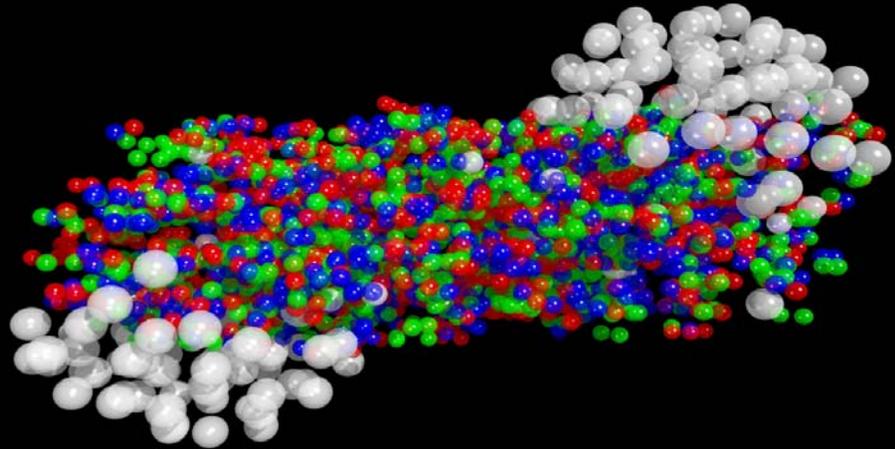


Déconfinement et plasma dans les collisions d'ions lourds

- Plasma de quarks et de gluons
- Le Petit Bang
- RHIC/LHC

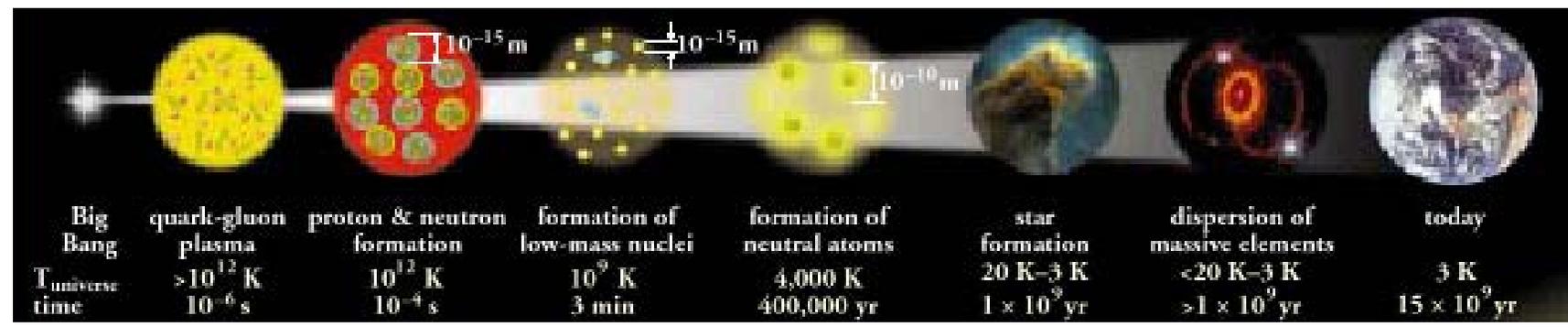


Journées 2002 de la Division Physique
Nucléaire de la SFP

Plasma de quarks et de gluons

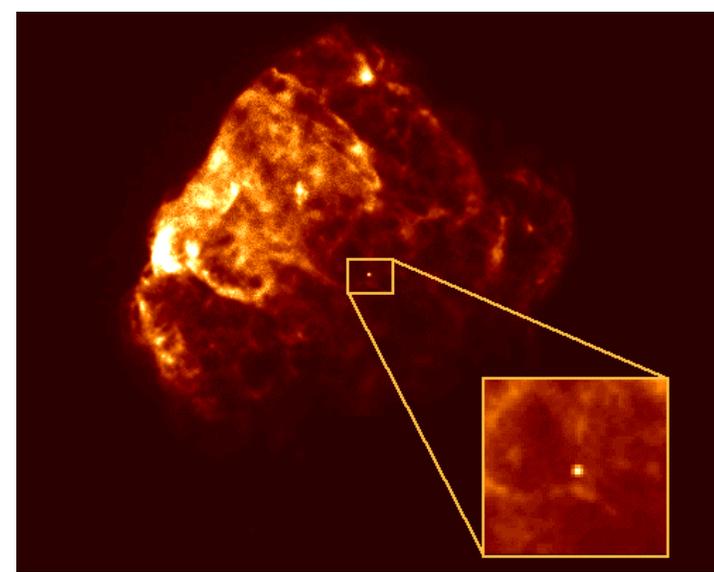
- Big Bang

- haute température (10^{12} K) \rightarrow grande densité d'énergie
- 10^{-6} s. : Plasma \rightarrow matière confinée



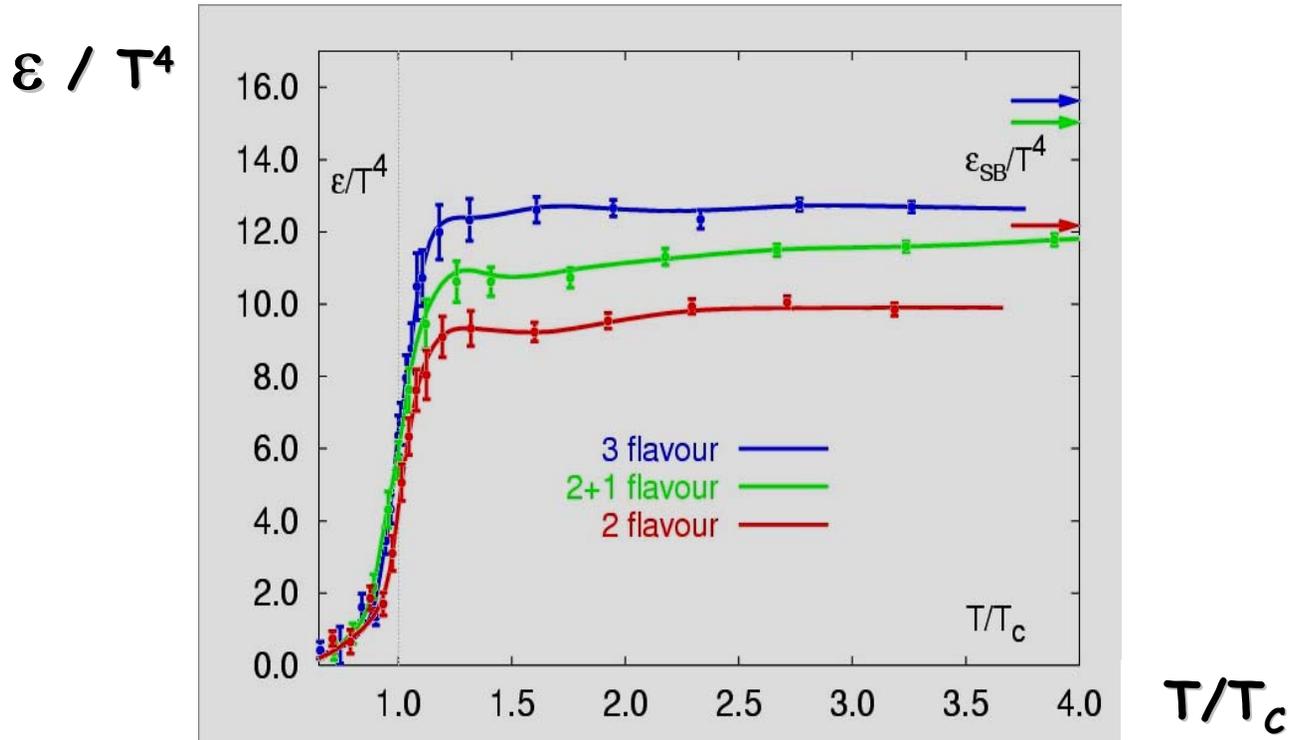
- Etoiles à neutrons

- effondrement d'étoile
- forte densité de matière
(5 à 10 fois la densité nucléaire classique)
- matière confinée \rightarrow plasma

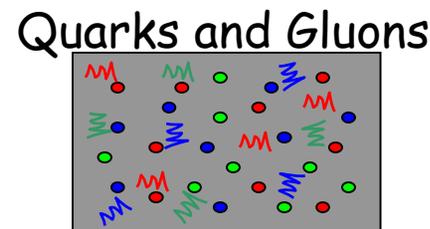
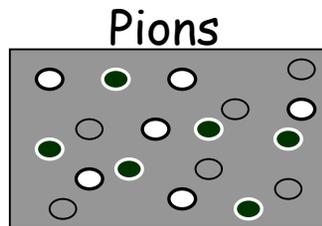


PQG : transition de phase

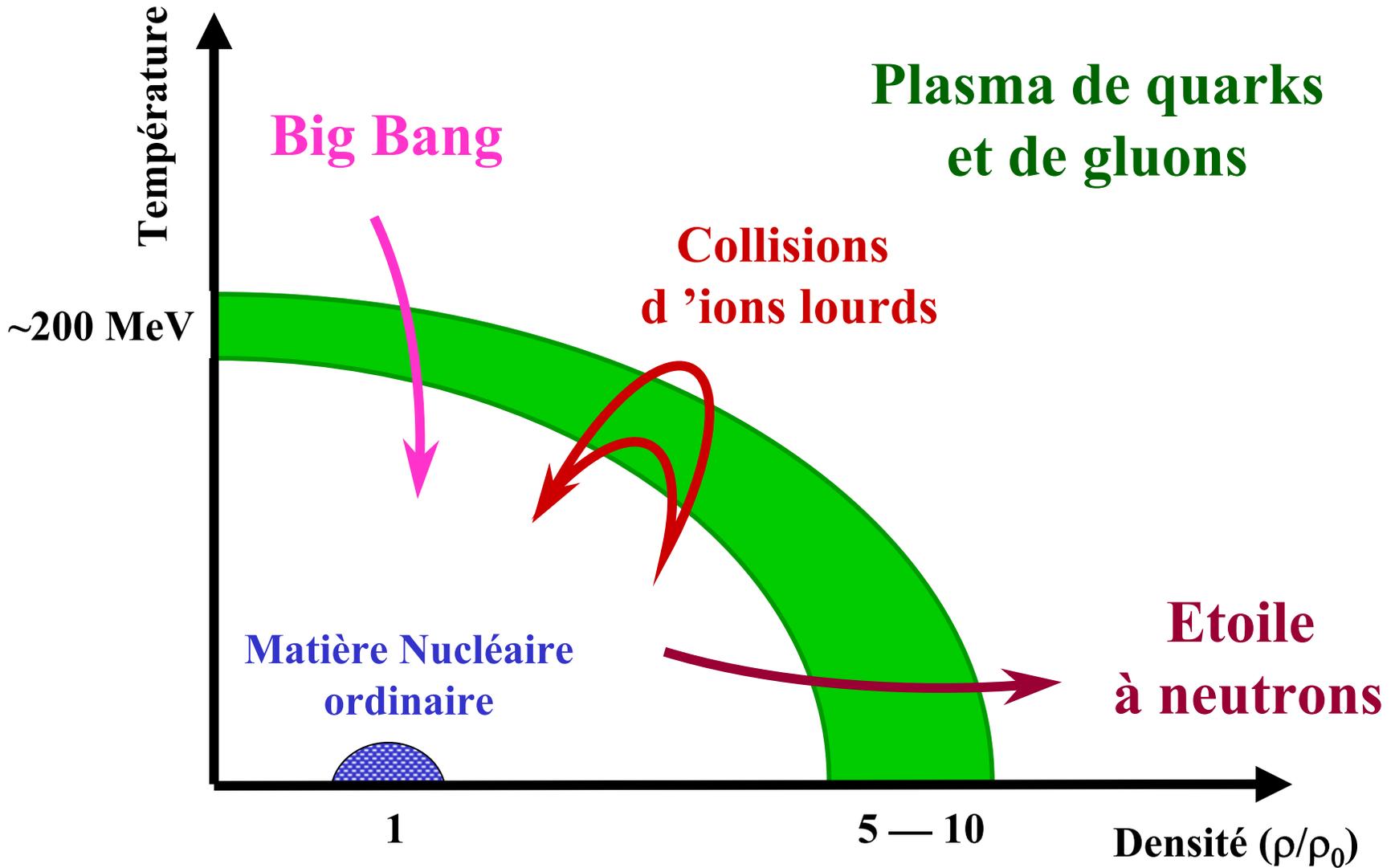
- QCD sur réseau



$N_{d.o.f} = 3$ \longrightarrow $N_{d.o.f} = 37$ (2-flavor)



PQG : diagramme de phase

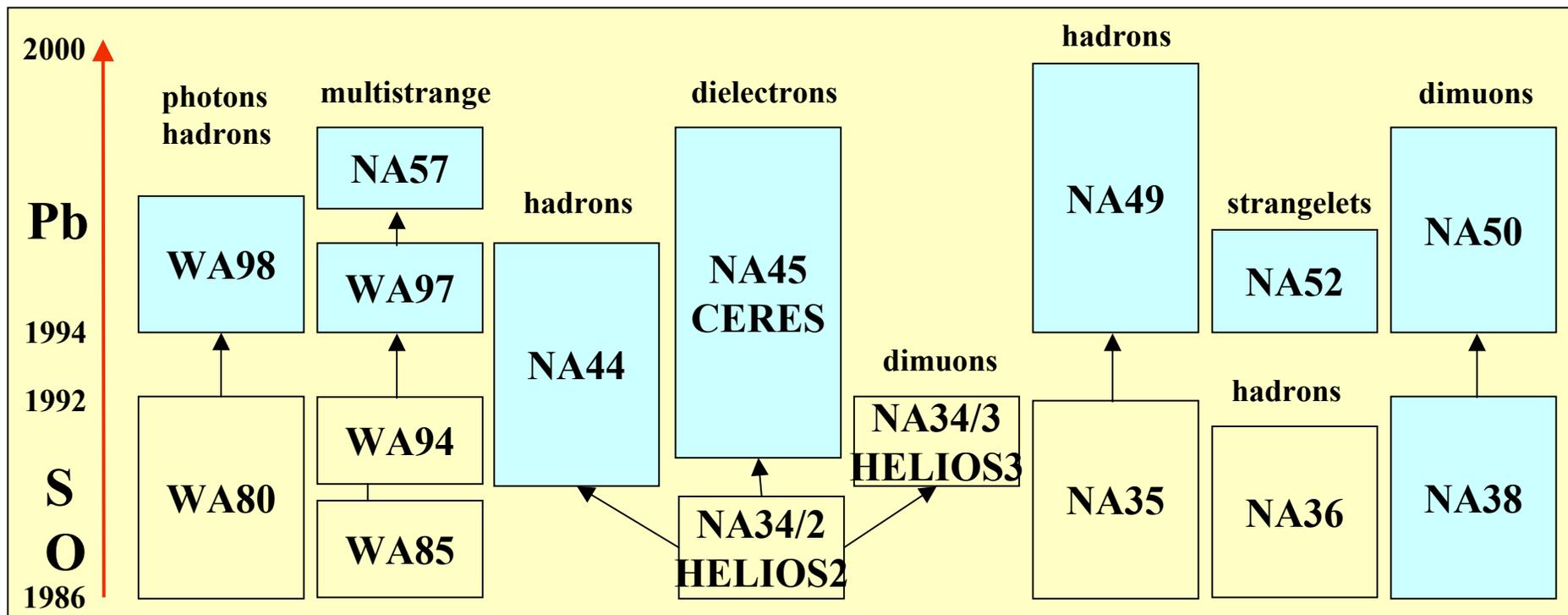


PQG : collisions d'ions lourds

- 15 ans de recherche au CERN

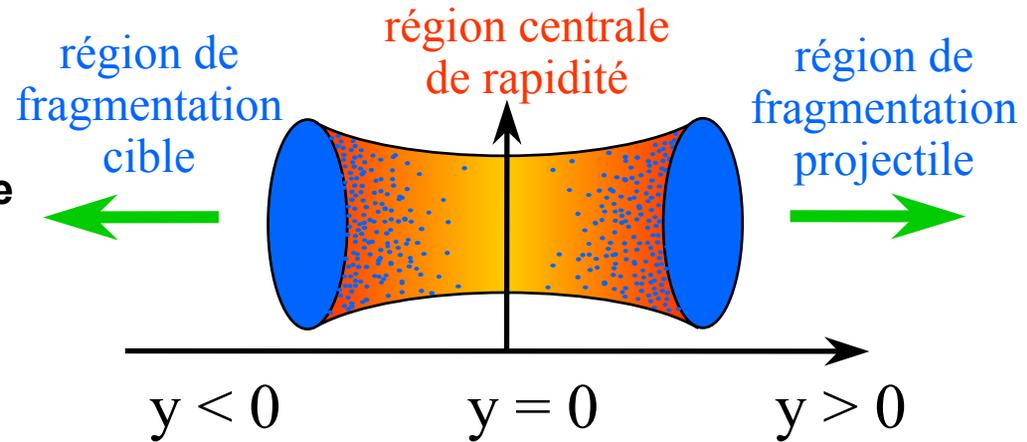
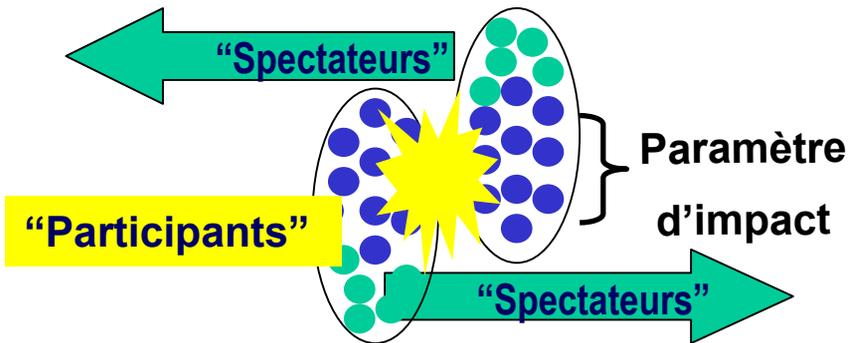
- 1986 - 1987 : Oxygène @ 60 & 200 GeV/nucléon
- 1987 - 1992 : Soufre @ 200 GeV/nucléon
- 1994 - 2000 : Plomb @ 40, 80 & 158 GeV/nucléon

+ pp et pA
pour des études
de référence

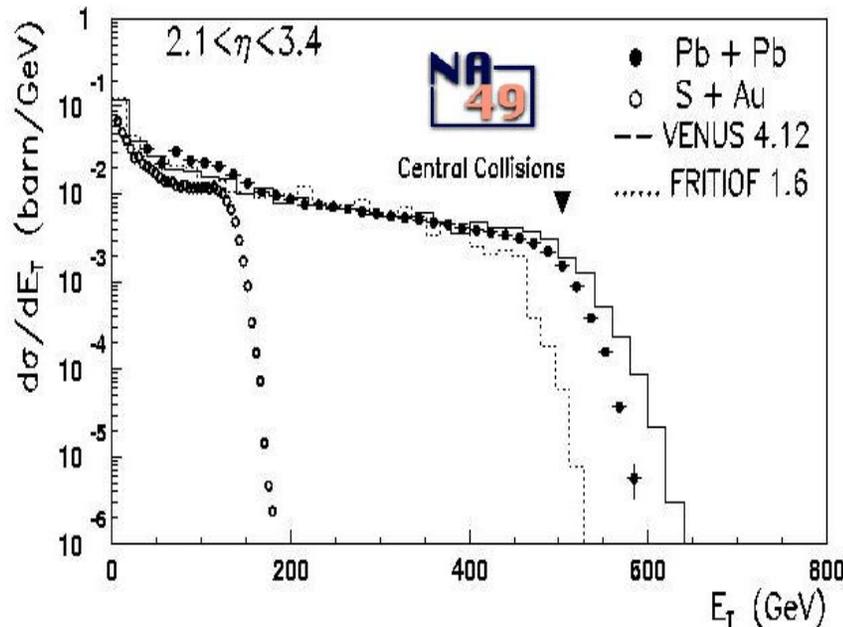


PQG : collisions d'ions lourds

- Collisions



- Densité d'énergie



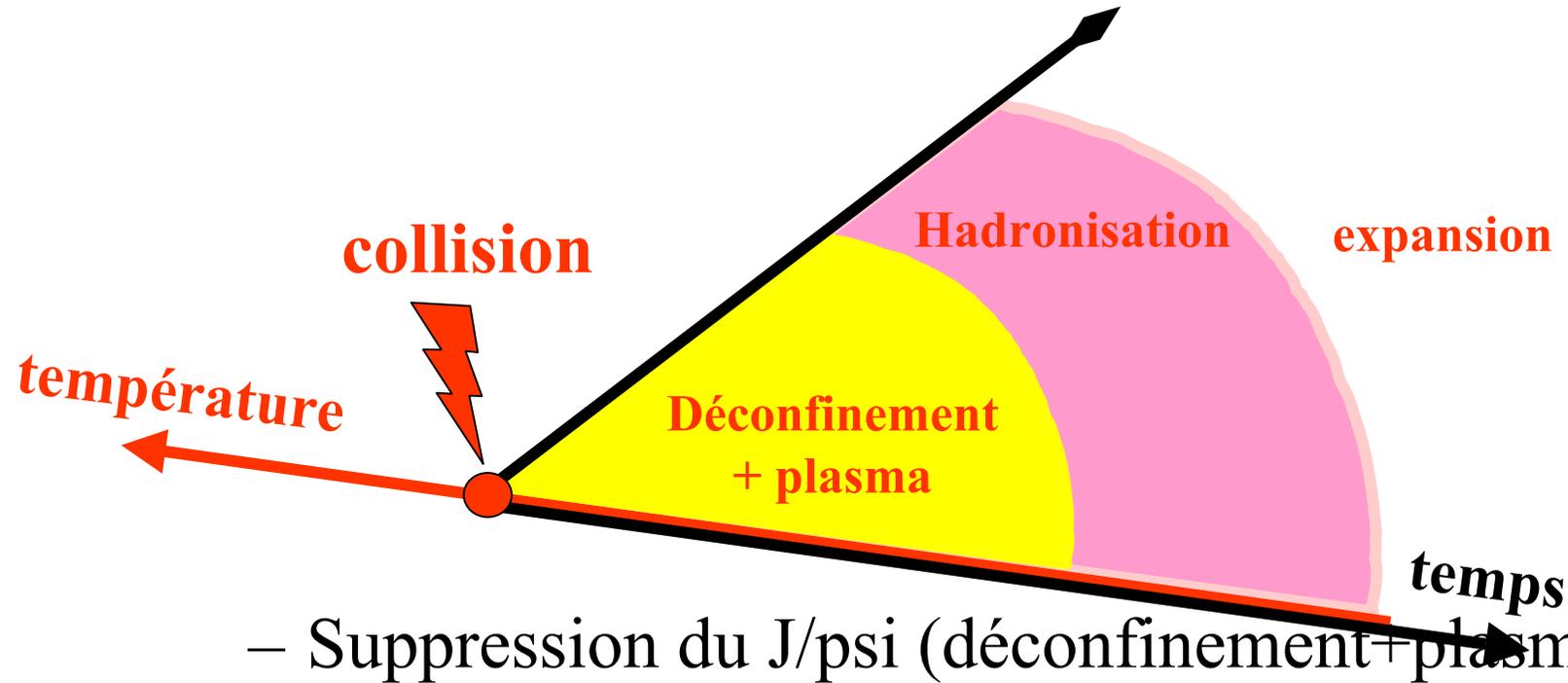
Formule de Bjorken :

$$\varepsilon = \frac{dE_T}{dy} \Bigg|_{y=0} \frac{1}{S_{\perp} \tau}$$

$\varepsilon \approx 3 \text{ GeV/fm}^3$

PQG : Le « Petit Bang »

- Quelques résultats du CERN - SPS

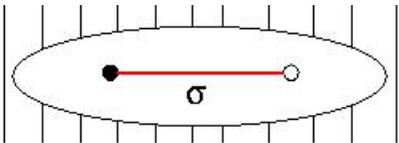


- Suppression du J/ψ (déconfinement+plasma)
- Augmentation d'étrangeté (plasma)
- photons directs et di-leptons (plasma)
- gel chimique (hadronisation)
- gel thermique (expansion)

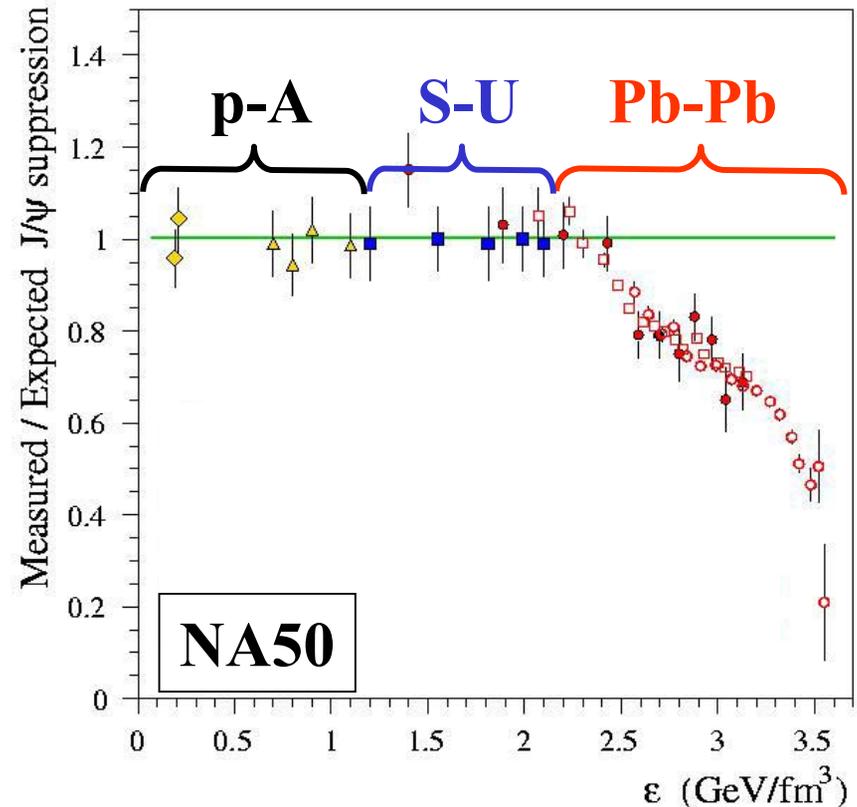
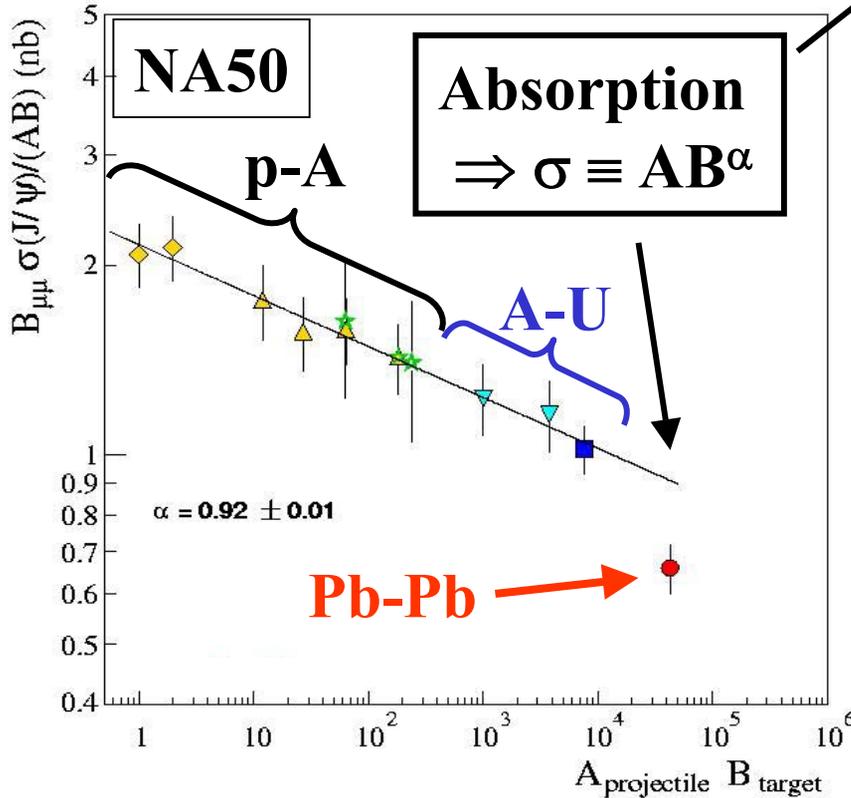
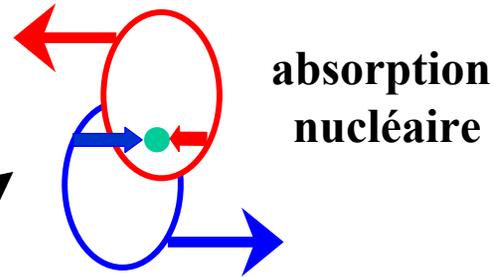
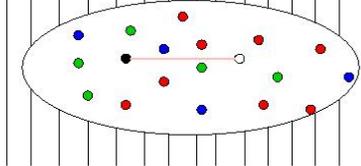
Petit Bang : signatures du PQG

- Plasma \rightarrow écrantage de couleur \rightarrow suppression du J/Ψ

quarkonium



écrantage



Petit Bang : signatures du PQG

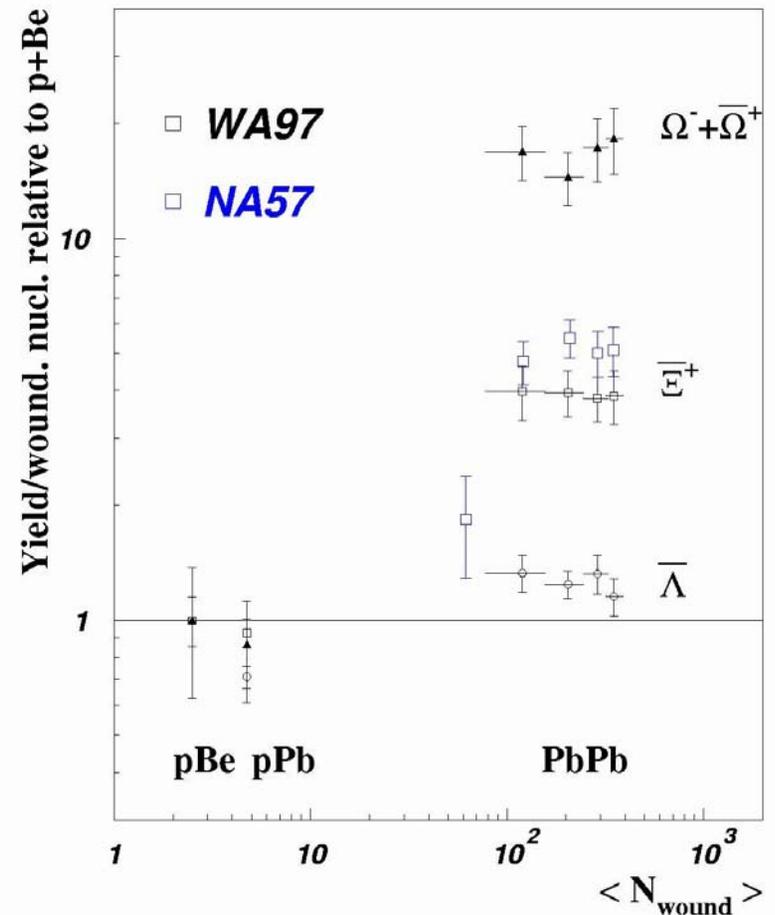
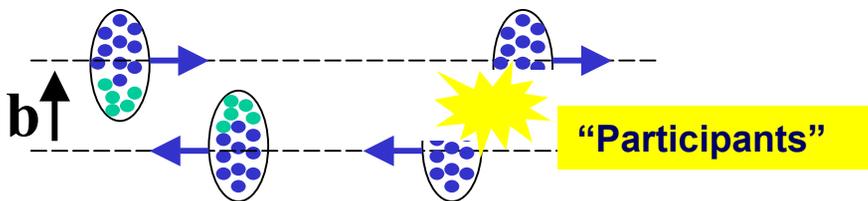
- Augmentation anormale d'étrangeté
 - plasma → augmentation de la production de particules étranges

$$\Omega (sss) > \Xi (dss) > \Lambda(uds)$$

$$\Rightarrow \Lambda(uds) \rightarrow \times 1,5$$

$$\Rightarrow \Xi (dss) \rightarrow \times 5$$

$$\Rightarrow \Omega (sss) \rightarrow \times 17$$



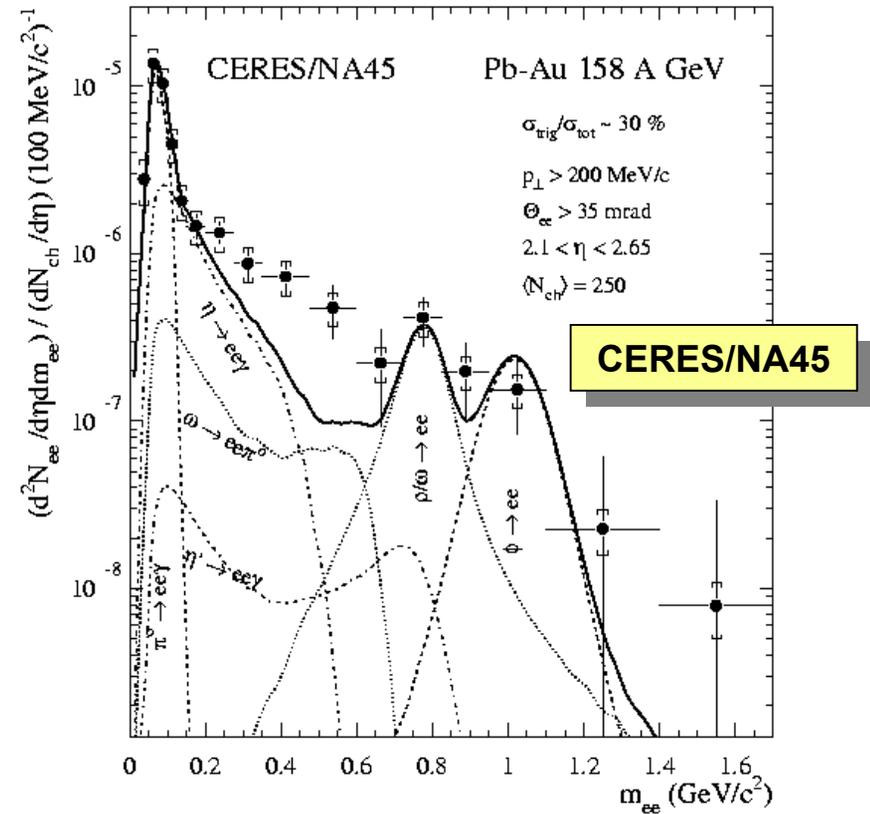
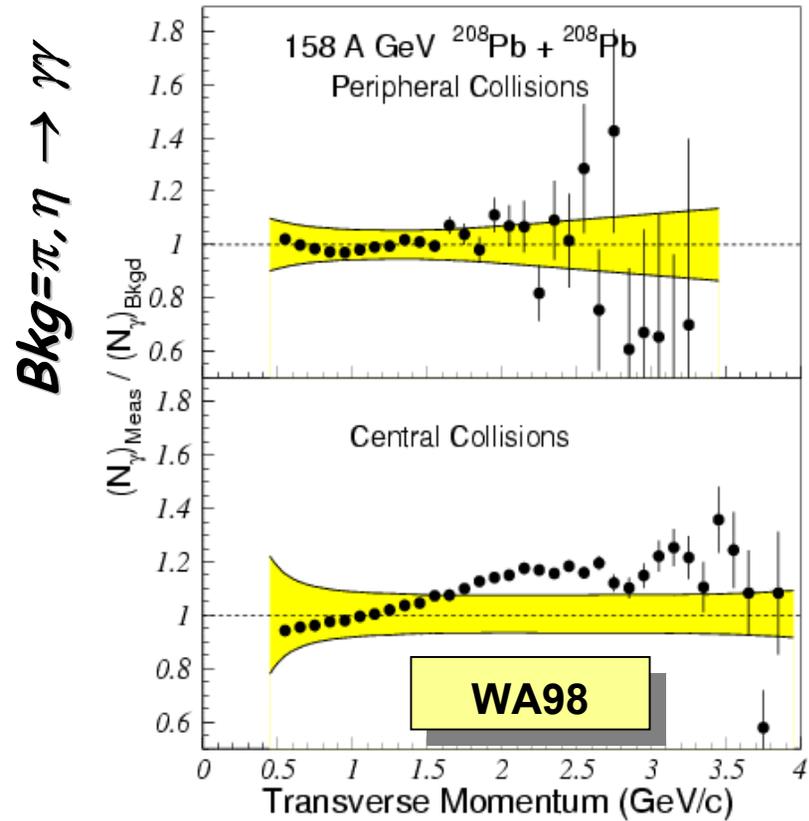
Petit bang : signatures du PQG

- photons direct

- di-électrons

Plasma → augmentation de la production de photons directs à grand PT

plasma → augmentation de la production de di-leptons.



- compatible avec modèle hydro ($T \sim 330 \text{ MeV}$)
- données p-A correctement reproduites

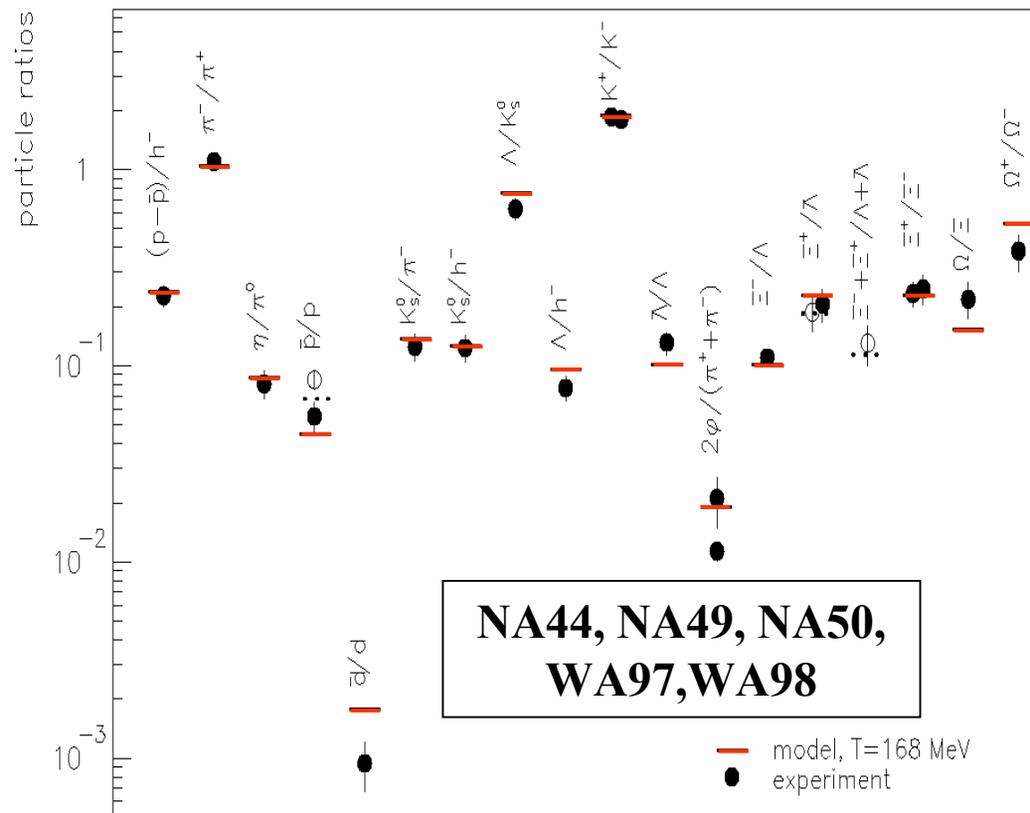
Petit Bang : gel chimique

- Abondances

density of the particles of species i in an equilibrated fireball:

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

with particle density n_i , spin degeneracy g_i , $\hbar = c = 1$, momentum p , total energy E and chemical potential $\mu_i = \mu_B B_i - \mu_S S_i - \mu_{I_3} I_i^3$.



- Des modèles thermiques reproduisent les abondances mesurées

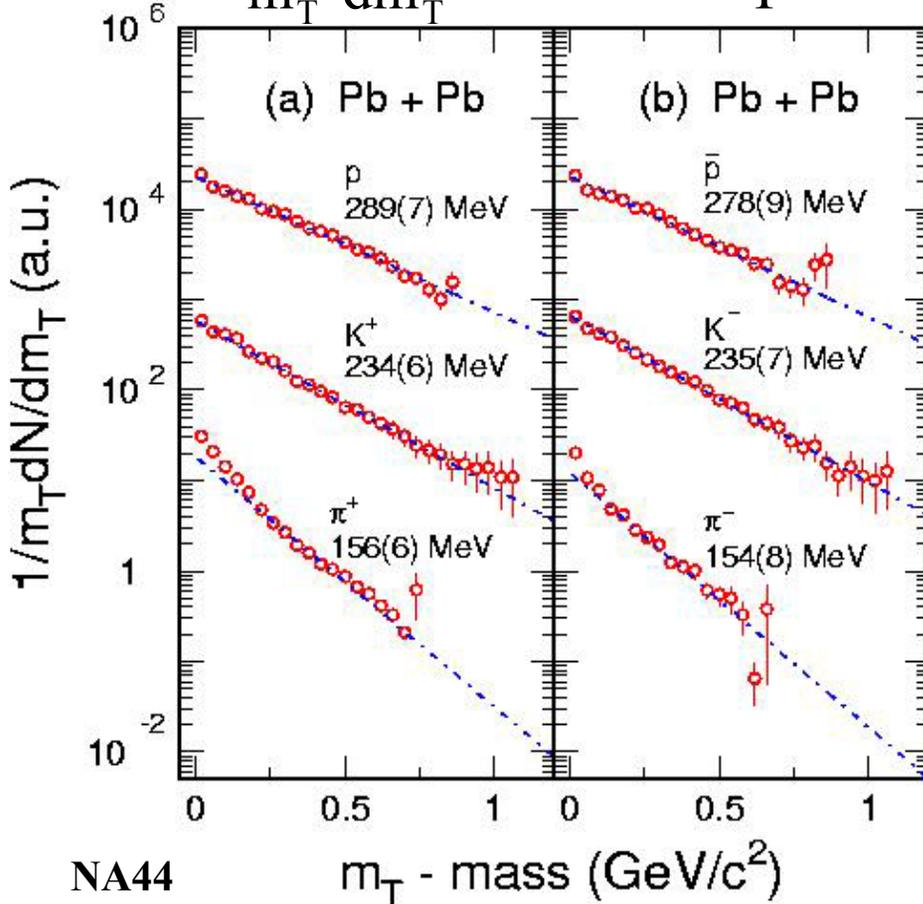
← T ≈ 170 MeV

P. Braun-Munzinger et al.

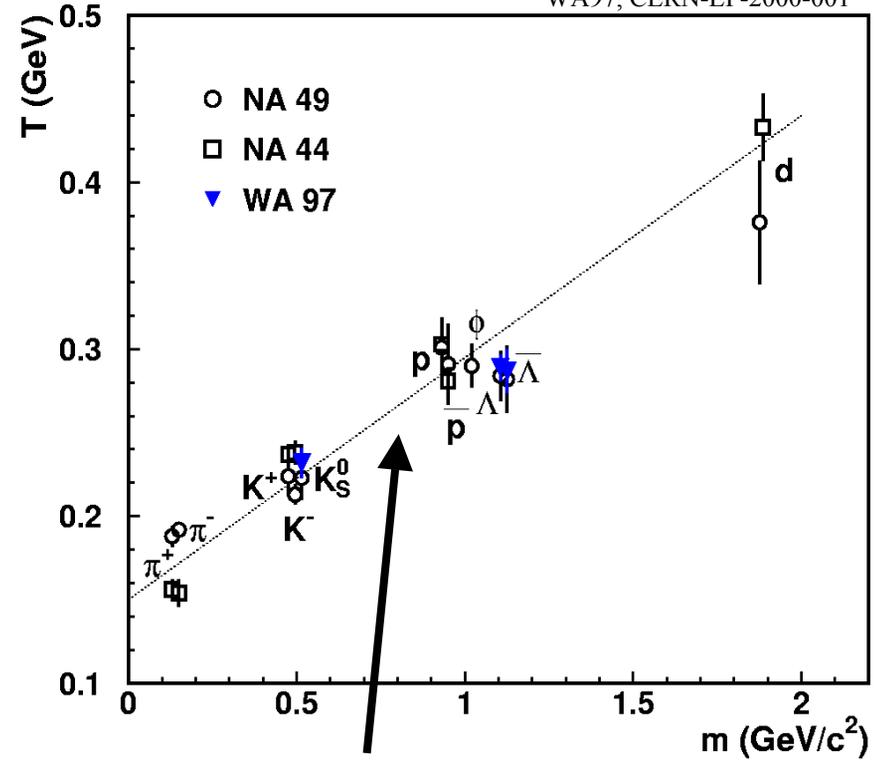
Petit Bang : gel thermique

- Spectre des particules

$$\frac{1}{m_T} \frac{dN}{dm_T} = A \exp\left(-\frac{m_T}{T}\right)$$



WA97, CERN-EP-2000-001



$$T = T_{\text{gel}} + \frac{1}{2} m \langle V_{\perp} \rangle^2$$

← équilibre thermique ← mouvement collectif

$T_{\text{gel}} \sim 140 \text{ MeV}$
 $\langle V_{\perp} \rangle \sim 0,4 c$

Petit Bang : bilan

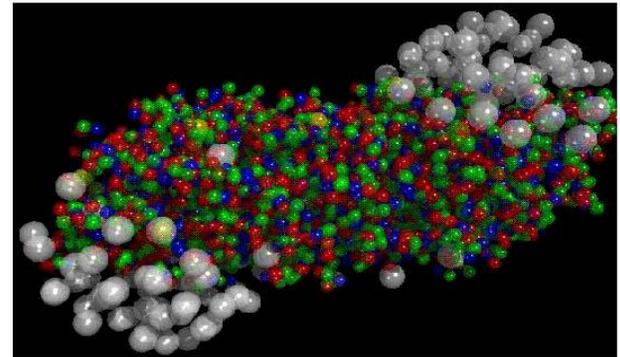
- La vision globale



Organisation Européenne pour la Recherche Nucléaire
European Organization for Nuclear research
Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics
Europäisches Laboratorium für Teilchenphysik
Laboratorio europeo per la fisica delle particelle

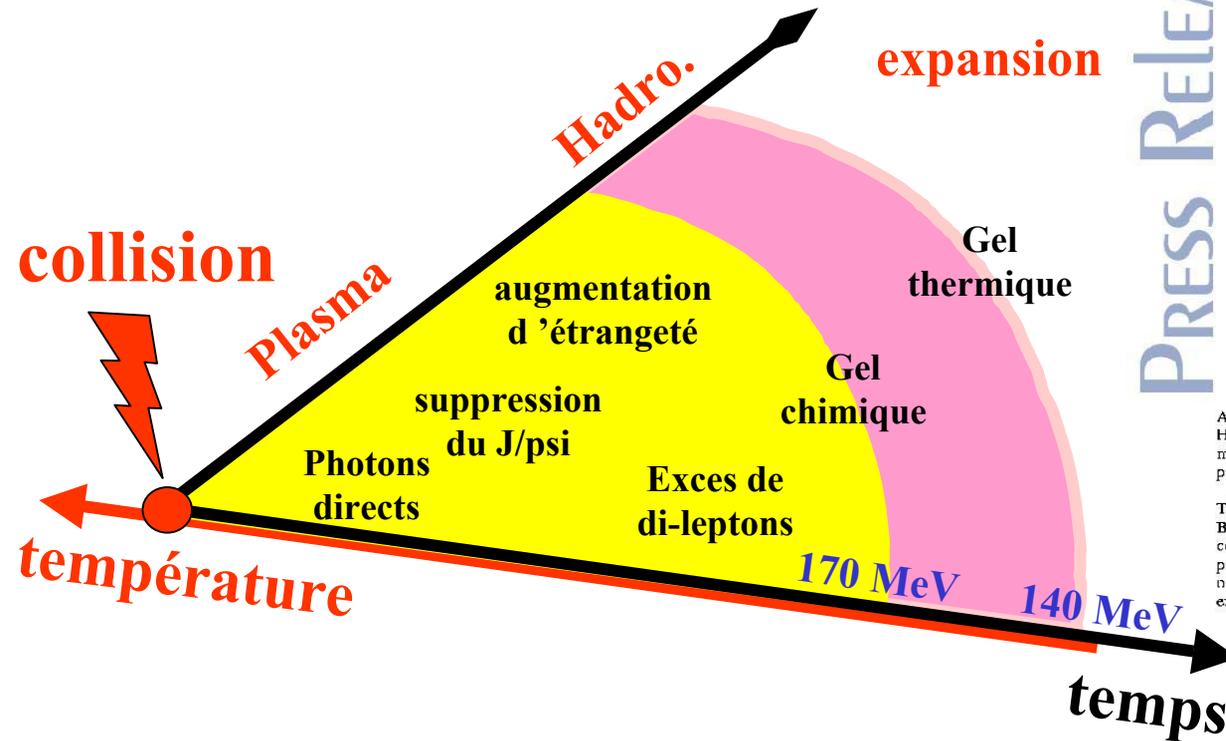
PRESS RELEASE

New State of Matter created at CERN



At a special seminar on 10 February, spokespersons from the experiments on CERN* 's Heavy Ion programme presented compelling evidence for the existence of a new state of matter in which quarks, instead of being bound up into more complex particles such as protons and neutrons, are liberated to roam freely.

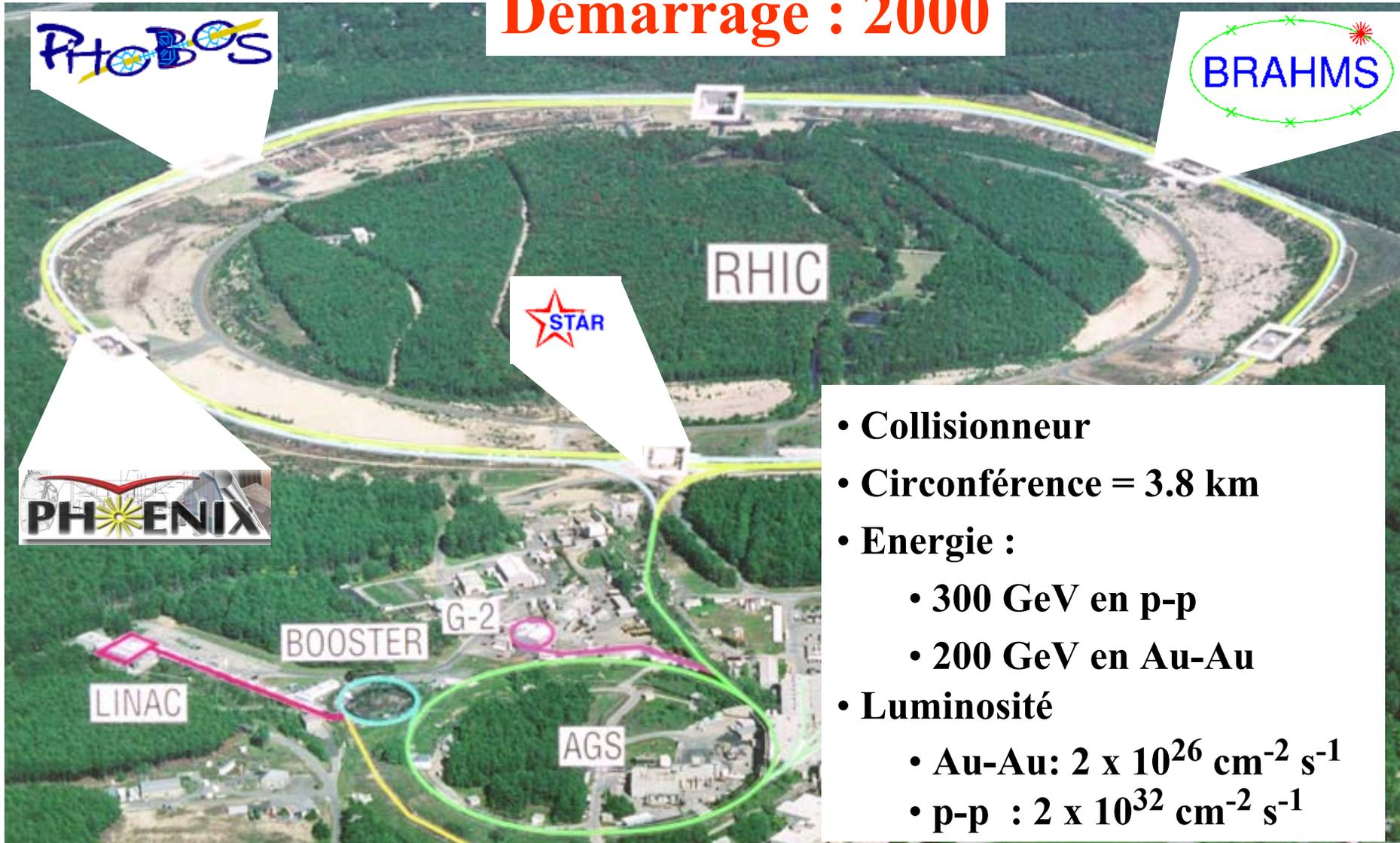
Theory predicts that this state must have existed at about 10 microseconds after the Big Bang, before the formation of matter as we know it today, but until now it had not been confirmed experimentally. Our understanding of how the universe was created, which was previously unverified theory for any point in time before the formation of ordinary atomic nuclei, about three minutes after the Big Bang, has with these results now been experimentally tested back to a point only a few microseconds after the Big Bang.



PQG à RHIC

- La machine

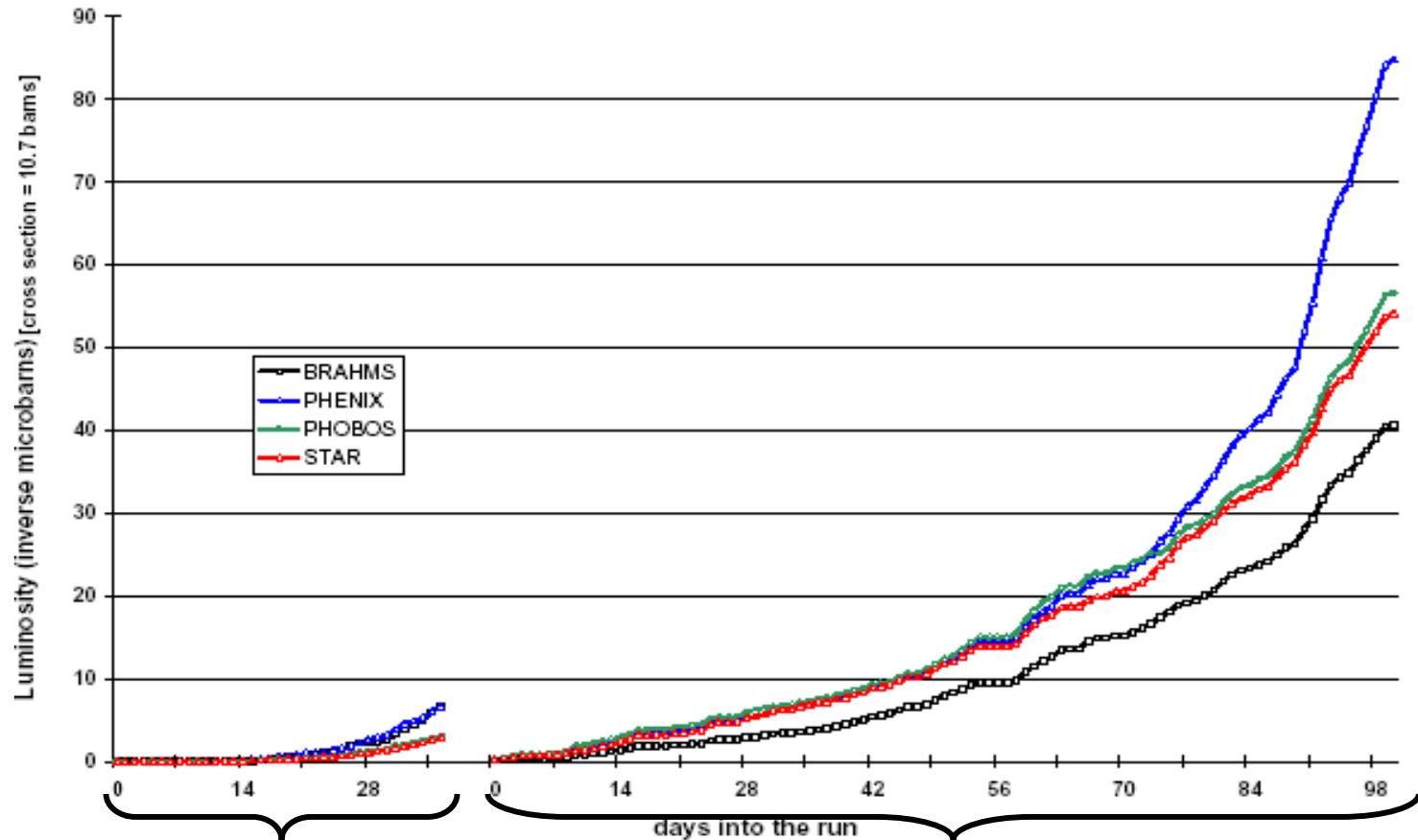
Démarrage : 2000



- Collisionneur
- Circonférence = 3.8 km
- Energie :
 - 300 GeV en p-p
 - 200 GeV en Au-Au
- Luminosité
 - Au-Au: $2 \times 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$
 - p-p : $2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

PQG à RHIC

RHIC Experiment Integrated Luminosity -- Gold Ion Operations
fy'00, & fy01-02



été 2000
5 semaines (130 GeV)

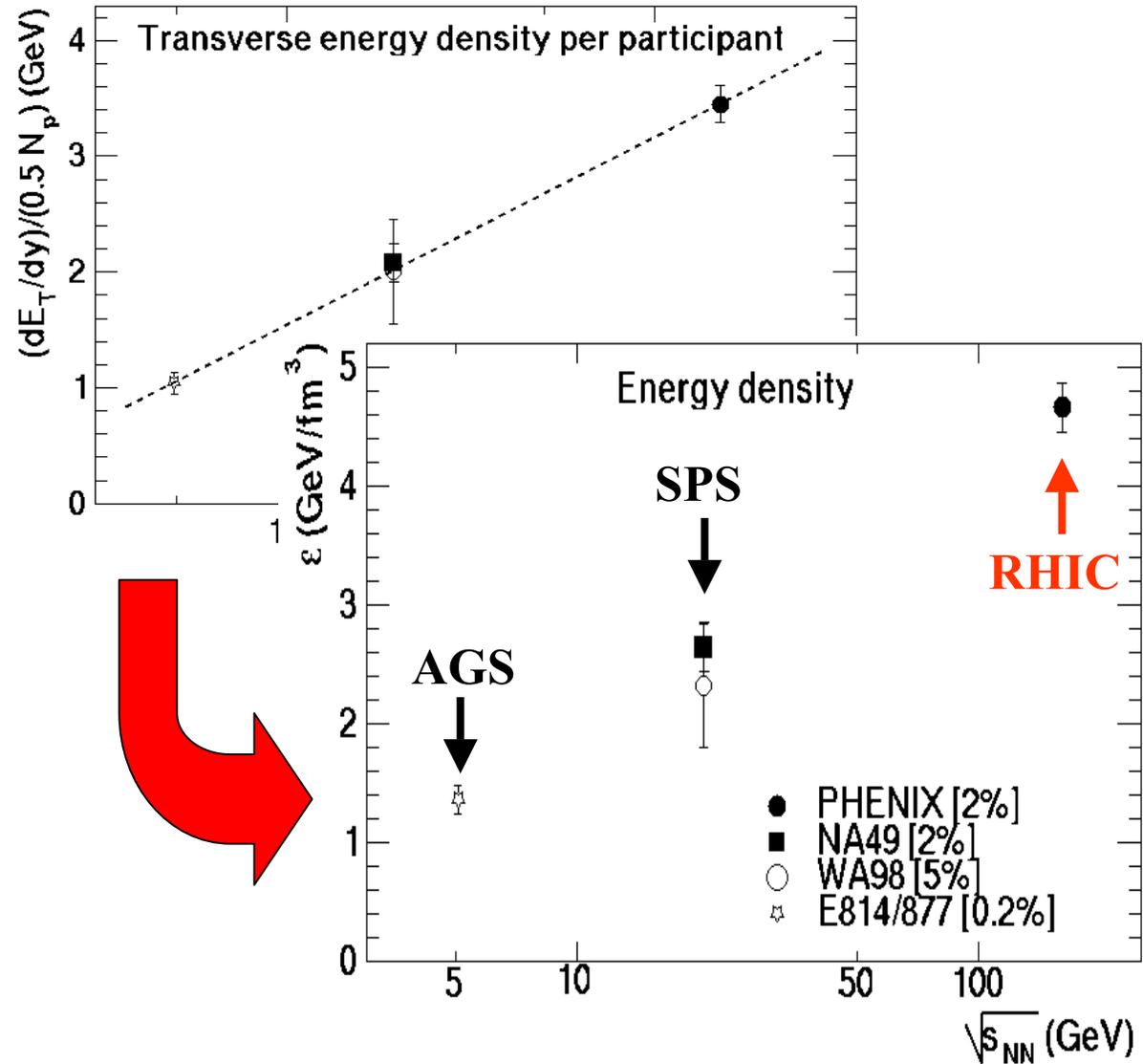
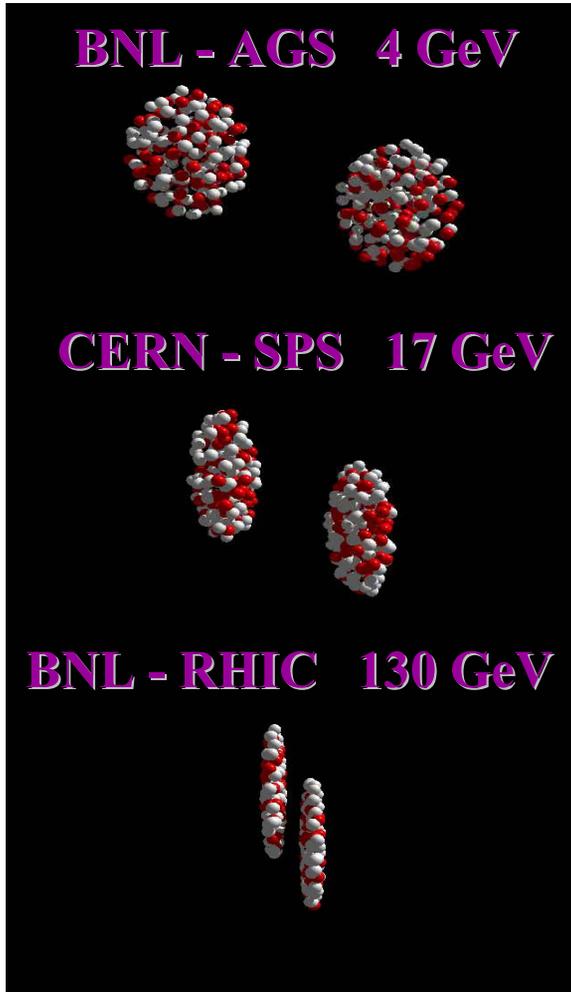


Premiers résultats

Sept. - Déc. 2001
15 semaines (200 GeV)

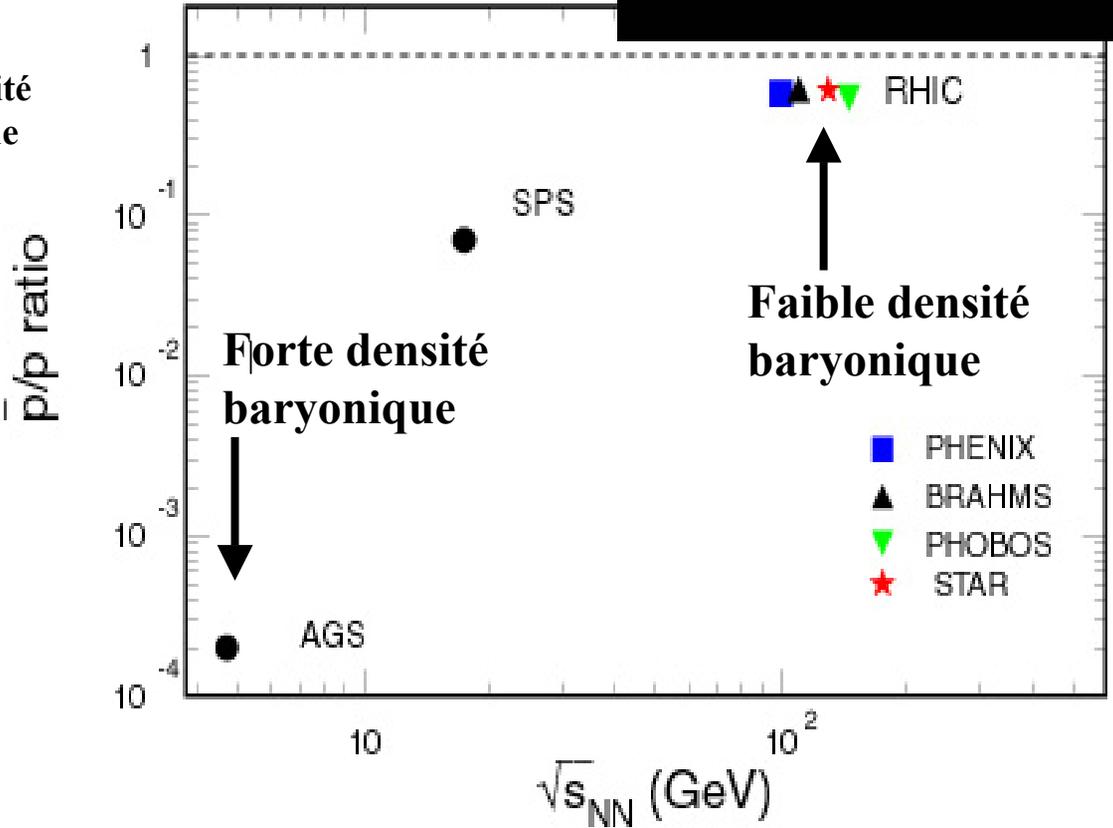
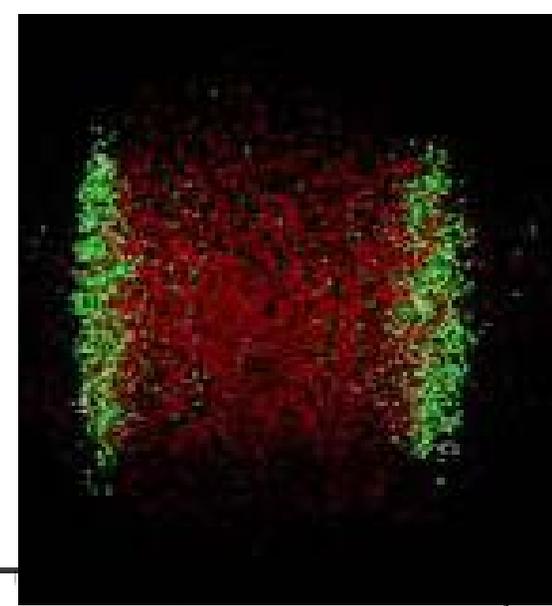
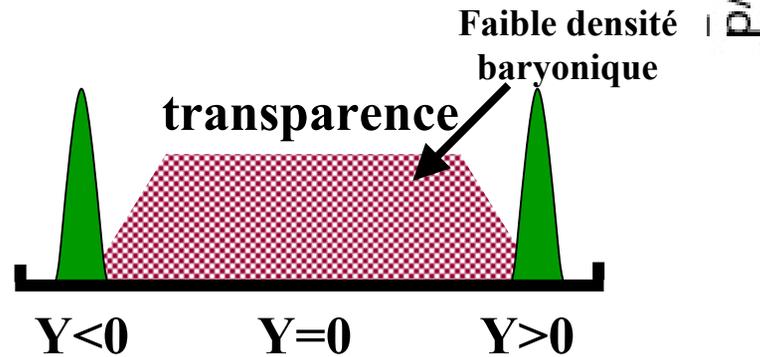
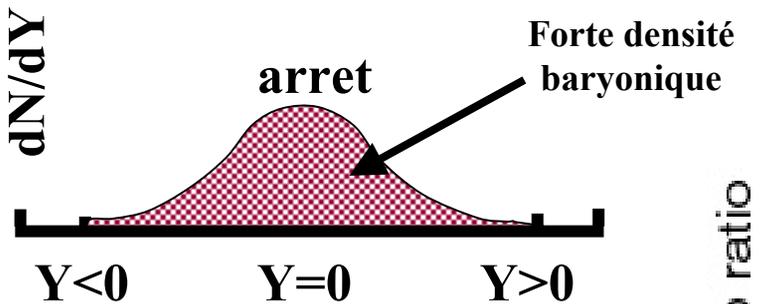
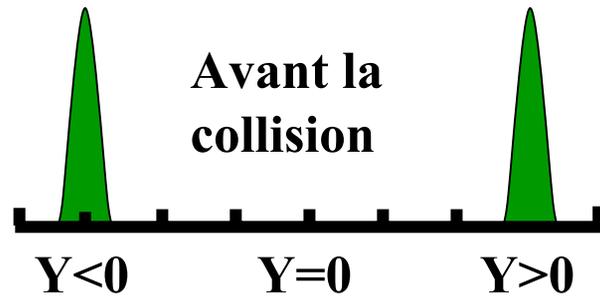
PQG à RHIC

- Premiers résultats : densité d'énergie



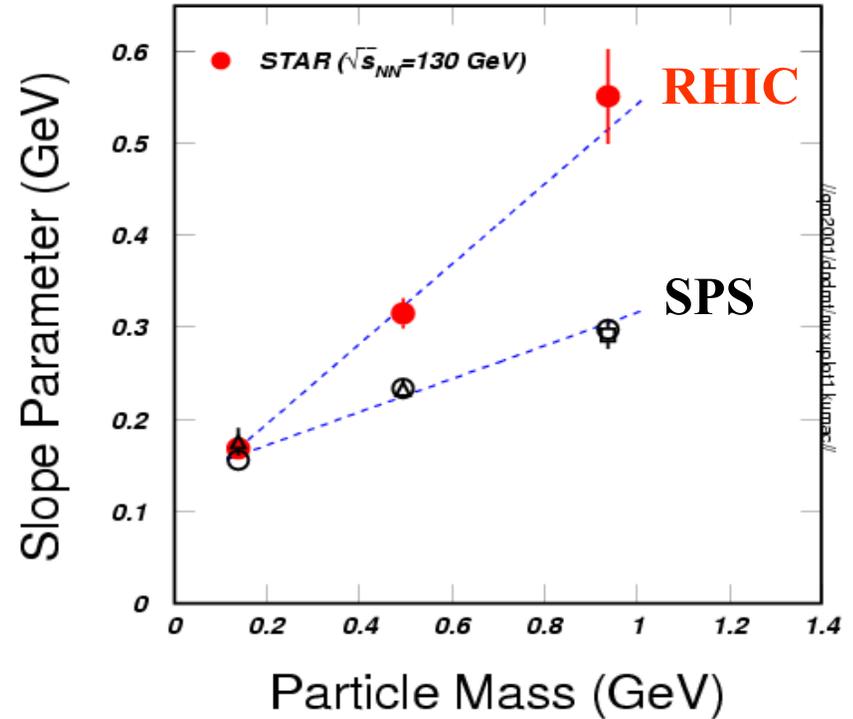
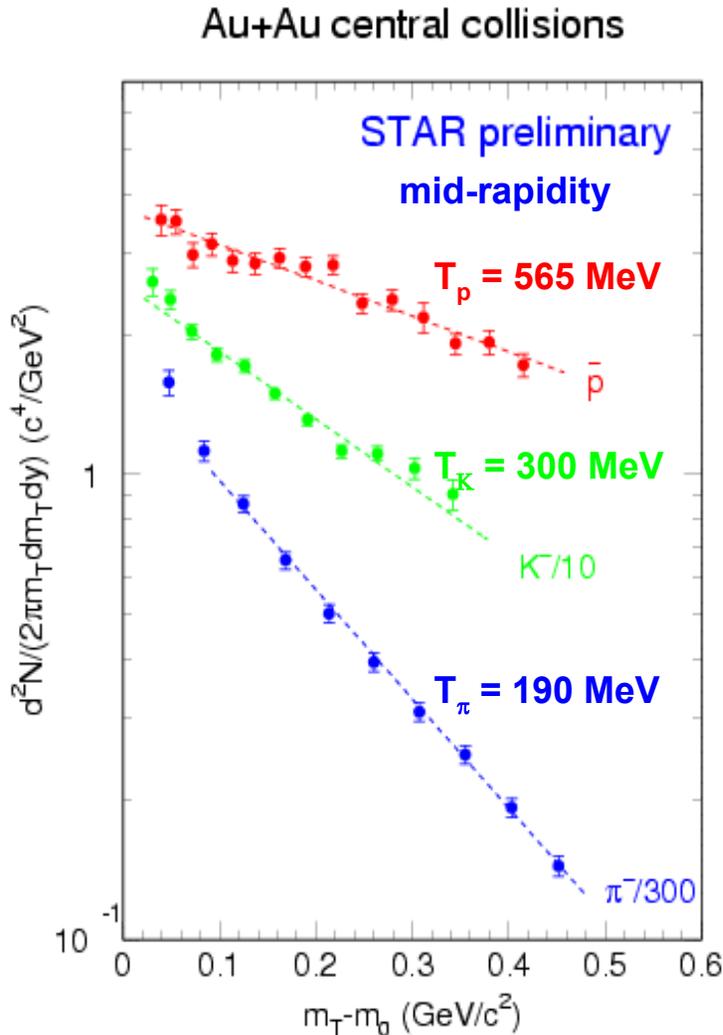
PQG à RHIC

- Premiers résultats : transparence



PQG à RHIC

- Premiers résultats : gel thermique
 - flot radial plus important à RHIC → plus forte pression



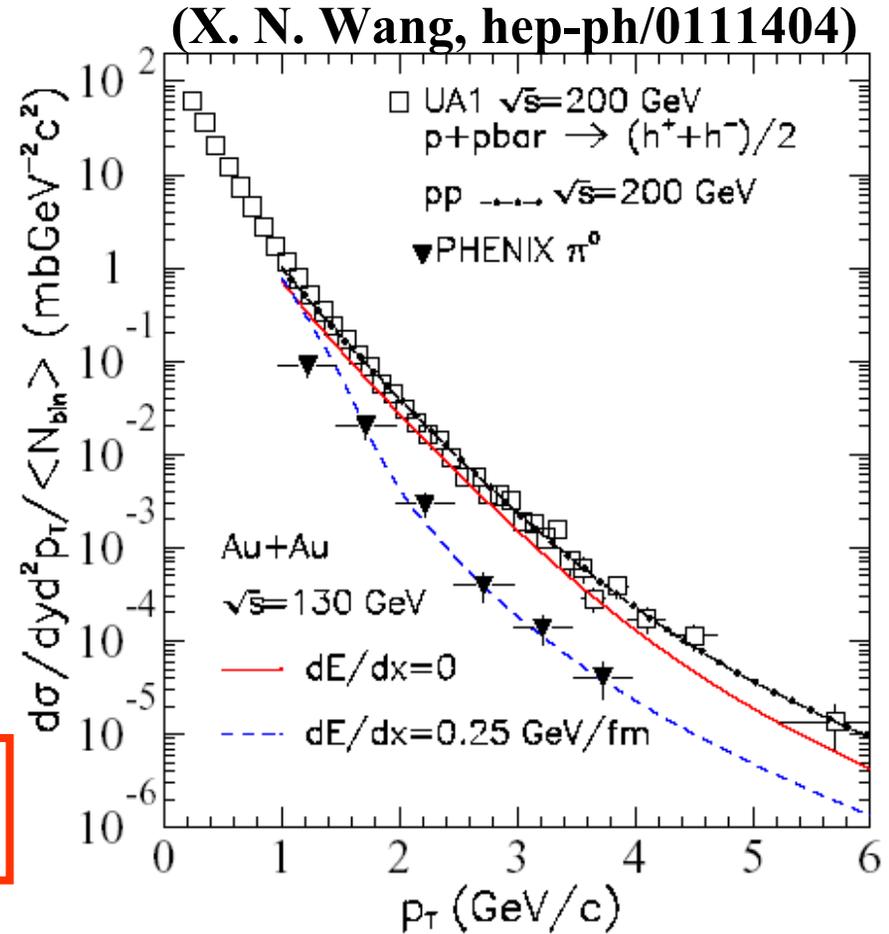
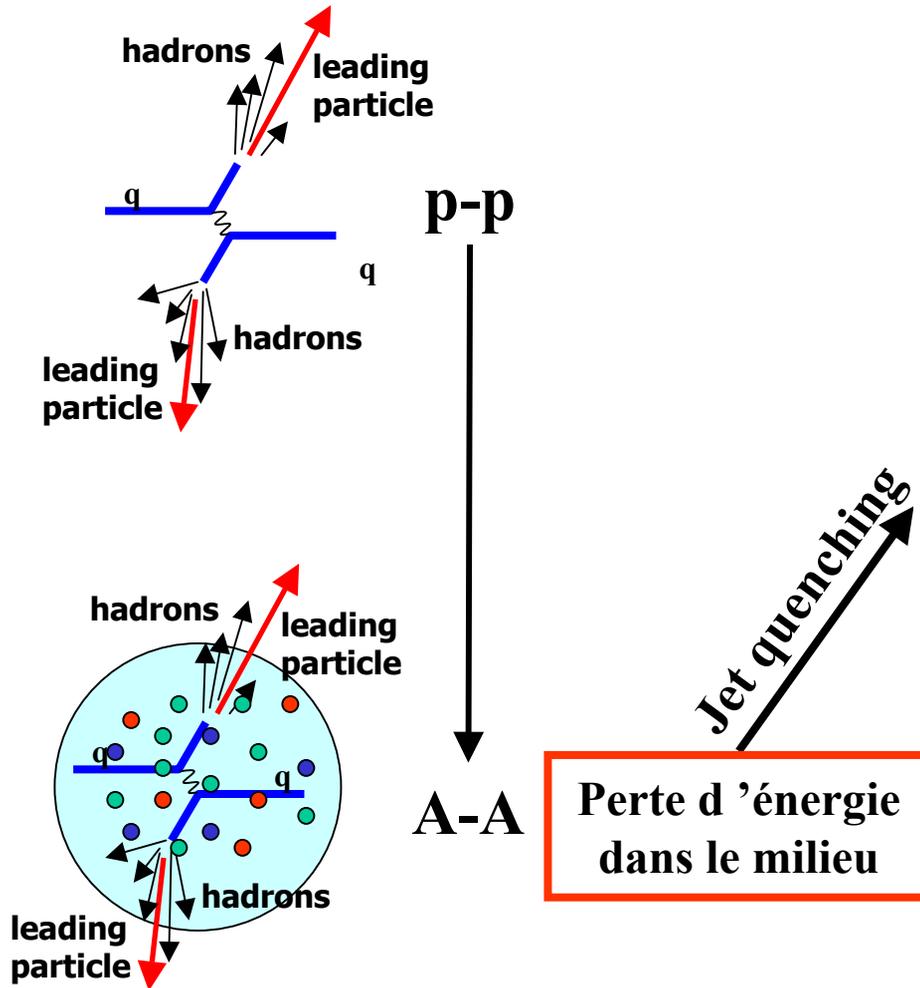
$$T = T_{\text{gel}} + \frac{1}{2} m \langle V_{\perp} \rangle^2$$

$$T_{\text{gel}} (\text{RHIC}) \sim 140 \text{ MeV} \quad \langle V_{\perp} \rangle (\text{RHIC}) \sim 0,52 c$$

$$T_{\text{gel}} (\text{SPS}) \sim 140 \text{ MeV} \quad \langle V_{\perp} \rangle (\text{SPS}) \sim 0,4 c$$

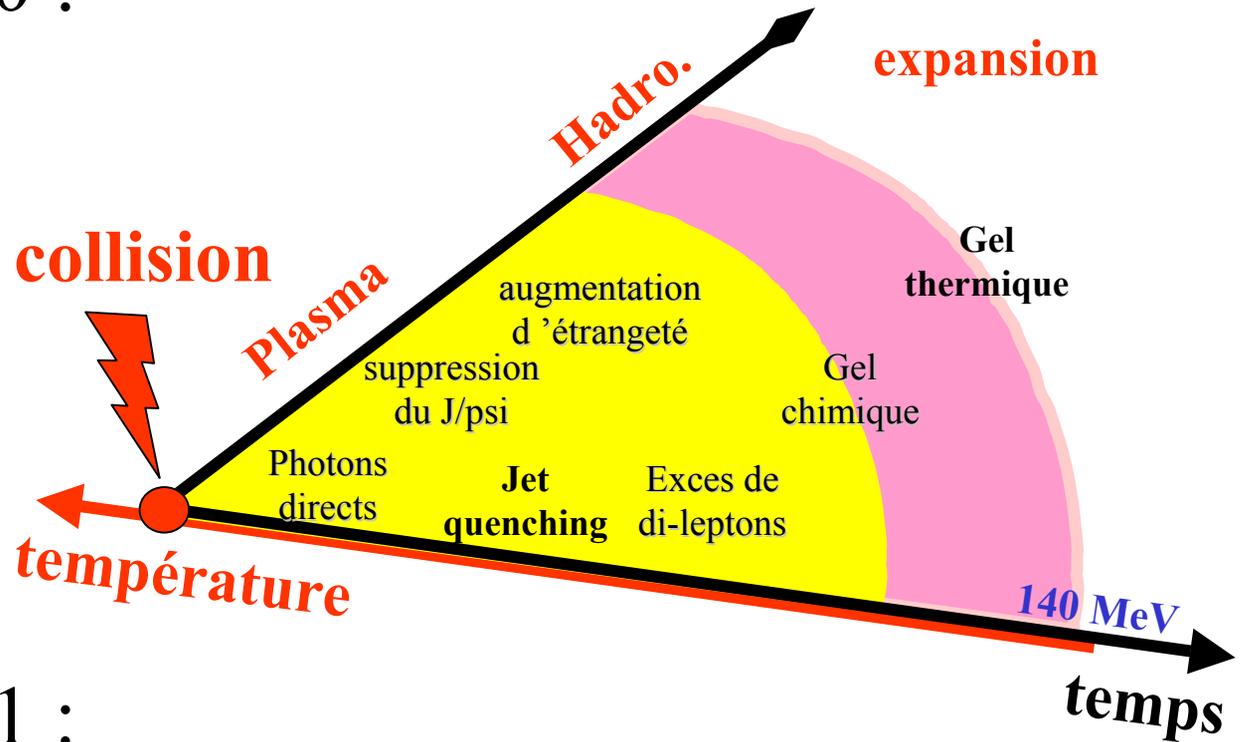
PQG à RHIC

- Premiers résultats : jet quenching



PQG à RHIC

- Données 2000 :



- Données 2001 :

- J/Ψ , étrangeté, photons directs, di-leptons
- premiers résultats → QM2002 : Nantes (18-24 juillet)

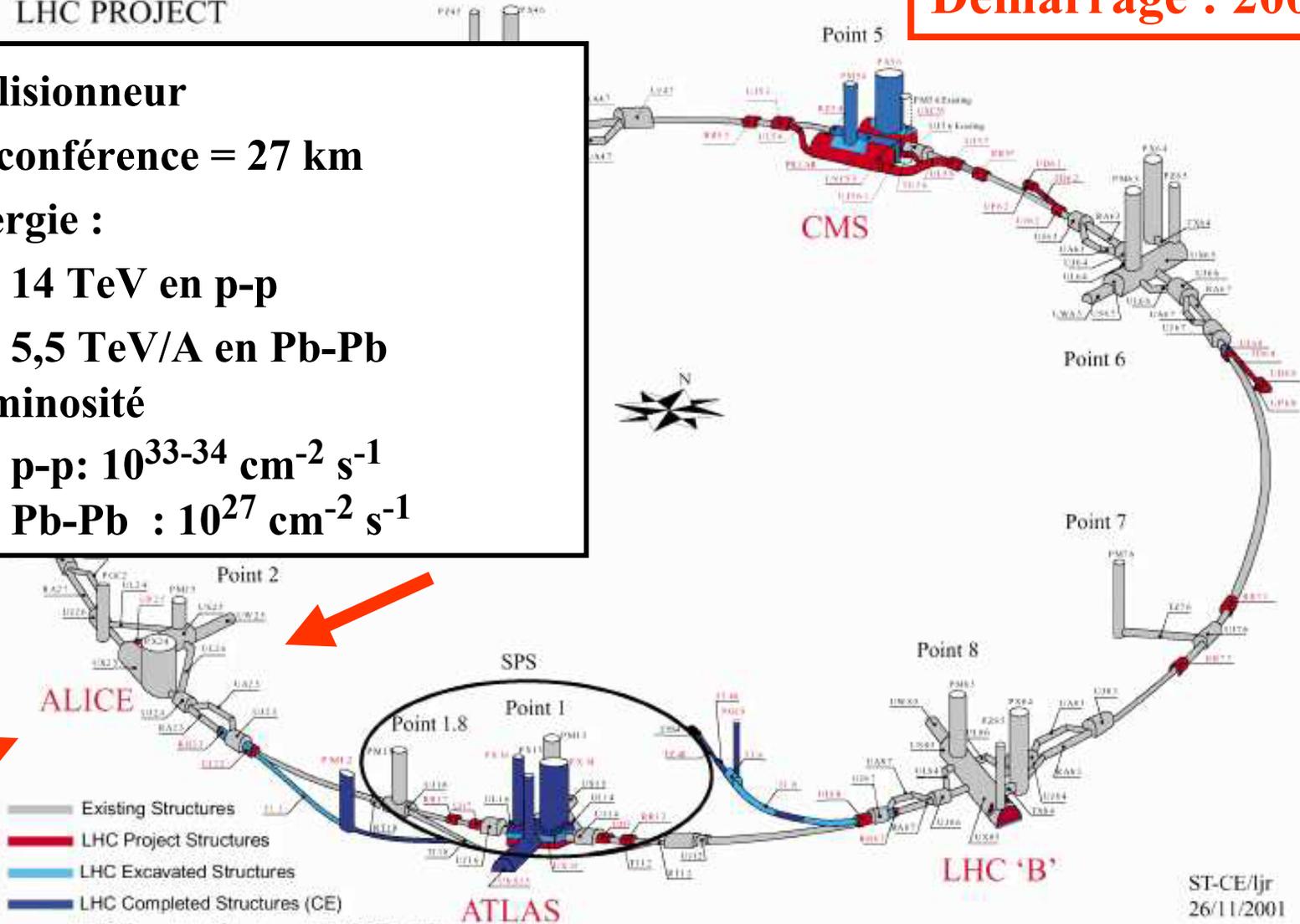
PQG au LHC

- La machine

Démarrage : 2007

- Collisionneur
- Circonférence = 27 km
- Energie :
 - 14 TeV en p-p
 - 5,5 TeV/A en Pb-Pb
- Luminosité
 - p-p: $10^{33-34} \text{ cm}^{-2} \text{ s}^{-1}$
 - Pb-Pb : $10^{27} \text{ cm}^{-2} \text{ s}^{-1}$

LHC PROJECT



ST-CE/ljr
26/11/2001

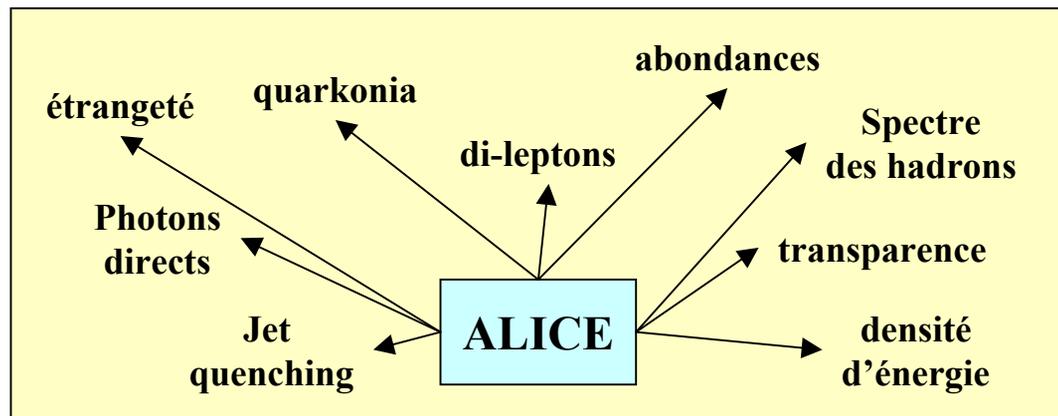
PQG au LHC

- LHC .vs. plasma

- plus dense
- plus grand
- plus longtemps

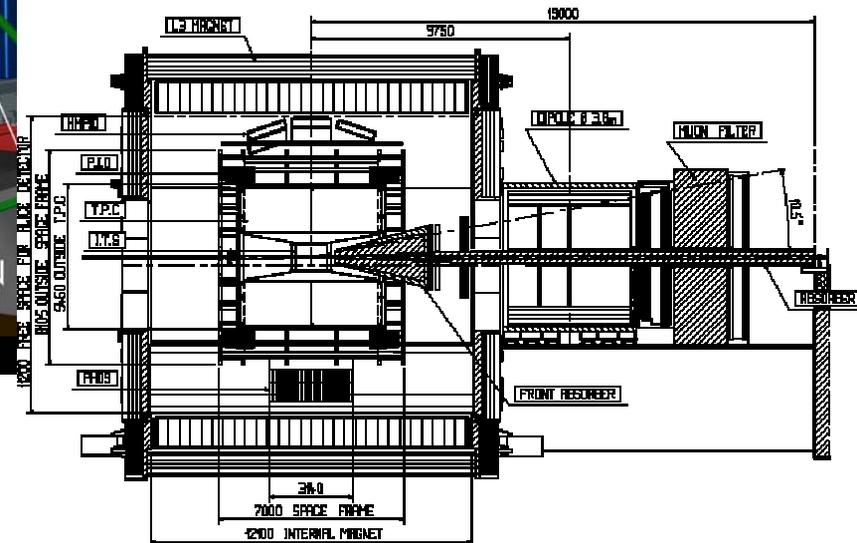
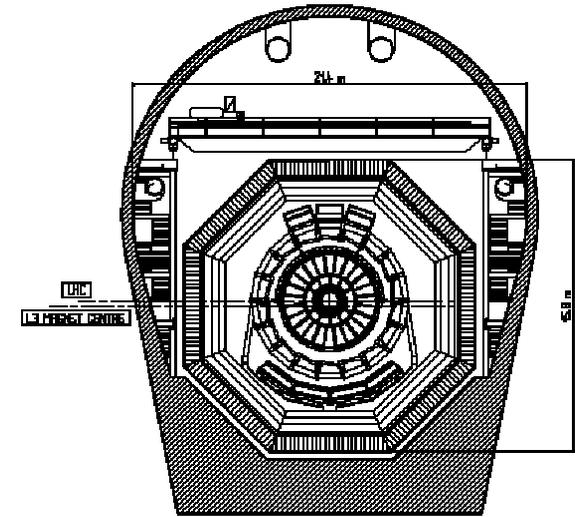
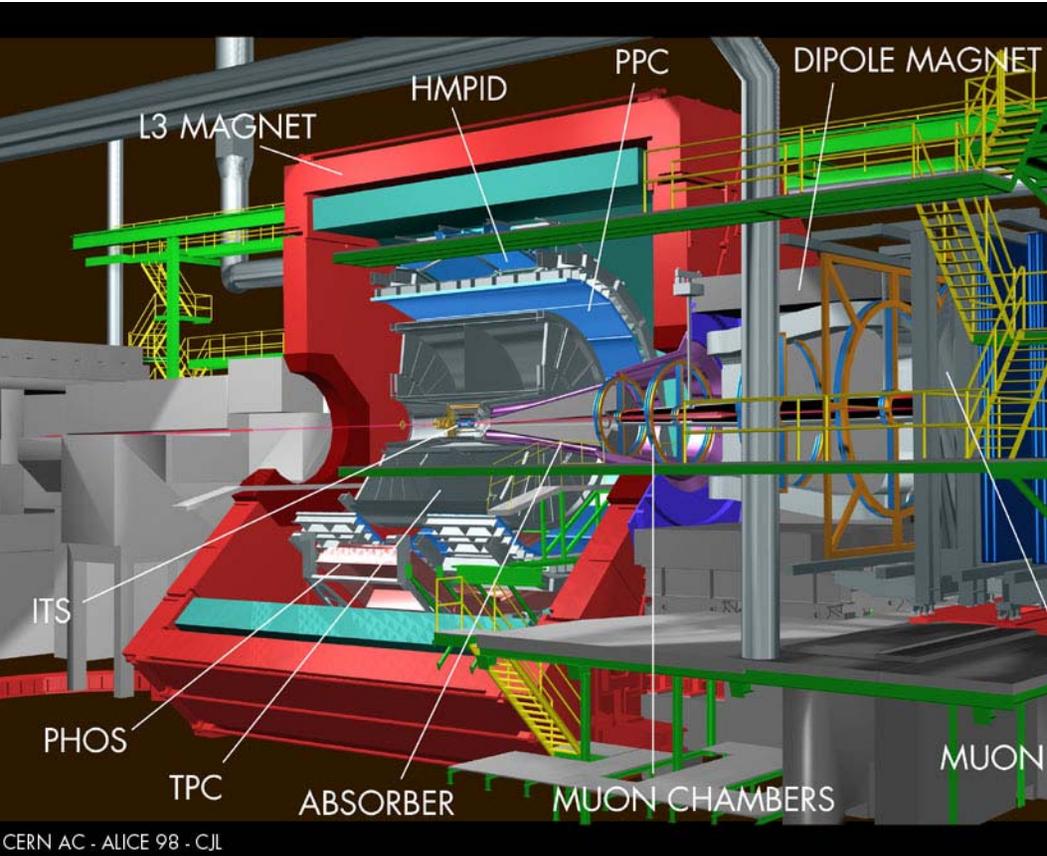
	SPS	RHIC	LHC
\sqrt{s} (GeV)	17	200	5500
DN_{ch}/dy	500	650	$3-8 \times 10^3$
ϵ (GeV/fm ³)	2.5	5	15-40
V_f (fm ³)	10^3	7×10^3	2×10^4
$\tau_{plas.}$ (fm/c)	<1	1.5-4	4-10

- physique du plasma



PQG au LHC

- L'expérience ALICE



Conclusion

- *CERN-SPS*

- 1986 → 2000
- collisions Pb-Pb à 17 GeV/A
- « un nouvel état de la matière créé au CERN »

- *BNL-RHIC*

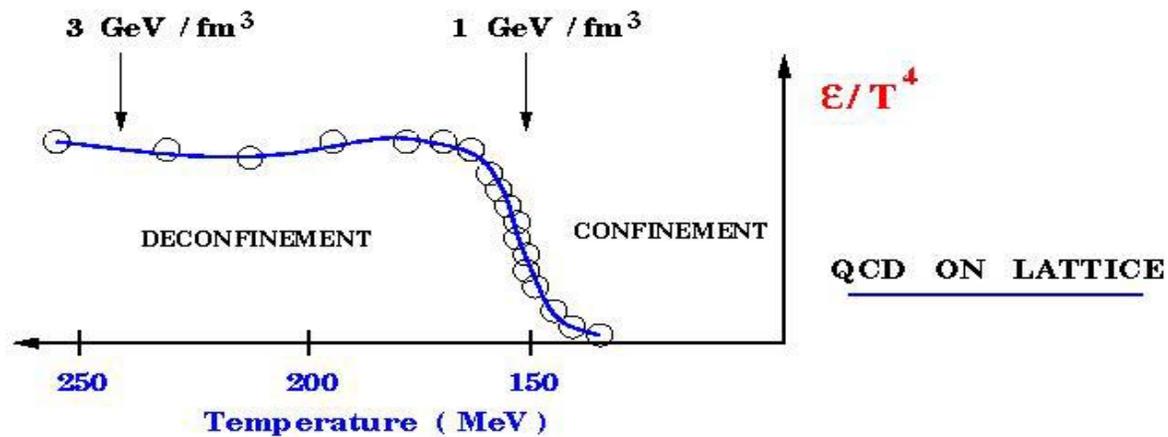
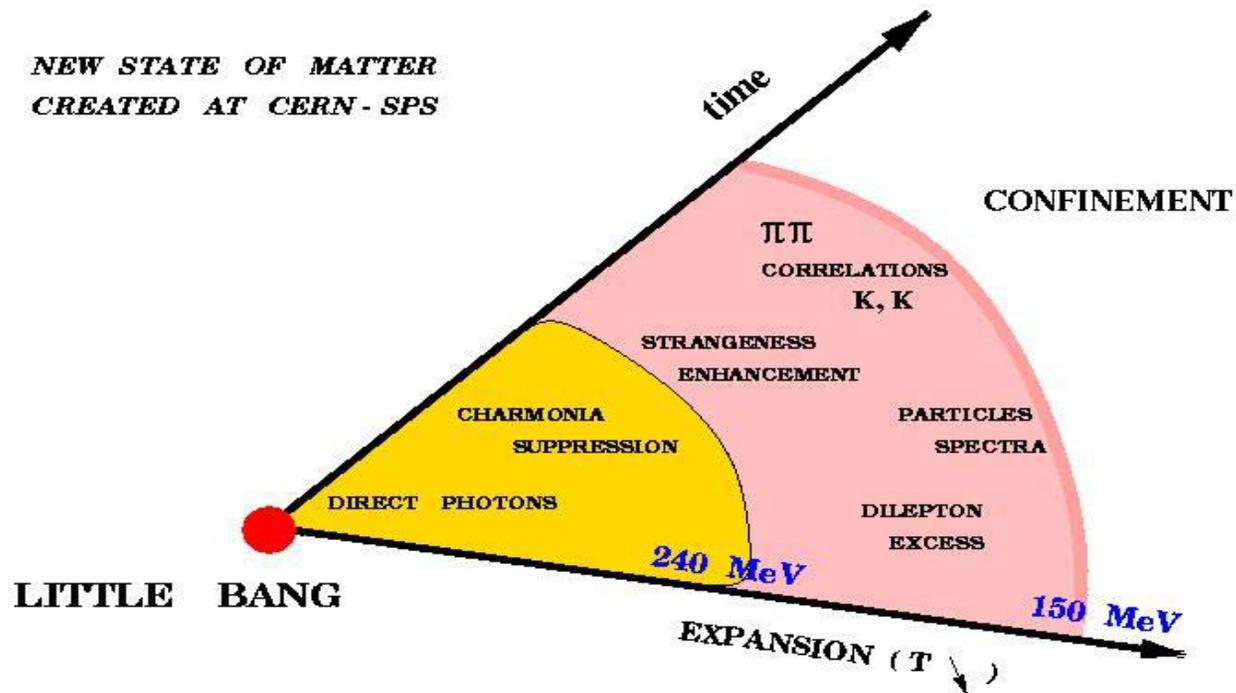
- collisions Au-Au à 200 GeV/A
- confirmation et premières études
- 2000 → ~ 2007

- *CERN-LHC*

- collisions Pb-Pb à 5,5 TeV/A
- étude complète

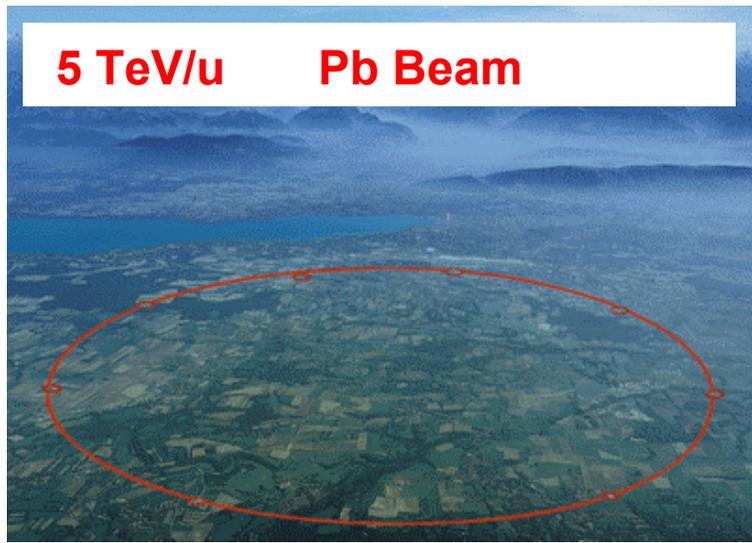
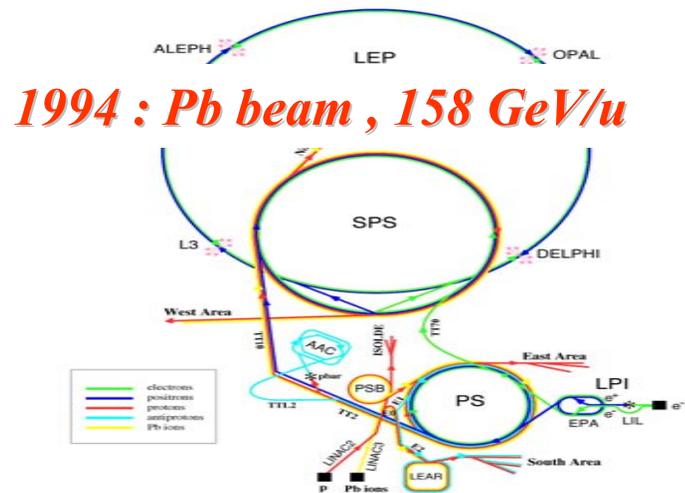
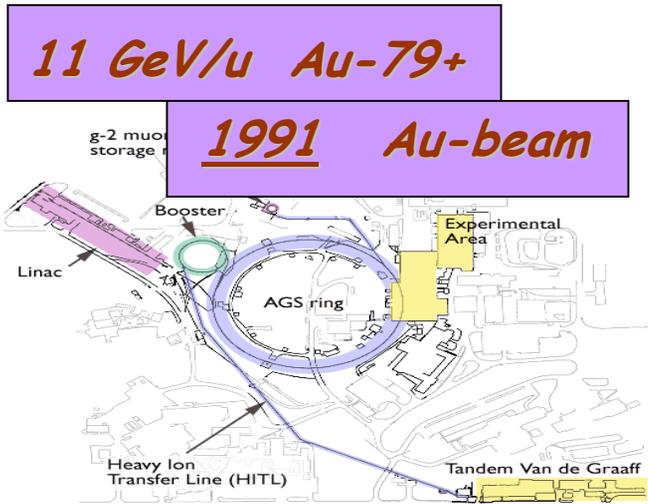
THE "FINAL" PICTURE

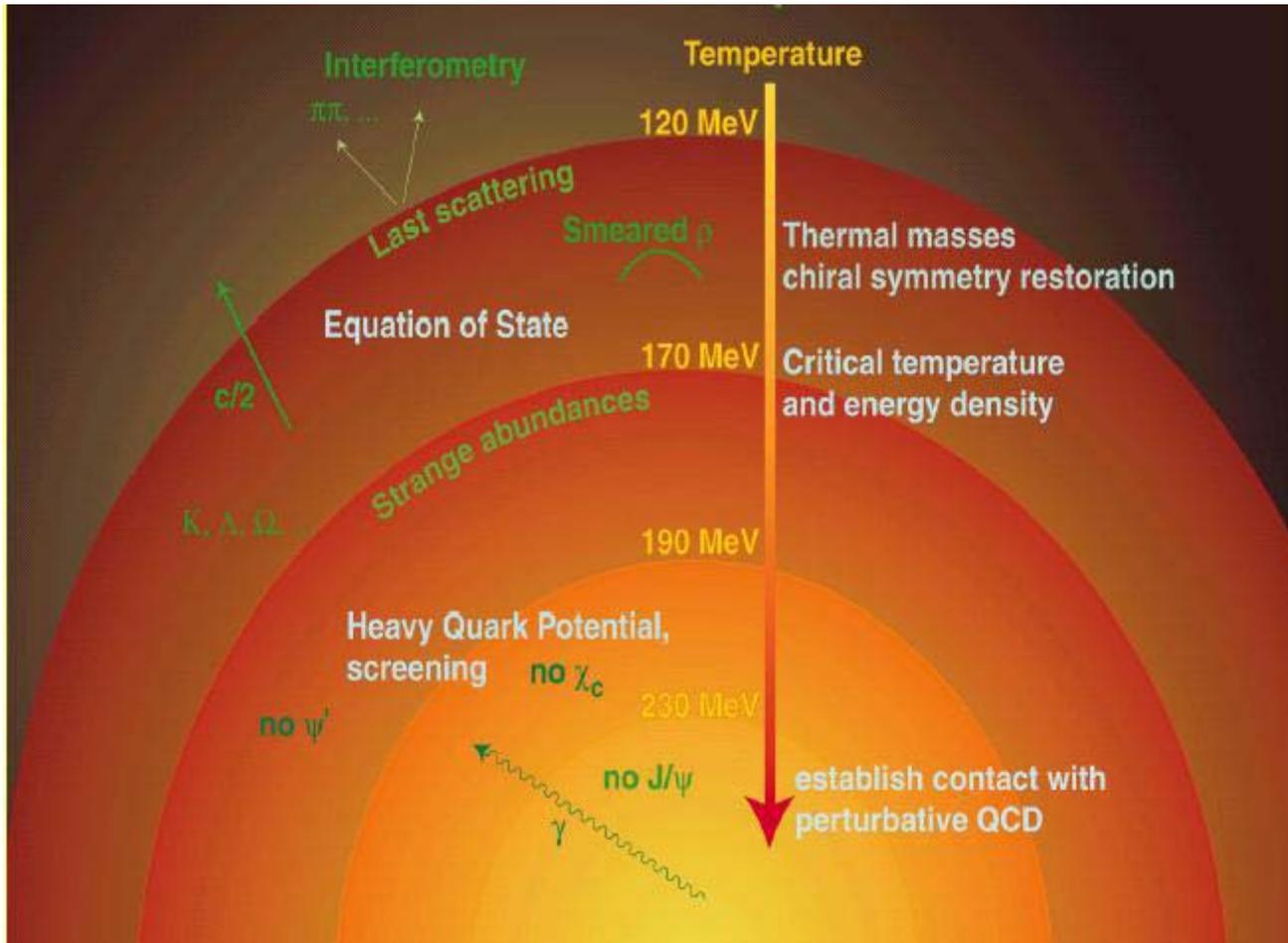
NEW STATE OF MATTER
CREATED AT CERN - SPS



PQG : auprès des collisionneurs

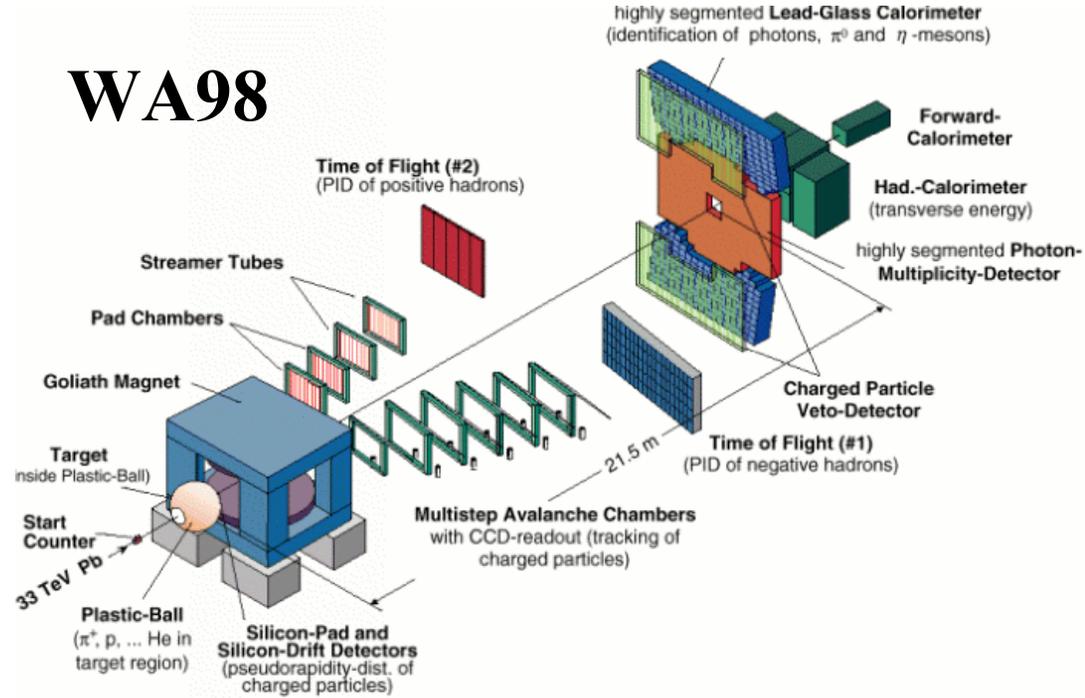
- AGS/SPS/RHIC/LHC



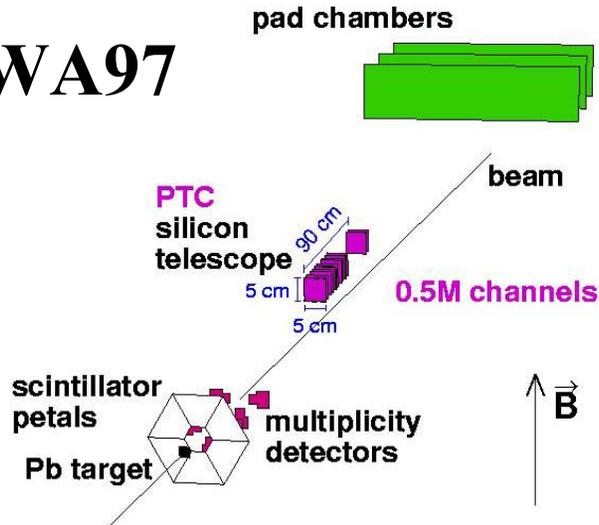


SPS

WA98

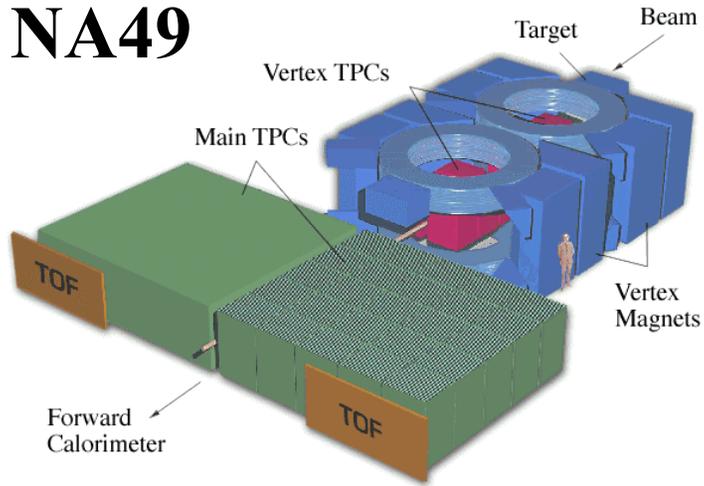


WA97

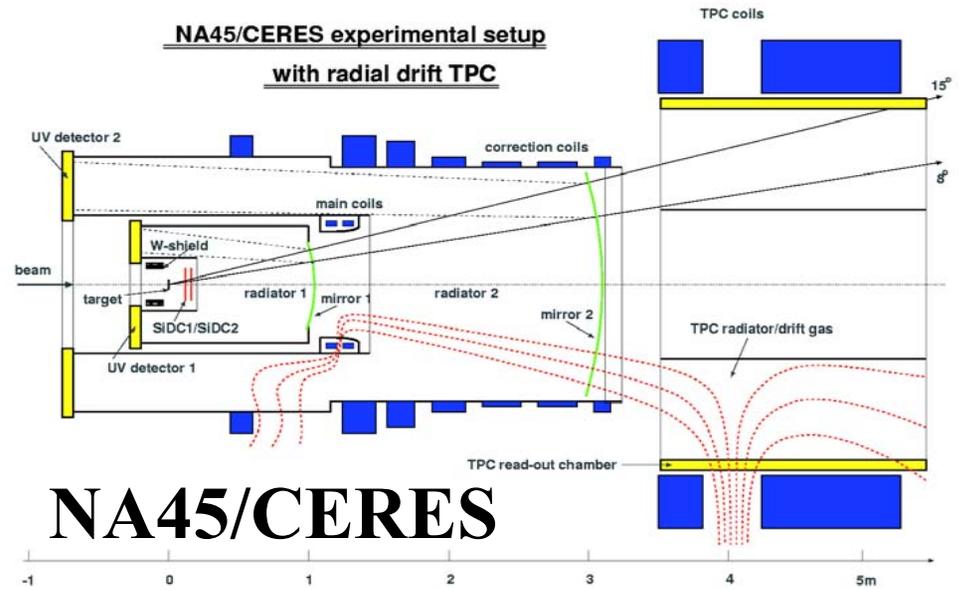


SPS

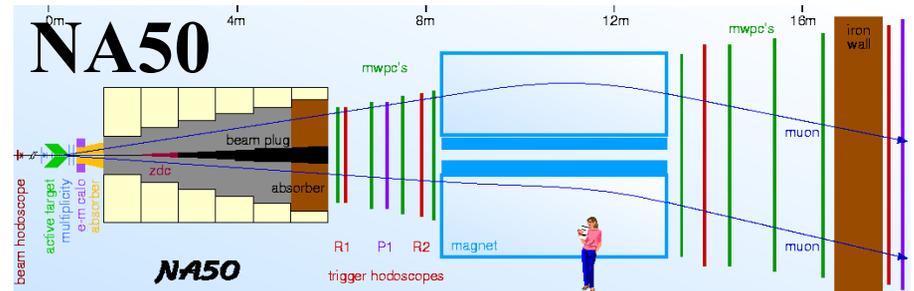
NA49



NA45/CERES experimental setup with radial drift TPC



NA45/CERES

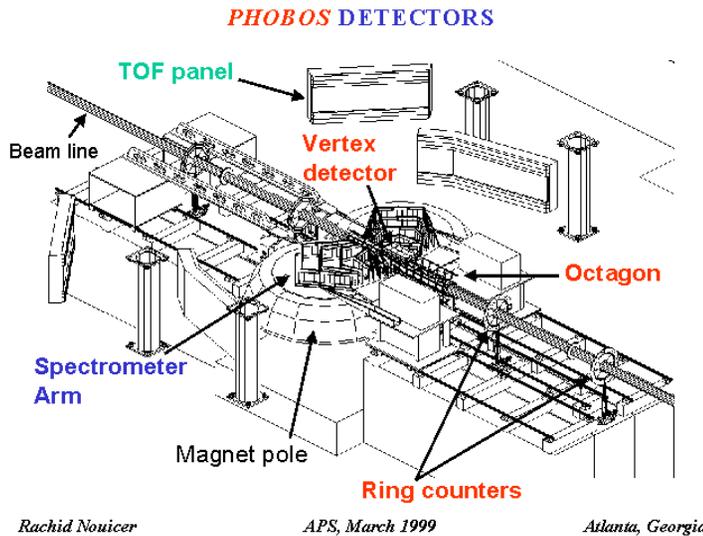


RHIC

• PHOBOS & BRAHMS

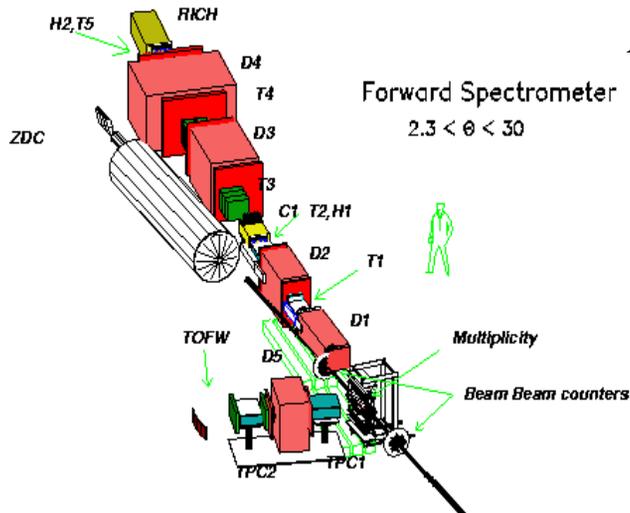
An experiment with a philosophy:

- **Global phenomena**
 - large spatial sizes
 - small momenta
- **Minimize the number of technologies:**
 - All Si-strip tracking
 - Si multiplicity detection
 - PMT-based TOF
- **Unbiased global look at very large number of collisions ($\sim 10^9$)**



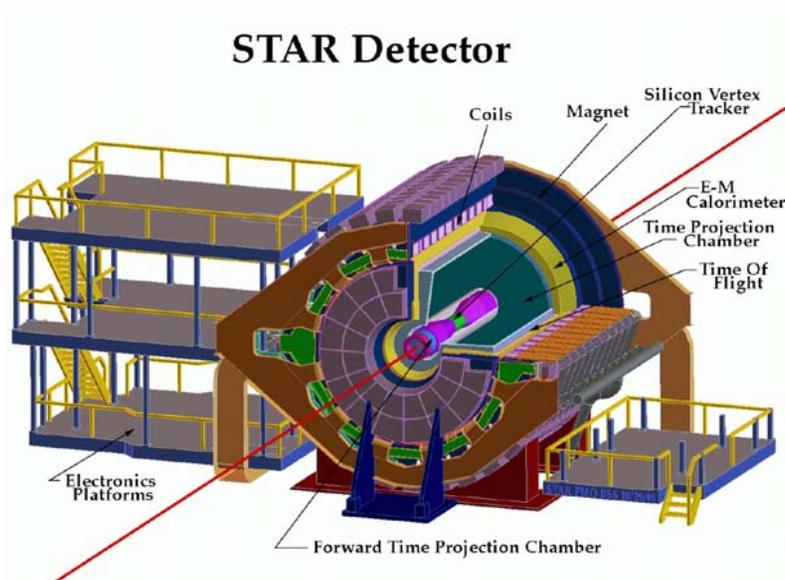
An experiment with an emphasis:

- **Quality PID spectra over a broad range of rapidity and p_T**
- **Special emphasis:**
 - Where do the baryons go?
 - How is directed energy transferred to the reaction products?
- **Two magnetic dipole spectrometers in “classic” fixed-target configuration**

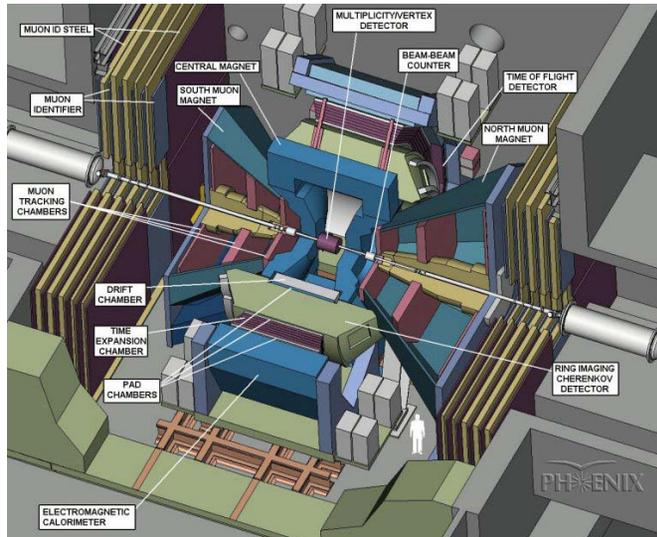


RHIC

- STAR & PHENIX



- An experiment with a challenge:
 - Track ~ 2000 charged particles in $|\eta| < 1$
- Large acceptance

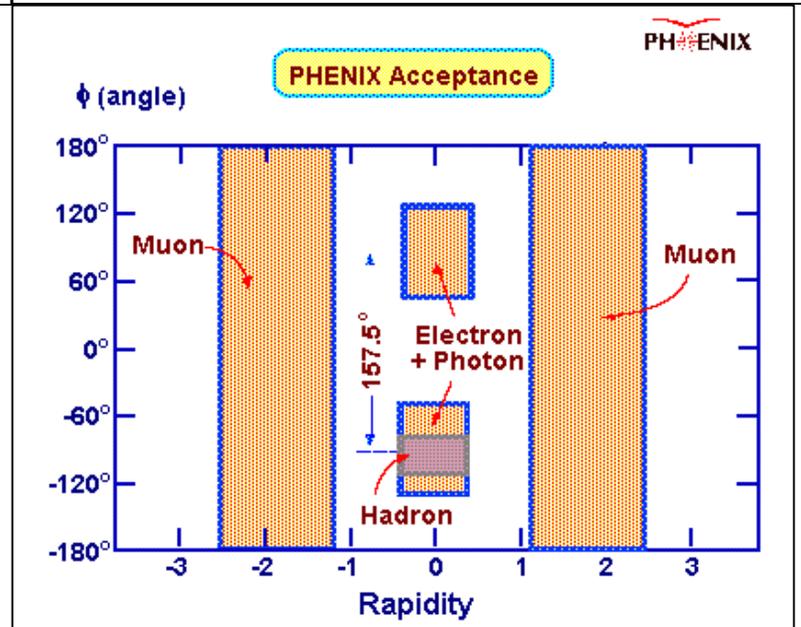
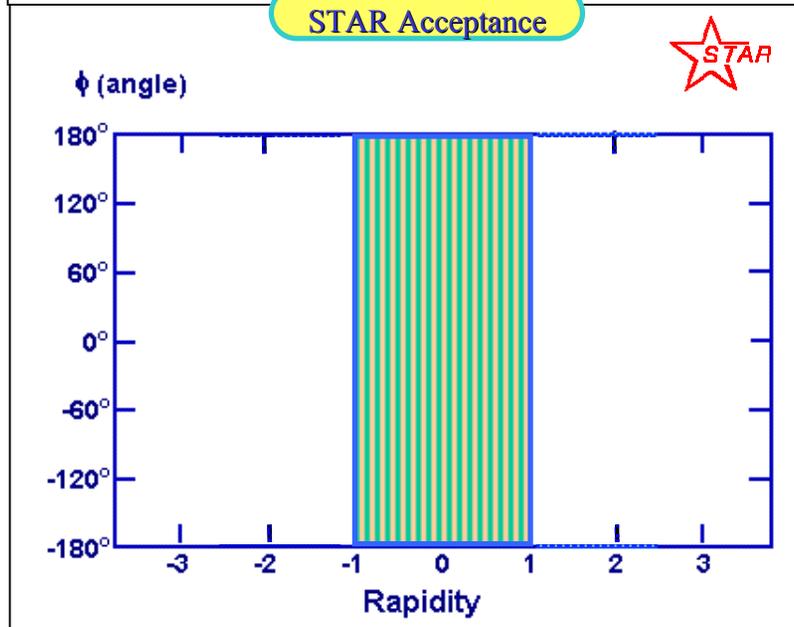
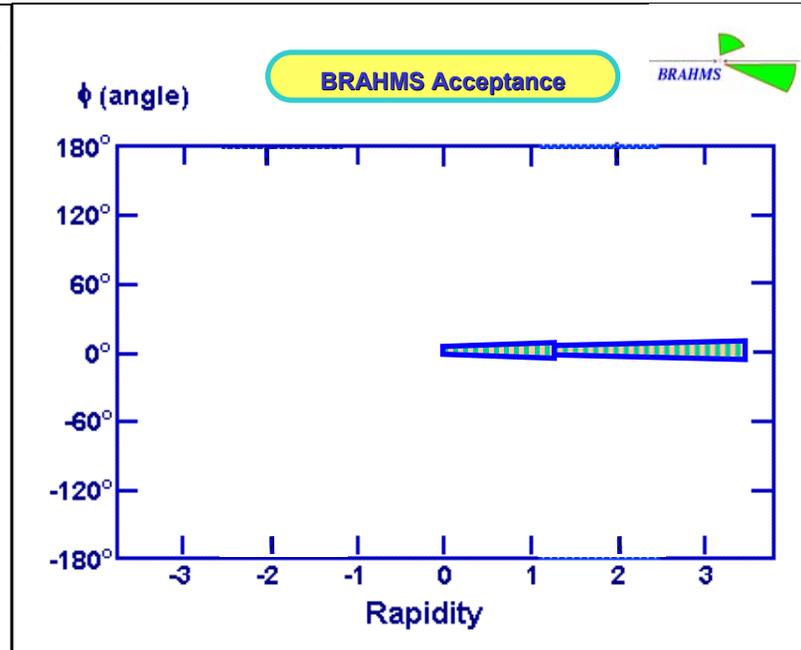
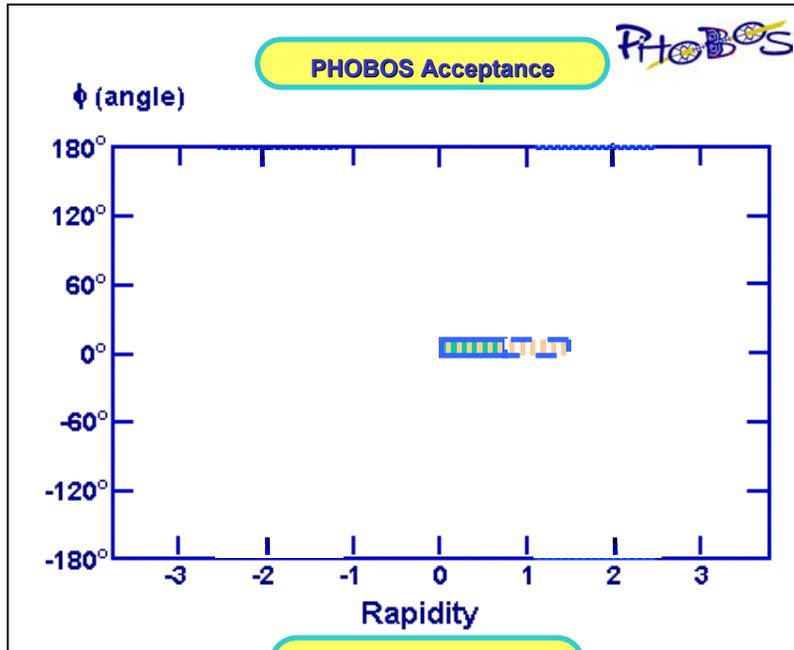


- An experiment with something for everybody
- A complex apparatus to measure
 - Hadrons
 - Muons
 - Electrons
 - Photons

Executive summary:

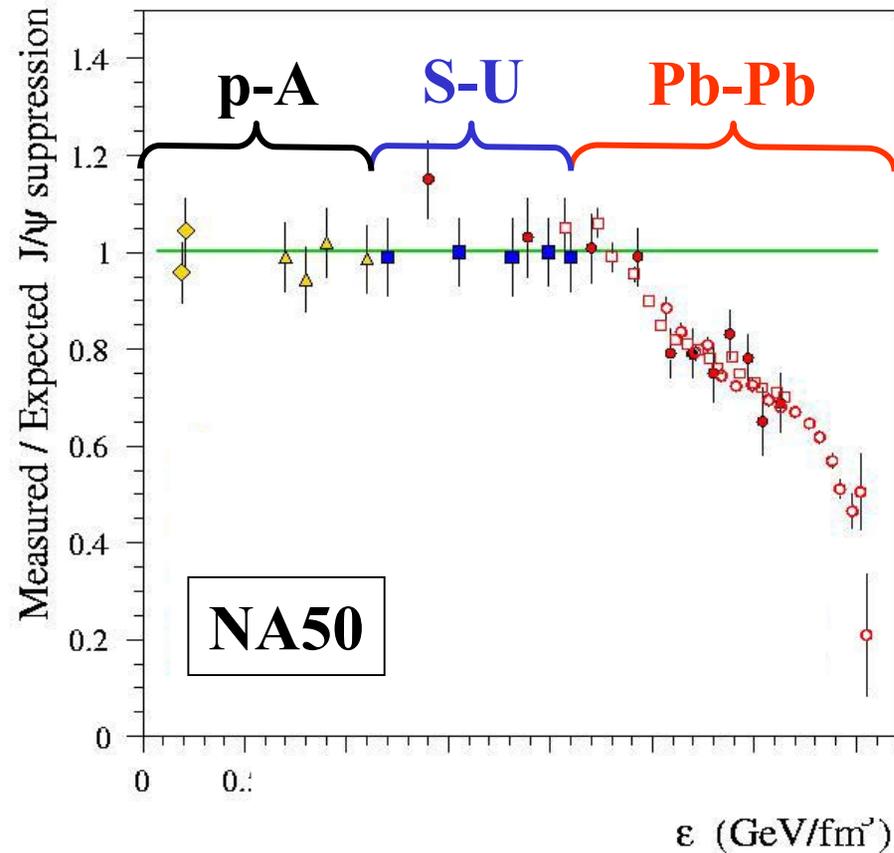
- High resolution
- High granularity

(PID) Acceptances

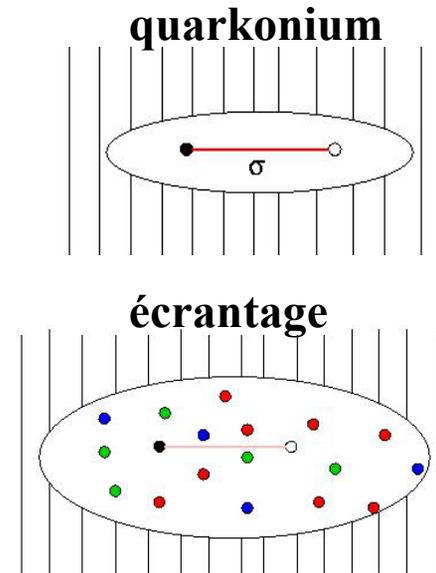


Petit Bang : signatures du QGP

- Suppression anormale du J/Ψ
 - plasma \rightarrow écranage de couleur



$\chi \rightarrow \gamma \psi$ (30%)



(Satz et al.)	ΔE (GeV)	T_D/T_C
χ	0,24	1
J/Ψ	0,64	1,2

Physics Menu

* Needs upgrade

		SPS	RHIC			
			BRAHMS	PHENIX	PHOBOS	STAR
Global and Hadrons	Multiplicity	NA49, WA80	X	X	X	X
	E_T	NA49, WA80		X		X
	Spectra and ratios	All	X	X	X	X
	Flow & Correlations	NA44+ ...		X		X
	Multi – strange	WA 97				X
Rare / Penetrating Probes	Photons	WA98, CERES		X		X
	Low-mass e^+e^-	CERES		X*		
	Vector mesons $\rho \ \omega$	NA50		X		
	$\phi \rightarrow l^+l^-$	NA50		X		
	K^+K^-	NA49		X		X
	$J/\psi \rightarrow e^+e^-$			X		X
	$\mu^+ \mu^-$	NA50		X		
	$\Upsilon \rightarrow \mu^+ \mu^-$			X*		
	Open charm	NA60		X*		X*
High p_T	(CERES, WA98)		X		X	