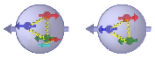
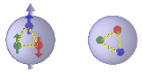
Highlights

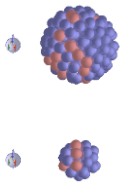
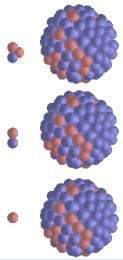
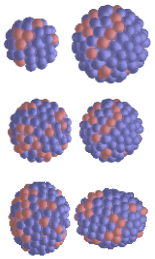
RHIC/AGS User meeting
October 23, 2020

Ralf Seidl (RIKEN),
for the PHENIX collaboration

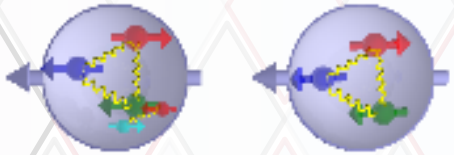
RIKEN

Data sets, energies

	$\vec{p}+\vec{p}$	$p+p^{\uparrow}$	p+p	$p^{\uparrow}$+ Al, Au	p + Au, d + Au, ^{3}He + Au	Au + Au, U + U, Cu + Au
510	Central: π^0, η, $\pi^{\pm}$, γ A_{LL}, Jet A_{LL} W→e A_L Forward: π^0 A_{LL} W→μ A_L	Very forward n AN	γ, jet, π xsec, Central + forward Λ polarization, bbar production , Onium	Red: To be discussed today		
200	Central: π^0, η, $\pi^{\pm}$, γ A_{LL}, HF e A_{LL}	Central: π^0, η, $\pi^{\pm}$, γ A_N, HF e A_N Forward: π^0,η A_N HF μ A_N Very forward: n A_N	Onium xsec, γ-hadron/h-h correlations, HF electron charm/bottom separation	Neutron A_N, J/Psi A_N R_{pA} for many final states	Thermal photons, R_{dA} for many final states, γ-hadron/h-h correlations, Small systems v_n,	Thermal photons, Charm/bottom v2, R_{AA} for many final states, γ-hadron/h-h correlations



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \mathcal{L}_G + \mathcal{L}_q$$

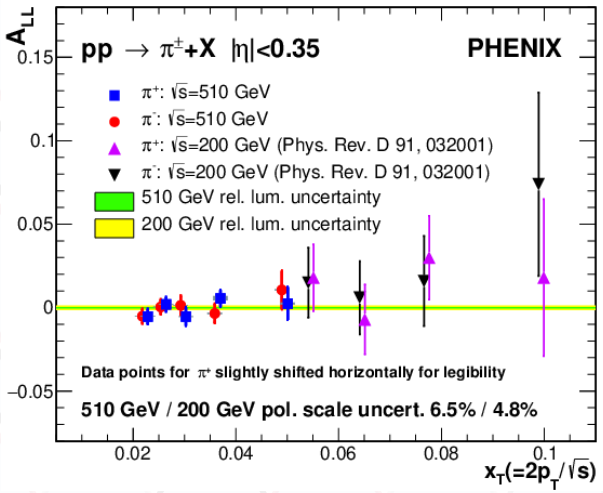
Longitudinal Spin

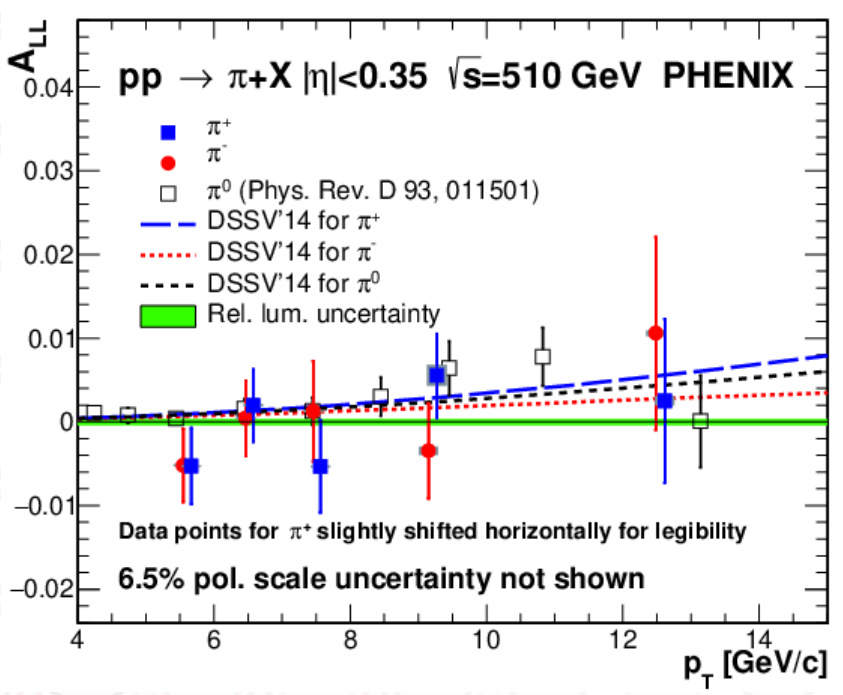
Main questions at PHENIX and RHIC:

- Gluon spin contribution
- Role of sea quarks

Charged pion A_{LL}s at 510 GeV

- Lower x reach compared to previously published 200 GeV A_{LL} data
- Ideally sign of $\Delta g(x)$ visible in charge ordering of pion A_{LL}s
- Statistics limited due to EM shower based trigger, but important imput for global fits

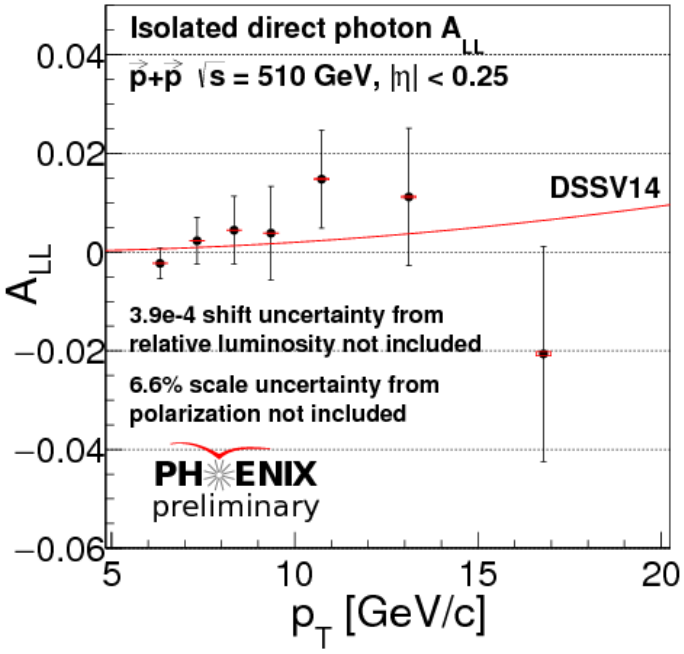


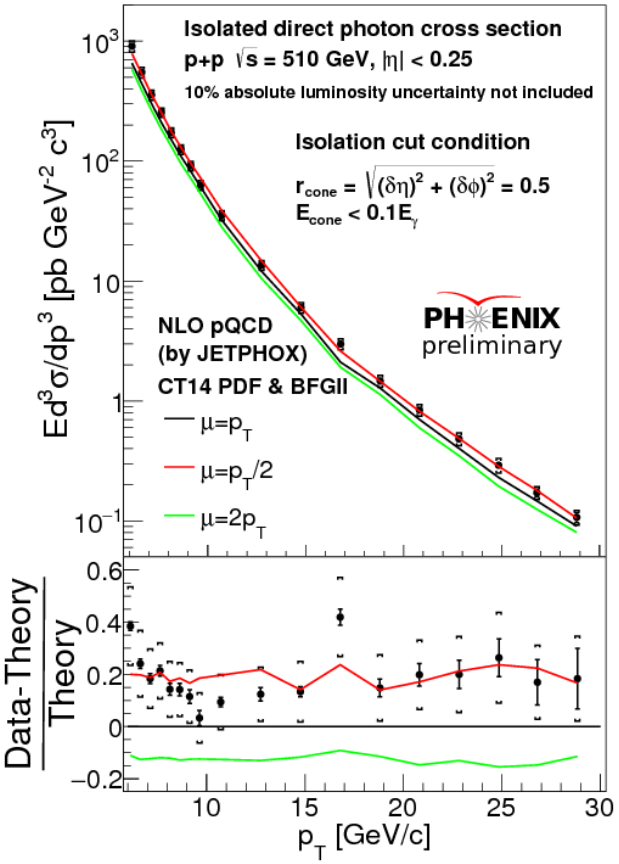


Phys.Rev.D 102 (2020) 3, 032001

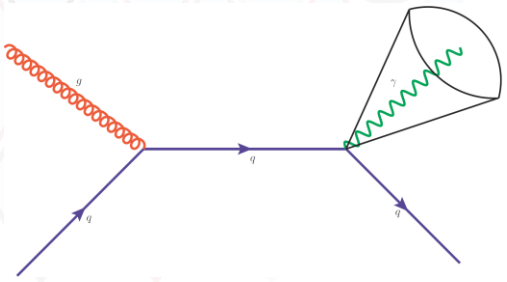
For CNM related details: see Milap Patel's talk

First direct photon xsec and A_{LL} at 510 GeV



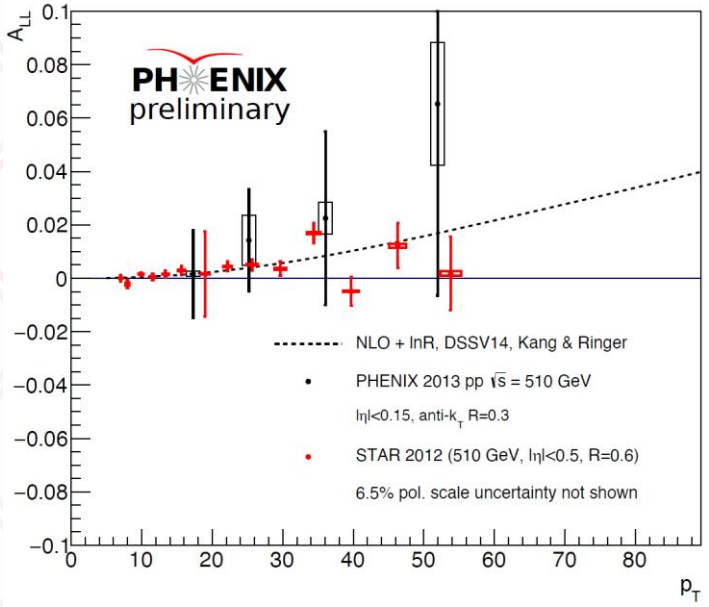


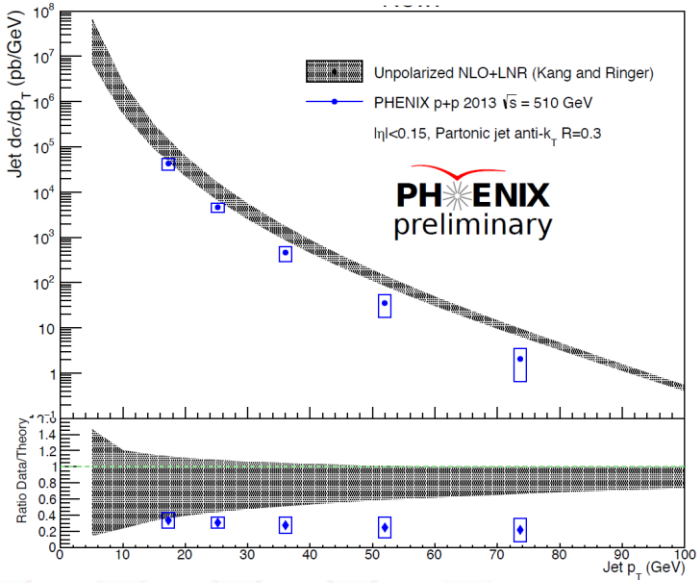
- Part of initial RHIC-Spin suggestions in the `90s
- Theoretically, the Golden channel to access gluon polarization as hard interaction mostly q-g
- Since EM process, statistically limited but consistent with global fit results



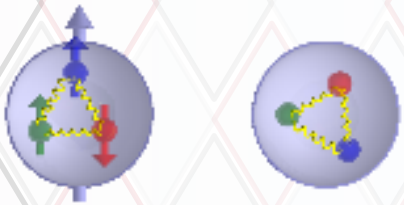
Jet cross section and A_{LL} measurements

- Jet measurements difficult in limited acceptance of PHENIX → relatively small R=0.3
- Successfully performed A_{LL} measurement
- confirms nonzero gluon polarization findings based on STAR Jet and PHENIX π^0 A_{LL} results
- Cross sections below NLO predictions, but similar findings for small R seen at LHC





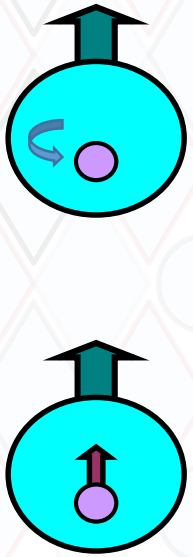
For CNM related details: see Milap Patel's talk



Transverse spin

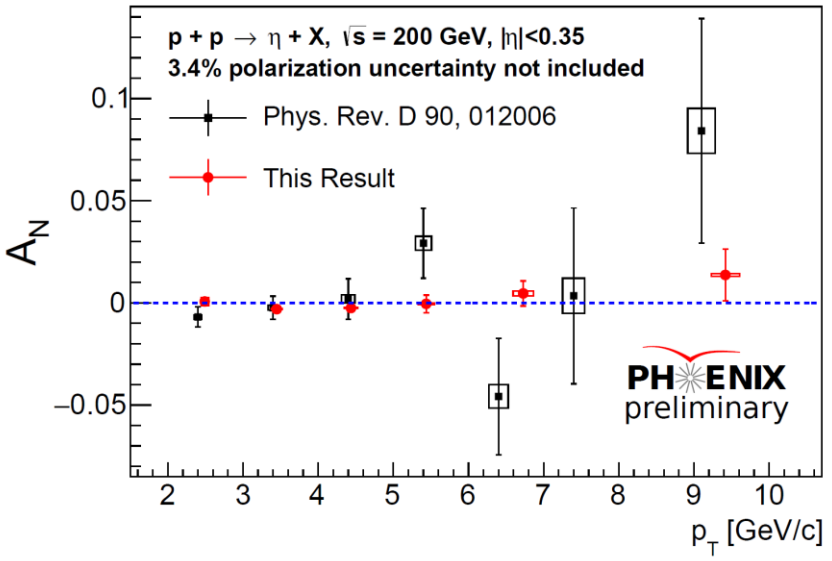
Main questions:

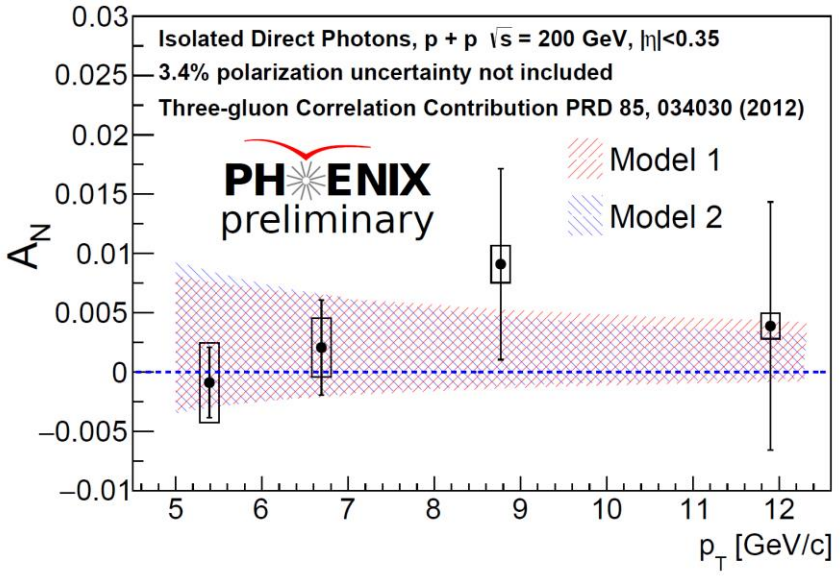
- Origin of large A_Ns: initial state? Final state?
- Connections between higher twist and TMDs
- Nuclear/low-x modification of A_Ns?



Updated precision for central A_ns and γ!

- Substantial updates for π^0 and η single spin asymmetries at central rapidity
  - Possible effects pushed below the 1% level
- First direct photon A_N extracted at RHIC:
  - Mostly sensitive to initial state effects (quark-gluon correlation function)
  - Power to constrain trigluon correlation part





For CNM related details: see Milap Patel's talk

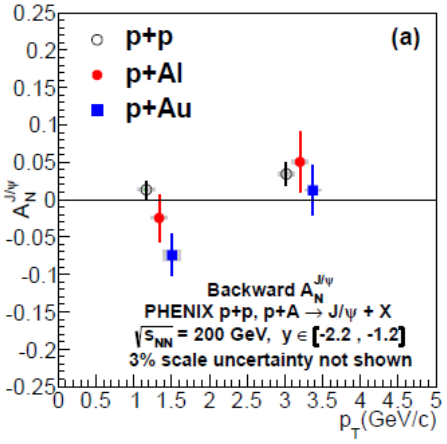
Nuclear effects

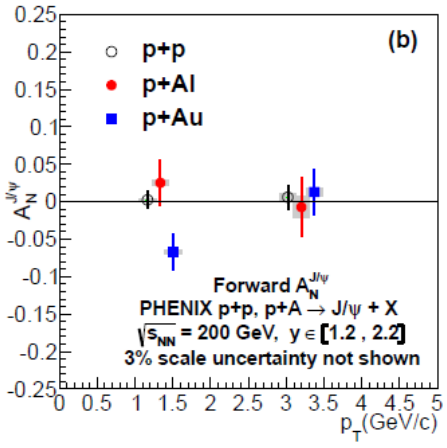
- Cold NM effects (p+A, d+A, p+p), vs QGP related effects (Au+Au,Cu+Au,U+U)
- System size dependence p, D, ^{3}He and Al, Au, U
- Unpolarized p+p baseline measurements

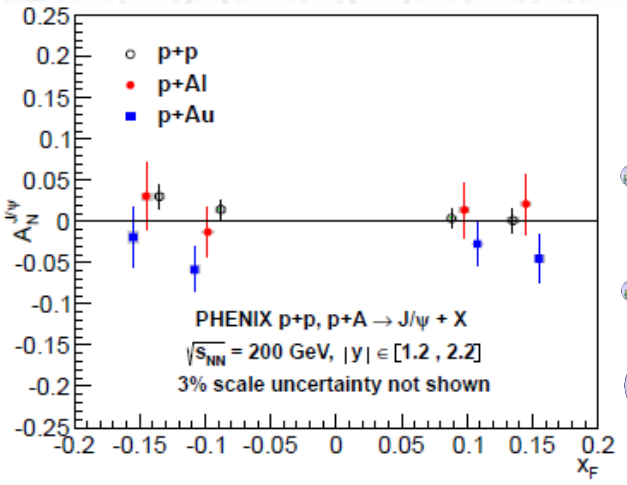
J/Psi A_Ns

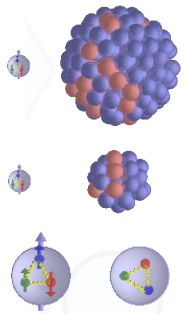
- Surprising nonzero J/Psi A_Ns seen in p+Au collisions while p+p Asymmetries are mostly consistent with zero
- Nonzero effect only visible at the lowest available Pt
- Diffractive effects as cause not very likely due to coincidence with hard collision trigger
- P+Al data consistent with zero

PRD98 (2018) 012006





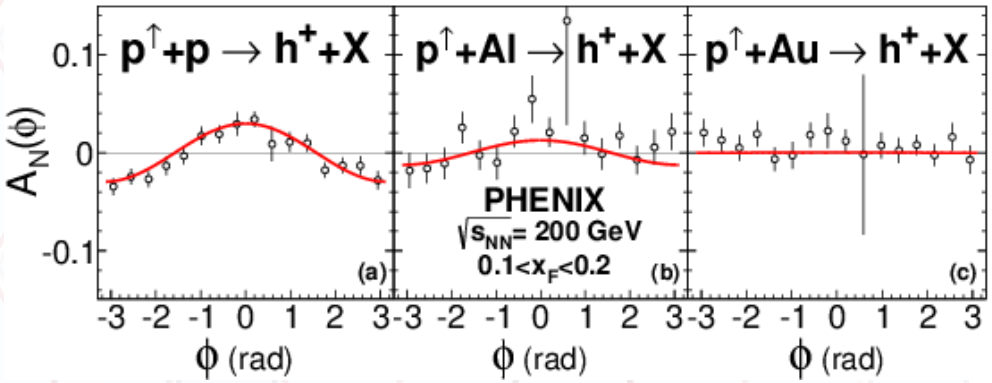


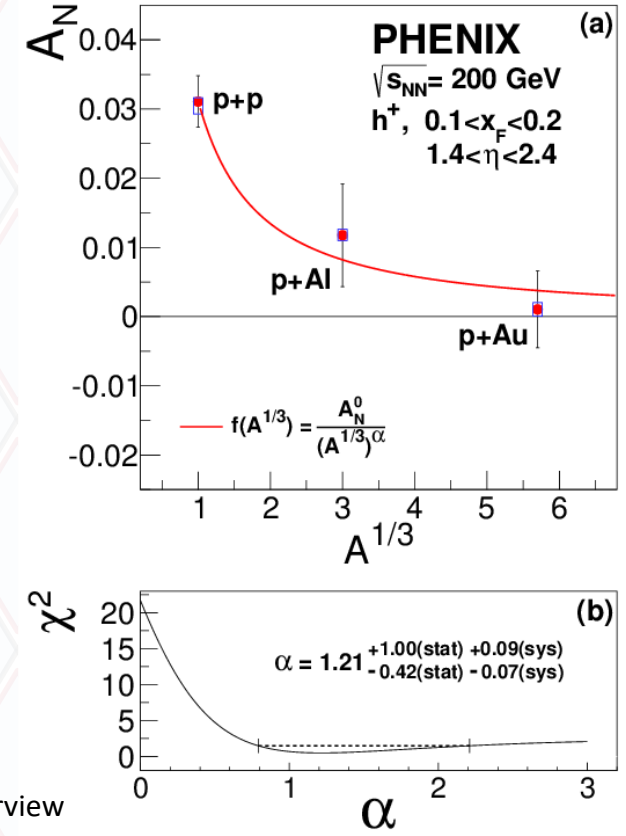


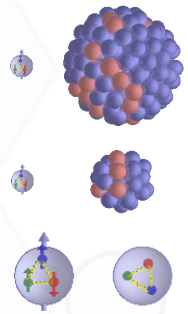
Phys.Rev.Lett. 123 (2019) 122001

A dependence of A_Ns

- Asymmetries consistent with $A^{1/3}$ dependence as (initially) predicted by some CGC related nuclear effects (Hatta`17)
- No A dependence is ruled out
- Also consistent with suppression with increasing number of binary collisions
- However, probed x and scale too large for expected CGC effects! (S.Benic and Y.Hatta, PRD99, 094012 - Twist-3 fragmentation + gluon saturation)



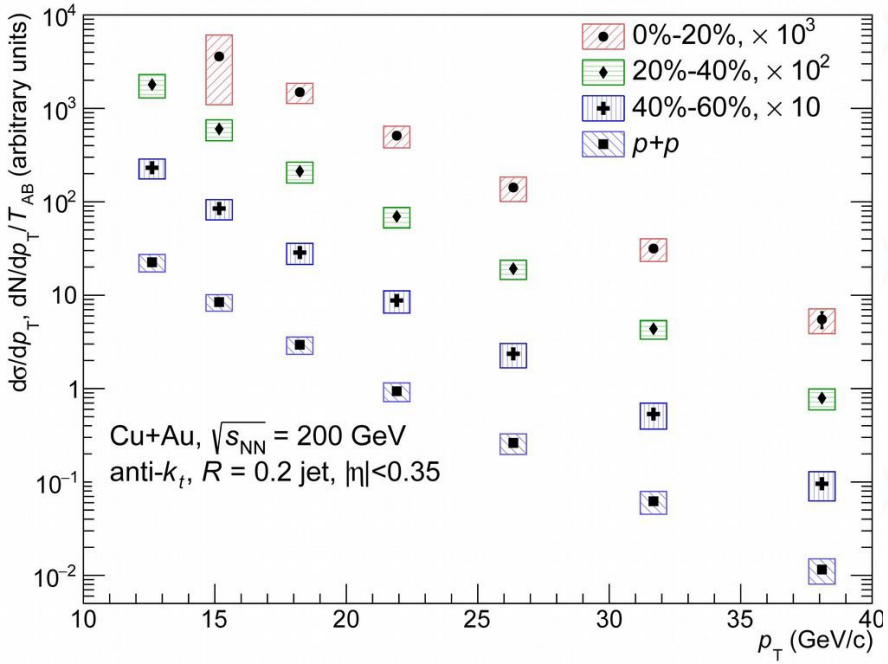


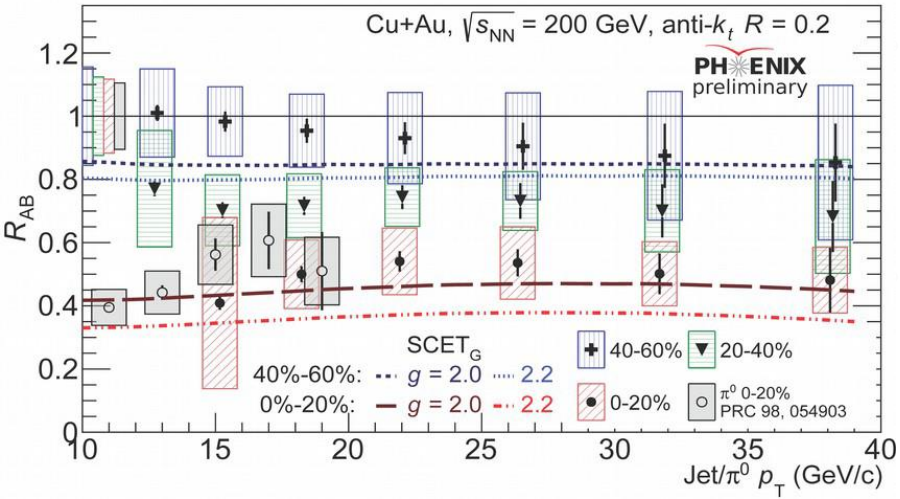


For CNM related details: see Milap Patel's talk

Jet modification in Cu+Au

- Anti-kt jets, fake-jet removed,
- smearing and reconstruction efficiencies unfolded
- Jet suppression of most central collisions consistent with π^0 suppression



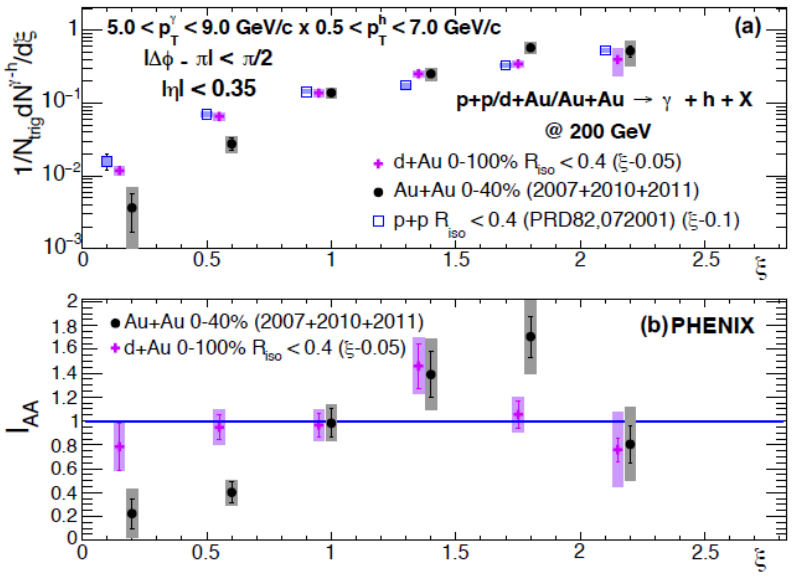


For jet/energy loss related details: see Anthony Hodge's talk

Photon-hadron correlations/fragmentation

- Back-to-back photon-hadron correlations have been studied in p+p, d+Au and Au+Au
- Able to study jet modification in hot and cold nuclear matter
- Little suppression seen in d+Au while substantial suppression in hot matter visible at high z

arxiv:2005.14270



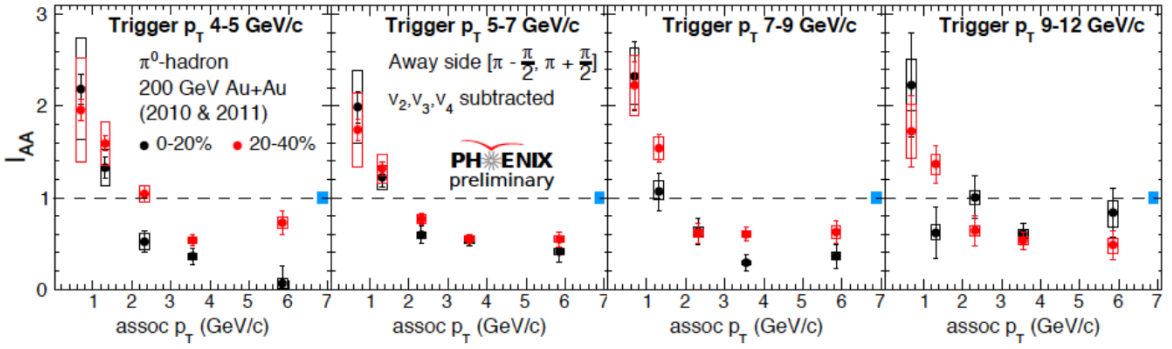
$$\xi = \ln(1/z)$$

$$z = \frac{P_h}{P_\gamma}$$

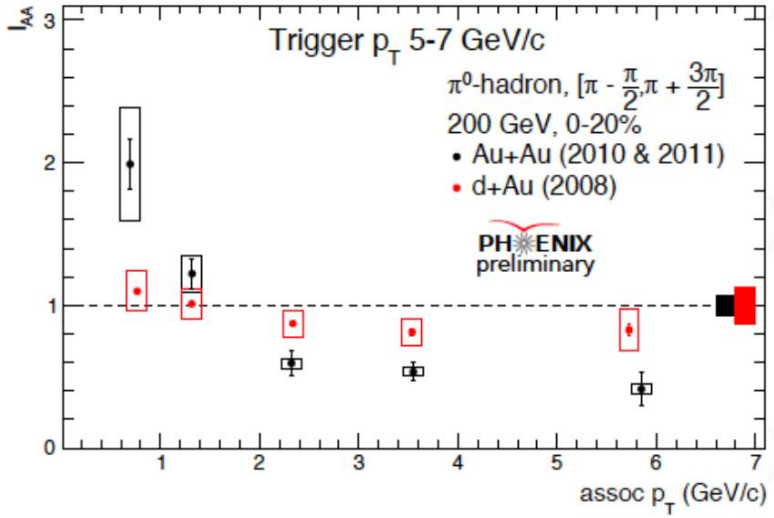
For jet/energy loss related details: see Anthony Hodge's talk

Back-to-back h-h correlations in d+Au, Au+Au

- Enhancement of low momentum particles at away-side in Au-Au, suppression of higher momentum particles
- Little to no suppression seen in d+Au for higher p_T particles



$$I_{AA} = \frac{Y^{AA}_{Away}}{Y^{pp}_{Away}}$$



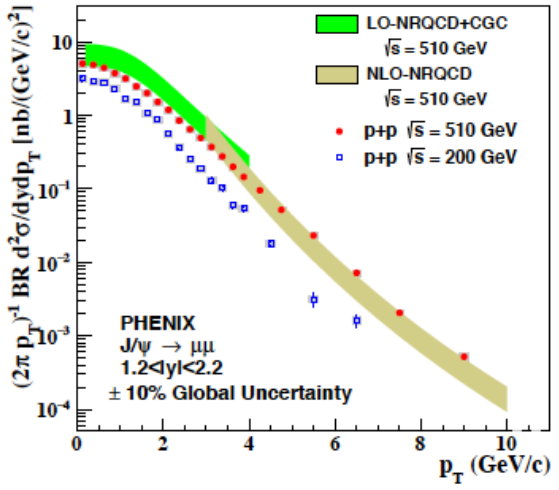
For jet/energy loss related details: see Anthony Hodge's talk

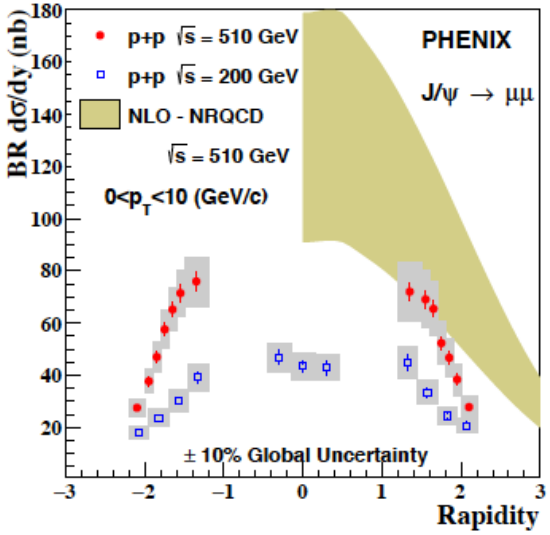
Quarkonia

For HF related details:
see Takashi Hachya's talk

Phys.Rev.D 101 (2020), 052006

- Precise measurements of differential cross sections for J/Psi and Psi' at central and forward rapidities at 200 and 510 GeV
- Substantial improvement to theoretical description of J/Psi production expected

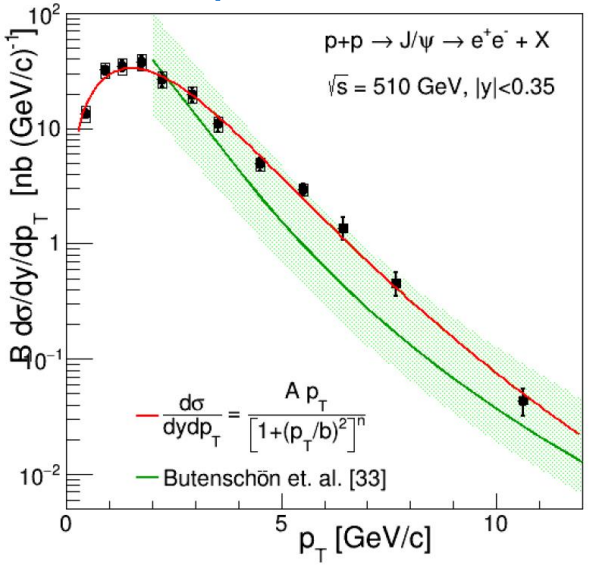


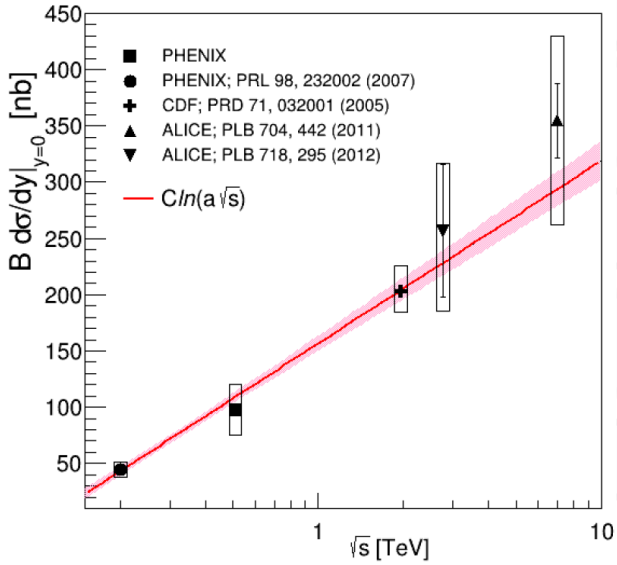


J/Psi Cross section and production rate

- First central rapidity measurement at 510 GeV also now available
- Consistent with theory predictions, but with higher precision
- Nicely connects 200 GeV RHIC and LHC measurements

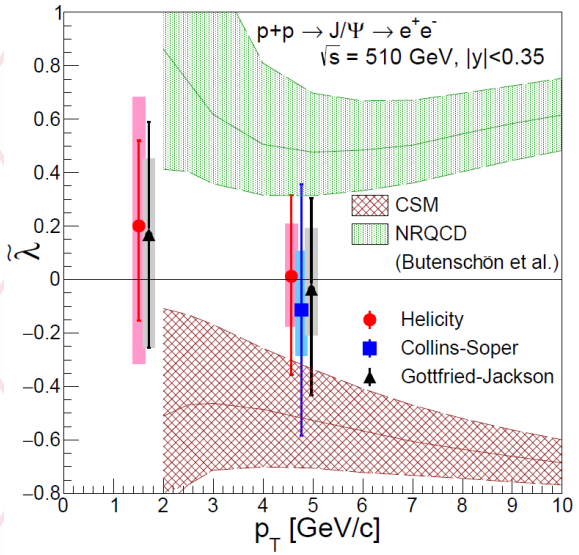
hep-ex:2005.14273

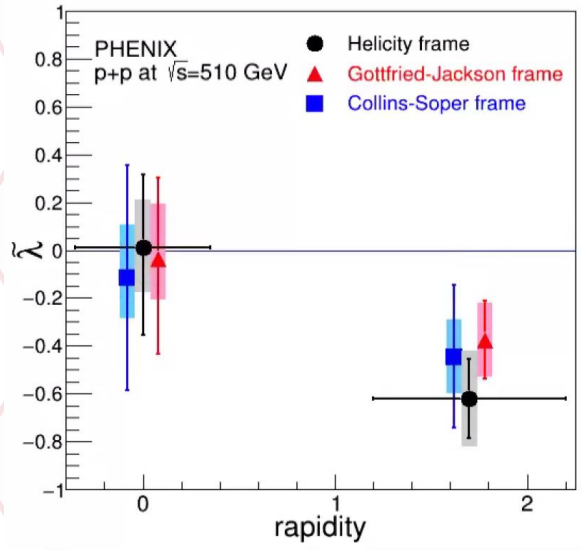




J/Psi polarization at 510 GeV

hep-ex:2005.14273





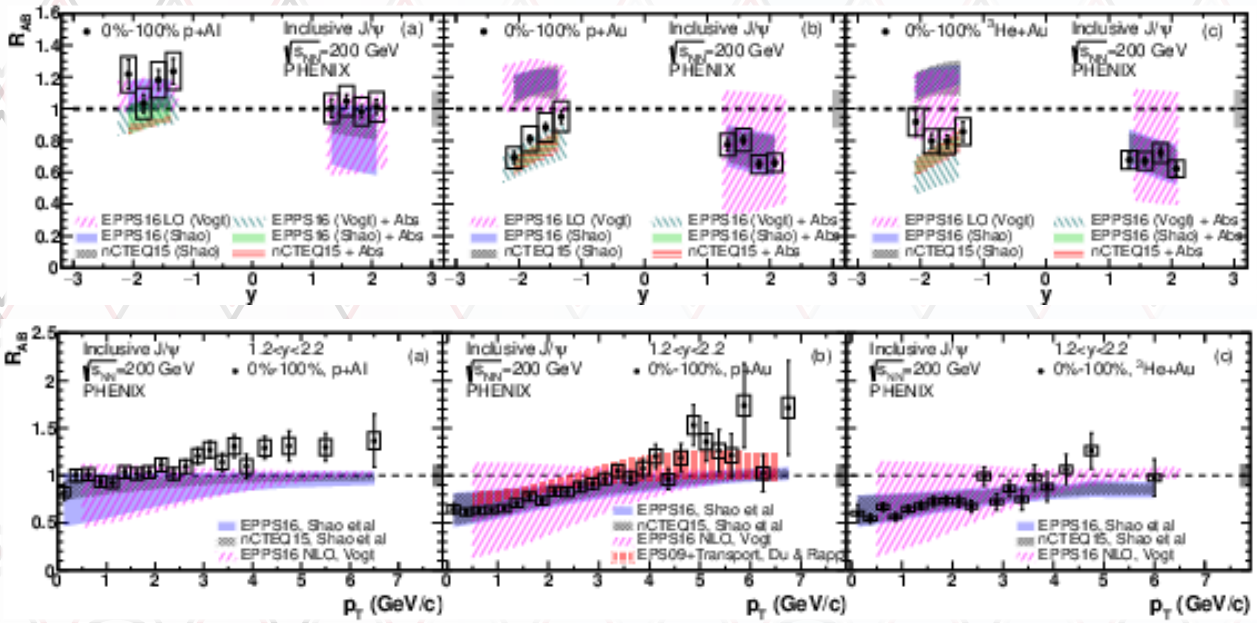
- Central rapidity measurements are consistent with no net polarization
- Different assumptions in theory calculations with very different predictions
- Central values between predictions, but neither can be excluded
- Substantial polarization seen at forward rapidities
- *Earlier PHENIX polarization measurements:*
  - *Forward J/Psi at 510 GeV, Phys.Rev.D 95 (2017) 092003*
  - Central J/Psi at 200 GeV, *Phys.Rev.D 82 (2010) 012001*

Theory: M. Butenschön and B. A. Kniehl, Phys. Rev. Lett. 108, 172002 744 (2012)

For HF related details:
see Takashi Hachya's talk

Nuclear modification of J/Psi

Phys.Rev.C 102 (2020), 014902

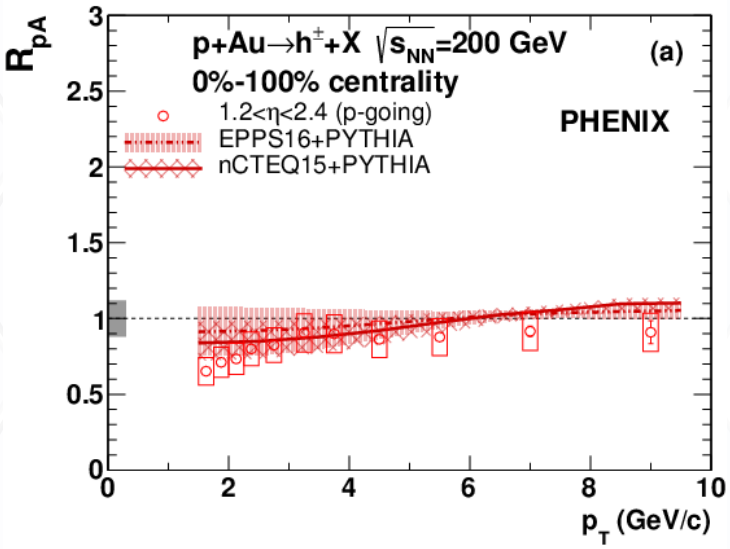


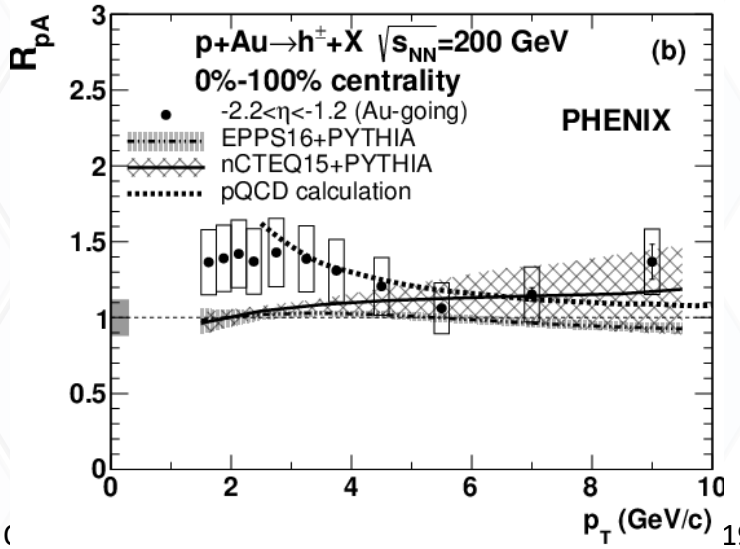
- 4+1 different systems studied
- Little dependence on small beam type (p/d/He3)
- Nuclear dependence clearly seen from Al →Au
- Will improve initial state (nPDFs) significantly

Nuclear modification of forward hadrons

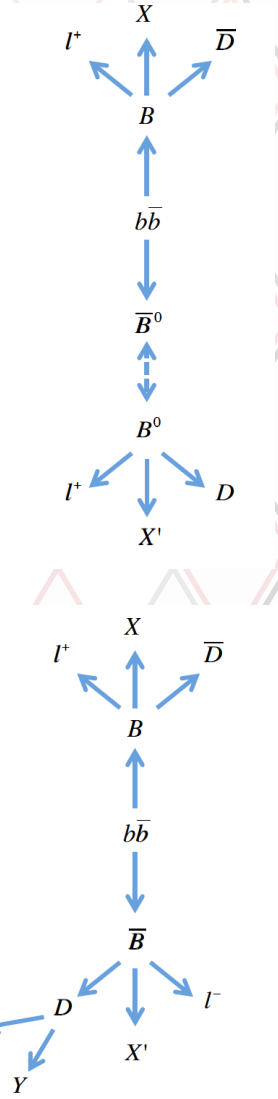
Phys.Rev.C 101 (2020), 034910

- Lower-p_T forward region (lower Au x) shows indication of suppression that will improve nPDFs
- Lower suppression for p+Al, as expected (not shown)
- Enhancement at higher x backward region disagrees with nPDF calculations, but can be understood via pQCD calculation when including multiple interactions

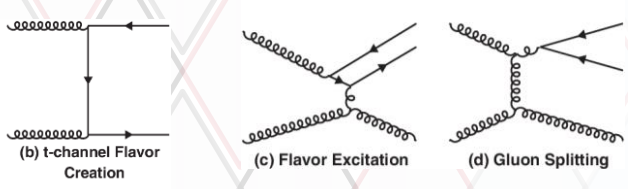


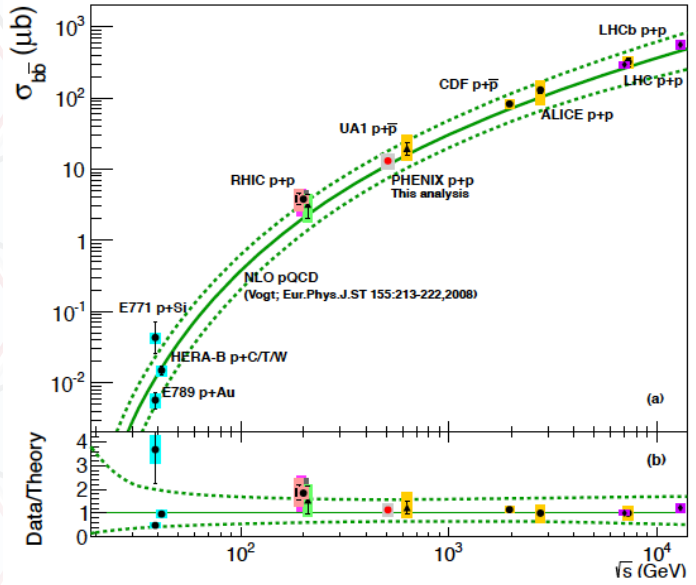


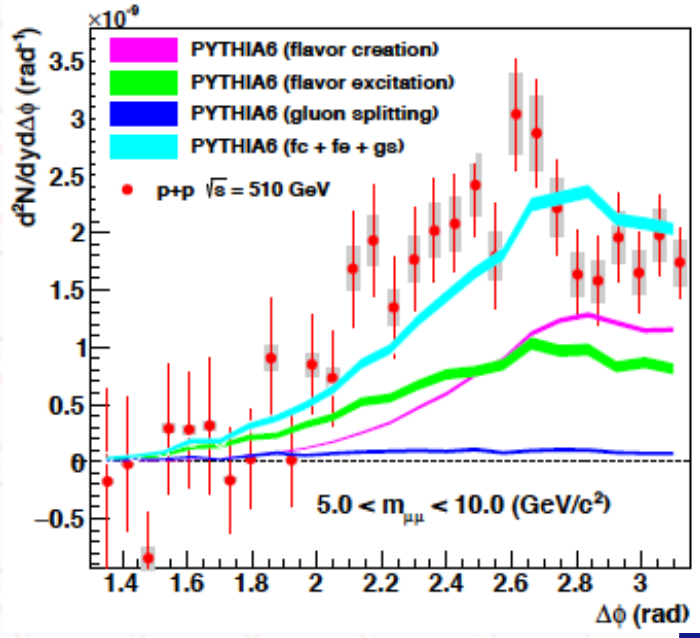
$b\bar{b}$ production via μ pairs



- Opposite-charge muon pairs mix of charm, bottom and DY production
- Like sign pairs predominantly from B meson pair decays
- Consistent with Pythia 6 predictions for b-pair production mechanisms



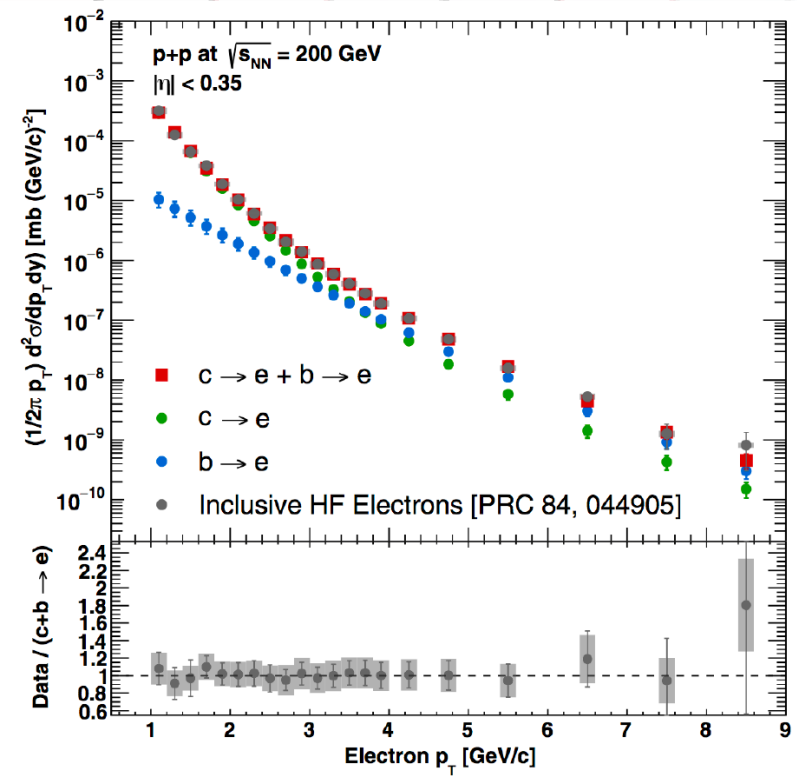




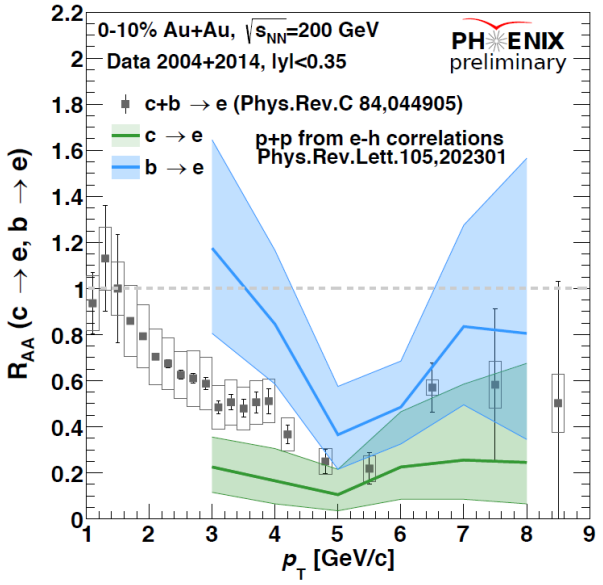
arxiv.org:2005.14276

Charm and bottom separation in HF electrons

PRD 99, 092003 (2019)



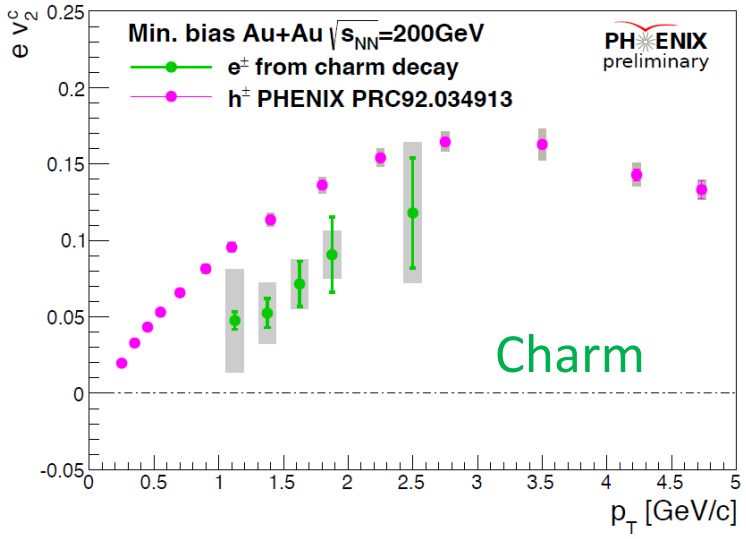
- Improved determination of charm and bottom → electron p+p cross sections via DCA measurements published
- Will improve baseline for corresponding R_{AA}s

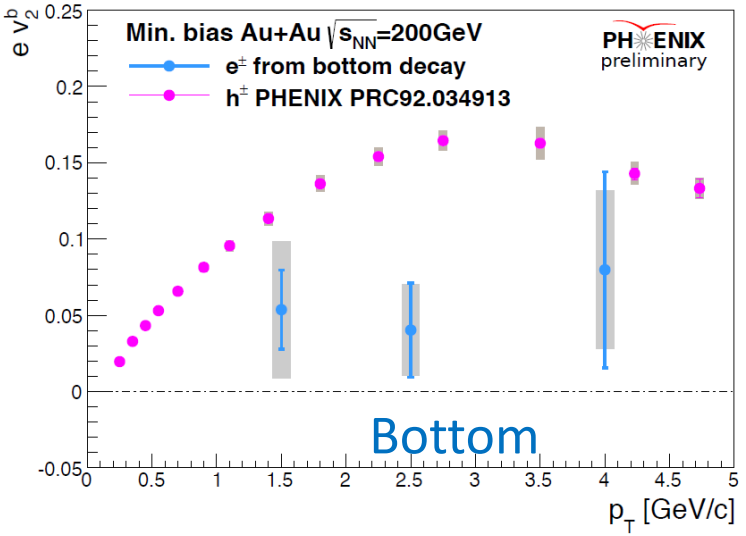


HF related results: see Takashi Hachya's presentation

Heavy Flavor electron v_2

- Both charm and Bottom v_2 nonzero
- Smaller than hadron v_2
- Bottom decay electrons appear to have a smaller v_2 than charm decay electrons

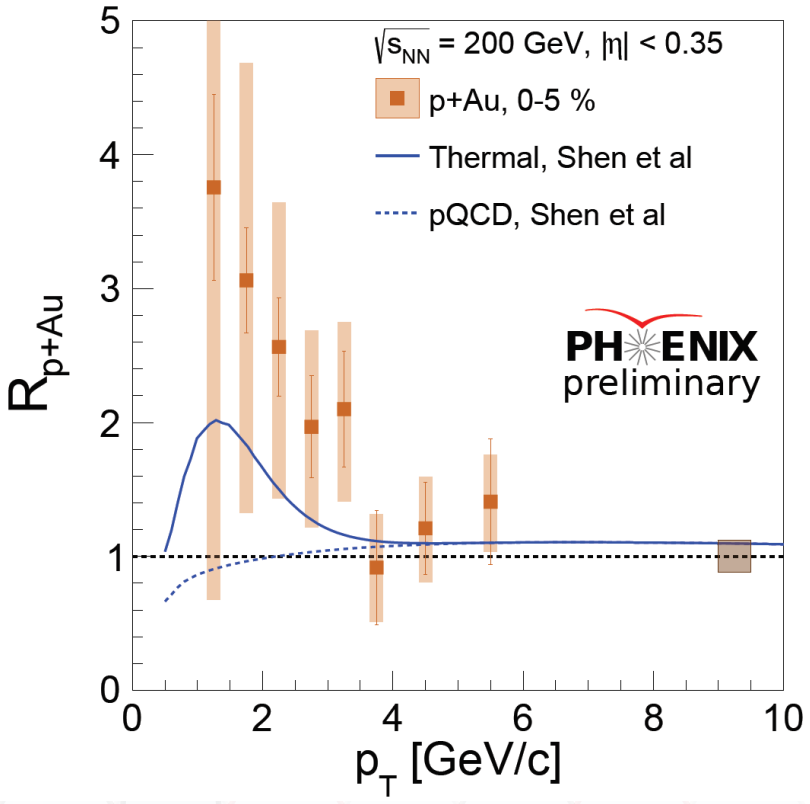




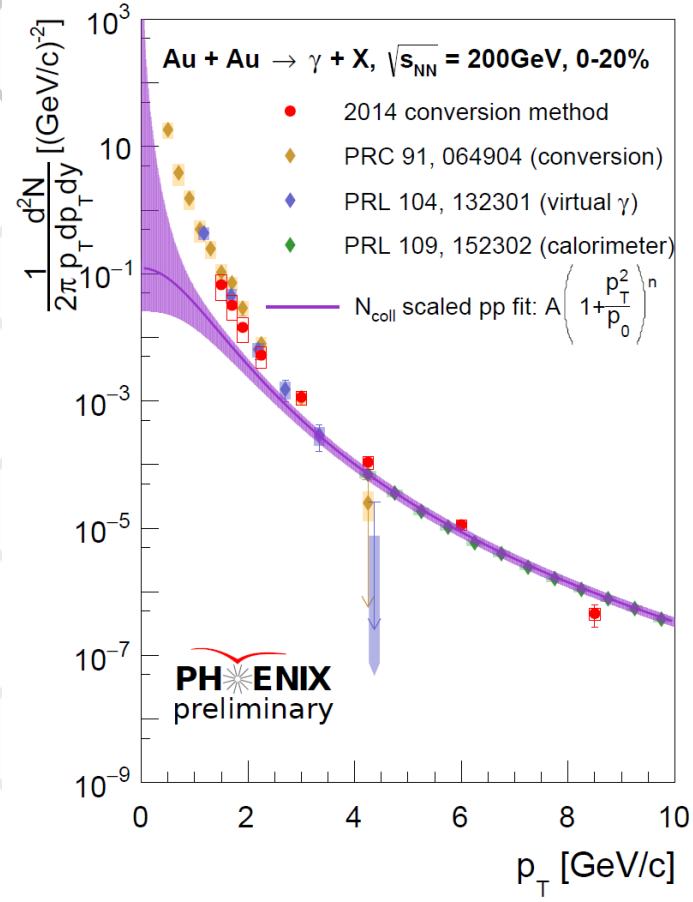
HF related results: see Takashi Hachya's presentation

Thermal photons in small systems

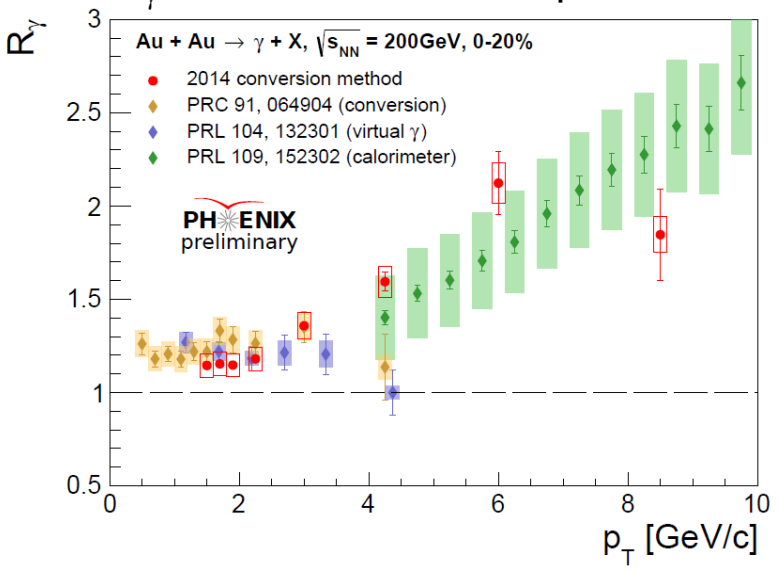
- Enhancement of low p_T photons in central p+Au
- Consistent with expected thermal photon predictions: PRC 95 014906 (2017)



Thermal Photons in Au+Au Collisions

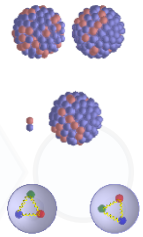


R_γ = inclusive/hadronic photons

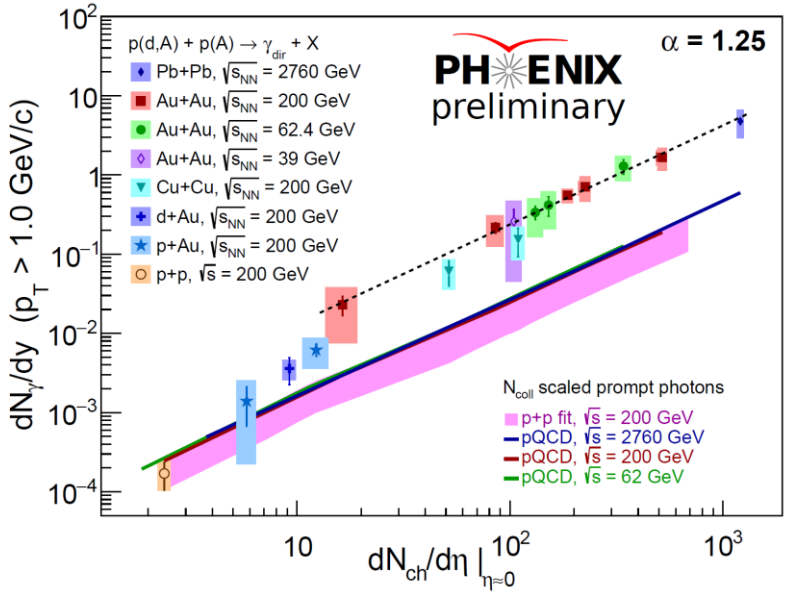


- Comparison of various photon reconstruction methods:
  - Virtual photons
  - Conversion photons
  - Conventional photons in Calorimeter
- Good consistency

Thermal Photons in Small Systems

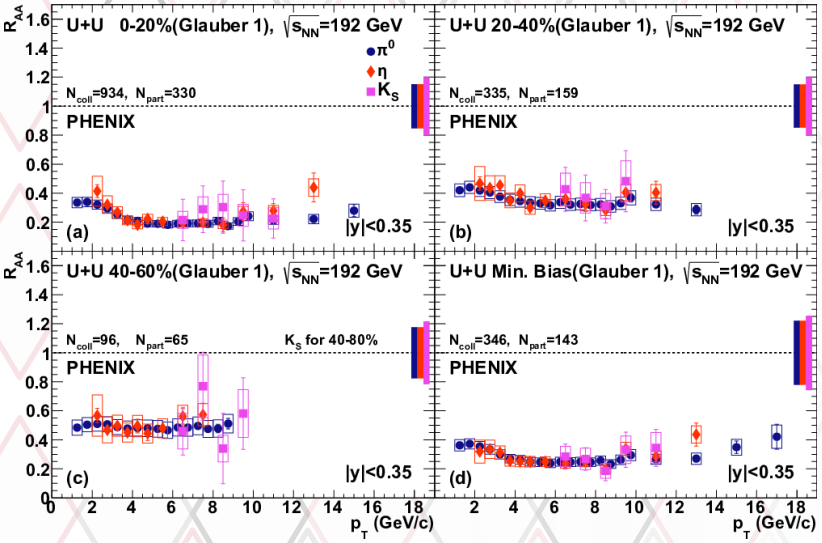


- Conversion result from 2014 Au+Au data taking is consistent with older PHENIX results
- ALICE results results (not shown here) are also consistent with PHENIX
- Slopes similar to p+p slopes but shifted
- Smaller systems gradually return to the p+p line at lower multiplicities

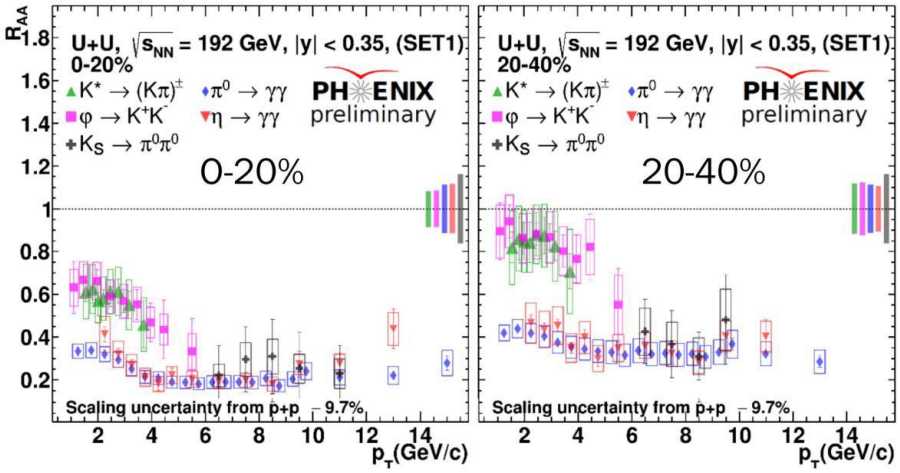


Nuclear modification in U+U

arxiv.org:2005.14686

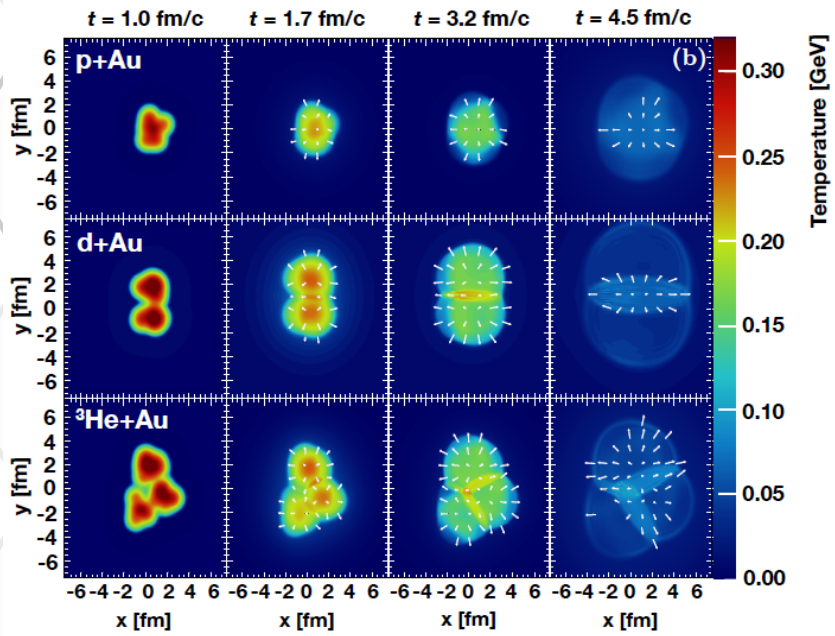


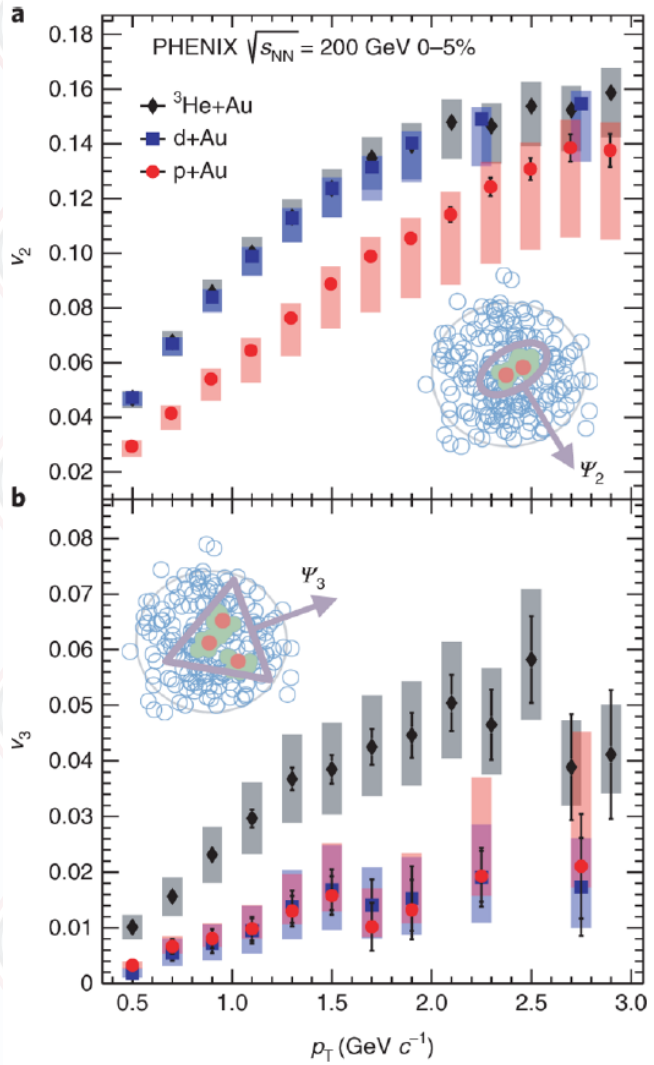
- Various final states studied in U+U collisions
- PS mesons show similar suppression
- Vector mesons less suppressed at low p_T



Hadron modification in small systems

Nature Physics **15**, 214–220 (2019)





- Collision system geometry seems to relate to v_n:

  Lower v_2 in p+Au

  Higher v_3 in ^{3}He+Au

- Can be described by Hydrodynamic models

For small systems related details: see Ron Belmont's talk

Summary

- IP-8 is nearly empty now, but the PHENIX physics program continues!
- Many exciting results released or published in the last year!
- Still more to come in the future