Probing Quark-Gluon Matter with the ALICE Experiment at the CERN-LHC

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DESY Seminar 24./25.4.07

BMBF Forschungsschwerpunkt
ALICE Experiment 201
ALICE

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Introduction
Physics at the Large Hadron Collider

LHC startup planned this year

Main physics objectives:

- Higgs boson
- Physics beyond the standard model (Supersymmetry, etc.)
- Other ... ?

This talk:

- Heavy ion physics at the LHC
- ALICE: Dedicated heavy ion experiment at the LHC

Heavy Ion Physics: A Different Paradigm

"In high-energy physics we have concentrated on experiments in which we distribute a higher and higher amount of energy into a region with smaller and smaller dimensions.

In order to study the question of 'vacuum', we must turn to a different direction; we should investigate some bulk phenomena by distributing high energy over a relatively large volume"

T.D. Lee
Rev. Mod. Phys. 47 (1975) 267.

Outline

Heavy ion physics

Observables

The ALICE experiment

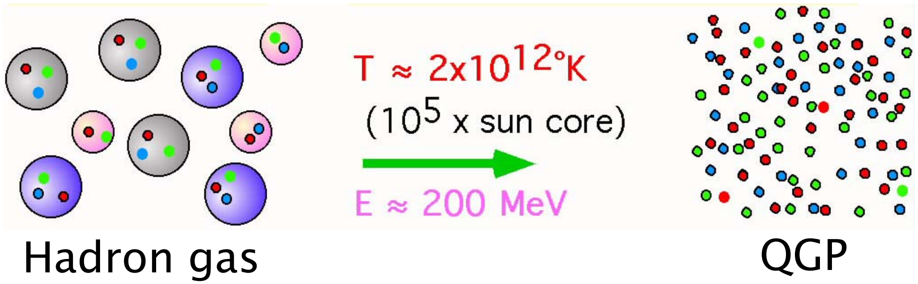
Physics performance

Heavy Ion Physics
Objectives

Study of matter at extreme temperatures and densities

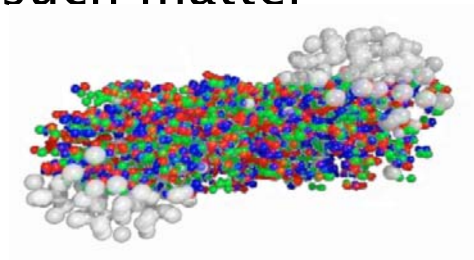
Quark-Gluon Plasma (QGP)

- Deconfined quarks and gluons, “colored” medium
- Restoration of chiral symmetry (i.e. ~massless partons)



Heavy ion collisions only means to create such matter in the laboratory

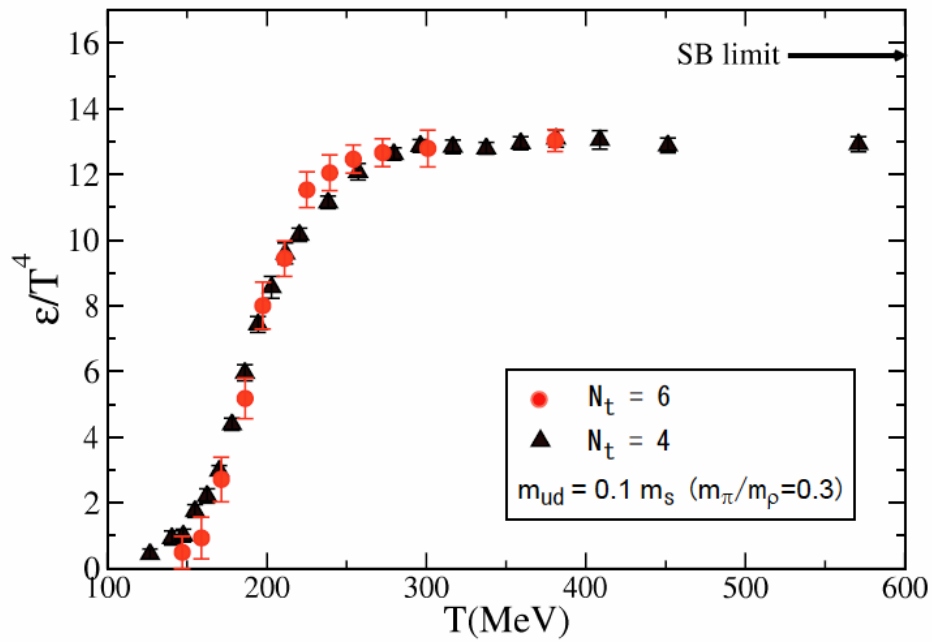
- Establish the existence of QGP phase
- Measure its properties



Heavy Ion Physics
Lattice QCD Predictions

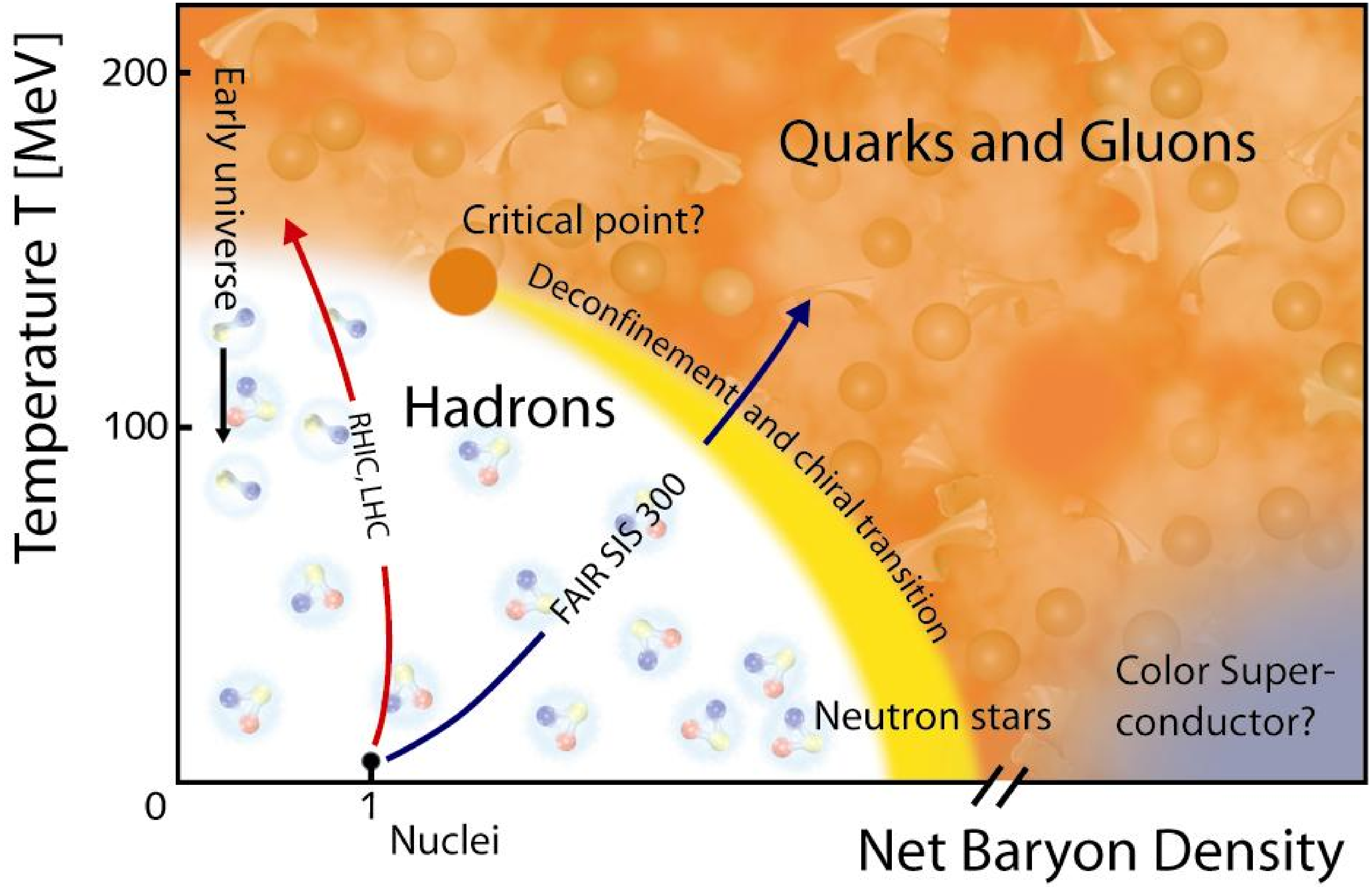
Lattice QCD:

- Theoretical access to non-pertubative QCD regime from first principles
- Lots of progress in recent years
  (improved actions, physical quark masses, etc.)
- Predicts crossover transition for LHC condition ($\mu_B = 0$)

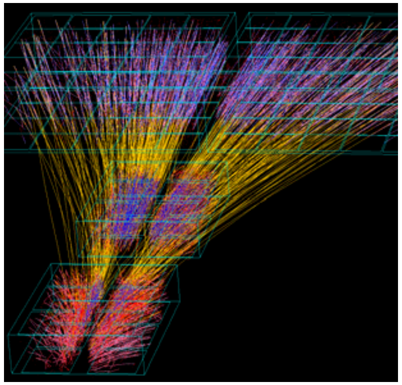


Energy density in a full QCD calculation ($N_f = 2+1$):
MILC Collaboration, hep-lat/061001

Heavy Ion Physics
Phases of Strongly Interacting Matter

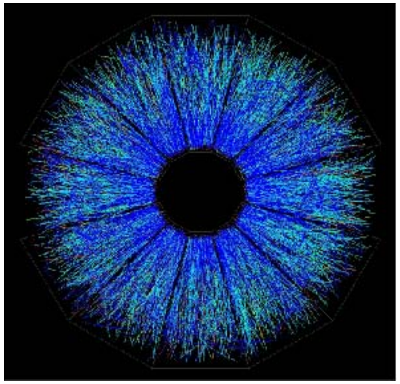


Heavy Ion Physics
History of Experiments



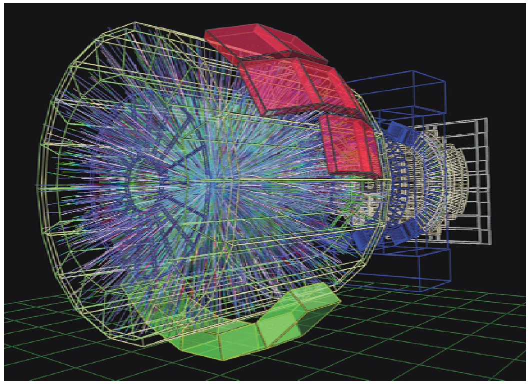
SPS
$\sqrt{s_{NN}} = 6 - 17\text{GeV}$

Fixed target experiments



RHIC
$\sqrt{s_{NN}} = 20\text{–}200\text{GeV}$

Collider experiments (STAR, PHENIX, PHOBOS, BRAHMS)

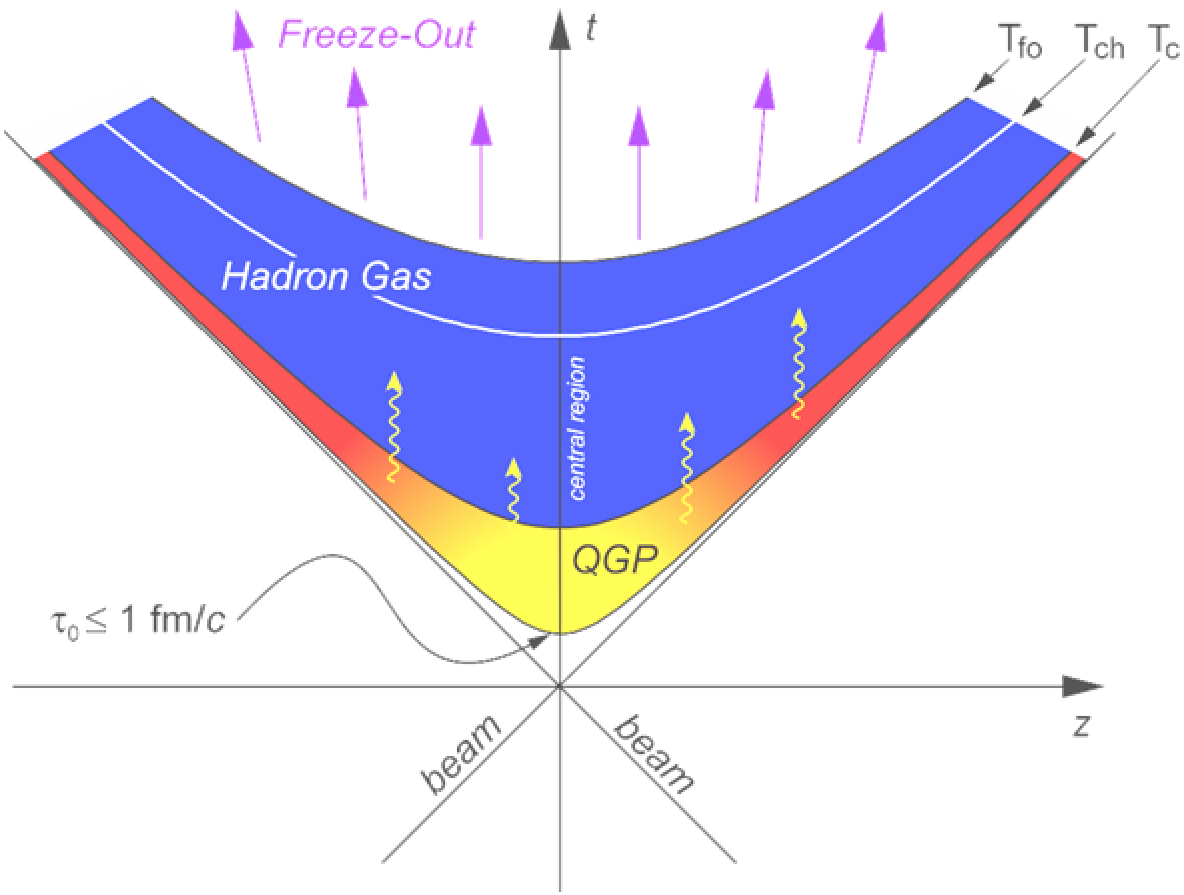


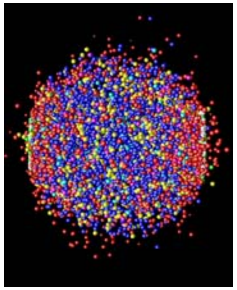
LHC
$\sqrt{s_{NN}} = 5.5\text{TeV}$

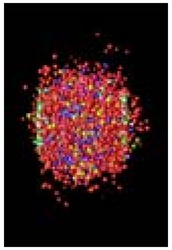
ALICE: dedicated heavy ion experiment

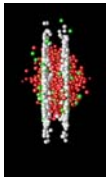
ATLAS+CMS: Heavy ion program planned

Time Evolution of a Heavy Ion Collision




Freeze–Out


Hadronization


QGP Formation


Hard Scattering


Incoming Nuclei

Observables

Time Evolution of a Heavy Ion Collision

System undergoes a rapid dynamical evolution

- Different observables test different phases
- Rich phenomenology

Observables needed that convey information from early stages

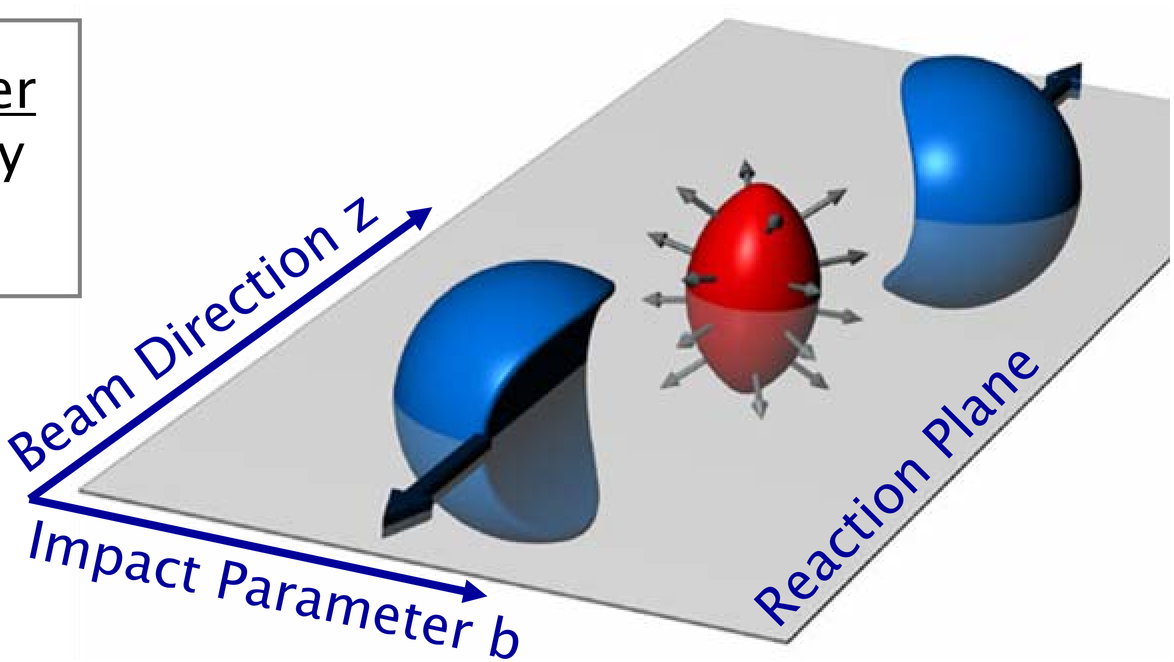
- Try to charaterize QGP phase → hard probes essential

Three examples:

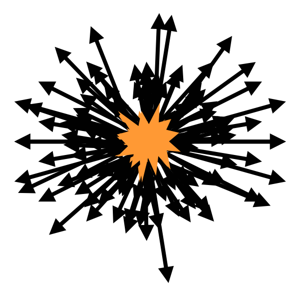
- Flow
- Jet-quenching
- Quarkonia

Observables
Flow

Sensitive to matter properties at early stage of collision



Initial spatial anisotropy:
- → Different pressure gradients
- → Momentum anisotropy relative to reaction plane



Independent p+p collisions:
No anisotropy

Interacting matter:
Anisotropy due to larger in-plane pressure

Observables

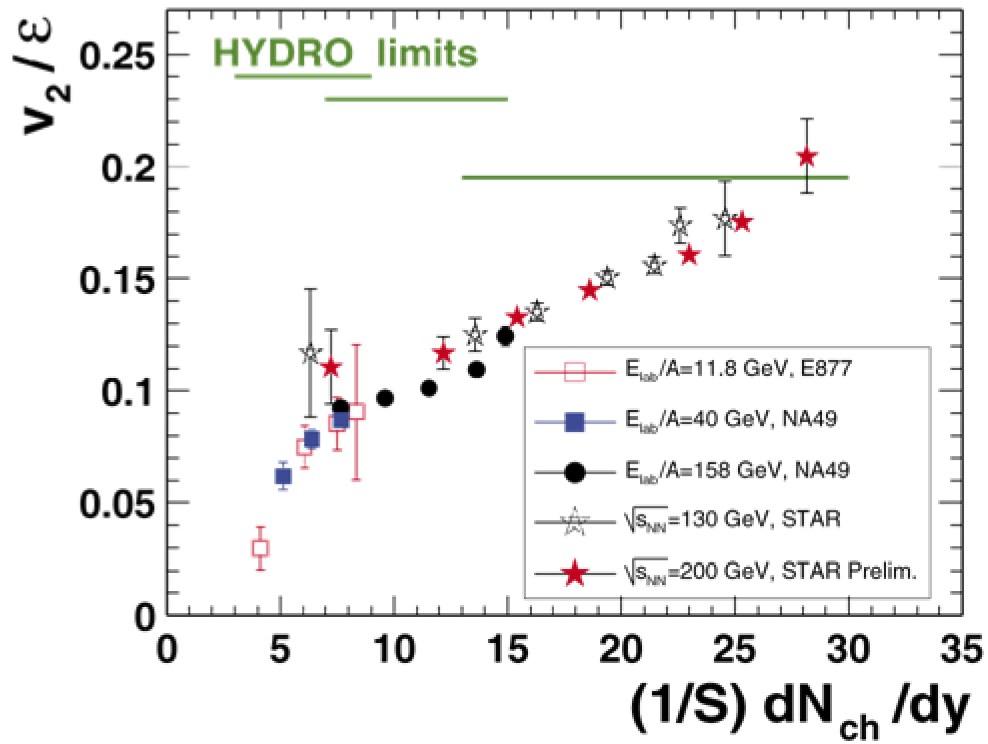
Flow: Experimental Results

Flow is quantified by second Fourier component v_2

Observed flow is approaching the limit of ideal hydrodynamics!

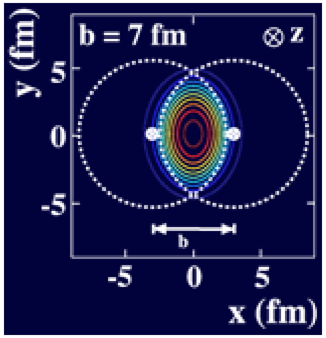
Liquid with very low viscosity
(~zero mean free path)

$\rightarrow$ "*Perfect Liquid*"
(close to String theory conjecture: $\eta/s \geq 1/4\pi$)



Initial eccentricity ε:

$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$



Observables
Jet-Quenching

Two-jet event in p+p

Scattered quarks fragment in vacuum

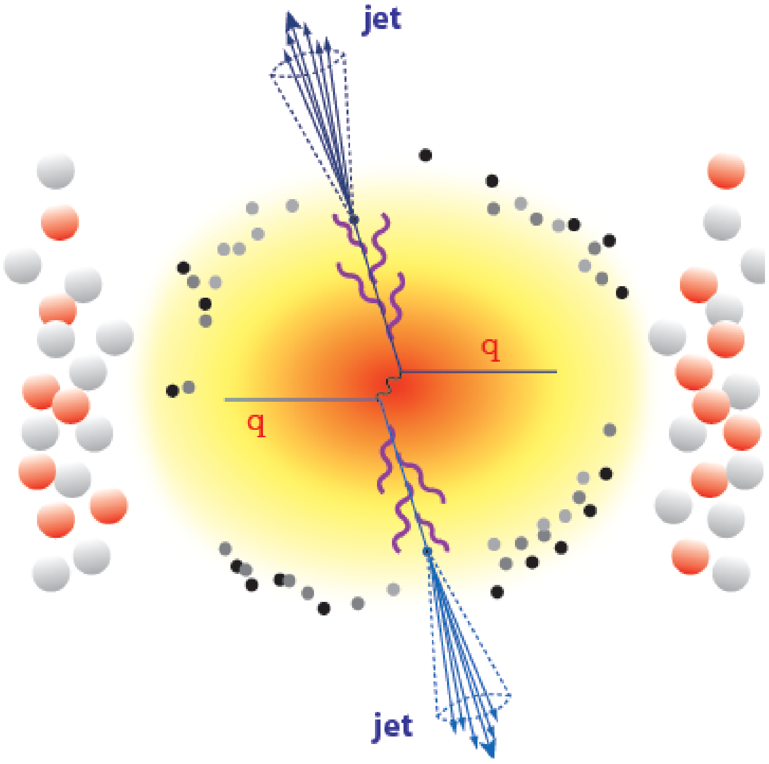
Basic idea:

Use scattered partons as a probe of the medium

Jets in medium:

Energy loss due to induced gluon radiation + elastic scattering

Much stronger in QGP than in cold nuclear matter



Jet-Quenching: Theoretical Approaches

Original Idea by J.D. Bjorken

Enhanced energy loss due to elastic scattering

FERMILAB-Pub-82/59-THY
August, 1982

Energy Loss of Energetic Partons in Quark-Gluon Plasma:
Possible Extinction of High p_T Jets in Hadron-Hadron Collisions.

J. D. BJORKEN
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

Induced gluon radiation

Main source of energy loss

Energy loss depends on traversed path length L and gluon density ρ_{glue}

Different approximations

Thick plasma approximation:
Baier, Dokshitzer, Müller, Peigné, Schiff

$$\Delta E_{BDMPS} = \frac{C_R \alpha_S}{4} \hat{q}\, L^2\, \tilde{v}$$

$$\hat{q} = \frac{\mu_{Debye}}{\lambda_{glue}} \propto \alpha_S\, \rho_{glue}$$

Thin plasma approximation:
Gyulassy, Levai, Vitev

$$\Delta E_{GLV} = C_R\, \alpha_S^3 \int \mathrm{d}\tau\, \tau\, \rho_{glue}(\tau) \log\left(\frac{2E_{jet}}{\mu^2 L}\right)$$

Observables

Jet-Quenching: Nuclear Modification Factor

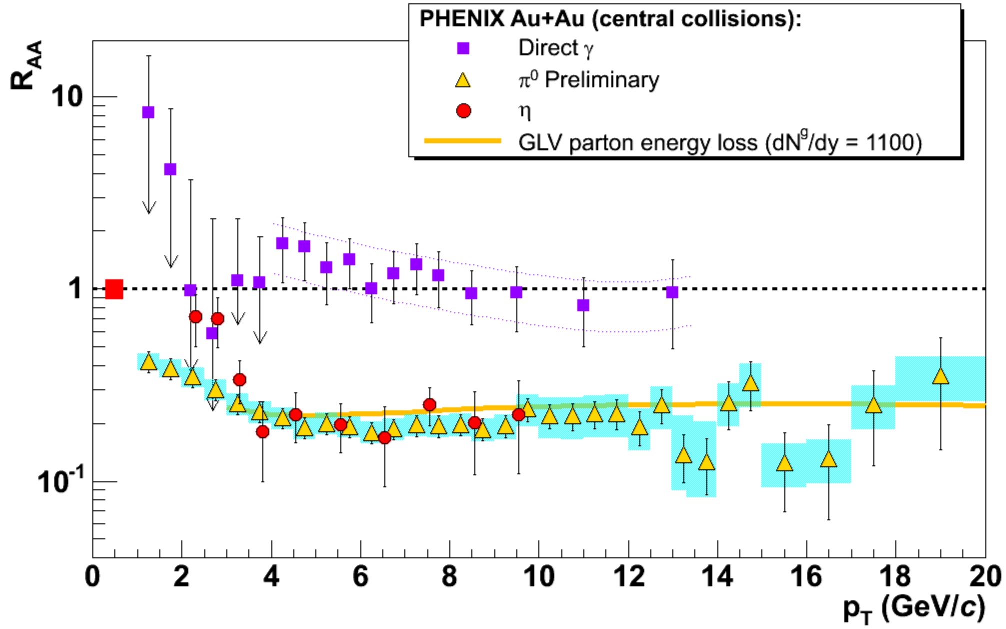
Simple observable:

Compare scaled p+p to A+A at high p_t

$R_{AA}=1$: No effect (binary scaling for hard processes)

$R_{AA}>1$: Enhancement (e.g. Cronin effect in p+A collisions)

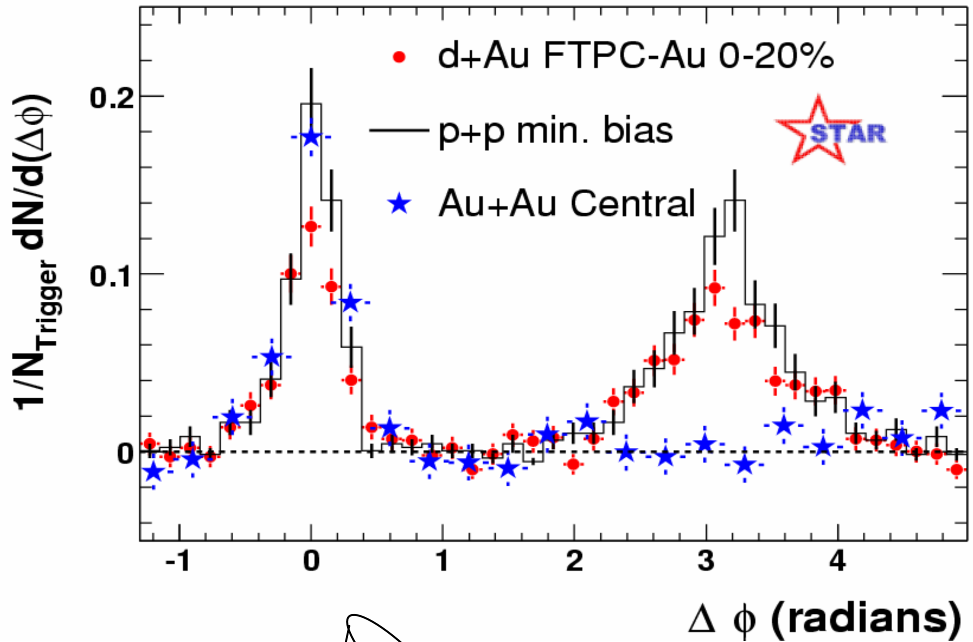
$R_{AA}<1$: Suppression

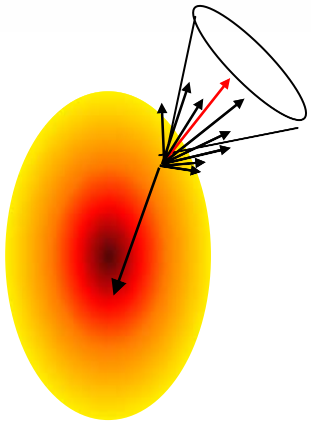


$$R_{AA}(p_t) = \frac{\sigma_{inel}^{pp}}{\langle N_{coll} \rangle} \frac{d^2N_{AA}/(dp_t\,dy)}{d^2\sigma_{pp}/(dp_t\,dy)}$$

Jet-Quenching: Correlations

- Jet studies via azimuthal correlations
  - Reconstruction of full jets difficult in heavy ion collisions
  - Huge "underlying event"
- Away side peak disappears in A+A !
  - Clearly seen in p+p and d+Au
    $\rightarrow$ Final state effect
  - Very dense system !



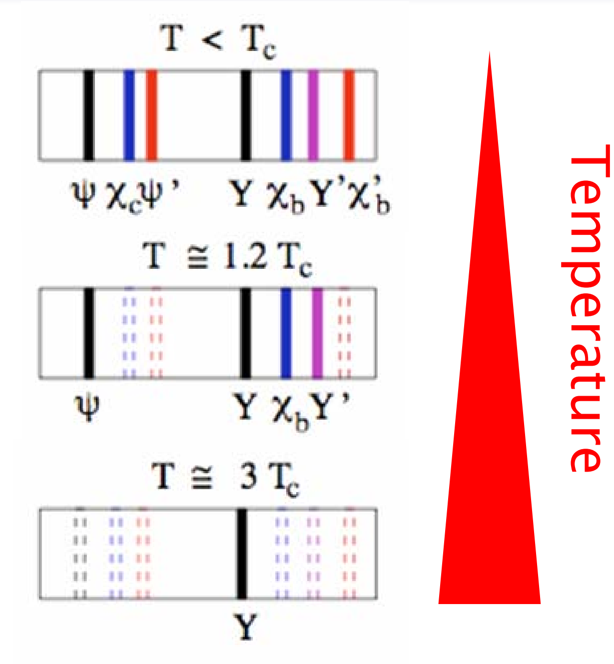


Observables
Quarkonia

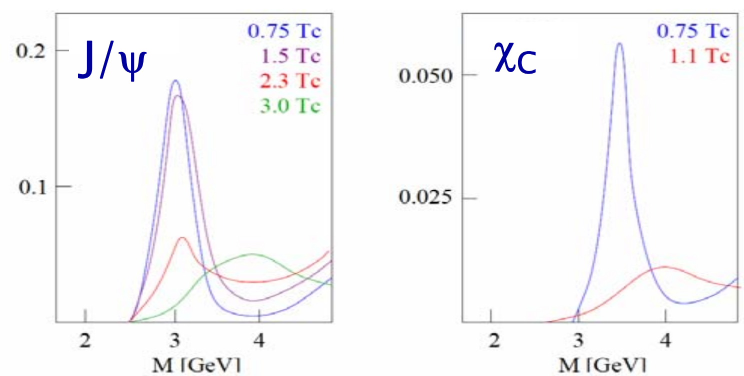
Suppression of Charmonia
one of the earliest proposals for a QGP signature
(Matsui and Satz, 1986)

Screening of $q\bar{q}$-potential in colored medium expected

- Analogous to Debye-screening in e.m. plasma
- Screening length λ_D depends on temperature of matter
  Different states are dissolved at different T
- $\rightarrow$ QCD thermometer



Lattice-QCD:



Datta, Karsch, Petreczky & Wetzorke, hep-lat/0312034

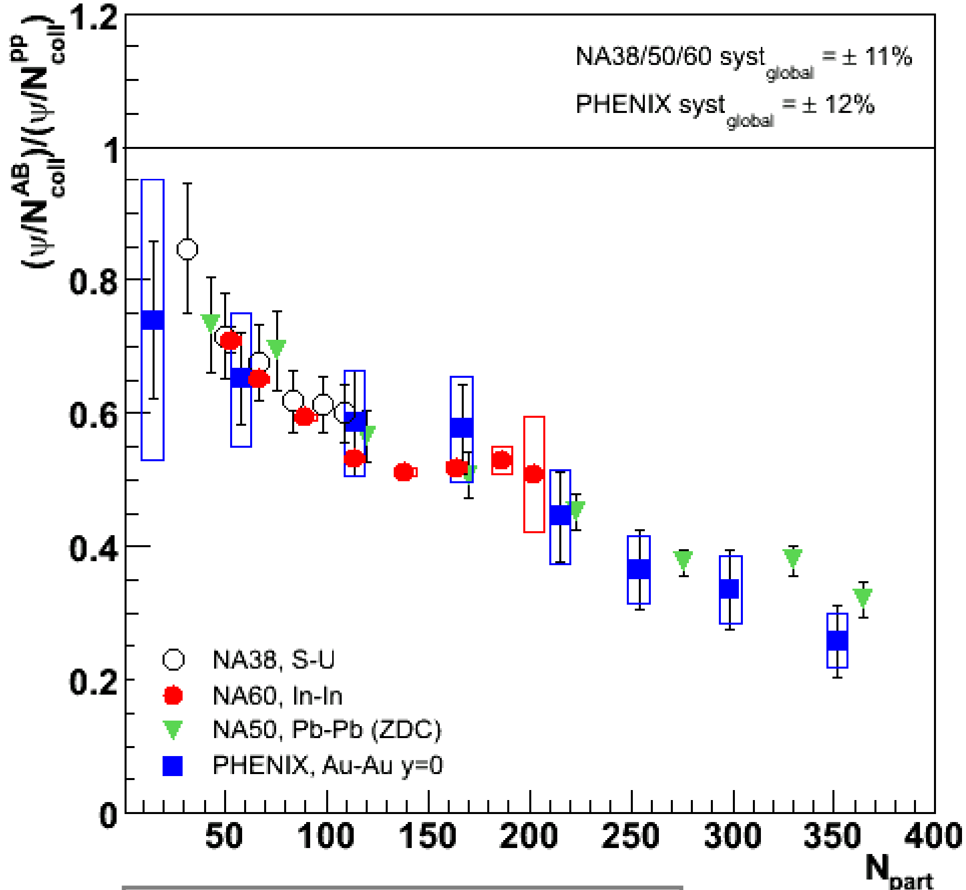
Quarkonia: Measurements

Suppression of J/ψ yield relative to p+p

- Nuclear modification factor decreases with system size N_{part}

<u>However</u>:
Consistent theoretical understanding is still missing !

- Less suppression observed at RHIC than expected
- Interplay of different mechanism ?



$$R_{AA}(J/\psi) = \frac{\langle N^{pp}_{coll} \rangle}{\langle N^{AA}_{coll} \rangle} \frac{N_{AA}(J/\psi)}{N_{pp}(J/\psi)}$$

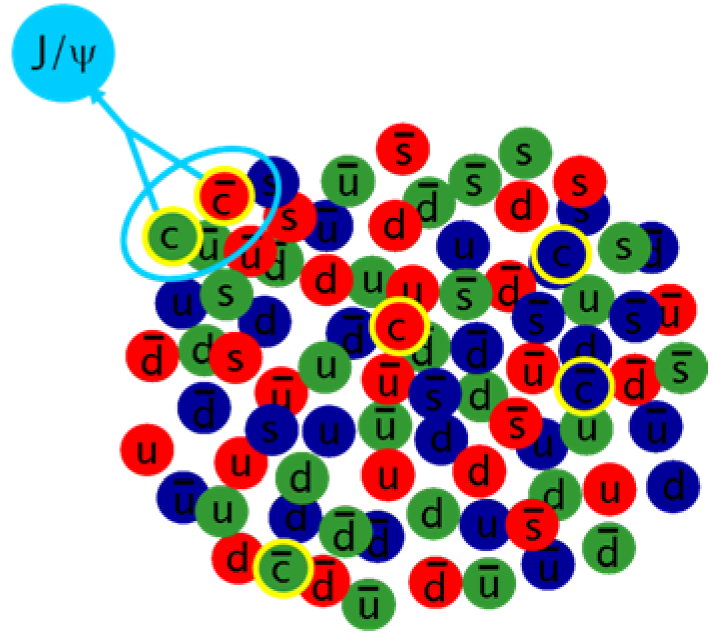
Observables
Quarkonia: Coalescence

Number of produced $c\bar{c}$–pairs is substantial at higher energies

- RHIC ($\sqrt{s_{NN}}$=200GeV): $N(c\bar{c}) > 10$

Contribution of quark coalescence to J/ψ yield possible

- Yield increases with system size
- Opposite effect to suppression mechanism



$$c + \bar{c} \leftrightarrow J/\psi + g$$

Summary so far

Results from SPS and RHIC strongly suggest that a new state of matter is formed in heavy ion collisions at high energies

- Clear evidence for collective, thermal “matter”
- Cannot be understood as hadronic matter !

This matter has peculiar properties

- Almost ideal fluid ($\eta / s \approx 0.1$)
- Very strongly interacting matter with partonic degrees of freedom: sQGP
- Remarkably strong absorbtion of jets
- J/ψ suppression seen (but not really understood)

Observables
Why Heavy Ions at the LHC ?

Move from discovery phase to precision studies

- Quantitative characterization of quark–gluon matter
- Resolve ambiguities of RHIC and SPS results
- New properties to be studied

New probes will be available

- Heavy quarks (open beauty, upsilon–states)
- Real jet studies in heavy ion environment
- Weakly interacting probes (Z^0, $W^{\pm}$)

System will be larger and hotter

- Better defined environment

	SPS	RHIC	LHC
$\sqrt{s_{NN}}$ (GeV)	17	200	5500
dN_{ch}/dy	~450	~850	1500–4000
ε(GeV/fm^3)	3	5	15–60
τ_{QGP} (fm/c)	≤ 2	2–4	≥ 10

Observables
What will be new at LHC ?

Dominated by hard processes

$\sigma_{hard}/\sigma_{total} \approx 98\%$

Very useful tools

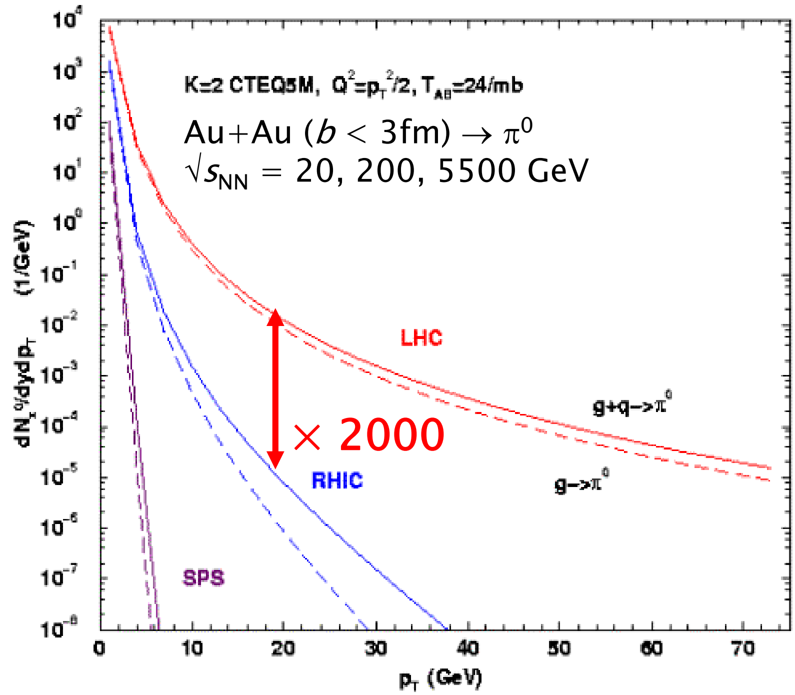
Probes for the early phases of matter

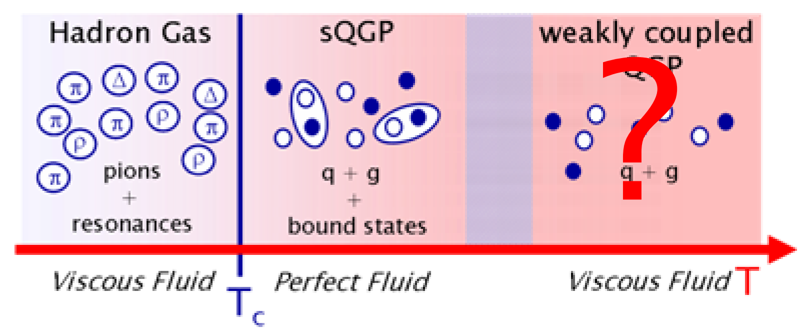
Calculable with pQCD

New regime

Parton dynamics will dominate fireball evolution

Change from sQGP (RHIC) to a weakly coupled QGP ?





Observables
Kinematic Range at LHC

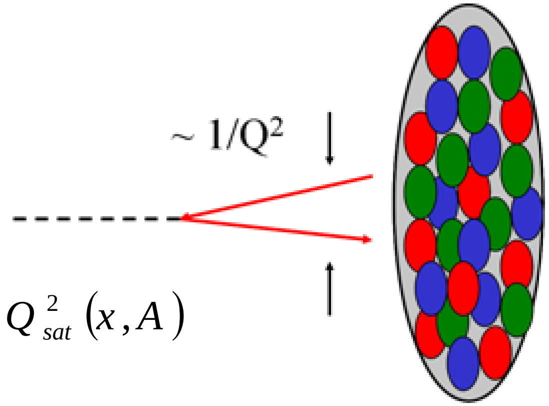
Physics a smaller x

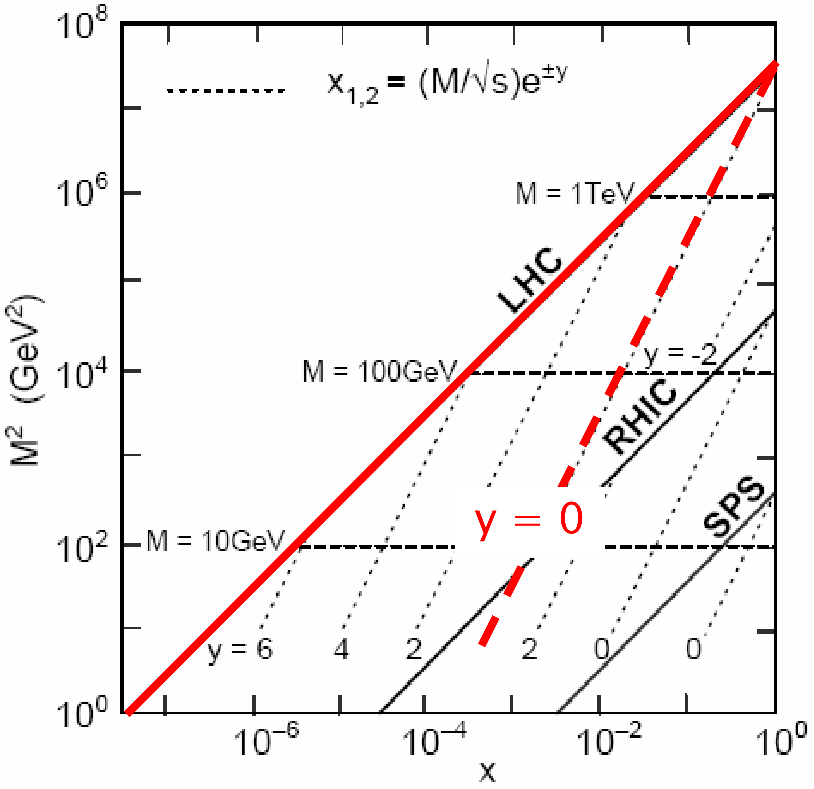
Bulk physics: $10^{-4} < x < 10^{-3}$
Forward regions: $x \approx 10^{-5}$

Different initial state?

Saturation of gluons

Color Glass Condensate
“glasma” (L. McLarren)





Detector Requirements

Robust tracking performance

Needs to digest highest multiplicities (O(10^5) tracks !)

Need to cover low p_t region (~100 MeV/c)

Soft physics important for event characterization

But the high p_t region as well (>100 GeV/c)

Hard probes transmit information about early phase

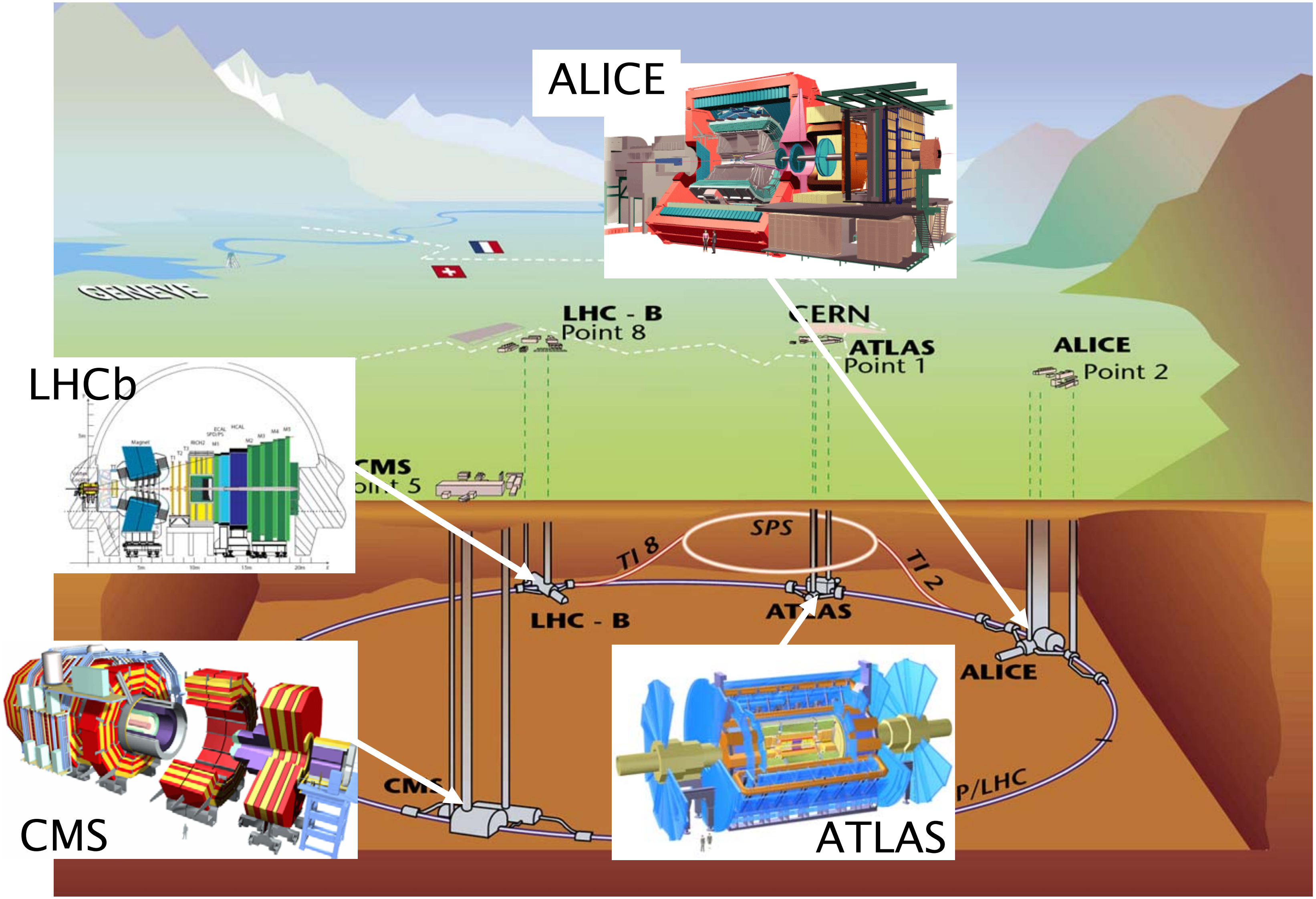
Good PID capabilities over large p_t–range essential

Many effects are flavour dependent

Sensitivity to rare probes

Heavy flavour, quarkonia, photons, ...

Experiments at the LHC



Collaboration

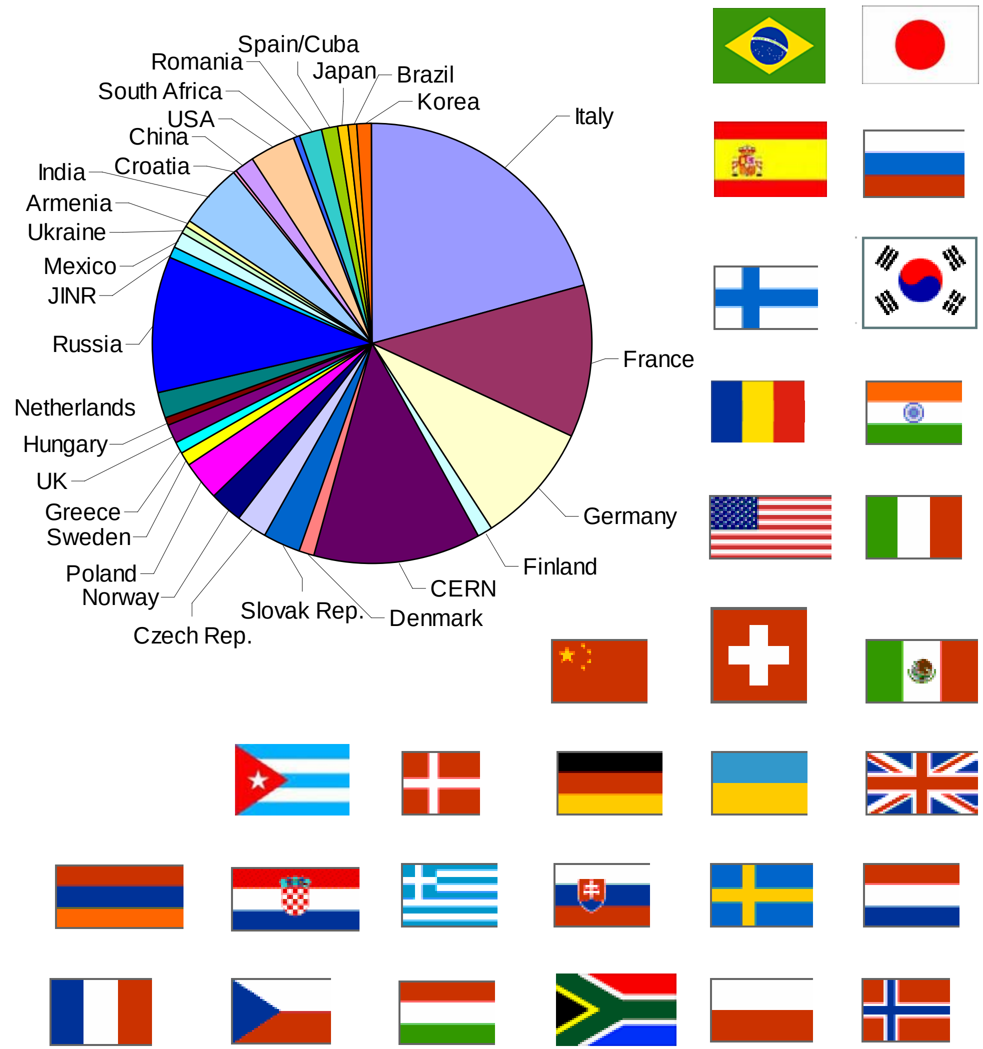
Some numbers:

Members: ca. 1000
Institutes: ca. 100
Countries: 30

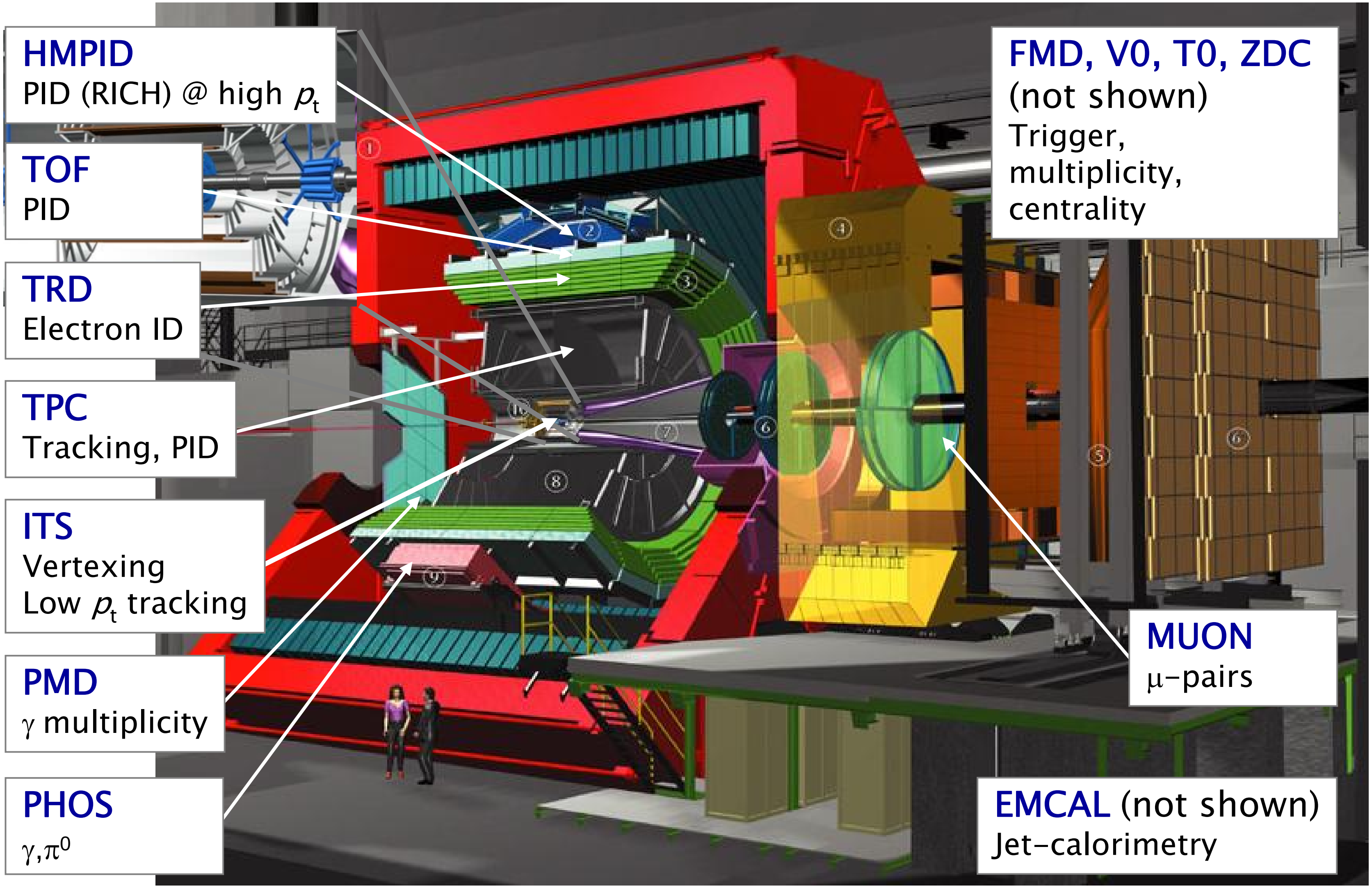
Costs: 150MChF
(+ free magnet)

German institutions:

GSI Darmstadt
TU Darmstadt
Universität Frankfurt
Universität Heidelberg
FZK Karlsruhe
FH Köln
Universität Münster
FH Worms



The ALICE Experiment
Overview

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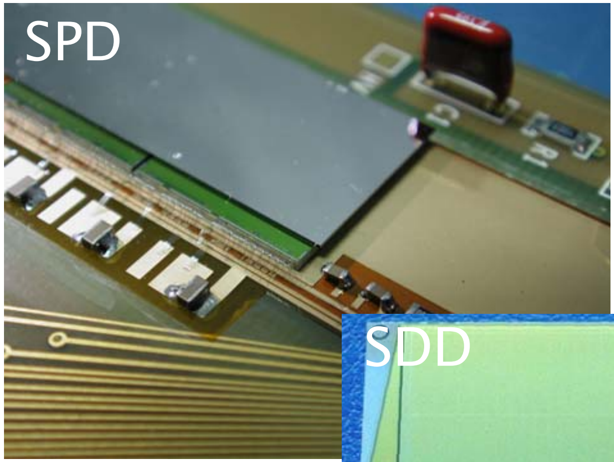
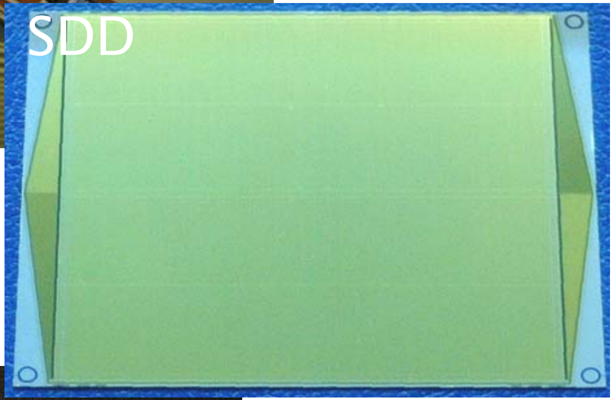
SDEM

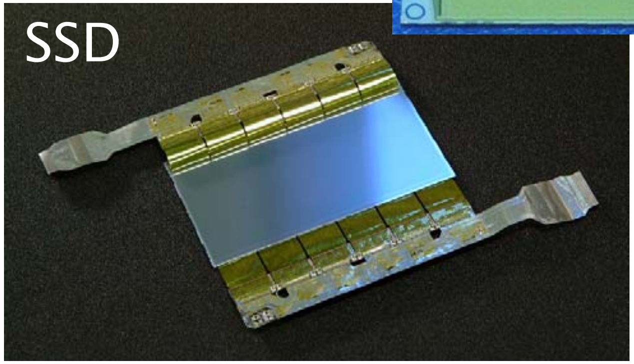
The ALICE Experiment
Inner Tracking System (ITS)

6 Layers with three different detector technologies:

- **S**ilicon **P**ixel **D**etector
- **S**ilicon **D**rift **D**etector
- **S**ilicon **S**trip **D**etector





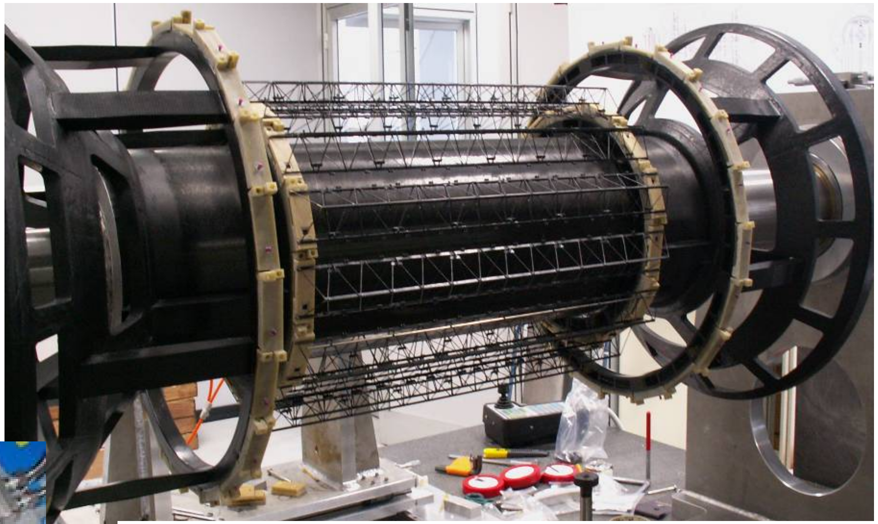


Layer		R (cm)	σ rφ (μm)	σ Z (μm)
1	SPD	4	12	100
2	SPD	8	12	100
3	SDD	15	38	28
4	SDD	24	38	28
5	SSD	38	17	800
6	SSD	43	17	800

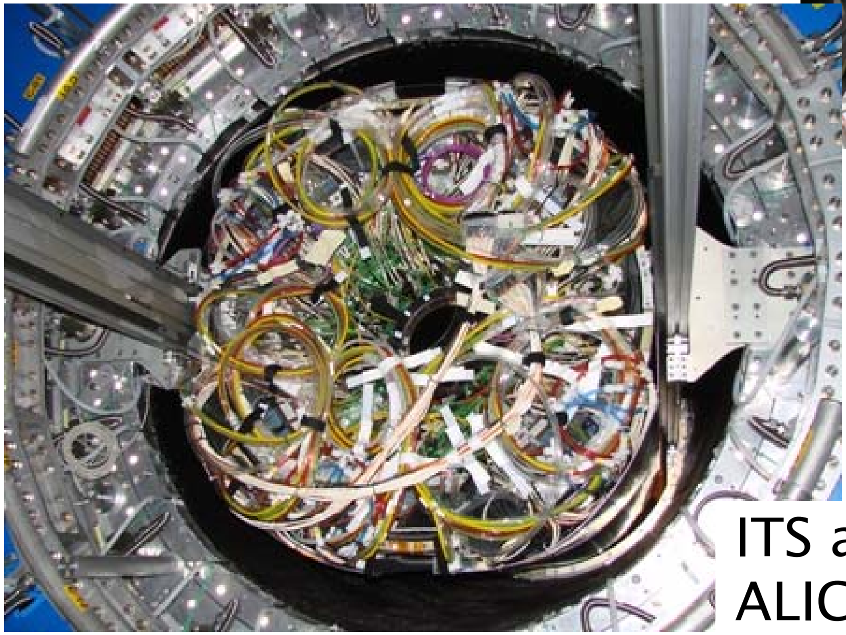
The ALICE Experiment
Inner Tracking System (ITS)

Number of readout channels: 9.8×10^6

Materialbudget: 7% X_0

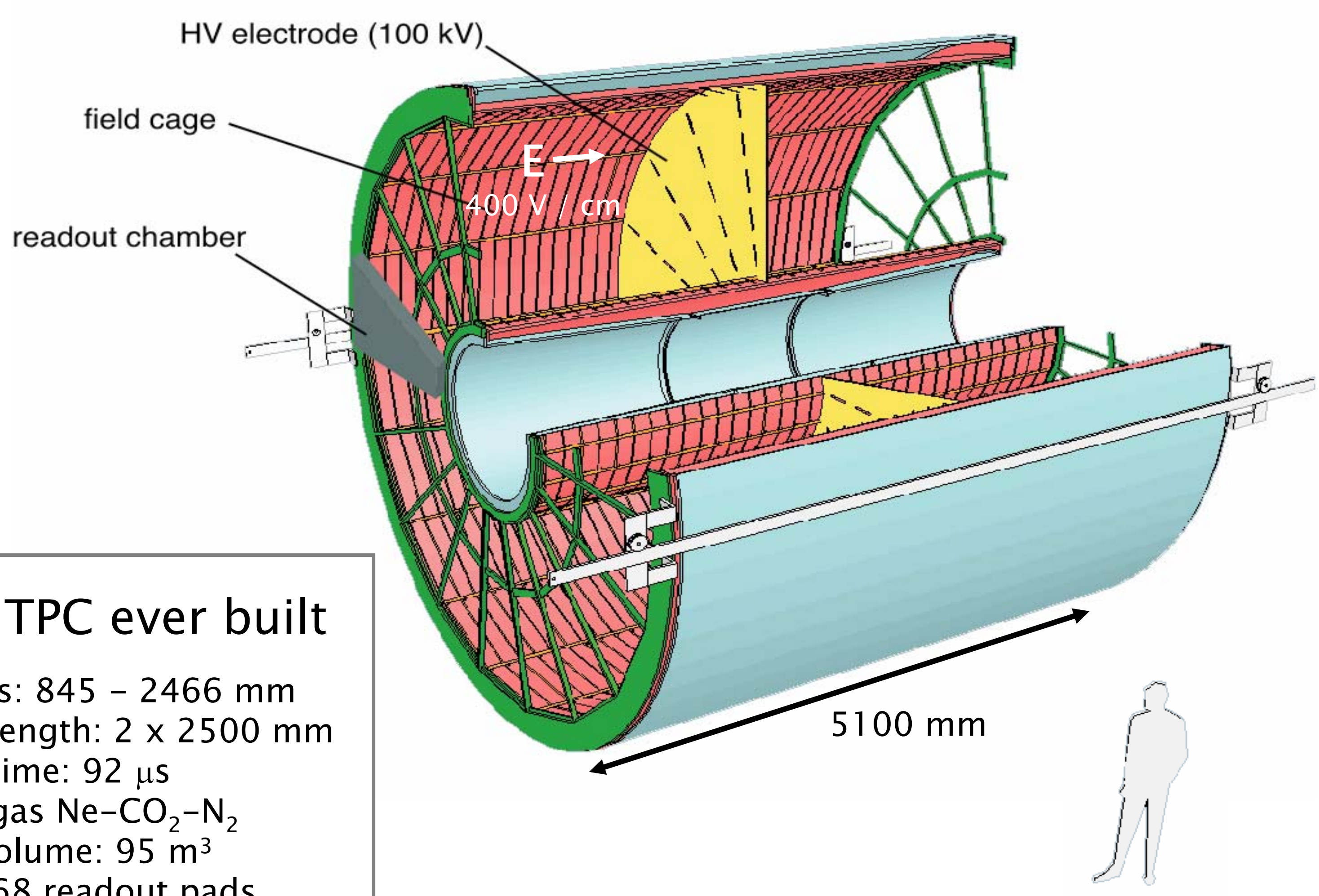


Support frame: carbon fiber



ITS as inserted in ALICE setup (15/3/07)

The ALICE Experiment
Time Projection Chamber (TPC)



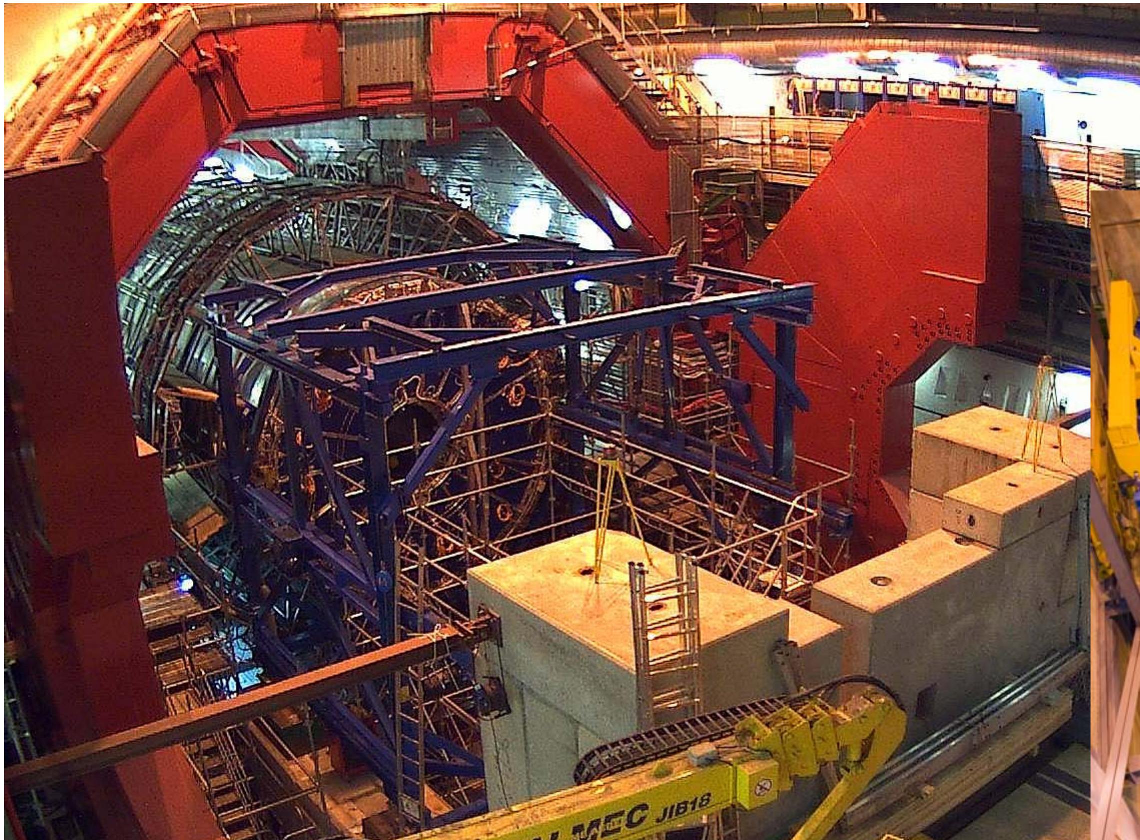
Largest TPC ever built

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

The ALICE Experiment
Time Projection Chamber (TPC)

TPC during assembly

Time Projection Chamber (TPC)



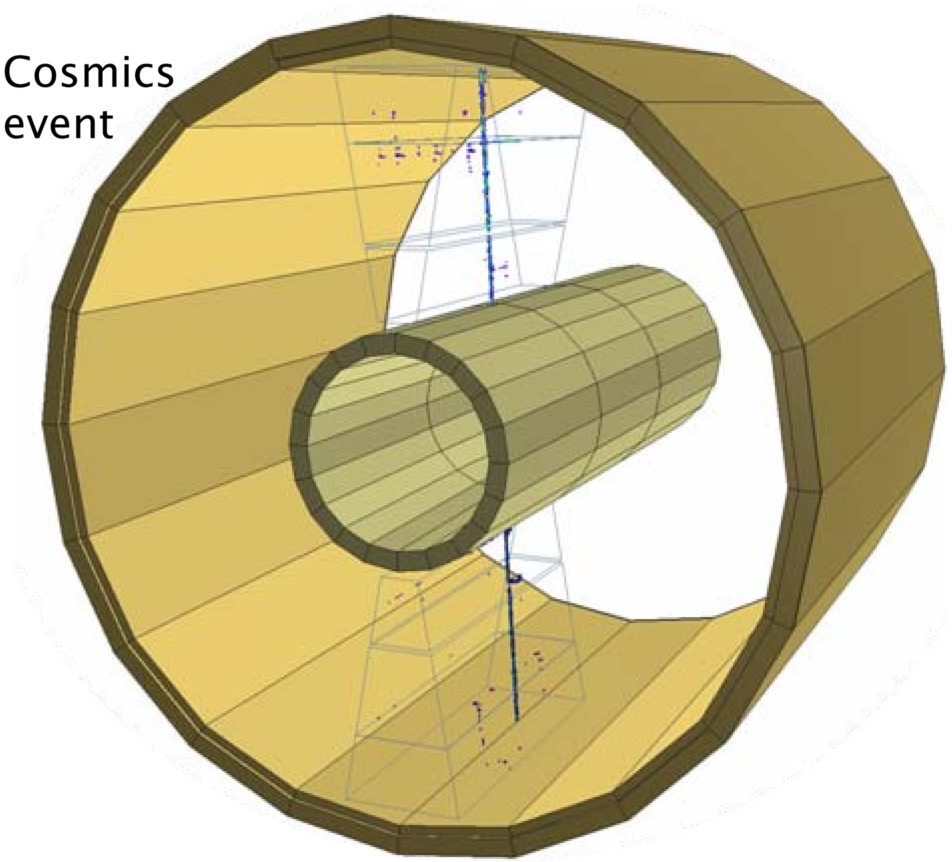
Lowering and insertion
of ALICE TPC (15/01/07)

Time Projection Chamber (TPC)

TPC assembled and installed

- Commissioning on ground
- Performance according to design specifications
- Ongoing: Installation of services
- Final commisioning until 11/2007

Cosmics event



The ALICE Experiment
Transition Radiation Detector (TRD)

Purpose:

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

Some numbers:

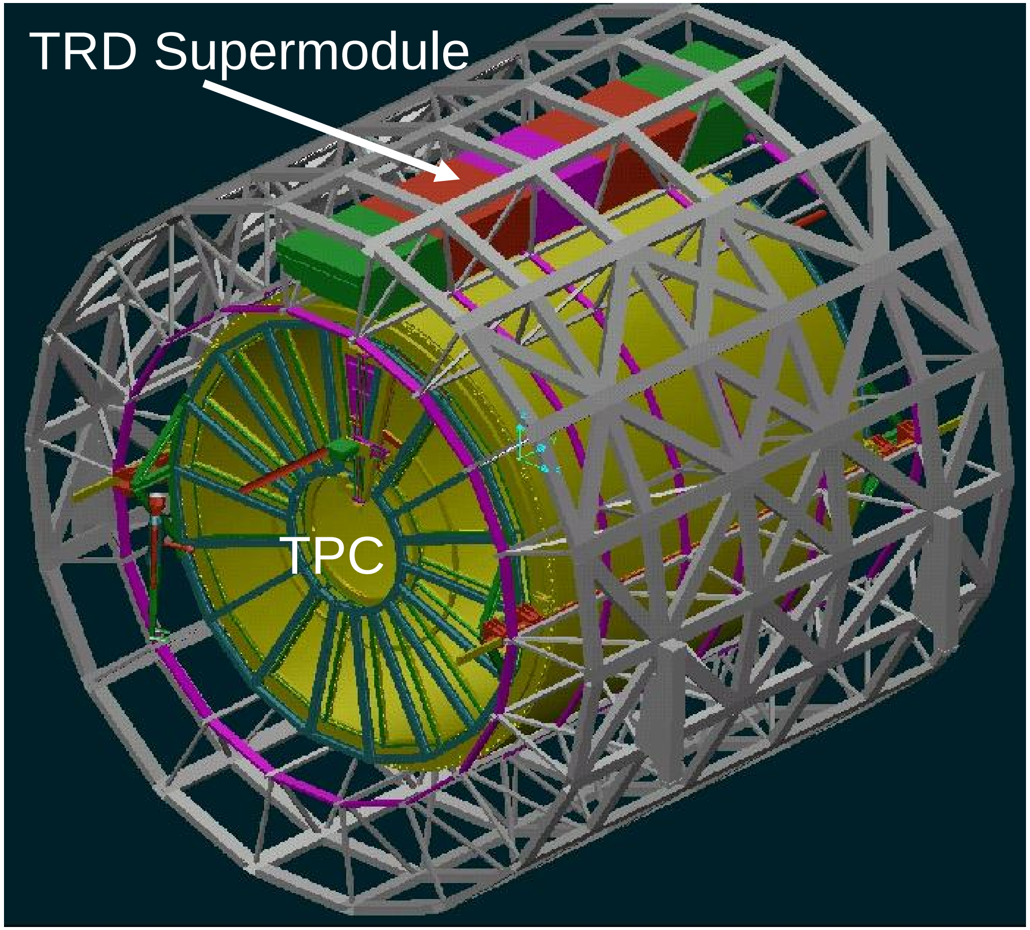
540 chambers

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

Gas volume: 27.2 m^3

Resolution
$(r\varphi)$ 400 mm

Number of read out channels: 1.2×10^6



The ALICE Experiment
Transition Radiation Detector (TRD)

Drift chamber

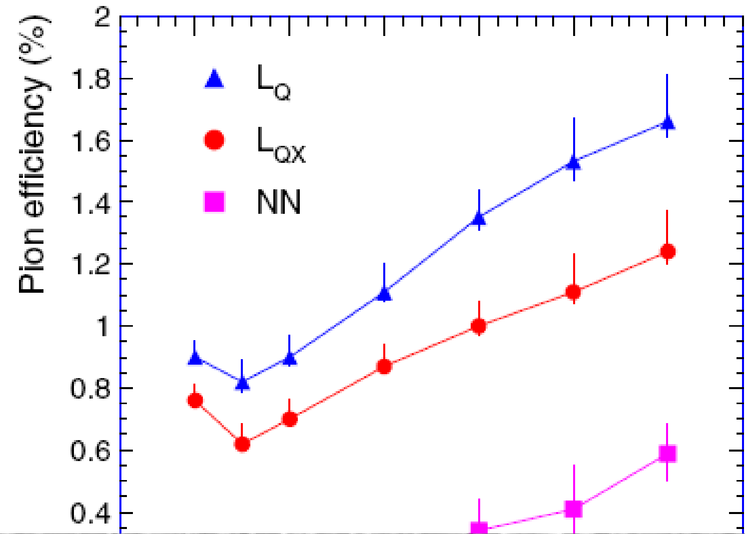
Gas: Xe–CO_2
Drift length: 3cm

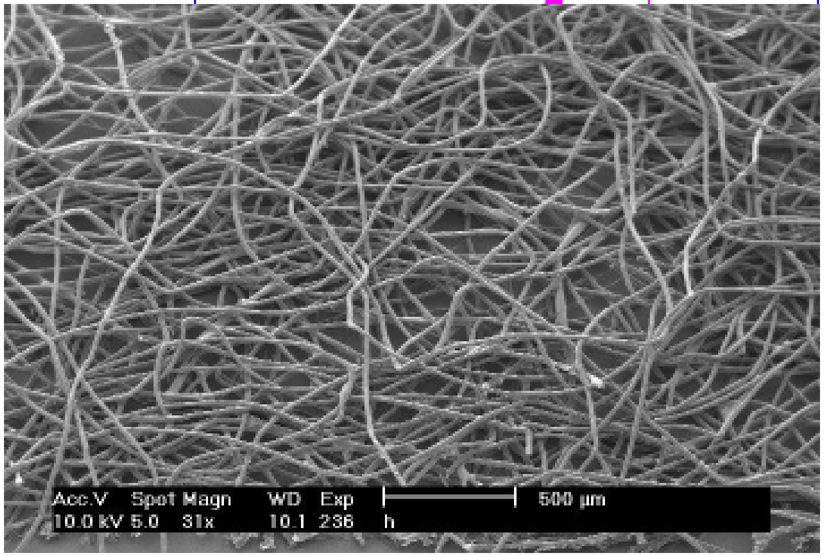
Radiator

Fiber/foam sandwich
PP, 17μm

e/π–discrimination ~ 10^{-2}

For 90% e–efficiency



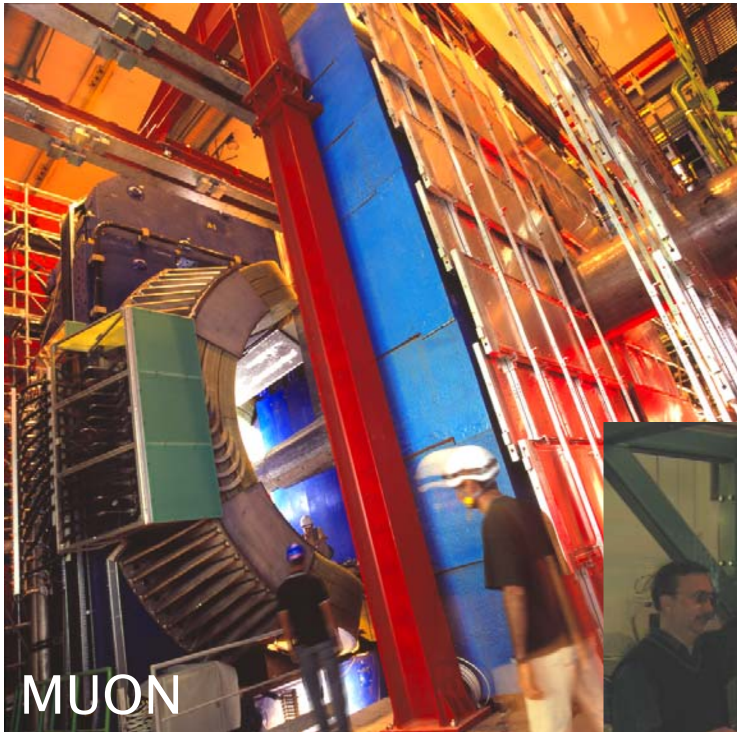


The ALICE Experiment
Transition Radiation Detector (TRD)


TOF supermodule
TRD Supermodule

The ALICE Experiment

More Detectors ...



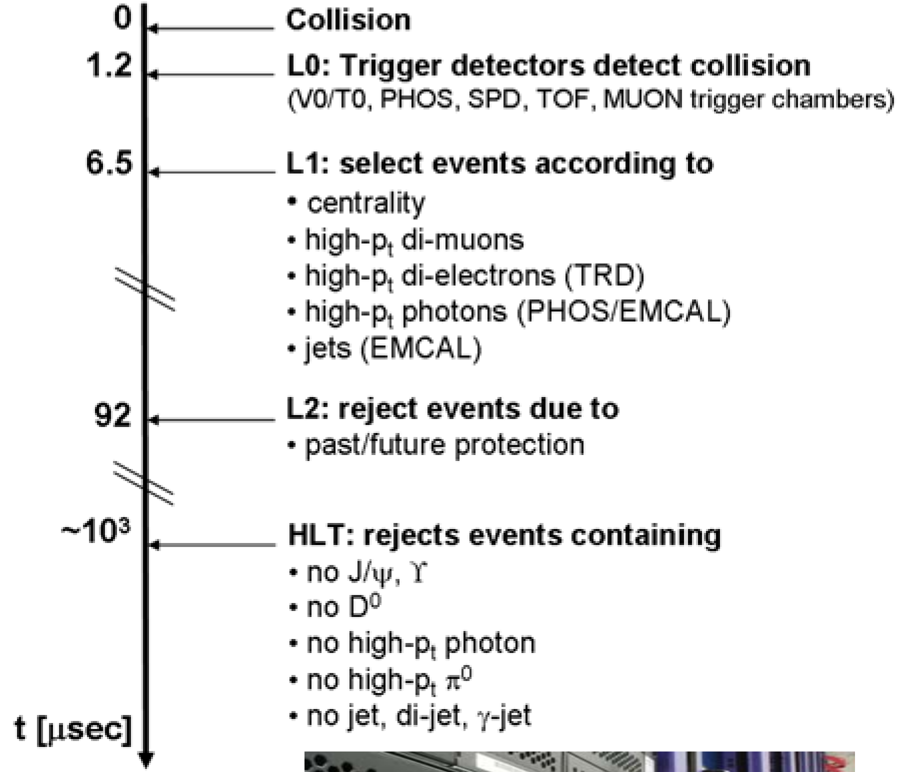
The ALICE Experiment
Trigger

Hierarchical architecture

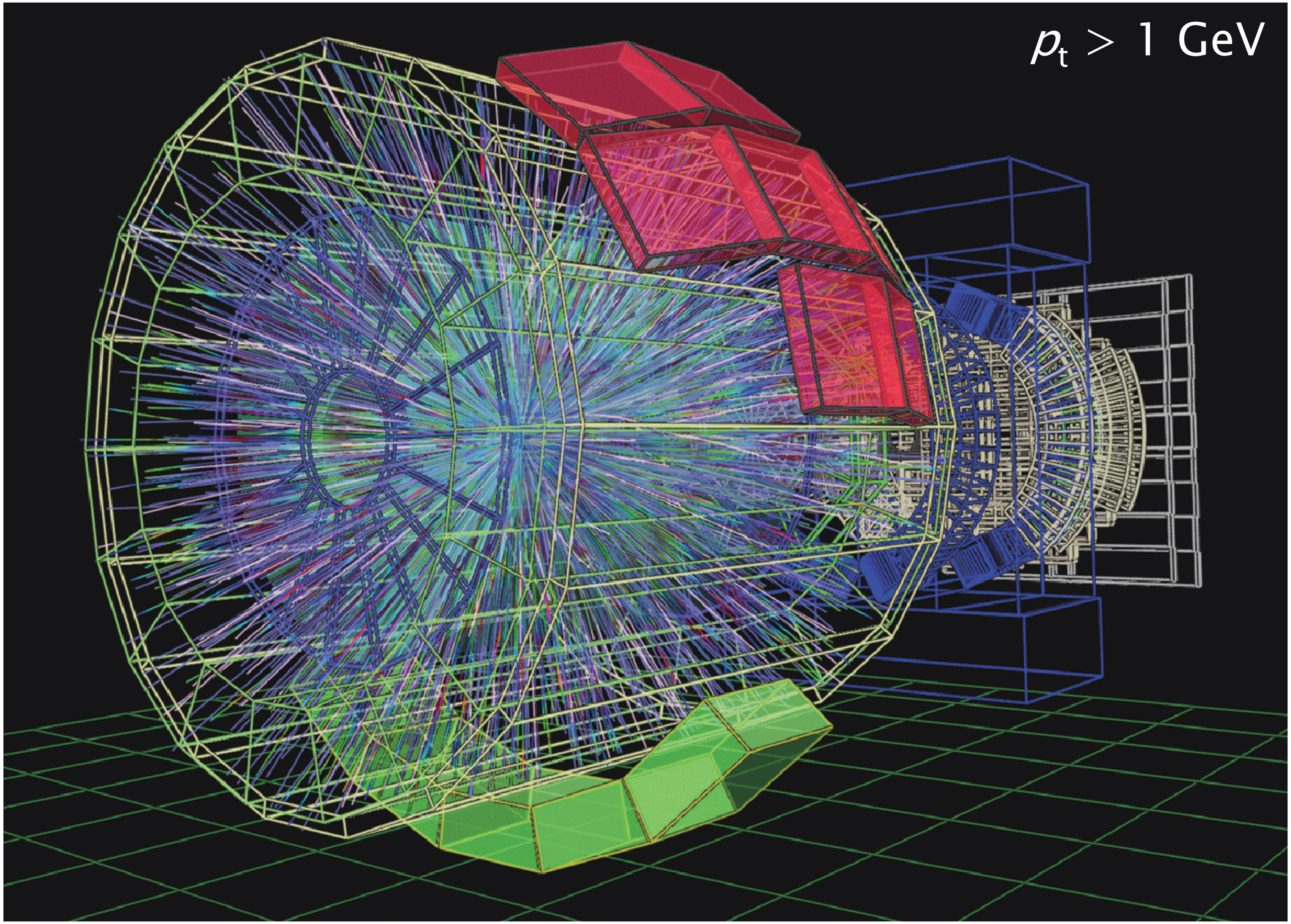
- L0, L1, L2, and HLT

High Level Trigger (HLT)

- Online reconstruction using ~500-600 PCs + FPGAs
- Input rate 200Hz (central Pb-Pb) → up to 20 GByte/s
- Generate physics trigger (e.g. jets, Upsilons, D^0, ...)
- Online data compression
- Calibration tasks



Physics Performance
ALICE Event Display



Physics Performance

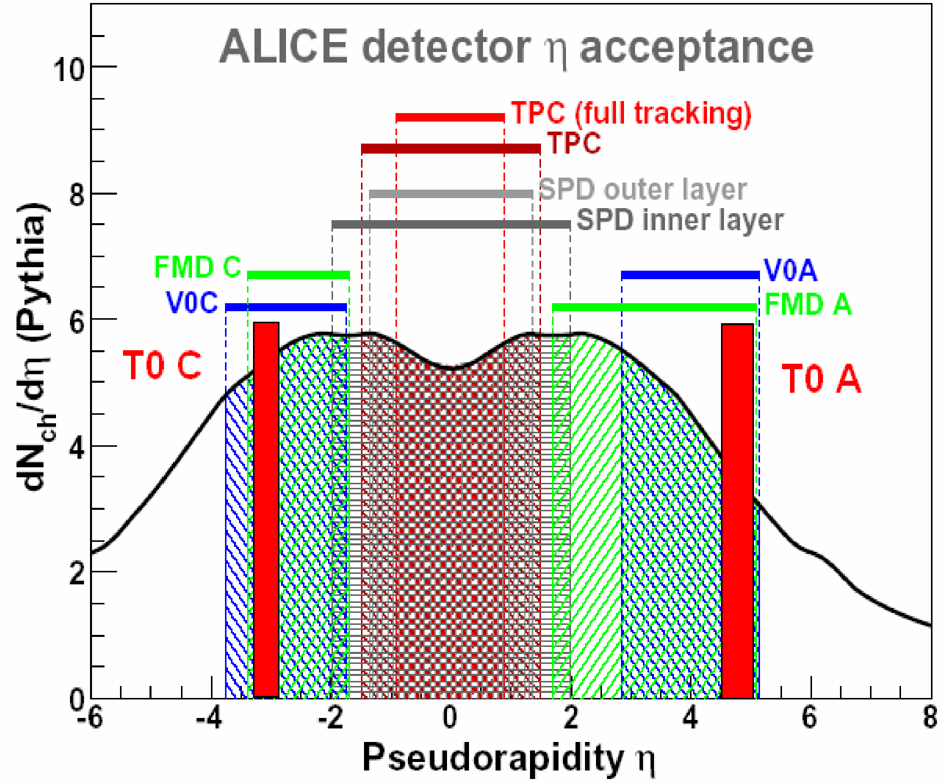
Acceptance for Charged Hadrons

Central barrel

- $-0.9 < \eta < 0.9$
- ITS, TPC, TRD, TOF
- 2π tracking + PID
- Single arm RICH

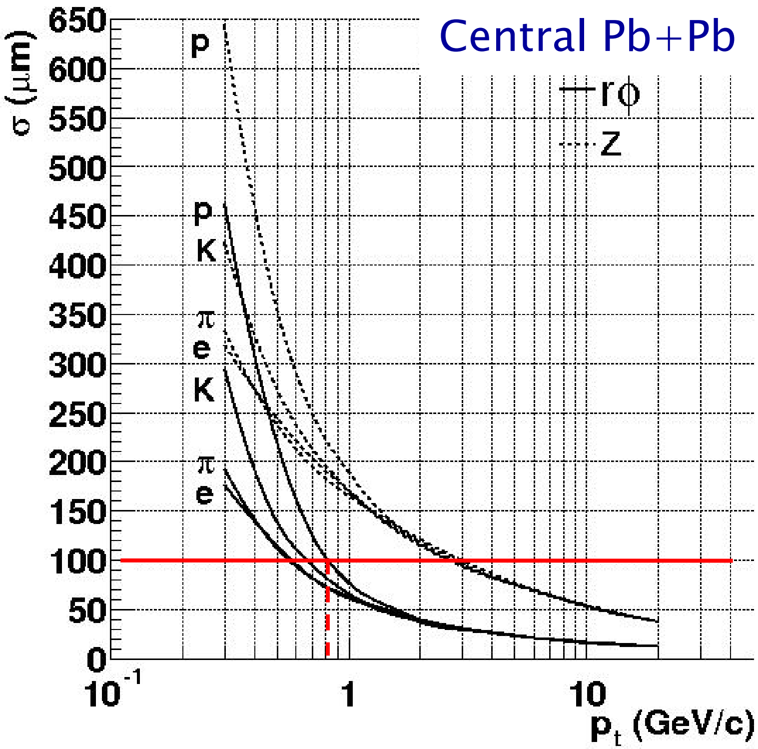
Forward detectors

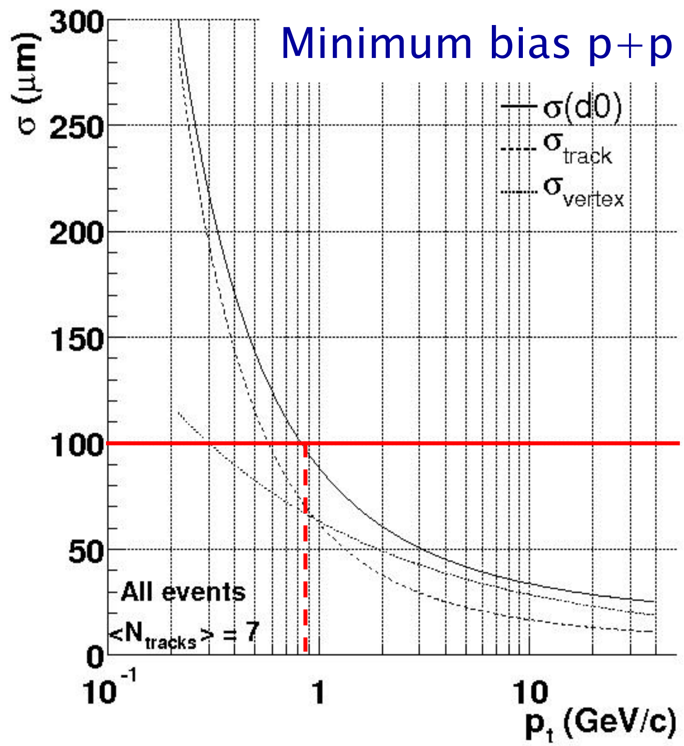
- **FMD**: Silicon strip
- **T0**: PMT array
- **V0**: Scint. paddles



Physics Performance

Impact Parameter Reconstruction





Crucial for heavy flavour measurements

e.g. D^0: $c\tau = 123\mu m$

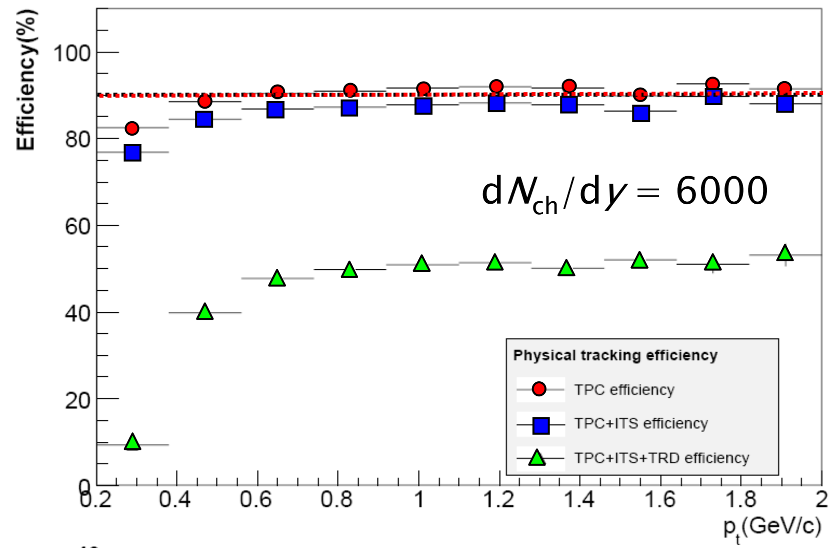
Physics Performance
Tracking Efficiency and Resolution

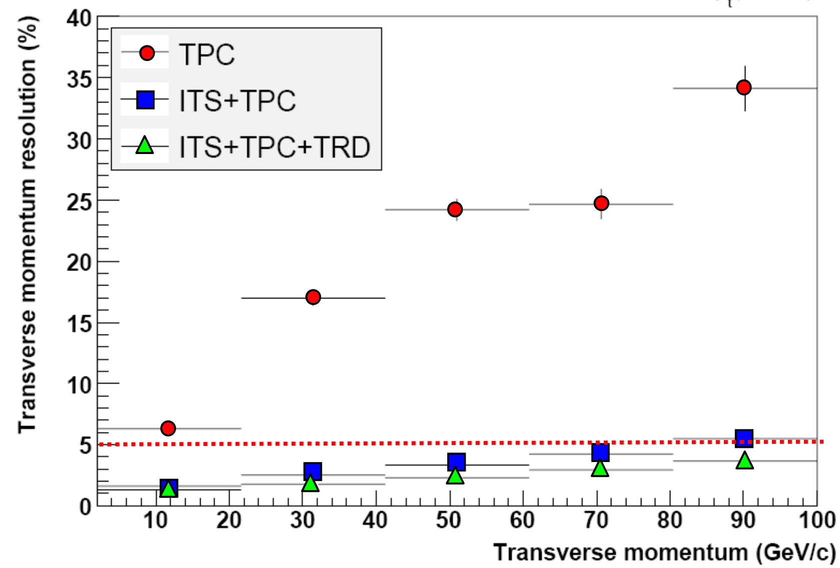
Efficiency

- Approaches TPC acceptance (90%)
- Only very little dependence on track multiplicity

Momentum resolution

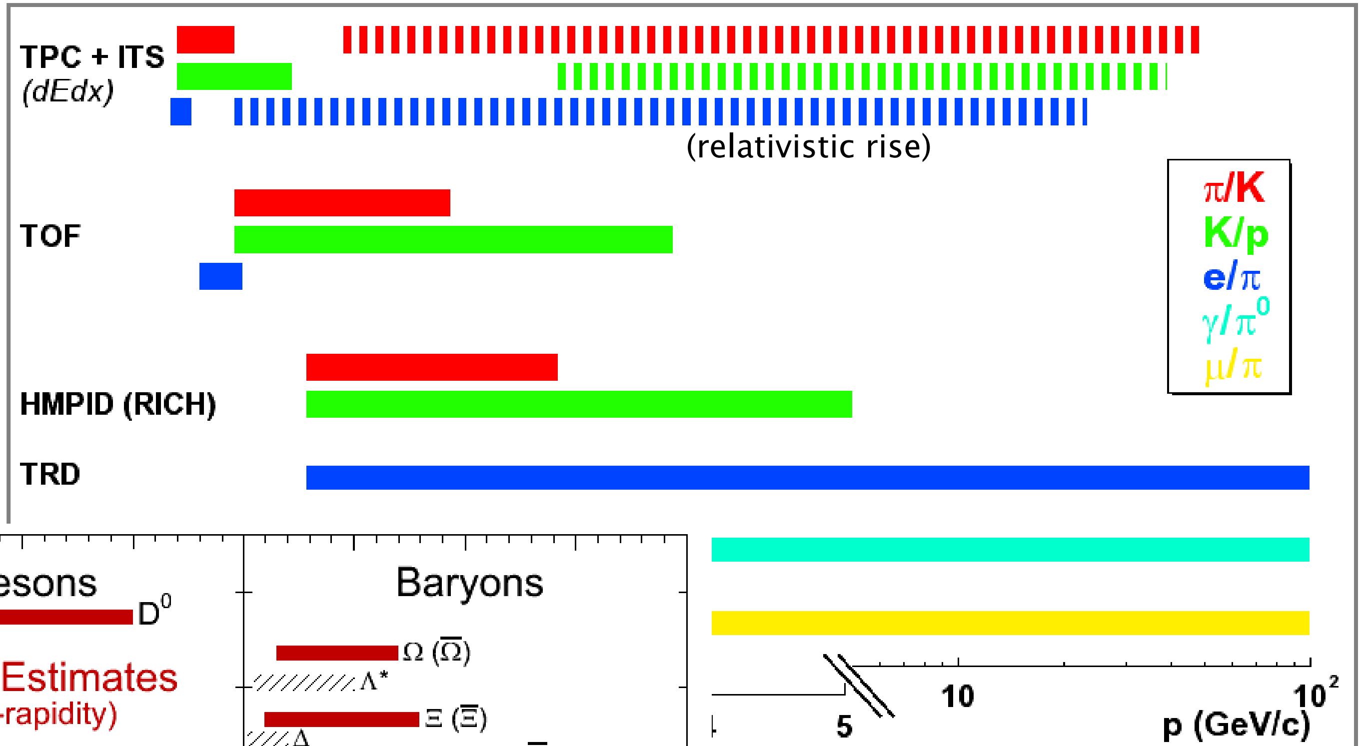
- Long lever arm ITS + TPC + TRD (4cm < r < 370cm)
- $\delta p_t / p_t \leq 5\%$ at $p_t = 100$ GeV/c and $B = 0.5$T

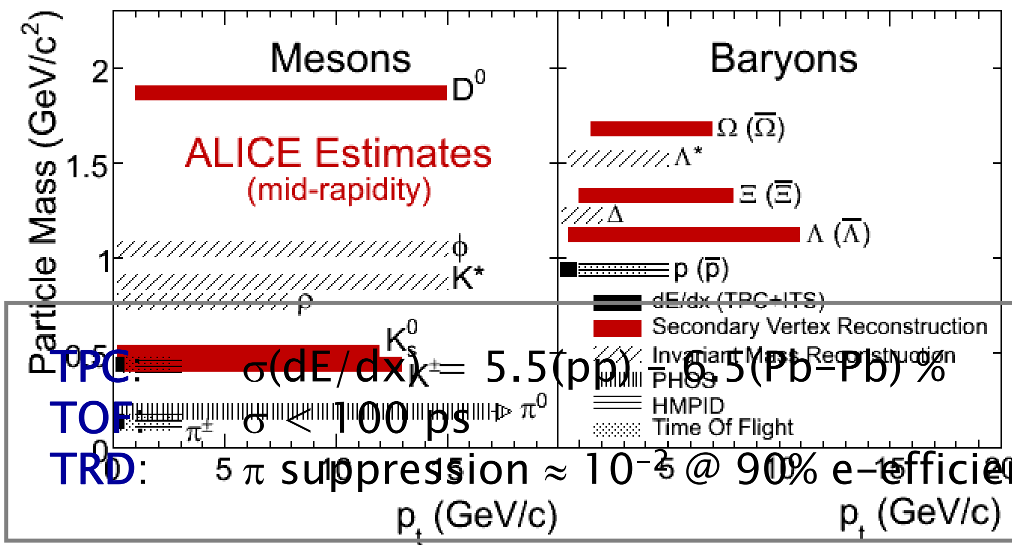




Physics Performance

PID Capabilities





TPC: $\sigma(dE/dx) = 5.5(pp) - 6.5(Pb{-}Pb)$ %

TOF: $\sigma < 100$ ps

TRD: π suppression $\approx 10^{-2}$ @ 90% e–efficiency

Physics Performance
Heavy Flavour

Will provide important information

- Parton energy loss mechanisms should be flavour dependent
- Expected to be stronger for light than heavy quarks

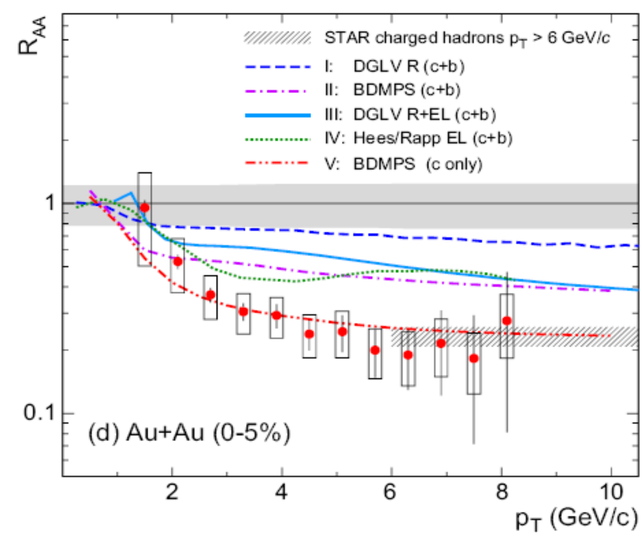
Large abundance of charm and beauty at the LHC

- First direct heavy flavour measurements in heavy ion possible

System	p+p	Pb+Pb (5% cent.)
$\sqrt{s_{NN}}$ (TeV)	14	5.5
NN cross section (mb)	11.2 / 0.5	6.6 / 0.2
Shadowing	---	0.65 / 0.85
Total multiplicity	0.16 / 0.007	115 / 4.6

$c\bar{c}$ / $b\bar{b}$

RHIC: So far non-photonic electrons only



Physics Performance
Heavy Flavour: D-Mesons

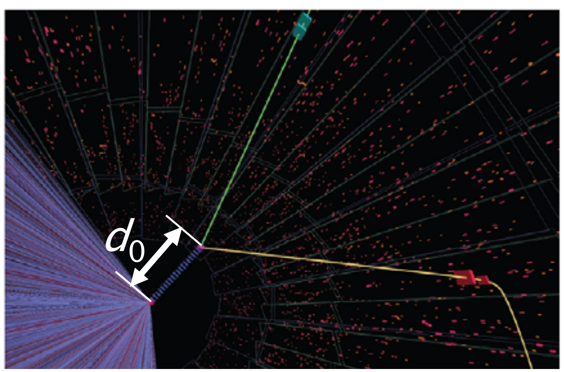
Example: $D^0 \rightarrow K^- \pi^+$

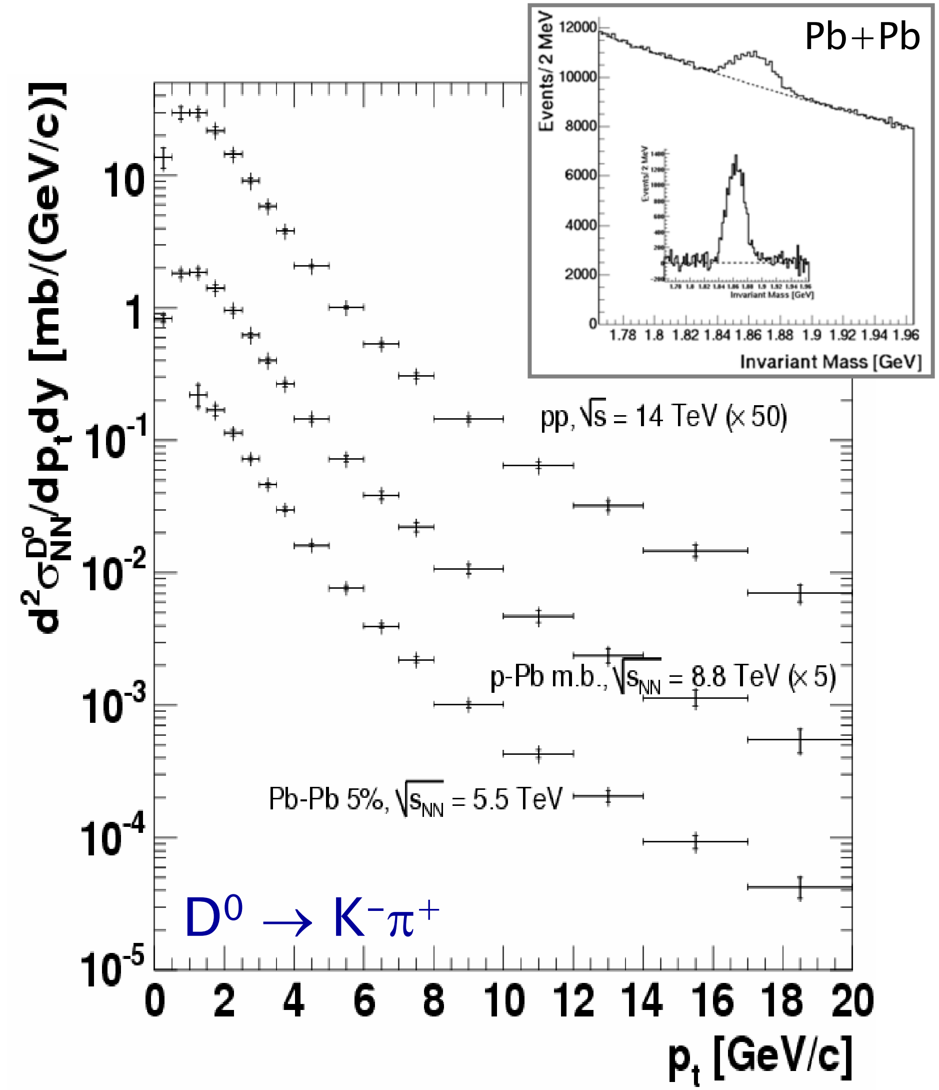
Full reconstruction of D-decays

Separation of charm and beauty

$S/B \approx 10\%$
Significance ≈ 40
(1 month Pb+Pb running)

Similar in p+p



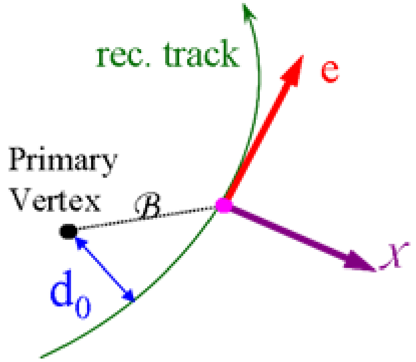


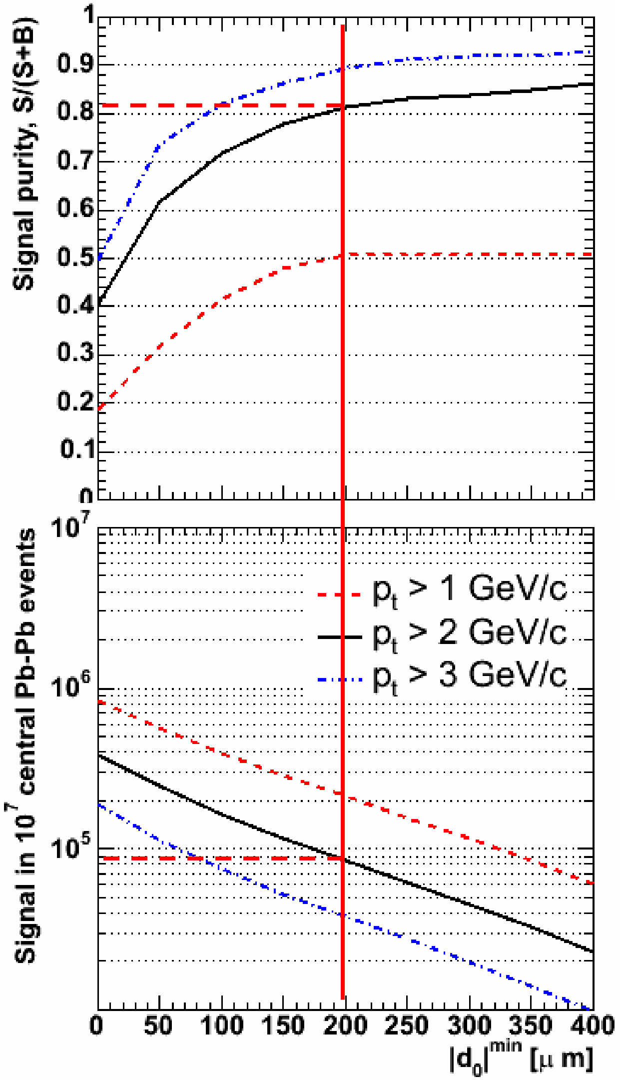
Physics Performance
Heavy Flavour: B-Mesons

Example: B $\rightarrow e^{\pm} + X$

e-Identification: TRD
Impact parameter: ITS

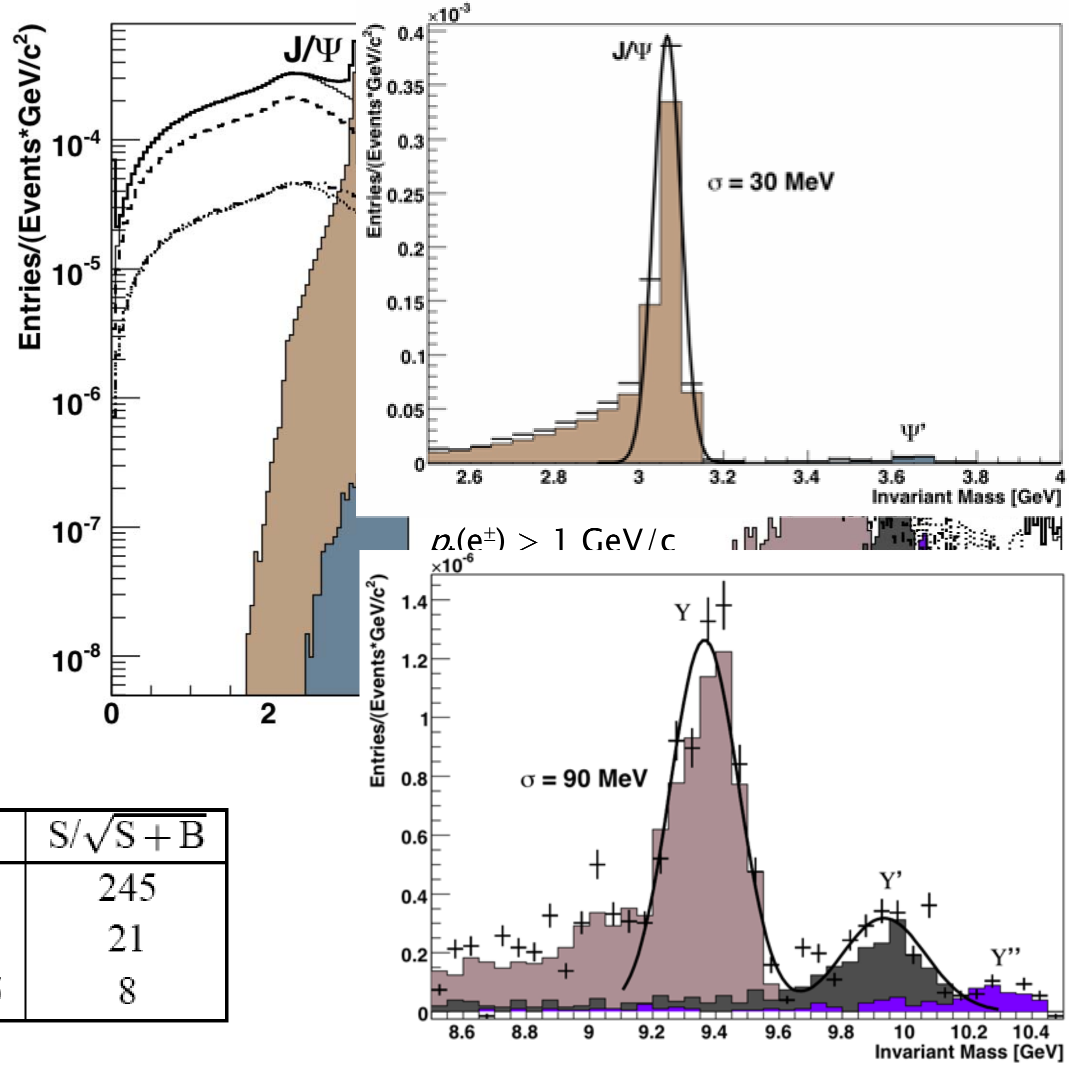
Impact parameter cut:
$d_0 > 200\mu m$, $p_t > 2 GeV/c$
$\rightarrow$ 80% purity
$\rightarrow 8 \times 10^4$ $e^{\pm}$ from B's
in central Pb+Pb
(1 month Pb+Pb running)





Central barrel
- ITS+TPC+TRD
- $-0.9 < \eta < 0.9$
- Di-electrons

Forward region
- MUON arm
- $2.4 < \eta < 4.0$
- Di-muons



Di-electron in central barrel

State	S ($\times 10^3$)	B ($\times 10^3$)	S/B	$S/\sqrt{S+B}$
J/ψ	110.7	92.1	1.2	245
Υ	0.9	0.8	1.1	21
Υ'	0.25	0.7	0.35	8

Physics Performance
Jets

Direct jet reconstruction

- Overcome limitations of R_{AA} (leading particles)
- Study modifications of fragmentation functions due to gluon radiation
  (less biased measurement)

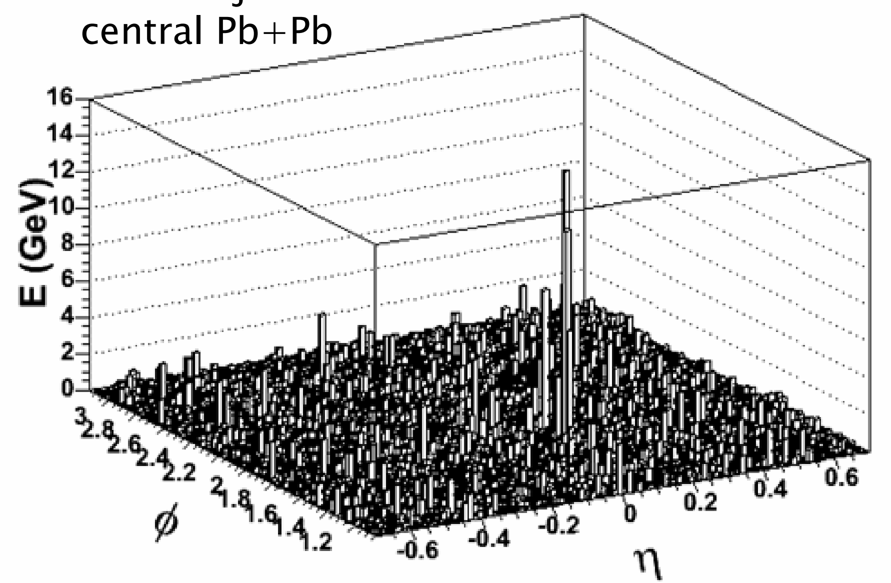
High jet rates at LHC

- Difficulty: Large underlying event
- Algorithms with reduced cone size $R < 0.4$

$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

1 month of running	
$E_T >$	N_{jets}
50 GeV	2.0×10^7
100 GeV	1.1×10^6
150 GeV	1.6×10^5
200 GeV	4.0×10^4

100GeV jet in central Pb+Pb



Jets: Calorimeter

Charged jet reconstruction

- Charge ↔ neutral fluctuations dominate

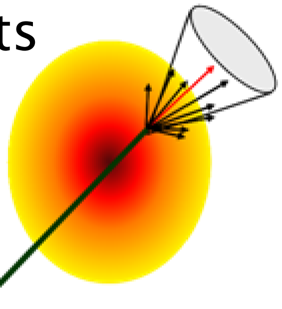
E.m. calorimeter EMCAL

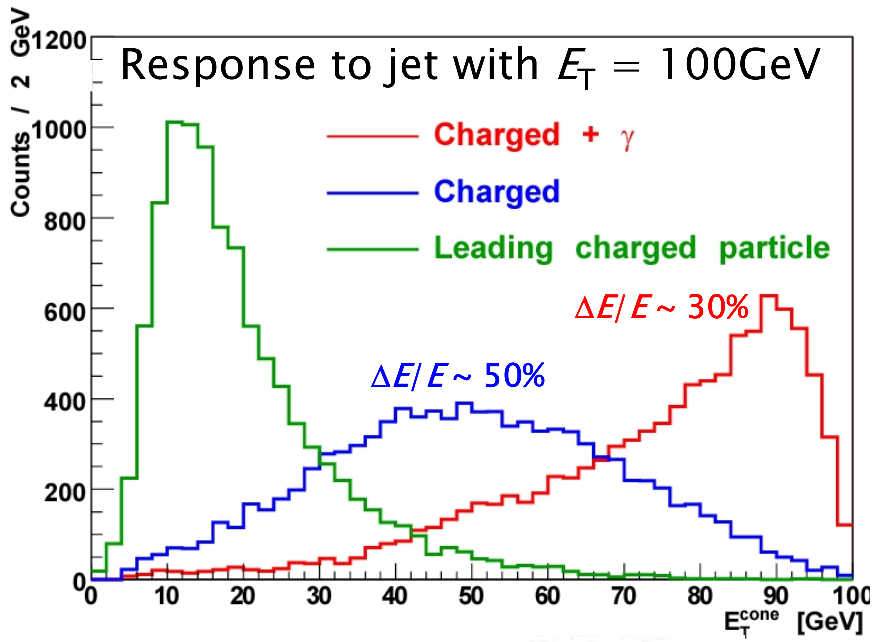
- Pb-scint. sampling calor.
- Improves resolution and kinematic range
- Trigger capabilities

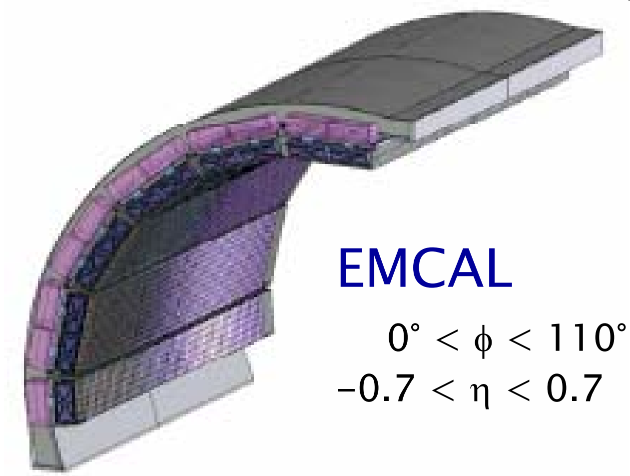
Photon tagged jets

- EMCAL+PHOS

$g + q \rightarrow \gamma + q$
$q + \bar{q} \rightarrow \gamma + g$







$0° < \phi < 110°$
$-0.7 < \eta < 0.7$

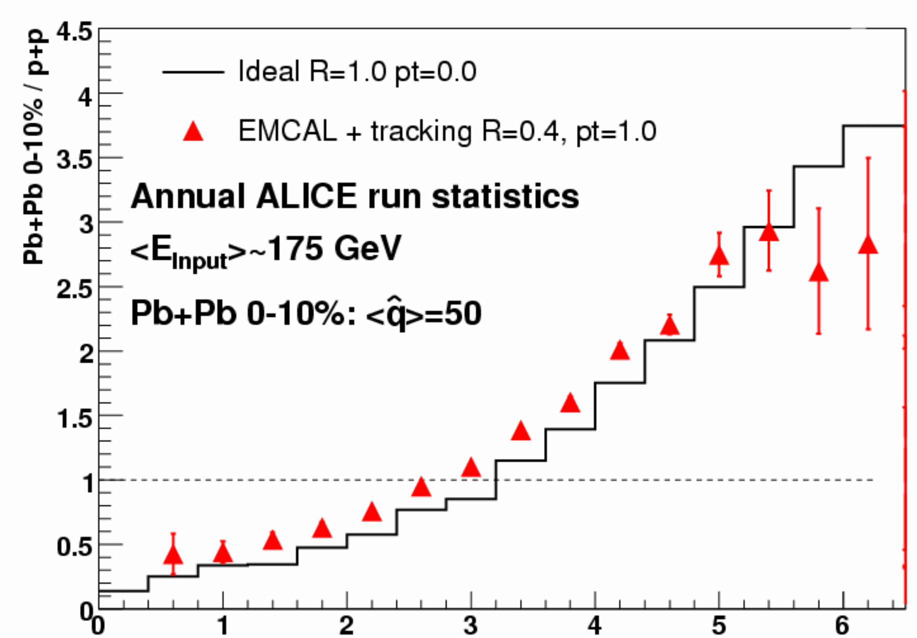
Physics Performance
Jets: Fragmentation Functions

Sensitive to energy loss mechanisms

- Quenching of leading hadron
- Additional hadrons by gluon radiation
- Transverse heating

Observable:

- Ratio of fragmentation functions: $\frac{FF(\text{Pb+Pb})}{FF(\text{p+p})}$



$$\xi = \ln\left(\frac{1}{z}\right) = \ln\left(\frac{E_t^{jet}}{p^{hadron}}\right)$$

Physics Performance
Running Scenarios

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

*L_{max} (ALICE) = 10^{31}

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

+ Other ions (Sn, Kr, O) & energies (e.g.: pp @ 5.5 TeV)

Startup Plans

Timeline:

August 2007: close experiment
September – November: commissioning

November – December: pp commissioning run (??)
($\sqrt{s} = 0.9$ TeV)
2008: First pp run
($\sqrt{s} = 14$ TeV)

Followed by first Pb–Pb run (end 2008 ?)
$\sqrt{s} = 5.5$ TeV, $L = 5 \cdot 10^{25}$ cm^{-2}s^{-1}

Startup configuration for 2007:

Complete: ITS, TPC, HMPID, MUON arm,
PMD, trigger dets (V0, T0, ZDC, Accorde)

Partially complete: PHOS(1/5), TOF(9/18),
TRD (2–3/18), DAQ (20%)

Summary

Heavy ion physics will do a big steap ahead with LHC startup

Era of precision measurements of the QGP matter

ALICE will be ready for data taking with the first pp run

Experimental setup is multi-purpose and flexible

Summary of *foreseen* ALICE physics:

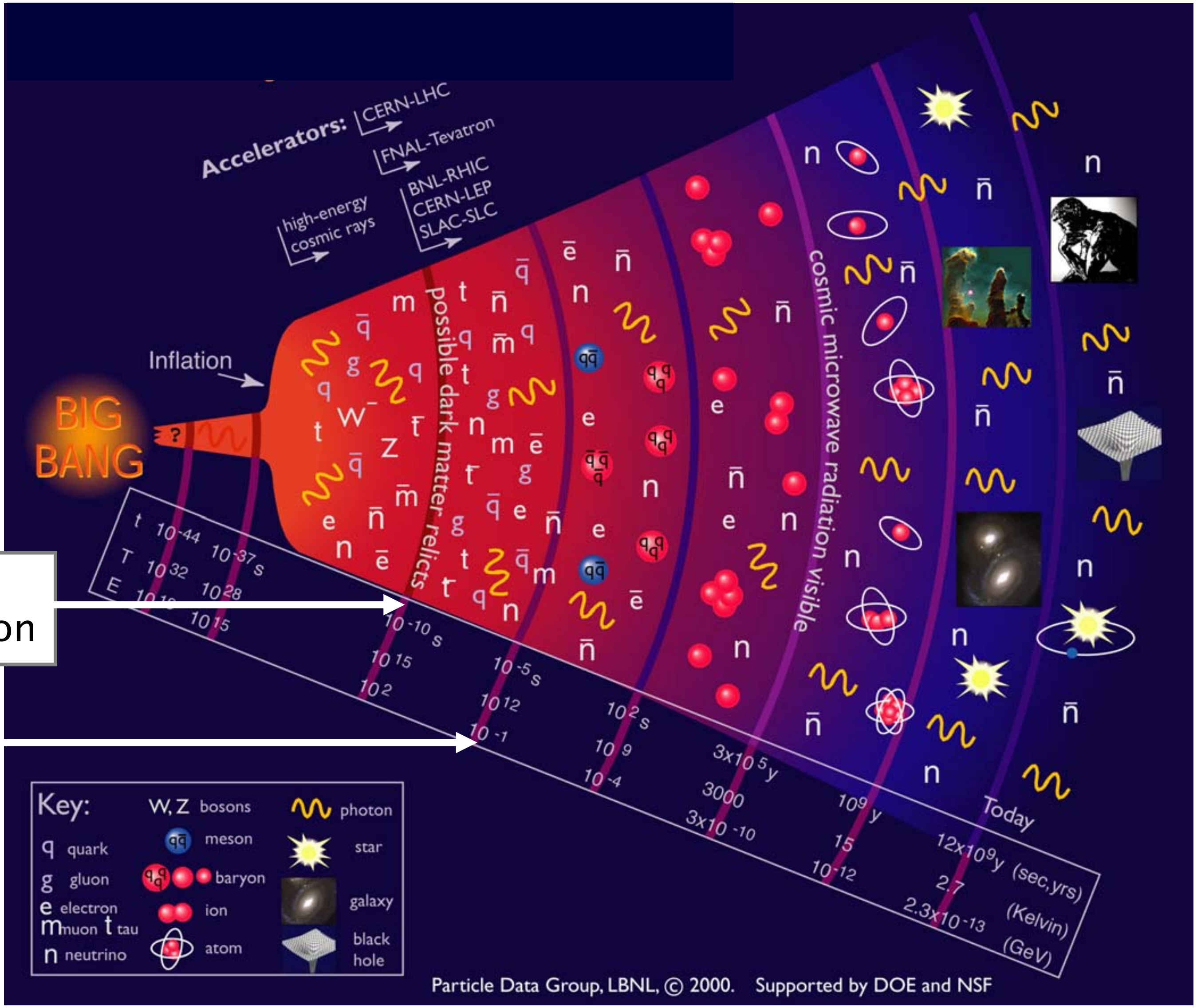
ALICE Physics Performance Report, Vol. II,
J. Phys. G32 (11), 2137 (2006)

We will enter unchartered territory ⇒ Surprises ahead !

Need to be prepared for the unforeseen !

The End

History of the Universe

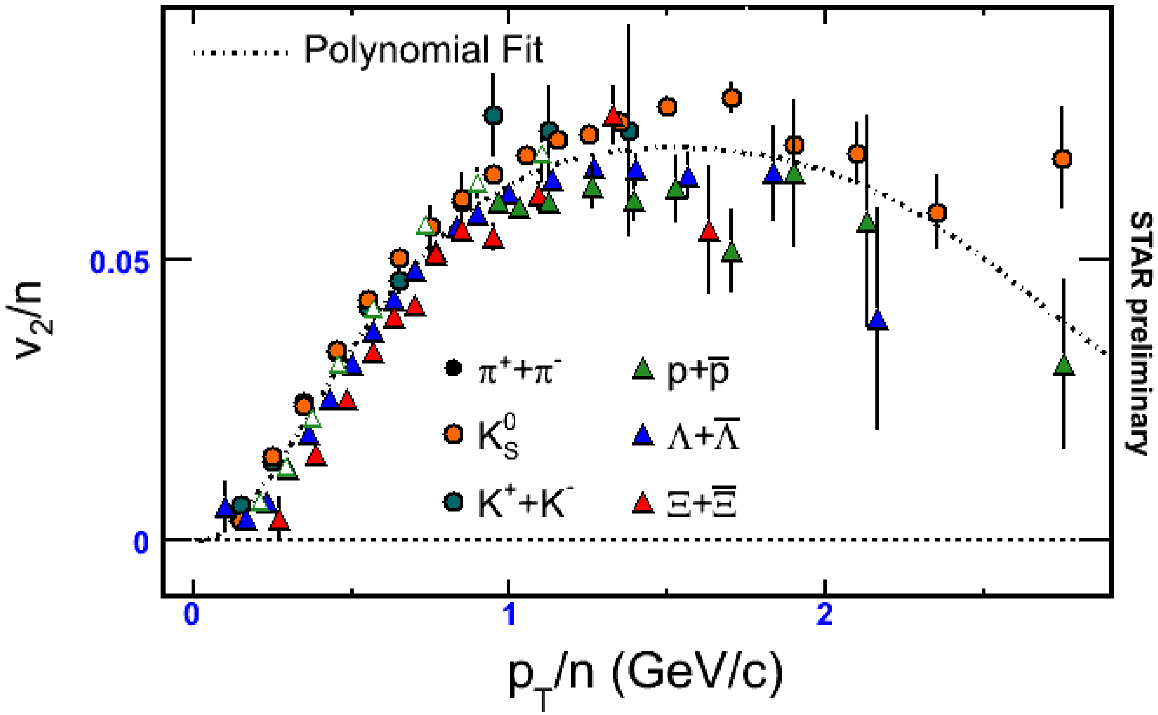


Electroweak phase transition

QCD phase transition

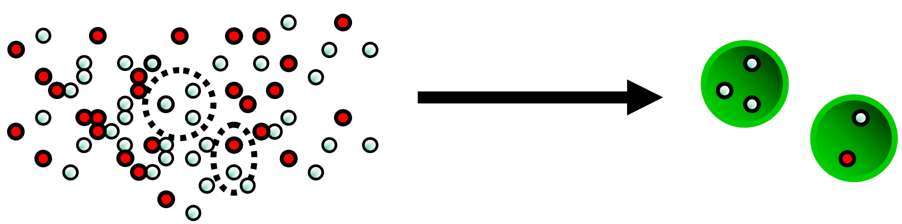
Flow: Quark Number Scaling

Common scaling after division with number of constituent quarks *n*



Evidence for quark degrees of freedom ?

Alternative hadronization mechanism:
Quark coalescence ↔ Fragmentation



p+p / p+A Physics

Major part of ALICE physics program

Reference data for A+A physics

- Any A+A measurement needs pp benchmark
- pp @ $\sqrt{s}$ = 5.5 TeV important

Interesting on its own

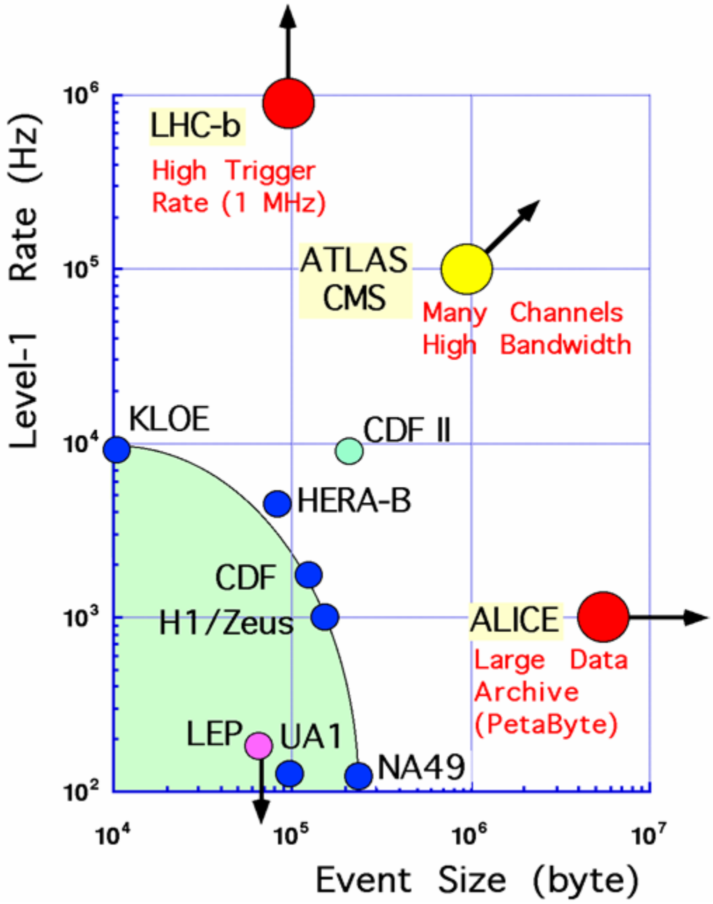
- ALICE detector to large extent complementary to ATLAS+CMS, but still with large overlap (e.g. $p_t > 100\,\mathrm{GeV}/c$)
- PID capabilities
- Low p_t coverage:
  - Multiplicities ($dN_{ch}/d\eta$)
  - Cross sections of heavy flavour production
  - Baryon transport
  - ...

Data volume

1.2 GByte/s to storage
$\rightarrow$ 2 PByte/year raw data

GRID Computing

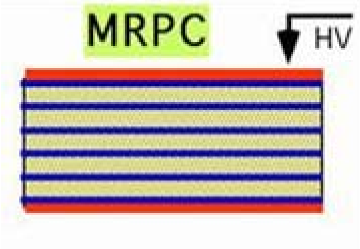
ESD production @ Tier1 (CERN)
MC production + analysis @ Tier2



The ALICE Experiment
Time Of Flight (TOF)

Multi-gap resistive plate chambers (MRPC)

- Small gaps: 10 x 250 μm
- > 8000 channels/ SM



Resolution:

- $\sigma < 100$ps

Muon Arm (MUON)

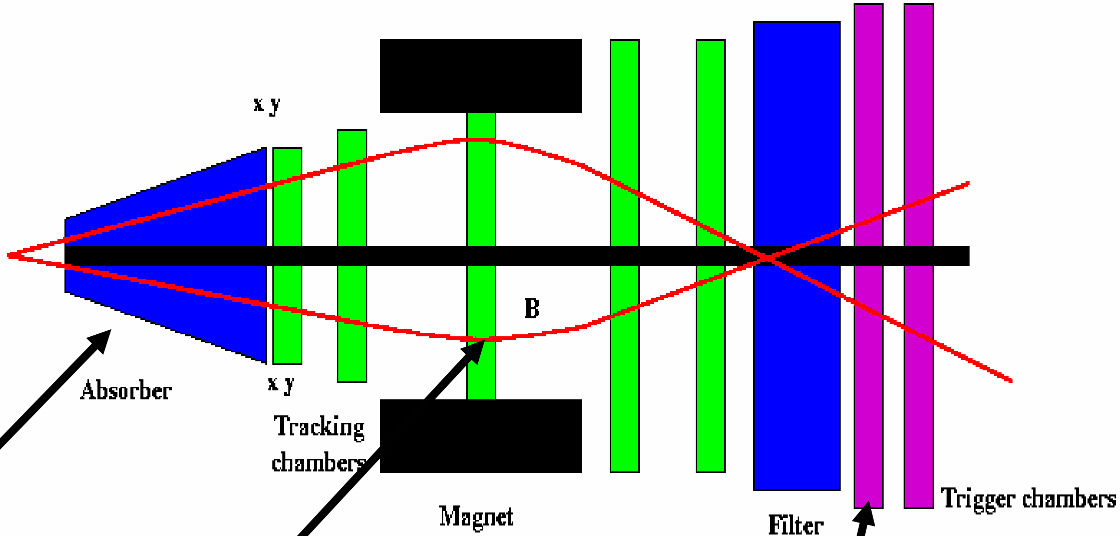
Purpose:

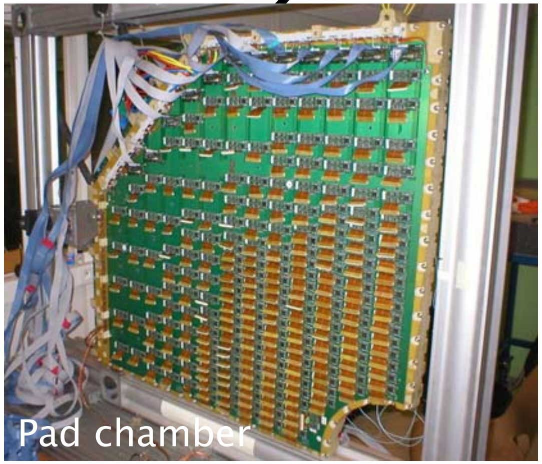
Muon ID

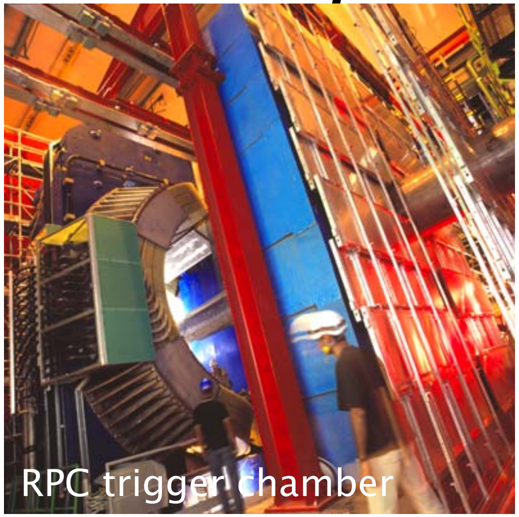
Quarkonia $\rightarrow \mu^+\mu^-$
Heavy flavour

Acceptance:

$2.4 < \eta < 4.0$



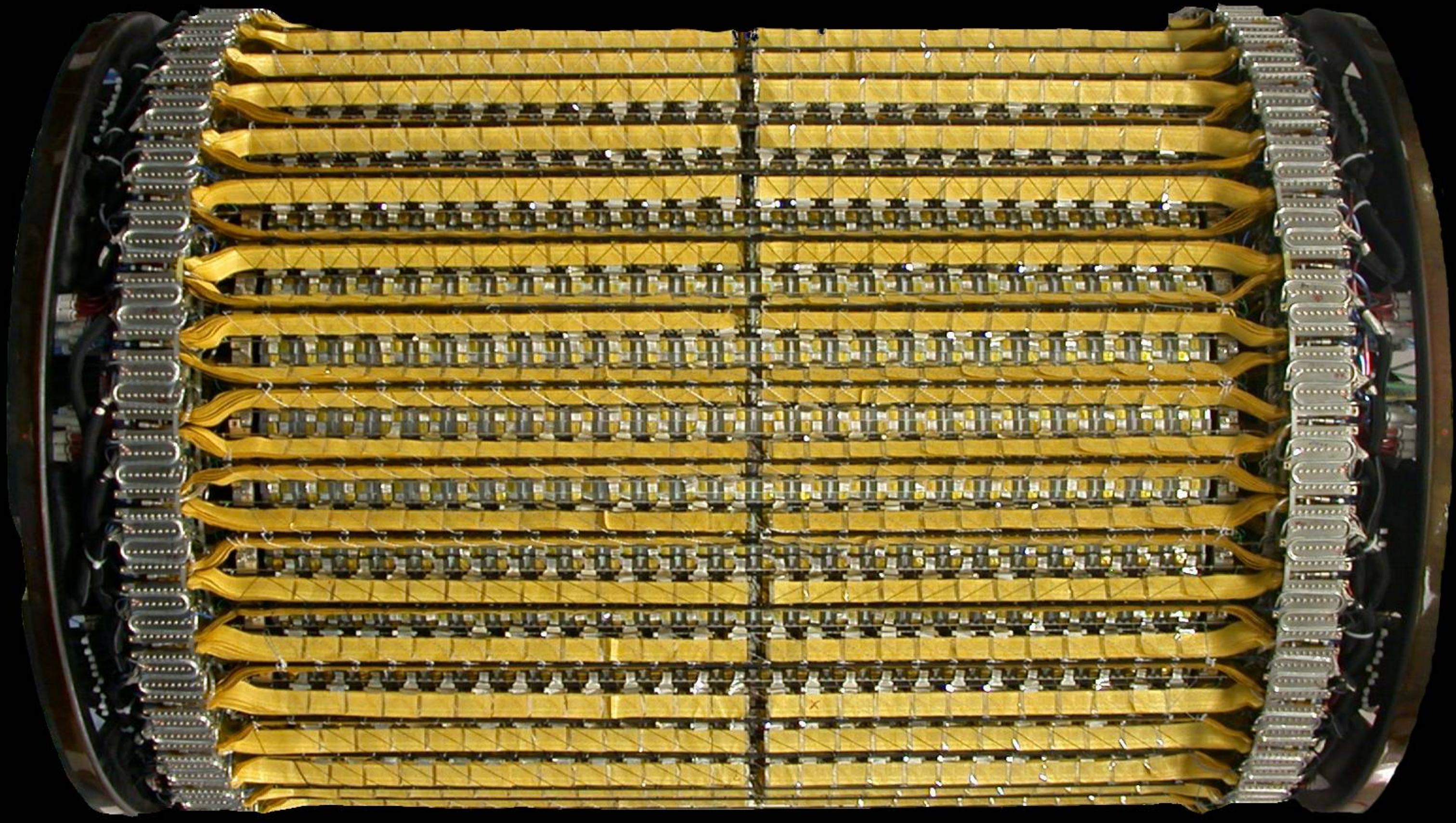




The ALICE Experiment
Dipole Magnet

Inner Tracking System (ITS)

Silicon Strip Detector (SSD)



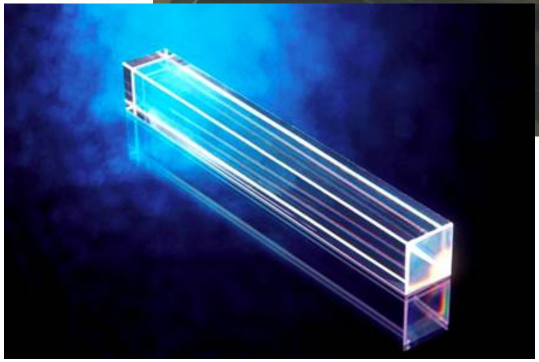
Photon Spectrometer (PHOS)

Single arm e.m. calorimeter

- Photons, neutral mesons, γ–jet tagging

Technique

- Dense (X_0 < 0.9cm) crystals $PbWO_4$ (cooled to –25° C)
- Good energy resolution
  - Stochastic: 2.7%/$\sqrt{E}$
  - Noise: 2.5%/E
  - Constant: 1.3%
- Channels: ~18k
- Area: $8m^2$



Open charm:

$D^0 \rightarrow K^- + \pi^+$ ($c\tau$ = 123 μm, BR = 3.8 %)

See next slides

$D^+ \rightarrow K^- + \pi^+ + \pi^+$ ($c\tau$ = 312 μm, BR = 9.5 %)

Pb+Pb (central): $S/B \approx 0.1$, $S \approx 10^4$ D^+ in 10^7 central events

$D \rightarrow e^\pm\ (\mu^\pm) + X$

D_s, ...

Open beauty:

$B \rightarrow e^\pm\ (\mu^\pm) + X$ ($c\tau \approx$ 500 μm, BR = 10.9 %)

(+ $B \rightarrow D\ (\rightarrow e^\pm\ (\mu^\pm) + X) + X'$, BR ≈ 10%)

See next slides

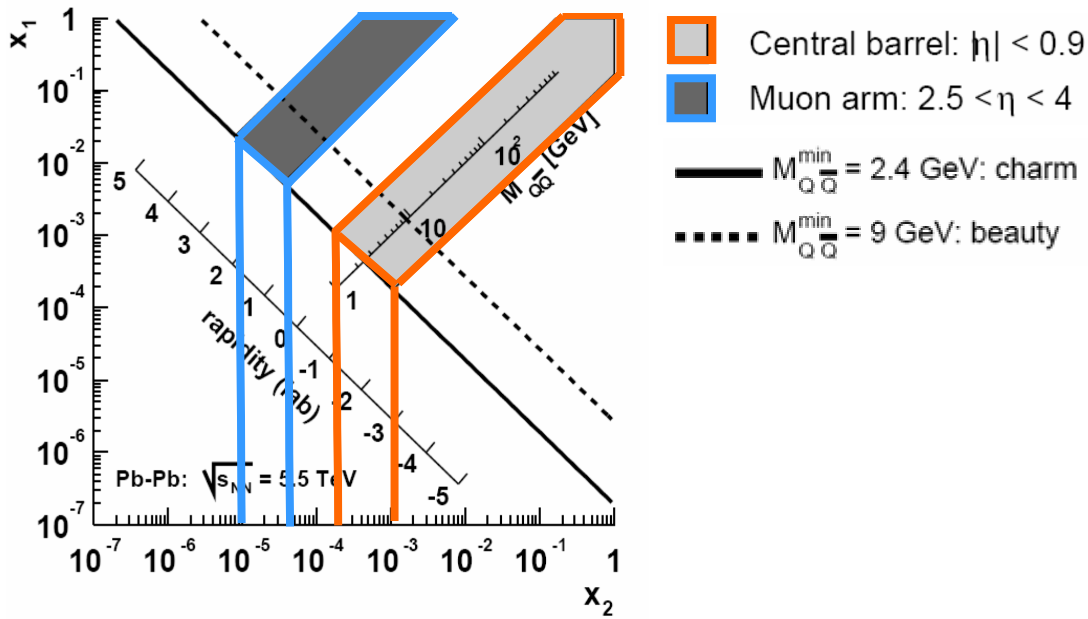
$B \rightarrow J/\psi\ (+ X) \rightarrow e^+e^-$ ($c\tau \approx$ 500 μm, BR = 0.07 %)

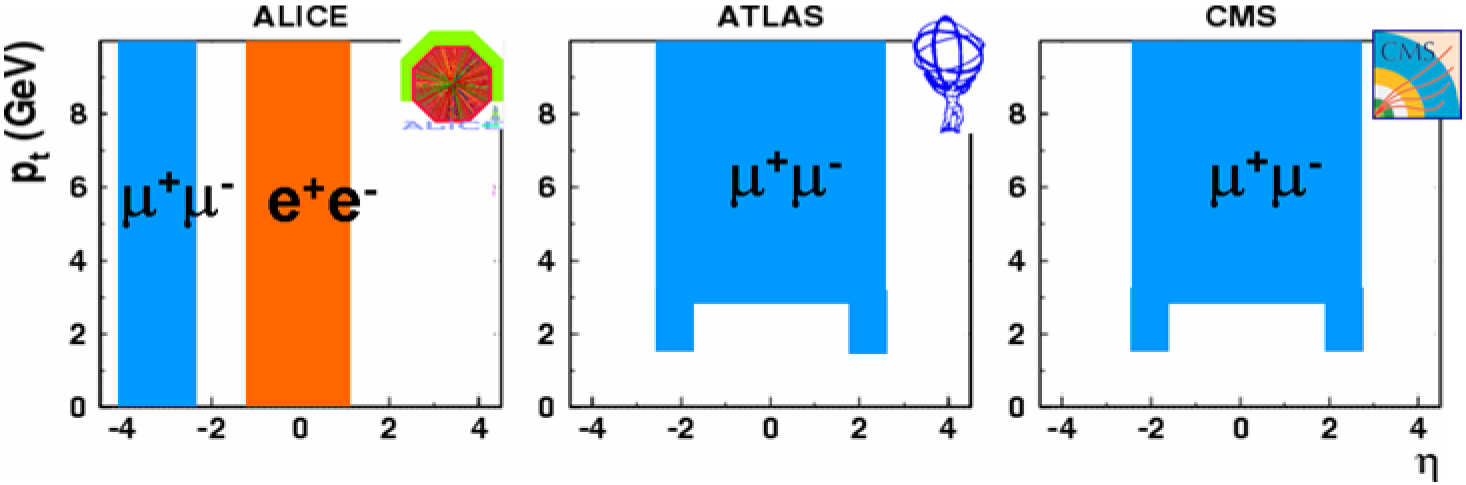
...

Quarkonia: Acceptance

x–Range:
$10^{-3} - 10^{-5}$

Large p_t–coverage
($p_t = 0$)





Physics Performance
Quarkonia: Di-Muons

MUON-arm

Forward region
$2.4 < \eta < 4.0$

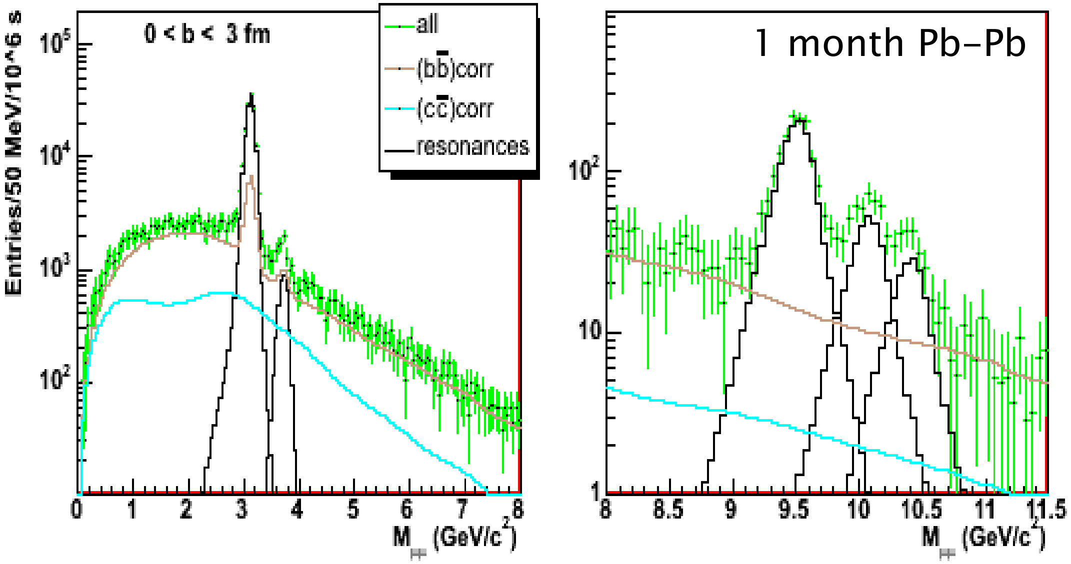
Resolution:
$\sigma_m(J/\psi) \approx$ 70MeV
$\sigma_m(\Upsilon) \approx$ 100MeV

Sensitivity
$(e^+e^-/\mu^+\mu^-)$

J/ψ, Υ, Υ' : High with normal stat.

Υ'': Needs 2-3 years high lum.

ψ' : Difficult



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
$\Upsilon(1S)$	1.3	0.8	1.7	29
$\Upsilon(2S)$	0.35	0.54	0.65	12
$\Upsilon(3S)$	0.20	0.42	0.48	8.1

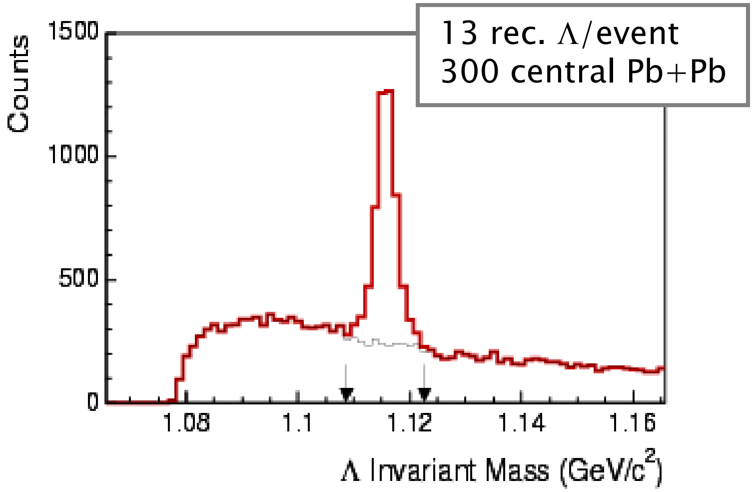
Physics Performance
Soft Physics

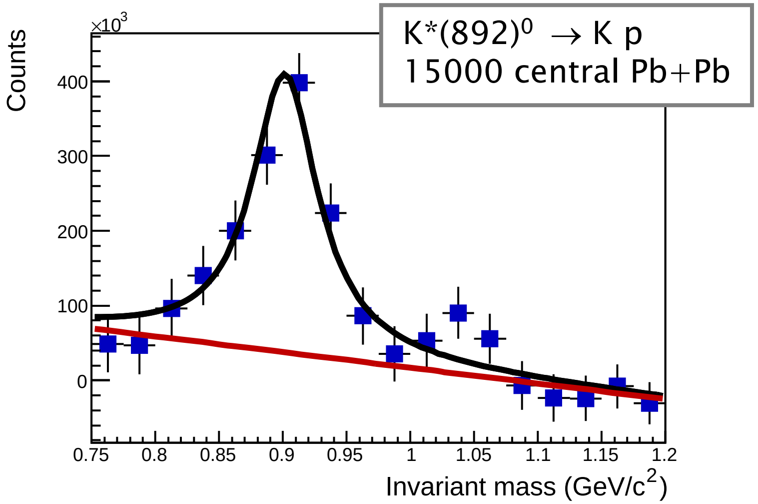
List of observables:

- Strangeness
- Resonances
- Flow v_2 (v_4, ...)
- Correlations
- Fluctuations

Similar performance than RHIC

- Higher statistics !





Physics Performance
Photons

PHOS:

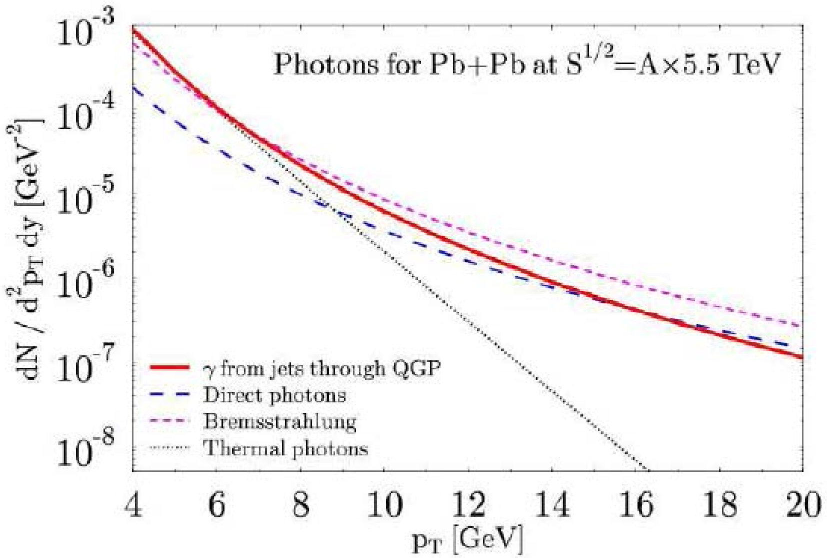
Optimized for thermal photons ($p_t < 5$GeV/c)

EMCAL:

High E photons

Central Barrel:

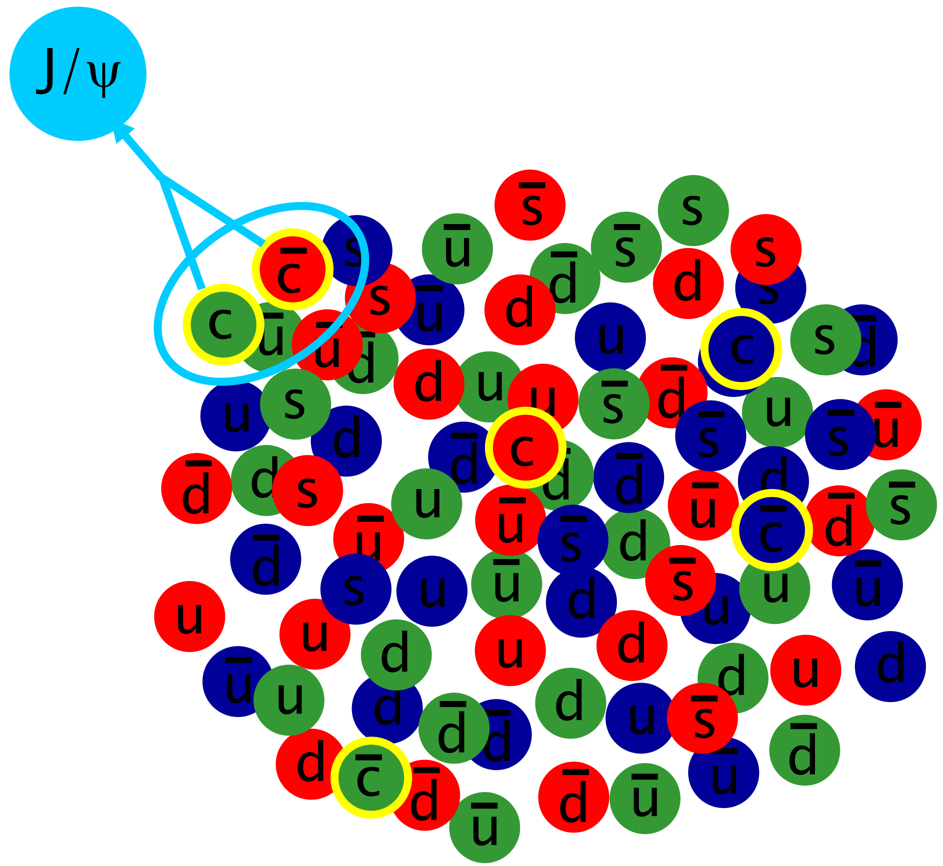
$\gamma \rightarrow e^+e^-$

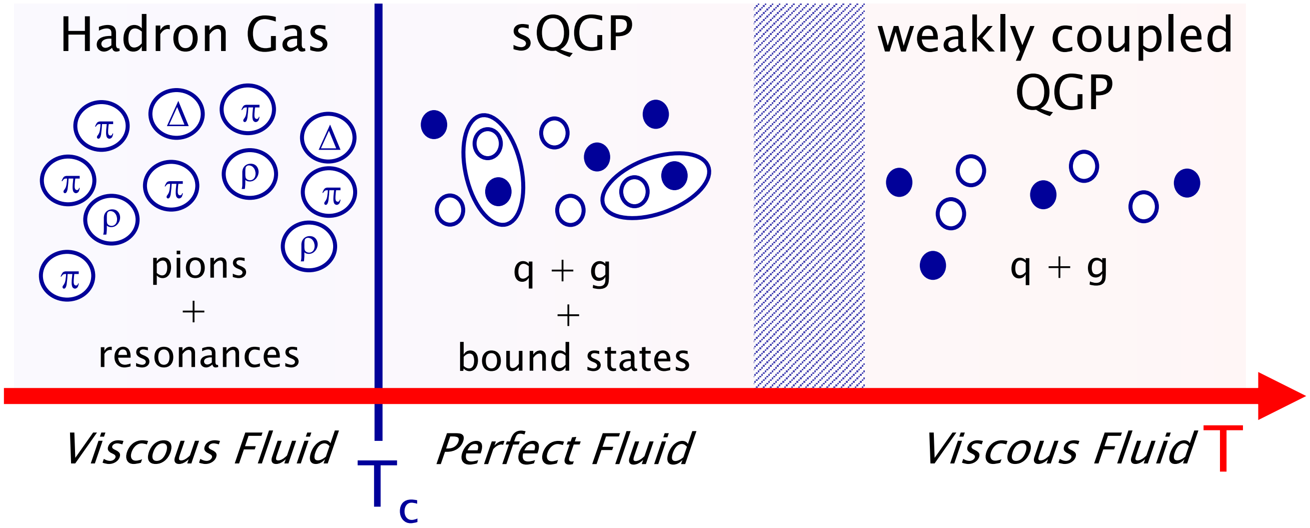


	p_t^{max} (1year) (GeV/c)		High-p_t trigger
	γ	π^0	
PHOS	~100 (shower shape)	~150 (inv. mass)	✓
EMCAL	~150 (shower shape)	~200 (inv. mass)	✓
CENTRAL BARREL	~20 ($\gamma \rightarrow e^+e^-$)	–	✓

Observables

Quarkonia: Coalescence




Hadron Gas
sQGP
weakly coupled QGP
π
Δ
ρ
pions
+
resonances
q + g
+
bound states
q + g
Viscous Fluid
Perfect Fluid
Viscous Fluid
T
c
T