QCD and Heavy Ions: LHC prospects

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cnrs dépasser les frontières
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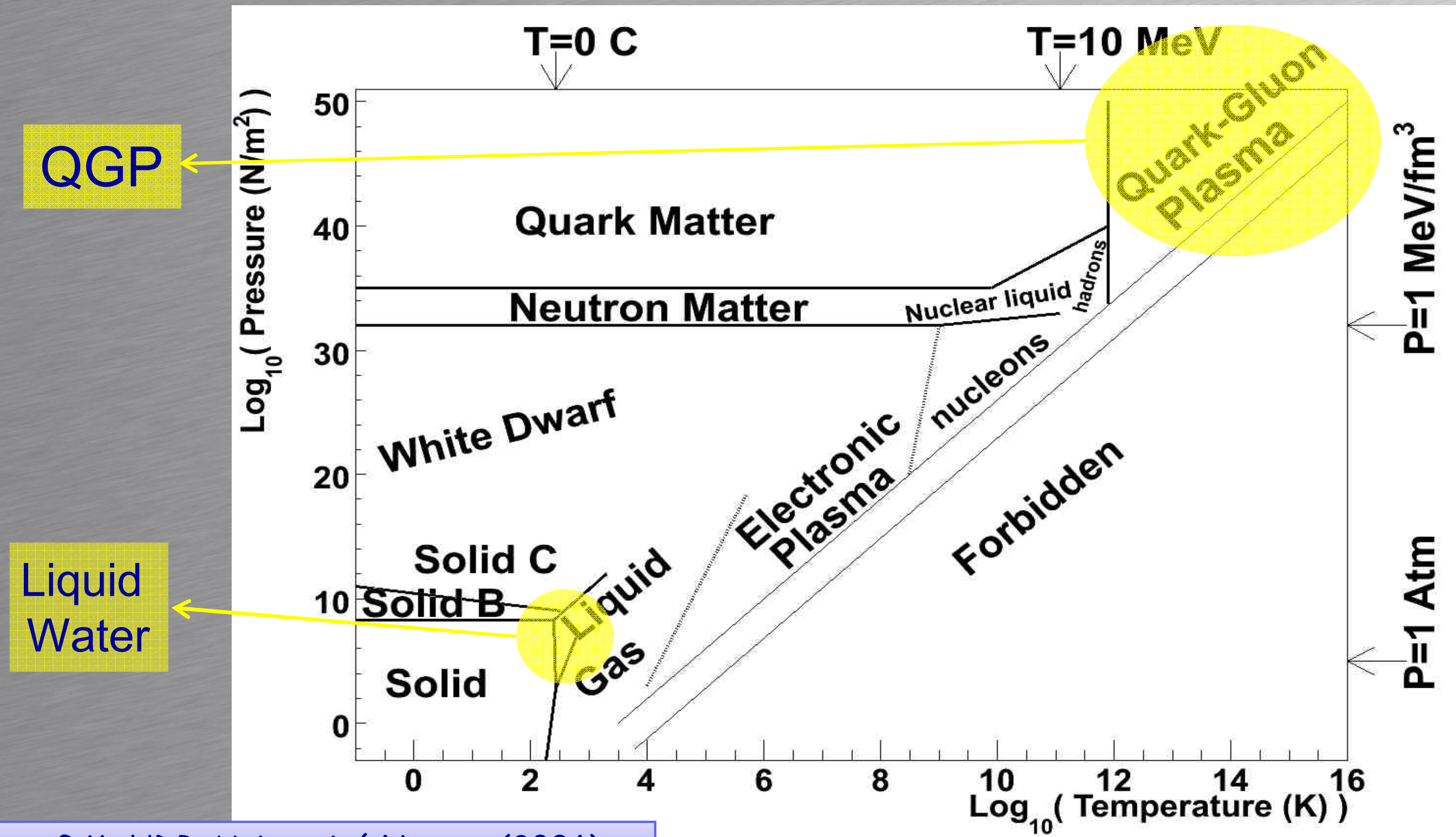
Subatech

Phase Diagram of Matter



G.M. HDR, Université Nantes (2006)

Preface

- Heavy Ions collisions open the possibility to study the QGP in the laboratory; Bjorken PRD27 140 (1983)
- Experimental program started 25 year ago: SPS and RHIC;
- I will not review results of the HI experimental program;
- I will focus on motivations of HI programme at LHC;
- I will not review exhaustively the performances and characteristics of the LHC experiments;
- My presentation, my responses to questions, etc … will surely be "ALICE biased".

Outlook

- ✓ Why a LHC HI program?
- ✓ Reminder of the Bjorken scenario;
- ✓ LHC HI program;
- ✓ Global properties of the highly excited strongly interacting matter at LHC;
- ✓ Probing the QGP at LHC.

Heavy Ion Facilities

- SPS Heavy Ion accelerator, CERN (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;

Motivation for a HI program at LHC

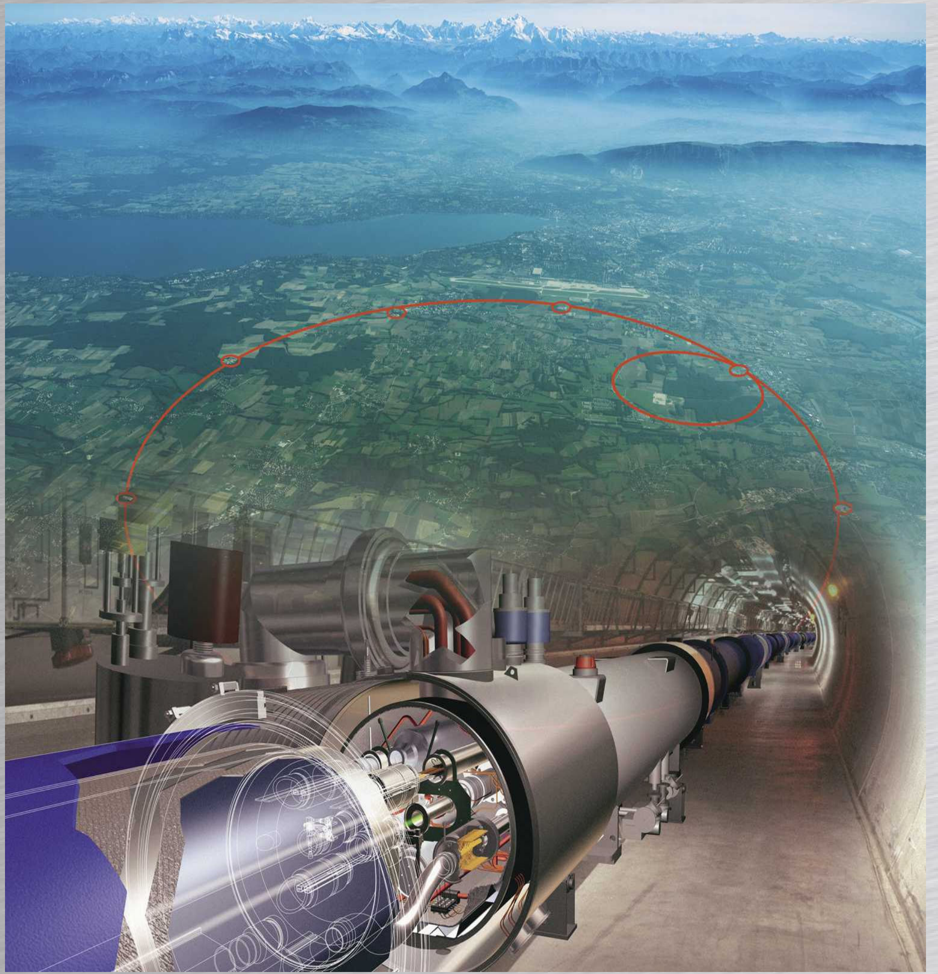
30-fold step in energy at a luminosity 10^{27} cm^{-2} s^{-1}: PbPb coll. rate 8kHz;

- limited by physics;

① QGP: hotter, bigger and longer;

② Baryon free matter;

③ Large production cross-sections of hard (penetrating) probes;



QGP and Heavy Ion Collisions

- A+A collisions (AuAu, PbPb, etc...);
- Large Lorentz factor (γ>10, sqrt(s)>17 GeV);

QGP and Heavy Ion Collisions

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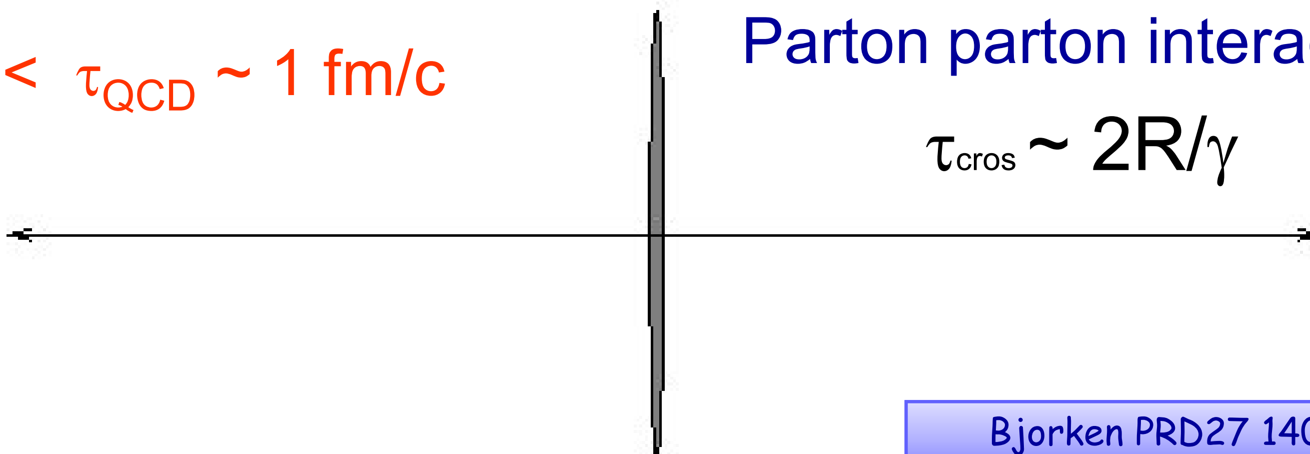
- Number of binary NNcoll ~ 1900 in central HIC;

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

Parton parton interactions

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



Bjorken PRD27 140 (1983)

QGP and Heavy Ion Collisions

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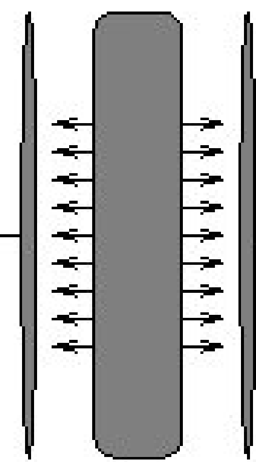
- At LHC, ε_0~10-40 GeV/fm^3, T_i~300-500 MeV

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

Bjorken PRD27 140 (1983)



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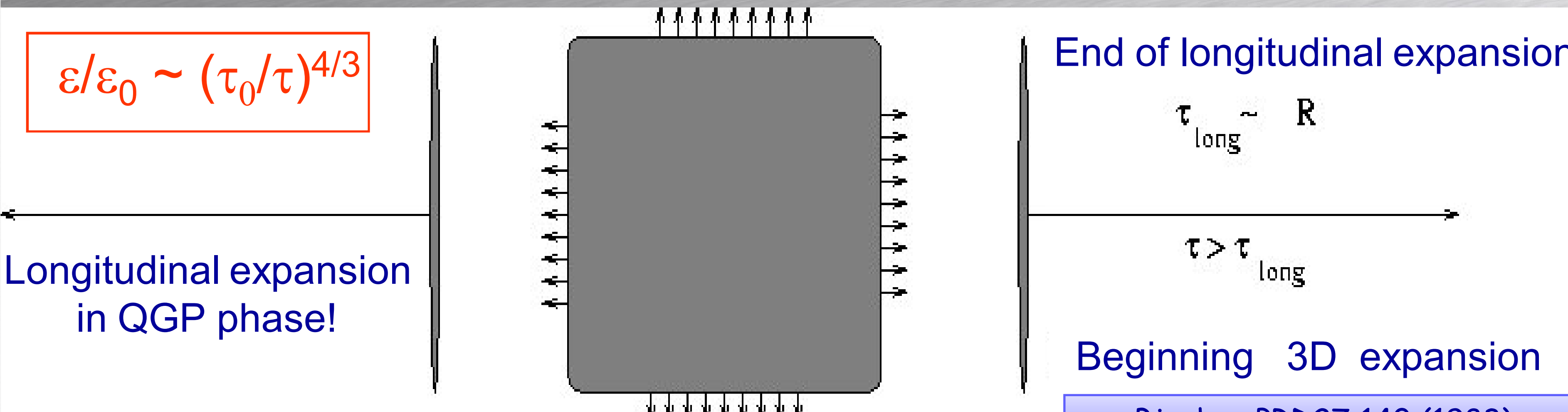
$$\varepsilon/\varepsilon_0 \sim (\tau_0/\tau)^{4/3}$$



Bjorken PRD27 140 (1983)

QGP and Heavy Ion Collisions

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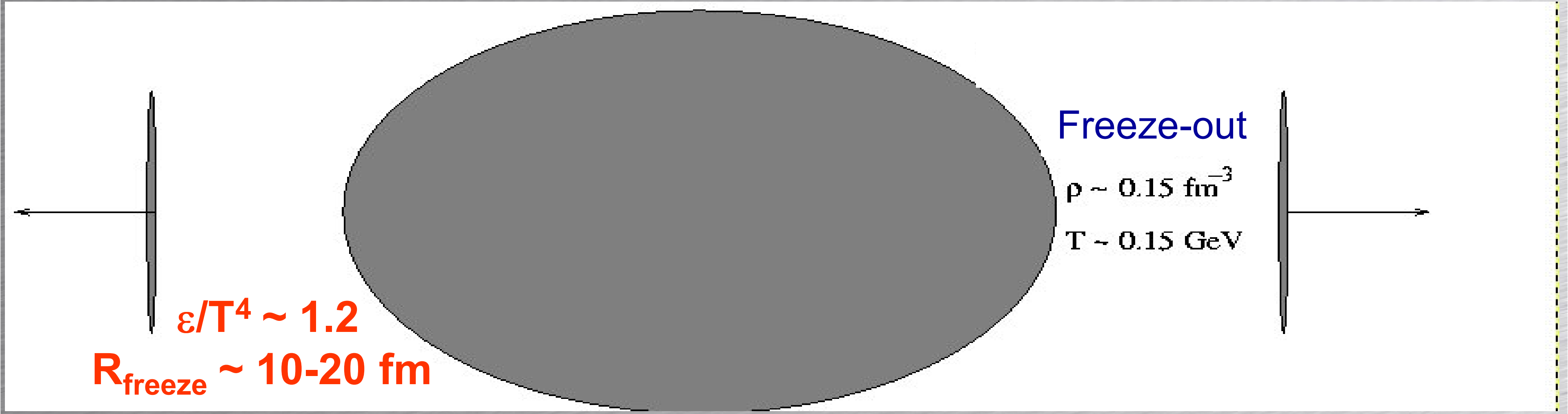
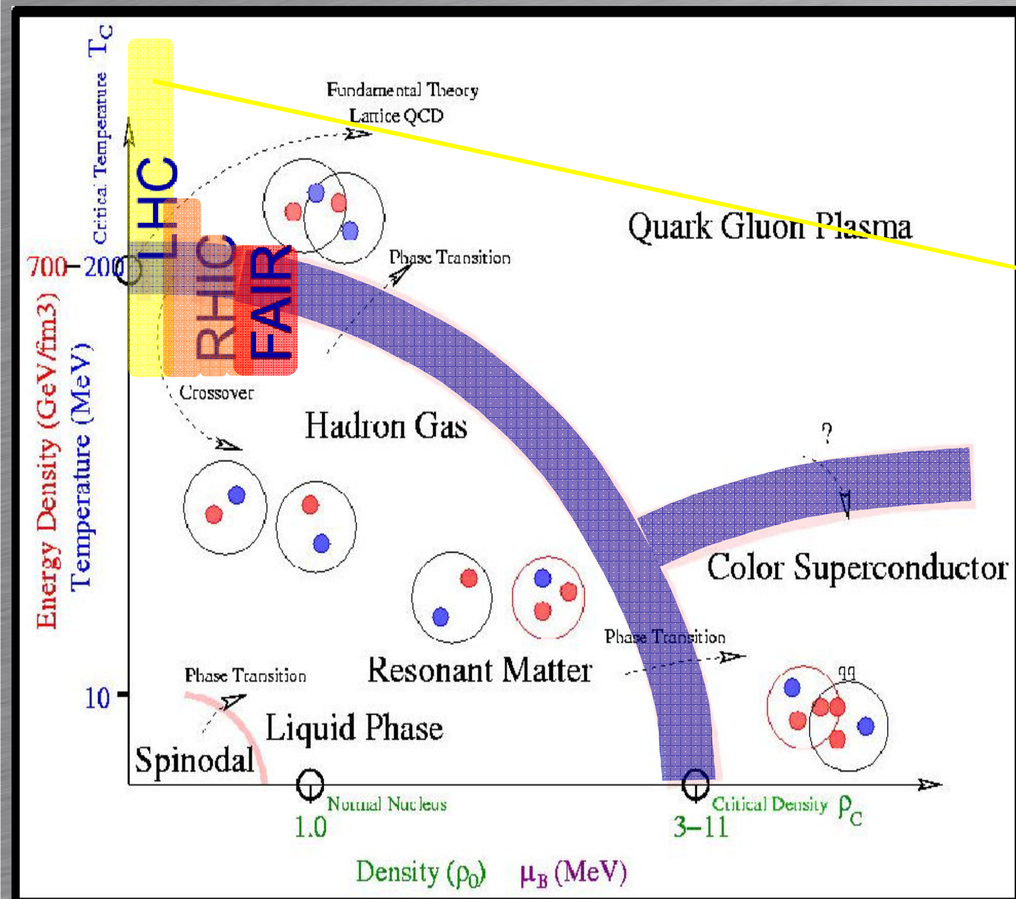
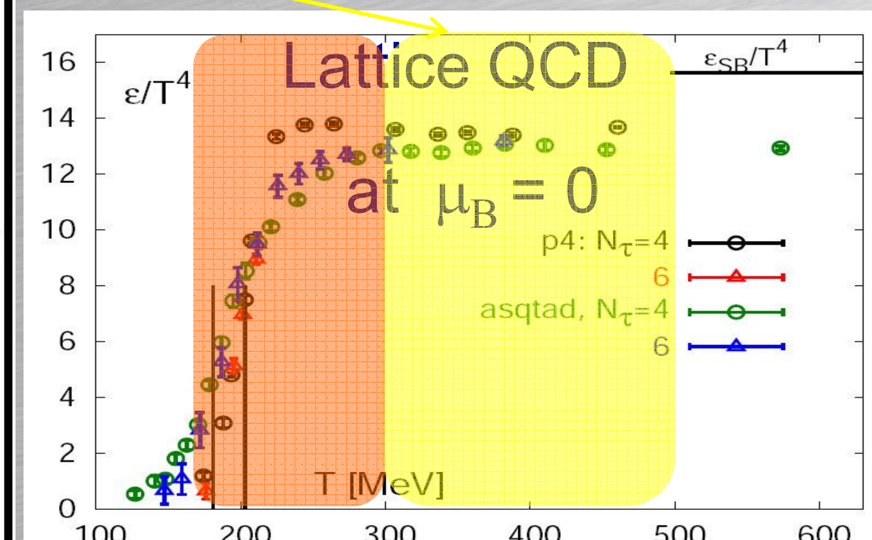


Exploring the phase diagram at LHC

- Predictions by lattice QCD calculations;
- Ideal relativistic gas or sQGP as at RHIC?





Karsch, Quark Matter 2006

ALICE Heavy-Ion Program

Nominal conditions

System	$s_{NN}^{1/2}$(TeV)	L_0($cm^{-2}s^{-1}$)	$\langle L\rangle/\langle L_0\rangle$	Run time (s yr^{-1})	σ (b)	Ncollisions
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 TeV, pPb (dPb), lighter ions (O, Ar, Kr, In);
- Available energy in the center of mass: 14 $(Z_1Z_2/A_1A_2)^{1/2}$ TeV: 7 TeV for ArAr;
- Rapidity shift : $\Delta y = 0.5 \ln(Z_1A_2/A_1Z_2)$: 0.47 for pPb, 0.12 for dPb;

✓ Expect ~10 years “baseline” program 2009-2019 (1 month per year);
✓ First 5 years: 1 PbPb run low luminosity, 2 PbPb runs at nominal luminosity, pPb and ArAr runs;
✓ Second 5 years (based on previous experimental results): lower energies, pp at 5.5 TeV, other AA or pA, more statistics;

ALICE Collaboration et al., J. Phys. G30, 1517 (2004)

LHC HI experiments

ALICE, devoted to HIC. ~ 1000 interested people. Low/high p_T, good PID, high granularity for jets studies and low p_T charmonium physics;

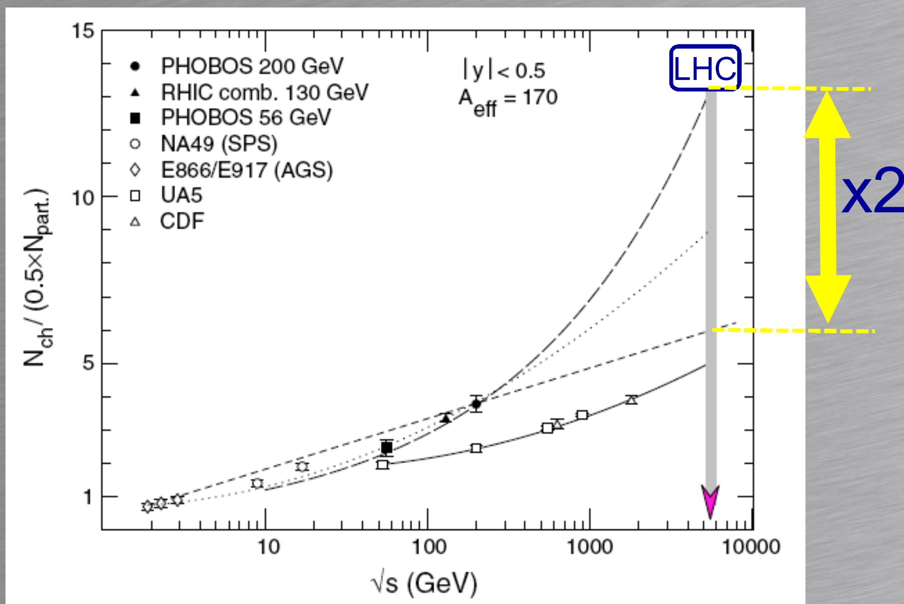
CMS, multipurpose program aiming for SM and beyond processes. Large HI group (150 interested people). Large acceptance at high p_T, jet and upsilon physics;

ATLAS, multipurpose program aiming for SM and beyond processes. Small HI group (growing!). Large acceptance at high p_T, jet physics;

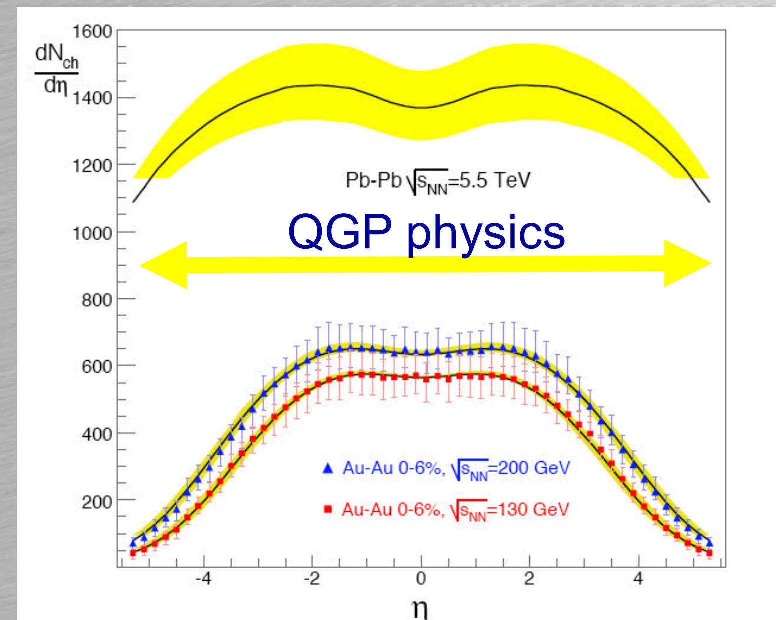
① QGP, hotter, longer, bigger

Initial Energy Density

- Charge-particle rapidity density



ALICE Collaboration et al., J. Phys. G30, 1517 (2004)



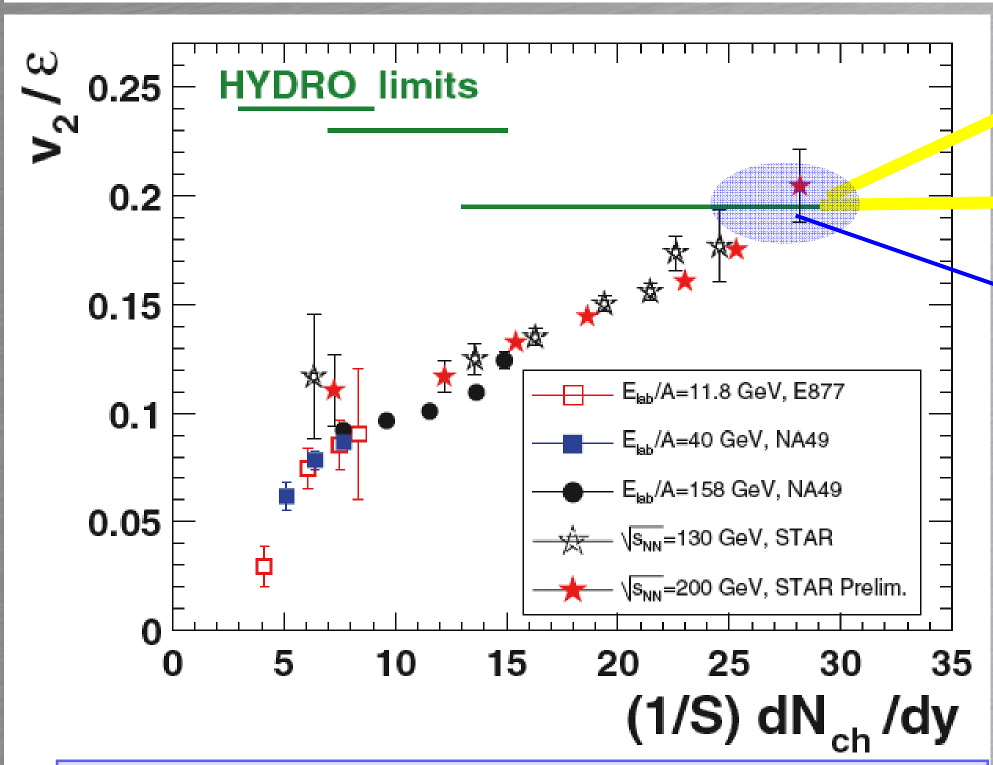
N. Armesto et al., arXiv:0711.0974v1 & J.Phys.G35,054001 (2008) (S. Abreu et al sec.1.1)

Charged particle multiplicity distribution, hadron p_T distribution, identified hadron yields etc …

Properties of QGP fluid

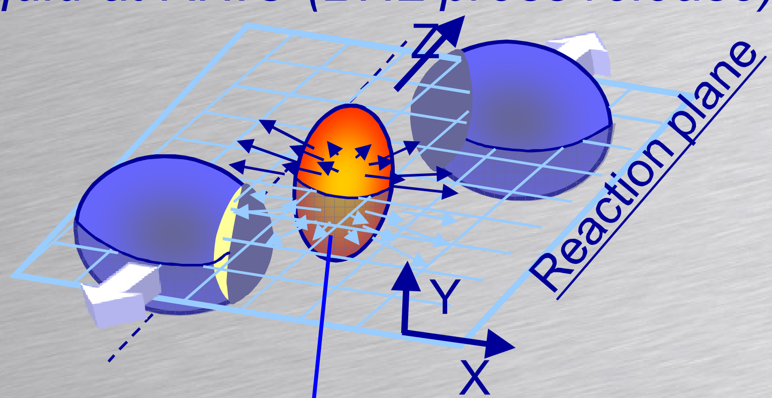
$$E\frac{d^3N}{d^3\vec{p}} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left[1+\sum_{n=1}^{\infty}\left\{2v_n\cos\left[n(\phi-\Psi_R)\right]\right\}\right]$$

→ v_2: elliptic flow



LHC is *Terra Incognita*

New state behaves as a perfect liquid at RHIC (BNL press release)

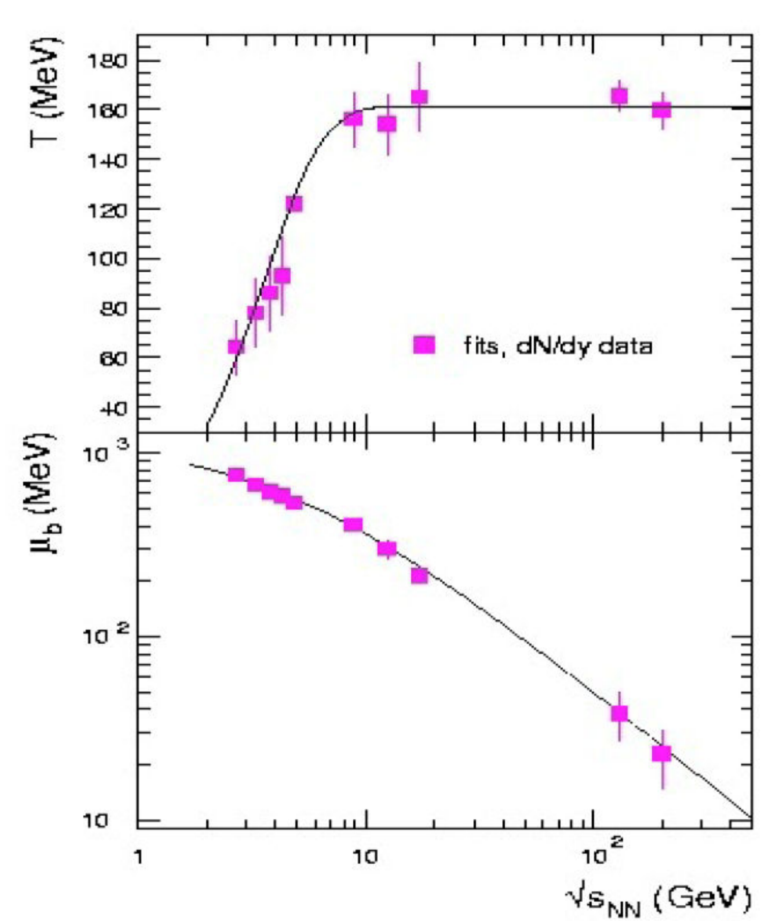


eccentricity $\varepsilon=[\langle y^2\rangle-\langle x^2\rangle]/[\langle y^2\rangle+\langle x^2\rangle]$

NA49 Collaboration, PRC68 2003, 034903 (2003)
ALICE Collaboration, J. Phys. G32, 1295 (2006)

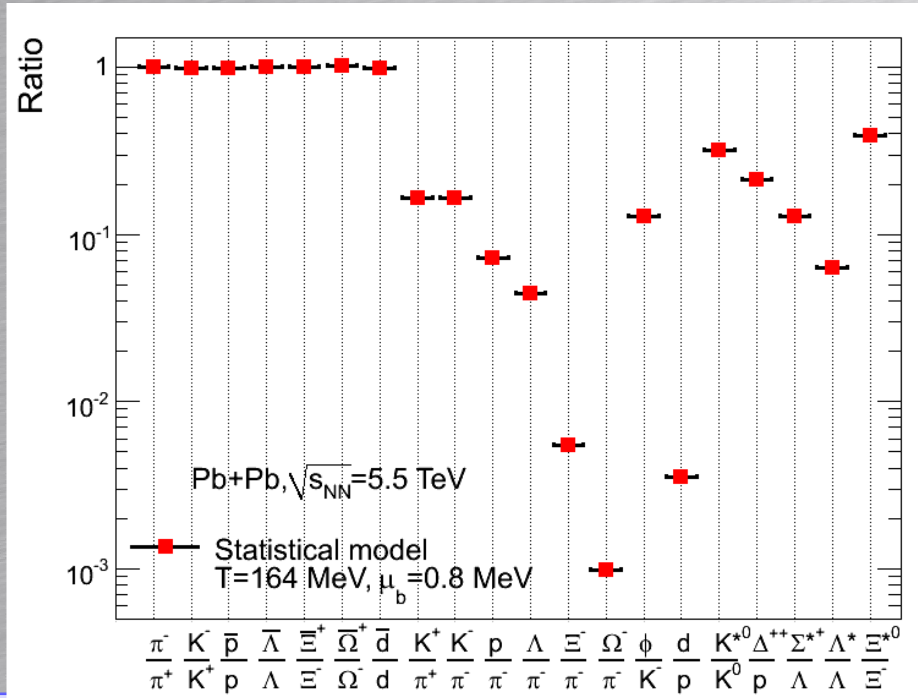
② Baryon free matter

Statistical Hadronization



A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A772 167 (2006), Nucl-th/0511071

- Two free parameters:
  - T_{ch} and μ_B :



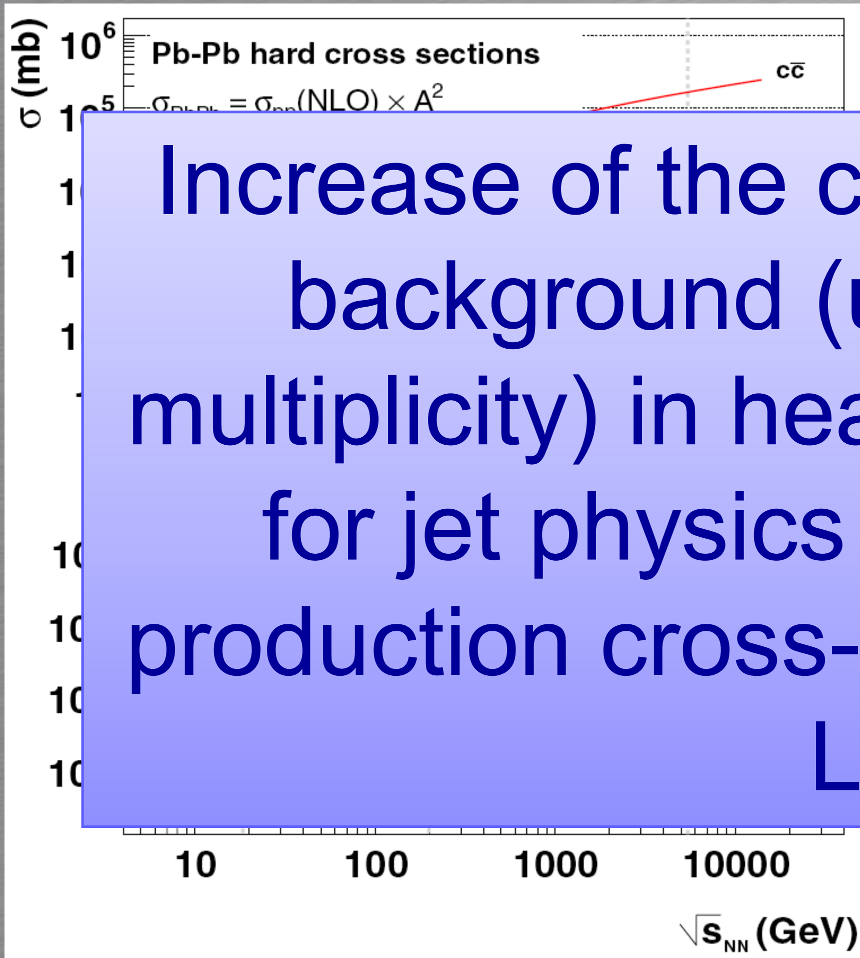
A. Andronic, Private communication (2009)
J.Phys.G35:054001,2008, arXiv 0711.0974
Phys. Lett. B 673 (2009) 142, arXiv:0812.1186

③ Large production cross-sections of hard (penetrating) probes:

Jet production
Heavy Flavour production

Hard probes production yields

LHC/RHIC



Increase of the charged particle soft background (underlying event multiplicity) in heavy-Ion. Challenging for jet physics in spite of the jet production cross-sections increase at LHC!

…);

- Jet recons in HIC;
- Photon-jet studies;

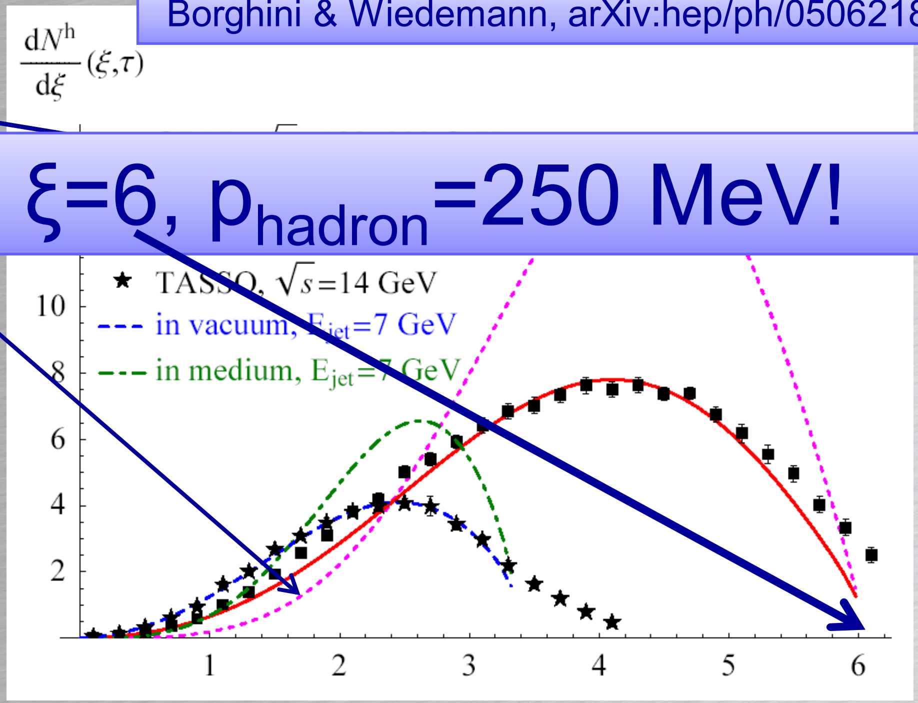
D. d'Enterria, J. Phys. G 35 104039 (2008)

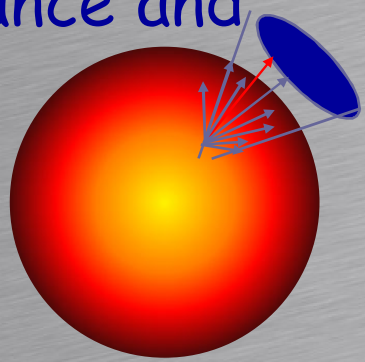
Hump-Backed plateau

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

For a E_{Jet}=100 GeV and ξ=6, p_{hadron}=250 MeV!

Borghini & Wiedemann, arXiv:hep/ph/0506218



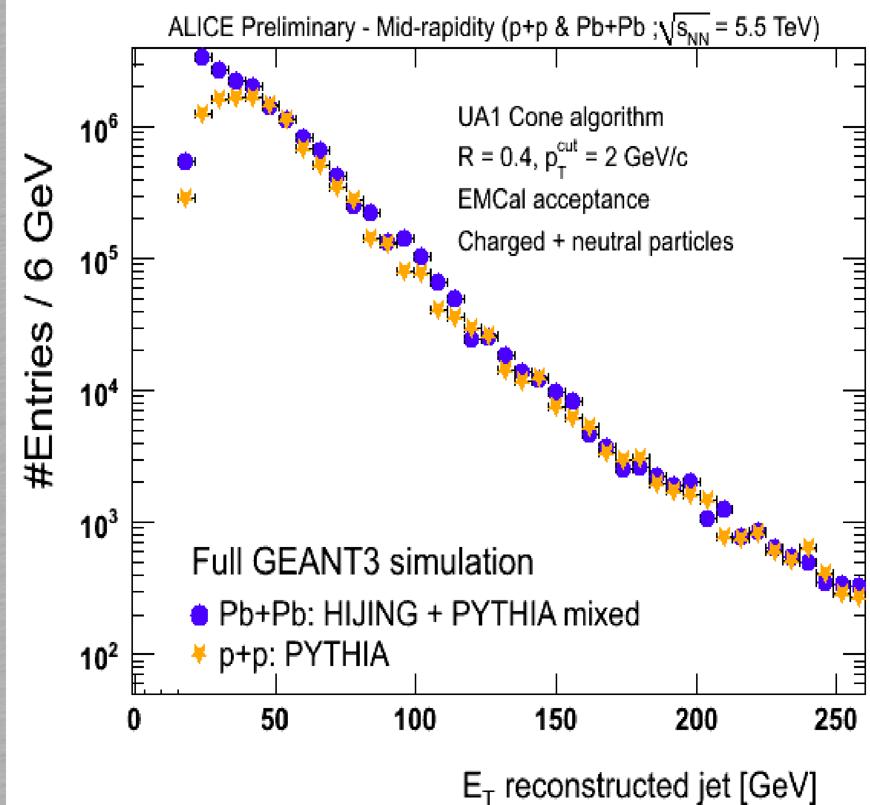


$\xi=\ln(E_{Jet}/p_{hadron})$

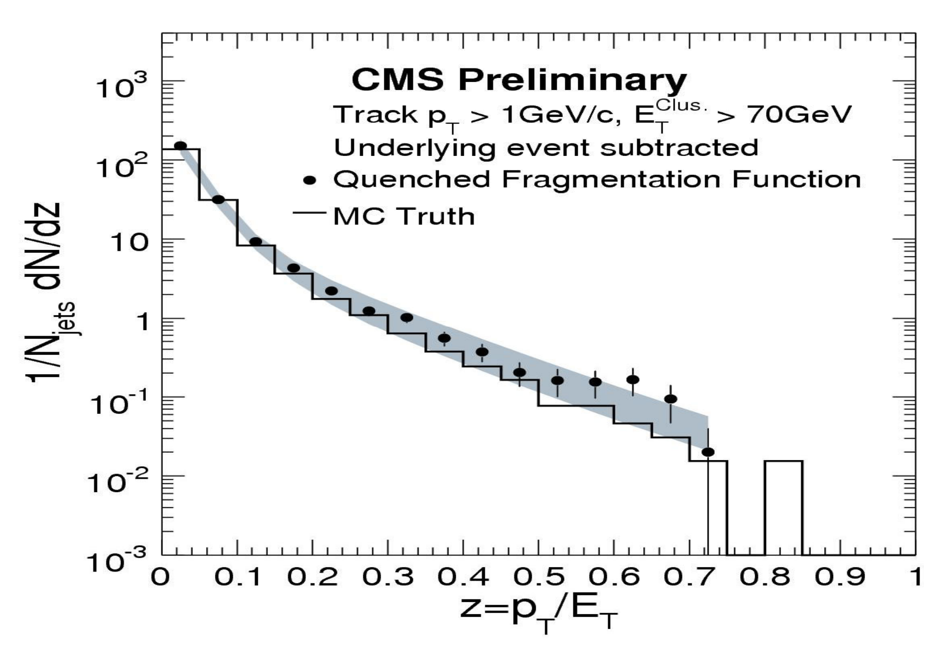
ALICE experiment will be very competitive: high granularity in track reconstruction (ITS+TPC), good PID, good jet triggering (EMCAL)

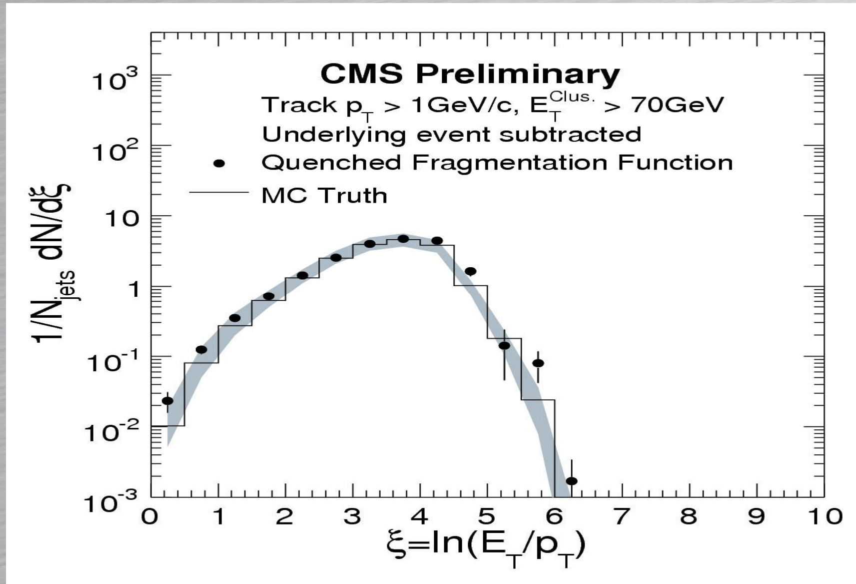
Jet Physics in ALICE

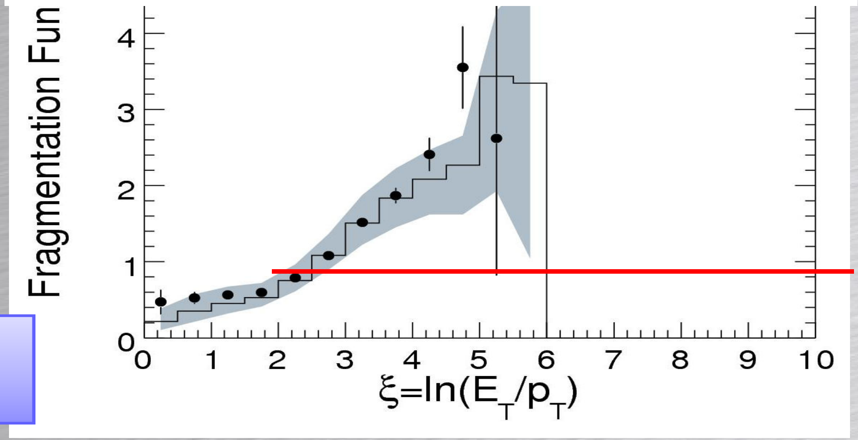
- Statistic of 1 month PbPb running at nominal conditions;
- Jet reconstruction in HIC possible for E>40 GeV;
- Hump-backed plateau analysis up to E~150 GeV.



Jet fragmention from γ-jet events







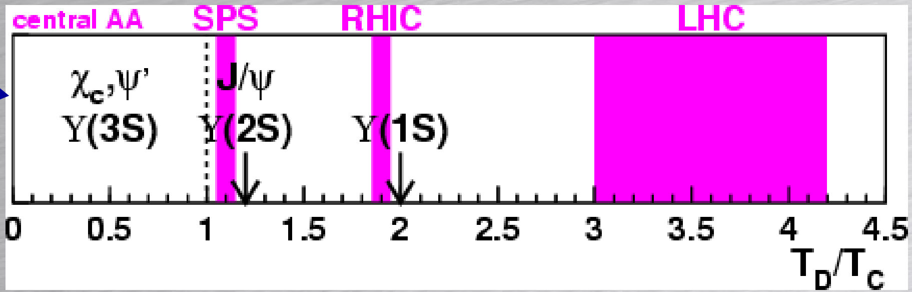
Require photon $E_T > 70$ GeV
~4500 γ-jet events in a nominal PbPb run.

Olga Kodolova, Quark Matter 2008
D. d'Enterria, J. Phys. G 35 104039 (2008)

HQ in Heavy-Ion Collisions at LHC

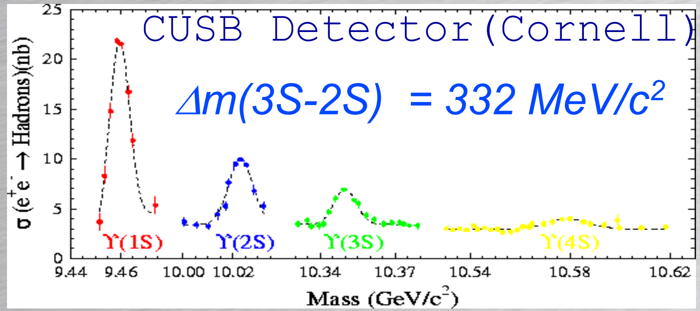
- Bottomonium color screening
- Copious charm production;
- HQ thermalization;
- HQ energy loss;
- J/ψ elliptic flow.

A.Mocsy et al. PRL99 211602 (2007);

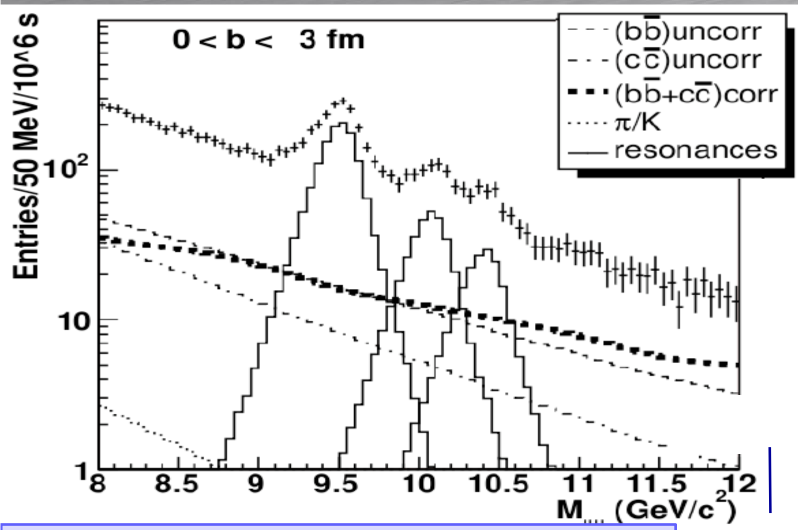


New regime for charmonium production in Heavy Ion Collisions: Deconfinement Ultime Probe
P. Braun-Munzinger & J. Stachel arXiv:0901.2500

	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**



Muon channel 2.5<|η|<4.0



		J/ψ	ψ'	ϒ	ϒ'	ϒ''
PbPb MB 5.5 TeV	S (×10³)	680	19	6	2	1
	S/B	0.3	0.02	2.5	1.0	0.74
	S/√S+B	413	19	67	30	21

Estimation from Binary scaling with average shadowing factor: 0.6 for J/ψ and 0.76 for ϒ .

σ (J/ψ)= 70 MeV ;
σ (ϒ)=100 MeV

In a nominal PbPb;

- Large J/ψ statistics: centrality, elliptic flow, polarization;

□ ψ' will be difficult in central HIC;

- ϒ and ϒ', good statistics;

ALICE Collaboration et al., J. Phys. G32, 1295 (2006)

Conclusions

- ✓30-fold step in energy will take place with the first Heavy-Ion collisions at LHC;
- ✓QGP will be hotter, bigger and longer;
- ✓Penetrating probes of QGP will benefit of the centre of mass available at LHC, that will increase by large factors the hard probe production cross-sections;

Strong interaction/hadron physics made it hard to understand T > 100 MeV ~ 10^{12} K. Ideal-gas thermal QCD makes high temperatures tractable theoretically since 1973;

We are now delivering on a 30-year old promise to probe high T QCD gas experimentally. Some results confirm standard picture, but non-ideal gas nature of QCD may have new consequences;

Adapted from the talk « *Quark-Gluon Plasma: The Stuff of the Early Universe* » by Paul Stankus (Oak Ridge Nat'l Lab) APS 09 April Meeting

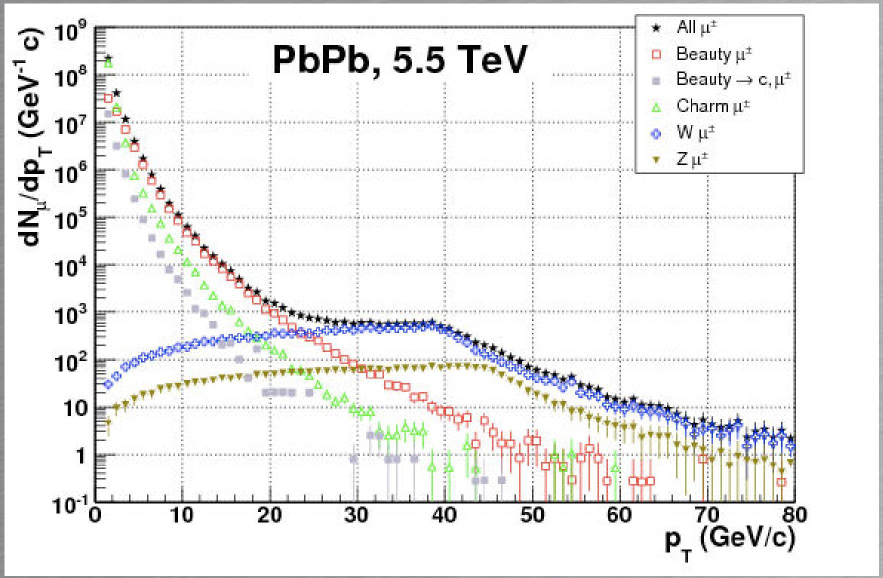
Detailed studies of the Heavy-Quarks, Jets and electroweak bosons (γ, W, Z) **in HIC at LHC** will allow to characterize the **QCD high energy density medium**.

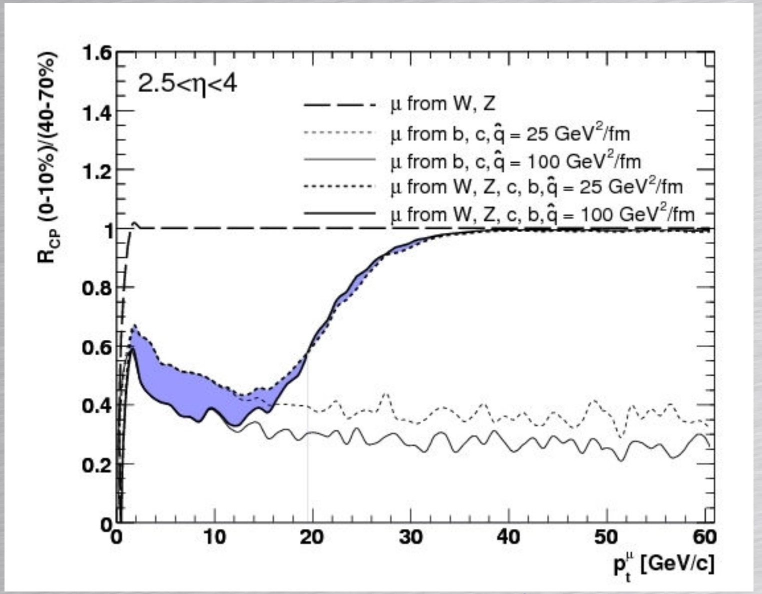
Thanks for your attention, Gines

Back-up slides

p-pbar ratio at LHC energies

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

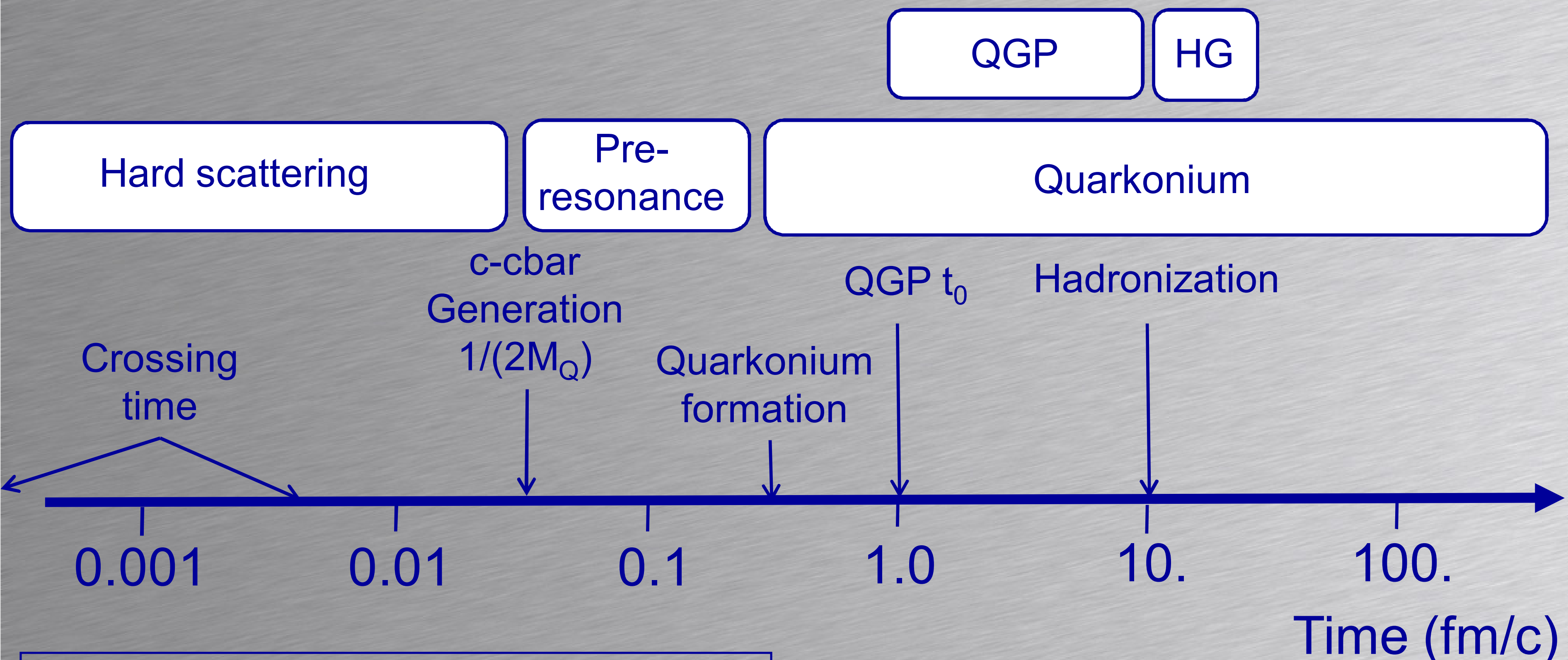
- W as a medium blind reference of the beauty Eloss in QGP.

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

ALICE

Time scales at LHC

At LHC times scale changes: crossing time 0.007fm/c



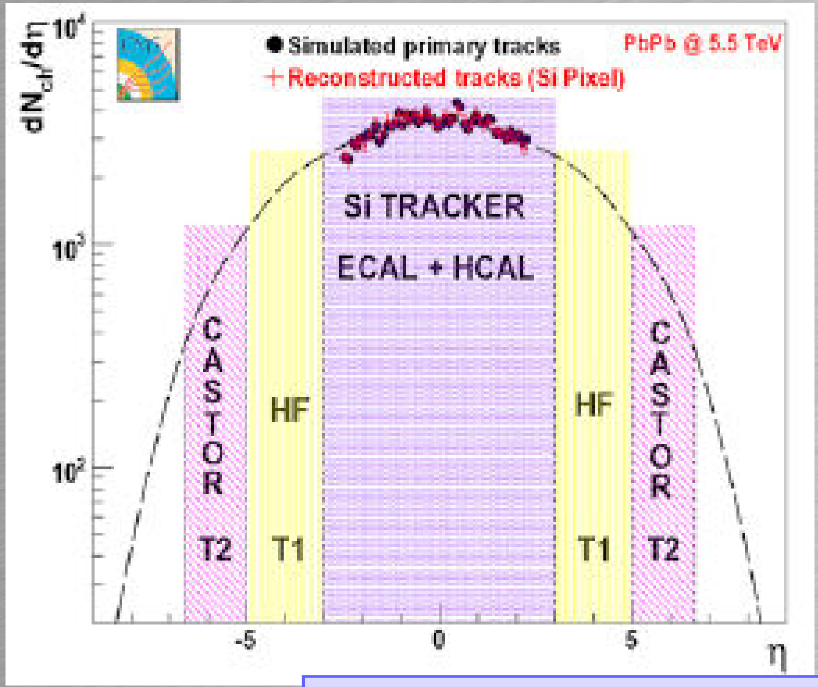
H. Satz, J. Phys. G32 R25 (2006)
P. Braun-Munzinger, Trento (2009)

Quarkonia Normalization

Normalization	Advantages	Disadvantages
R_{AA} and R_{CP}	Easy and natural.	Mixing of hot and cold effects; Cold effects not very well known (pA needed).
Higher resonances	Sensitivity to medium size and temperature of the medium.	Difficult for charmonia. Feed-down
Open heavy flavour	Most natural. Sensitivity to recombination process.	HQ thermalisation and quenching in the medium.
Electroweak Bosons	No hot medium effect.	Production dominated by qqbar collisions; Different Q^2 domain. Z^0 statistics;

Inspired from P. Crochet UCLA 2009.

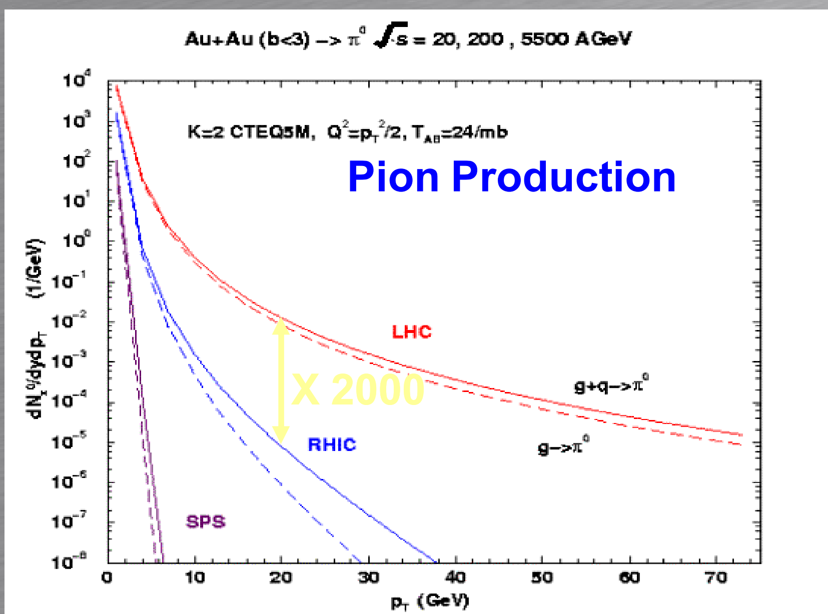
Example of the CMS measurement



CMS Collaboration J. Phys. G: Nucl. Part. Phys. 35 104150 (2008) (arXiv:0805.0809)
F. Sikler @ QM2008

Jets in Heavy-Ion Collisions at LHC

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



Pb Pb jet rates |η| < 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**