PHENIX: ψ' to J/ψ in p+p, p+Al, p+Au, ^{3}He+Au at $\sqrt{s}$ = 200 GeV

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PHENIX: arXiv:1609.06550

Introduction

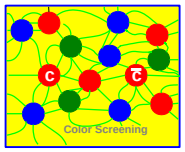
PHENIX dimuon measurements

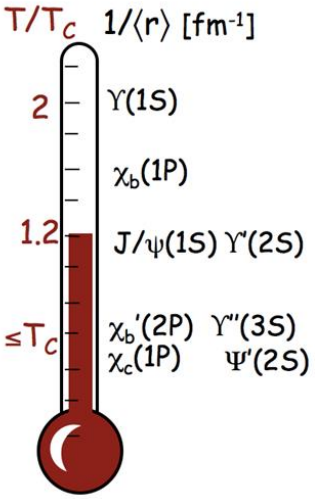
Results

Summary

Quarkonium Suppression a Signature for Deconfinement

- **Original idea of color screening (Matsui and Satz 1986):**
  - **Quarkonium in QGP suppressed (Debye screening of QCD)**
  - **Sequential melting of quarkonium states as QGP thermometer**





- **Alternative Scenario Statistical Hadronization**
  - **Color screening**
  - **Recombination at phase boundary**

- **Cold Nuclear Matter effects**
  - **Nuclear parton distribution functions**
  - **Nuclear absorption**
  - **Hadron comover dissociation**

To date no agreed upon interpretation of quarkonia measurements

Charmonium Production in A+A Collisions:

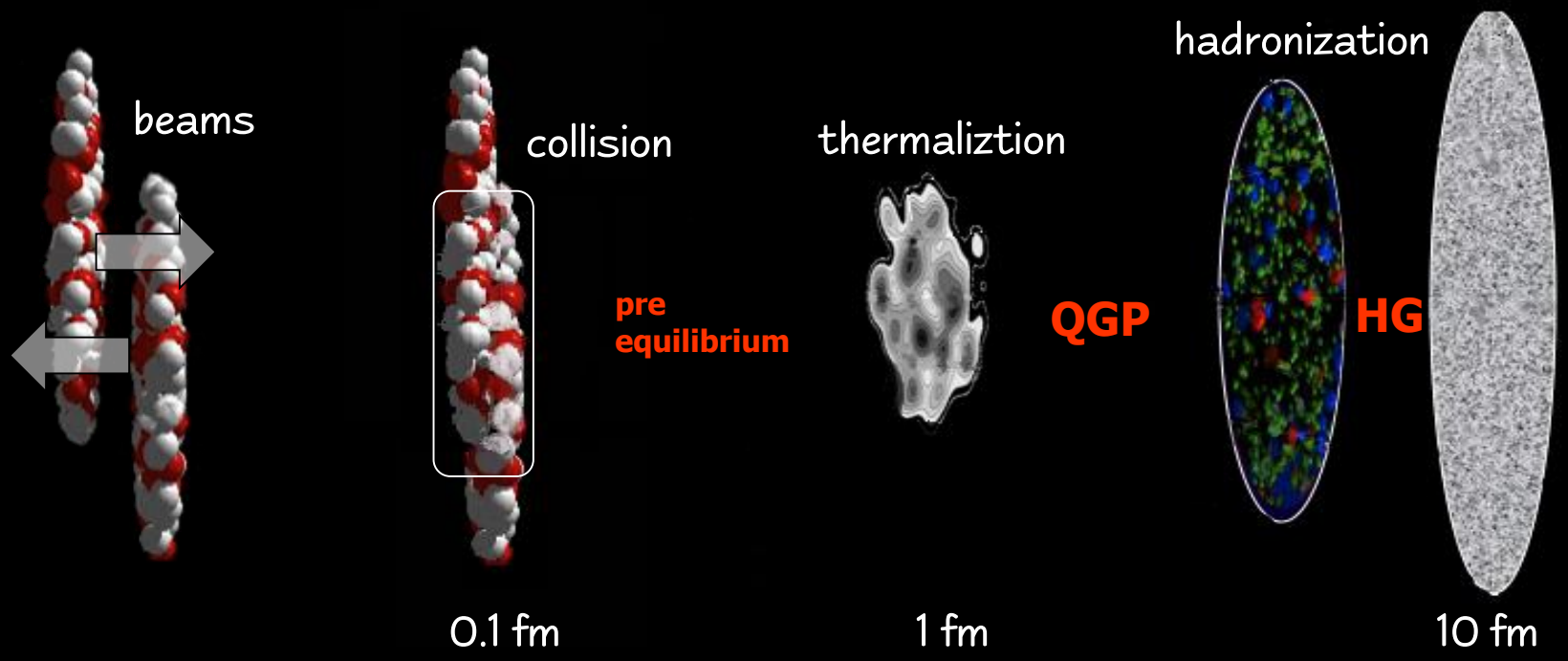
Vacuum formation:

$c\bar{c}$ precursor

J/ψ, ψ'

$t_f \sim 0.35\ \text{fm} \times \gamma$

freeze out



Complex interplay of different effects in matter:

Nuclear PDFs

~~Nuclear absorption~~

Not at RHIC & LHC

color screening

recombination

comover dissociation

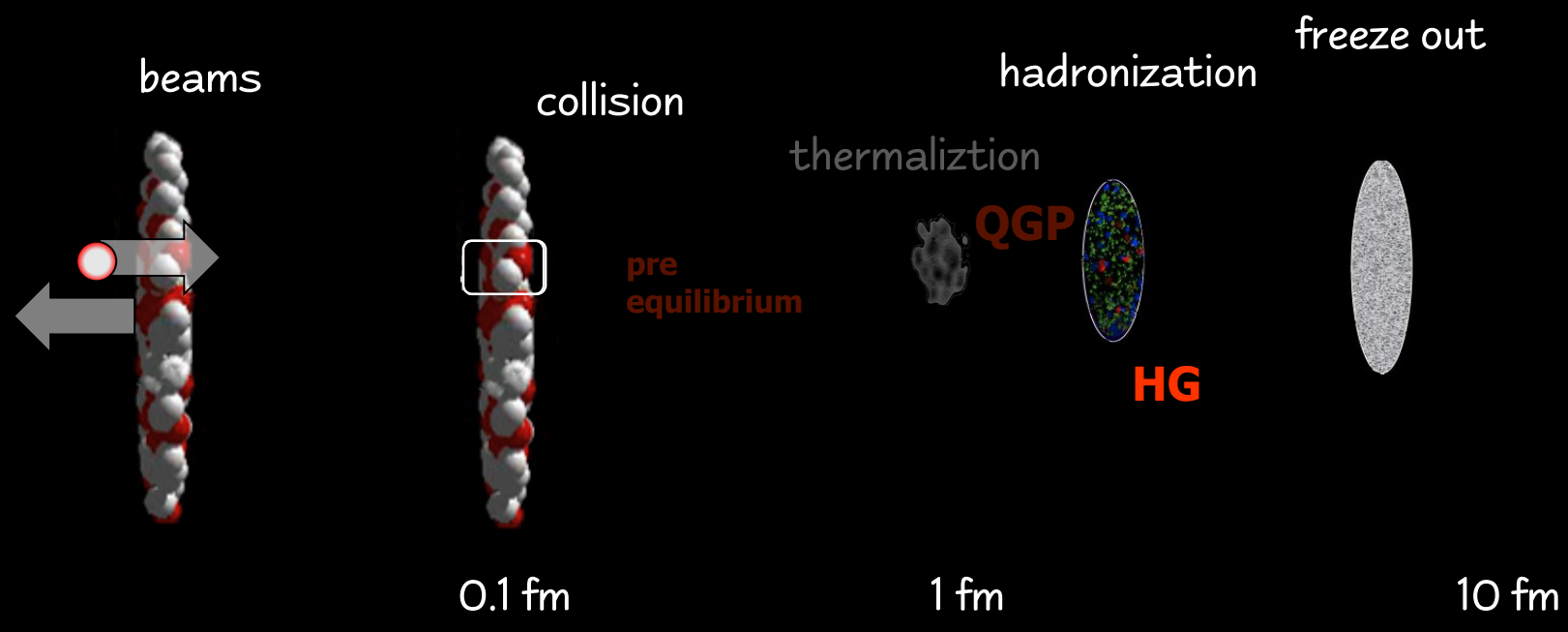
Charmonium in Small Systems:

Vacuum formation:

$c\bar{c}$ precursor

J/ψ, ψ'

$t_f \sim 0.35\ \text{fm} \times \gamma$



Emphasis late stage effects on charmonium:

Nuclear PDFs

recombination

color screening

comover dissociation

Charmonium in Small Systems:

Vacuum formation:

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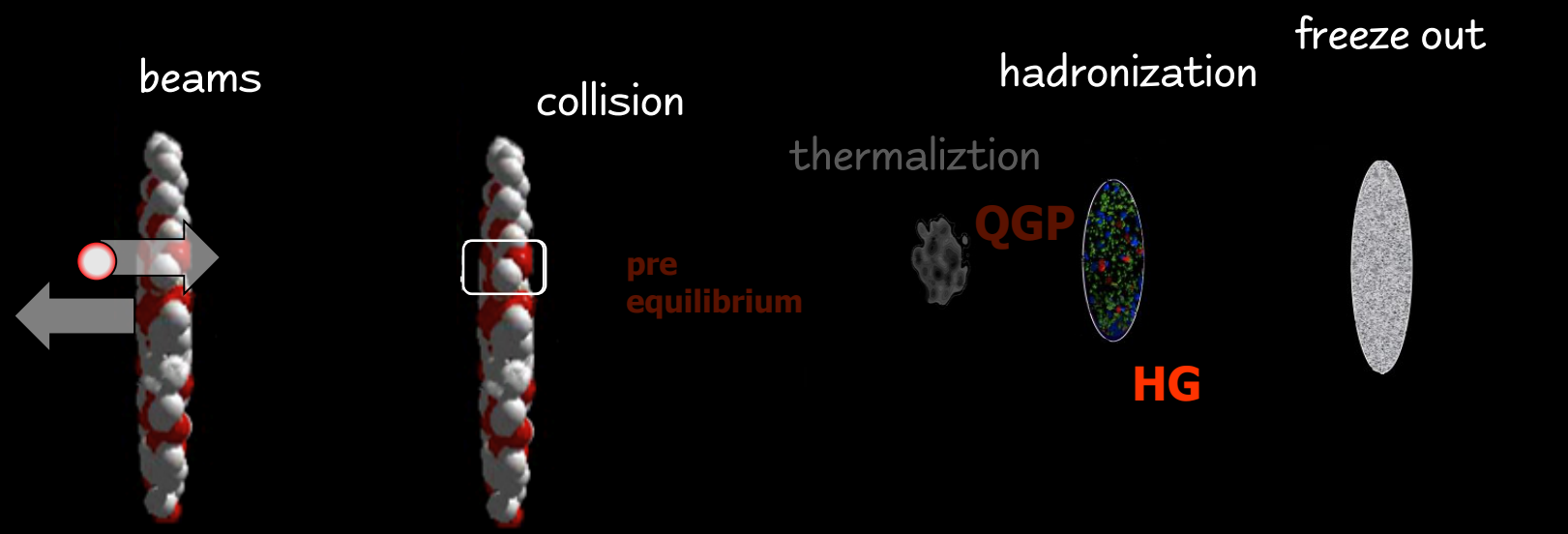


Emphasis late stage effects on charmonium:

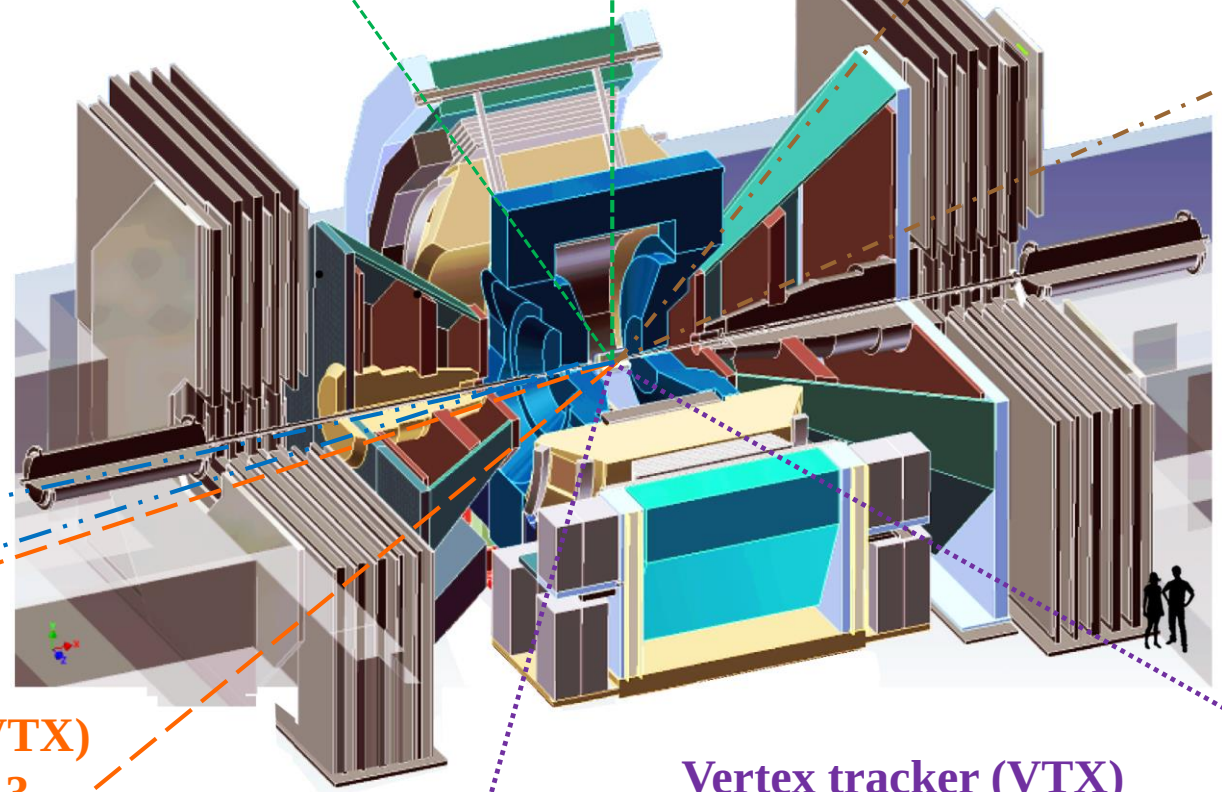
Study ψ' to J/ψ with system size and rapidity

Nuclear PDFs

color screening

comover dissociation

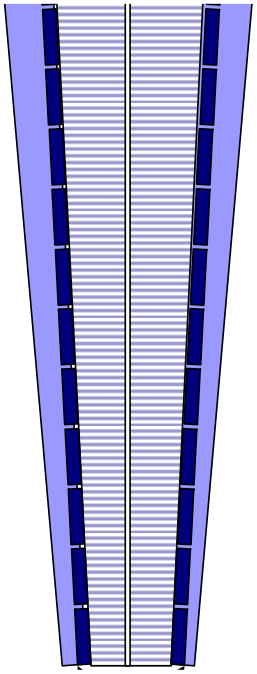
The PHENIX Experiment

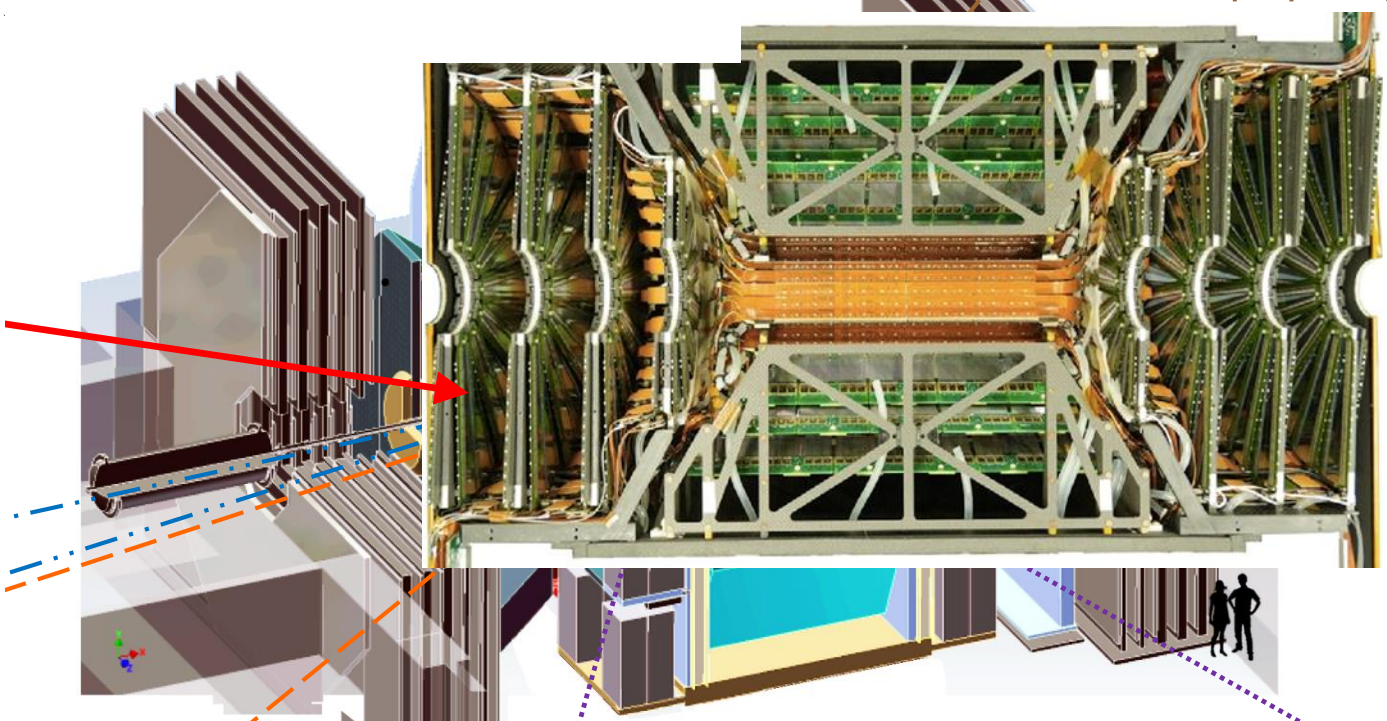


The PHENIX Experiment

4 disks per arm (z = 20, 25, 31, 38 cm)
48 overlapping sensor wedges per disk
each wedge:
2 columns of strips 2.8 to 11.2 mm in rϕ
75 μm spacing in r

Muon Arms
$1.2 < |\eta| < 2.2$
$J/\psi, \psi' \rightarrow \mu\mu$



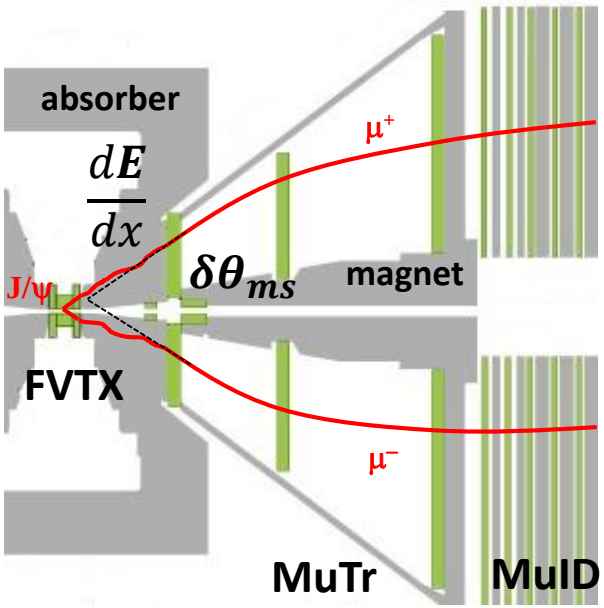


Vertex tracker (FVTX)
$1 < |\eta| < 3$
Improved μμ mass resolution

Vertex tracker (VTX)
$|\eta| < 1.2$

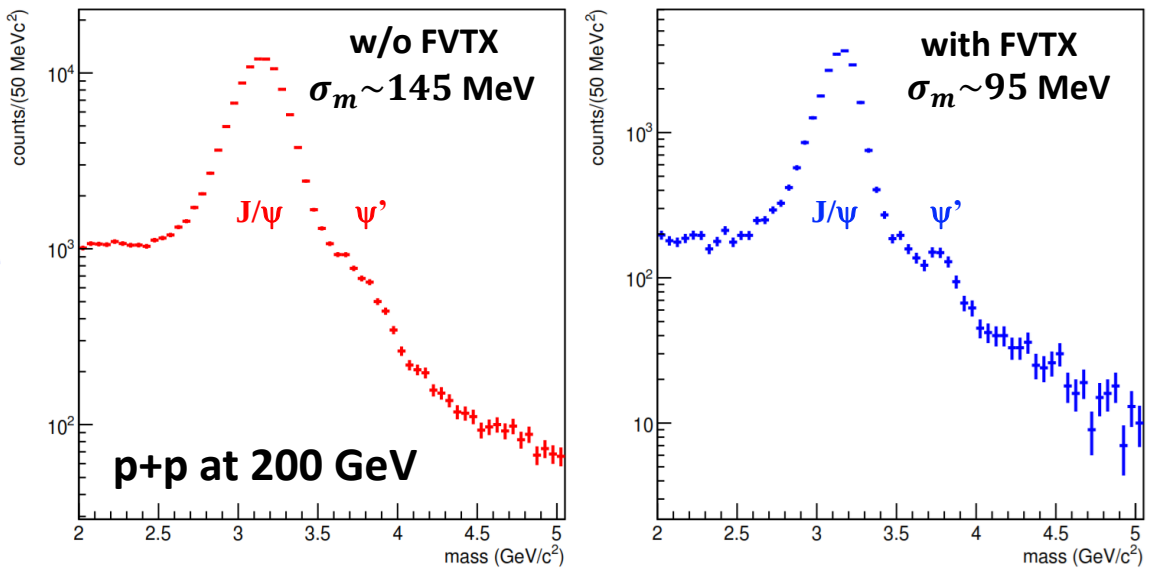
Improved Mass Resolution with FVTX

- $\mu^+\mu^-$ pair detection
  - FVTX: tracking before absorber
  - absorber: dE/dx and $\delta\theta_{ms}$
  - MuTr: momentum after absorber
  - MuID: μ identification



- Mass resolution w/o FVTX
  - p-resolution negligible
  - dE/dx correction ~50%
  - $\delta\theta_{ms}$ contribution ~50%

- Mass resolution with FTVX
  - p-resolution negligible
  - dE/dx correction ~100%
  - $\delta\theta_{ms}$ contribution negligible



With FVTX ψ' peak clearly visible

Available Data Sets

- **Available data sets at $\sqrt{s_{NN}}$ = 200 GeV**

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Collision system	Rapidity interval	$N_{meas}^{\psi(1s)}$	$N_{meas}^{\psi(2s)}$
$p+p$	$1.2 < \|y\| < 2.2$	17120±392	519±51
p+Al	$1.2 < y < 2.2$ (p-going)	1497±142	52±11
p+Al	$-2.2 < y < -1.2$ (Al-going)	1463±109	25±11
p+Au	$1.2 < y < 2.2$ (p-going)	3893±147	117±18
p+Au	$-2.2 < y < -1.2$ (Au-going)	3561±180	51±18
^{3}He+Au	$1.2 < y < 2.2$ (^{3}He-going)	959±64	27±9.3
^{3}He+Au	$-2.2 < y < -1.2$ (Au-going)	1772±132	35±15

relative trigger efficiency from MB data ~ 0.97

- **ψ' to J/ψ ratio**

$$\frac{B_{\mu\mu}^{\psi'}\sigma_{\psi'}}{B_{\mu\mu}^{J/\psi}\sigma_{J/\psi}} = \frac{N_{meas}^{\psi'}}{N_{meas}^{J/\psi}} \frac{\Omega_{\psi'}\epsilon_{\psi'}}{\Omega_{J/\psi}\epsilon_{J/\psi}} \frac{\epsilon_{\psi'}^{trig}}{\epsilon_{J/\psi}^{trig}}$$

relative acceptance ×efficiency
GEANT simulation: ~ 0.8

p+p Data

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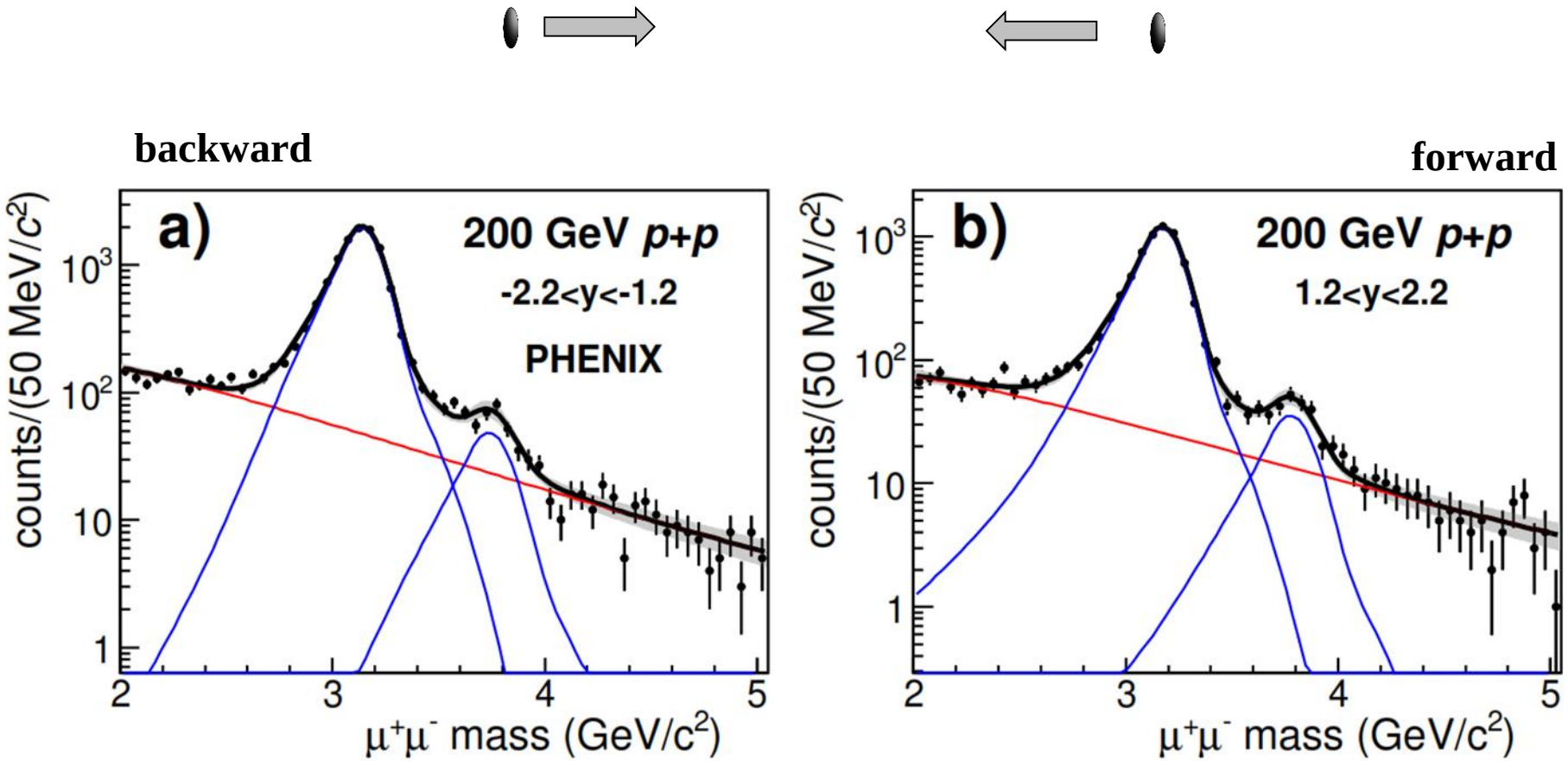

J/ψ and ψ' yields consistent in forward and backward rapidity

ψ' to J/ψ Ratio for p+p Collisions at 200 GeV

- **Integrated ψ' /(J/ψ)**

$$\left[\frac{B^{\psi'}_{\mu\mu}\,\sigma_{\psi'}}{B^{J/\psi}_{\mu\mu}\,\sigma_{J/\psi}}\right]^{pp} = 2.43 \pm 0.18(stat) \pm 0.29(sys)$$

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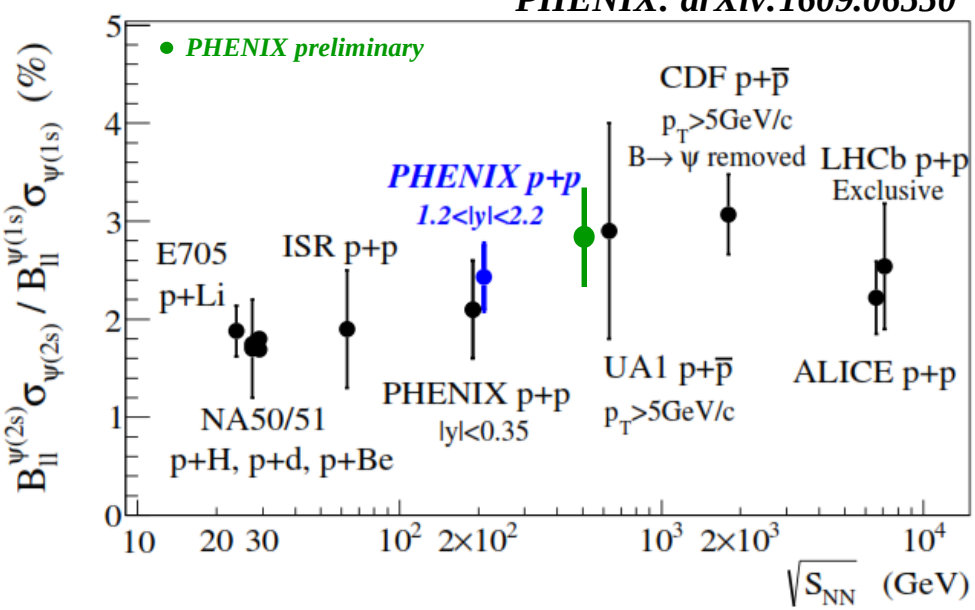

- not very sensitive to √s

Good agreement with world data ψ' /(J/ψ) and $c\bar{c}$ cross section approximately factorize

- **ψ' /(J/ψ) vs p_T**
  - **PHENIX data is not feed down corrected**

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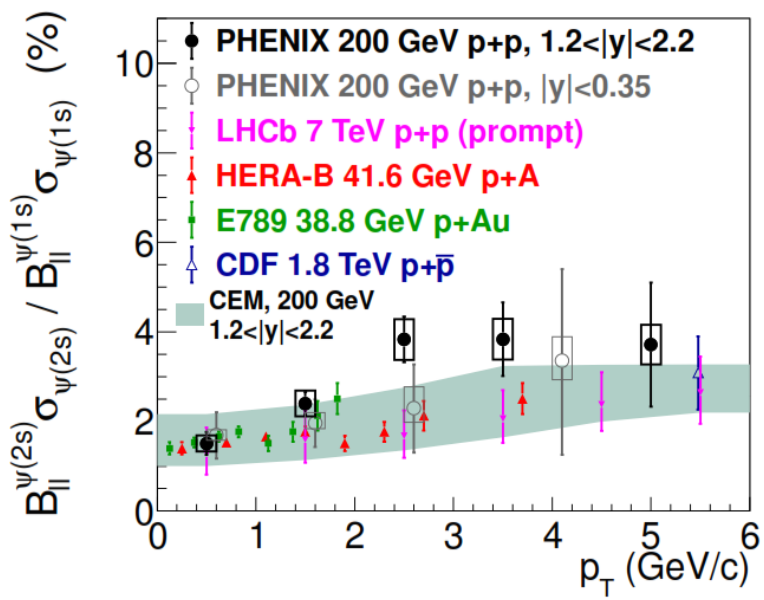

- **Only moderate p_T dependence**
- **Small deviation around 2-3 GeV possibly related to bottom feed down**

p+Au Data

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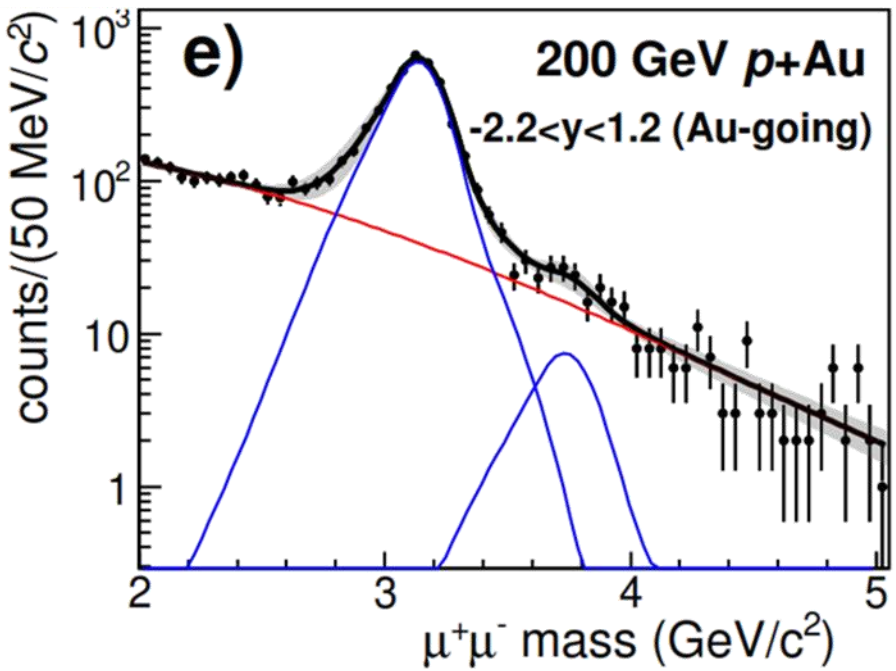
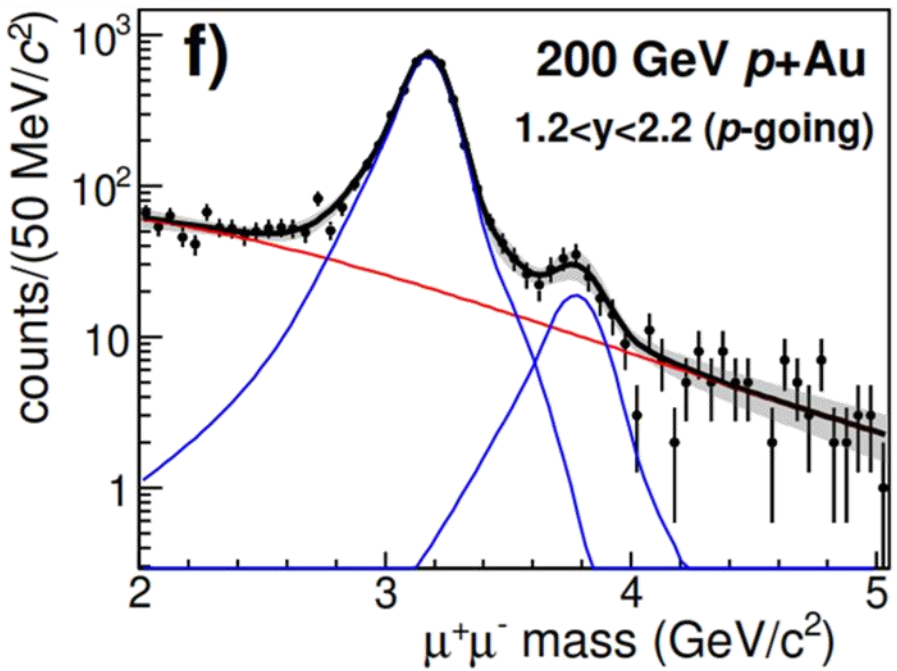
backward **forward**





consistent J/ψ yields and
visibly smaller ψ' yield Au-going rapidity

p+Al Data

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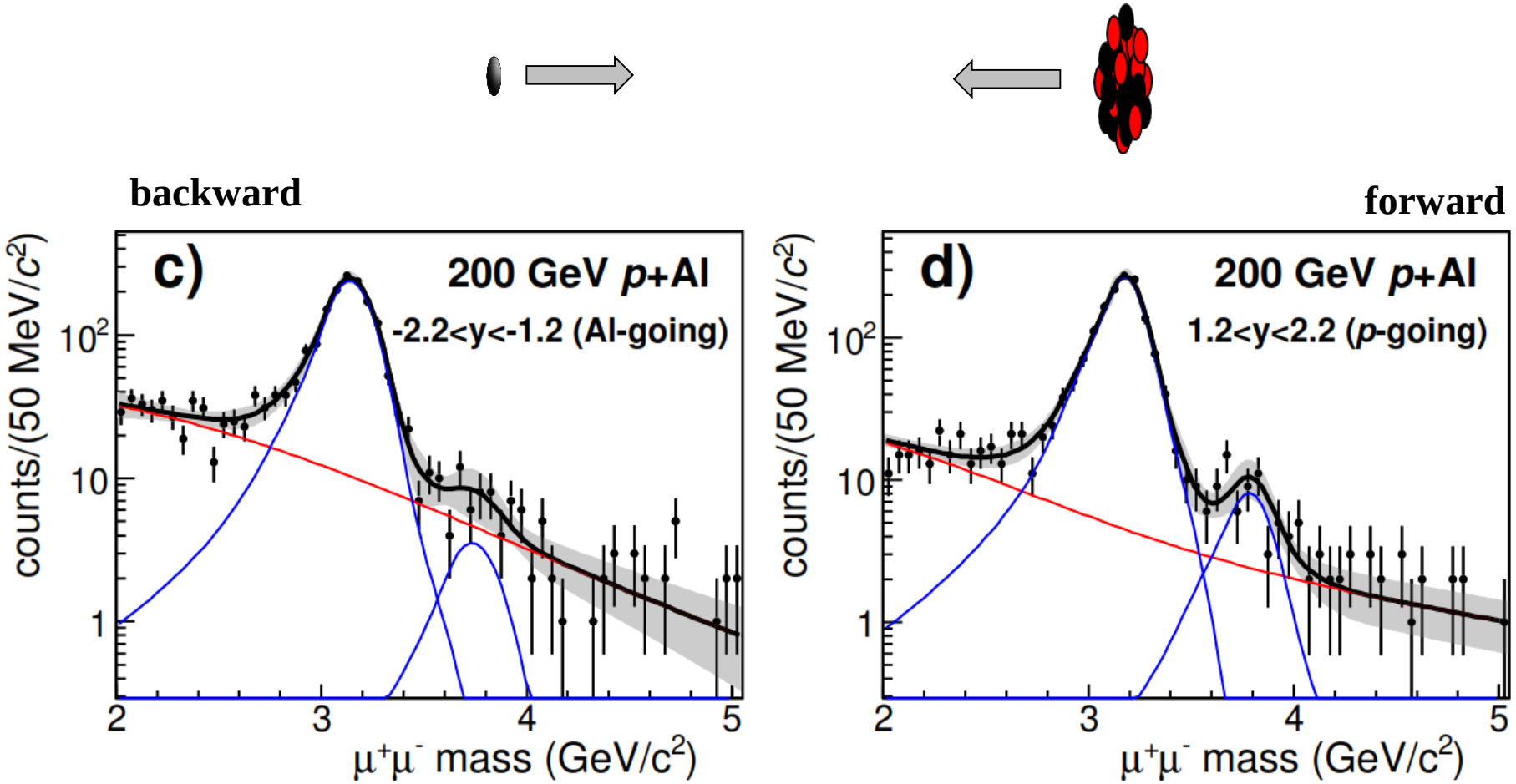

Low ψ' statistics,
indication for smaller ψ' yield Au-going rapidity

^{3}He+Au Data

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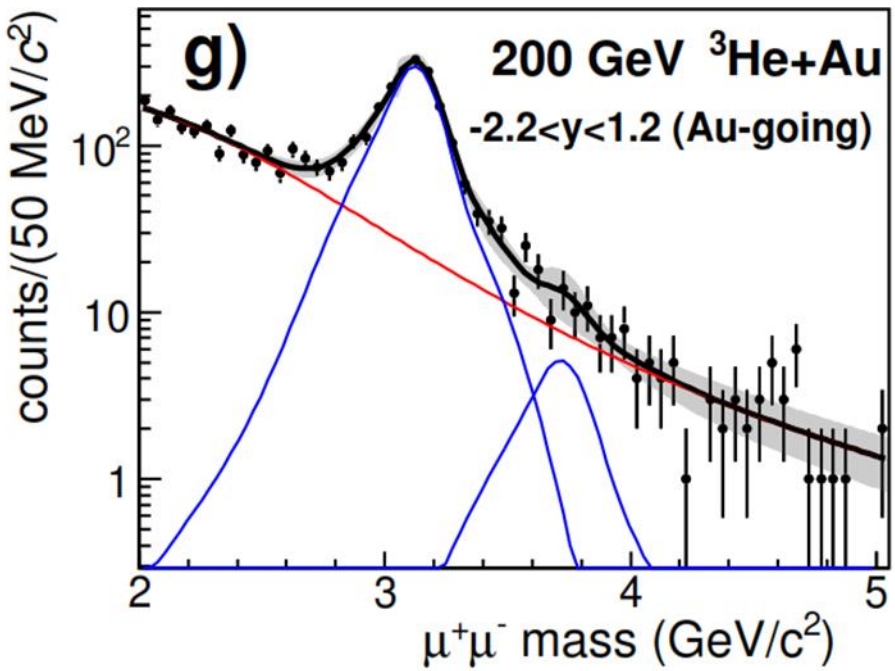
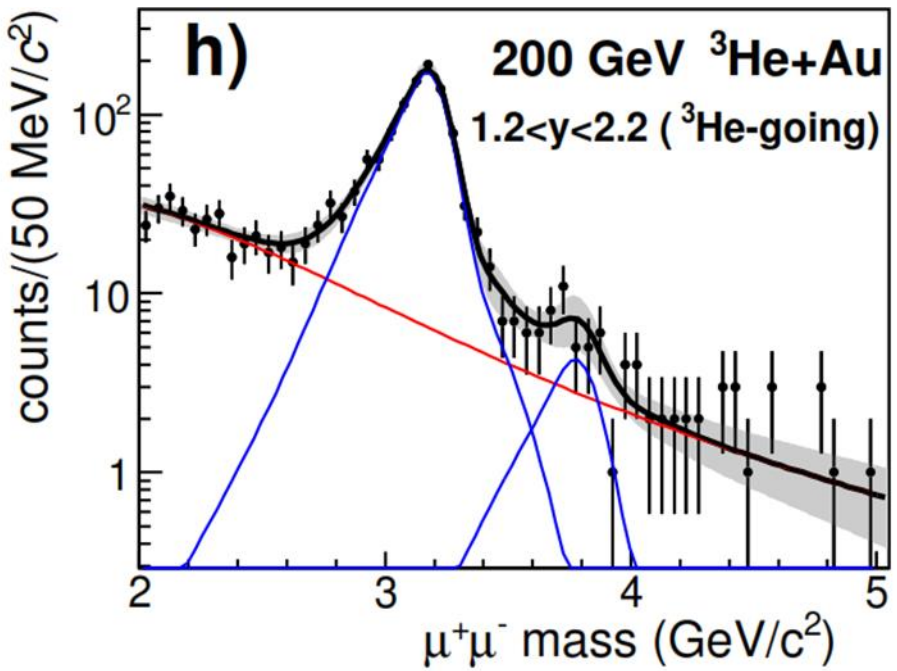
backward **forward**





Low ψ' statistics,
indication for smaller ψ' yield Au-going rapidity

Double Ratio vs Rapidity

- **Double ratio method minimizes systematic uncertainties**
  - **acceptance × efficiency factors cancel**
  - **Branching ratios cancel**
  - **Insensitive to cross section changes that effect both J/ψ and ψ**

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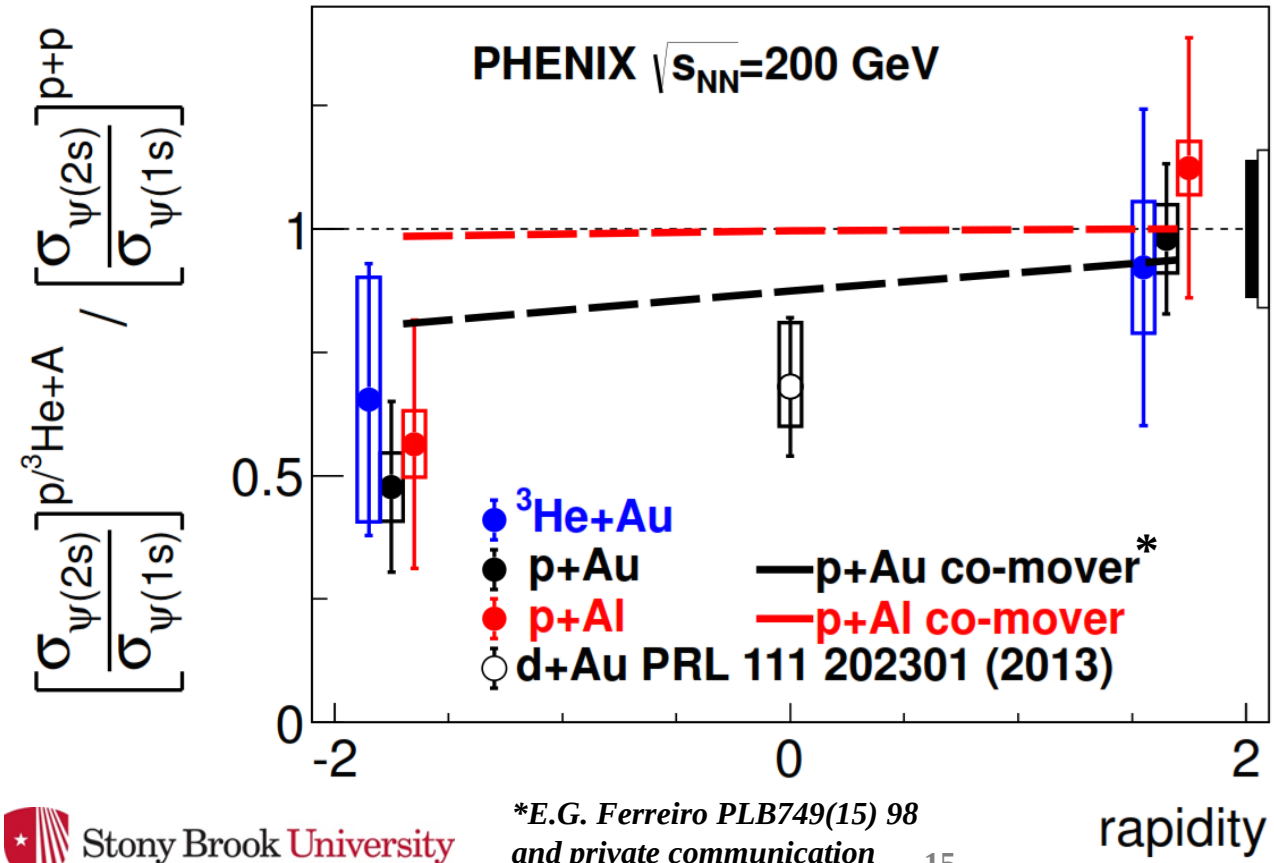
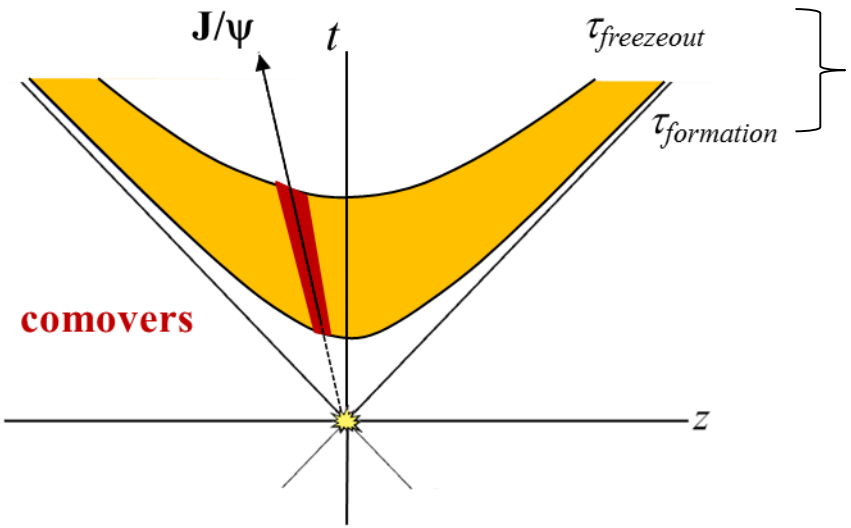


p(He)-going side like pp

ψ' is suppressed on A going side

E.G. Ferreiro PLB749(15) 98 and private communication

Comover Dissociation of Quarkonium



Dissociation by comovers with cross section $\sigma^{co}_{\psi'}$ and $\sigma^{co}_{J/\psi}$

Given transverse comover density ρ^{co}

Survival probability: $S \sim e^{-\sigma^{co}\rho^{co}}$

Assume only comover dissociation:

$$\left[\frac{\sigma_{\psi'}}{\sigma_{J/\psi}}\right]^{p+A} \Big/ \left[\frac{\sigma_{\psi'}}{\sigma_{J/\psi}}\right]^{p+p} \propto \frac{S_{\psi'}}{S_{J/\psi}} \approx 1 - (\sigma^{co}_{\psi'} - \sigma^{co}_{J/\psi})\rho^{co}$$

Plot $\left[\frac{\sigma_{\psi'}}{\sigma_{J/\psi}}\right]^{p+A} \Big/ \left[\frac{\sigma_{\psi'}}{\sigma_{J/\psi}}\right]^{p+p}$ vs ρ^{co}

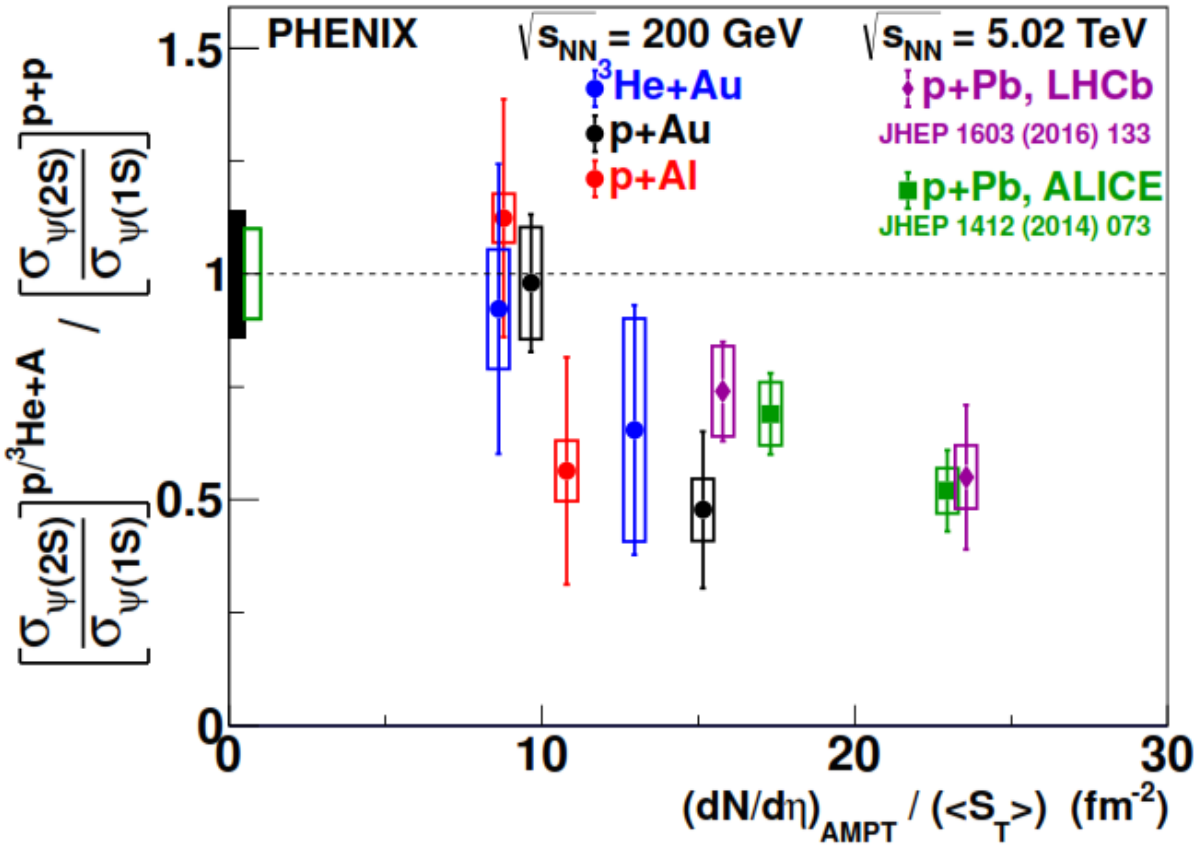
Comover Dissociation of Quarkonium

PHENIX: arXiv:1609.06550

from AMPT

Approximate comover density: $\rho^{co} \propto \left(\frac{dN}{dy}\right) / \langle S_T \rangle$

transverse size from Glauber MC



Comover Dissociation of Quarkonium

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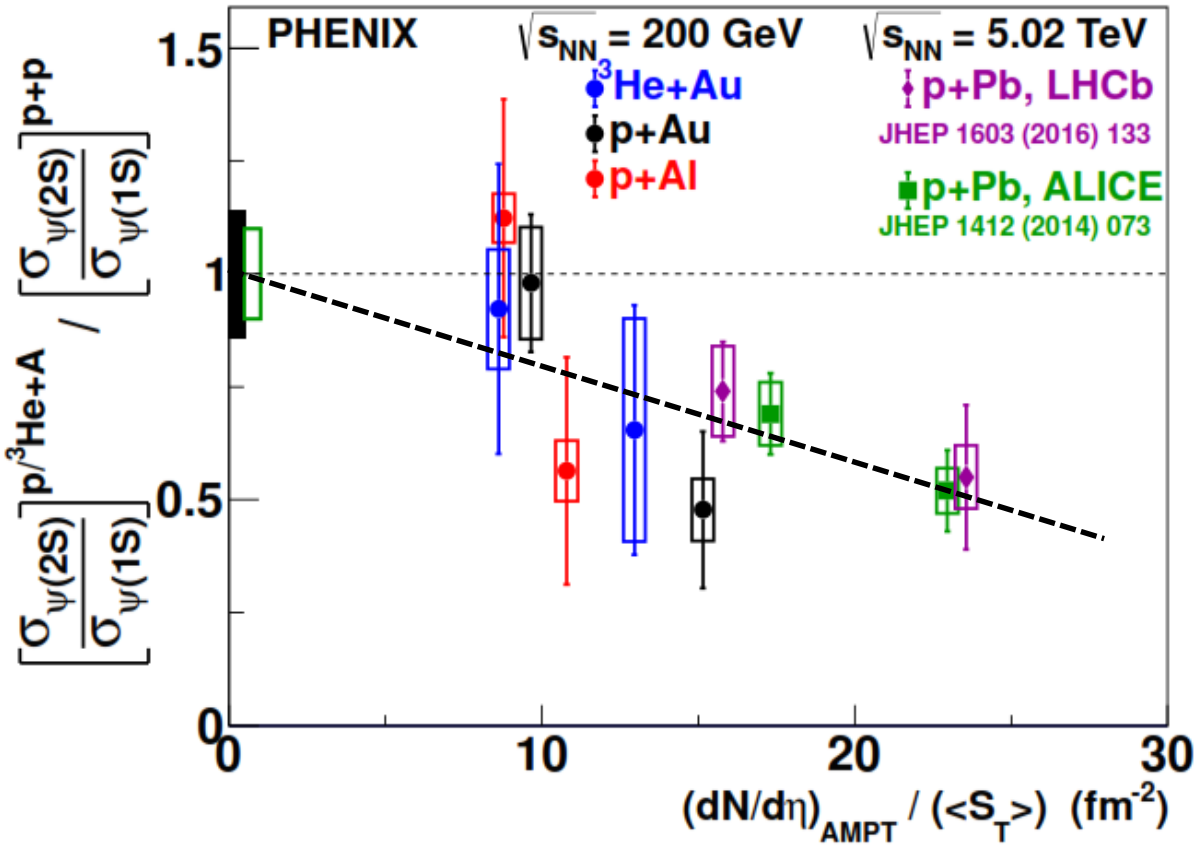
transverse size from Glauber MC



RHIC and LHC data from small systems consistent with comover interpretation

Summary

- **PHENIX measured ψ' over J/ψ small systems √s 200 GeV**
  - **p+p, p+Al, p+Au and ^{3}He+Au**
  - **forward and backward rapidity 1.2 <|y|<2.2**

- **ψ' over J/ψ in p+p collisions**
  - **Consistent with data at other collision energies**
  - **cc production and J/ψ, ψ' formation approx. factorize**

- **ψ' over J/ψ in small systems**
  - **Forward rapidity (p/He-going) consistent with p+p collisions**
  - **Backward rapidity (A going) ψ' is suppressed**

- **ψ' suppression is consistent with comover dissociation within large experimental uncertainties**

Thank you