PHENIX Beam Use Proposal Run-14 and Run-15

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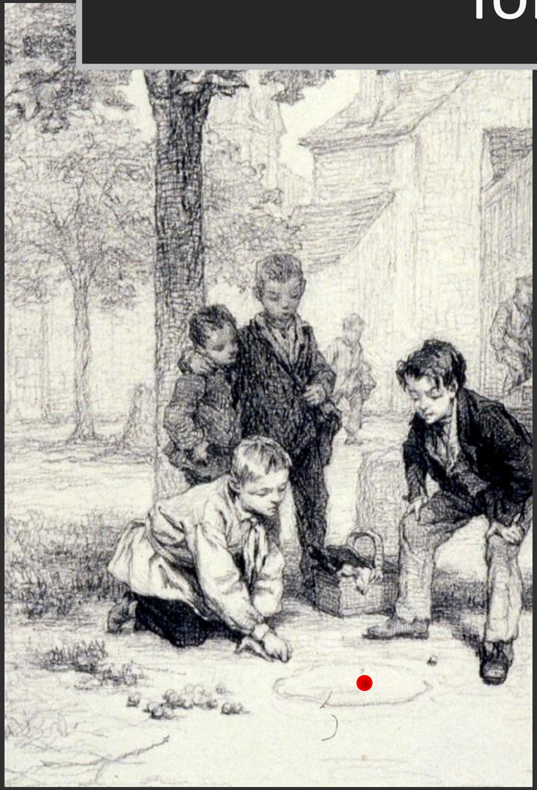
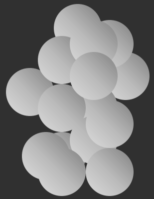
for the PHENIX Collaboration



Curiosity driven program…

Quantitative assessments…

Taking maximal advantage of RHIC uniqueness and versatility



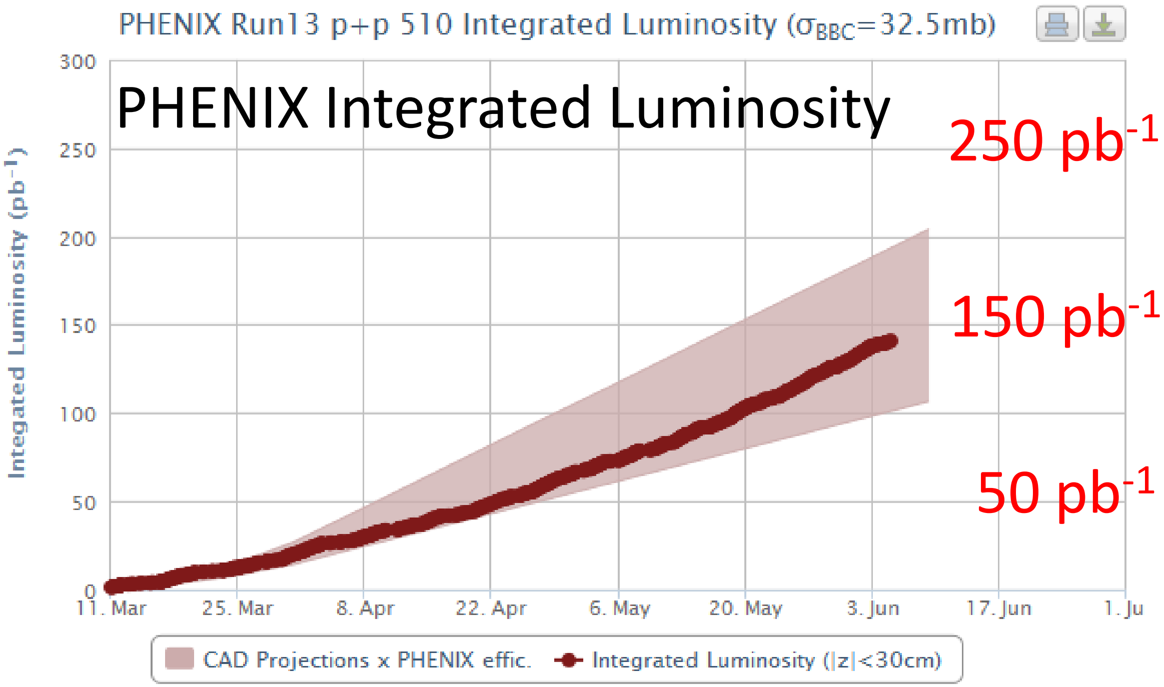
Run-13 Report

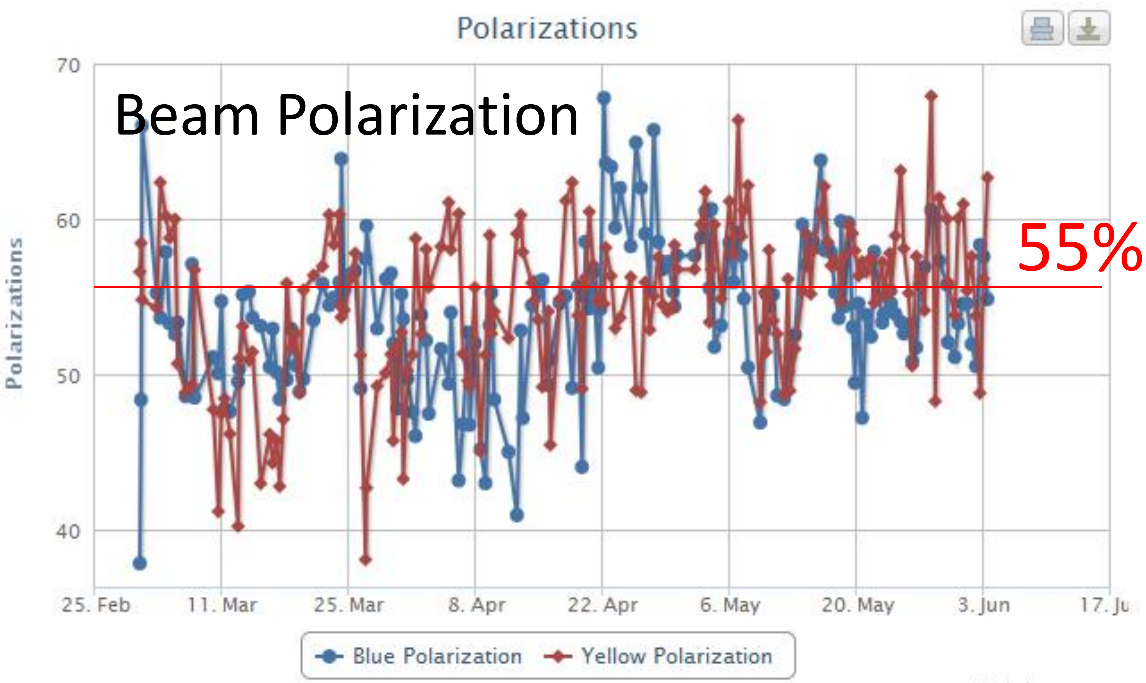
Last year, PAC recommended highest priority was to integrate sufficient luminosity for p+p @ 500 GeV for a definitive W measurement (750 pb^{-1} delivered)

Note that this translates into 250 pb^{-1} sampled by PHENIX within $|z|<30$ cm

The entire Run-13 has been p+p @ 500 GeV following the PAC guidance

Multiple machine / polarization issues early on… Goal seemed very far away, and then some key breakthroughs and an extension of the run



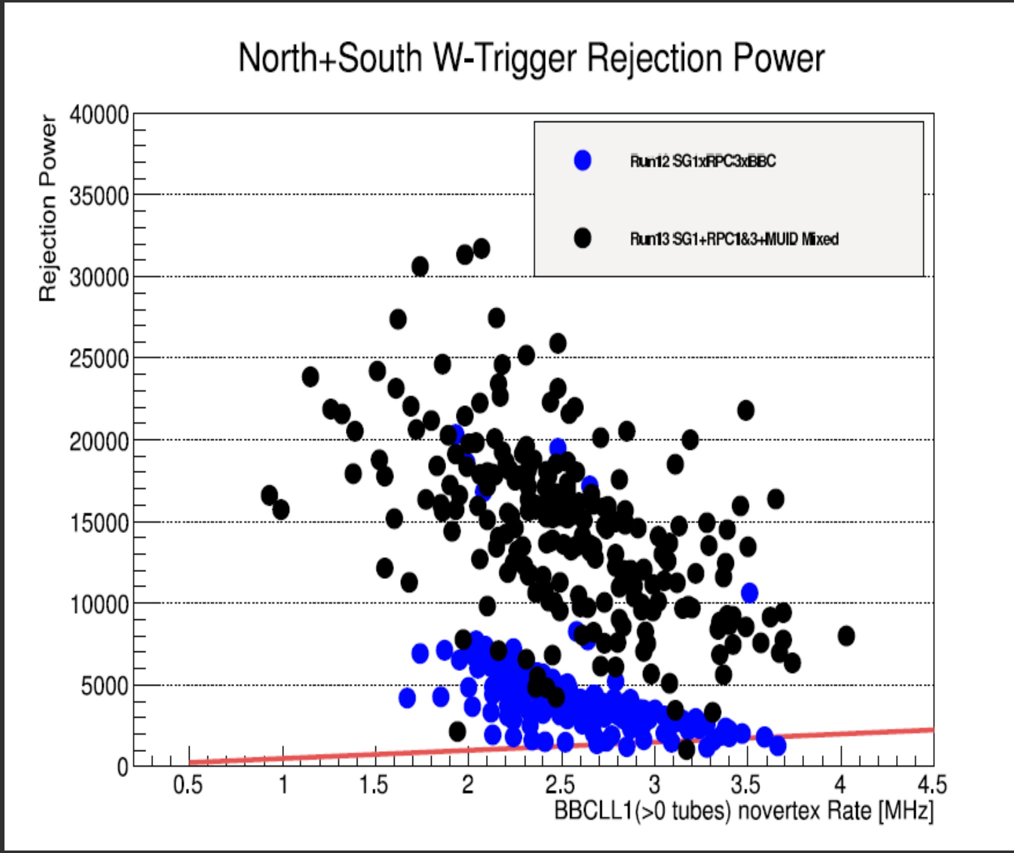


Early May, polarization issues had been largely resolved and luminosities delivered were nearing or exceeding CA-D projected maximum values.

More modest goal of 150 pb^{-1} was set (compare to 250 pb^{-1}) **and ~150 pb^{-1} is now on tape!**

PHENIX Detector Performance in Run-13

- W→μ trigger now fully implemented and gave more than sufficient rejection for full luminosity sampling
- High DAQ livetime > 90%
- Good PHENIX uptime ~ 70%
- FVTX working very well and demonstrated benefit for W background rejection



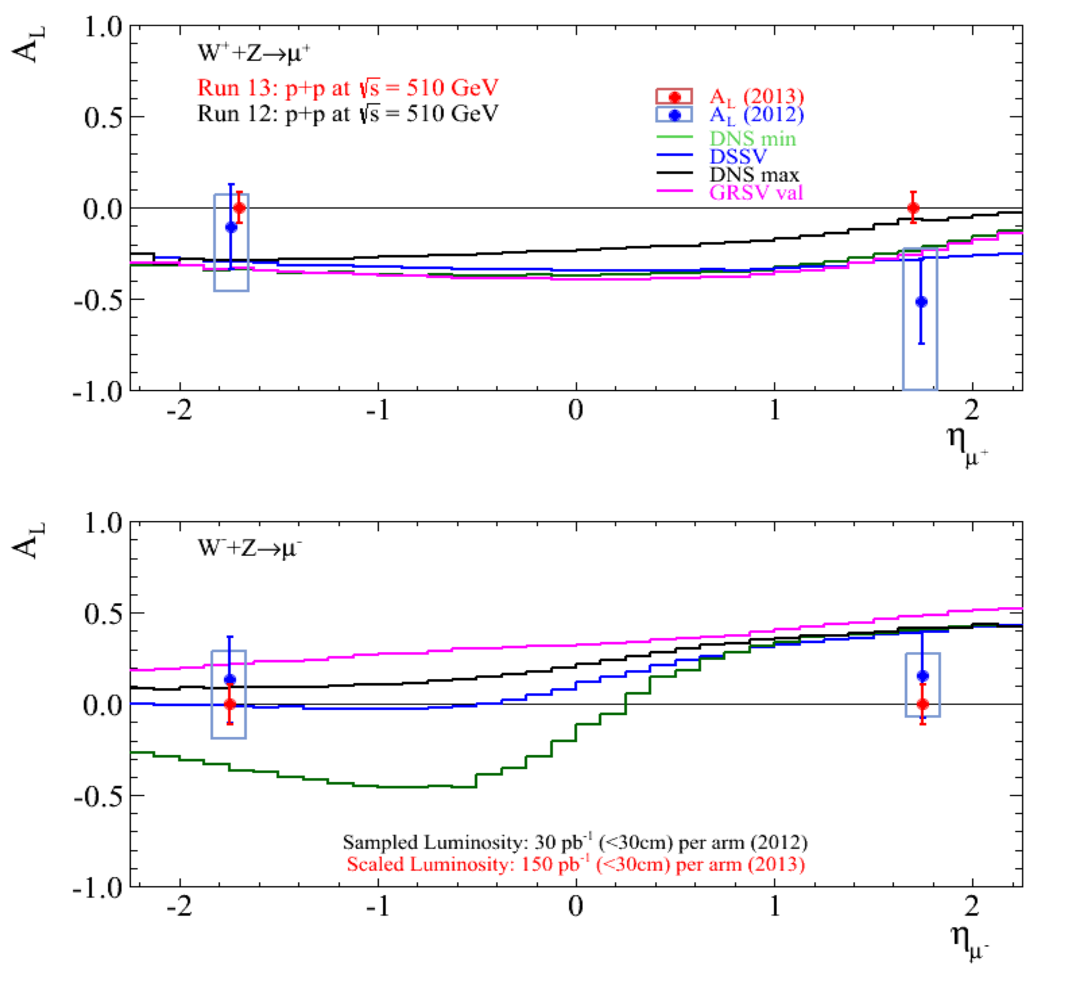
Major problem with VTX cooling leak.
Since not critical for p+p @ 500 GeV physics goals, decision to remove and maximize time for readiness in Run-14.

Producing W→μ data set is nearly real-time.
Full data set production expected to be finished in 2-3 weeks.

One month long SpinFest at RIKEN in July 2013 is planned and expect first look at full statistics physics result.

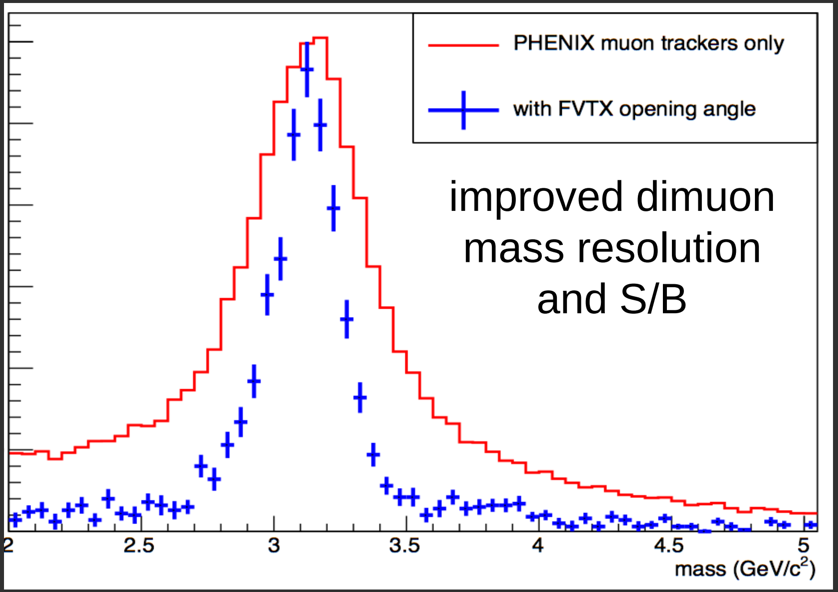
Conservative S/B projected uncertainties from Run-13 150 pb^{-1}

We are very hopeful that the PHENIX and STAR data combined will result in exciting new insights on the u(ubar), d(dbar) spin contributions

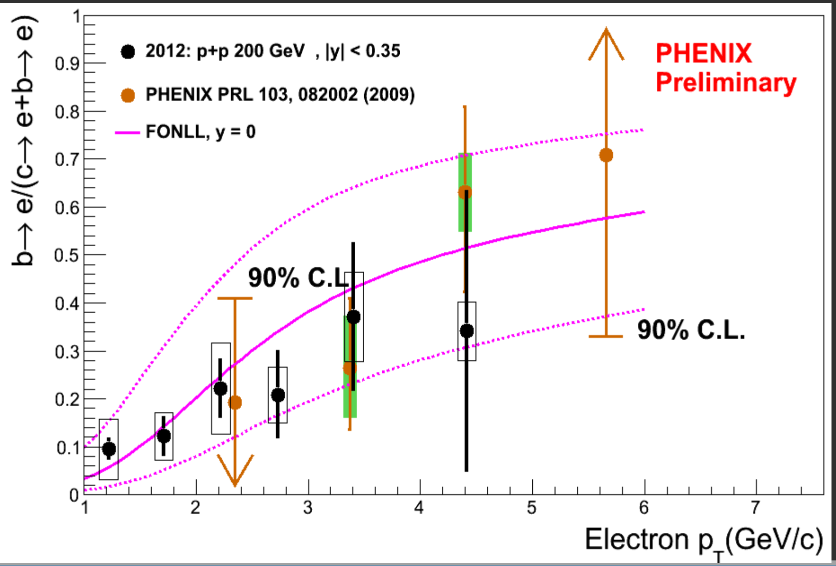


Run-14/15 Key Detector Upgrades (Silicon Vertex Detectors)

- FVTX (forward rapidity) commissioning run in Run-12
- > 96% live active area
- Fast analysis results indicate performance exceeding specifications
- Displaced vertex results for open heavy flavor from Run-12 Cu+Au expected soon



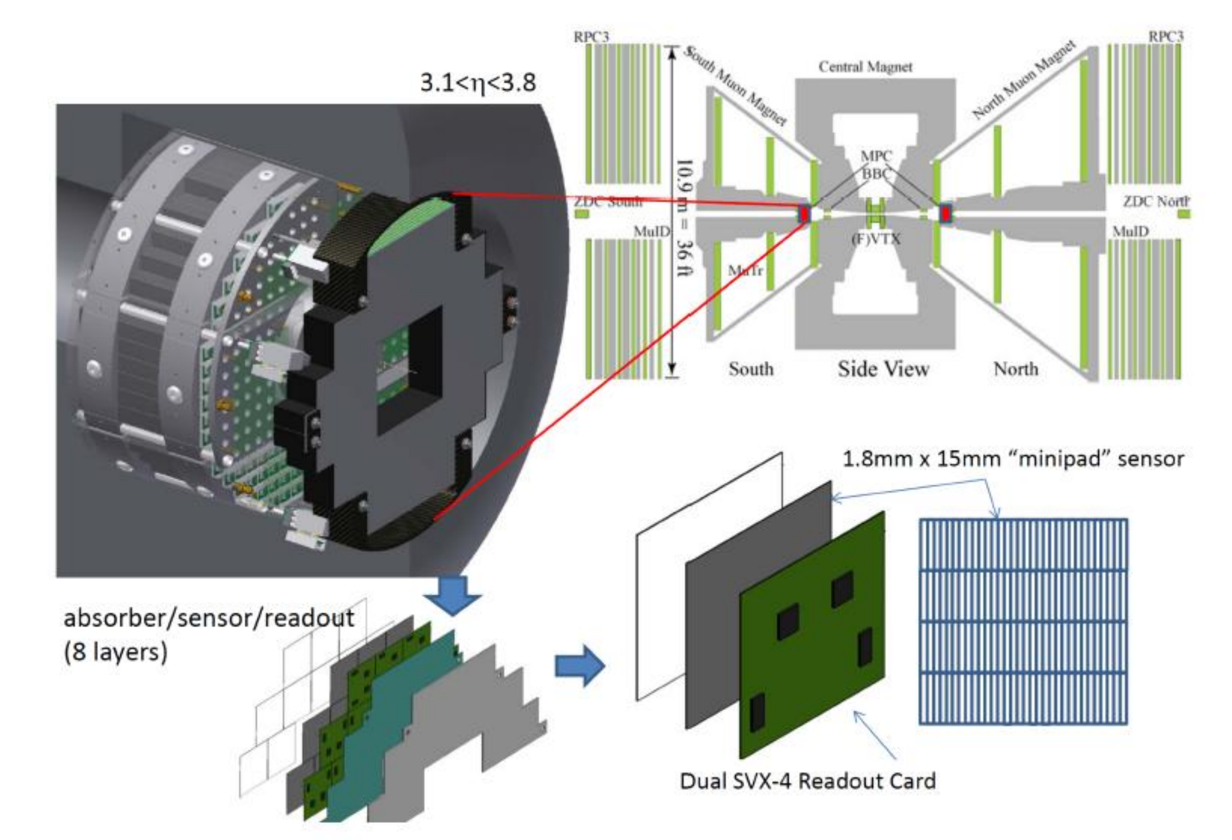
- VTX commissioning run in Run-11
- Preliminary p+p charm/beauty results
- Significant detector performance issues have slowed progress
- Repair plans in place for Run-14 readiness



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

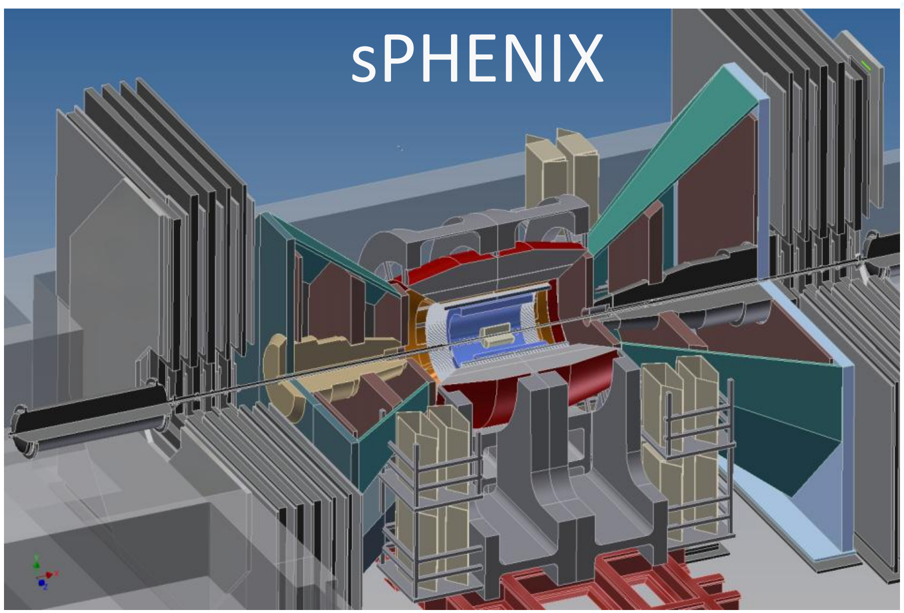


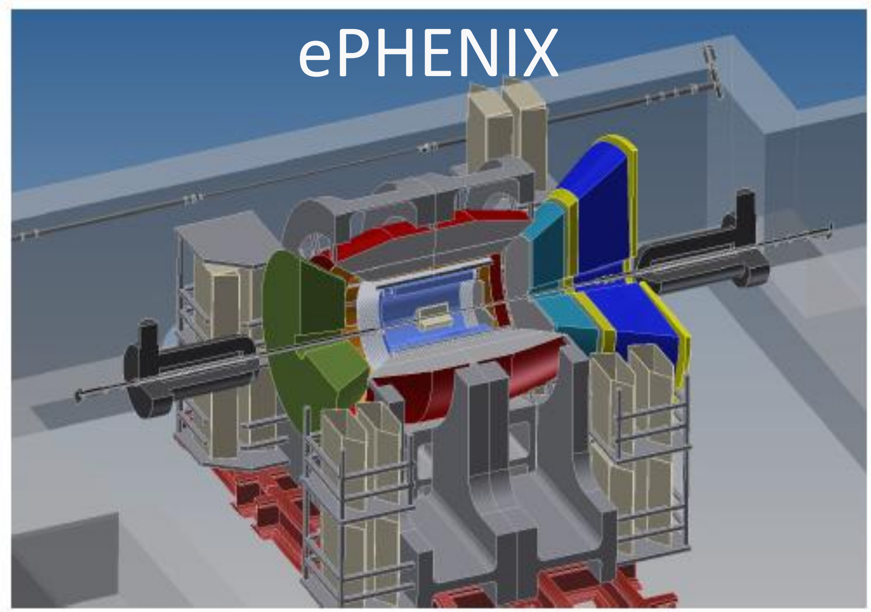
Beam test in fall, and section available for integration tests in Run-14

Full detector available for physics in Run-15

sPHENIX & ePHENIX

- Major changes in PHENIX detector
- Greatly increased acceptance (x20-50 in many channels) and key new detector capabilities
- Some current PHENIX capabilities no longer available after 2016 – 2017…





Brookhaven Lab Timeline

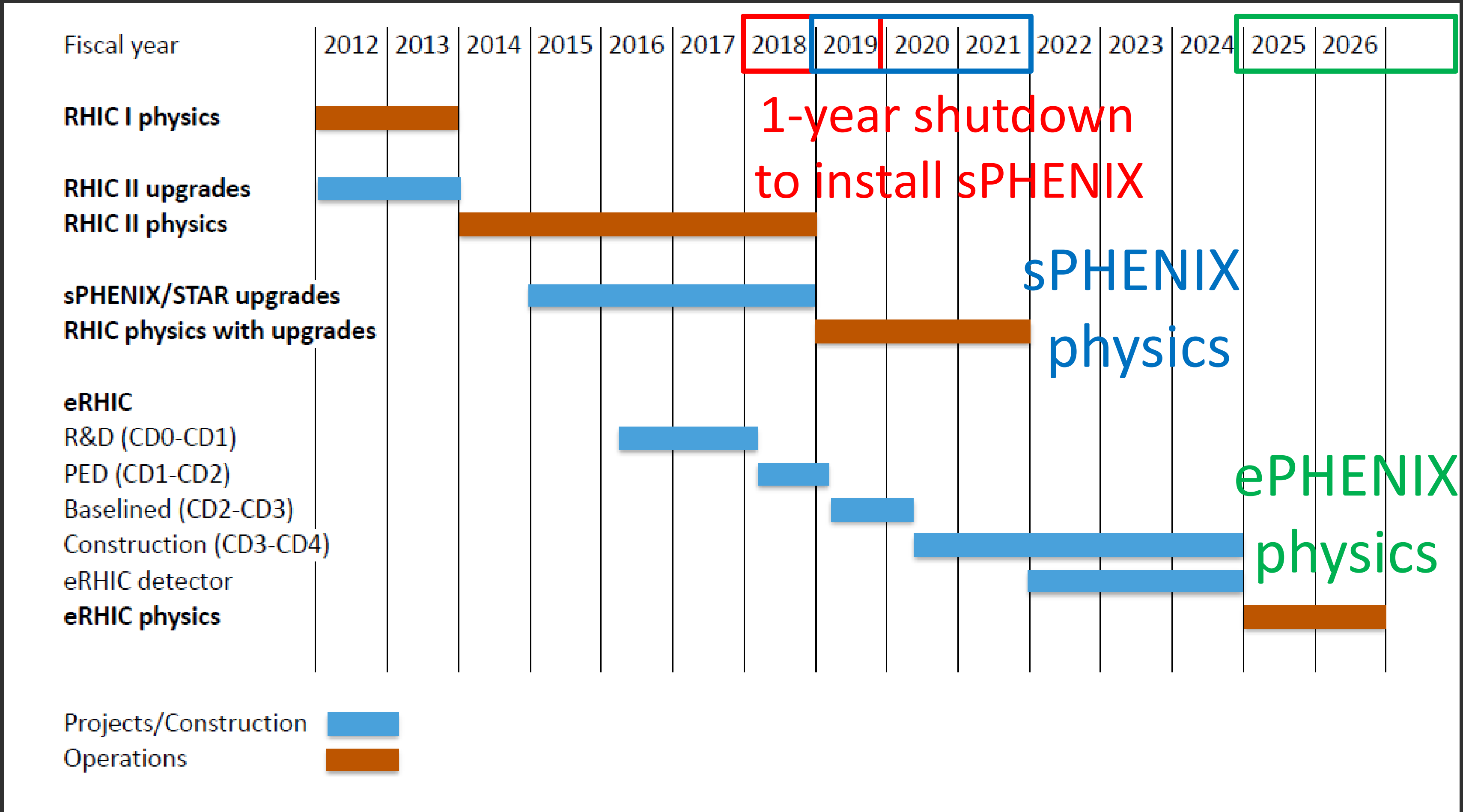


Figure 1: Official BNL timeline through the mid-2020s, including a transition to eRHIC.

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

Run-14 Request

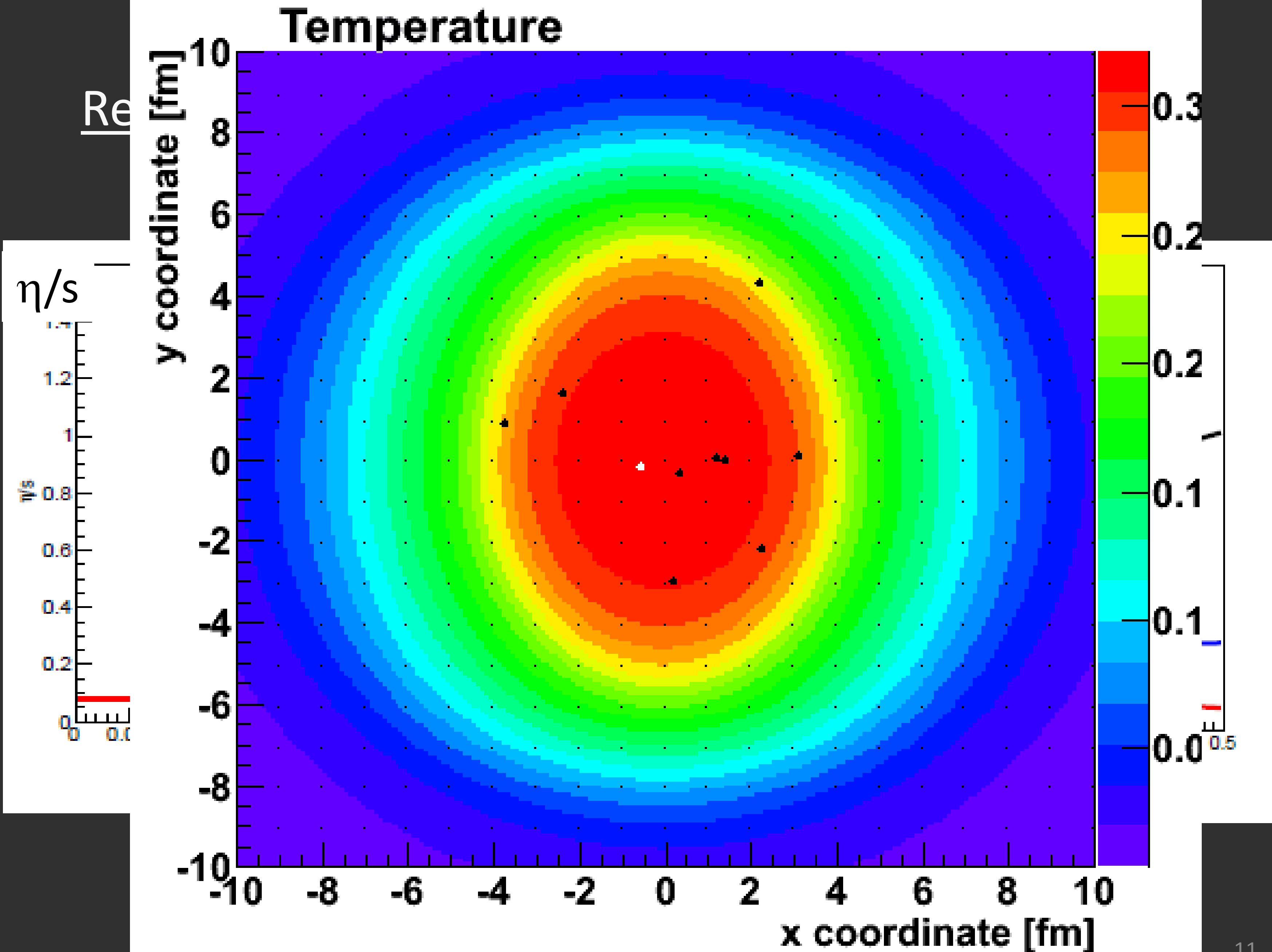
Run-14 Proposal (22 cryo-weeks)

- Au+Au @ 200 GeV for 12 weeks [Physics driven goal is 1.5 nb^{-1} recorded within $|z| < 10$ cm]
- $p+p$ @ 200 GeV with longitudinal polarization for 6.5 weeks [Physics driven goal is 30 pb^{-1} sampled within $|z| < 30$ cm and $\langle \mathcal{P} \rangle = 60\%$]

In the scenario of only 15 cryo-weeks, we would only be able to run Au+Au @ 200 GeV

Re

η/s



Temperature
y coordinate [fm]
x coordinate [fm]
10
8
6
4
2
0
-2
-4
-6
-8
-10
-10
-8
-6
-4
-2
0
2
4
6
8
10
0.3
0.2
0.2
0.1
0.1
0.0

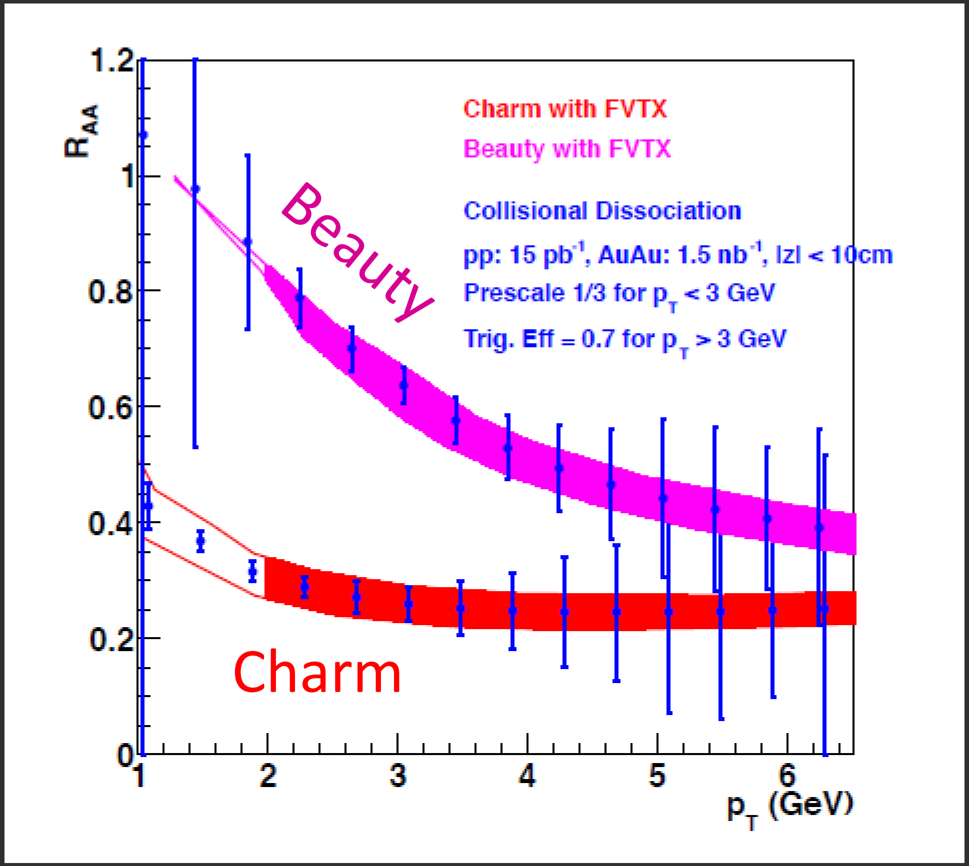
Run-14 Au+Au @ 200 GeV Request

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

FVTX first Au+Au data set

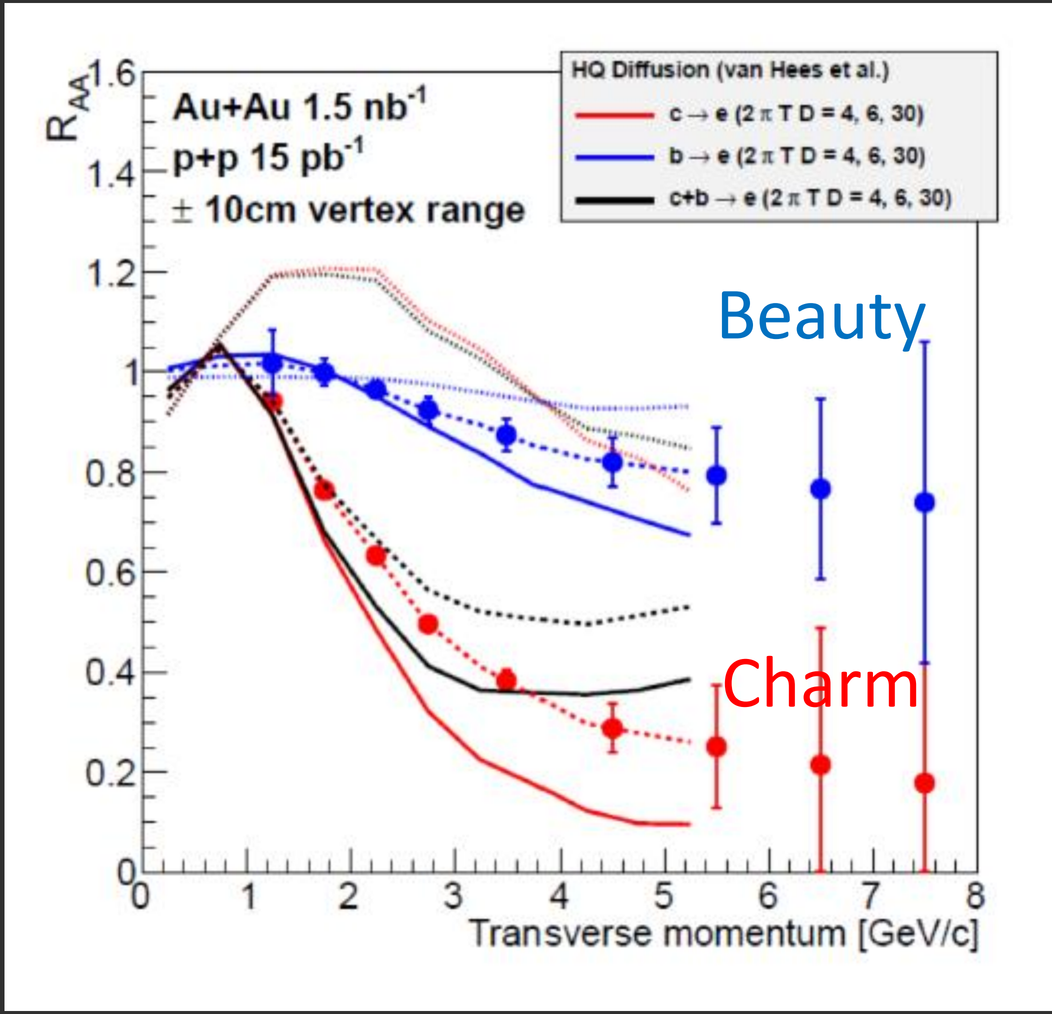
Example projected uncertainties in collisional dissociation model

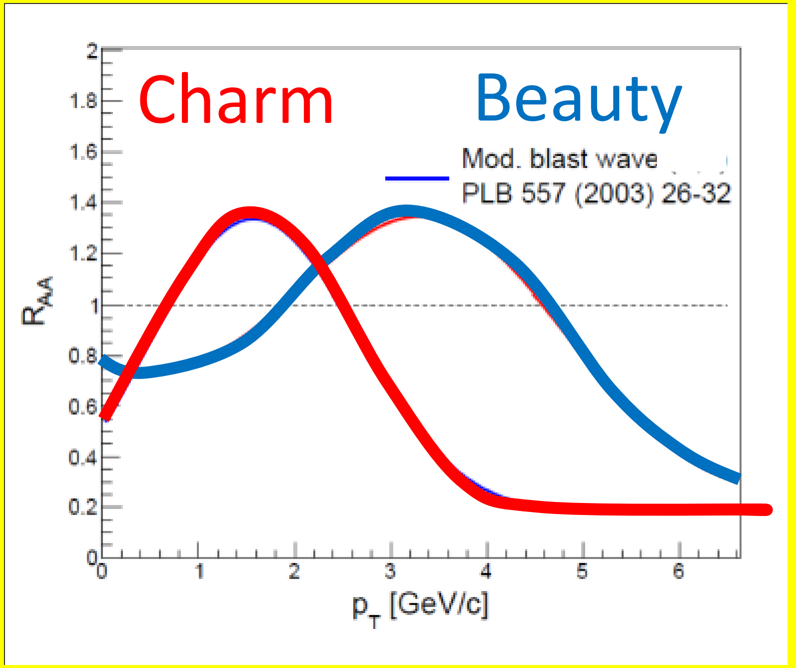
Bands include unfolding systematic uncertainties



12 weeks is our estimate to obtain the physics driven goal (see backup slides for full details)

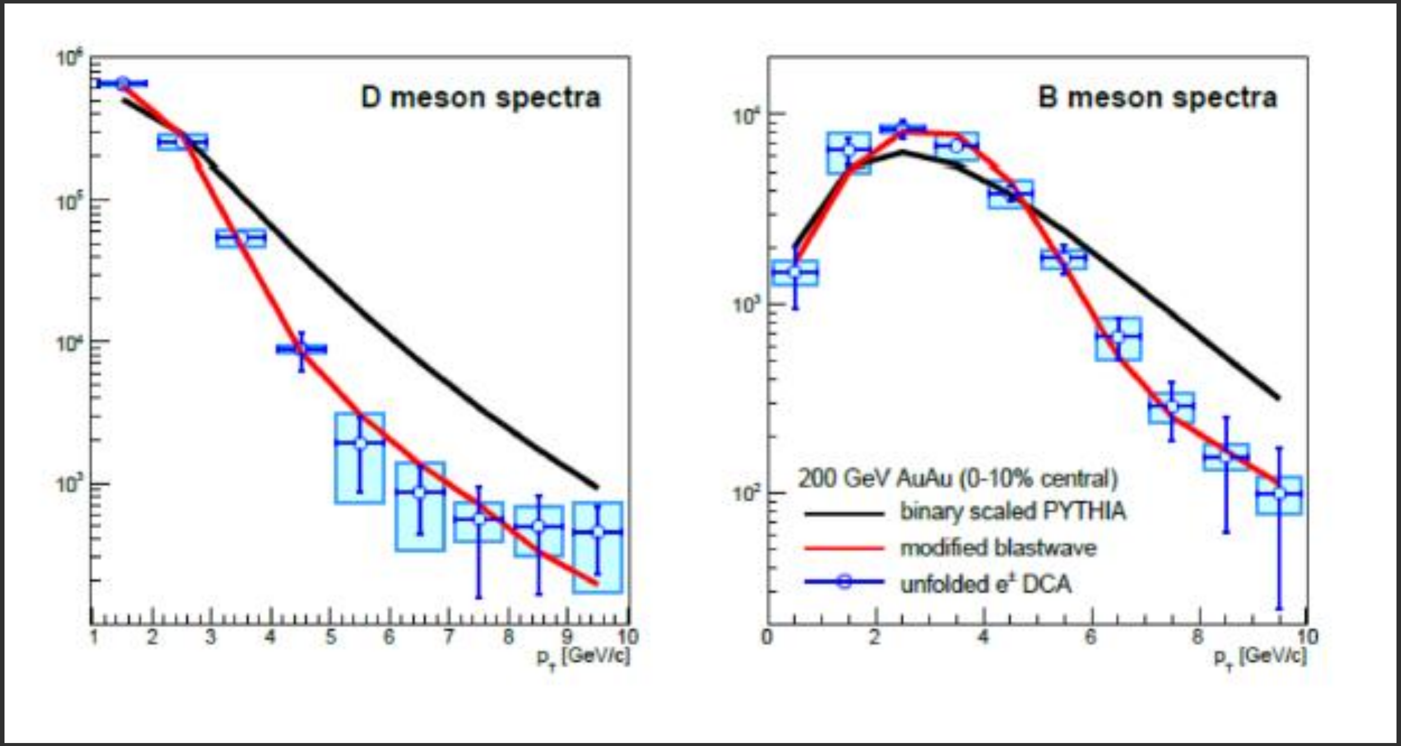
VTX projected uncertainties and sensitivity relative to heavy quark diffusion parameter





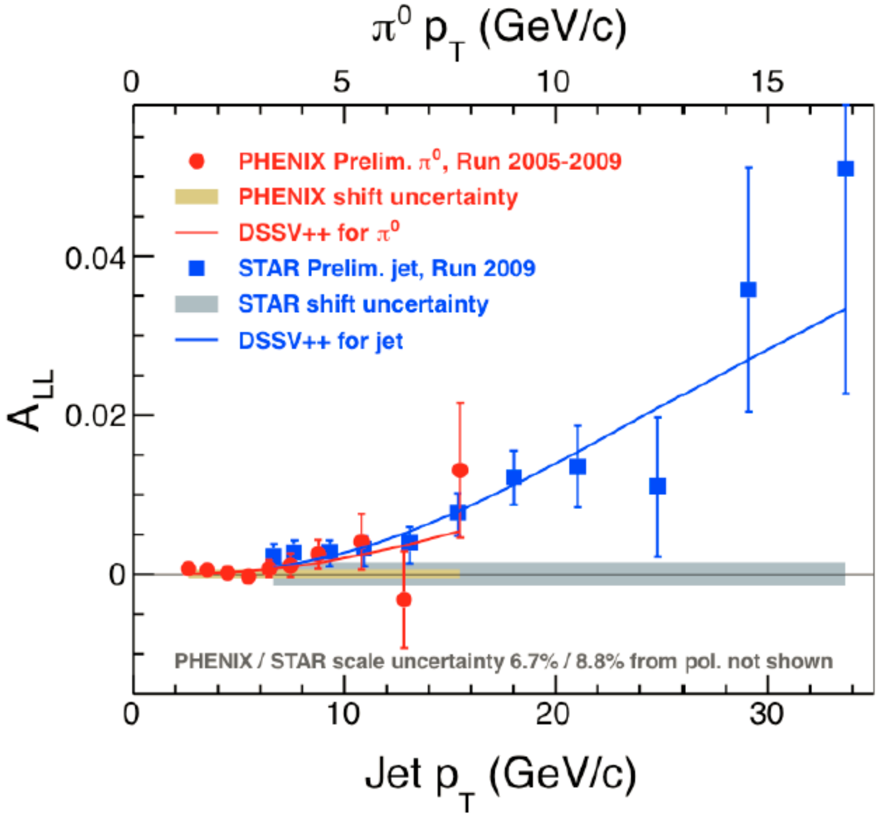
In extreme scenario of beauty quarks following flow field, very different prediction

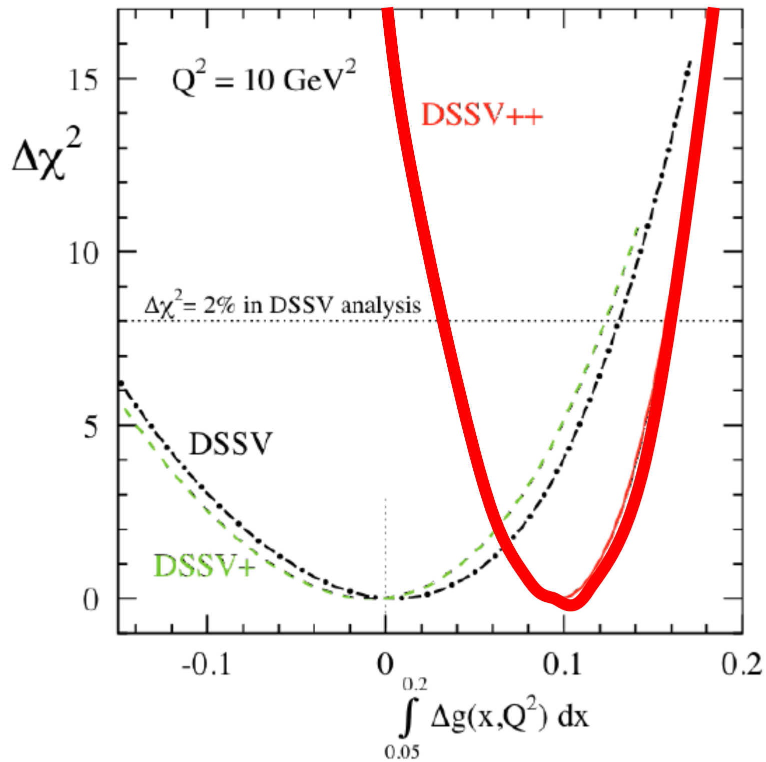
Example full unfolding from DCA electrons to parent mesons



- Au+Au data set will also provide a factor of 2.5 more statistics for all measurements
- For J/ψ and ψ′, significantly improved mass resolution and background rejection
- Definitive Heavy Quark + Quarkonia Au+Au Data Set

Run-14 p+p (Long. Pol) @ 200 GeV Request



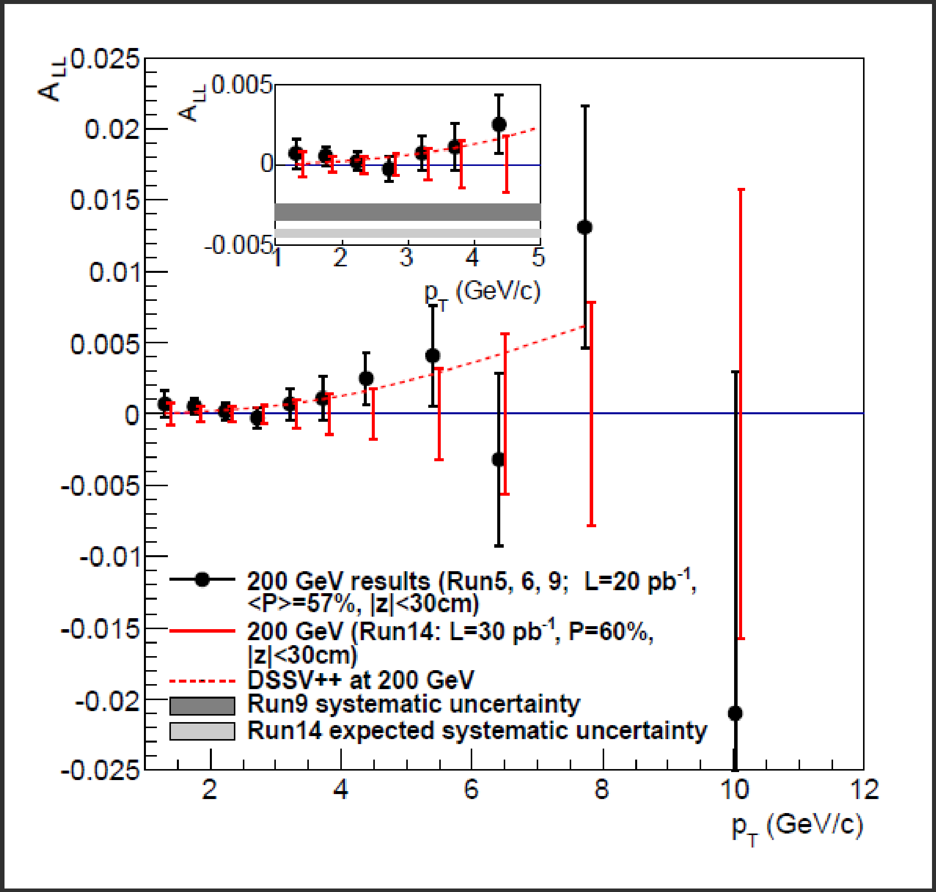


First indication of non-zero gluon contribution to proton spin!

PHENIX publication of these results in the next month.

Critical to improve the low-x (low p_T π^0 A_{LL}) constraint!

p+p (long. pol.) @ 200 GeV for 6.5 weeks (30 pb^{-1} |z|<30cm)



Doubling statistical precision, and more importantly significantly reduced systematic uncertainty

Also provides timely baseline measure for Au+Au data

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 4 weeks [Physics driven goal is 150 nb^{-1} sampled within $|z| < 40$ cm and $\langle \mathcal{P} \rangle = 60\%$]
- Geometry studies with $d+$Au @ 200 GeV and ^{3}He+Au @ 200 GeV for 1 week each [Physics driven goal is recording 1 billion minimum bias events for each]
- $p+$Si, $p+$Cu @ 200 GeV for 2 weeks each [Physics driven goal is 450 nb^{-1} and 225 nb^{-1}, respectively, sampled within $|z| < 40$ cm and $\langle \mathcal{P} \rangle = 60\%$]

In the scenario of only 15 cryo weeks, we would only be able to run a shorter p+p and p+Au @ 200 GeV

Note that not utilizing additional collision combinations greatly diminishes the utility of the measurements 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)

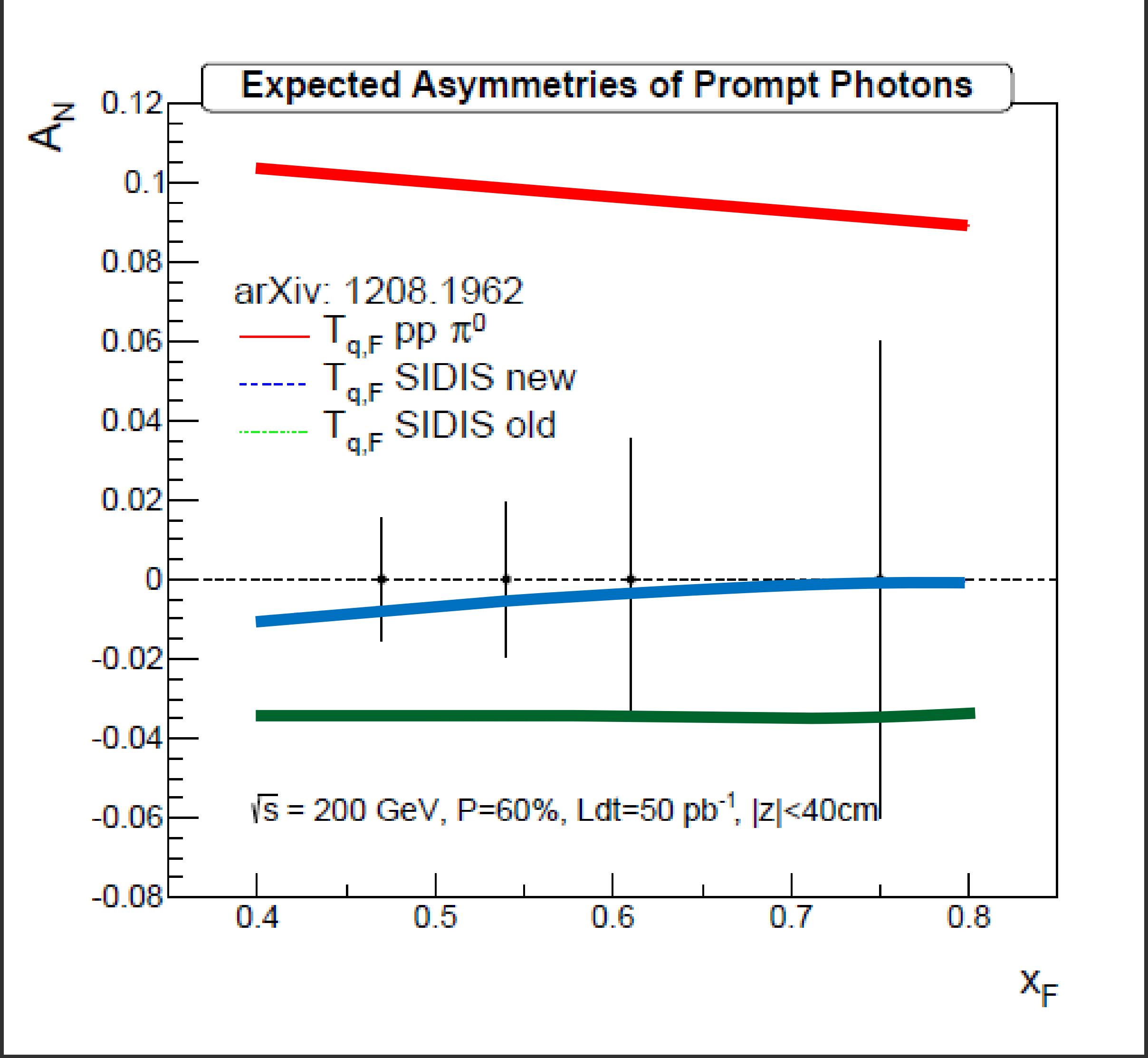
Different theoretical approaches
(TMD factorization and Collinear twist-three factorization)
TMDs include Sivers and Collins functions

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 $T_{q,F}$

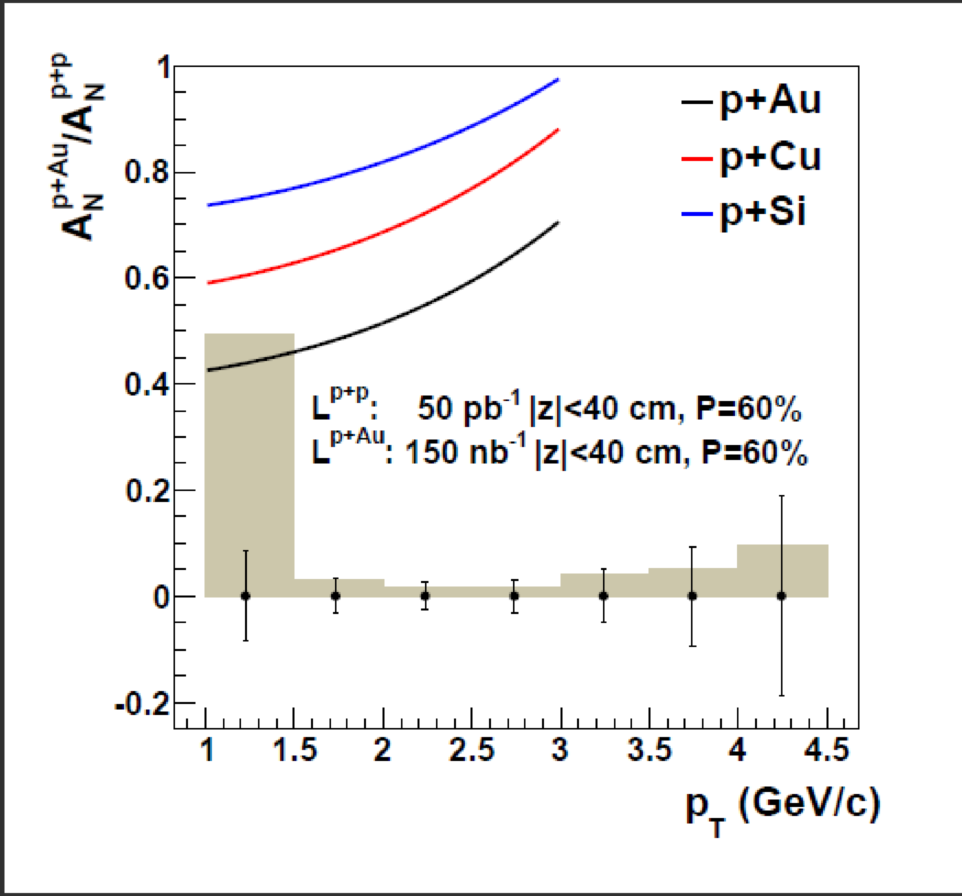
p+Au with transversely polarized proton

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 4 weeks (150 nb^{-1} |z|<40cm)

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



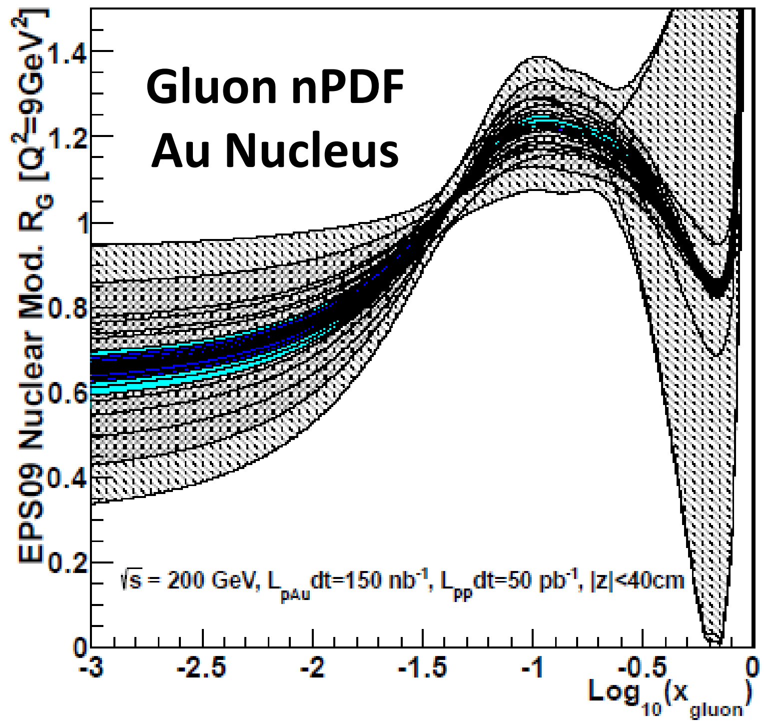
Constraining Gluon nPDFs

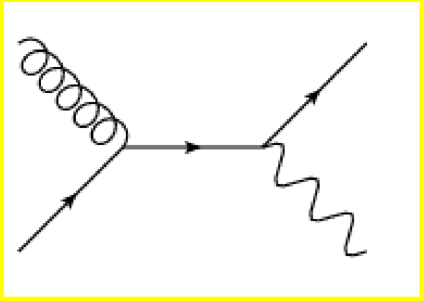
Strong indications of low-x shadowing/saturation physics with d+Au J/ψ, e-μ correlations, h-h correlations, single muons, electrons, …

And yet, all have final state interactions.

Golden channel direct photon

MPC-EX Direct Photon





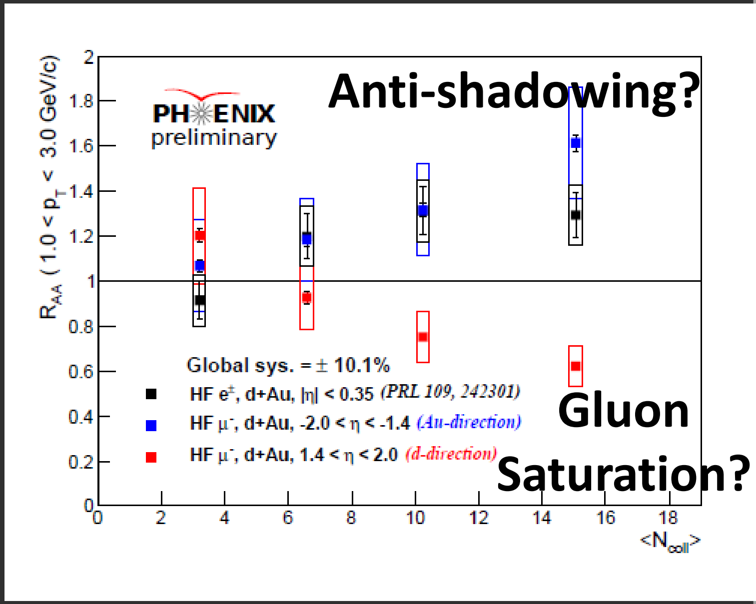
Using full statistical / systematic constraint method on EPS09 nPDFs, blue bands indicate projected measurement (**1, 2 σ** level)

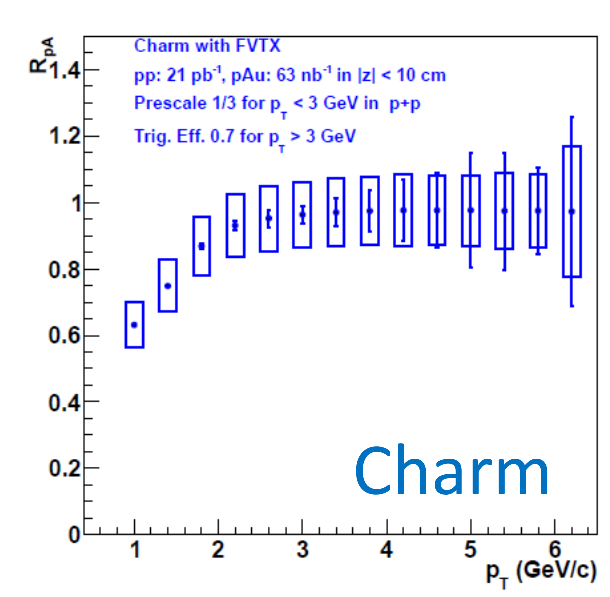
Open Heavy Flavor Probes of nPDFs and More

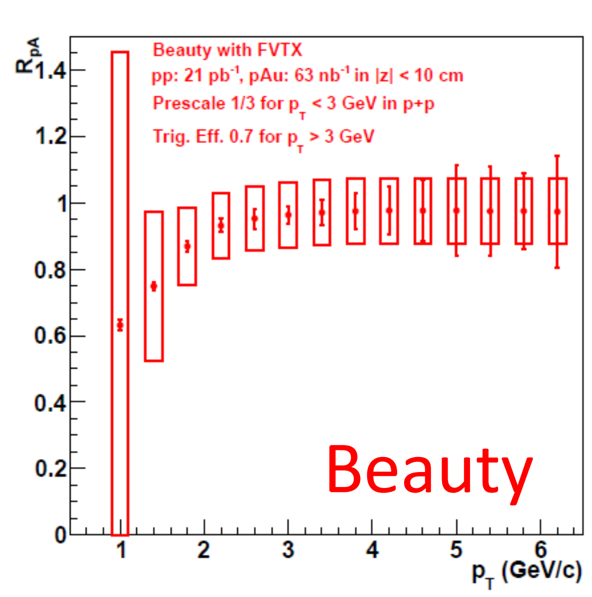
Another handle on gluon nPDF and critical baseline for quarkonia

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

Can we run p+Au and Au+p for systematic checks (*a la* LHC p+Pb)?





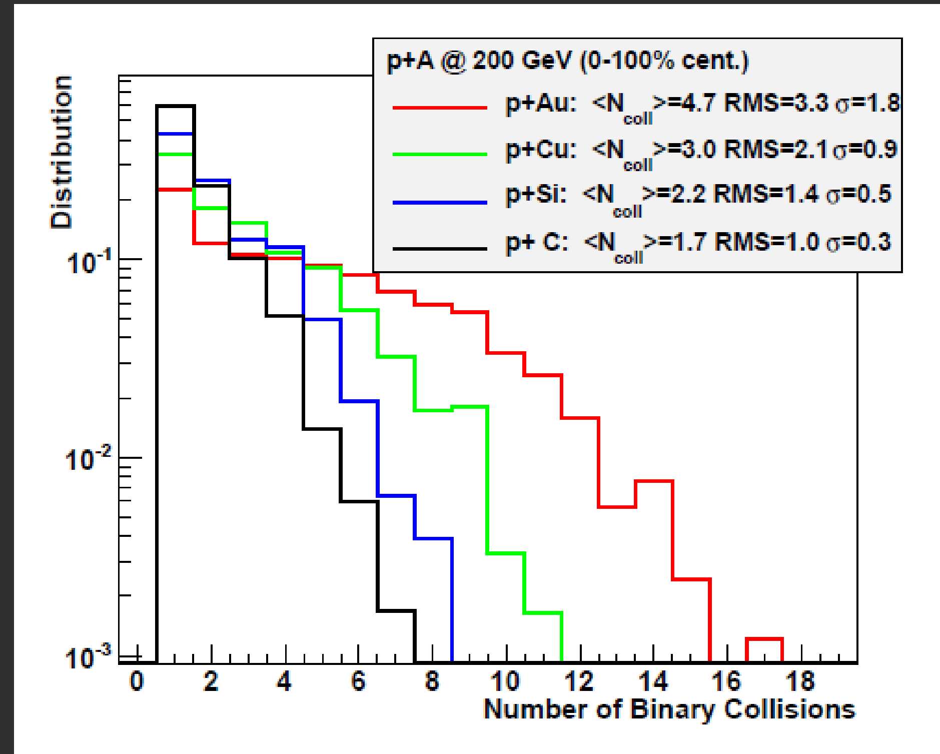


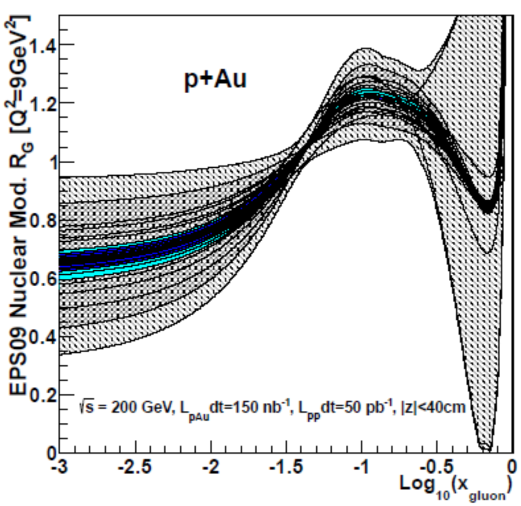
Geometry Test

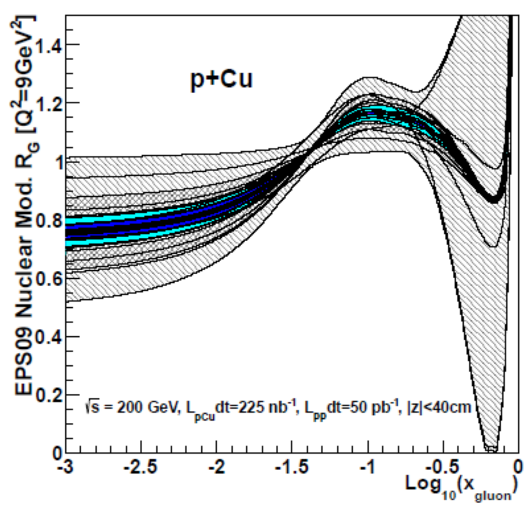
DIS measures give geometry averaged nPDF

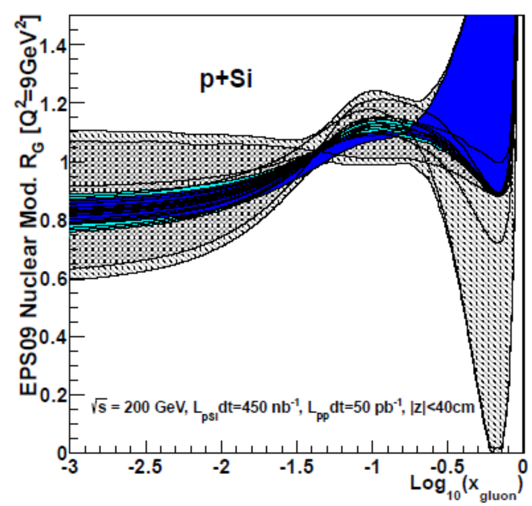
Utilized d+Au centrality measures to date…

Excellent opportunity to validate with direct photons nPDF of different nuclei



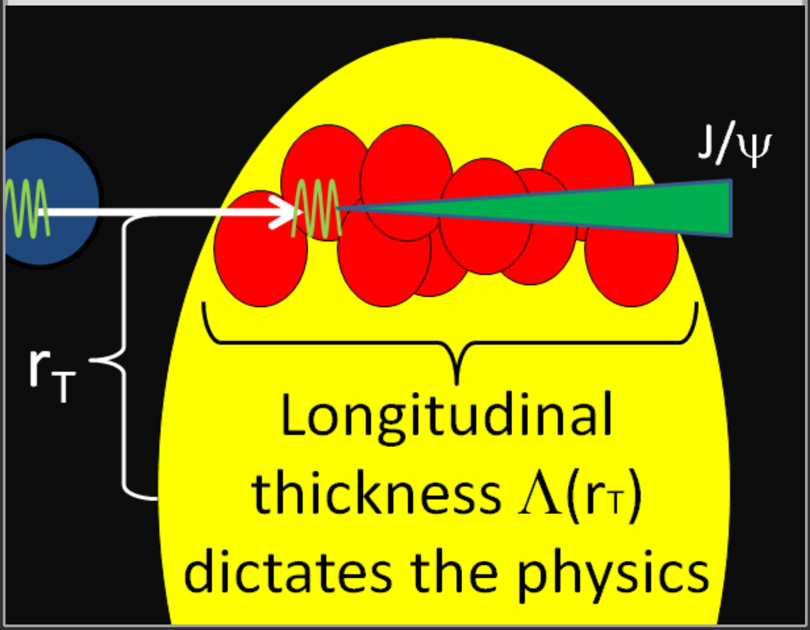


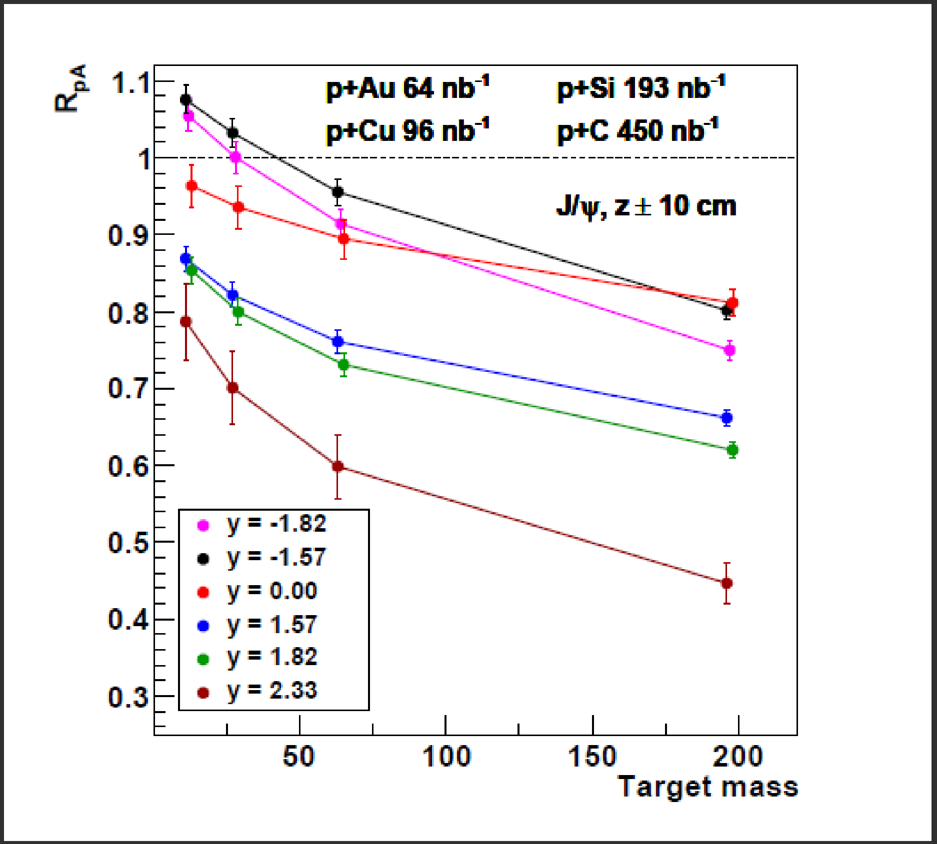




Quarkonia in Medium (Cold or Hot)

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

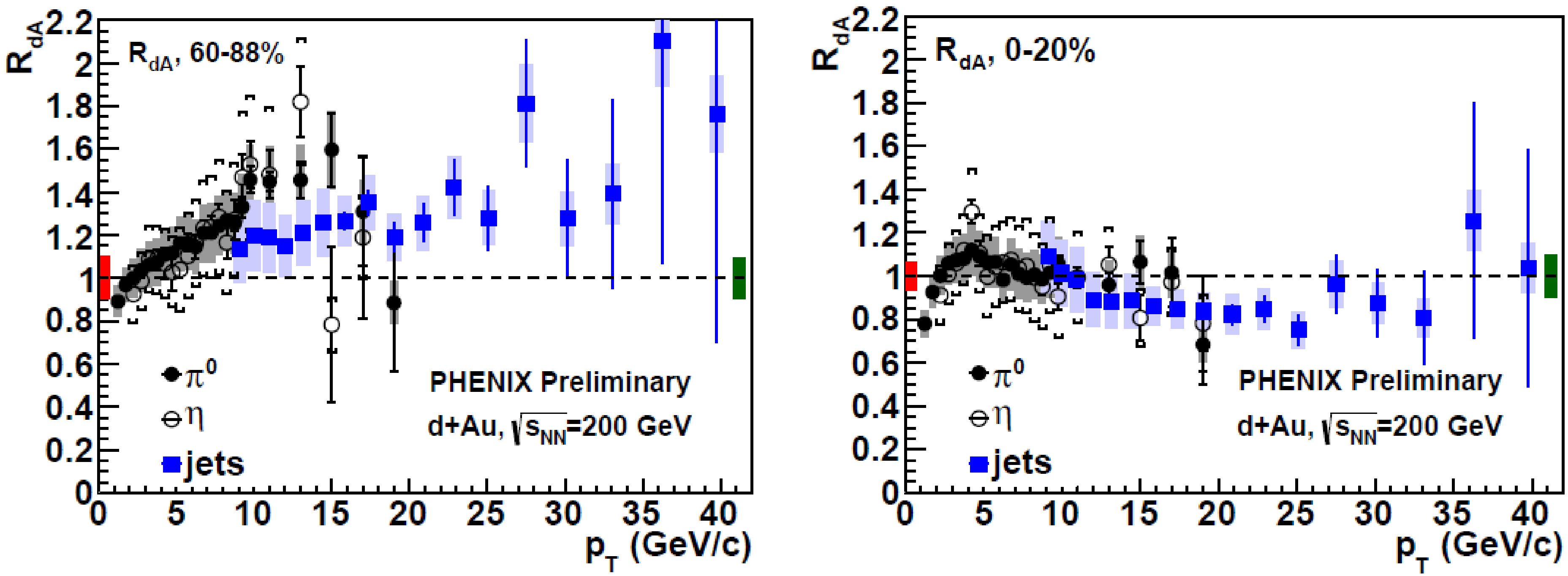




Instead of d+Au centrality selection, another method to change nuclear density is with **different targets**

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

Cracking the Geometry Code

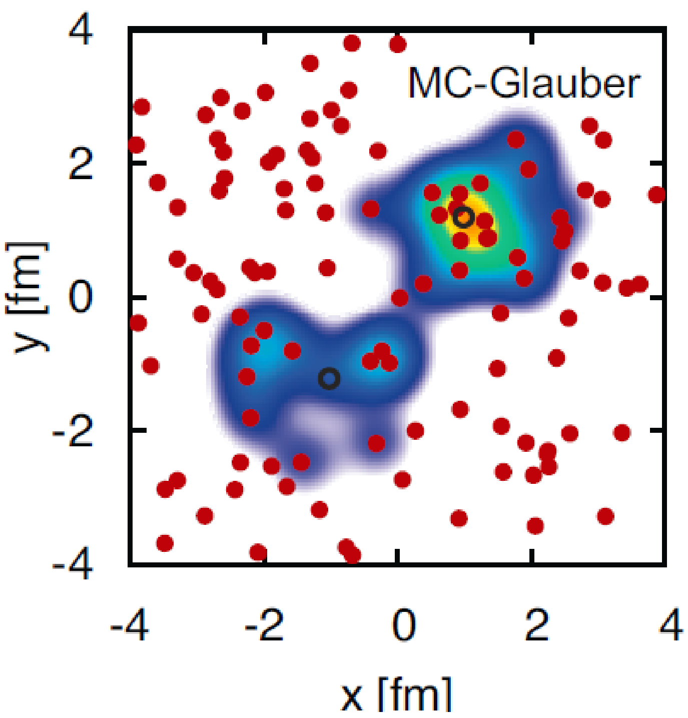


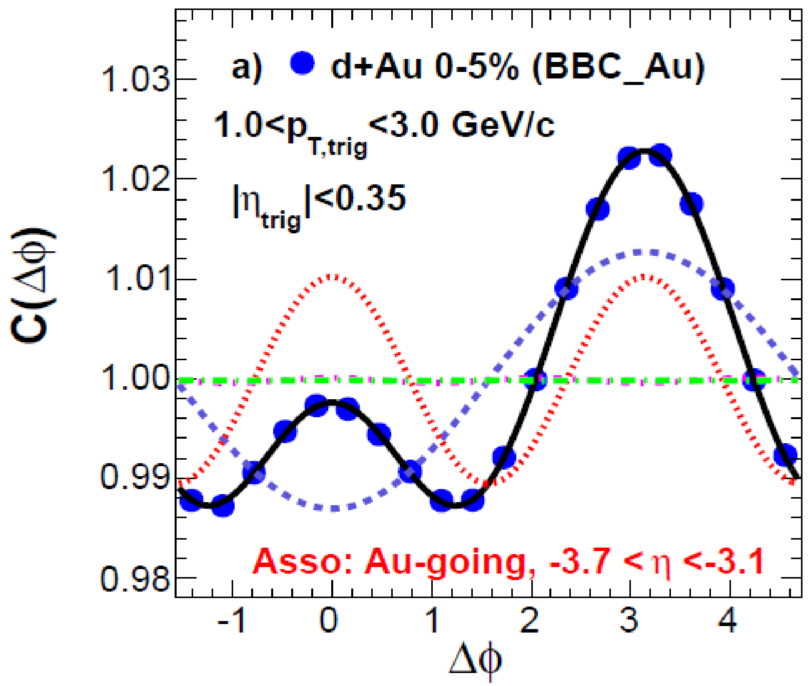
Are there competing partonic effects at play at high p_T?

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

2 weeks of p+Si gives $<N_{coll}>$ ~ (d+Au 60-88% central), better statistical precision, and no centrality categorization required (i.e. definitive test)

Can a nearly inviscid fluid be created in p(d) + A too?



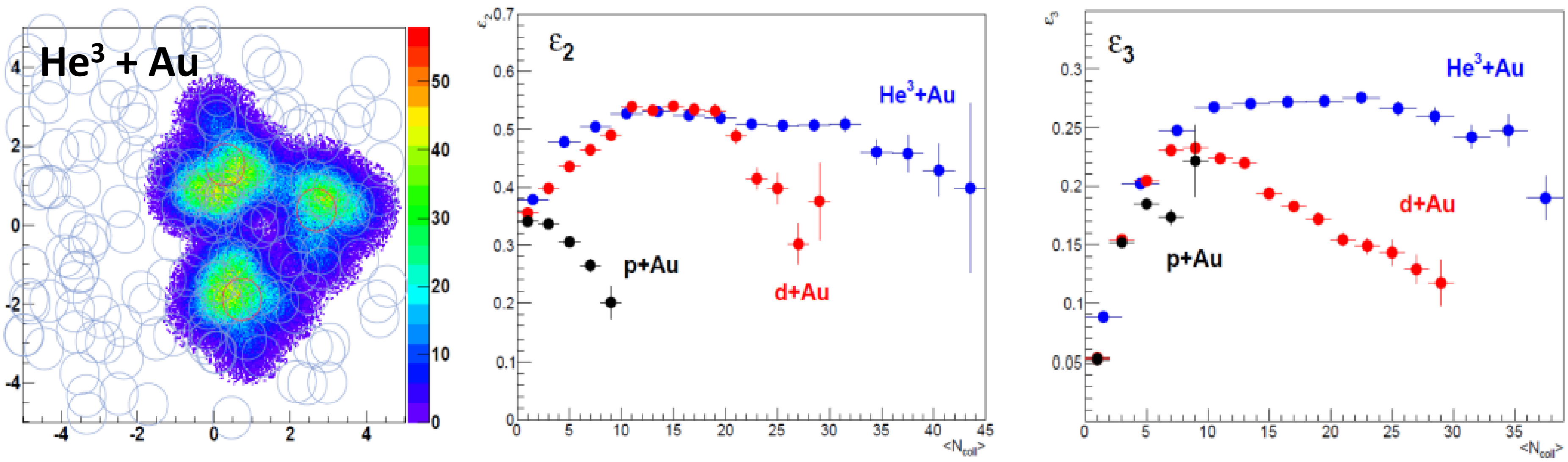


Hydrodynamic flow? Glasma diagrams? Something else?

LHC has highest parton densities…

RHIC has unique access to geometry controls…

Geometry Control



Large PHENIX Acceptance: VTX, FVTX, MPC-EX

1 billion events with larger acceptance detectors will yield 20++ times the statistics of current measurements

Only takes ~ 1 week with high rate PHENIX DAQ
Low luminosity requirement. How quickly can CA-D switch?

PHENIX BUP Summary

- Exciting physics program for Run-14 and Run-15
- Lots of debate within PHENIX because of all the top science opportunities
- Running periods need to be sufficient to make definitive measurements
- Run-15 in particular emphasizes the truly unique RHIC capabilities to provide definitive new insights

Additional Material

Explanations of Weeks to Physics Goals

How are the number of weeks for Run-14 calculated?

We have attempted to closely follow CA-D guidance as provided at:
http://www.rhichome.bnl.gov/RHIC/Runs/RhicProjections.pdf

Example with Run-14 and 22 cryo-weeks (following chart on page 2 in doc.)

Cool-down from 50 K to 4 K	1 week	
Set-up mode 1 (Au-Au at 100 GeV/nucleon)	1 week	(no dedicated time for experiments)
Ramp-up mode 1	½ weeks	(8 h/night for experiments)
Data taking mode 1	11 weeks	
Set-up mode 2 (p↑-p↑ at 100 GeV)	1 week	(no dedicated time for experiments)
Ramp-up mode 2	½ weeks	(8 h/night for experiments)
Data taking mode 2 -1 with further ramp-up	6 1/2 weeks	
Warm-up	½ week	

$1 + 1 + 0.5 + 11 + 1 + 0.5 + 6.5 + 0.5 = 22$ cryo-weeks

Note that we quote 12 weeks of Au+Au physics running in our request

Past experience has a very quick turn on for Au+Au (optimist view)

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.

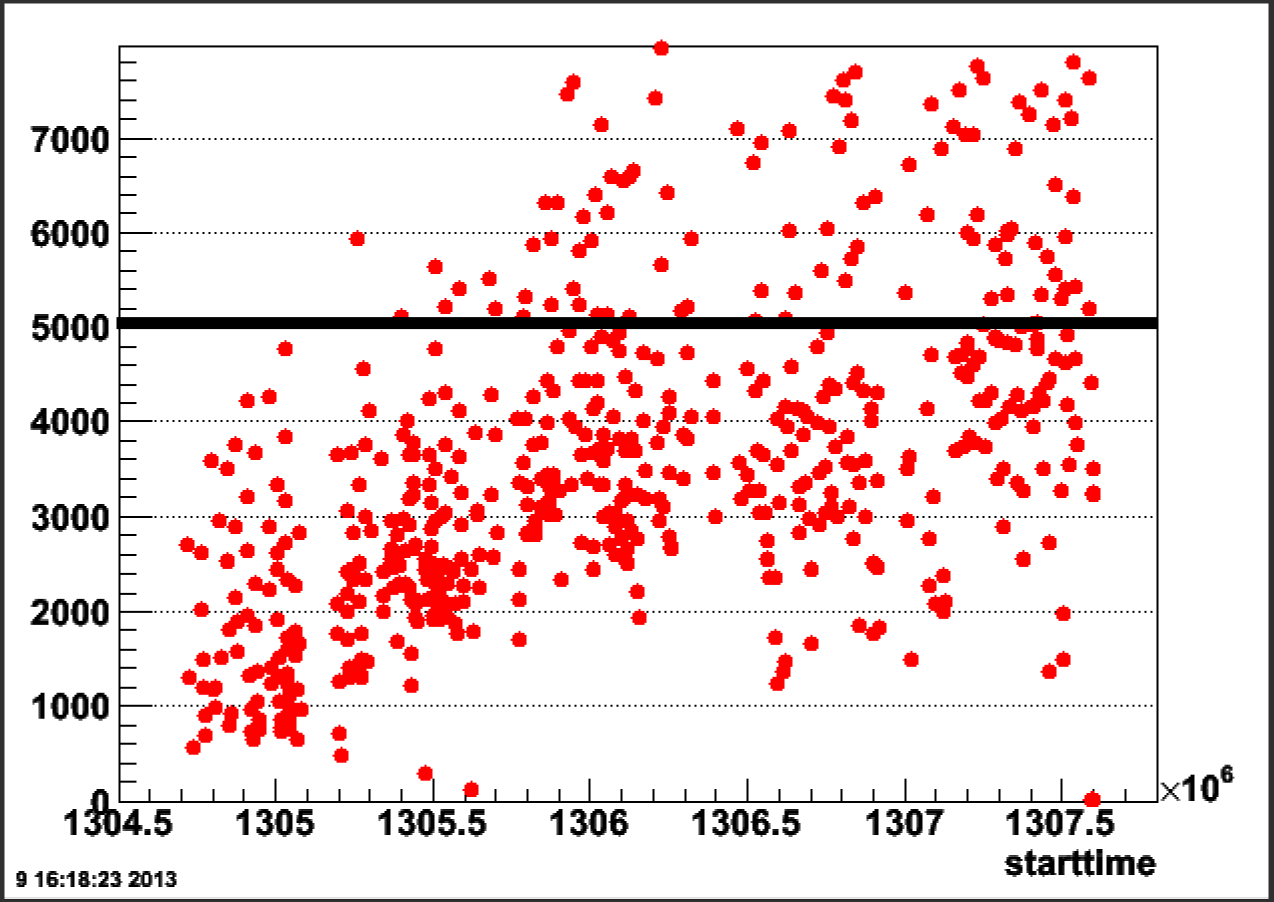
However, there is some ramp-up time for luminosity to exceed the 5 kHz DAQ bandwidth. There is also some vertex trigger resolution.

Based on past experience, scale luminosity/wk x 0.75

and that gives the 12 week request.

Run-11 Au+Au @ 200 GeV Performance

Au+Au interaction rate within |z| < 10 cm



Time Tag throughout Run-11

CA-D Quoted Run-11 Achieved: L (peak) 50×10^{26} [31 kHz] L(ave) = 30×10^{26} [18 kHz]

Fraction of all interactions within |z| < 10 cm → 0.30

Thus, within |z| < 10 cm these correspond to peak 9 kHz and average 6 kHz

How did we calculate 6.5 weeks p+p for 30 pb^{-1} recorded by PHENIX within $|z| < 30$ cm. (Central Arm π^0 acceptance)

Physics driven goal (set by desire substantially improve low-x constraint on gluon contribution to proton spin).

For the p+p @ 200 GeV, we took the first two weeks at the minimum (9.3 pb^{-1} per week) and then 4.5 weeks at the mean of the minimum/maximum, and that gives us the total for 6.5 weeks. The Figure 5 has a slower ramp on than the minimum, on the other hand it is quite possible to achieve higher than the mean of the min/max for the running duration afterwards.

We then fold in the PHENIX uptime and the z-vertex selection factors.

How are the number of weeks calculated (Run-15)?

Cool-down from 50 K to 4 K	1 week	
Set-up mode 1 (p-p at 100 GeV/nucleon)	1 week	(no dedicated time for experiments)
Ramp-up mode 1	½ week	(8 h/night for experiments)
Data taking mode 1	9 weeks	
Set-up mode 2 (p-Au @ 100 GeV/nucleon)	1 week	(no dedicated time for experiments)
Ramp-up mode 2	½ week	(8 h/night for experiments)
Data taking mode 2	4 weeks	
Set-up/Ramp-up/Data taking mode 3 d-Au	1 week	(note very low luminosity requirement)
Set-up/Ramp-up/Data taking mode 4 He^3-Au	1 week	(note very low luminosity requirement)
Mode 5 (p+Si/Al, p+Cu)	2.5 weeks	(what fits depends on earlier perform.)
Warm-up	½ week	

$1 + 1 + 0.5 + 9 + 1 + 0.5 + 4 + 1 + 1 + 2.5 + 0.5 = 22$

Exact switching times and ramp-up for p+A needs more guidance. Aggressive physics driven schedule. Modes 3-5 will need prioritization depending on running time and switching time.

Phil Pile requested values for RHIC delivered luminosities corresponding to the PHENIX BUP requests. They are provided below. Of course, the physics projections require the PHENIX recorded/sampled luminosities within specified z-vertex cuts and the PHENIX uptime.

Run-14: p+p @ 200 GeV Long --> delivered = 30 pb^-1 x (1/0.7) x (1/0.6) = 71 pb^-1

Run-15: p+p @ 200 GeV Trans --> delivered = 50 pb^-1 x (1/0.7) x (1/0.7) = 102 pb^-1

Run-15: p+Au @ 200 GeV Trans --> delivered = 150 nb^-1 x (1/0.7) x (1/0.7) = 306 nb^-1

Run-15: p+Si @ 200 GeV Trans --> delivered = 450 nb^-1 x (1/0.7) x (1/0.7) = 918 nb^-1

Run-15: p+Cu @ 200 GeV Trans --> delivered = 225 nb^-1 x (1/0.7) x (1/0.7) = 459 nb^-1

These values above have a straightforward correspondence as outlined in the BUP.

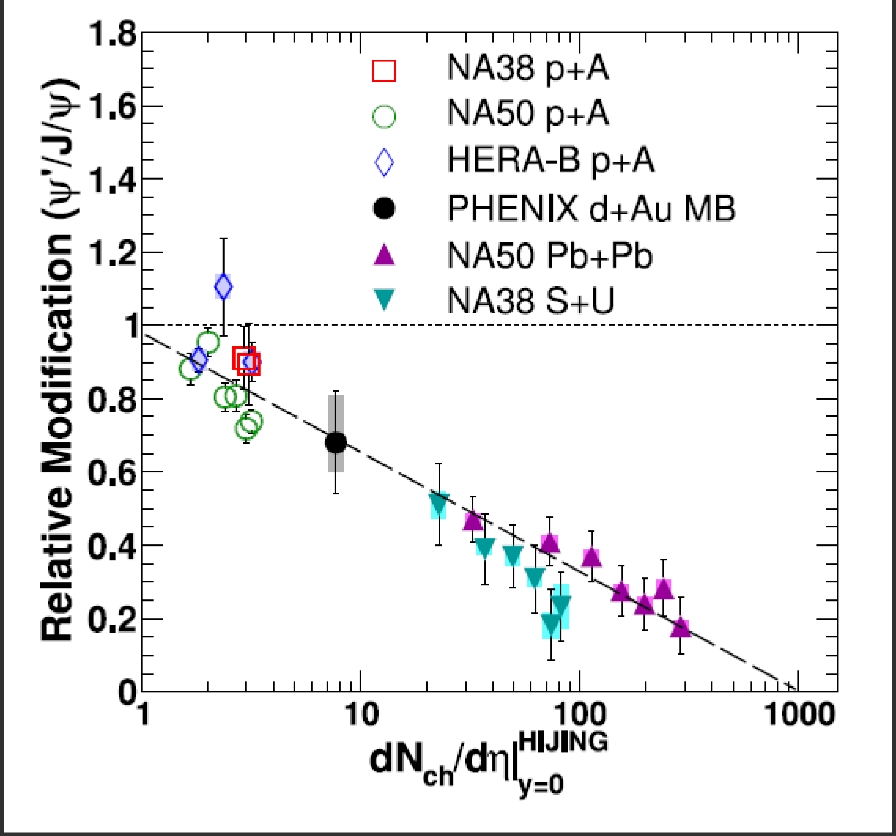
For the Run-14 Au+Au request, the main physics driver is bandwidth limited at 5 kHz by the PHENIX DAQ. Thus, what matters is the RHIC uptime and when the luminosity within $|z| < 10$ cm exceeds this 5 kHz limit. See earlier slide.

For the Run-15 d+Au and Run-15 He^3+Au these are again bulk observables and come from the minimum bias trigger sample. Thus, the calculation to get 1 billion events is simply 5000 (DAQ rate) x 60 x 60 x 24 x 5 (days) x 0.7 (PHENIX uptime) x 0.6 (RHIC delivery). The luminosities required during these 5 days much less than 10% of the minimum value quoted for delivered luminosities.

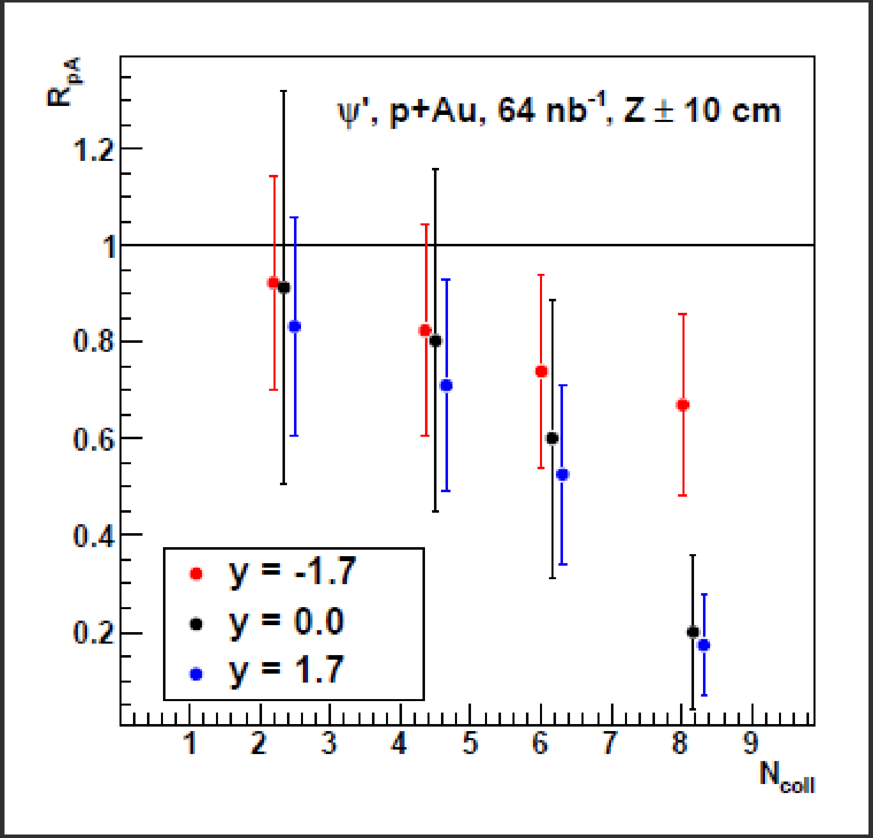
EXTRAS

ψ' Physics Implications

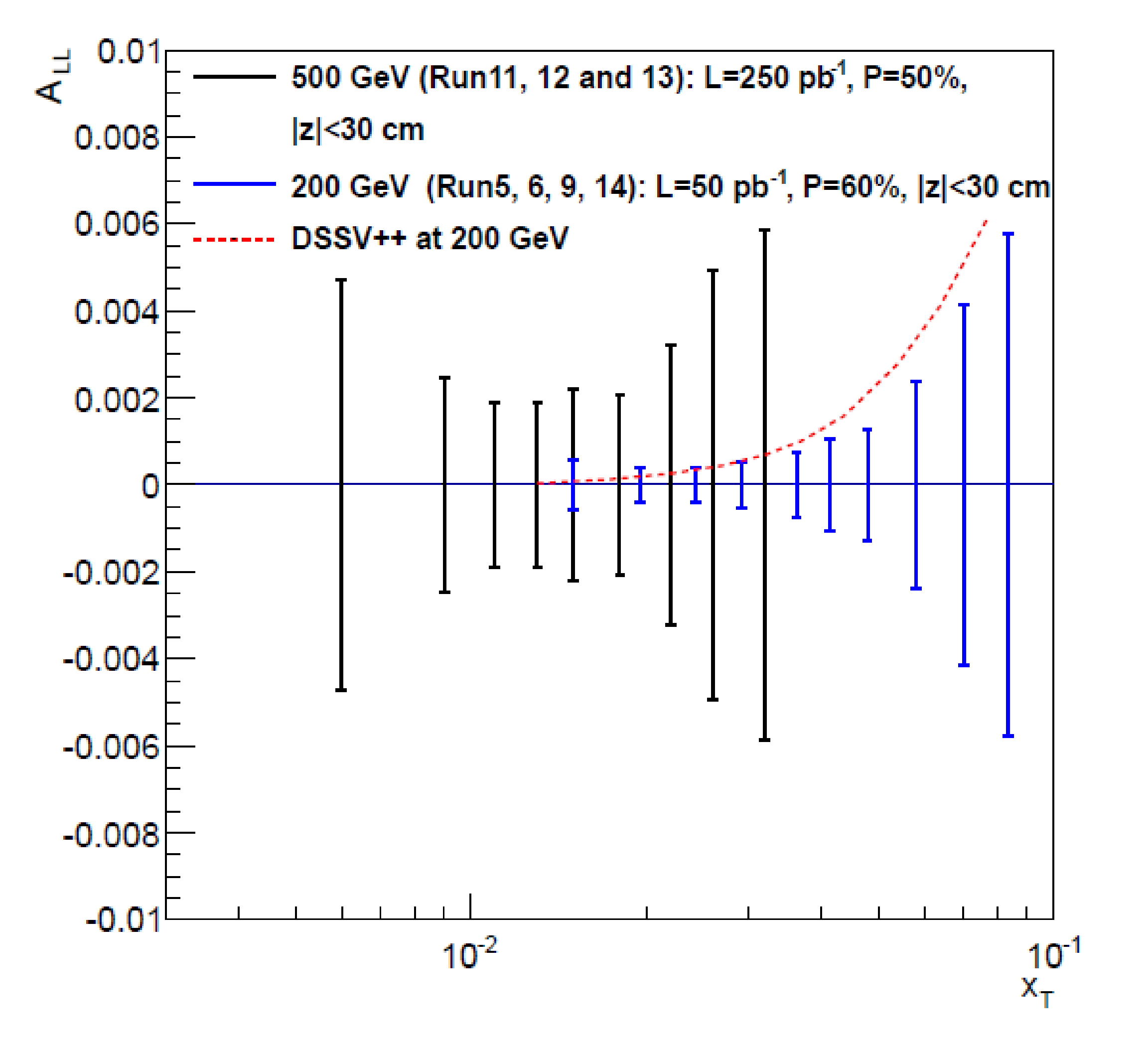
http://arxiv.org/abs/arXiv:1305.5516



Projections Run-15



Why does a smaller p+p @ 200 GeV data set constrain the low-x gluon spin contributions better than larger p+p @ 500 GeV data set?



Single transverse spin asymmetry of prompt photon production

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We study the single transverse spin asymmetry of prompt photon production in high energy proton-proton scattering. We include the contributions from both the direct and fragmentation photons. While the asymmetry for direct photon production receives only the Sivers type of contribution, the asymmetry for fragmentation photons receives both the Sivers and Collins types of contributions. We make a model calculation for quark-to-photon Collins function, which is then used to estimate the Collins asymmetry for fragmentation photons. We find that the Collins asymmetry for fragmentation photons is very small, thus the single transverse spin asymmetry of prompt photon production is mainly coming from the Sivers asymmetry in direct and fragmentation photons. We make predictions for the prompt photon spin asymmetry at RHIC energy, and emphasize the importance of such a measurement. The asymmetry of prompt photon production can provide a good measurement for the important twist-three quark-gluon correlation function, which is urgently needed in order to resolve the "sign mismatch" puzzle.

Transverse Motion of Partons in a Proton

Two theoretical approaches to the correlation between parton k_T and proton spin:

TMD: Correlation between nucleon spin and parton k_T.

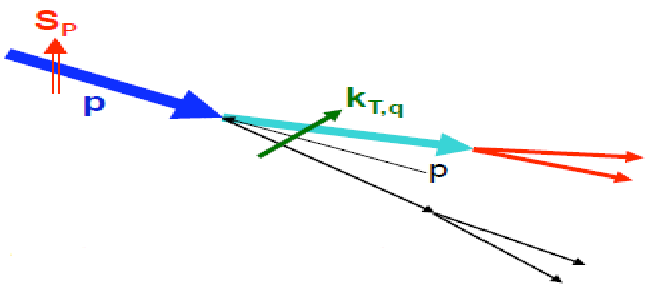
Phys. Rev. D **41**, 83 (1990)
Phys. Rev. D **43**, 261, (1991)

$$\boxed{d\sigma^{\uparrow} \propto \underbrace{\bar{f}_{1T}^{\perp q}(x, k_\perp^2)}_{\text{“Sivers” distribution}} \cdot D_q^h(z)}$$

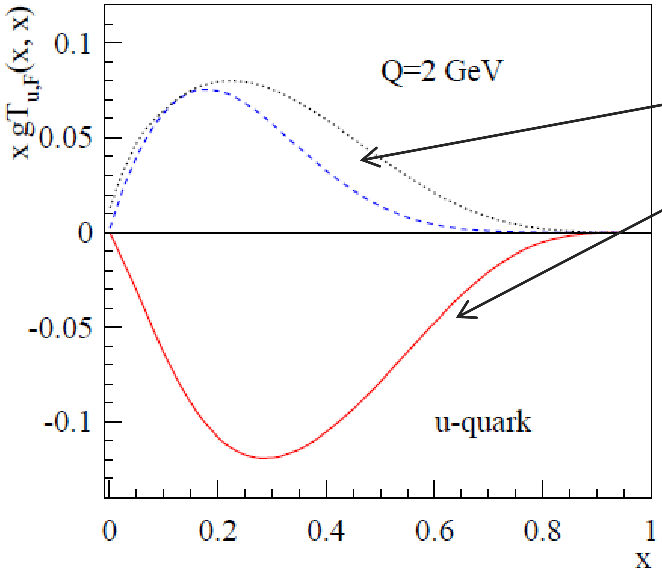
Twist-3: Quark-gluon correlations in polarized hadron

Phys. Rev. D **59**, 014004 (1998)

$$gT_{q,F}(x,x) = -\int d^2k_\perp \frac{|k_\perp|^2}{M} f_{1T}^{\perp q}(x, k_\perp^2)$$



Approaches are related and shown to be equivalent at intermediate k_T.



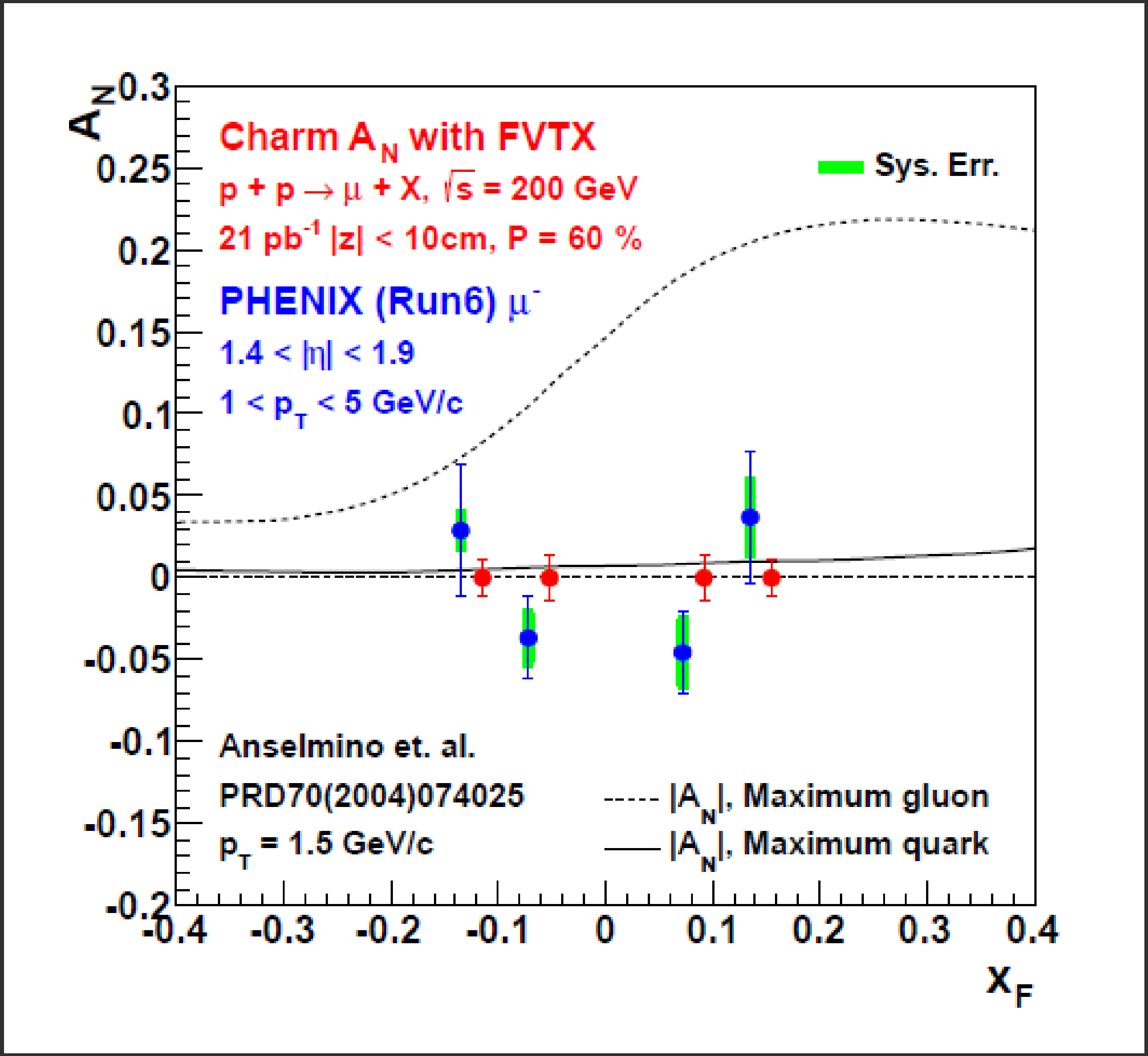
Extracted from SIDIS data *(extrapolated x>0.3)*

Extracted from $p^{\uparrow} + p \rightarrow h + X$

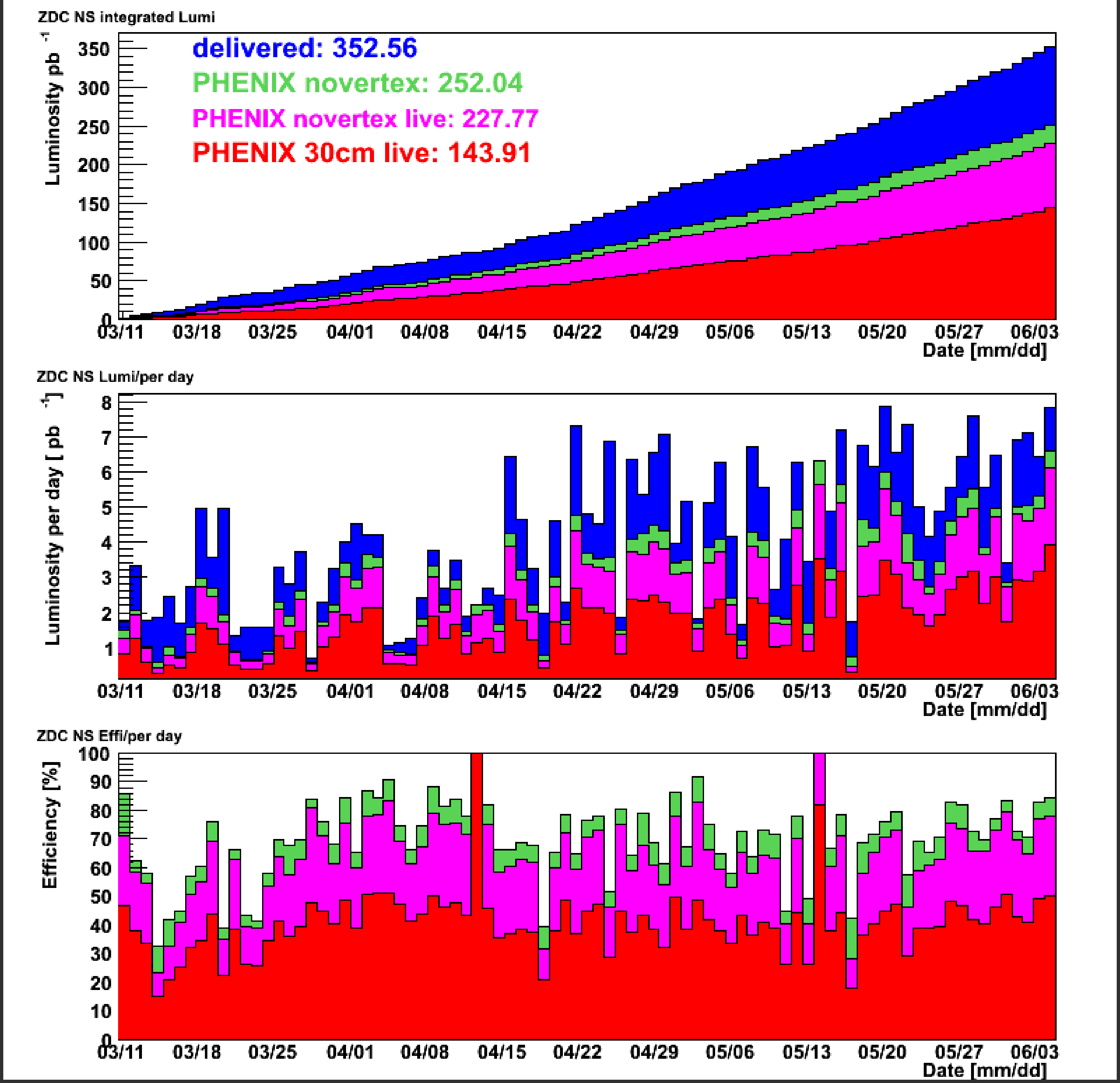
(Assuming that transverse motion dominates the hadronic A_N)

Two Possibilities:

- Transverse motion not responsible for hadronic A_N
- SIDIS extrapolation to large x not valid



Charm A_N with FVTX
$p + p \rightarrow \mu + X$, $\sqrt{s}$ = 200 GeV
21 pb^{-1} |z| < 10cm, P = 60 %
PHENIX (Run6) μ^-
1.4 < |η| < 1.9
1 < p_T < 5 GeV/c
Sys. Err.
Anselmino et. al.
PRD70(2004)074025
p_T = 1.5 GeV/c
$|A_N|$, Maximum gluon
$|A_N|$, Maximum quark
A_N
x_F
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4



ZDC NS integrated Lumi
Luminosity pb -1
delivered: 352.56
PHENIX novertex: 252.04
PHENIX novertex live: 227.77
PHENIX 30cm live: 143.91
03/11 03/18 03/25 04/01 04/08 04/15 04/22 04/29 05/06 05/13 05/20 05/27 06/03
Date [mm/dd]
ZDC NS Lumi/per day
Luminosity per day [pb -1]
ZDC NS Effi/per day
Efficiency [%]

June 3, 2013