

PHENIX Highlights

From Protons to Heavy Ions, and Back

Jin Huang (BNL)

For PHENIX Collaboration

PHENIX Overview

MPC/MPC-EX/BBC
 $3.1 < |\eta| < 3.9$
 γ

Central Arms
 $|\eta| < 0.35$
 e^\pm, γ, π, K, p

Muon Arms
 $1.2 < |\eta| < 2.2$
 μ

ZDC $|\eta| > 5.9$

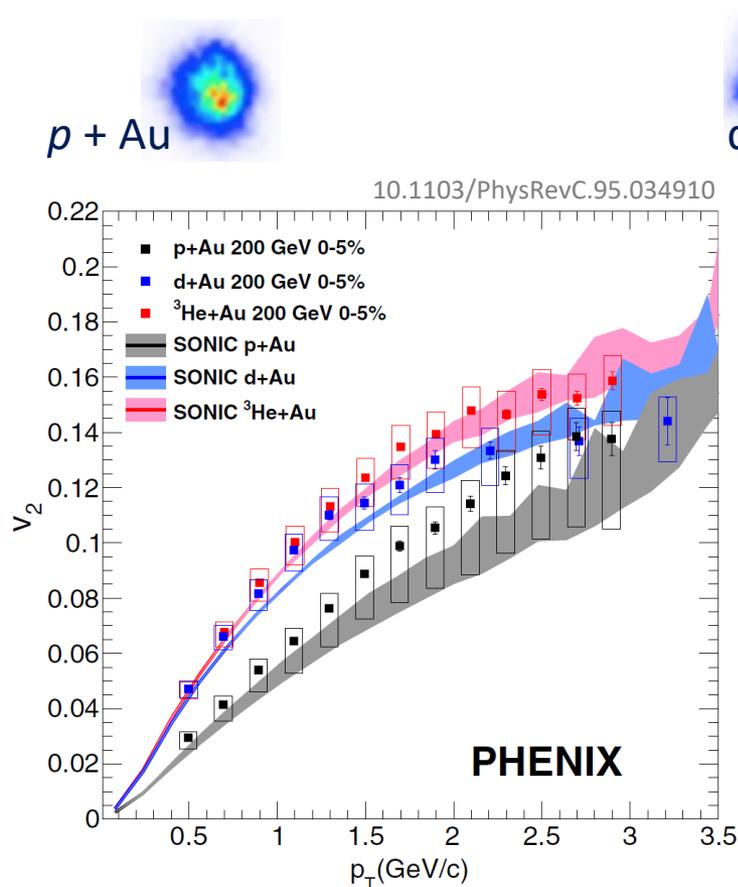
Vertex tracker (FVTX)
 $1 < |\eta| < 3$

Vertex tracker (VTX)
 $|\eta| < 1.2$

\sqrt{s} [GeV]	 p+p	 p+Al	 p+Au	 d+Au	 $^3\text{He}+\text{Au}$	 Cu+Cu	 Cu+Au	 Au+Au	 U+U
510	✓								
200	✓	✓	✓	✓	✓	✓	✓	✓	✓
130								✓	✓
62.4	✓			✓		✓		✓	✓
39				✓				✓	✓
27								✓	✓
20				✓		✓		✓	✓
14.5								✓	✓
7.7								✓	✓

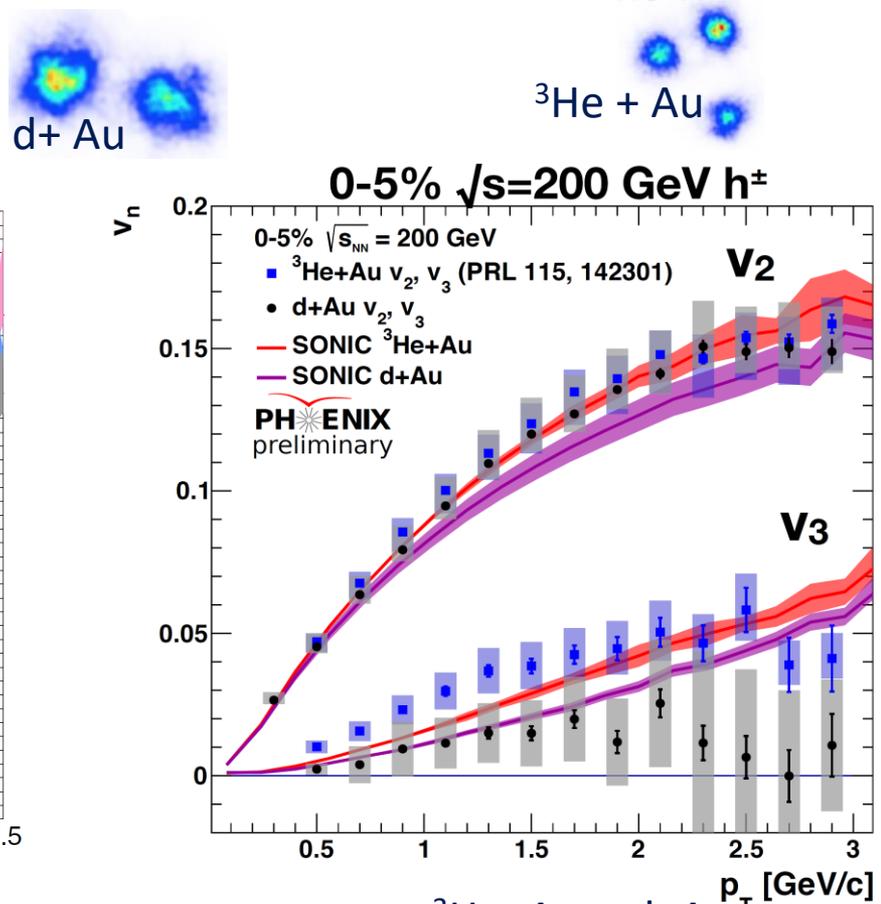
- ▶ Since last AUM: Productive year for PHENIX with a comprehensive set of new results
- ▶ Large data sets on disk
- ▶ Active analysis,
 - Finalizing traditional channels
 - Exploring new

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

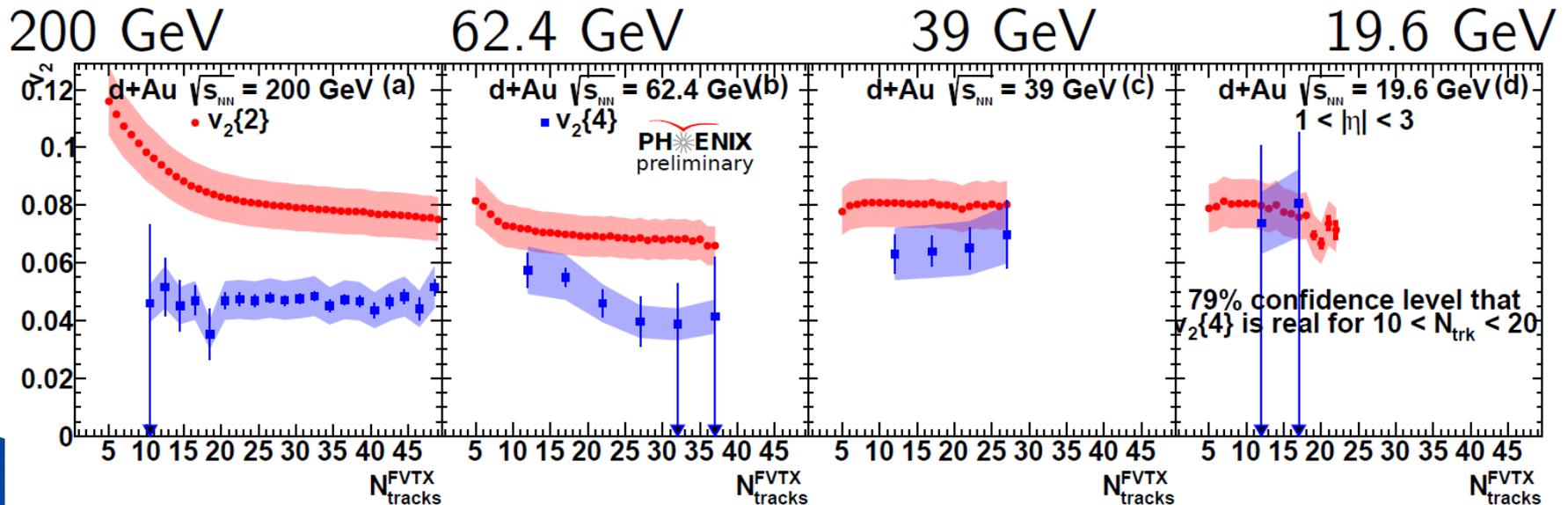
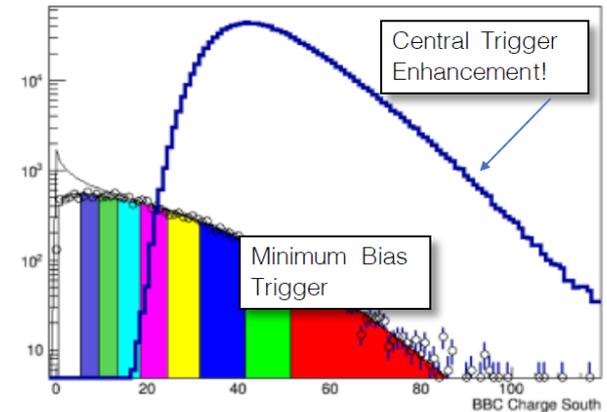


$v_3: {}^3\text{He}+\text{Au} > d+\text{Au}$

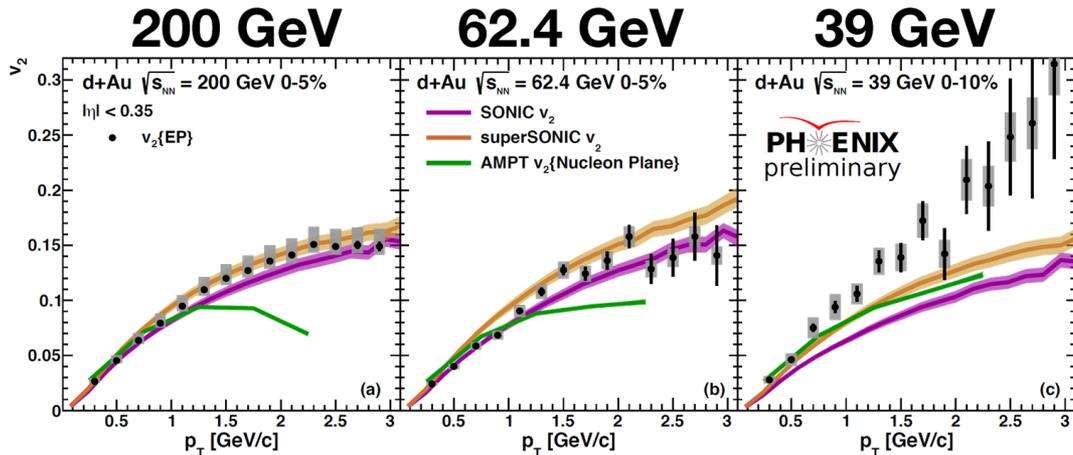
Small systems : d-Au energy scan

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

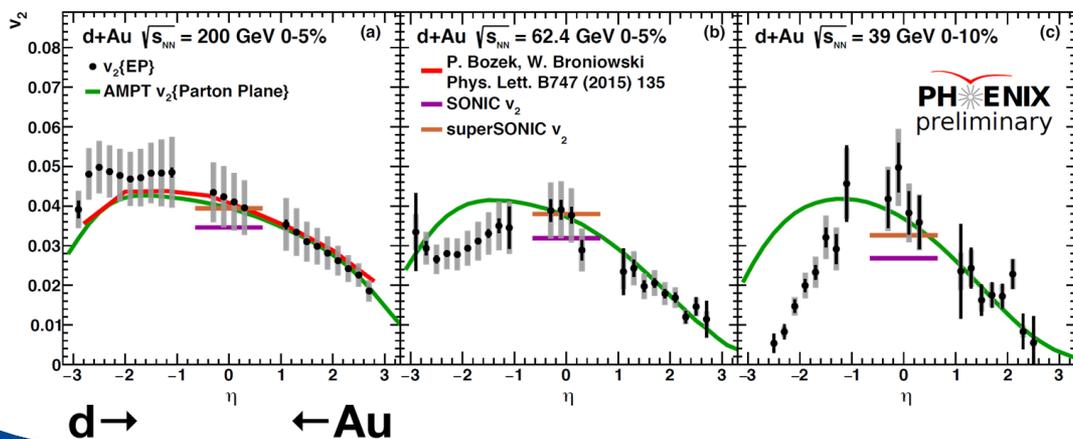
62 GeV



Small systems : d-Au energy scan

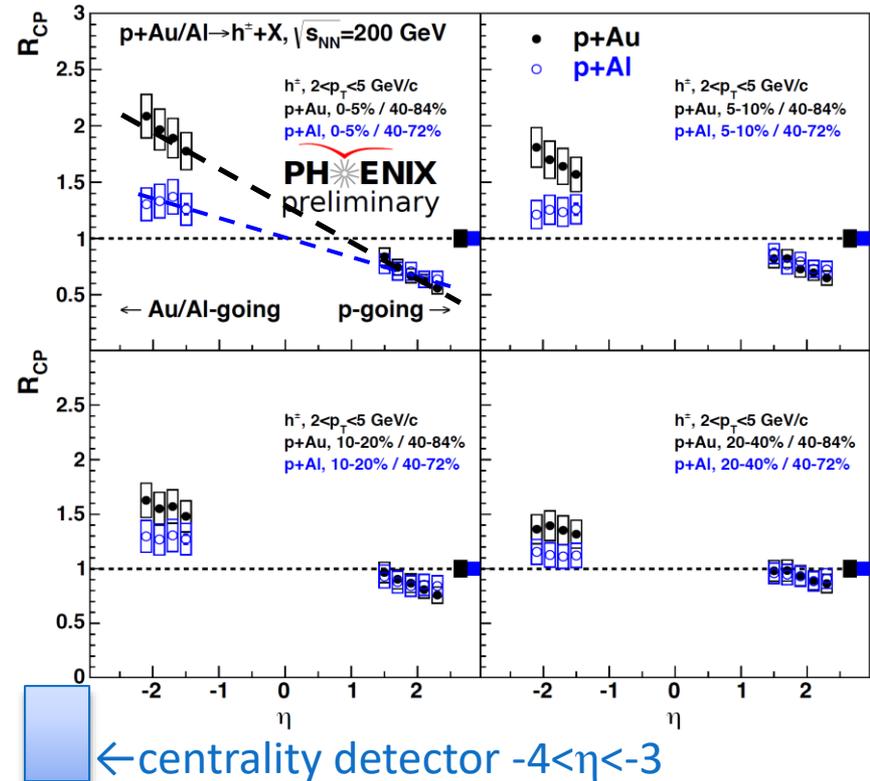
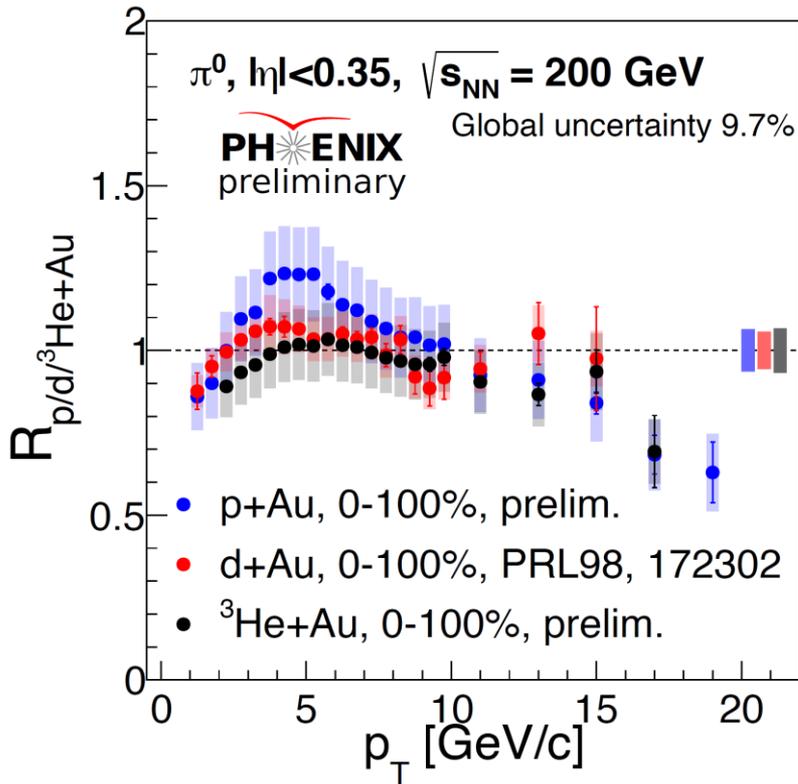


- ▶ Hydro theory agrees with higher energies very well, under-predicts lower energies
- ▶ At low p_T : AMPT similar to hydro



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

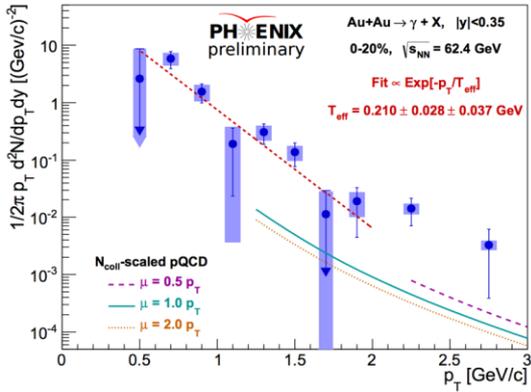
Small systems : high p_T hadrons



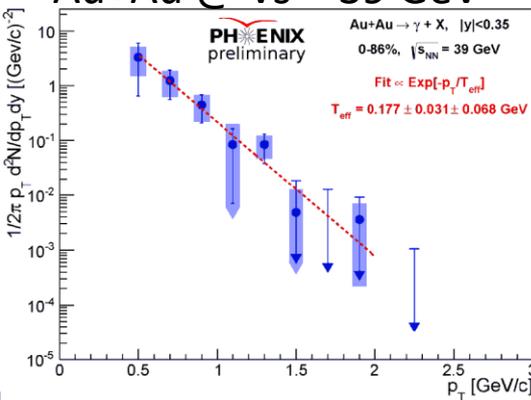
- ▶ System size dependent enhancement at $p_T \sim 5 \text{ GeV/c}$: $R_{p+\text{Au}} > R_{d+\text{Au}} > R_{{}^3\text{He+Au}}$
- ▶ \sim linear pseudorapidity dependence: Backward enhancement – p+Au > p+Al
 Forward suppression – p+Au \approx p+Al

Large systems : Effective temperature

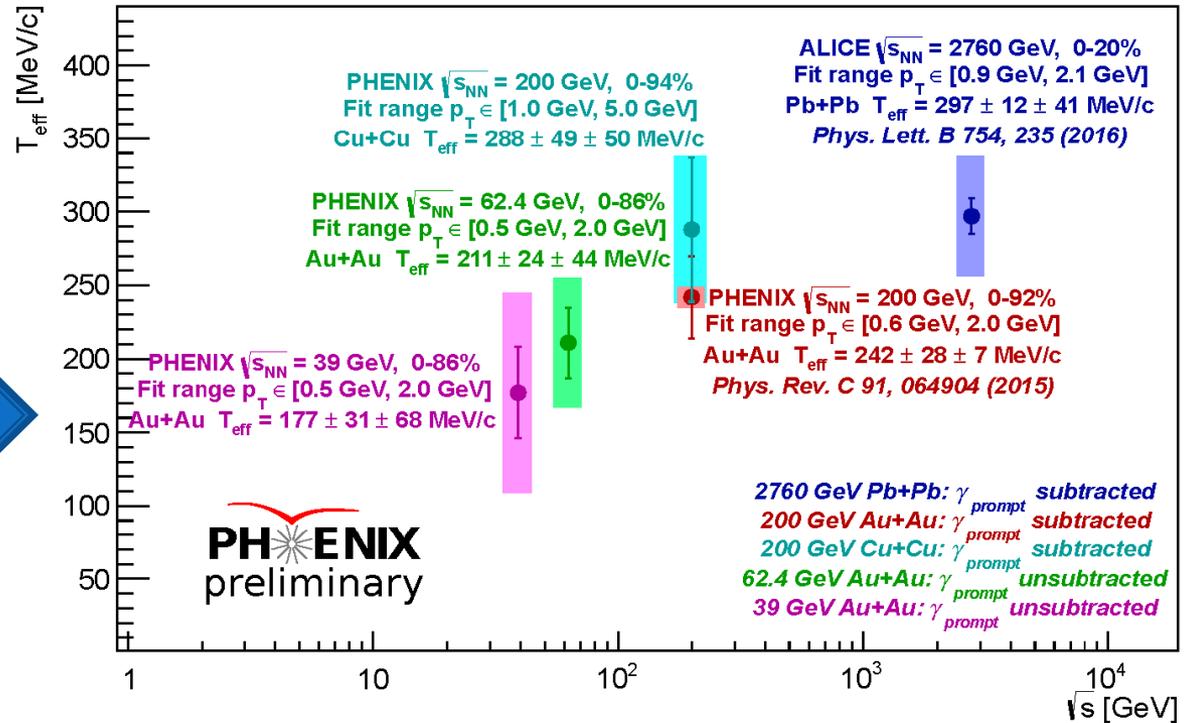
Au+Au @ $\sqrt{s} = 62$ GeV



Au+Au @ $\sqrt{s} = 39$ GeV

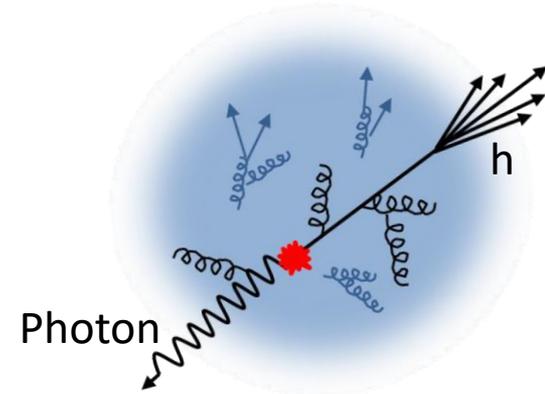


T_{eff} vs. collision energy

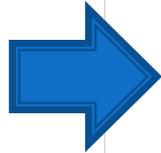
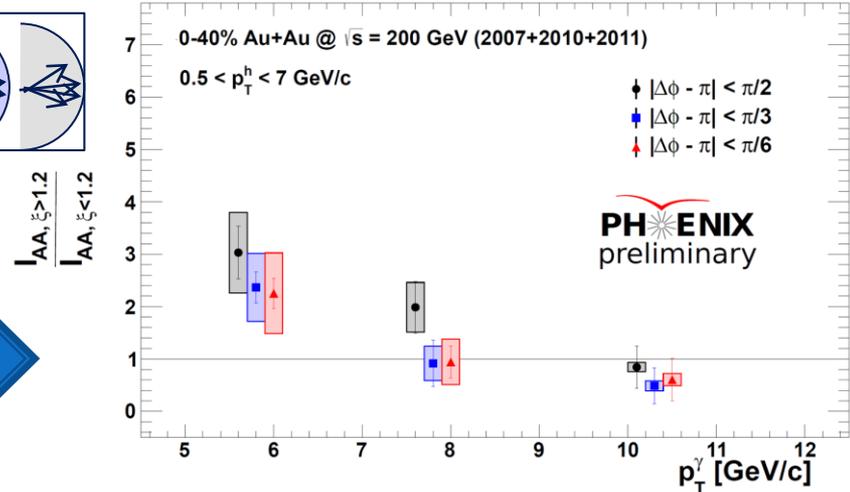
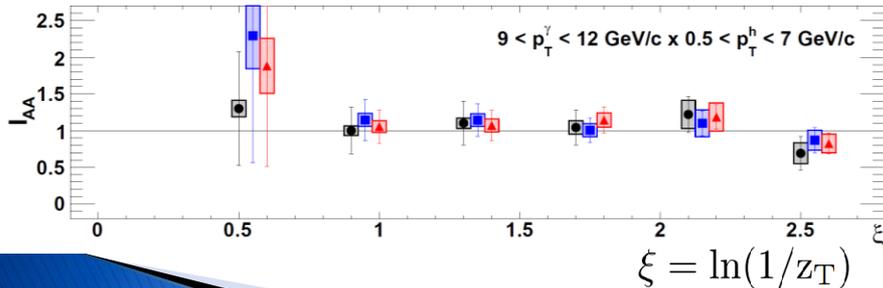
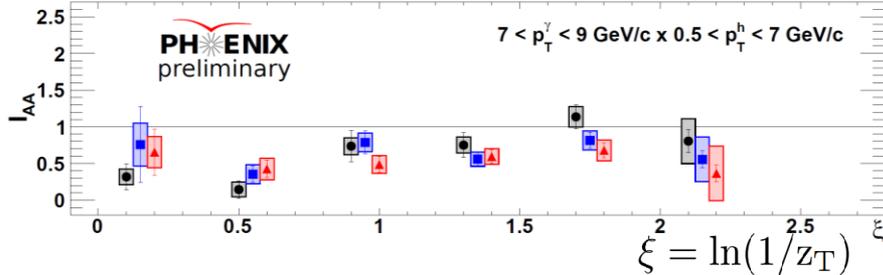
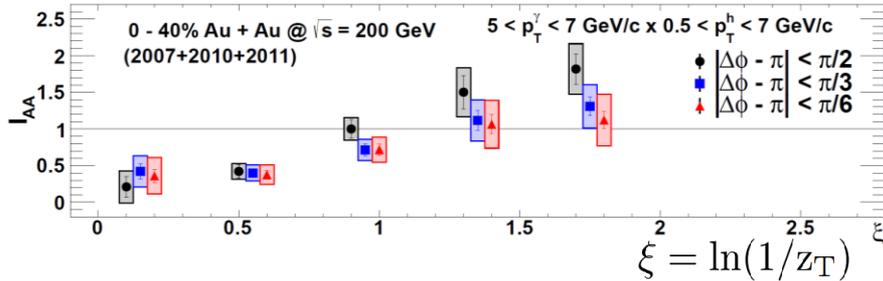


- ▶ Photon excesses are observed in Au+Au at 62 and 39 GeV
- ▶ $\sqrt{s} = 200$ GeV : T_{eff} consistent between Cu+Cu and Au+Au

Large systems : Modification of fragmentation



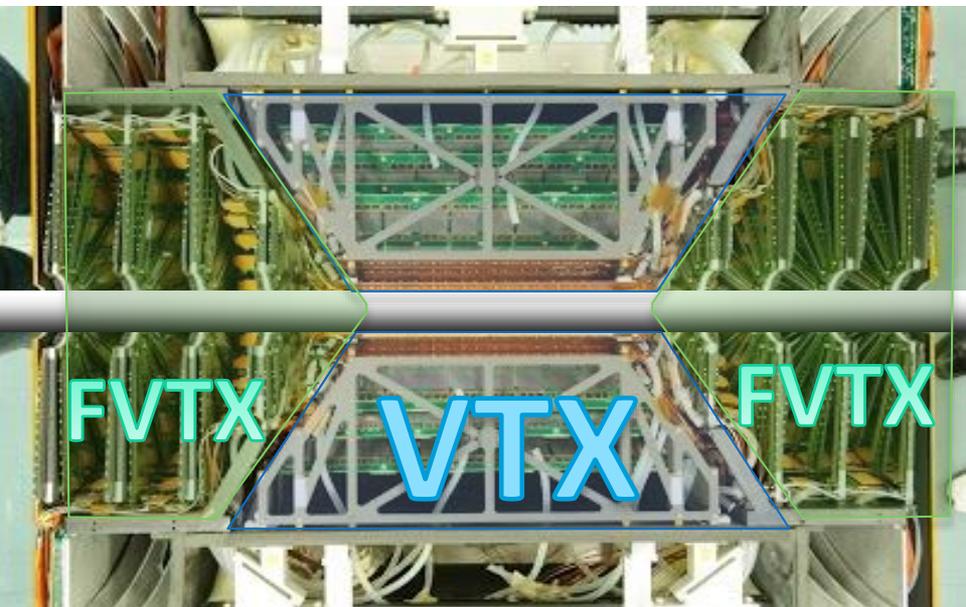
γ -h pairs in 0-40% C. Au+Au @ $\sqrt{s} = 200$ GeV



- ▶ Tagging parton kinematics using photons
- ▶ Softer partons (< 7 GeV GeV/c):
More broadened -> particles produced from jet-induced medium excitations?
- ▶ Harder partons (~10 GeV/c):
More collimated -> particles more correlated with the jet?

See also: H. Ge (Tue)

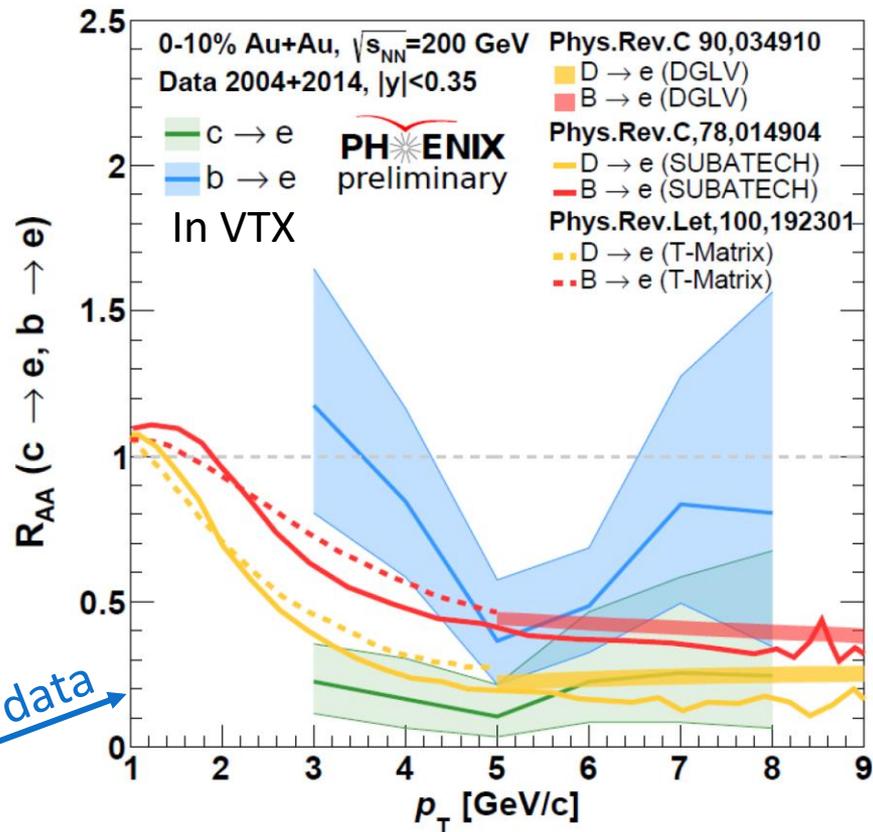
PHENIX Silicon detectors and Heavy Flavor Results



\sqrt{s} [GeV]	p+p	p+Al	p+Au	d+Au	$^3\text{He}+\text{Au}$	Cu+Cu	Cu+Au	Au+Au	U+U
510	✓							✓	✓
200	✓	✓	✓	✓	✓	✓	✓	✓	✓
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62.4	✓			✓		✓		✓	✓
39				✓				✓	✓
27				✓				✓	✓
20				✓		✓		✓	✓
14.5								✓	✓
7.7								✓	✓

VTX/FVTX

1/4 data

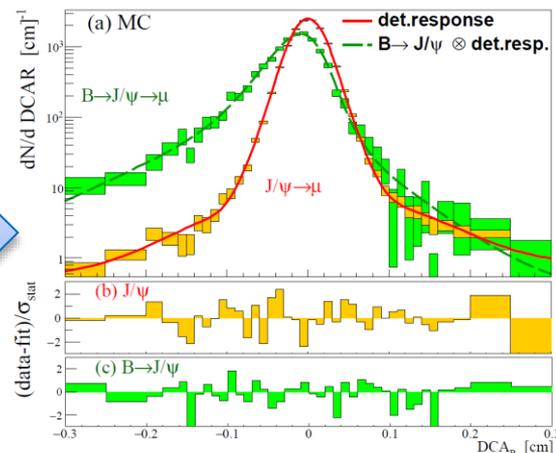
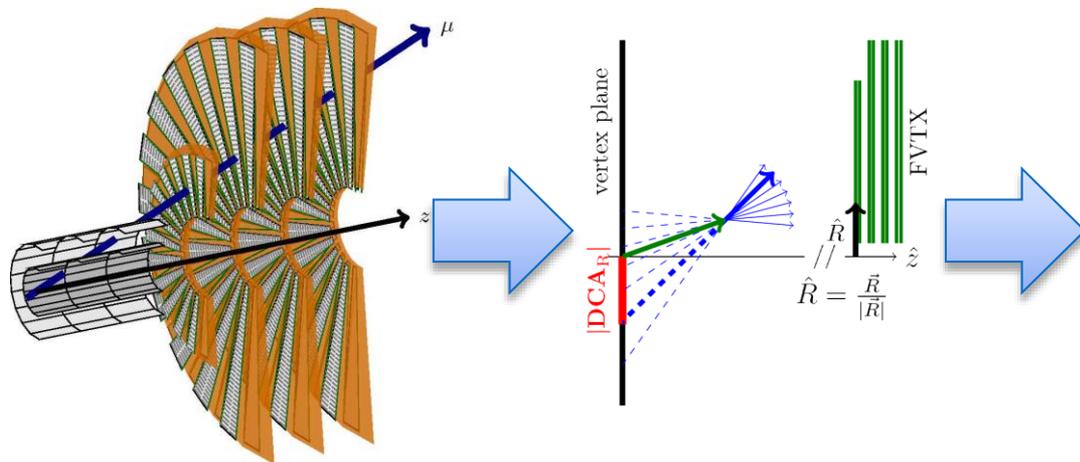


- Confirms b -quark is less suppressed than c -quark in QGP
- Expect full stat. final Run14 results by next AUM!

See also: M. Lomnitz (Tue)

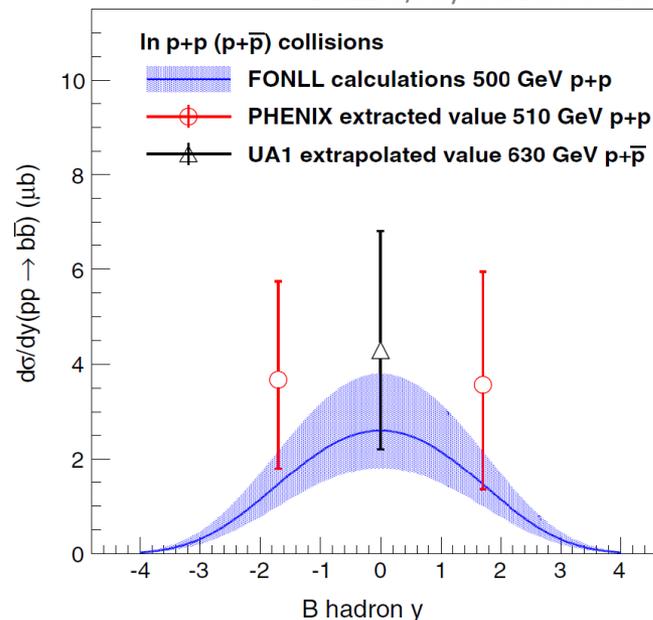
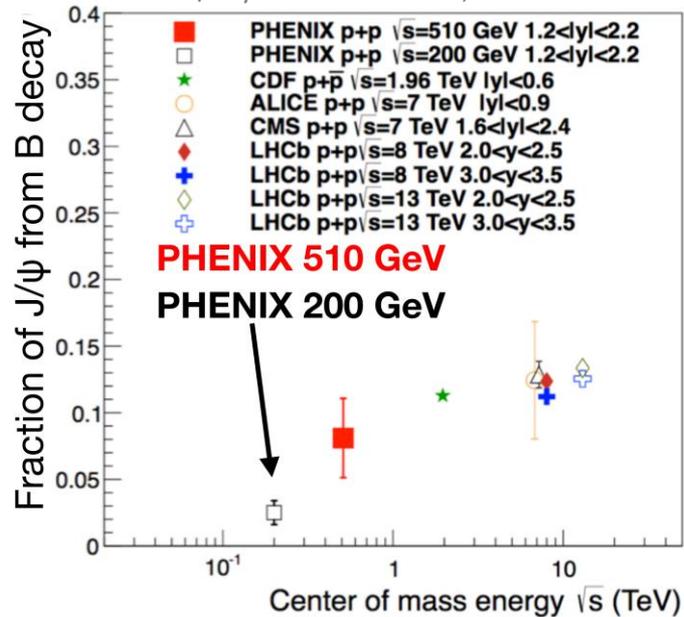
First open-HF FVTX results:

Open- b production via non-prompt J/ψ

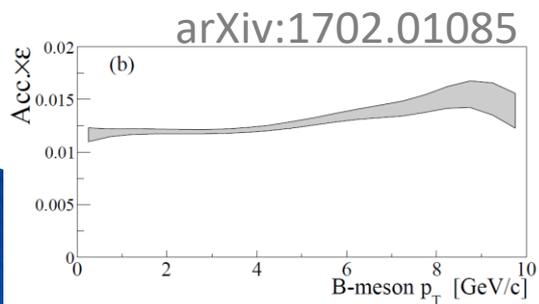
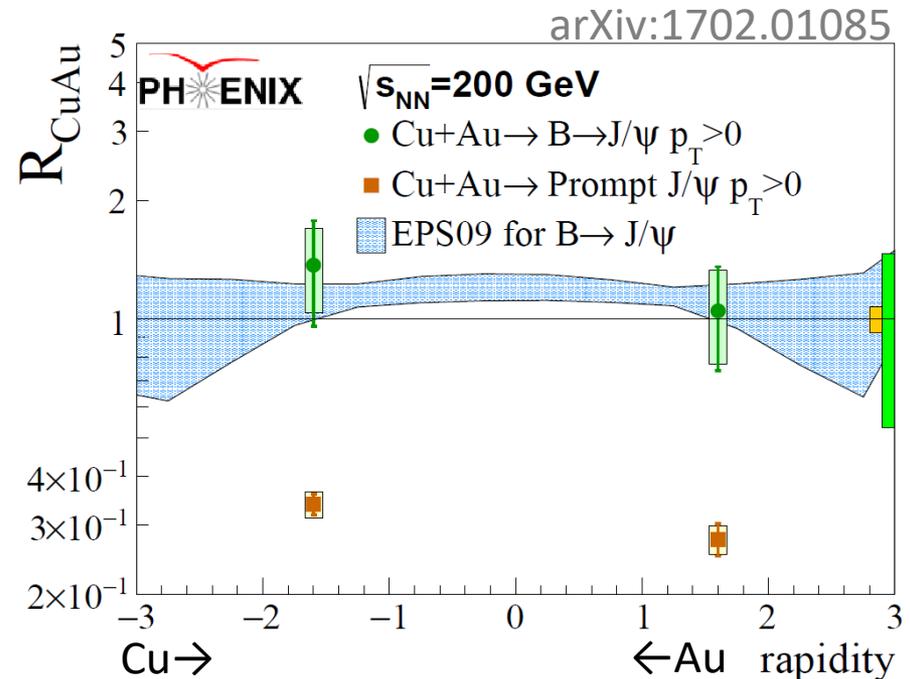
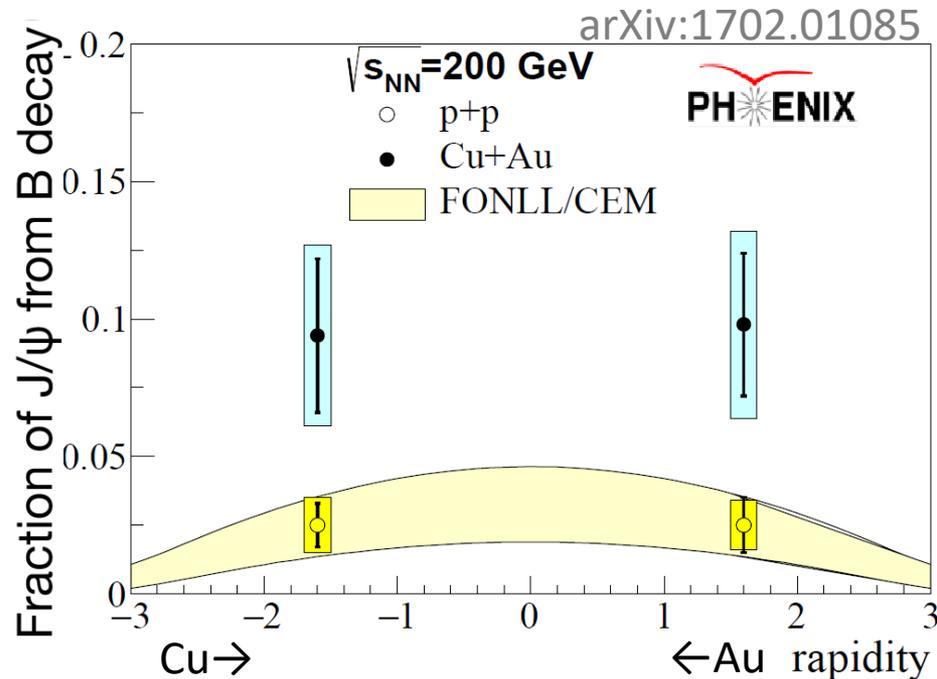


10.1103/PhysRevD.95.092002, arXiv:1702.01085

10.1103/PhysRevD.95.092002



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

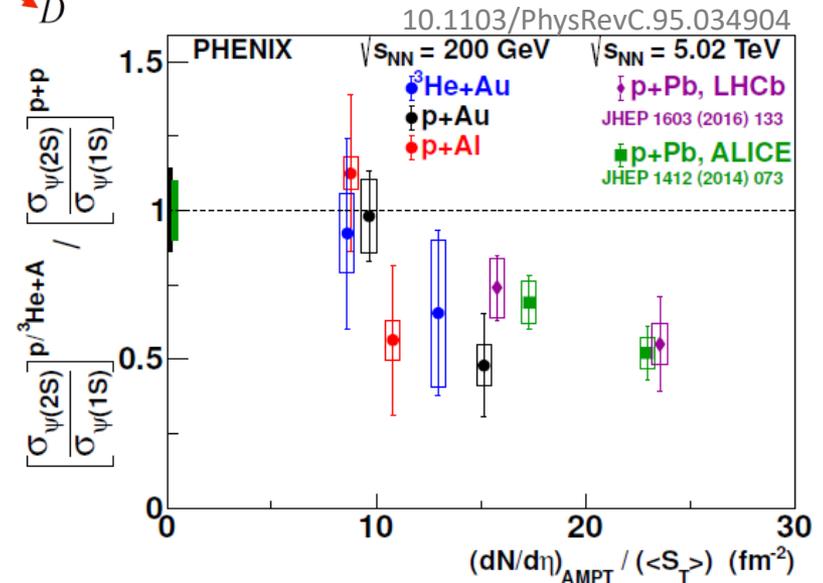
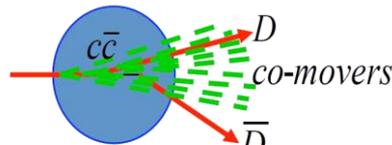
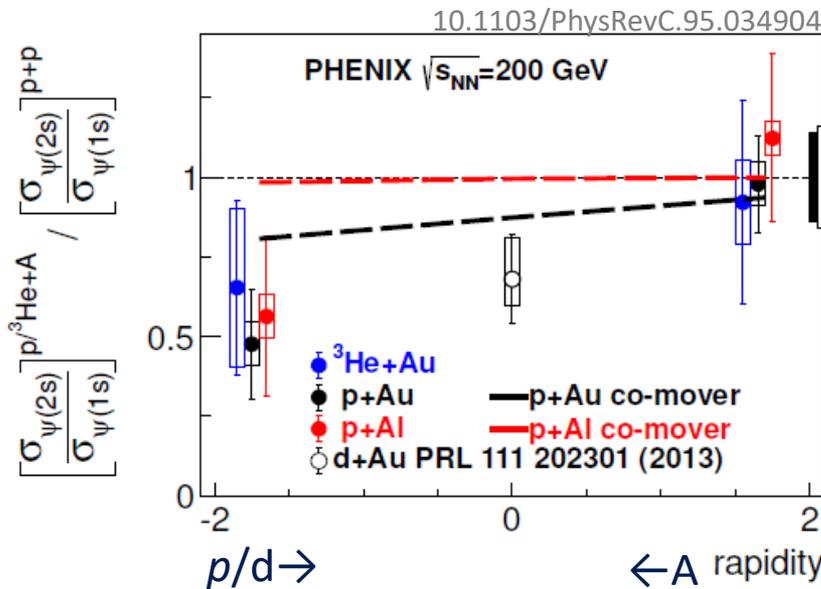
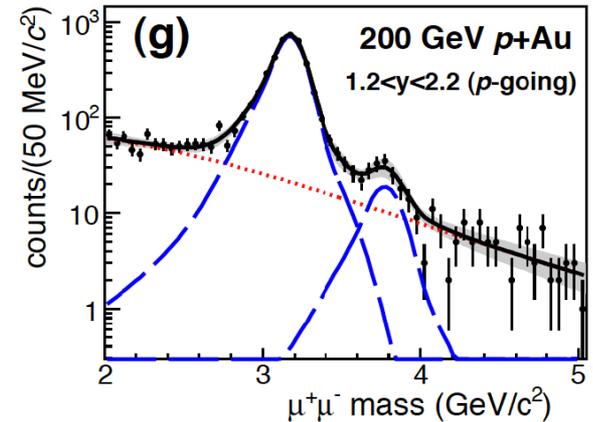


- ▶ *p+p* consistent with FONLL + CEM
- ▶ Non-prompt J/ψ R_{CuAu} consistent with nPDF EPS09 initial state effects
- ▶ Acceptance down to zero- p_T by detecting decay along z
- ▶ Next: Run14 Au+Au, single muons

See also: M. Lomnitz (Tue)

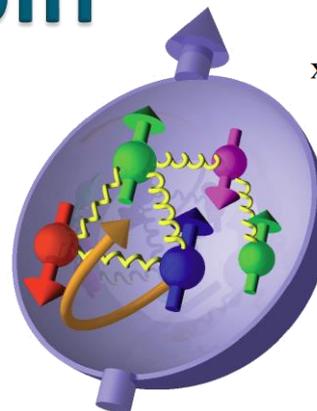
Relative suppression of ψ'

- ▶ Relative suppression of forward $\psi' \rightarrow \mu^+ \mu^-$ in multiple collision system with assist of FVTX
- ▶ Indicate breakup from final state interactions

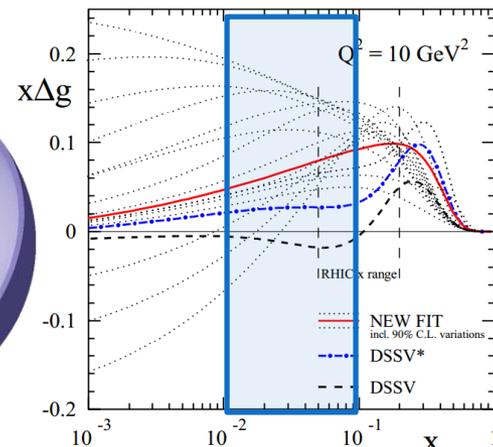


Hunt for the gluon spin

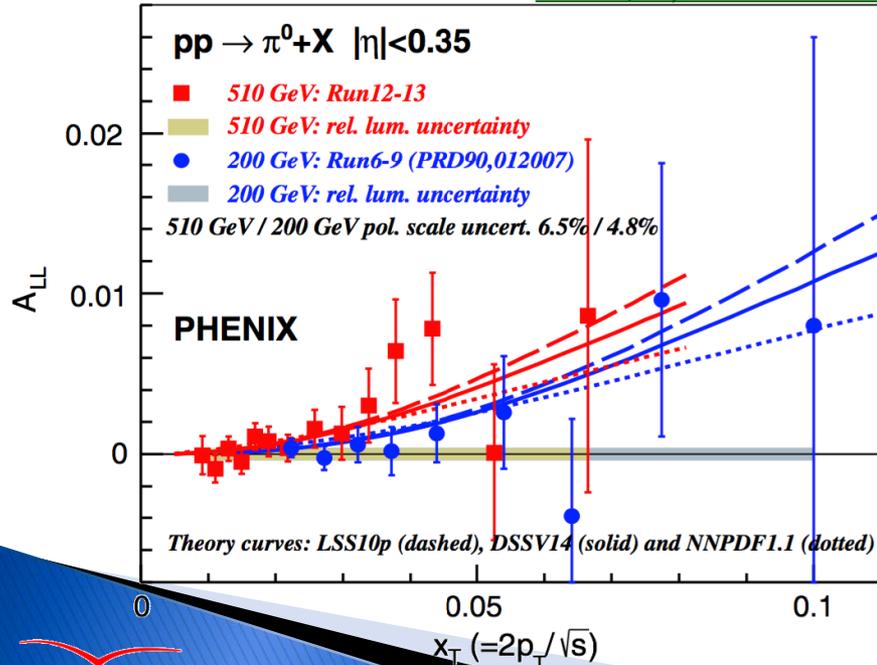
- ▶ Finalized PHENIX π^0 double spin asymmetry published in 2016
- ▶ Favor positive gluon polarization in $x \sim 10^{-2}$
- ▶ Additional constrains in global fit on gluon helicity beyond DSSV14



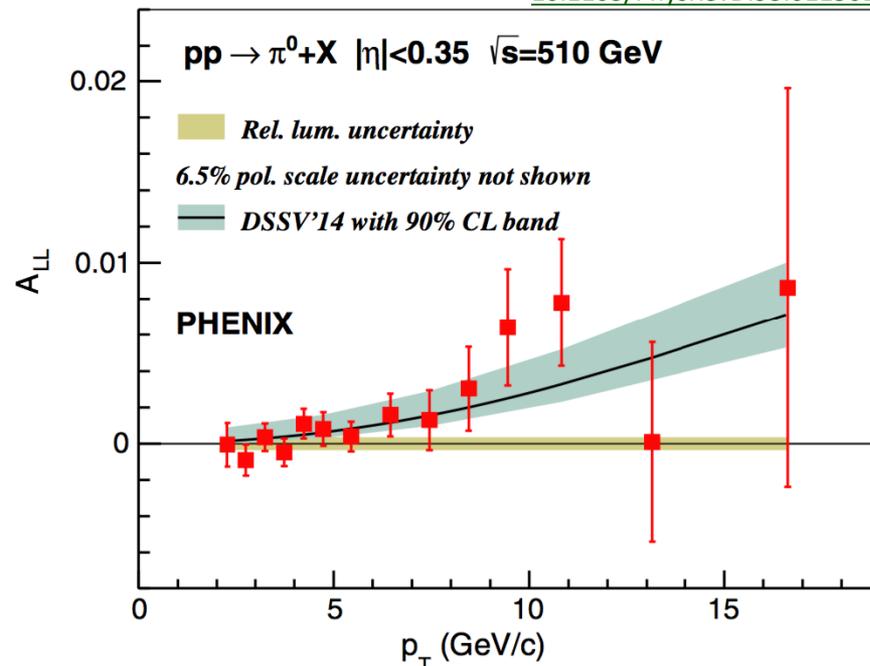
DSSV14: 10.1103/PhysRevLett.113.012001



10.1103/PhysRevD.93.011501

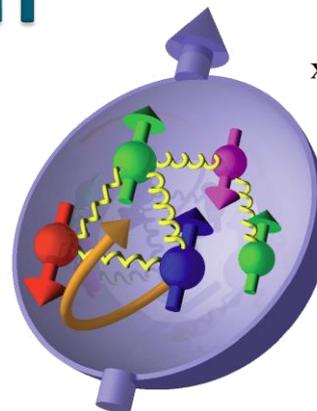


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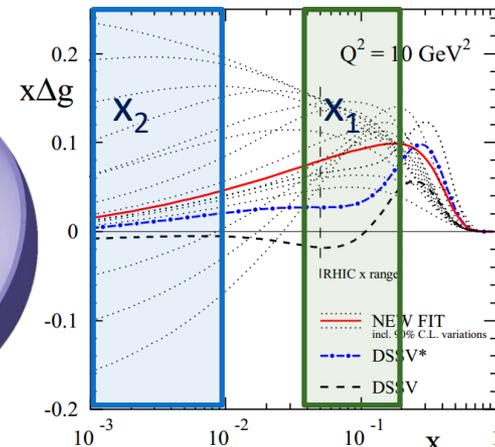


Hunt for the gluon spin

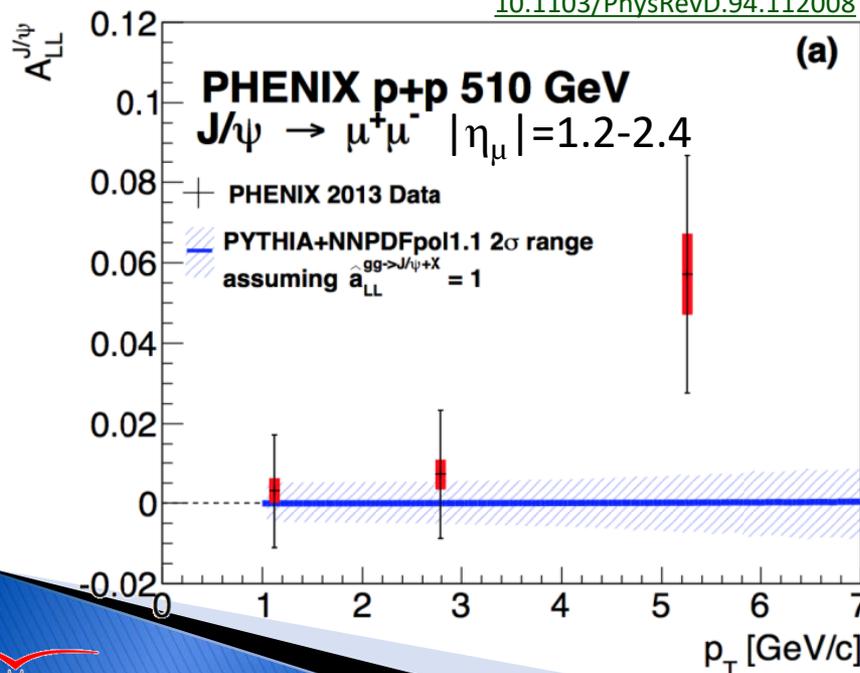
- ▶ Forward J/ψ asymmetry couples better-known region ($x \sim 10^{-1}$) and much less constraint region ($x \sim 10^{-3}$)
- ▶ Consistent with current gluon polarization band from light-quark process
- ▶ Demonstrate constrain additional constraint (under assumptions)



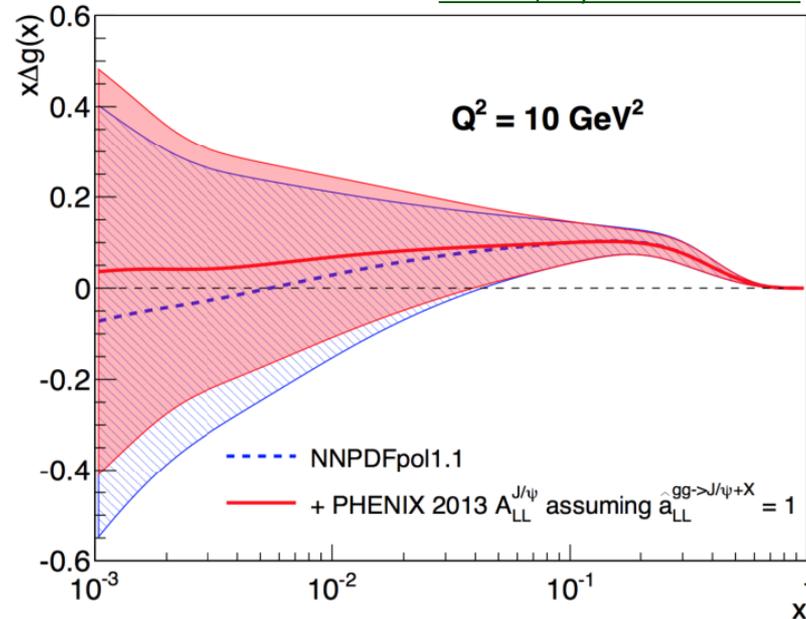
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10.1103/PhysRevD.94.112008

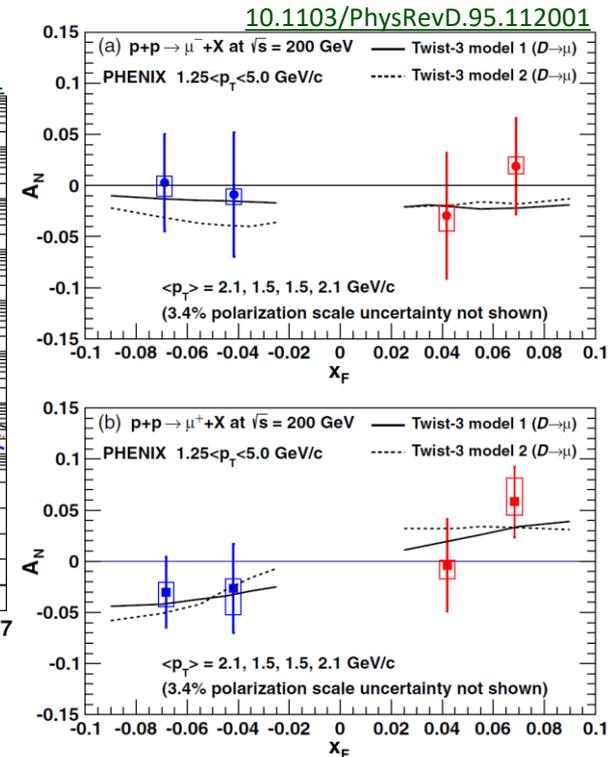
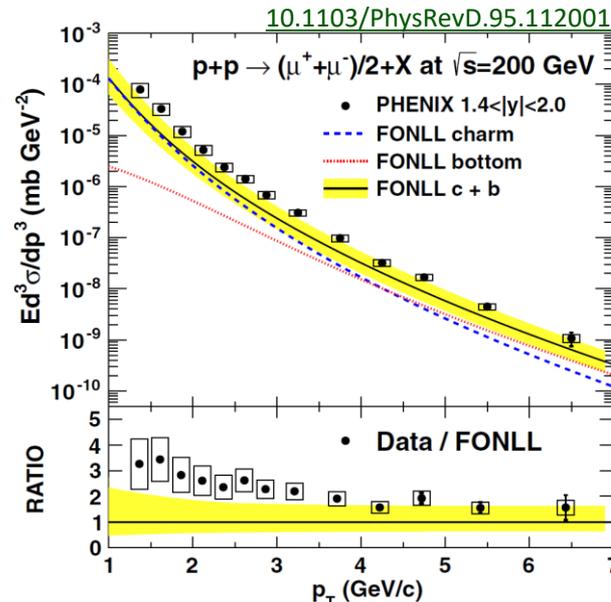
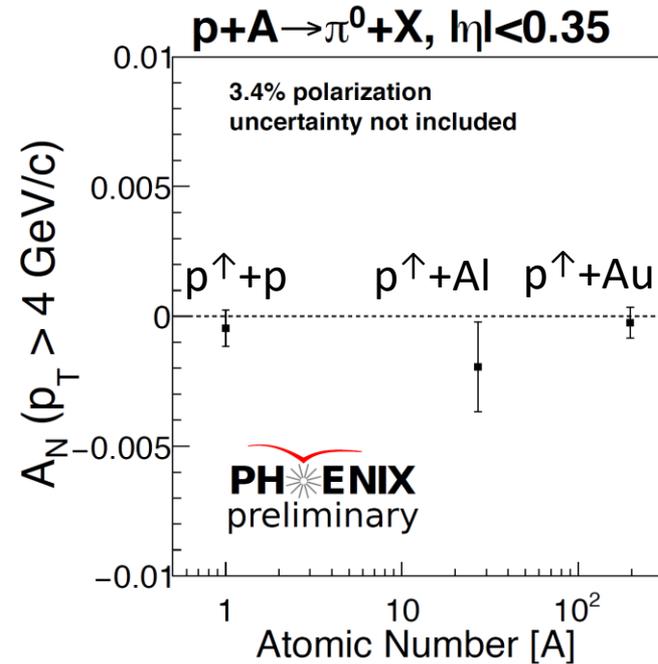


10.1103/PhysRevD.94.112008



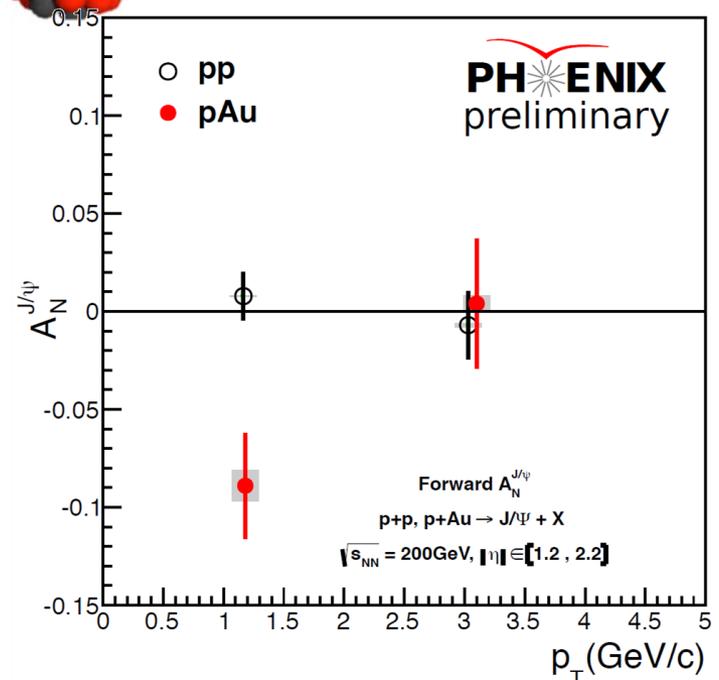
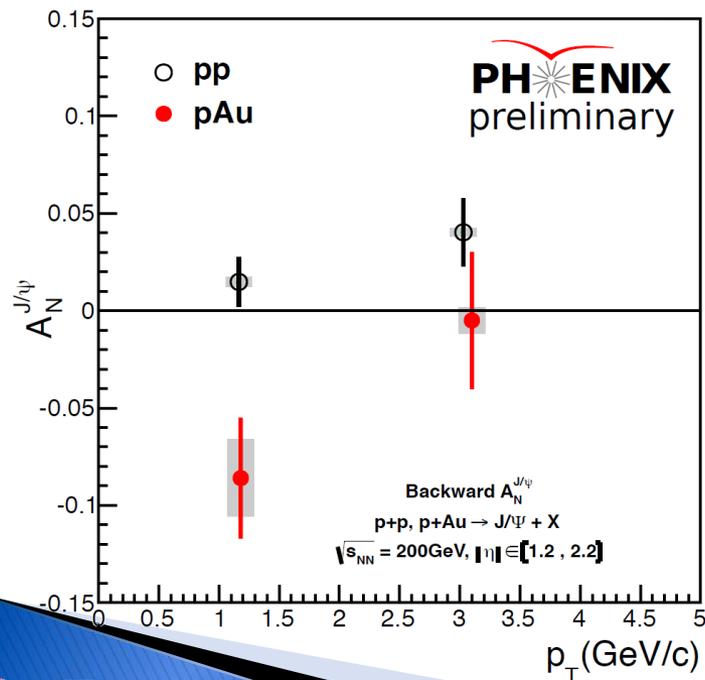
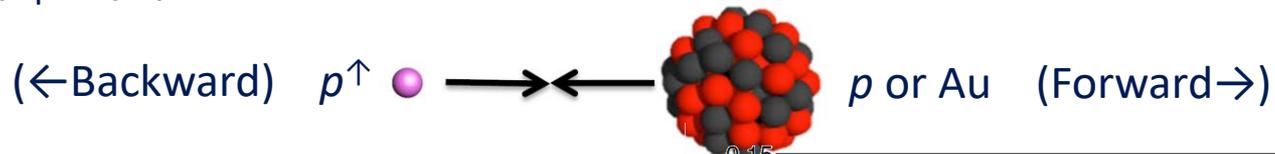
Hunt for gluon transverse spin effect

- ▶ π^0 @ $x_F \sim 0$: transverse spin effect is small for $p+p$, $p+Al$ and $p+Au$
- ▶ 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



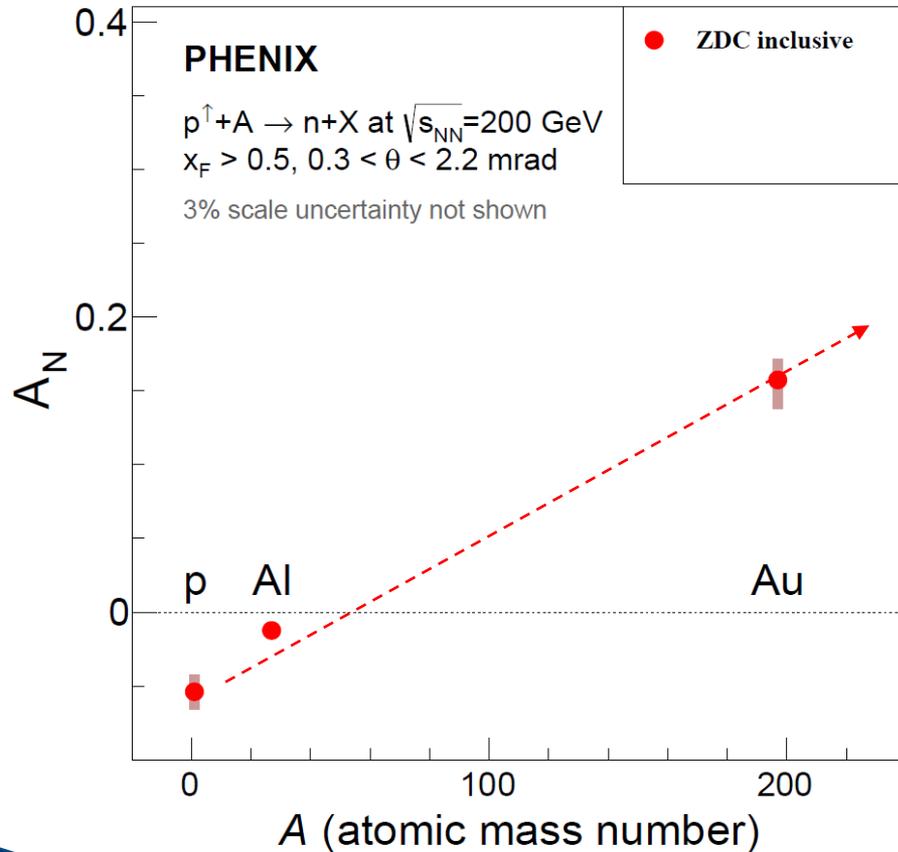
Hunt for gluon transverse spin effect: Forward J/ψ production

- ▶ The results indicate large unexpected effect in $p+Au$ at lower p_T region.
- ▶ Indication that alternative mechanism playing important roles at $p+Au$ at lower p_T J/ψ production?

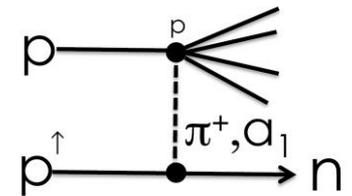


New explorations: Neutron transverse asymmetry in ZDC

arXiv:1703.10941



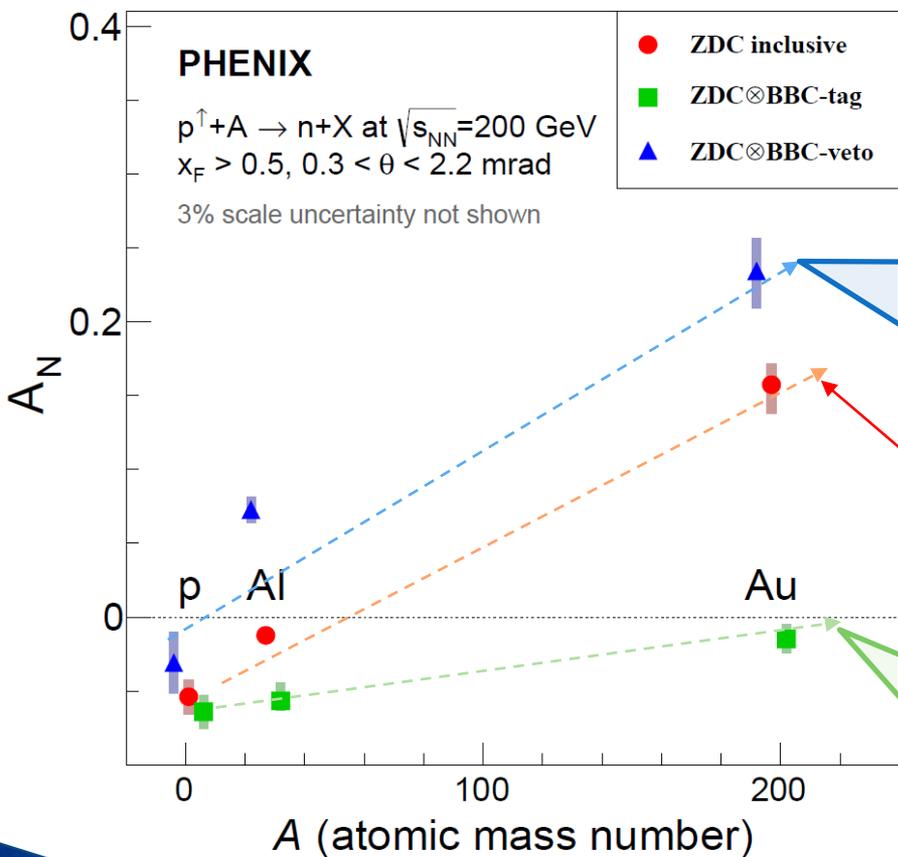
- ▶ Inclusive A_N in $p^\uparrow + p/A \rightarrow n (@ZDC) + X, |\eta| > 5.9$
- ▶ Show surprising sign change and enhancement in asymmetry
- ▶ Indicates that a process additional to π - a_1 int. model becomes dominant in “zero”-degree neutron production in the $p+A$ collision



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

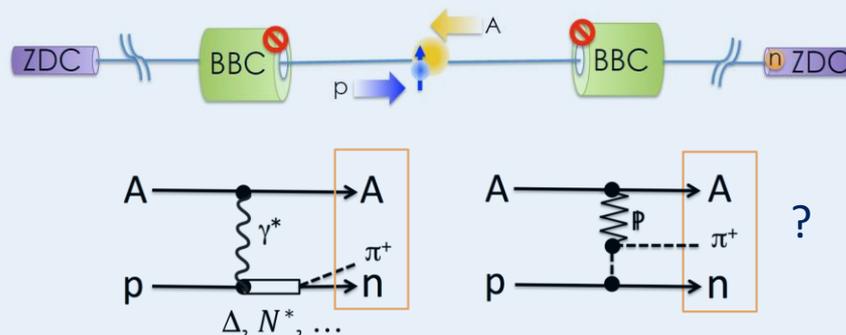
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See also: M. Skoby (Tue), S. Park (Wed)

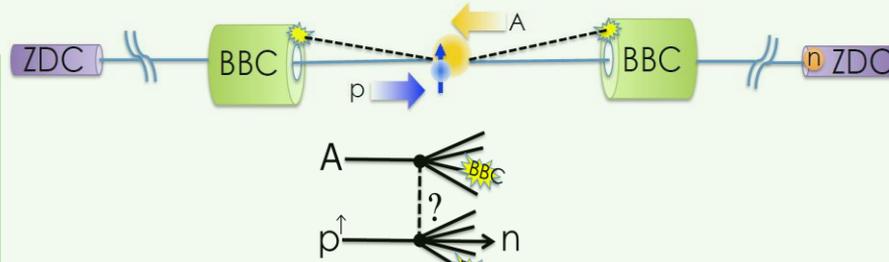
Require BBC veto ($3.1 < |\eta| < 3.9$)
 Enhancing QED-type process



Inclusive A_N

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

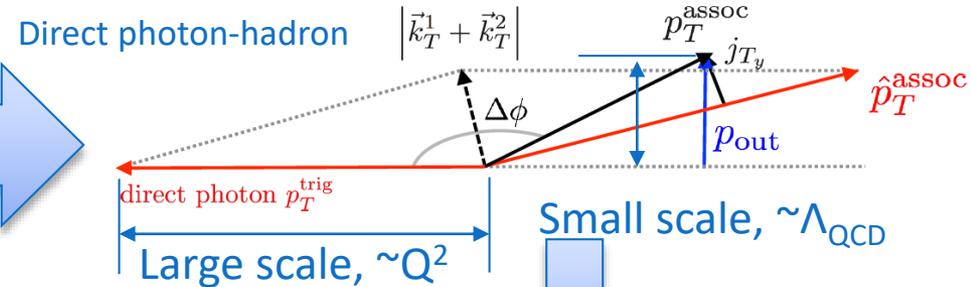
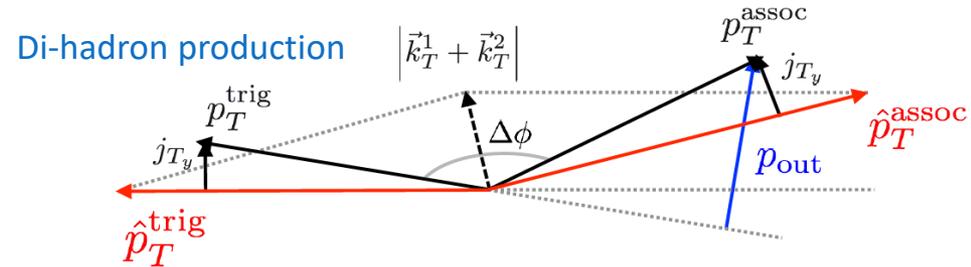
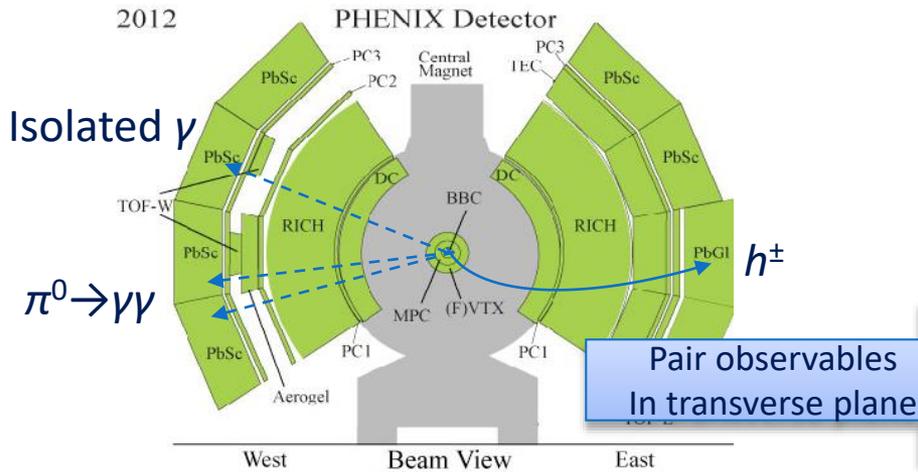
Require BBC coincidence ($3.1 < |\eta| < 3.9$)
 Suppress QED-type process



Jin Huang <jhuang@bnl.gov>

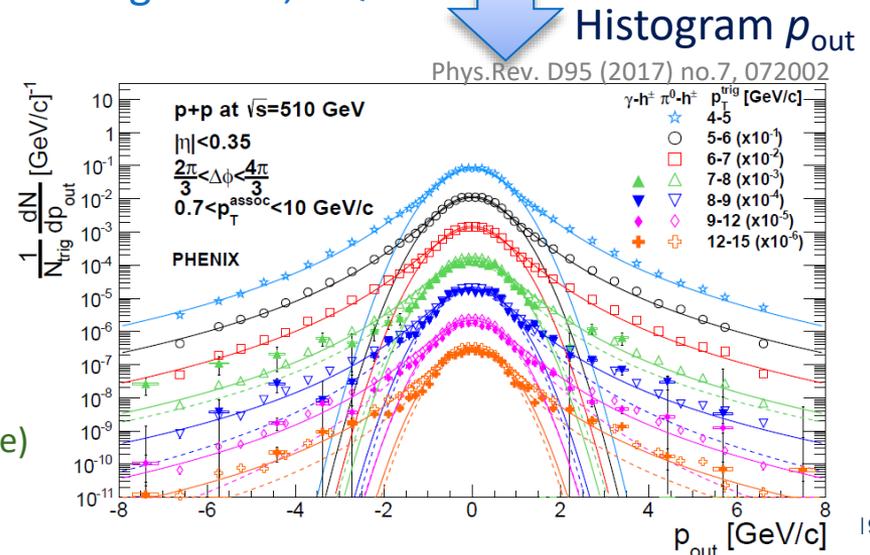
PHENIX AUM 2017

New explorations: Access the Non-Abelian nature of gluon field



- ▶ Sensitivity to initial and final transverse momentum
- ▶ Not factorizable in TMD framework
- ▶ But how is their behavior different from the factorizable observables (like Drell-Yan)?

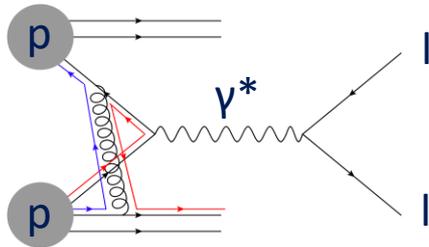
See also: H. Ge (Tue), M. Skoby (Tue)



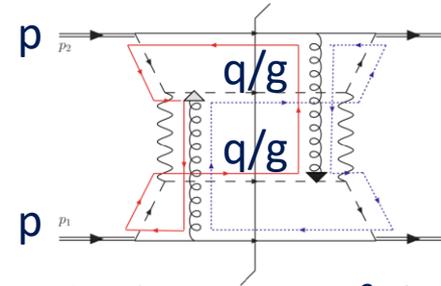
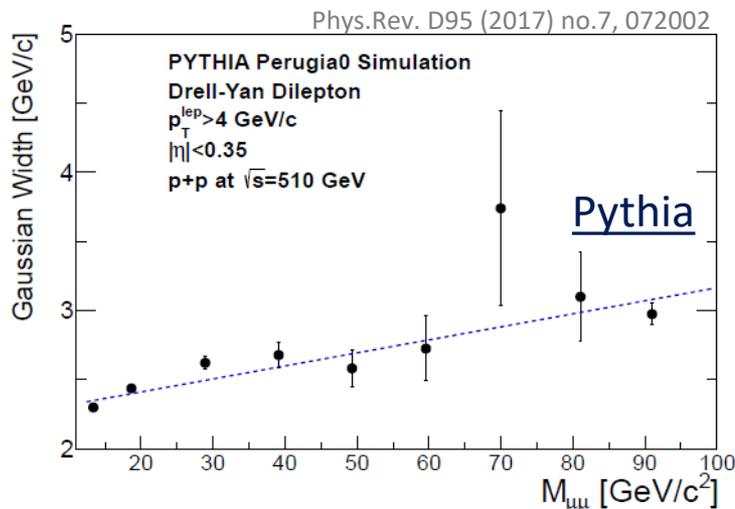
New explorations:

Phys.Rev. D95 (2017) no.7, 072002

Access the Non-Abelian nature of gluon field

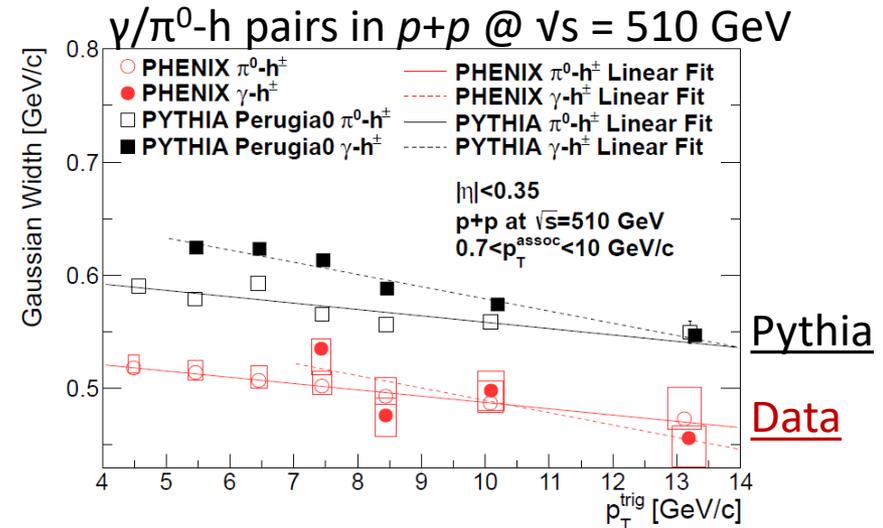


Example of TMD-factorized process:
DY in Pythia simulation
Positive width against scale (M)
As expected in CSS evolution



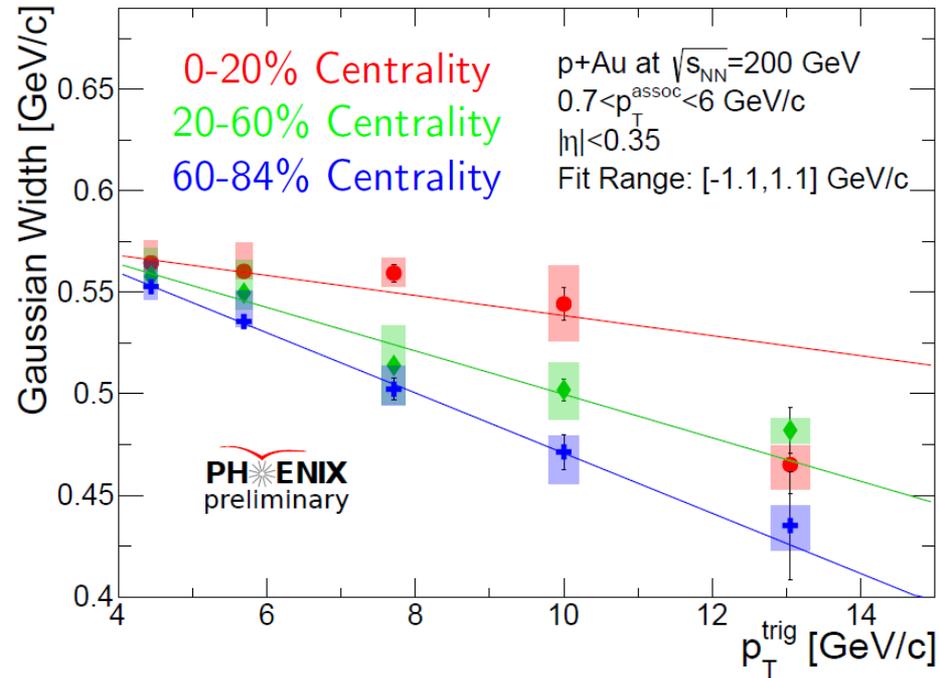
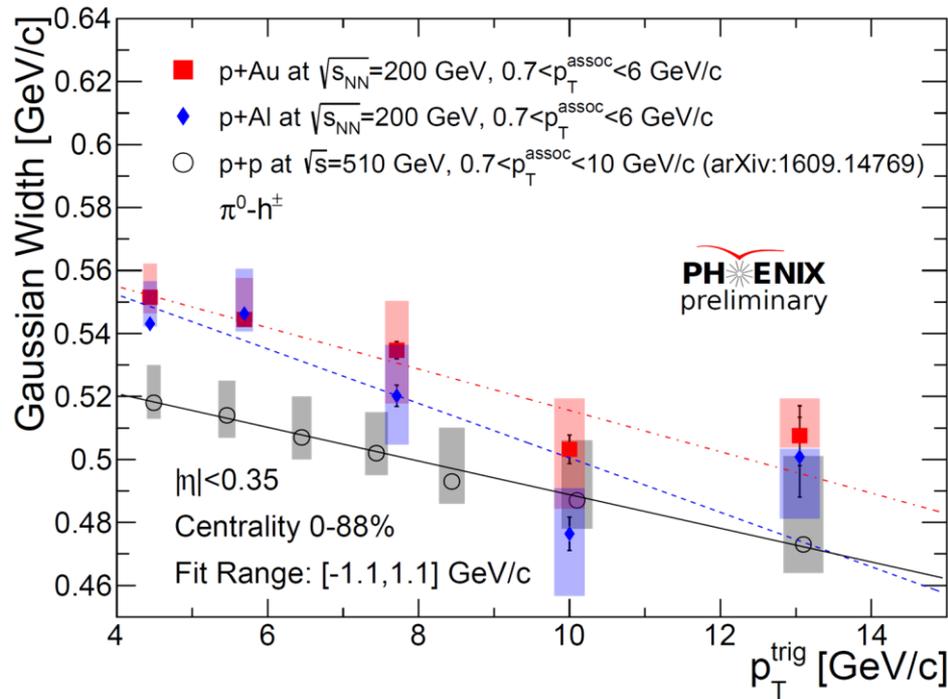
Non-TMD-factorized process: $\pi^0+h, \gamma+h$
Data and Pythia simulation:

Both show negative width slope against scale (p_T^{trig})
Opposite to CSS indicate impact from color flow



New explorations:

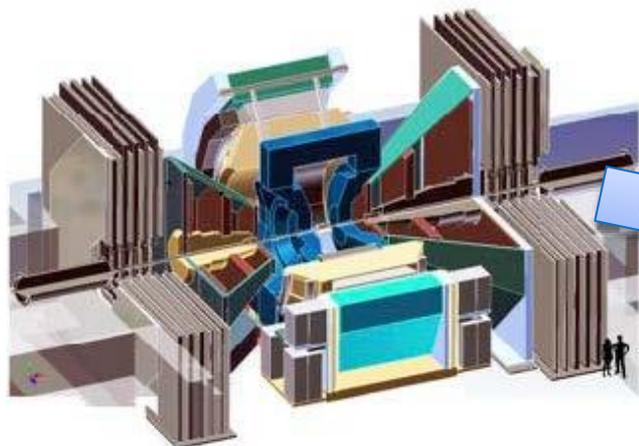
Mystery deepens in $p + A \rightarrow \pi^0 + h (+ X)$



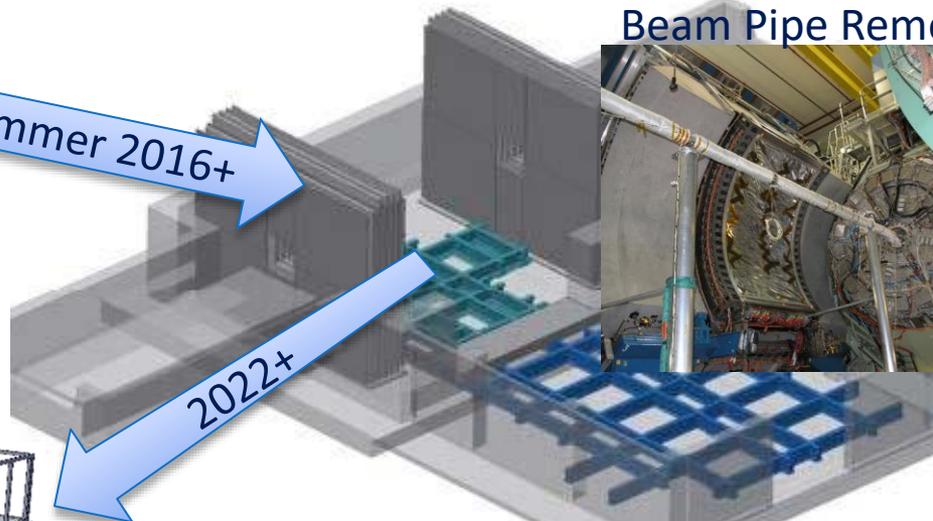
- ▶ Wider Gauss core for p_{out} in $p+A$ collisions: multiple scattering in A?
- ▶ Stronger p_T^{trig} dependence in peripheral $p+Au$: Ideas for interpretation?

PHENIX hall is being upgraded to sPHENIX

- Many detector preserved, reused in future exp.
- Thanks to the removal and repurposing crew!



Summer 2016+

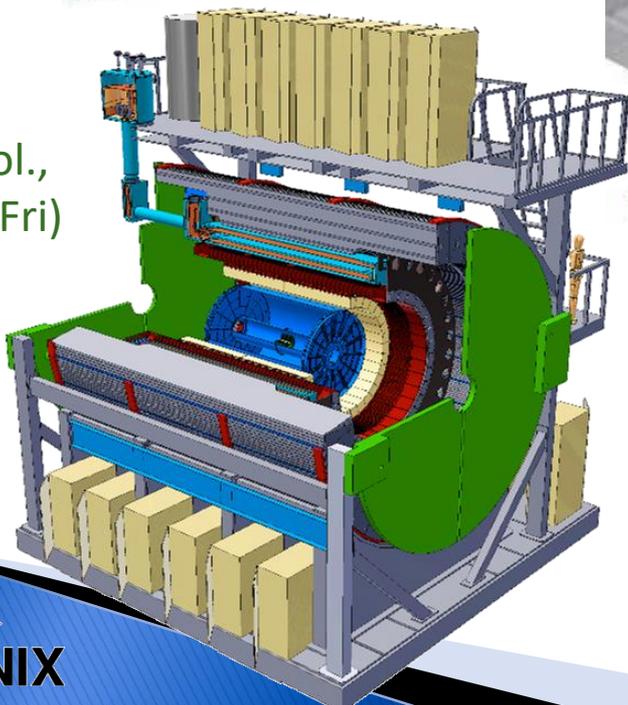


Beam Pipe Removed



2022+

sPHENIX col.,
A. Sickles (Fri)



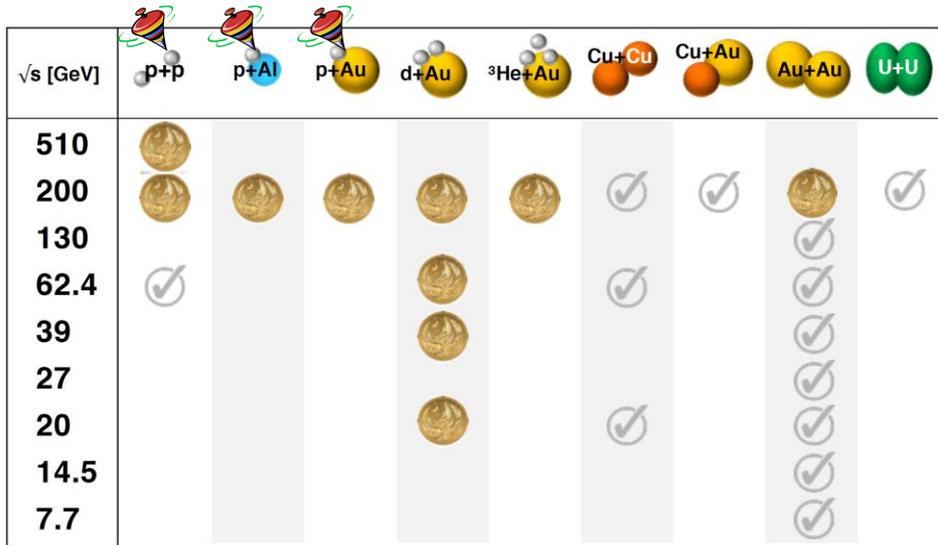
East Arm



South Muon Arm

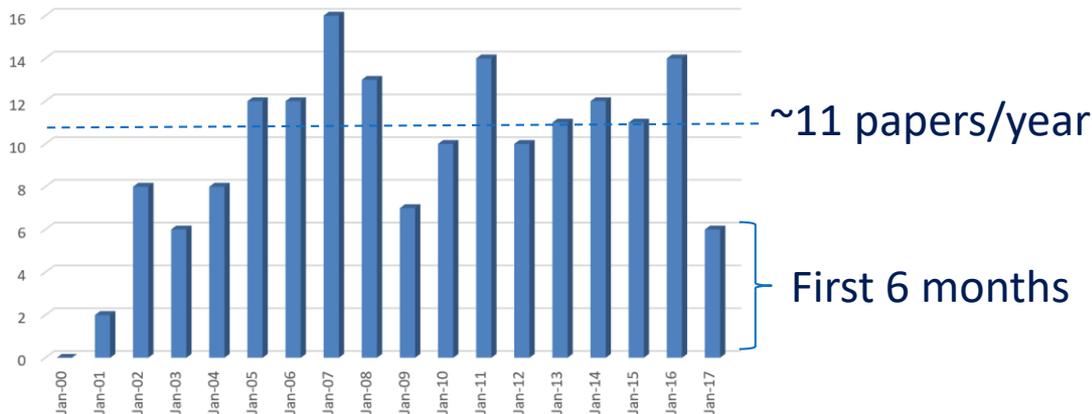


PHENIX collaboration maintains high productivity in analysis and publication

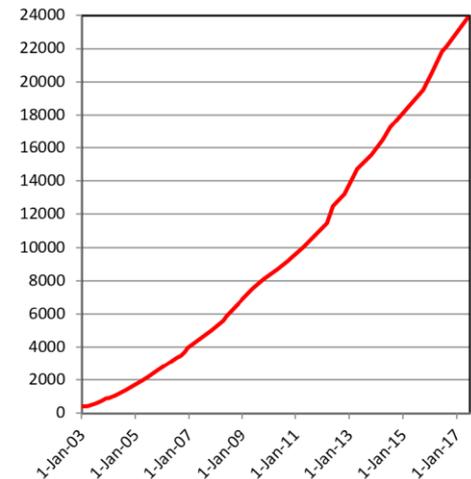


- ▶ Large data set in analysis
- ▶ Multiple golden data sets (🏆), from decades of hard work
- ▶ Expect many new result from existing data

Published PHENIX papers in each year

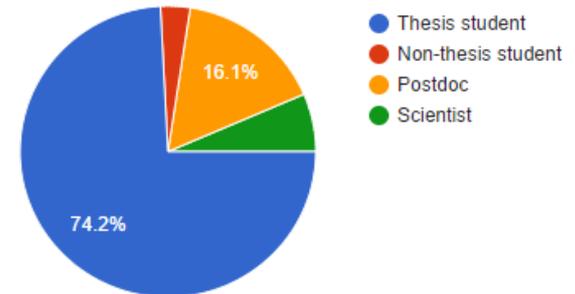


Cumulative Citations of PHENIX papers



Building analysis force: latest event

- ▶ Just before AUM: 1st PHENIX School
- ▶ Pass on analysis know-how
- ▶ 30+ registrants, $\frac{3}{4}$ are thesis students
- ▶ 3-day full-day lectures + weekend social



Summary

- ▶ Since last AUM: a productive year for PHENIX with a comprehensive set of new results:
 - Systematic study of collective dynamics in small systems
 - Parton mass dependence of suppression, b -production cross sections
 - Investigations of the interaction of hard probes with hot and cold medium
 - Map effective temperature over collision energies
 - Gluonic spin structure of proton
 - Exploring rich transverse dynamic of nucleon/nuclei collisions
 - And many more that I couldn't cover
- ▶ The PHENIX experiment is being upgraded to sPHENIX
- ▶ The PHENIX collaboration maintains its productivity, is committed to completing data analysis, publishing results and exploring new measurements