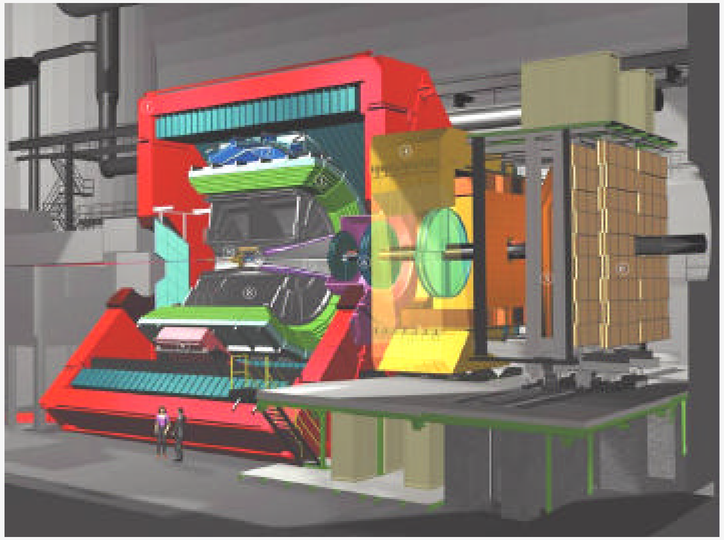
Heavy-Ion Physics @ LHC

The ALICE program

- Scientific objectives
- Strategy



Scientific objectives of HI physics

RHIC + GSI

- Study the QCD phase transition and the physics of the QGP state:

LHC

  - How to apply and extend the SM to a complex and dynamically evolving system of finite size;
  - Understand how collective phenomena and macroscopic properties emerge from the microscopic laws of elementary particle physics;
  - Answer these questions in the sector of strong interaction by studying matter under conditions of extreme temperature and density.

Novel aspects @ LHC:

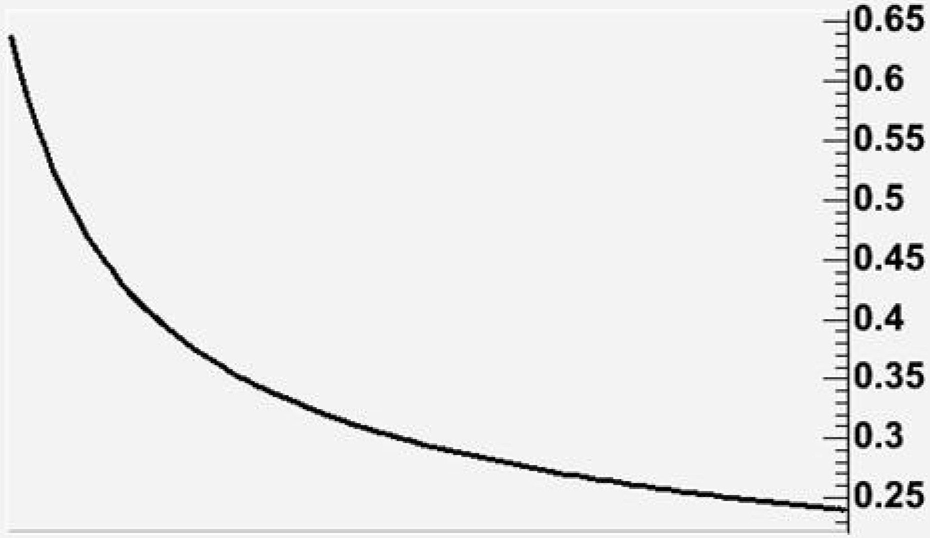
Quantitatively new regime

	SPS	RHIC	LHC	
v s_{NN} (GeV)	17	200	5500	X 28
dN_{ch}/dy	500	850	1500-8000	?
τ^0_{QGP} (fm/c)	1	0.2	0.1	faster
T/T_c	1.1	1.9	3.0-4.2	hotter
ε (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)	few 10^3	few 10^4	few 10^5	bigger

Novel aspects @ LHC:

Qualitatively new regime

- Thermodynamics of the QGP phase ≡ Thermodynamics of massless 3-flavor QCD.
- Parton dynamics (τ_{QGP}/τ_0>50-100) dominate the fireball expansion and the collective features of the hadronic final state.



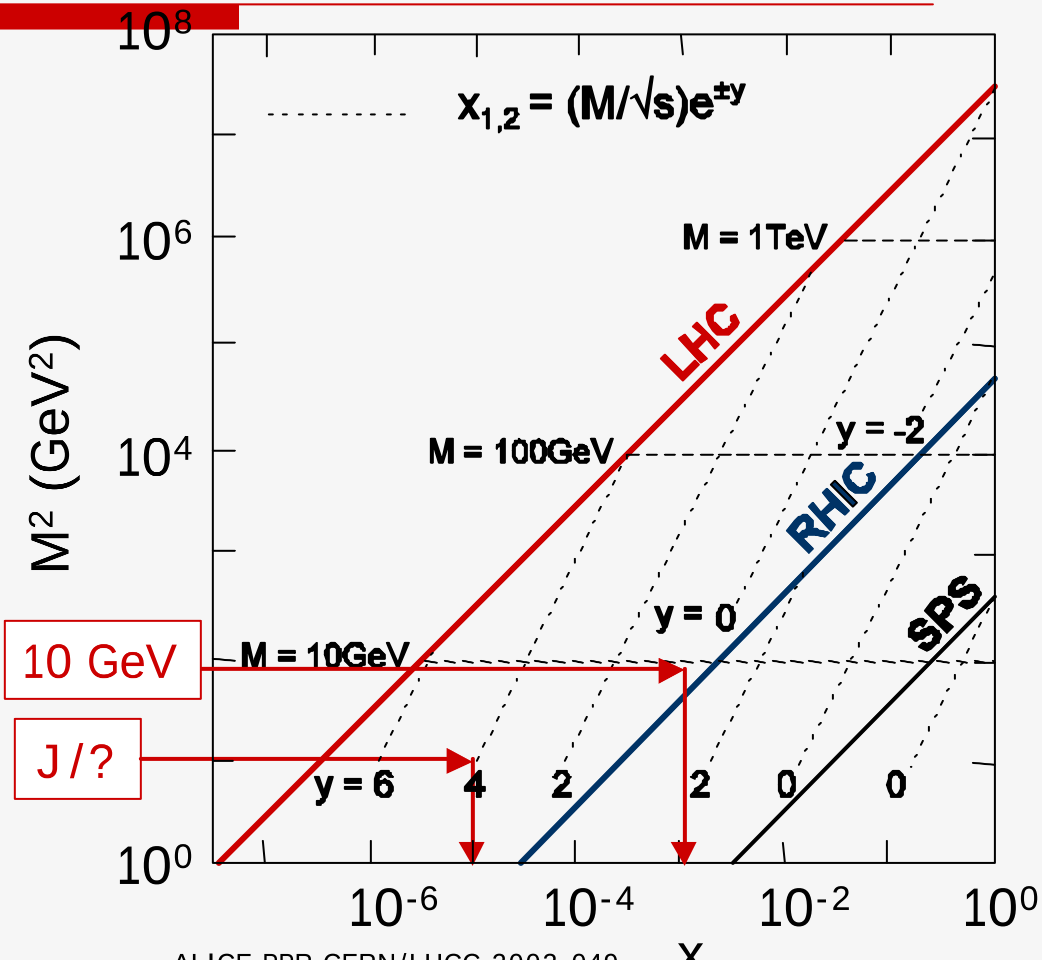
$\alpha_s(T)=4\pi/(18\log(5T/Tc))$

$m_u = m_d = m_s$
$m_u = m_d$
$m_u = m_d$; $m_s > m_{u,d}$
HQ suppressed $\exp(-m_{c,b,t}/T)$

Novel aspects @ LHC:

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=0.2$A^{1/6}$v s^{δ}= 2.7 GeV): evolution (non-linear ?) of a saturated gluon distribution which generates the bulk properties of the collision measured at mid-rapidity

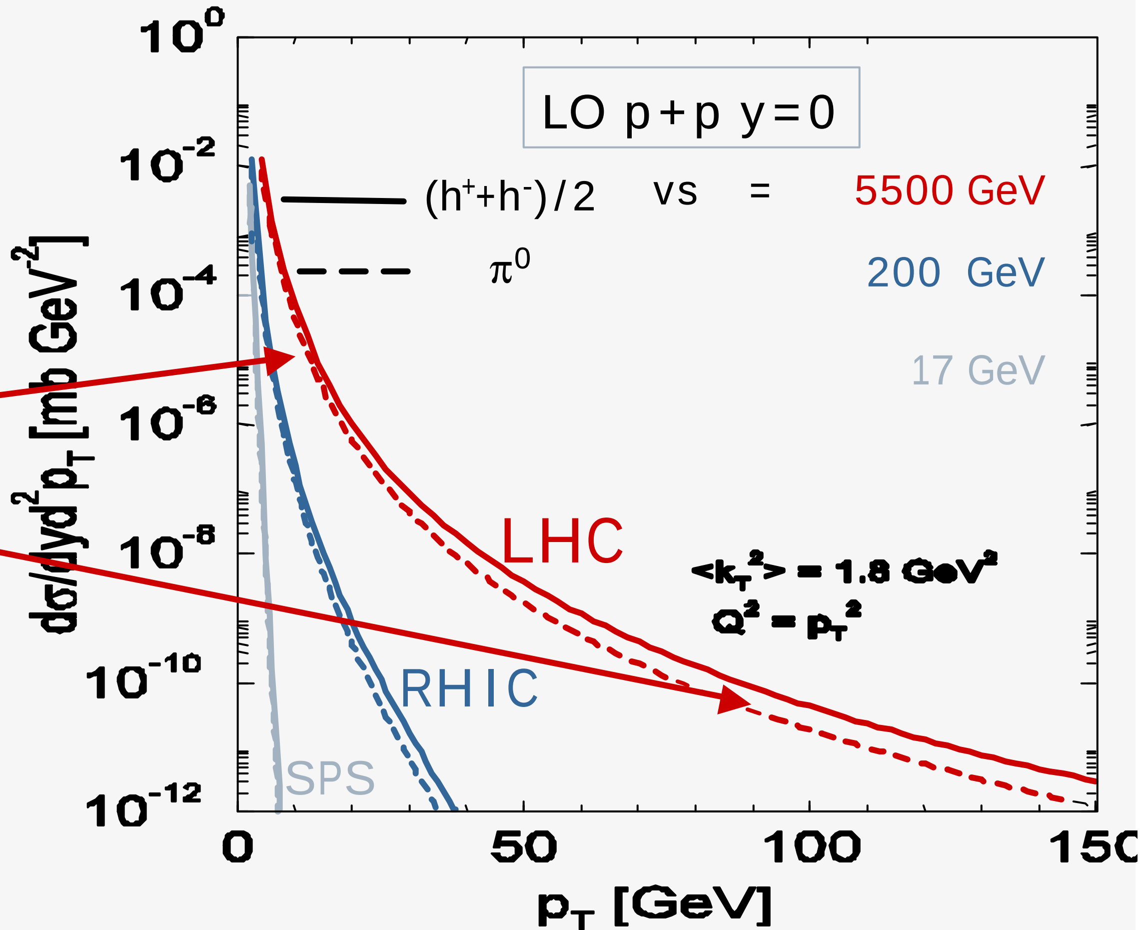


ALICE PPR CERN/LHCC 2003-049

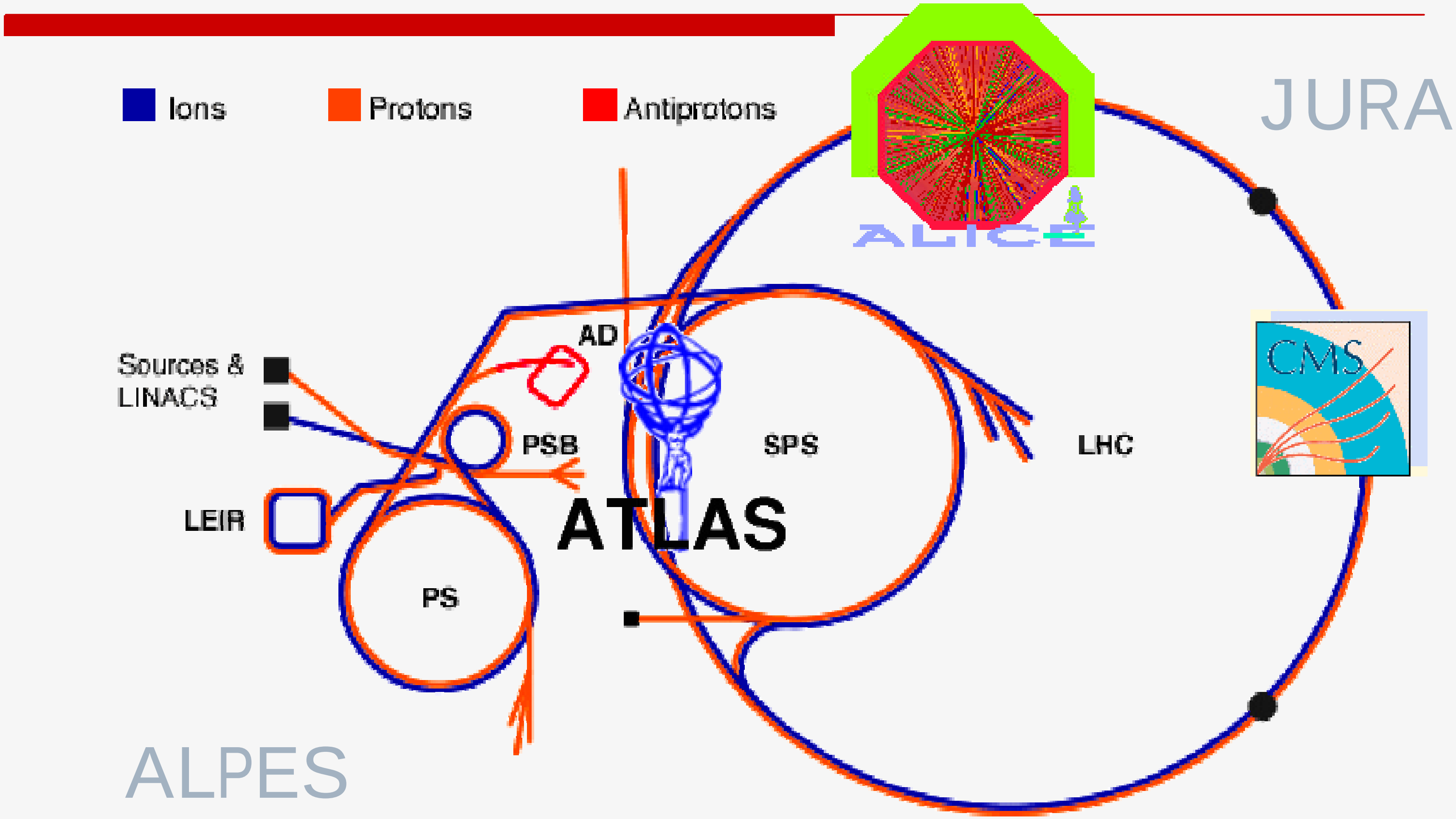
Novel aspects @ LHC:

Qualitatively new regime

- Hard processes contribute significantly to the total AA cross-section (s^{hard}/s^{tot} = 98%):
  - Bulk properties dominated by hard processes;
  - Very hard probes are abundantly produced.
- Weakly interacting probes become accessible (γ, Z^0, $W^{\pm}$).
- LHC will substantiate what RHIC cannot measure.

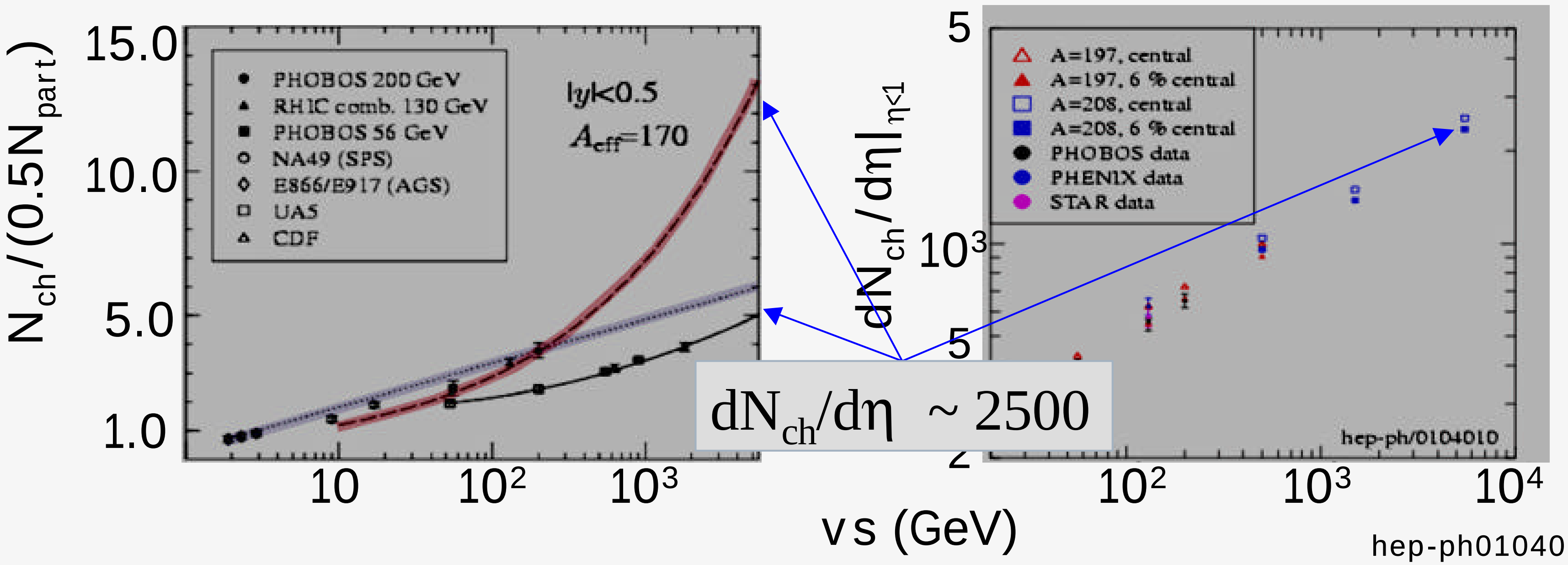


1+2 experiments



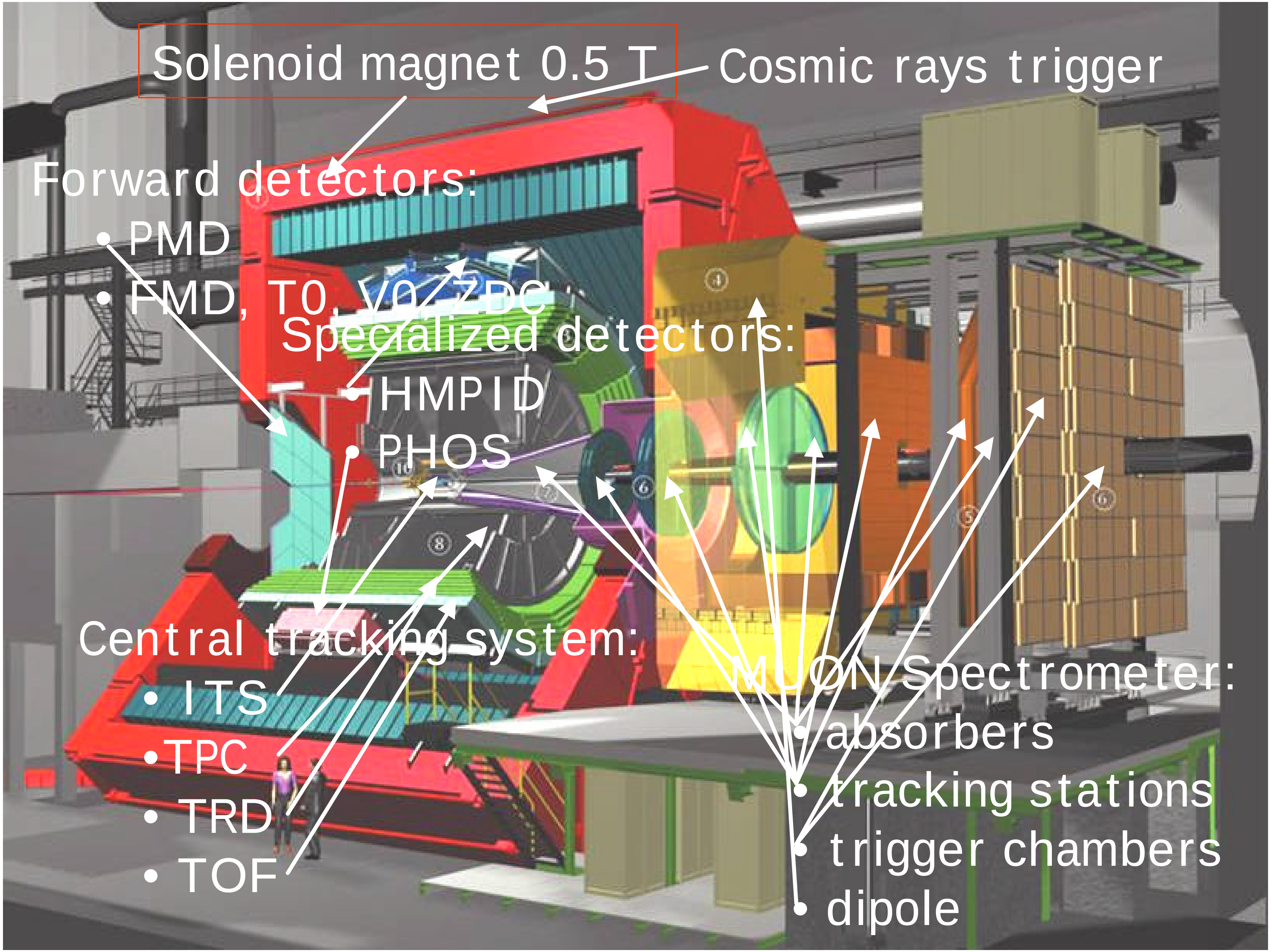
HI experiments

- Which particle multiplicity to expect at LHC ?



hep-ph0104010

- ALICE optimized for dN_{ch}/dY = 4000, checked up to 8000 (reality factor 2).

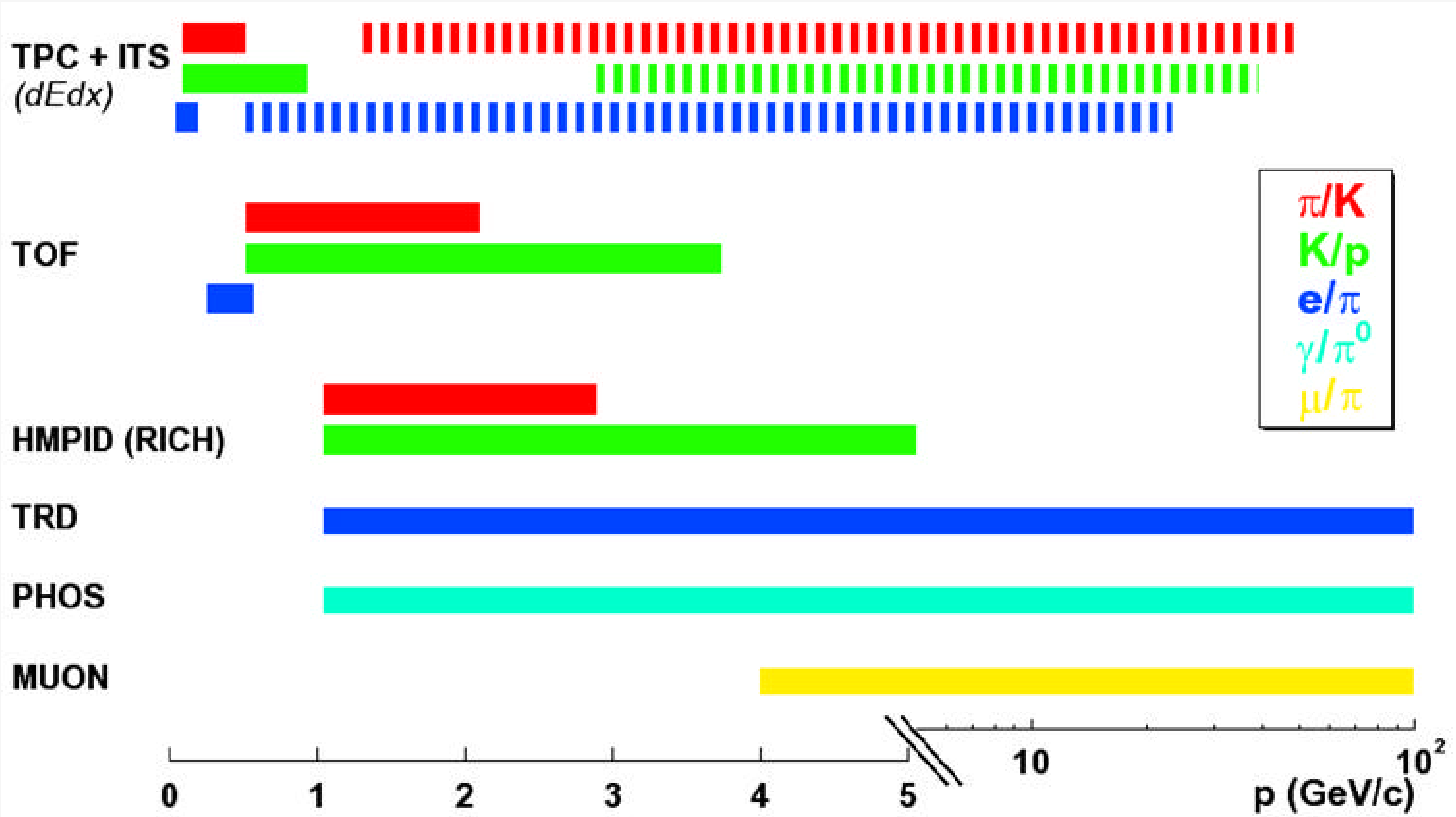

Solenoid magnet 0.5 T
Cosmic rays trigger
Forward detectors:
• PMD
• FMD, T0, V0, ZDC
Specialized detectors:
• HMPID
• PHOS
Central tracking system:
• ITS
• TPC
• TRD
• TOF
MUON Spectrometer:
• absorbers
• tracking stations
• trigger chambers
• dipole

ALICE: the dedicated HI experiment

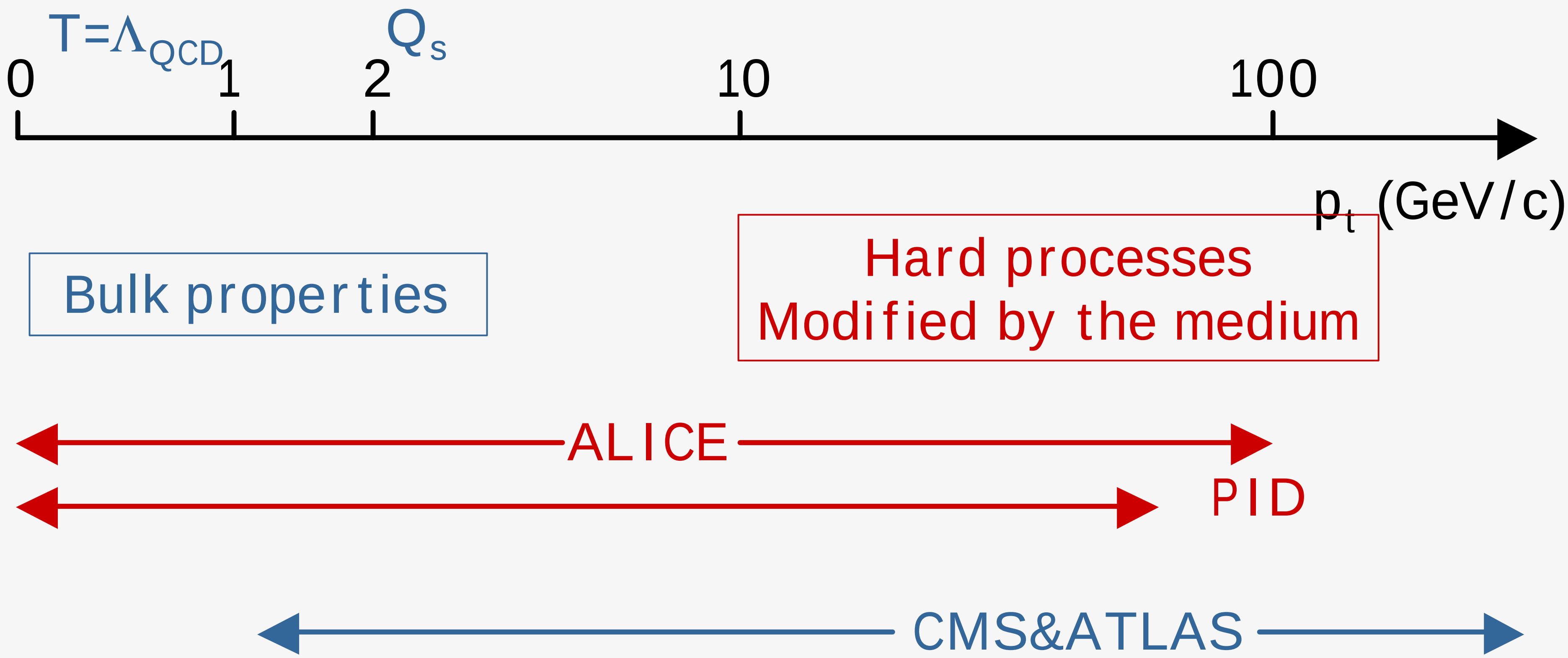
- Measure flavor content and phase-space distribution event-by-event:
  - Most (2π * 1.8 units η) of the hadrons (dE/dx + ToF), leptons (dE/dx, transition radiation) and photons (high resolution EM calorimetry);
  - Muons at large rapidities ($2.5 < \eta < 4$)
  - Track and identify from very low (< 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



1+2 Experiments



QGP probes: hard processes modified by the medium

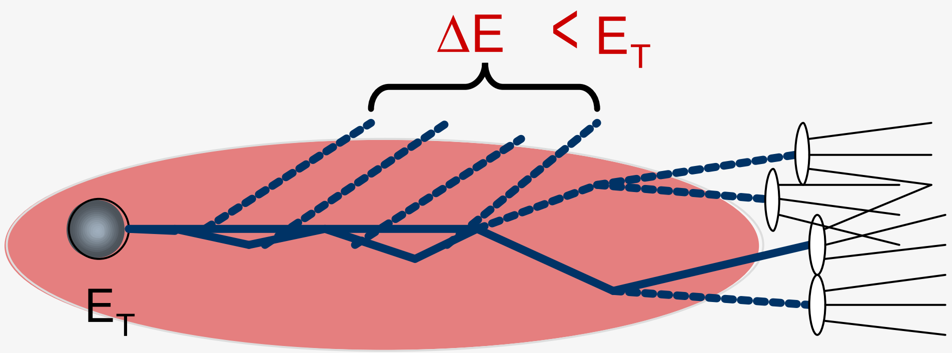
$$Q \gg \Lambda_{QCD}, T, Q_s \Rightarrow \Delta\tau, \Delta r \sim 1/Q$$

- Jet tomography:
  - 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.

DIS of QGP: Jet tomography

Medium modified hadronization

Hadronization in vacuum



hadronic final state

- does equilibration occur in the medium ?
- are the degrees of freedom partonic or hadronic ?

$L_{hadr} \sim E_T / Q^2_{hadr} > L_{medium}$

$L_{medium} < L_{therm} \sim \sqrt{E_T / \hat{q}} < L_{hadr}$

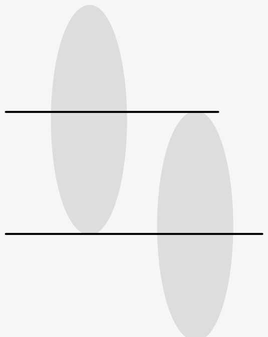
Verified at $p_T^{parton} > 10$ GeV/c ($p_T^{hadron} > 6$ GeV/c)

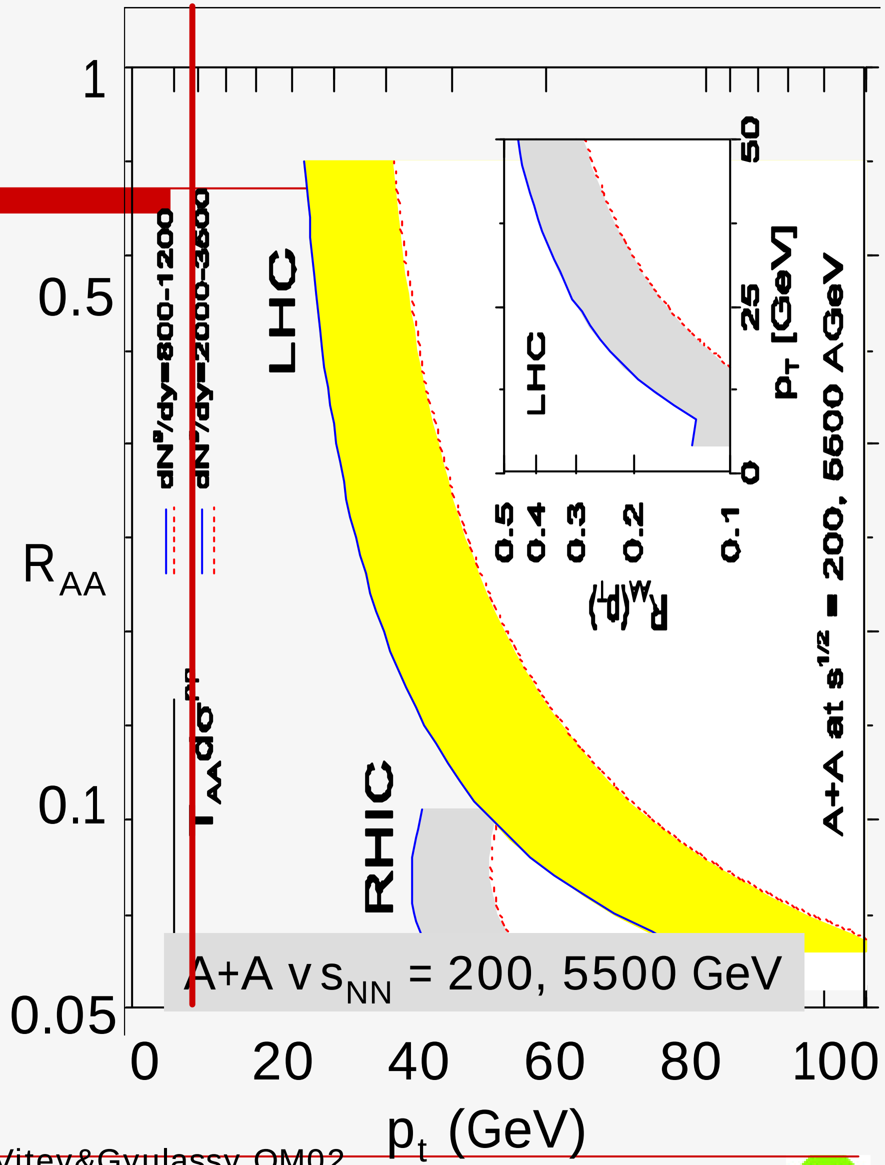
Suppression of leading hadron

- Nuclear modification factor (compare pp, pA and AA):

$$R_{AA}(p_T,h)=\frac{dN^{AA}/dp_T dh}{n_{coll}\, dN^{NN}/dp_T dh}$$

$$n_{coll}=\frac{T_{AA}(b)\sigma_{NN}}{\sigma_{AA}(b)}$$

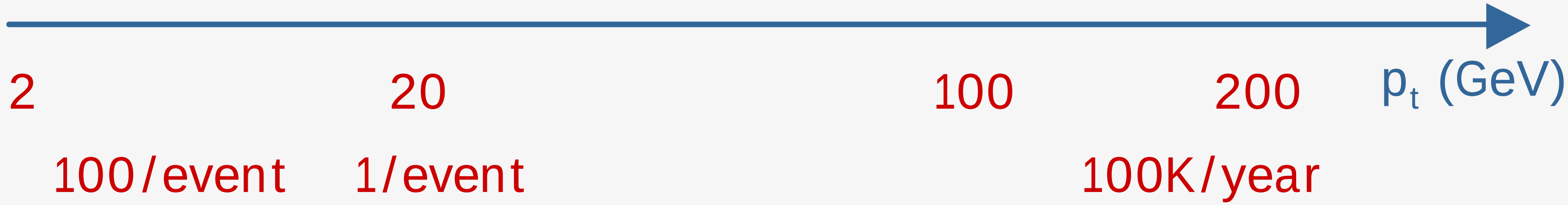


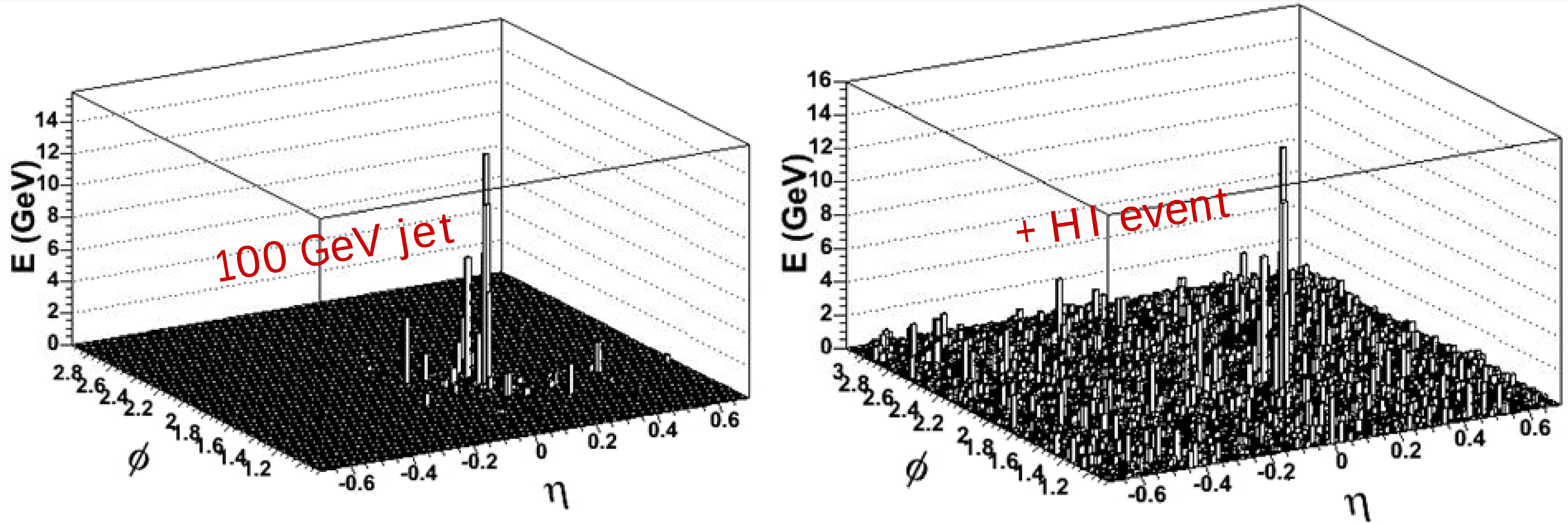


Vitev&Gyulassy QM02

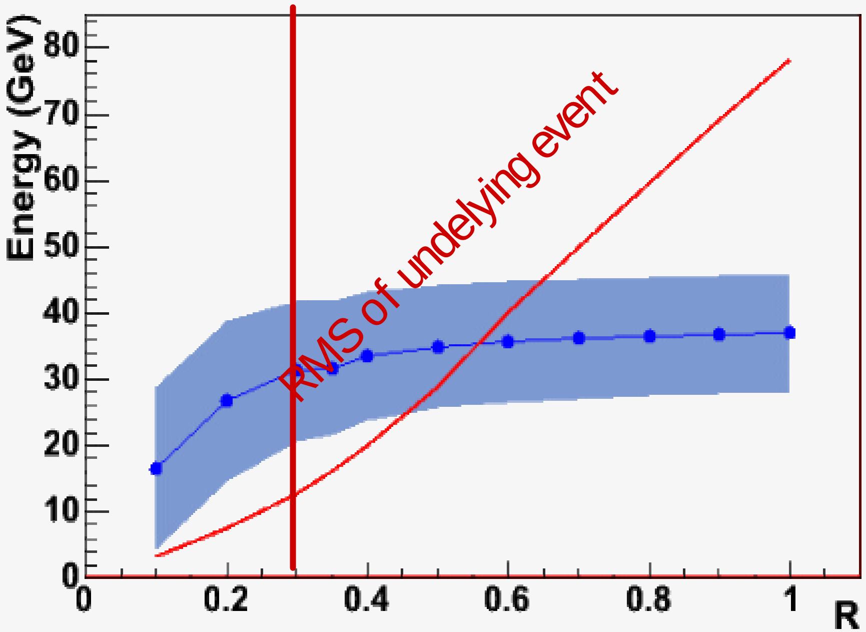
Jets reconstruction

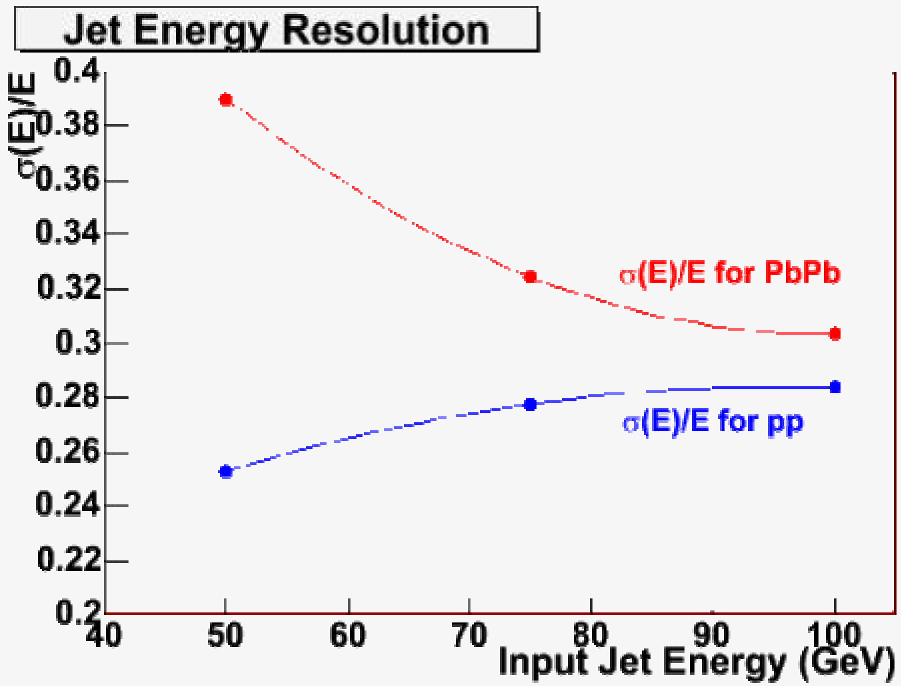
- Jets are produced copiously.





Jet reconstruction

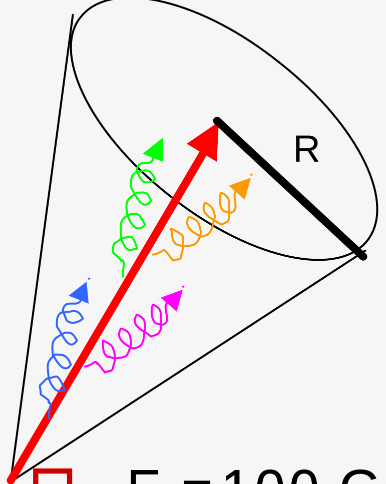




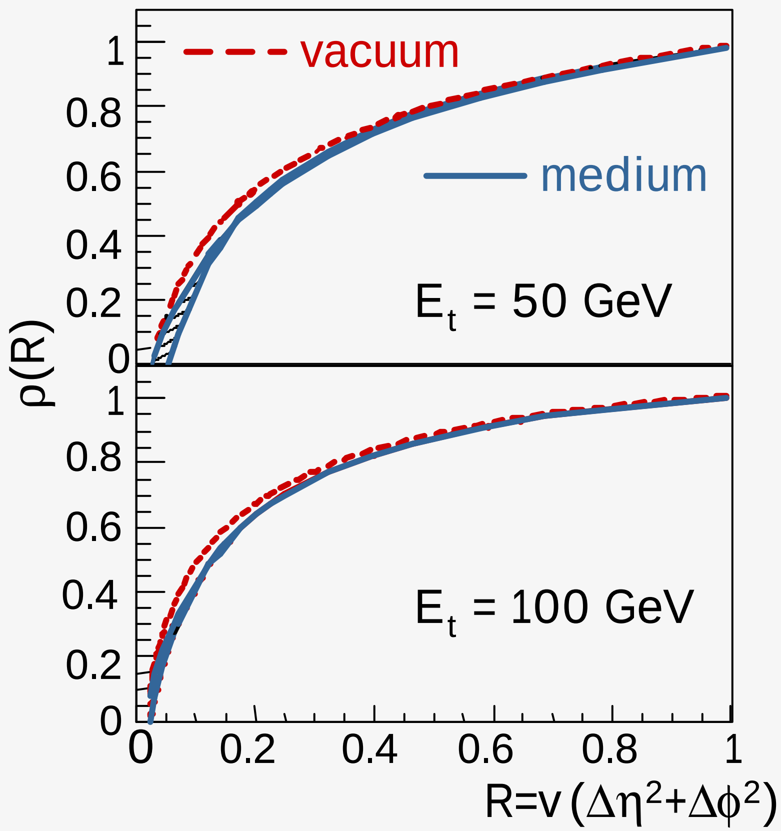
- Seed Energy: 4.6 GeV
- Minimum jet energy: 14 GeV
- Track p_T-cut: 2GeV/c

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 $\Delta E/E$=3%
  - E_t^{UE} ~ 100 GeV

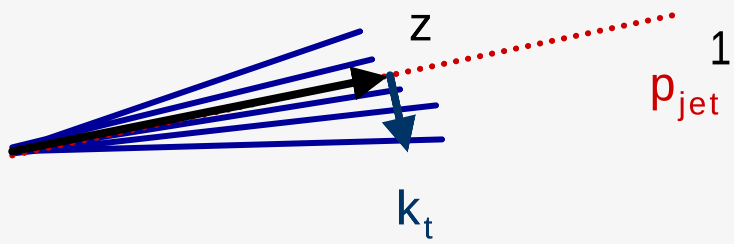
Exclusive jets: Redistribution of jet energy

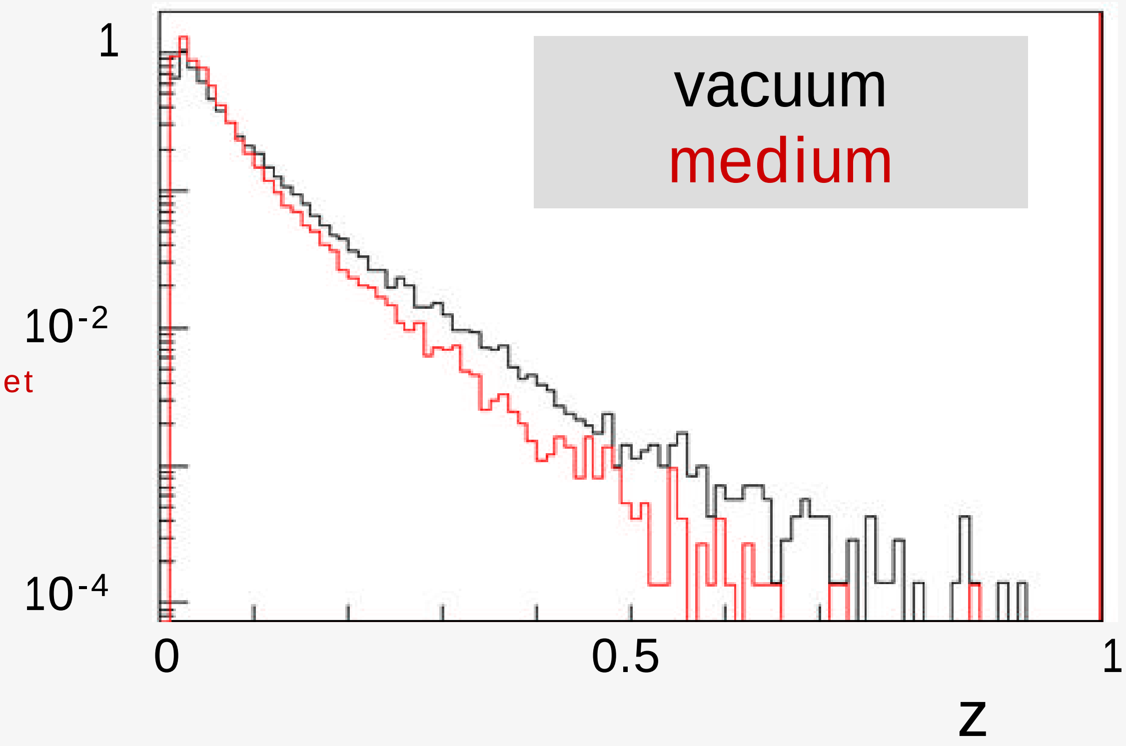
- Jet shape: distance R to leading particle;
- p_T of particles for $R < R_{max}$;
- Multiplicity of particles for $R < R_{max}$;
- Heating: $k_T = p \times \sin(\theta(\text{particle, jet axis}))$;
- Forward backward correlation: $\Delta\phi$(particle, jet axis);
- Fragmentation function: $F(z)=1/N_j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

Requires high quality tracking down to low p_t .

$z=p_t/p_{jet}$

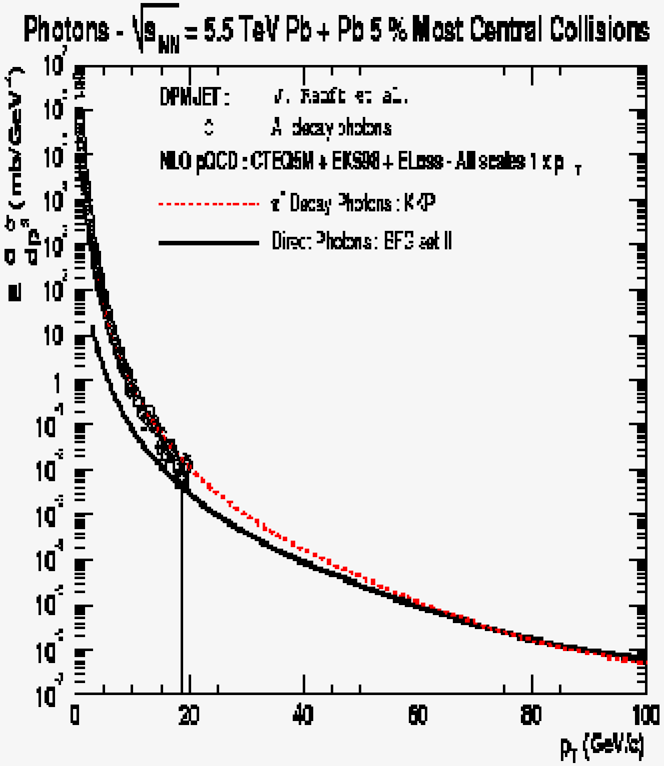
Fragmentation functions



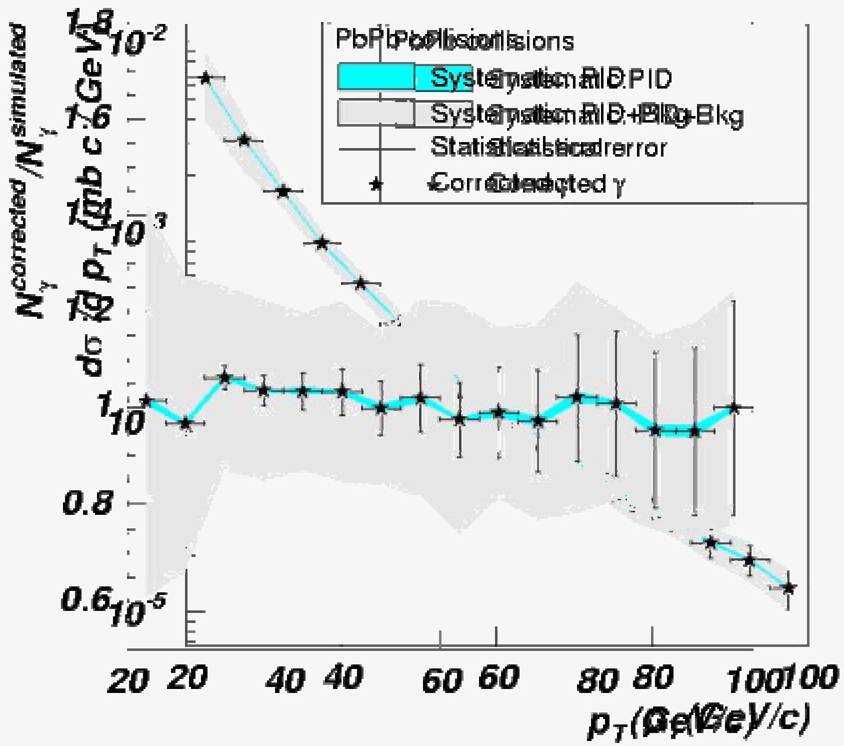


Direct photon identification

Predictions 2004

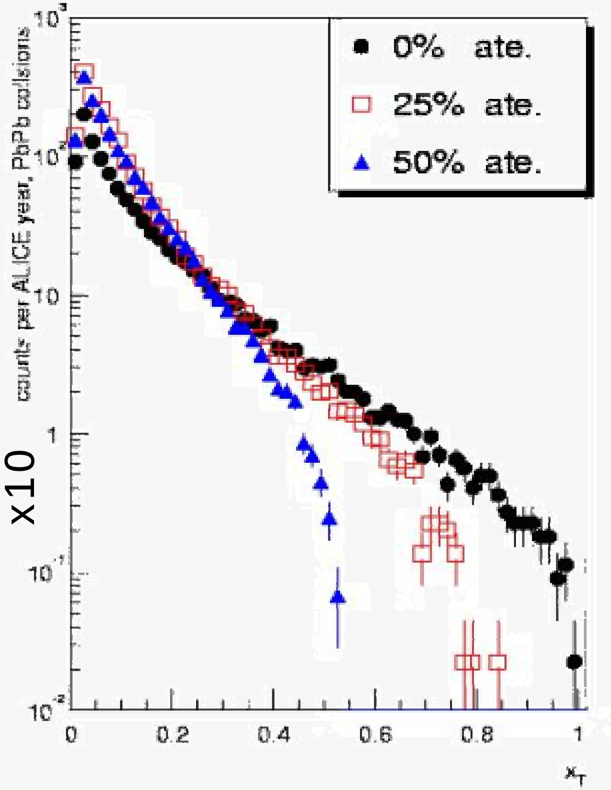


Measurement after 1 HI year



Exclusive jets: Tagging

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

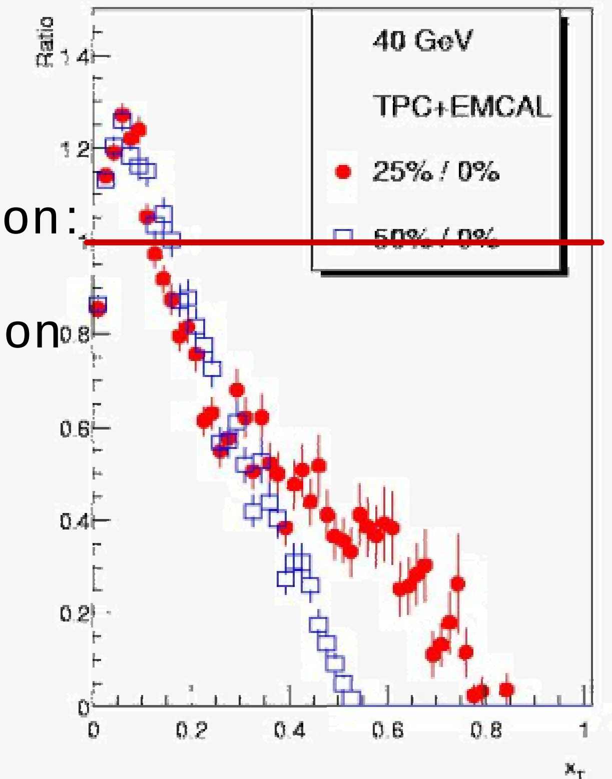


E_γ = 40 GeV

Jet in opposite direction:

- fragmentation function
- R_{AA}

$z = p_T/E_\gamma$



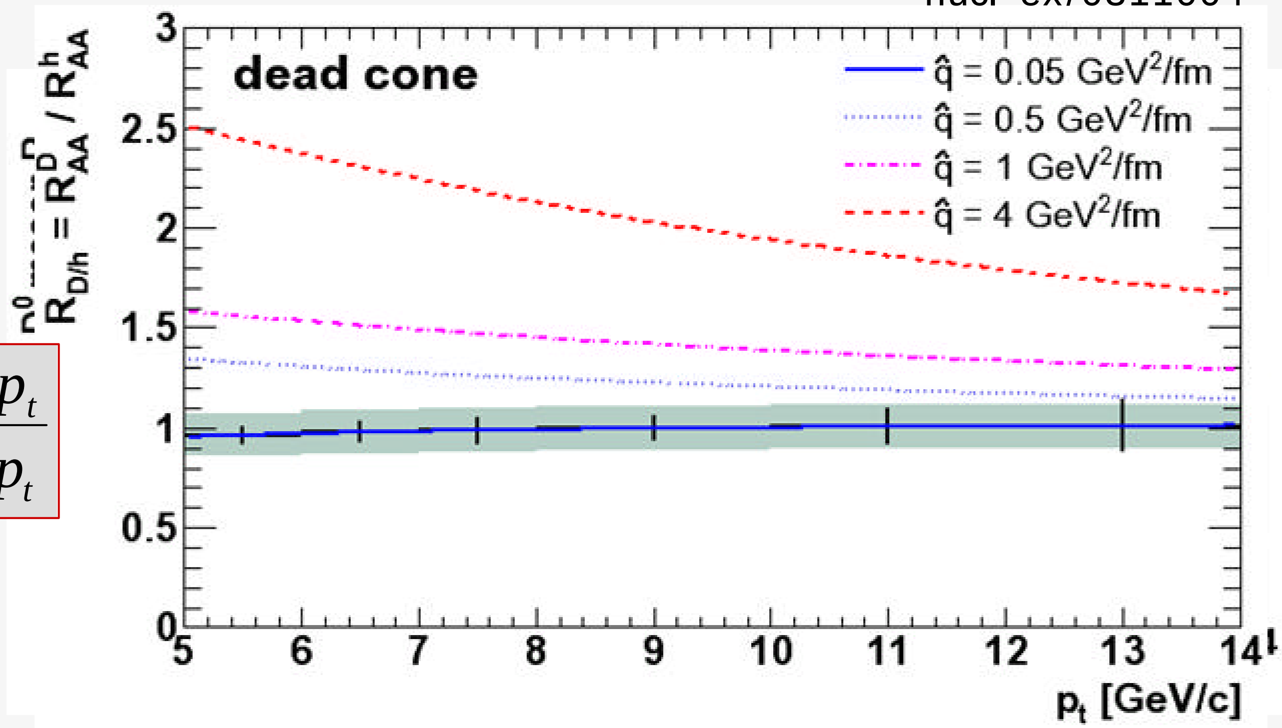
Heavy flavor quenching observables

- 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? Dlν) & displaced vertex
  - Hadronic decay (ex. $D^{0}\rightarrow K^{-}\pi^{+}$) & displaced vertex

D quenching (D^0 →K$^-\pi^+$)

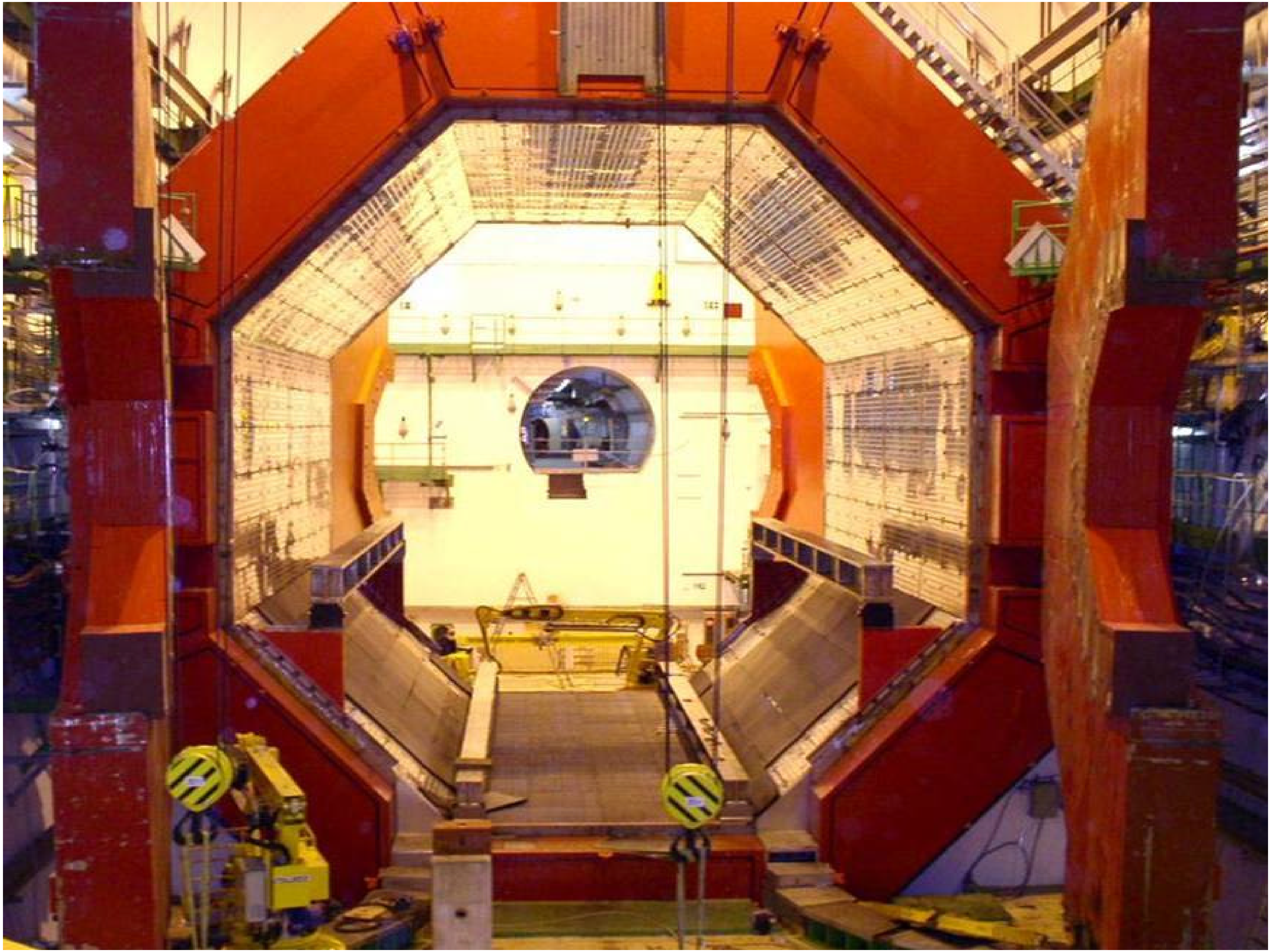
nucl-ex/0311004

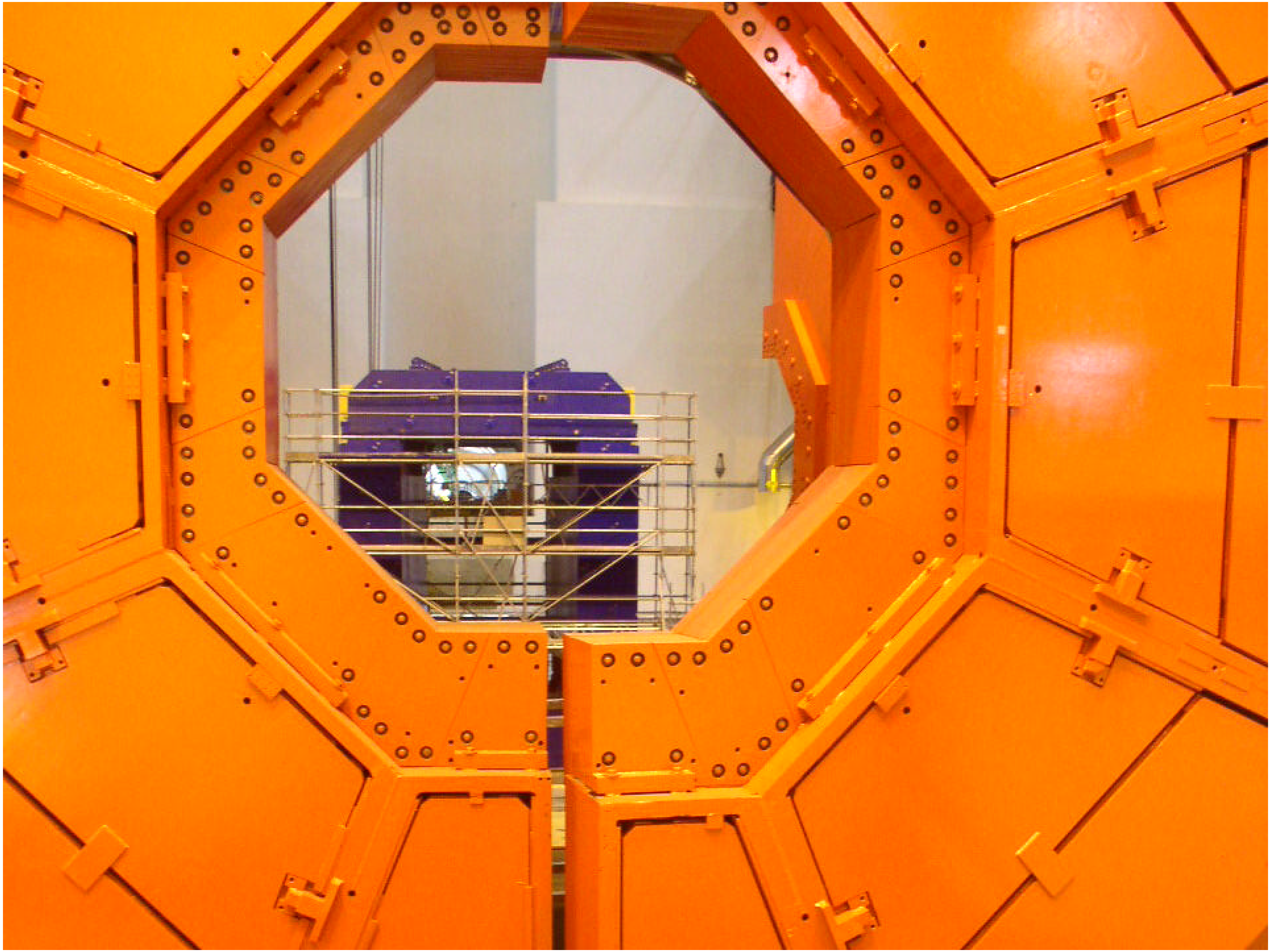
- Reduced

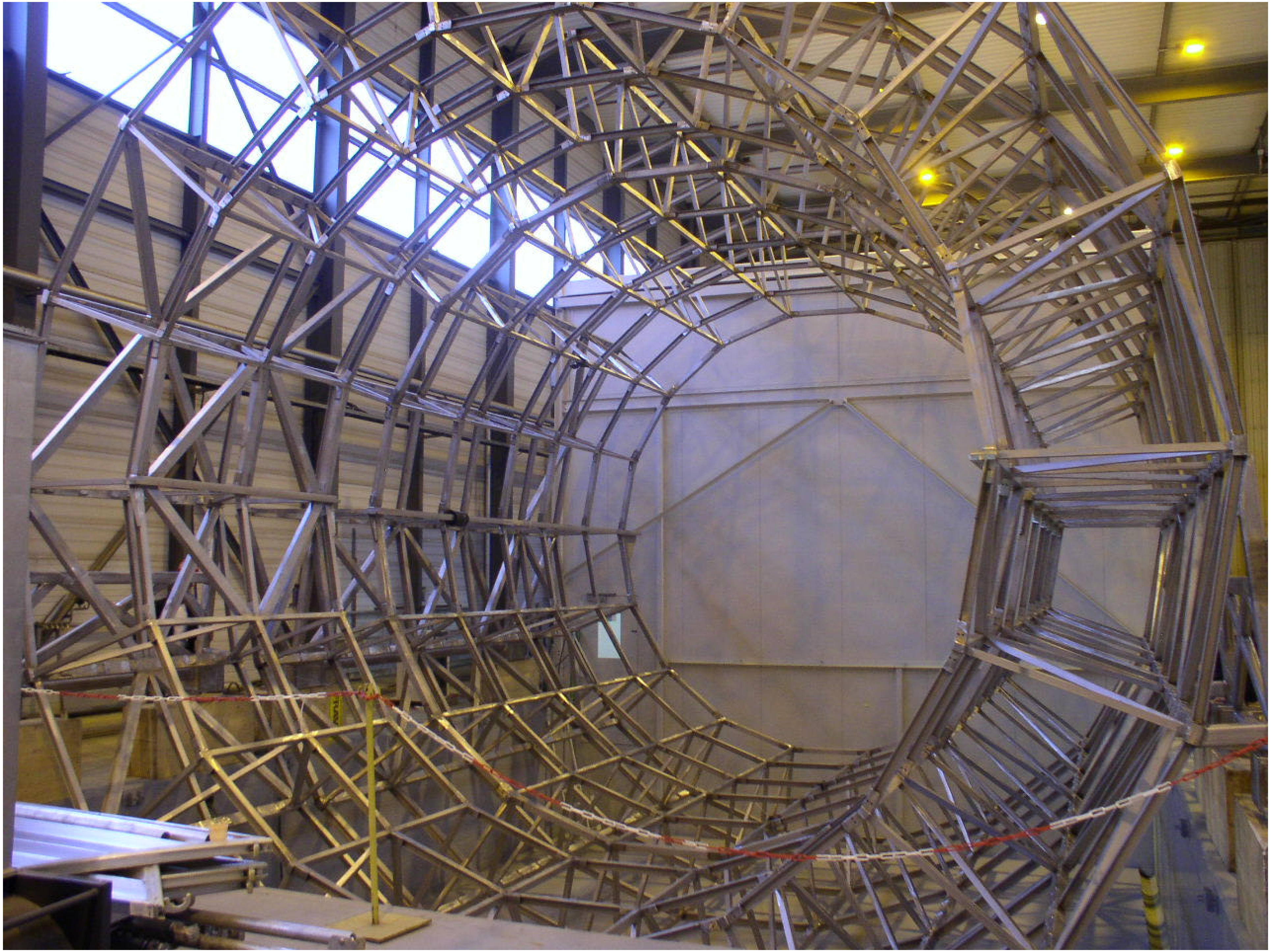


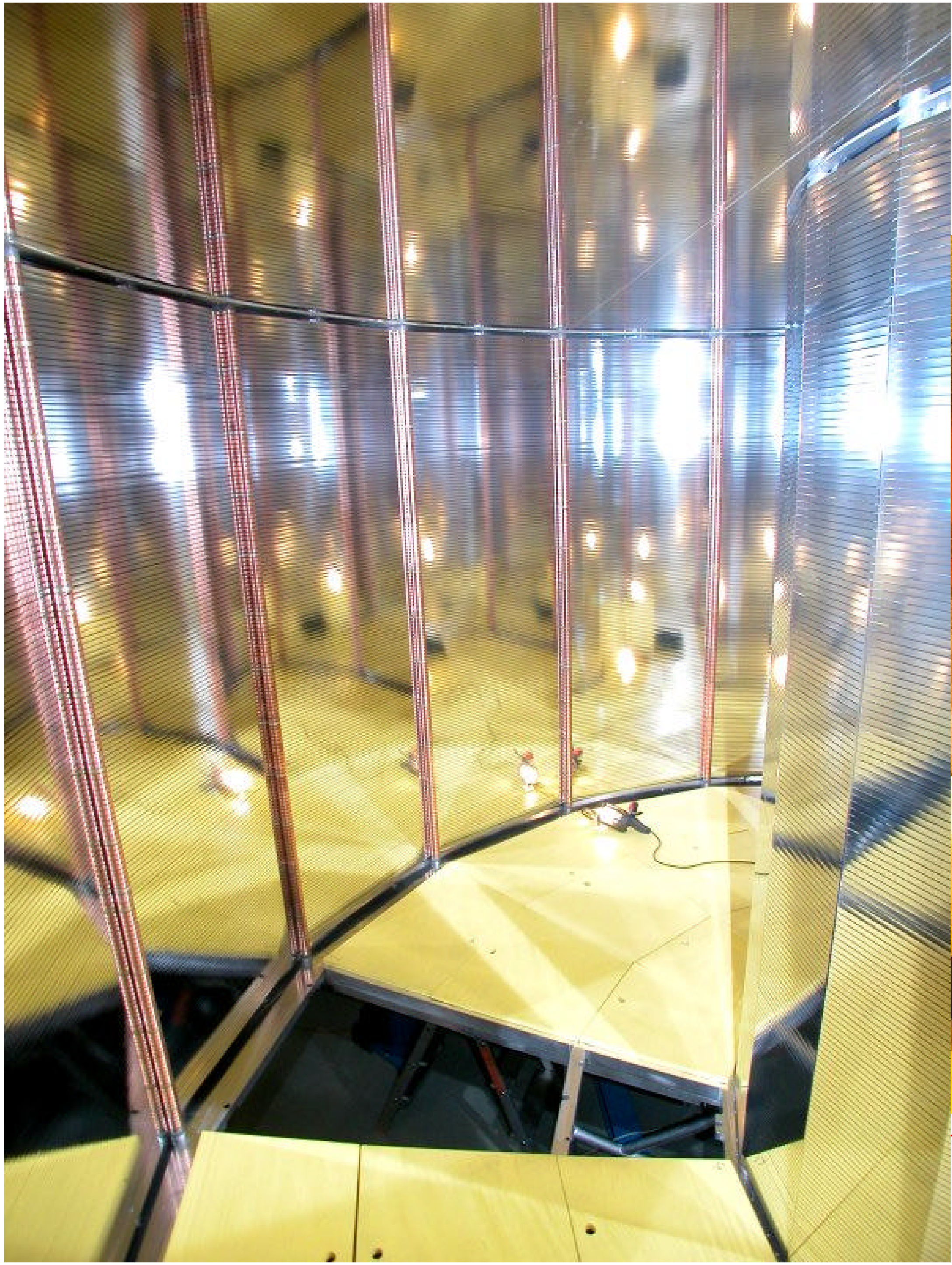
$$R_{AA} = \frac{1}{N_{coll}} \times \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t}$$

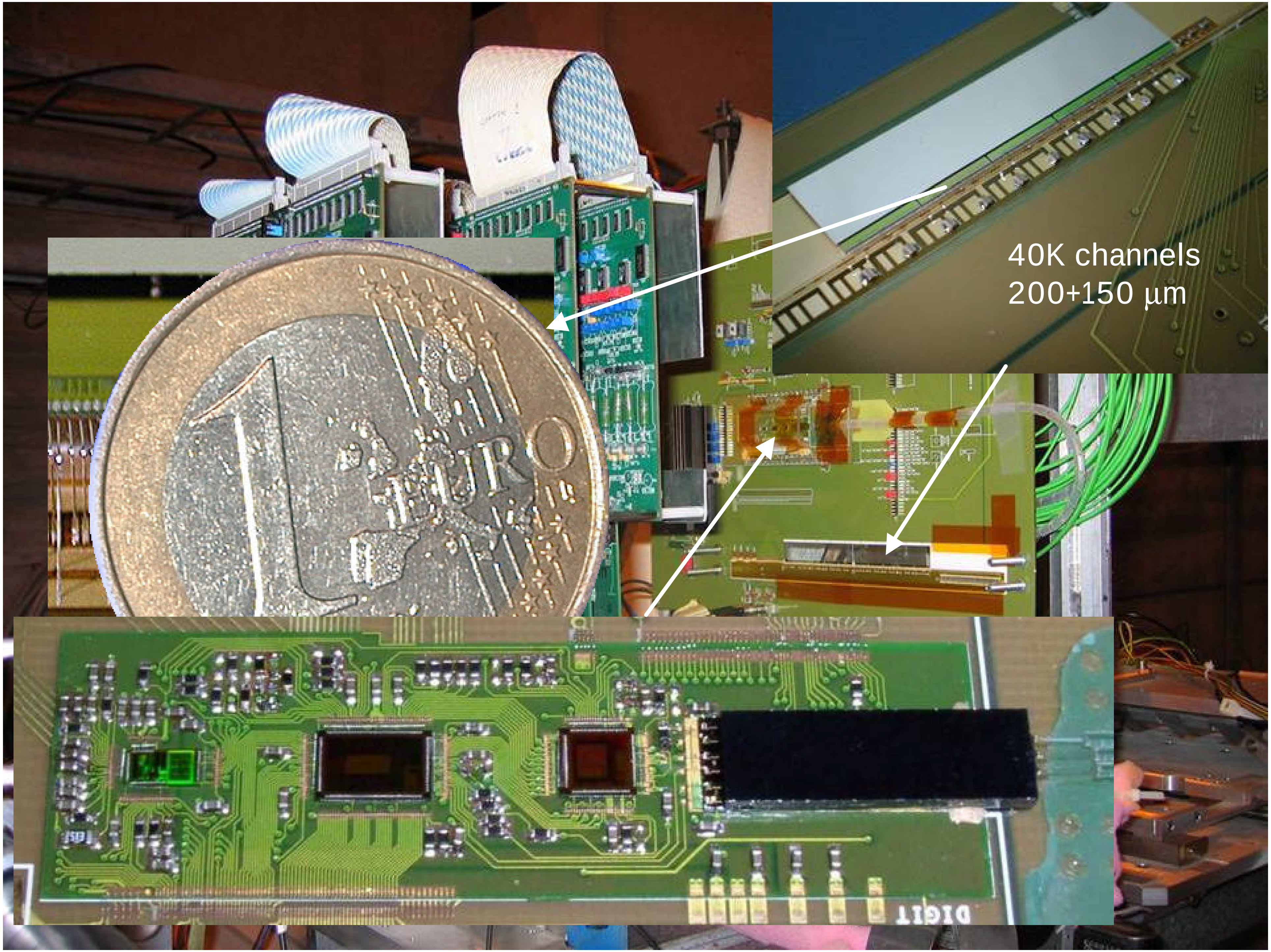
- Ratio D/hadrons (or D/π^0) enhanced and sensitive to medium properties.







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200+150 µm
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