Heavy-Ion Physics @ LHC

- Program
- Detectors
- Observables

Heavy-Ion Physics @ LHC

- ~1100 participants:
  - 1000 ALICE
  - 60 CMS
  - 25 ATLAS
- 26 experimental contributions QM04
  - 6 oral: P. Glaessel, V. Manzari, A. Vestbo, H. Takai, B. Wyslouch, S. Blyth.
  - 20 posters: Spectra 23, HBT 1, High p_T 17, 20, 21, Flavor 18, 19, 23, Instr. 1, 2, 7, 8, 10, 12, 14, 15, 16, 17, 22, 30.

The LHC facility

- Running conditions:

Collision system	$\sqrt{s_{NN}}$ (TeV)	$\mathcal{L}_0$ ($cm^{-2}s^{-1}$)	$<\mathcal{L}>/\mathcal{L}_0$ (%)	Run time (s/year)	σ_{geom} (b)
pp	14.0	10^{34*}		10^7	0.07
PbPb					

$^*\mathcal{L}_{max}$(ALICE) = 10^{31}

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PbPb	5.5	10^{27}	70-50	10^6 **	7.7

** $\mathcal{L}_{int}$(ALICE) ~ 0.7 nb^{-1}/year

The LHC facility

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- + other collision systems: pA, lighter ions (Sn, Kr, Ar, O) & energies (pp @ 5.5 TeV).

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April 2007					
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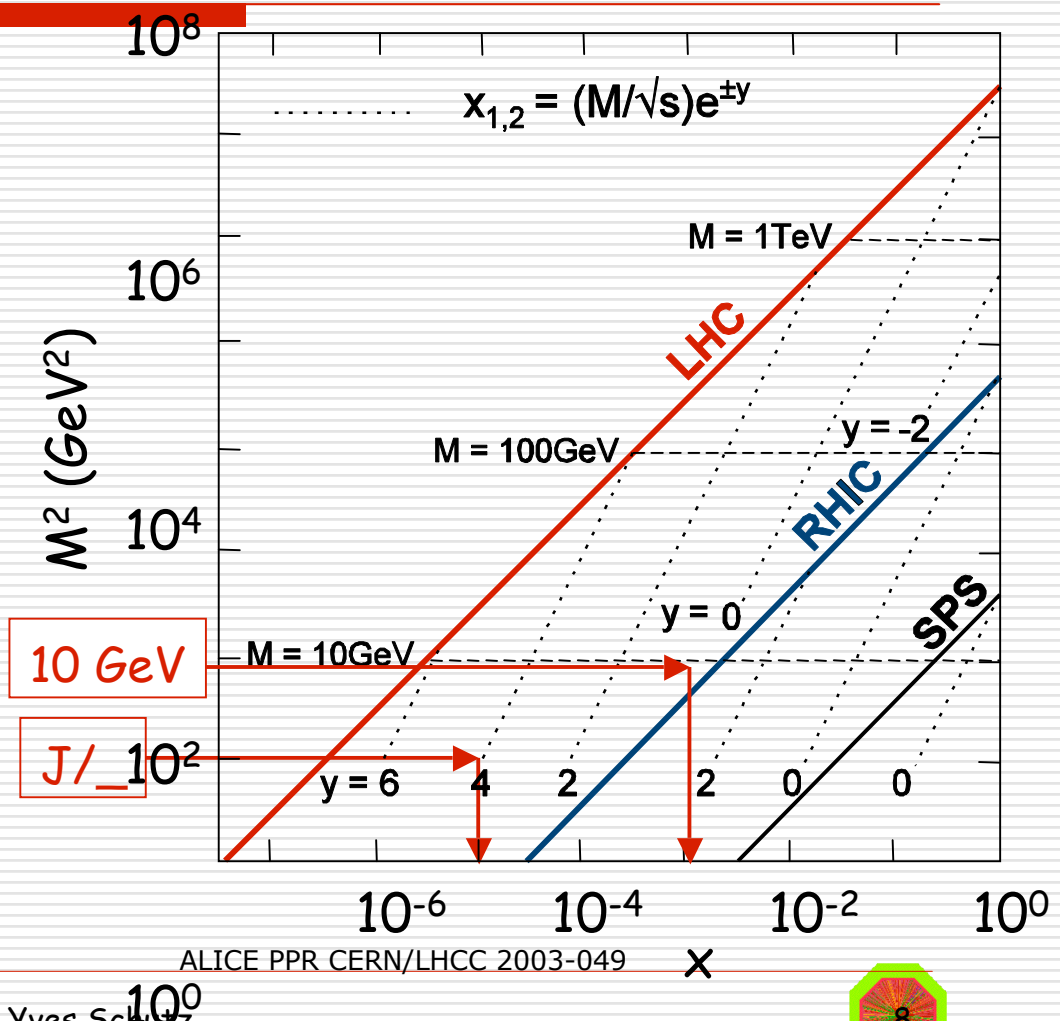
End 2007
Early 2008

- + other collision systems: pA, lighter ions (Sn, Kr, Ar, O) & energies (pp @ 5.5 TeV).

Novel aspects: Qualitatively new regime

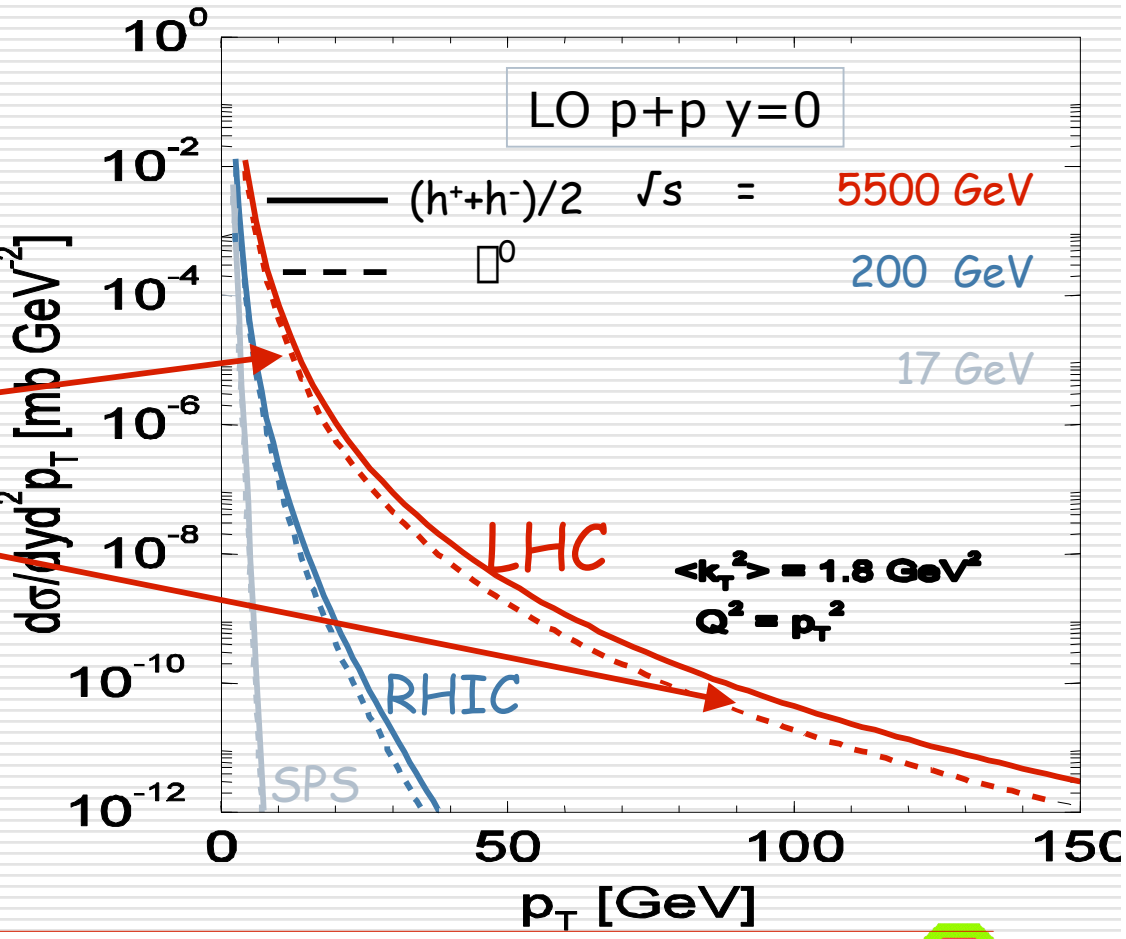
- Probe initial partonic state in a novel Bjorken-x range (10^{-3}-10^{-5}):
  - nuclear shadowing,
  - high-density saturated gluon distribution.
- Larger saturation scale ($Q_S=0.2A^{1/6}\sqrt{s}$ = 2.7 GeV): particle production dominated by the staturation region.



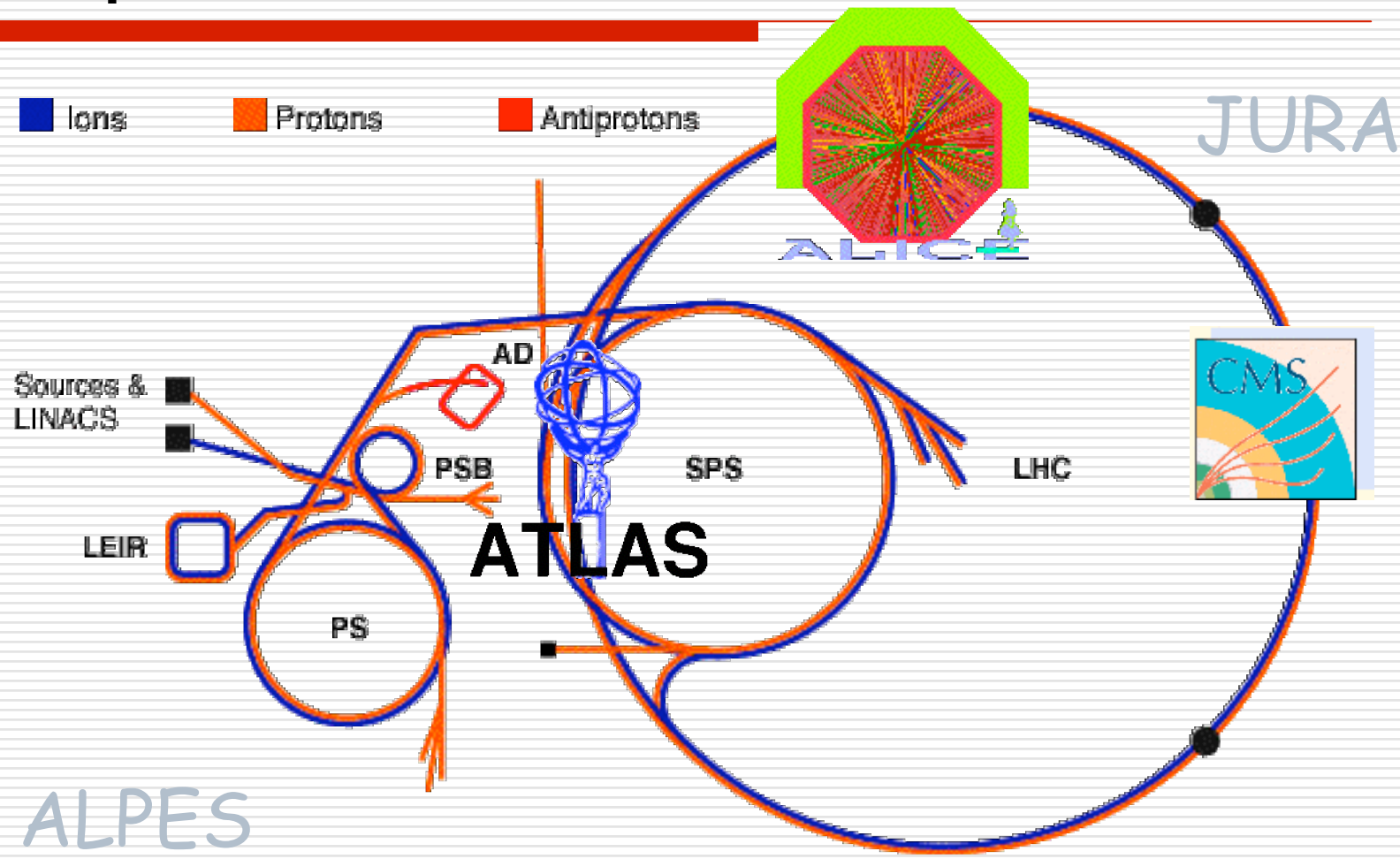
ALICE PPR CERN/LHCC 2003-049

Novel aspects: Qualitatively new regime

- Hard processes contribute significantly to the total AA cross-section ($\sigma_{hard}/\sigma_{tot} = 98\%$):
  - Bulk properties dominated by hard processes;
  - Very hard probes are abundantly produced.
- Weakly interacting probes become accessible (γ, Z^0, $W^{\pm}$).

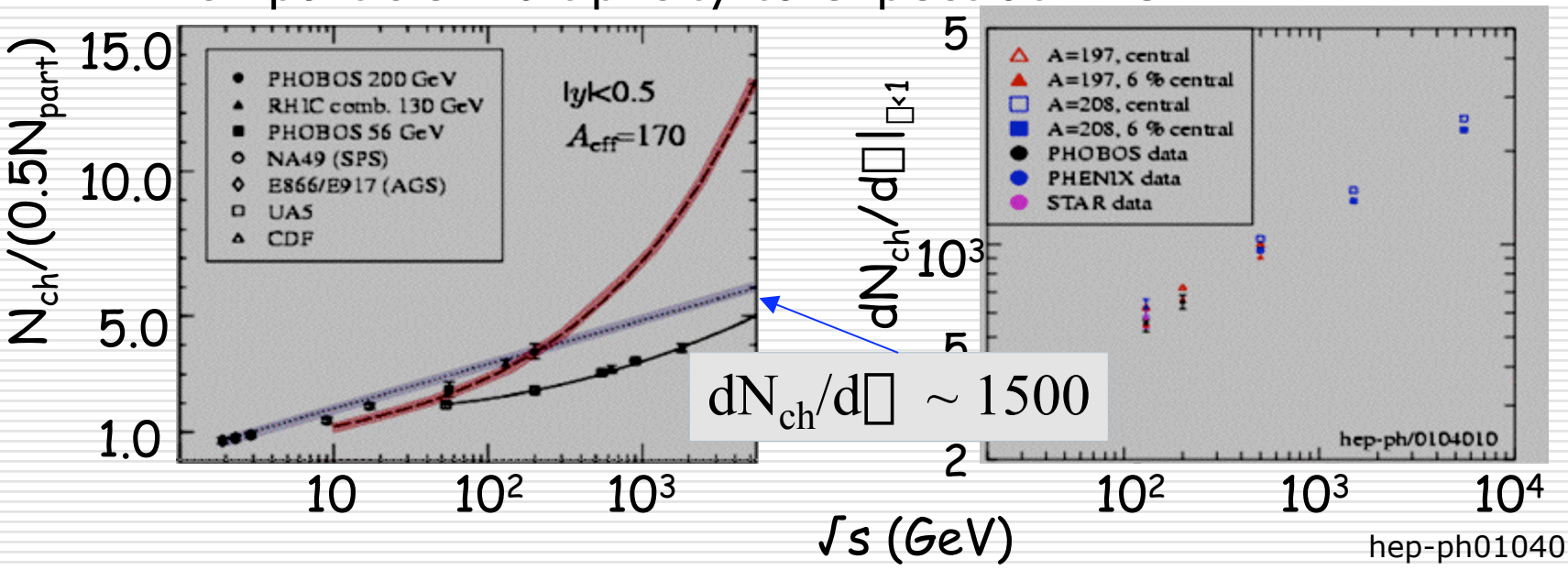


3 experiments



HI experiments

- Which particle multiplicity to expect at LHC ?



HI experiments

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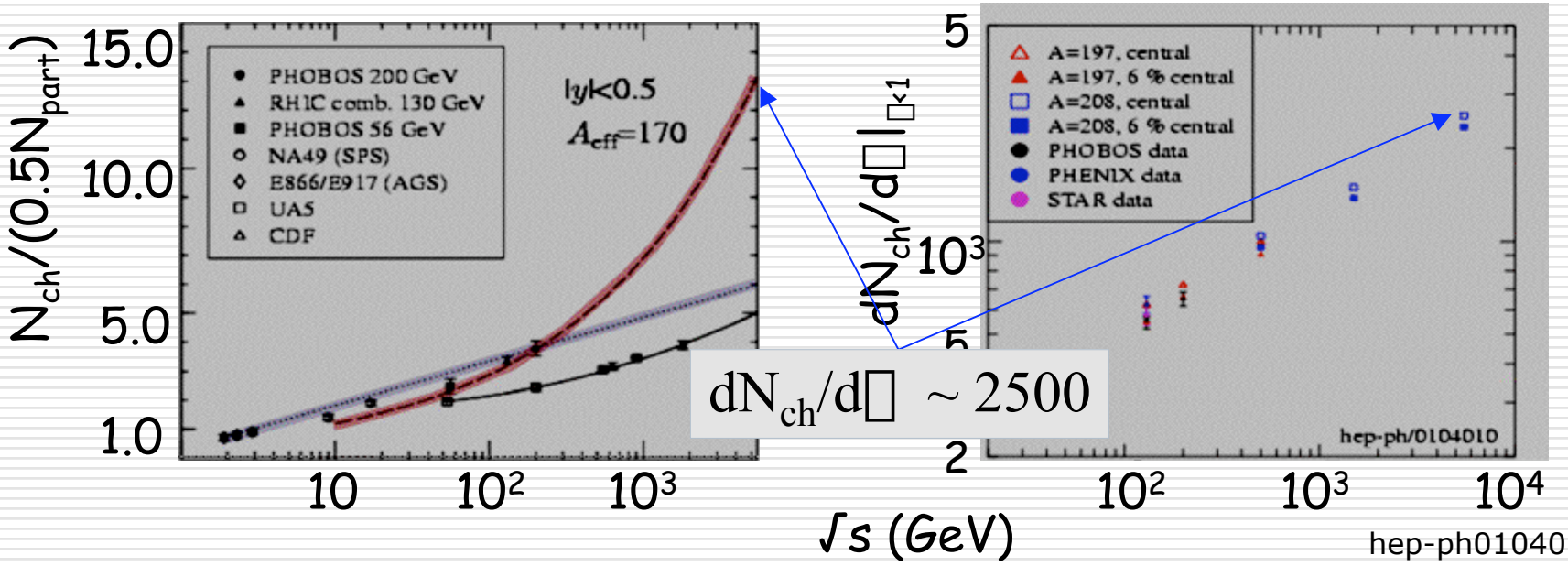
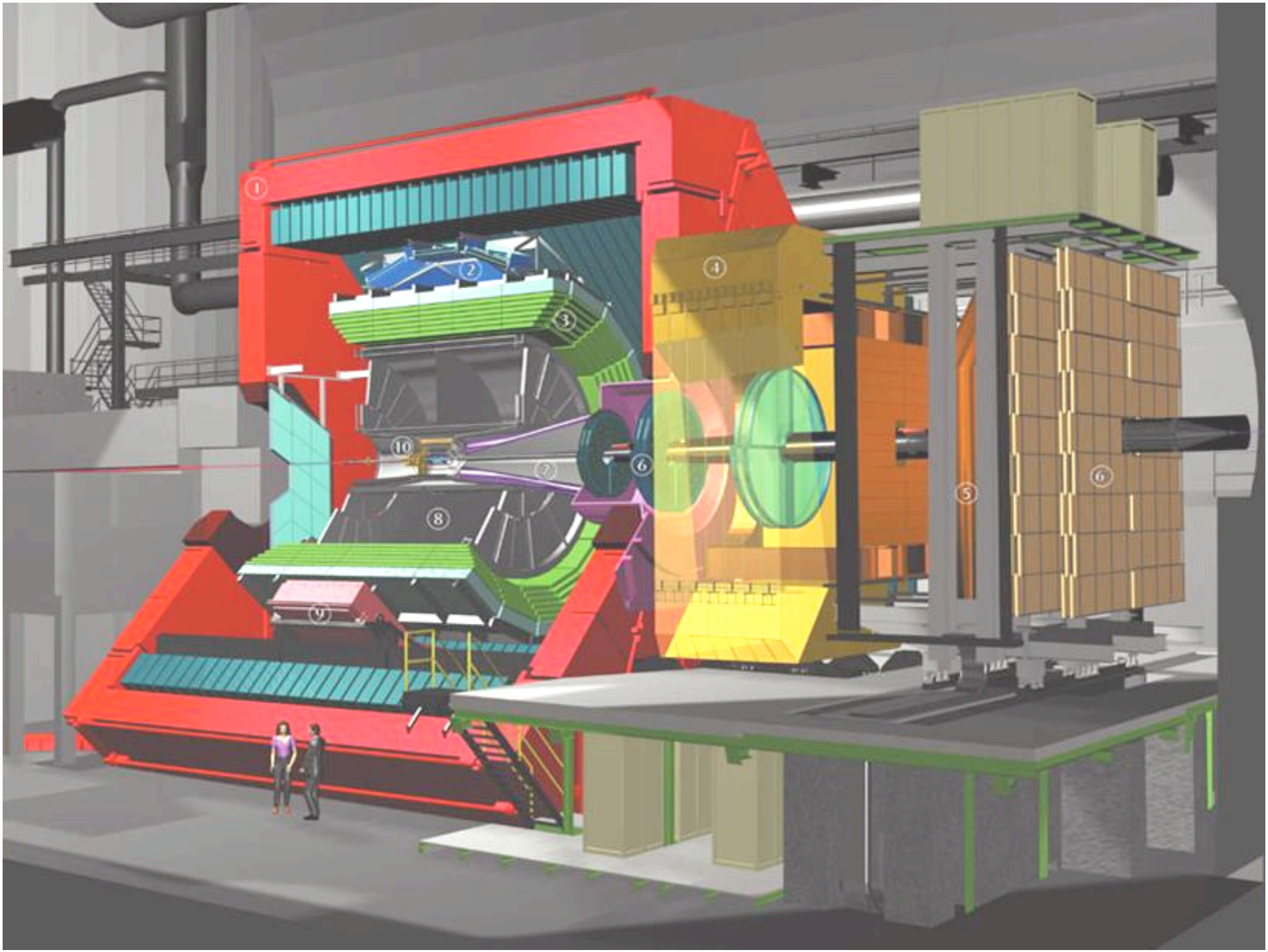


hep-ph0104010

- ALICE optimized for dN_{ch}/dY = 4000, checked up to 8000 (reality factor 2).
- CMS & ATLAS (checked up to 7000) will provide good performances over the expected range.

ALICE: the dedicated HI experiment


1
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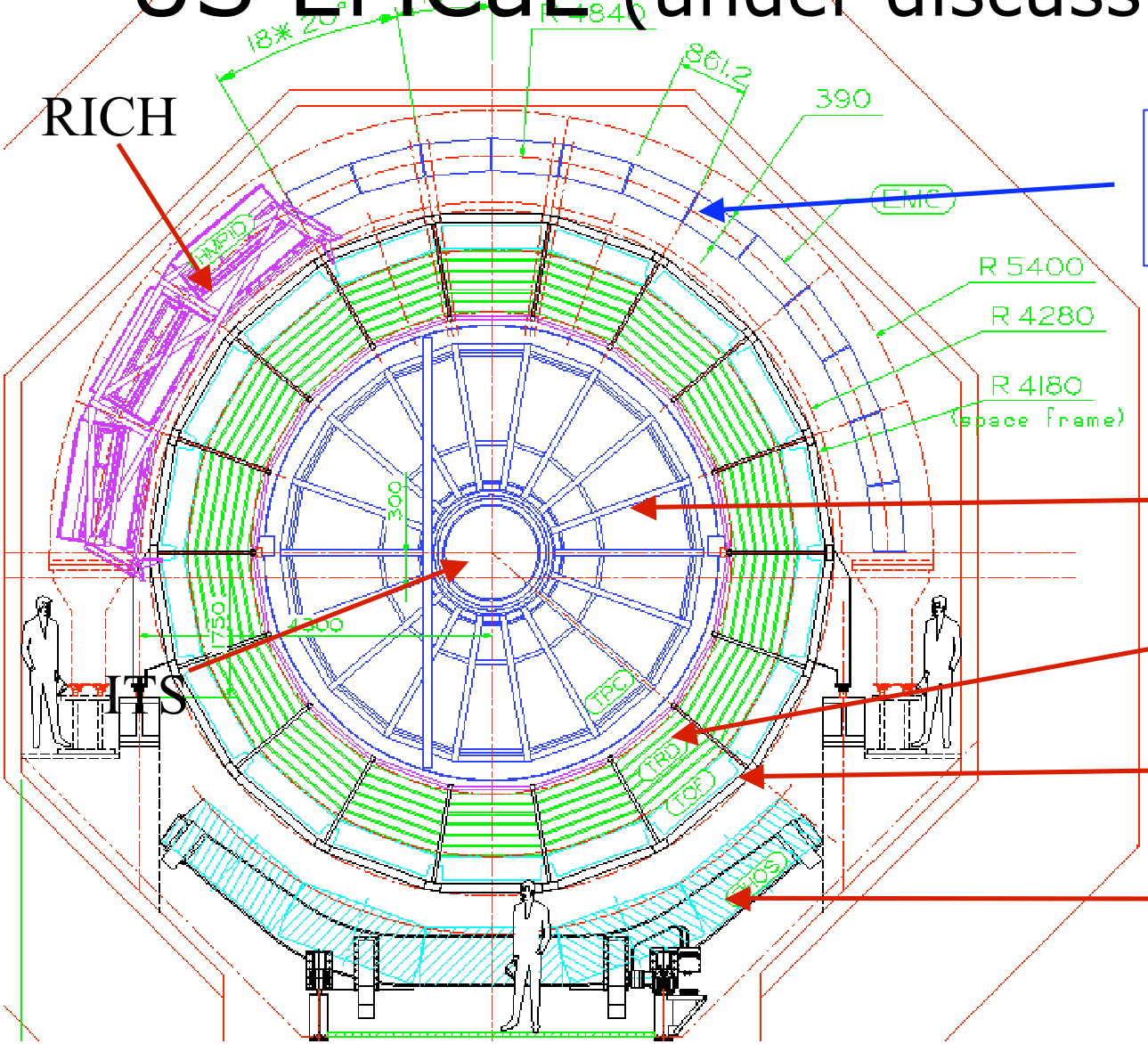
US EMCaL (under discussion)



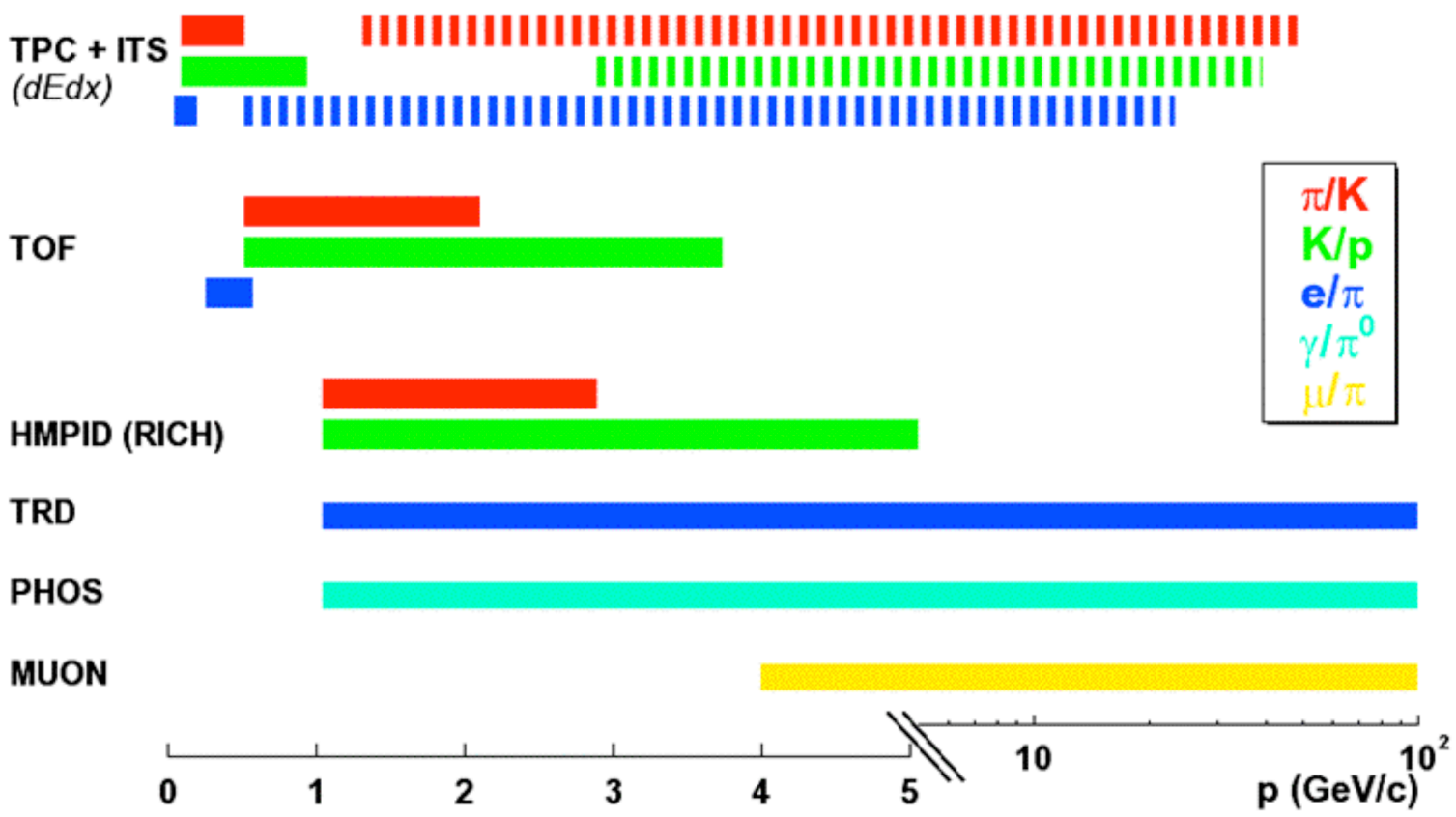
Pb/Sci EMCal
□□ x □□ = 1.4 x 2□/3

ALICE: the dedicated HI experiment

- Measure flavor content and phase-space distribution event-by-event:
  - Most (2□ * 1.8 units □) of the hadrons (dE/dx + ToF), leptons (dE/dx, transition radiation, magnetic analysis) and photons (high resolution EM calorimetry);
  - Track and identify from very low (< 100 MeV/c; soft processes) up to very high p_t (~100 GeV/c; hard processes);
  - Identify short lived particles (hyperons, D/B meson) through secondary vertex detection;
  - Jet identification;

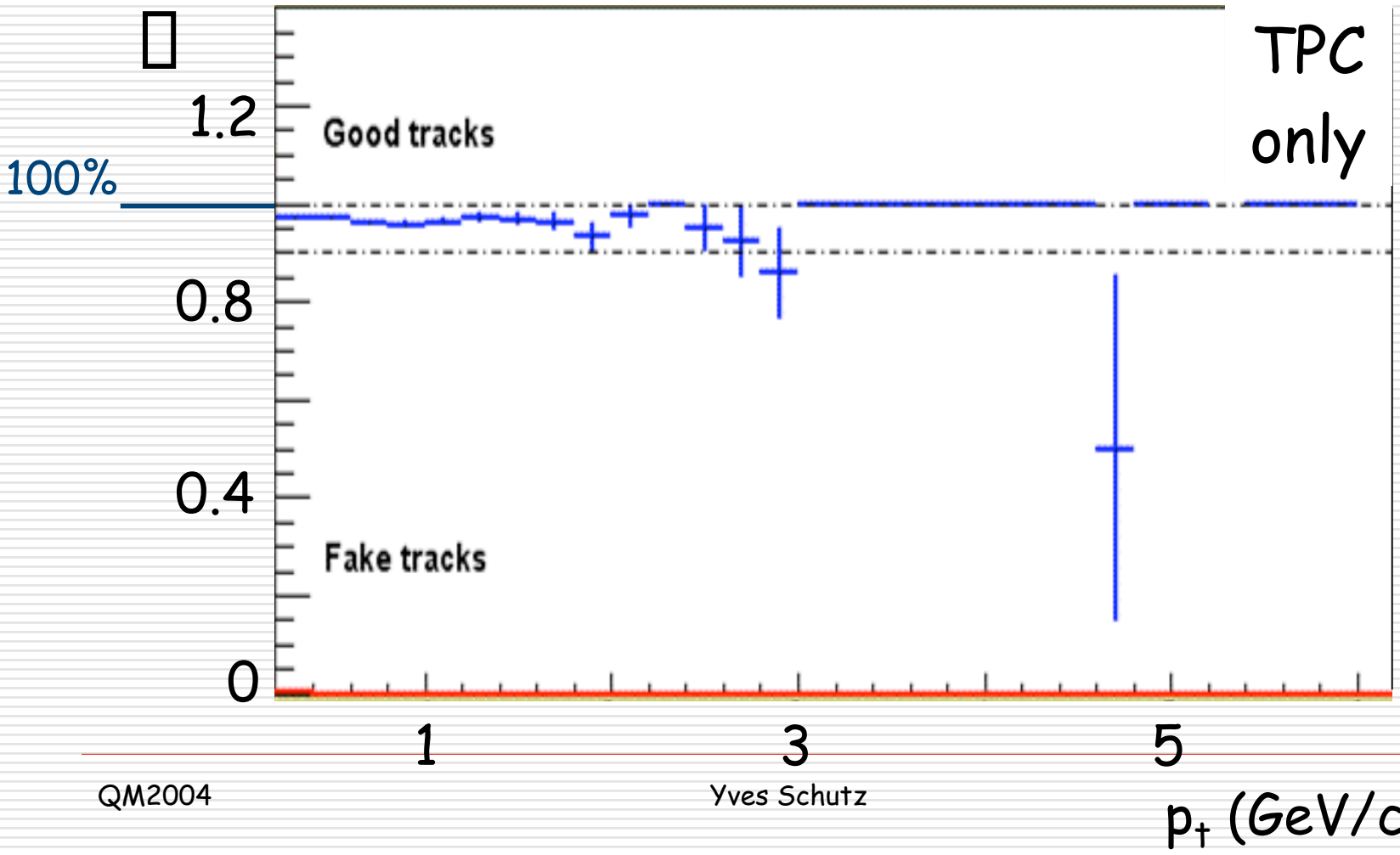
ALICE PID performances

ALICE PPR CERN/LHCC 2003-049



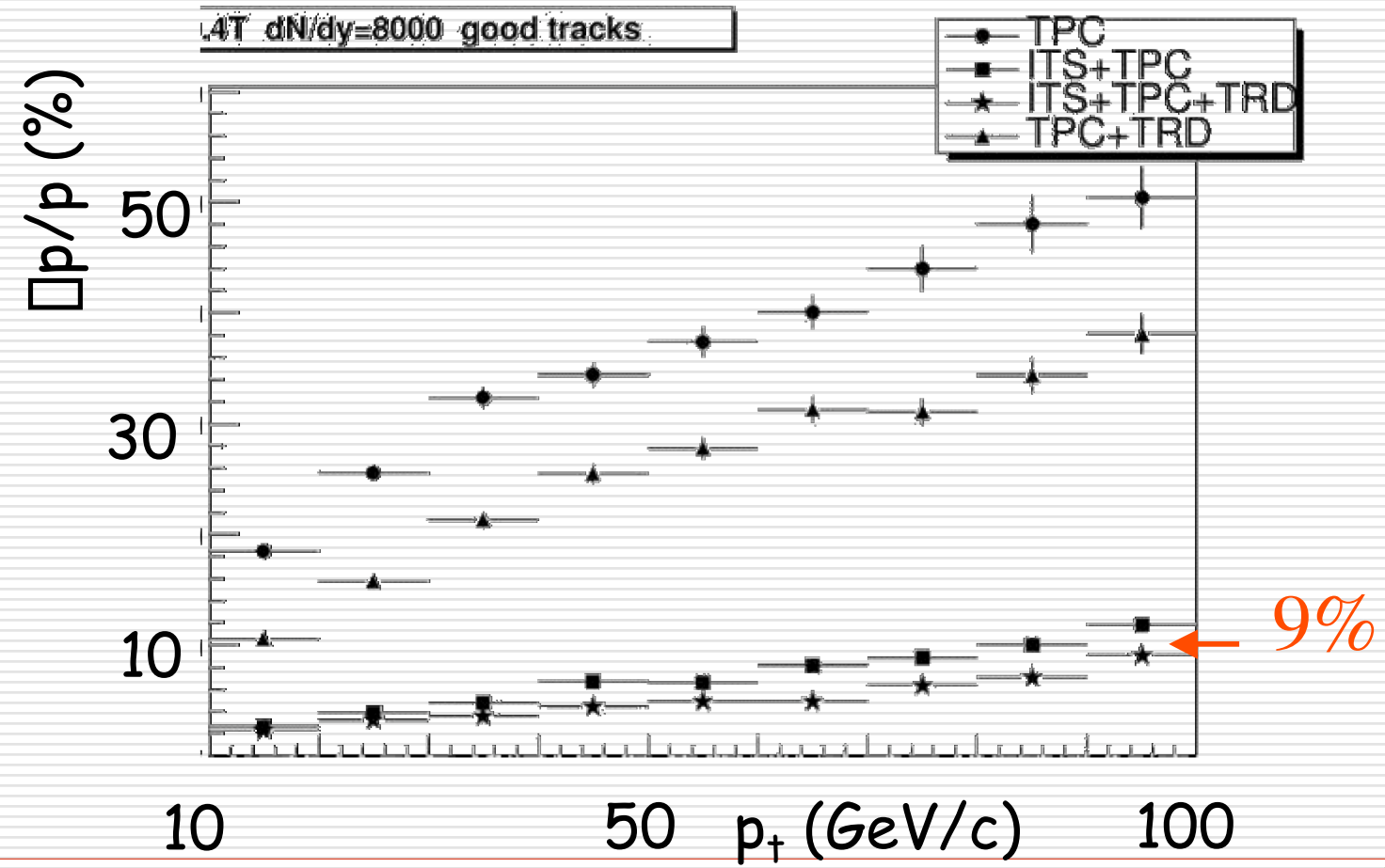
ALICE tracking efficiency

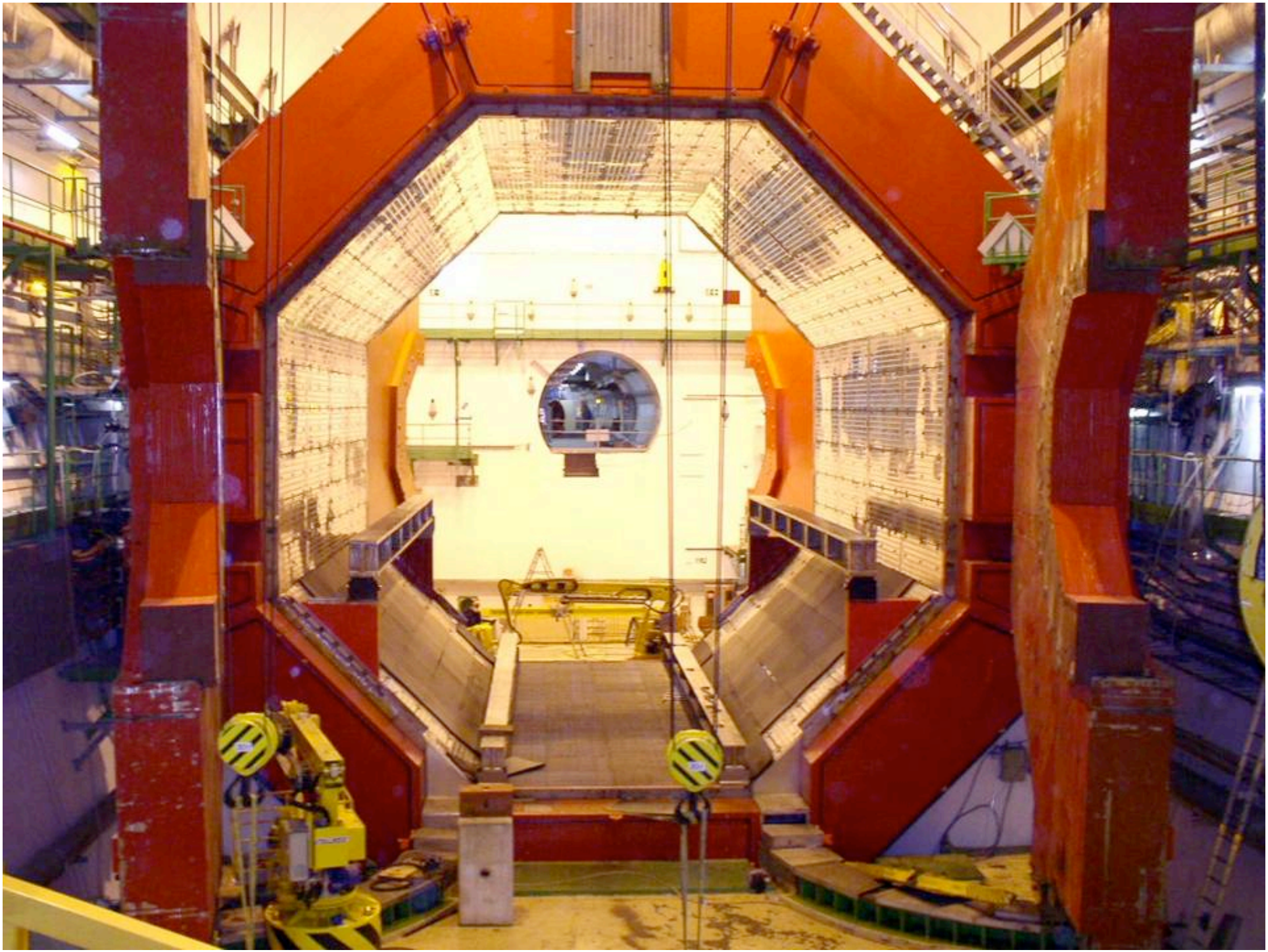
ALICE PPR CERN/LHCC 2003-049

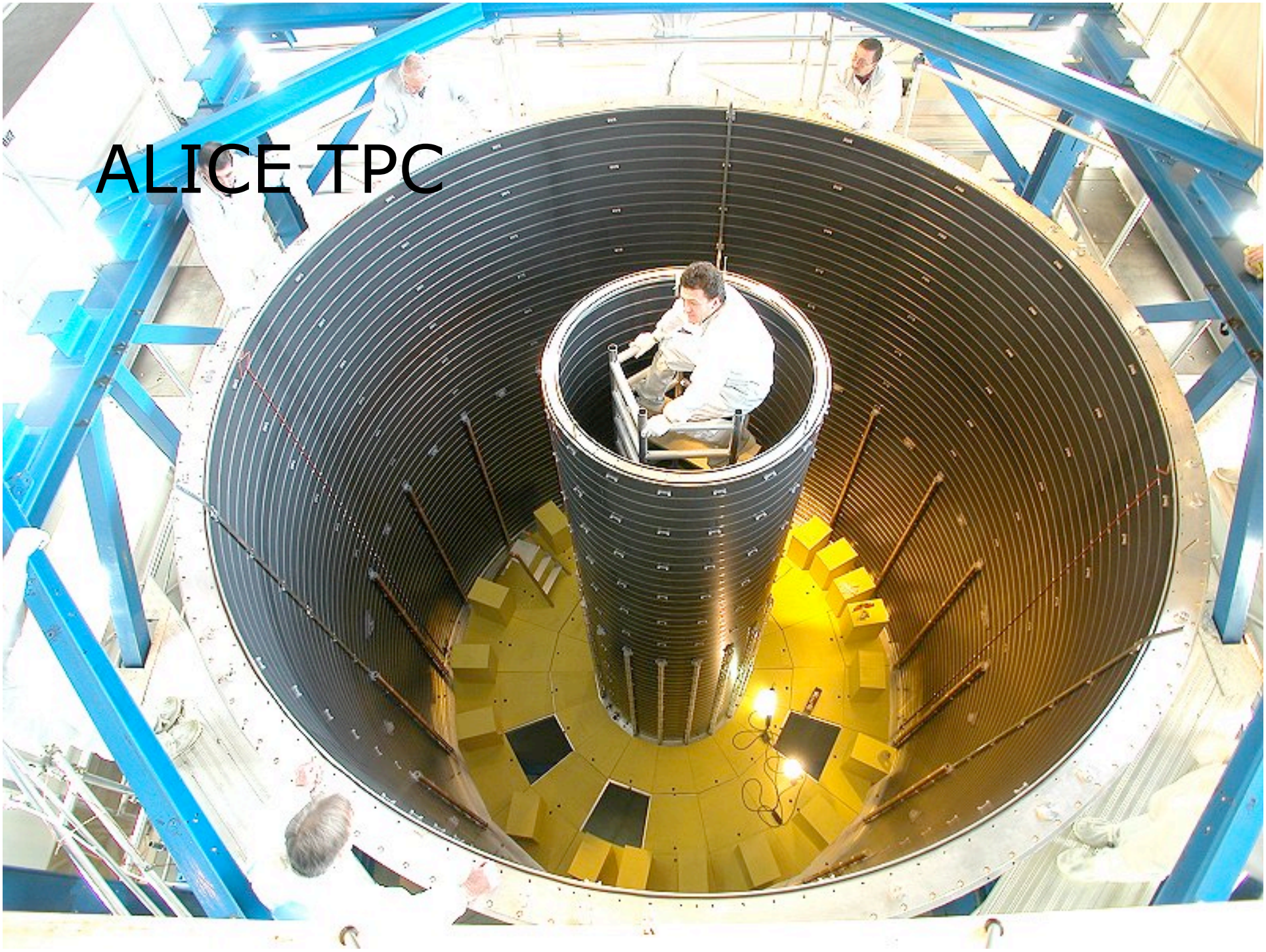


ALICE track resolution at high p_t

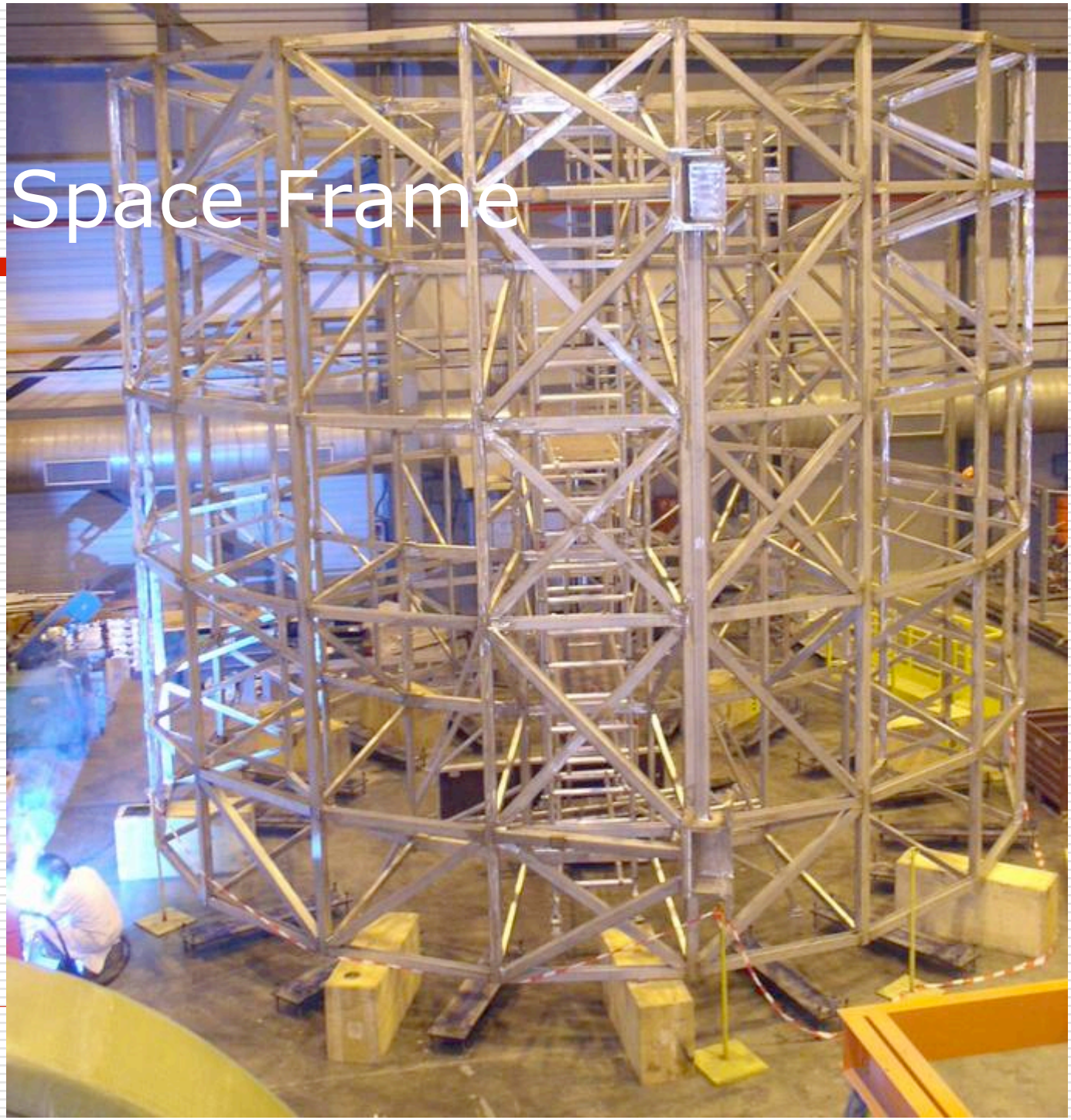
ALICE PPR CERN/LHCC 2003-049



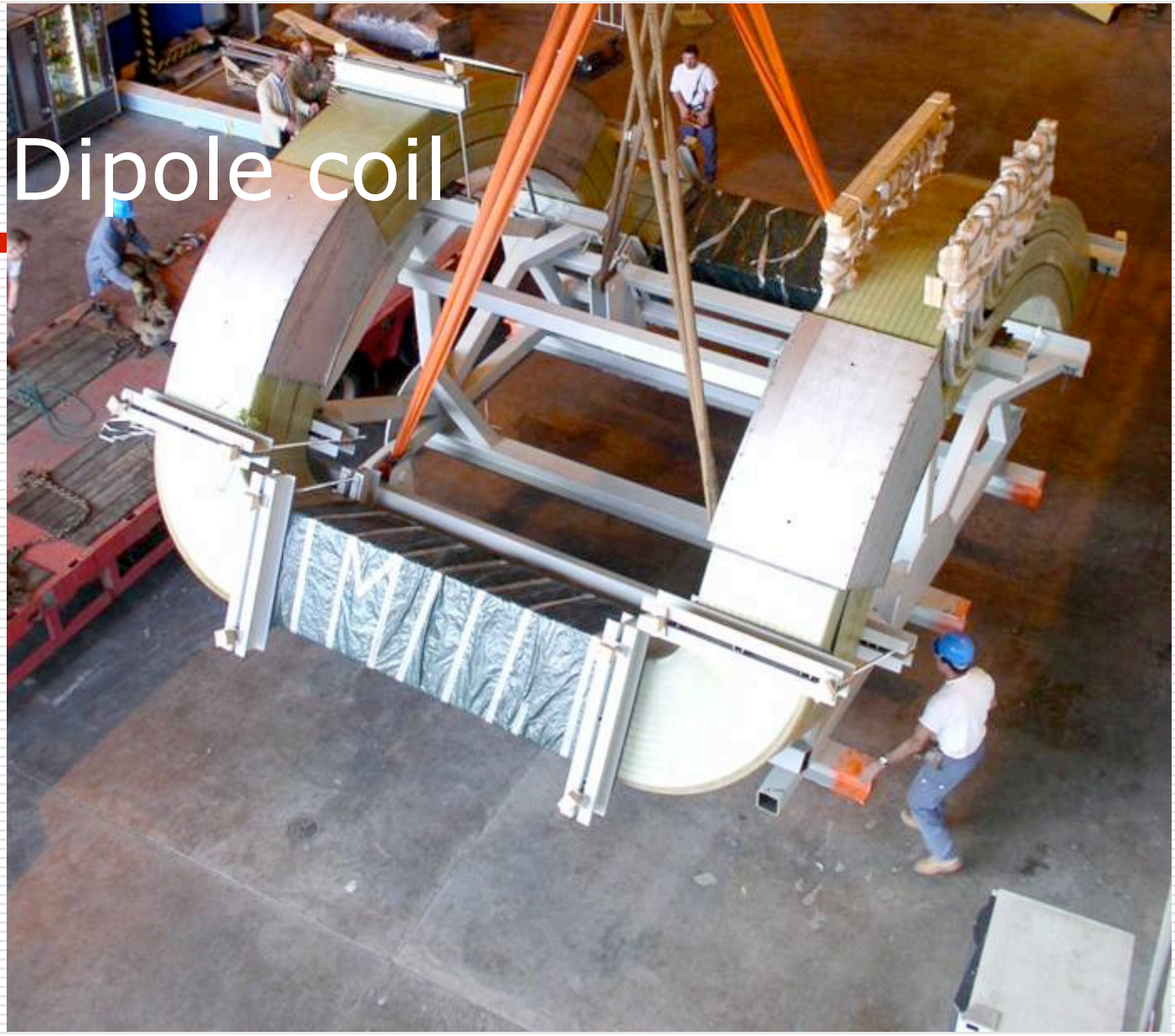



ALICE TPC

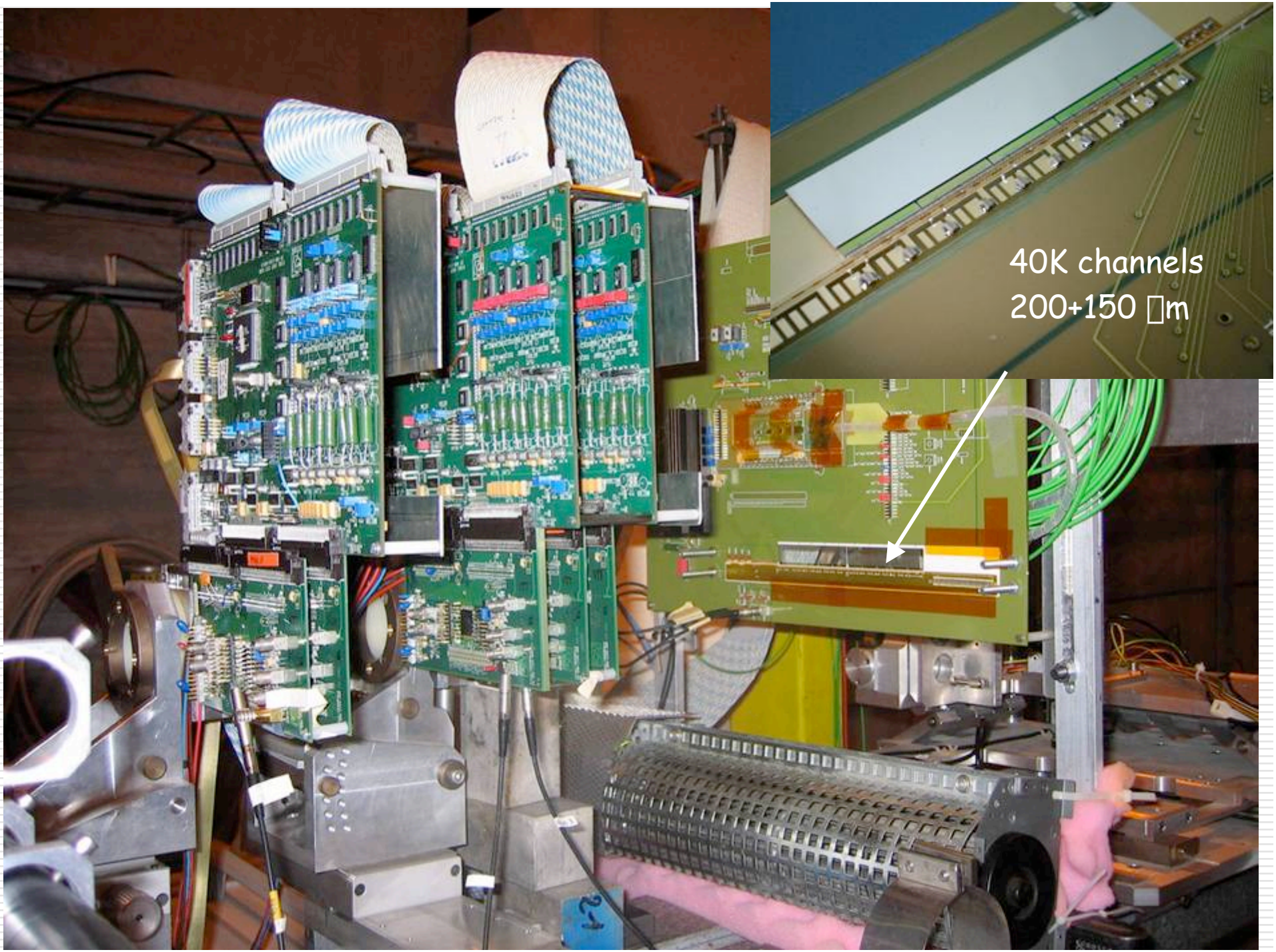
ALICE Space Frame

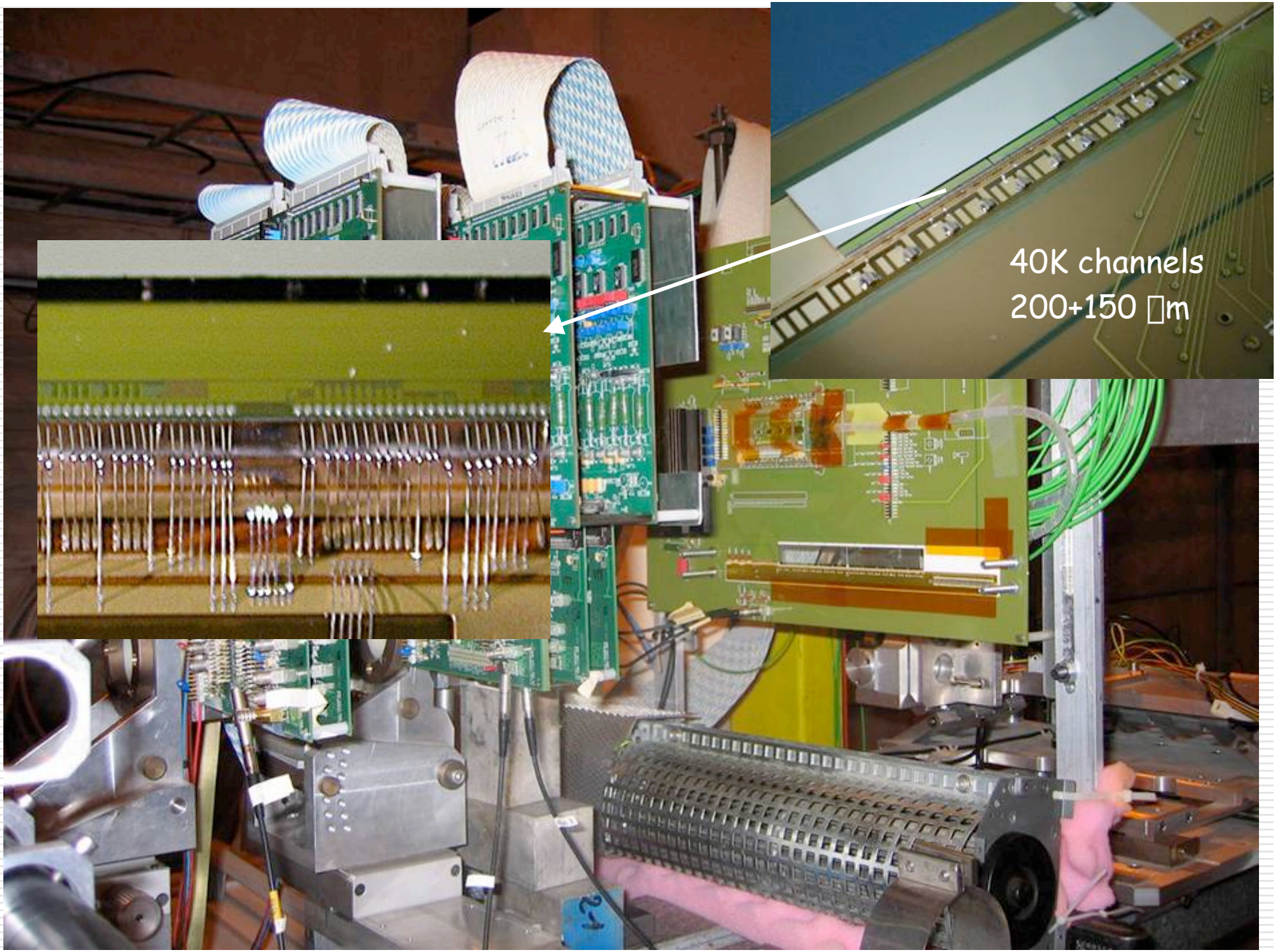


ALICE Dipole coil



ALICE pixel


40K channels
200+150 □m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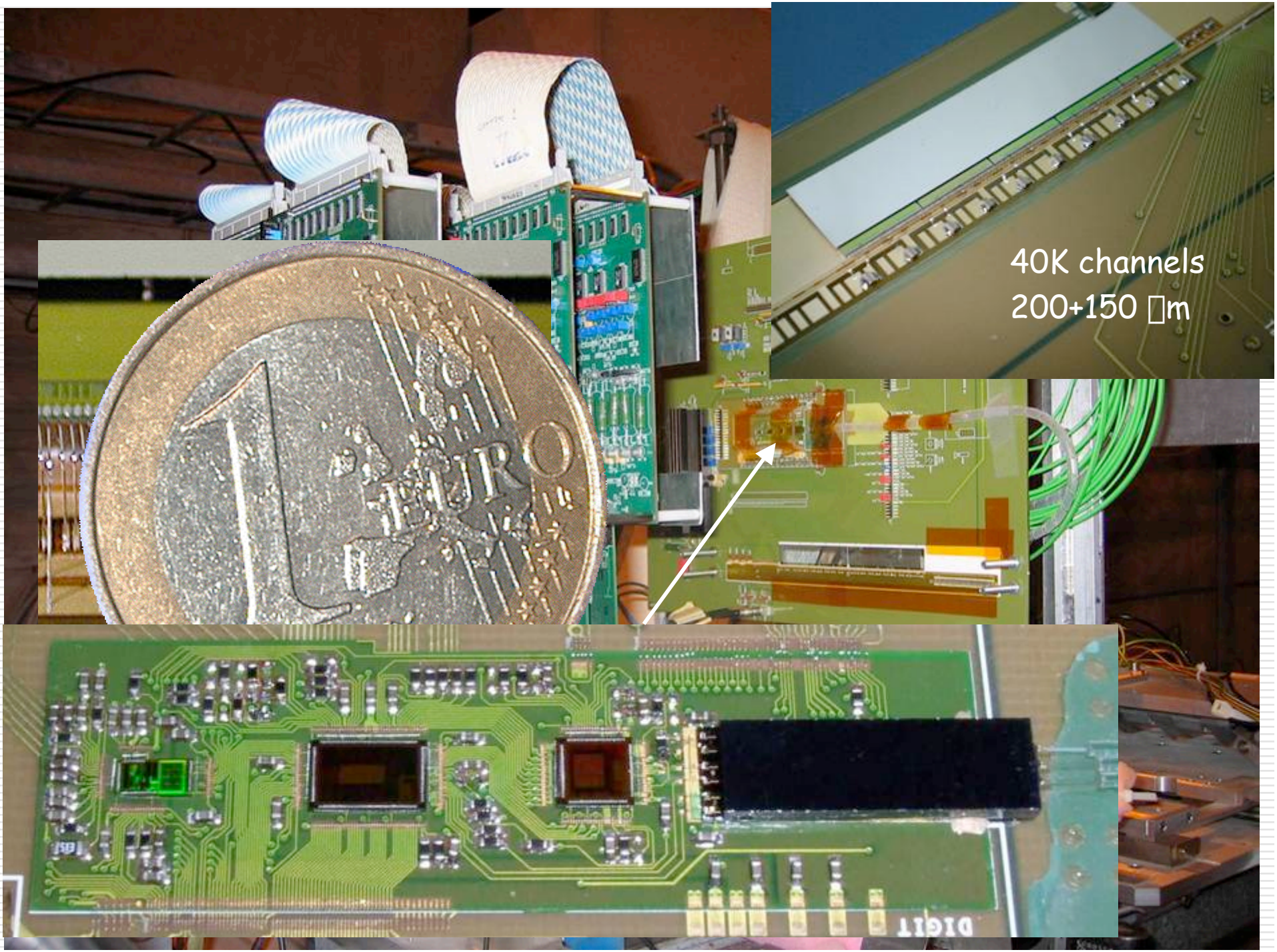
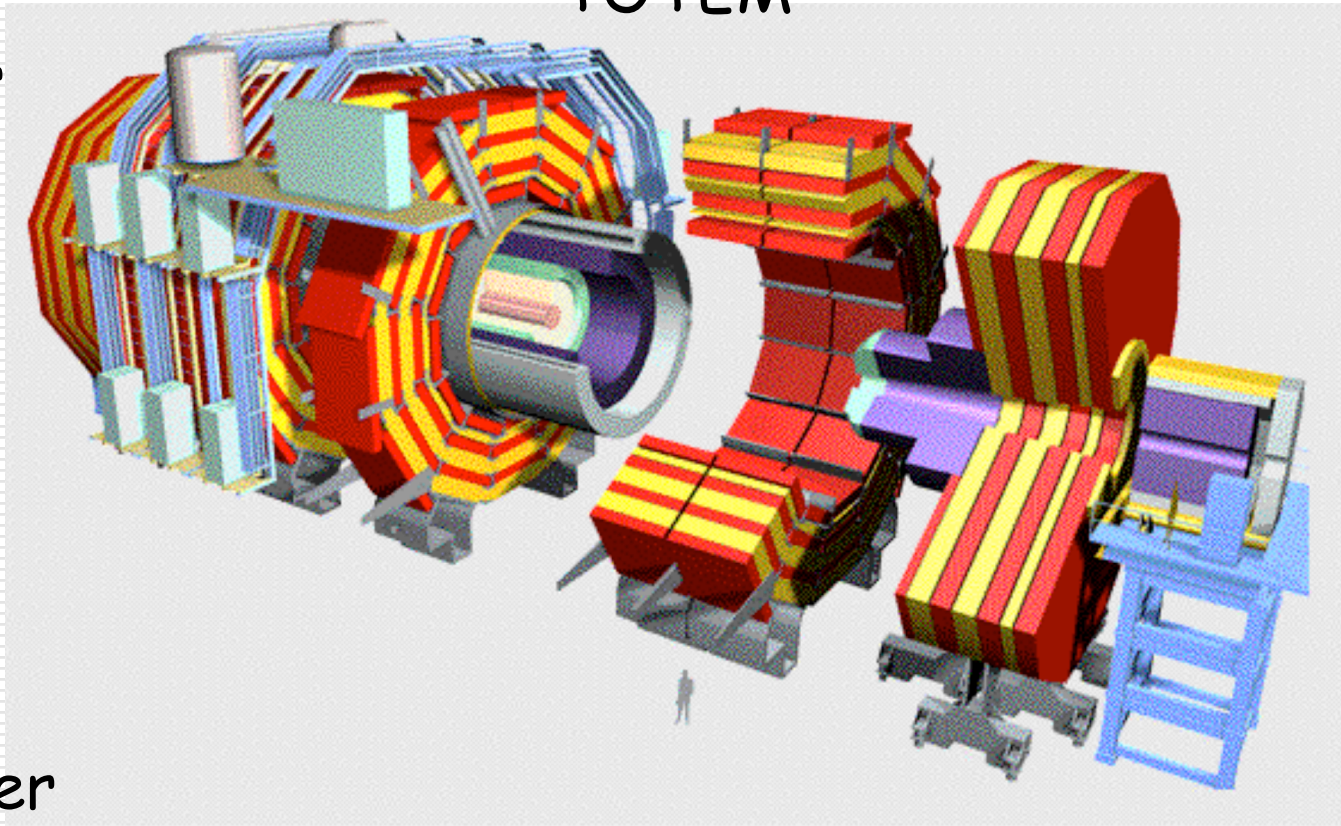

40K channels
200+150 □m

CMS

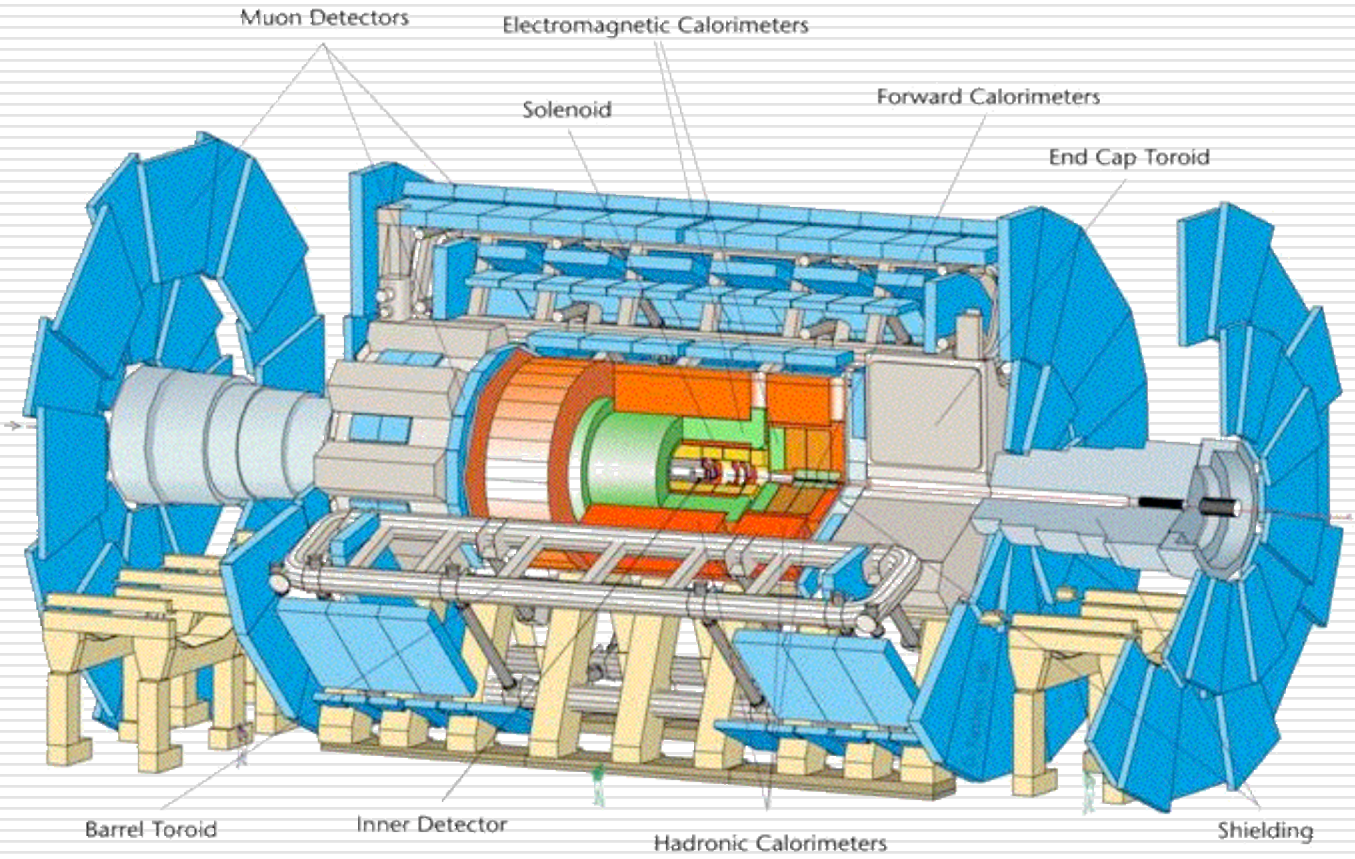
- Very forward calorimeters
  - ZDC
  - CASTOR
  - TOTEM

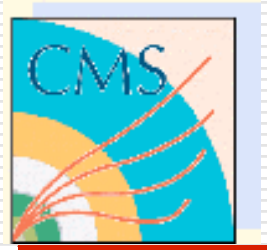
- Central tracker
- High resolution EM calorimeter
- Hadronic calorimeter



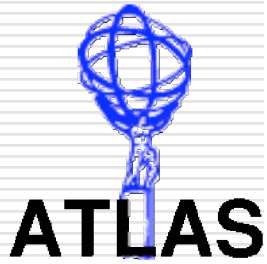
- Muon spectrometer

ATLAS


Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

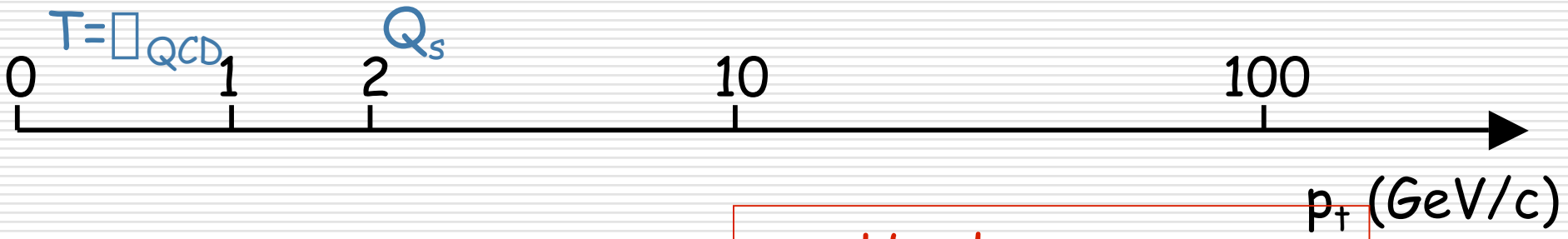


CMS & ATLAS



- Experiments designed for high p_t physics in pp collisions:
  - Precise tracking systems in a large solenoid magnetic field;
  - Hermetic calorimeters (EM+Hadronic) systems with fine grain segmentation;
  - Large acceptance muon spectrometers;
  - Accurate measurement of high energy leptons, photons and hadronic jets.
- Provide adequate performances for selected high p_t (> 1 GeV/c) probes for HI physics.

3 Experiments



Bulk properties

Hard processes
Modified by the medium

ALICE

PID

CMS&ATLAS

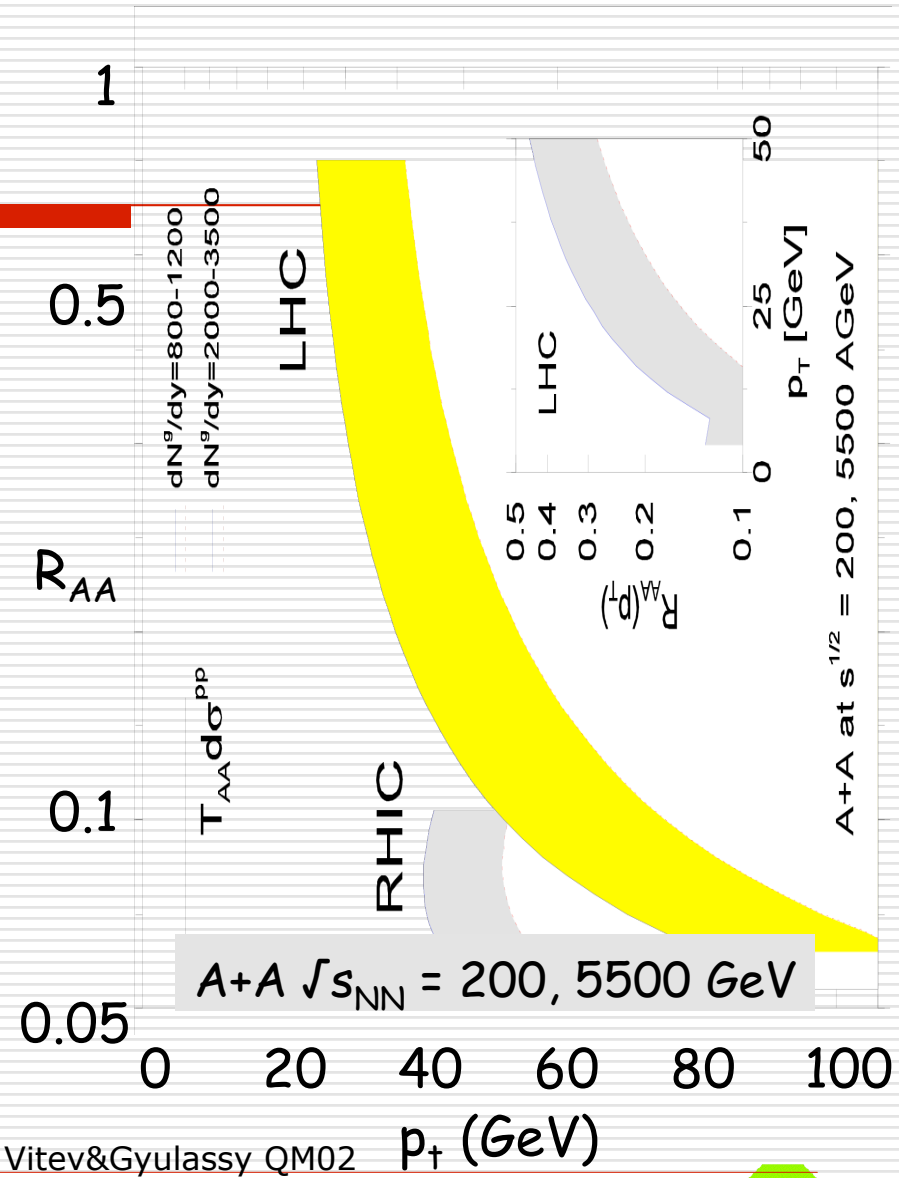
QGP probes: hard processes modified by the medium

$$Q \gg \Lambda_{QCD},\ T,\ Q_s \quad \Delta r \sim 1/Q$$

- Jet quenching:
  - Energy degradation of leading hadrons, p_t dependence;
  - Modification of genuine jet observables;
  - Mass dependence of energy loss (light and heavy quarks).
- Dissolution of c'onium & b'onium bound states.

Leading hadron quenching

- Nuclear modification factor pattern very different at LHC:
  - Final state interactions (radiative & collisional energy loss) dominate over nuclear effects (shadowing+Cronin).
- Measurement of suppression pattern of leading partons remains experimentally the most straightforward observable for jet-tomography analysis.



Vitev&Gyulassy QM02

Jets reconstruction

- Jets are produced copiously.

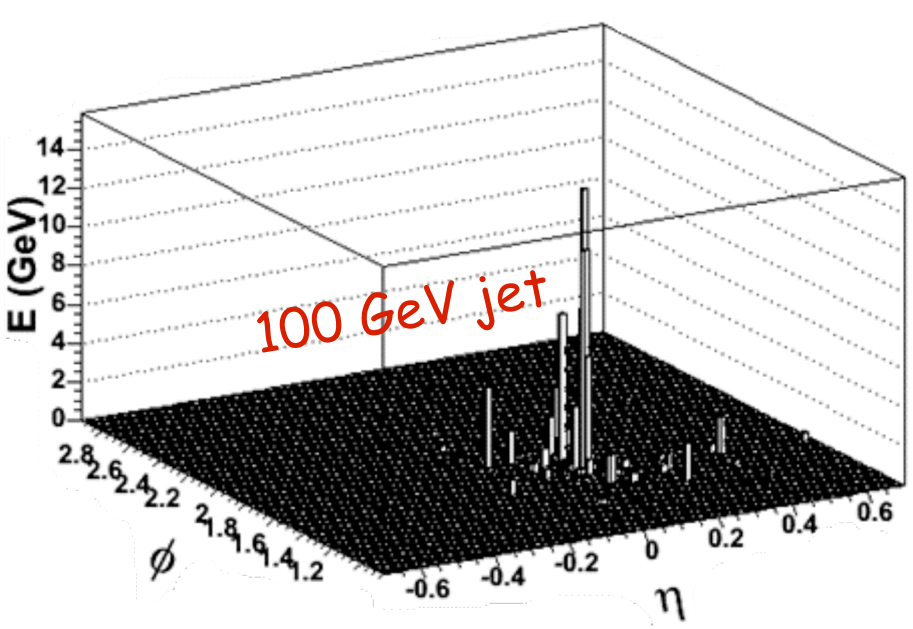
- Jets are distinguishable from the HI underlying event.

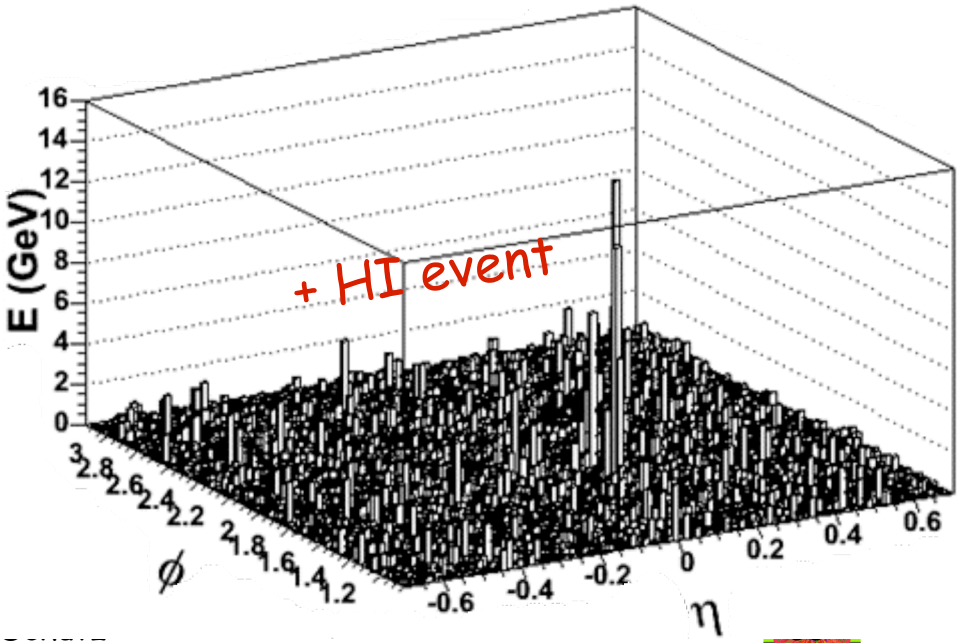
Jets reconstruction

- Jets are produced copiously.

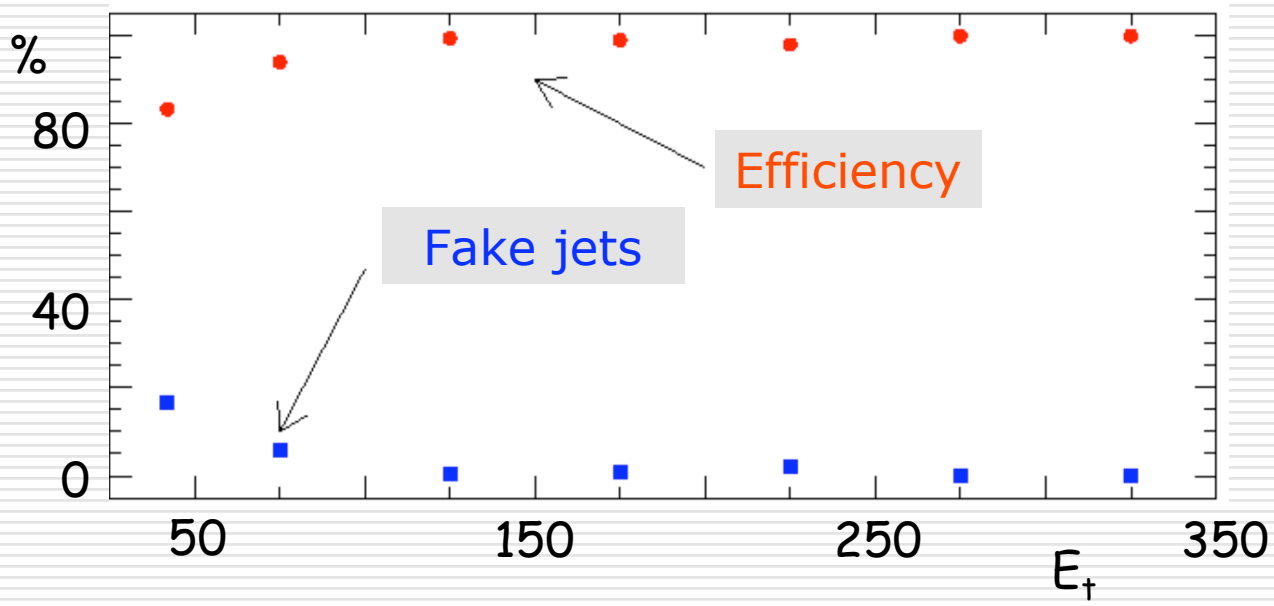
2 20 100 200 p_t (GeV)

100/event 1/event 100K/year



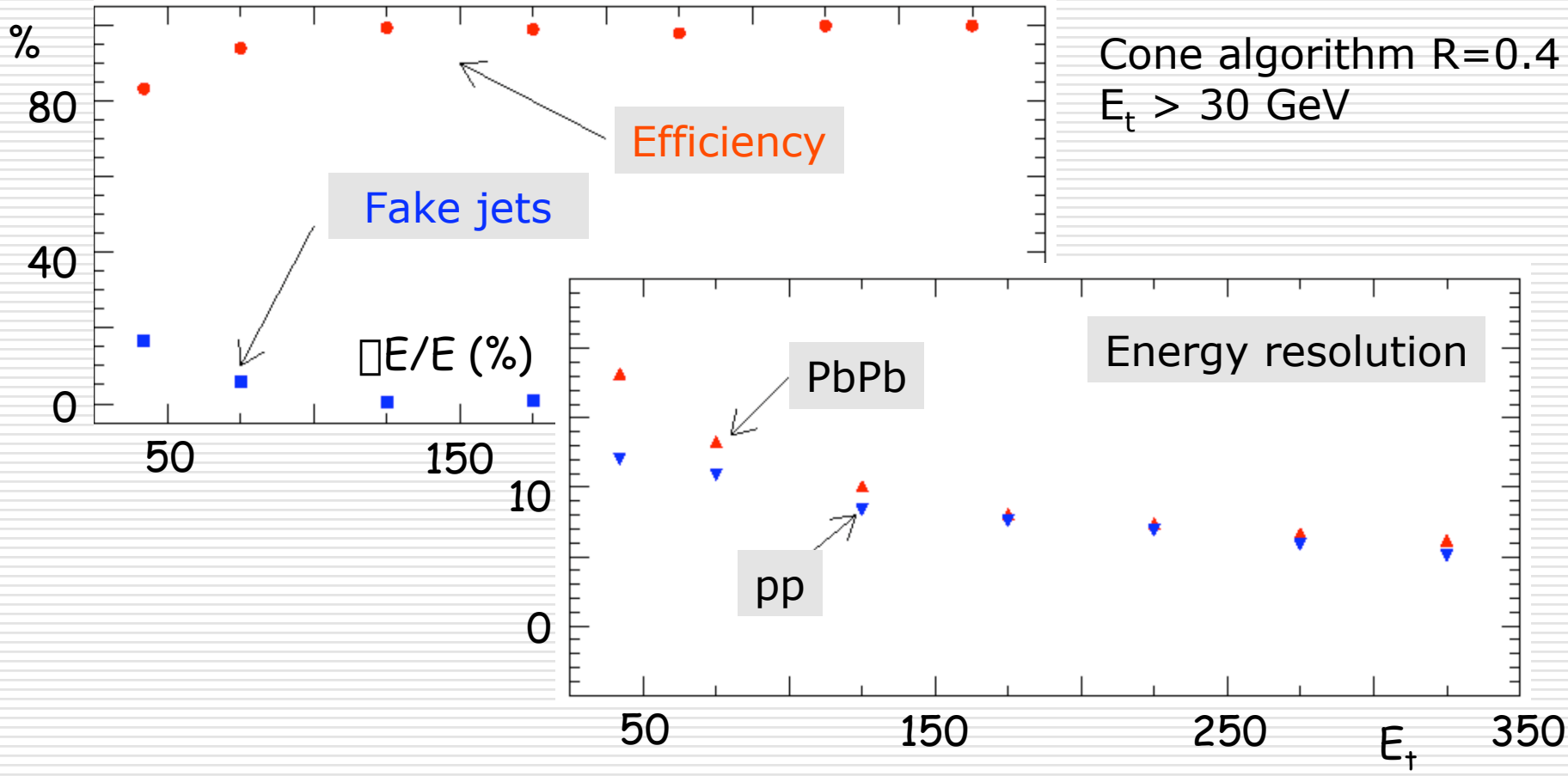


Performance by ATLAS



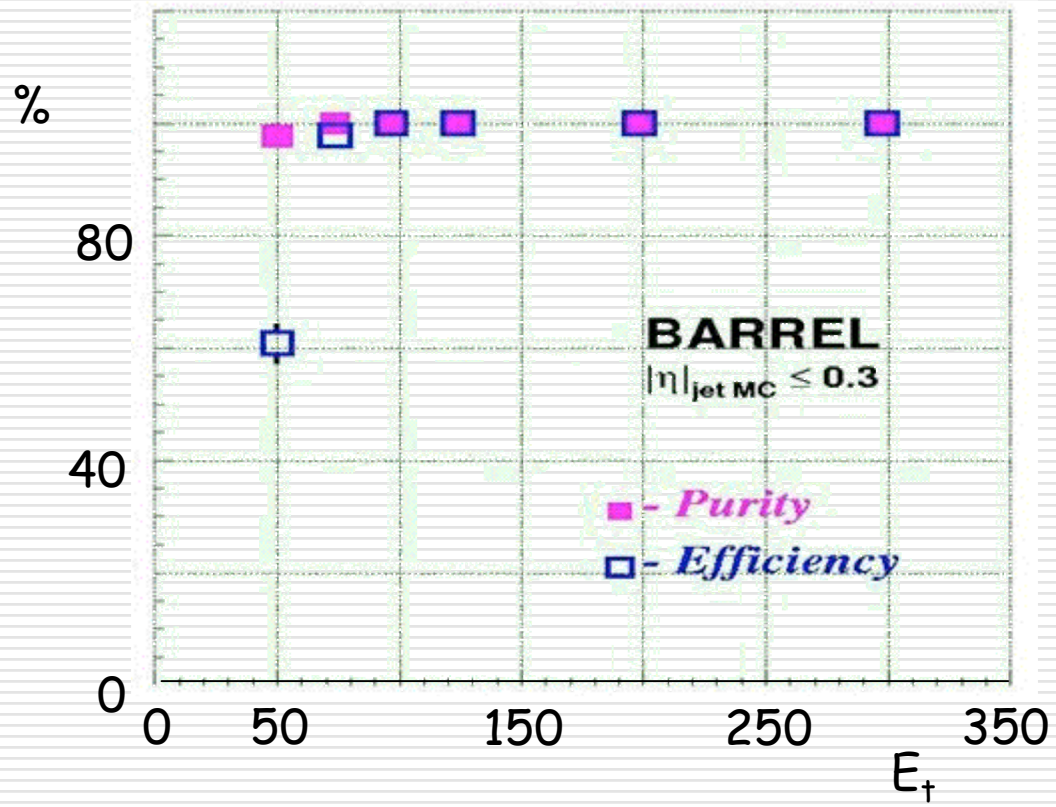
Cone algorithm R=0.4
E_t > 30 GeV

Performance by ATLAS



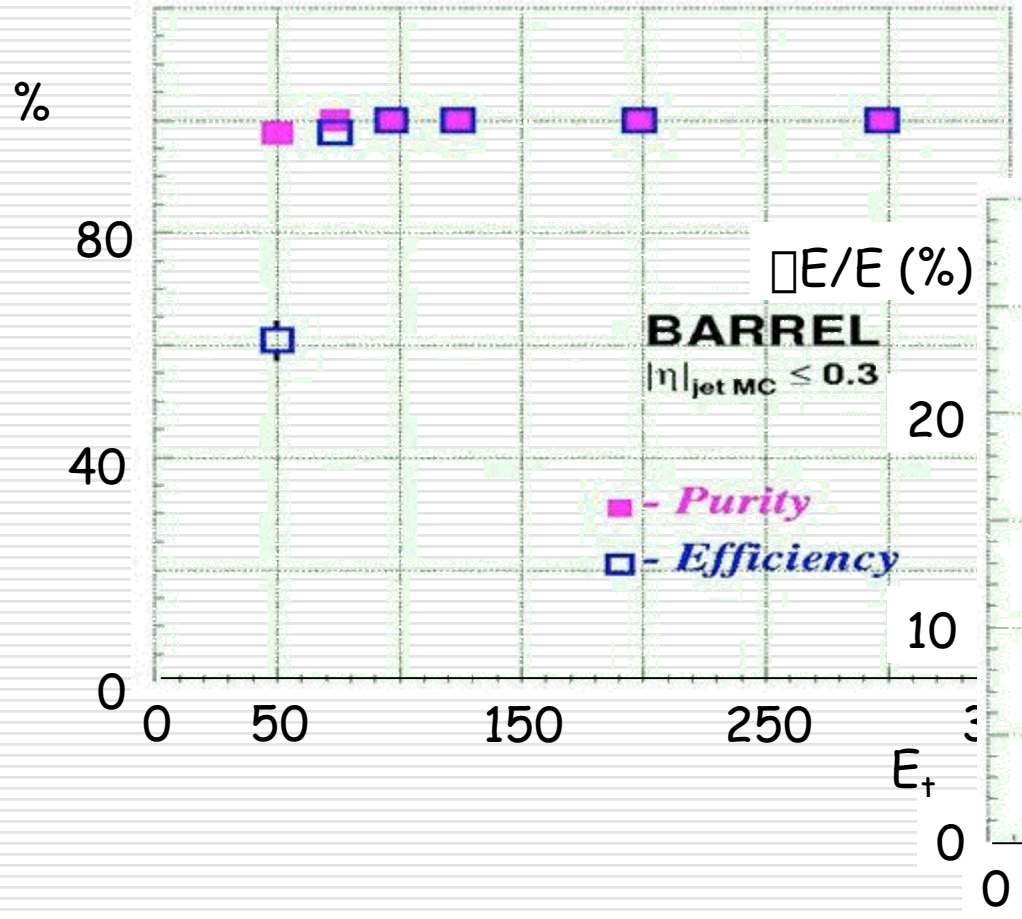
Cone algorithm R=0.4
E_t > 30 GeV

Performance by CMS

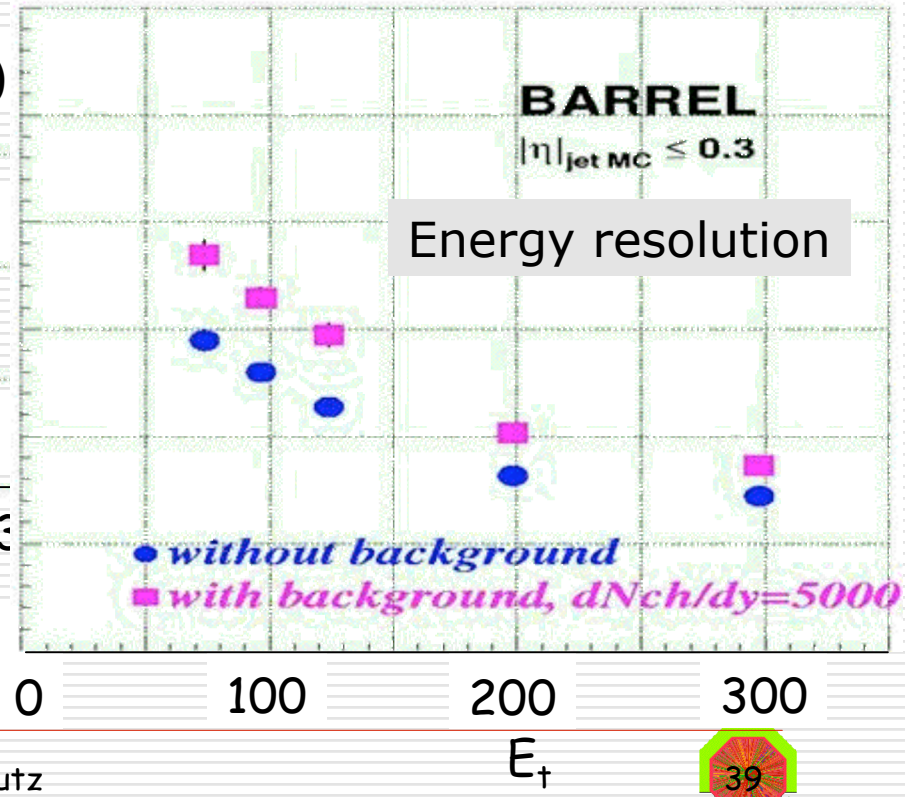


Cone algorithm R=0.5
E_t > 30 GeV

Performance by CMS

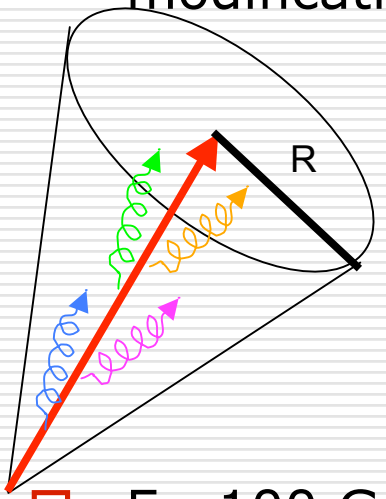


Cone algorithm R=0.5
E_t > 30 GeV

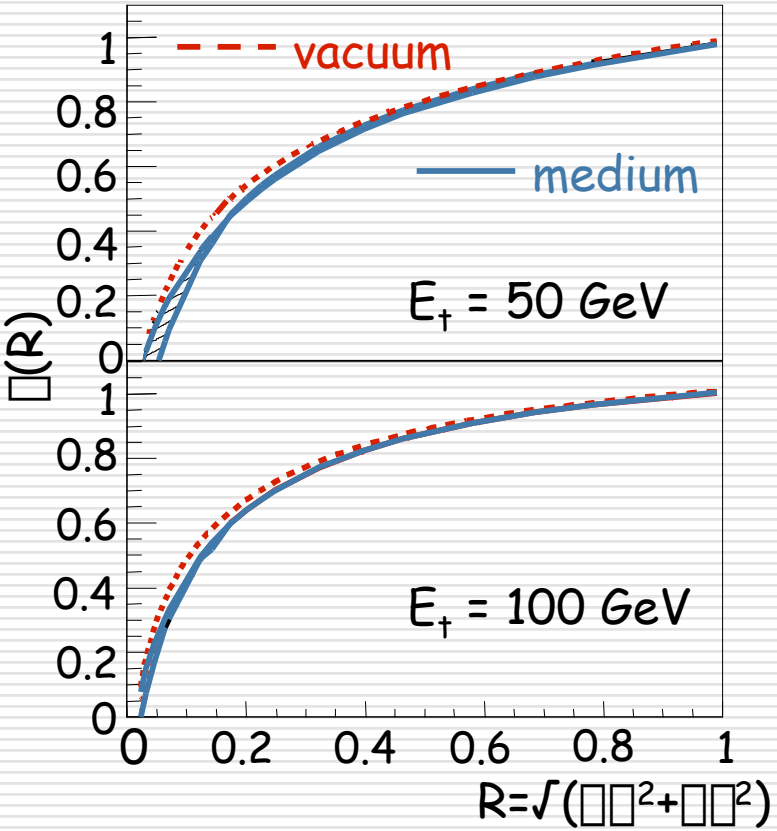


Jet quenching

- Excellent jet reconstruction… but challenging to measure medium modification of its shape…



Medium induced redistribution of jet energy occurs inside cone.



C.A. Salgado, U.A. Wiedemann hep-ph/0310079

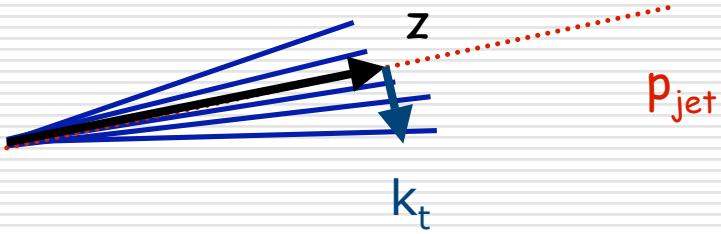
- E_t=100 GeV (reduced average jet energy fraction inside R):
  - Radiated energy ~20%
  - R=0.3 □E/E=3%
  - E_t^{UE} ~ 100 GeV

Exclusive jets: Redistribution of jet energy

- Jet shape: distance R to leading particle;
- p_T of particles for $R < R_{max}$;
- Multiplicity of particles for $R < R_{max}$;
- Heating: $k_T = p \cdot \sin(\angle(\text{particle, jet axis}))$;
- Forward backward correlation: $\angle\angle(\text{particle, jet axis})$;
- Fragmentation function: $F(z)=1/N_j \cdot dN_{ch}/dz$ $z=p_t/p_{jet}$.

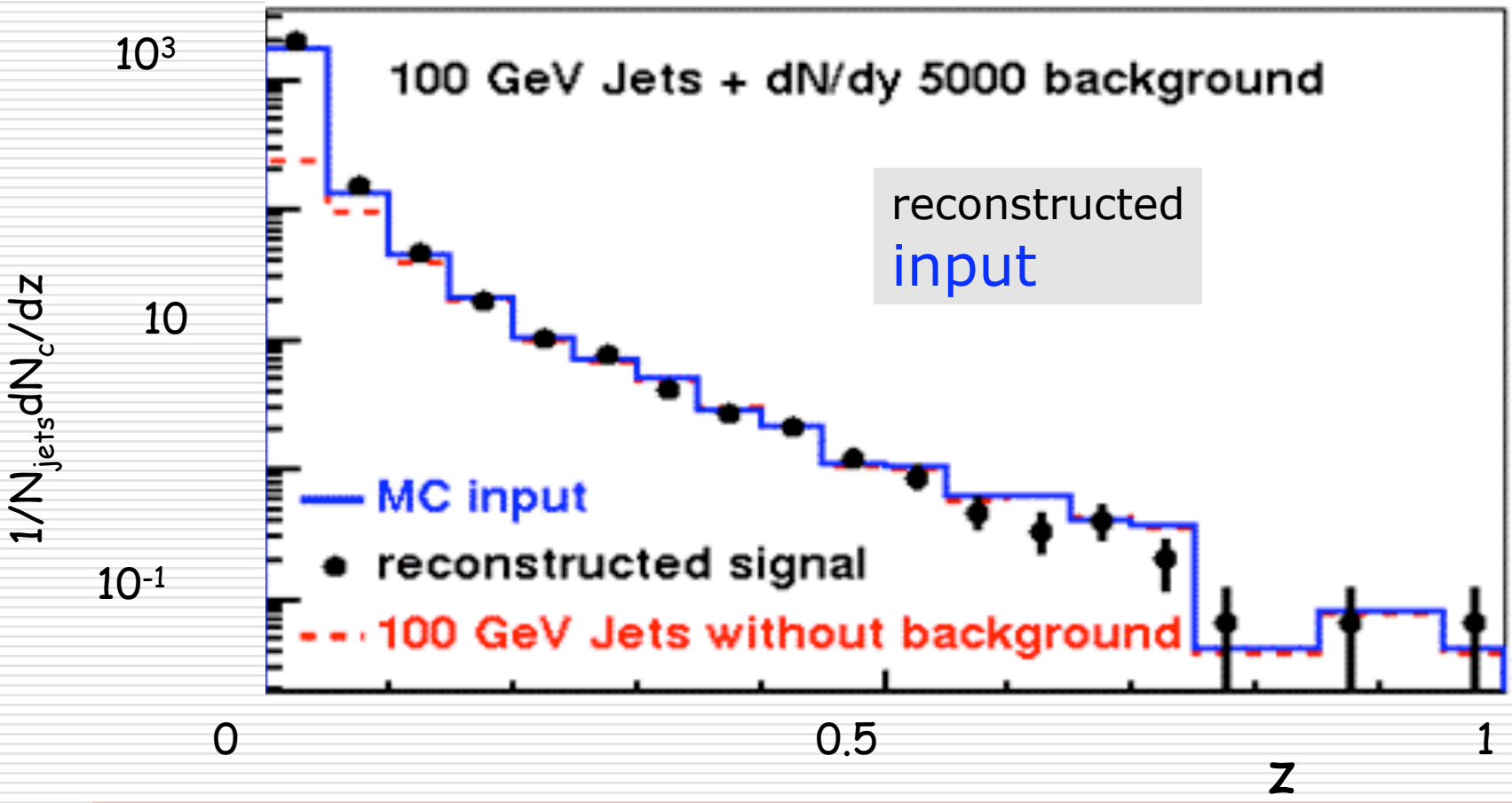
Requires high quality tracking down to low p_t .

Fragmentation functions

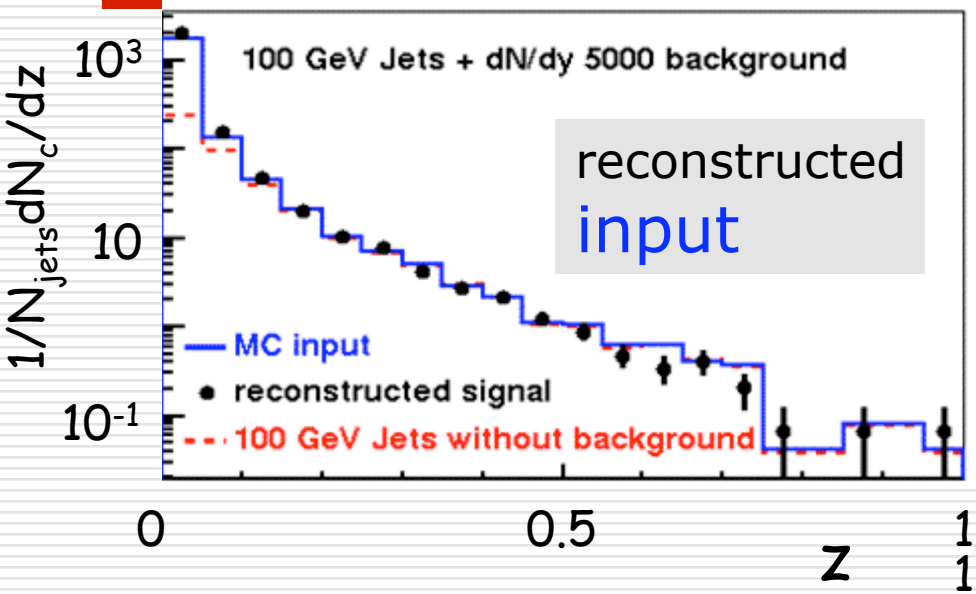


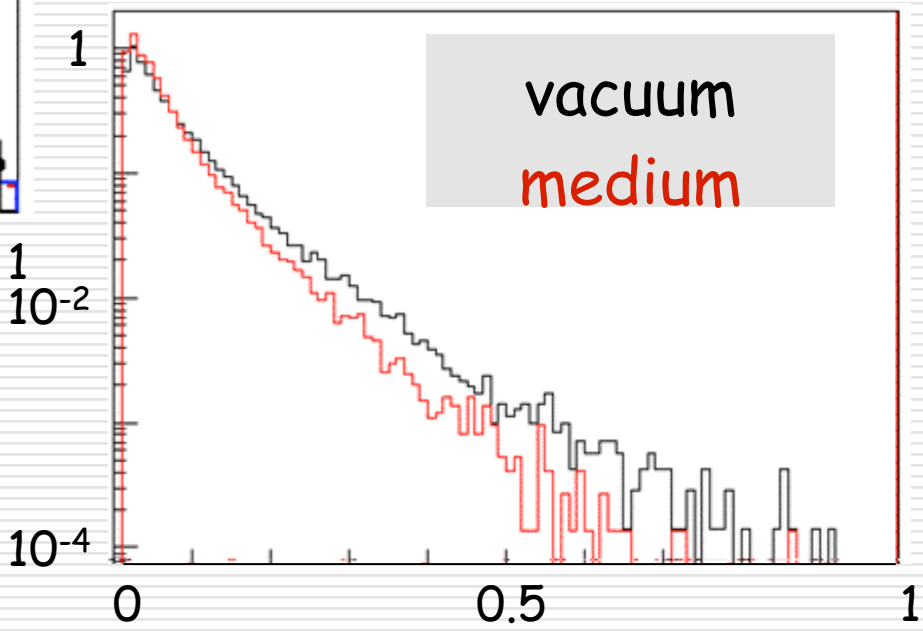
$z = p_t / p_{jet}$

Fragmentation functions



$z=p_t/p_{jet}$ Fragmentation functions





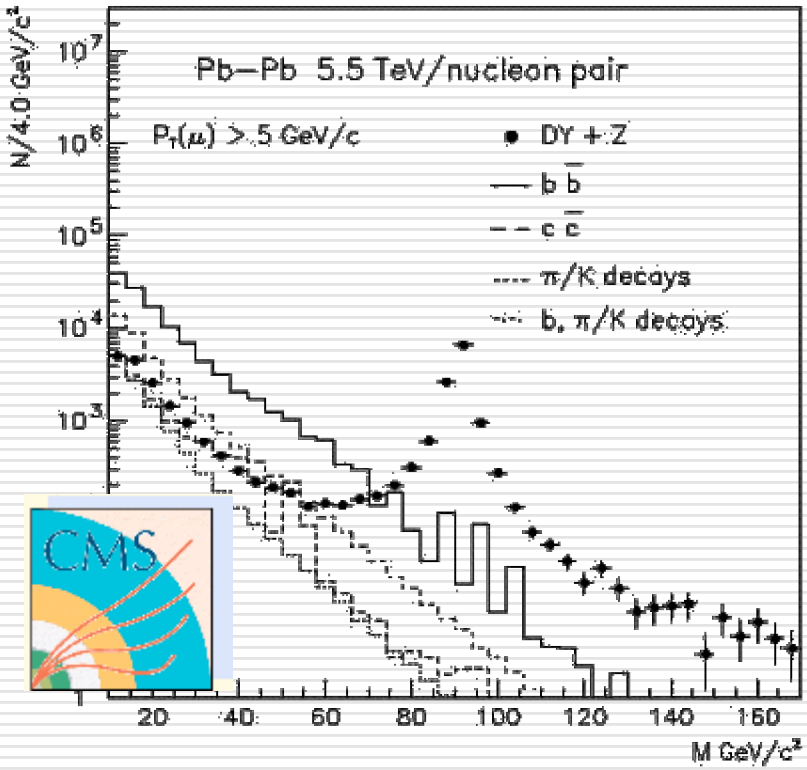
Exclusive jets: Tagging

- Direct measurement of jet energy: □, □*, Z^0

Channel	Statistics (evts/month)	p_t (GeV)
□-jet	10^6 6□10^3	50 100
□*(□ _$^+$ _$^-$)- jet	10^4	50
Z^0 (□ _$^+$ _$^-$)-jet	500 600	40 50

Exclusive jets: Tagging

- Direct measure of jet energy: □, □*, Z^0



Low (< 10%) background as compared to □/□^{0}

Heavy flavor quenching observables

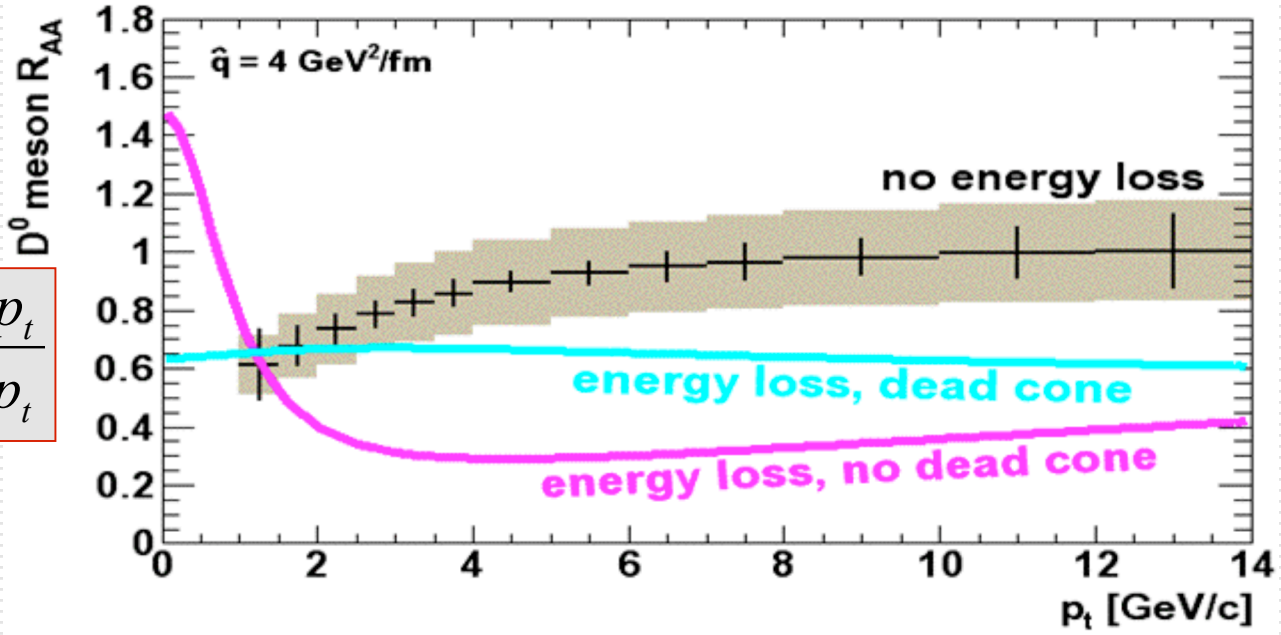
- Inclusive:
  - Suppression of dilepton invariant mass spectrum ($D\bar{D} \rightarrow l^+l^-$, $B\bar{B} \rightarrow l^+l^-$, $B \rightarrow D^+ \rightarrow l^+)l^-$
  - Suppression of lepton spectra
- Exclusive jet tagging:
  - High- p_T lepton ($B \rightarrow Dl$) & displaced vertex
  - Hadronic decay (ex. $D^0 \rightarrow K^-\pi^+$) & displaced vertex

D quenching ($D^0 \to K^-\pi^+$)

nucl-ex/0311004

- Reduced

$$R_{AA} = \frac{1}{N_{coll}} \cdot \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t}$$



- Ratio D/hadrons (or D/π^0) enhanced and sensitive to medium properties.

D quenching (D^0 → $K^-\pi^+$)

- Reduced

$$R_{AA} = \frac{1}{N_{coll}} \cdot \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t}$$

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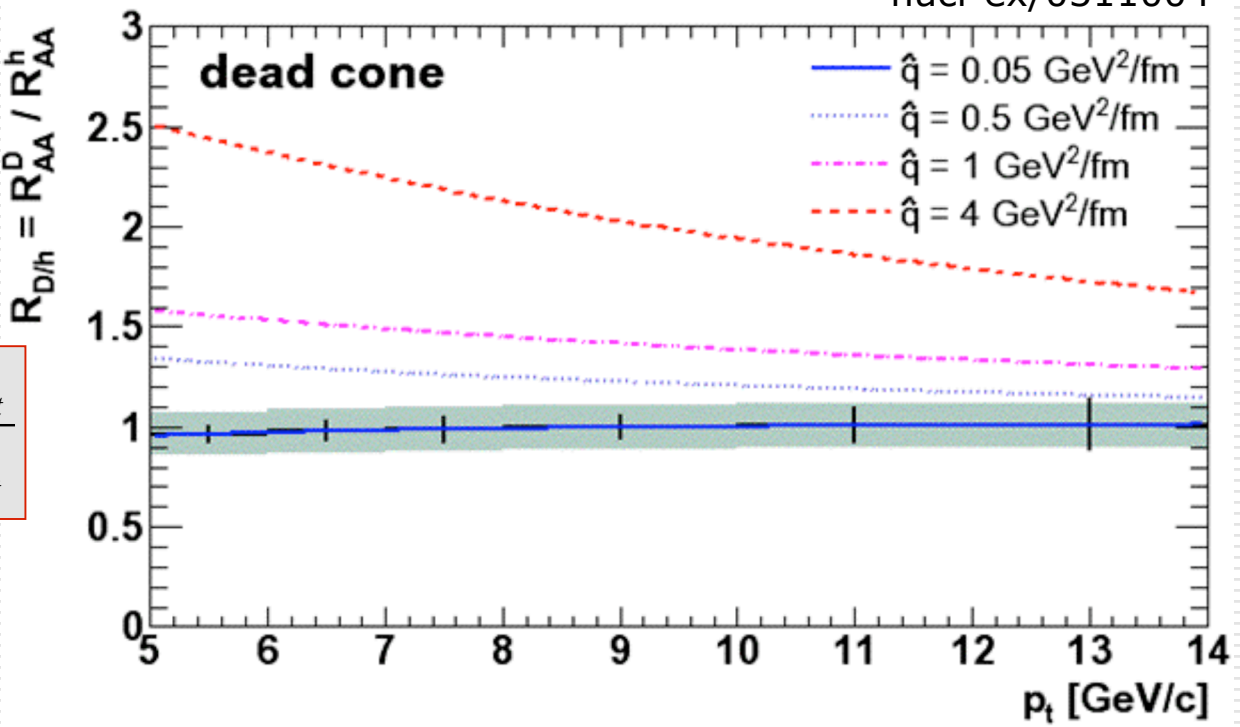
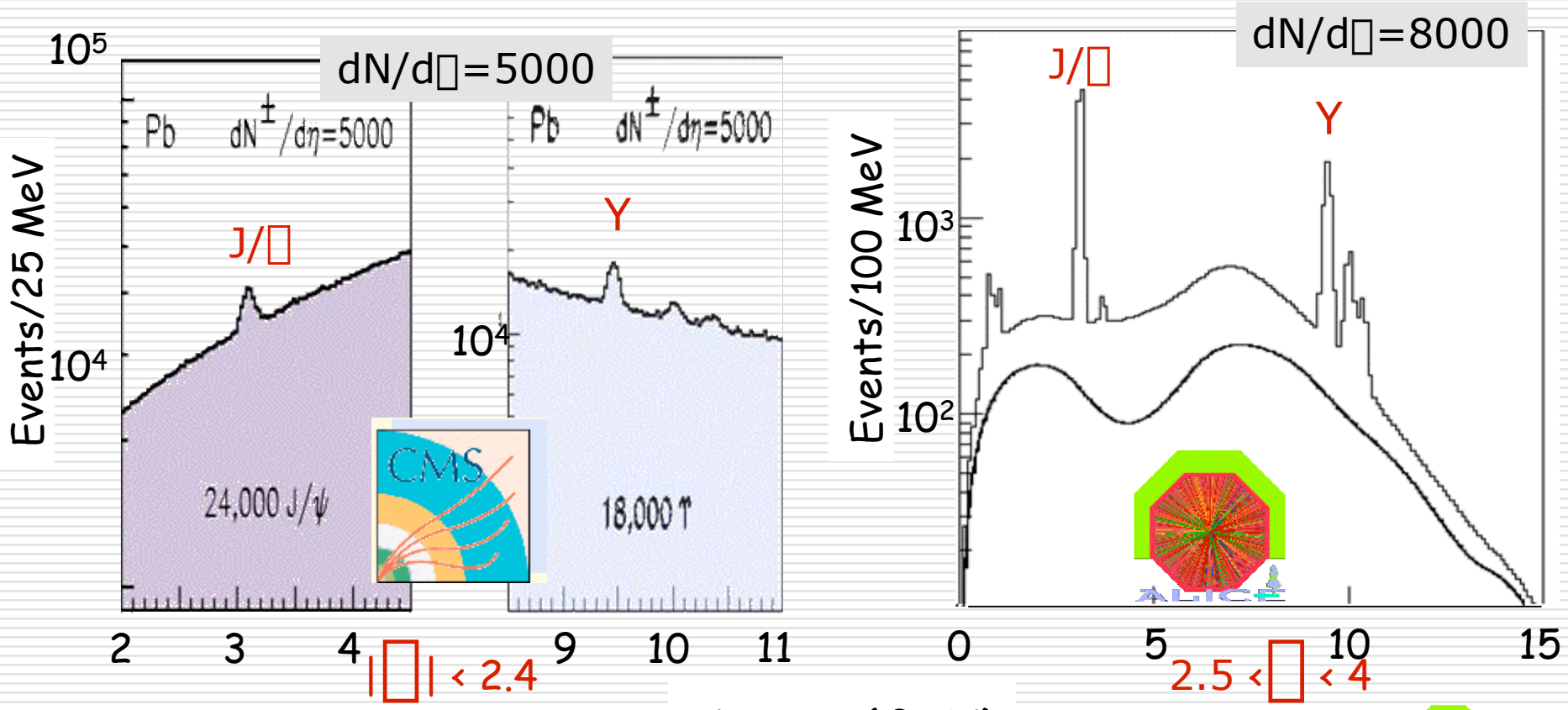


- Ratio D/hadrons (or D/π^0) enhanced and sensitive to medium properties.

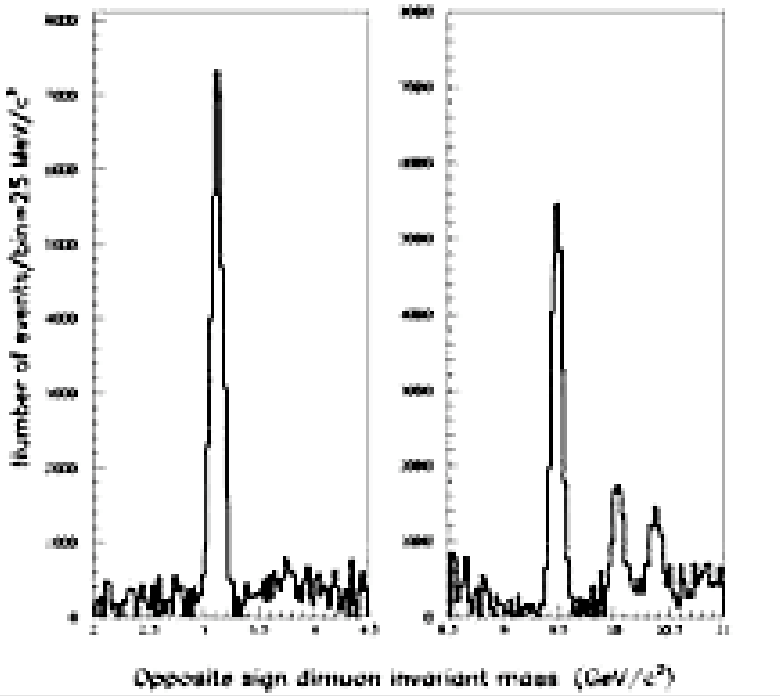
c/b Quarkonia

- 1 month statistics of PbPb $\sqrt{s_{NN}}$=5.5 TeV;



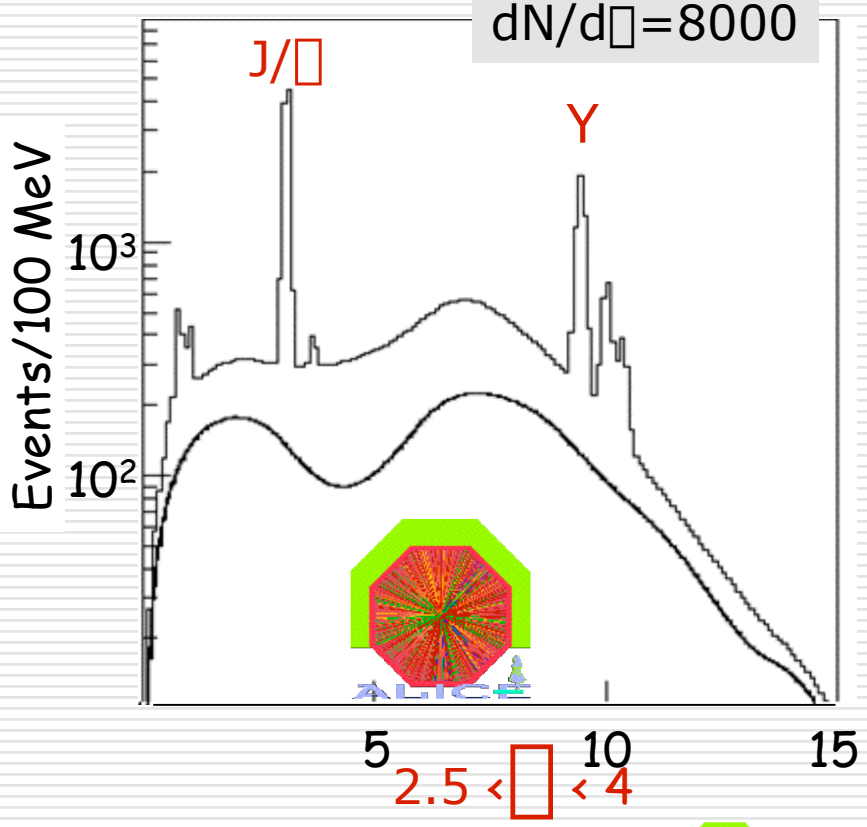
c/b Quarkonia

- 1 month statistics of PbPb $\sqrt{s_{NN}}$=5.5 TeV;



|η| < 2.4

dN/dη=8000



2.5 < η < 4

Looking forward

- For a timely completion of LHC and experiments construction in April 2007;
  - Accelerators and experiments are today in the production phase.
- For an exciting decade of novel HI physics in continuation of the SPS and complementary to RHIC;
  - Detailed physics program, complementary between 1+2 experiments, takes shape (see PPRs, Yellow reports…).
- The 2004 challenge: demonstrate world-wide distributed Monte-Carlo production and data analysis.