J/Ψ production in p+p, d+Au and Au+Au collisions at $\sqrt{S_{NN}}$ = 200 GeV by the PHENIX experiment at RHIC

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Outline

- Motivation
- Experimental setup
- J/Ψ results
- Conclusion and perspectives

Introduction

- PHENIX, at RHIC, measures and studies the formation of a Quark-Gluon-Plasma in relativistic heavy ion collisions. About 500 scientists, 12 countries, 60 labs.
- Our group joined the PHENIX collaboration in 2001.
  Contributed to financing the electronics of one Muon spectrometer.
  Study J/Ψ production at forward rapidity in pp, pA and AA collisions.

Until 2007:

2 permanent scientists

1 PhD thesis (Yann Cobigo) completed in 2005

1 PhD thesis (Catherine Silvestre) started in Oct 2005.

From 2007:

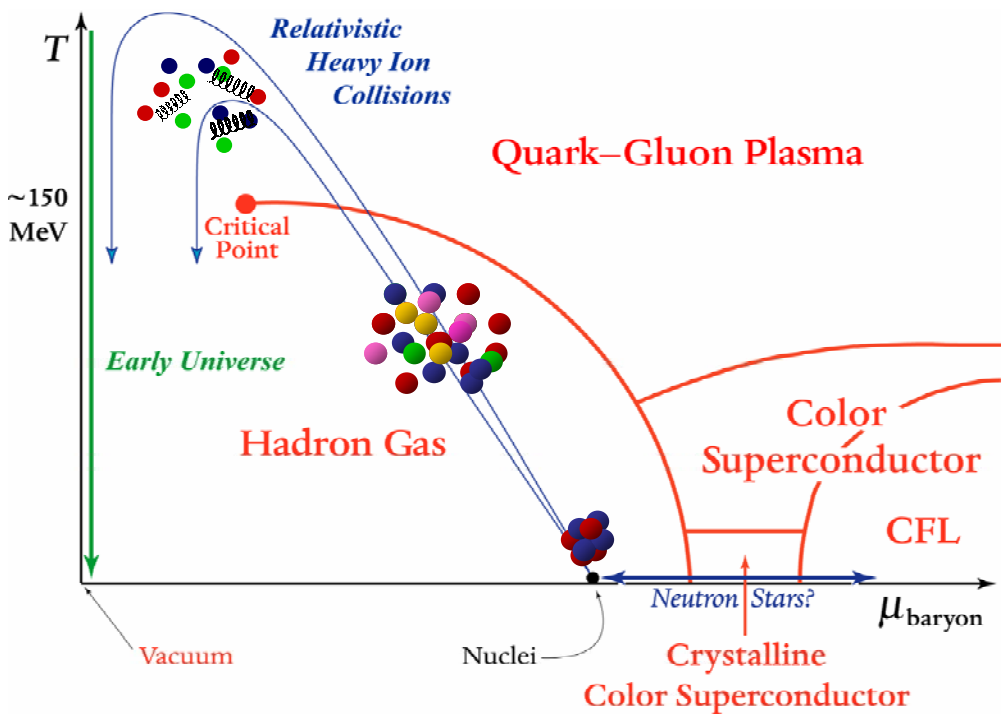
One permanent scientist

1 PhD student

The Quark-Gluon Plasma

The Quark-Gluon Plasma is a state where the quarks and gluons can evolve freely on distances larger than the nucleon size.

Predicted by lattice-QCD to be formed above T_c = 150 – 200 MeV.



Motivation (1)

J/Ψ is a heavy quarkonia (3.1GeV) formed of two charm quarks.

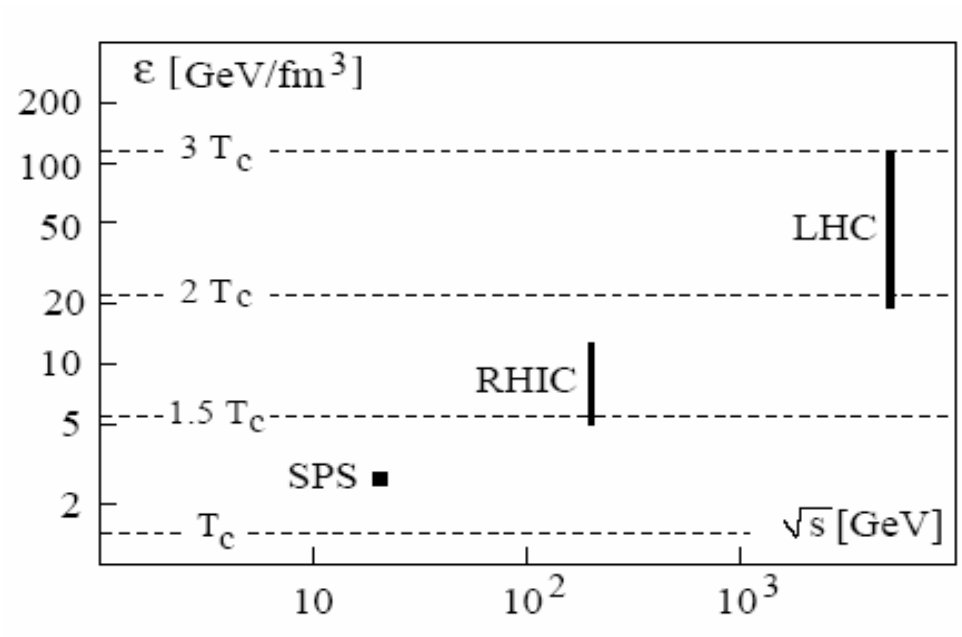
It is produced at the early stage of the collision via gluon-gluon fusion

Sensitive to the formation of a quark-gluon plasma via color screening.

Dissociation temperature:

for χ_c and Ψ': $T_d \sim 1.1\ T_c$

for J/Ψ : $T_d \sim 1.5$ to $2\ T_c$



Motivations (2)

But J/Ψ is also sensitive to **Cold Nuclear Matter** effects such as:

- Shadowing/anti-shadowing (modifications of the parton distribution functions)
- Parton energy loss
- Cronin (initial elastic parton scattering)
- normal nuclear absorption
- interaction with hadronic co-movers

Studying J/Ψ requires

- good p+p reference for baseline
- test experiment using pA (or dA) to control cold nuclear matter effects
- correct extrapolation from dA to AA
- measurement in AA collisions

Experimental Setup

BNL Facility

length: 3.83 km

Capable of colliding *any* nuclear species

Maximum energy:

500 GeV for p-p

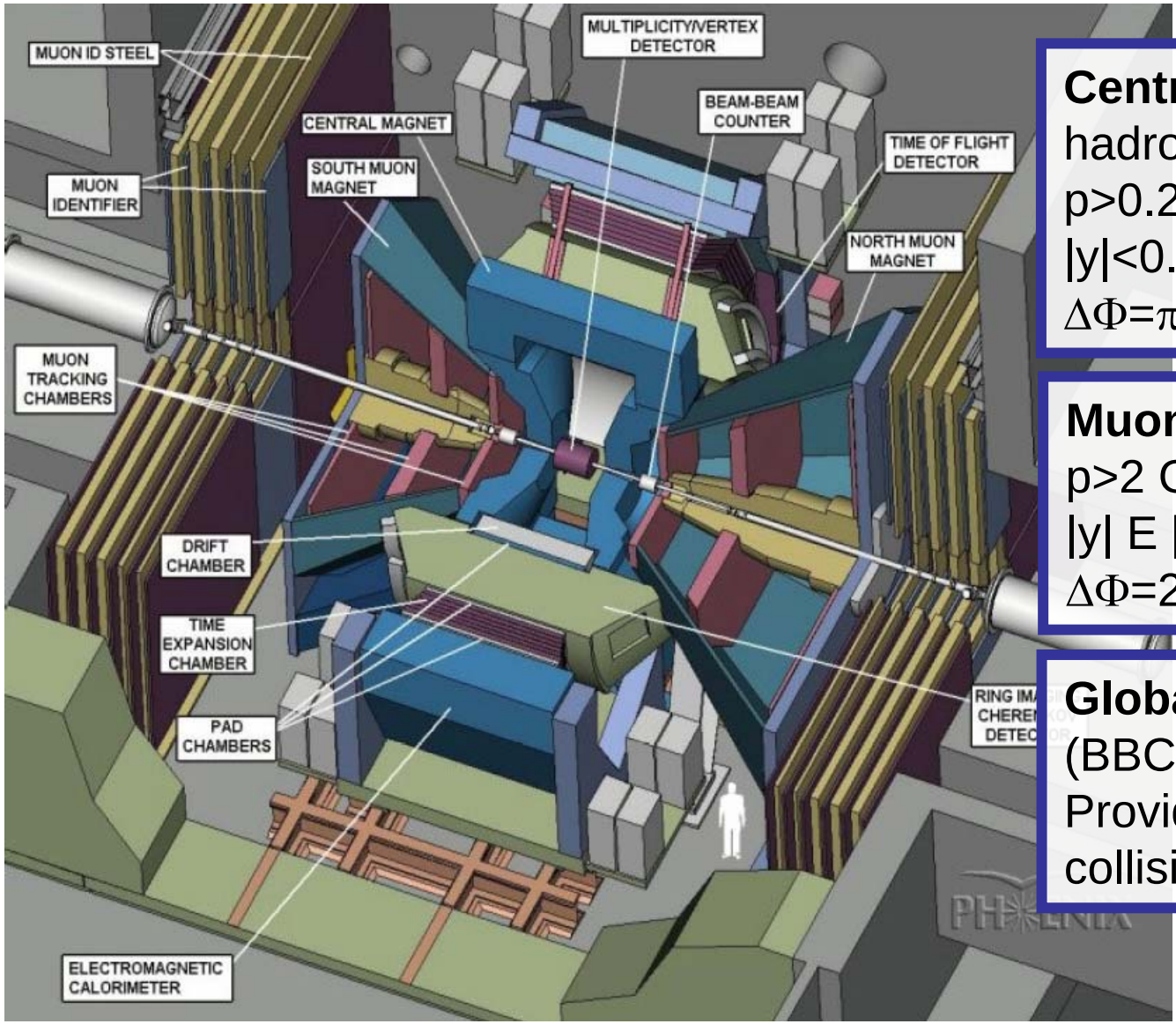
200 Gev for Au-Au

(per N-N collision)

protons: Linac → Booster → AGS → RHIC

ions: Tandems → Booster → AGS → RHIC

The PHENIX detector



Central arm
hadrons; photons; electrons
p>0.2 GeV/c
|y|<0.35
$\Delta\Phi=\pi$

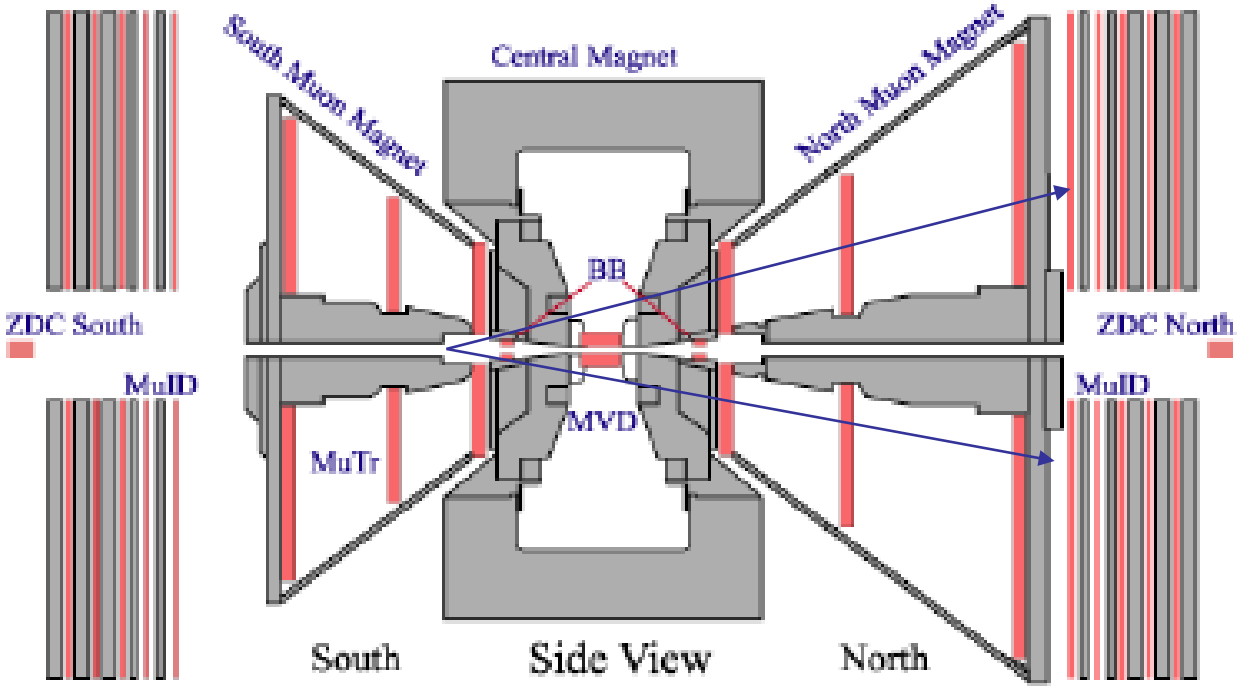
$J/\Psi \rightarrow e^+e^-$

Muon arms
p>2 GeV/c
|y| E [1.2,2.4]
$\Delta\Phi=2\pi$

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

Global detectors
(BBC, ZDC)
Provide vertex position and collision centrality

J/Ψ measurement in the muon spectrometers

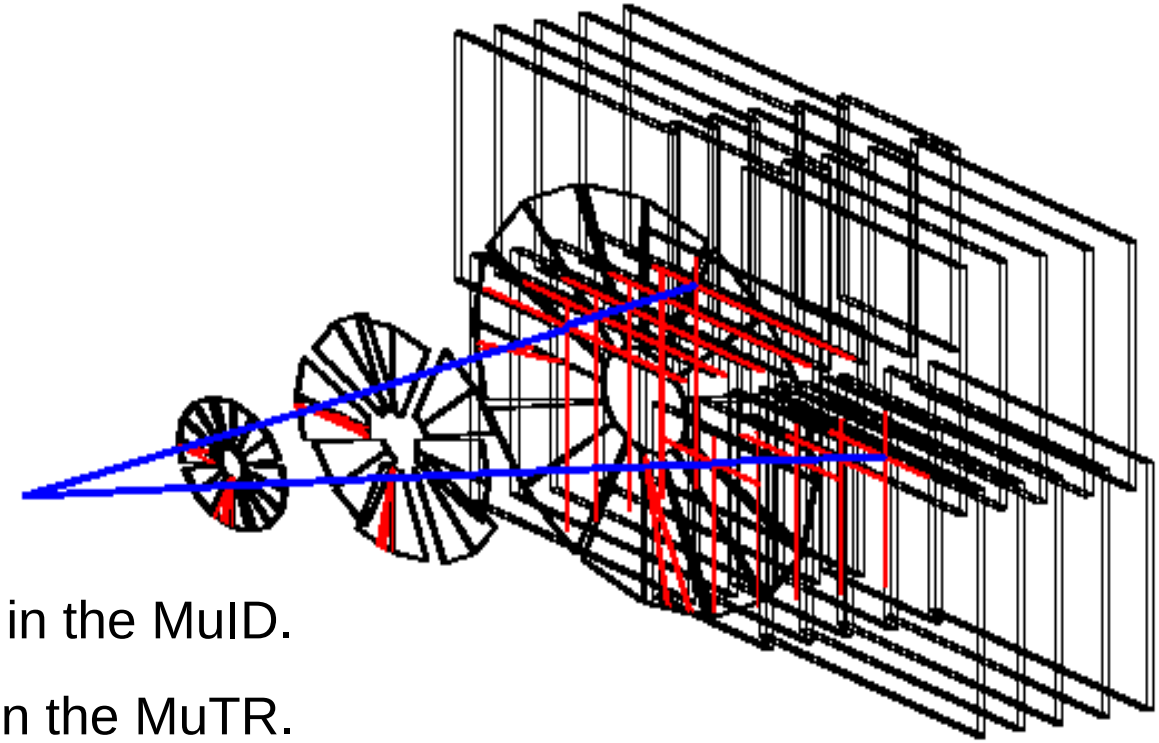


Front absorber to stop hadrons

MuTR: 3 stations of cathode strip chambers with radial magnetic field for momentum measurement

MuID: 5 detection planes (X and Y) and absorber, for muon selection and trigger

Tracking in the muon spectrometers



Find straight tracks in the MuID.

Find matching hits in the MuTR.

Extrapolate tracks to station 3, then 2, then 1.

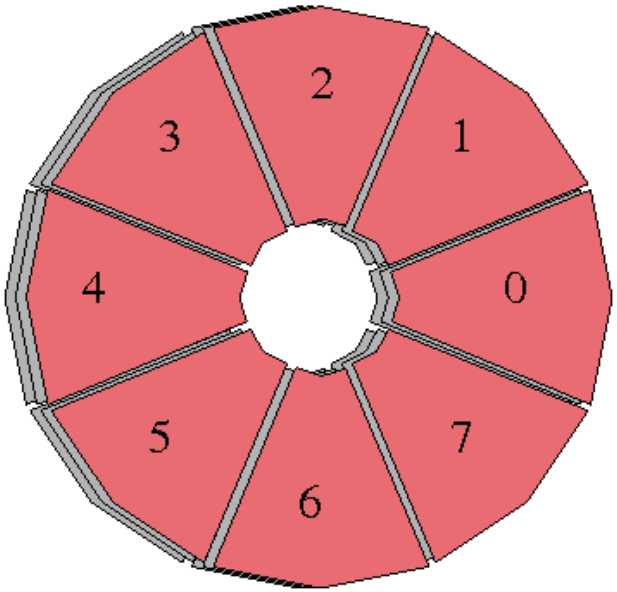
Fit using a Kalman filter.

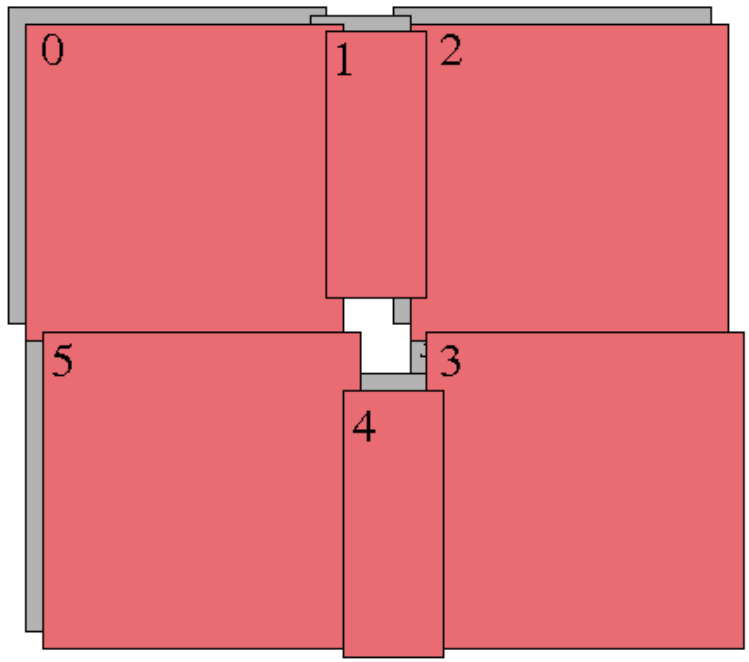
Extrapolate to vertex (through front absorber).

Fit pairs of tracks together with vertex and calculate invariant mass.

Detector alignment (1)

The alignment consists in describing offline the ***true*** position of the detectors





8 Octants (16 half-octants) for each MuTR cathode plane.

2x6 panels for each MuID plane.

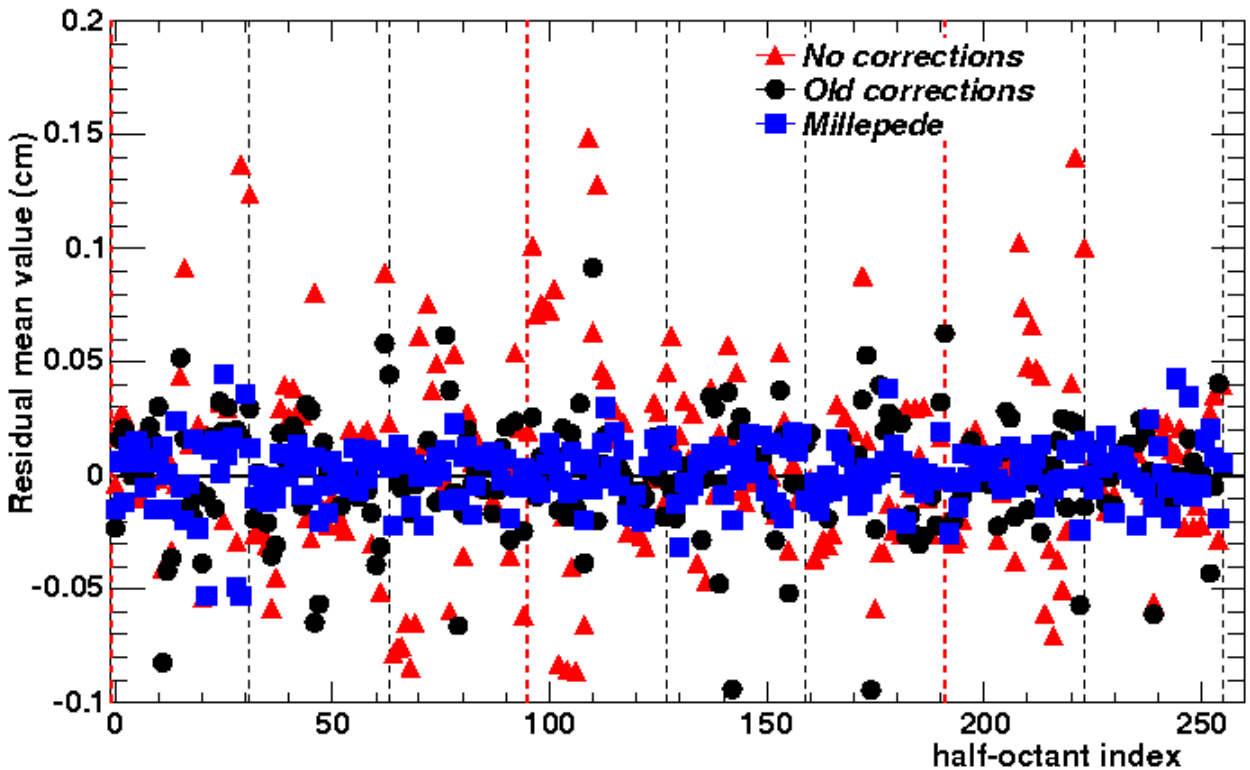
In total 328 independent detectors to align for each muon arm.

Detector alignment (2)

Alignment procedure based on the simultaneous minimization of the chi-square of many tracks with respect to both track parameters and alignment parameters. No iterations needed.

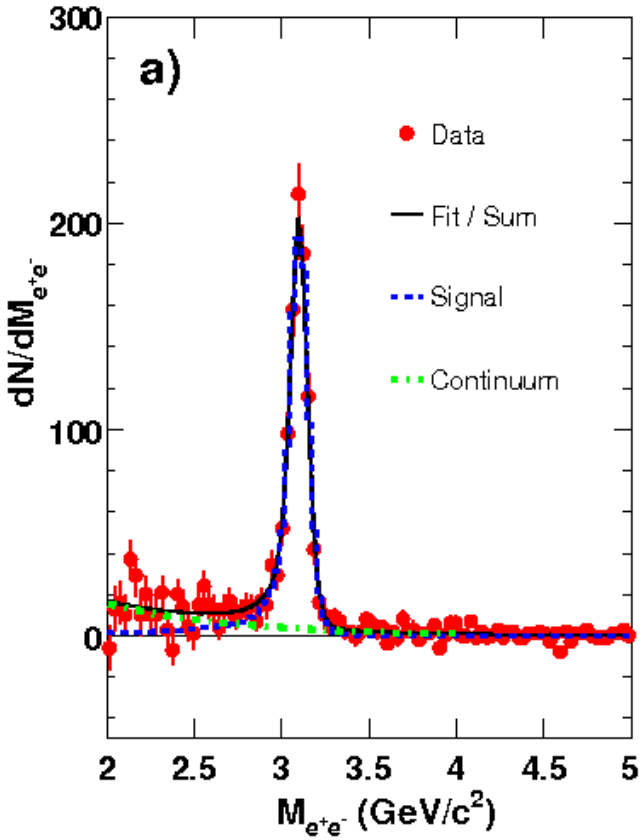
Method used at Desy and in Compass. Implemented for Alice muon arm.

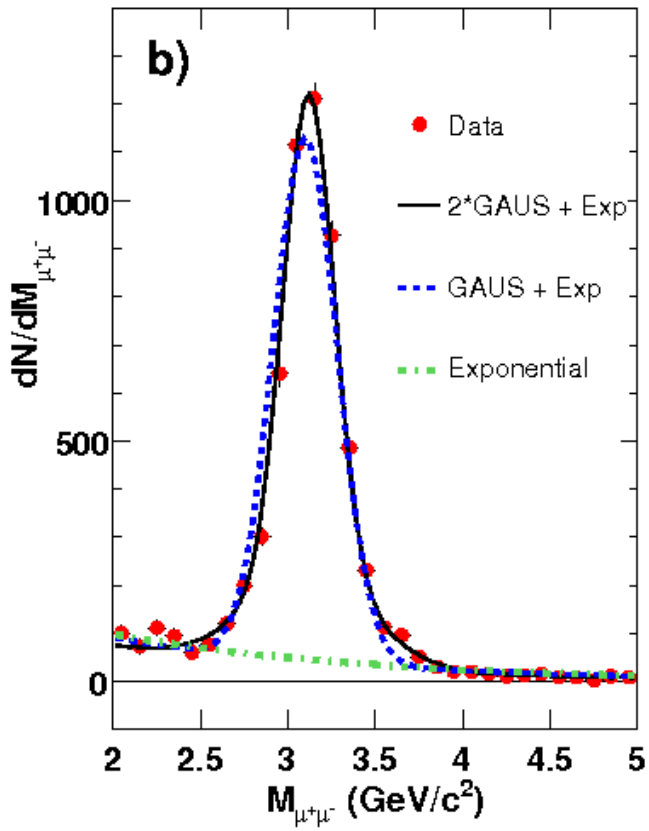
Mean value of the residual distribution in each MuTR detector



J/psi results

Di-lepton invariant mass (2005 p+p)





$J/\Psi \rightarrow e^+e^-$
resolution: ~35 MeV
counts: ~1500 J/psi

$J/\Psi \rightarrow \mu^+ \mu^-$
resolution: ~170 MeV
counts: ~8000 J/psi

J/Ψ yield and nuclear modification factor

J/Psi invariant production yield and cross-section:

$$BdN_{J/\Psi}/dy = \frac{N_{J/\Psi}}{\Delta y . A \varepsilon_{J/\Psi} . \varepsilon^{J/\Psi}_{BBC}} \frac{\varepsilon^{MB}_{BBC}}{N_{MB}}$$

$$Bd\sigma_{J/\Psi}/dy = BdN_{J/\Psi}/dy \, . \, \sigma_{pp}^{inel}$$

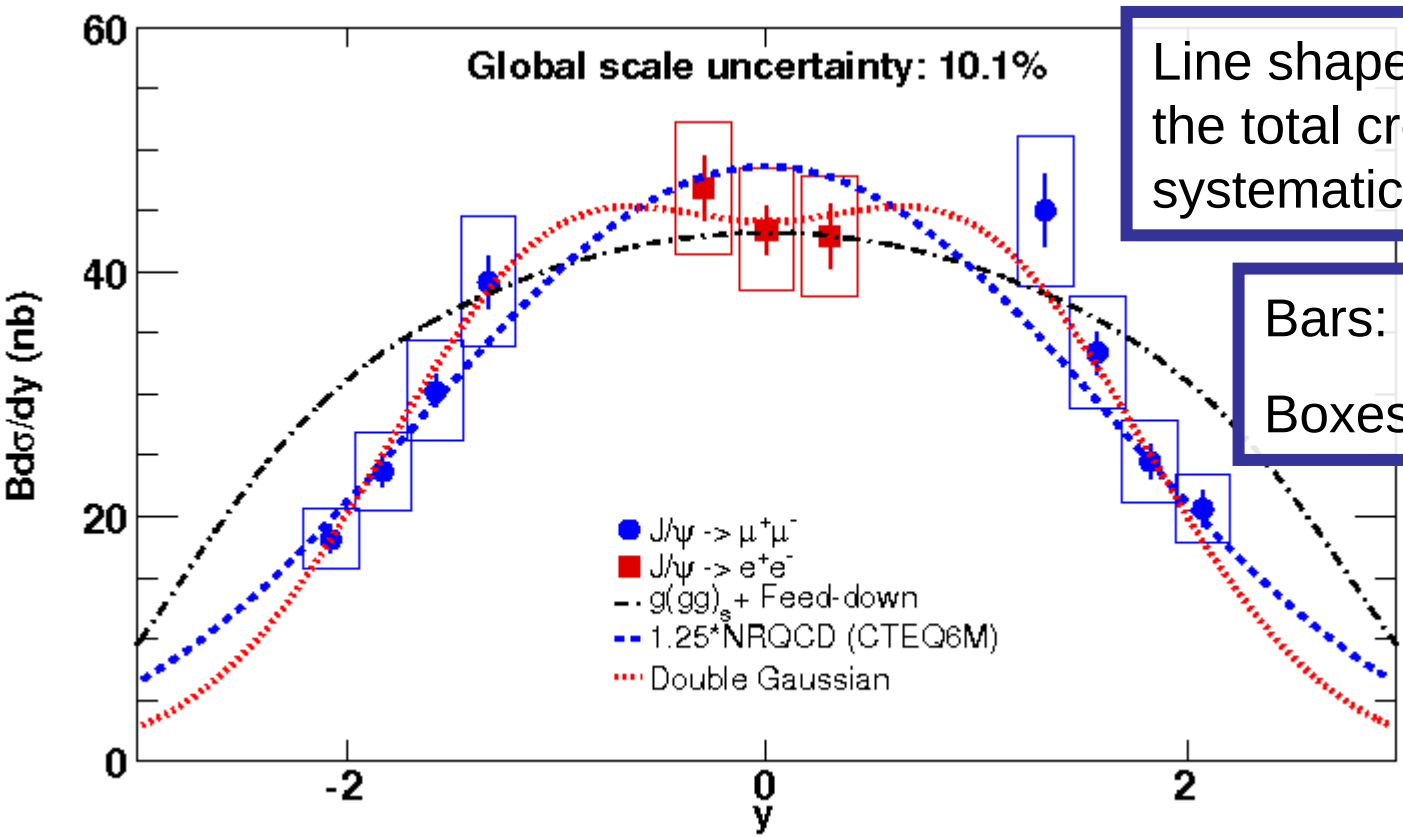
Nuclear modification factor:

$$R_{AA} = \frac{\text{yield in AA}}{N_{col} . \text{ yield in pp}}$$

N_{col} = number of equivalent nucleon-nucleon collisions

J/Ψ yield as a function of rapidity

Measurement from 2005 p+p (hep-ex/0611020)



Line shapes used to estimate the total cross-section and systematic error.

Bars: uncorrelated errors

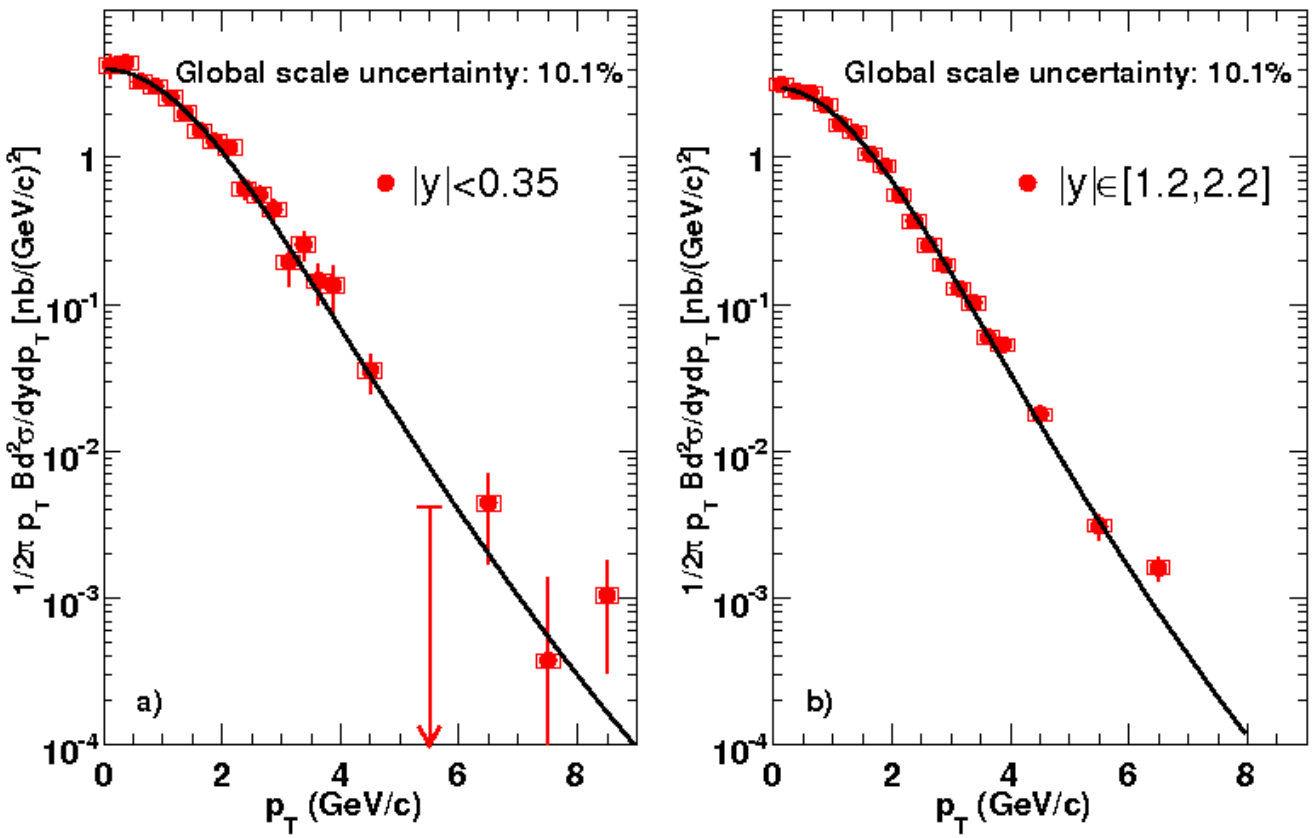
Boxes: correlated errors

Total cross-section:

$B.\sigma(pp \rightarrow J/\Psi) = 178 \pm 3 \pm 53 \pm 18$ nb

J/Ψ yield as a function of transverse momentum

Measurement from 2005 p+p (hep-ex/0611020)



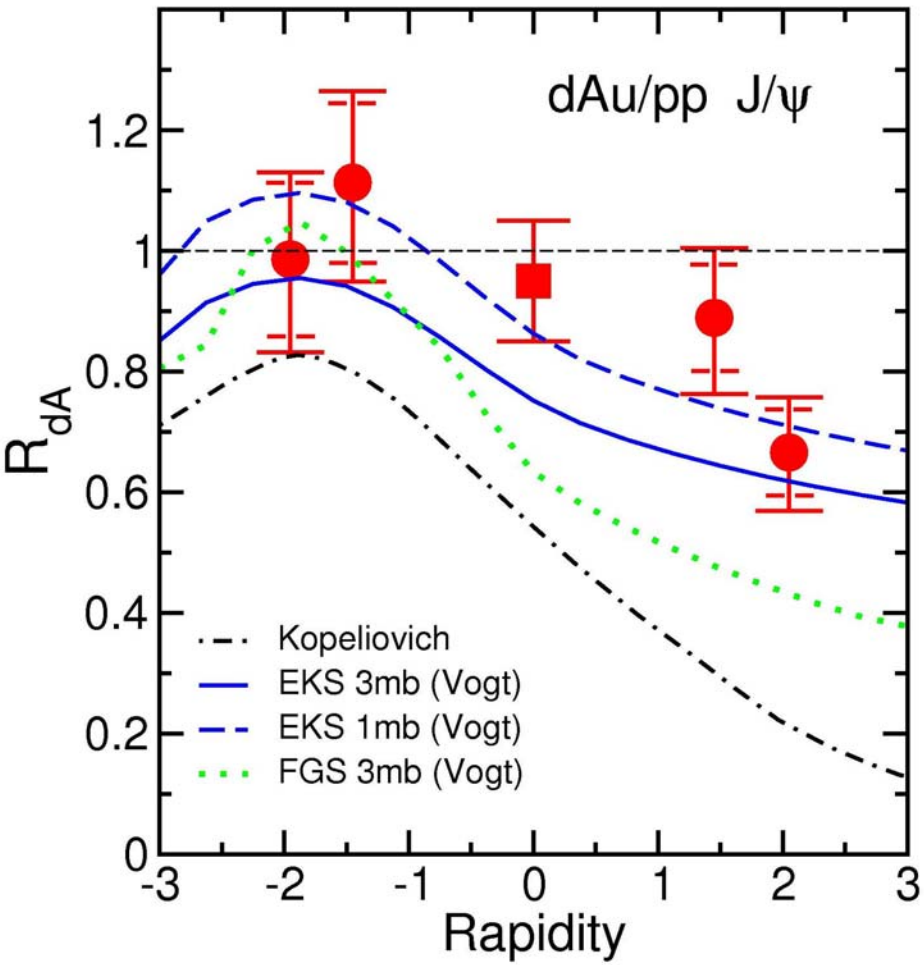
Mean square transverse momentum:

$J/\Psi \rightarrow e^+e^-$: $\langle p_T^2 \rangle = 4.25 \pm 0.24 \pm 0.14\ (GeV/c)^2$

$J/\Psi \rightarrow \mu^+ \mu^-$: $\langle p_T^2 \rangle = 3.57 \pm 0.06 \pm 0.15\ (GeV/c)^2$

R_{dAu} as a function of rapidity

Measurement from 2003 d+Au - PRL96 (2006) 012304



R_{dAu} vs rapidity

Compared to various parameterization for the nuclear shadowing + nuclear absorption

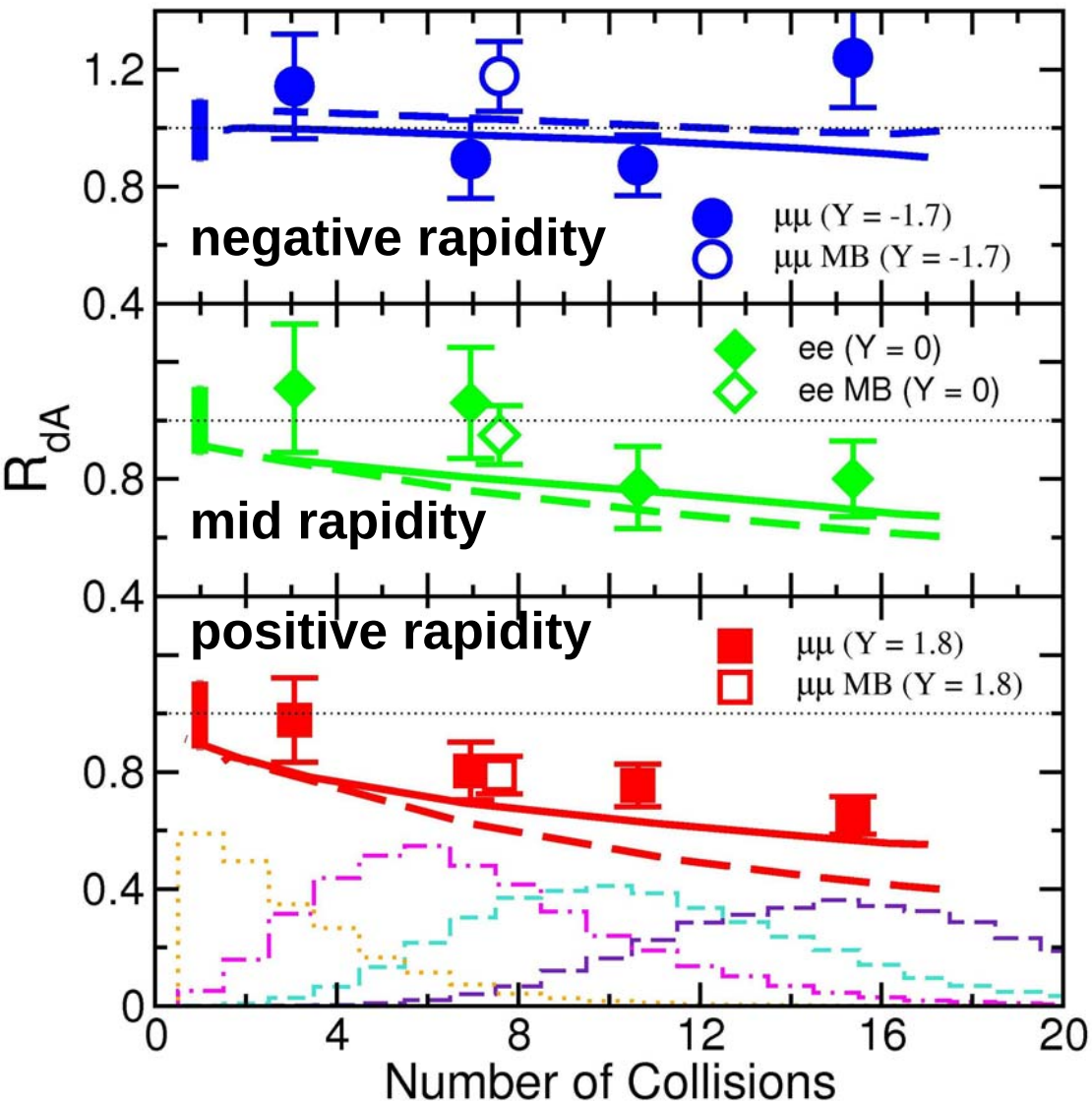
y<0 (deuteron side)
large x_{Au} (~0.09)
anti-shadowing region

y>0 (gold side)
small x_{Au} (~0.003)
shadowing region

Measurements reproduced using shadowing + nuclear absorption of 1 – 3mb

Centrality dependence

Measurement from 2003 d+Au - PRL96 (2006) 012304



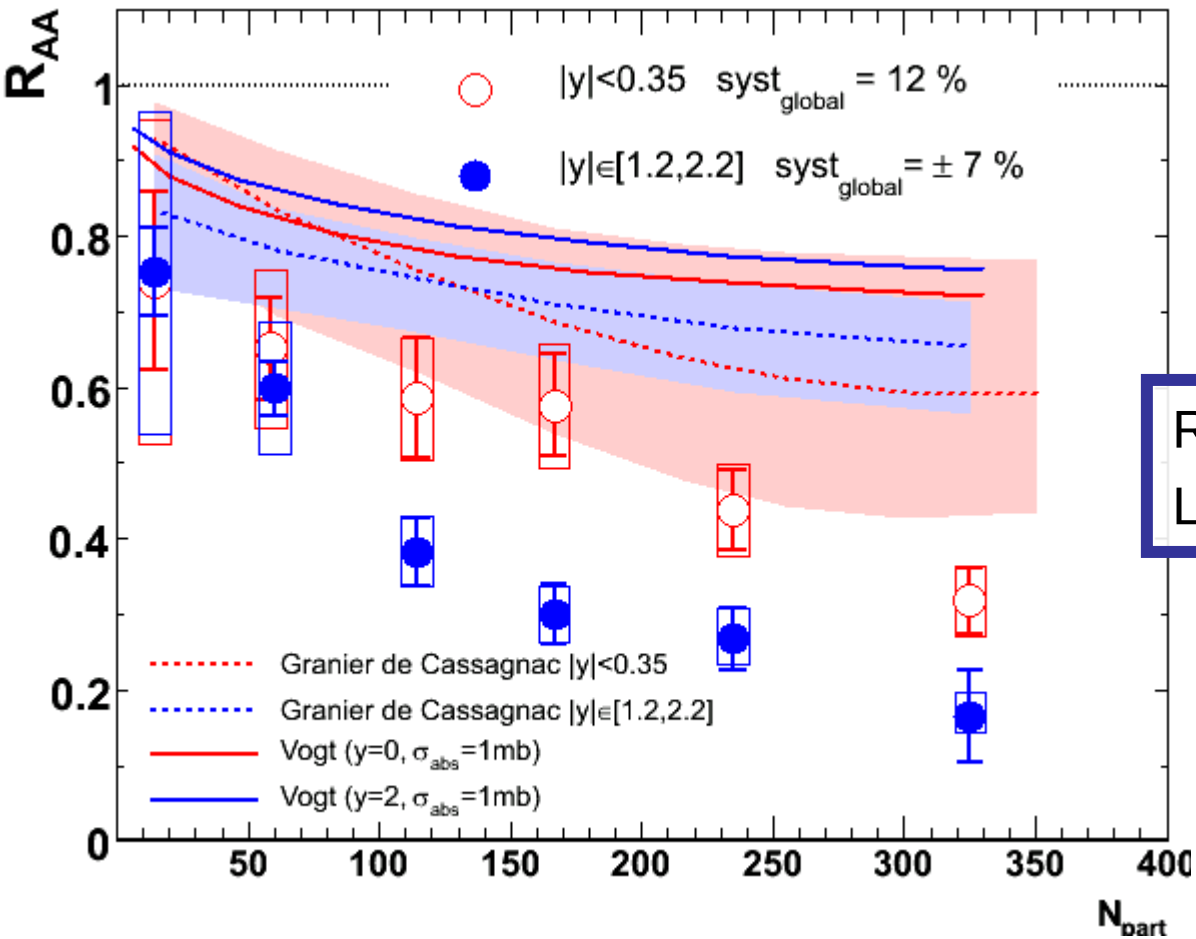
R_{dAu} vs centrality

Compared to various parameterization for the nuclear shadowing + nuclear absorption

Measurements reproduced using shadowing + nuclear absorption of 1 – 3mb

Nuclear modification factor in Au+Au

Measurement from 2004 Au+Au (nucl-ex/0611020)



Bars: uncorrelated errors

Boxes: correlated errors

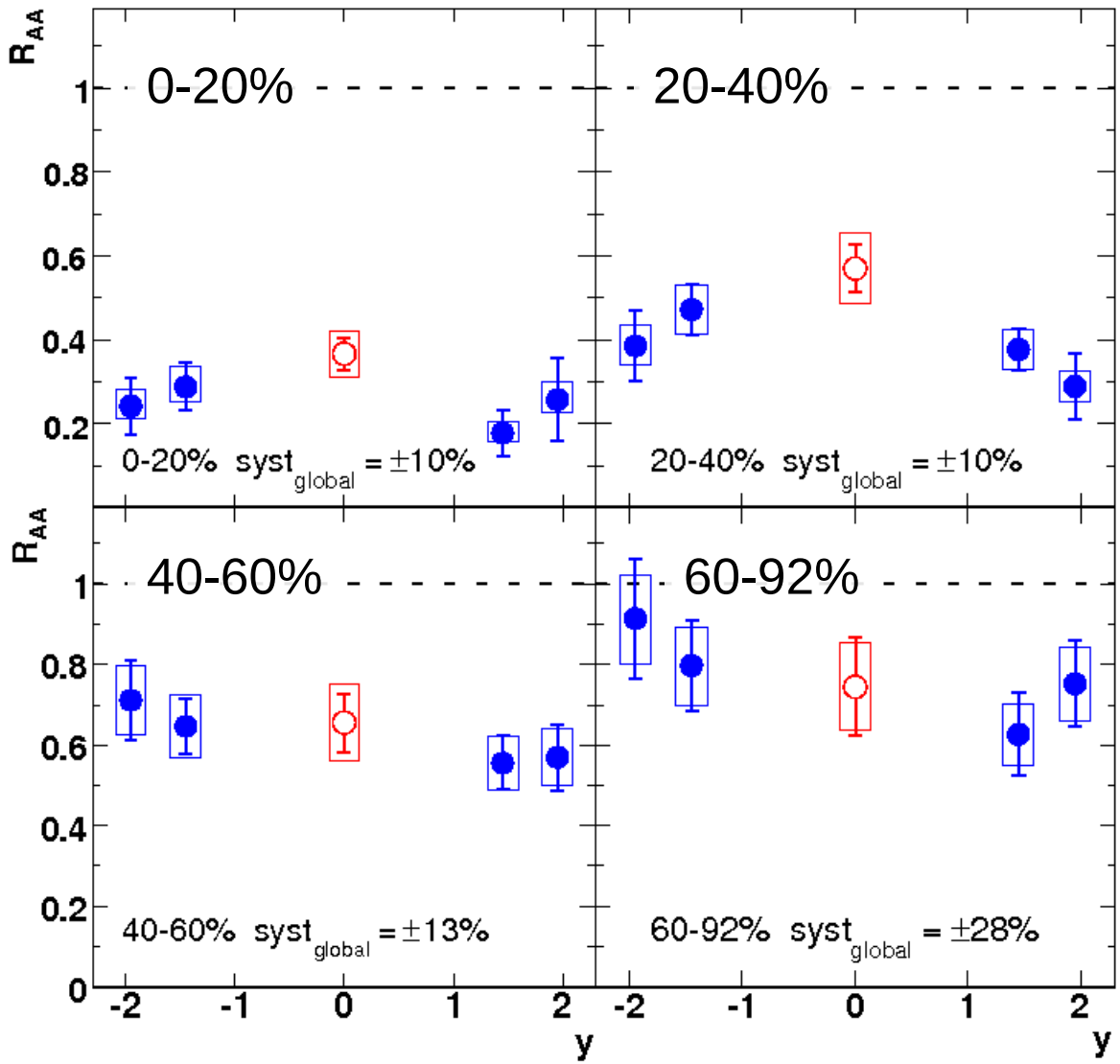
R_{AA} ~ 0.3 for central collisions

Larger suppression at |y|>1.2

First J/Ψ suppression observed in Au+Au collisions at 200 GeV

Nuclear modification factor vs rapidity in Au+Au

Measurement from 2004 Au+Au (nucl-ex/0611020)



Peripheral collisions:

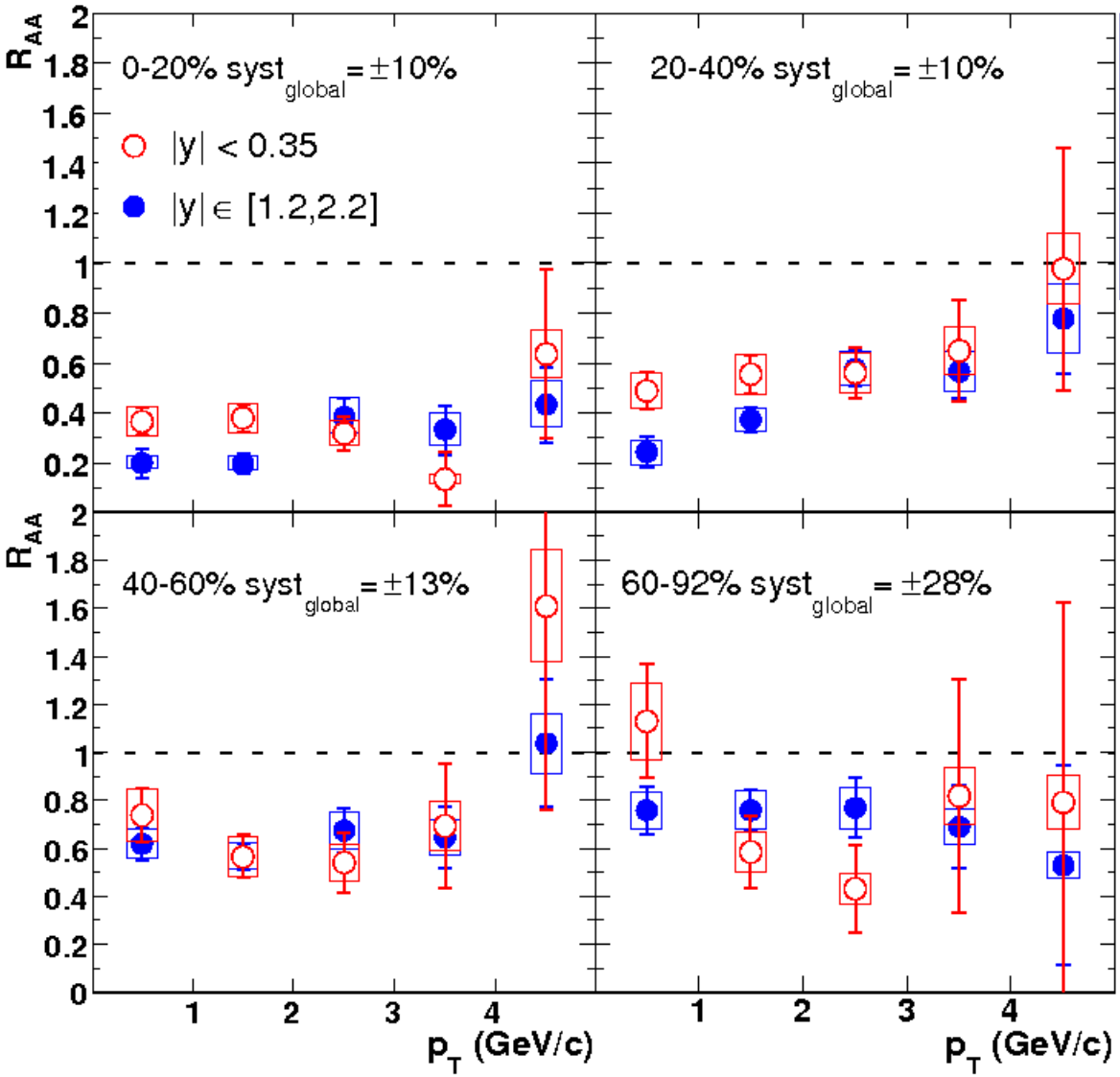
no modification of the rapidity distribution with respect to p+p collisions

Central collisions:

narrowing of the rapidity distribution

Nuclear modification factor vs p_T in Au+Au

Measurement from 2004 Au+Au (nucl-ex/0611020)



No significant change of the p_T distributions with respect to p+p, but error bars are large

Conclusion and perspective

Physics conclusion

- First observation of a J/Ψ suppression in Au+Au collisions at 200 GeV
- Solid p+p reference from 2005 data
- Too few statistics in d+Au collisions to fully quantify cold nuclear matter effects

Models to describe the data:

- QGP models: thermal gluons, sequential suppression
- Suppression + charm quarks recombination (relies on open charm production cross-section)
- Interaction with hadronic/partonic co-movers (relies on co-movers density)

So far none of these models can simultaneously describe the data with respect to N_{part}, p_T and y, at both mid and forward rapidity.

Summary of the group responsibilities

- Maintenance of Muon Arms electronics and detector expertise during data taking
- Development and maintenance of Muon Tracker pattern recognition software.
- Development of a global alignment procedure for the muon spectrometers.
- Leading role in the Run4 Au+Au and Run5 p+p J/Ψ analysis. Significant contribution to the Run5 Cu+Cu J/Ψ analysis.
- Since begin 2007 coordination of all PHENIX simulation projects.

Perspectives

- **2007**
  Au+Au collisions at 200GeV. Expect 4 times more statistics than for 2004. More precise results; larger p_T range; J/Ψ elliptic flow.

- **2008 or 2009**
  d+Au run with higher statistics (hopefully more than x10).
  Mandatory to quantify the *anomalous* J/Ψ suppression in Au+Au

- **2010 and later**
  RHIC luminosity upgrade, PHENIX detector upgrade.
  - direct measurement of open charm
  - measurement of Ψ', χ_c, Υ

Backup

Motivation (1)

J/Ψ is a heavy quarkonia formed of two charm quarks.

It is produced at the early stage of the collision via gluon fusion

~60 % direct J/Ψ

~30 % via $\chi_c \rightarrow$ J/Ψ + x

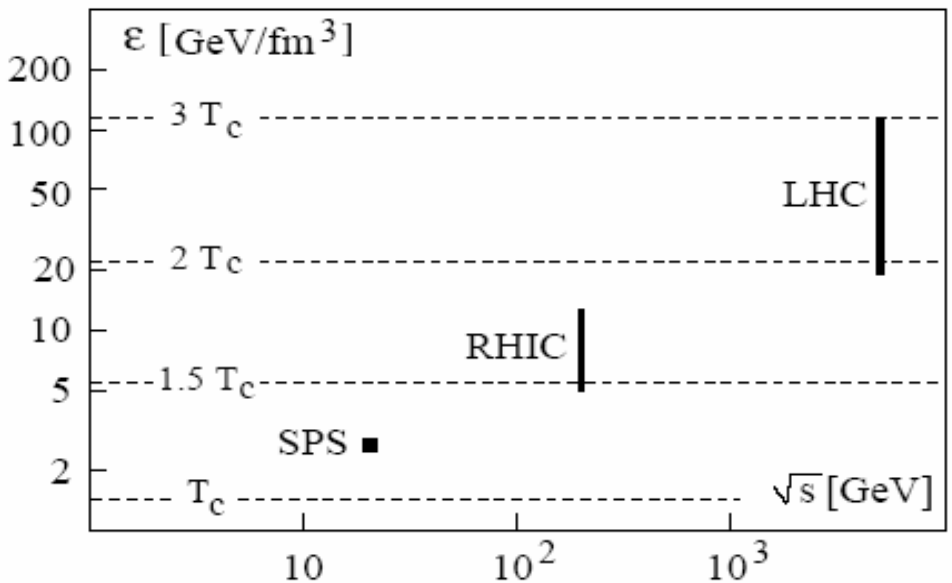
~10 % via Ψ'$\rightarrow$ J/Ψ + x

Sensitive to the formation of a quark gluon plasma via color screening.

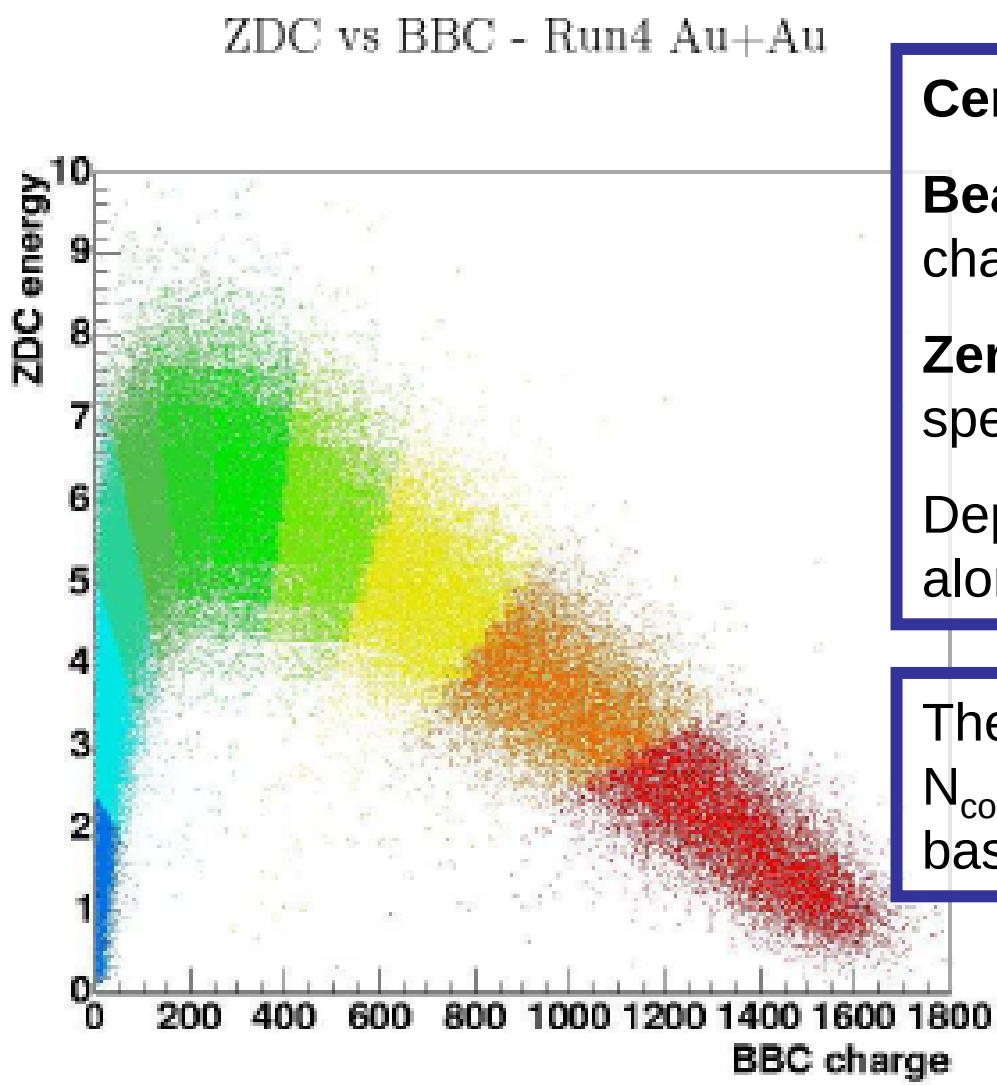
Dissociation temperature:

for χ_c and Ψ': T_d ~ 1.1 T_c

for J/Ψ : T_d ~ 1.5 to 2 T_c



Collision centrality determination



Centrality measurement using:

Beam beam counters to count charged particles at forward rapidity

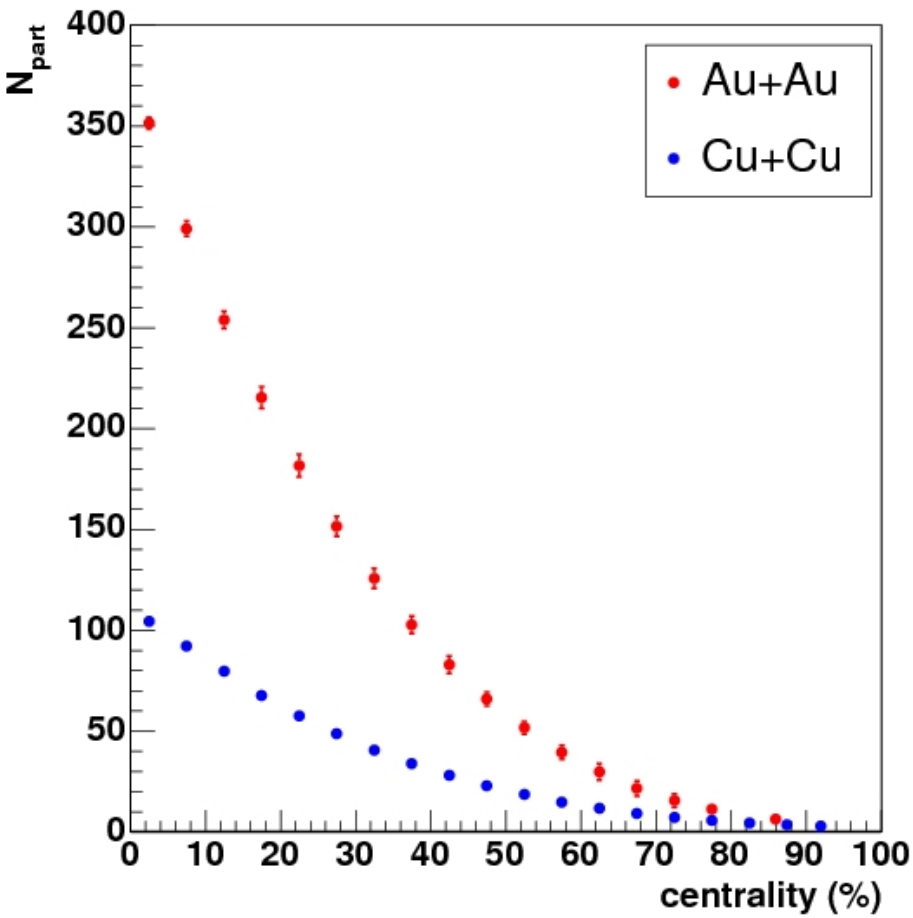
Zero degree calorimeters to count spectator neutrons

Depending on the run either BBC alone or BBC + ZDC are used

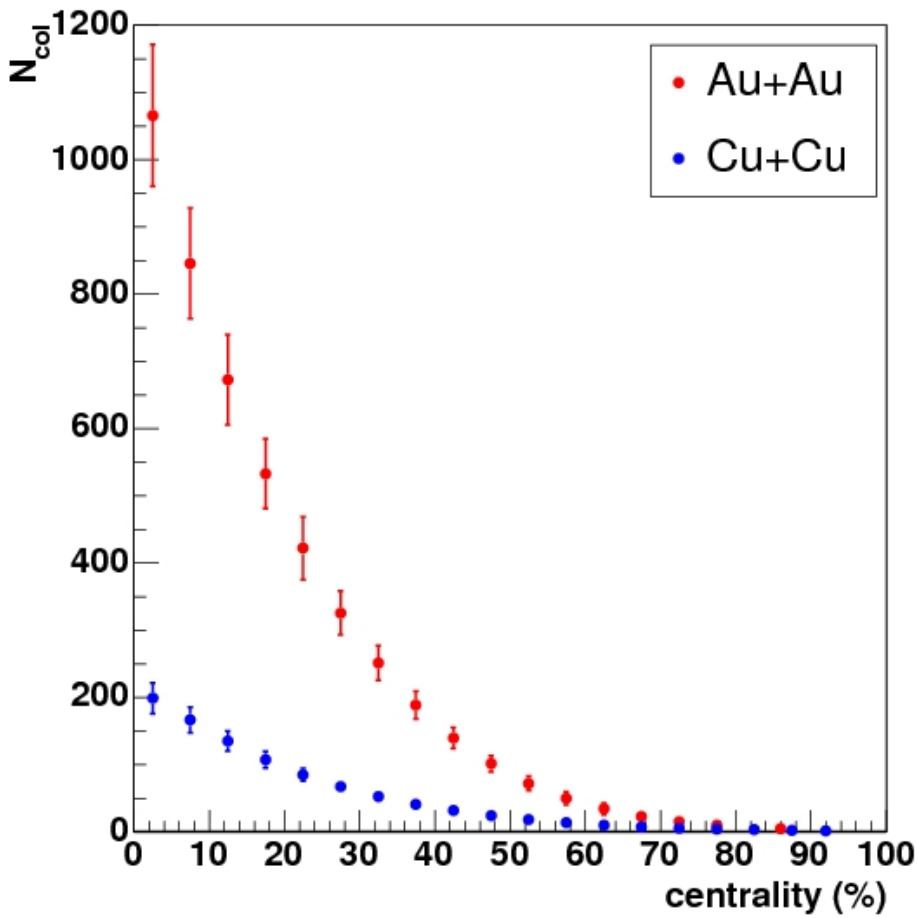
The centrality is mapped into N_{part}, N_{col}, b, etc. using a simulation based on a **Glauber** model.

Collision centrality (2)

N_{part} vs centrality (5% bins)

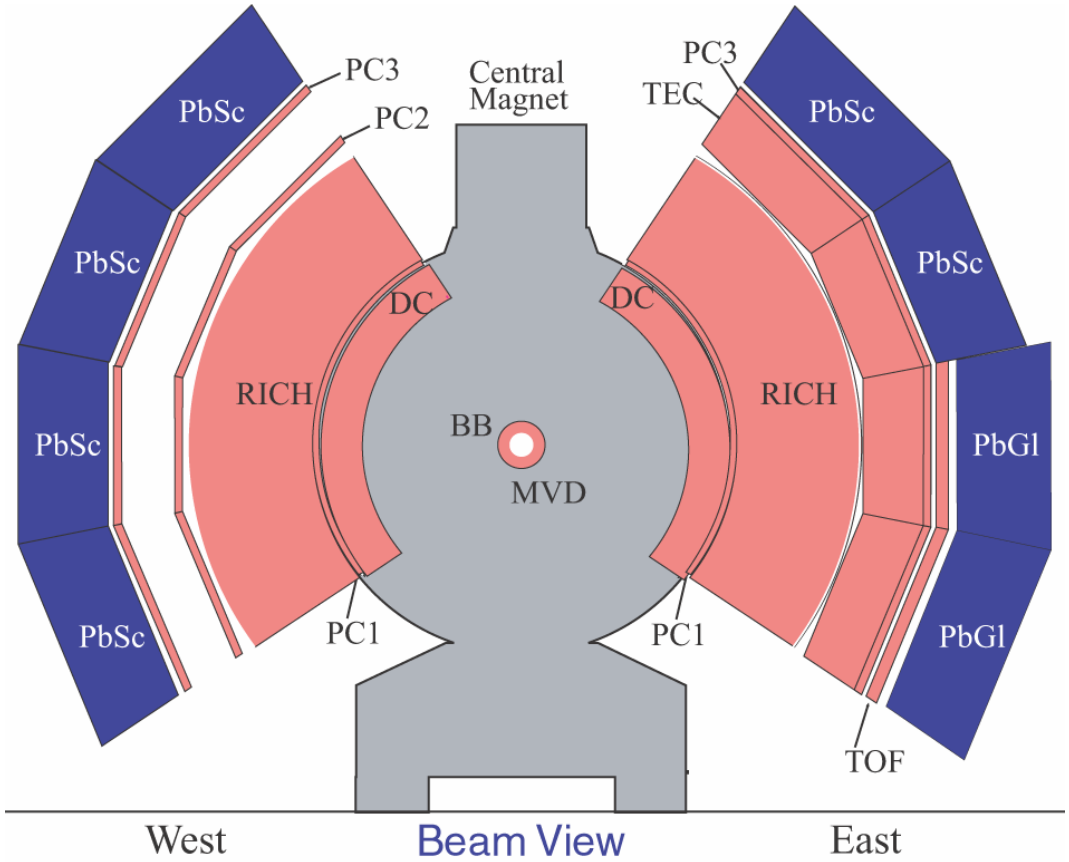


N_{col} vs centrality (5% bins)



J/Ψ measurement at mid rapidity

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



Drift chambers for momentum measurement

RICH and EMCal for electron identification and trigger (level1 and offline level2)

Collision species and energy

Run	Year	Species	Energy (GeV)	# J/Ψ (ee+μμ)
01	2000	Au+Au	130	0
02	2001/2002	Au+Au p+p	200 200	13 + 0 46 + 66
03	2002/2003	d+Au p+p	200 200	360 + 1660 130 + 450
04	2003/2004	Au+Au Au+Au	200 62	~ 1000 + 5000 13 + 0
05	2004/2005	Cu+Cu Cu+Cu Cu+Cu p+p	200 62 22.5 200	~ 1000 + 10000 10 + 200 ~ 1500 + 10000
06	2006	p+p p+p p+p	200 62 500	~ 3000 + 30000

Extrapolation from dA to AA collisions

Different approaches:

1. A model of shadowing and nuclear absorption as used in previous slides (here EKS shadowing and 1 to 3mb nuclear absorption) extrapolated to AA (Ramona Vogt, nucl-th/0507027)

2. A direct extrapolation of measured R_{dA} to AA using a simulation based on Glauber model
(R. Granier de Cassagnac, hep-ph/0701222)

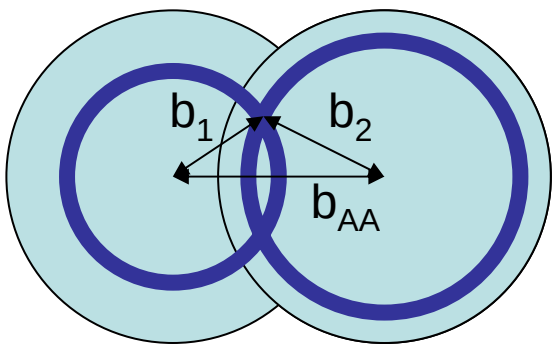
Direct extrapolation of measured R_{dA} to AA

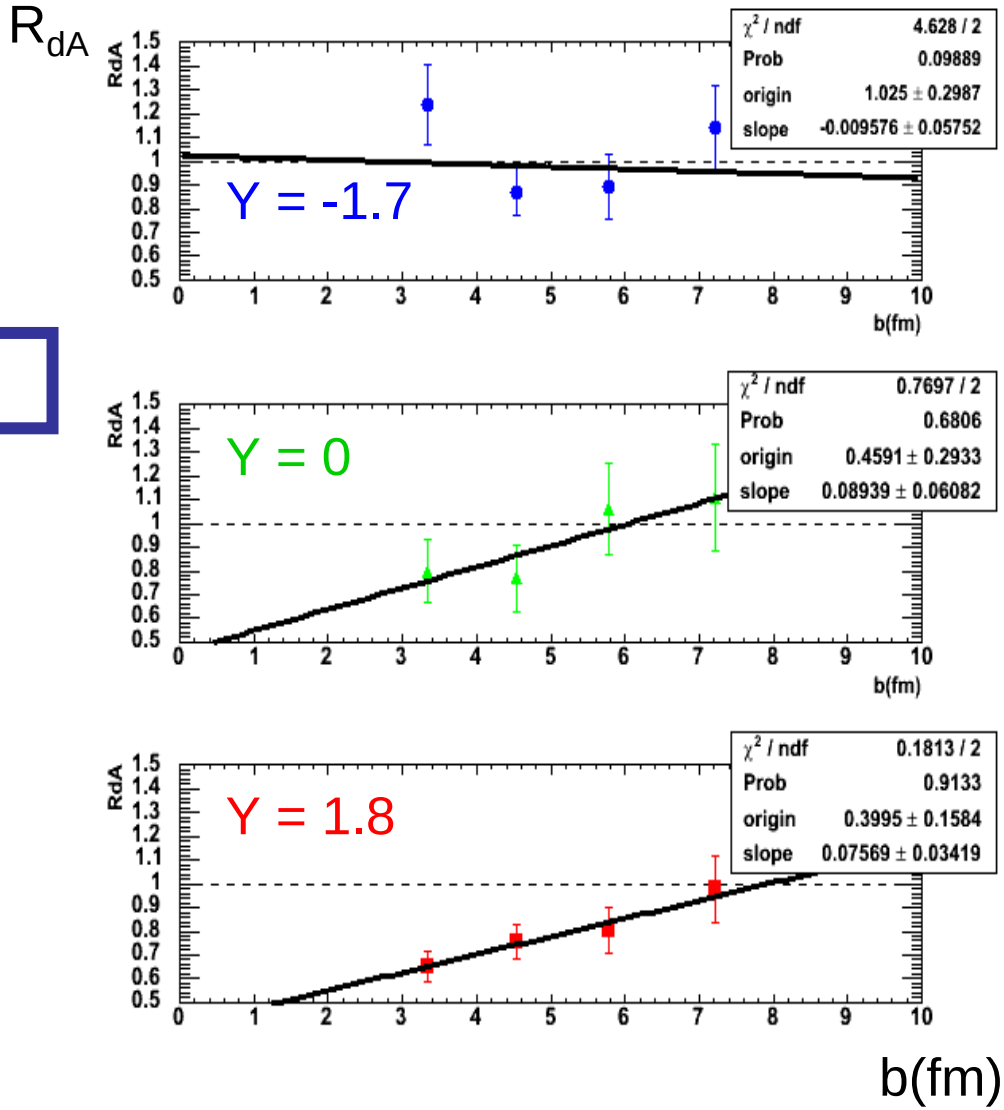
Use a simple fit of RdA vs b

Plug $R_{dA}(b)$ into an AA Glauber simulation:

$$R_{AA}(y,b_{AA}) = \Sigma[R_{da}(-y,b_1).R_{dA}(y,b_2)]$$

where b_1 and b_2 are determined for each nucleon-nucleon collision in the simulation at a given b_{AA}.





Heavy flavors at RHIC II and LHC

	RHIC II	LHC
Heavy flavor yields/year	similar	
QGP temperature	$2T_c$	$4T_c$
QGP lifetime	~7fm/c	~17fm/c
N_{cc}/collision	10	115
N_{bb}/collision	0.05	5
J/psi mechanism	suppression + coalescence	coalescence
Upsilon mechanism	suppression	suppression + coalescence
Open b		easier $\Leftarrow$ high cross section
Open c		harder $\Leftarrow$ high feed down from b