PHENIX Beam Use Proposal Run-15 and Run-16

Jamie Nagle
for the PHENIX Collaboration

Taking maximal advantage of RHIC uniqueness and versatility

Utilizing new detector capabilities

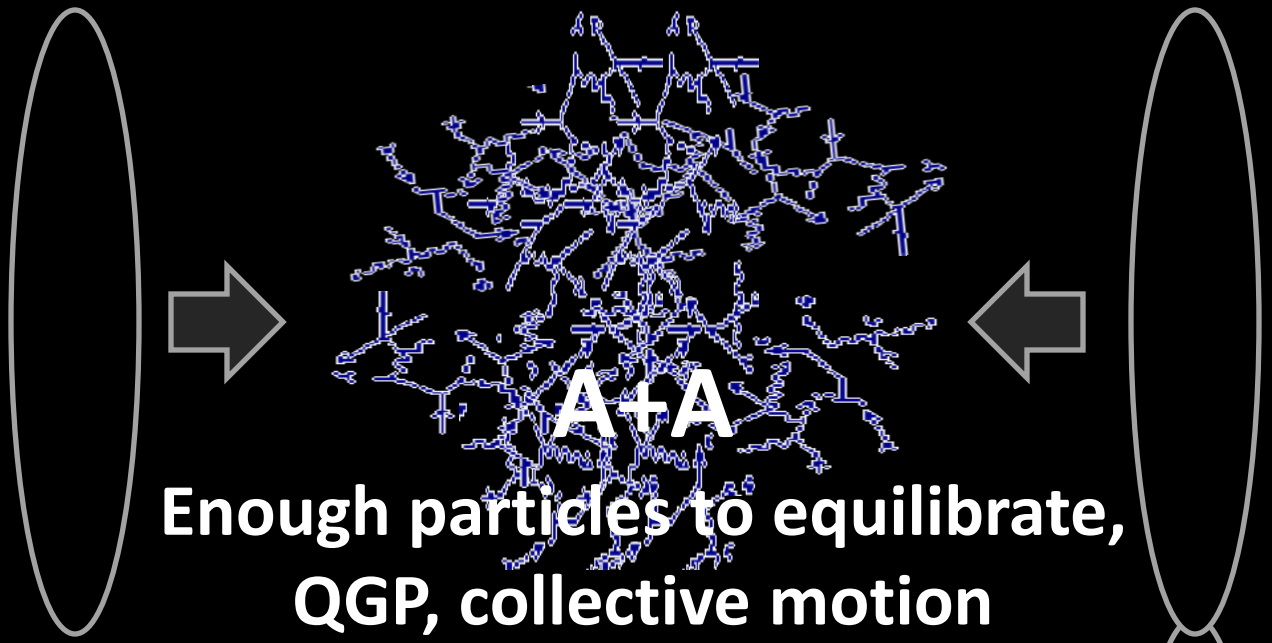
Following up on surprising new observations

Outline

- Brief highlights of a few recent accomplishments
  - Run-14 Au+Au data taking status
  - Run-15 Beam Use Request
  - Run-16 Beam Use Request

Brief highlights of a few recent accomplishments

Scientific Paradigm (Shift)

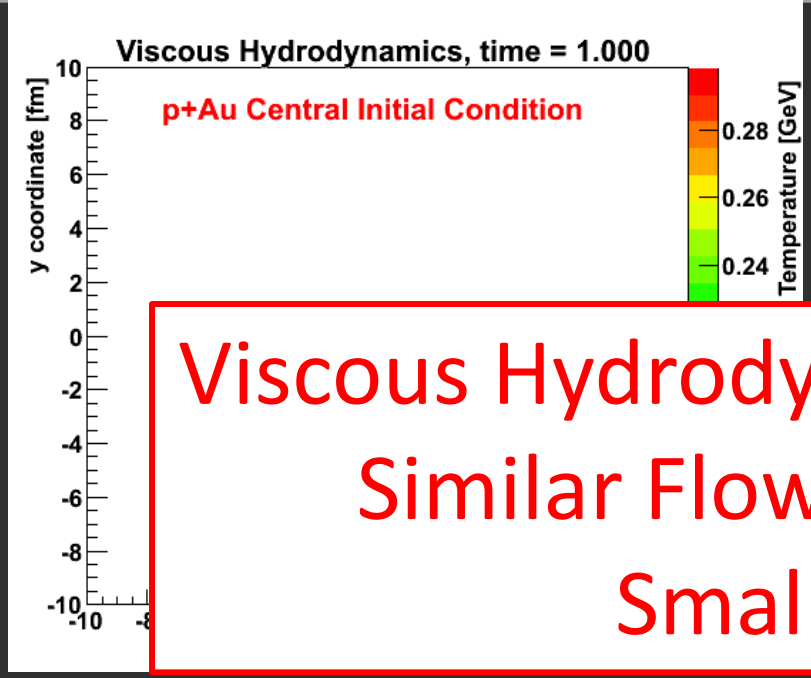


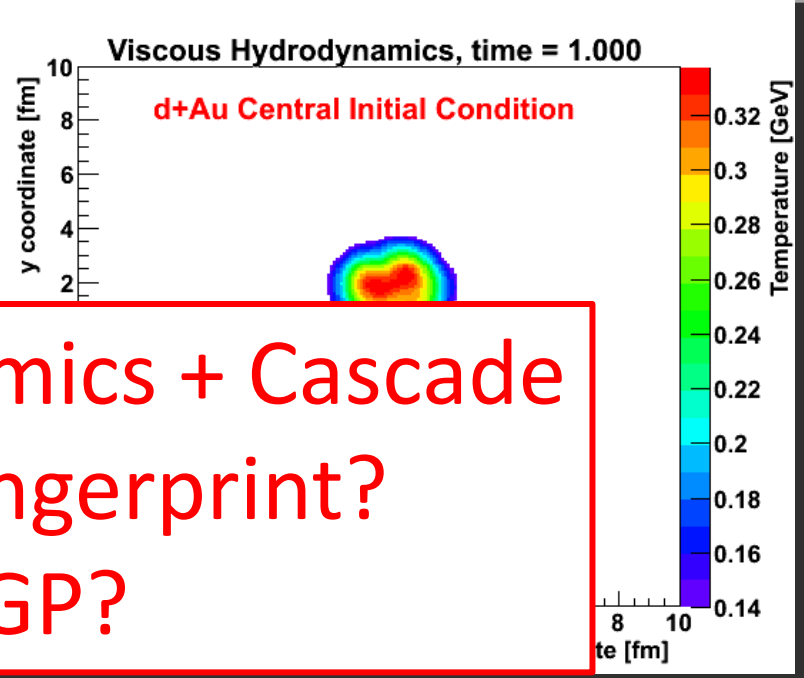
A+A

Enough particles to equilibrate, QGP, collective motion

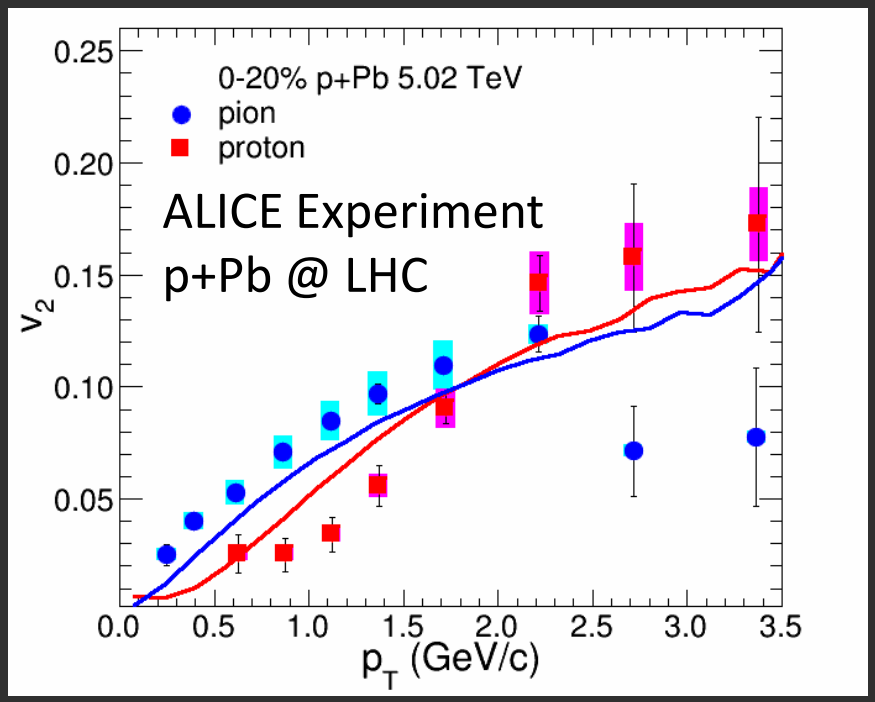
p+A

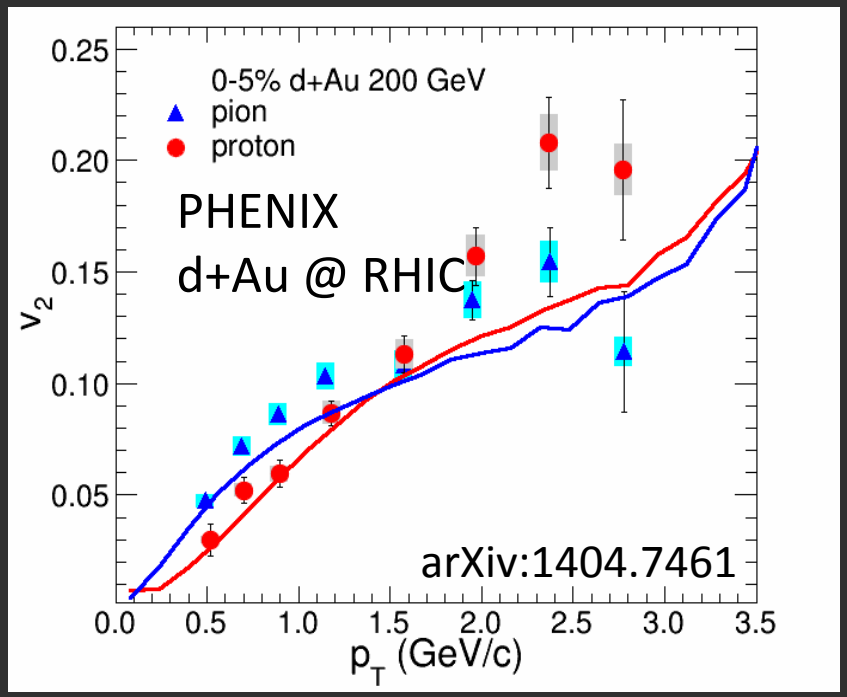
Not enough particles to equilibrate, control experiment (?)





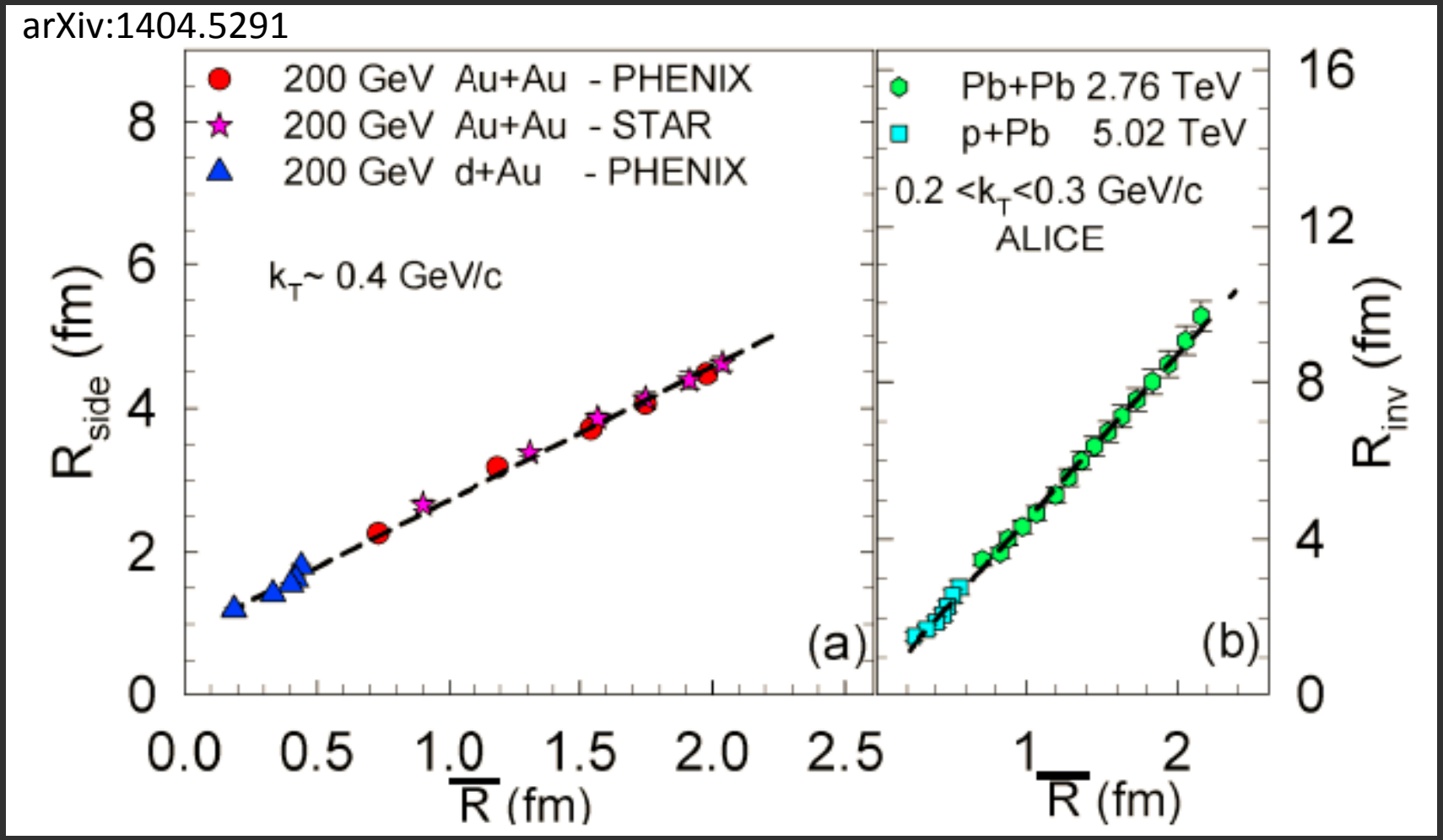
Viscous Hydrodynamics + Cascade
Similar Flow Fingerprint?
Small QGP?





HBT Source Size in d+Au

arXiv:1404.5291

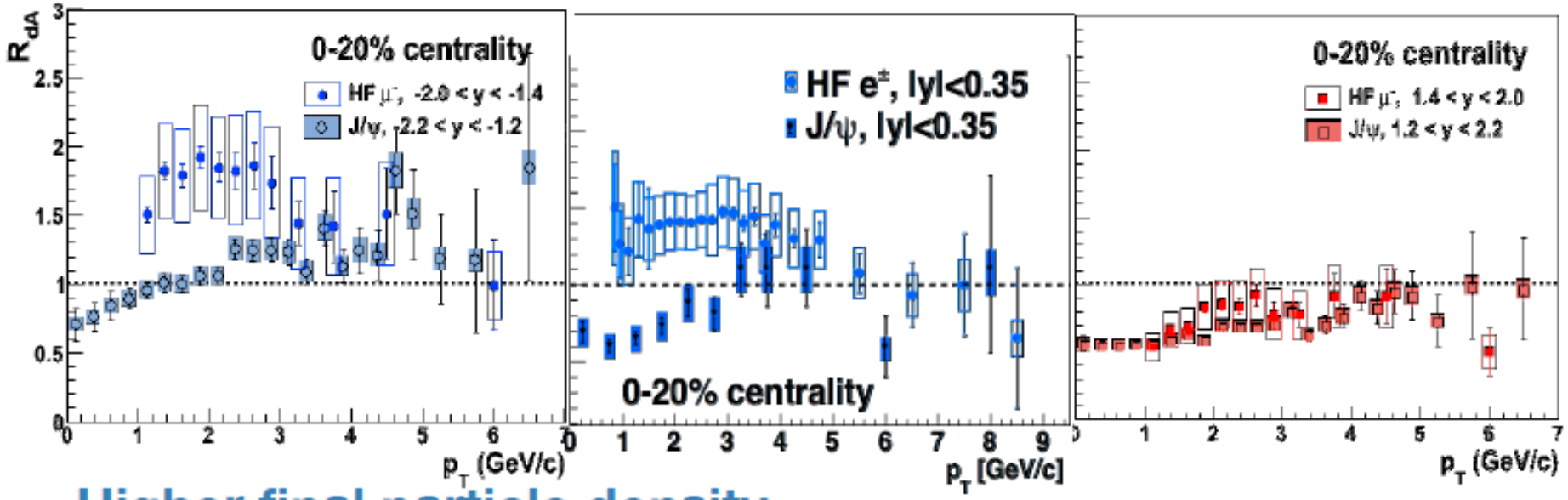


Smooth trend of final size with initial geometry

p(d)+A central has smaller initial size than A+A peripheral

Charm electrons in d+Au

arXiv:1310.1005, Phys.Rev.Lett. 109 (2012) 24, 242301, Phys.Rev. C87 (2013) 3, 034904

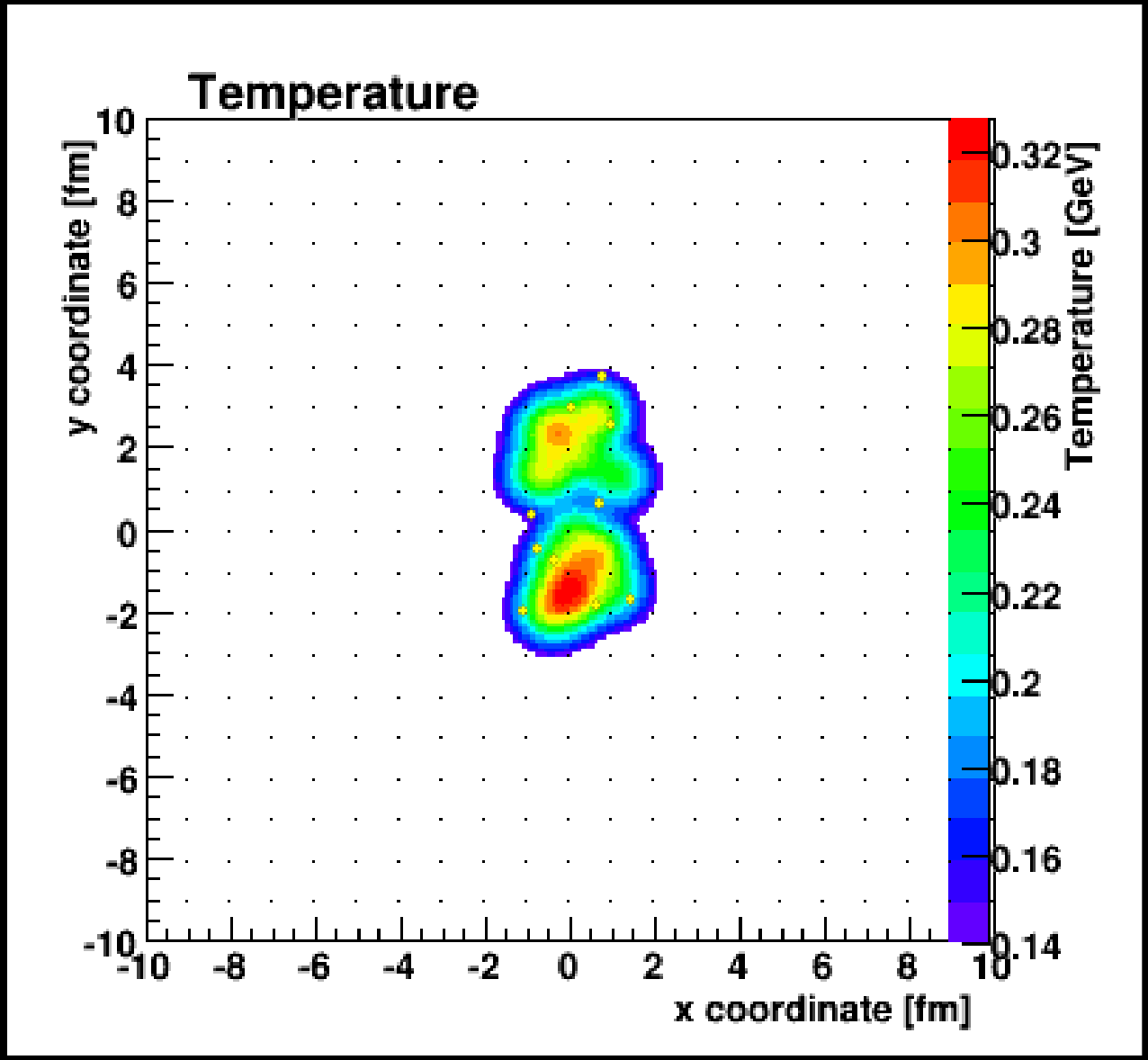


Higher final particle density

Probing lower-x gluons in Au

- Open charm enhancement at mid and backward rapidity
- Open charm and J/ψ suppression at forward rapidity
- Enhancement much larger than anti-shadowing expectations
- **Radial push of charm quarks even in d+Au?**

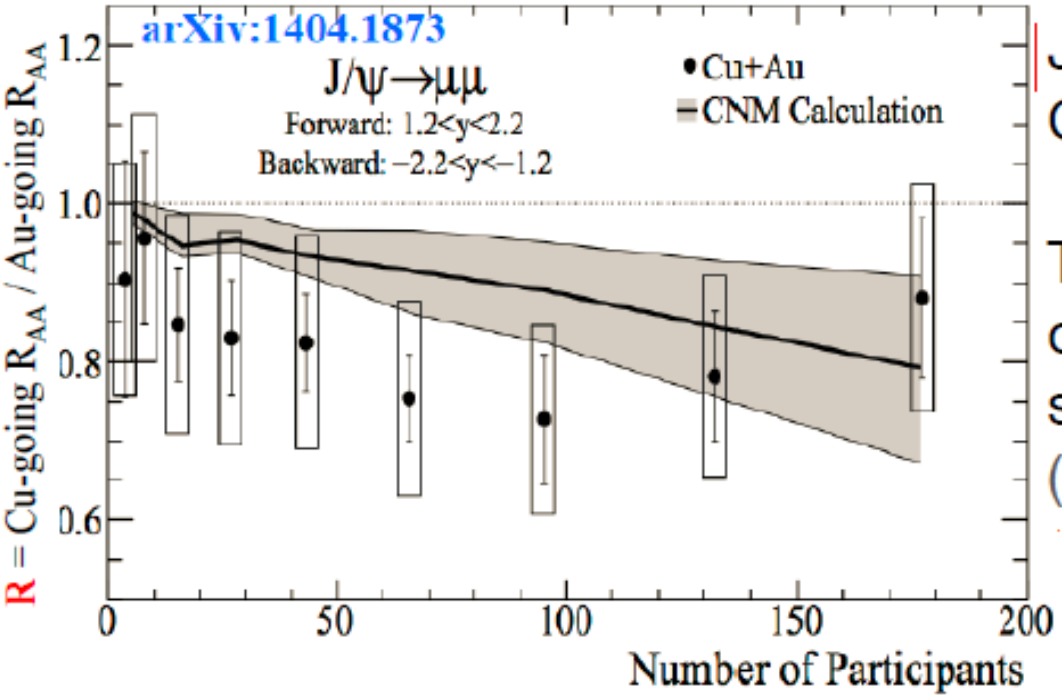
Charm Flow in d+Au (?)



J/ψ in Cu+Au

J/ψ Cu-going / J/ψ Au-going R_{AA}

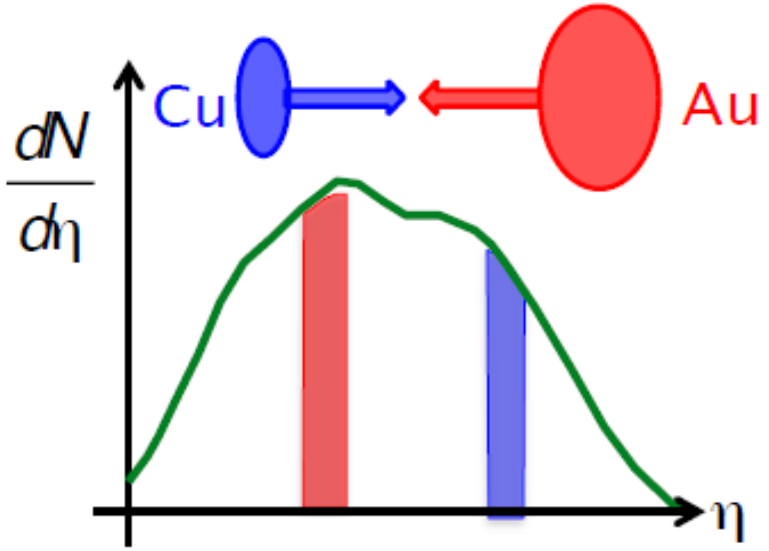
arXiv:1404.1873



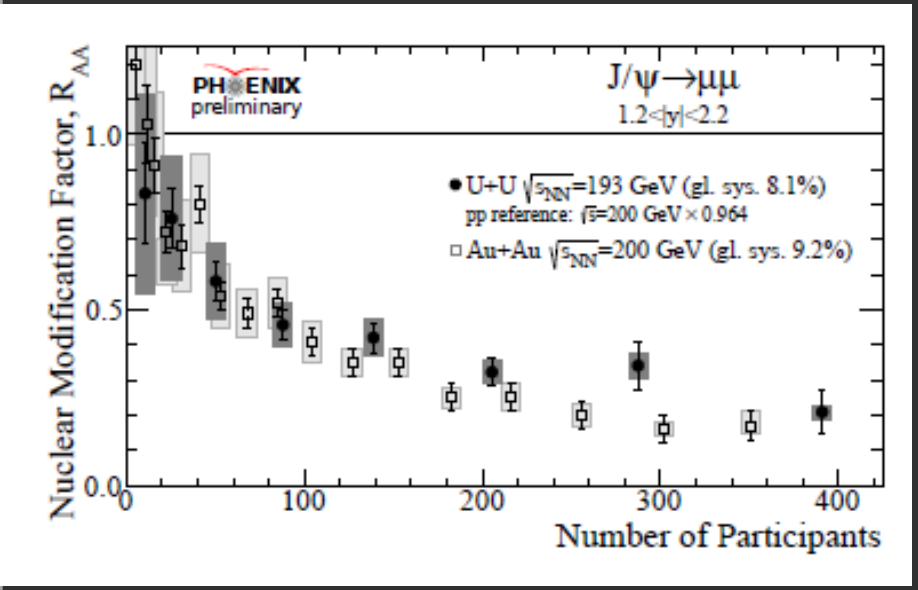
J/ψ is more suppressed in Cu-going direction!

Trend is consistent in the direction of more low-x shadowing in Au than Cu (ratio is calculated with EPS09)

Less suppression in region of **lower particle density** would produce a rising trend in the ratio above.

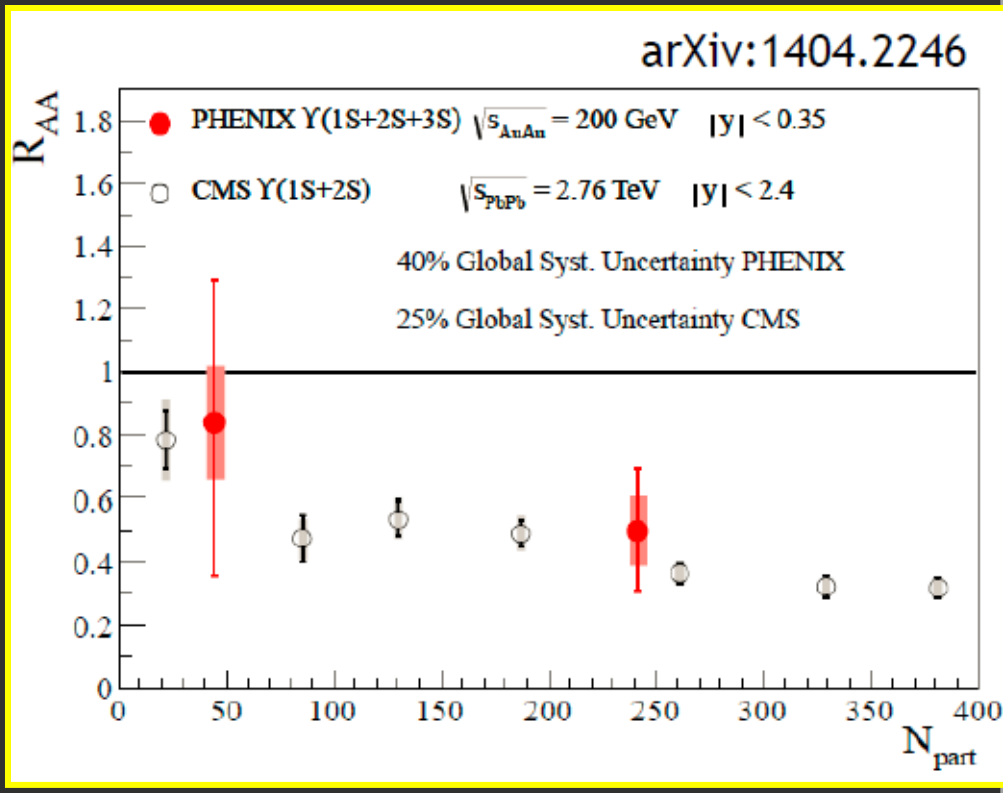


J/ψ in U+U and Upsilon in Au+Au

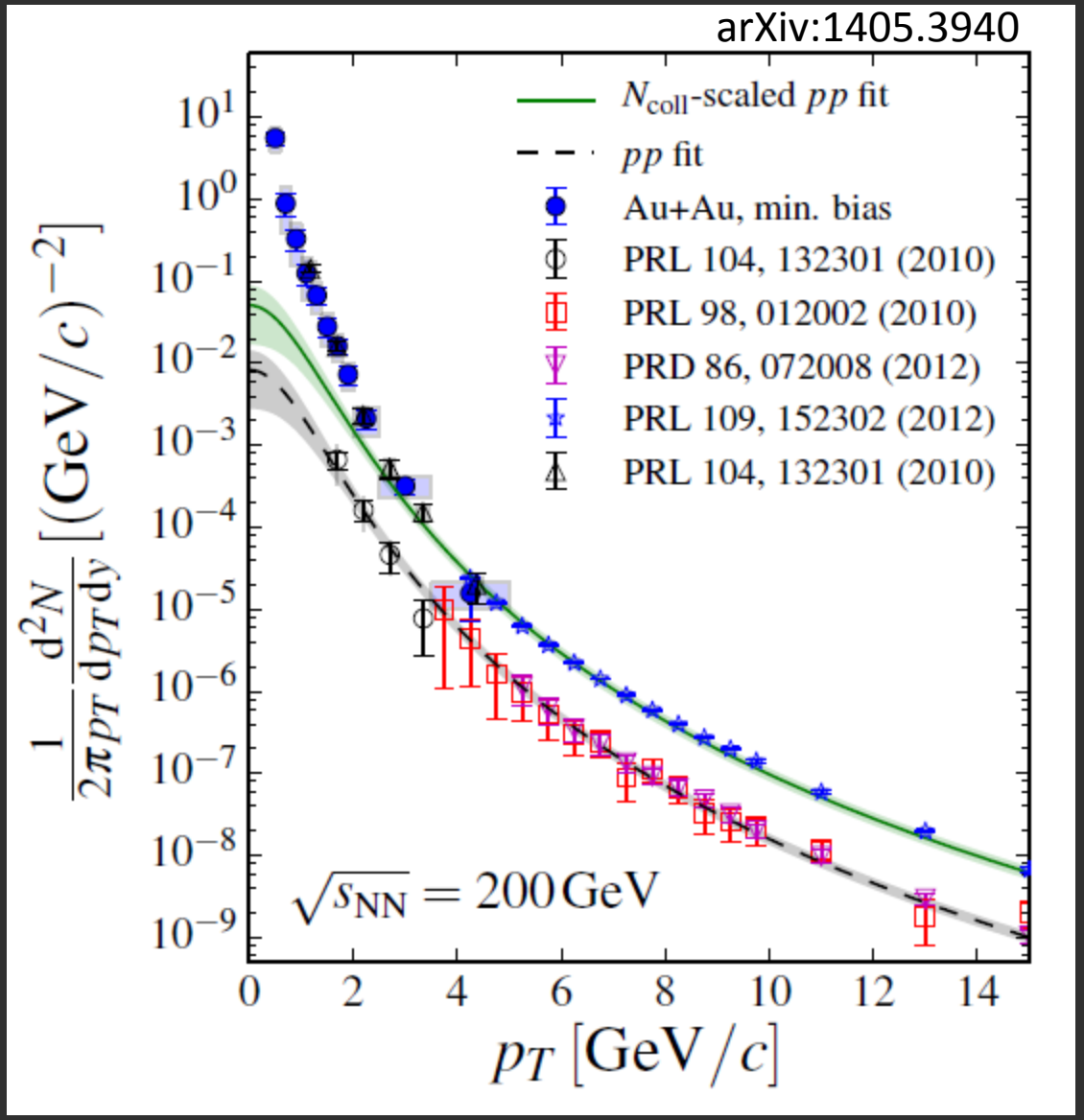


J/ψ in U+U
Similar trend to Au+Au results

Υ(1s,2s,3s) in Au+Au
Within uncertainties
same pattern as CMS at LHC
and melting of 2s and 3s



Precision Direct Photons in Au+Au

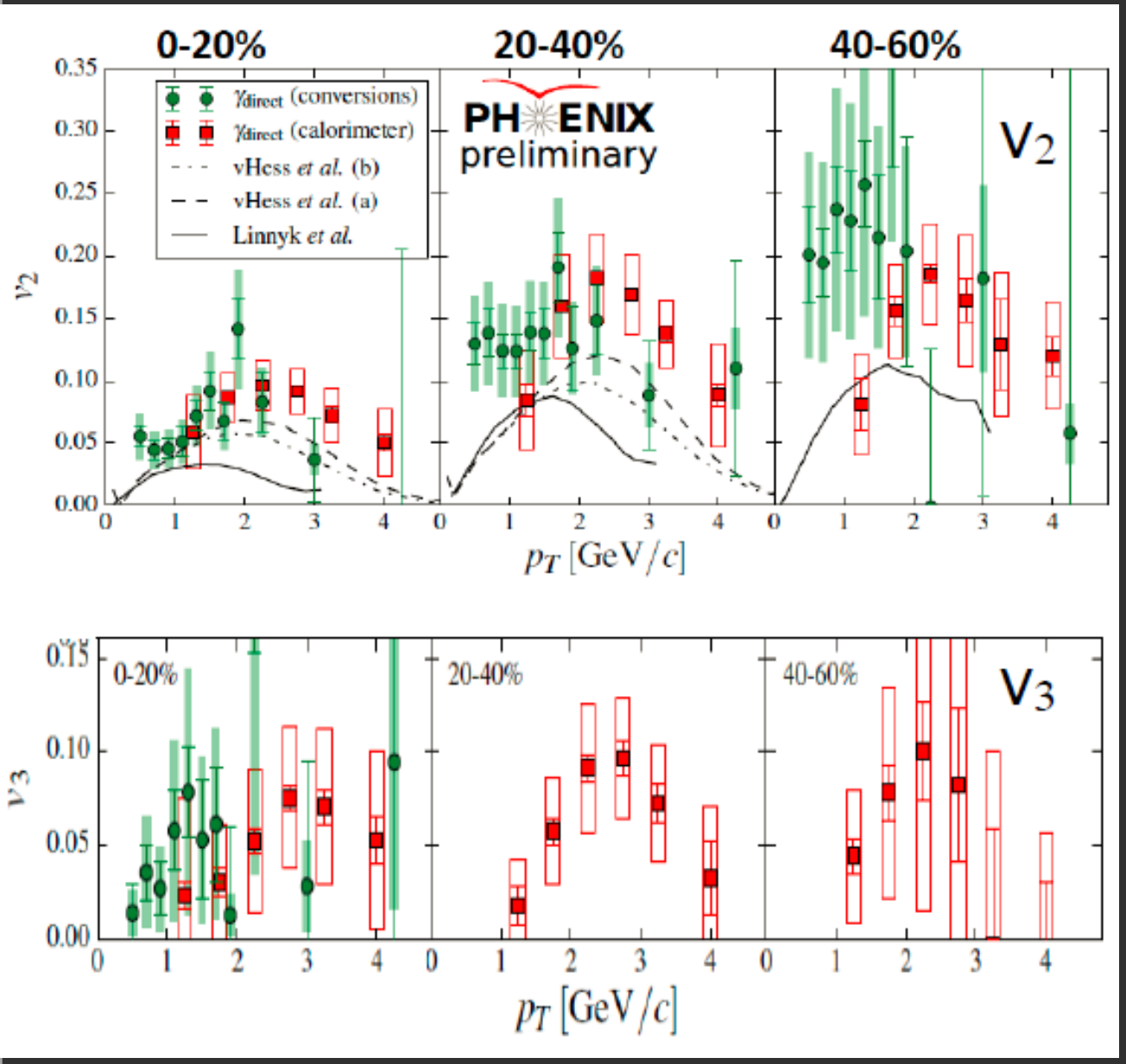


Method using conversion of real photons

Confirms published result with virtual photons

Extends low p_T reach, centrality, and precision

v_2 and v_3 of Direct Photons



Two new analysis methods indicate large v_2 for direct photons and also first measure of v_3

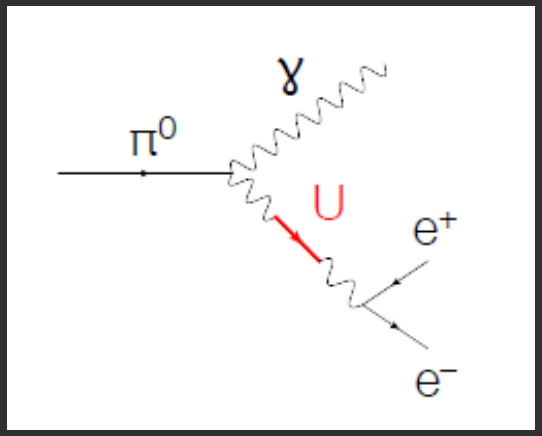
Attempts to reconcile with theory assume much stronger coupled QGP near T_c (e.g. Rapp *et al.*)

Exotic mechanisms too (B field)

Real Photons, Virtual Photons, Dark Photons (?)

Muon g-2 experiment (E821) has 3.6σ result beyond the Standard Model

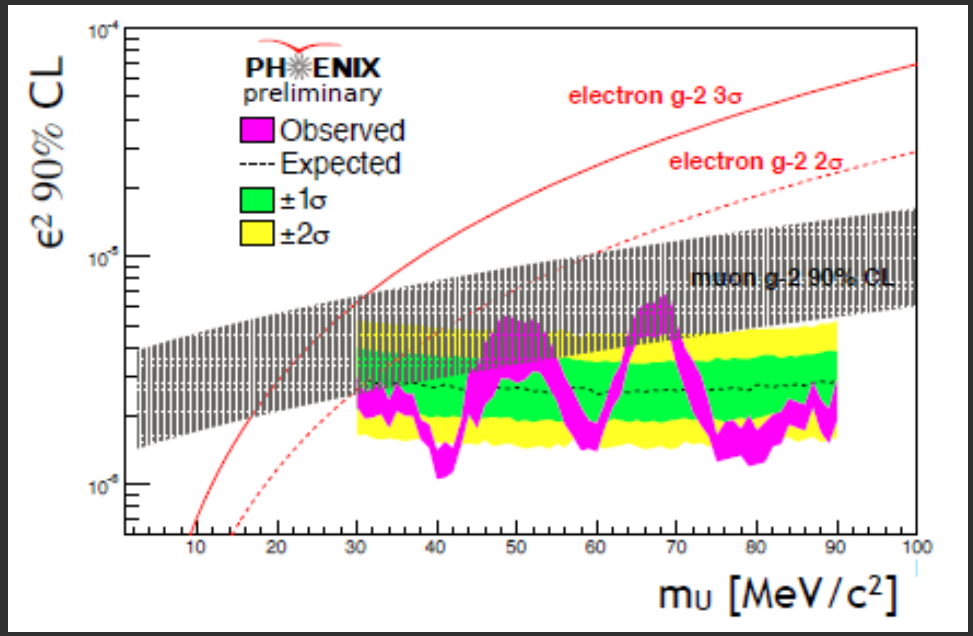
One explanation is the dark photon – Low mass, weak coupling



PHENIX has excellent dark photon search capabilities

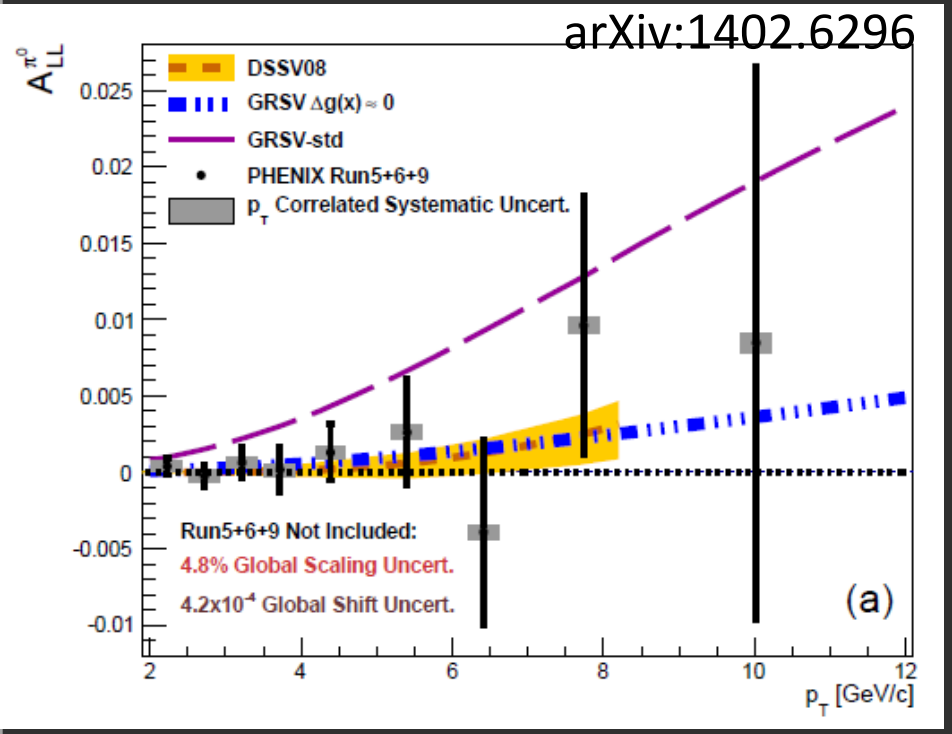
No dark photon signal seen

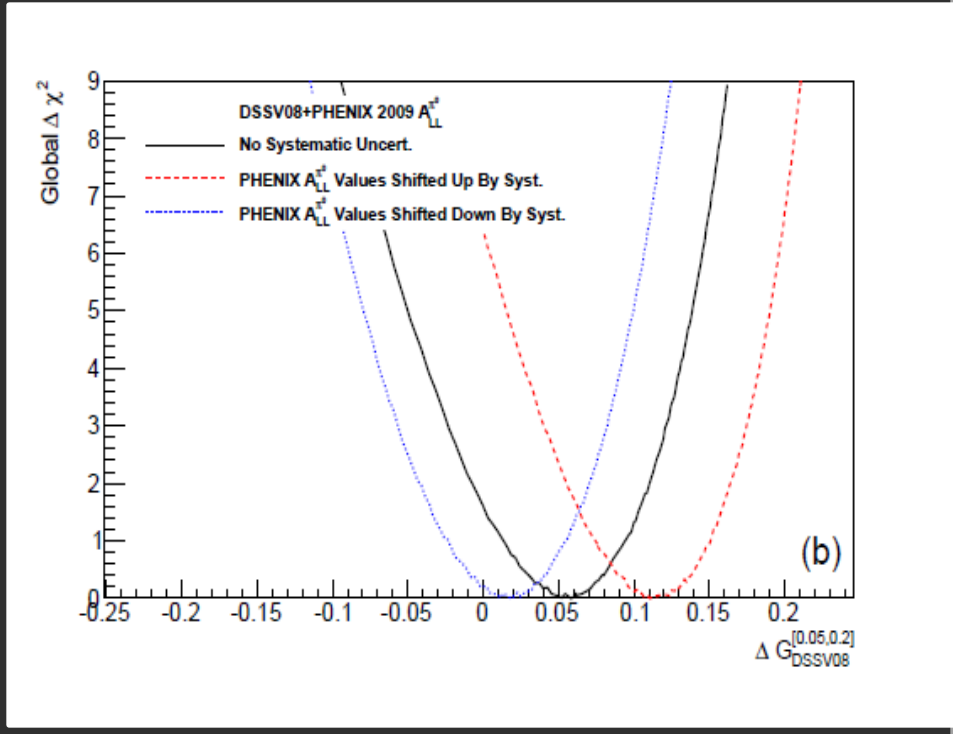
Our upper limit, plus others Nearly rules out dark Photons as g-2 explanation



Spin Results

arXiv:1402.6296





Final neutral meson double spin asymmetry results submitted

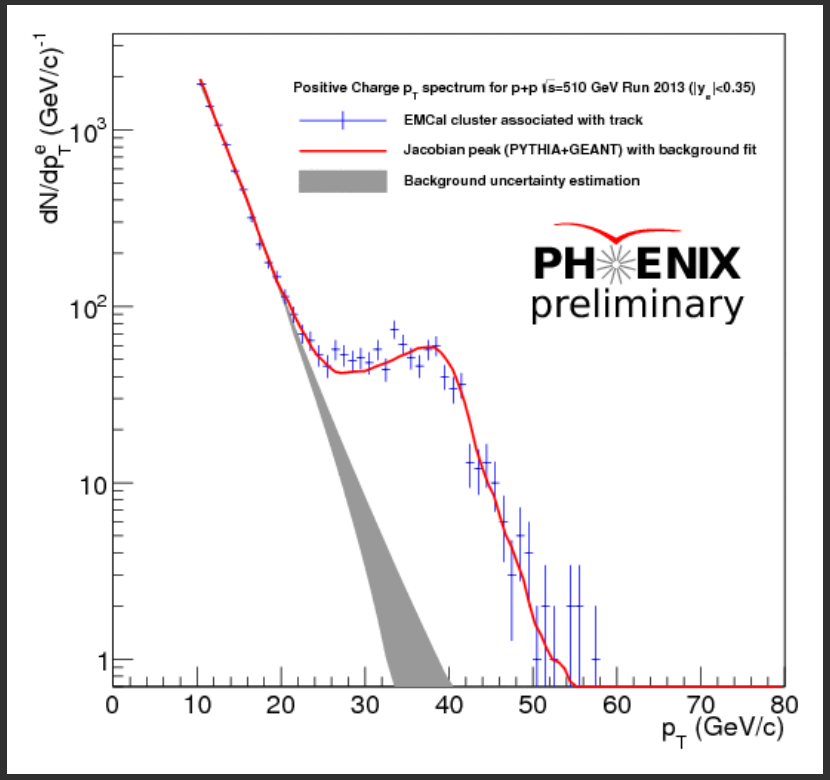
Constraint on lower-x gluon spin contribution

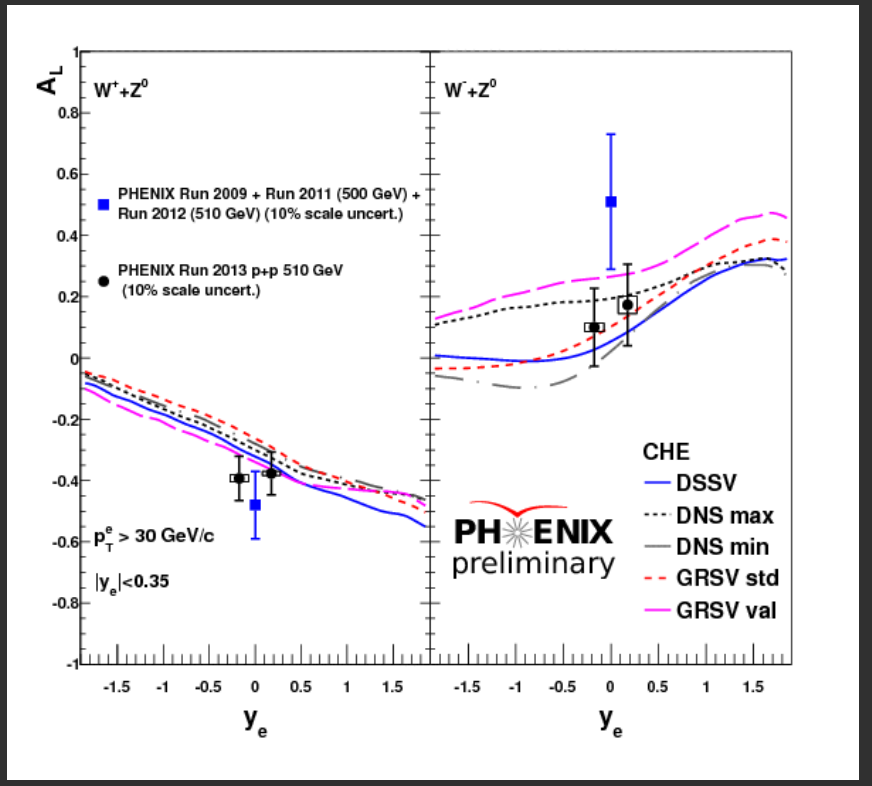
Highlights that global theory fits need to include systematics

W Analysis Update

Full Run-13 p+p @ 500 GeV data set production complete

Preliminary W→e result show with full statistics, paper soon





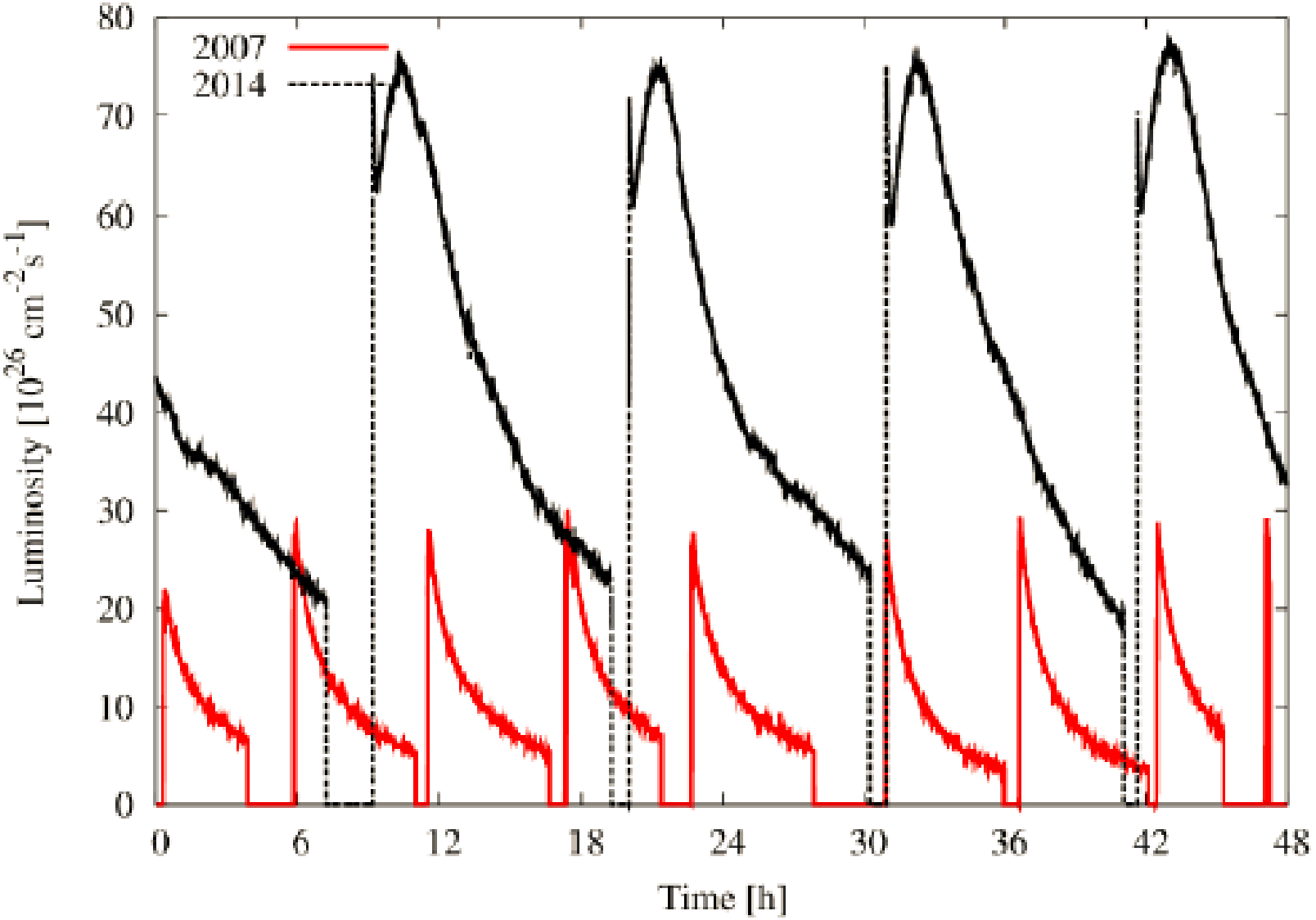
Focused effort of forward W→μ results for final result

21 PHENIX Papers Submitted in Last 12 Months

1.Cross section for bb^{-} production via dielectrons in d+Au collisions at s_{NN}−−−√=200 GeV
2.Low-mass vector-meson production at forward rapidity in p+p collisions at s√=200 GeV
3.Centrality dependence of low-momentum direct-photon production in Au+Au collisions at s_{NN}−−−√=200 GeV
4.Measurement of $K0S$ and $K*0$ in p+p, d+Au, and Cu+Cu collisions at s_{NN}−−−√=200 GeV
5.Heavy-quark production and elliptic flow in Au+Au collisions at s_{NN}−−−√=62.4 GeV
6.Measurement of long-range angular correlation and quadrupole anisotropy of pions and (anti)protons in central d+Au collisions at s_{NN}−−−√=200 GeV
7.Comparison of the space-time extent of the emission source in d+Au and Au+Au collisions at s_{NN}−−−−√=200 GeV
9.Measurement of Υ(1S+2S+3S) production in p+p and Au+Au collisions at s_{NN}−−−√=200 GeV
10.Nuclear matter effects on J/ψ production in asymmetric Cu+Au collisions at s_{NN}−−−√ = 200 GeV
11.Inclusive double-helicity asymmetries in neutral pion and eta meson production in $\vec{p}+\vec{p}$ collisions at s√=200 GeV
12.Concept for an Electron Ion Collider (EIC) detector built around the BaBar solenoid
13.Azimuthal-angle dependence of charged-pion-interferometry measurements with respect to 2nd- and 3rd-order event planes in Au+Au collisions at s_{NN}−−−√=200 GeV
14.Transverse-energy distributions at midrapidity in p+p, d+Au, and Au+Au collisions at s_{NN}−−−√=62.4--200~GeV and implications for particle-production models
15.Measurement of transverse-single-spin asymmetries for midrapidity and forward-rapidity production of hadrons in polarized p+p collisions at s√=200 and 62.4 GeV
16.Heavy-flavor electron-muon correlations in p+p and d+Au collisions at s_{NN}−−−√ = 200 GeV
17.System-size dependence of open-heavy-flavor production in nucleus-nucleus collisions at s_{NN}−−−√=200 GeV
18.Centrality categorization for R_{p(d)+A} in high-energy collisions
19.Cold-nuclear-matter effects on heavy-quark production at forward and backward rapidity in d+Au collisions at s_{NN}−−−−√=200 GeV
20.Azimuthal anisotropy of pi^0 and eta mesons in Au+Au collisions at sqrt(s_NN)=200 GeV
21. Cross Section and Transverse Single Spin Asymmetry of η Mesons in $p^{\uparrow}+p$ collisions at $\sqrt{s}$\,=\,200~GeV at Forward Rapidity

Run-14 Au+Au
data taking status

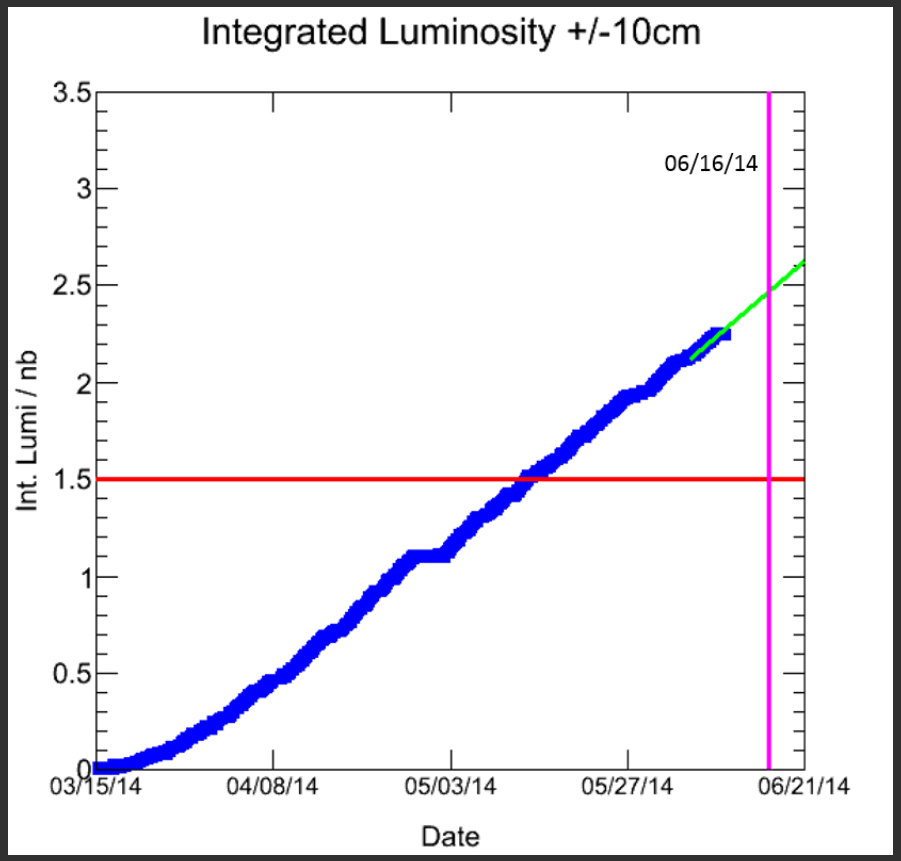
Run-14 Fantastic RHIC Performance!

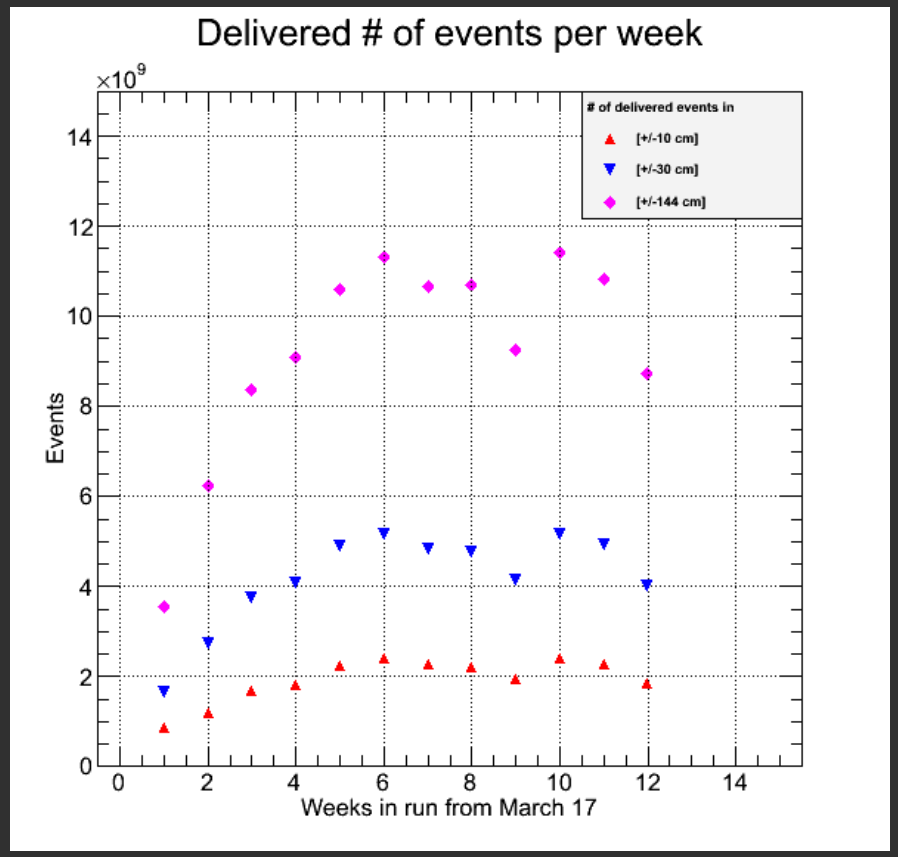


End of Run-0 Celebration (1999)

Imagined Run-14 Celebration (2014)

Steady Beam Week-after-Week!





Our goal was 1.5 nb^{-1} within $|z| < 10$ cm.

Achieved earlier and now exceeded by 55%

Very quick ramp up, PHENIX uptime > 80%

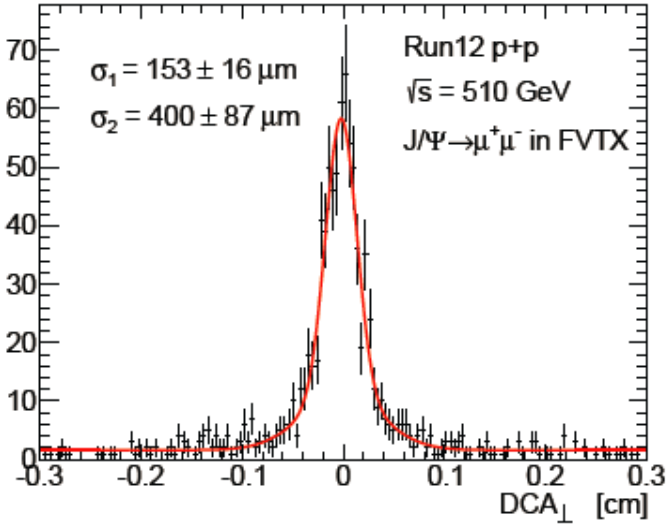
PHENIX Performance in Run-14

Overall very stable PHENIX detector and running

Stable long stores are a major contributing factor

Special Thanks to our Run Coordinator Klaus Dehmelt!

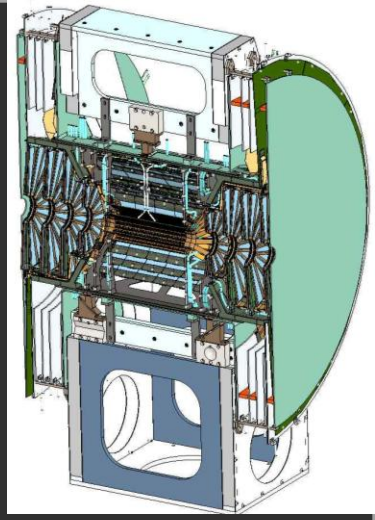
PHENIX Forward Silicon (FVTX)

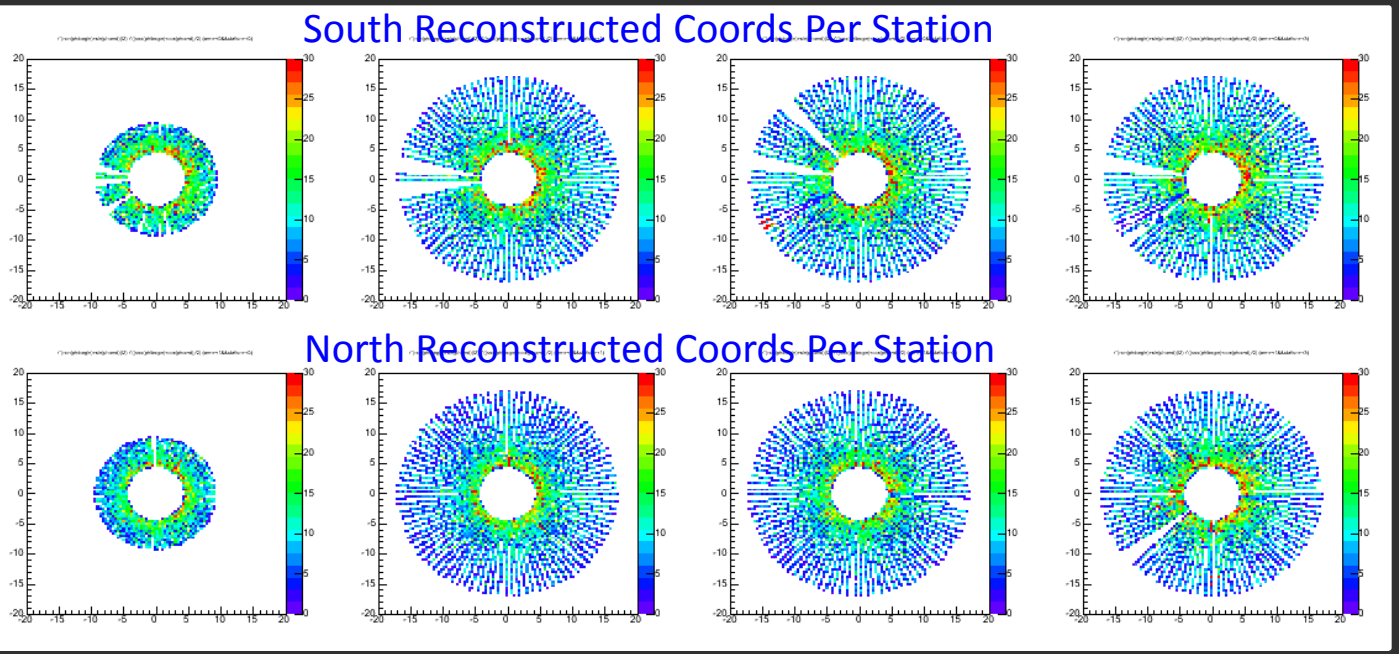


DCA Analysis from Run-12 data

Detector meeting resolution specifications

arXiv:1311.3594 (accepted NIM)

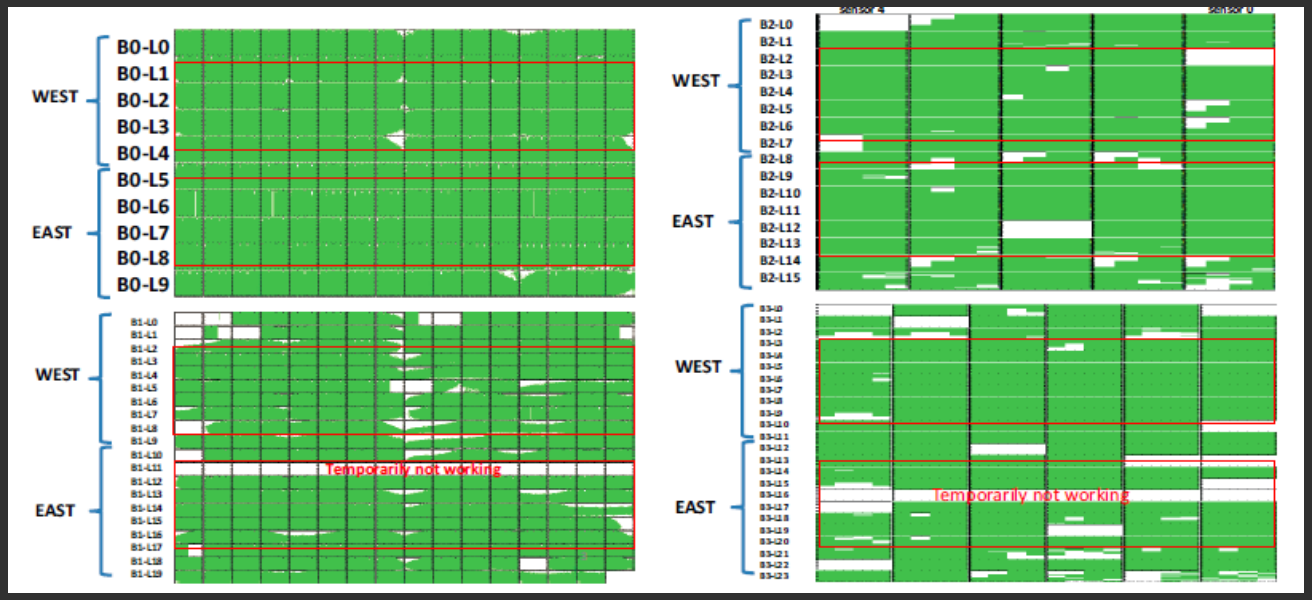




FVTX Run-14

- Live > 95%
- Internal alignment within 4 μm

PHENIX Barrel Silicon (VTX)

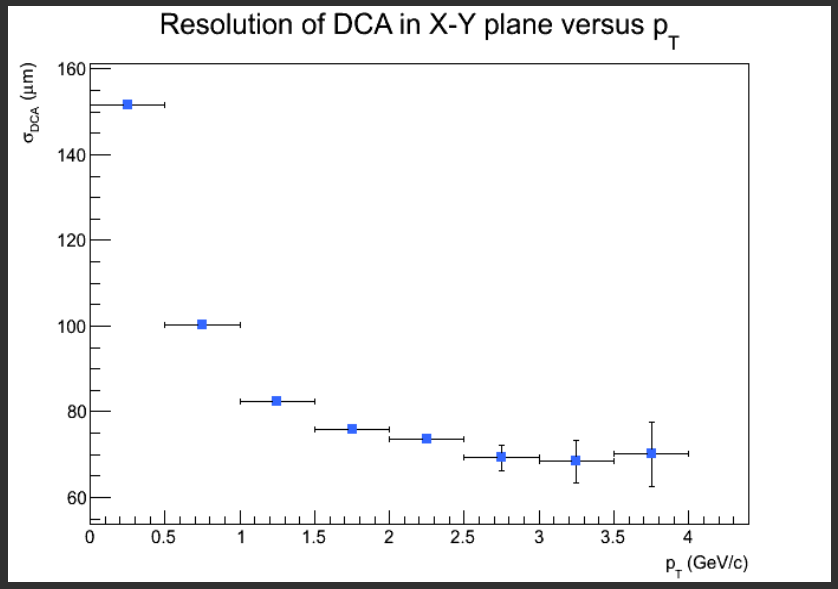


Run-14

Repairs successful

Pixel Live > 80%, Very Stable

Strip-pixel > 85%



DCA Resolution from Run-14 alignment already exceeds 100 μm specification

Full VTX / FVTX alignment with MILLIPED underway

Run-15 and Run-16 Beam Use Requests

Brookhaven Lab Timeline

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2014	15 GeV Au+Au 200 GeV Au+Au	Heavy flavor flow, energy loss, thermalization, etc. Quarkonium studies QCD critical point search	Electron lenses 56 MHz SRF STAR HFT STAR MTD
2015-16	p+p at 200 GeV p+Au, d+Au, ^{3}He+Au at 200 GeV High statistics Au+Au	Extract η/s(T) + constrain initial quantum fluctuations More heavy flavor studies Sphaleron tests Transverse spin physics	PHENIX MPC-EX Coherent e-cooling test
2017	No Run		
2018-19	5-20 GeV Au+Au (BES-2)		
2020	No Run		Complete sPHENIX installation STAR forward upgrades
2021-22	Long 200 GeV Au+Au with upgraded detectors p+p, p/d+Au at 200 GeV	Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism Color screening for different quarkonia	sPHENIX
2023-24	No Runs		Transition to eRHIC

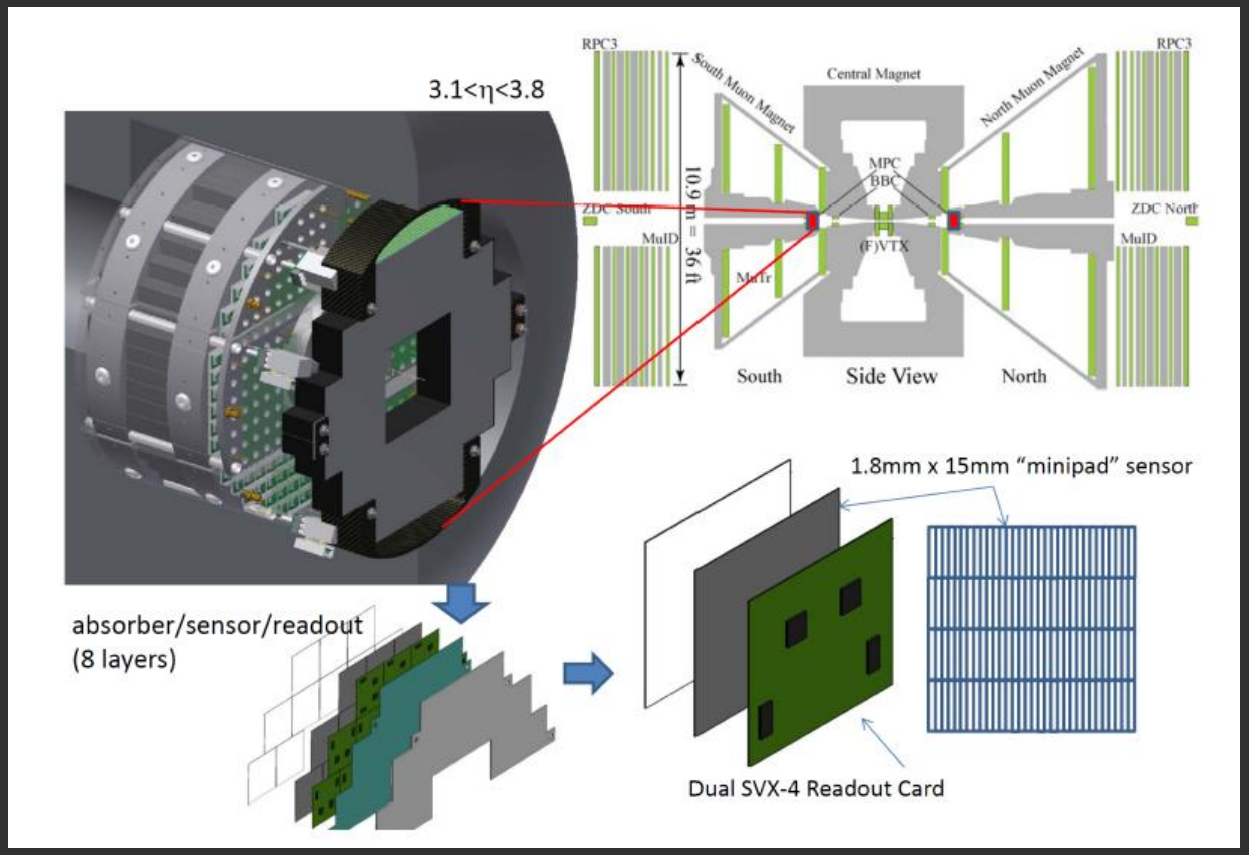
Plan to remove PHENIX after Run-16 for installation of sPHENIX

Run-14/15/16: Thinking in terms of definitive measurements (not hints to return to later)

MPC-EX Upgrade

The PHENIX MPC Crystal Calorimeter ($|\eta|$=3.1-3.8) has played a critical role in our forward (low-x) and transverse spin physics program

MPC-EX upgrade adds novel silicon tracking / preshower detector to enable *direct photon* identification and $\pi^0 \rightarrow \gamma\gamma$ to higher momentum



Beam test in fall, and section installed for integration tests in Run-14

Full detector available for physics in Run-15

MPC-EX Section in Situ

The "Wiggler"

Coherent electron Cooling (CeC) test is key for EIC

The Coherent electron Cooling Proof-of-Principle project was planning to install the electron beam line including the undulator in IP2 this summer for first beam tests during RHIC Run-15. We are also planning to run pA during Run-15 and this asymmetric configuration limits the available aperture in the undulator.

We are now proposing to set up the electron beam line parallel to the RHIC IR but separate from RHIC to avoid this potential interference. All the tests on the electron beam can still be completed. During the summer of 2015 the undulator section would then be moved parallel to itself into the RHIC beam for the full cooling tests during Run-16. For this to work we would need your agreement to schedule only symmetric RHIC beam configurations during Run-16.

Thus we have not proposed any p+A running in Run-16. That said, the MPC-EX physics program provides crucial new measurements and we should not prematurely decide that all p+A physics must come from only Run-15.

What did the PAC (you) say last year?

For Run 15 the PAC recommends the following (*in order of priority*)

1. 200 GeV $\vec{p}+\vec{p}$ collisions,
2. 200 GeV $\vec{p}$+Au running, and
3. Additional full energy mixed species running ($\vec{p}$+Si, $\vec{p}$+Cu, d+Au, ^{3}He+Au).

It should be noted that STAR measurements at high η are not symmetric and would benefit from the ability to switch from p+Au to Au+p collisions. PHENIX expressed a similar desire as a means to minimize systematics in these measurements. It will be important to next year's discussion that the PAC receives clear guidance regarding the impact of these swaps on both the machine and the detectors.

http://www.bnl.gov/npp/docs/Pac0613/recommendations_0613_final.pdf

PHENIX Run-15 Request

Run-15 Proposal (22 cryo-weeks)

- p+p @ 200 GeV with transverse polarization for 9 weeks [Physics driven goal is 50 pb^{-1} recorded within $|z| < 40$ cm and $\langle \mathcal{P} \rangle = 60\%$]
- p+Au @ 200 GeV with transverse polarization of the proton for 5 weeks [Physics driven goal is 190 nb^{-1} sampled within $|z| < 40$ cm and $\langle \mathcal{P} \rangle = 60\%$. We note that the request is with half the data switching the beams to Au+p.]
- p+Si @ 200 GeV with transverse polarization of the proton for 2 weeks [Physics driven goal is 450 nb^{-1} sampled within $|z| < 40$ cm and $\langle \mathcal{P} \rangle = 60\%$]

Note that not utilizing additional collision combinations diminishes total knowledge gain and does not fully exploit the uniqueness of RHIC

Transverse Spin Physics

Single spin asymmetries A_N in transversely polarized p+p collisions may contain key information on the parton's transverse motion in the transversely polarized proton (i.e. language already hinting at orbital angular motion)

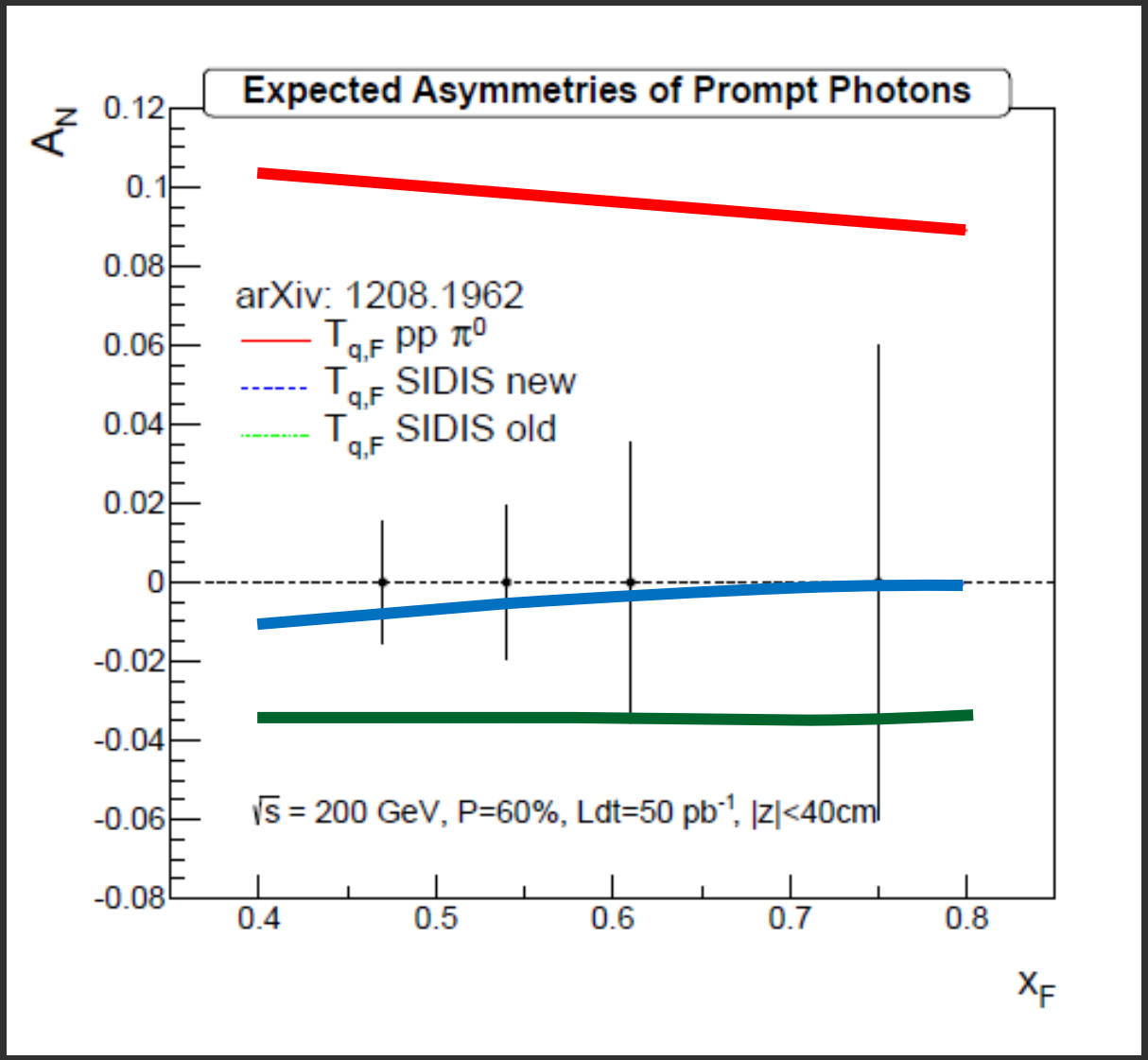
Different theoretical approaches
(TMD factorization and Collinear twist-three factorization)
TMDs include Sivers and Collins functions

Direct photon A_N is an excellent clean test
almost exclusively sensitive to Sivers

Also, good measure of twist-three quark-gluon correlator $T_{q,F}$

p+p (transverse pol.) @ 200 GeV for 9 weeks

(50 pb^{-1} $|z|<40cm$)



Utilize unique capabilities of MPC-EX upgrade

Direct photon with no final state interactions

Uncertainties clearly resolve sign disagreement for $T_{q,F}$

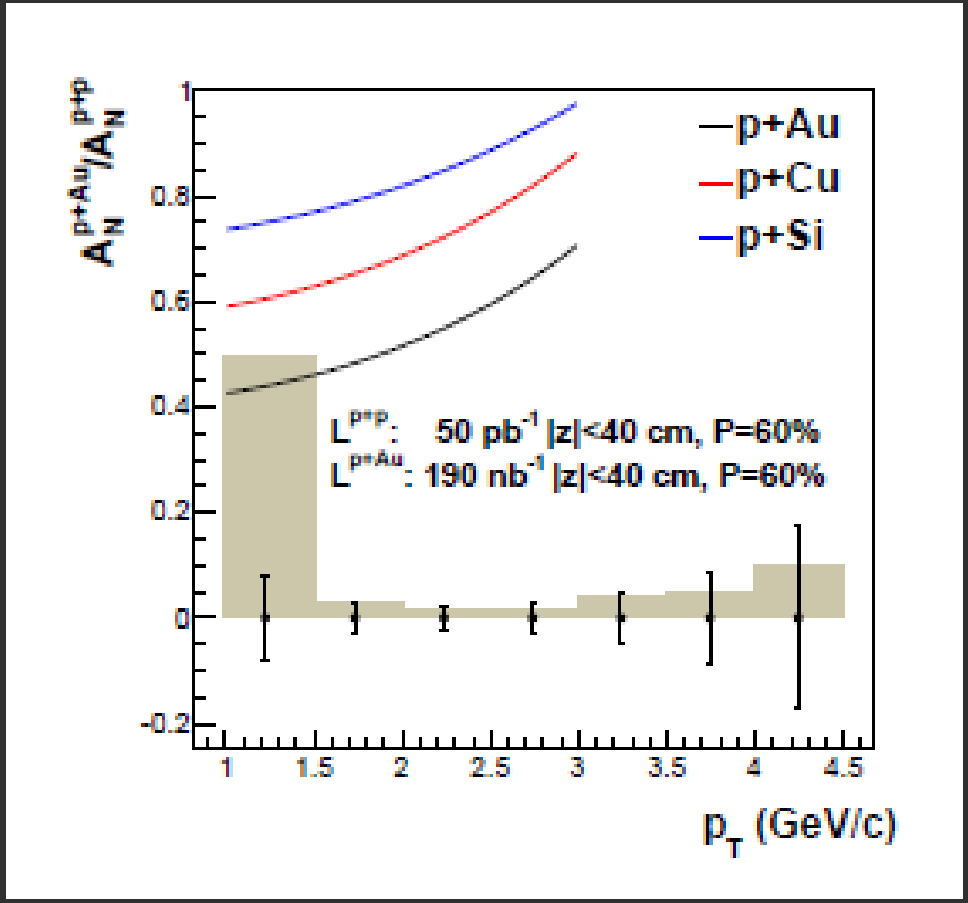
p+Au with transversely polarized proton

New theory developments… Transverse polarization A_N in p+A scales with the saturation scale for $p_T < Q_s$

Completely unique RHIC access to saturation physics

p+Au measurement with projected uncertainties in 190 nb^{-1} |z|<40cm

Testing geometric scaling with Si target nuclei
Comparable uncertainties with 2 week runs

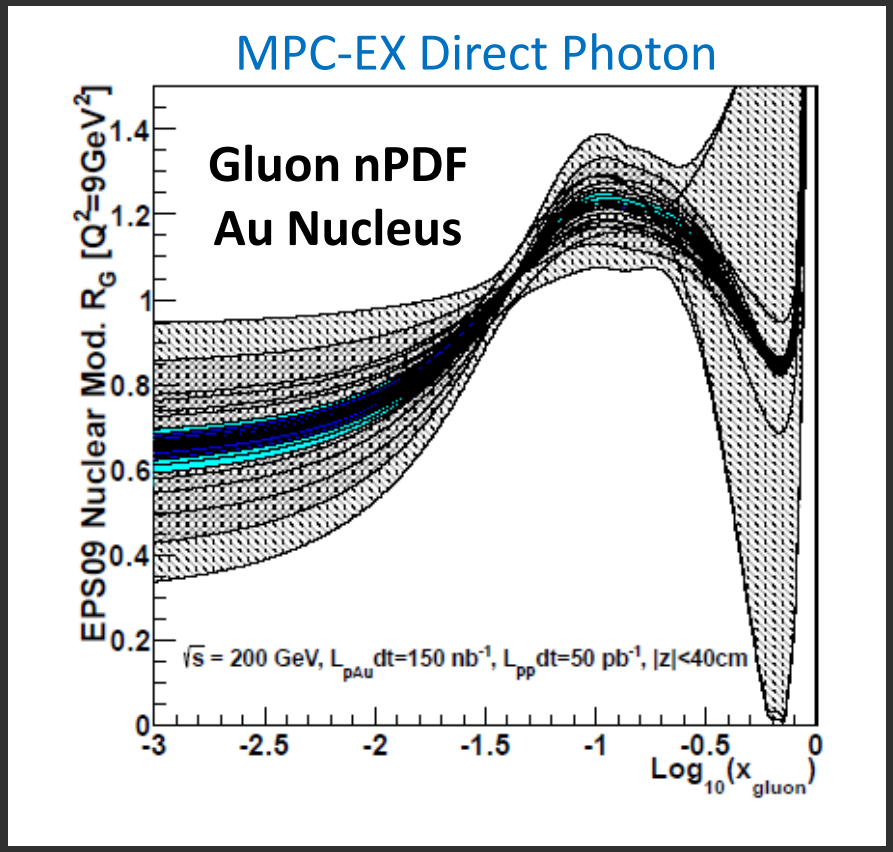


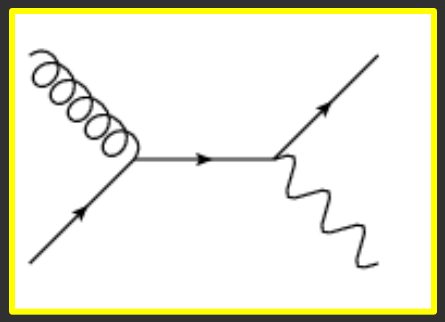
Constraining Gluon nPDFs

Strong indications of low-x shadowing/saturation physics with d+Au J/ψ, e-μ correlations, h-h correlations, single muons, electrons, …

And yet, all have final state interactions.

Golden channel direct photon





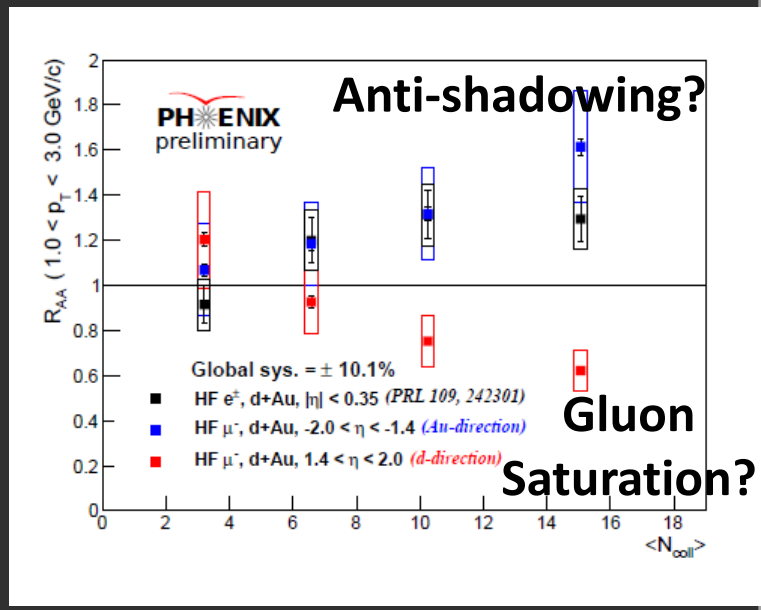
Using full statistical / systematic constraint method on EPS09 nPDFs, blue bands indicate projected measurement (**1, 2 σ** level)

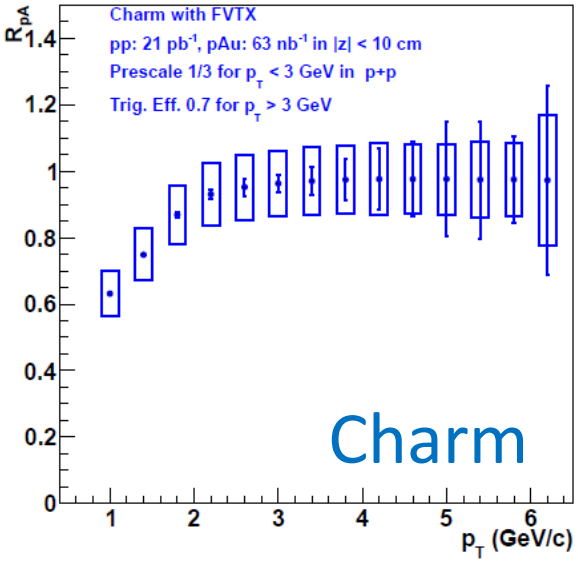
Open Heavy Flavor Probes of nPDFs and More

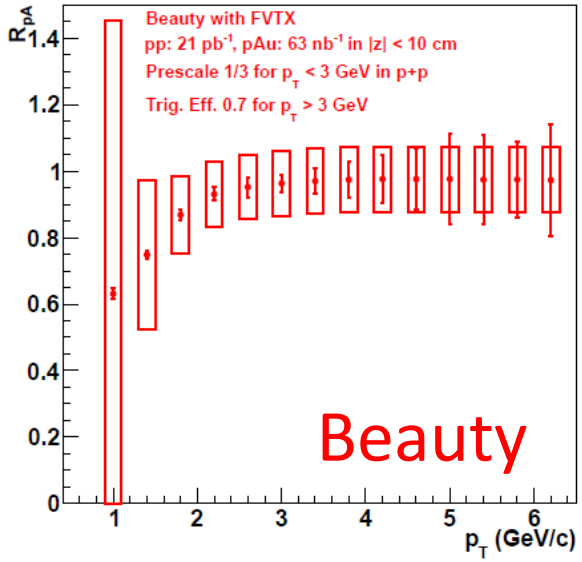
Another handle on gluon nPDF and critical baseline for quarkonia

Measure open charm and beauty at forward/backward rapidity with FVTX

We request p+Au and Au+p for systematic checks (*a la* LHC p+Pb)?





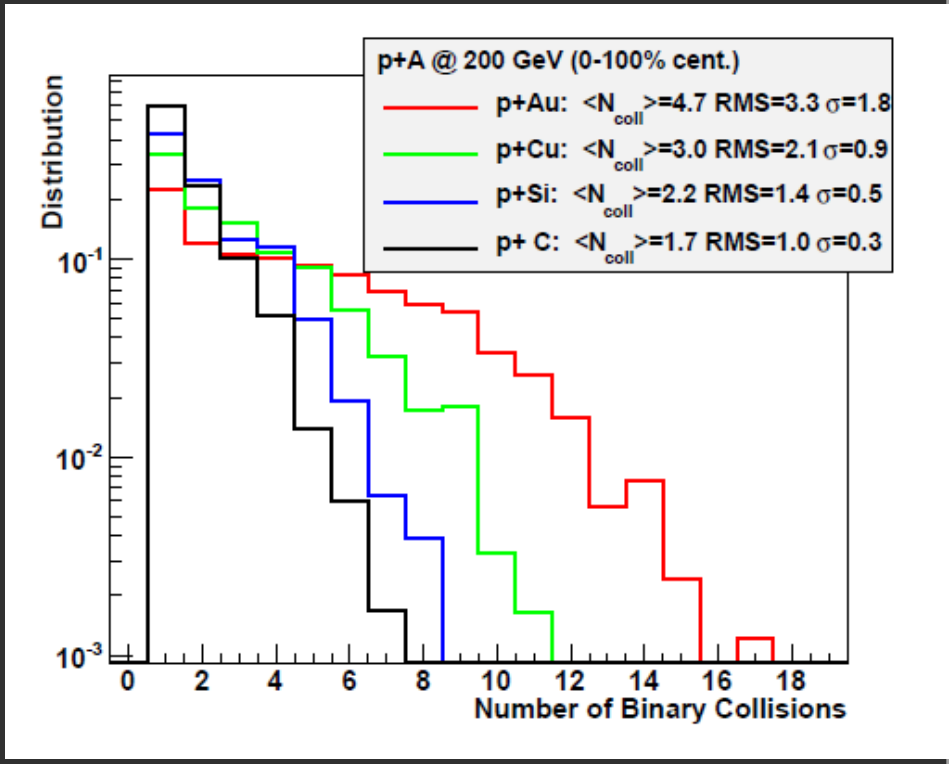


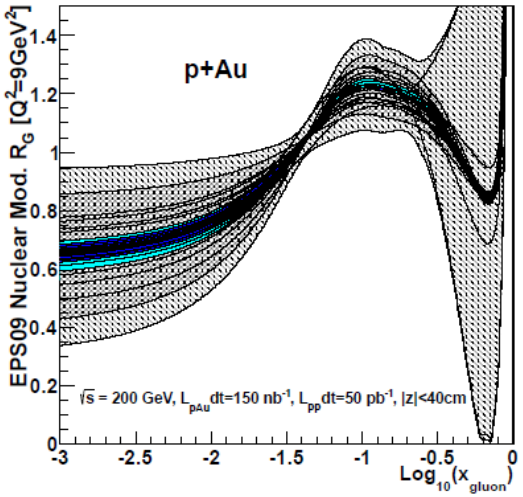
Geometry Test

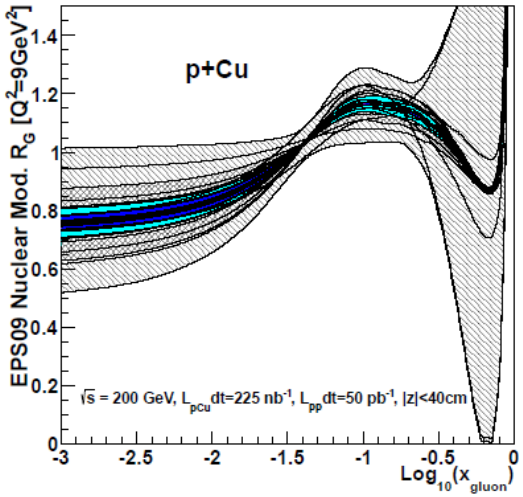
DIS measures give geometry averaged nPDF

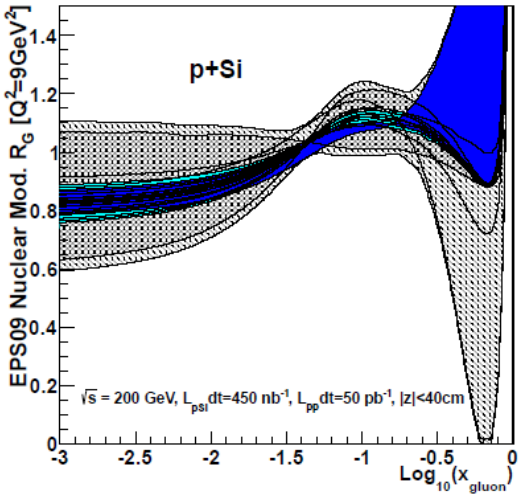
Utilized d+Au centrality measures to date…

Excellent opportunity to validate with direct photons nPDF of different nuclei



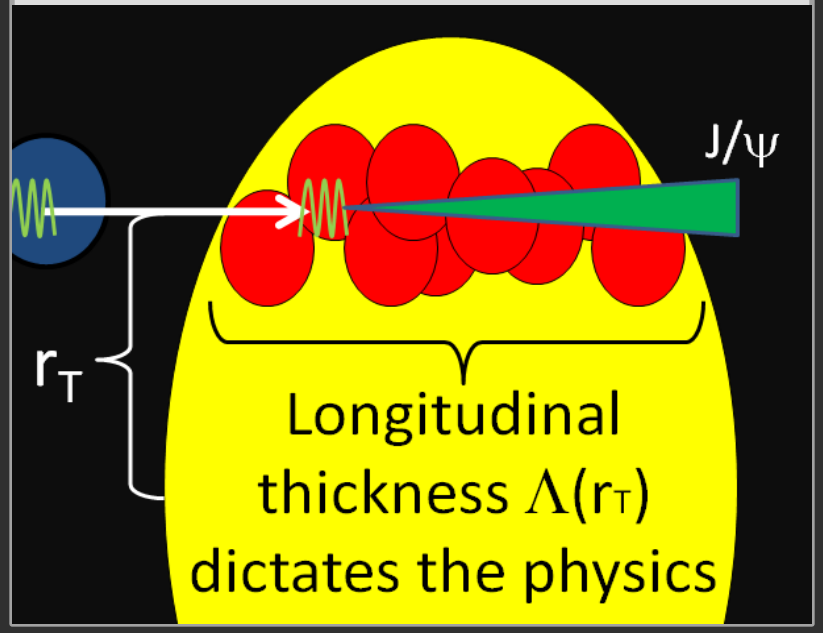


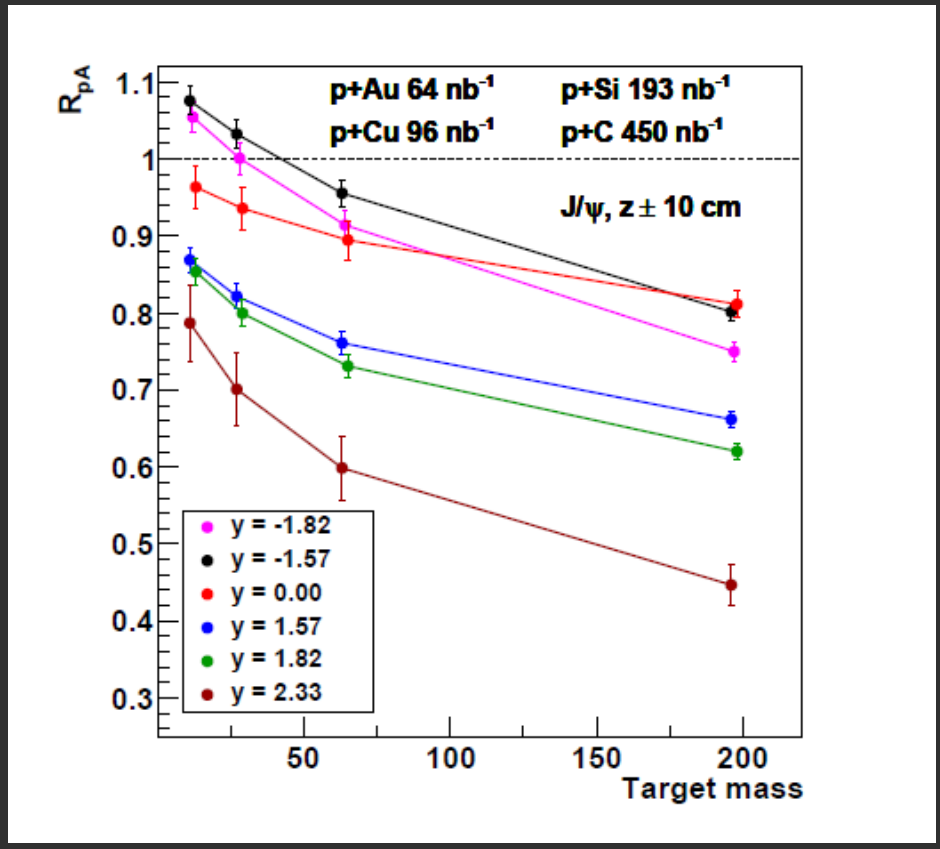




Quarkonia in Medium (Cold or Hot)

J/ψ and ψ' are hard to explain w/ nPDF & $\sigma_{breakup}$

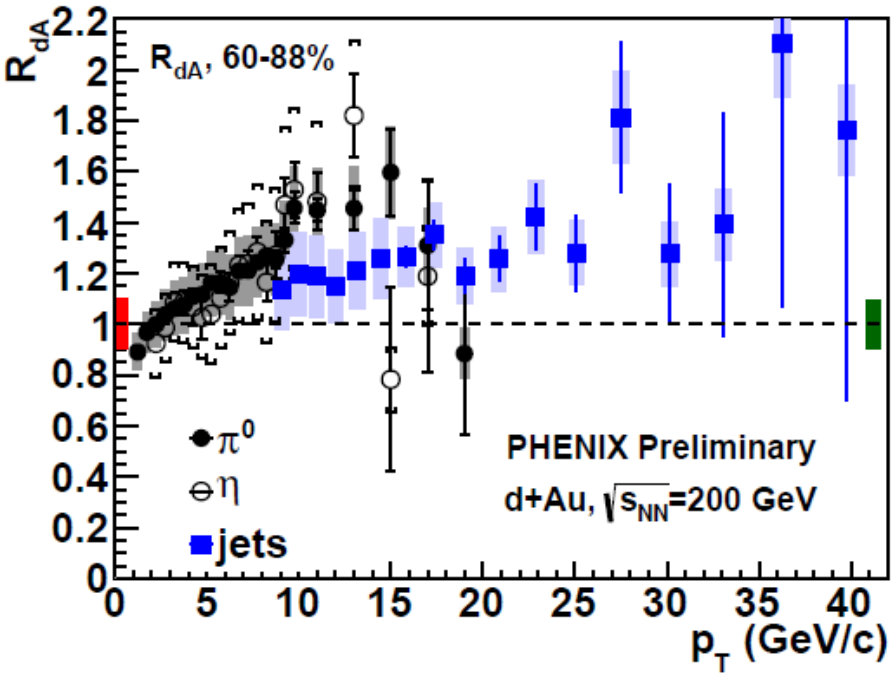


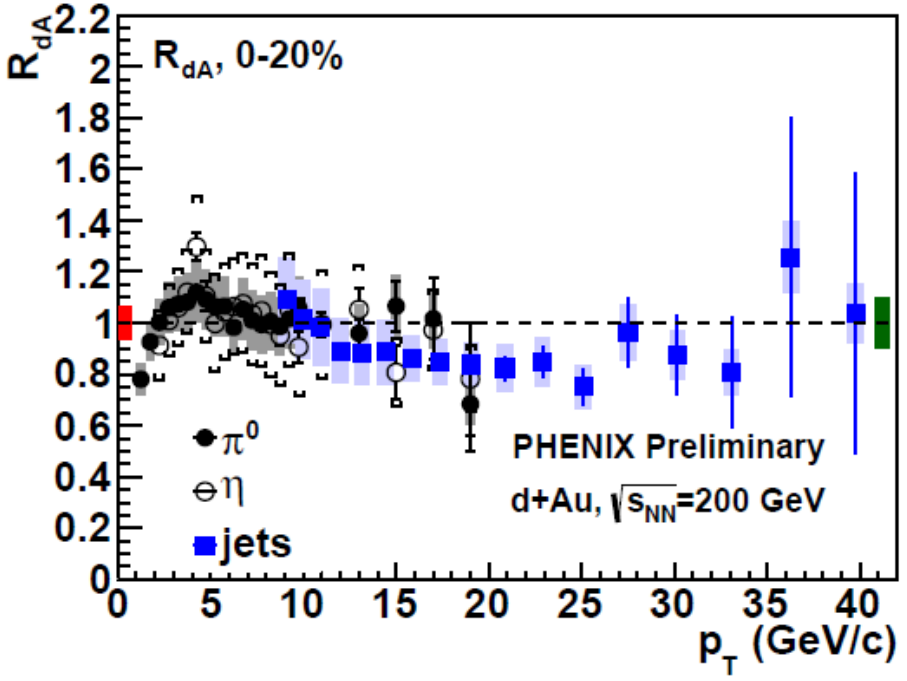


Instead of d+Au centrality selection, another method to change nuclear density is with **different targets**

Also combined with improved S/B and for the first time ψ' at forward and backward rapidity (FVTX)

Cracking the Geometry Code





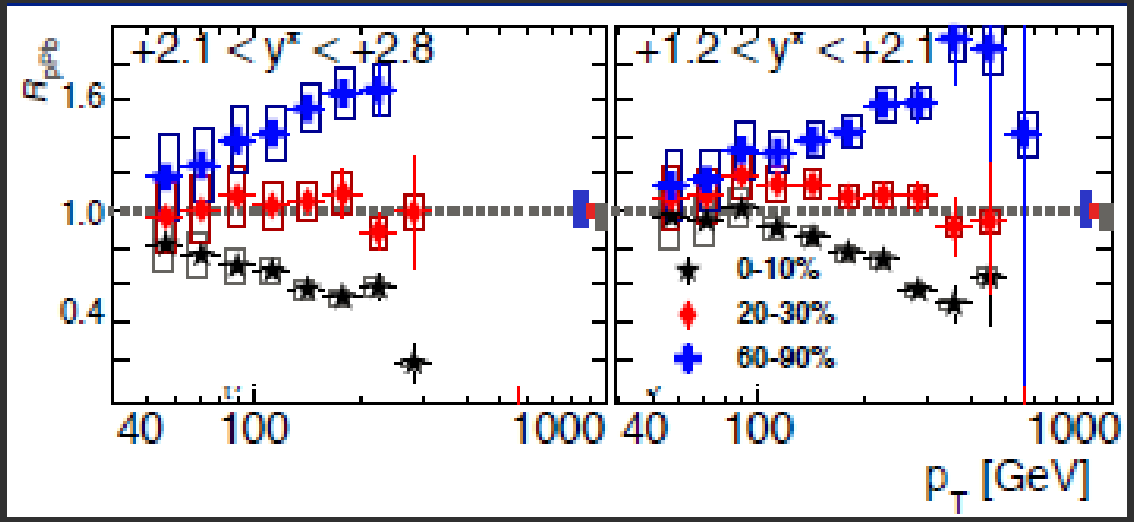
Are there competing partonic effects at play at high p_T?

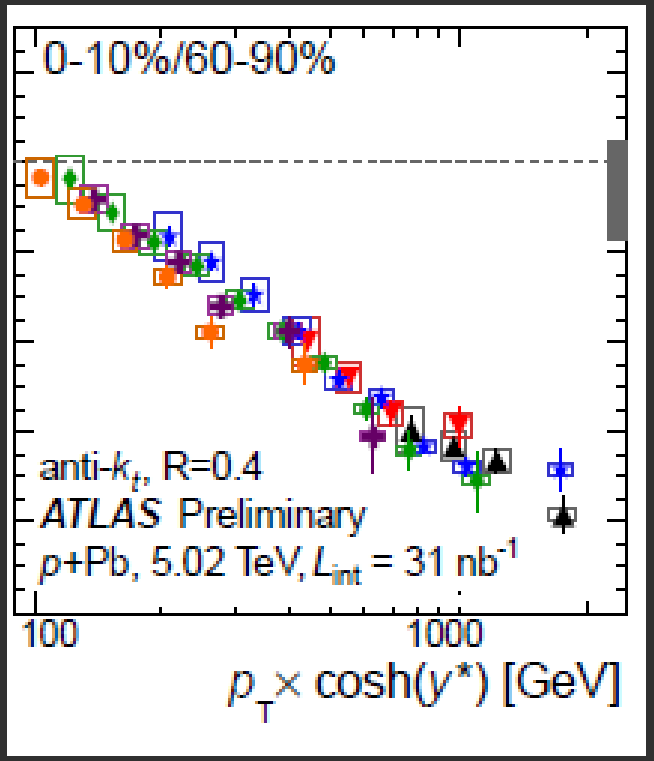
Are there auto-correlations beyond those accounted for between centrality measure and particle of interest?

2 weeks of p+Si gives $\langle N_{coll} \rangle$ ~ (d+Au 60-88% central), better statistical precision, and no centrality categorization required

RHIC / LHC Physics Connection

ATLAS in p+Pb also observes enhancement in peripheral and suppression central



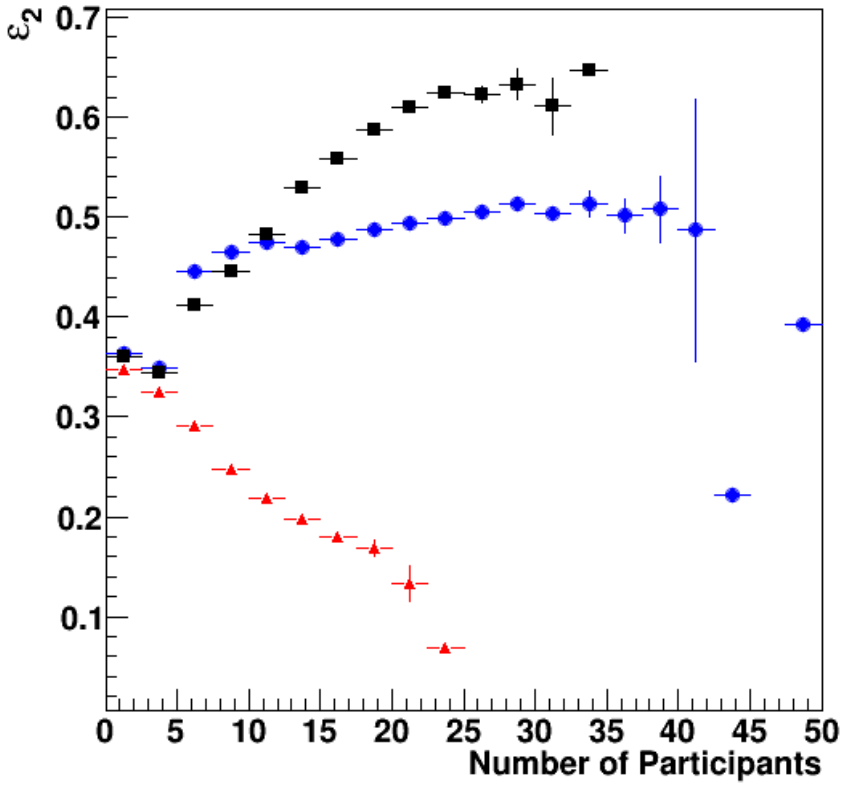


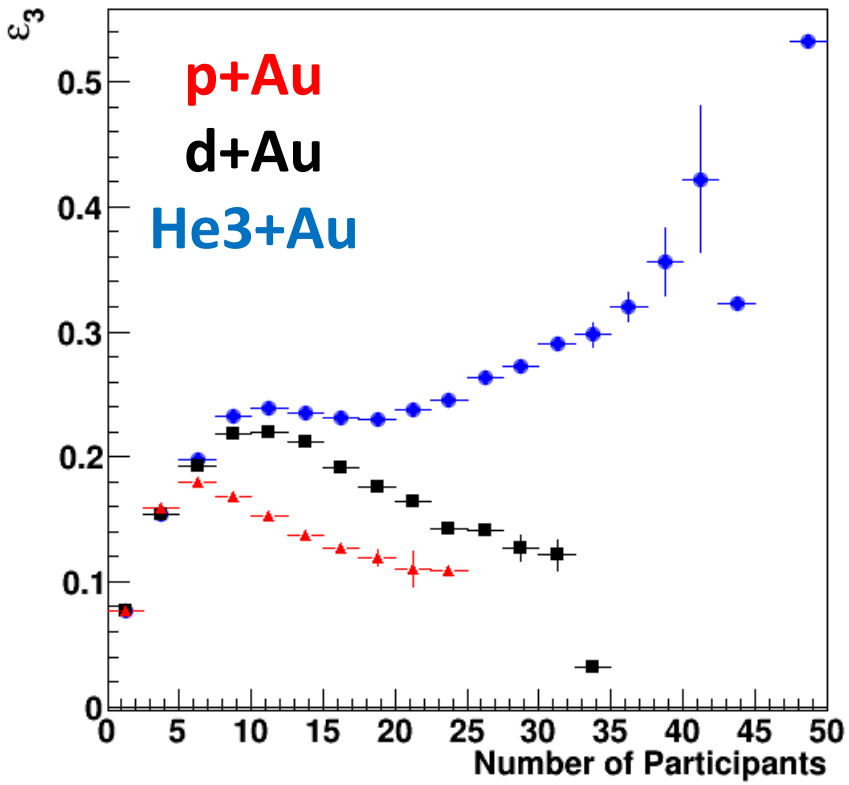
Scaling trend with jet Energy

Fluctuating proton size/shape and auto-correlations (?)

RHIC is uniquely position to test peripheral enhancement with p+Si

Geometry Control





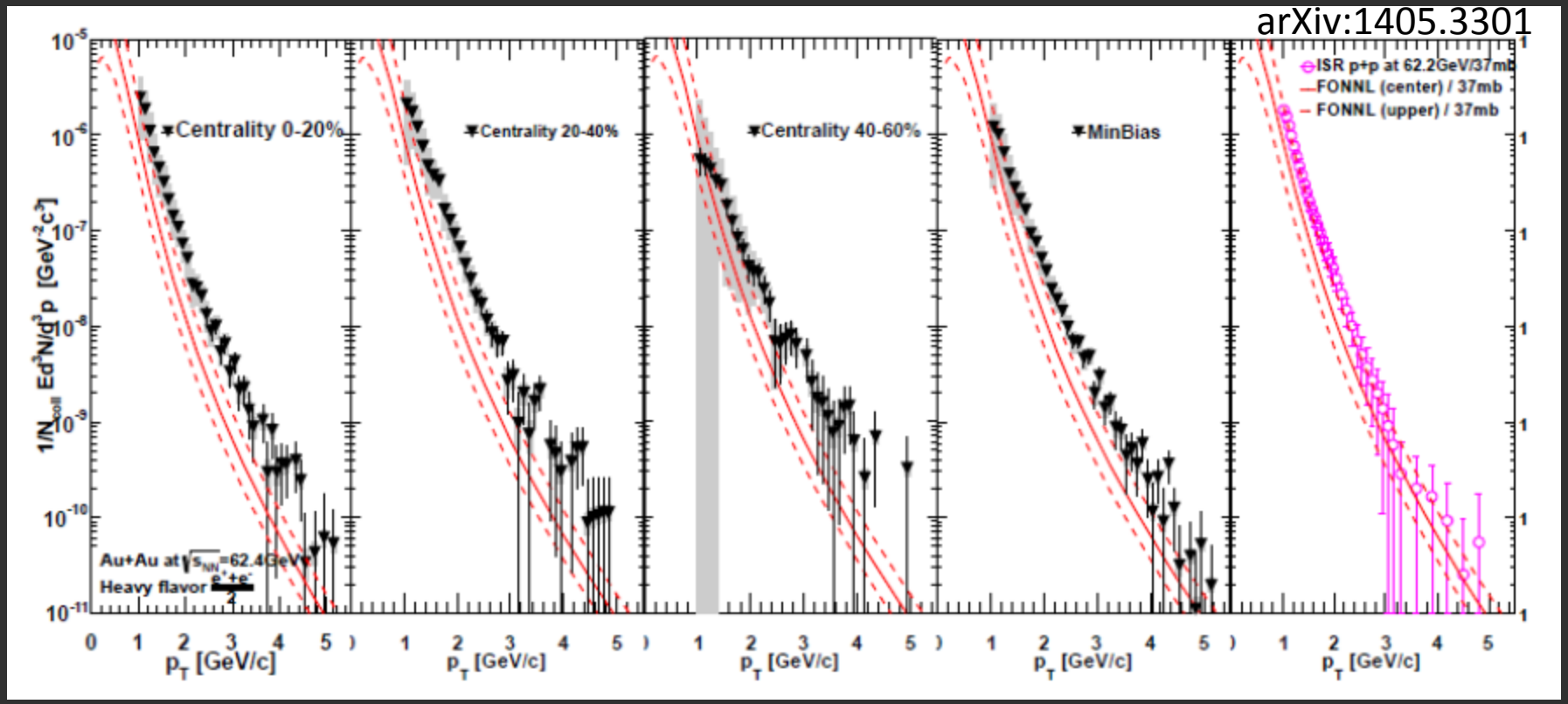
Comparison of different geometries provides key tests of underlying physics (initial conditions, equilibration time, medium properties, etc.)

PHENIX Run-16 Request

Run-16 Proposal (22 cryo-weeks)

- $p+p$ @ 62 GeV with longitudinal polarization for 6.5 weeks [Physics driven goal is 0.8 pb^{-1} recorded within $|z| < 10$ cm and $\langle \mathcal{P} \rangle = 60\%$]
- Au+Au @ 62 GeV for 9 weeks [Physics driven goal is 0.4 nb^{-1} recorded within $|z| < 10$ cm]
- $p+p$ @ 510 GeV for 1 week [Physics goal is driven by RHICf requirements — as detailed in their separate proposal]

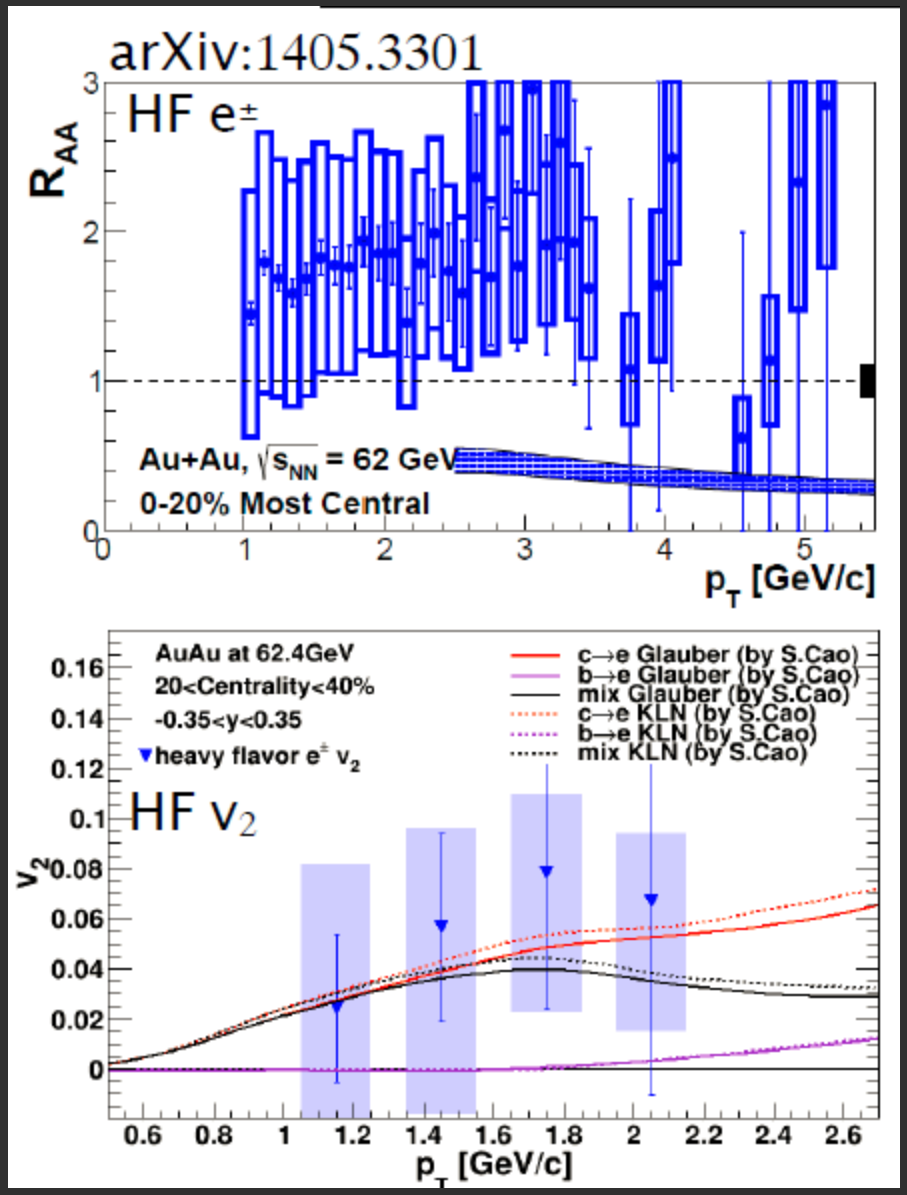
Why 62 GeV?



Heavy Flavor electrons enhanced (not suppressed) in Au+Au collisions at 62 GeV !

STAR has similar preliminary result

Strange Heavy Quark Trends



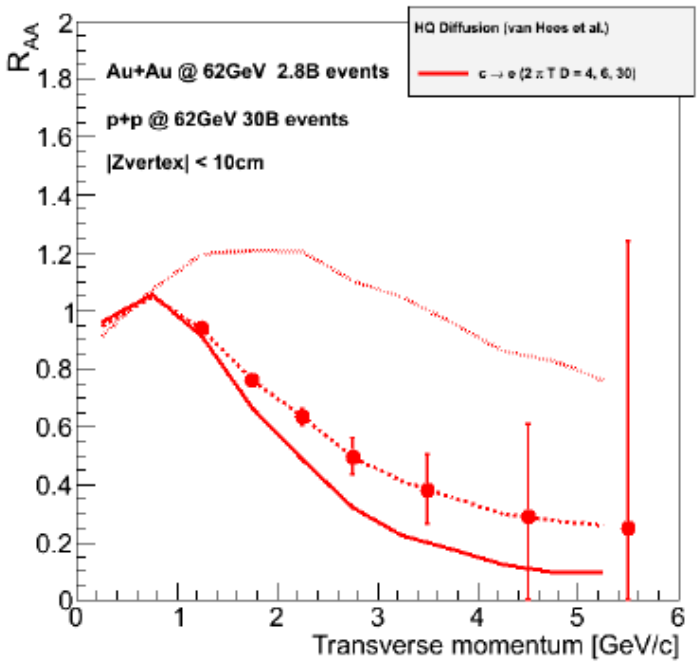
Nuclear modification factor uncertainties dominated by lack of p+p RHIC reference

Quenching theory predicts suppression

What about charm flow?

Elliptic flow
Uncertainties are too large

Projections with PHENIX Silicon Detectors



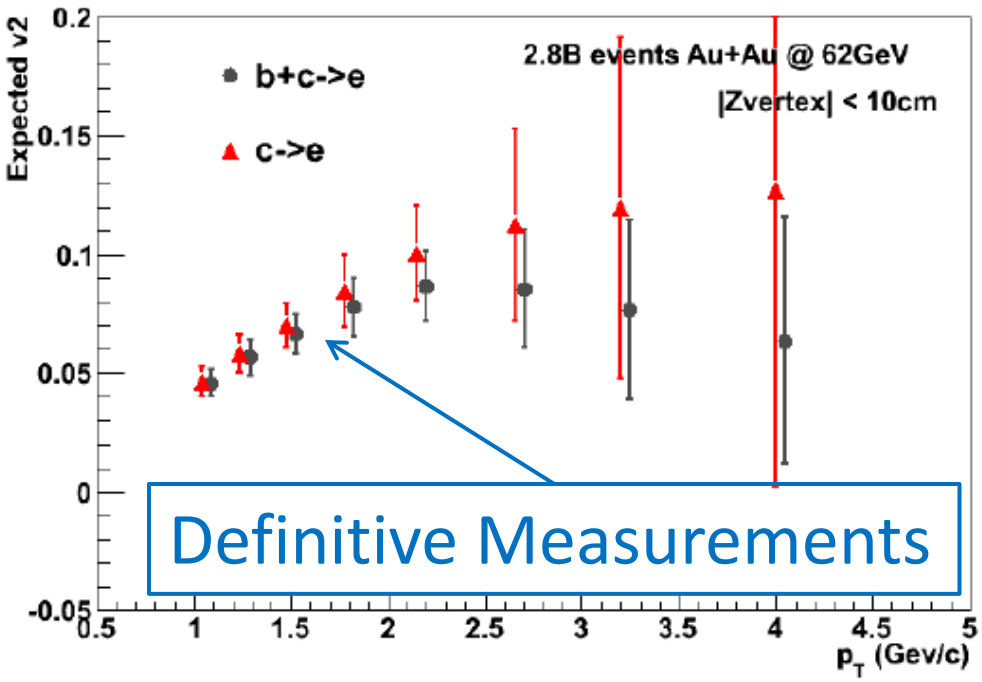


Table 3.2: C-AD providing information on p+p, p+A, Au+Au running at 62 GeV.

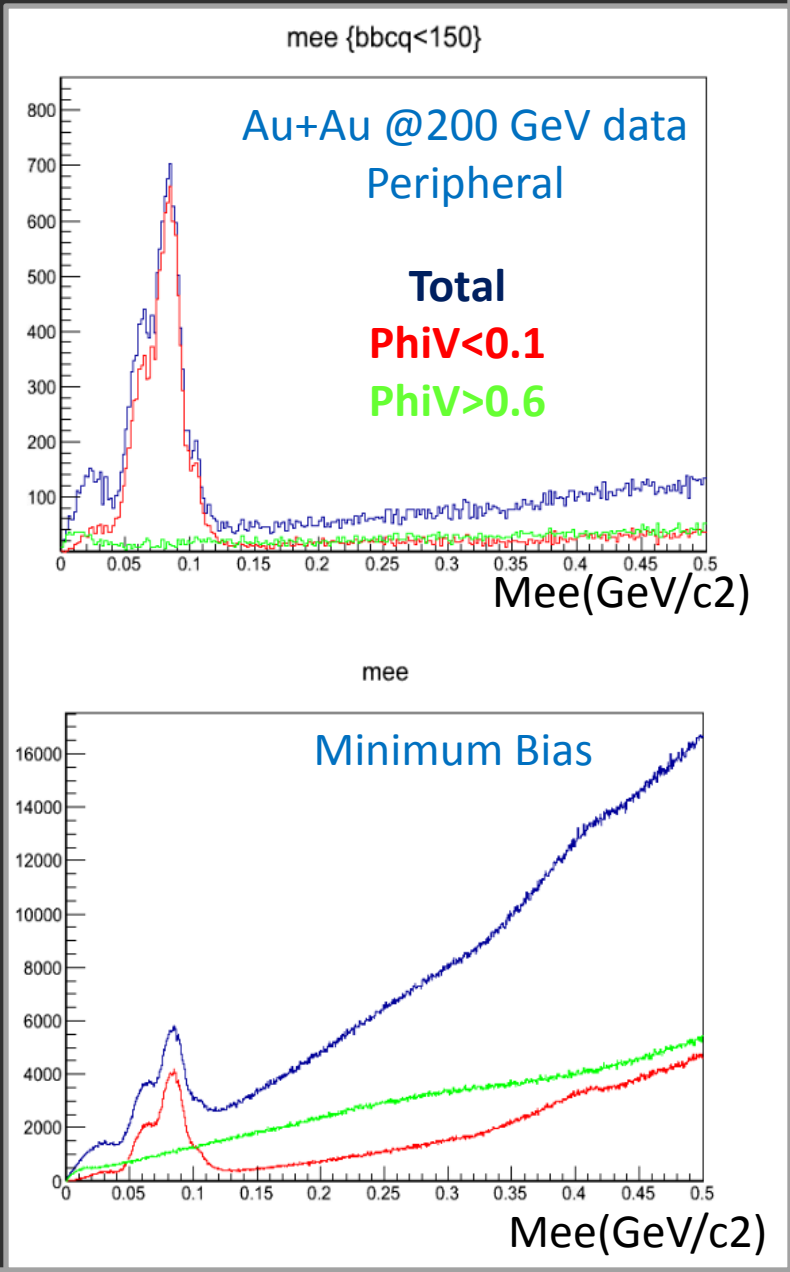
Collision System	Luminosity	L($\|z\| < 30$ cm)/Ltot	L($\|z\| < 10$ cm)/Ltot
Au+Au @ $\sqrt{s_{NN}} = 62$ GeV	400 μb^{-1}/week	45%	15%
p+p @ $\sqrt{s_{NN}} = 62$ GeV	2.1 pb^{-1}/week	23%	8%
p+Au @ $\sqrt{s_{NN}} = 62$ GeV	20 nb^{-1}/week	35%	12%

Photons via Conversion Electron Pairs

As in our Au+Au @ 200 GeV analysis, we can measure direct photons via conversion electron pairs in the VTX

Measurement of direct photon yield and possible v_2 and v_3 with early time closer to T_c is very exciting

Applying proven techniques and utilizing energy flexibility of RHIC machine (with stochastic cooling benefits too)



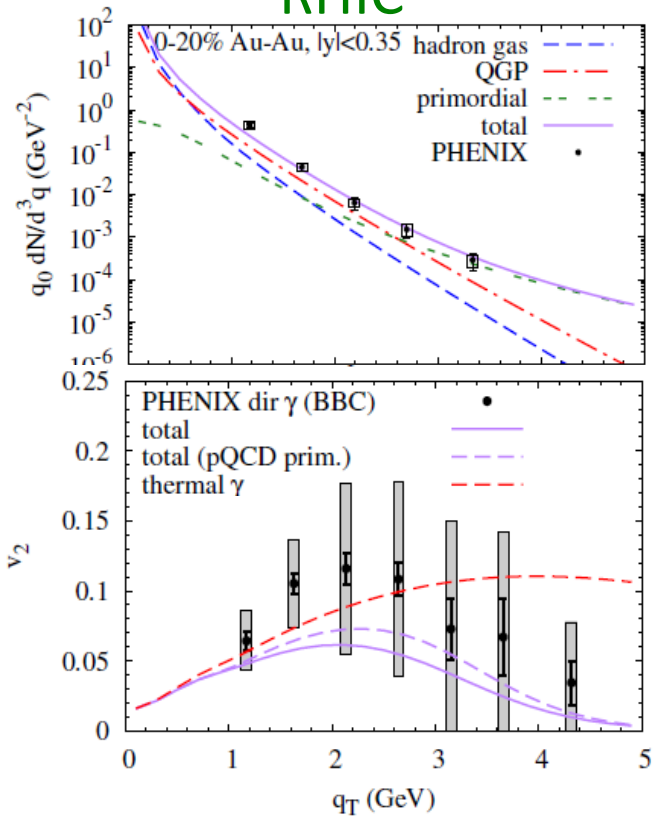
QGP Strongest coupling near T_c

Slide from Ralf Rapp at QM14

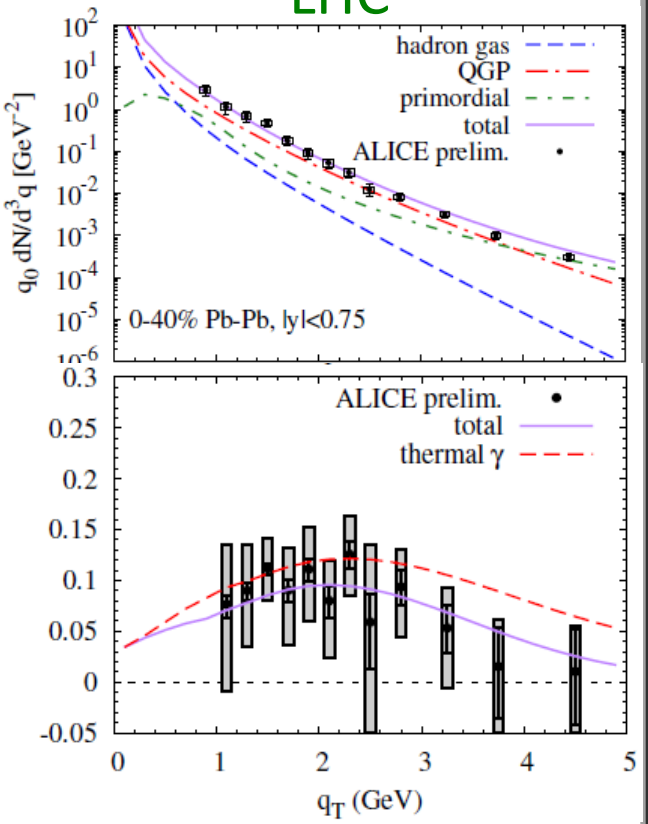
Enhanced Photon Rates in Hydro

- upscale photon rates by factor of 2, up to 3 for $T_{pc} \pm 30$MeV

RHIC

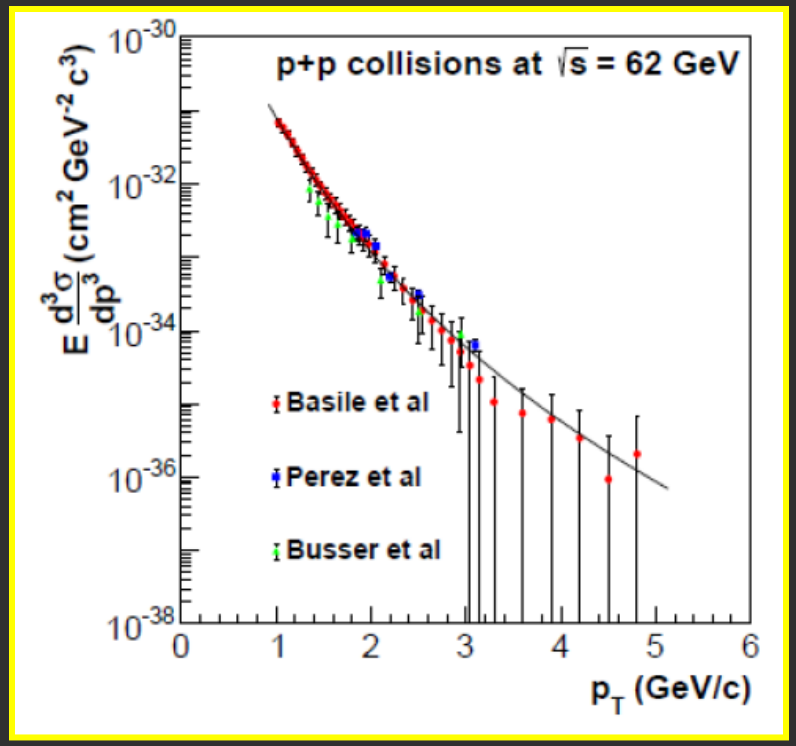


LHC



- getting close(r) to the data (more so with fireball)

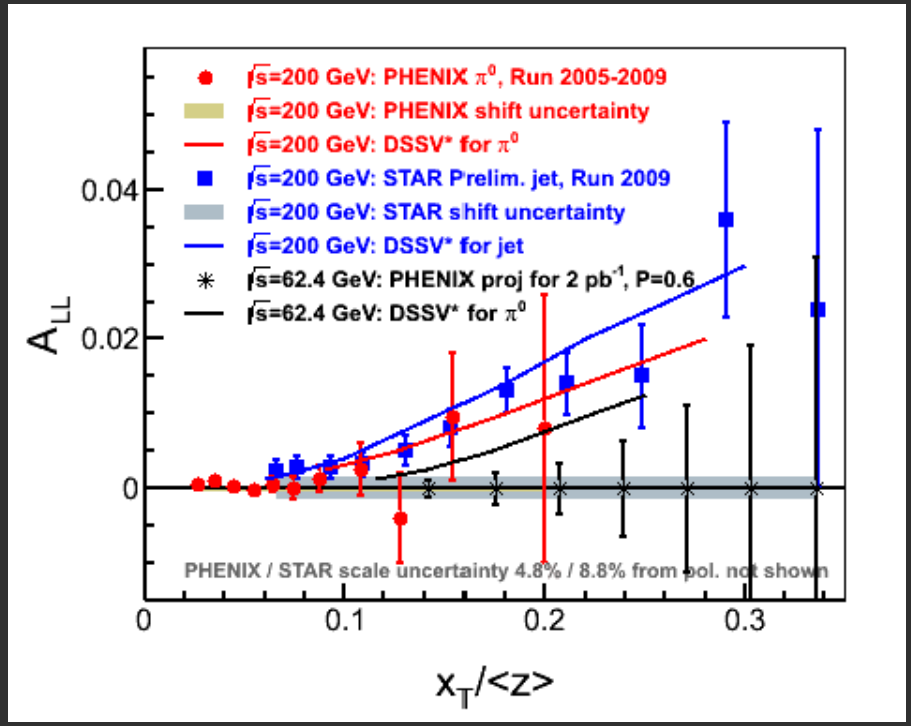
p+p @ 62 GeV



Provides critical baseline for heavy flavor and photon measurements

Also p+A @ 62 GeV would be very useful

At the same time, longitudinal polarized measurement of π^0 A_{LL} would provide check in same kinematics of STAR positive jet A_{LL}



Run-16 Alternative Considerations (I)

PHENIX considered more Au+Au @ 200 GeV running

No new detector capabilities

Run-14 has been so successful, hard to beat

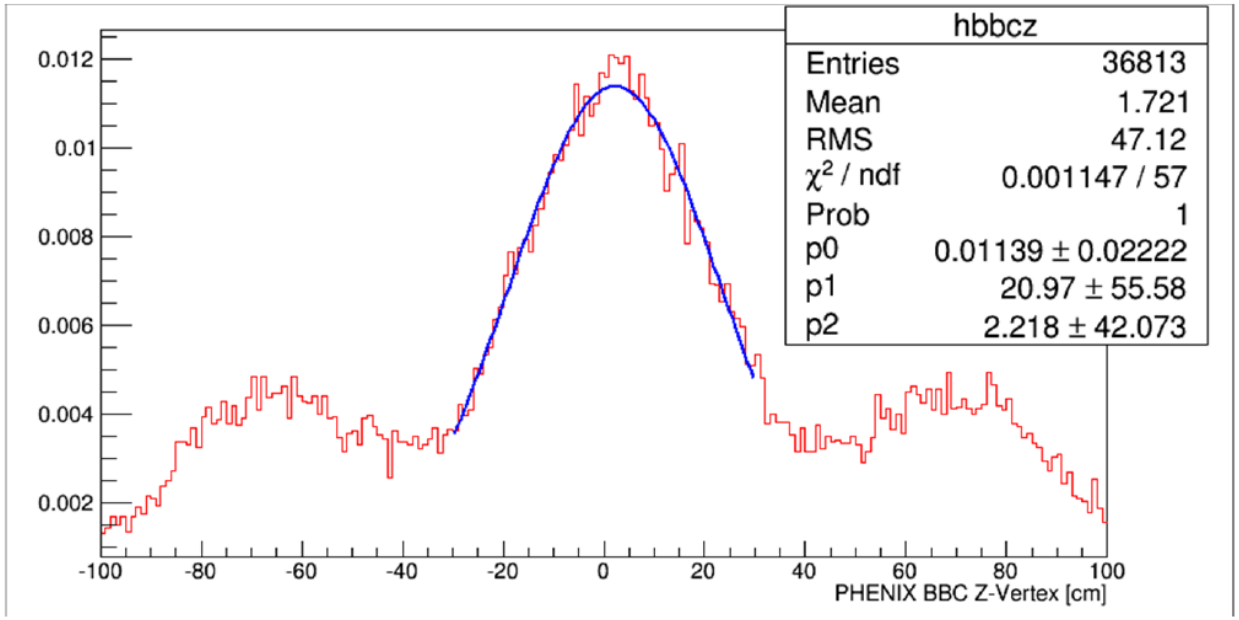
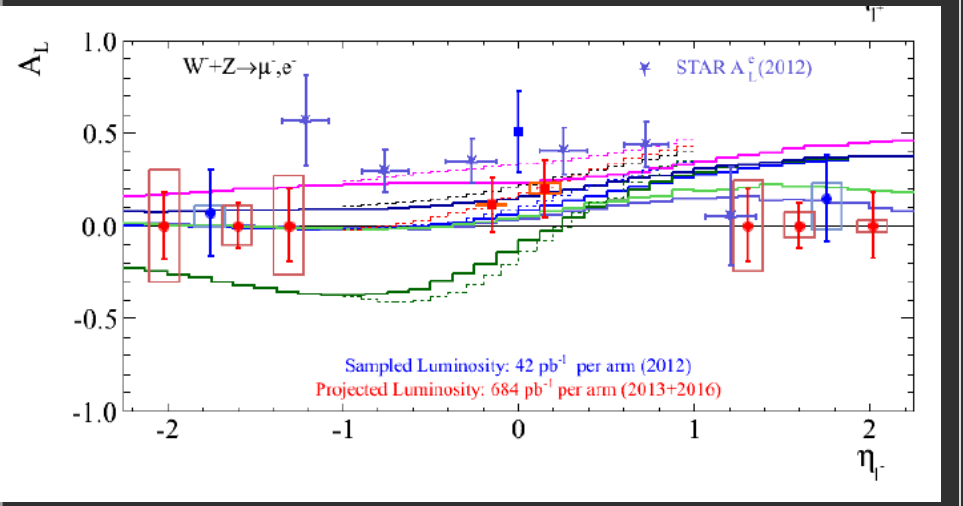


Figure 3.15: Run-14 Au+Au z-vertex distribution.

In optimistic scenario with 10 weeks, one might increase our statistics by 150%

Run-16 Alternative Considerations (II)

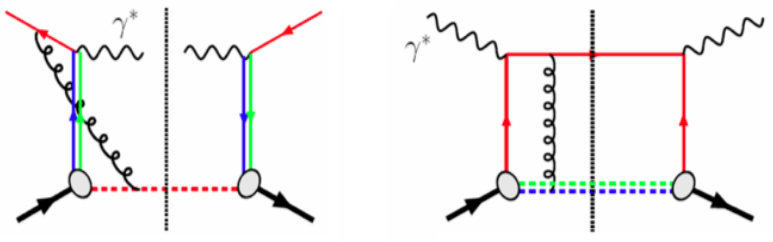
p+p @ 500 GeV Longitudinal



Not clear non-dedicated run would significantly add to the measurement

MUID Efficiency dropping at highest luminosities

p+p @ 500 GeV Transverse



$p^\uparrow + p \to [\gamma^* \to \ell^+\ell^-] + X$

DY: repulsive

$\ell + p^\uparrow \to \ell + \pi + X$

SIDIS: attractive

$$\Delta^N f_{q/h^\uparrow}^{\mathrm{SIDIS}}(x, k_\perp) = -\Delta^N f_{q/h^\uparrow}^{\mathrm{DY}}(x, k_\perp)$$

Possible Low-mass DY measurement with sufficient significance

Lots of debate about meaning of low-mass DY at higher p_T (where better S/B)

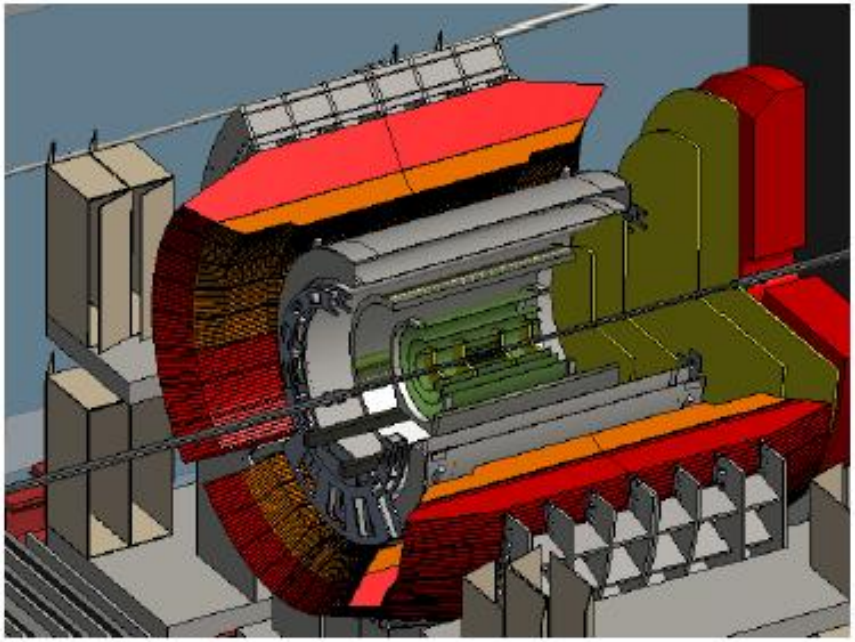
Bright Physics Future

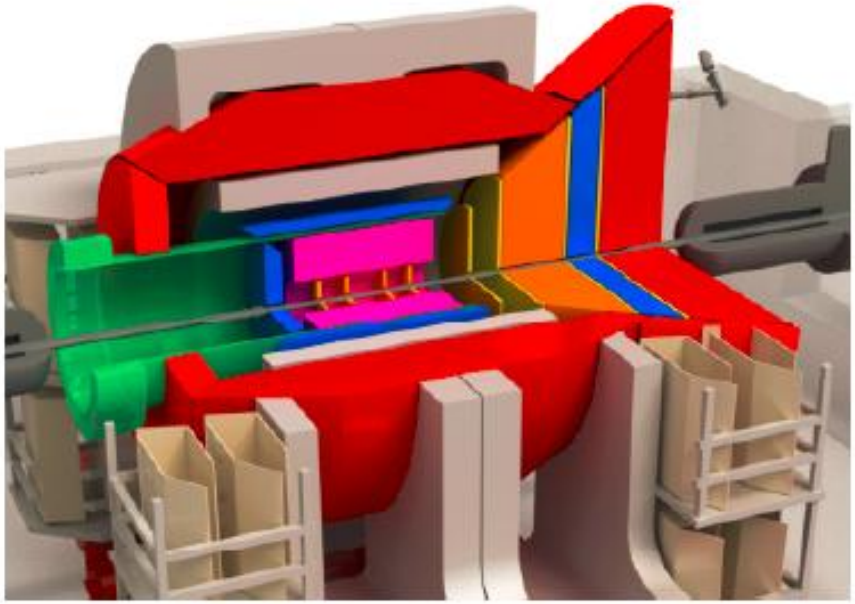
sPHENIX moving forward

Acquired 1.5 T BaBar magnet

Excellent jet, dijet, γ-jet, h-jet, quarkonia capabilities

DOE Science Review in July 2014





Excitement about Electron-Ion Collider

BaBar magnet and sPHENIX calorimetry are excellent foundation for an EIC Detector

arXiv:1402.1209

PHENIX BUP Summary

- Outstanding C-AD delivered performance in Run-14

- Exciting physics program for Run-15 and Run-16

- Running periods need to be sufficient to make definitive measurements and to take full advantage of the unique capabilities at RHIC

- Request emphasizes the truly unique RHIC capabilities to provide definitive new insights

- Bright future with sPHENIX and EIC on the horizon

EXTRAS

Run-15 PHENIX Proposal - Details

1 week cool-down
1 week setup p+p
1 week ramp up p+p
9 weeks data
1 week setup p+Au
1 week ramp up p+Au
5 weeks data p+Au [also switch to Au+p]
0.5 week switch/setup p+Si
2 week data (p+Si)
0.5 week warm-up → 22 cryo weeks

- C-AD possible constraint on only p+A in Run-15
- BUP draft expresses concern and need to maintain flexibility to ensure MPC-EX results and to follow the physics
- BUP assumes we run He3+Au at the end of this run

How did we calculate 12 weeks Au+Au for 1.5 nb^{-1} recorded by PHENIX within |z| < 10 cm. (VTX/FVTX optimal acceptance)

Physics driven goal (set by desire to decompose charm and beauty contributions over a wide p_T range).

Low to moderate p_T electrons/muons come from minimum bias data sample (no Level-1 trigger selection).

Excellent DAQ bandwidth 5 kHz even with silicon detectors.

Thus, the key is running time and luminosity exceeding 5 kHz for |z|< 10 cm (mostly true with current projections)

Evts / week = 5000 x 60x60x24x7 x 0.7 x 0.55 = 1.16 B = 0.17 nb^{-1}/wk

Note 0.7 (PHENIX Uptime), 0.55 (RHIC Uptime)

Thus, it *might* only take 9 weeks to achieve this goal.

However, there is some ramp-up time for luminosity to exceed the 5 kHz DAQ bandwidth. There is also some vertex trigger resolution.

Based on past experience, scale luminosity/wk x 0.75

and that gives the 12 week request.

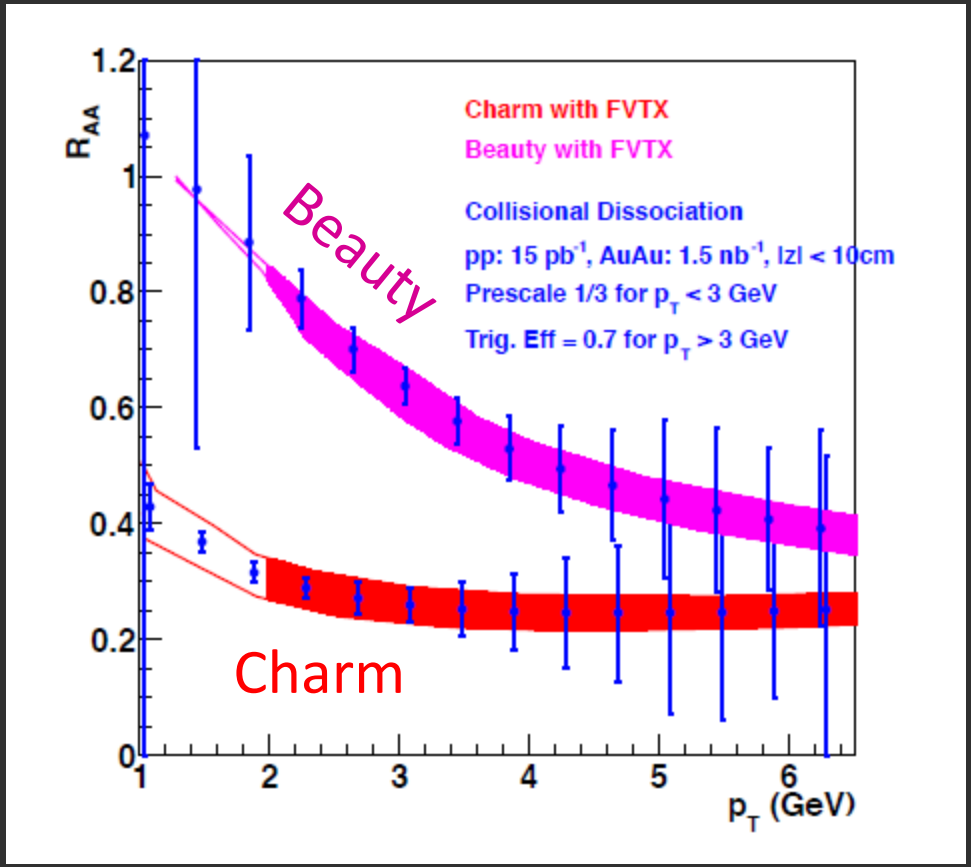
Run-14 Au+Au @ 200 GeV Request

1.5 nb^{-1} request is driven by charm / beauty physics

FVTX first Au+Au data set

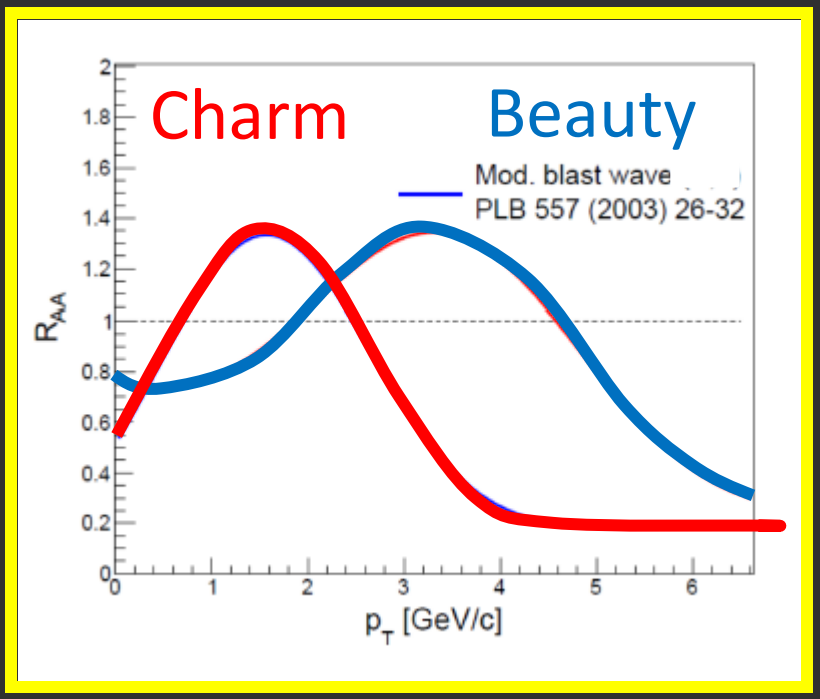
Example projected uncertainties in collisional dissociation model

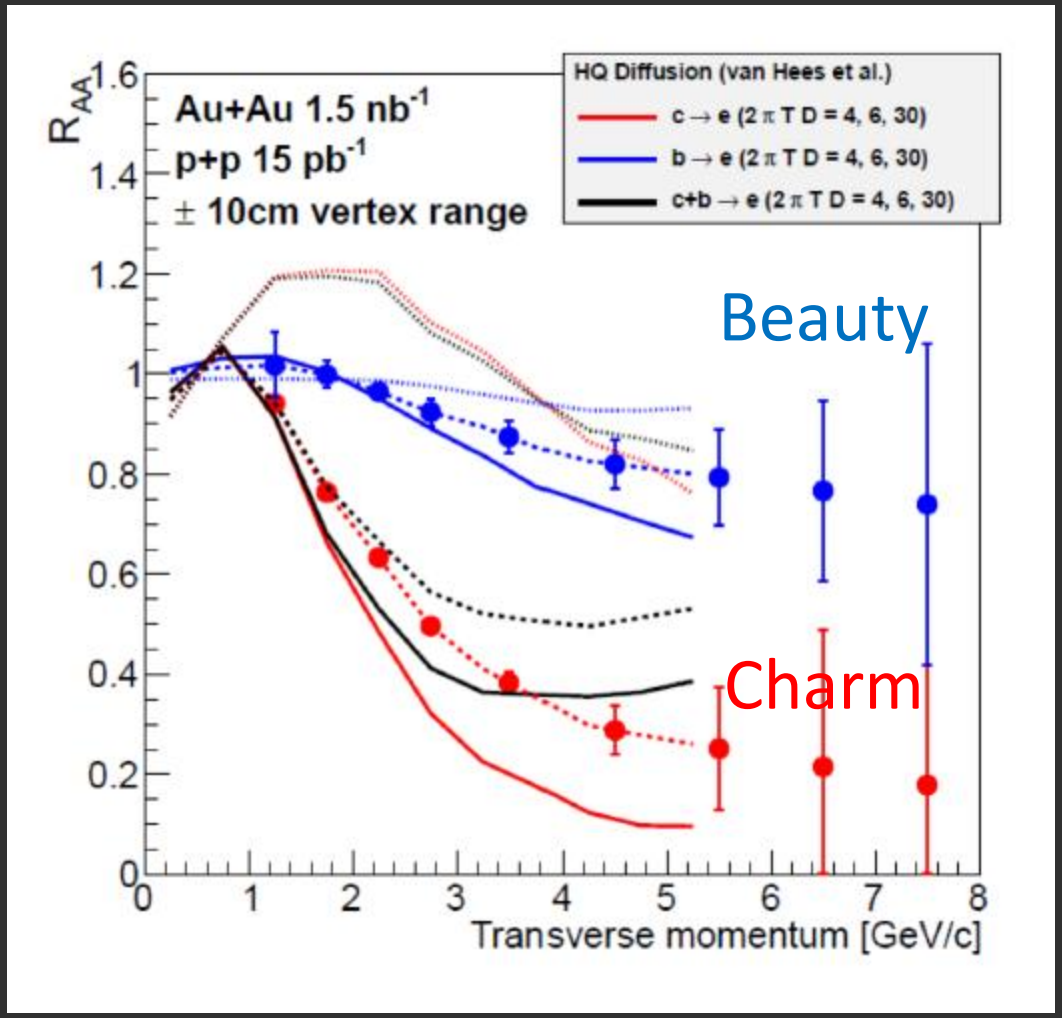
Bands include unfolding systematic uncertainties



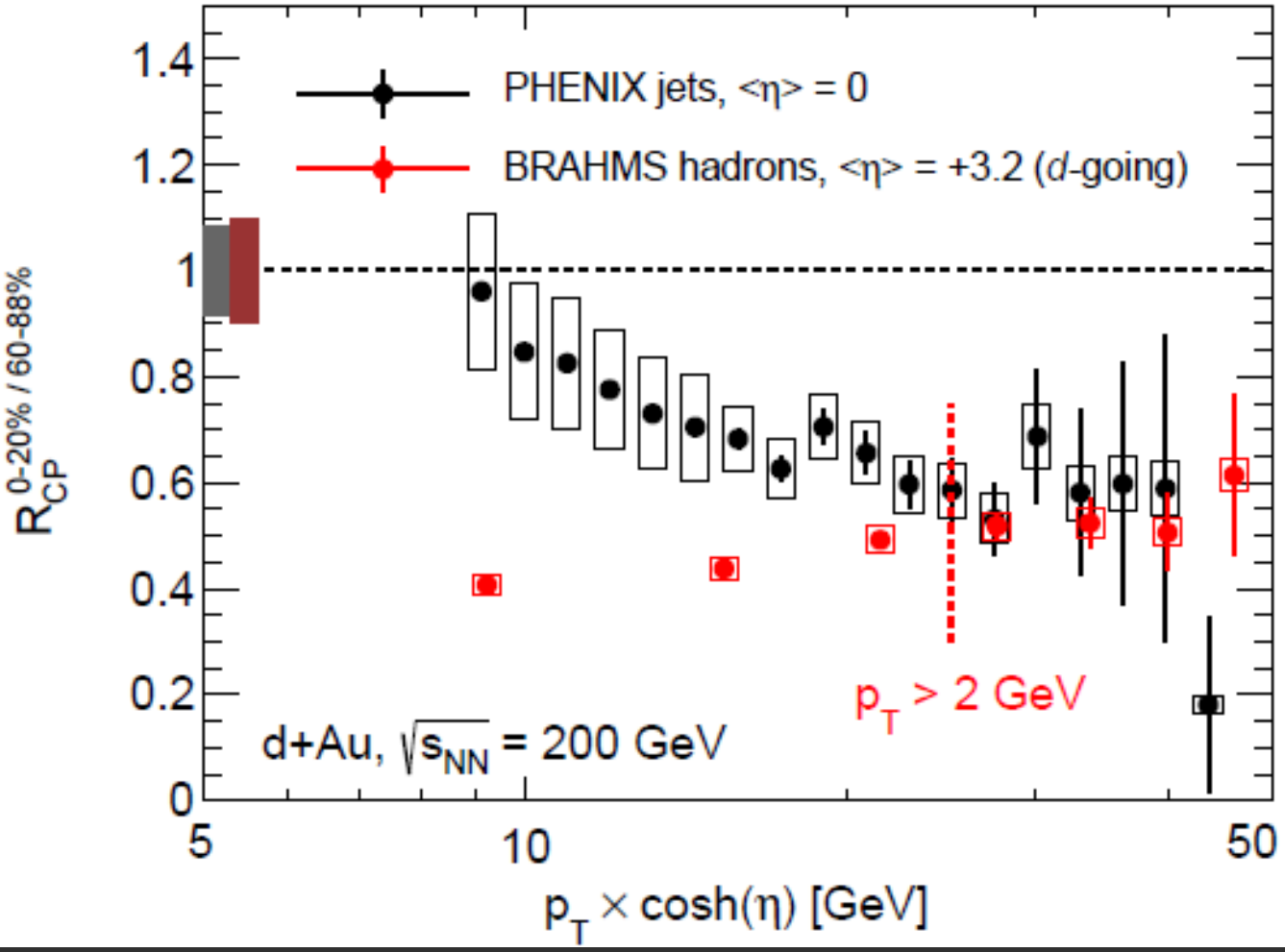
12 weeks is our estimate to obtain the physics driven goal

VTX projected uncertainties and sensitivity relative to heavy quark diffusion parameter



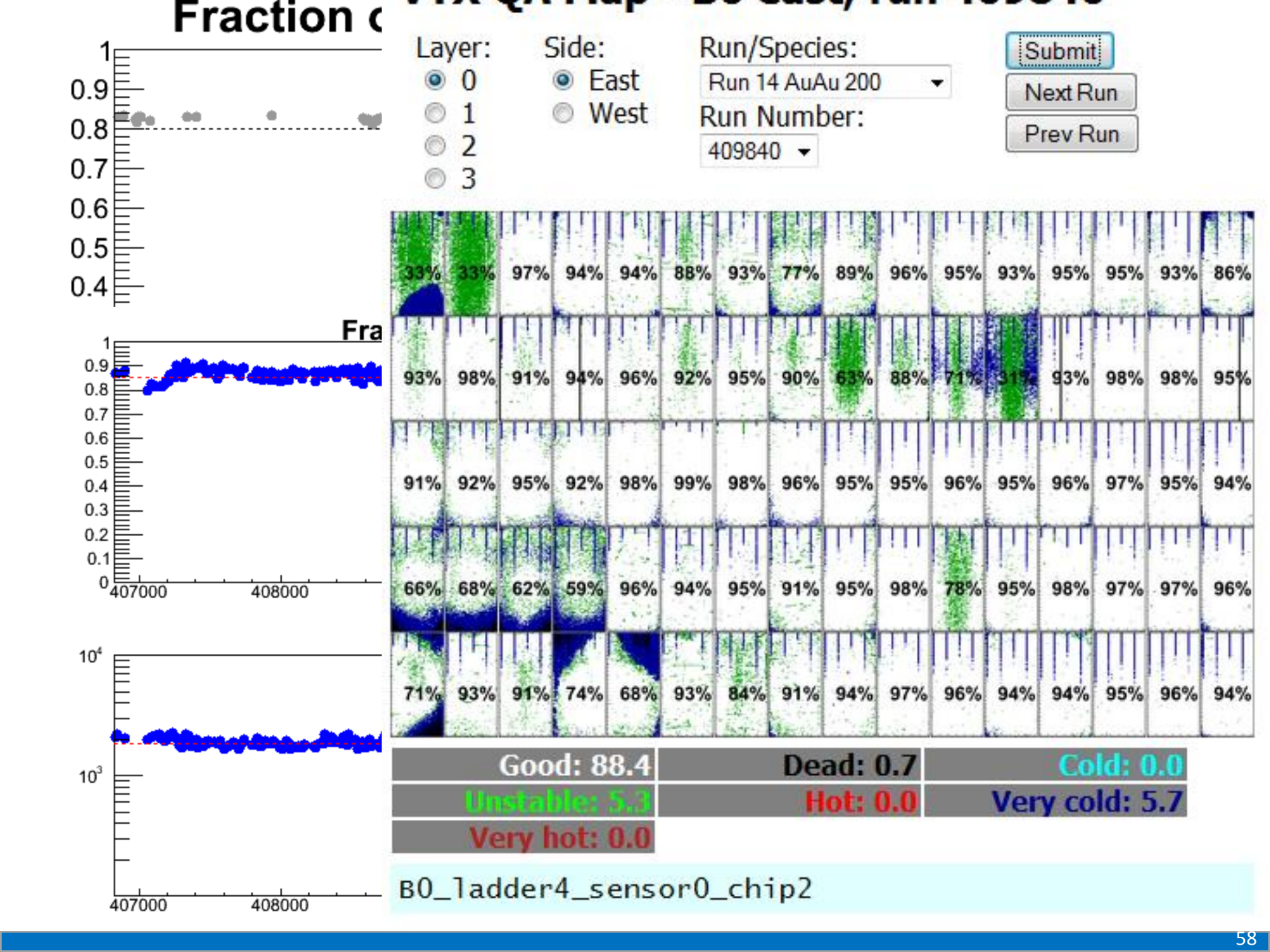


In extreme scenario of beauty quarks following flow field, very different prediction

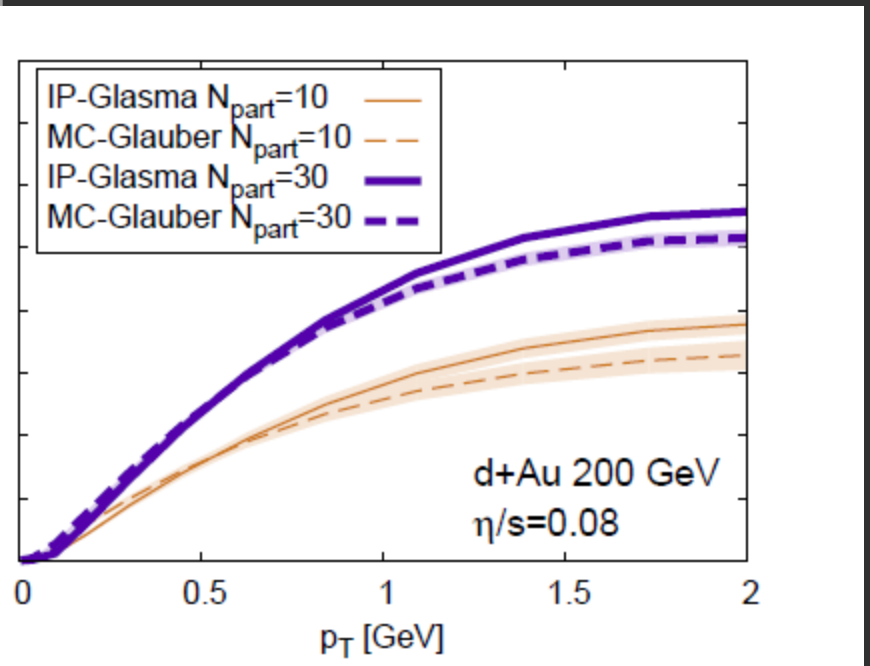


10.1016/j.nuclphysa.2013.02.184

nucl-ex/0403005


Fraction
Layer:
0
1
2
3
Side:
East
West
Run/Species:
Run 14 AuAu 200
Run Number:
409840
Submit
Next Run
Prev Run
Fra
407000
408000
407000
408000
Good: 88.4
Dead: 0.7
Cold: 0.0
Unstable: 5.3
Hot: 0.0
Very cold: 5.7
Very hot: 0.0
B0_ladder4_sensor0_chip2

Can a nearly inviscid fluid be created i



Color online) $v_2(p_T)$ for charged hadrons in d+Au
fixed $N_{\rm part} = 10$ (thin lines) and 30 (thick lines)
Glauber (dashed) and IP-Glasma (solid) model.

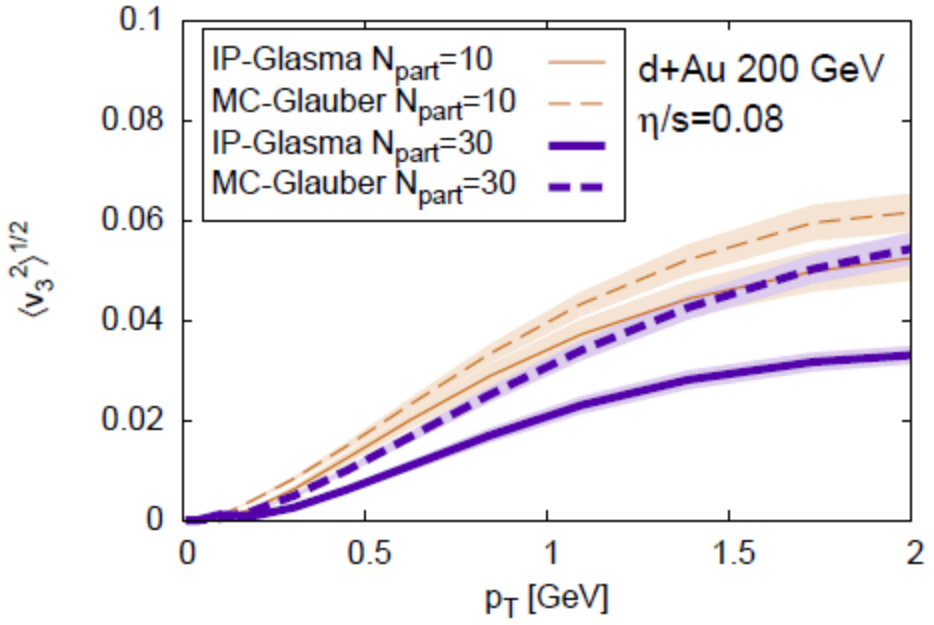
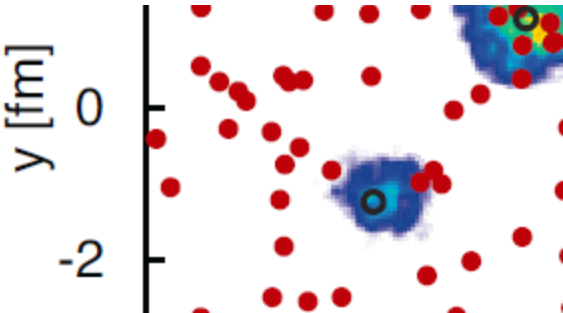
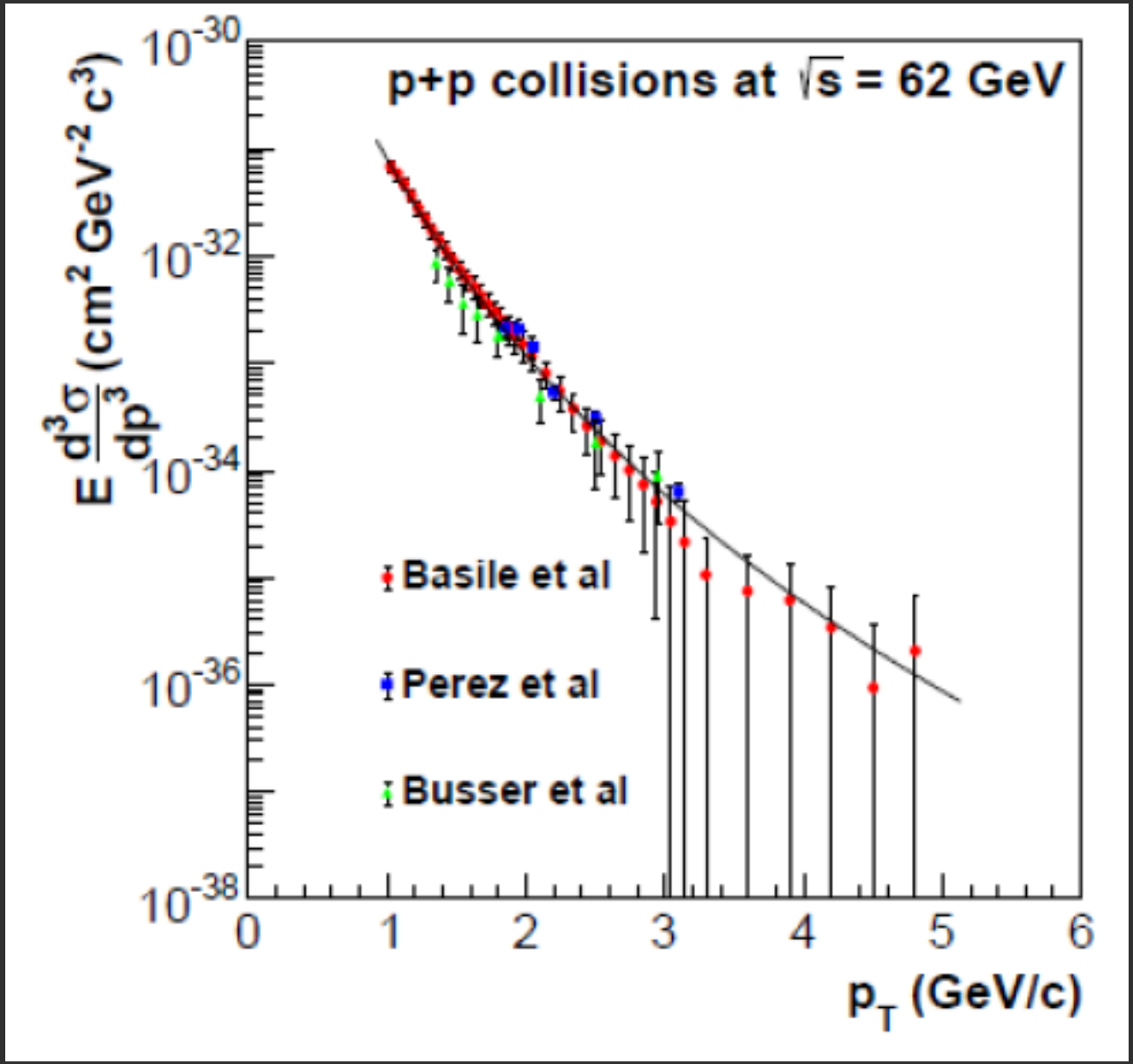


FIG. 11. (Color online) $v_3(p_T)$ for charged hadrons in d+A
collisions at fixed $N_{\rm part} = 10$ (thin lines) and 30 (thick line
in the MC-Glauber (dashed) and IP-Glasma (solid) model.

LHC has highest parton densi

RHIC has unique access to geometr




p+p collisions at √s = 62 GeV
$E\frac{d^3\sigma}{dp^3}$ (cm^2 GeV^{-2} c^3)
10^{-30}
10^{-32}
10^{-34}
10^{-36}
10^{-38}
0
1
2
3
4
5
6
p_T (GeV/c)
Basile et al
Perez et al
Busser et al