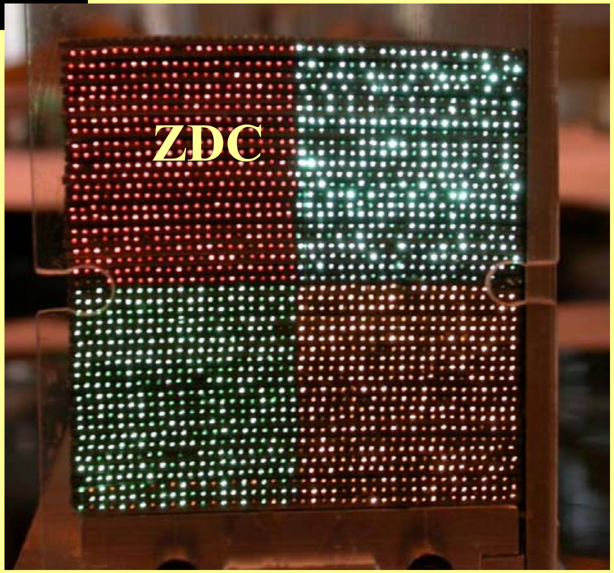






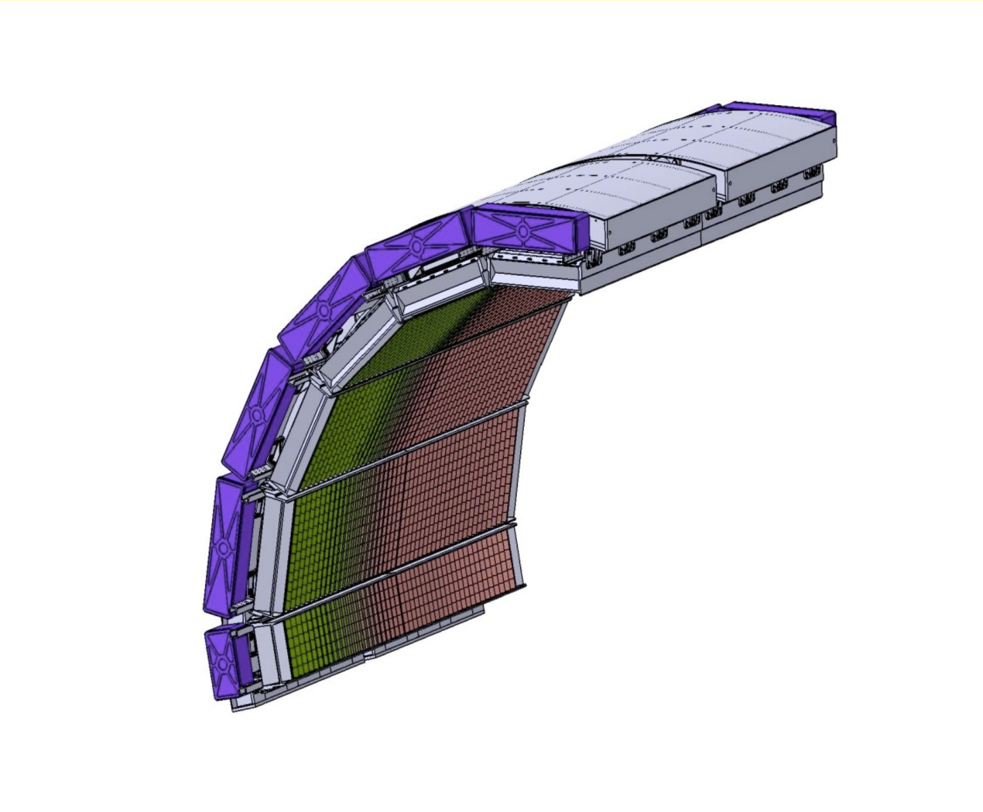






ALICE Electromagnetic Calorimeter

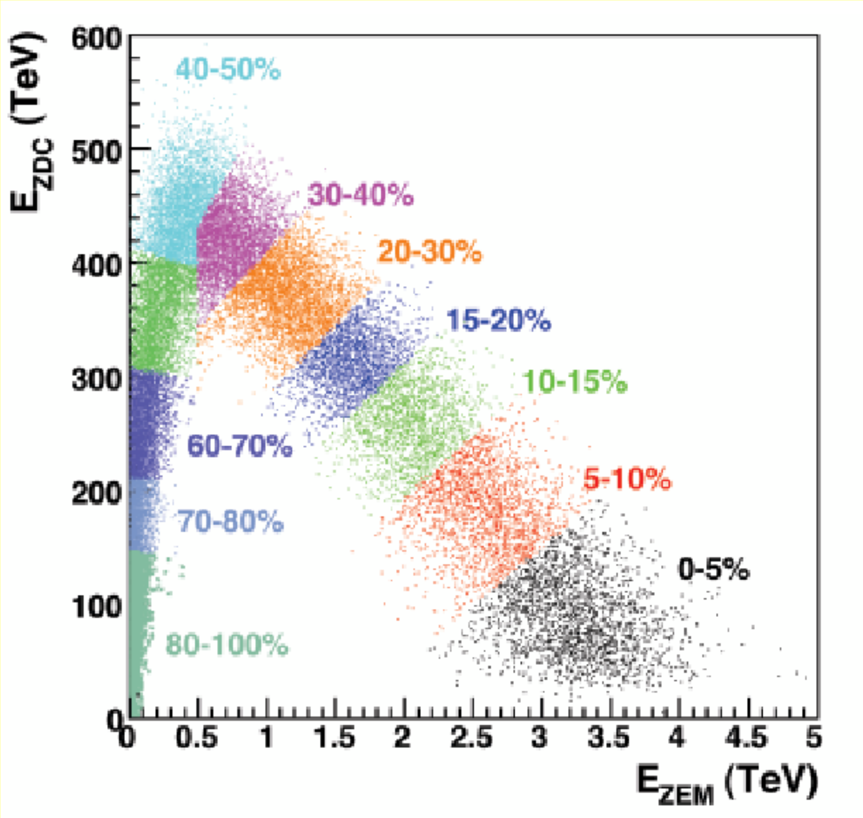
US + Italy + France contribution

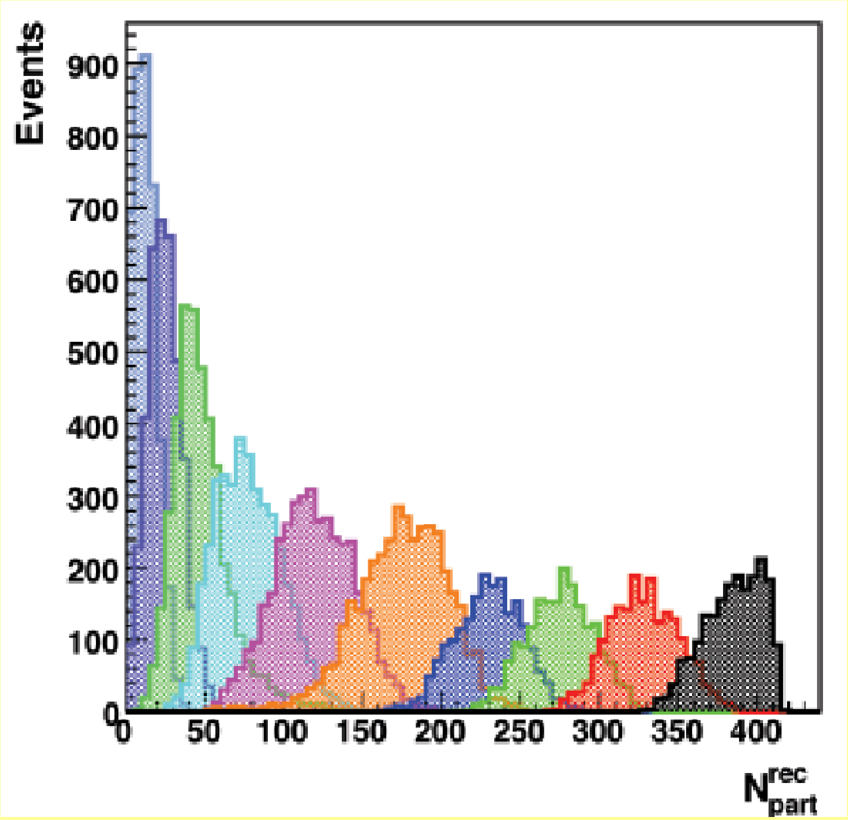


Lead scintillator sampling calorimeter
$\Delta\phi = 110^o$
$|\Delta\eta| = 0.7$
Number of towers is about 13 000

It will enhance the ALICE capabilities for jet measurement. It enables triggering on high energy jets (enhancement factor 10-15), reduces the bias for jet studies and improves the jet energy resolution.

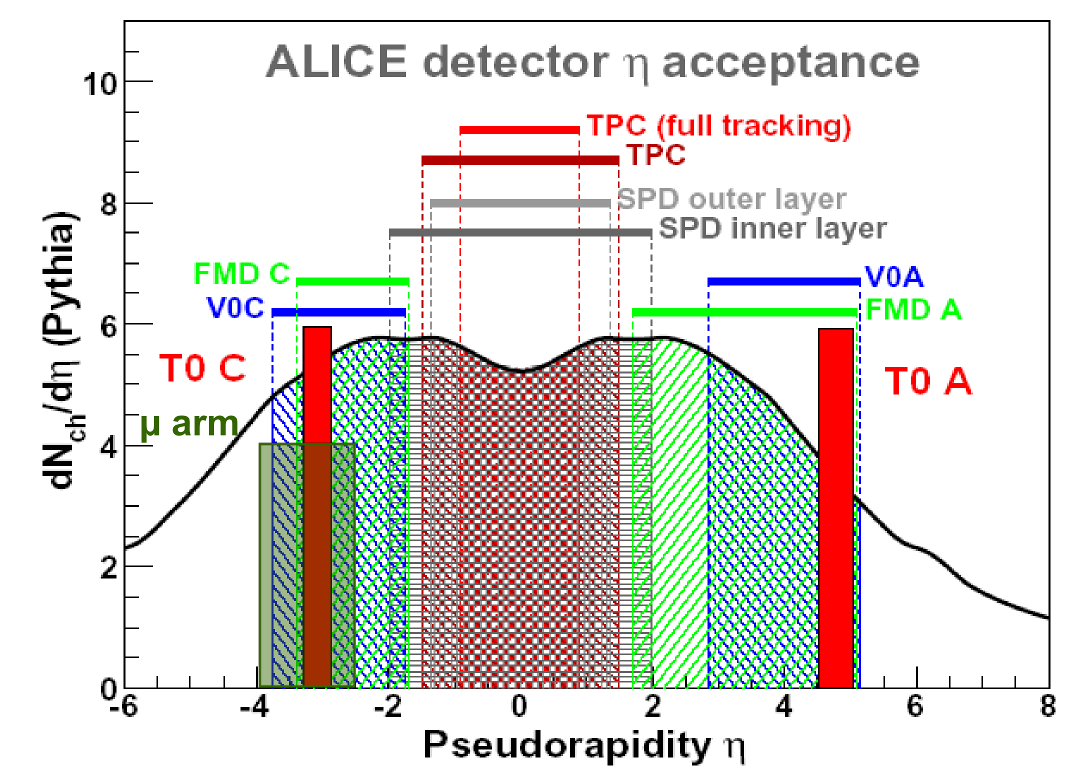
Centrality determination in ALICE





Event by event determination of the centrality :
Zero degree hadronic calorimeters (ZDC) +
electromagnetic calorimeters (ZEM)
EZDC , EZEM → Nspec → Npart → Impact parameter (b)

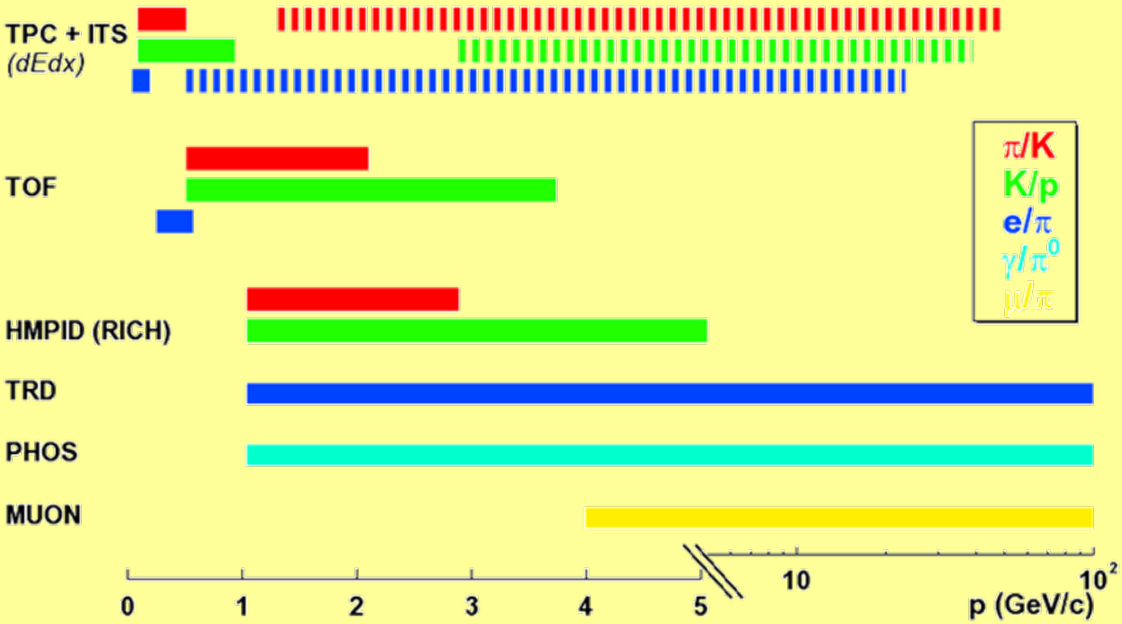
Charged particle acceptance



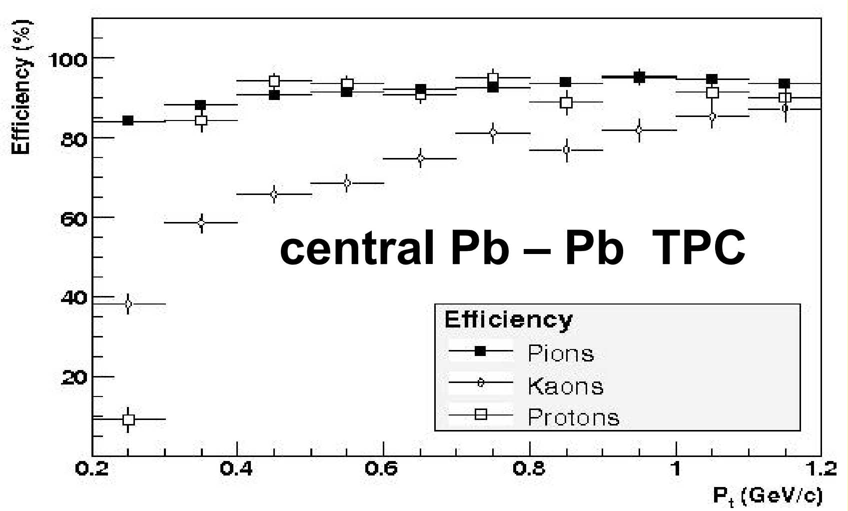
- Minimum Bias trigger provided by a coincidence between V0 counters ($-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$).
- We expect a $dN/d\eta$ excellent measurement in the central region thanks to the ITS + TPC detector
- V0 and FMD in the forward region.

Particle Identification

excellent particle ID up to ~ 50 to 60 GeV/c



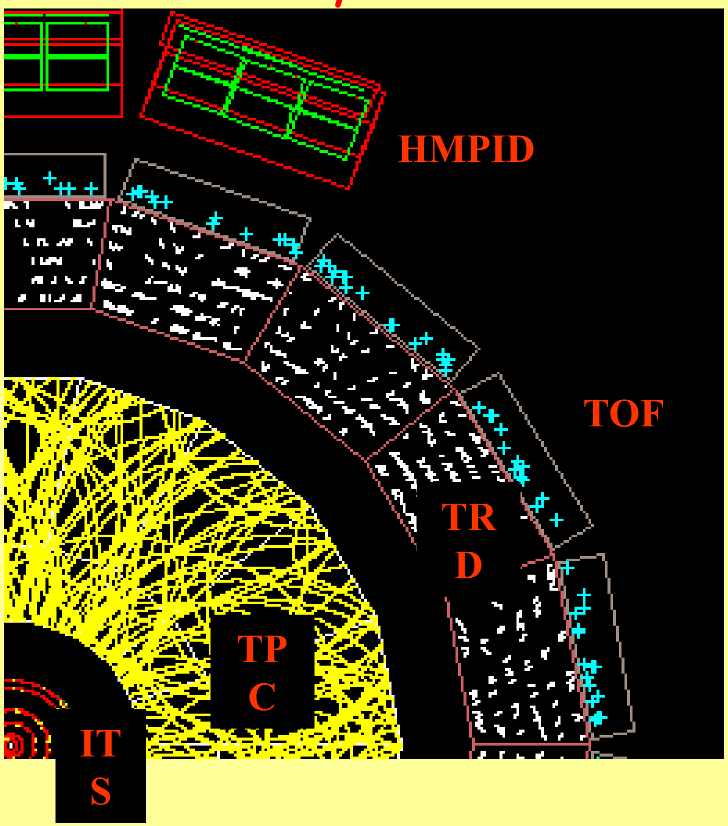
•Identification short lived particles (hyperons, D/B meson) through secondary vertex detection
•Most (2p * 1.8 units h) of the hadrons (dE/dx + ToF), leptons (dE/dx, TOF, transition radiation) and photons (high resolution EM calorimetry, conversions);
•Tracking and identification from very low (< 100 MeV/c) up to very high pt (>100GeV/c);

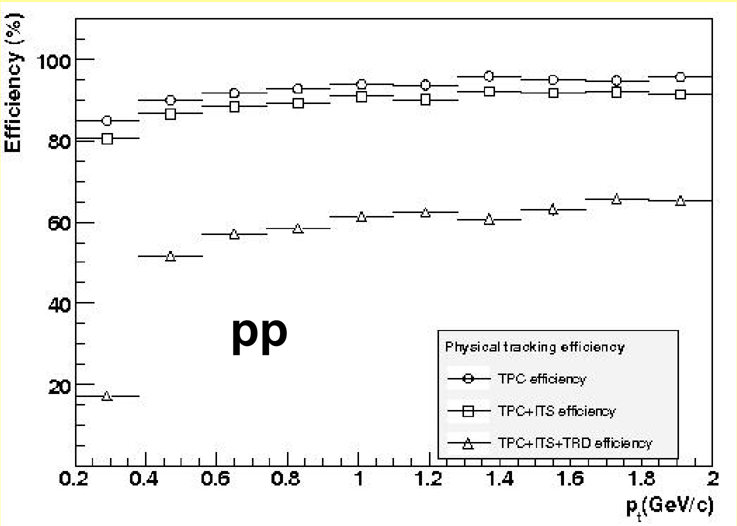


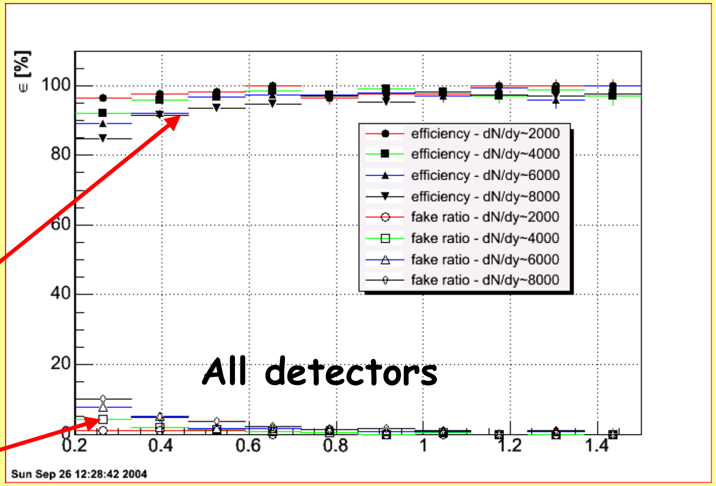
π,K,p: dE/dx (in TPC & ITS) + TOF & RICH
100 MeV < p < a few tens GeV
electrons: TRD p >1 GeV
muons: p > 4 GeV
photons: PHOS 1 < p < 80 GeV

Tracking efficiency

dN/dy =8000







For realistic particle densities
dN/dy = 2000 – 4000
combined efficiency well above 90%
and fake track probability below 5%

Selected ALICE physics hints

Details of ALICE physics one can find in

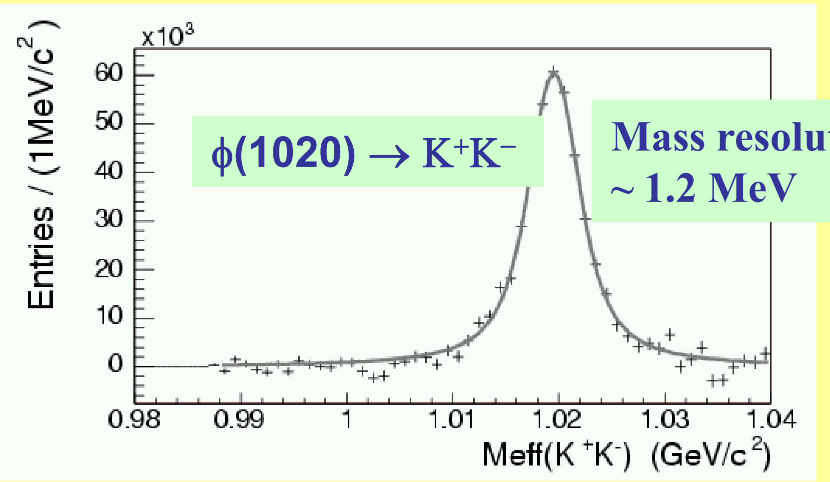
ALICE Physics Performance Report:

Volume 1: J. Phys. G: Nucl. Part. Phys. 30, 1517 (2004);

Volume 2: 32, 1295-2040 (2006)

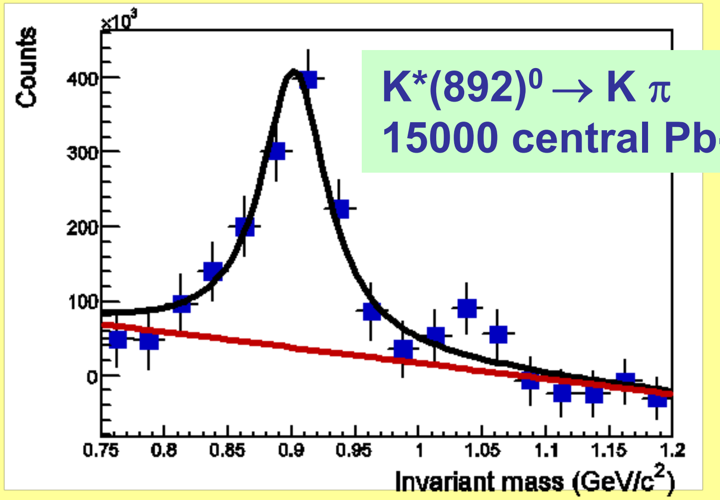
Resonances (ω, ϕ, K*…)

Invariant mass reconstruction, background subtracted (like-sign method)
Mass resolutions ~ 1.5 - 3 MeV p_T stat. limits from 8 (ρ) to 15 GeV (ϕ,K*)

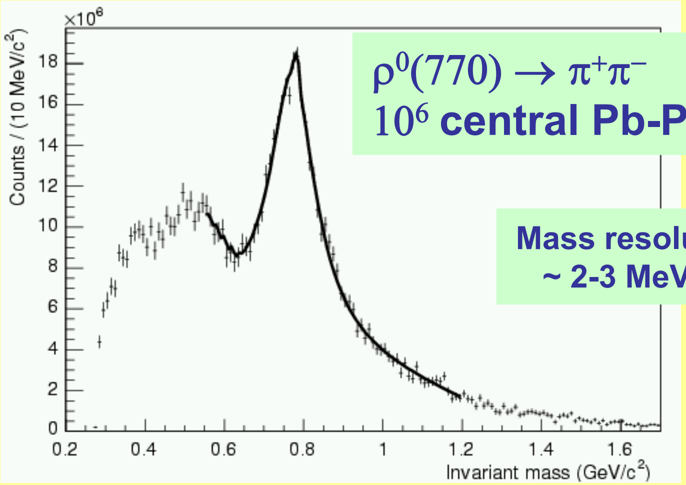


$\phi(1020) \rightarrow K^+K^-$

Mass resolution ~ 1.2 MeV

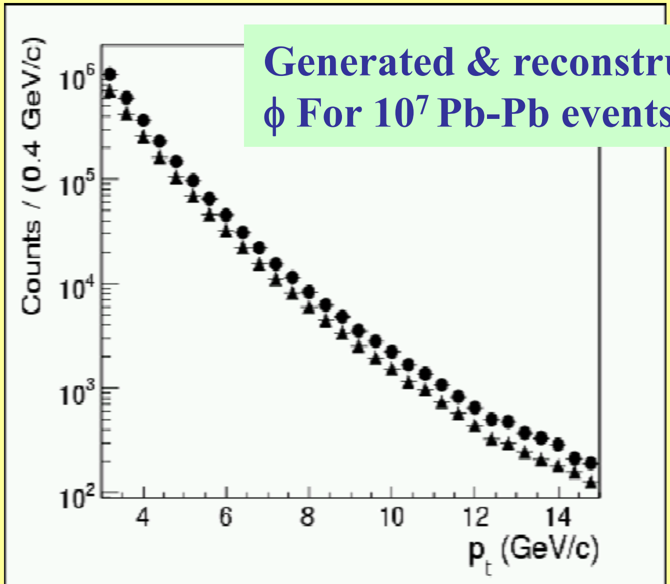


$K^*(892)^0 \rightarrow K\,\pi$
15000 central Pb-Pb



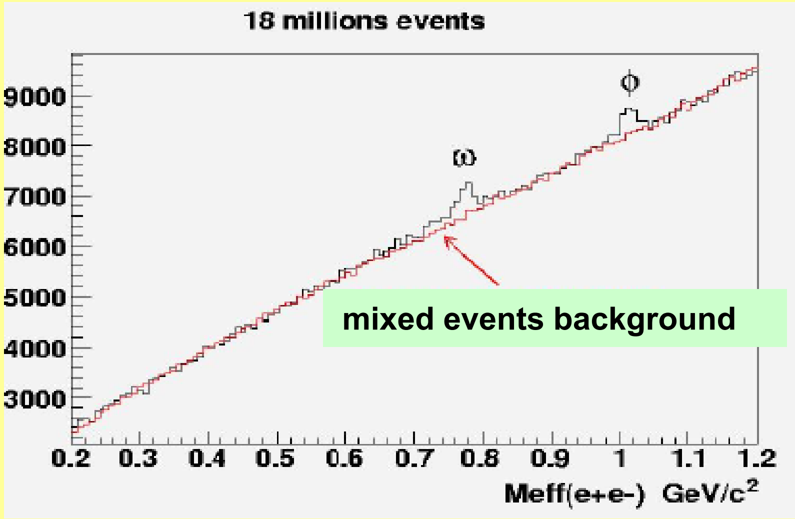
$\rho^0(770) \rightarrow \pi^+\pi^-$
10^6 central Pb-Pb

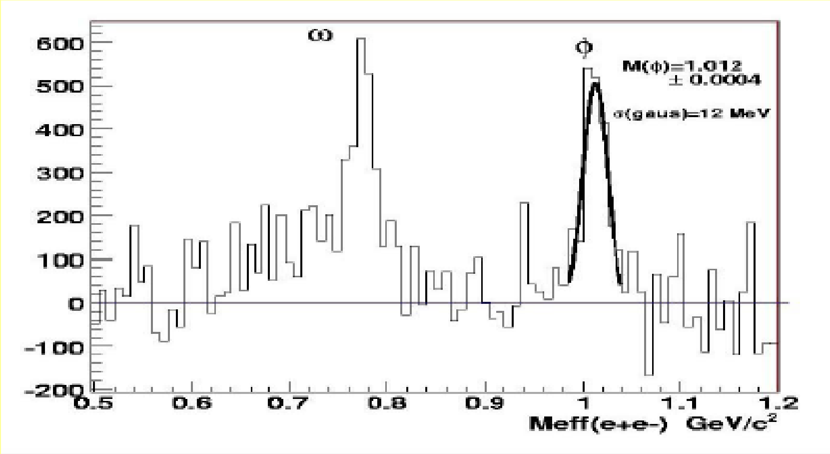
Mass resolution
~ 2-3 MeV



Generated & reconstructed
ϕ For 10^7 Pb-Pb events

ω, ϕ reconstruction via e^+e^- channel





10^7 Pb – Pb events

Fast simulation *dNch/dy* ~ 2000 for tracking and PID in the ITS, TPC and TRD

Cocktail generator for the fast simulation:

- the sources of e^+/e^- at $p_t > 1$ GeV/c;

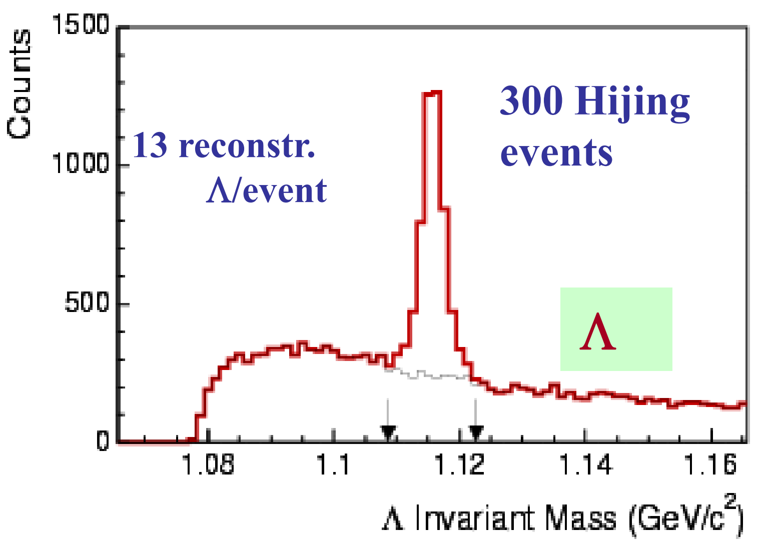
- contamination of $\pi\pm$ and p/pbar;

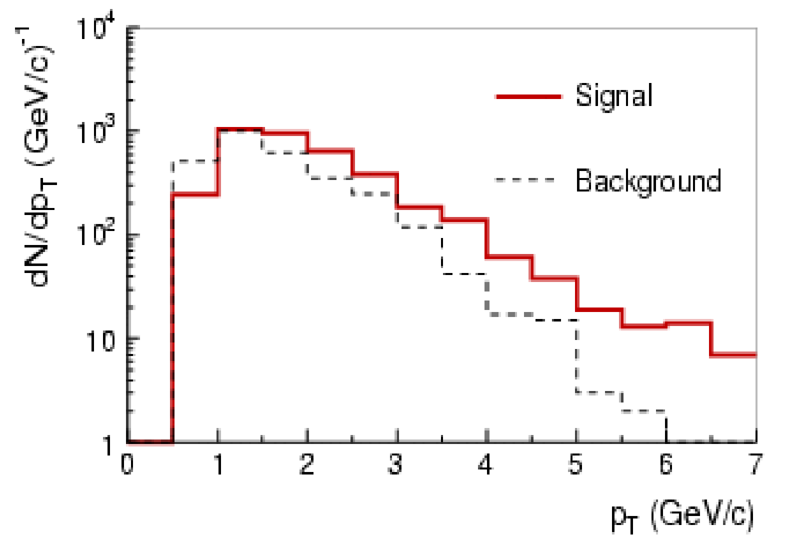
-contribution from γ - conversion.

Topological identification of strange particles

Statistical limit for 1 year: ~ 10^7 central Pb-Pb, 10^9 min. bias pp

p_T ~11 - 13 GeV for K^+, K^-, K^0_s, Λ p_T ~ 7 - 10 GeV for Ξ, Ω





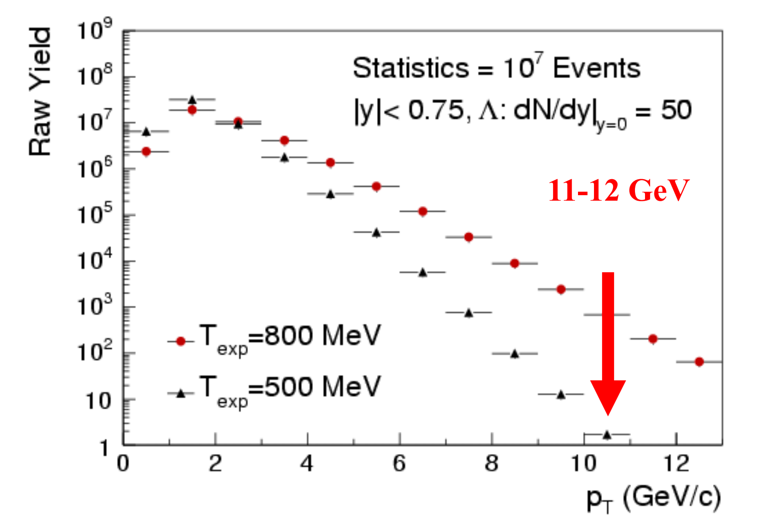
Secondary Vertex and Cascade Finding

Reconstruction rates:

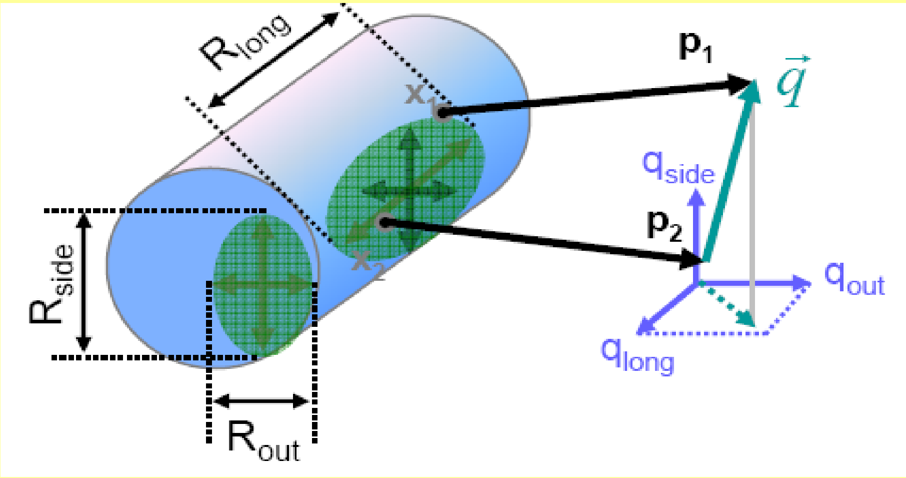
Ξ: 0.1/event Ω: 0.01/event

p_T: 1 $\rightarrow$ 7-10 GeV

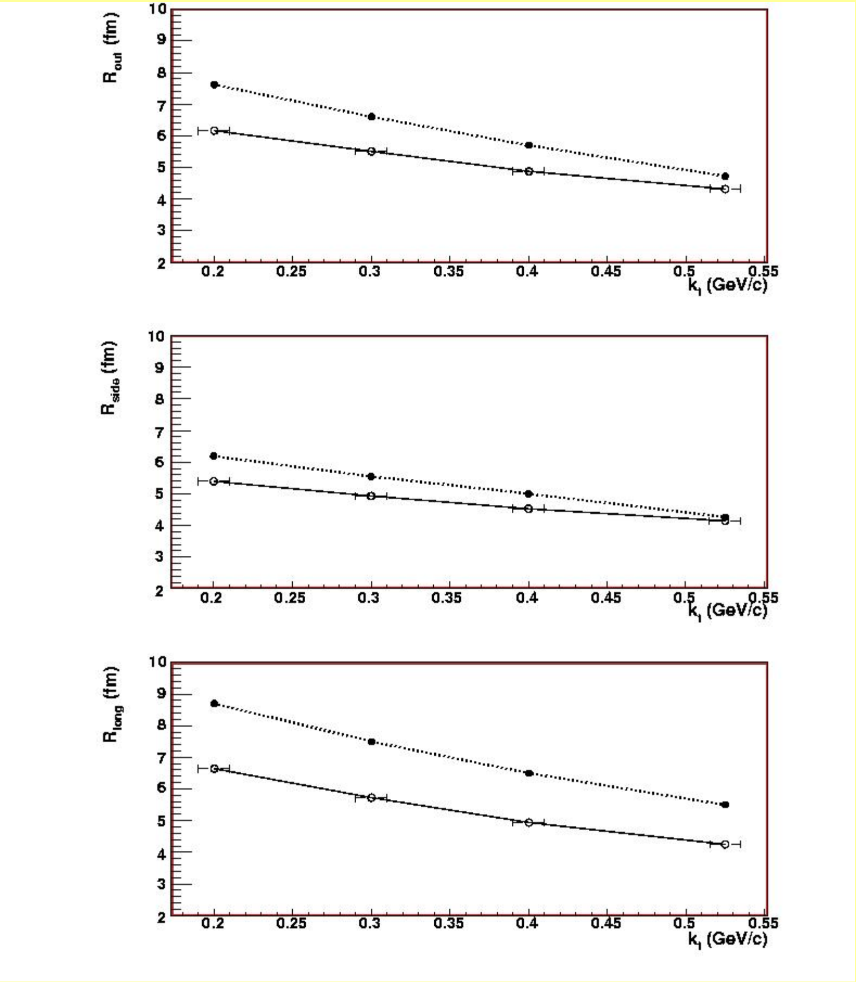
10^7 central Pb – Pb events



Femtoscopy (HBT)



Predictions for LHC: spectra



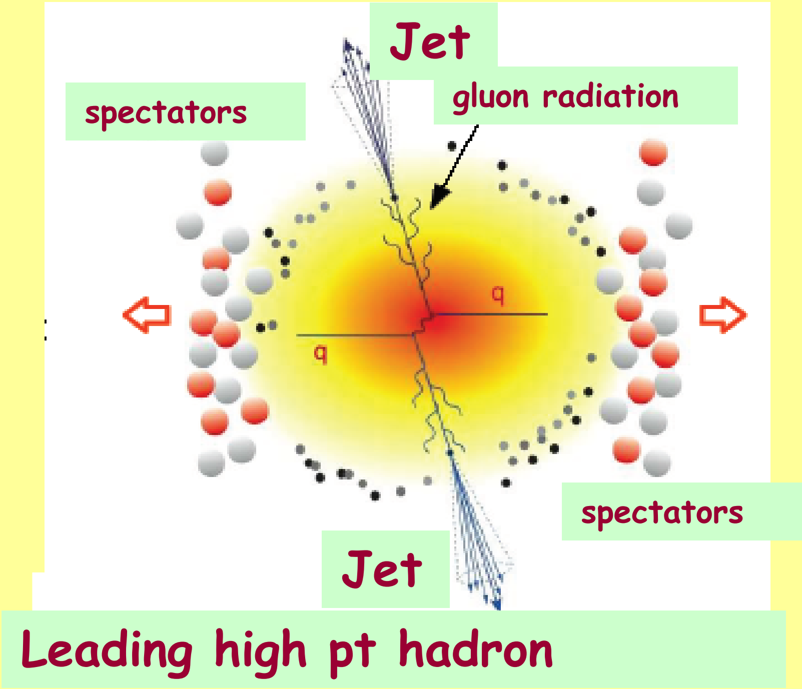
The HBT RHIC puzzle:

R_{out}/R_{side} does not increase as expected from hydro which predicts a long system lifetime …

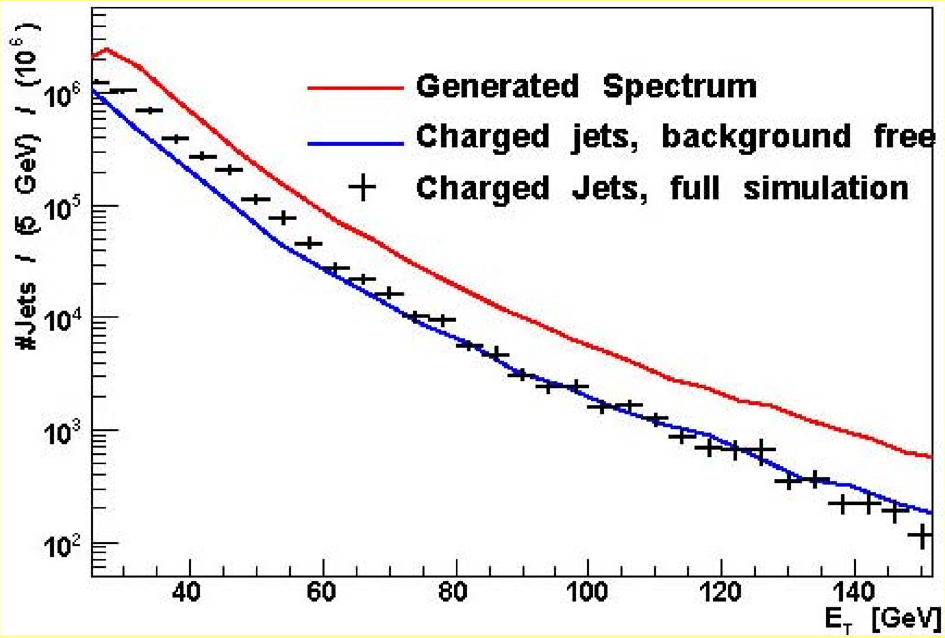
p_T dependence of R_{out}/R_{side} also not reproduced by hydro …

$$CF(p_1, p_2) = 1 + \lambda \bullet \exp(-R_{out}^2 q_{out}^2 - R_{side}^2 q_{side}^2 - R_{long}^2 q_{long}^2 - 2R_{out,long}^2 q_{out} q_{long})$$

Jets



10^7 central Pb – Pb events



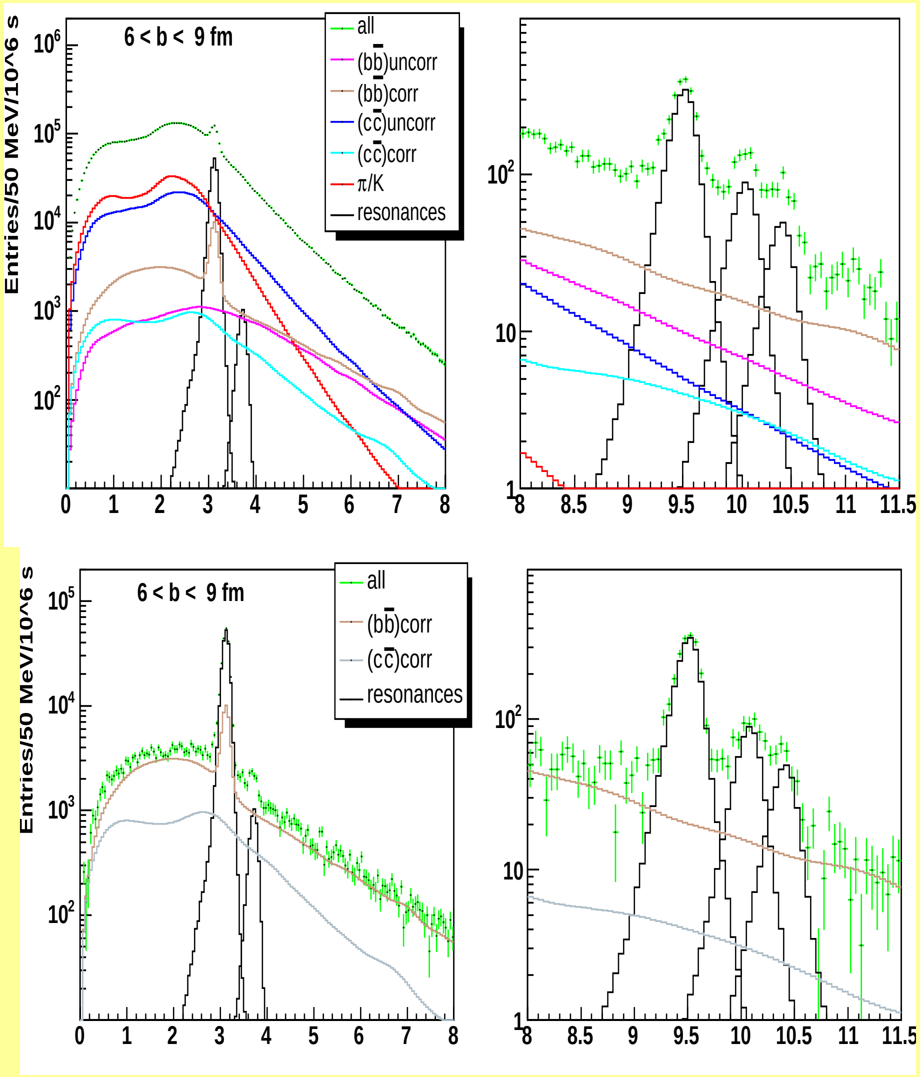
•Study properties of the medium through the modifications on the transverse jet structure

• Study hard processes with low p_T observables by measuring the fragmentation function to low p_T. Energy loss and radiated energy

Quarkonia → e^+e^-, $\mu^+\mu^-$

Dielectron channel (ITS and TPC tracking + identification with TRD) at midrapidity. Dimuon channel (forward spectrometer) in $2.5<\eta<4.0$

J/ψ family ϒ family



1 month of Pb-Pb collisions

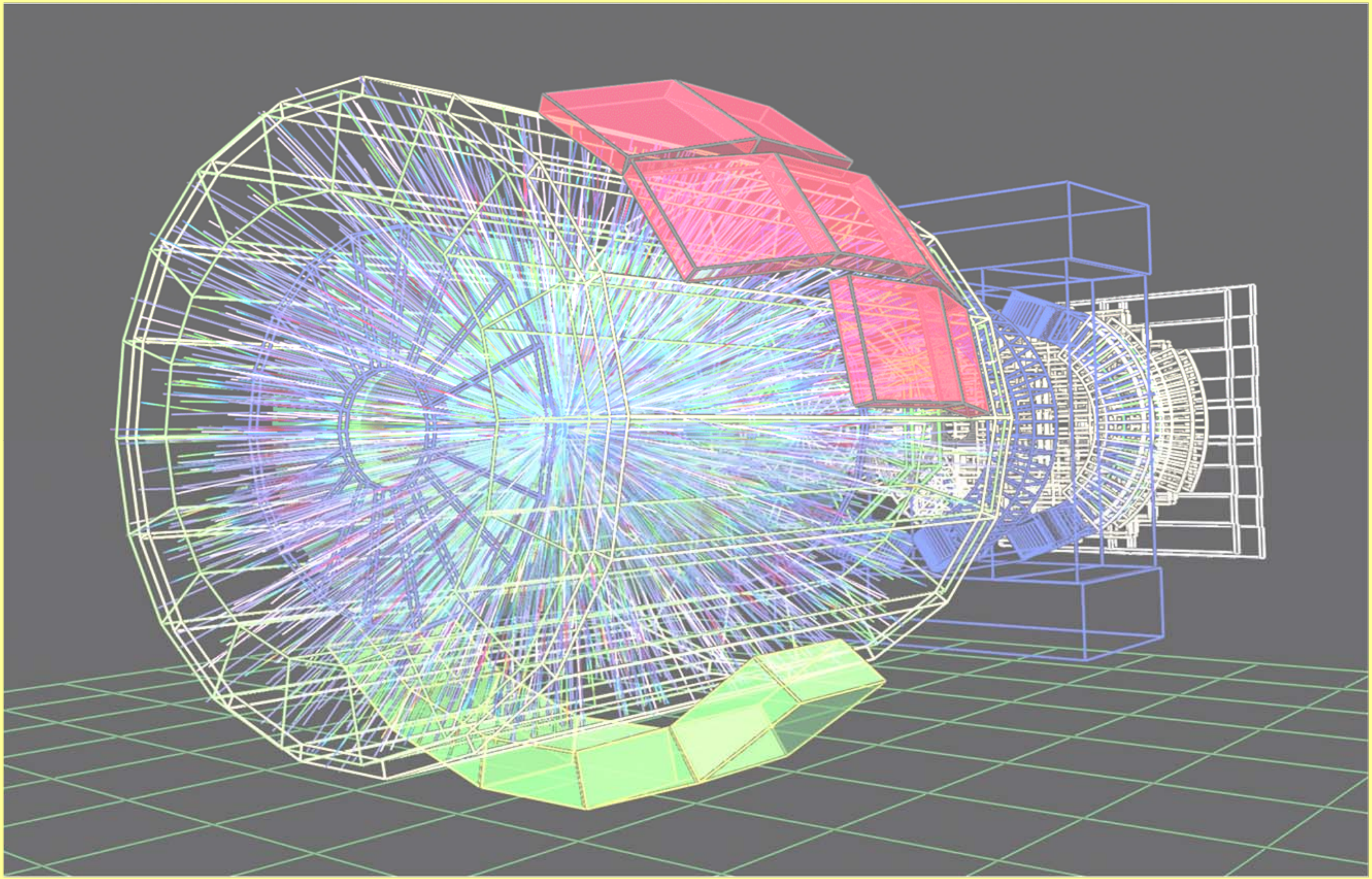
Expected yields

- -ψ′ poor significance
- -ϒ (1S,2S) : 0 – 8 GeV/c
- -ϒ (3S) : more than 1 run is needed
- -J/Ψ high statistics: 0-20 GeV/c

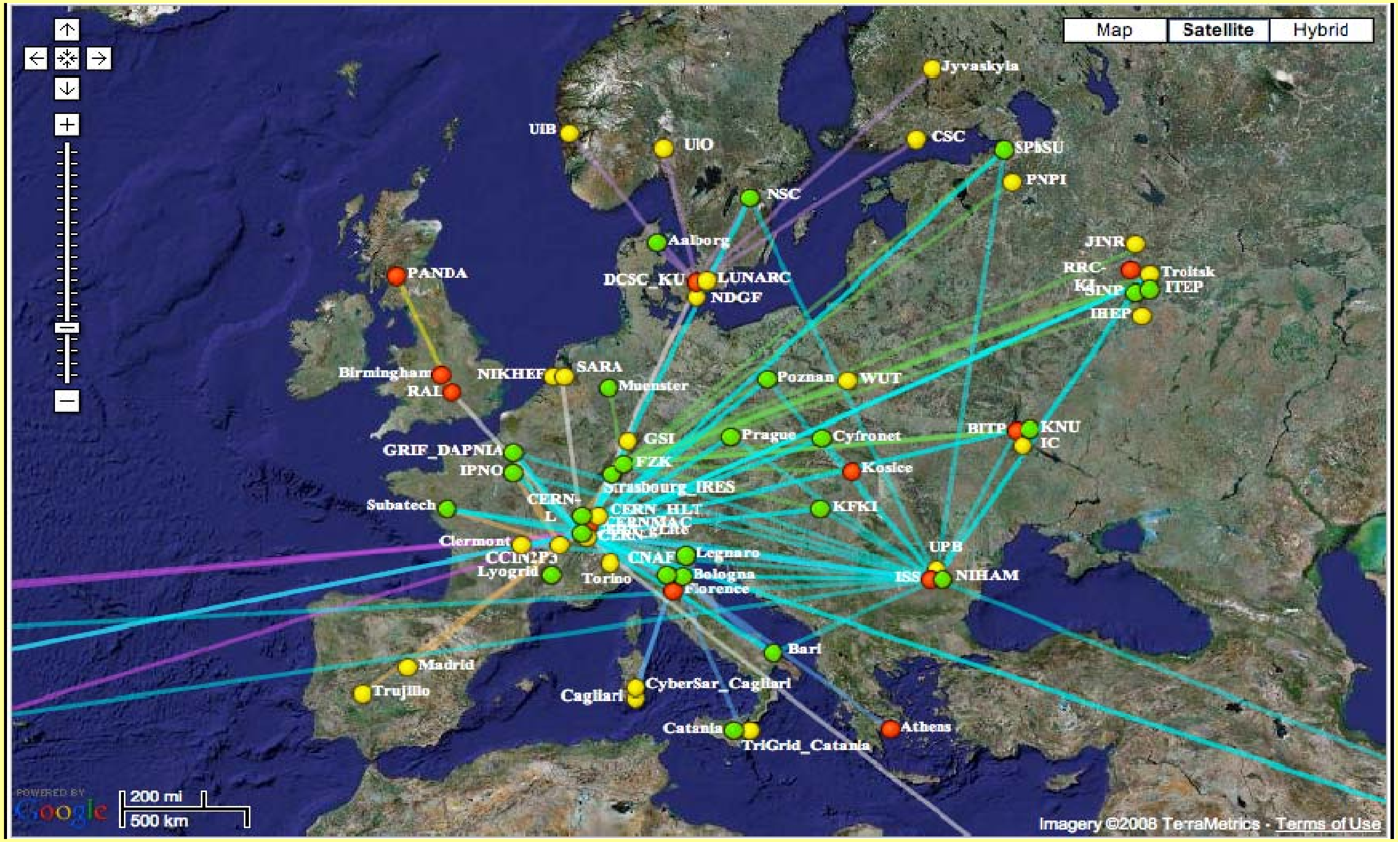
Pb-Pb central events 0 fm<b<3 fm

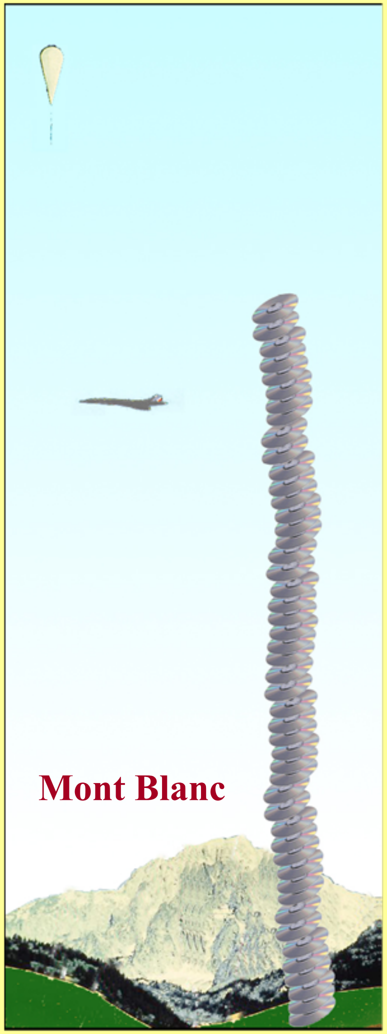
State	S[10^3]	B[10^3]	S/B	S/(S+B)$^{1/2}$
J/Ψ	130	680	0.20	150
Ψ’	3.7	300	0.01	6.7
ϒ(1S)	1.3	0.8	1.7	29
ϒ(2S)	0.35	0.54	0.65	12
ϒ(3S)	0.20	0.42	0.48	8.1

ALICE event display



ALICE computing





ALICE Computing Model

- **Three kinds of data analysis:**

  1. **Fast pilot analysis** of the data "just collected" to tune the first reconstruction at CERN Analysis Facility (CAF)
  2. **Scheduled batch analysis** using GRID (**Event Summary Data** and **Analysis Object Data**)
  3. **End-user interactive analysis** using PROOF and GRID (AOD and ESD)

- **CERN**
  - Does: first pass reconstruction
  - Stores: one copy of RAW, calibration data and first-pass ESD's
- **Tier 1**
  - Does: reconstructions and scheduled batch analysis
  - Stores: second collective copy of RAW, one copy of all data to be kept, disk replicas of ESD's and AOD's
- **Tier 2**
  - Does: simulation and end-user interactive analysis
  - Stores: disk replicas of AOD's and ESD's

RDIG CPUs for ALICE at different sites

Normalised CPU time (SpectInt2000 = 1000)

Sites:

☐ FIAN ☐ GCRAS ☑ IHEP ☐ IMPB ☑ INR ☐ IPCP ☑ ITEP ☑ JINR ☐ KIAM ☐ KIPT ☐ MEPHI ☑ PNPI ☑ RRC-KI ☑ SINP ☑ SPbSU ☐ SPbSU-Phys

(check all | uncheck all)

VOs:

☑ alice ☐ ams ☐ atlas ☐ batch ☐ biomed ☐ cms ☐ dteam ☐ eearth ☐ esr ☐ fusion ☐ fusion_rdig ☐ gear ☐ hone ☐ iteam ☐ lhcb ☐ nw_ru ☐ ops ☐ pamela ☐ photon ☐ rdteam ☐ rgstest ☐ sgmeearth ☐ staff

(check all | uncheck all)

Show data for SITE as function of DATE

Interval selection: October 2007 - February 2008 Plot

*	Oct 2007	Nov 2007	Dec 2007	Jan 2008	Feb 2008	Total
IHEP	1381.47	1651.26	127.65	55.58	21.42	3237.38
INR	10004.49	9044.77	6651.89	25414.86	1464.03	52580.03
ITEP	180939.58	72151.83	86027.53	104313.43	9522.05	452954.42
JINR	266148.24	247834.79	232140.00	215135.31	164.26	961422.59
PNPI	90378.71	52283.43	83295.45	32416.26	0.00	258373.86
RRC-KI	0.61	0.00	0.00	0.00	0.00	0.61
SINP	407.38	1112.48	7880.81	33121.01	2936.48	45458.17
SPbSU	308.20	485.08	2013.63	2485.35	1187.79	6480.06
Total	549568.67	384563.64	418136.98	412941.80	15296.04	1780507.12

ALICE running strategy

- **p-p**

Regular pp runs at 14 TeV. First run at 10 TeV (900 GeV ?)

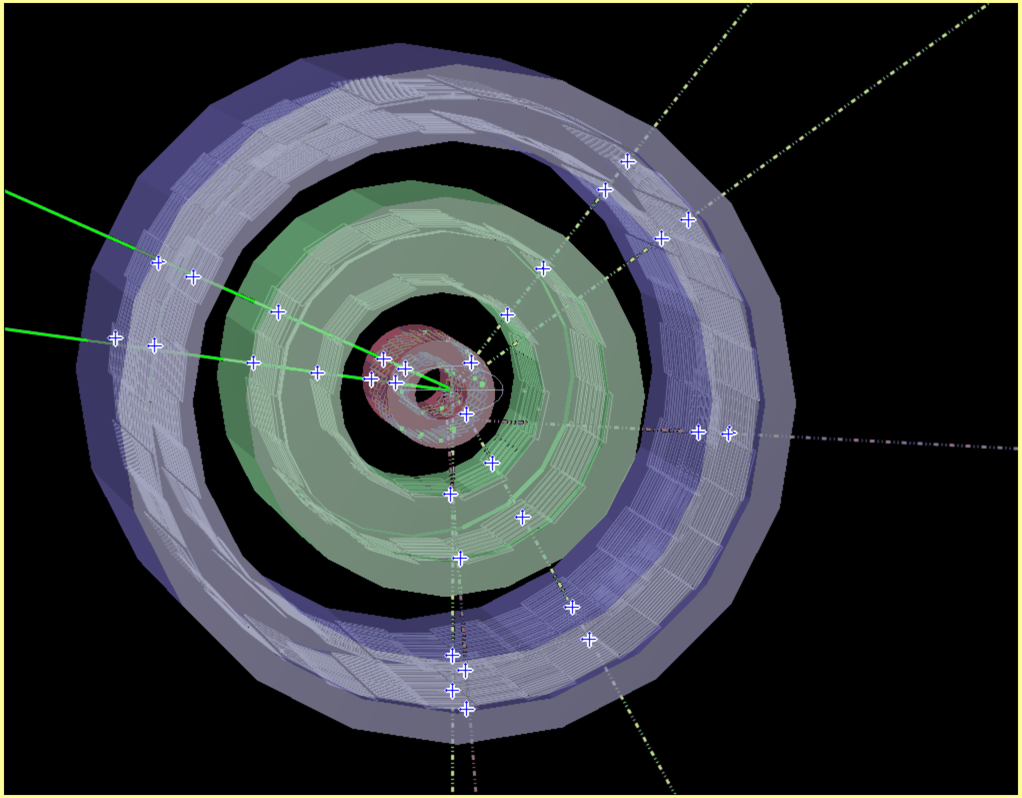
- **Initial heavy-ion programme (~ 5 years):**
    - **Pb-Pb pilot run**
    - **1-2 years Pb - Pb**
    - **1 year p - Pb like collisions**
    - **1-2 years another A – A collisions**

- **Later options:**
    - **dedicated p - p at 5.5 TeV**
    - **another intermediate mass A - A system**
    - **possibly another p - A system**

C O N C L U S I O N

Start – up of LHC

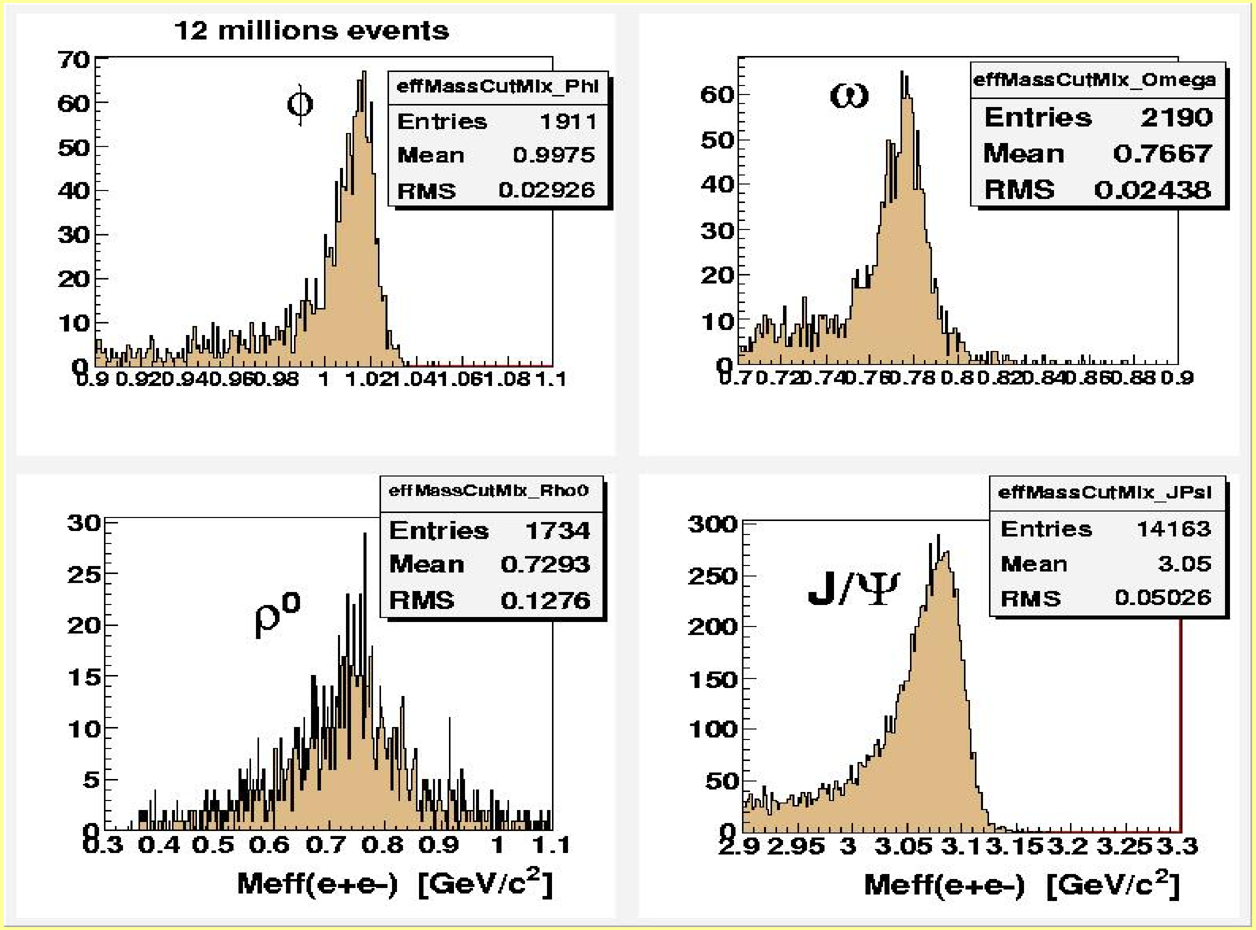
Interaction of the circulating proton beam w/ the residual gas reconstructed in the ALICE Innner Tracking System



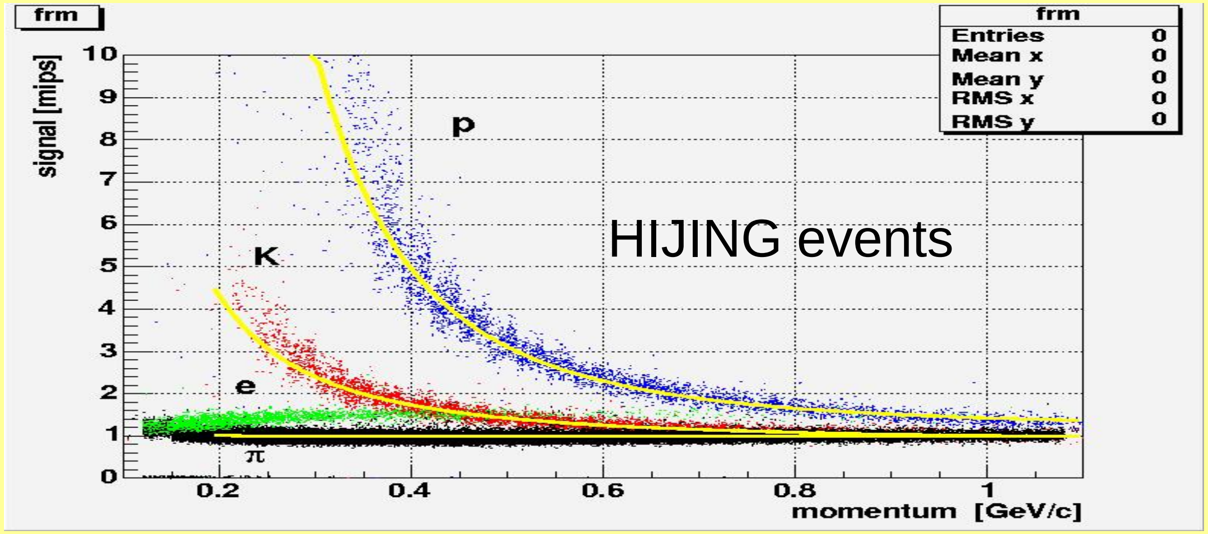
ALICE is ready for Physics!

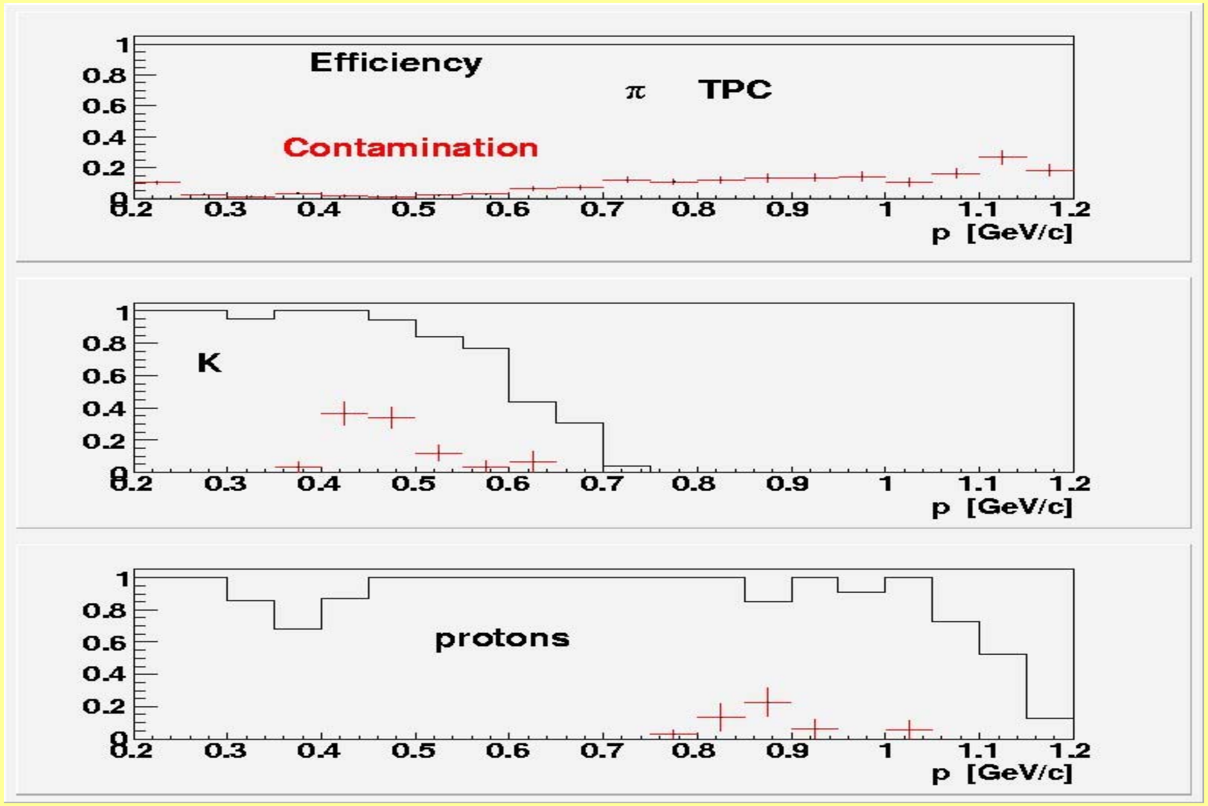
Backup slides

Results for 6.5×10^6 Cocktail events (p-p).



Effective mass (GeV/c2) distributions of (e+e-) pairs from decays of ϕ, ϖ, ρ^o, J/Ψ.



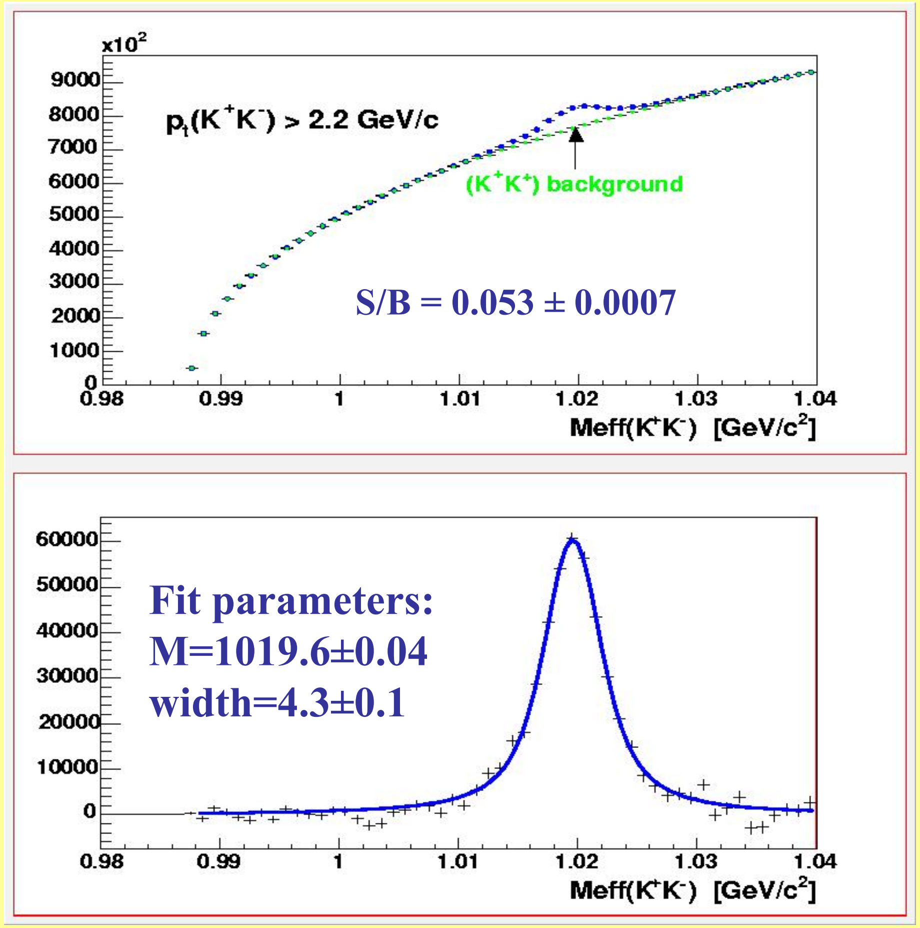


Pb – Pb events

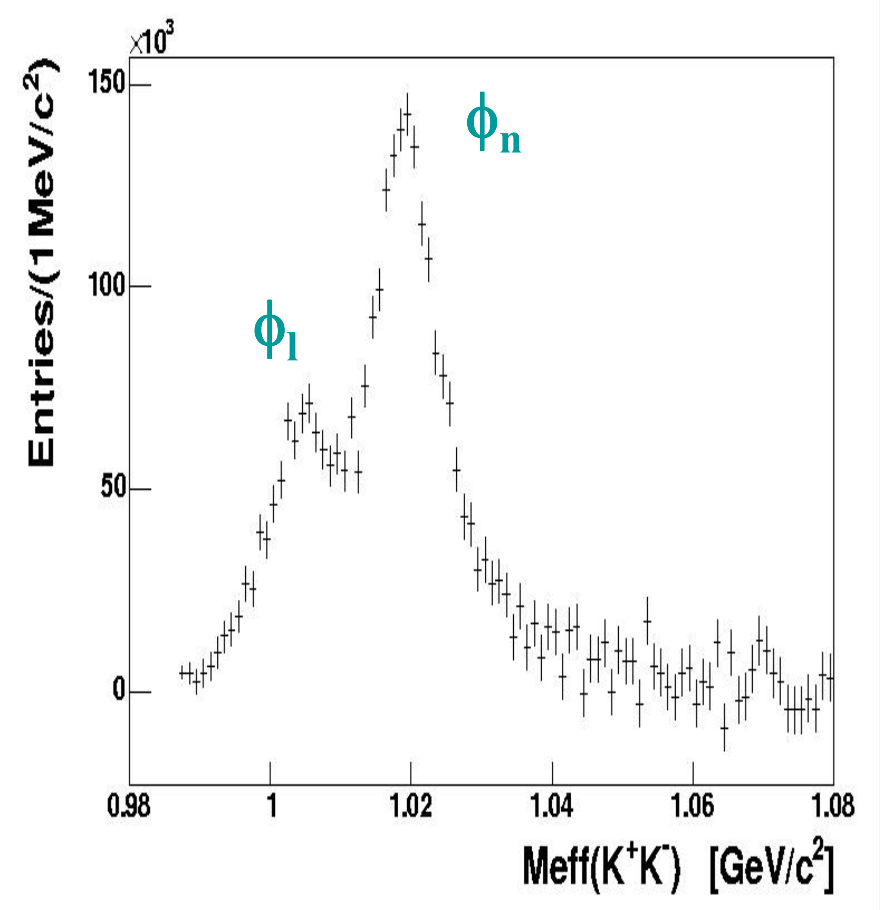
PID results in the TPC obtained from 5×10^4 p-p events at 14 TeV

Almost all contamination for kaons are $e^{\pm}$ (see below) which ordinary can be decreased by combination with the ITS.

Simulation results for $\phi \rightarrow K^+K^-$ in Pb-Pb 10^6 central events in ALICE using ITS, TPC and TOF.

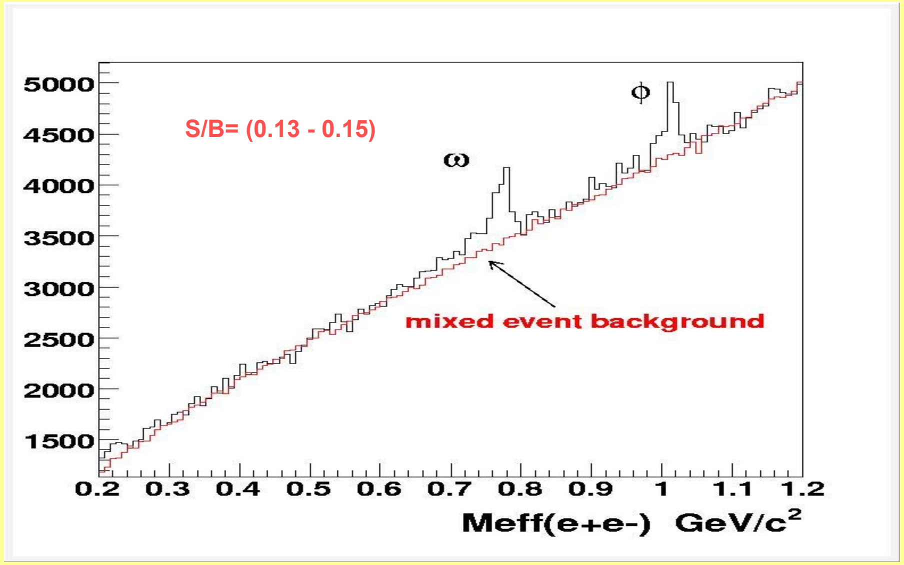


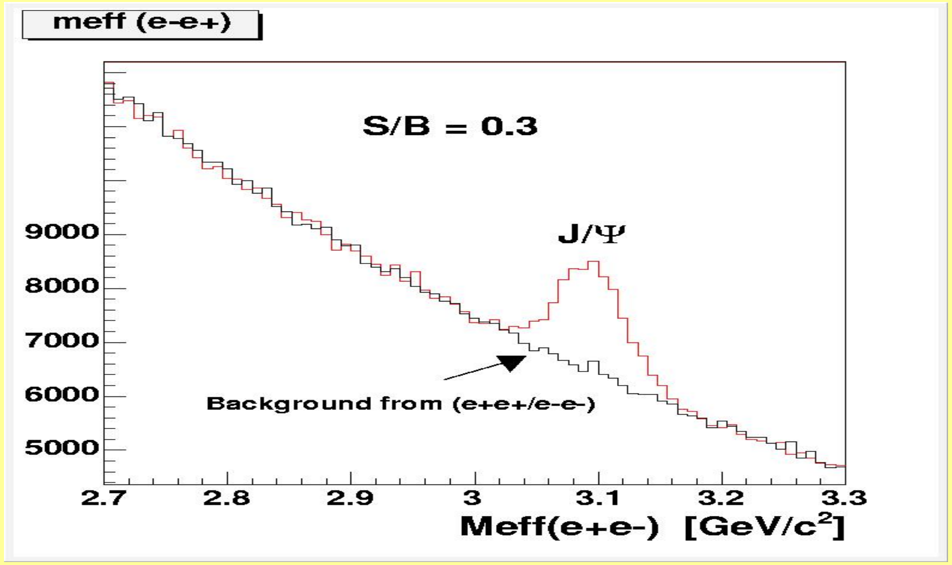
The resonance peak after subtraction of the background.

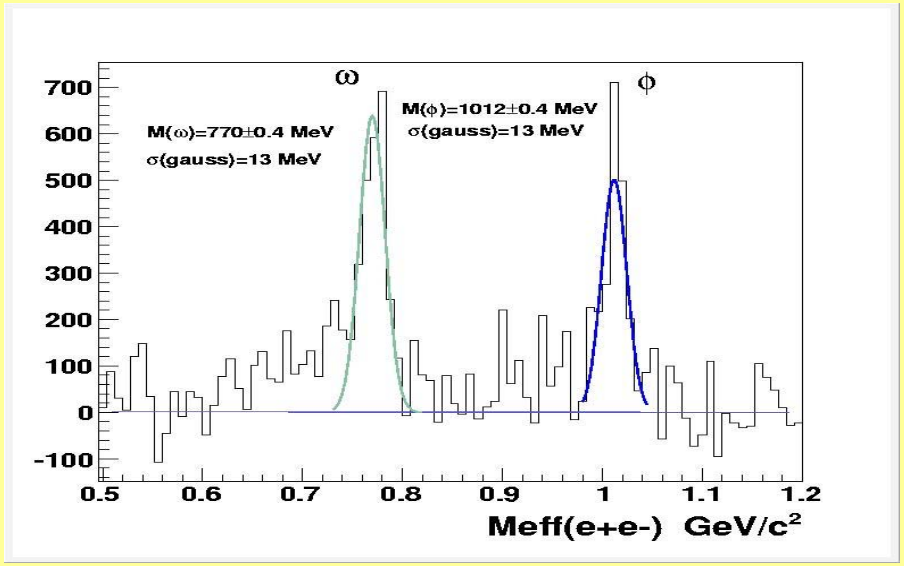


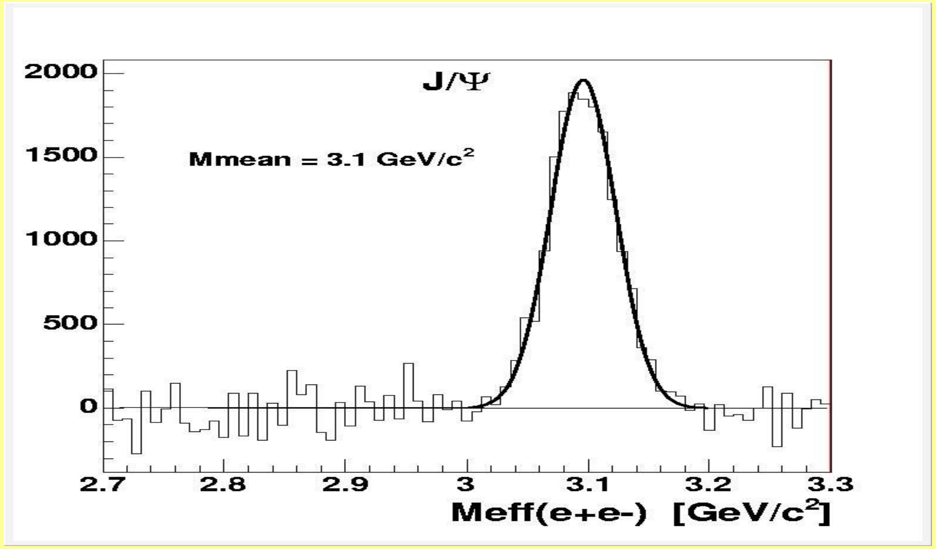
The double peak resolution possibility in ALICE.

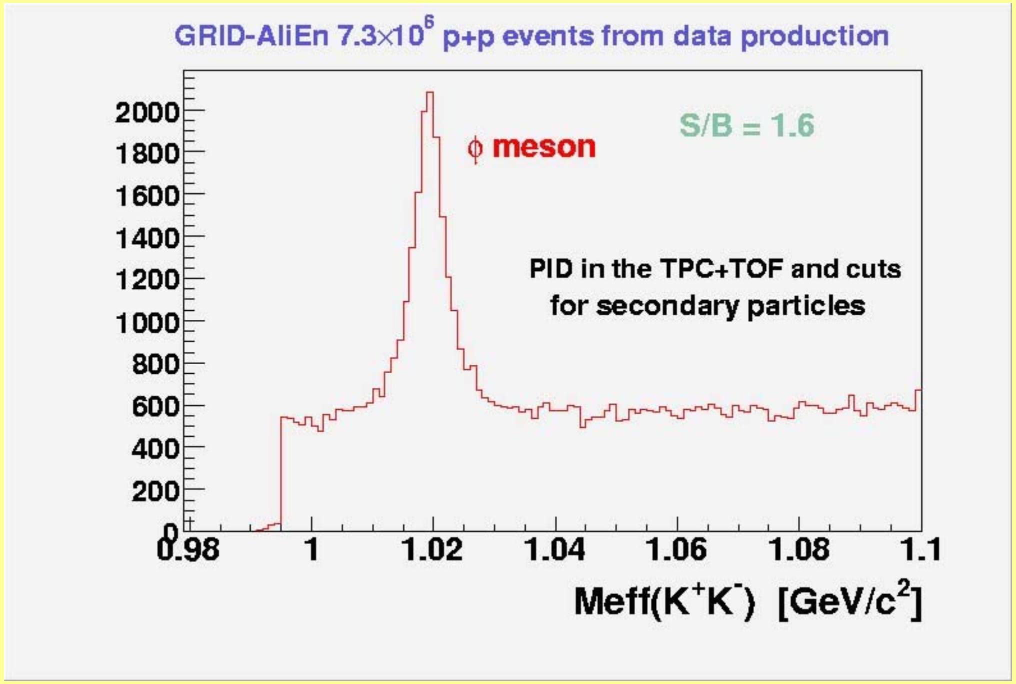
Simulation results for dielectron decays of ω, ϕ and J/ψ in 10^7 central Pb-Pb events using ITS, TPC and TRD in ALICE.

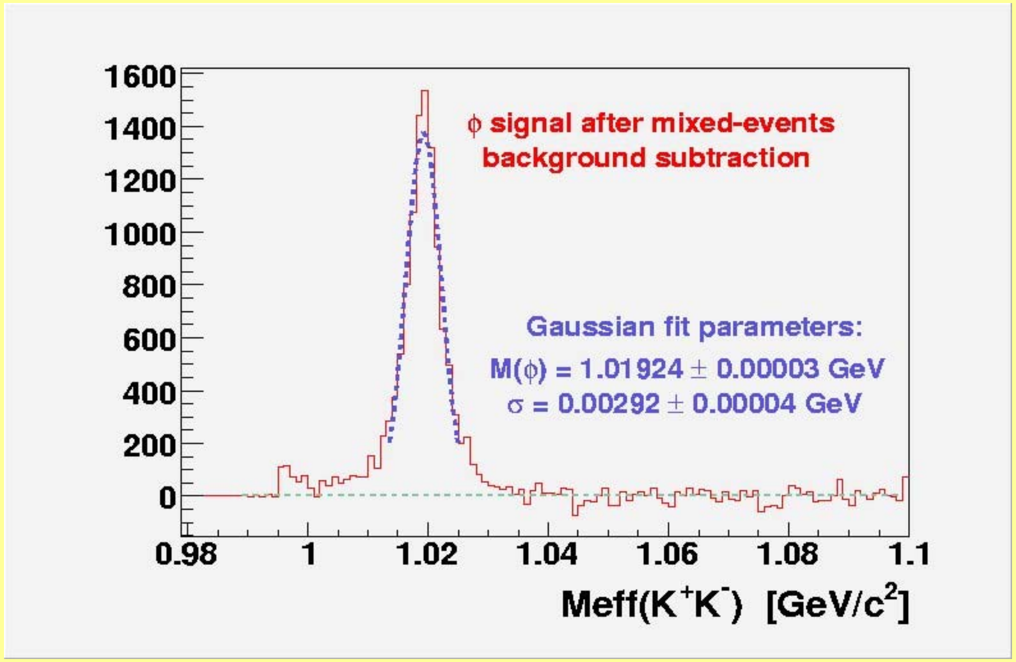












G R I D

The first year physics in ALICE for p+p at 14 TeV.

Simulation results for $\phi \to K^+K^-$ using GRID production and analysis system (40 – 50 PC processors simultaneously)

7.3×10^6 events were analyzed with the ITS, TPC and TOF for the tracking and kaon identification.

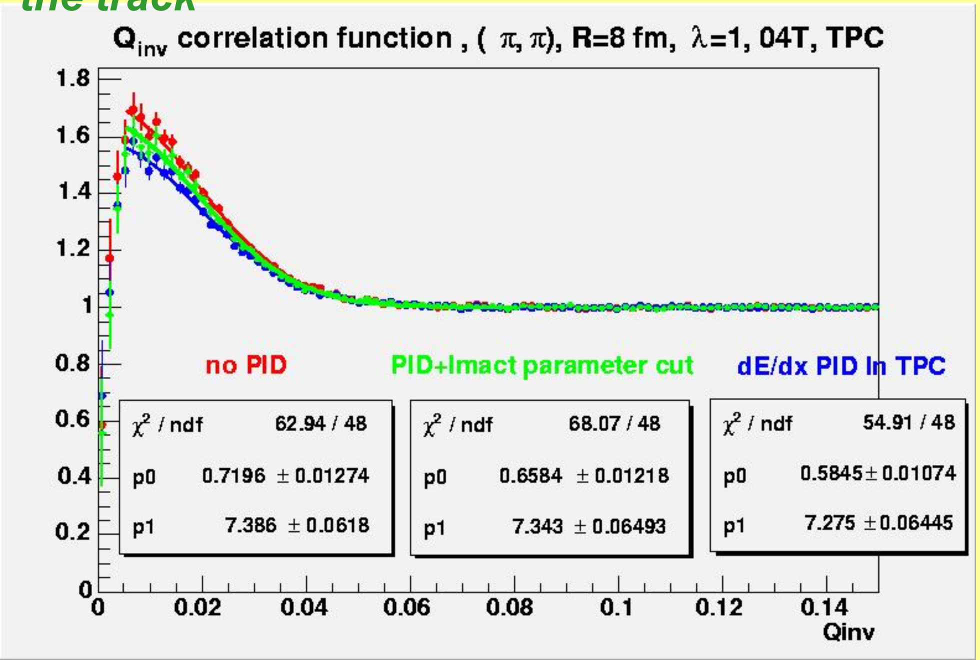
Momentum correlations (HBT)

Influence of particles identification and resolutions effects in ALICE detectors: TPC, ITS, TOF on correlation functions was studied using HIJING model and Lednitsky's algorithm for calculation of particle correlations.

Example: Qinv CF of (π,π).

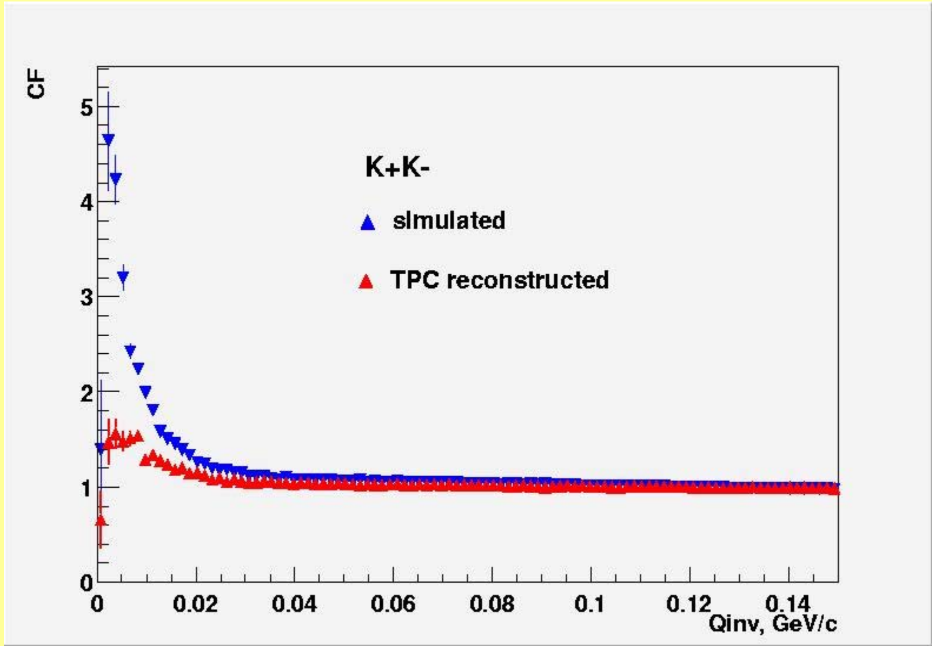
Perfect PID, resolution effects in TPC only,

PID by dE/dx in TPC and impact parameter of the track



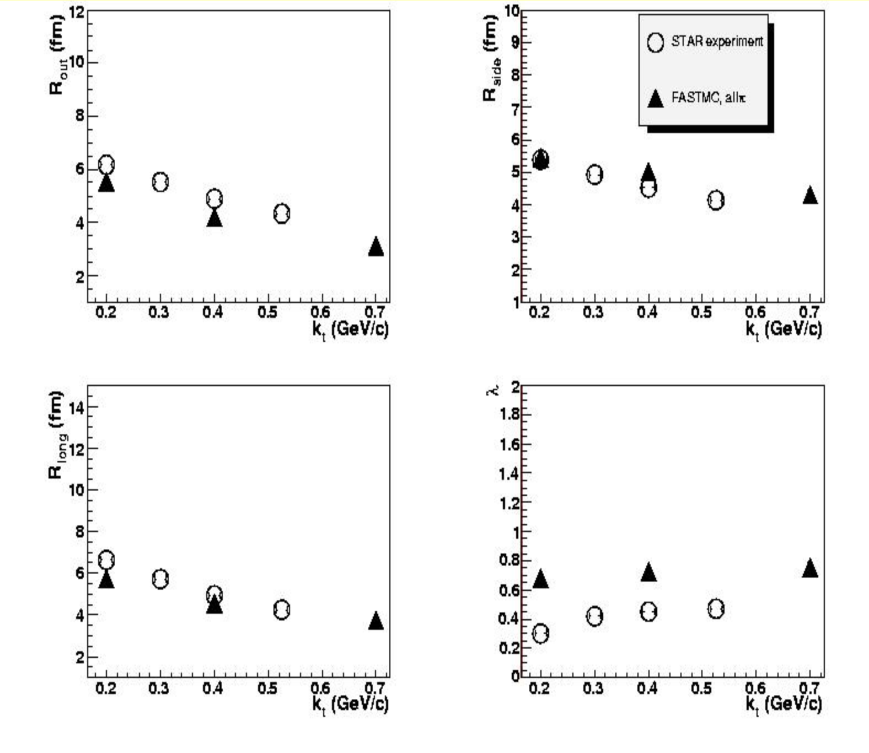
Example: Qinv CF of (K+,K-).

Perfect PID, resolution effects in TPC only



Momentum correlations for two like-sign pions

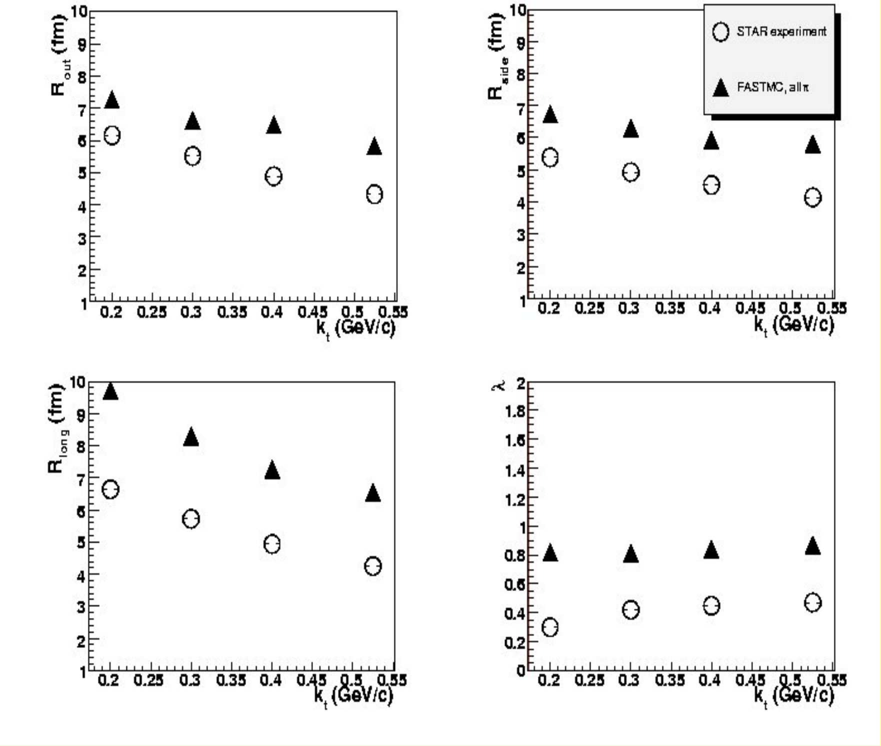
k_t dependences of correlation radii and parameter λ:
the triangle points - UHKM(FASTMC) results,
the open points - STAR mesurements.



The discrepensy for the λ relates to an absence of particle identification efficiency in the model.

Simulation results after tuning of the UHKM(FASTMC) model parameters to the LHC energy and processing of the events through the AliRoot package

(the STAR data are shown for comparison).

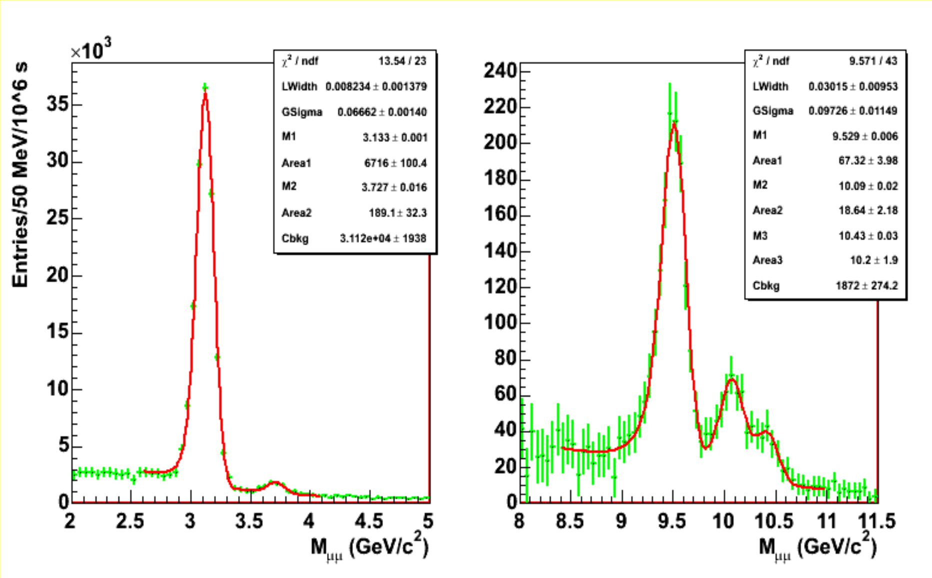


The next plans for the UHKM using is more detailed study of resonanse influence to the CF and the CF of kaon pairs: identical and nonidentical, charged and neutral.

$J/\psi \to \mu^+\mu^-$ and $\Upsilon \to \mu^+\mu^-$ detection in the ALICE in Pb-Pb, p-Pb, Ph-h

Muon pairs may be detected in the ALICE forward muon spectrometer in the pseudorapidity interval $2.5 < \eta < 4$ and with the mass resolutions about 70 (100) MeV/c^2 for $J/\psi(\Upsilon)$.

The simulation was carried out for 5% centrality bins of Pb-Pb events by a fast code including acceptance cuts and detector efficiencies and resolutions. The statistics corresponds to the one month running time at the luminosity of 5×10^{26}cm^{-2}s^{-1}.



Effective mass spectra of ($\mu^+\mu^-$) pairs for 4% most central collisions

1.3×10^5 $J/\psi \to \mu+\mu-$ at S/B = 0.2,
1300 $\Upsilon \to \mu+\mu-$ at S/B = 1.7,
350 $\Upsilon' \to \mu+\mu-$ at S/B = 0.7,
200 $\Upsilon'' \to \mu+\mu-$ at S/B = 0.5

All ather muon sources (the decays of π, K, D, B) were included in the simulation. The trigger cuts for muon p_t > 1.0 GeV/c for J/ψ and pt > 2.0 GeV/c for ¤ were used.

ALICE Computing - Russia