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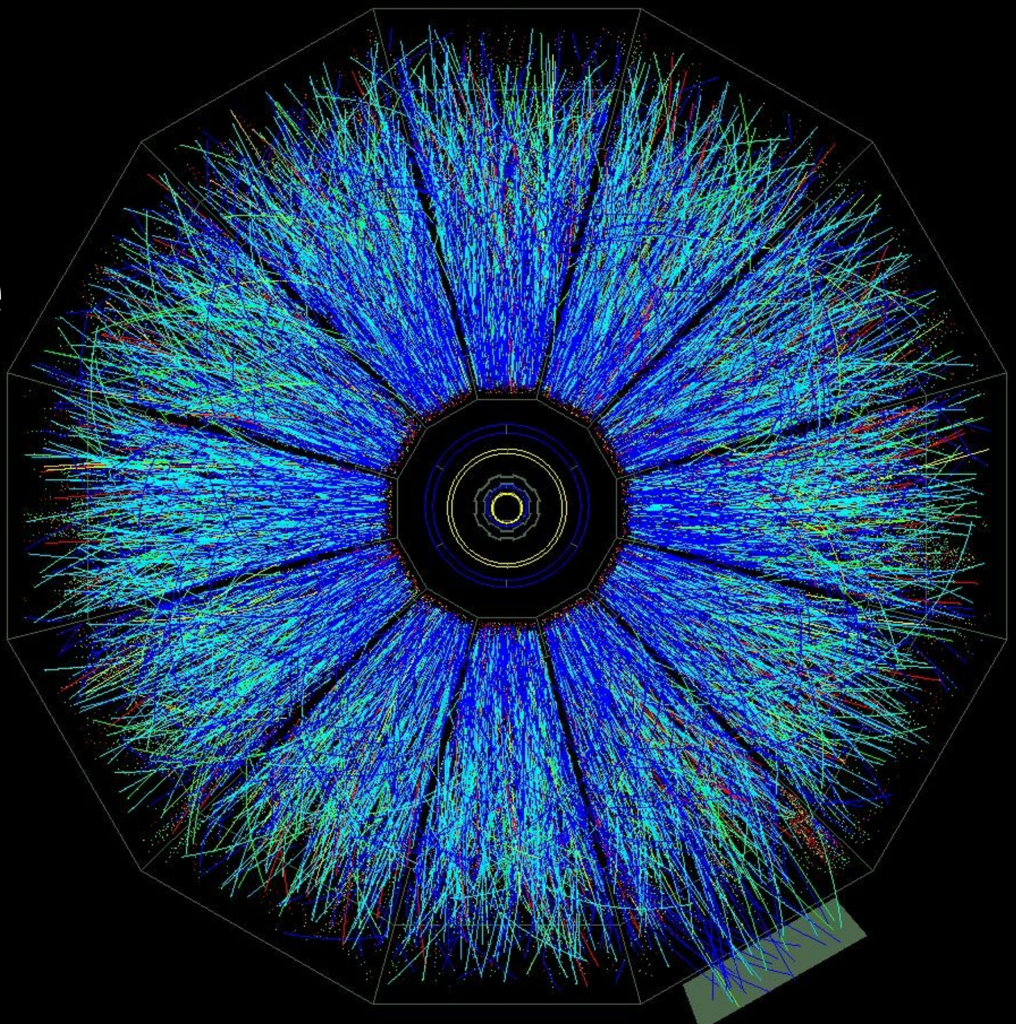
UNIVERSITÉ DE STRASBOURG

Let the Universe be at $t = 10^{-6}$ s …

(Heavy-ion physics and Quark-Gluon Plasma)



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I.1 – **Foreword** : the PhD question

- QGP, physics of « ultra-relativistic heavy ions » ?!

the $100 question of any PhD student in turmoil.

→ *Who am I ?*

Here, Nuclear physicist or Particle physicist ?

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- 1st attempt :

  Let's analyse the wording …
  a) « … *heavy ions ...* » = nuclear physics ?
  b) but we sit at the LHC = particle physics ?
  → clueless

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→ clueless

Aristotle …
Diogenes …
… Immanuel Kant …
… Friedrich Nietzsche Chuck Noris …
… Plato …
Jean-Paul Sartre !! → « *The other holds the secret of what I am …* »

- 2nd attempt : resort to philosophy textbooks.

I.2 – Foreword : a sort of answer ...

Jumping-off point :

ask your PhD supervisor

...

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Jumping-off point :
ask your PhD supervisor

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Long-standing inquiry,
that could boils down to 2 examples :

1. Another PhD student, in nuclear physics, every day at lunch time :
"But you're *just* a particle physicist !"

I.2 – Foreword : a sort of answer ...

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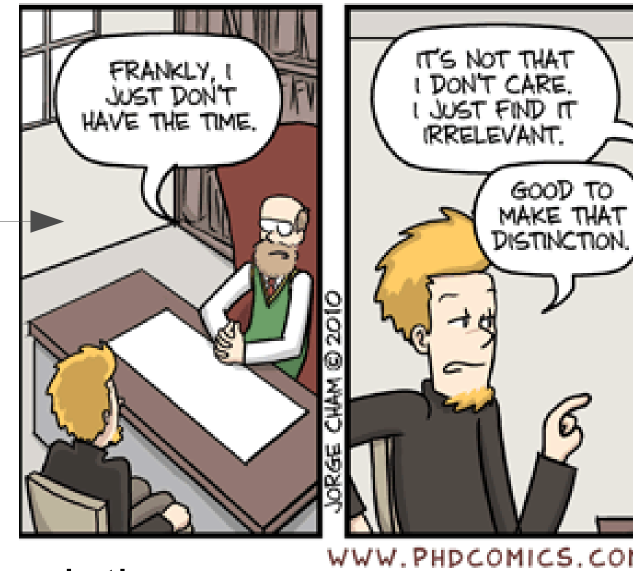
ask your PhD supervisor →



...

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2. LHCb member in a conference :
"It may be difficult for you, nuclear physicist, to do particle physics !"
(Looking at me, as serious as one could be, no tongue in cheek
but with a bit of compassion ...)

I.2 – **Foreword** : a sort of answer ...

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- Well, ...
If everybody disagrees, it may somehow mean that you are kind of ... *unique !*

Outline

A. - Quark-Gluon Plasma on paper :

I. Standard Model

II. QCD

III. QGP

– Pause : Questions –

B. - Quark-Gluon Plasma in practice :

IV. Heavy-ion collisions

V. Parentheses : « pp vs. AA » or « from pp to AA » ?

– Pause : Questions –

C. - Experimental Signatures

VI. Strangeness (...)

VII. Quarkonia suppresion (...)

VIII. Hydrodynamics

IX. Jet quenching

References :

→ arXiv hyperlinks throughout the slides ...

+ http://cerncourier.com/cws/article/cern/46055
+ http://en.wikipedia.org/wiki/Quark-gluon_plasma
+ http://public.web.cern.ch/public/en/LHC/Facts-en.html
+ CERN, Summer Student Prog. https://indico.cern.ch/conferenceDisplay.py?confId=91704

Part A :

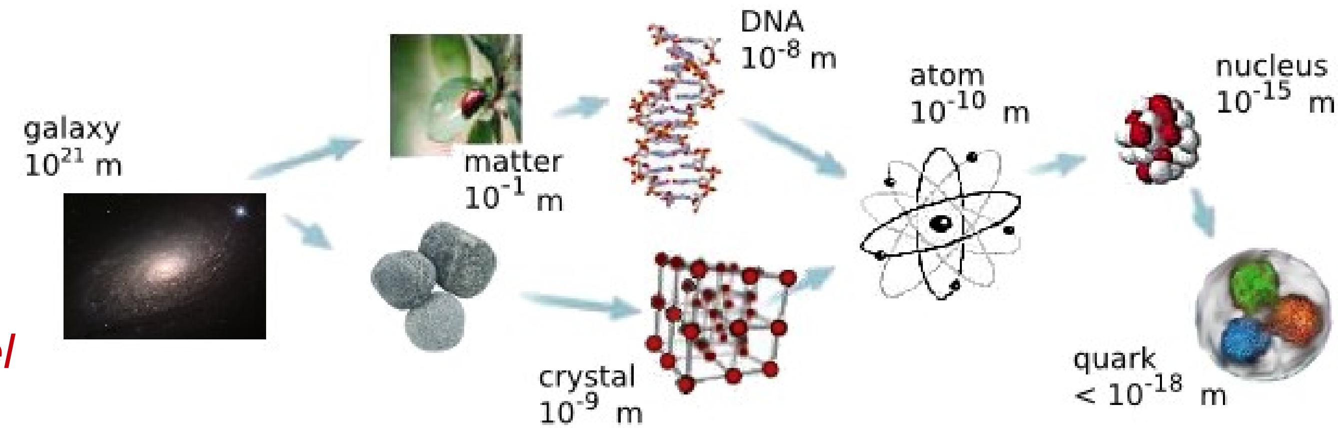
QGP on paper

I.1 – **Std Model** : matter panel

- Idea :

Physics of matter
at its most fundamental level

→ diptych of *Standard Model*



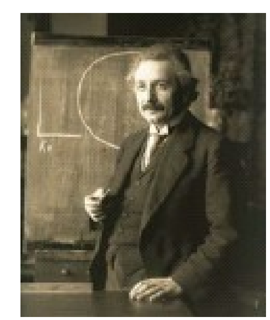
+ Part. Data Gr.
cpepweb.org

Leptons spin =1/2		
Flavor	Mass GeV/c^2	Electric charge
ν_L lightest neutrino*	$(0-0.13)\times10^{-9}$	0
e electron	0.000511	–1
ν_M middle neutrino*	$(0.009-0.13)\times10^{-9}$	0
μ muon	0.106	–1
ν_H heaviest neutrino*	$(0.04-0.14)\times10^{-9}$	0
τ tau	1.777	–1

Quarks spin =1/2		
Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.002	2/3
d down	0.005	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	173	2/3
b bottom	4.2	–1/3

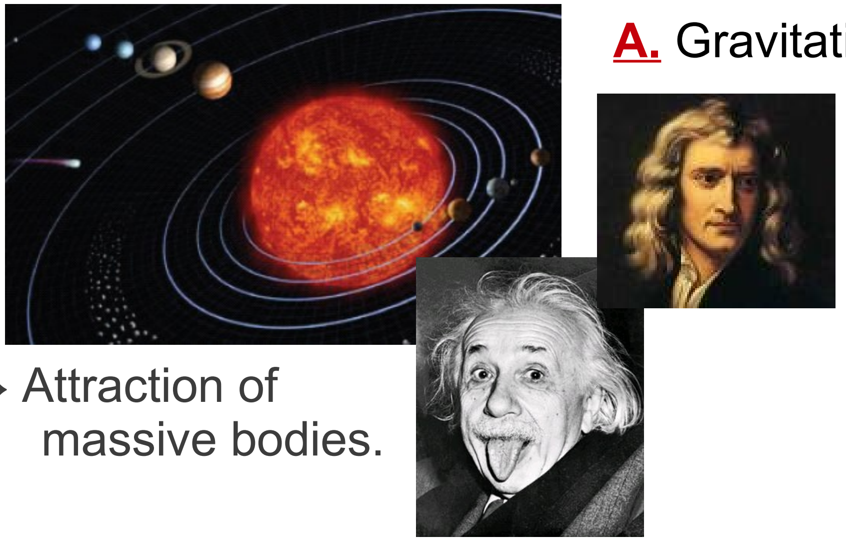
Stable familly ...

How to recreate the unstable elements ?
Natural ways (cosmic rays)
or artificial ones (colliders)
Key : $E = mc^2$



Matter and its interactions = intertwined.
A particle that interacts = a particle that is observable.
→ How can one speak about matter for a particle, if it does not interact ?

I.2 – **Std Model** : the 4 interactions

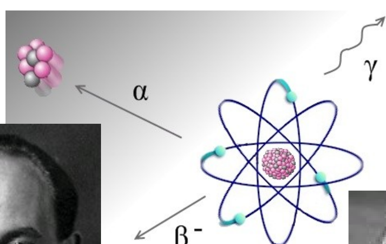


A. Gravitation

→ Attraction of massive bodies.

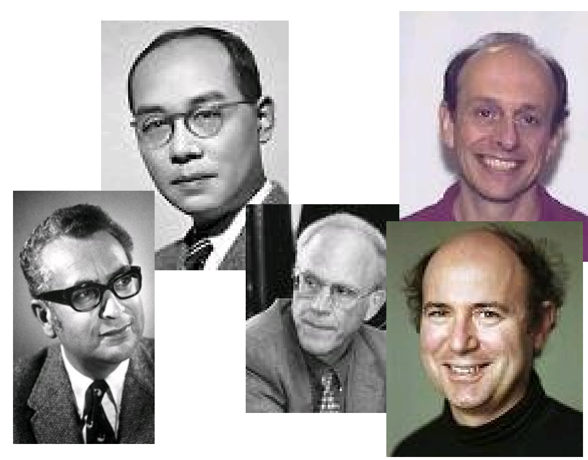
B. Electromagnetism

→ light, atom formation (electrons), whole chemistry (!), force of frictions, magnets, information information technologies, ...

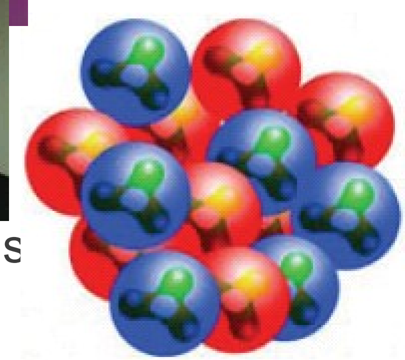


C. Weak force

→ Radioactiviyé, role in the core of the Sun, ...



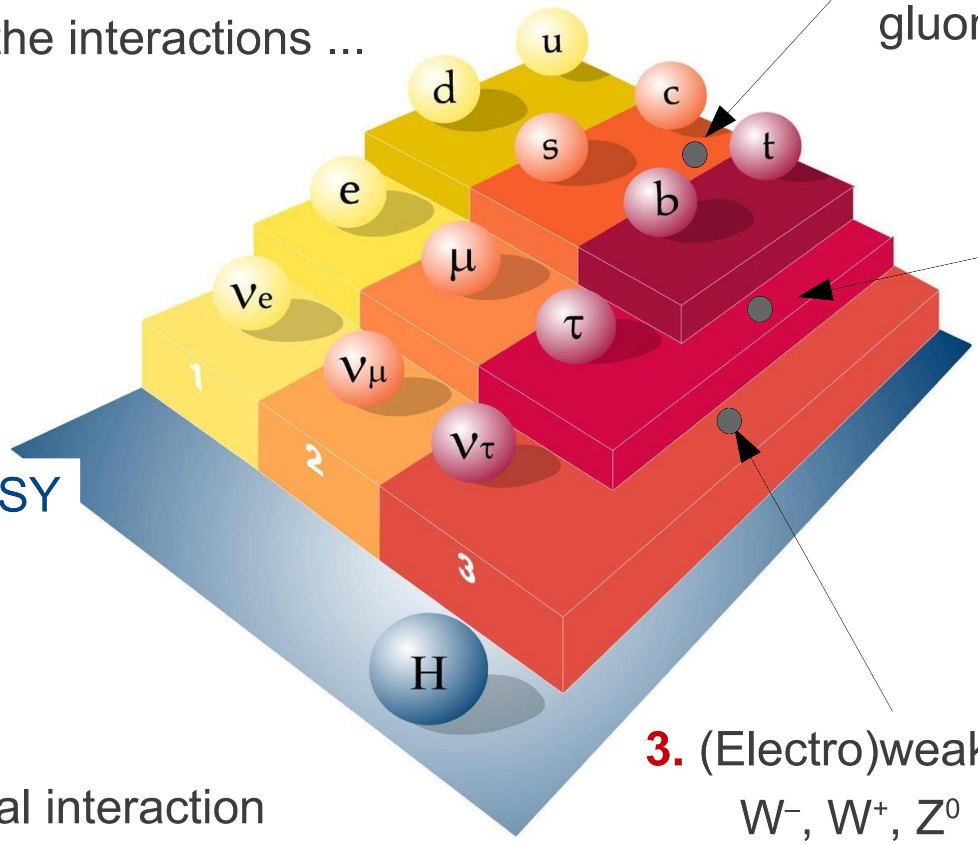
D. Strong force



→ Cohesion of nucleus cohesion of quarks.

I.3 – Std Model : interaction panel

Bosons,
convey the interactions ...



1. Strong interaction
gluons
*Intensity : **1***

Strong (color) spin =1		
Name	Mass GeV/c^2	Electric charge
g gluon	0	0

2. Electromagnetic interaction
photons
*Intensity : ≈ **1/137***

3. (Electro)weak interaction
W^-, W^+, Z^0
*Intensity : ≈ **10^{-5}***

Unified Electroweak spin = 1		
Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.39	–1
W^+ W bosons	80.39	+1
Z^0 Z boson	91.188	0

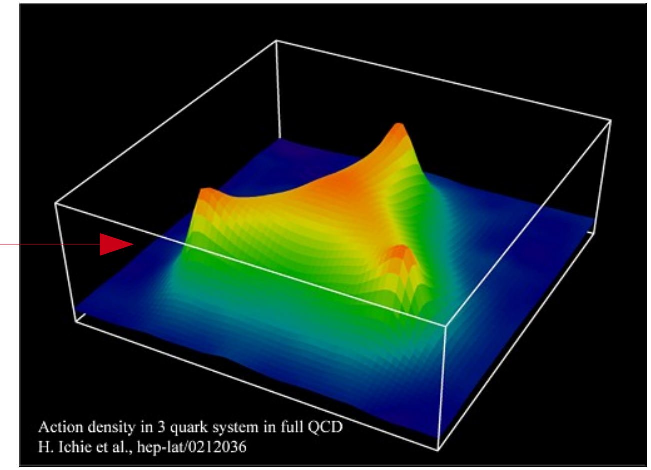
4. gravitational interaction
graviton
*Intensity : < **10^{-30}***

II.1 – QCD : basic rules

Charges : 3 colours = *red, green, blue* + anti-colours

Key feature 1 : *quark confinement*

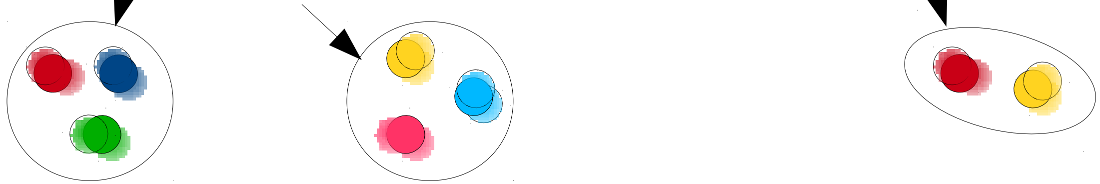
« no isolated quark » → obligation to be colour neutral !



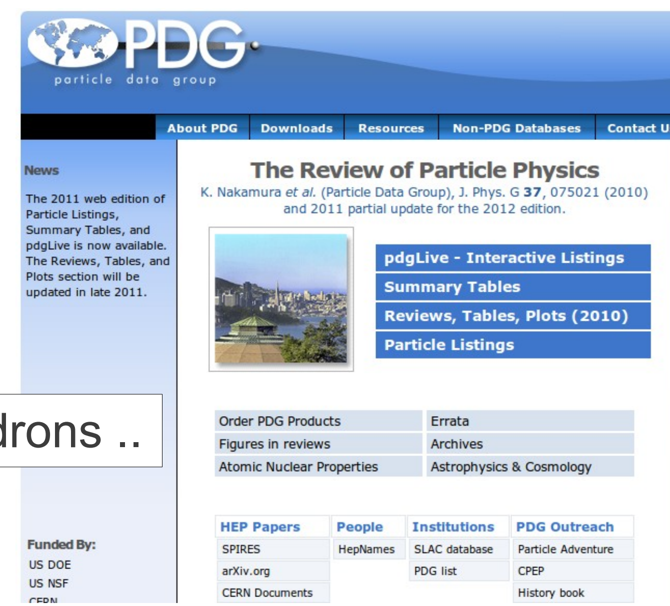
http://arxiv.org/abs/hep-lat/0212036

HADRONS

BARYONS	*MESONS*
Valency quarks :	Valency quarks :
$q_1q_2q_3$, with 3 colours	$q_1\bar{q}_2$ with 1 colour
or $\bar{q}_1\bar{q}_2\bar{q}_3$, with 3 anti-colours	+ 1 anti-colour



From the 6 elementary quarks → > 200 existing hadrons ..



Part. Data Gr. / Chap.9 - QCD

II.2 – QCD : confinement

- The potential of strong interaction rises with the distance !

  (different from gravitation, from electromagnetism ...)

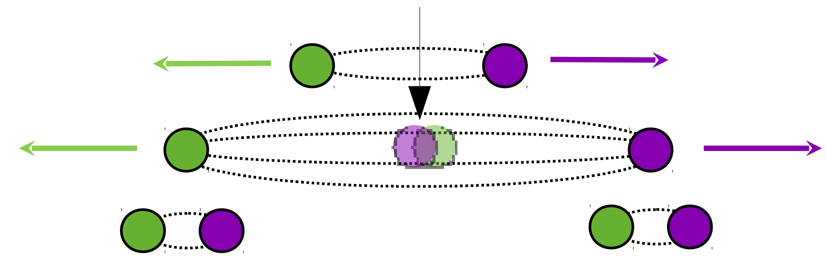
Phenomenological approach :

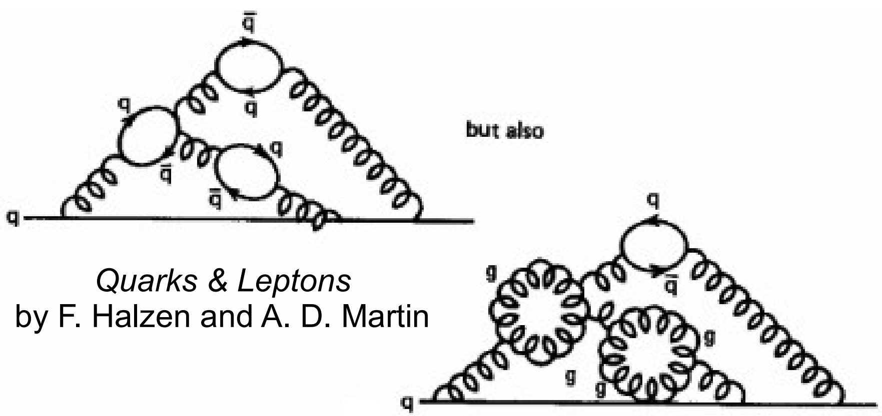
$$V_{QCD} = -\frac{4}{3}\frac{\alpha_s \hbar c}{r} + kr$$

~ coulombian at small distance (d ~ 0.1 fm)

~ like a spring at larger distance → *Fragmentation*

E = mc²

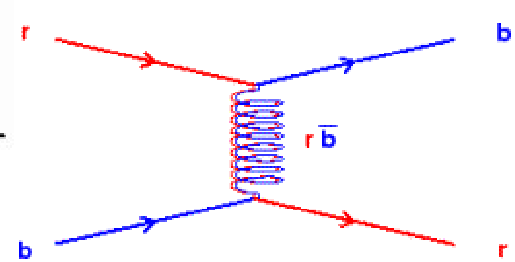




Quarks & Leptons
by F. Halzen and A. D. Martin

- Why ?

→ 8 gluons do carry a colour charge ($r\bar{g}$, $r\bar{b}$, $g\bar{r}$, ...) , so can interact together



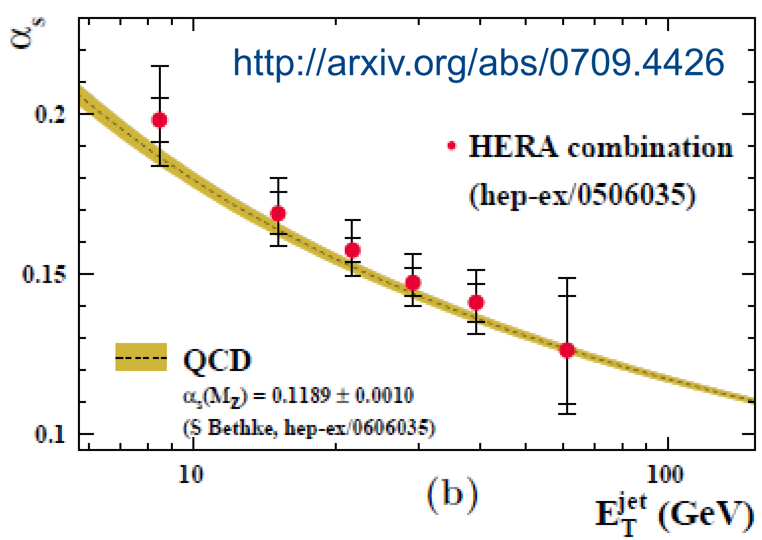
Note 1 : quite ≠ from photons in QED …

Note 2 : *g*auge Group = SU(3), non-Abelian gr. ...

II.3 – QCD : confinemt / running coupling const.

The potential of strong inter. rises with the distance !

$$V_{QCD} = -\frac{4}{3}\frac{\alpha_s \hbar c}{r} + kr$$



non-perturbative regime …
(ex : LQCD)

perturbative regime
(pQCD)

Large distance ...

Small distance

- **Why ?**

→ 8 gluons do carry a colour charge ($r\bar{g}$, $r\bar{b}$, $g\bar{r}$, ...) , so can interact together

Consequence :
running of the coupling constant, α_S...

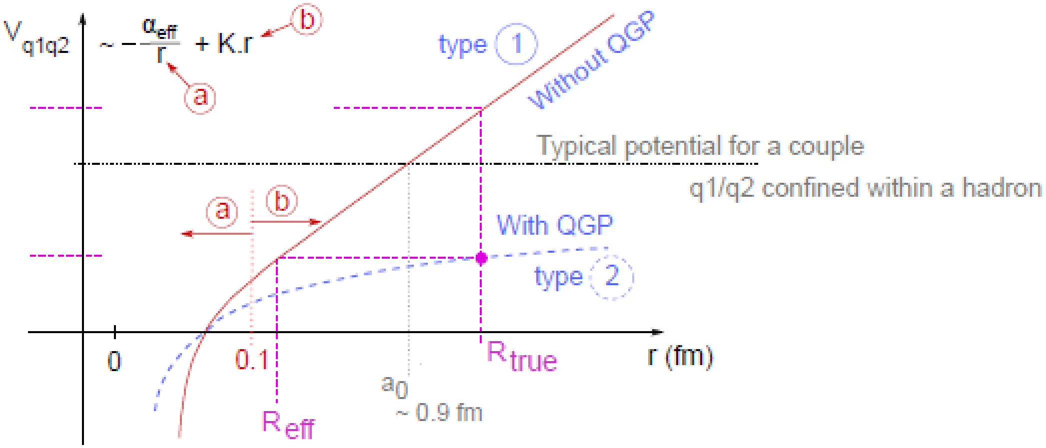
Towards asymptotic freedom ...

III.1 – QGP : confinem^{t} / asympt. freedom

- Deconfinement

Let's imagine a particular thing that is still white.

= QGP !
(// electromag. plasma)

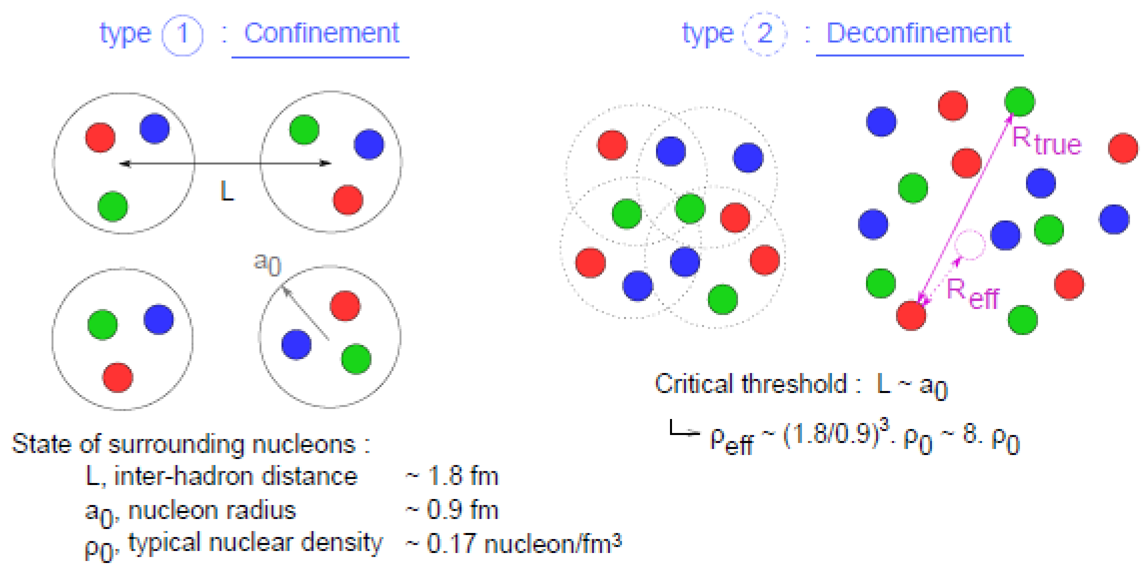


Let's imagine we bring hadrons closer and closer

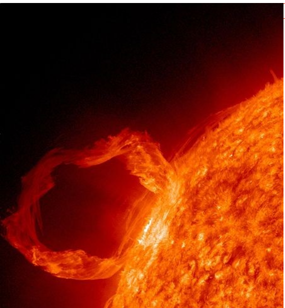
→ ~~confinement~~ + screening ...

Continuous interactions of partons, but free to move within a medium.

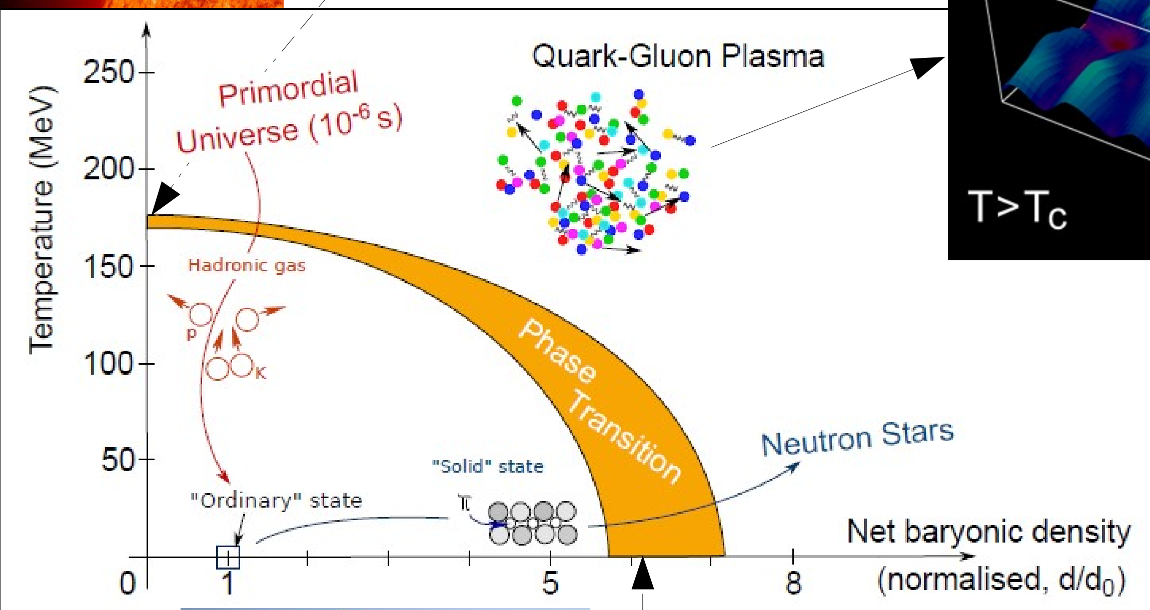
(Loss of indentity + memory ...)



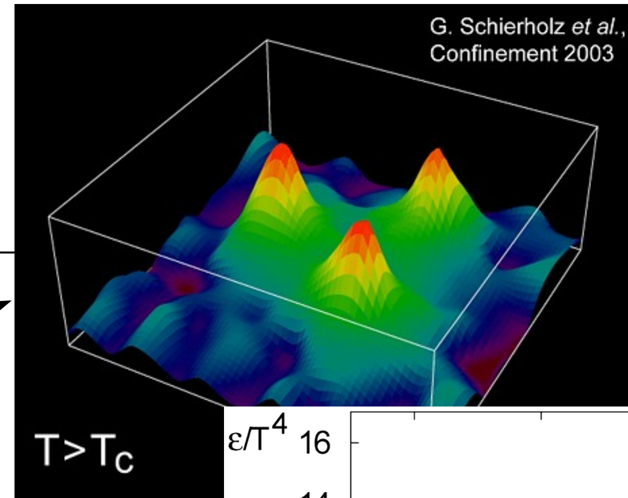
III.2 – QGP : phase diagram



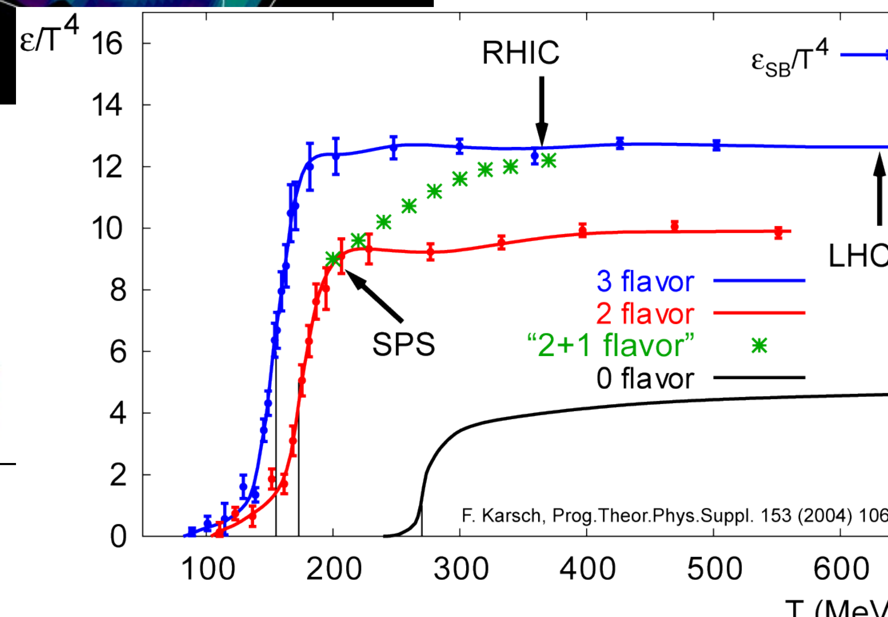
Tc ~ 170 MeV
~ 2.5 x 10^{12} K
(to be compared with T_{SUN} in the core ...)



New phase predicted by LQCD calculations ...



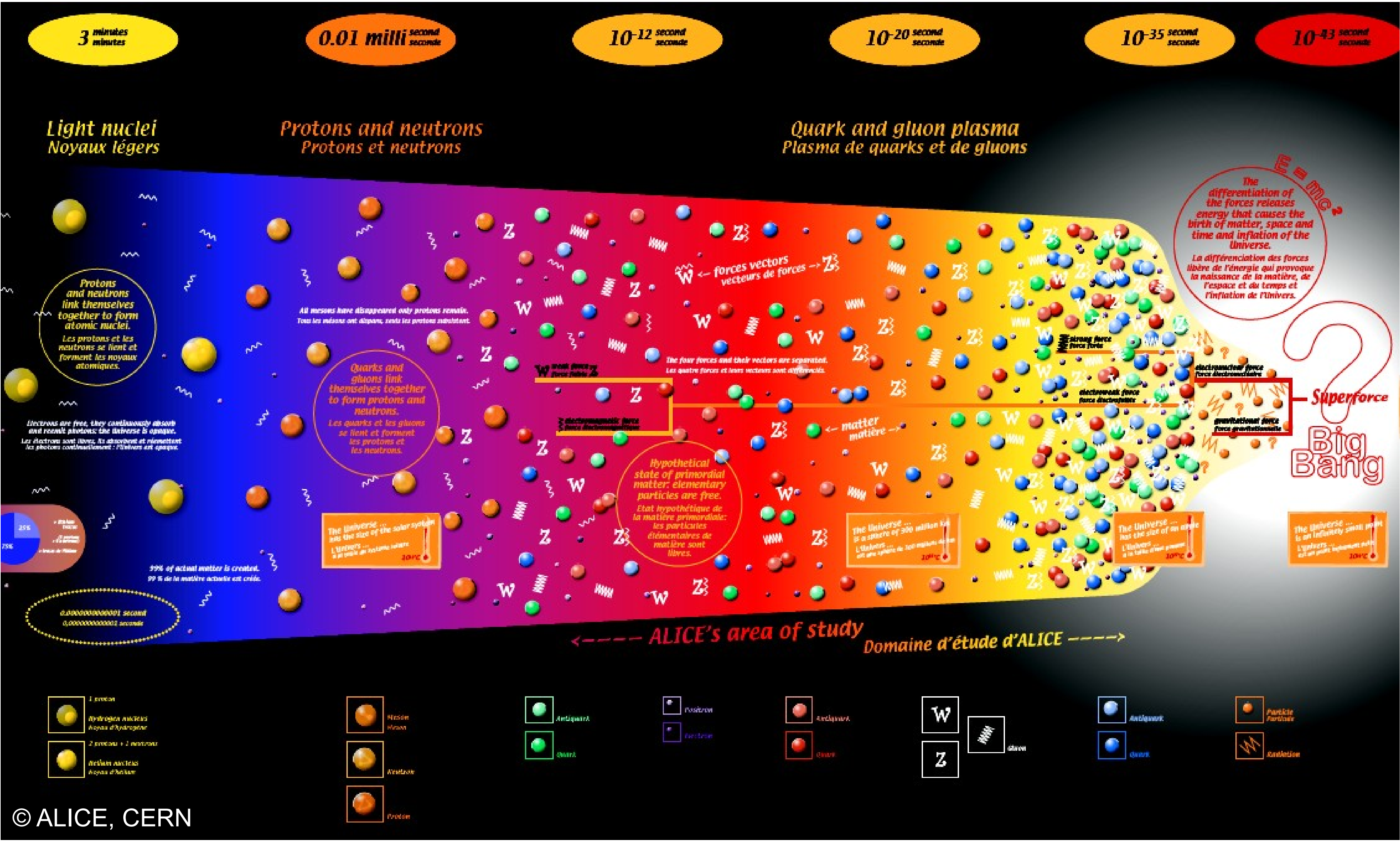
= <u>phase</u> of partons *deconfined* and *thermalised* (intern. thermodyn. eq.)



http://arxiv.org/abs/hep-lat/0401031

density ~ 1-2 x 10^{18} kg/m^3
(Kheops pyramid in a pinhead)

III.3 – QGP : the 2 infinities ...



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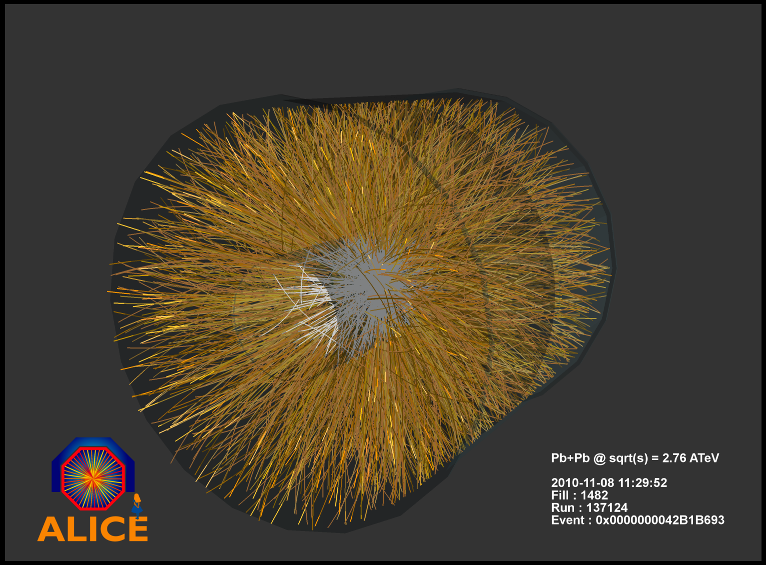
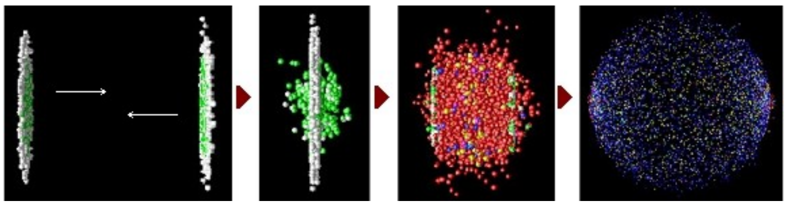
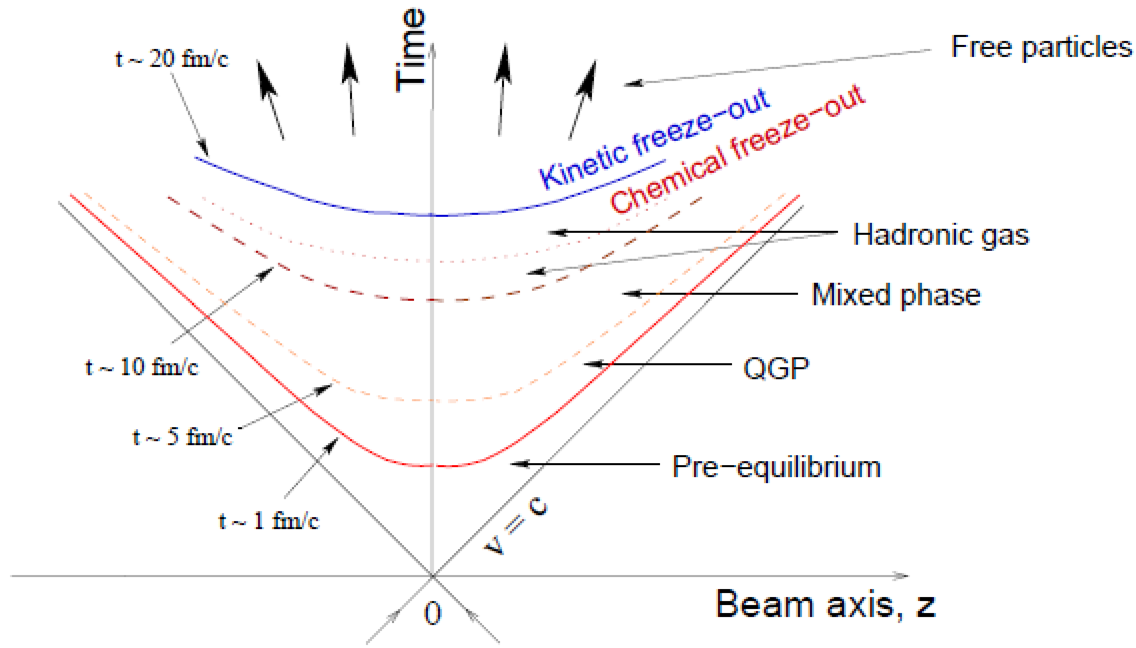
Part B :
QGP in practice



IV.1 – Heavy-ion coll. : Bjorken scenario

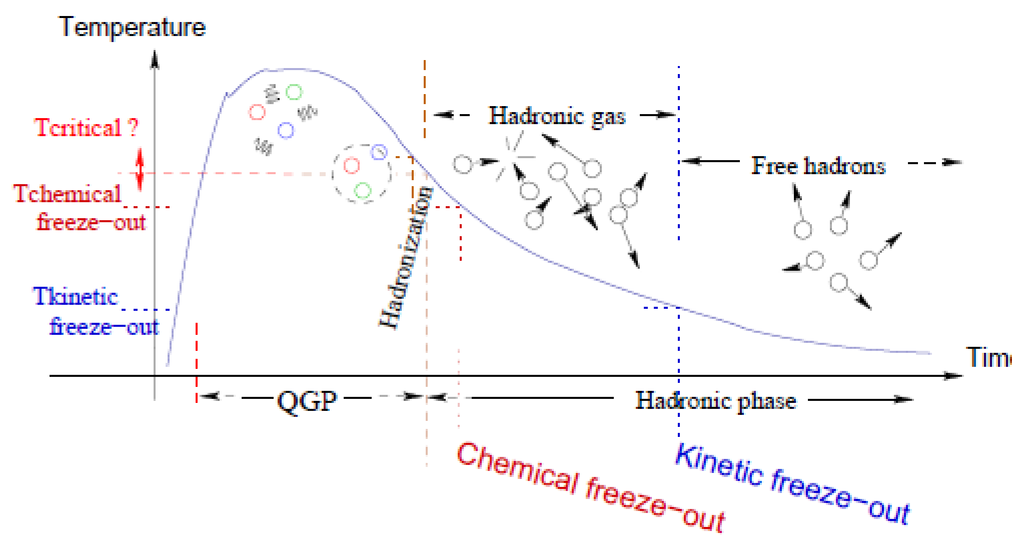




→ Remark :

No such thing as a live vision !
but always, an observation based on remnants from the past ...

(NB : physics ~ 10^{-24} s / electronic readout > 10^{-12} s)

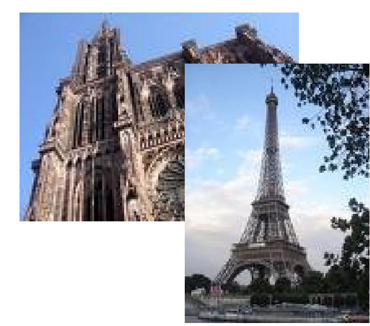


IV.2 – Heavy-ion coll. : facilities

PDG (coll. params)

	RHIC (Brookhaven)				LHC† (CERN)	
Physics start date	2001	2000	2004	2002	2009	2010
Physics end date	—				—	
Particles collided	pp (pol.)	Au Au	Cu Cu	d Au	pp	Pb Pb
Maximum beam energy (TeV)	0.25 34% pol	0.1 TeV/n	0.1 TeV/n	0.1 TeV/n	7.0 (3.5)	2.76 TeV/n (1.38 TeV/n)
Luminosity (10^{30} cm^{-2}s^{-1})	85 (pk) 55 (ave)	0.0040 (pk) 0.0020 (ave)	0.020 (pk) 0.0008 (ave)	0.27 (pk) 0.14 (ave)	1.0×10^4 (170)	1.0×10^{-3} (1.3×10^{-5})
Time between collisions (ns)	107	107	321	107	24.95 (49.90)	99.8 (1347)
Full crossing angle (μ rad)	0				≈ 300	≤ 100 (0)
Energy spread (units 10^{-3})	0.15	0.75	0.75	0.75	0.113 (0.116)	0.11
Bunch length (cm)	55	30	30	30	7.55 (5.87)	7.94 (5.83)
Beam radius (10^{-6} m)	90	135	145	145	16.6 (45)	15.9 (45)
Free space at interaction point (m)	16				38	38
Particles per bunch (units 10^{10})	11	0.12	0.45	d: 10 Au: 0.1	11.5 (7)	0.007
Bunches per ring per species	111	111	37	95	2808 (796)	592 (62)
Circumference (km)	3.834				26.659	
Interaction regions	6 total, 2 high $\mathscr{L}$				2 high $\mathscr{L}$ +2	1 dedicated +2

IV.3 – Heavy-ion coll. : RHIC & LHC

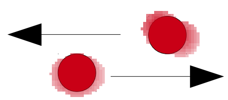


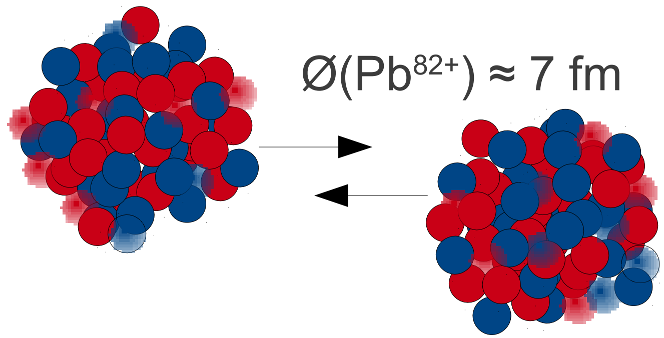
(pp and AA)

V.1 – pp vs. AA : different physics ?

$p + p\left({}^{1}_{1}H \right)$

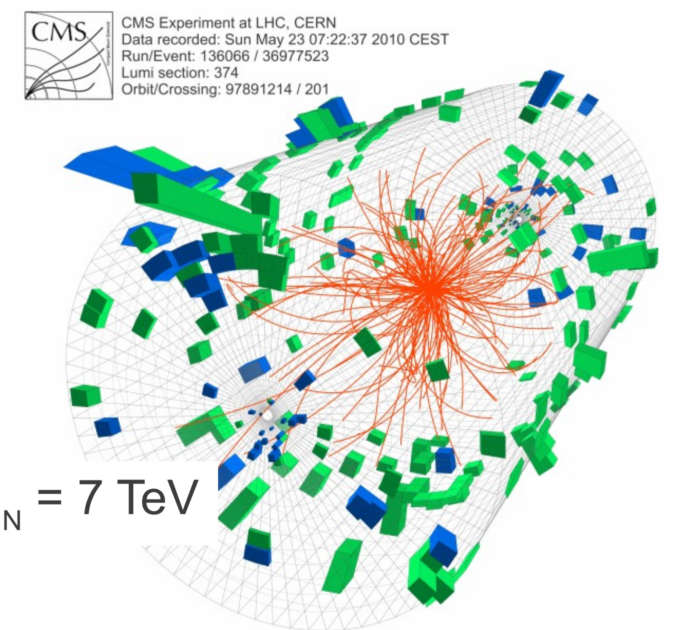
Ø(H⁺) ≈ 1 fm



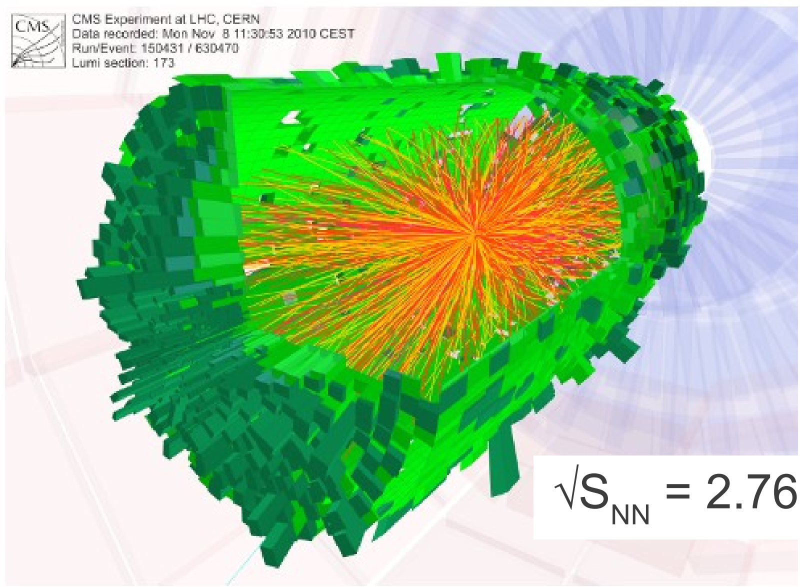


Ø(Pb^{82+}) ≈ 7 fm

$Pb + Pb\left({}^{207}_{82}Pb \right)$



$\sqrt{S_{NN}}$ = 7 TeV



$\sqrt{S_{NN}}$ = 2.76 TeV

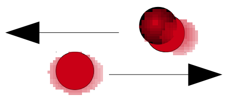
At the same $\sqrt{S_{NN}}$, the question is :

(p+p) x 207 ≈ 1 x (Pb+Pb) ?

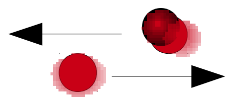
(Notes :
1. the "NN" → √S < 570 TeV
2. the achievable energy density)

V.2 – pp vs. AA : continuum of physics ?

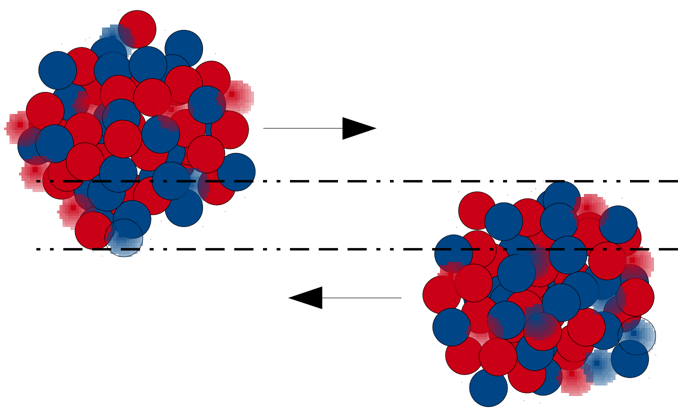
1. p+p, Min. Bias



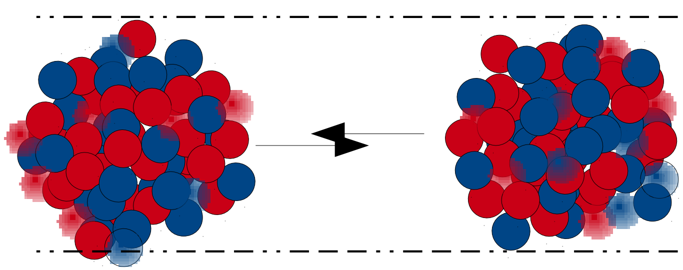
2. p+p, High Multilplicity

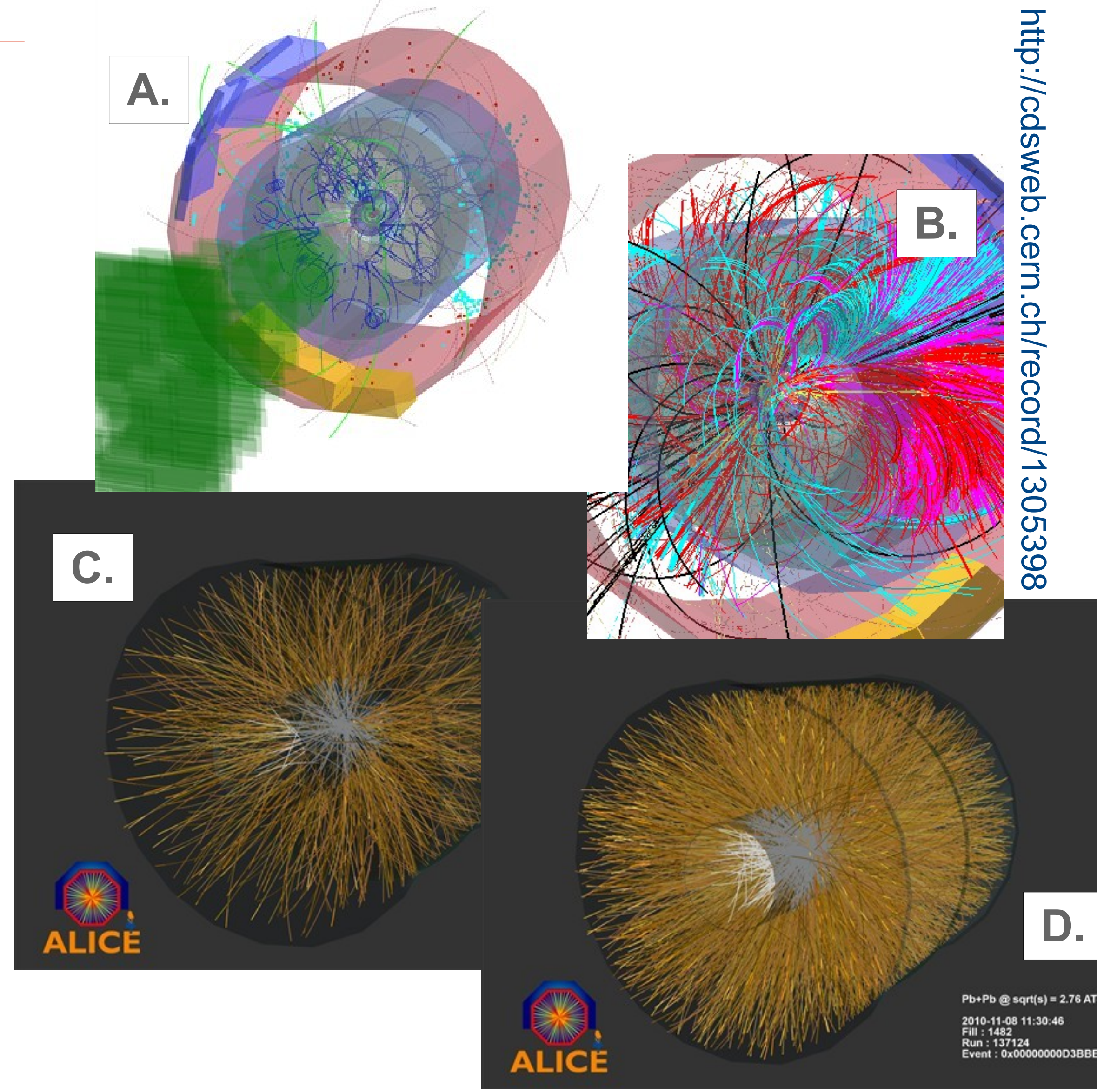


3. Pb+Pb, low centrality



4. Pb+Pb, most central events

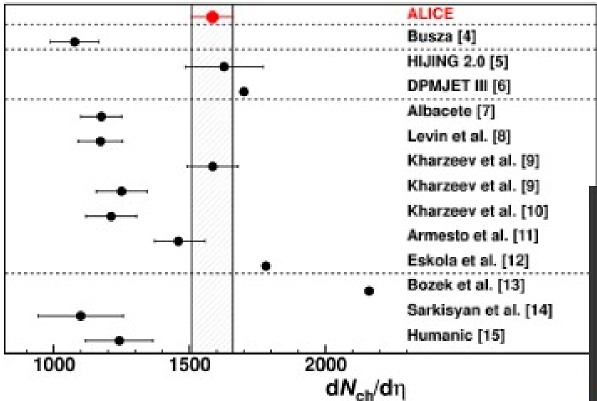




http://cdsweb.cern.ch/record/1305398

V.3 – pp vs. AA : multiplicity

http://arxiv.org/abs/1011.3916



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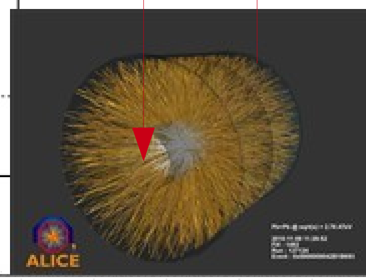

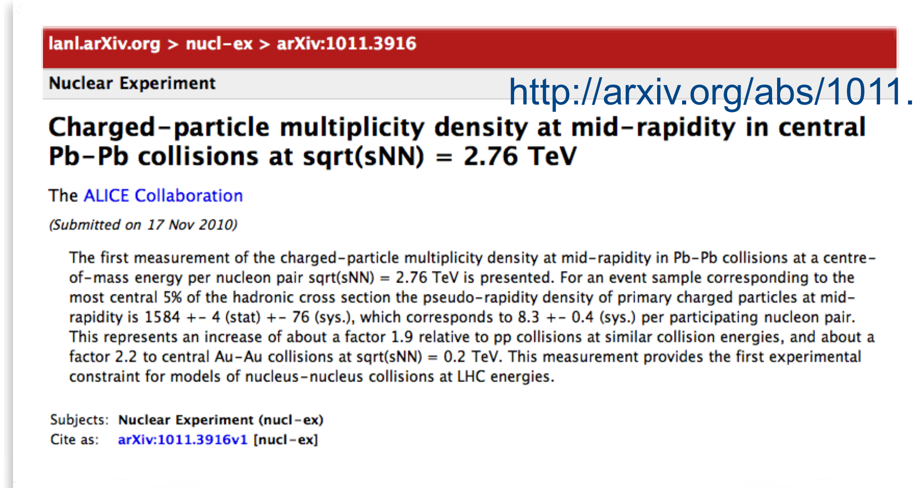

lanl.arXiv.org > nucl-ex > arXiv:1011.3916

Nuclear Experiment

Charged-particle multiplicity density at mid-rapidity in central Pb-Pb collisions at sqrt(sNN) = 2.76 TeV

The ALICE Collaboration

(Submitted on 17 Nov 2010)

The first measurement of the charged-particle multiplicity density at mid-rapidity in Pb-Pb collisions at a centre-of-mass energy per nucleon pair sqrt(sNN) = 2.76 TeV is presented. For an event sample corresponding to the most central 5% of the hadronic cross section the pseudo-rapidity density of primary charged particles at mid-rapidity is 1584 +- 4 (stat) +- 76 (sys.), which corresponds to 8.3 +- 0.4 (sys.) per participating nucleon pair. This represents an increase of about a factor 1.9 relative to pp collisions at similar collision energies, and about a factor 2.2 to central Au-Au collisions at sqrt(sNN) = 0.2 TeV. This measurement provides the first experimental constraint for models of nucleus-nucleus collisions at LHC energies.

Subjects: Nuclear Experiment (nucl-ex)
Cite as: arXiv:1011.3916v1 [nucl-ex]

http://arxiv.org/abs/1011.3916

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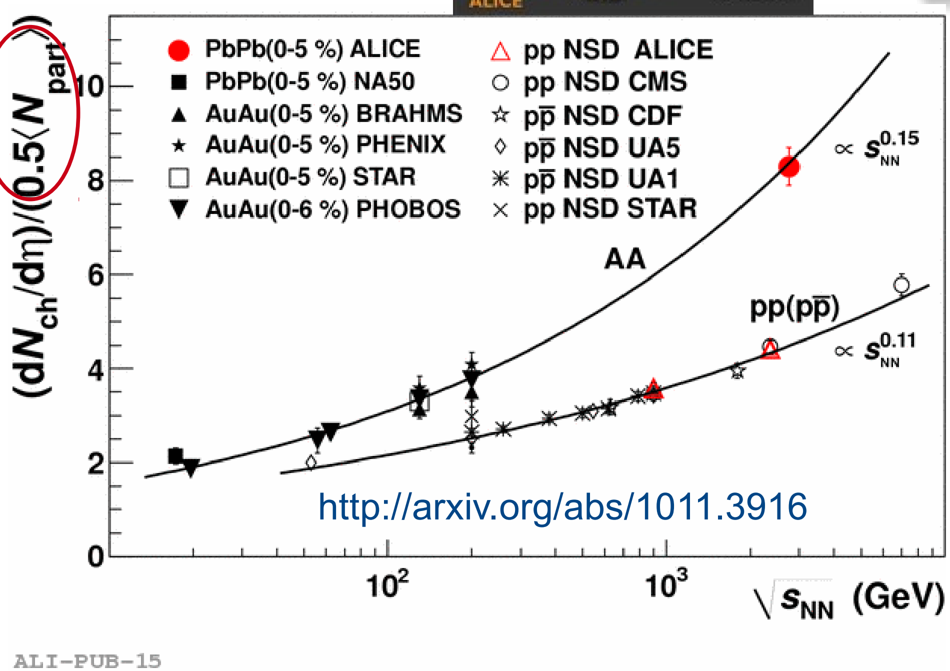
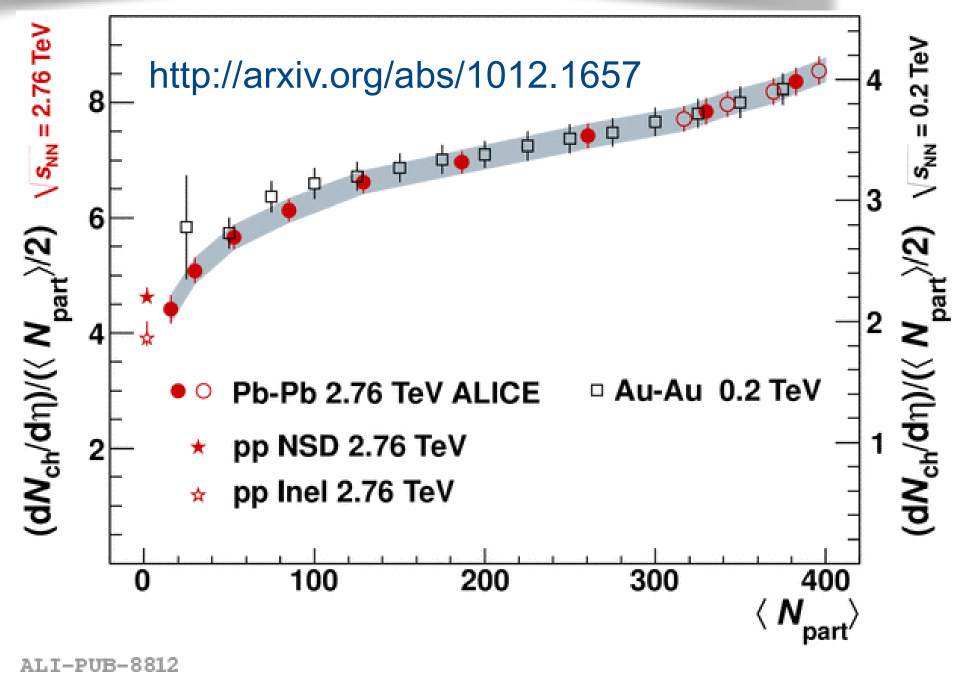
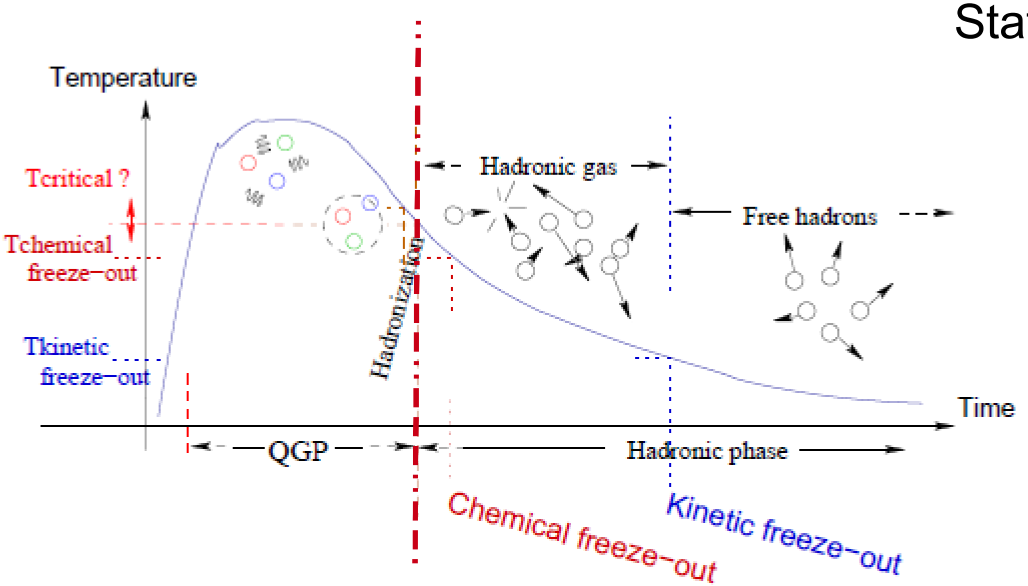
to
apple
...





V.4 – pp vs. AA : thermal models



Statistical thermal models :

description of the system at the chemical freeze-out i.e. system ≠ QGP !

but a gas of hadrons in equilibrium ...

(Fit to the data : rate of production and ratios between particles)

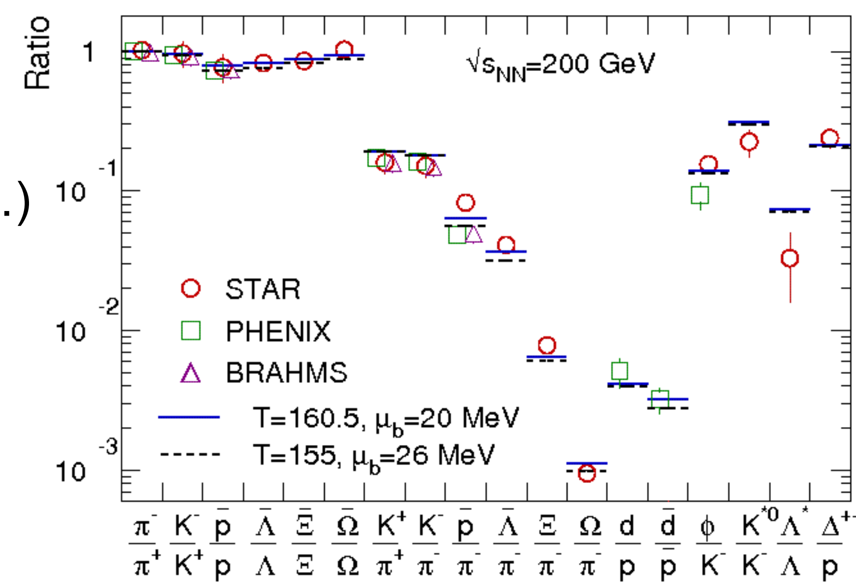
Key : Grand-canonical formalism
(equilibrium, conservation of all quantum numbers, …)

2 free parameters :

Baryo-Chemical potential μ_B

\+ Température at the chemical freeze-out, T_{ch}

$\rightarrow T_{MODEL} \sim T_C$



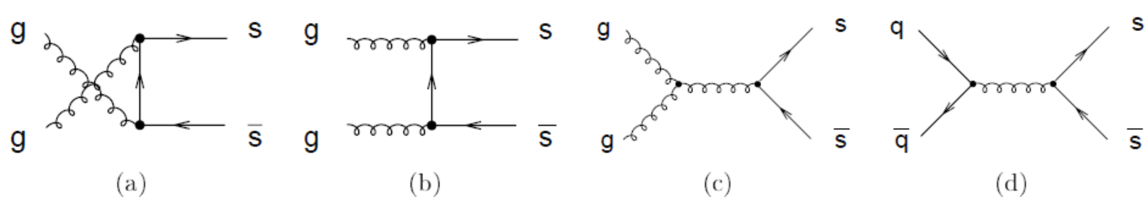
Nucl.Phys.A772:167(2006)

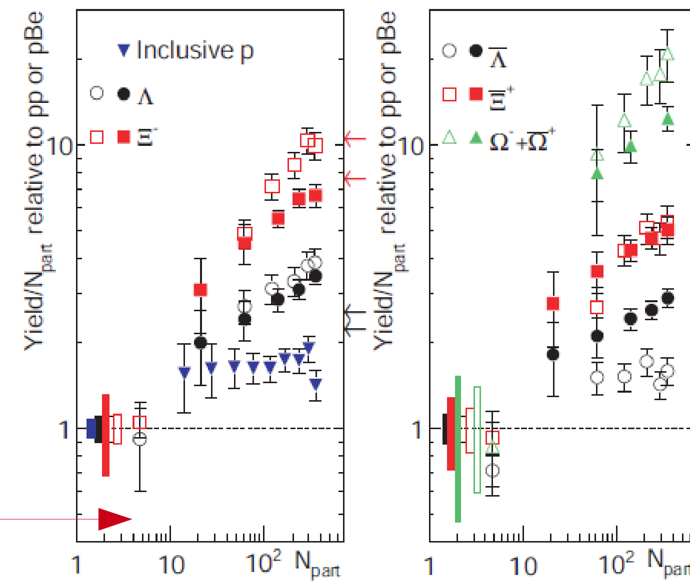
Part C :

QGP Signatures

VI.1 – **Strangeness** : enhancement ?

1. Historical signature : "*strangeness enhancement*"
= Gluon fusion : **gg → s$\bar{\text{s}}$**
from Rafelski & Müller, Phys.Rev.Lett 48 : 1066 (1982)…



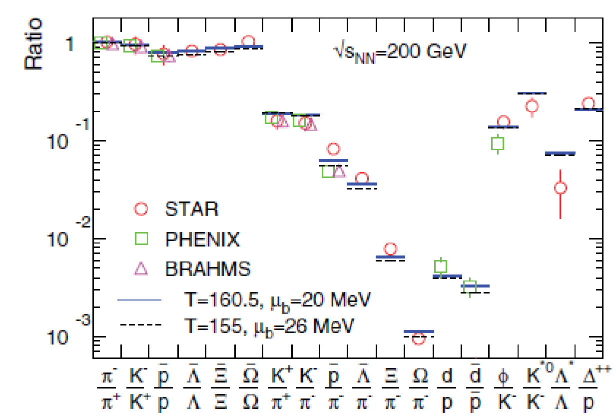


STAR, PhysRevC.77.044908

Experimental results : NA57, STAR

But ≠ "smoking gun"
→ complex phenomenon,
leading to long-standing debate
(ex. : a. Normalisation to pp, pA
b. Centrality dependence
c. Canonical suppression, ...)

2. *s* quarks seem thermalised as *u*,*d* quarks
→ *s* belong to bulk physics ...



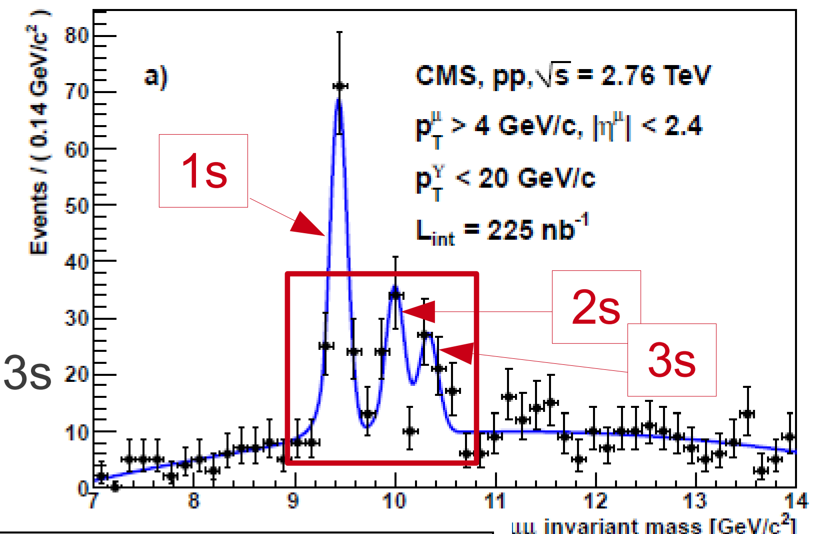
Nucl.Phys.A772:167(2006)

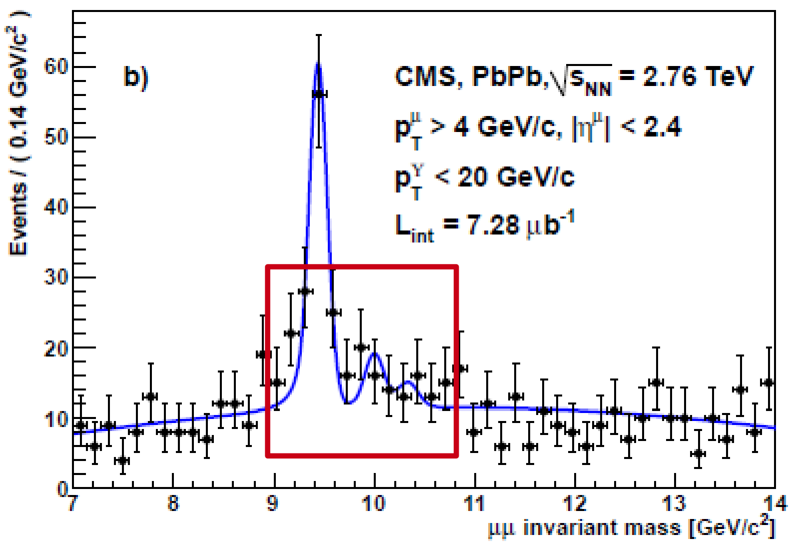
3. Need proper study of the benchmark system : pp ...

VII.1 – Quarkonia : J/Ψ, Υ... suppression ?

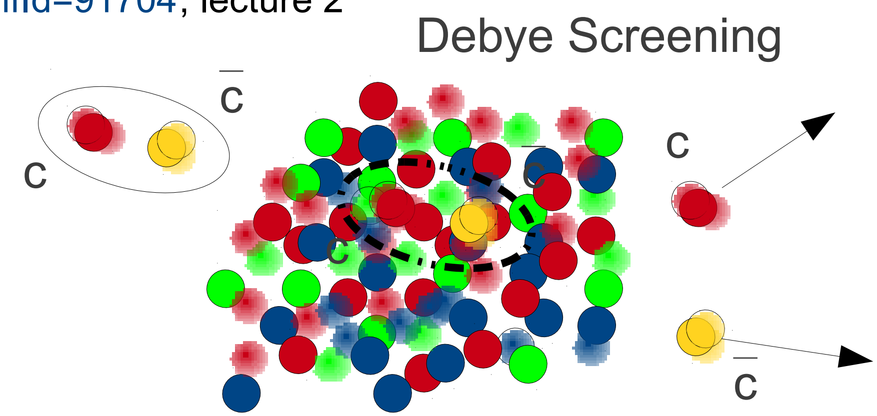
See also CERN, SSP https://indico.cern.ch/conferenceDisplay.py?confId=91704, lecture 2

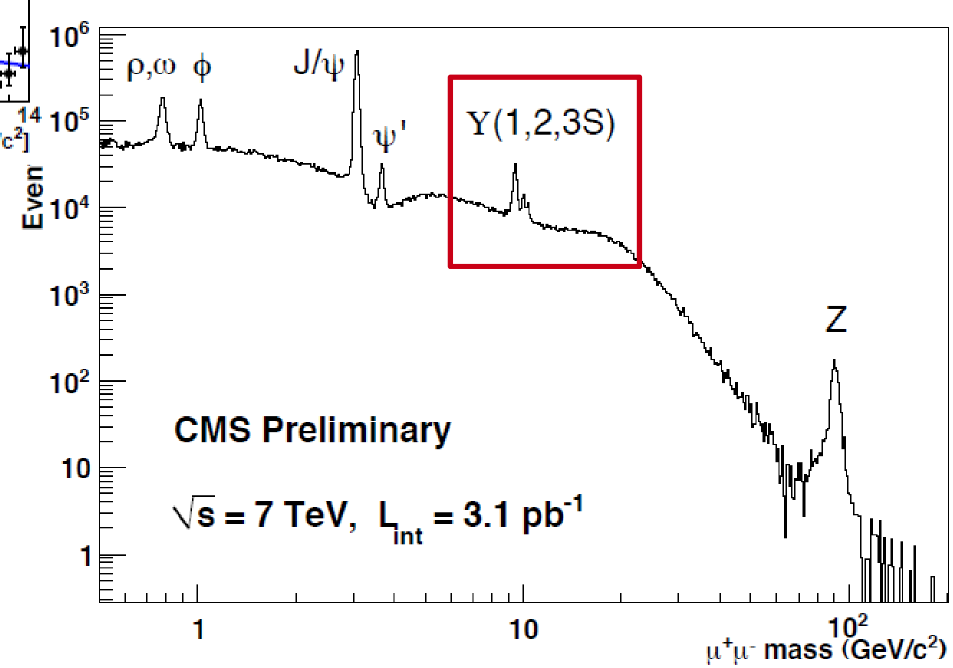
Ex: CMS
Υ($b\bar{b}$)
States : 1s, 2s, 3s





http://arxiv.org/abs/1105.4894





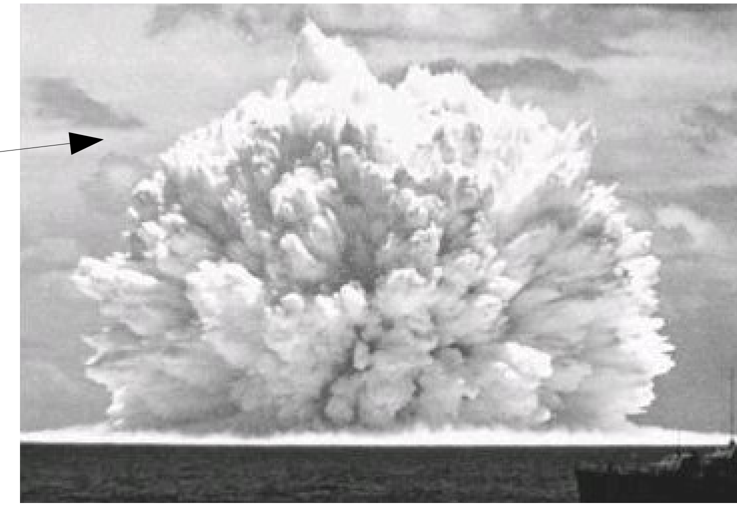
VIII.1 – Hydrodynamics : 2 aspects

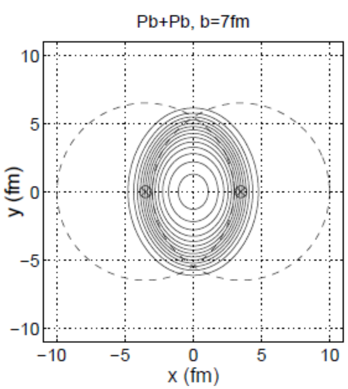
2 manifestations :

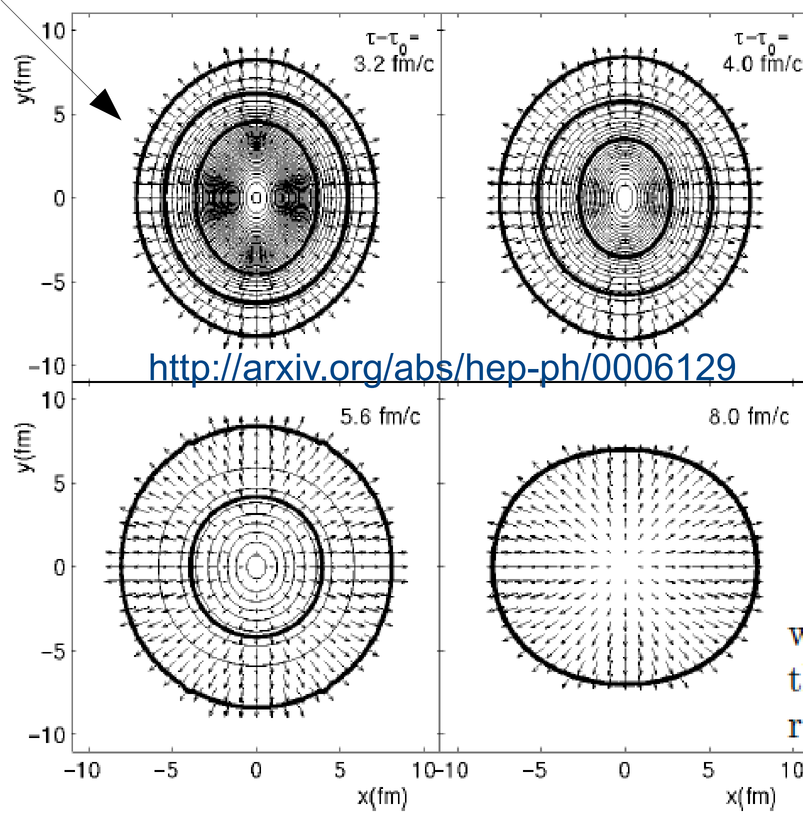
J.Y. Ollitrault (1992), Voloshin (1994)

a. Radial flow

b. elliptic flow, v2







http://arxiv.org/abs/hep-ph/0006129

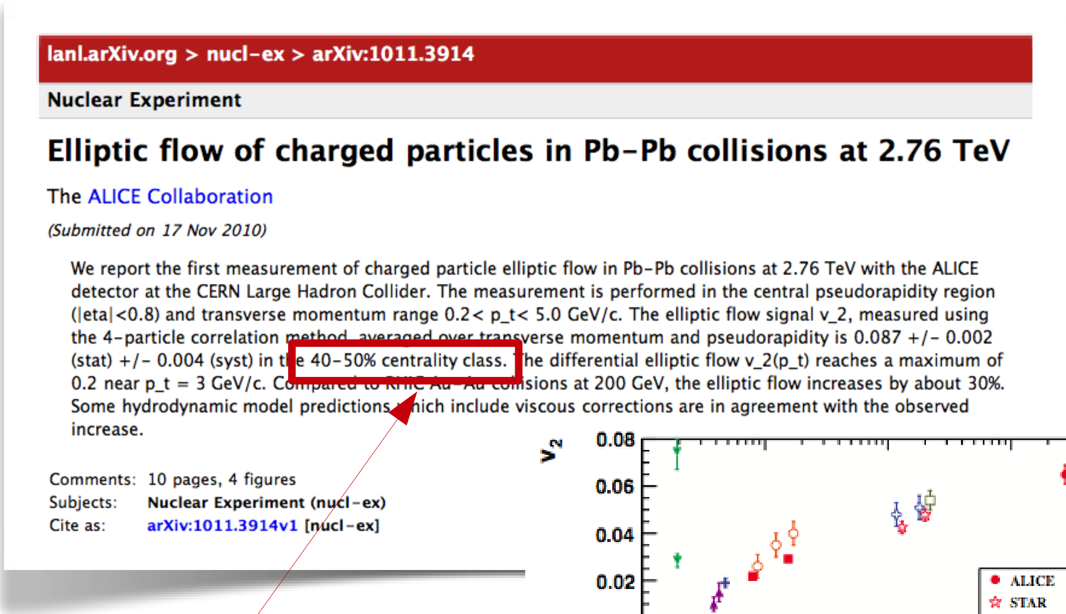
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos[n(\phi-\Psi_R)]\right), \quad (1)$$

where E is the energy of the particle, p the momentum, p_t the transverse momentum, ϕ the azimuthal angle, y the rapidity, and Ψ_R the reaction plane angle. The reaction

VIII.2 – Hydrodynamics : results

PHOBOS: Phys. Rev. Lett. **89**, 222301 (2002)
STAR: Phys. Rev. Lett. **86**, 402 (2001)

STAR: Phys. Rev. Lett. 90, 032301 (2003)


lanl.arXiv.org > nucl-ex > arXiv:1011.3914

Nuclear Experiment

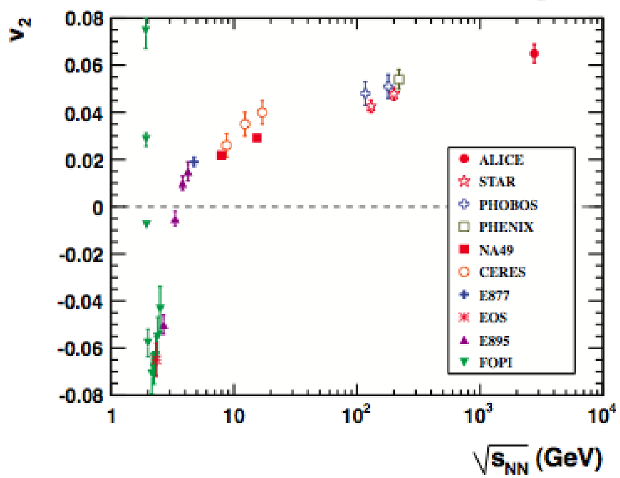
Elliptic flow of charged particles in Pb-Pb collisions at 2.76 TeV

The ALICE Collaboration

(Submitted on 17 Nov 2010)

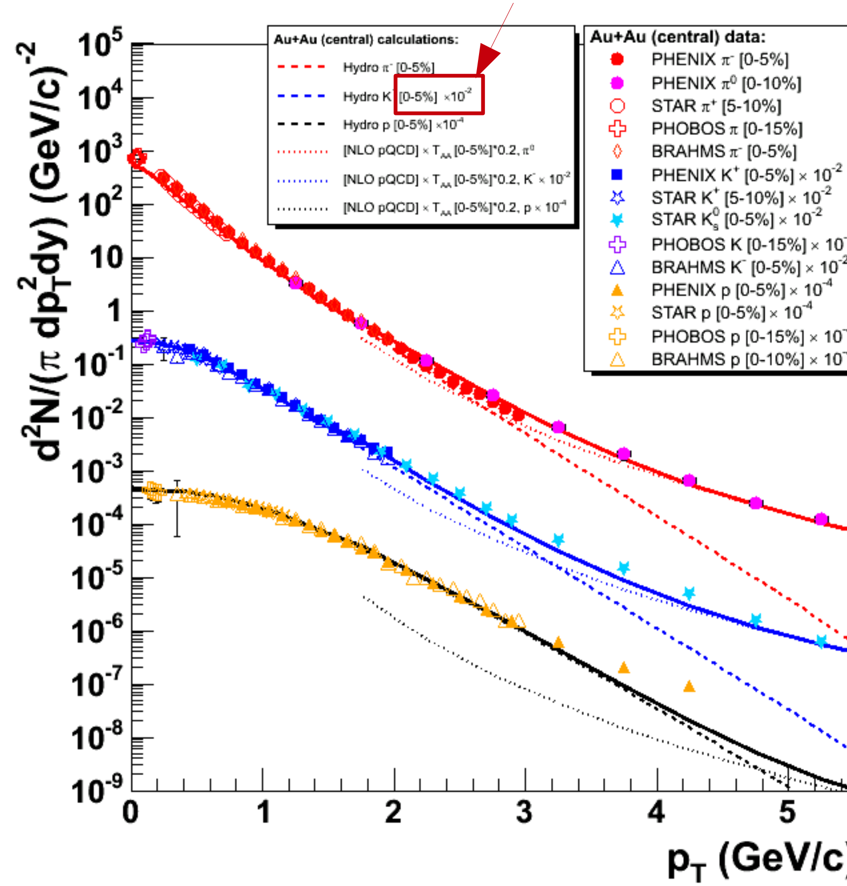
We report the first measurement of charged particle elliptic flow in Pb-Pb collisions at 2.76 TeV with the ALICE detector at the CERN Large Hadron Collider. The measurement is performed in the central pseudorapidity region (|eta|<0.8) and transverse momentum range 0.2< p_t< 5.0 GeV/c. The elliptic flow signal v_2, measured using the 4-particle correlation method, averaged over transverse momentum and pseudorapidity is 0.087 +/- 0.002 (stat) +/- 0.004 (syst) in the 40-50% centrality class. The differential elliptic flow v_2(p_t) reaches a maximum of 0.2 near p_t = 3 GeV/c. Compared to RHIC Au-Au collisions at 200 GeV, the elliptic flow increases by about 30%. Some hydrodynamic model predictions which include viscous corrections are in agreement with the observed increase.

Comments: 10 pages, 4 figures
Subjects: Nuclear Experiment (nucl-ex)
Cite as: arXiv:1011.3914v1 [nucl-ex]



v2 in semi-central coll.

radial flow in most central coll.



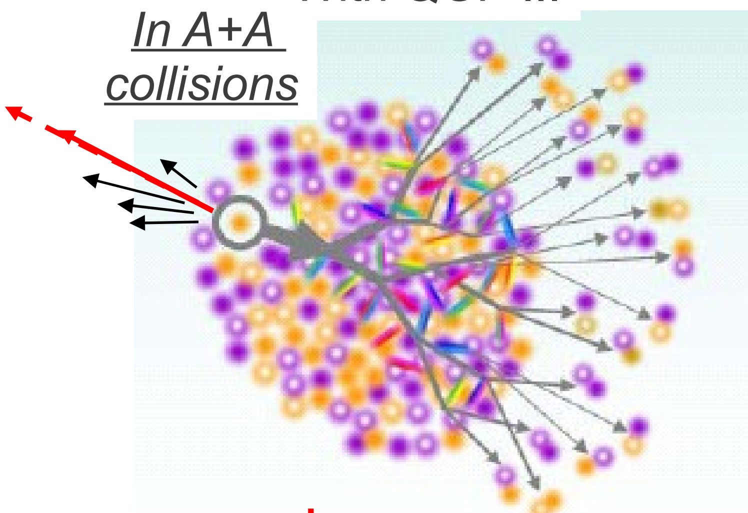
At low pt, quantitative agreement between data + ideal hydro model ~ no viscosity, perfect fluid !

IX.1 – Jet quenching : no back-to-back

$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})\, d^2N_{ch}^{AA}/d\eta dp_T}{\langle N_{coll}\rangle\,(1/N_{evt}^{pp})\, d^2N_{ch}^{pp}/d\eta dp_T}$$

With QGP ...

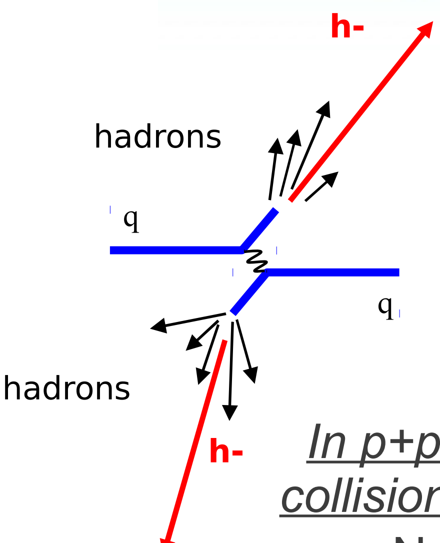
In A+A collisions



Like trying to run in the middle of the crowd (small mean free path ...)

here, ex. : $\pi^{\pm}$

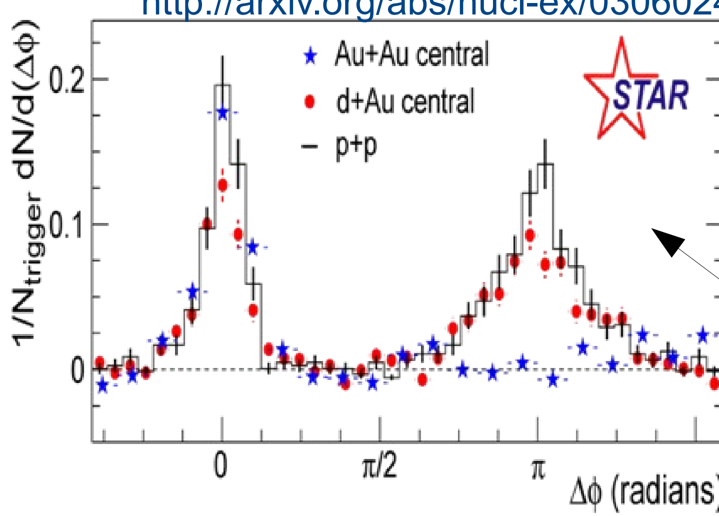
Exercise : consider the photon case for Raa ... Expectations ?

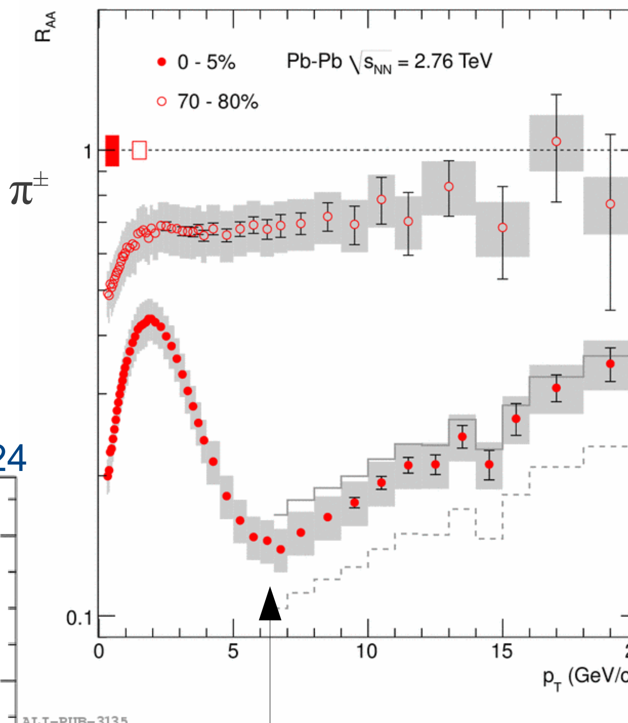


In p+p collisions

No QGP ...

http://arxiv.org/abs/nucl-ex/0306024





http://arxiv.org/abs/1012.1004

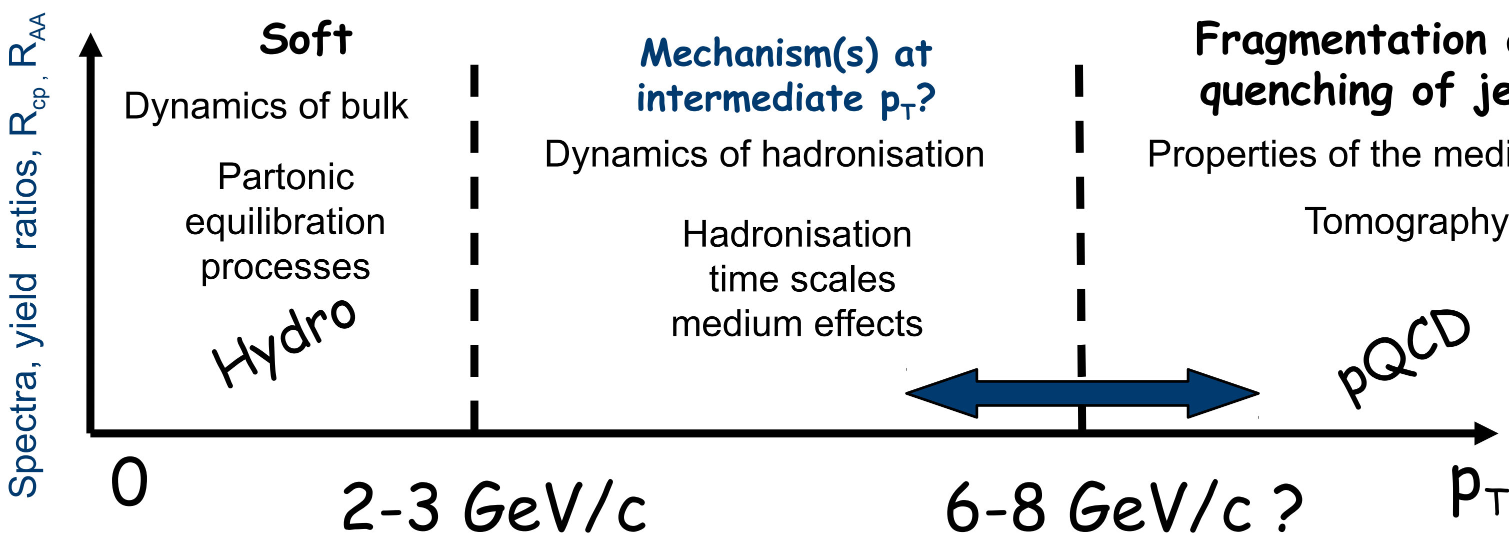
Parton energy loss by gluon bremsstrahlung in AA collisions

Conclusions :

Conclusions

QGP physics = unique, ... *(as the other fields of HEP can be !)*

→ concept, experiment, evidences ...



Thanks to Boris Hippolyte, Christian Kuhn ...

Appendices

App. A – Heating or compressing ?

App. B – $^{2}\overline{D}$, $^{3}\overline{He}$

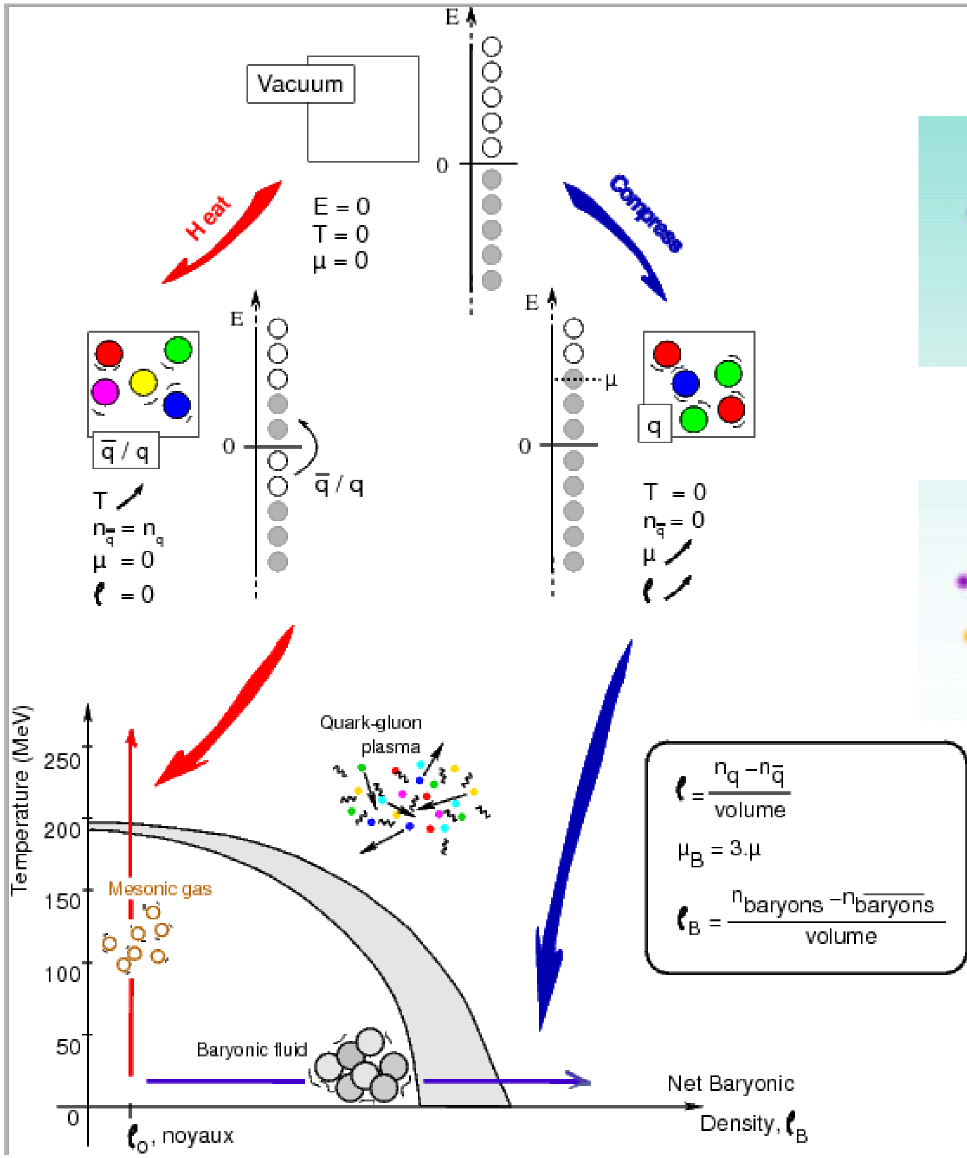
App. C – Deep Inelastic Scattering

App. D – the « *Black Hole* » issue

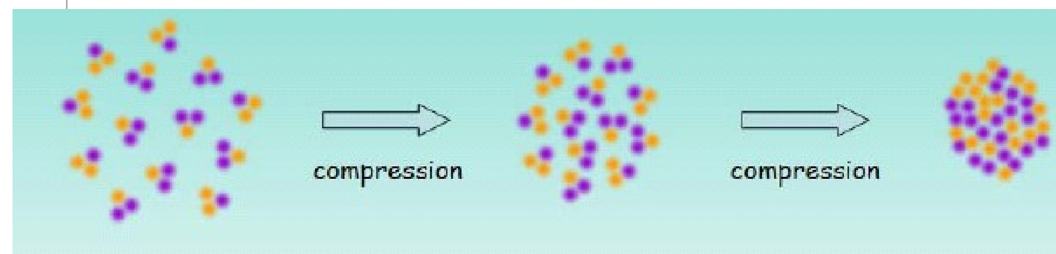
App. E – Quark condensate + chiral symm.

App. F – the LHC machine

A.1 – Heating or Compressing ?

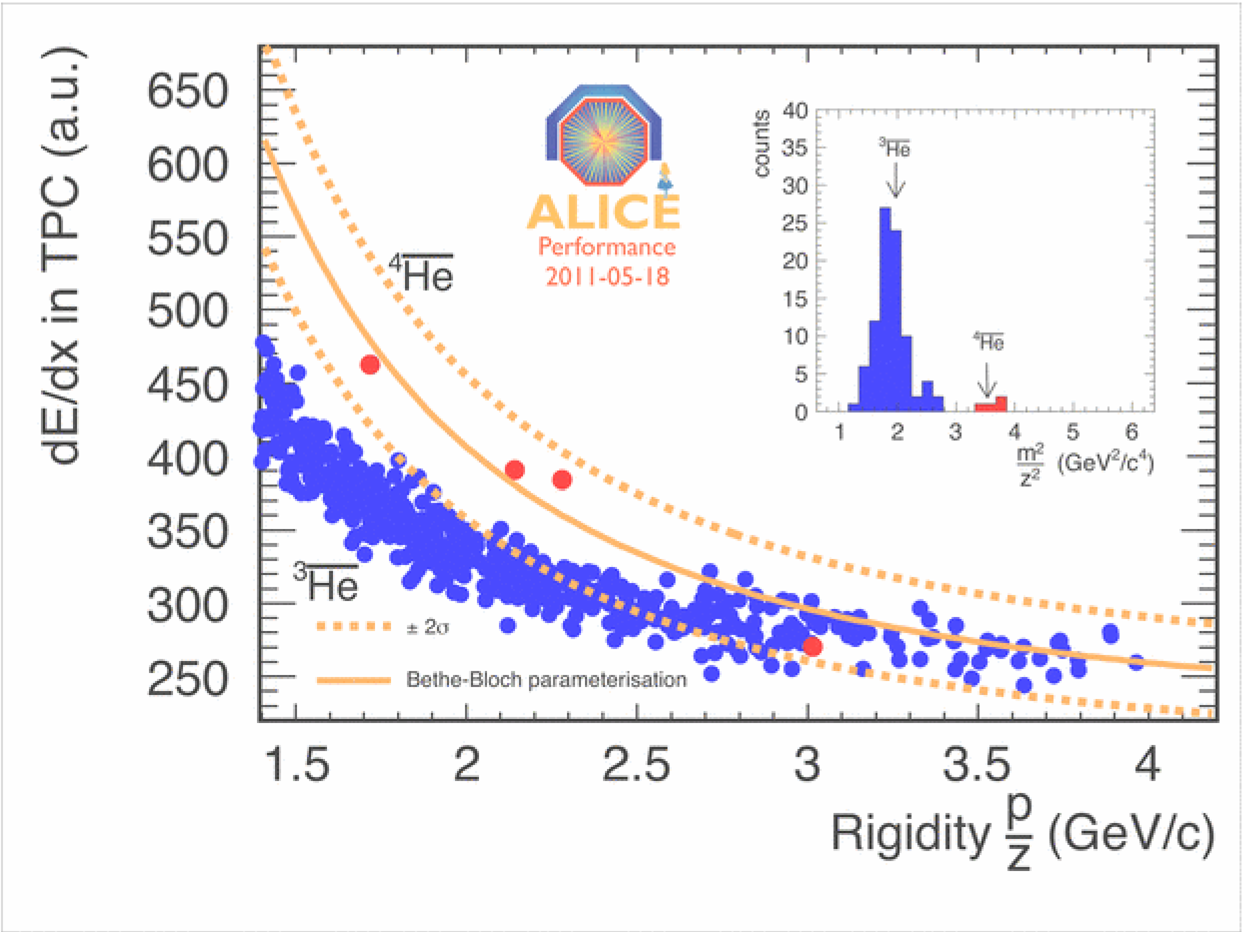


Compressing :



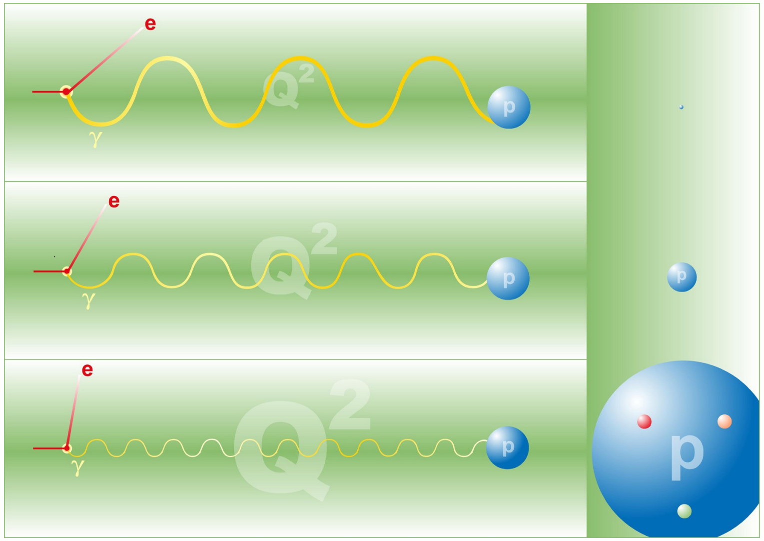
Heating :

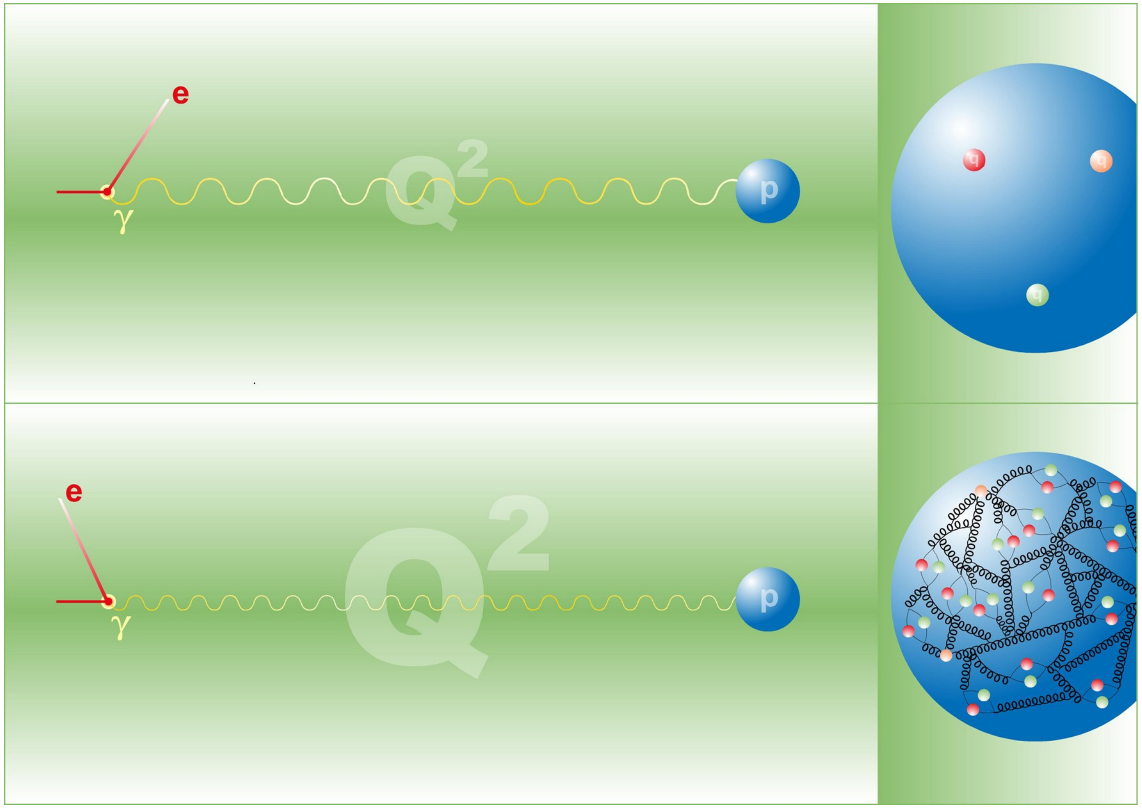
B.1 – Anti-nuclei



ALI-PERF-4884

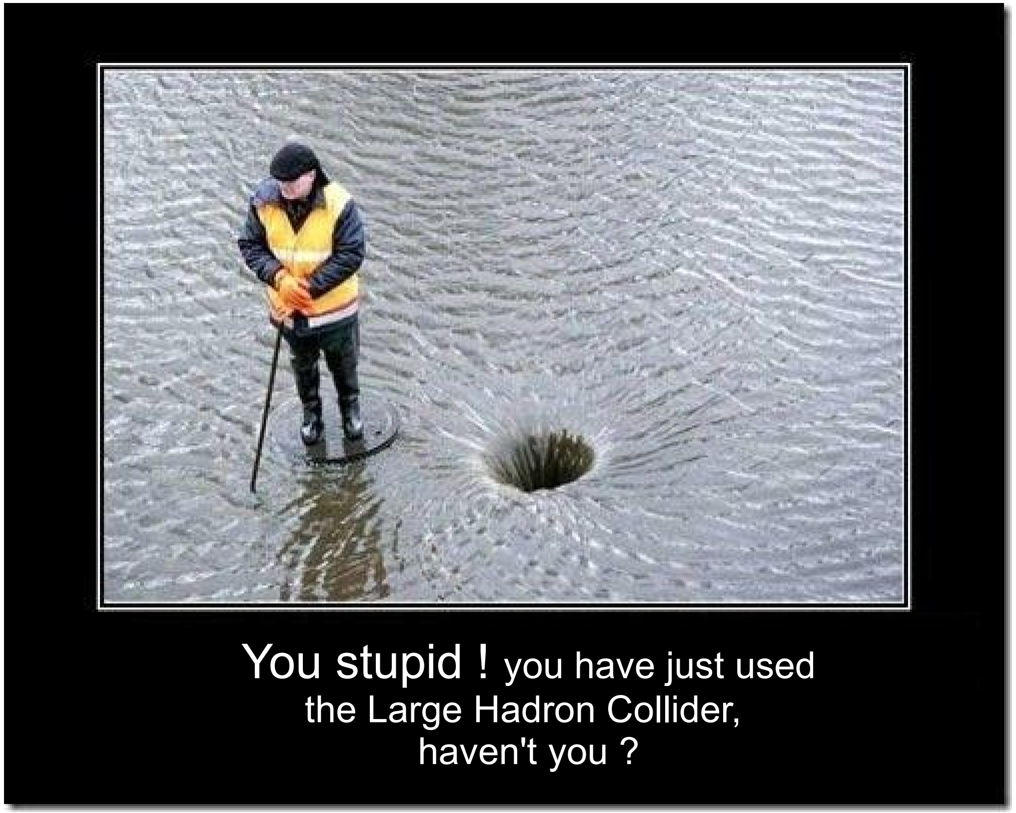
C.1 – D.I.S. : sea of partons





D.1 – Black Holes

The Black Hole Case: The Injunction Against the End of the World
http://arxiv.org/abs/0912.5480



http://en.wikipedia.org/wiki/AdS/QCD
http://en.wikipedia.org/wiki/AdS/CFT_correspondence

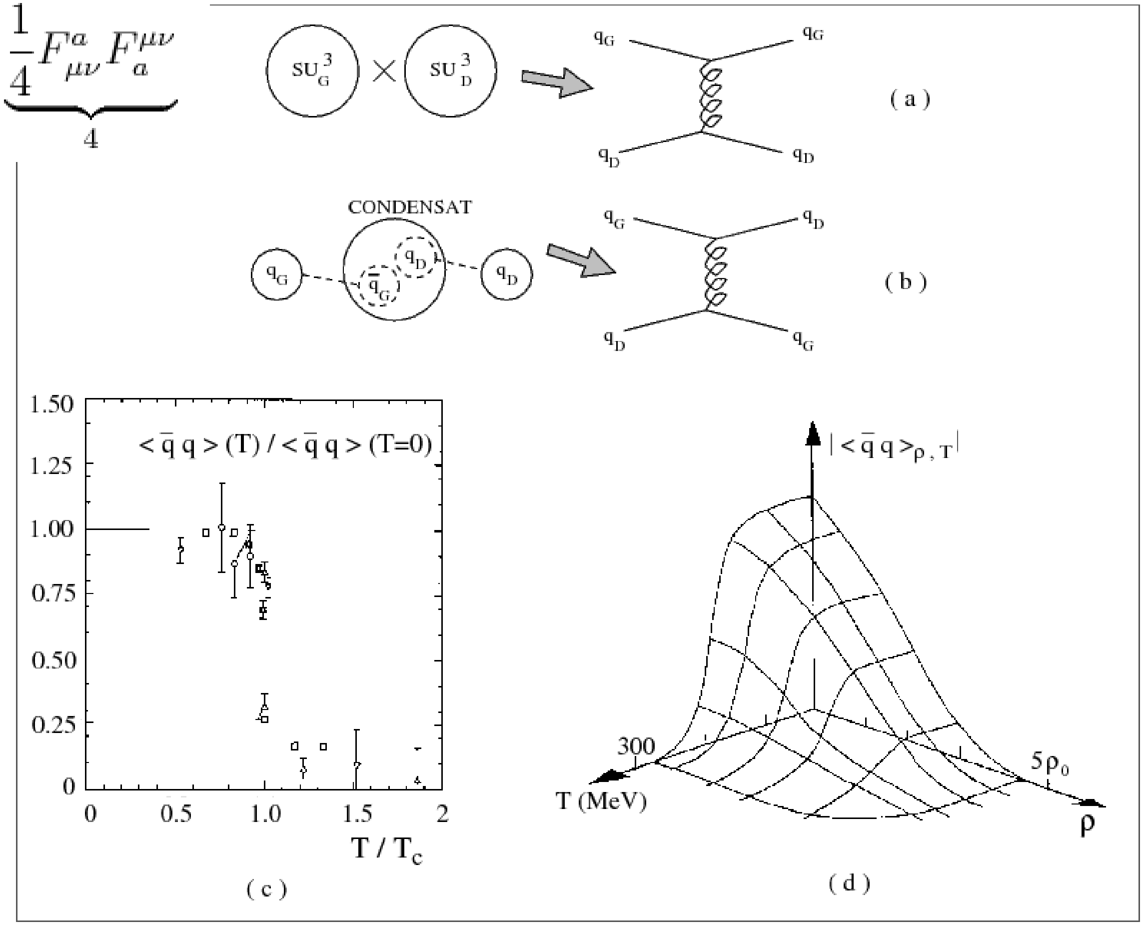
E.1 – Chiral Sym.

C. Kuhn – HDR, Chap.1

$$L_{QCD} = \underbrace{i\bar{\psi}\gamma^\mu(\partial_\mu}_{1} - \underbrace{igA_\mu)\psi}_{2} - \underbrace{m\bar{\psi}\psi}_{3} - \underbrace{\frac{1}{4}F^a_{\mu\nu}F^{\mu\nu}_a}_{4}$$

$$i\bar{\psi}O\psi = i\bar{\psi}_D O\psi_D + i\bar{\psi}_G O\psi_G$$

$$m\bar{\psi}\psi = m(\bar{\psi}_D\psi_G + \bar{\psi}_G\psi_D)$$



- In normal life,
  exists a quark condensate
  with a non-zero value on average

→ The vacuum is not that « empty » ...
 ~ quark sea
 ~ explanation of the dynamical
  mass of the hadrons …

- If chiral symmetry is restored (QGP …) → The vaccuum is really « empty » !
  $SU(3)_L$ and $SU(3)_D$ = 2 different worlds
  Quarks are massless

II. Accélérateur LHC

II.2 – **La machine LHC**: 14TeV ds $10^{-15 \times 3}$ m^3

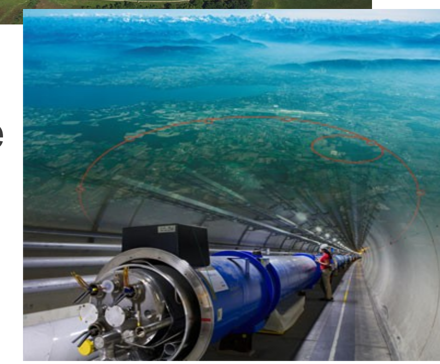
- *Des accélérateurs :*

  il existe / a existé différents accélérateurs dans le monde …
  SIS à GSI, *LEP* au CERN, *HERA* à DESY, *RHIC* à BNL,
  Tevatron au FNAL ...

  – Tevatron = une des 2 machines les plus puissantes au monde

  → collisions p-$\bar{p}$ à 1,96 TeV

  – LHC = l'autre ...



- Le LHC en 1 chiffre :

Pour avancer en physique des particules, il faut désormais :

– collisions p-p à **2x 7 TeV** /

– collisions Pb^{82+} – Pb^{82+} à **2x 2,76 TeV**

→ 14 TeV ≈ E_{cin}(moustique en vol) …

Tout ça pour ça ?! Mais … 14 TeV dans le volume d'un proton,

soit : E_{cin}(moustique en vol) dans V(moustique) / $(10^{12})^3$

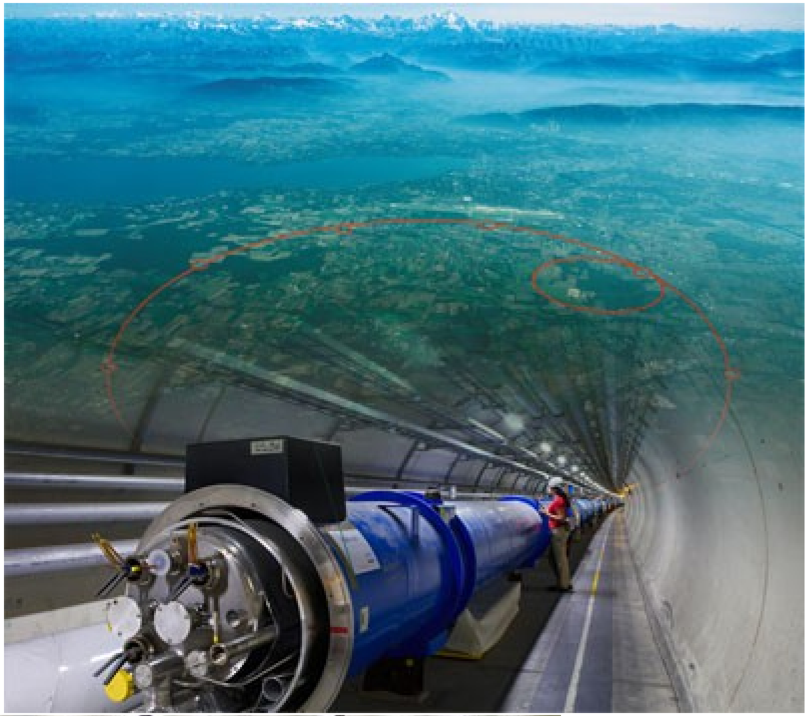
→ Clé : ≠ l'énergie, mais la **densité d'énergie**.

II.3.a – La machine LHC : en 8 chiffres

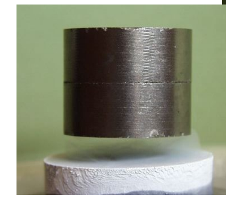
Faisceaux de protons à 7 TeV impliquent ...

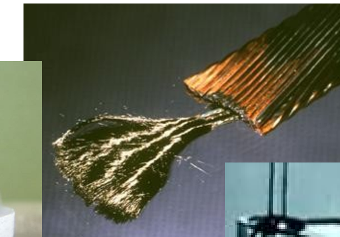
1. *vitesse* = 99, 999 999 1 % de c_0
2. *longueur* = anneau de 26,7 km de circonférence
3. *champs magnétiques* = 8,33 T
4. *courant de bobine* = 11 850 A
5. *température* = 1,9 K = -271,3° C
6. *pression* = 10^{-13} atm
7. *énergie stockée dans le faisceau* = 346 MJ
8. *collisions* = 600.10^{6} s^{-1}

...



II.3.c – La machine LHC : courber ...





Faisceaux de protons à 7 TeV impliquent ...

1. *vitesse* = 99, 999 999 1 % de c_0
2. *longueur* = anneau de 26,7 km de circo
3. *champs magnétiques* = 8,33 T
4. *courant de bobine* = 11 850 A
5. *température* = 1,9 K = -271,3° C
6. *pression* = 10^{-13} atm

Objectif : maintenir un proton de 7 TeV sur une orbite de 27 km ?

→ $B_{dipôle}$ = …

Comment générer B ?

→ I_{bobine} = ...

Soit, et pour canaliser un tel courant ?

→ *bobine supraconductrice …*

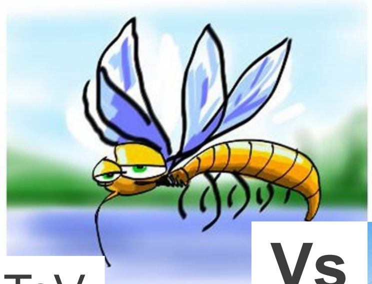
Oui, mais à quel température ?

→ T_{bobine} = …

Et comment se fait le refroidissement ?

→ *hélium superfluide.*

II.3.e – La machine LHC : accumuler ...



7 TeV

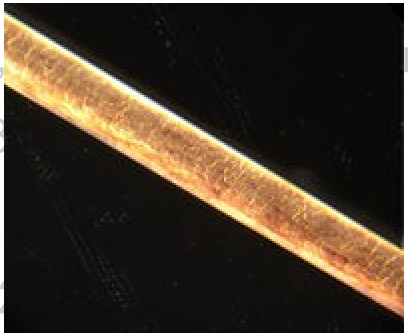
Vs

346 MJ

Faisceaux de protons à 7 TeV impliquent ...

1. *vitesse* = 99, 999 999 1 % de c_0
2. *longueur* = anneau de 26,
3. *champs magnétiques* = 8
4. *courant de bobine* = 11 8
5. *température* = 1,9 K = -
6. *pression* = 10^{-13} atm
7. *énergie stockée dans le faisceau* = 346 MJ
8. *collisions* = 600.10^{6} s^{-1}

...

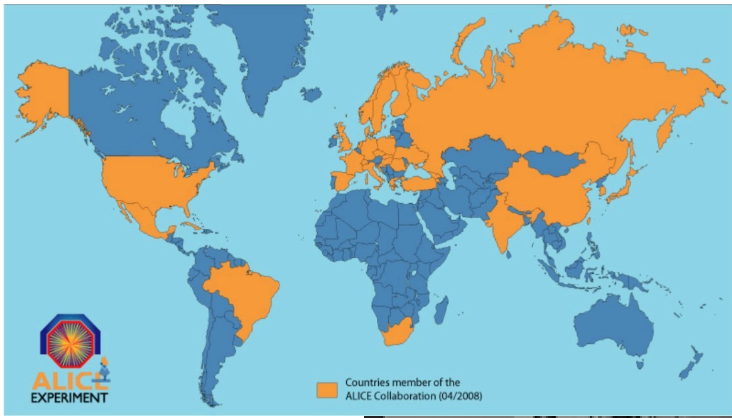


1. Faisceau =
   2808 paquets, ~10^{11} p/paquets
   diam. = 16,6 µm
   L_{paquet} = 7,55 cm

2. Pertes tolérables ~10 mW/cm^3

3. *Pb :* physique de la rareté
   < 40 interactions entre les
   2.10^{11} protons des 2 paquets
   en approche

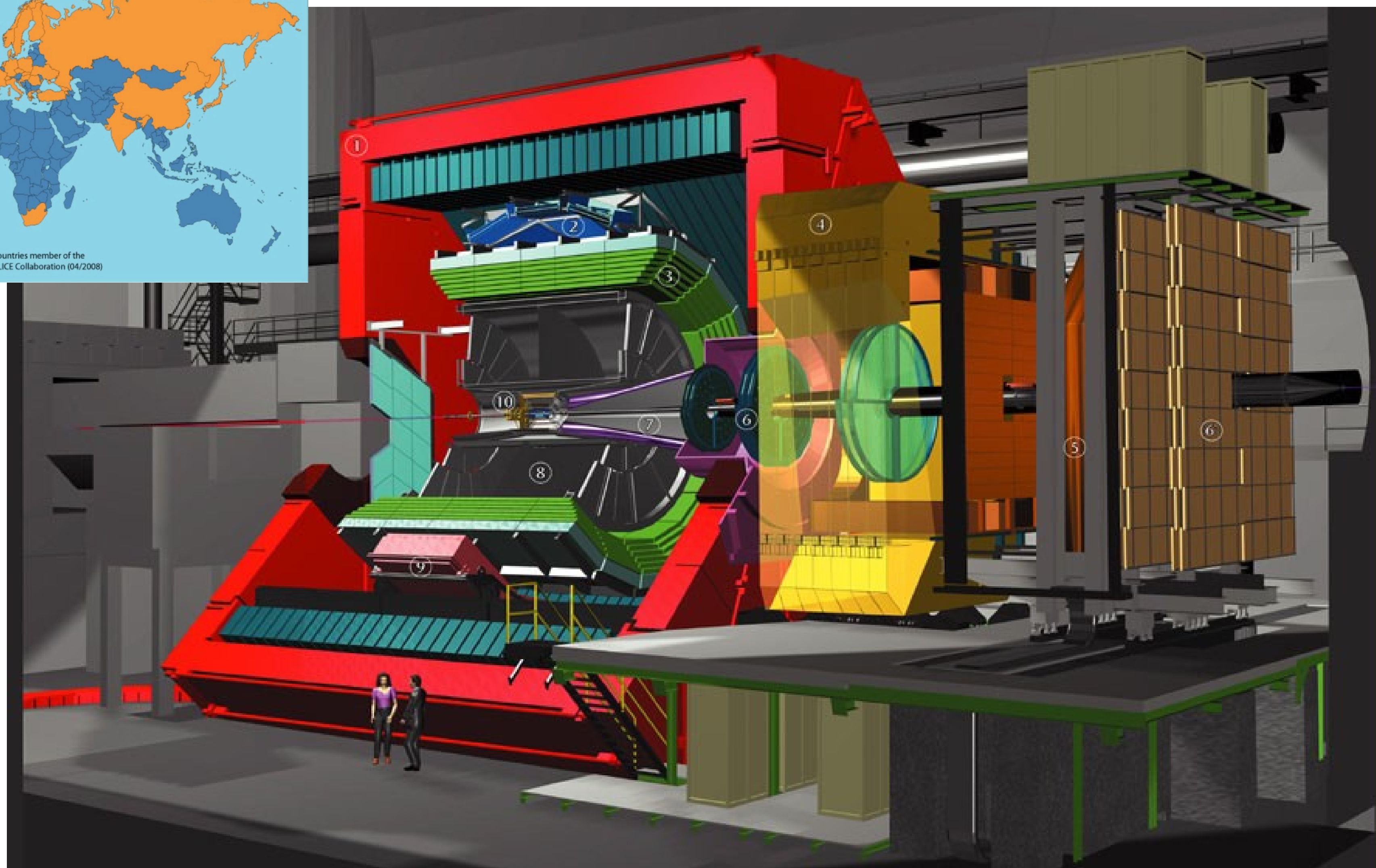
III.5.a – Un détecteur : exemple d'ALICE



31 pays
111 Instituts
10^3 membres

dans

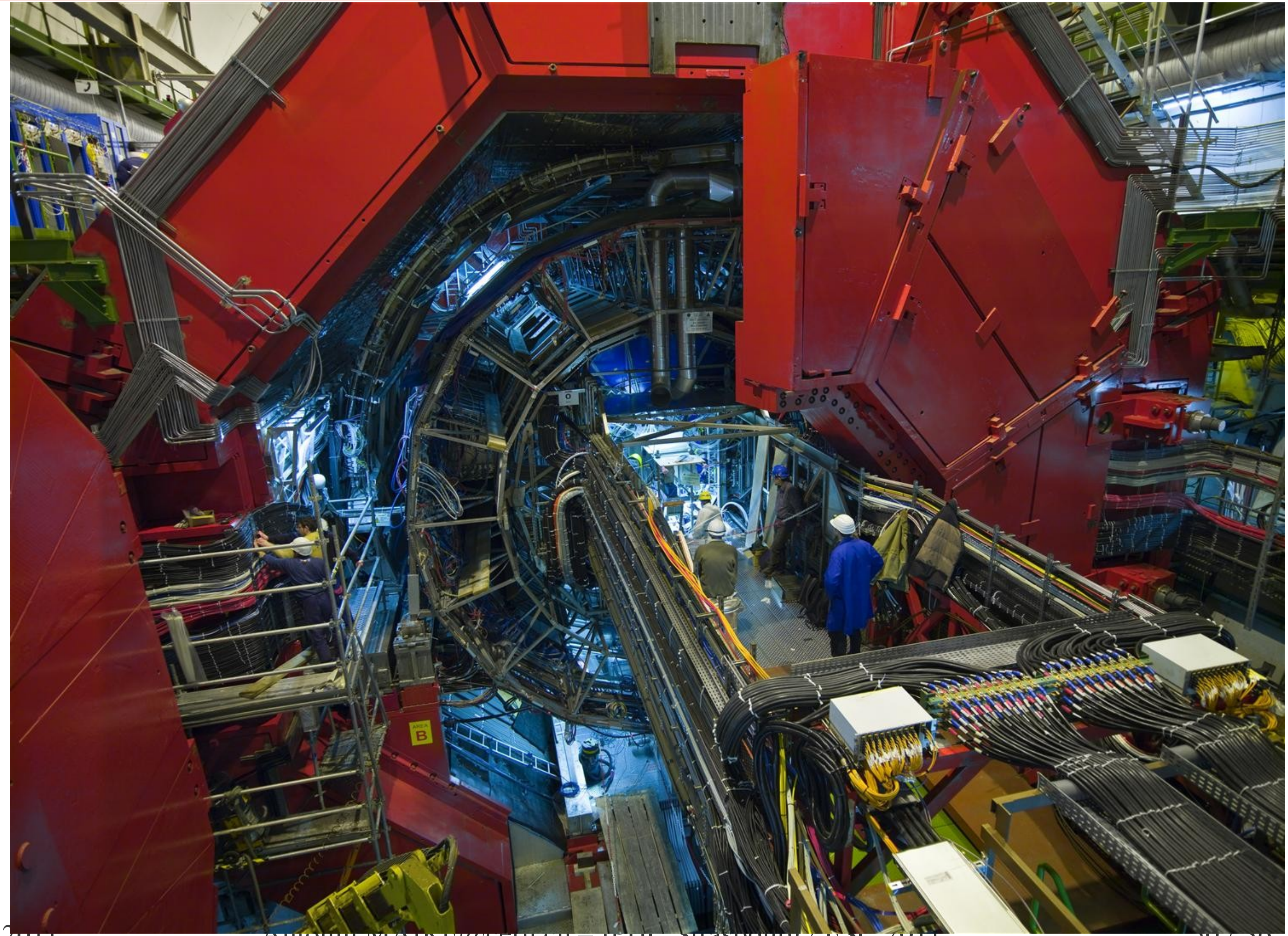
16x16x26 m^3
10 000 t
80 M€



III.5.b – Un détecteur : exemple d'ALICE

Situation en Aout 2003

III.5.c – **Un détecteur** : exemple d'ALICE



Situation en Juillet 2008

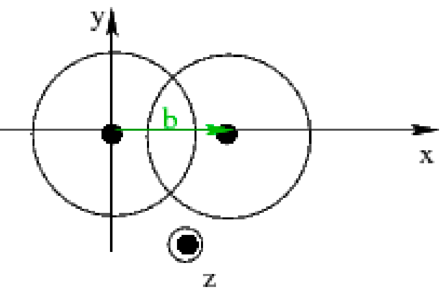
III.5.d – Un détecteur : exemple d'ALICE


First proton–proton collisions at the LHC as observed with the ALICE detector: measurement of the charged-particle pseudorapidity density at $\sqrt{s} = 900$ GeV

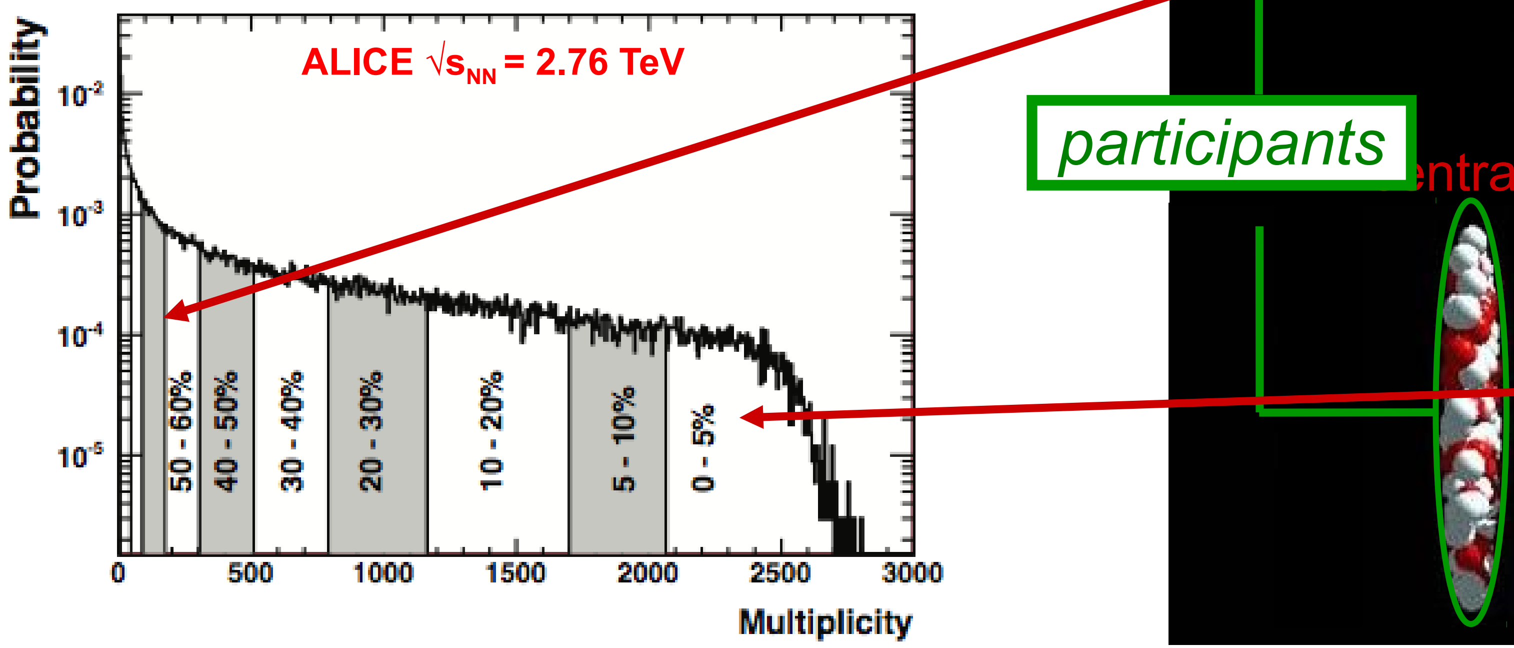
ALICE collaboration

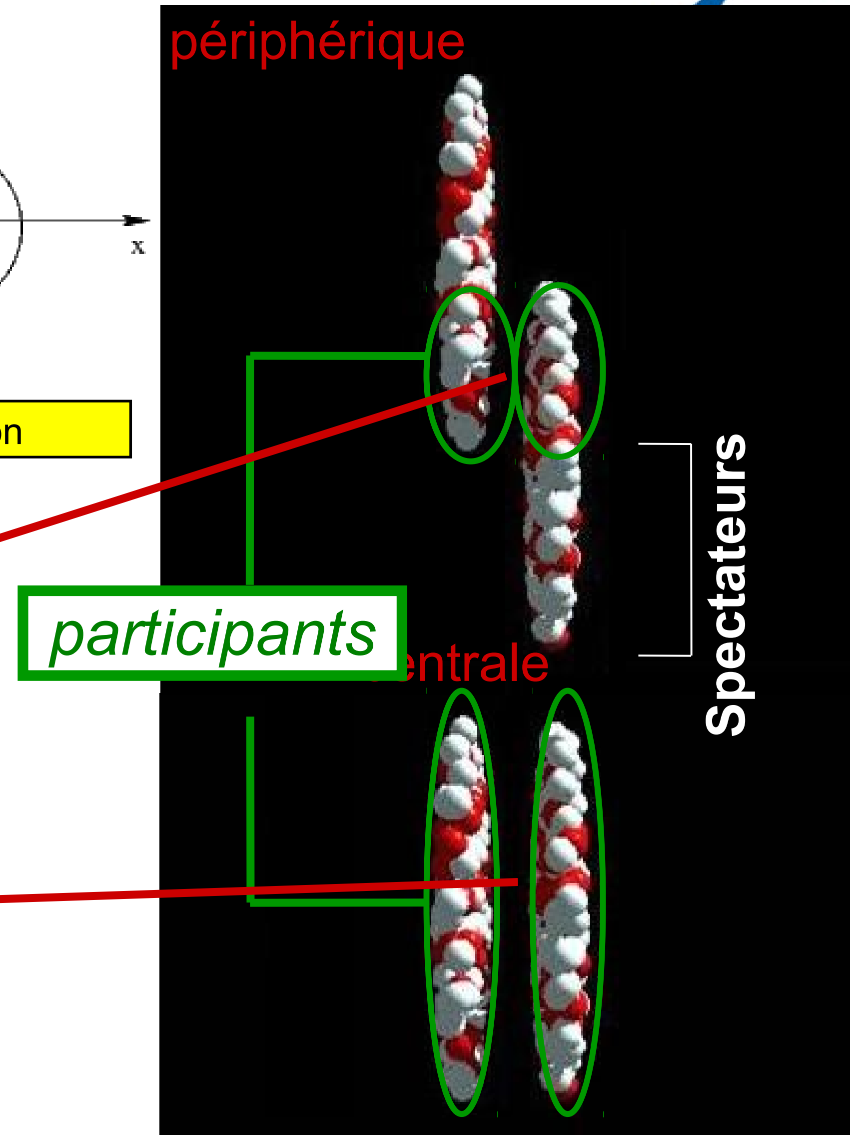
arXiv:0911.5430v2 [hep-ex] 1 Dec 2009

Les collisions noyau-noyau (A-A) ne sont pas toutes “centrales”: la zone de recouvrement des nucléons peut varier… C’est cependant dans les collisions les plus centrales que la densité d’énergie est la plus élevée donc la probabilité de former un QGP...



Le nombre de particules dépend de la centralité de la collision





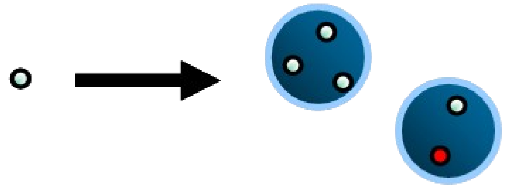
Nombre de participants (N_{part}): nucléons dans la région de recouvrement

Nombre de collisions binaires (N_{bin}): nombre équivalent de collisions inélastiques nucléon-nucléon

$N_{bin} \geq N_{part}$

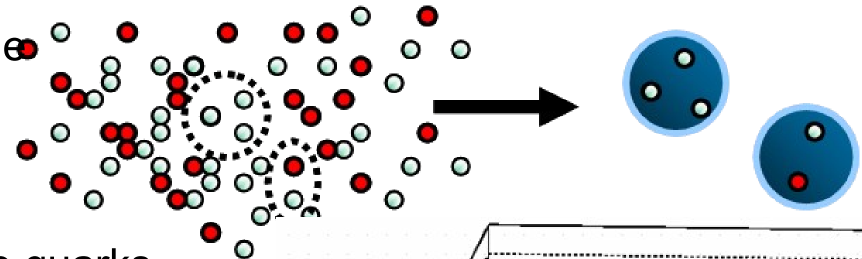
Recombinaison / Coalescence vs. Fragmentation

Hadronisation d'un parton: fragmentation



système dilué de partons
virtualité élevée

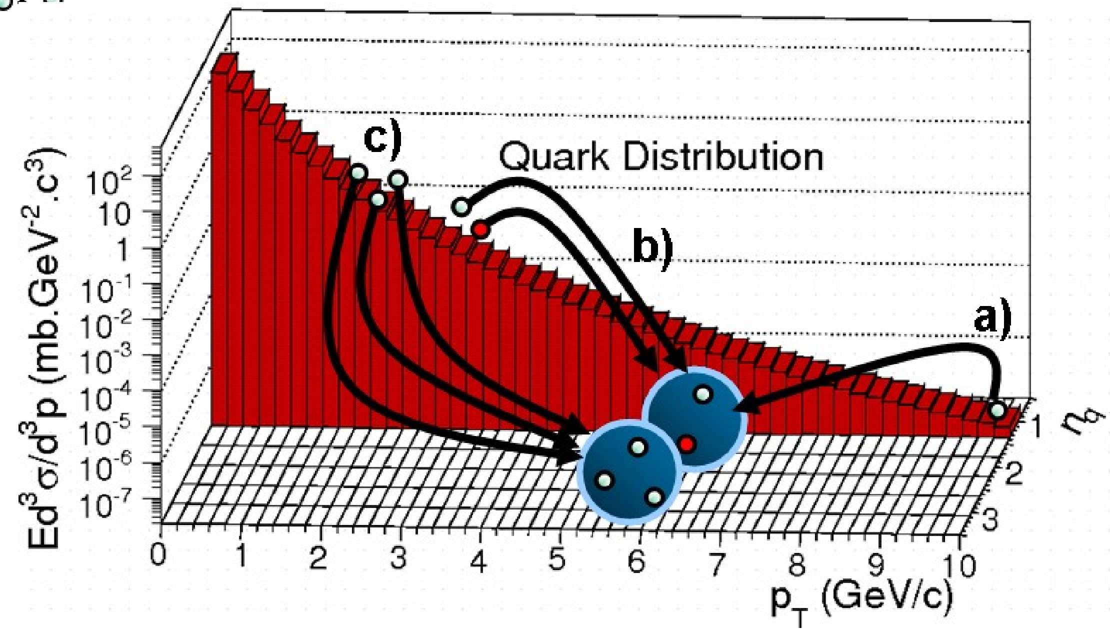
Si l'espace des phase est rempli de partons: on peut envisager une hadronisation par recombinaison / coalescence



système dense de partons
virtualité basse

La fragmentation dans le vide de quarks de haut p_T est en compétition avec la recombinaison dans le milieu de quarks de faible impulsion

a) 6 GeV/c pion avec 1x 10 GeV/c quark: fragmentation
b) 6 GeV/c pion avec 2x 3 GeV/c quark: recombinaison
c) 6 GeV/c proton avec 3x 2GeV/c quark recombinaison



Mesures: Rapports Baryon/Méson
Constituent Quark Scaling (e.g. v_2)
Corrélations avec contributions Soft+Hard

"...requires the assumption of a thermalized parton phase... (which) may be appropriately called a quark-gluon plasma." Fries *et al.*, PRC 68, 044902 (2003)

Remarque: initialement invoqué pour décrire le devenir des fragments de faisceaux 2 x p.

IV. Grille de calcul

IV.1 – La grille de calcul : enjeu

- Difficulté native : ~ 3 Po/s

  Flux énorme de données

~ 78 Mpx

$$40.10^6\, collisions/s \times 78.10^6\, octets$$
$$\rightarrow 3.10^{15}\, octets/s$$

1 MEGA : 10^6
1 GIGA : 10^9
1 TERA : 10^{12}
1 PETA : 10^{15}

1 CD : 700 Mo

- Atténuer la difficulté :

  Se ramener à < 100 Mo/s, par expérience,
  en période de prise de données
  → ~ 10-15 Po/an,
  = possible via une sélection grossière, à la volée.

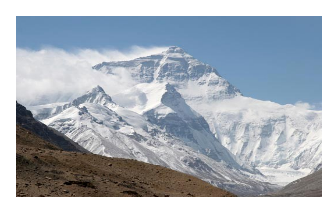
- 10-15 Po/an ...

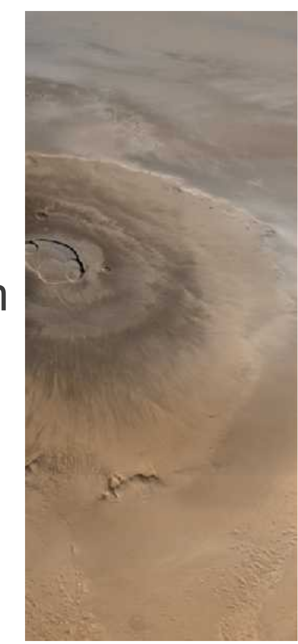
A chaque seconde : CMS enregistre 100 Mb
1 CD / 7 secondes

Chaque jour : CMS enregistre 10 To (10 000 Gb)
14 000 CD.j^{-1}

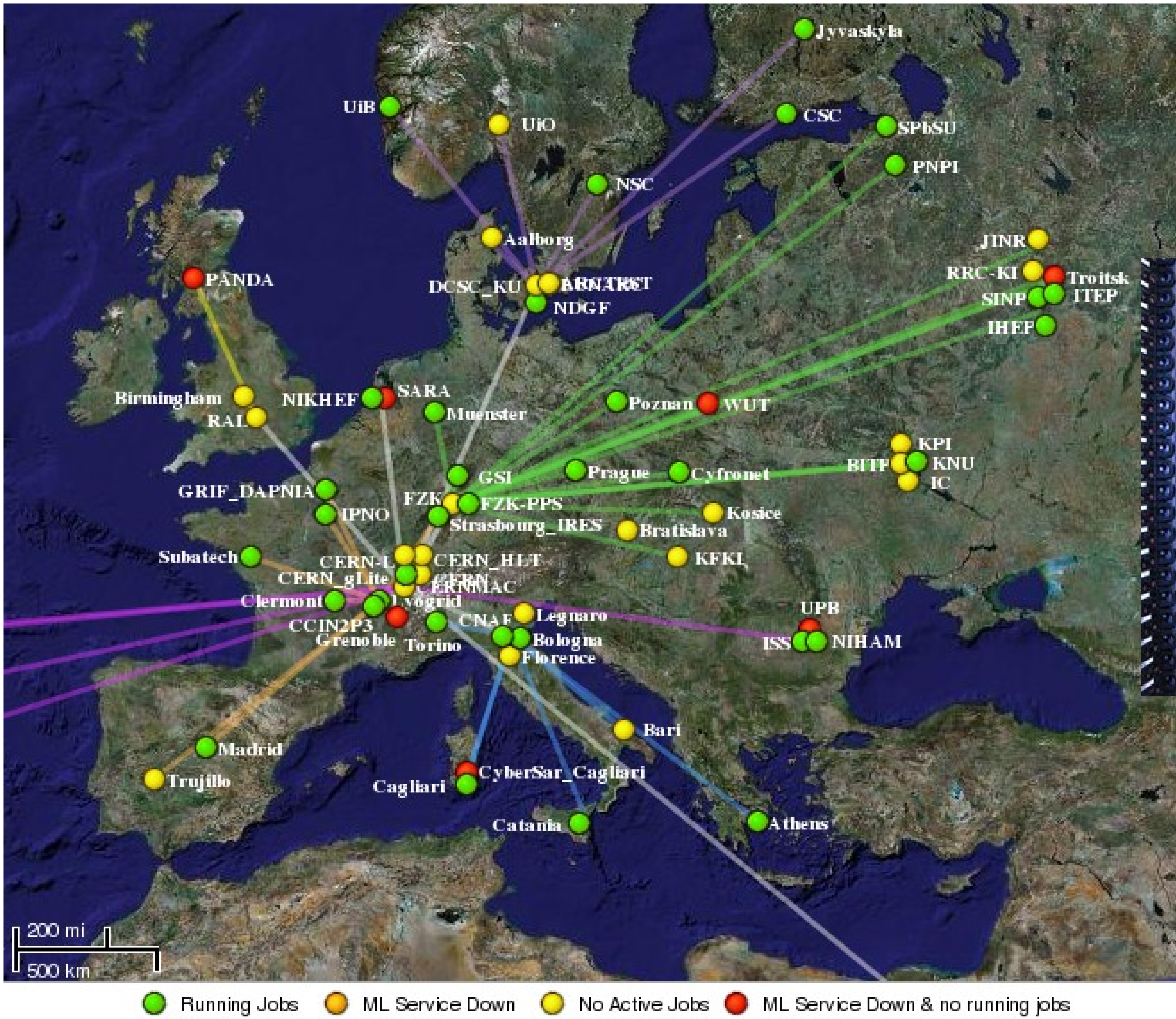
Or : 4 expériences sur le LHC du CERN
Production de 30 To par jour
43 000 CD.j^{-1} jour soit 30 CD.min^{-1}

Pile de ~20 km de CD





IV.2 – La grille de calcul : solution



Démultiplier,
Répartir la charge ...

→ ferme de fermes de PC