Studying QCD with ALICE

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INFN Padova & CERN

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  - QCD and ultrarelativistic nucleus-nucleus collisions
  - signals from the SPS and RHIC
- Views from the ALICE experiment
  - set-up
  - commissioning
- Expected physics capabilities: an example
  - heavy flavour quenching
- Conclusion

Two puzzles in QCD

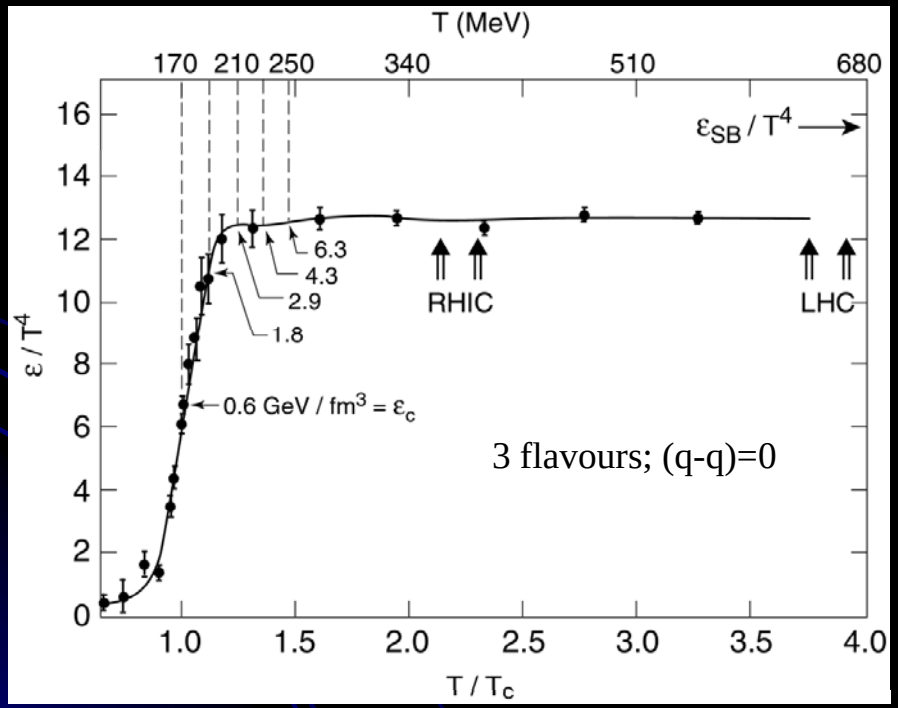
- quark confinement
  - one half of fundamental fermions are not observable...
- generation of hadron masses
  - 3 × m(u,d) ~ 12 MeV $\leftrightarrow$ m(proton) = 938 MeV

  $\rightarrow$ generally thought to be related

- With ultrarelativistic nucleus-nucleus collisions we hope to be able to access experimentally the phenomenology of confinement ←→ deconfinement

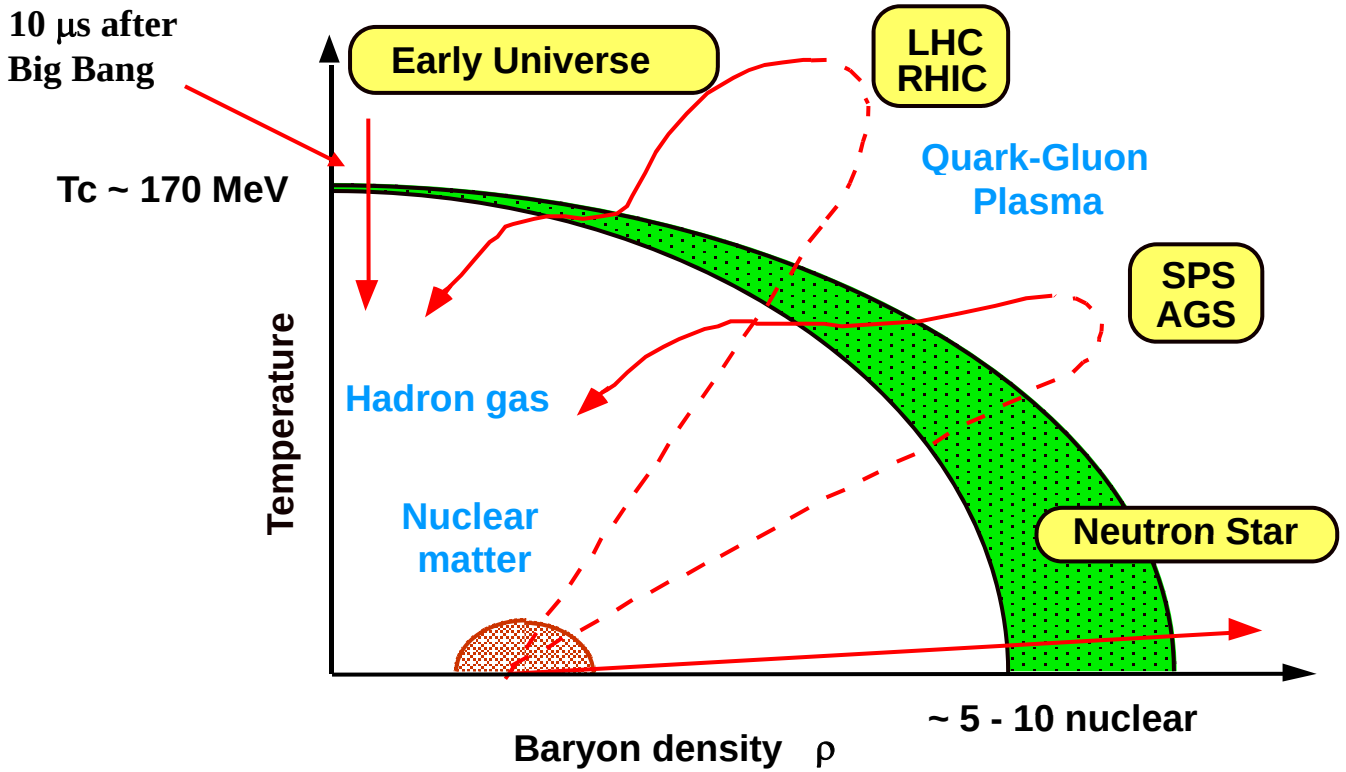
Lattice QCD

- In lattice QCD, non-perturbative problems are treated by discretization on a space-time lattice. As a result, ultraviolet (large momentum scale) divergencies can be avoided



- zero baryon density, 3 flavours
- ε changes rapidly around T_c
- T_c = 170 MeV:
  $\rightarrow \varepsilon_c$ = 0.6 GeV/fm^3
- at $T \sim 1.2\ T_c$ ε settles at about 80% of the Stefan-Boltzmann value for an ideal gas of $q, \bar{q}\ g$ (ε_{SB})

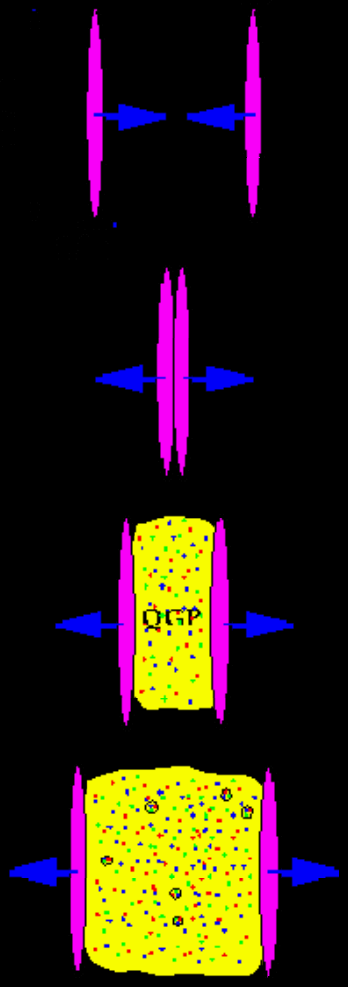
QCD phase diagram



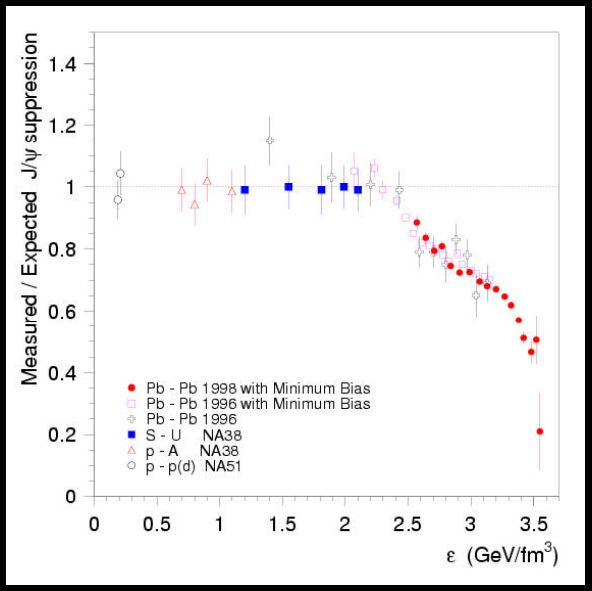
$\varepsilon_c \sim 1\ \mathrm{GeV/fm^3}$

Nucleus-nucleus collisions

- How do we test this in the lab?
- How can we compress/heat matter to such cosmic energy densities?
- By colliding two heavy nuclei at ultrarelativistic energies we hope to be able to recreate, for a short time span (about 10^{-23}s, or a few fm/c) the appropriate conditions for deconfinement

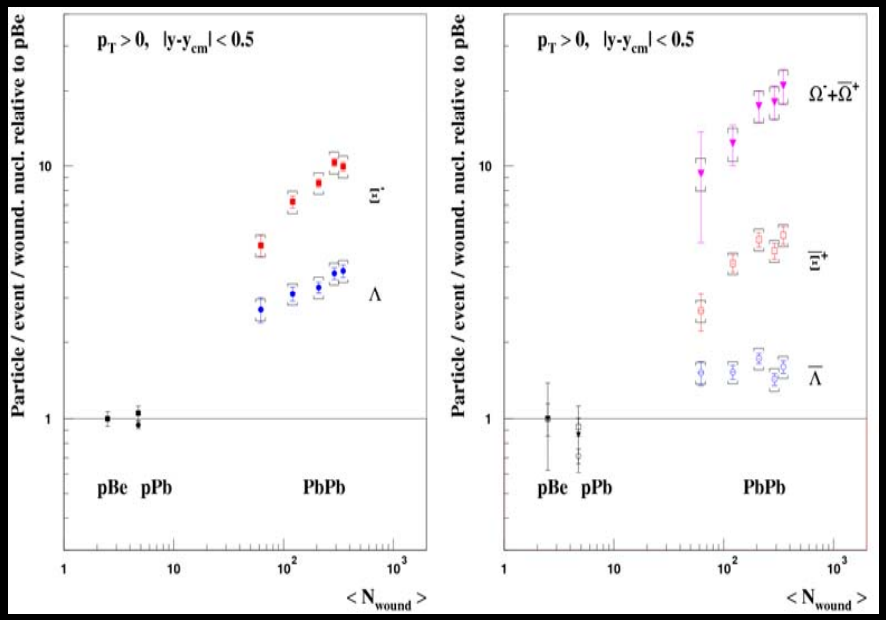


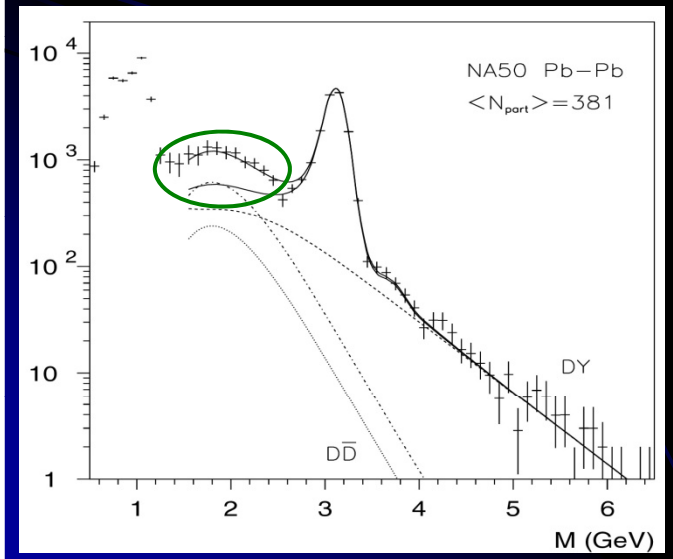
SPS: the "historic" signals



- J/ψ suppression
  NA50, NA60

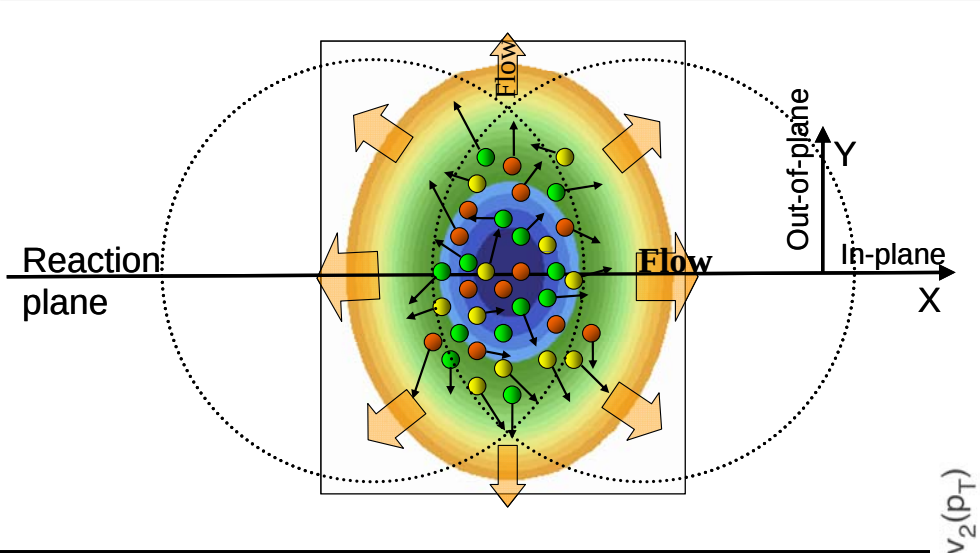
- Hyperon enhancements
  WA97, NA49, NA57





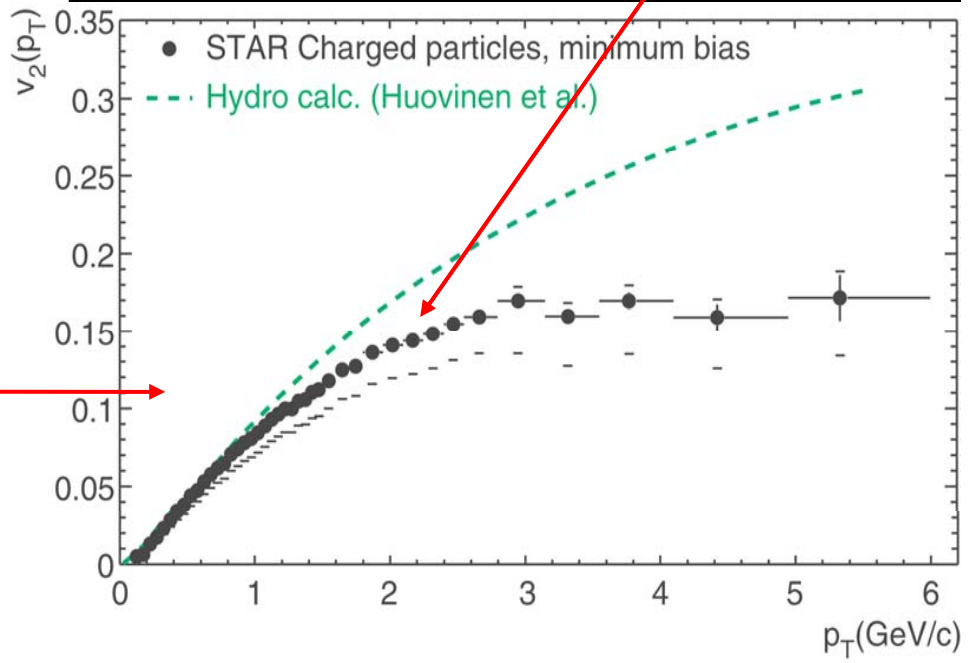
- excess dileptons
  NA38, NA45, NA50, NA60

RHIC: "Perfect Liquid"?



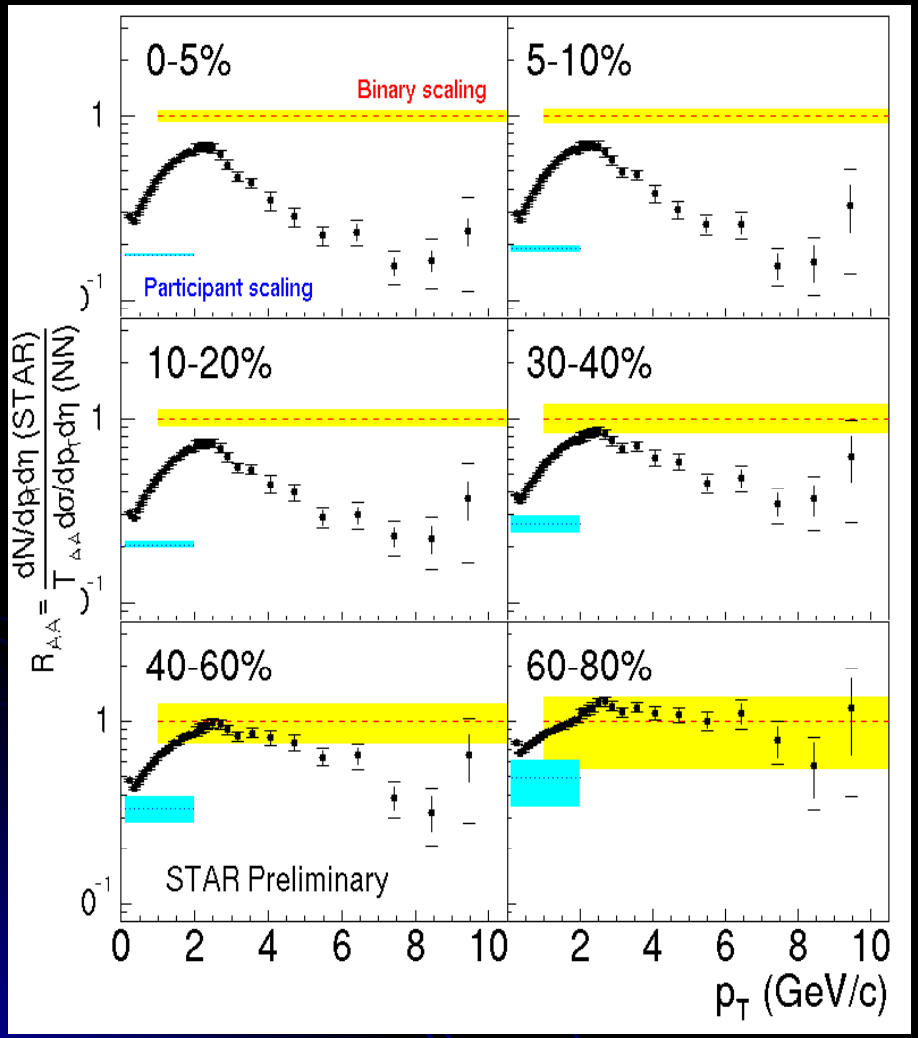
- Transfer of spatial asymmetry to momentum space provides a measure of the strength of collective phenomena

$$\frac{dN}{p_T dp_T dy d\varphi} = \frac{1}{2\pi}\frac{dN}{p_T dp_T dy}\left(1 + 2v_1\cos(\varphi) + 2v_2\cos(2\varphi) + \ldots\right)$$



- at low p_T: azimuthal asymmetry as large as expected at hydro limit

RHIC: High p_T suppression



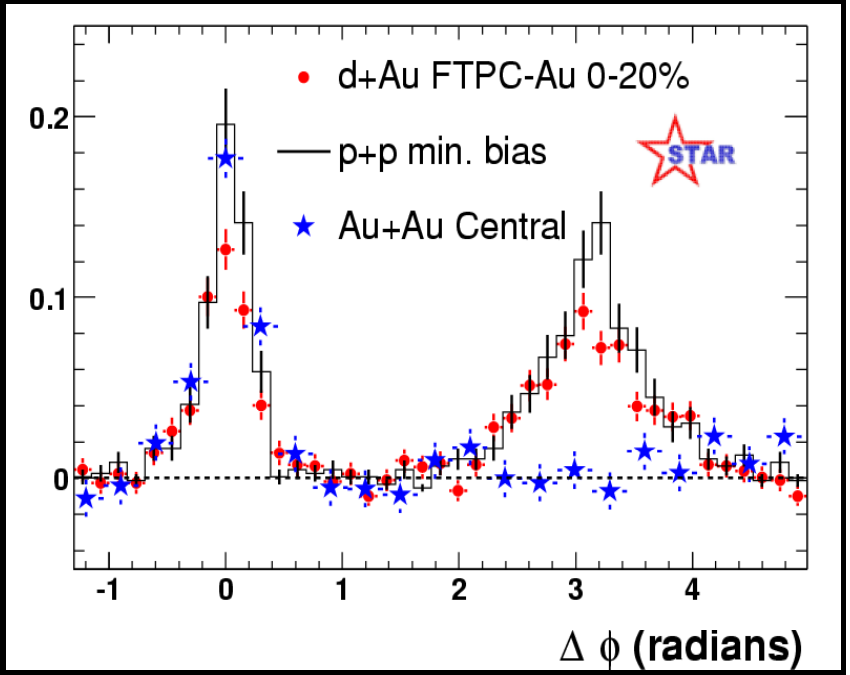
$$R_{AA} = \frac{\text{Yield}_{AA}}{\text{Yield}_{pp}} \cdot \frac{1}{\langle Nbin \rangle_{AA}}$$

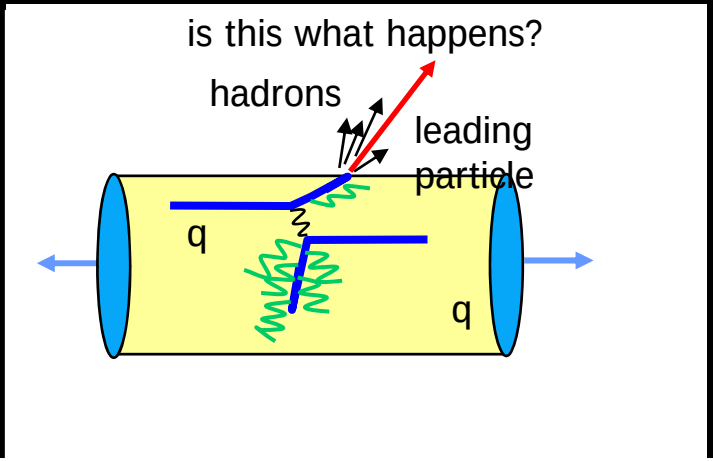
- High p_T particle production expected to scale with number of binary NN collisions if no medium effects
- Clearly does not work for more central collisions
- Interpretation: energy loss

RHIC: Azimuthal Correlations

- STAR:
  - "trigger" particle: $4 < p_T < 6$ GeV/c
  - associated particles: $p_T > 2$ GeV/c
- away-side jet still present in dAu
- but disappears in central AuAu
- away-side jet "quenched"?

Adams *et al.*, Phys. Rev. Let. 91 (2003)





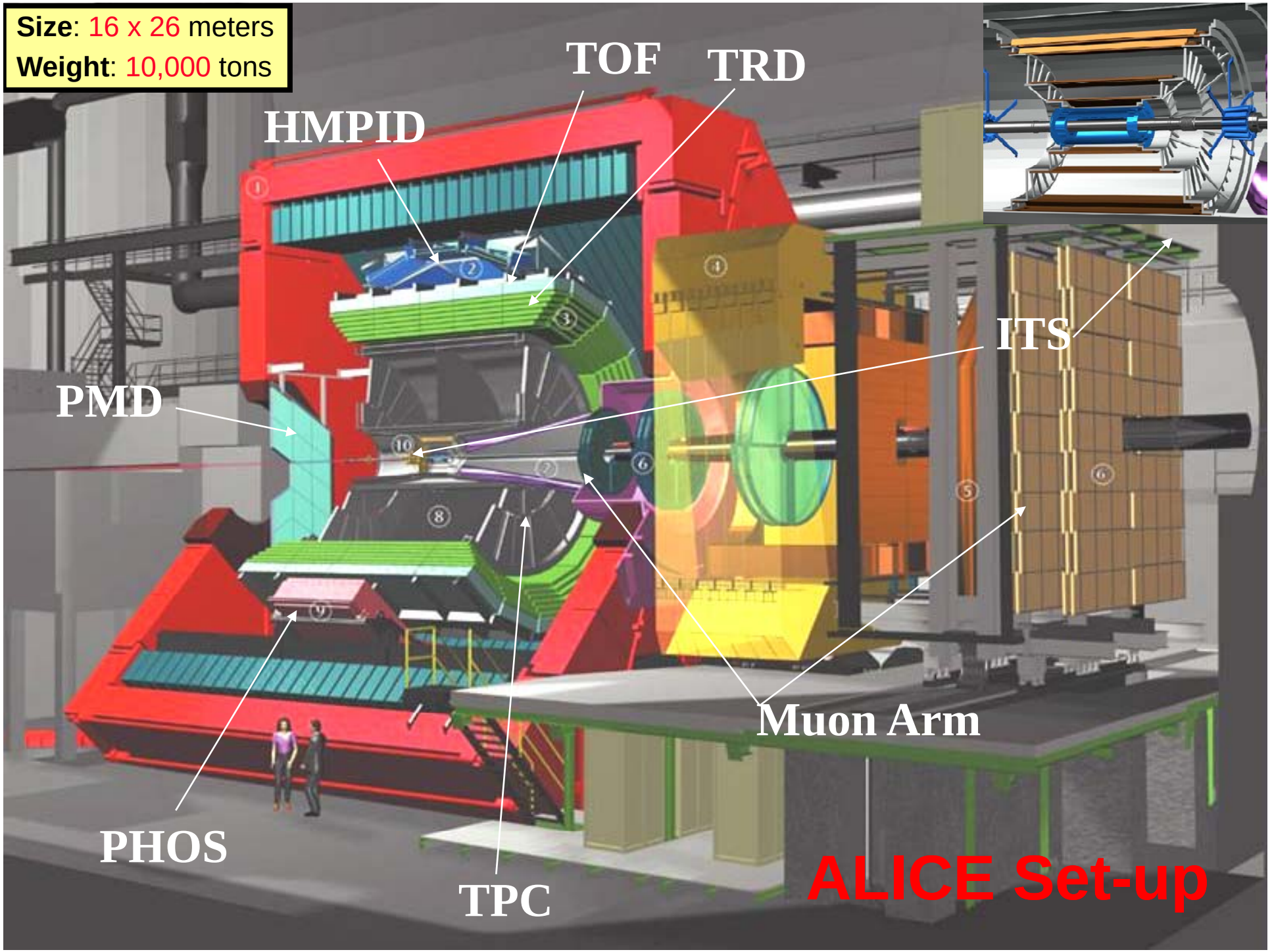
So, where do we stand?

- SPS (1994 – 2003)
  - first evidence: "historic" QGP signatures
    - strangeness enhancement
    - J/ψ suppression

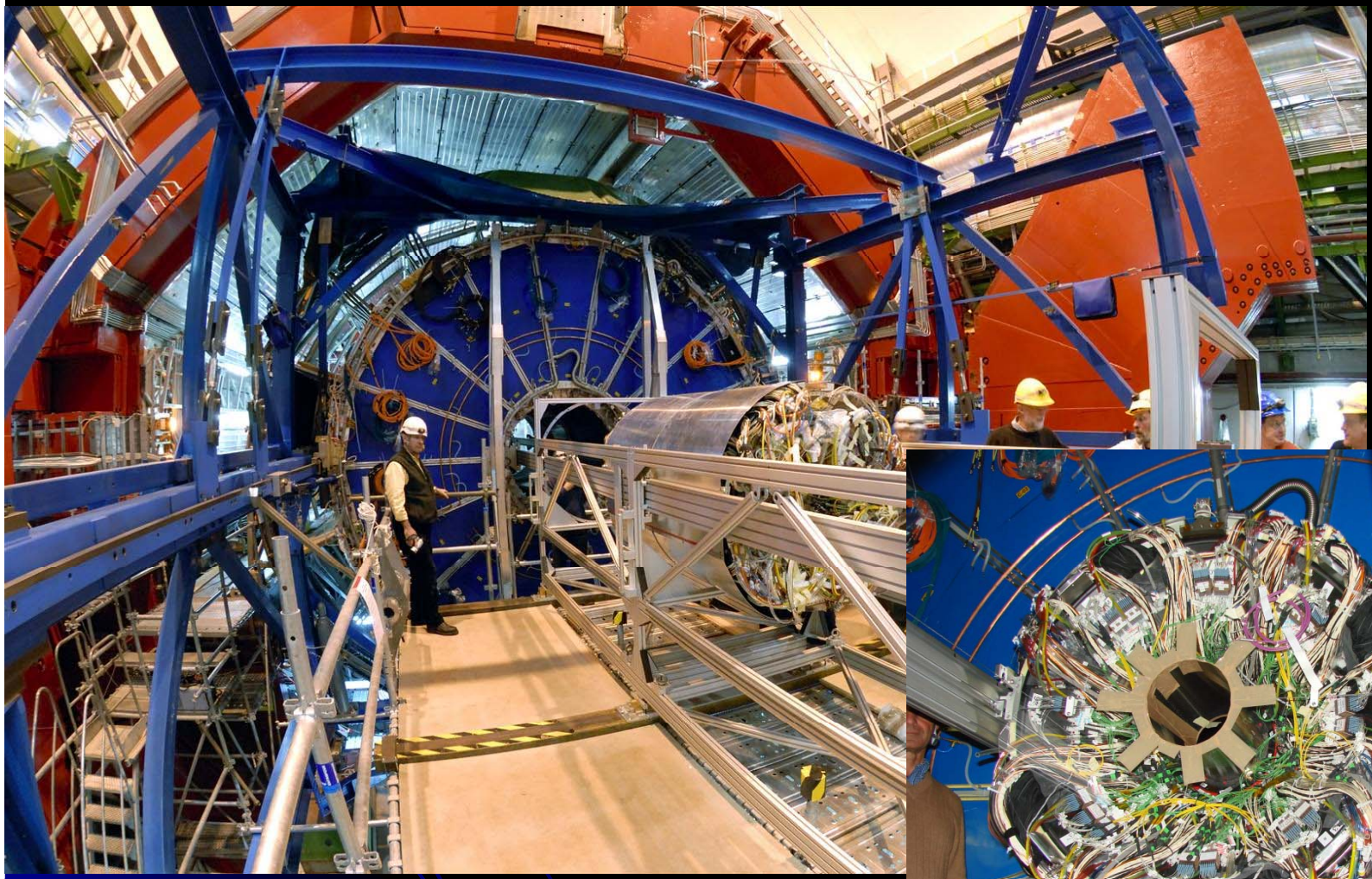
- RHIC (2000 – now)
  - system close to ~ ideal hydrodynamic behaviour
  - evidence of interaction of fast partons with medium → quenching

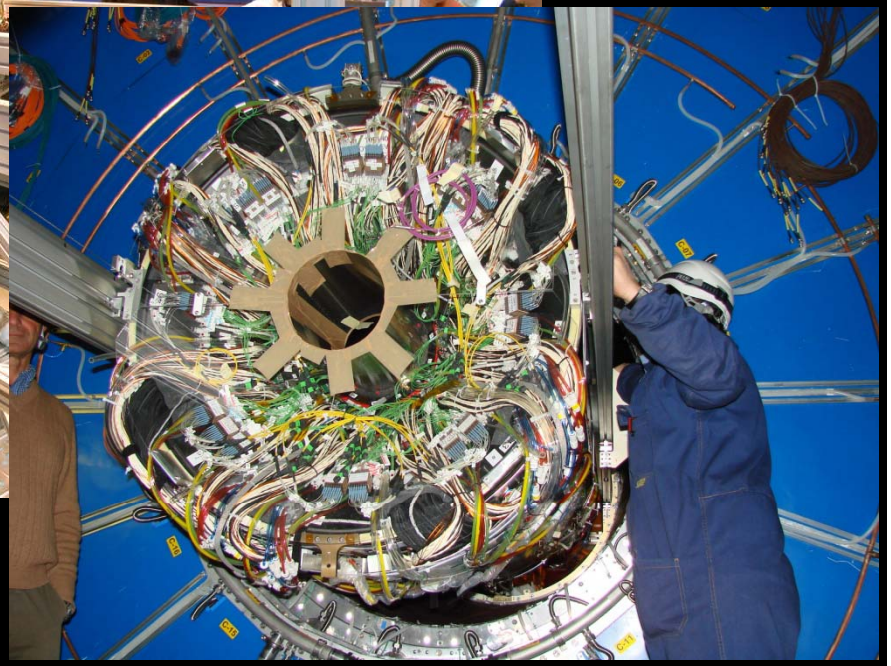
The next step

- LHC
  - study the properties of the medium with "calibrated", calculable hard probes
    - → heavy flavours, jets, …

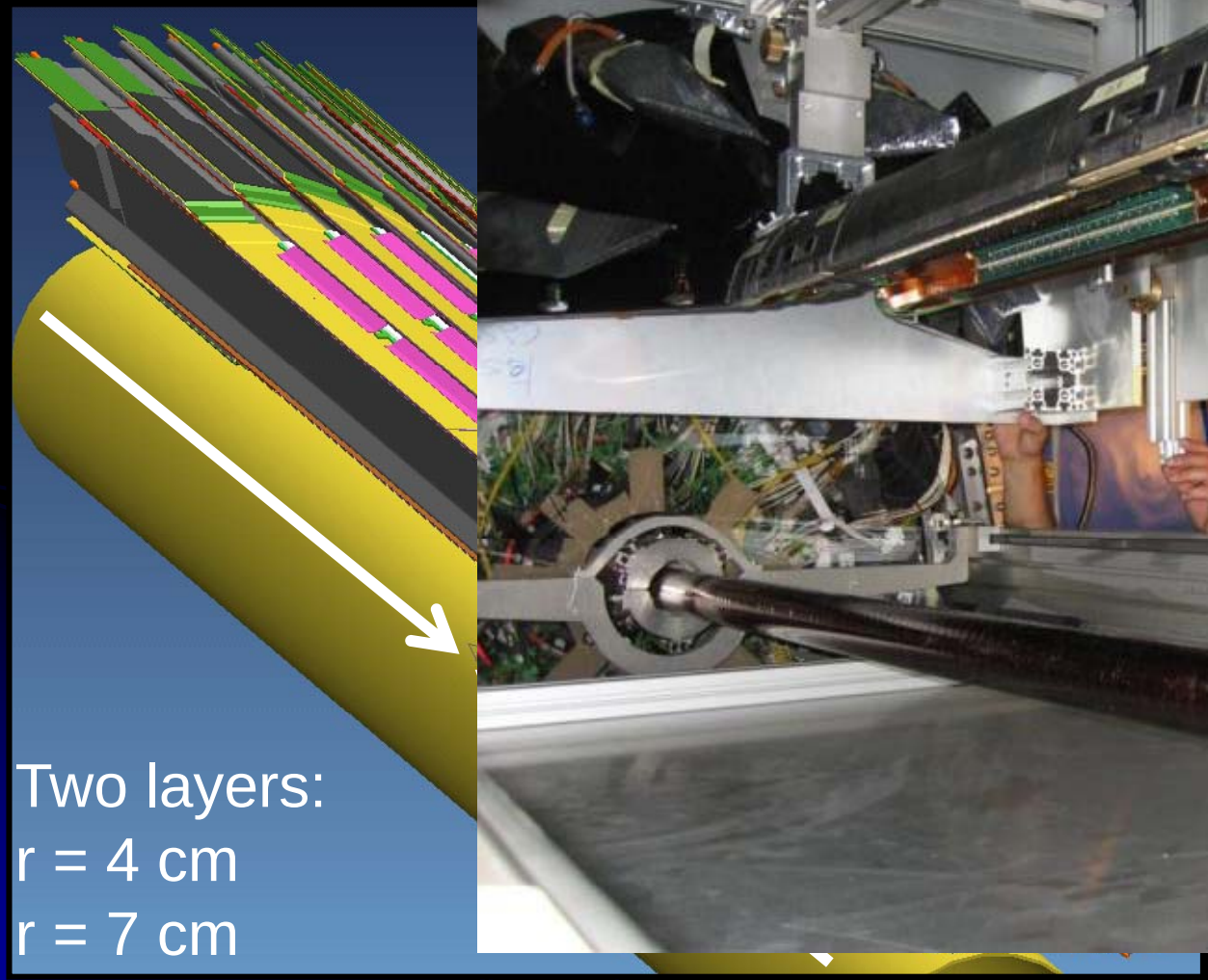

Size: 16 x 26 meters
Weight: 10,000 tons
TOF
TRD
HMPID
ITS
PMD
Muon Arm
PHOS
TPC
ALICE Set-up

ITS and TPC

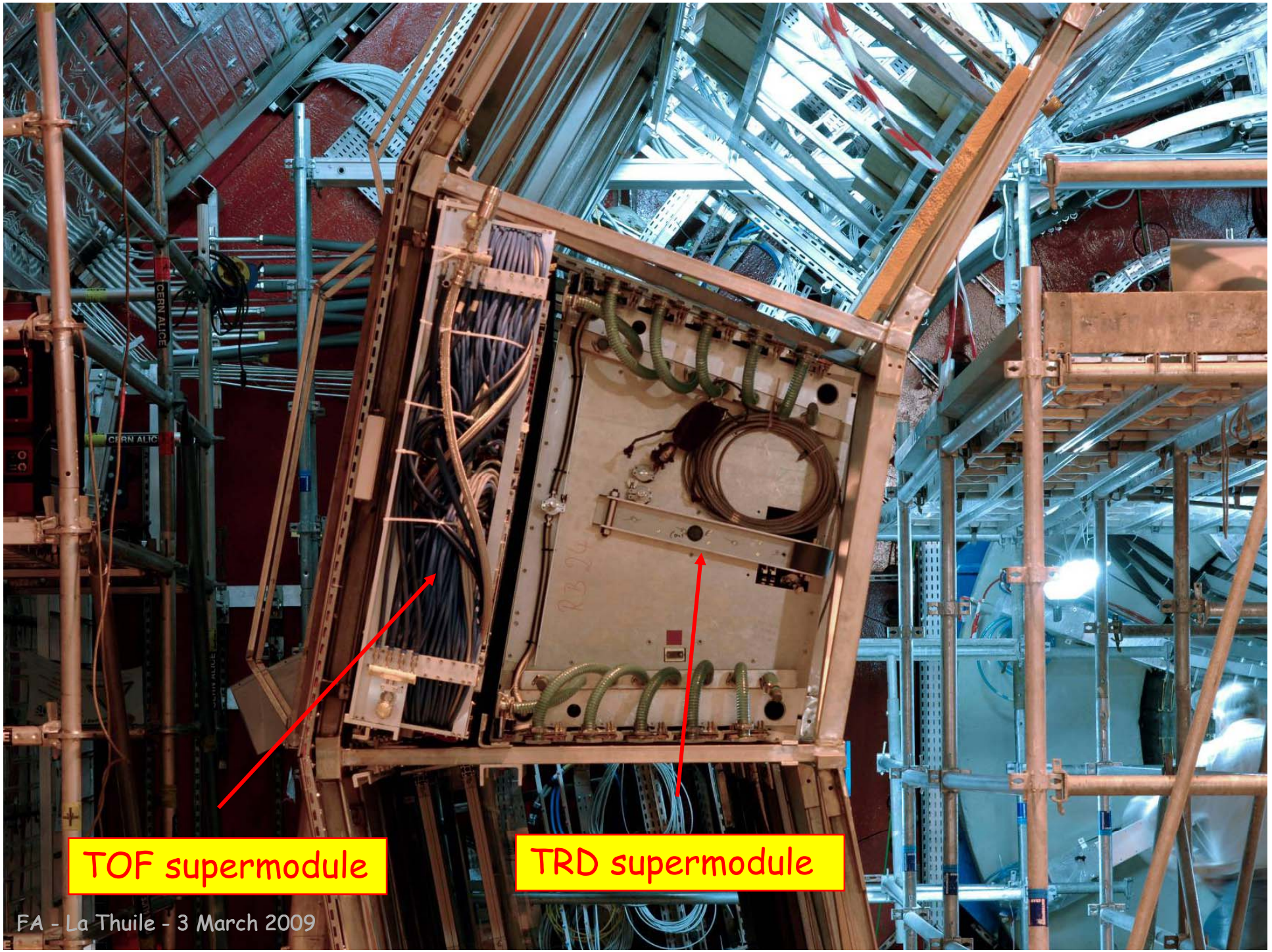


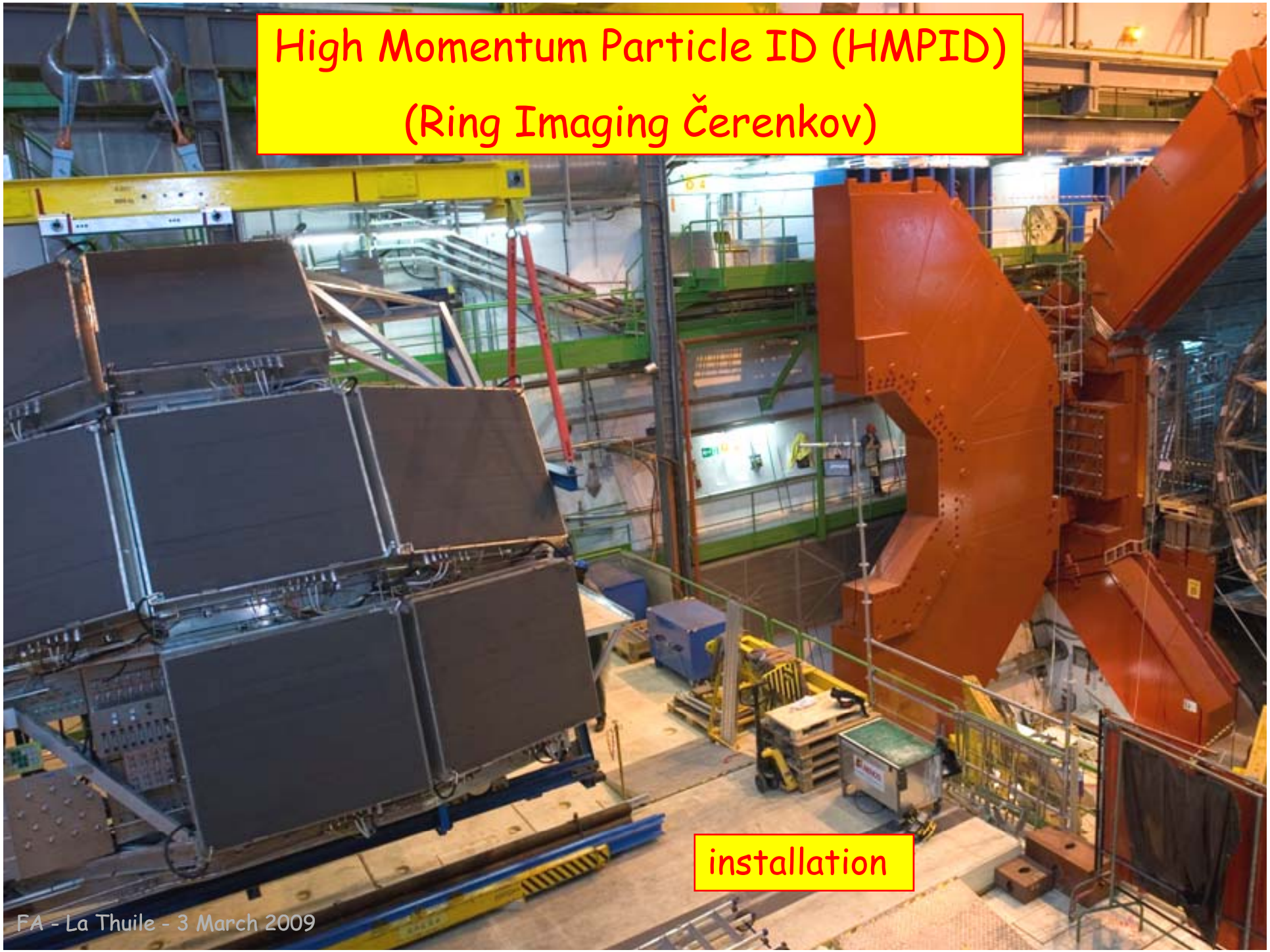


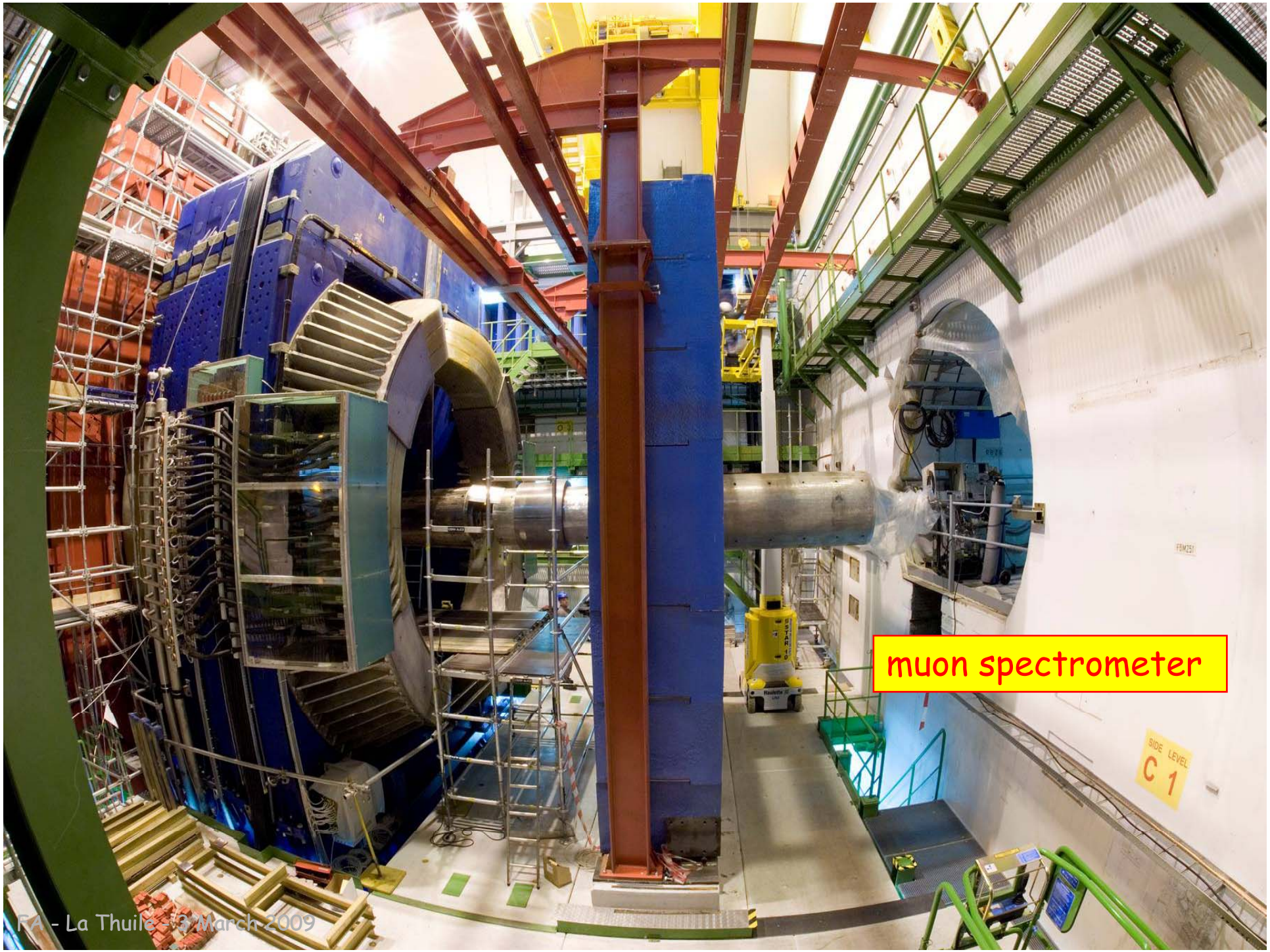
Silicon Pixel Detector (SPD)



Two layers:
r = 4 cm
r = 7 cm

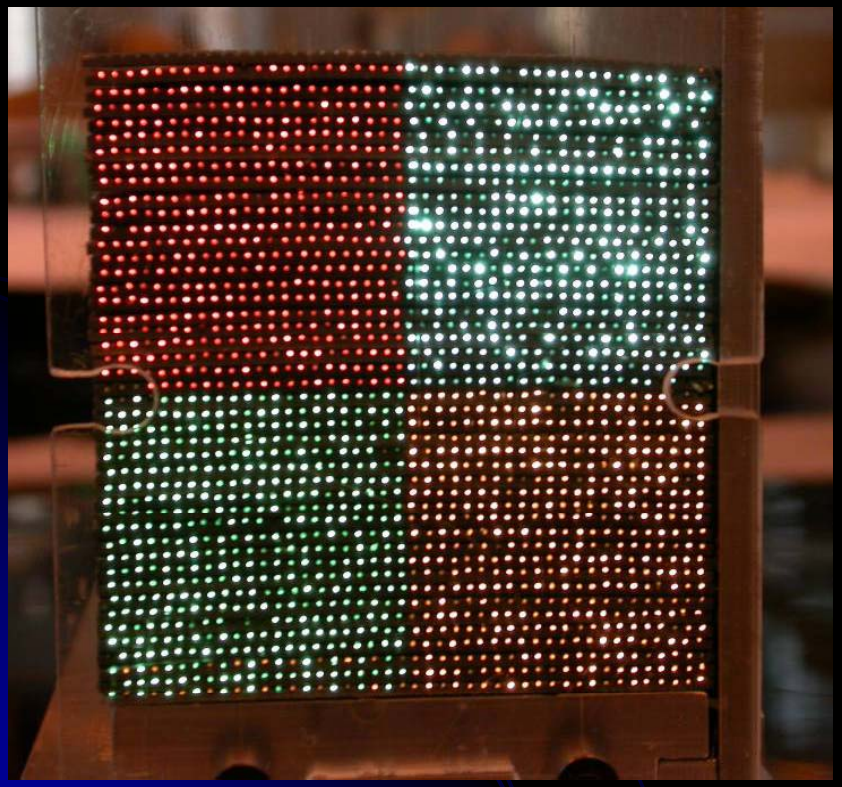

TOF supermodule
TRD supermodule

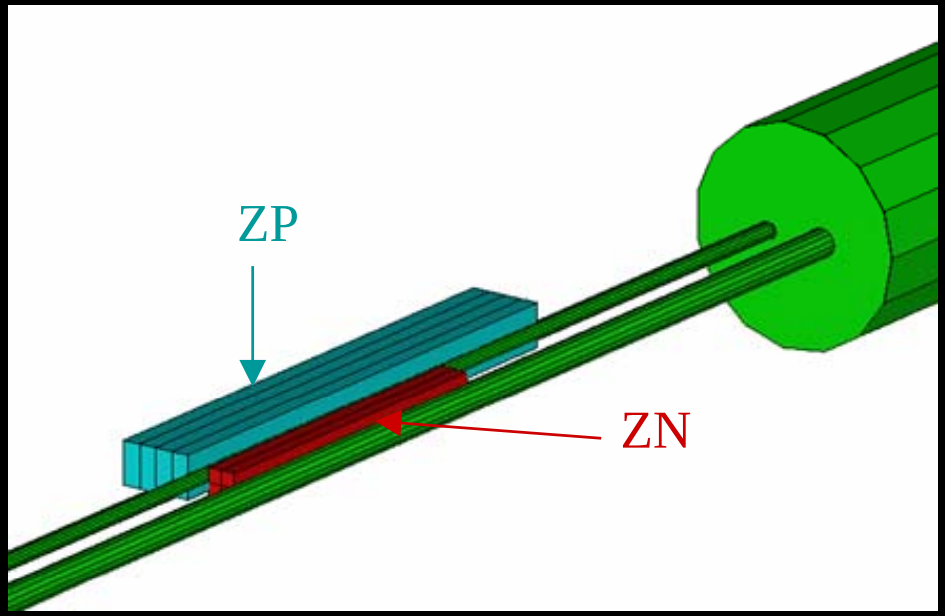

High Momentum Particle ID (HMPID)
(Ring Imaging Čerenkov)
installation


muon spectrometer
SIDE LEVEL
C 1

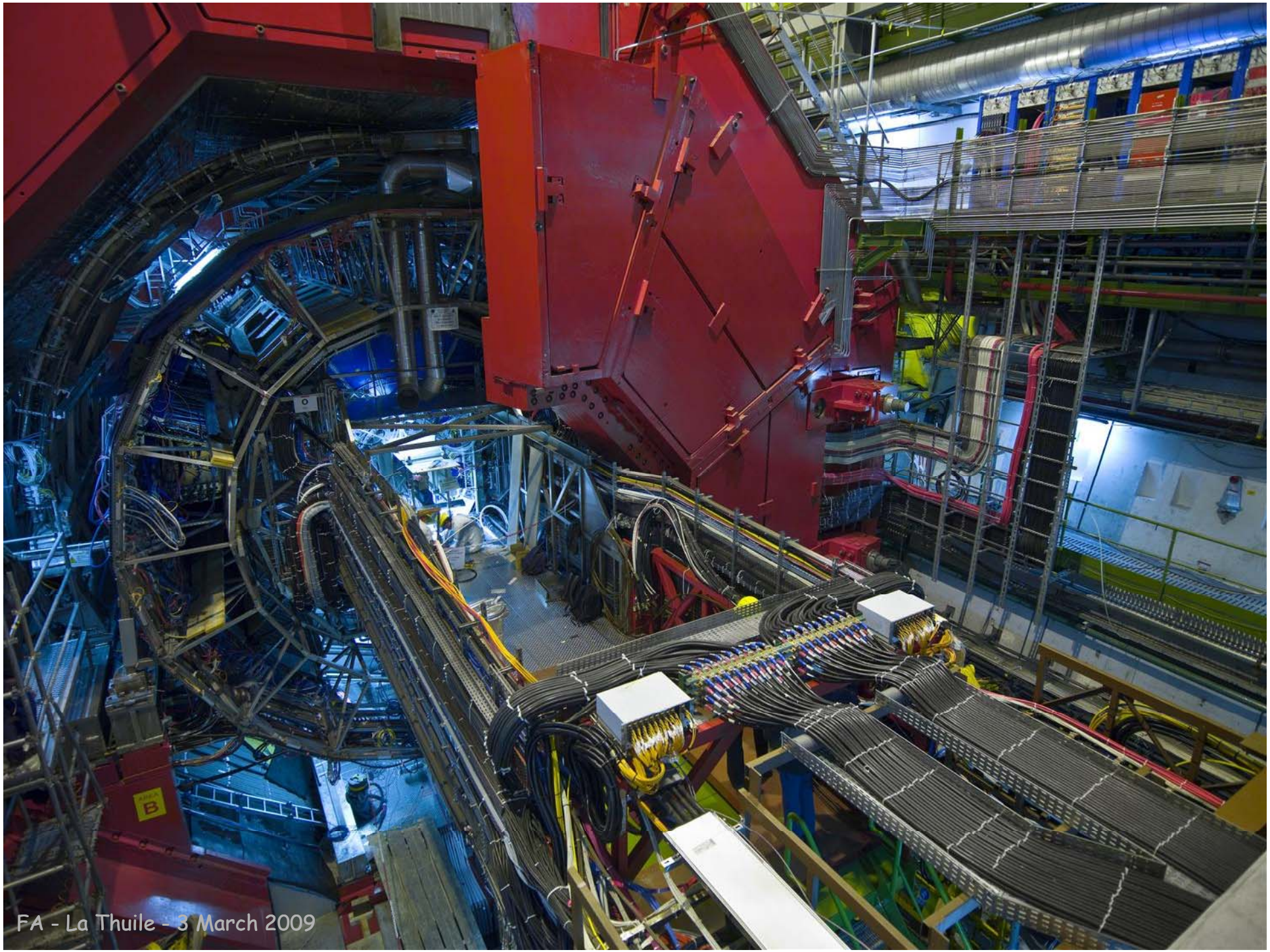
Zero Degree Calorimeters (ZDC)

6 calorimeters:
8 m (EM) and 116 m (ZP, ZN)
from IP





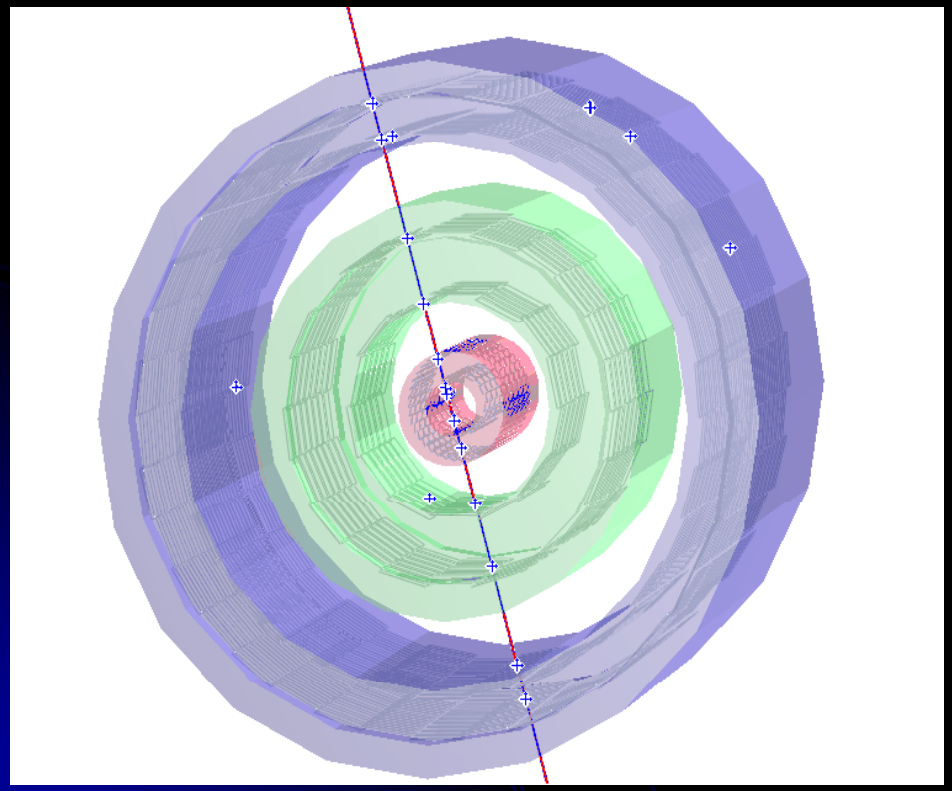
trigger on spectators
measurement of v1
grey, black tracks in pA



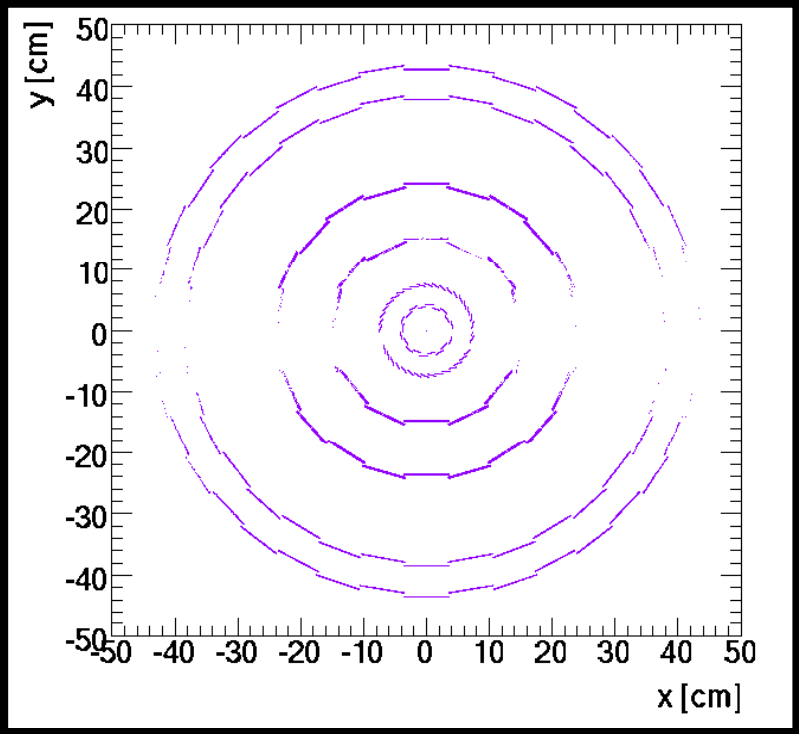
FA - La Thuile - 3 March 2009

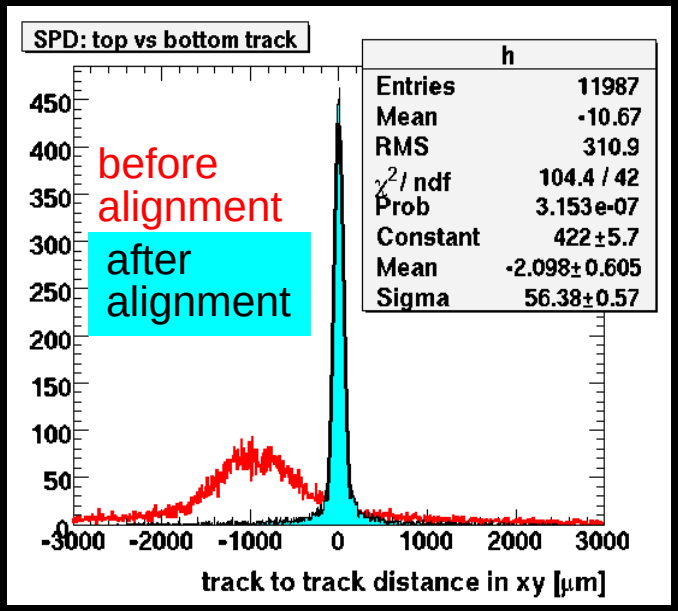
Alignment of the ALICE ITS

- 2200 volumes → 13k degrees of freedom
  - Millepede, "hierarchical" alignment
- ~ 50 k cosmic events (SPD trigger ~ 0.1 Hz)

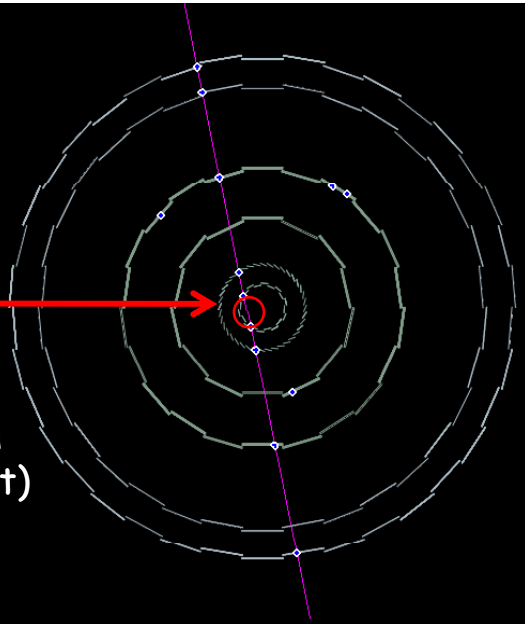


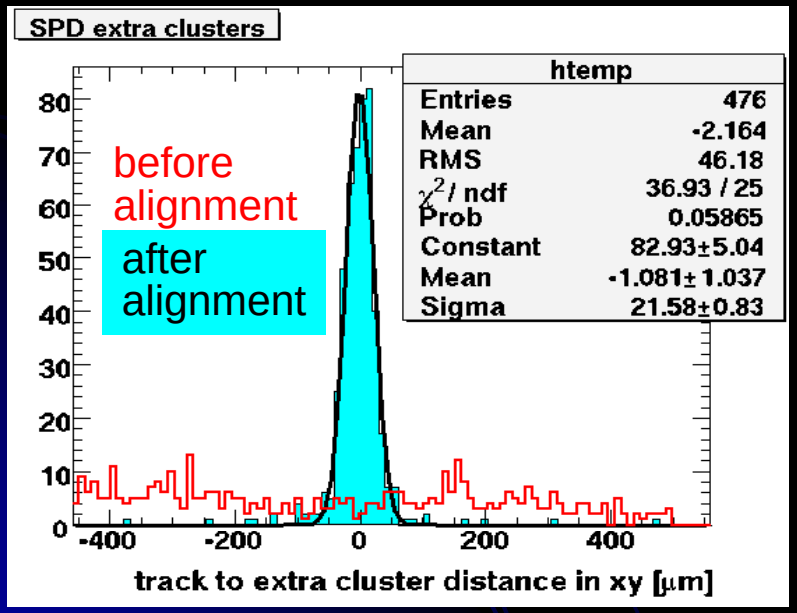
Hit distribution in the 6 layers of the ITS



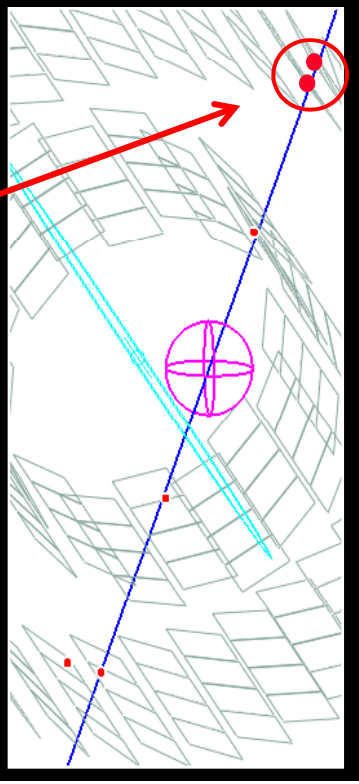


- Distance between upper and lower track segments
  - σ = 56 μm
  - (40 μm in simulation with no misalignment)

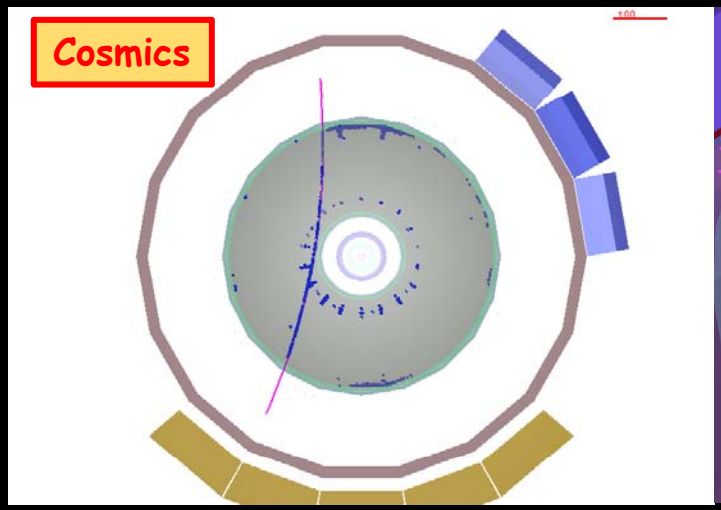


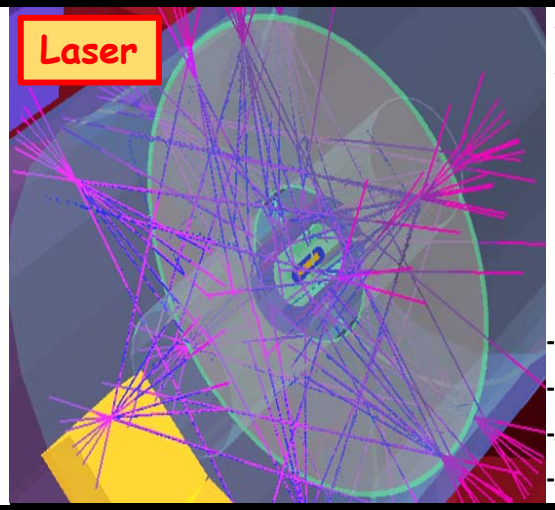


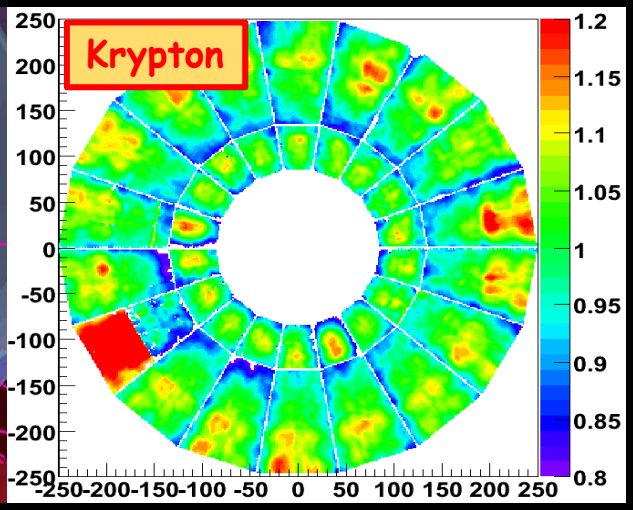
- Distance between hit and track in the overlap region
  - σ = 22μm
  - (15 μm μm in simulation with no misalignment)

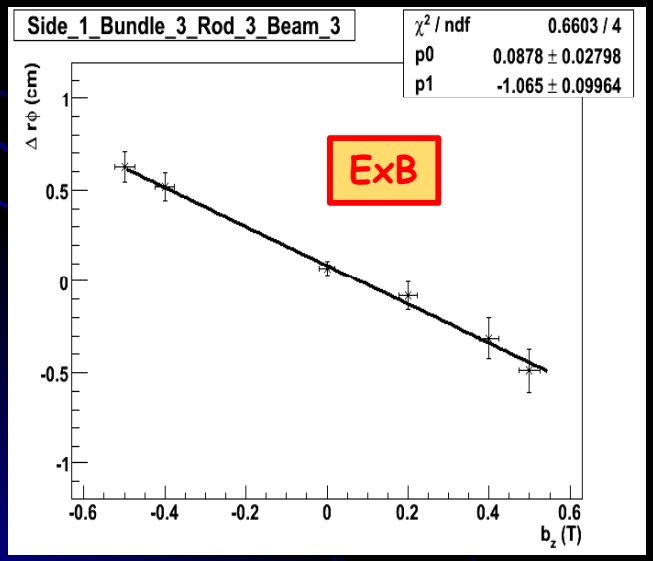


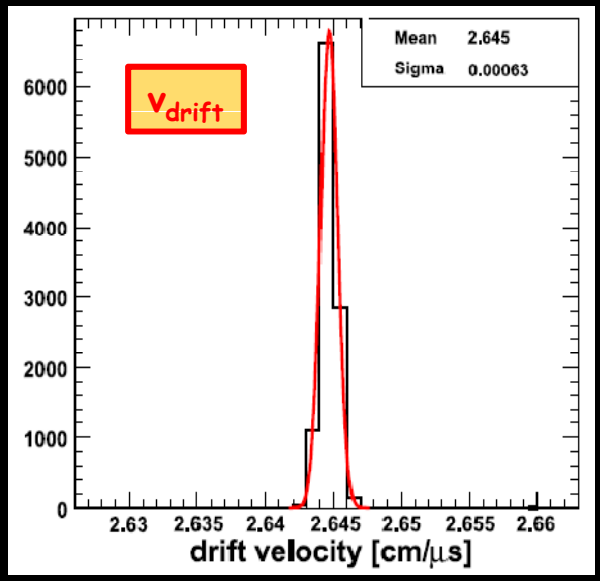
ALICE TPC


Cosmics


Laser

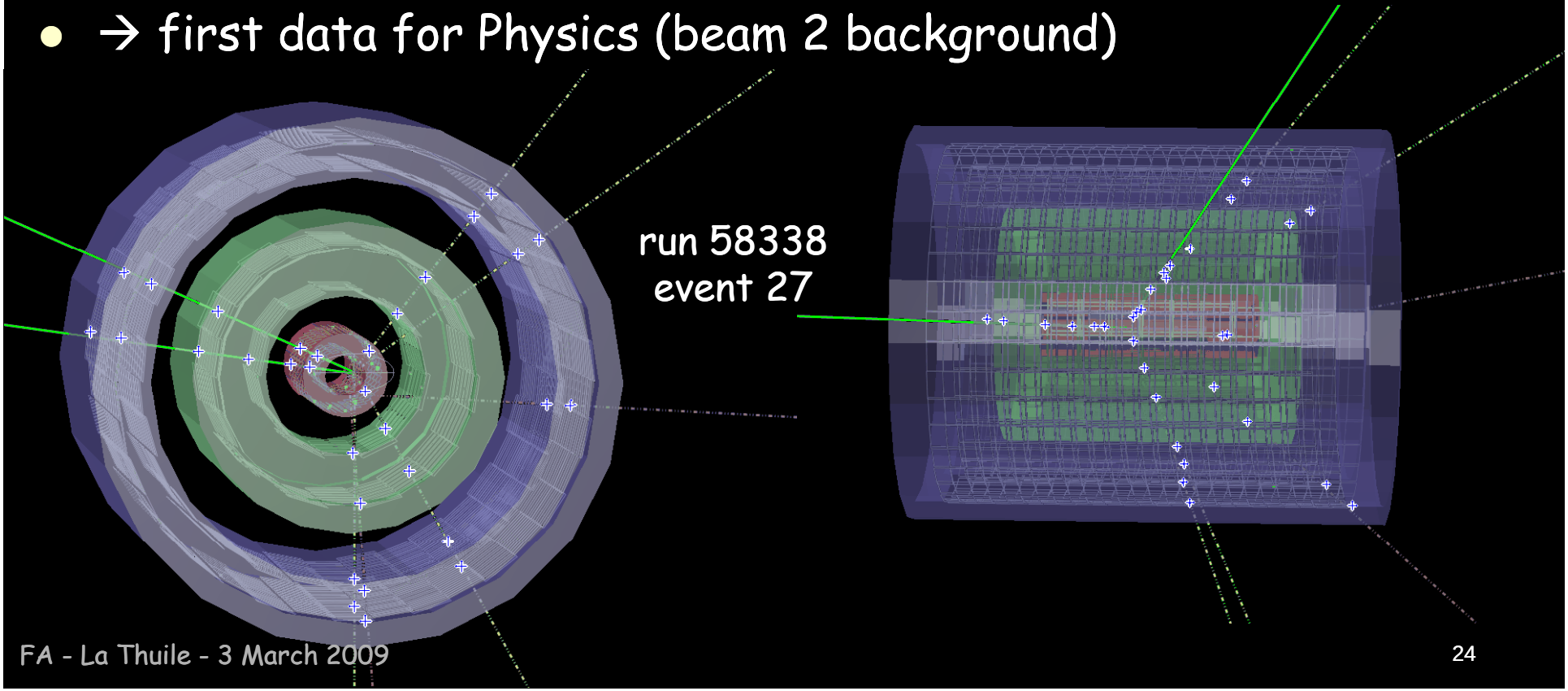

Krypton
250
200
150
100
50
0
-50
-100
-150
-200
-250
-250-200-150-100 -50 0 50 100 150 200 250
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8


Side_1_Bundle_3_Rod_3_Beam_3
χ² / ndf 0.6603 / 4
p0 0.0878 ± 0.02798
p1 -1.065 ± 0.09964
ExB
Δ rφ (cm)
1
0.5
0
-0.5
-1
-0.6 -0.4 -0.2 0 0.2 0.4 0.6
b_z (T)


Mean 2.645
Sigma 0.00063
V_drift
6000
5000
4000
3000
2000
1000
0
2.63 2.635 2.64 2.645 2.65 2.655 2.66
drift velocity [cm/μs]

11 September 2008: RF capture (first data for Physics!)

- 11 September 2008, ~ 22:35 first capture
  - beam 2 kept in orbit for over 10 minutes!
- series of injections with tens of mins RF capture during night
  - in ALICE: 673 events in total
- → first data for Physics (beam 2 background)

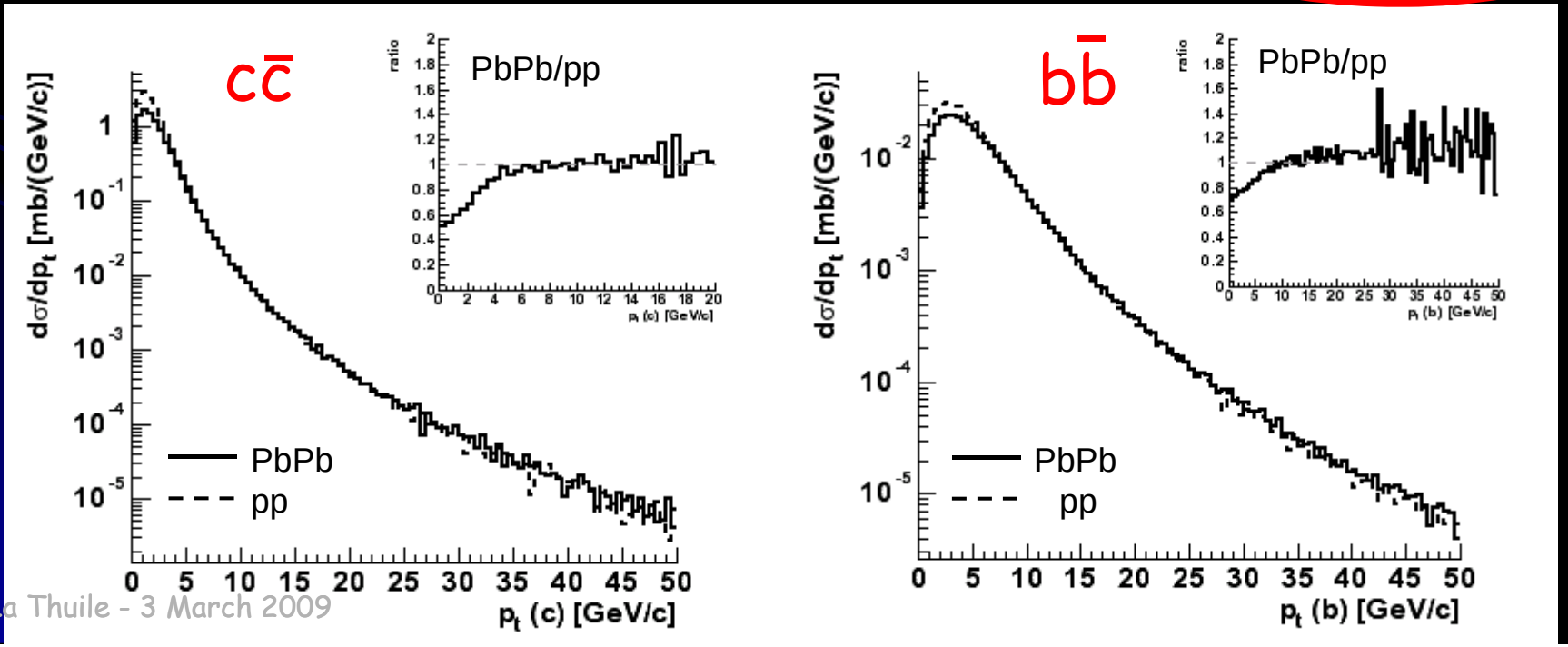


Expected Physics Capabilities an example: heavy flavours

LHC is a Heavy Flavour Machine!

- $c\bar{c}$ and $b\bar{b}$ rates
  - ALICE PPR (NTLO + shadowing)

system	NN x-sect (mb)	shadowing	total multiplicity
pp 14 TeV	11.2 / 0.5	1 / 1	0.16 / 0.007
Pb-Pb 5.5 TeV (5% cent)	6.6 / 0.2	0.65 / 0.85	115 / 4.6



Parton Eloss by gluon radiation

$$\langle \Delta E \rangle \propto \alpha_s C_R \hat{q} L^2$$

average energy loss

Casimir coupling factor

transport coefficient of the medium

distance travelled in the medium

→ R.Baier et al., Nucl. Phys. **B483** (1997) 291 ("BDMPS")

Energy loss for heavy flavours is expected to be reduced:

i) Casimir factor

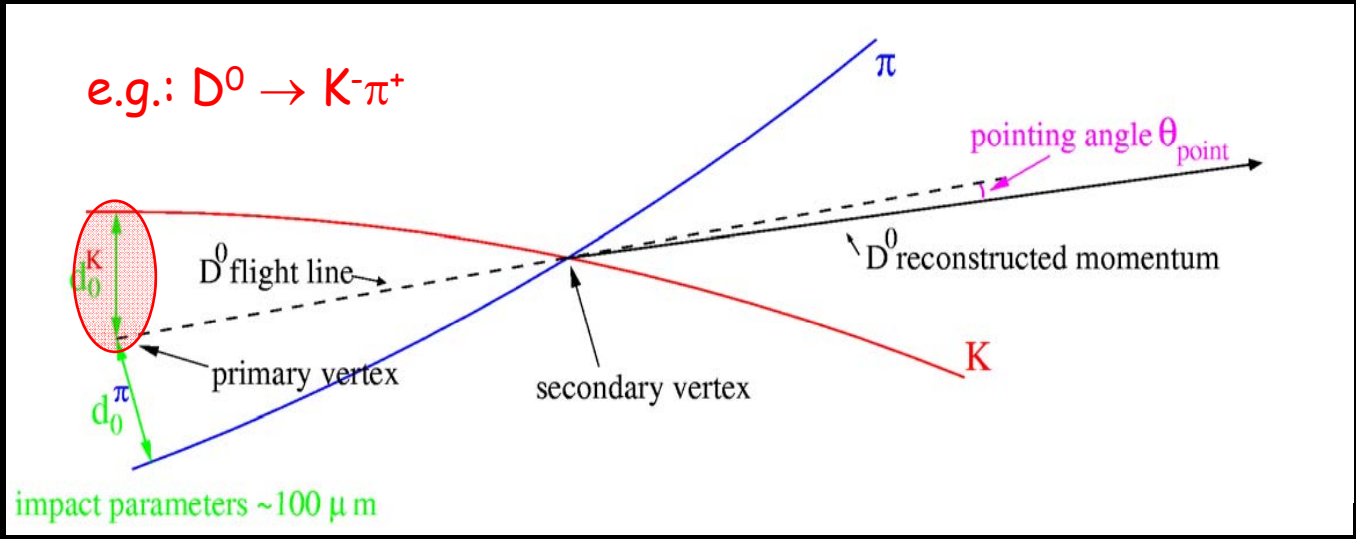
- light hadrons originate predominantly from gluon jets, heavy flavoured hadrons originate from heavy quark jets
- C_R is 4/3 for quarks, 3 for gluons

ii) dead-cone effect

- gluon radiation expected to be suppressed for $\theta < M_Q/E_Q$

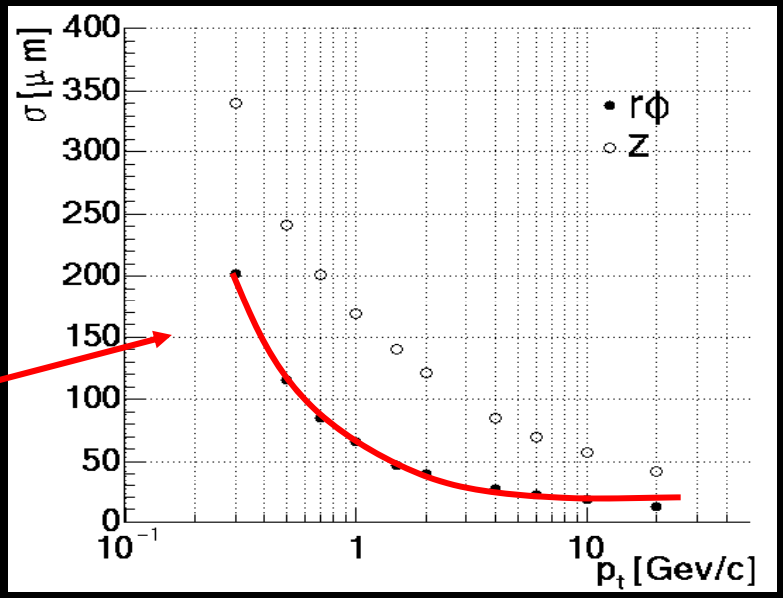
  [Dokshitzer & Karzeev, Phys. Lett. **B519** (2001) 199]
  [Armesto et al., Phys. Rev. D69 (2004) 114003]

Impact parameter measurement



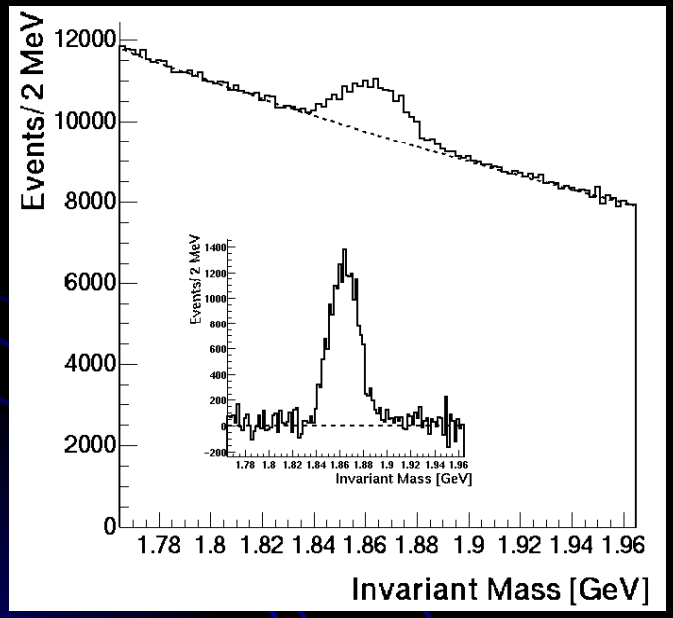
- → full reconstruction of D decays
- → b/c separation
- → control heavy flavour purity of non-photonic sample

- expected resolution (ITS)

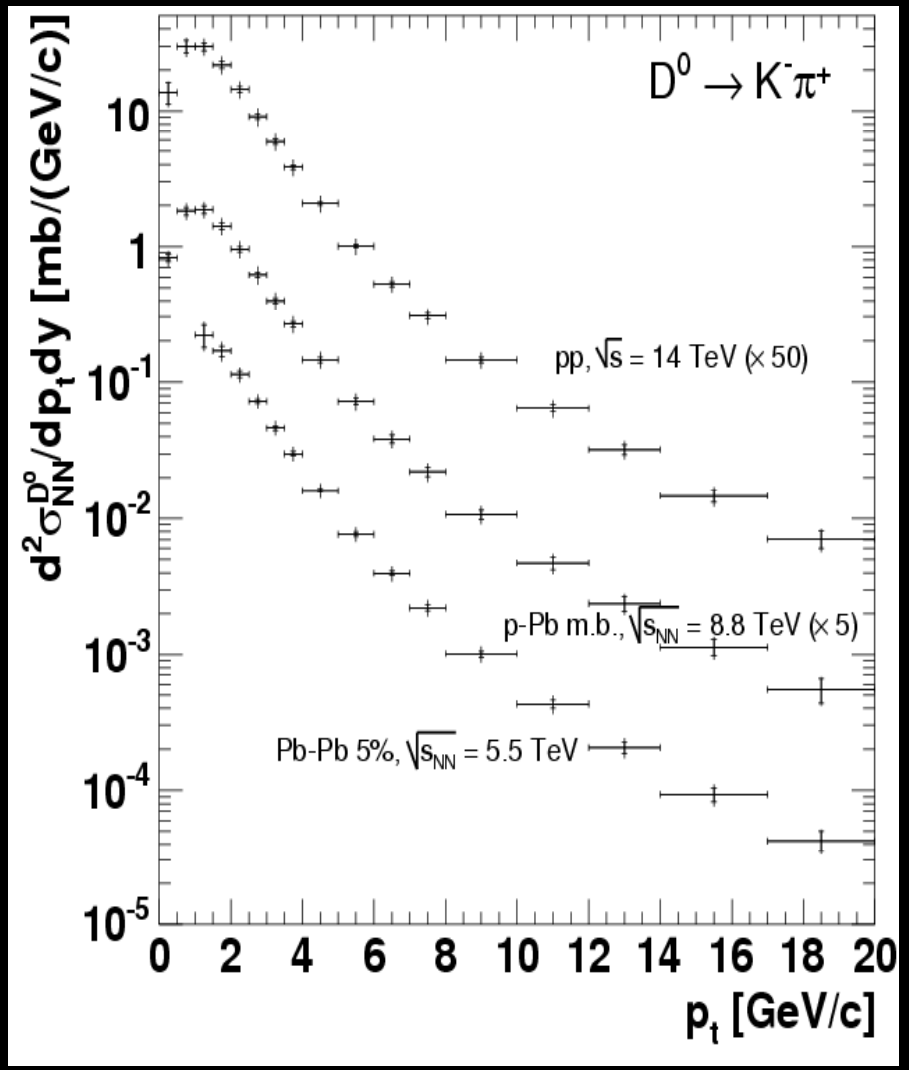


$D^0 \rightarrow K^-\pi^+$

- expected ALICE performance
  - S/B ≈ 10 %
  - S/√(S+B) ≈ 40
    (1 month Pb-Pb running)



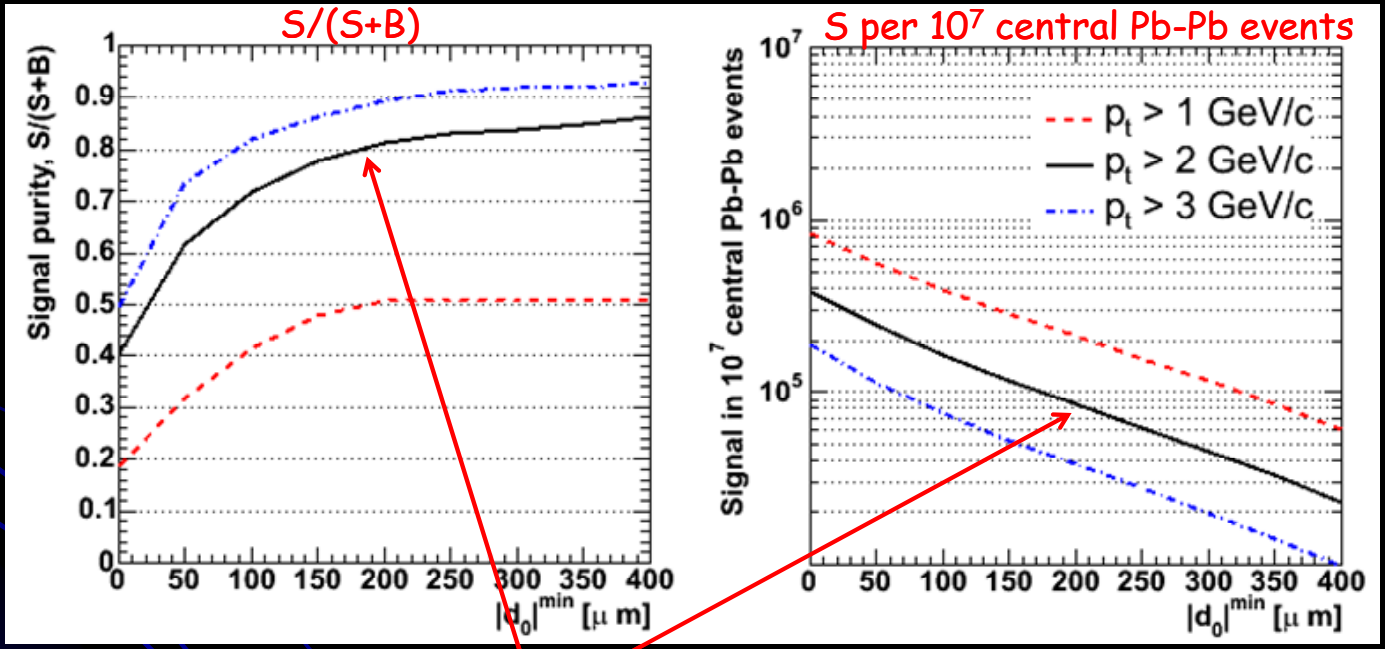
→ similar performance in pp
  - (wider primary vertex spread)



p_T - differential

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

- Expected ALICE performance (1 month Pb-Pb)
  - $e^{\pm}$ identification from TRD and dE/dx in TPC
  - impact parameter from ITS



$p_t > 2$ GeV/c , $200 < |d_0| < 600$ μm

80% purity
8×10^4 e from B

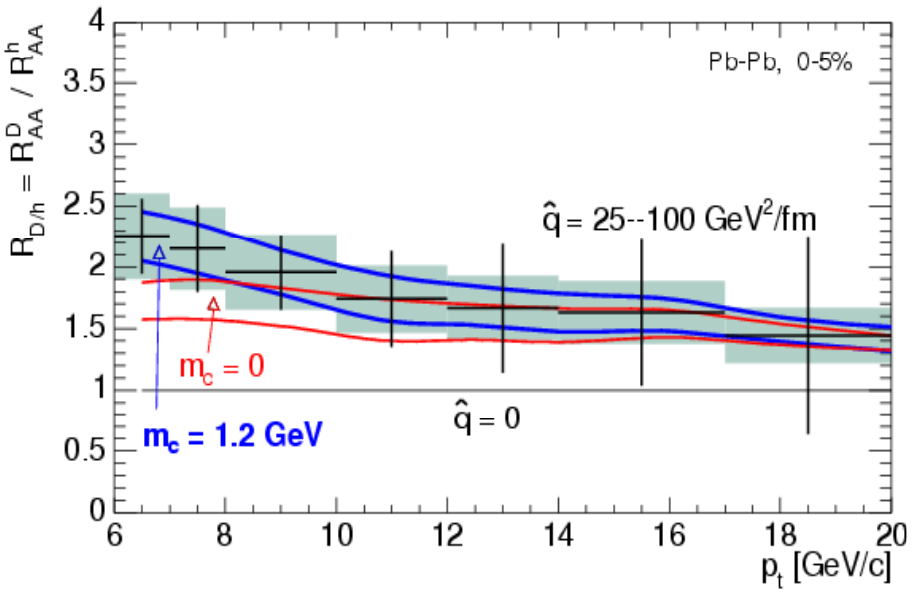
Expected performance on D, B R_{AA}

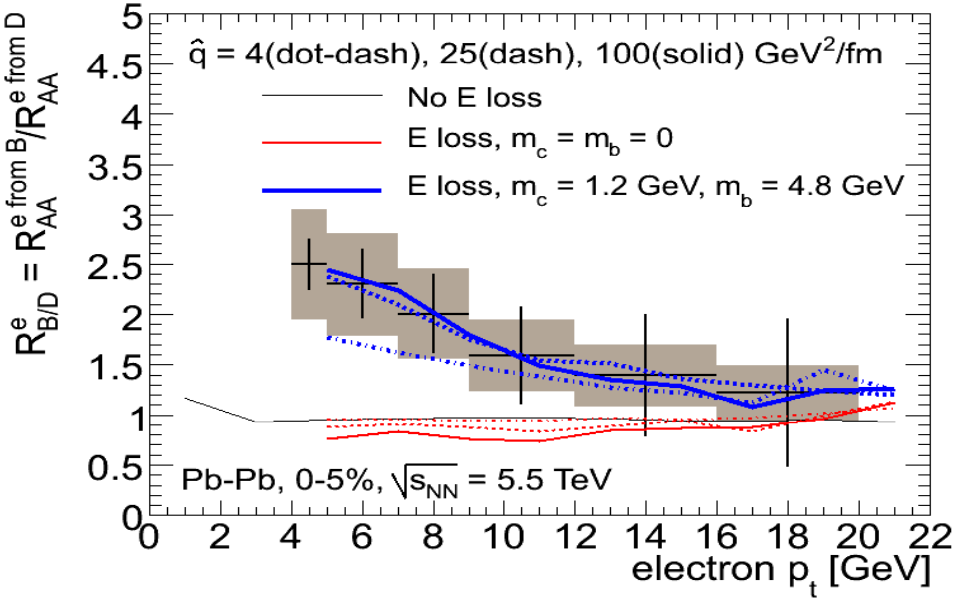
colour charge dependence

$$R_{D/h}(p_t) = R_{AA}^{D}(p_t) \big/ R_{AA}^{h}(p_t)$$

mass dependence

$$R_{B/D}(p_t) = R_{AA}^{\text{e from B}}(p_t) \big/ R_{AA}^{\text{e from D}}(p_t)$$



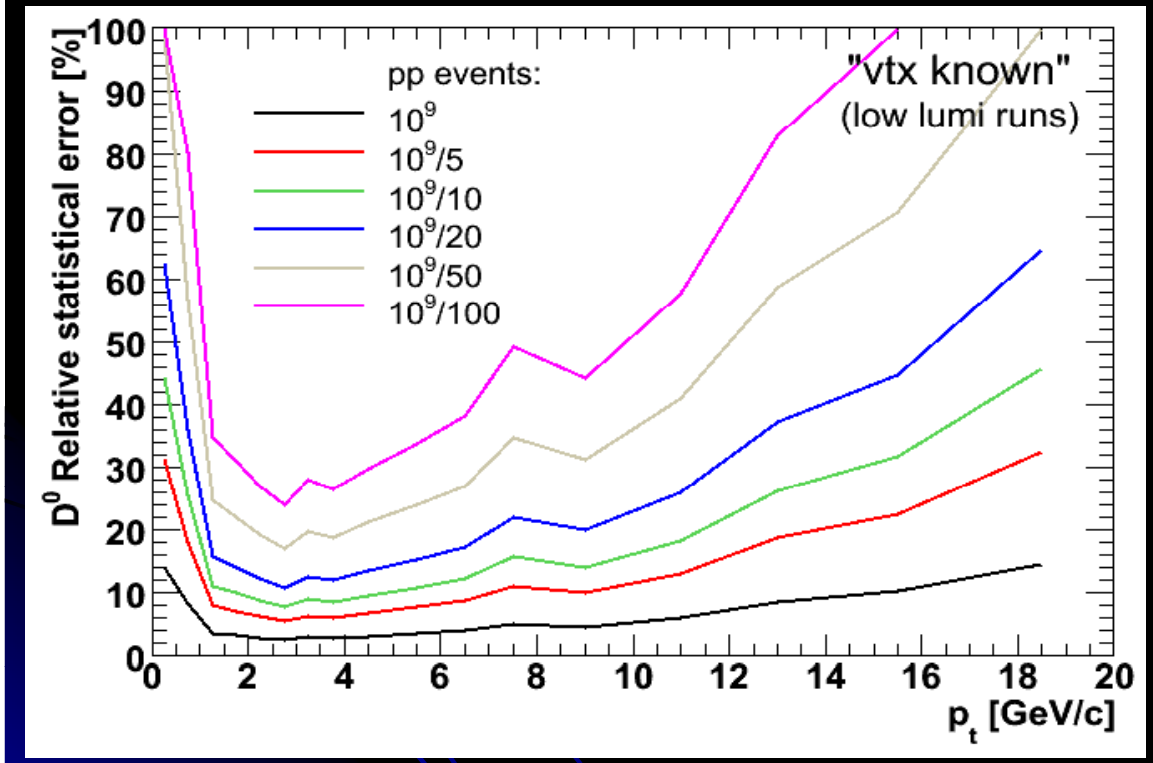


1 year at nominal luminosity
(10^7 central Pb-Pb events, 10^9 pp events)

- study of medium properties with "calibrated" probes

Expected pp performance vs stats

- e.g.: $D^0 \rightarrow K^-\pi^+$



- for $\mathcal{L} > 10^{28}$ cm^{-2}s^{-1}
  (1 bc per orbit @ 10 TeV)

→ O(10^7)events/day

Conclusions

- Ultrarelativistic nucleus-nucleus collisions allow us to recreate in the laboratory a high-density QCD medium
- At the LHC we shall finally be able to study its properties with "hard", calibrated probes
- The ALICE experiment is well equipped and ready for this adventure