Relativistic Heavy Ion Collisions. The ALICE Experiment at LHC. First Results in p+p Collisions

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on behalf of the ALICE collaboration

Subatech, Nantes, France

Outlook

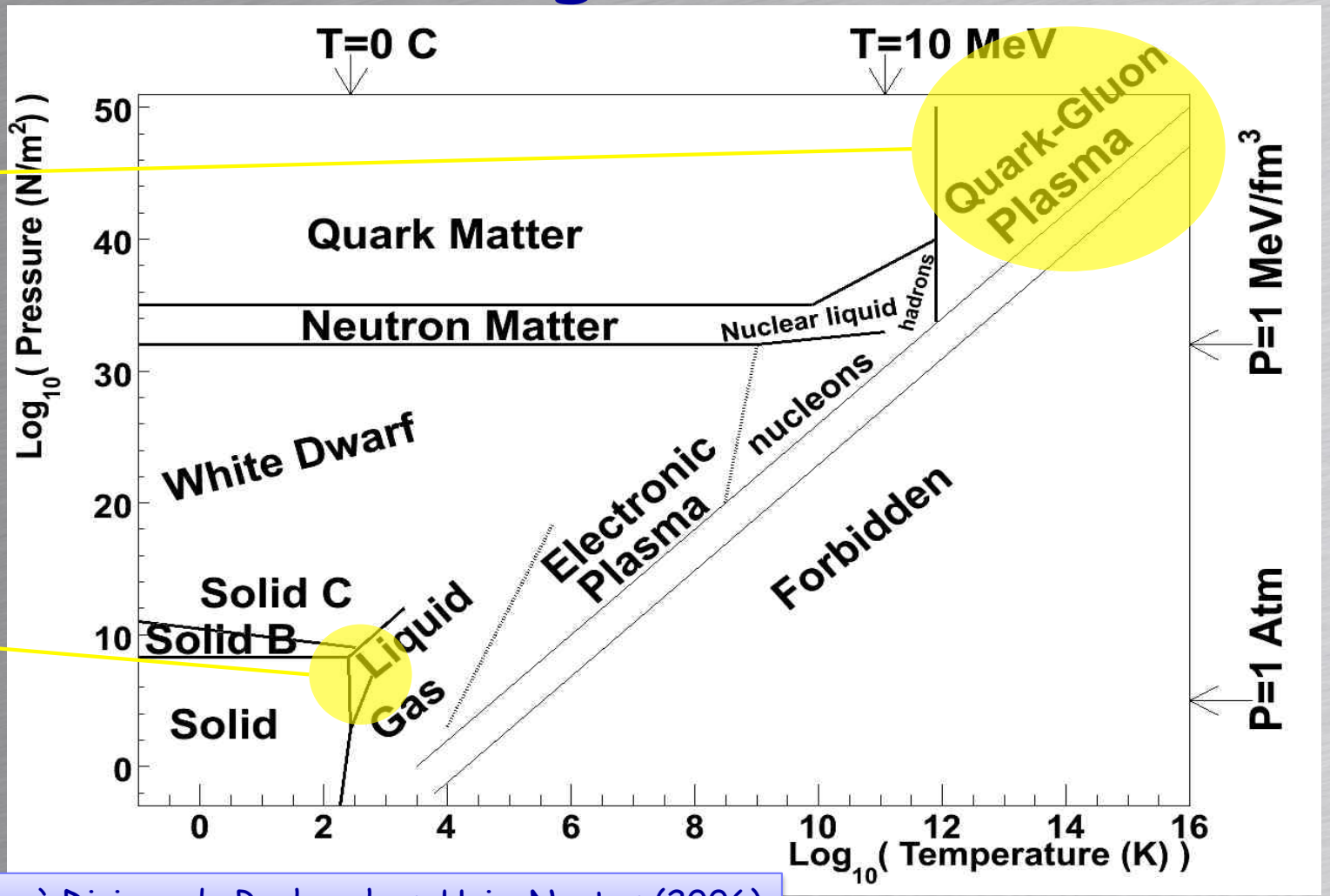
① Introduction to the Heavy Ion Physics;
② From SPS & RHIC to LHC heavy ion program;
③ QGP physics at LHC;
④ First ALICE data pp@900GeV and pp@7TeV;

ATLAS and, to a great extend, CMS develop a Heavy Ion Program. Their performances, often complementary to ALICE, are not discussed here.
Very simplified overview of experimental results obtained at SPS and RHIC.
Many ALICE items will not be addressed: offline, computing, daq, trigger …

Phase Diagram of Matter

QGP

Liquid Water



G.M. Habilitation à Diriger de Recherches, Univ. Nantes (2006)

A little bit of history …

- Hagedorn in 1965 got a value of the limiting temperature of matter ~ 170 MeV.

D.J. Gross, H.D. Politzer, F. Wilczek, Nobel prize (2004)

- Soon after the discovery of the asymptotic freedom;
- Quarks and gluons behave as a relativistic ideal gas of particles at very high T :

Cabbibo PLB59 67 (1975)
Collins & Perry PRL34 1353 (1975)

  - $\varepsilon = 15.62\ T^4$ [MeV^4] (like black body radiation);
  - Early universe (10^{-6}s) big QGP;
- Quark Gluon Plasma in Had. Coll.;

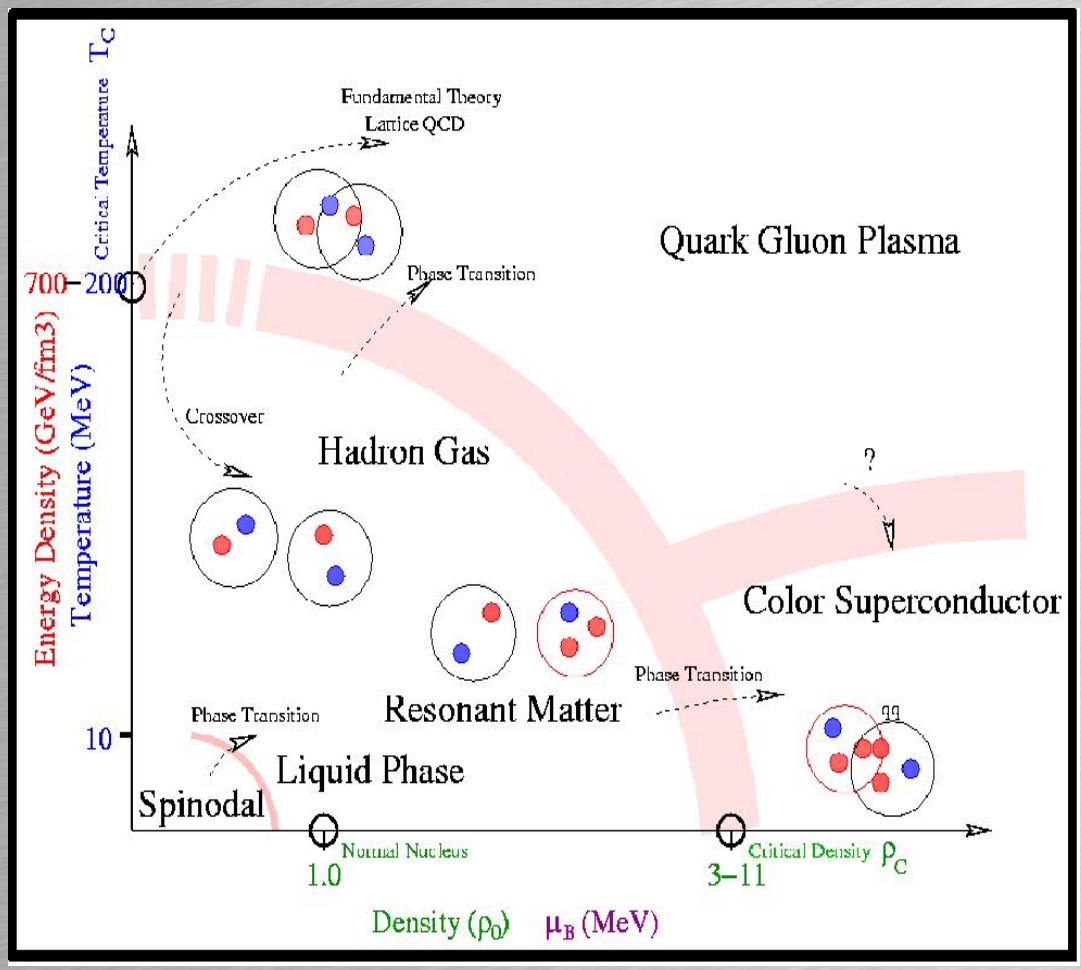
Shuryak PLB78 150 (1978)
Bjorken PRD27 140 (1983)

- Lattice QCD calculations predict the QGP transition at T ~ 175 MeV (μ_B=0). Same transition as the Chiral transition.

Hadronic Matter Phase Diagram

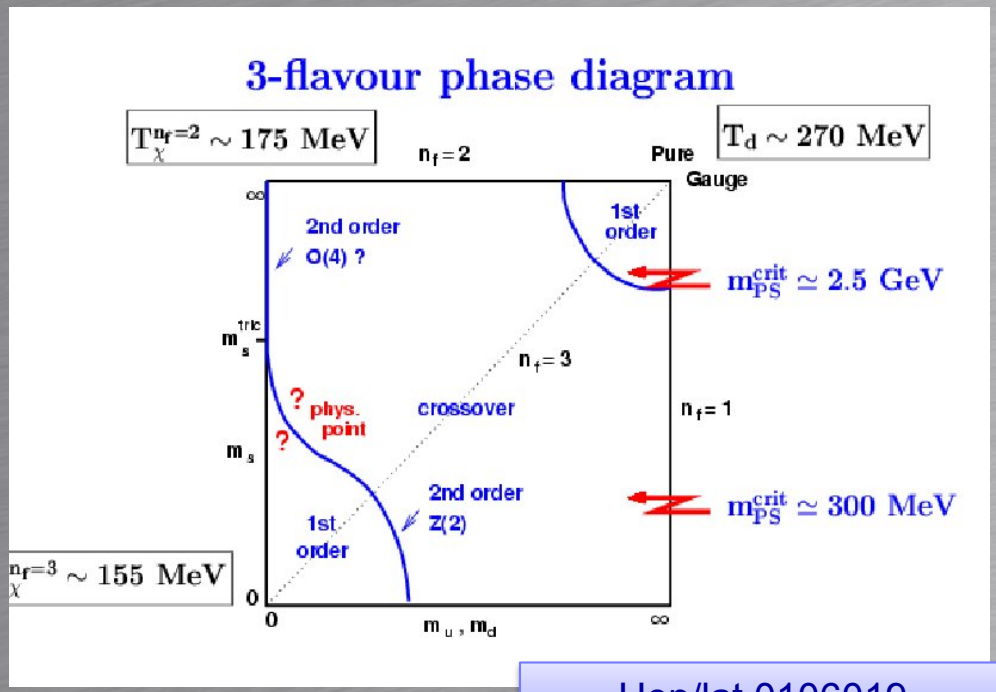
Description based on lQCD and QCD models:

- Cross-Over at μ_B=0 at T~200 MeV (lQCD);
- Critical Point at μ_B~300 MeV;
- Color superconducting matter at high ρ;



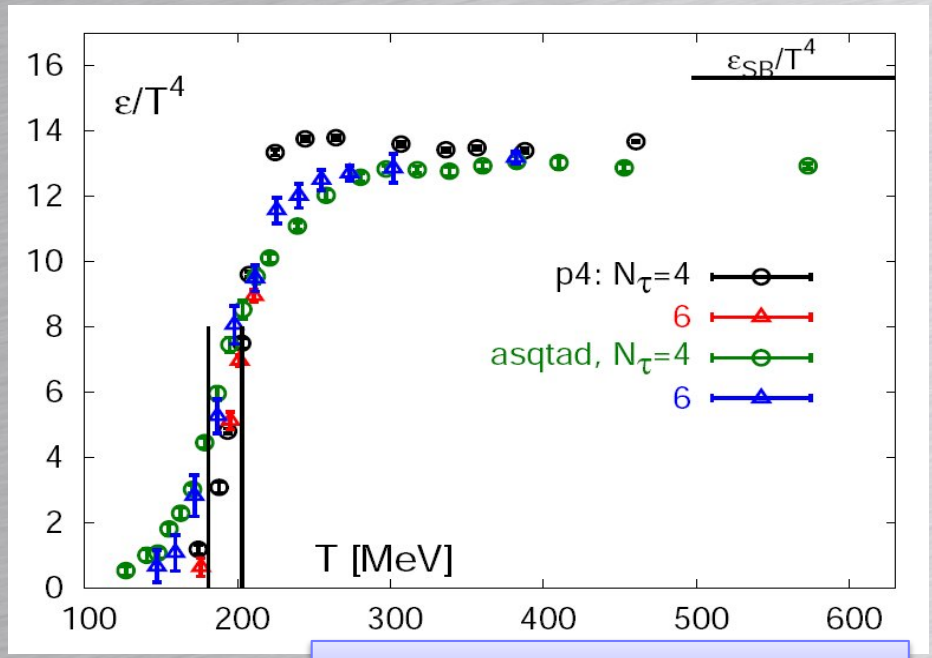
Lattice QCD calculations

Cross-over vs transition at μ_B=0



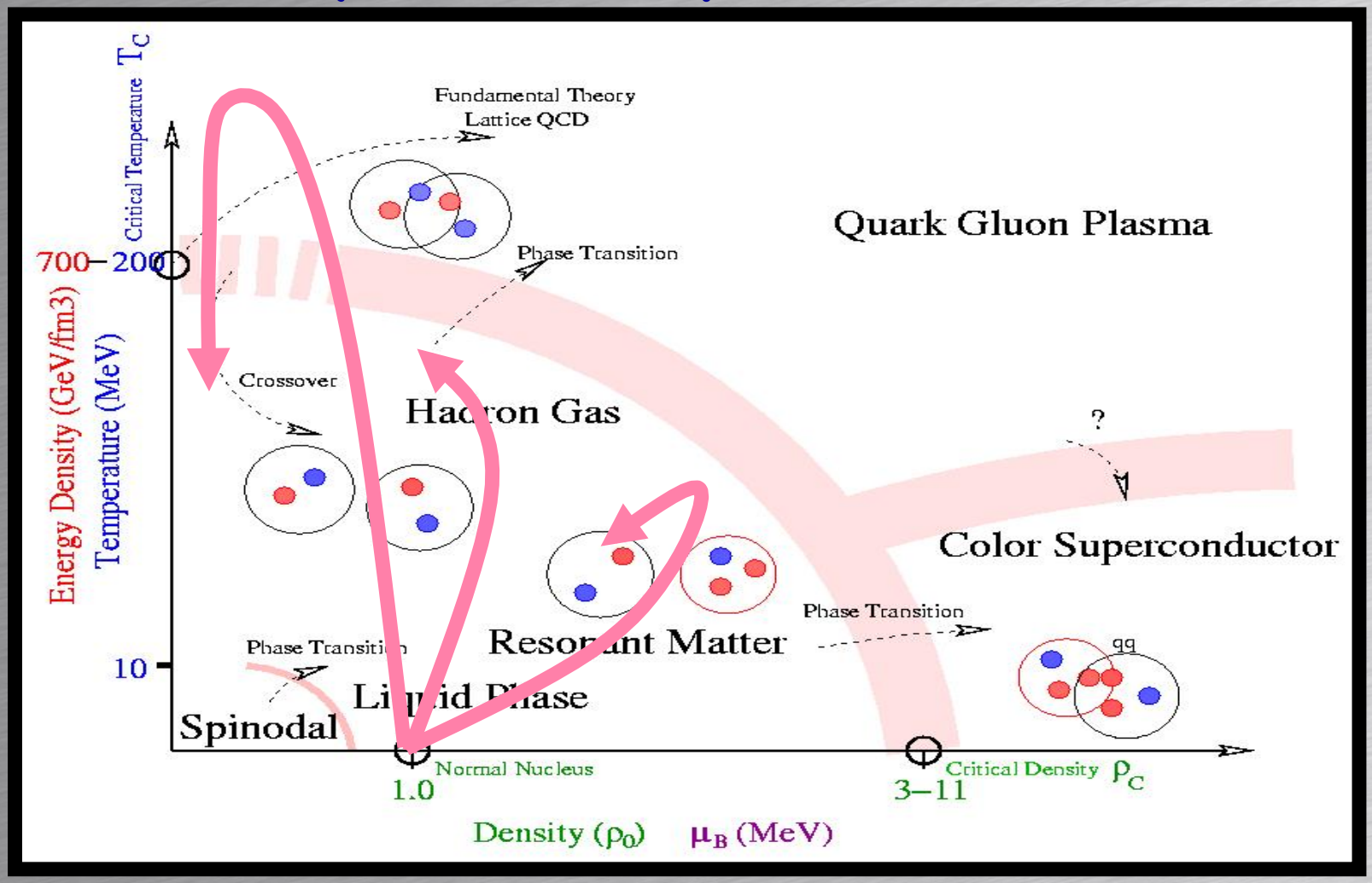
Hep/lat 0106019

Equation of State: An ideal gas?



Karsch, Quark Matter 2006

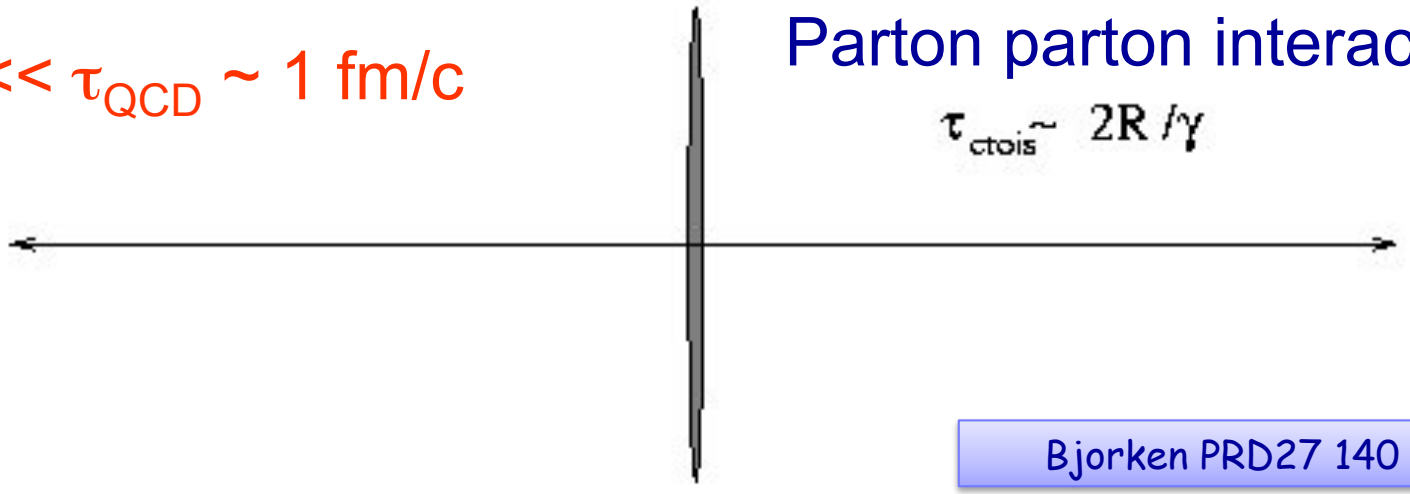
Heavy Ion Exploration of PD



QGP and Heavy Ion Collisions

- A+A collisions (AuAu, PbPb, etc…);
- Large Lorentz factor (γ>10, sqrt(s)>17 GeV);
- Number of binary NN collisions ~ 1000;

$\tau_{crois} << \tau_{QCD} \sim 1$ fm/c



Parton parton interactions

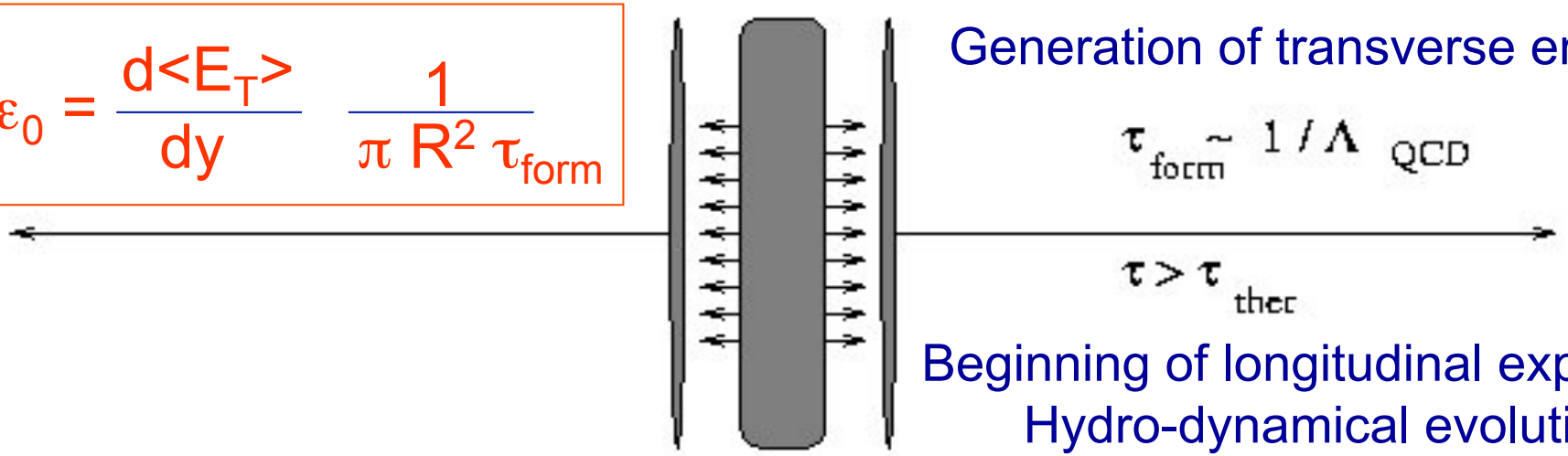
$\tau_{ctois} \sim 2R/\gamma$

Bjorken PRD27 140 (1983)

QGP and Heavy Ion Collisions

- A+A collisions (AuAu, PbPb, etc…);
- Large Lorentz factor (γ>10, sqrt(s)>17 GeV);
- Number of binary NN collisions ~ 1000;
- At LHC, ε_0~10-40 GeV/fm^3, T_i~400-750 MeV

$$\varepsilon_0 = \frac{d\langle E_T \rangle}{dy} \quad \frac{1}{\pi R^2 \tau_{form}}$$



Generation of transverse energy

$\tau_{form} \sim 1/\Lambda_{QCD}$

$\tau > \tau_{ther}$

Beginning of longitudinal expansion
Hydro-dynamical evolution

QGP and Heavy Ion Collisions

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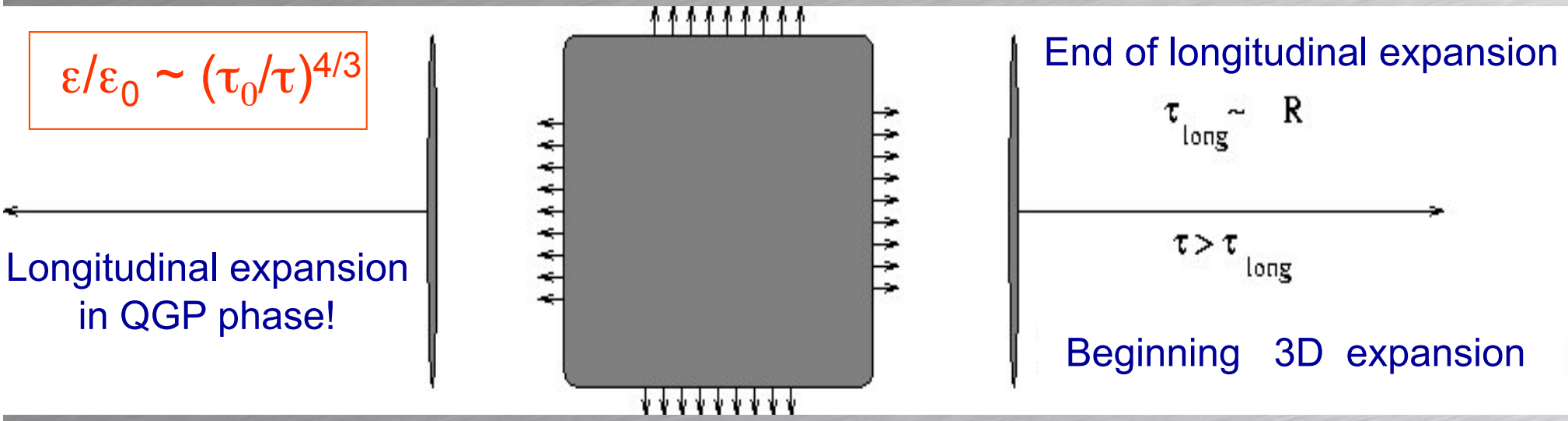
$$\varepsilon/\varepsilon_0 \sim (\tau_0/\tau)^{4/3}$$



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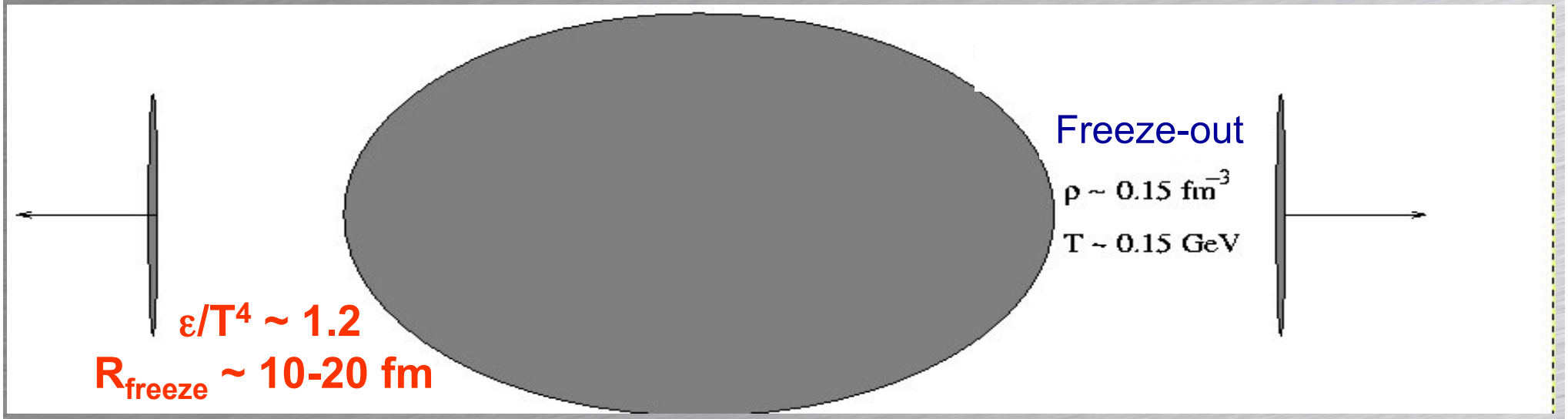


Heavy Ion Facilities

- SPS Heavy Ion accelerator (1986-):
  - Pb, In at 158A GeV, O, S at 200A GeV on fixed target;
  - NA35,WA80, CERES, WA98, NA50, NA49, NA57, NA60..
- RHIC, BNL (2000 - ?):
  - Au+Au at 62, 130, 200A GeV, d+Au at 200 GeV, p+p at 200GeV and Cu+Cu at 62 and 200A GeV;
  - PHENIX, STAR, PHOBOS, BRAHMS;
- LHC, CERN (2009 - ?):
  - PbPb at 5.5A TeV;
  - ALICE, CMS, ATLAS;

Probes of QGP

- Global Probes: Multiplicity, Centrality dependence, transverse energy, …
- Hadronic Phase Probes (freeze-out): hadron yields, hadron y and pT distributions, elliptic flow, HBT hadron correlations, Hadron resonances, vector mesons …
- Penetrating (QGP) Probes : Photons, Dileptons, Jets and Heavy Quarks;
- Initial state probes: Photons, Dileptons, Electro-Weak Bosons and, naturally, pp and pA collisions;

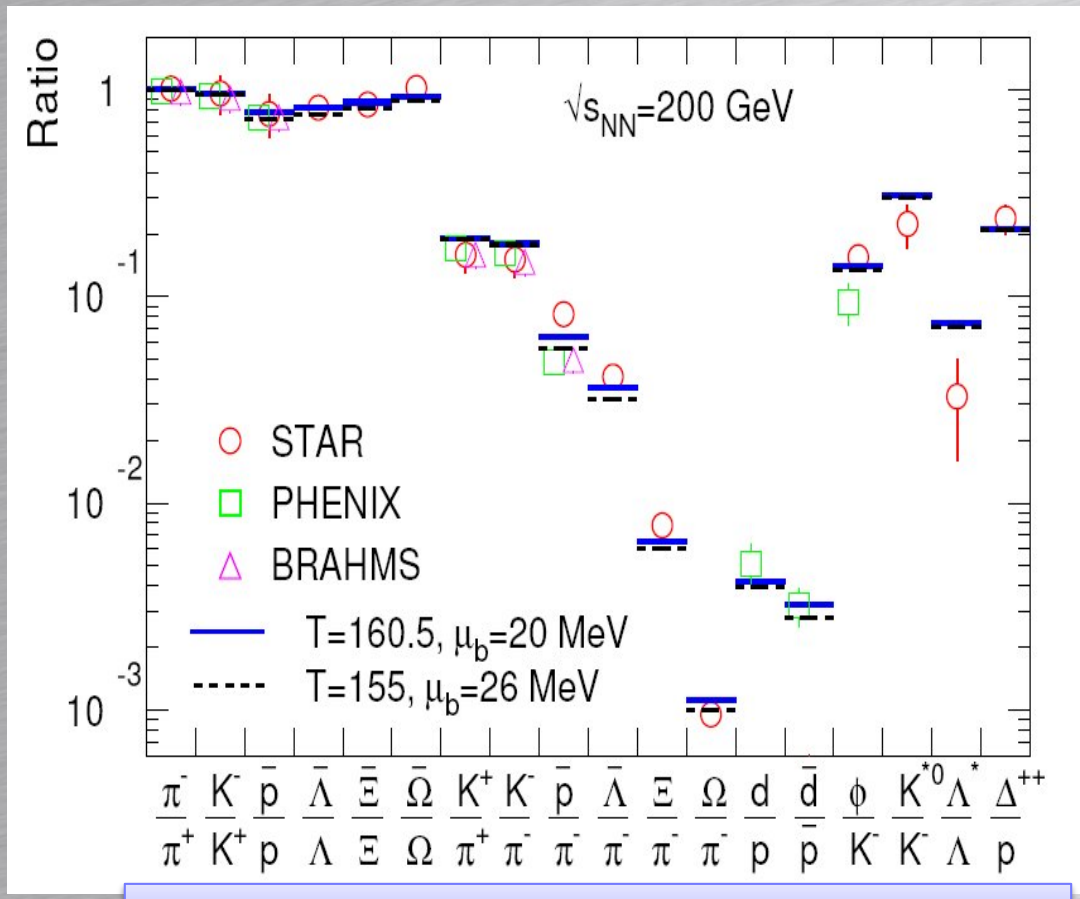
Statistical Hadronization at RHIC

- Chemical freeze-out;

$$n_i = \frac{N_i}{V} = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2 dp}{\exp[(E_i-\mu_i)/T]\pm 1}$$

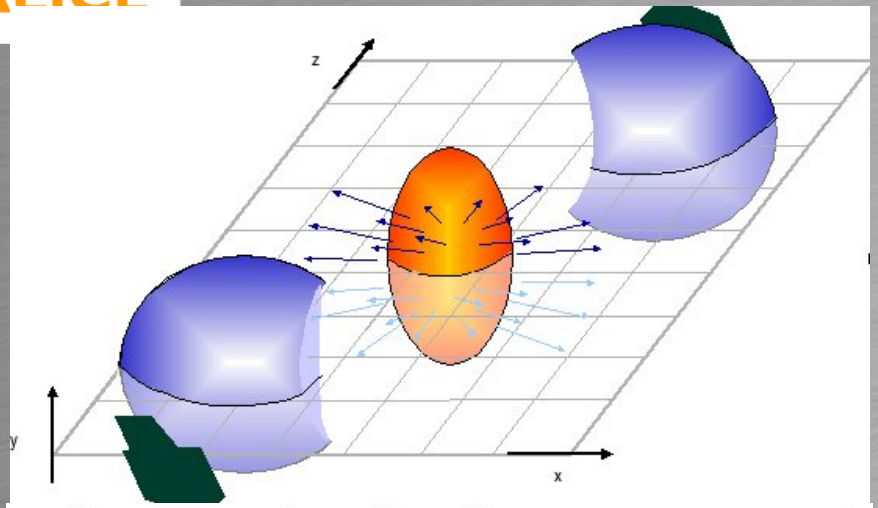
$$\mu_i = B_i\mu_b + S_i\mu_s + I_3\mu_{I_3}.$$

- Two parameters: T_{ch} and μ_B;
  - T_{ch} = (160±2) MeV;
  - μ_B ;= (20±4) MeV

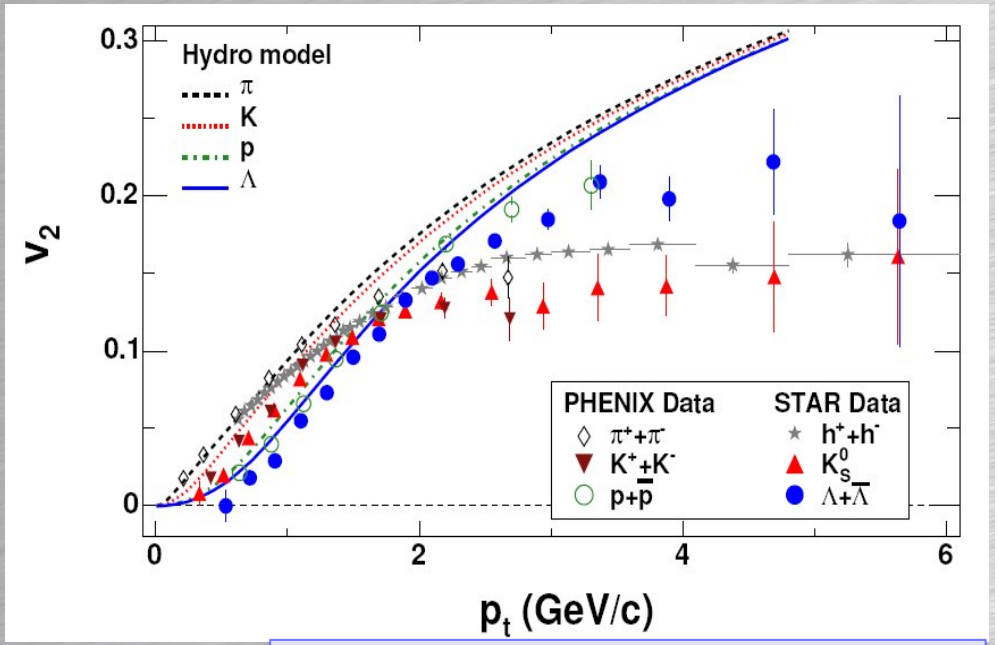


A. Andronic et al., arXiv:nucl-th/0511071v3

Elliptic Flow (v_2) at RHIC



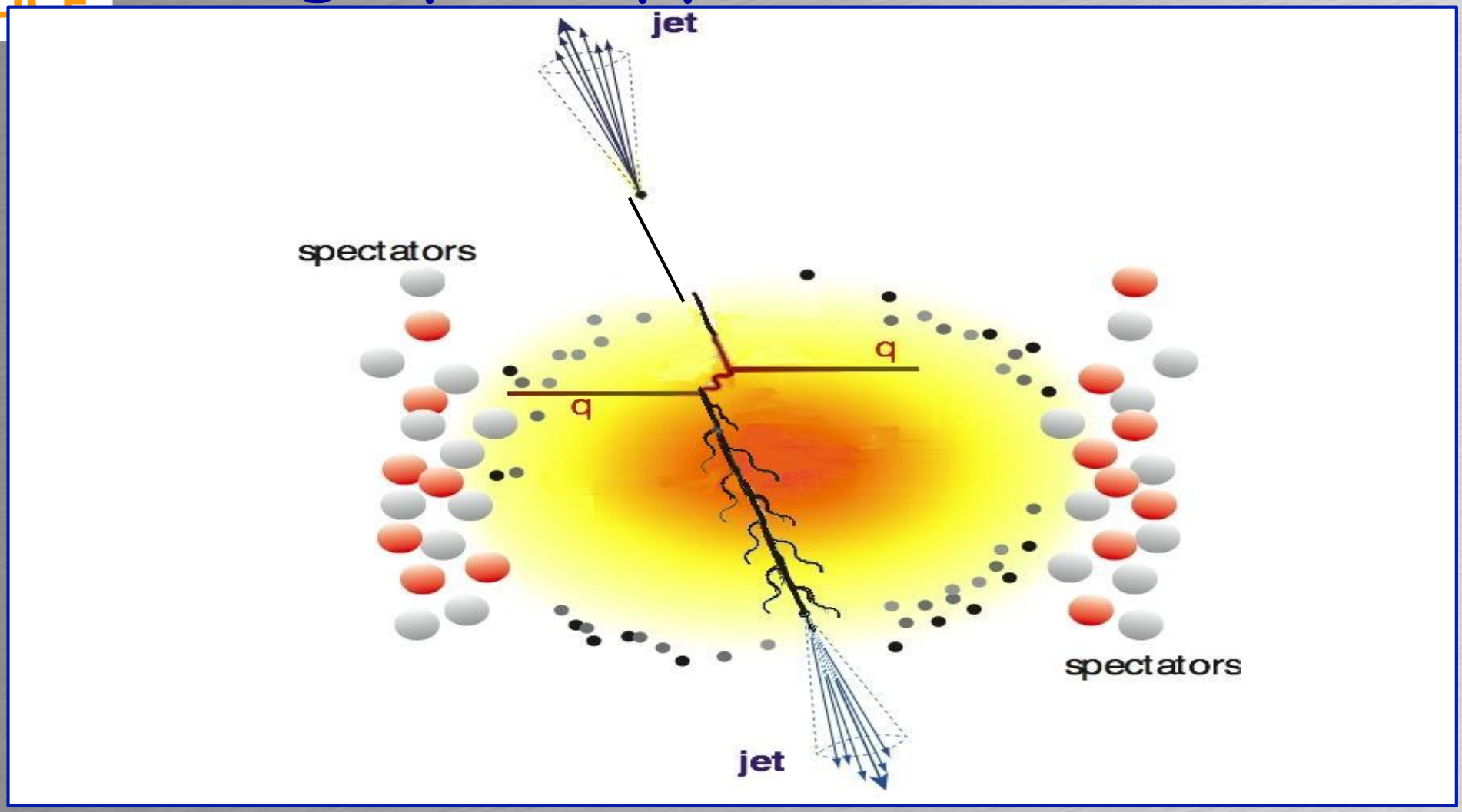
$$E\frac{d^3N}{d^3\vec{p}} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left[1 + \sum_{n=1}^{\infty}\left\{2v_n \cos\left[n(\phi - \Psi_R)\right]\right\}\right]$$



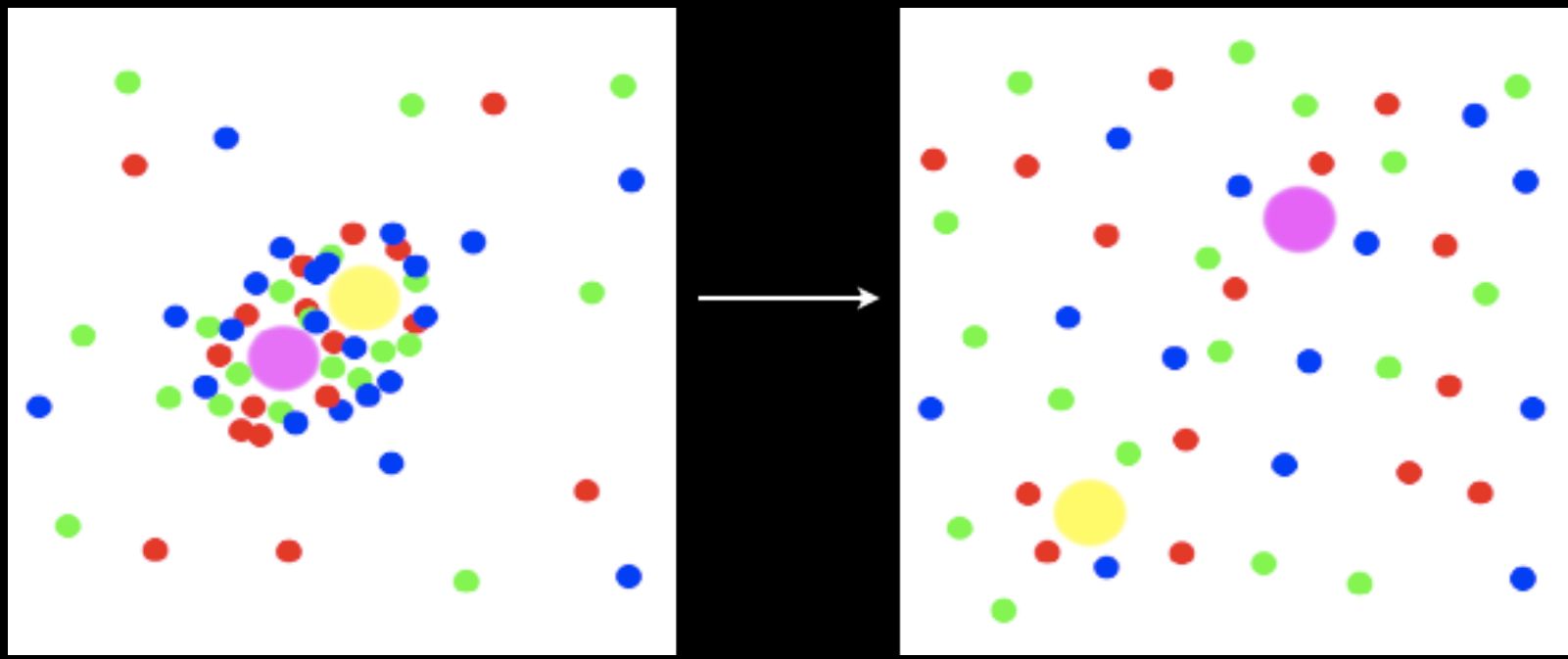
STAR coll., PRC72(2005)014904

- Elliptic flow is important in HIC;
- *Well understood* at RHIC with Hydrodynamical models;
  - sQGP concept has been suggested;

High pT suppression at RHIC

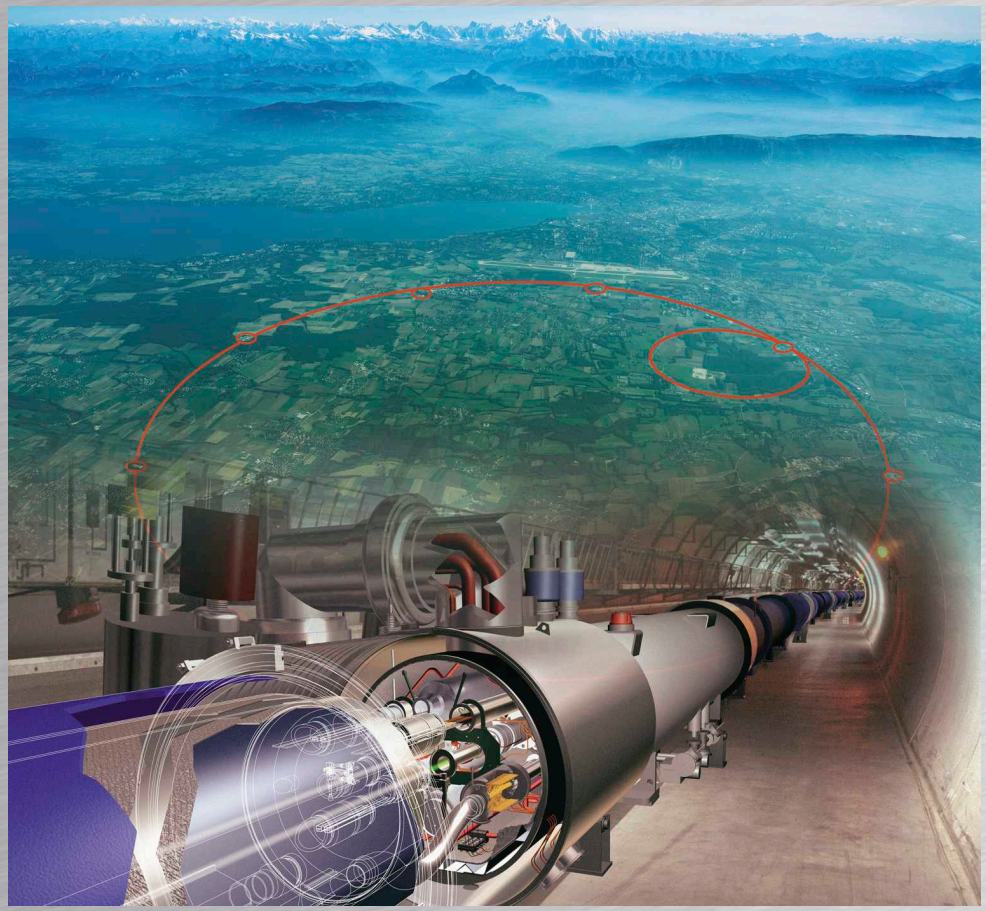


Quarkonia suppression at SPS



Large Hadron Collider

- PbPb collisions at 5.5A TeV (x30 step);
- Luminosity 10^{27} cm^{-2} s^{-1};
  - Limited by physics;
- QGP: hotter, bigger and longer;
- Baryon free matter;
- Large production cross-section of hard (penetrating) probes;



Expected LHC running conditions

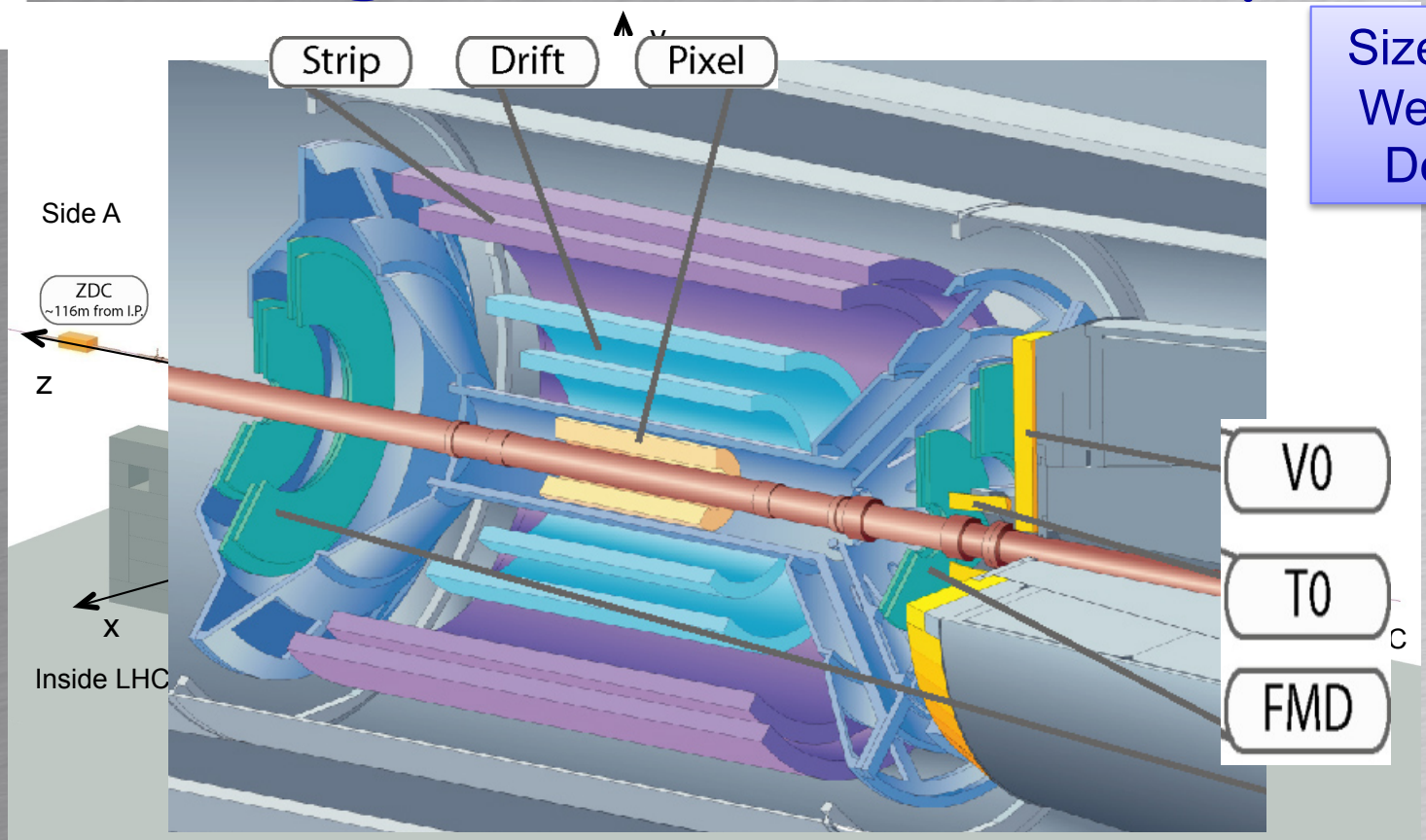
Nominal conditions

System	$s_{NN}^{1/2}$(TeV)	L_0(cm^{-2}s^{-1})	<L>/<L_0>	Run time (s yr^{-1})	σ (b)	Statistics
pp	14	<10^{31}		10^7	0.07	7 10^{12}
PbPb	5.5	10^{27}	~50%	10^6	7.7	4 10^9

- Other Heavy-Ion like systems: pp 5.5, pPb, lighter ions (O, Ar, Kr, Sn);
- Available energy in the center of mass: 14 $(Z_1Z_2/A_1A_2)^{1/2}$ TeV: 7 TeV for ArAr;
- Rapidity shift : $\Delta y = 0.5 \ln(Z_1Z_2/A_1A_2)$: 0.47 for pPb, 0.12 for dPb;

✓ Expect ~10 years “baseline” program 2010-2020 (1 month per year);
✓ First 5 years: 1 PbPb low luminosity, 2 PbPb runs at nominal luminosity, pPb run and ArAr run;
✓Second 5 years (based on experimental results): lower energies, pp at 5.5 TeV, other AA or pA, more statistics;
✓ Modest detector modifications or upgrades are being considered;

A Large Ion Collider Experiment

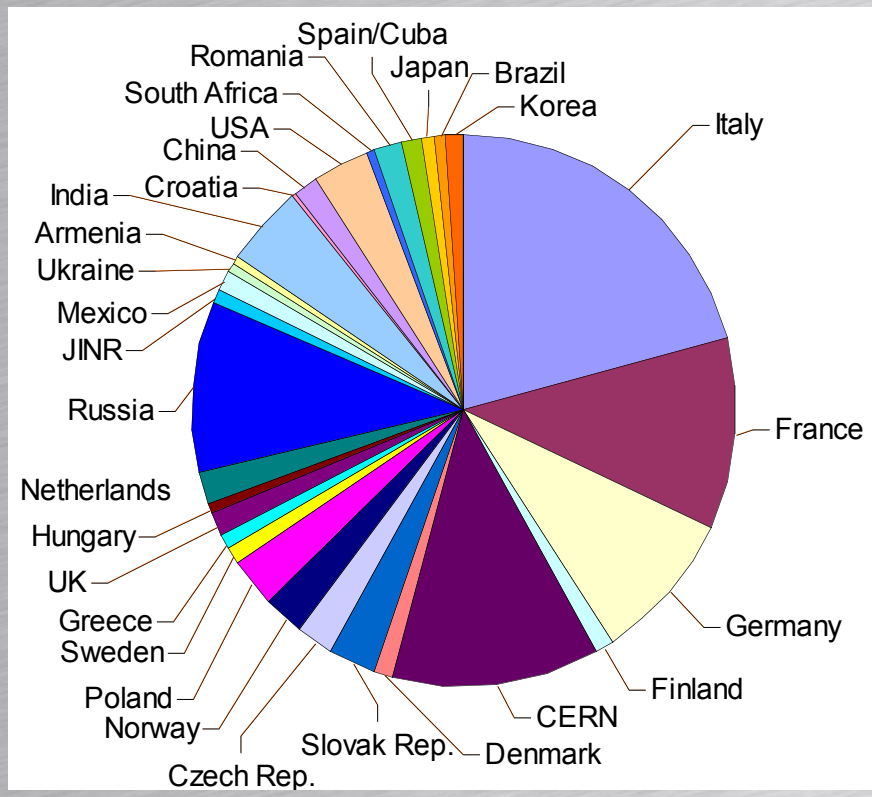


Size 16m x 26m;
Weight 10,000t;
Detectors 18;

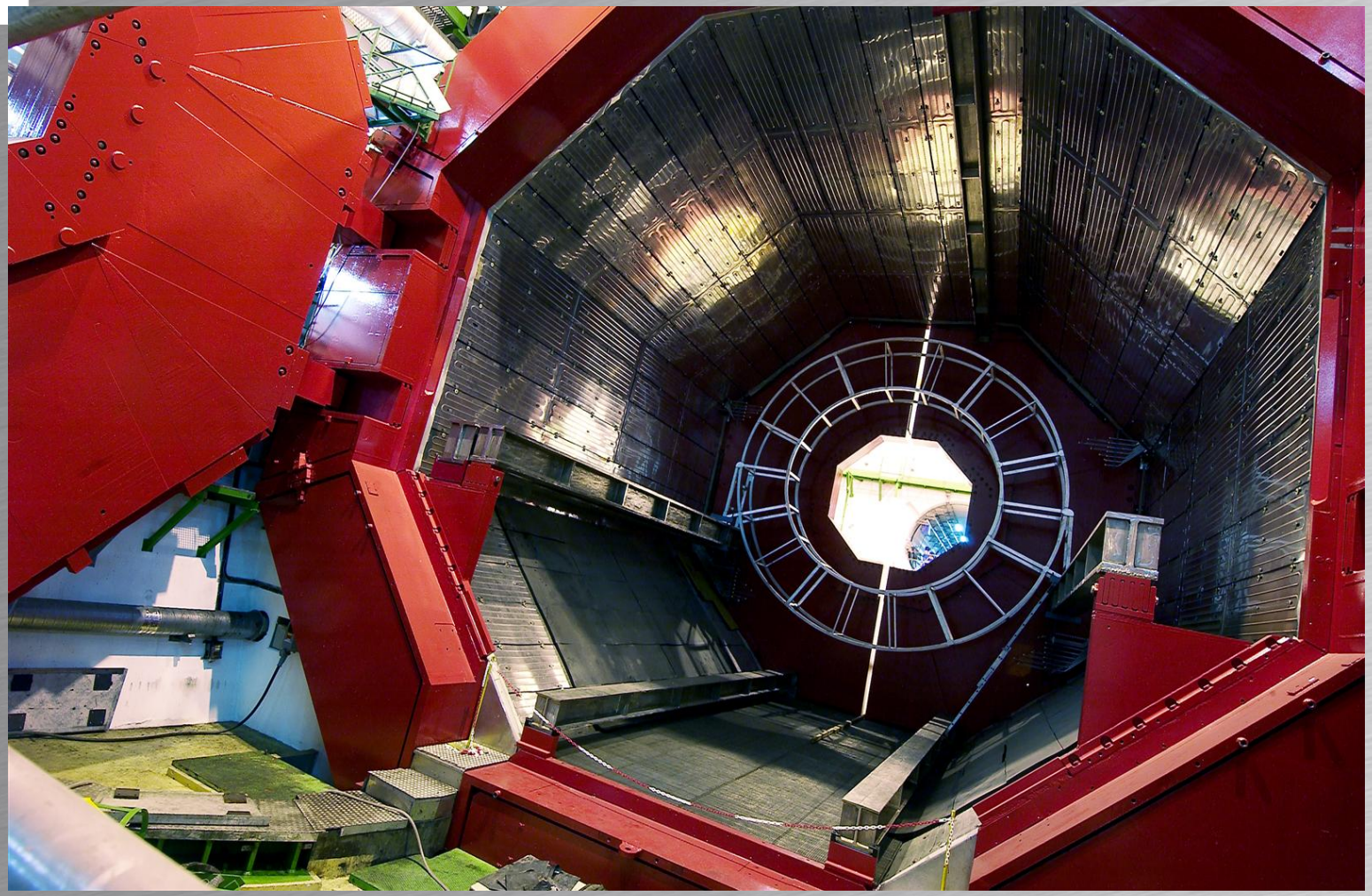
LoI LHCC-93-16 (March 1st 1993), TP LHCC 95-71, TDRs (1997-2008), PPRs JoP G30 11 (2004) & JoP G32 10 (2006), 1st Physics publication expected in Dec 2009.

Collaboration ALICE

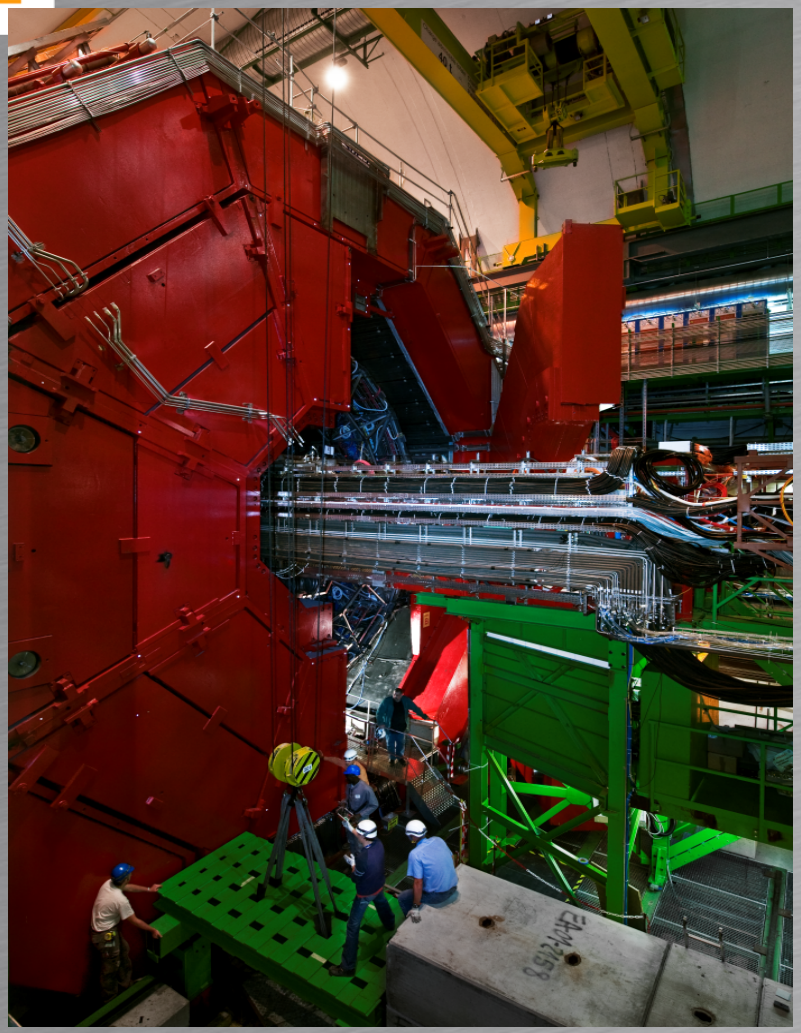
- ~ 1000 members (63% from CERN member states);
- 30 countries;
- 100 laboratories;
- 150 MCHF ("free" central magnet);



Status of ALICE in 2004



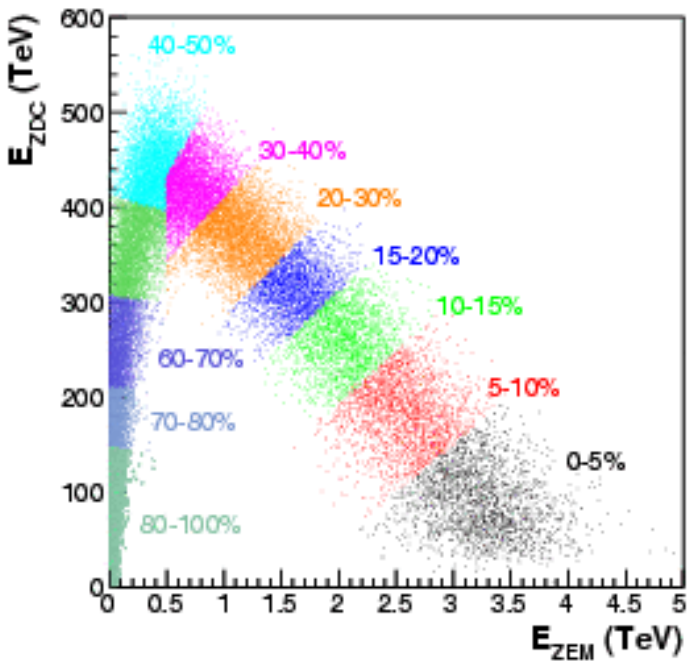
Status of ALICE June 12th2008

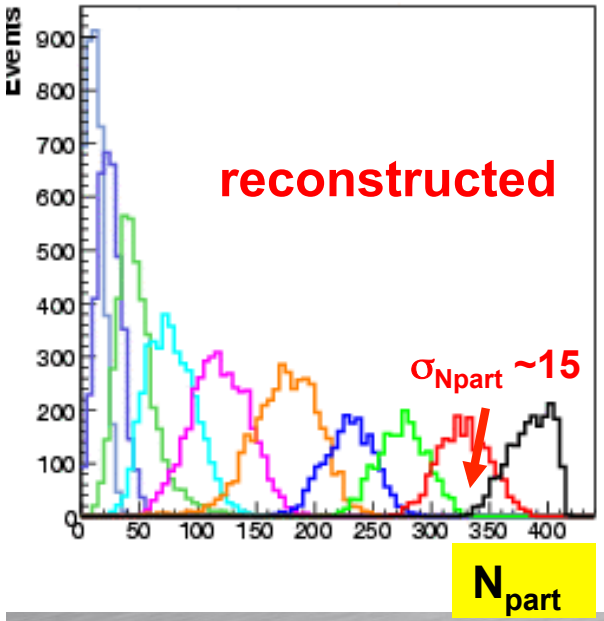


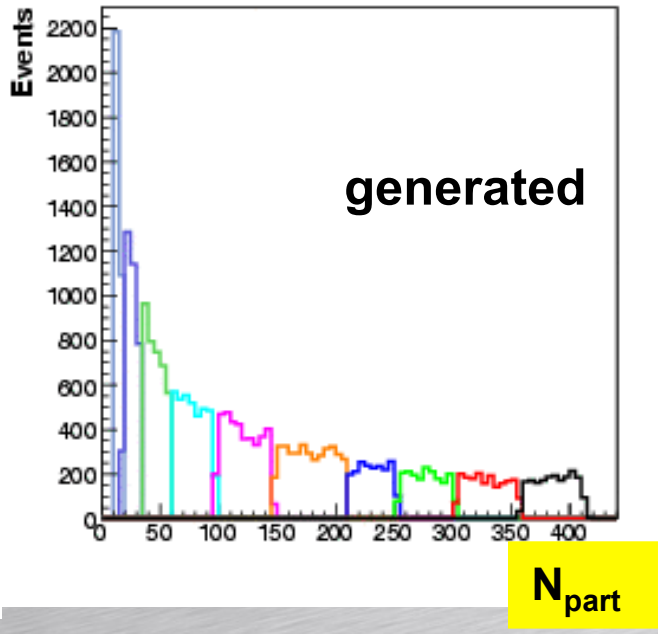
ALICE ready (August 6th 2008)

Reaction centrality

- Event by event determination of centrality:
  - ZDC hadronic and ZEM electromagnetic calorimeter;
  - E_{ZDC} v E_{ZEM} => N_{part}, impact parameter;

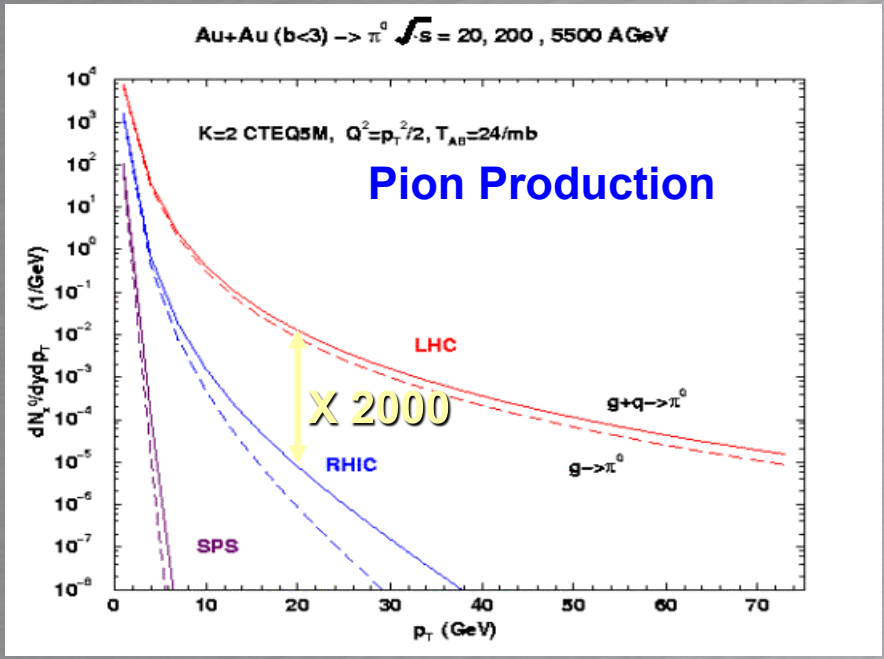






Jets in Heavy Ion Collisions at LHC

- Large production cross-sections;
- Jet physics in HIC: a promising probe of QGP;

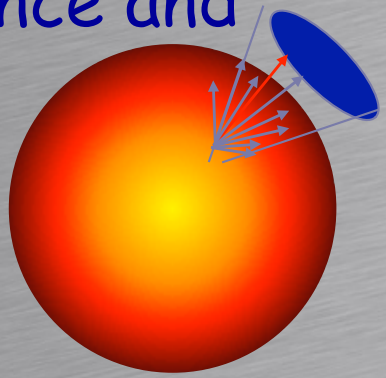


Pb Pb jet rates $|\eta| < 0.5$:

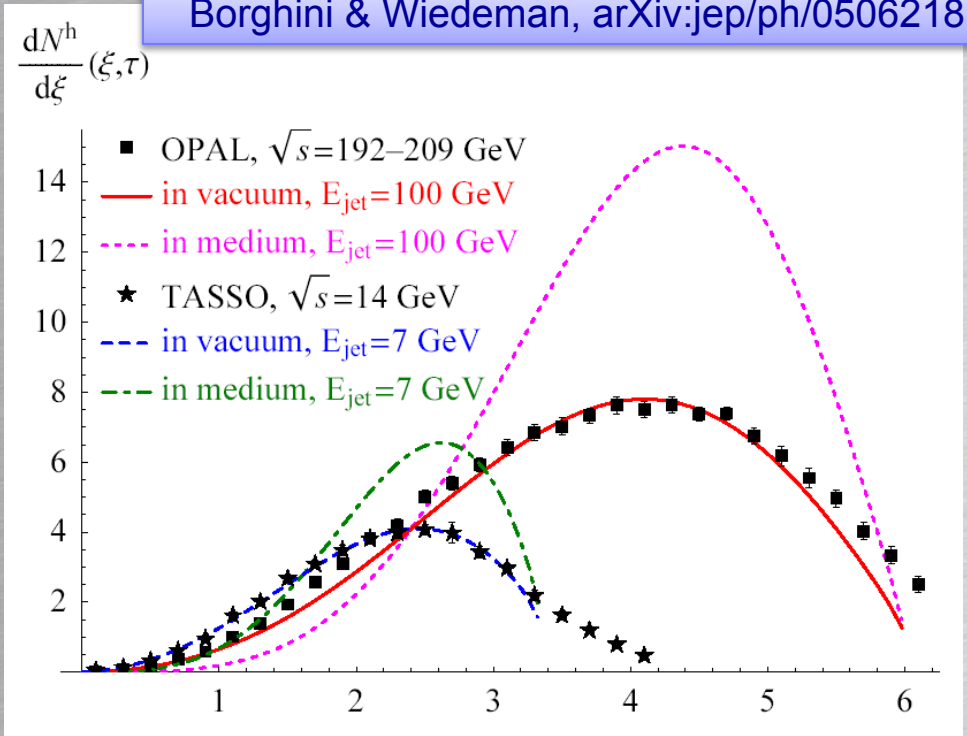
p_t jet > (GeV/c)	jets/event (central)	jets/0.5 nb-1
5	>200	
20	**2**	**$2\ 10^9$**
50	$5\ 10^{-2}$	$5\ 10^7$
100	$2.5\ 10^{-3}$	$2.5\ 10^6$
200	**10^{-4}**	**10^5**

Hump-Backed plateau

- Jet-QGP interaction:
  - Suppression at low ξ;
  - Enhancement at high ξ;
  - Jet broadening & radiation out of cone;
  - Increase of di-jet energy inbalance and acoplanarity;



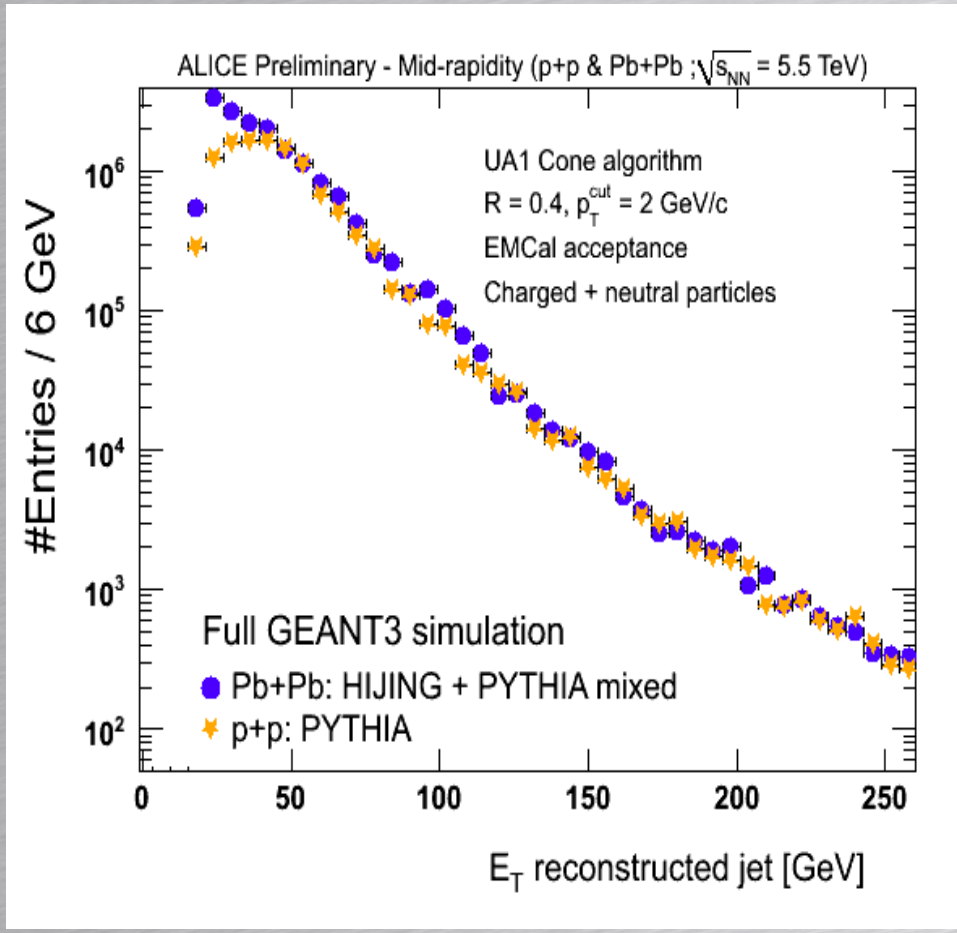
Borghini & Wiedeman, arXiv:jep/0506218



$\xi = \ln(E_{Jet}/p_{hadron})$

Jet Physics in ALICE

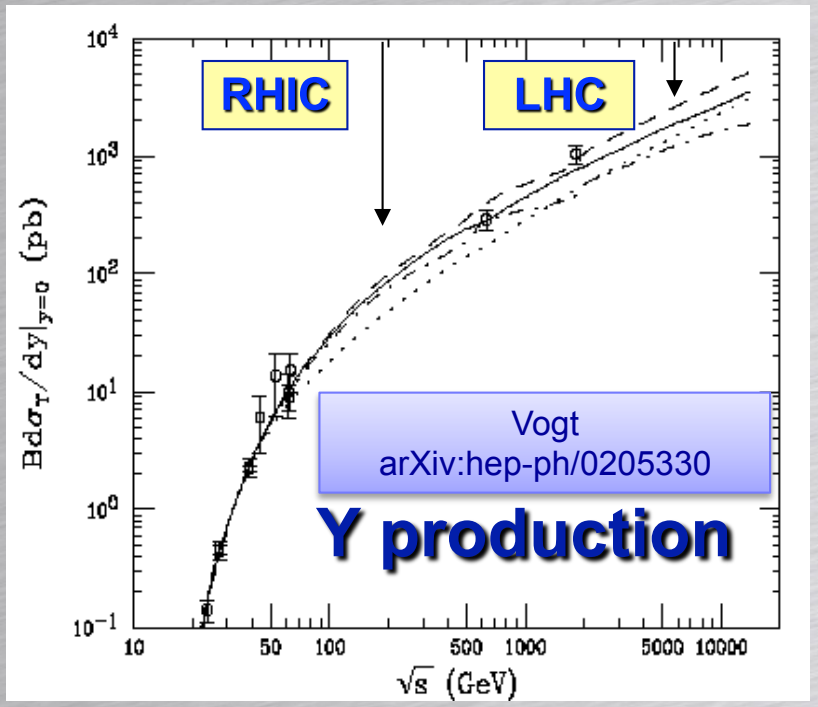
- Statistic of 1 month PbPb running at nominal conditions;
- Jet reconstruction in HIC possible for E>40 GeV;
- Hump-backed plateau analysis up to E~150 GeV;

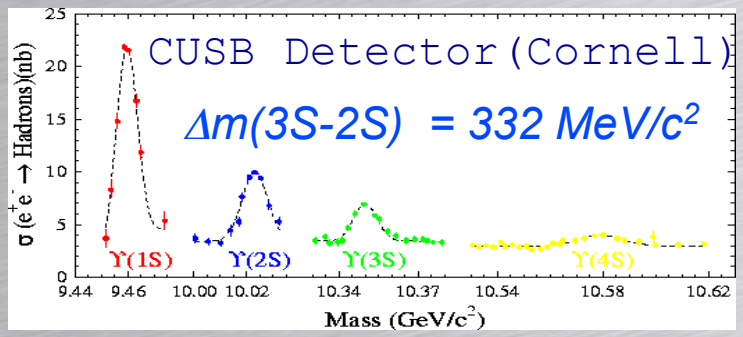


HQ in Heavy Ion Collisions at LHC

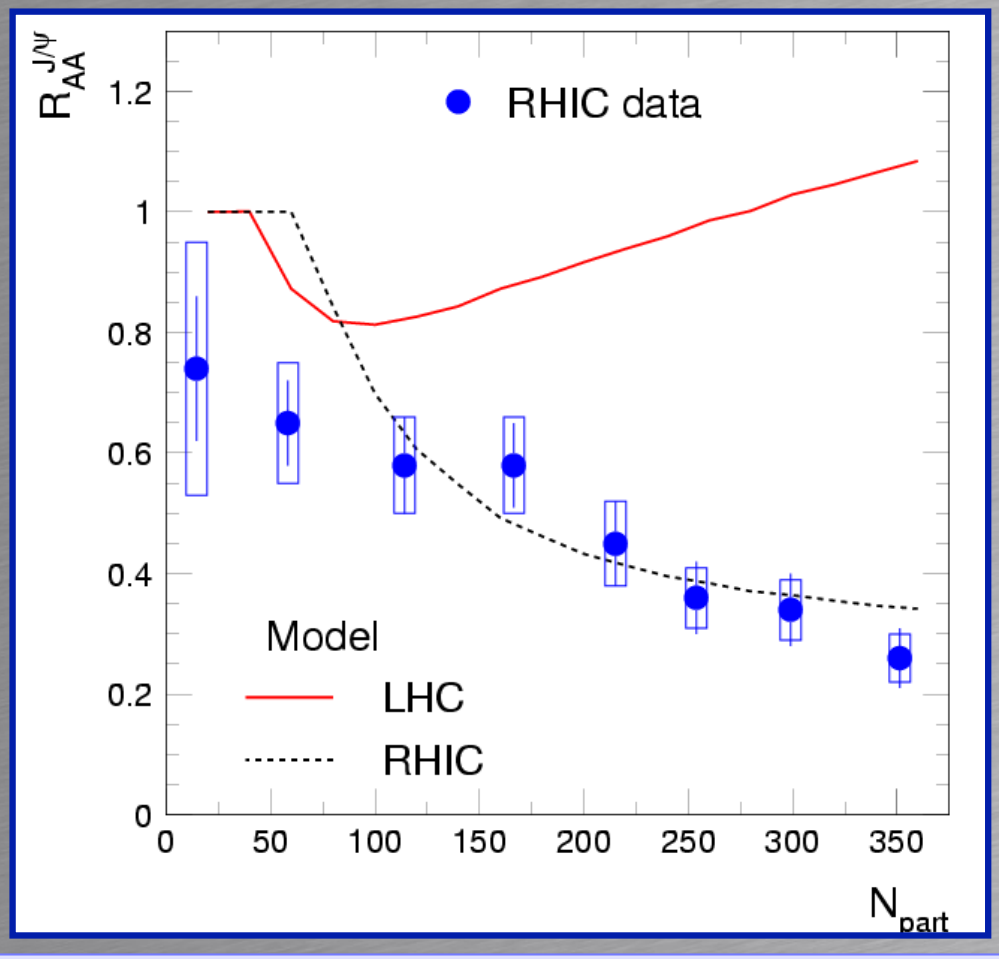
- Copious charm production;
- HQ thermalization;
- HQ energy loss;
- J/ψ elliptic flow;
- HQ colour screening in bottomonia.

	SPS PbPb Cent	RHIC AuAu Cent	LHC pp	LHC pPb	**LHC PbPb Cent**
N_{cc}/evt	0.2	10	0.2	1	**115**
N_{bb}/evt	-	0.05	0.007	0.03	**5**





Charm Quark Recombination

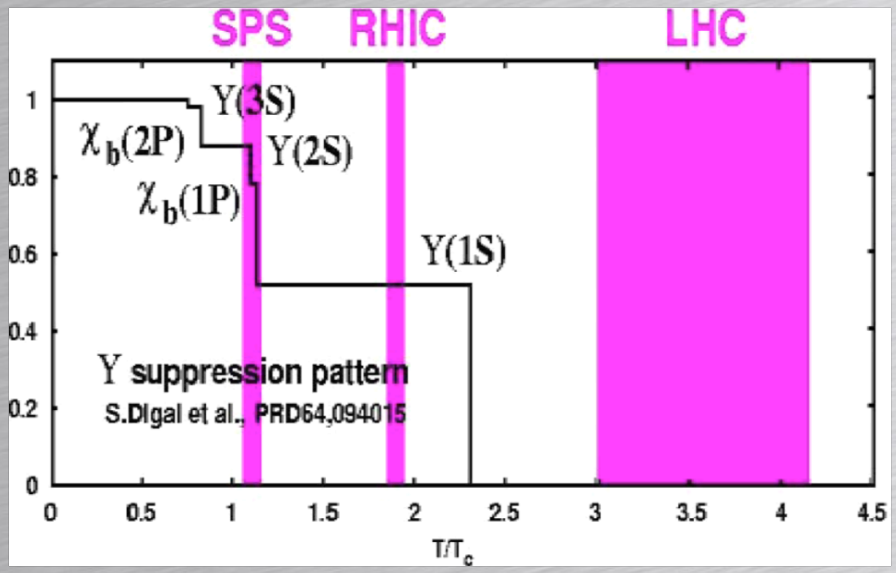


- Strongly depending on the open charm production;
- Direct probe of deconfinement;
- Statistical hadronization is one of the foreseen scenarii;

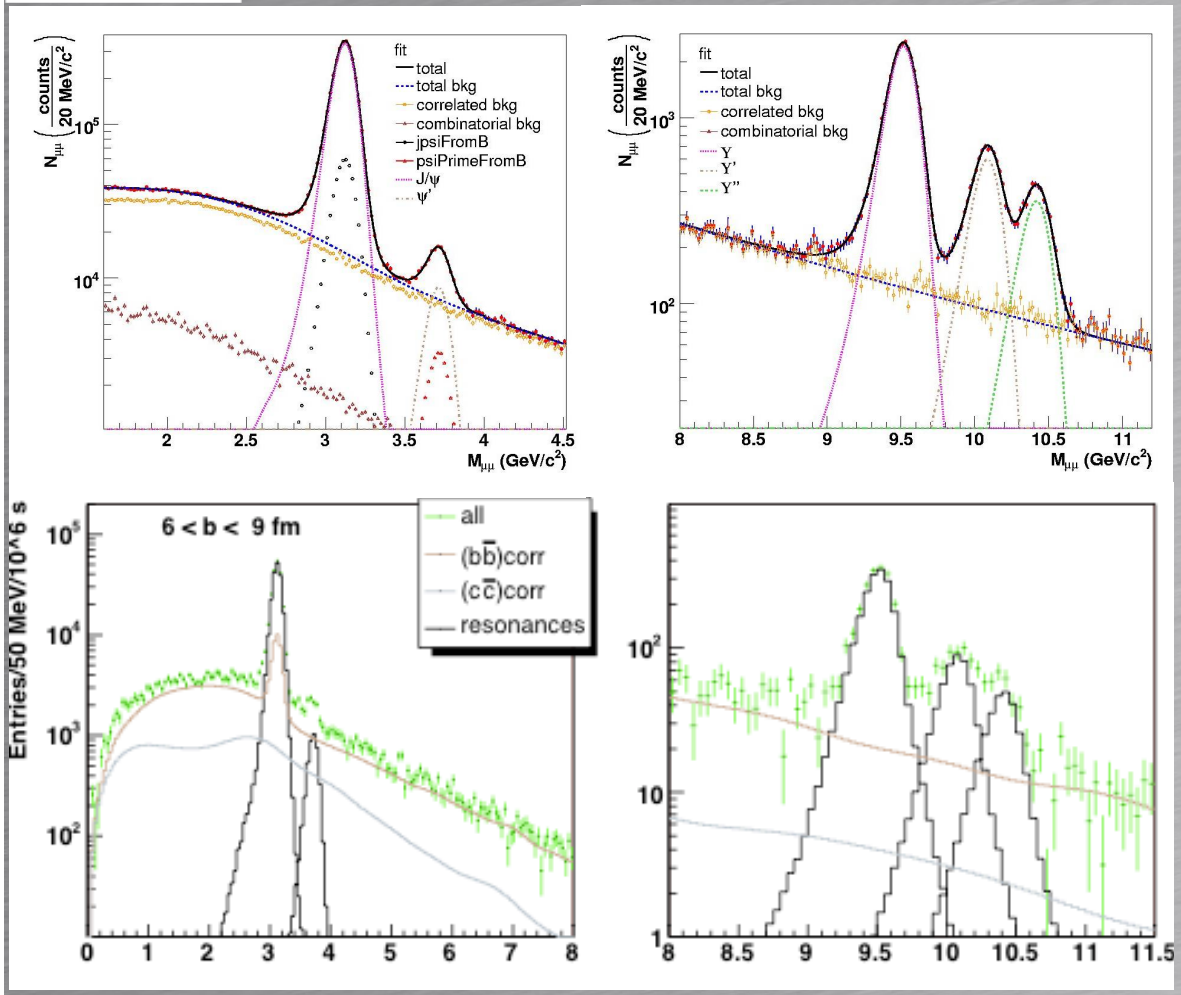
A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, Phys. Lett. B 652 (2007) 259.

Upsilon family in Heavy Ions

- Upsilon (1S) should only melt at LHC;
- Upsilon (2s) should behave as J/psi;
- Relative yield of upsilon resonances would solve the never-ending problem of quarkonium normalization in heavy ion collisions



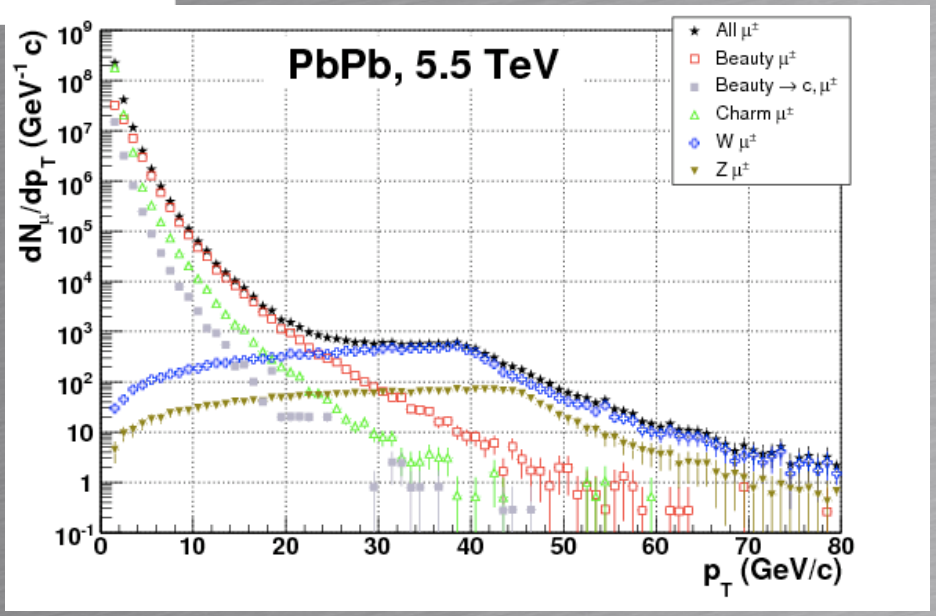
Quarkonia in the muon channel

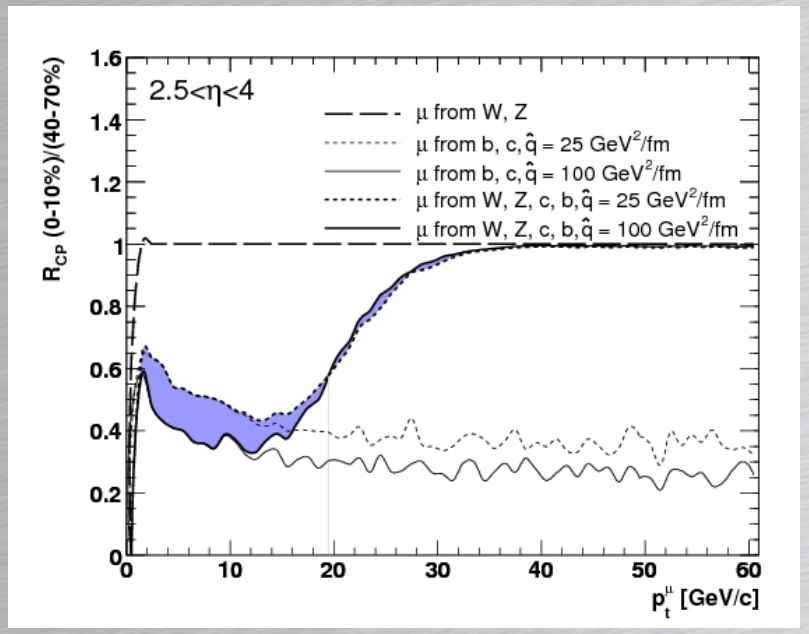


PbPb nominal run:

- High J/ψ statistics;
  - Centrality, v_2, p_T;
- Ψ' marginal;
- Υ(1S) ok;
- Υ(2S) low;
- Υ(3S) several runs needed;

W boson the muon channel





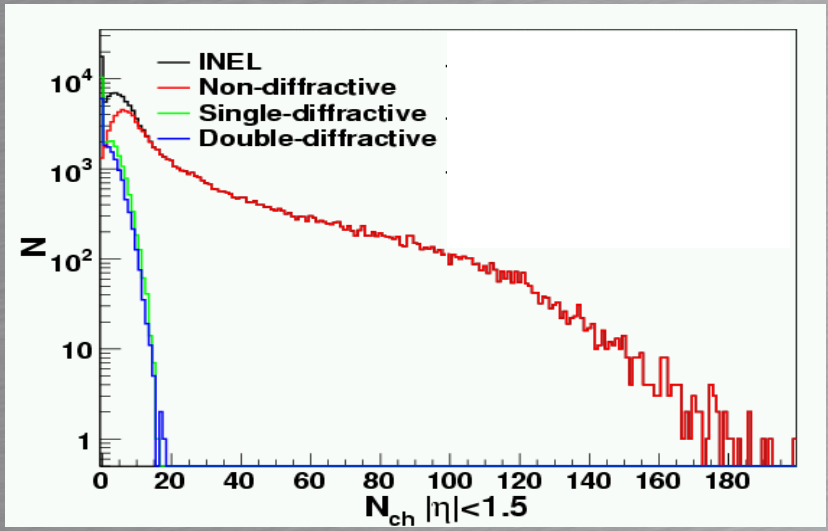
Decay	Collision	Statistics
Muonic	p-p, 14 TeV	86 000
Muonic	Pb-Pb, 5.5 TeV, MB	14 000
Muonic	Pb-Pb, 5.5 TeV, 0-10CC	6000

- W as a medium blind reference of the beauty Eloss in QGP.

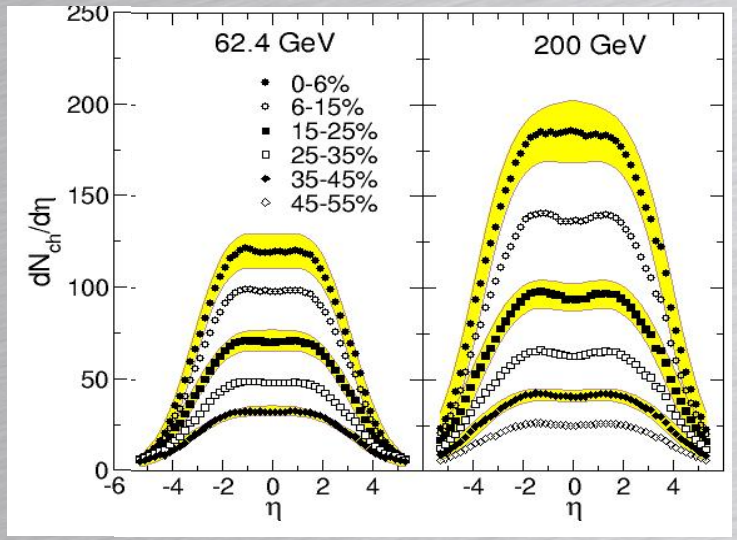
Z. Conesa del Valle et al. PLB663, 202 (2008)

QGP in p+p collisions at LHC?

- High particle densities: $dN_{ch}/d\eta$ ~ 50-100 like mid-central Cu+Cu at RHIC;
- Small volume ~5 fm^2;
- Higher energy density in the p+p collisions;



Phobos Cu-Cu

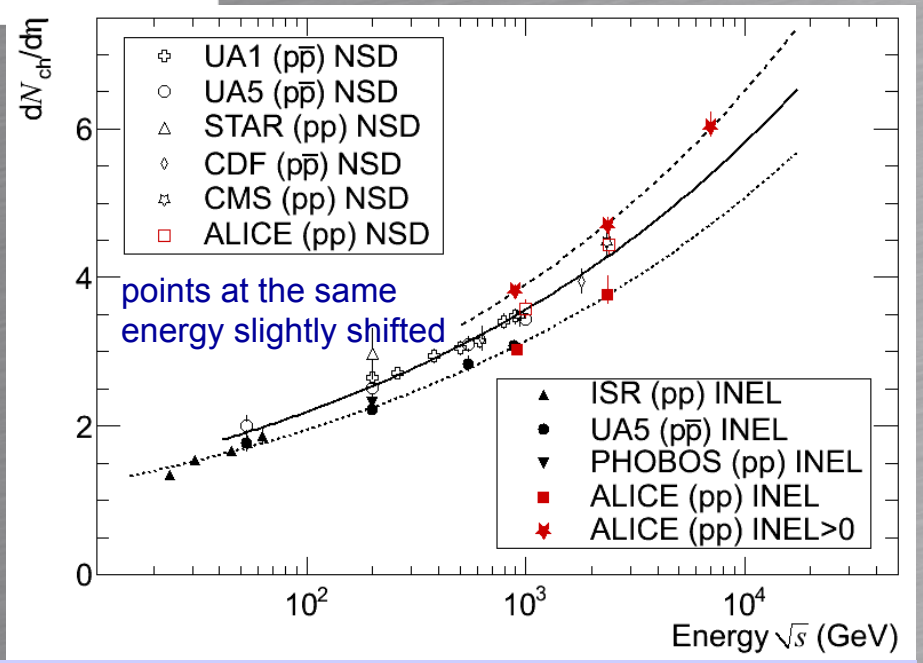


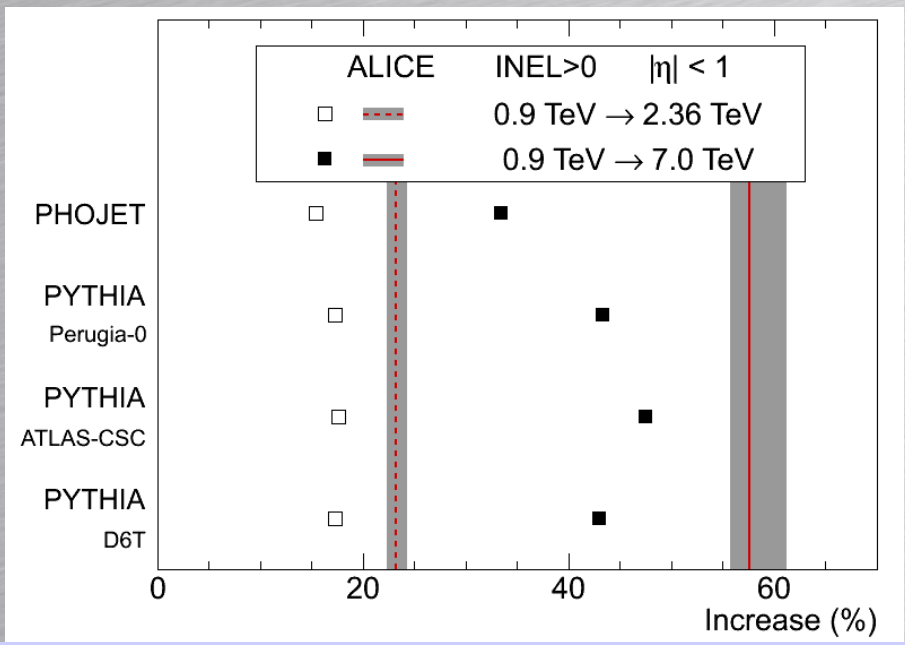
Data on tape

- Proton+Proton at 900 GeV (10^6 MinBias events);
- Proton+Proton at 2.36 TeV (10^5 MinBias events);
- Proton+Proton at 7 TeV (10^8 MinBias events and still running and enriching the data sample with rare triggers: high multiplicity trigger, muon single trigger, …)

$dN_{ch}/d\eta$

arXiv:1004.3514





Power law dependence fits well

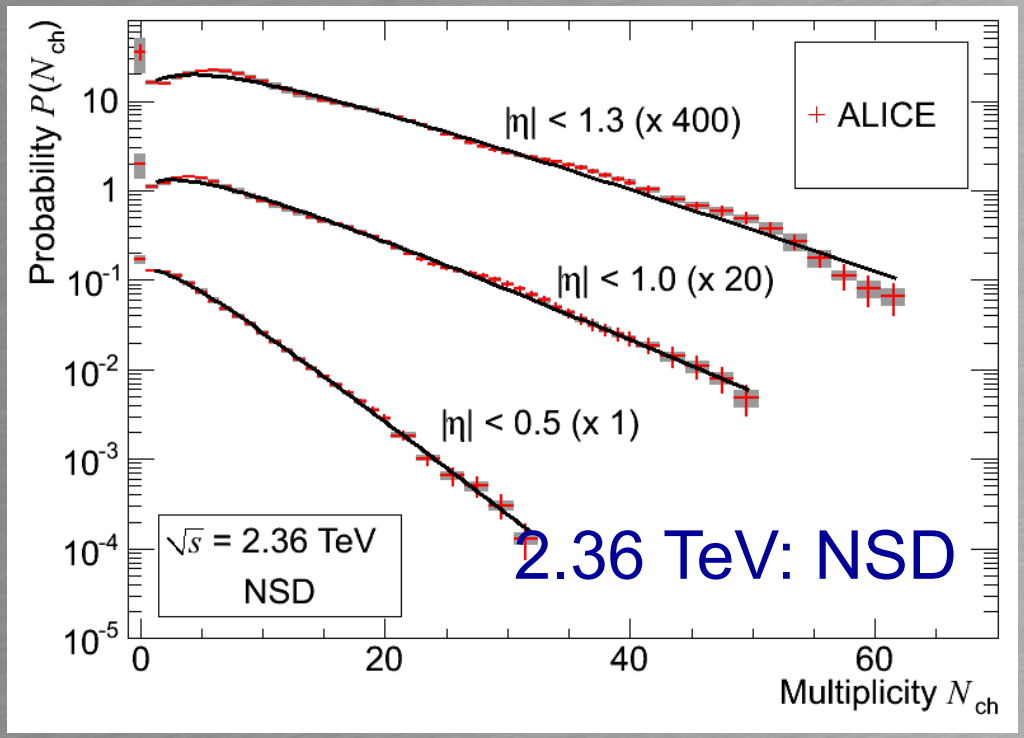
Significantly larger increase from 0.9 to 7 TeV than in MCs

Increase in $dN_{ch}/d\eta$ in $\|\eta\| < 1$ for INEL > 0 arXiv:1004.3514	$\sqrt{s}$	ALICE (%)	MCs (%)
	0.9 → 2.36 TeV	$23.3 \pm 0.4\ ^{+1.1}_{-0.7}$	15 – 18
	0.9 → 7 TeV	$57.6 \pm 0.4\ ^{+3.6}_{-1.8}$	33 – 48

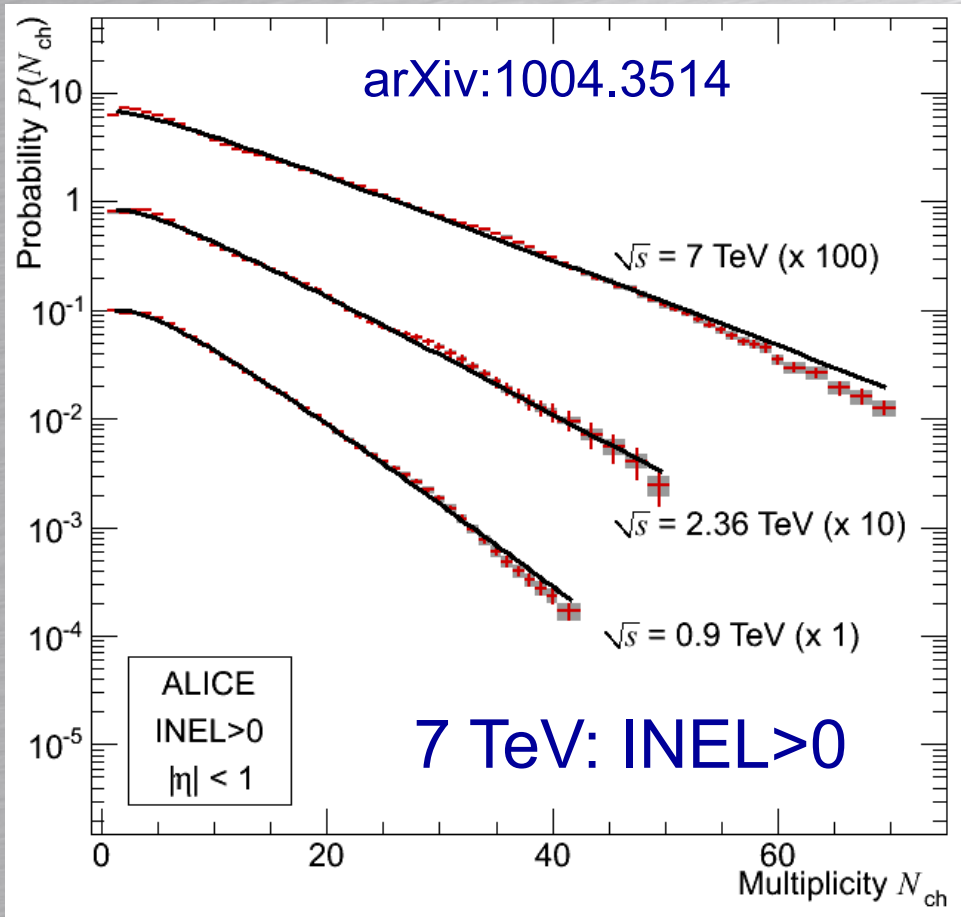
Multiplicity distributions

- Fits with one NBD work also at 2.36 and 7 TeV

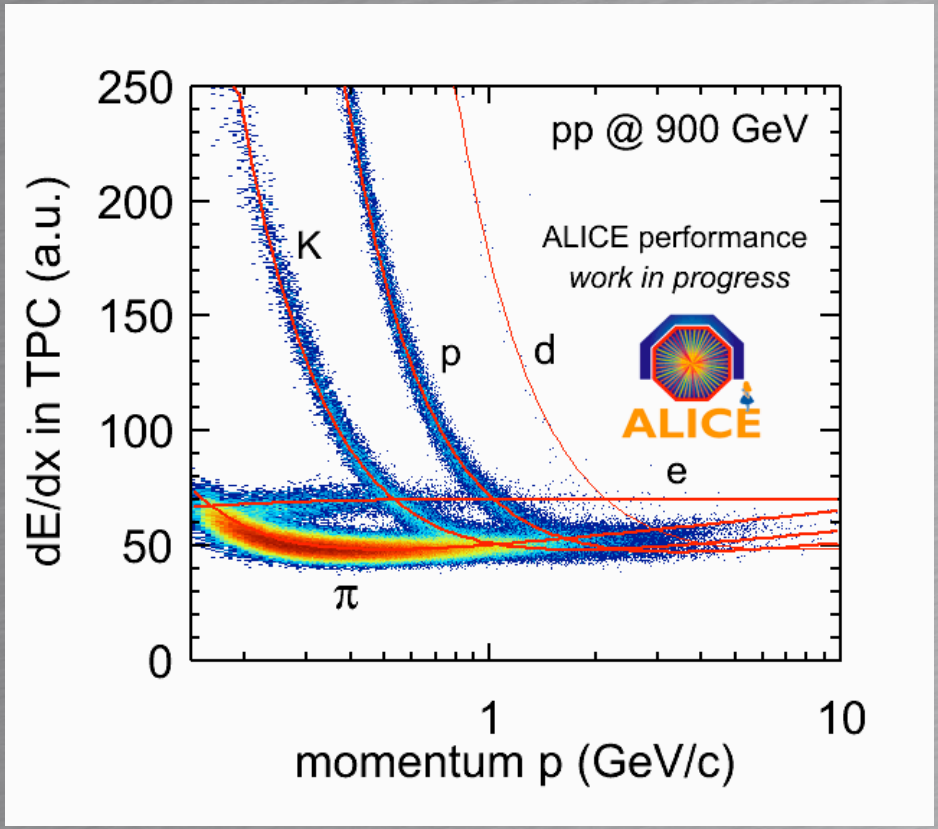
arXiv:1004.3034

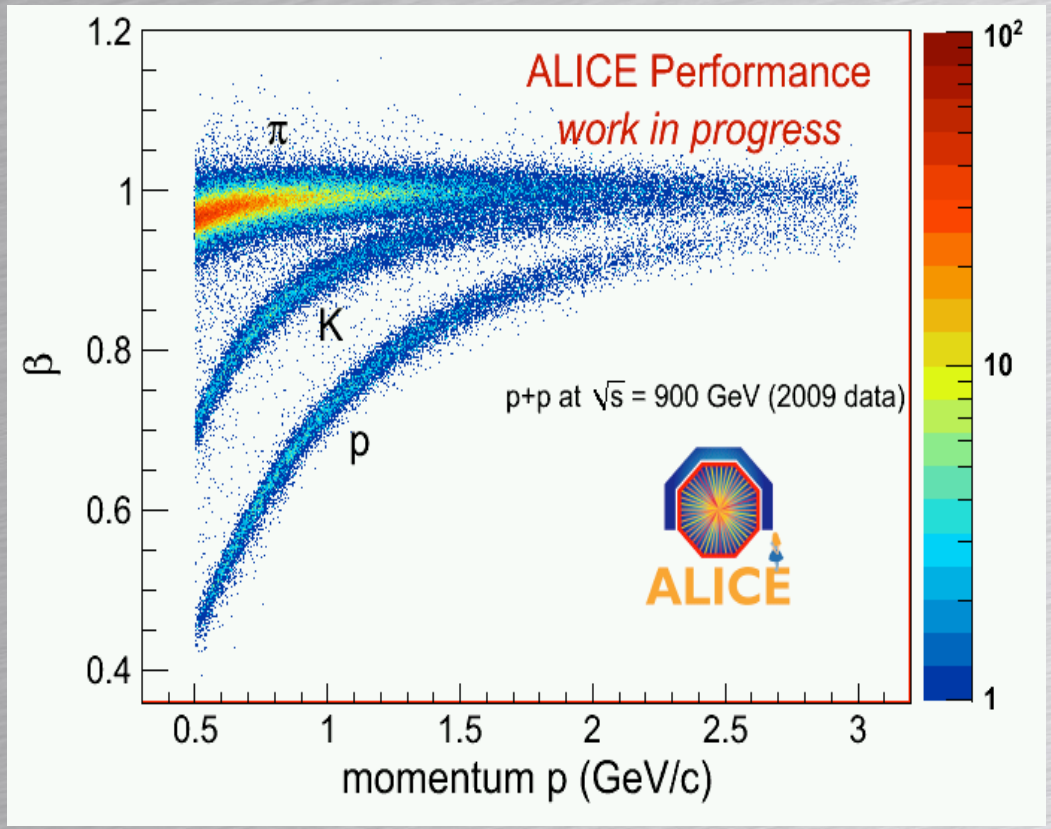


arXiv:1004.3514

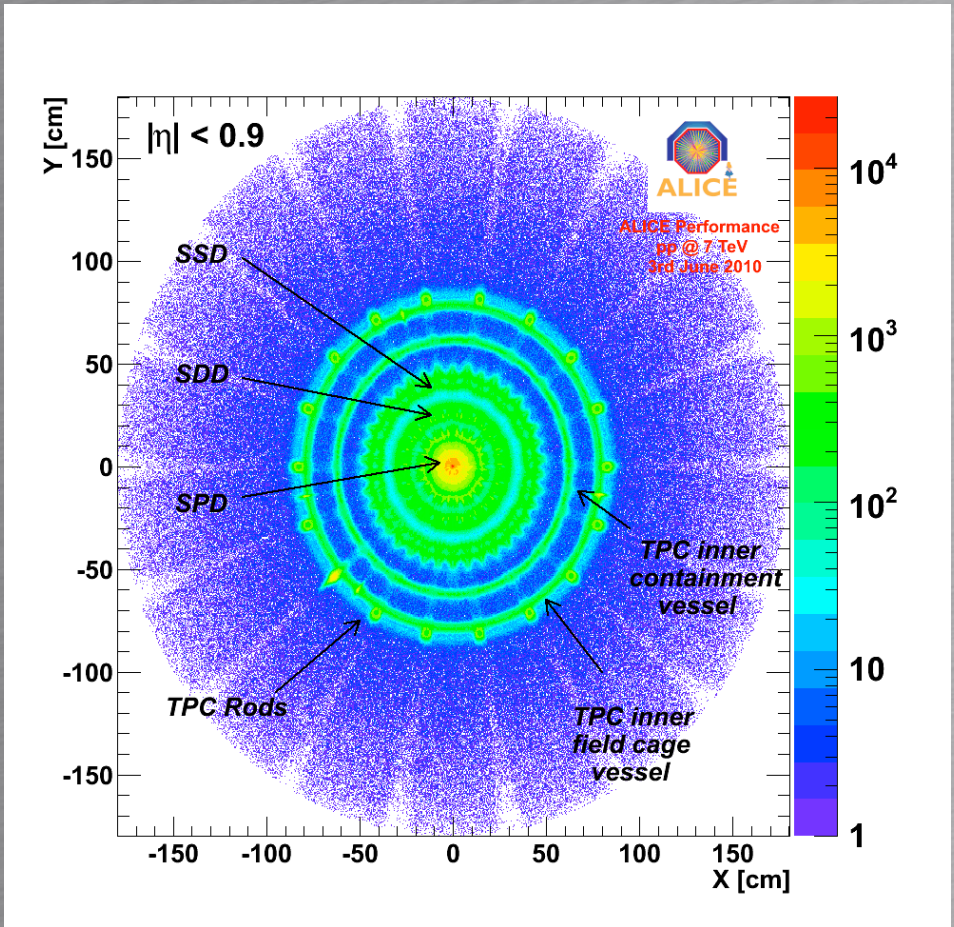


Particle Identification





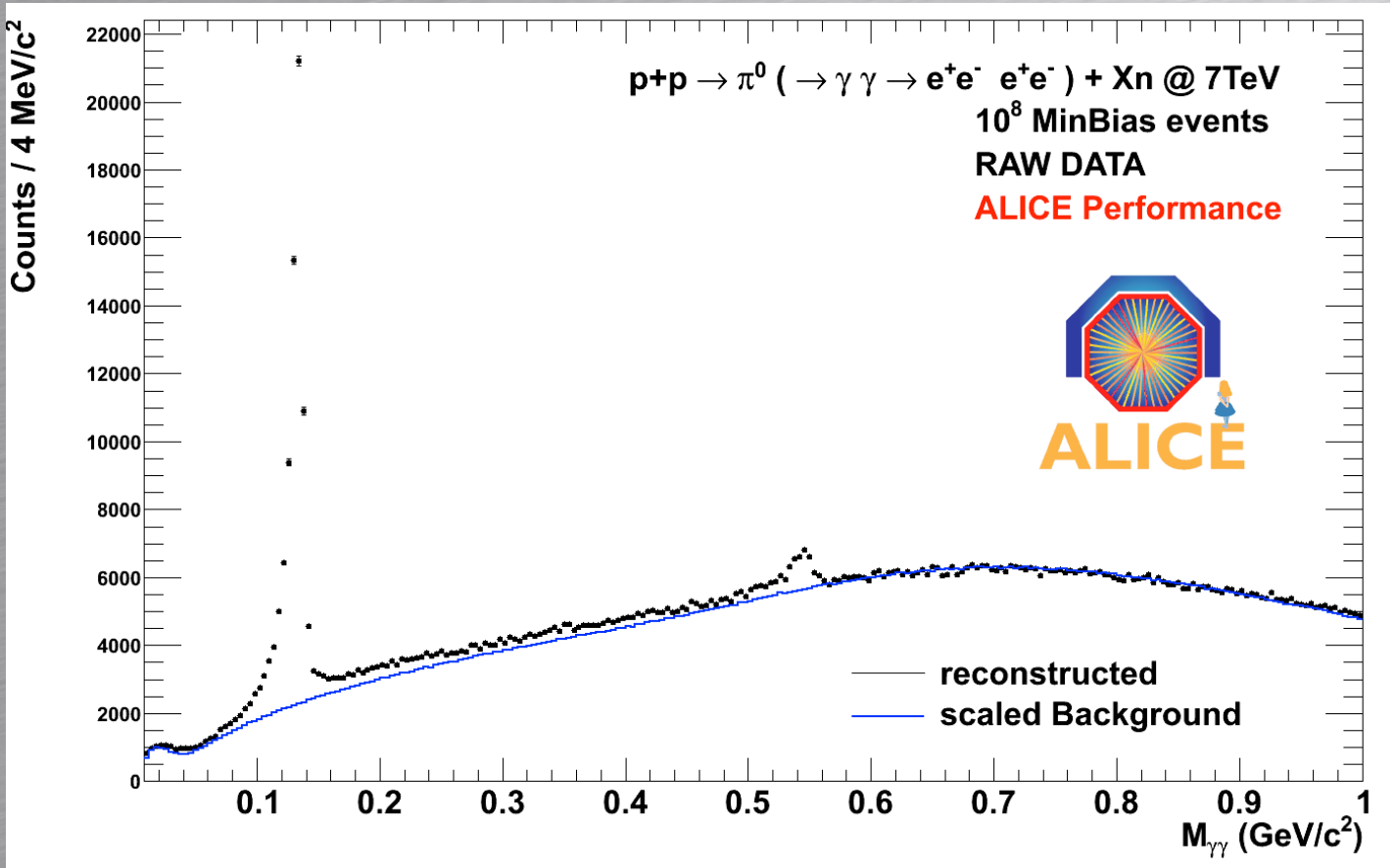
Material Budget



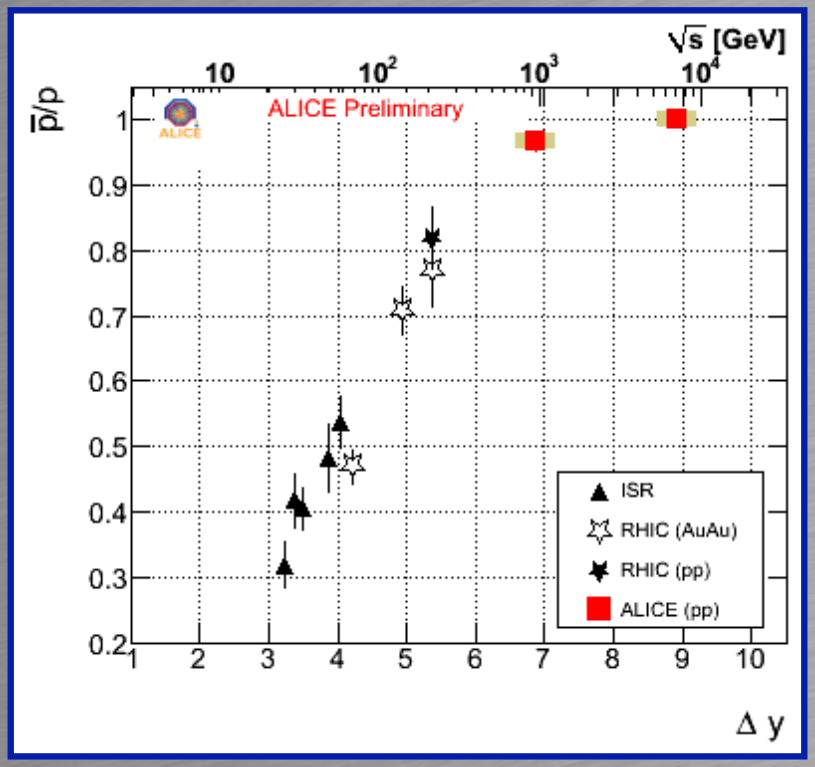
- (X,Y) position of photon conversion vertices;
- Depending on density and average Z of the material;
- Electrons and positrons identified by dE/dx in the ALICE TPC;
- Agreement with MC ~5%;

π^0 and η mesons

- From gamma conversions; excellent resolution: 3-4 MeV/c^2.

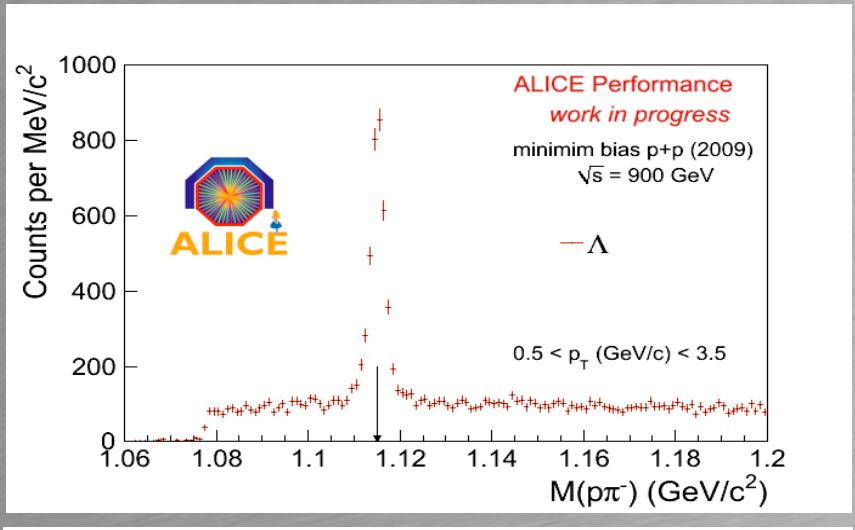


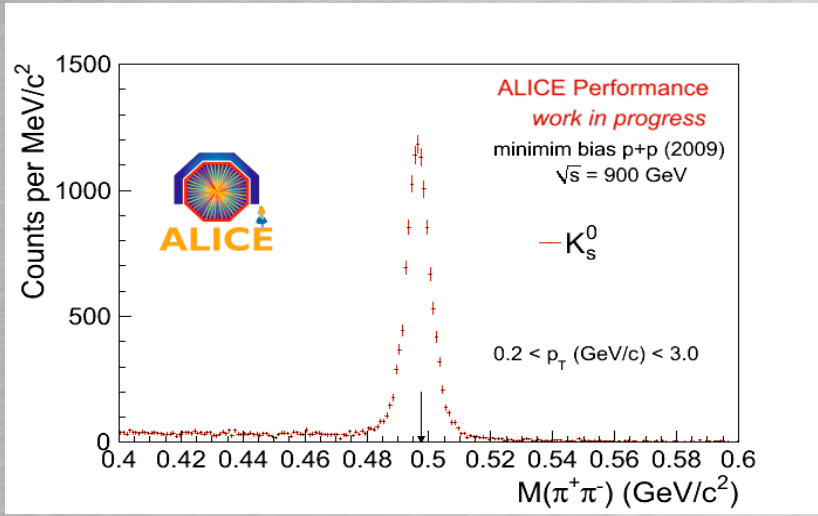
Pbar/p ratio

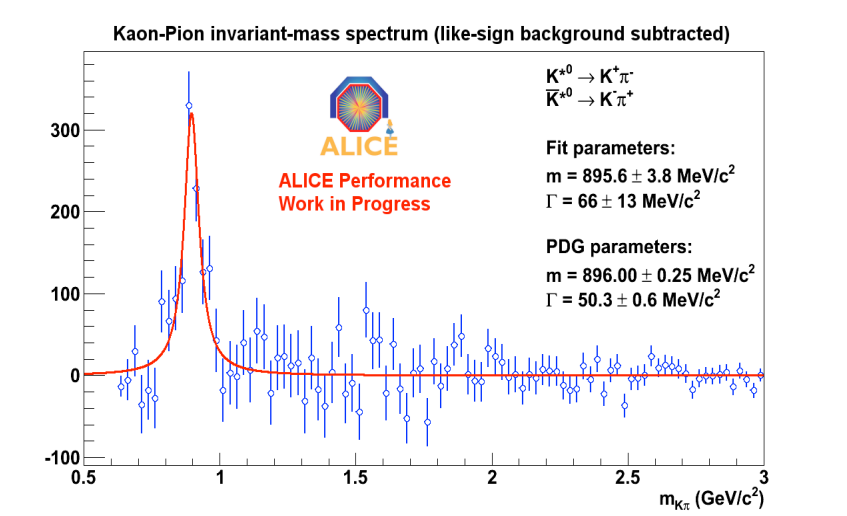


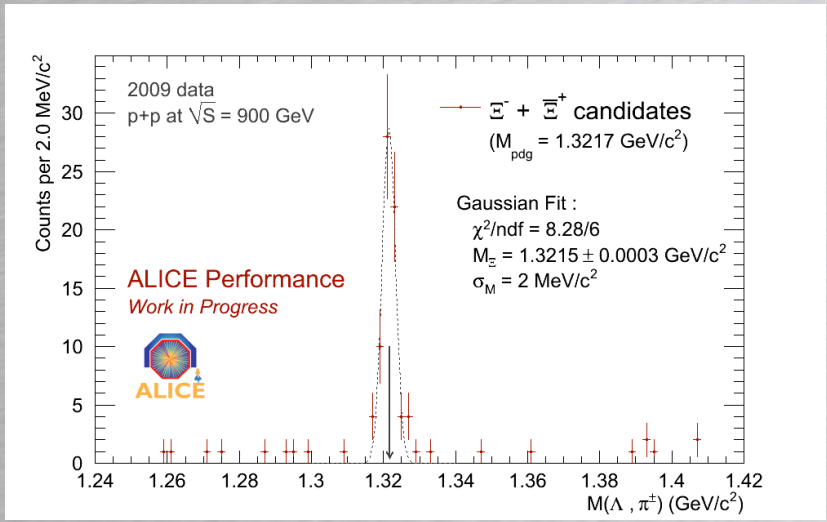
- Pbar and p identification by dE/dx in the TPC;
- Ratio at $|y|<0.5$ and $pT>450$ MeV;
- At LHC close to unity;
- In PbPb collisions a primordial QGP (null net baryon density) is expected;

Many more resonances





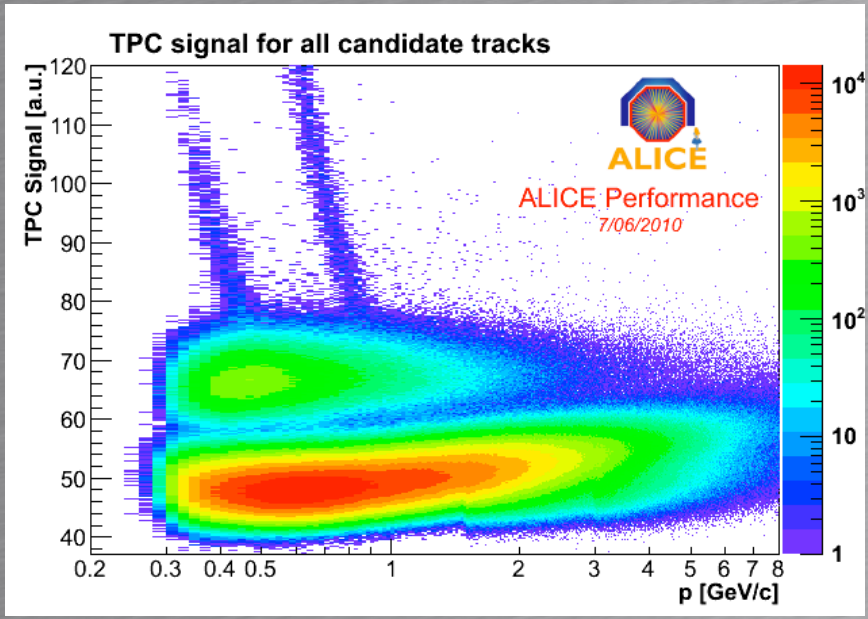


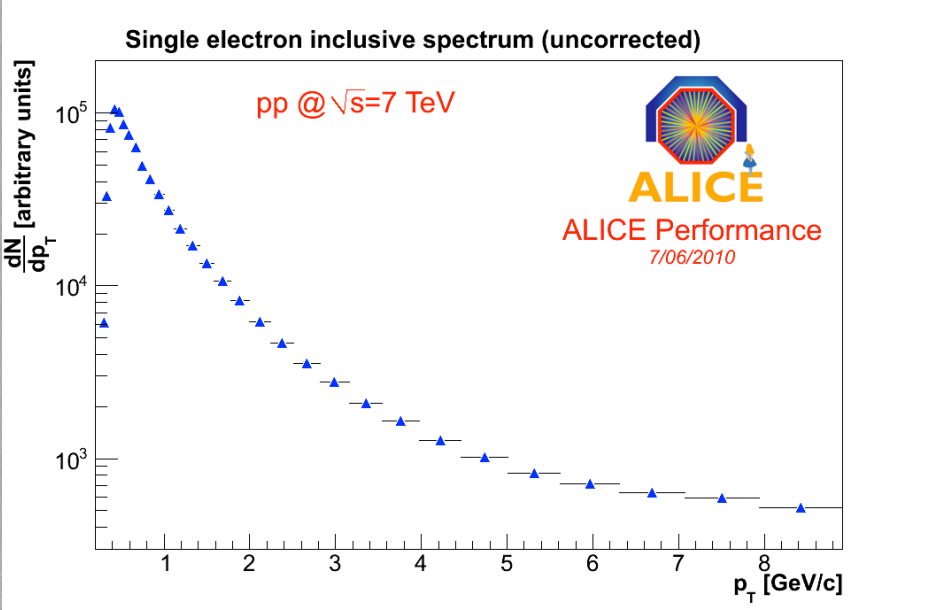


Heavy Flavour measurements

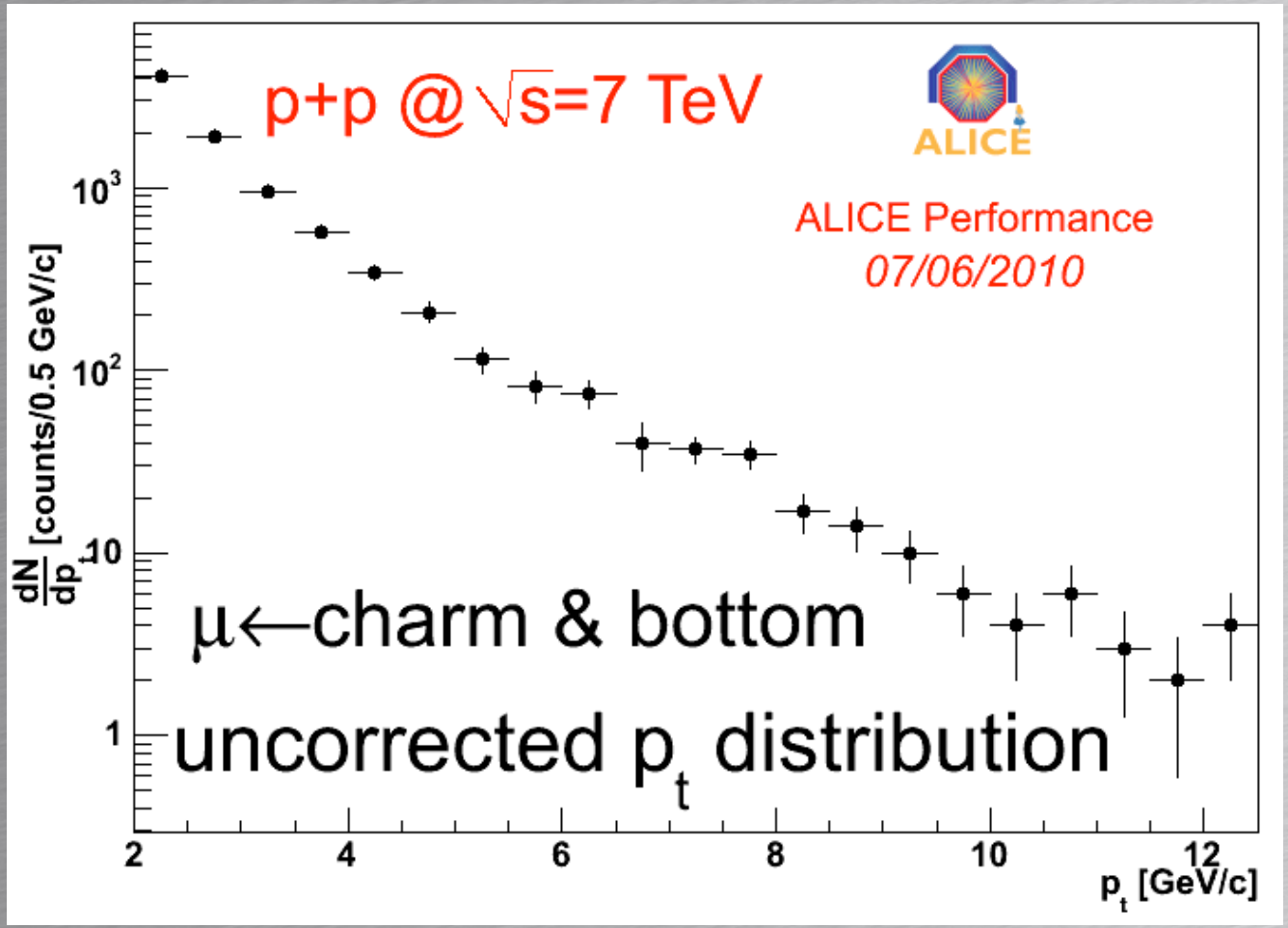
- Good progress on three channels:
  - Inclusive electron p_T distribution:
    - TPC+TOF electron PID;
    - Photonic electrons have not been subtracted yet.
  - Heavy Flavour muon p_T distribution
    - Pseudo-rapidities 2.5-4.0;
    - Preliminary subtraction of primary muon from pions and kaons;
  - Reconstruction of D mesons:
    - D^0 in $K\pi$, D^* in $D^0\pi$ are observed and D^+ in $K\pi\pi$;

Electron Channel

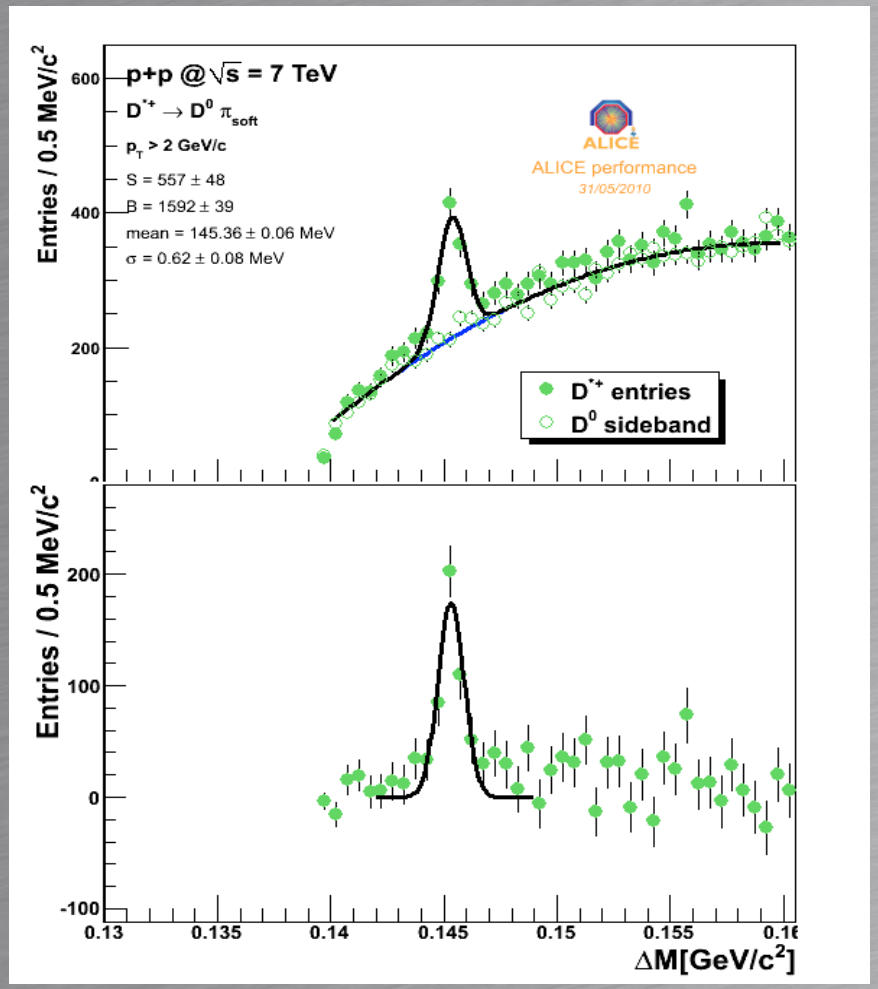


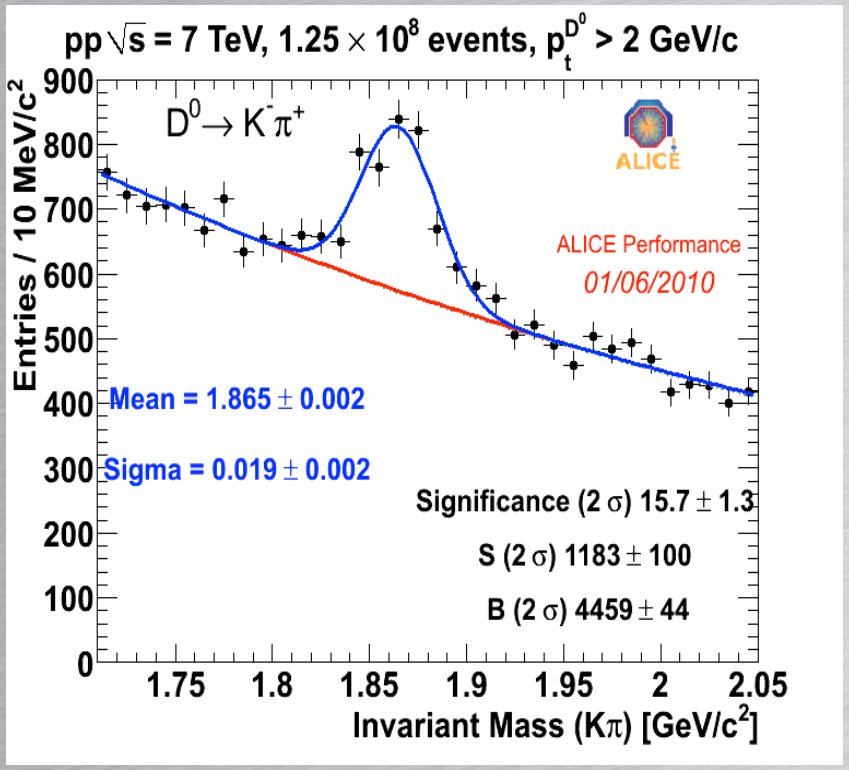


Muon Channel

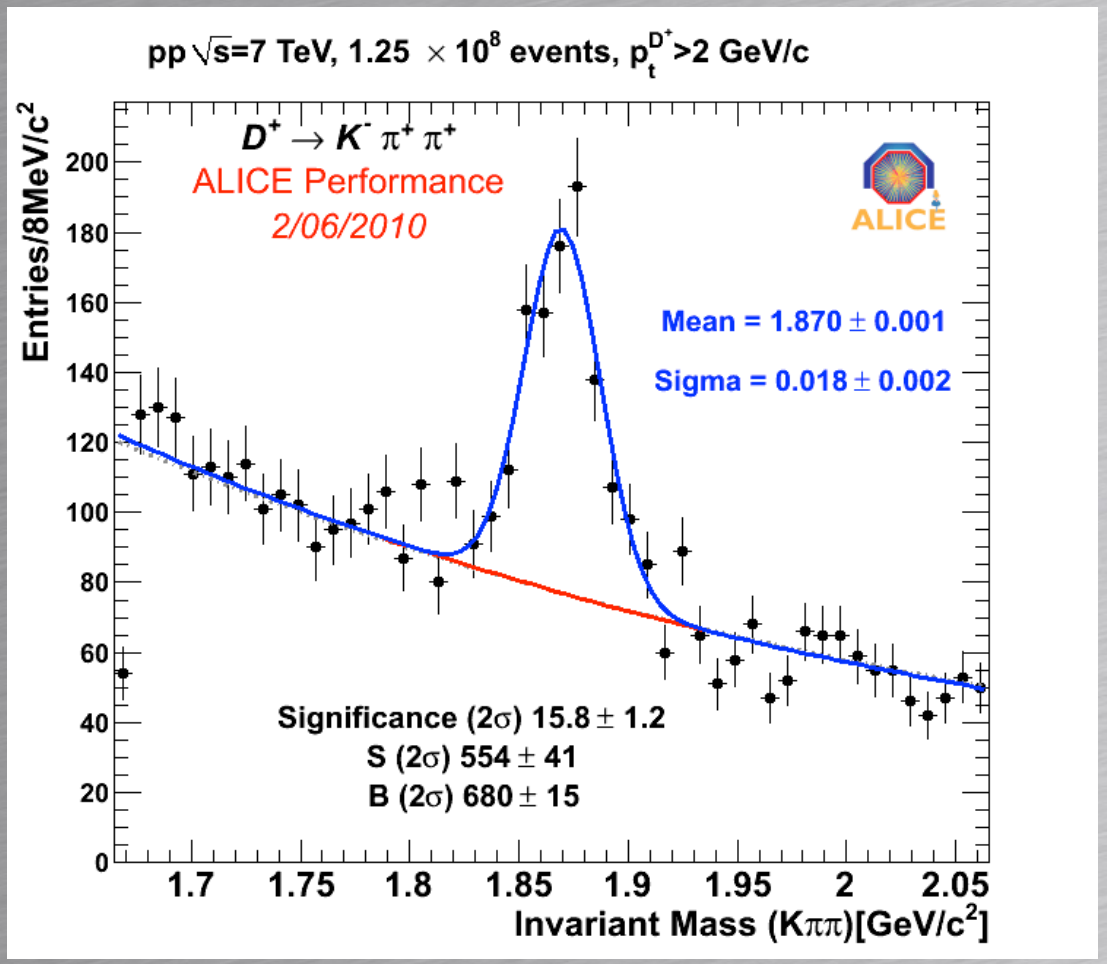


Charmed hadrons (D^*, D^0)





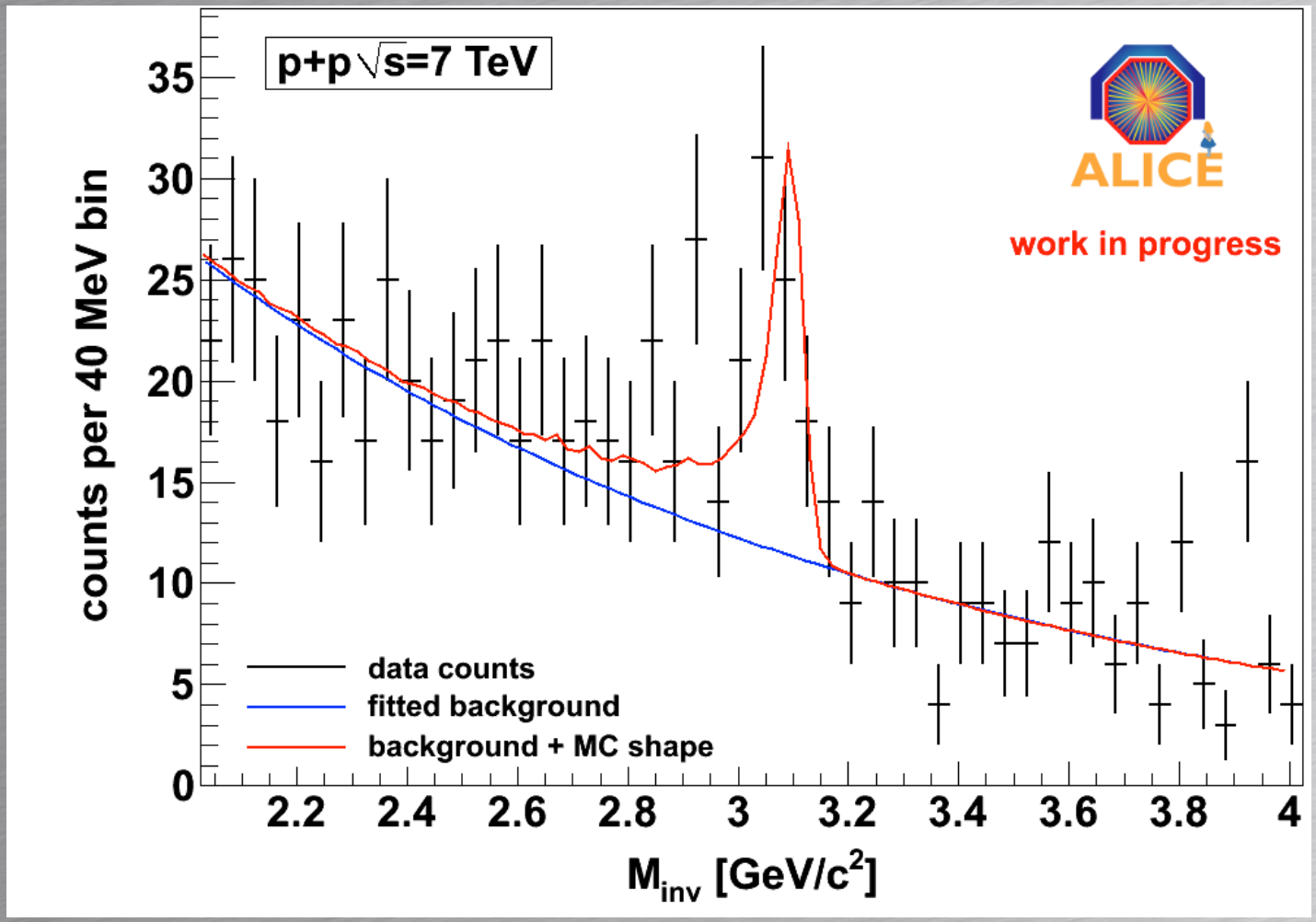
Charmed hadrons (D^+)



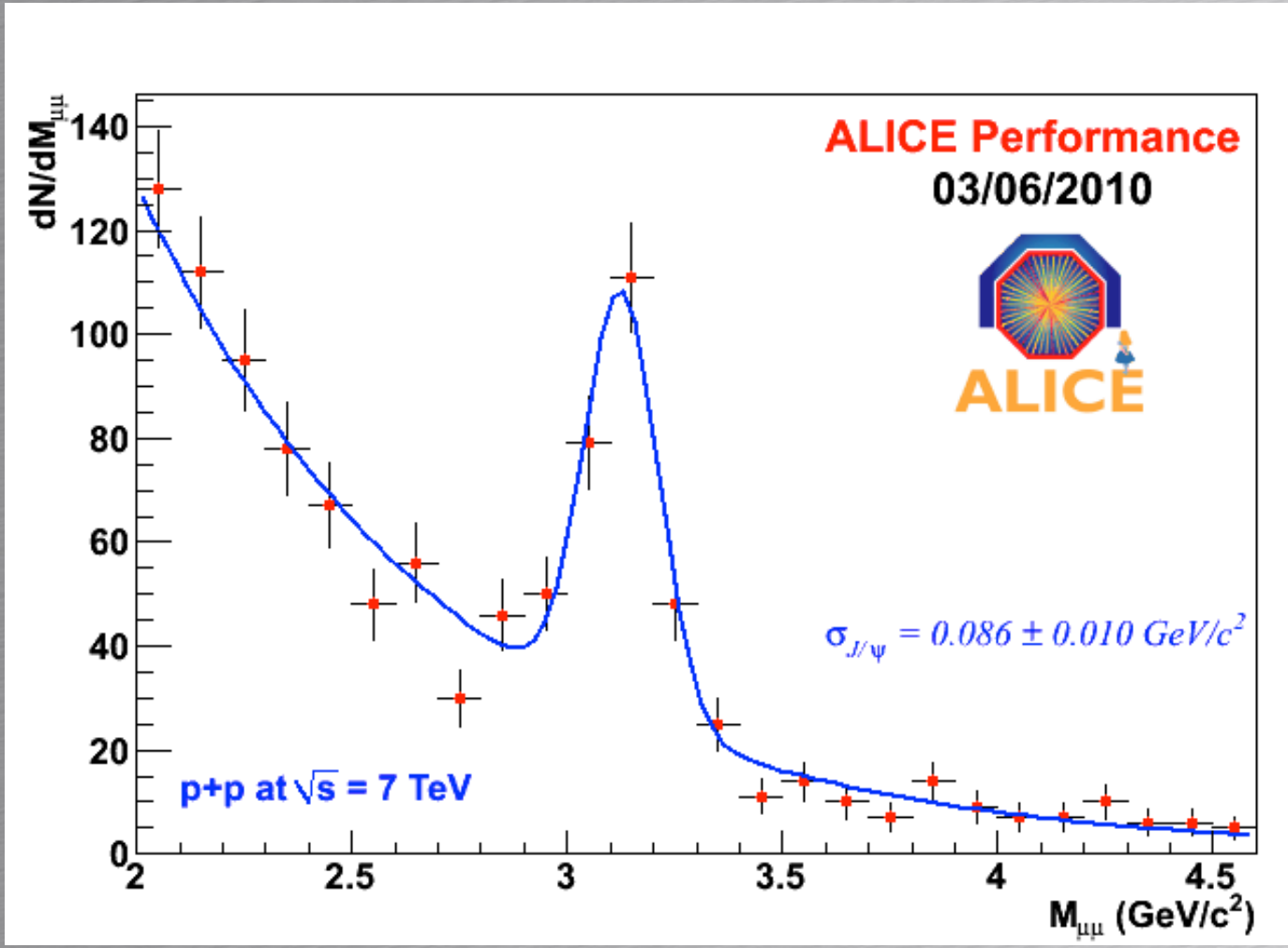
Quarkonium measurements

- Good progress in two channels:
  - J/psi in dielectron in the central barrel;
  - J/psi in dimuon in the muon spectrometer.

Dielectron


p+p √s=7 TeV
ALICE
work in progress
counts per 40 MeV bin
data counts
fitted background
background + MC shape
M_inv [GeV/c²]
0
5
10
15
20
25
30
35
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4

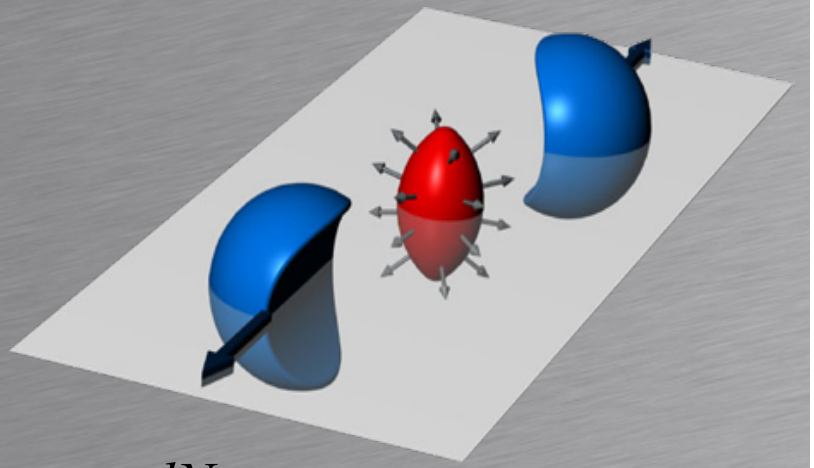
Dimuon


ALICE Performance
03/06/2010
ALICE
$\sigma_{J/\psi} = 0.086 \pm 0.010$ GeV/c^2
p+p at $\sqrt{s}$ = 7 TeV
dN/dM$_{\mu\mu}$
M$_{\mu\mu}$ (GeV/c^2)
0
20
40
60
80
100
120
140
2
2.5
3
3.5
4
4.5

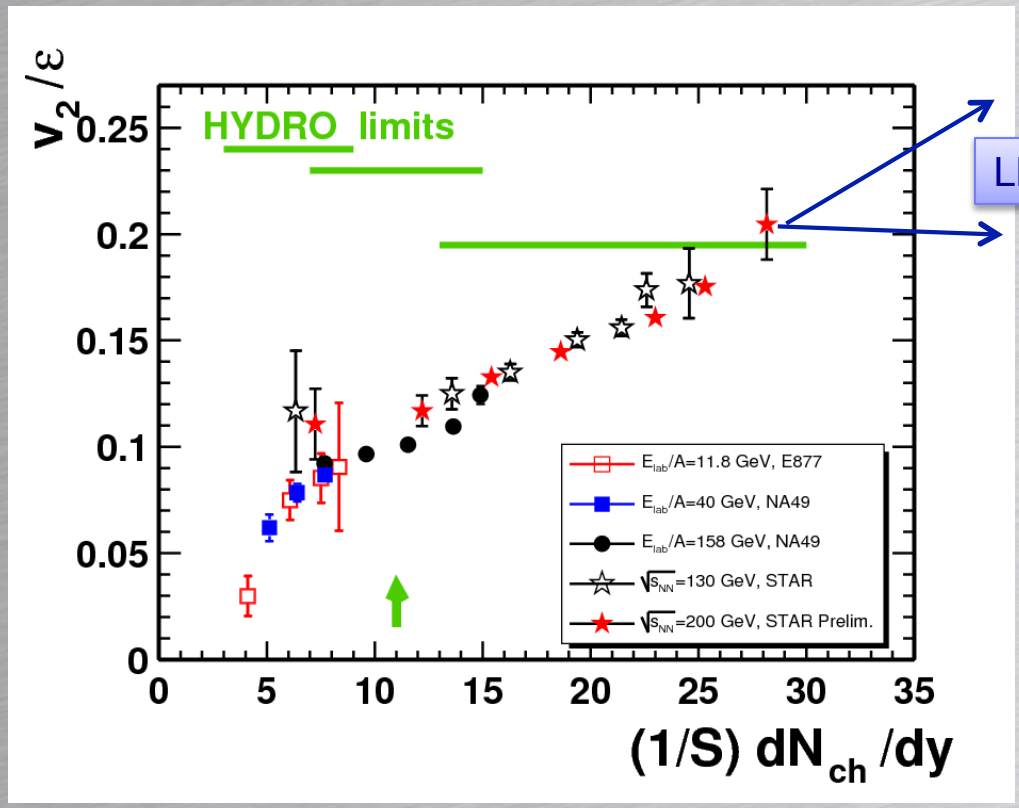
PbPb run in 2010

- First Heavy Ion Run expected in November 2010:
  - PbPb at 2.76 TeV (82/208 x 7 TeV);
  - Max luminosity 10^{25} $cm^{-2}s^{-1}$ ~ 100 Hz Minimum Bias;
- First expected physics:
  - Elliptic flow measurement;
  - Particle correlations;
  - Multiplicity per participant;
  - Mean p_T;
  - Indentified particle spectra.

First measurement could be:



$$\frac{dN}{d\Delta\phi} \propto \left(1 + 2v_2 \cos 2\Delta\phi\right)$$



NA49, PRC68, 034903

Additional runs in 2010

- We are asking for a specific run proton proton at 2.76 TeV:
  - Same energy as PbPb run;
  - Baseline QGP physics;
  - Cross-checking interpolations;

Conclusions

- After 2 weeks of running in pp@900GeV and 2 months in pp@7TeV, ALICE has provided plenty of results:
  - First LHC publication at 900 GeV and 7 TeV;
  - Larger multiplicities that expected;
  - Rediscovering particle zoology;
- High multiplicity events in pp collisions are being studied;
- After 10 years, data in heavy ion collisions at LHC are getting closer and closer: November 2010;

Merci !
Thanks !
Grazie mille !
Muchas gracias !
Danke schön !
Spasiba !