

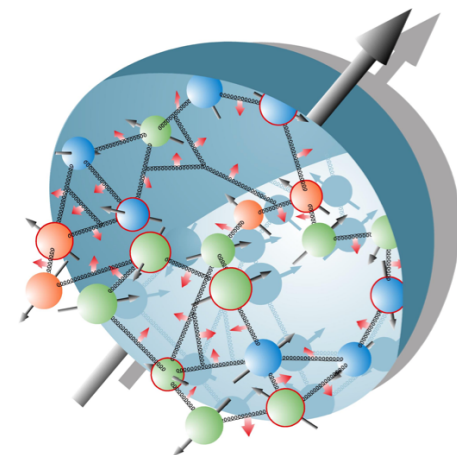
Recent PHENIX Highlights

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for PHENIX Collaboration
The 21st Particles & Nuclei International Conference
Sep. 1-5 2017, IHEP, Beijing, China

Selected Recent PHENIX Highlights

❖ Spin in $p + p$ and $p + A$

- Gluon polarization: π^0 , J/ψ A_{LL}
- Transverse spin effect, π^0 , single muon from HF decay, J/ψ
- New exploration: Forward neutron A_N

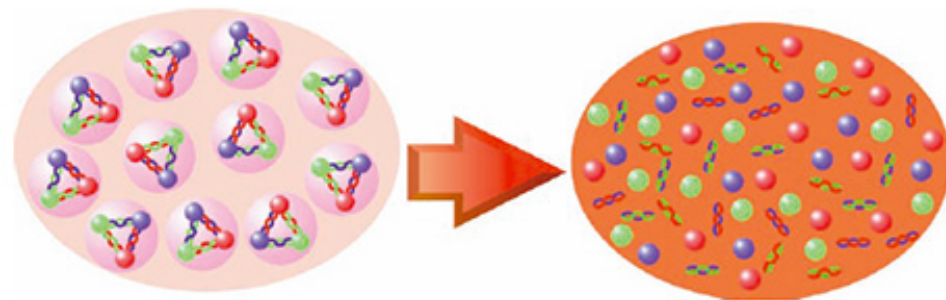


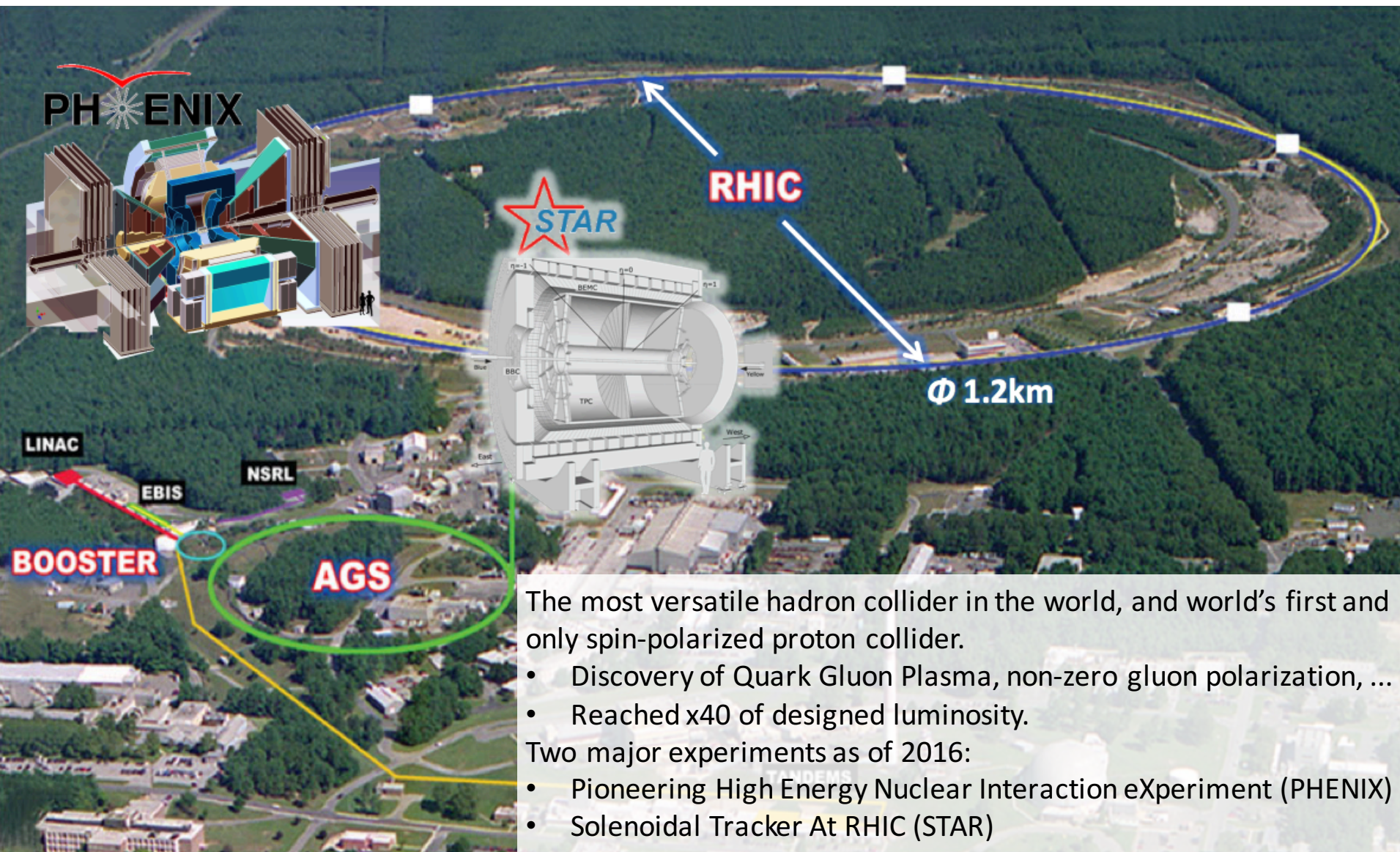
❖ Collectivity in small systems/lower energies

- Flow in $p/d/{}^3\text{He} + \text{Au}$
- $d + \text{Au}$ energy scan

❖ Heavy flavor production

- R_{AuAu} of $C/B \rightarrow e$ in mid-rapidity
- $B \rightarrow J/\psi$ at forward-rapidity, R_{CuAu}
- Relative modification $\psi(2S)/\psi(1S)$





The most versatile hadron collider in the world, and world's first and only spin-polarized proton collider.

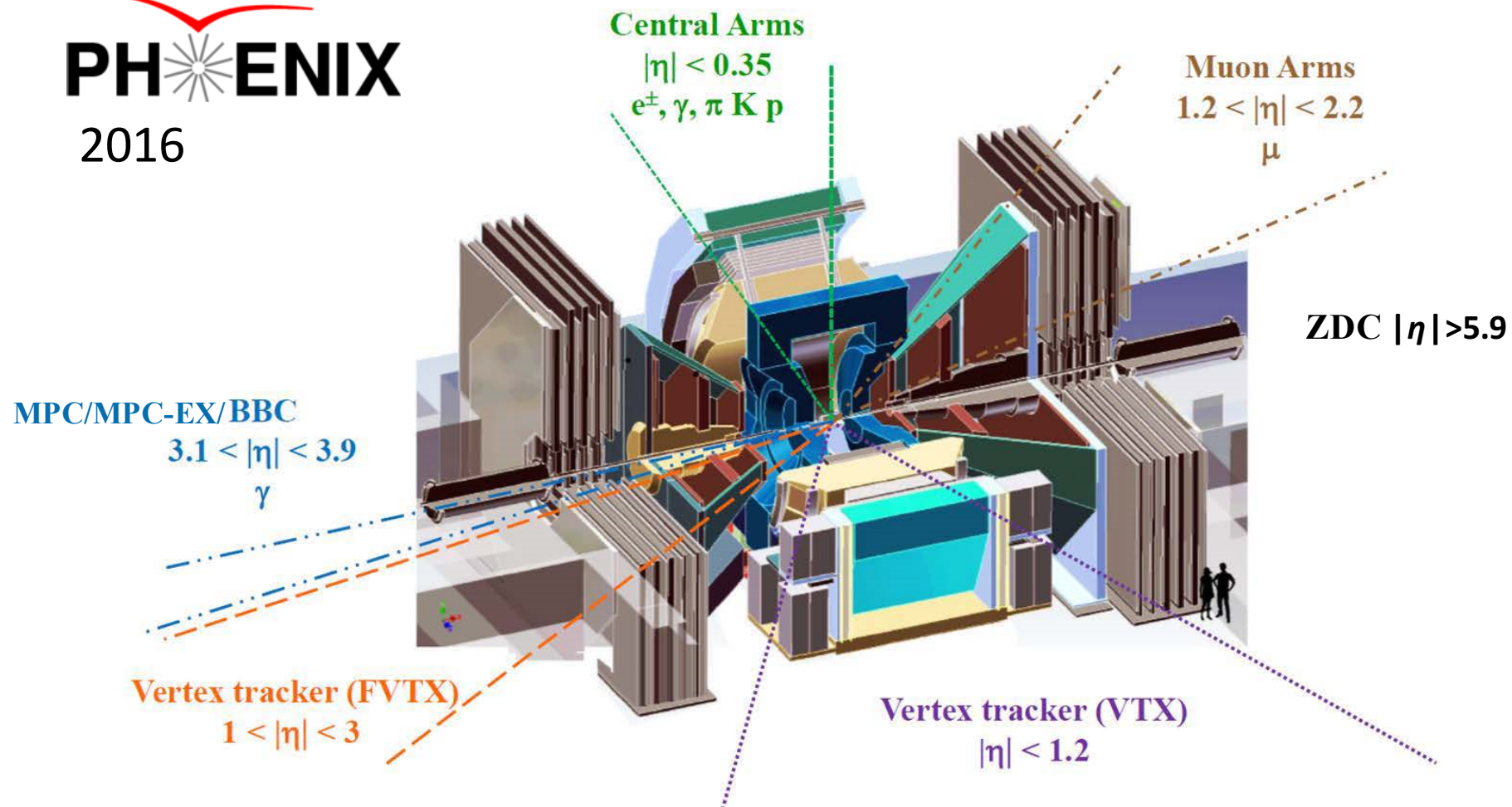
- Discovery of Quark Gluon Plasma, non-zero gluon polarization, ...
- Reached x40 of designed luminosity.

Two major experiments as of 2016:

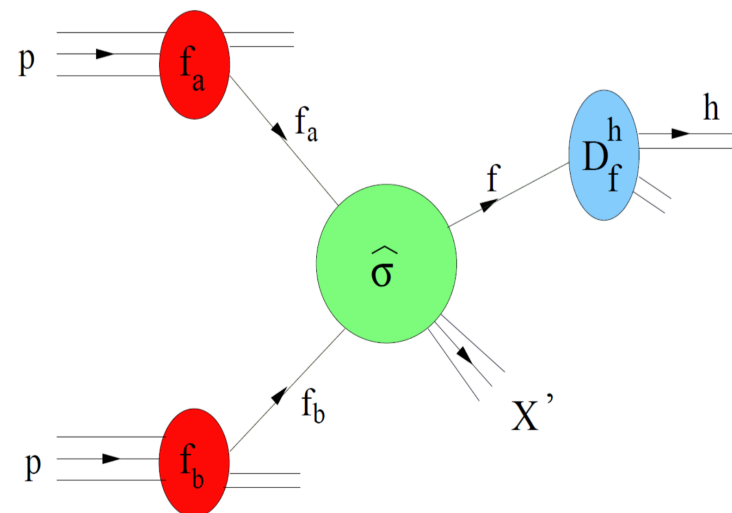
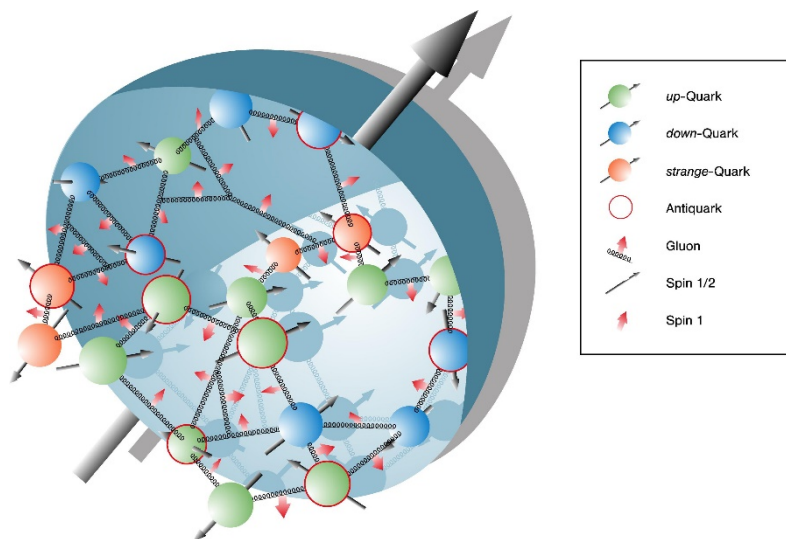
- Pioneering High Energy Nuclear Interaction eXperiment (PHENIX)
- Solenoidal Tracker At RHIC (STAR)



2016



Proton Spin Structure



Know very little

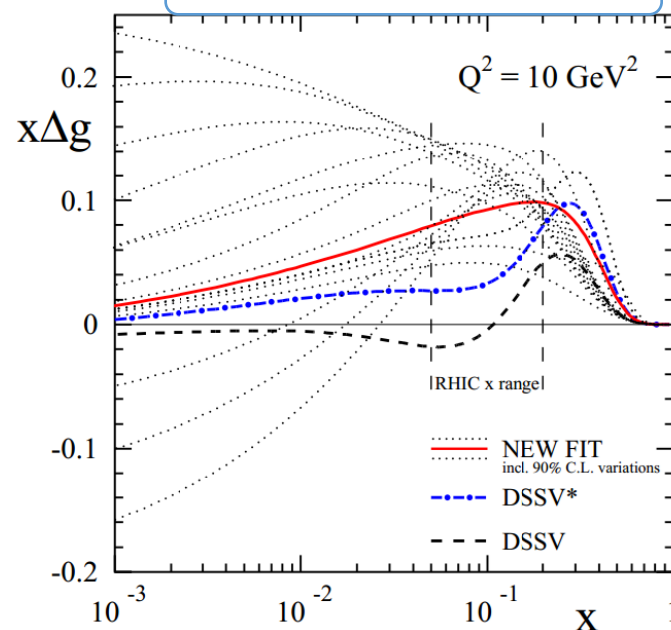
$$\frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + \Delta L_q + \Delta L_g$$

~ 0.33
(small)

Poorly
constrained

Manohar-Jaffe sum rule:

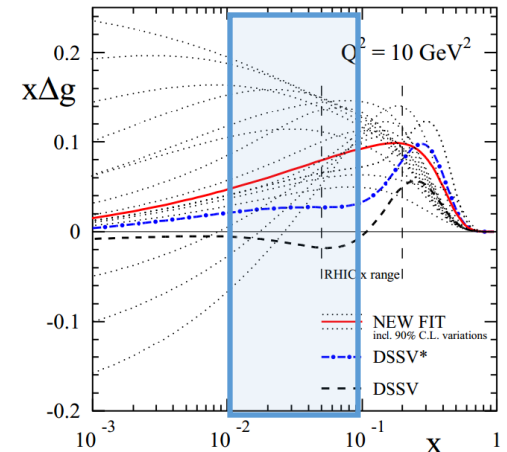
[Phys. Rev. Lett. 113, 012001 \(2014\)](#)



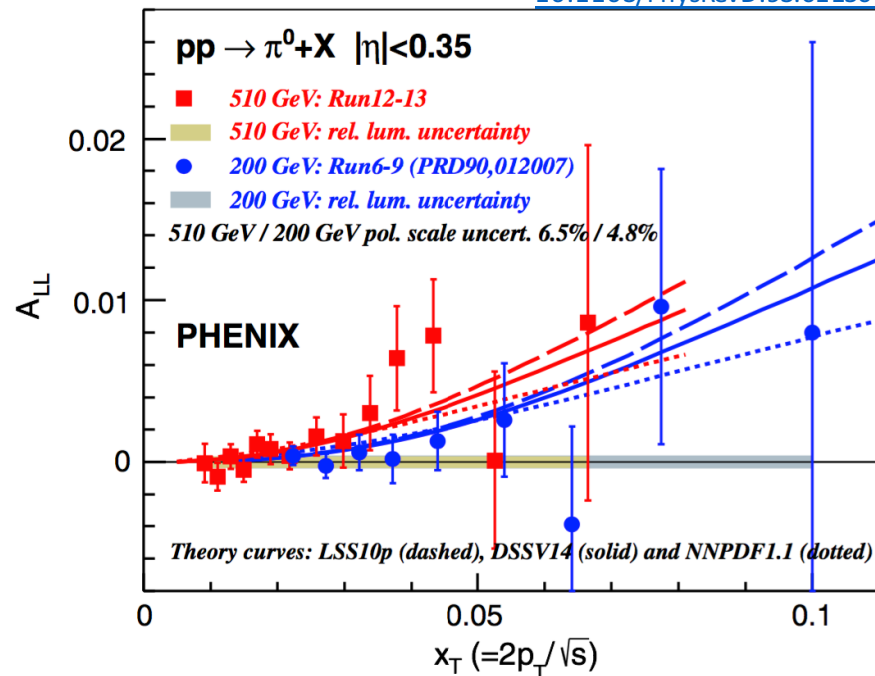
Hunt for the gluon spin: $\pi^0 A_{LL}$ @ 510 GeV

DSSV14: 10.1103/PhysRevLett.113.012001

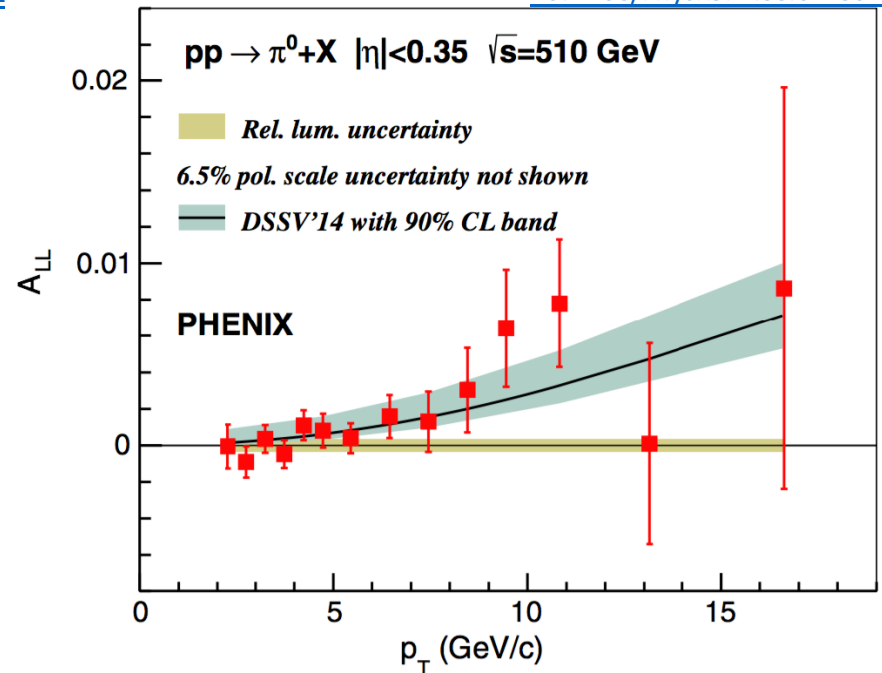
- Higher energy and more statistics pushed gluon sensitivity to smaller $x \sim 10^{-2}$
- Favor positive gluon polarization in $x \sim 10^{-2}$
- Finalized PHENIX π^0 double spin asymmetry published in 2016
- Additional constraints in global fit on gluon helicity beyond DSSV14



10.1103/PhysRevD.93.011501



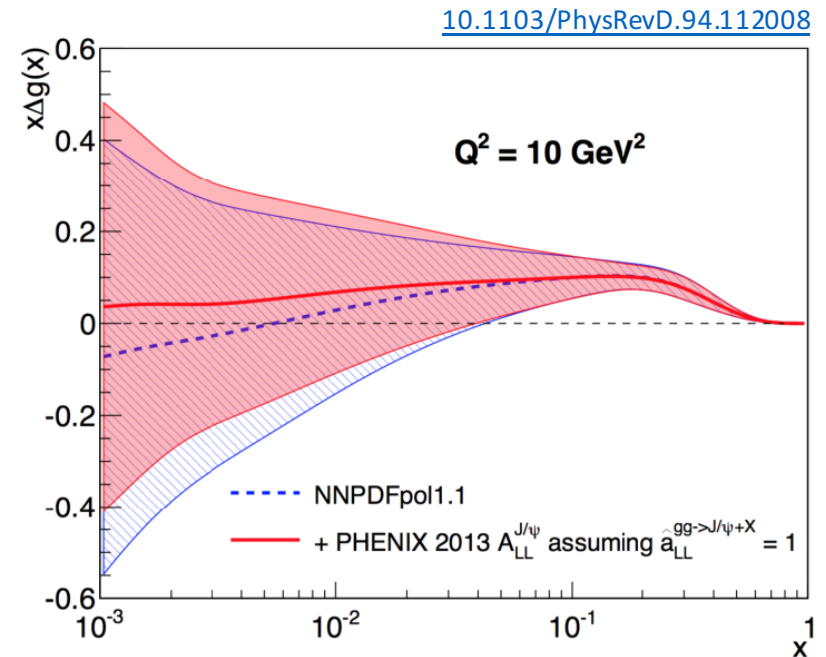
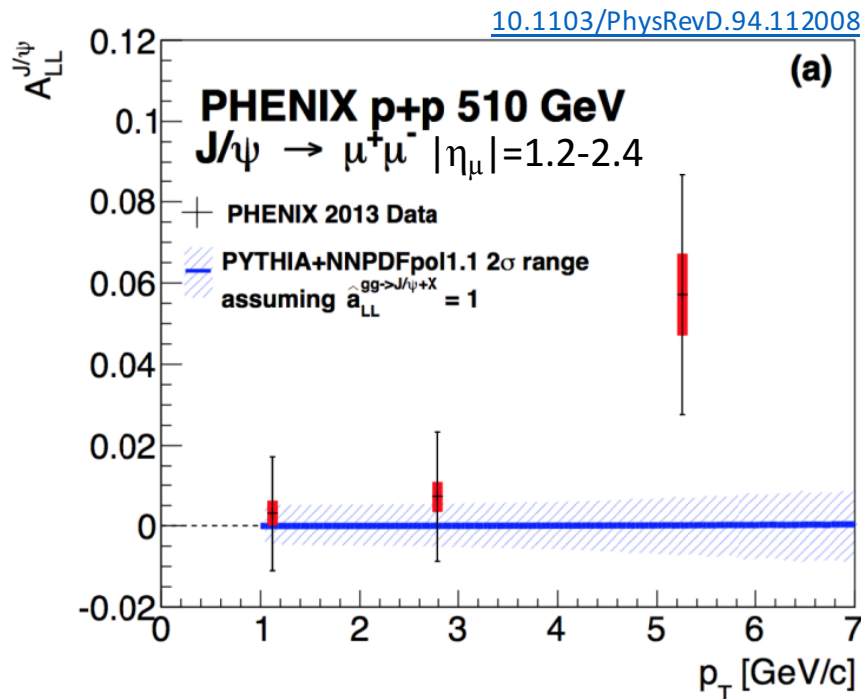
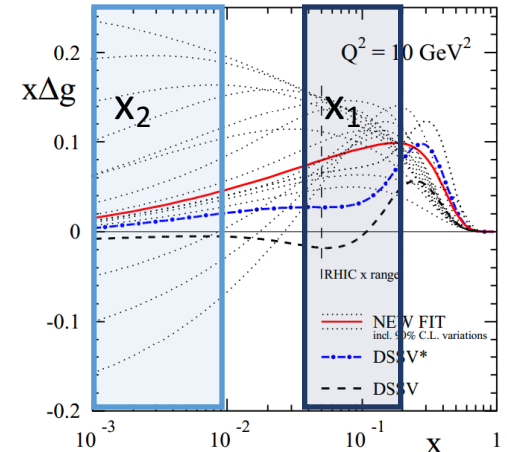
10.1103/PhysRevD.93.011501



Hunt for the gluon spin: $J/\psi A_{LL}$

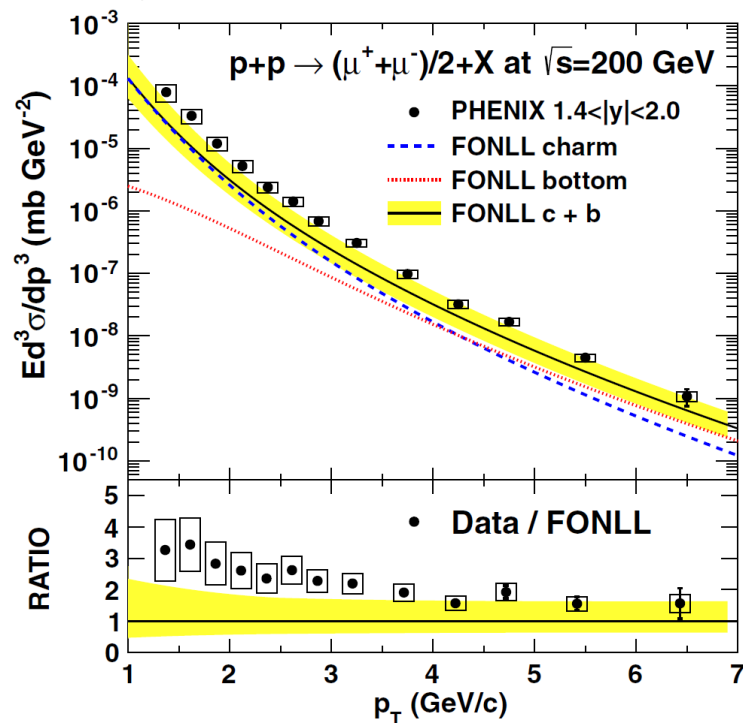
- Forward ($1.2 < |\eta| < 2.4$) J/ψ asymmetry couples better-known region ($x \sim 10^{-1}$) and much less constraint region ($x \sim 10^{-3}$)
- Consistent with current gluon polarization band mainly from light-quark process \rightarrow Universality test
- Demonstrate additional constraint (under assumptions) with refitting the NNPDFpol1.1

DSSV14: 10.1103/PhysRevLett.113.012001

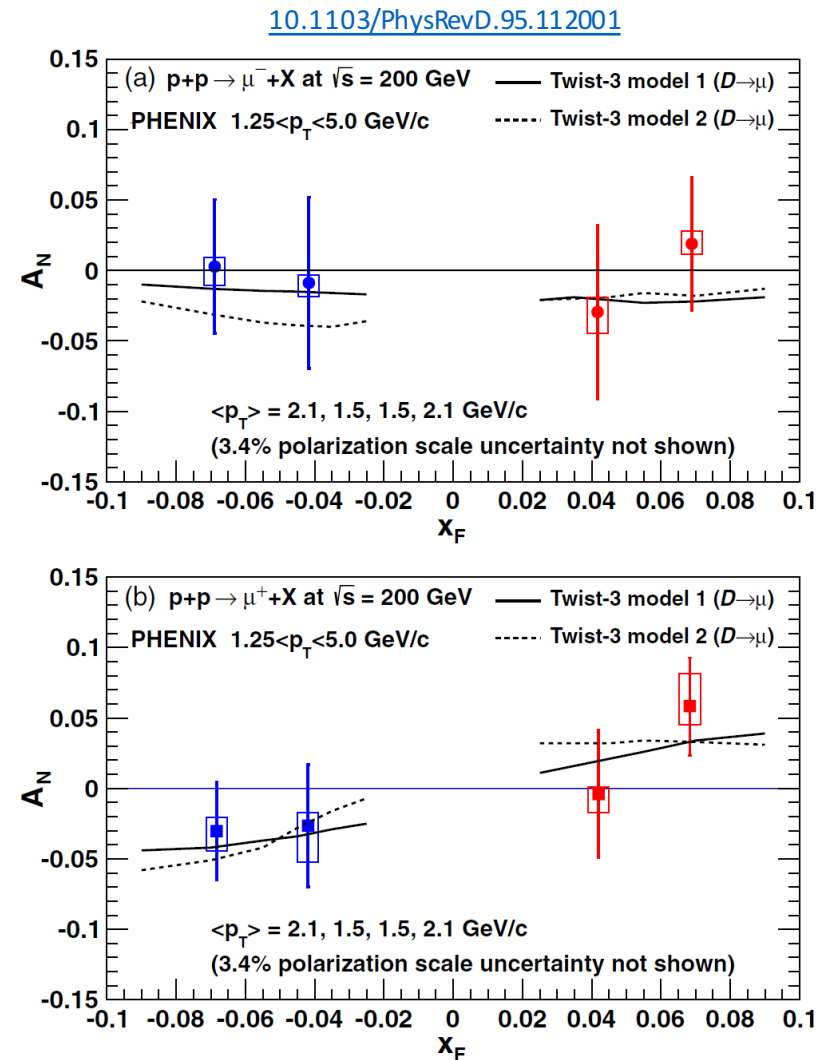


Hunt for transverse spin effect: HF single muon

- Use transverse spin (left-right asymmetry) to probe gluon dynamics
- Forward heavy flavor muon
 - Cross section hints higher than FONLL calculation
 - Transverse spin asymmetry consistent with $D \rightarrow \mu$ models using tri-gluon correlation functions. Larger data set of Run15 data being analyzed

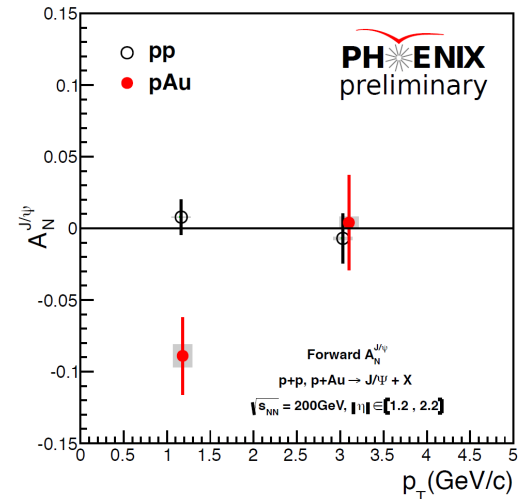
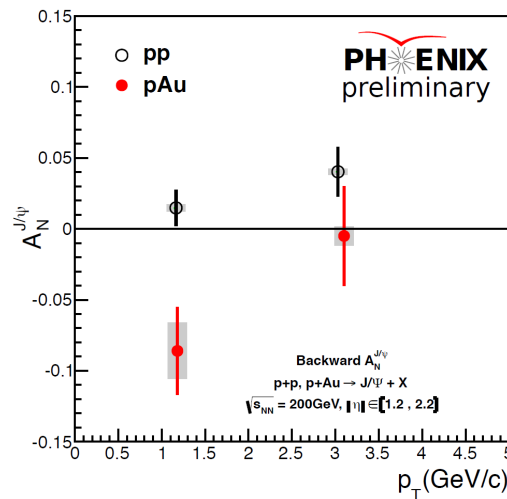
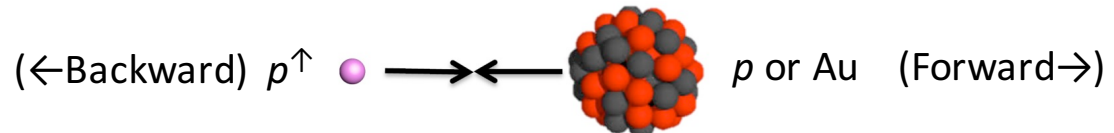
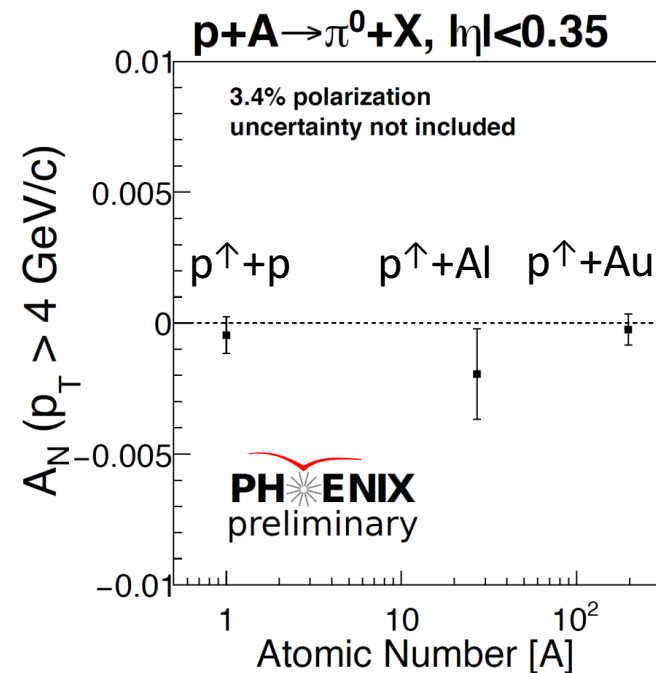


[10.1103/PhysRevD.95.112001](https://arxiv.org/abs/10.1103/PhysRevD.95.112001)



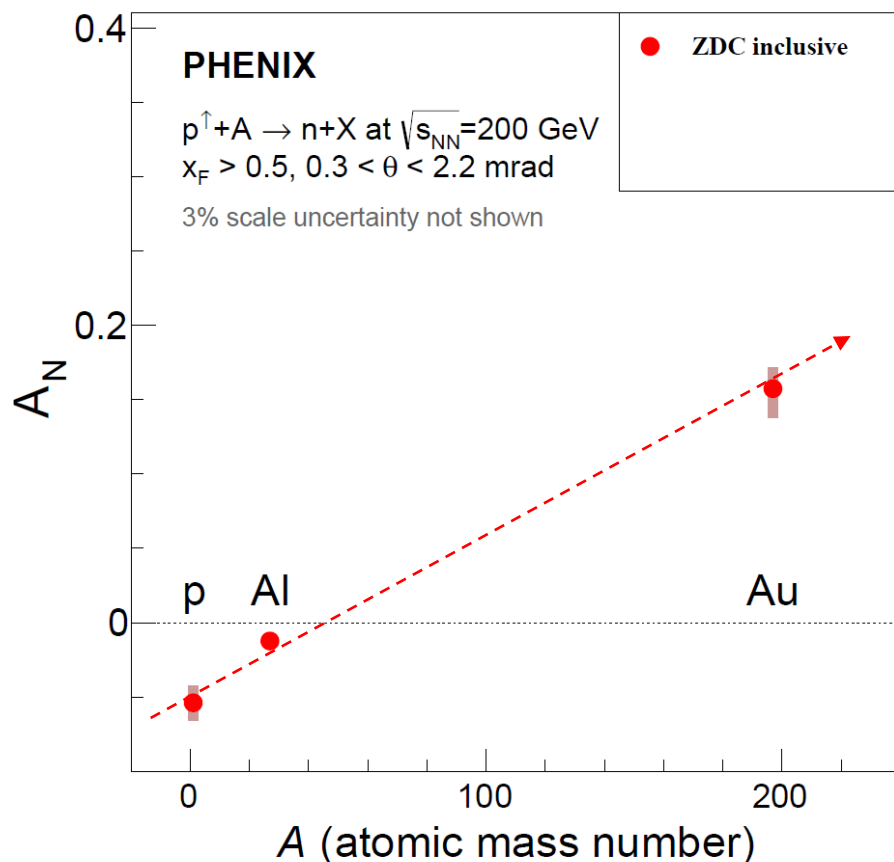
Hunt for transverse spin effect: π^0 and J/ψ production

- $\pi^0 A_N$ @ $x_F \sim 0$: transverse spin effect is small for $p + p$, $p + \text{Al}$ and $p + \text{Au}$
- Forward $J/\psi A_N$: indication large unexpected effect in $p + \text{Au}$ at lower p_T region
- Evidence that alternative mechanism playing important roles at $p + \text{Au}$ at lower p_T
 J/ψ production?

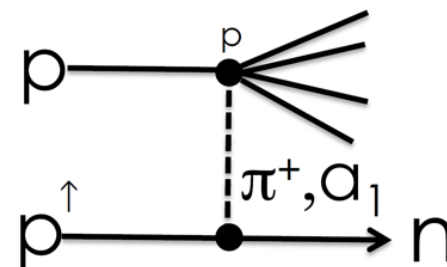


New exploration: Neutron transverse asymmetry in ZDC

arXiv:1703.10941



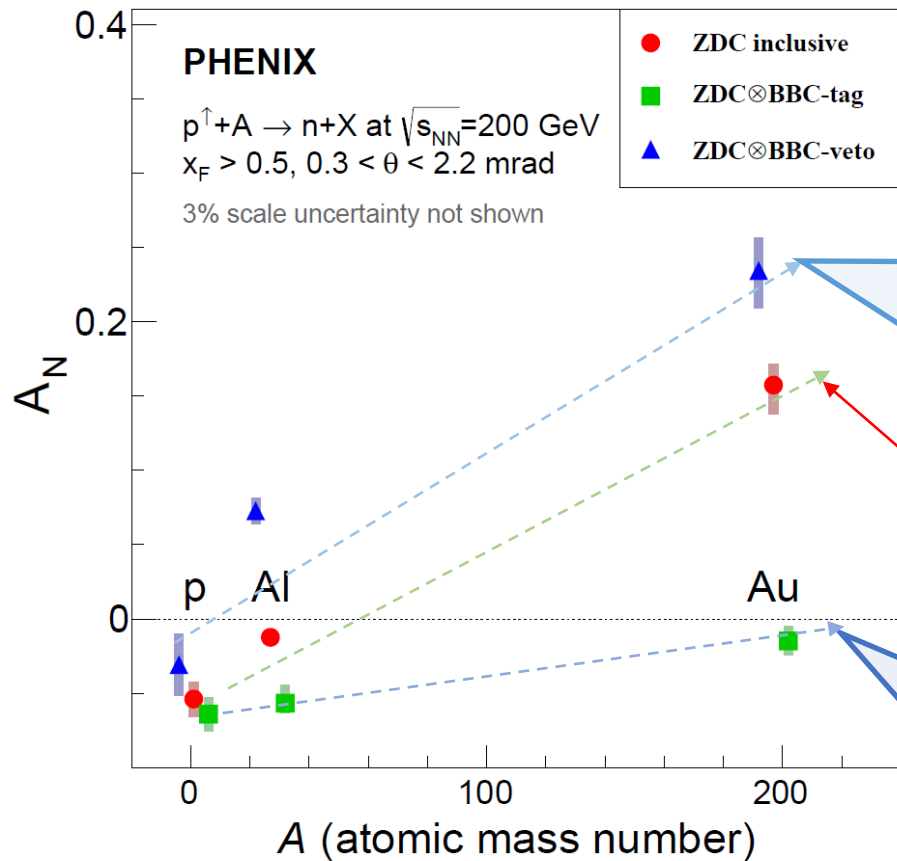
- Inclusive A_N in $p^\uparrow + p/A \rightarrow n (@ZDC) + X$, $|\eta| > 5.9$
- Show surprising sign change and enhancement in asymmetry
- Indicates that a process additional to π - a_1 -Reggeon interference model becomes dominant in “zero”-degree neutron production in the $p + A$ collision. More in Mitsuka, Eur.Phys.J.C75:614,2015



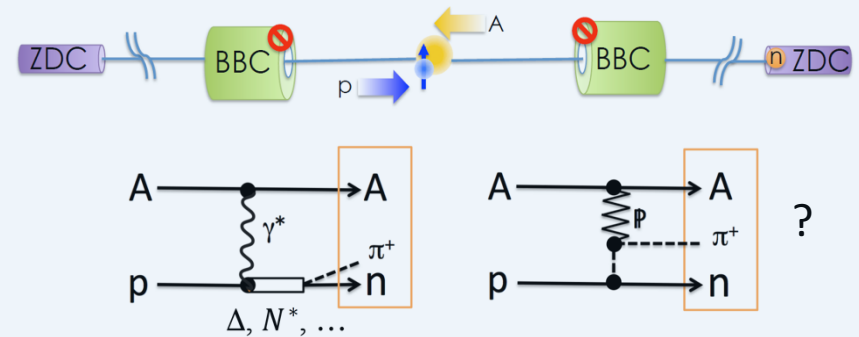
$$\text{Inclusive } A_N \sim \text{had} * \text{had} + \text{had} * \text{EM} + \text{EM} * \text{had} + \text{EM} * \text{EM}$$

New exploration: Neutron transverse asymmetry in ZDC

arXiv:1703.10941



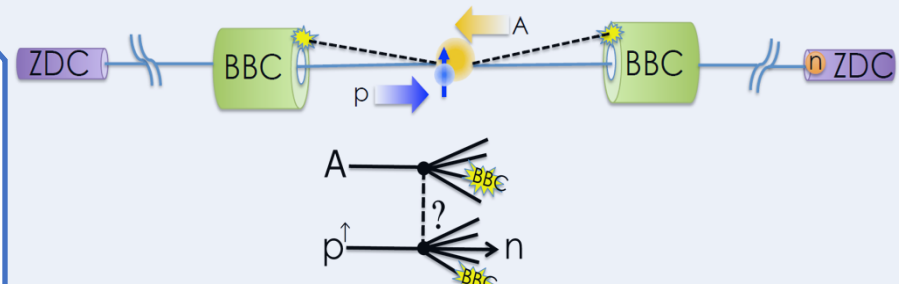
Require BBC **veto** ($3.1 < |\eta| < 3.9$)
 Enhancing QED-type process



Inclusive A_N

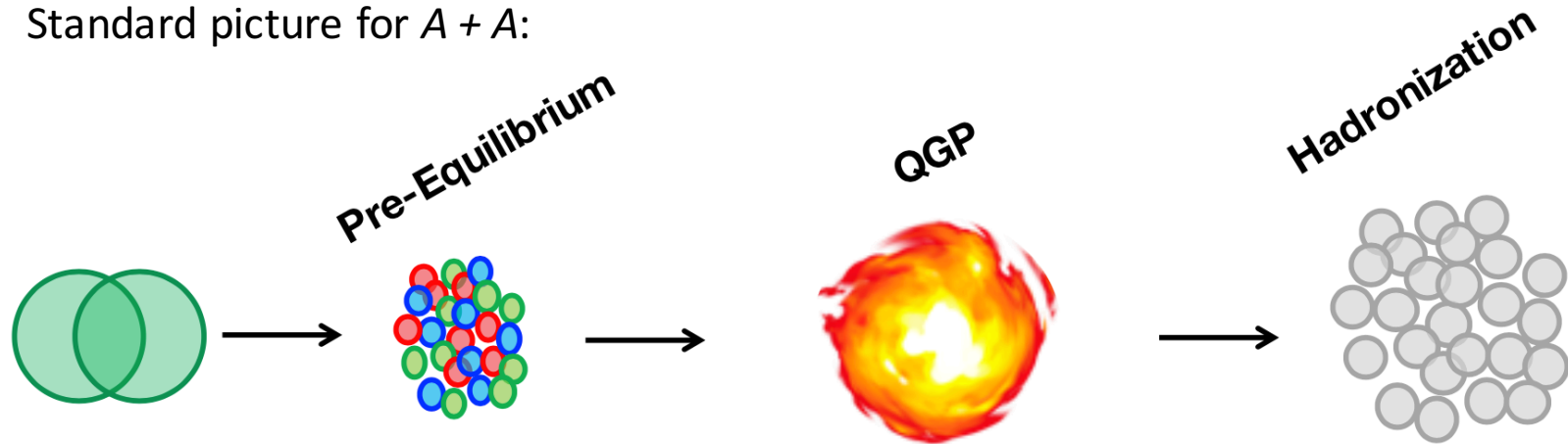
$\sim \text{had} * \text{had} + \text{had} * \text{EM} + \text{EM} * \text{had} + \text{EM} * \text{EM}$

Require BBC **coincidence** ($3.1 < |\eta| < 3.9$)
 Suppress QED-type process



Testing hydro by controlling system size

Standard picture for $A + A$:

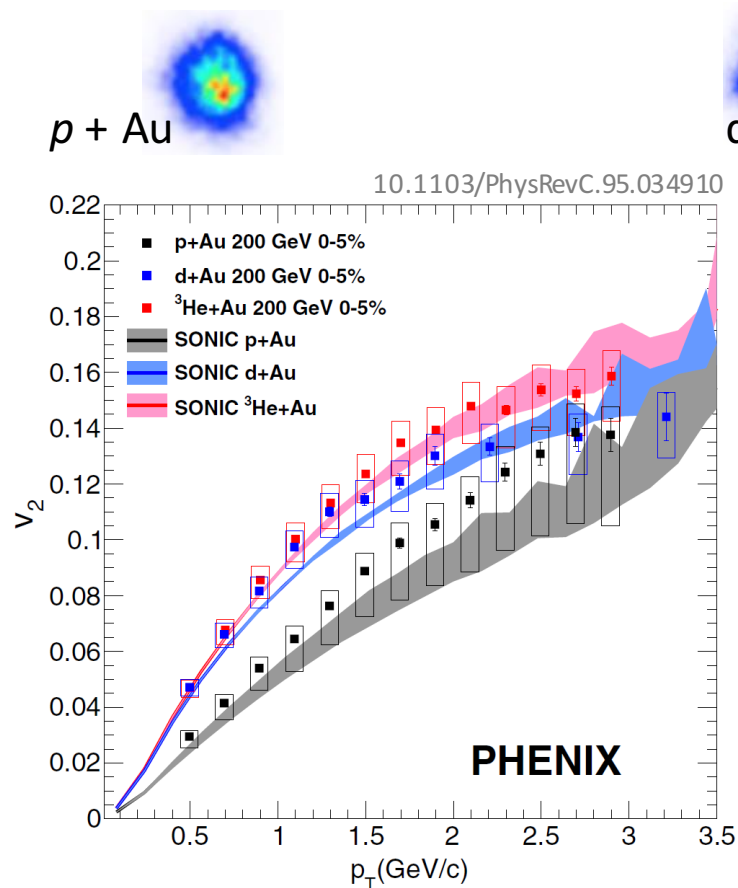


- The QGP behaves like nearly ideal, highly opaque liquid
- Reasonably described by viscous hydrodynamic models

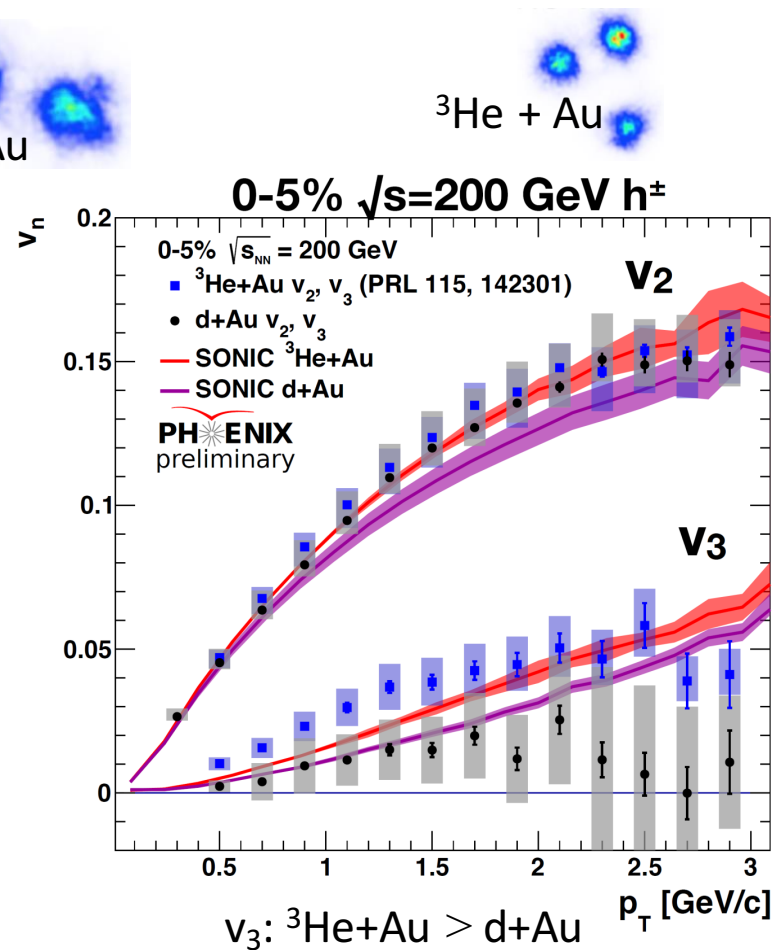
What about small systems? And lower energies?

- Use collision species and energy to control system size, test limits of hydro applicability

Small systems : $p/d/^3\text{He} + \text{Au}$ flow



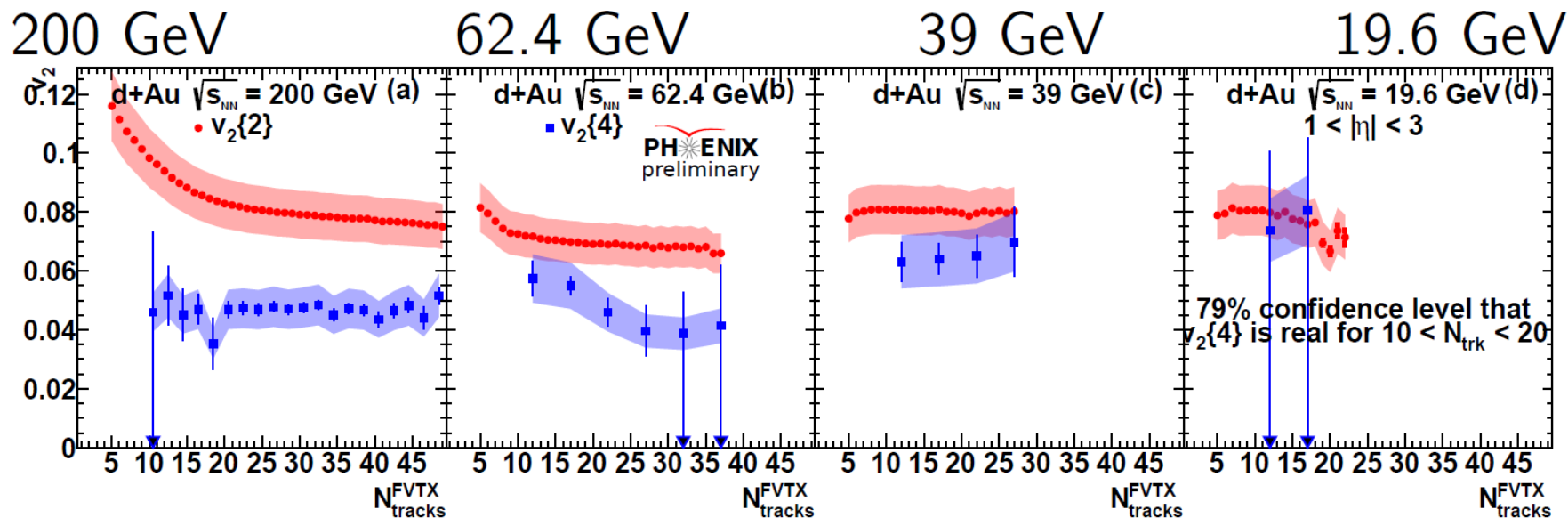
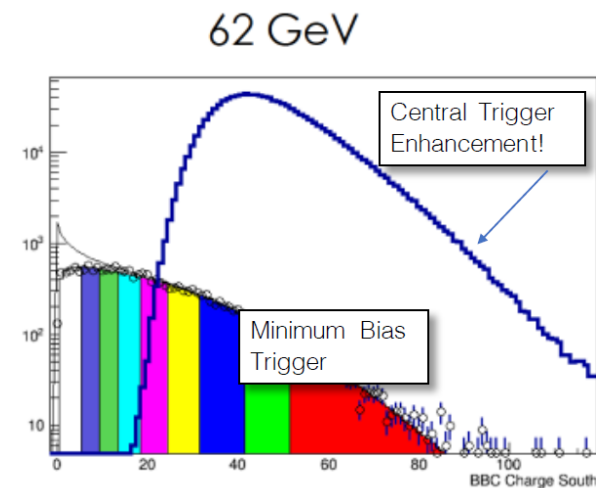
$v_2: ^3\text{He} + \text{Au} \approx d + \text{Au} > p + \text{Au}$



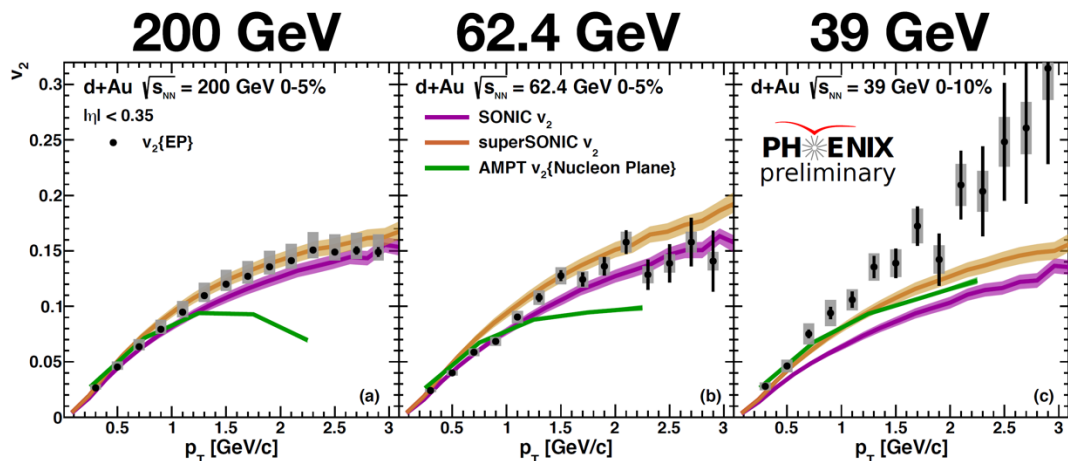
- Well reproduced by hydrodynamic model calculations
- Indicating initial geometry is the source of final state anisotropy

Small systems : d-Au energy scan

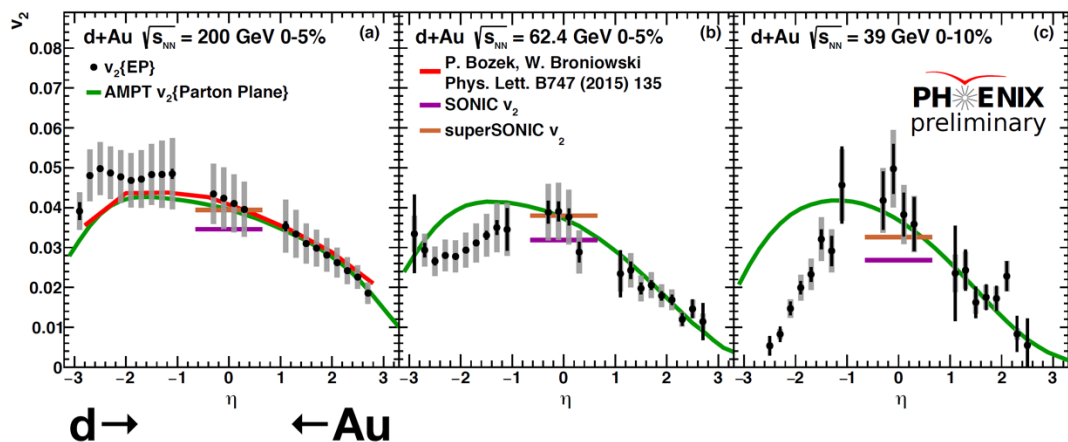
- Dedicated centrality trigger
- Observation of $v_2\{4\}$ in $d + Au$ at all energies
- Strong evidence of collectivity



Small systems : d-Au energy scan

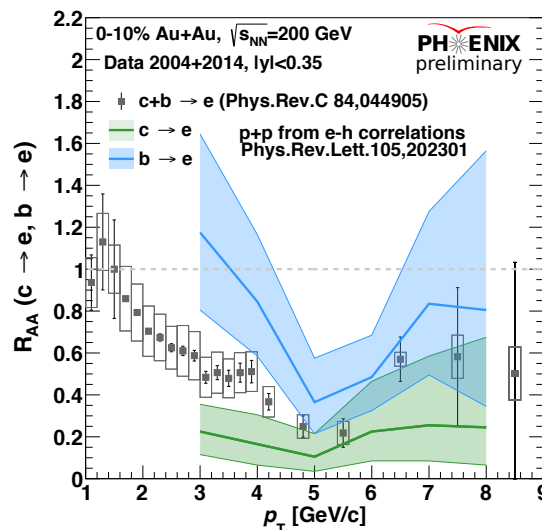
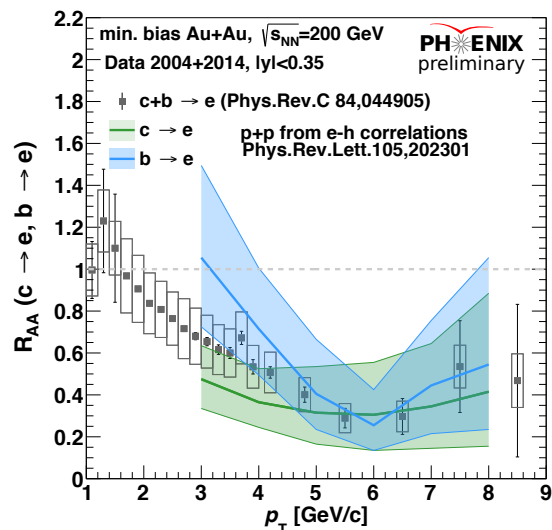
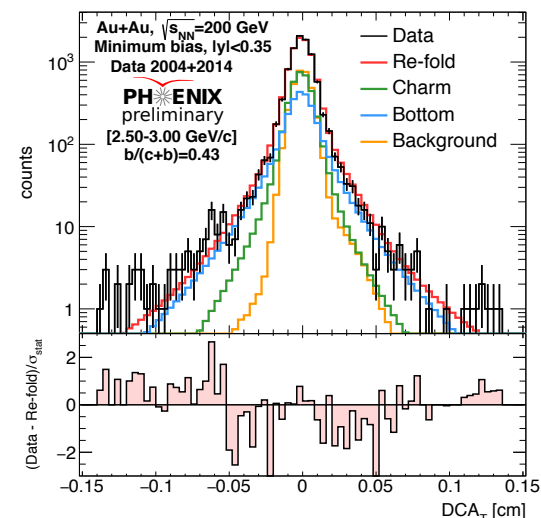
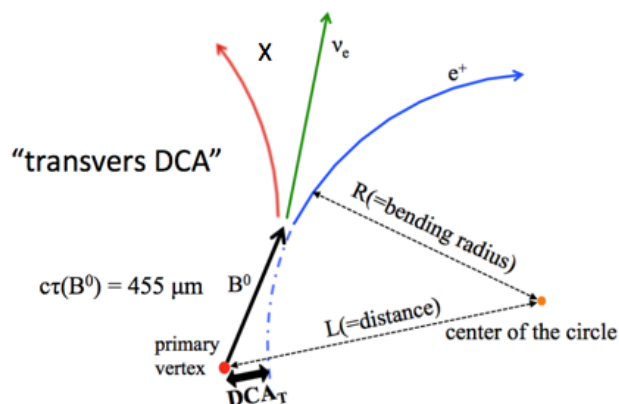
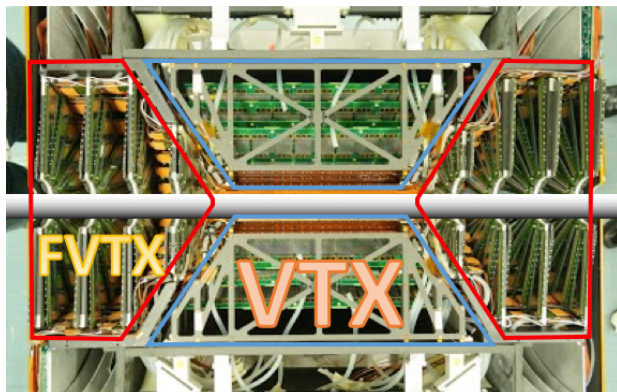


- Hydro theory agrees with higher energies very well, under-predicts lower energies
- At low p_T : AMPT (green) similar to hydro



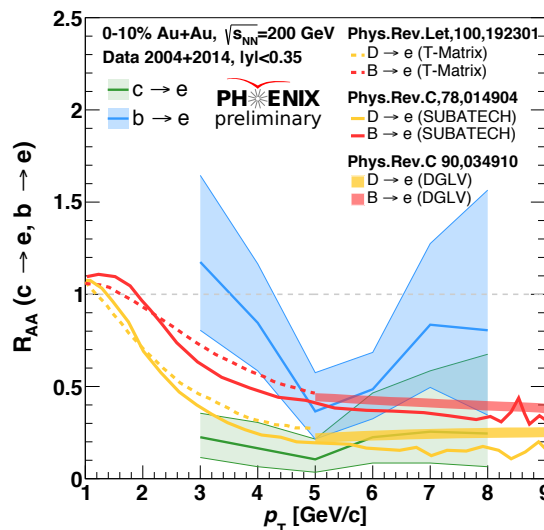
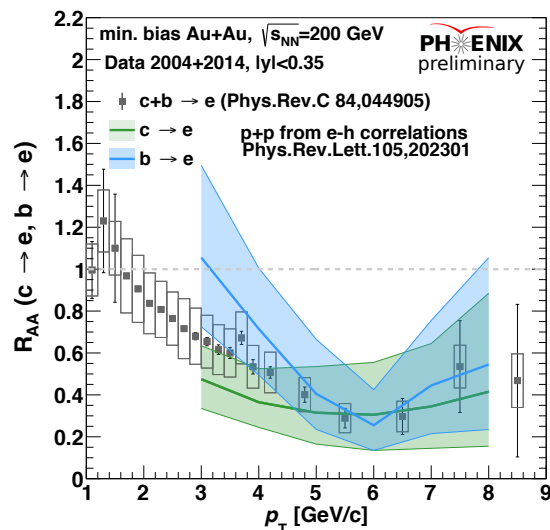
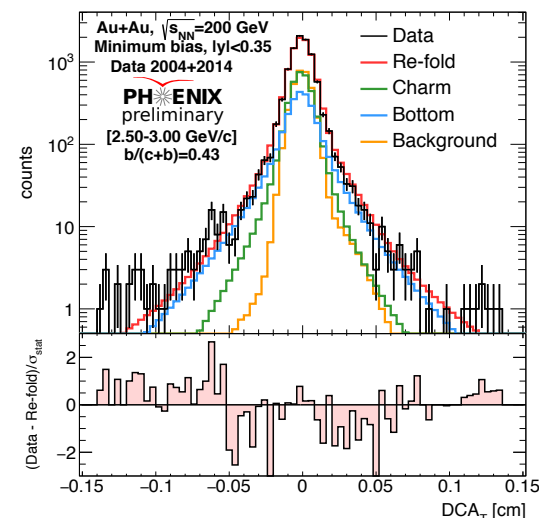
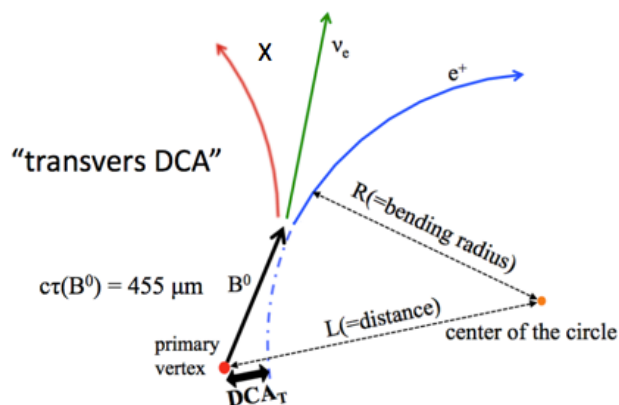
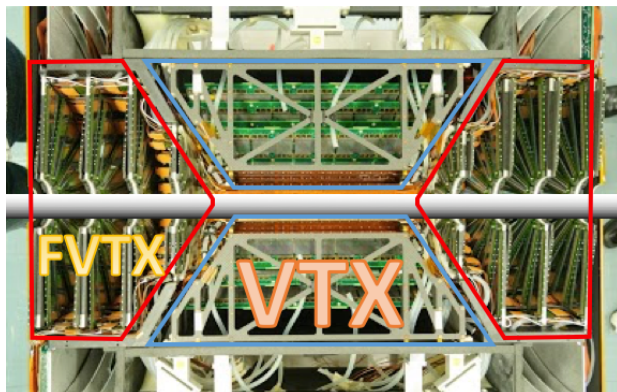
- ▶ At 200 GeV, AMPT and hydro models describe data well
- ▶ At lower energies, AMPT only describes very well at mid and forward

PHENIX Silicon detectors and Heavy Flavor Results



- Larger suppression for $D \rightarrow e$ observed in 0-10% events compared to Min-Bias sample
- Indication of less suppression for $B \rightarrow e$ vs. $D \rightarrow e$ in 0-10% events

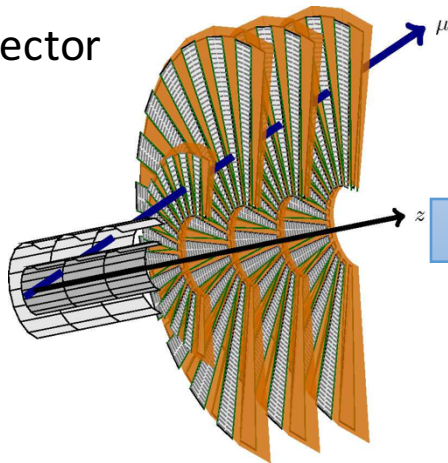
PHENIX Silicon detectors and Heavy Flavor Results



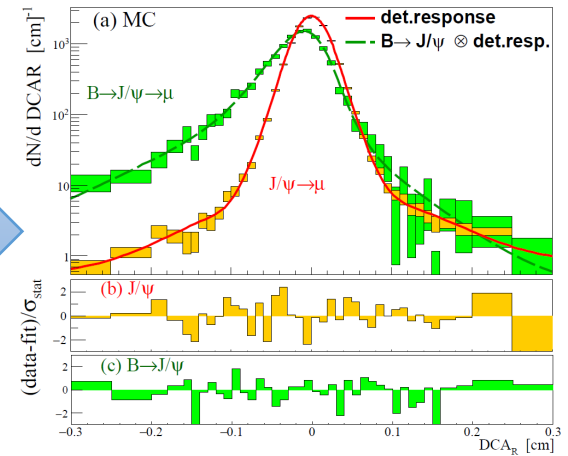
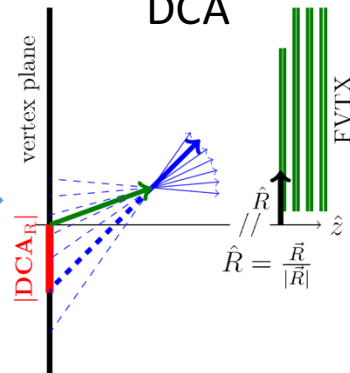
- Reasonable agreement (within uncertainties) with models including strong coupling between heavy quarks and the QGP medium ($D(2\pi T) < 4$)
- Coming soon: reduced uncertainties and broader p_T range once full datasets from 2014 + 2016 are analyzed

First open-HF FVTX results: Open- b production via non-prompt J/ψ

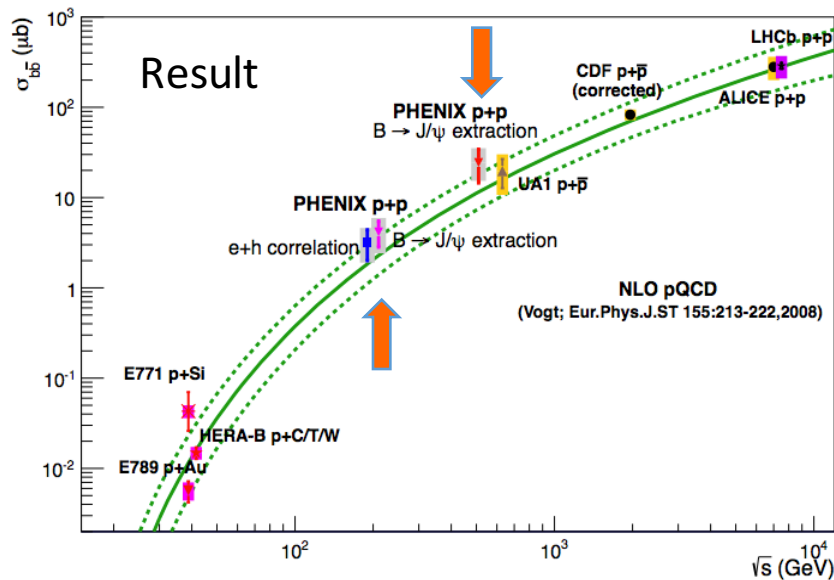
Detector



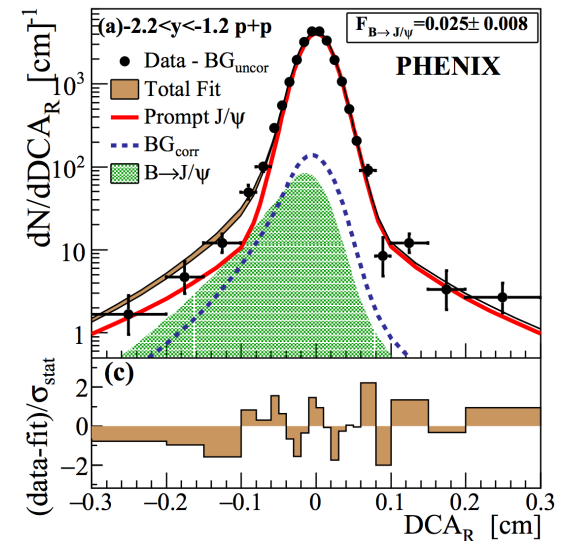
DCA



Shape

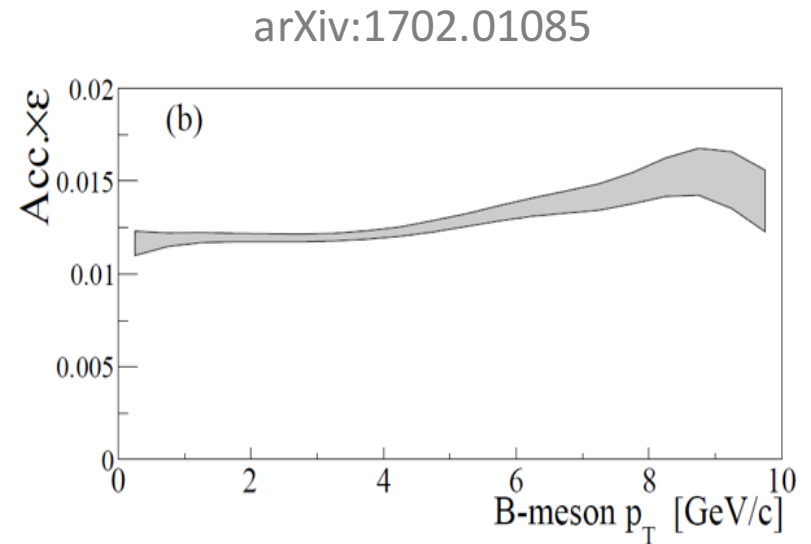
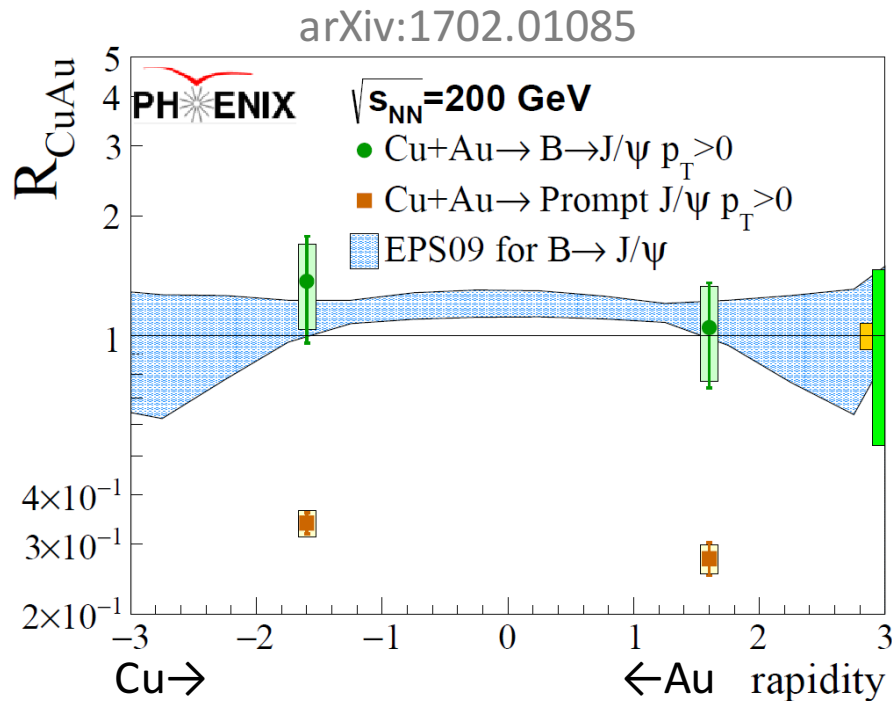


Result



Fit

First open-HF FVTX results: Open- b production via non-prompt J/ψ

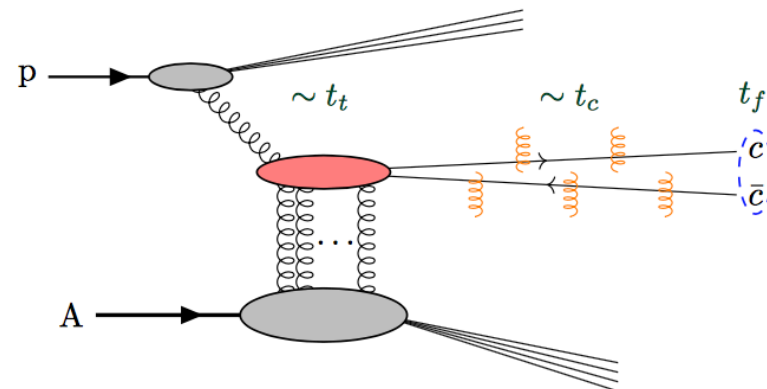


- Prompt J/ψ number is not preserved in final interactions:
 - breaking/melting in medium
- Non-prompt J/ψ R_{CuAu} consistent with nPDF EPS09 initial state effects
 - Acc. \times Eff. down to zero- p_T by detecting decay along z
- Next: Run14 Au+Au and single muons

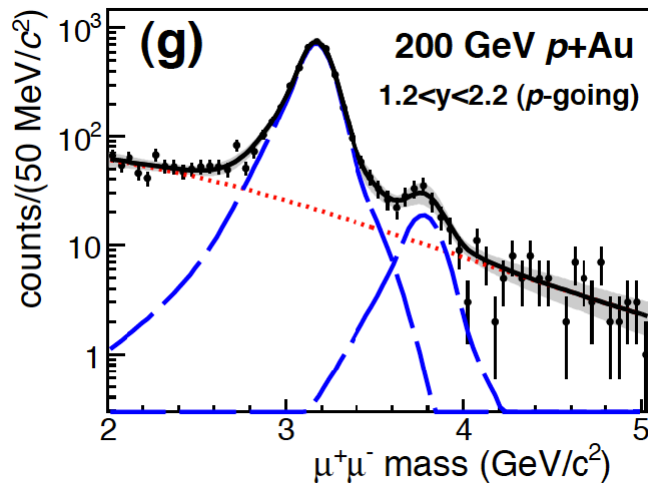
Relative suppression of $\psi(2S)/\psi(1S)$

- Relative suppression of forward $\psi' \rightarrow \mu^+\mu^-$ in multiple collision system with assist of FVTX
- Final state breakup due to co-mover effect? Factorization violating soft color exchanges, Ma et. al. arXiv:1707.07266

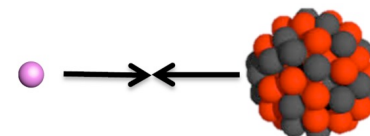
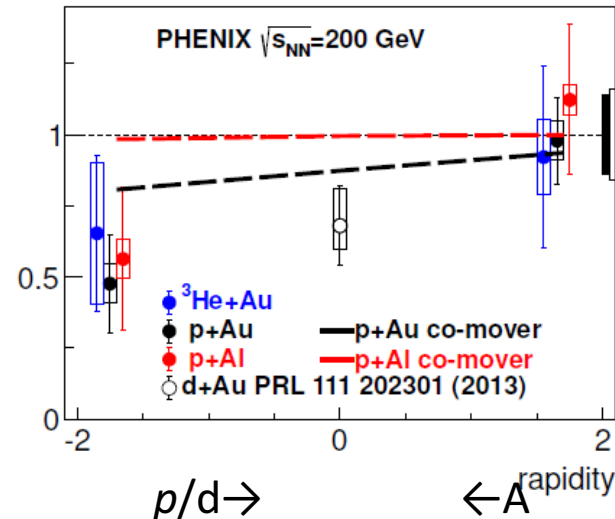
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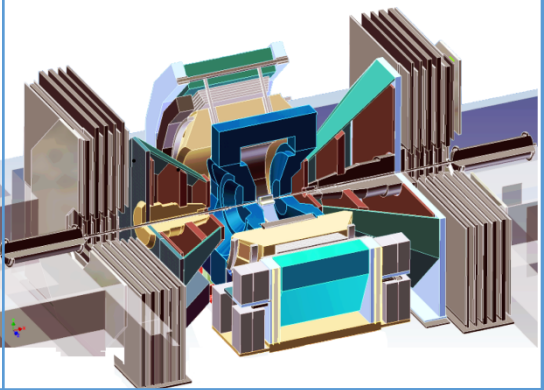
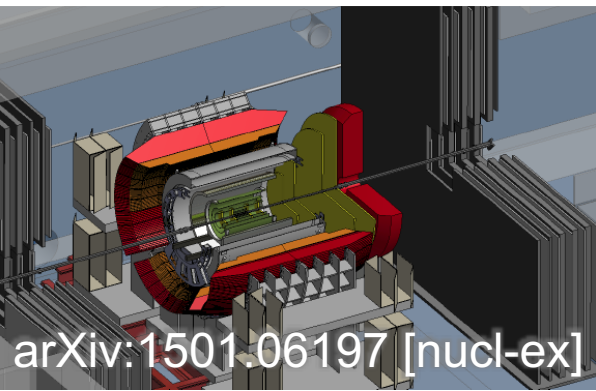
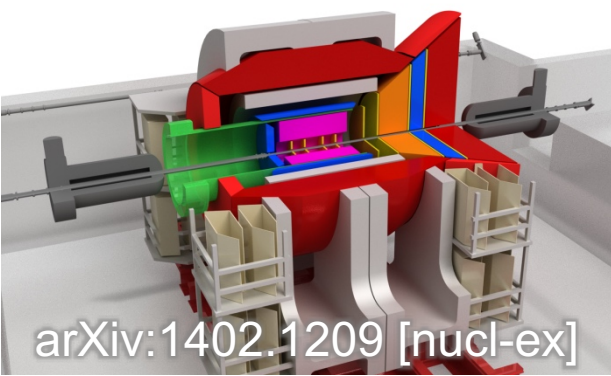
10.1103/PhysRevC.95.034904



$$\frac{\left[\frac{\sigma_{\psi(2S)}}{\sigma_{\psi(1S)}} \right]_{p^3\text{He}+A}}{\left[\frac{\sigma_{\psi(2S)}}{\sigma_{\psi(1S)}} \right]_{p+p}}$$

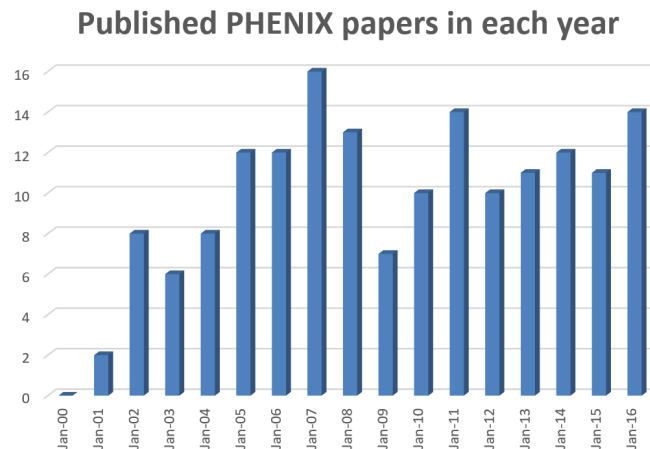


Evolution of the PHENIX Interaction region

PHENIX experiment	sPHENIX	An EIC detector
<ul style="list-style-type: none"> • 16y+ operation • Broad spectrum of physics (QGP, Hadron Physics, DM) • 170+ physics papers with 24k citations • Last run in this form 2016 	<ul style="list-style-type: none"> ▶ Comprehensive central upgrade base on BaBar magnet ▶ Rich jet and beauty quarkonia physics program → nature of QGP ▶ Possible forward tracking, and calorimeter → Spin, CNM  <p>arXiv:1501.06197 [nucl-ex]</p>	<ul style="list-style-type: none"> ▶ Path of PHENIX upgrade leads to a capable EIC detector ▶ Large coverage of tracking, calorimetry and PID ▶ Open for new collaboration/new ideas  <p>arXiv:1402.1209 [nucl-ex]</p>
<p>RHIC: A+A, spin-polarized p+p, spin-polarized p+A</p>		<p>EIC: e+p, e+A</p>

Summary

- ❖ Rich results impact our understanding of proton spin and the QGP
- ❖ In 2016 PHENIX took the last DAQ run. Multiple golden datasets. The collaboration maintains high productivity in analysis and publication
- ❖ Exciting opportunities at the PHENIX IR with the sPHENIX project and future EIC detector



Cumulative Citations of PHENIX papers

