Prospects for d-Au physics with the PHENIX experiment at RHIC

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Why d-A?
- Understand Effects of Nuclear Medium

Gluon and quark shadowing - reduction in cross section, dependence on Bjorken x (depletion of gluons and quarks at small momentum fraction (x))

Absorption - reduction in cross section, may be larger at small x_F

Energy loss, jet quenching, multiple scattering (Cronin effect) - modification of p_T spectra

Must understand above contributions before you can determine whether A-A measurements of suppression (or enhancement) indicate quark gluon plasma formation or could be explained with cold nuclear matter effects.

Measurement of d-A (or p-A) particle production over large kinematic ranges necessary to try to separate and understand all these contributions.

Suppression of high p_T hadrons

Nuclear modification factor:

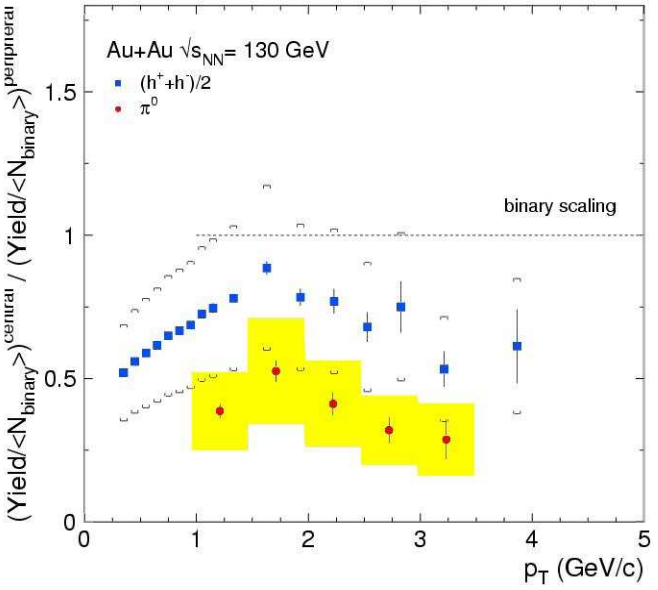
$$R_{AB} = \frac{1}{N_{binary}} \left(\frac{d^2\sigma_{AB}}{d^2 y dp_t^2} \right) / \left(\frac{d^2\sigma_{pp}}{d^2 y dp_t^2} \right)$$

At high p_T PHENIX Coll. PRL88:022301 (2002)

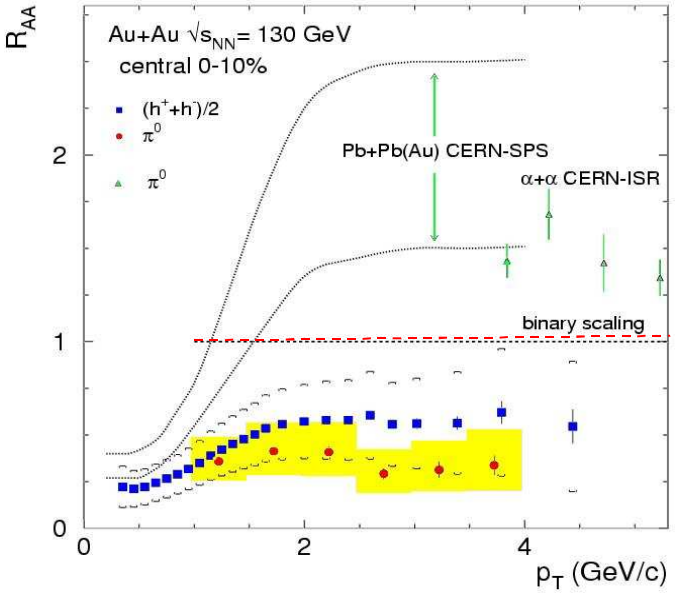
- R_{AB} = 1 : incoherent point-like scaling
- R_{AB} >1 : Cronin effect (SPS)
- R_{AB} ~ 0.4 - 0.6 @ RHIC !

Deficit of high-p_T particles relative to expected N_{coll} scaling:

Ratio AuAu(cent.) / AuAu(periph)



Ratio AuAu / *pp* ref.

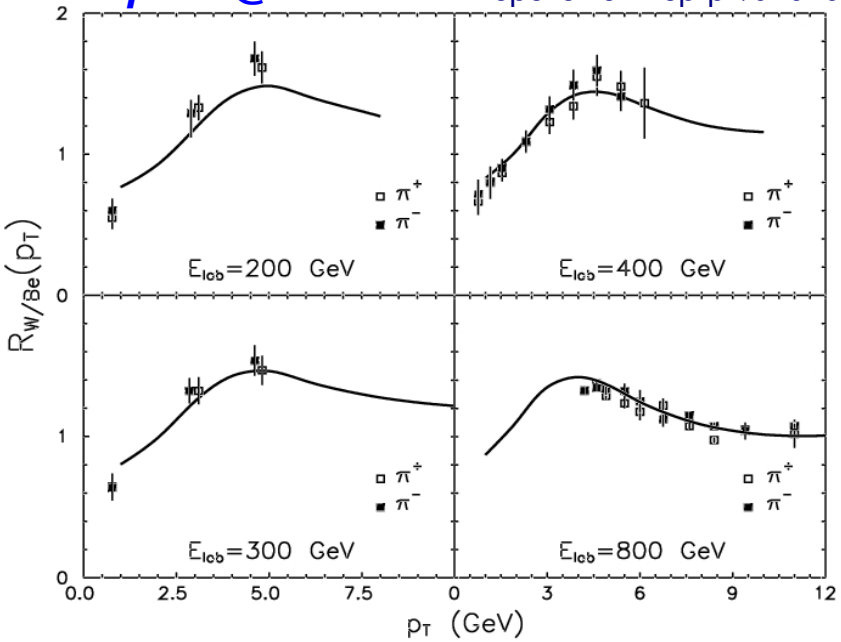


Cronin Effect

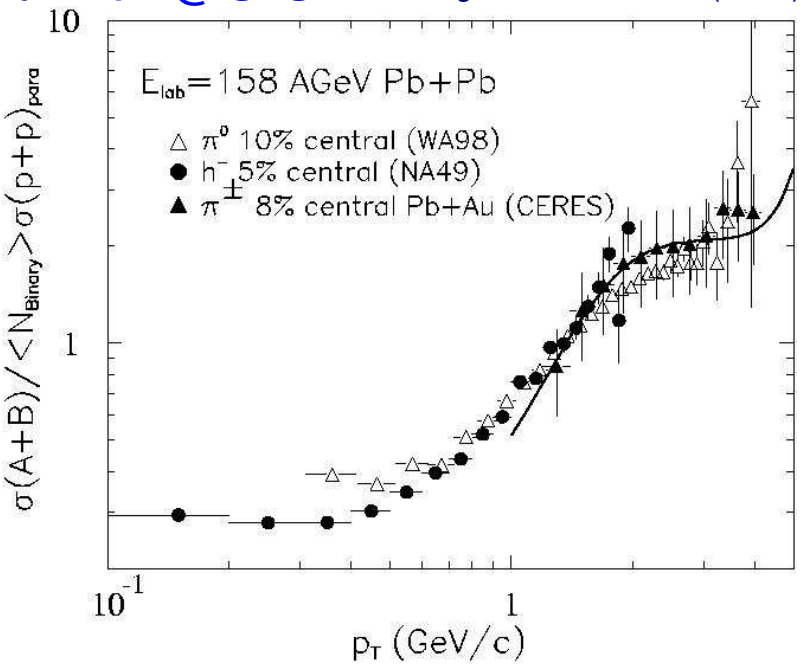
Cronin enhancement: multiple interactions in nuclear matter leading to increased high-p_T production in pA, AA collisions:

$R_{AB} > 1$ (for $p_T > 2$ GeV/c)

***p* +A @ FNAL** B.Z Kopeliovich hep-ph/0201010



A+A @ SPS X.N.Wang PRC64:034901 (2001)



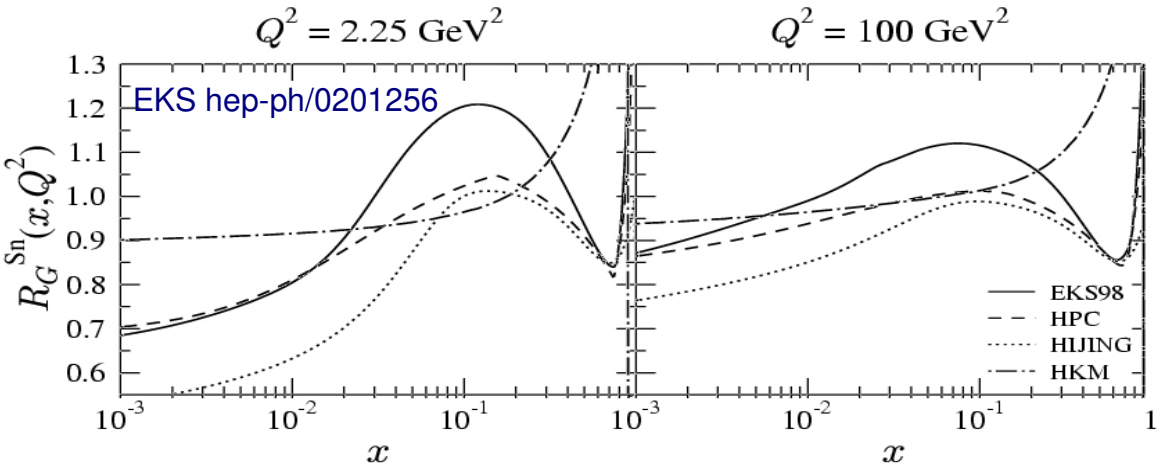
- At RHIC : $R_{AB} \sim 0.5$ (for $p_T > 2$ GeV/c)

No p-A expectation is available.

Gluon Shadowing

$R(x,Q^2,A) \equiv f_i^A(x,Q^2) / [A\, f_i^N(x,Q^2)] < 1$ →

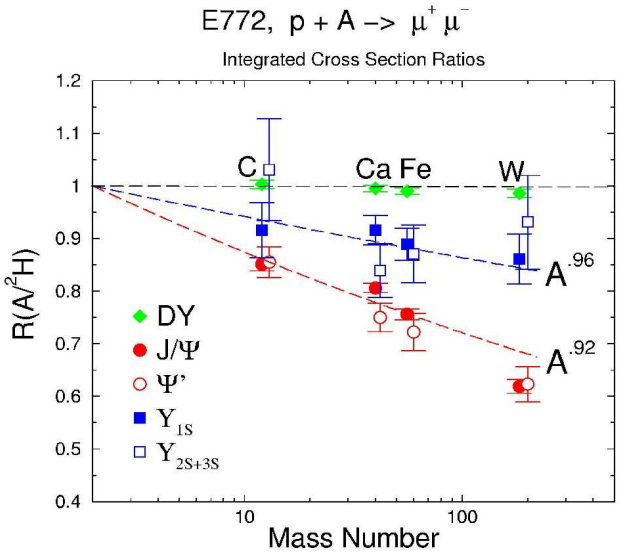
Shadowing (partons recombining)

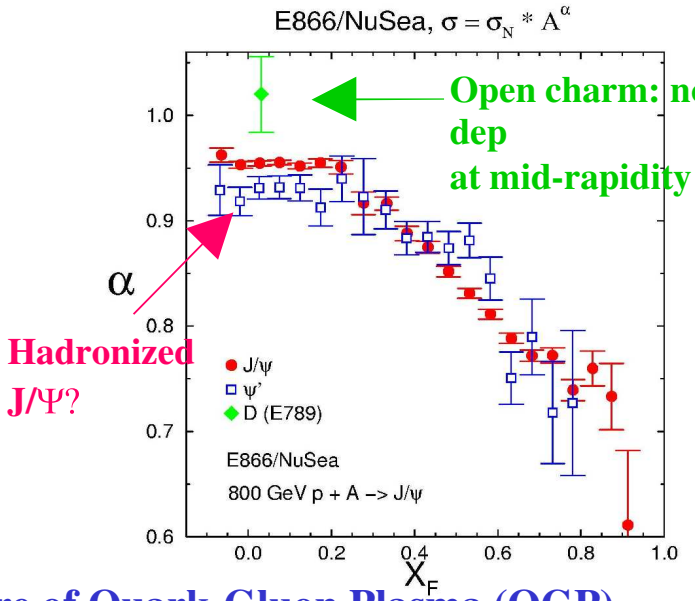


For PHENIX, x for the central arms gives an R_G value of about 0.9. In the muon arms; $x_2 \sim 2 * 10^{-3}$ and shadowing is thus very important for the rate estimates to be presented later.

Gluon shadowing effects for nuclei, for the relevant x and Q^2 regions, have large uncertainties.

Nuclear Dependence of J/Ψ Production I





J/Ψ suppression – an effective signature of Quark-Gluon Plasma (QGP) formation?

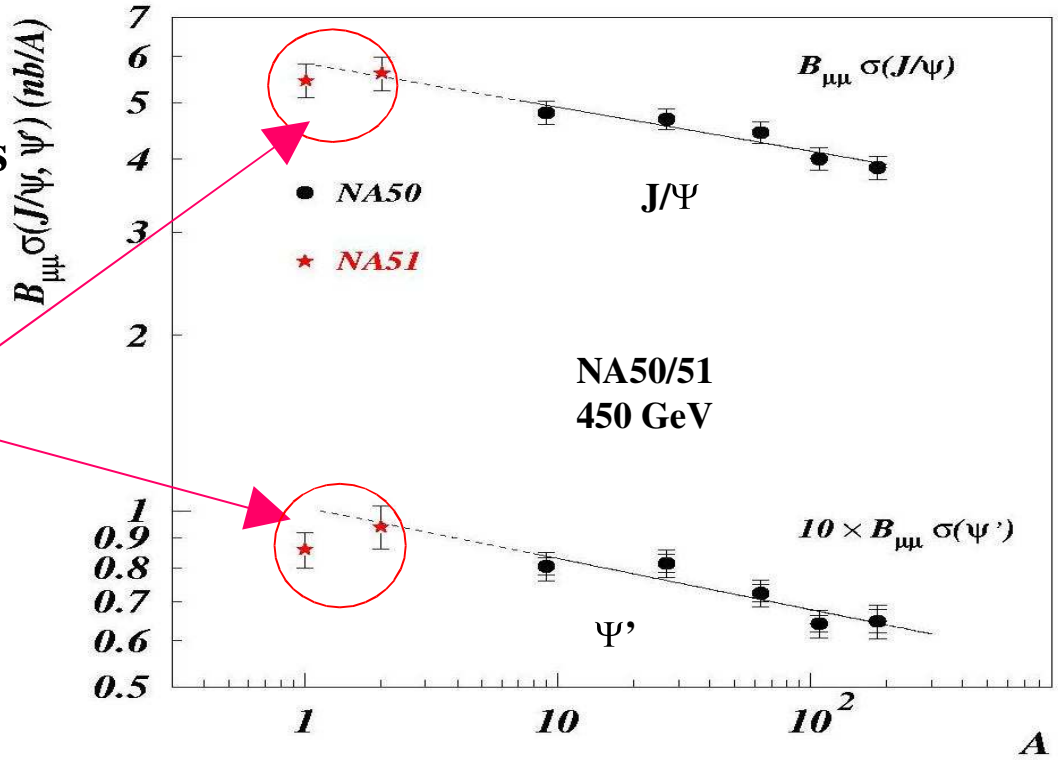
Color screening in a QGP would destroy $c\bar{c}$ pairs before they can hadronize into charmonium

But ordinary nuclear effects also absorb or modify J/Ψ's

We need a comprehensive understanding of open charm and charmonium production

Nuclear Dependence of J/Y Production II

Charmonia cross sections from NA50/51 for p-A collisions at 450 GeV/c



p-p & p-d

Expt.	E(GeV)	Y_{CM}	$\alpha_{J/\psi}$	$\alpha_{J/\psi} - \alpha_{\psi}$
E866	800	-0.4 to 1.0	.954 ± .001	.027 ± .006*
NA50	450	-0.4 to 0.6	.925 ± .018	.029 ± .014
NA38	200	0 to 1.0	.911 ± .034	

* mid-rapidity part of E866 data

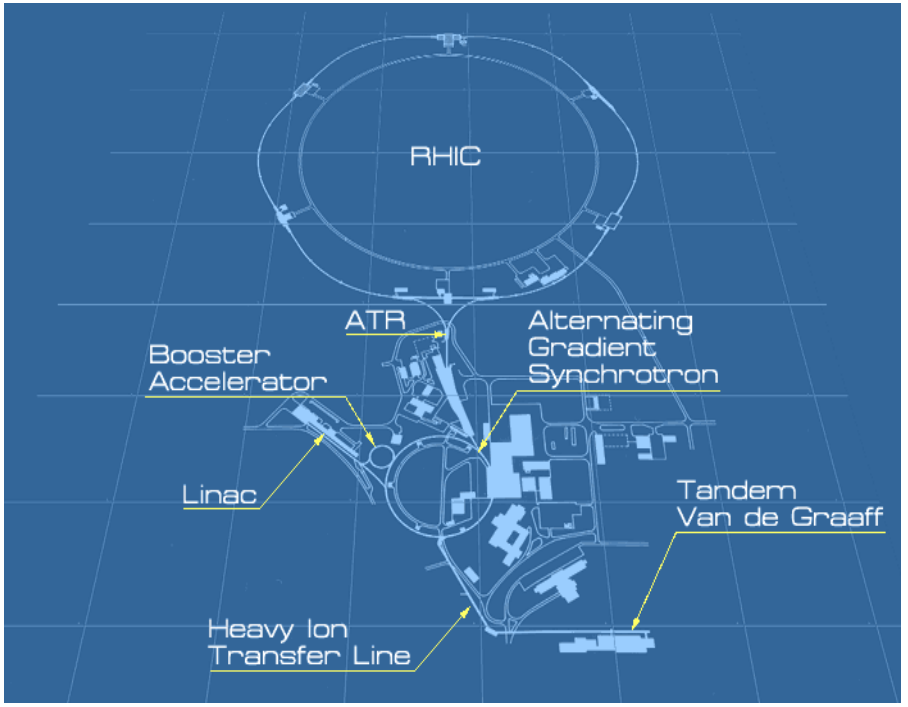
RHIC

Perfomance achieved (2001-2002):

24 $(\mu b)^{-1}$ week^{-1} for Au-Au

0.3 $(pb)^{-1}$ week^{-1} for p-p

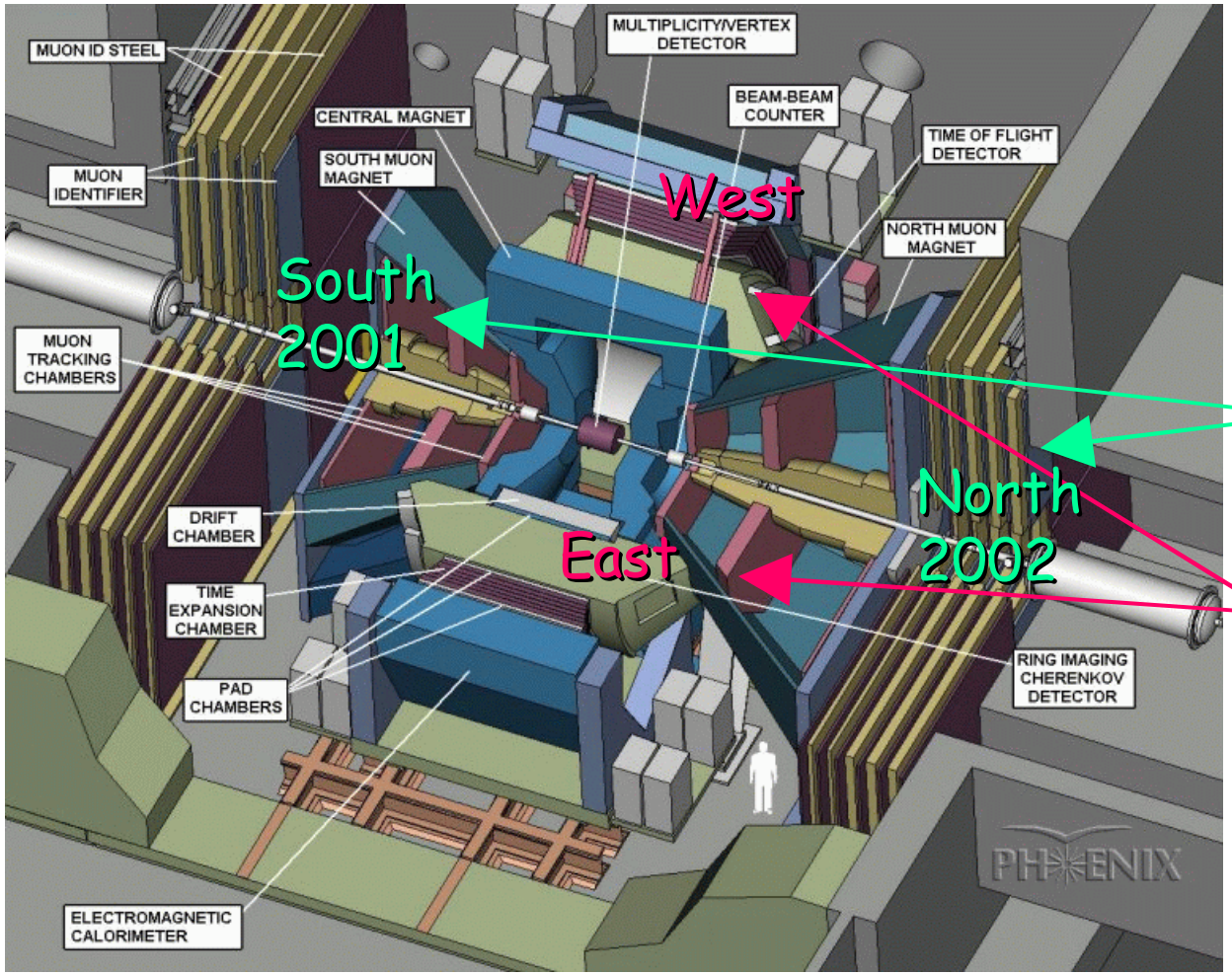
For future runs: d-Au is preferred over p-Au due to more similar beam rigidities of the two species.



Goals of Run3:
(likely minimum values: factor of 3 to 10 lower)

Mode	L_{goal} (week) [week^{-1}]	$L_{int\ goal}$ (3 weeks, 3 modes)	$L_{int\ goal}$ (7 weeks, 2 modes)
Au - Au $[(\mu b)^{-1}]$	70	210	490
p - p $[(pb)^{-1}]$	2.8	8.4	19.6
d - Au $[(nb)^{-1}]$	5	15	35

PHENIX experiment @ RHIC



Run2:
Collected 24 $(\mu b)^{-1}$
Au-Au (170 M events)
and 0.15 $(pb)^{-1}$ p-p.

12 sub-detectors :

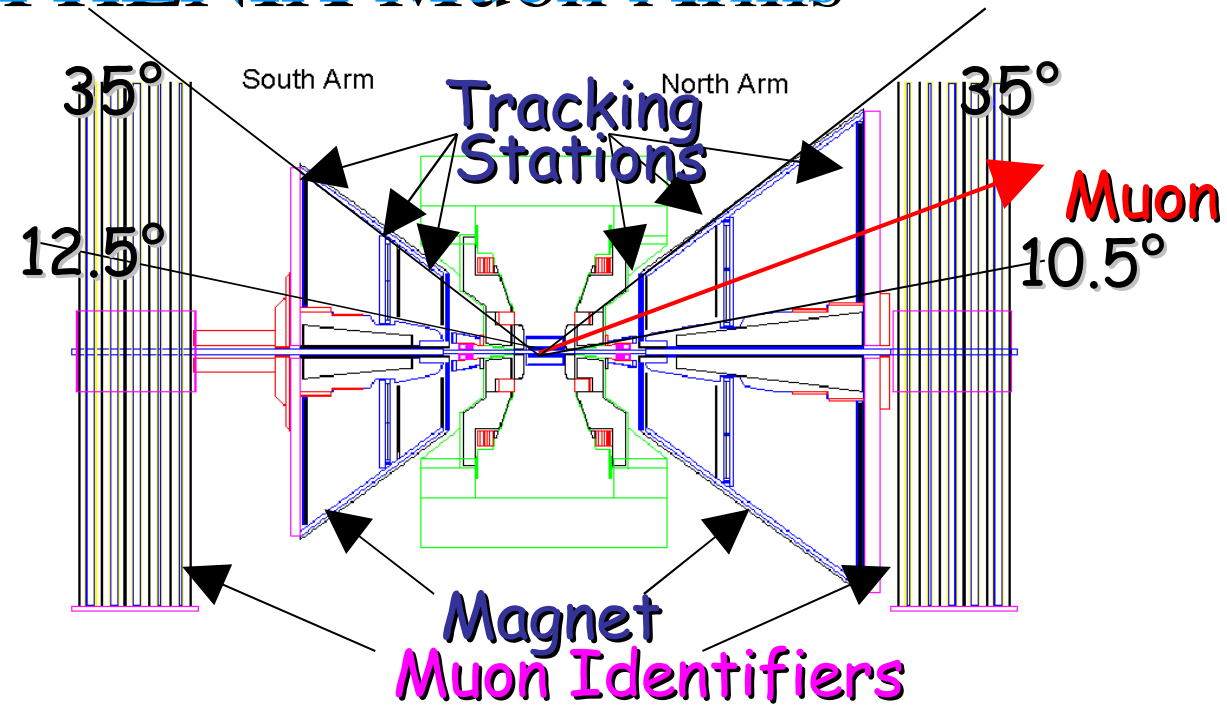
2 Muon Arms

2 Central Arms
measure photons,
hadrons, electrons

Global
detectors :
2 BBC
2 ZDC

PHENIX Muon Arms

2 Muon Trackers =
2x3 stations
2 Muon Identifiers
= 2x5 planes



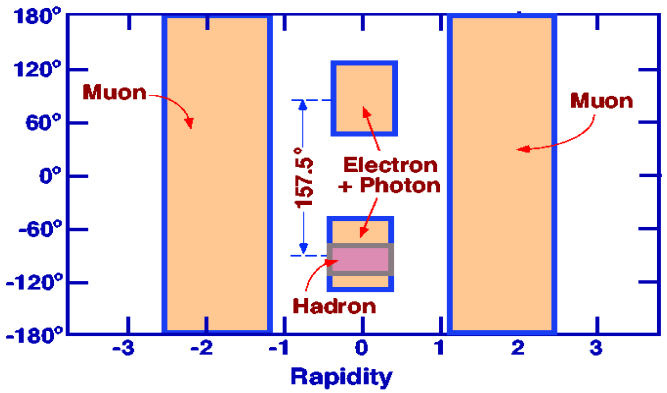
South Arm:
Began operations
in 2001-2002 run.

North Arm:
Installed in 2002.

Acceptance : $1.2 < |\eta| < 2.4$

$\Delta\Phi = 2\pi$

Muon minimum momentum ~ 2 GeV/c



d-Au Collision Geometry

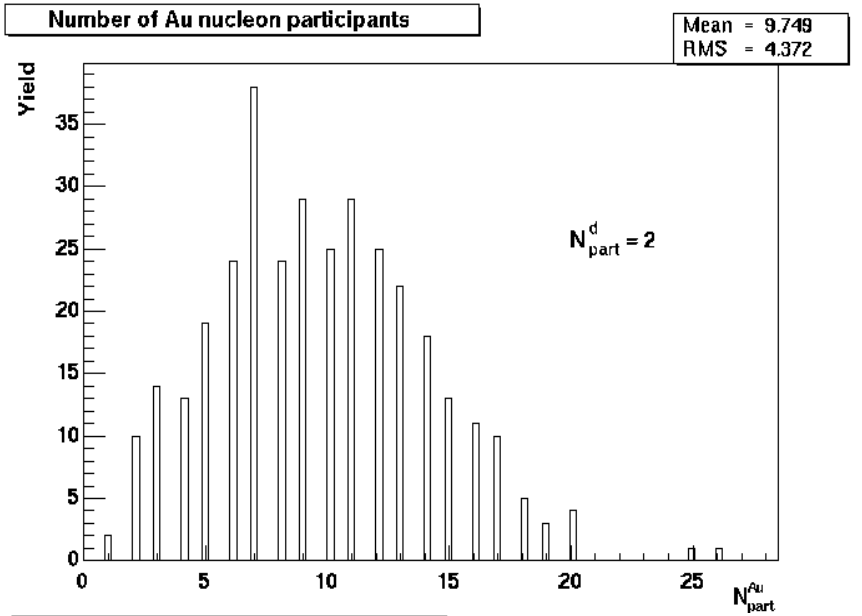
N_{part} is estimated from a Glauber calc.

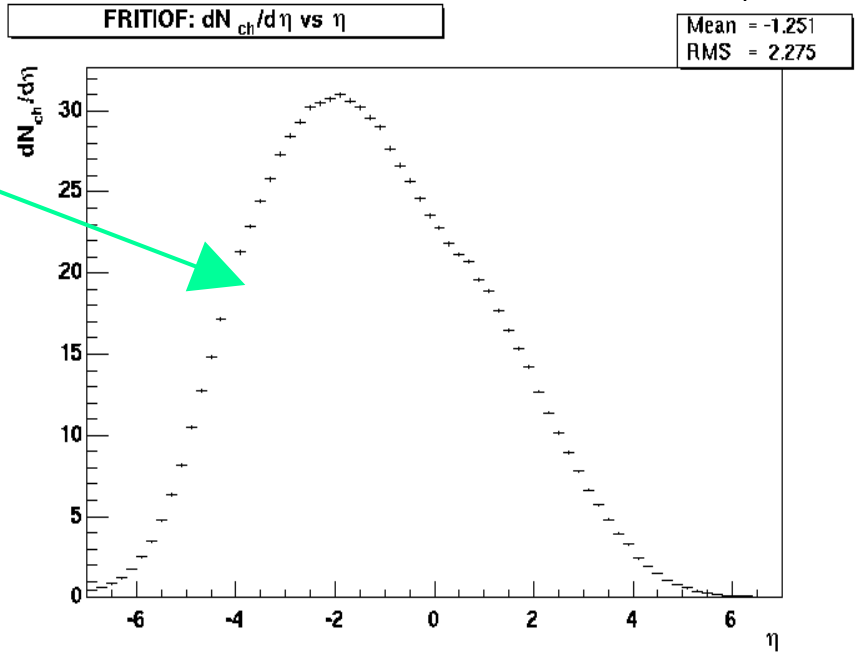
Results in qualitative agreement with the simple formula for a central collisions between homogenous nuclei A and B:

$N_{part} = A + B - (A^{2/3} - B^{2/3})^{3/2}$

Prediction from the FRITIOF model for $dN_{ch}/d\eta$ for rather central collisions: b < 3 fm.

See also poster by S.C. Johnson.





Expected Rates

$L_{goal} = 5\ (nb)^{-1}\ week^{-1}$

PHENIX could collect: ~ 2 $(nb)^{-1}$ $week^{-1}$ (vertex cut, up time).

Assume 50% trigger and reconstruction efficiency: ~1 $(nb)^{-1}$ $week^{-1}$

σ_{geo} ~ 2 b => **$2*10^9$ recorded collisions per week.**

Assuming binary scaling for hard processes and using a calculation from X.N. Wang, this would be equivalent of a p_T reach out to ~12 GeV/c for π^0

For J/Ψ rate estimate, let's use α =0.92. σ_{pp} (J/Ψ) ~= 3.3 μb (Gavin, 1995)

=> σ_{dAu} (J/Ψ) ~= $3.3 * 2^{\alpha} * 197^{\alpha}$ ~= 800 μb

Note: Other choice of PDF can give a factor 2 larger σ.

With BR(J/Ψ–>μμ) = 6%, Muon Acceptance for J/Ψ decays ~= 3%, we should thus be able to detect ~ 4000 recorded J/Ψ for a 3-week run.

Note: gluon shadowing could (Kopeliovich et al. (hep/ph-020515)) give α = 0.74

=> rate reduced by a factor of 3! And delivered luminosity from RHIC might be rather different from the set goal..

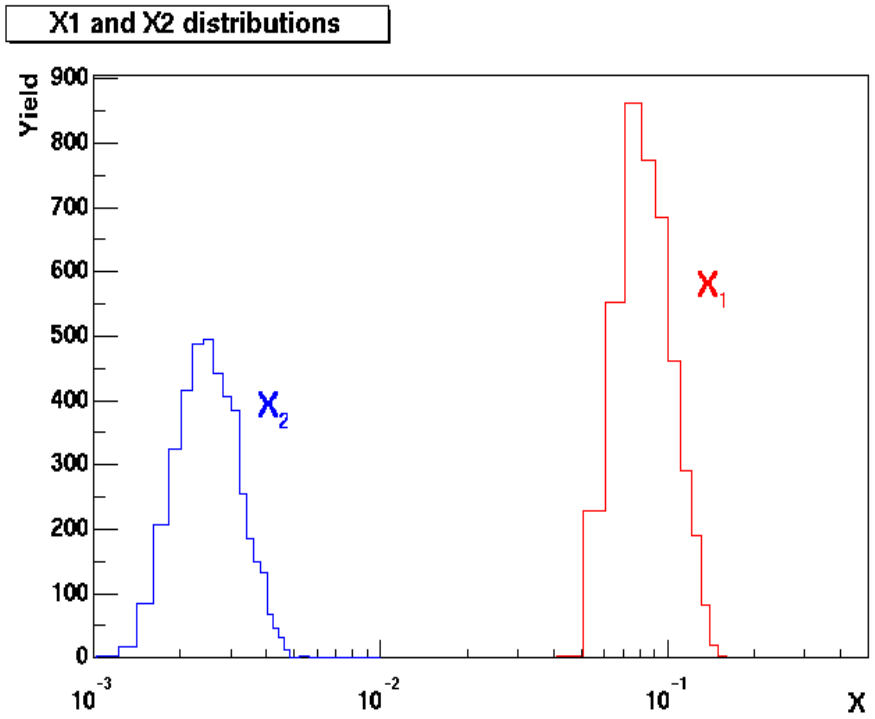
Kinematics: Accepted J/Ψ–>μμ

A simple event generator was used to generate heavy vector mesons (can also generate Drell-Yan continuum). It throws masses, x_F, p_T and cos(θ) within specified ranges. x_F is defined as $x_F = 2*p_z/sqrt(s)$. With the help of $\tau = m^2/s$, we can obtain x_1 and x_2:

$x_1 = (x_F+sqrt(x_F^2+4*\tau))$; $x_2 = x_1 - x_F$

At the large s value of RHIC, τ is small, as is therefore also x_2. The x_1 and x_2 distributions are plotted for J/Ψ's that have been processed thru PISA (PHENIX Integrated Simulation Application, GEANT 3 package) and fall within the acceptance.

The statistics correspond to about 4000 accepted J/Ψ.

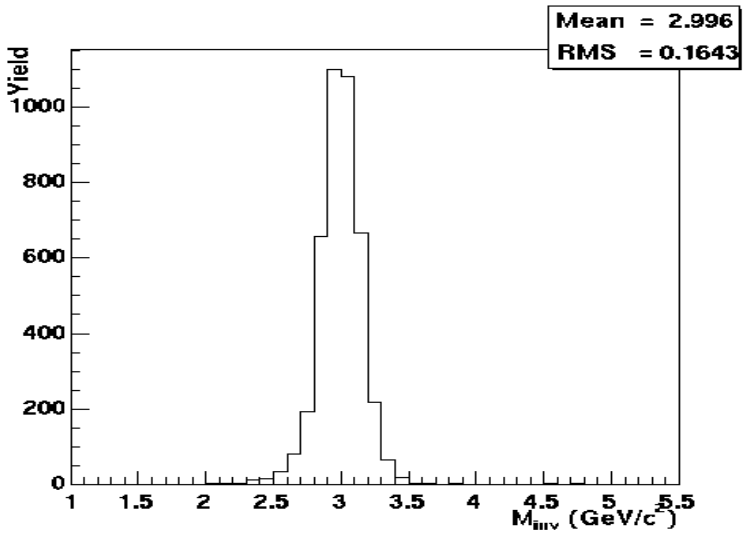


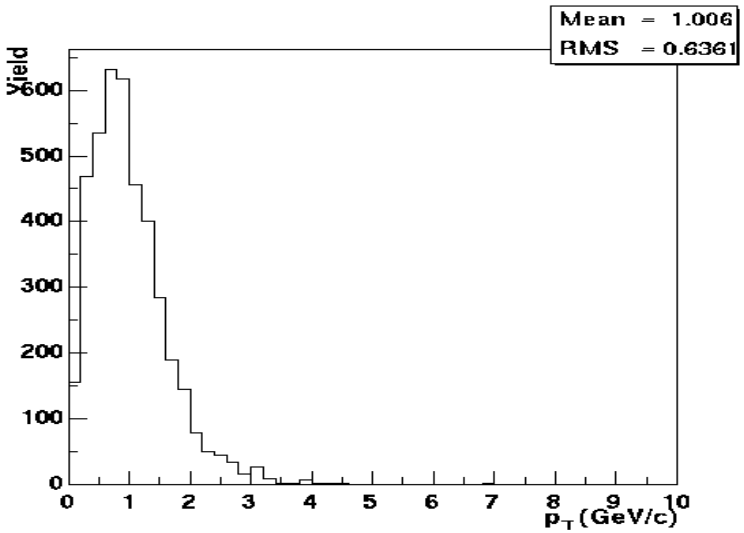
Kinematics cont'd

Plotted below are the reconstructed M_{inv} and p_T distributions for the same ~ 4000 J/Ψ events. This statistics is approx. equivalent to three weeks of running at the goal luminosity.
The number of p_T counts in the range 2-3 GeV/c) are 220.

Measuring the J/Y cross section, as well as its p_T dependence for lower p_T values seems within reach both for the 3 and 7 week scenarios.

The Ψ', with a production rate of about 2% relative to the J/Ψ, would be more challenging to observe for a short d-Au run at this luminosity.





Summary

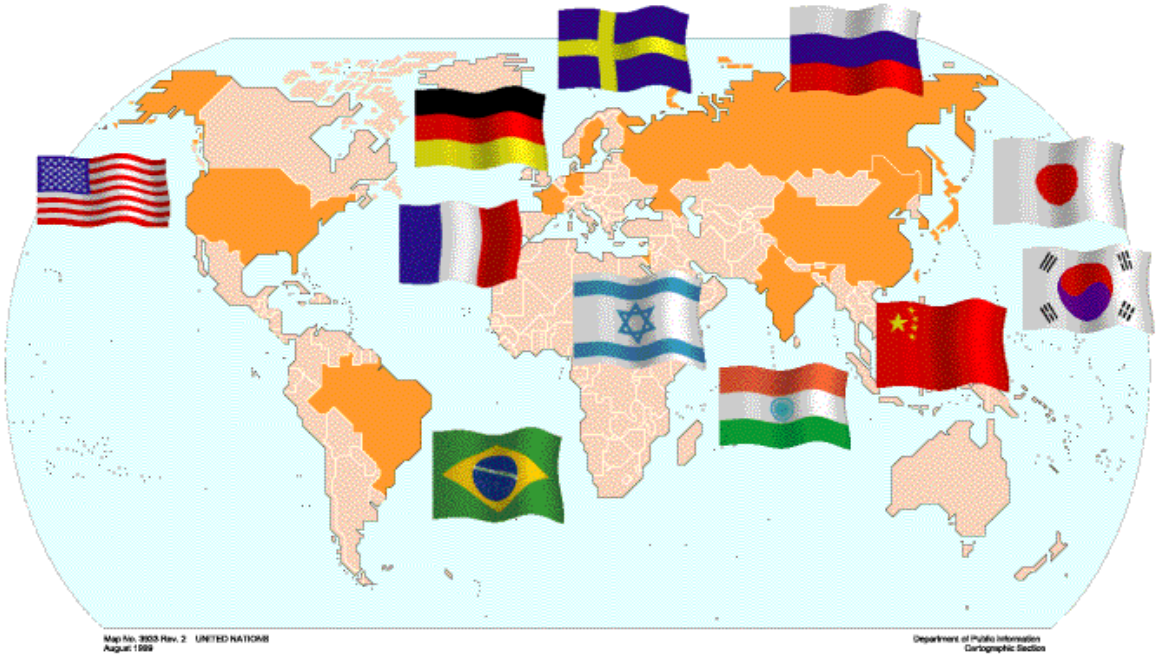
d-Au measurements are important to provide a baseline for comparisons with Au-Au results, and are interesting in themselves.

Of particular interest are suppression of high p_T hadrons, gluon shadowing and J/Ψ suppression.

Even with a modest run, and reasonable luminosities, the p_T reach for hadrons should extend out to sufficiently high values for an Au-Au result comparison.

Likewise, a J/Ψ measurement that could give valuable insights into shadowing seems entirely feasible.

PHENIX



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