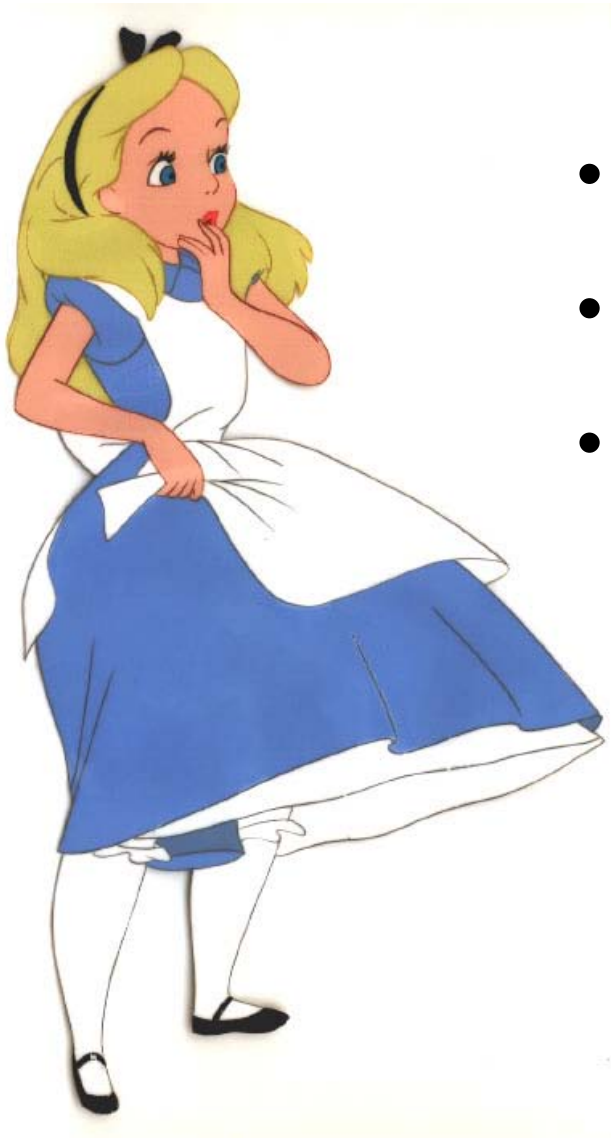
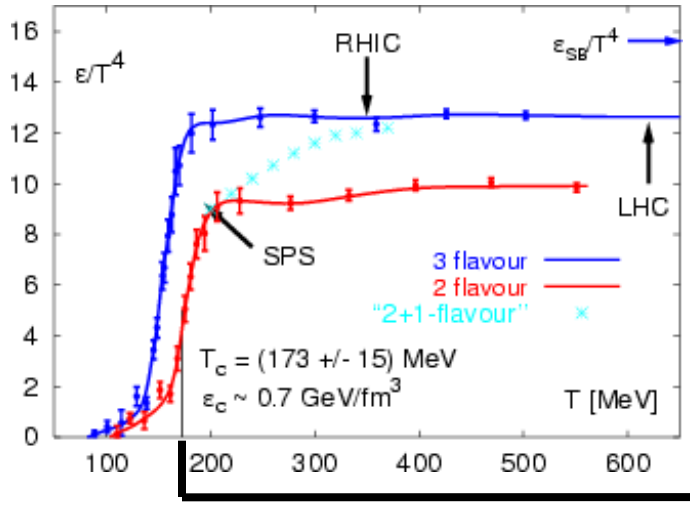
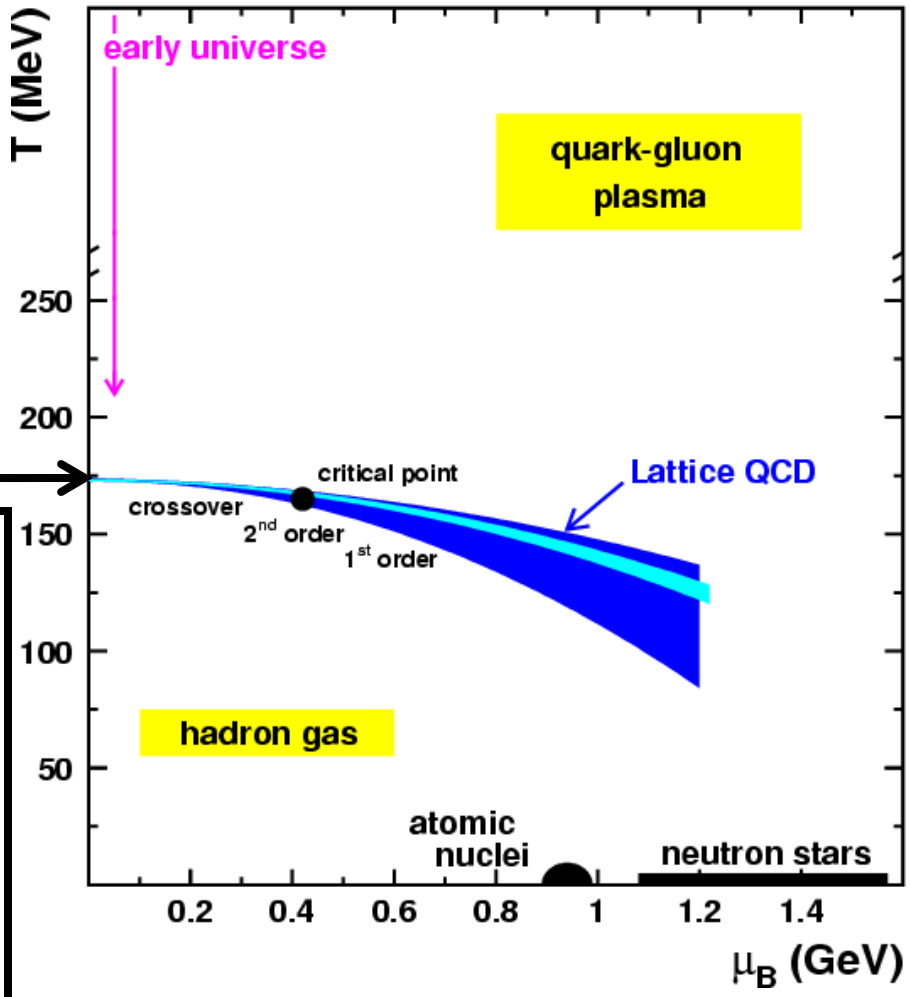
The ALICE experiment at the CERN-LHC



- heavy-ion collisions & QGP
- heavy-ion collisions @ LHC
- ALICE
  - overview
  - selected physics performance
  - installation
  - first data taking

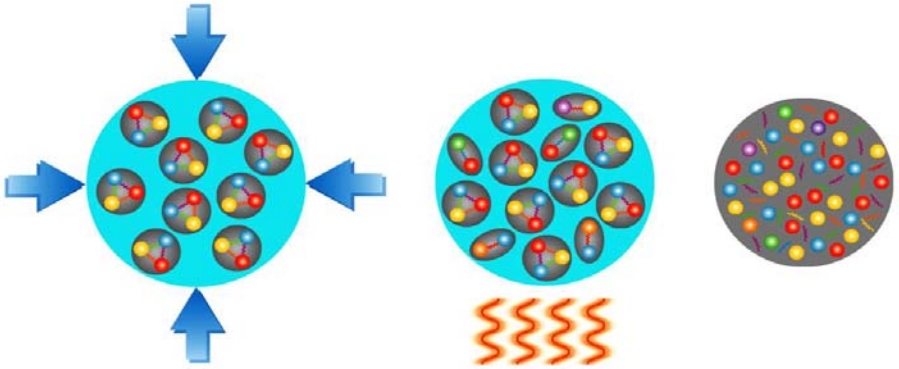
The QCD phase diagram



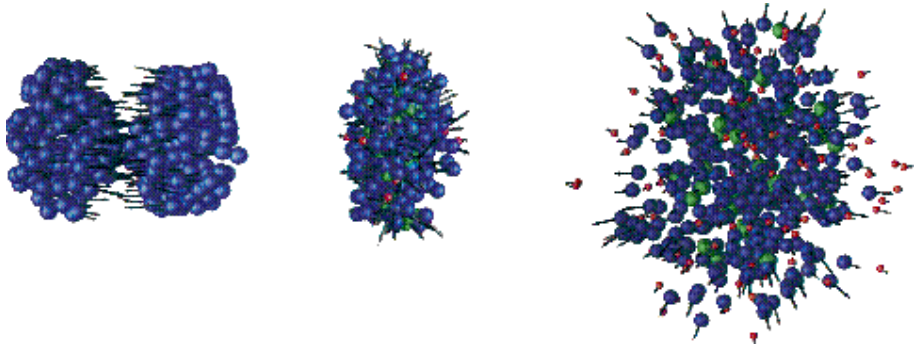


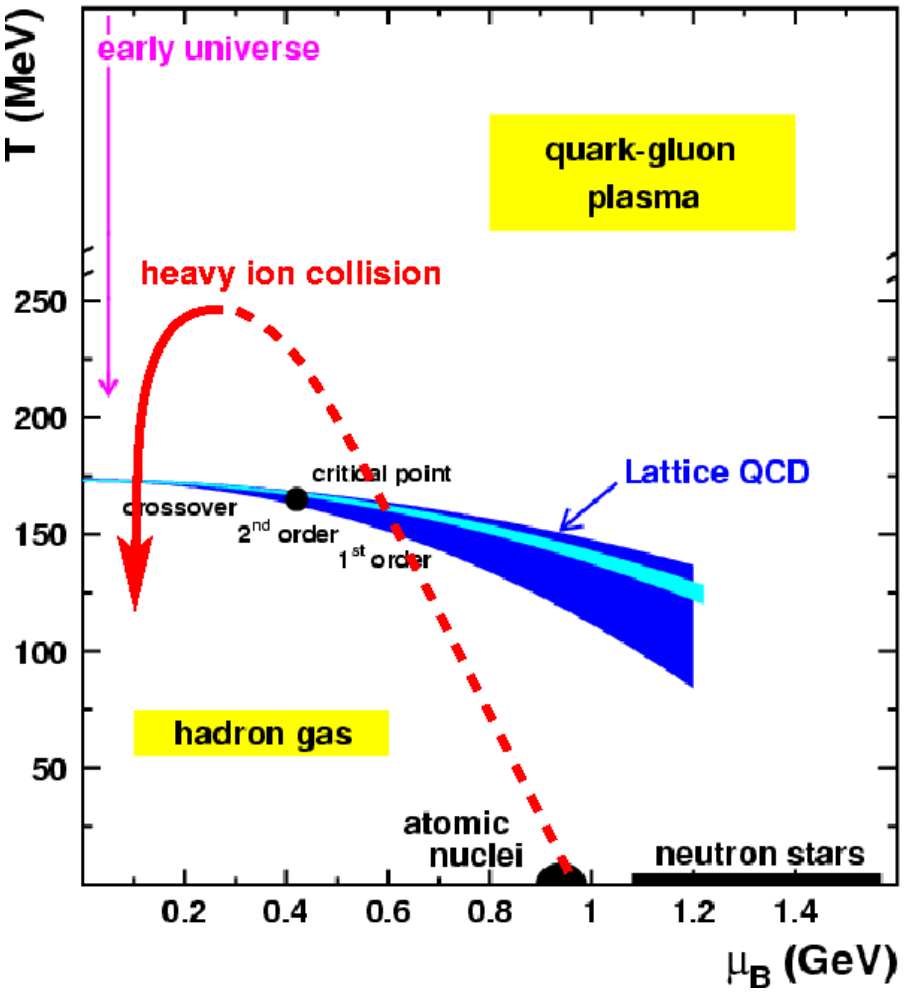
- $\mu_B = 0$:
  - $T_c = 173 \pm 15$ MeV
  - $\varepsilon_c = 0.7 \pm 0.3$ GeV/fm^3
  - "crossover"-like transition
- $\mu_B > 0$:
  - large uncertainties
  - order of transition unknown
  - existence of a critical point
- chiral sym. rest. coincides with deconf.
- the QGP is not an ideal gas
- $\mu_B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

Recreating the QGP with heavy-ion collisions



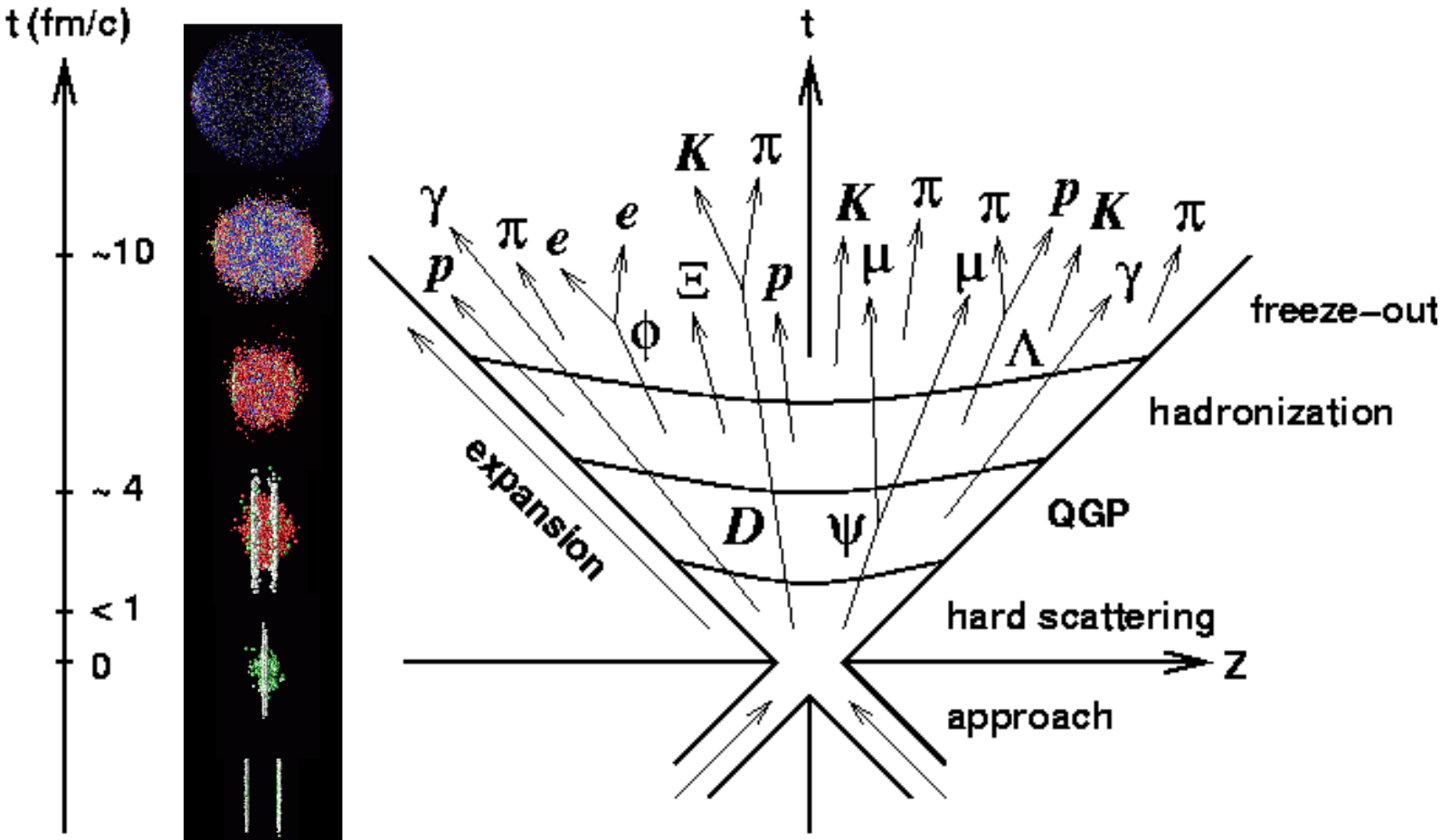
pressure + heat ⇒ QGP



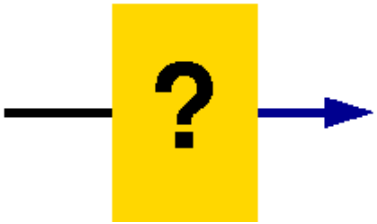


key parameters: bombarding energy, collision centrality, particle transverse momentum

Space-time evolution of a heavy-ion collision



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



QGP signatures

modification of low-mass resonances

suppression of high-mass resonances

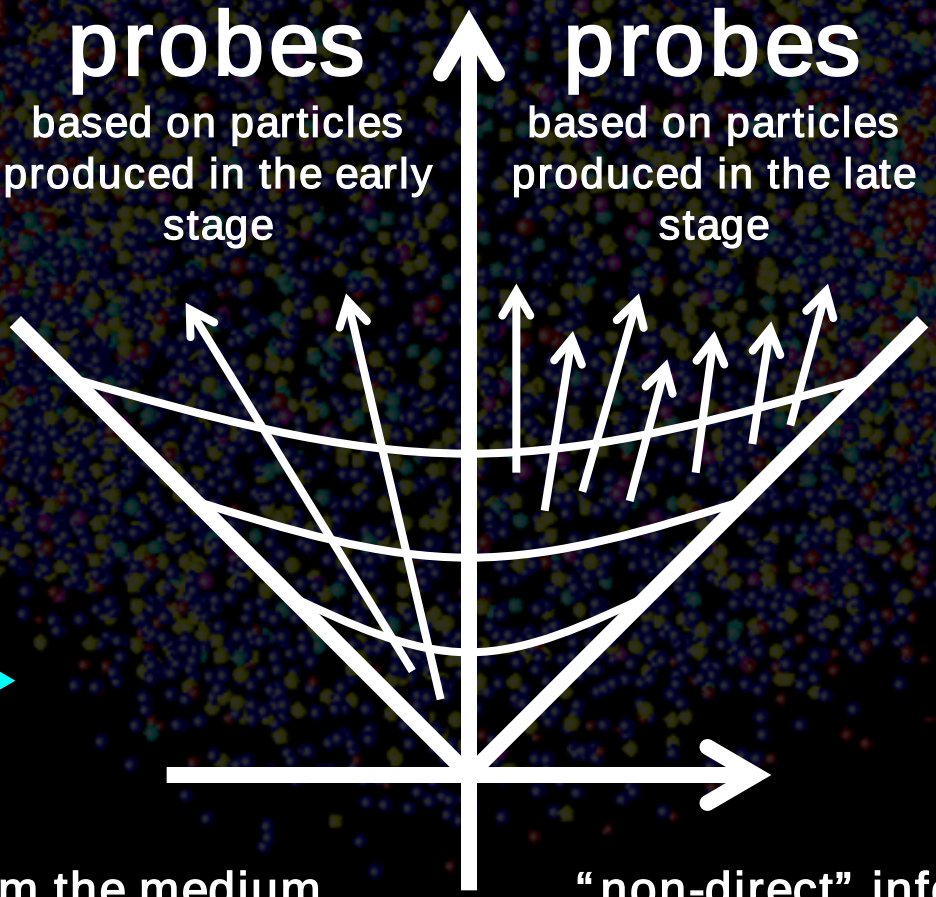
strangeness enhancement

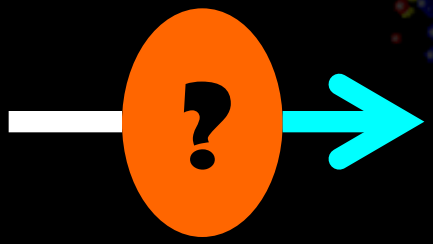
photon production

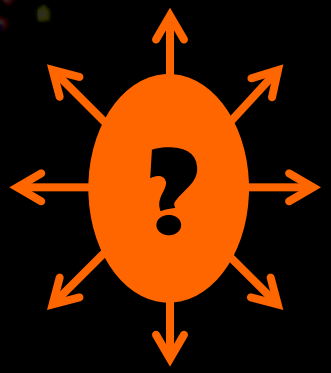
flow profile

jet quenching

..etc



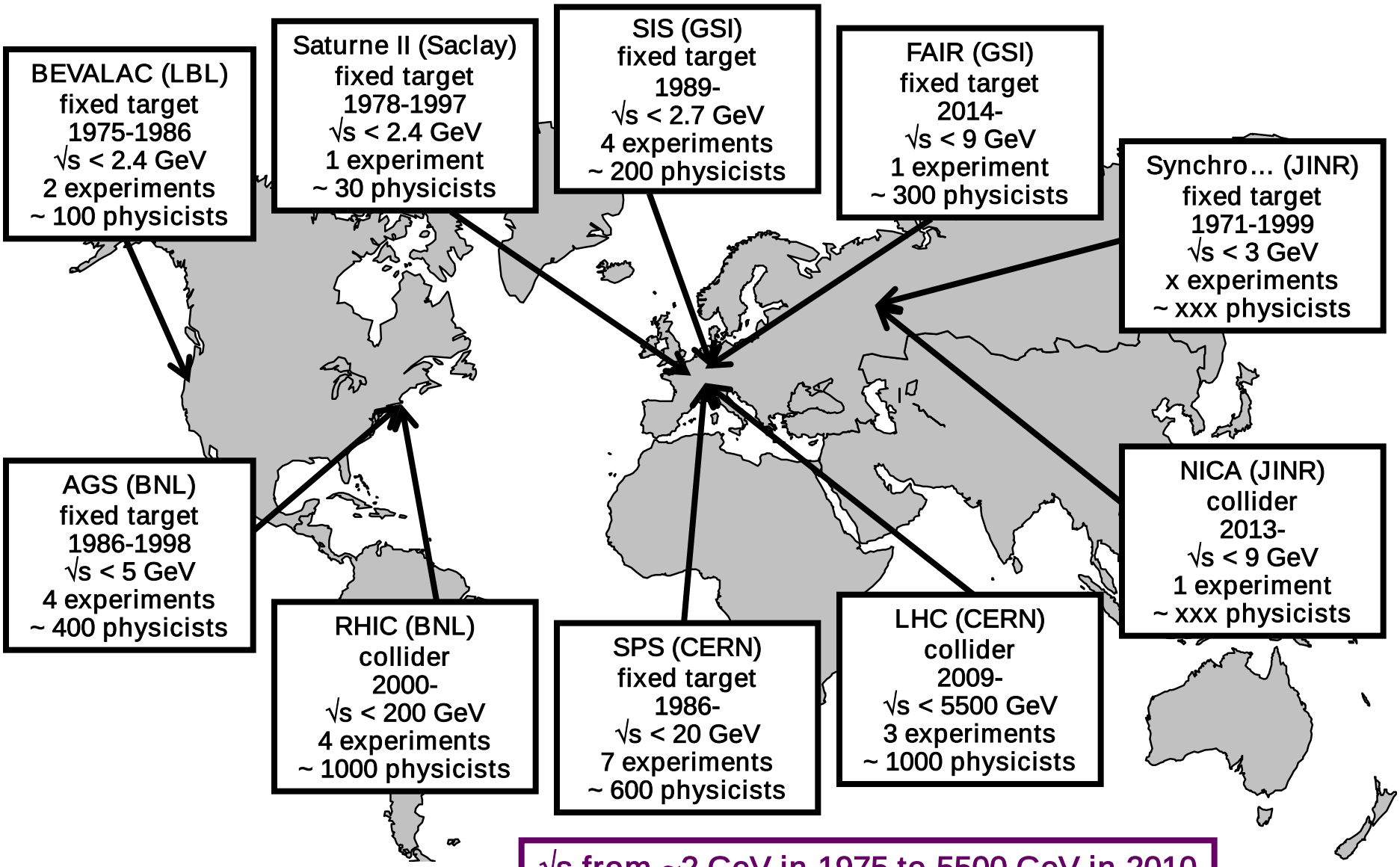




"direct" info from the medium

"non-direct" info from the medium

1975-2010: 35 years of heavy-ion collisions

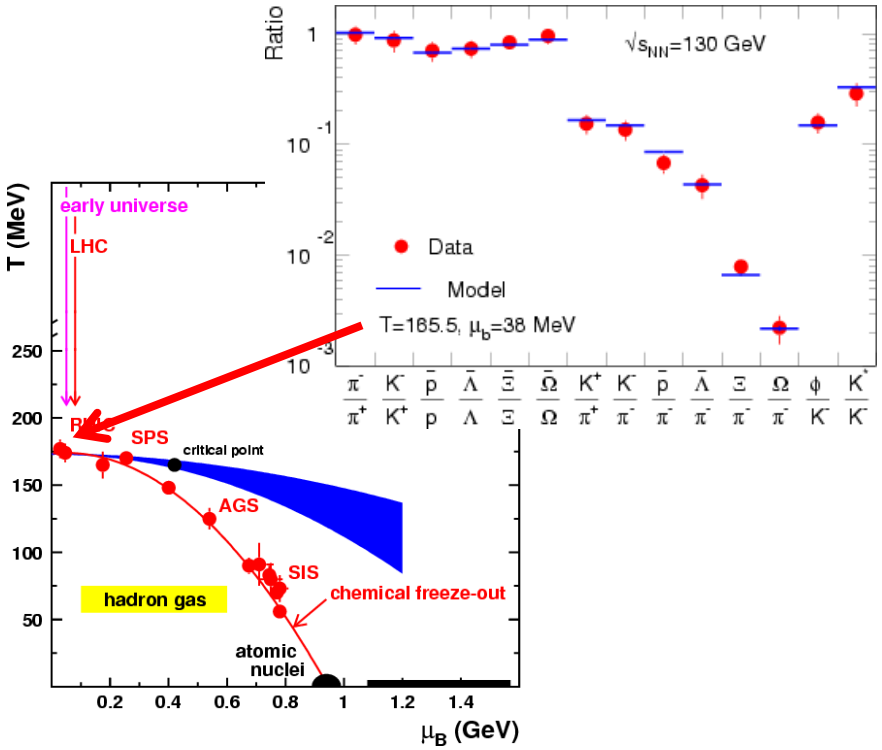


√s from ~2 GeV in 1975 to 5500 GeV in 2010

Can one reach the QGP with heavy-ion collisions?

- freeze-out temperature

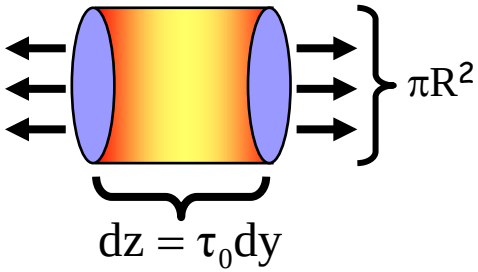
$$n_i = \frac{g}{2\pi^2}\int_0^\infty \frac{p^2 dp}{e^{(E_i(p)-\mu_i)/T} \pm 1}$$

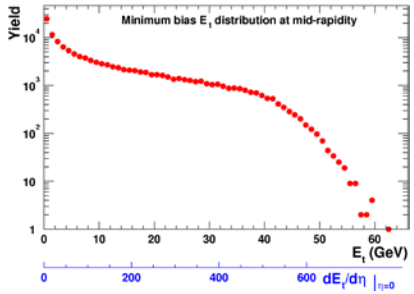


…coincides with critical value (173 MeV)

- energy density

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





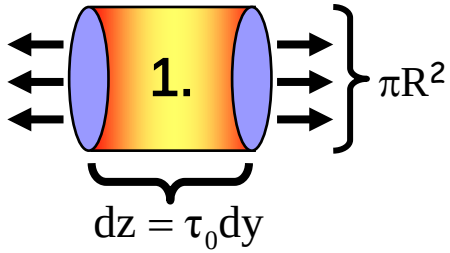
system	√s (GeV)	ε (GeV/fm³)
Pb+Pb	17	2.5
Au+Au	200	4.6

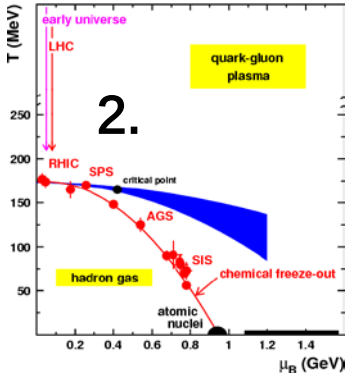
…larger than critical value (0.7 GeV/fm³)

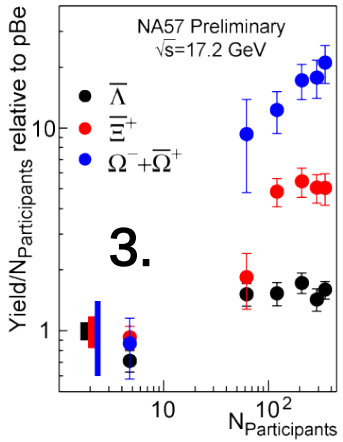
SPS & RHIC findings in 8 plots

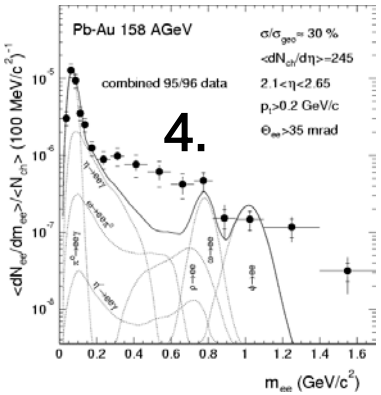
the medium produced in heavy-ion collisions:

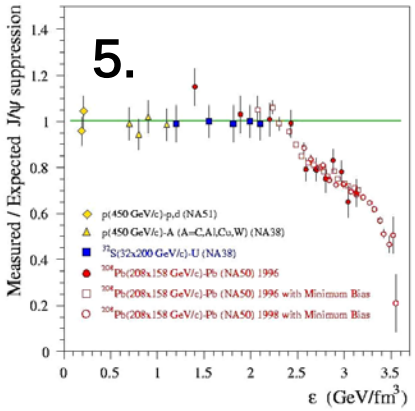
1. has an energy density > than ε_c
2. has a freeze-out temperature ~ T_c
3. over-produces strangeness
4. modifies properties of low-mass resonances
5. dissolves high-mass resonances
6. over-produces photons
7. exhibits quark & gluon degrees of freedom
8. quenches jets

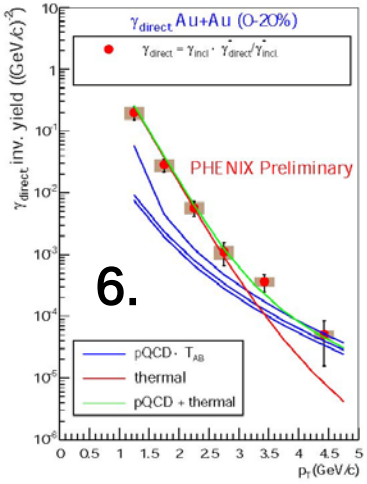


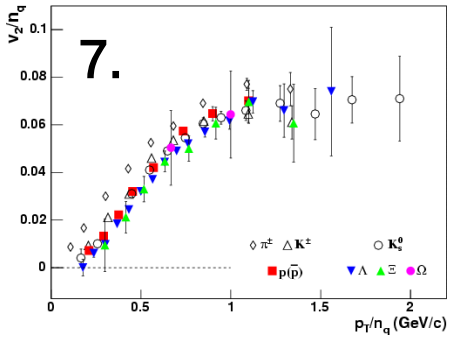


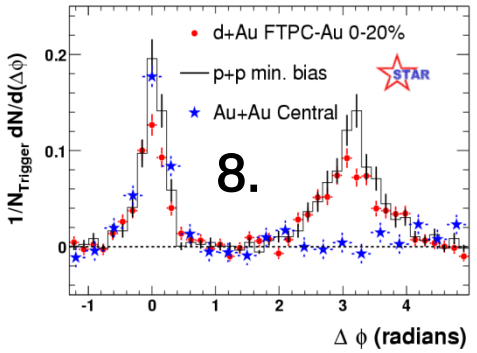












the medium behaves like a quark-gluon plasma

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

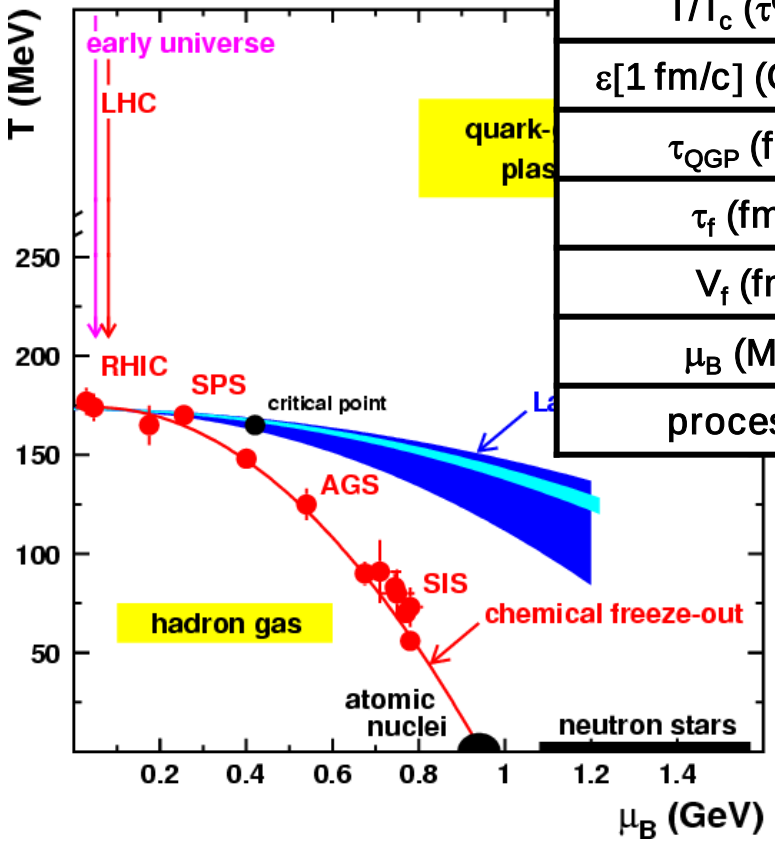
the LHC is the ideal place for studying the QGP (next slide)

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



- new environment
- better conditions for studying the QGP
- each collision is a "Little Bang"

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

The LHC (Large Hadron Collider) @ CERN
(European Organization for Nuclear Research)

The LHC in numbers

mean depth: 100 meters, circumference: 27 km, 9593 magnets

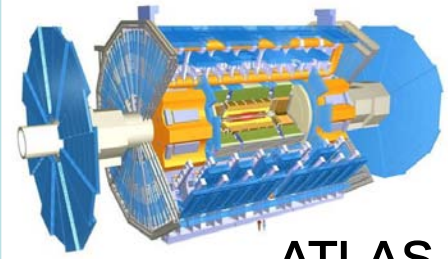
beam energy: 2.75 TeV Pb, 7 TeV proton (= 99.9999991 % of speed of light)

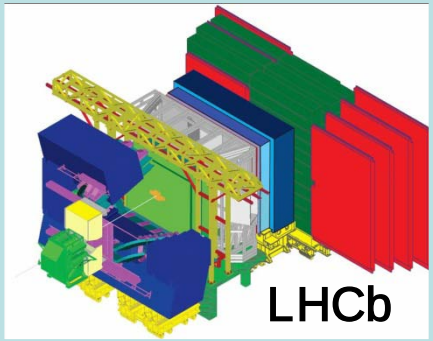
2808 bunches, 10^{11} protons/bunch, 11245 turn/s, 600 millions collisions/s

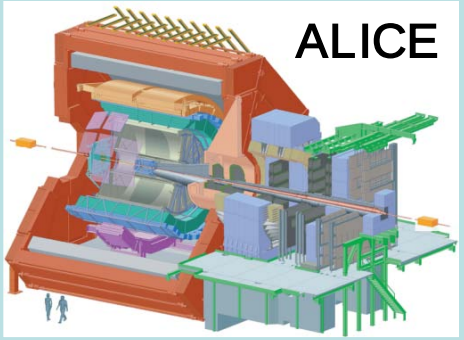
4 detectors

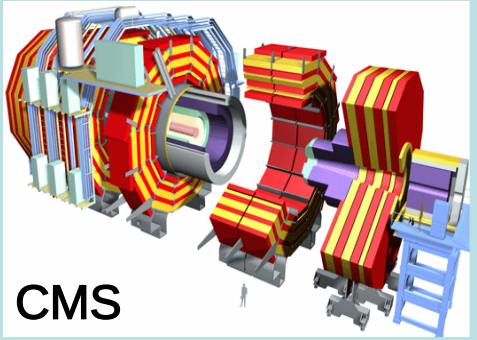
LHC detectors

1990-1996 : design
1992-2002 : R&D
2000-2010 : construction
2002-2007 : installation
2002-2009 : commissioning
Dec. 2009 → data taking


ATLAS


LHCb


ALICE

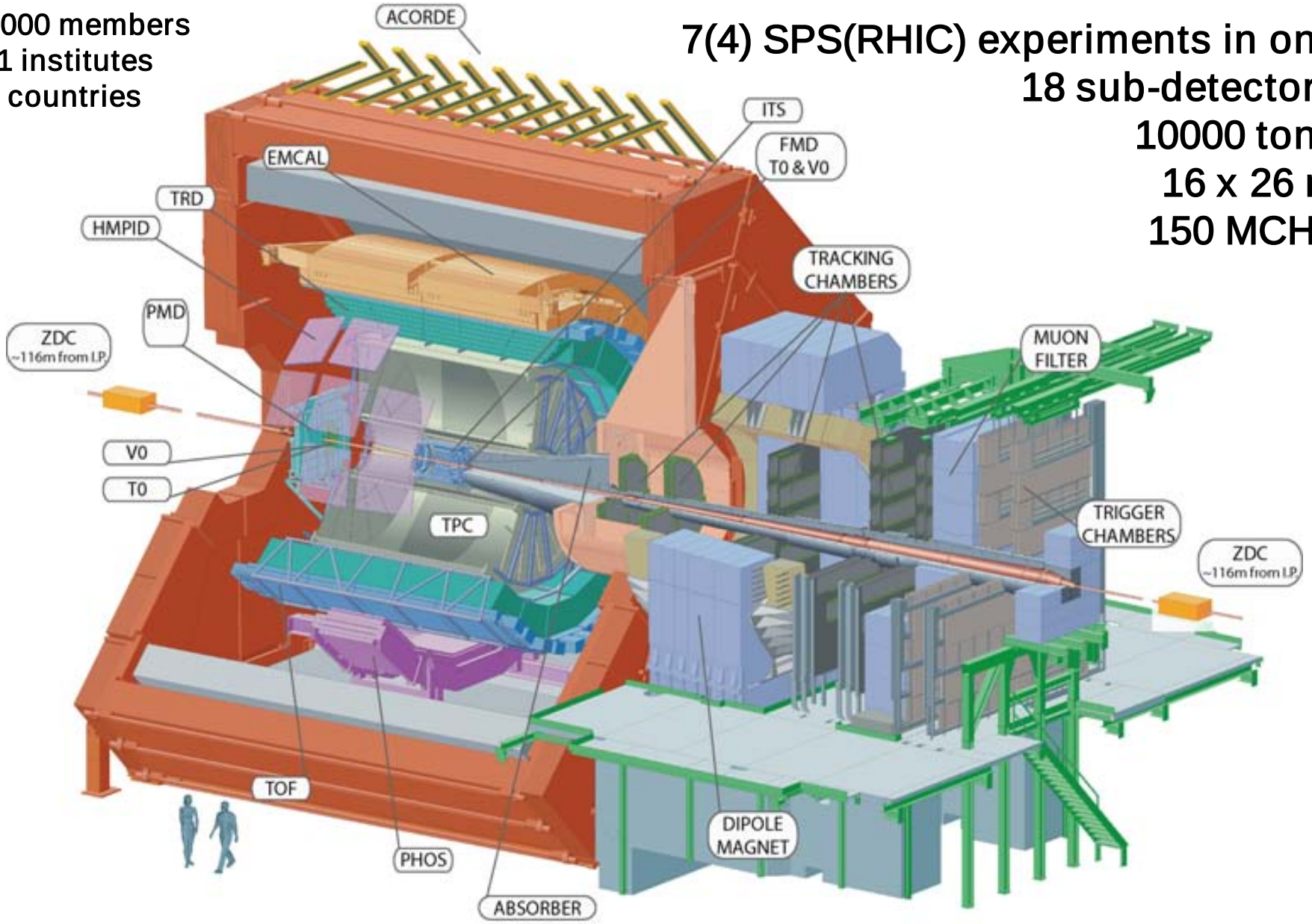

CMS

LHC research program (key words): Higgs, supersymmetry, dark matter, dark energy, matter-antimatter imbalance, quark-gluon plasma, extra-dimensions…

ALICE (A Large Ion Collider Experiment)

~1000 members
111 institutes
31 countries

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



ALICE shopping list

time

hard scattering	deconfinement	hadronization	freeze-out
• hard photons ⇨ pQCD • heavy flavours ⇨ pQCD • jets ⇨ pQCD	• thermal photons ⇨ QGP temperature • heavy flavours ⇨ QGP properties • jet quenching ⇨ QGP density	• EbyE fluctuations ⇨ critical behavior • l.m. dileptons, DCC ⇨ chiral symmetry • exotica ⇨ QGP condens.	• particle yields, spectra, flow & HBT ⇨ thermal & chemical conditions ⇨ dynamical evol. ⇨ indirect info from the early stage

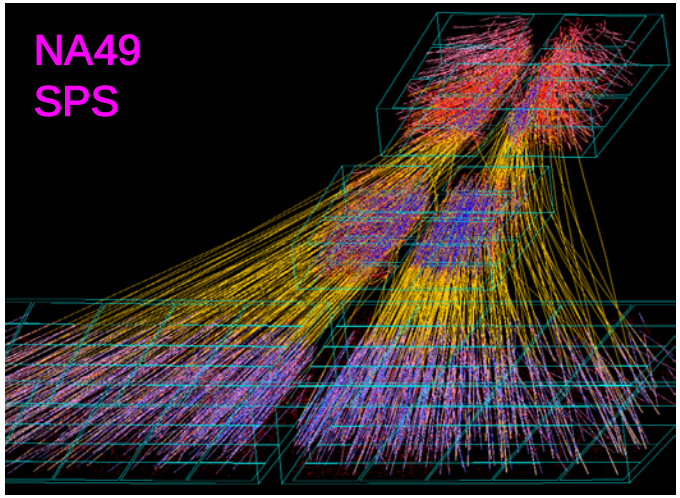
p_t

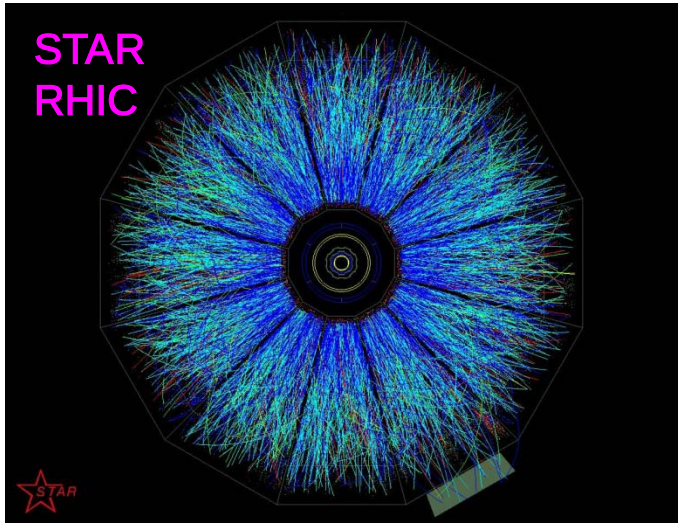
ALICE is designed to explore a broad p_t range and to correlate most of the signals

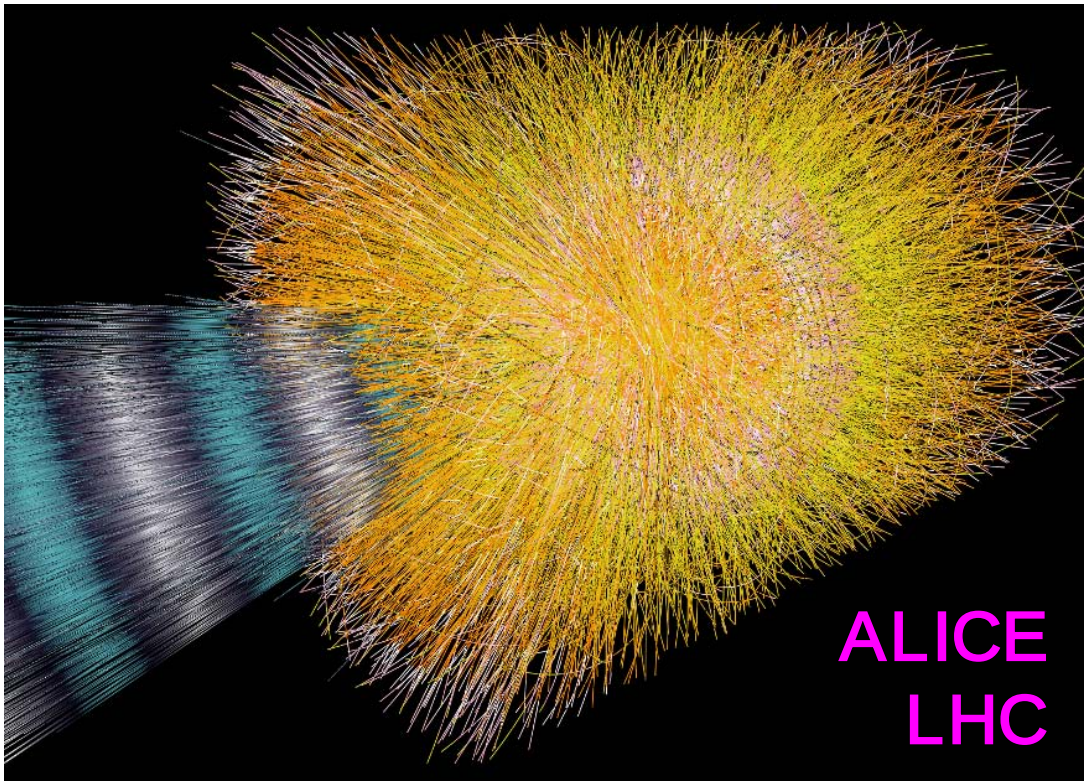
large acceptance & granularity, selective triggers, good tracking capabilities, wide momentum coverage, good secondary vertex reconstruction, hadron, lepton & photon id.

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

Expected track density

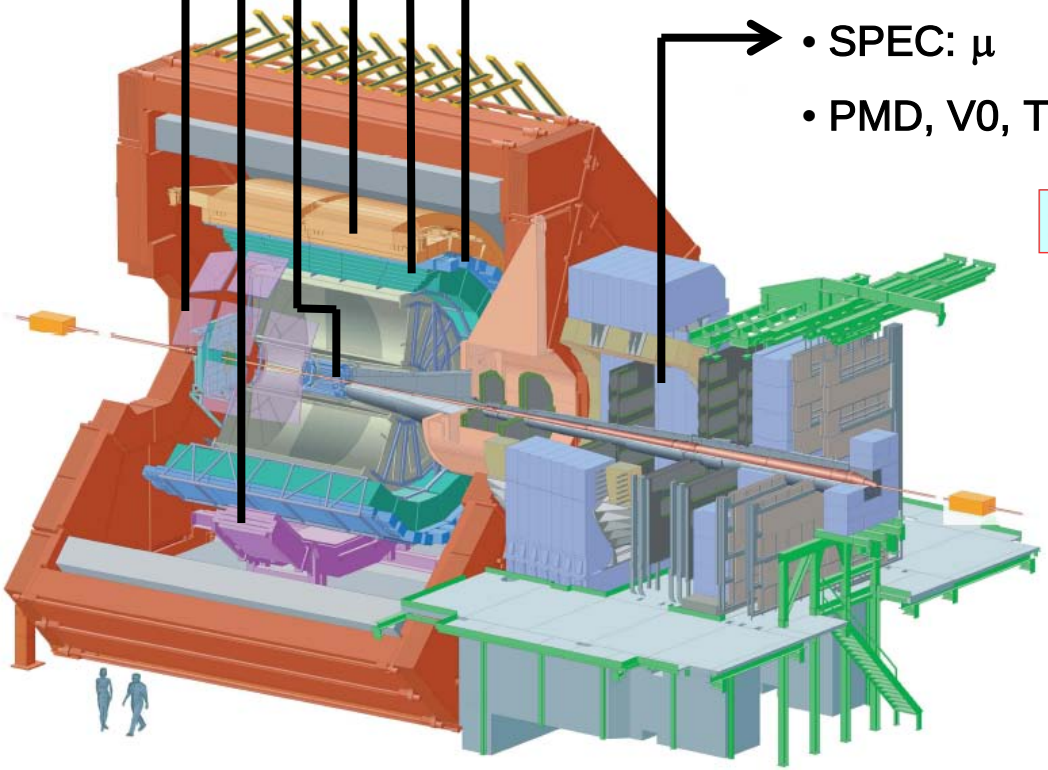


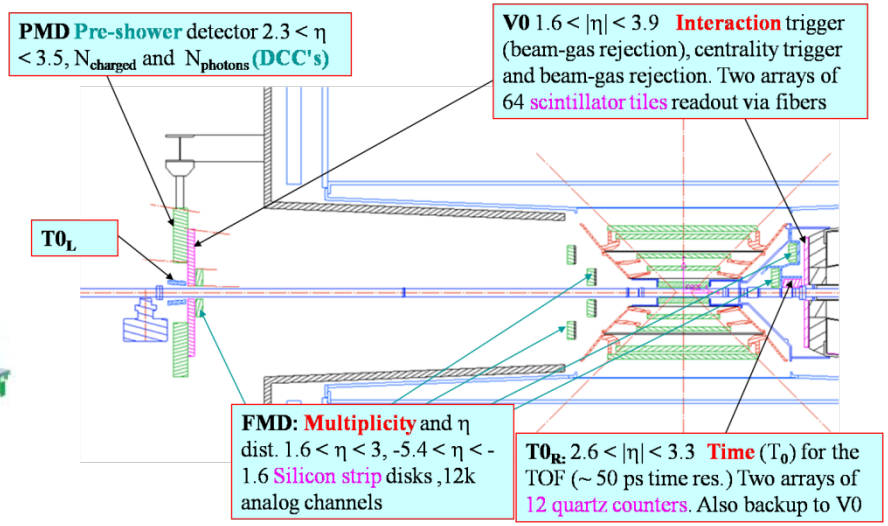




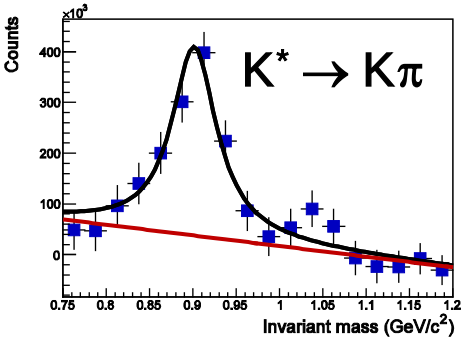
Particle identification with ALICE

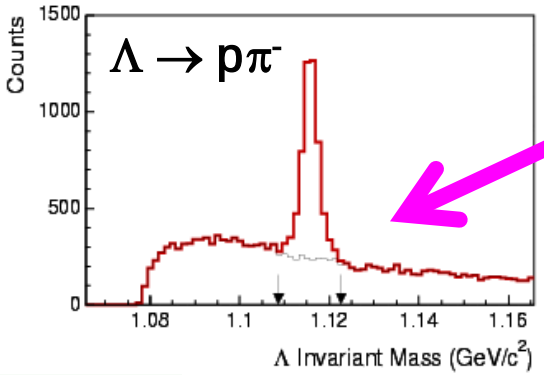
- ITS + TPC: low & intermediate p_t e,π,K,p
- TOF: higher p_t π,K,p
- HMPID: even higher p_t π,K,p
- TRD: intermediate p_t e
- EMCAL: high p_t γ,e,π^0
- PHOS: lower p_t γ,e,π^0
- SPEC: μ
- PMD, V0, T0, FMD, ZDC: trigger, vertex, lum., γ,π^0…

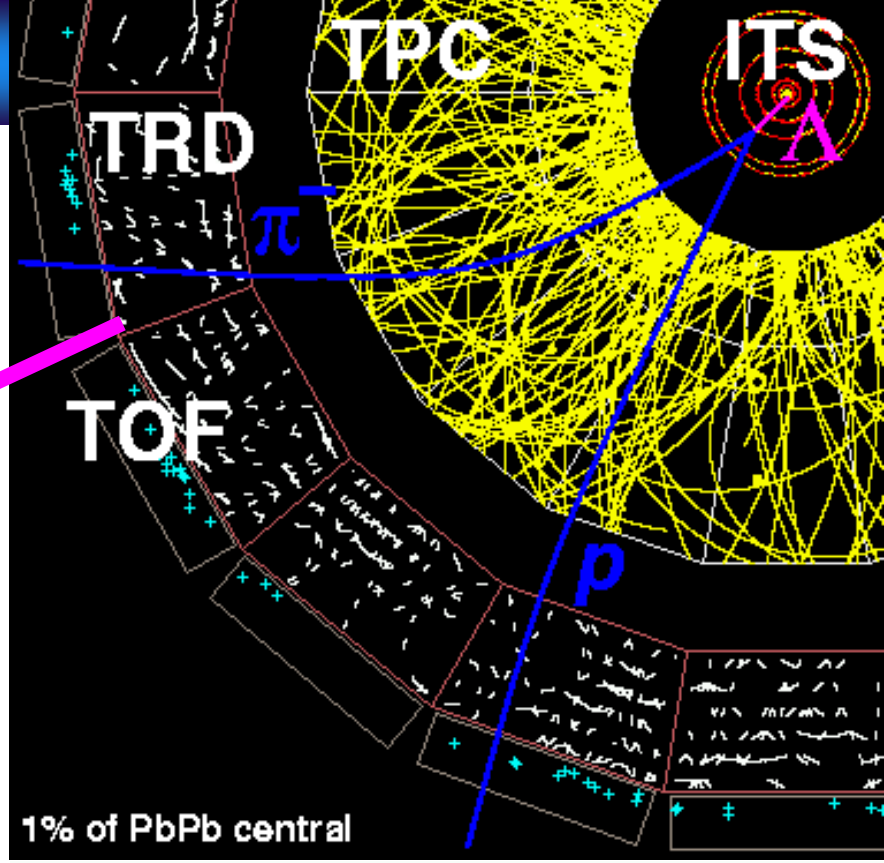


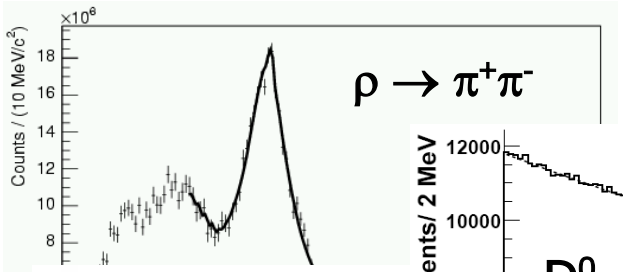


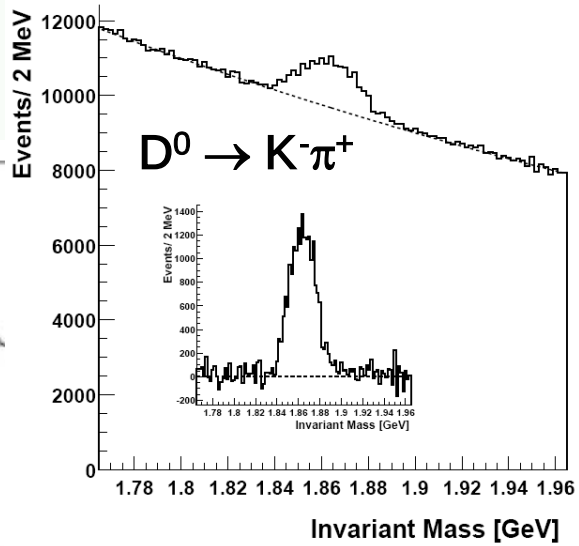
Resonances

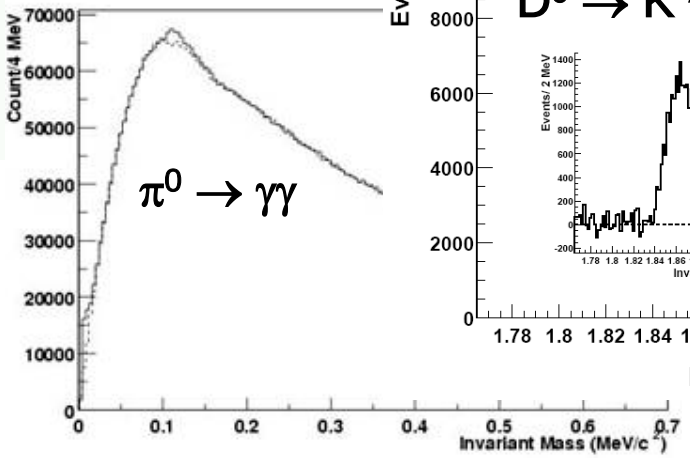




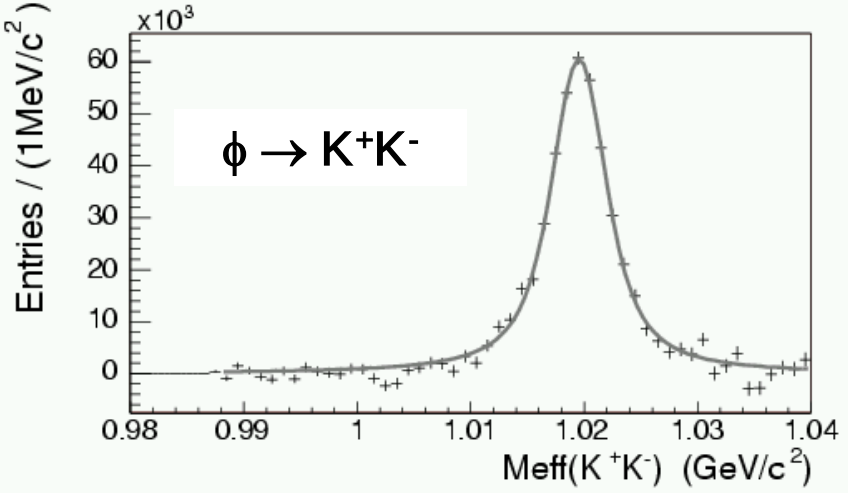




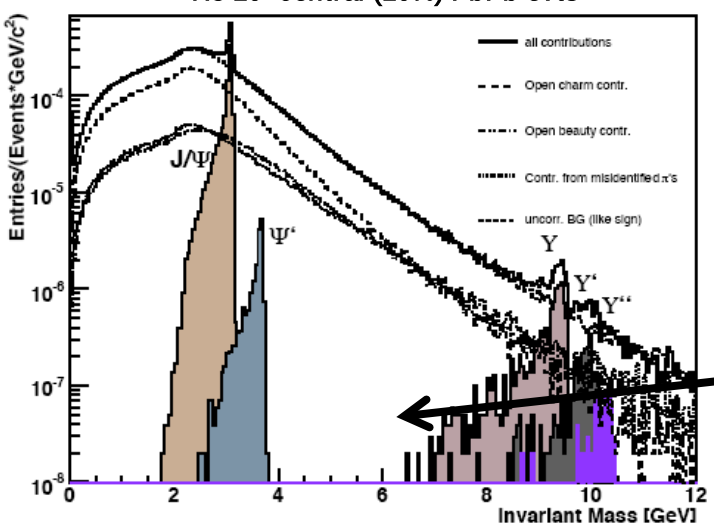


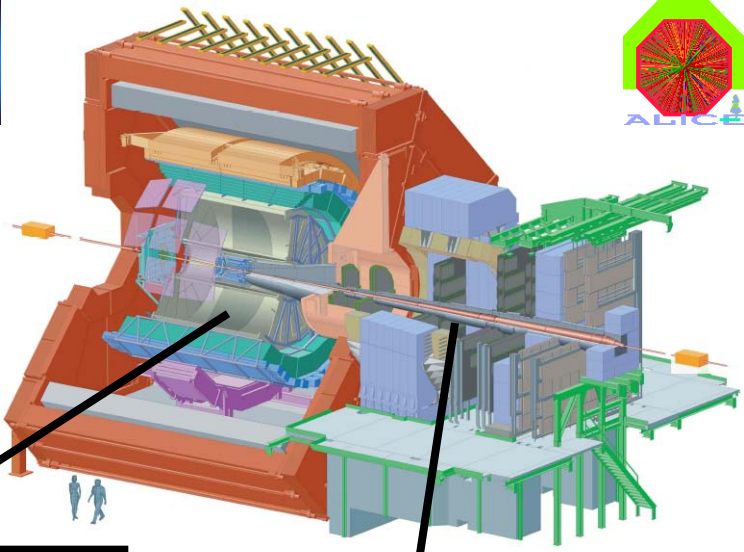


etc…



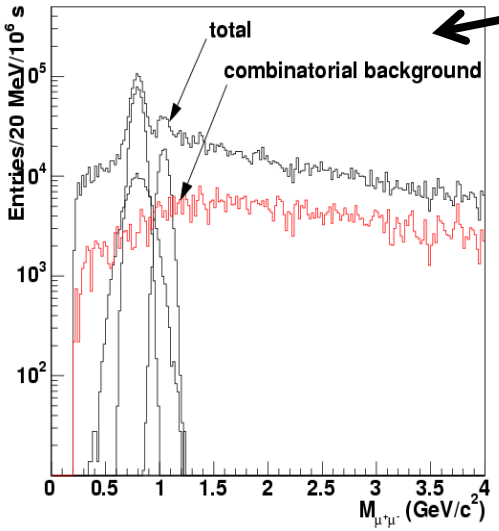
(di-)leptons

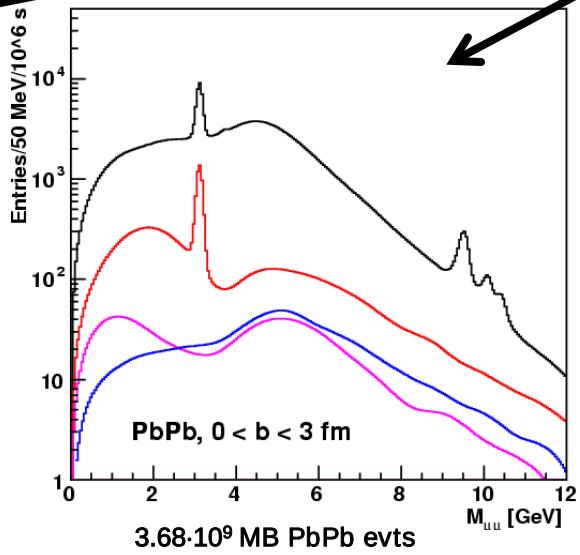




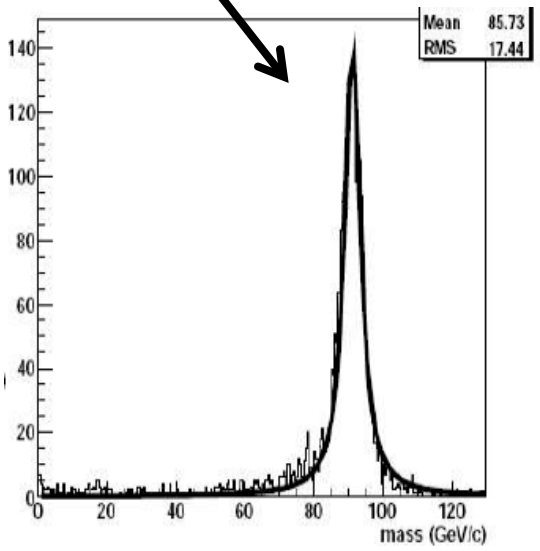
ρ, ω, ϕ, J/ψ, ψ', ϒ, ϒ', ϒ'', Z^0, $W^{\pm}$, charm, bottom → e^+e^-

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

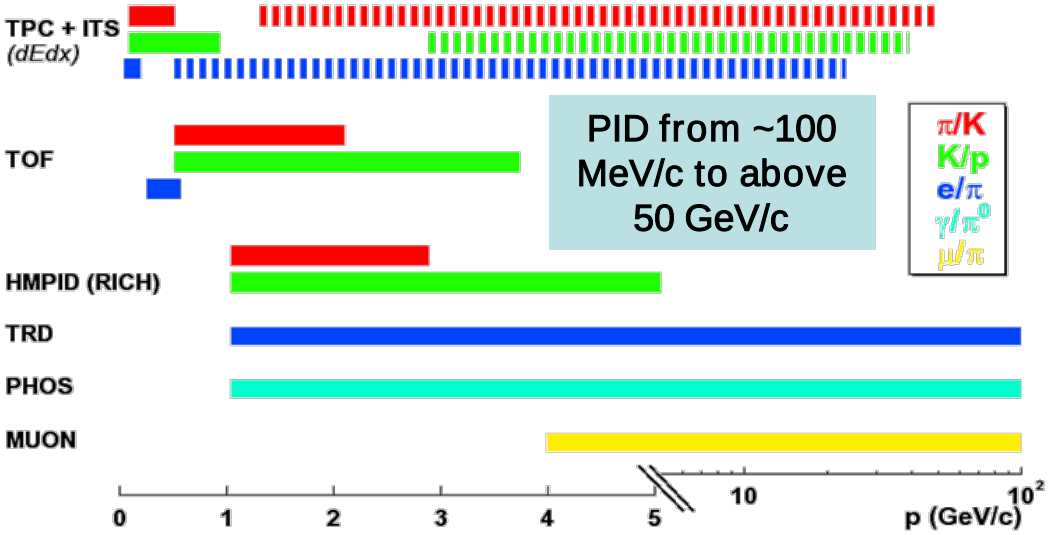




3.68·10⁹ MB PbPb evts

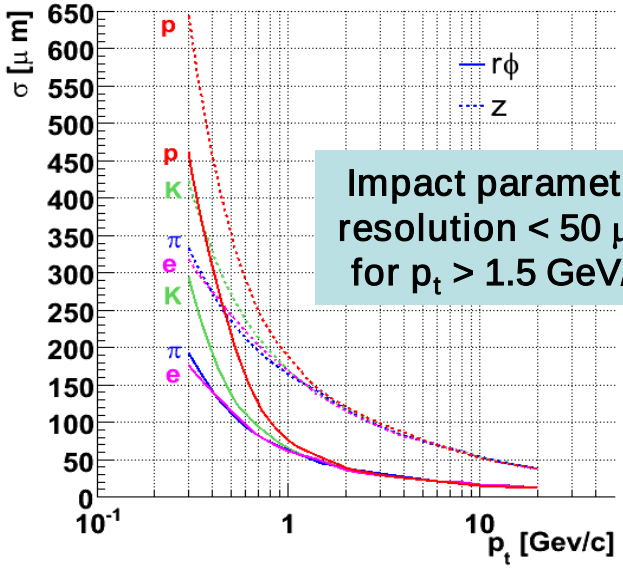


Selected expected performances

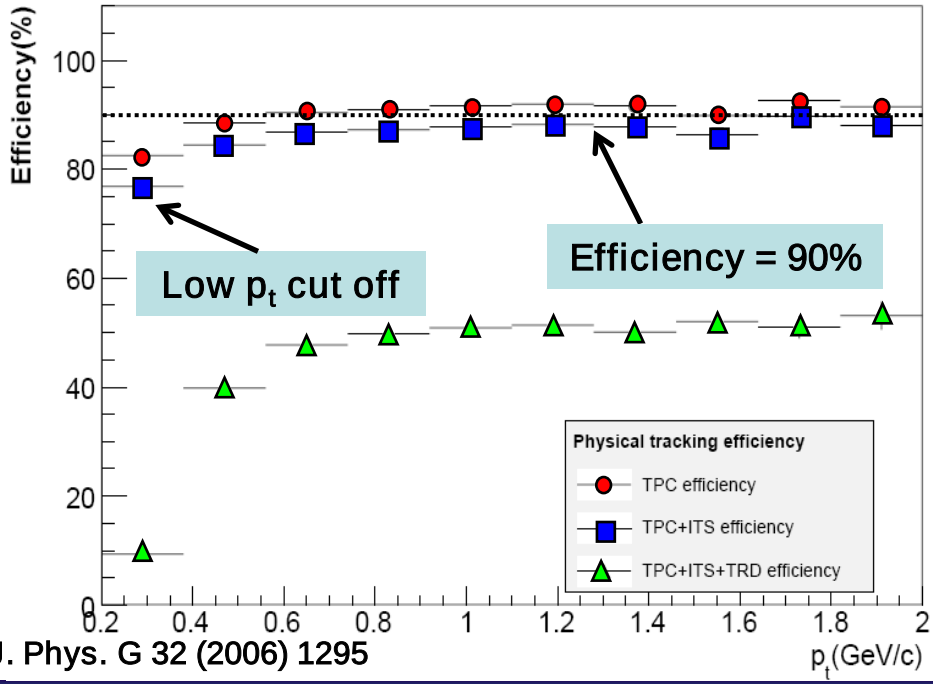


PID from ~100 MeV/c to above 50 GeV/c

π/K
K/p
e/π
γ/π^0
μ/π



Impact parameter resolution < 50 μm for p_t > 1.5 GeV/c



Low p_t cut off

Efficiency = 90%

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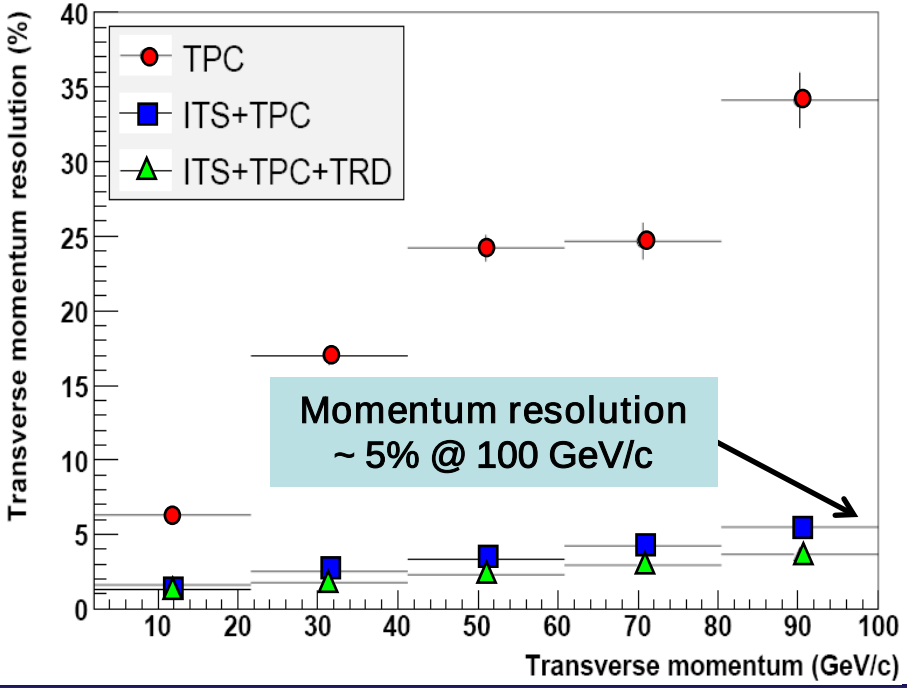


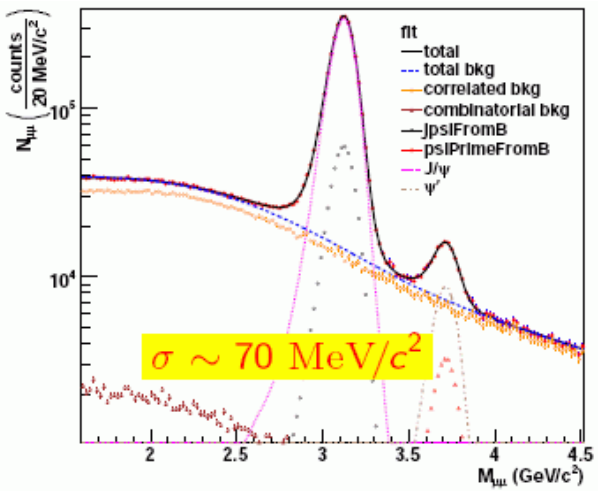
Momentum resolution ~ 5% @ 100 GeV/c

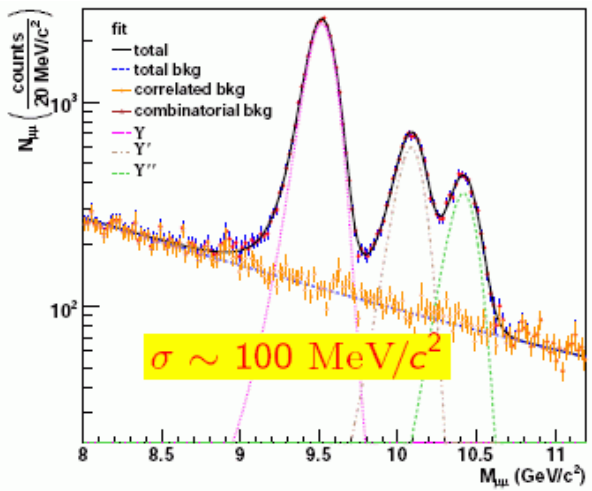
Example of physics performance: Expected statistics in the heavy flavour sector

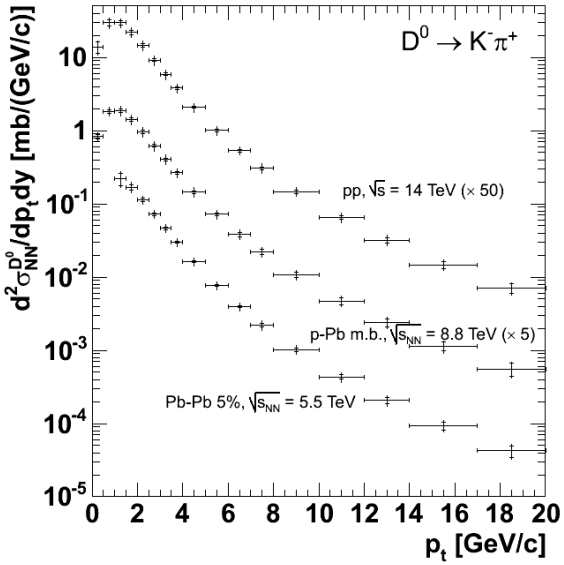
1 LHC year = 7 months pp (10^7s, $3\cdot10^{30}$cm^{-2}s^{-1}) + 1 month AA (10^6s, $5\cdot10^{26}$cm^{-2}s^{-1})

		muon channel				
		J/ψ	ψ'	ϒ	ϒ'	ϒ''
PbPb MB 5.5 TeV $3.68\cdot10^9$ evts	S (×10^3)	681.4	18.92	6.33	1.8	1.02
	S/B	0.33	0.02	2.46	1.03	0.74
	S/√S+B	413	19.53	67.14	30.19	20.85
pp 14 TeV $2.1\cdot10^{12}$ evts	S (×10^3)	4670	122	44.7	11.4	6.9
	S/B	12.6	0.55	5.8	1.9	1.3
	S/√S+B	2081	209	195	86	62

		$D^0 \to \pi k$
PbPb 5% 5.5 TeV 10^7 evts	S (×10^3)	13
	S/B	0.11
	S/√S+B	37
pp 14 TeV 10^9 evts	S (×10^3)	21
	S/B	0.5
	S/√S+B	84







Many more channels e.g. D*, Λ_c, c,b → lepton+X, etc

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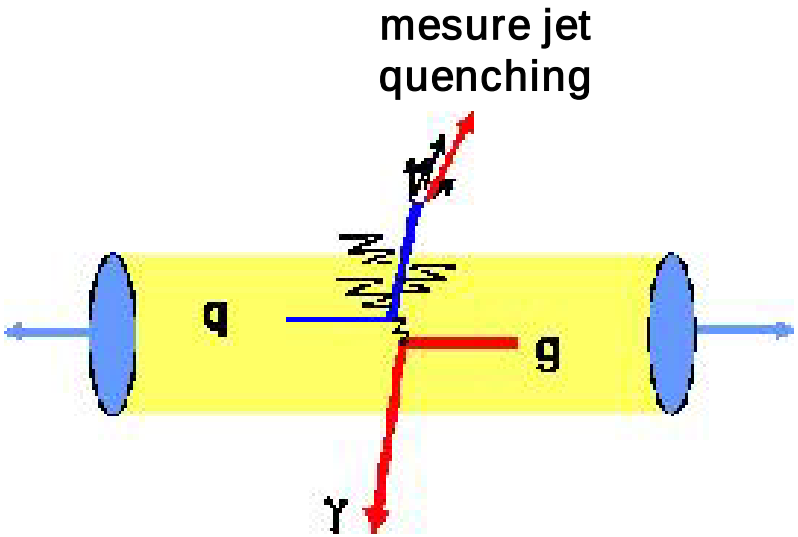
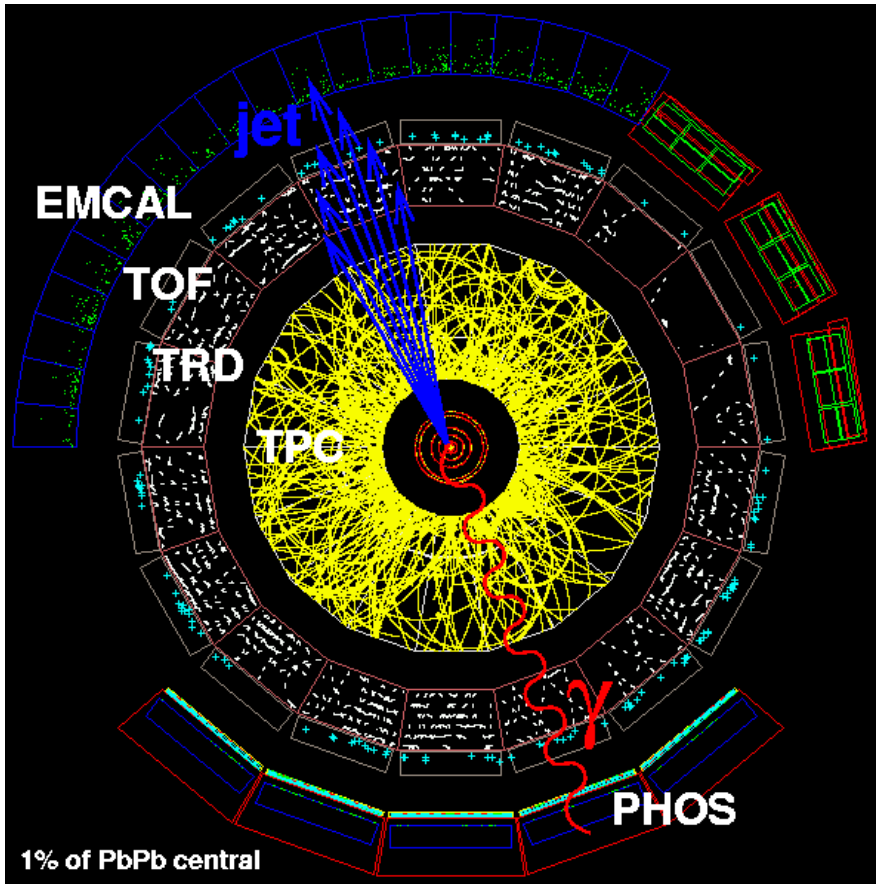
Example of sophisticated measurement: γ-jet correlations

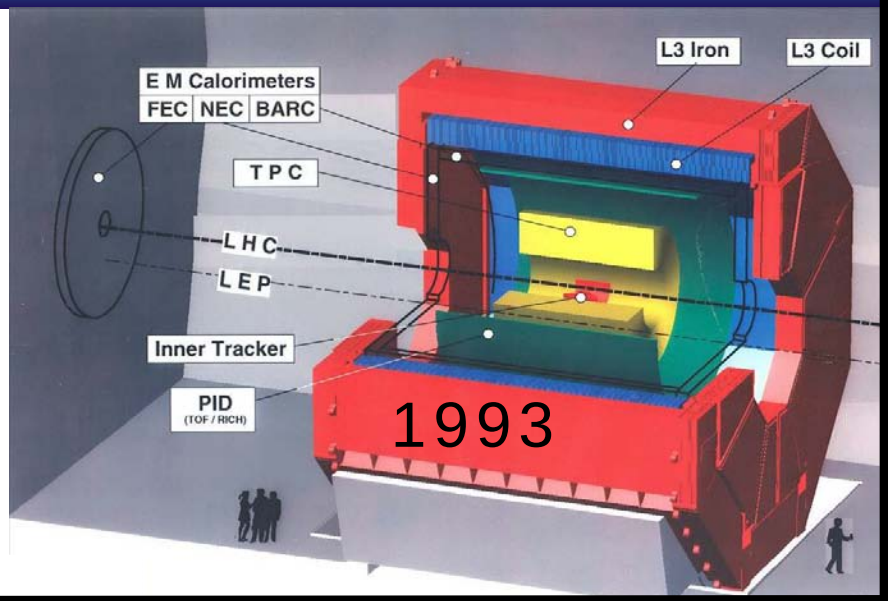
direct calibration of jet quenching

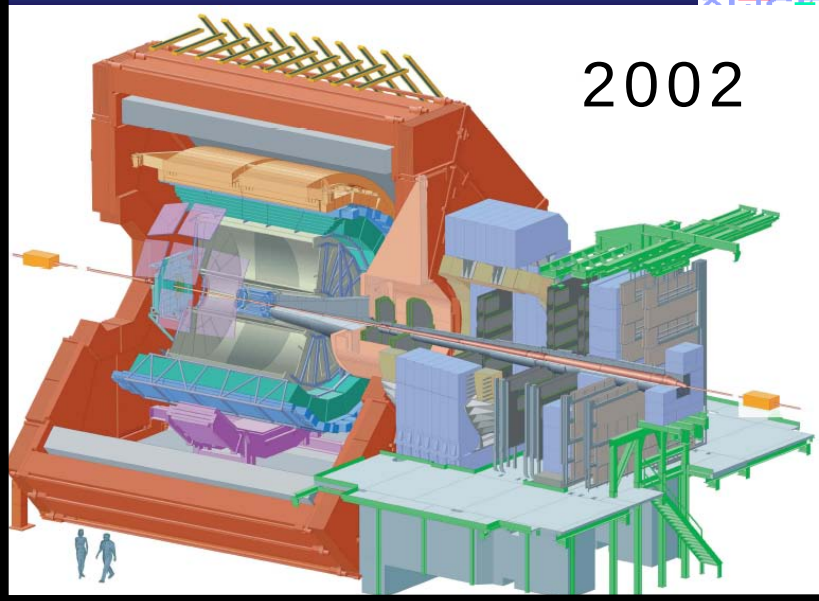




combination of PHOS, EMCAL, particle tracking & Id. allows to get jet trigger, energy loss, particle composition, transverse structure & fragmentation function down to low p_t

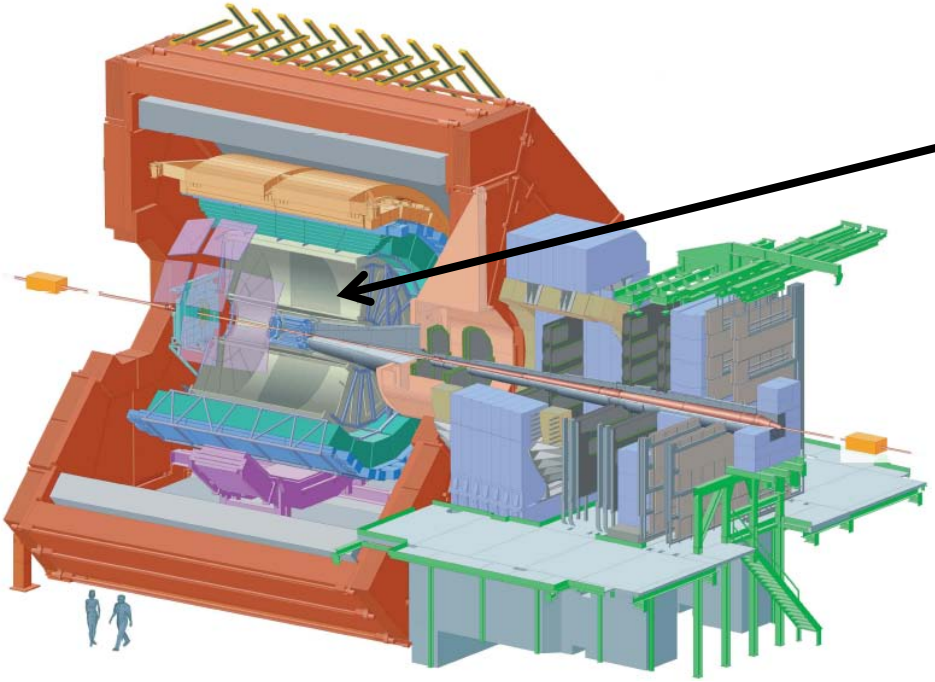
ALICE from first design to reality

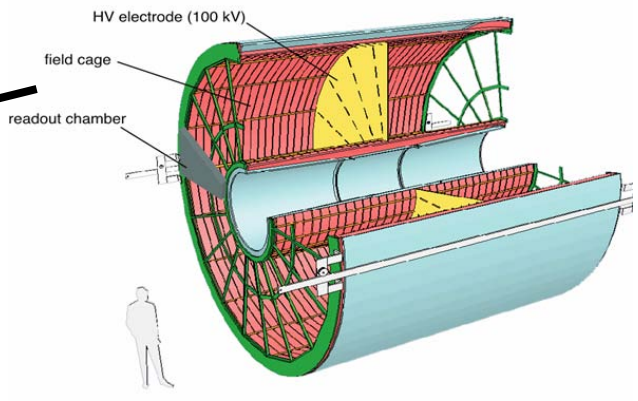




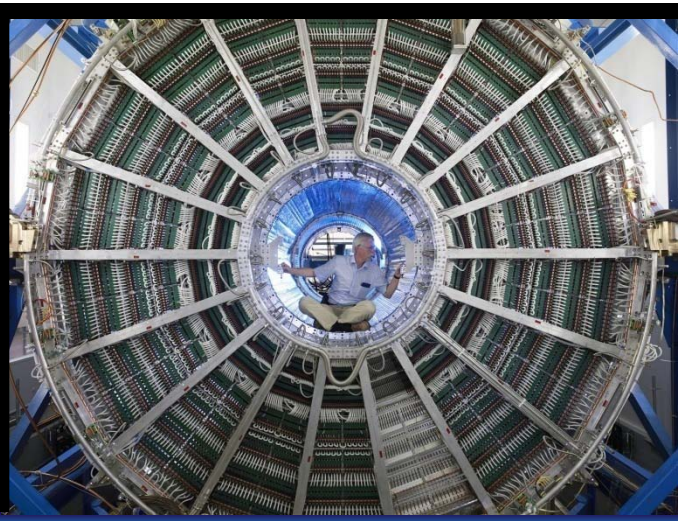
next slides from J. Schukraft @ CERN (2007)

TPC (central piece of ALICE)





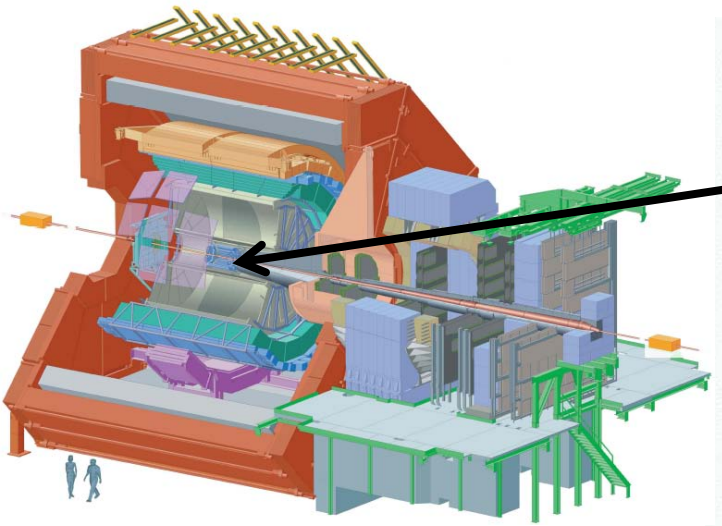
- the biggest in the world
- 510 x 560 cm, 88 m^3, 10 tons
- 570 k channels, 80 MB/evt
- 5 years of const. & assembly

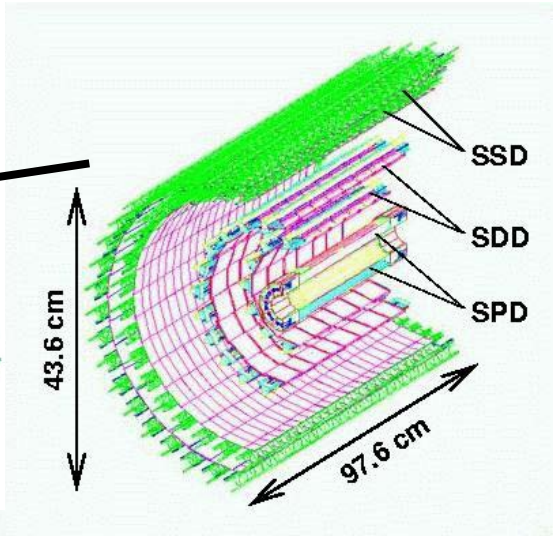


Installation of the TPC (jan. 2007)

~ 100 m horizontal, ~ 100 m vertical
in 2 days: <v> = 4 m/hour

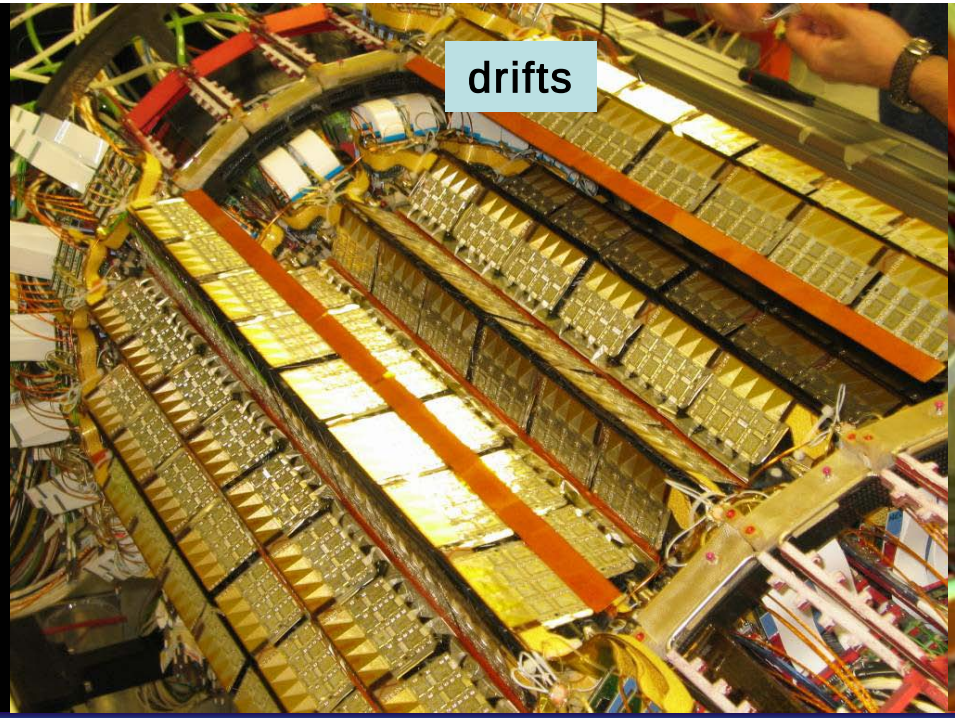
ITS (Inner Tracking System)

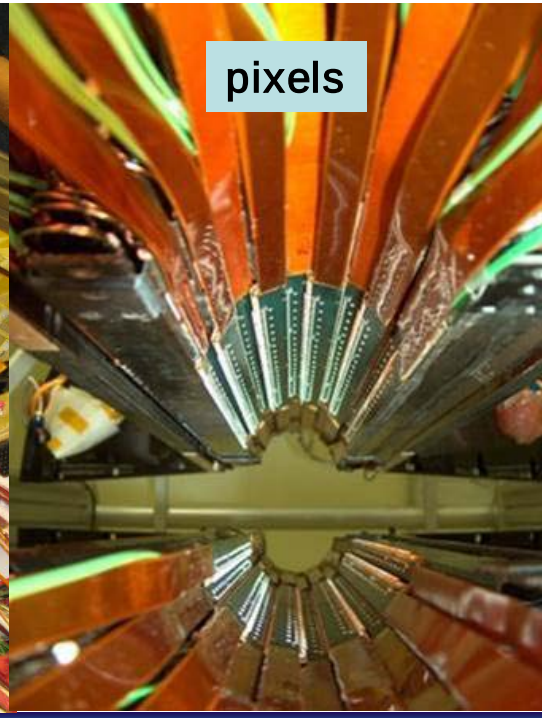




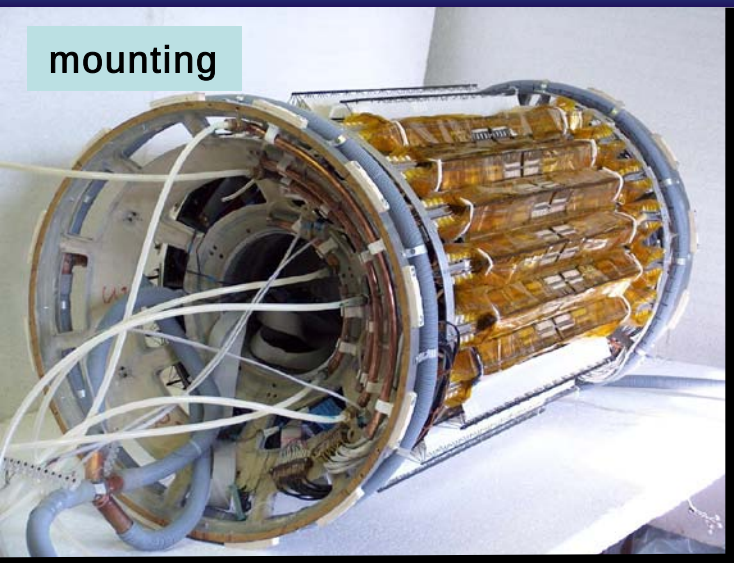
type	surface	# channels
SPD (pixel)	0.2 m^2	9.8 M
SDD (drift)	1.3 m^2	1.33 k
SSD (strip)	4.9 m^2	2.6 M

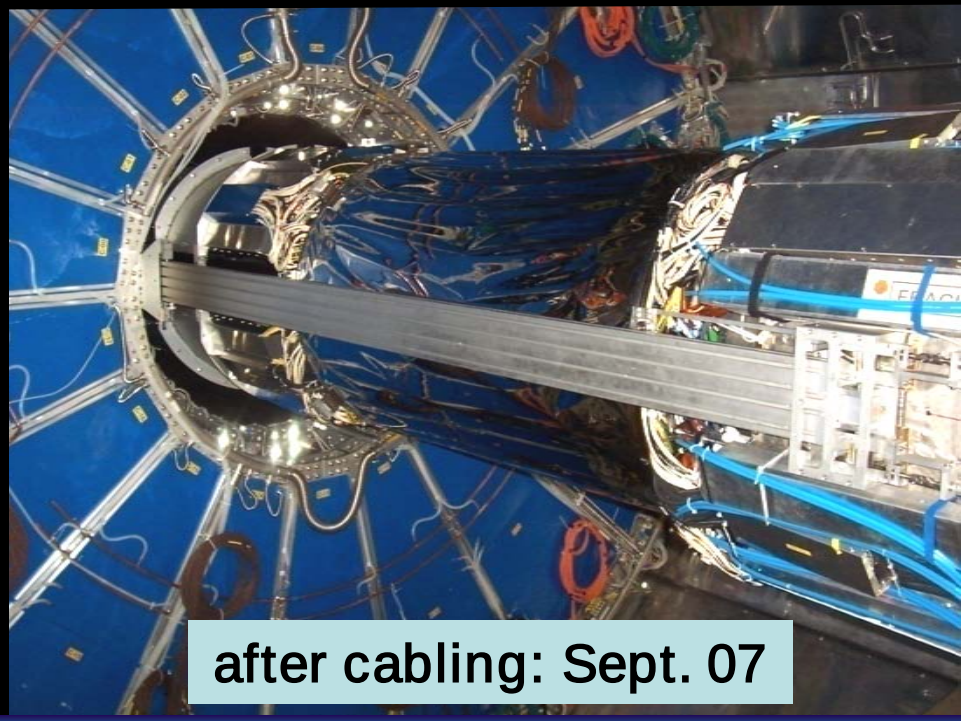
should be able to identify
~90 particles/cm^2/collision
every 100 ns





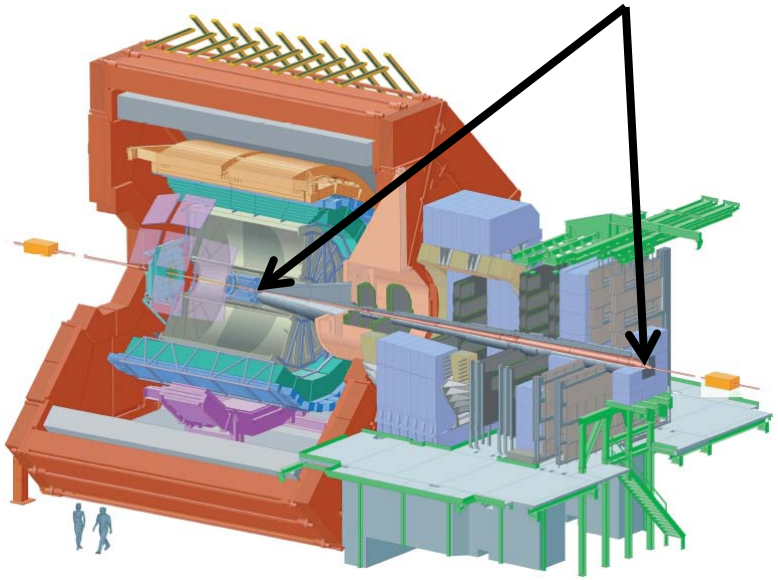
Installation of the ITS





A complex mechanical structure

front absorber of the muon spectrometer



100 tons, 18 m, W, Pb, Fe, graphite, concrete…

concrete: France, engineering & supervision: CERN, design: Russia

Polyethylene: Italy

Tungstene: China

Lead: UK

Support: Italy

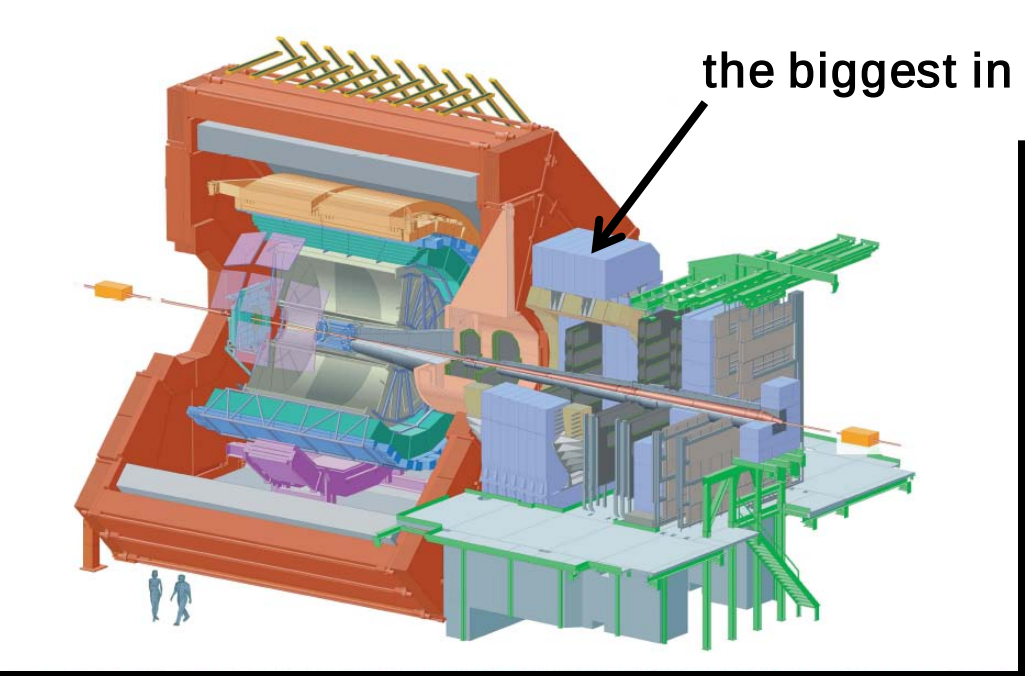
Graphite: Inde

Steel: Finland

Aluminum: Armenia

Steel: India

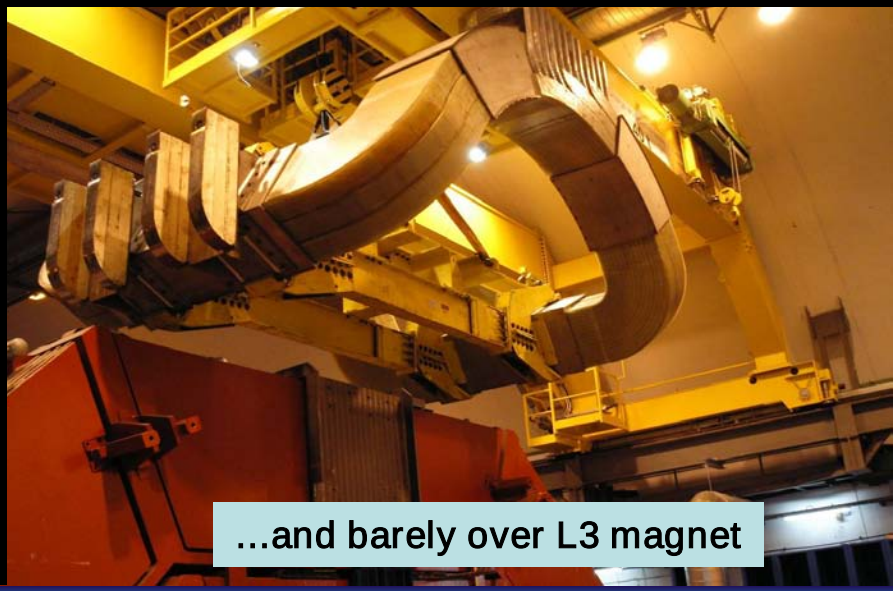
Muon spectrometer dipole (I)



the biggest in the world, 0.7 T, 3 Tm, 4 MW, 800 tons

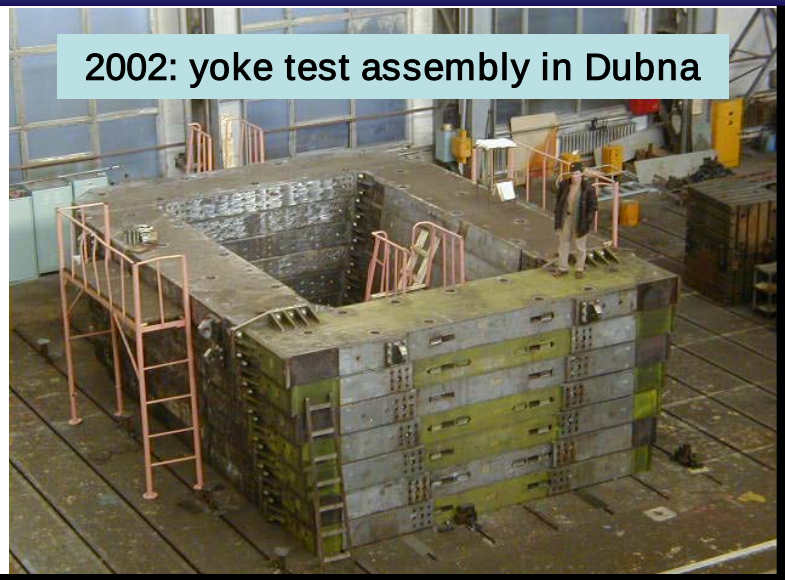
Sept. 2003: arrival of coils at CERN

fitting barely under the bridge



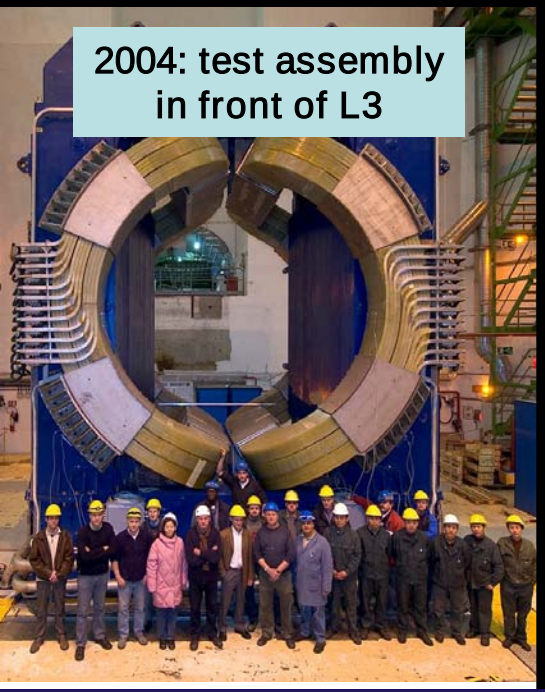
...and barely over L3 magnet

Muon spectrometer dipole (II)



2002: yoke test assembly in Dubna

2003: transport Dubna-CERN delayed by 10 months

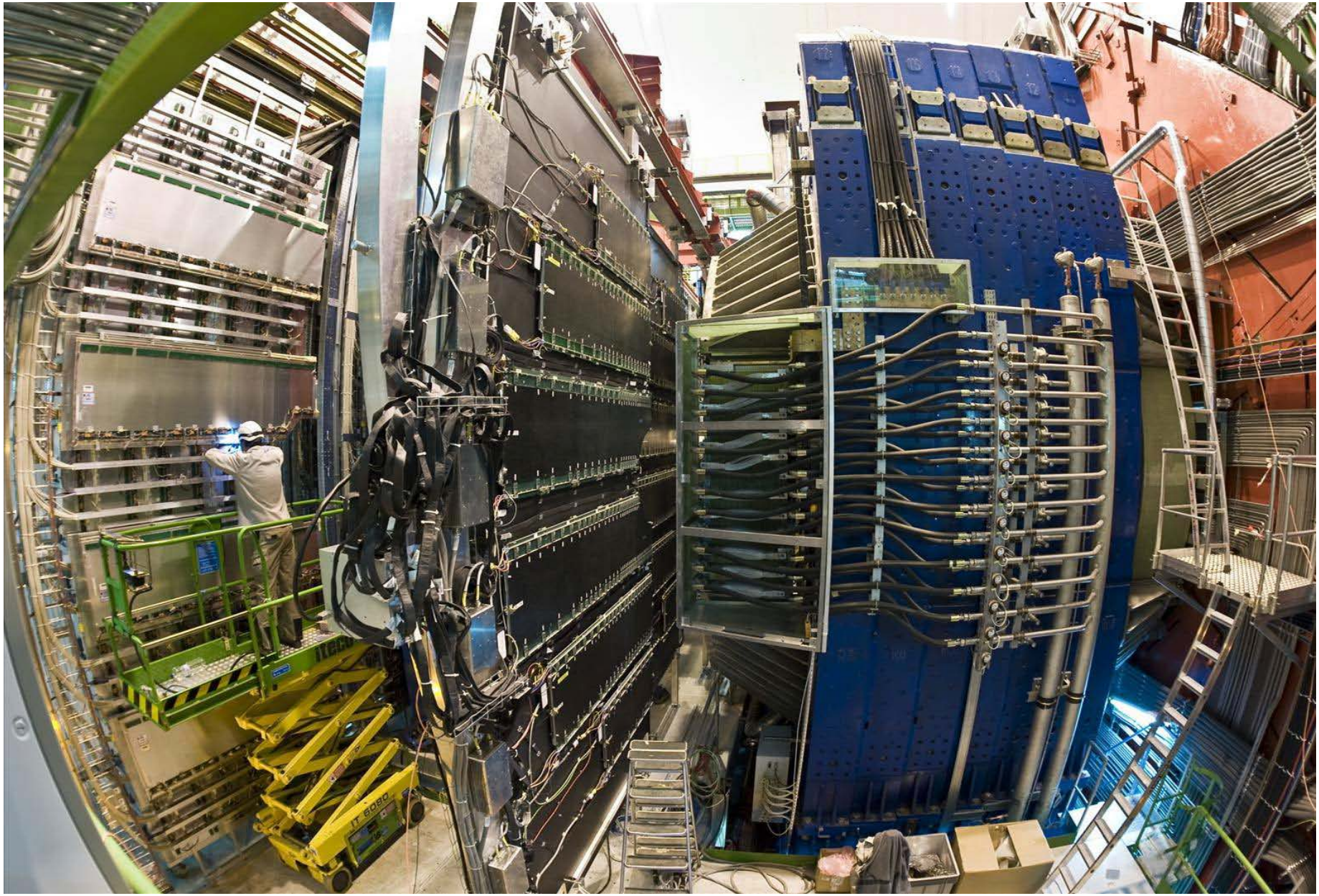


2004: test assembly in front of L3

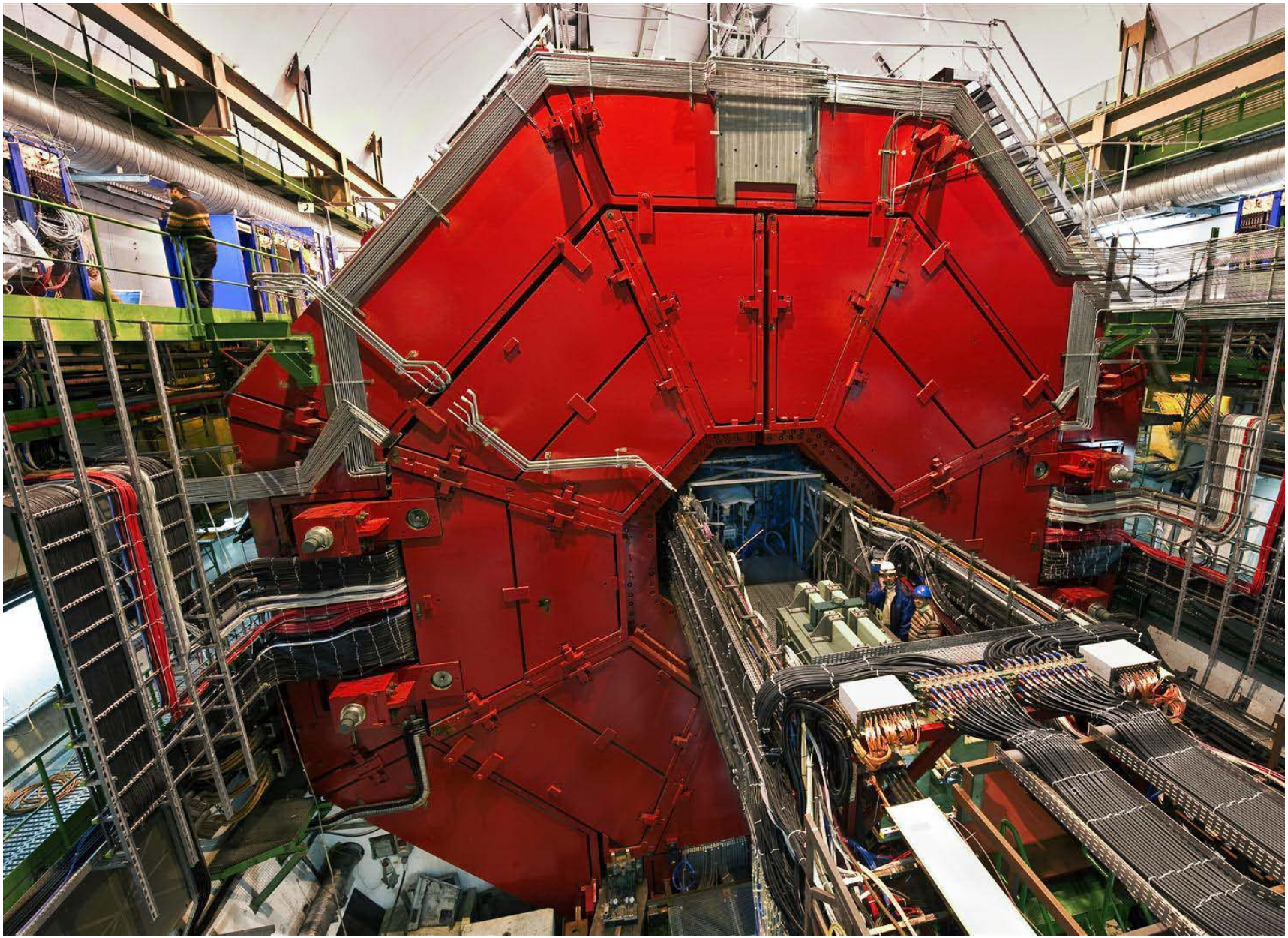
March 2004: closure of L3 back doors

2005: final assembly behind L3

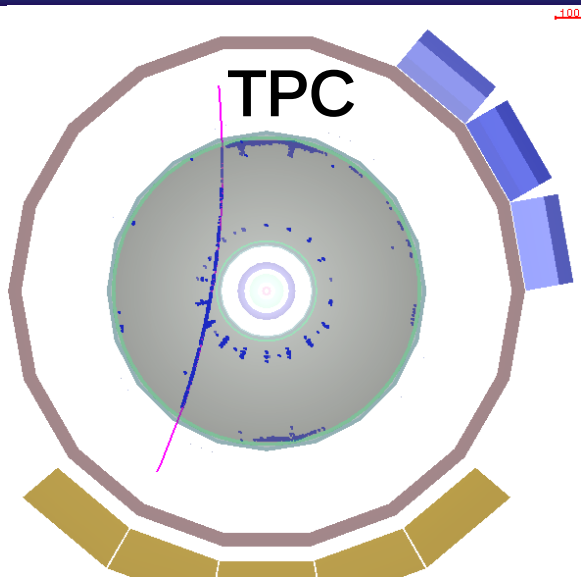
Muon spectrometer installed (spring 2008)

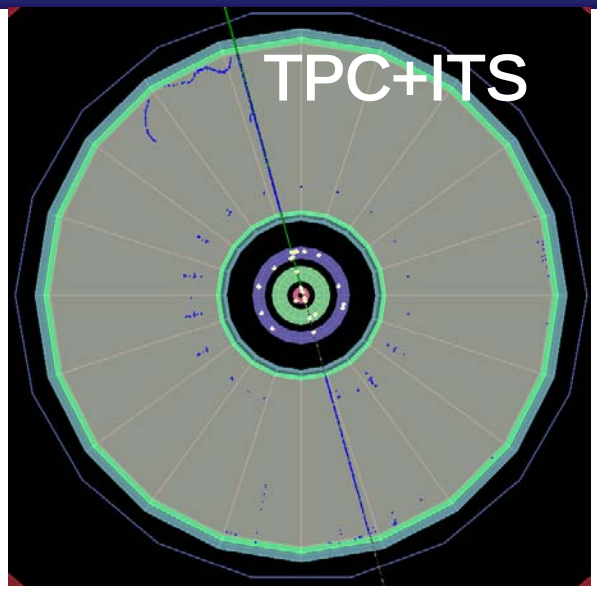


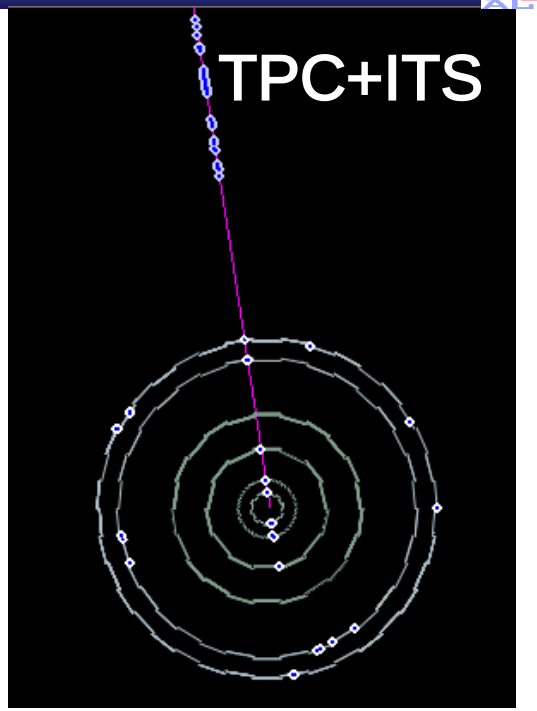
Central barrel detectors installed in 2008

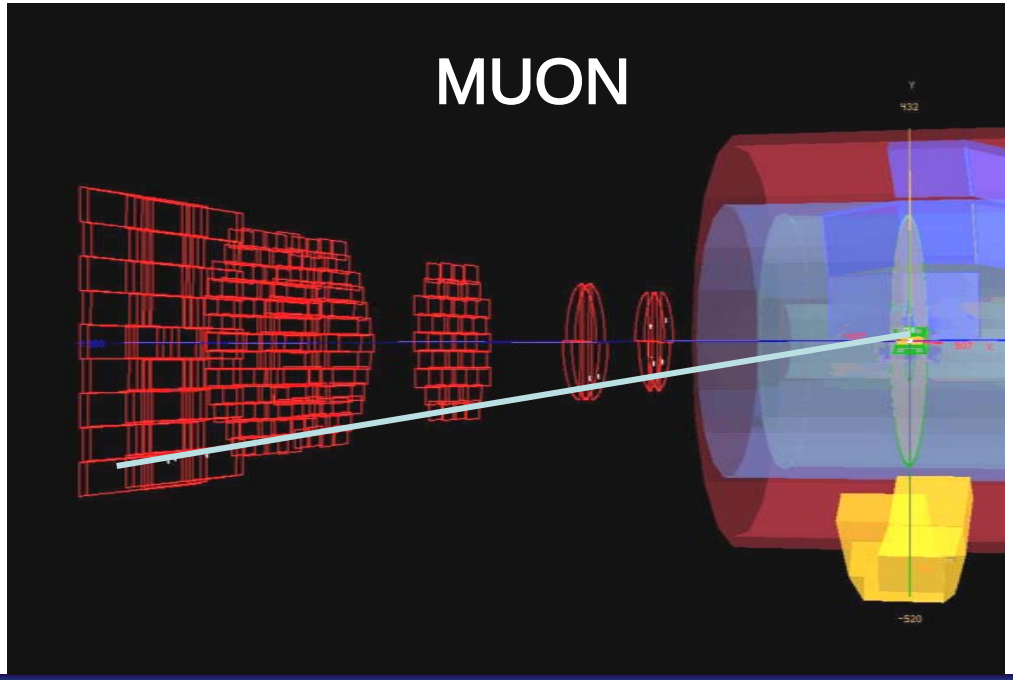


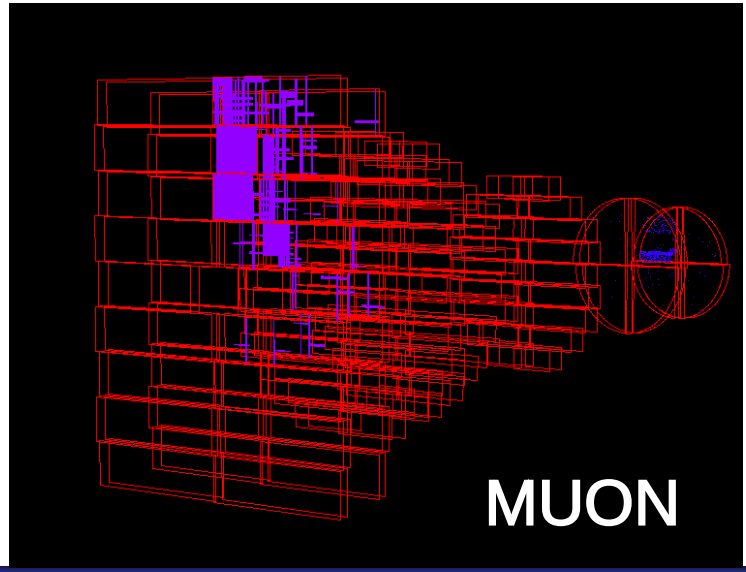
January 08 – August 08: cosmics



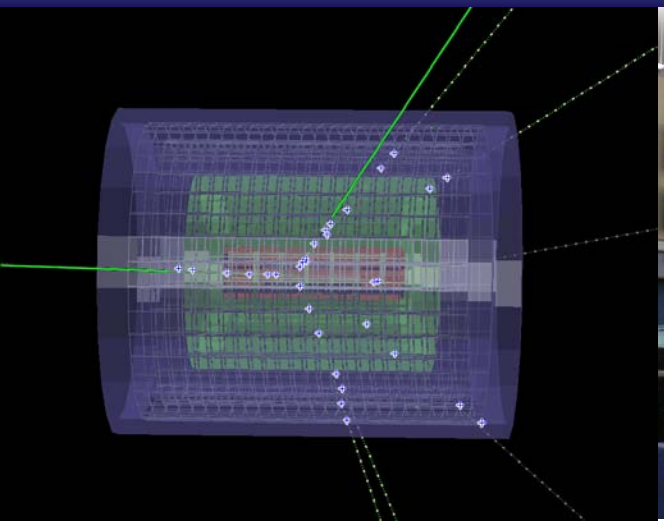


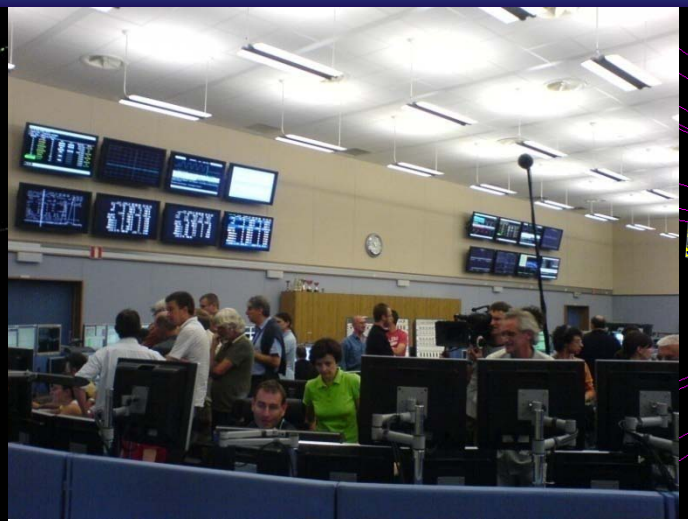


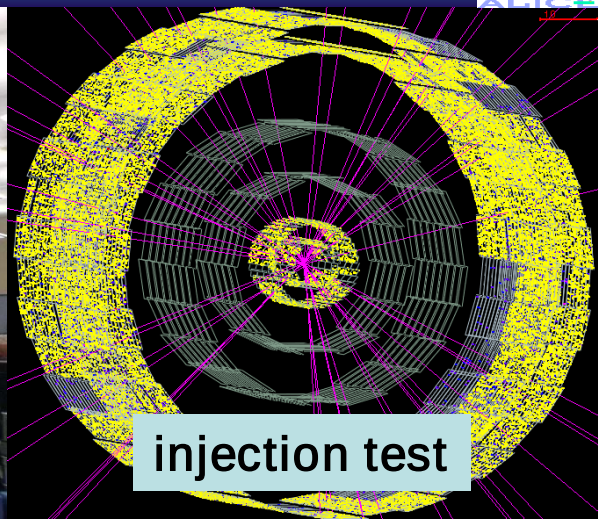




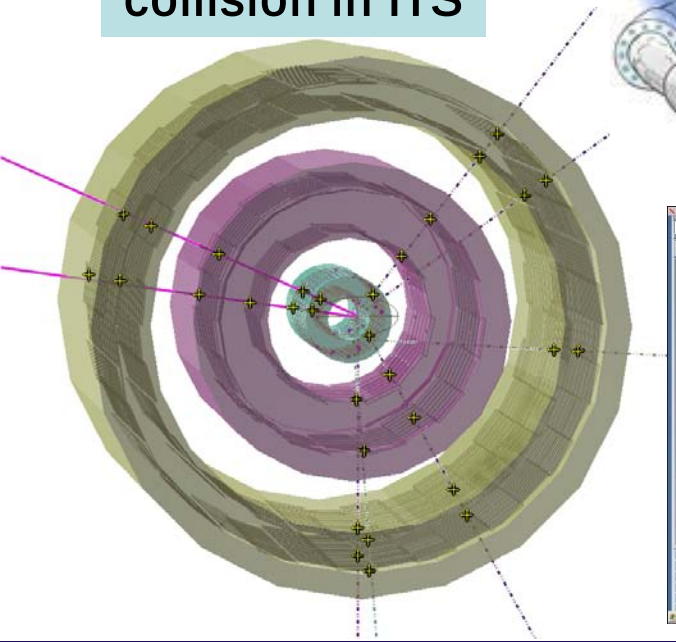
September 10th 2008: first beams

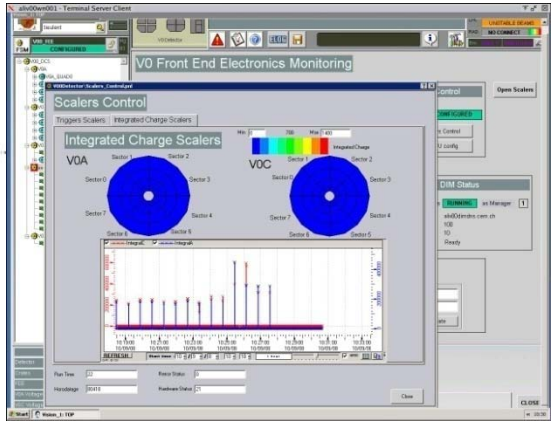




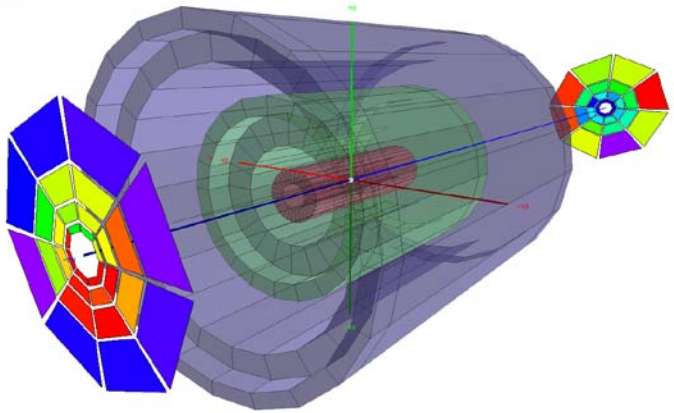


beam-gas collision in ITS

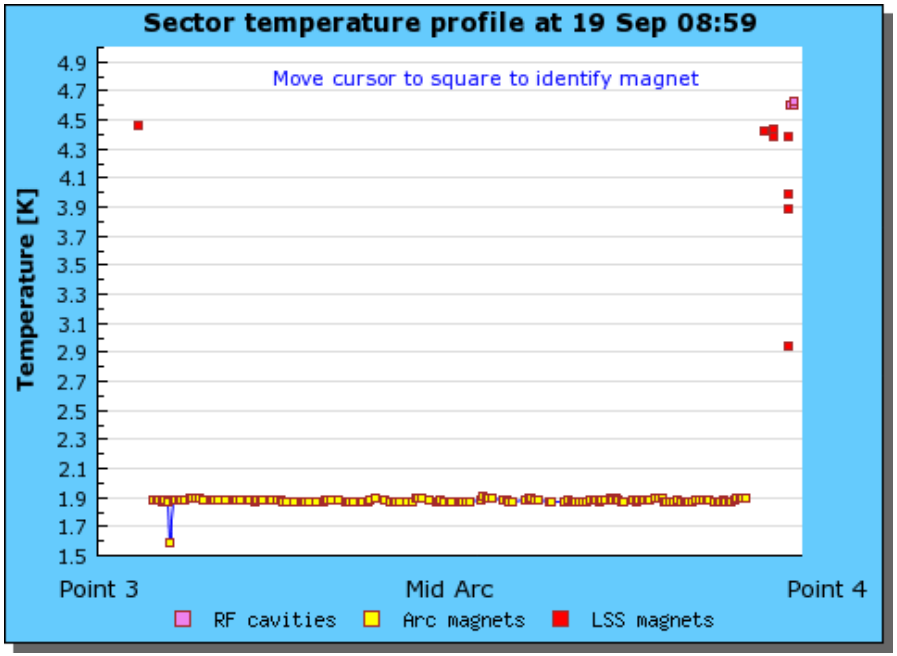




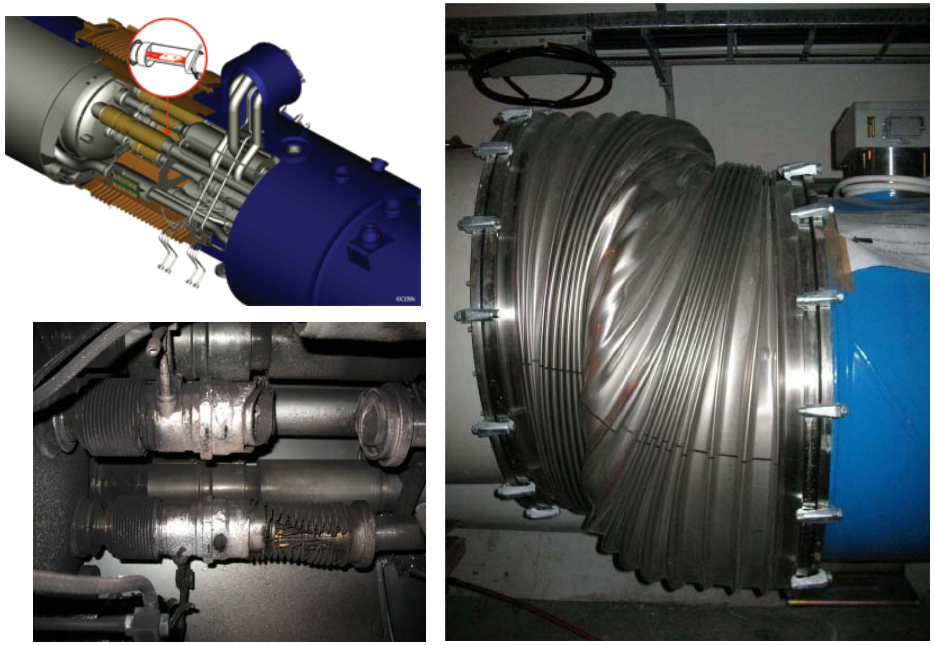
beams in V0s



September 19th 2008: major incident



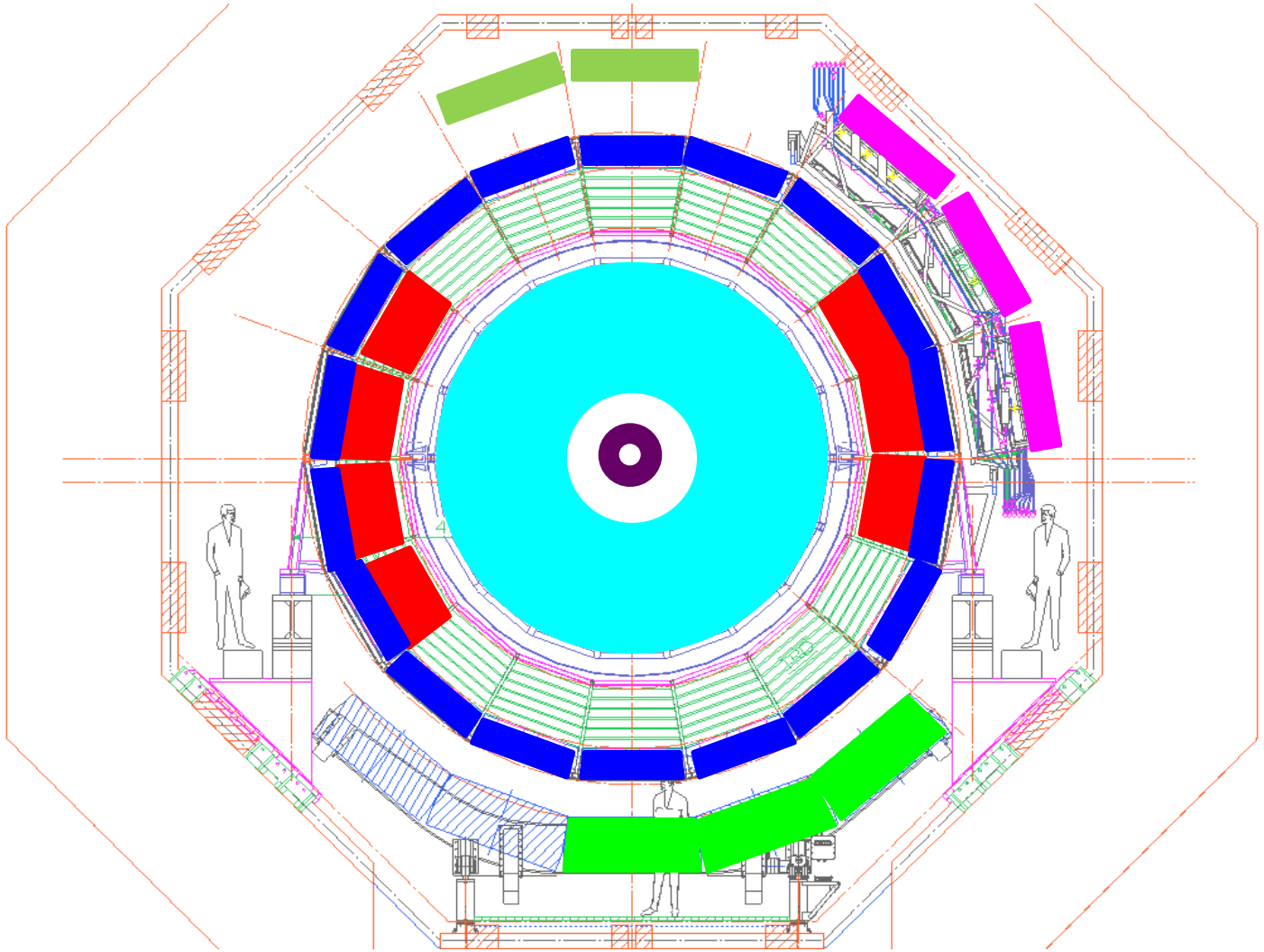
temperature in sector 34



electrical arc between 2 magnets

- important mechanical damage and helium leak
- machine: shutdown for more than a year for repairs
- detectors: commissioning and installation of missing parts

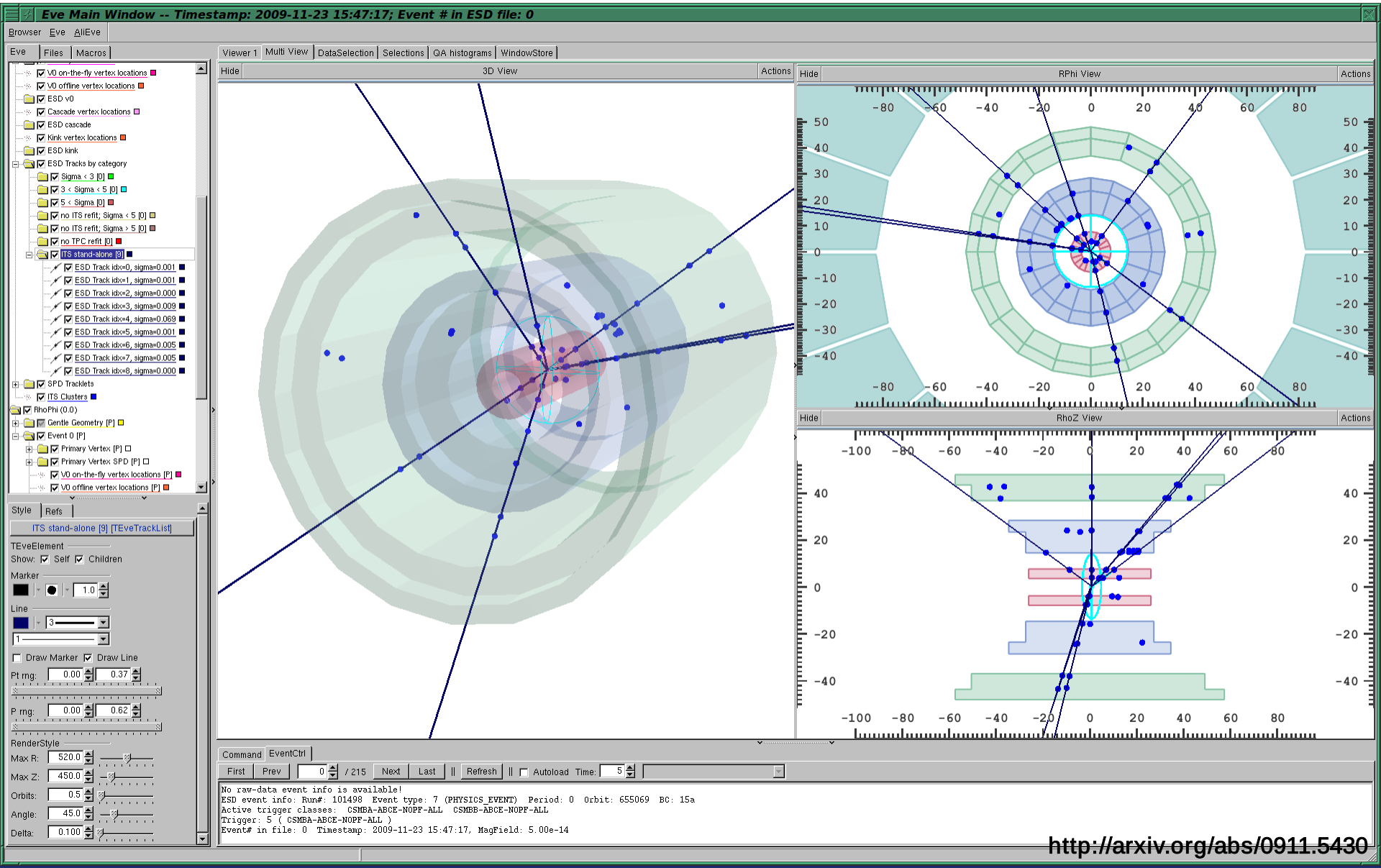
ALICE installation status in November 2009



- full: ITS, TPC, TOF, HMPID, MUON, PMD, FMD, T0, V0, ZDC
- partial: TRD (7/18), PHOS (3/5), EMCAL (4/10)

It works!

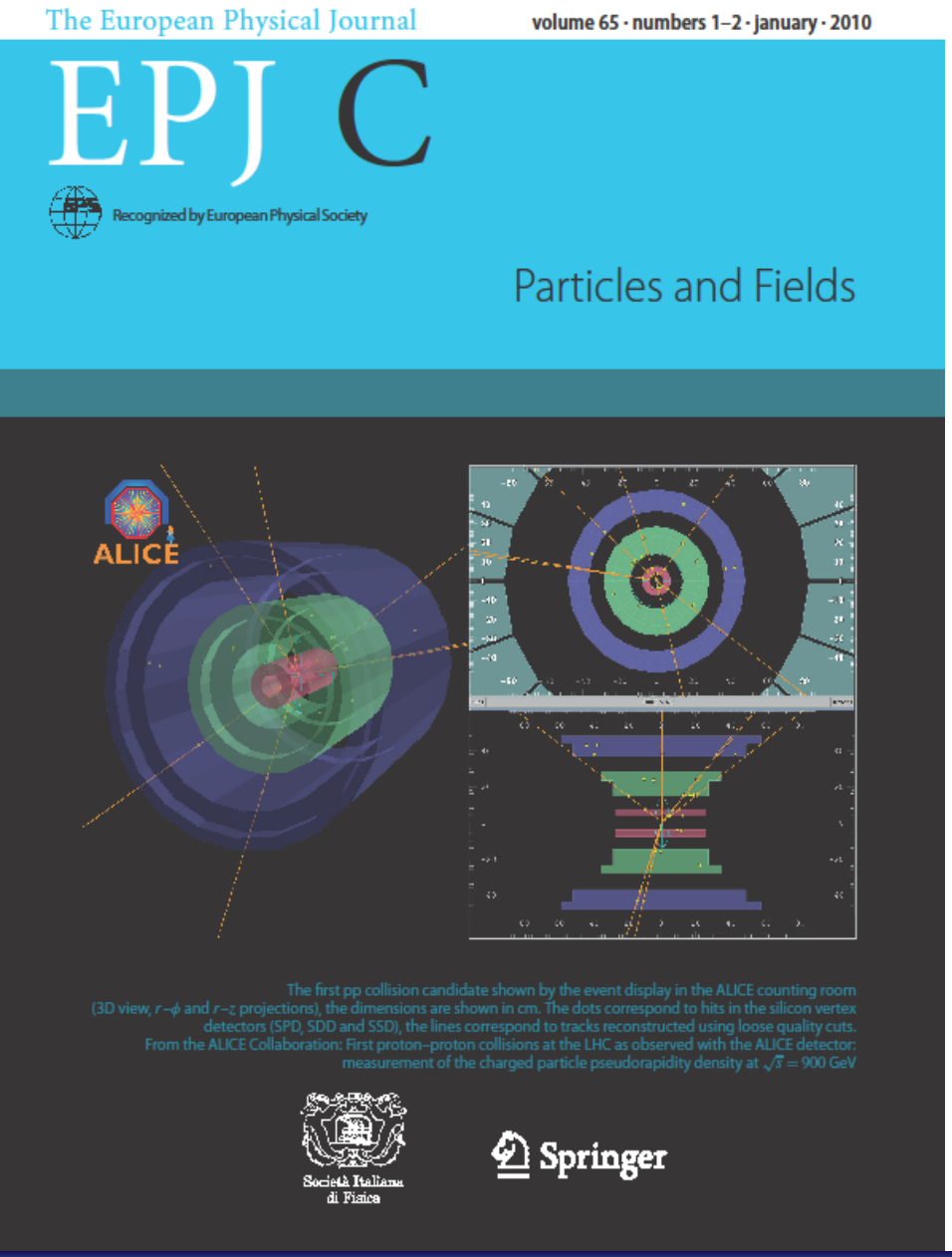
November 23th 2009 16:47, first proton-proton collision



http://arxiv.org/abs/0911.5430

It works!

The first (LHC) ALICE paper

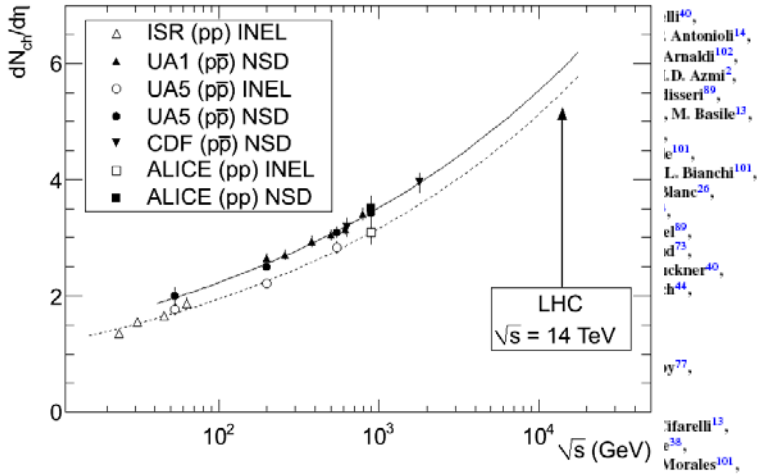


Eur. Phys. J. C (2010) 65: 111–125
DOI 10.1140/epjc/s10052-009-1227-4
THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Experimental Physics

First proton–proton collisions at the LHC as observed with the ALICE detector: measurement of the charged-particle pseudorapidity density at $\sqrt{s} = 900$ GeV

The ALICE Collaboration

K. Aamodt[78], N. Abel[43], U. Abeysekara[30], A. Abrahantes Quintana[42], A. Acero[63], D. Adamová[86], M.M. Aggarwal[25], G. Aglieri Rinella[40], A.G. Agocs[18], S. Aguilar Salazar[66], Z. Ahammed[55], A. Ahmad[2], N. Ahmad[2], S.U. Ahn[50,b], R. [100], A. [68], D. [70], P. [102], A. [65], A. [13], E. [40], V. [14], A. [102], T. [2], S. [89], A. [13], V. [101], B. [26], I. [101], N. [44], F. [89], M. [73], V. [40], B. [44], R. [77], Z. [34], A. [77], E. [13], P. [38], F. [101], Z. [101], T.M. Cormier[34], P. Cortese[1], L. Cortés Maldonado[84], M.R. Cosentino[21], F. Costa[40], M.E. Cotallo[63], E. Crescio[64], P. Crochet[26], E. Cuautle[65], L. Cunqueiro[38], J. Cussonneau[73], A. Dainese[59,d], H.H. Dalsgaard[28], A. Danu[16], I. Das[54], S. Das[54], A. Dash[11], S. Dash[11], G.O.V. de Barros[93], A. De Caro[90], G. de Cataldo[40,n], J. de Cuveland[43,c], A. [19], M. [44], J. [40], D. [90], A.P. de Haas[106], N. [102], R. [105]



- data taken on Nov. 23th
  (284 events in 43 minutes)
- paper submitted on Nov. 28th
- paper accepted on Dec. 1st

http://arxiv.org/abs/0911.5430

Short summary

ALICE is fully operational and has already taken (and published) proton-proton data

Plans for 2010:

- **LHC restarts in February with proton beams**
- **first heavy-ion beams in November**