

COLLISION D'IONS LOURDS au SPS (CERN) et à RHIC (Brookhaven)



COLLISION D'IONS LOURDS au SPS (CERN) et à RHIC (Brookhaven)

INTRODUCTION

DERNIERS RESULTATS au SPS → NA50

AMBITIONS de RHIC → PHENIX

PREMIERS RESULTATS de RHIC

Anncy, le 15 juin 2001

Raphaël Granier de Cassagnac

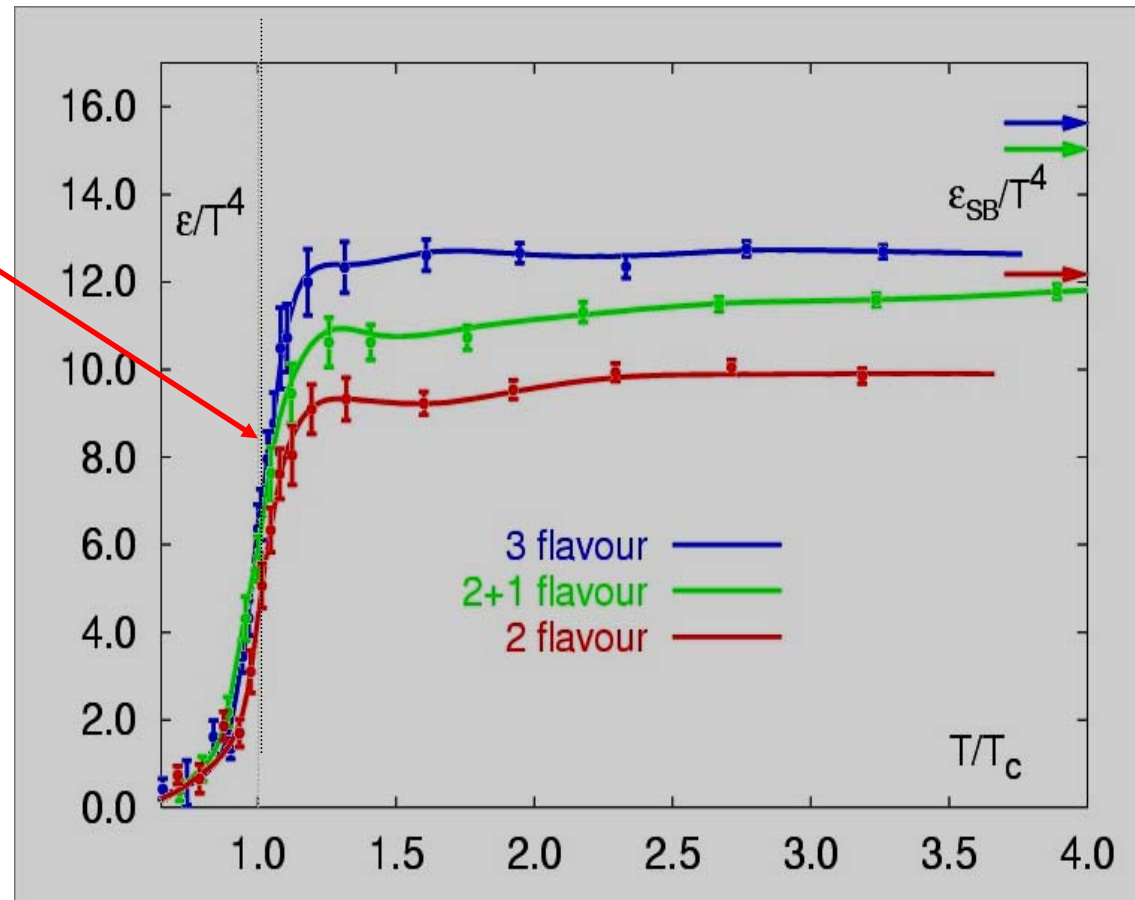
(LPNHE-X et PHENIX)

Prédiction théorique

- Calcul de chromodynamique quantique (sur réseau)

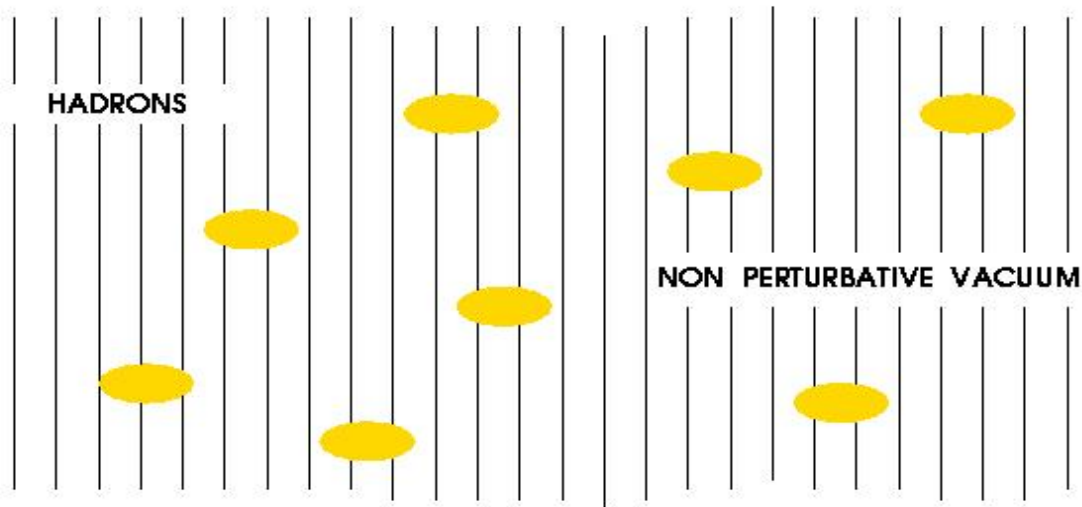
Transition de Phase
confinement
→ déconfinement

$T_c \sim 160 \text{ MeV}$
environ 10^{13} K
(Soleil = 10^8 K)



(F. Karsch et al.)

CONFINEMENT (QCD)

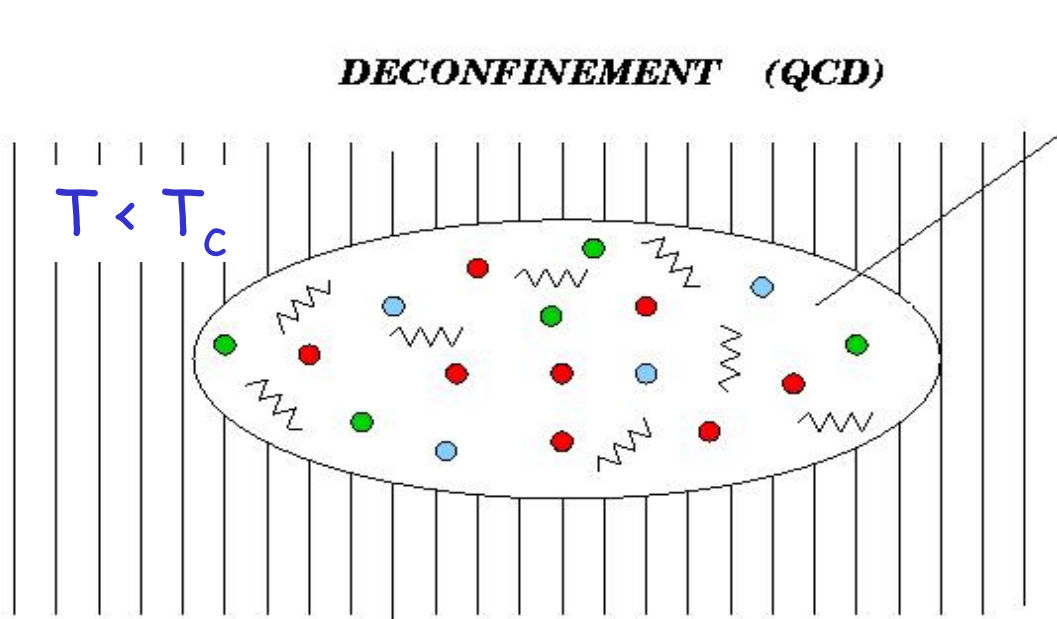


Prédiction
théorique

Les quarks sont confinés
dans les hadrons

Gaz de hadrons

DECONFINEMENT (QCD)

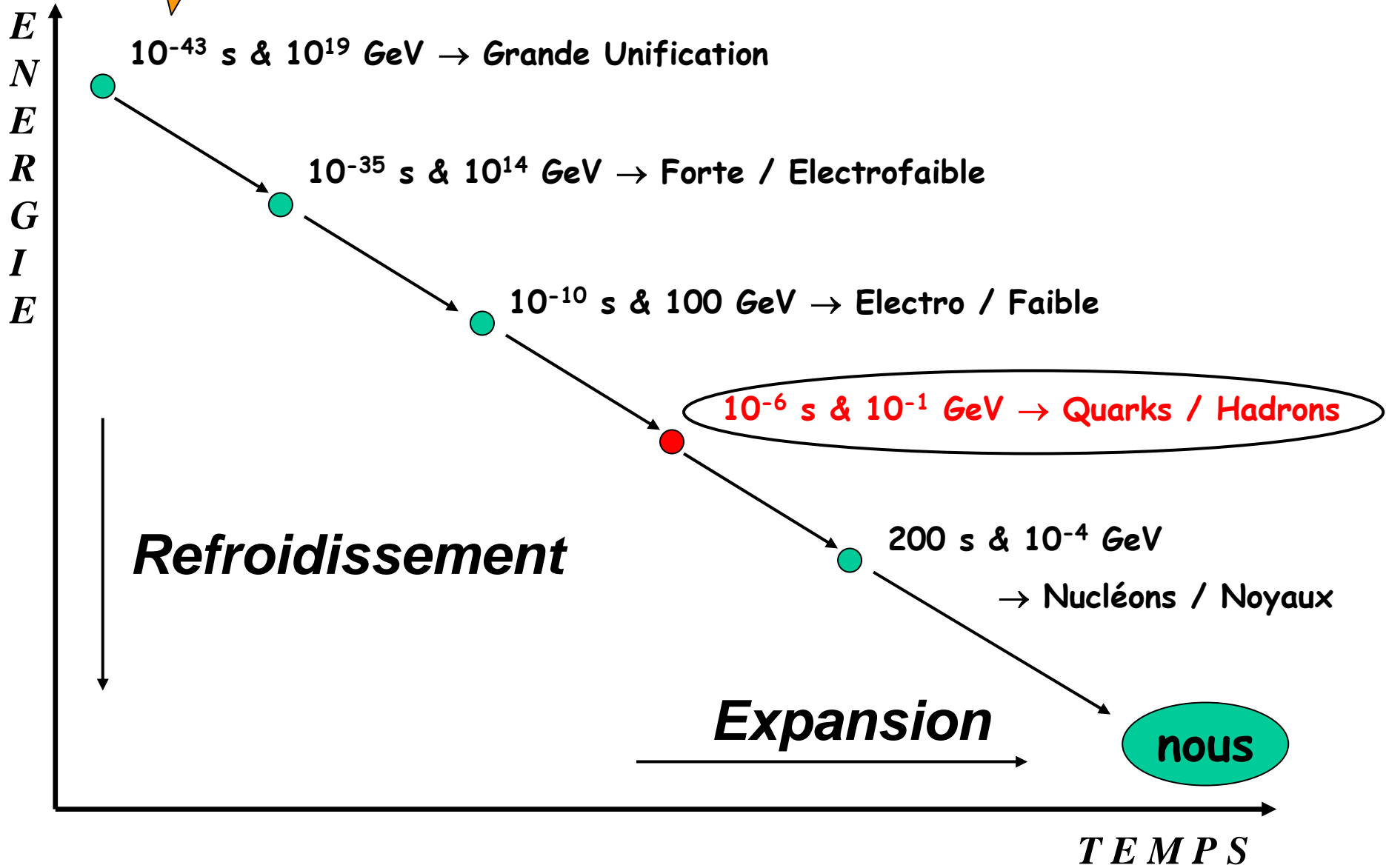


Les quarks et les gluons
se libèrent

Plasma de quarks
et de gluons

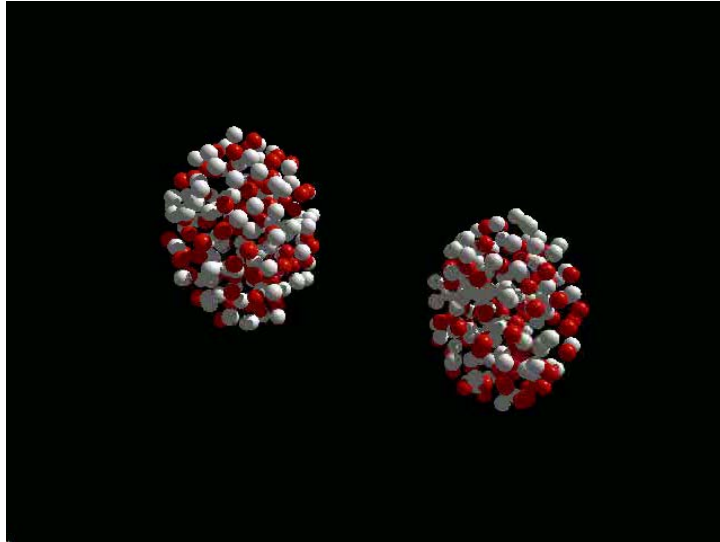


Jalons historiques (I)

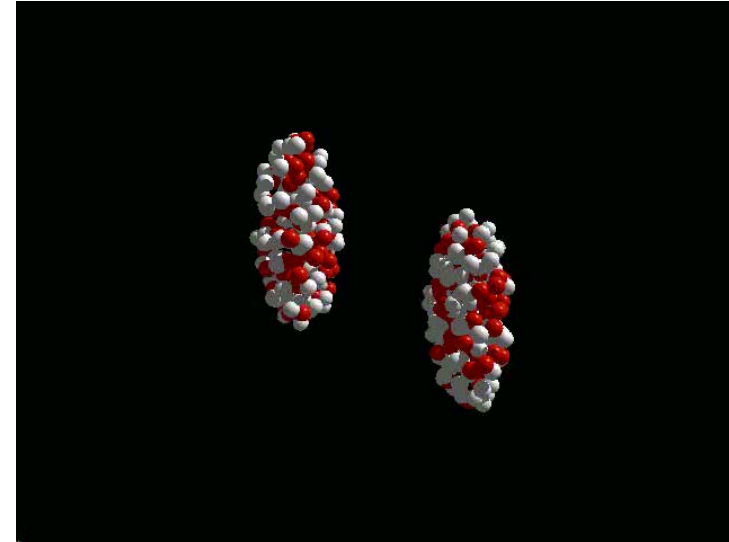


Jalons historiques (II)

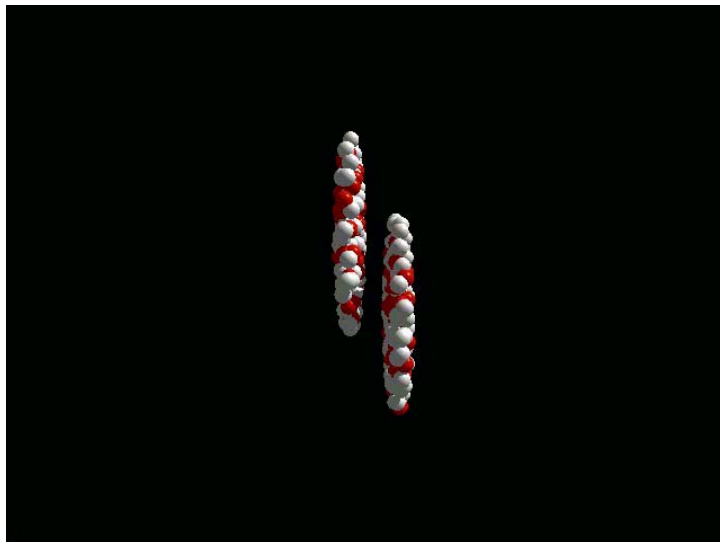
1986 BNL - AGS 4 GeV



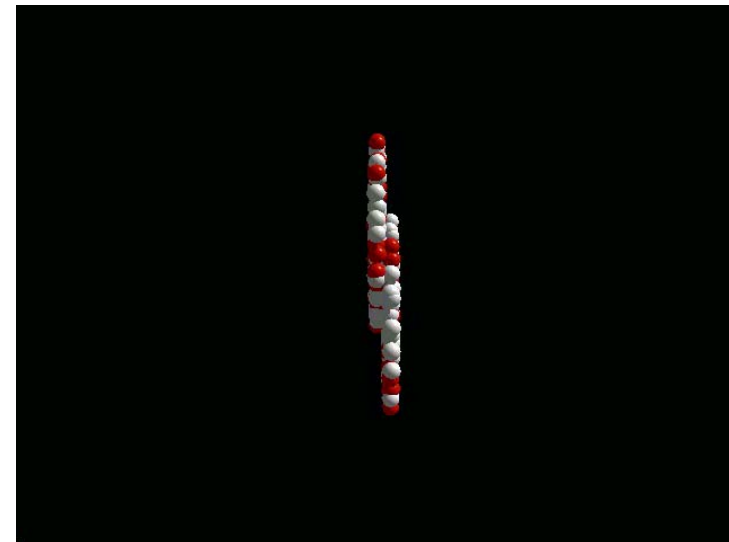
1994 CERN - SPS 20 GeV



2000 BNL - RHIC 200 GeV

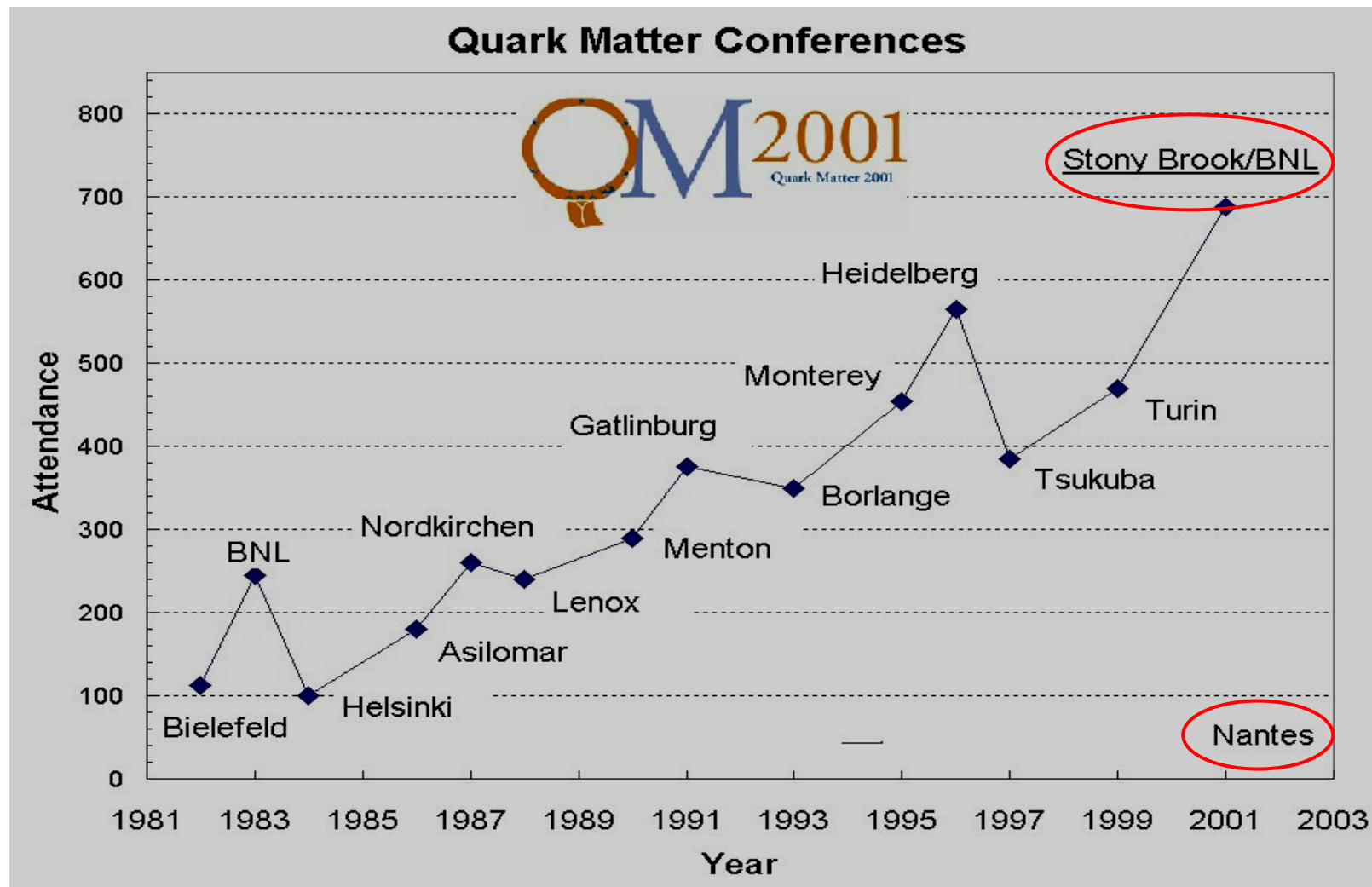


2006 CERN - LHC 5 TeV



Jalons historiques (III)

→ Un domaine de recherche à la mode



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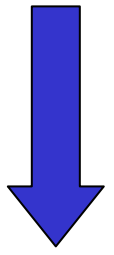
AMBITIONS de RHIC → PHENIX

PREMIERS RESULTATS de RHIC

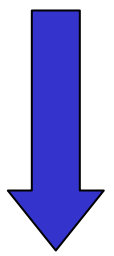
Suppression des charmonia

Paire charm / $\overline{\text{charm}}$

Température nulle

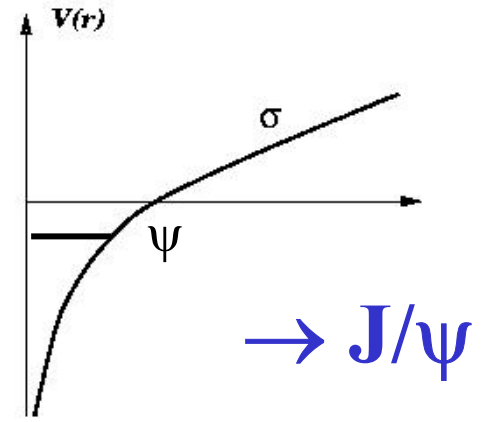
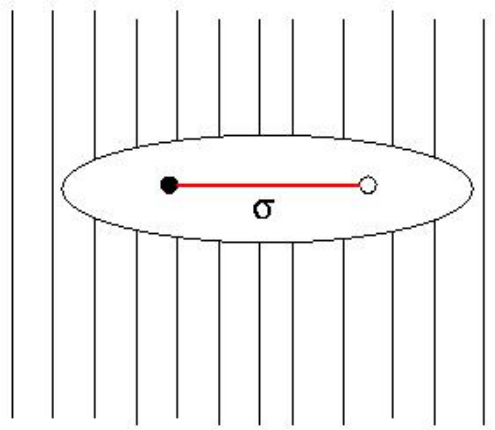


Température de déconfinement : T_c

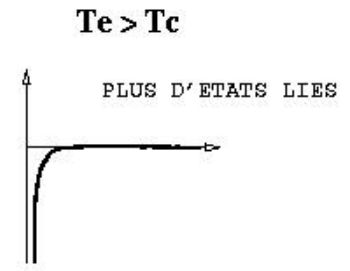
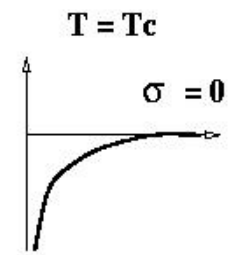
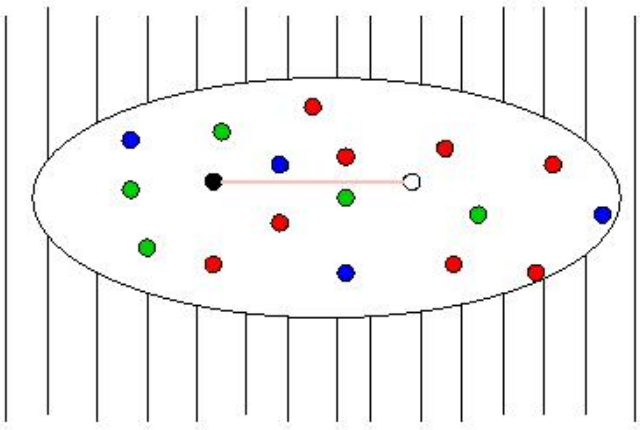


Température «d'écrantage» : T_e

Suppression du J/ψ

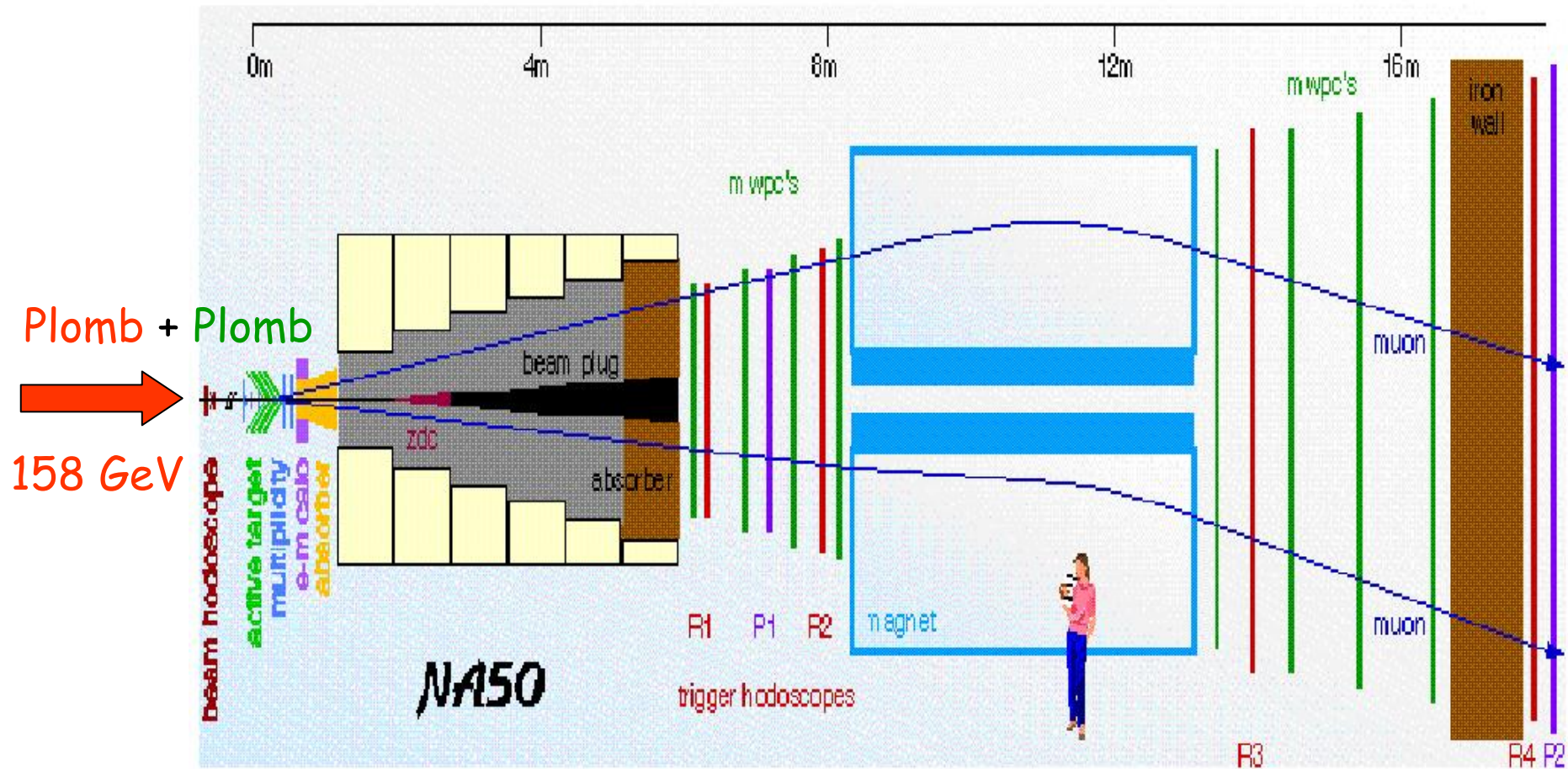


DECONFINEMENT --> ECRANTAGE



$$T_e(\psi') < T_e(\chi) < T_e(\psi) < T_e(Y)$$

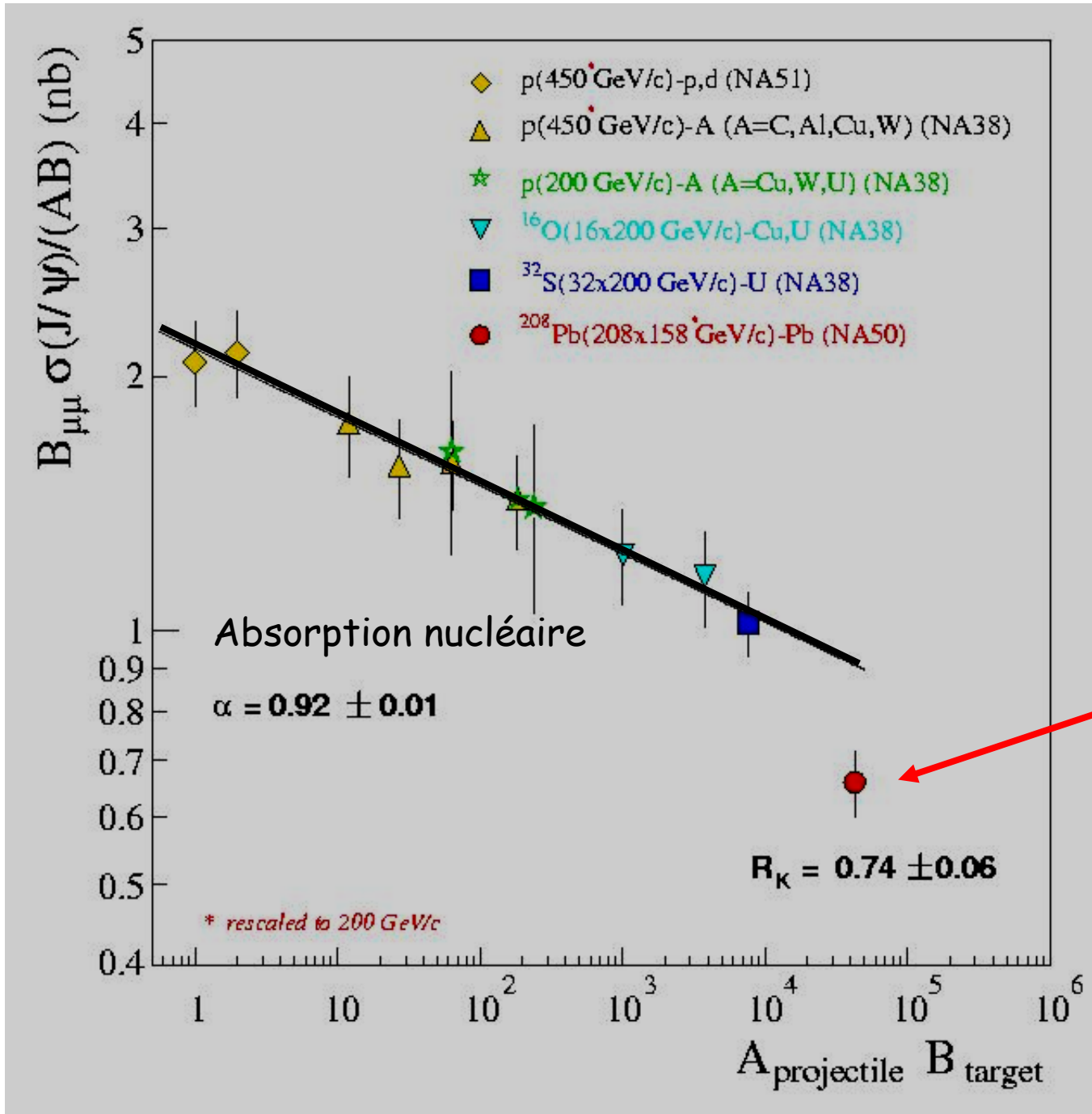
Expérience NA50



$\sqrt{s} = 18 \text{ GeV/nucleons}$

$J/\psi \rightarrow \mu^+ \mu^- \quad (6\%)$

Résultats NA50



Suppression

$N_{\text{proj}} \times N_{\text{cible}}$



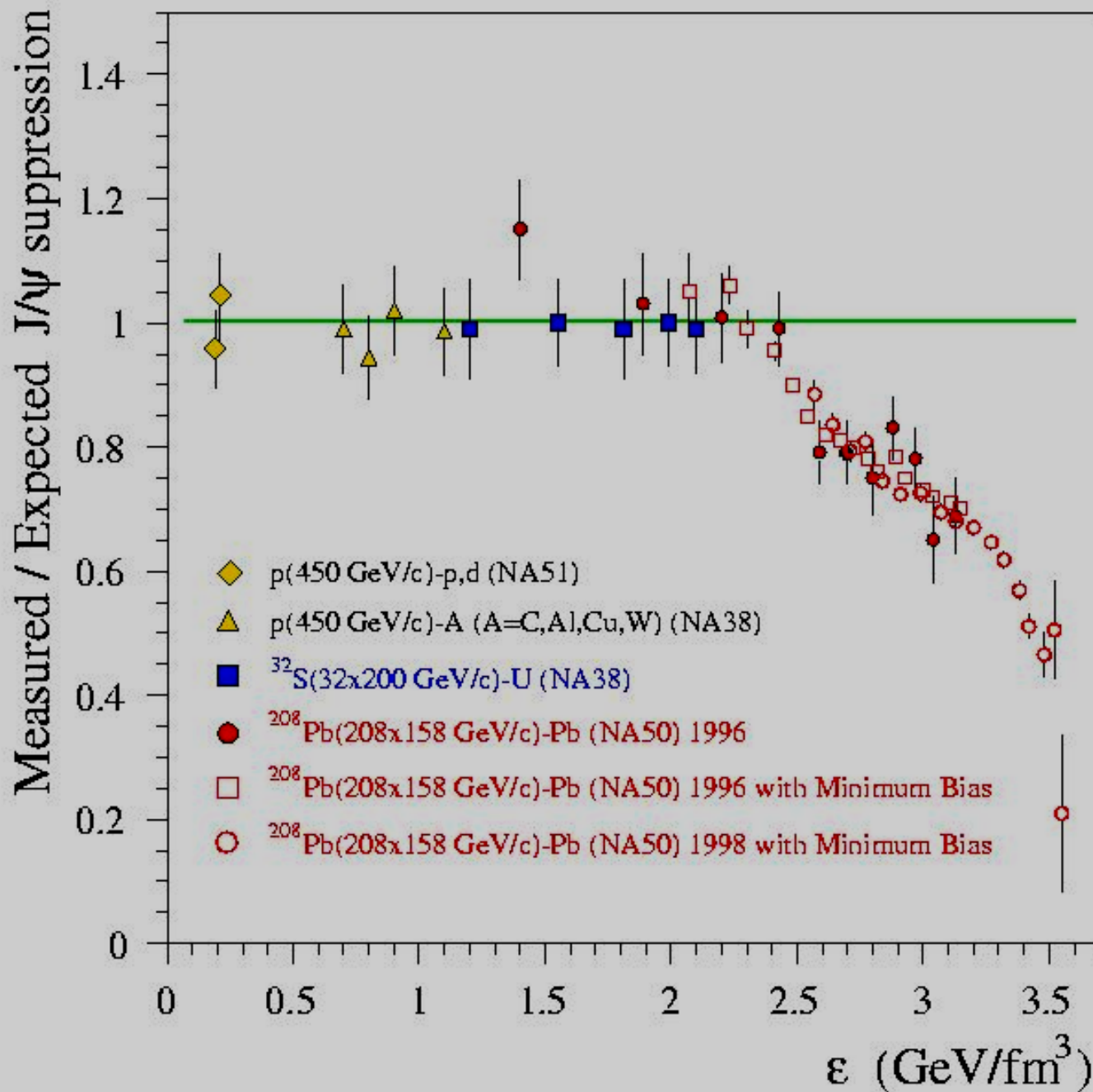
Résultats NA50

« expected »



Drell-Yann

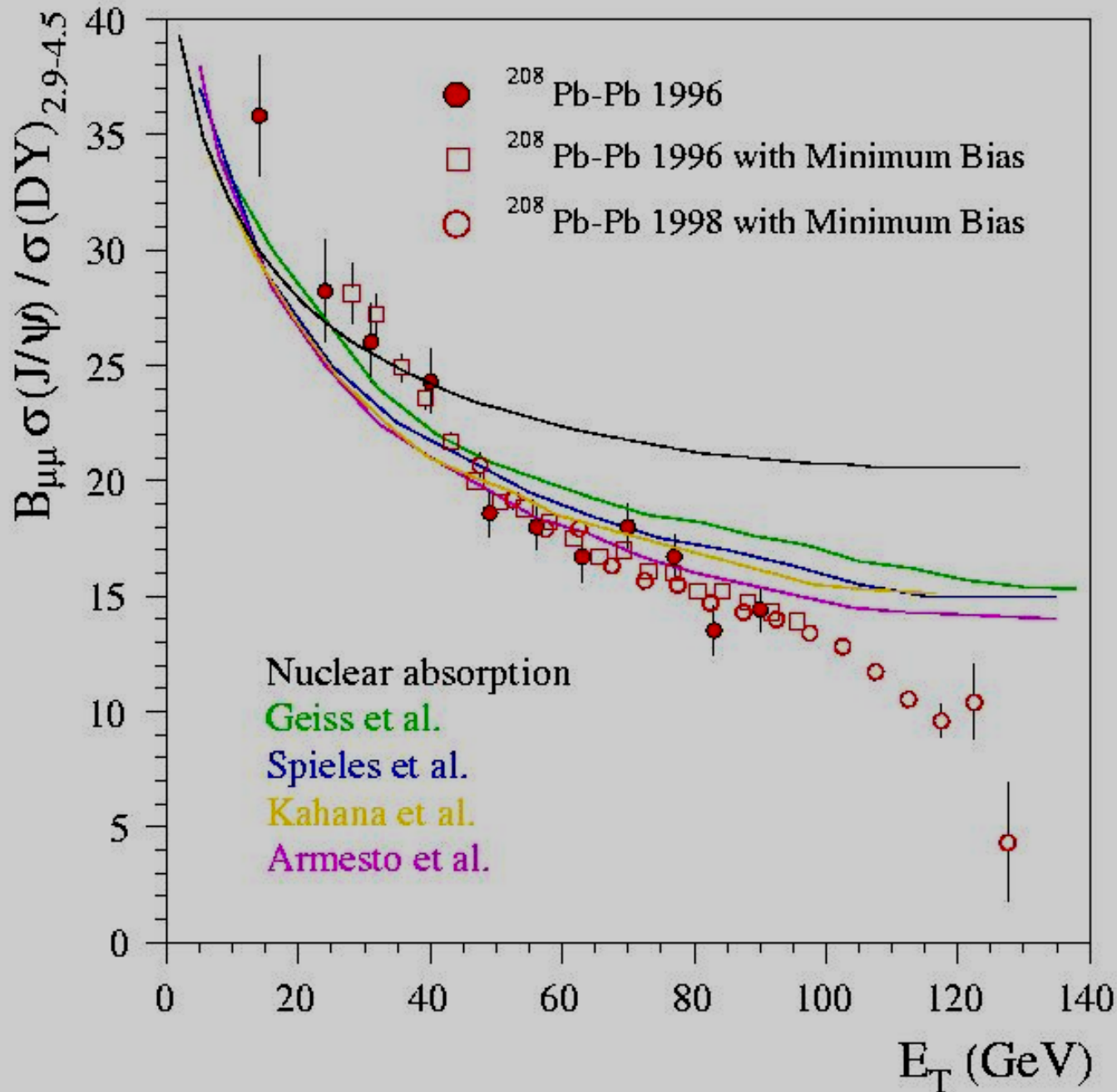
Densité
d'énergie



Résultats NA50

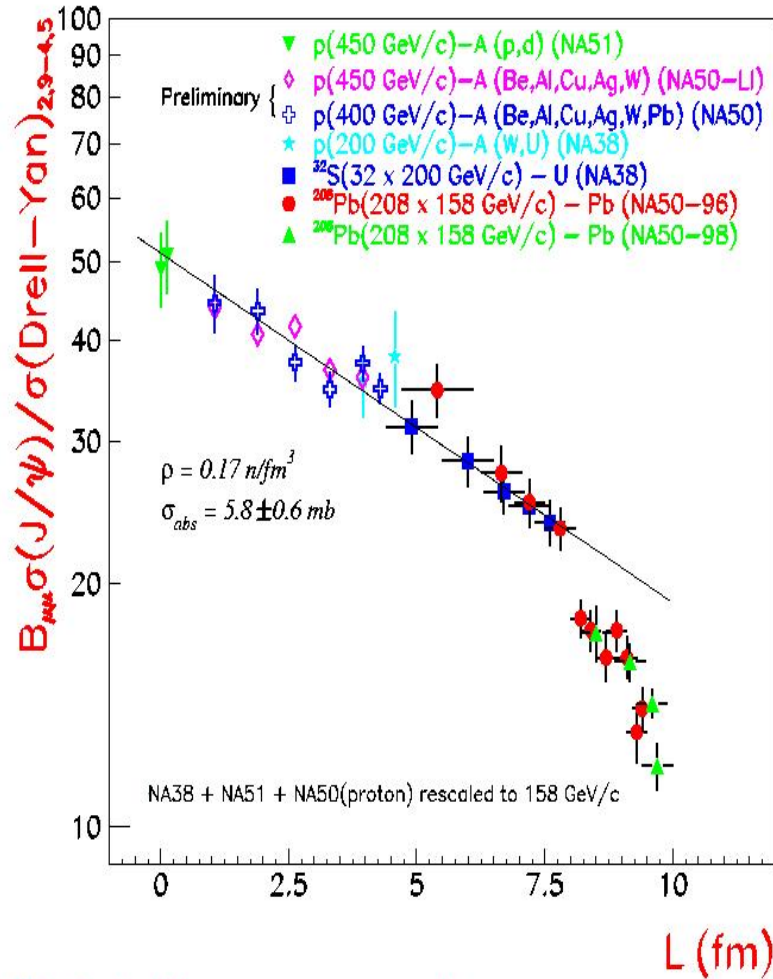
Inexplicable
par la seule
absorption
nucléaire

Energie
transverse

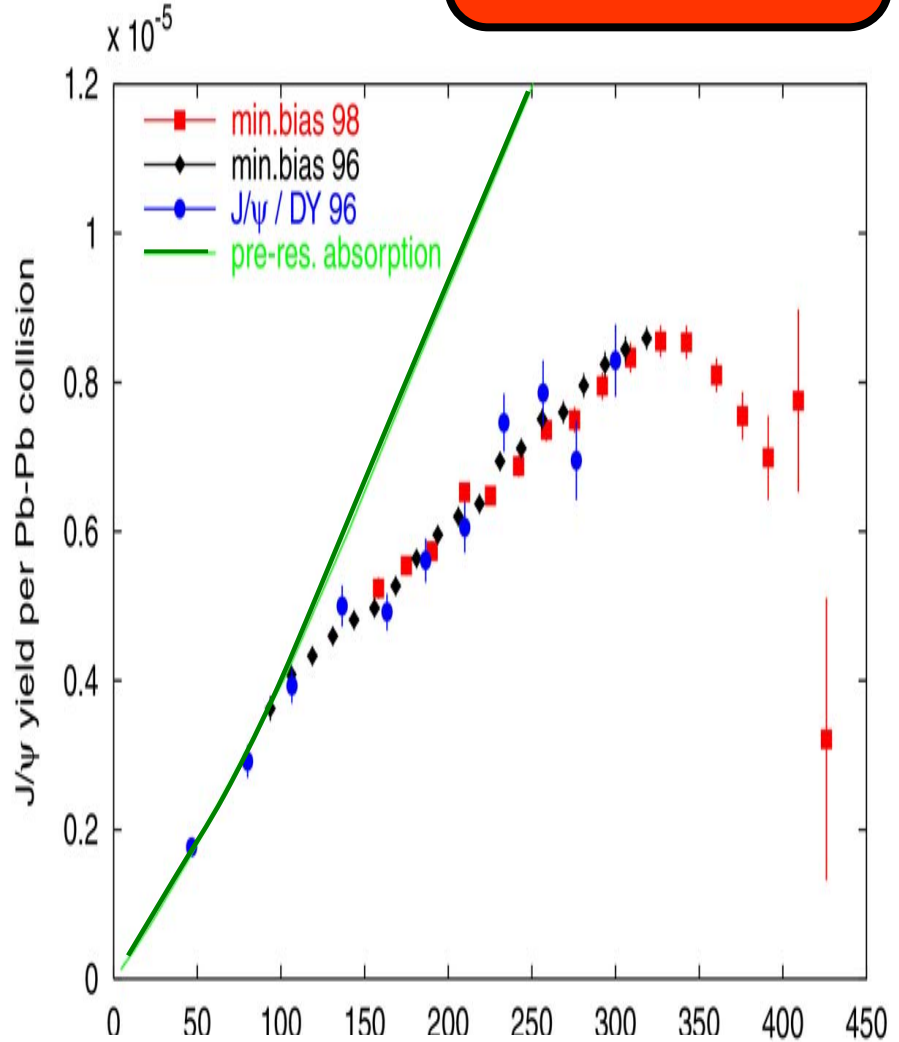


D'après Quark-Matter 2001

Résultats NA50



Longueur de parcours →

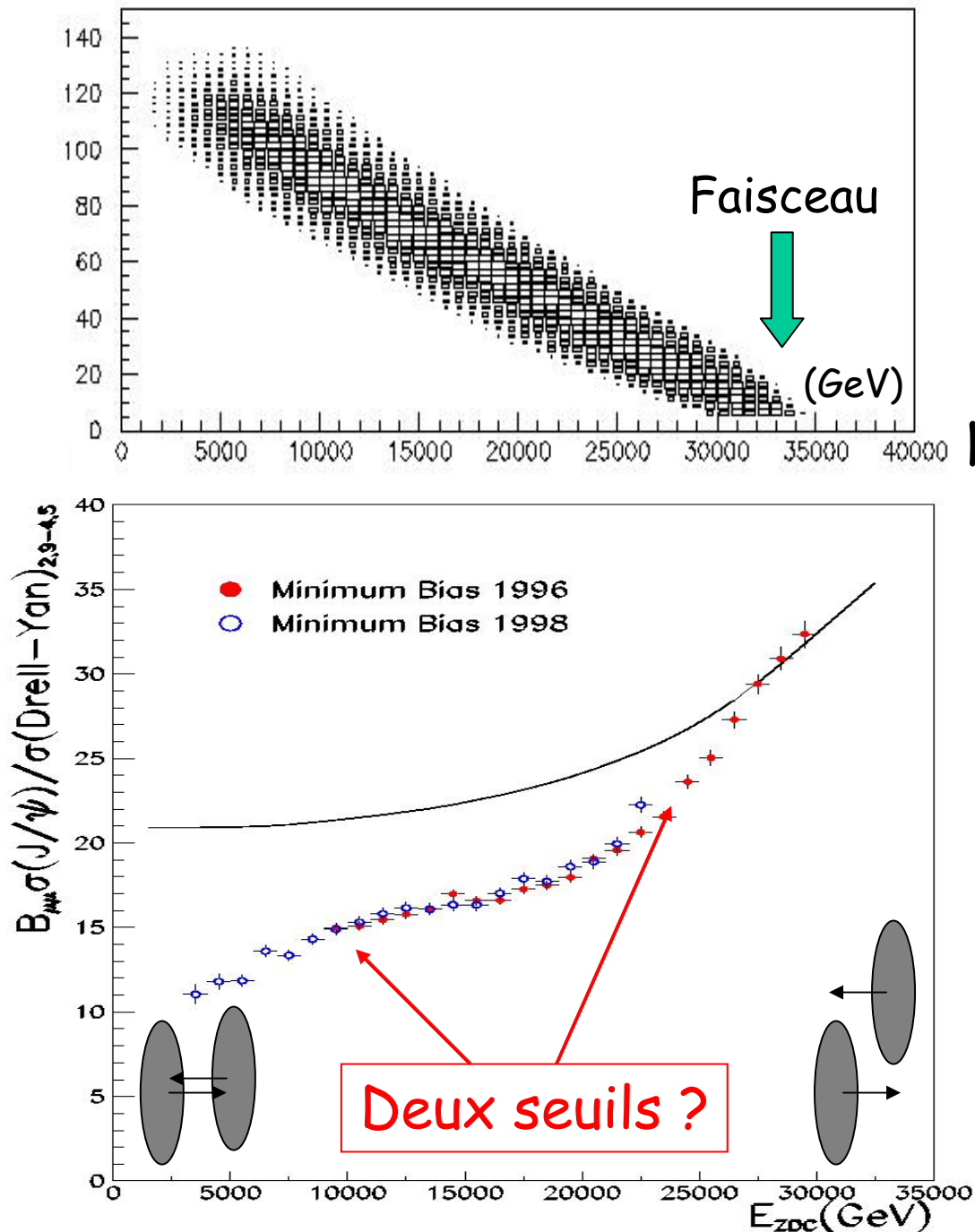


Nombre de participants →

Résultats NA50

Nouvelles analyses à
Quark Matter 2001 :

Longueur de parcours,
Nombre de participants...



Une hypothèse :

Suppression du χ

$$T_e(\chi) < T_e(\psi)$$

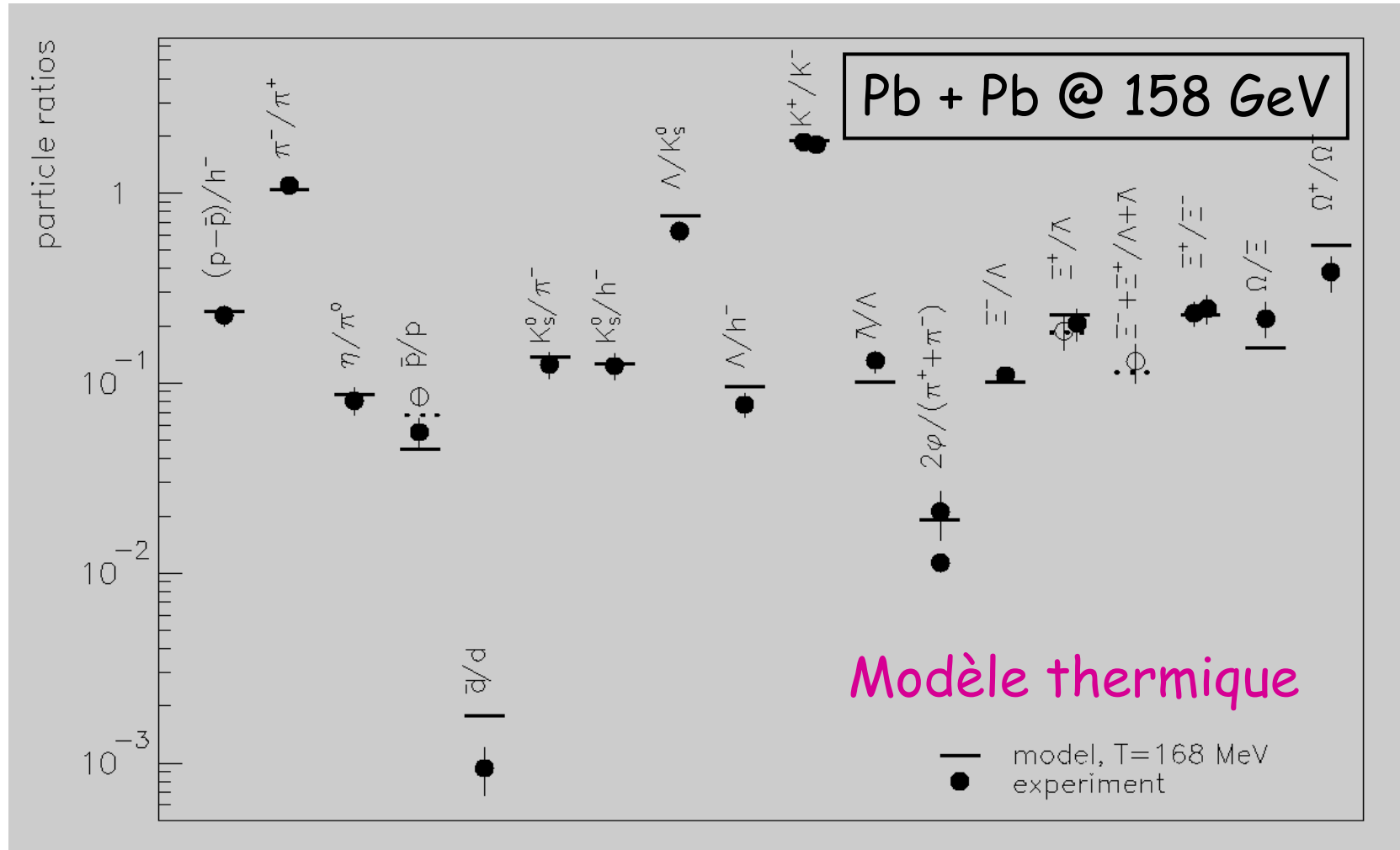
$$\chi \rightarrow \psi + \gamma \quad (30 \%)$$

Energie dans le
Calorimètre à 0°



Production de hadrons au SPS

Abondances



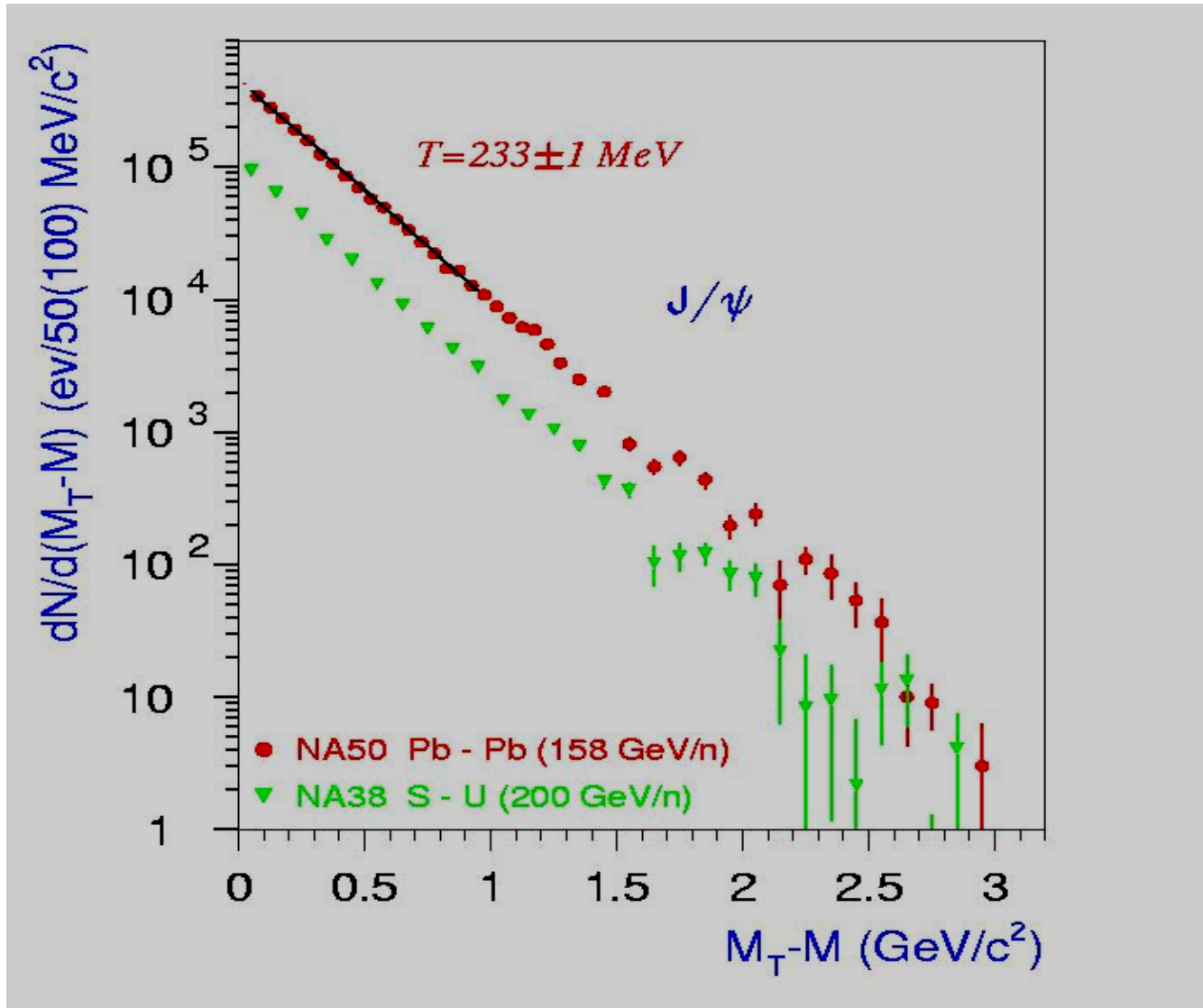
P. Braun-Munzinger et al.,
Phys. Lett. B 465 (1999) 15

→ Température de gel ~ 170 MeV

Résultats NA50

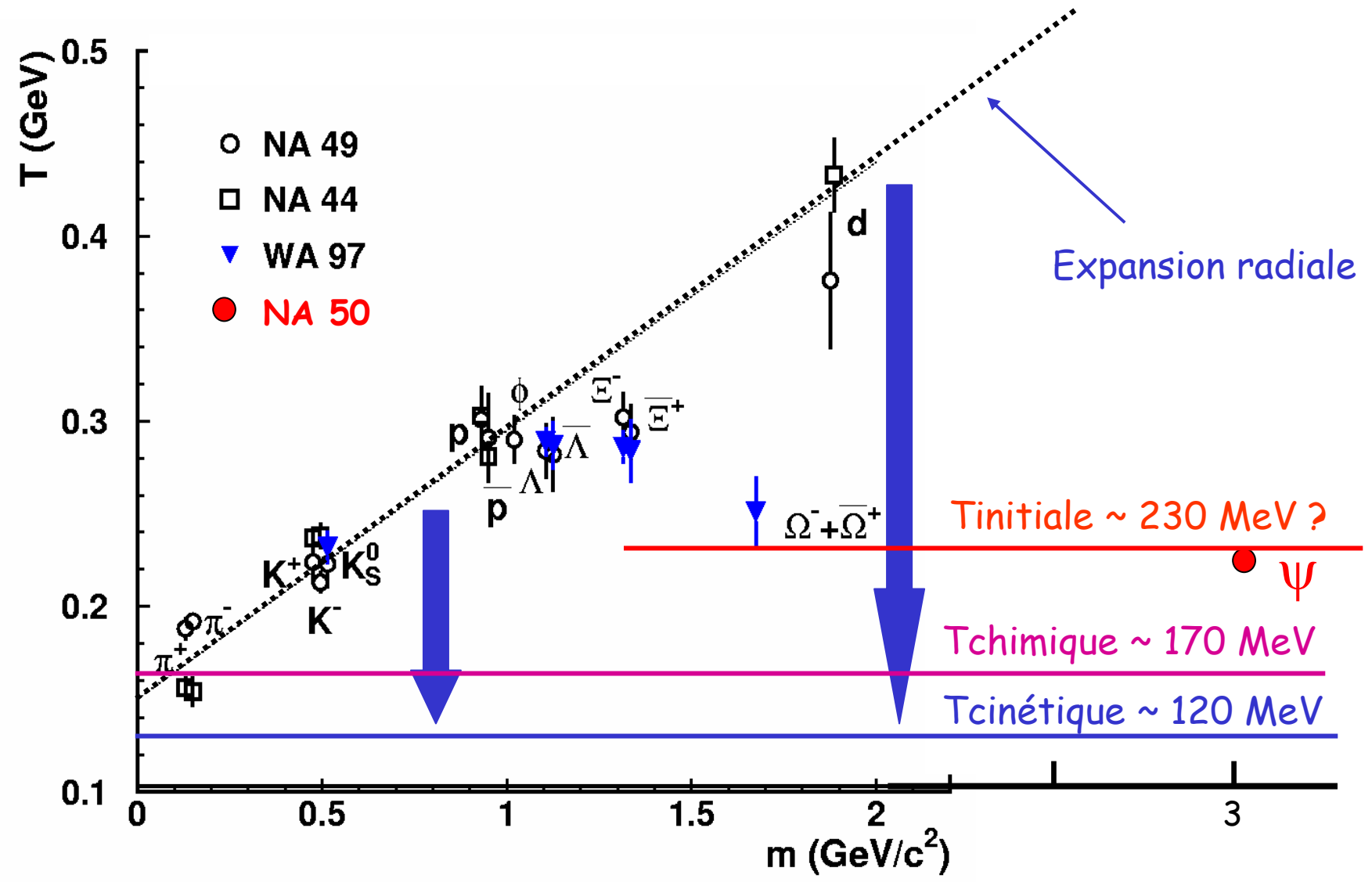
(QM 2001)

Température
de gel
« cinétique »
du J/ψ
 ~ 230 MeV



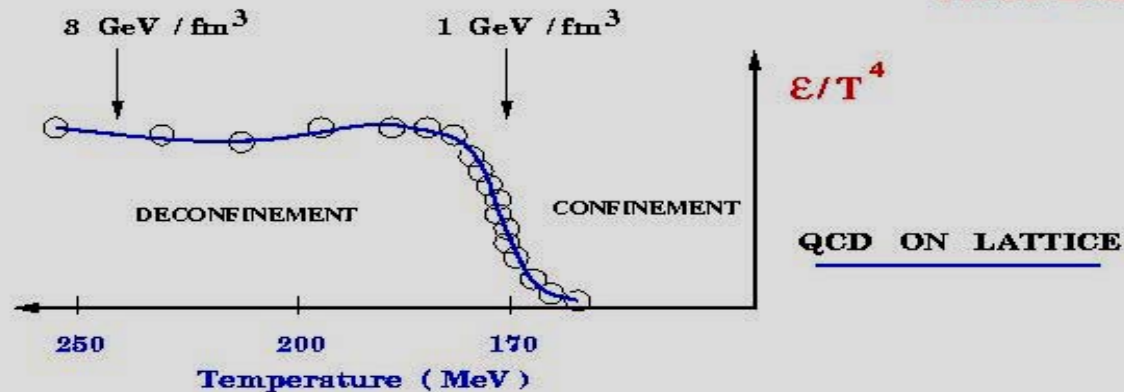
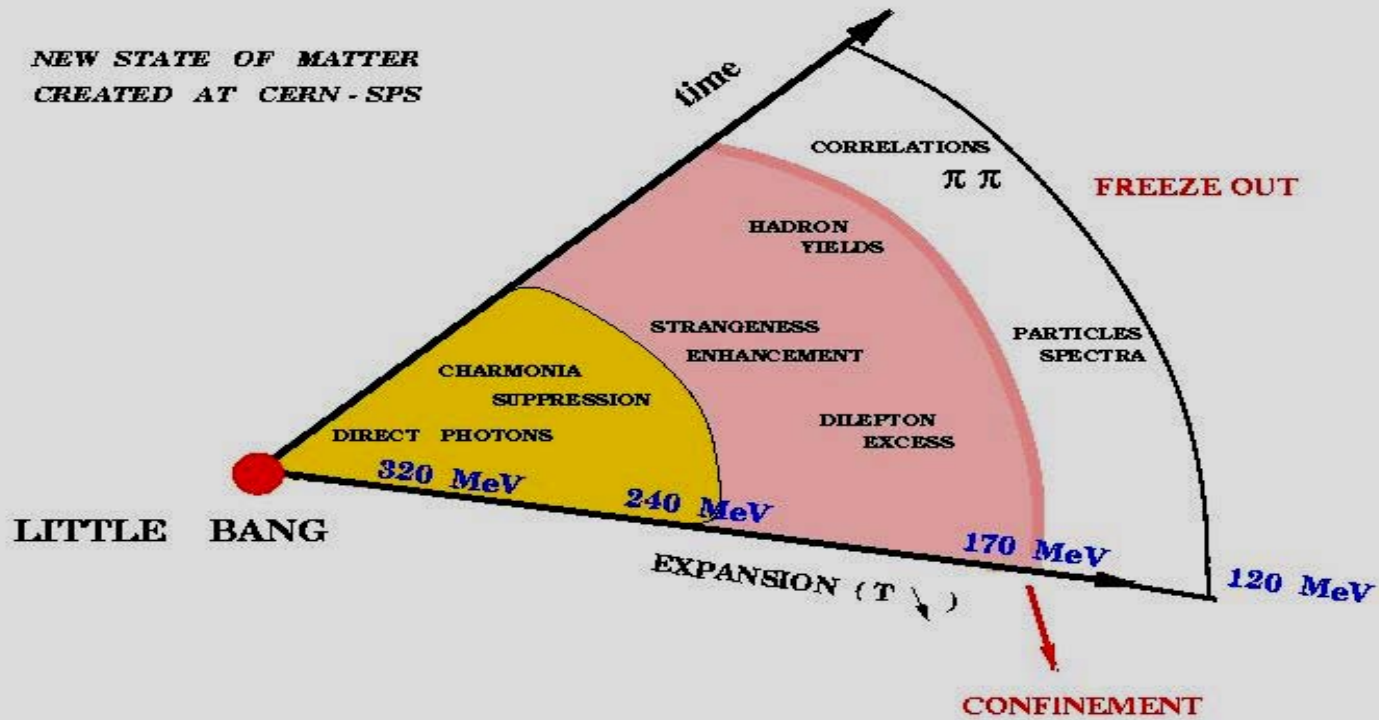
Spectre en masse transverse du J/ψ

Production de hadrons au SPS



Le petit bang

NEW STATE OF MATTER
CREATED AT CERN - SPS





Organisation Européenne pour la Recherche Nucléaire
European Organization for Nuclear research

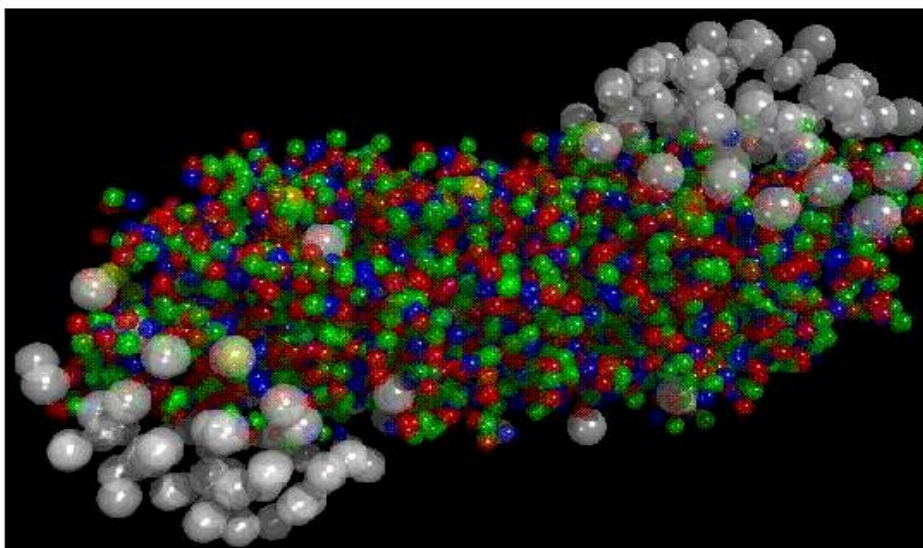
Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics
Europäisches Laboratorium für Teilchenphysik
Laboratorio europeo per la fisica delle particelle

Conclusion du CERN

PRESS RELEASE

New State of Matter created at CERN

10 Février 2000



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.

Mais pas de
consensus
général...

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PREMIERS RESULTATS de RHIC

July 18 1999

BRITAIN



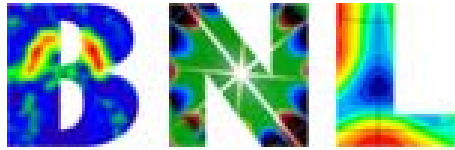
©

Ready for blastoff: a Brookhaven engineer puts finishing touches to the ion collider

Big Bang machine could destroy Earth

by [Jonathan Leake](#)
Science Editor

A NUCLEAR accelerator designed to replicate the Big Bang is under investigation by international physicists because of fears that it might cause "perturbations of the universe" that could destroy the Earth. One theory even suggests that it could create a black hole.

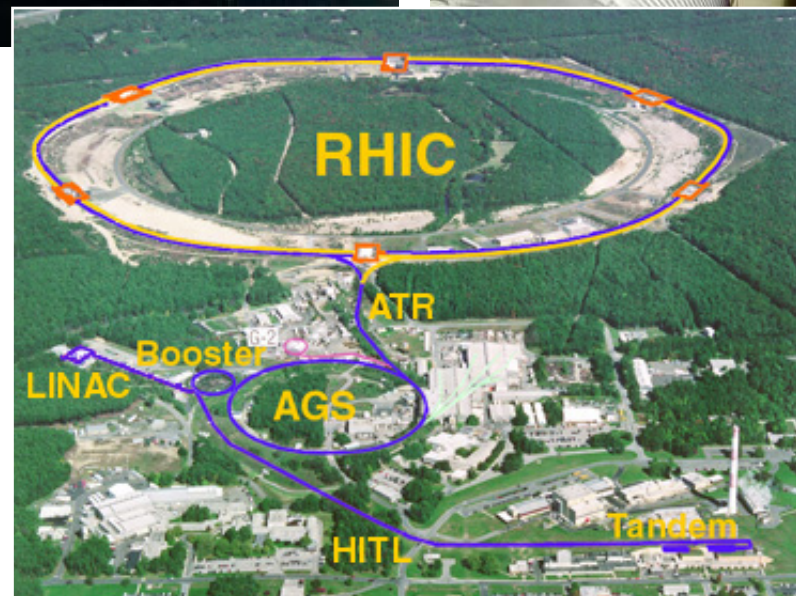


Relativistic Heavy Ion Collider



(run 2001)

- 60 paquets/anneau
- Croisement : 106 ns
- 10^9 Au/paquet
- $2 \times 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$
- 200 GeV/Nucléons

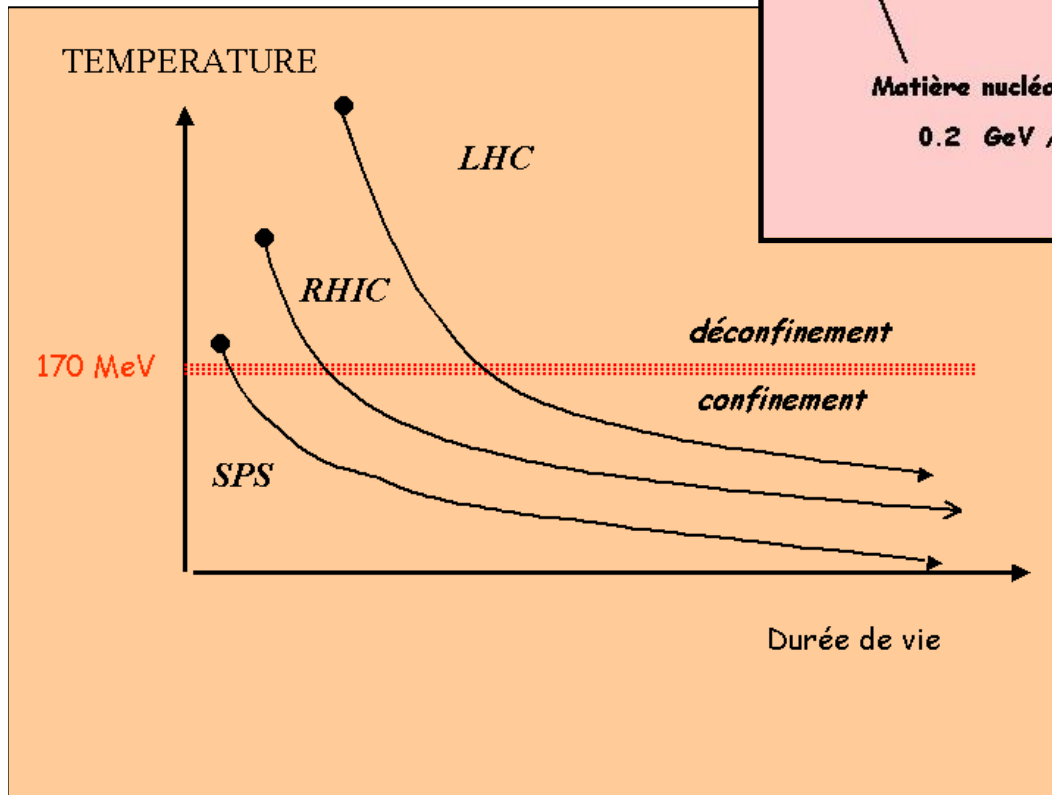
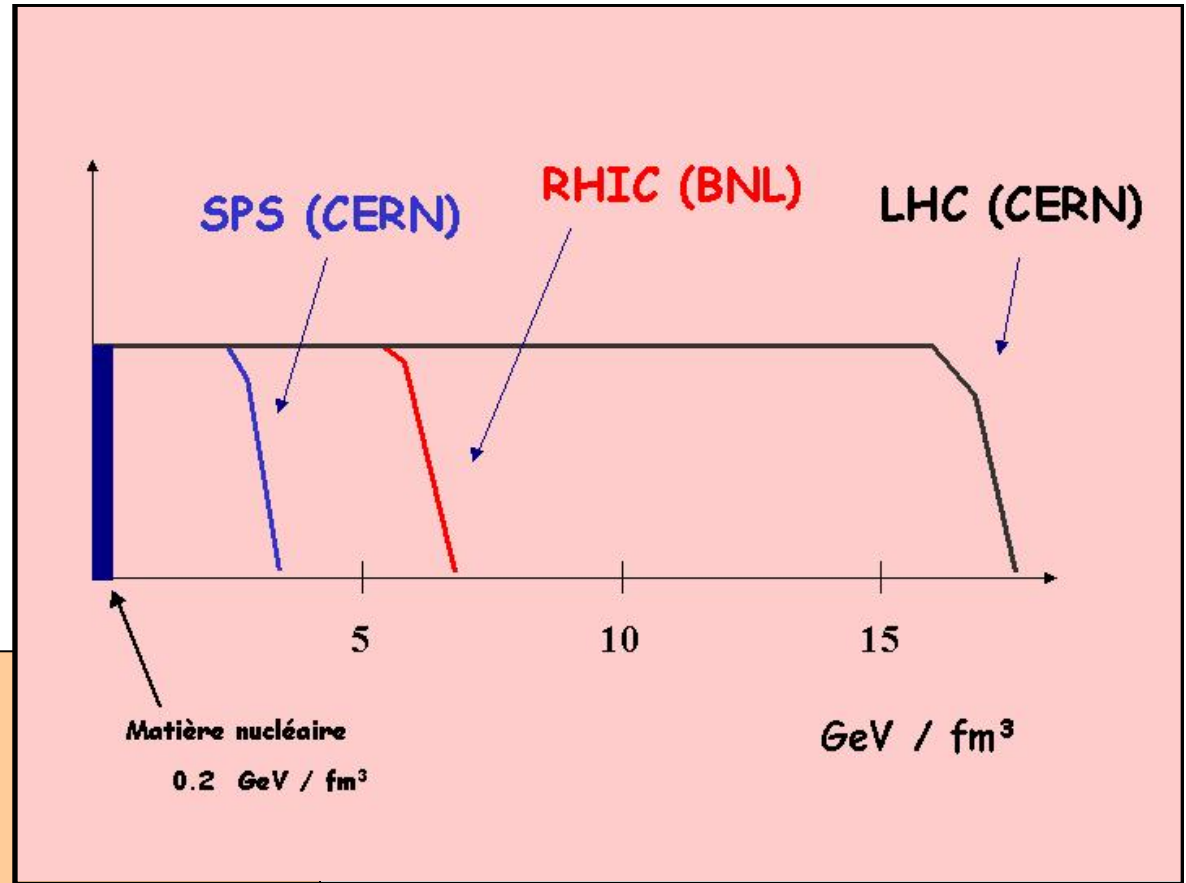


Aimants supra
3.5 Tesla

- Protons polarisés
- Autres noyaux

Mérites comparés

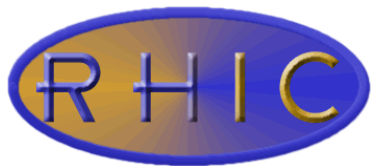
Densité d'énergie



Durée de vie du Plasma

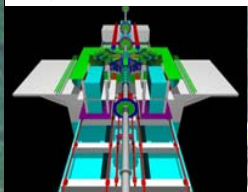
SPS : 1 fm/c $\sim 10^{-23}$ s

LHC ~ 10 fm/c

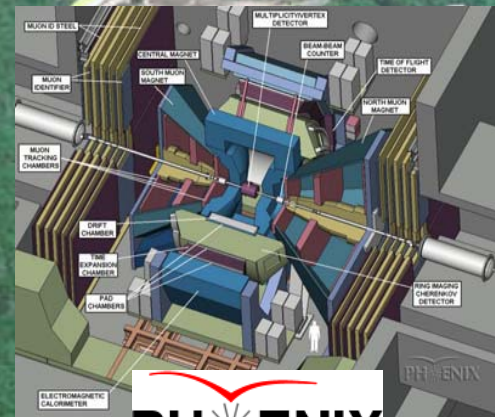
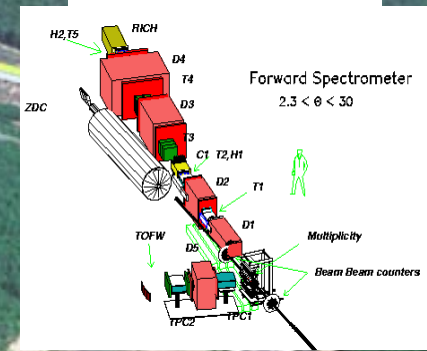


Relativistic Heavy Ion Collider

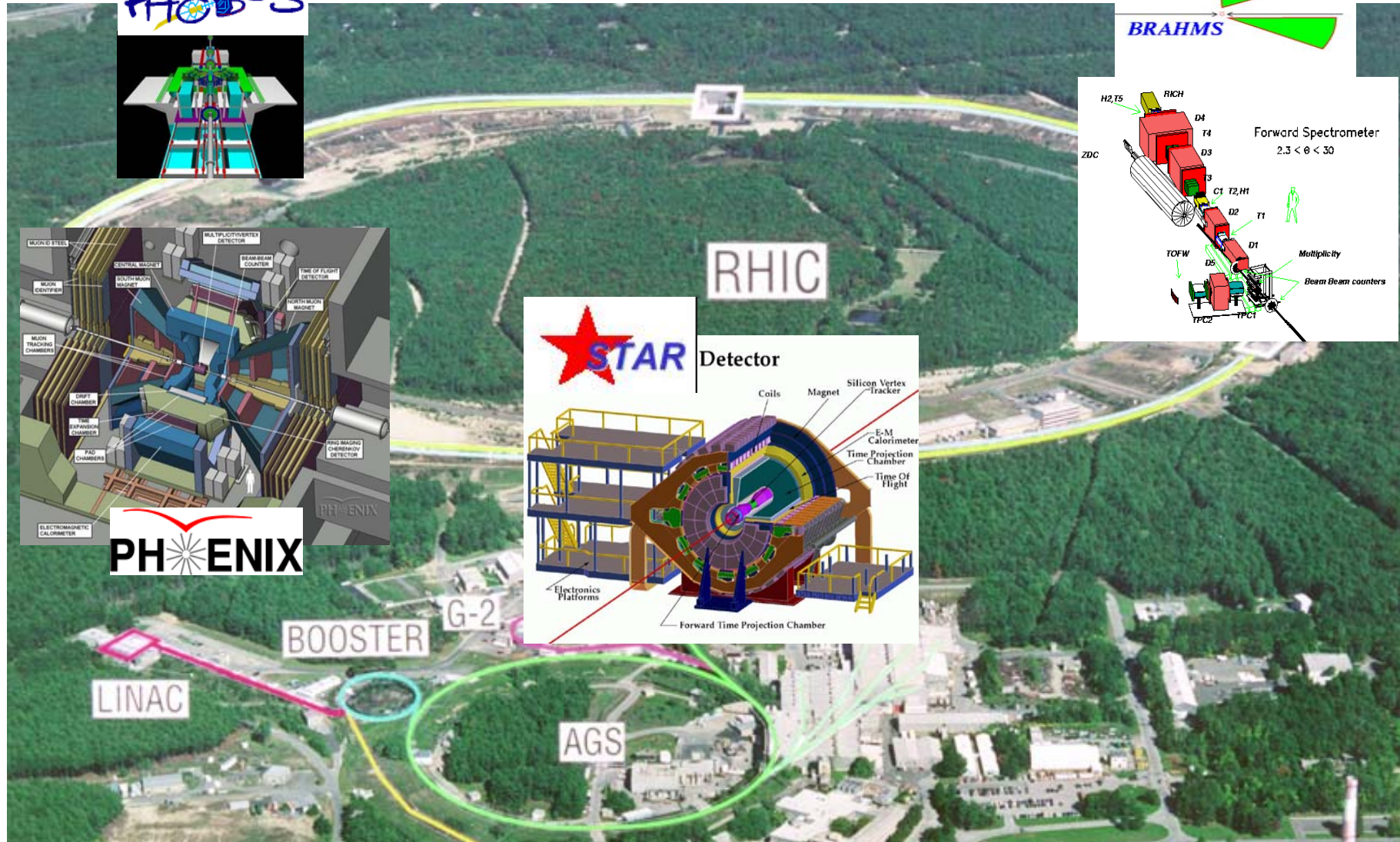
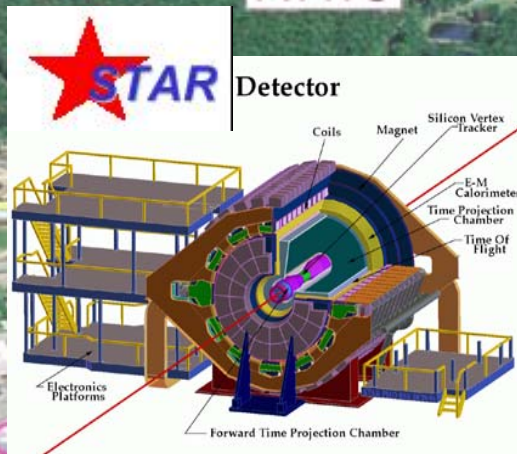
PHOBOS



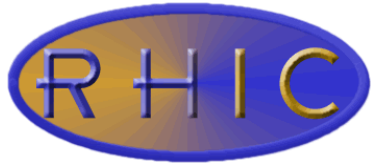
BRAHMS



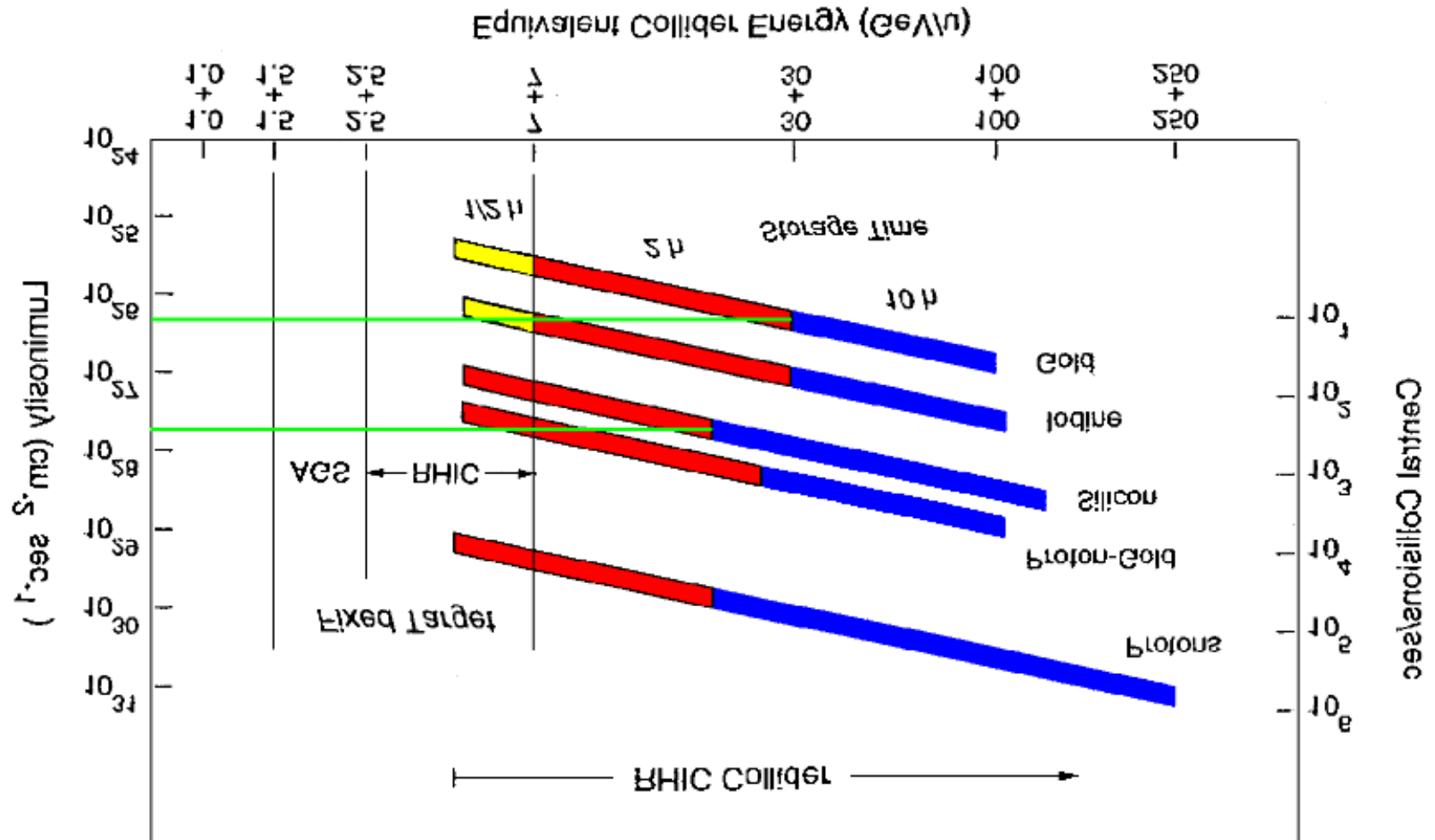
PHENIX



Quatre Expériences à RHIC : deux grandes, deux plus petites



Relativistic Heavy Ion Collider



Un collisionneur pour l'étude du plasma de quarks et de gluons

Participation française sur RHIC



IReStrasbourg, Subatech Nantes → **Hadrons**



<http://phenix-france.in2p3.fr/>

→ **Photons**

Subatech Nantes

→ **Dimuons**

Clermont Ferrand

CEA DAPNIA

IPN Orsay

LPNHE/Polytechnique

La participation française à l'expérience PHENIX

PHENIX

[English version](#) [Avec frames](#)

- [Le lien avec le site de l'expérience](#)
- [Les membres de la Collaboration](#) **UPDATED** Jan 12, 2000 [E-MAIL](#)
- [Nos pages privées](#) **UPDATED** Jun 6, 2001
- [Informations hardware](#) **UPDATED** May 10, 2001
- [Informations software](#) **UPDATED** Jun 11, 2001
- [La page PHENIX à Subatech](#)
- [Informations sur le run 2001](#) **UPDATED** Mar 07, 2001

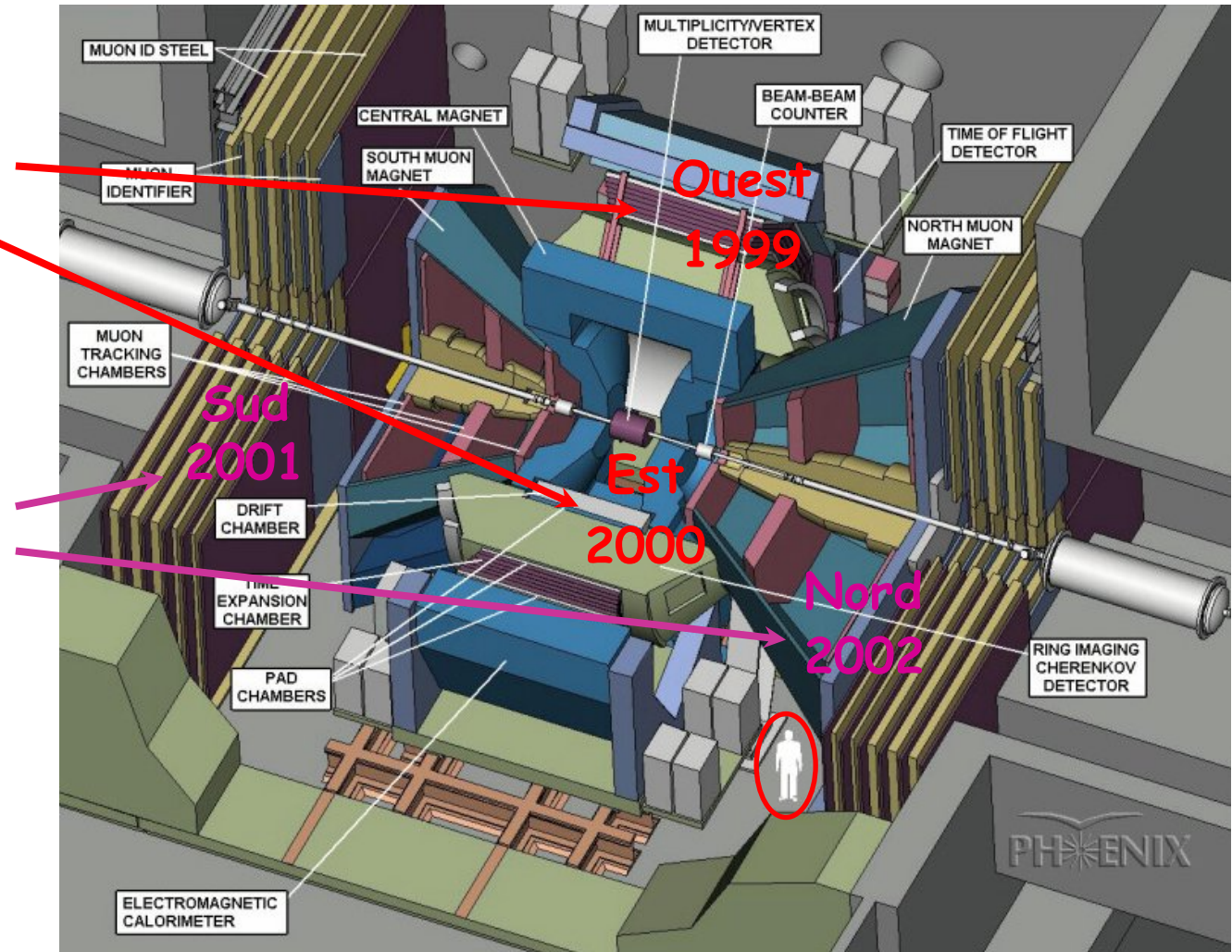


PHENIX

Deux spectromètres centraux

Deux spectromètres avant

Trois détecteurs globaux



Participation française au détecteur PHENIX

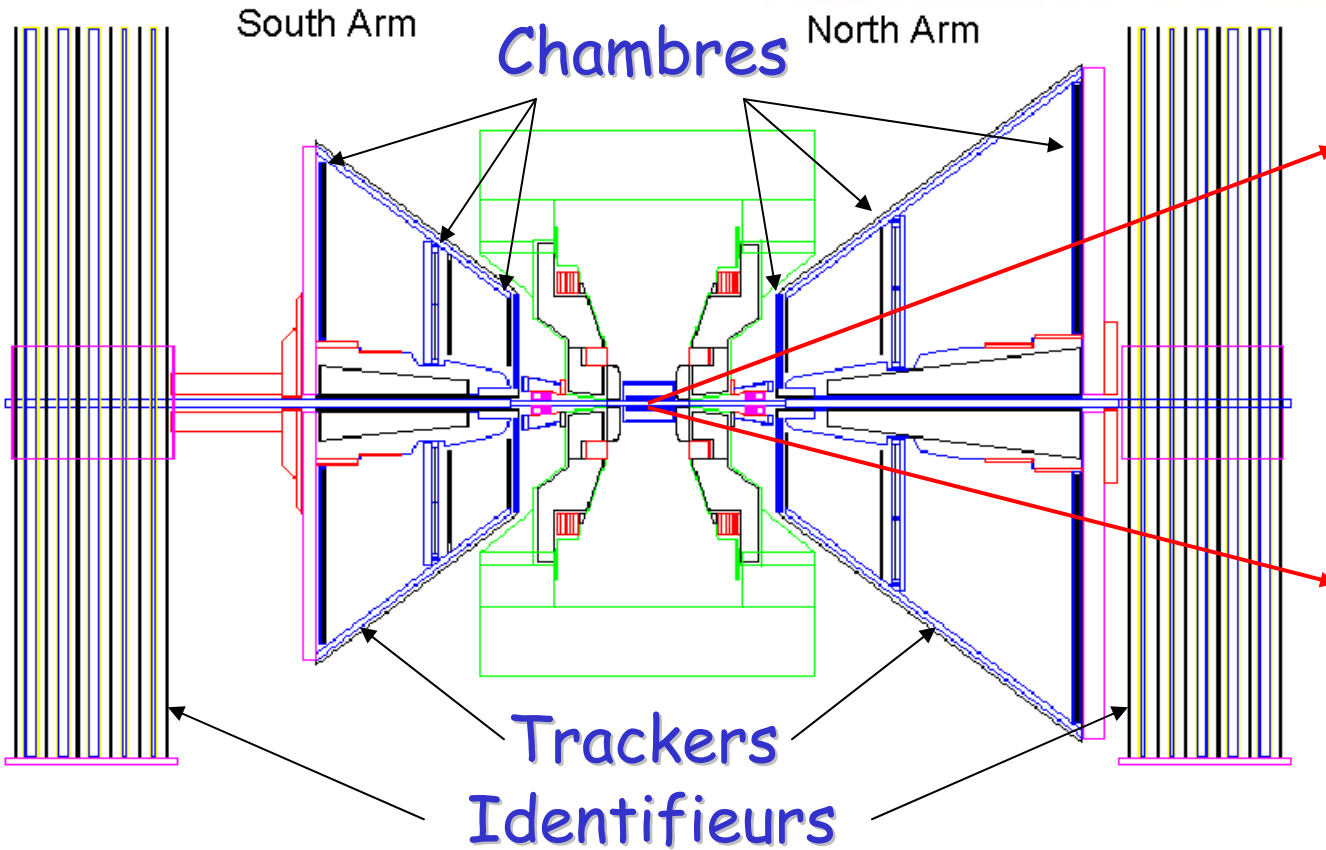
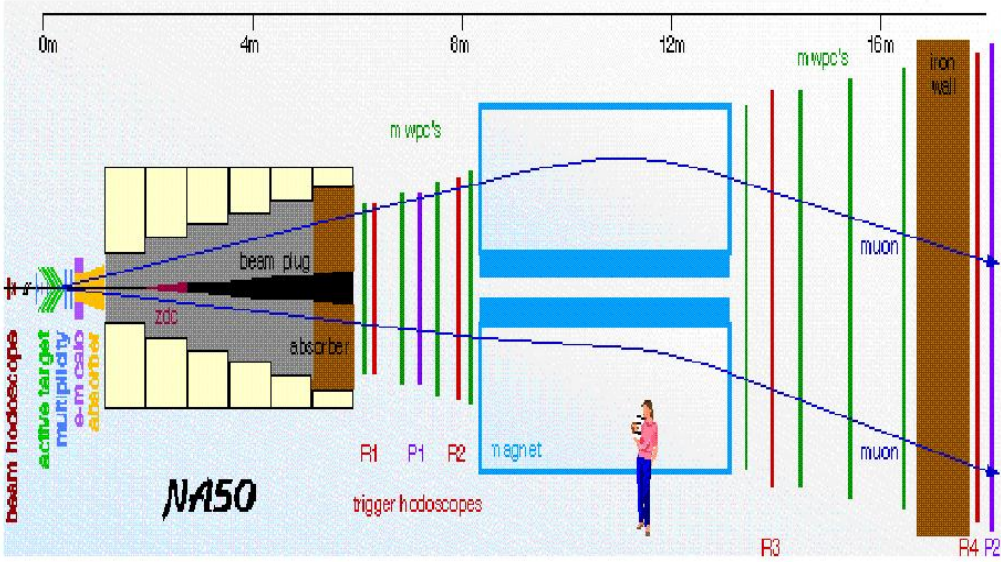
Électronique du bras nord

- La production représente :
 - 124 Cartes Fond de panier
 - 248 Cartes Logique
 - 496 Cartes Analogique
- Le test sera organisé de la manière suivante:
 - Test de niveau I développé au PNHE
 - Test de niveau II effectué à BROOKHAVEN avant installation

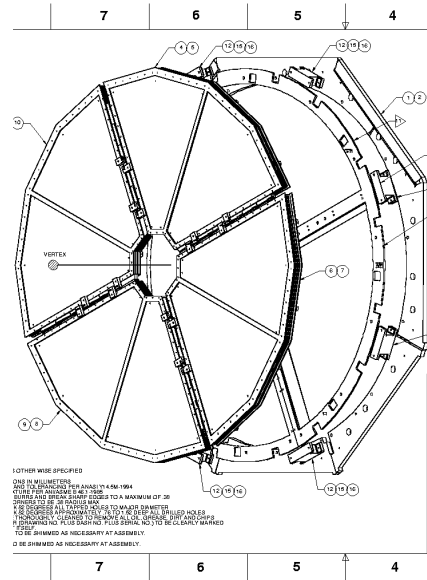


(prototype des cartes CROC)

Bras dimuons NA50/PHENIX



Muons



Taux de charmonia (ψ , ψ') dans PHENIX

$$N_{\text{evt}} = \text{Luminosité} \times s(\psi) \times B(\psi \rightarrow \mu\mu) \times \text{Acceptance}$$

- **Luminosité** = $2 \cdot 10^2 \text{ b}^{-1} / \text{s}$


$$\Delta t = 36 \text{ semaines} , \text{ L.T.} \sim 100\% , \text{ D.F.} \sim 50\%$$

- **Acceptance** = 4 % , **$B(\psi \rightarrow \mu\mu)$** = 6 %

- $s^{\text{NN}}(\psi) = 3 \times 10^{-6} \text{ b}$ (extrap. à $\sqrt{s} = 200 \text{ GeV}$)

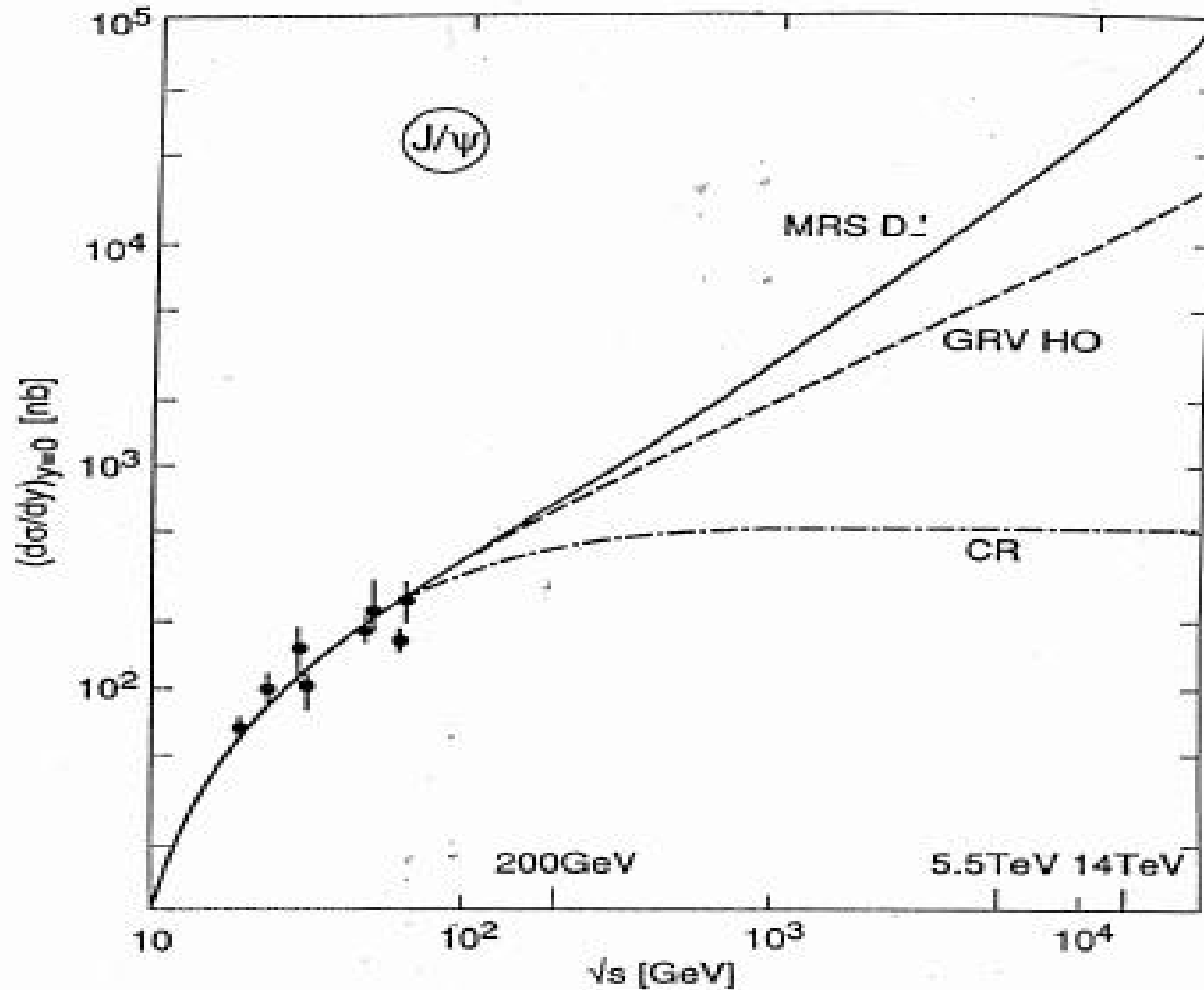
$$s^{\text{Au-Au}}(\psi) = (197 \times 197)^{0.90} \times 3 \times 10^{-6} \text{ b} = 4 \times 10^{-2} \text{ b}$$

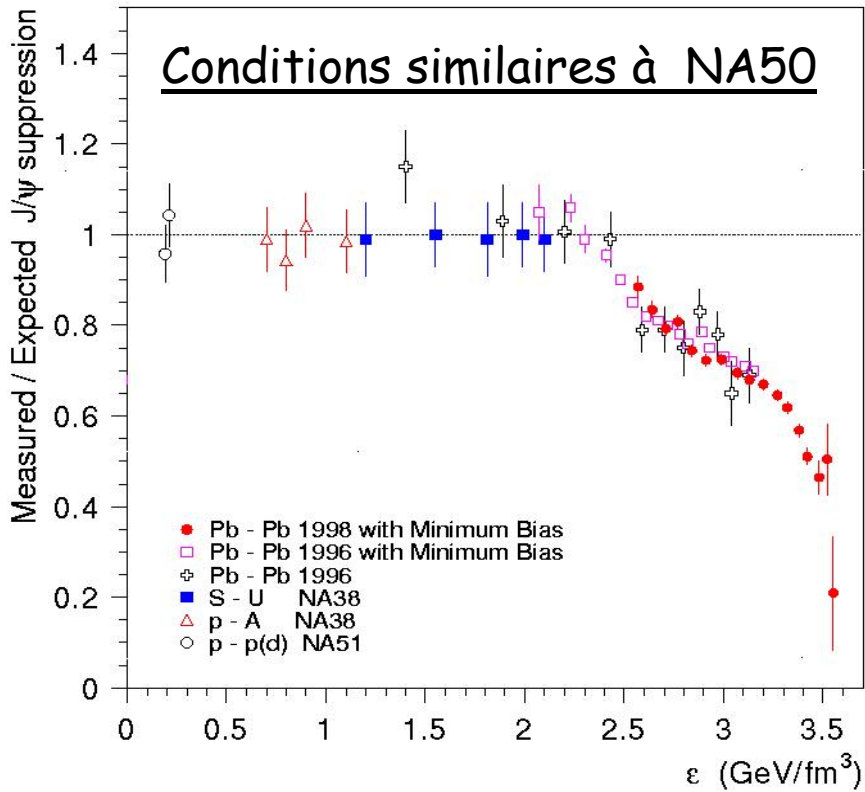
$$(s^{\text{Pb-Pb}}(\psi) = 10^{-3} \text{ b au CERN } \sqrt{s} = 17 \text{ GeV})$$


$$\begin{aligned} N(\psi) &\sim 4 \times 10^5 \\ N(\psi') &\sim 4 \times 10^3 \end{aligned} \quad / \text{ an en Or+Or}$$

Sans écrantage !...

Taux de charmonia (ψ, ψ') dans PHENIX



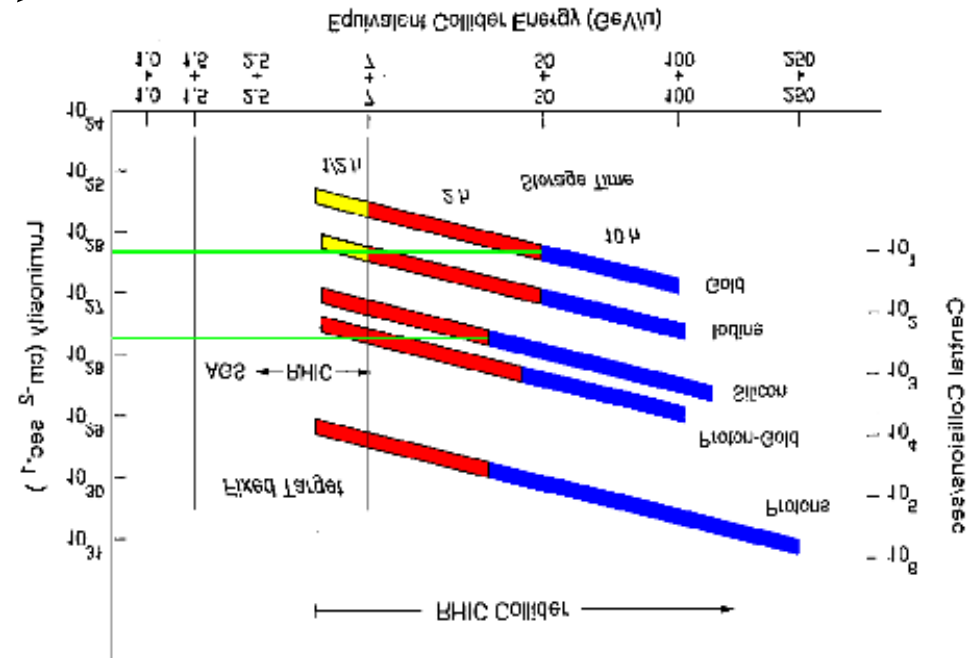


	SPS	RHIC
$3 \text{ GeV}/\text{fm}^3$	Pb - Pb	Cu - Cu
$1 \text{ GeV}/\text{fm}^3$	S - S	C - C

si ϵ est la bonne variable...

$$N^{\text{Cu-Cu}}(\psi) \cong 5 \cdot 10^6 / \text{an}$$

$$N^{\text{C-C}}(\psi') \cong 5 \cdot 10^4 / \text{an}$$

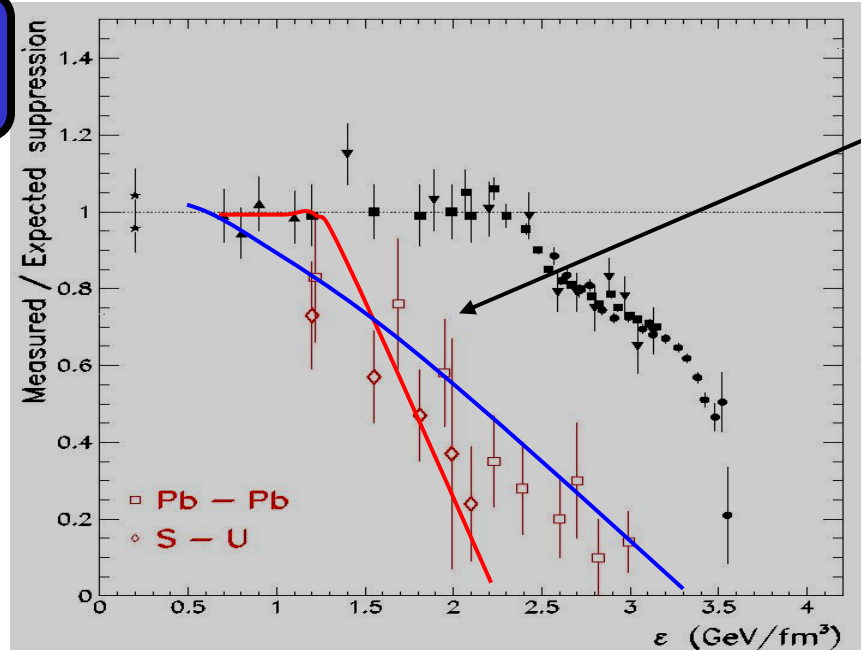


ψ' dans PHENIX

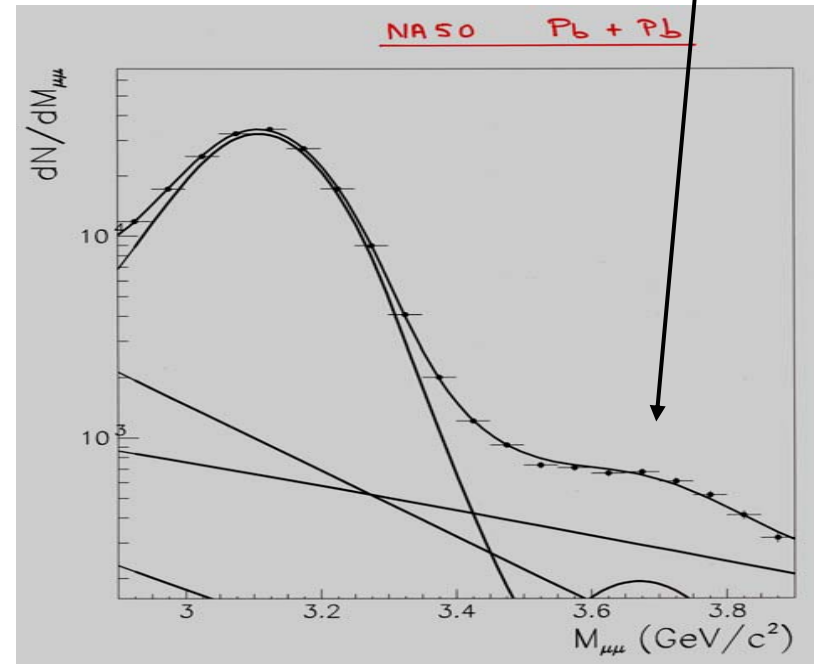
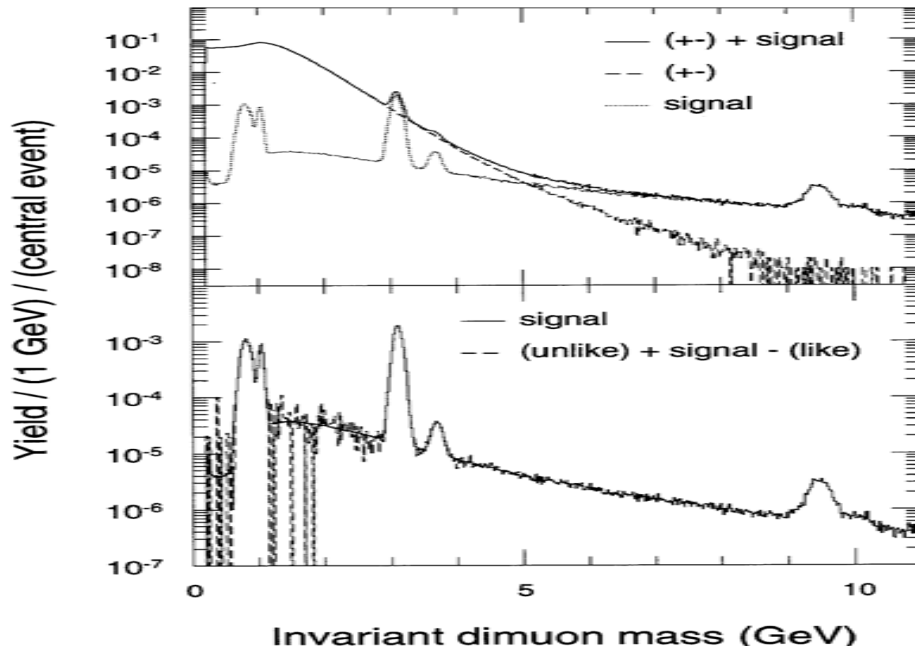
Dissociation ?

Screening ?

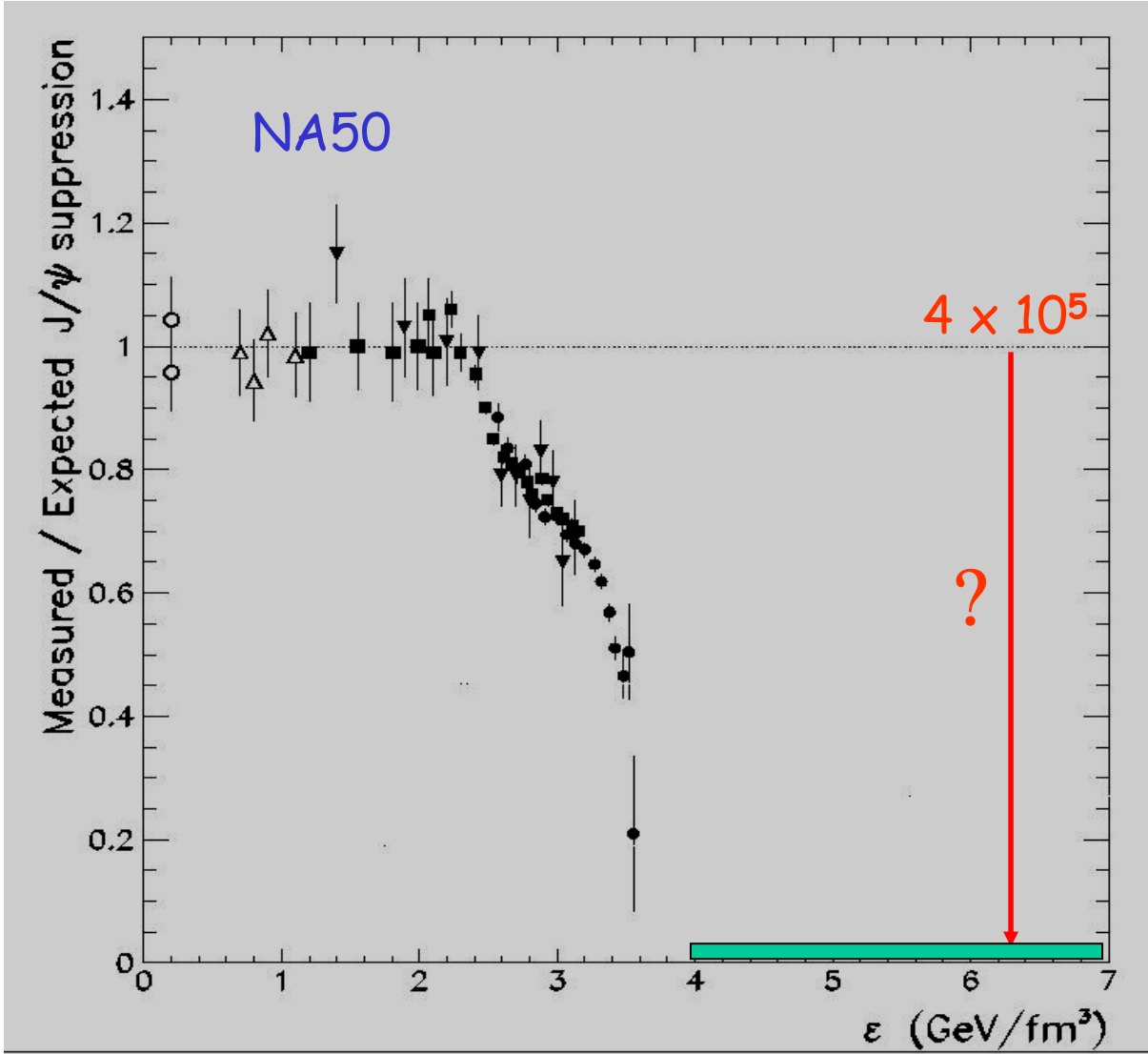
Phenix
50000 ψ'



NA50
600 ψ'



ψ dans PHENIX



Désintégrations de mésons B ?

$B \rightarrow \psi + \dots$

$\Gamma_i / \Gamma = 2 \times 10^{-3}$

$\sigma_{bb} / \sigma_{\Upsilon} \sim 10^2$

$(\sigma_{cc} / \sigma_{\psi} \sim 10^2)$

Pas d'écrantage

Pas de dissociation

↓

$N(\psi) \sim 7000 / \text{an}$

Simulations en cours ...

Taux de bottomia (Υ^*) dans PHENIX

Acceptance = 2 % , $B(\psi \rightarrow \mu\mu) = 2\%$

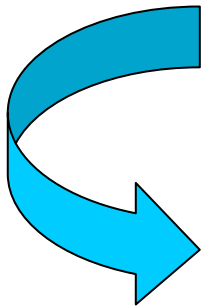
$$\Upsilon_T = \Upsilon + \Upsilon' + \Upsilon'' = \Upsilon + \Upsilon^*$$

$$s^{NN}(\Upsilon_T) = 3 \times 10^{-8} \text{ b} \quad (\sqrt{s} = 200 \text{ GeV})$$

$$s^{AuAu}(\Upsilon_T) = (197 \times 197)^{0.96} \times s^{NN}(\Upsilon_T)$$

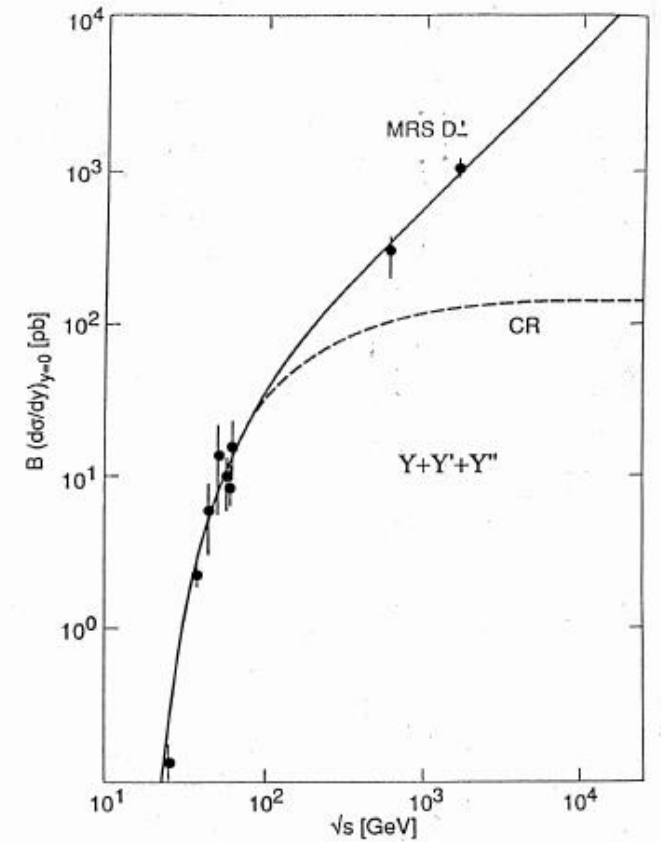


$$\begin{aligned} N(\Upsilon_T) &\cong 1200 \\ N(\Upsilon^*) &\cong 400 \end{aligned} \quad / \text{ année en Au+Au}$$



Mais écrantage aussi en Cu+Cu

$$\begin{aligned} N(\Upsilon_T) &\cong 15000 \\ N(\Upsilon^*) &\cong 5000 \end{aligned} \quad / \text{ année en Cu+Cu}$$



Sans écrantage !...

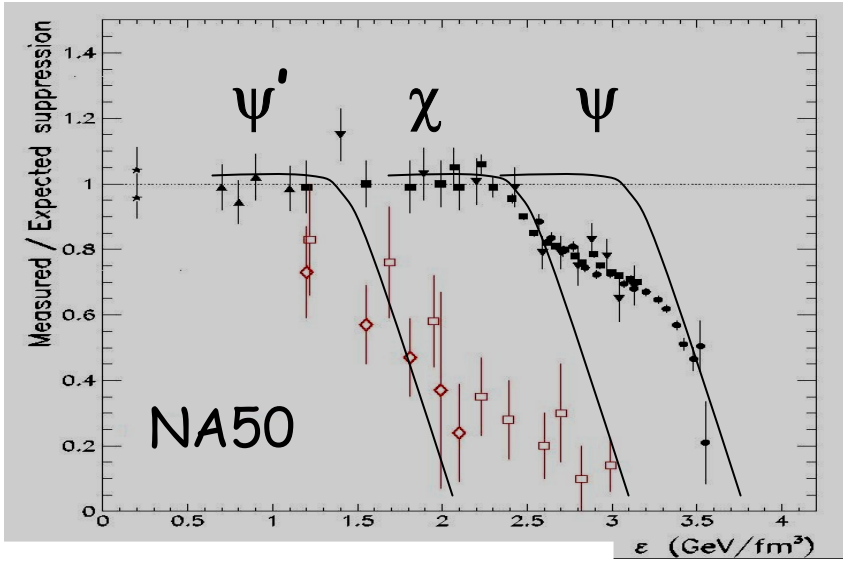
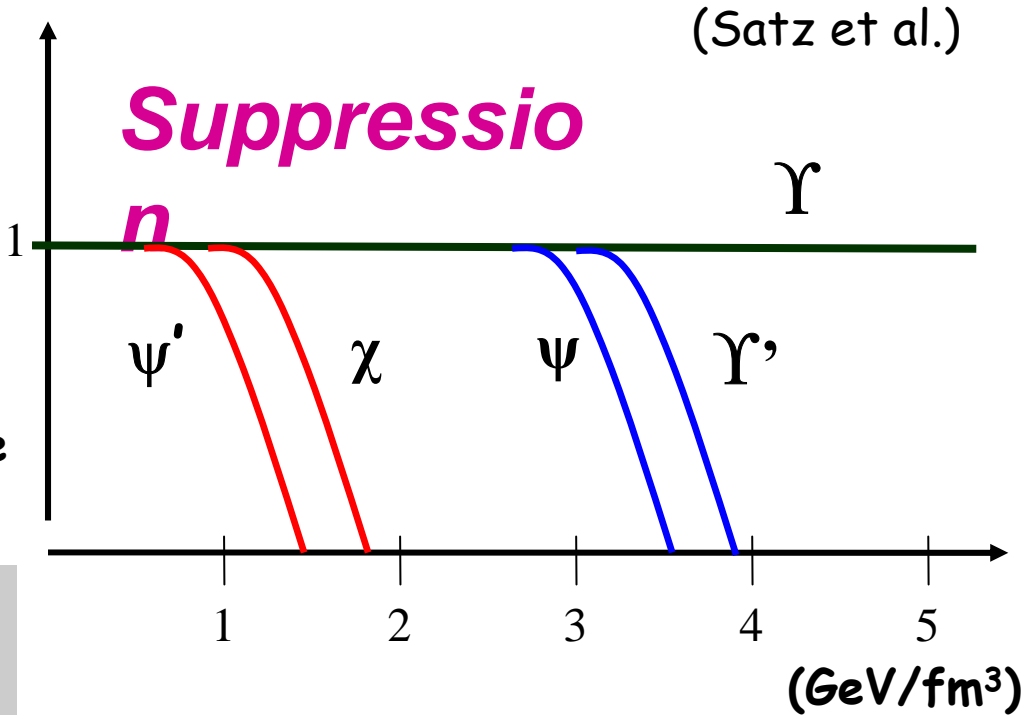
Écrantage des quarkonia

Température d'écrantage

ψ'	40	T_c	1.0
χ	240	T_c	1.0
ψ	670	$1.4 T_c$	3.8
Υ'	640	$1.4 T_c$	3.8
Υ	1100	$3.2 T_c$	100

Energie de Liaison (MeV)

Densité d'énergie (GeV/fm³)



Υ peut servir de référence à RHIC

Résumé : études de quarkonia dans PHENIX

Possibilités d'études :

Physique du ψ' : écrantage et/ou dissociation

Physique du Υ^* : écrantage (prédiction de T_e)

Nouvelle référence pour ces processus :

SPS – CERN (NA50)

→ *Drell -Yan*

→ *Mini bias (D – Y)*

- $\psi / (D-Y)$

RHIC (PHENIX)

Υ (*Heavy Quark Bound State*)

- ψ' / Υ

- Υ^* / Υ

- ψ / Υ

COLLISION D'IONS LOURDS au SPS (CERN) et à RHIC (Brookhaven)

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PREMIERS RESULTATS de RHIC

2000 : première prise de données à RHIC

Première collision :

15 juin 2000

Dernière collision :

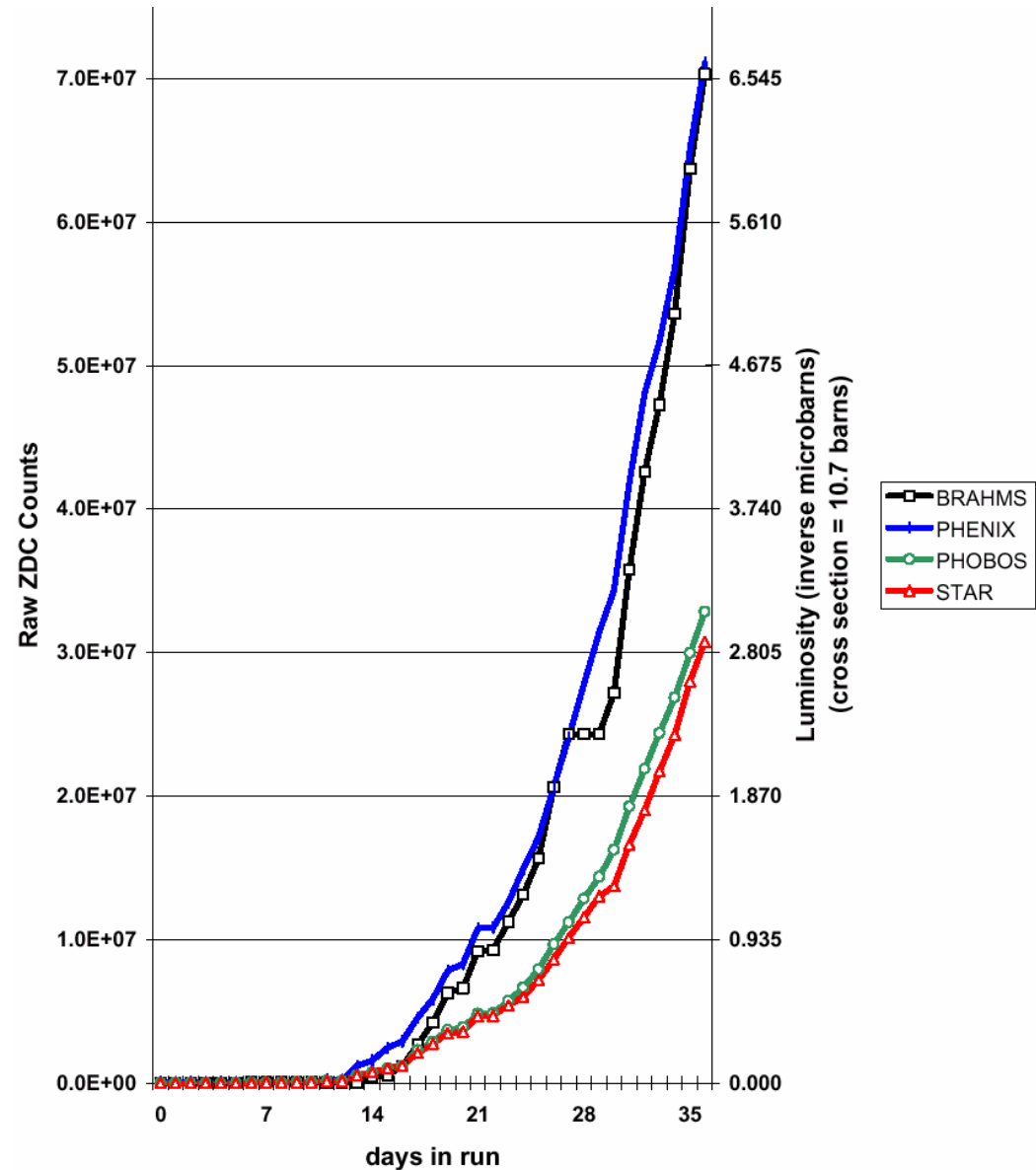
04 sept. 2000

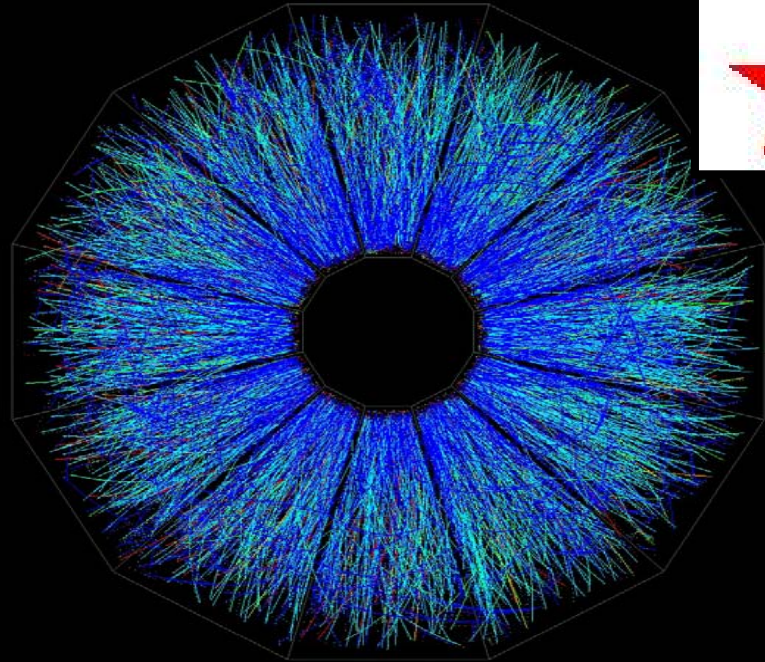
60 paquets/anneau

5×10^8 Au/paquet

$2 \times 10^{25} \text{ cm}^{-2} \text{ s}^{-1}$

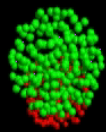
130 GeV/Nucléons



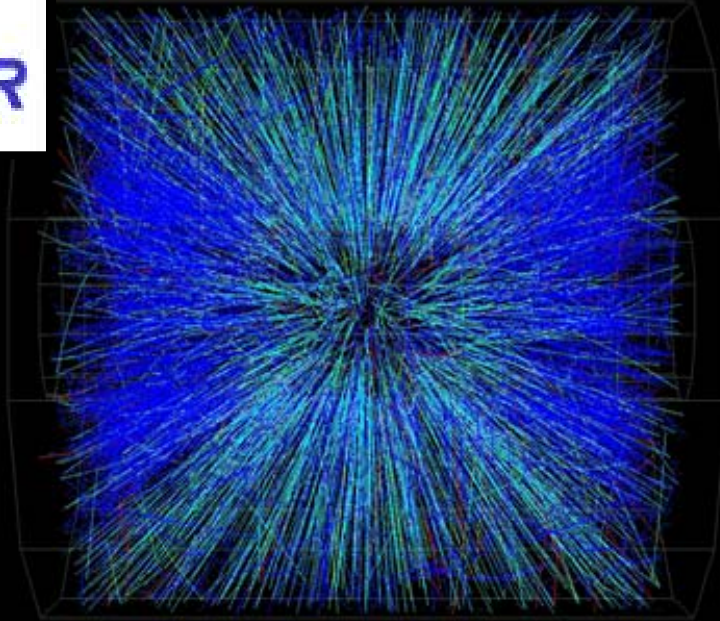


Pb+Pb 160 GeV/A

$t = -0.1732$ fm/c

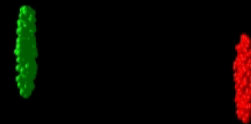


UrQMD Frankfurt/M



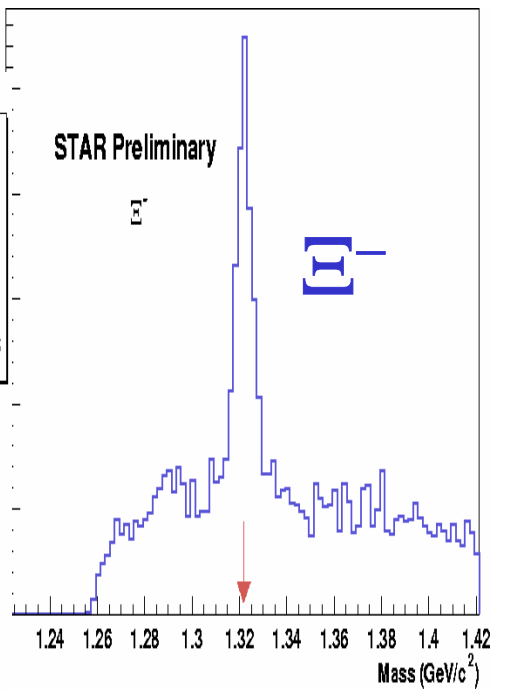
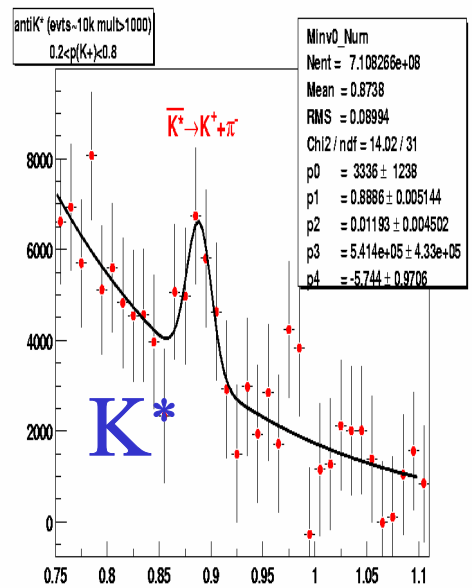
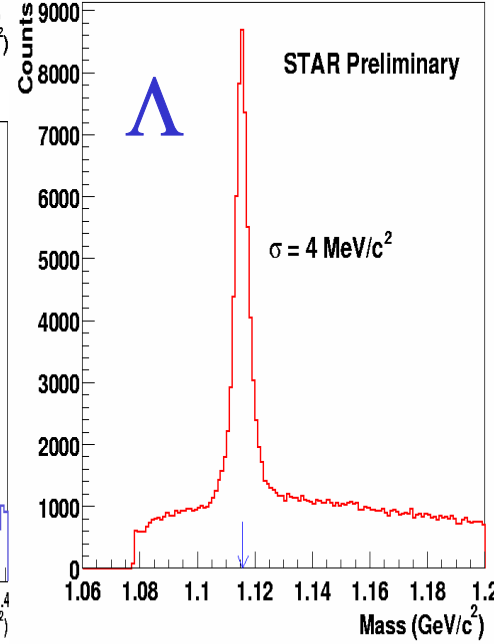
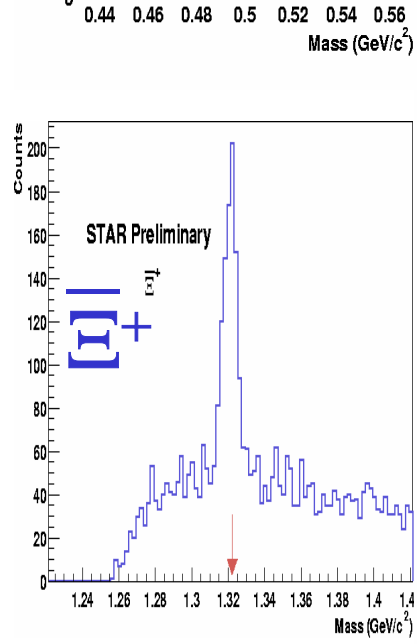
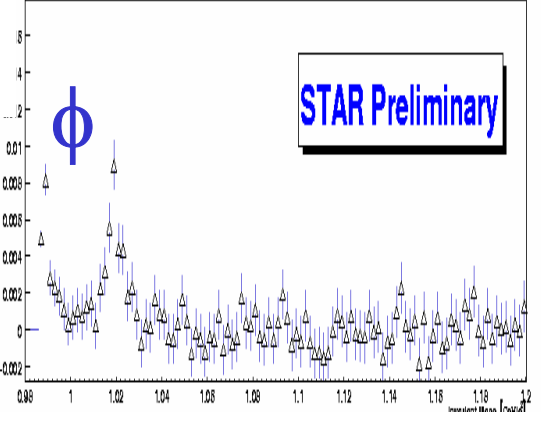
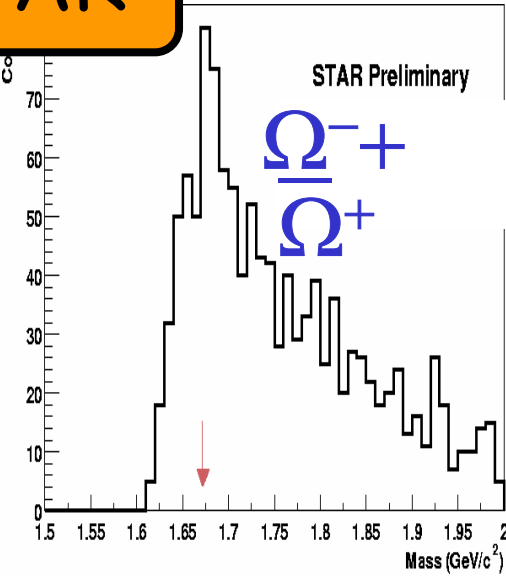
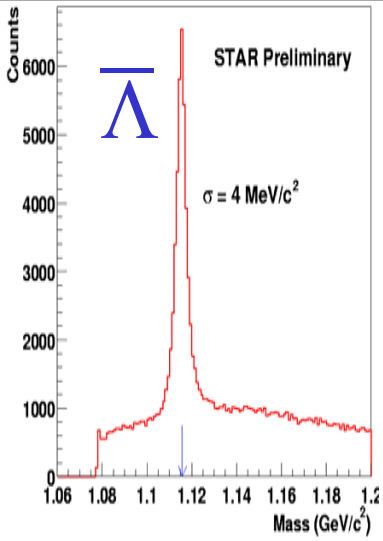
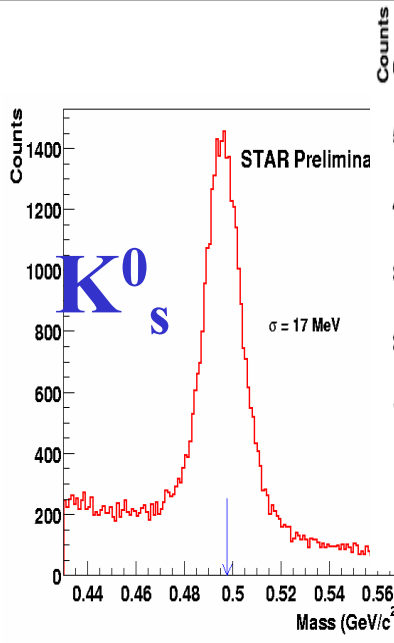
Pb+Pb 160 GeV/A

$t = -0.1732$ fm/c



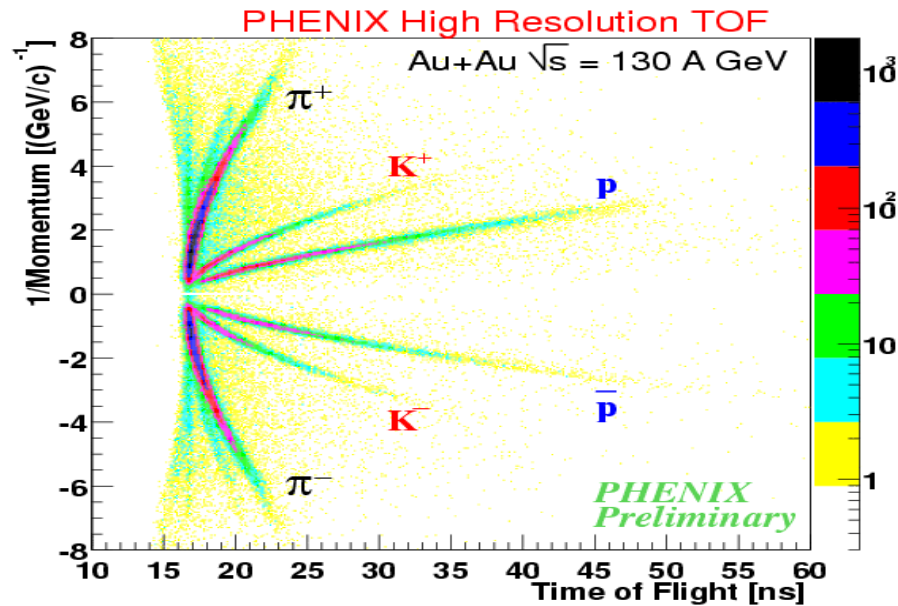
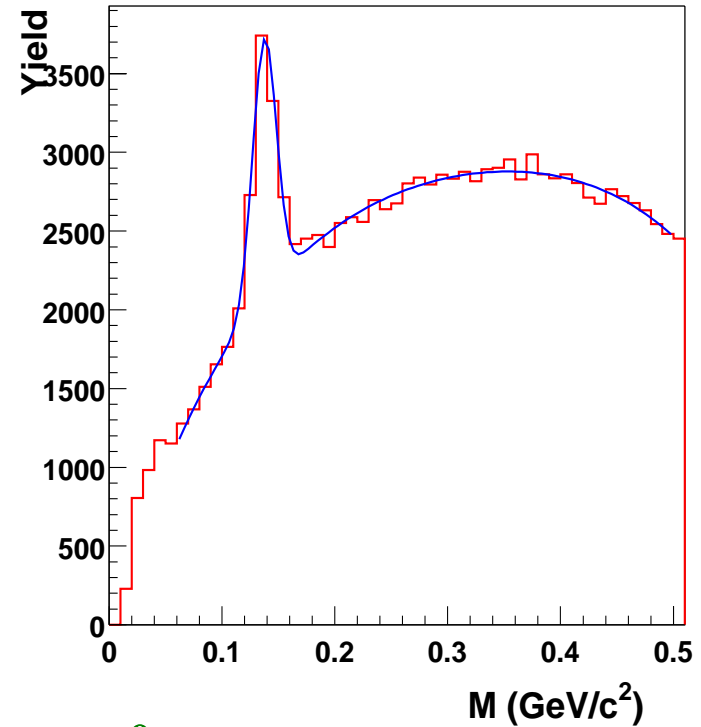
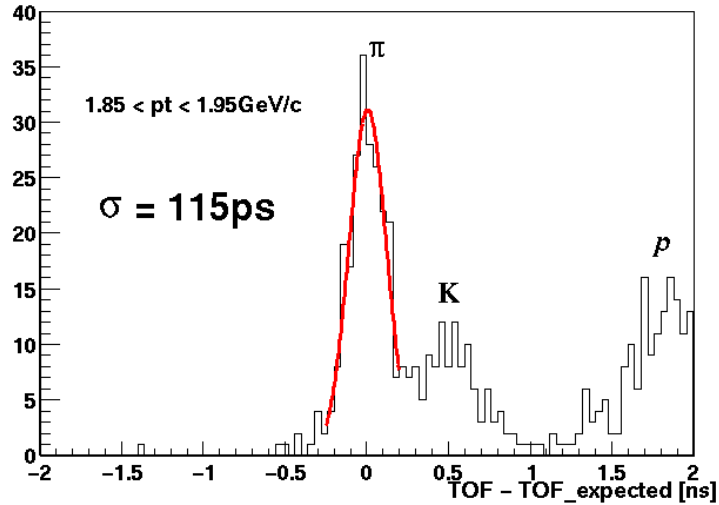
UrQMD Frankfurt/M

Les hadrons de STAR



(QM2001 : J. Harris et al.)

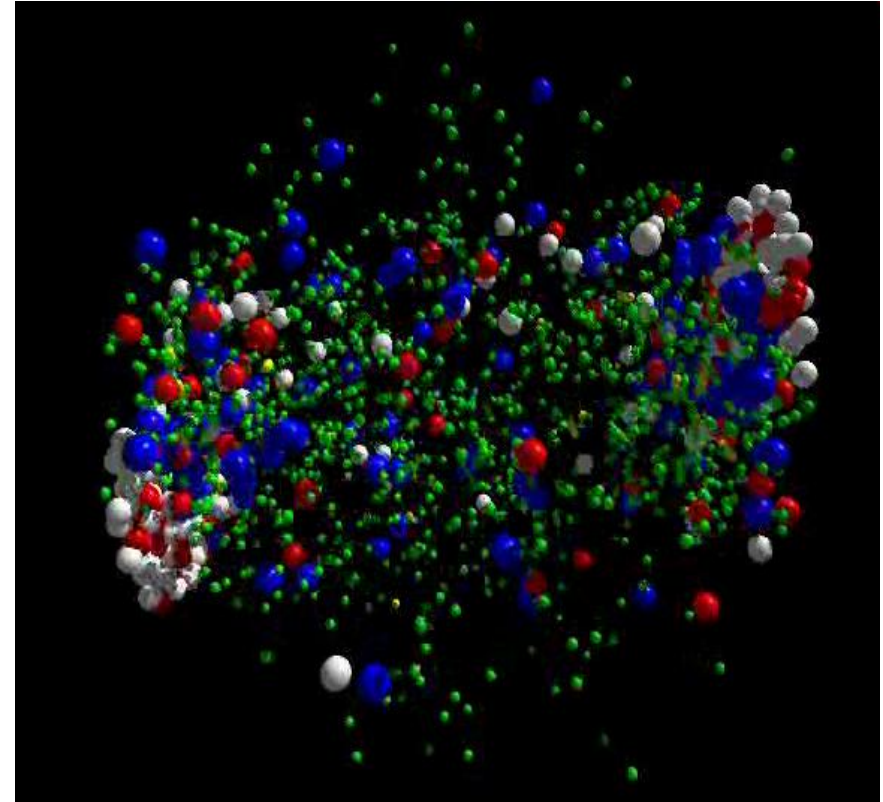
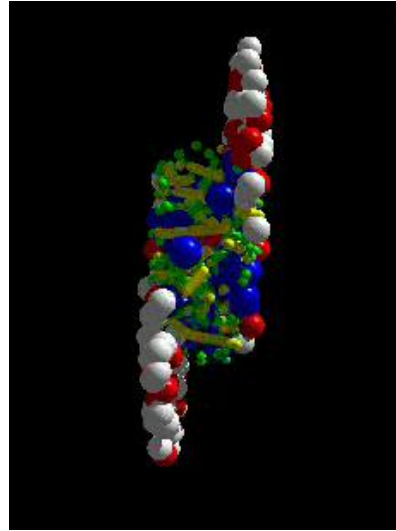
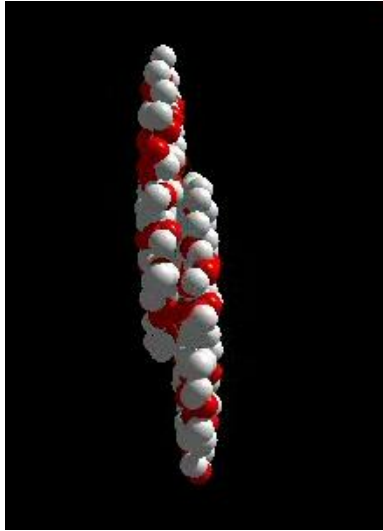
Identification dans PHENIX



π^0 's
 $p_T > 2\text{ GeV}$, asym < 0.8

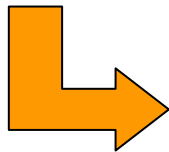
(QM2001 : W. Zajc et al.)

Sélection de Résultats de RHIC



Conditions initiales

- Transparence baryonique
- Densité d'énergie



Premiers instants

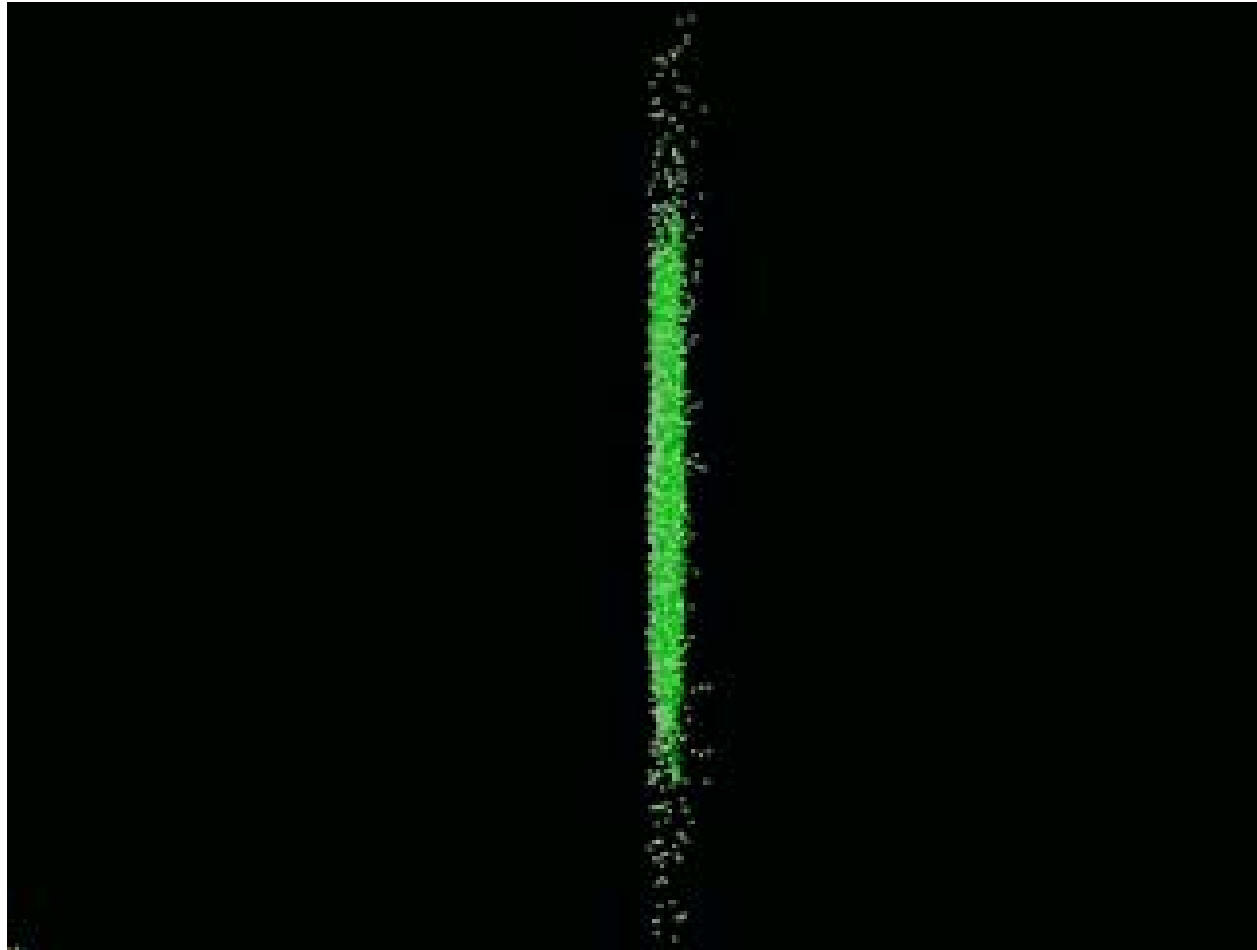
- Jet quenching ?
- Flux elliptique



Refroidissement & hadronisation

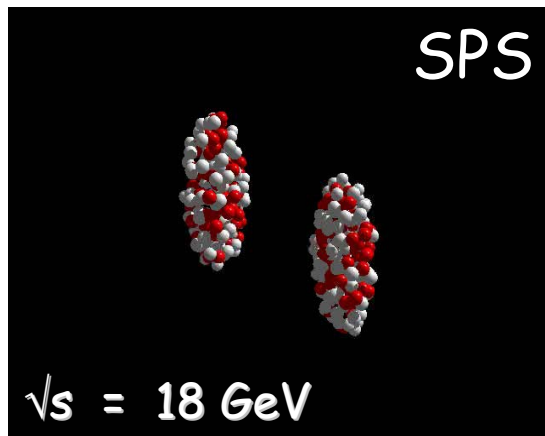
1. Conditions initiales à RHIC

Densité baryonique à l'origine du petit bang ?



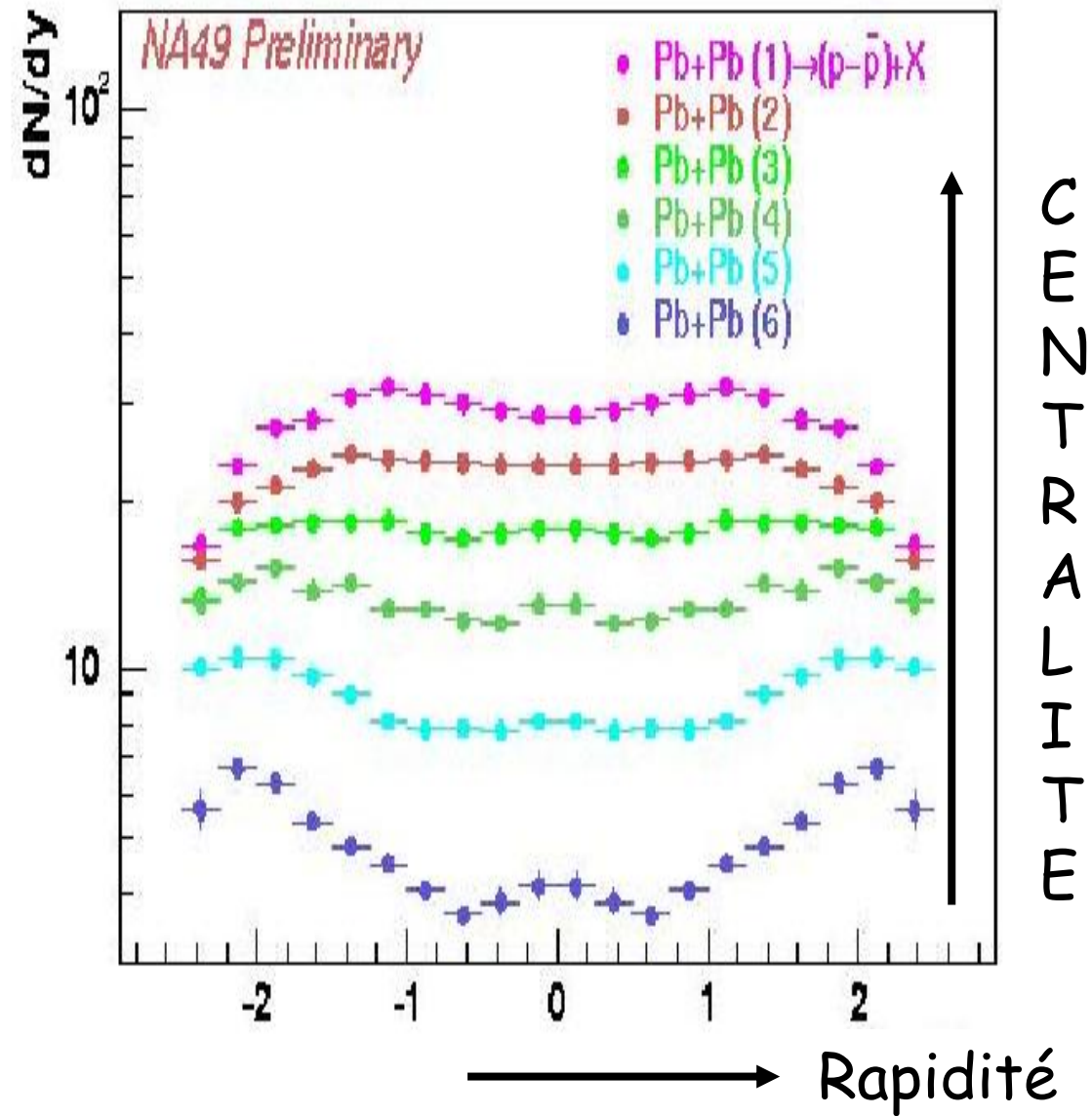
Simulation de transparence à RHIC

Transparence
au SPS ?

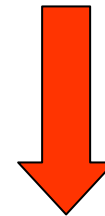
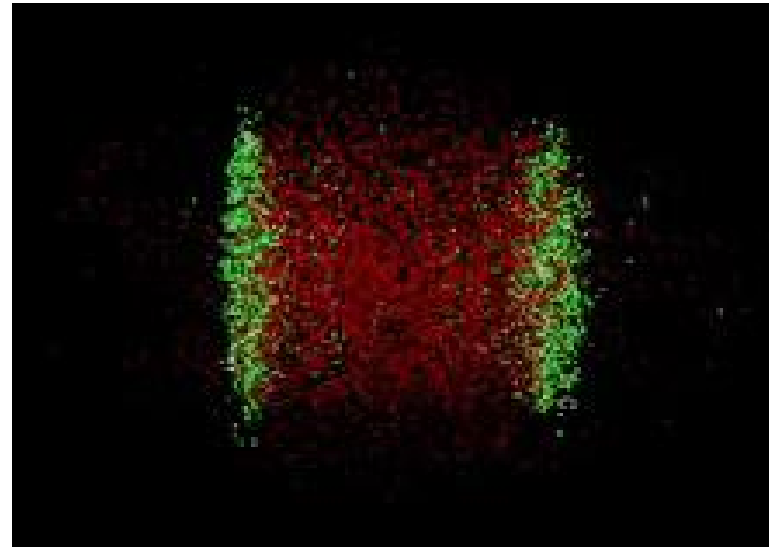
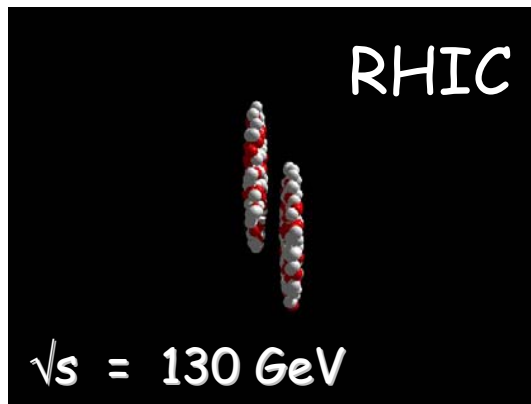


→ Légère
transparence

Nombre de protons - antiprotons



Transparence
à RHIC !



Pas de « baryons »

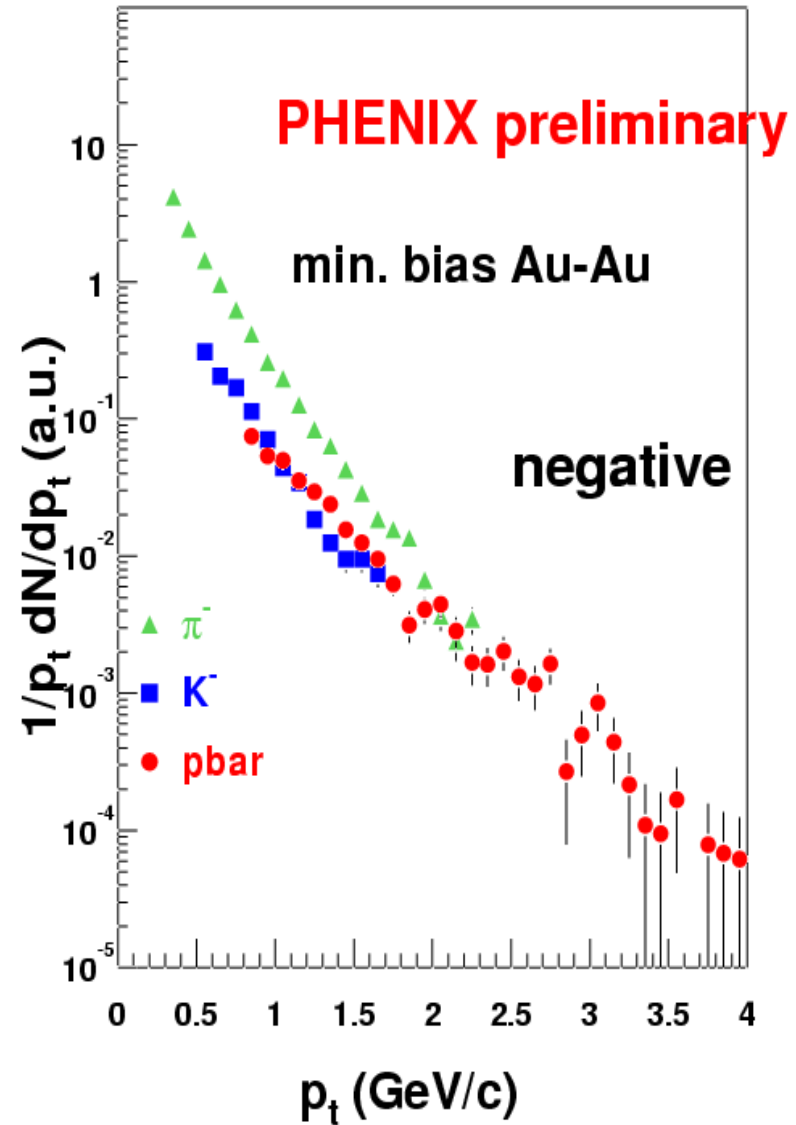
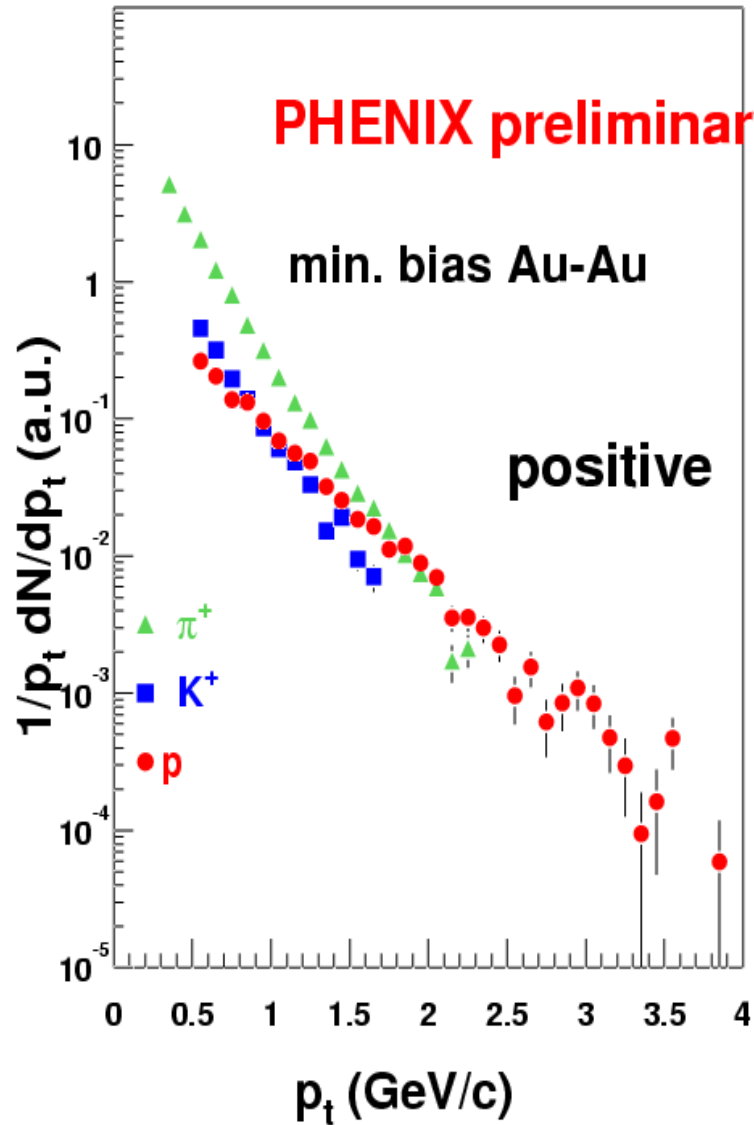
$$n_B = 0$$

$$n(q) \approx n(\bar{q})$$

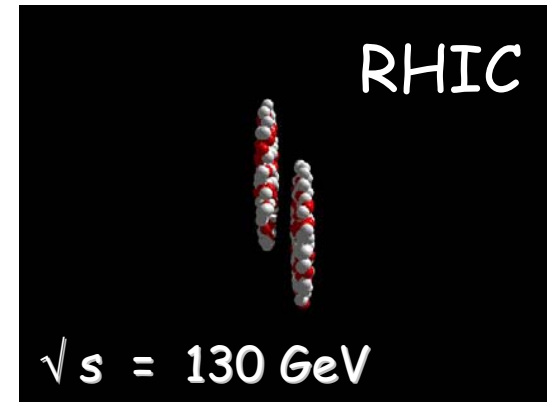
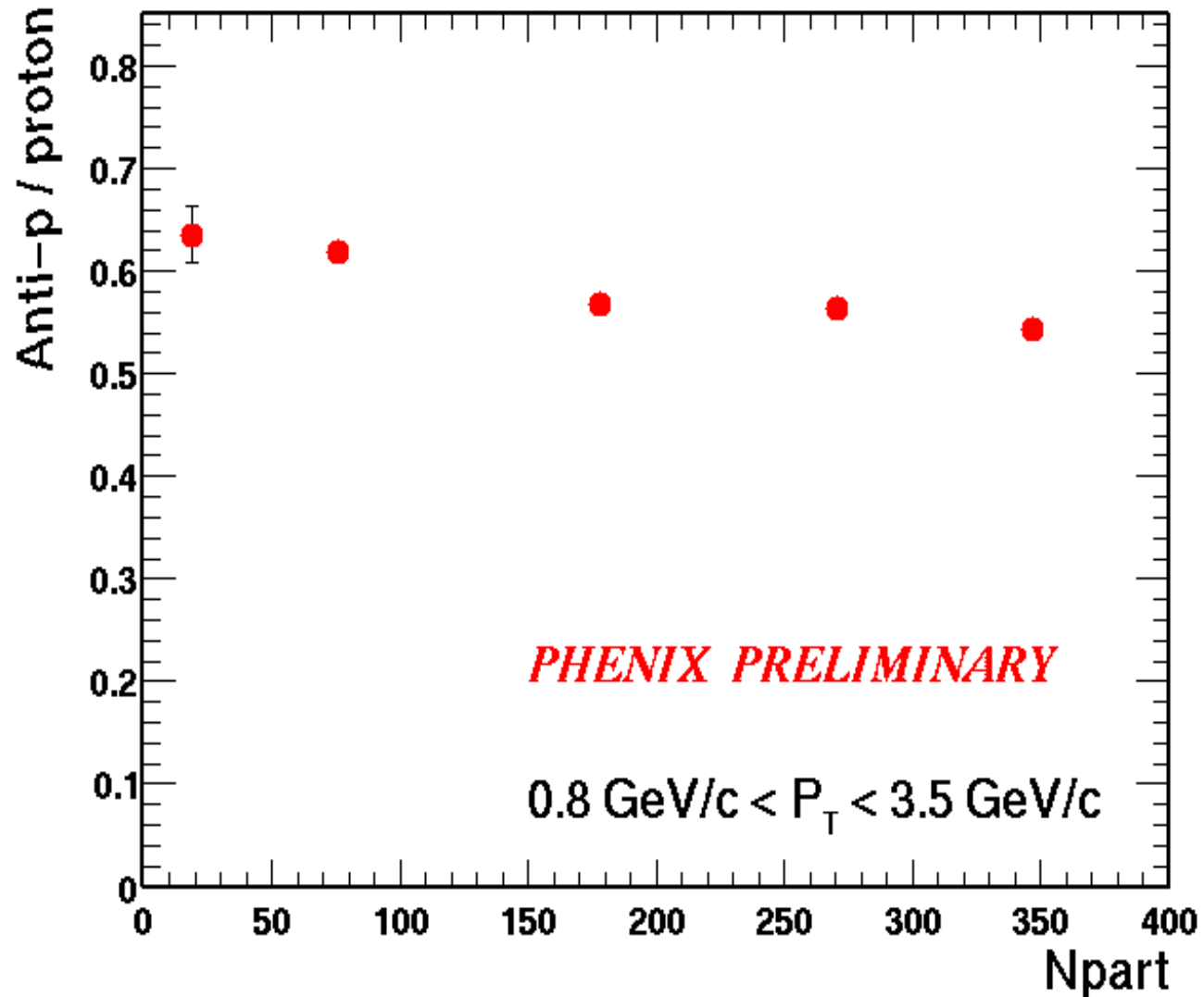


Rapports particule /
antiparticule

Spectres dans PHENIX

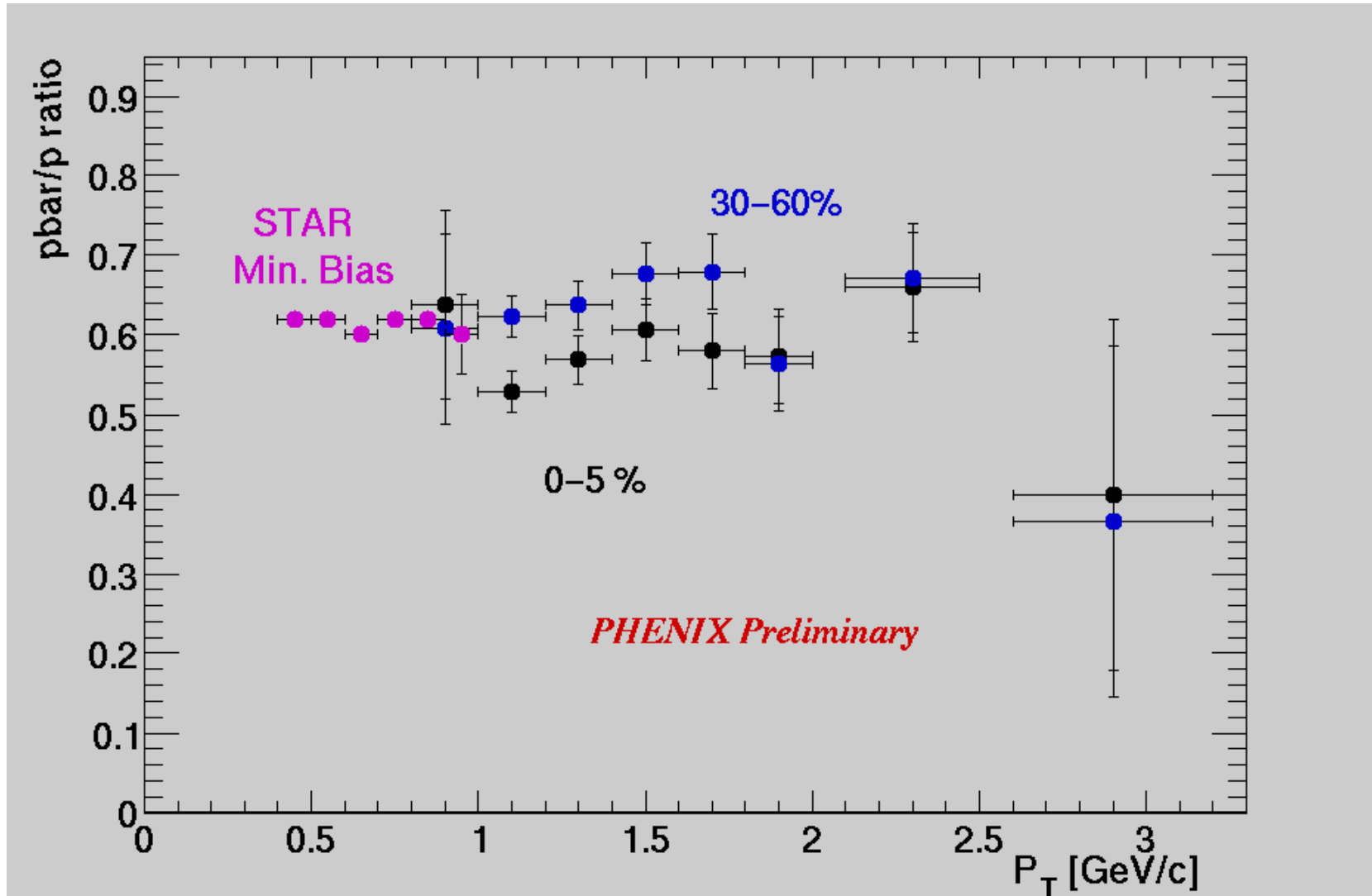


Proton/antiproton dans PHENIX



~ 60 %

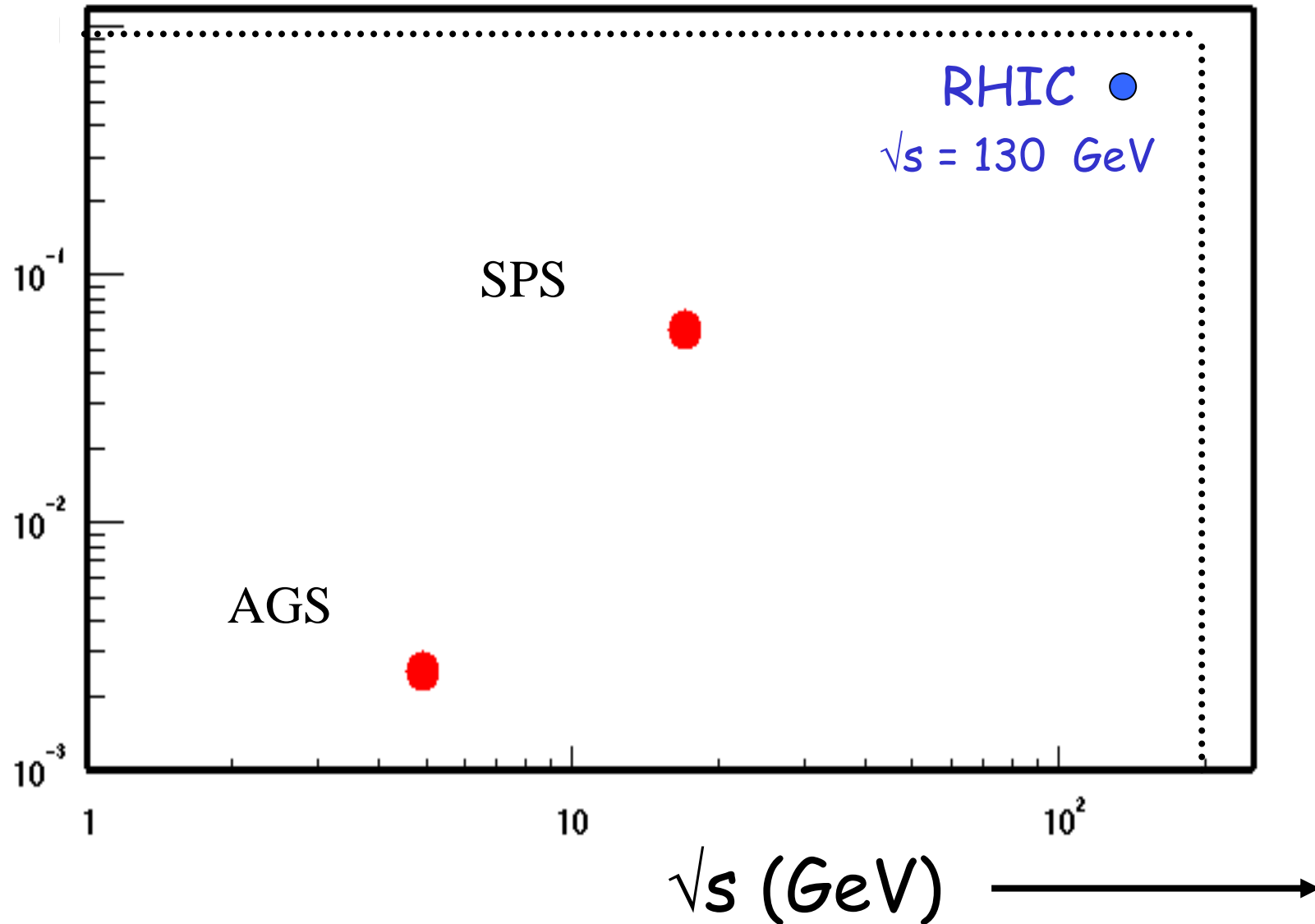
Proton/antiproton dans PHENIX+STAR



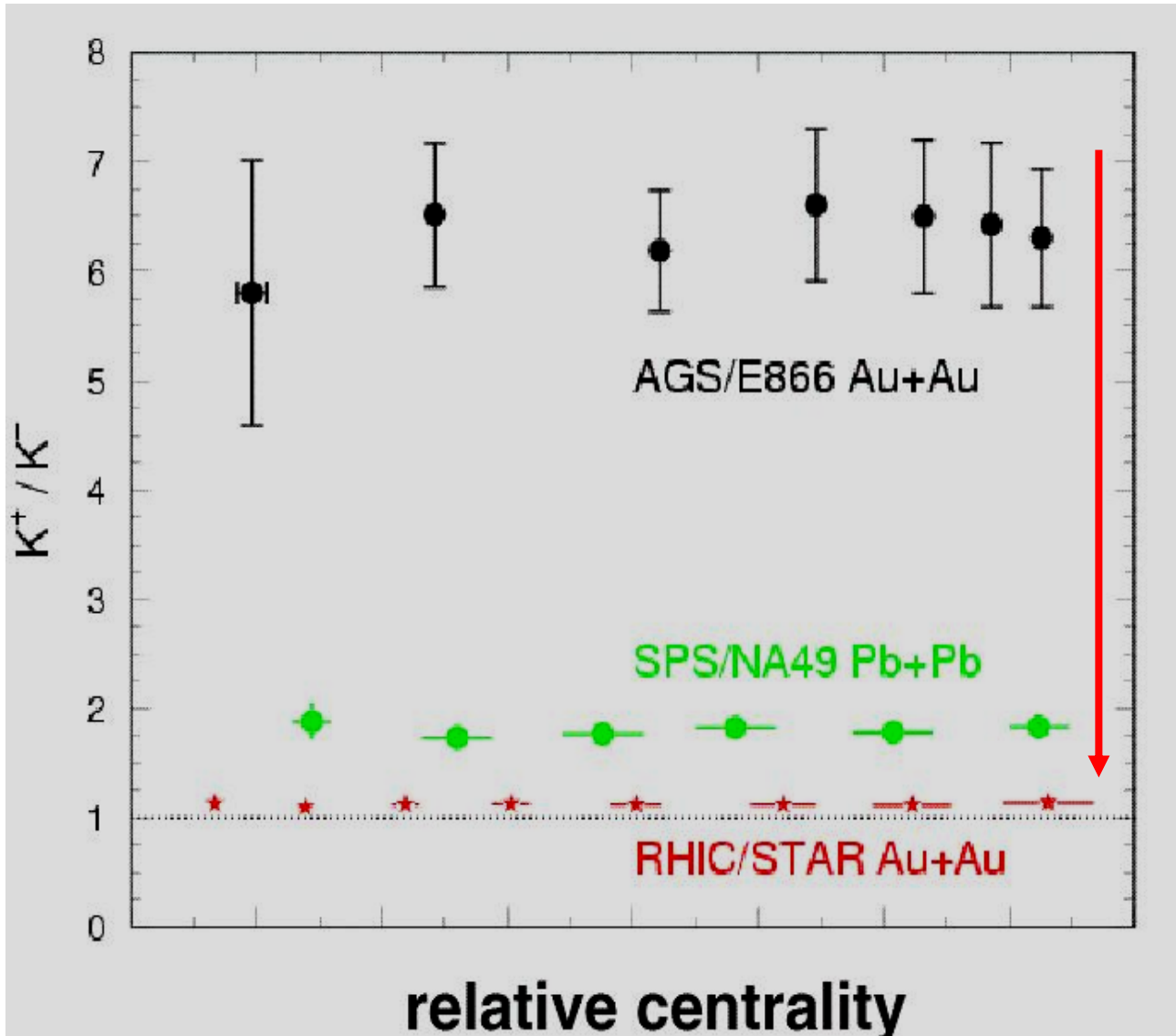
Proton/antiproton

Transparence à

$\sqrt{s} = 200 \text{ GeV}$



K⁺/K⁻ dans STAR



$$K^+ / K^- = 1,12 \pm 0,06$$

$$K^+ / K^- \rightarrow 1$$

Idem pour

$$\bar{p} / p$$

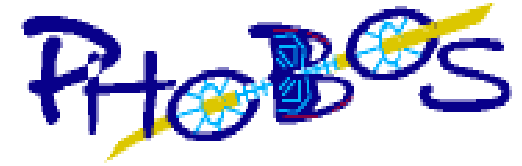
$$\bar{\Xi} / \Xi$$

$$\bar{\Lambda} / \Lambda$$

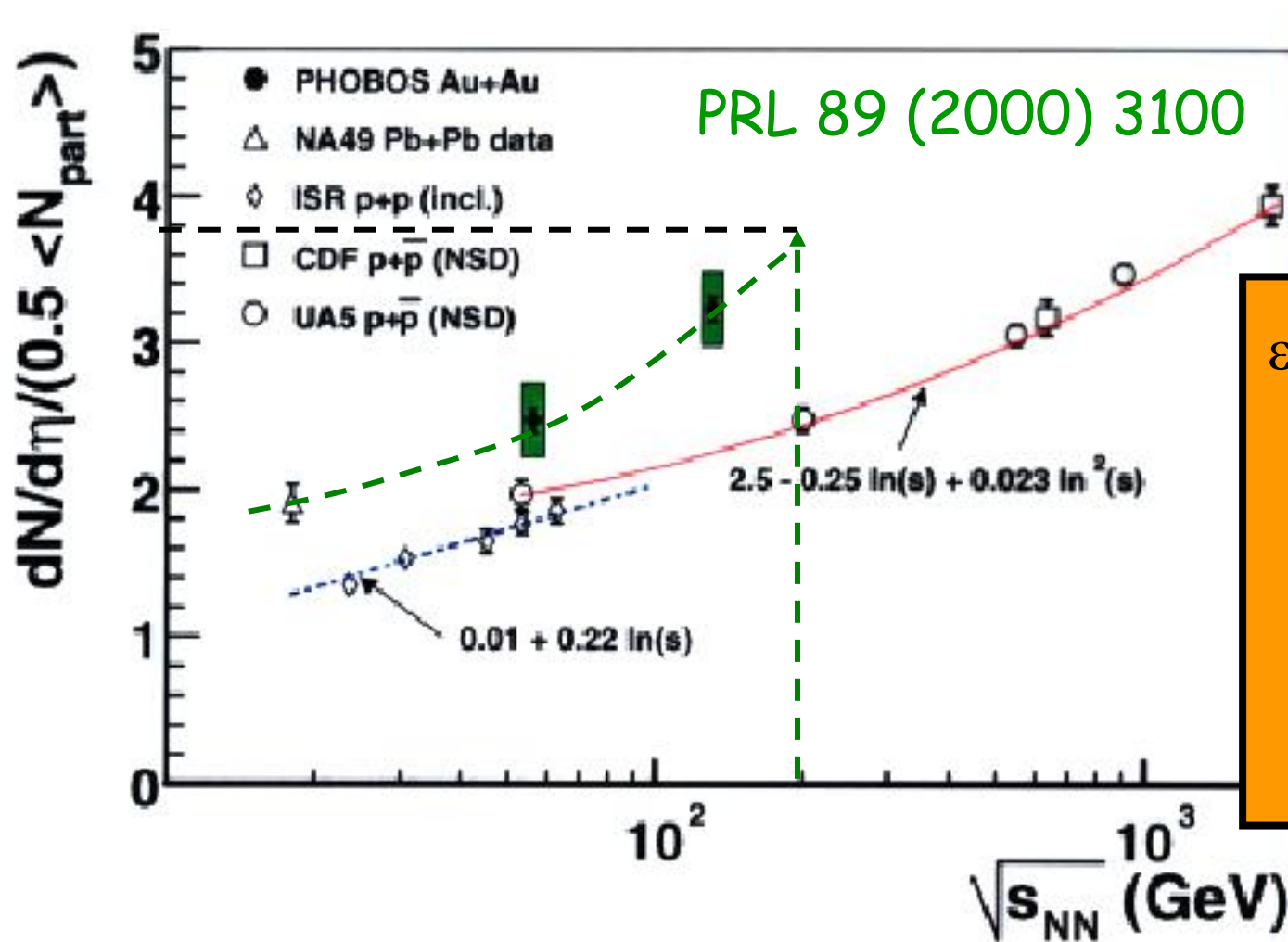


Quasitransparence

Densité de particules chargées



Mesures de $dN_{ch}/d\eta$ @ $\eta=0$ à 56 et 130 GeV



$\epsilon_{RHIC} \sim 1,7 \epsilon_{SPS}$

$5 \text{ GeV}/\text{fm}^3$

@ 130 GeV

$6 \text{ GeV}/\text{fm}^3$

@ 200 GeV

Conditions initiales

\mathcal{E}_{max} (GeV/fm³)

Transparence

AGS

≈ 1

non

SPS

≈ 3

légère

RHIC

≈ 6

oui

$T = 180 \text{ MeV} \Rightarrow 250 \text{ MeV} \Rightarrow 280 \text{ MeV}$

2. Premiers instants de RHIC

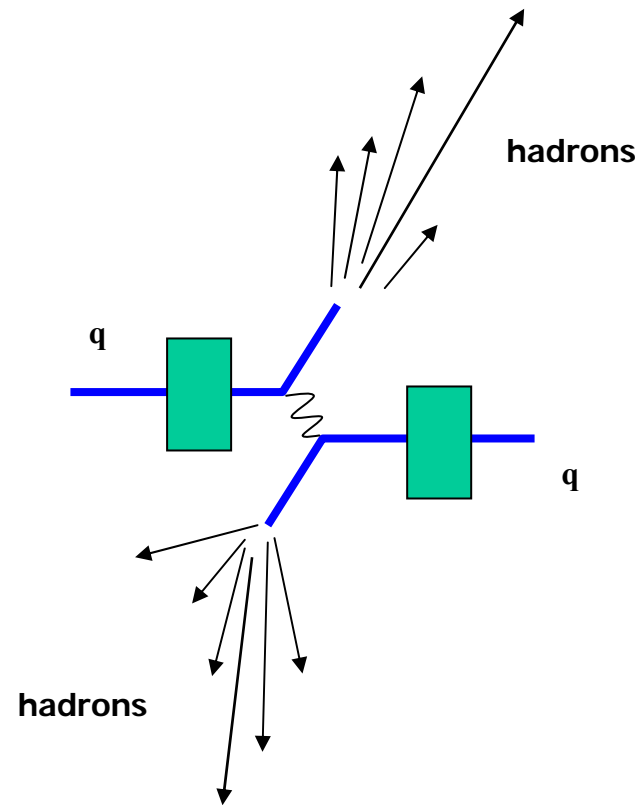
(sans les quarkonia)

« Jet Quenching » ?

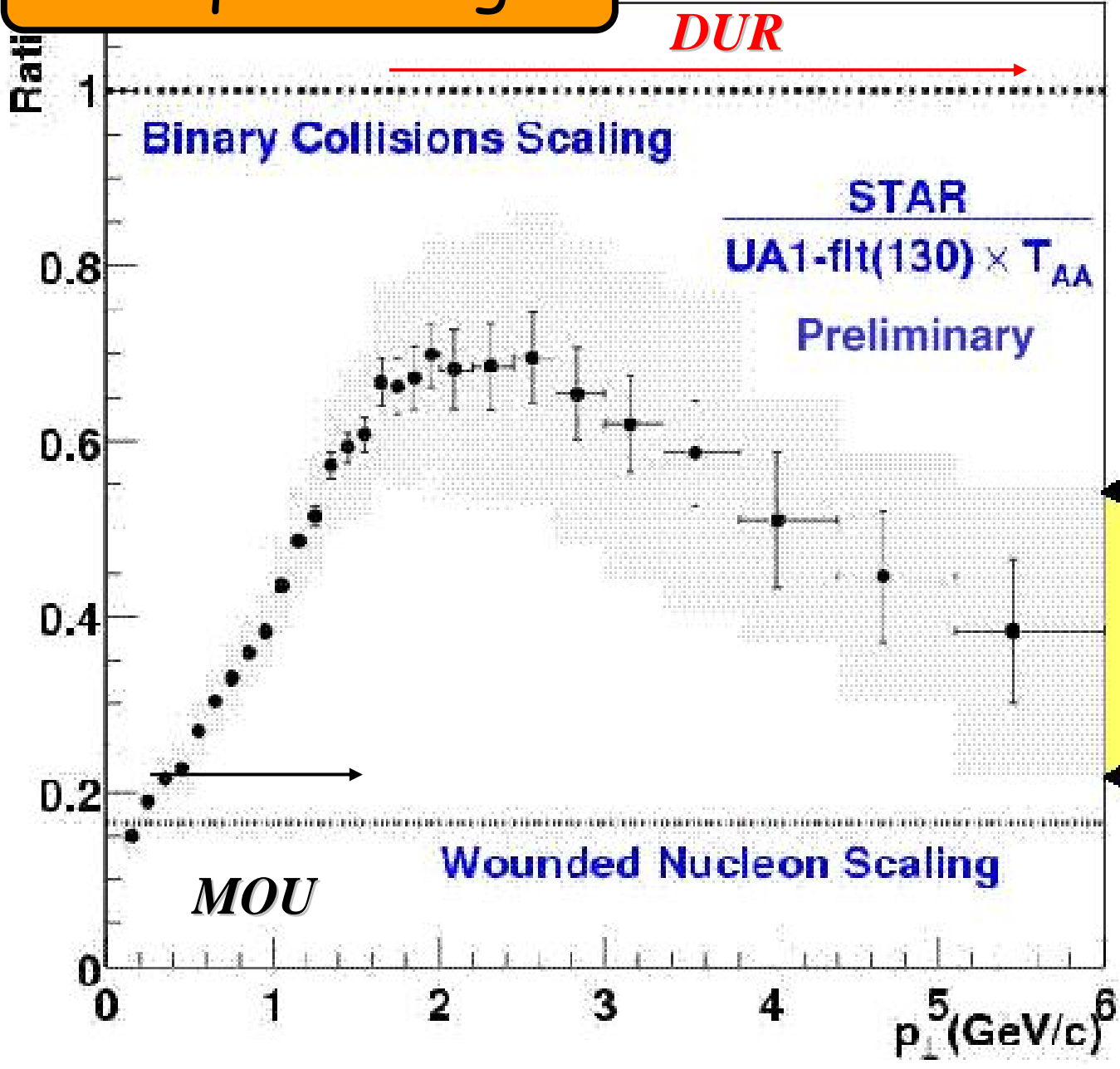
Déconfinement



Suppression des jets
par perte d'énergie



Jet quenching ?



Spectre normalisé des hadrons négatifs

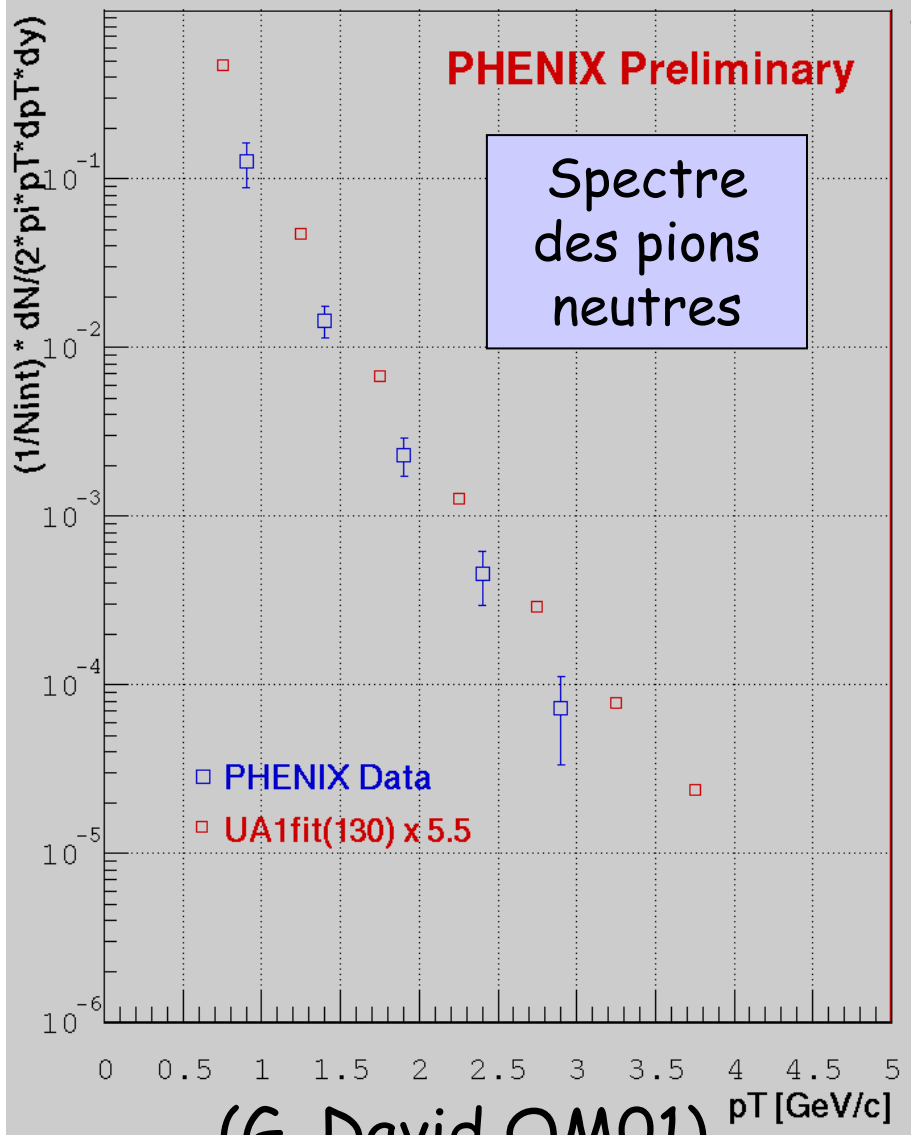
Déficit à grande impulsion transverse

(J.Dunlop QM01)

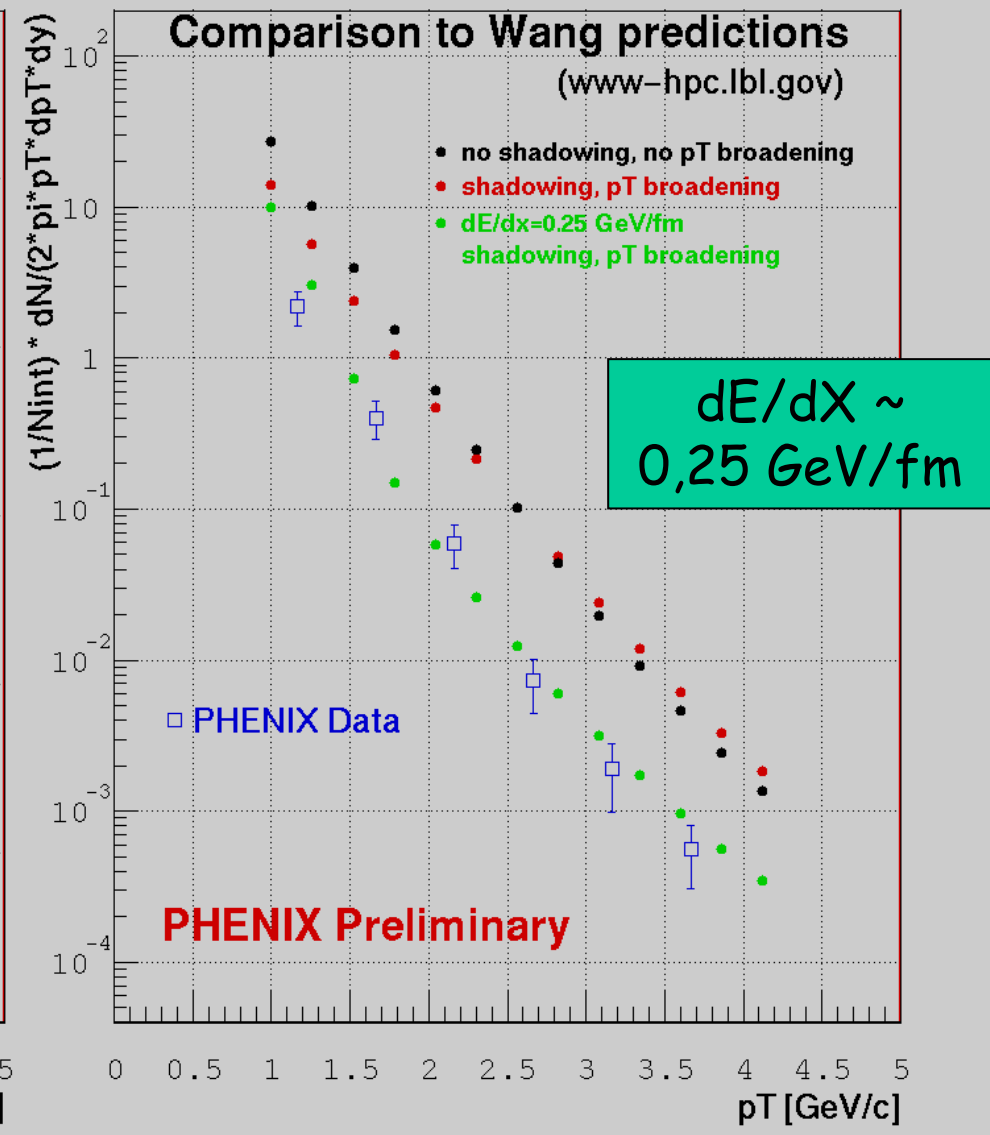
Jet quenching ?



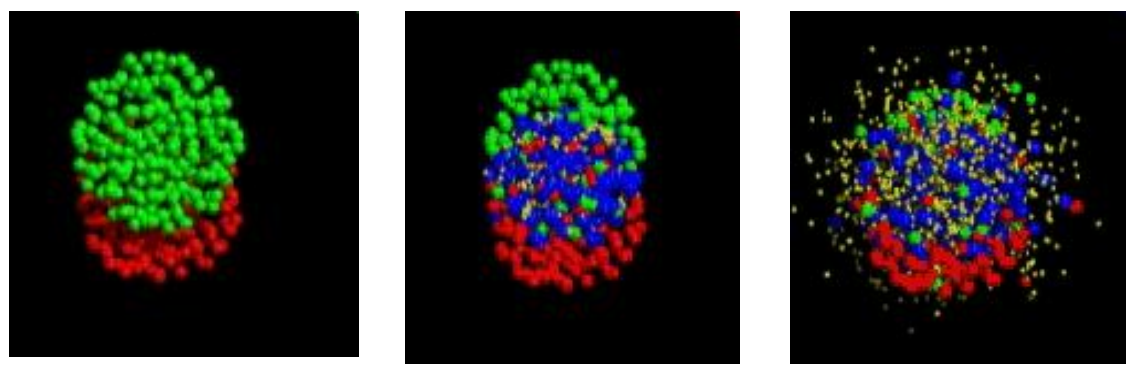
Neutral pion pT – peripheral



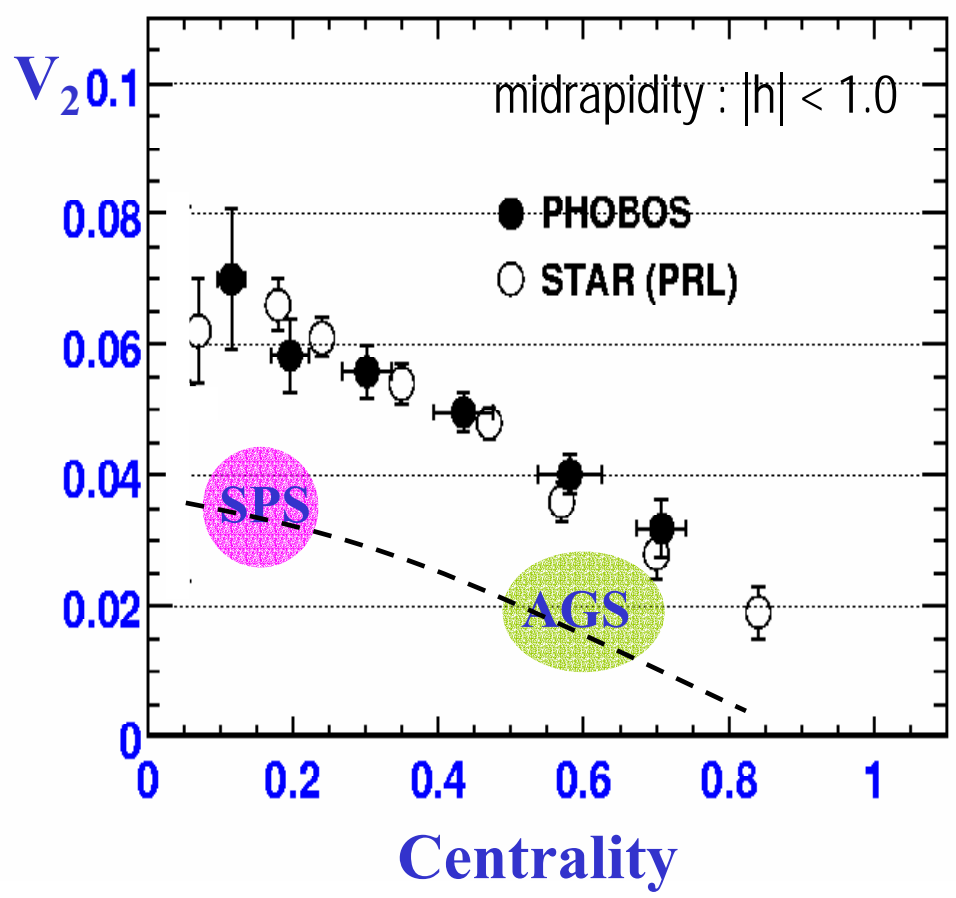
Neutral pion pT – 10% central



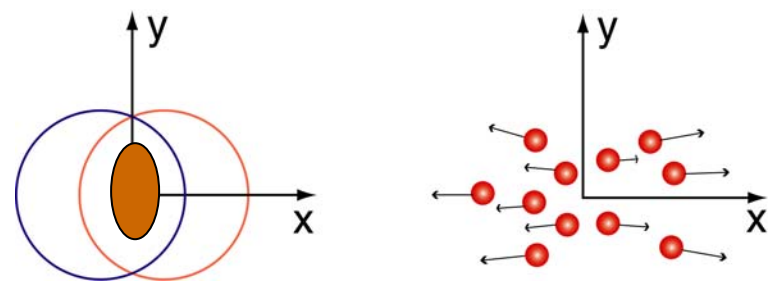
Flux elliptique



Centrality Dependence



Gradient de pression
→ Flux anisotropique



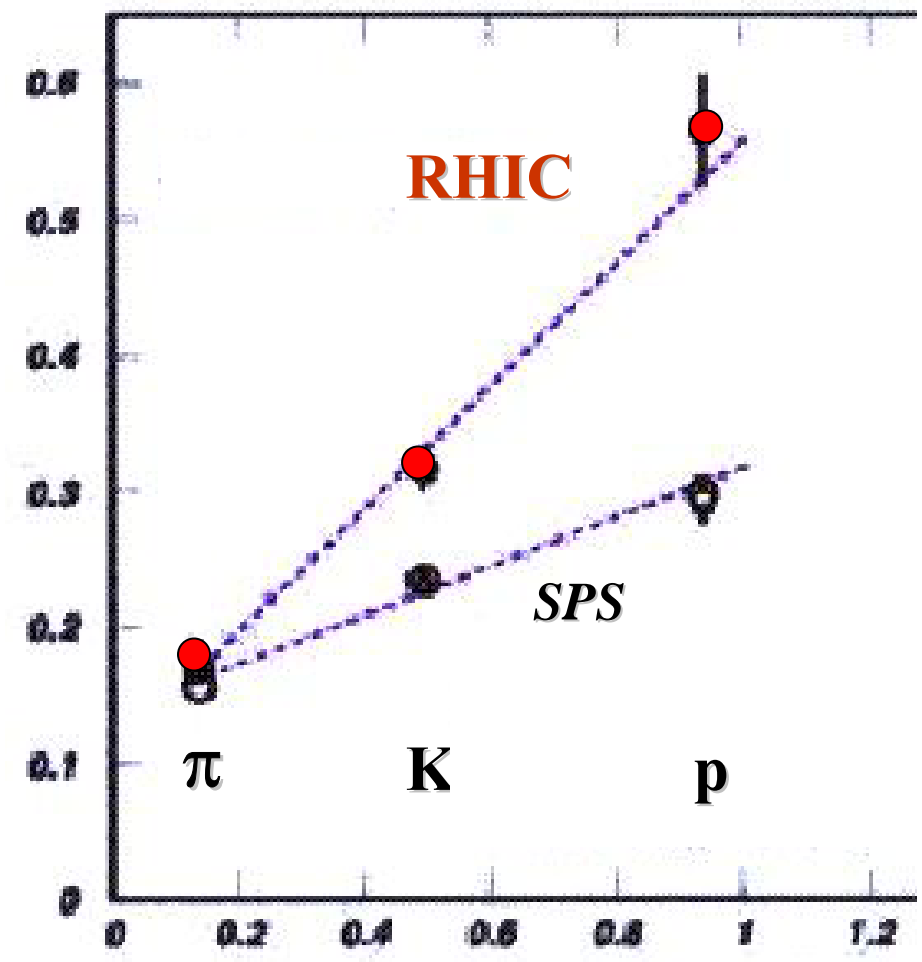
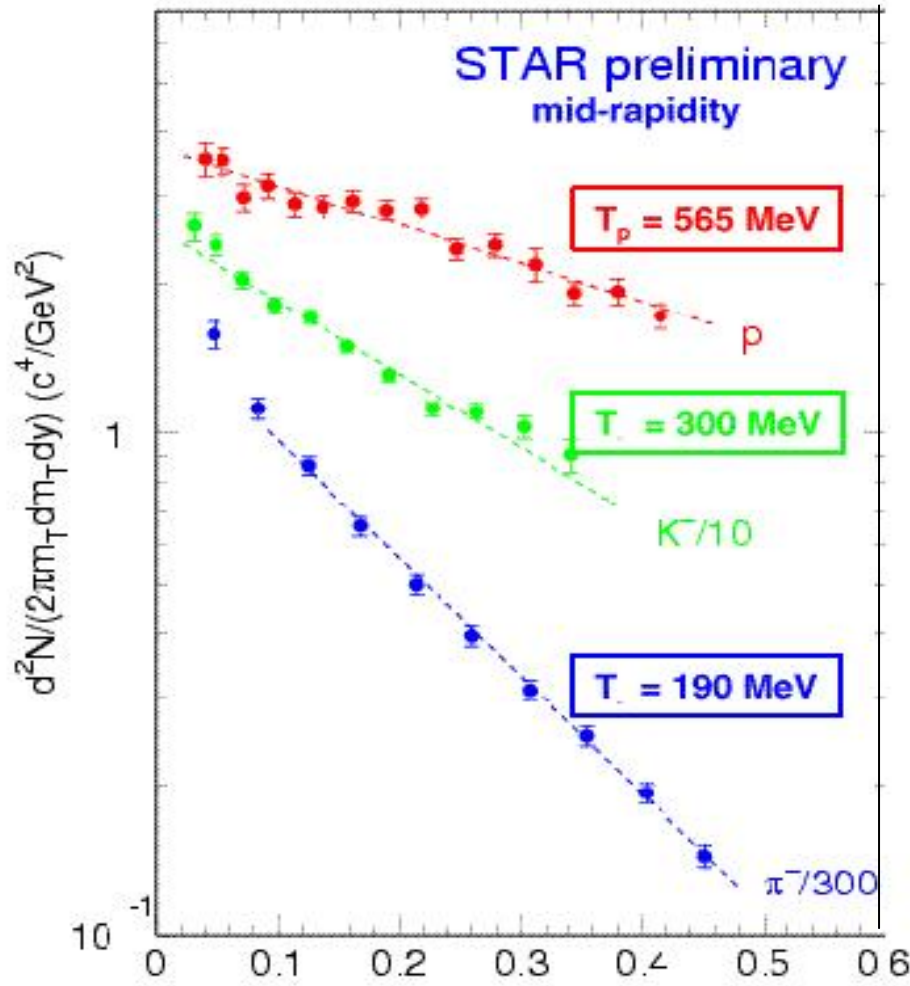
$$v_2 = \langle \cos 2\phi \rangle$$

$$\phi = \text{atan} \frac{p_y}{p_x}$$

3. Refroidissement et hadronisation

(les derniers instants ...)

Au+Au central collisions



Expansion violente de la matière hadronique

article mass (GeV)

COLLISION D'IONS LOURDS à RHIC (Brookhaven)

RUN 2000



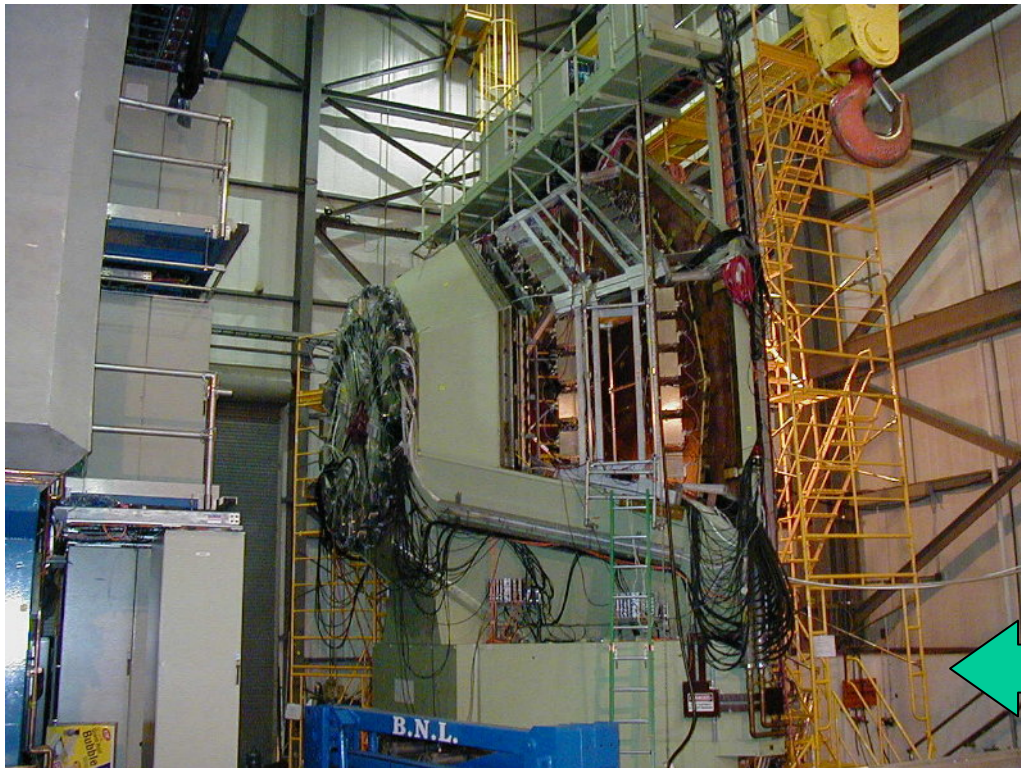
Résultats prometteurs :

- Densité d'énergie
- Indice de quenching ?

RUN 2001



- Données 2000 = un jour de 2001
- 200 GeV/nucléons
- Suppression des quarkonia ?



2001 : dimuons dans PHENIX

Un muon cosmique vu par PHENIX début juin 2001

