$p\uparrow A \rightarrow Xn$:
Forward neutrons for polarimetry

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Polarization/polarimetry
@ EIC workshop
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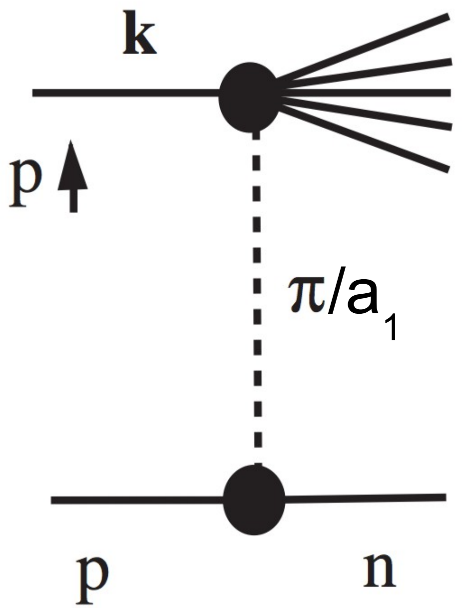
- $p\uparrow p \rightarrow Xn$ & $p\uparrow A \rightarrow Xn$ results @ RHIC:
  azimuthal asymmetries A_N
- Model for $p\uparrow A \rightarrow Xn$:
  - UPC (Ultra Peripheral Collision) photons $A \rightarrow A\gamma$
  - $\gamma p\uparrow \rightarrow N^* \rightarrow n\pi^+(\pi^0)$ asymmetries A_N
- Apply model → fixed target kinematics: polarimetry
- Comparisons pC and $pA \rightarrow Xn$ polarimeters
  - technologies
  - stability, absolute polar. scale, rates @ EIC
- Immediate questions: full model estimates
  PHENIX data
  target possibilities
- Possible tests @ RHIC

$p\uparrow p \to Xn$ @ RHIC

- Early RHIC $p\uparrow p \to Xn$ result:
  forward neutrons in Zero Degree Calorimeter (ZDC)
  have significant azimuthal asymmetry $A_N \sim$ few %

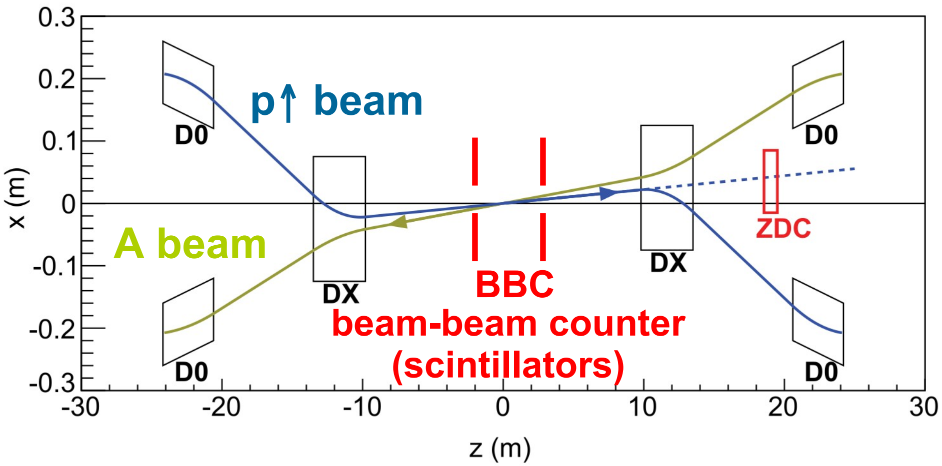
- Kopeliovich *et al.* model explains A_N:
  - interference of π^+ (spin-flip) &
  - a_1^+ (spin-nonflip) exchanges

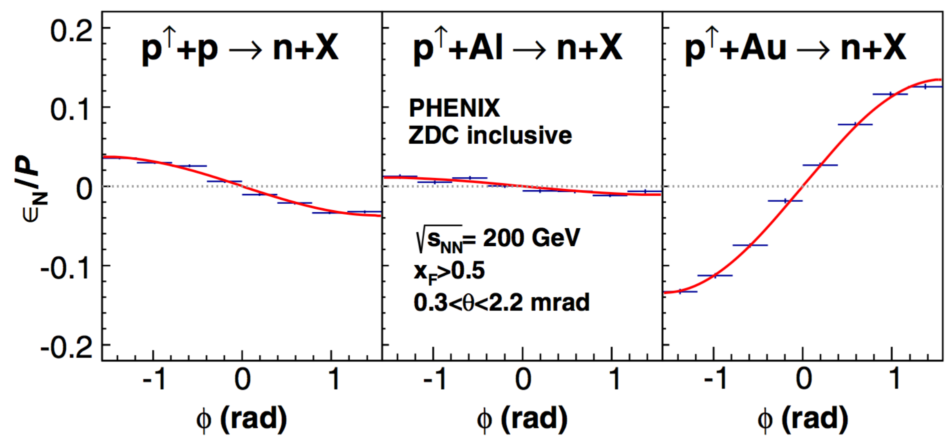


- This A_N ~few % routinely used as tool for local polarimetry:
  for longitudinally polarized proton collisions,
  tune spin rotators so azimuthal asymmetry $\to 0$

p↑A→Xn @ RHIC

- Surprise in 2015 p↑A→Xn data (A = Al, Au, 100 GeV/N beams): PHENIX measured forward neutron asym. in proton direction*

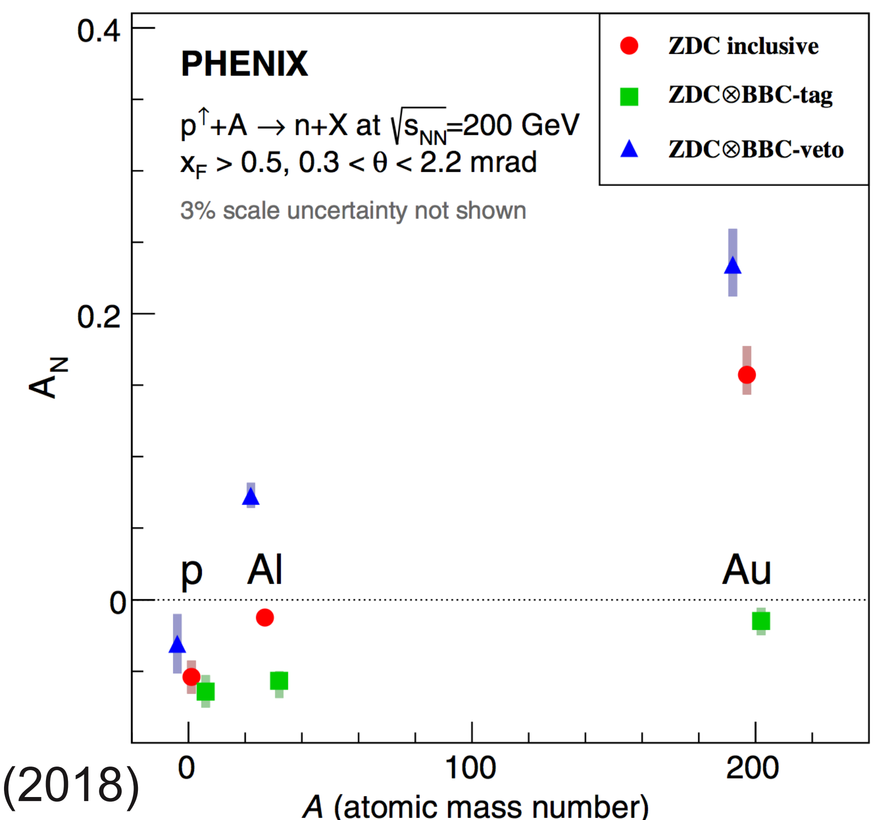




- Very large A_N observed for Au, opposite sign as p↑p→Xn

- Select low multiplicity (~elastic) events: BBC veto
  Al & Au large, opposite sign A_N

- Clearly something else is going on here ➘



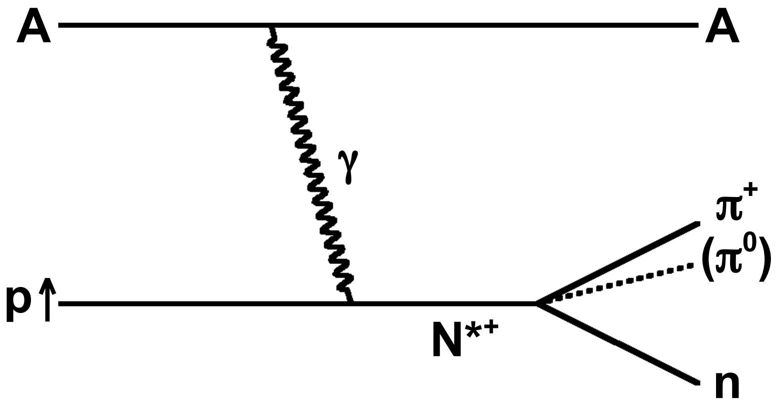
*PHENIX Coll., C. Aidala et al., PRL 120, 022001 (2018)

Model for p↑A→Xn

Convincing description: G. Mitsuka, PHYSICAL REVIEW C **95**, 044908 (2017)

Sum 2 processes:

- Kopeliovich *et al.* π/a_1 exchange model (slide 2), Glauber extend p→A
- UPC photon from A, photoproduction on p↑:



Well founded inputs to UPC model:

- Upper vertex photon flux from STARlight
  Klein *et al.*, Comput. Phys. Commun. **212**, 258 (2017)
  UPC industry standard, well verified
- Lower vertex $\gamma p\uparrow \rightarrow n\pi^+(\pi^0)$ photoproduction from MAID2007 Drechsel *et al.*, Eur. Phys. J. A **34**, 69 (2007)
  unitary isobar model analysis world data,
  here azim. asym. vs. W = γp c.m. energy:

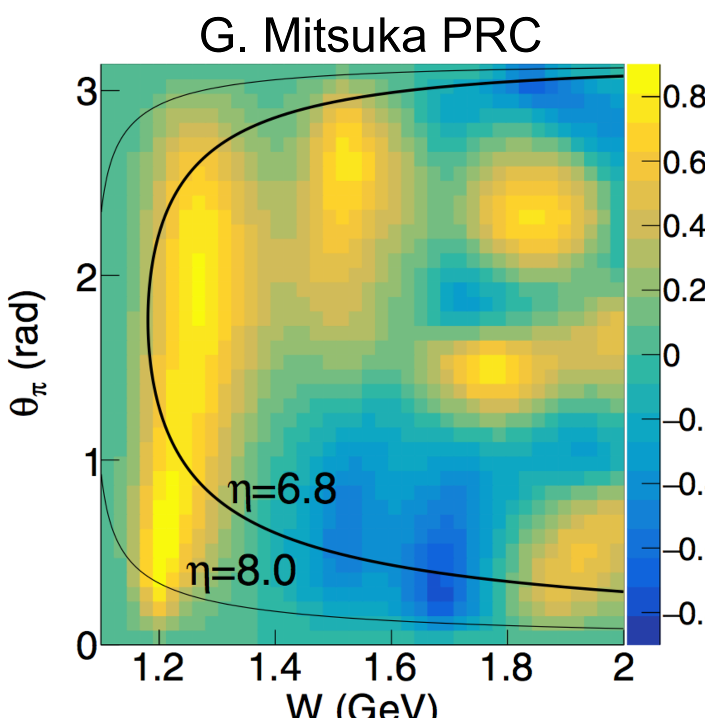
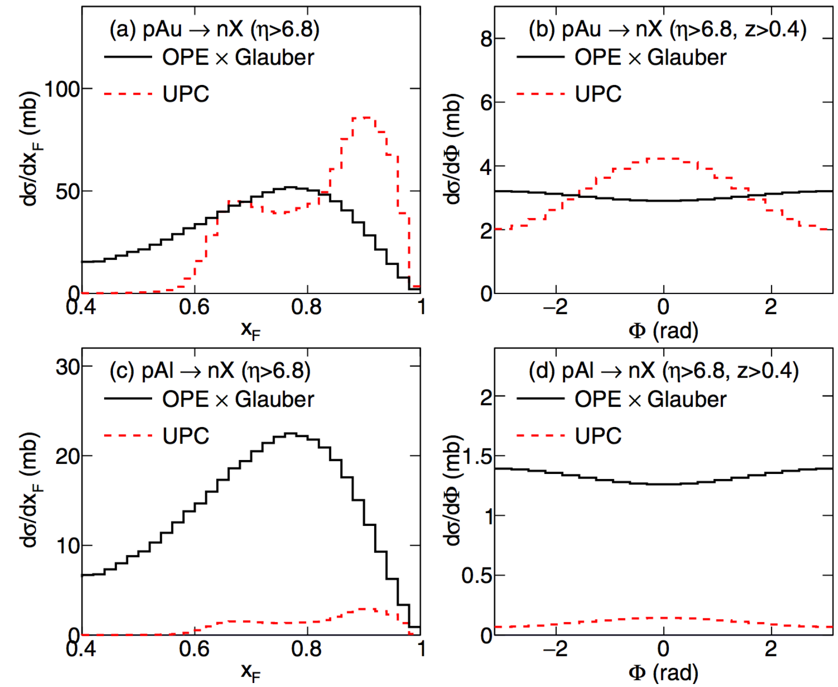


FIG. 2. Target asymmetry $T(\theta_\pi)$ of the $\gamma^* p^\uparrow \rightarrow \pi^+ n$ interaction as function of W. In the detector reference frame, the curves correspond to the rapidity of produced neutrons $\eta = 6.8$ and 8.0.

Model for p↑A→Xn

plots:
G. Mitsuka PRC

- Two processes cross section vs. x_F and azimuthal angle distributions: (Au top row, Al bottom row)



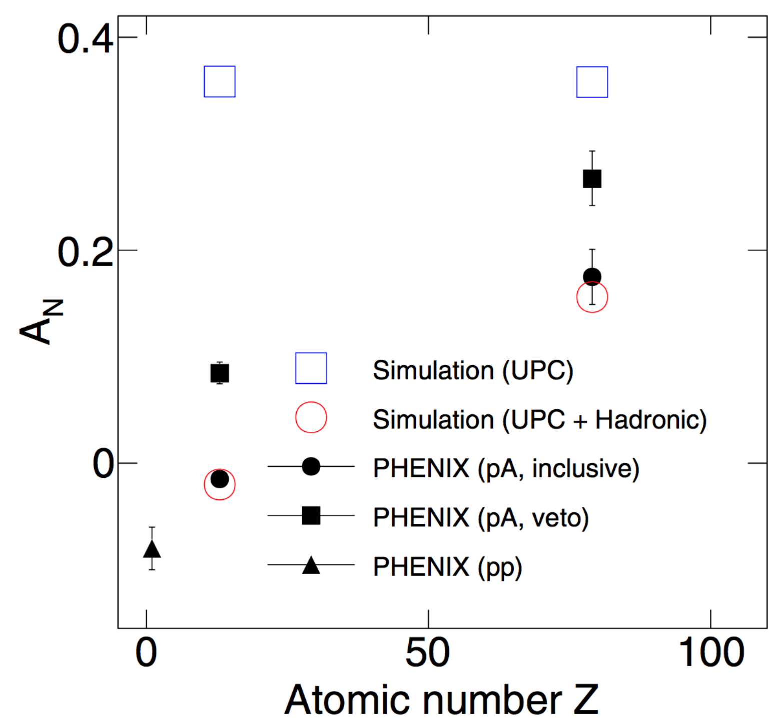
- Opposite azim. asym. for UPC, meson exchange processes

- UPC σ rises rapidly $\propto Z^2$

  π/a_1 exchange σ rises slowly with A

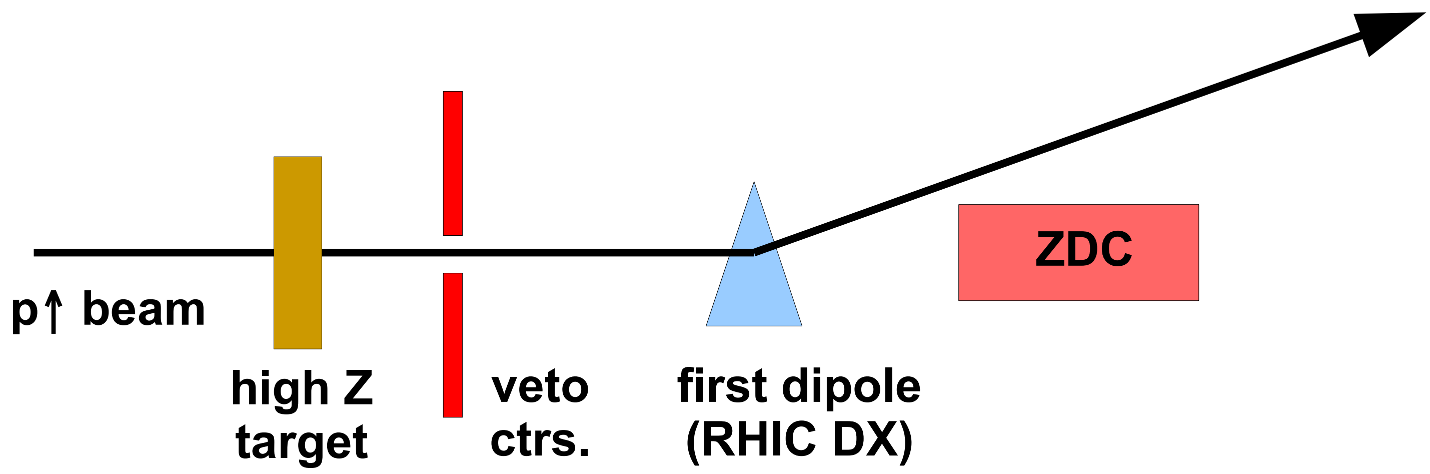
- Sum two processes, A_N from azim. dist.
- Excellent agreement w/ PHENIX data

- This model is on firm ground
- Use for polarimetry ↘



p↑Au→Xn for polarimetry

- Proton beam leaving EIC straight section (not an I.P.):
  (or @ and I.P. for local polarimetry, reuse experiment ZDC)



- This is just a fixed target version of p↑A→Xn process
- Detector: ZDC, proven technology (this experiment's already been done)
- Target?

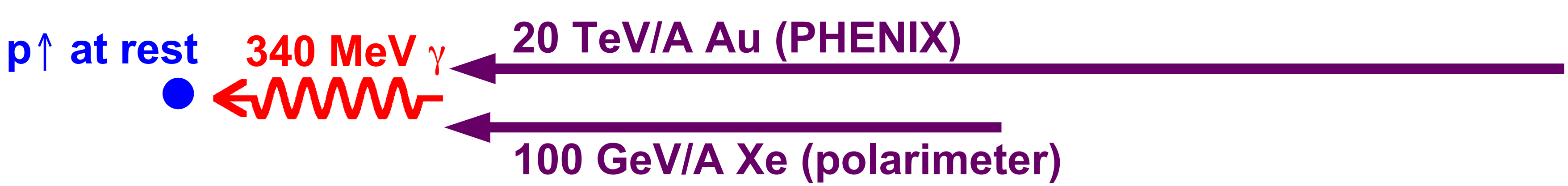
  - 1st thought: Au wire across beam
    quickly shot down: wire destroys beam
  - Suggestion (A. Zelenski): Xe gas jet
    highest Z usable noble gas

Xe target rates

First need cross section

- Mitsuka's model good for A_N; cross section?
  - for PHENIX conditions, ZDC acceptance: σ_{UPC} ~ 20 mb
- Consistent with rates observed in PHENIX (A. Bazilevsky)
  - model σ_{UPC} is also verified ✓
- Fixed target case:
  - $\gamma p \rightarrow Xn$ kinematics (& ZDC acceptance) identical to colliding case
  - just different source (& flux) of photons
- E.g. for $\gamma p \rightarrow \Delta(1232)$ in lab frame:

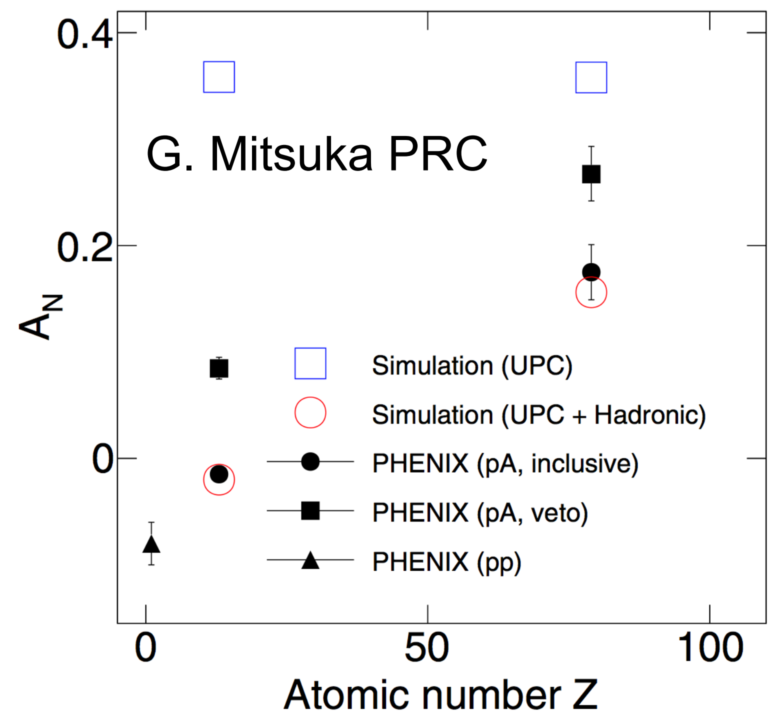
- Or in proton rest frame (where flux calculated):



- Ratio fluxes* polarimeter/PHENIX ~ 0.1 *Klein, Nystrand, Phys.Rev.C60:014903,1999
- So for fixed target polarimeter: σ_{UPC} ~ 2 mb

Xe target rates

- Proton current: I_p = 0.75-1 A (EIC parameter table)
- Xe gas target density:
  - Q: can it be ~same as polarized Hjet, 1.2×10^{12} atoms/cm^2?
  - A: “looks feasible” (A. Zelenski)
- Cross section, current, target density ⇒ **rate ~ 12 kHz**



<u>stat. precision P</u>

- Interpolate Al→Au: A_N(Xe) ~ 0.1
  (uncertain, mix hadronic/UPC processes)
- Suppose typical P ~ 50%
- 2% stat. uncert. on P:
  1M events ~ 90 seconds
- Many 2% measurements per fill
- Alternatively:
  narrow Xe jet ~200 μ, lower density
  ⇒ measure transverse P profile

- **Rates well within range for reasonable P measurements**
  Caveat: many of these numbers best guesses for now

p↑C vs p↑A→Xn polarimetry
COMPLEMNTARITY

- Rates etc. adequate as **alternative to pC polarimeter**
- Compare kinematics, detectors two methods:

<u>pC</u>

- C nuclei 100's keV energy
- Calorimetry in Si strips:
  calib. α source ↔ Si dead layer
- PID via TOF in Si strips

<u>pA→Xn</u>

- neutrons 100's GeV energy
- Calorimetry e.g. Pb-scint.:
  calib. e.g. beam-gas neutrons
- ~100's GeV hadronic shower after sweeping magnet ⇒ neutrons (or K_L)
- Personally I'm more familiar with this, standard HEP technology

p↑C vs p↑A→Xn polarimetry

Absolute polarization scale?

- Original hope was to calibrate pC scale w/ Hjet, drop Hjet
- In practice pC systematics too unstable; compare to pA:

pC:

A_N steep dependence on E_{carbon}

significant effect $E_{carbon} \rightarrow E_{measured}$:

- Si calibration uncertain, Si dead layer not well measured ✘
- Significant energy loss exiting targets, unstable target geometry ✘

pA→Xn:

A_N dominated by resonances,

kinematics defined by E_{beam}'s

- Good ZDC E-scale syst. has been achieved (ZEUS FNC 2%*) ✔
- Negligible target effect on 100's GeV measured neutrons ✔

- Systematics of pAu→Xn much better controlled
- Absolute scale calibration w/ Hjet may be possible

High bunch ×ing rate @ EIC?

- pC→pC: many bunch ×ings in system, bkg. overlap w/ neighbors ✘
- pA→Xn: neutrons β~1, prompt with beam ✔

⇒ Some challenges @ EIC mitigated

*ZEUS Coll., S. Chekanov et al., Nuclear Physics B 776 (2007) 1–37

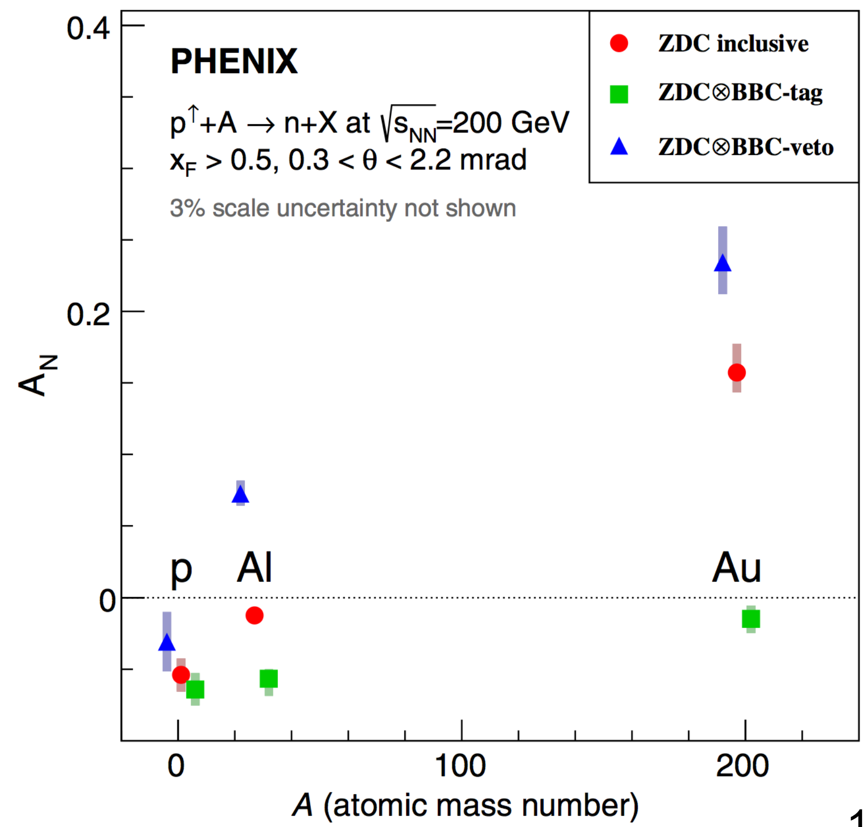
Immediate questions

<u>G. Mitsuka's model</u>

- Estimates here for fixed target rate, A_N:
  back-of-envelope, factors of 2 or so
- Need to reapply full model for fixed target kinematics, nucleus A, both processes UPC & meson exchanges
- Looking for help!

<u>PHENIX data</u>

- Full analysis still in progress...
- Apply BBC detectors:
  scintillators along beam line
- Veto on BBC (blue) significant increase A_N over inclusive (red)
- Maybe reduces meson exchange, enhance UPC?
- Compare to model
- More to milk from this data...



Immediate questions: targets?

Xe gas target

- How feasible? How big a deal?
- What densities?
- Jet narrower than beam?
  Jet transversely movable? ⇒ measure transverse P profile

Other high Z

- Some way to get Au across beam without destroying it?
- Other high Z? W (tungsten)? high melting, boiling temps.

A lot of questions

pC polarimeter targets

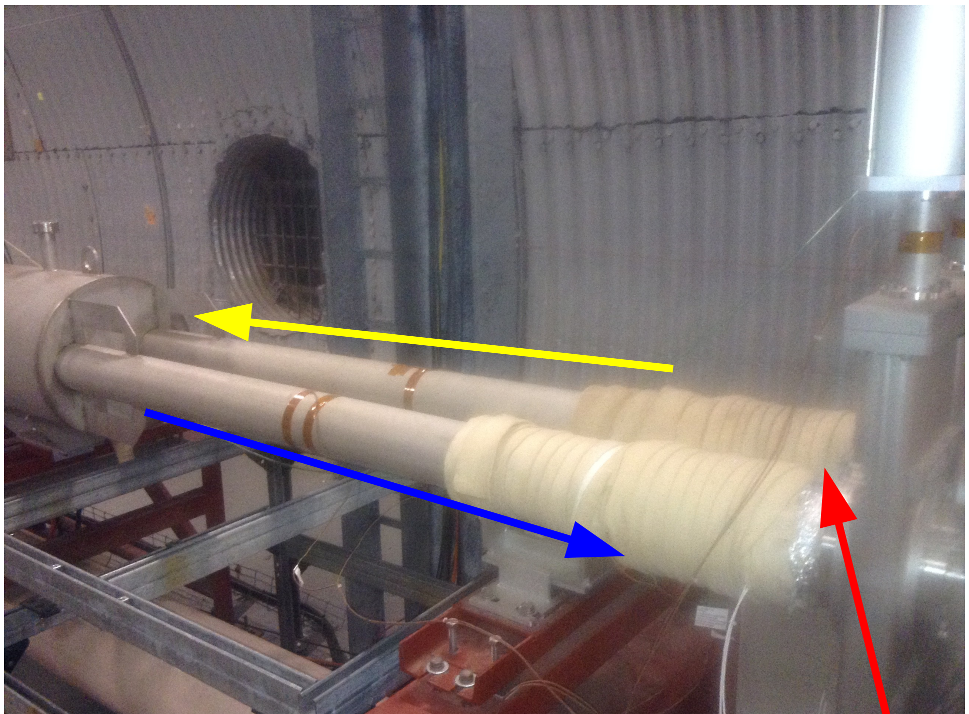
- pC→pC polarimeter needs alternative target technology for EIC
- Any pursuit should consider needs for pA→Xn polarimeter (high Z)

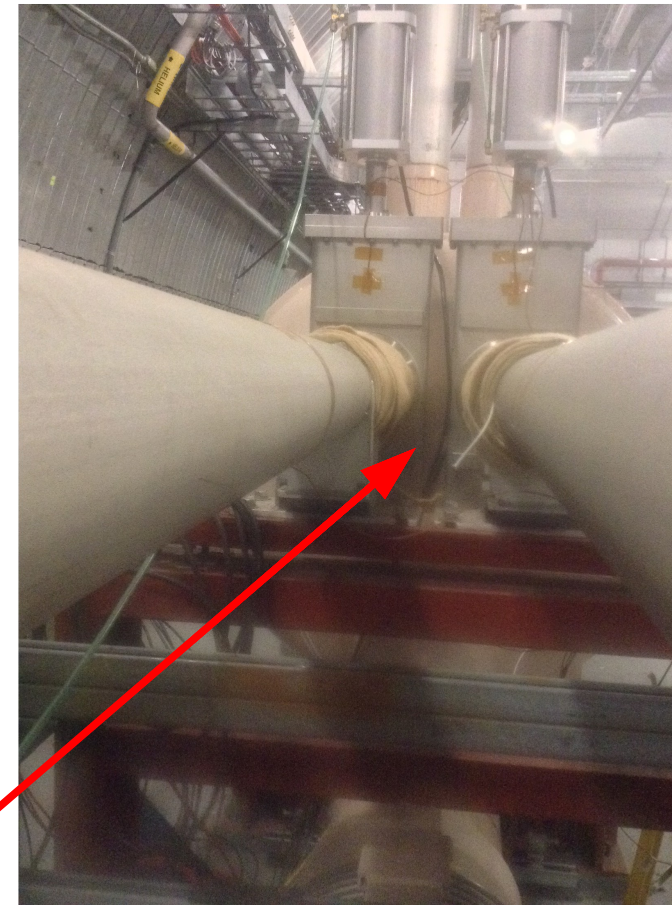
Tests at RHIC

<u>Could test in remaining RHIC runs</u>

- Would need target station near Hjet
- Here 15-18 m clockwise from Hjet:

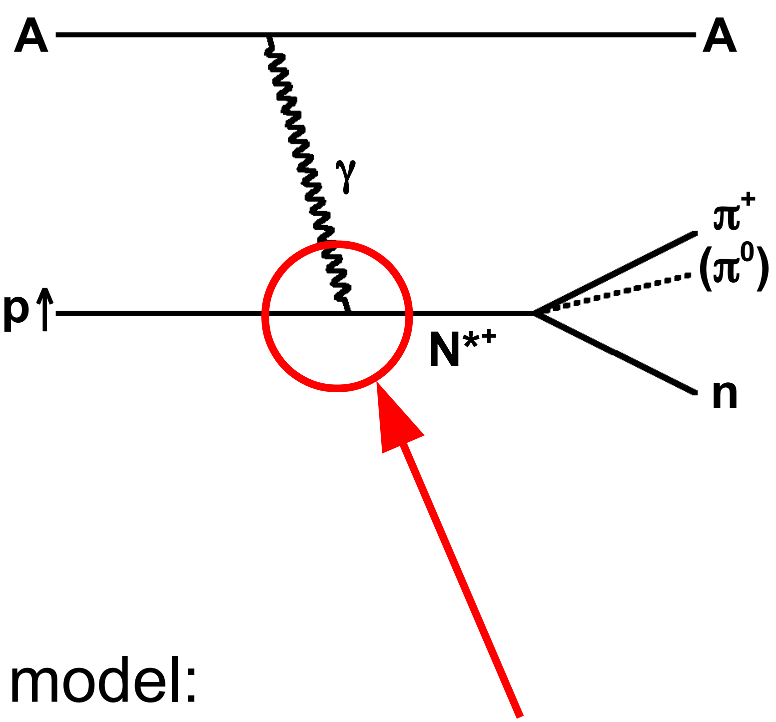
DX magnet





- After DX splits blue/yellow beams, space for ZDC between beam pipes
- Same place as @ STAR, PHENIX
- Spares available (PHOBOS, BRAHMS, PHENIX?)

Light ion polarimetry?



- pA→Xn model:
  lower vertex based on $\gamma p\uparrow \rightarrow n\pi^+(\pi^0)$ data
- Similar data for $\gamma d\uparrow$, $\gamma\,^3He\uparrow$?
  apply model for light ion polarimetry

Summary

- Significant forward neutron asymmetries seen in pA @ RHIC
- Cross section, asymmetry convincingly described by model:

  based on well known physics and/or measurements

- Model: asymmetry can be used for fixed target polarimetry
- Detector techniques straightforward
- Alternative to pC polarimeter:
  many shortcomings addressed
- Studies needed:
  - firm up model expectations for fixed target
  - suitable target not clear, merits further study
- Possible to study at RHIC (need new target station)
- Light ions?

Compelling promise, should pursue this further!

Thanks for discussions: A. Bazilevsky, G. Mitsuka, A. Zelenski

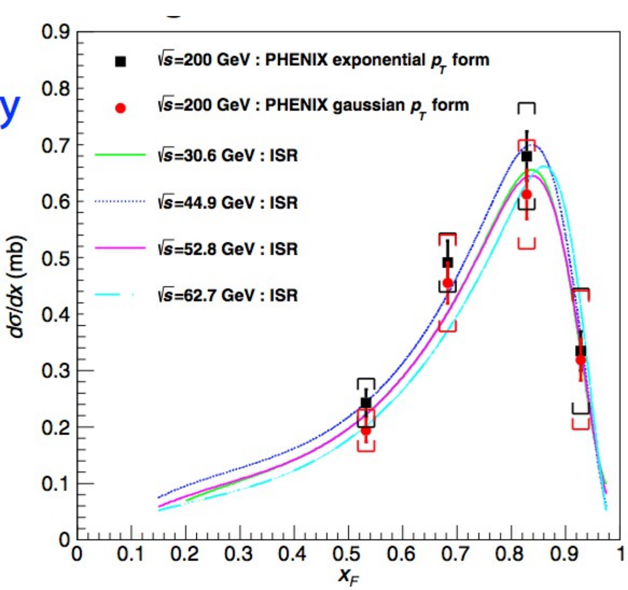
Extras

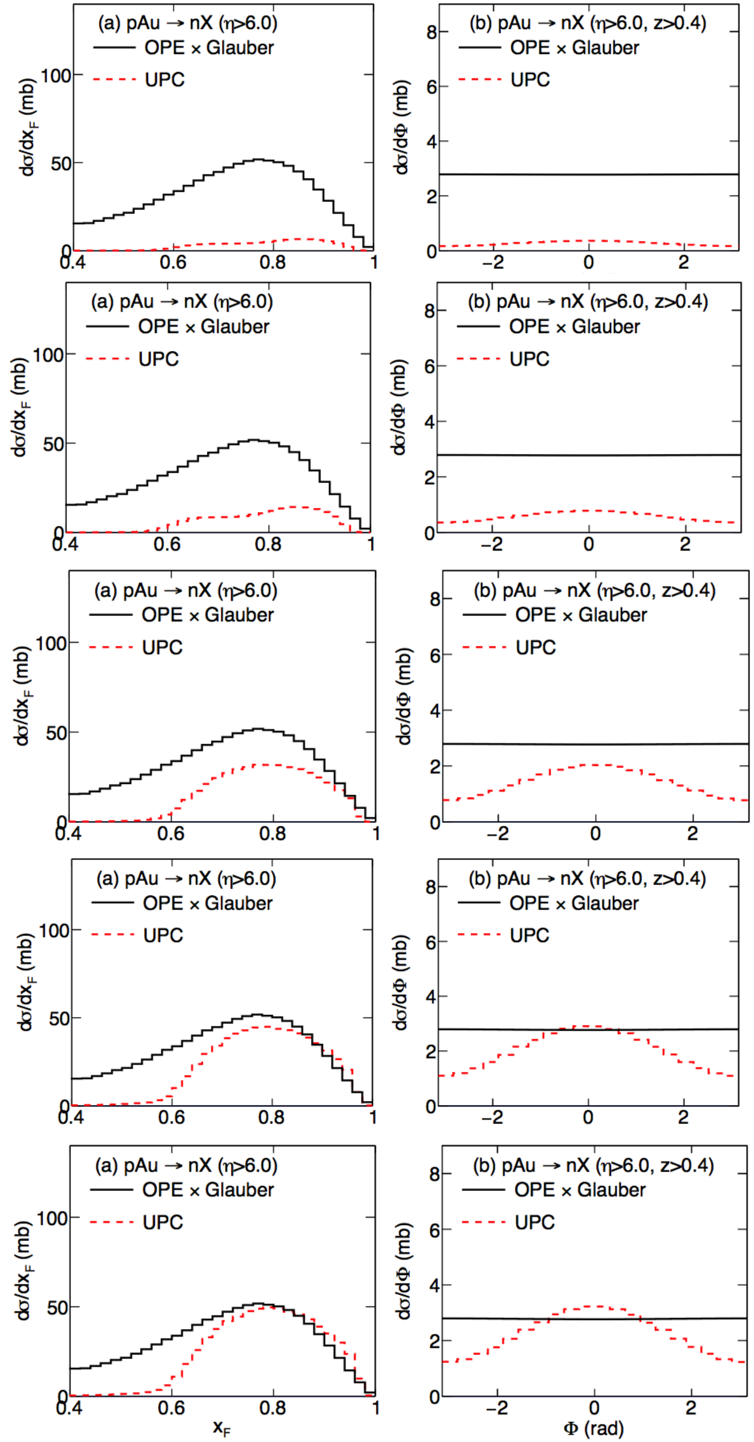
Fixed target p↑Au→Xn various E_{beam}

E_{beam} dependence:

- UPC σ rises
- π/a_1 exchange

  σ ~constant





$E_{beam} = 24$ GeV
$\sigma_{\mathrm{UPC}} = 4.7\,\mathrm{mb}$

$E_{beam} = 50$ GeV
$\sigma_{\mathrm{UPC}} = 10.3\,\mathrm{mb}$

$E_{beam} = 100$ GeV
$\sigma_{\mathrm{UPC}} = 17.3\,\mathrm{mb}$

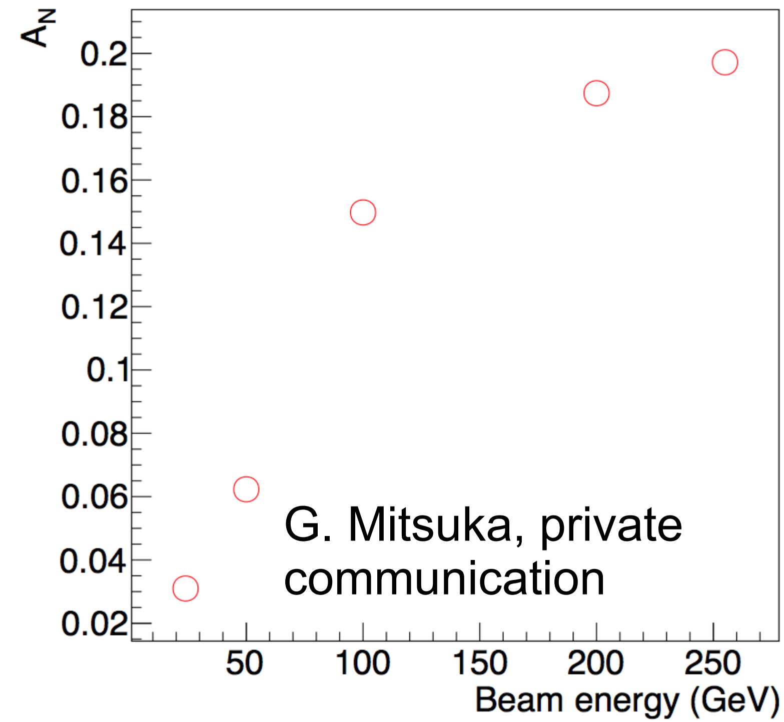
G. Mitsuka, private communication

$E_{beam} = 200$ GeV
$\sigma_{\mathrm{UPC}} = 24.4\,\mathrm{mb}$

$E_{beam} = 255$ GeV
$\sigma_{\mathrm{UPC}} = 27.0\,\mathrm{mb}$

p↑Au→Xn for polarimetry

- Sum two processes, A_N from azim. dist.
- Significant asymmetries at proton collision energies
- Perhaps even useful diagnostic at injection energy



<u>Detector technologies are straightforward & well known*</u>

- ZDC: e.g. Pb-scintillator calorimeter
- Veto counters: scintillators

- Useful: compare to present p↑C→pC polarimeter ↘

* for reasonable bunch ×ing frequencies