Spectra of identified particles, geometry categorization and bias and global observables in d+Au Collisions

Sarah Campbell
for the PHENIX Collaboration
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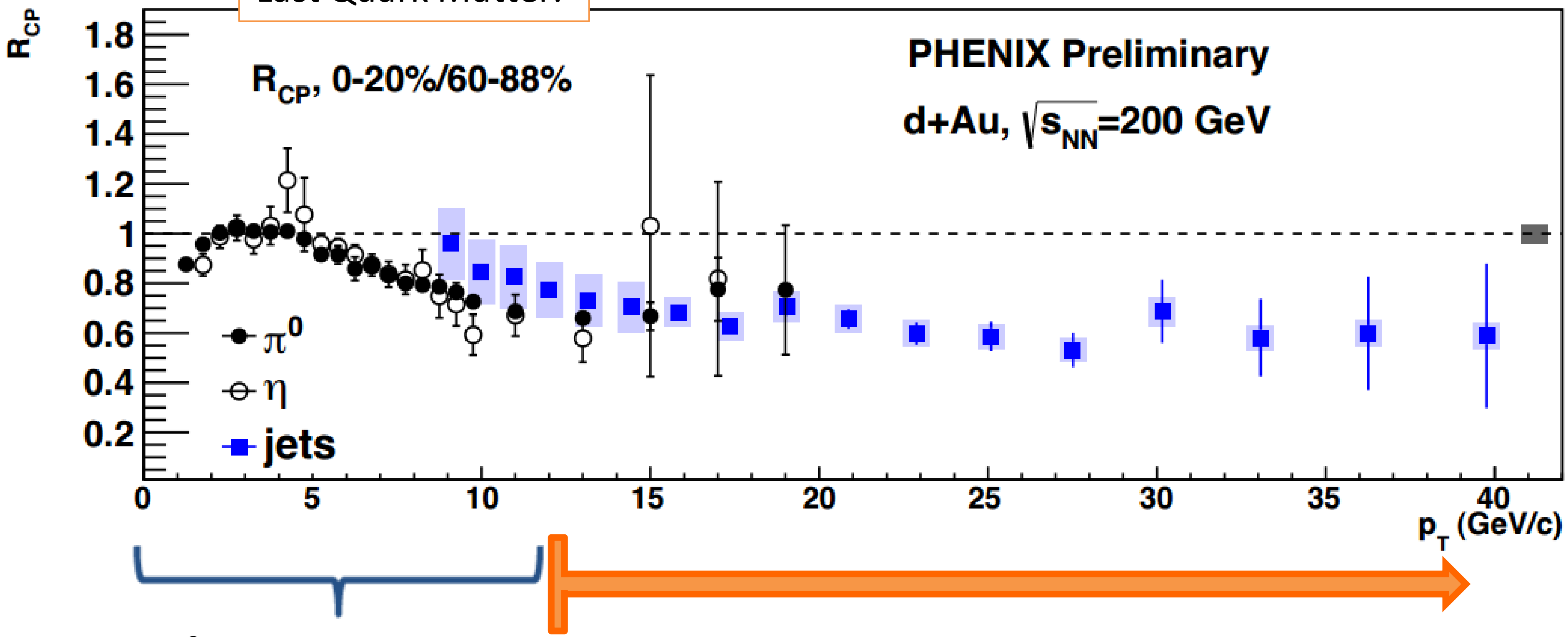
Quark Matter
Darmstadt, Germany

Outline

- Why discuss d+Au centrality?
- How do we determine centrality, global observables & geometry?
  – Correcting for auto-correlation bias
- What is interesting in d+Au with centrality?
  – Identified particle results
- Conclusions/Future

Why discuss d+Au centrality?

Last Quark Matter:

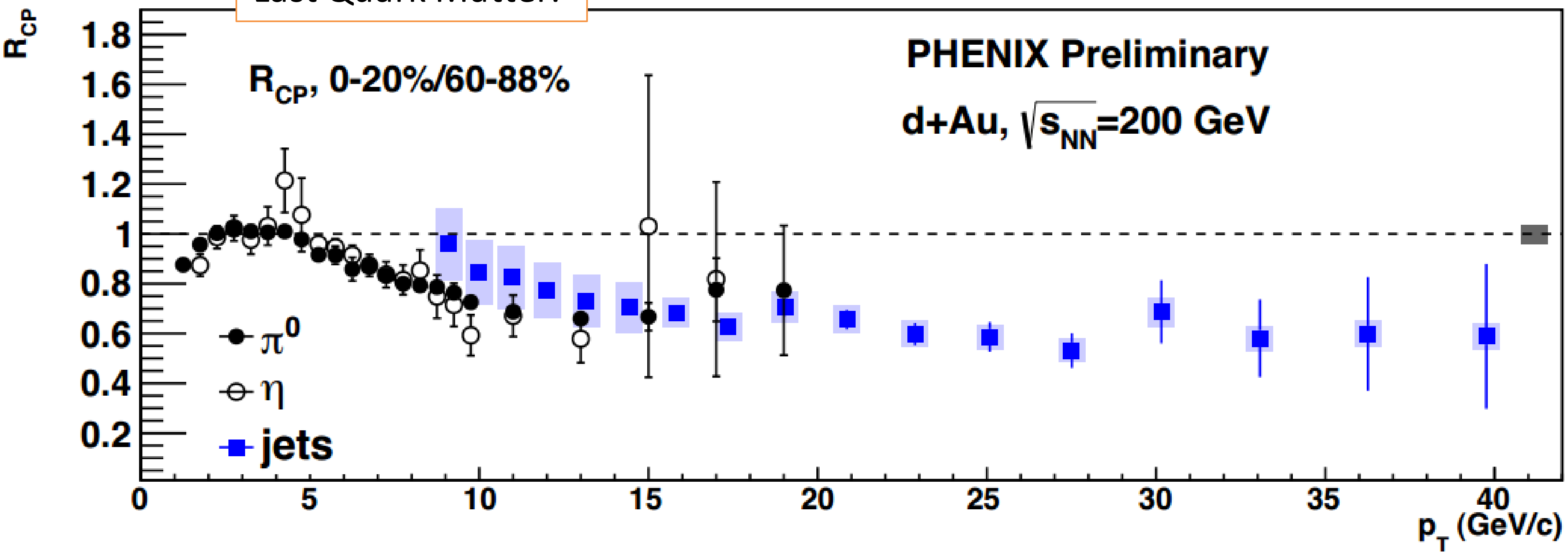


π^0 R_{dA} will be shown

Unclear how much of the R_{CP} is due to suppression in central d+Au versus an enhancement in peripheral d+Au

Why discuss d+Au centrality?

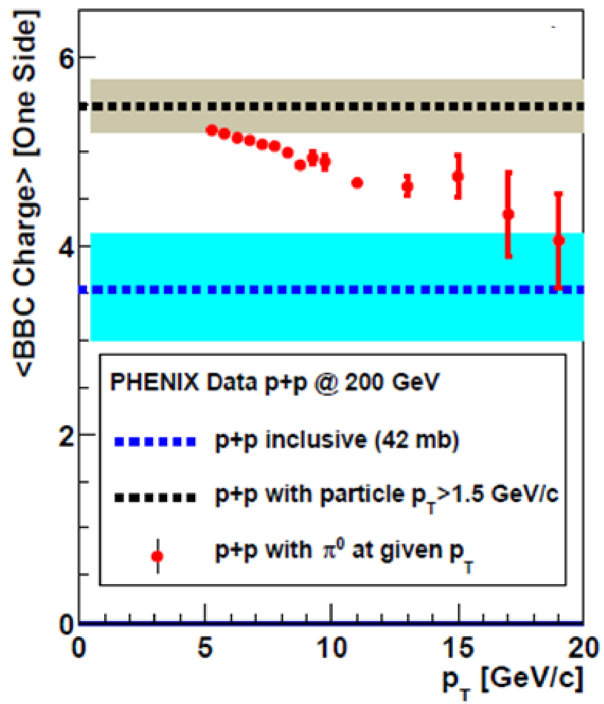
Last Quark Matter:



An auto-correlation bias effect?

Why discuss d+Au centrality?

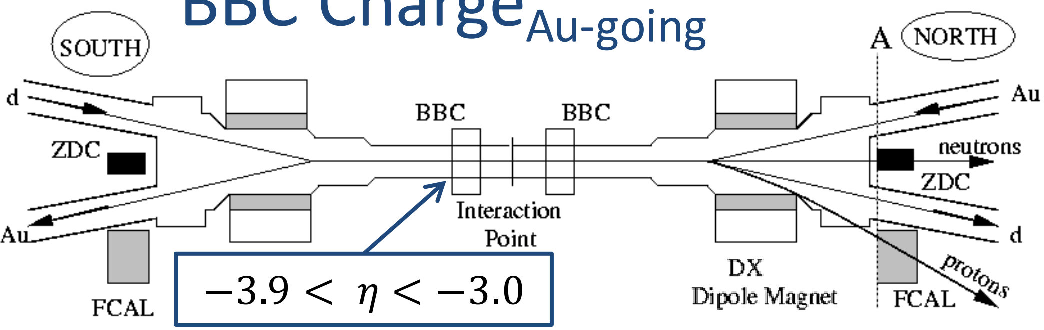
p_T dependence of multiplicity effect in the auto-correlation bias



- Review centrality determination
- Review auto-correlation bias correction
- Discuss p_T dependence

Observable ⟺ Map ⟺ Geometry, global information

BBC $\text{Charge}_{\text{Au-going}}$

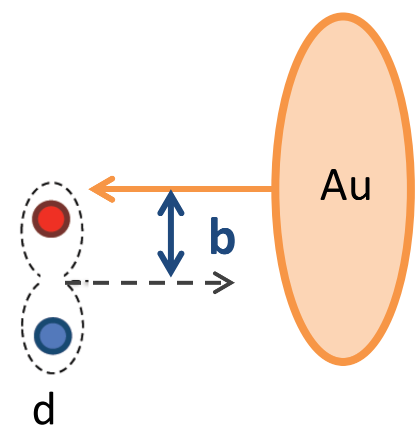


N_{Coll}, N_{Part}, b, etc.

Number of participating nucleons

Number of binary collisions

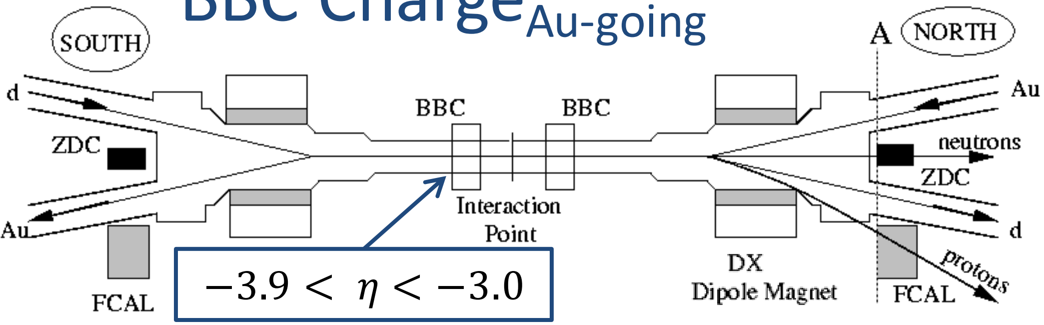
$$BBC\ Charge_{Au} \propto N_{Coll}$$

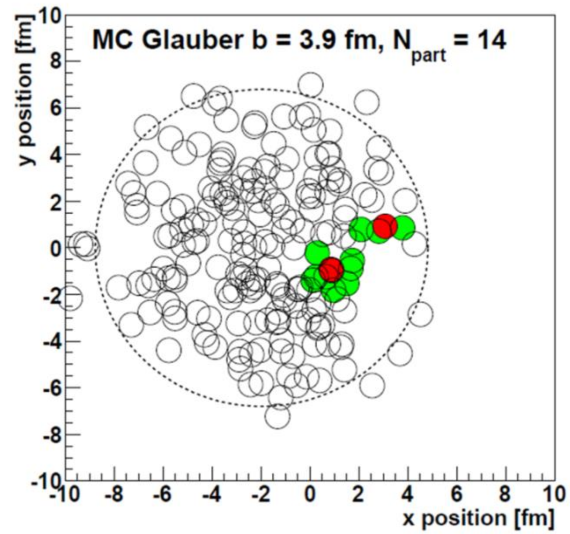


Observable ⟺ Map ⟺ Geometry, global information

BBC $\text{Charge}_{\text{Au-going}}$

N_{Coll}, N_{Part}, b, etc.





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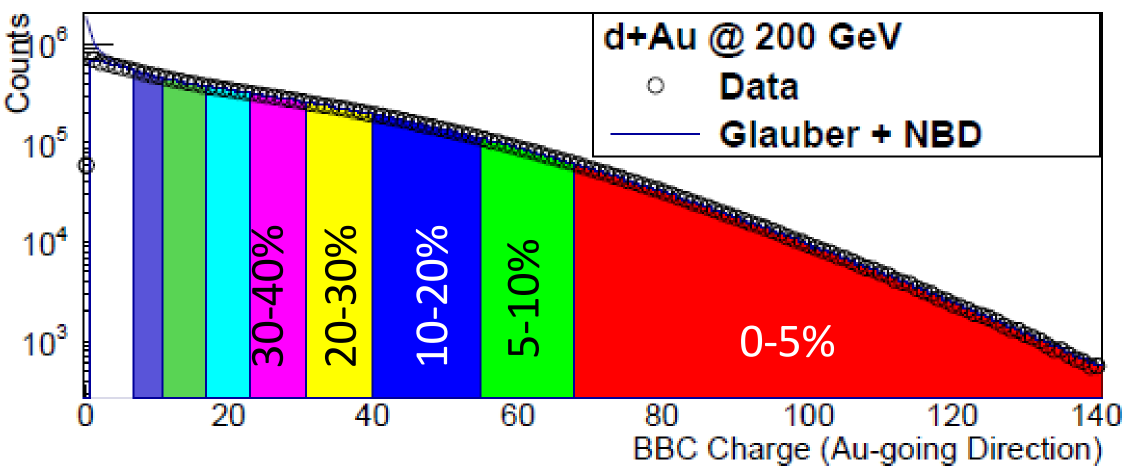


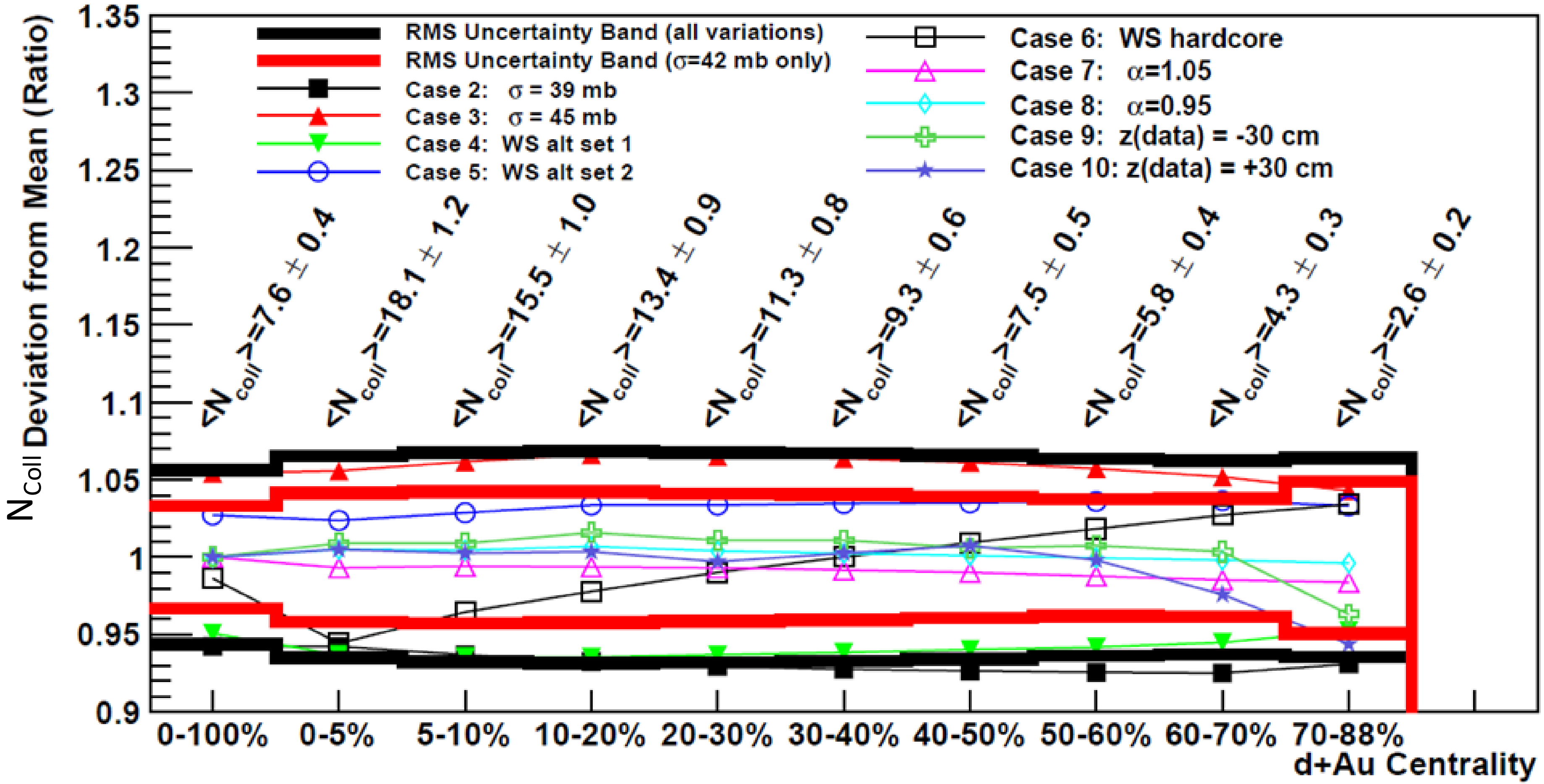
Glauber Monte Carlo

- d: Hulthen ψ(r)
- Au: Woods-Saxon ρ(r)

arXiv:1310.4793

Systematic Uncertainties

81 variations of parameters



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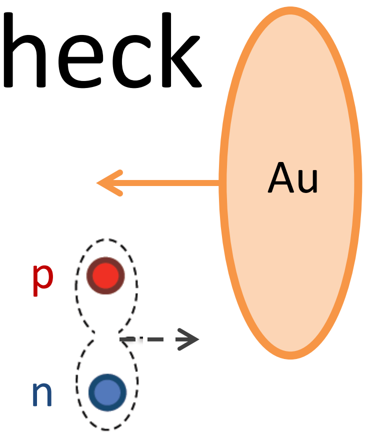
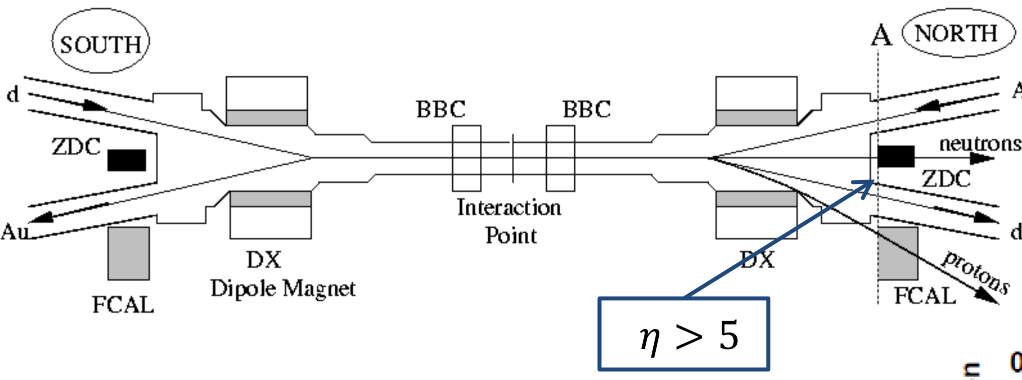
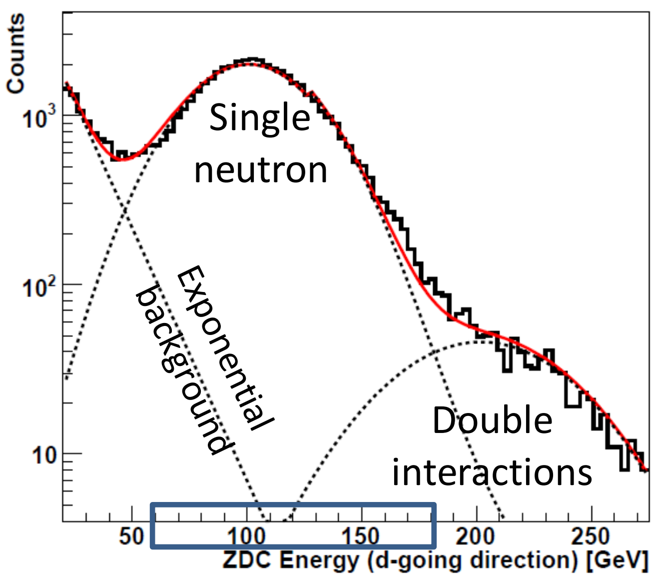
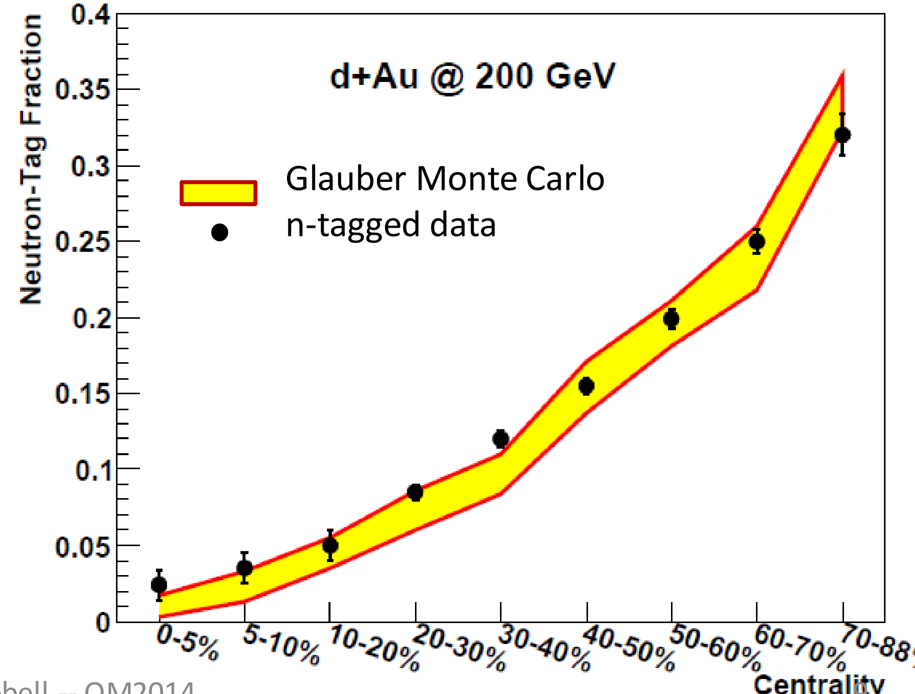
n-tagged Cross Check





Good agreement





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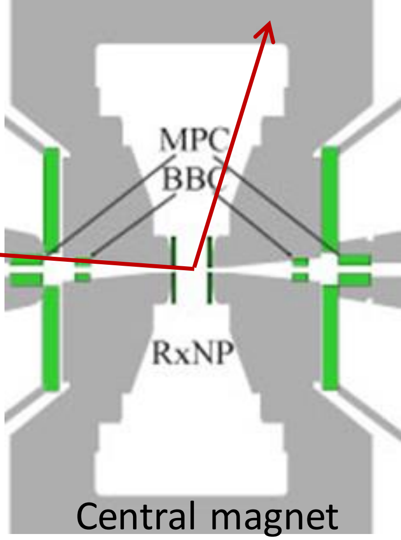
Auto-correlation Bias



In p+p — Trigger biased to non-diff. events → more mid-y particles

From Data: ⇨ $\frac{\epsilon_{mid-y}{}^{p+p}}{\epsilon_{BBC}{}^{p+p}} = \frac{75 \pm 3\% \; of \; particles}{52 \pm 4\% \; of \; events}$

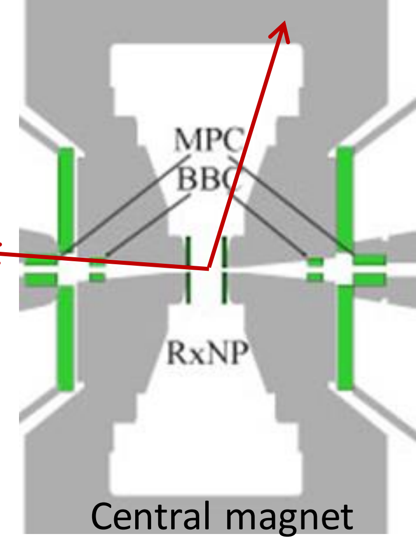
$$\sigma_{MB}{}^{pp} = \sigma_{non-diff} + \sigma_{1-diff} + \sigma_{2-diff}$$

From Pythia: $42mb = 28mb + 10mb + 4mb$

Primarily produces particles at mid-rapidity

arXiv:1310.4793

Auto-correlation Bias



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$$\frac{\epsilon_{mid-y}{}^{p+p}}{\epsilon_{MB}{}^{p+p}} = \frac{75 \pm 3\% \; of \; Particles}{52 \pm 4\% \; of \; Events}$$

In d+Au Trigger bias

↳ Effect in peripheral collisions, low ϵ_{MB} ⇒ $\frac{Particles}{Event}$ too high

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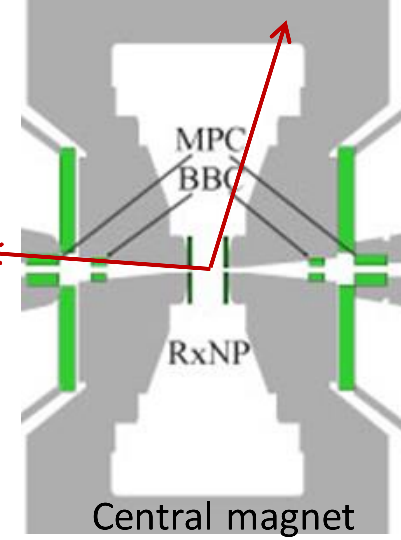
Auto-correlation Bias



In p+p Trigger biased to non-diff. events → more mid-y particles

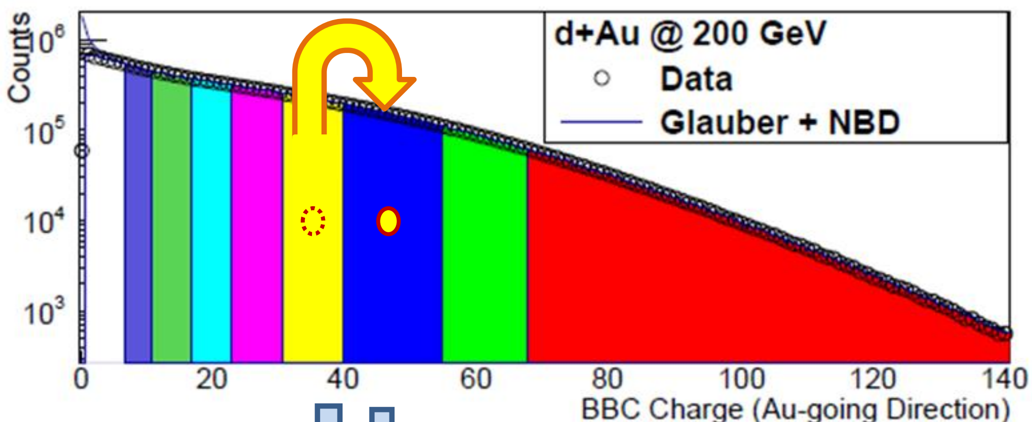
$$\frac{\epsilon_{mid-y}{}^{p+p}}{\epsilon_{BBC}{}^{p+p}} = \frac{75 \pm 3\% \; of \; Particles}{52 \pm 4\% \; of \; Events}$$

In d+Au Trigger bias **AND** Multiplicity effect

→ Peripheral $\frac{Particles}{Event}$ too high

→ Events with mid-y particles have higher multiplicity

→ A hard interaction deposits 1.55 x charge in the BBC



Lose high multiplicity events, Decrease $\frac{Particles}{Event}$

Gain high multiplicity events, Increase $\frac{Particles}{Event}$

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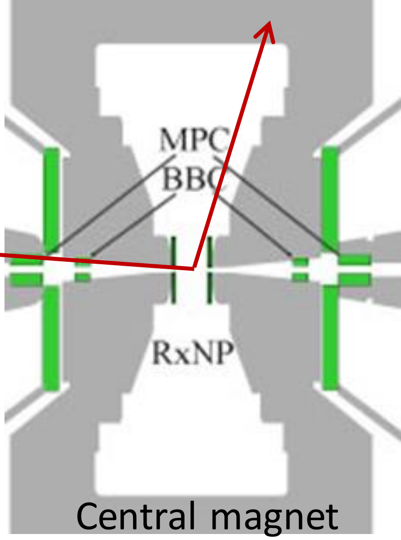
Auto-correlation Bias



In p+p — Trigger biased to non-diff. events → more mid-y particles

$$\frac{{\epsilon_{mid-y}}^{p+p}}{{\epsilon_{BBC}}^{p+p}} = \frac{75 \pm 3\%\ of\ Particles}{52 \pm 4\%\ of\ Events}$$

In d+Au — Trigger bias **AND** Multiplicity effect

- Trigger bias → Peripheral $\frac{Particles}{Event}$ too high
- Multiplicity effect → Peripheral $\frac{Particles}{Event}$ too low; Central $\frac{Particles}{Event}$ too high

Correction factor, c

$$R_{dA} = \frac{c\, dN^{d+Au}/dy}{\langle N_{Coll}\rangle\, dN^{p+p}/dy}$$

Centrality	Bias Factor, c
0-20%	0.94 ± 0.01
20-40%	1.00 ± 0.01
40-60%	1.03 ± 0.02
60-88%	1.03 ± 0.06

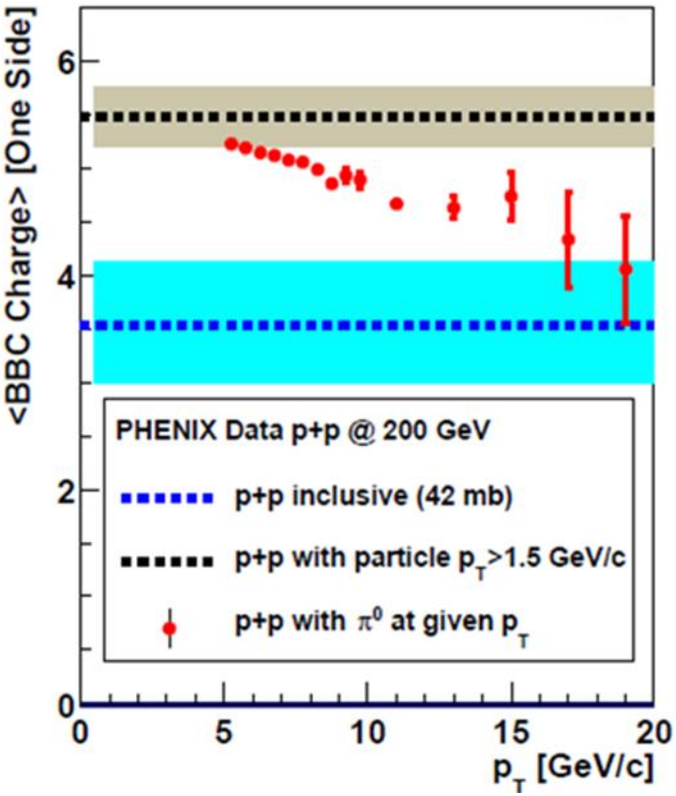
Multiplicity effect only (0-20%)

Competing effects (60-88%)
- Trigger bias: 0.89
- Multiplicity effect: 1.16

These corrections are in **all** of our d+Au publications, both the 2003 and 2008 data

arXiv:1310.4793

p_T Dependence of Multiplicity Effect



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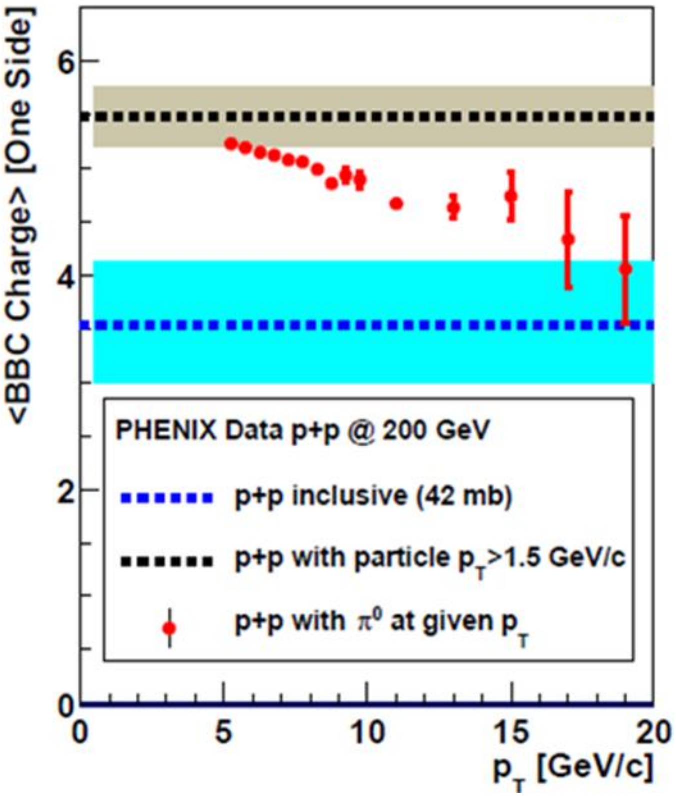
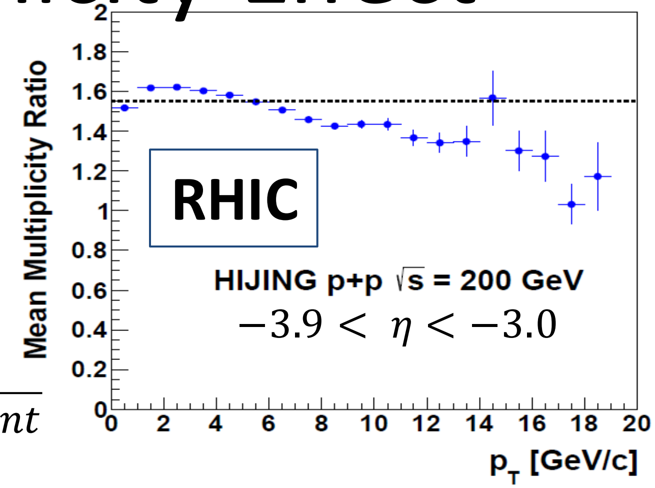


Model with Hijing

$$c = \frac{true\ sim.yield/event}{'measured'\ sim.yield/event}$$



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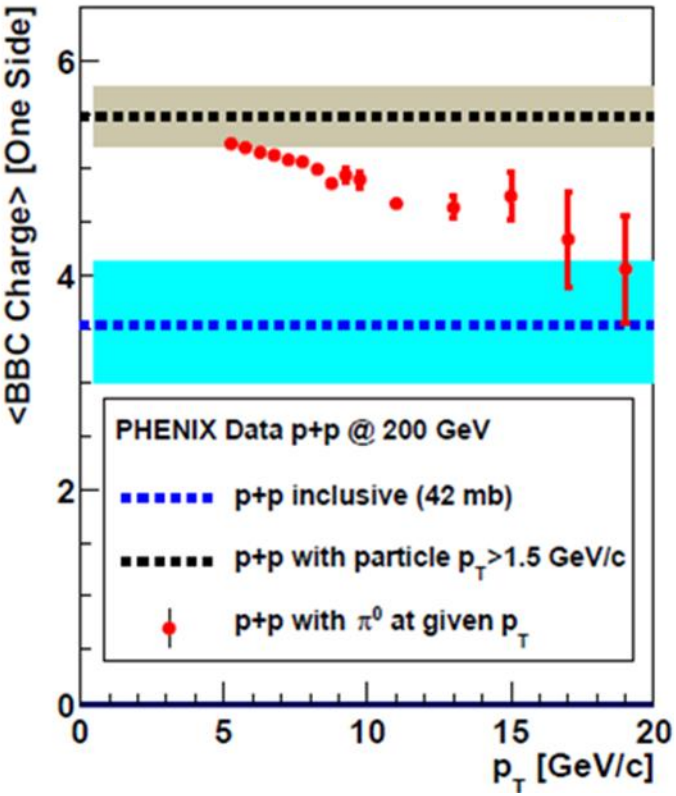

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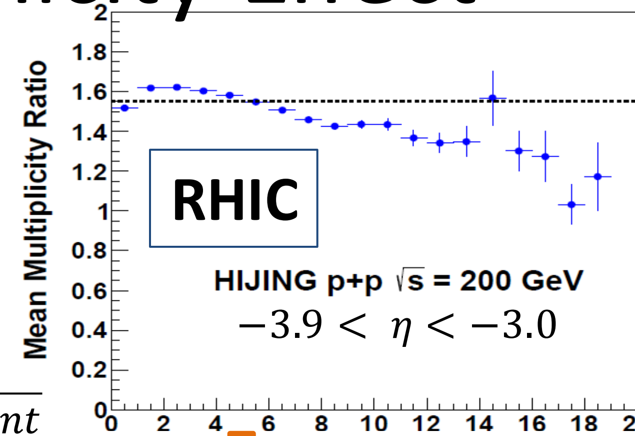
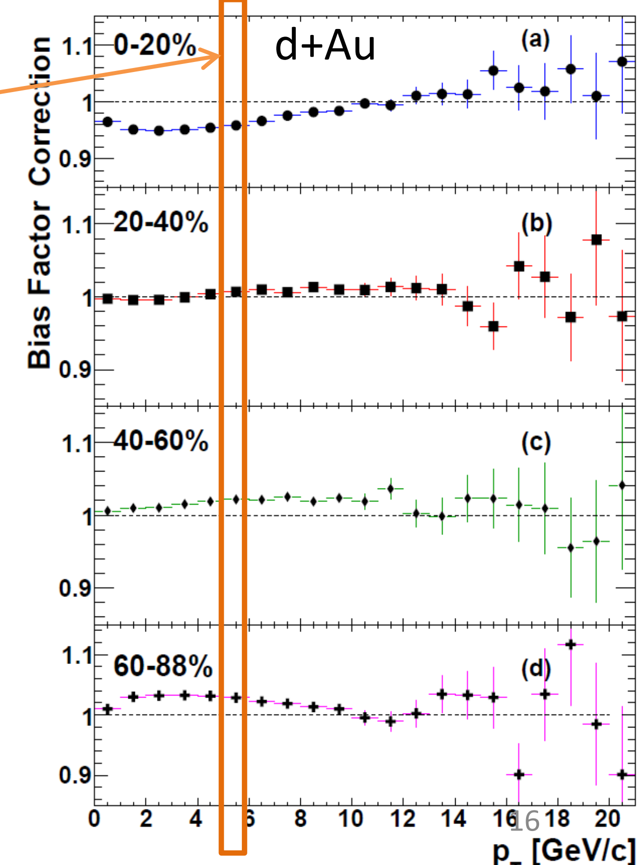


vary < 5%



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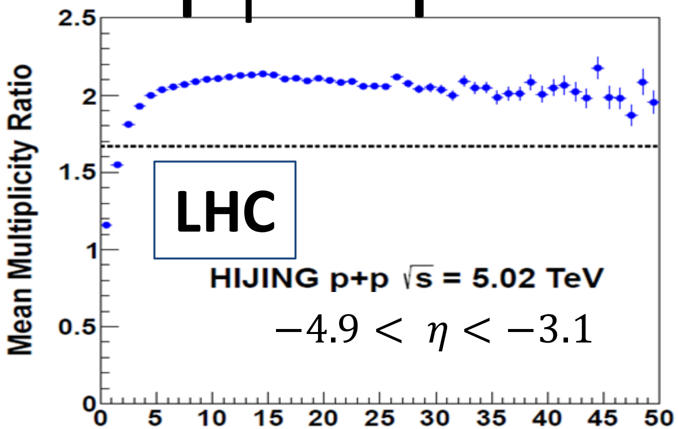

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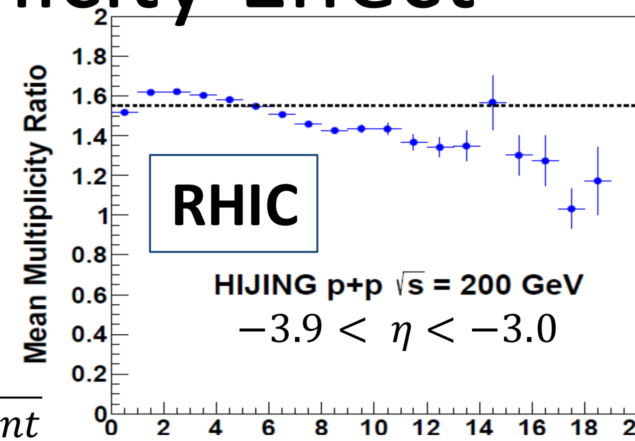

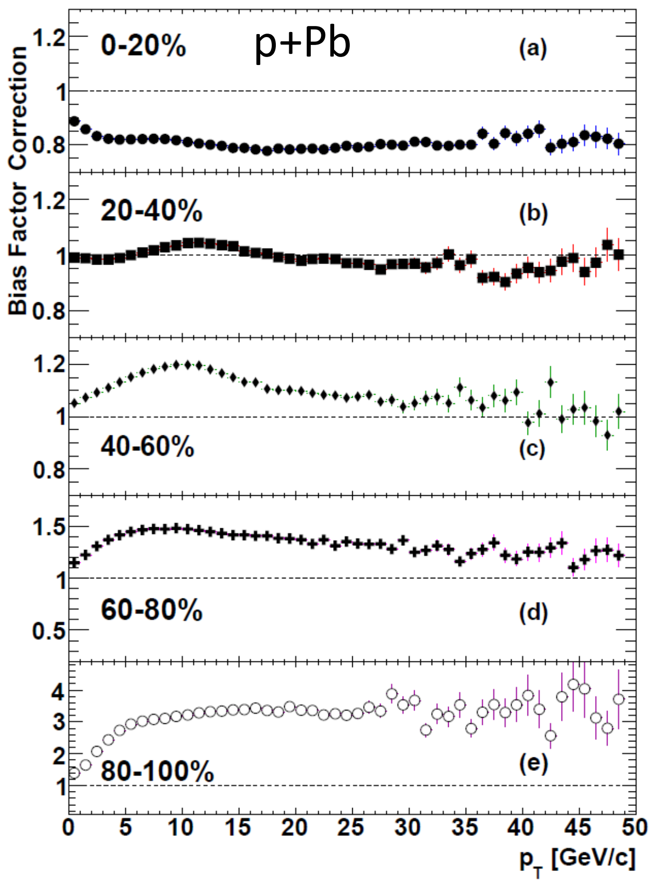

Much larger effect at LHC!

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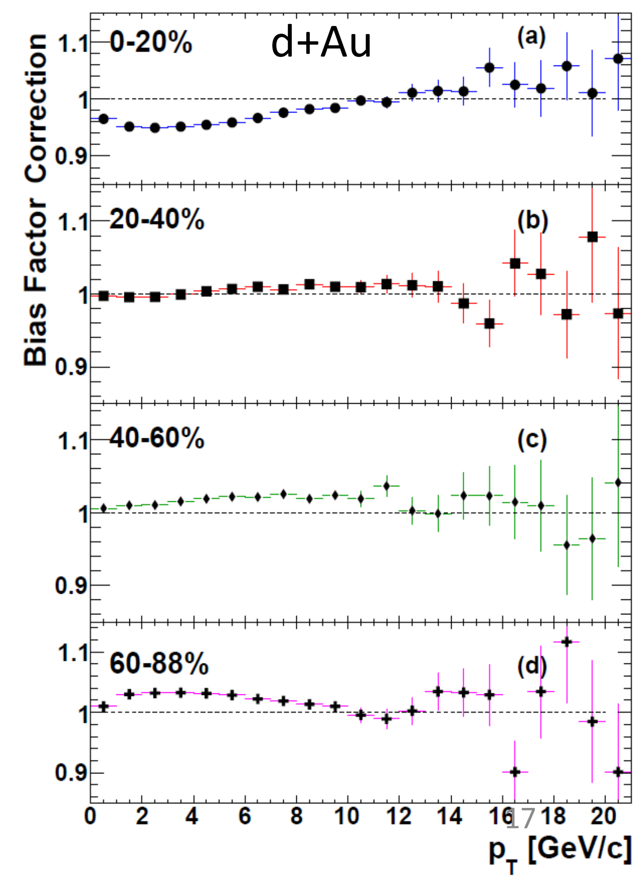
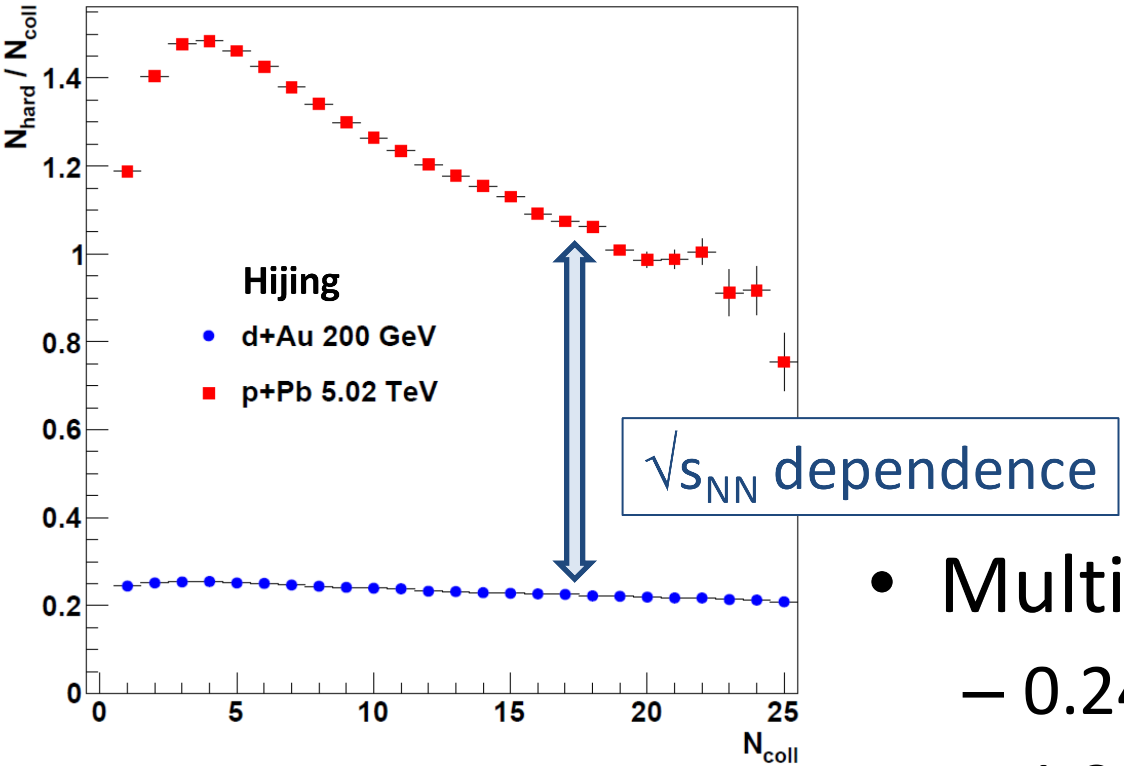


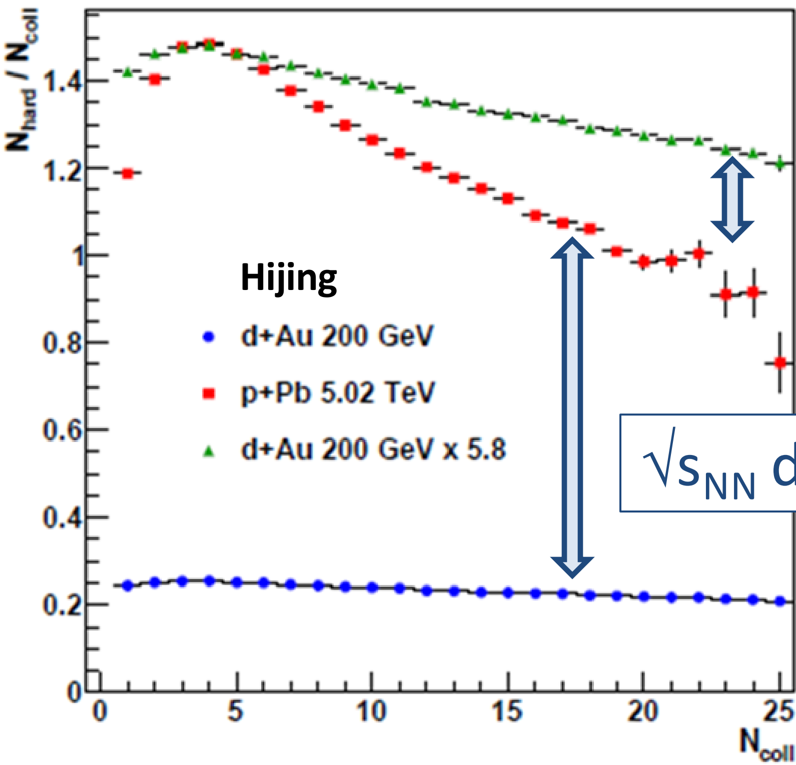
What causes the RHIC/LHC difference ?



- Multiparton interactions
  - 0.24 in 200 GeV d+Au
  - 1.36 in 5.02 TeV p+Pb

arXiv:1310.4793

What causes the RHIC/LHC difference ?



N_{Coll} shape dependence

$\sqrt{s_{NN}}$ dependence

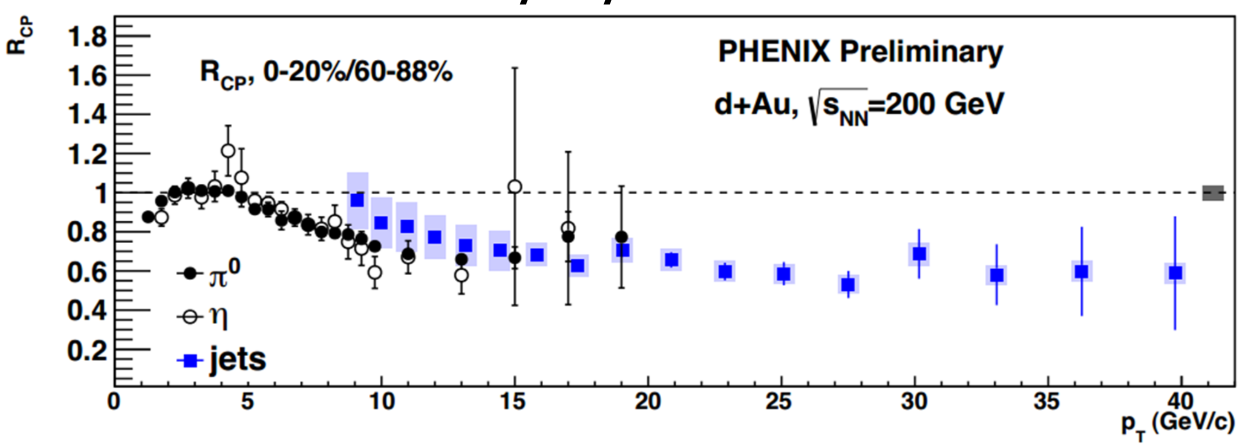
- Multiparton interactions
  - 0.24 in 200 GeV d+Au
  - 1.36 in 5.02 TeV p+Pb

RHIC auto-correlation bias is well understood & under control

arXiv:1310.4793

Mini-summary

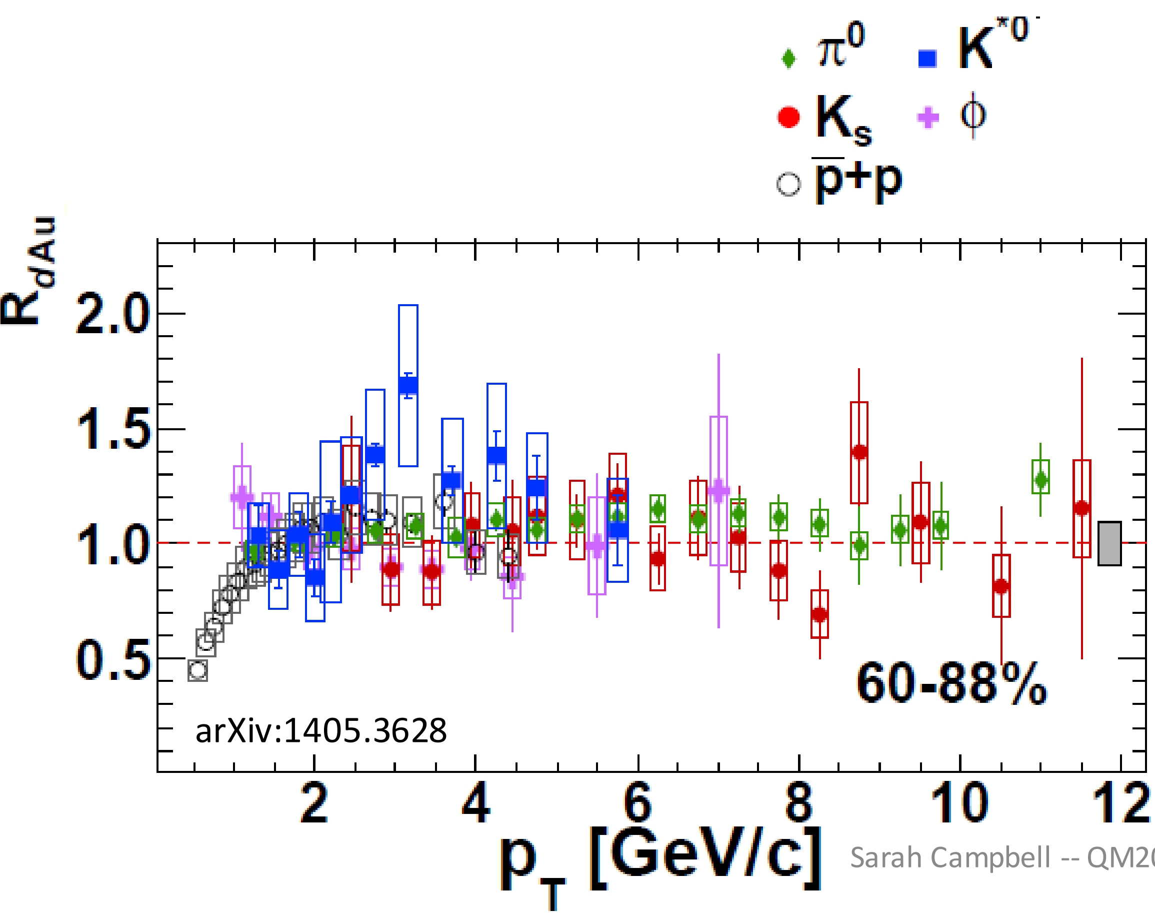
- p_T dependence of multiplicity effect is within the uncertainty of auto-correlation bias correction
- Auto-correlation factors correct for this bias
- π^0 + jet R_{CP} is robust
  - Can not be described solely by auto-correlation bias in Hijing



Next: Nuclear Modification of identified hadrons in d+Au

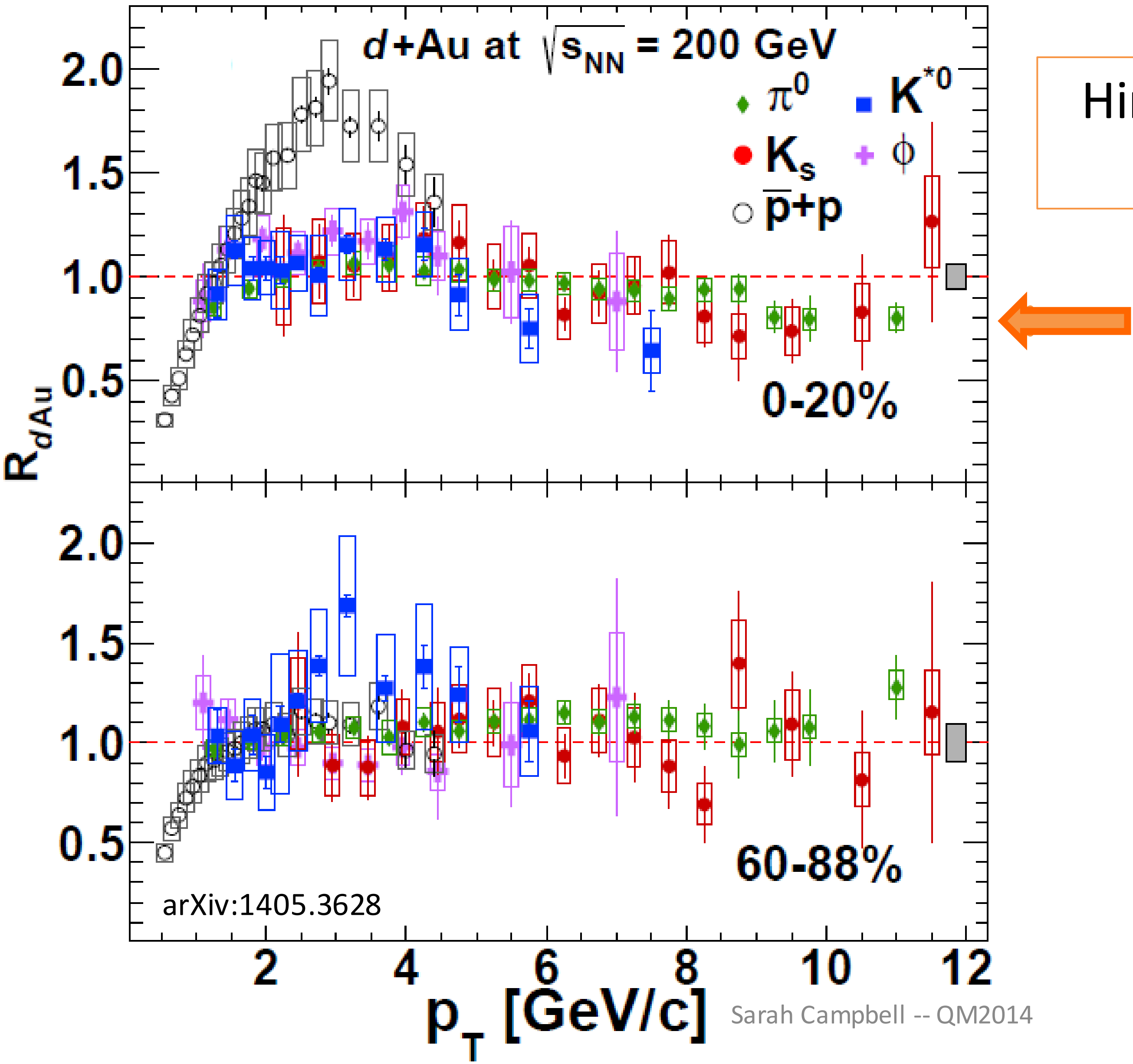
- π, K, p, K_S^0, K^{*0}

Nuclear modification factor in d+Au



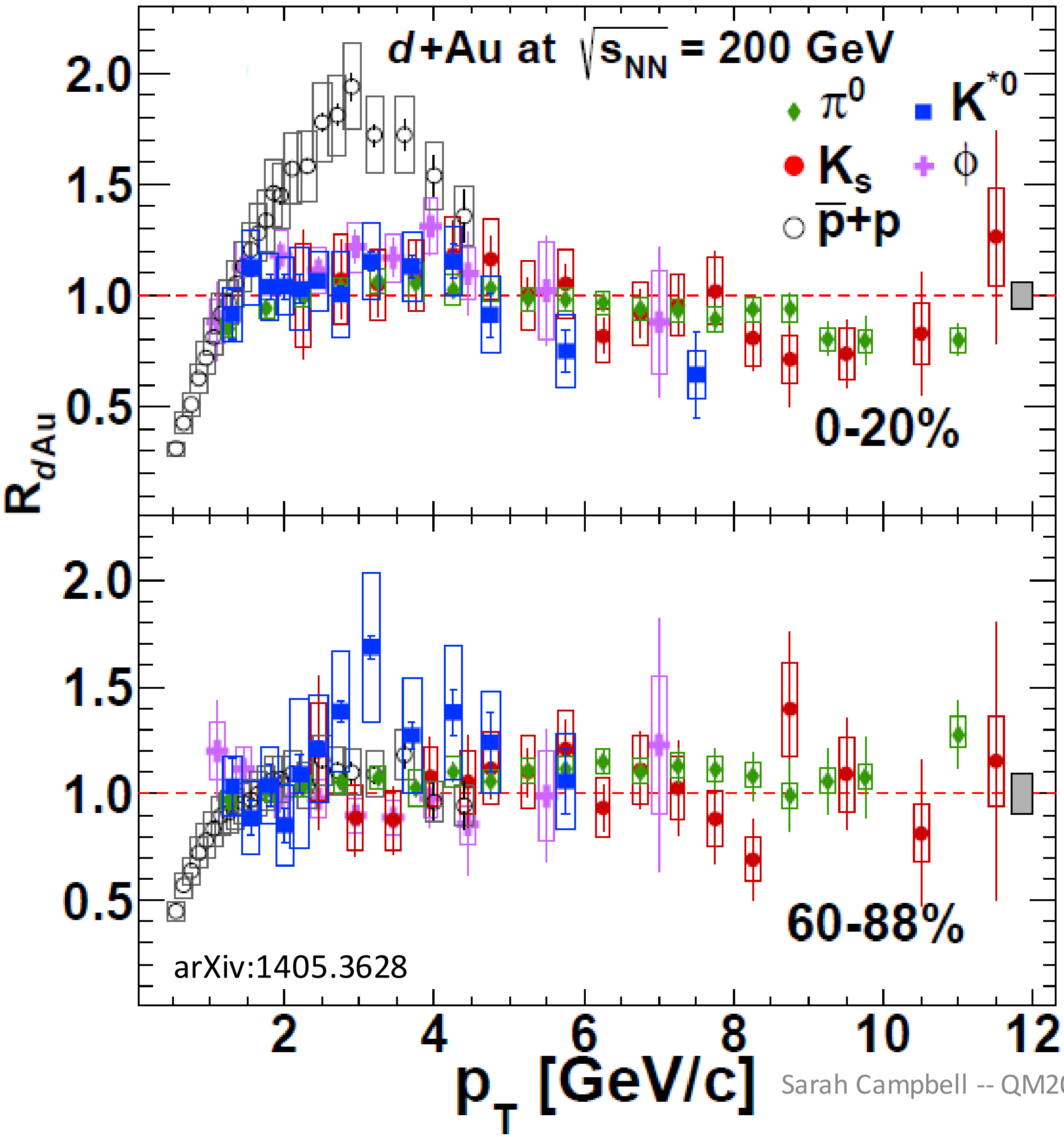
Consistent with N_{Coll}-scaled p+p

Nuclear modification factor in d+Au



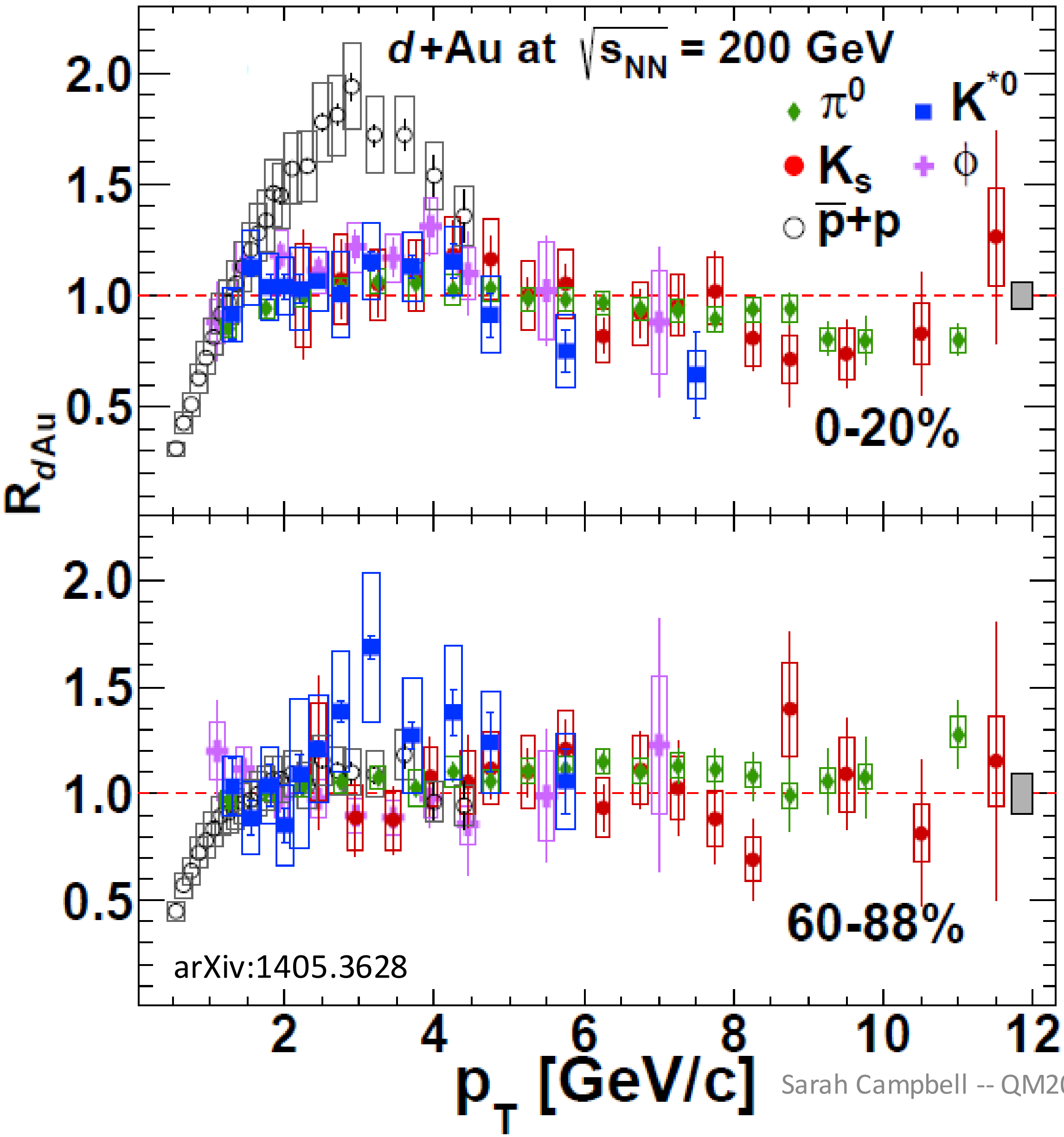
Hint of suppression at high p_T

Nuclear modification factor in d+Au



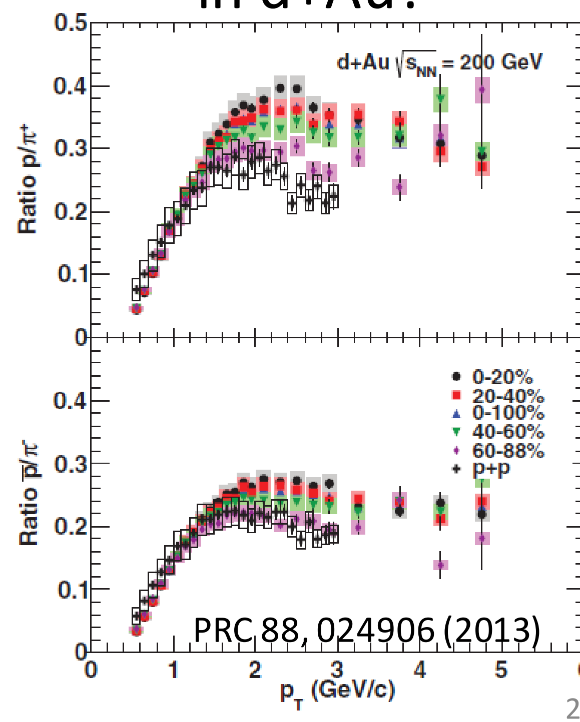
Baryons enhanced in central d+Au

Nuclear modification factor in d+Au

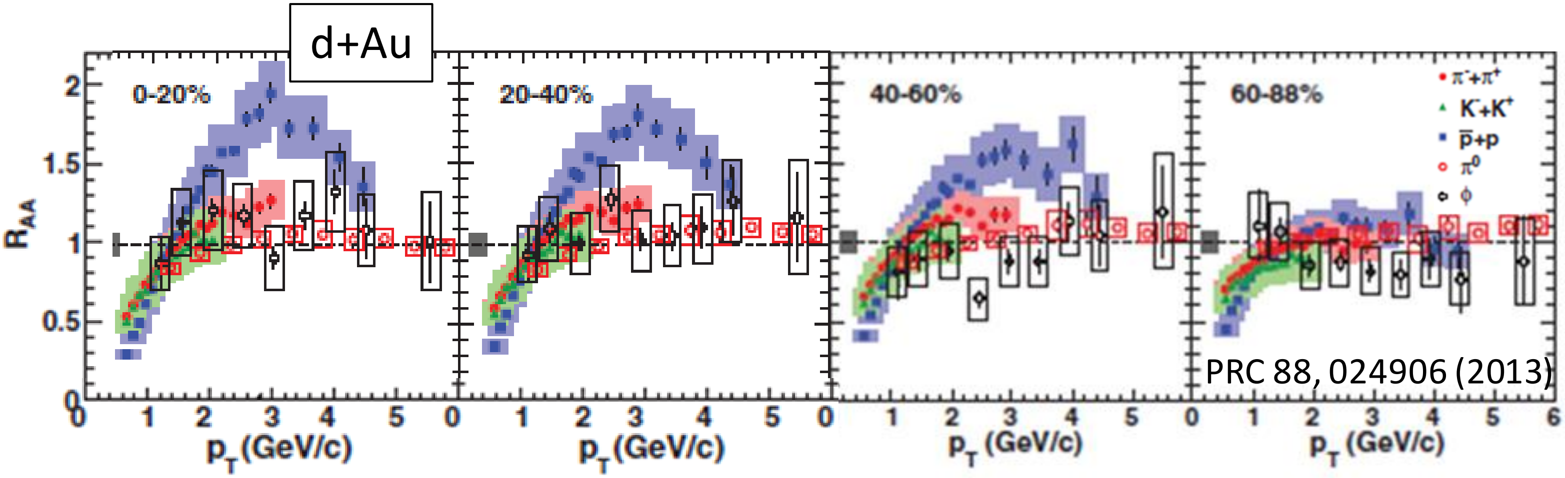


Baryons enhanced in central d+Au

Recombination in d+Au?

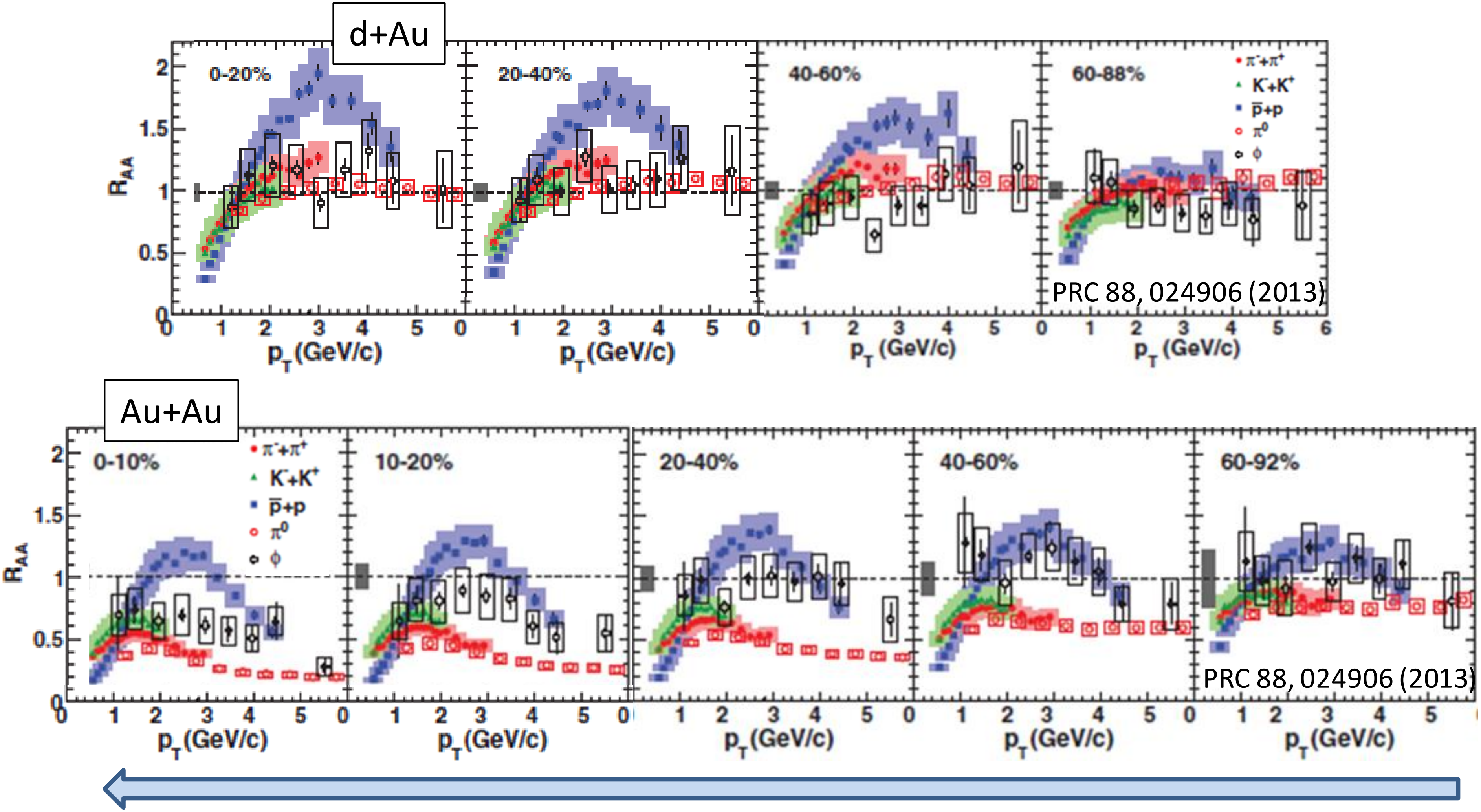


Nuclear Modification Factors



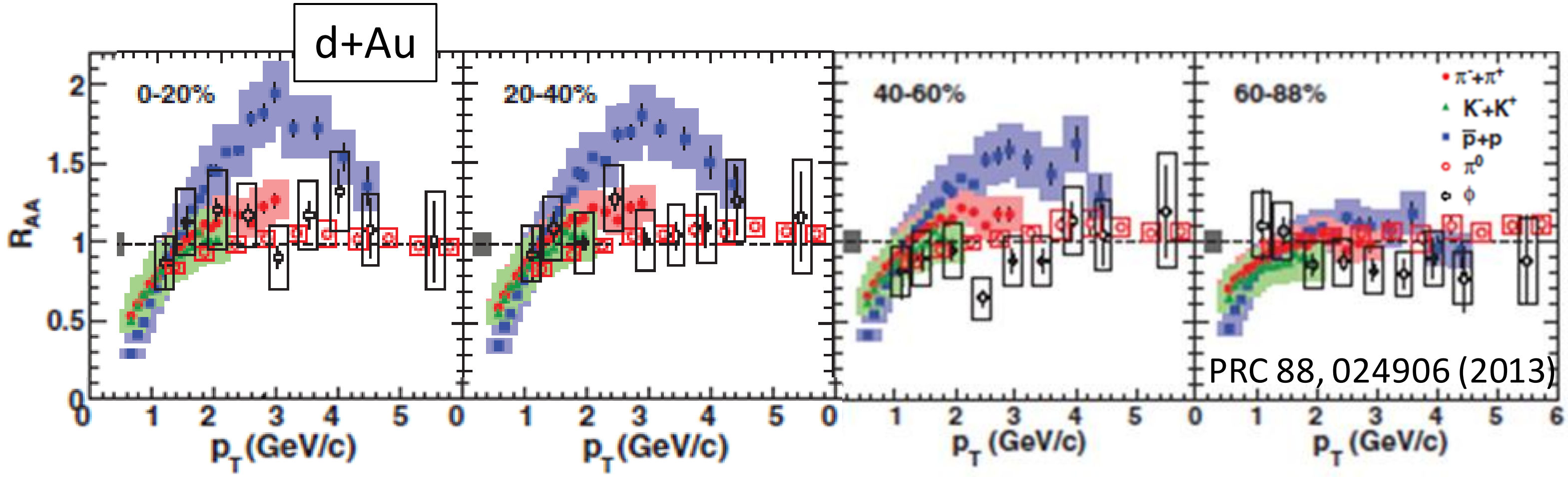
Baryon enhancement increases with d+Au centrality

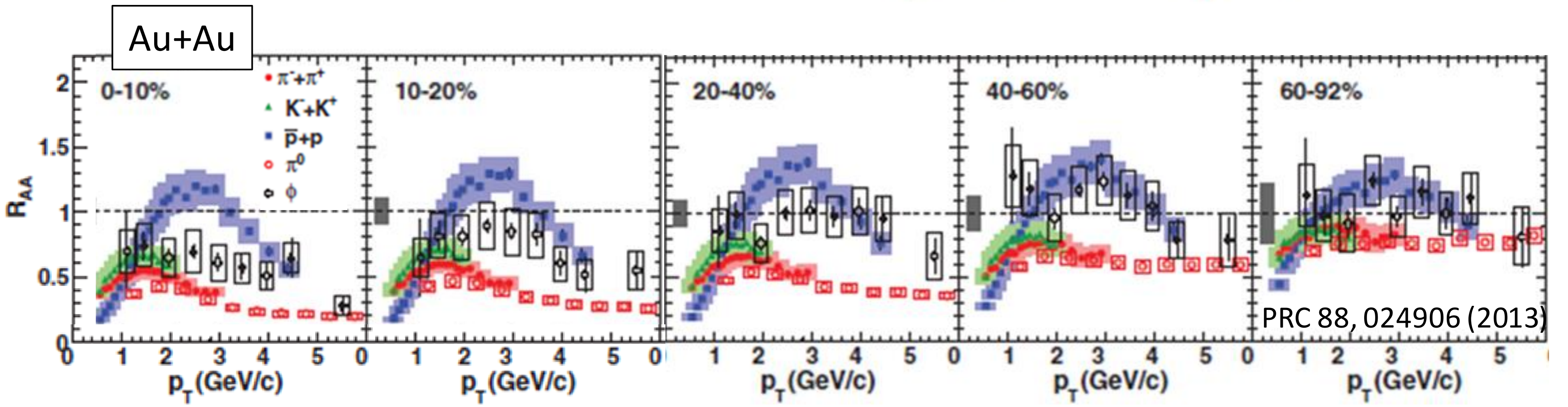
Nuclear Modification Factors



Suppression increases with Au+Au centrality

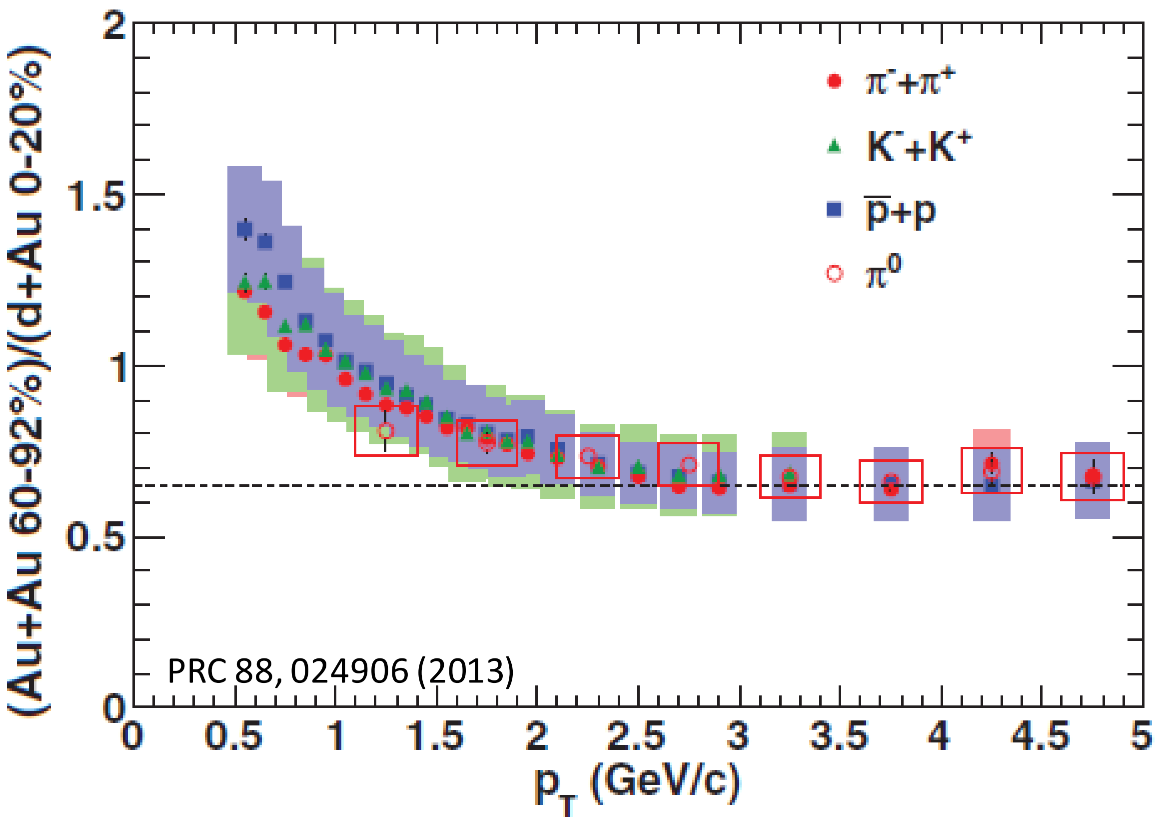
Nuclear Modification Factors





Protons are suppressed in Au+Au relative to 0-20% d+Au

Compare 60-92% Au+Au and 0-20% d+Au



No N_{coll}-scaling applied

System	<Ncoll>
Au+Au 60-92%	14.8 ± 3.0
d+Au 0-20%	15.1 ± 1.0

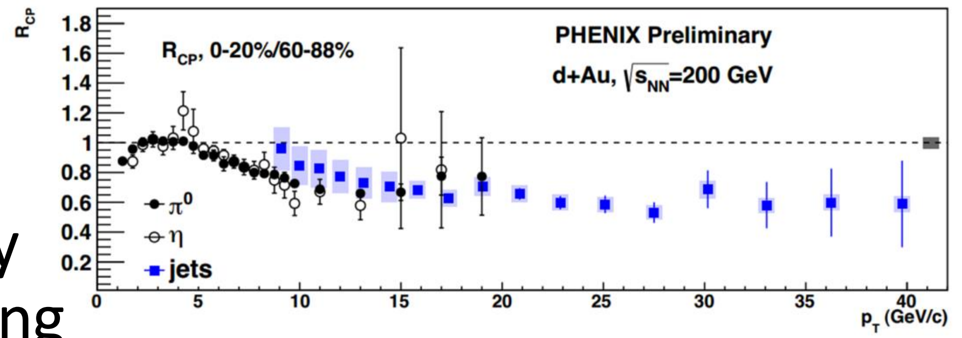
Energy loss in peripheral Au+Au?

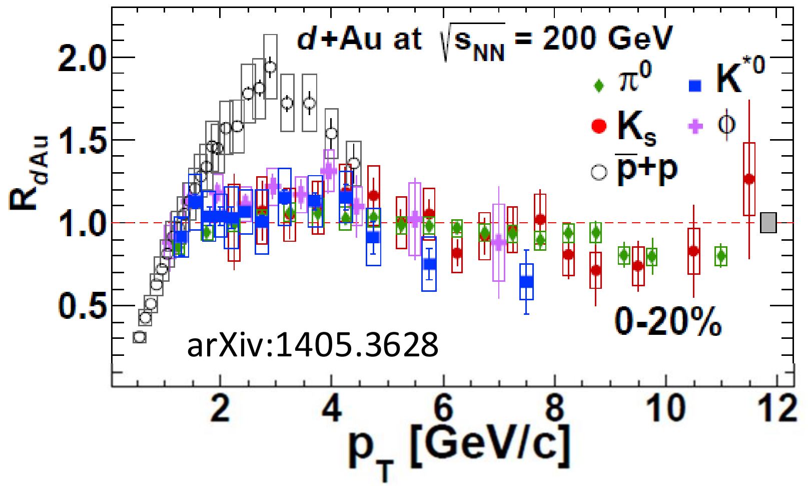
or Effect of rapidity shift in particle production?

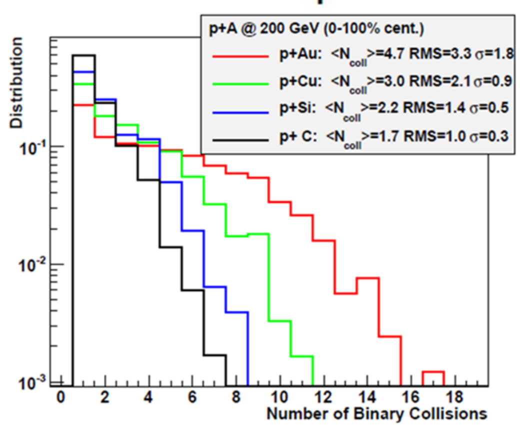
or Hydrodynamic effect?

Conclusions

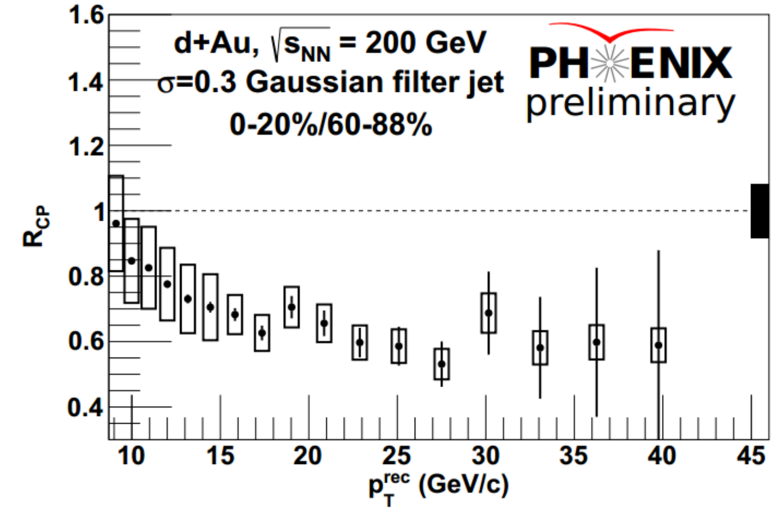
- Auto-correlation bias well understood
  - π^0 + jet R_{CP} not described by auto-correlation bias in Hijing
- Baryon enhancement in d+Au
  - Peripheral d+Au consistent with N_{Coll}-scaled p+p
  - Recombination in central d+Au?
- Future
  - Run14: ^{3}He+Au
  - Run15: p+Au, p+Si
  - How to interpret behavior of $\frac{60-92\%\ Au+Au}{0-20\%\ d+Au}$?

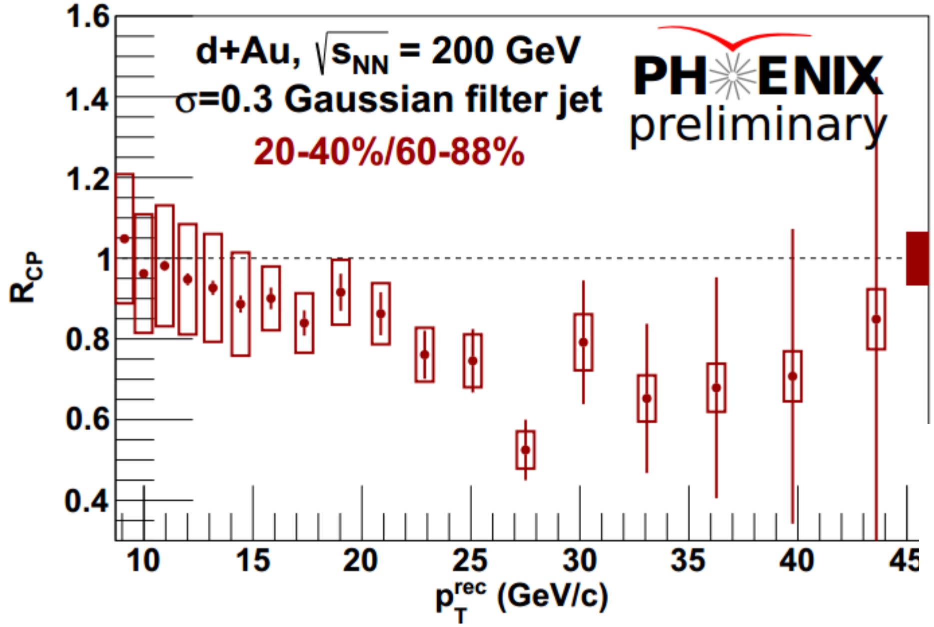






Backup


d+Au, $\sqrt{s_{NN}}$ = 200 GeV
σ=0.3 Gaussian filter jet
0-20%/60-88%
PHENIX preliminary
R_{CP}
p_T^{rec} (GeV/c)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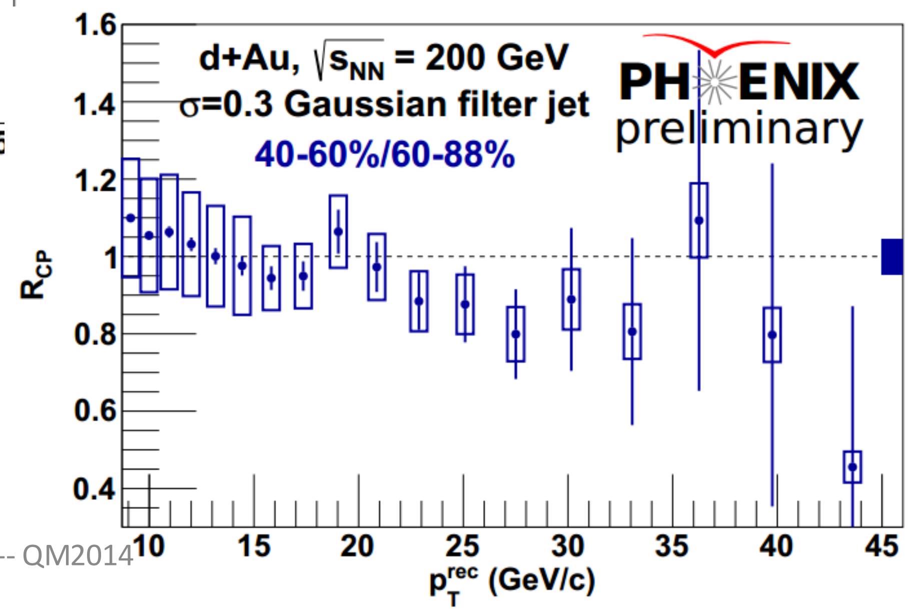
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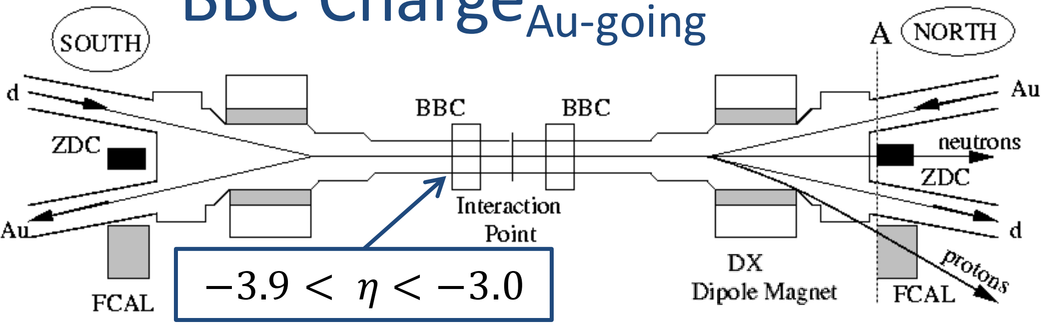
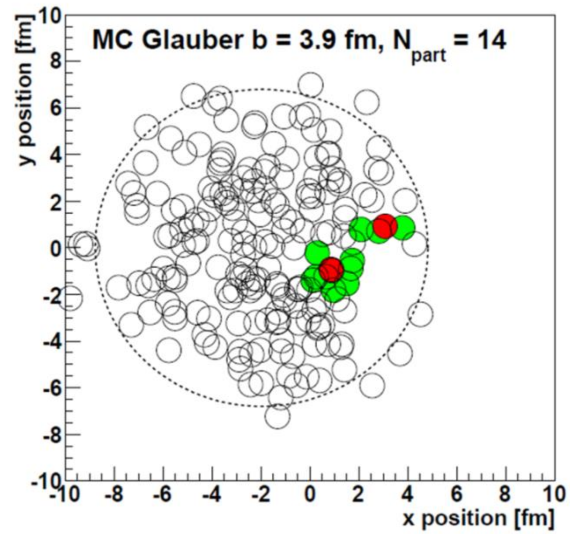
Observable ⟺ Map ⟺ Geometry, global information

BBC $Charge_{Au\text{-}going}$

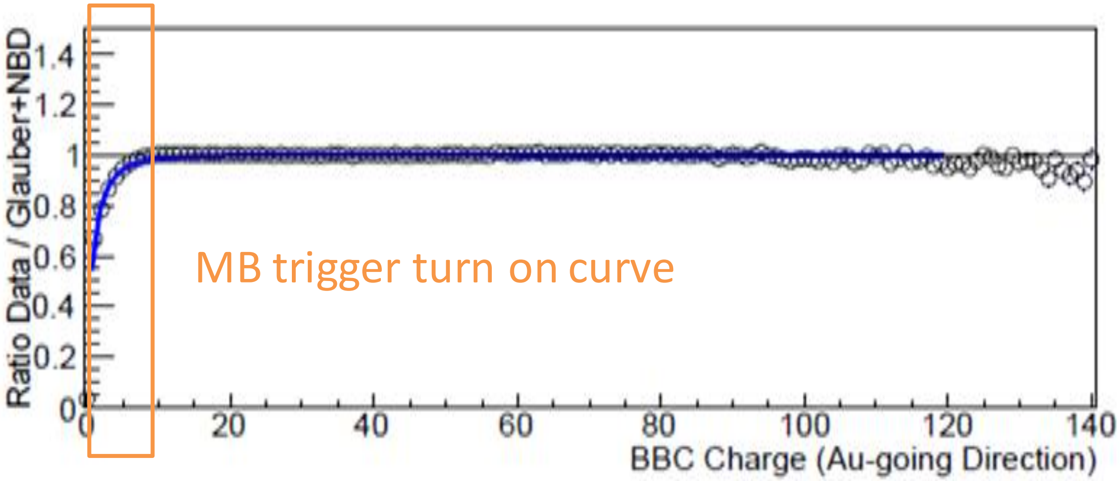
N_{Coll}, N_{Part}, b, etc.



$-3.9 < \eta < -3.0$



$$BBC\ Charge_{Au} \propto N_{Coll}$$



MB trigger turn on curve

Glauber Monte Carlo

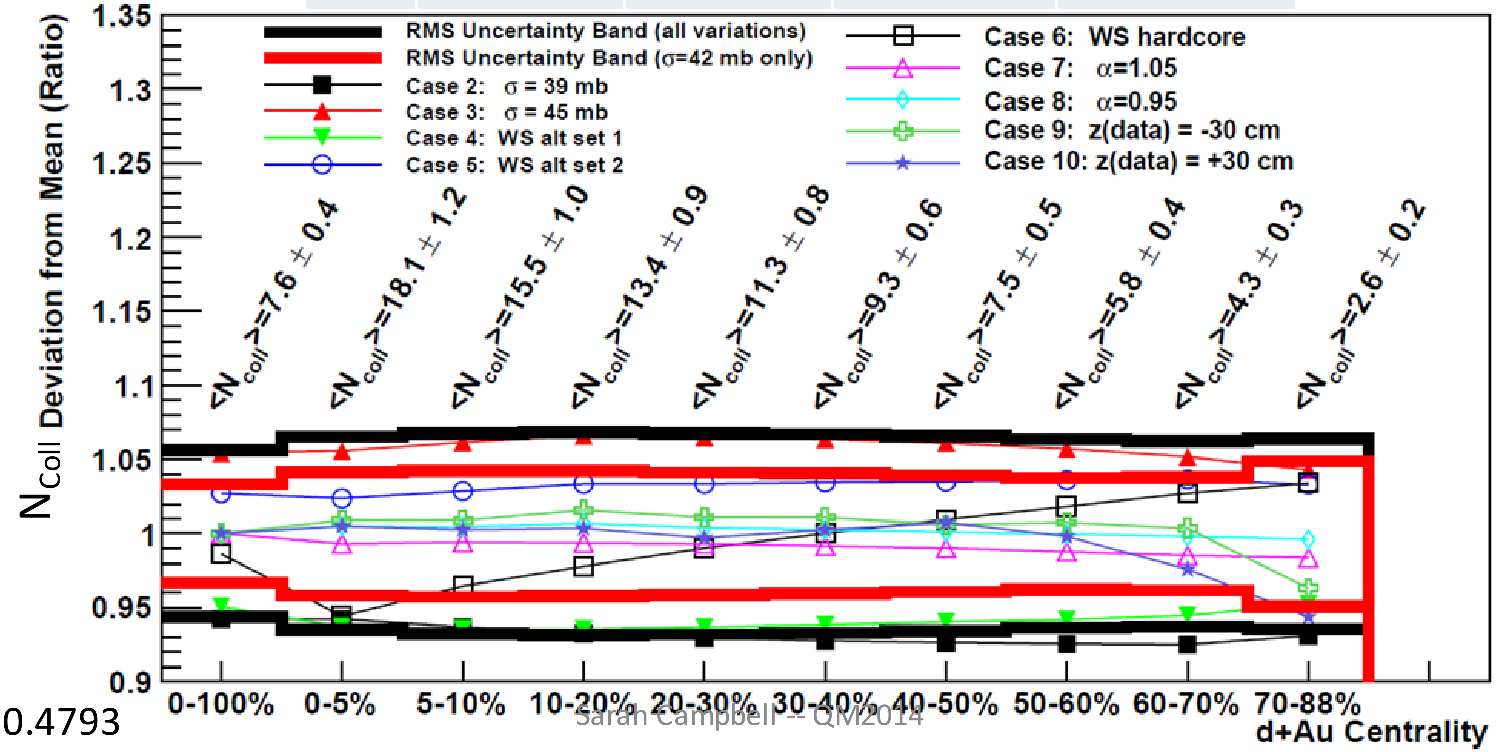
- d: Hulthen ψ(r)
- Au: Woods-Saxon ρ(r)

arXiv:1310.4793

Systematic Uncertainties

81 variations of parameters

	Default	Min	Max	
σ_{NN}	42mb	39mb	45mb	
W-S $\rho(r)$	R = 6.38 fm a = 0.54 fm	Less dense R = 6.65 fm a = 0.55 fm	More dense R = 6.25 fm a = 0.53 fm	Hard-core $r_{h\text{-}c}$ = 0.4 fm
$N_{Coll}{}^{\alpha}$	$\alpha = 1$	$\alpha = 0.95$	$\alpha = 1.05$	
z-vtx	< 5cm	-25- -30cm	25-30 cm	



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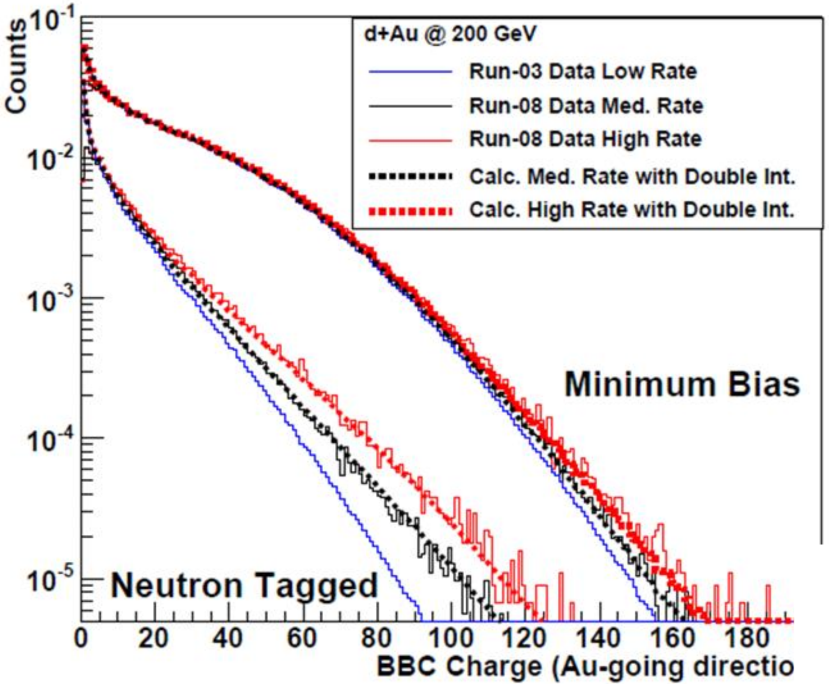
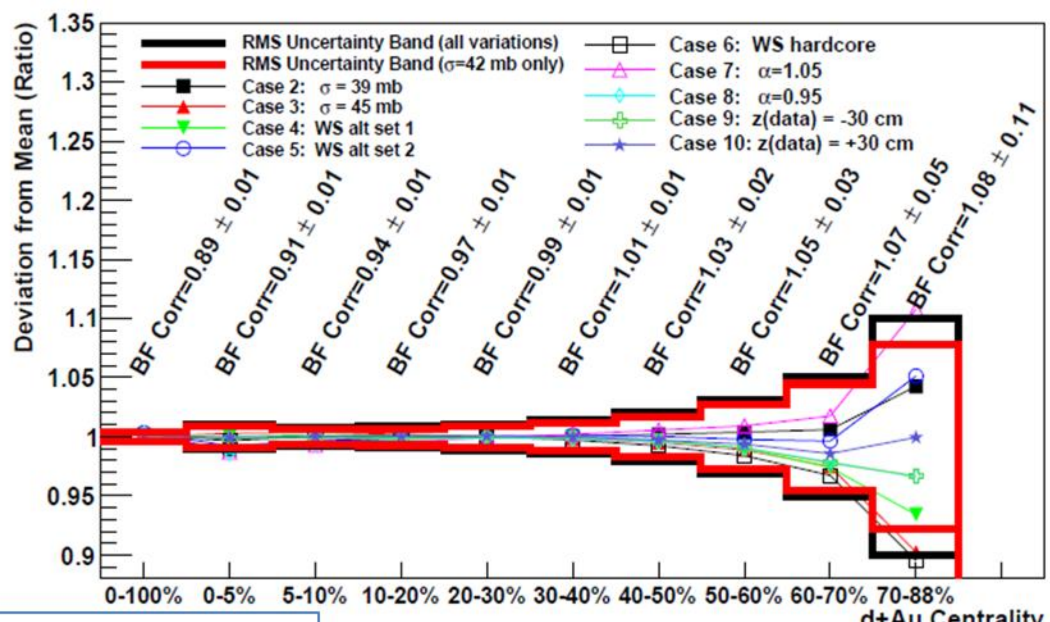
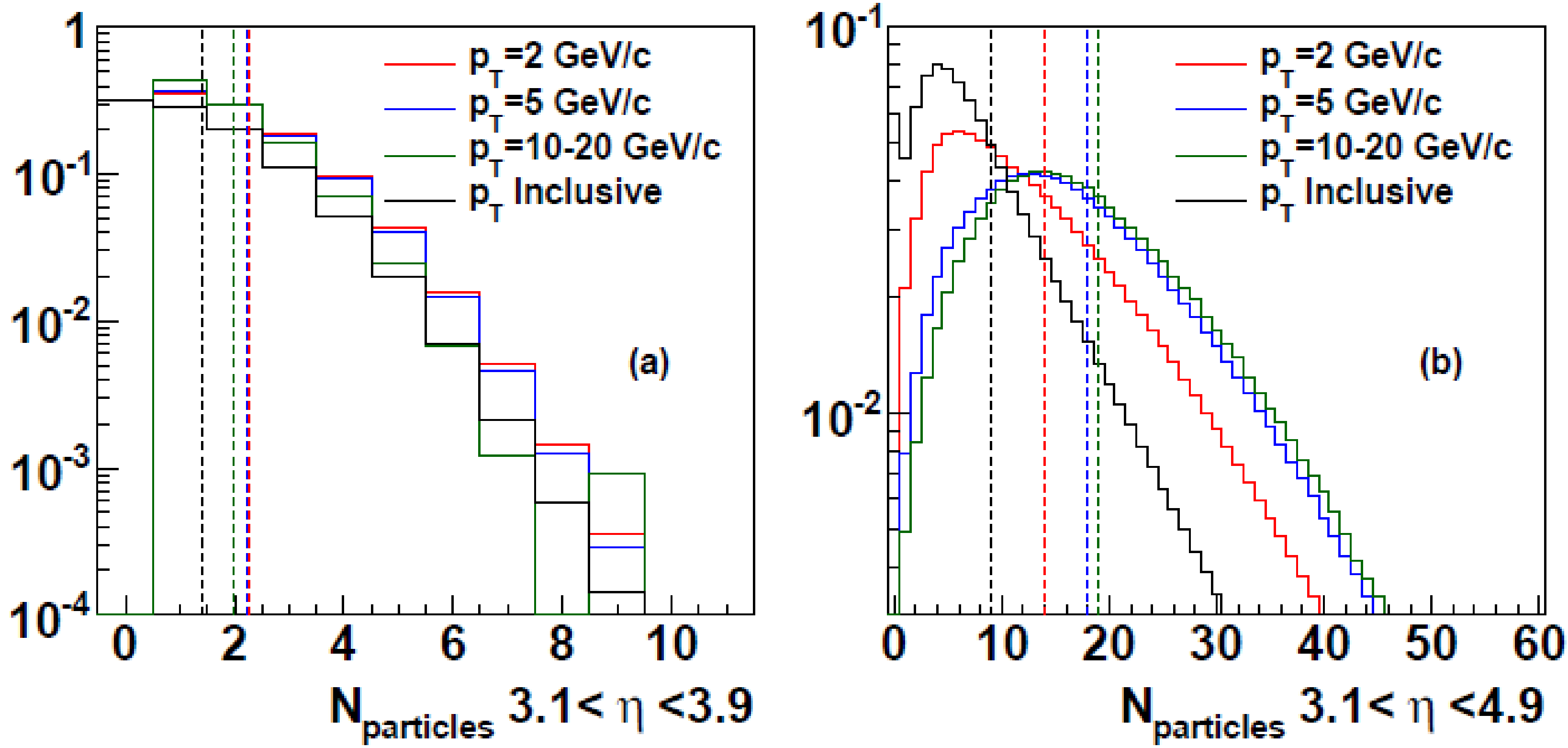
PHENIX





Bias-factor correction



1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0 2 4 6 8 10
p_T=2 GeV/c
p_T=5 GeV/c
p_T=10-20 GeV/c
p_T Inclusive
(a)
$N_{particles}$ 3.1< η <3.9
10^{-1}
10^{-2}
0 10 20 30 40 50 60
p_T=2 GeV/c
p_T=5 GeV/c
p_T=10-20 GeV/c
p_T Inclusive
(b)
$N_{particles}$ 3.1< η <4.9

Where do these numbers come from?

In p+p Trigger biased

$$\frac{\epsilon_{mid-y}{}^{p+p}}{\epsilon_{BBC}{}^{p+p}} = \frac{75 \pm 3\% \; of \; Particles}{52 \pm 4\% \; of \; Events}$$

Likelihood BBC trigger fires assuming 42mb σ_{NN}

Likelihood trigger fires from mid-y π^0, charged hadron, J/ψ

In d+Au Trigger bias **AND** Multiplicity effect

Centrality	Bias Factor, c
0-20%	0.94 ± 0.01
20-40%	1.00 ± 0.01
40-60%	1.03 ± 0.02
60-88%	1.03 ± 0.06

Multiplicity effect only
Trigger always fires

Competing effects
- Trigger bias: 0.89
- Multiplicity effect: 1.16

Trigger less efficient

Assume a hard interaction deposits 1.55 x charge in the BBC

Scale NBD accordingly for that interaction

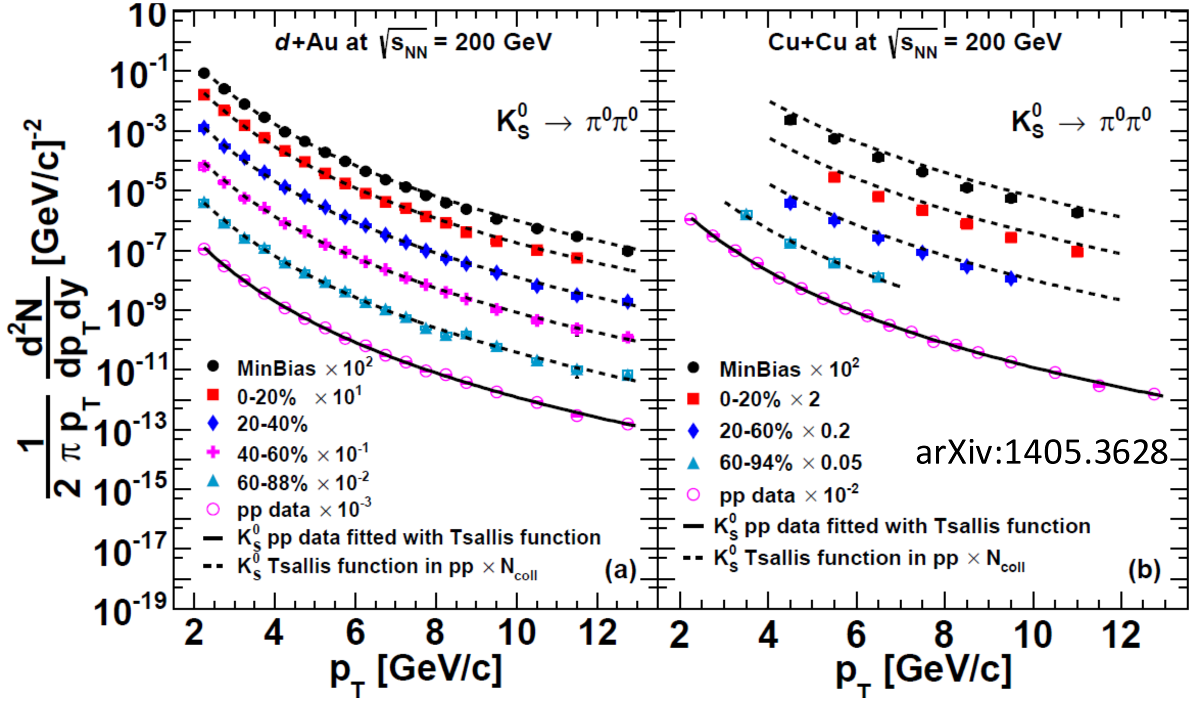
Consider 1 hard interaction among the N_{Coll} in that event

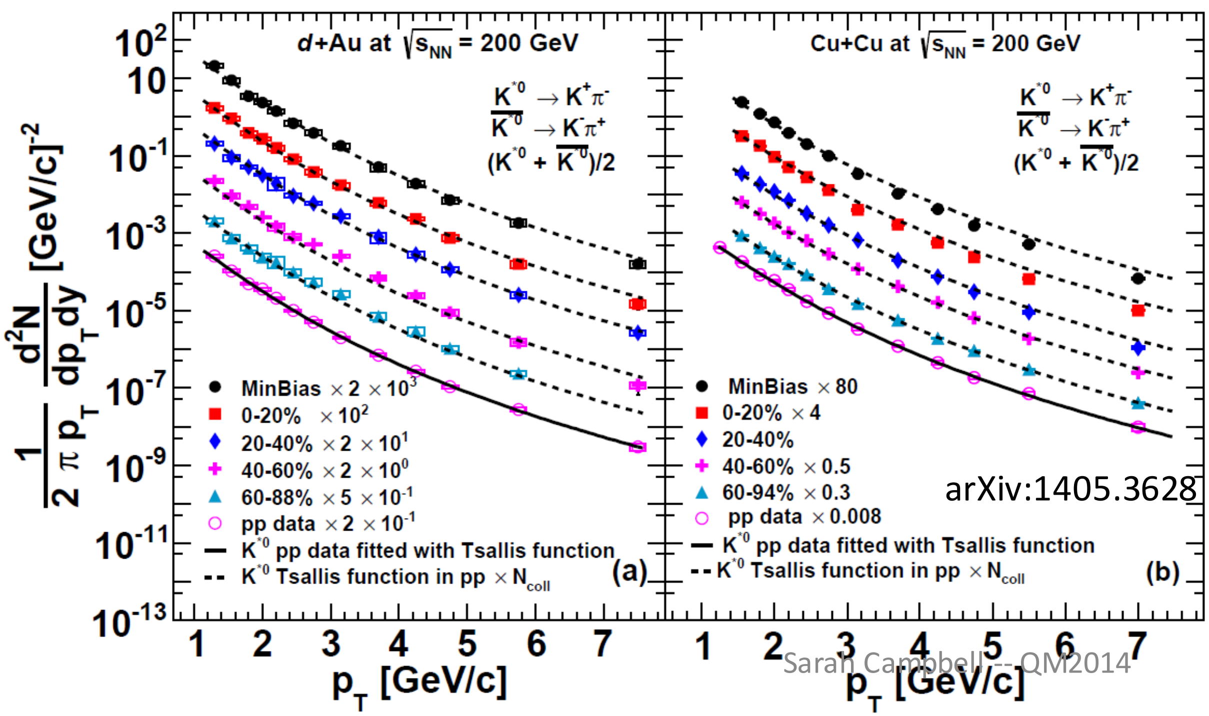
Calculate yield with and without multiplicity effect to get correction

Hijing info

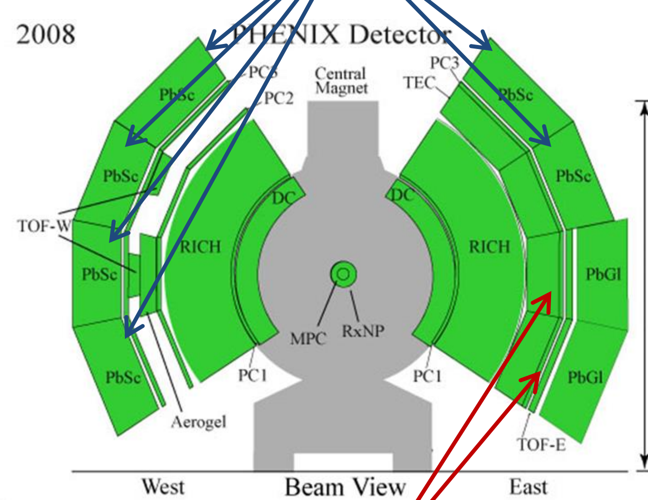
- Model BBC response and trigger
  - Full GEANT for each event, $O(10^9)$ events, takes too long
  - In p+p, require minimum of 1 particle in each BBC
    - 48% → 52 +/- 4% in data
  - In d+Au:
    - 83% → 88 +/- 4% in data, separated into centrality bins
- Model central arm response for $p_T > 1$ GeV mid-y particle
  - BBC multiplicity increase 1.62 → 1.55 in data
  - Trigger probability 62% → 75 +/- 3% in data
    - Because of 1-diff, 2-diff handling in Hijing?
- Get mid-y yield/event from simulated BBC ‘measured’ centrality bins → ‘measured’ value
  - Calculate N_{Coll} from generator ‘truth’ info in these ‘measured’ bins
- Get mid-y yield/event from events in ‘truth’ centrality bins with the same N_{Coll} → ‘truth’ value

K_S^0 and K^{*0} in d+Au, Cu+Cu



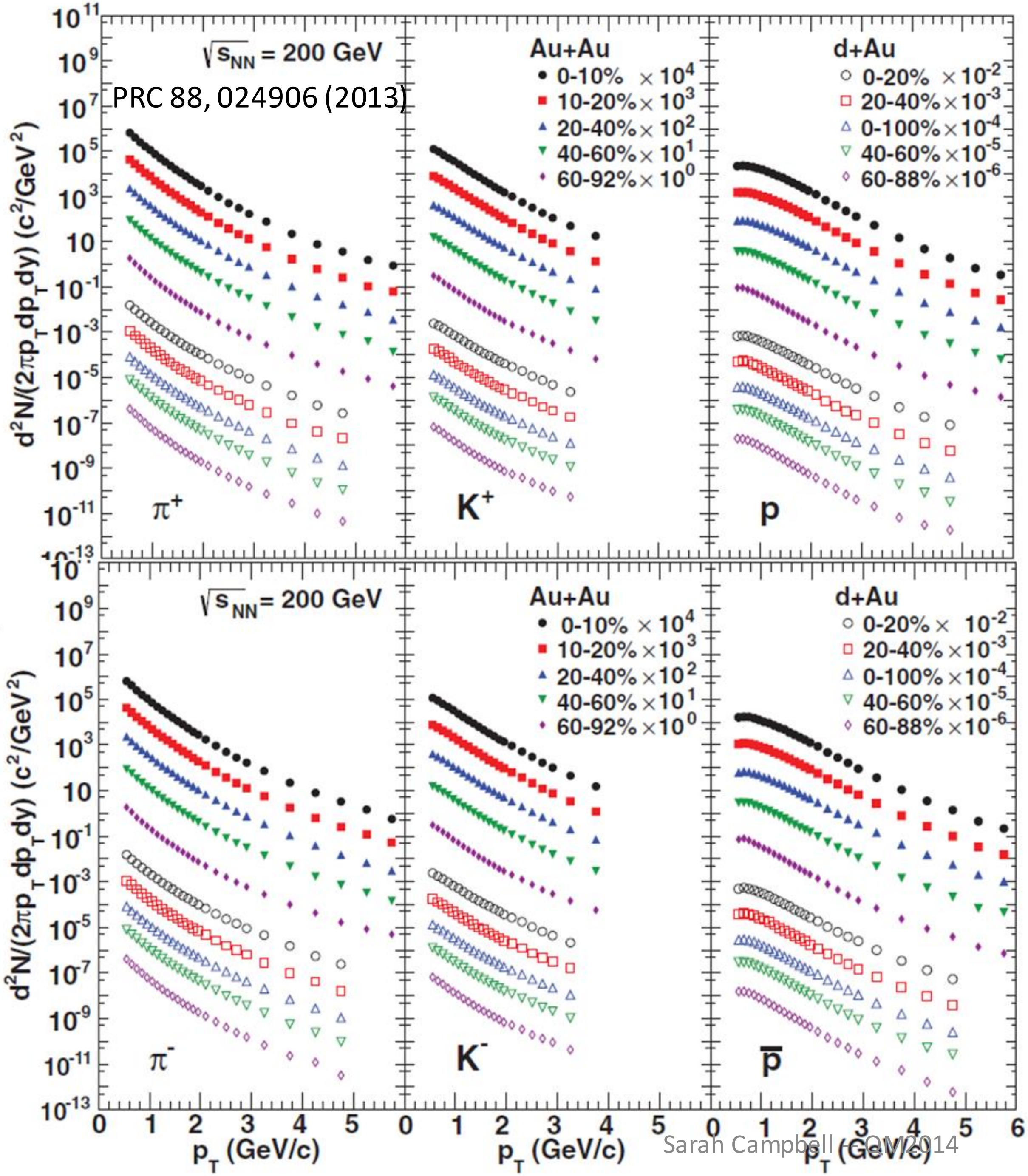


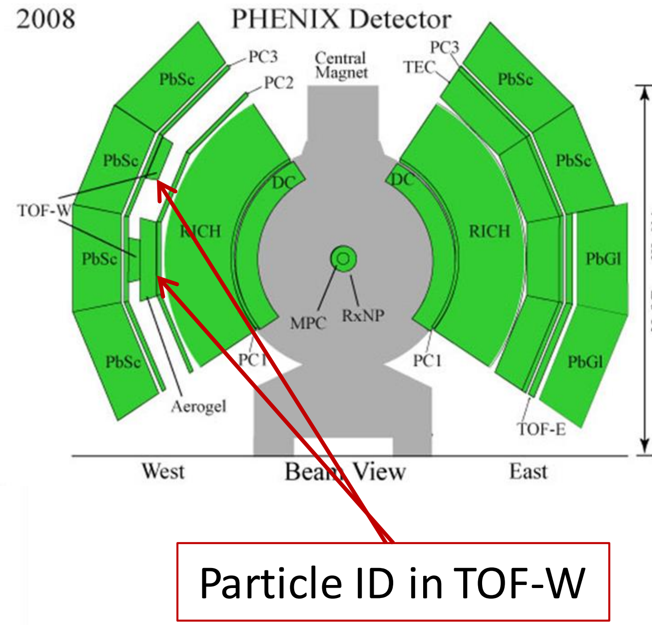
π^0: Photon ID in EMC



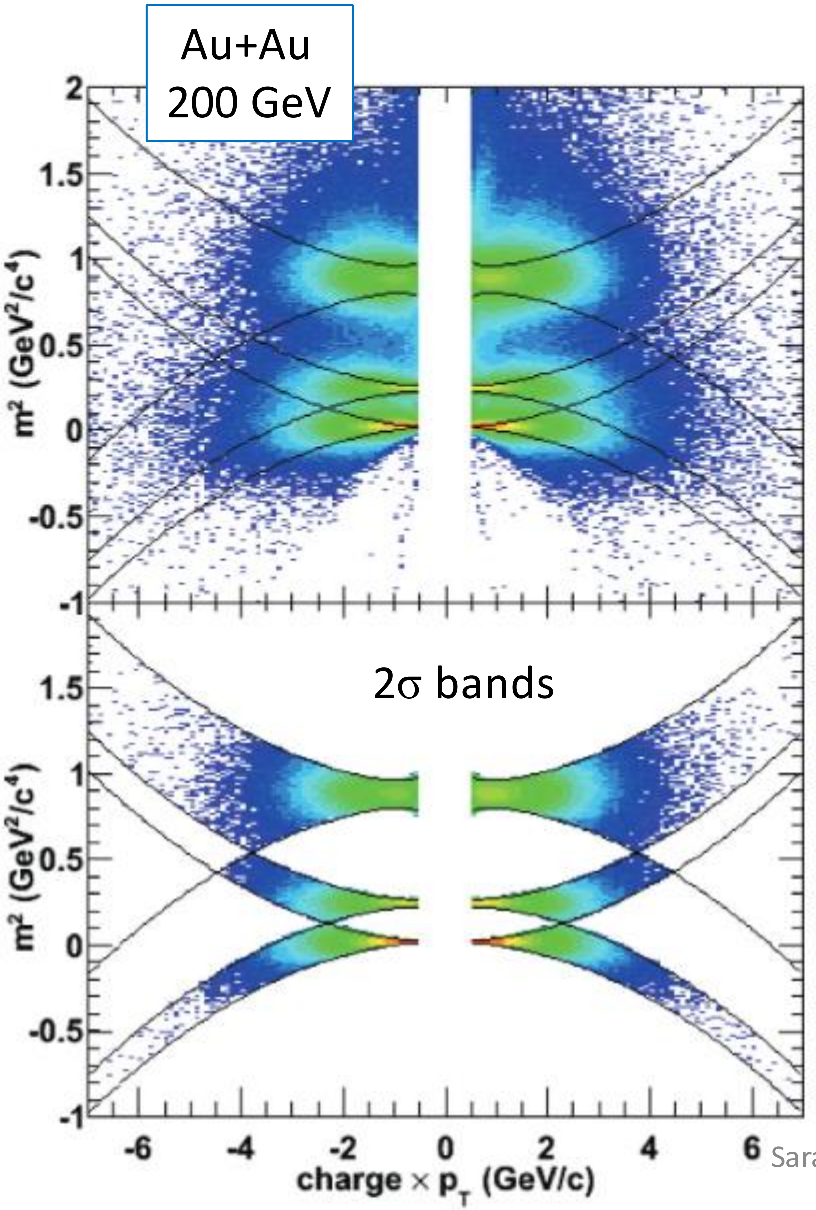
Particle ID in TOF-E

π, K, p in d+Au, Au+Au





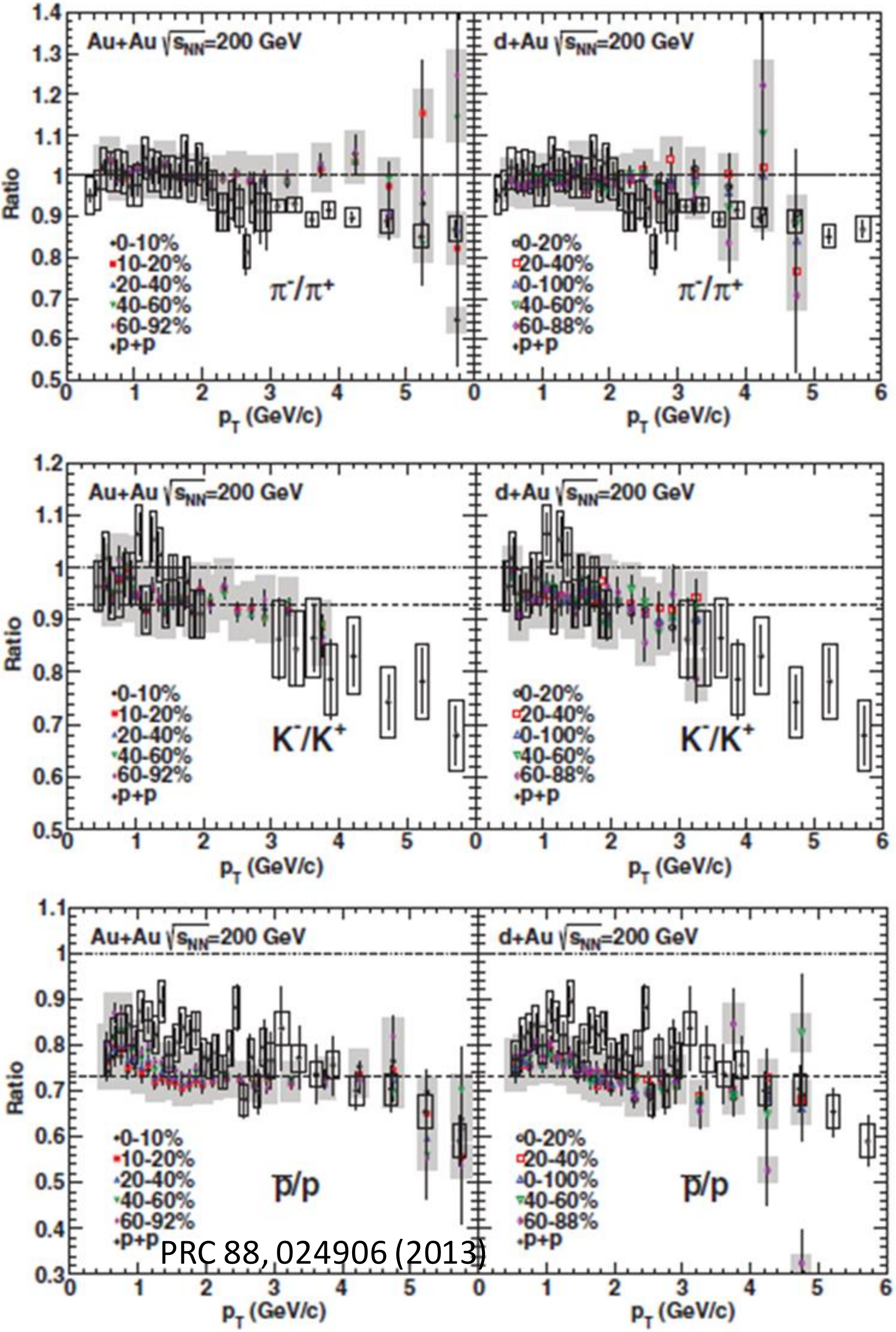
Time of Flight measurement



$$m^2 = \frac{p^2}{c^2}\left(\frac{t^2c^2}{L^2} - 1\right)$$

Component	Resolution
Charged tracking	1.050
Multiple scattering	1.000
Total timing	0.095 (95ps)

- pID purity better than 90%

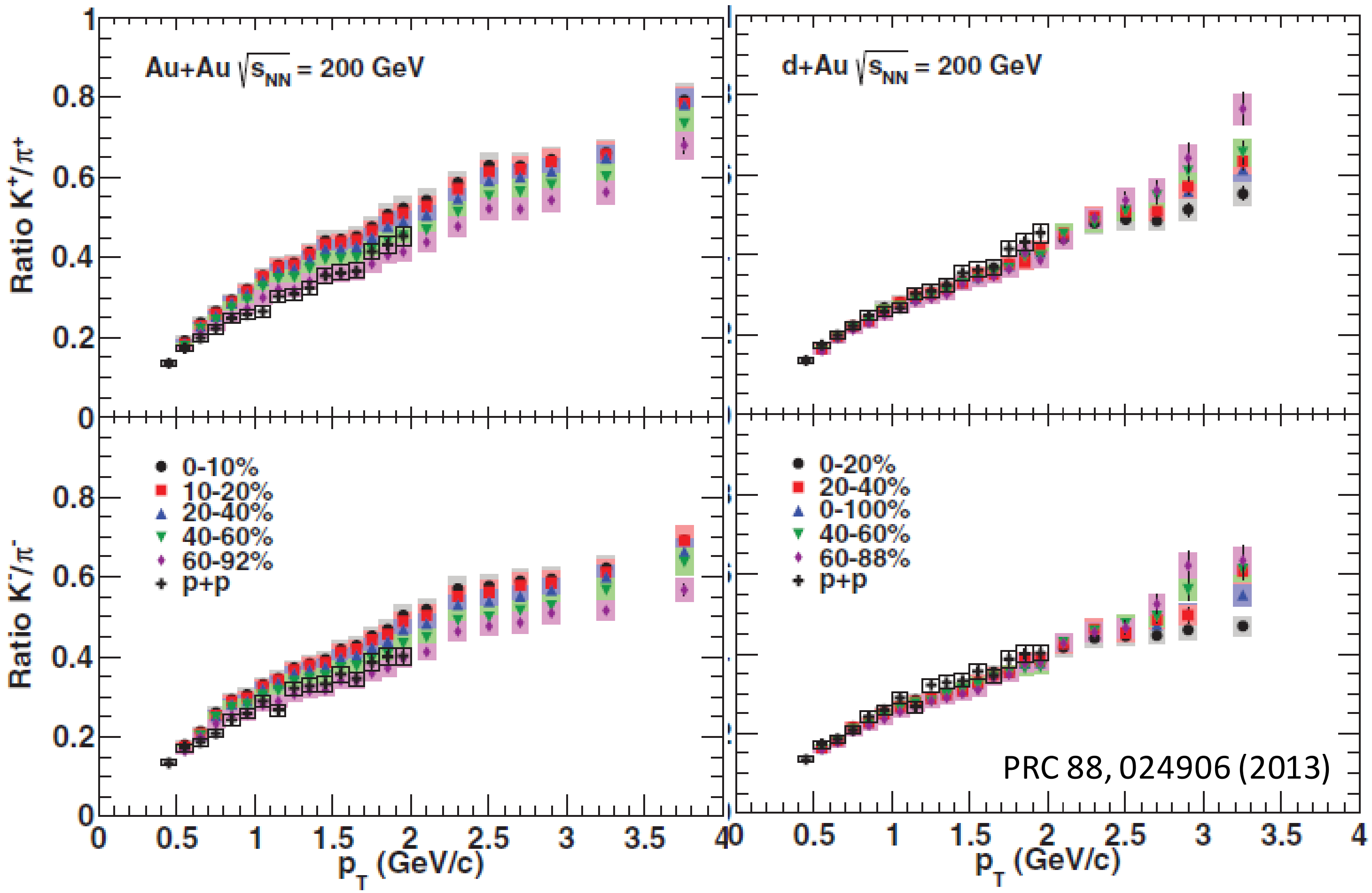


Charge ratios

	p+p	d+Au	Au+Au
Centrality dependence	N.A.	X	X
p_T dependence	✔	X	X

Isospin effect at high p_T

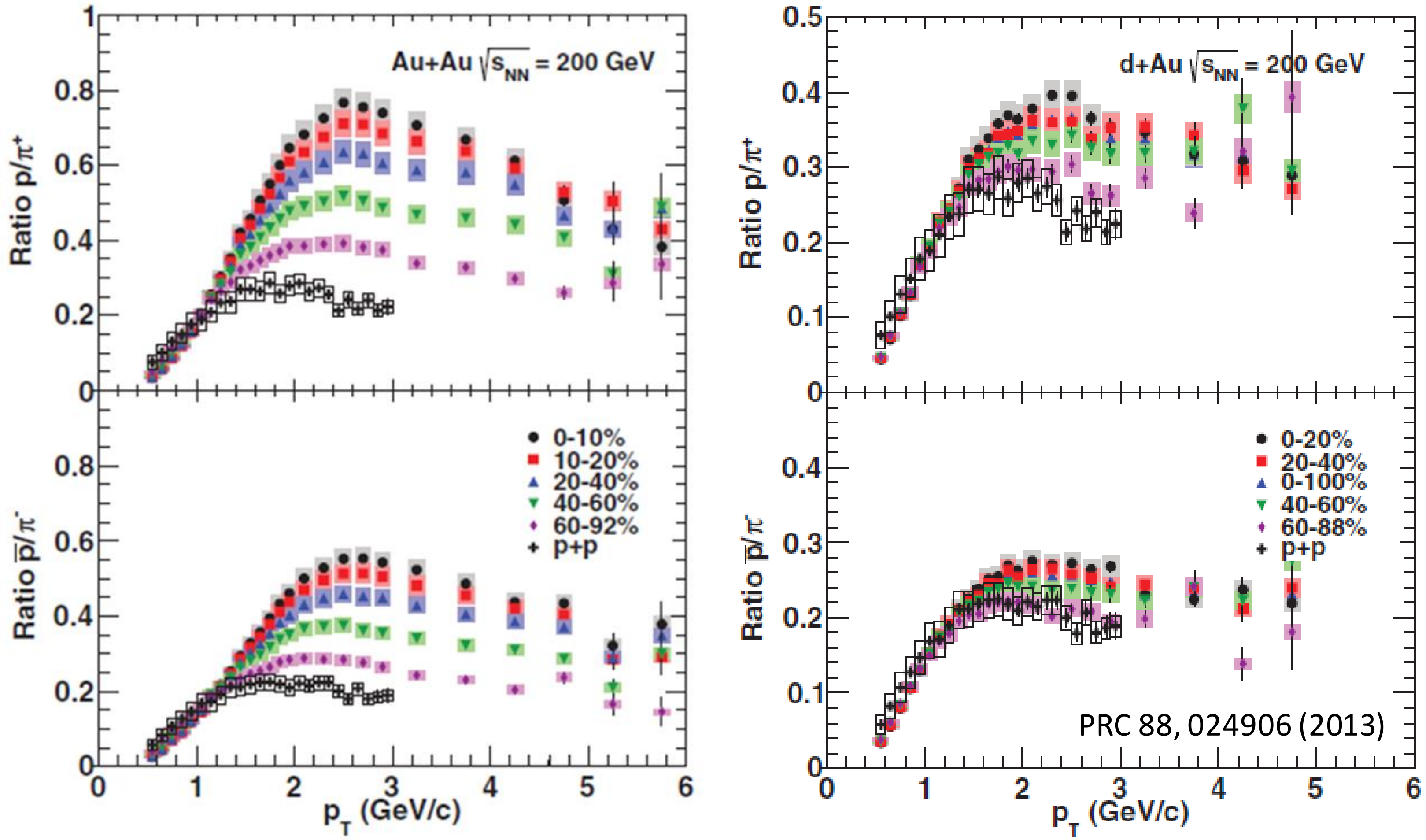
K/π Ratio



Strangeness enhancement in Au+Au

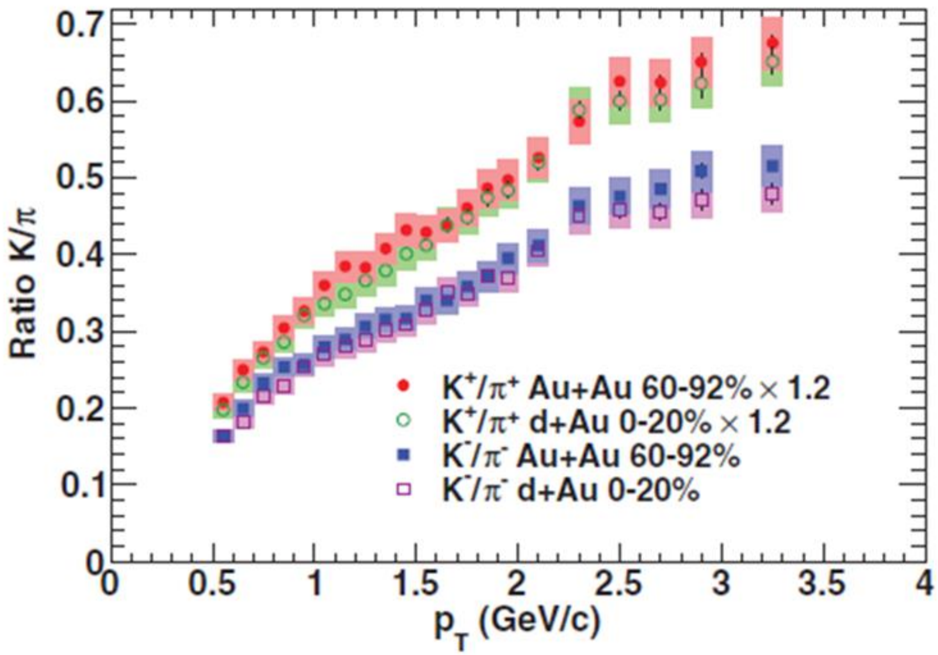
No strangeness enhancement in d+Au

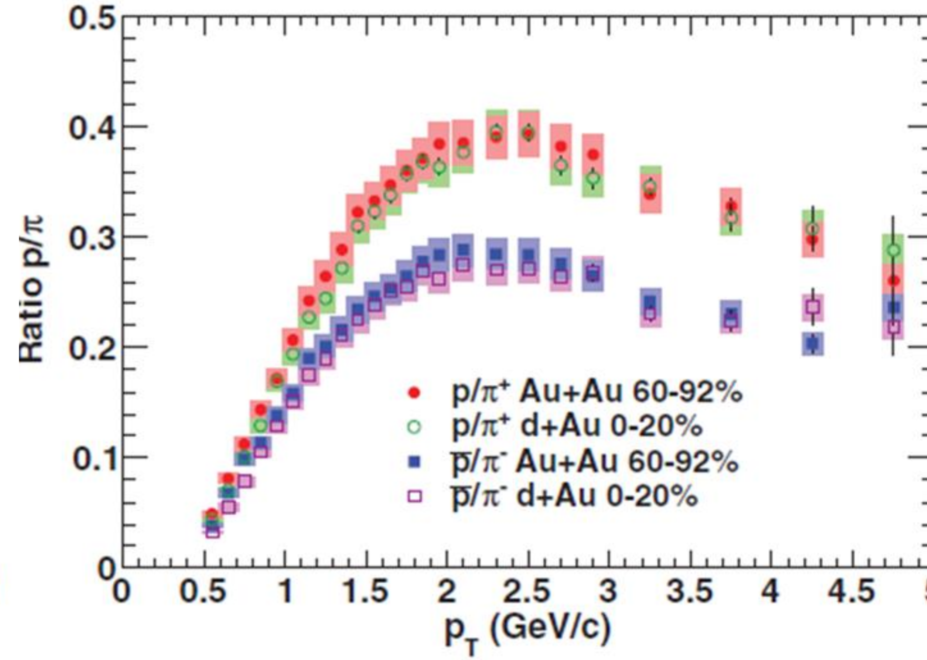
p/π Ratio



Baryon enhancement in Au+Au and d+Au

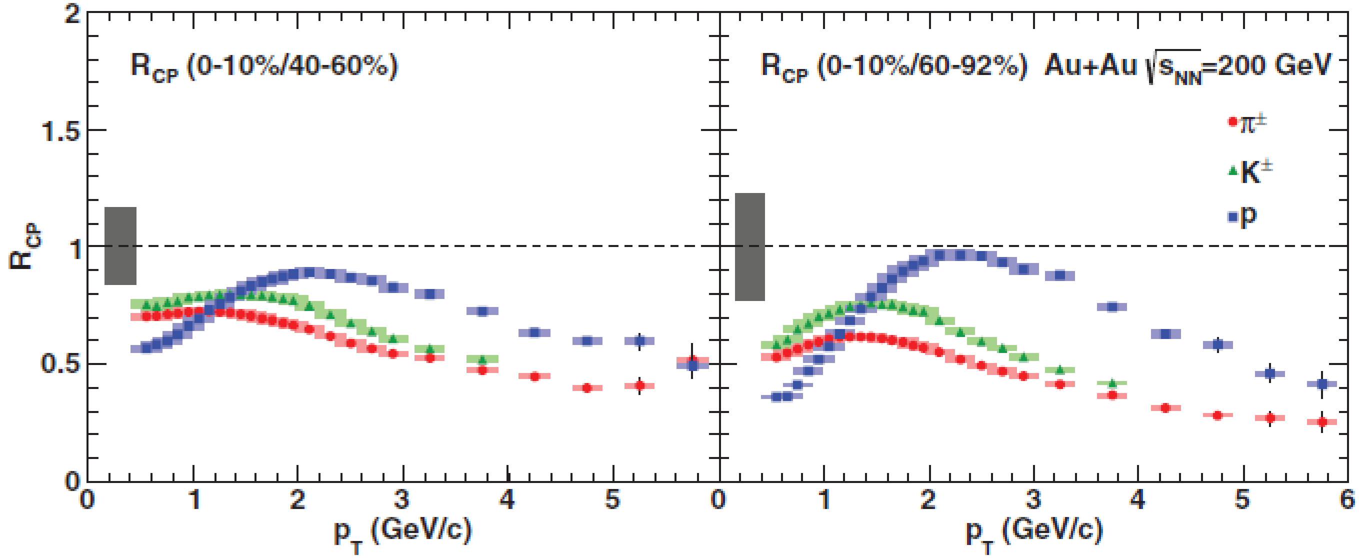
Compare d+Au, Au+Au





System	<Ncoll>	<Npart>
Au+Au 60-92%	14.8 ± 3.0	14.7 ± 2.9
d+Au 0-20%	15.1 ± 1.0	15.3 ± 0.8

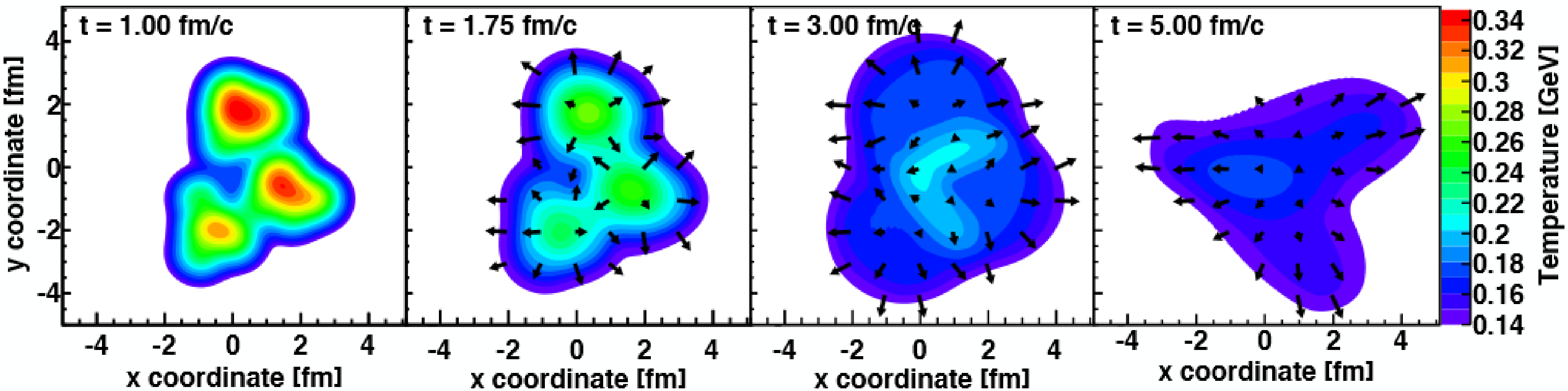
Similar particle production mechanisms in d+Au and peripheral Au+Au

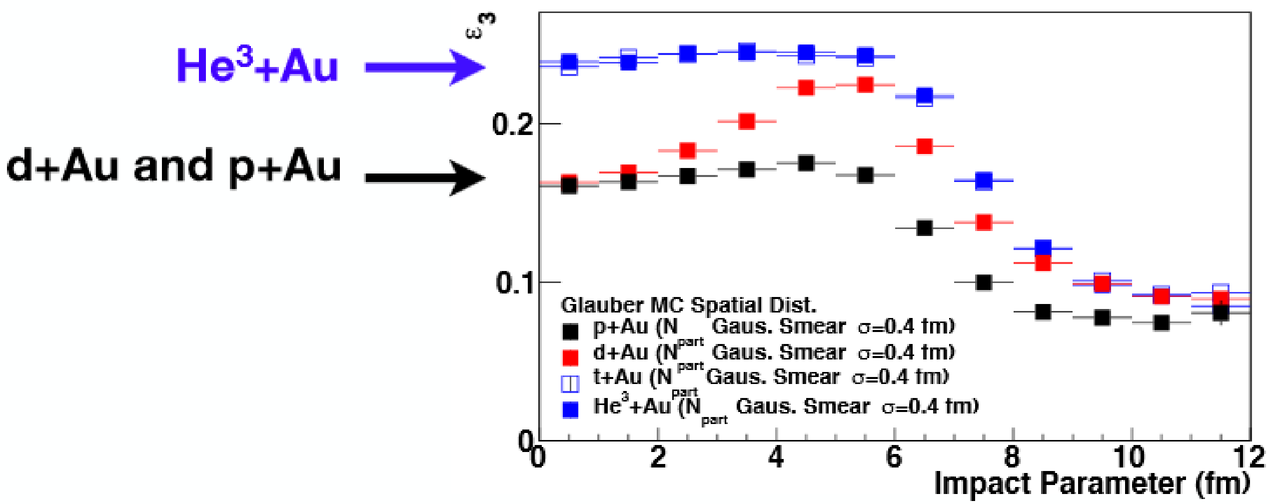


R_{CP} (0-10%/40-60%)
R_{CP} (0-10%/60-92%) Au+Au $\sqrt{s_{NN}}$=200 GeV
$\pi^{\pm}$
$K^{\pm}$
p
R_{CP}
p_T (GeV/c)
p_T (GeV/c)

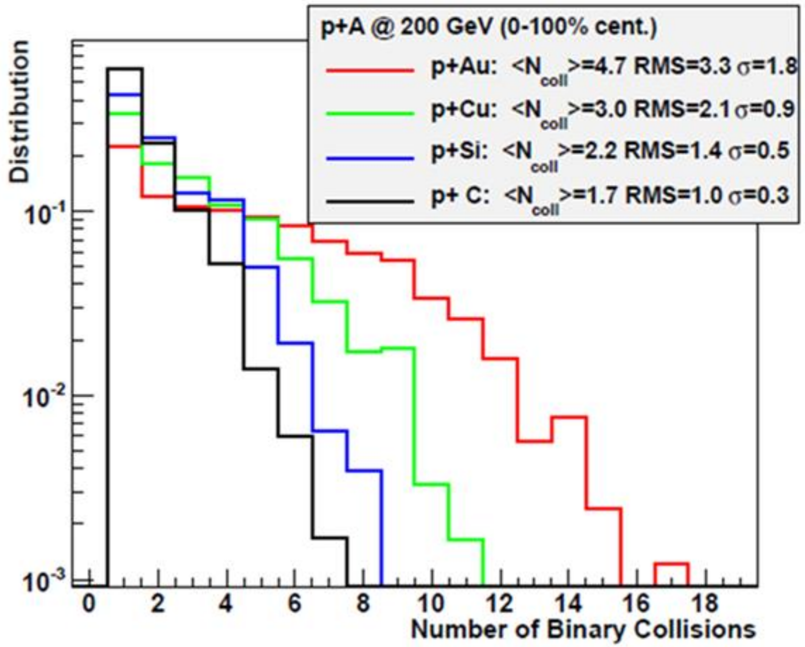
He^3+Au *provides an larger, intrinsic triangular collision geometry*

Nagle, et al (MM), arXiv:1312.4565

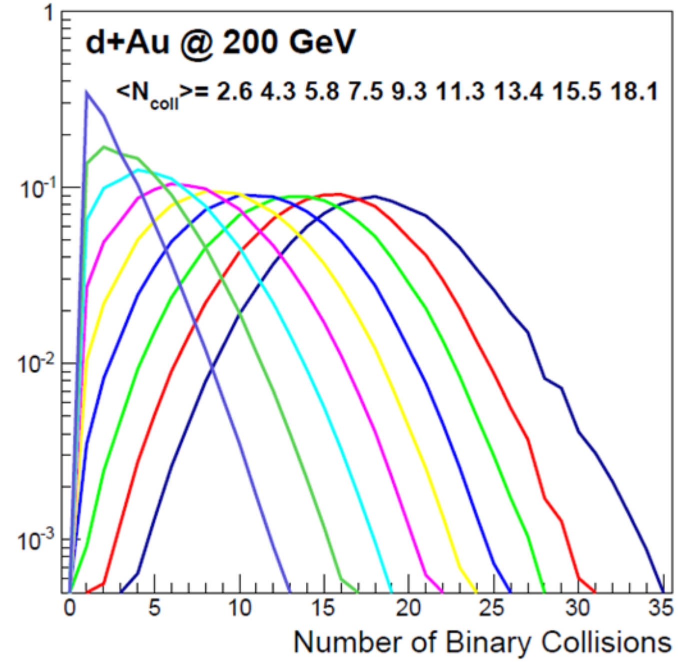




backup



p+A @ 200 GeV (0-100% cent.)
p+Au: <N_coll>=4.7 RMS=3.3 σ=1.8
p+Cu: <N_coll>=3.0 RMS=2.1 σ=0.9
p+Si: <N_coll>=2.2 RMS=1.4 σ=0.5
p+ C: <N_coll>=1.7 RMS=1.0 σ=0.3
Distribution
Number of Binary Collisions



d+Au @ 200 GeV
<N_coll>= 2.6 4.3 5.8 7.5 9.3 11.3 13.4 15.5 18.1
Number of Binary Collisions