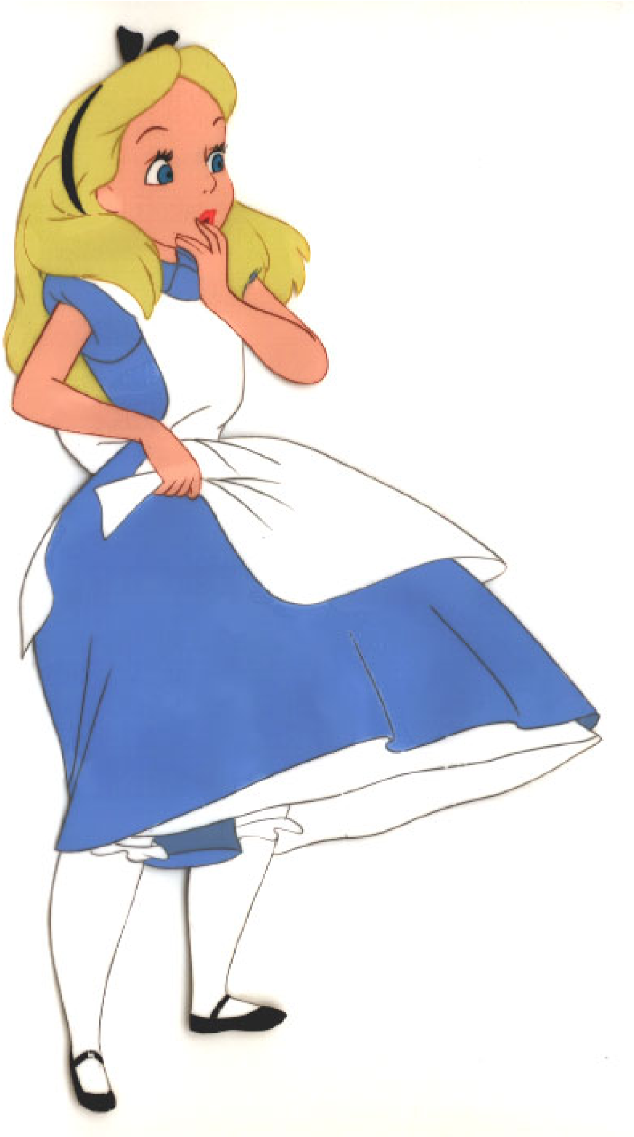
The ALICE experiment at the LHC



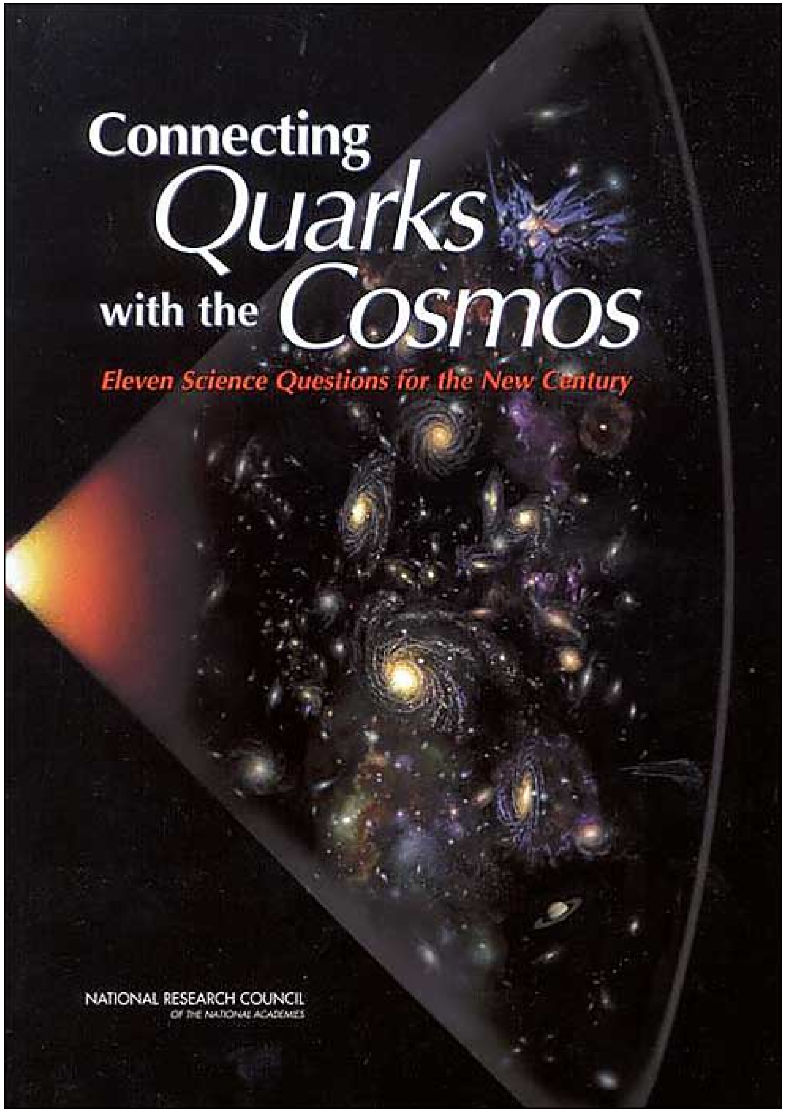
- heavy ion collisions & QGP
- heavy ion collisions @ LHC
- ALICE detector overview
- ALICE physics program

Philippe.Crochet@clermont.in2p3.fr

Séminaire, LAL, 09/06/09

The 11 most important questions…

…to understand the universe at its two extremes: the very large and the very small

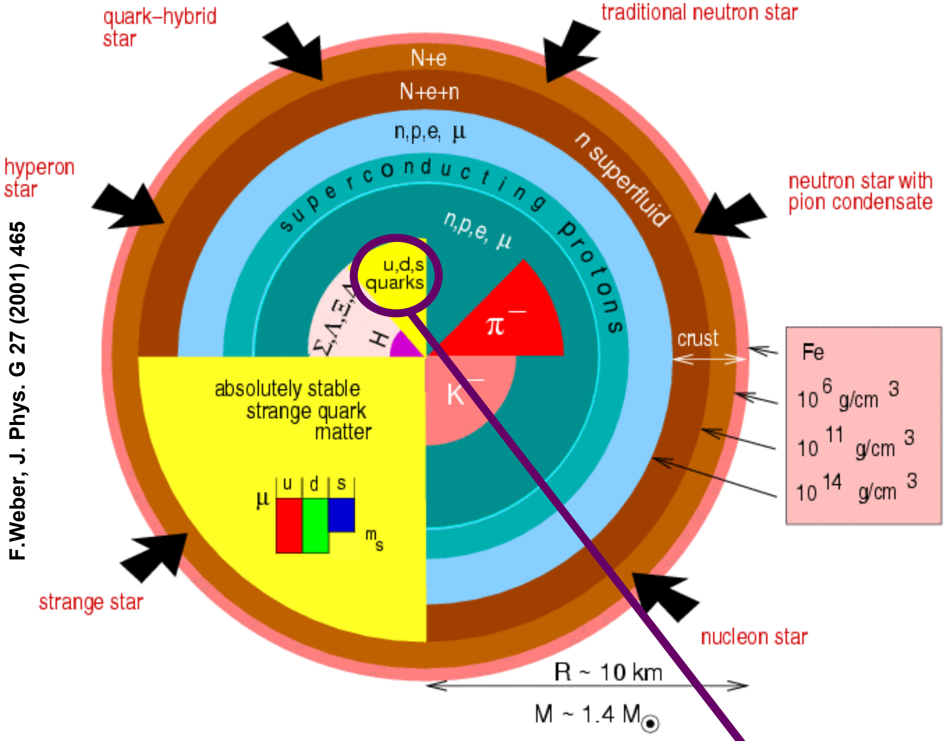


1. What is dark matter?
2. What is the nature of dark energy?
3. How did the universe begin?
4. Did Einstein have the last word on gravity?
5. What are the masses of the neutrinos, and how have they shaped the evolution of the universe?
6. How do cosmic accelerators work and what are they accelerating?
7. Are protons unstable?
8. What are the new states of matter at exceedingly high density and temperature?*
9. Are there additional space-time dimensions?
10. How were the elements from Iron to Uranium made?
11. Is a new theory of matter and light needed at the highest energies?

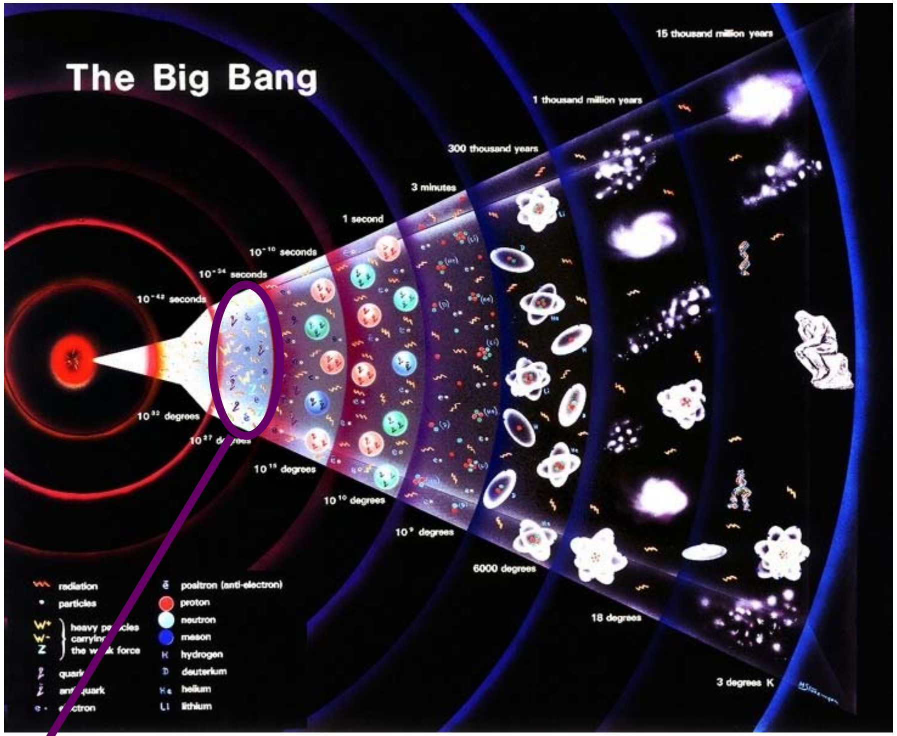
*"At high energies, neutrons and protons may "dissolve" into a undifferentiated "soup" of quarks and gluons, which can be probed in heavy-ion accelerators."

National research committee on the physics of the universe (2003)

Neutrons Stars, Big Bang & Quark Gluon Plasma



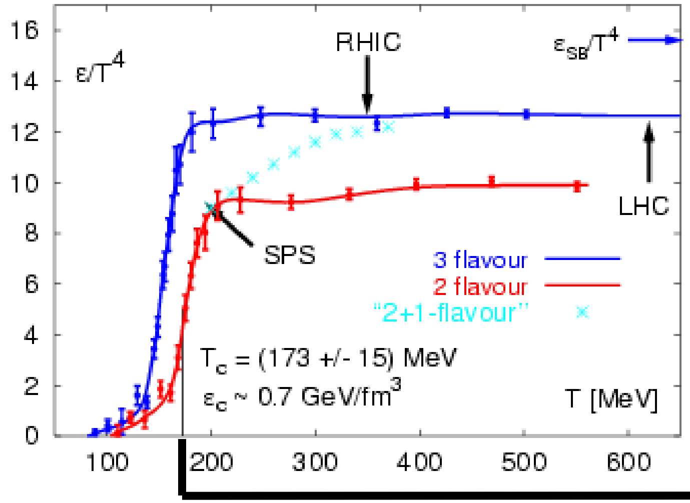
F.Weber, J. Phys. G 27 (2001) 465

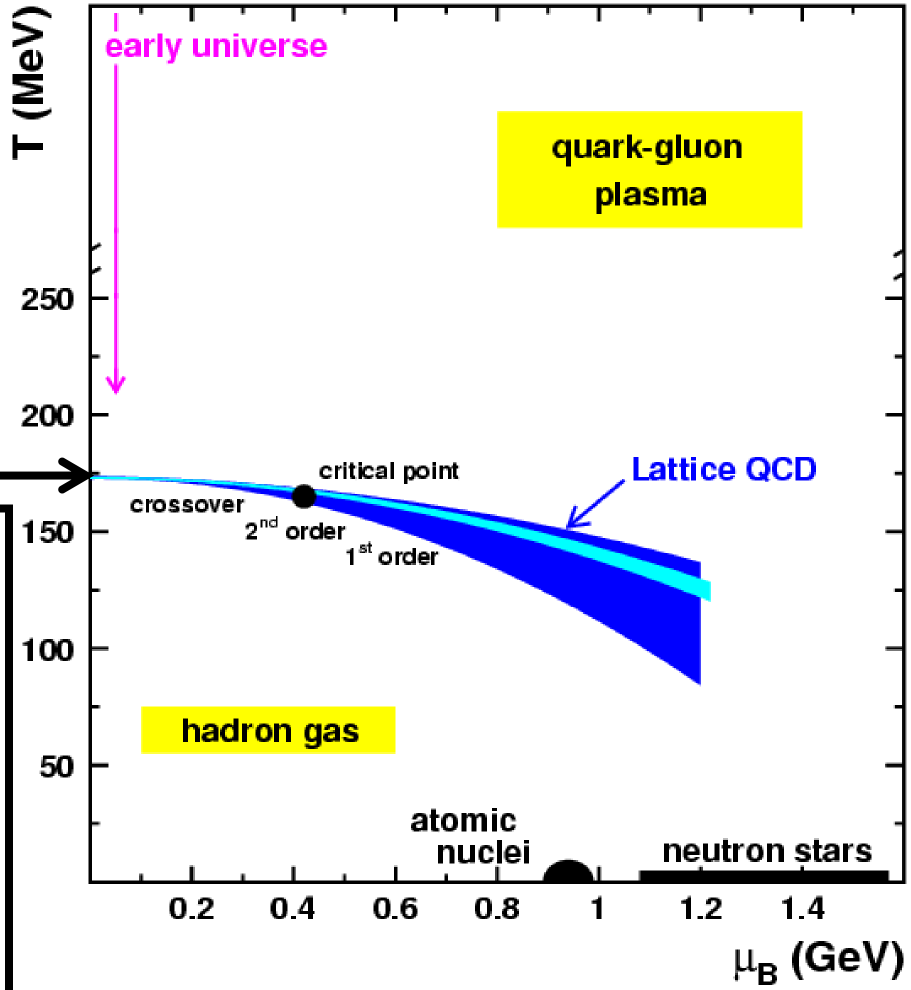


"When the energy density ε exceeds some typical hadronic value (~ 1 GeV/fm^3), matter no longer exists of separate hadrons (protons, neutrons, etc), but as their fundamental constituents, quarks and gluons. Because of the apparent analogy with similar phenomena in atomic physics we may call this phase of matter the QCD (or Quark Gluon) plasma."

E.V. Shuryak, Phys. Rept. 61 (1980) 71

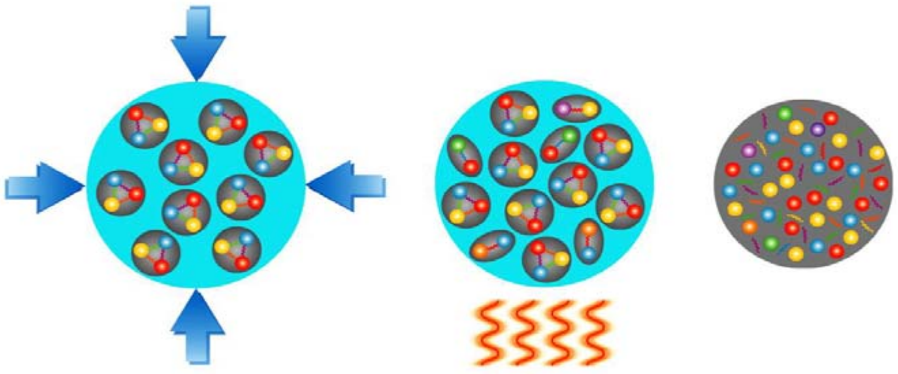
What QCD tells



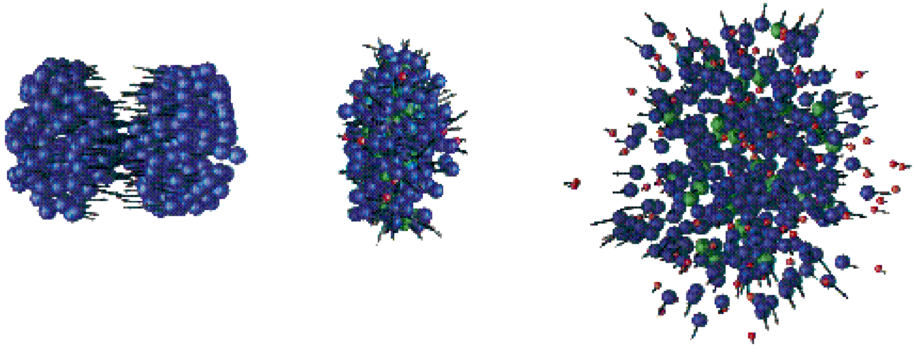


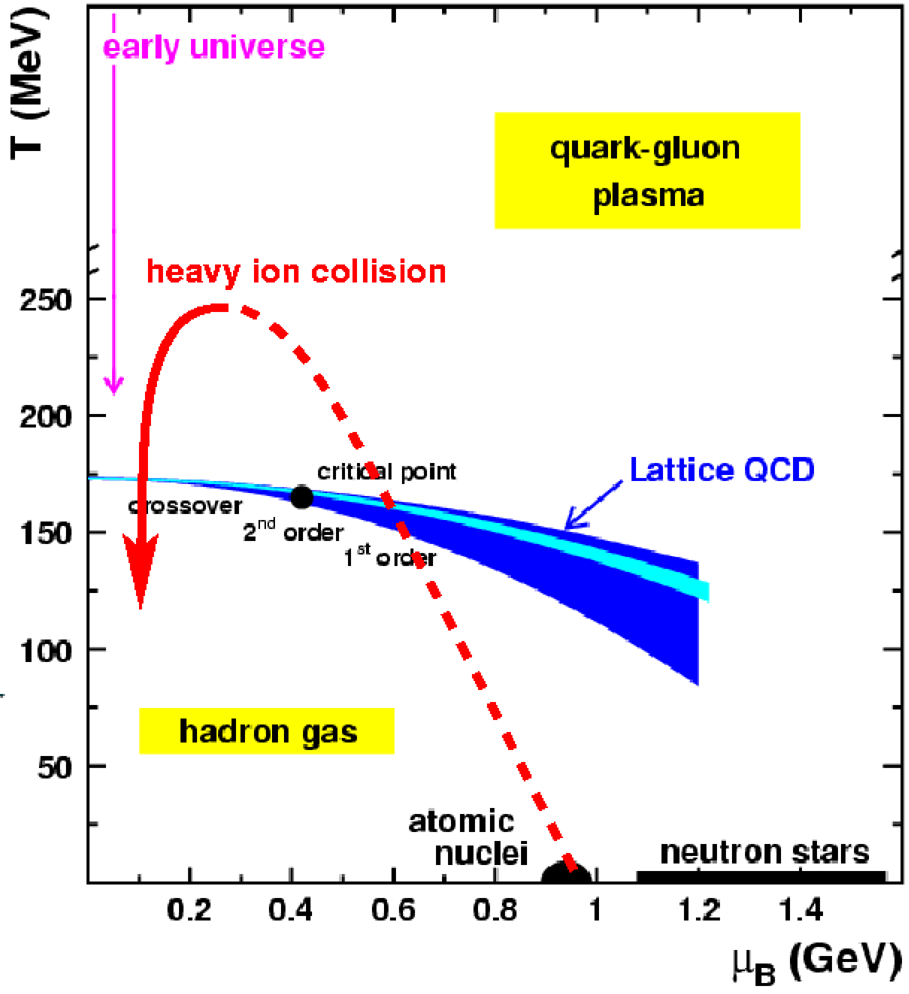
- **$\mu_B = 0$:**
  - **$T_c = 173 \pm 15$ MeV**
  - **$\varepsilon_c = 0.7 \pm 0.3$ GeV/fm^3**
  - **"crossover"-like transition**
- **$\mu_B > 0$:**
  - **large uncertainties**
  - **order of transition unknown**
  - **existence of a critical point**
- **chiral sym. rest. coincides with deconf.**
- **the QGP is not an ideal gas**
- **$\mu_B \gg 0$: color superconductivity (not shown)**

Recreating the QGP with heavy ion collisions



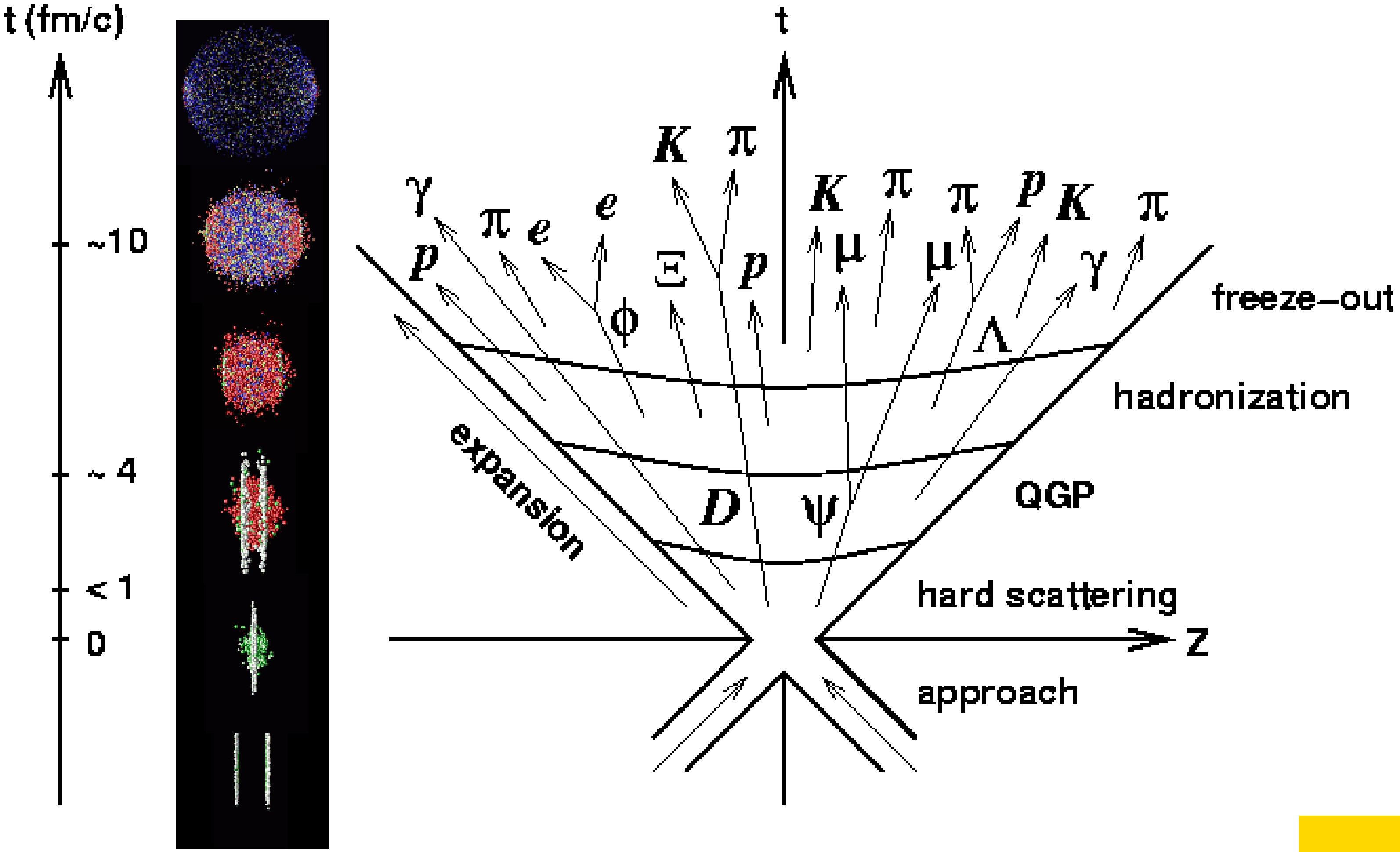
pressure + heat ⇒ QGP



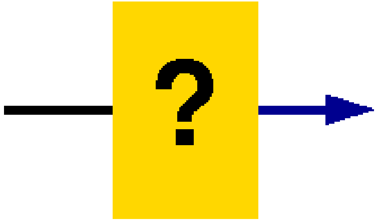


key parameters: bombarding energy, collision centrality, particle transverse momentum

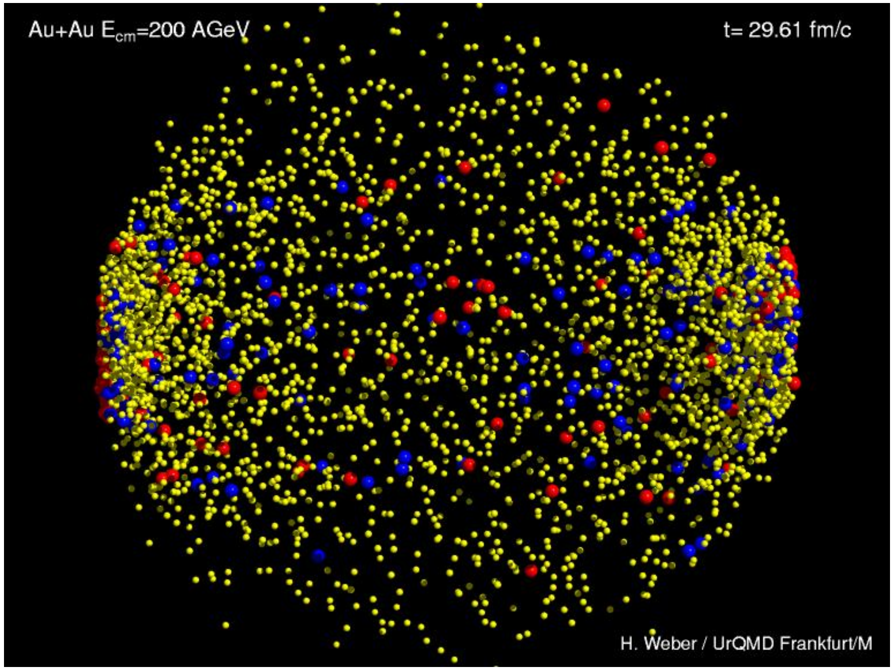
Schematic space-time evolution of a heavy ion collision



- 4 main “distinct” phases
- strategy: use produced particles as probes of the medium

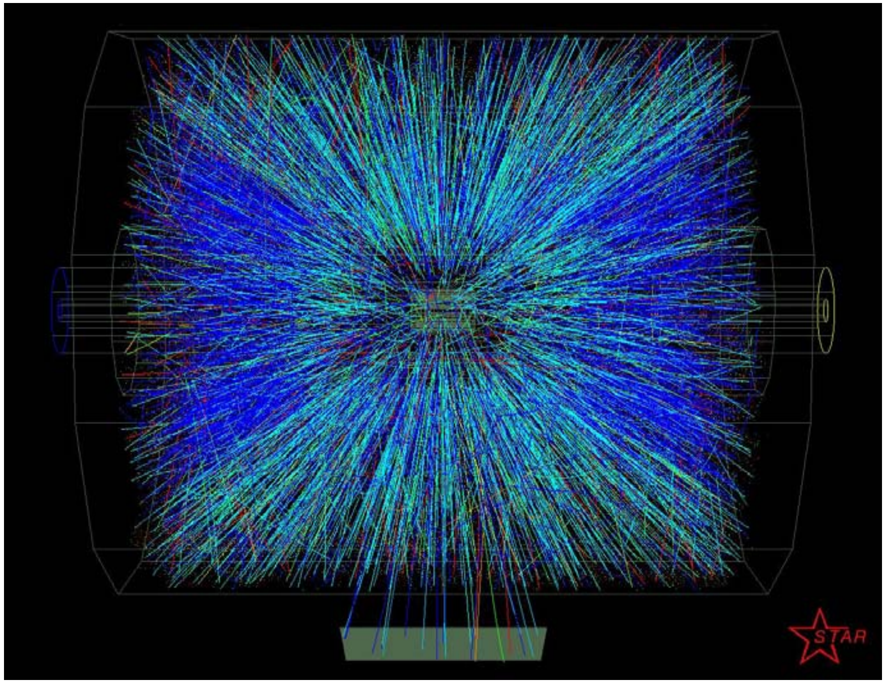


Not that simple…



← a simulated heavy ion collision

the same collision in real life →



Strategy for studying the QGP

1. **Measure a quantity**
   - **whose value (from theoretical predictions) is expected to be different with or w/o a QGP. Most appropriate: central AA collisions**
2. **Validate the measurement**
   - **by comparing the quantity to theoretical predictions with & w/o QGP**
   - **by comparing the quantity to the same quantity measured in pp (reference), then in pA & peripheral AA (no QGP but cold nuclear effects) and then in central AA**
3. **Validate the result**
   - **repeat 1. and 2. with as many quantities as possible**
4. **Extract QGP properties**
   - **tune models & repeat comparisons**

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QGP signatures

suppression of high-mass resonances

photon production

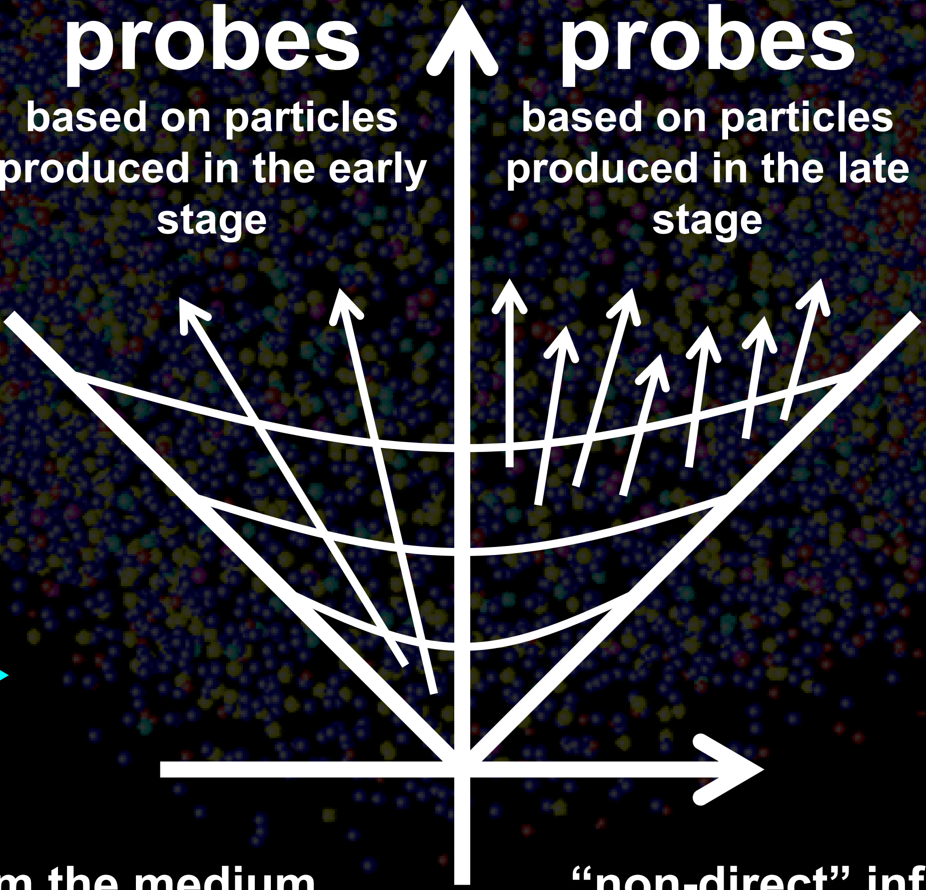
jet quenching

modification of low-mass resonances

strangeness enhancement

flow profile

..etc

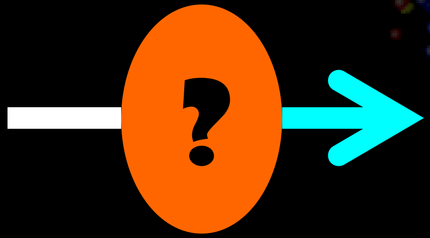


hard probes

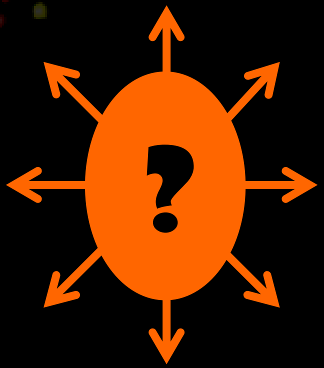
based on particles produced in the early stage

soft probes

based on particles produced in the late stage



“direct” info from the medium

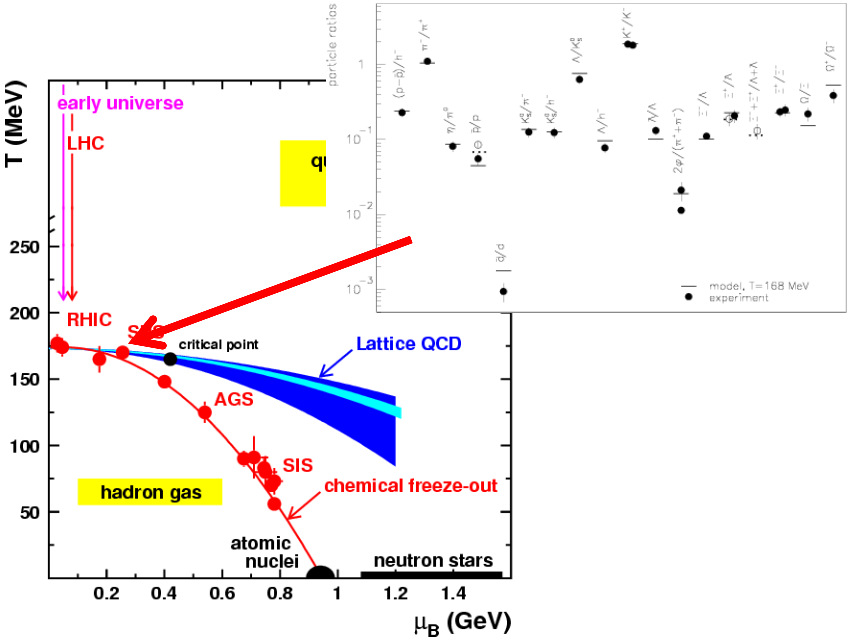


“non-direct” info from the medium

Do we reach the thermodynamical conditions of the QGP in HIC?

- **freeze-out temperature**

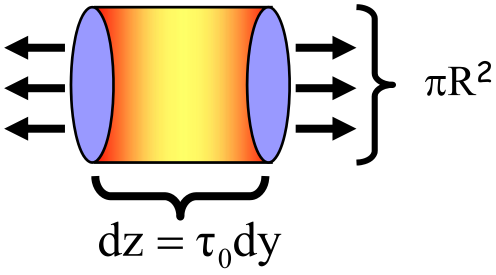
$$n_i = \frac{g}{2\pi^2}\int_0^\infty \frac{p^2\,dp}{e^{(E_i(p)-\mu_i)/T} \pm 1}$$

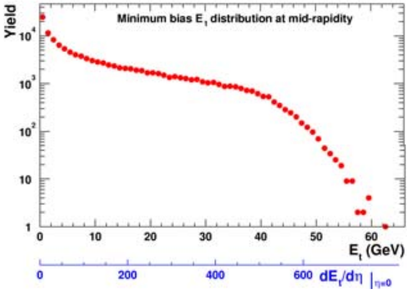


…coincides with critical value

- **energy density**

$$\varepsilon_{Bj} = \frac{1}{\pi R^2}\,\frac{1}{\tau_0}\,\frac{dE_T}{dy}$$

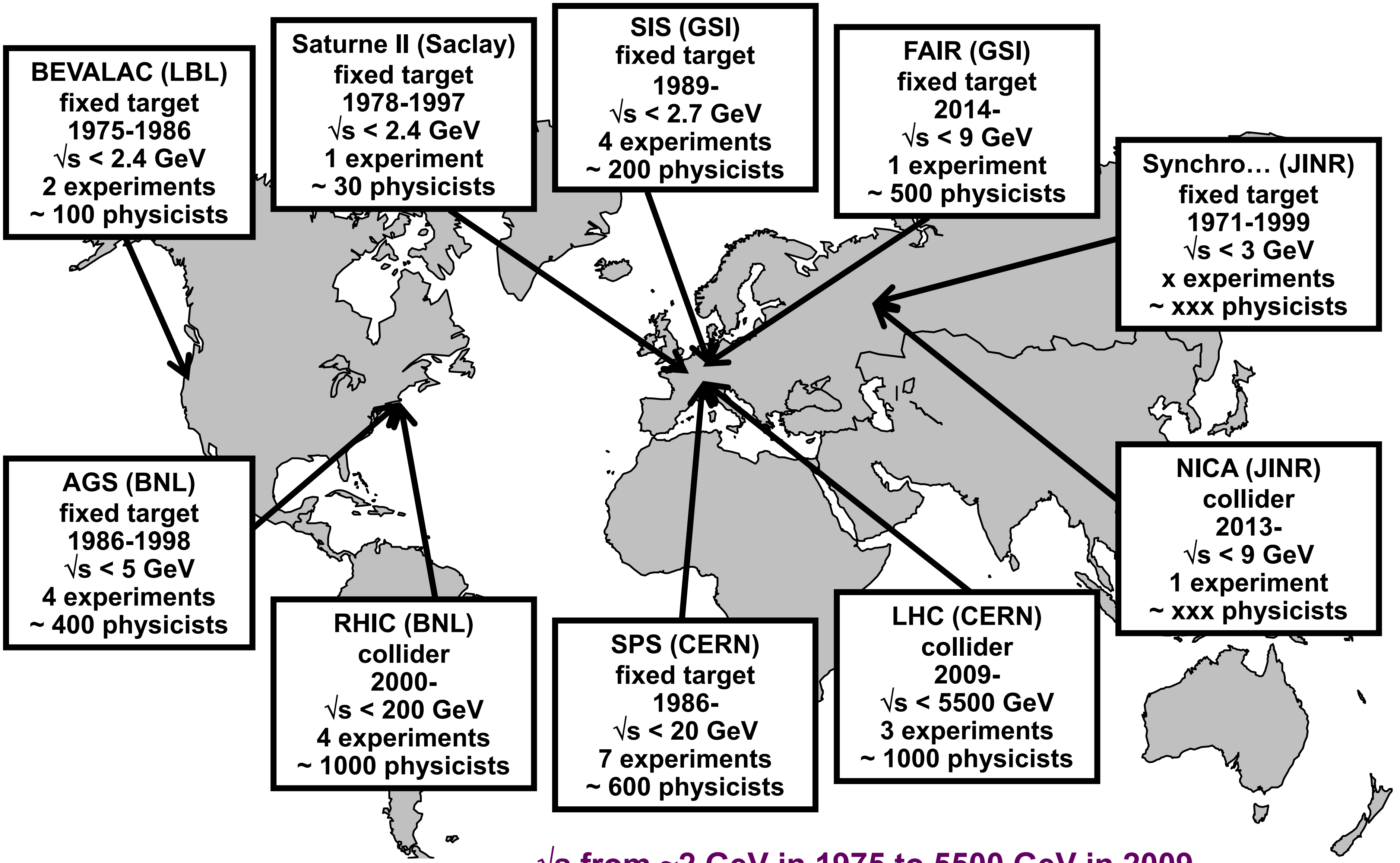




system	√s (GeV)	ε (GeV/fm³)
Pb+Pb	17	2.5
Au+Au	200	4.6

…larger than critical value

1975-2009: 34 years of heavy-ion collisions



BEVALAC (LBL)
fixed target
1975-1986
$\sqrt{s} < 2.4$ GeV
2 experiments
~ 100 physicists

Saturne II (Saclay)
fixed target
1978-1997
$\sqrt{s} < 2.4$ GeV
1 experiment
~ 30 physicists

SIS (GSI)
fixed target
1989-
$\sqrt{s} < 2.7$ GeV
4 experiments
~ 200 physicists

FAIR (GSI)
fixed target
2014-
$\sqrt{s} < 9$ GeV
1 experiment
~ 500 physicists

Synchro… (JINR)
fixed target
1971-1999
$\sqrt{s} < 3$ GeV
x experiments
~ xxx physicists

AGS (BNL)
fixed target
1986-1998
$\sqrt{s} < 5$ GeV
4 experiments
~ 400 physicists

RHIC (BNL)
collider
2000-
$\sqrt{s} < 200$ GeV
4 experiments
~ 1000 physicists

SPS (CERN)
fixed target
1986-
$\sqrt{s} < 20$ GeV
7 experiments
~ 600 physicists

LHC (CERN)
collider
2009-
$\sqrt{s} < 5500$ GeV
3 experiments
~ 1000 physicists

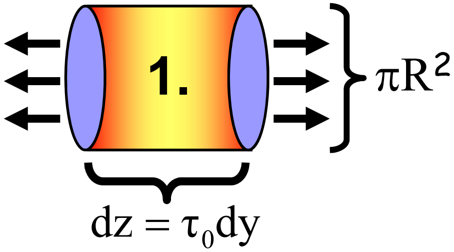
NICA (JINR)
collider
2013-
$\sqrt{s} < 9$ GeV
1 experiment
~ xxx physicists

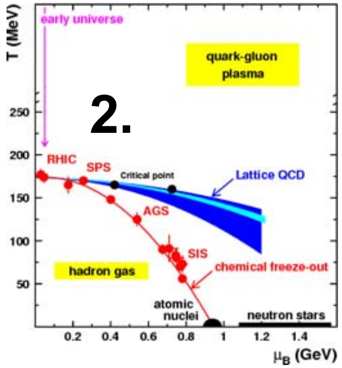
$\sqrt{s}$ from ~2 GeV in 1975 to 5500 GeV in 2009

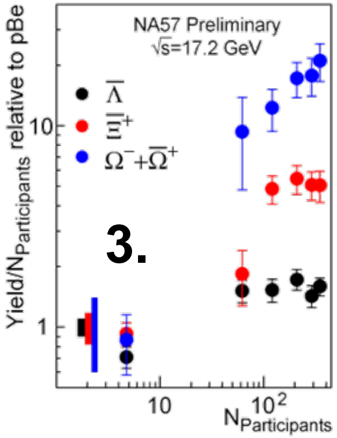
Résumé (très succint) des résultats SPS & RHIC

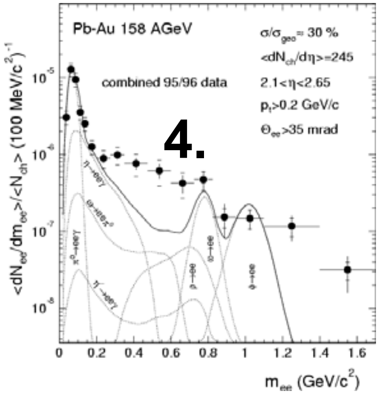
le système produit par collisions d’ions lourds :

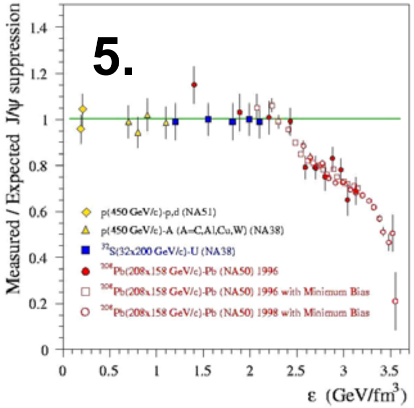
1. a une densité d’énergie > à ε_c
2. a une température au freeze-out ~ à T_c
3. surproduit de l’étrangeté
4. modifie les résonances légères
5. dissout les résonances lourdes
6. rayonne des photons
7. a des degrés de liberté partoniques
8. absorbe les jets

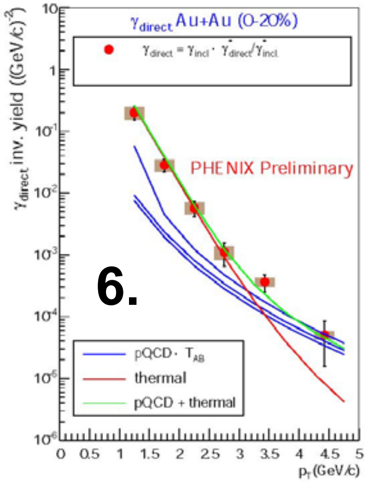


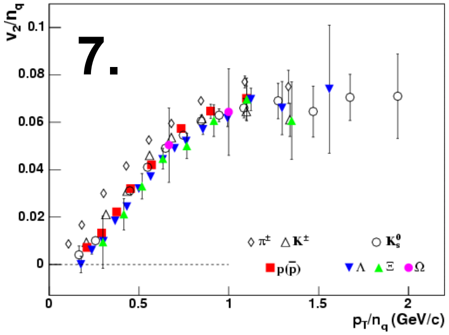


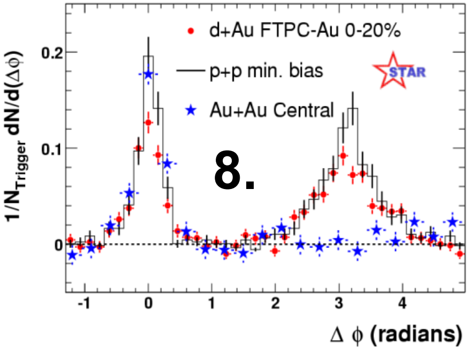












comportement attendu d’un plasma de quarks et de gluons

So why going for the QGP @ LHC?

assumption: QGP has been established @ RHIC prior to LHC

SEARCH for the QGP may be essentially over

DISCOVERY of the QGP is well under way

MEASURING QGP parameters has hardly begun

QGP @ LHC versus RHIC = Z/W @ LEP versus SppS

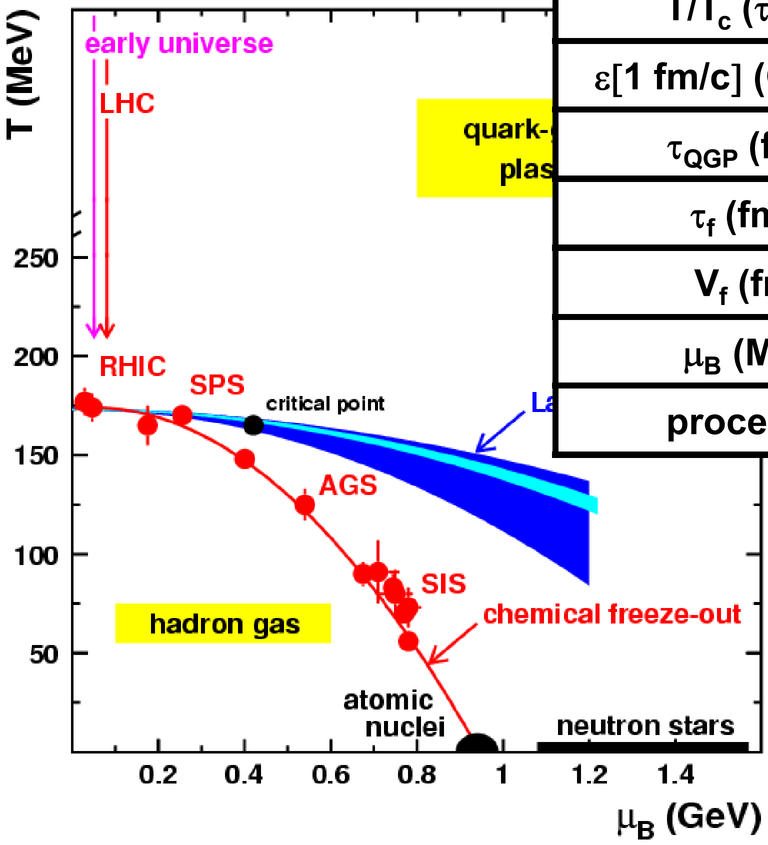
the LHC is the ideal place for studying the QGP (next slides)

adapted from J. Schukraft @ Split06

Heavy ion collisions & QGP @ LHC

the biggest step in energy in the history of heavy-ion collisions

machine	SPS	RHIC	LHC	
$\sqrt{s}$ (GeV)	17	200	5500	= 0.18 mJ
N_{ch}	1000	4000	50 000	
τ^0_{QGP} (fm/c)	1	0.2	0.1	⇒ faster
T/T_c (τ^0_{QGP})	1.1	1.9	3.0-4.2	⇒ hotter
ε[1 fm/c] (GeV/fm^3)	3	5	15-60	⇒ denser
τ_{QGP} (fm/c)	≤ 2	2-4	≥ 10	⇒ longer
τ_f (fm/c)	~ 10	20-30	30-40	
V_f (fm^3)	~ 10^3	~ 10^4	~ 10^5	⇒ bigger
μ_B (MeV)	250	20	1	⇒ cleaner
processes	soft →	semi-hard →	hard	⇒ harder



ε, vol. & τ QGP × 10(4) from SPS(RHIC) to LHC

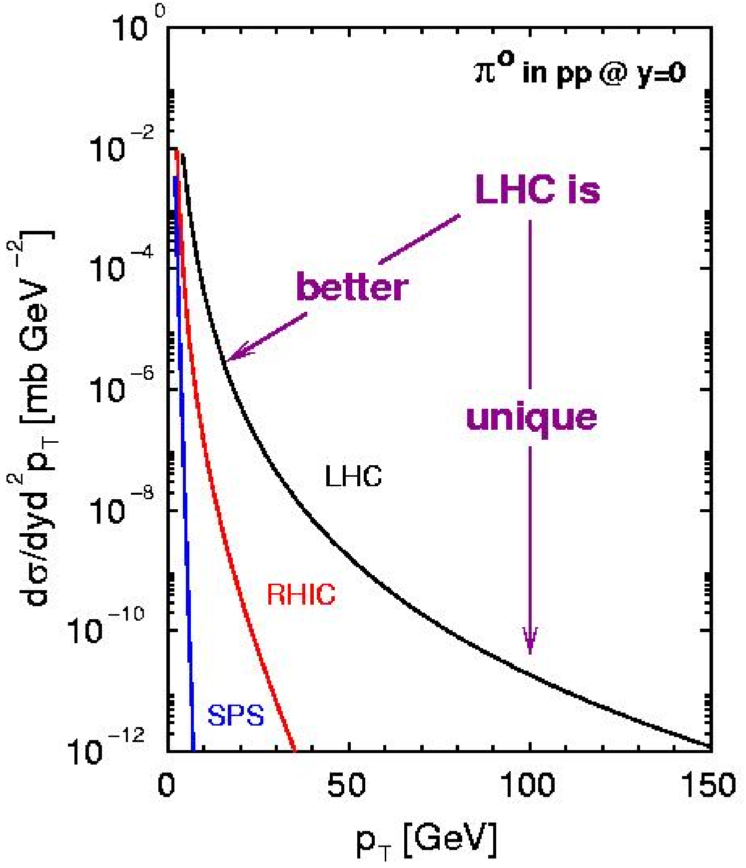
“...the LHC will become the ideal facility for a systematic exploration and quantitative confirmation of the insights obtained at RHIC, aided by the plentiful abundance of hard probes.”

B. Müller, hep-ph/0410115

J. Schukraft, Nucl. Phys. A 698 (2002) 287

Hard processes: what is different @ LHC

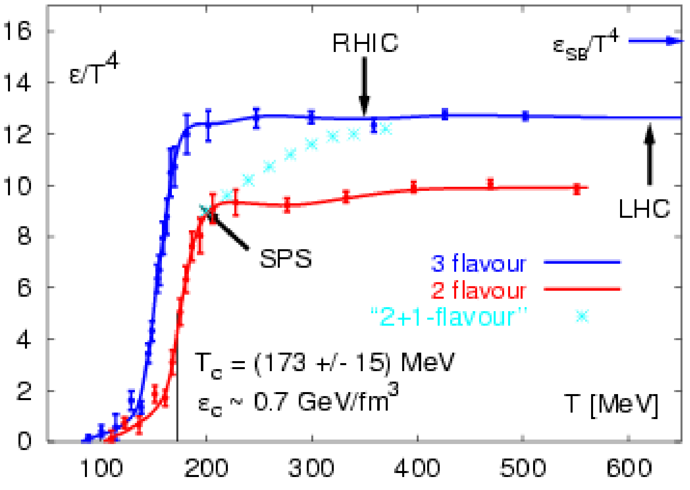
huge cross-section



$\sigma^{hard}/\sigma^{tot}$ = 2/50/98% @ SPS/RHIC/LHC

K. Kajantie, Nucl. Phys. A 715 (2003) 432

pQCD under better control



$$\sigma_{pp}^{hard} = O(\alpha_s) + O(\alpha_s^2) + O(\alpha_s^3) + \ldots$$

$$\alpha_s(T) \propto \frac{4\pi}{18\log(5T/T_c)} = \begin{matrix} 0.43 @ T = T_c \\ 0.23 @ T = 4T_c \end{matrix}$$

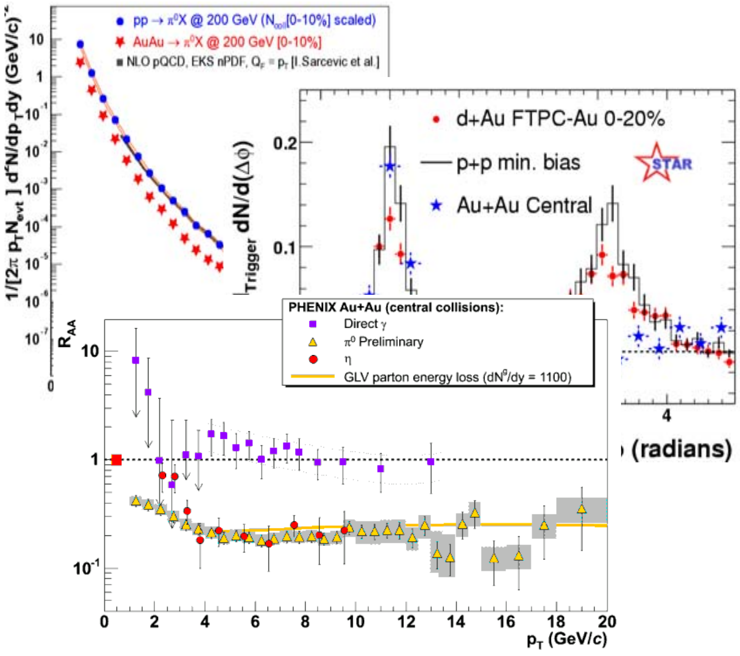
3/4/5th order terms are ~ 7/12/23 times smaller @ LHC than @ SPS

Jets: what is different @ LHC

RHIC-like analyses **20** **Tevatron-like analyses** **200** E_t (GeV)

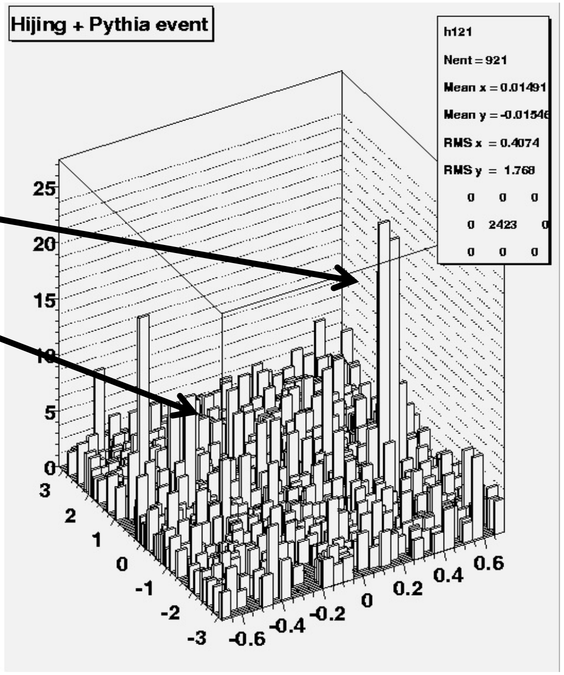
inclusive distributions

evt-by-evt reconstruction



dN/dp$_t$, R$_{AA}$, R$_{cp}$, ΔΦ with unlimited statistics

100 GeV jet (PYTHIA)
PbPb (HIJING)



- **jet energy**
- **parallel & perpendicular momentum dist.**
- **tagging with photons**
- **fragmentation functions**

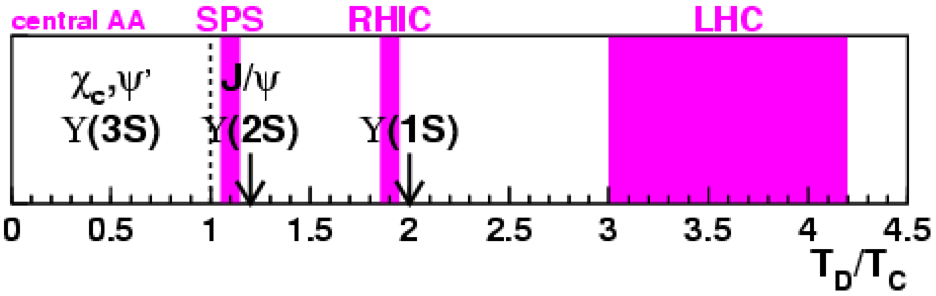
Heavy flavors: what is different @ LHC

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

	SPS	RHIC	LHC
charm	0.2	10	130
bottom	---	0.05	5

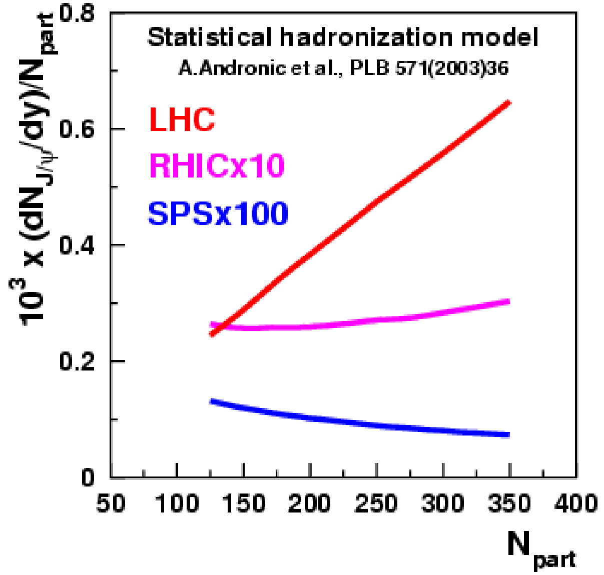
quarkonium dissociation temperatures

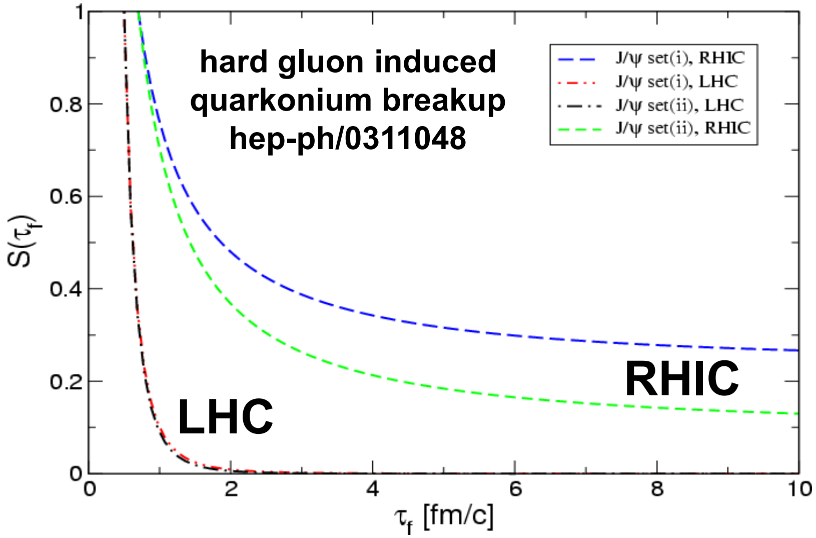
A. Mocsy & P. Petreczky, Phys. Rev. Lett. 99 (2007) 211602



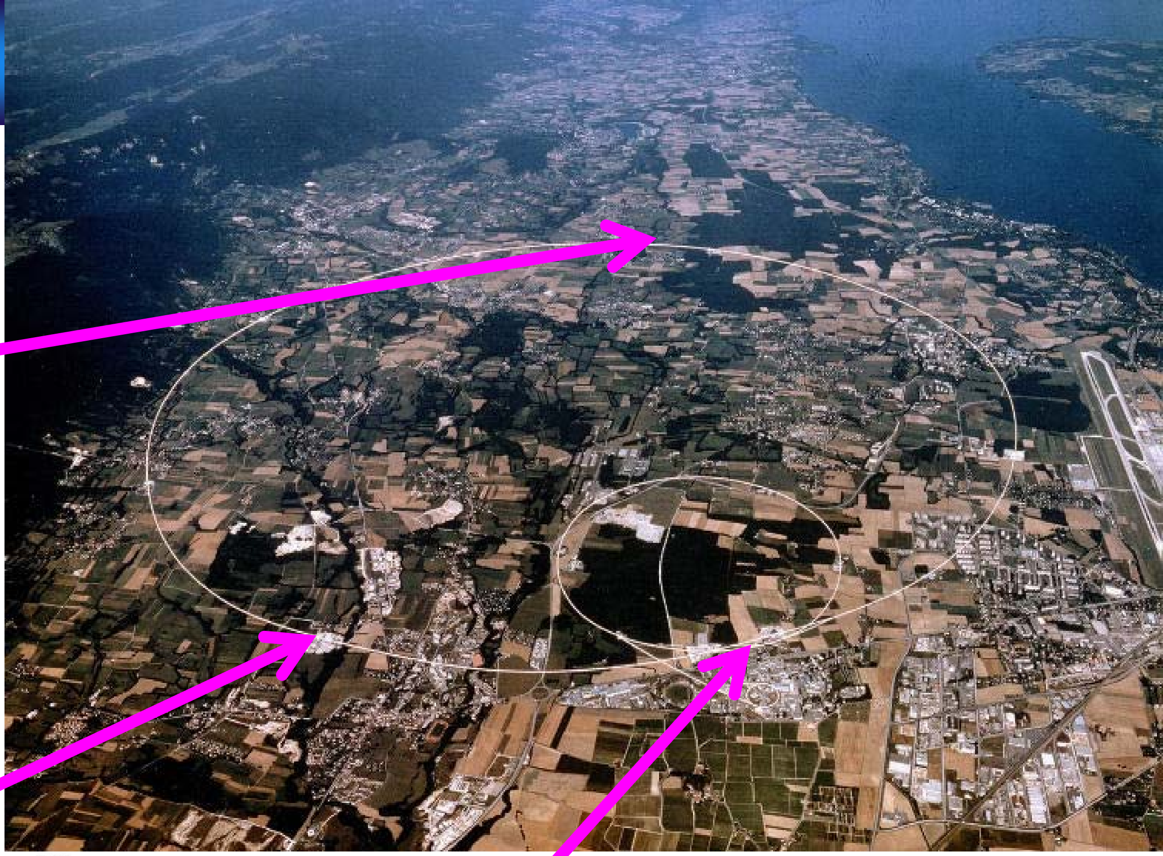
- **large primary production**
- **melting of $\Upsilon(1S)$ by color screening**
- **none of the primary J/ψ survives the (PbPb)QGP**
- **a lot of charmonia from b hadron decay (> 20 %)**
- **large secondary production of charmonia**

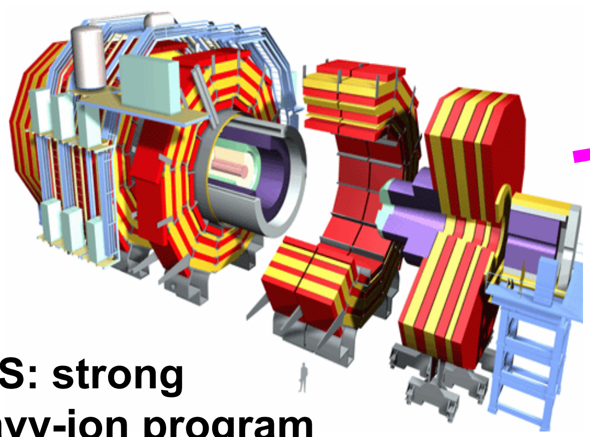
statistical hadronization, kinetic recombination, DDbar annihilation



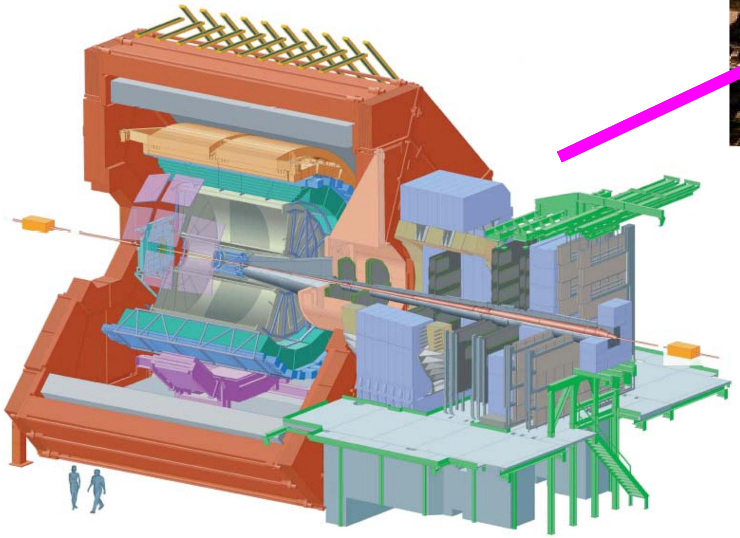


Heavy ions @ LHC

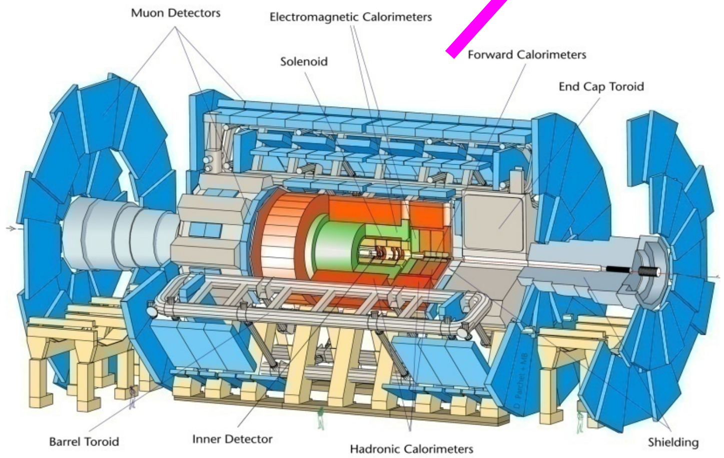




CMS: strong heavy-ion program

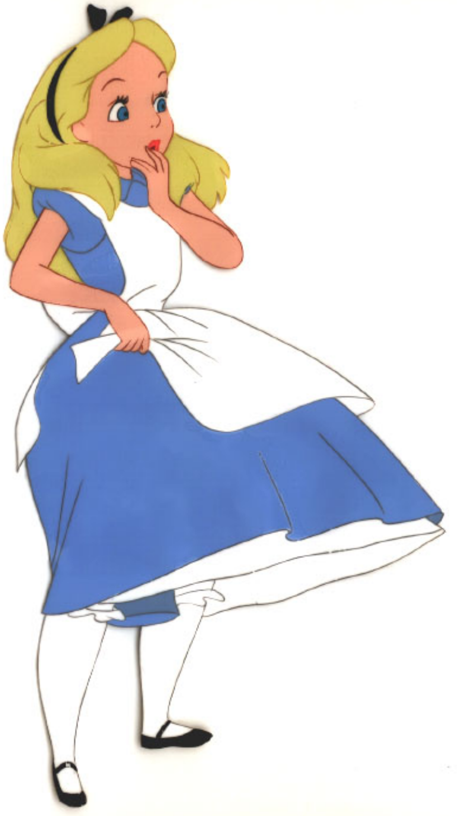


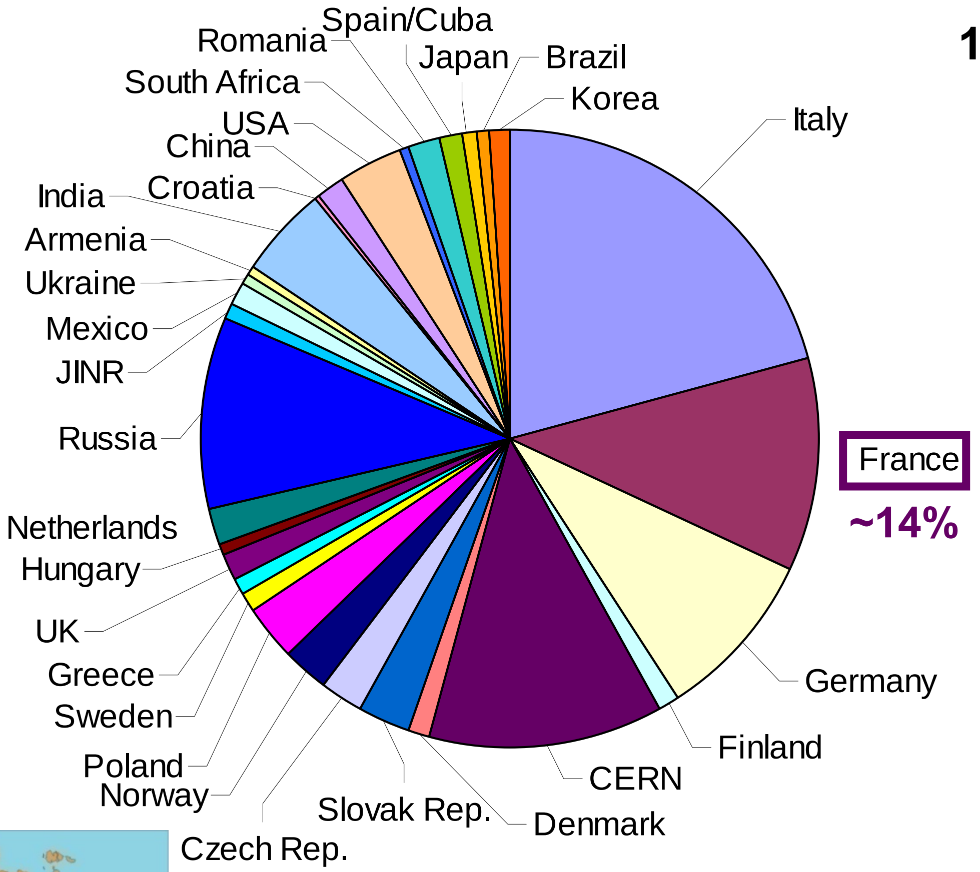
ALICE: the dedicated heavy-ion experiment



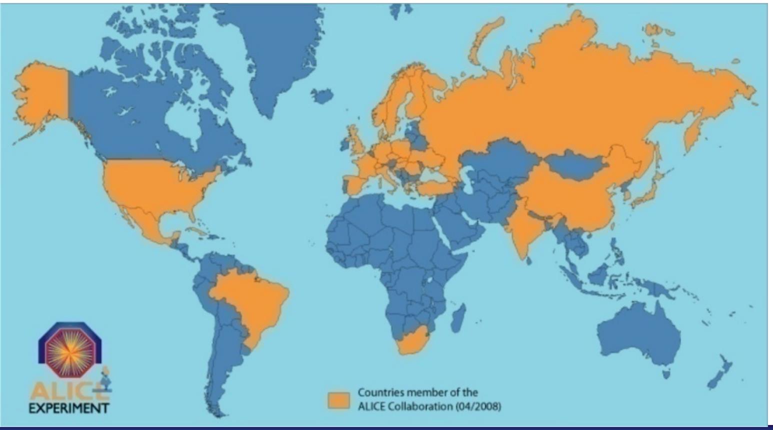
ATLAS: heavy-ion LOI (2004)

The ALICE collaboration

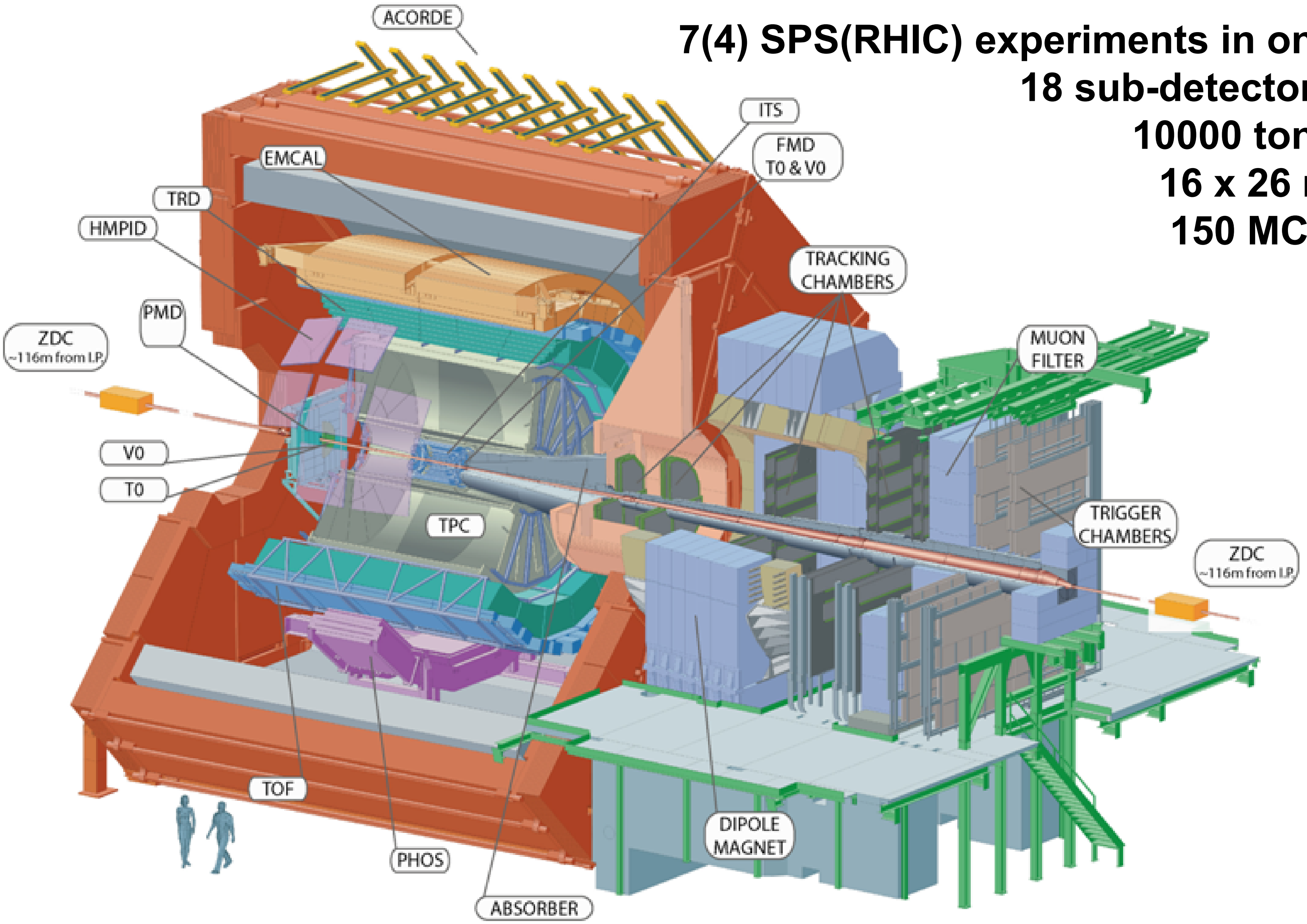




1000 members
109 institutes
31 countries



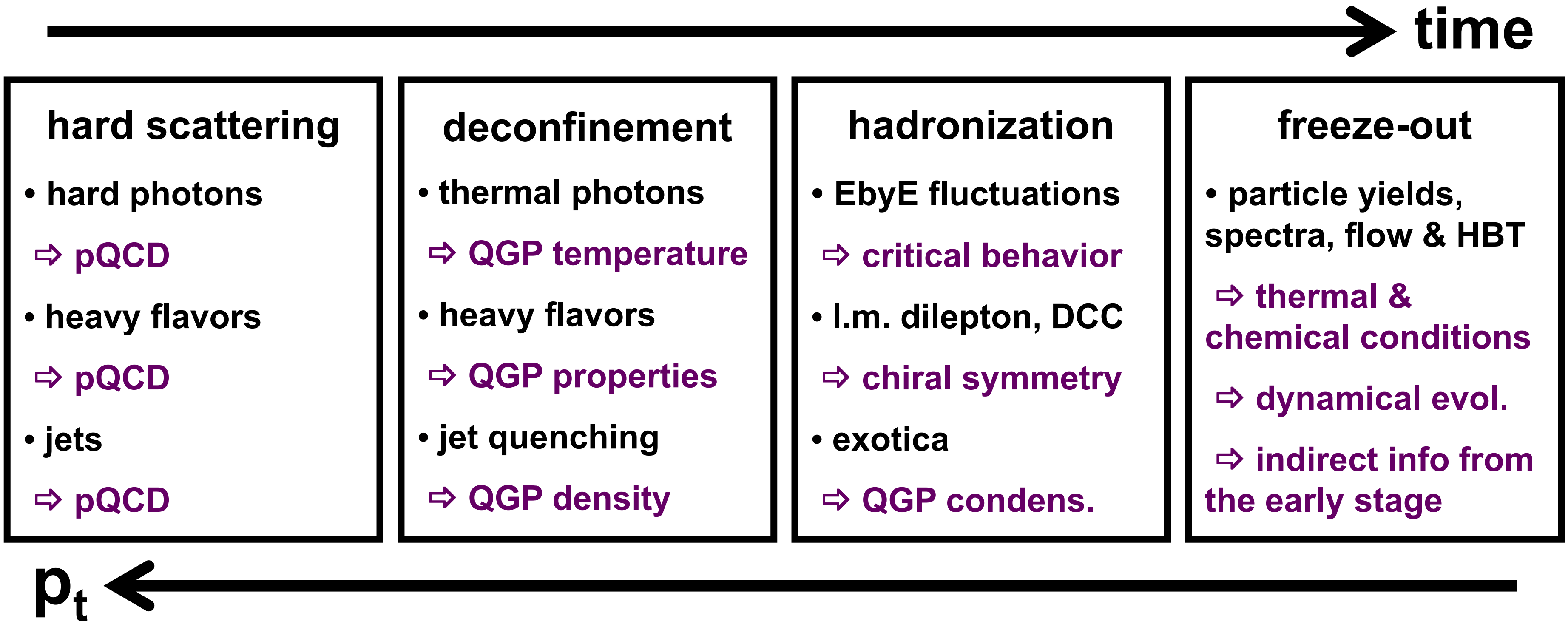
ALICE (A Large Ion Colider Experiment)



7(4) SPS(RHIC) experiments in one
18 sub-detectors
10000 tons
16 x 26 m
150 MCH

Philippe.Crochet@clermont.in2p3.fr

ALICE shopping list



time

hard scattering

- hard photons

⇨ pQCD

- heavy flavors

⇨ pQCD

- jets

⇨ pQCD

deconfinement

- thermal photons

⇨ QGP temperature

- heavy flavors

⇨ QGP properties

- jet quenching

⇨ QGP density

hadronization

- EbyE fluctuations

⇨ critical behavior

- l.m. dilepton, DCC

⇨ chiral symmetry

- exotica

⇨ QGP condens.

freeze-out

- particle yields, spectra, flow & HBT

⇨ thermal & chemical conditions

⇨ dynamical evol.

⇨ indirect info from the early stage

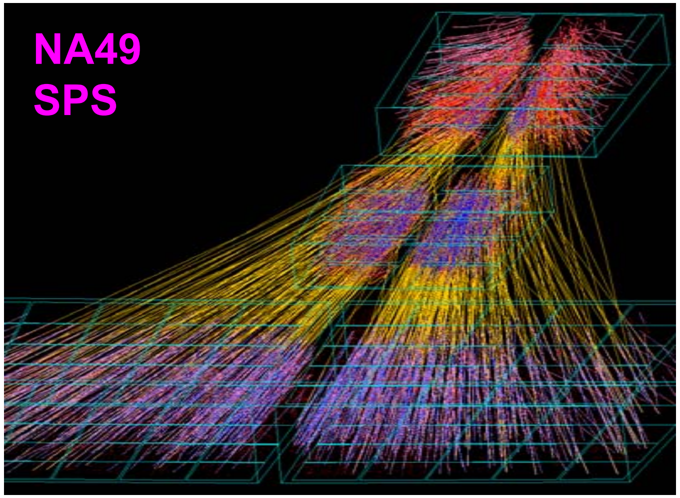
p_t

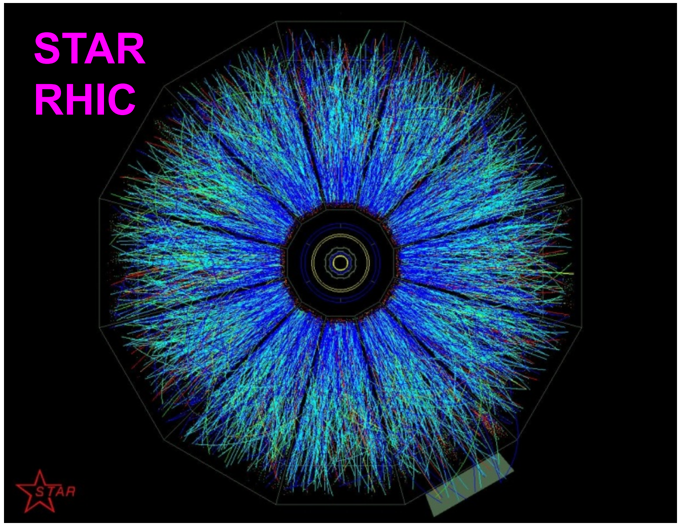
ALICE is designed to explore a broad p_t range and to correlate most of the signals

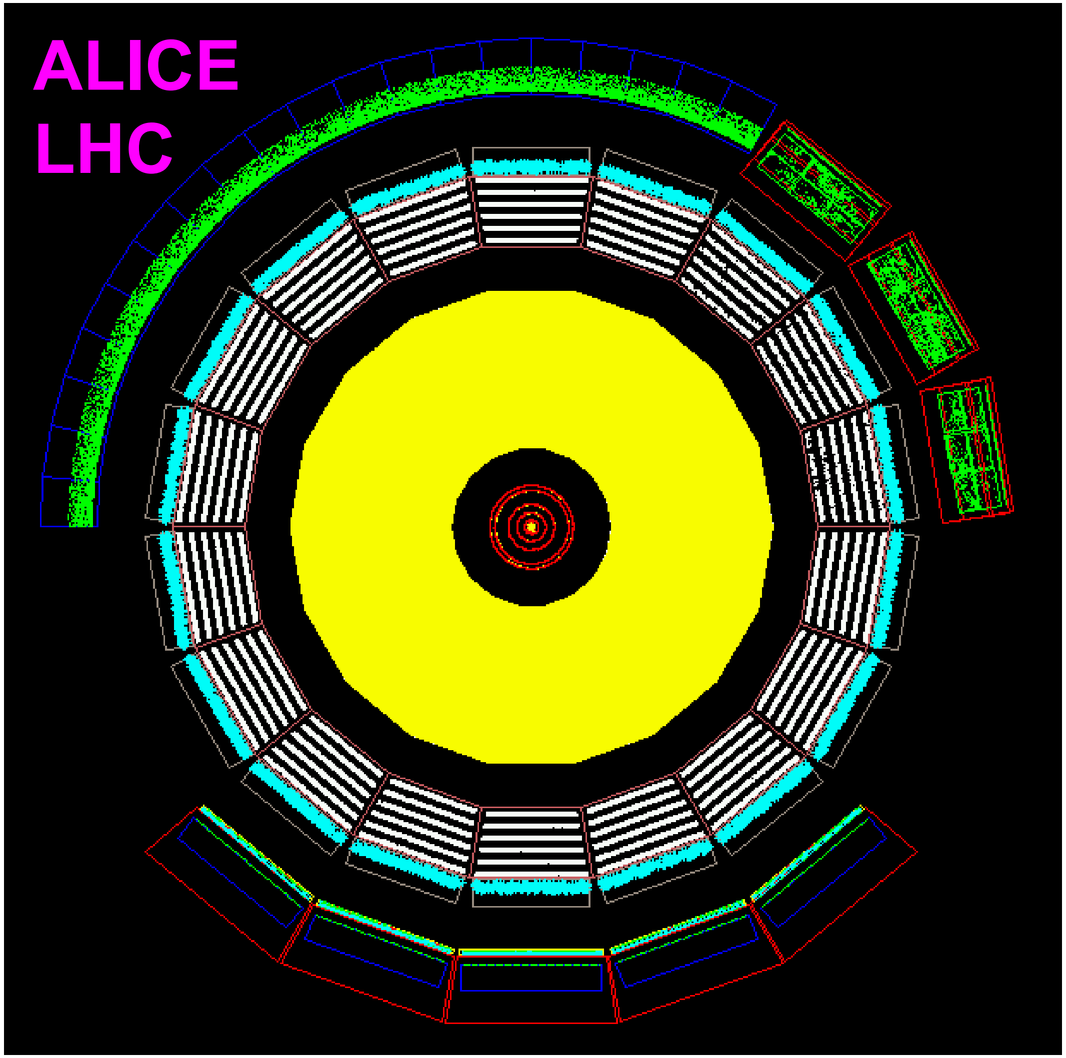
large acceptance & granularity, selective triggers, good tracking capabilities, wide momentum coverage, good secondary vertex reconstruction, hadron, lepton & photon id.

soft sector: observables & expected performances comparable to that of RHIC
hard sector: new observables, new analyses

Ce à quoi il faut s'attendre







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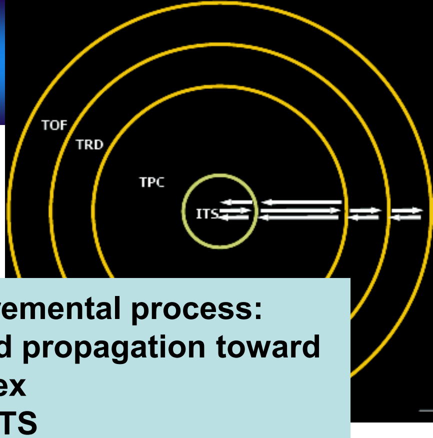
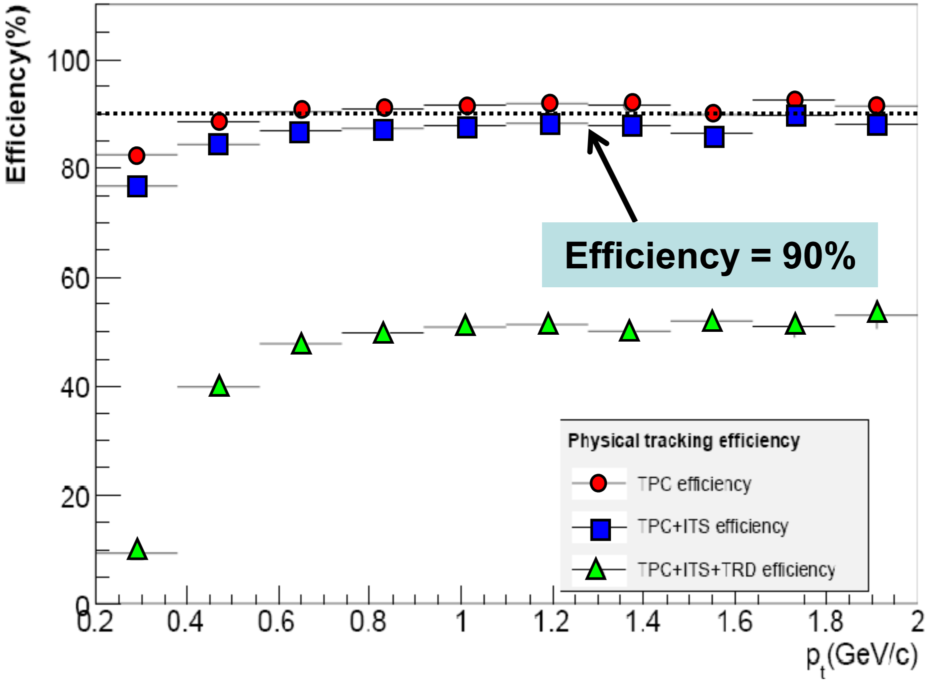
Particle tracking in ALICE central barrel

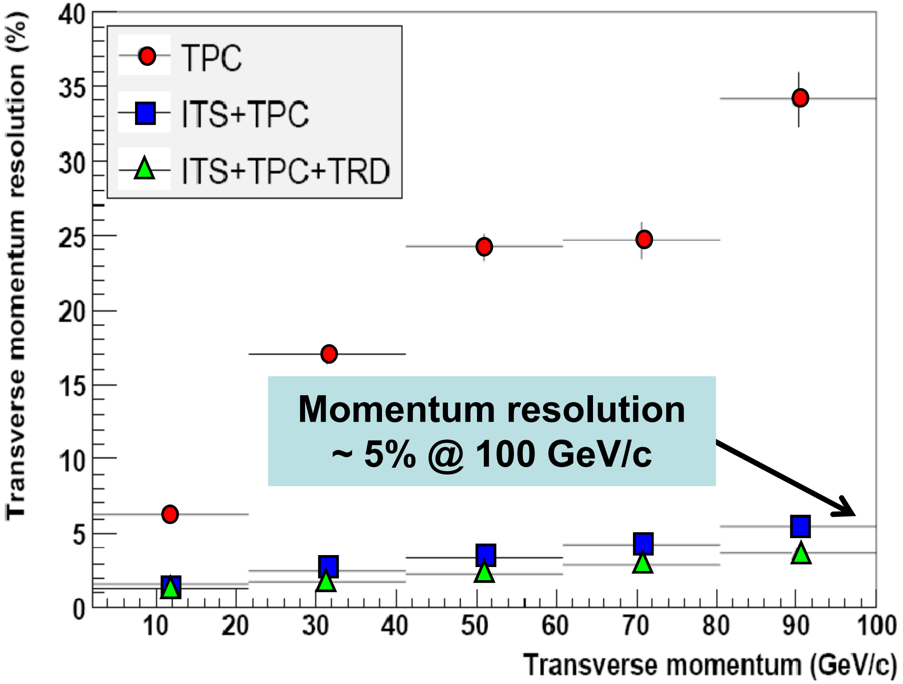


- robust & redundant tracking from 100 MeV/c to 100 GeV/c
  - modest solenoidal field (0.5 T) → easy pattern recognition
  - long level arm → good momentum resolution
  - small material budget (~10% X_0)
- full GEANT simulation, central PbPb with $dN_{ch}/dy = 6000$
  - very little dependence on dN_{ch}/dy up to 8000
  - simulation + reconstruction ~ 4±1 hours

Incremental process:
- forward propagation toward the vertex
TPC → ITS
- backward propagation
ITS → TPC → TRD → TOF
- refit inward
TOF → TRD → TPC → ITS



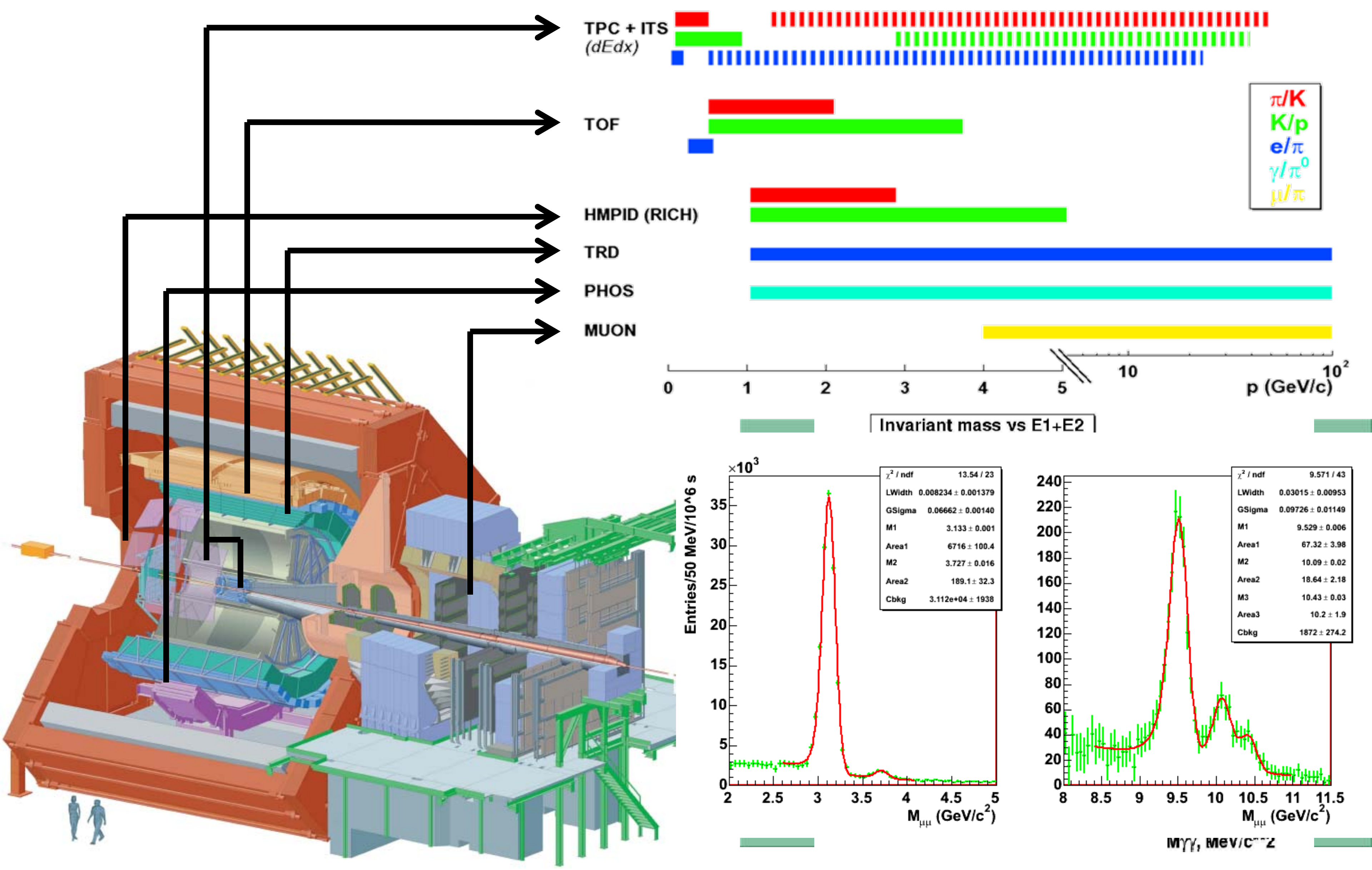
Efficiency = 90%



Momentum resolution ~ 5% @ 100 GeV/c

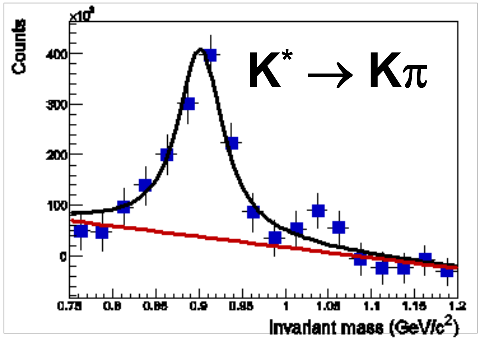
J. Schukraft @ Split06

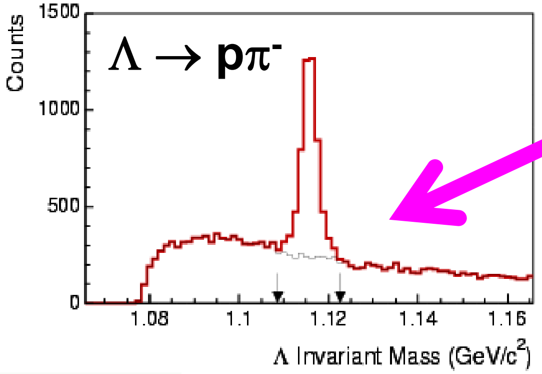
Particle identification with ALICE (from 100 MeV/c to > 50 GeV/c)

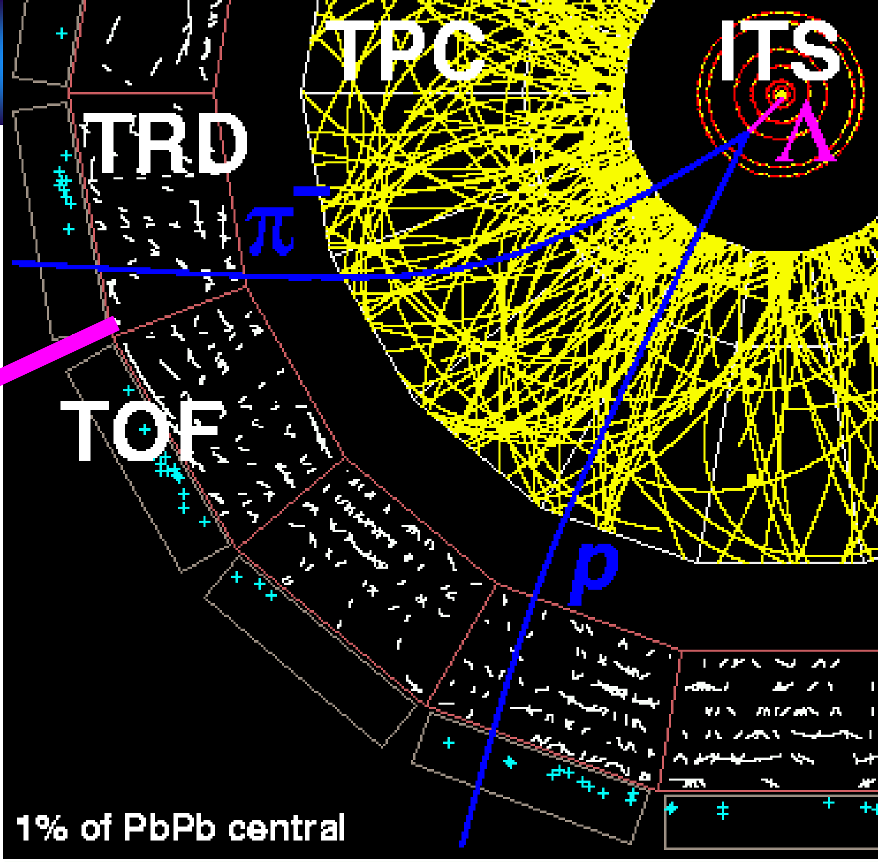


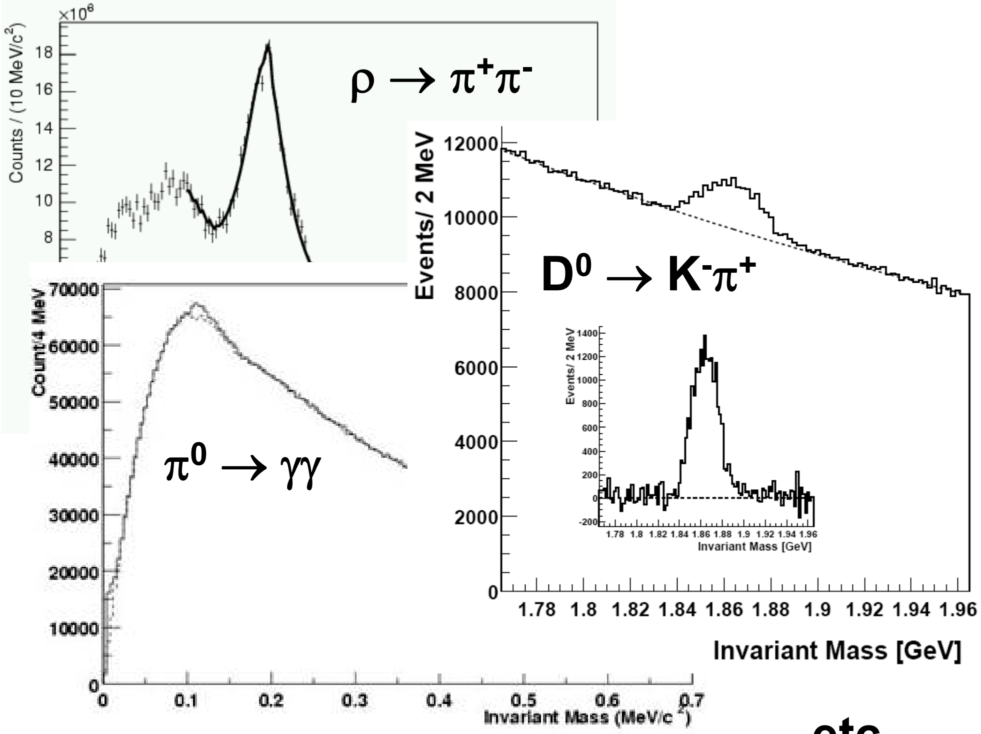
Philippe.Crochet@clermont.in2p3.fr

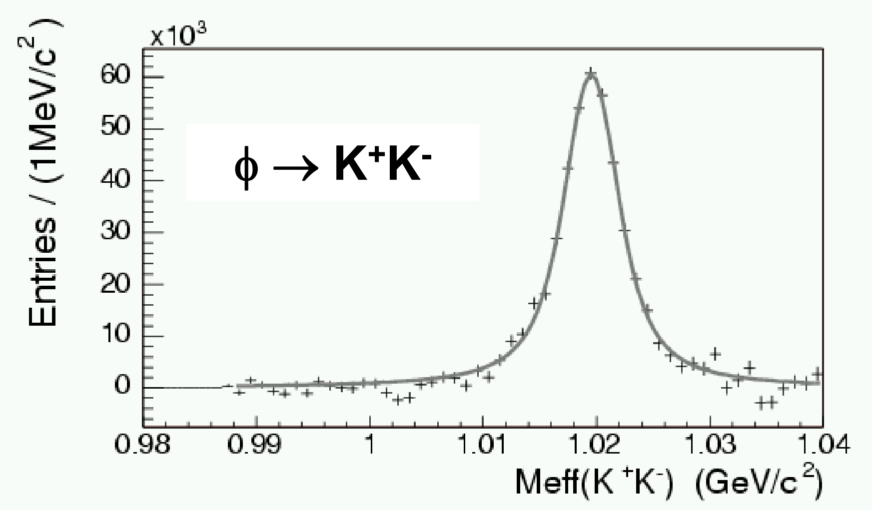
Reconstruction des résonances





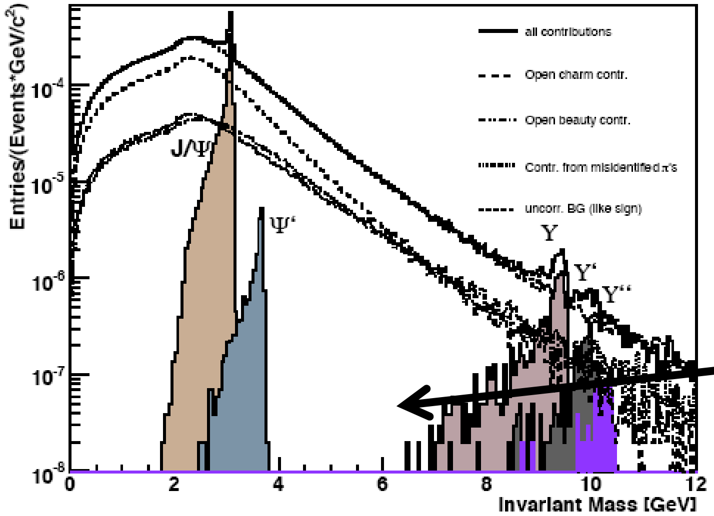


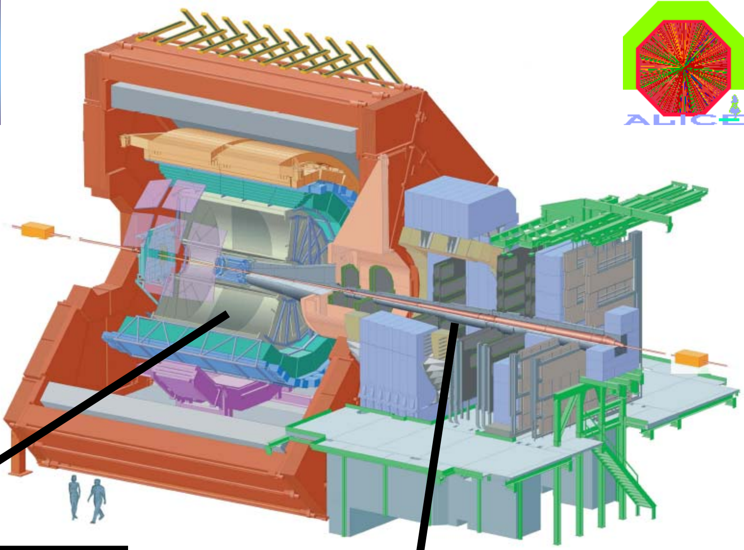




etc…

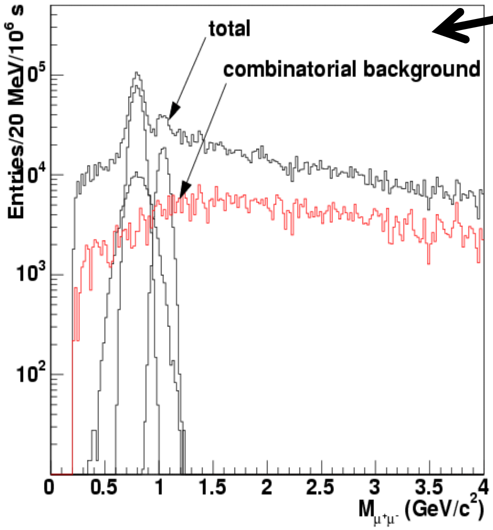
Mesure des (di-)leptons

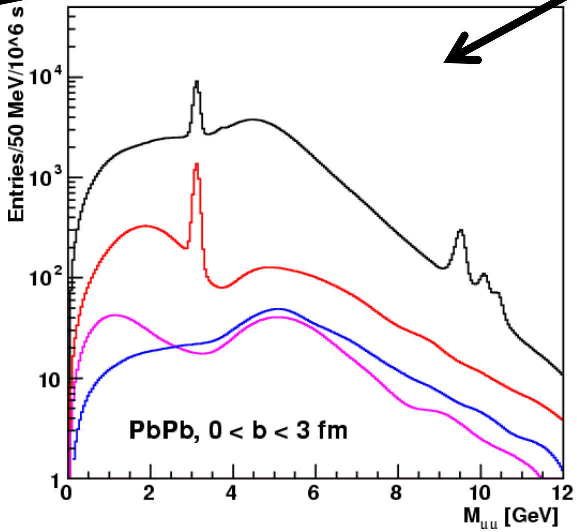


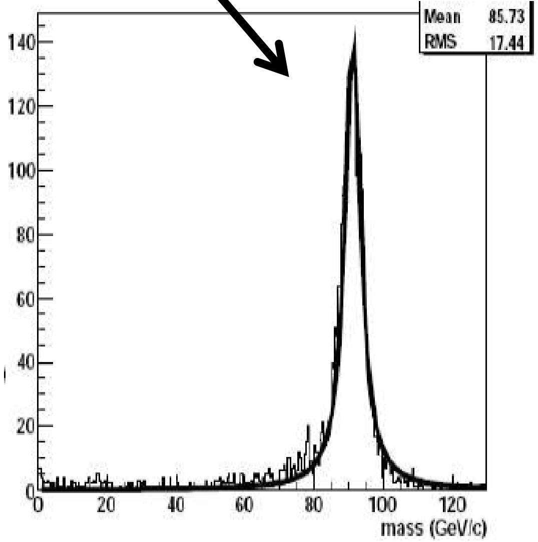


ρ, ω, ϕ, J/ψ, ψ', ϒ, ϒ', ϒ'', Z^0, $W^\pm$, charm, bottom → e^+e^-

ρ, ω, ϕ, J/ψ, ψ', ϒ, ϒ', ϒ'', Z^0, $W^\pm$, charm, bottom → $\mu^+\mu^-$

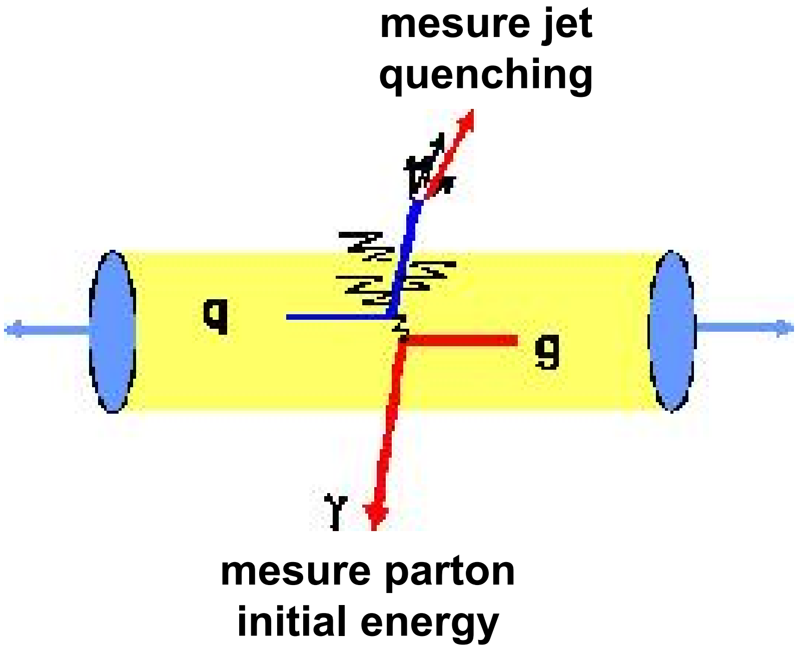


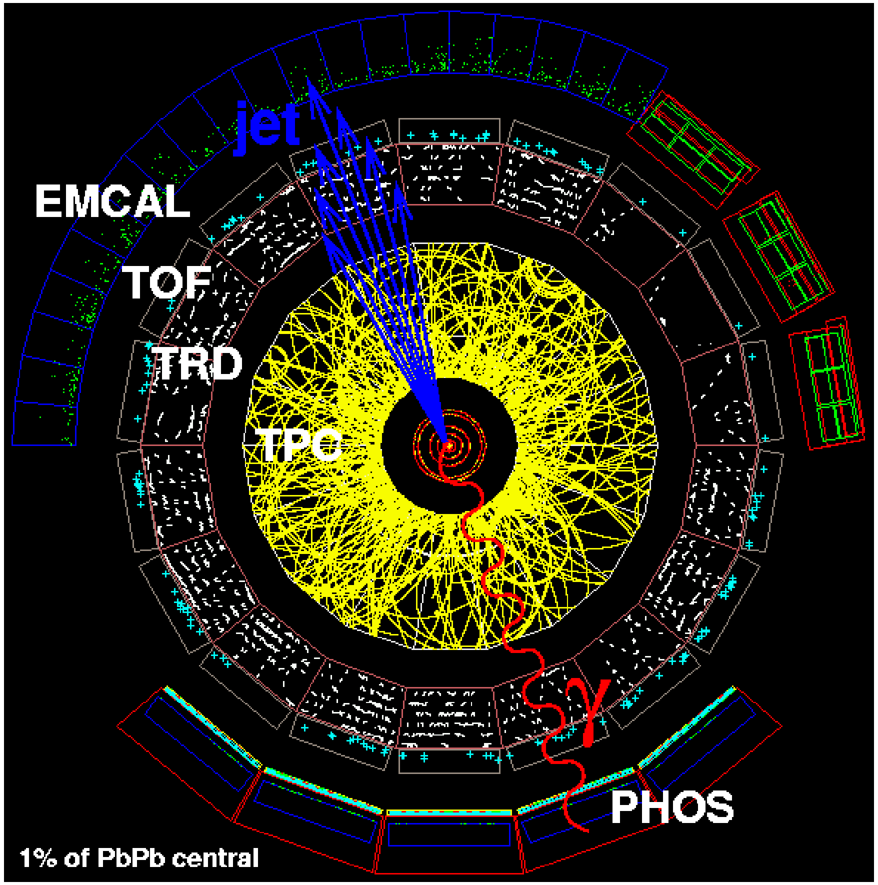




More: γ-jet correlations

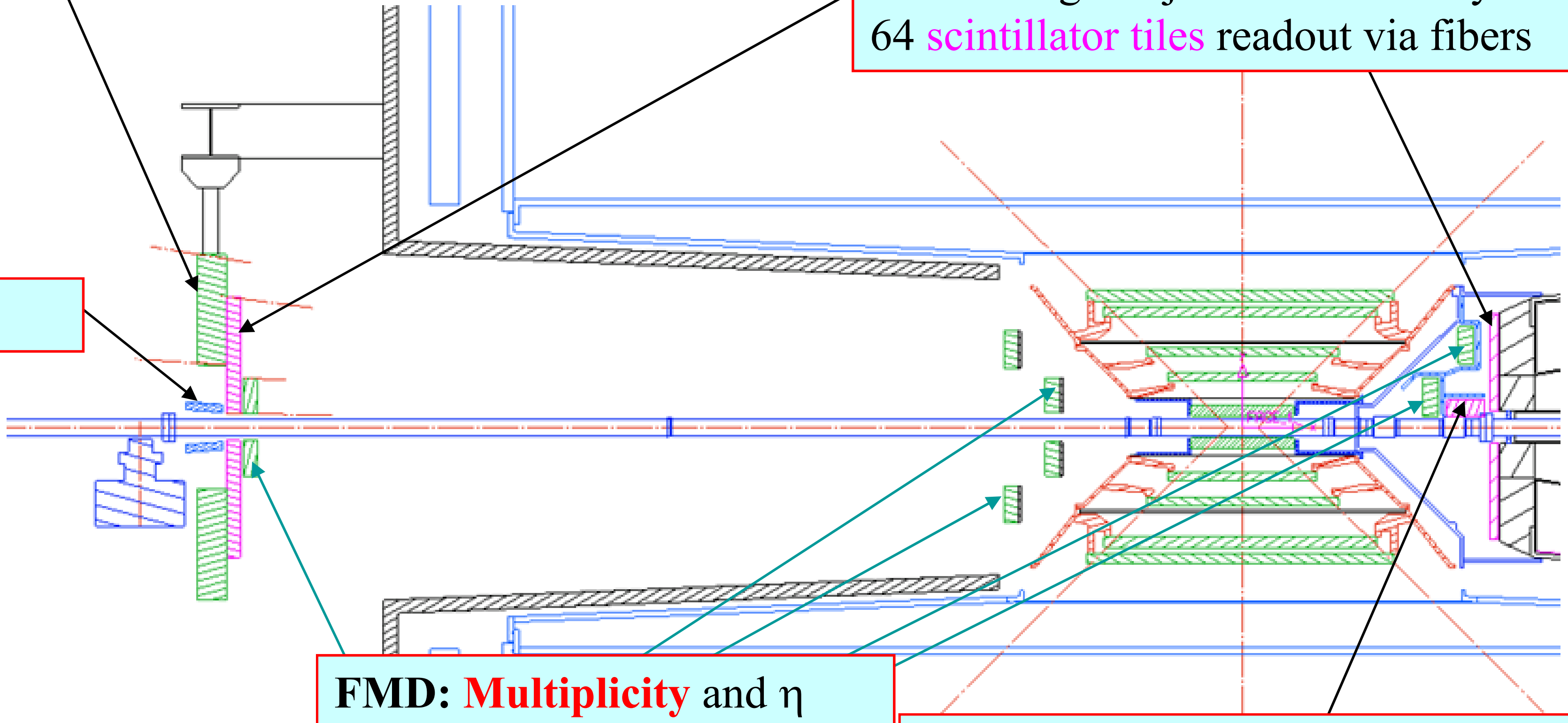
direct calibration of jet quenching





combination of PHOS, EMCAL, particle tracking & Id. allows to get jet trigger, energy loss, particle composition, transverse structure & fragmentation function down to low p_t

Détecteurs à petit angle



PMD **Pre-shower** detector 2.3 < η < 3.5, $N_{charged}$ and $N_{photons}$ **(DCC's)**

$T0_L$

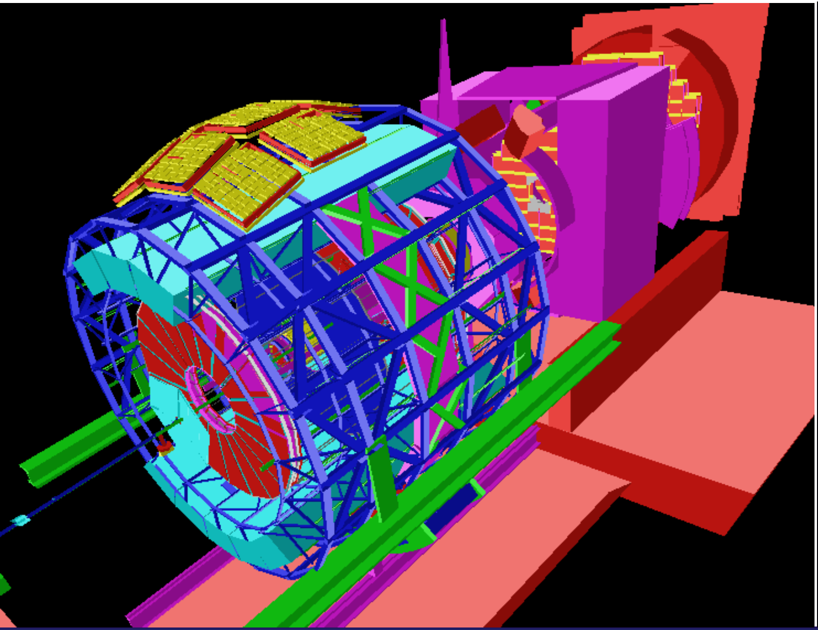
V0 1.6 < |η| < 3.9 **Interaction** trigger (beam-gas rejection), centrality trigger and beam-gas rejection. Two arrays of 64 scintillator tiles readout via fibers

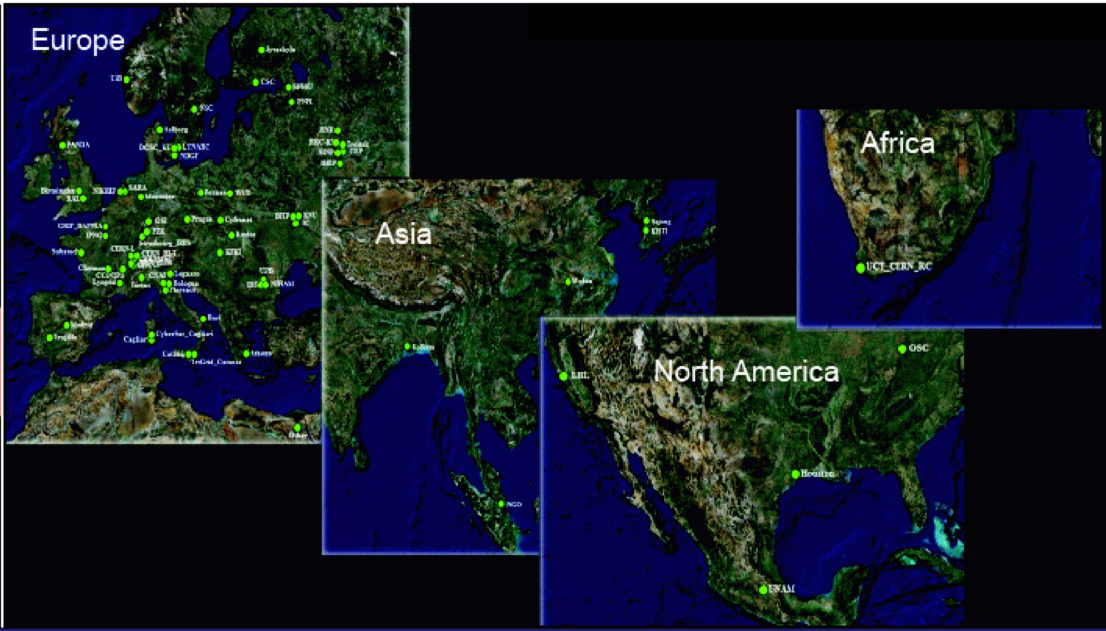
FMD: **Multiplicity** and η dist. 1.6 < η < 3, -5.4 < η < -1.6 Silicon strip disks ,12k analog channels

$T0_{R:}$ 2.6 < |η| < 3.3 **Time** (T_0) for the TOF (~ 50 ps time res.) Two arrays of 12 quartz counters. Also backup to V0

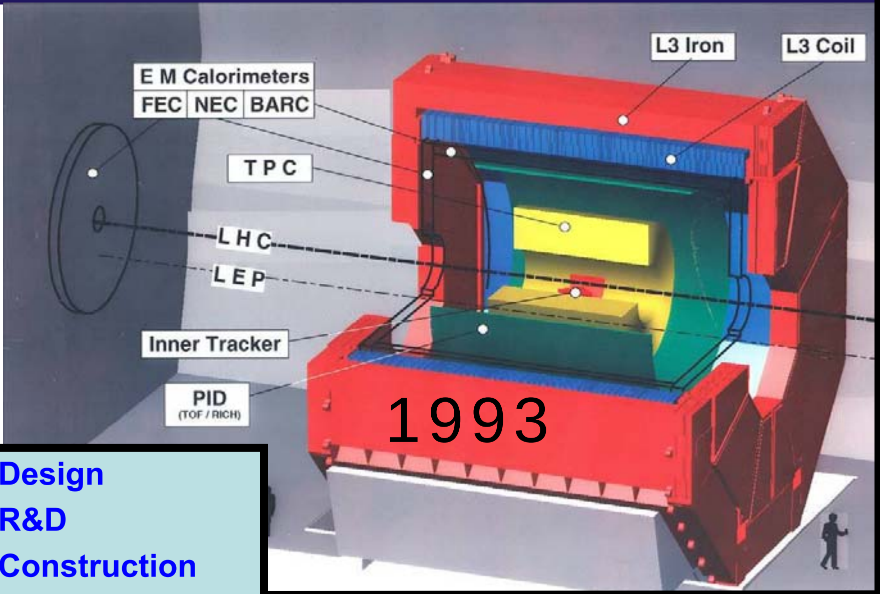
ALICE in numbers

- ALICE uses (almost) all known particle detection techniques
- largest TPC, TRD & warm dipole ever built
- up to 6000 particles per central PbPb event in the central part
- data taking rate (PbPb): 1.2 GB/s (~ 1 PB/month)
- software: 900 kLoC
- data analysis & storage is world distributed

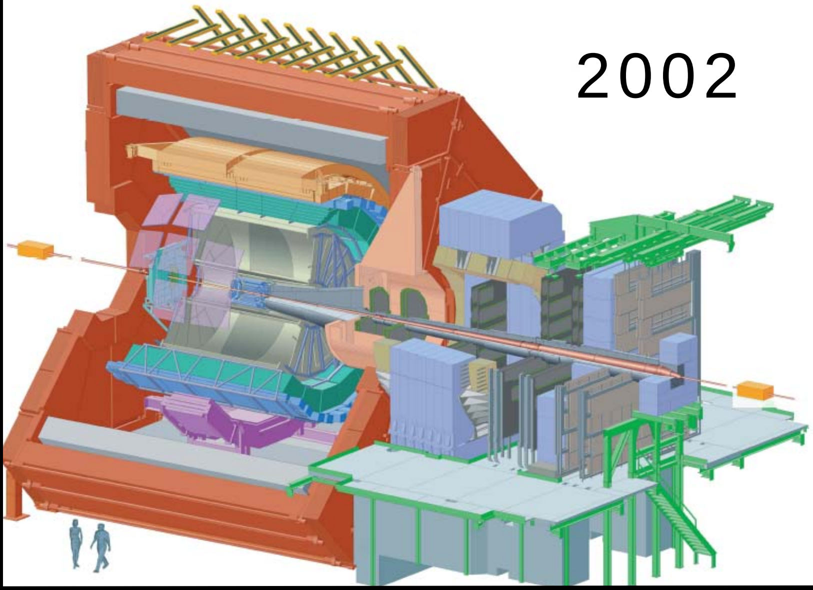




Evolution d'ALICE



1993



2002

1990-1996 : Design
1992-2002 : R&D
2000-2010 : Construction
2002-2007 : Installation
2002-2009 : Commissioning
2009→ : Data taking

fin 2001

juillet 2008

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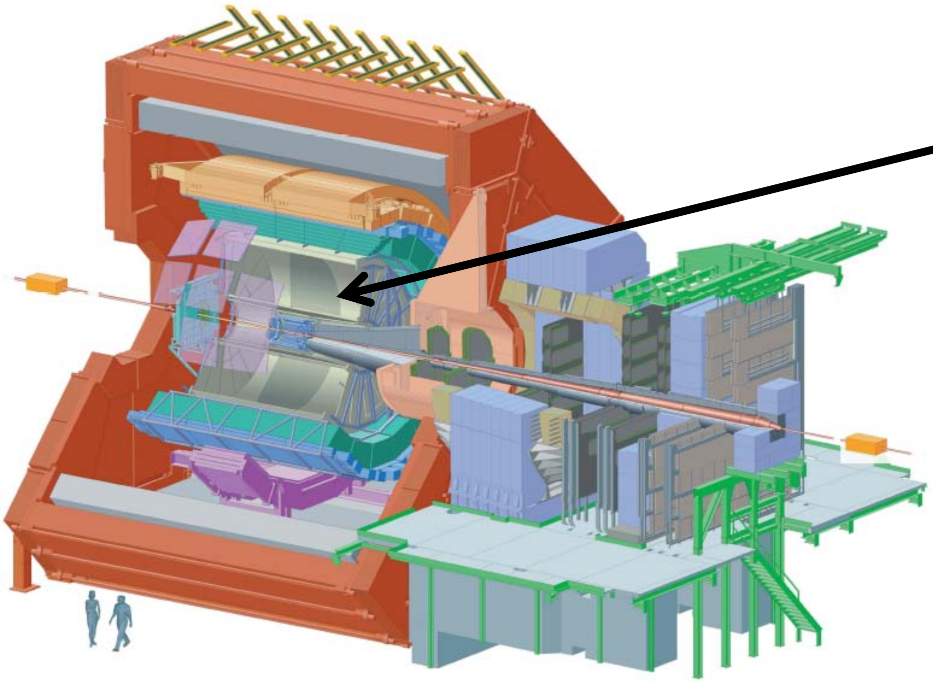
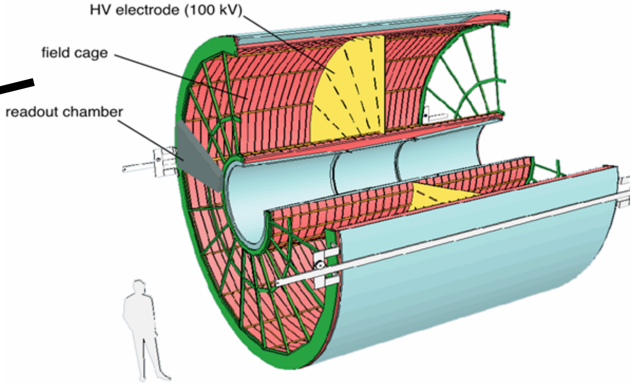
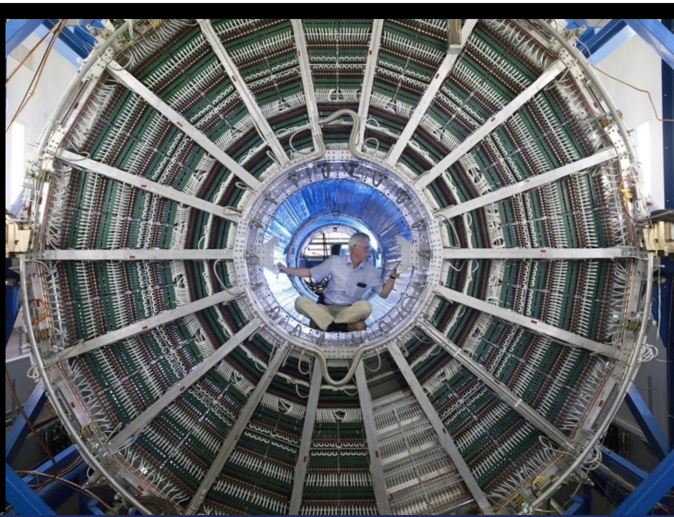
La TPC (la pièce centrale d'ALICE)





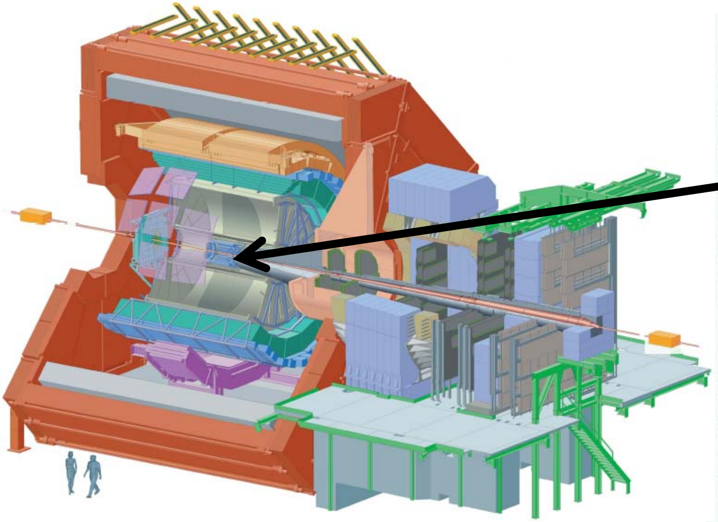
- la plus grande au monde
- 510 x 560 cm, 88 m^3, 10 tonnes
- 570 k canaux, 80 MB/evt
- 5 ans de const. et d'assemblage

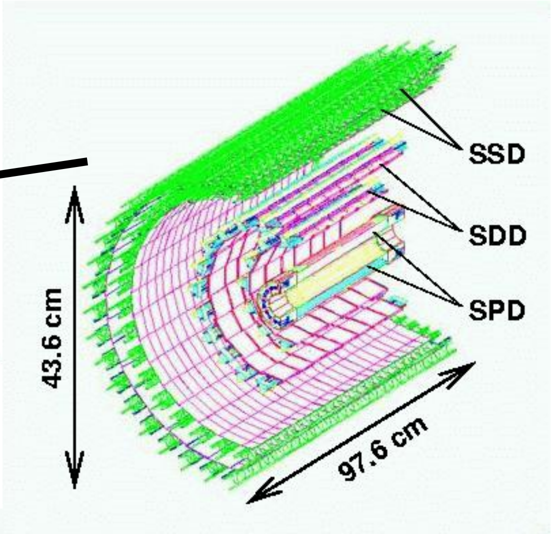


Installation de la TPC (jan. 2007)

~ 100 m horizontal, ~ 100 m vertical
en 2 jours : <v> = 4 m/heure

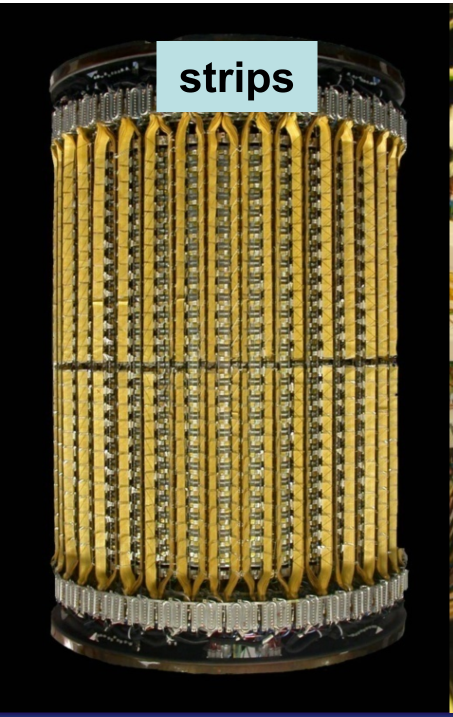
L’ITS (Internal Tracker System)

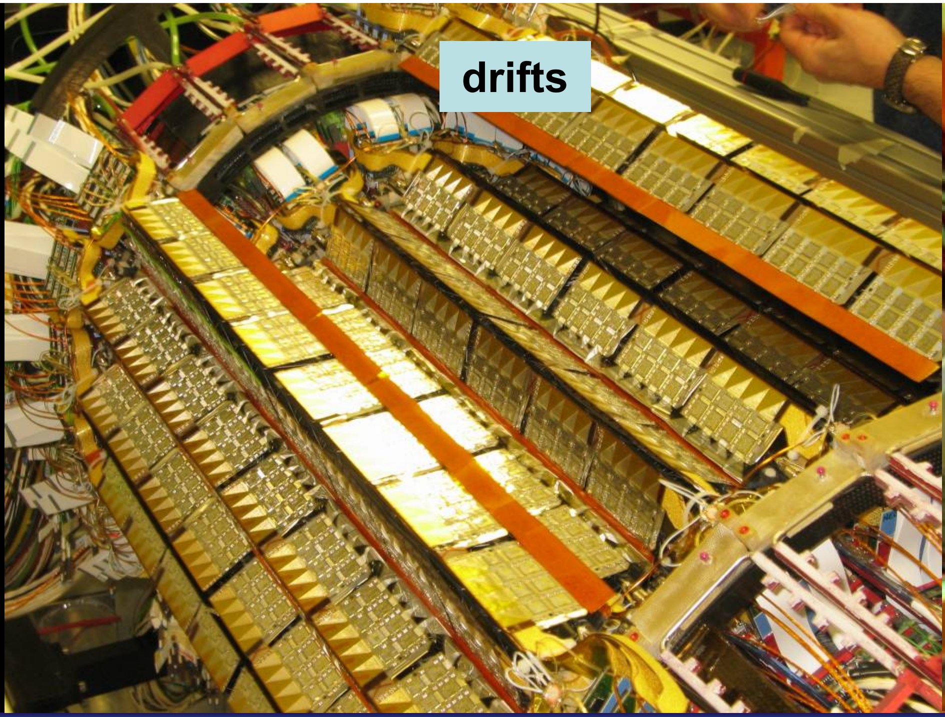


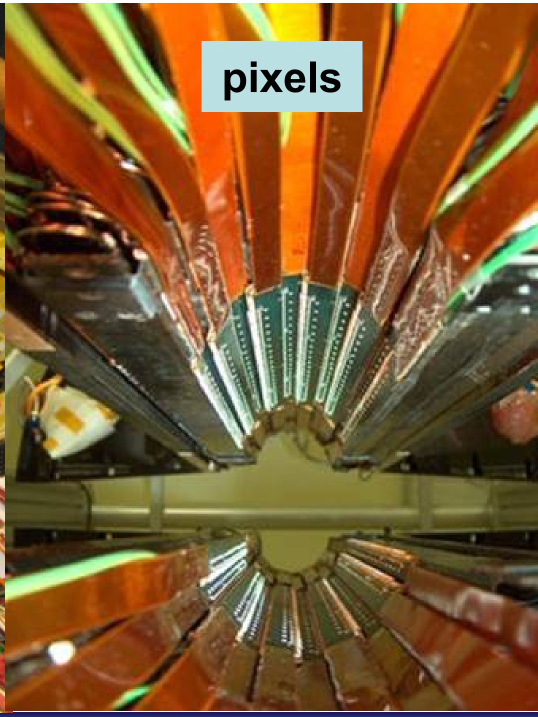


type	surface	# canaux
SPD (pixel)	0.2 m^2	9.8 M
SDD (drift)	1.3 m^2	1.33 k
SSD (strip)	4.9 m^2	2.6 M

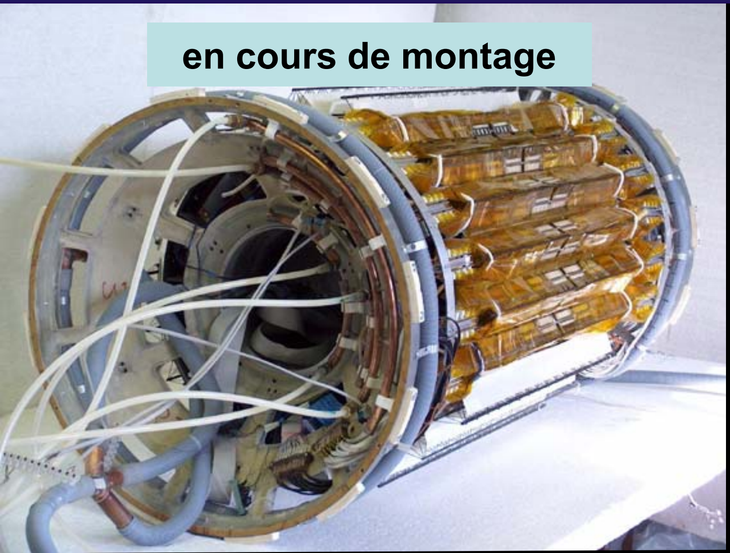
doit pouvoir identifier de l’ordre de 90 particules/cm^2 par collision toutes les 100 ns





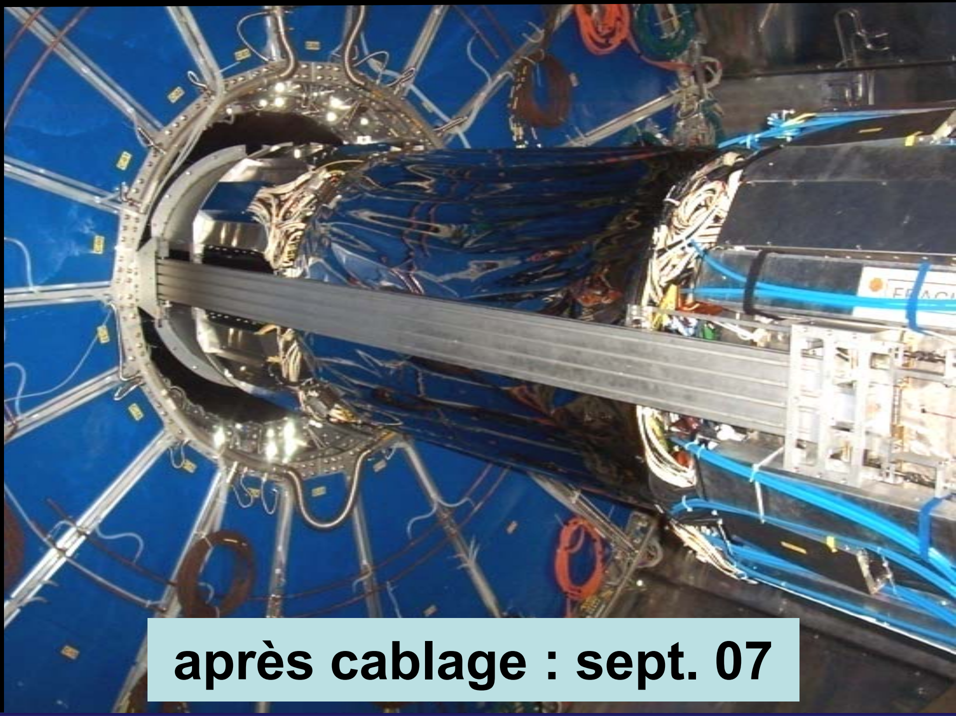


Installation et cablage de l'ITS


en cours de montage

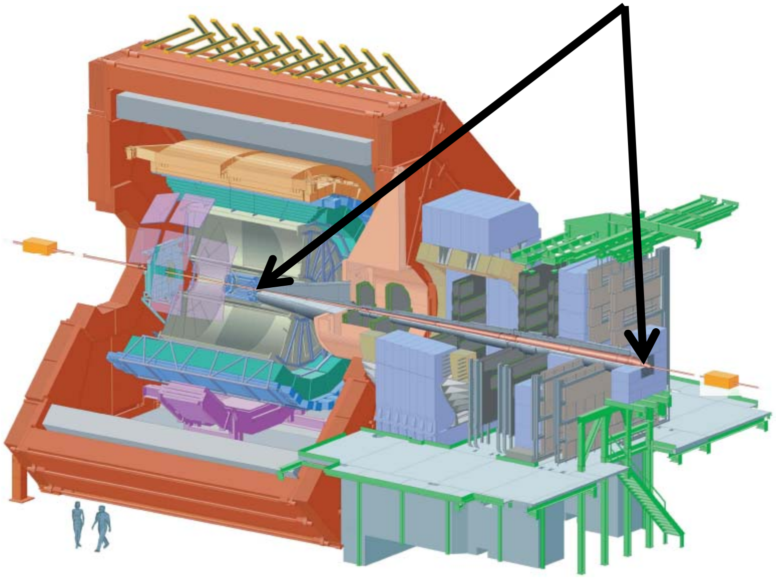

descente dans la caverne


installation : 15/03/07


après cablage : sept. 07

Un exemple de réalisation mécanique complexe

L'absorbeur frontal du spectromètre à muons



100 tonnes, 18 m, W, Pb, Fe, graphite, béton…

béton : France, engineering & supervision : CERN, design : Russie

Polyéthylène : Italie

Tungstène : Chine

Plomb : UK

Support : Italie

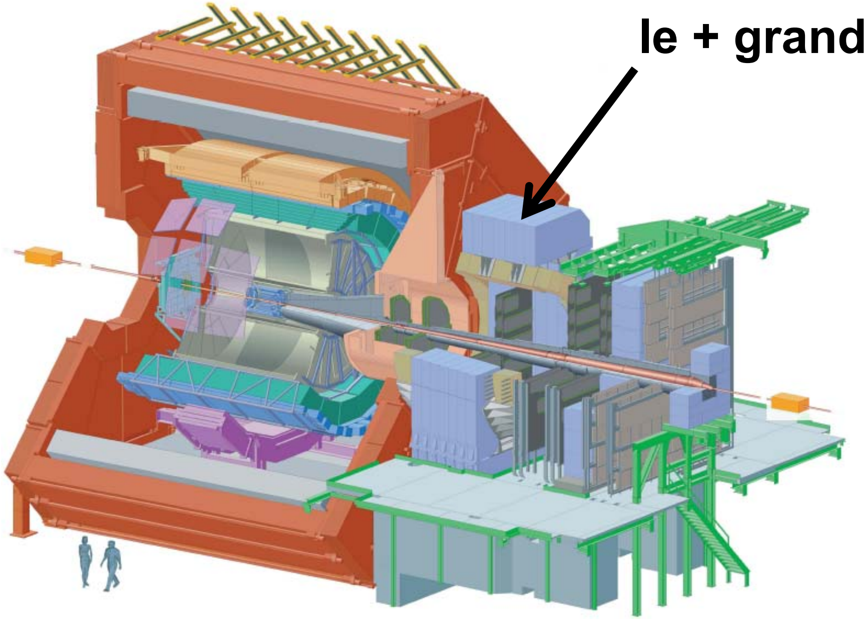
Graphite : Inde

Acier : Finlande

Aluminium : Arménie

Acier : Inde

Le dipôle du spectromètre à muons (I)



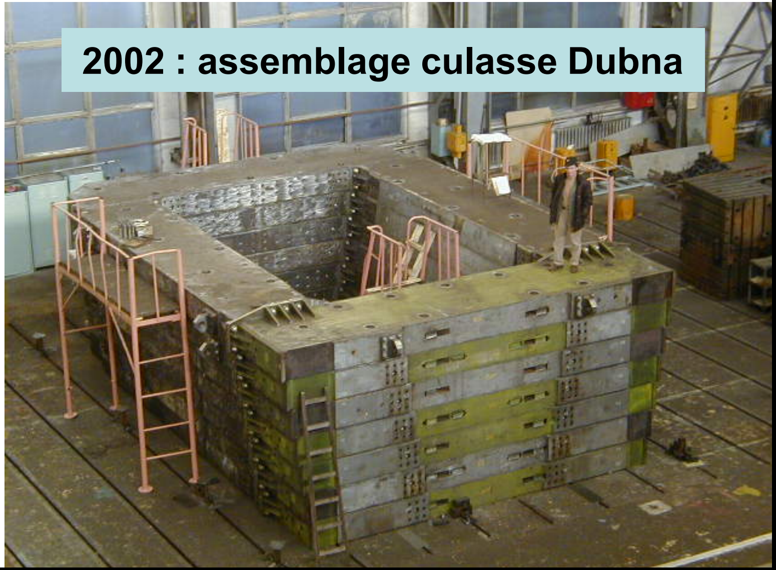
le + grand du monde, 0.7 T, 3 Tm, 4 MW, 800 tonnes

Sept. 2003 : arrivée au CERN des bobines après un “tour de France”

passage difficile sous les ponts

…et dans la caverne

Le dipôle du spectromètre à muons (II)


2002 : assemblage culasse Dubna

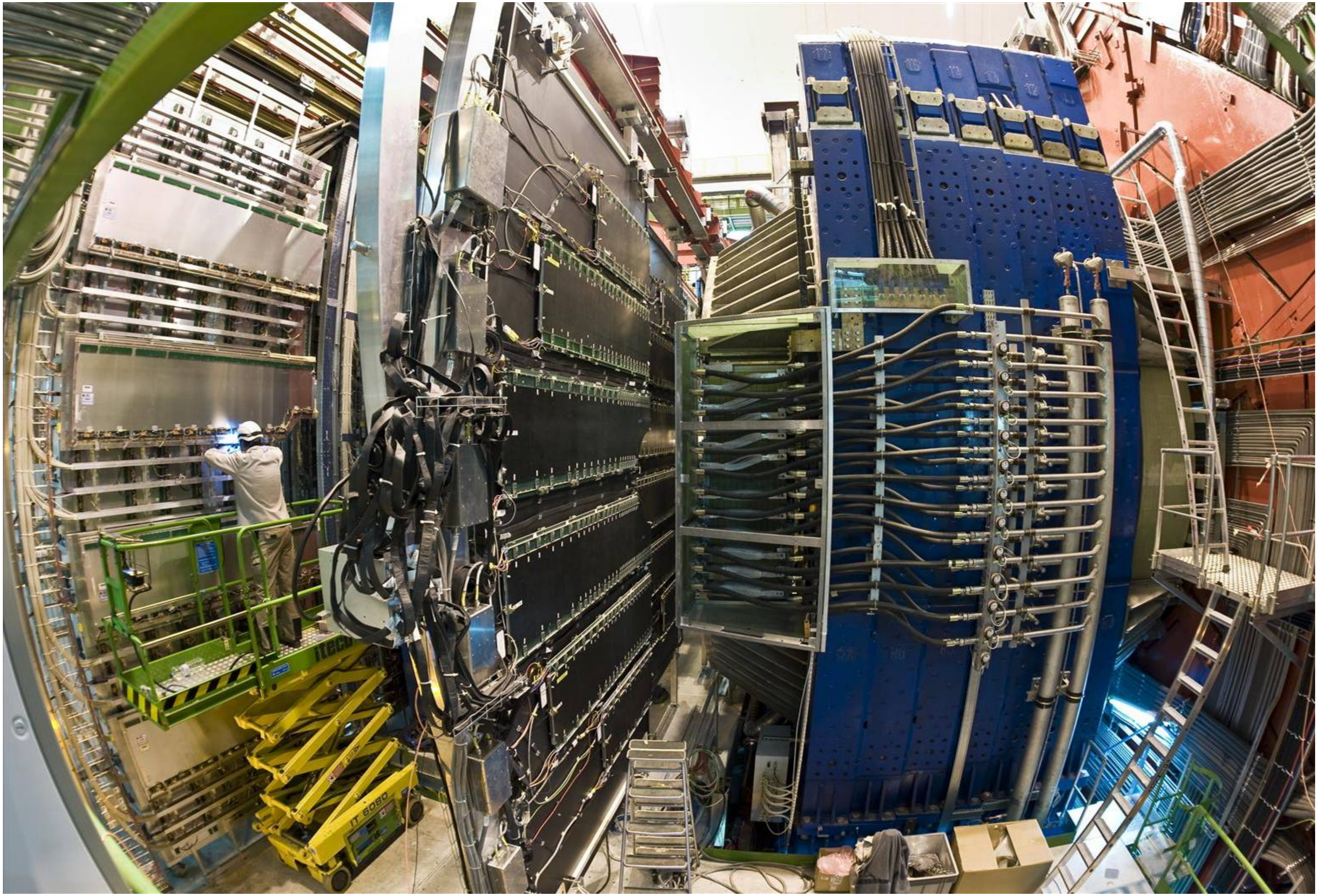

2003 : transport culasse Dubna-CERN retardé de 10 mois


2004 : assemblage test devant L3


sept. 2004 : fermeture des portes de L3 coté MUON


2005 : assemblage final

Le spectromètre à muons installé (printemps 2008)



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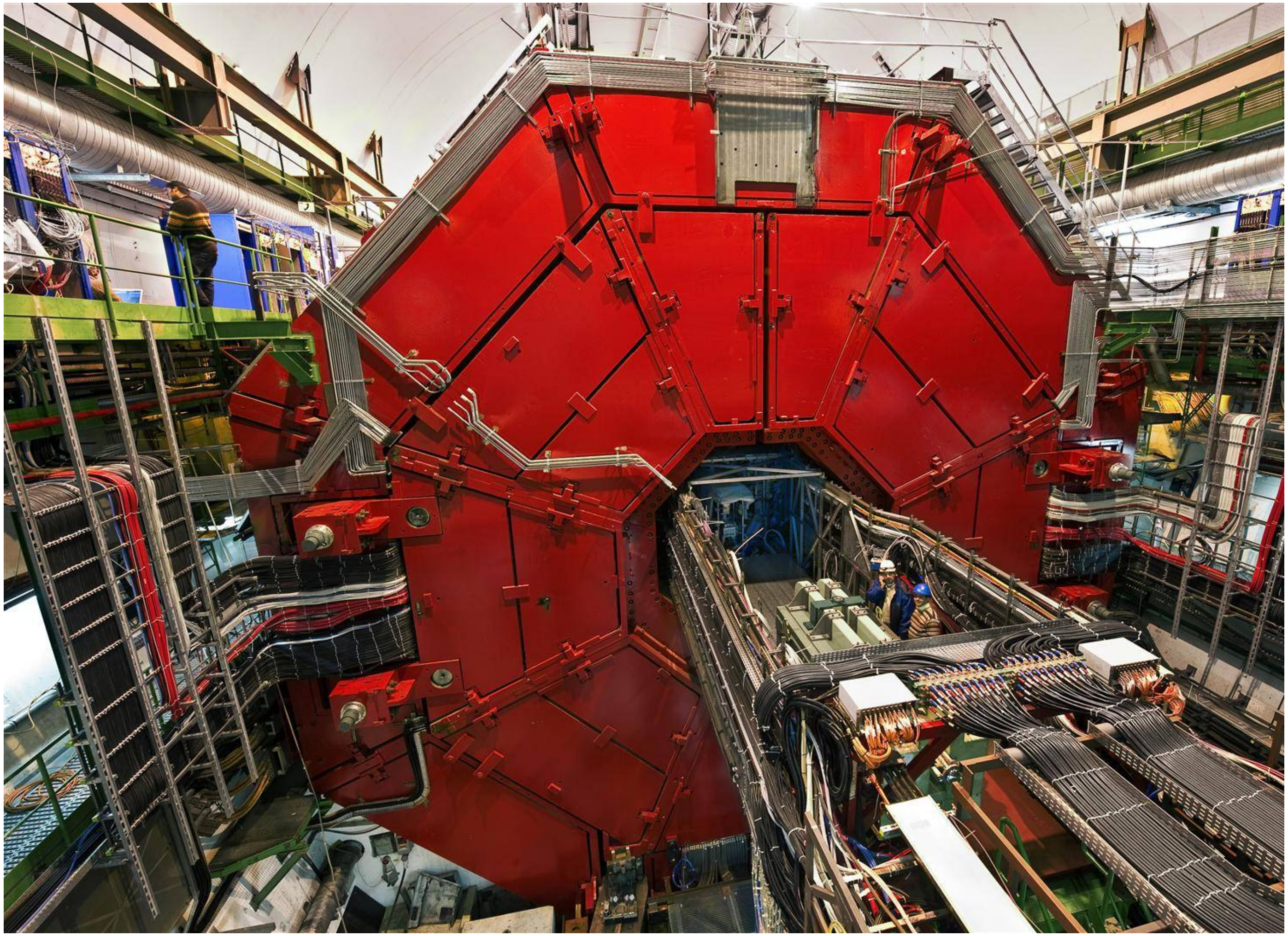
Etat d'installation d'ALICE en septembre 2008

ITS, TPC, MUON, TOF, HMPID, T0, V0, FMD, PMD, ZDC, ACCORDE, 1/5 PHOS, 4/18 TRD, 0/6 EMCal



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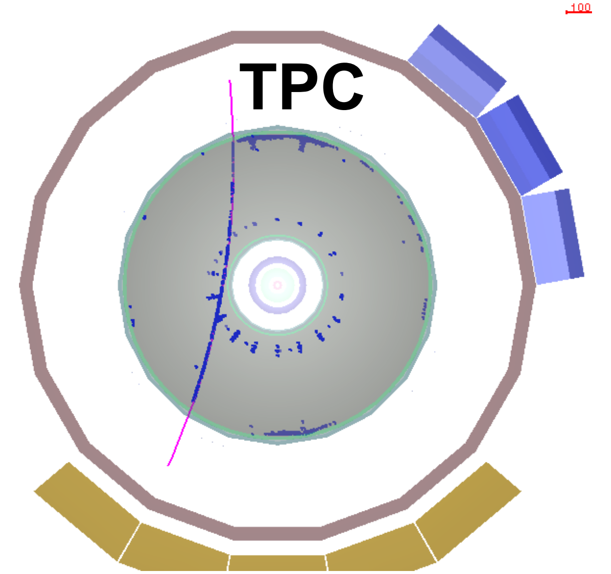
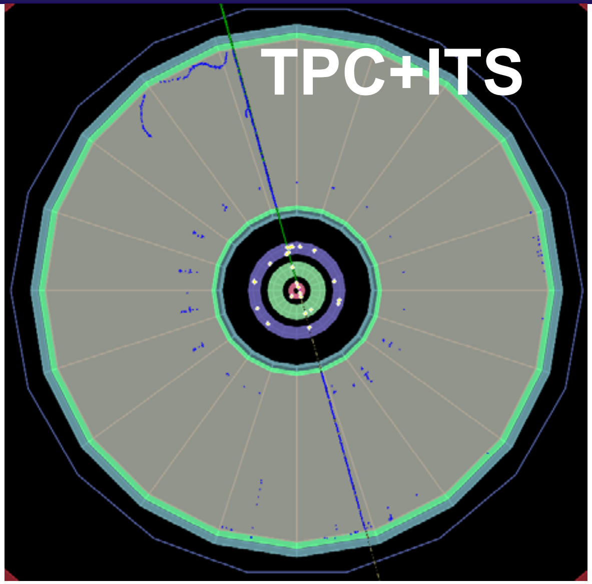
Séminaire, LAL, 09/06/09

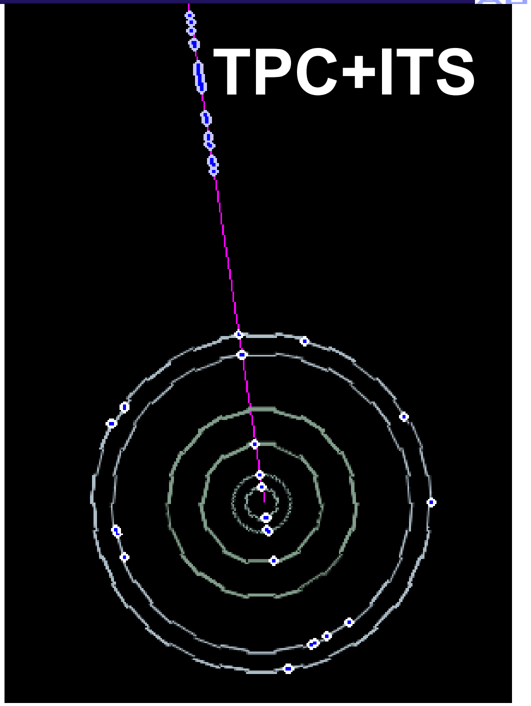
Janvier 08 – Août 08 : cosmiques



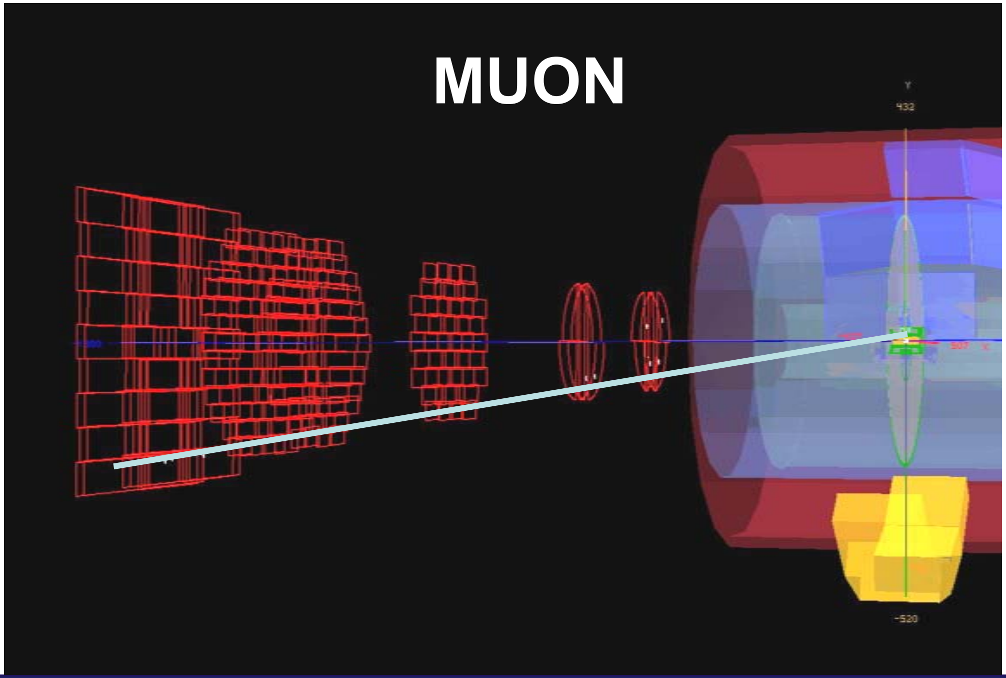
TPC



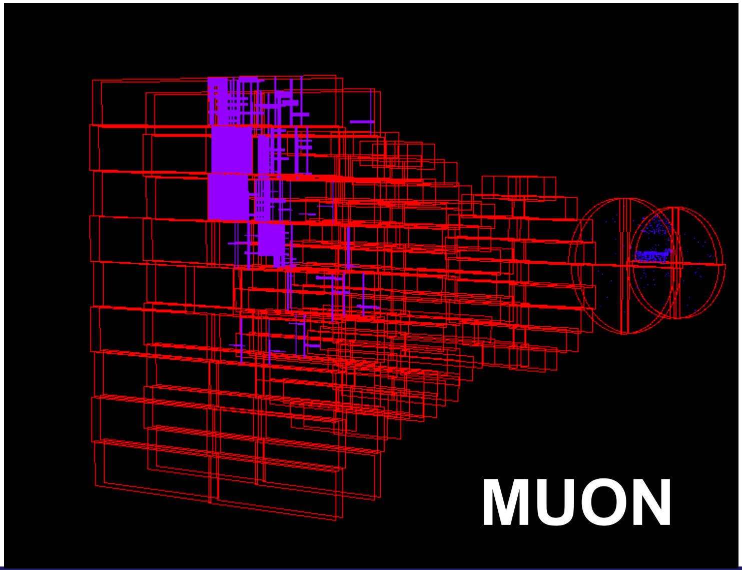
TPC+ITS



TPC+ITS

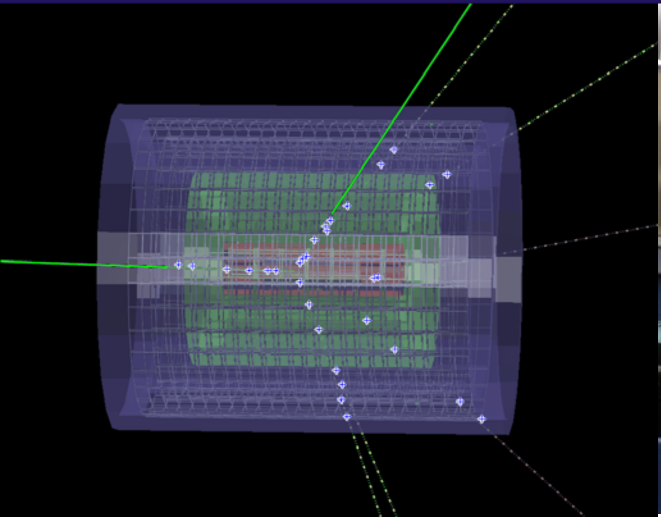


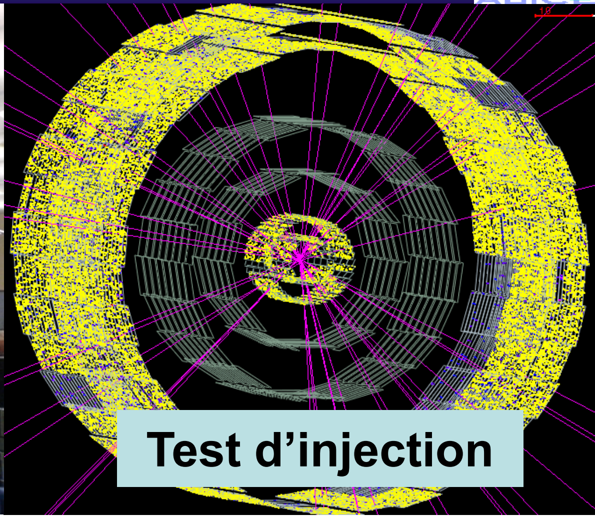
MUON



MUON

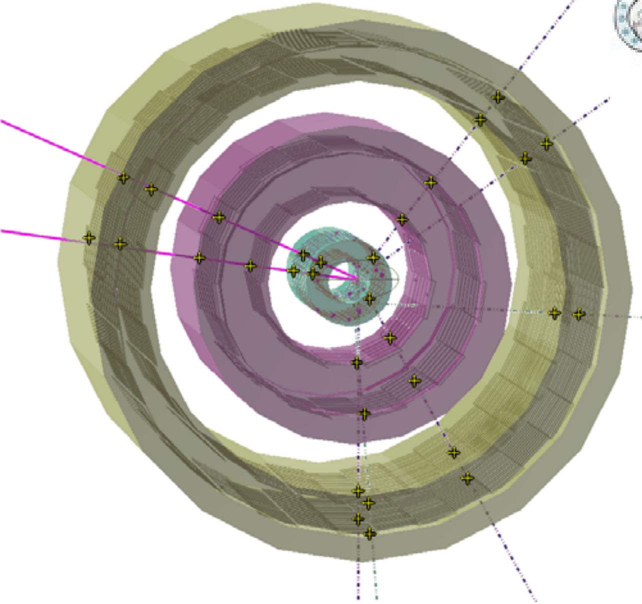
10 sept 08 : premiers faisceaux et premières collisions



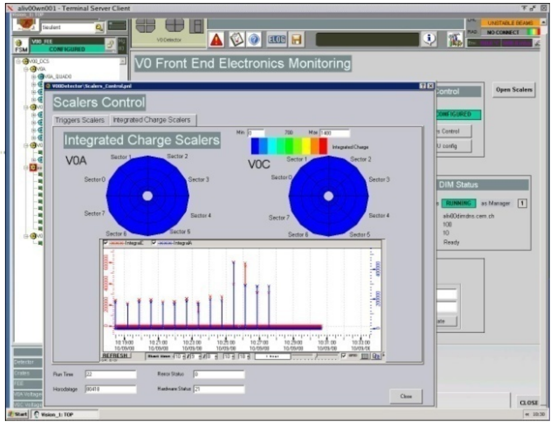


Test d'injection

Collision faisceau-gaz dans l'ITS



Les faisceaux dans les V0



aliv00wn001 - Terminal Server Client

V00_FEE CONFIGURED

V0 Front End Electronics Monitoring

V00Detector\Scalers_Control.pnl

Scalers Control

Integrated Charge Scalers

Min 0 700 Max 1400

Run Time 22

Reeco Status 0

Horodatage 80418

Hardware Status 21

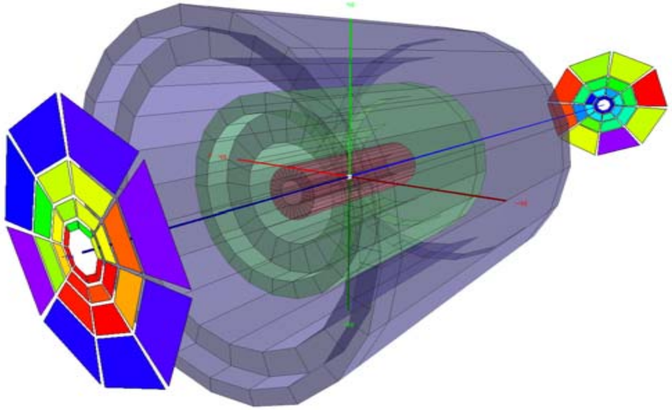
DIM Status RUNNING as Manager 1

aliv00dimdns.cern.ch

100

10

Ready



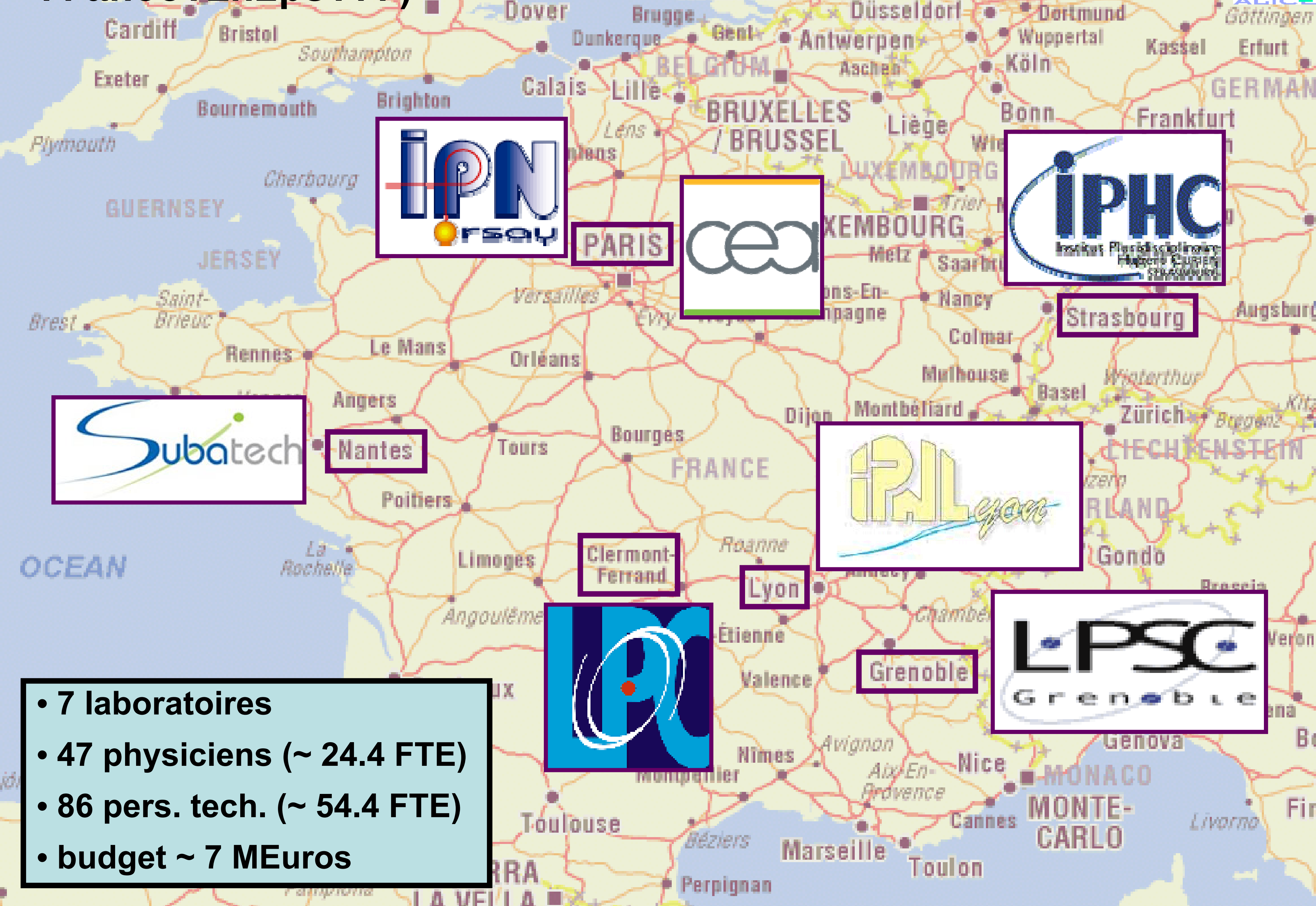
ALICE data taking scenario

1 LHC year = 7 months pp (10^7s, $3{\cdot}10^{30}$cm^{-2}s^{-1}) + 1 month AA(-like) (10^6s, $5{\cdot}10^{26}$cm^{-2}s^{-1})

- **5 first years:**
  - regular pp runs at 14 TeV: commissioning, reference, dedicated pp physics
  - first PbPb run at low luminosity: global observables, large x-sections
  - 2 PbPb runs at high luminosity (L^{int} = 0.5nb^{-1}/year): small x-sections
  - 1 pA run: cold nuclear matter effects (shadowing, absorption…)
  - 1 light ion run: energy density dependence
- **later** (different options depending on the first results):
  - pp (or pp-like) at 5.5 TeV
  - other light or intermediate-mass systems
  - other systems p-likeA
  - PbPb at low energy
  - PbPb at 5.5 TeV & high luminosity

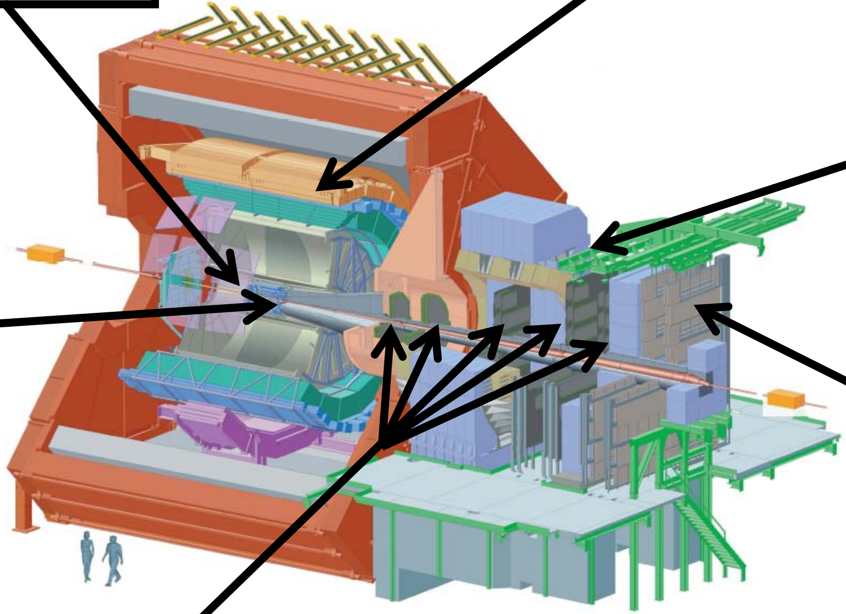
J. Phys. G 30 (2004) 1517

Participation française à ALICE (`alice-france.in2p3.fr`)



- 7 laboratoires
- 47 physiciens (~ 24.4 FTE)
- 86 pers. tech. (~ 54.4 FTE)
- budget ~ 7 MEuros

Contribution française à ALICE



ITS/SSD

SUBATECH, IPHC
(+ CERN, Italie, Pologne, Russie, Ukraine, Hollande, Finlande)

EMCAL

SUBATECH, IPHC, LPSC
(+ USA, Italie)

MUON-GMS

IPNL, LPSC
(+ Arménie)

V0

IPNL
(+ Mexique)

MUON-trigger

LPC, SUBATECH
(+ Italie)

MUON-tracking

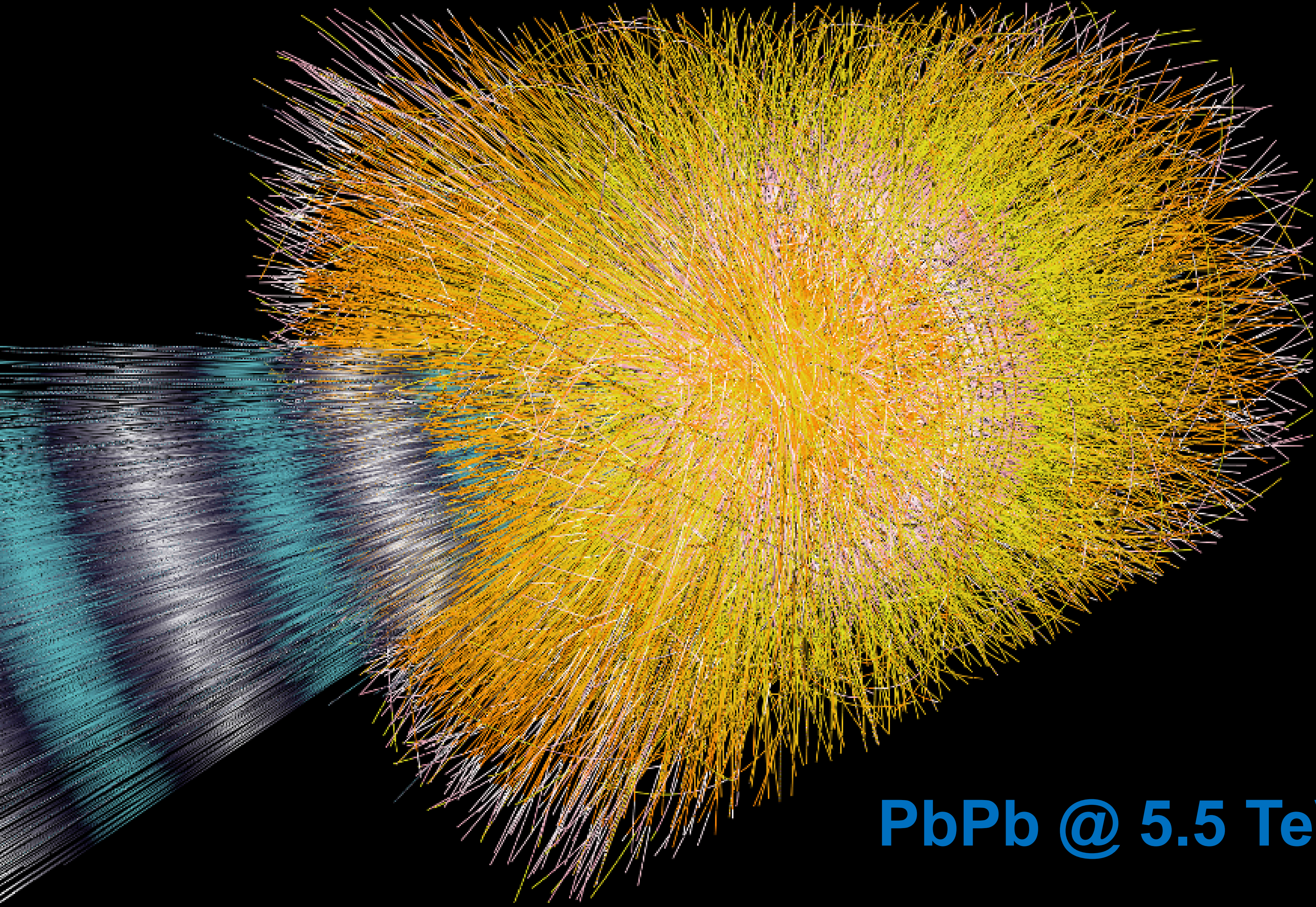
SUBATECH, IPNO, SACLAY
(+ Italie, Inde, Russie)

offline, online, computing, management

physique

- quarkonia et saveurs lourdes
- physique soft et étrangeté
- jets et photons

Waiting for data…



PbPb @ 5.5 TeV