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

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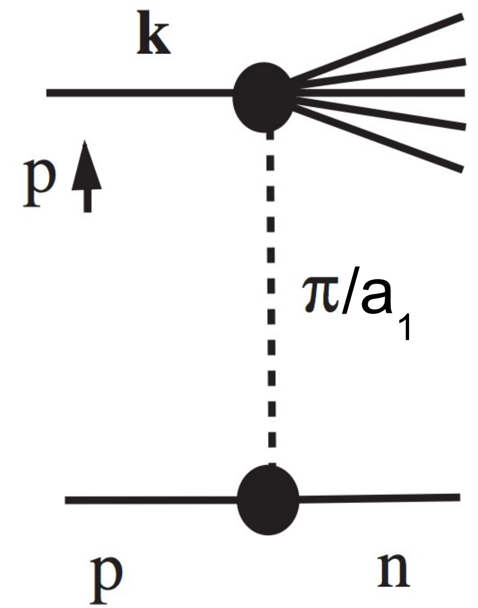
1st EIC polar. mtg.
30.11.18

- $p\uparrow p \rightarrow Xn$ & $p\uparrow A \rightarrow Xn$ 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
- Model results for fixed target kinematics: polarimetry
- Comparisons $pC \rightarrow pC$ and $pA \rightarrow Xn$ polarimeters
  - technologies
  - stability, absolute polar. scale?
- Target for pA: problems with Au
  other A?
- Places for possible studies: AGS, RHIC

$p\uparrow p \rightarrow Xn$ @ RHIC

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

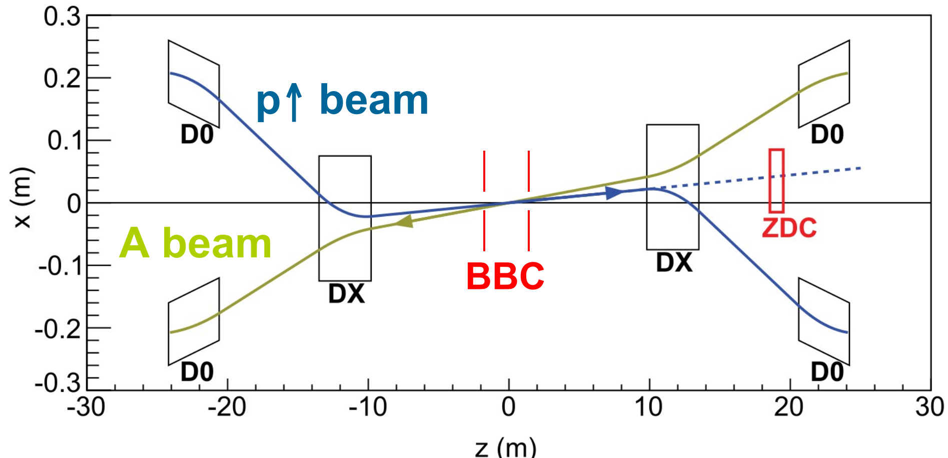
- Kopeliovich *et al.* model explains A_N:
  interference of π^+ (spin-flip) &
  a_1^+ (spin-nonflip) exchanges



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

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*



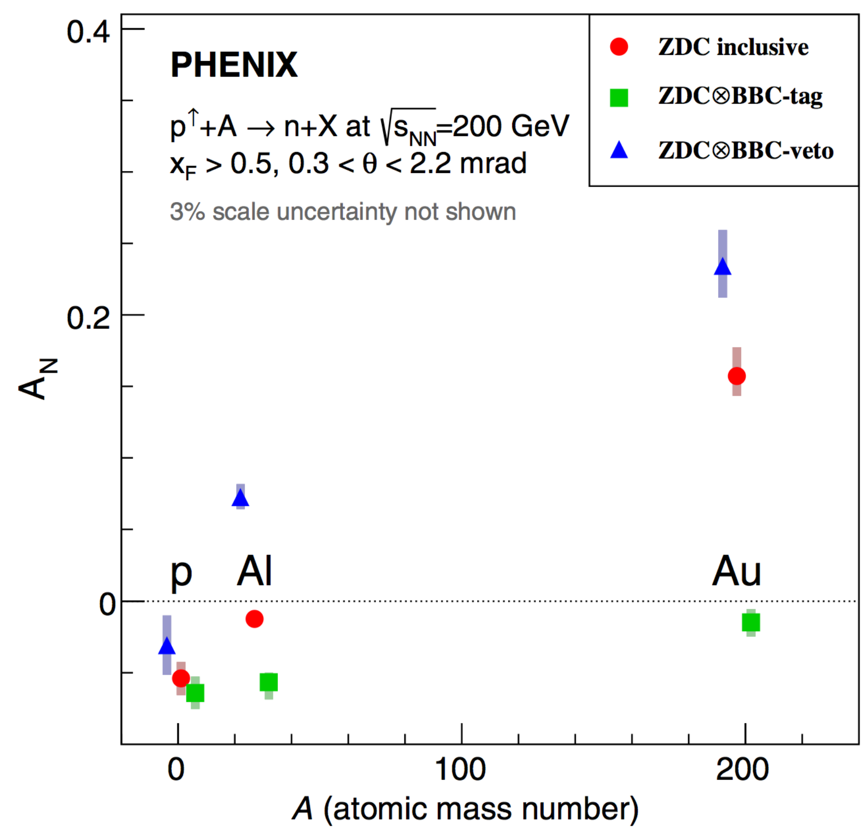
*PHENIX Coll., C. Aidala et al., PRL 120, 022001 (2018)

BBC = beam-beam counter (scintillators)

- 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 ➘

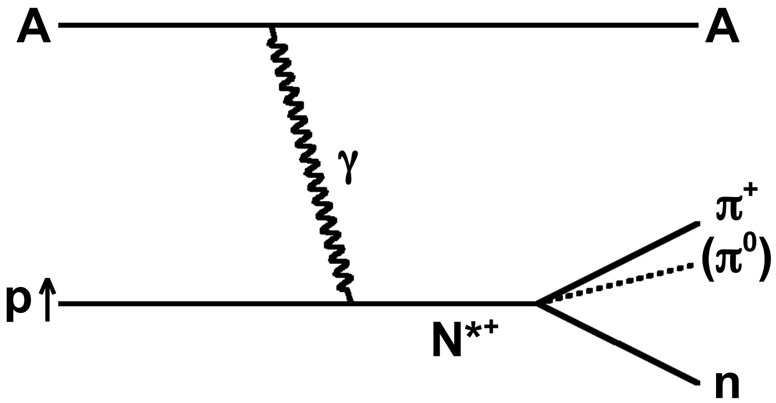


Model for p↑A→Xn

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 $\gamma p\uparrow \to n\pi^+(\pi^0)$ 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:

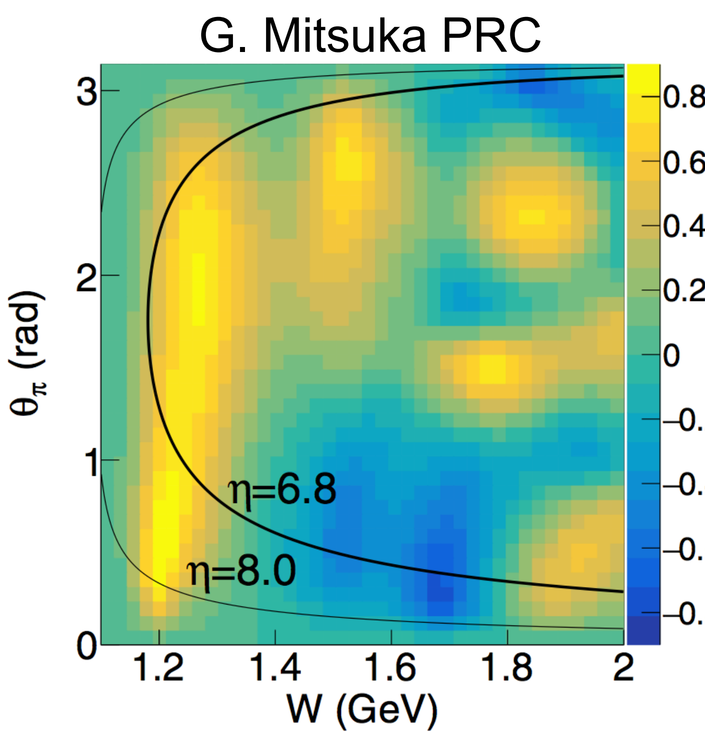
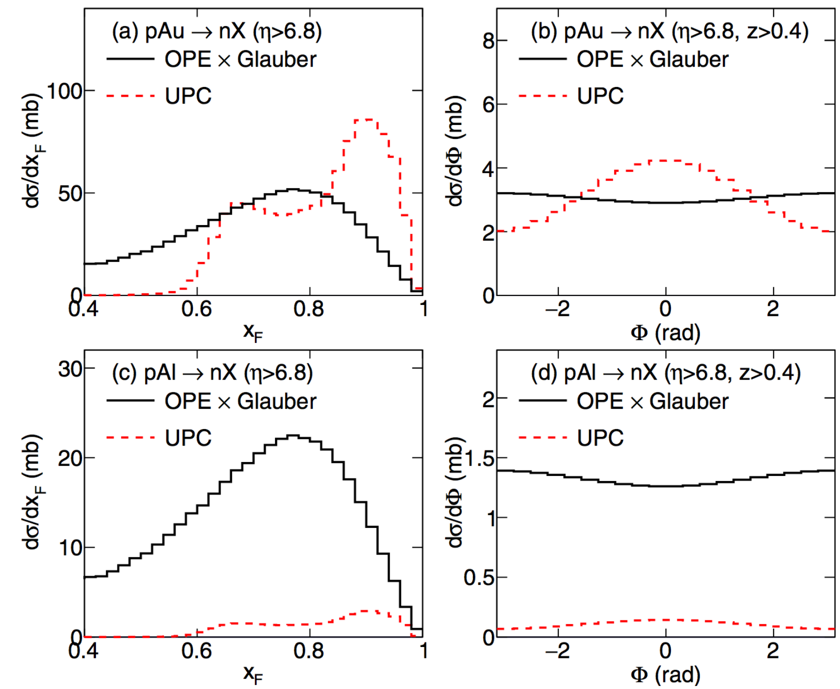


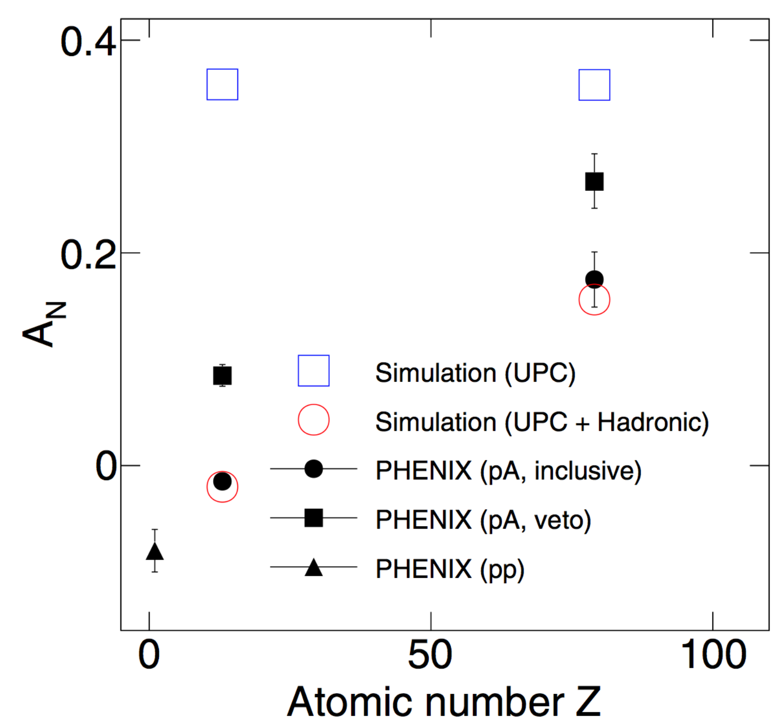
FIG. 2. Target asymmetry $T(\theta_\pi)$ of the $\gamma^* p^\uparrow \to \pi^+ n$ interaction as function of W. In the detector reference frame, the curves correspond to the rapidity of produced neutrons $\eta = 6.8$ and 8.0.

Model for p↑A→Xn

plots:
G. Mitsuka PRC

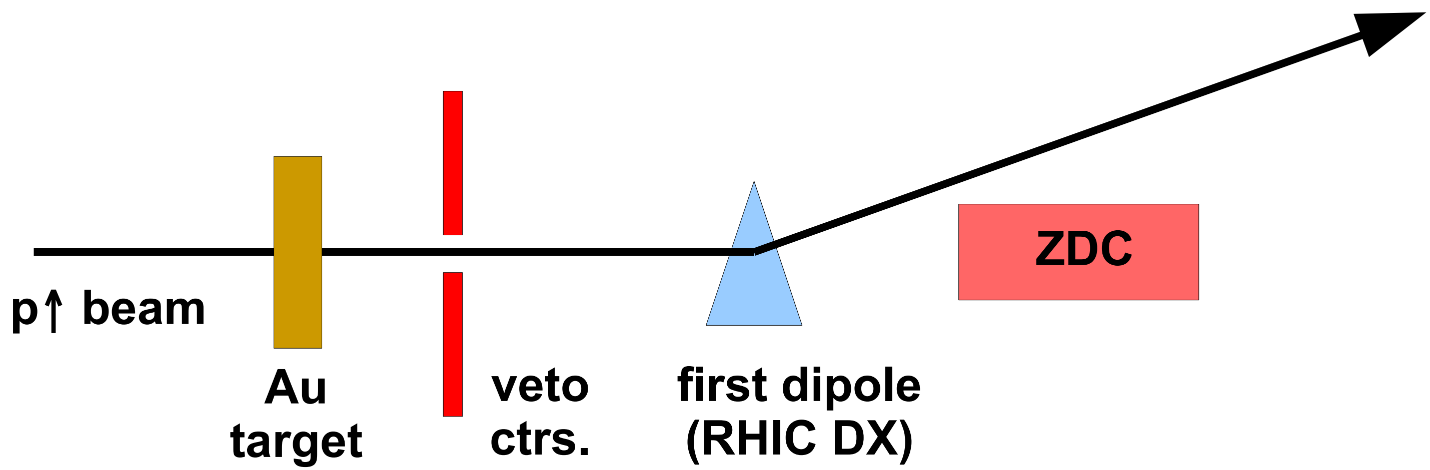
- Two processes cross section vs. x_F and azimuthal angle distributions: (Au top row, Al bottom row)
- Opposite azim. asym. for UPC, meson exchange processes
- UPC σ rises rapidly $\propto Z^2$
  π/a_1 exchange σ rises slowly with A
- Sum two processes, A_N from azim. dist.
- Excellent agreement w/ PHENIX data
- This model is on firm ground
- Use for polarimetry ↘





p↑Au→Xn for polarimetry

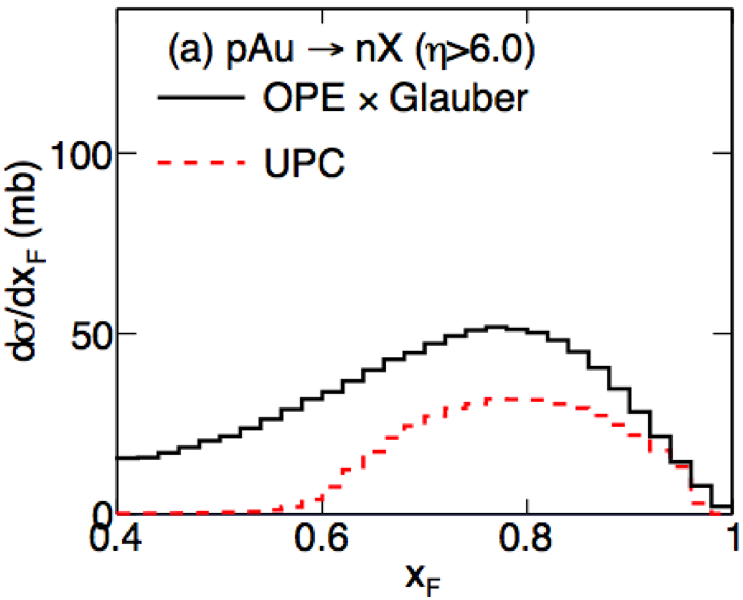
- Proton beam leaving EIC straight section (not an I.P.):
  (or @ and I.P. for local polarimetry, reuse experiment ZDC)

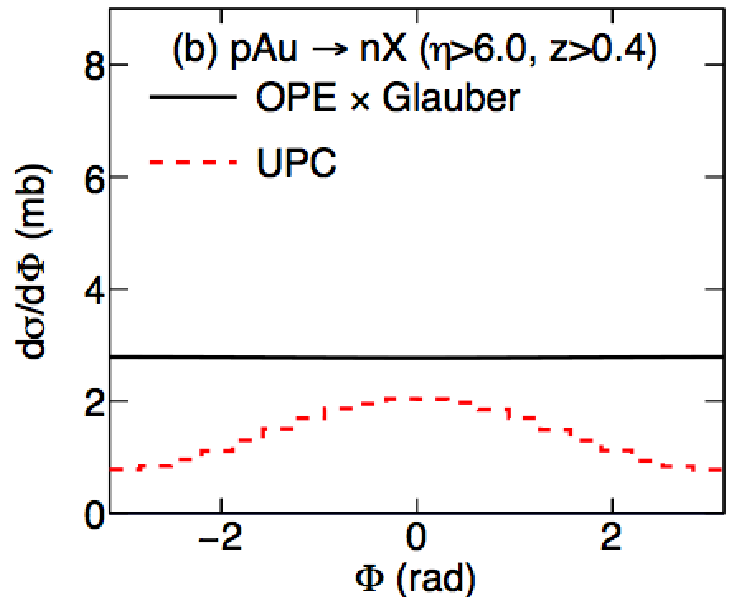


- This is just a fixed target version of p↑Au→Xn process
- Gaku Mitsuka kindly ran his calculations
  for fixed target kinematics (many thanks!)
- ZDC geometry similar to PHENIX, 18 m from Au target
  defines neutron η range (bottom right plot slide 4)

p↑Au→Xn for polarimetry

- Significant asymmetries at proton collision energies

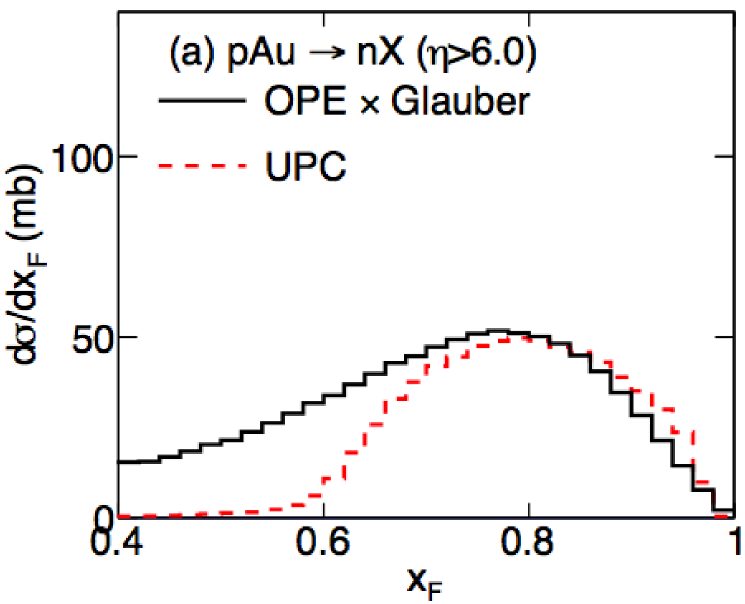


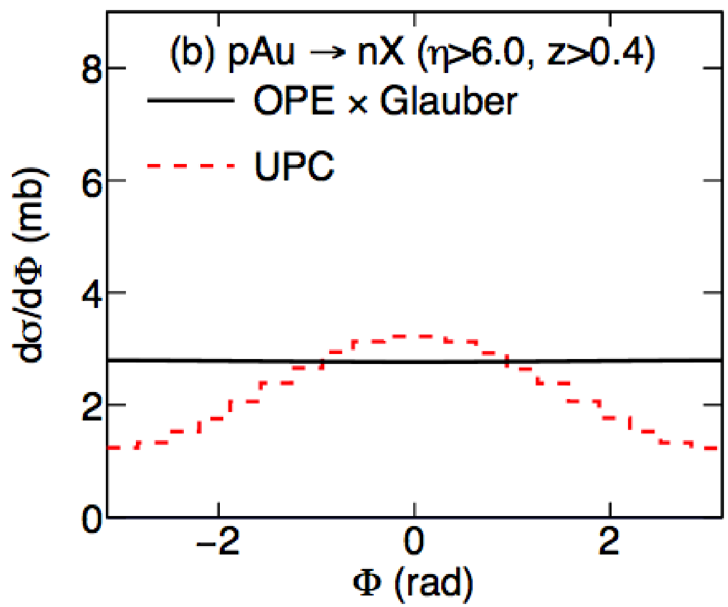


$E_{beam} = 100$ GeV

$\sigma_{UPC} = 17.3\,\text{mb}$

plots: G. Mitsuka
private communication
more energies
on extra slide



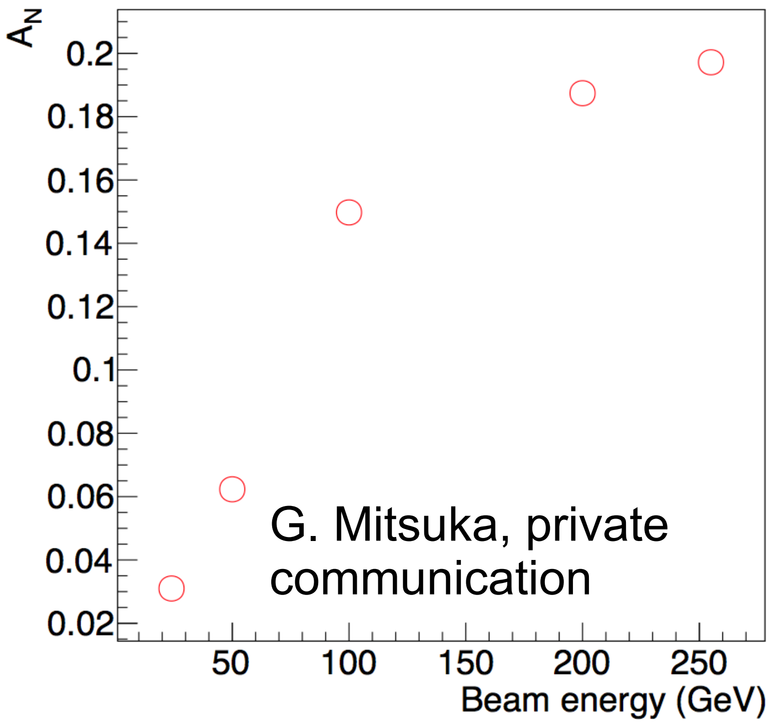


$E_{beam} = 255$ GeV

$\sigma_{UPC} = 27.0\,\text{mb}$

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

p↑C→pC vs p↑Au→Xn polarimetry

- Compare kinematics, detectors two methods:

<u>pC→pC</u>

- C nuclei 100's keV energy
- Calorimetry in Si strips:
  calib. α source, different Si depth
  Si dead layer
- TOF in Si strips:
  bunches overlap @ EIC ×ing rate

<u>pAu→Xn</u>

- neutrons 100's GeV energy
- Calorimetry e.g. Pb-scint.:
  calib. e.g. beam-gas neutrons
- neutrons β~1, prompt w/ beam

- Personally I'm more comfortable with this
- I also find the physics more familiar

p↑C→pC vs p↑Au→Xn polarimetry

Absolute polarization scale?

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

pC→pC:

A_N depends on E_{carbon}, significant effects on measured E_{carbon}:

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

pAu→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 measured neutrons

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

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

Sticking point: Au targets? a lot of questions...

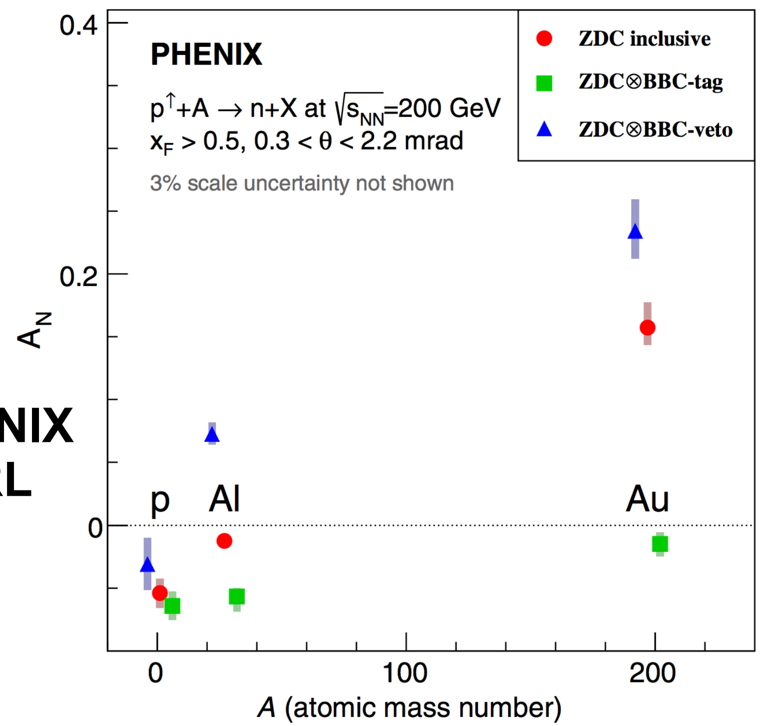
- Want something similar to carbon targets:
  small transverse size relative to beam, measure pol. profile
- Check rates: try 1μ Au wire
  some version eRHIC beam params.
  pAu cross section from G. Mitsuka calculations
- Get: 10's of neutrons / bunch $\times$ing, way too much
  can't measure individual neutron positions
- In any case, a 1μ Au wire would likely destroy beam (?)
- How small a wire nondestructive to beam?
- How small a wire not destroyed by beam?

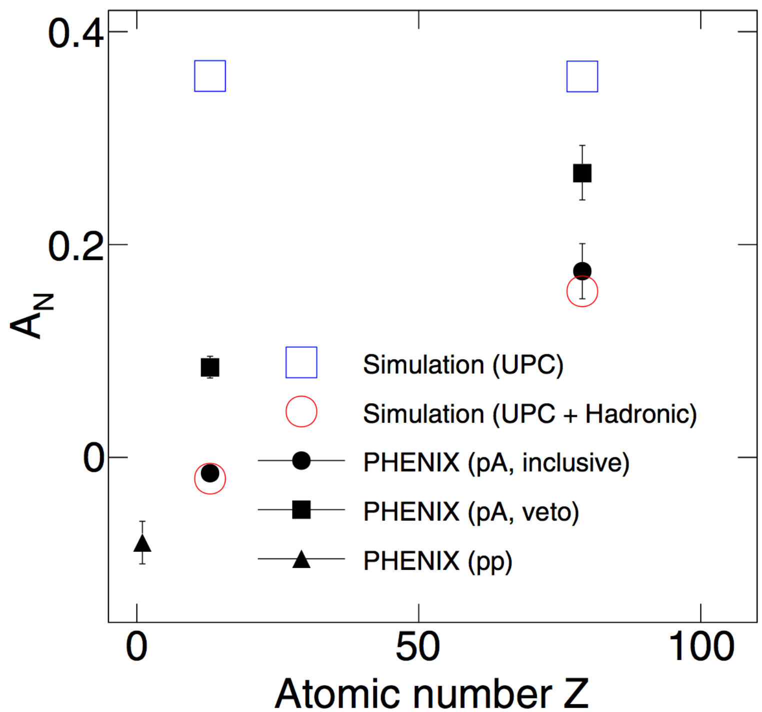
- Instead of wire, shoot μ-scopic Au pellets/droplets across beam?
  - electrostatic deflections in beam,
    control transverse position for profile measurement?

Other A targets?

- We know we can build carbon targets that survive beam
- But need high-Z for UPC process to be dominant
- For PHENIX data & Mitsuka calc. have Au (Z=79) & Al (Z=13):

PHENIX PRL

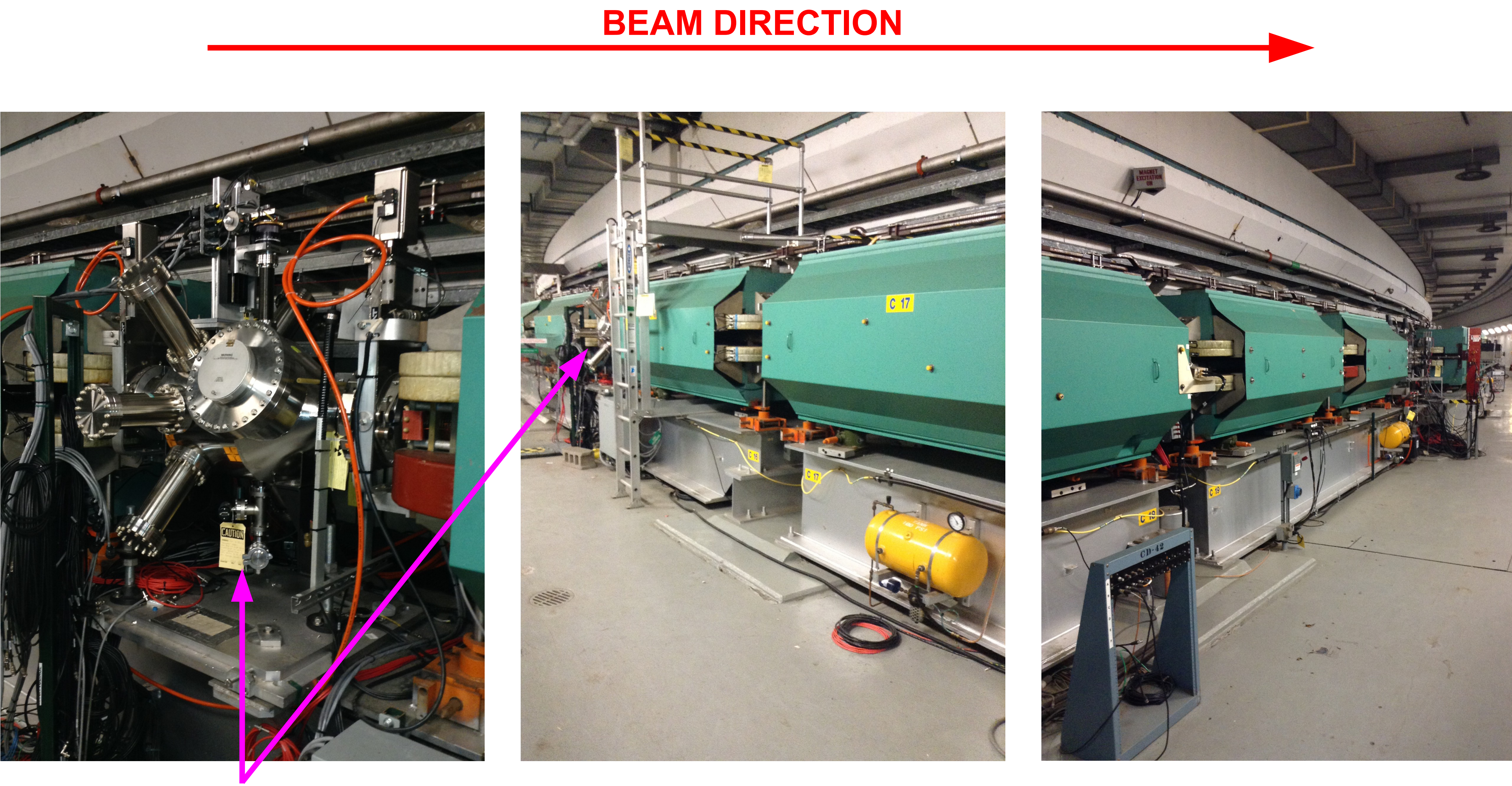




Mitsuka PRC

- BBC veto in Al data seems to enhance UPC component, leaves sizable A_N~7%
- Perhaps can get sizable A_N with carbon (Z=6) target & BBC veto?
- Room for further study with model, and measurements ↘

In AGS tunnel

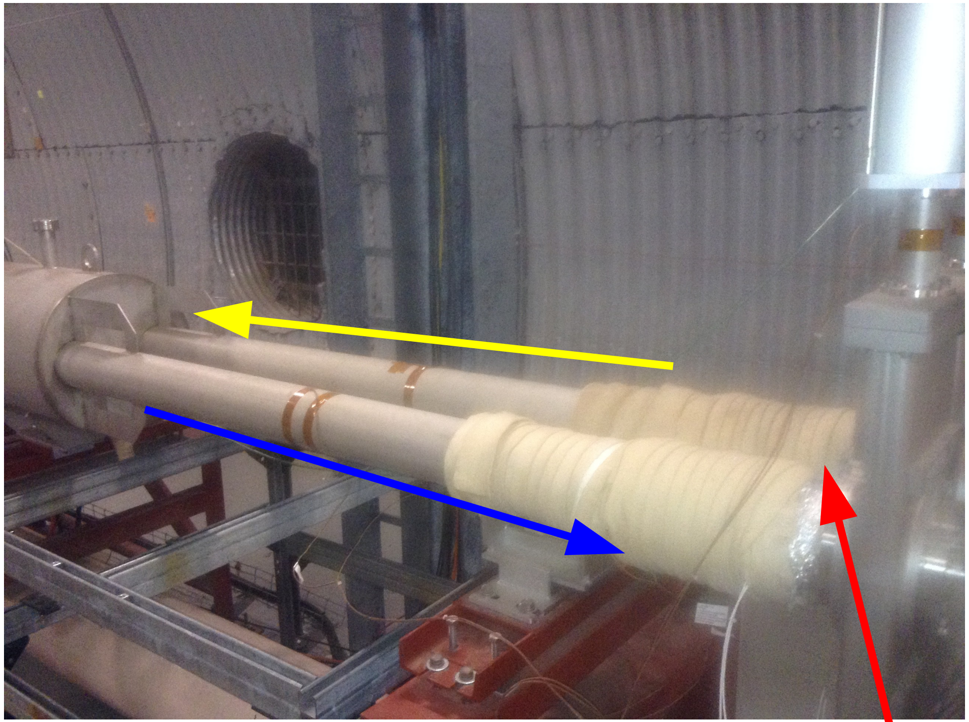


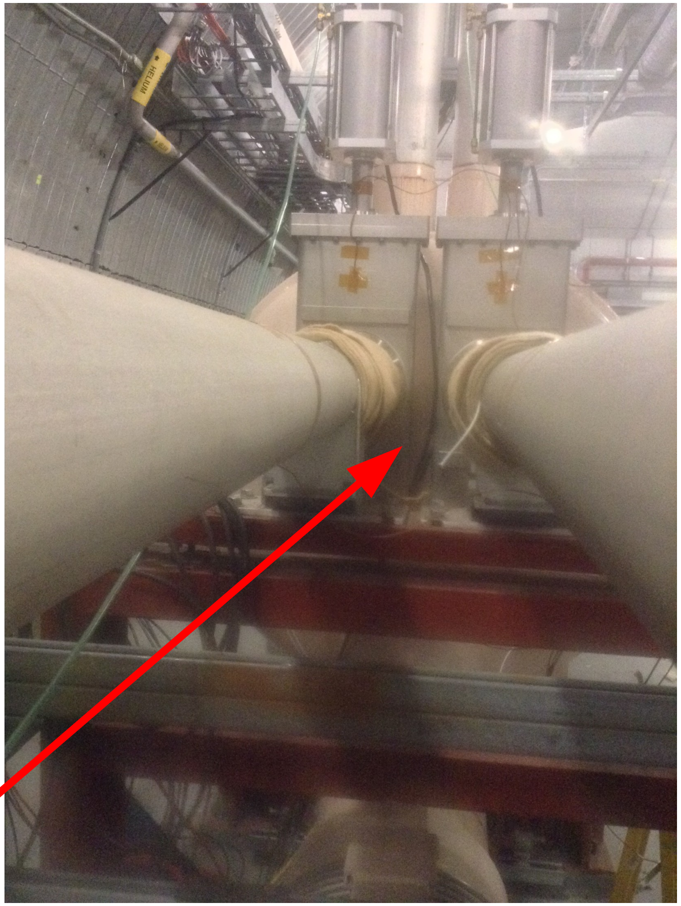
- Existing pC polarim.
- Target platform, can easily test targets

- Downstream from existing pC polarim.
- Find hole for neutrons to exit, place a ZDC
- Find places for veto counters

In RHIC tunnel

- Clockwise from Hjet @ IP12
- Would need target station near Hjet
- Here 15-18 m from Hjet:





- After DX splits blue/yellow beams, space for ZDC between beam pipes
- Same place as @ STAR, PHENIX

Brief summary

- Significant forward neutron asymmetries seen in pA @ RHIC
- Convincingly described by model:

  based on well known physics and/or measurements
- Model: asymmetry can be used for fixed target polarimetry
- Detector techniques straightforward
- Suitable target not clear, merits further study
- Places available to study at: AGS (easy)

  & RHIC (need new target station)

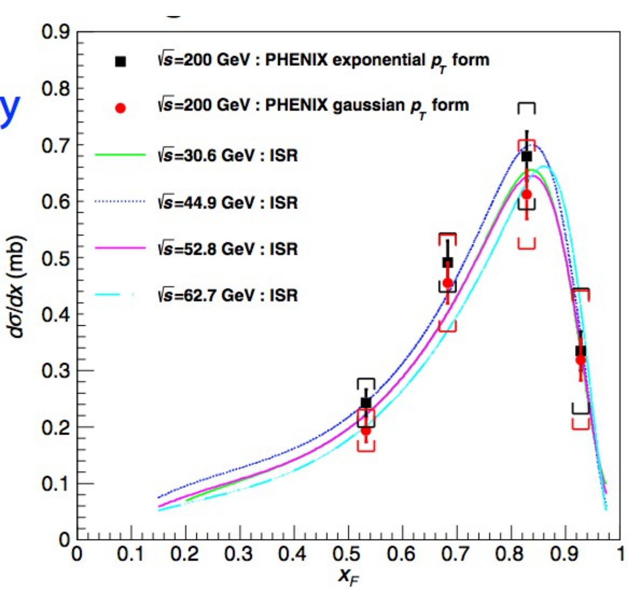
Extras

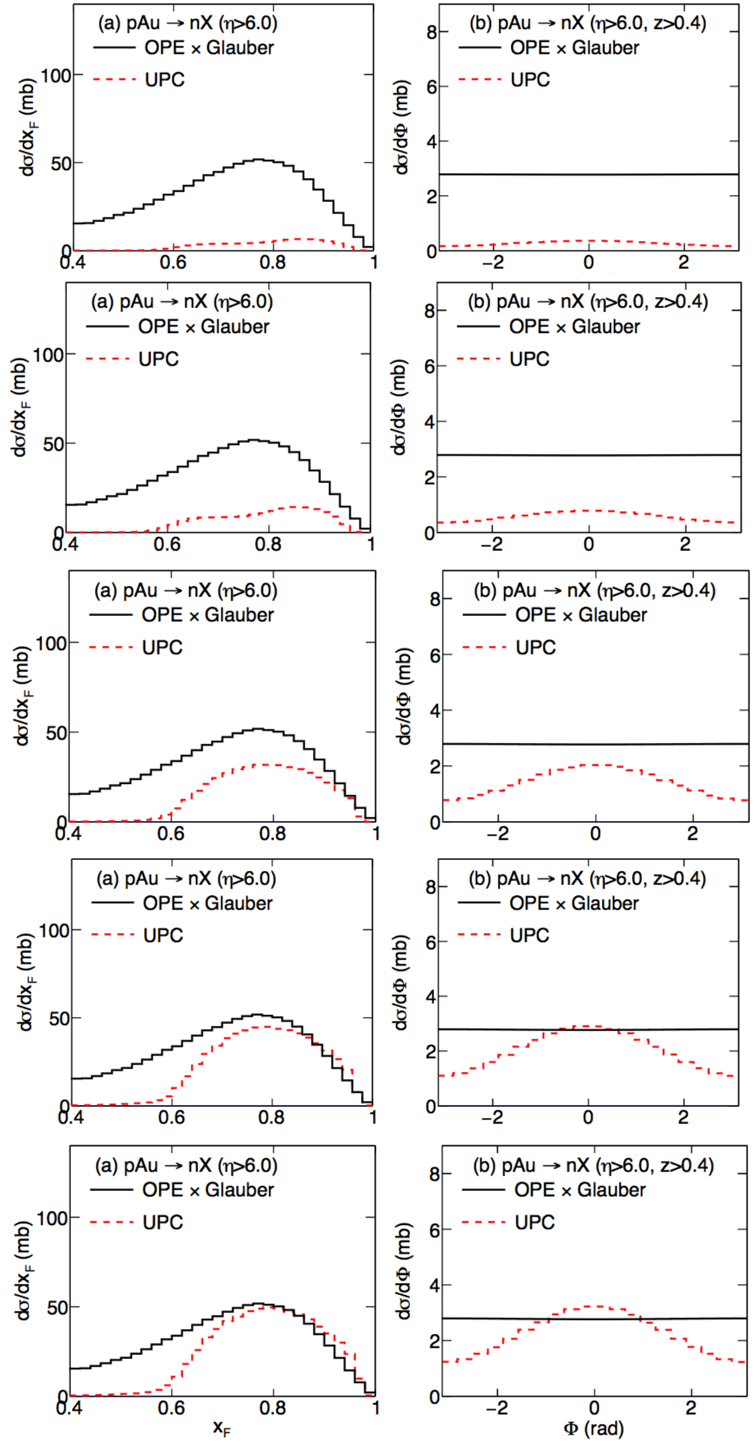
Fixed target p↑Au→Xn various E_{beam}

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 $\sigma_{\mathrm{UPC}} = 17.3\,\mathrm{mb}$

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

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