Heavy Ions @ LHC with ALICE

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on behalf of ALICE for HEPD PNPI session

OUTLINE

► Heavy Ion Physics
(in VERY general terms)

► ALICE Project

- Collaboration
- Goals
- Detector
- Performance

Heavy Ion Collisions: What for ?

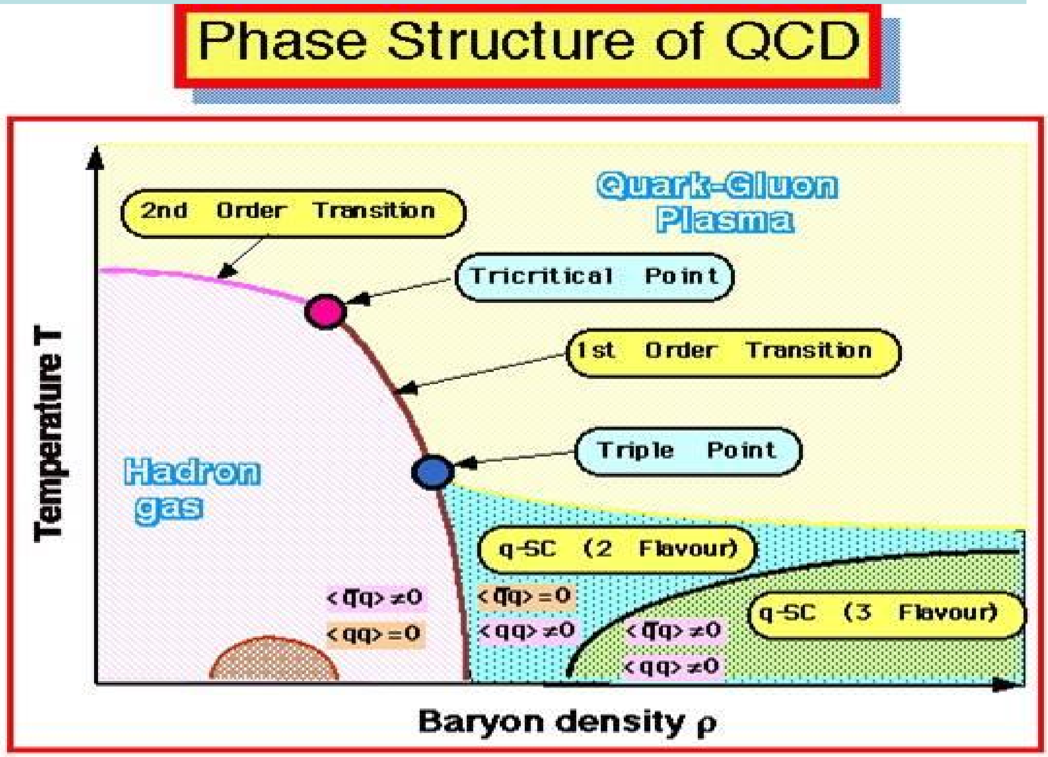
Investigation of the hadron matter states at extreme temperatures and densities is important for understanding of:

Ø The fundamental properties and QCD predictions such as:

§ Confinement

§ QCD mass generation via broken chiral symmetry

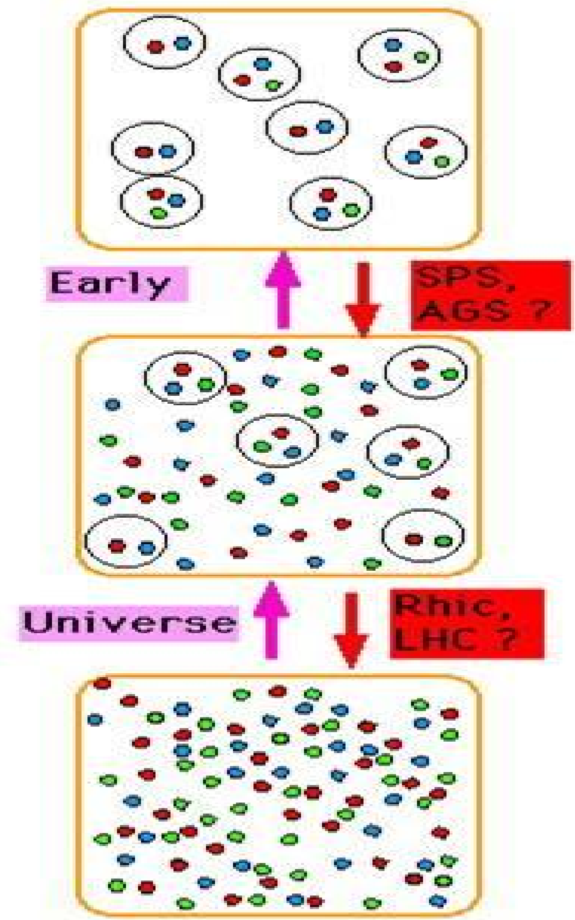
Ø The physics of the early Universe evolution



- low T, large ρ: colour superconductor ?
  - $\langle qq \rangle \neq 0$: quark-pair condensation (Cooper pairs)
  - a) 2 flavour SC: chiral symmetry restored
  - b) 3 flavour SC: chiral symmetry broken (again)
- medium T, medium ρ: tricritical point ?
  - seperates 1st & 2nd order phase boundaries
  - leads to large event-by-event fluctuations

The QCD Phase Transition

- **QCD prediction:**
  - ⇨ increase of ε => new phase of matter



hadronic matter

ε(nucleus) ≈ 0.13 GeV/fm³

ε(proton) ≈ 0.5GeV/fm³

q's are confined

q's have large 'effective' mass

$m_u \approx m_d \approx 1/3\, m_p \approx 300$ MeV

$m_s \approx 500$ MeV

phase transition

hadrons & 'vacuum' melt

1st or 2nd order transition ?

latent heat, critical fluctuations

Quark-Gluon-Plasma

ε > 1-2 GeV/fm³

T> 150 MeV

ρ ≈ 5 - 10ρ(nucleus)

q's are deconfined

colour conductivity

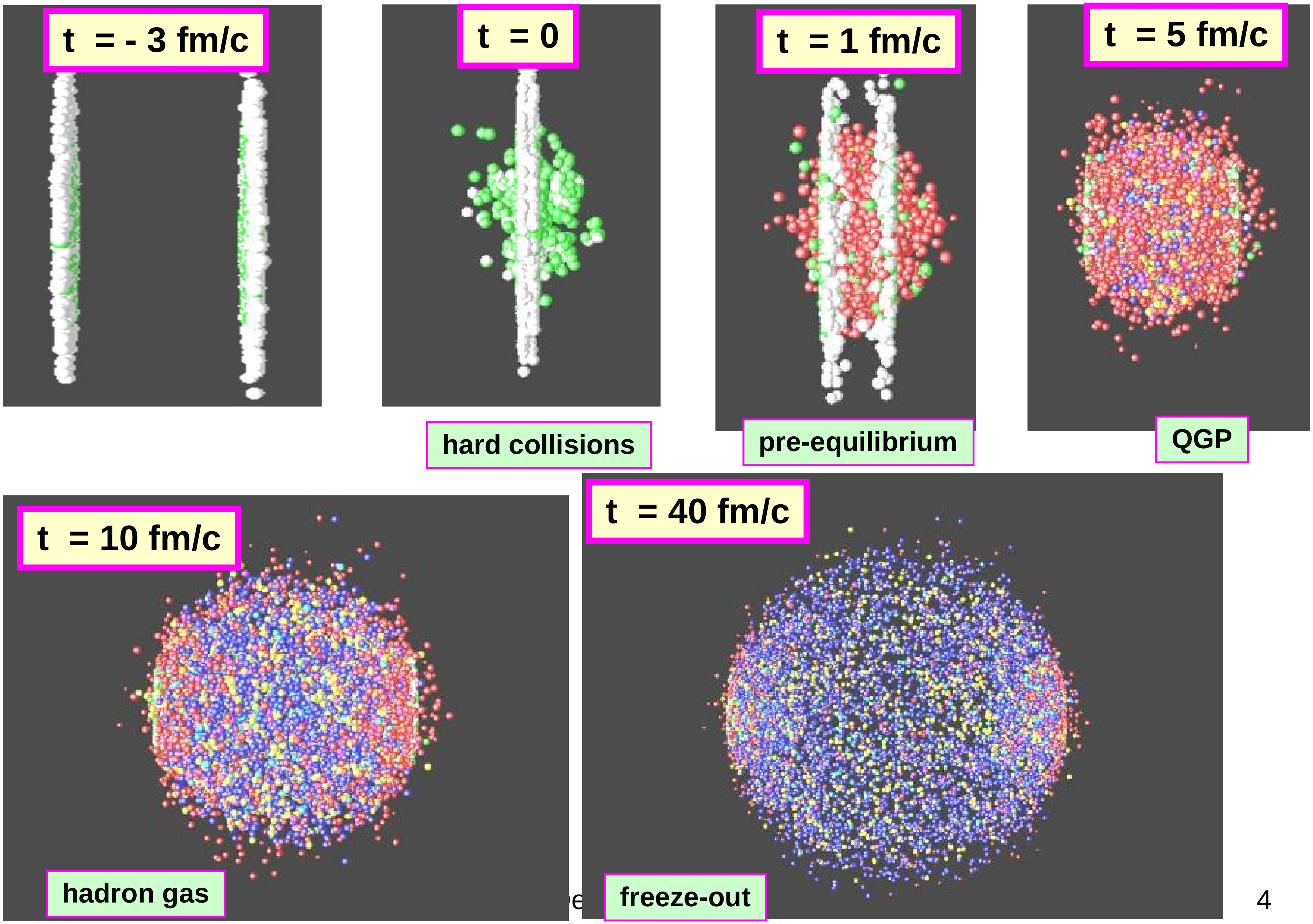
q's have small 'bare' mass

chiral symmetry restored

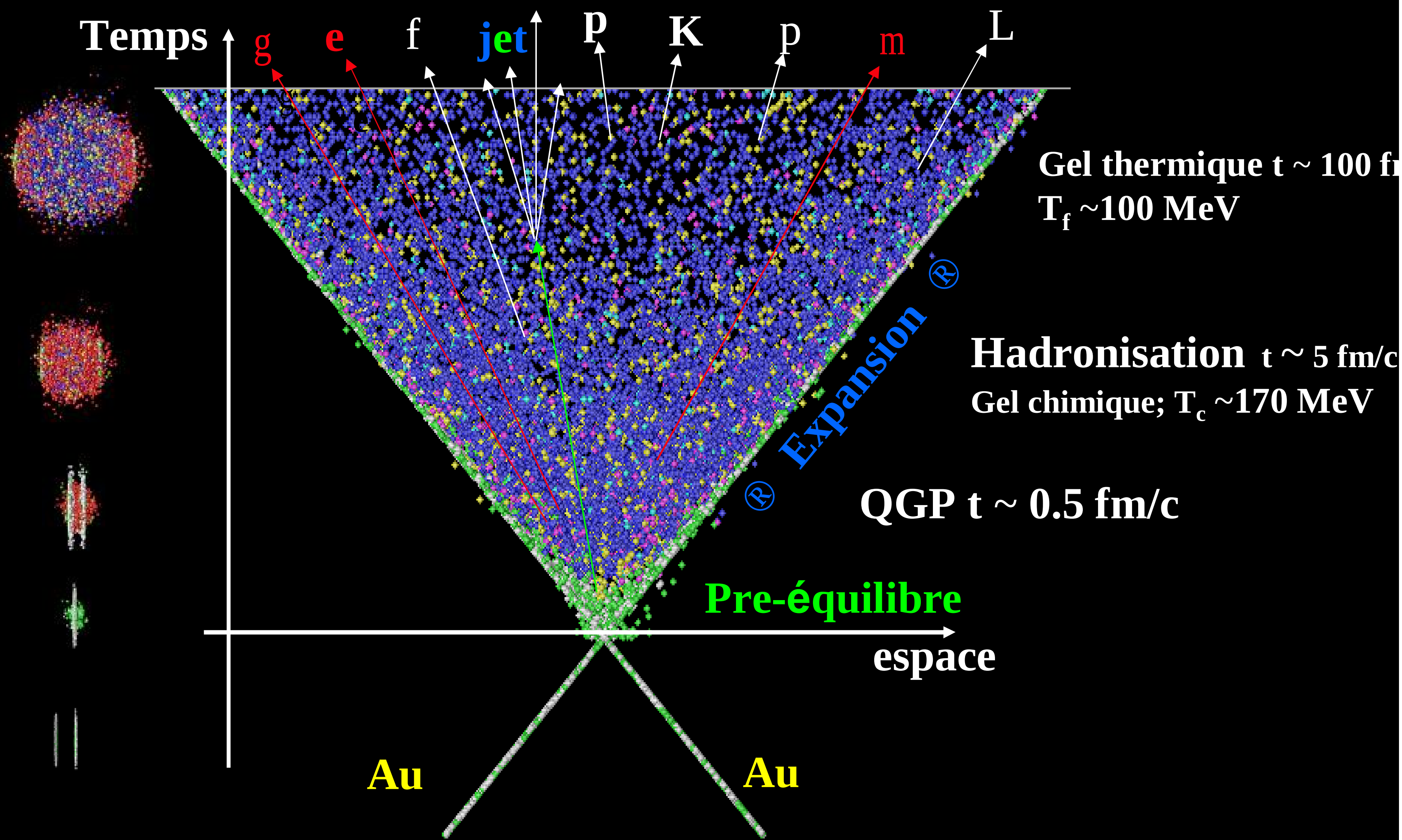
$m_u \approx m_d \approx 5$ MeV

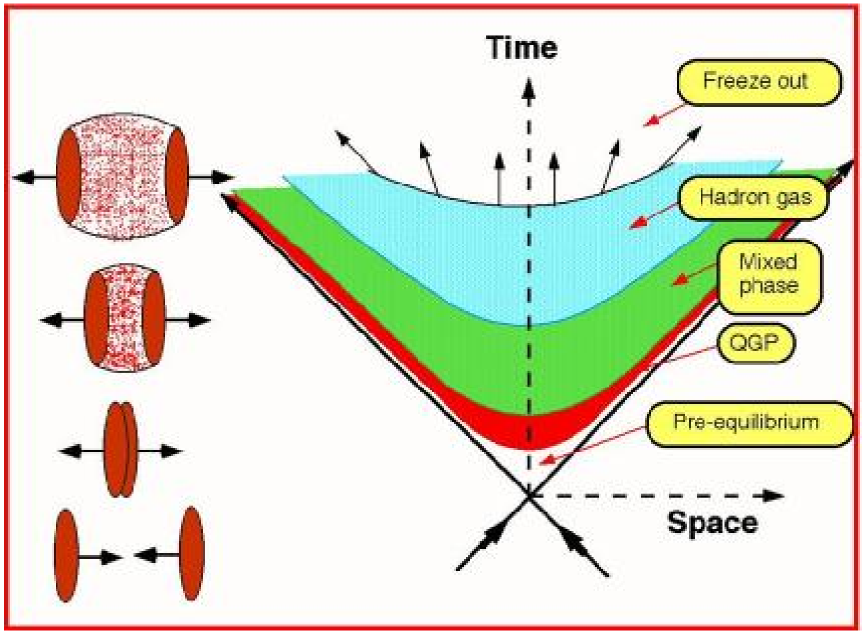
$m_s \approx 150$ MeV

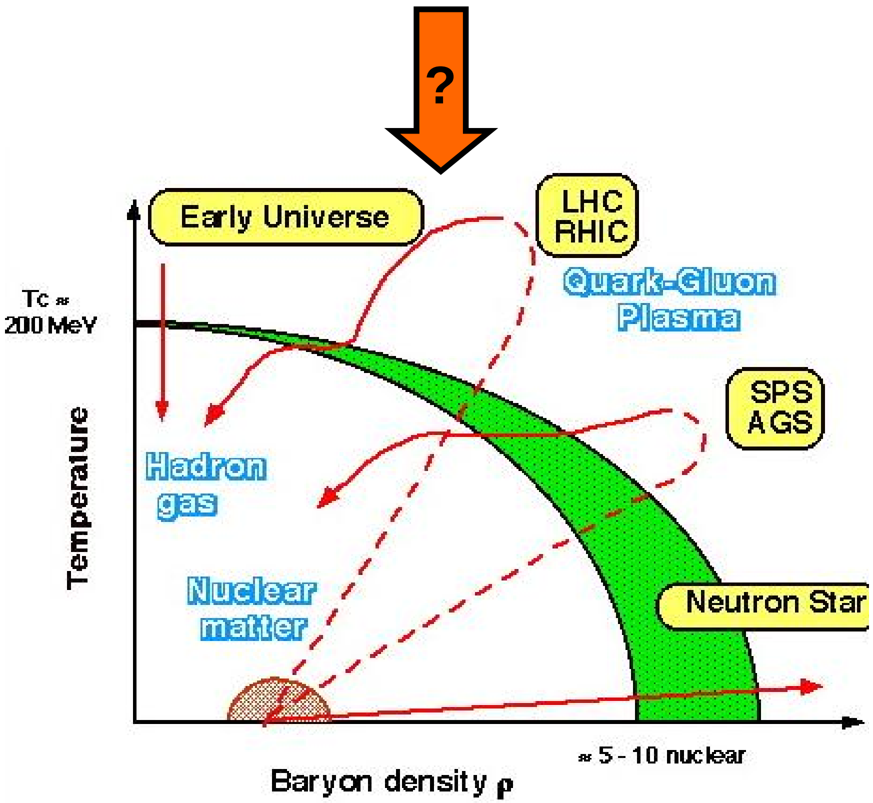
Heavy Ion Collision



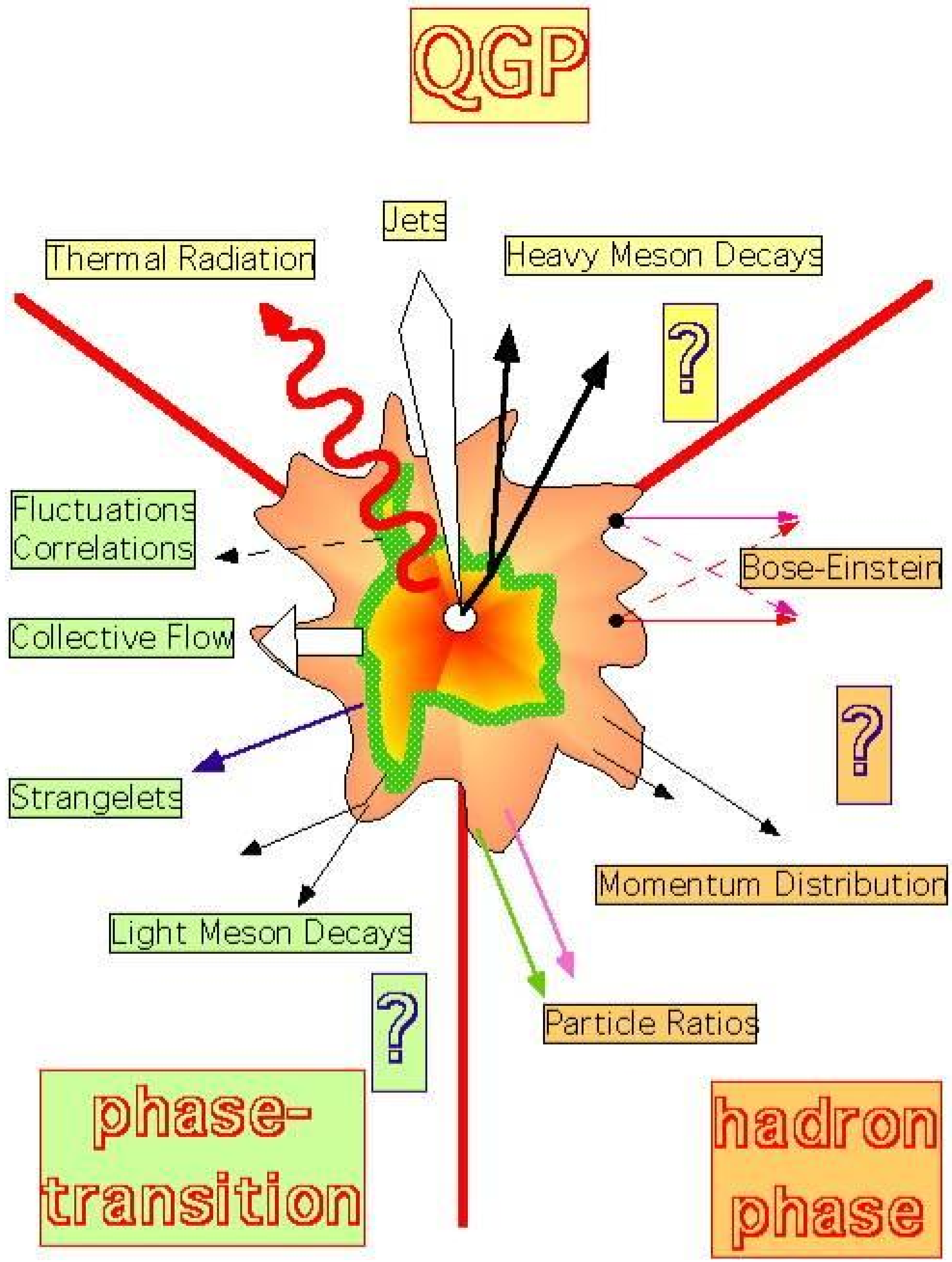
Evolution spatio-temporelle de la collision





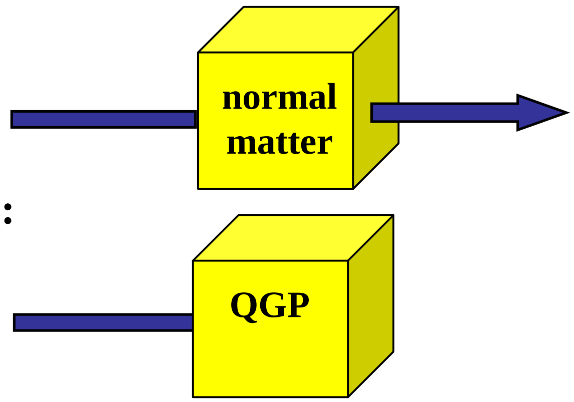


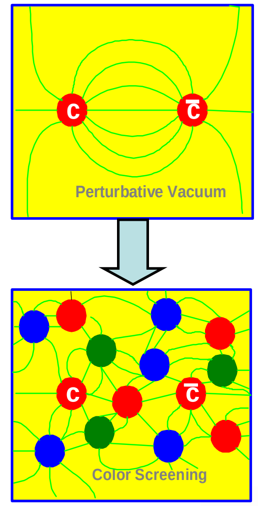
Signals & Observables

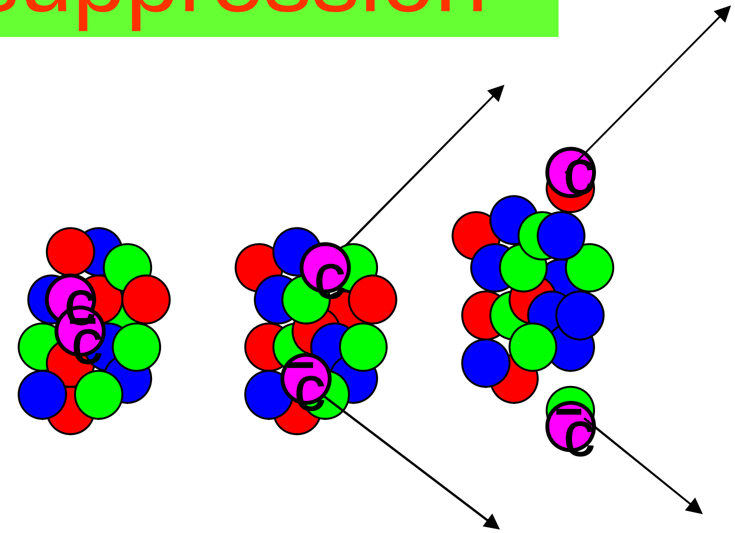


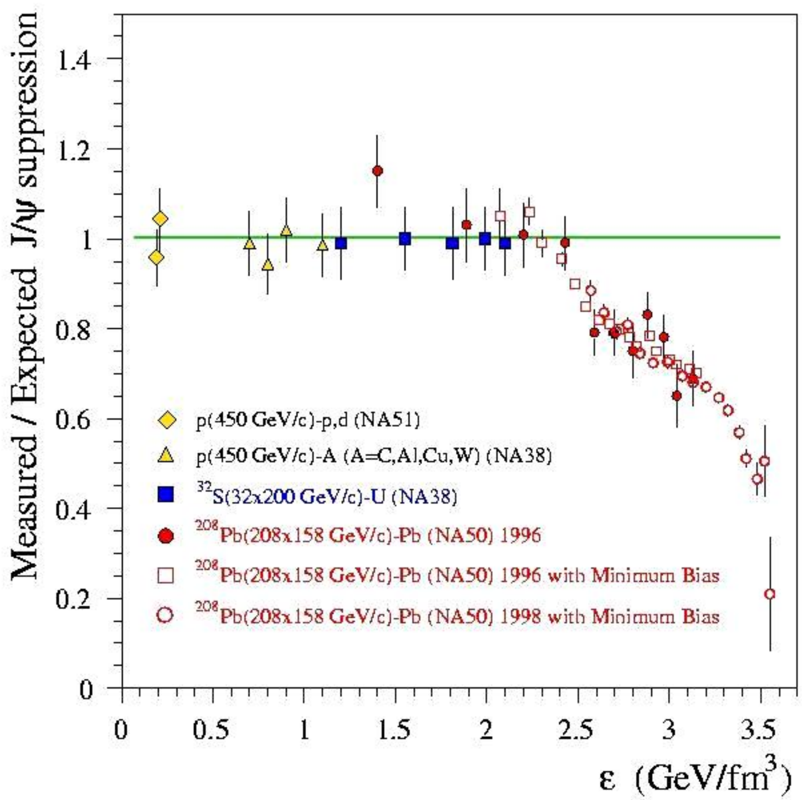
Hard Probes I) J/Psi suppression

beams of
hard probes:
jets, J/y ….

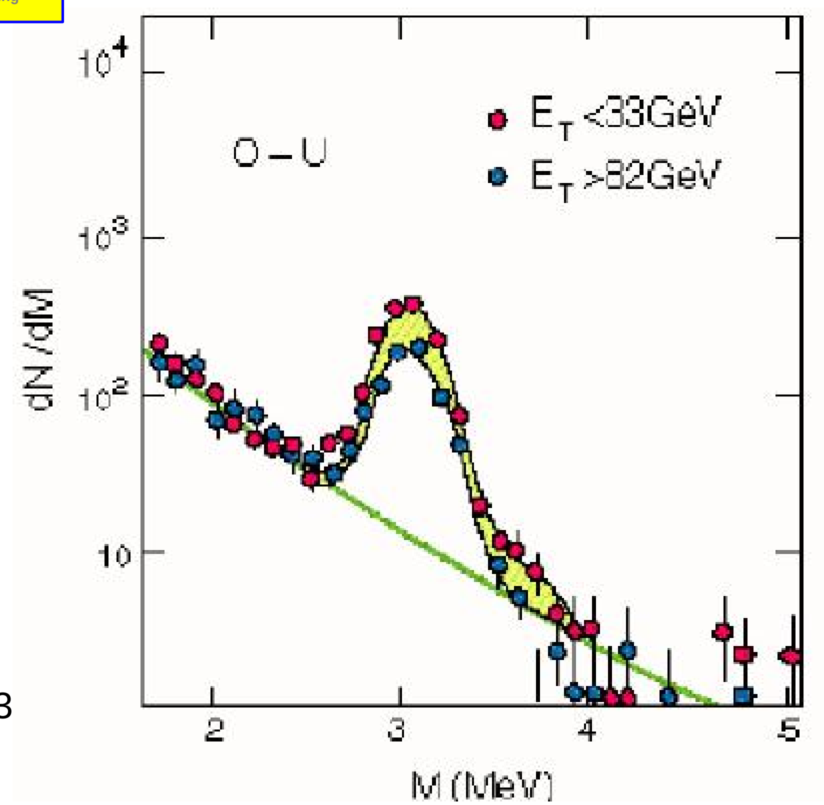






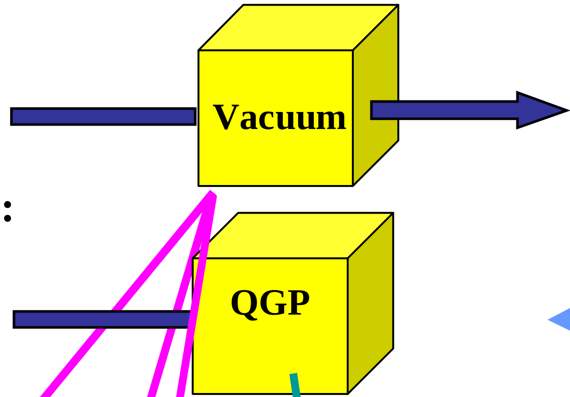


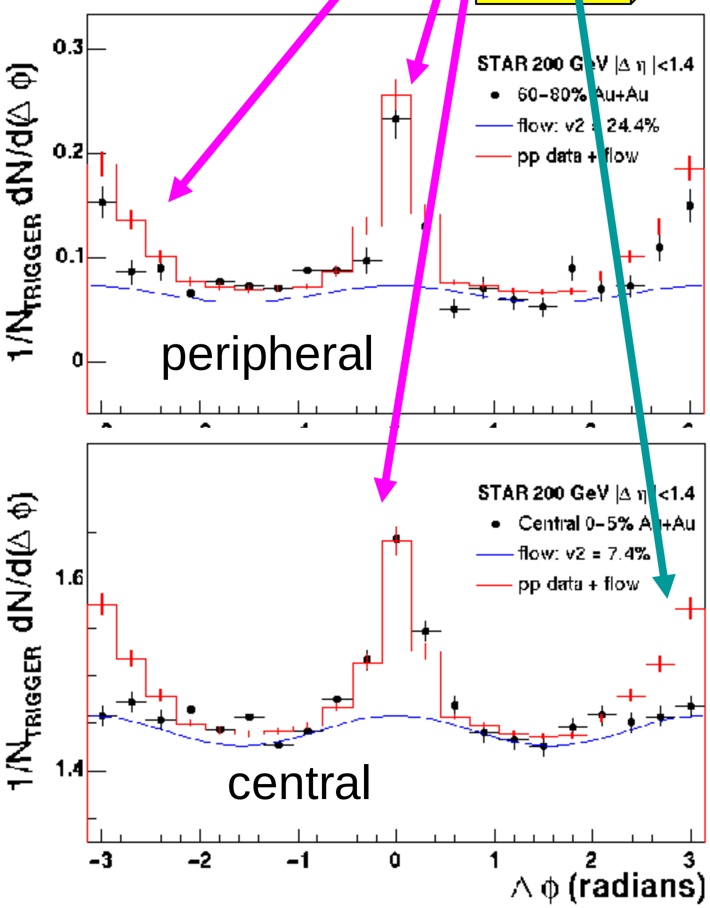
December 2003

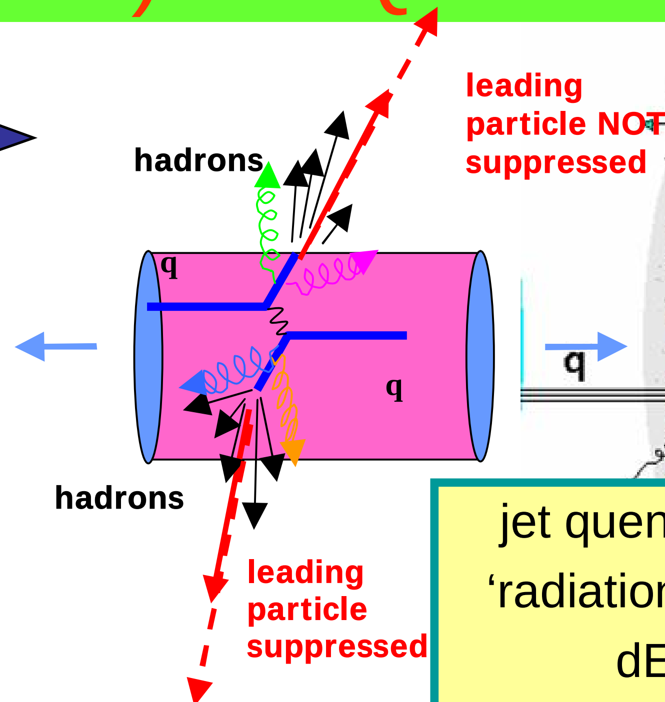


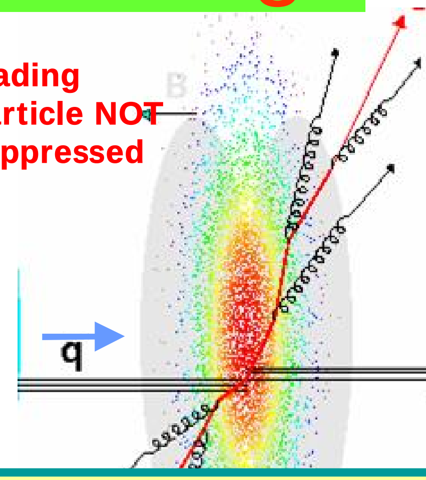
Hard Probes II) Jet Quenching

beams of hard probes: jets, J/y ….





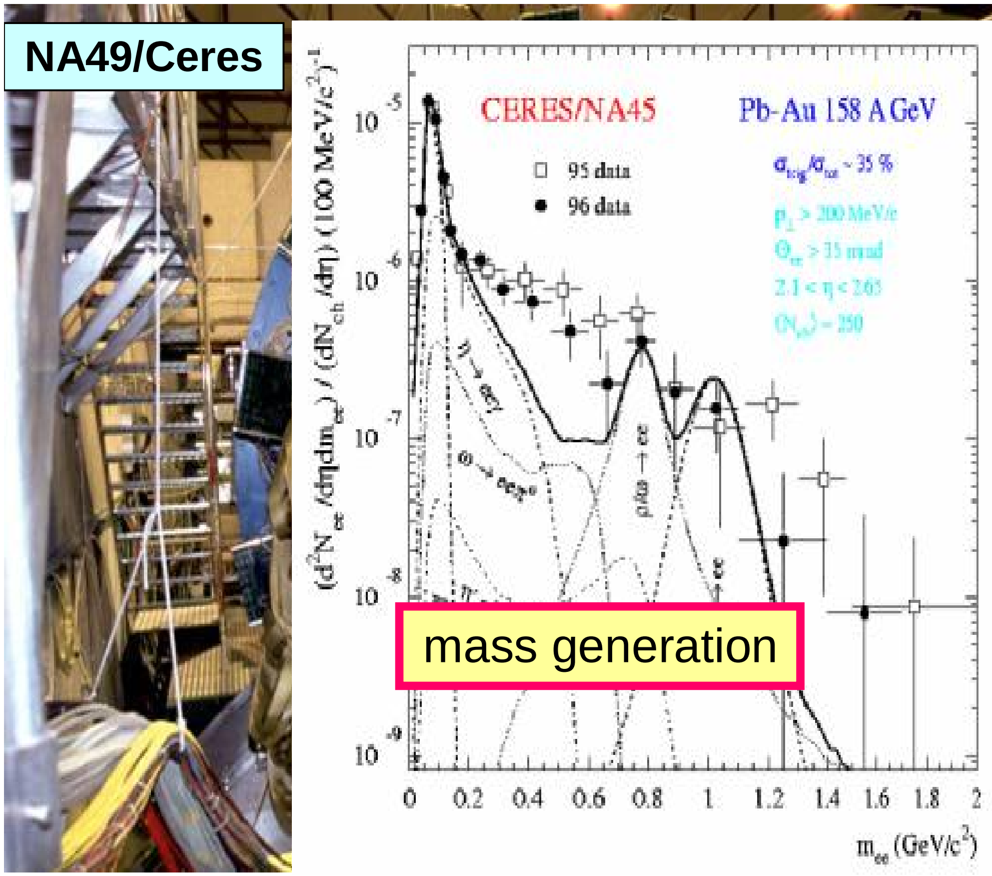


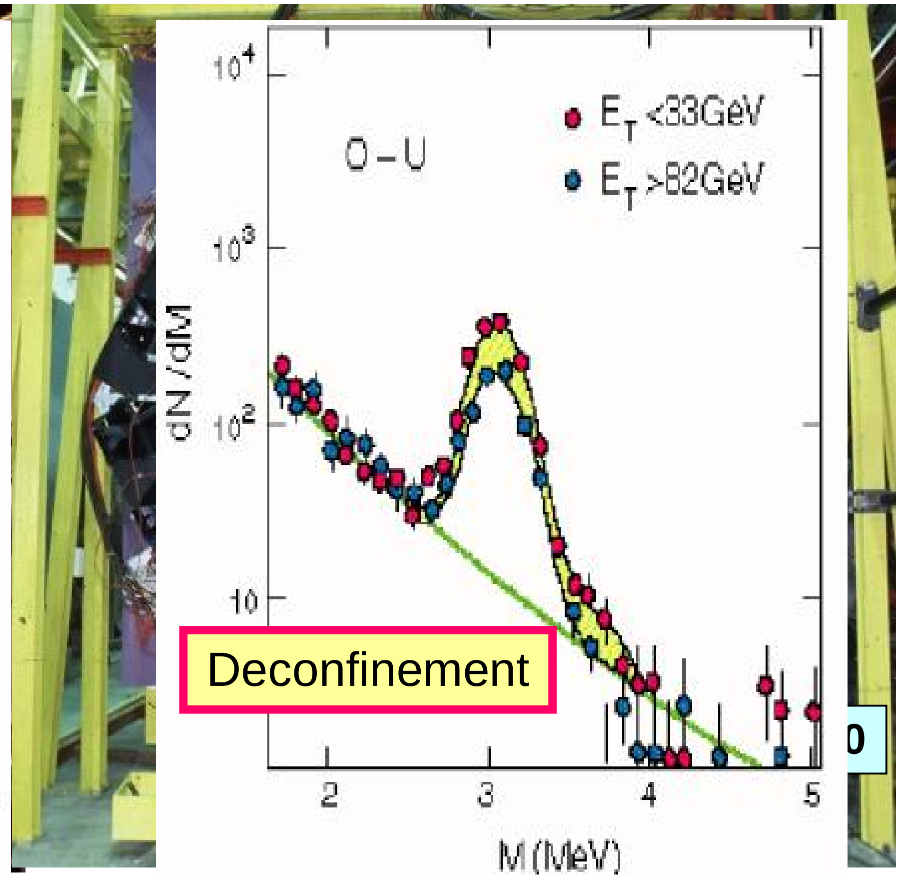


jet quenching measures
'radiation ' length of QGP
$dE \sim \mu_D^2 \times L^2$
μ_D = Debye screening mass

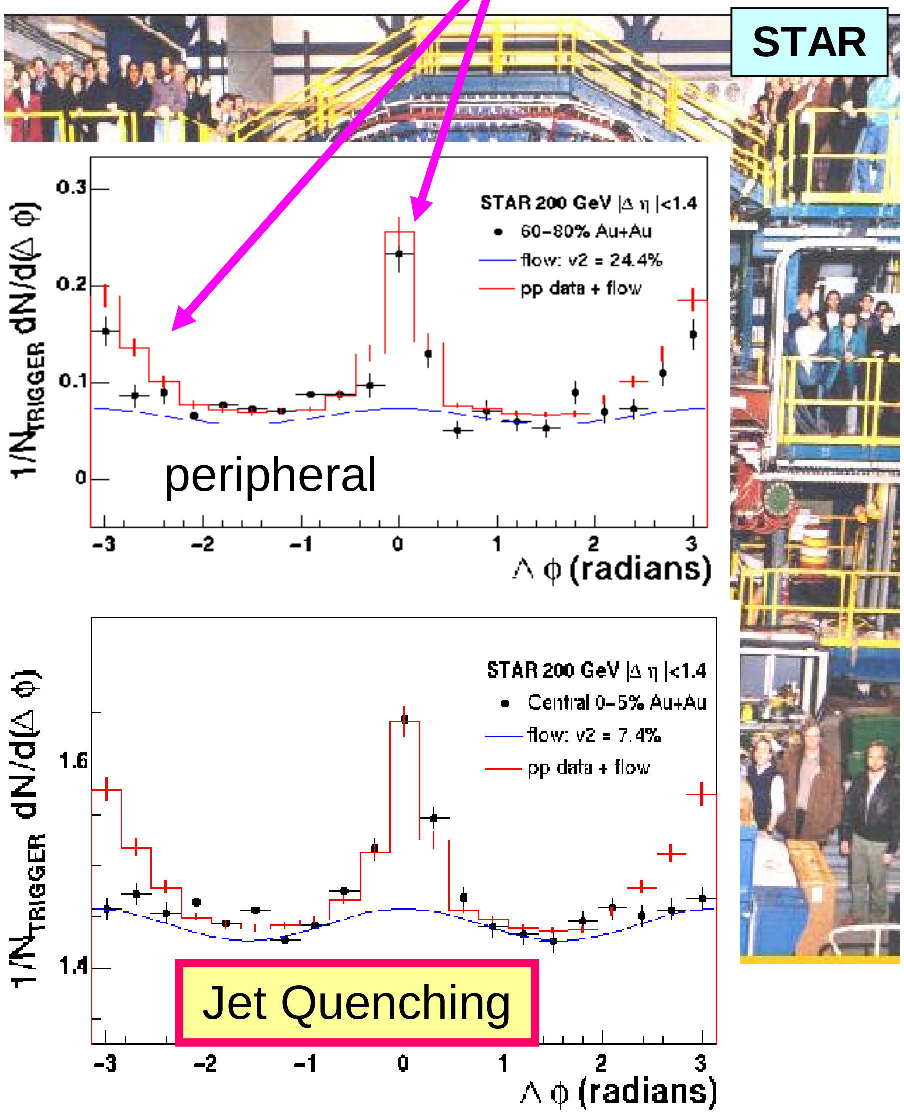
- **high p_t partons:**
  - **Vacuum: fragment into hadrons => JETS**
  - **Matter: additional scattering => more gluon radiation**
    - **normal 'cold' matter: <u>small effect</u>**
    - **QGP: <u>strong effect</u> (up to several 10 GeV)**
  - **observables of 'jet quenching'**
    - **leading parton looses energy**
    - **energy shows up in soft partons around jet axis**

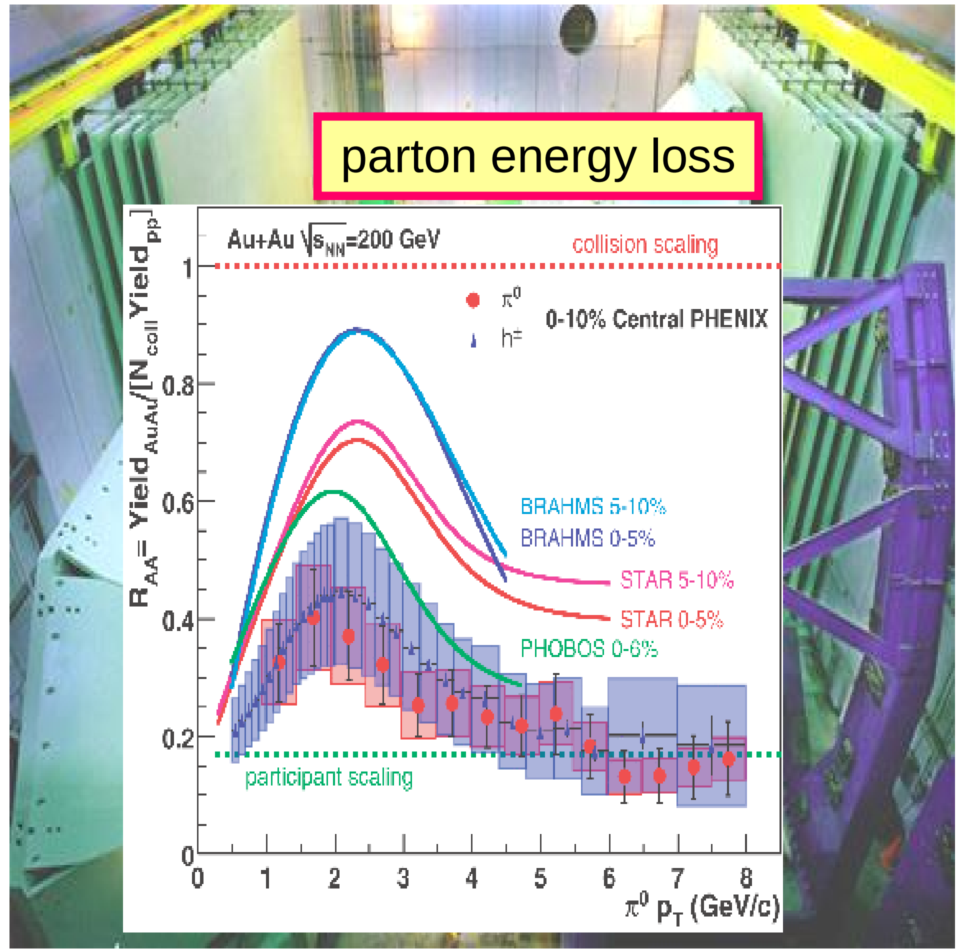
SPS Experiments





Experiments RHIC





Heavy Ions in LHC

- energy
  - Ös = **5.5 TeV/A** (Pb-Pb), **14 TeV** (pp)
- beams
  - **possible combinations: pp, pA, AA**
    - initial emphasis on Pb-Pb, Ar-Ar to vary energy density
    - pp and pA comparison runs
  - later options: different ion species, lower energy AA and pp

	Pb-Pb	**Ar-Ar**	**pp**
L [$cm^{-2}s^{-1}$]	**10^{27}**	**3×10^{27} to 10^{29}**	**10^{29} to 3×10^{30}**
Rate [kHz]	**8**	**8 to 250**	**7 to 200**

Initial Conditions

- **pre- RHIC guess (QM2001)**
  - **still expect conditions to be significantly different**
  - **only LHC will give the final answer !**

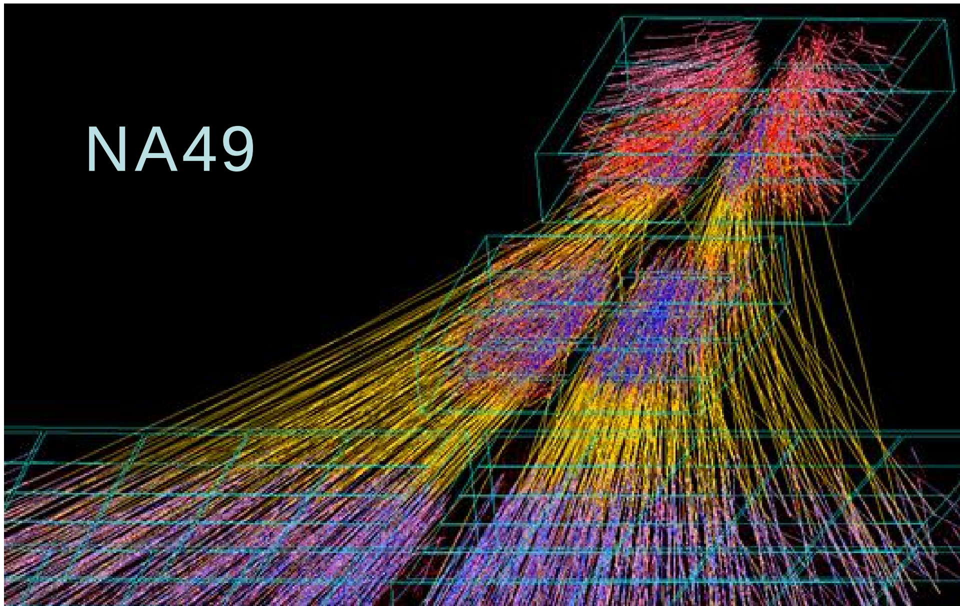
Central collisions	**SPS**	**RHIC**	**LHC**
$s^{1/2}$(GeV)	17	200	5500
dN_{ch}/dy	430	700-1500	2-8 $\times 10^3$
ε (GeV/fm^3)$_{\tau 0=1fm}$	2.5	3.5-7.5	15-40
V_f(fm^3)	10^3	(?)7×10^3	2×10^4
τ_{QGP} (fm/c)	<1	1.5-4.0	4-10
τ_0 (fm/c)	~1	~0.5	<0.2

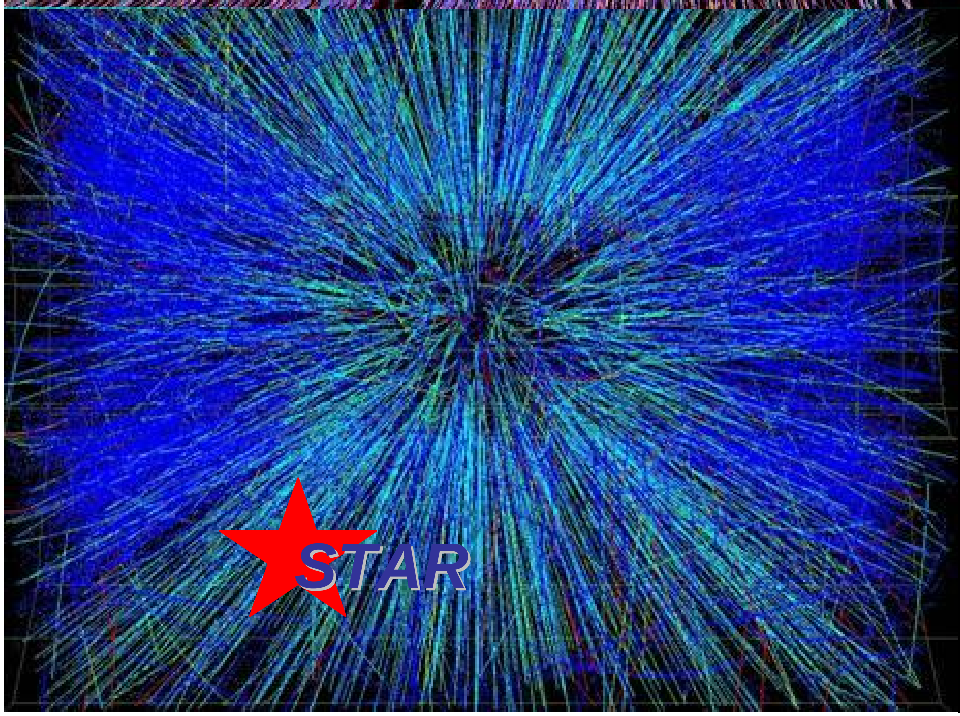
Significant gain in e, V, t

≈ x 10 SPS -> LHC

≈ x 3-5 RHIC -> LHC

Tracking Challenge

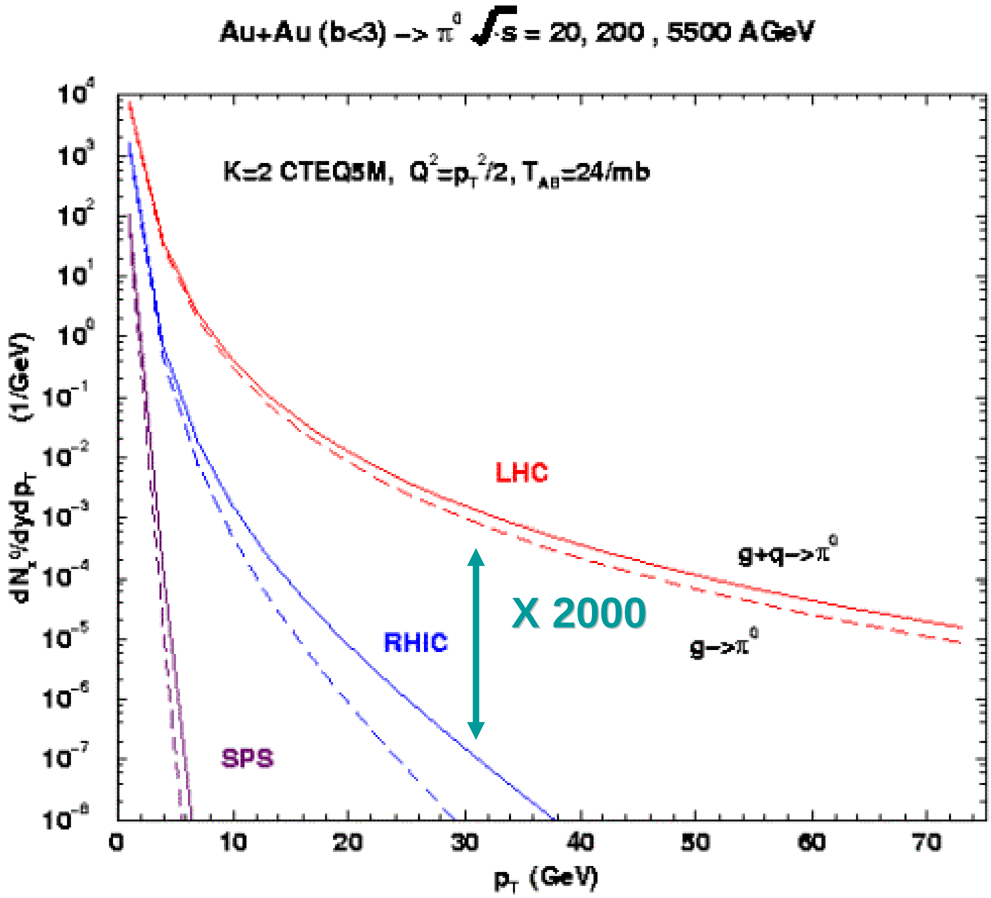




ALICE 'worst case' scenario:
dN/dy_{ch} = 8000

Hard Probes @ LHC

- LHC: the full 'spectrum'
  - **soft** -> **semihard** -> **hard** (>> 20 GeV)
  - high p_t important in order to leave even tails of 'hydrodynamics'



Jets in ALICE |η|<0.9

- **ideal energy for jet-quenching:**
  around 100 GeV
  - **pQCD applicable**
  - **jets measurable above soft background**
  - **energy loss still relatively large effect**
    - **DE/E ~ O(10%), decreasing with E !**

Reasonable rate up to E_T ~300 GeV

First TRD studies ~ 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

Pb Pb rates:

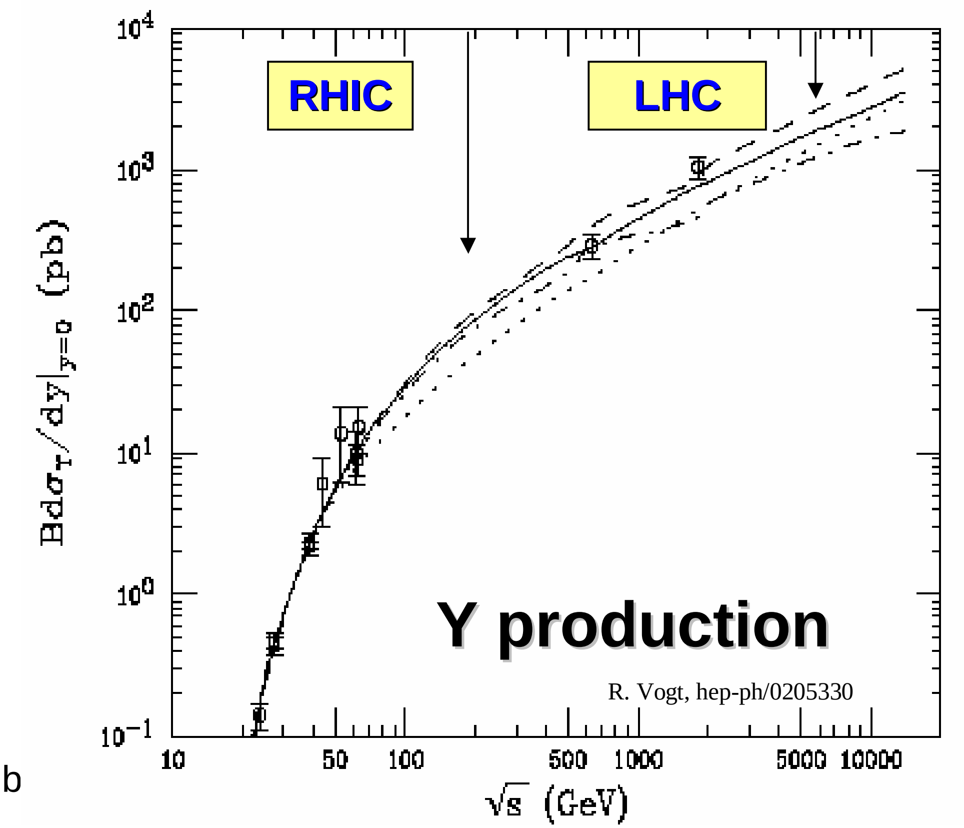
p_t jet > (GeV/c)	jets/event	accepted jets/month
5	$3.5\ 10^{2}$	$4.9\ 10^{10}$
50	$7.7\ 10^{-2}$	$1.5\ 10^{7}$
100	**$3.5\ 10^{-3}$**	**$8.1\ 10^{5}$**
150	$4.8\ 10^{-4}$	$1.2\ 10^{5}$
200	$1.1\ 10^{-4}$	$2.8\ 10^{4}$

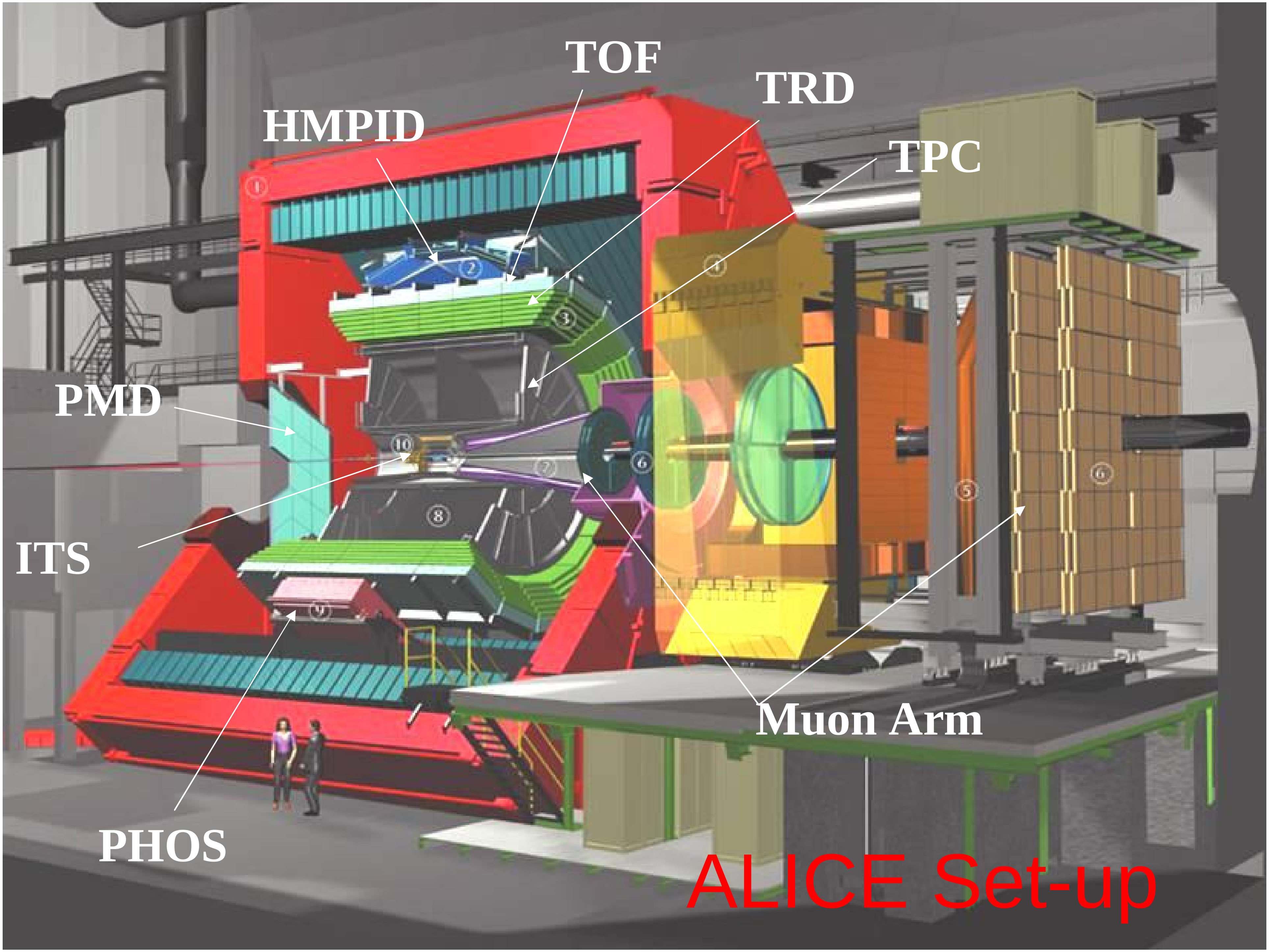
Heavy Quarks & Quarkonia

- copious heavy quark production
  - **strange** @ SPS ► **charm** @ LHC
    - jet-quenching with heavy quarks
- beauty Υ - dσ/dy LHC ~ 20 x RHIC, even at LHC Υ'' is difficult

N($q\bar{q}$) per central AA (b=0)

	SPS	RHIC	LHC
charm	0.2	10	200
bottom	---	0.05	6




TOF
TRD
HMPID
TPC
PMD
ITS
PHOS
Muon Arm
ALICE Set-up


The ALICE
Magnet:
The ALICE detector will be *here*!

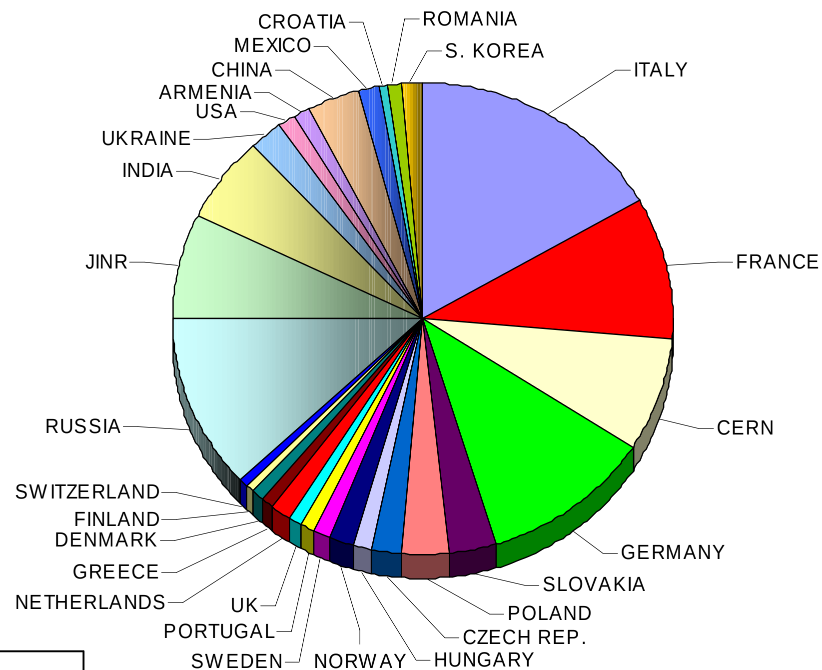
ALICE Collaboration

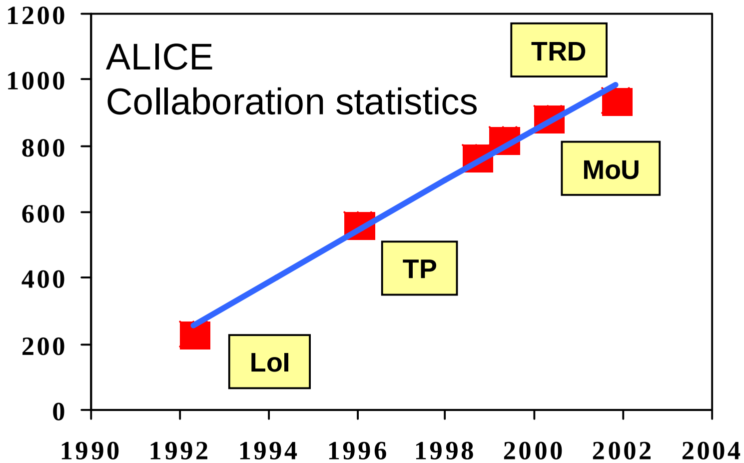
~ 1000 Members

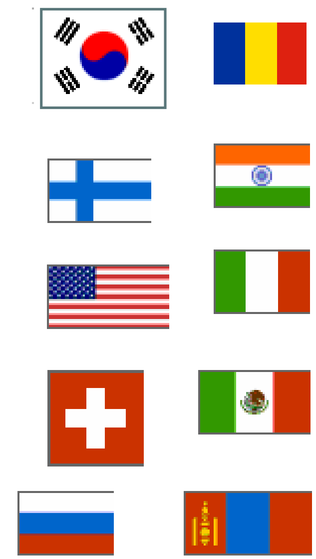
(63% from CERN MS)

~30 Countries

~80 Institutes







ALICE Subsystems

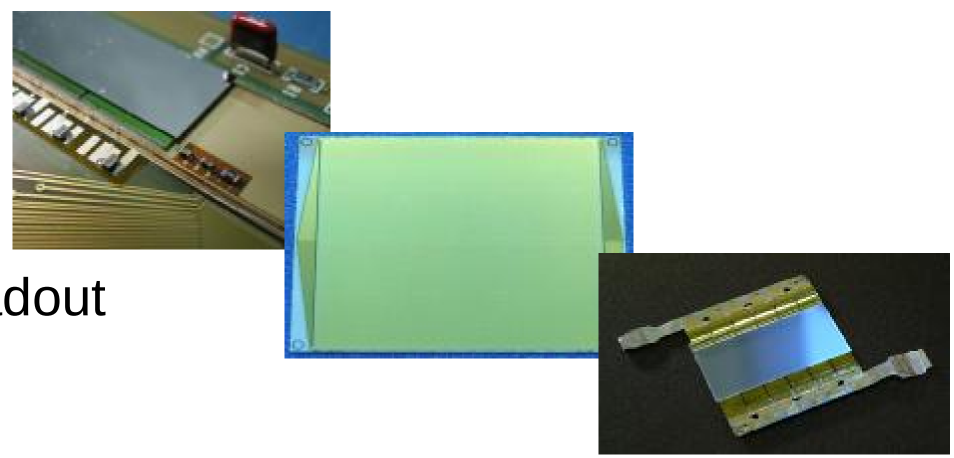
- Tracking (H=0.5 T; robust, redundant, from 60 MeV to 100 GeV)
  - ITS 4 cm < r < 44 cm, stand-alone tracking for low P_T
  - TPC 90 cm < r < 250 cm
  - TRD 290 cm < 370 cm
- Particle Identification
  - TPC (Track curvature, dE/dx)
  - HMPID (Cerenkov ring imaging)
  - TOF
  - TRD
- Forward detectors (centrality, multiplicity, timing, trigger, BG rejection)
  - T0, V0, SiFMD, HPMD, ZDC
- Calorimeters (PHOS, EmCal?)
- Forward Muon Arm

ITS (Inner Tracking System)
A low momentum spectrometer

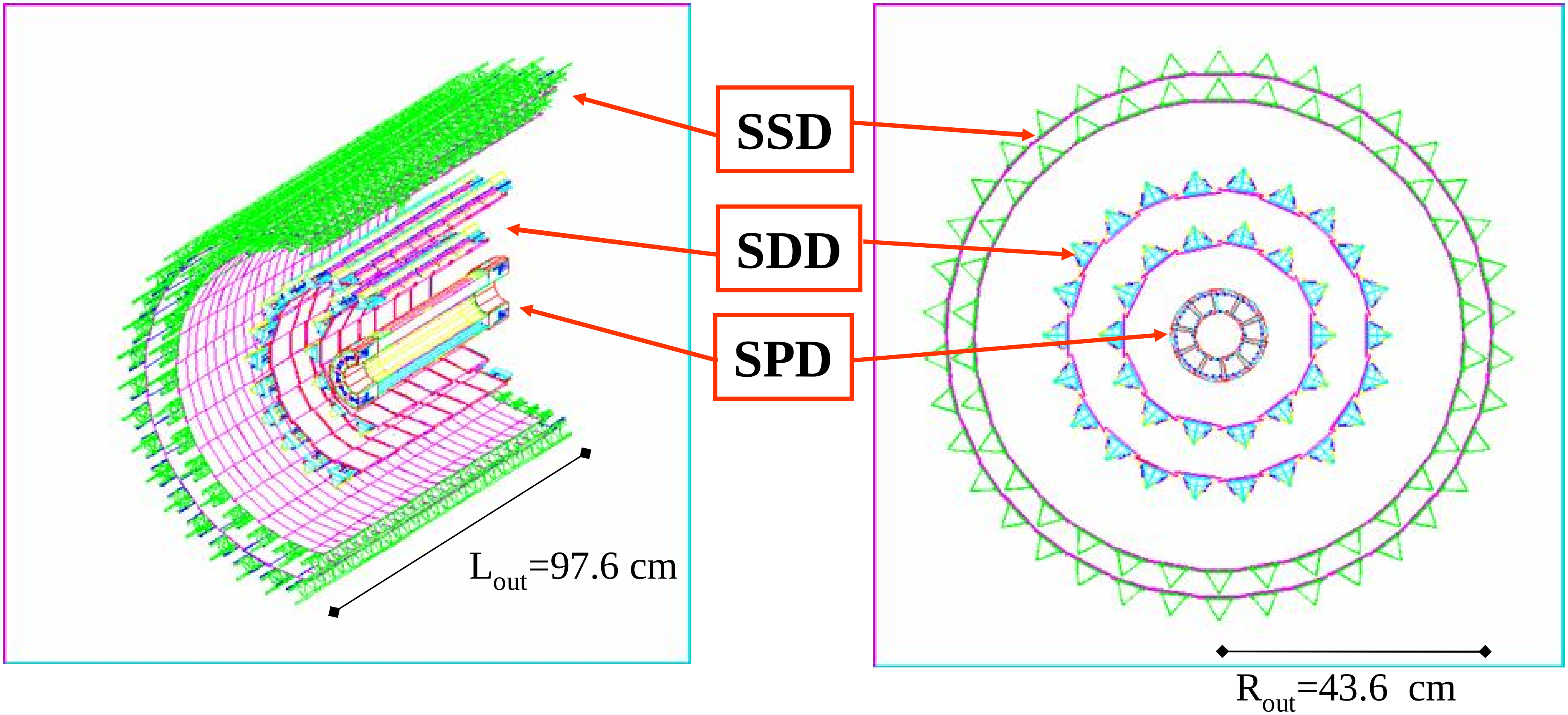
- Tracking and identification of low p_T (< 100 MeV/c)
- Primary & secondary vertex (resolution < 100 μm)
- Assist TPC tracking
- High particle densities (ε < 90 particles/cm^2)
- 6 layers (R_{ip} = 4, 7, 15, 24, 39, 44 cm) and 3 technologies
  - Pixel (SPD)
  - Drift (SDD)
  - Strip (SSD)

2D: Pixel (SPD), Drift (SDD)

Analog readout: Drift (SDD), Strip (SSD)



Inner Tracking System (ITS)

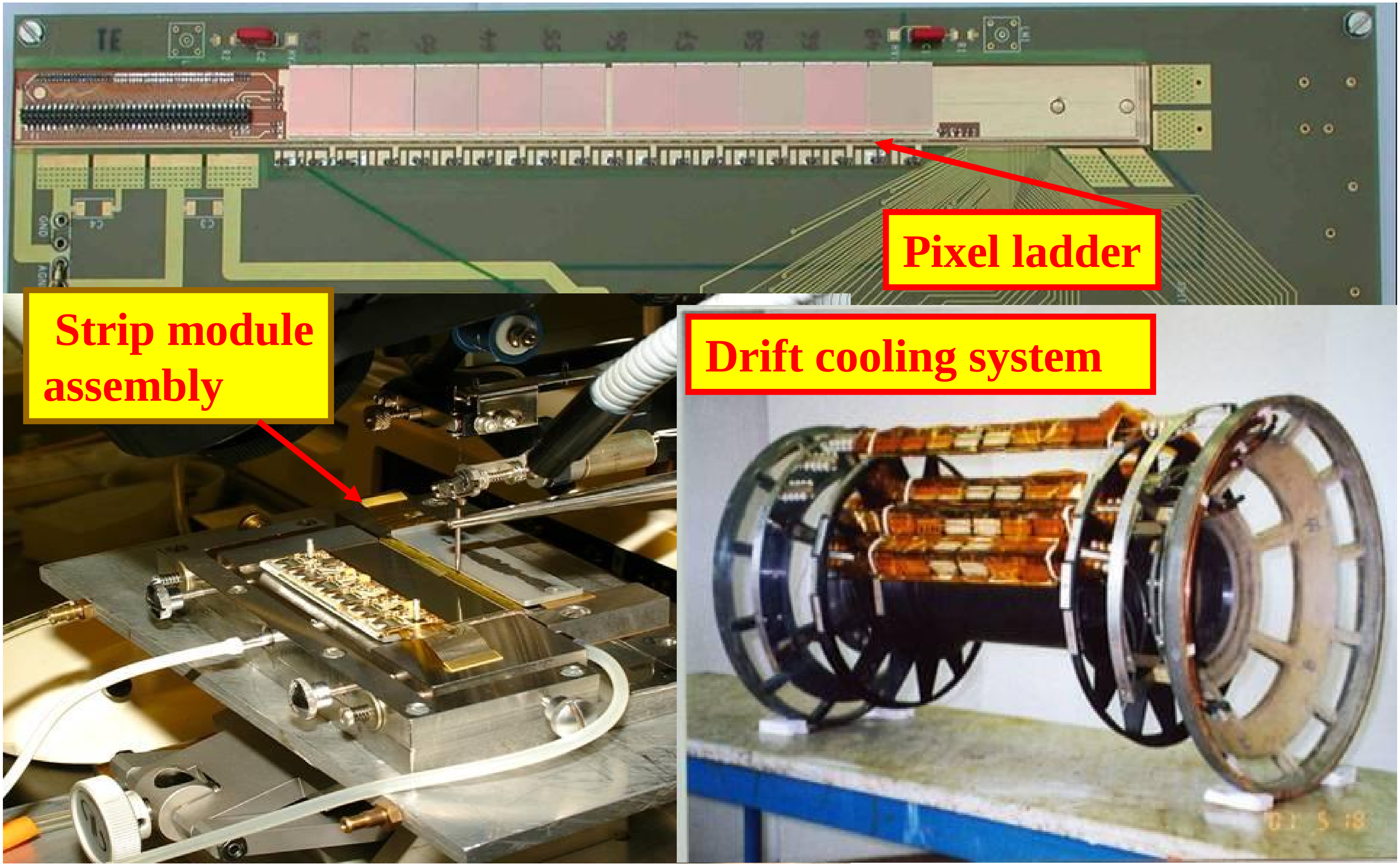


- 6 Layers, three technologies (keep occupancy ~constant **~2%** for max mult)
  - **Silicon Pixels** (**0.2 m^2**, **9.8 Mchannels**)
  - **Silicon Drift** (**1.3 m^2**, **133 kchannels**)
  - **Double-sided Strip Strip** (**4.9 m^2**, **2.6 Mchannels**)

Major technological challenge!

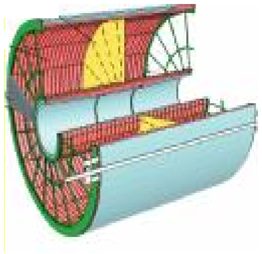
Material Budget: < 1% X_0 per layer !

System testing and setting up of series production



TPC (Time Projection Chamber)

Hadron/lepton spectrometer @ $p_T < 10$ GeV/c



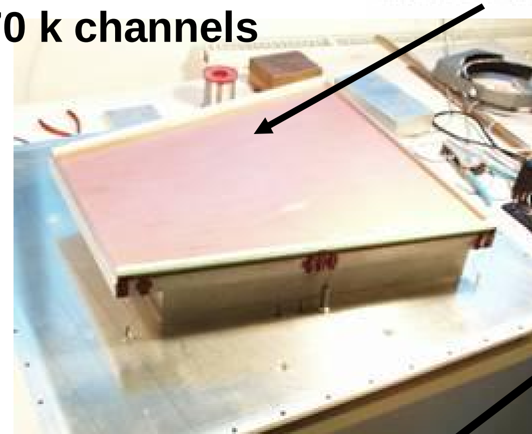
- Track finding (2-tracks resolution $\Delta \mathbf{p} < 5$ MeV/c)
- Momentum measurement

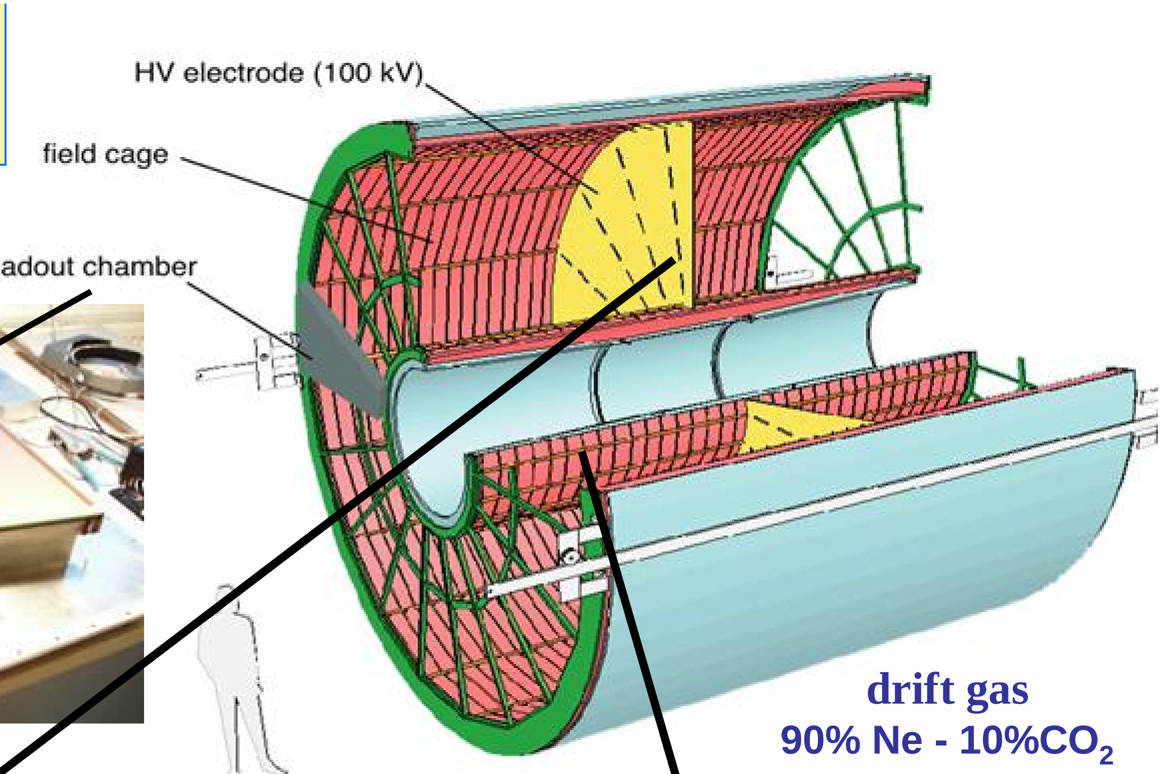
  (few % below 5 GeV/c, 9% @ 100 GeV/c)
- Particle Identification dE/dx

  (5.3 – 6.8 % depending on multiplicity)
- Track matching with ITS, TOF/TRD (> 90 %)

TPC

- **Largest ever built**
  - **88 m^3, 570 k channels**





drift gas
90% Ne - 10%CO_2

Central Electrode Prototype
25 µm aluminized Mylar on Al frame

TPC Field Cage

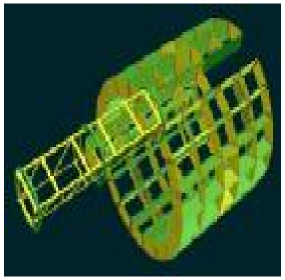
TRD (Transition Radiation Detector)

High p_T electron spectrometer

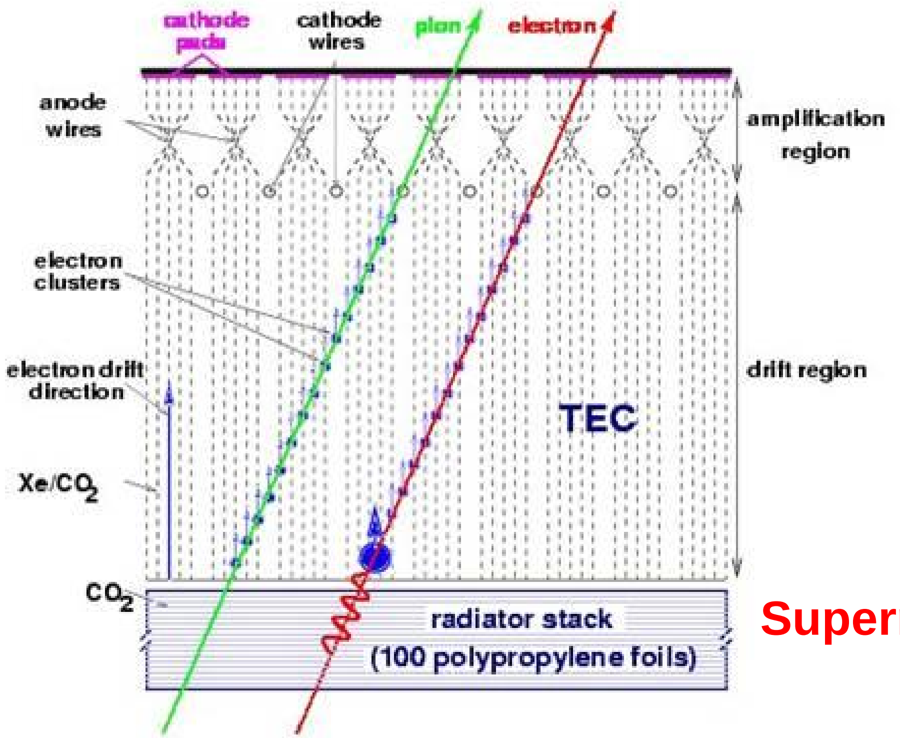
- Electron identification for $p_T > 1$ GeV/c
- e/π discrimination (rejection factor 100 @ pT > 3 GeV/c): light vector mesons, charmonium
- Momentum resolution & matching to TPC:

  5% @ 5 GeV/c, mass resolution 100 MeV/c2 @ Υ
- High pT (> 3 GeV/c) hadron trigger (jet)

$\|\eta\|$	Spatial resolution [rφ, z] [μm]	Gas MWPC	e [cm] X/X_0	# channels [M]	Occupancy [%]
0.9	400	Xe(85%) CO_2	6x4.8 / 14.3%	1.16	34



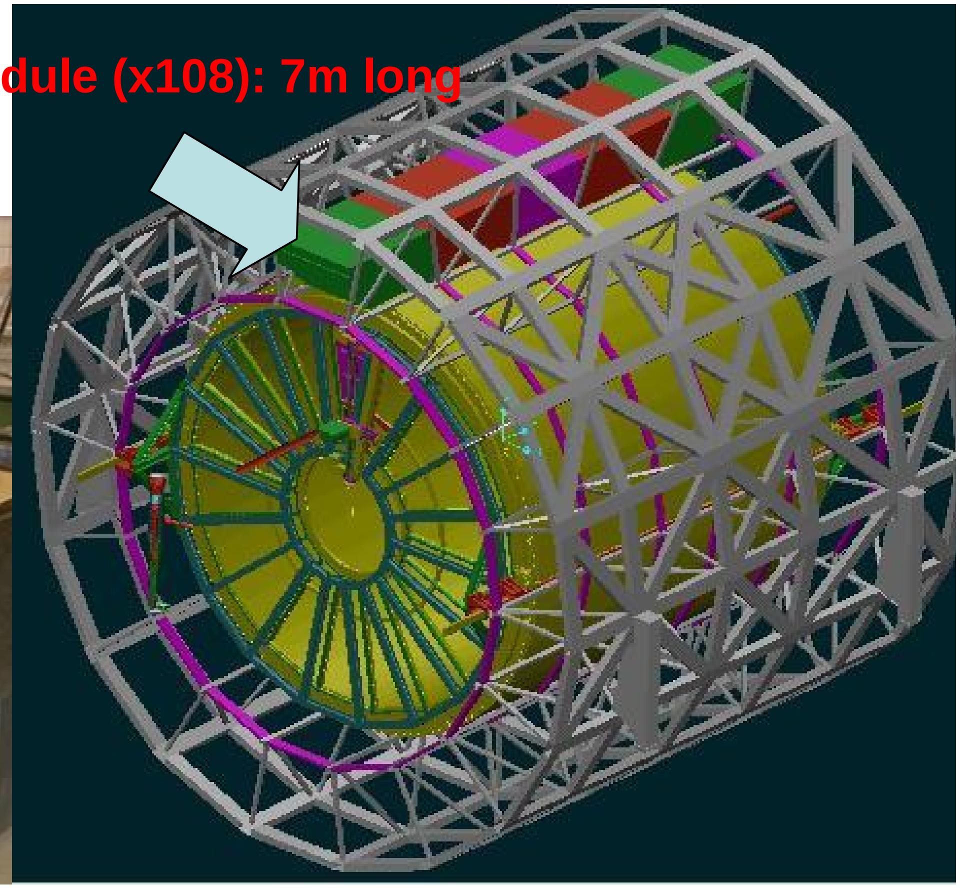
Transition Radiation Detector



- identify & trigger on electrons
- used also in tracking
- trigger on jets (high pt hardons)

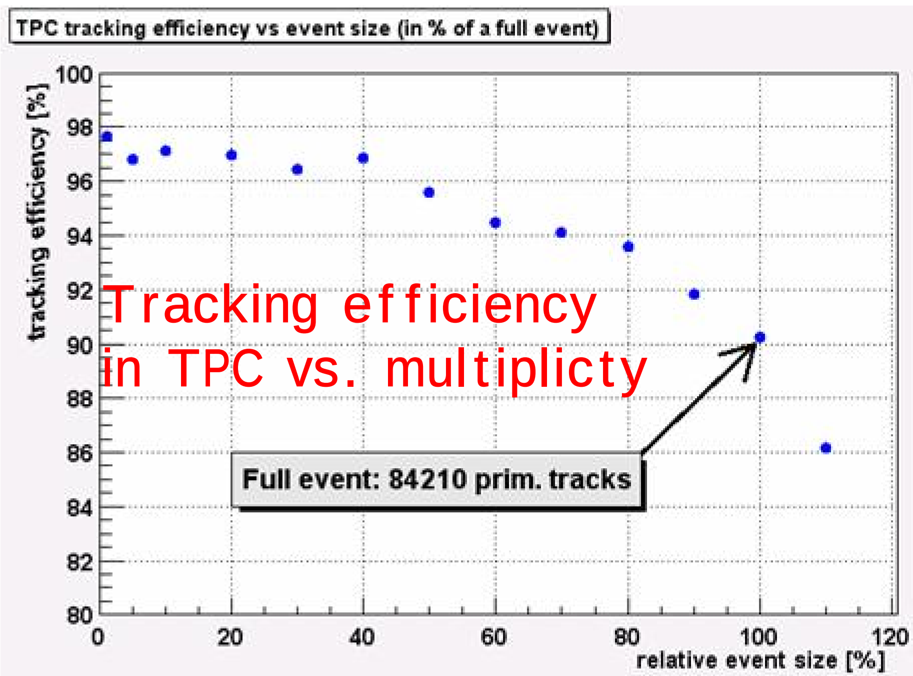
currently ~ 60% funded

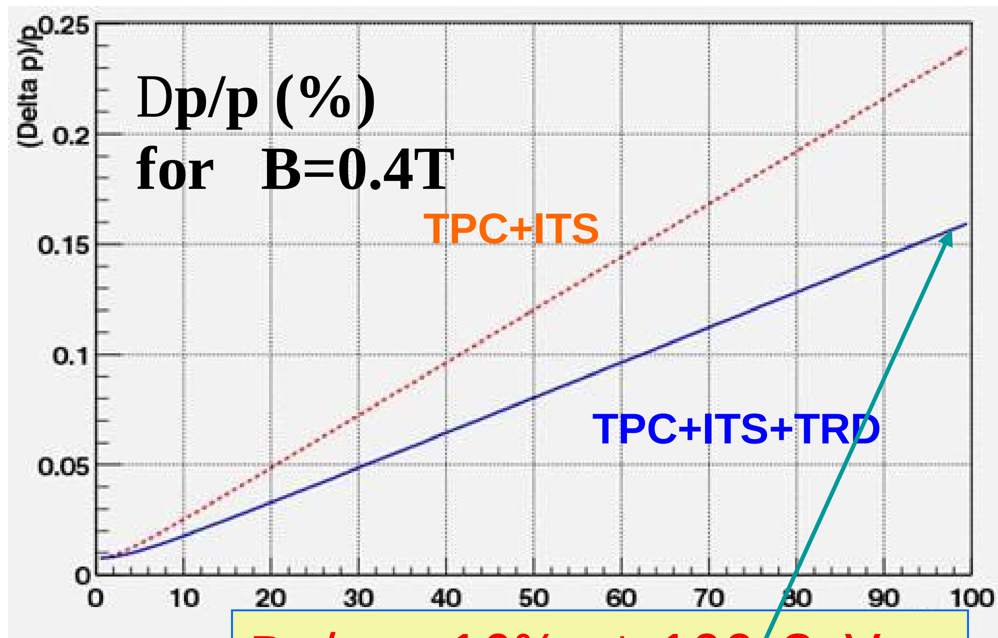
Full scale prototype



Tracking

- **robust, redundant tracking from 60 MeV to 100 GeV**
  - modest soleniodal field (0.5 T) => easy pattern recognition
  - long lever arm => good momentum resolution
  - **silicon vertex detector** (ITS) 4 cm < r < 44 cm
    - stand-alone tracking at low p_t
  - **Time Projection Chamber** (TPC) 90 cm < r < 250 cm
  - **Transition Radiation Detector** (TRD) 290 cm < 370 cm





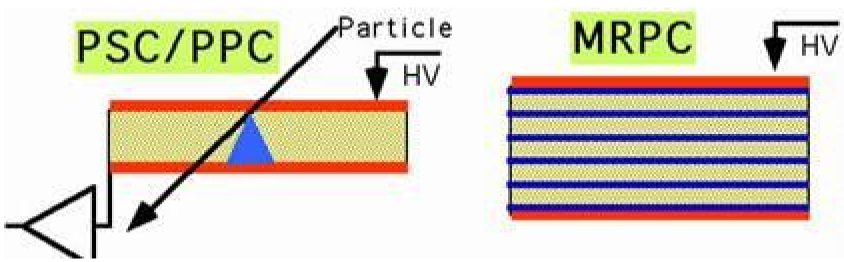
Dp/p ~ 16% at 100 GeV

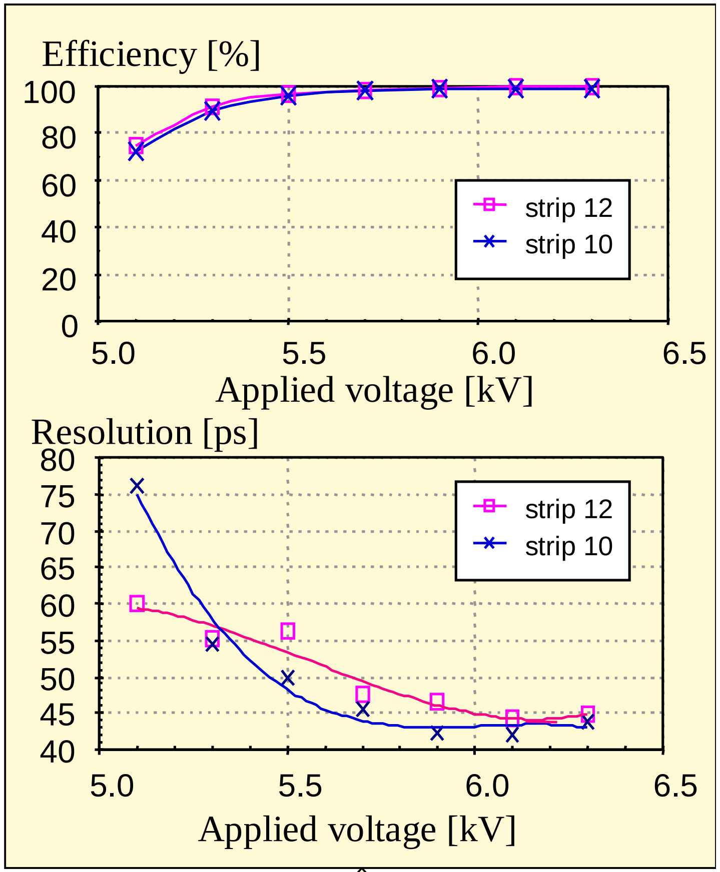
(~ 11% at dN/dh = 2000)

Time of Flight (TOF)
Hadron spectrometer

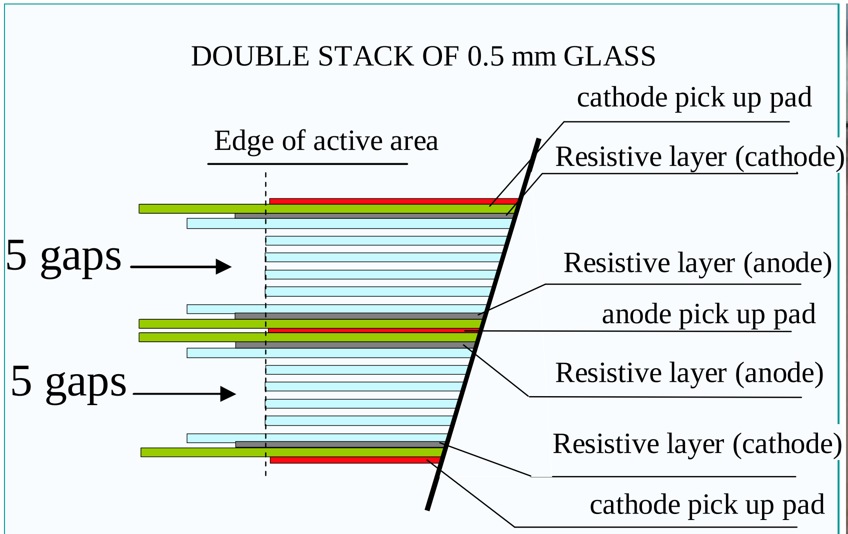
Particle identification in the intermediate momentum range ($0.2 < p_T < 2.5$ GeV/c)

Multi-gap Resistive-Plate Chamber (MRPC)





Typical performance



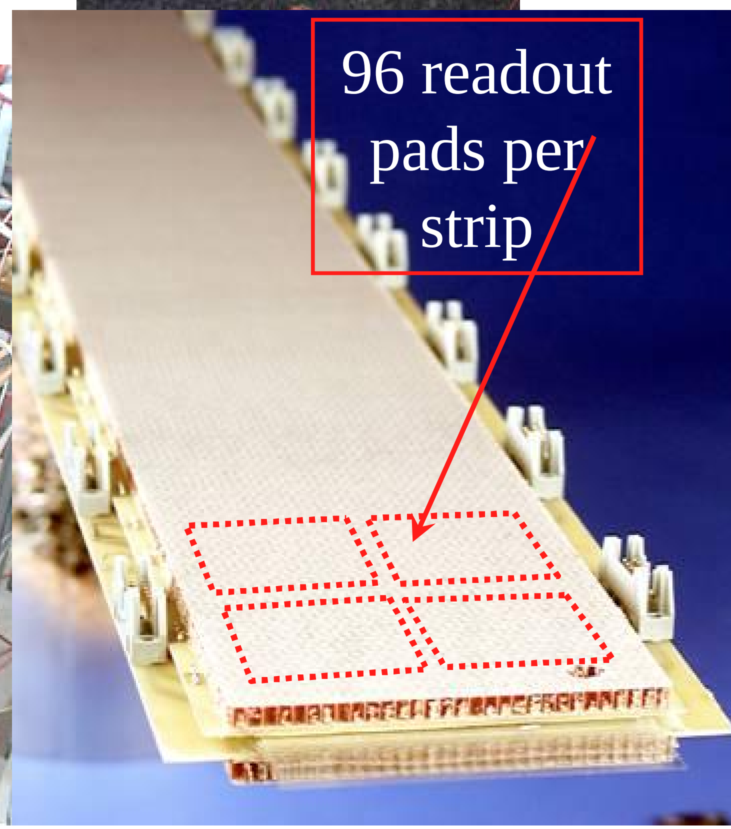
Multigap Resistive Plate Chambers

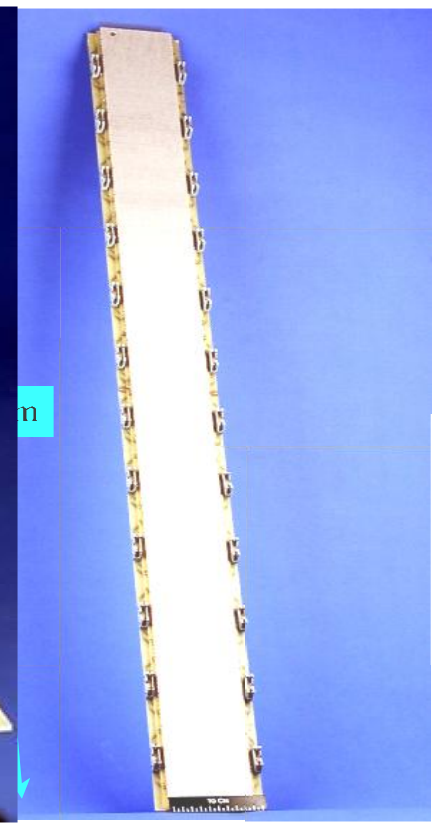
Time Of Flight

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

160 m^2, 160 k channels
r = 3.7 m, s < 100 ps

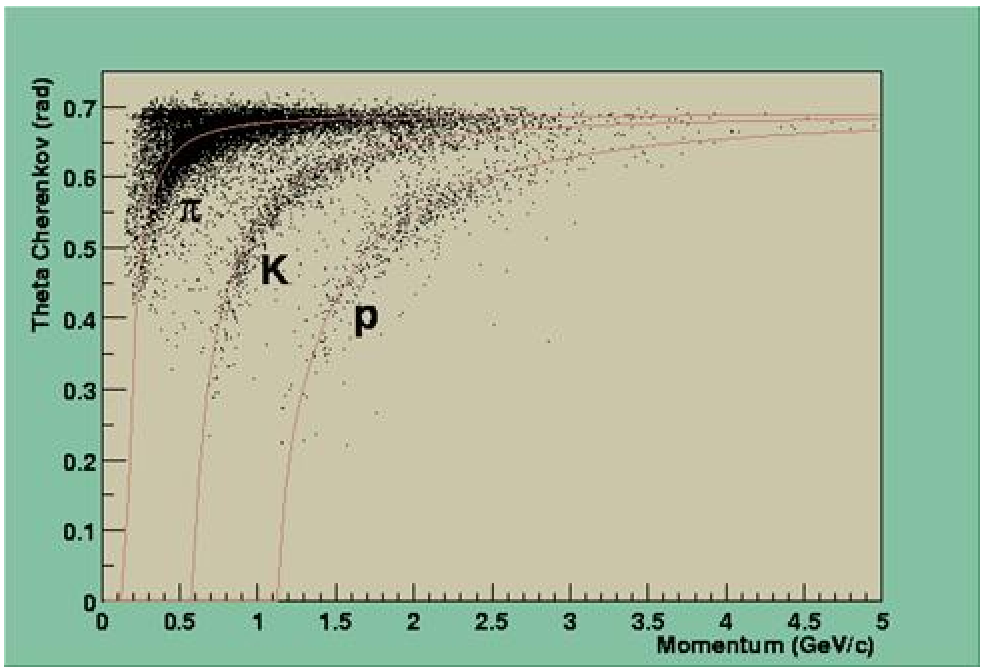
full size TOF modules under test

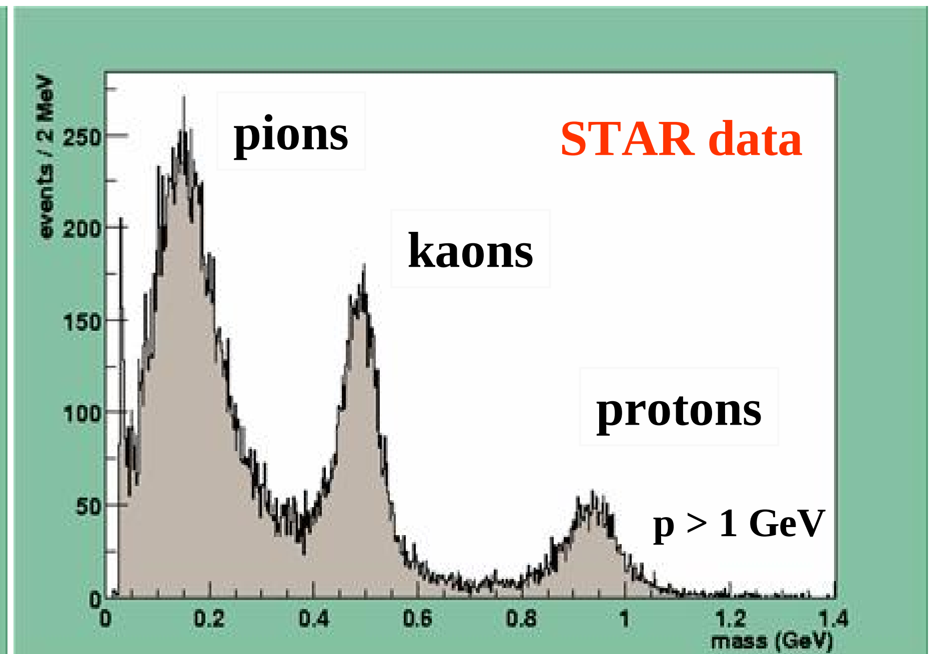




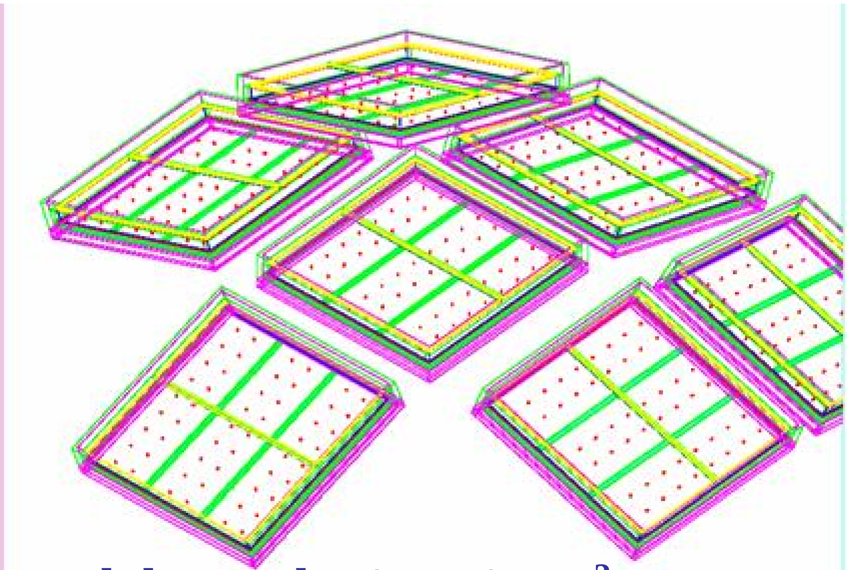
HMPID
(High Momentum Particle Identification)

- High momentum hadron spectrometer
  - Hadron identification $p_T > 1$ GeV/c
  - Discrimination p/K $p_T < 3$ GeV/c, K/p $p_T < 5$ GeV/c

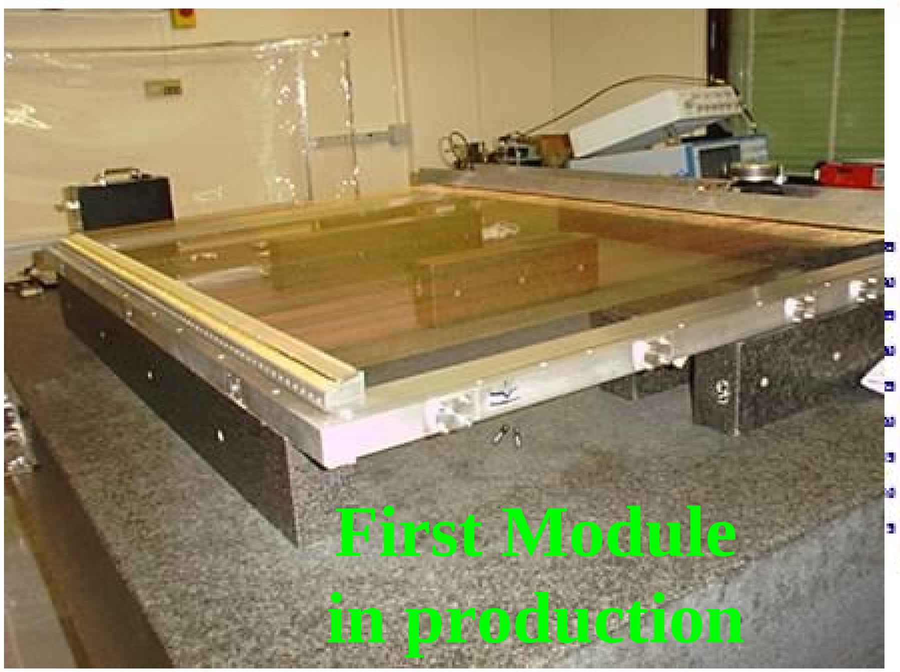




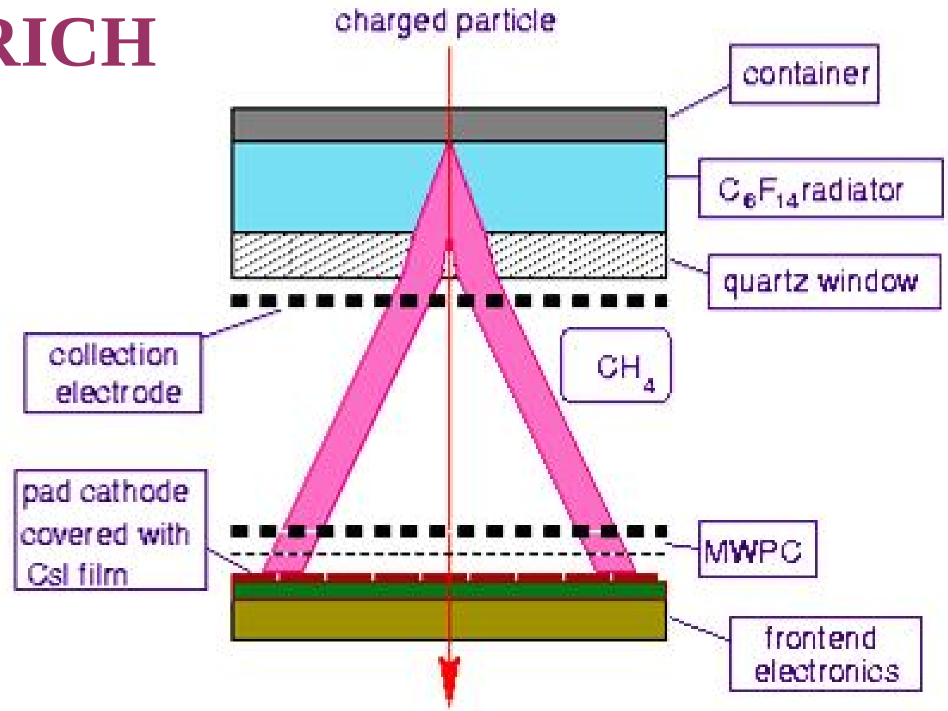
High Momentum Particle Identification



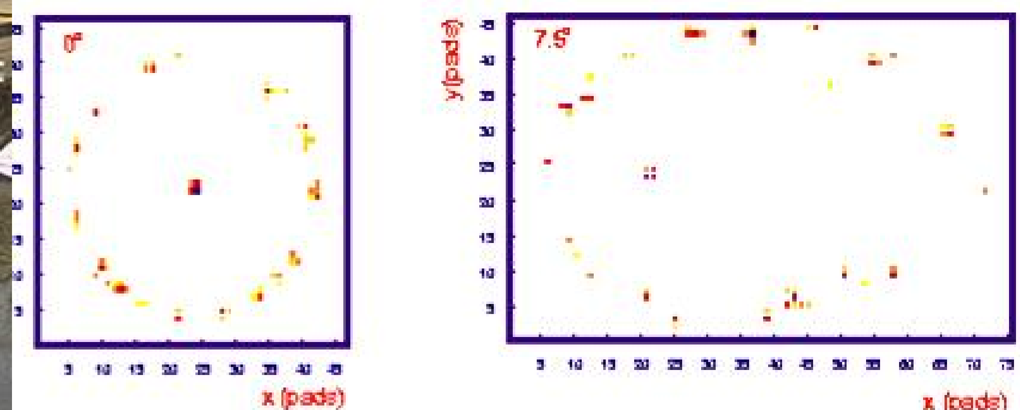
7 modules, each ~1.5 x 1.5 m^2

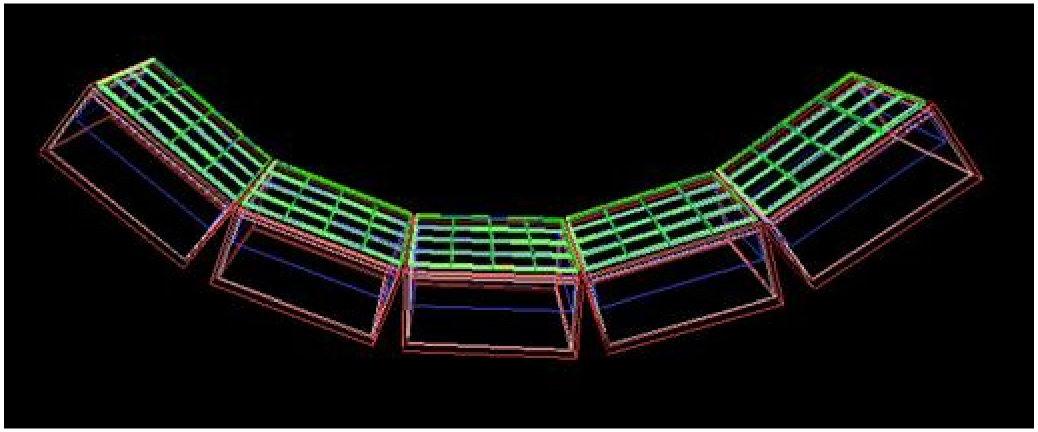


RICH



STAR data





PHOS

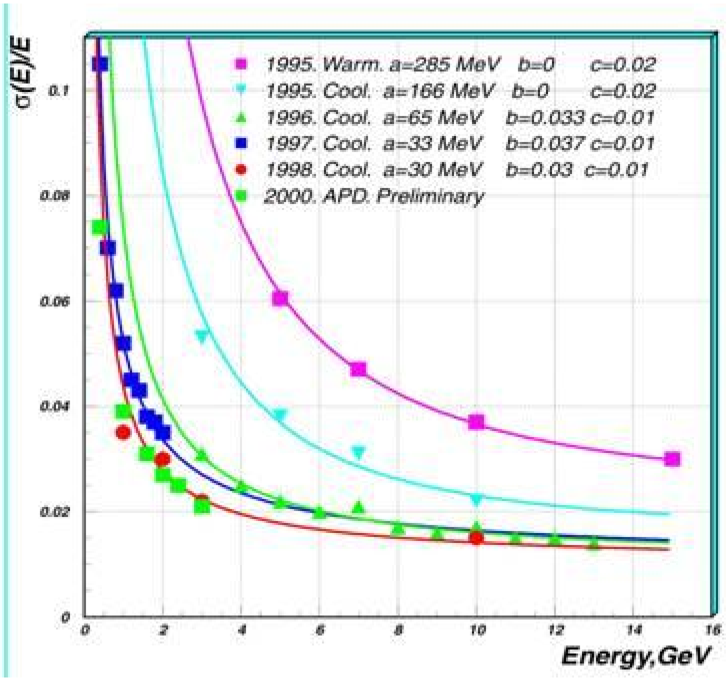
(Photon Spectrometer)

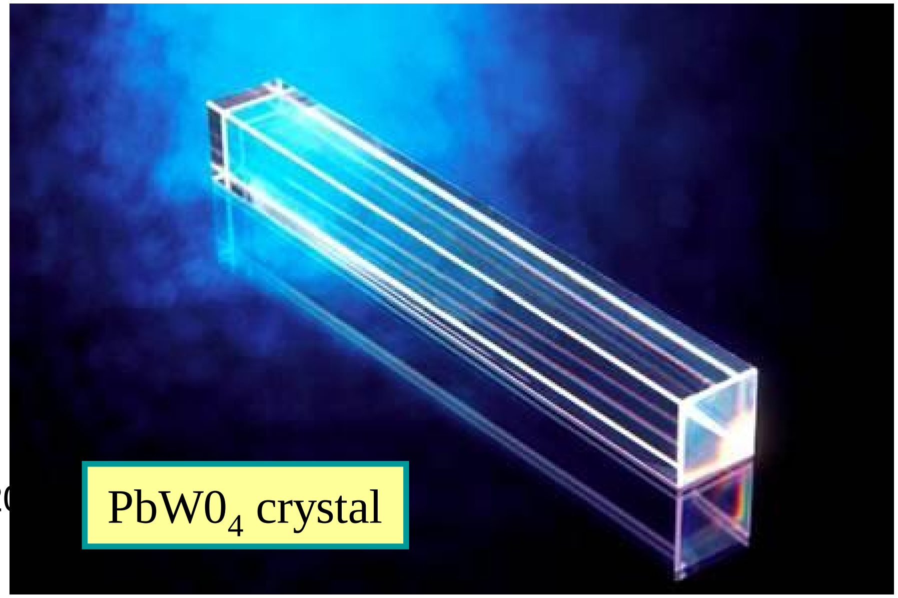
for photons, neutral mesons and g - jet tagging

- **single arm em calorimeter**
  - **dense, high granularity crystals**
    - **novel material: $PbW0_4$**
  - **~ 18 k channels, ~ 8 m^2**
  - **cooled to -25º**

$PbW0_4$: Very dense: $X_0 < 0.9$ cm
Good energy resolution (after 6 years R&D):

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

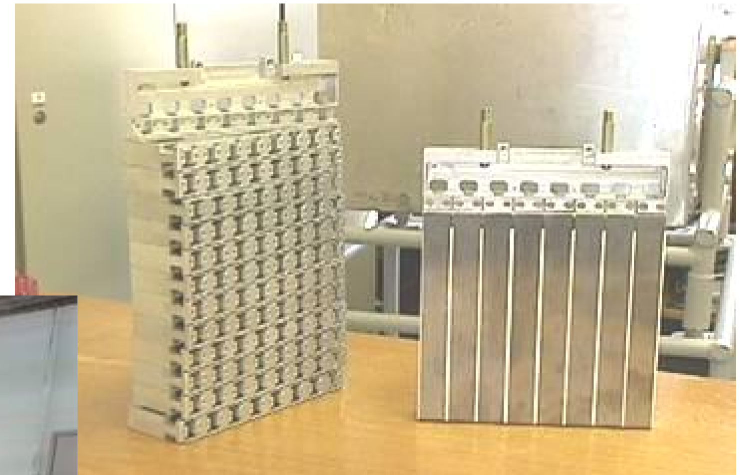




PHOS

- mass production of crystals started
  - Apatity, Russia
- Light Read-out
  - APD's (Avalanche Photo Diodes)
  - FEE still in design phase

PHOS 256 Channel Prototype



Collaboration:
- Russia + Norway
- China (?)
Needs strengthening !

Particle Identification

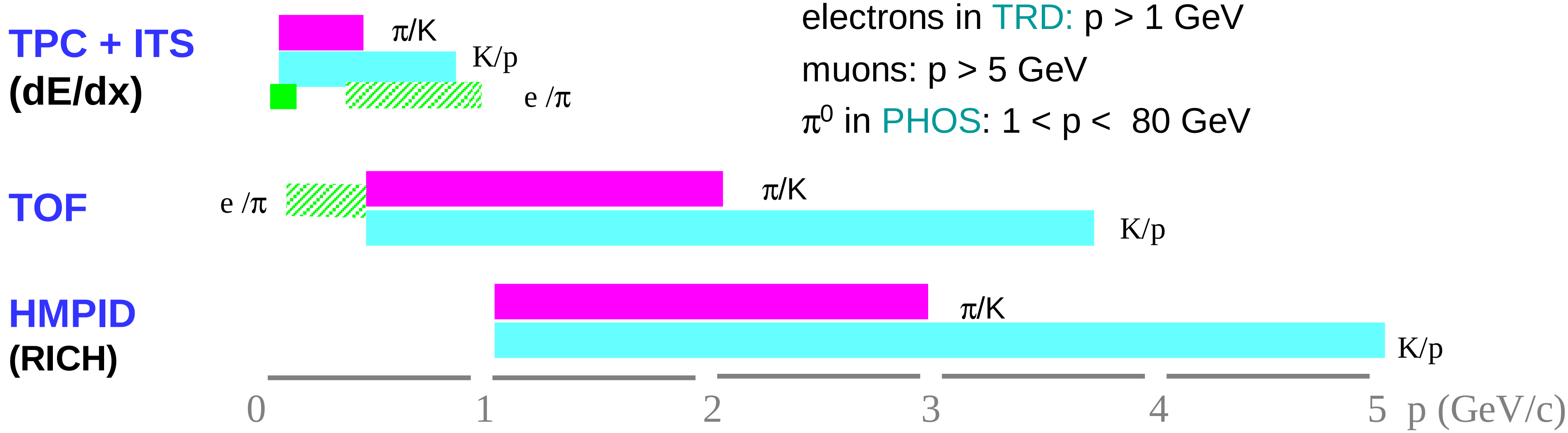
- **stable hadrons (p, K, p): 100 MeV < p < 5 GeV**
  - dE/dx in silicon (ITS) and gas (TPC) + Time-of-Flight (TOF) + Cerenkov (RICH)
  - dE/dx relativistic rise under study => extend PID to several 10 GeV ??
- **decay topology (K^0, K^+, K^-, L)**
  - still under study, but expect K and Λ decays up to at least 10 GeV
- **leptons (e, m), photons, p^0**

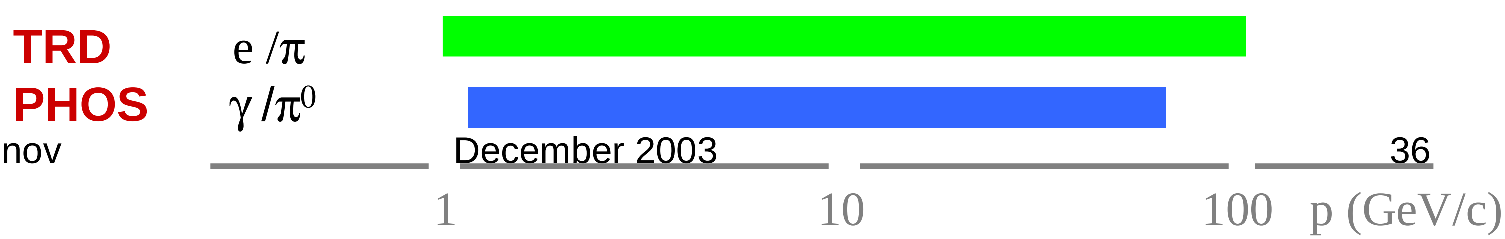
Alice uses ~ all known techniques!

electrons in TRD: p > 1 GeV

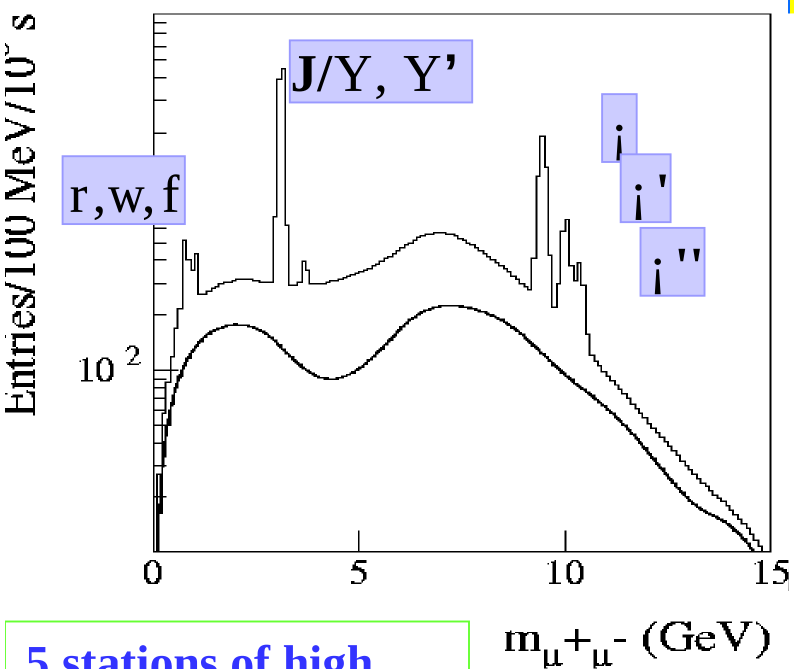
muons: p > 5 GeV

π^0 in PHOS: 1 < p < 80 GeV





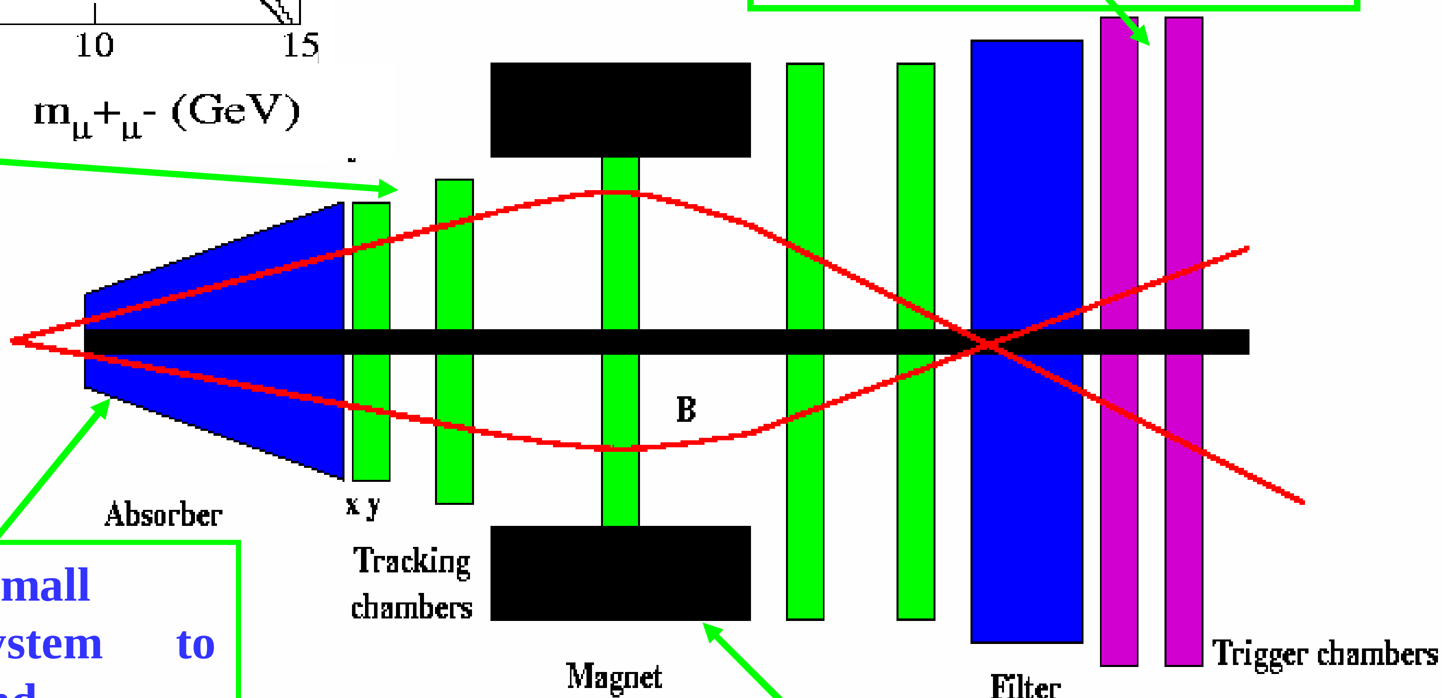
Dimuon Spectrometer



Study the production of the J/Y, Y', U, U' and U'' decaying in 2 muons, 2.4 <h < 4

Resolution of 70 MeV at the J/Y and

100 MeV at the U



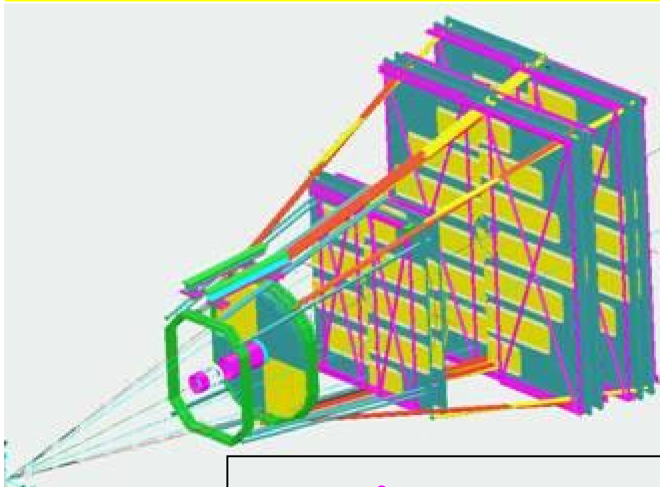
RPC Trigger Chambers

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

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

Dipole Magnet: bending power 3Tm

Muon Chambers

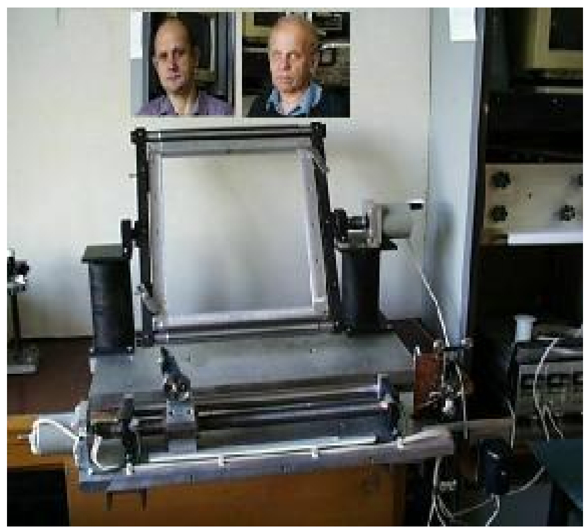


Station 3-4: Slats

Station 1&2: Quadrants

Trigger RPC

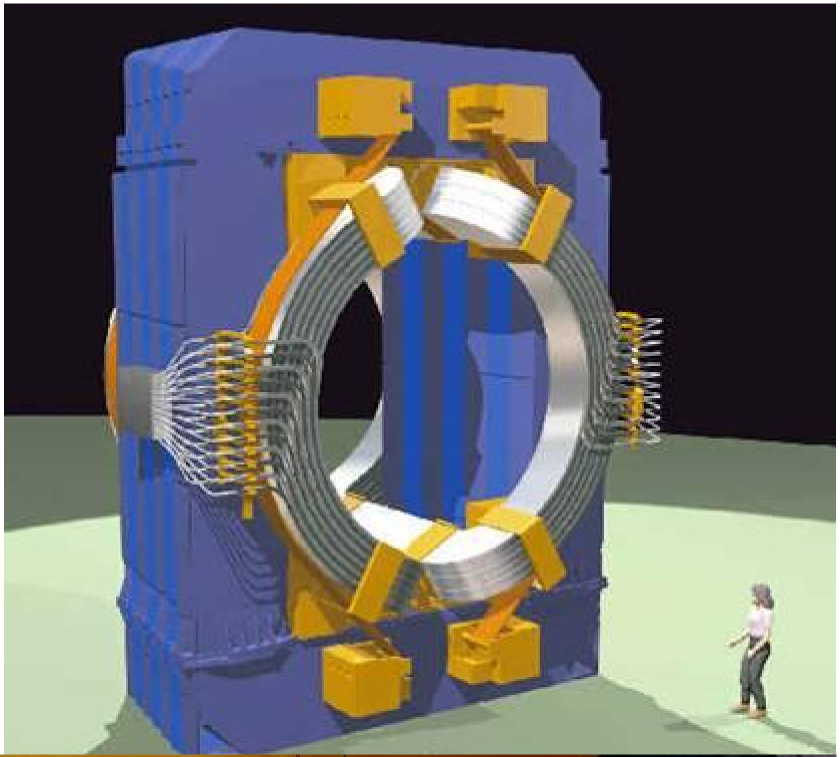
Разработано и изготовлено оборудование для производства модулей мюонных камер

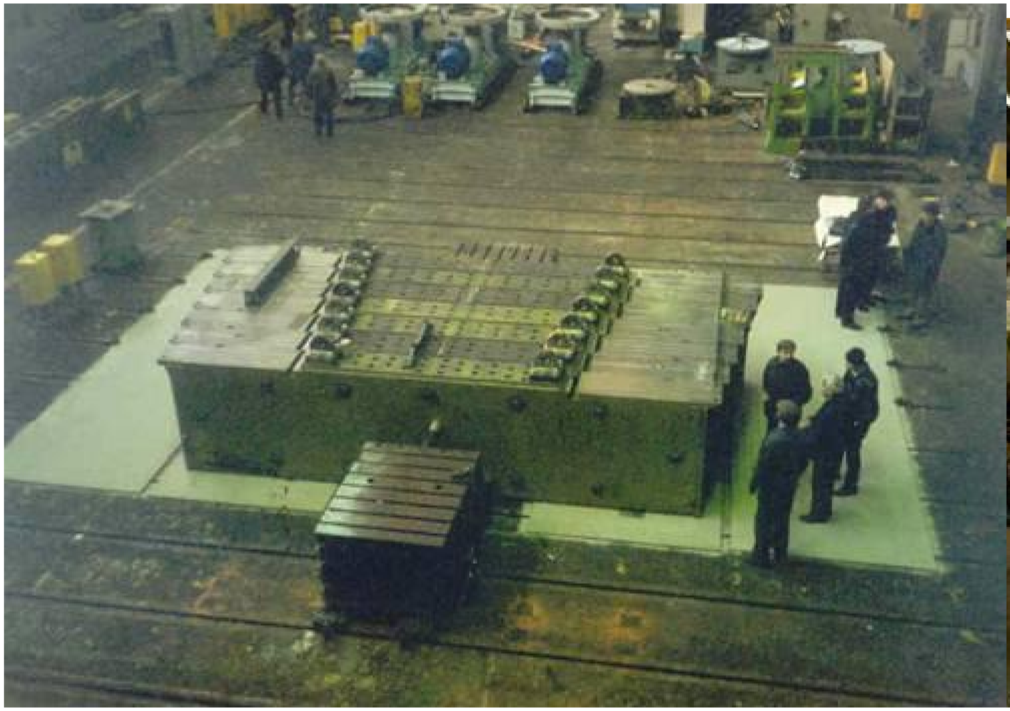


Оборудована и подготовлена к началу серийного производства трековых камер мюонного спектрометра чистая сборочная зона.

Muon Magnet

- Dipole Magnet
  - 0.7 T and 3 Tm
  - 4 MW power, 800 tons
  - World's largest warm dipole
- Progress:
  - Coil production in progress in France
  - Yoke finished end 2002 in Russia





Forward Detectors

PMD **Photon Multiplicity Detector**

$2.3 < \eta < 3.5$,

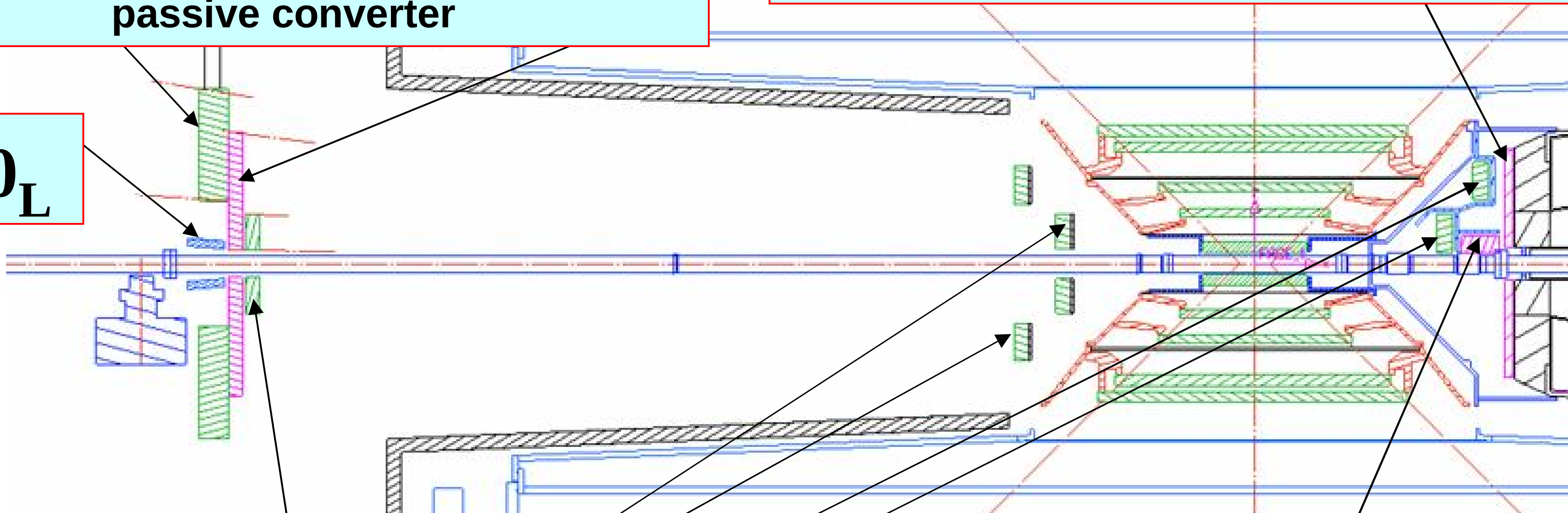
measures $n_{charged}$ and $n_{photons}$
2 gas detectors, honeycomb-cell proportional chamber, sandwiching a passive converter

V0 **Interaction trigger**
(centrality trigger and beam-gas rejection)

$1.6 < |\eta| < 3.9$.

Two arrays of 72 scintillator tiles readout via fibers

$T0_L$



FMD **Forward Multiplicity Detector**

$1.6 < \eta < 3, -5.4 < \eta < -1.6$

4 rings of **silicon pad detector disks (slow readout) with 12k analog channels**

$T0_R$ **Measure event Time (T_0)**
for the TOF (~ 50 ps time res.)

$2.6 < |\eta| < 3.3$

Two arrays of 12 quartz counters.
Also backup to V0

Computing Phase Transition

The Problem:

- **Online: storing up to 1.2 Gbyte/s**
  - – whole WWW in few hours on tape !
  - – ~ 10 x RHIC !
- **Offline: 1800 kSI95**
  - – 300,000 PC's in 2000 (500 Mhz)
  - – ~ 100 x RHIC !!

The Answer:

cheap mass market components

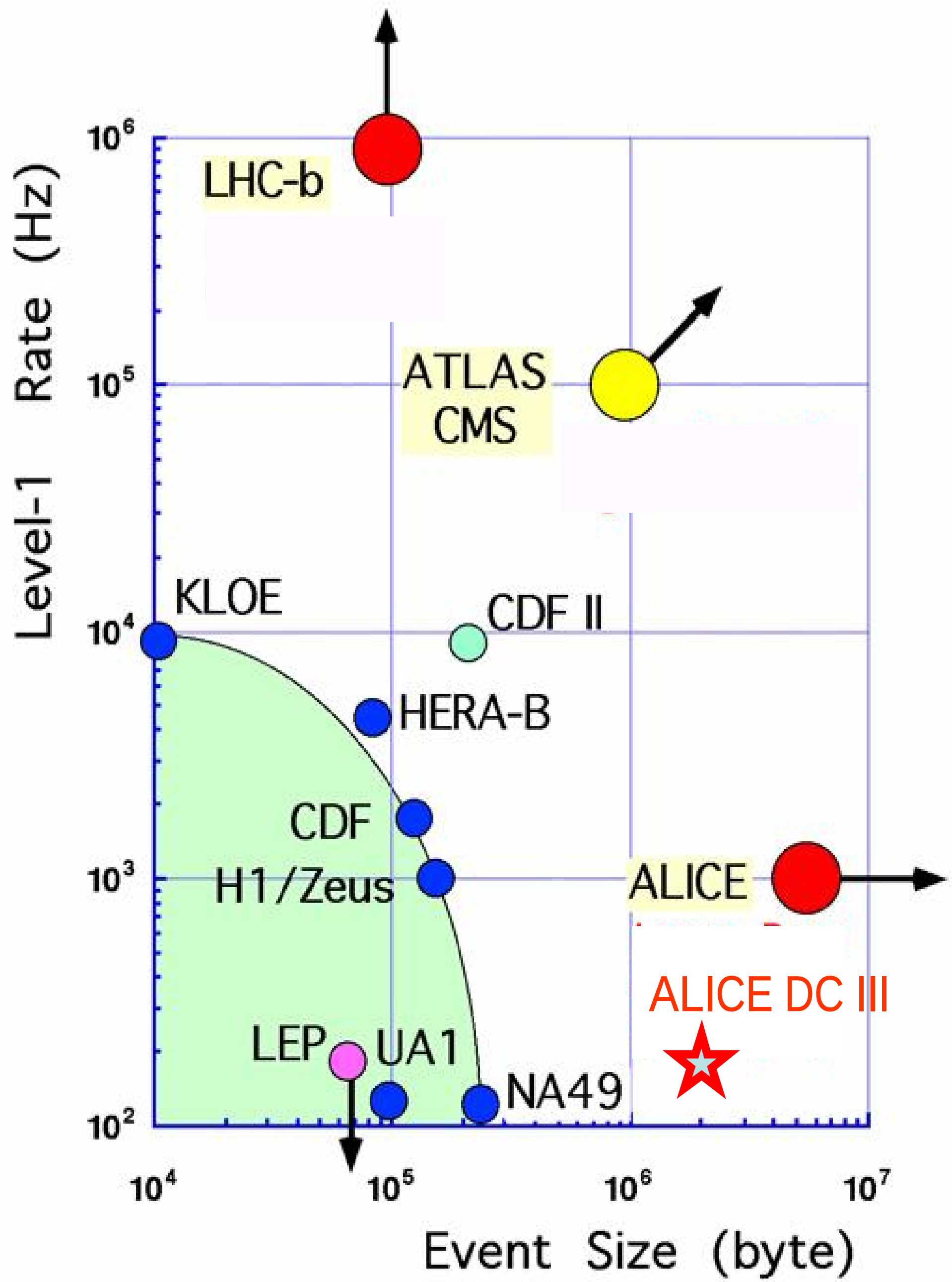
Industry & Moore's law

The Challenge:

make 10,000 mice do the
work of one elephant

new computing paradigm:

The GRID



ALICE Running Scenario (endorsed at LHCC WS)

1 LHC year = 10^7 s of pp + 10^6 s of AA

- Year 1 (2007)
  - pp: detector commissioning & physics data
  - PbPb physics pilot run: global event-properties, observables with large cross-section
- Year 2 (in addition to pp @ 14 TeV, L< 3.10^{30} cm^{-2}s^{-1})
  - PbPb @ L~ 10^{27} cm^{-2}s^{-1}: rare observables
- Year 3
  - p(d, α)Pb @ L~ 10^{29} cm^{-2}s^{-1} : Nuclear modification of structure function
- Year 4 (as year 2)
- Year 5
  - ArAr @ L~ 10^{27} -10^{29} cm^{-2}s^{-1} : energy density dependencies
- Options for later
  - pp @ 5.5 TeV, pA (A scan to map A dependence), AA (A scan to map energy-density dependence), PbPb (energy-excitation function down towards RHIC), ….

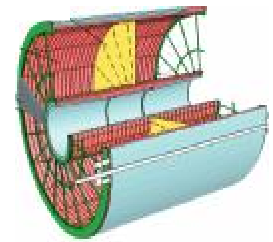
Спасибо за внимание

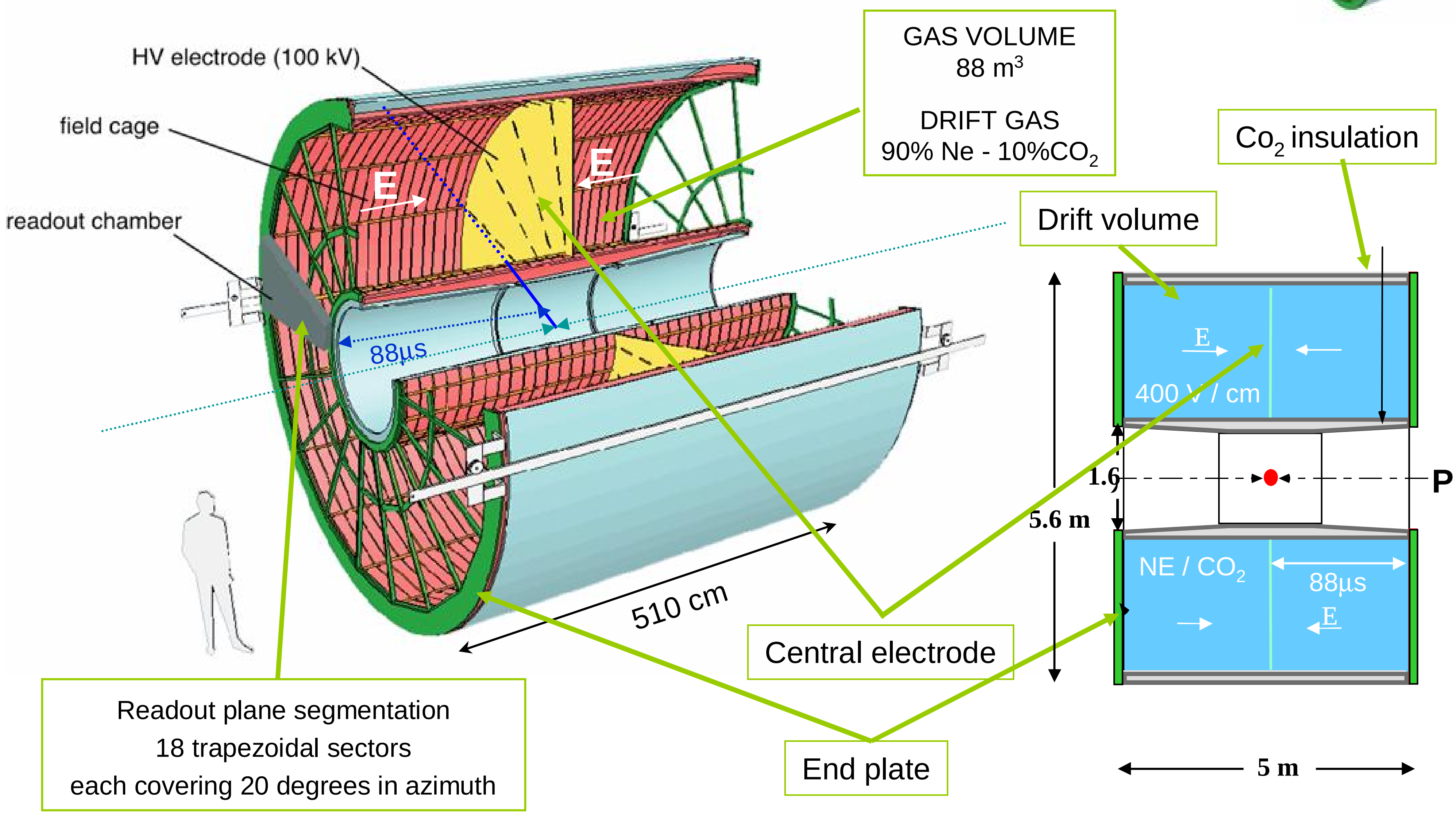
В 2003 году проведена работа по подготовке производства мюонных камер

- Разработаны и изготовлены **устройства для прецизионной обрезки печатных плат**, для института Саха (Калькутта, Индия) и INFN (Каглиари,Италия)
- Разработаны и изготовлены **4 высоковольтных испытательных стендов для модулей**
- Разработана, изготовлена и испытана **намоточная машина**
- Разработаны и изготовлены **4 автоматизированных устройств для измерения натяжения проволок в модуле**
- Разработан, изготовлен и испытан **стенд для испытаний модулей с помощью β-частиц**
- Оборудована и подготовлена к началу серийного производства трековых камер мюонного спектрометра **чистая сборочная зона.**
- **Участие в изготовлении, тестировании и анализе** прототипов модулей трековых камер
- Выполнен проект **Мюонного фильтра**

TPC

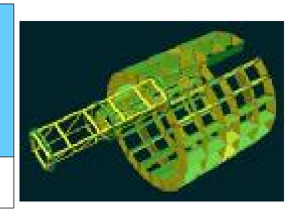
|h|	Spatial resolution [rj , z] [mm]	Gas	X/X_0 [%]	# channels [M]	Occupancy [%]
0.9	800 - 1100	Ne(90%) CO_2	3.5 - 5	0.56	40 – 15

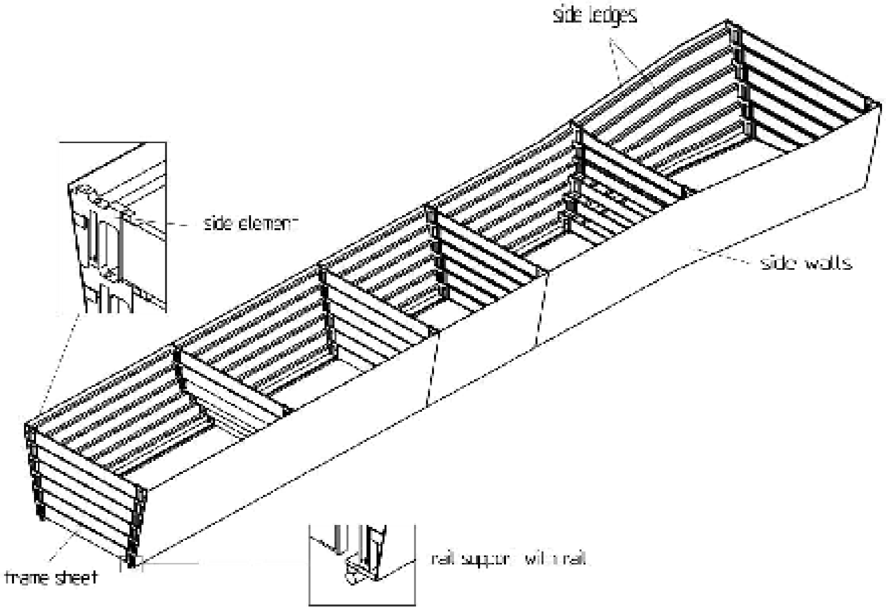




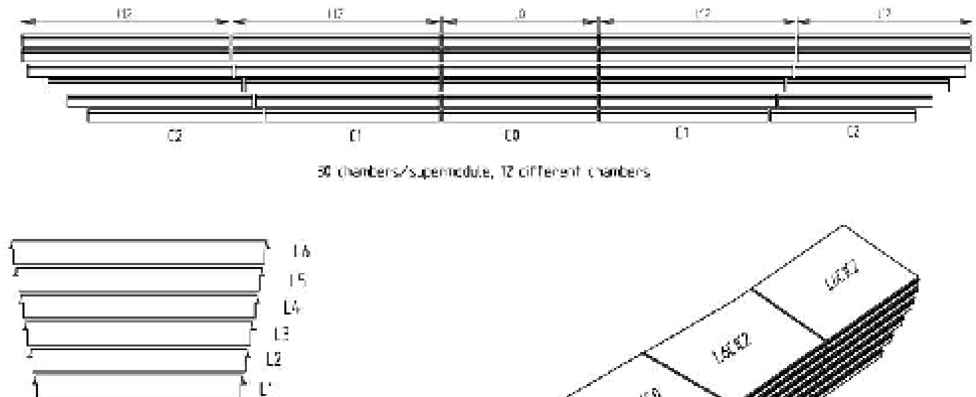
TRD

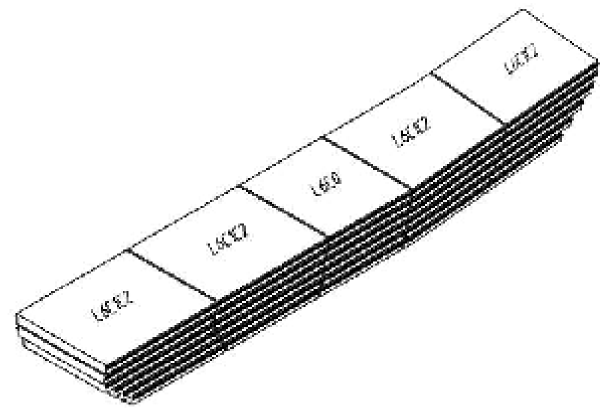
|h|	Spatial resolution [r j , z] [mm]	Gas MWPC	e [cm] X/X_0	# channels [M]	Occupancy [%]
0.9	400	Xe(85%) CO	6x4.8 / 14.3%	1.16	34





Supermodule (x108): 7m long



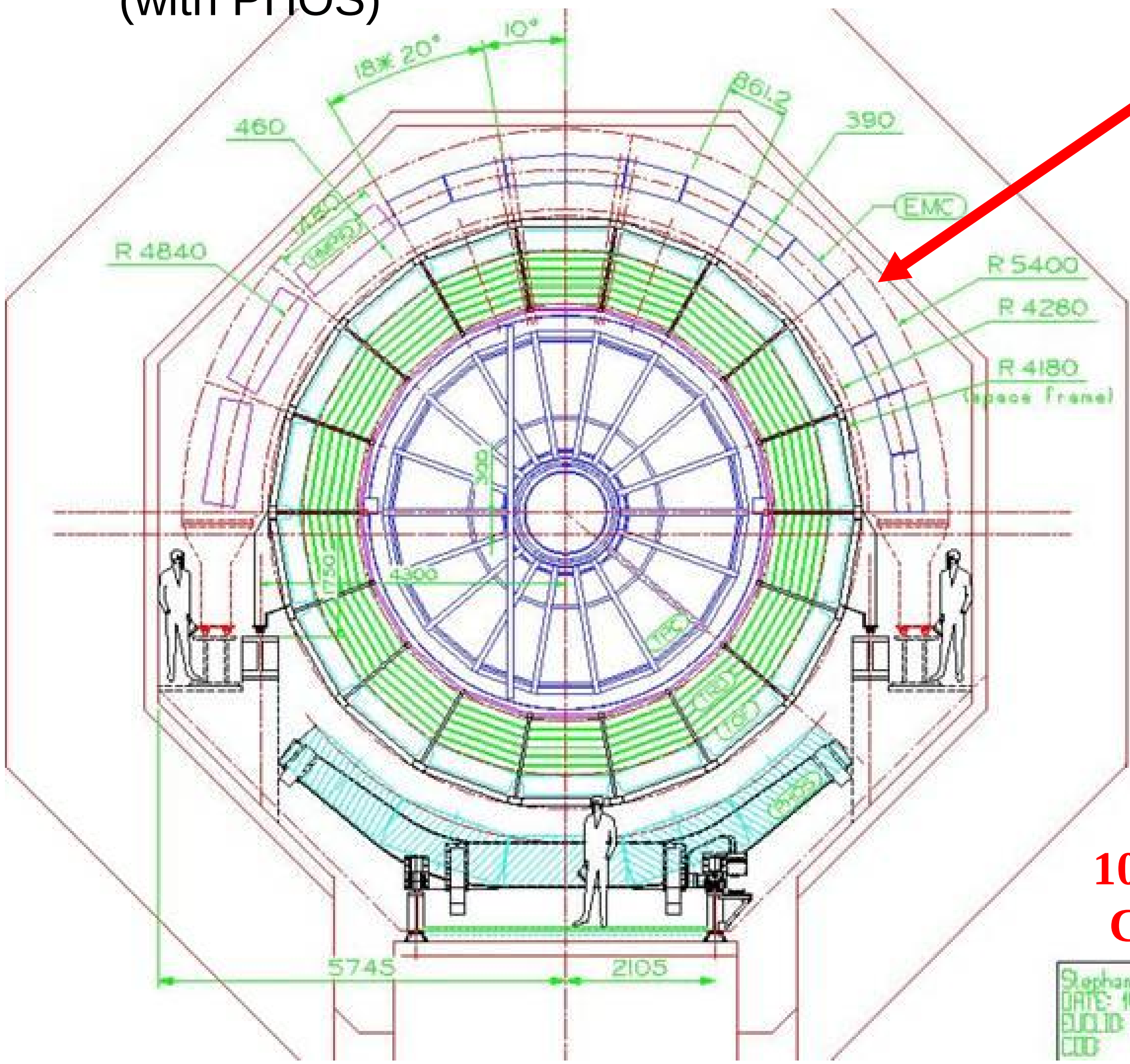


Module (x5): 6 layers of chambers

ALICE-TRD, overview of different chambers in one supermodule

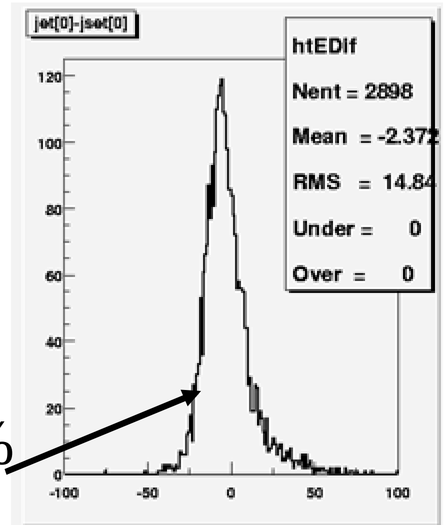
US proposal: large emcal

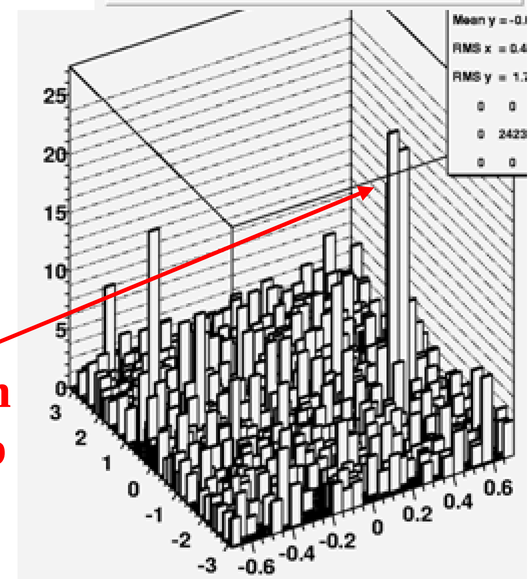
- **large area electromagnetic calorimeter (a la STAR)**
  - – hadronic energy in TPC + em energy in calorimeter
  - – trigger on jets, improve energy resolution, γ-jet coincidences (with PHOS)



Proposed EMCAL
|h|<0.7
Df ~ 120º

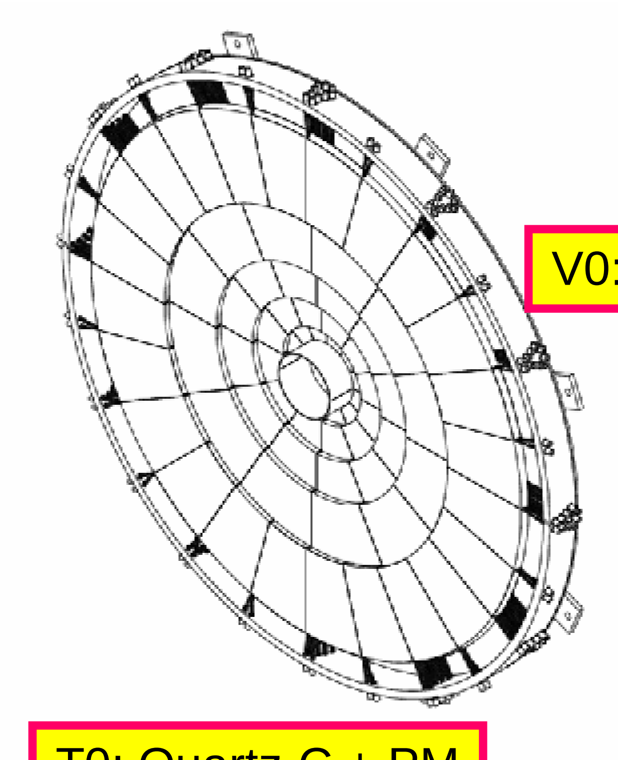
σ(P_T) ~15%





100 GeV Jet in Central PbPb

Trigger Counters T0/V0/PMD

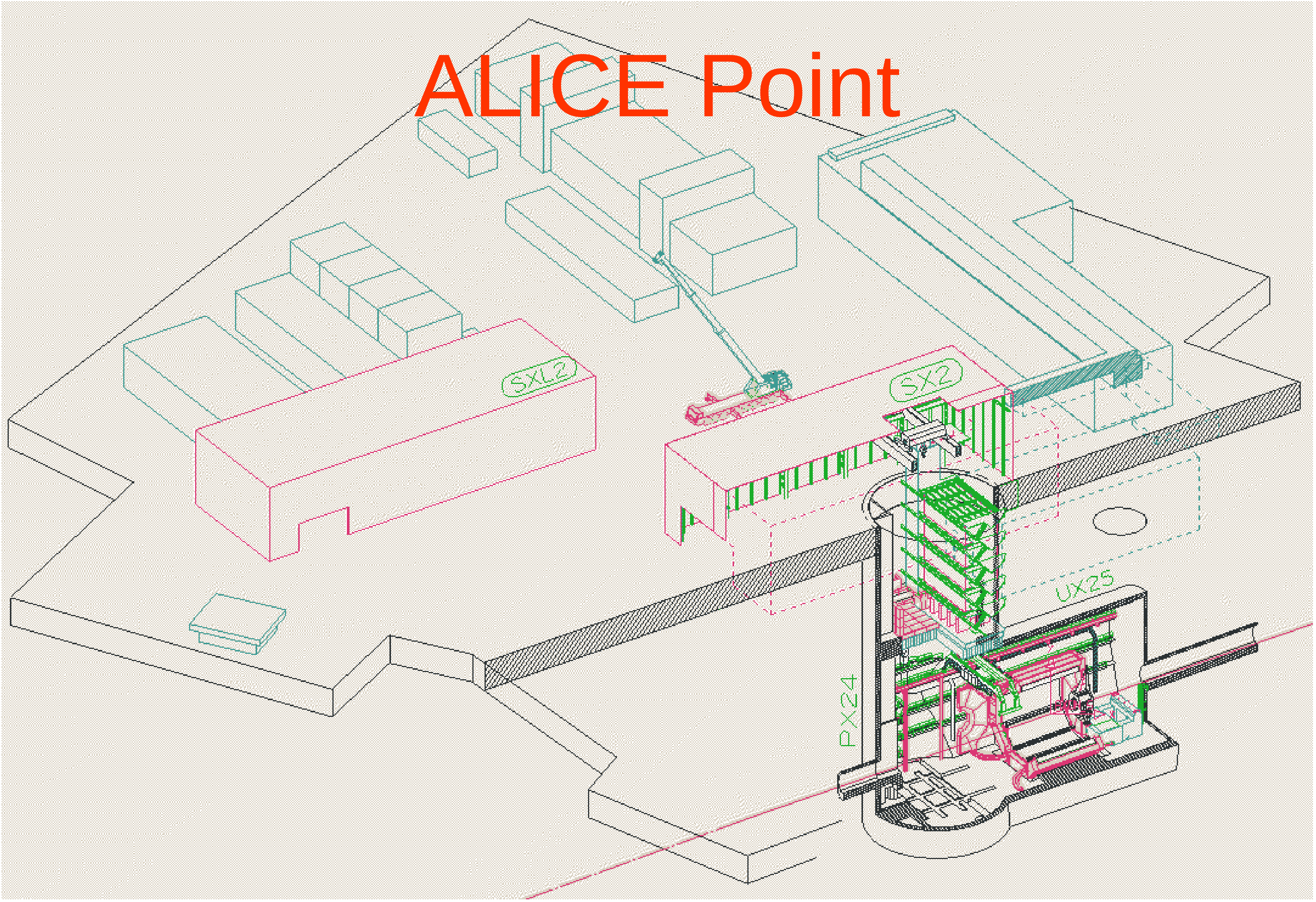


V0: Scintillator + PM

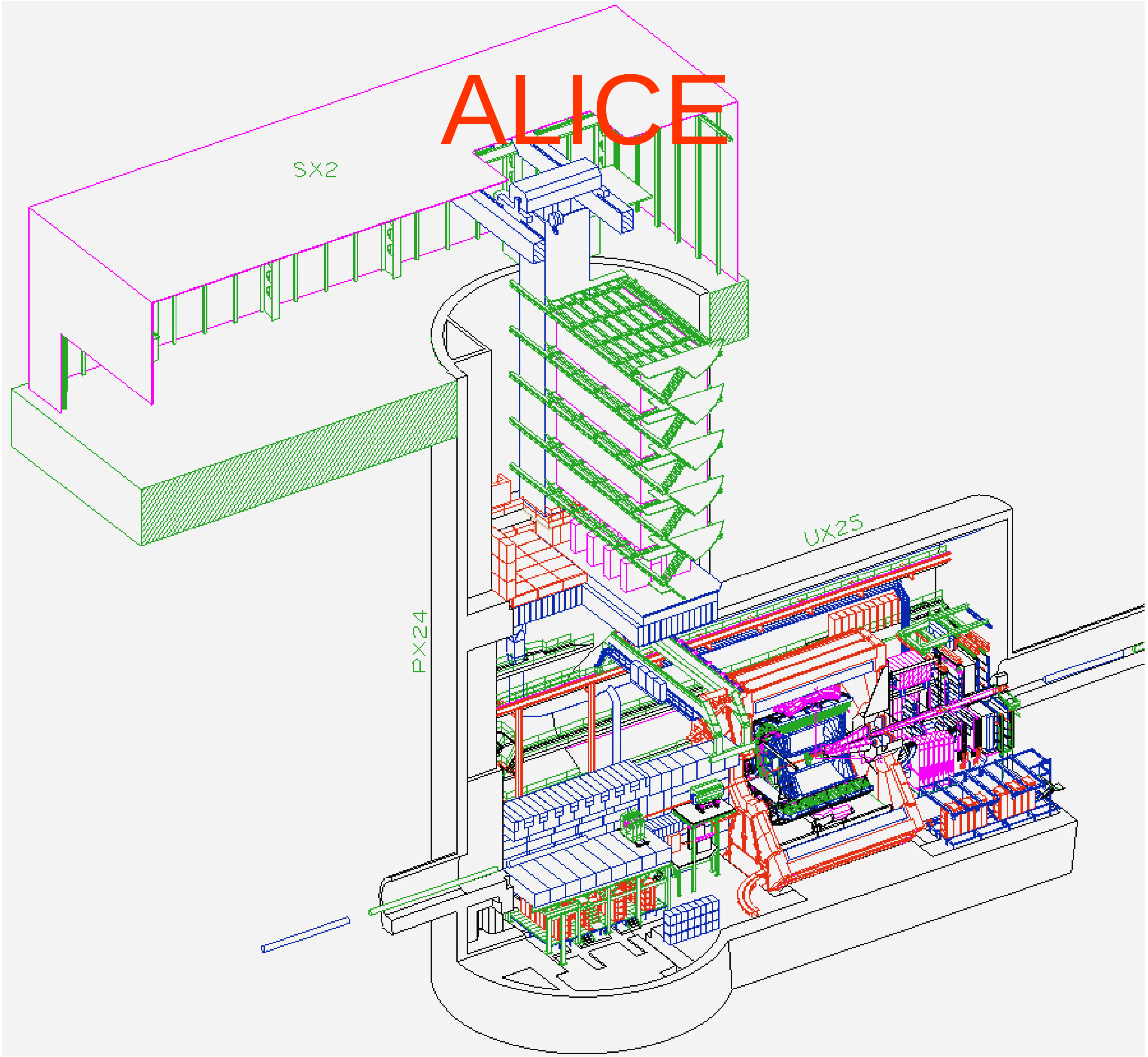
PMD Photon Multiplicity Detector

T0: Quartz-C + PM

ALICE Point

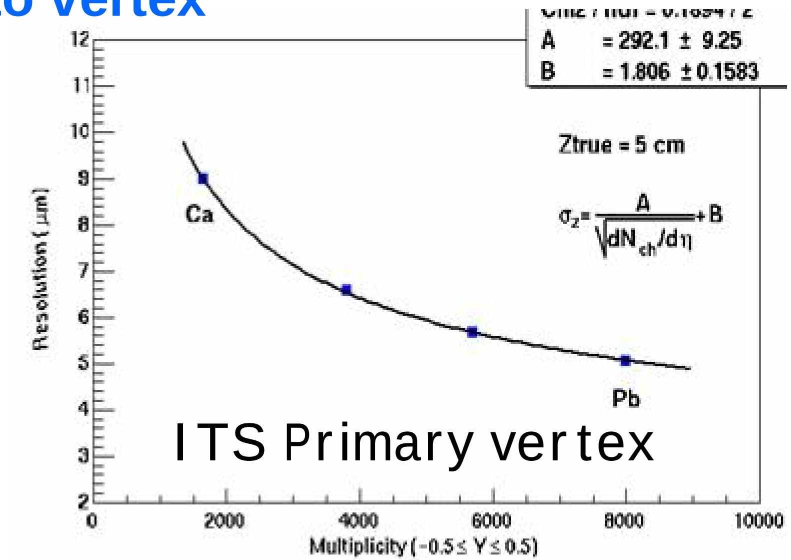


ALICE

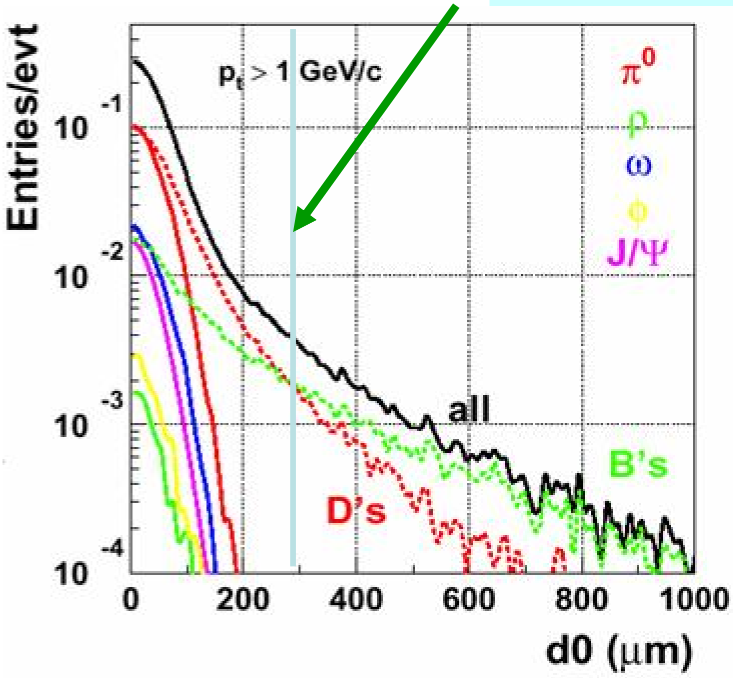


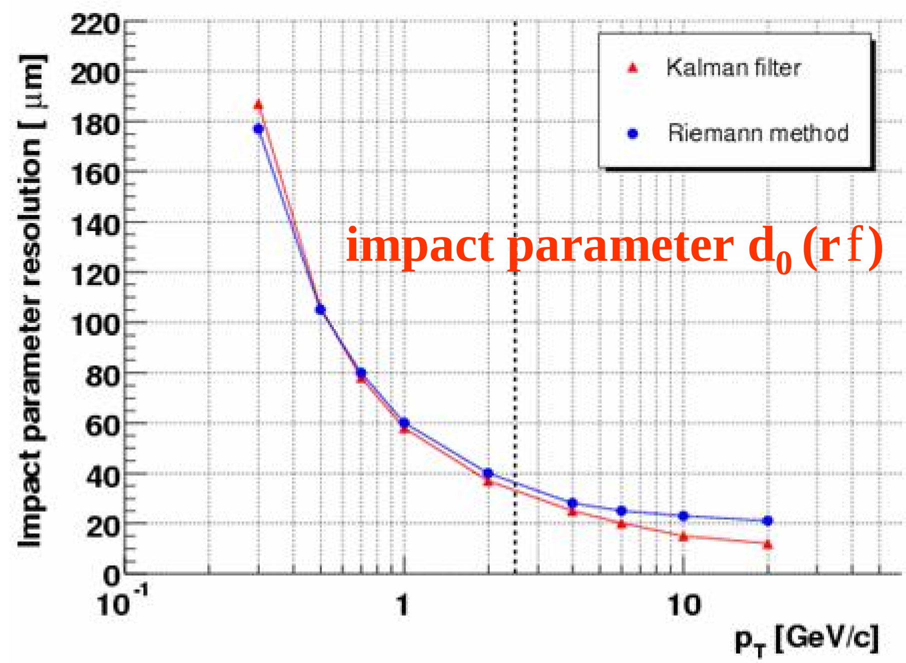
Vertex Finding

- **little material + good resolution + close to vertex**
  - primary vertex:
    - 15 mm (rf) x 5 mm (z)
  - secondary vertices:
    - heavy quarks (100's mm)
    - hyperons (cm)

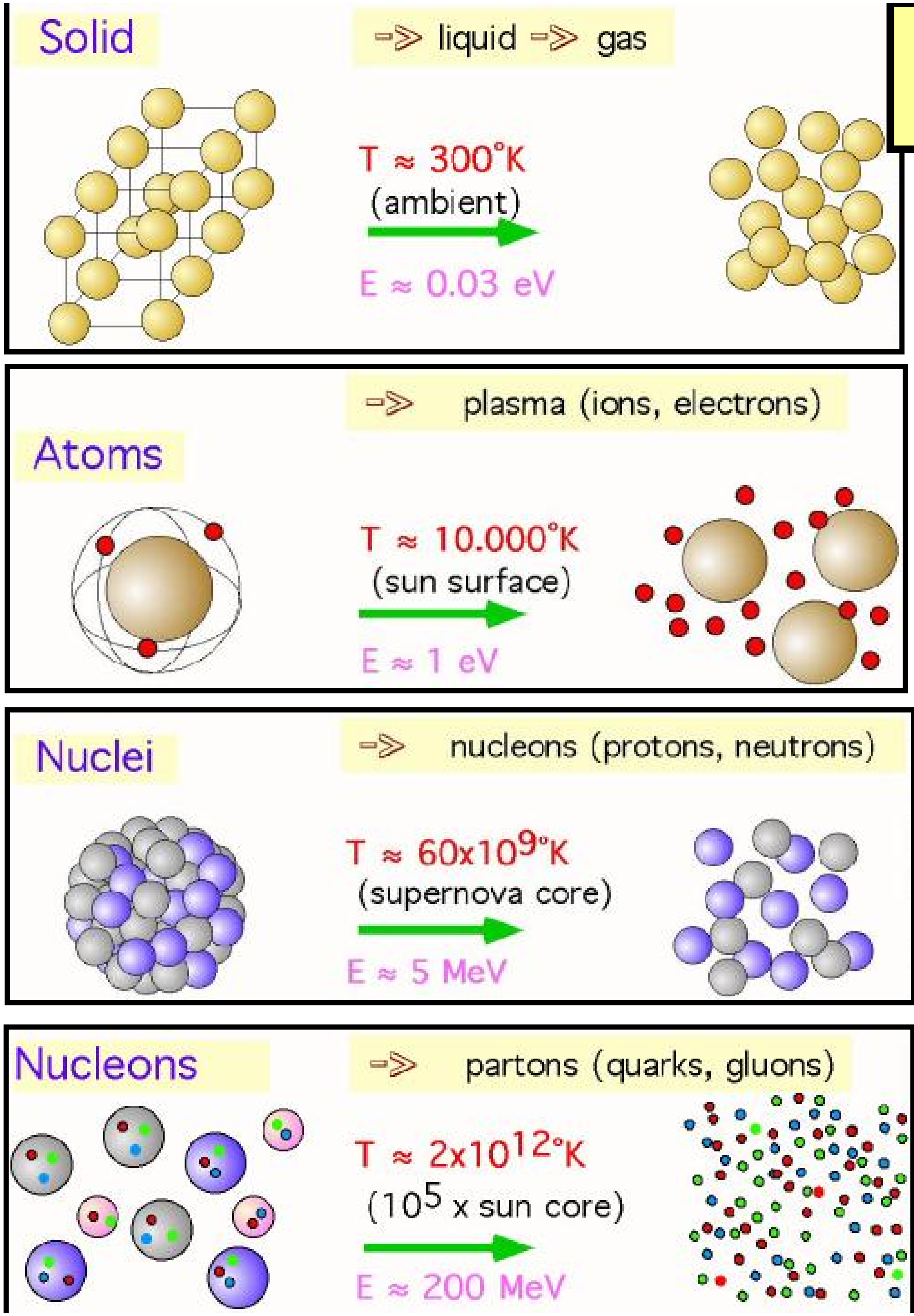


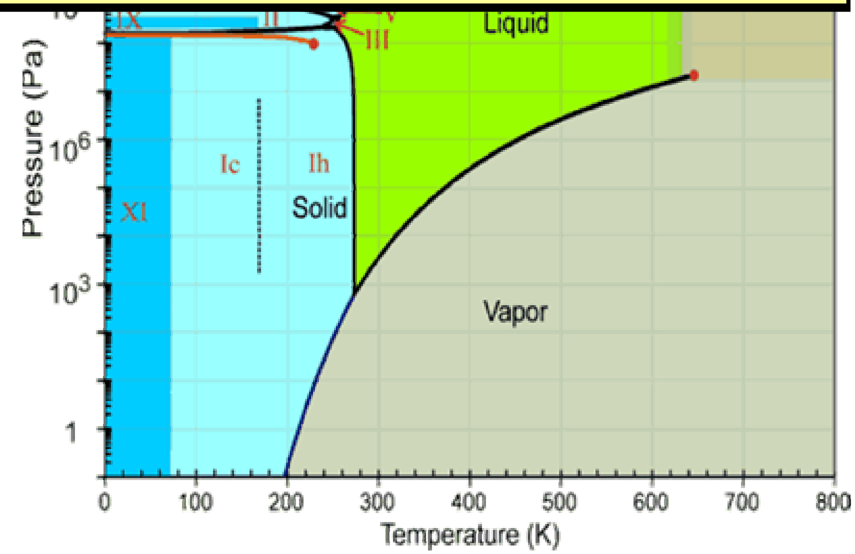
d_0 < cut à resonances
d_0 > cut à D,B mesons

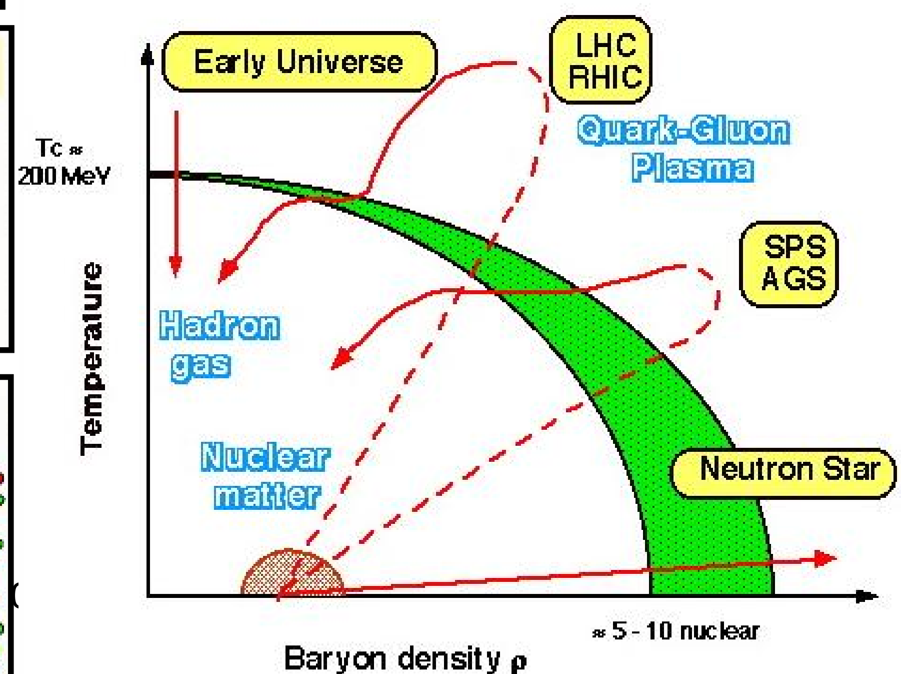


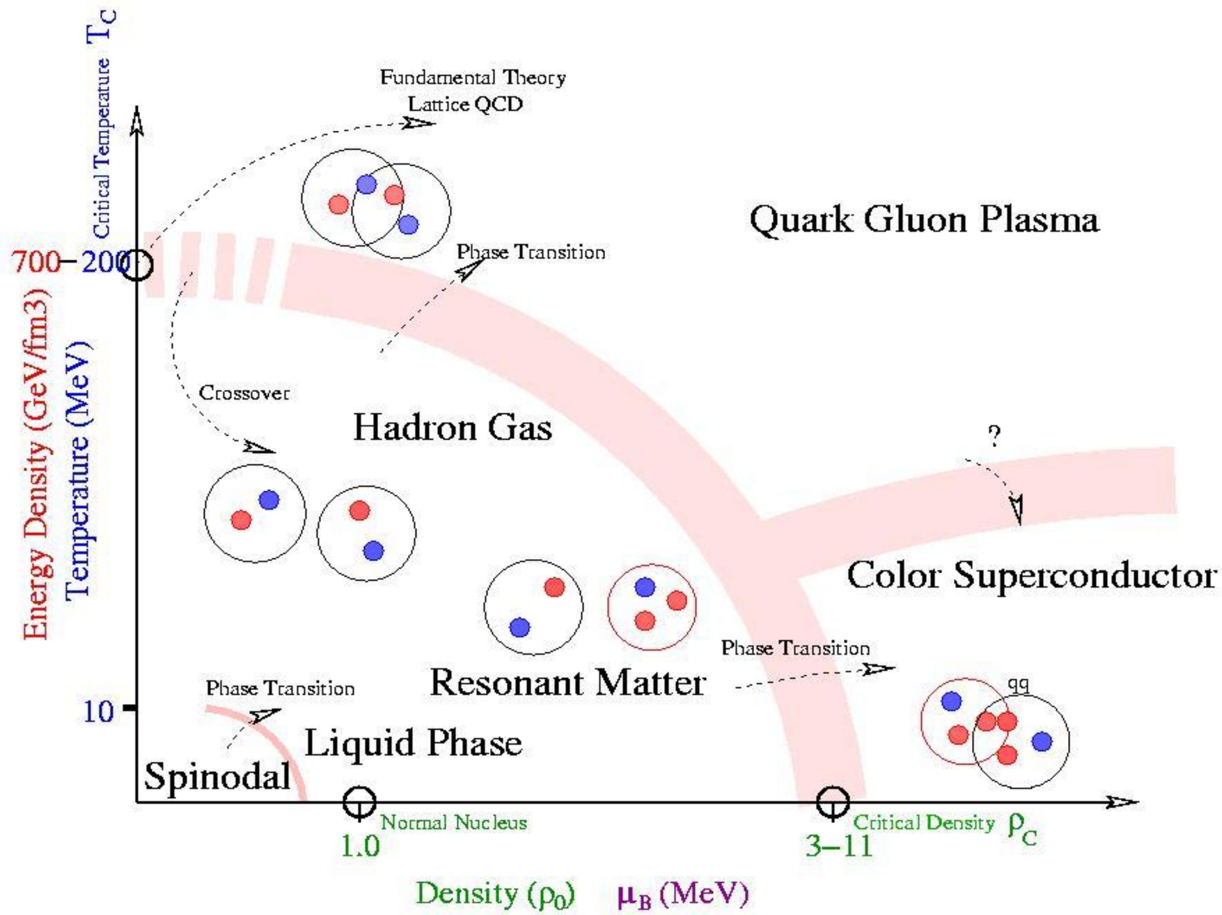


Melting Matter









Critical Temperature T_C
Fundamental Theory
Lattice QCD
Quark Gluon Plasma
700–200
Phase Transition
Energy Density (GeV/fm3)
Temperature (MeV)
Crossover
Hadron Gas
?
Color Superconductor
Phase Transition
Resonant Matter
Phase Transition
qq
10
Liquid Phase
Spinodal
Normal Nucleus
1.0
3–11
Critical Density ρ_C
Density (ρ_0)
μ_B (MeV)