Highlights from the PHENIX Experiment
- Part 2 -

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Brookhaven National Laboratory
for the PHENIX Collaboration

Quark Matter - Budapest , Aug. 4 2005

The Outline of the Talk

1. The PHENIX White paper
2. The soft-hard transition
3. Jet quenching
4. Chiral symmetry

5. **Thermal Radiation**
6. **J/ψ suppression**
7. **Modification of jets**

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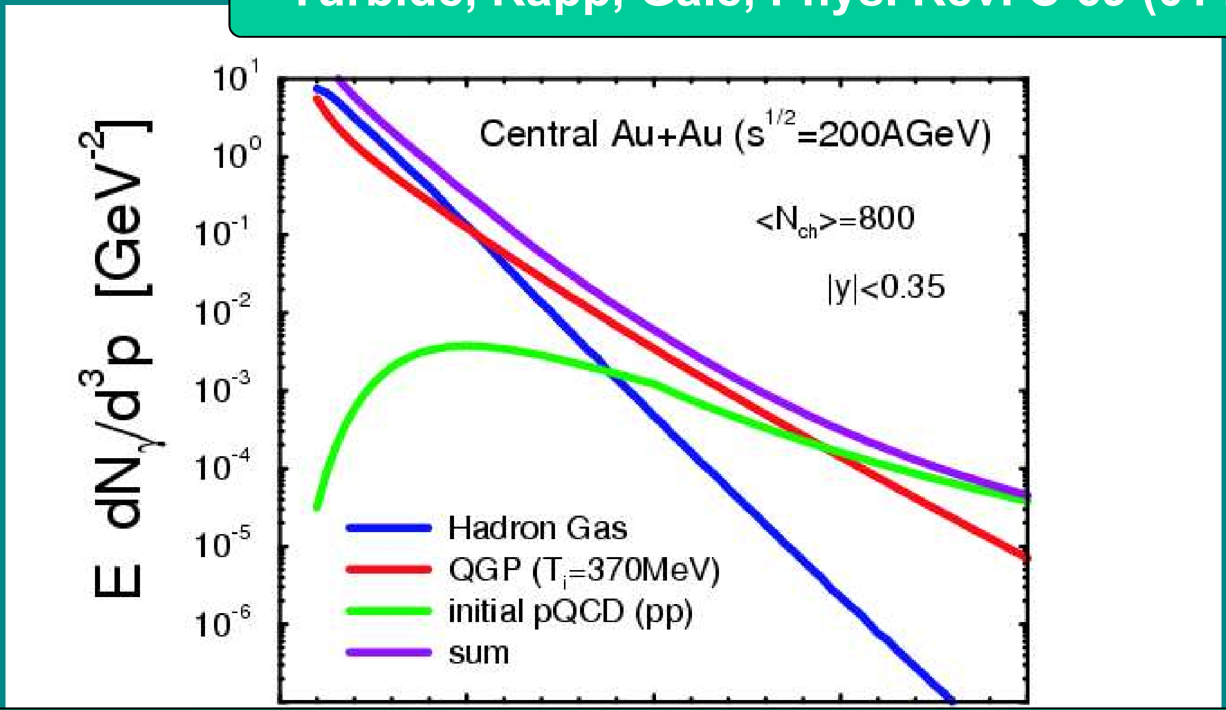
PHENIX

Thermal Radiation

What can we expect?

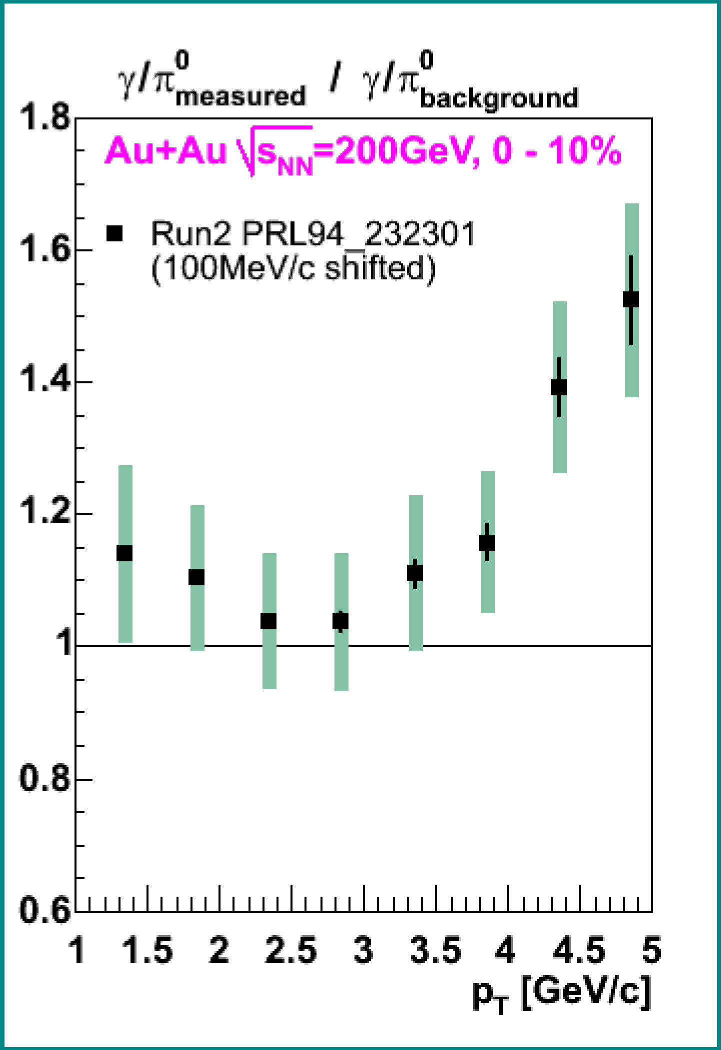
Turbide, Rapp, Gale, Phys. Rev. C 69 (014903), 2004



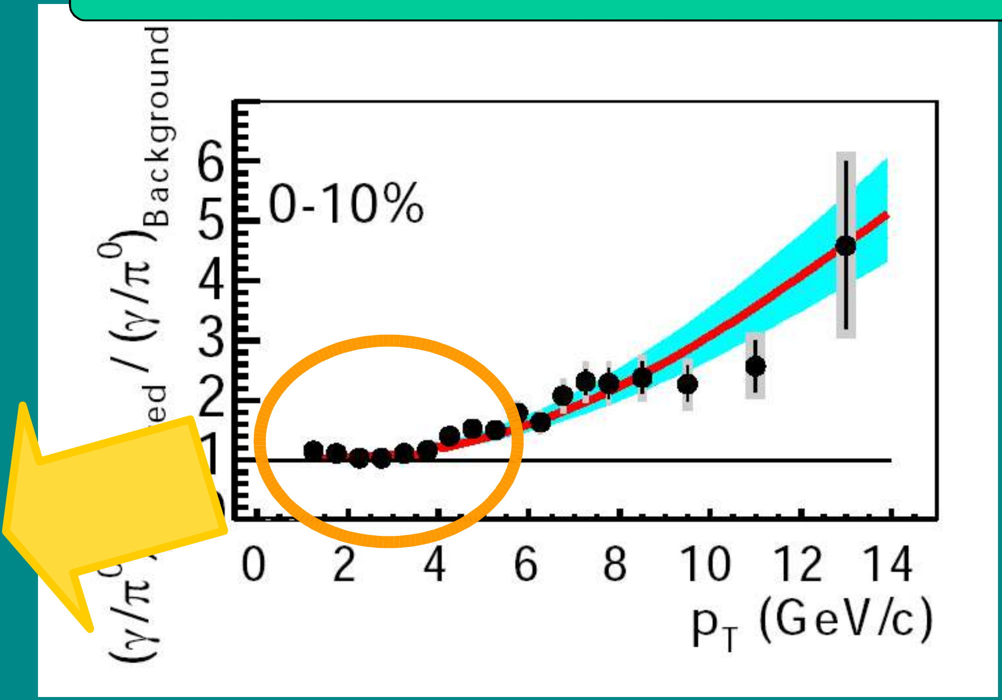
Can we measure photons at lower p_T ?

Can we measure thermal radiation ?

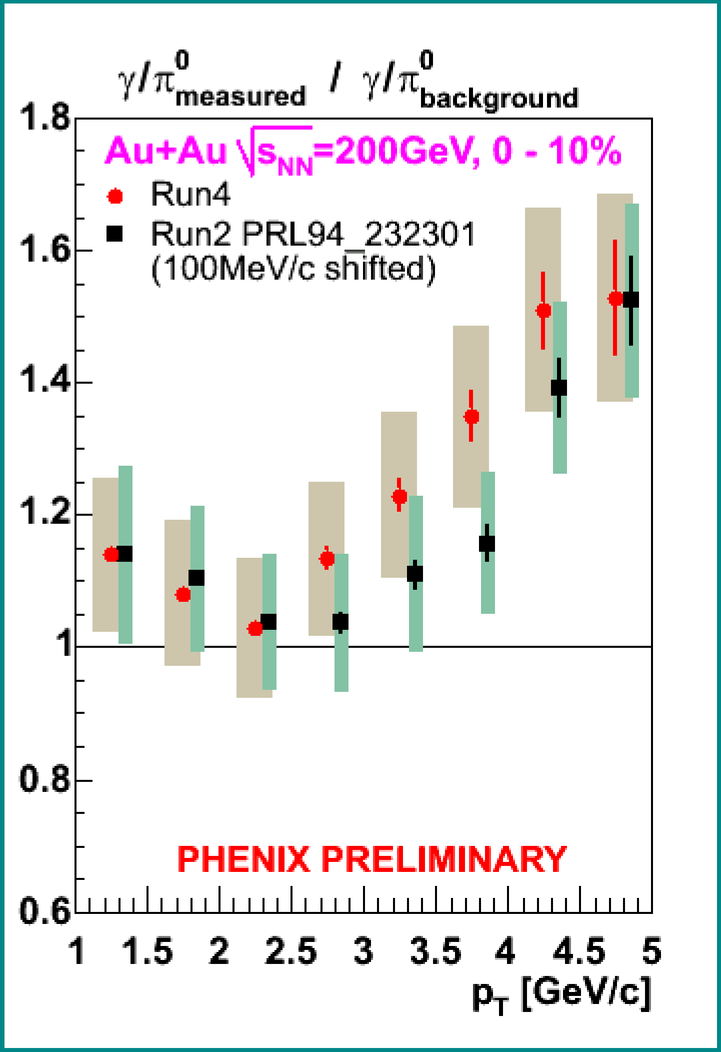
What's new since Run2 ?



Phys. Rev. Lett. 94, 232301 (2005)



What’s new since Run2 ?



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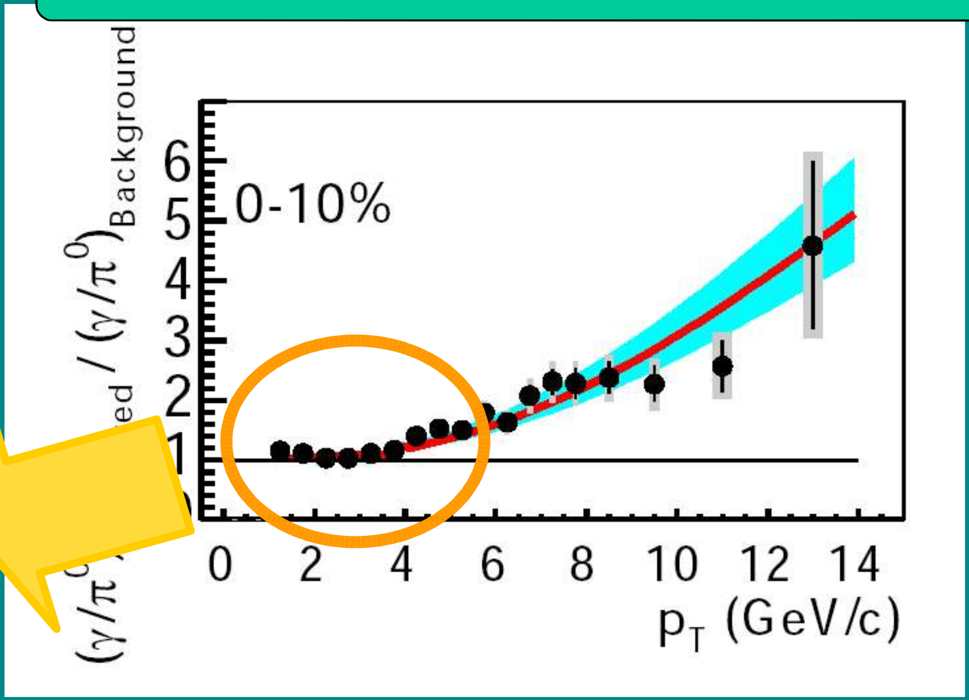
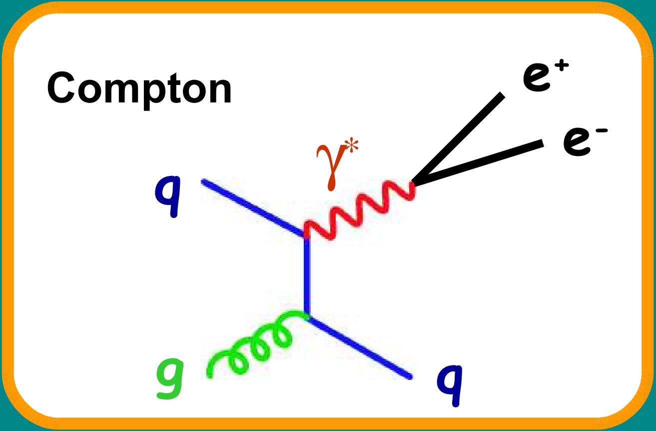


A New Approach in Our Field…

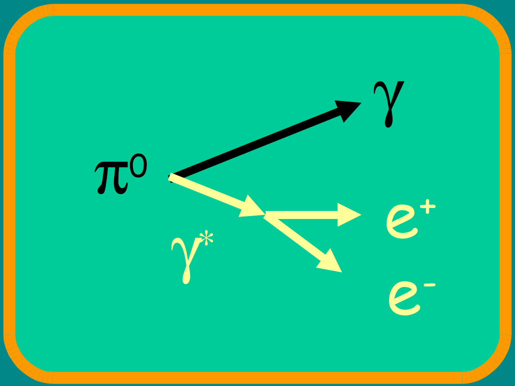


Use lepton pairs to measure

virtual γ

$$\frac{\gamma^*_{direct}}{\gamma^*_{incl.}} = \frac{\gamma_{direct}}{\gamma_{incl.}}$$

Any source of real γ emits virtual γ with very low mass



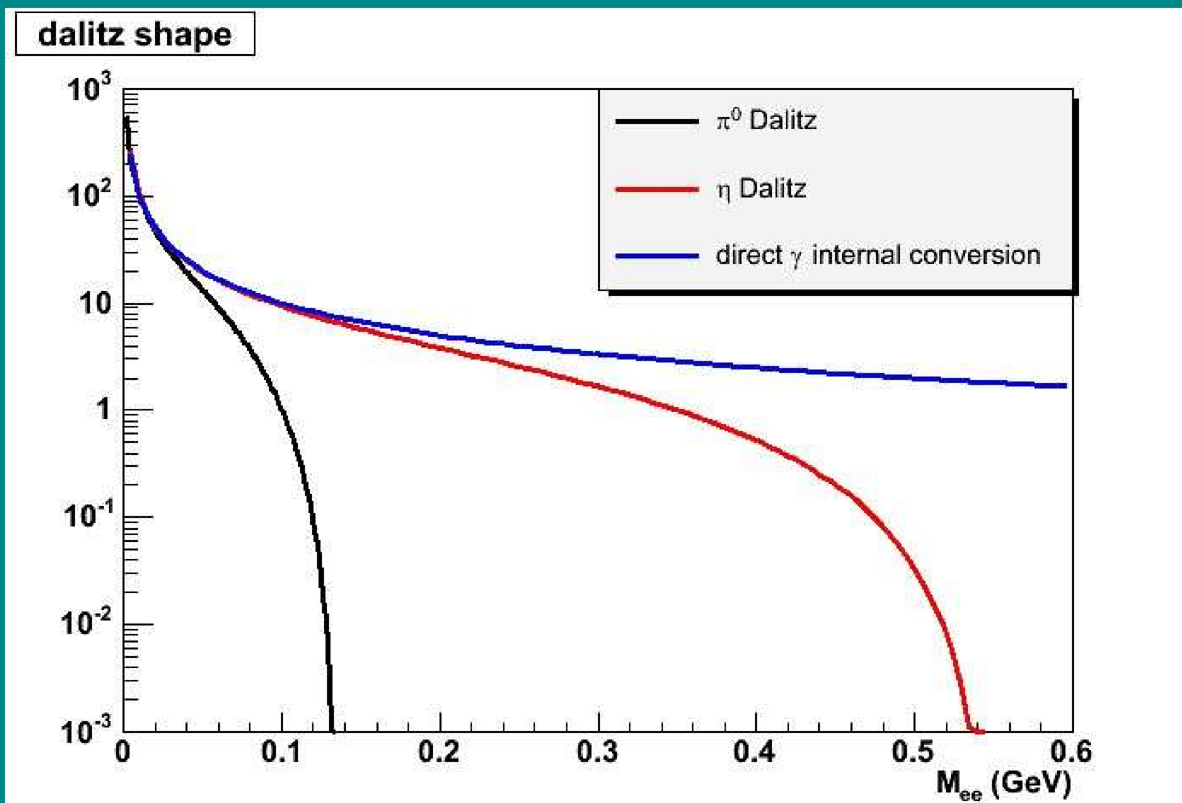
Background from Dalitz decay

PHENIX features

- ***Low conversion rate***
- ***Excellent mass resolution***
- ***High statistics in Run2004***

Inv. Mass Distribution of Dalitz Pairs

$$\frac{1}{N_\gamma}\frac{dN_{ee}}{dm_{ee}} = \frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right)\frac{1}{m_{ee}}\left|F(m_{ee}^2)\right|^2\left(1-\frac{m_{ee}^2}{M^2}\right)^3$$



phase space factor

→ 1 for high p_T γ

Inv. Mass Distribution of Dalitz Pairs

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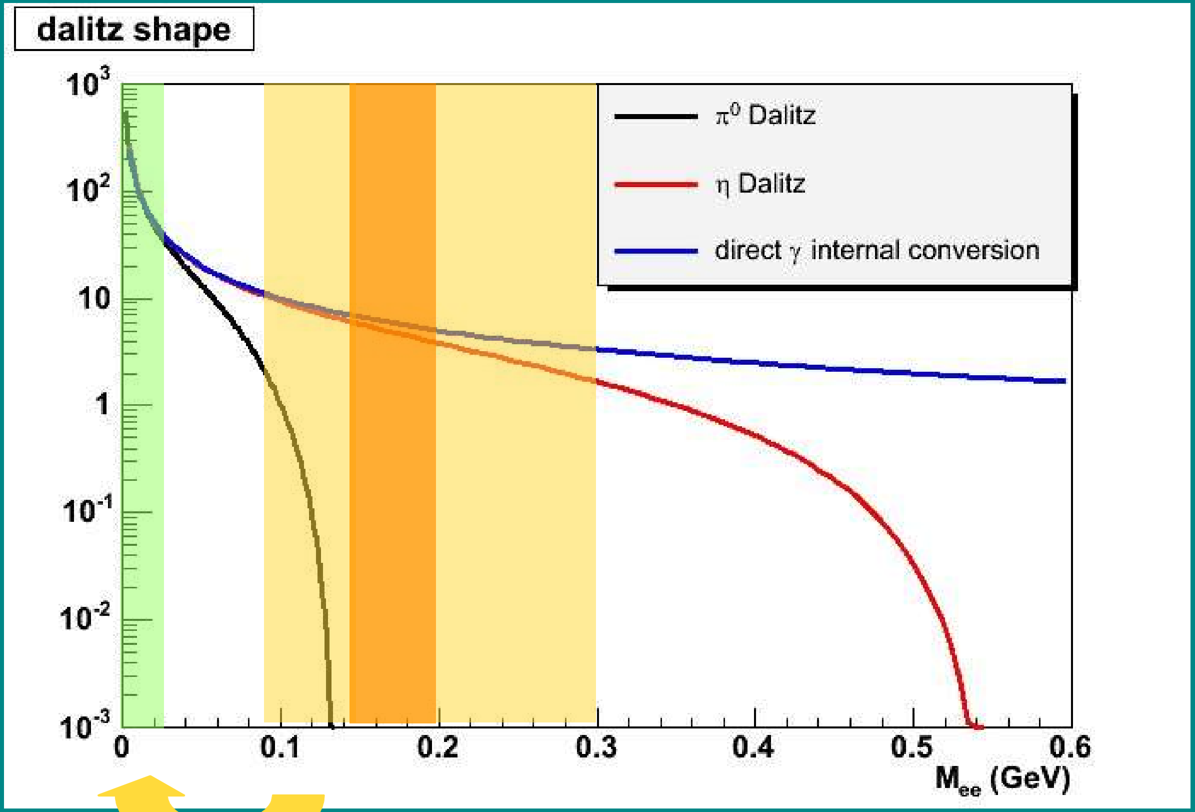


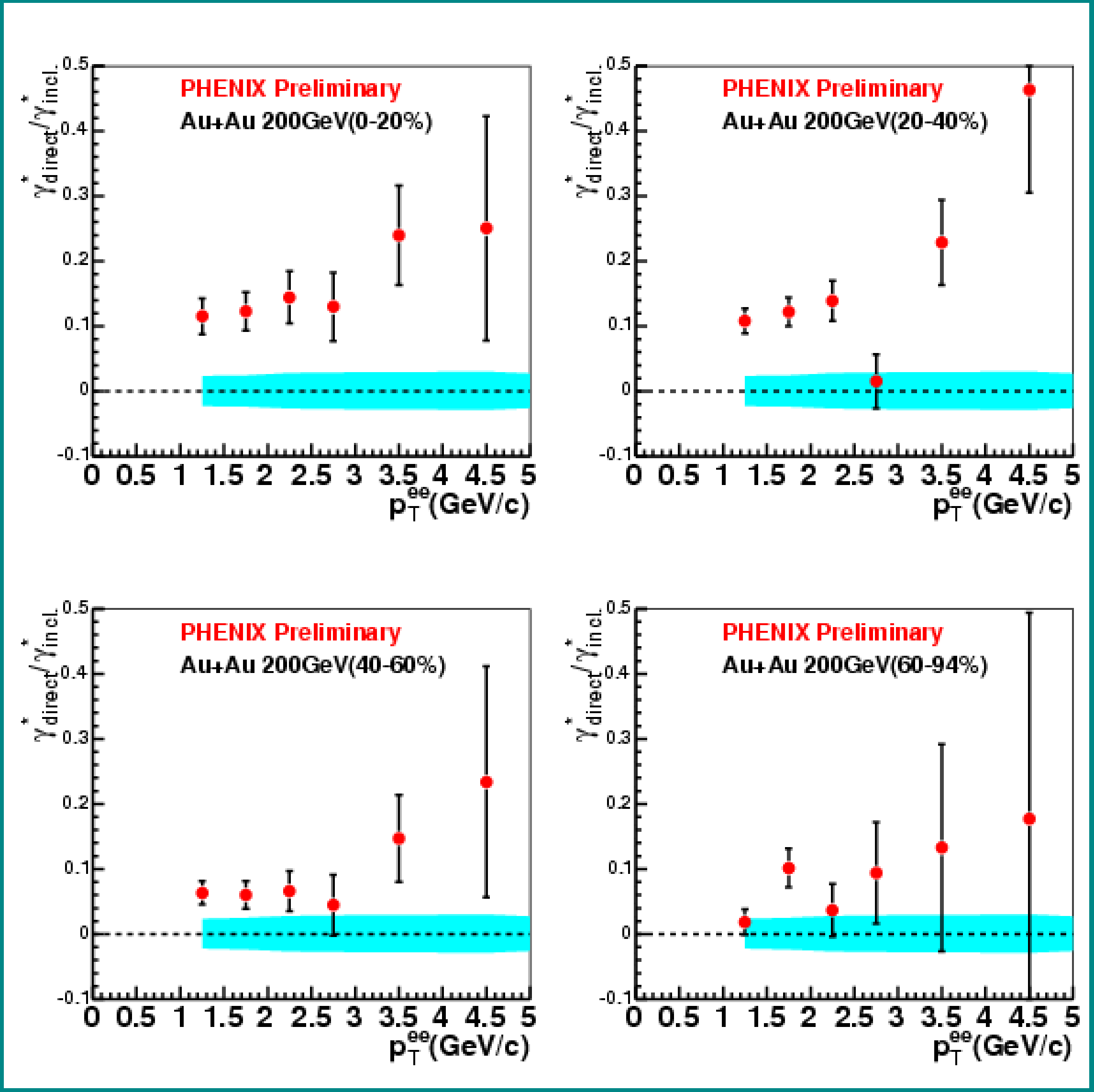
phase space factor
→ 1 for high p_T γ

- **Ratios of M_{inv} bins to lowest one**
- **If no direct photons: ratios can be calculated from Dalitz decays**
- **If excess: direct photons**

γ^*_{direct} / $\gamma^*_{inclusive}$

0-20%

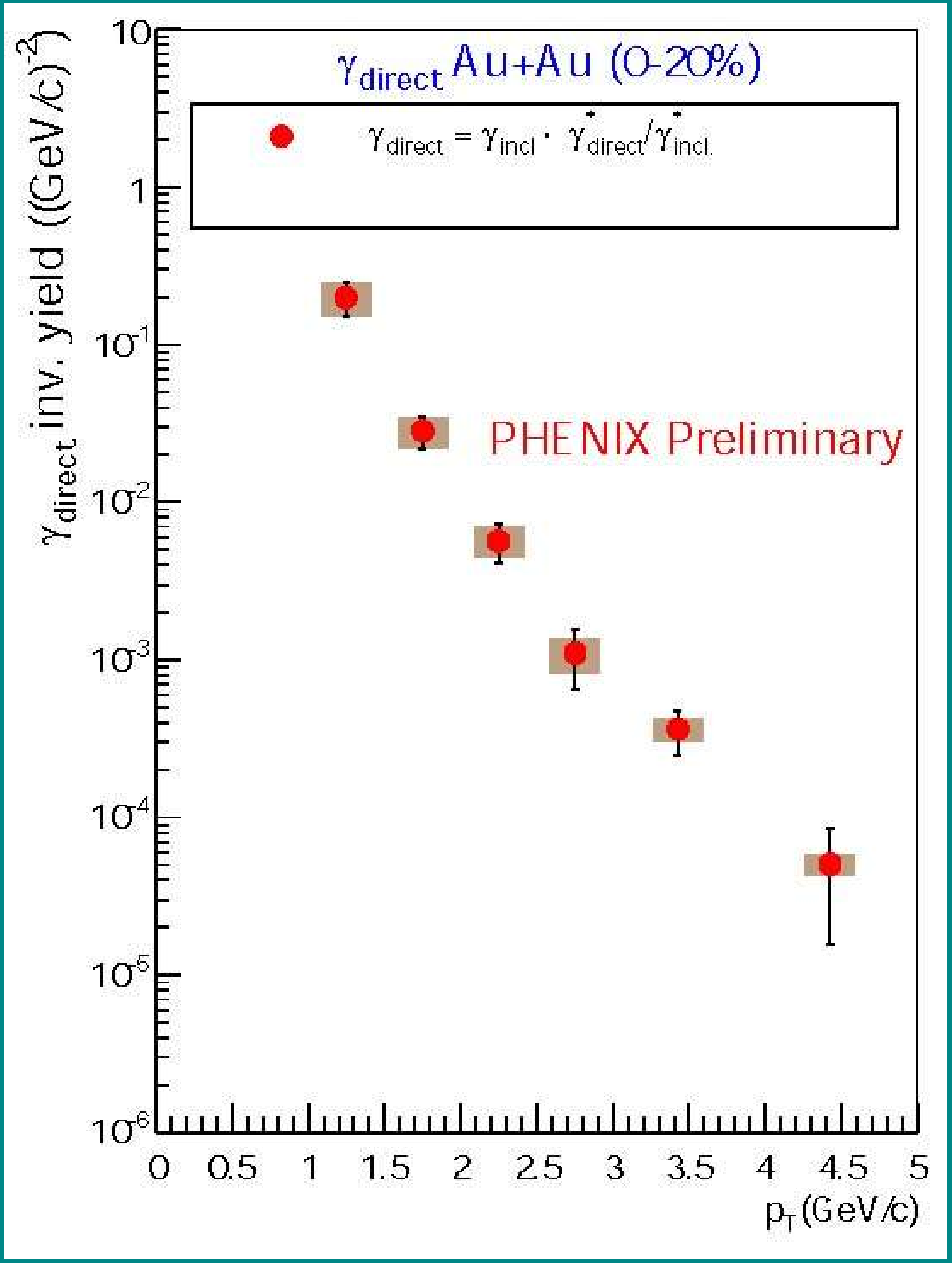
20-40%



40-60%

60-94%

Extracting the Yield

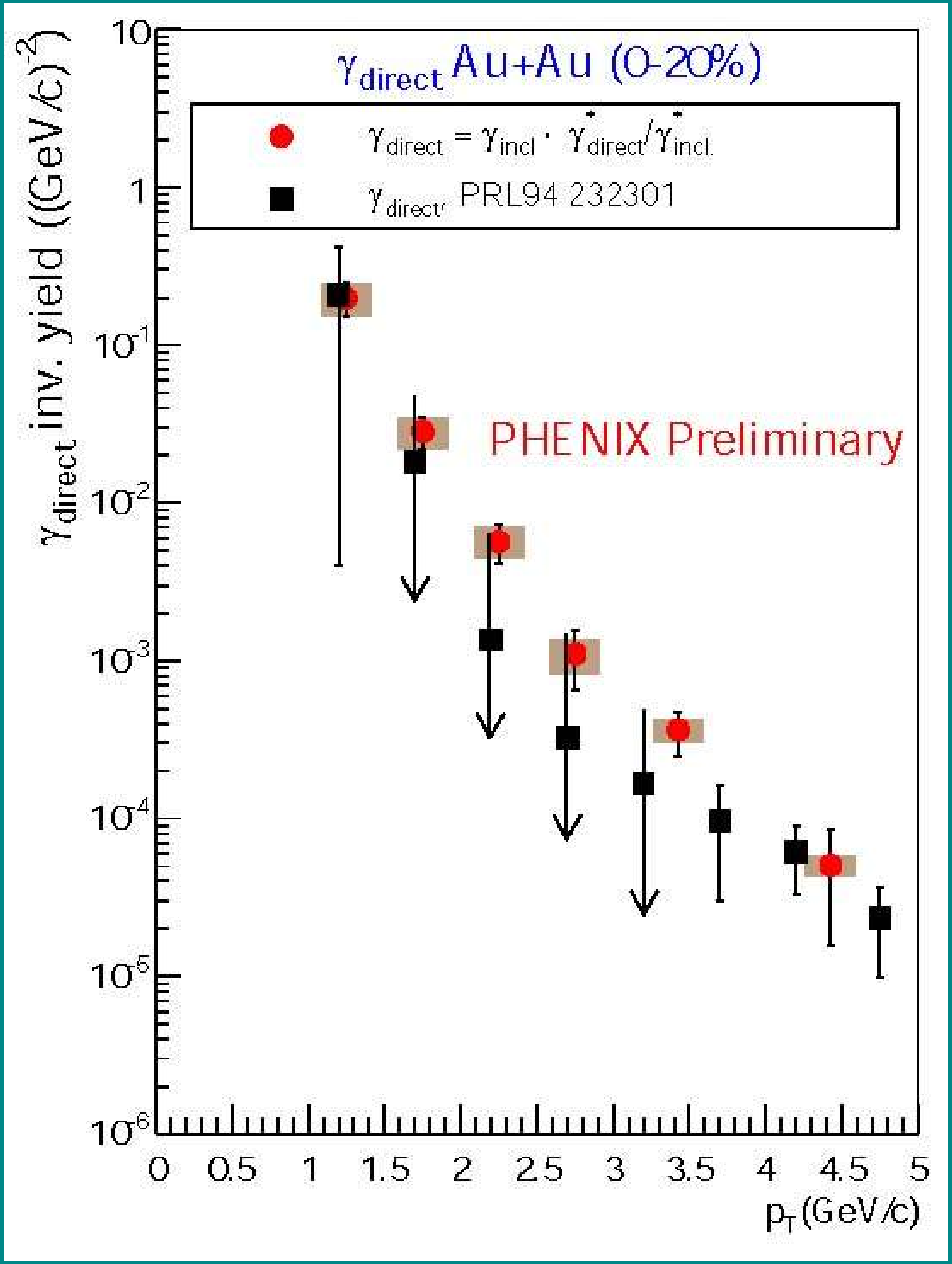


$$\gamma_{direct} = \gamma_{incl.}(\gamma^*_{direct} / \gamma^*_{incl.})$$

New Ratio

Measured inclusive spectrum

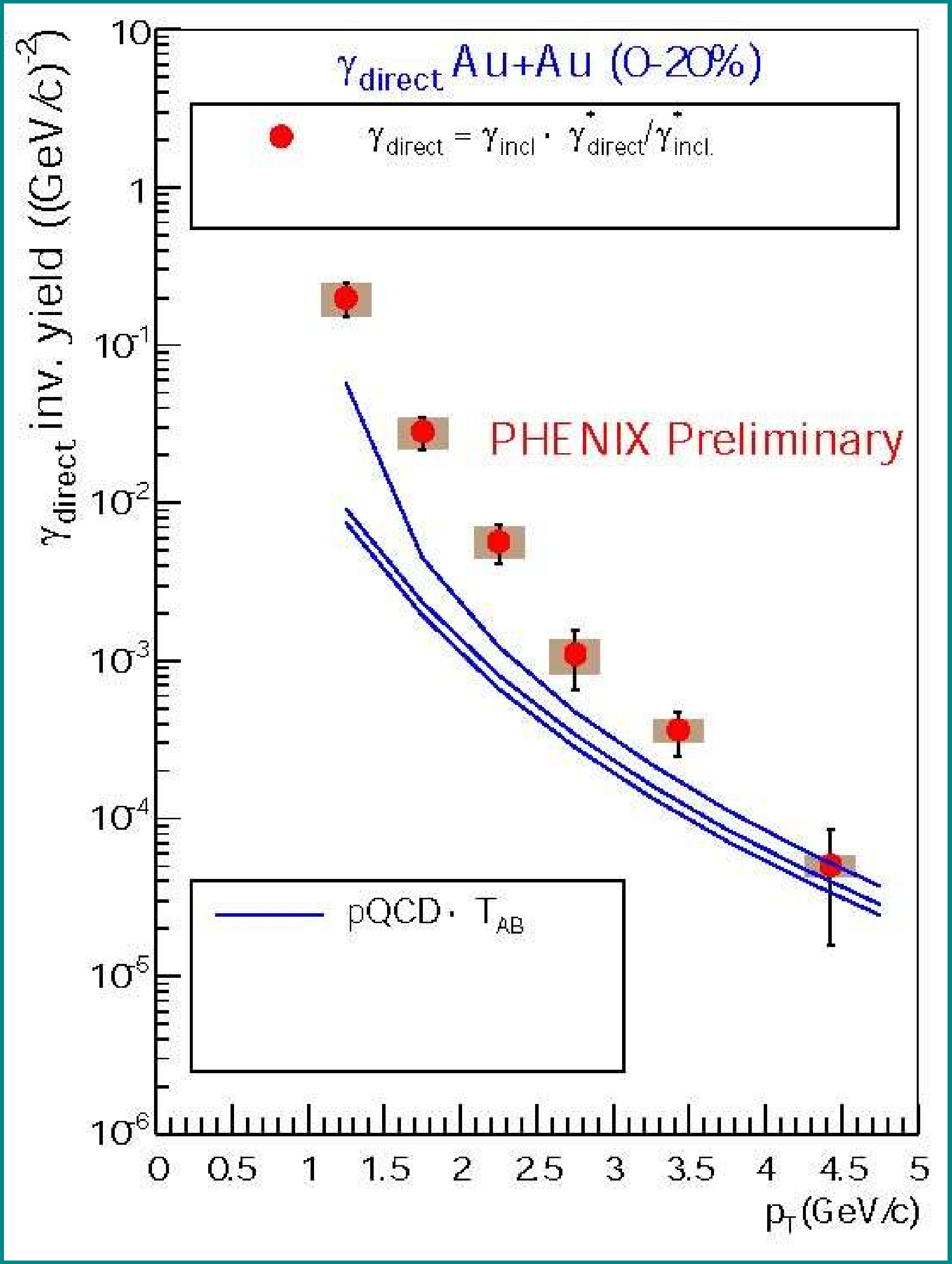
Extracting the Yield



$$\gamma_{direct} = \gamma_{incl.}(\gamma^*_{direct} / \gamma^*_{incl.})$$

Run2 data:
Phys. Rev. Lett. 94, 232301 (2005)

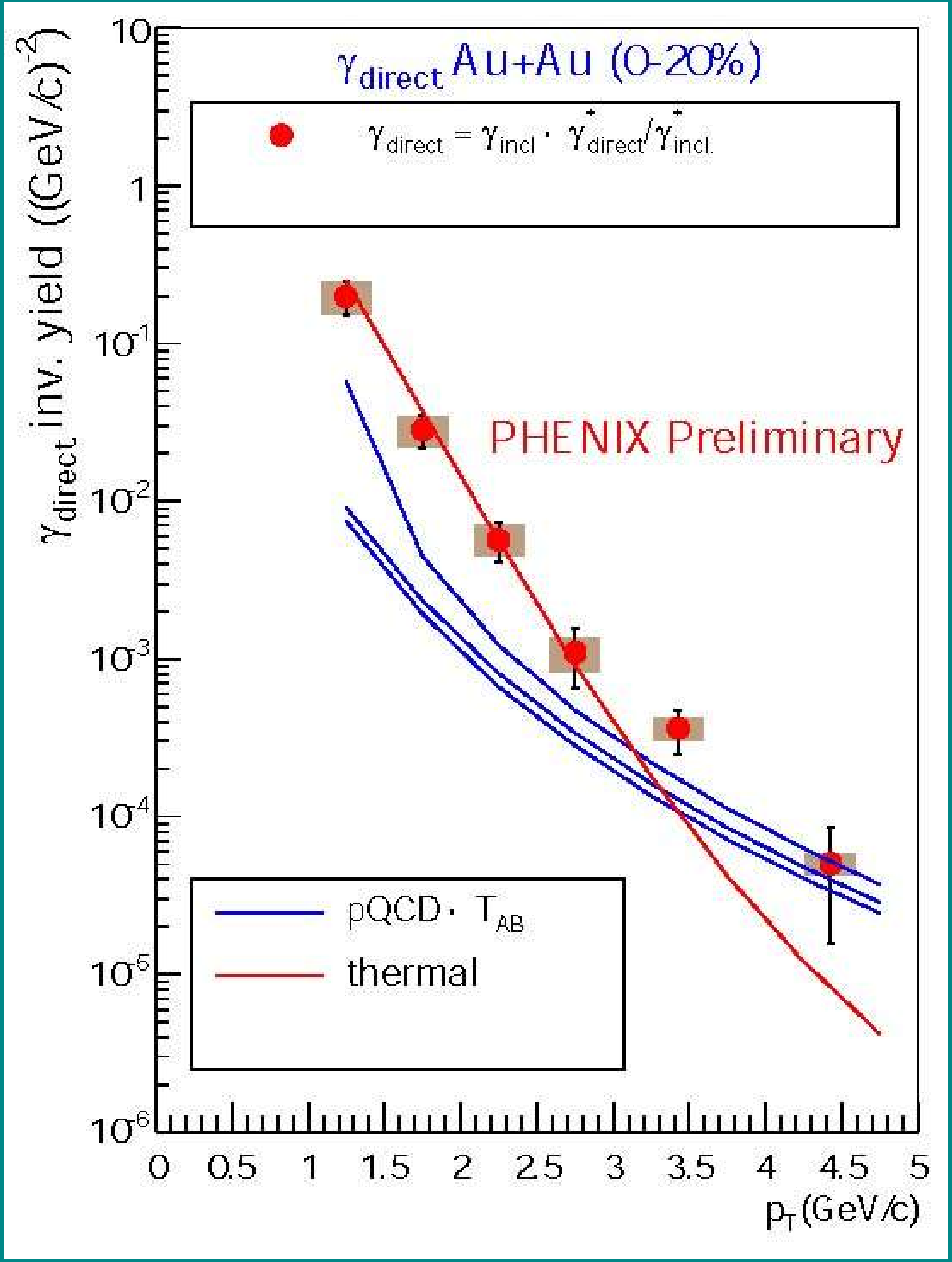
Extracting the Yield



$$\gamma_{direct} = \gamma_{incl.}(\gamma^*_{direct} / \gamma^*_{incl.})$$

pQCD x T_{AB}:
L.E.Gordon and W. Vogelsang
Phys. Rev. D48, 3136 (1993)

Extracting the Yield



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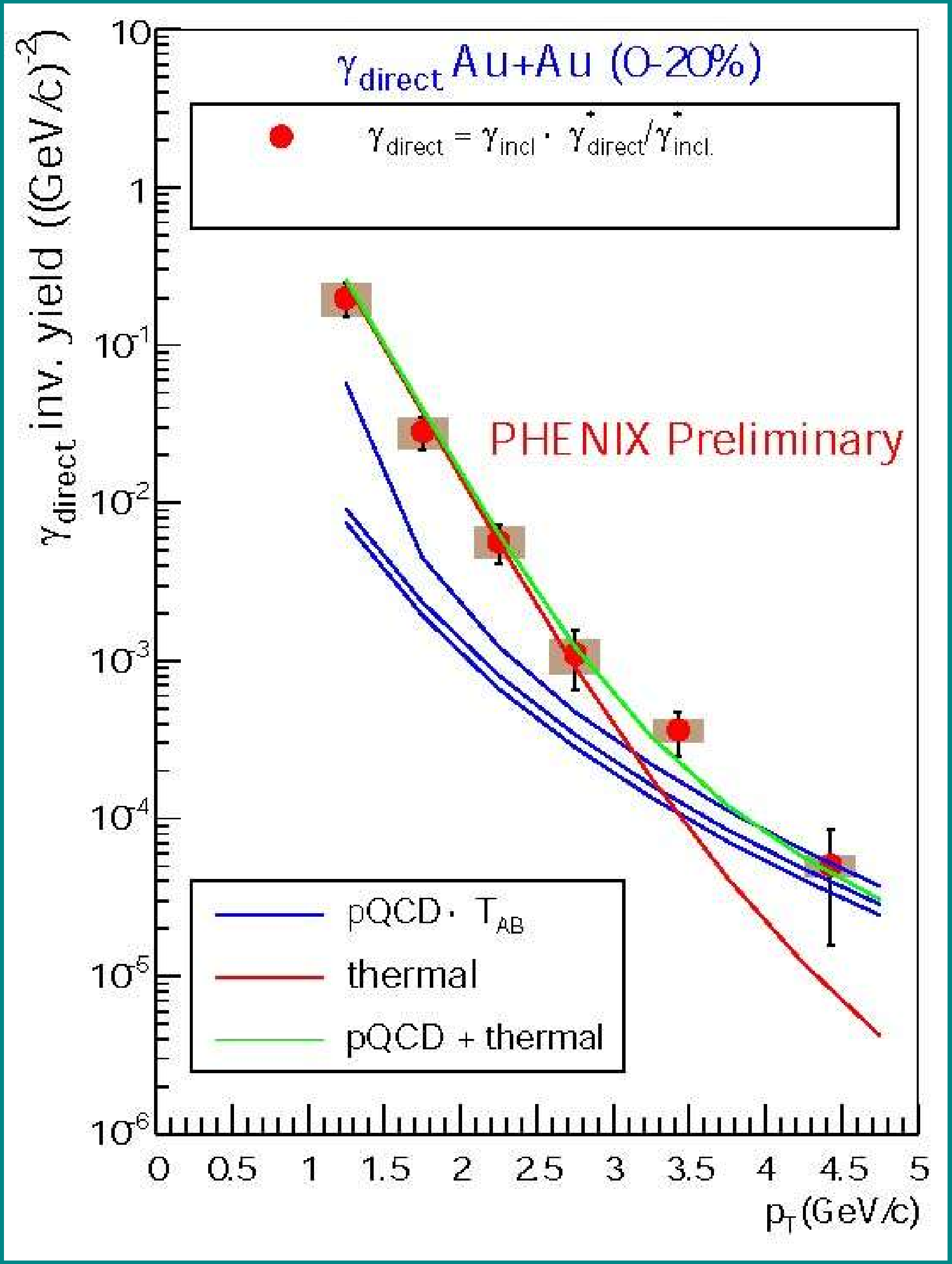
thermal:
D. d'Enterria, D. Perresounko
nucl-th/0503054
2+1 hydro
T_0=590 MeV
τ_0=0.15 fm/c

Extracting the Yield



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6b Stefan Bathe

Conclusion

- First promising results to measure direct photon production at low p_T
- ***Thermal radiation?***

- ***Reference measurement needed***
  pp and dAu
  Same analysis method

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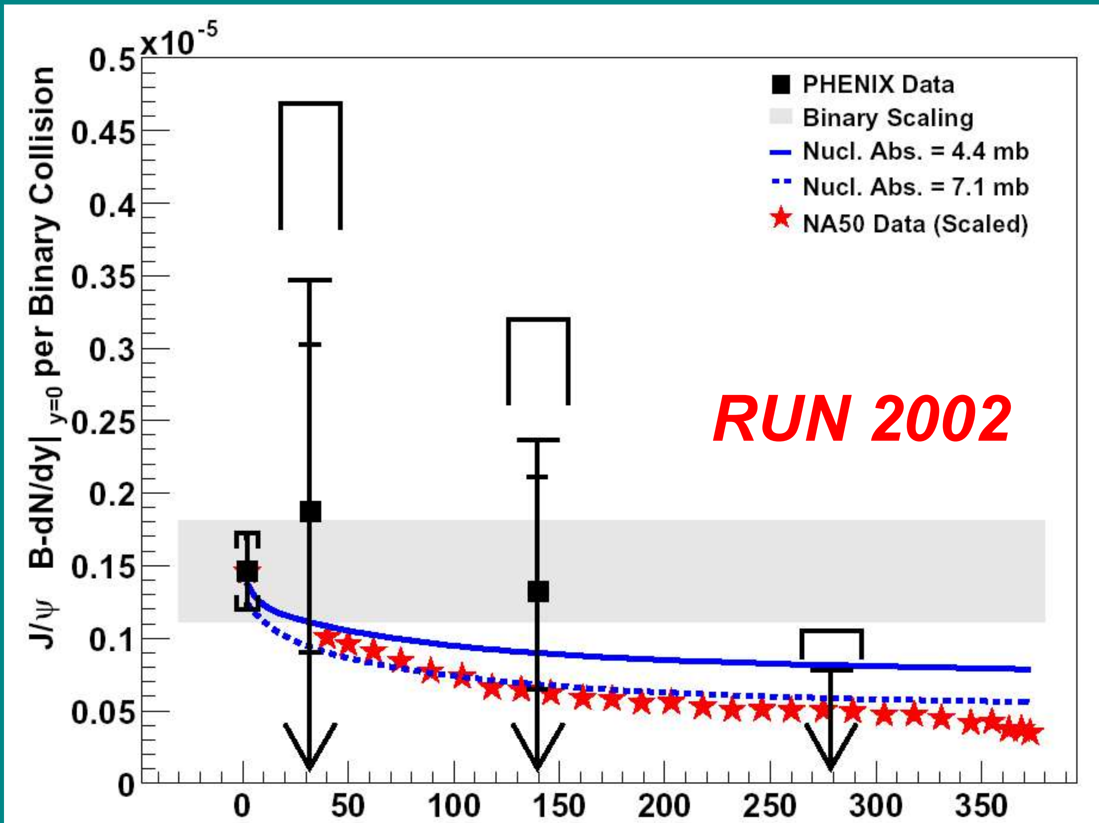
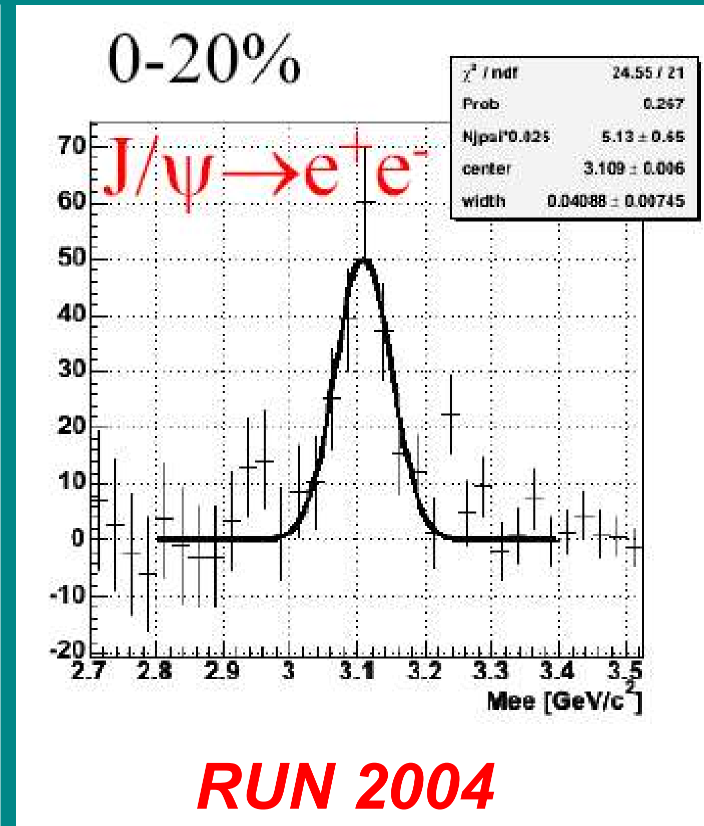
PHENIX

J/ψ Suppression

A Long Way Since Run2..

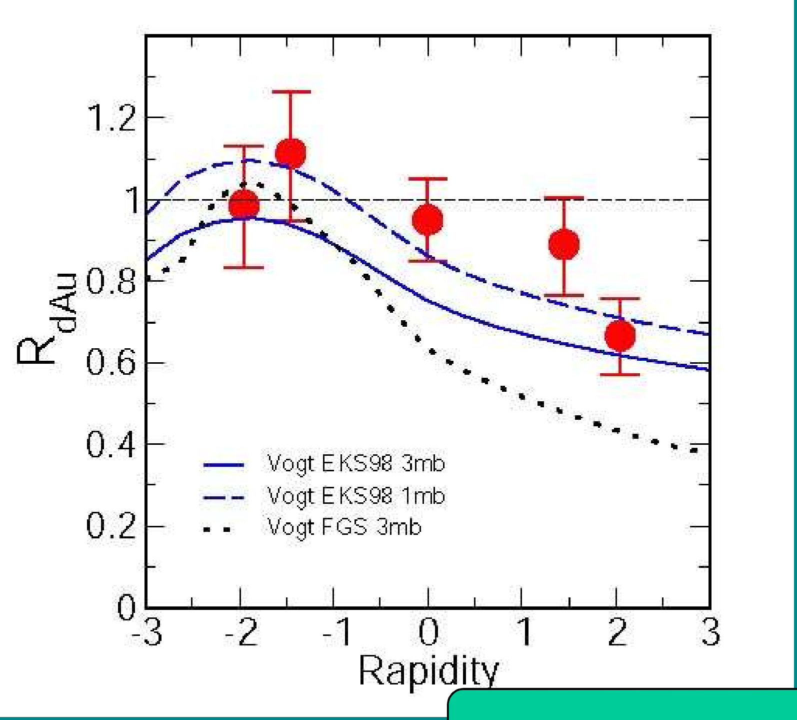




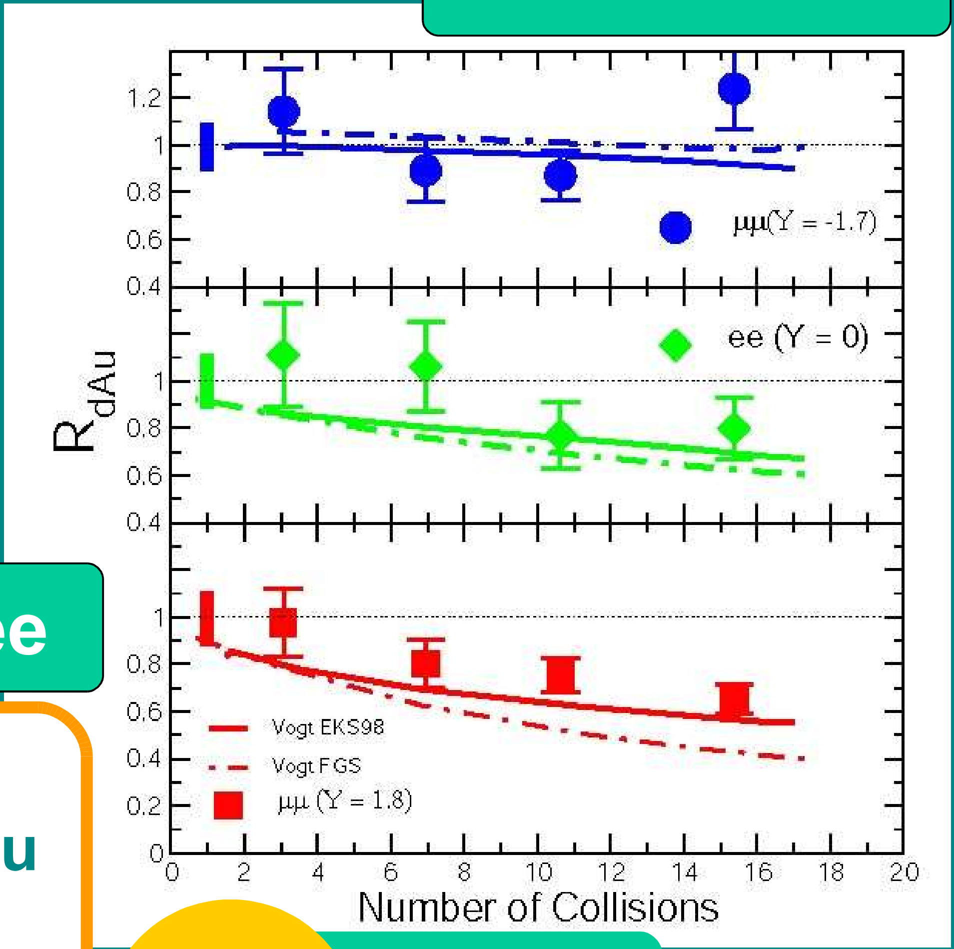
?

Is the J/ψ production consistent with normal nuclear matter effects?

Setting the Stage: dAu, pp



nucl-ex / 0507032



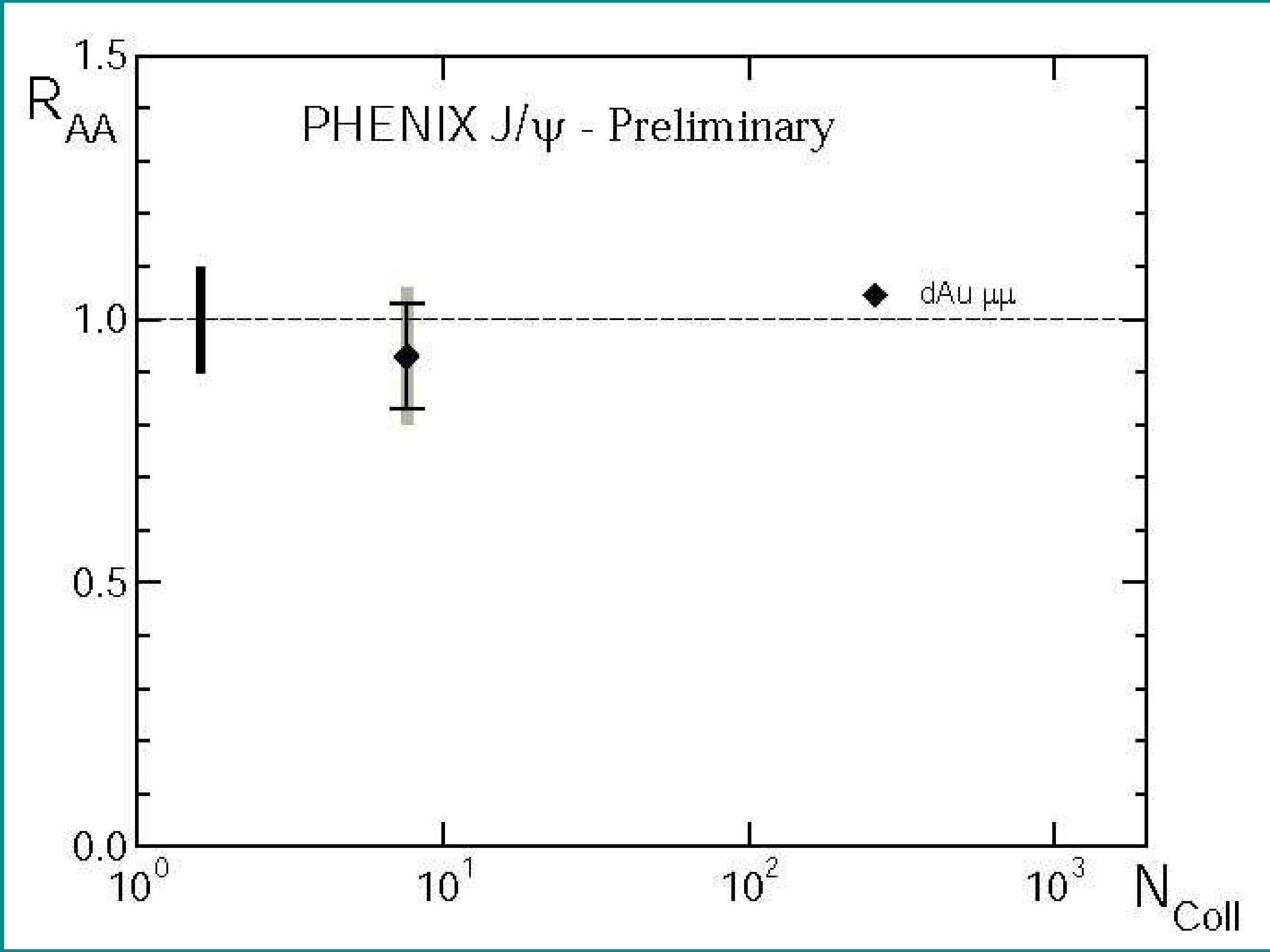
J/ψ → μμ,ee

- Theory: σ_{abs} = 1-3 mb
- Baseline for AA: pp and dAu
- Need higher statistics
- Better pp data from run5
- New run needed for (p)dAu

5c

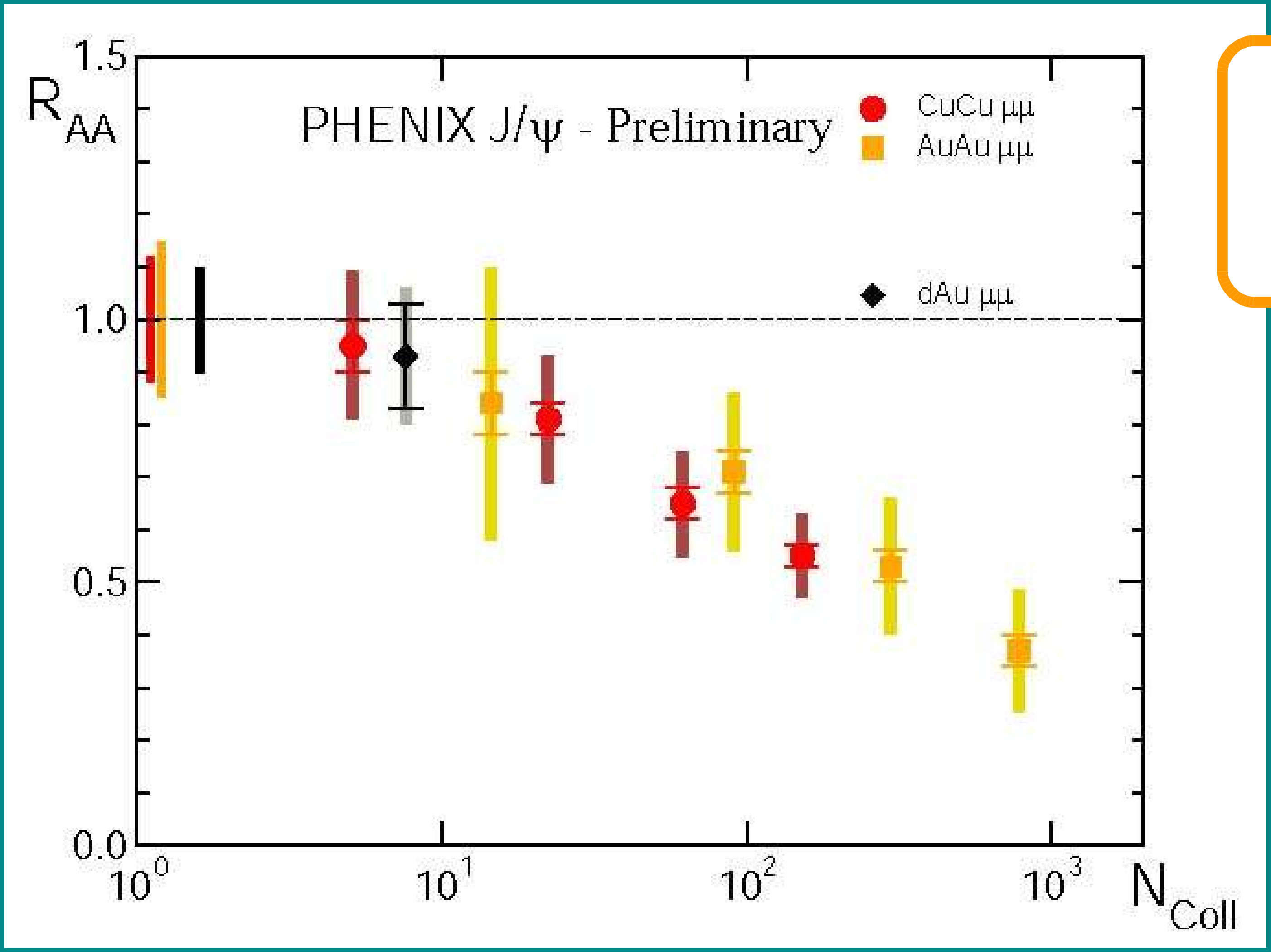
Xie Wei

System-Size Dependence



dAu
μμ
200 GeV/c

System-Size Dependence



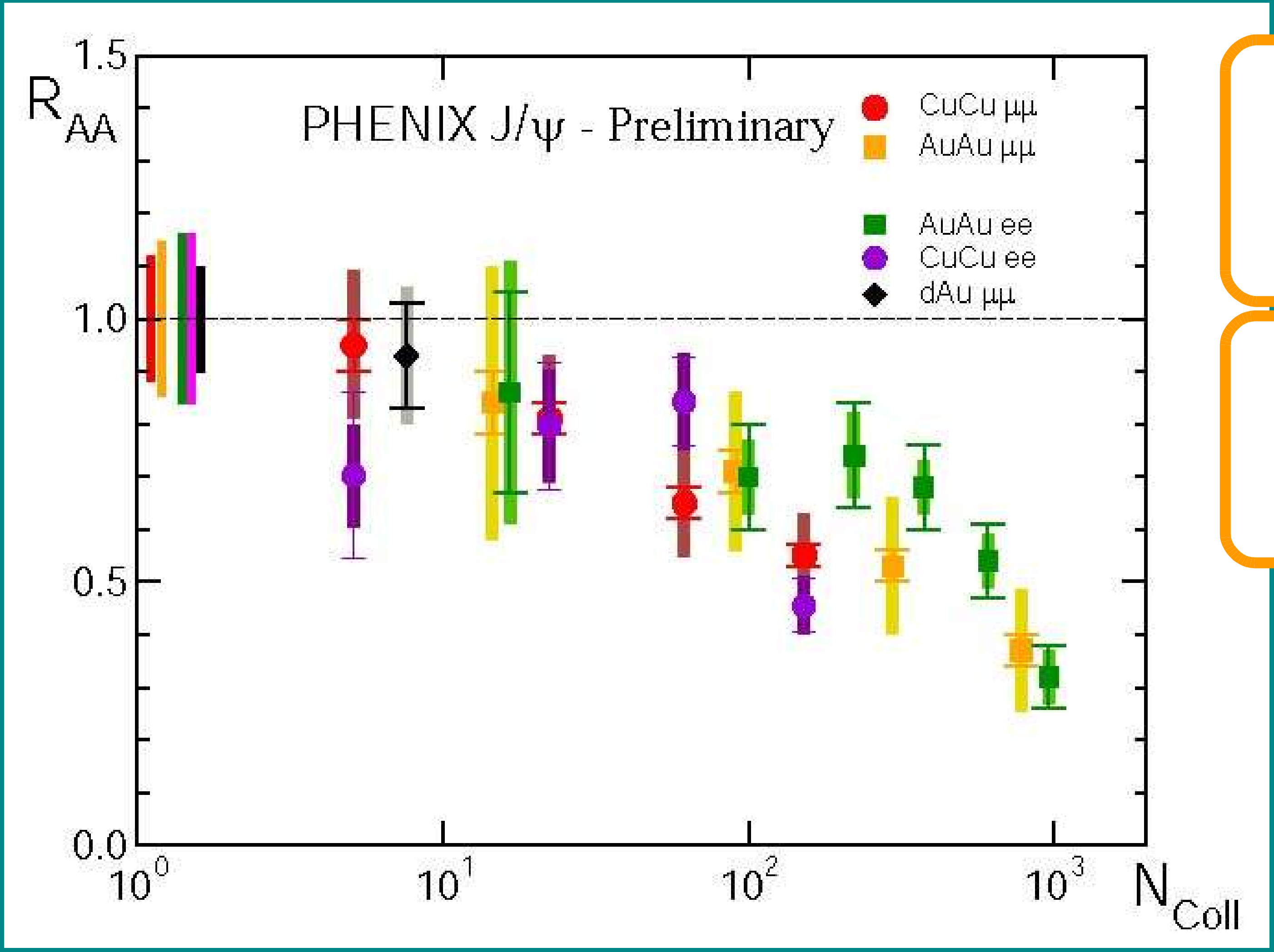
J/ψ → μμ
muon arm
1.2 < |y| < 2.2

dAu
μμ
200 GeV/c

AuAu
μμ
200 GeV/c

CuCu
μμ
200 GeV/c

System-Size Dependence

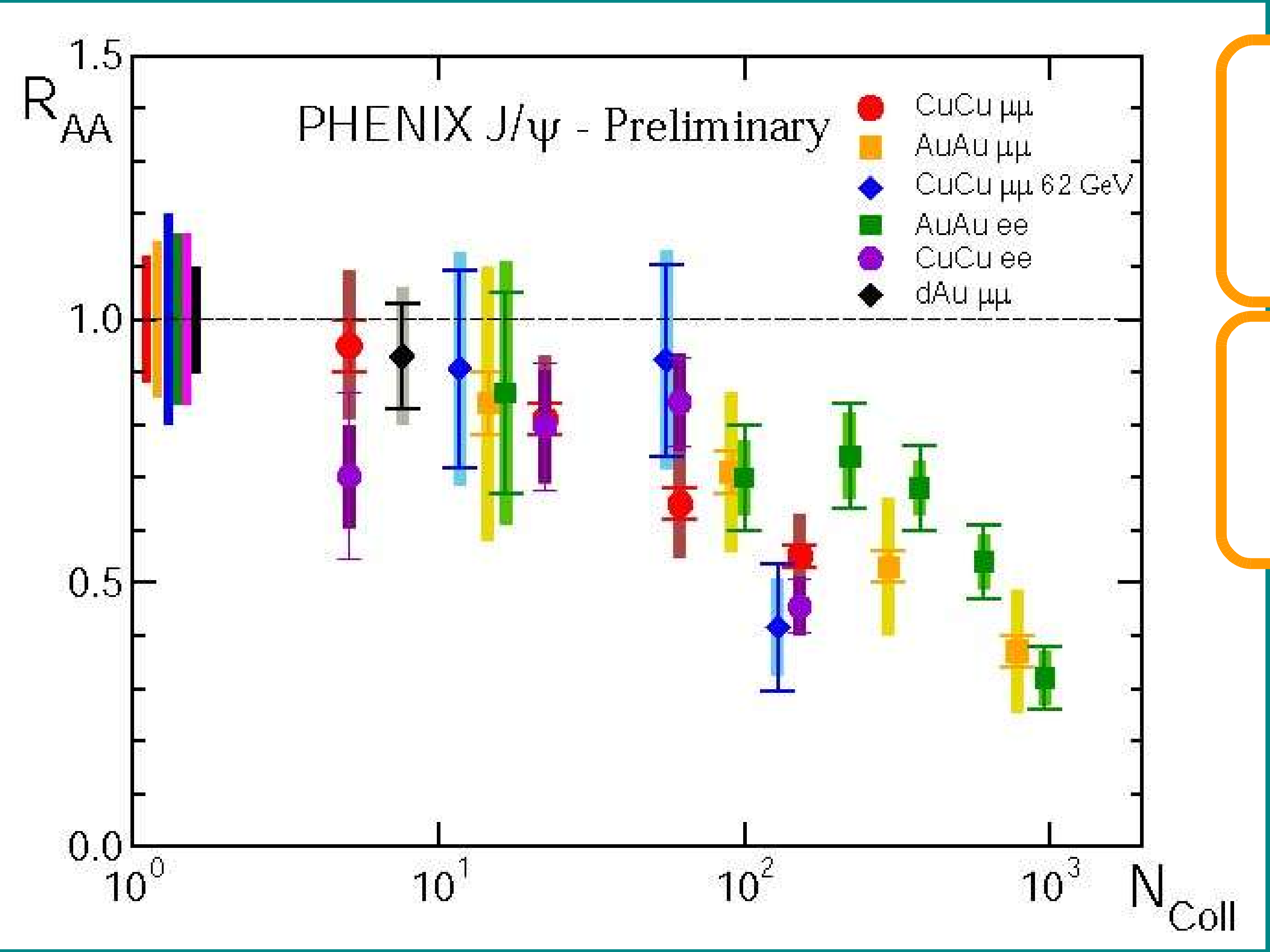


J/ψ → μμ
muon arm
1.2 < |y| < 2.2

J/ψ → ee
Central arm
-0.35 < y < 0.35

dAu	AuAu	CuCu	AuAu	CuCu
μμ	μμ	μμ	ee	ee
200 GeV/c	200 GeV/c	200 GeV/c	200 GeV/c	200 GeV/c

System-Size Dependence

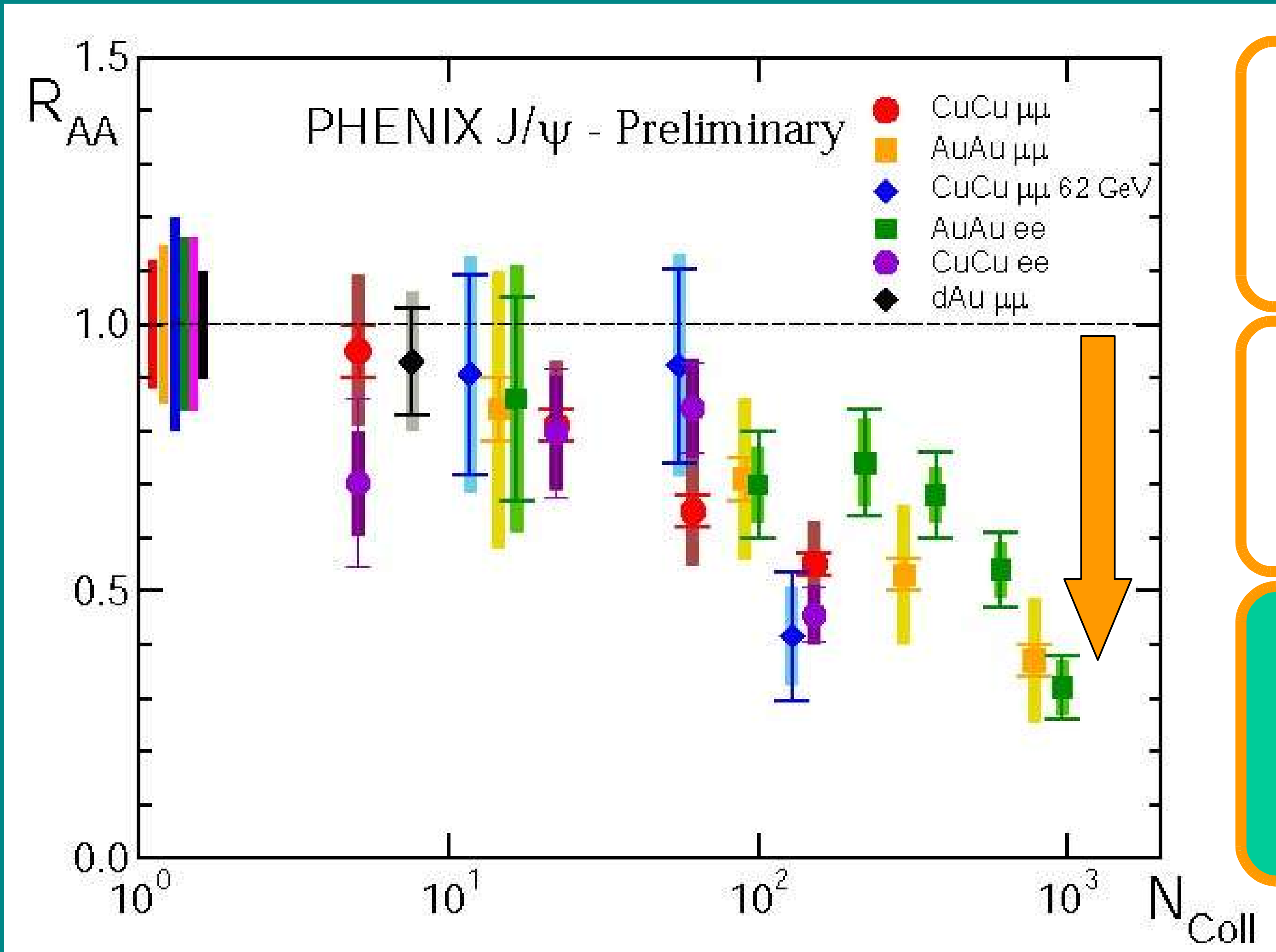


J/ψ → μμ
muon arm
1.2 < |y| < 2.2

J/ψ → ee
Central arm
-0.35 < y < 0.35

dAu μμ **200 GeV/c**	**AuAu** μμ **200 GeV/c**	**CuCu** μμ **200 GeV/c**	**AuAu ee 200 GeV/c**	**CuCu ee 200 GeV/c**	**CuCu** μμ **62 GeV/c**

System-Size Dependence



J/ψ → μμ
muon arm
1.2 < |y| < 2.2

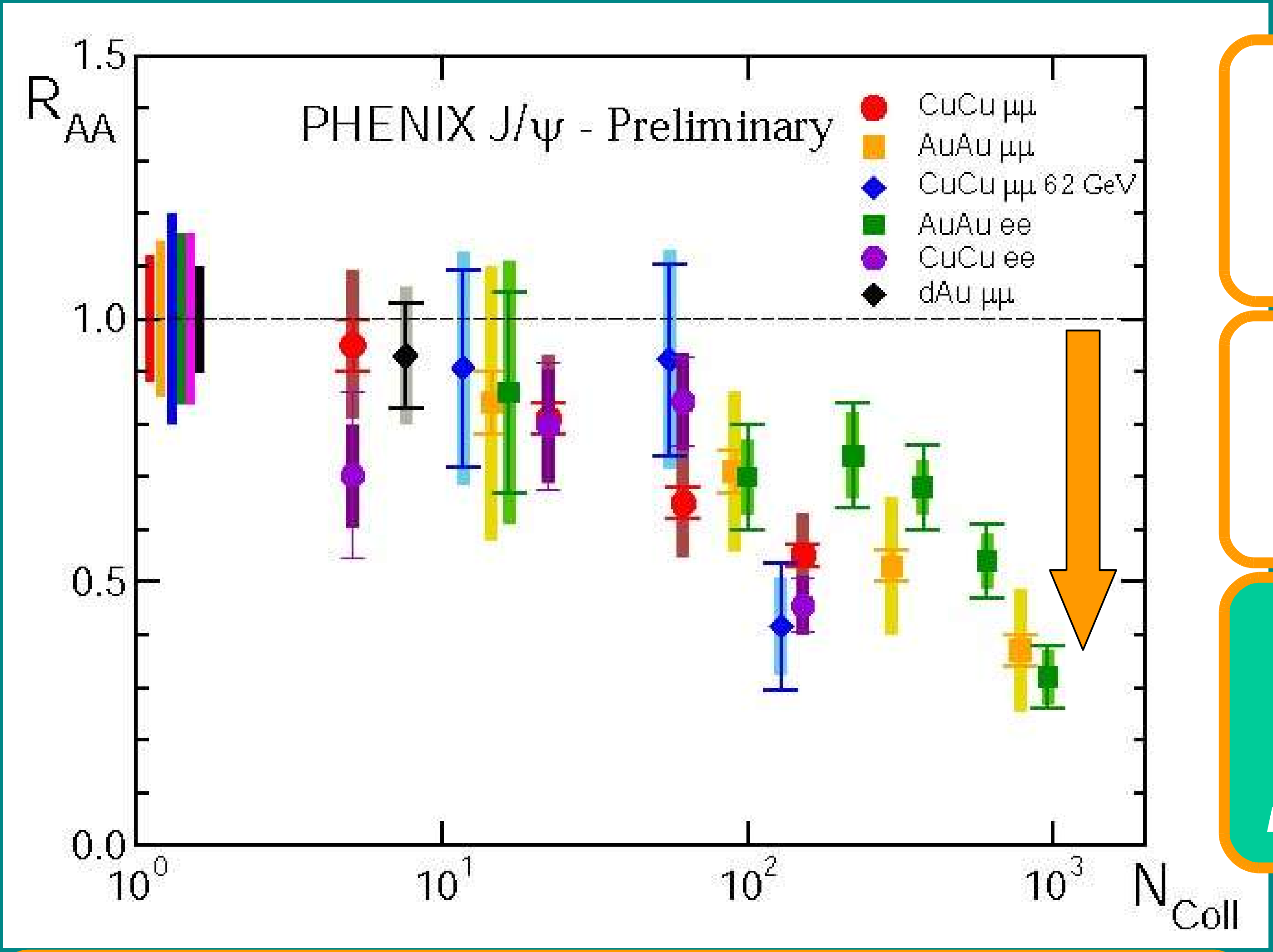
J/ψ → ee
Central arm
-0.35 < y < 0.35

Factor ~3 suppression in central events

!

dAu	**AuAu**	**CuCu**	**AuAu**	**CuCu**	**CuCu**
μμ	μμ	μμ	**ee**	**ee**	μμ
200 GeV/c	**200 GeV/c**	**200 GeV/c**	**200 GeV/c**	**200 GeV/c**	**62 GeV/c**

System-Size Dependence



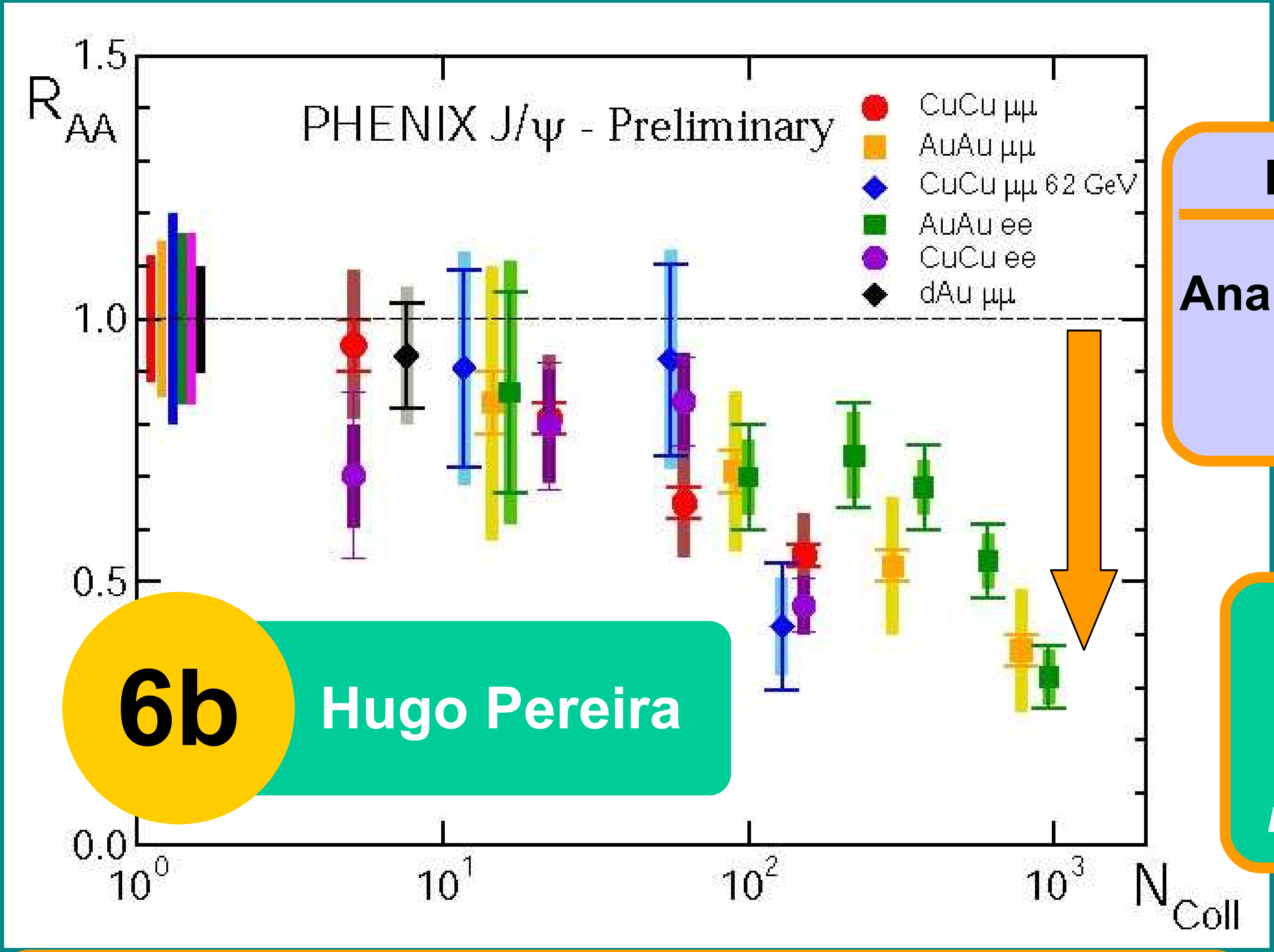
J/ψ → μμ
muon arm
1.2 < |y| < 2.2

J/ψ → ee
Central arm
-0.35 < y < 0.35

Factor ~3 suppression in central events!

Data show the same trends within errors for all species and even 62 GeV

System-Size Dependence



6b Hugo Pereira

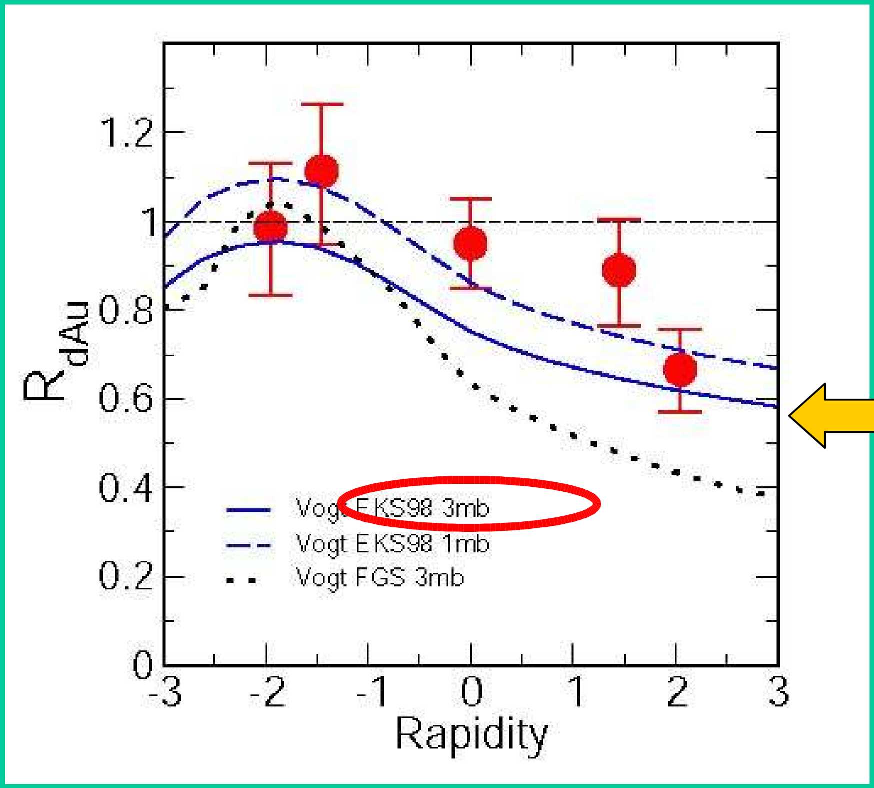
PHENIX feature

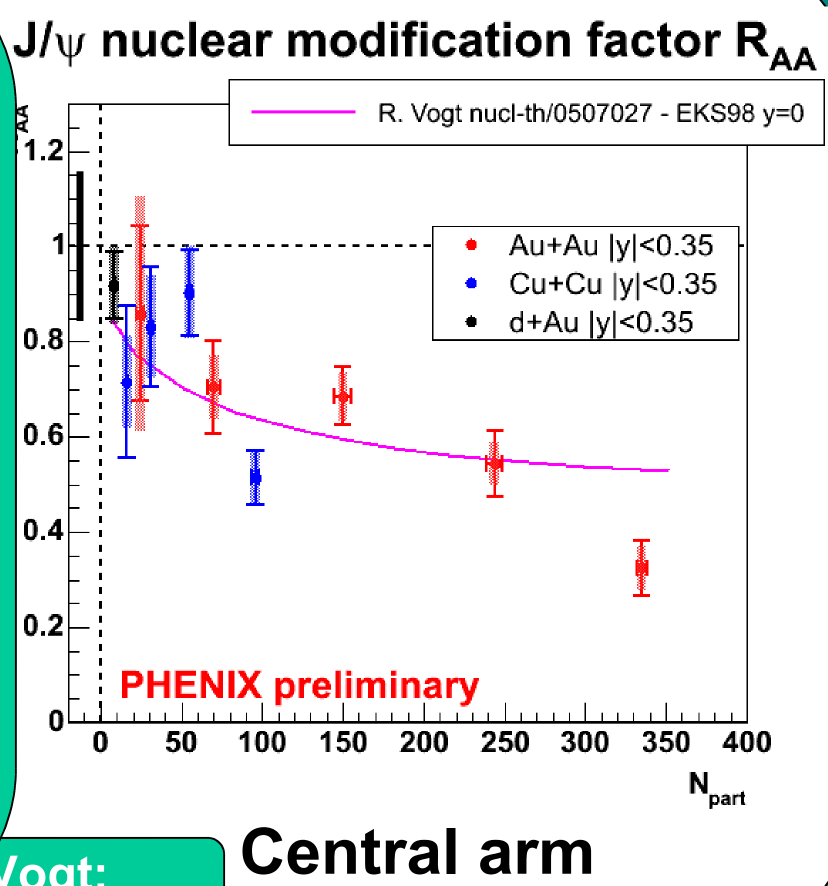
Analyzed full statistics
- **AuAu Run2004**
- **CuCu Run2005**

Factor ~3 suppression in central events

Data show the same trends within errors for all species and even 62 GeV

Comparison to Theory

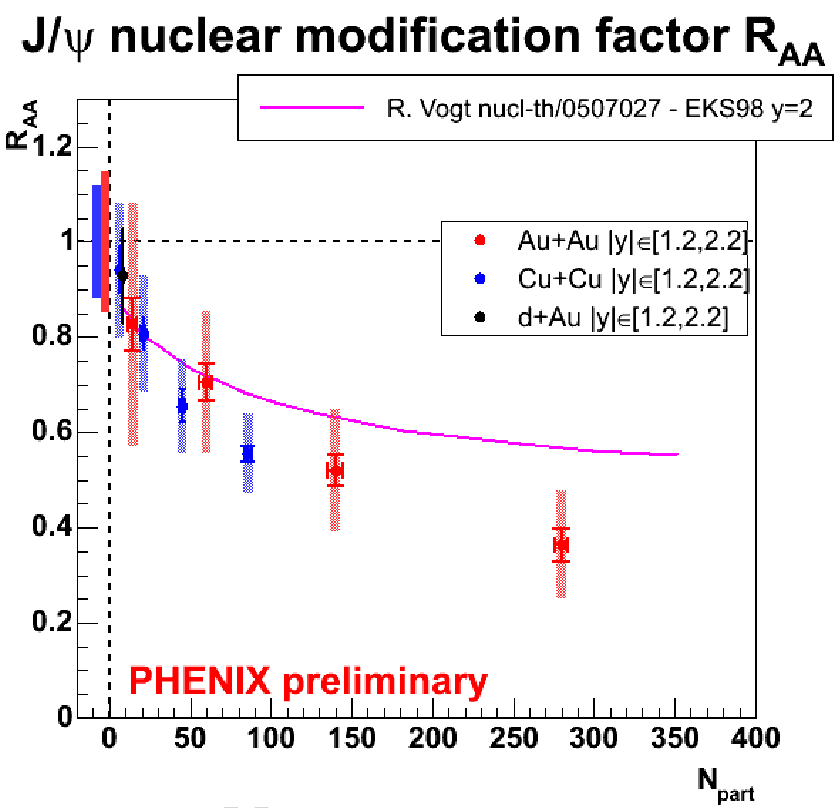




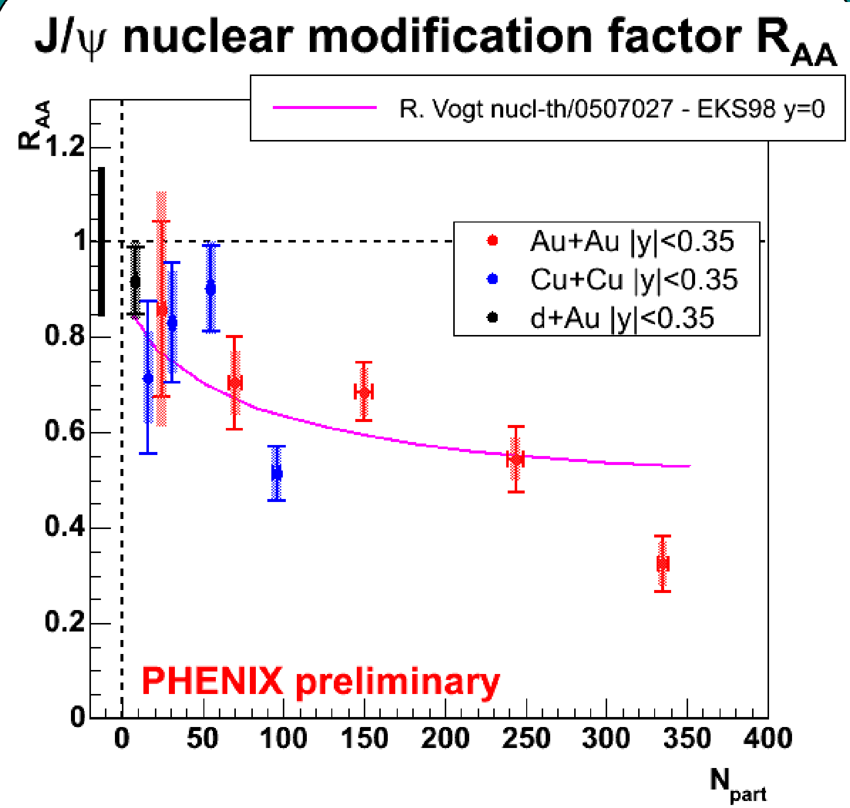
Vogt:
nucl-th/0507027

Model of cold nuclear matter effects in agreement with dAu:

Comparison to Theory



Muon arm

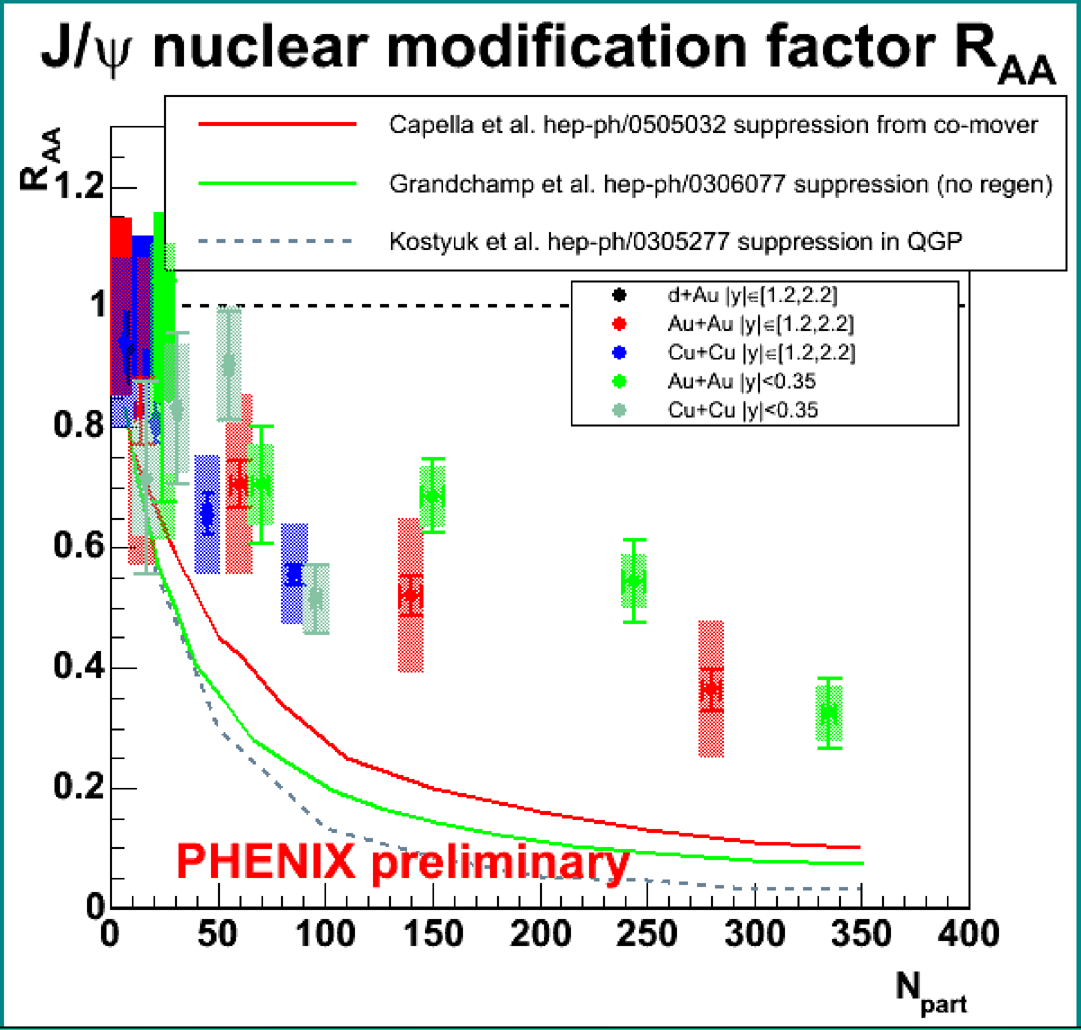


Central arm

Theory Vogt:
nucl-th/0507027

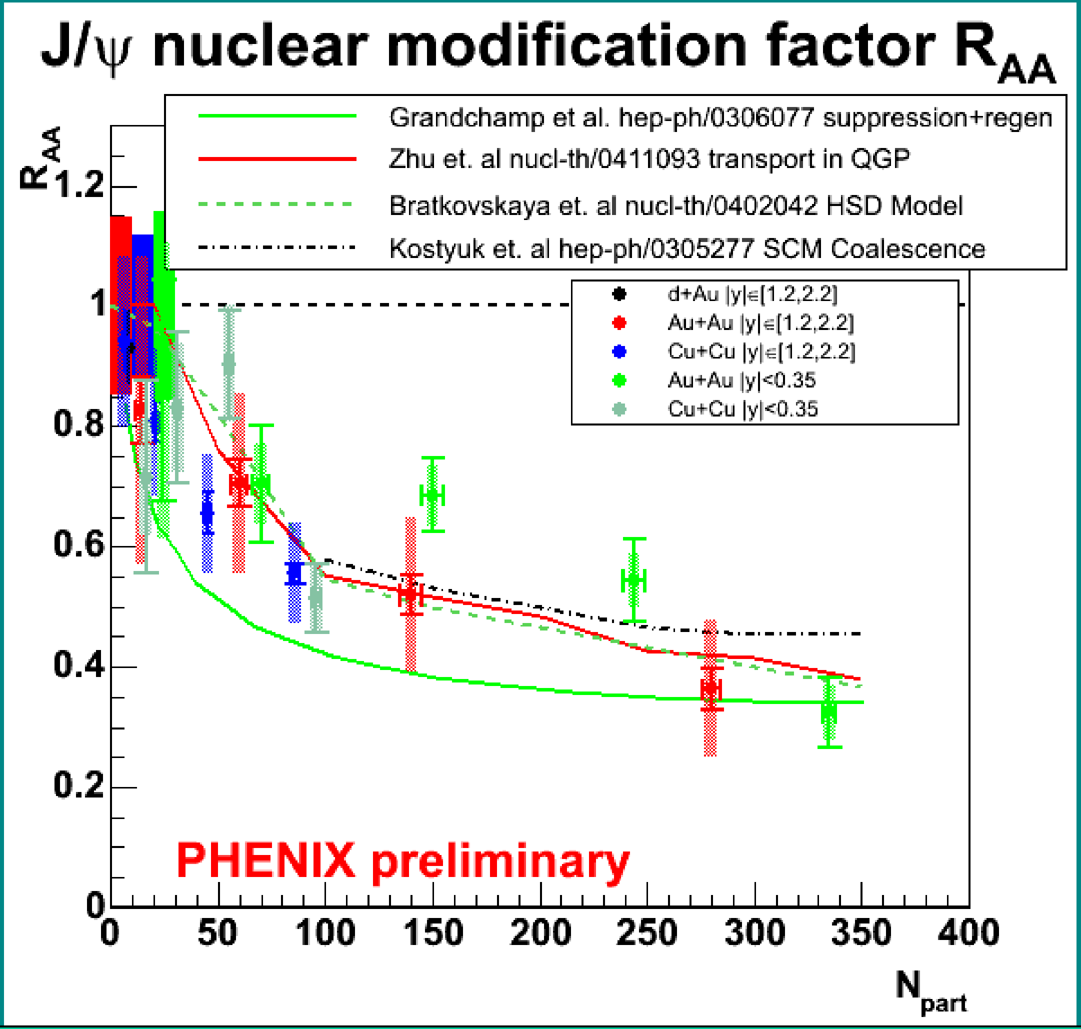
Model of cold nuclear matter effects in agreement with dAu: Tendency to underpredict suppression in most central AuAu and CuCu events

System-Size Dependence



Models that were successful in describing SPS data fail to describe data at RHIC - too much suppression -

System-Size Dependence



Implementing regeneration:
much better agreement with the data

So, what do we see?

PHENIX J/ψ centrality dependence:

2) Models with only cold nuclear matter effects don't quite have enough suppression

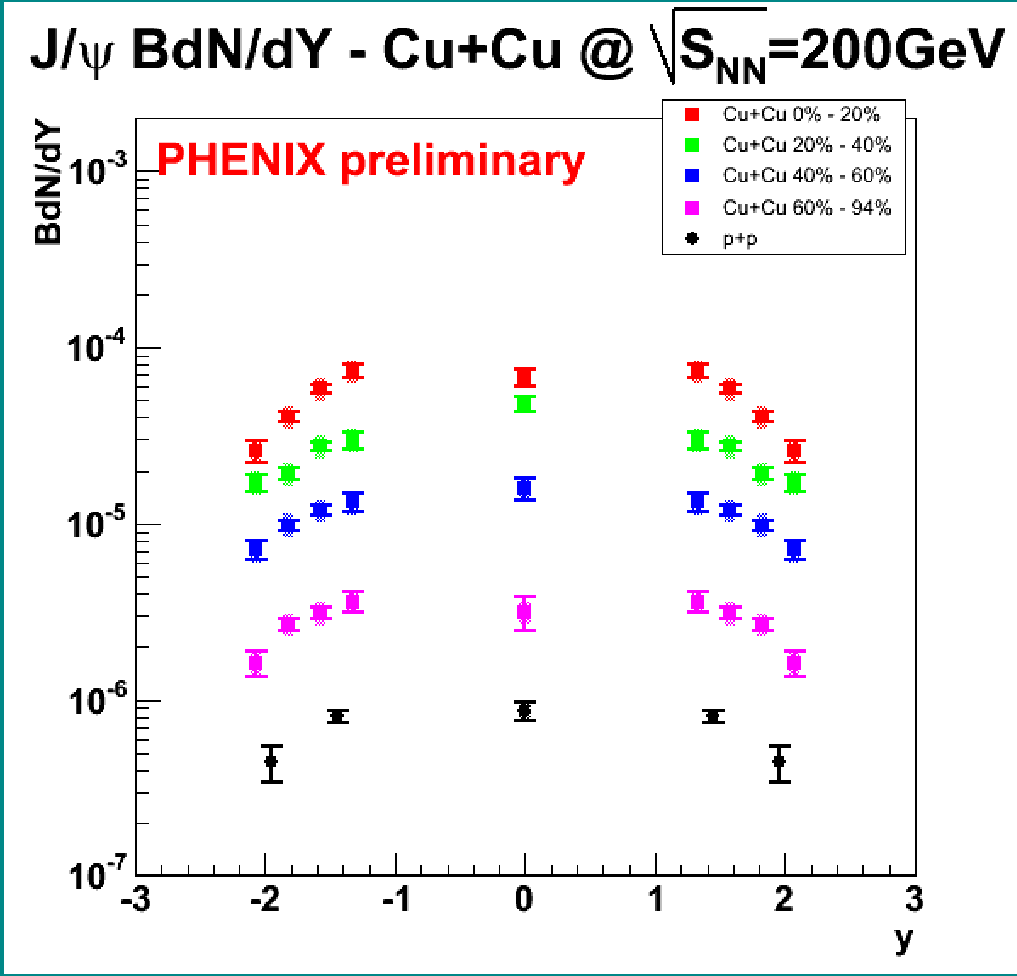
2) Models with color screening or comovers and without recombination have too much suppression

3) Models with recombination are in reasonable agreement with the data

- Suppression for most central collisions is similar to NA50
- Energy density and gluon density at RHIC should be much higher (2-3 times) !?
- At RHIC: Recombination compensates stronger QGP screening?

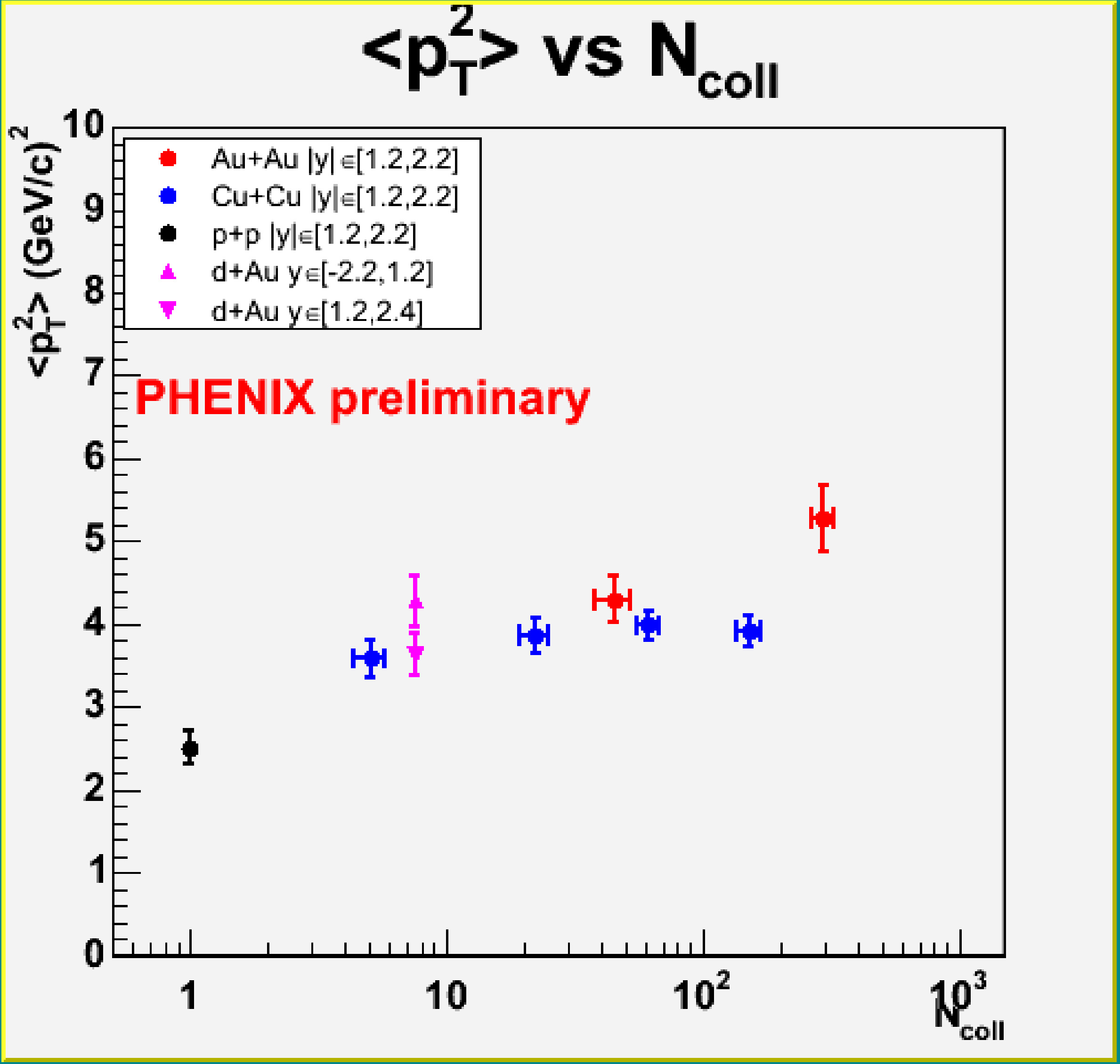
Test for Recombination:
Rapidity and pT-Distribution

J/ψ Rapidity Dependence

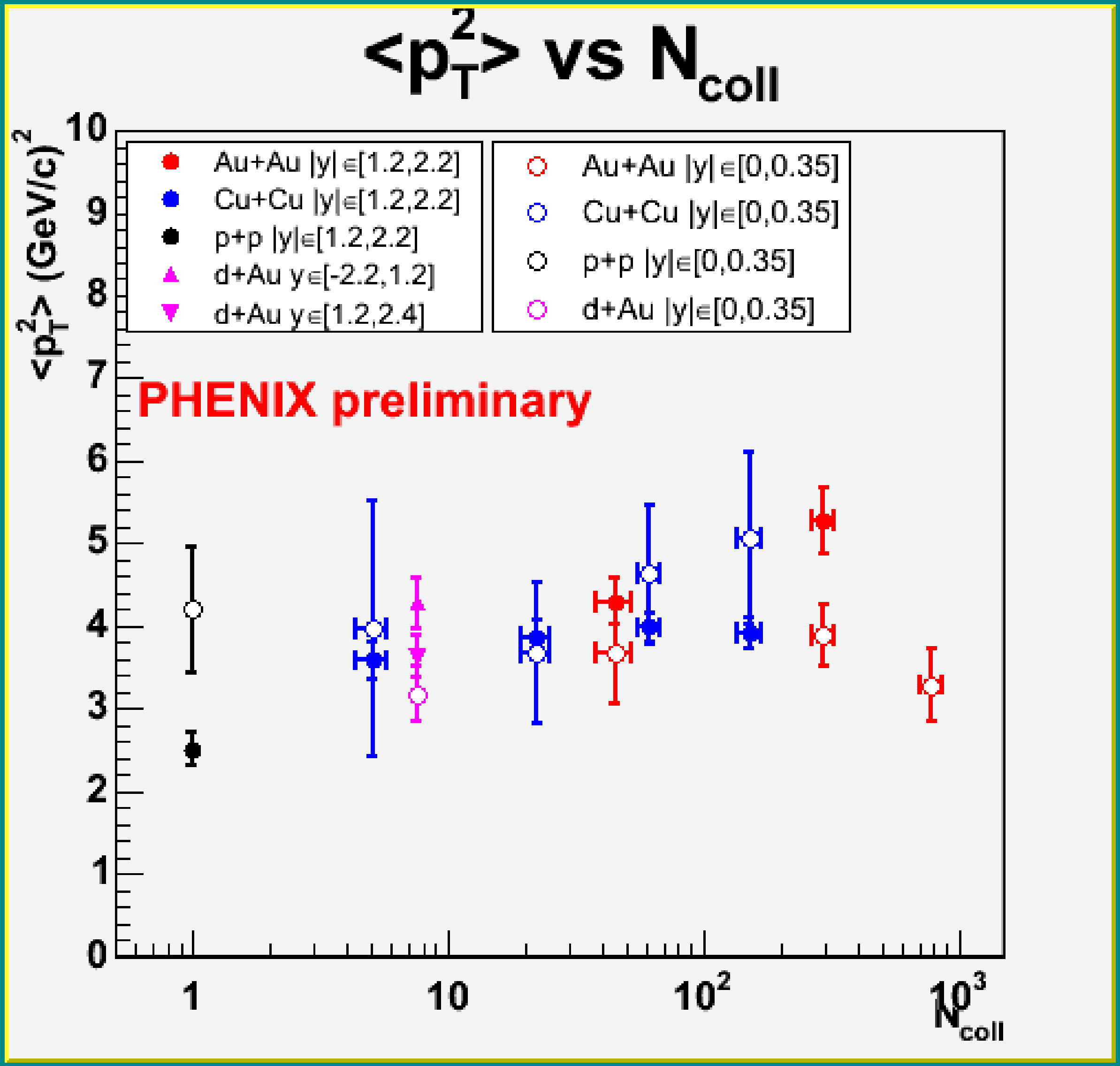


Recombination expects narrowing of rapidity distribution

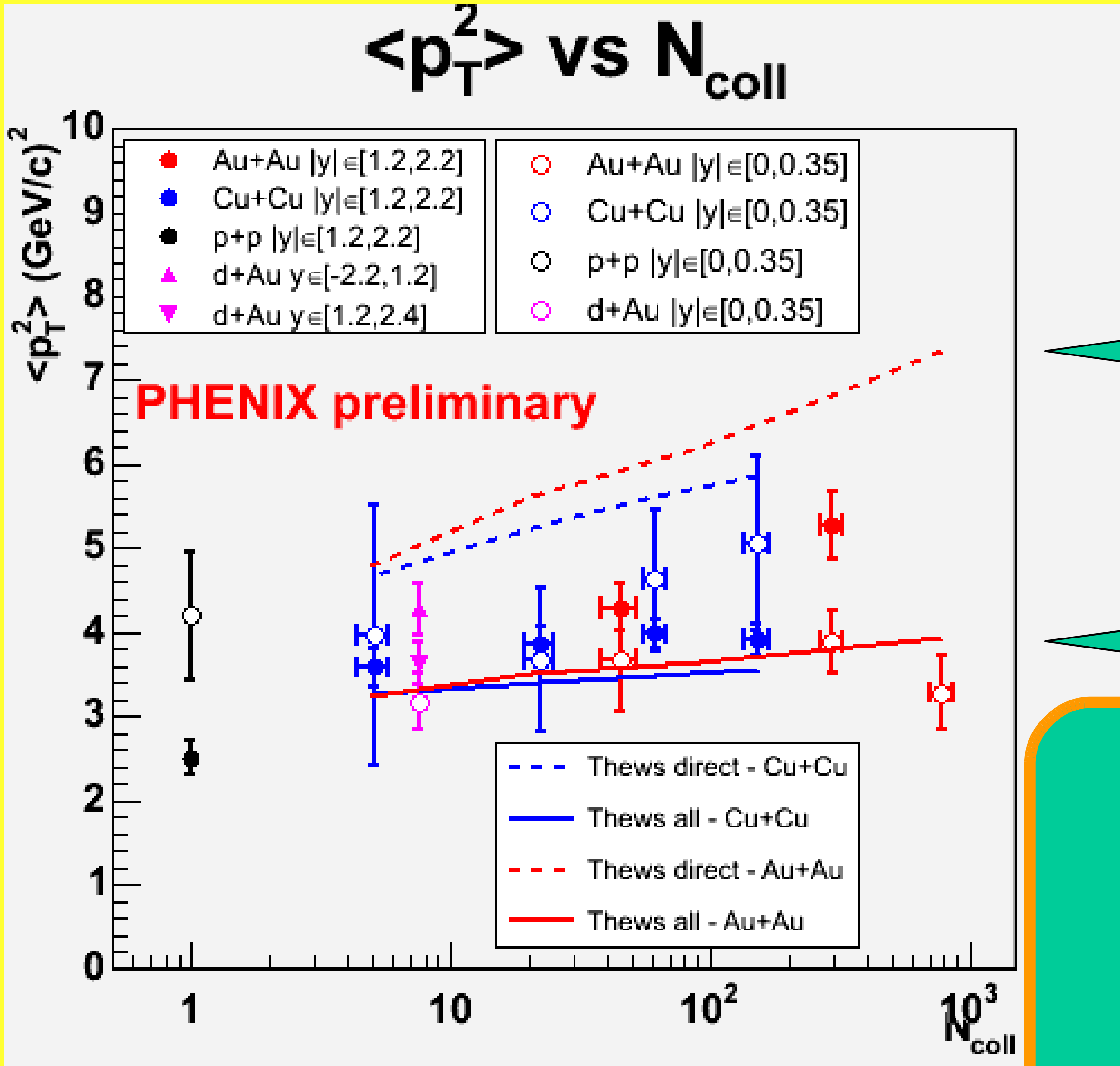
J/ψ p_T Dependence



J/ψ p_T Dependence



J/ψ p_T Dependence



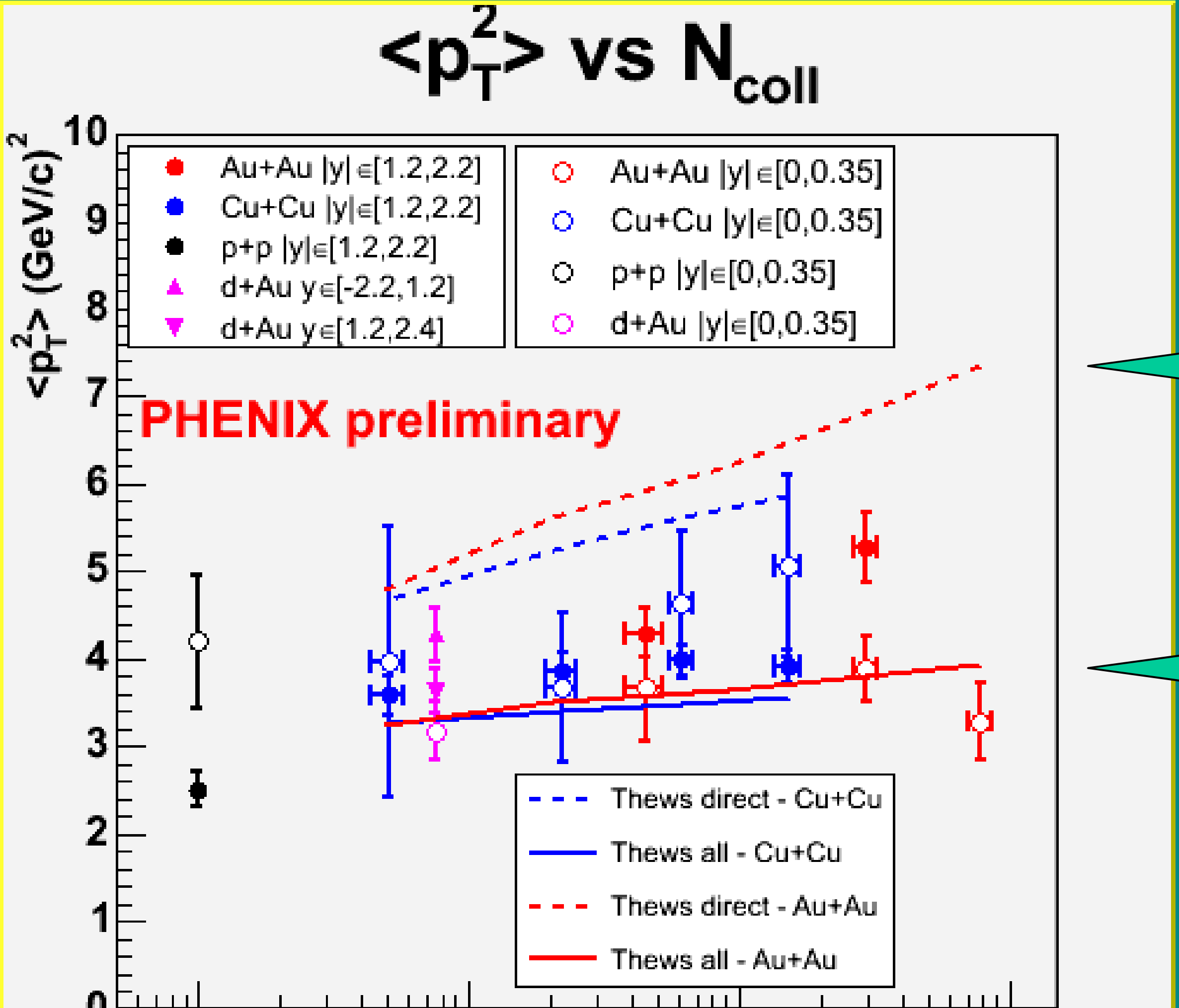
without recombination only p_T broadening

with recombination + p_T broadening

Increase of <p_T^2> vs. centrality due to p_T broadening not really seen

Recombination favors reduction in <pt2>

J/ψ p_T Dependence



without recombination only p_T broadening

with recombination + p_T broadening

$<p_T^2>$ distribution seems to favor model that includes recombination. We did not find a realistic prediction for the rapidity narrowing. Therefore we cannot make this comparison yet.

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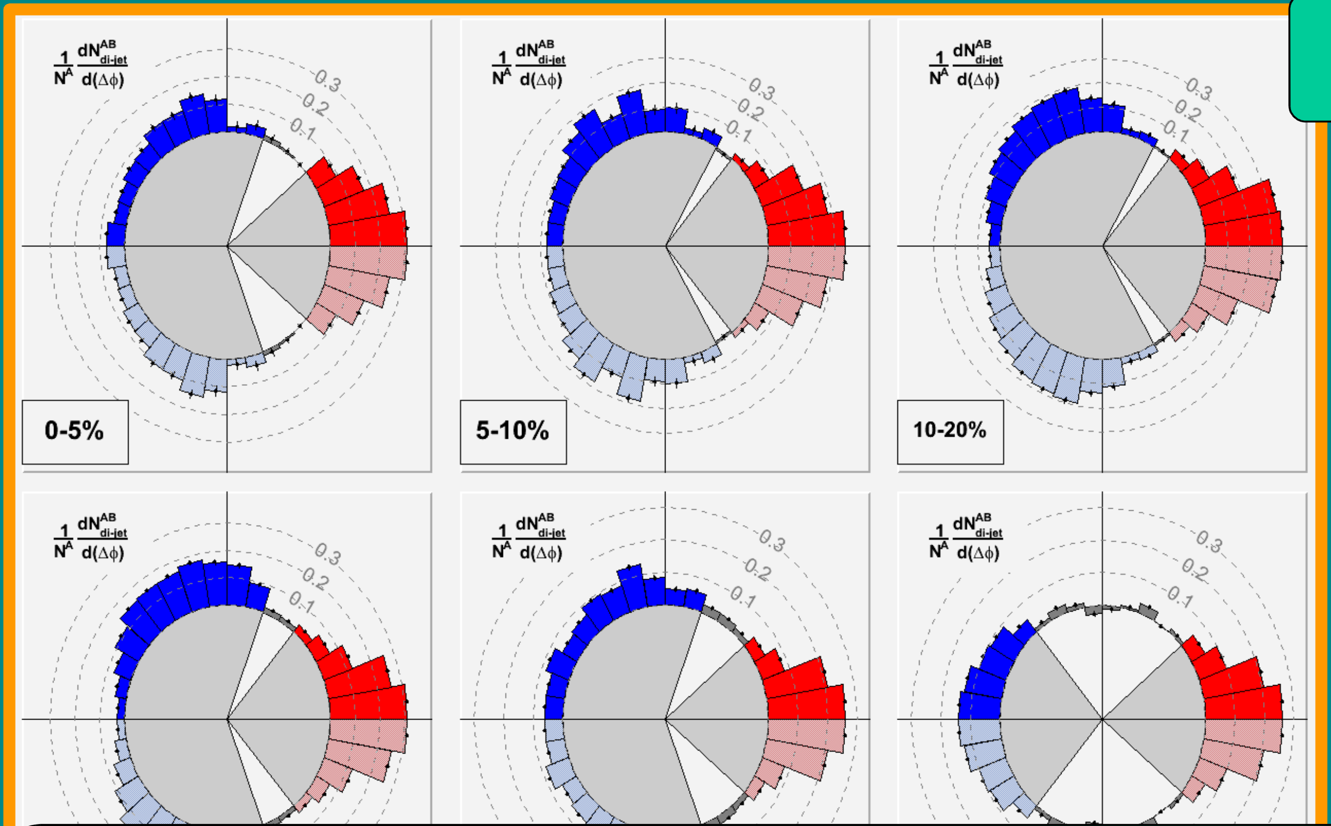
PHENIX

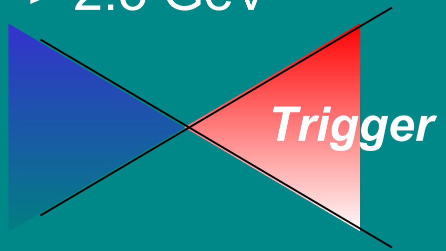
Modification of Jets

Let's start with an observation…



nucl-ex / 0507004

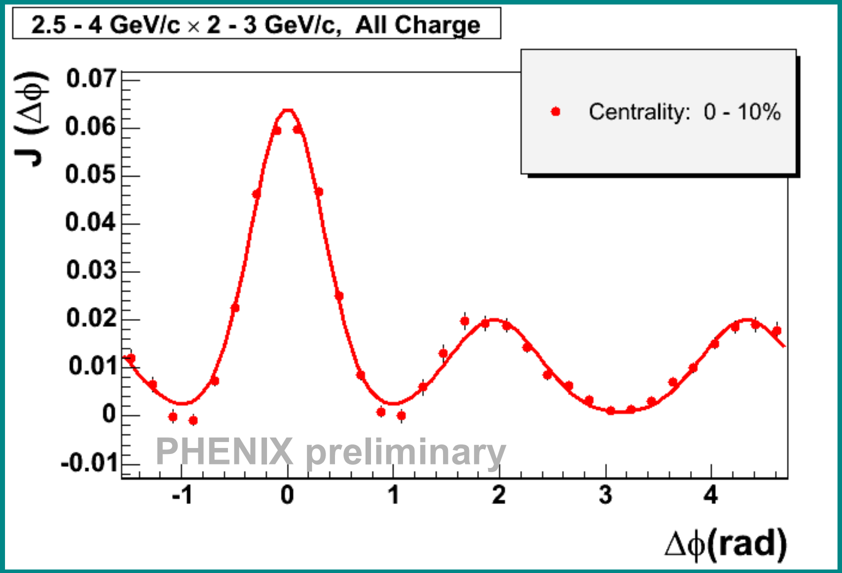
Trigger particle p_T > 2.5 GeV



jet-pair partners $p_T > 1.0$ GeV

Can we learn more…
…about the "splitting" pattern?
…about modifications of the "peaks"?
…about the jet-composition ?

Short remarks

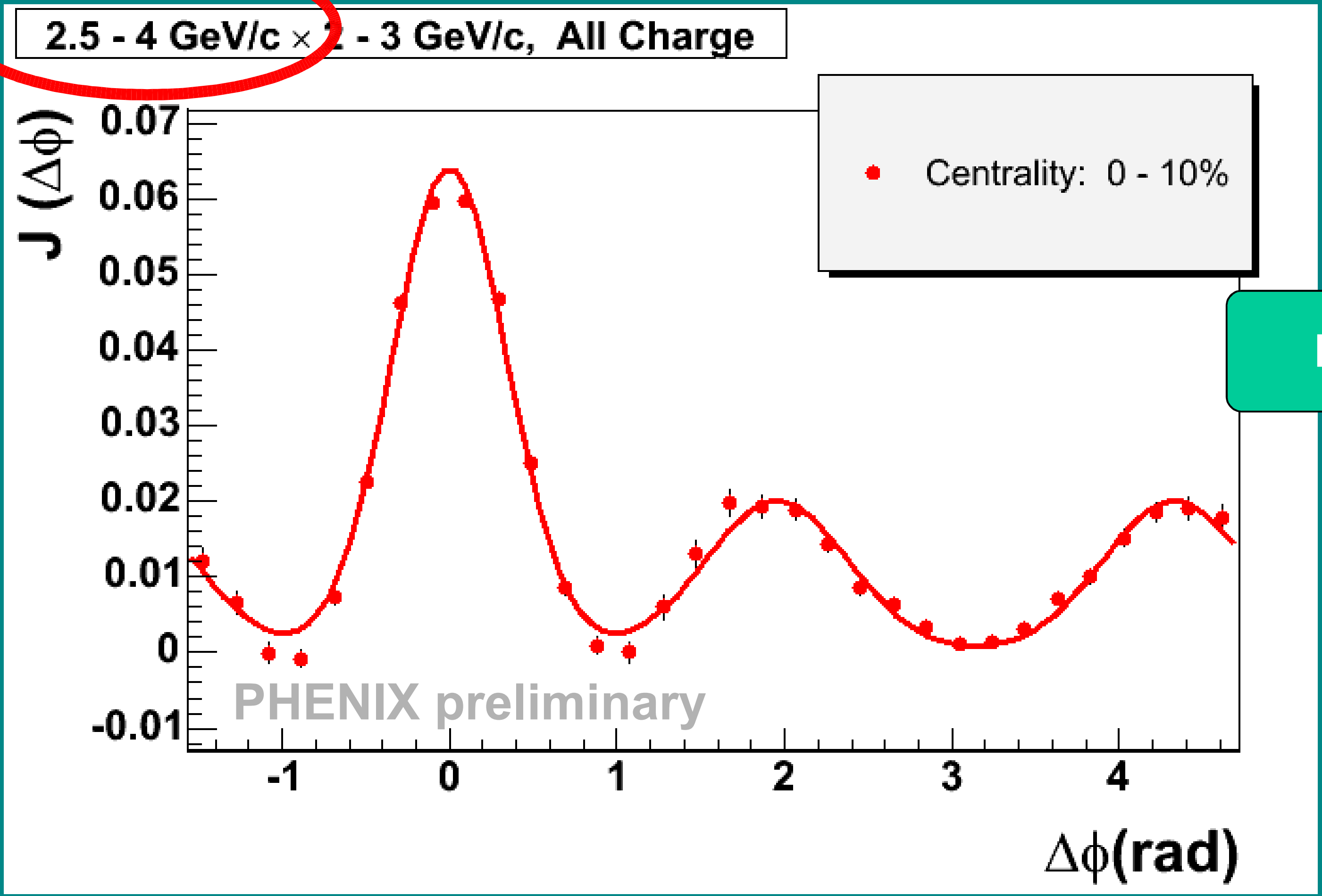


All data presented in this section where measured in **AuAu** collisions

Here we always show the conditional yield **after** subtraction of the flow components.

We developed various methods to subtract flow contributions, will be discussed in more detail in parallel talks.

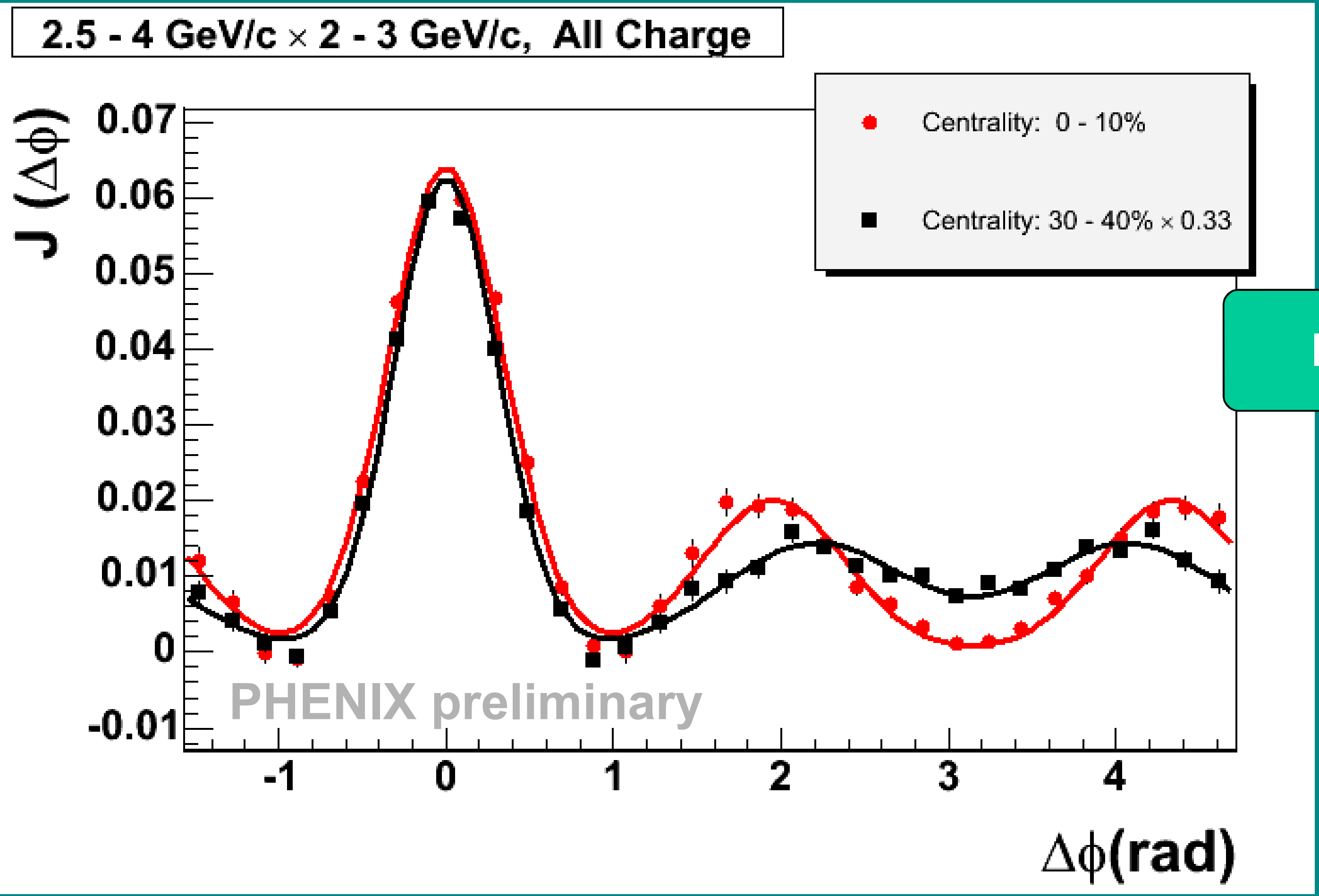
The Far Side...



hadron-hadron

High Trigger p_T ⟷ *Intermediate Trigger* p_T !

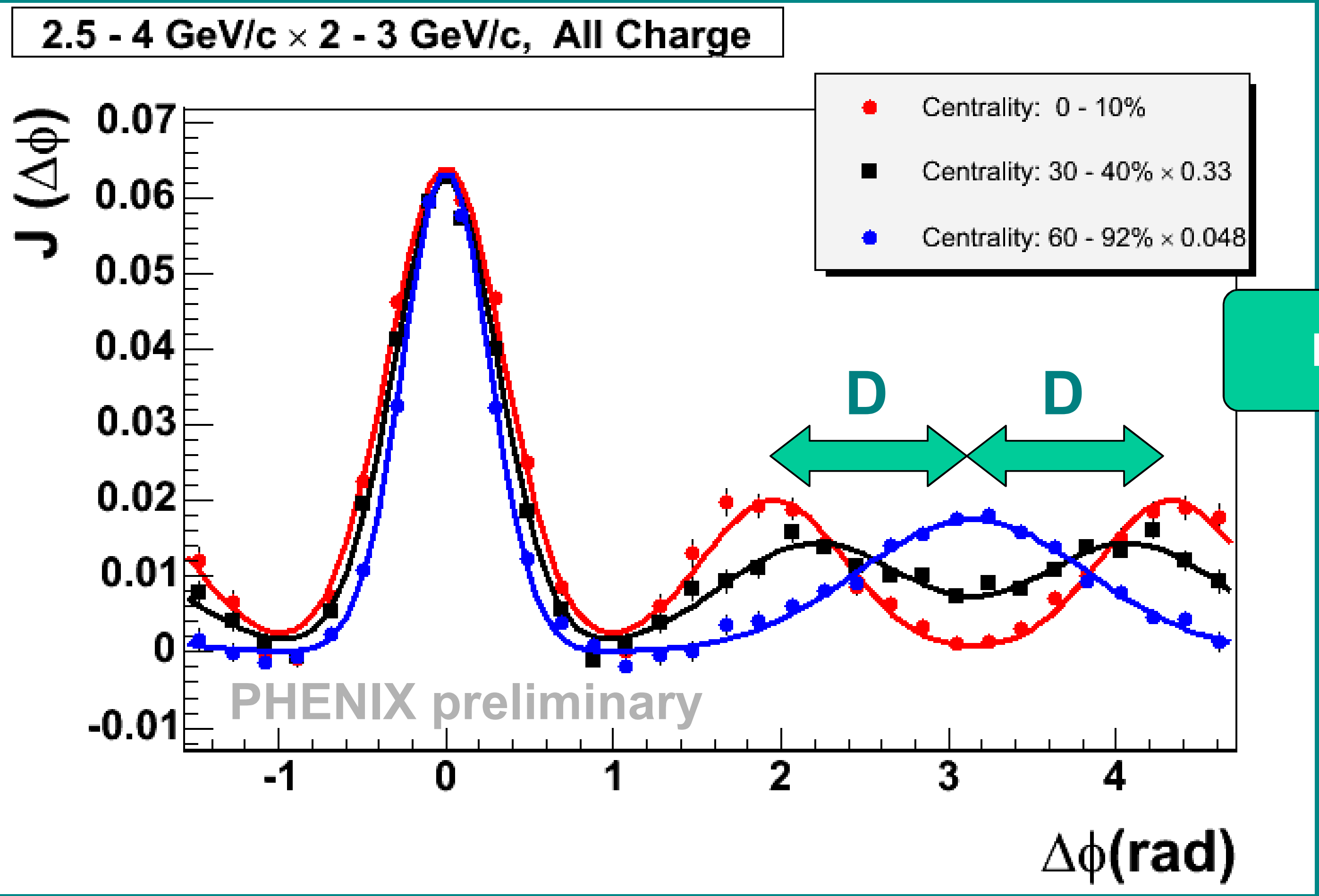
The Far Side… Centrality



hadron-hadron

High Trigger p_T ⟷ *Intermediate Trigger p_T* !

The Far Side… Centrality



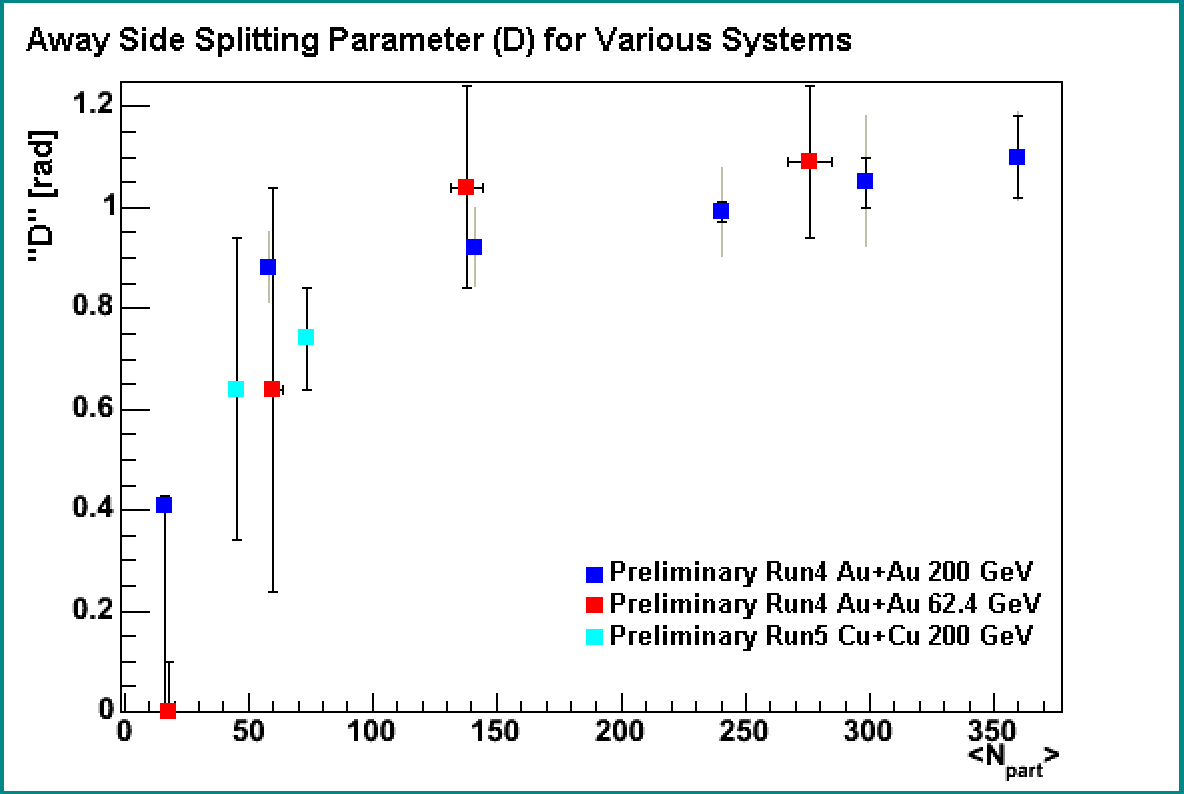
hadron-hadron

Splitting parameter D

High Trigger p_T ⟷ *Intermediate Trigger p_T*

!

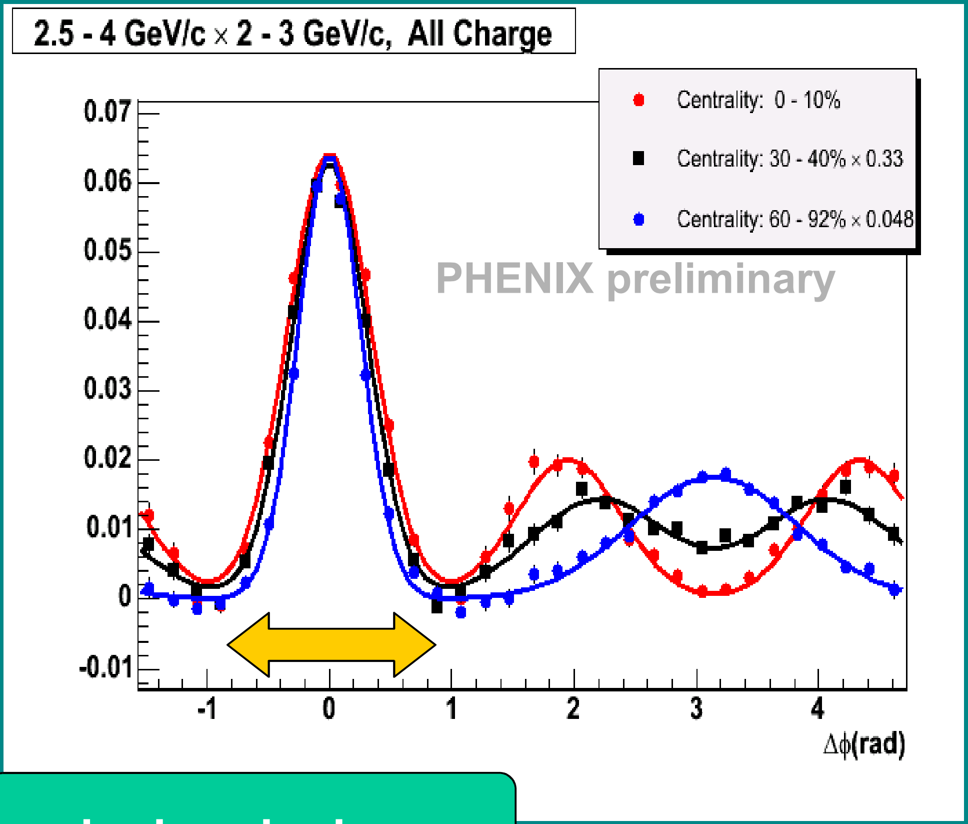
Systematics with Centrality



!

Splitting Parameter D increasing with centrality
Similar trend for all systems and energies
"Geometrical Effect"

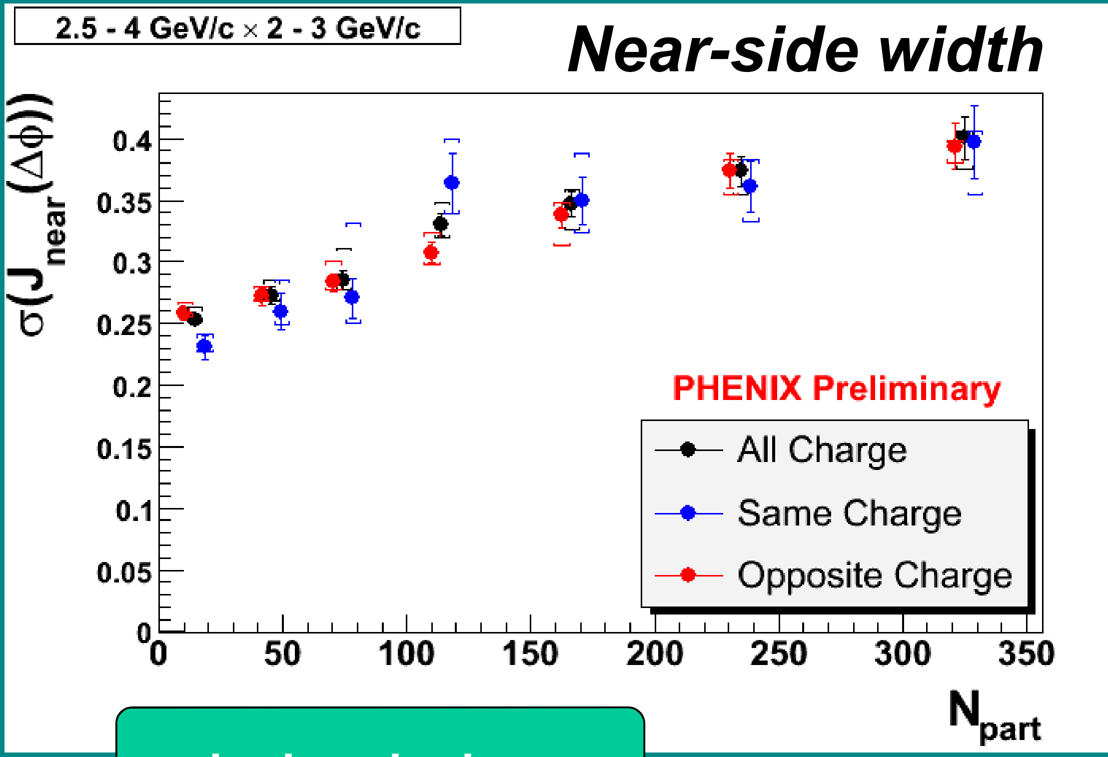
Now to the near side…



hadron-hadron

High Trigger p_T ⟷ *Intermediate Trigger p_T*

Now to the near side…



hadron-hadron

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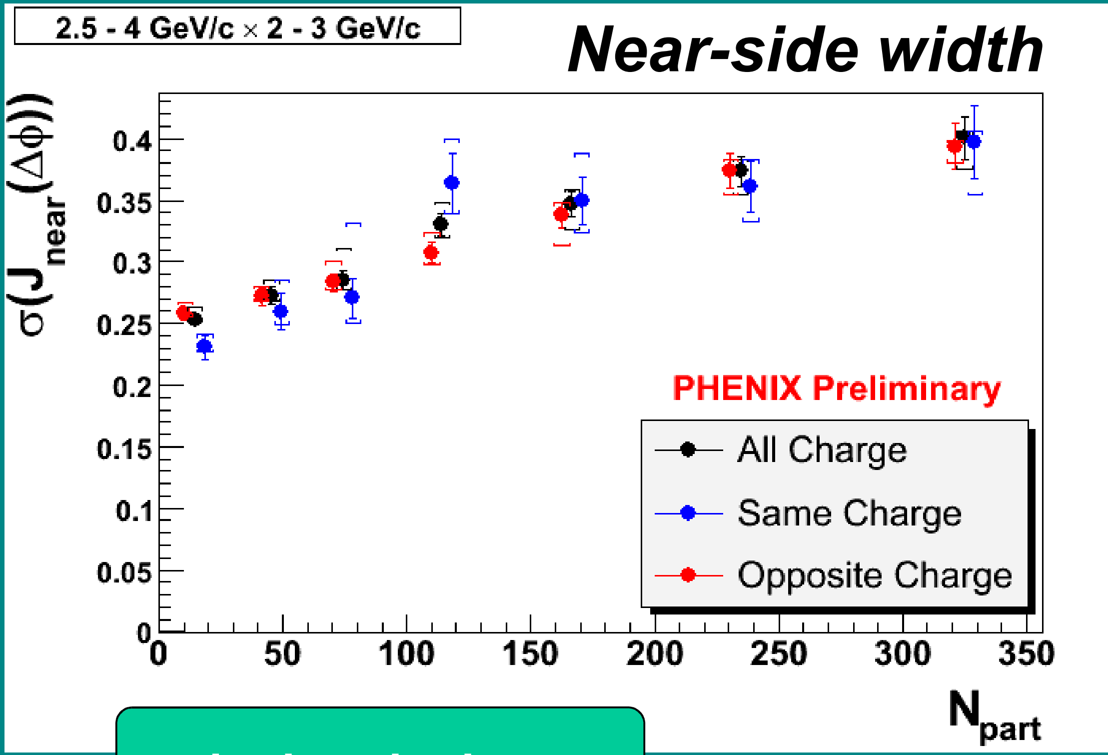

hadron-hadron

High Trigger p_T ⟷ *Intermediate Trigger p_T*

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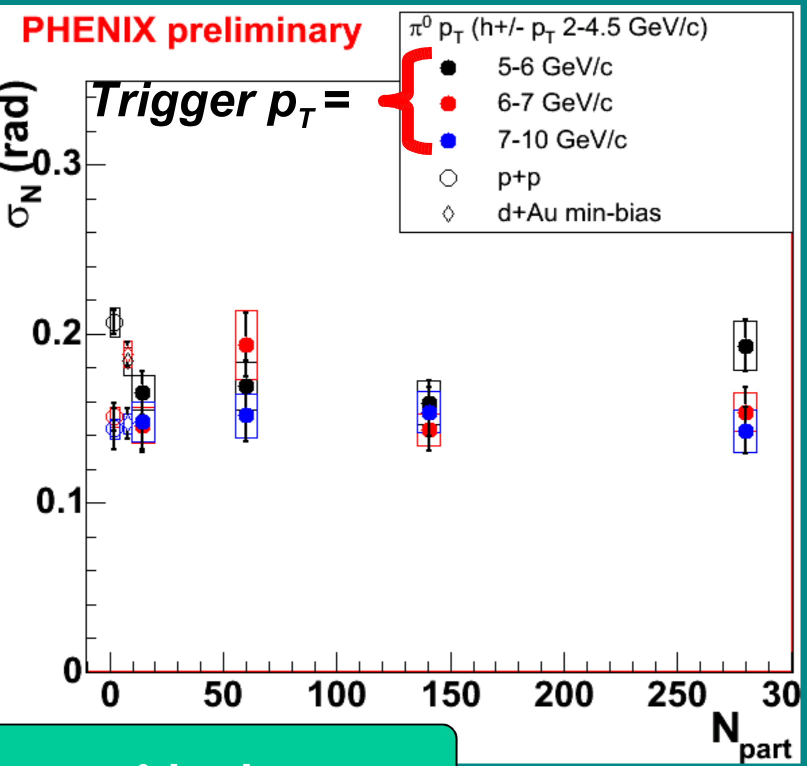
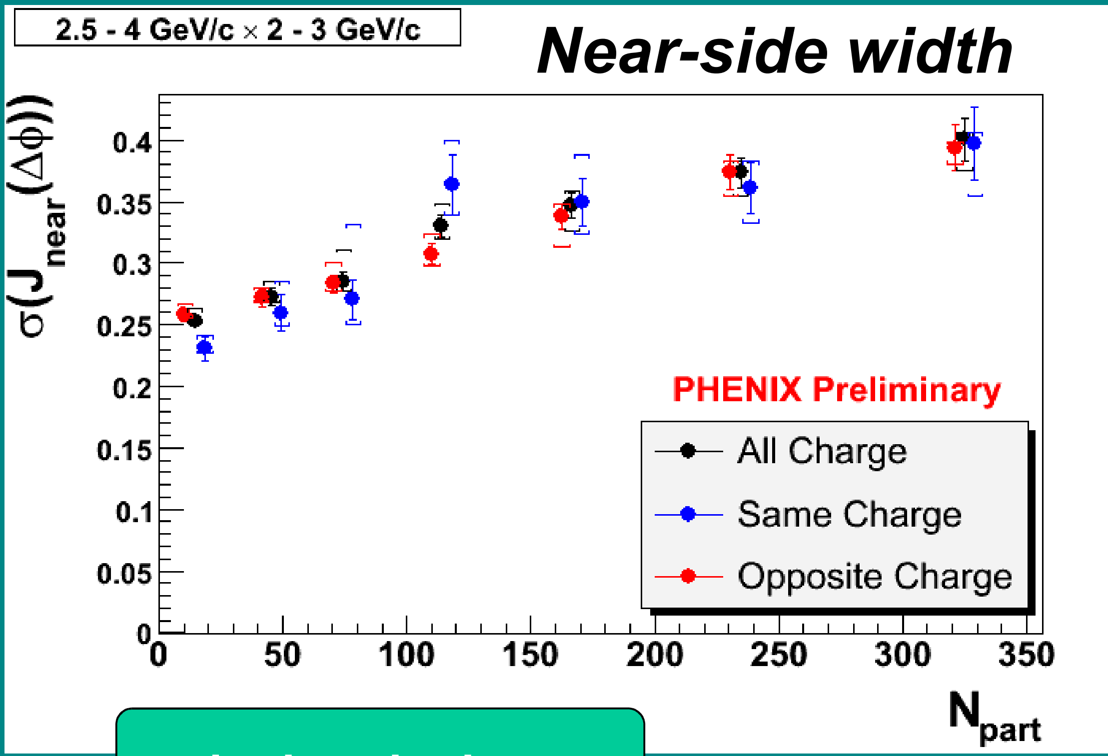


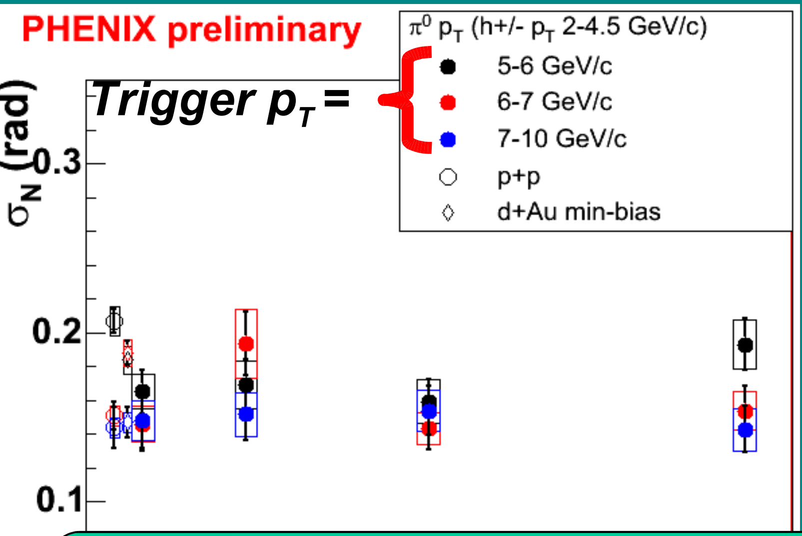


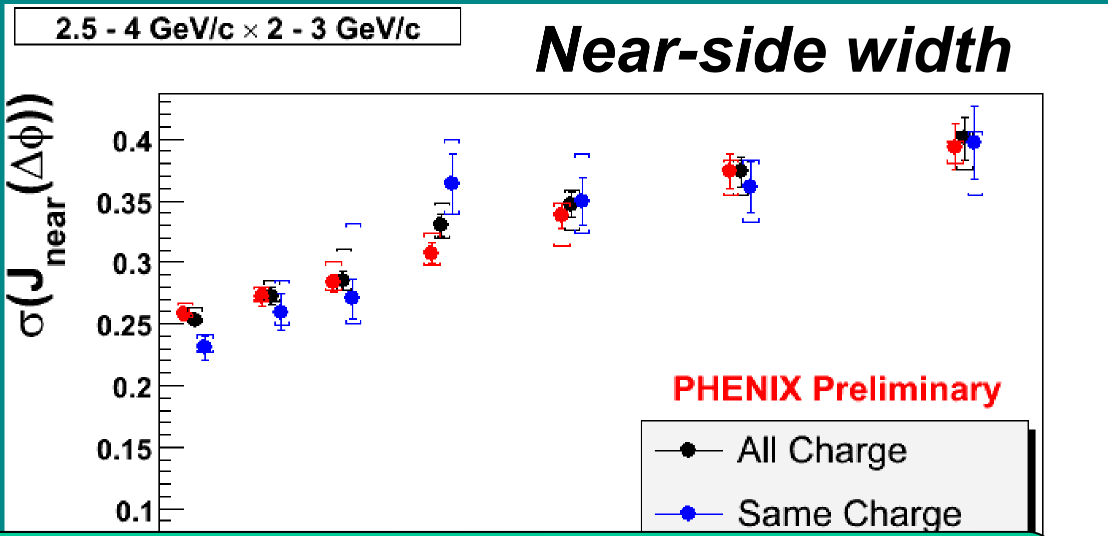
π^0-hadron

hadron-hadron

High Trigger p_T ⟷ *Intermediate Trigger p_T*

Now to the near side…





For intermediate trigger p_T :

Near side seems to broaden as function of centrality

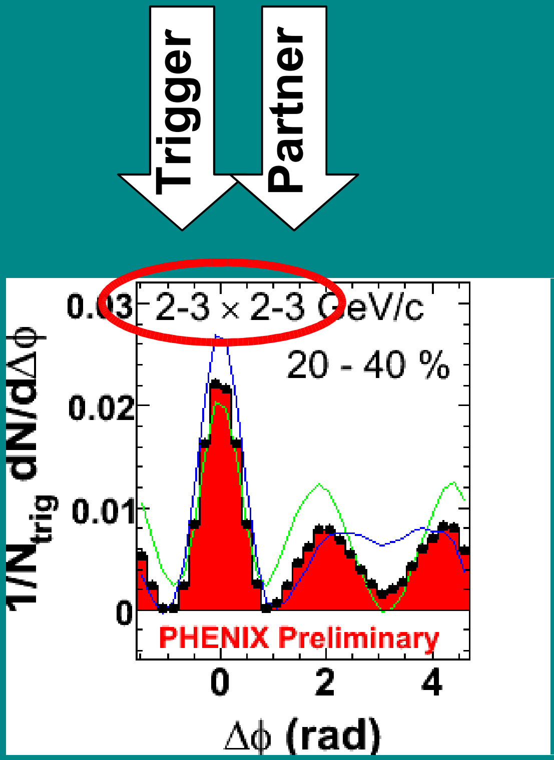
For high trigger p_T:

Near-side width independent of centrality

Away-side peak only modified at intermediate p_T as well……

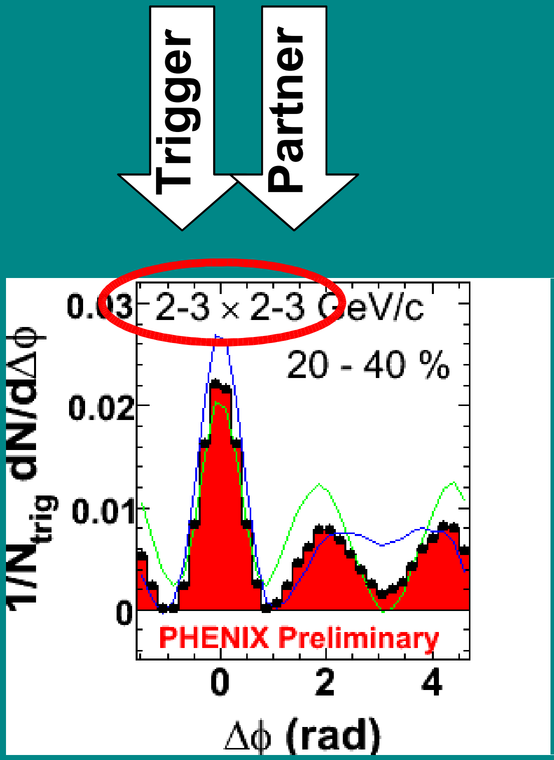
Modifications of the jet due to the medium seem to show up at intermediate trigger p_T

Evolution of Away-Side Jet Shape



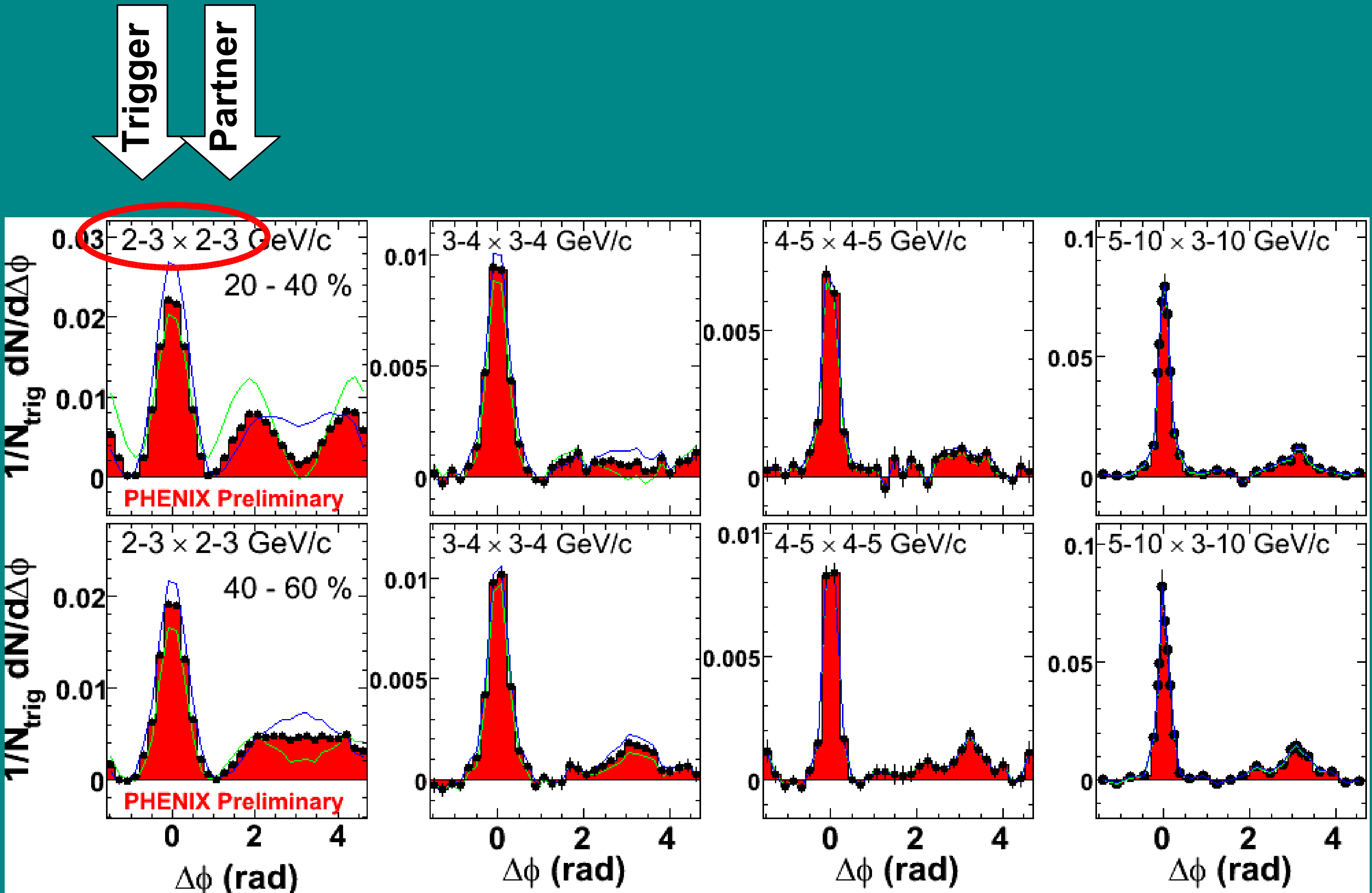
hadron-hadron

Evolution of Away-Side Jet Shape

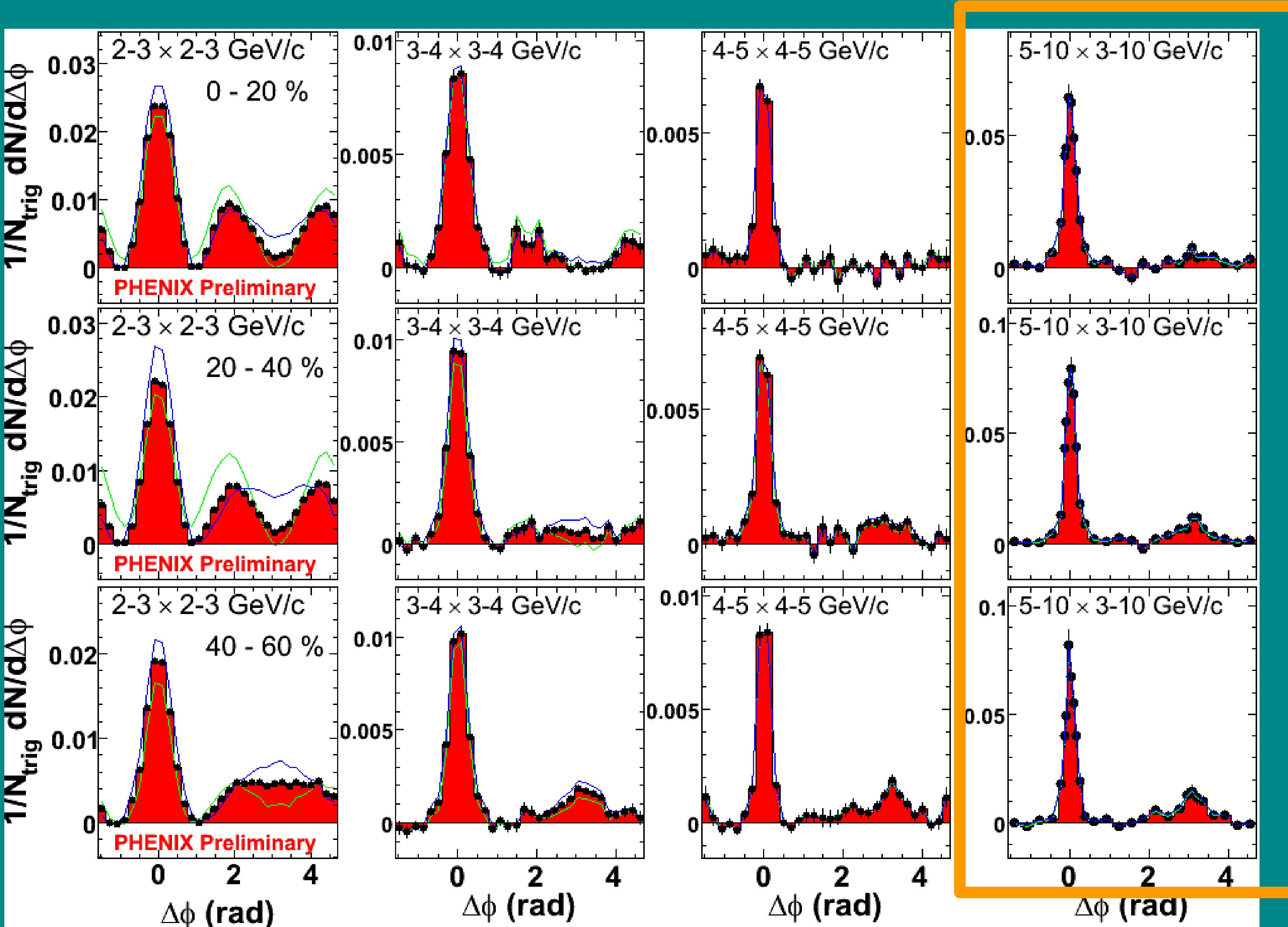


trigger and partner p_T

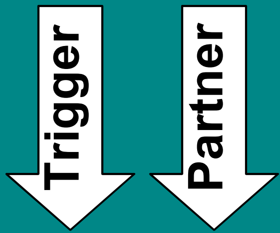
Evolution of Away-Side Jet Shape



Evolution of Away-Side Jet Shape

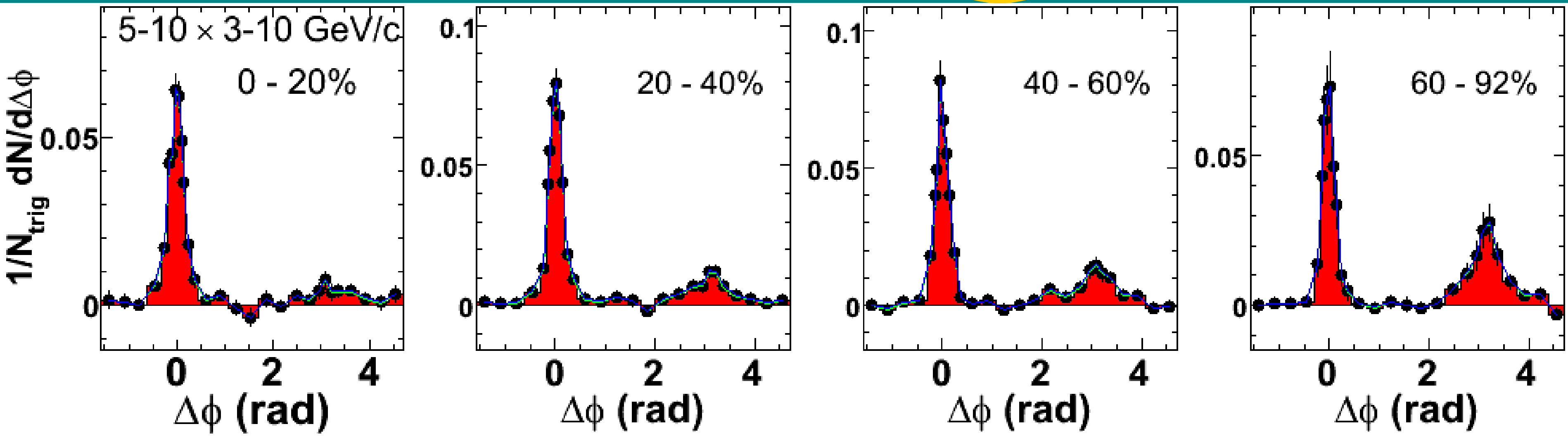


Evolution of Away-Side Jet Shape



3b

Nathan Grau

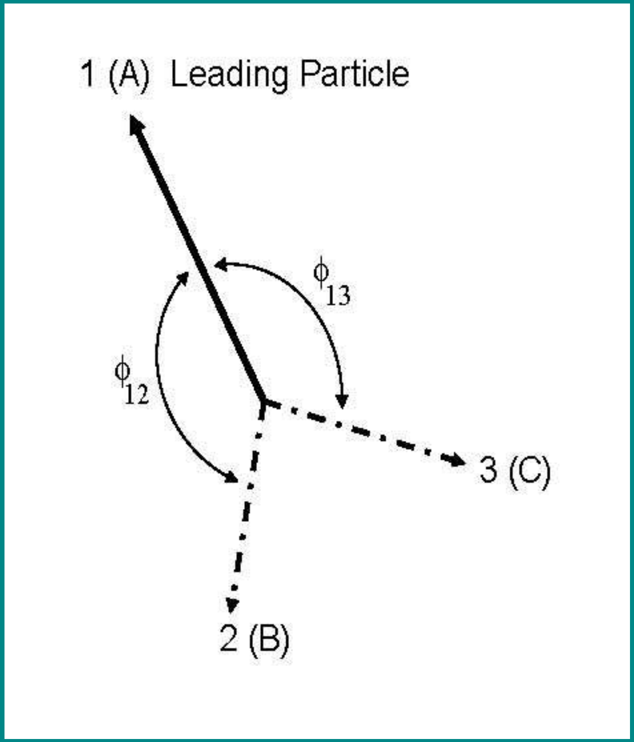


With increasing p_T:
Evolution of away-side jet is observed

In central collisions and at high trigger p_T:
Jet-like peak clearly visible

At high trigger-p_T:
Suppression of away-side peak increasing with centrality

3-Particle Jet Functions

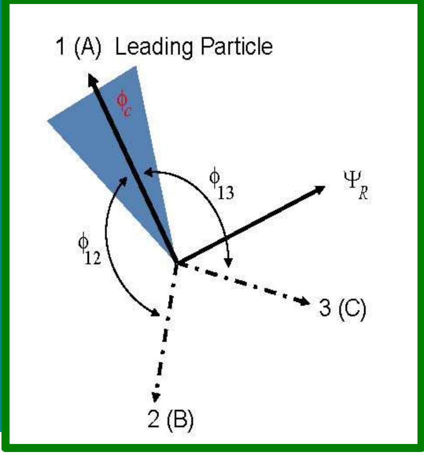


New Method to "control flow":

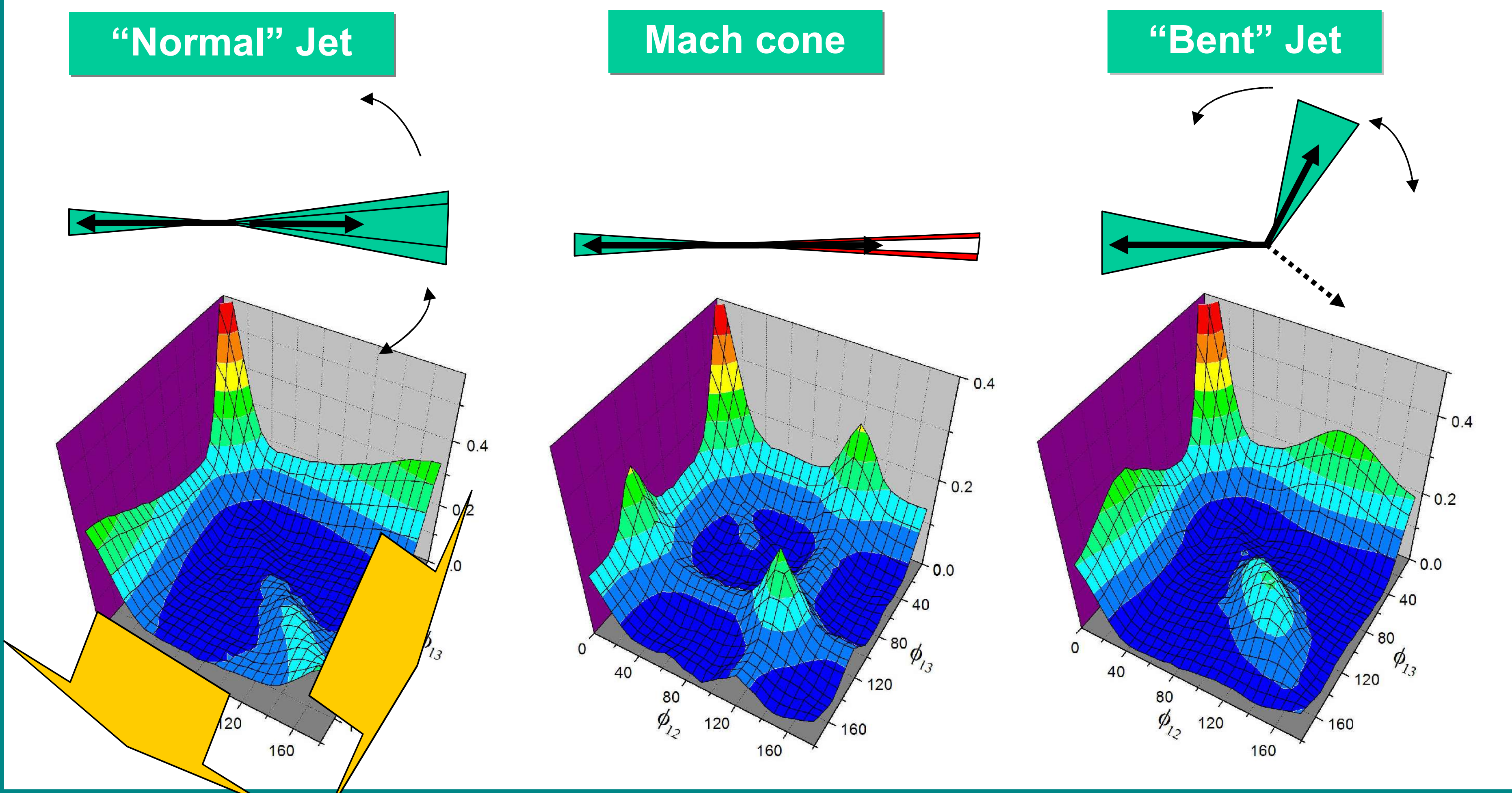
Chose angle of trigger particle relative to reaction plane to ***extinguish*** *Flow contribution*

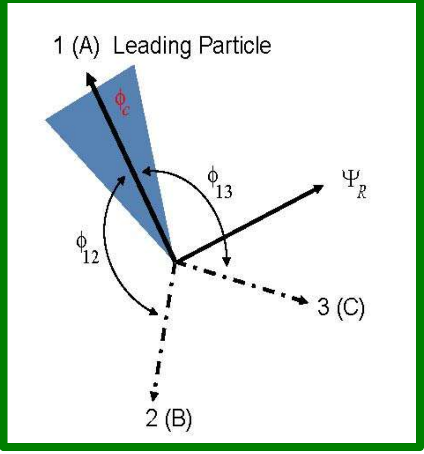
3c **N.N. Ajitanand**

3-Particle Jet Functions



Simulation !!

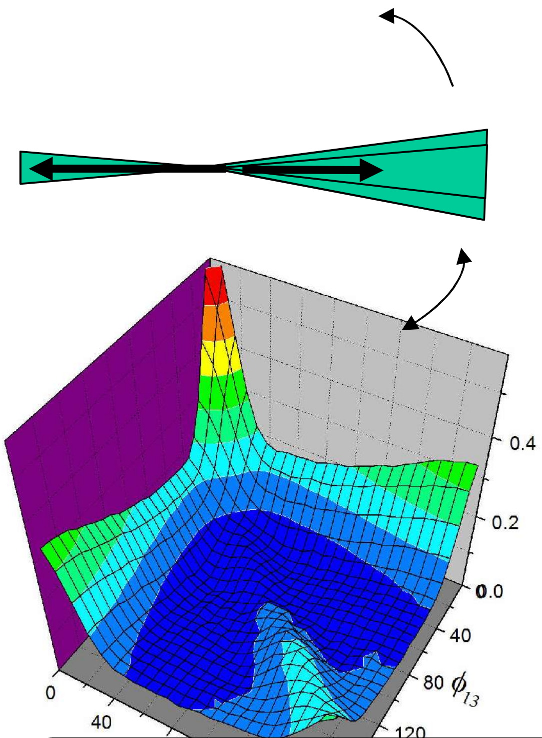




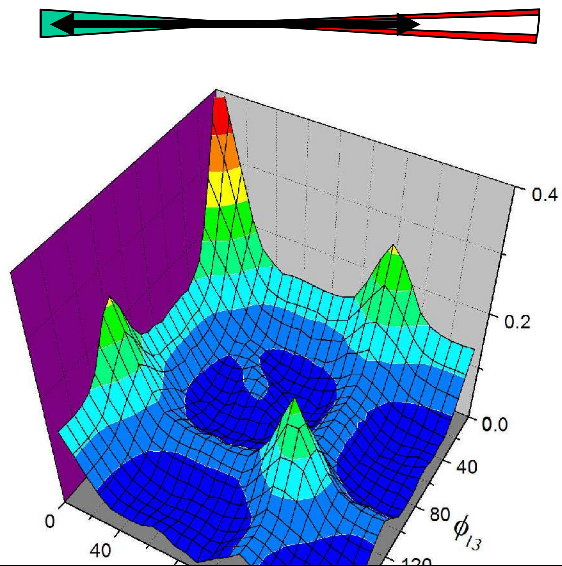
3-Particle Jet Functions

Simulation !!

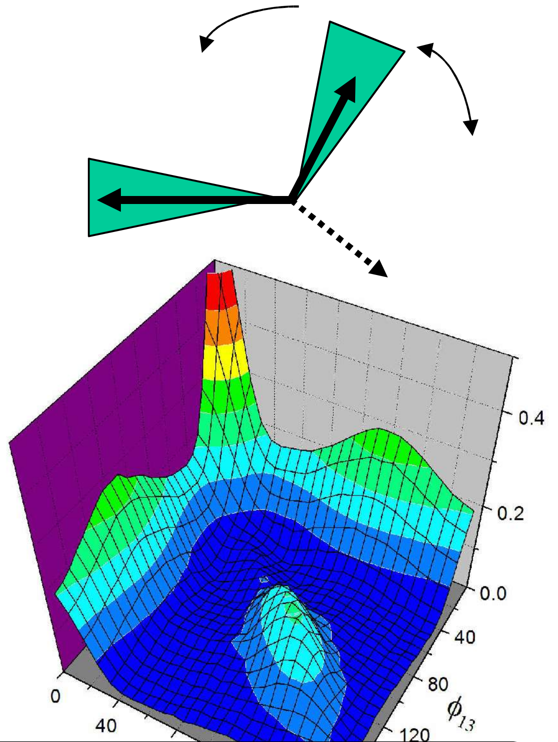
“Normal” Jet



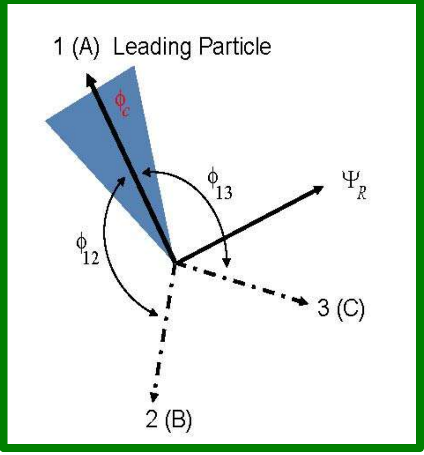
Mach cone



“Bent” Jet



Characteristic jet function expected for “Mach cone”



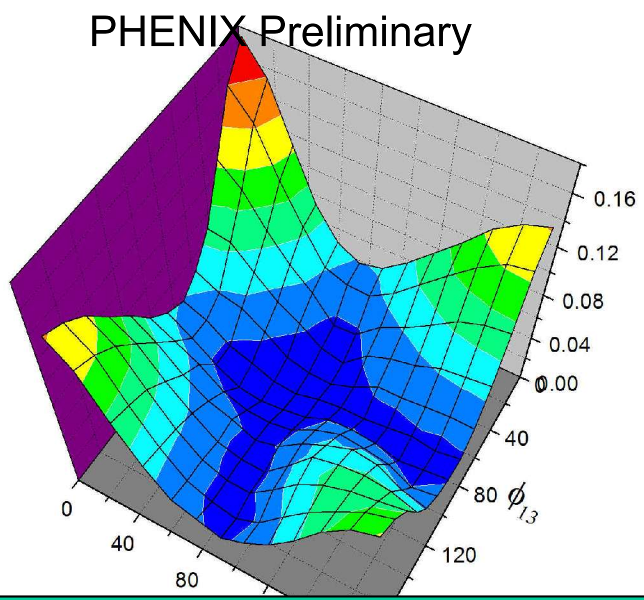
3-Particle Jet Functions

DATA

$$2.5 < p_T^{LP} < 4.0 \quad \text{(Gev/c)}$$

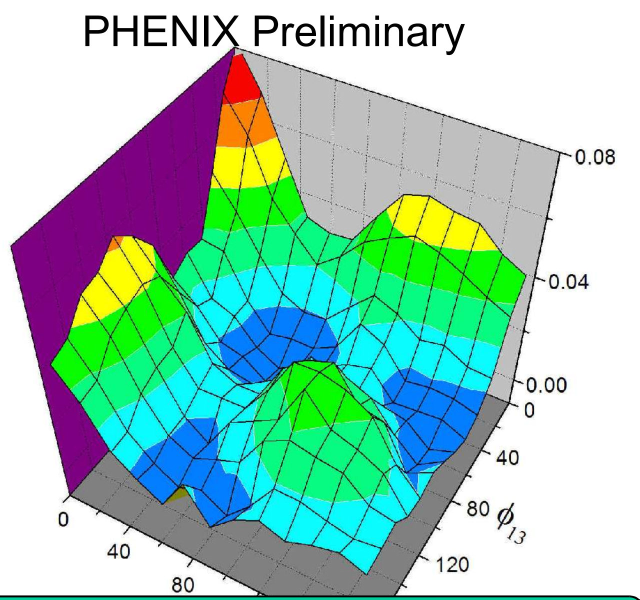
$$1.0 < p_T^{assoc-2} < 2.5, \; 1.0 < p_T^{assoc-3} < 2.5$$

Flow + Jet

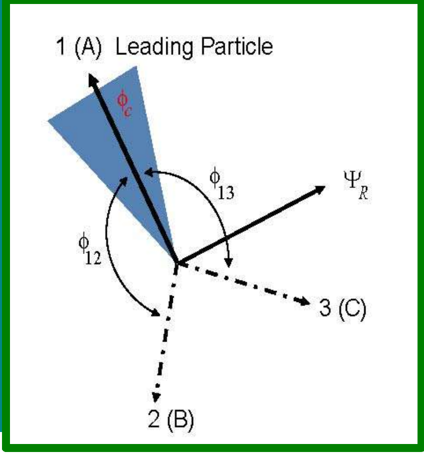


extinguish flow

Jet Only



Jet function compatible with expected features of "Mach cone"



3-Particle Jet Functions

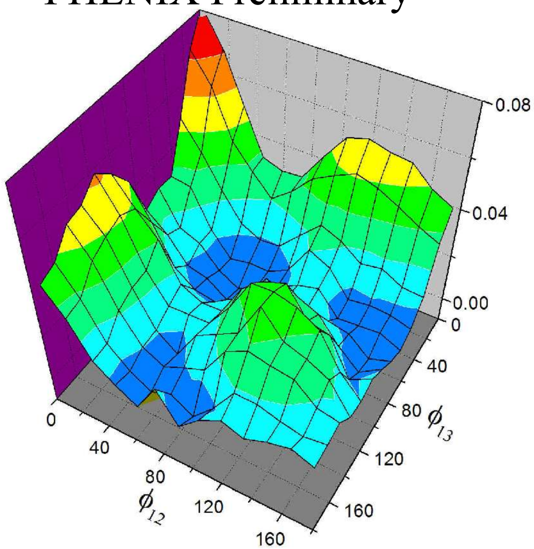
$$2.5 < p_T^{LP} < 4.0 \quad \text{(Gev/c)}$$
$$1.0 < p_T^{assoc-2} < 2.5$$
$$1.0 < p_T^{assoc-3} < 2.5$$

Hadron-
Hadron-Hadron

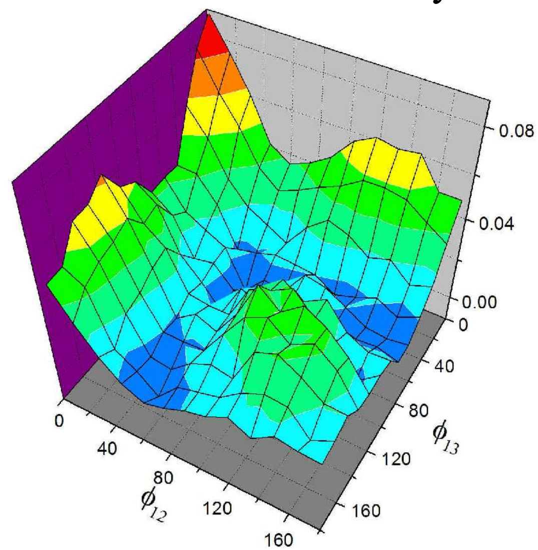
Hadron-
Meson-Meson

Hadron-
Baryon-Baryon

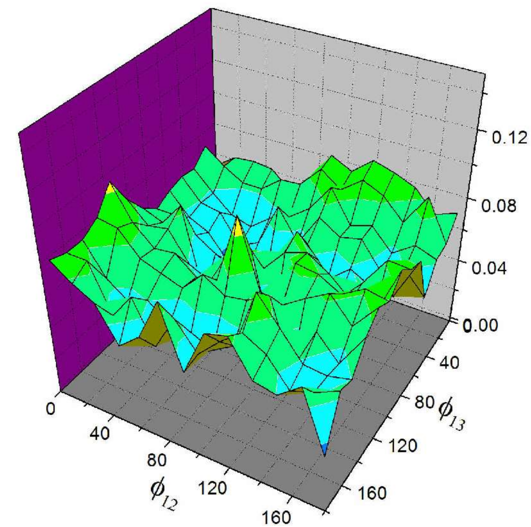
PHENIX Preliminary



PHENIX Preliminary



PHENIX Preliminary

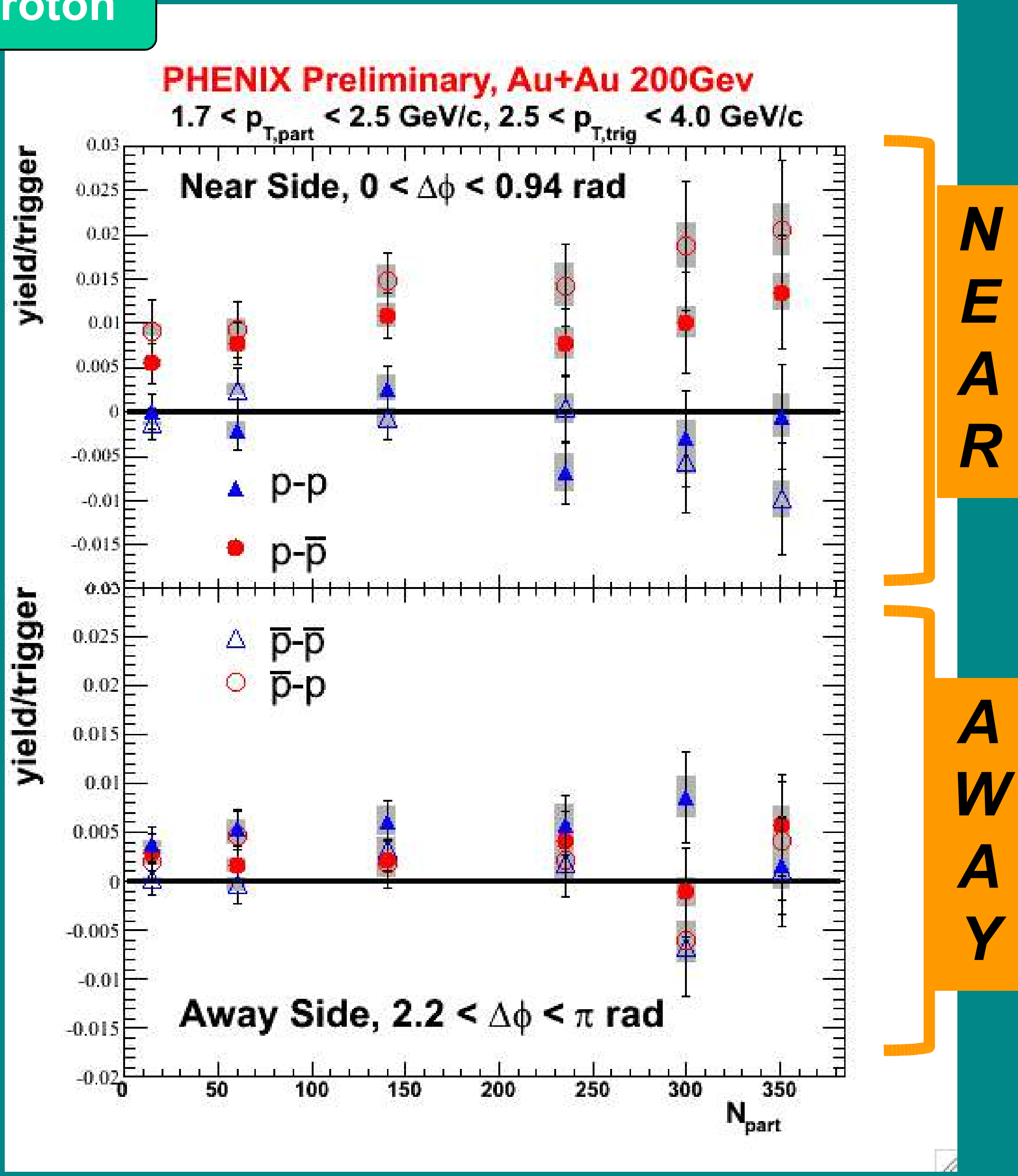


Outlook: Proton-Antiproton Jets

Yield per Trigger Proton or Anti-Proton

Trigger on proton:
Cond. Yield for anti-proton higher than for another proton

Trigger on proton:
Cond. Yield for proton and anti-proton similar



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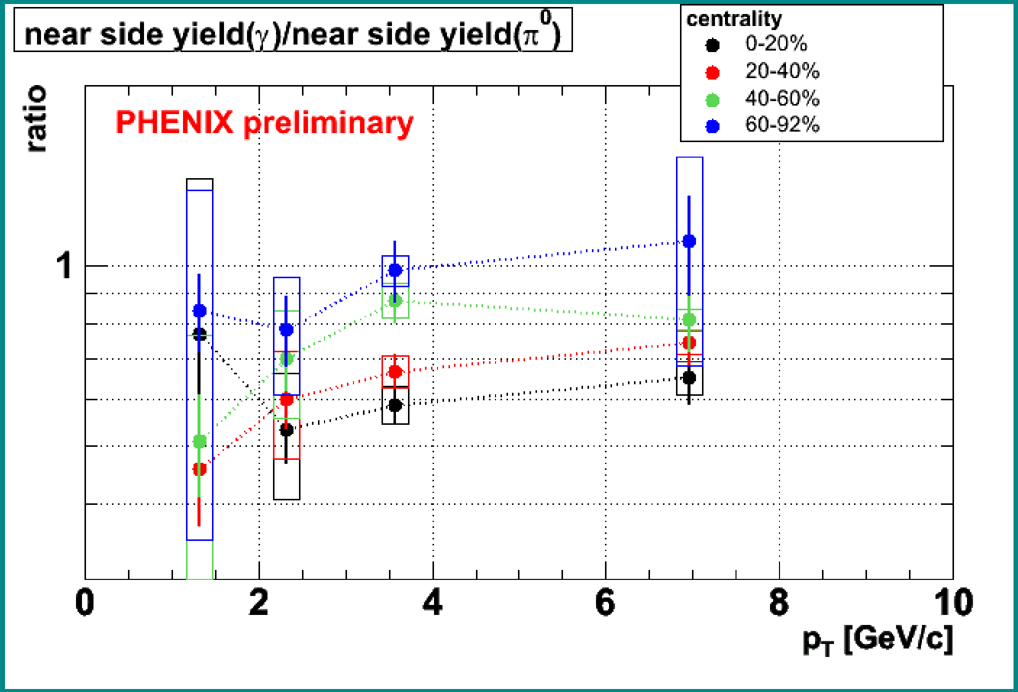
PHENIX

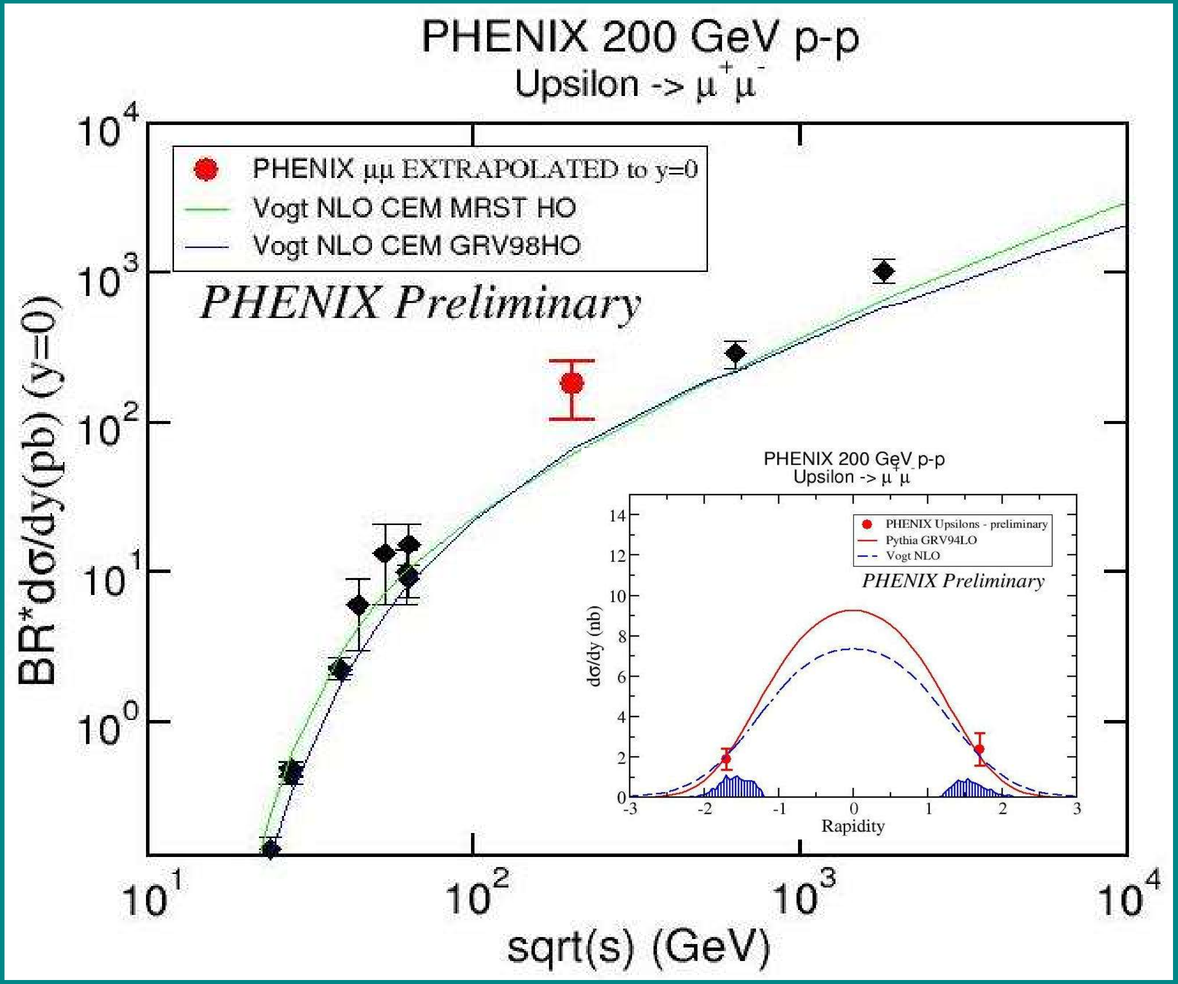
and much more ...

Only Highlights…



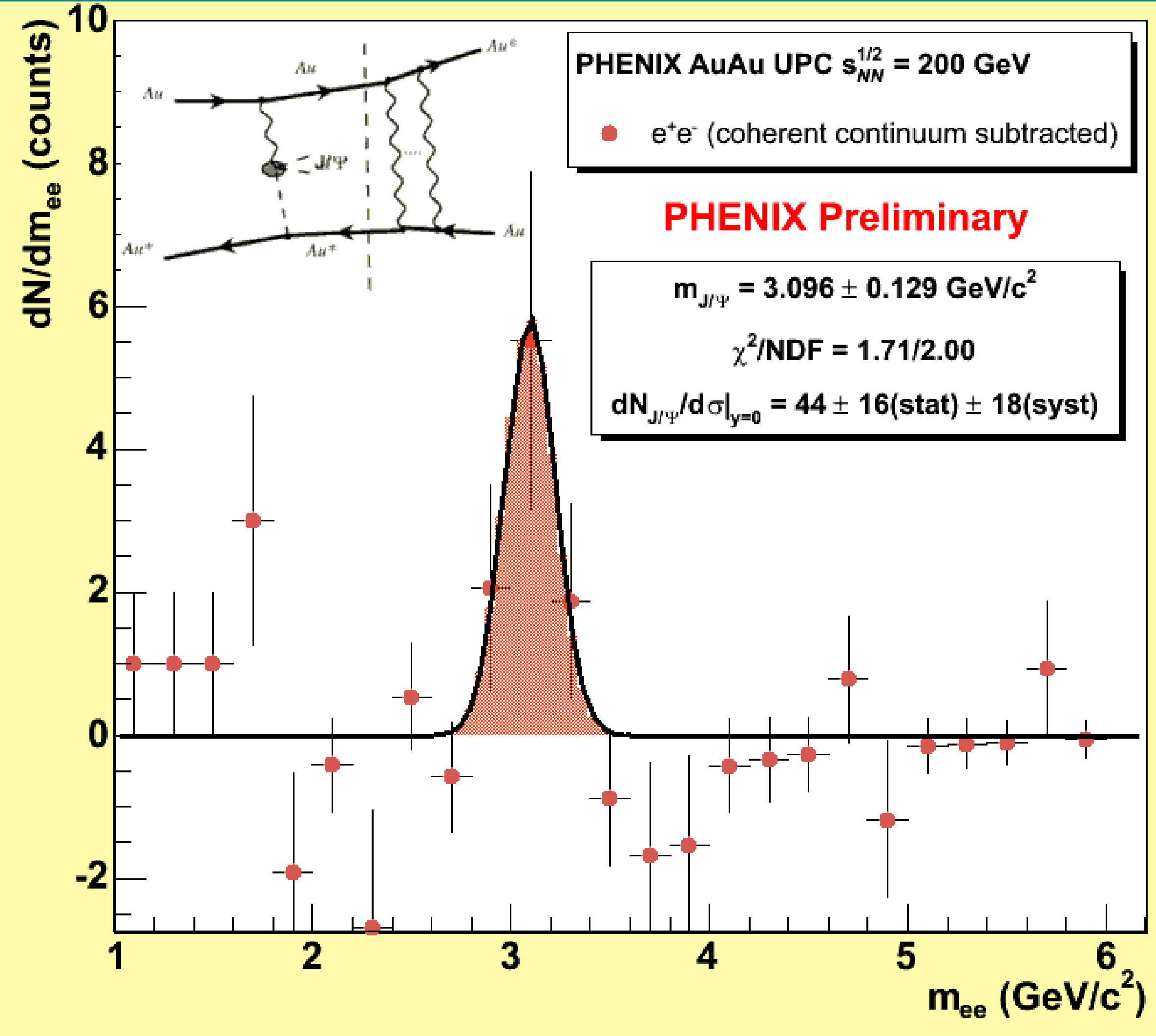
- γ->Jet

Only Highlights…



- γ->Jet
- Upsilon

Only Highlights…



- γ->Jet
- Upsilon
- J/ψ in ultraperipheral collisions
- …

Conclusions

- **PHENIX added exciting new results since our review in the "PHENIX White Paper" on**
  - Direct photon production at low p_T (thermal radiation?)
  - J/ψ production
  - Modifications of jets
- **Search for thermal radiation:**
  - Improvement of our established method of direct photon measurement at lower p_T
  - First significant results on a new technique in HI to extract direct photon signal based on dilepton analysis
- **J/ψ production:**
  - Wealth of new data on J/ψ production in Au+Au and Cu+Cu at various energies and rapidities
  - Suppression by factor 3 in most central collisions compared to binary scaled p+p

Conclusions II

- Centrality dependence more consistent with models that include color screening and recombination
- Need better understanding of effects of recombination on rapidity and p_T dependence

- **Jets:**
  - At intermediate trigger p_T:
    - Clear signal of broadening of away-side jet with increasing centrality
    - Clear signal of "dip" structure in away-side jet increasing with increasing centrality
    - Signal of near-side broadening
  - At high trigger p_T:
    - Suppression of away-side peak increasing with increasing centrality
    - In central collisions and highest trigger pT bin jet shape still visible
  - New method introducing 3-particle correlations


PHENIX
OVER ONE BILLION SERVED

1a Maya Shimomura : High pT π^0, η, charged hadrons

Masahiro Konno: Identified particle production 1a

1b Dipali Pal: Yield and flow for ϕ mesons

Hiroshi Masui: anisotropic flow 2a

3a David Winter : High pT with respect to reaction plane

Nathan Grau : High pT jets with Di-hadron and γ-hadron 3b

3c N.N. Ajitanand : Flavor Dependence of jet-correlations

Paul Chung:Long-range pion emission source 4a

4a Mate Csanad: Three-particle correlations

Tomoaki Nakamura: Event-by-event fluctuations 4b

5b Sergey Butsyk : Heavy flavor production in Au+Au

Xie Wei :J/ψ in p+p and d+Au 5c

5c Youngil Kwon: Heavy flavor production in p+p and d+Au

V. Ryabov : ω-meson production 6b

6b Stefan Bathe : Direct Photons

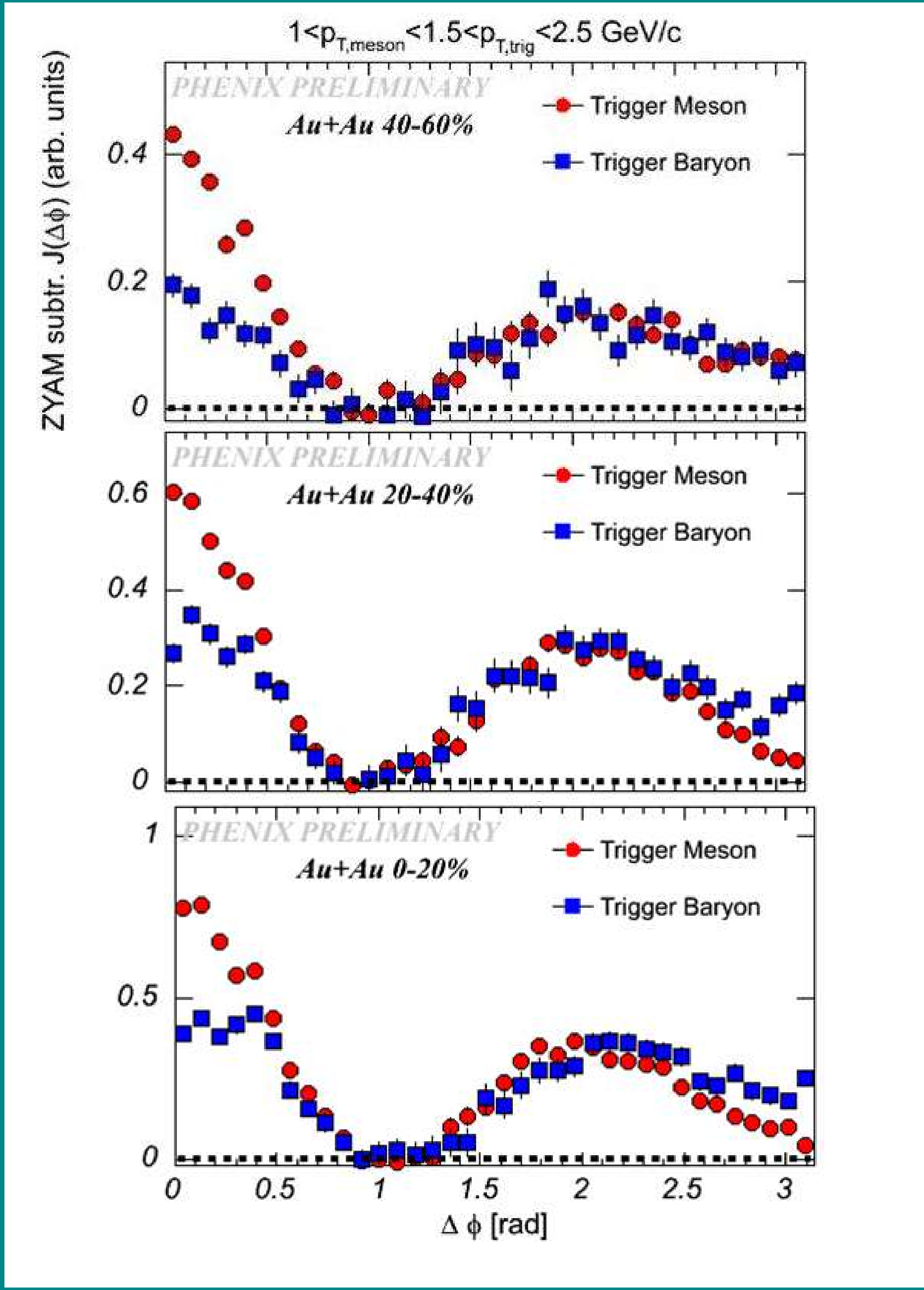
Alexander Kozlov : ϕ properties, di-leptons and hadr. Channel 6b

6b Hugo Pereira Da Costa : J/ψ in Au+Au and Cu+Cu

Alberica Toia: Low mass dielectron continuum 6b

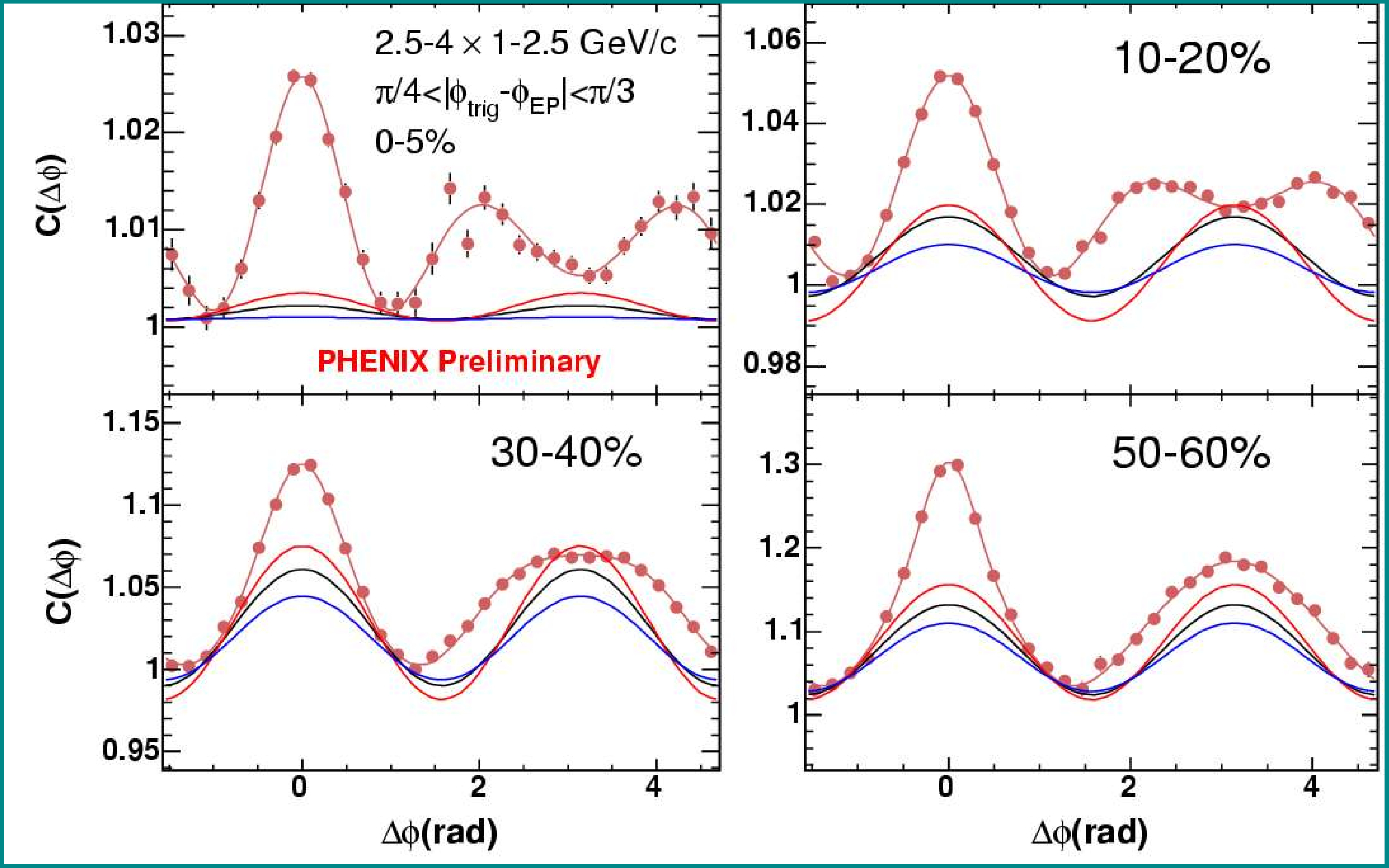
Backup

Baryon-Meson Dependence



Clear baryon-meson dependent shape evolution of away-side with increasing centrality

The dip



2.5-4 × 1-2.5 GeV/c
π/4<|φtrig-φEP|<π/3
0-5%
PHENIX Preliminary
10-20%
30-40%
50-60%
C(Δφ)
Δφ(rad)
1.03
1.02
1.01
1
1.06
1.04
1.02
0.98
1.15
1.1
1.05
0.95
1.3
1.2
1.1
0
2
4

Test of N_{part} scaling