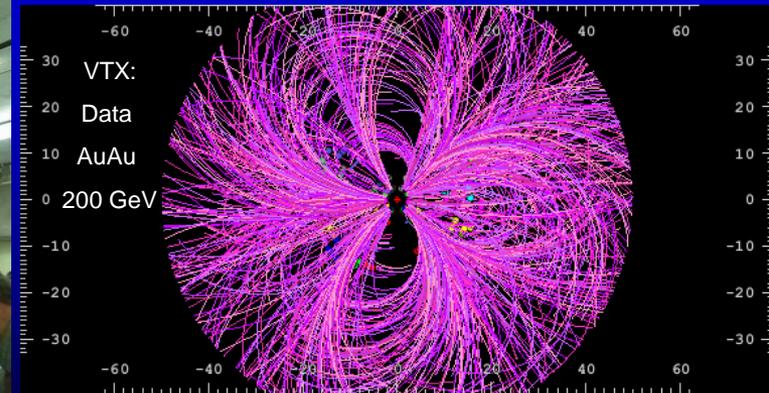
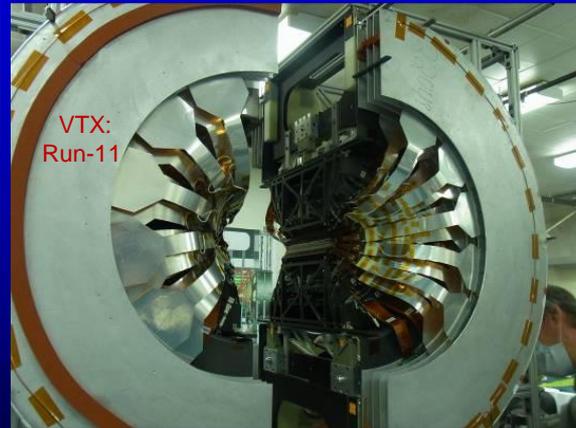
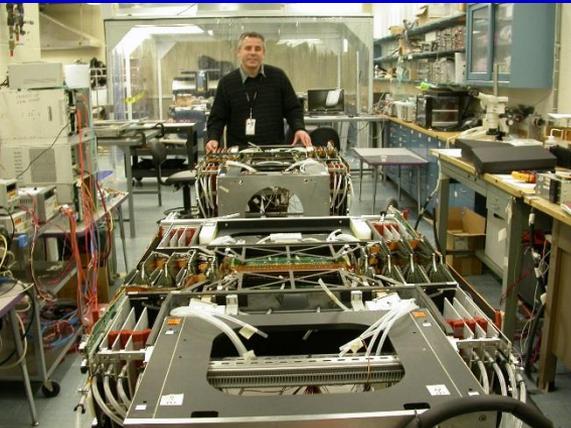


Nouvel État de la Matière Nucléaire dans les Collisions des Ions Lourds au RHIC: Physique et Détecteurs

Rachid Nouicer

Physicien au Brookhaven National Laboratory, New York
Adjunct Professeur à l'Université de Stony Brook, New York



Plan de l'Exposé

- Motivation scientifique de la recherche d'un nouvel état de la matière nucléaire
- Construction des détecteurs silicium, analyse des données expérimentales, publications des résultats scientifiques et prédictions pour le LHC
- Points culminants des résultats du RHIC : découverte du "Fluide Quasi parfait de Quarks et de Gluons" (PQG)
- Étude détaillée des propriétés du milieu nucléaire dense créé dans les collisions :
 - Détecteurs de traces en silicium (VTX, FVTX): mesure des saveurs lourdes
 - Sonde des saveurs lourdes: i.e charme et beauté ouverts, Charmonium
- Conclusions

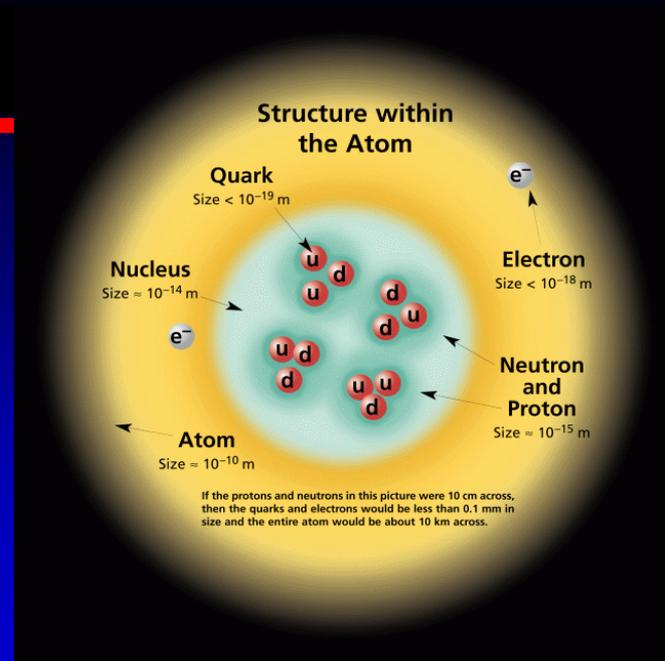
Quelques Notions sur l'Interaction Forte

✓ Les **hadrons** sont les particules participant à l'interaction forte, telle que des protons, des neutrons et des pions.

✓ Nous savons que (depuis au moins 50 ans) les protons, les neutrons et les autres hadrons ne sont pas élémentaires, mais sont faits de **quarks** :

- Les quarks portent une charge de couleur : **Rouge, Vert, Bleu**
- Les anti-quarks portent l'anti-couleur correspondante
- La combinaison de ces couleurs dans les hadrons doit être incolore
- Les hadrons se déclinent en baryons (3 quarks) et mésons (1 quark et 1 anti-quark)

✓ Les combinaisons des 6 quarks et les différents états spectroscopiques ont permis de reproduire ou prédire l'ensemble des particules existantes (hors leptons et bosons de jauge)



Three Generations of Matter (Fermions)

	I	II	III	
mass	2.4 MeV/c ²	1.27 GeV/c ²	171.2 GeV/c ²	0
charge	2/3	2/3	2/3	0
spin	1/2	1/2	1/2	1
name	u up	c charm	t top	γ photon
	4.8 MeV/c ²	104 MeV/c ²	4.2 GeV/c ²	0
	-1/3	-1/3	-1/3	0
	1/2	1/2	1/2	1
Quarks	d down	s strange	b bottom	g gluon
	<2.2 eV/c ²	<0.17 MeV/c ²	<15.5 MeV/c ²	91.2 GeV/c ²
	0	0	0	0
	1/2	1/2	1/2	1
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	Z⁰ Z boson
	0.511 MeV/c ²	105.7 MeV/c ²	1.777 GeV/c ²	80.4 GeV/c ²
	-1	-1	-1	±1
	1/2	1/2	1/2	1
Leptons	e electron	μ muon	τ tau	W[±] W boson

Gauge Bosons

Quelques Notions sur l'Interaction Forte : Confinement ...

✓ L'interaction entre charges de couleur, et donc entre quarks, se fait par l'intermédiaire de gluons. Ils ont la particularité de porter aussi une couleur et donc d'interagir avec eux-mêmes ! C'est une particularité importante de l'interaction forte qui lui donne ses caractéristiques si particulières.

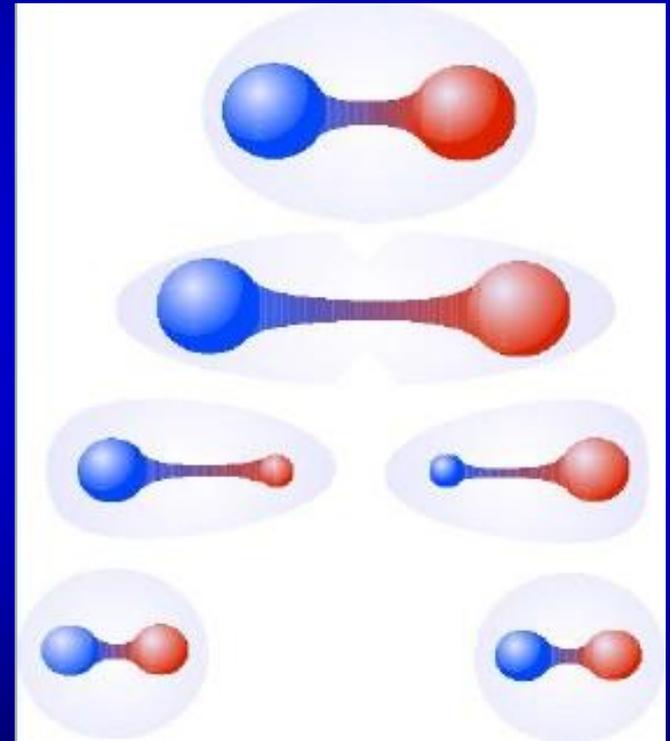
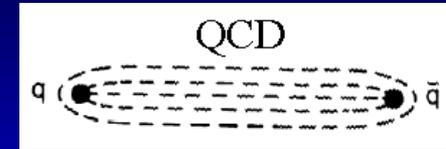
✓ Il est impossible d'isoler une charge de couleur. L'intensité de l'interaction forte augmente avec la distance r :

$$V_{long} = kr \quad \text{avec} \quad k \sim 1\text{GeV}/\text{fm}$$

✓ Les quarks sont donc confinés dans les hadrons.

✓ L'interaction forte est décrite par une théorie :
la Chromo-Dynamique Quantique (QCD)

[voir D. Perkins, p.179]



Caractéristique Essentielle de QCD: Liberté Asymptotique

✓ QCD “liberté asymptotique” :

– le potentiel court de distance est du type :

$$V_{short} = -\frac{4\alpha_s(r)}{3r}$$

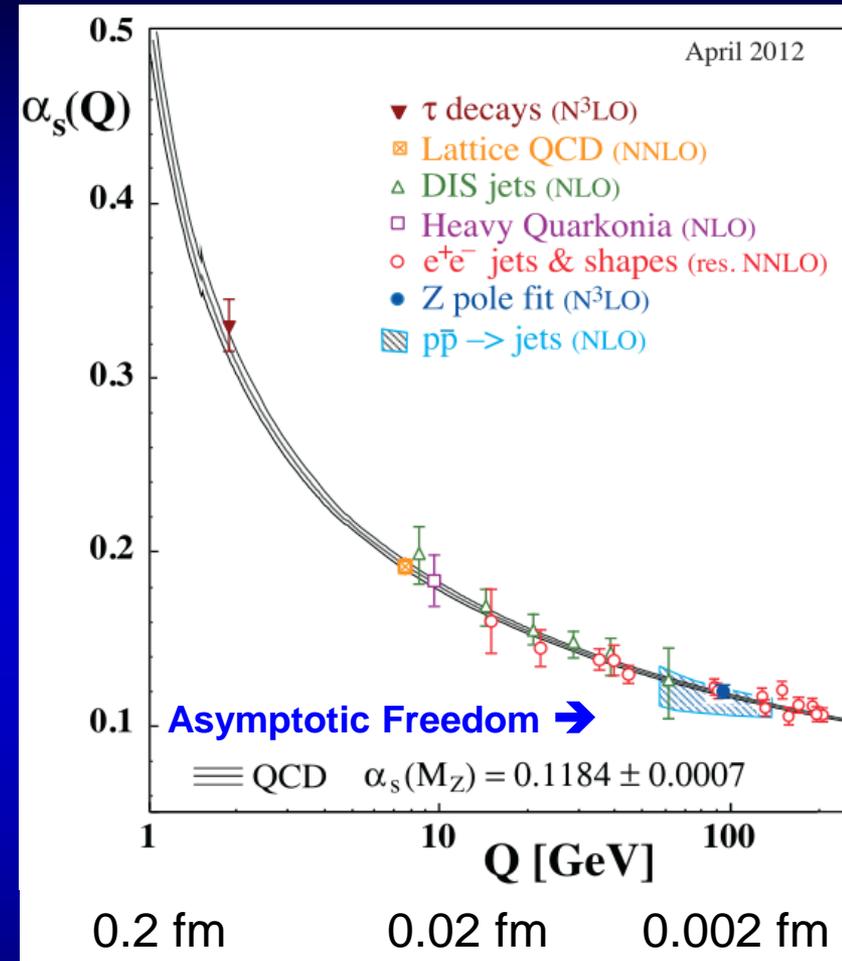
[voir D. Perkins, p.172]

– la constante de couplage dépend de r de telle manière que :

$$\lim_{r \rightarrow 0} \alpha_s(r) = 0$$

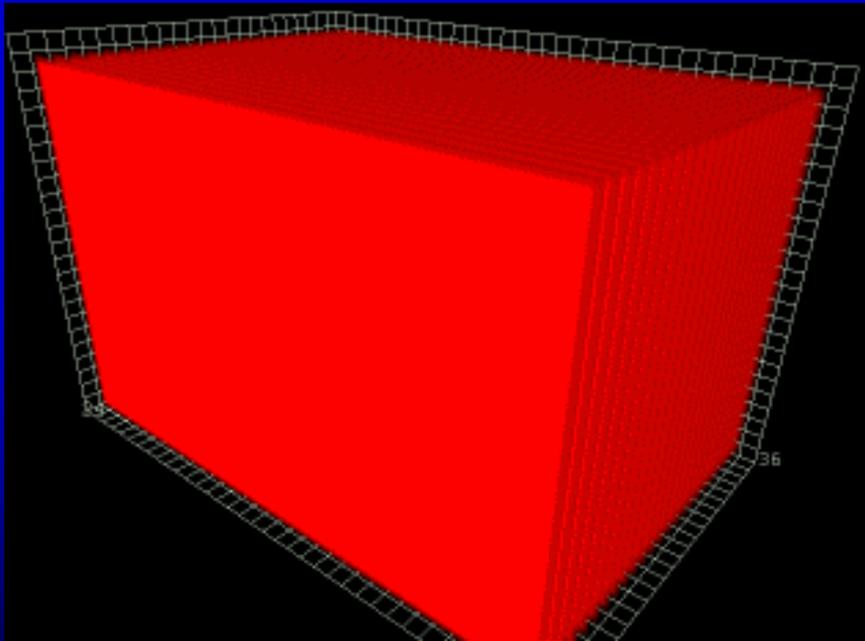
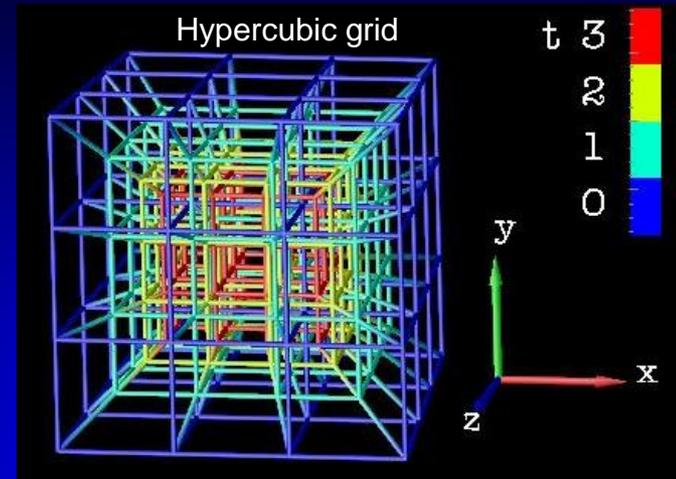
✓ La théorie de la perturbation peut être appliquée à courte distance et à haut moment de transfert

$$\alpha_s(Q^2) = \frac{12\pi}{(33 - 2N_F)\log(\frac{Q^2}{\Lambda_{QCD}^2})} \sim \frac{1}{\log(\frac{Q^2}{\Lambda_{QCD}^2})} \text{ avec } \Lambda_{QCD} = 0.2 \text{ GeV}$$

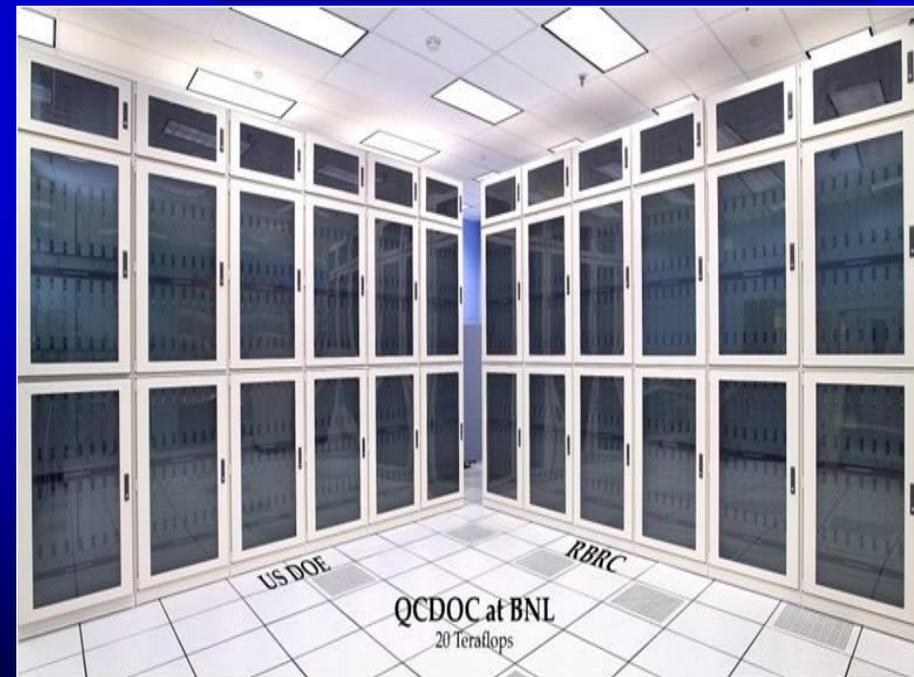


Lattice QCD

Dans lattice QCD, les problèmes non-perturbatifs sont traités par la discrétisation sur un réseau d'espace-temps. Ceci exige un calcul (parallèle) massif



Lattice QCD calculation



Résultats de Lattice QCD

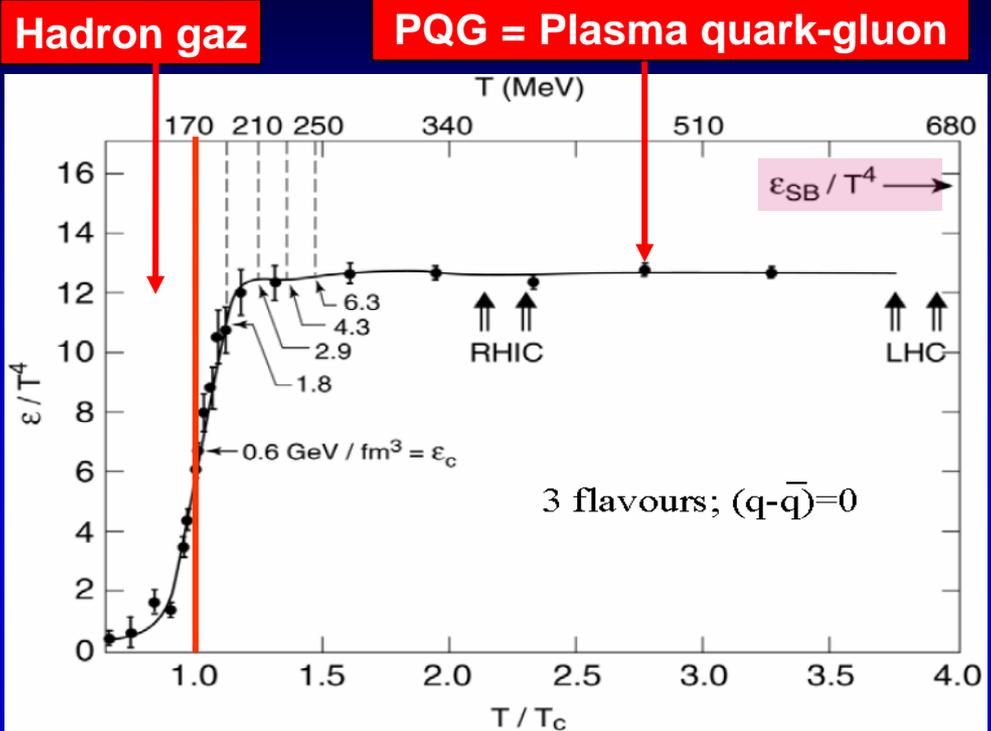
Stefan-Boltzmann pour un gaz de particules sans interaction (gaz libre)

$$\frac{\epsilon}{T^4} = v \frac{\pi^2}{30} a$$

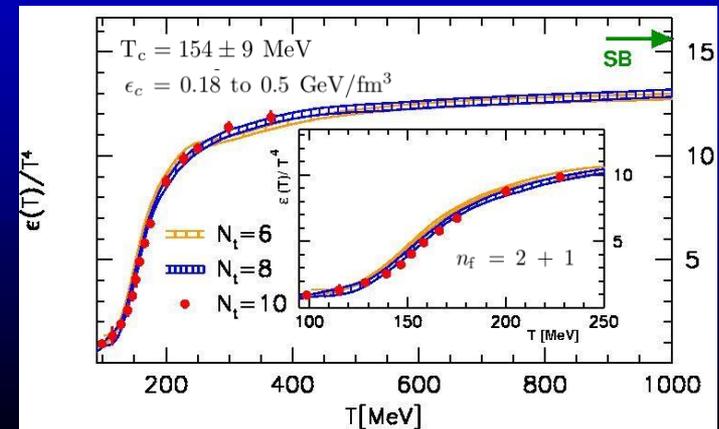
- ✓ Densité de baryon nulle, 3 saveurs
- ✓ ϵ/T^4 change rapidement autour T_c

- ✓ $T_c = 170$ MeV
 $\rightarrow \epsilon_c = 0.6$ GeV/fm³

$T \sim 1.2 T_c$ la valeur de ϵ est à environ 80% de la valeur de Stefan-Boltzmann pour un gaz idéal de q, \bar{q}, g (ϵ_{SB})

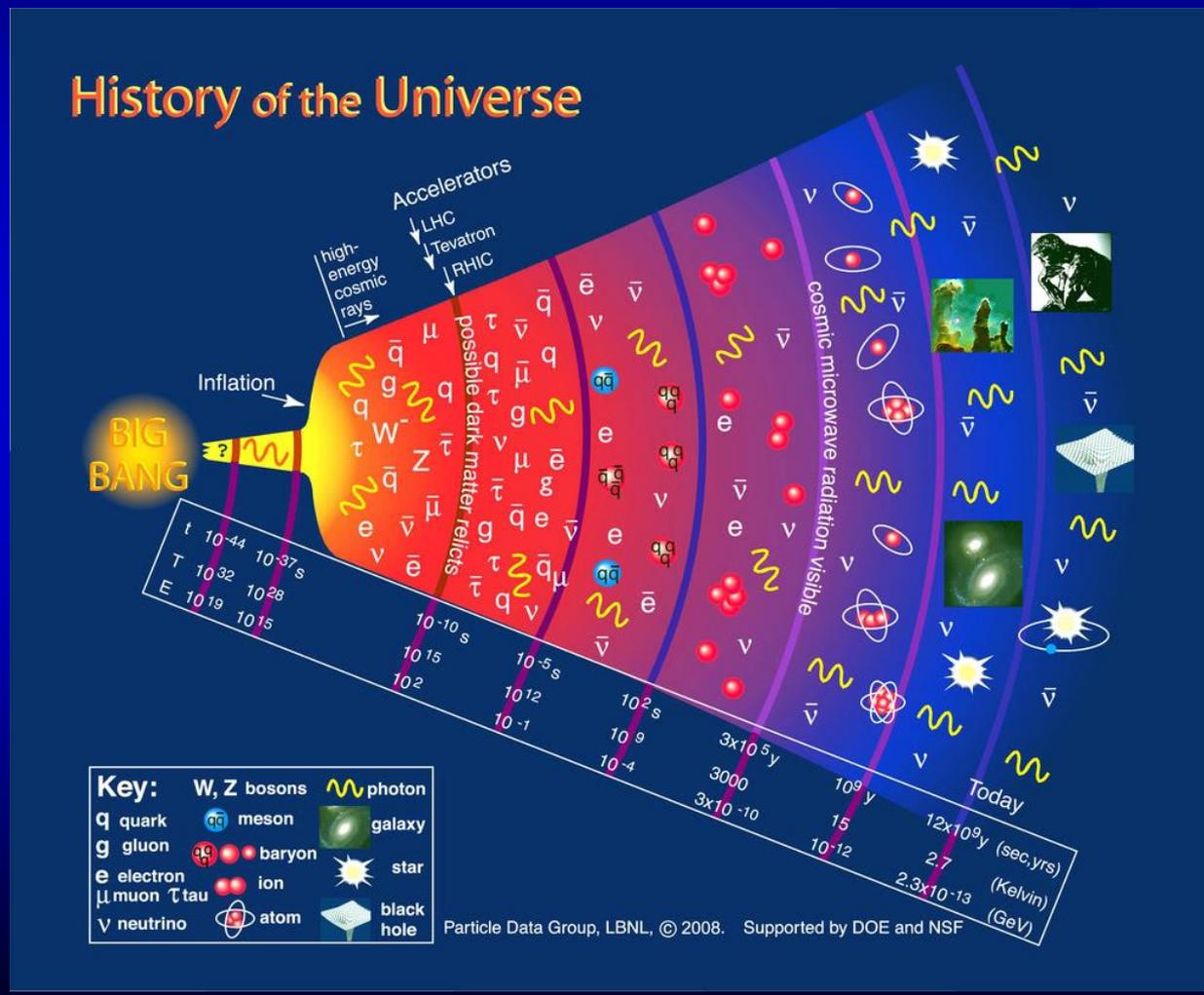


Calculs récents : Phys. Rev. D 90 (2014) 094503



But Scientifique : Matière Extrême (QCD) dans des CLs

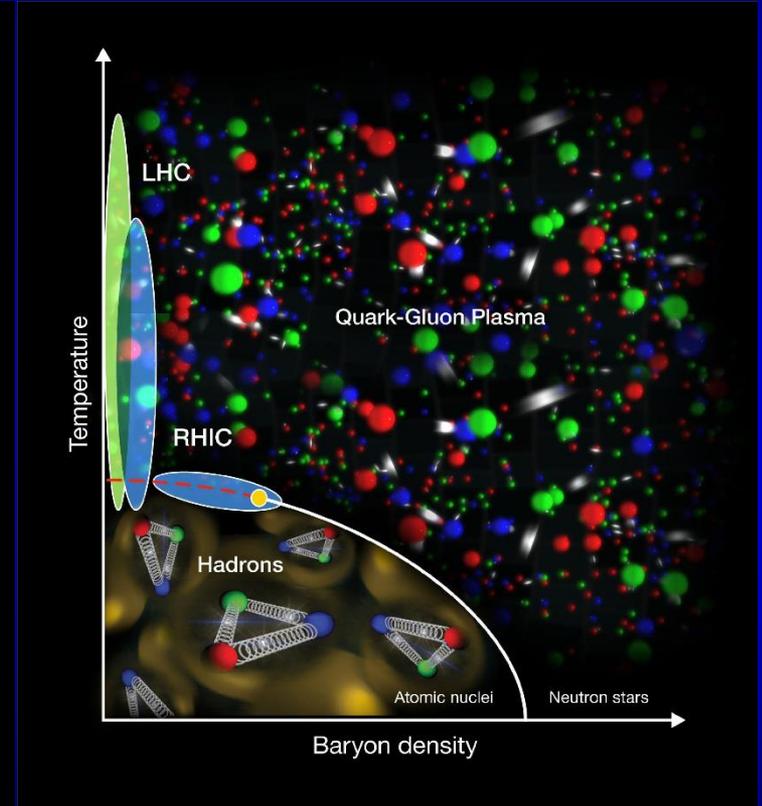
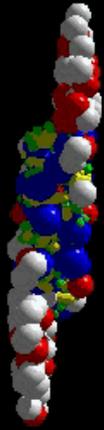
Comprendre les premiers instants de l'évolution de notre Univers et certains phénomènes astrophysiques



But Scientifique : Matière Extrême (QCD) dans des CILs

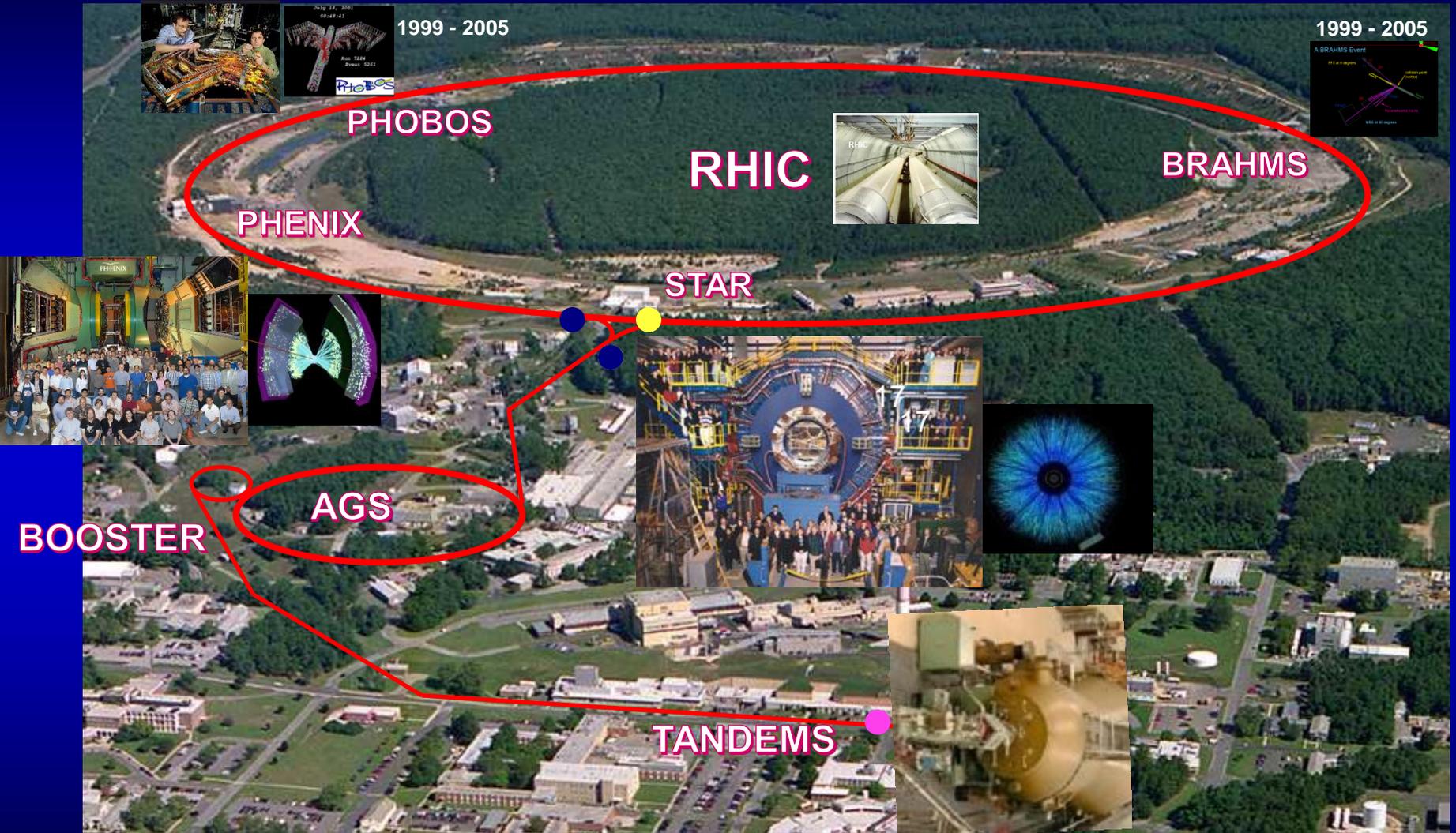
Les Collisions des Ions Lourds (CIL) produisent des systèmes à assez haute températures/densités

Comprendre les premiers instants de l'évolution de notre Univers et certains phénomènes astrophysiques



Les CILs nous permettent d'étudier des systèmes complexes gouvernés par QCD et comprendre les propriétés fondamentales de la matière.

Relativistic Heavy Ion Collider (RHIC)



Relativistic Heavy Ion Collider (RHIC)

Quels sont les faisceaux délivrés par le RHIC jusqu'ici ?

Run	Faisceaux	Énergie centre-de-masse [GeV]	Luminosité totale [mb ⁻¹]
I (2000)	Au+Au	56	< 0.001
	Au+Au	130	20
II (2001/2002)	Au+Au	200	25.8
	Au+Au	19.6	0.4
	p+p	200	1.4x10 ⁻⁶
III (2003)	d+Au	200	73x10 ⁻³
	p+p	200	5.5x10 ⁻⁶
IV(2004)	Au+Au	200	3.53x10 ⁻³
	Au+Au	62.4	67
	p+p	200	7.1x10 ⁻⁶
V (2005)	Cu+Cu	200	42.1x10 ⁻³
	Cu+Cu	62.4	1.5x10 ⁻³
	Cu+Cu	22.4	0.02x10 ⁻³
	p+p	200	29.5x10 ⁻⁶
	p+p	410	0.1x10 ⁻⁶
VI (2006)	p+p	200	88.6x10 ⁻⁶
	p+p	62.4	1.05x10 ⁻⁶
VII (2007)	Au+Au	200	7.25x10 ⁻³
	Au+Au	9.2	Small

Run	Faisceaux	Énergie centre-de-masse [GeV]	Luminosité totale [mb ⁻¹]
VIII(2008)	d+Au	200	437x10 ⁻³
	p+p	200	38.4x10 ⁻⁶
	Au+Au	9.6	Small
IX (2009)	p+p	500	110x10 ⁻⁶
	P+p	200	114x10 ⁻⁶
X(2010)	Au+Au	200	10.3x10 ⁻³
	Au+Au	62.4	544
	Au+Au	39	206
	Au+Au	7.7	4.23
	Au+Au	11.5	7.8
XI(2011)	p+p	500	166x10 ⁻⁶
	Au+Au	19.6	33.2
	Au+Au	200	9.79x10 ⁻³
	Au+Au	27	63.1
XII(2012)	p+p	200	74x10 ⁻⁶
	p+p	510	283x10 ⁻⁶
	U+U	193	736
	Cu+Au	200	27x10 ⁻³
XIII(2013)	p+p	510	1.04x10 ⁻⁹
XIV (2014)	Au+Au	14.6	44.2
	Au+Au	200	43.9x10 ⁻³
	³ He+Au	200	134x10 ⁻³
XV(2015)	p+p	200	282x10 ⁻⁶
	p+Au	200	1.27x10 ⁻⁶
	p+Al	200	3.97x10 ⁻⁶

Construction des Détecteurs au RHIC:

- Détecteurs Silicium Pixels PHOBOS (1998-2007)
- Détecteurs de Traces Silicium PHENIX (2007 à présent)

inside RHIC

Chronicling recent research at the Relativistic Heavy Ion Collider

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Monday, March 19, 2012

New Era of Heavy Flavor Measurements at RHIC: PHENIX Silicon Vertex Tracker

By Rachid Nouicer

One of the striking discoveries from the heavy-ion program at the Relativistic Heavy Ion Collider (RHIC) is that the medium created in central 200 AGeV Au-Au collisions behaves like a nearly perfect fluid. This finding was rated the top physics news story of 2005 and the four experiments at RHIC: BRAHMS, PHENIX, PHOBOS, and STAR published White Papers discussing the evidence of the existence of this new form of matter [1].

To investigate the properties of this new state of matter, usually referred to as the Quark Gluon Plasma (QGP), penetrating and well calibrated probes are essential to quantitatively deduce the effect of the medium on those probes. One type of such probe are hadrons which carry a heavy flavor - a charm quark with mass $m_c \approx 1.5$ GeV or a beauty quark with mass $m_b \approx 5$ GeV - like D- and B-mesons. These mesons present a powerful tool to study the properties of the hot, dense medium created in high-energy nuclear collisions as they are generated early in the reaction and subsequently diffuse through the created matter.

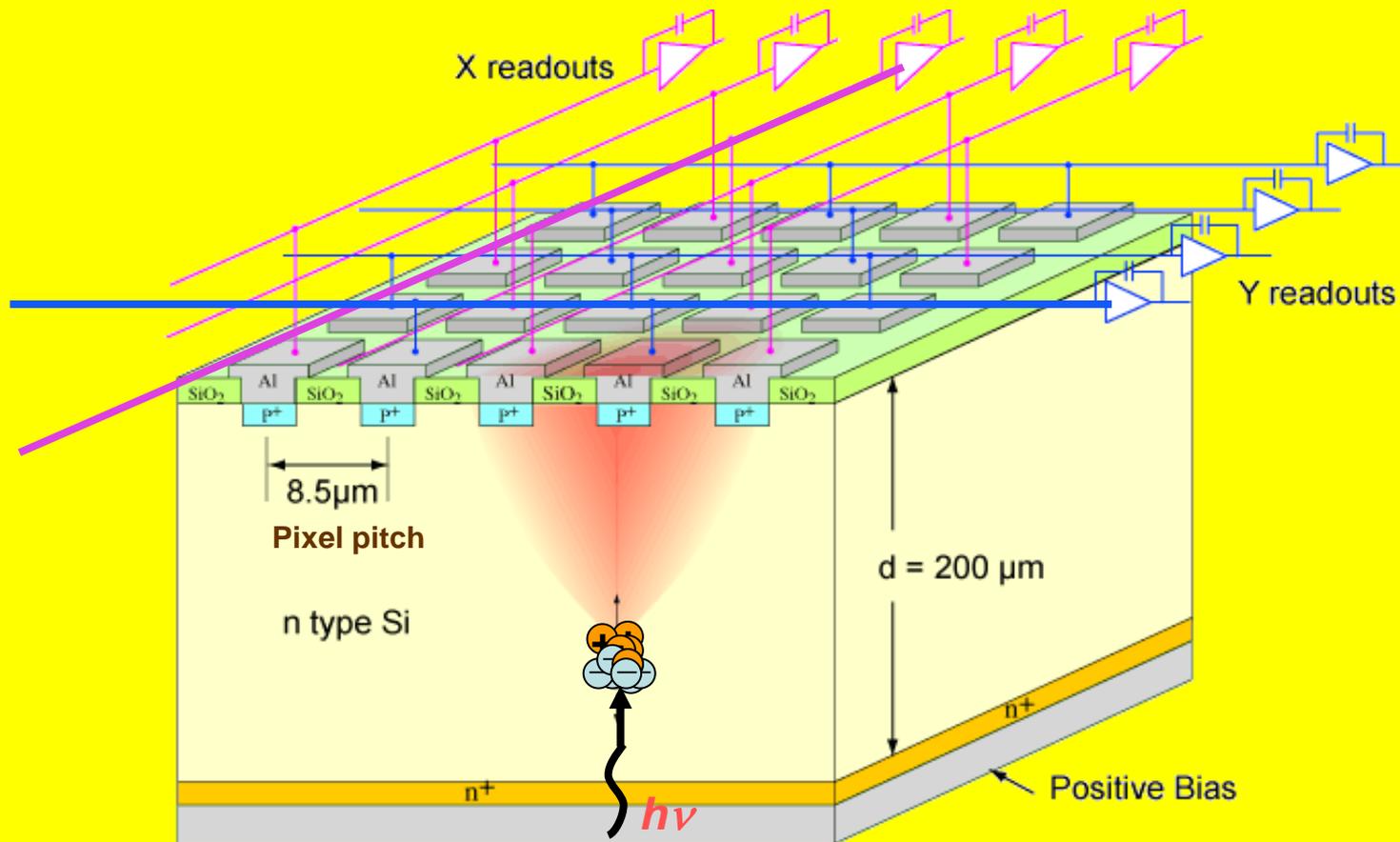
At RHIC, the PHENIX experiment currently studies heavy-quark production *indirectly* via the measurement of electrons from complementary decays of hadrons carrying charm or beauty without



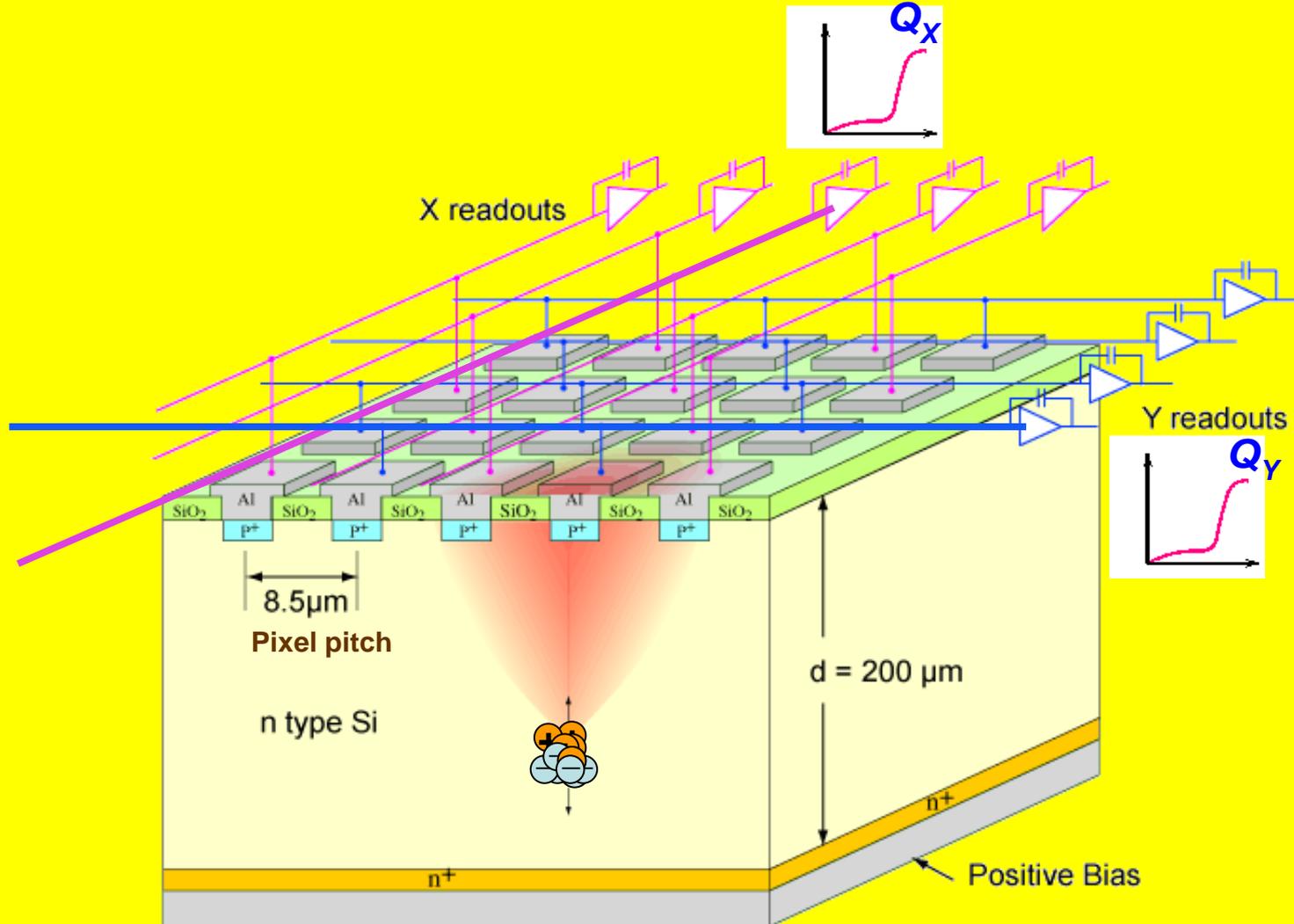
Recent Stories

- [Search for Associate Laboratory Director for High Energy and Nuclear Physics](#)
- [The Annual State of RHIC Report](#)
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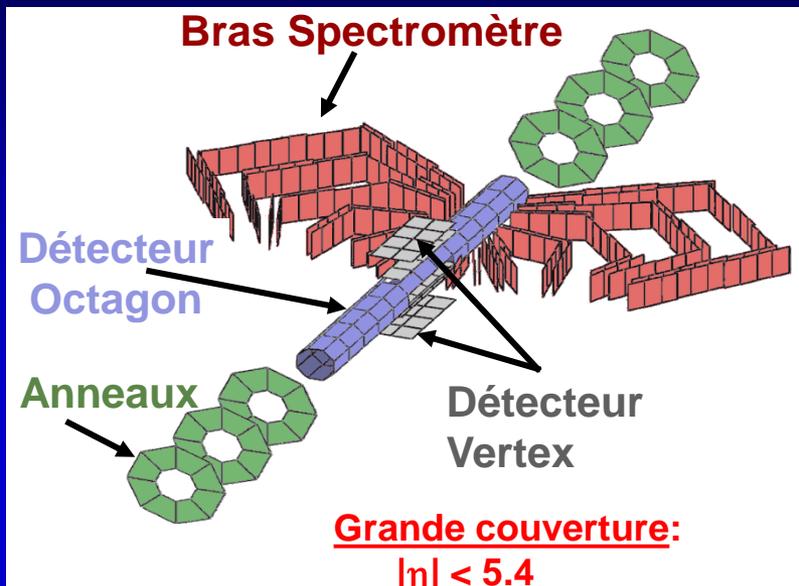
Détecteur Silicium: Jonction P-N



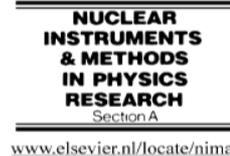
Détecteur Silicium: Jonction P-N



Détecteurs Silicium Pixels PHOBOS (1998-2005)



Nuclear Instruments and Methods in Physics Research A 461 (2001) 143–149



www.elsevier.nl/locate/nima

Silicon pad detectors for the PHOBOS experiment at RHIC

R. Nouicer^{a,*}, B.B. Back^b, R.R. Betts^a, K.H. Gulbrandsen^c, B. Holzman^a,
W. Kucewicz^a, W.T. Lin^d, J. Mülmenstädt^c, G.J. van Nieuwenhuizen^c,
H. Pernegger^c, M. Reuter^a, P. Sarin^c, G.S.F. Stephans^c, V. Tsay^c,
C.M. Vale^c, B. Wadsworth^c, A.H. Wuosmaa^b, B. Wyslouch^c

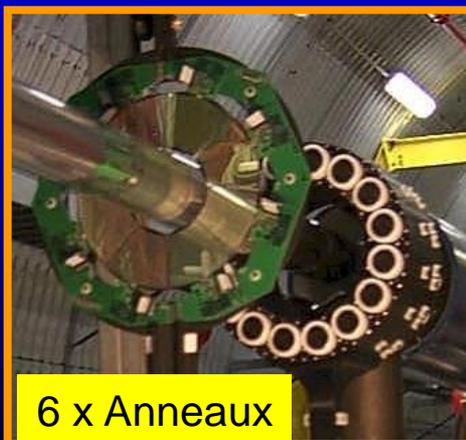
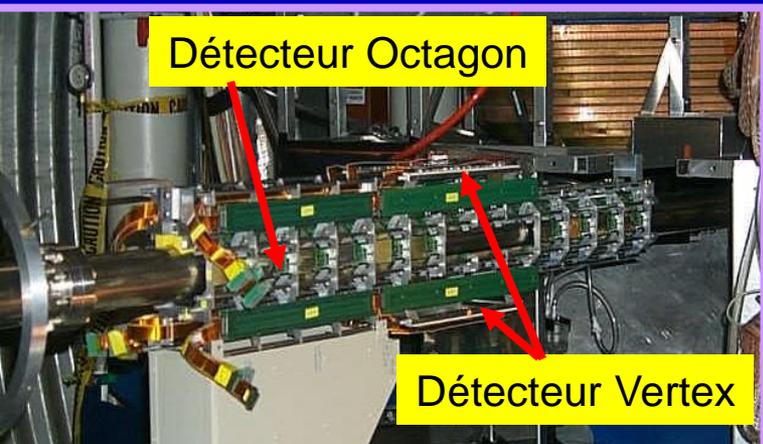
^a Department of Physics, University of Illinois at Chicago, 845 West Taylor St., Chicago, IL 60607-7059, USA

^b Physics Division, Argonne National Laboratory, 9700 South Cass Ave., Argonne, IL 60439-4843, USA

^c Massachusetts Institute of Technology, 77 Mass. Ave., Cambridge, MA 02139, USA

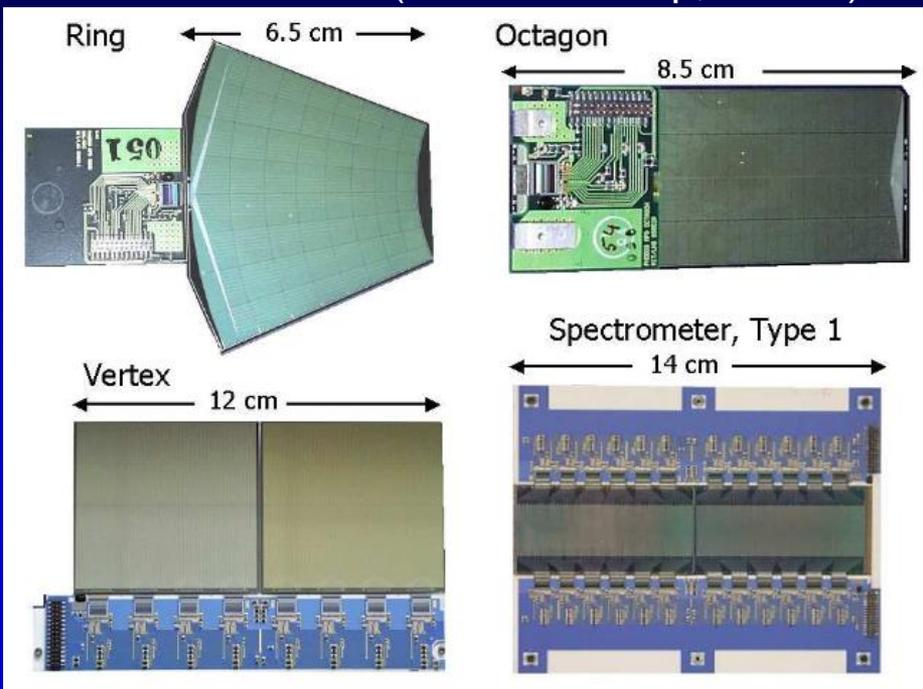
^d High Energy Physics Group, National Central University, Department of Physics, 32054 Chung-Li, Taiwan

^e Miracle Technology Co. Ltd., Hsin-Chu, Taiwan

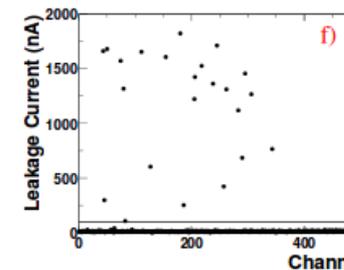
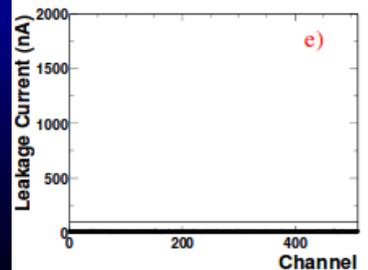
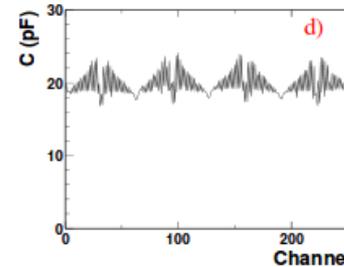
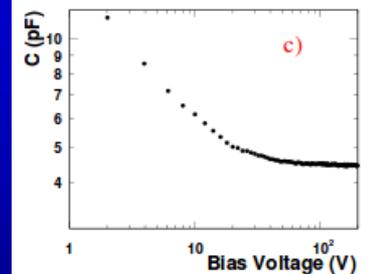
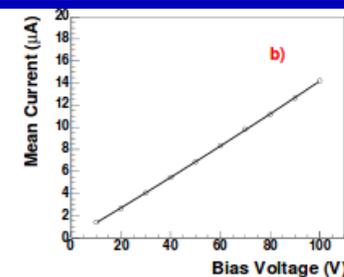
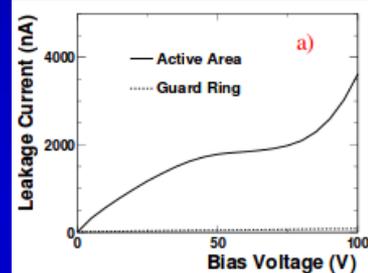
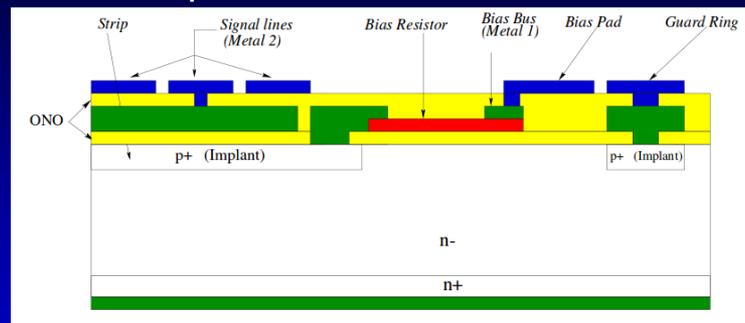


Détecteurs Silicium Pixels PHOBOS (1998-2005)

Modules silicium (VA-HDR-1 chip, IDEAS)



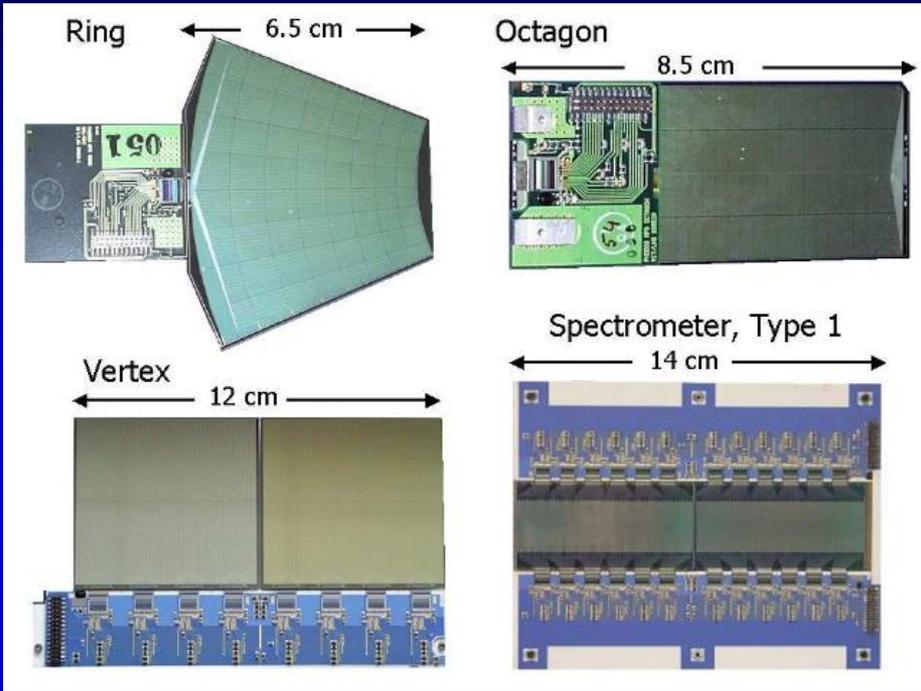
Vue en coupe de la structure interne et les tests



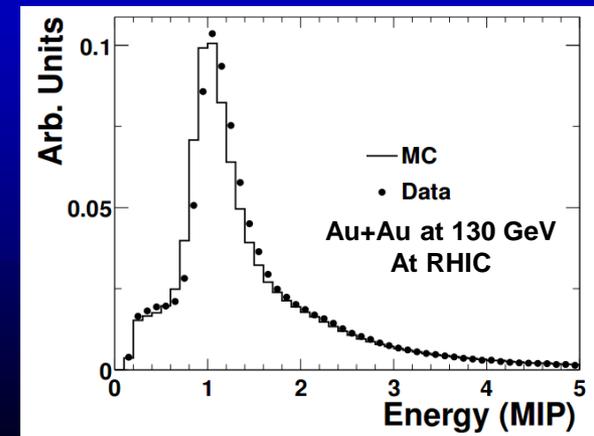
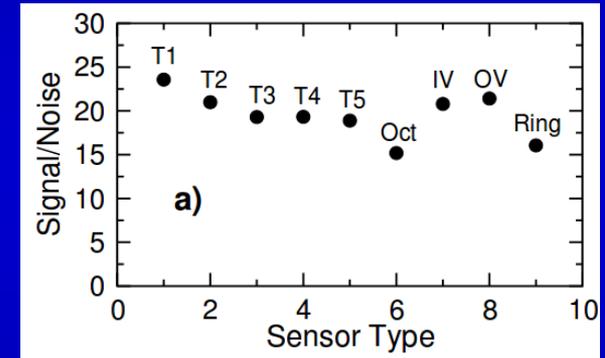
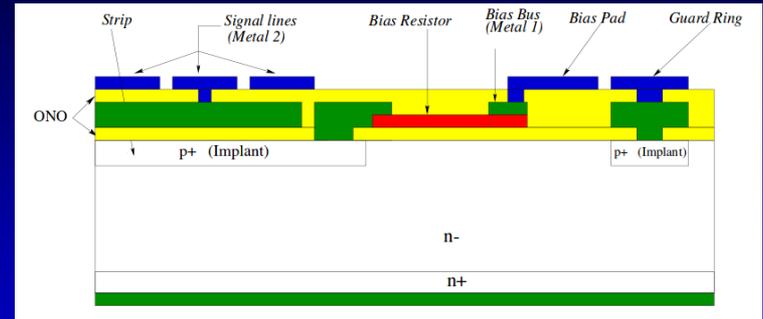
Détecteur silicium	Type de capteur	Surface active [mm ²]	Nombre de pixels	Taille du pixel [mm ²]
Multiplicité	Octogone Ring	34.9 x 81.3 3600	30 x 4 8 x 8	2.75 x 8.75 20 - 105
Vertex	Inner	60.6 x 48.18	4 x 256	0.5 x 12.1
	Outer	60.6 x 48.18	2 x 256	0.5 x 24.1
Spectromètre	1	70.0 x 22.0	70 x 22	1.0 x 1.0
	2	42.7 x 30.0	100 x 5	0.4 x 6.0
	3	42.7 x 60.0	64 x 8	0.7 x 7.5
	4	42.7 x 60.0	64 x 4	0.7 x 15.0
	5	42.7 x 76.0	64 x 4	0.7 x 19.0

Détecteurs Silicium Pixels PHOBOS (1998-2005)

Modules silicium (VA-HDR-1 chip, IDEAS)



Vue en coupe de la structure interne et les tests

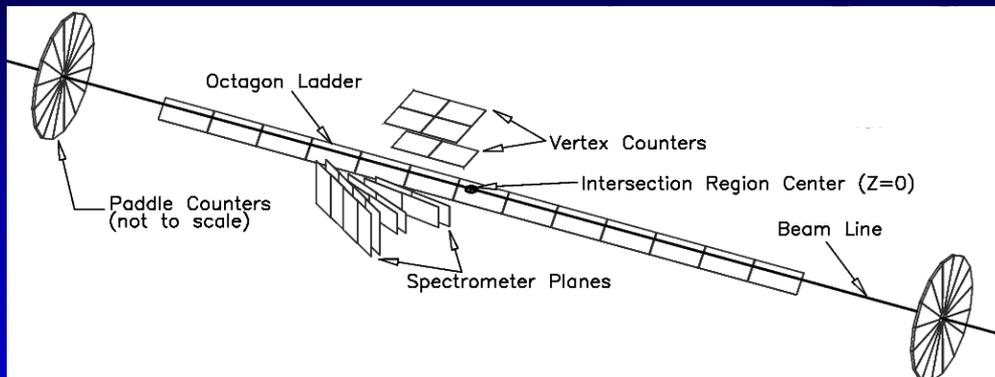
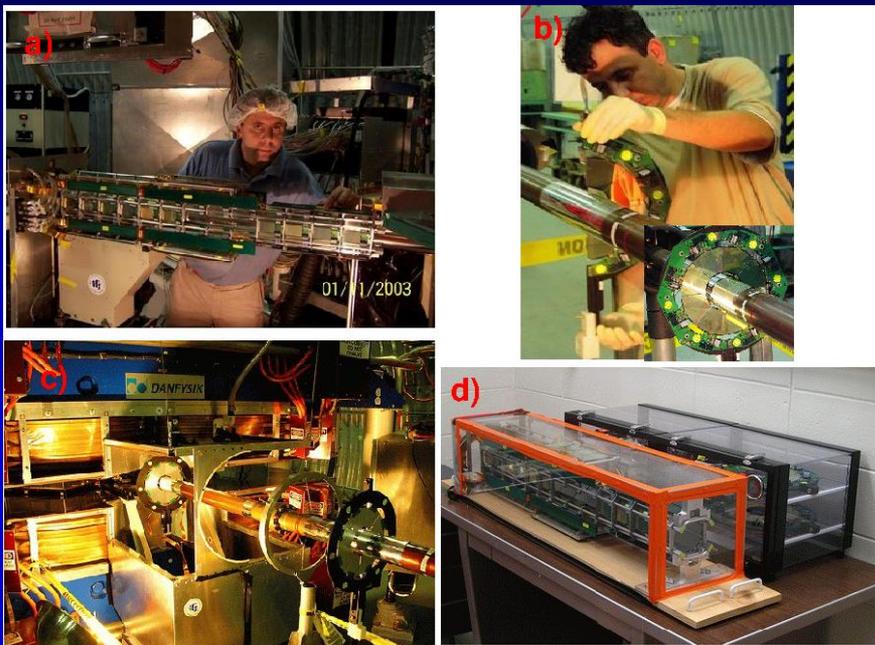


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Premier Succes du RHIC: PHOBOS PRL 85 (2000) 3100

Responsable de la construction, assemblage et opération

Premiers résultats du RHIC: Physical Review Letters 85 (2000) 3100



Sur les actualités scientifiques : succès du détecteur silicium et premiers résultats de PHOBOS à RHIC

Inside Science Research — Physics News Update

Number 505, October 5, 2000 by Phillip F. Schewe and Ben Stein

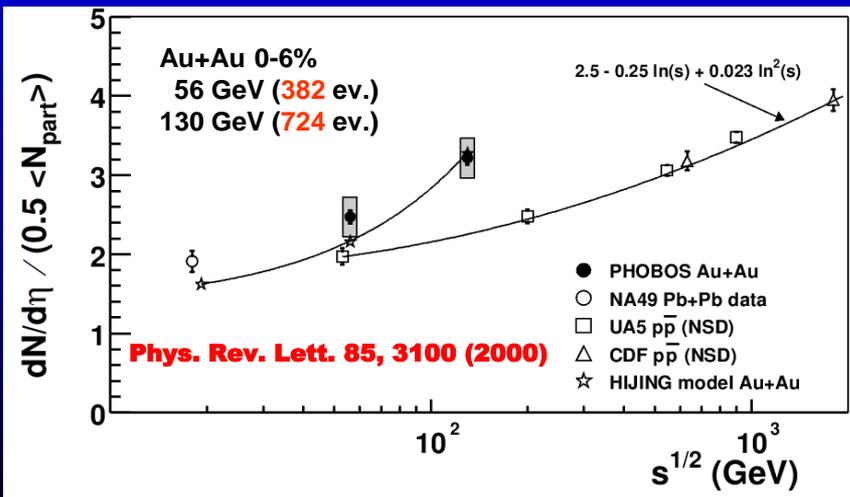
First Results from RHIC

Brookhaven's Relativistic Heavy Ion Collider (RHIC) had their first heavy-ion collisions back in June and since then extremely energetic smashups between gold atoms have been lighting up detectors in the four interaction halls, creating fireballs that approximate tiny pieces of the universe as it might be only microseconds after the big bang.

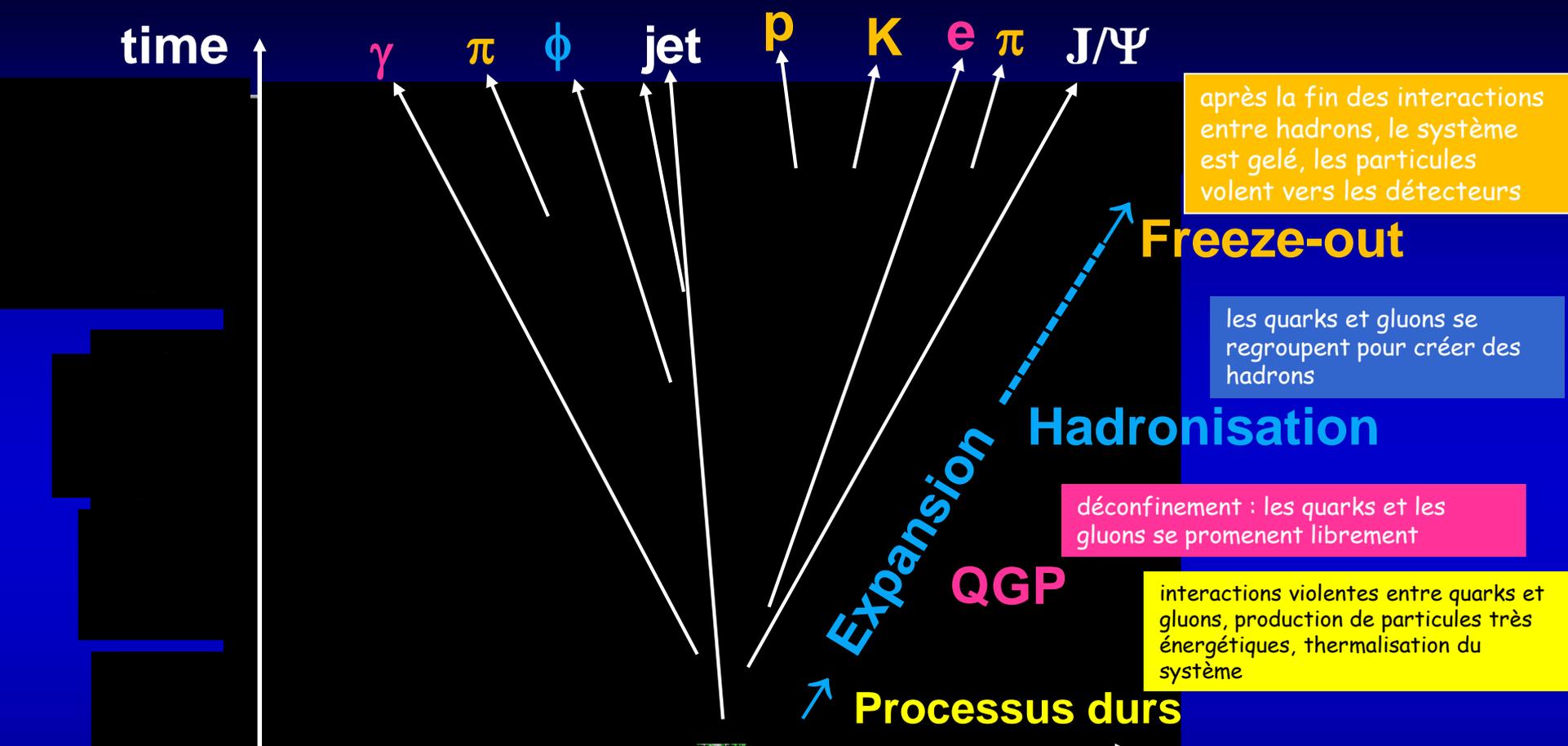
One conspicuous goal at RHIC is to rip apart protons and neutrons inside the colliding nuclei in order to create novel new forms of nuclear matter, such as quark gluon plasma. The beam energies have been as high as 130 GeV per nucleon and the beam density is up to about 10% of its design value.

In this first published RHIC paper, the PHOBOS collaboration (contact Gunther Roland, MIT, gunther.roland@cern.ch) describes the "pseudorapidity" (related to the velocity along the direction of the beams) of the myriad particles emerging from the collisions. The researchers pay special attention to particles emerging at right angles to the incoming beams. These particles emanate from the most violent of collisions, which on average create about 6000-7000 particles per event, more than have ever been seen in accelerator experiments before. The number of particles produced in turn is indicative of the energy density of the fireball produced at the moment of collision; this density, 70% higher than in previous heavy-ion experiments, carries the RHIC researchers into a new portion of the nuclear phase diagram.

The data presented here help to constrain models of this high-density nuclear realm. ([Back et al.](#), *Physical Review Letters*, 9 Oct, [Select Articles](#).) All four RHIC detector groups (STAR, PHENIX, and BRAHMS are the three others) will be presenting their first scientific findings at the [American Physical Society Division of Nuclear Physics Meeting](#) in Williamsburg, VA on October 4-7). While no announcement of a quark gluon plasma is expected, researchers plan to describe numerous impressive aspects of RHIC's early operation.



Shémas: Evolution d'une Collision Centrale Entre Ions Lourds (VNI)



après la fin des interactions entre hadrons, le système est gelé, les particules volent vers les détecteurs

Freeze-out

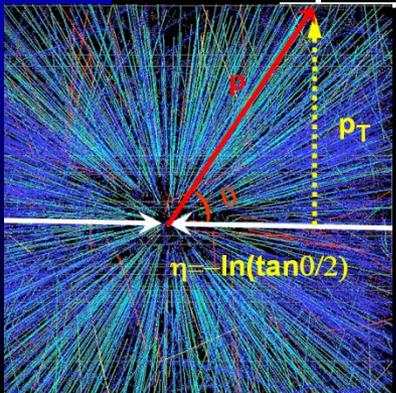
les quarks et gluons se regroupent pour créer des hadrons

Hadronisation

déconfinement : les quarks et les gluons se promènent librement

interactions violentes entre quarks et gluons, production de particules très énergétiques, thermalisation du système

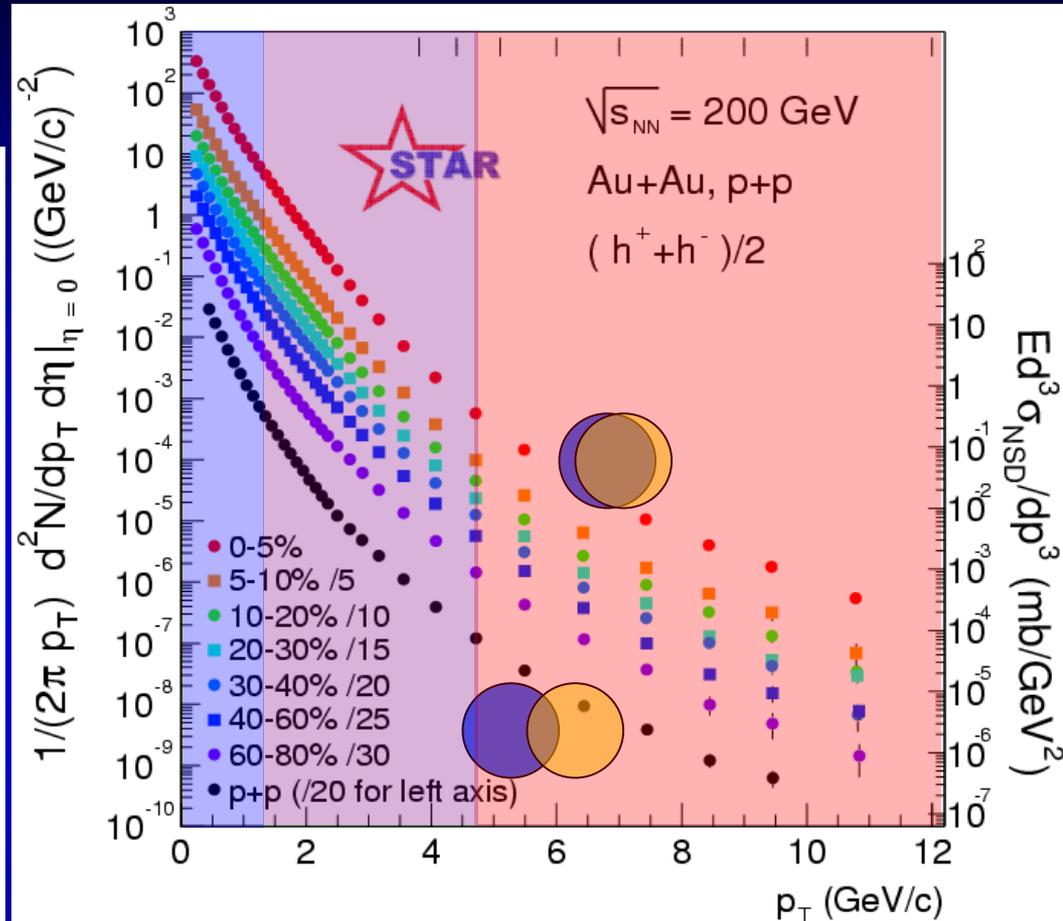
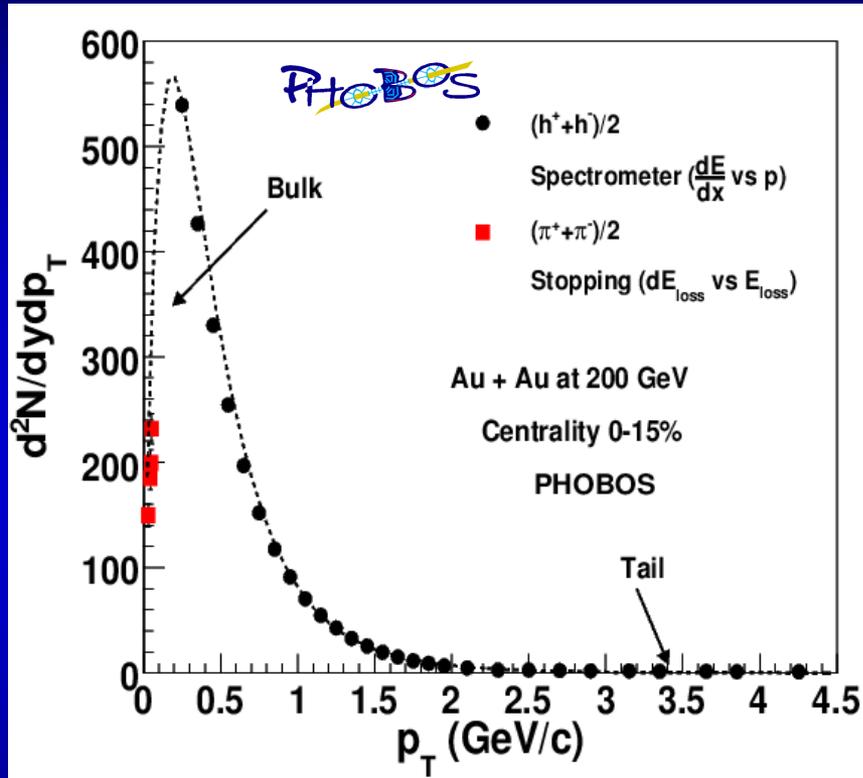
les noyaux, en phase d'approche, sont "aplatis" par la contraction de Lorentz



Principe de l'étude du QGP : on utilise les particules produites pour sonder les propriétés du système formé lors de la collision

Production des Particules: Différentes Régions à Étudier

R. Nouicer et al.
European Physical Journal C33 (2004) S606

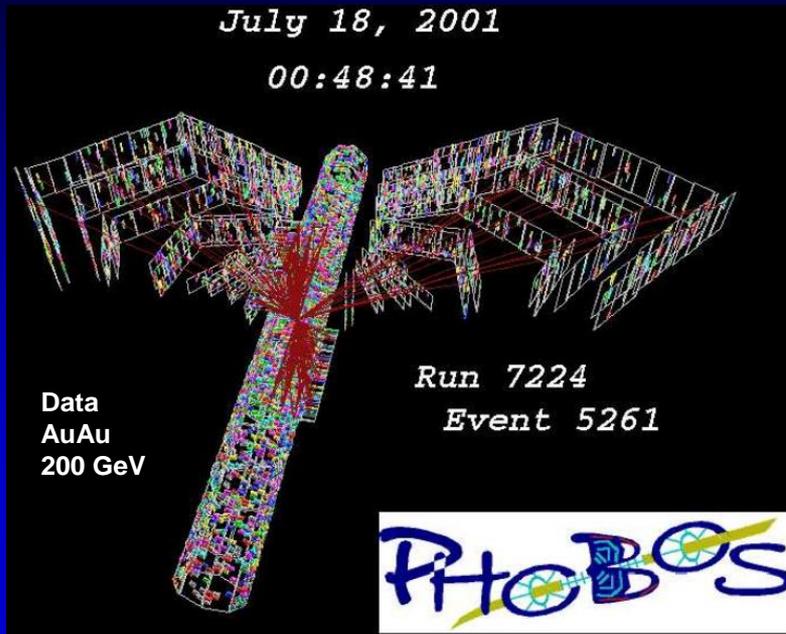


Basse impulsion p_T : majeure partie (95%)/propriétés globales/interactions molles

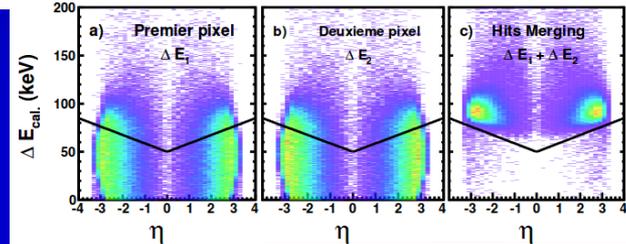
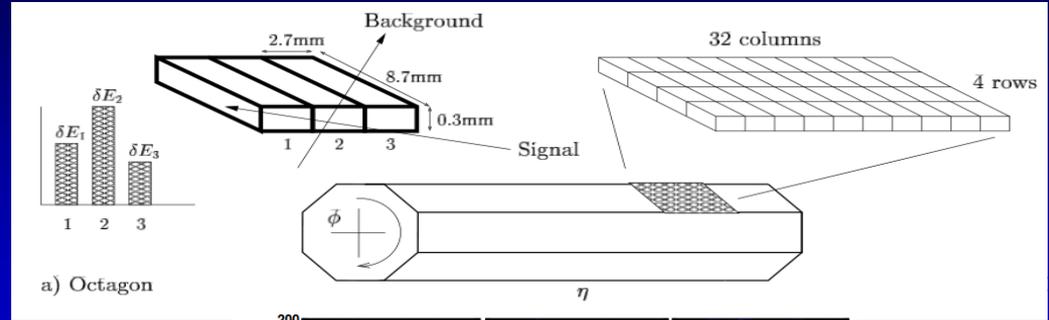
Grande impulsion p_T : petite section efficace, interactions dures

“Intermédiaire” impulsion p_T : effets des interactions molles/dures, surprises ?

Mon travail d'Analyse dans PHOBOS: Multiplicité de h^\pm



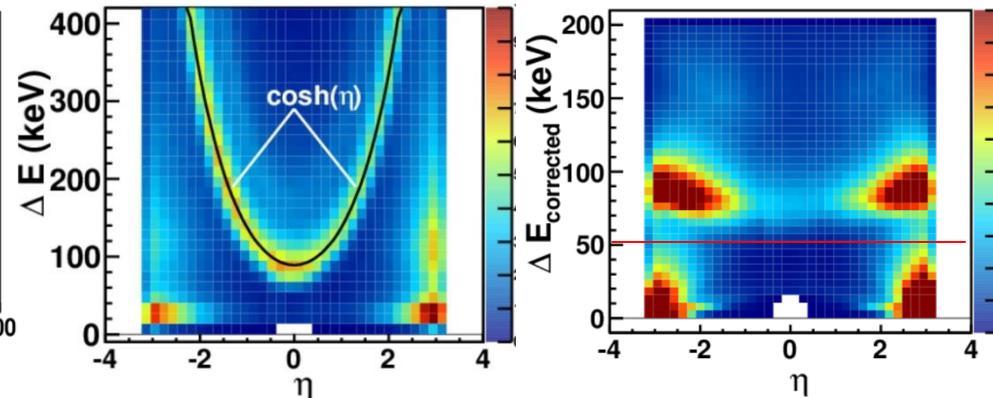
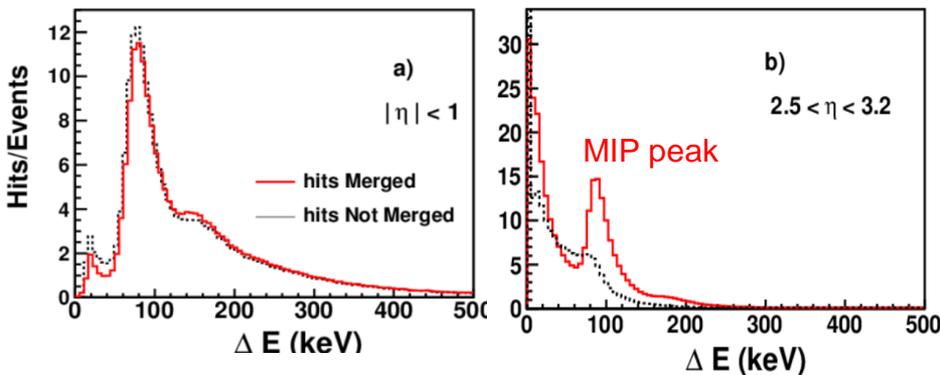
Introduit un algorithme pour fusionner les hits des pixels adjacents "hits-Merging" (éviter le comptage excessif : double/triple comptage)



Spectres de dépôt d'énergie de particules des collisions Au+Au at 200 GeV

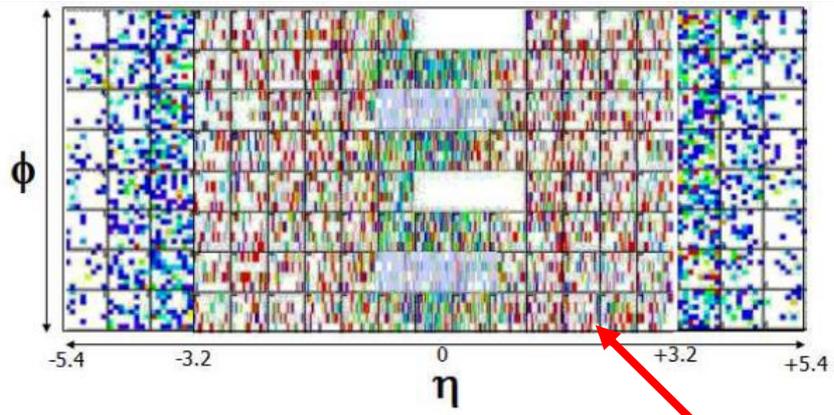
Sans et avec fusionnement des hits de particules

Avec fusionnement des hits de particules

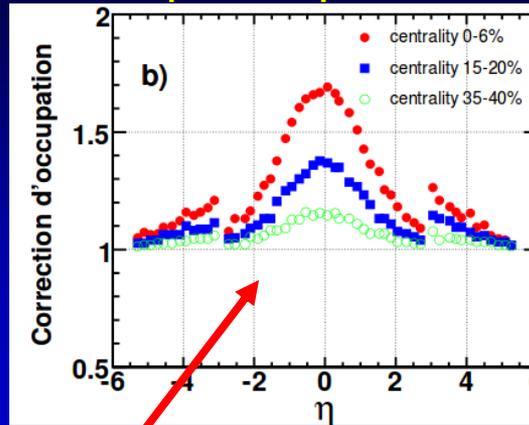


Mon travail d'Analyse dans PHOBOS: Multiplicité de h^\pm

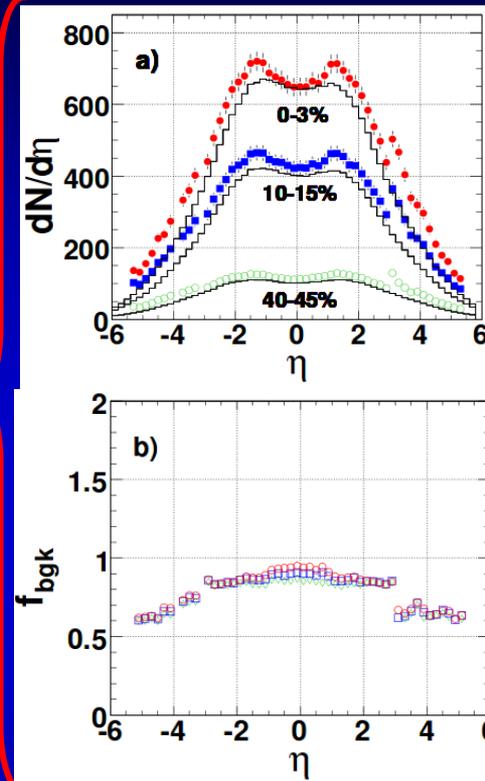
Hits de particules



Occupation de particules

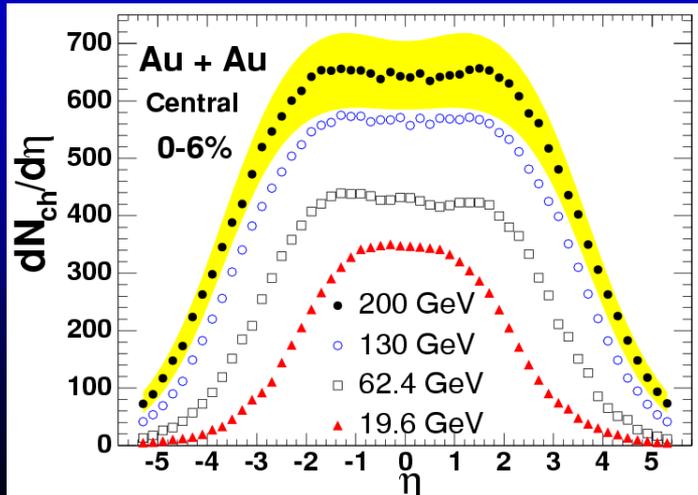


Particules secondaires

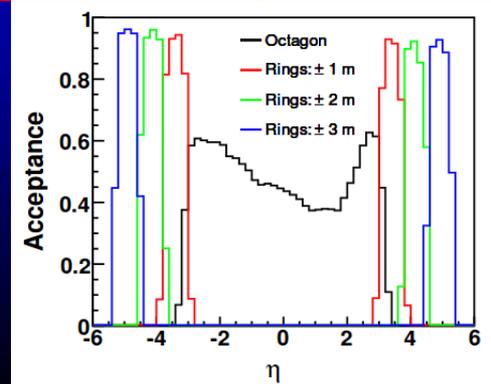


$$\frac{dN_{ch}}{d\eta}(\eta, b) = \frac{1}{N(b)} \sum_{hits} \frac{N_{hits}(\eta, b) \times O(\eta, b)}{\Delta\eta \times Acc(\eta, z_{vtx})} \times f_{bkg}(\eta, b)$$

Distribution de la densité de pseudorapidité des particules chargées primaires



Acceptance



Mon travail d'Analyse dans PHOBOS: Multiplicité de h^\pm

Rachid Nouicer exposé Conférence QM 2004
Journal of Physics G 30 (2004) S1133

Collisions Au+Au

- ✓ Physical Review C74 (2006) 021901(R)
- ✓ Physical Review C70 (2004) 021902(R)
- ✓ Physical Review Letters 91 (2003) 052303
- ✓ Physical Review C74 (2006) 021902(R)
- ✓ Nuclear Physics A757 (2005) 28
- ✓ Physical Review C65 (2002) 061901(R)
- ✓ Physical Review Letters 88 (2002) 22302
- ✓ Physical Review C65 (2002) 031901

Collisions d+Au :

- ✓ Physical Review Letters 93 (2004) 082301
- ✓ Physical Review C72 (2005) 03190 (R)

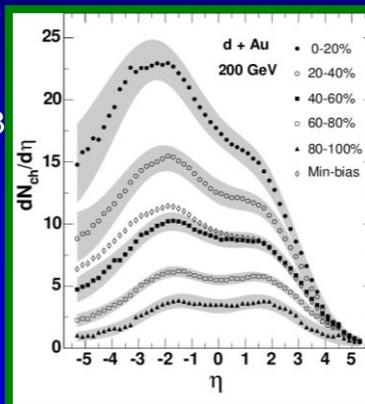
Collisions Cu+Cu

- ✓ Physical Review Letters 102 (2009) 142301

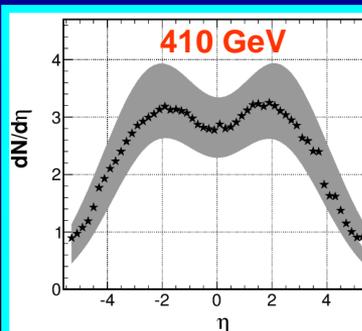
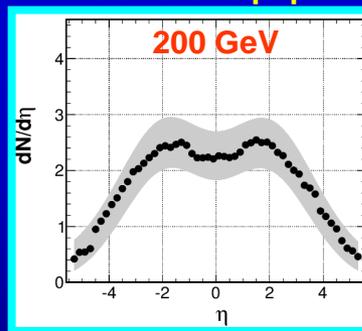
Papier final: Au+Au, Cu+Cu, d+Au et p+p

- ✓ Physical Review C83 (2011) 024913

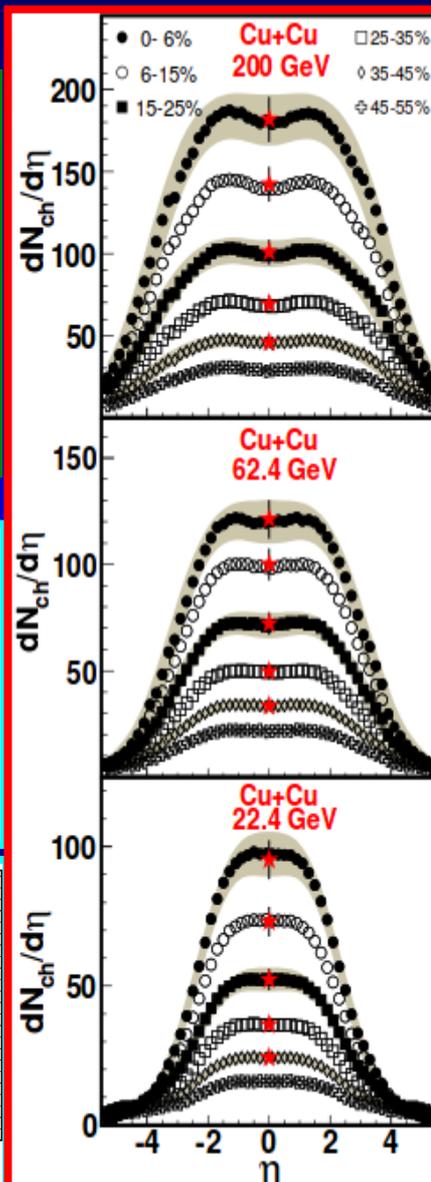
Collisions d+Au



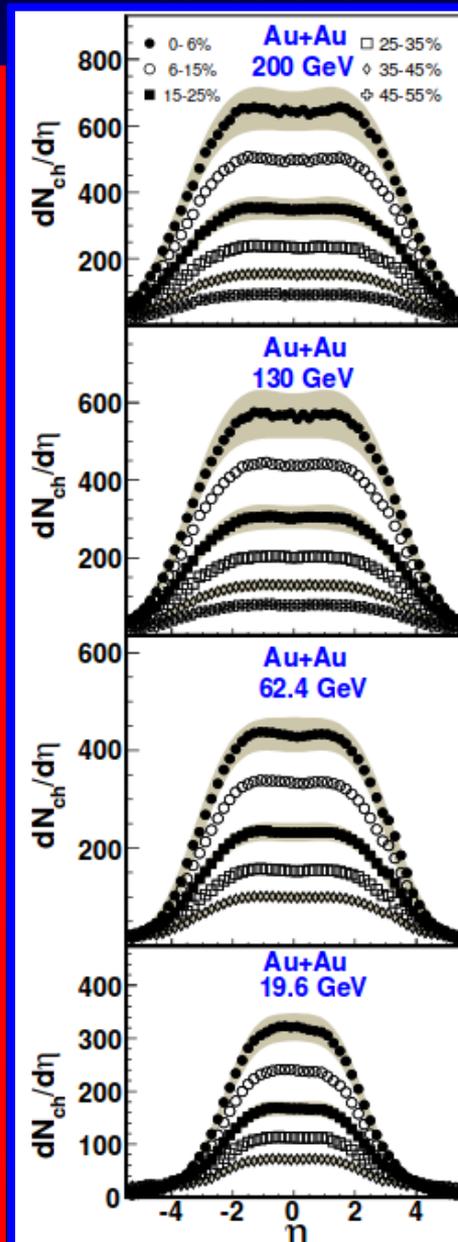
Collisions p+p



Collisions Cu+Cu



Collisions Au+Au



Extended Longitudinal Scaling (ELS) "Limiting Fragmentation"

Rachid Nouicer exposé
Conférence QM 2004
Journal of Physics
G 30 (2004) S1133

Collisions Au+Au

- ✓ Physical Review C74 (2006) 021901(R)
- ✓ Physical Review C70 (2004) 021902(R)
- ✓ Physical Review Letters 91 (2003) 052303
- ✓ Physical Review C74 (2006) 021902(R)
- ✓ Nuclear Physics A757 (2005) 28
- ✓ Physical Review C65 (2002) 061901(R)
- ✓ Physical Review Letters 88 (2002) 22302
- ✓ Physical Review C65 (2002) 031901

Collisions d+Au :

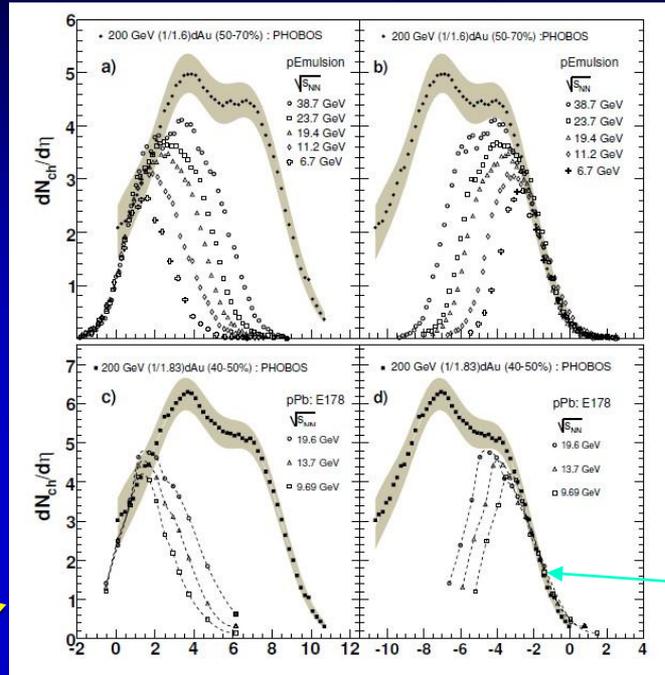
- ✓ Physical Review Letters 93 (2004) 082301
- ✓ Physical Review C72 (2005) 03190 (R)

Collisions Cu+Cu

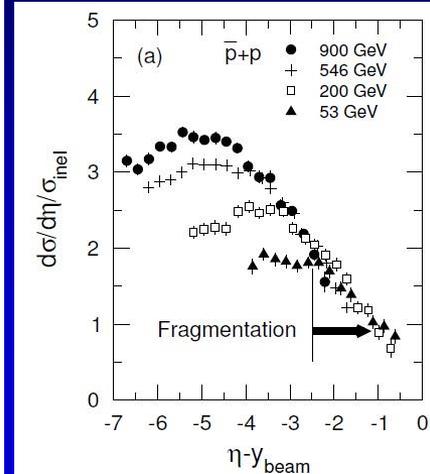
- ✓ Physical Review Letters 102 (2009) 142301

$$\eta' = \eta - y_{beam}$$

Collisions d+Au, pEm, pPb

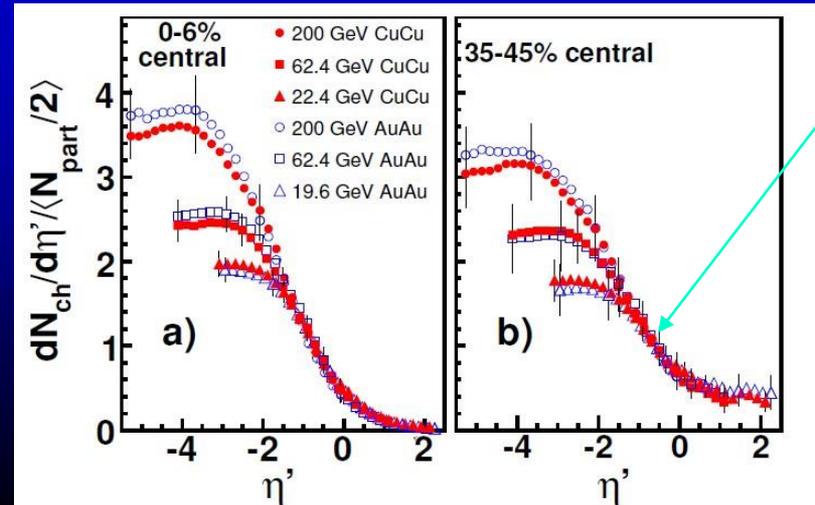


Collisions p + p (UA5)



ELS

Collisions Au+Au et Cu+Cu



Phénomène "Scaling" au même Volume Nucléaire " $N_{part}/2A$ "

Collisions Cu+Cu

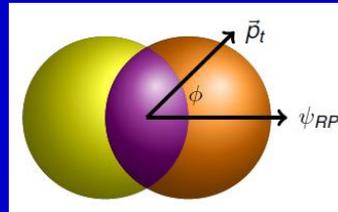
✓ **Physical Review Letters 102 (2009) 142301** →

La géométrie ($N_{part}/2A$) est définie comme la fraction du volume nucléaire total de la région d'interaction formée par les deux noyaux en collision:

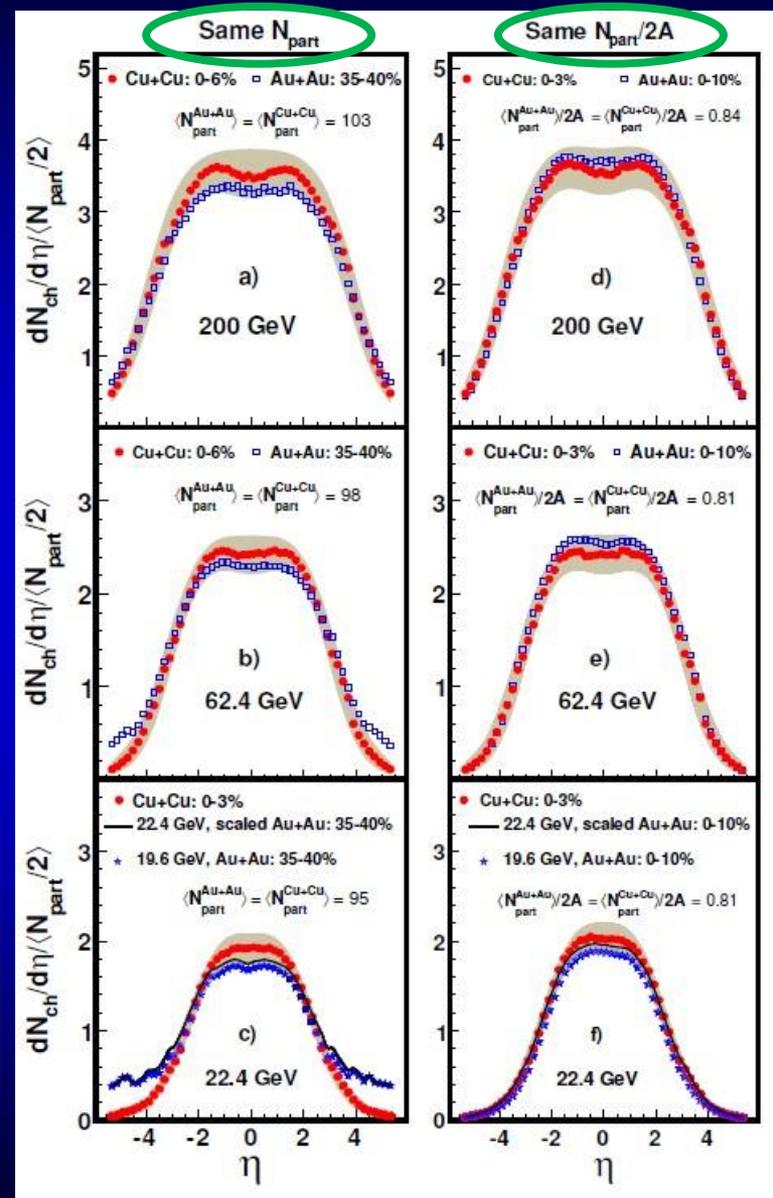
$$N_{part}/2A$$

ou A est le nombre atomique de noyau

$$N_{spec} = 2A - N_{part}$$

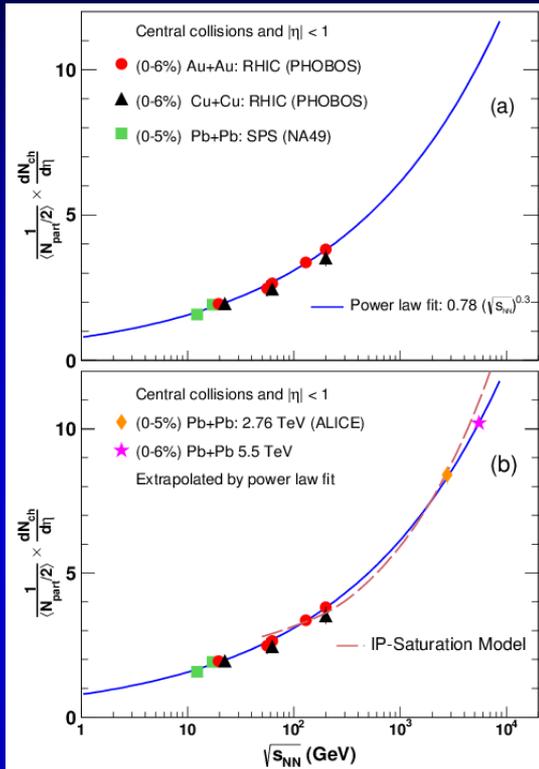


Nous observons une excellente concordance entre les distributions des deux systèmes, Au+Au et Cu+Cu, sur toute la gamme de η et à toutes les énergies lorsqu'on fait une comparaison par rapport au volume nucléaire de la région d'interaction ($N_{part}/2A$)

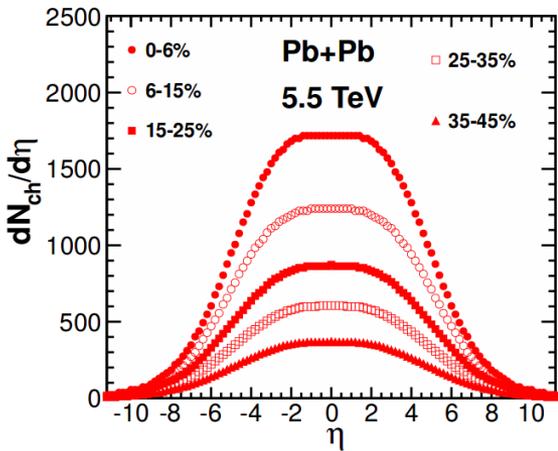
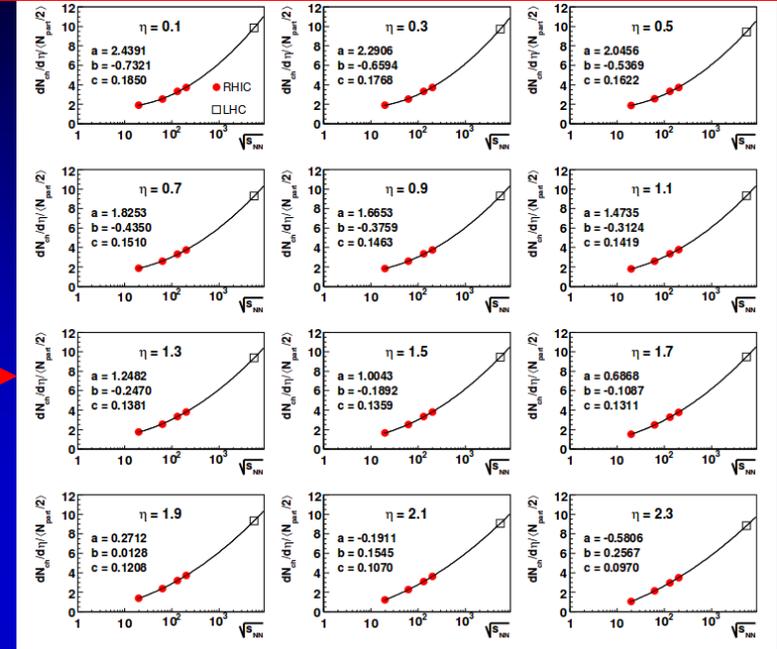


Mes Préddictions pour le LHC : Multiplicité de h^\pm

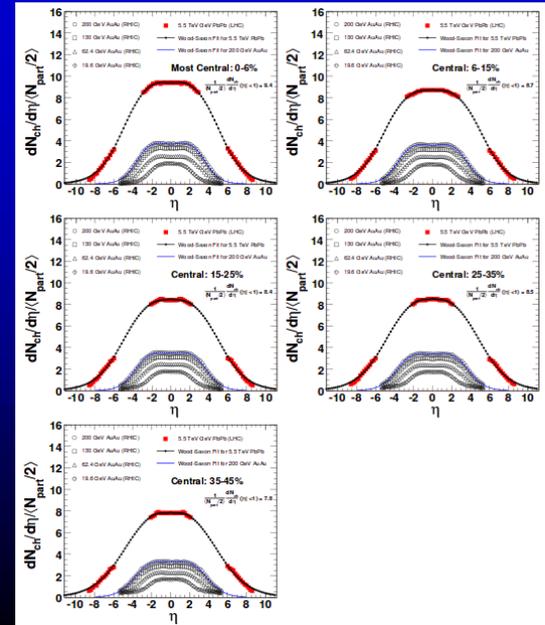
H.D.R. <https://tel.archives-ouvertes.fr/tel-00925262>



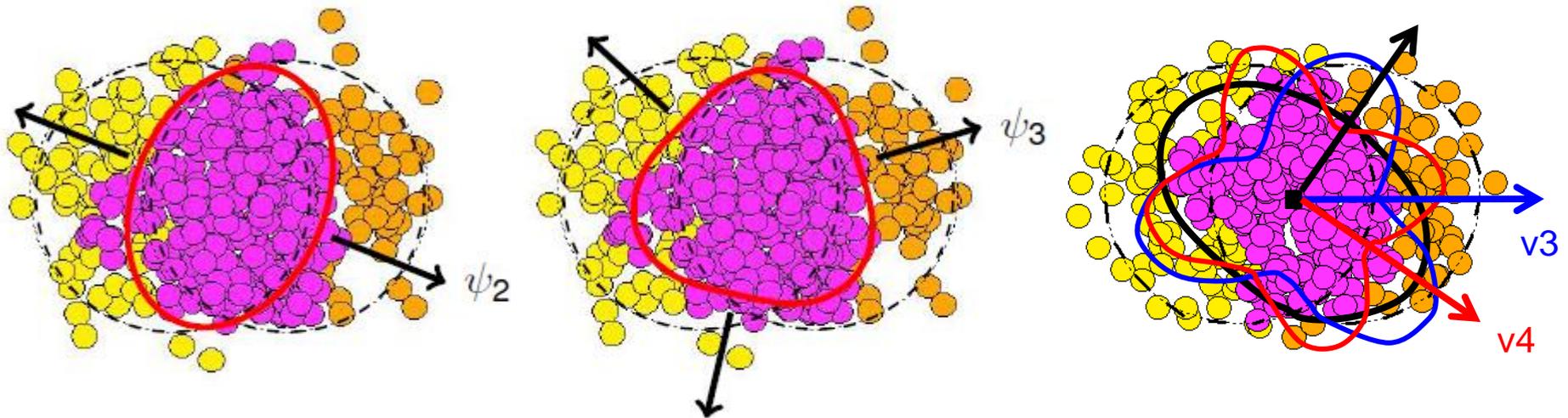
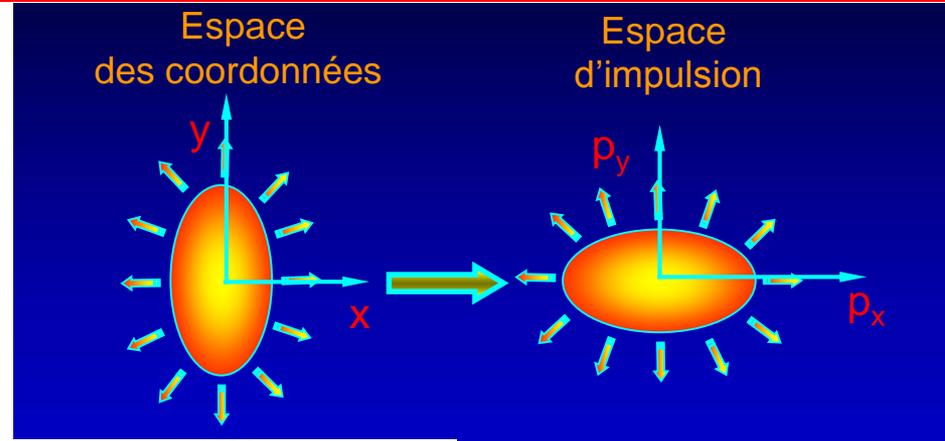
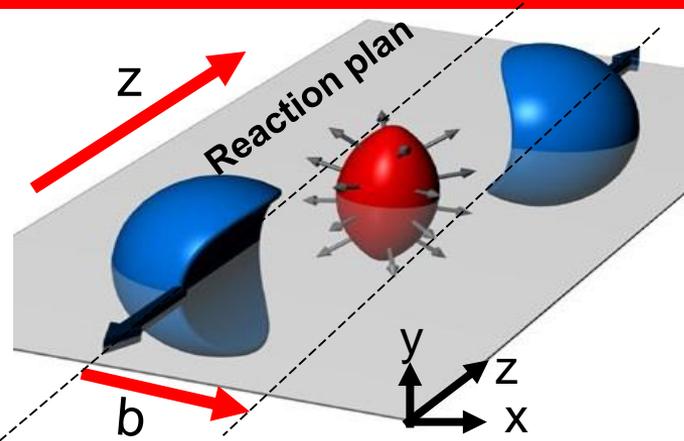
Mi-rapacité



Distributions en 4π



Le "Flot": une Sonde Unique !



Transformée de Fourier des particules produites en distribution azimuthale

$$\frac{dN}{d\phi} = 1 + 2v_2 \cos[2(\phi - \Psi_2)] + 2v_3 \cos[3(\phi - \Psi_3)] + 2v_4 \cos[4(\phi - \Psi_4)] + 2v_5 \cos[5(\phi - \Psi_5)] + \dots$$



Pourquoi l'écoulement elliptique est-il intéressant ?

Les corrélations d'écoulement fournissent une sonde importante

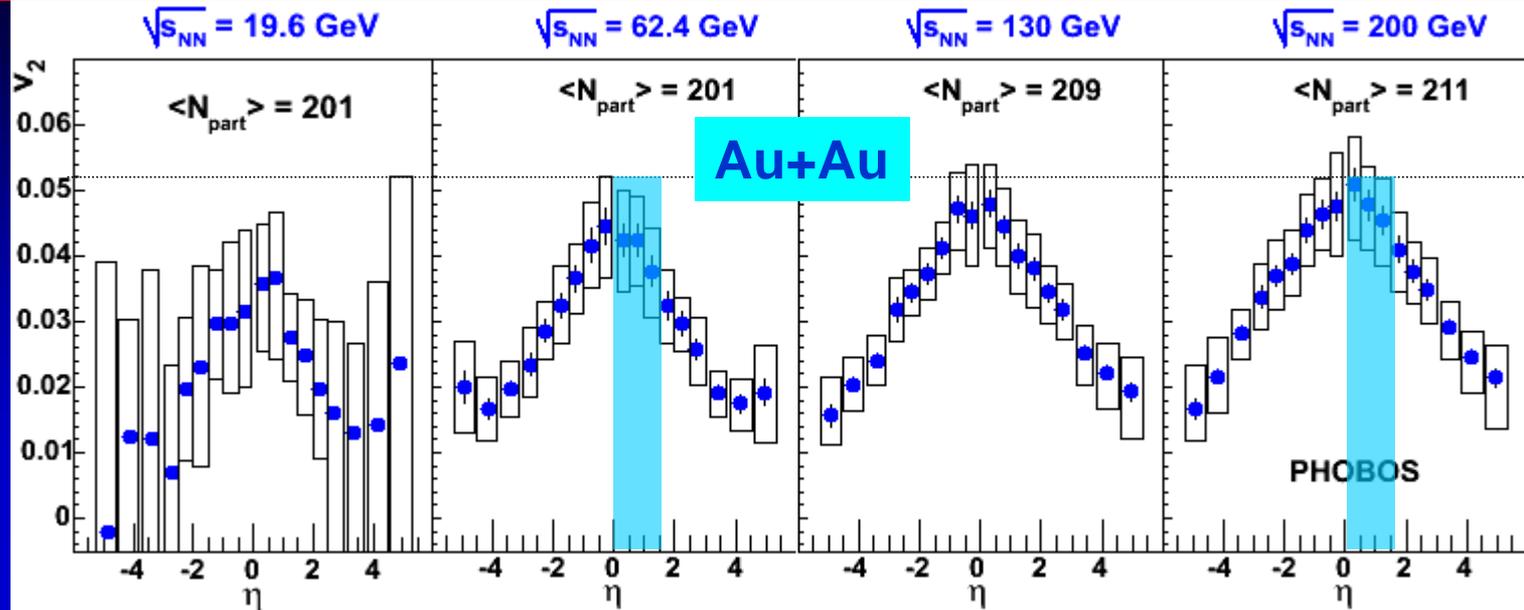
- ❖ *Fournit des évaluations fiables de pression & des gradients de pression ?*
- ❖ *Peut éclaircir les questions liées à la thermalisation*
- ❖ *Donne des analyses sur la dynamique transversale et longitudinale du milieu*
- ❖ *Permet d'accéder aux propriétés du milieu
- EOS, viscosité, etc.*

Participation à l'Analyse : Mesure du Flot Elliptique

Rachid Nouicer exposé
Conférence QM 2006
J. Phys. G34 (2007) S887

v_2 mesuré :

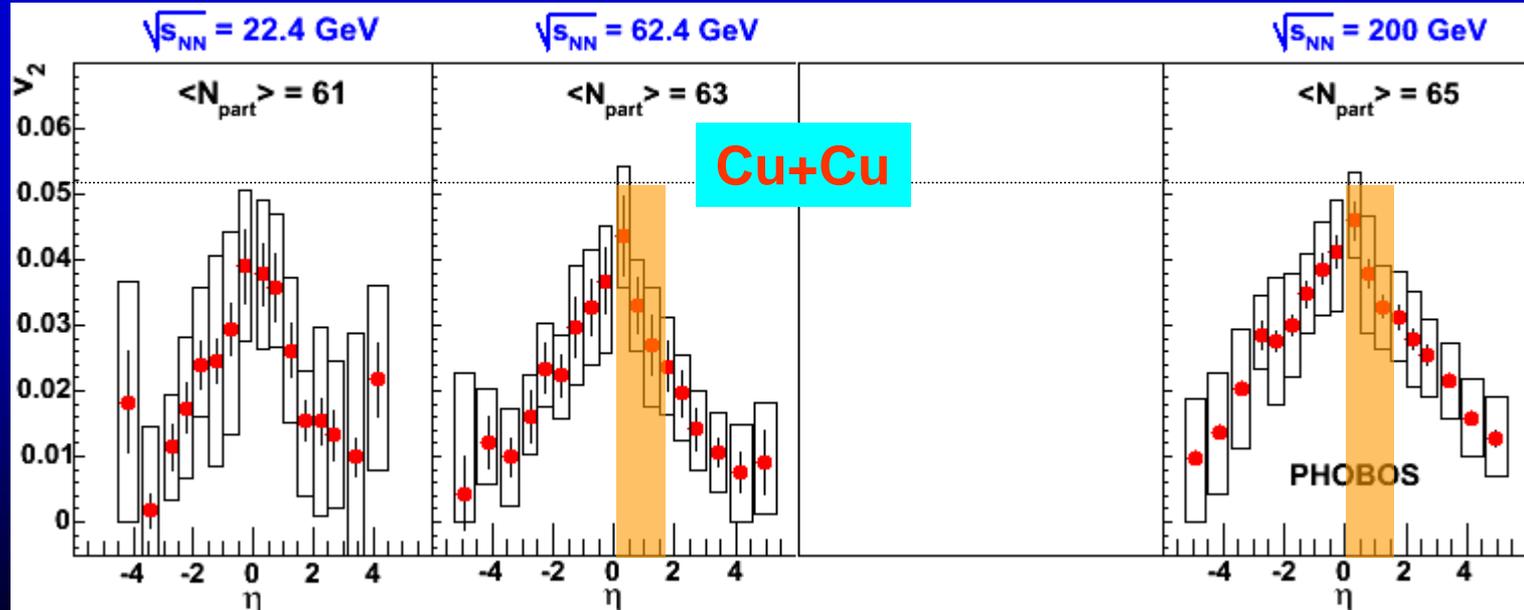
- grande couverture en η
- plusieurs énergies



Observations sur

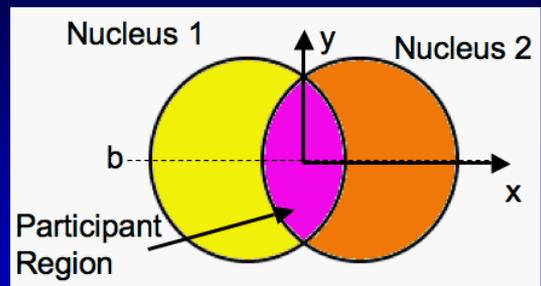
v_2 de Cu+Cu :

- Grande amplitude
- Semblable à la forme Au+Au

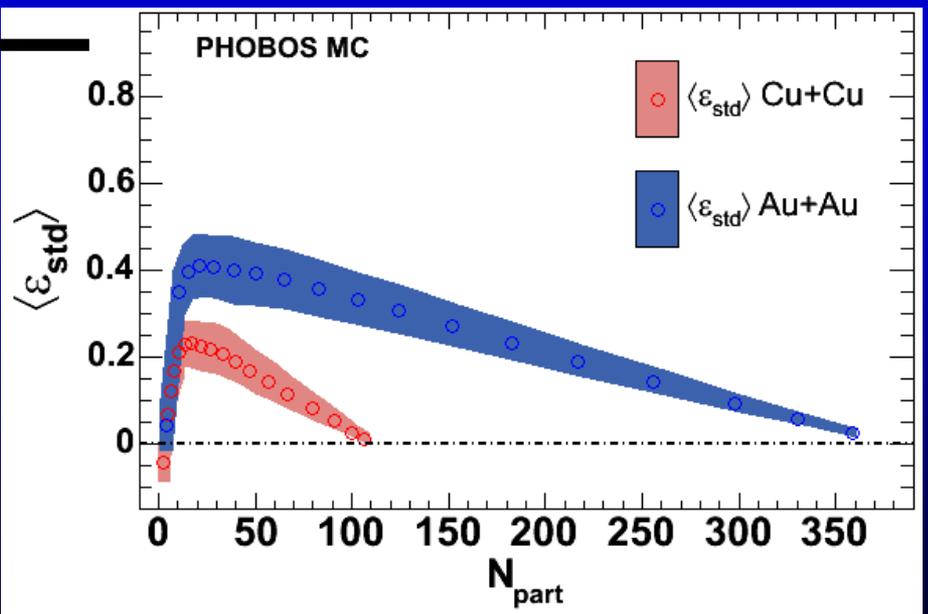
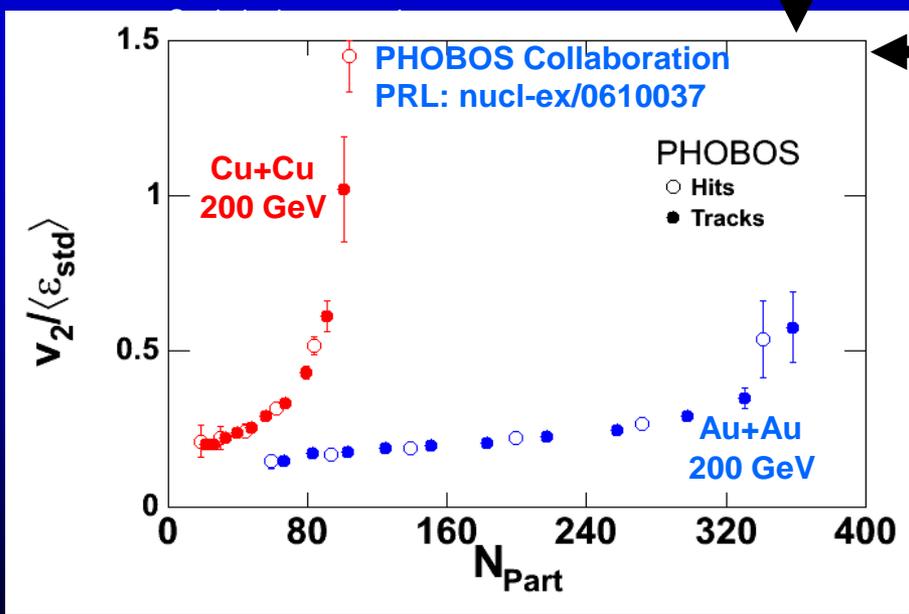
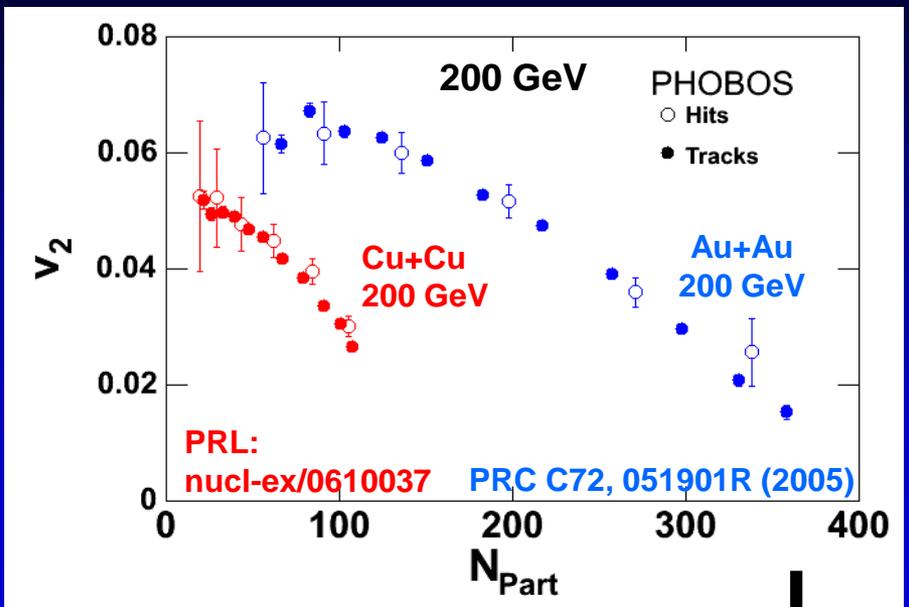


Standard Eccentricity Calculation

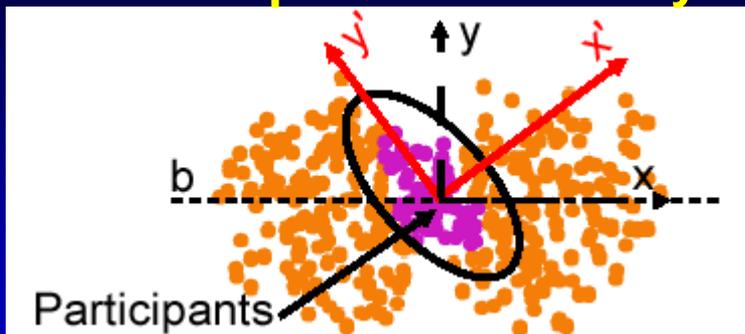
Standard Eccentricity



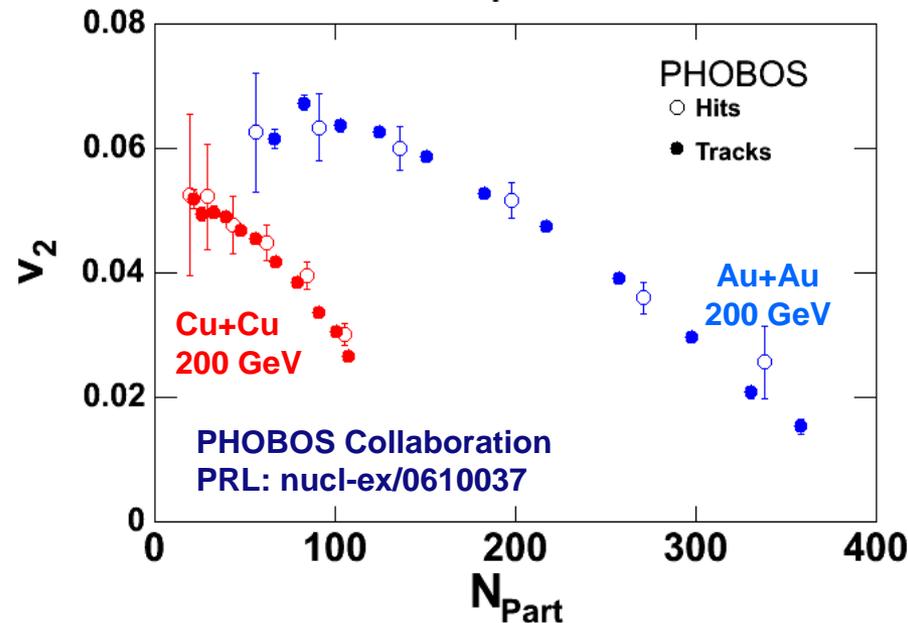
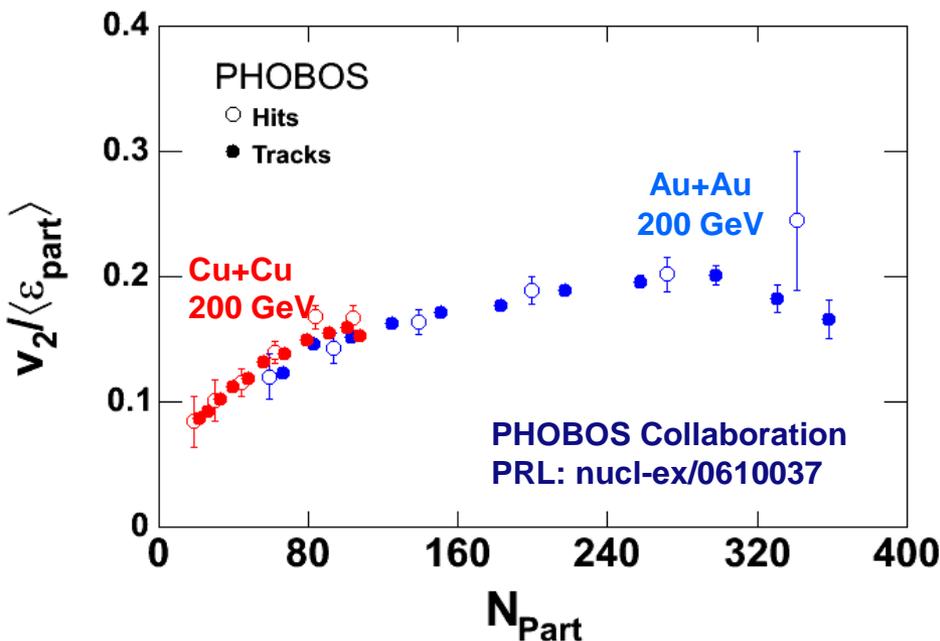
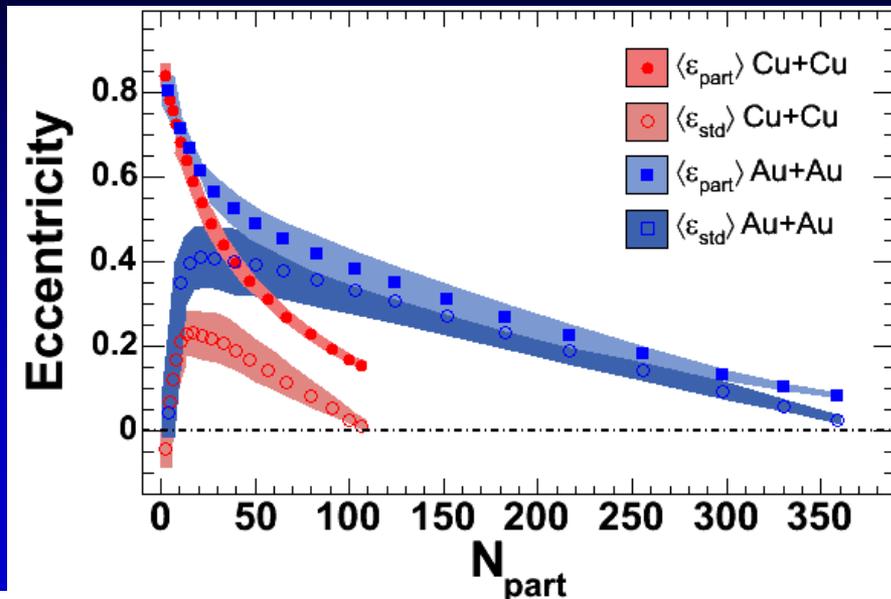
$$\epsilon_{std} = \frac{\langle y^2 - x^2 \rangle}{\langle x^2 \rangle + \langle y^2 \rangle}$$



Participant Eccentricity



$$\langle \varepsilon_{\text{part}} \rangle = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\sigma_{xy}^2}}{(\sigma_y^2 + \sigma_x^2)}$$

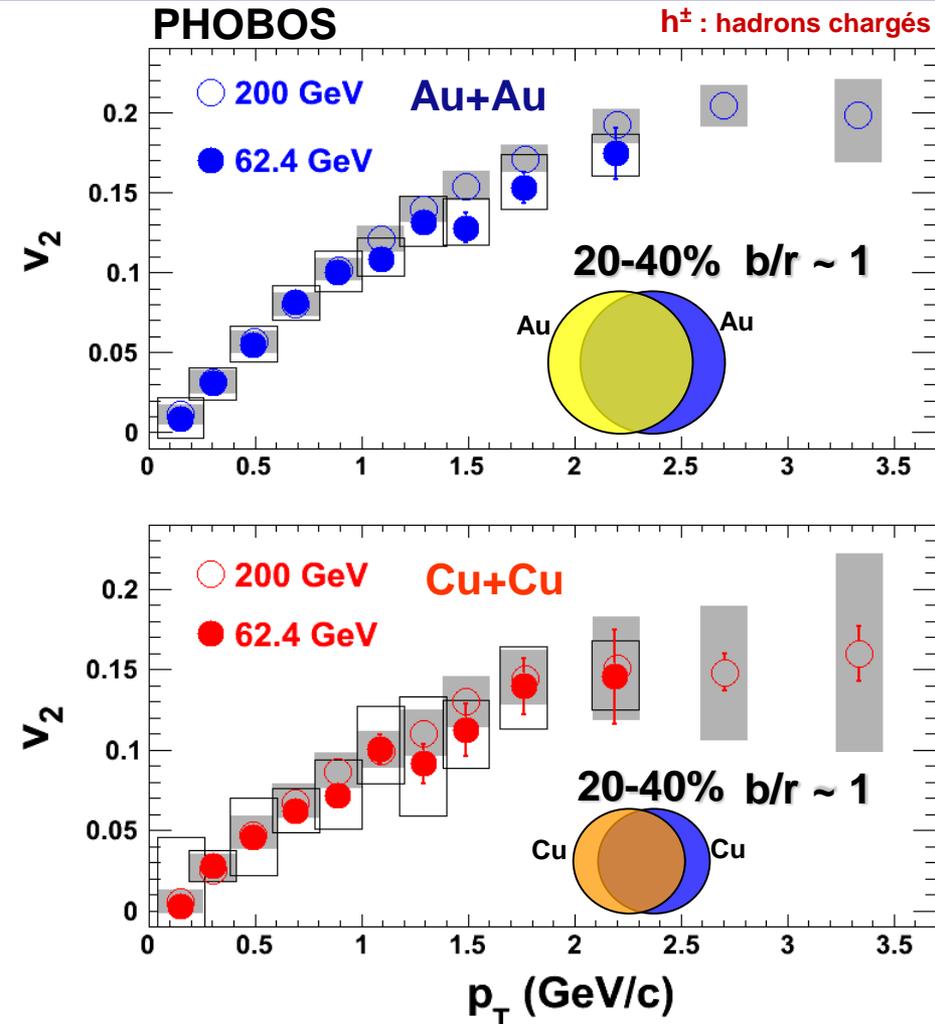


Partie du Groupe d'Analyse : Mesure du Flot Elliptique

Dépendance en moment d'impulsion transversale d'hadrons

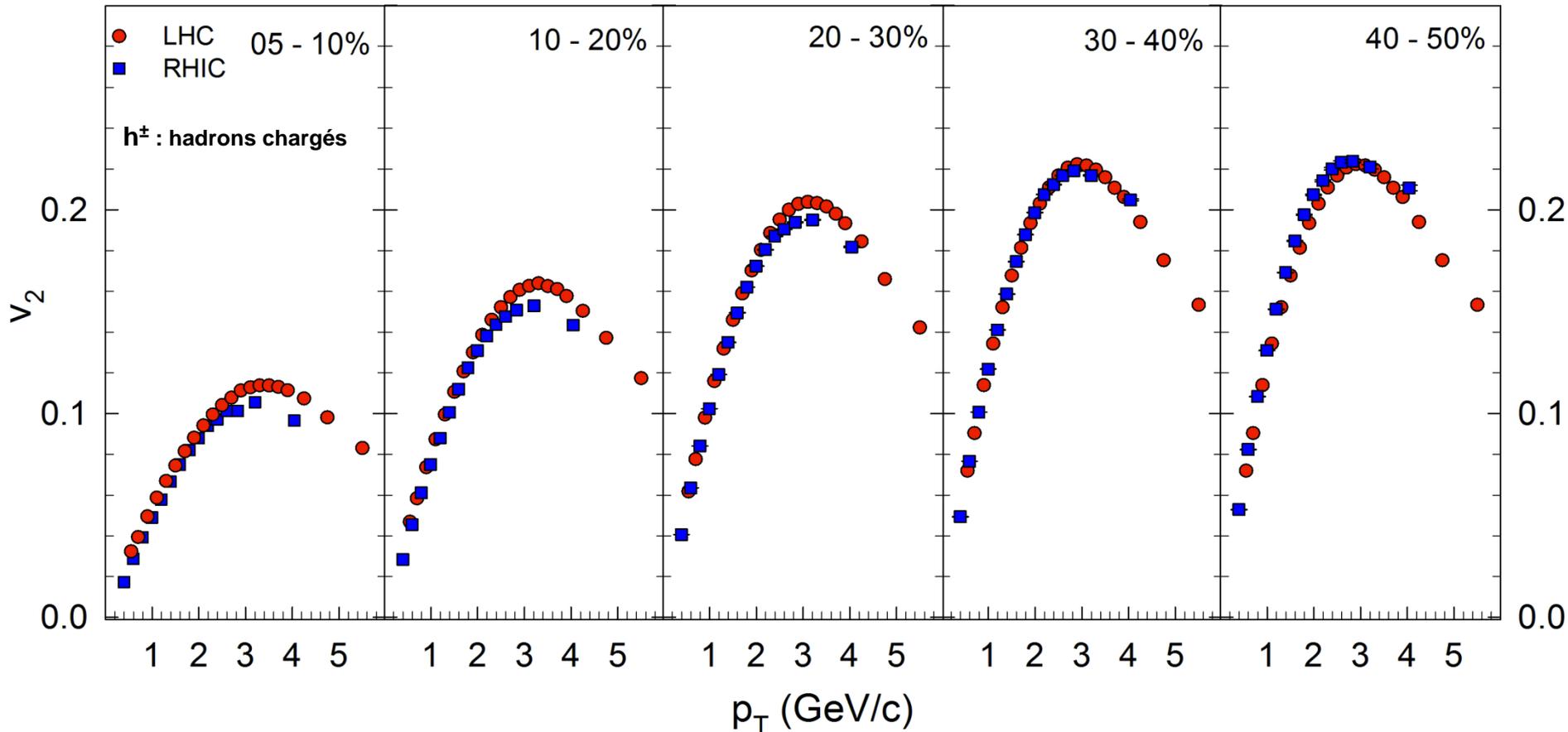
- ❖ Amplitude de v_2 augmente en fonction de p_T
- ❖ Amplitude de v_2 est régie par la forme de la région de recouvrement (excentricité) : v_2 (CuCu) \sim v_2 (AuAu) for mid-central (20 - 40%, $b/r = 1$)
 - indication d'un comportement hydrodynamique
- ❖ Amplitude de v_2 à 62.4 et 200 GeV est semblable
 - indication d'une limite hydrodynamique
 - Pour prouver la limite hydrodynamique, il faut mesurer v_2 à LHC
E (LHC : 2.76) \sim 10 E (RHIC)

Rachid Nouicer exposé Conférence QM 2006
J. Phys. G34 (2007) S887



Flot Elliptique à RHIC et LHC

Comparaison: RHIC (Au+Au at 0.2 TeV) et LHC (Pb+Pb a 2.76 TeV)



Surprise !

V_2 indique la bonne concordance des deux amplitudes et les tendances des deux ensembles de données RHIC et LHC pour une large gamme de p_T ainsi pour différentes centralités !

➔ une limite hydrodynamique est bien atteinte

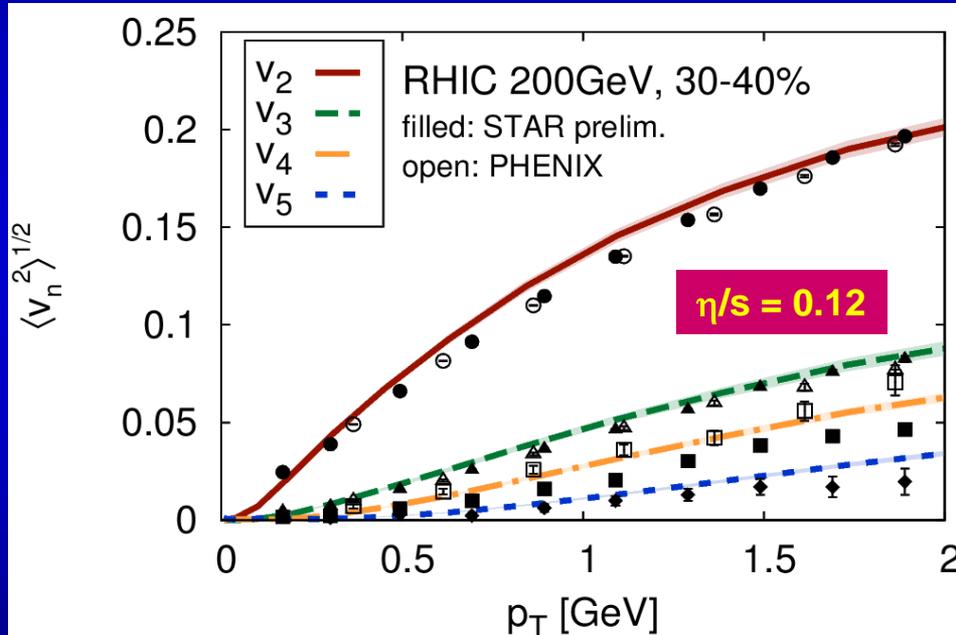
Viscosité/Entropie du Fluide (QGP) aux RHIC et LHC

Le système est considéré comme ayant atteint un équilibre thermique local :

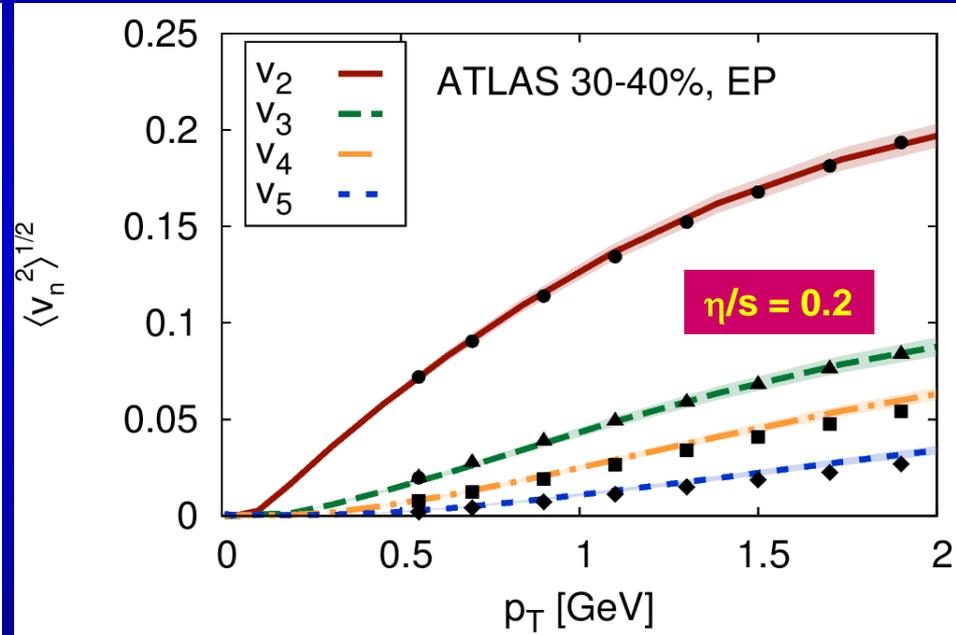
$$\partial_\mu T^{\mu\nu} = 0 \quad T^{\mu\nu} = (\epsilon + P)u^\mu u^\nu - P g^{\mu\nu} + \Delta T^{\mu\nu} \quad \Delta T^{\mu\nu} = \eta(\Delta^\mu u^\nu + \Delta^\nu u^\mu) + \left(\frac{2}{3}\eta - \zeta\right)H^{\mu\nu}\partial_\rho u^\rho$$

La première simulation hydrodynamique relativiste inclue la viscosité, les fluctuations et 3 +1 dimensions : Bjorn Shenke, Sangyong Jeon, and Charles Gale, Phys. Rev. Lett. 106, 042301 (2011)

RHIC



LHC

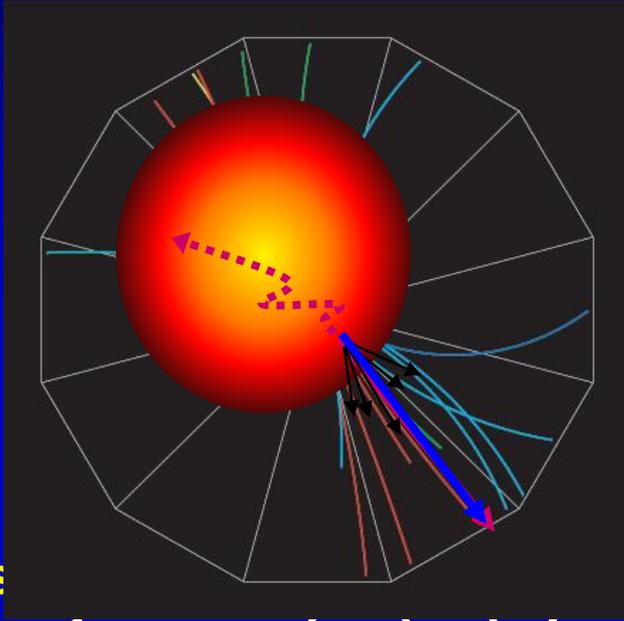


- Milieu est fortement interactif (l'amplitude de v_2 grande)
- Comparaisons modèle hydrodynamique visqueuse aux données RHIC et LHC semblent favoriser des valeurs pour η/s très petites. Ceci implique que la matière nucléaire créée est un fluide presque parfait. Les propriétés de ce fluide reste à déterminer.

**Y a-t-il une autre observable
physique
qui confirme
les résultats
FLOT ?**

Corrélations Azimutales de Grande p_T (Di-jet : Corrélations 2-particules)

STAR + Événements observés p+p

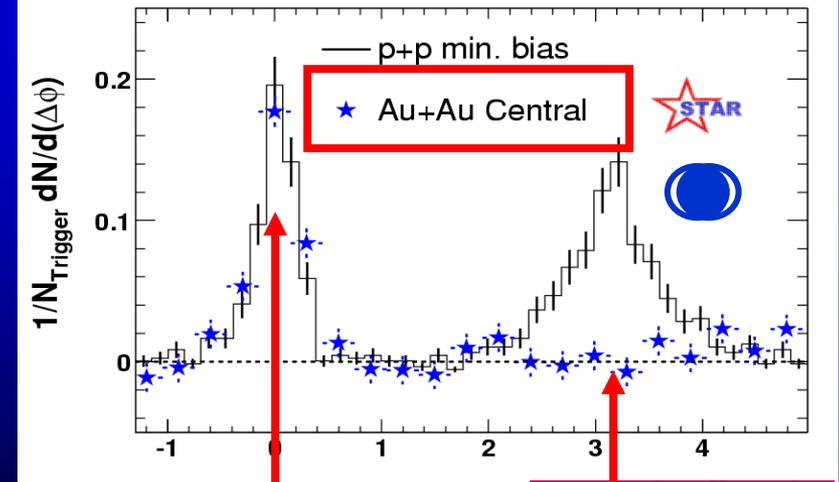
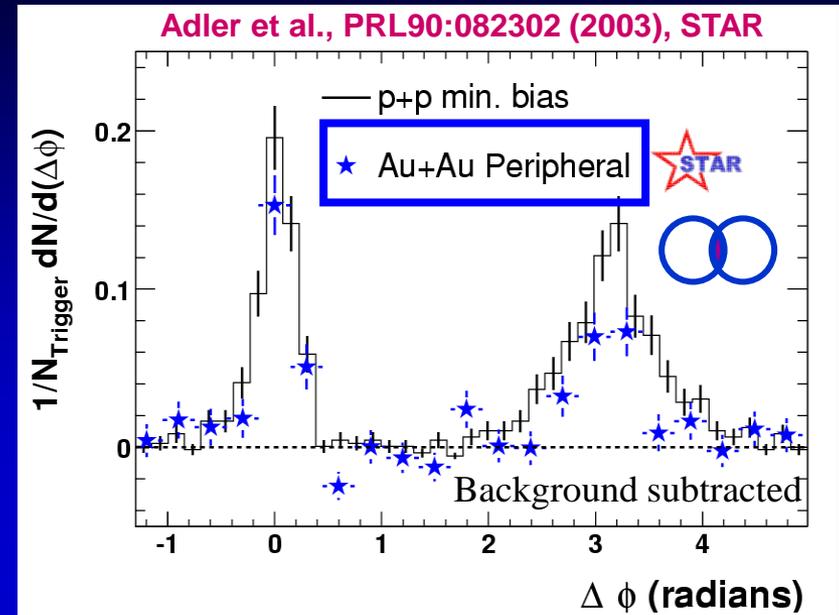


“Near-side”

- partons fragmenté près de la surface
 “Déclencheuse” $\Delta\phi = 0$
 (en dehors du milieu)

Corrélation claire des particules
 “Away-side” :

- partons sont absorbés par le milieu

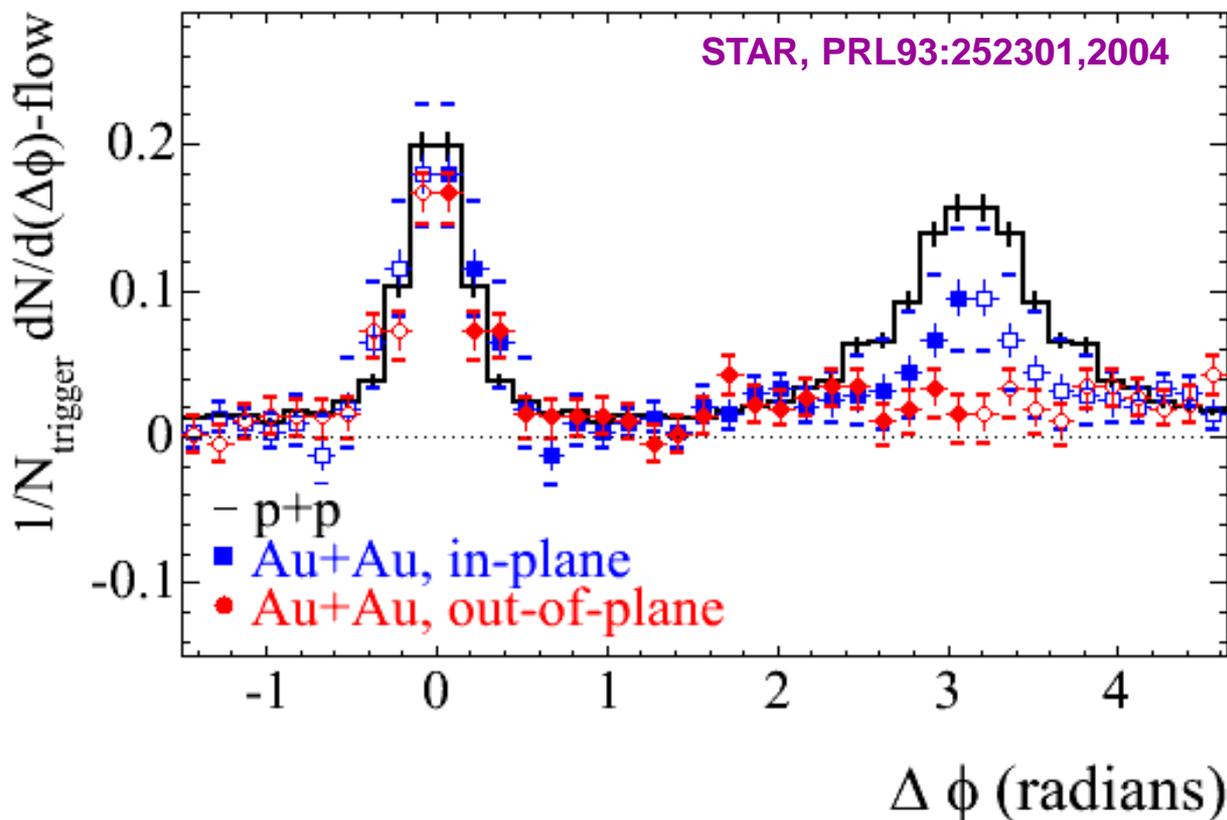


“Near side” jet identical!

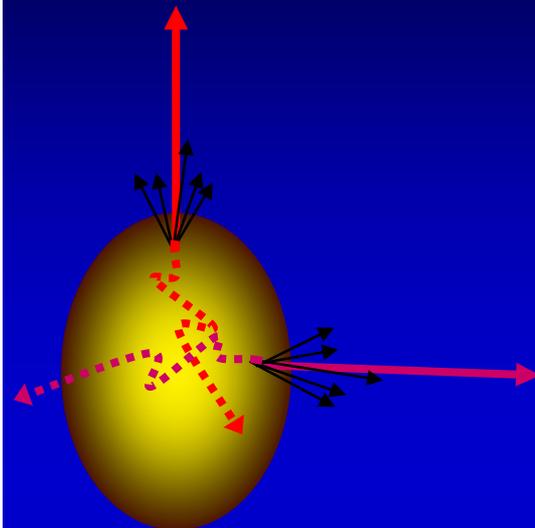
“Away side”

Comment pouvons-nous obtenir plus d'information ?

La géométrie de la suppression du "Away-side"



Non-central
Au+Au collisions



Suppression de "away-side" est plus grande hors du plan comparé dans le plan
Démonstration claire de la dépendance de la longueur du trajet ("path length")

Bon outil pour contraindre la théorie de perte d'énergie

**Y a-t-il une autre observable
physique
qui confirme
les résultats**

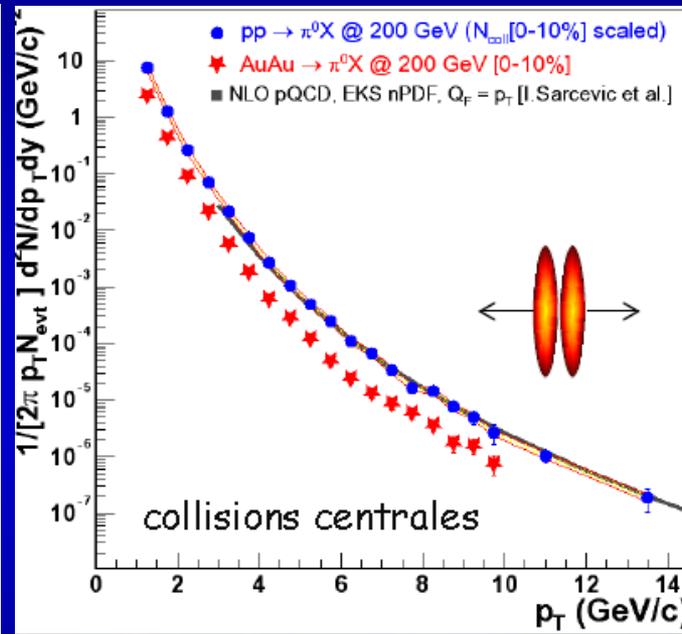
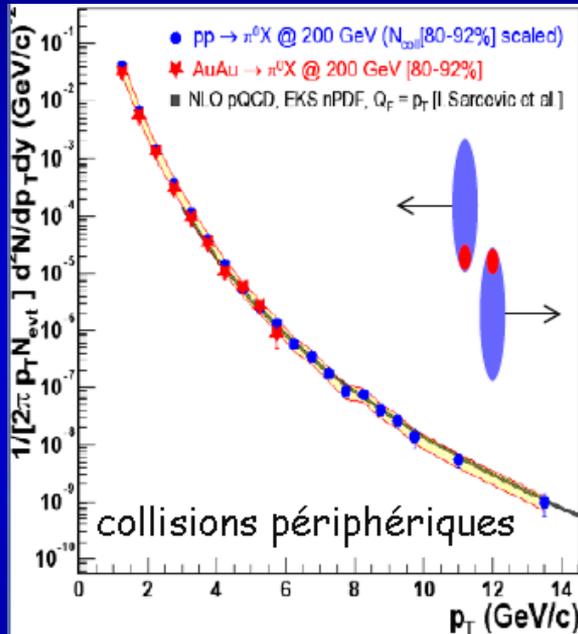
**FLOT
et**

Correlations Di-jet ?

Jet et "Jet Quenching"

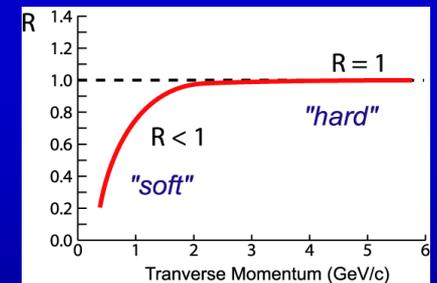
Principe : vérifier si les collisions Au+Au se comportent ou non comme une superposition de collisions p+p en terme de taux de particules produites

R_{AA} le facteur de modification nucléaire pour une centralité donnée :



$$R_{AA} = \frac{1}{N_{coll}} \frac{dN_{AA}}{dN_{pp}}$$

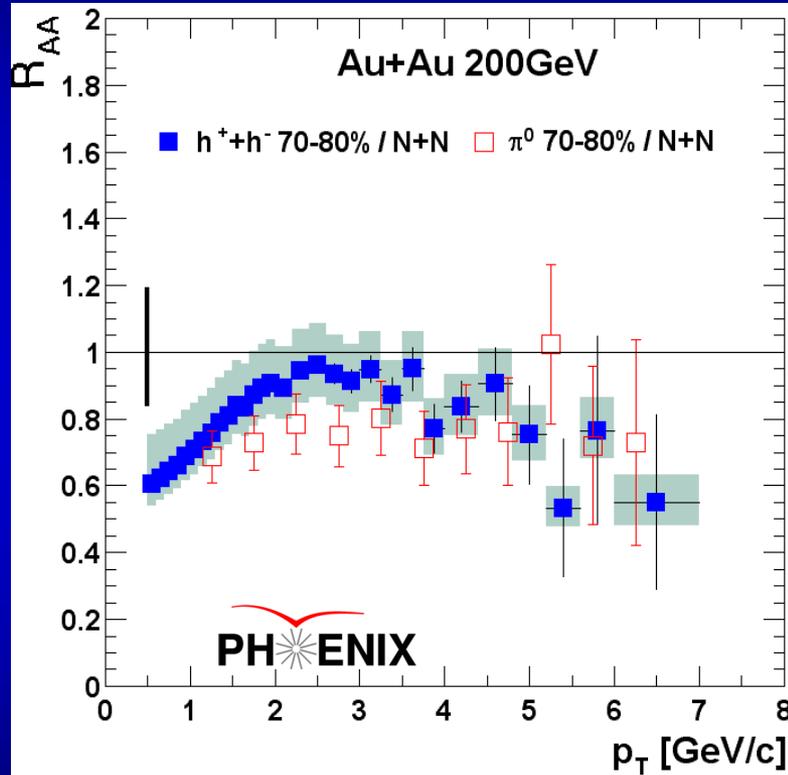
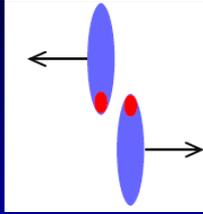
$$R_{AA} = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA} / dp_T d\eta}{d^2 \sigma_{pp} / dp_T d\eta}$$



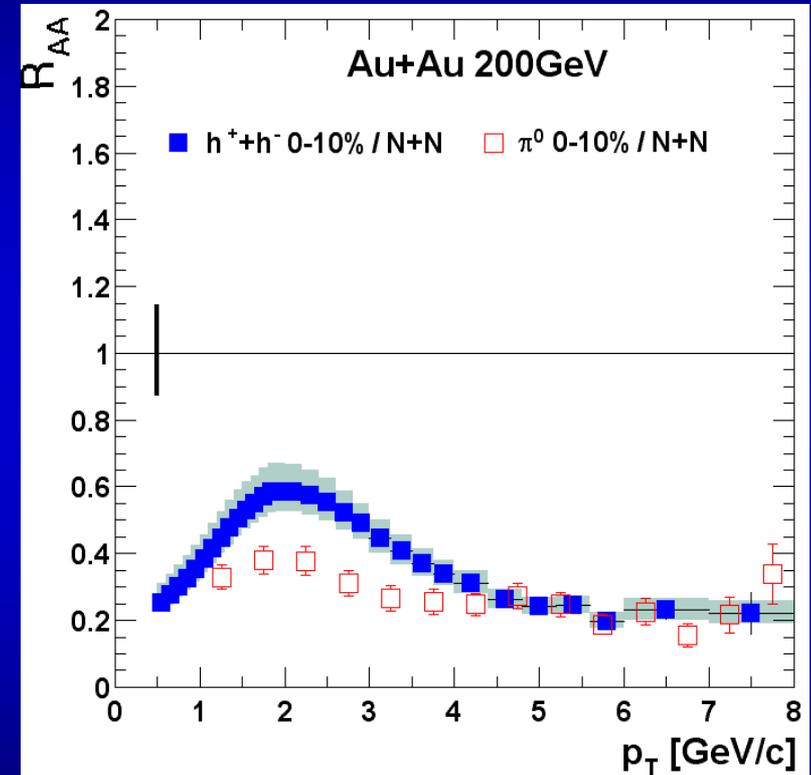
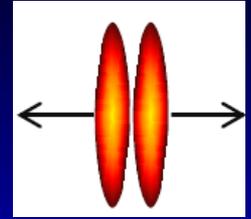
- Collisions périphériques : le taux de production de particules est en accord avec les collisions p+p (extrapolées) et les prédictions théoriques
- Collisions centrales : déficit de particules de grande p_T par rapport aux collisions p+p (extrapolées) et aux prédictions théoriques i.e. jet quenching

Jet et "Jet Quenching" – Facteur Modification Nucléaire

Au + Au at 200 GeV
Collisions périphériques



Au + Au at 200 GeV
Collisions centrales

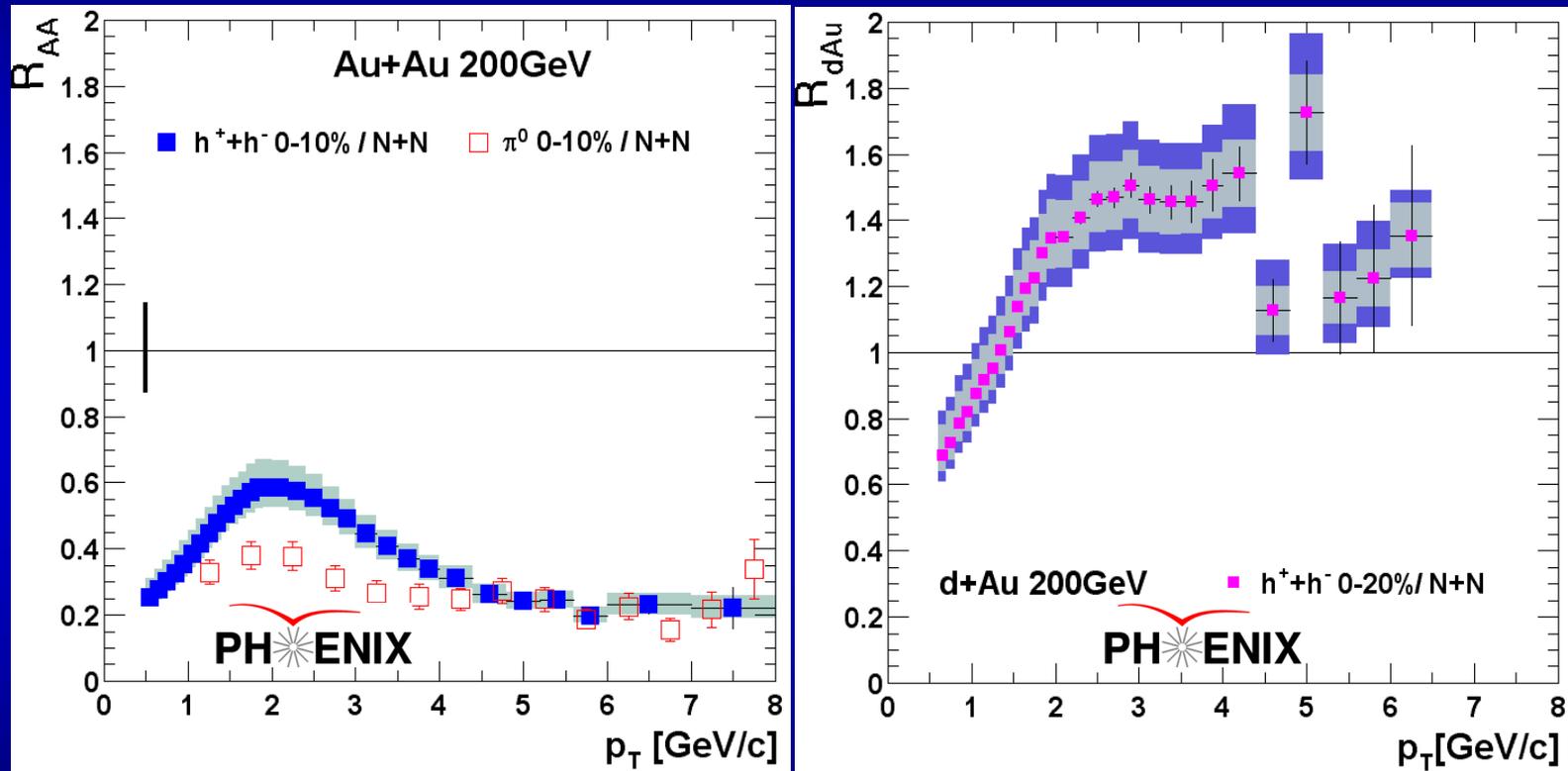


- Pas de suppression des particules de grande p_T dans les collisions périphériques
- Suppression des particules de grande p_T dans les collisions centrales : jet quenching ?
- Cette suppression est-elle un effet de l'état initial ou final ?

Jet et “Jet Quenching” – Facteur Modification Nucléaire

Cette suppression des particules est-elle un effet de l'état initial ou final ?

Au+Au versus d + Au

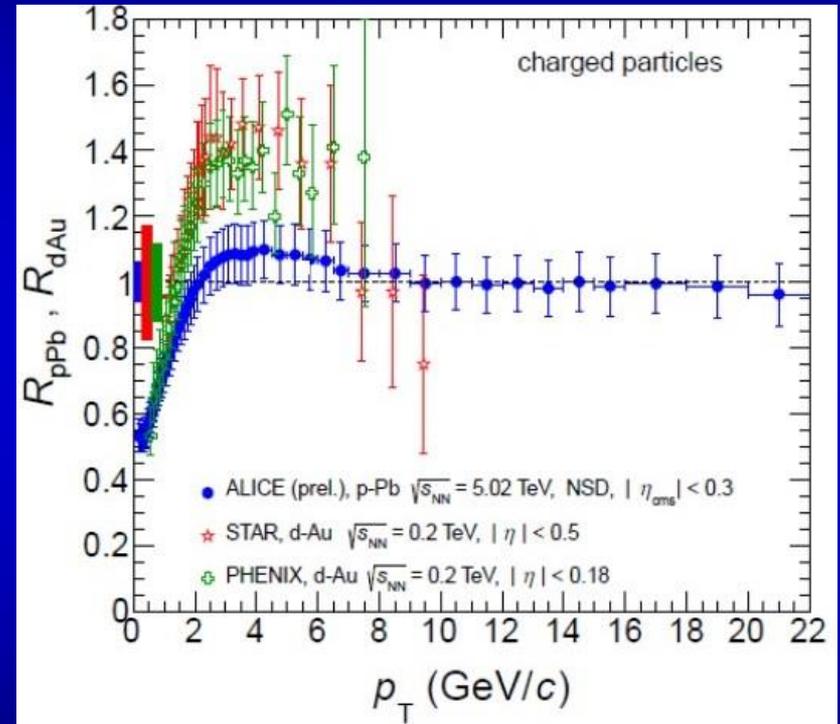
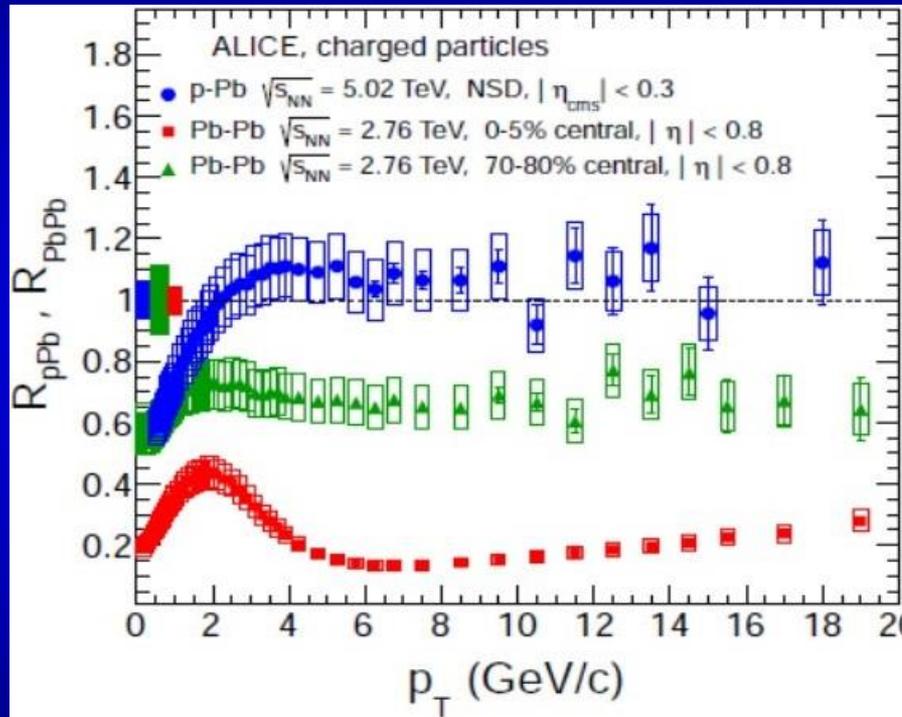


Suppression des particules de grande p_T dans les collisions centrales Au+Au est due aux effets dans l'état final

Jet et "Jet Quenching" – Facteur Modification Nucléaire

Cette suppression des particules est un effet de l'état initial ou final ?

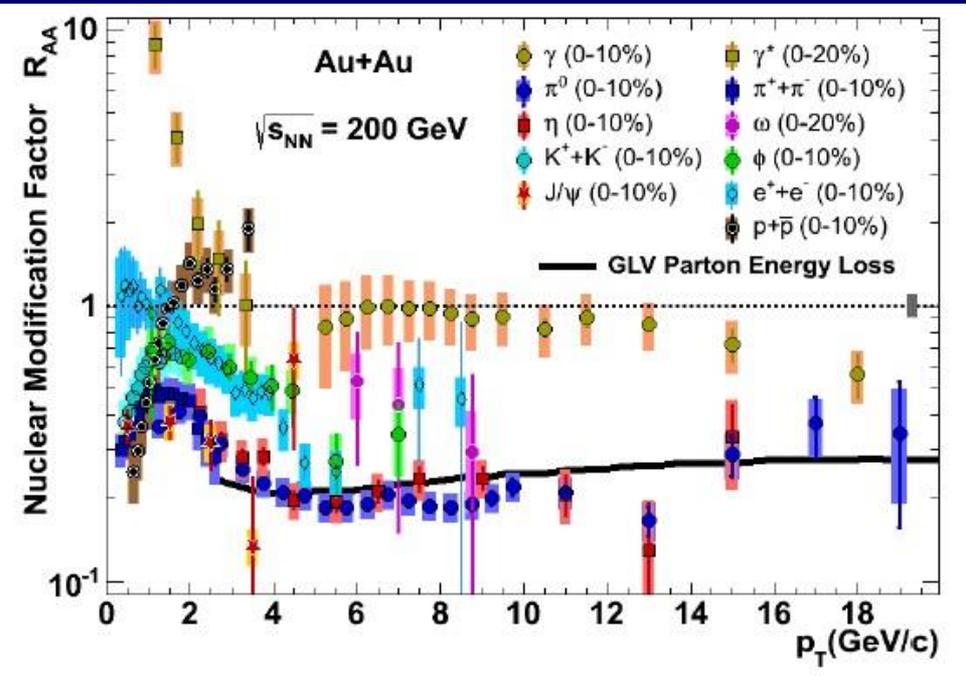
LHC: Pb+Pb versus p+Pb and d + Au



Suppression des particules de grande p_T dans les collisions centrales Pb+Pb (LHC) est due aux effets dans l'état final

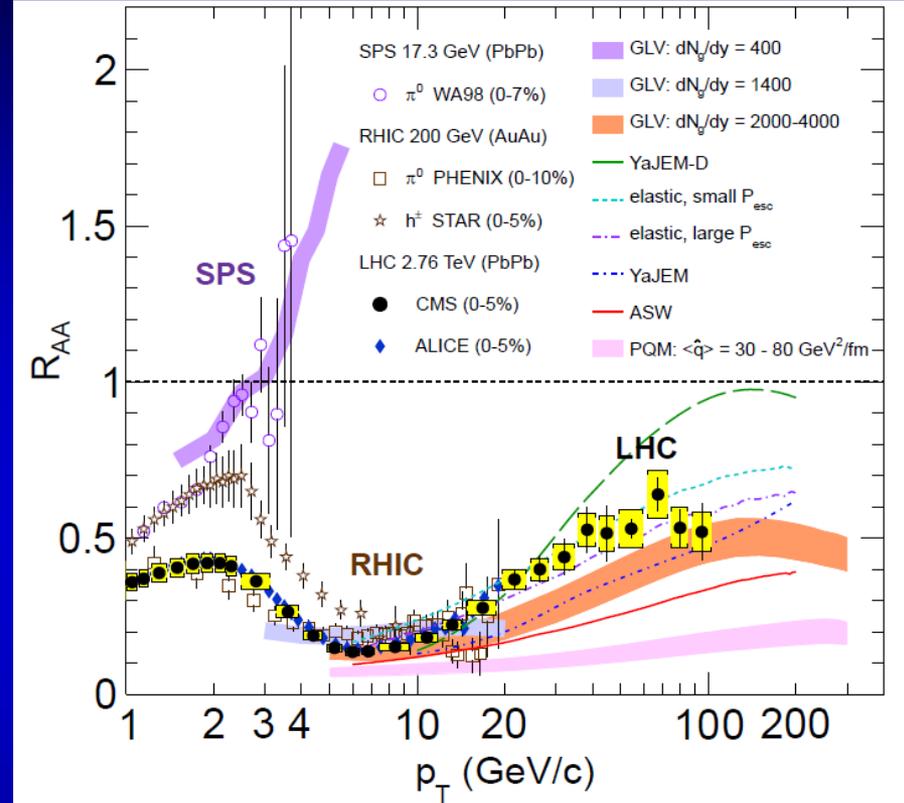
Jet et "Jet Quenching" : SPS, RHIC et LHC

RHIC



SPS, RHIC et LHC

Eur. Phys. J. C (2012) 72:1945

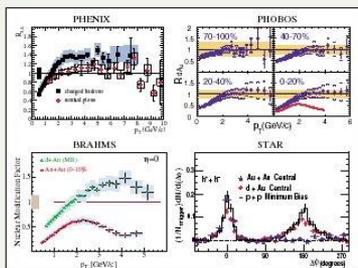


- Pas de suppression des photons directs; suivent prédictions de pQCD
- Suppression est plate à grande p_T (milieu Opaque aux interactions fortes)
- Modèle théorique (de perte d'énergie) : $dN_g/dy \sim 1000$ et la densité d'énergie $\sim 15 \text{ GeV}/\text{fm}^3$
- Les quarks lourds et les légers sont supprimés de la même manière !
- Accès de très grand p_T au LHC possibilité à partir des modèles, de quantifier la perte d'énergie des partons dans le milieu créé.

Découvertes de RHIC dans les Actualités

PHYSICAL REVIEW LETTERS

Articles published week ending
15 AUGUST 2003
Volume 91, Number 7



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Published by The American Physical Society

The Collaboration of the four experiments: PHENIX, BRAHMS, PHOBOS and STAR at RHIC

CONCLUDED
that **strongly-interacting matter**

has been created in most central Au+Au collisions at 200 GeV

RHIC Scientists Serve Up "Perfect" Liquid

New state of matter more remarkable than predicted -- raising many new questions

Monday, April 18, 2005

TAMPA, FL -- The four detector groups conducting research at the [Relativistic Heavy Ion Collider](#) (RHIC) -- a giant atom "smasher" located at the U.S. Department of Energy's Brookhaven National Laboratory -- say they've created a new state of hot, dense matter out of the quarks and gluons that are the basic particles of atomic nuclei, but it is a state quite different and even more remarkable than had been predicted. In [peer-reviewed papers](#) summarizing the first three years of RHIC findings, the scientists say that instead of behaving like a gas of free quarks and gluons, as was expected, the matter created in RHIC's heavy ion collisions appears to be more like a *liquid*.

"Once again, the physics research sponsored by the Department of Energy is producing historic results," said Secretary of Energy Samuel Bodman, a trained chemical engineer. "The DOE is the principal federal funder of basic research in the physical sciences, including nuclear and high-energy physics. With today's announcement we see that investment paying off."

"The truly stunning finding at RHIC that the new state of matter created in the collisions of gold ions is more like a liquid than a gas gives us a profound insight into the earliest moments of the universe," said Dr. Raymond L. Orbach, Director of the DOE Office of Science.

Also of great interest to many following progress at RHIC is the emerging connection between the collider's results and calculations using the methods of string theory, an approach that attempts to explain fundamental properties of the universe using 10 dimensions instead of the usual three spatial dimensions plus time.



Secretary of Energy Samuel Bodman

Hunting the Quark Gluon Plasma

RESULTS FROM THE FIRST 3 YEARS AT RHIC

ASSESSMENTS BY THE EXPERIMENTAL COLLABORATIONS

April 18, 2005



Relativistic Heavy Ion Collider (RHIC) • Brookhaven National Laboratory, Upton, NY 11974-5000



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RHIC Scientists Serve Up 'Perfect' Liquid: New State Remarkable Than Predicted

Apr. 25, 2005 — TAMPA, FL -- The four detector groups conducting research at the Relativistic Heavy Ion Collider (RHIC) -- a giant atom "smasher" located at the U.S. Department of Energy's Brookhaven National Laboratory -- say they've created a new state of hot, dense matter out of the quarks and gluons that are the basic particles of atomic nuclei, but it is a state quite different and even more remarkable than had



These images co and collective mo the predicted gas (Figure A, see mp that has been ob: RHIC (Figure B, s "force lines" and animated version degree of interact what is now being liquid. (Courtesy c Laboratory)

International Journal of High-Energy Physics

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20 November, 2013 at the Royal Society,
6 - 9 Carlton House Terrace, London, SW1V 5AG

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CERN COURIER

May 6, 2005

RHIC groups serve up "perfect" liquid

The four detector groups conducting research at the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven National Laboratory have announced results indicating that they have observed a state of hot, dense matter that is more remarkable than had been predicted. In papers summarizing the first three years of RHIC findings, to be published simultaneously by the journal *Nuclear Physics A*, the four collaborations (BRAHMS, PHENIX, PHOBOS and STAR) say that instead of behaving like a gas of free quarks and gluons, as was expected, the matter

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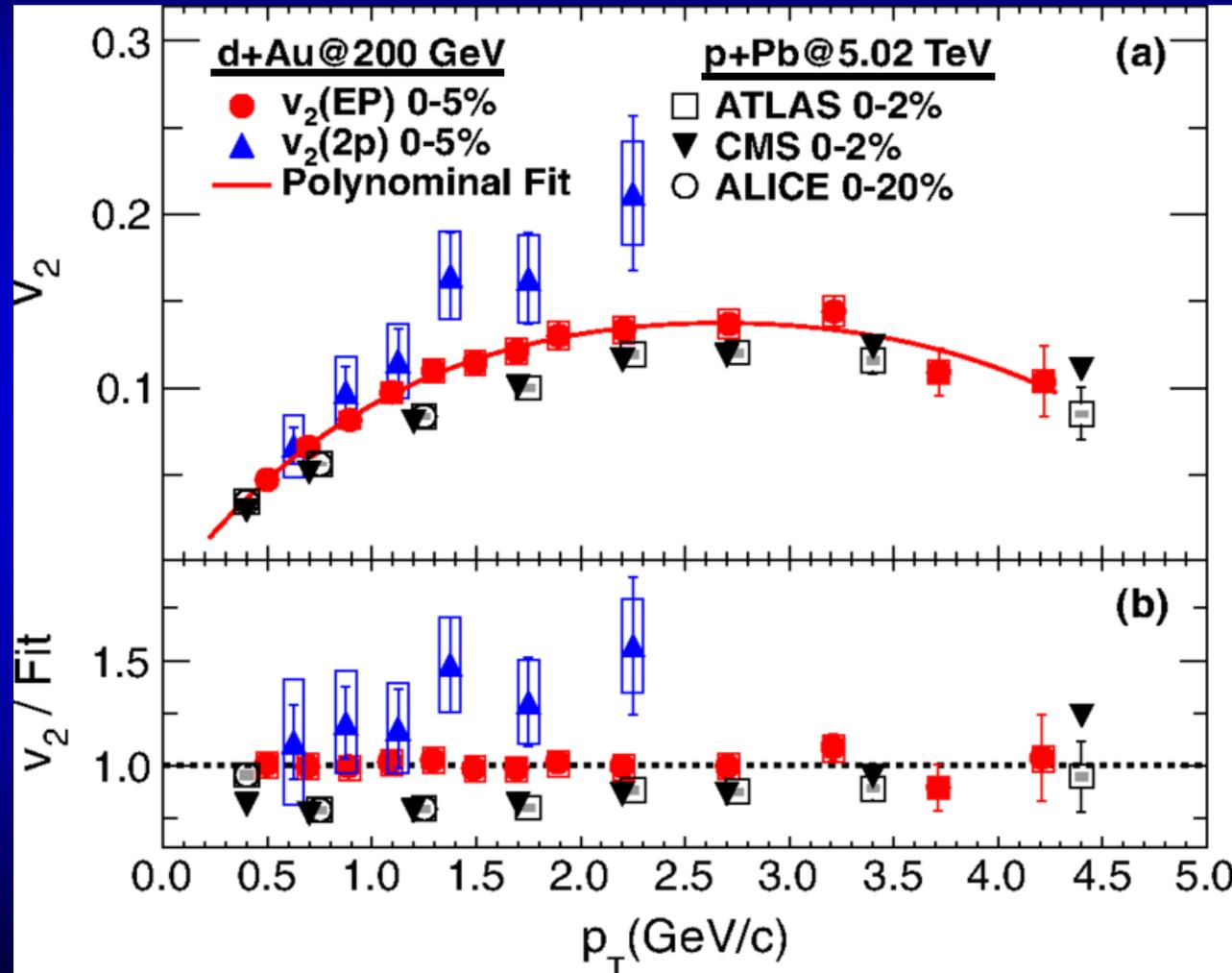


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Surprise: Collectivity-like in Small Colliding Systems

$v_2(\text{EP})$ of charged hadron in 0-5% d+Au

Phys. Rev. Lett. 114, 192301 (2015)

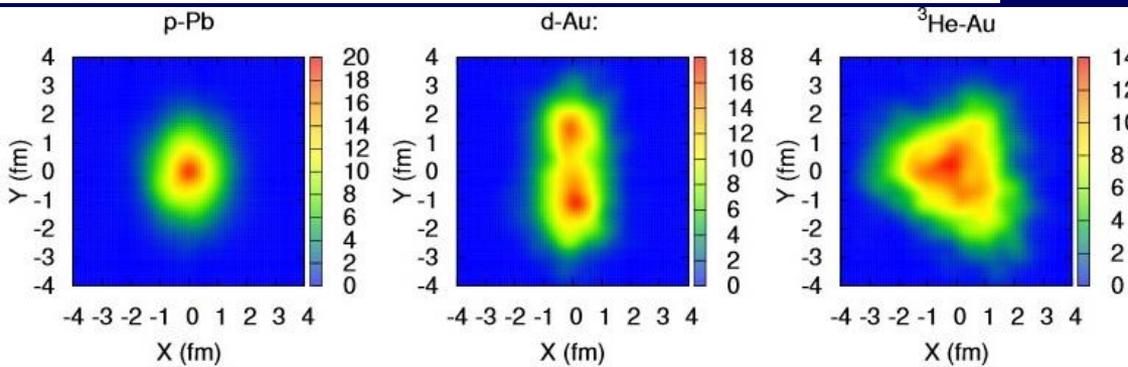


Hydro-like
shape
in $v_2(p_T)$?

Surprise: Collectivity-like in Small Colliding Systems

Central collision events of p-Pb, d-Au, ^3He -Au

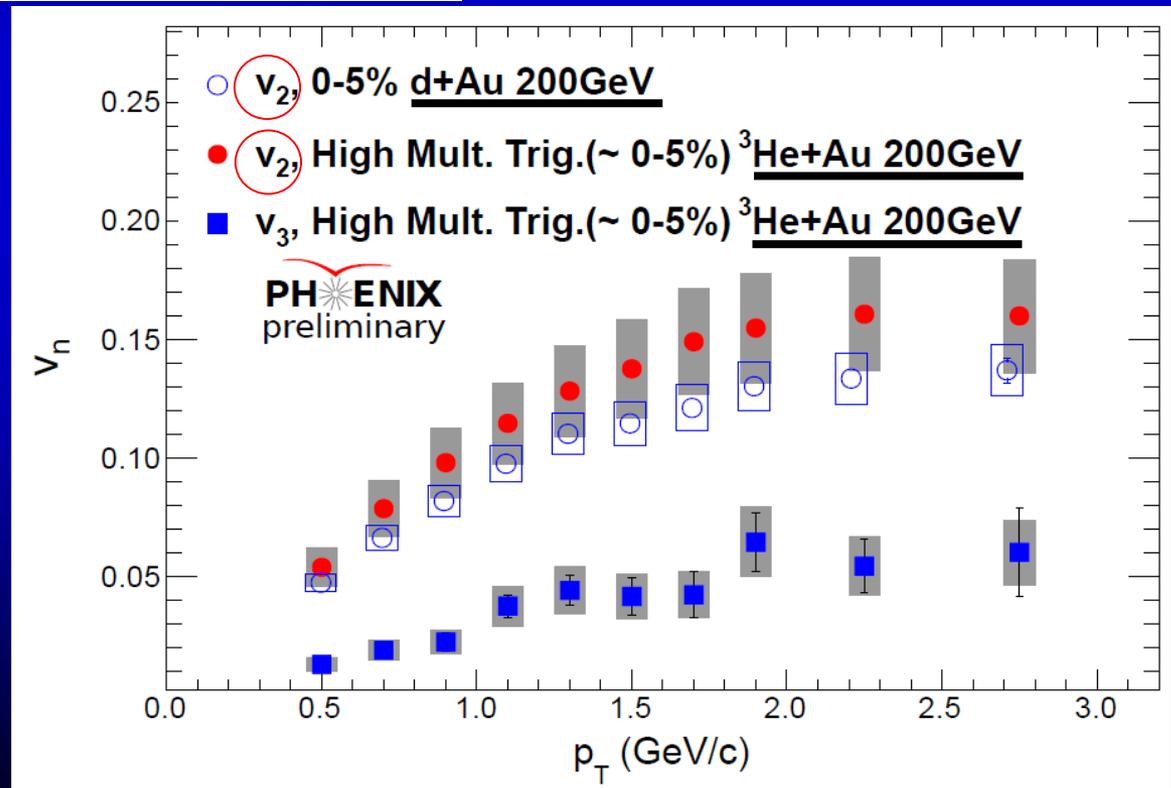
Averaged density profile of central events: (PHOBOS Monte Carlo Glauber)



Azimuthal flow, v_n ($n=2,3$) in $^3\text{He}+\text{Au}$

Li Yan, RBRC workshop

d+Au
He+Au
Hydro-like
shape
in $v_2(p_T)$?



Passons de la phase de la découverte à celle de l'étude détaillée des propriétés du milieu nucléaire dense créé dans les collisions

High precision measurements of hard probes
(heavy-flavor hadrons, quarkonia, photons and jets)

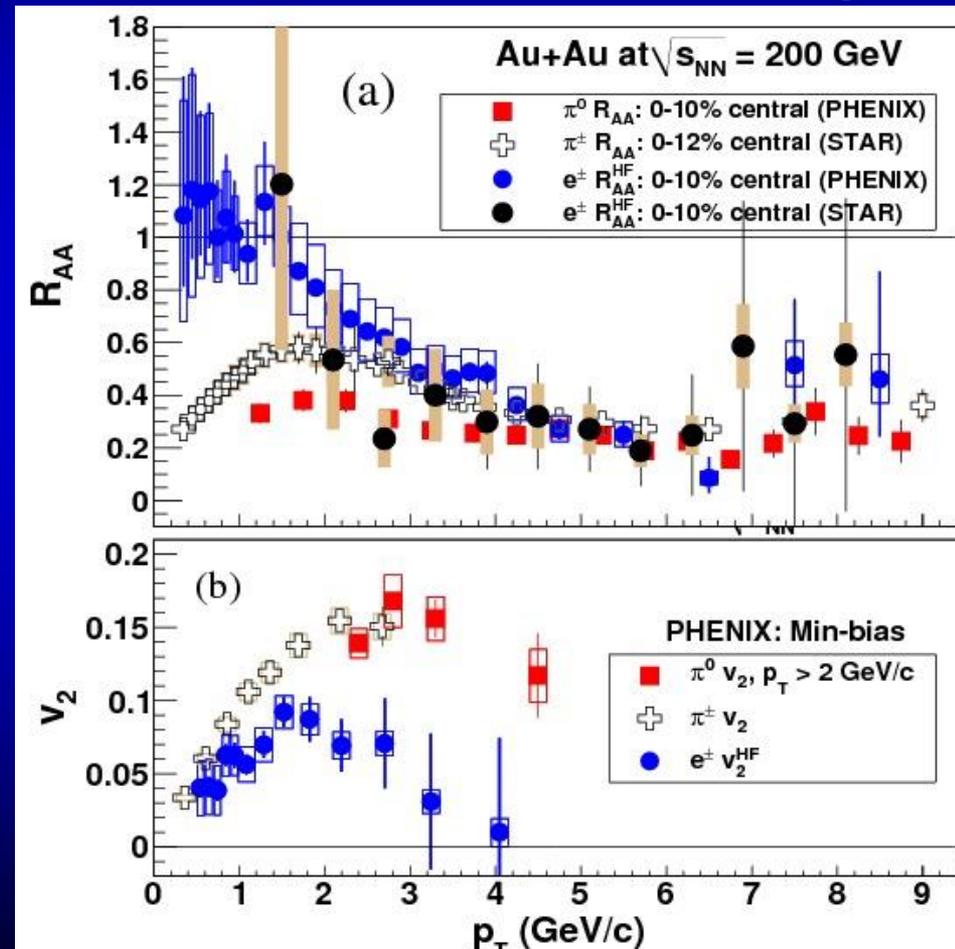
Intriguing Result: heavy-flavor hadrons

Sonde de Quarks lourds charme et de beauté (c, b)

$m_{\text{charme}} = 1.5 \text{ GeV}$, $m_{\text{beauté}} = 5 \text{ GeV}$

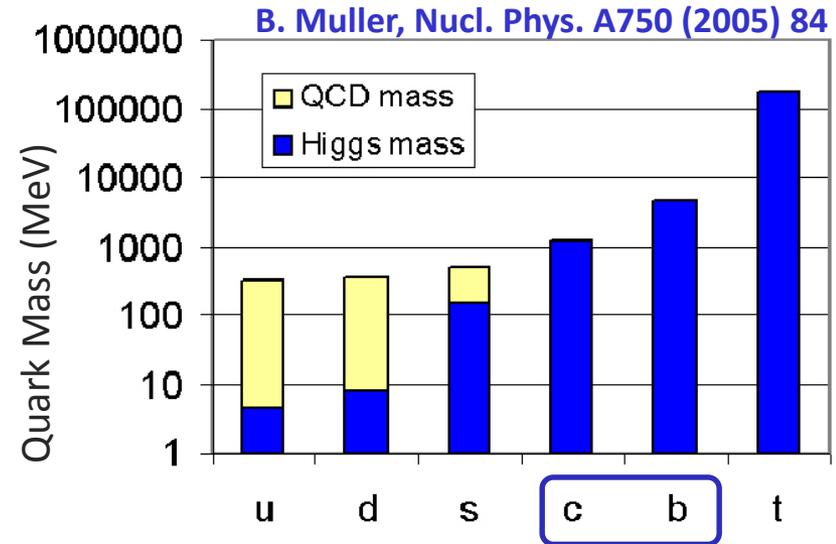
- Les électrons des quarks lourds sont supprimés et comparable à celle des hadrons légers
- Le comportement collectif est évident dans e^{HF} ; mais HF v_2 est inférieur que v_2 de π^0 pour $p_T > 2 \text{ GeV}/c$.
- La séparation du charme et de la beauté est la clé pour comprendre la hiérarchie de masse de la perte d'énergie.

R. Nouicer arXiv:0901.0910 [nucl-ex]



Heavy Flavors: Ideal Probes of Nuclear Matter

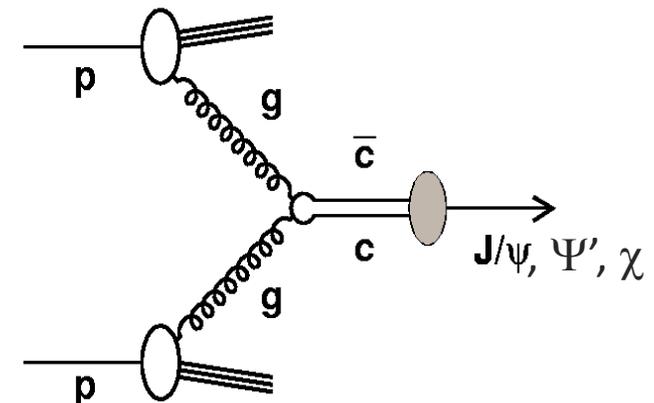
- ❖ Symmetry breaking
 - Higgs mass: electroweak symmetry breaking
→ **current quark mass**
 - QCD mass: chiral symmetry breaking
→ **constituent quark mass**
- ❖ Charm and beauty quark masses are not affected by QCD vacuum
→ **ideal probes to study QGP**



- ❖ Heavy quarks ($c\bar{c}$, $b\bar{b}$)
 - Bound states (J/ψ , Υ)

State	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ'_b	Υ''
Mass (GeV)	3.10	3.53	3.68	9.46	9.99	10.02	10.36	10.36
ΔE (GeV)	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
Radius (fm)	0.25	0.36	0.45	0.14	0.22	0.28	0.34	0.39

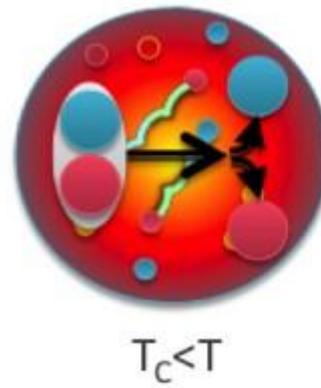
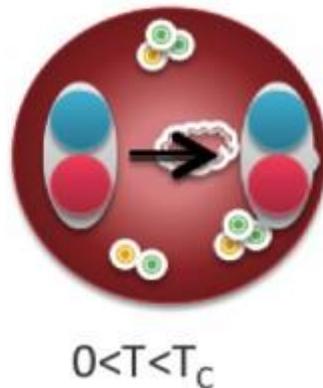
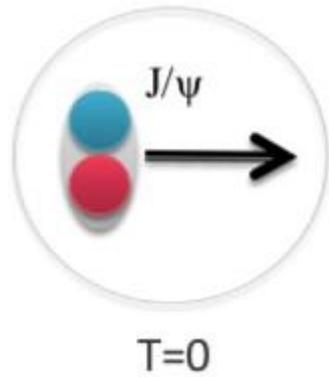
- ❖ Due to their mass ($m_Q \gg T_{\text{cri}}, \Lambda_{\text{QCD}}$)
→ **higher penetrating power**
- ❖ Gluon fusion dominates
→ **sensitive to initial state gluon distribution**



Quarkonia as Probe for Hot and Cold Nuclear Matter

Why study Quarkonia?

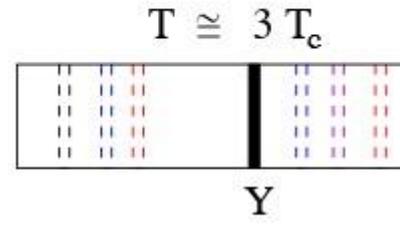
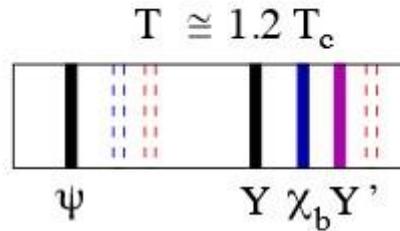
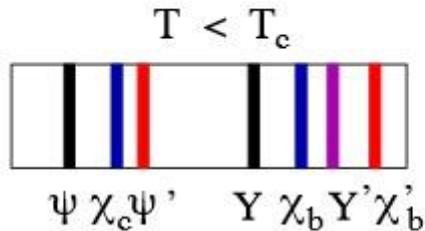
- To learn about thermal properties of QGP medium
 - ✓ Quarkonia are expected to dissociate due to Debye screening of heavy quark potential ($r_D \propto 1/T$) Phys. Lett. B178, 416



Charmonia ($c\bar{c}$):
 $J/\psi, \psi', \chi_c$

Bottomonia ($b\bar{b}$):
 $Y(1S), Y(2S), Y(3S), \chi_B$

Illustration: A. Rothkopf



Phys. Rev. D77, 014501

PHENIX Detector at RHIC

Pioneering High Energy Nuclear Interaction eXperiment

- 2 central spectrometers

Photon, hadron, electron

$$|\eta| < 0.35, \Delta\phi = \pi$$

Measure:

$$J/\psi, \psi', Y \rightarrow e^+e^-$$

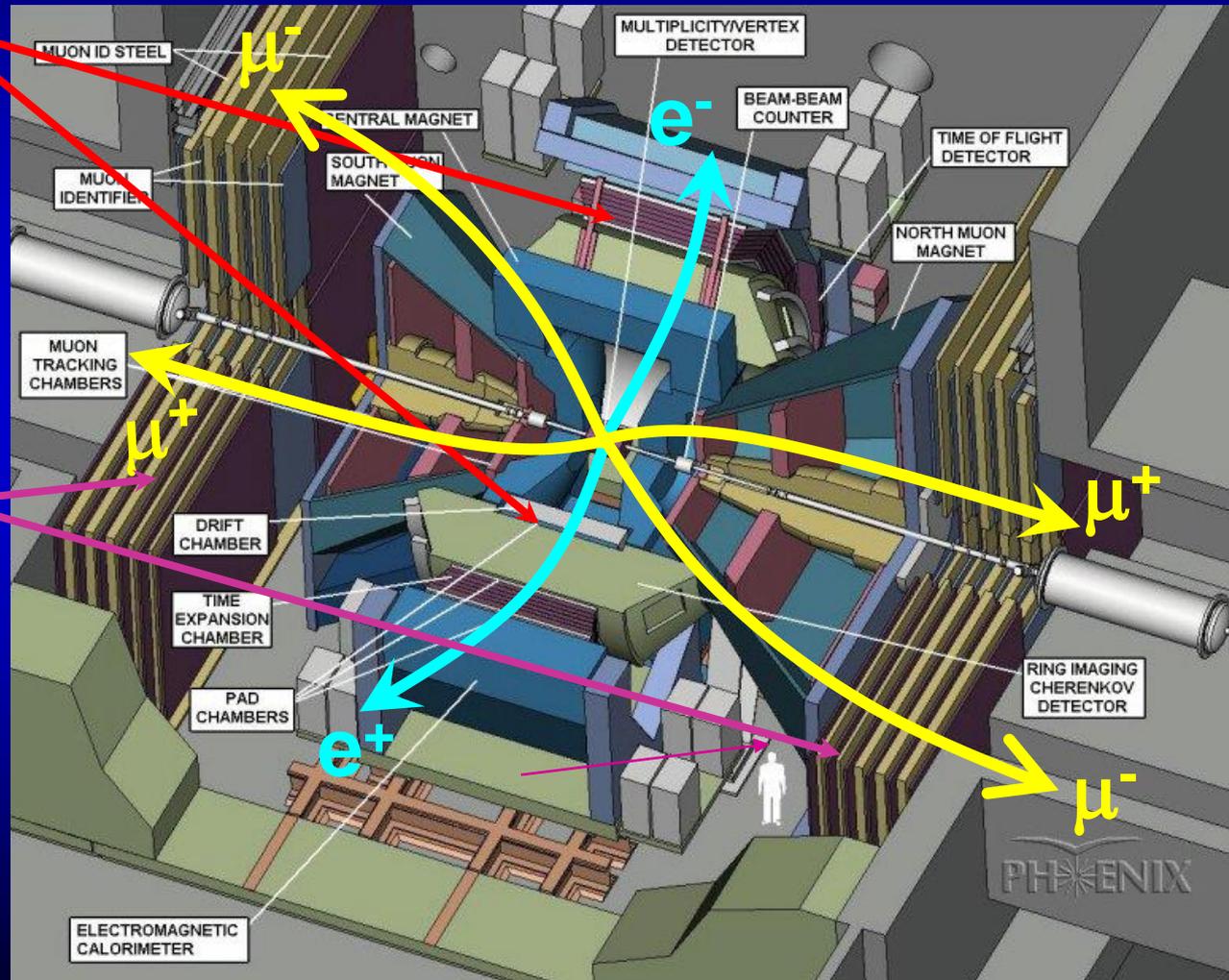
- 2 forward spectrometers

μ detection

$$1.2 < |\eta| < 2.4, 2\pi \text{ in } \phi$$

Measure:

$$J/\psi, \psi', Y \rightarrow \mu^+\mu^-$$

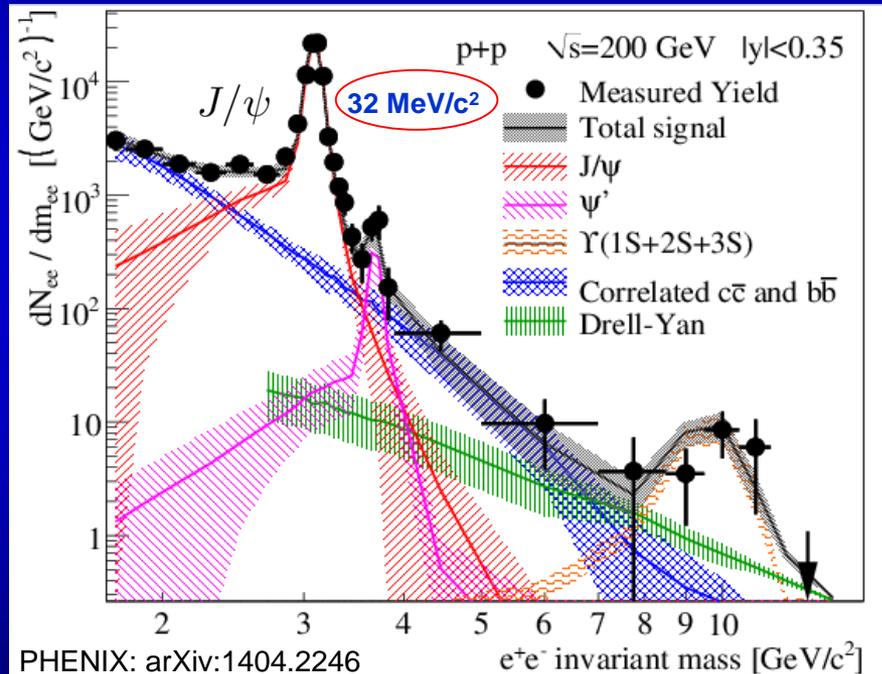


Bound Heavy Flavor: Di-leptons e^+e^- or $\mu^+\mu^-$

p+p at 200 GeV

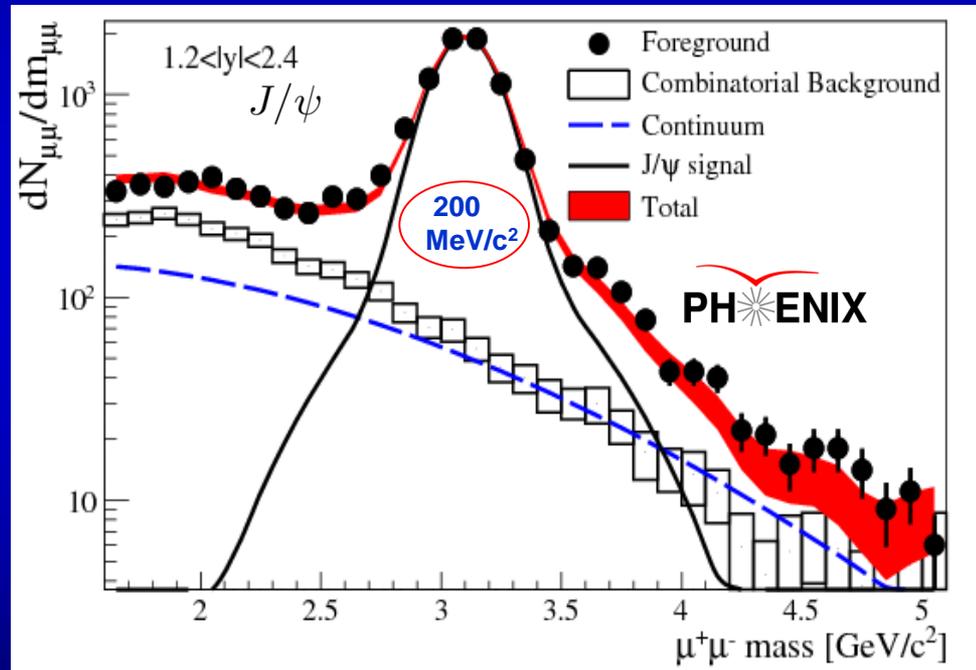
$$J/\psi \rightarrow e^+e^-$$

Di- e^{HF} : Mid-Rapidity $|\eta| < 0.35$



$$J/\psi \rightarrow \mu^+\mu^-$$

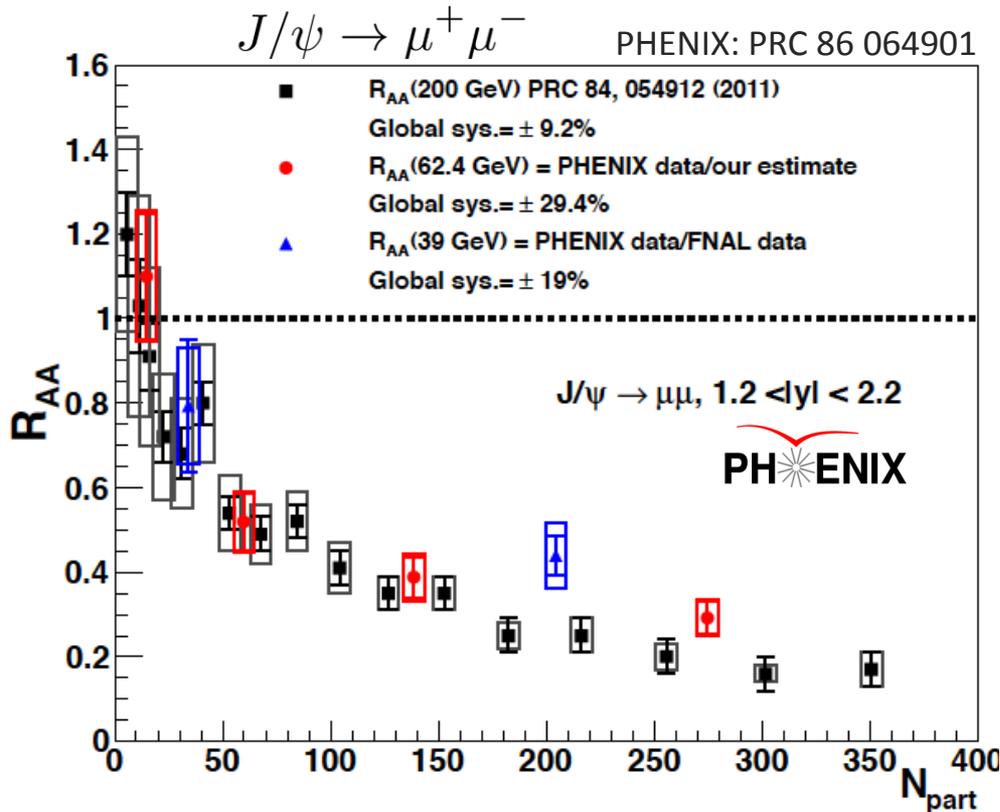
Di- μ^{HF} : Forward Rapidity $1.2 < |\eta| < 2.2$



PHENIX has capabilities of measuring different quarkonia states in di-electron and di-muon channels “but not good enough: upgrades for HF”

Bound Heavy Flavor: J/ψ R_{AA}

Au+Au at different energies

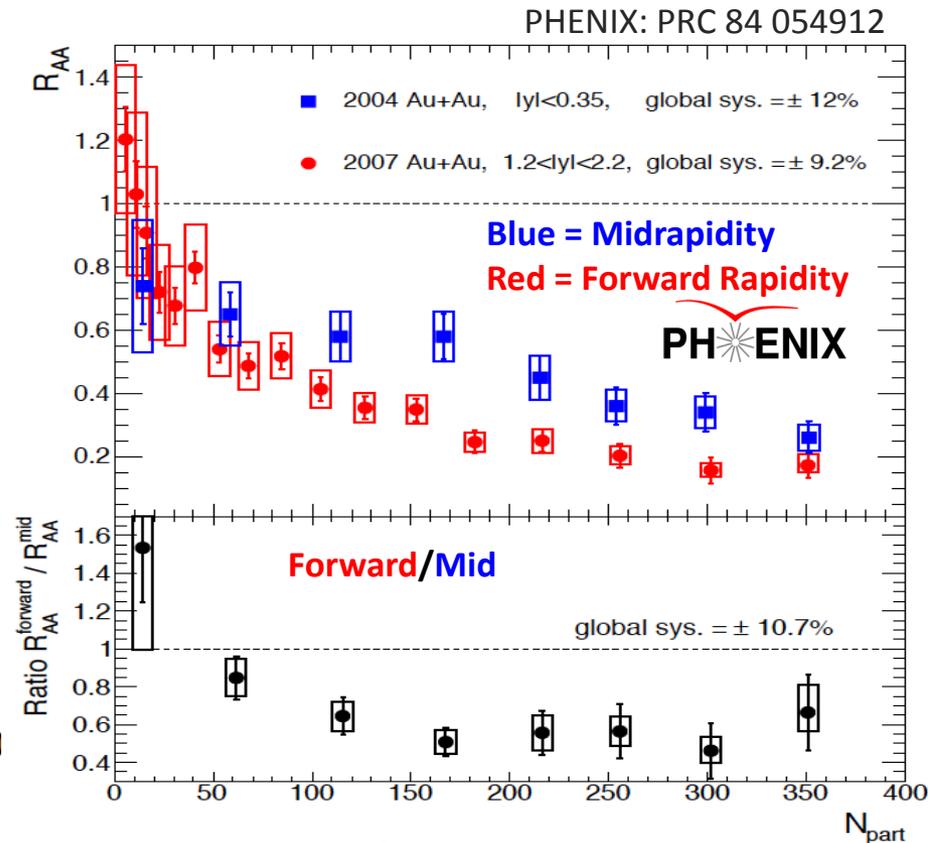


In Au+Au and at forward rapidity:

R_{AA} show similar suppression at different collision energies:

200, 62.4 and 39 GeV

Au+Au at 200 GeV mid- vs. forward rapidities



Significant J/ψ suppression at mid- and forward rapidity regions is observed in central Au + Au collisions

R_{AA} decreases with increasing N_{part}

Bound Heavy Flavor: J/ψ R_{AA}

System Size study:

Cu+Cu, Au+Au and U+U ≈ 200 GeV

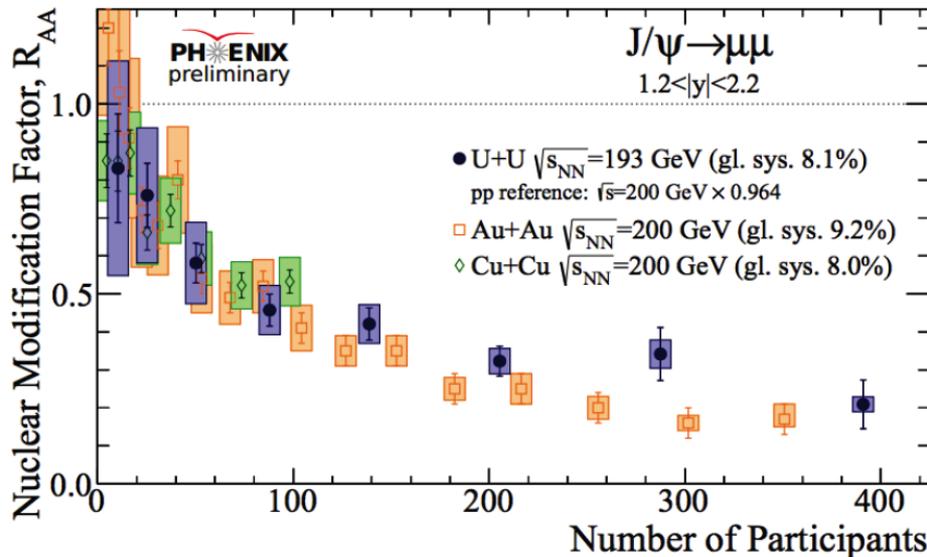
$J/\psi \rightarrow \mu^+ \mu^-$ at forward rapidity

$1.2 < |y| < 2.2$

System Size study:

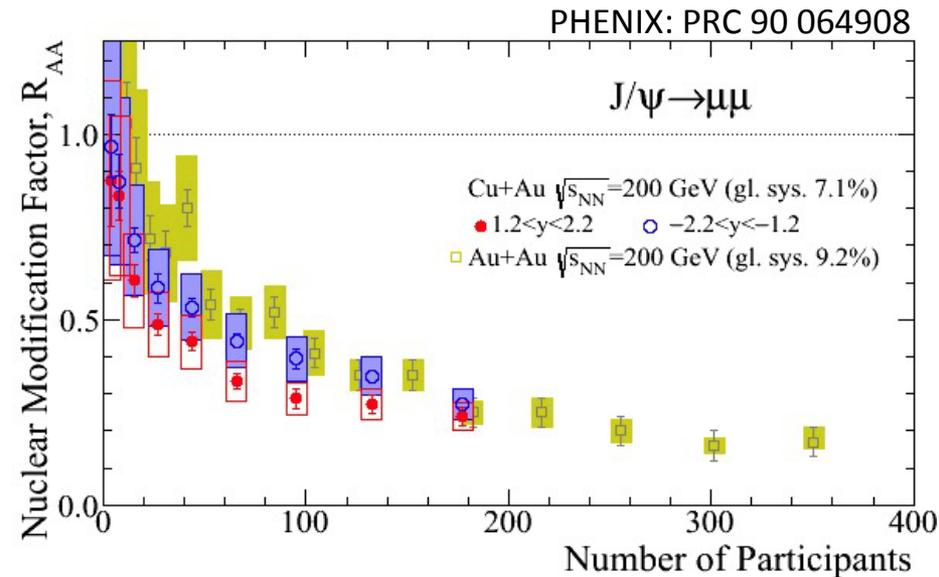
Cu+Au vs Au+Au at 200 GeV

$J/\psi \rightarrow \mu^+ \mu^-$



Not much net effect on R_{AA} at forward rapidity from increasing system size of colliding nuclei!

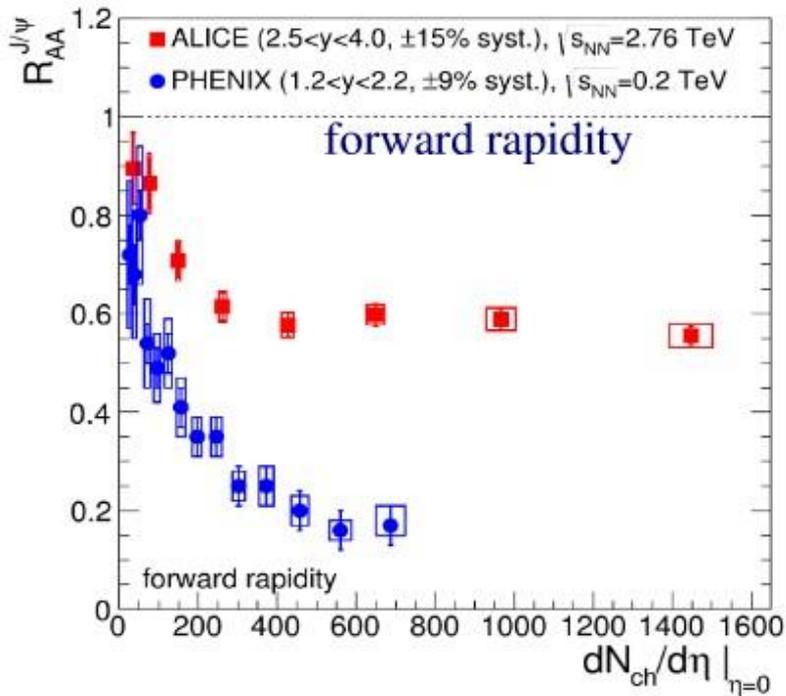
Is this what we expected?



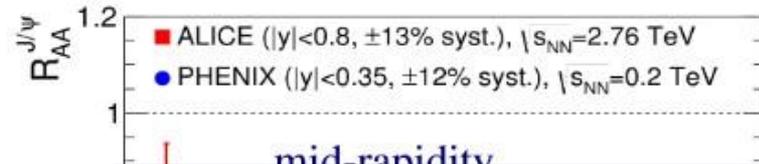
- Similar suppression in Cu+Au compared to Au+Au
- Forward (Cu-going) more suppressed than Backward \rightarrow CNM effects?

Bound Heavy Flavor: J/ψ R_{AA}

J/ψ production in Pb+Pb collisions: LHC relative to RHIC

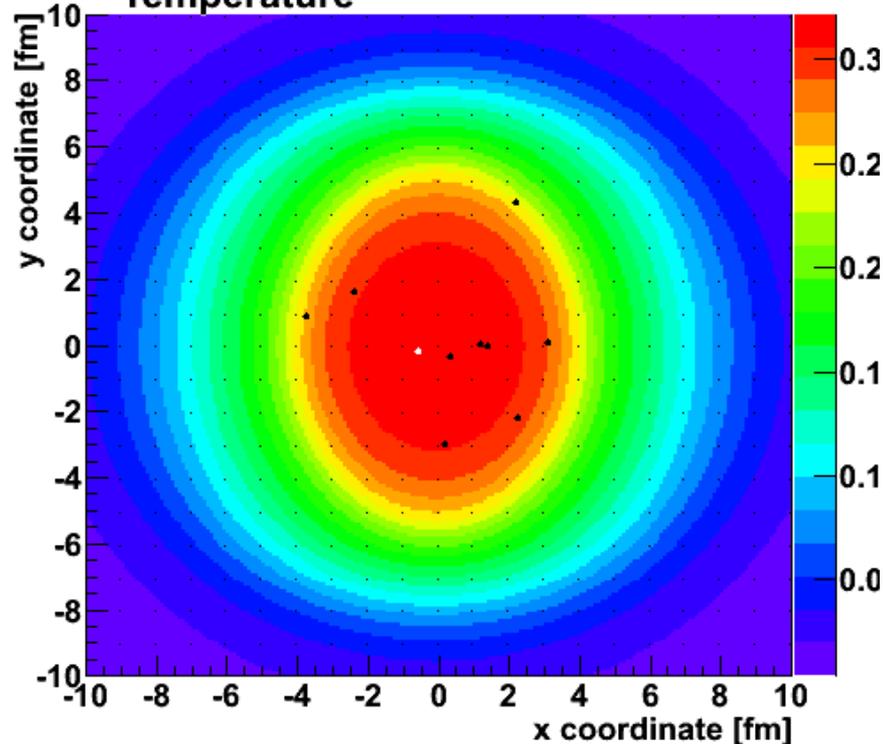


energy density



Charm – Anticharm Pairs
Drag/Diffuse in Perfect Fluid

Temperature

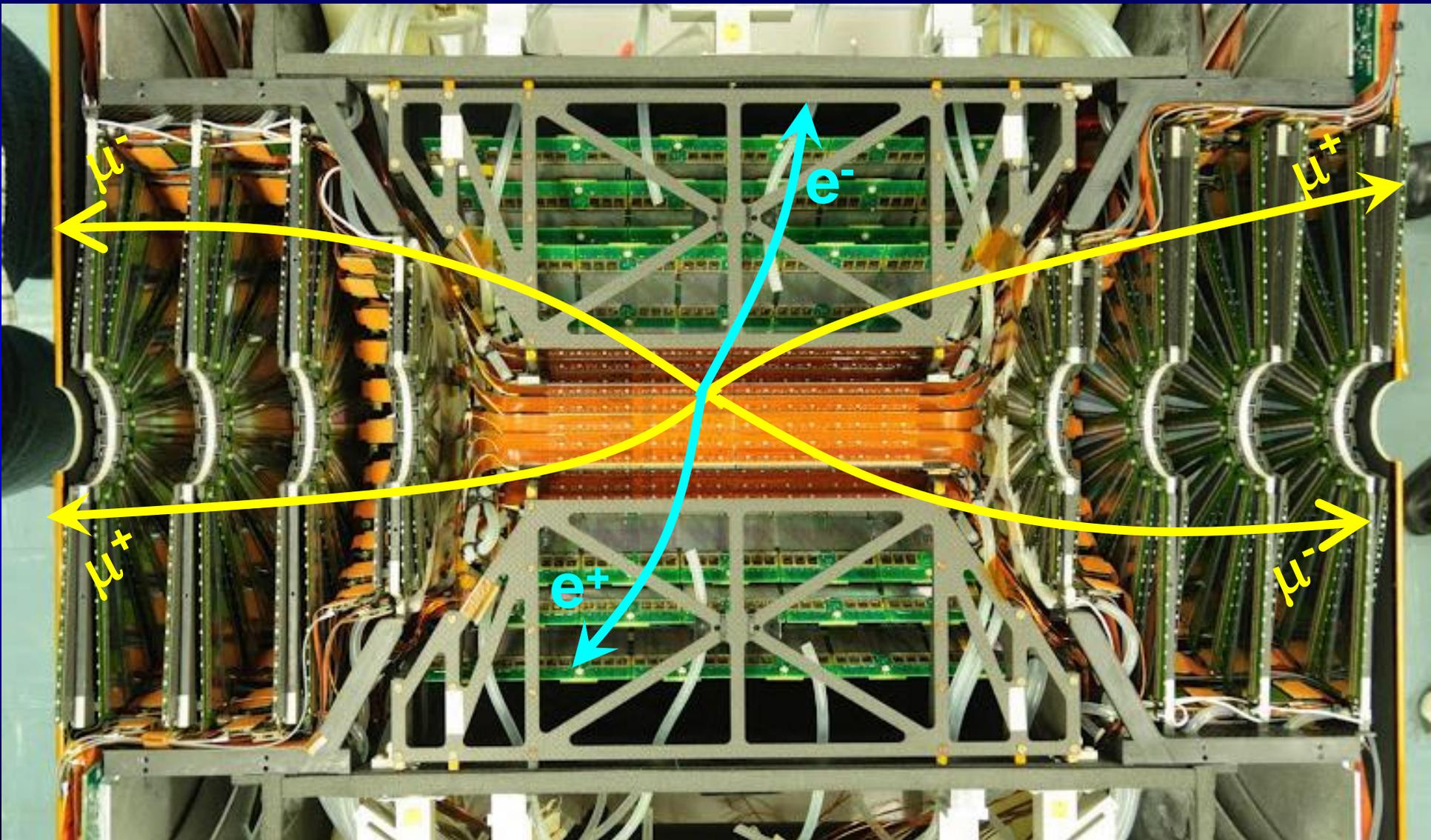


Enhancement with increasing energy density
(from RHIC to LHC and from forward-
to mid-rapidity)

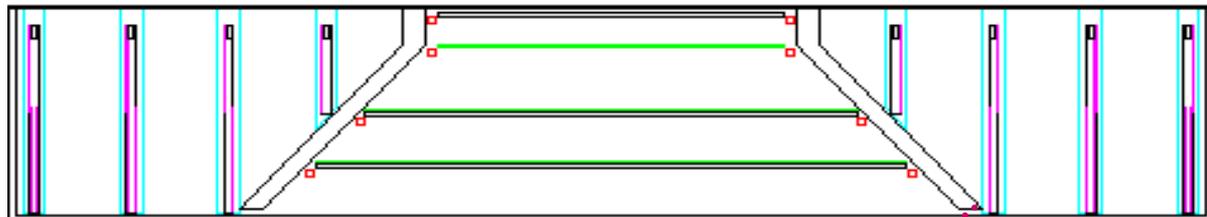
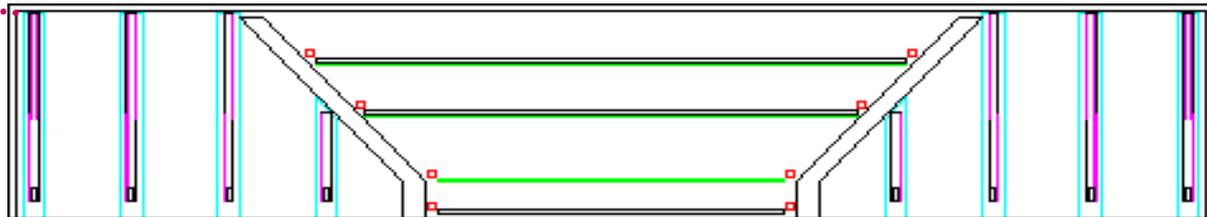
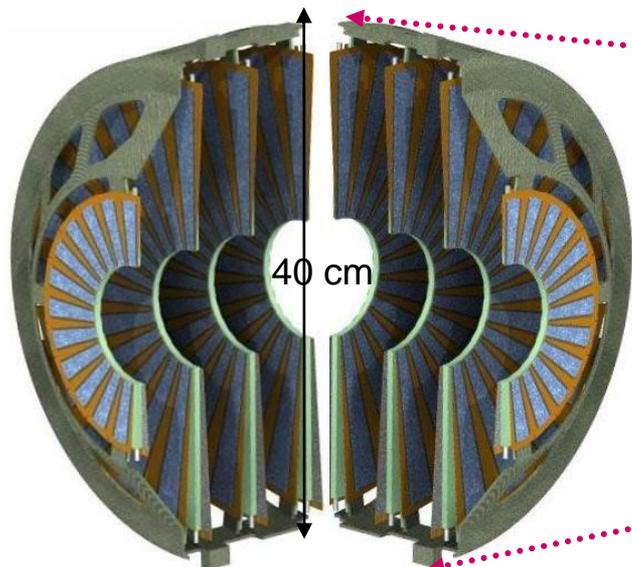
“Regeneration”

PHENIX Detector at RHIC

Silicon Tracker: VTX (e^\pm) + FVTX (μ^\pm)

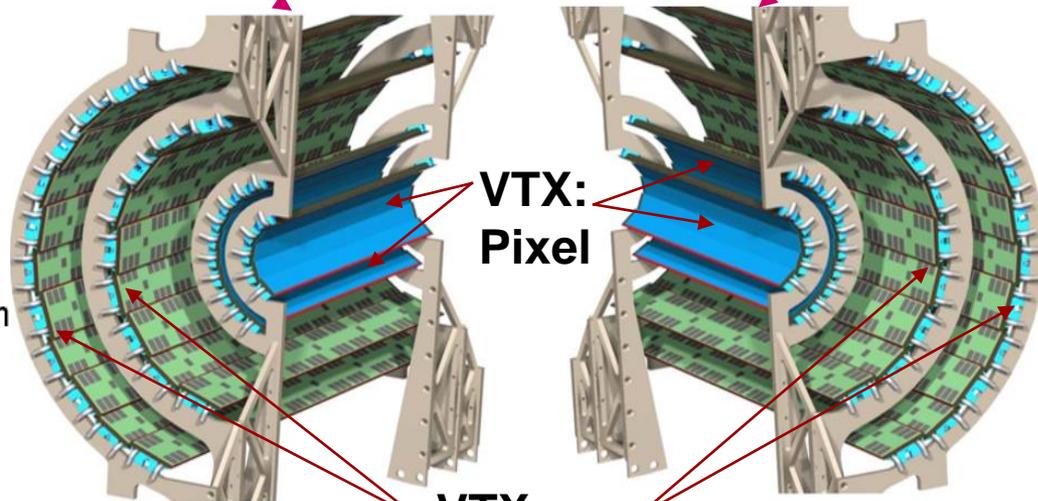
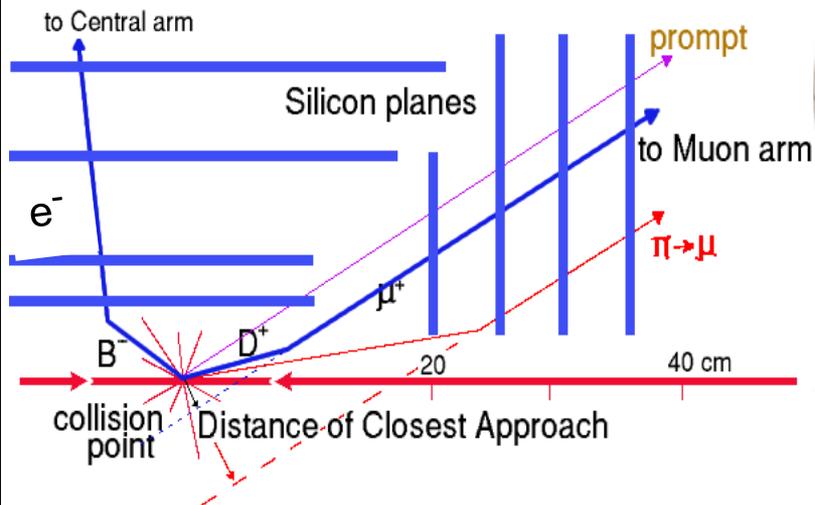


PHENIX Silicon Vertex Tracking Upgrades: 2007-2012



show7.kumac

FVTX:
Forward silicon VerTeX track

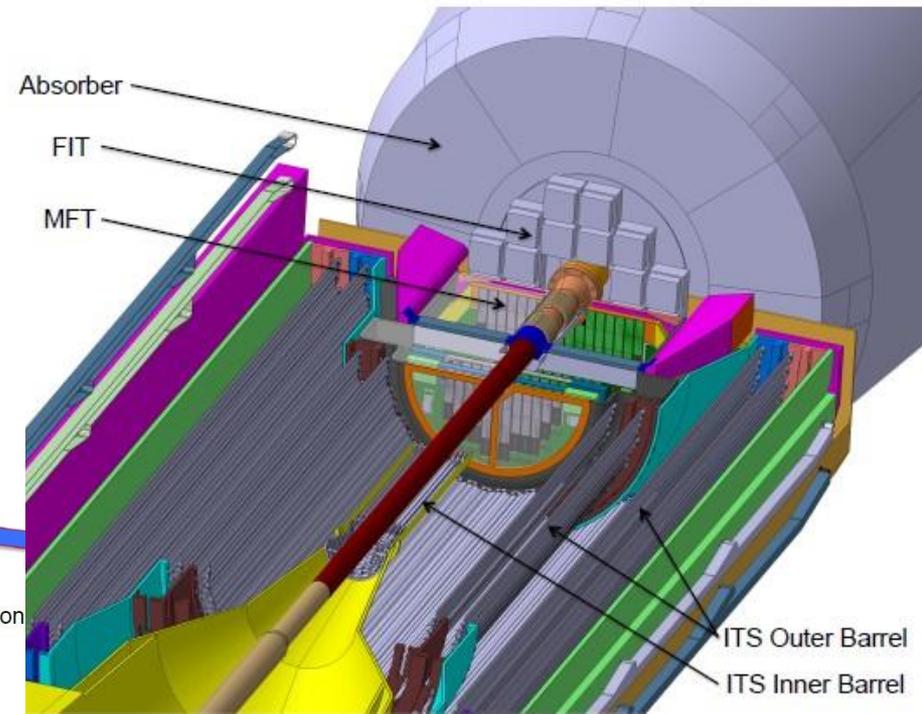
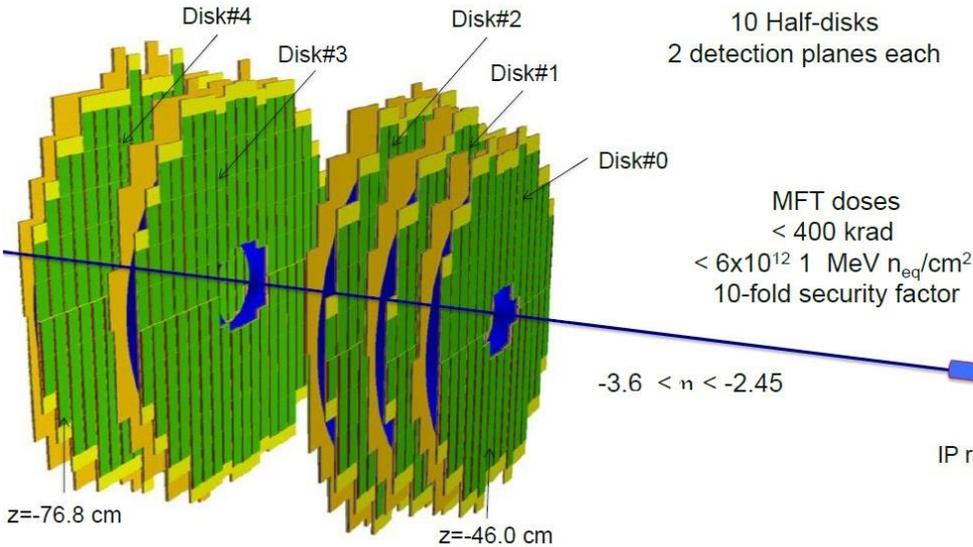


VTX: silicon VerTeX barrel tracker

Similar to ALICE present upgrades

MFT layout

896 silicon pixel sensors (0.4 m^2) in 280 ladders of 1 to 5 sensors each.



Ginés MARTINEZ, Subatech

LHCC referees – ALICE Meeting
November 18th 2014, CERN

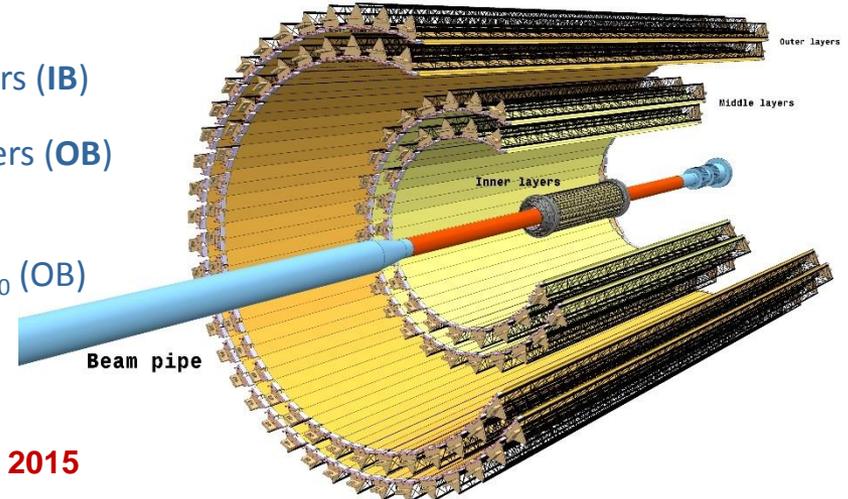
ITS layout: 7-layer barrel geometry based on MAPS

3 Inner Barrel layers (IB)

4 Outer Barrel layers (OB)

Material /layer :

$0.3\% X_0$ (IB), $1\% X_0$ (OB)



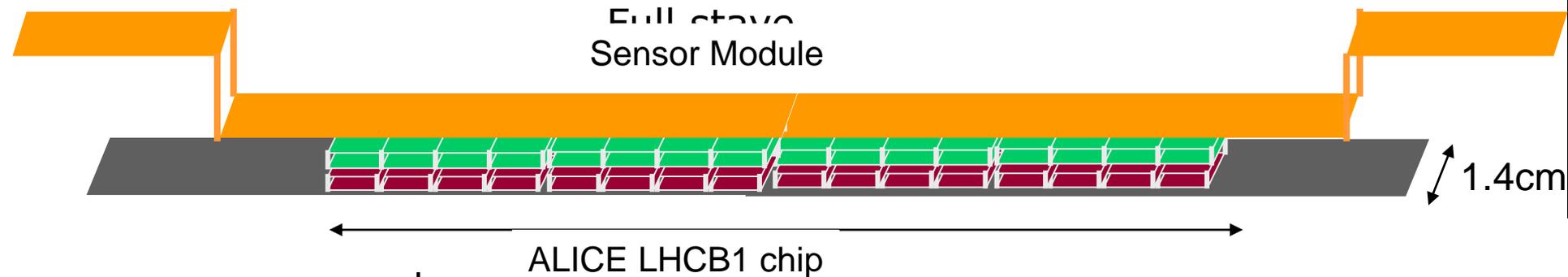
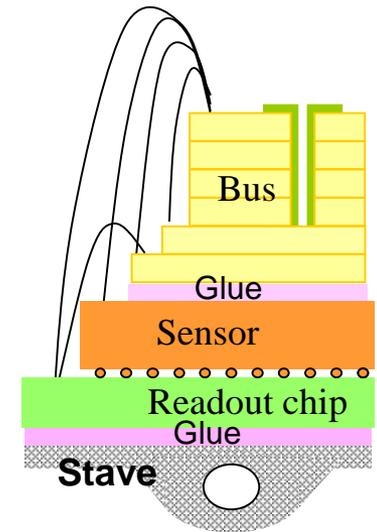
L. Musa - CERN

DOE Review Meeting

Washington , 21-23 April 2015

Technology Choices: VTX-Pixel (Barrels 1 & 2)

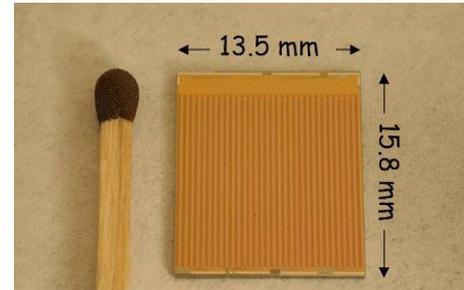
- Sensor module consists of 4 ALICE Pixel readout chips bump-bonded to silicon sensor
- One readout unit, half stave, made from two sensor modules
- Half stave is mounted on the support structure
- Pixel BUS to bring data out and send control signal into the readout chip is mounted on the half stave
- Each detector module is built of two half staves, read out on the barrel ends



Technology Choices: VTX-Pixel (Barrels 1 & 2)

ALICE1LHCb readout chip:

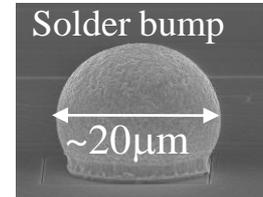
- ◆ Pixel: 50 μm (ϕ) x 425 μm (Z).
- ◆ Channels: 256 x 32.
- ◆ Output: binary, read-out in 25.6 μs @10MHz.
- ◆ Radiation Hardness: ~ 30 Mrad



Active area
 $\Delta r\Phi$
1.28 cm = 50mm x 256
 ΔZ
1.36 cm = 425mm x 32

Sensor module:

- ◆ 4 ALICE1LHCb readout chips.
- ◆ Bump-bonded (VTT) to silicon sensor.
- ◆ Thickness: 200 μm
- ◆ Thickness: r/o chips 150 μm



Half-ladder (2 sensor modules + bus)

- ◆ 1.36 cm x 10.9 cm.
- ◆ Thickness bus: < 240 μm .

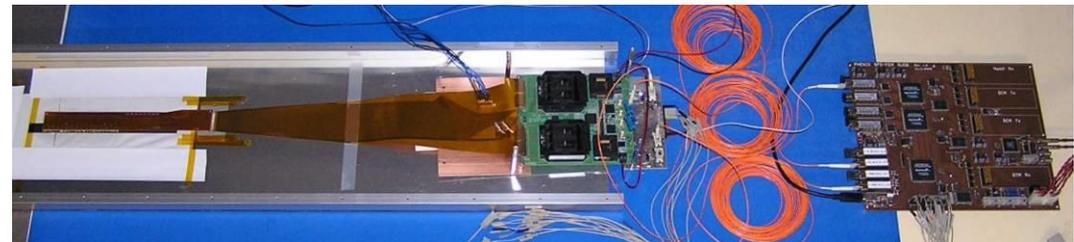


SPIRO module

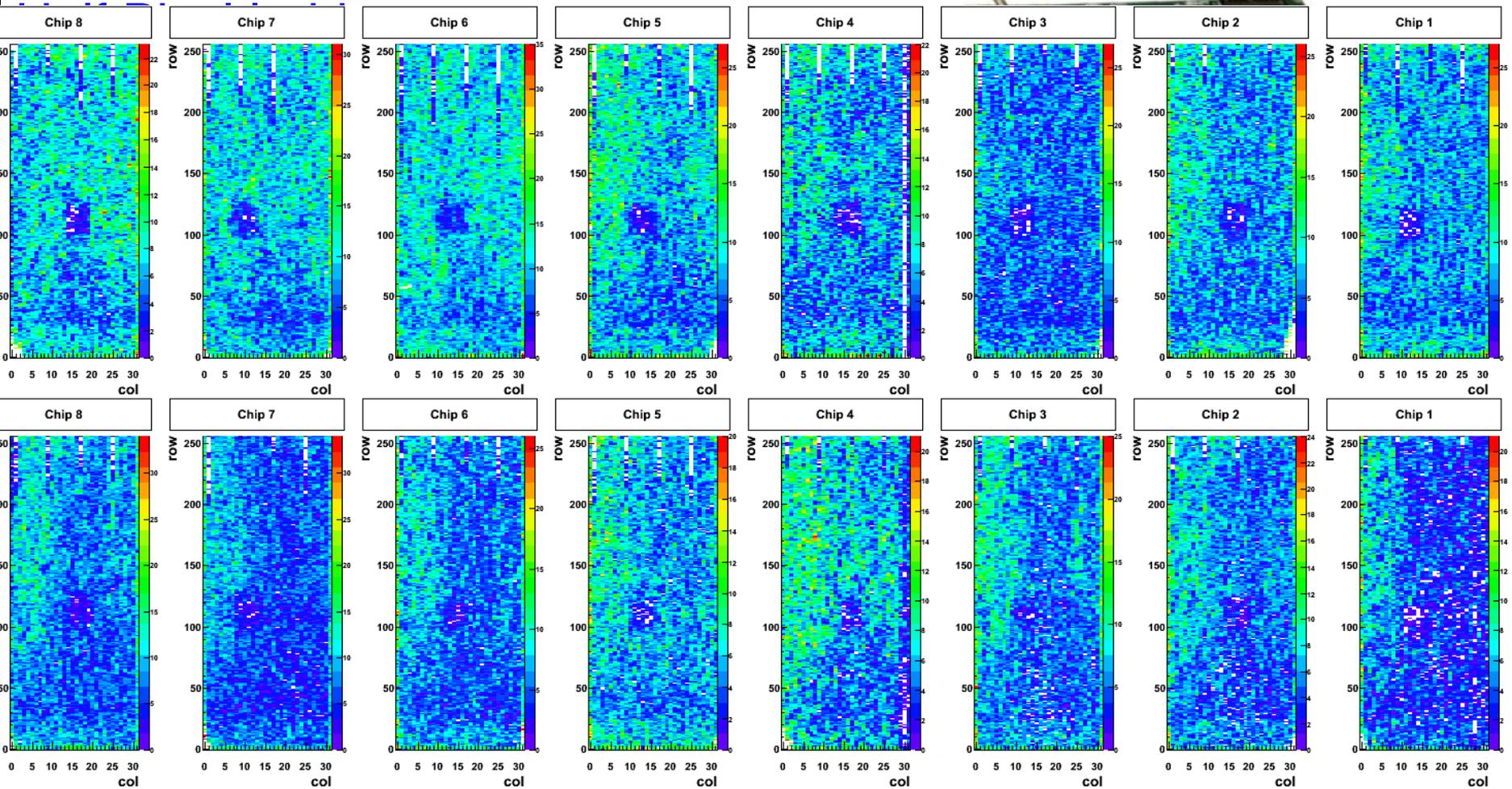
- ◆ Control/read-out a half ladder
- ◆ Send the data to FEM

FEM (interface to PHENIX DAQ)

- ◆ Read/control two SPIROs
- ◆ Interface to PHENIX DAQ



Technology Choices: VTX-Pixel (Barrels 1 & 2)



★ Production ladder of VTX-pixel



Technology Choices: VTX-Pixel (Barrels 1 & 2)

Layer 1 (PIXEL): 5x2 ladders



Layer 2 (PIXEL): 10x2 ladders



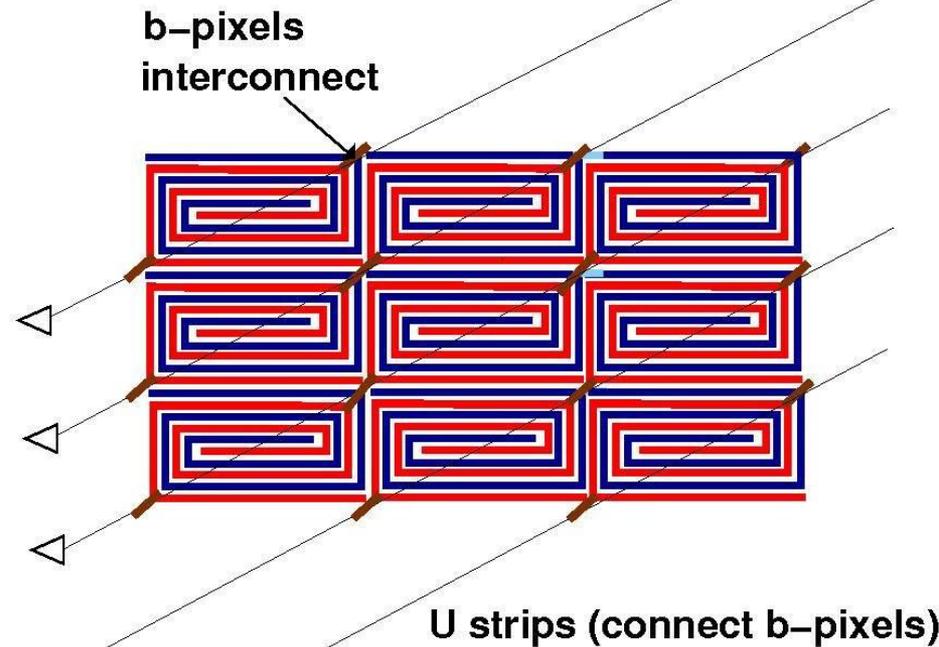
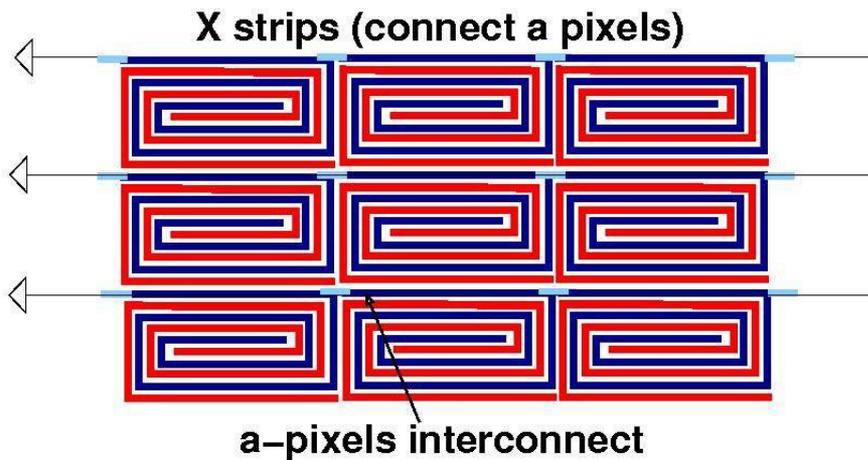
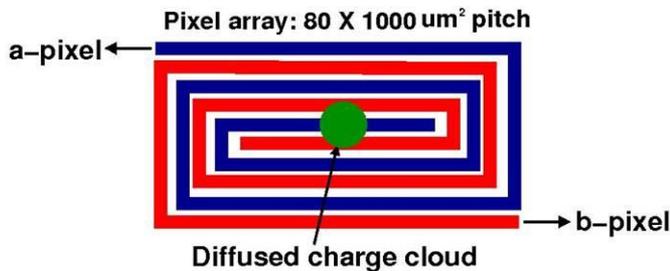
Spiro Board

Technology Choices: VTX-Stripixel (Barrels 3 & 4)

“New technology: unique to PHENIX”

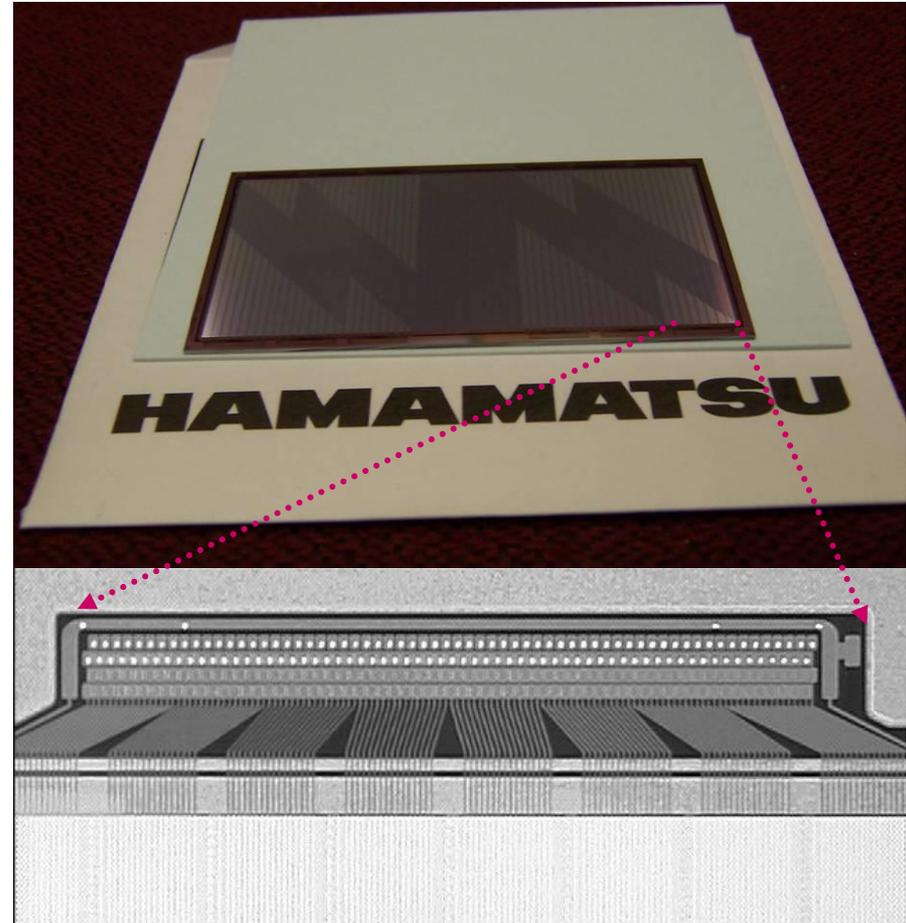
- Innovative design by BNL Instr. Div. : Z. Li et al., NIM A518, 738 (2004);
- R. Nouicer et al., NIM B261, 1067 (2007);
- R. Nouicer et al., Journal of Instrumentation, 4, P04011 (2009)

- DC-Coupled silicon sensor
- Sensor single-sided
- 2-dimensional position sensitivity by charge sharing



Technology Choices: VTX-Stripixel (Barrels 3 & 4)

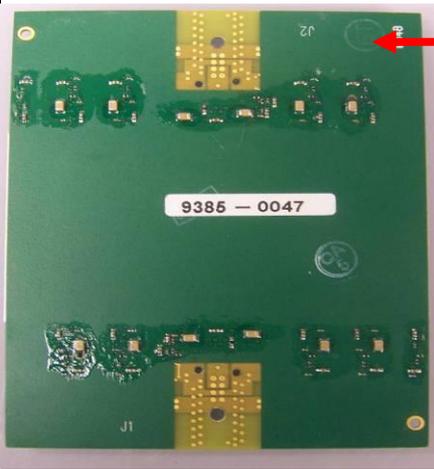
- ✧ Sensors produced by HPK with thickness of 625 μm
- ✧ Point-symmetric structure of readout lines wrt the center of the sensor
- ✧ Readout pads in longer edges for ladder structure design
- ✧ No dead space in the middle
- ✧ Sensor size : 3.4 \times 6.4 cm^2
- ✧ Pixel array : 80 \times 1000 μm^2 pitch
- ✧ # readout strip
 - x-strip : 128 \times 3 \times 2
 - u-strip : 128 \times 3 \times 2
 - Total : 1536 channels/sensor
- ✧ Current per strip: 0.12 nA
- ✧ Note: Stripixel sensor technology, including the mask design and processing technology has transferred from BNL to HPK.



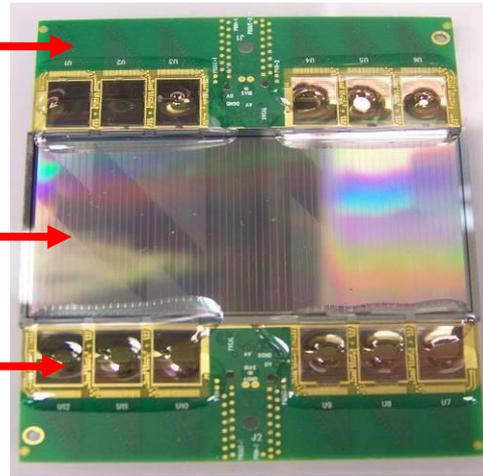
Technology Choices: VTX-Stripixel (Barrels 3 & 4)

★ Silicon Module assembly

• Bottom view



• Top view

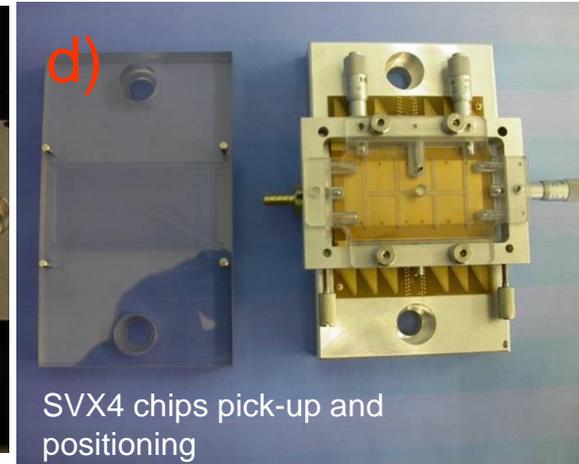
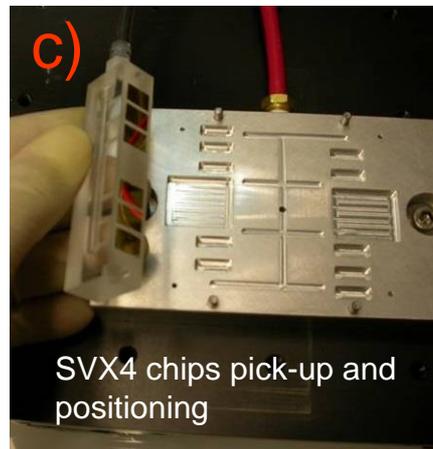
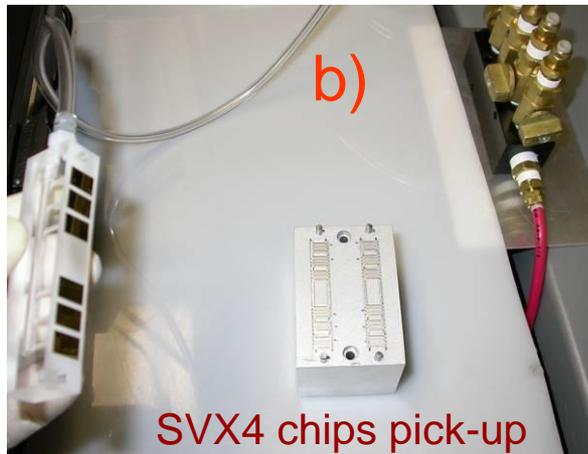
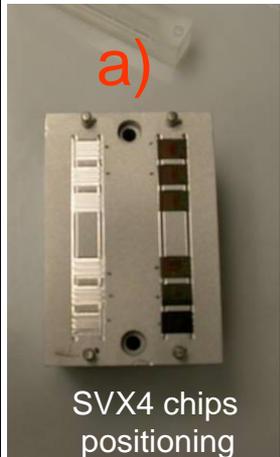
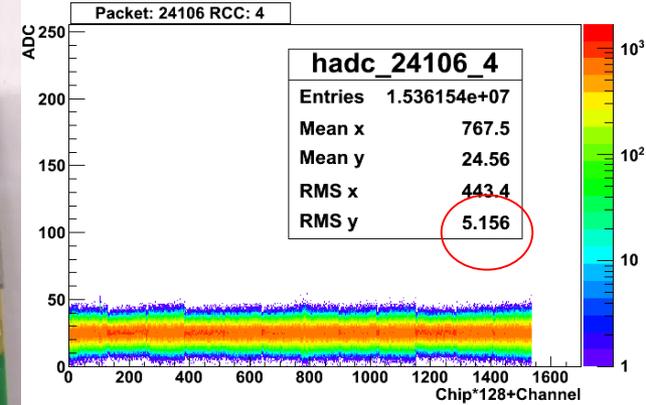


ROC
(readout card, ORNL)

Silicon sensor

SVX4 chips

ADC distributions corrected event-by-event pedestal subtraction



Technology Choices: VTX-Stripixel (Barrels 3 & 4)

Team: Tammy Hawke (wire-bonding), Mike Herren (encapsulation), Bert Gonzalez (trained on sensor placement), Steve Kaneti (trained on SVX4 placement), Manabu Togawa + Paul Kline (testing) and Rachid Nouicer (training people and ensuring success).

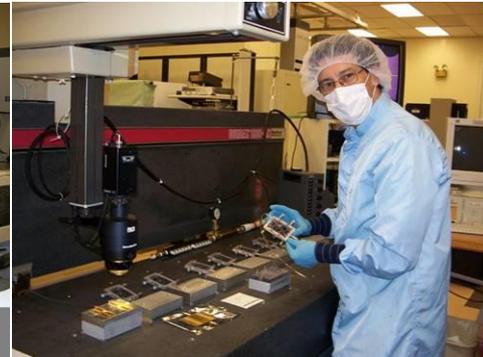
Tammy H.



Mike H.



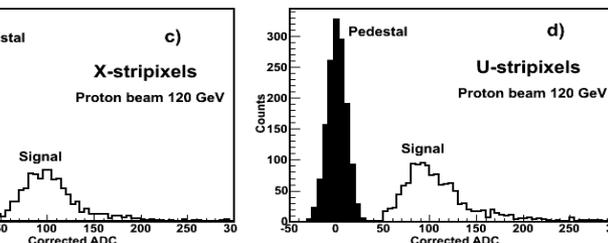
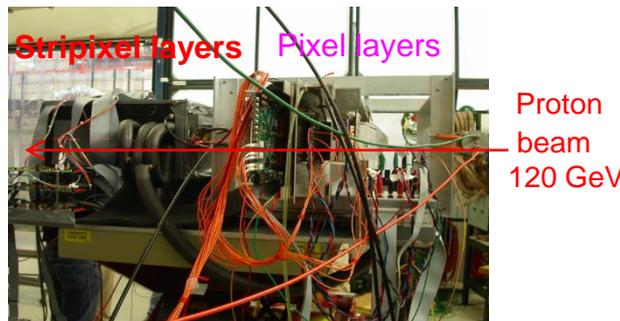
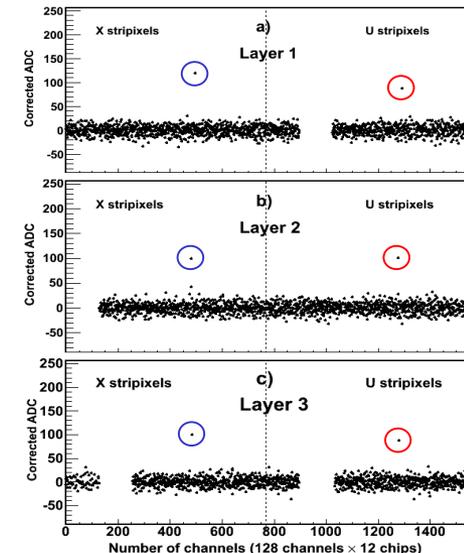
Bert G.



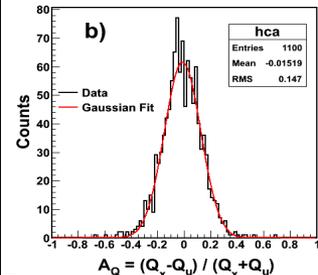
Steven K. & Rachid N.



Single Event Tracking: Linear Fit Track



Charged Sharing



Technology Choices: VTX-Stripixel (Barrels 3 & 4)

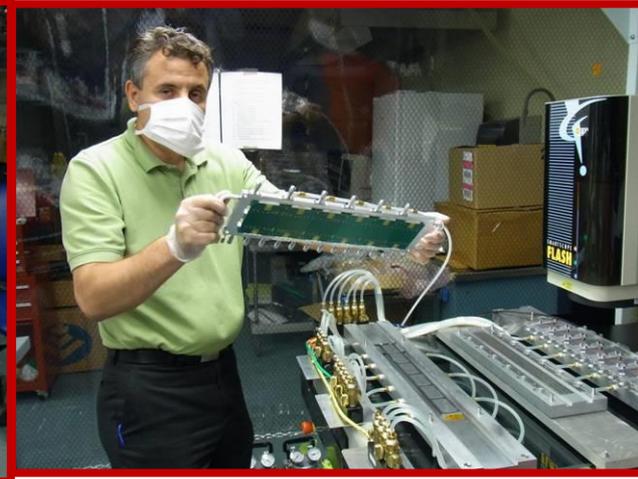
1) Laser scan of the stave (flatness)



2) Dow Corning (SE 4445): 50 [um]



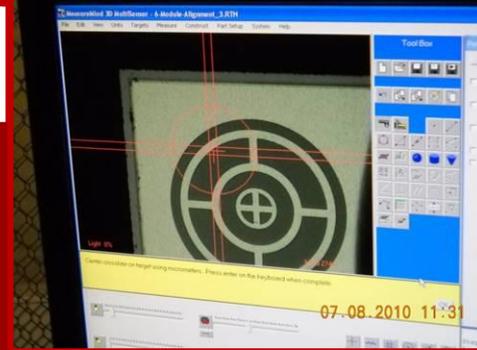
3) Placing modules on stave



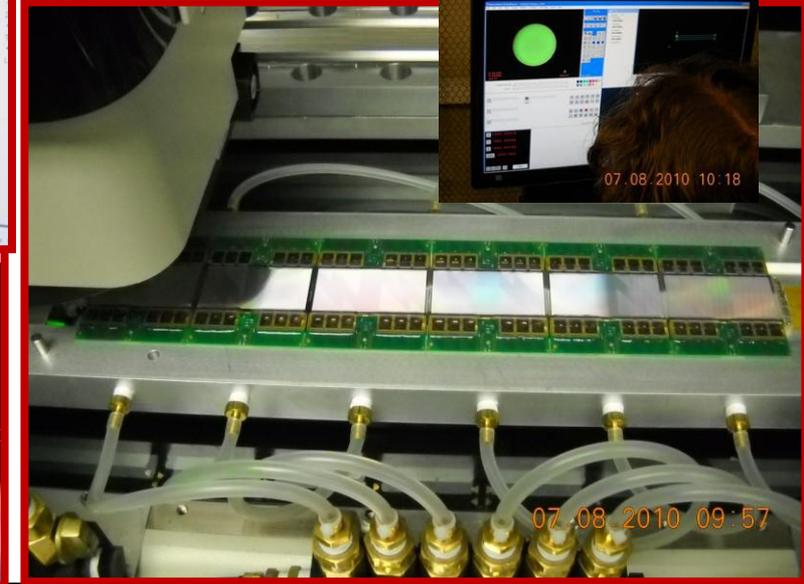
4) Modules alignment



5) Ladder survey



Measure the reference point of the stave



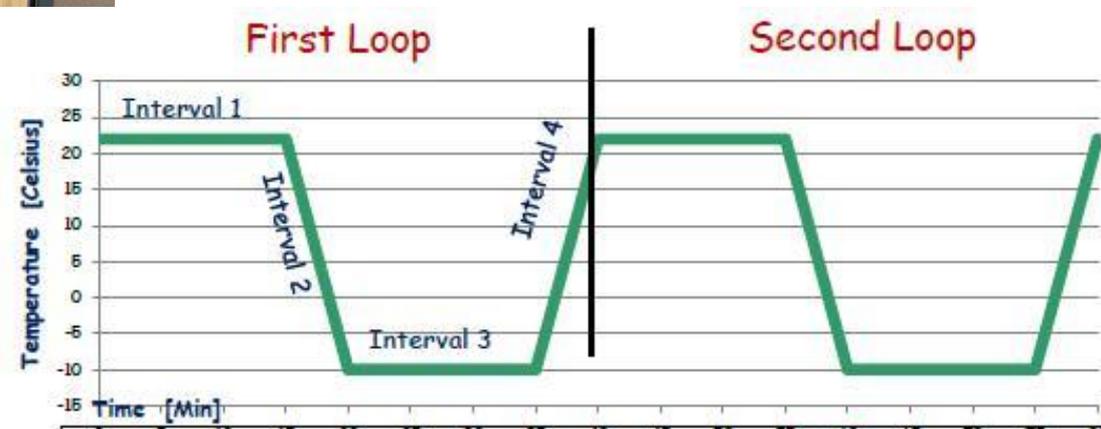
Thermal Cycling of Two Prototype Ladders: Barrels 3 &4

Programmable Thermal Cycling Chamber



Prototype short ladder (barrel #3):

- 5 silicon modules mass production
- 1 CFC stave mass production
- 5 RCCs mass production
- 1 production bus cable
- peek screws (sample)



Prototype long ladder (barrel #4) :

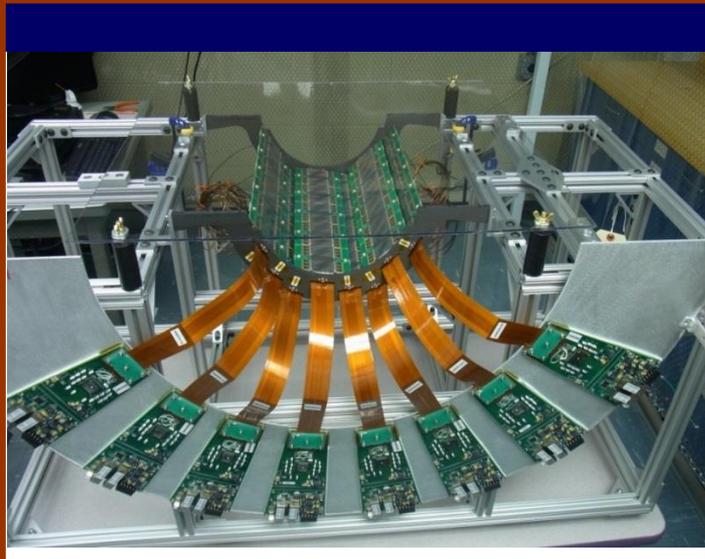
- 6 bad silicon modules
 - 1 bad CFC stave
 - 1 production bus cable
- goal: to check the glue and assembly procedure

Maximum temperature	22 Celsius
Minimum temperature	-10 Celsius
Interval 1 and 3	15 minutes
Interval 2 and 4	5 minutes
Total number of loops during test	135
Start	May 21 st at 18:00
Finished	May 25 th 9:00

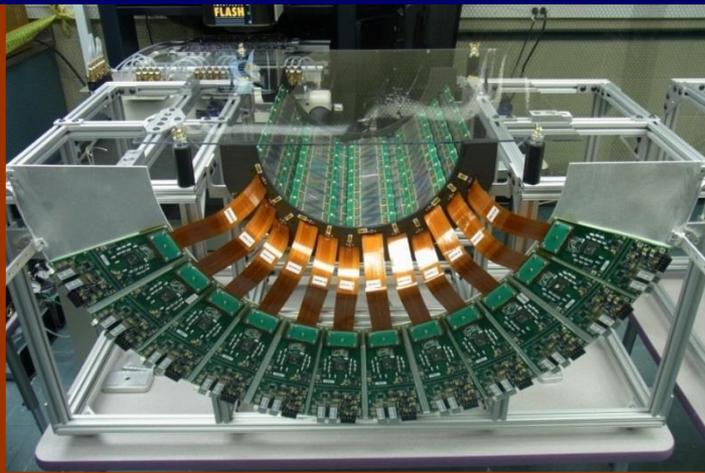
No visible damage after visual inspection

Technology Choices: VTX-Stripixel (Barrels 3 & 4)

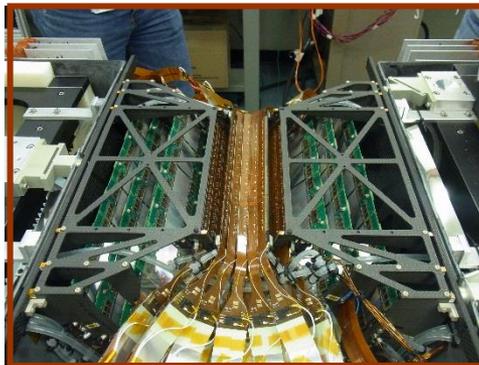
EAST: Layer 3 (Stripixel): 8 ladders



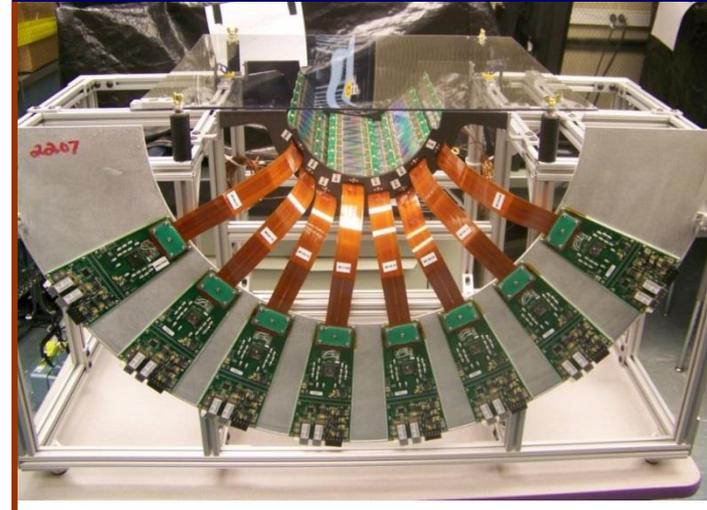
EAST: Layer 4 (Stripixel): 12 ladders



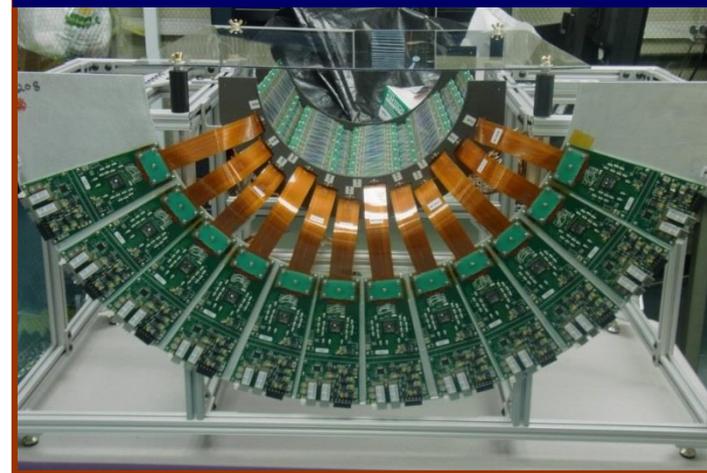
Very important: involve students in research



WEST: Layer 3 (Stripixel): 8 ladders

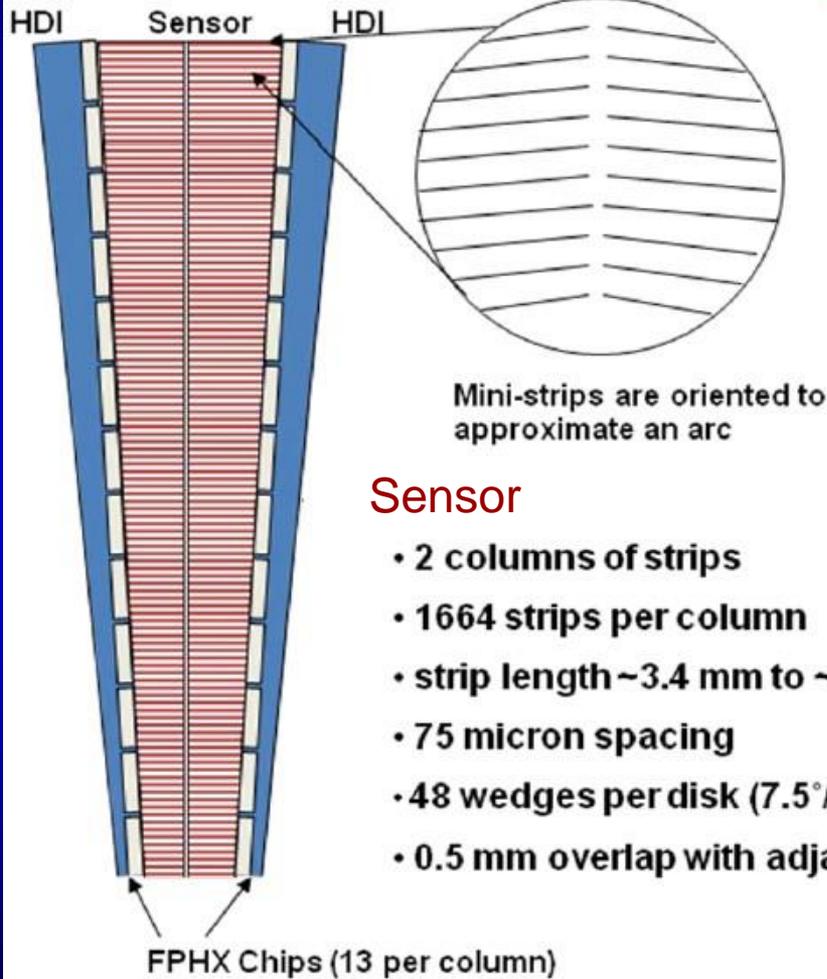


WEST: Layer 4 (Stripixel): 12 ladders



Technology Choices: Forward Silicon Vertex Tracker (FVTX)

FVTX sensor long wedge



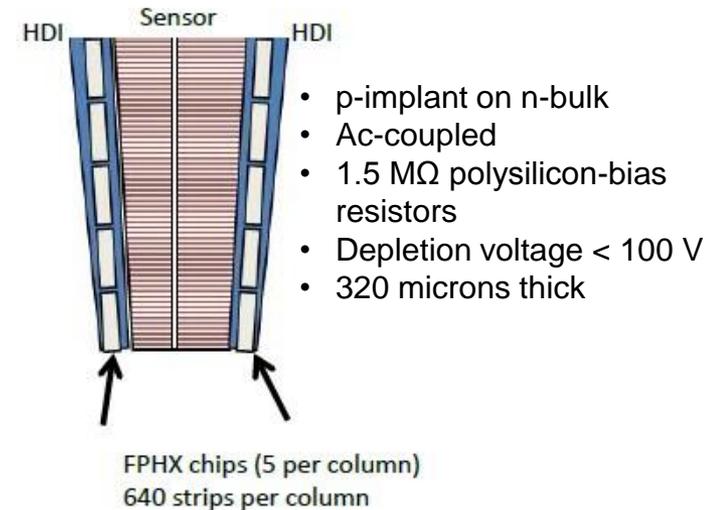
Sensor

- 2 columns of strips
- 1664 strips per column
- strip length ~3.4 mm to ~11.5 mm
- 75 micron spacing
- 48 wedges per disk (7.5°/sensor, 15°/wedge)
- 0.5 mm overlap with adjacent wedges

Overall length 126.8 mm
Overall width 8.8 mm i.r., 25.4 mm o.r.



FVTX sensor short wedge



- p-implant on n-bulk
- Ac-coupled
- 1.5 MΩ polysilicon-bias resistors
- Depletion voltage < 100 V
- 320 microns thick

Overall length 50.1 mm
Overall width 8.8 mm i.r., 15.3 o.r.

Technology Choices: Forward Silicon Vertex Tracker (FVTX)

Large Wedge Construction

Silicon sensor, 320 μm

HDI, 334 μm

Carbon back-plane, 1.56 mm, K13C2U

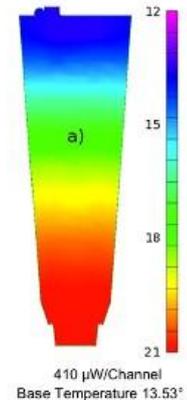
Spacers – POCO graphite, AXM5Q, 2 versions of each low and high profile

Hirose DF18 series connector, 100 pin for large and 60 pin for small

FPHX read-out-chips, 13 on each side of sensor, 128 channels each, 410. microwatts per channel, 1.36 watts/wedge

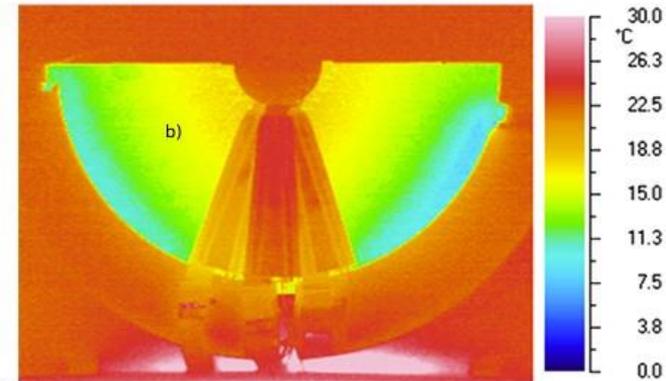
Separate ground connection point for Carbon

Finite element calculations



Estimate Temperature and temperature gradients

Using thermal Camera



Thermal path for heat generated on large Wedge

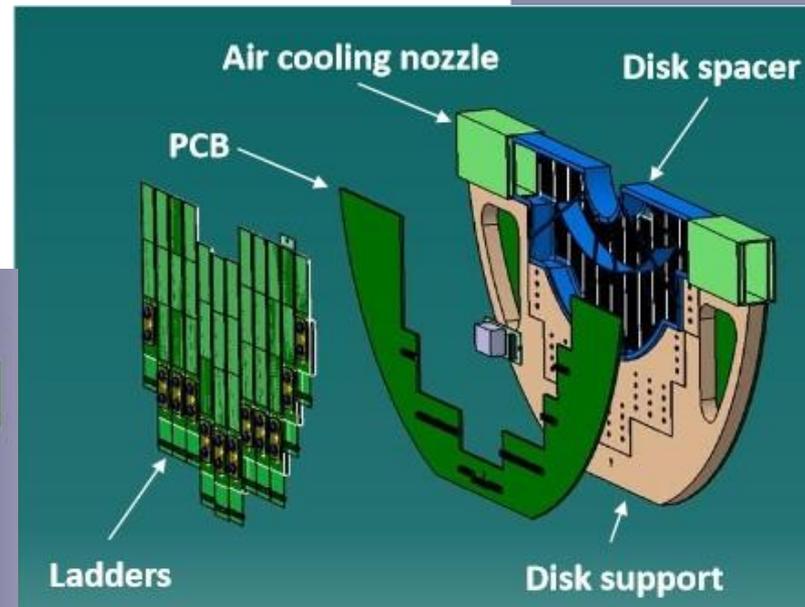
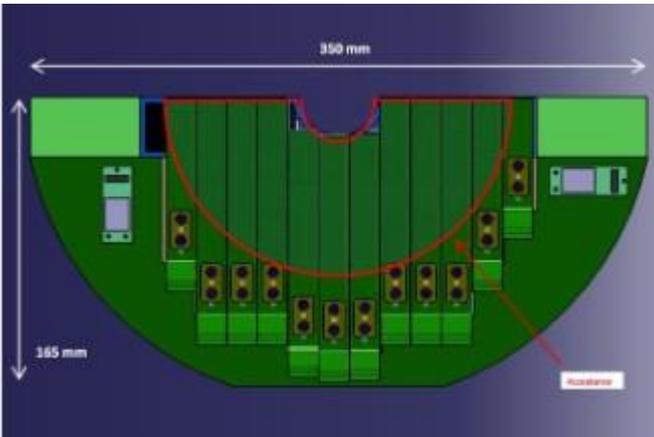
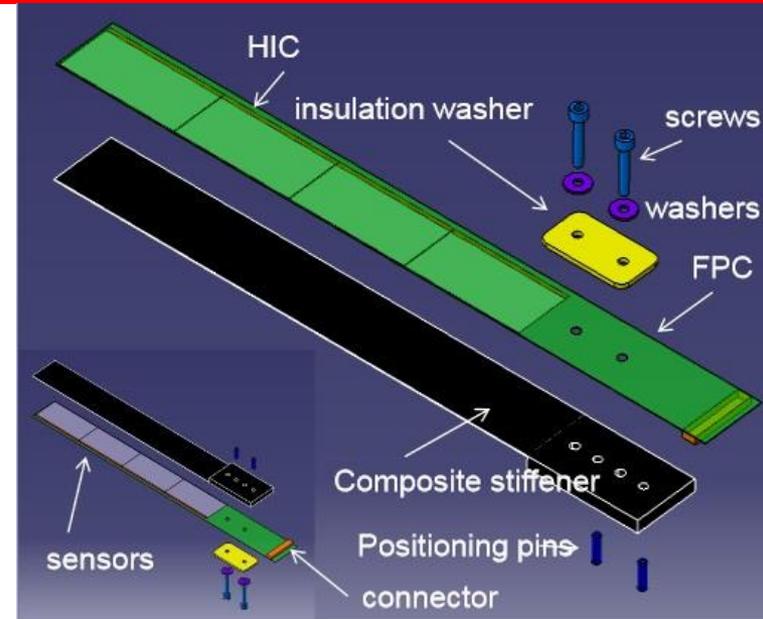
- Delta T on large Wedge is ~ 7.47 degrees C
- Heat from FPHX chips passes through HDI into Carbon backplane – through POCO graphite thermal block to Station Disk where coolant flows around perimeter – **NOVEC 7200 coolant**
- Delta T from Disk to Wedge ~ 8 . degrees C
- In analysis a temp constraint was set to keep peak FPHX chip temp at 21 degrees C
- Bonding of all elements of Wedge assembly, made using Arclad 7876 transfer adhesive, 50. μm thick.

Concept Similar to ALICE present upgrade: MFT

MFT: Muon Forward Tracker

Ginés MARTINEZ, Subatech

LHCC referees – ALICE Meeting
November 18th 2014, CERN



Technology Choices: Forward Silicon Vertex Tracker (FVTX)

Chip positioning

Stackup

Sensor positioning



Bond backplane to HDI
Bond FPHX chips to HDI
Wire bond FPHX chips to HDI

Chip readback
Pulser test



Bond sensor to HDI
Wire bond sensor to FPHX

Chip readback
Pulser test
Source Test

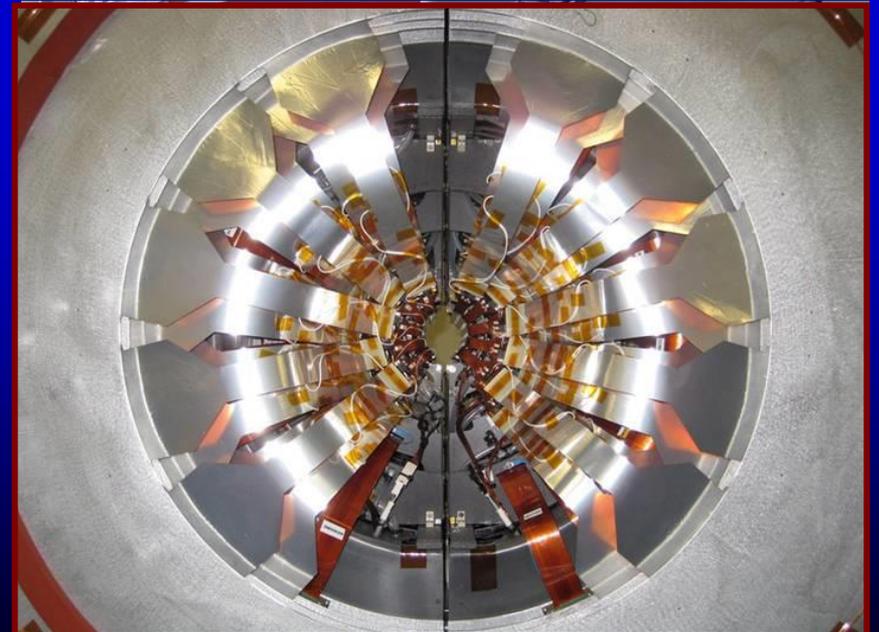
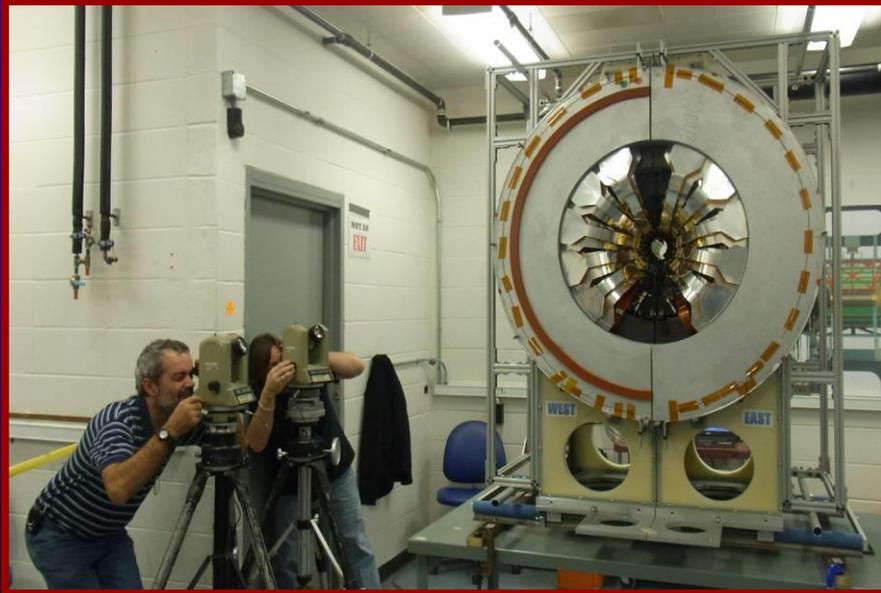
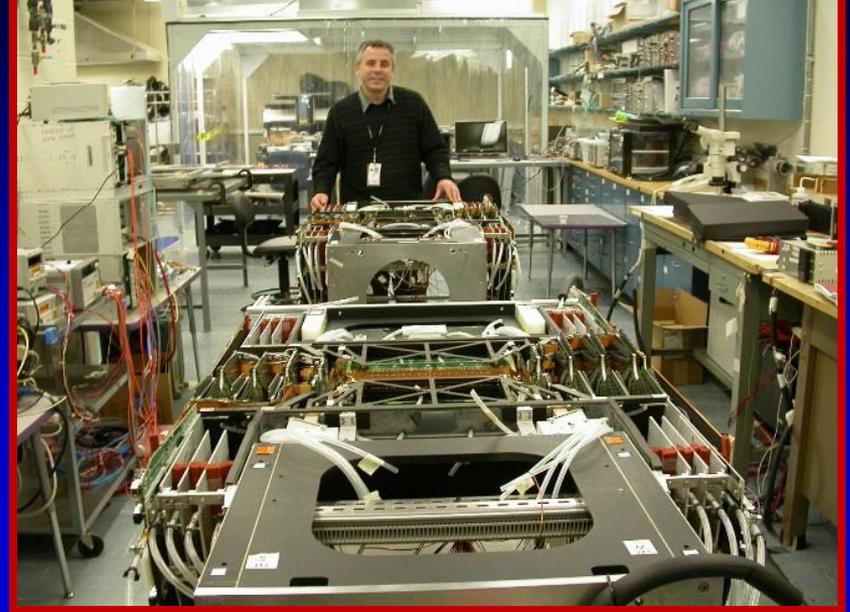
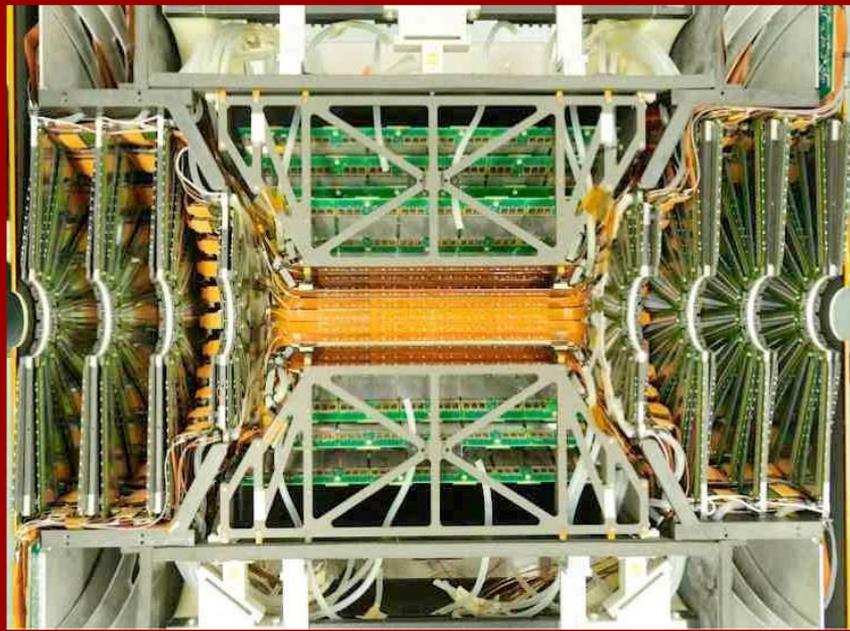


Encapsulate wire bonds

Chip readback
Pulser test
Source Test

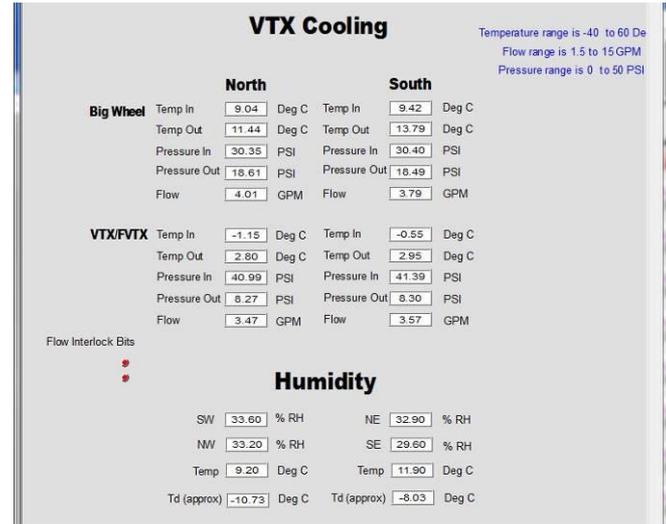
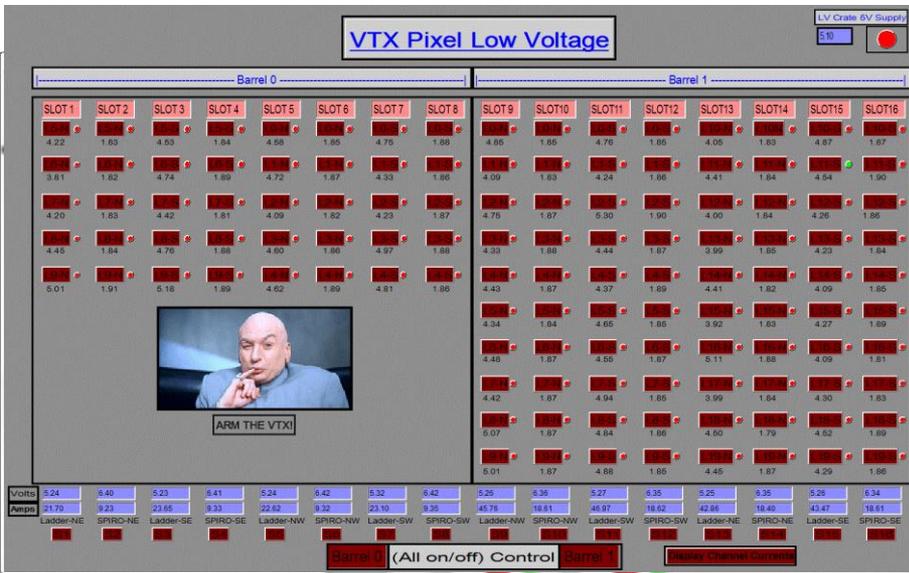


VTX Survey at the VTX/FVTX-Lab.



(F)VTX: Slow Control and Interlock Systems

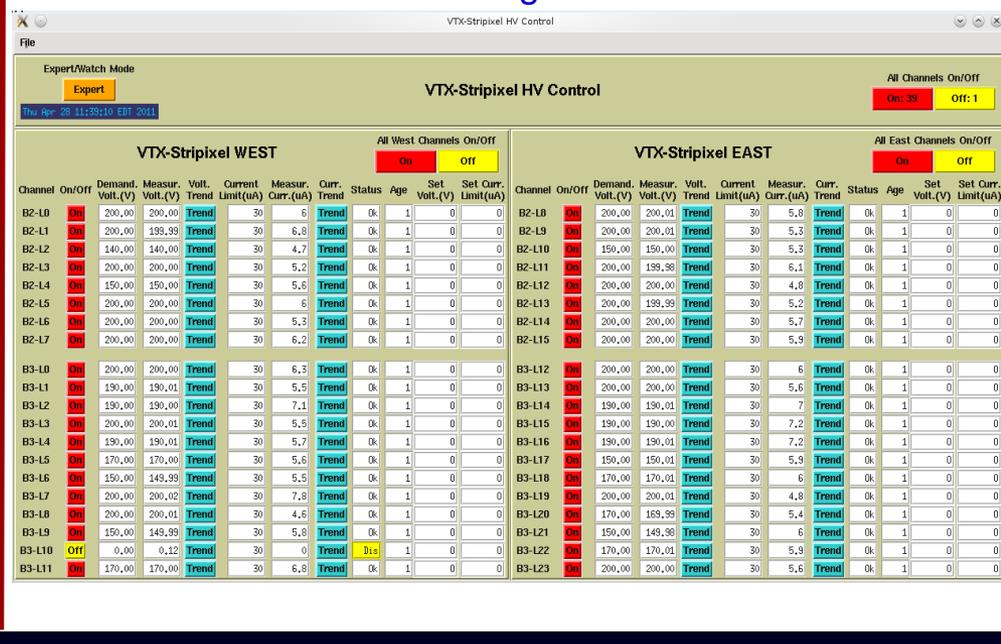
Cooling systems, humidity and temperature



Ladders and big wheels temperature

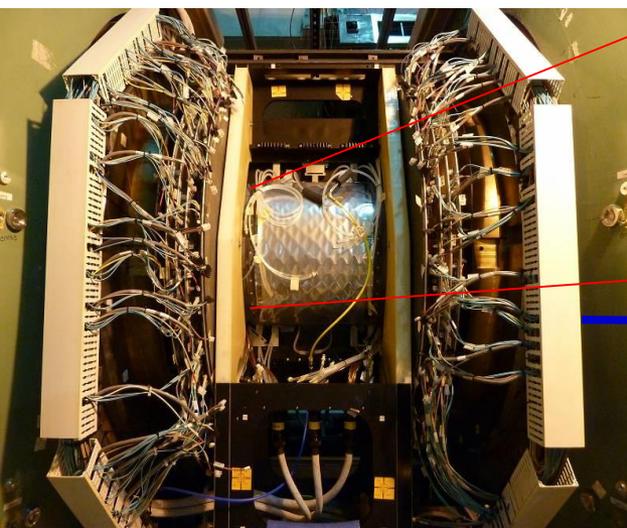


Bias Voltage

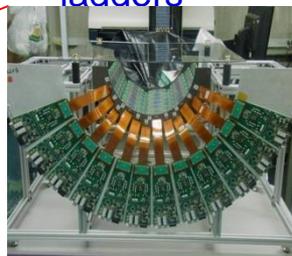


i.e.: VTX-Stripixel Detector: **Readout Chain**

Detector at the IR



Stripixel ladders

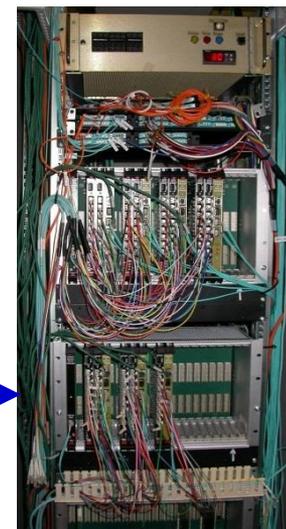


Optical cables
75 meters

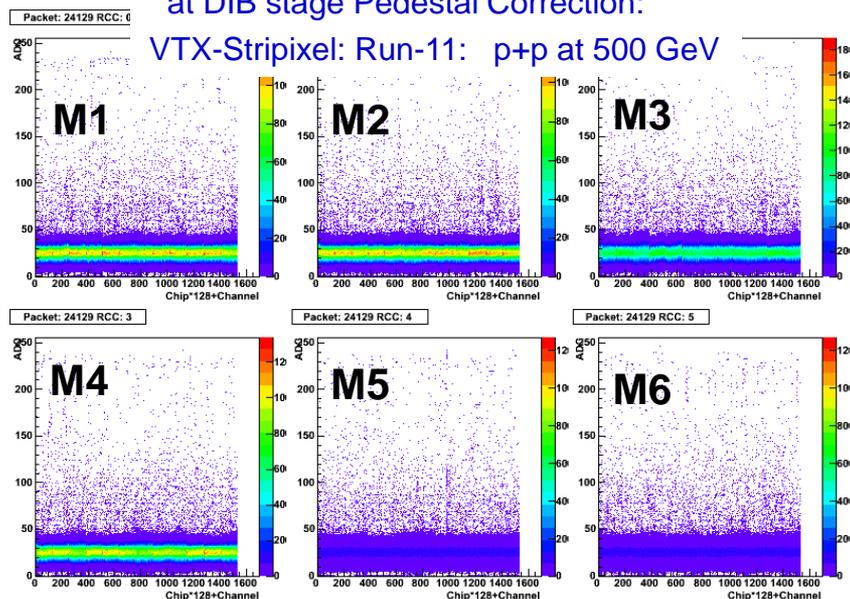
Stripixel DIB in the rack room



DCM2: Zero-Suppression

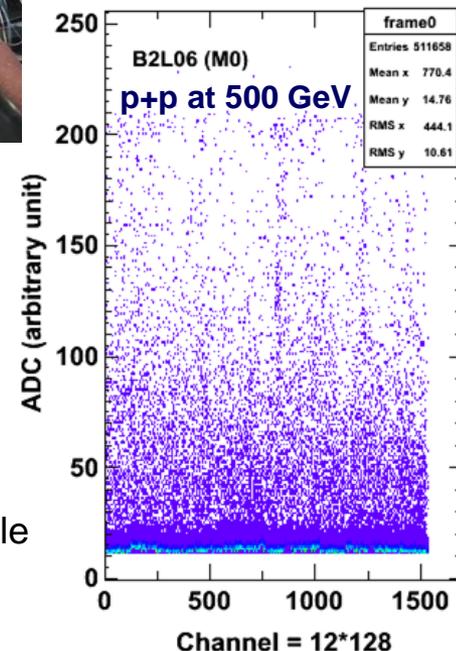


at DIB stage Pedestal Correction:
VTX-Stripixel: Run-11: p+p at 500 GeV



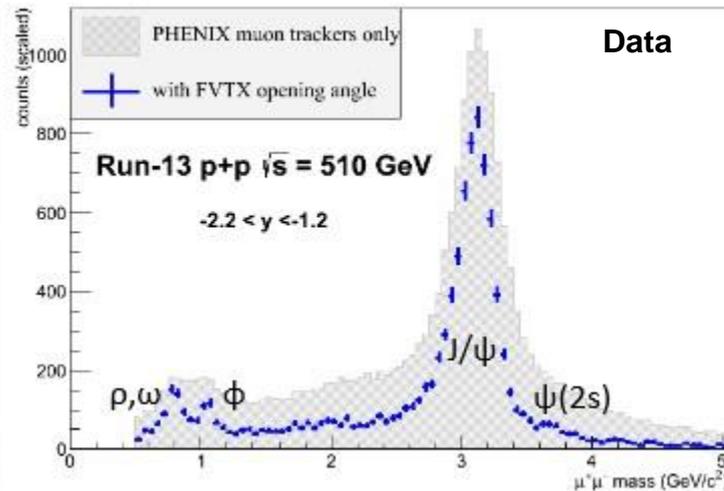
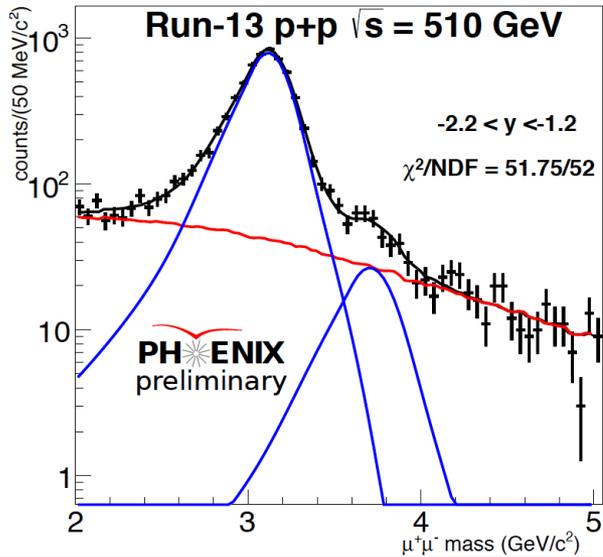
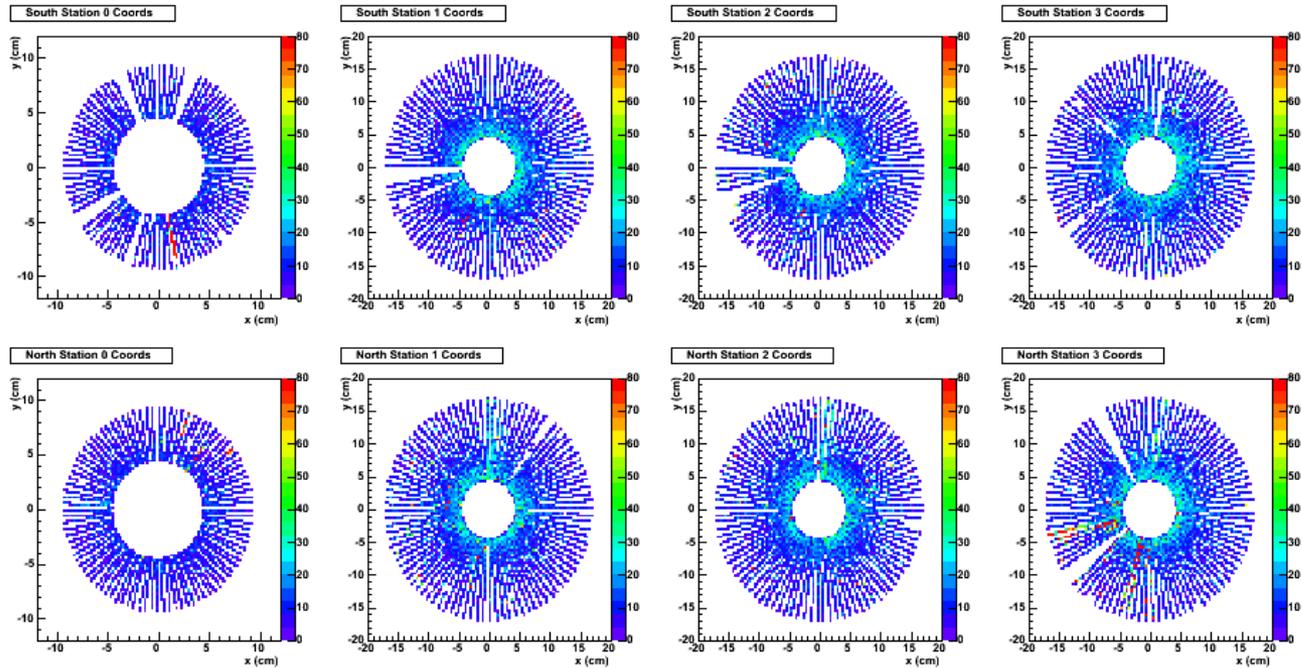
Data Transfer
DIB to DCM2

DIB: Data Interface Board
DCM: Data Collection Module



FVTX Performance

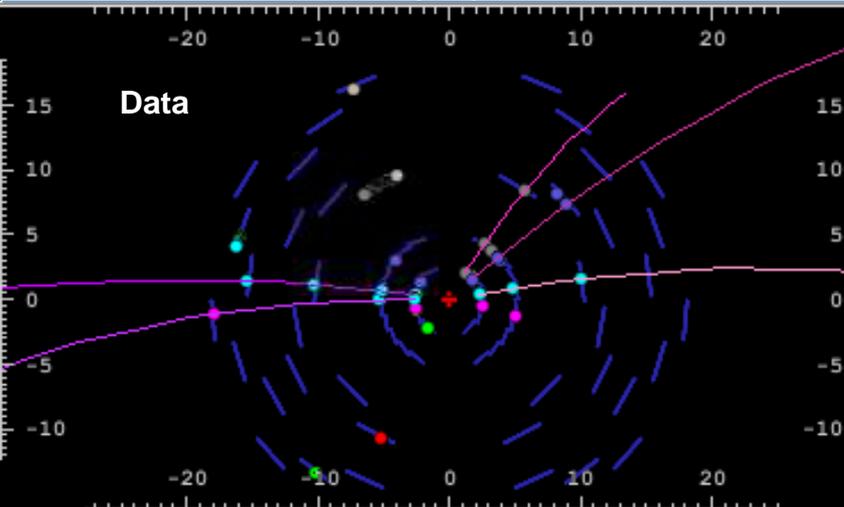
Raw FVTX acceptance in p+Au at 200 GeV Run-15



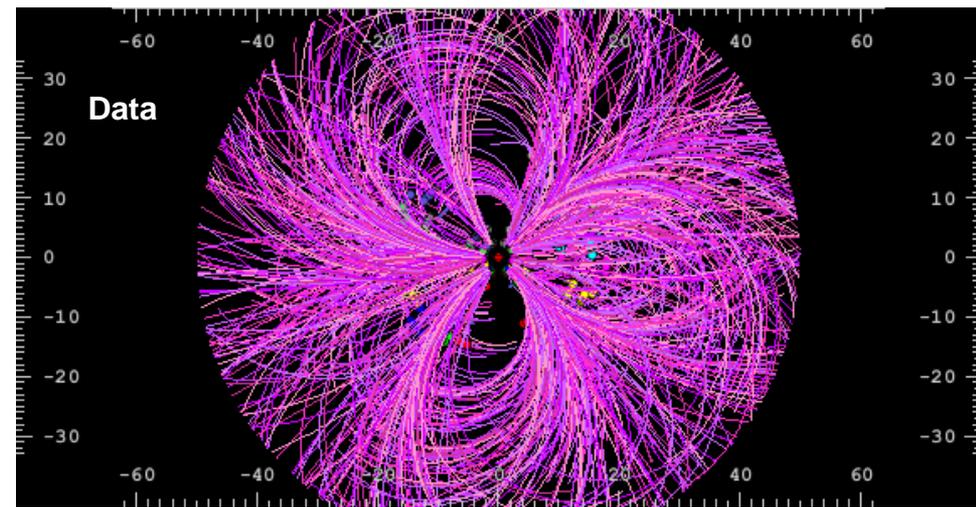
Opening angle in front of absorber:
 Greatly improved mass resolution and Background rejection

VTX : Affichage d'Événement Simple

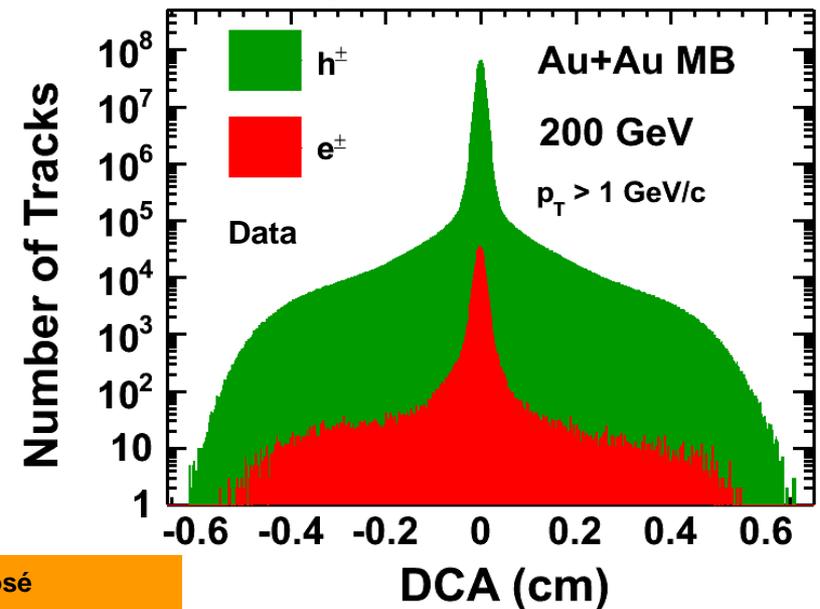
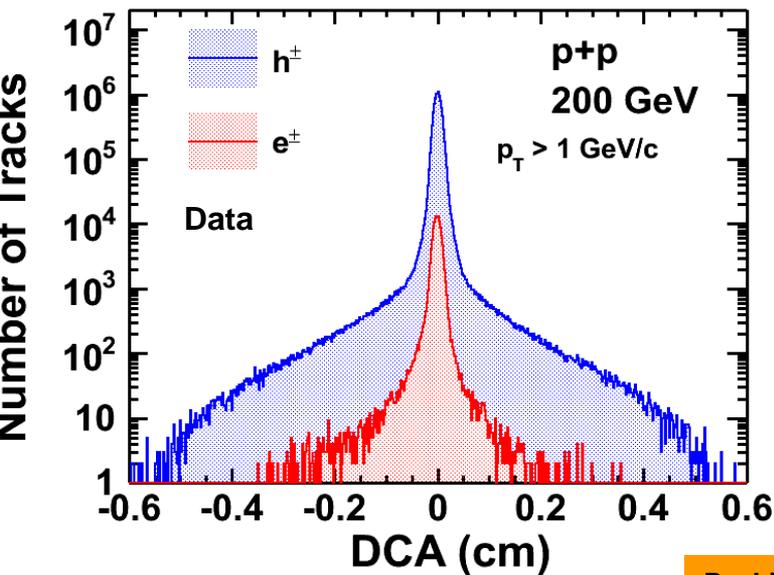
VTX RUN-12: p+p at 200 GeV



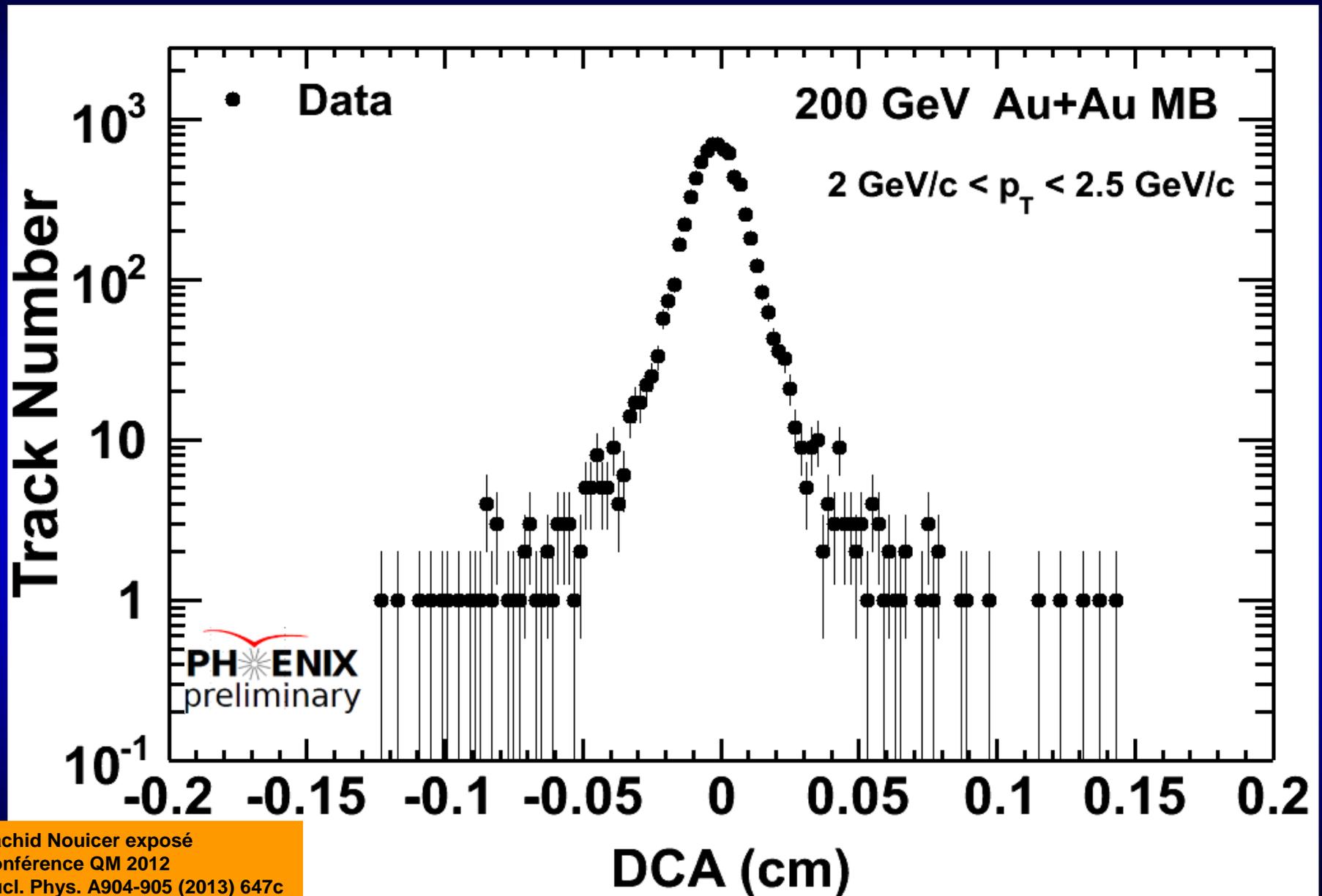
VTX RUN-11: Au+Au at 200 GeV



Distributions des Raw DCA des hadrons chargés et électrons

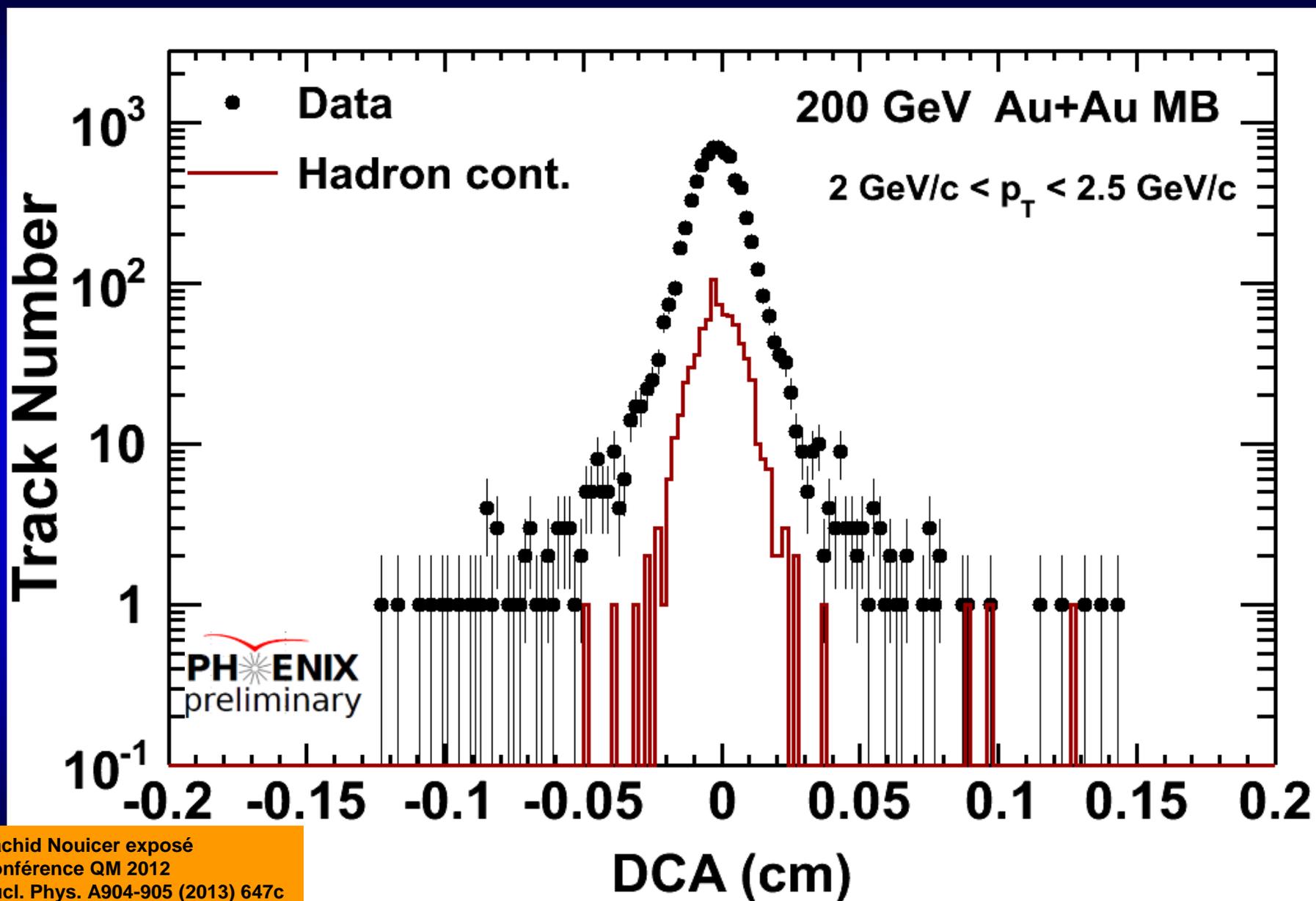


Électron: Distance of Closest Approach (DCA)



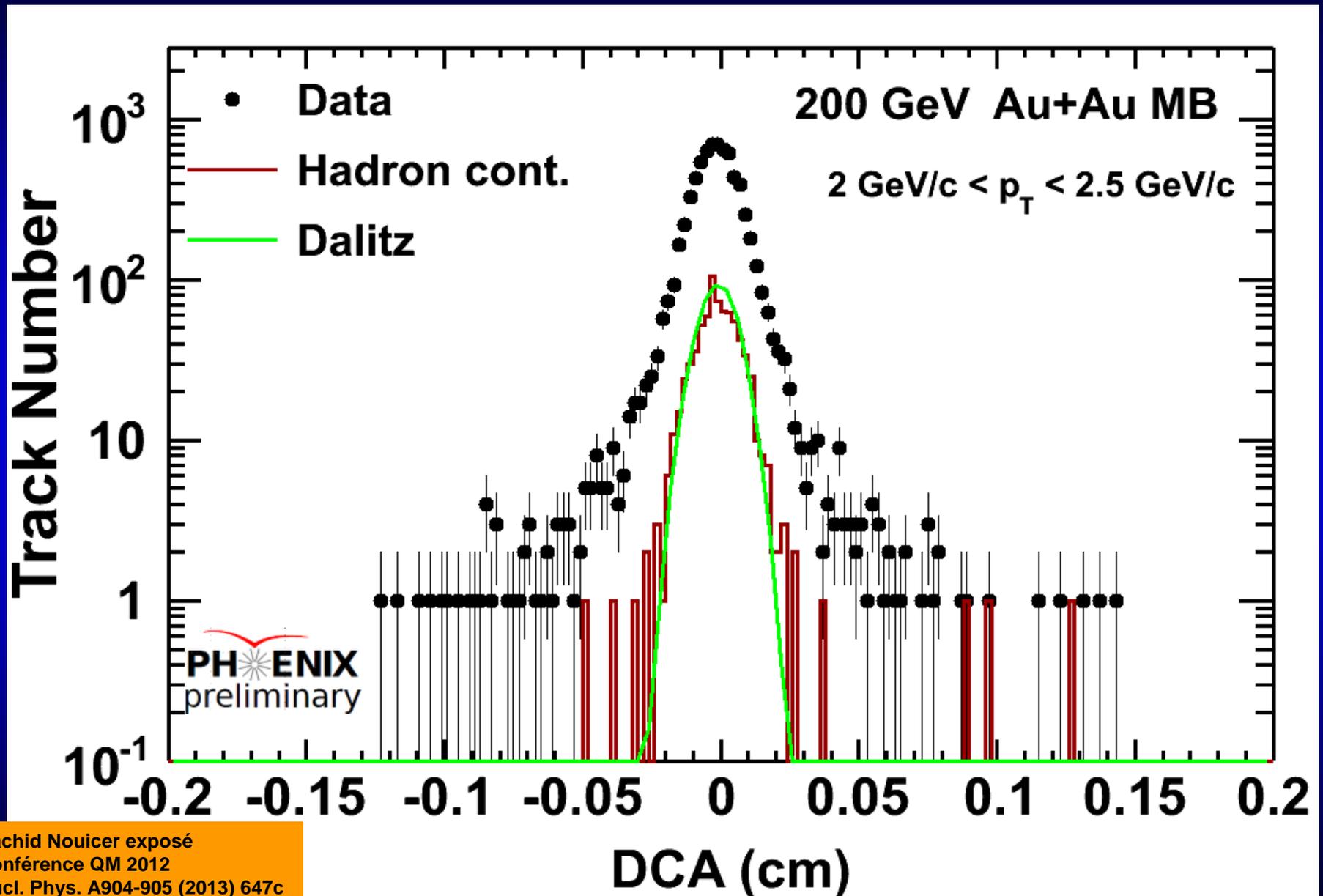
Rachid Nouicer exposé
Conférence QM 2012
Nucl. Phys. A904-905 (2013) 647c

Électron: Distance of Closest Approach (DCA)



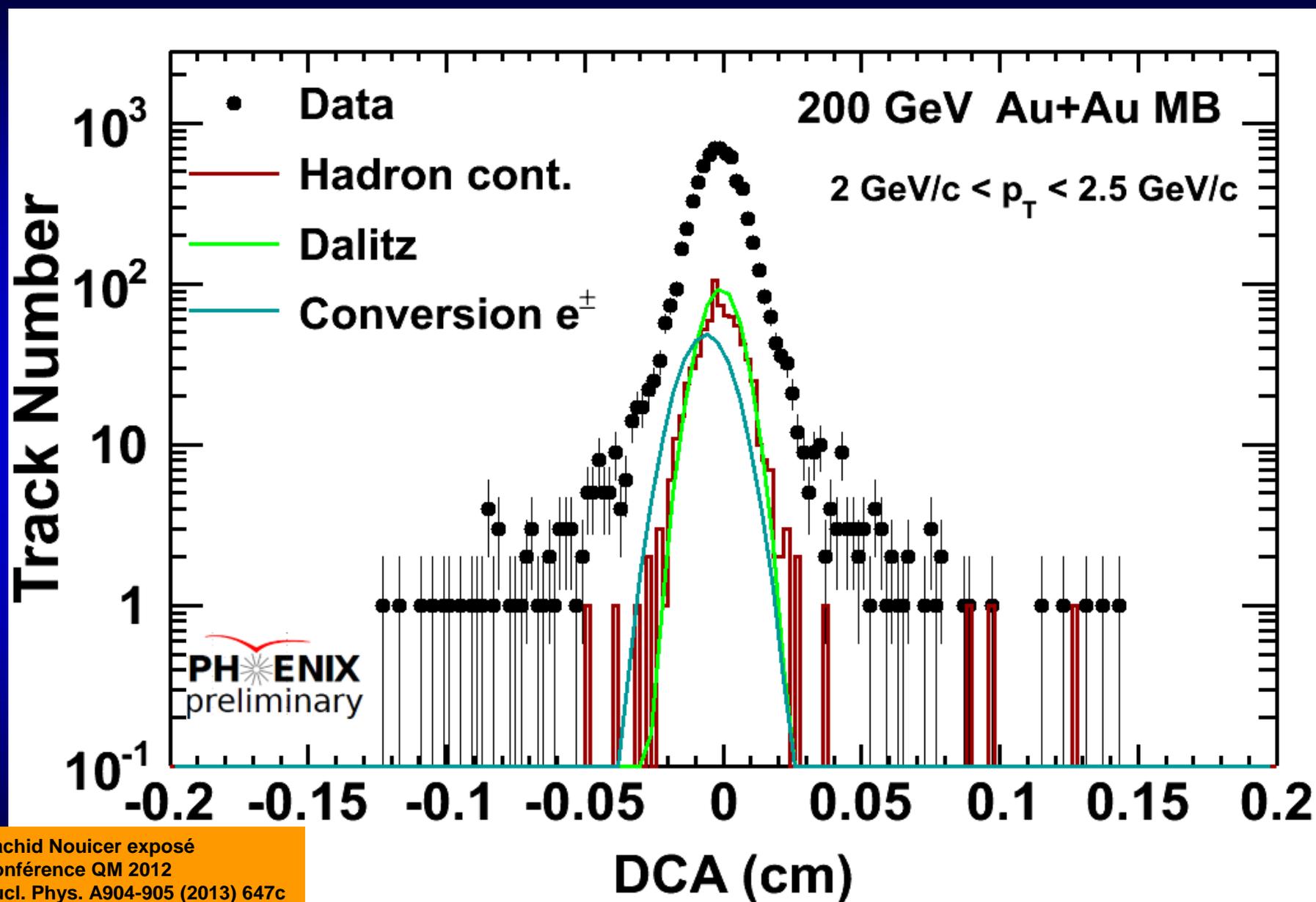
Rachid Nouicer exposé
Conférence QM 2012
Nucl. Phys. A904-905 (2013) 647c

Électron: Distance of Closest Approach (DCA)



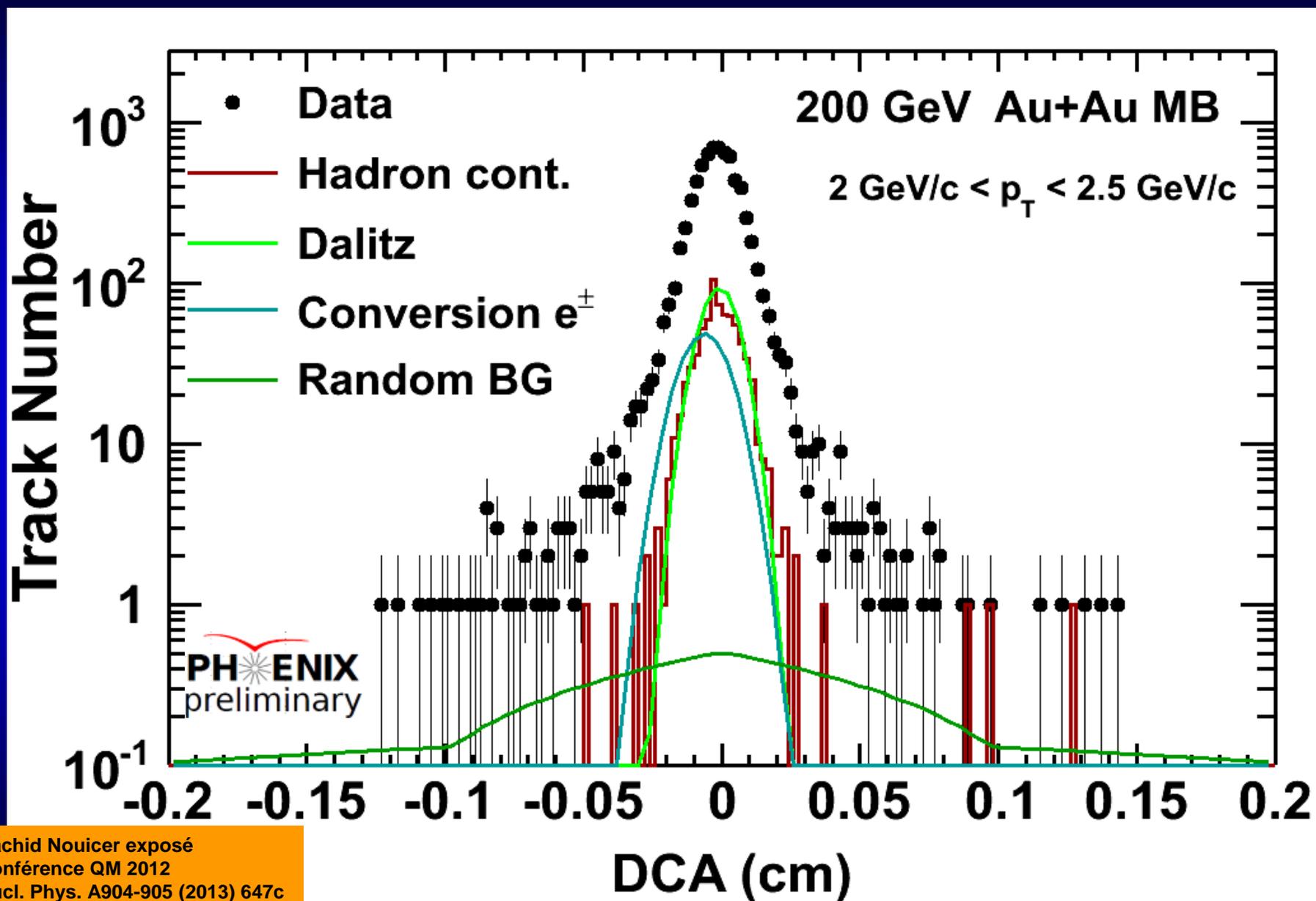
Rachid Nouicer exposé
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Électron: Distance of Closest Approach (DCA)



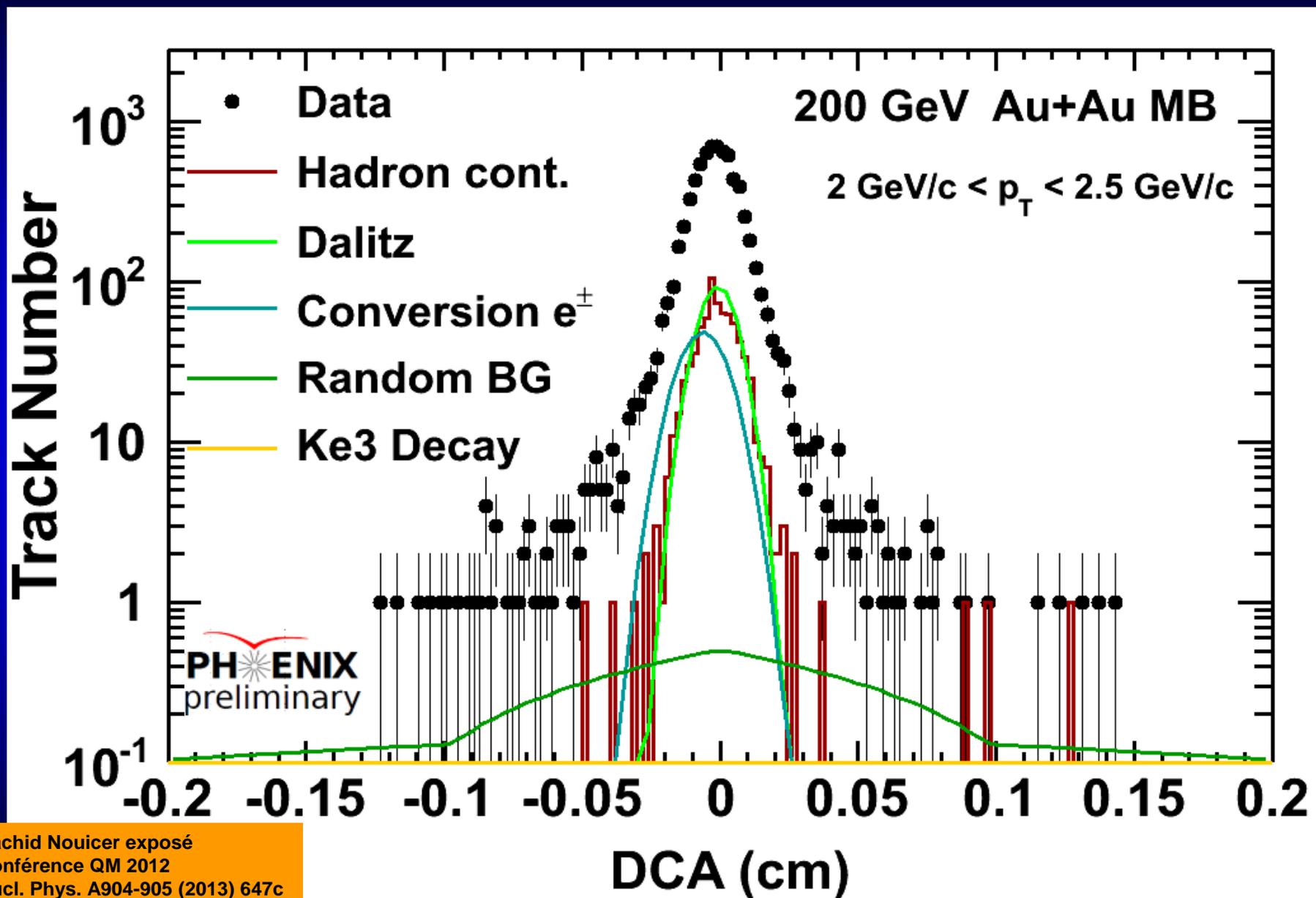
Rachid Nouicer exposé
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Électron: Distance of Closest Approach (DCA)



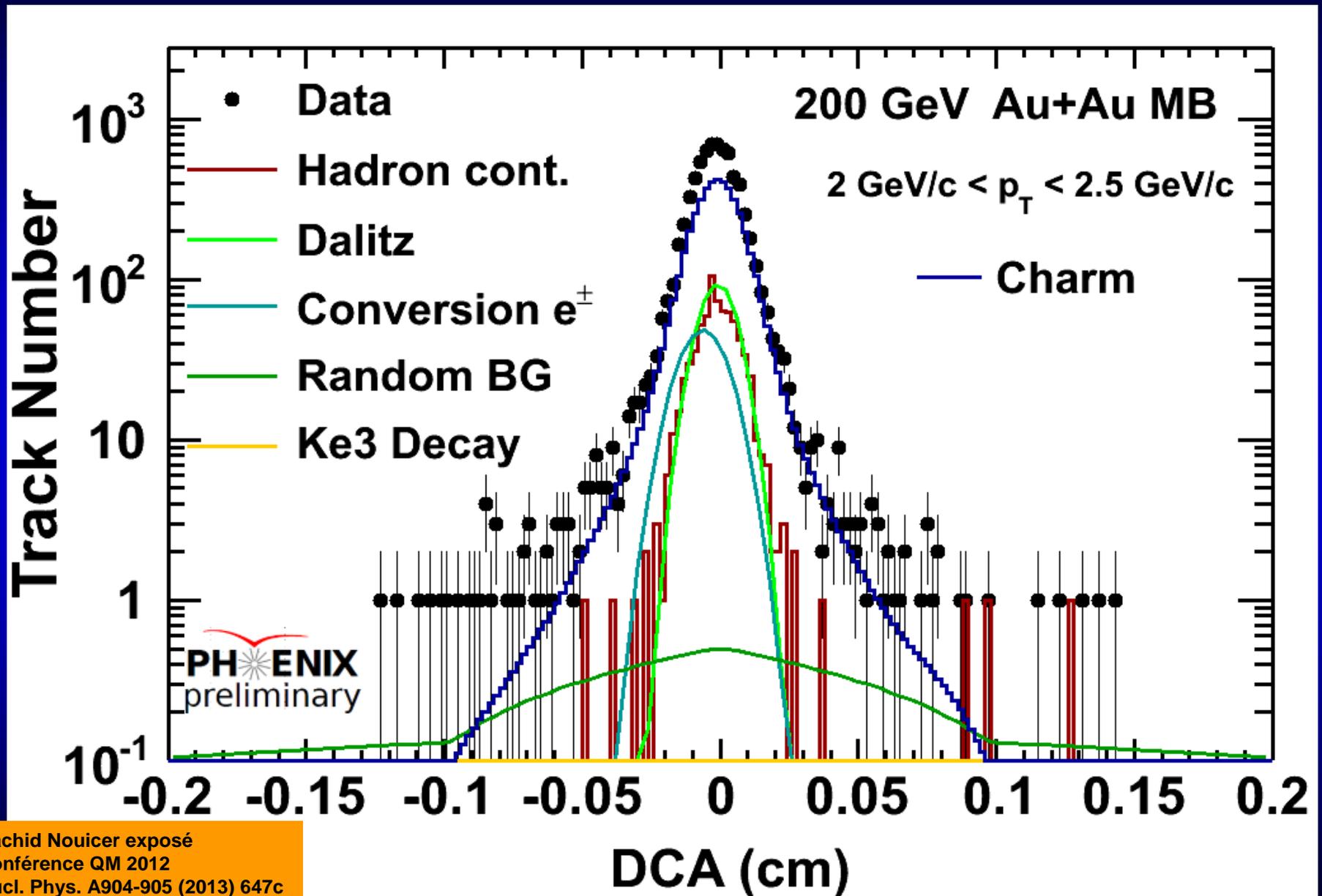
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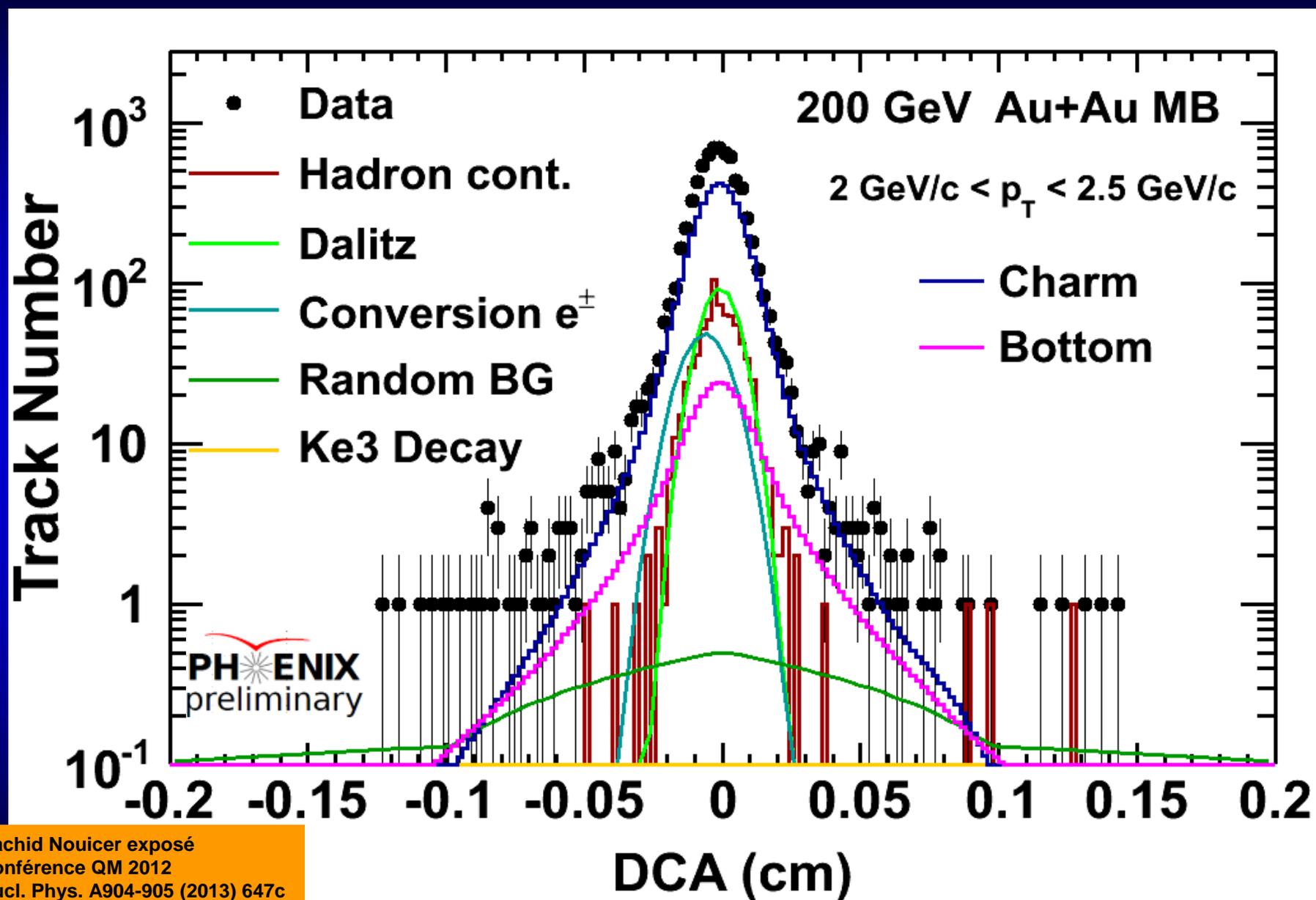
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Électron: Distance of Closest Approach (DCA)



Rachid Nouicer exposé
Conférence QM 2012
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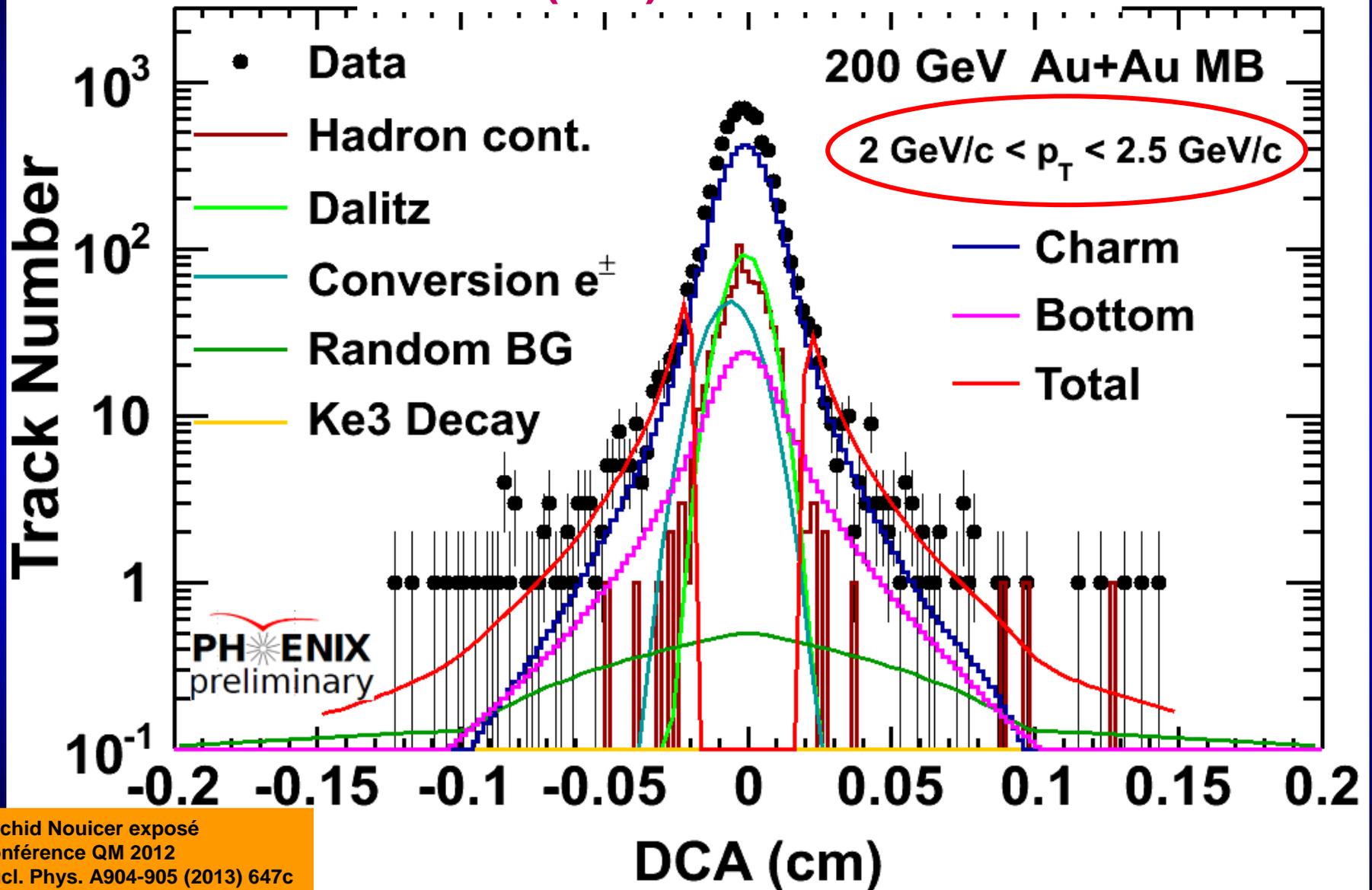
Électron: Distance of Closest Approach (DCA)



Rachid Nouicer exposé
Conférence QM 2012
Nucl. Phys. A904-905 (2013) 647c

Électron: Distance of Closest Approach (DCA)

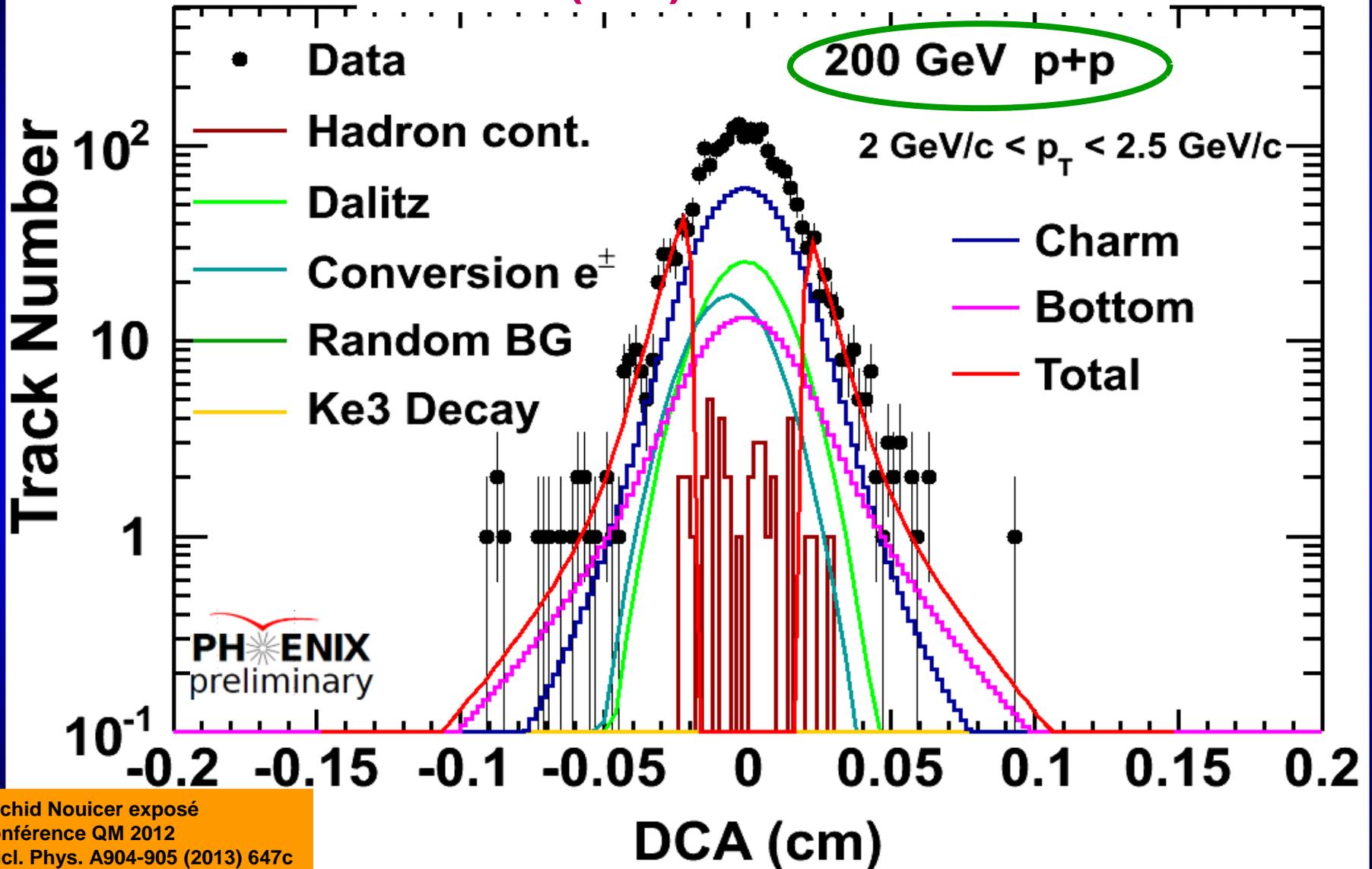
$$c/(b+c) = 0.92 \pm 0.02$$



Rachid Nouicer exposé
Conférence QM 2012
Nucl. Phys. A904-905 (2013) 647c

Electron: Distance of Closest Approach (DCA)

$$c/(b+c) = 0.78 \pm 0.06$$

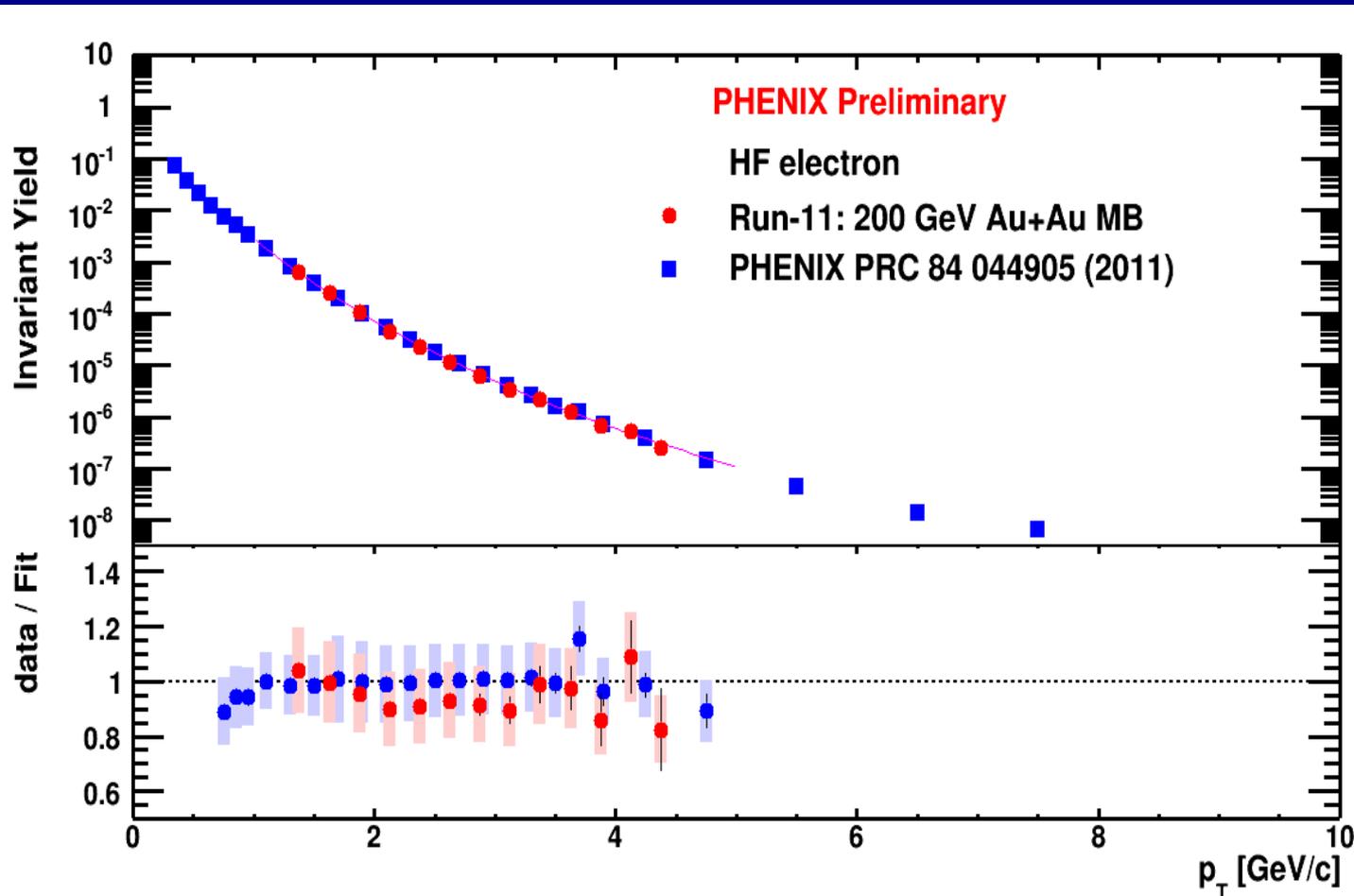


Rachid Nouicer exposé
Conférence QM 2012
Nucl. Phys. A904-905 (2013) 647c

Verification: Spectre Invariant e^{HF} Au + Au

Utilisant **VTX** pour étiqueter les "Dalitz" et électrons de conversion, nous mesurons le spectre d'électrons des saveurs lourdes (HF)

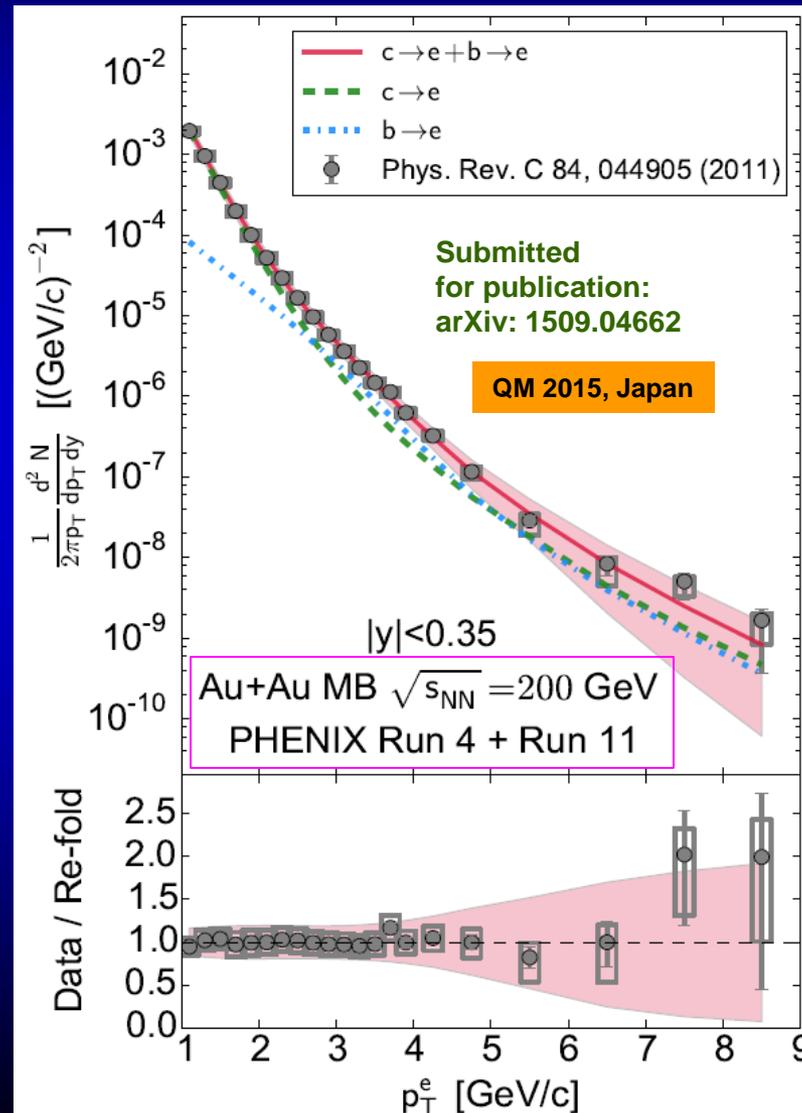
Spectres e^{HF}
du Run-11
(VTX) sont
compatibles
avec les
mesures sur
 e^{HF} publiées
par PHENIX



Verification: Spectre Invariant e^{HF} Au + Au

Utilisant **VTX** pour étiqueter les ``Dalitz'' et électrons de conversion, nous mesurons le spectre d'électrons des saveurs lourdes (HF)

Spectres e^{HF}
du Run-11
(VTX) sont
compatibles
avec les
mesures sur
 e^{HF} publiées
par PHENIX



Verification de
la méthode
d'analyse
``unfolding''

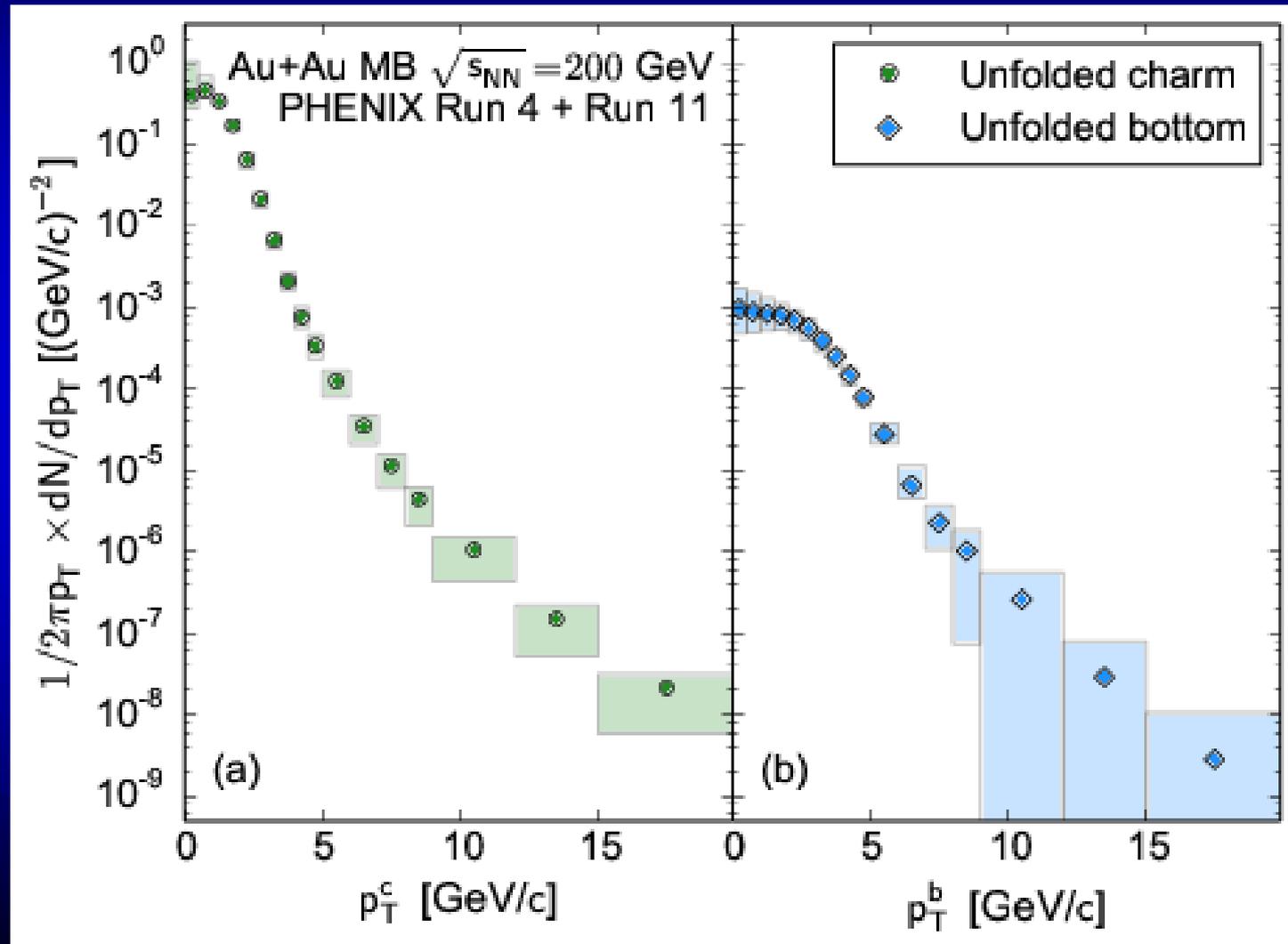
Charm (c)
+
bottom (b)

e^{HF} publié

Résultats: Production de Beauté dans Au+Au

En utilisant new analysis method "Unfolding": using VTX Silicon Detector

Première mesure de la production de Beauté dans Au+Au



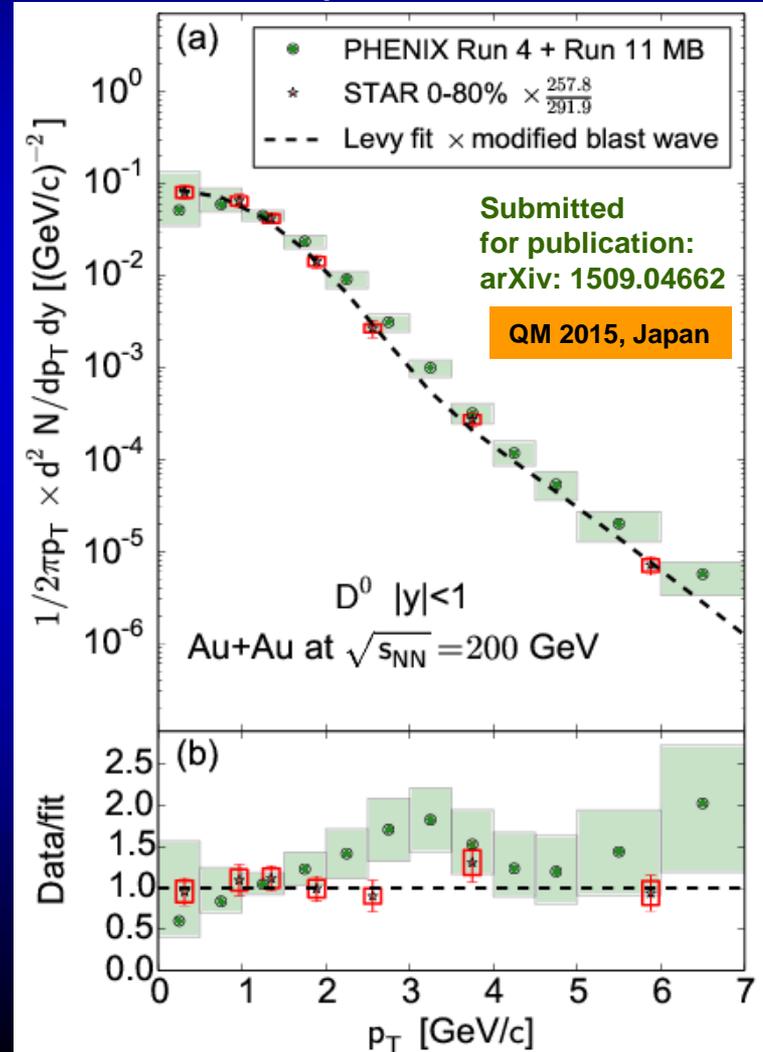
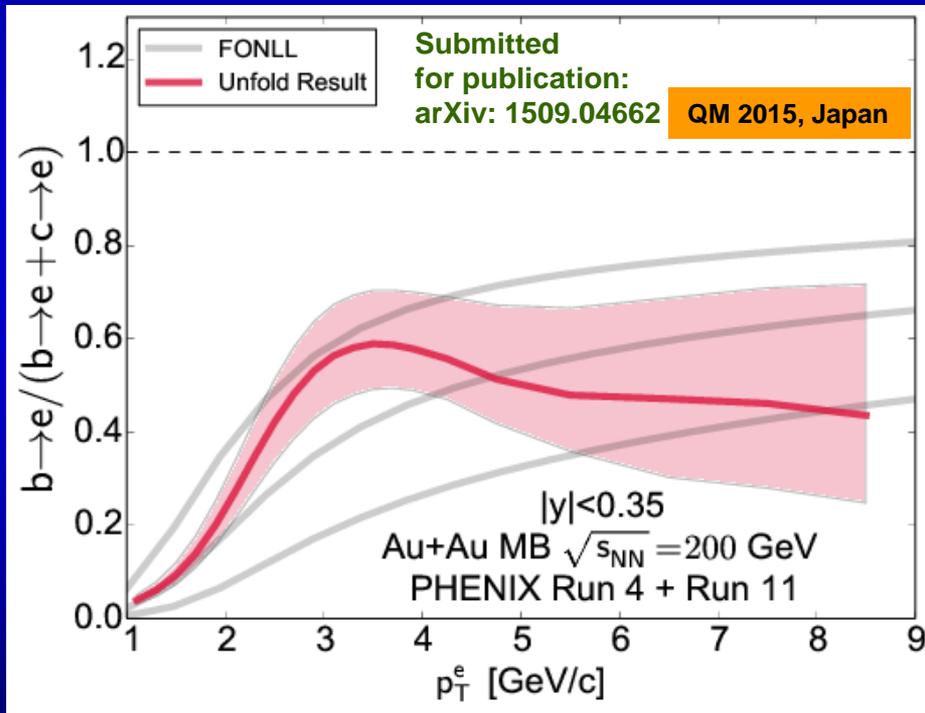
Résultats: Production de Beauté dans Au+Au

En utilisant new analysis method "Unfolding": using VTX Silicon Detector

Première mesure de la production de Beauté dans Au+Au

Charm: comparison to STAR

Fraction: b/e^{HF} et Comparison to FONLL

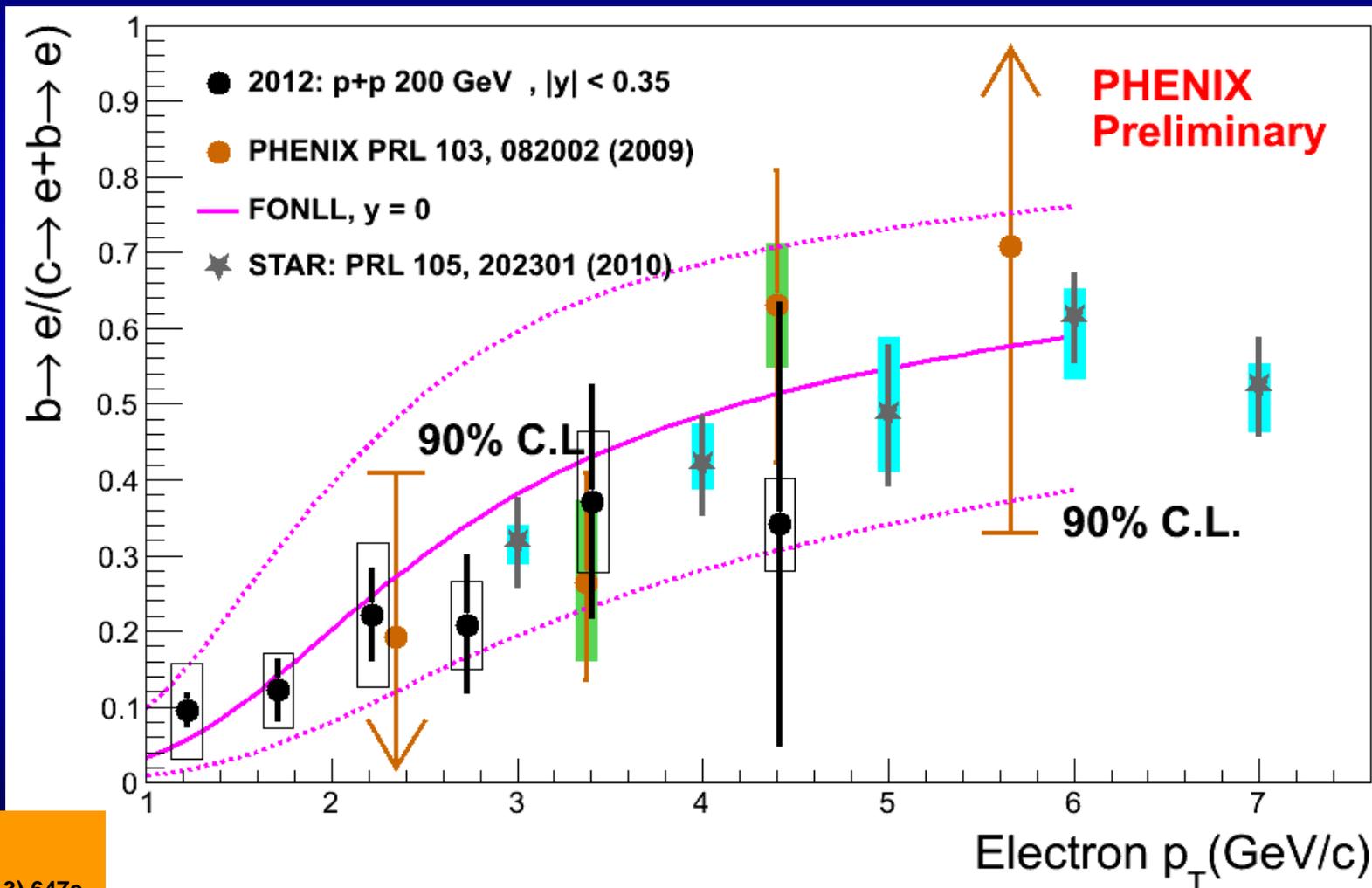


Résultats: Production de Beauté dans p+p

En utilisant le fit de la distribution du DCA

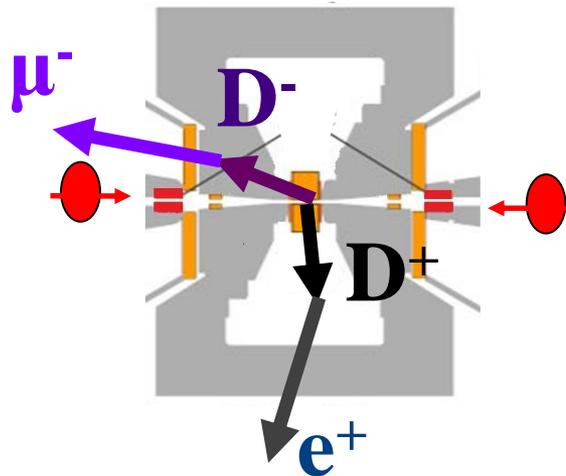
Première mesure directe de la production de Beauté in p+p

Mesures indirecte de STAR en accord avec les mesures de PHENIX

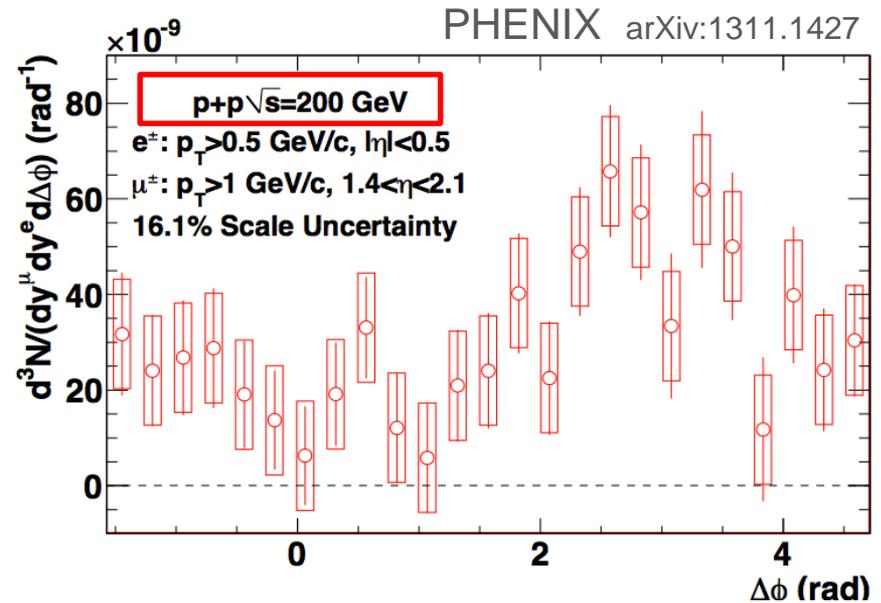


Rachid Nouicer exposé
Conférence QM 2012
Nucl. Phys. A904-905 (2013) 647c

Possible new physics: e^\pm vs μ^\pm de/correlation

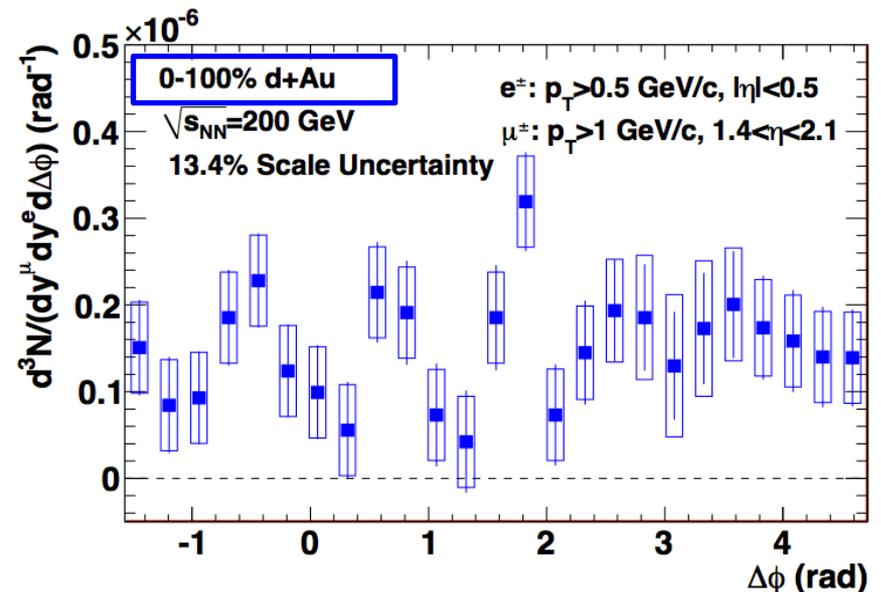


$p+p$



Back-to-back correlation of associated charm is decreased in d+Au; what is the site of any re-scattering?

d+Au



Conclusions

- Les complexes RHIC et LHC sont générateurs de grandes découvertes et représentent un des plus grand succès du programme de recherches de physique nucléaire
- Les comparaisons aux données RHIC et LHC de modèle hydrodynamique semblent favoriser des valeurs très petites de η/s . Ceci implique que la matière nucléaire créée est un **fluide presque parfait**
- Les mesures des particules de grande impulsion p_T montrent une suppression importante qui atteint un plateau indiquant que le **milieu est Opaque aux interactions fortes**
- Les résultats détaillés (petits systems: p+Pb, d+Au, $^3\text{He}+\text{Au}$) qui deviennent ainsi disponibles depuis quelques années questionnent des images bien établies: collectivité, corrélations à grandes différence de rapidité, suppression additionnelle du ψ' ,...
- L'étude détaillée des propriétés du milieu nucléaire dense créé au RHIC et au LHC va demander beaucoup de travail – les expériences de ces deux centres de recherche sont, dans cet objectif, non seulement complémentaires mais sont une source inépuisable de sujets d'interrogation et de recherches ...

Too many physics research topics for the students
in the heavy-ion physics program.

Thank you