Physics of Ultraperipheral Collisions at RHIC (focusing on forward neutrons)

PHENIX, arXiv:1703.10941
GM, EPJ. C **75**, 614 (2015)
GM, PRC **95**, 044908 (2017)

Gaku Mitsuka
(RIKEN BNL Research Center)

July 7th 2017
第12回「高エネルギー QCD・核子構造」勉強会
KEK東海

Motivation and Outline

- Transverse single spin asymmetries for forward neutrons
- What are ultraperipheral collisions (UPCs)?
- UPC simulation methodology
- Hadronic interactions (one-π exchange, OPE)
- Comparison of the RHIC data with the UPC+OPE simulation
- Summary

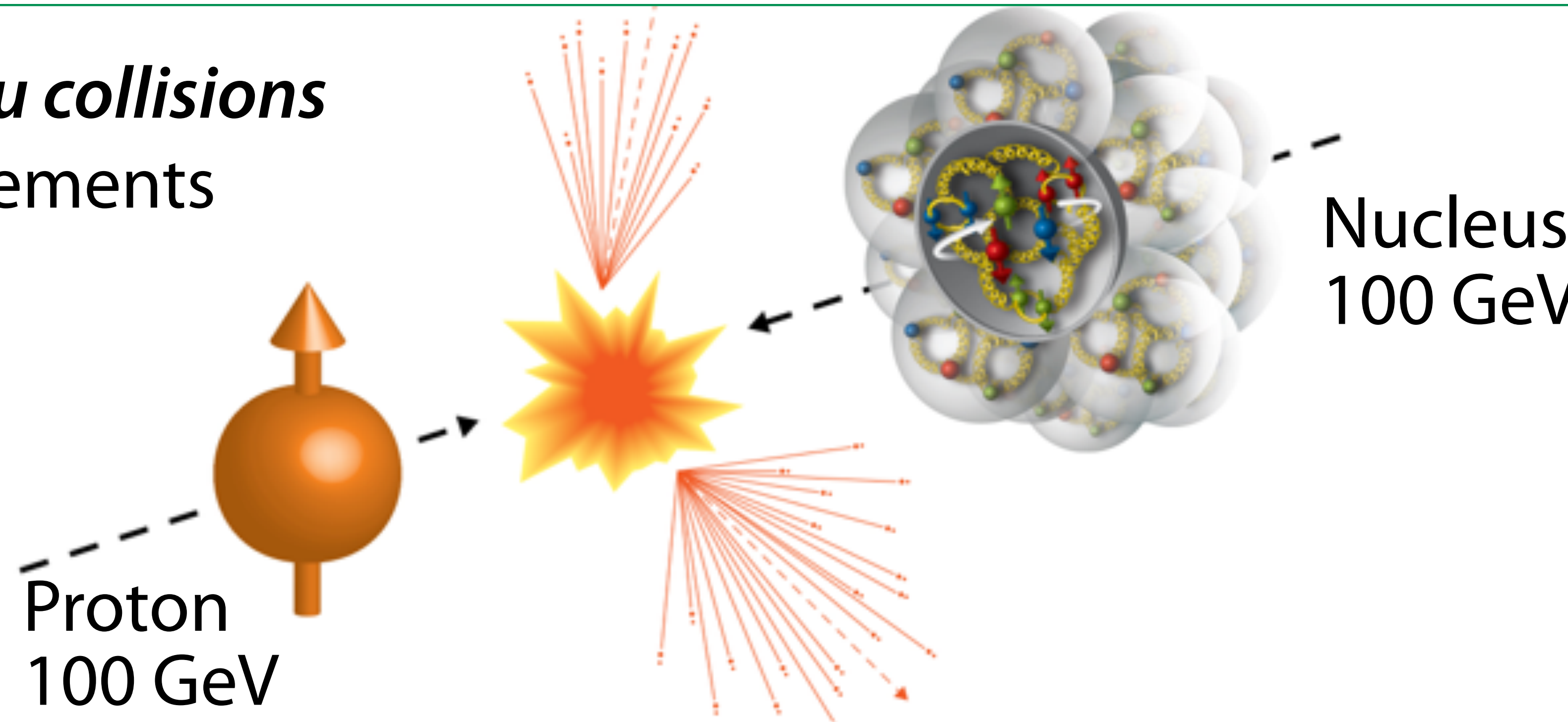
Transverse single spin asymmetries for forward neutrons

RHIC-15 run in p+Al and p+Au collisions

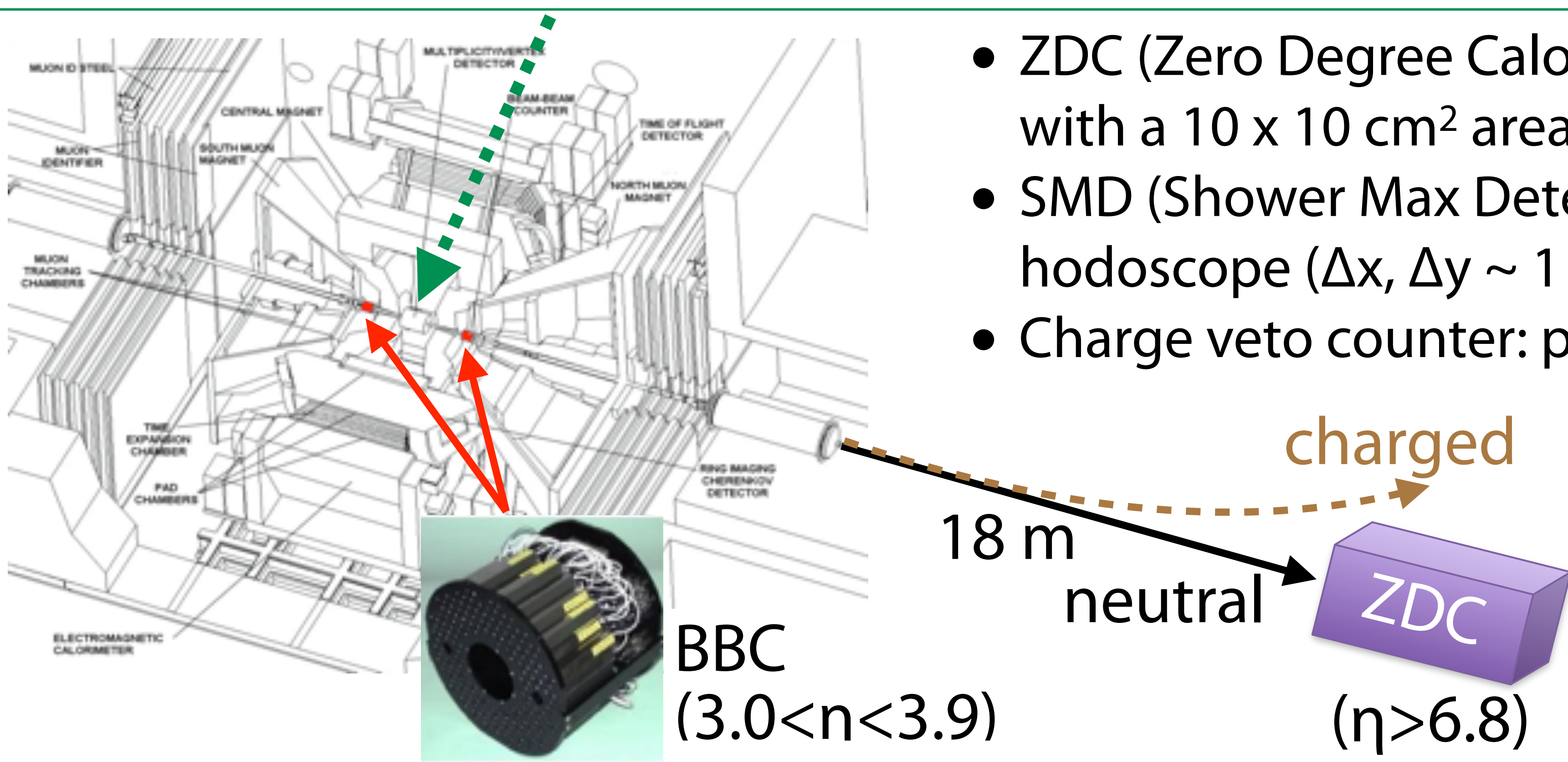
Dedicated run for A_N measurements

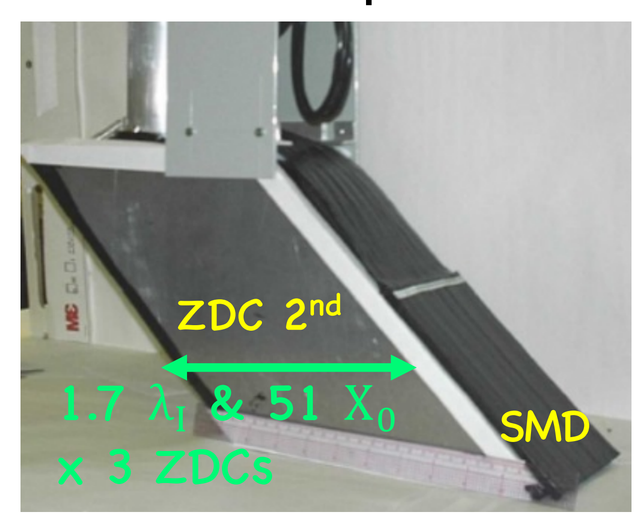
Average pol. ~ 0.5-0.6

(syst. uncertainty ~ 3%)



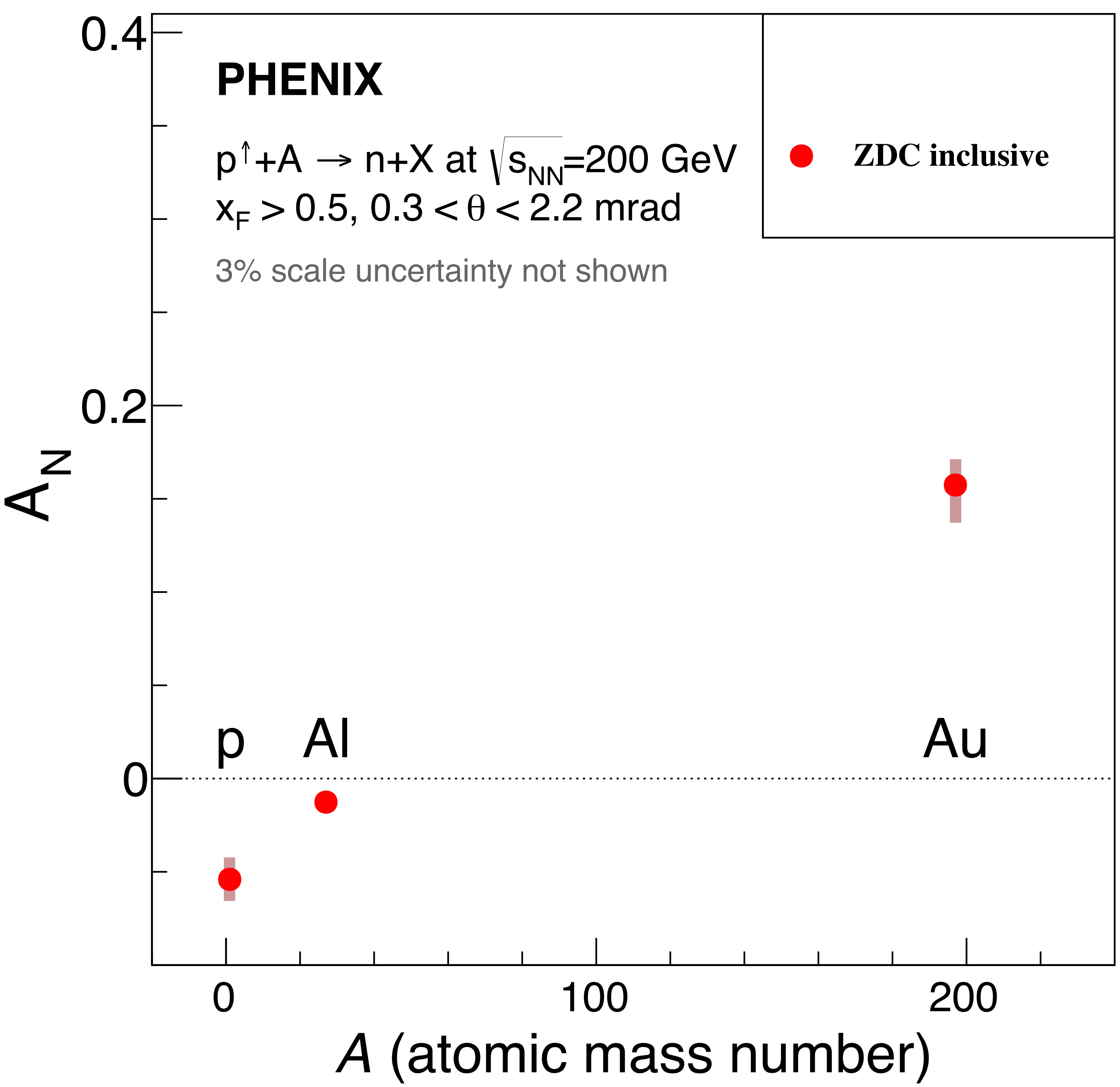
- ZDC (Zero Degree Calorimeter): hadron calorimeter with a 10 x 10 cm² area (ΔE/E ~ 20–30 %)
- SMD (Shower Max Detector): X-Y plastic scintillator hodoscope (Δx, Δy ~ 1 cm)
- Charge veto counter: plastic scintillator pad at front





Inclusive A_N for forward neutrons

PHENIX, arXiv:1703.10941



Prediction before the measurement:
weak A-dependence
(expected from Reggeon exc.)

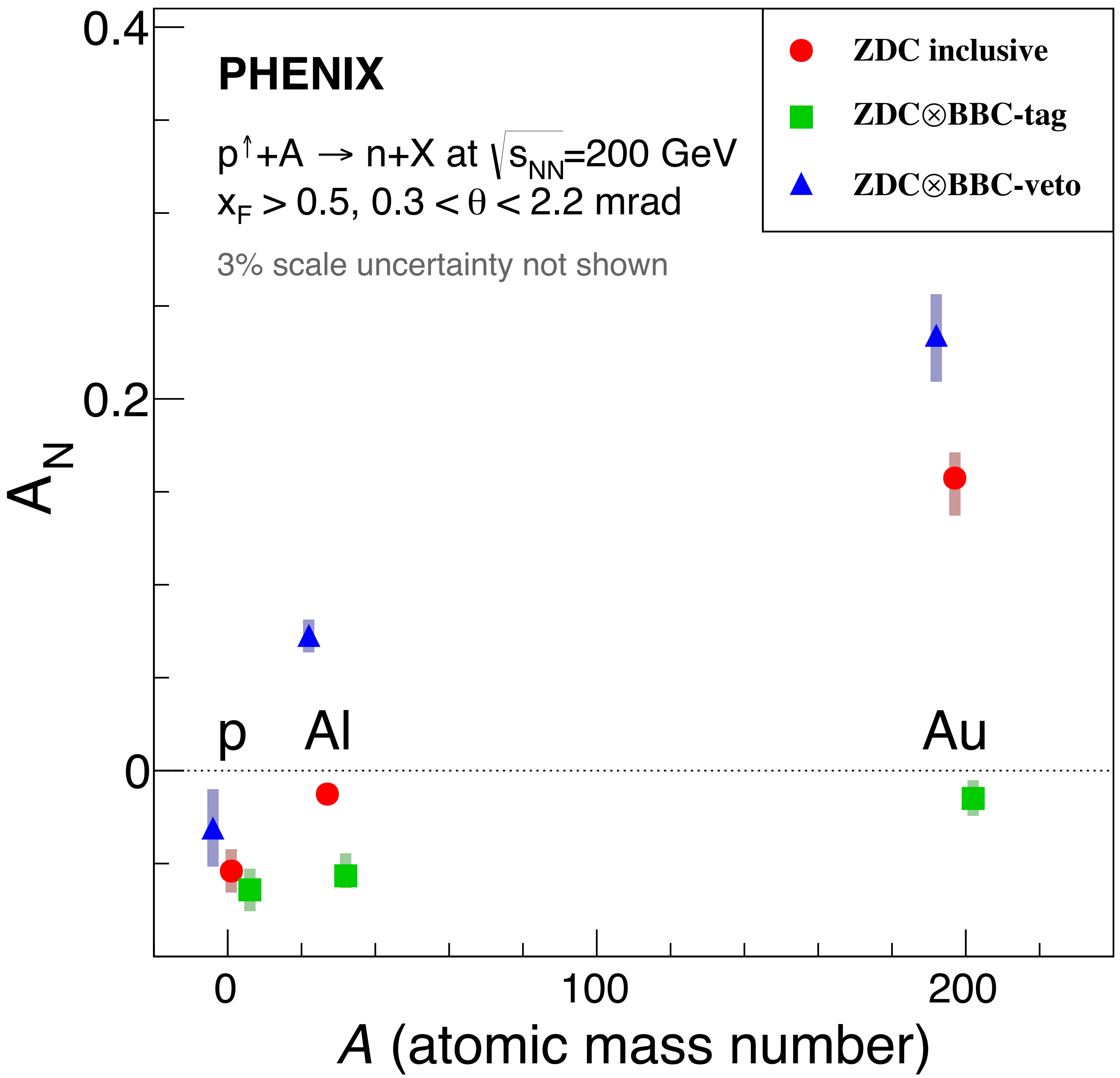
Surprisingly strong A-dependence

→ whats mechanisms do produce such strong A-dependence?

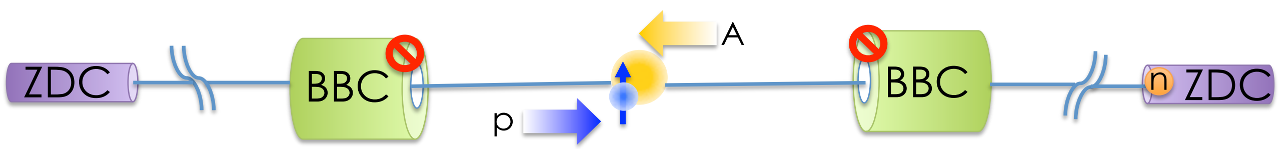
→ ***hint: how does A_N behave with the other triggers?***

BBC correlated A_N for forward neutrons

PHENIX, arXiv:1703.10941

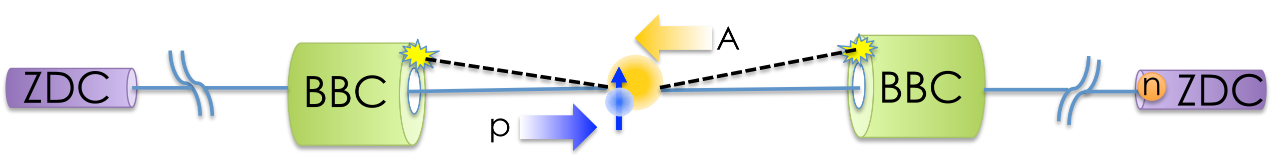


Particle veto at lower rapidities: ***BBC-VETO***



→ much stronger A-dependence

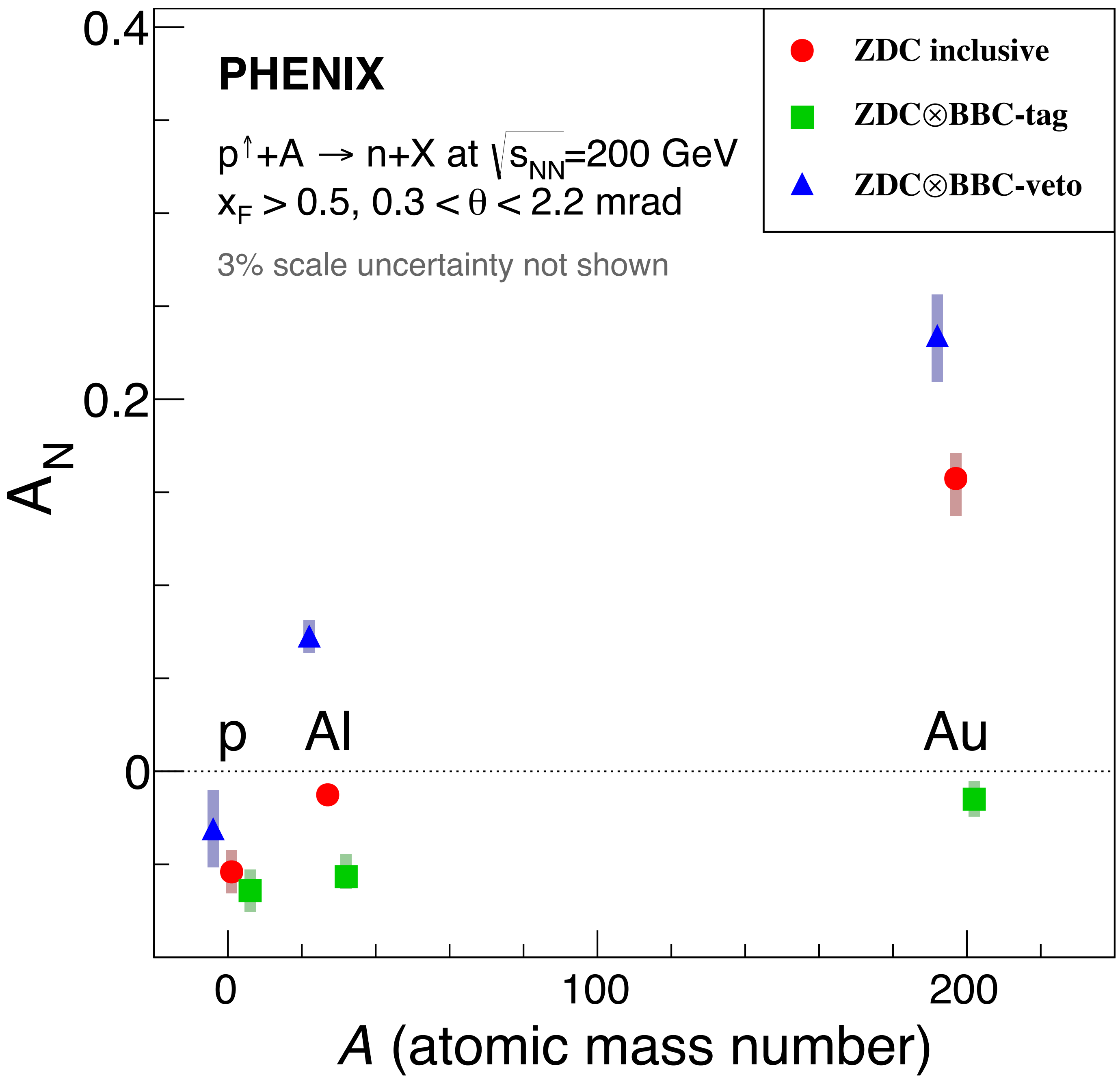
Particle hits at lower rapidities: ***BBC-TAG***



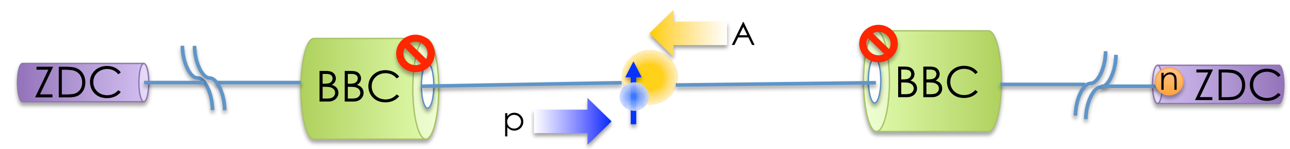
→ weak A-dependence

BBC correlated A_N for forward neutrons

PHENIX, arXiv:1703.10941



Particle veto at lower rapidities: ***BBC-VETO***



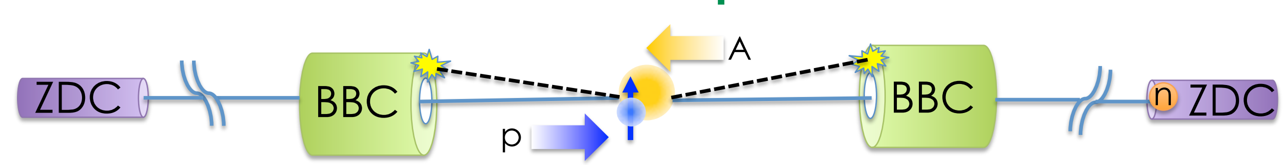
→ much stronger A-dependence

Large A_N when ***fewer*** underlying particles

Small A_N when ***ample*** underlying particles

Do not only hadronic interactions but also electromagnetic interactions play a crucial role in p+A?

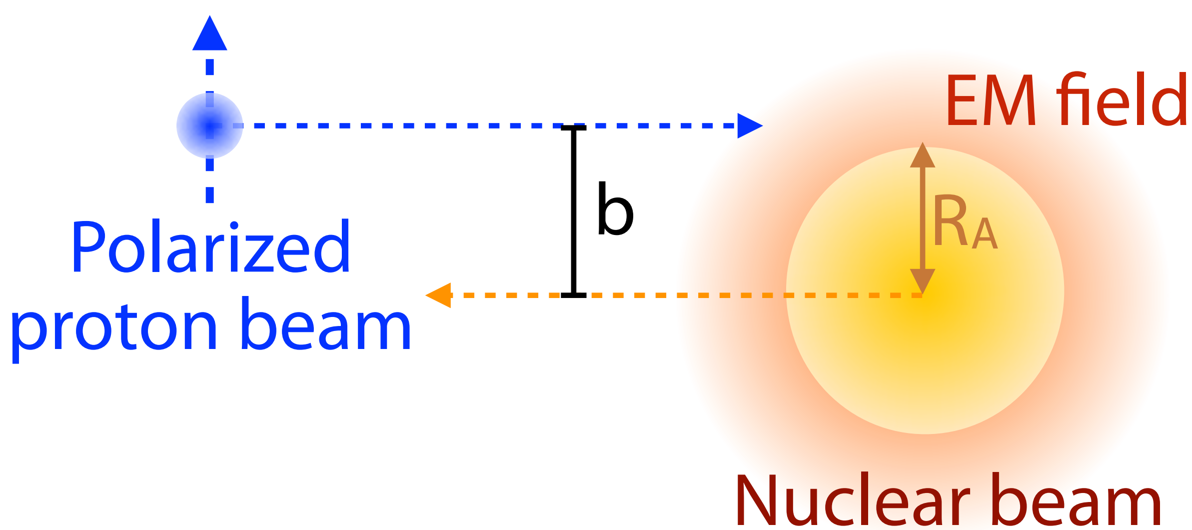
Particle hits at lower rapidities: ***BBC HIT***



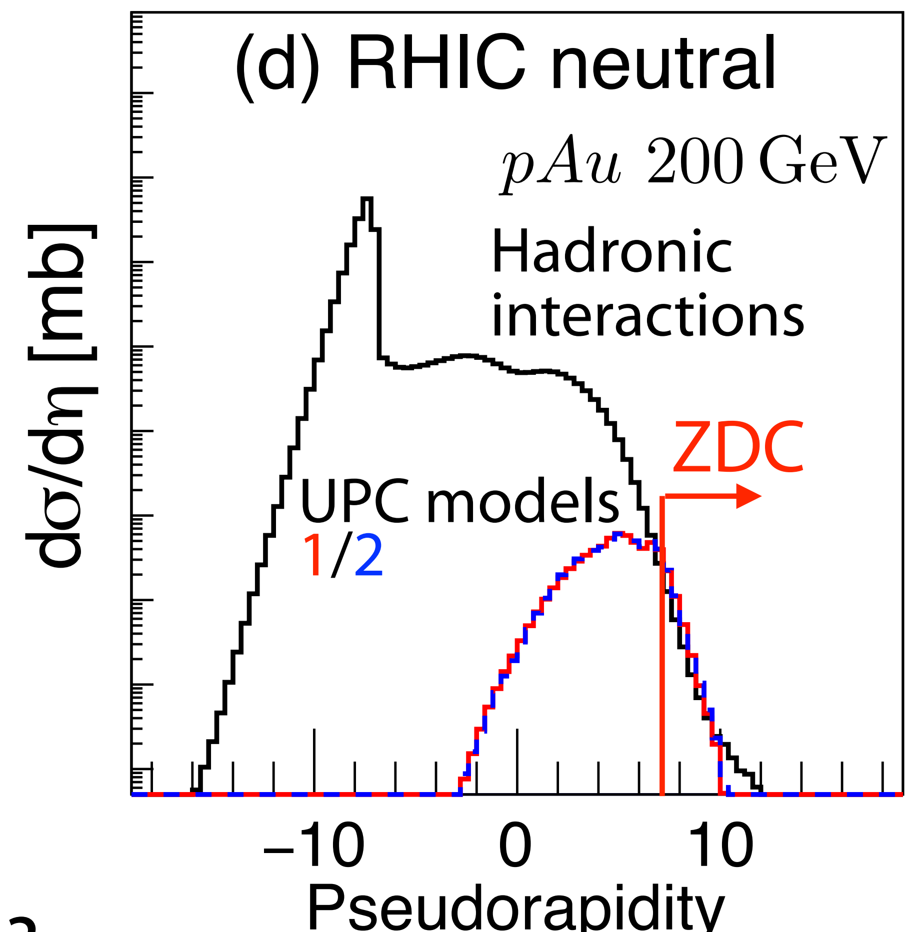
→ weak A-dependence

What are ultraperipheral collisions?

Particle production in Ultraperipheral p+A collisions (UPCs):
- a collision of a proton with the EM field made by a relativistic nucleus when the impact parameter b is larger than R_A+R_p
- fewer underlying particles unlike in hadronic interactions → smaller activity at BBC



GM, EPJ. C **75**, 614 (2015)



UPC cross section

γ* flux $\propto Z^2$

Does γ*p→π⁺n lead to large A_N?

$$\frac{d\sigma^4_{\mathrm{UPC}(p^\uparrow \mathrm{A}\to\pi^+ n)}}{dW\,db^2\,d\Omega_n} = \frac{d^3 N_{\gamma^*}}{dW\,db^2}\,\frac{d\sigma_{\gamma^* p^\uparrow\to\pi^+ n}(W)}{d\Omega_n}\,\overline{P_{\mathrm{had}}}(b)$$

$\sigma_{\mathrm{UPC}} \approx \sigma_{\mathrm{Had}}$ at η>7

Virtual photon flux

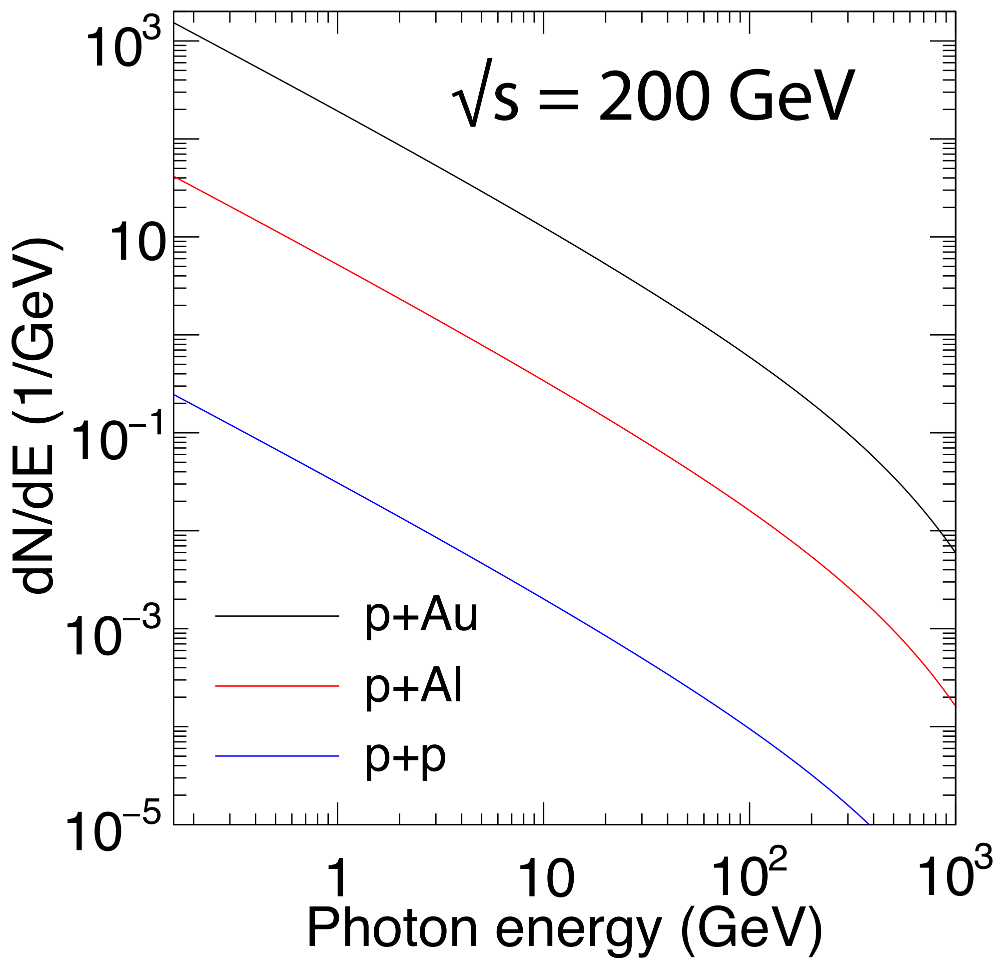
The number of virtual photons per energy and b is formulated by the Weizsacker-Williams approximation or QED (Phys. Rep 364 359, NPA 442 739, etc…):

$$\frac{d^3 N_{\gamma^*}}{d\omega_{\gamma^*}^{rest} db^2} = \frac{Z^2 \alpha}{\pi^2} \frac{x^2}{\omega_{\gamma^*}^{rest} b^2} \left(K_1^2(x) + \frac{1}{\gamma^2} K_0^2(x) \right)$$

Proportional to Z^2 (~6×10^3 for Au)

where $x = \omega_{\gamma^*}^{rest} b/\gamma$ and ω^{rest}_{γ} is the virtual photon energy in the proton rest frame.

Note that the virtual photon flux depends on the charge of photon source as Z^2.



- ***From the virtual photon flux, we see that low-energy photons dominate UPCs.***

Photon virtuality is limited by $Q^2 < \frac{1}{R^2}$. So, $Q^2 < 10^{-3}\,\mathrm{GeV}^2$

Do low-E γ*p interactions have large A_N?

Polarized γ*p cross sections

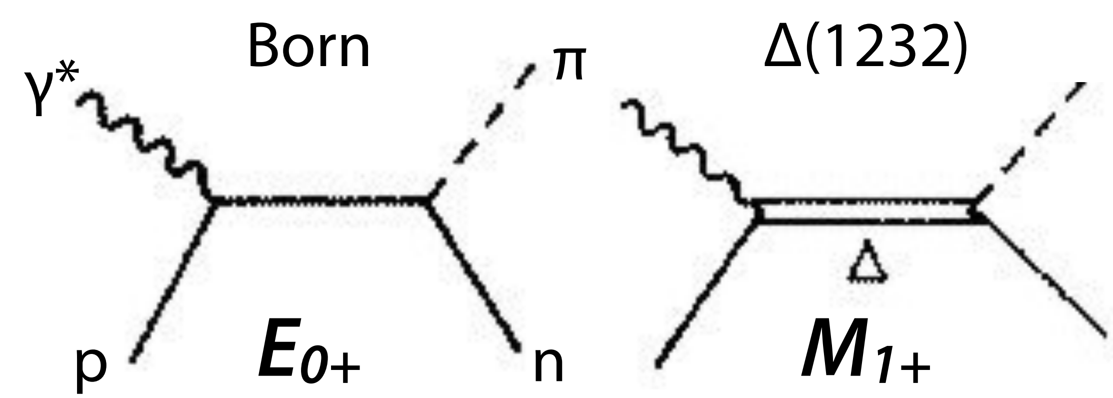
(Drechsel and Tiator, J. phys. G 18, 449 (1992))

$$\frac{d\sigma_{\gamma^* p^\uparrow \to \pi^+ n}}{d\Omega_\pi} = \frac{|q|}{\omega_{\gamma^*}}(R_T^{00} + P_y R_T^{0y}) = \frac{|q|}{\omega_{\gamma^*}} R_T^{00}(1 + P_2 \cos\phi_\pi T(\theta_\pi))$$

Equivalent to A_N → $T(\theta_\pi)$

$T(\theta_\pi)$ is decomposed into multipoles:

$$T(\theta_\pi) \equiv \frac{R_T^{0y}}{R_T^{00}} \propto \mathrm{Im}\{E_{0+}^*(E_{1+} - M_{1+}) - 4\cos\theta_\pi(E_{1+}^* M_{1+}) \ldots\}$$



Interference between E_{0+} and M_{1+} leads to large $T(\theta_\pi)$ in the Δ(1232) region

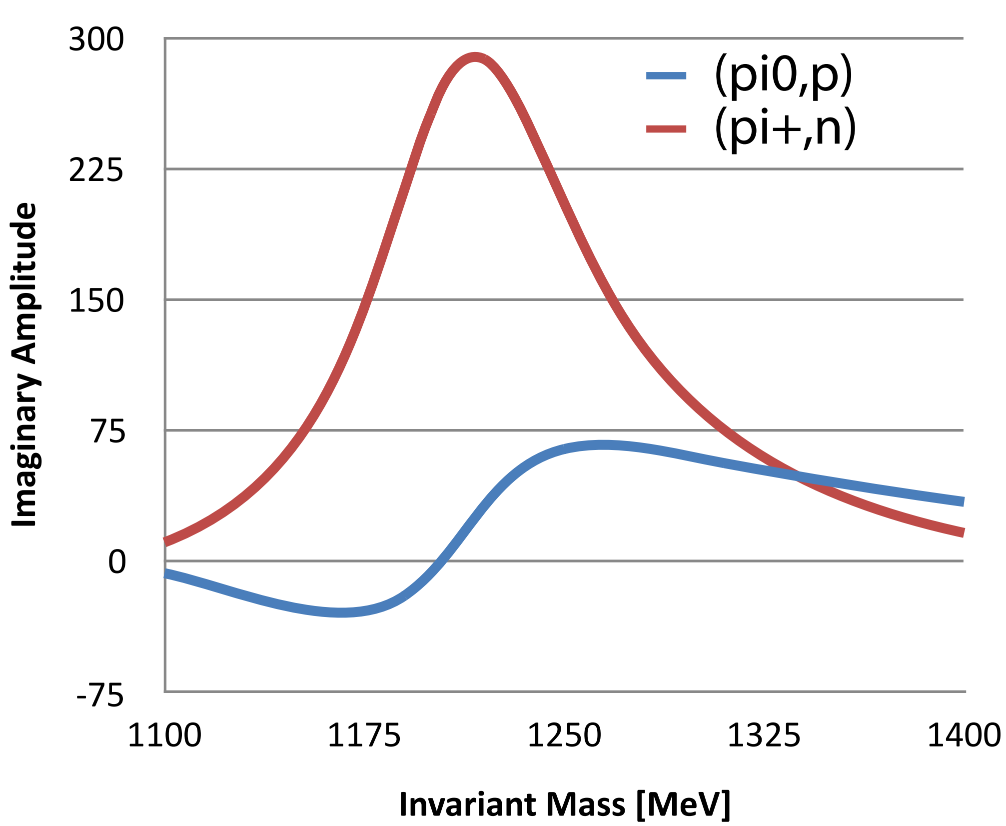
MC simulations of the polarized γ*p interactions are developed for testing $T(\theta_\pi)$, i.e. A_N in pA collisions.

Multipole decomposition of $T(\theta_\pi)$

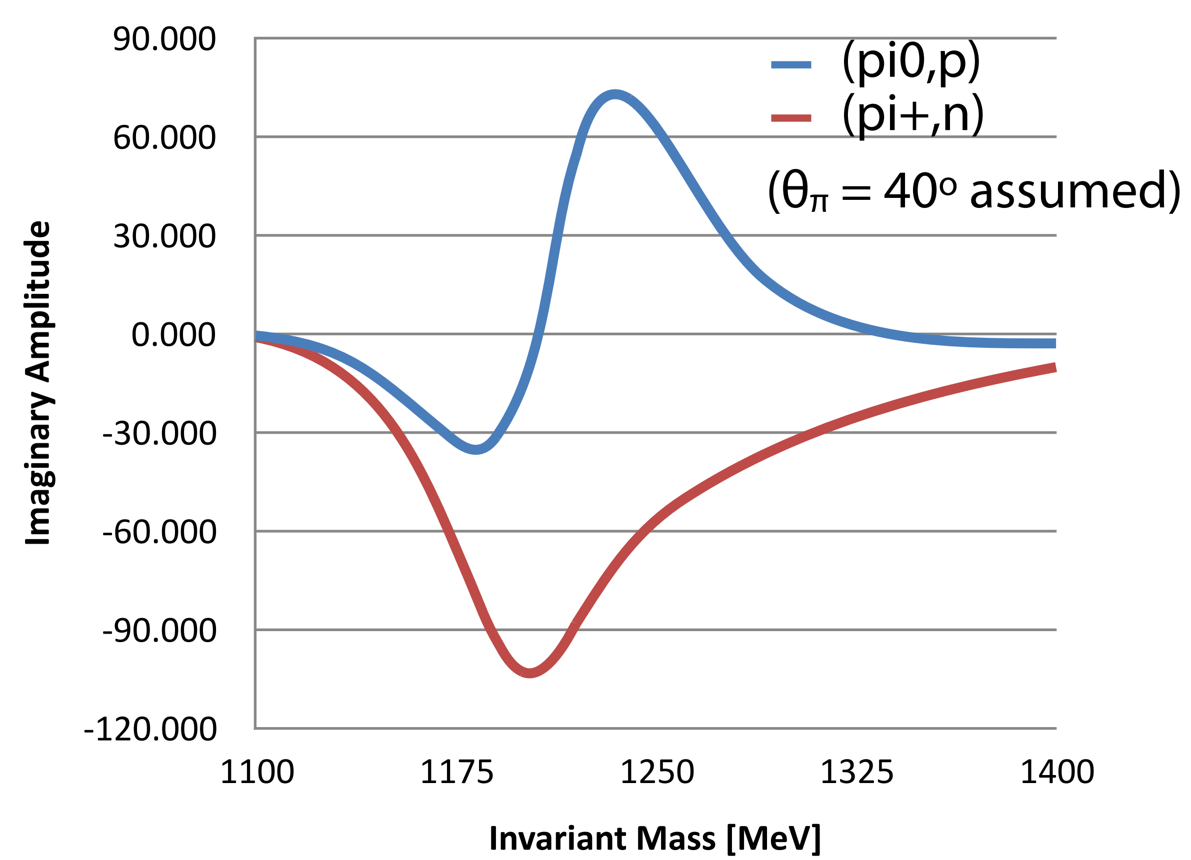
Leading part | Subleading part

$$A_N^{\mathrm{UPC}} \sim T(\theta_\pi) \equiv \frac{R_T^{0y}}{R_T^{00}} \propto \mathrm{Im}\{E_{0+}^*(E_{1+} - M_{1+}) - 4\cos\theta_\pi (E_{1+}^* M_{1+}) \ldots\}$$

Im{E0+*(E1+-M1+)



Im{4cos(40)(E1+*M1+)}

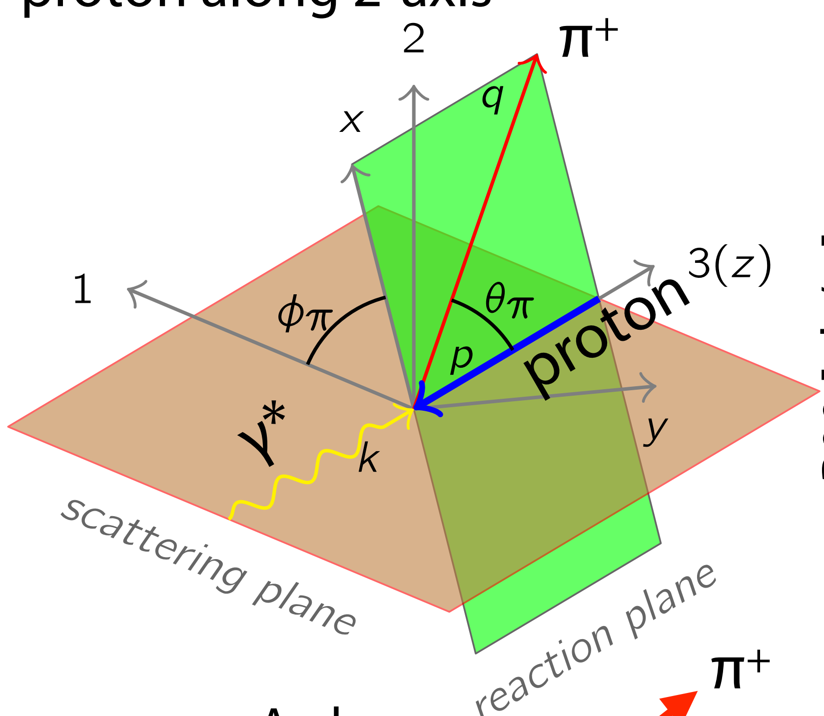


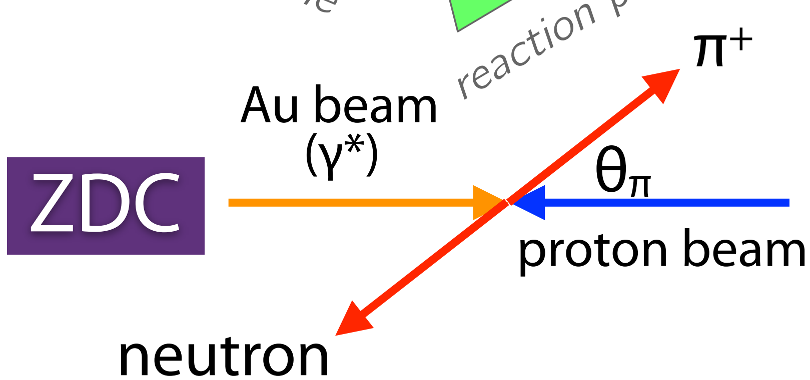
MC simulations for low-E γ*p interactions

- MC simulations based on the MAID2007 model (Drechsel et al. EPJ A 34, **69** (2007)) are performed for R_T^{00} and $T(\theta_\pi)$.
- $T(\theta_\pi)$~0.8 at Δ(1232), ~-0.5 at N(1680) → large A_N!!

γ*p center-of-mass system

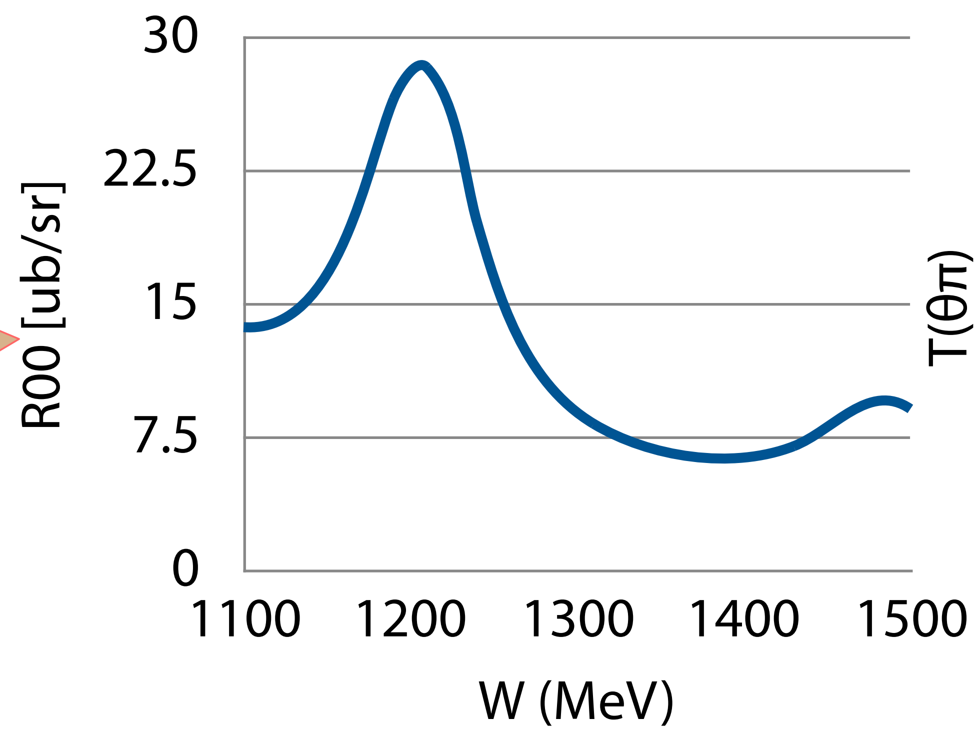
transversely polarized proton along 2-axis



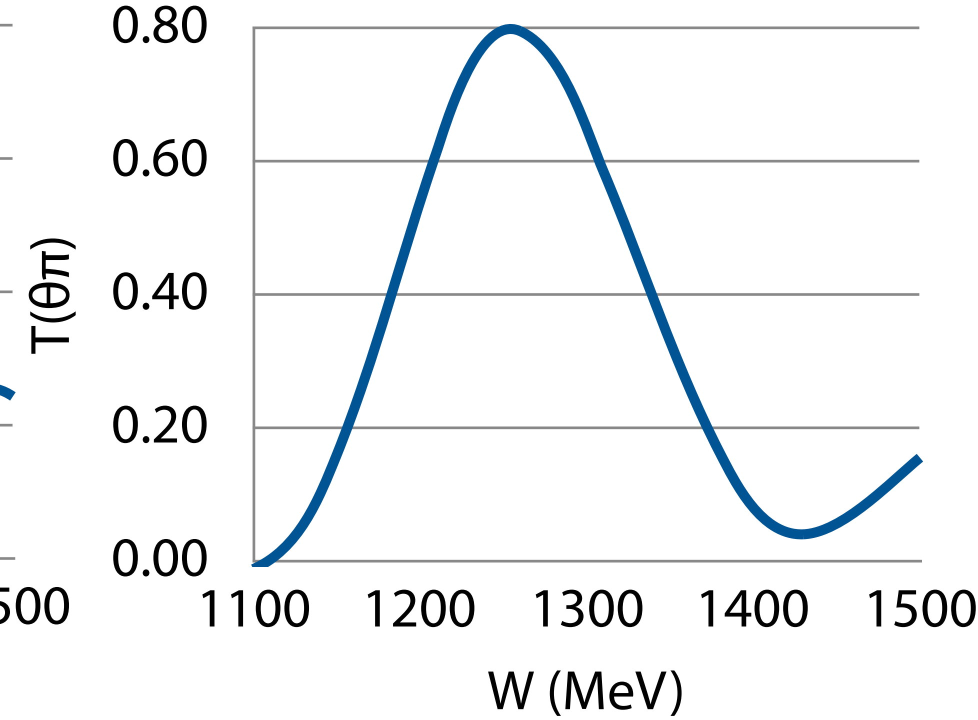


Numerical data from MAID 2007 ($Q^2 = 0$, θπ = 90 degree)

R_T^{00}



$R_T^{0y}/R_T^{00} = T(\theta_\pi)$

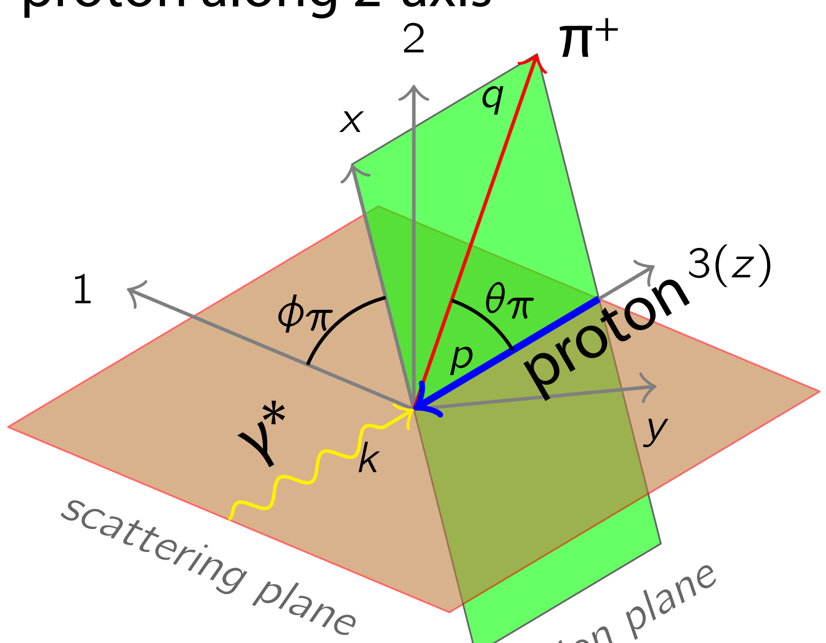


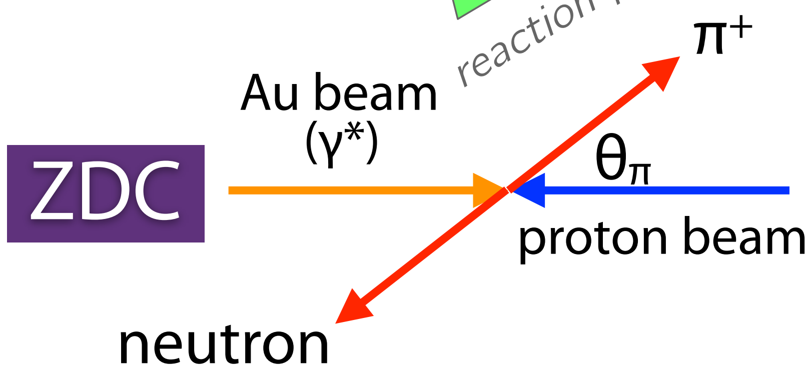
MC simulations for low-E γ*p interactions

- MC simulations based on the MAID2007 model (Drechsel et al. EPJ A 34, **69** (2007)) are performed for R_T^{00} and $T(\theta_\pi)$.
- $T(\theta_\pi)$~0.8 at Δ(1232), ~-0.5 at N(1680) → large A_N!!

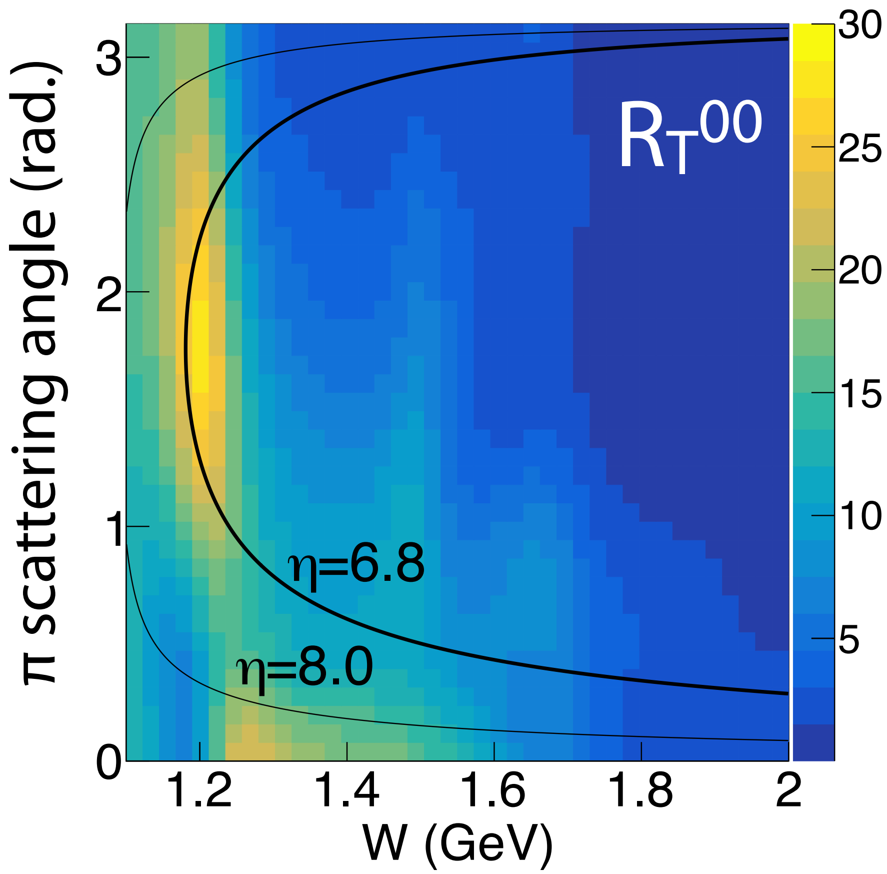
γ*p center-of-mass system

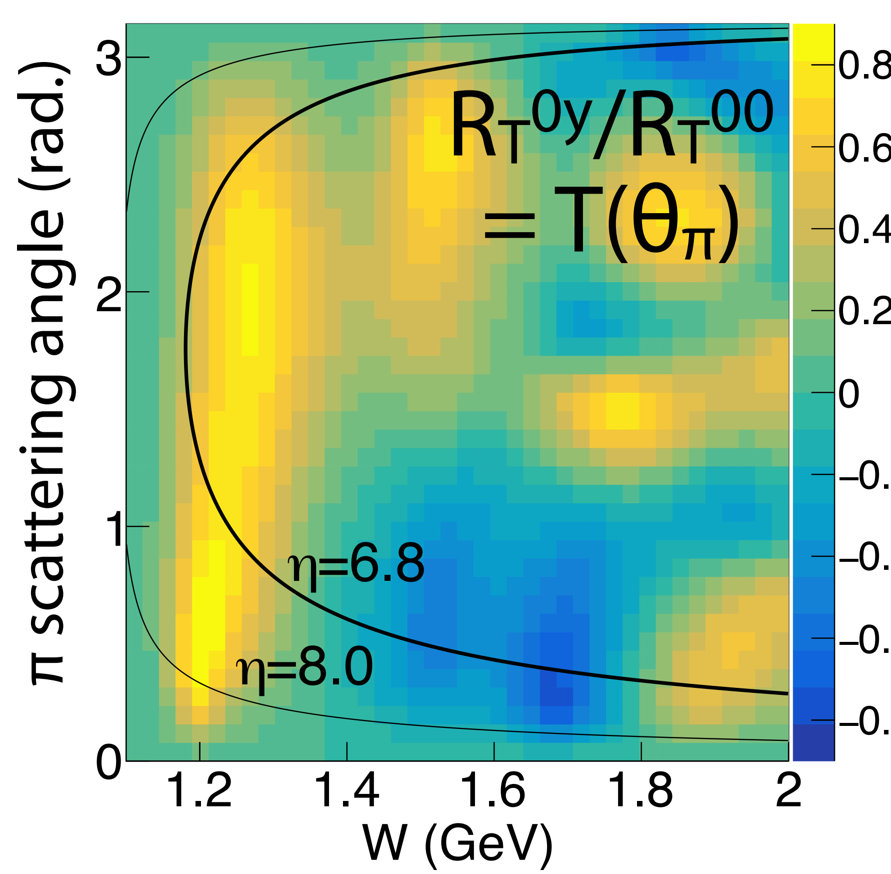
transversely polarized proton along 2-axis





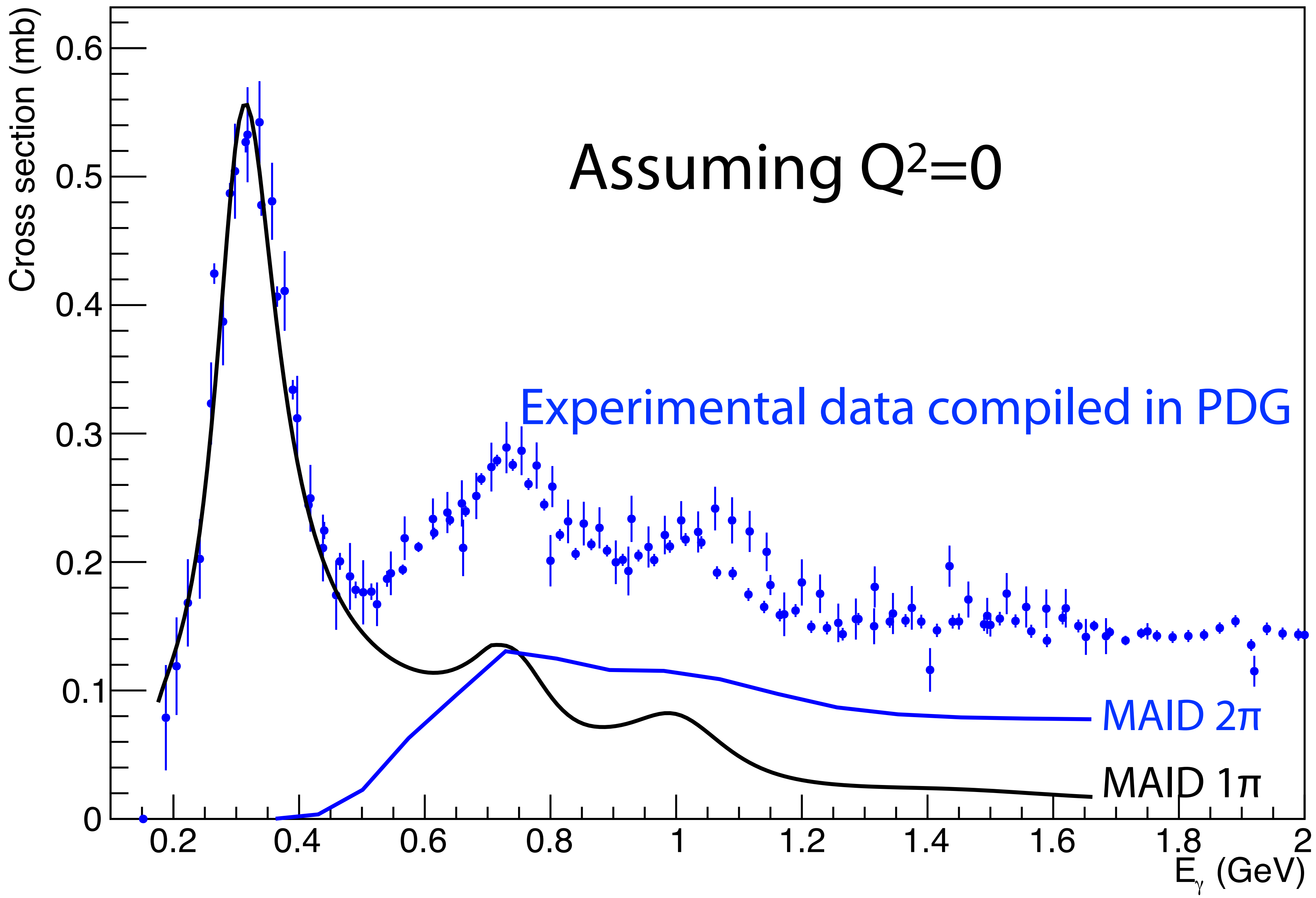
GM, PRC **95**, 044908 (2017)





- Solid curves indicate the ZDC acceptance.
- $T(\theta_\pi)$ with the weight of γ* flux = A_N

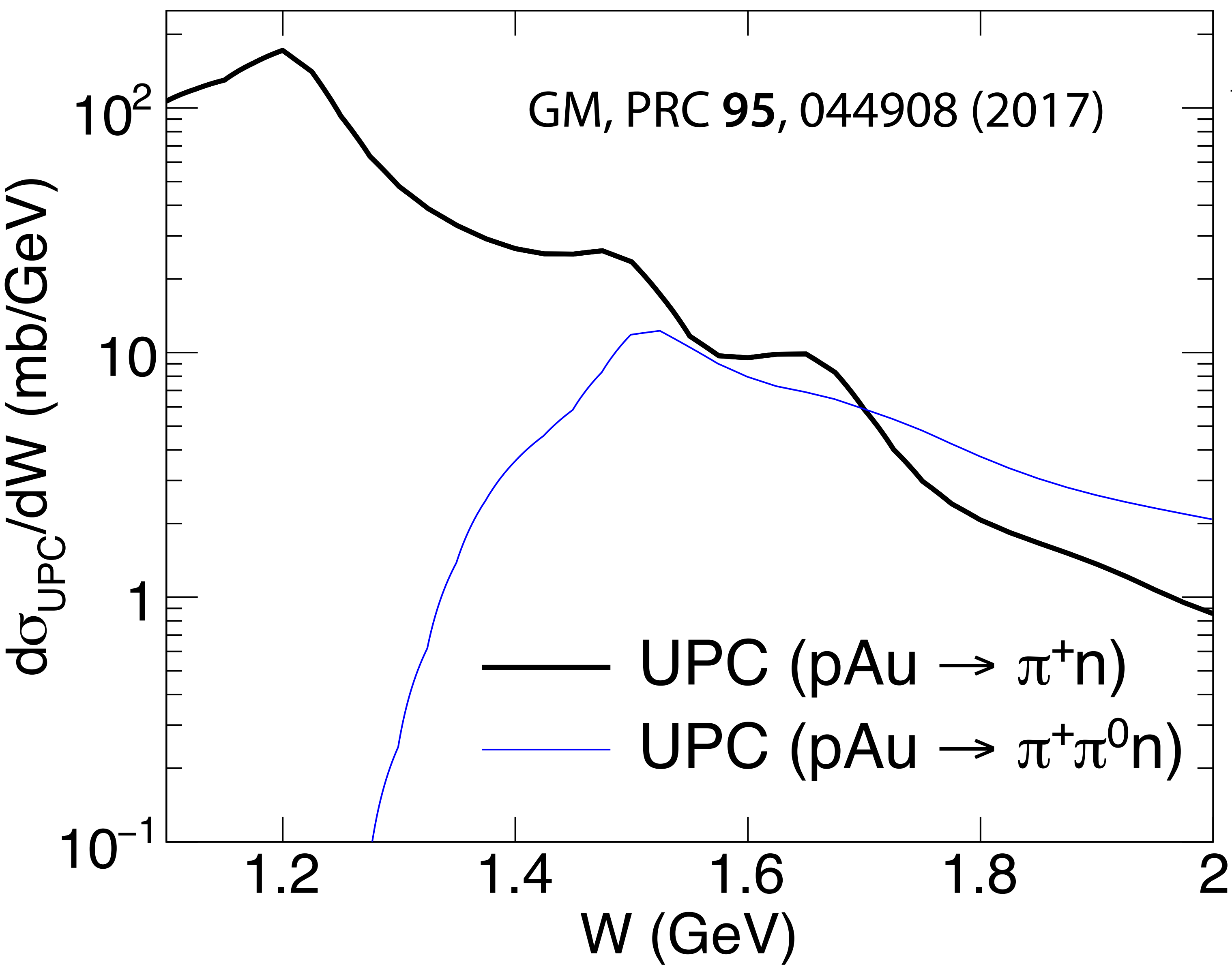
Inclusive cross sections of γp interactions



Only 1π channel is taken into account in this study.

Hard to simulate neutron momenta in 2π channels, leave for future study

UPC cross sections as a function of W



$$\frac{d\sigma^4_{\mathrm{UPC}(p^\uparrow \mathrm{A}\to\pi^+ n)}}{dW\,db^2 d\Omega_n} = \frac{d^3 N_{\gamma^*}}{dW\,db^2}\frac{d\sigma_{\gamma^* p^\uparrow\to\pi^+ n}(W)}{d\Omega_n}\overline{P_{\mathrm{had}}}(b)$$

- ***2π channels are anyway subdominant in UPCs.***
- ***Table I and II show the total cross sections in UPCs and hadronic interactions.***

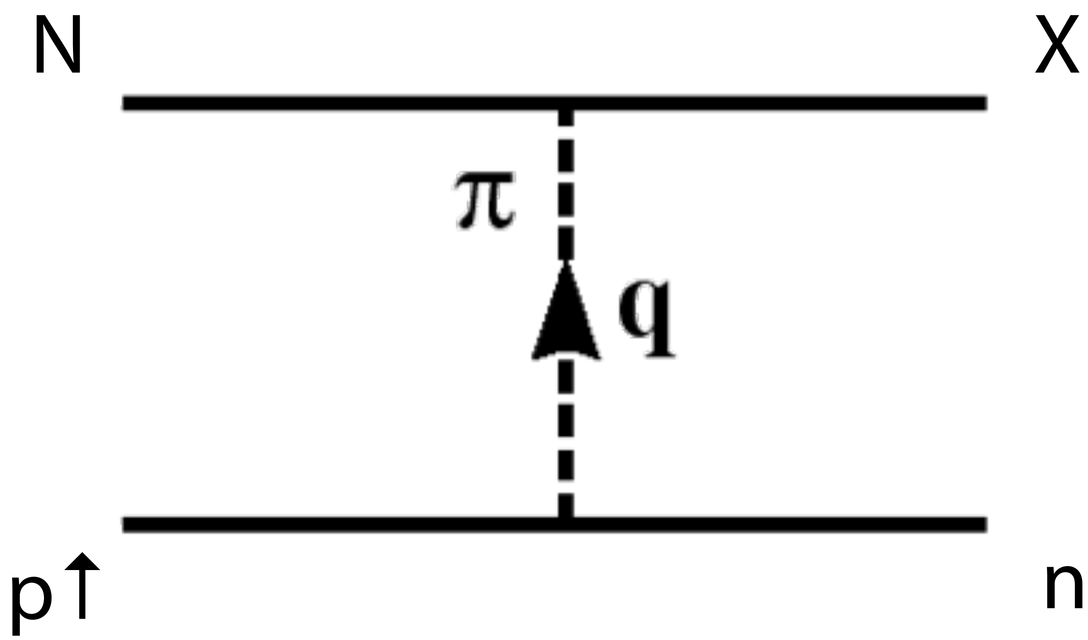
TABLE I. Cross sections for neutron production in ultraperipheral collisions and hadronic interactions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV. Cross sections in parentheses are calculated without η and z limits.

UPCs		Hadronic interactions	
$p^\uparrow$Al	$p^\uparrow$Au	$p^\uparrow$Al	$p^\uparrow$Au
0.7 mb (2.2 mb)	19.6 mb (41.7 mb)	8.3 mb	19.2 mb

TABLE II. Cross sections in ultraperipheral pAu collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV.

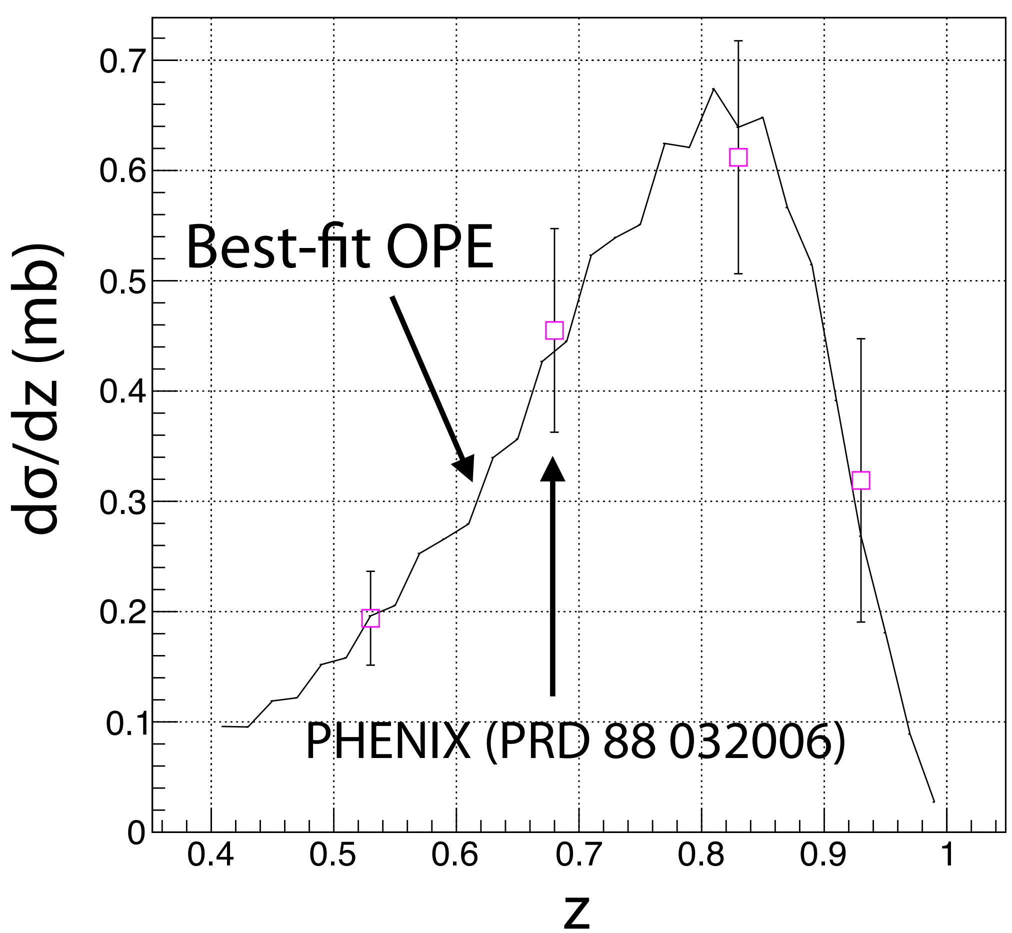
$p\mathrm{Au} \to nX$ ($\eta > 6.9$ and $z > 0.4$)			$p^\uparrow\mathrm{Au} \to \pi^+\pi^0 n$
< 1.1 GeV	1.1–2.0 GeV	> 2.0 GeV	1.25–2.0 GeV
0.6 mb	27.4 mb	1.8 mb	6.2 mb

Hadronic interactions (one-π exchange)



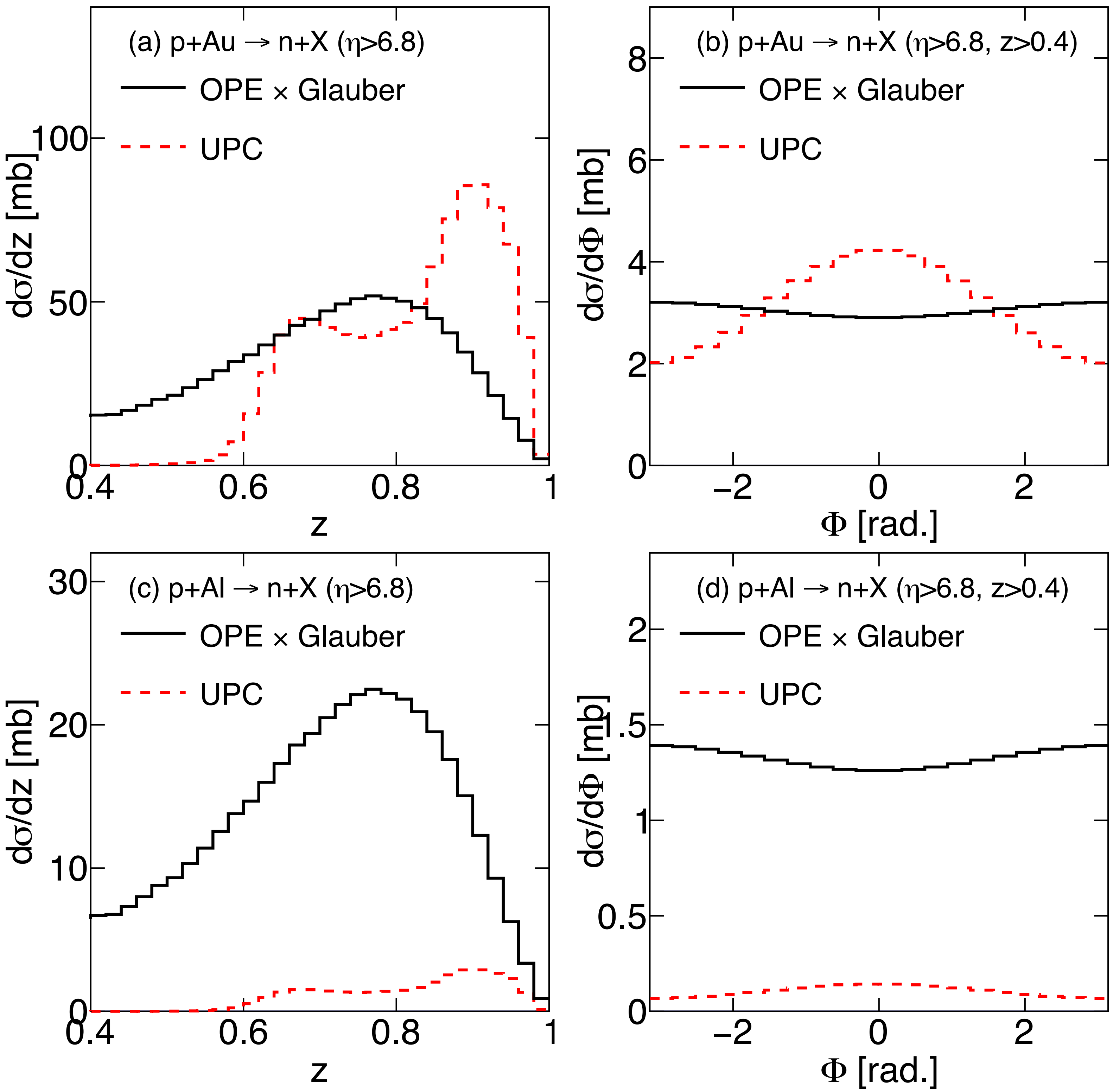
$$z\frac{d\sigma_{pp\to nX}}{dzdp_{\mathrm{T}}^2} = S^2\left(\frac{\alpha'_\pi}{8}\right)^2 |t|G^2_{\pi^+pn}(t)|\eta_\pi(t)|^2 \times (1-z)^{1-2\alpha_\pi(t)}\sigma^{\mathrm{tot}}_{\pi^++p}(M_X^2),$$

$$z\frac{d\sigma_{p^\uparrow A\to nX}}{dzdp_{\mathrm{T}}^2} = z\frac{d\sigma_{pA\to nX}}{dzdp_{\mathrm{T}}^2}(1+\cos\Phi A_{\mathrm{N}}^{\mathrm{HAD}(pA)}) = z\frac{d\sigma_{pp\to nX}}{dzdp_{\mathrm{T}}^2}A^{0.42}(1+\cos\Phi A_{\mathrm{N}}^{\mathrm{HAD}(pA)})$$



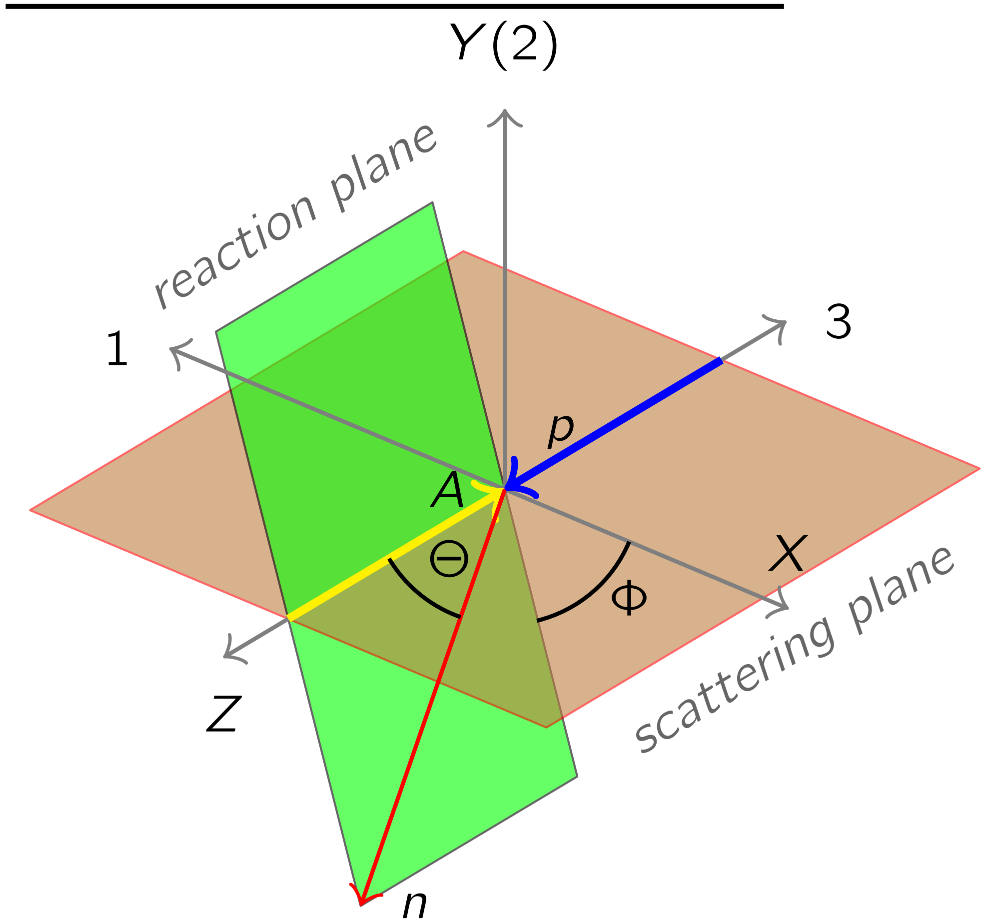
- *Kopeliovich et al. (PRD 84, 114012) propose an interference between π and a_1-Reggeon leading to negative asymmetry in p+p and p+A.*
- *In this study I omit an implementation of the interference. Alternatively, I simply apply (1+cosΦA_N) to the differential cross section of unpolarized proton and then effectively obtain the differential cross section of polarized proton.*
- *The coupling $G_{\pi+pn}$ and is the absorption S are chosen so that dσ/dz gives the best-fit to the PHENIX result.*

UPCs and OPE at the ZDC acceptance



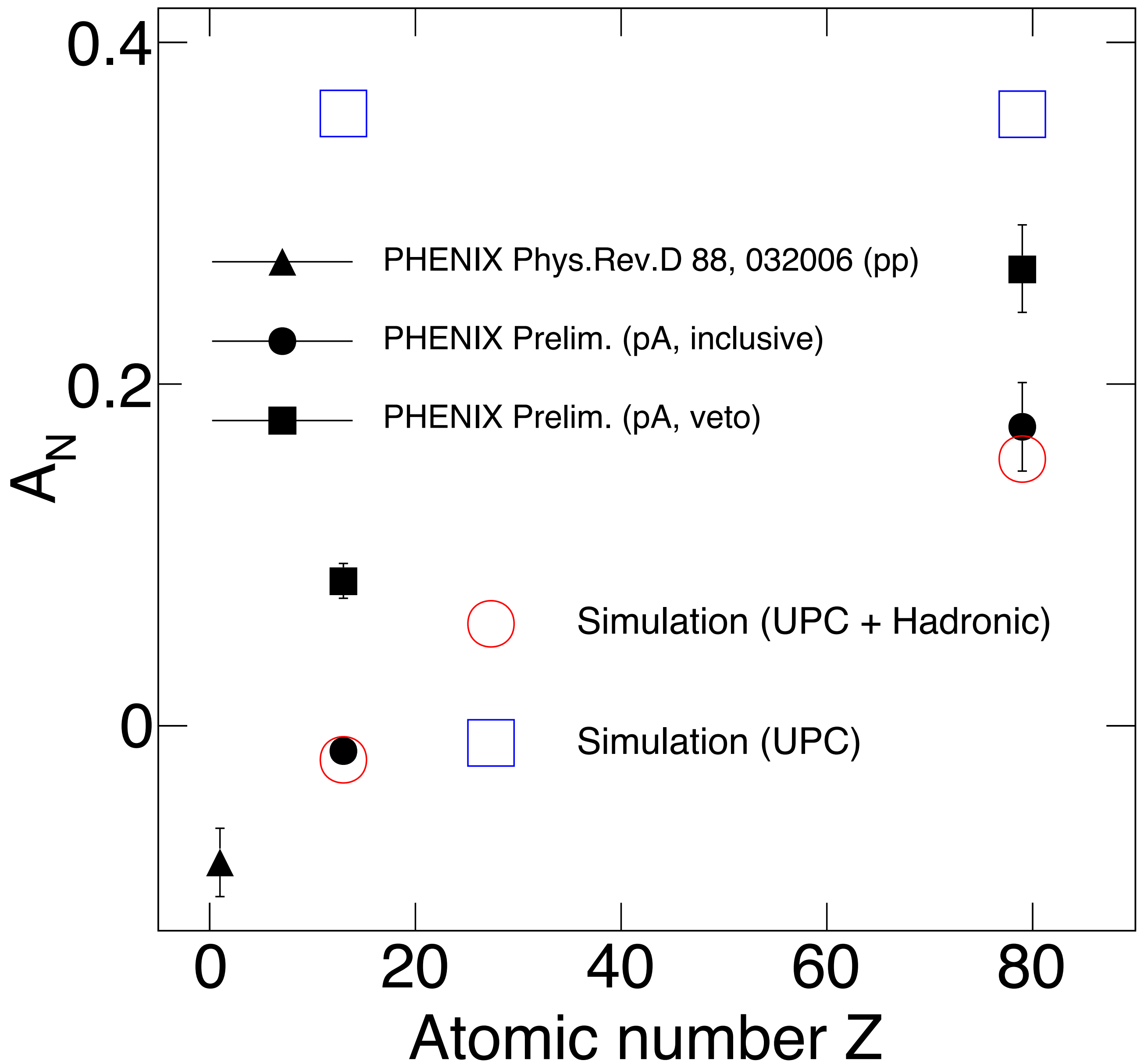
GM, PRC **95**, 044908 (2017)

Detector reference frame



- ***In p+Au collisions, UPC cross section is comparable with OPE. Large positive A_N of UPCs compensates negative A_N of hadronic interactions.***
- ***A_N including both UPCs and OPE can be obtained by $d\sigma^{(UPC+OPE)}/d\Phi$.***
- ***In p+Al collisions, UPC contribution is small to A_N.***

Neutron A_N: PHENIX vs. UPC+OPE model



GM, PRC **95**, 044908 (2017)

$$A_N^{\mathrm{UPC+OPE}} = \frac{\sigma_{\mathrm{UPC}} A_N^{\mathrm{UPC}} + \sigma_{\mathrm{OPE}} A_N^{\mathrm{OPE}}}{\sigma_{\mathrm{UPC}} + \sigma_{\mathrm{OPE}}}$$

- ***Simulations (UPC+OPE) are consistent with the PHENIX inclusive measurements in both p+Al and p+Au collisions.***
- ***Simulations (UPC) are larger than the PHENIX measurements. This may indicate that the PHENIX with BBC veto includes some levels of hadronic interactions.***
- ***More detailed comparisons need to estimate a rejection efficiency of hadronic interaction by the BBC veto.***

Summary

- Large A_N for forward neutrons was observed in p+Au. This was clearly different from that in p+p.
- $\sigma_{UPC} \sim \sigma_{HAD}$ at $\eta > 7$ in p+Au collisions.
- UPCs lead to large A_N only in p+A collisions and promotional to Z^2 unlike hadronic interactions.

Future Prospects

- Prospect 1: trying to explain the FNAL results (π^0+p) using this framework
- Prospect 2: UPCs contribute weaker than hadronic interactions at $p_T > 0.2$ GeV/c. Interesting to see below and above 0.2 GeV/c if experimentally feasible (can see a transition from positive large A_N to negative small A_N?)
- Prospect 3: Coulomb nuclear interference in forward neutron production

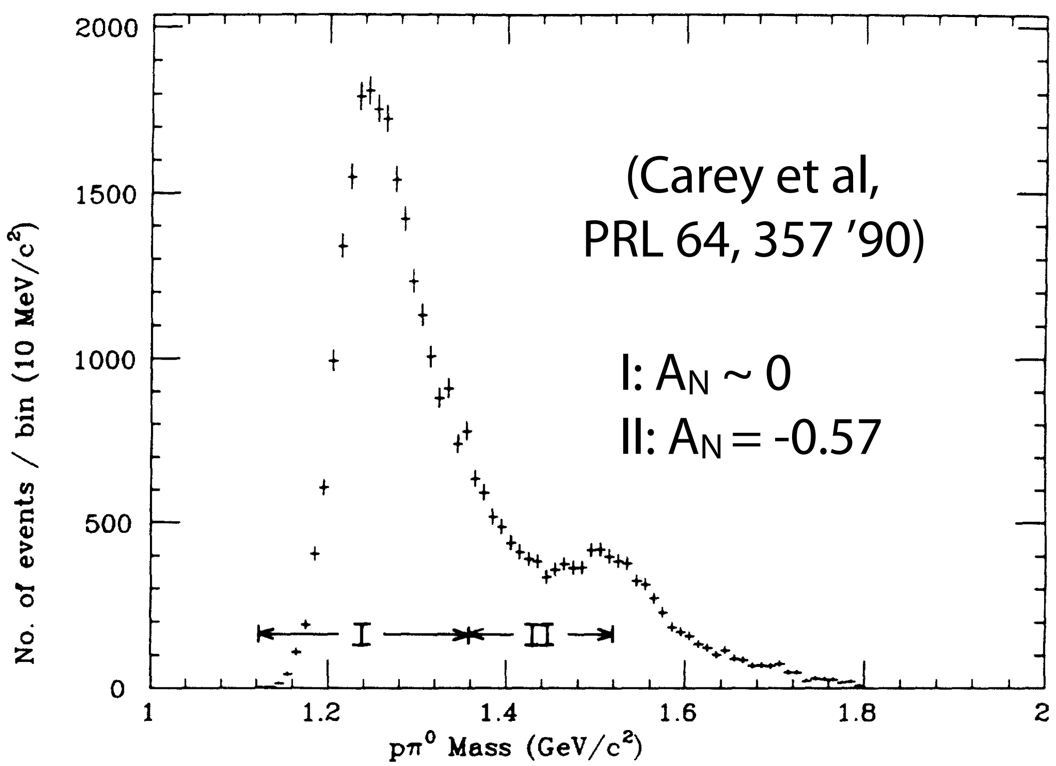
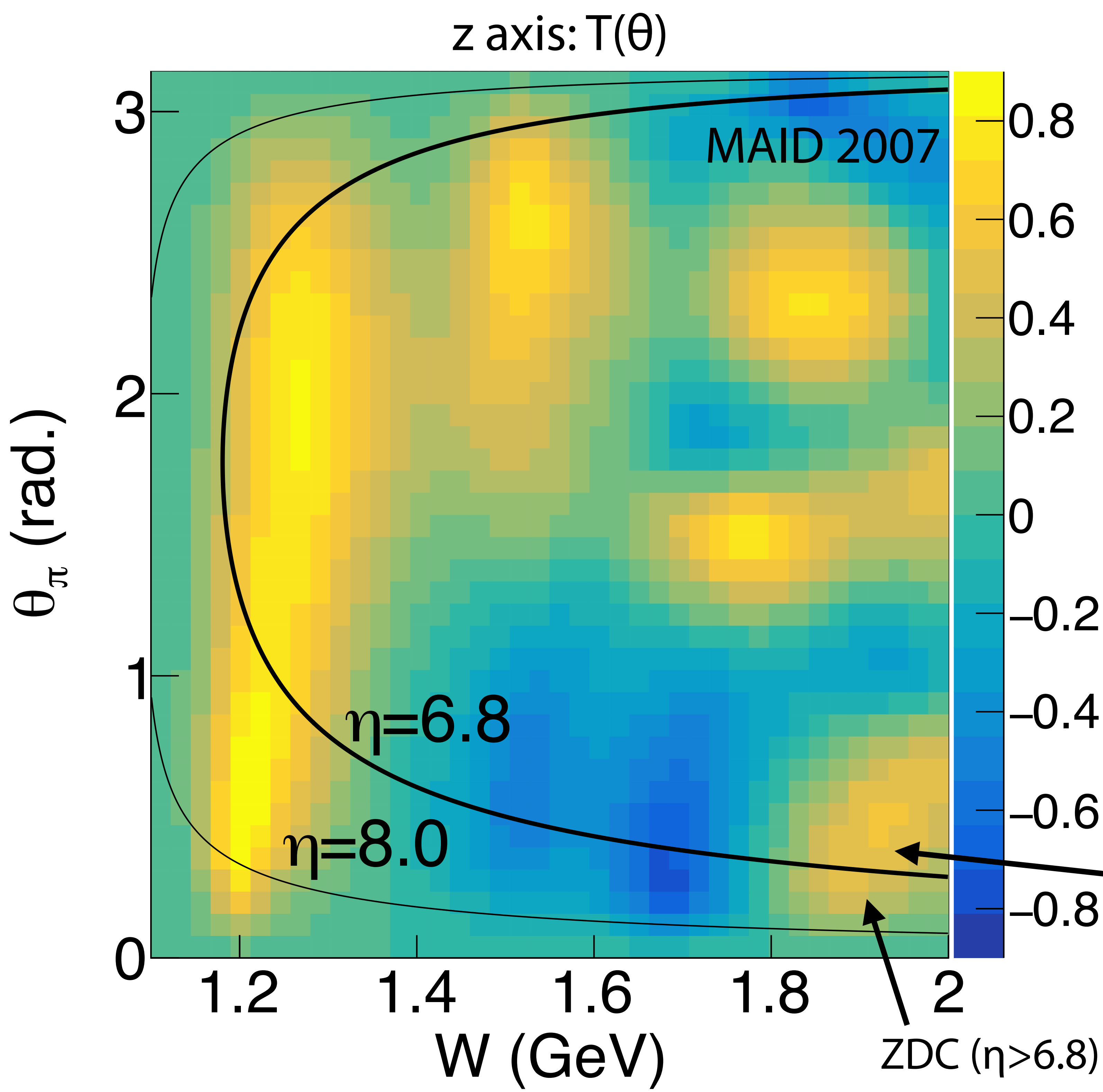
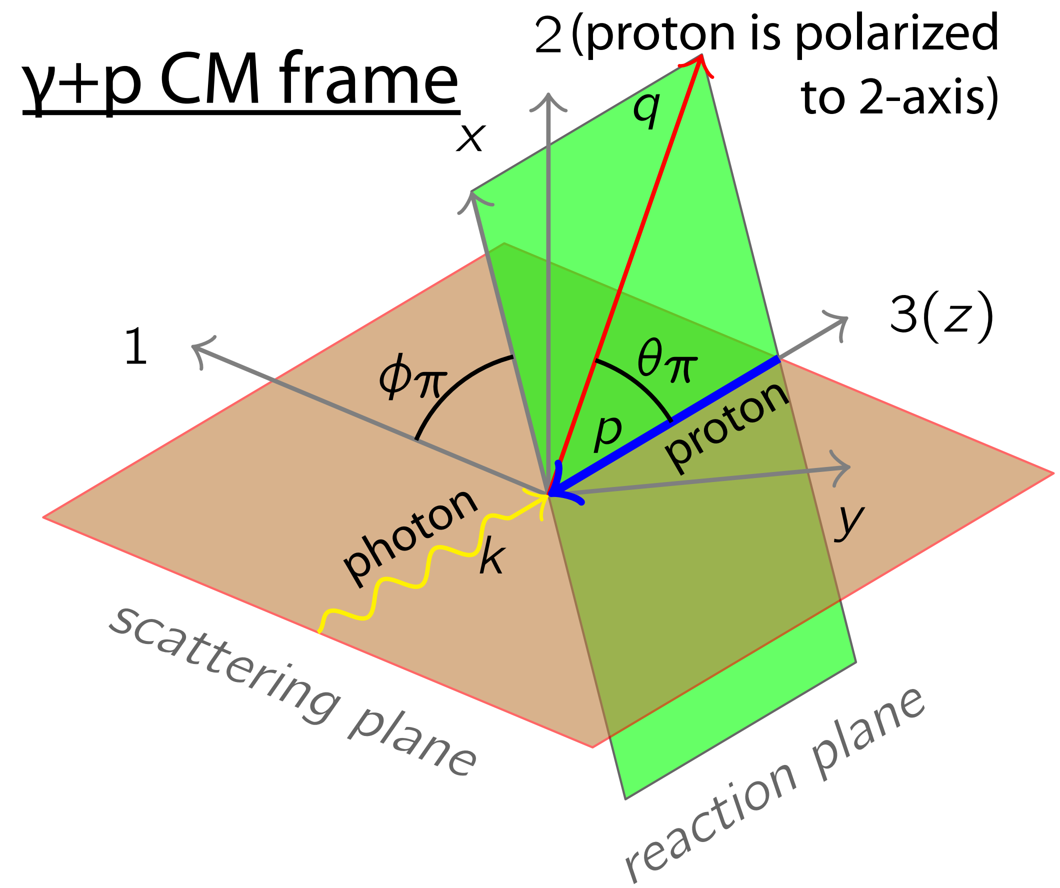


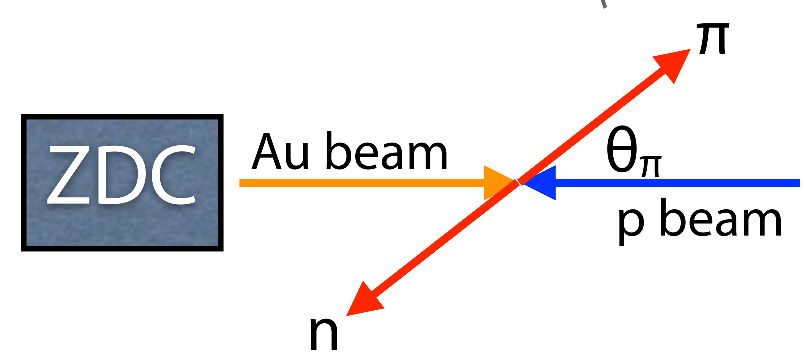
FIG. 2. The invariant-mass spectrum of the π^0-p system in $p+\mathrm{Pb}\rightarrow\pi^0+p+\mathrm{Pb}$ for $|t'|<1\times10^{-3}$ $(\mathrm{GeV}/c)^2$. Peaks due to the $\Delta^+(1232)$ and $N^*(1520)$ resonances are shown. Regions I and II are defined in the text.

Backup

Target asymmetry T(θ) as a function of W



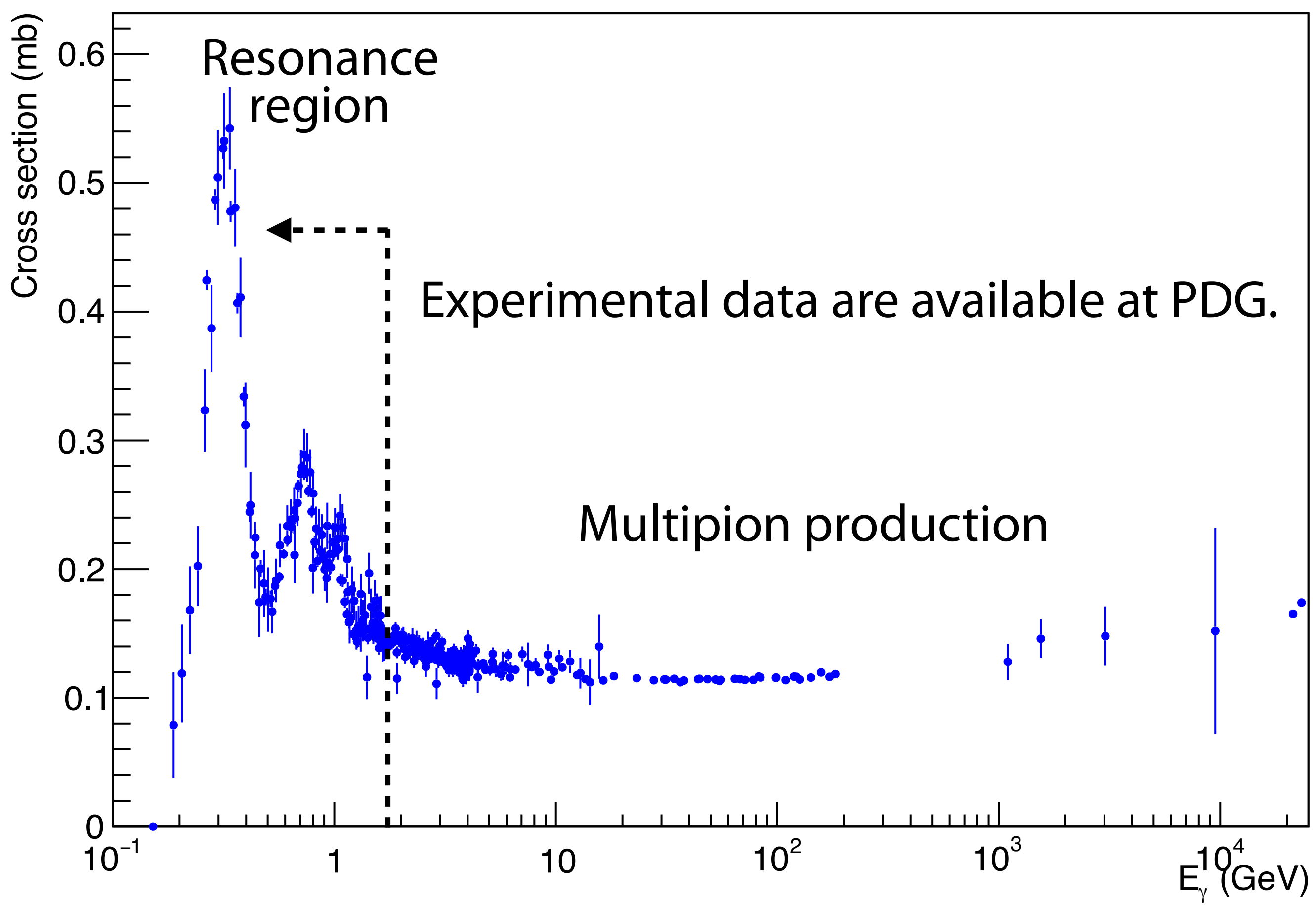




Neutrons emitted at θ_π ($\equiv\theta_n$-π) ~ π/2 have sizable p_T, thus they have larger rapidities.

ZDC (η>6.8) can detect neutrons in this region.

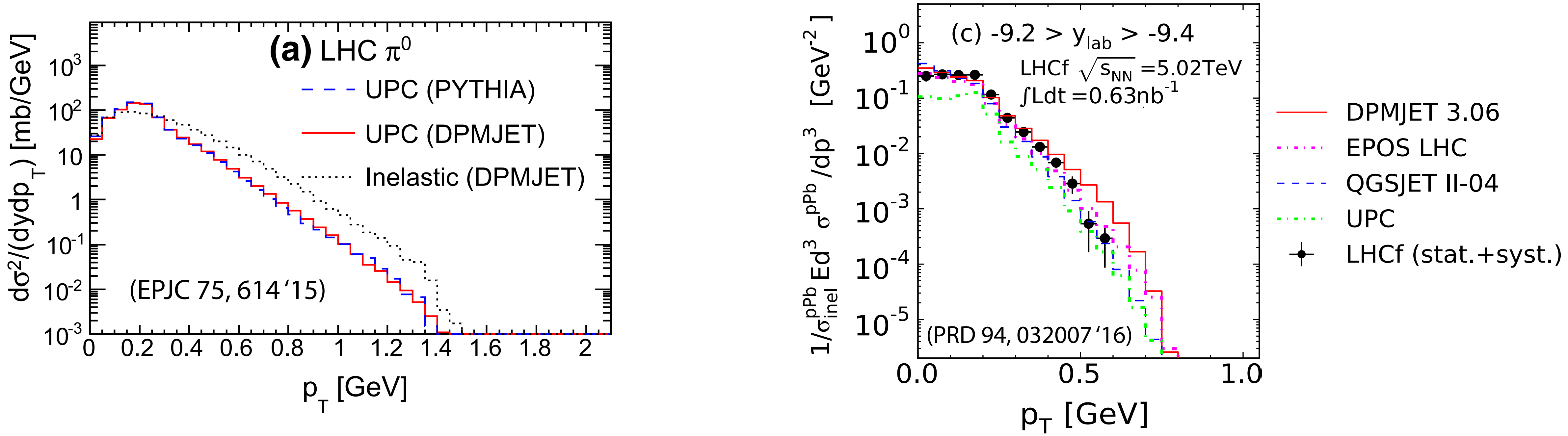
γp interactions



- ***Recalling the virtual photon flux and dominance of low-energy photons in UPCs, most UPCs occur at the baryon resonance region.***
- ***Namely, low-energy γ+p interactions (ω^{rest}_{γ}< 1.5 GeV) play major role in UPCs.***

Disentangling Z-dependent asymmetries for forward neutrons

- In my previous study (GM, EPJC 75, 614 '15), γp interactions are simulated by SOPHIA (W<7GeV) and DPMJET3/PYTHIA6 (W>7TeV). These models worked well for the LHCf π^0 analyses in (unpolarized) p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV (PRD 94, 032007 '16).



- ***But the previous UPC simulation framework can not deal with a proton polarization. Therefore, in this study, I change the γp interaction model to MAID 2007 which well explains low-energy photopion production on a polarized proton target.***

	Previous study (GM, EPJC 75, 614 '15)	This study
γp interactions	SOPHIA (low E) and DPMJET/PYTHIA (high E)	MAID isobar model 2007
Energy range	0.16 GeV < ω^{rest}_γ < 1.1 TeV	0.18 < ω^{rest}_γ < 1.7 GeV (1.1<W<2GeV)
Proton polarization	No	Yes
Neutron production	Isotropic	depending on W, θ, and φ

UPC formalism

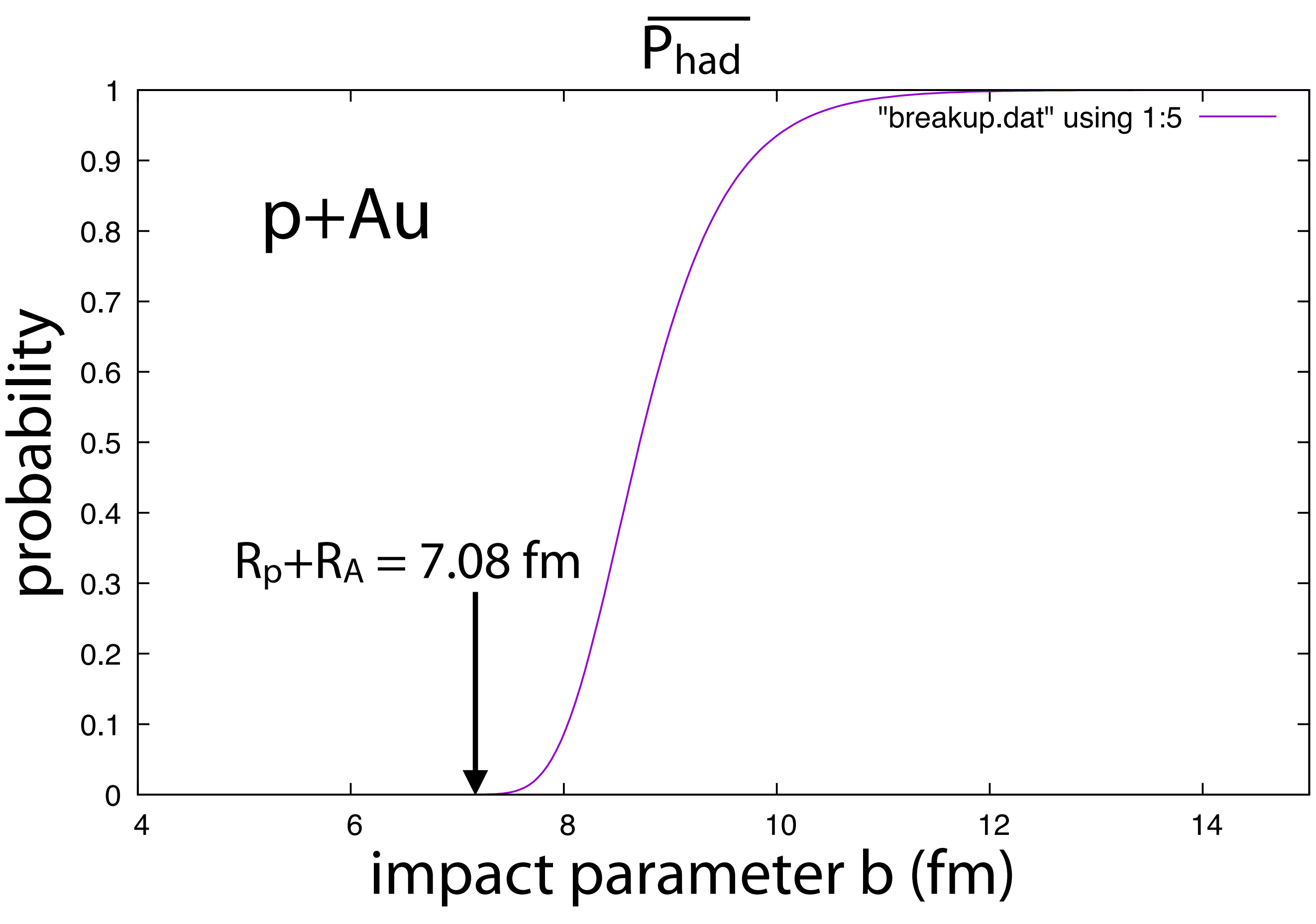
The UPC cross section is factorized as

$$\frac{d\sigma^4_{\mathrm{UPC}(p^\uparrow \mathrm{A}\to\pi^+ n)}}{dW\,db^2\,d\Omega_n} = \frac{d^3N_{\gamma^*}}{dW\,db^2}\frac{d\sigma_{\gamma^* p^\uparrow\to\pi^+ n}(W)}{d\Omega_n}\overline{P_{\mathrm{had}}}(b)$$

photon flux (N): quasi-real photons produced by a relativistic nucleus

$\sigma_{\gamma+p\to X}$: inclusive cross sections of γ+p interactions

$\overline{P_{had}}$: a probability not having a p+A hadronic interaction.



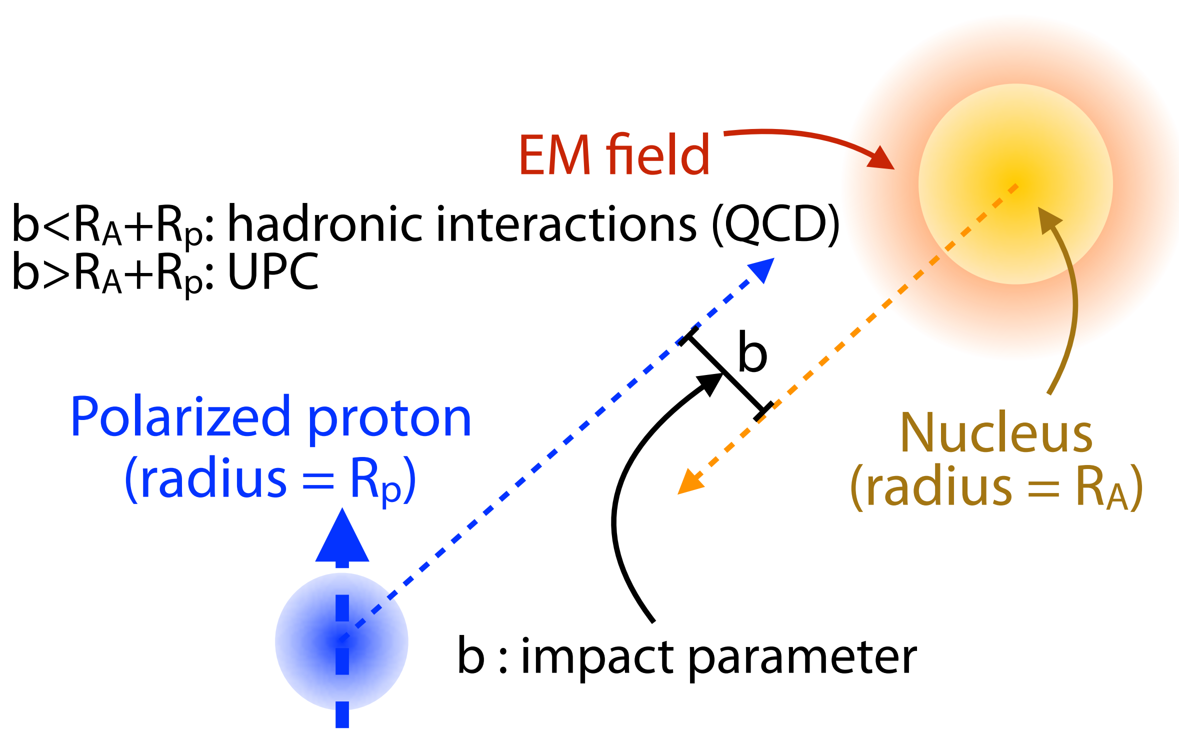
- ***$\overline{P_{had}}$ is calculated by using a Glauber MC simulation.***
- ***UPCs occur only if the impact parameter b is larger than the sum of radii R_p and R_A.***
- ***$\overline{P_{had}}$(b) distribution is important not only for the cross section but also for the energy distribution.***

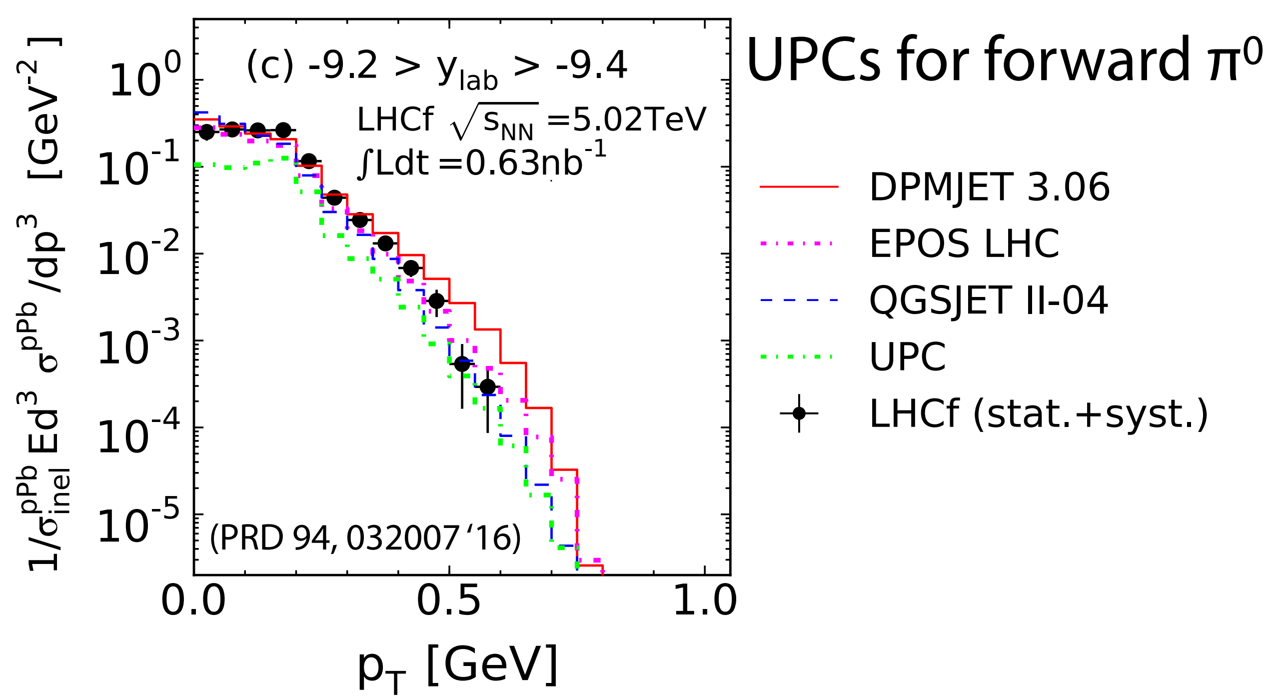
Forward particle production in UPCs

- Indications by large A_N in p-A:
  1) substantial nuclear effects in A target
  2) effects of electromagnetic (EM) field produced by relativistic A target.

- ***In order to test the second scenario, i.e. effects of EM field, I made the MC simulation framework that takes into account the both hadronic interactions and ultra-peripheral collisions.***

- Ultra-peripheral collisions (aka Primakoff effects);
  a collision of a proton with the EM field made by a relativistic nucleus when the impact parameter is larger than R_A+R_p.





Photopion production formalism

(Berends et al. NPB 4, 1 ‘67)

$$\frac{d\sigma}{d\Omega} = \frac{q}{k} \left|\langle \chi_f | \mathcal{F} | \chi_i \rangle\right|^2 , \qquad (A.1)$$

where

$$\mathcal{F} = i\boldsymbol{\sigma}\cdot\boldsymbol{\varepsilon}\,\mathcal{F}_1 + \boldsymbol{\sigma}\cdot\hat{q}\,\boldsymbol{\sigma}\cdot(\hat{k}\times\boldsymbol{\varepsilon})\,\mathcal{F}_2 + i\boldsymbol{\sigma}\cdot\hat{k}\,\hat{q}\cdot\boldsymbol{\varepsilon}\,\mathcal{F}_3 + i\boldsymbol{\sigma}\cdot\hat{q}\,\hat{q}\cdot\boldsymbol{\varepsilon}\,\mathcal{F}_4 . \qquad (A.2)$$

$$\sum_f \langle \chi_f | \mathcal{F} | \chi_i \rangle^\dagger \langle \chi_f | \mathcal{F} | \chi_i \rangle = \langle \chi_i | \mathcal{F}^\dagger \mathcal{F} | \chi_i \rangle$$

$$\langle \chi_i | \mathcal{F}_\pm^\dagger \mathcal{F}_\pm | \chi_i \rangle = (1 \mp \hat{k}\cdot\boldsymbol{P})\,\alpha + \beta \pm \sin\theta\,\hat{e}_1\cdot\boldsymbol{P}\gamma + \sin\theta\,\hat{e}_2\cdot\boldsymbol{P}\delta , \qquad (A.7)$$

where

$$\alpha = |\mathcal{F}_1|^2 + |\mathcal{F}|^2 - 2\cos\theta\,\mathrm{Re}(\mathcal{F}_1^*\mathcal{F}_2) + \sin^2\theta\,\mathrm{Re}\{\mathcal{F}_1^*\mathcal{F}_4 + \mathcal{F}_2^*\mathcal{F}_3\} , \qquad (A.8)$$

$$\beta = \tfrac{1}{2}\sin^2\theta\{|\mathcal{F}_3|^2 + |\mathcal{F}_4|^2 + 2\cos\theta\,\mathrm{Re}(\mathcal{F}_3^*\mathcal{F}_4)\} , \qquad (A.9)$$

$$\gamma = \mathrm{Re}\{\mathcal{F}_1^*\mathcal{F}_3 - \mathcal{F}_2^*\mathcal{F}_4\} + \cos\theta\,\mathrm{Re}\{\mathcal{F}_1^*\mathcal{F}_4 - \mathcal{F}_2^*\mathcal{F}_3\} , \qquad (A.10)$$

$$\delta = \mathrm{Im}\{\mathcal{F}_1^*\mathcal{F}_3 - \mathcal{F}_2^*\mathcal{F}_4\} + \cos\theta\,\mathrm{Im}\{\mathcal{F}_1^*\mathcal{F}_4 - \mathcal{F}_2^*\mathcal{F}_3\} - \sin^2\theta\,\mathrm{Im}(\mathcal{F}_3^*\mathcal{F}_4) . \qquad (A.11)$$

Polarized nucleon, unpolarized photon

$$\frac{d\sigma(\boldsymbol{P})}{d\Omega} = \tfrac{1}{2}\left\{\frac{d\sigma_+(\boldsymbol{P})}{d\Omega} + \frac{d\sigma_-(\boldsymbol{P})}{d\Omega}\right.$$

$$= \frac{q}{k}\{\alpha + \beta + \sin\theta\,\hat{e}_2\cdot\boldsymbol{P}\delta\} \rightarrow \frac{d\sigma_0}{d\Omega} = \frac{q}{k}(\alpha+\beta),\ A_N = \frac{\sin\theta\,\delta}{\alpha+\beta}$$

Photopion production

(Berends et al. NPB 4, 1 '67)

Eq. (A.2)

$$\tilde{\mathcal{F}}(s,t) = \sum_{l=0}^{\infty} \begin{bmatrix} G_l(x) & 0 \\ 0 & H_l(x) \end{bmatrix} \tilde{M}_l(s), \quad \tilde{M}_l = \begin{bmatrix} E_{l+} \\ E_{l-} \\ M_{l+} \\ M_{l-} \\ S_{l+} \\ S_{l-} \end{bmatrix}$$

G_l and H_l are Legendre polynomials, and $\tilde{M}_l$ are multipoles.

(Drechsel and Tiator, JphysG 18, 449 '92)

Multipole decomposition:

Several models provide their predicted multipoles. MAID2007 is available at https://maid.kph.uni-mainz.de.

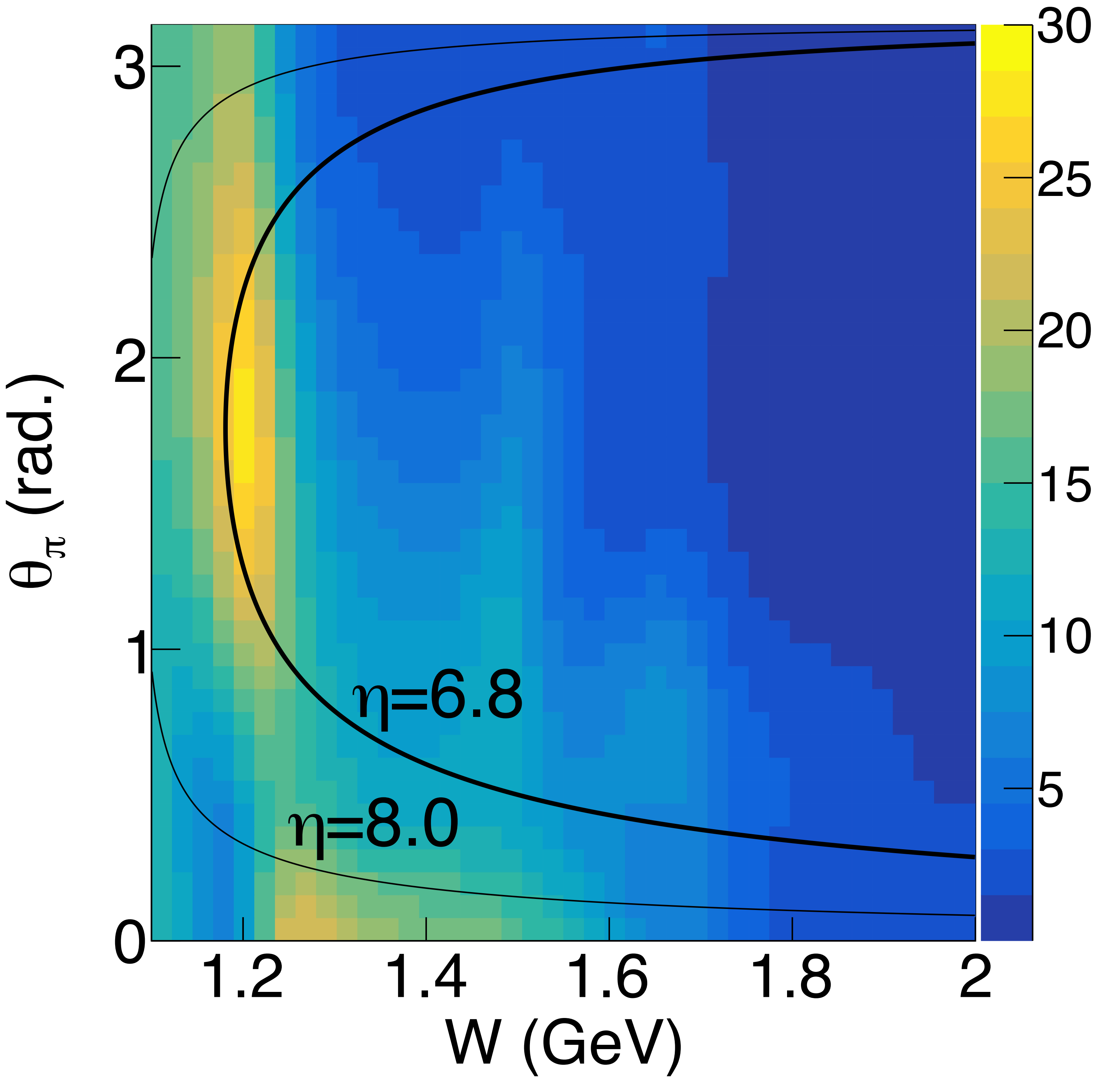
$$R_T = |E_{0+}|^2 + \tfrac{1}{2}|2M_{1+} + M_{1-}|^2 + \tfrac{1}{2}|3E_{1+} - M_{1+} + M_{1-}|^2$$
$$+ 2\cos\Theta \,\mathrm{Re}\{E_{0+}^*(3E_{1+} + M_{1+} - M_{1-})\}$$
$$+ \cos^2\Theta(|3E_{1+} + M_{1+} - M_{1-}|^2 - \tfrac{1}{2}|2M_{1+} + M_{1-}|^2$$
$$- \tfrac{1}{2}|3E_{1+} - M_{1+} + M_{1-}|^2)$$

$$R_T(n_i) = 3\sin\Theta\,\mathrm{Im}\{E_{0+}^*(E_{1+} - M_{1+}) - \cos\Theta(E_{1+}^*(4M_{1+} - M_{1-}) + M_{1+}^* M_{1-})\}$$

$$R_{\mathrm{T}}^{00} \equiv R_{\mathrm{T}} \text{ and } R_{\mathrm{T}}^{0y} \equiv R_{\mathrm{T}}(n_i) \qquad \frac{d\sigma_{\gamma^* p^\uparrow \to \pi^+ n}}{d\Omega_\pi} = \frac{|q|}{\omega_{\gamma^*}}(R_T^{00} + P_y R_T^{0y})$$
$$= \frac{|q|}{\omega_{\gamma^*}} R_T^{00}(1 + P_2\cos\phi_\pi T(\theta_\pi))$$

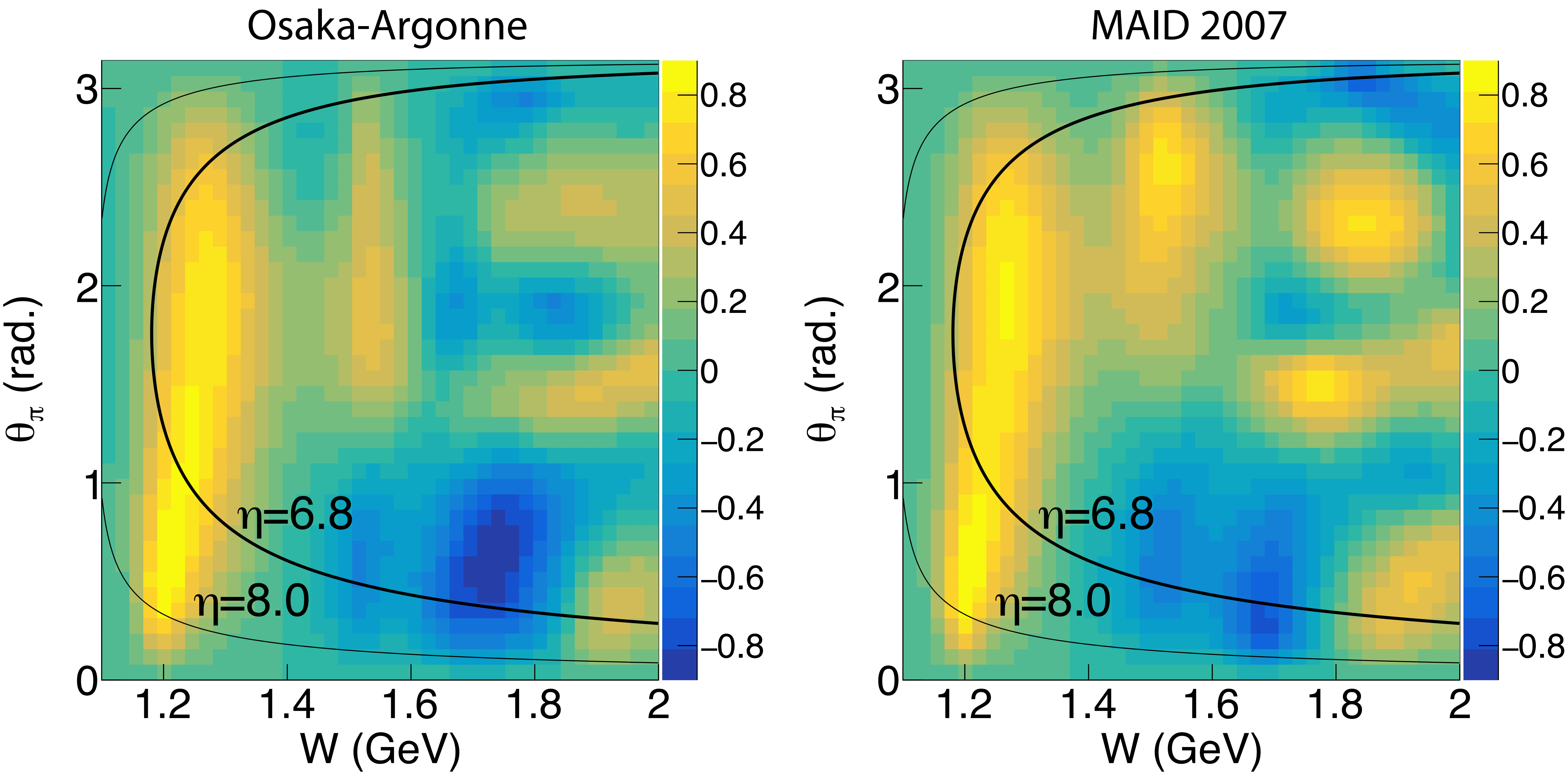
pion and neutron production in UPCs

R_{00} distribution



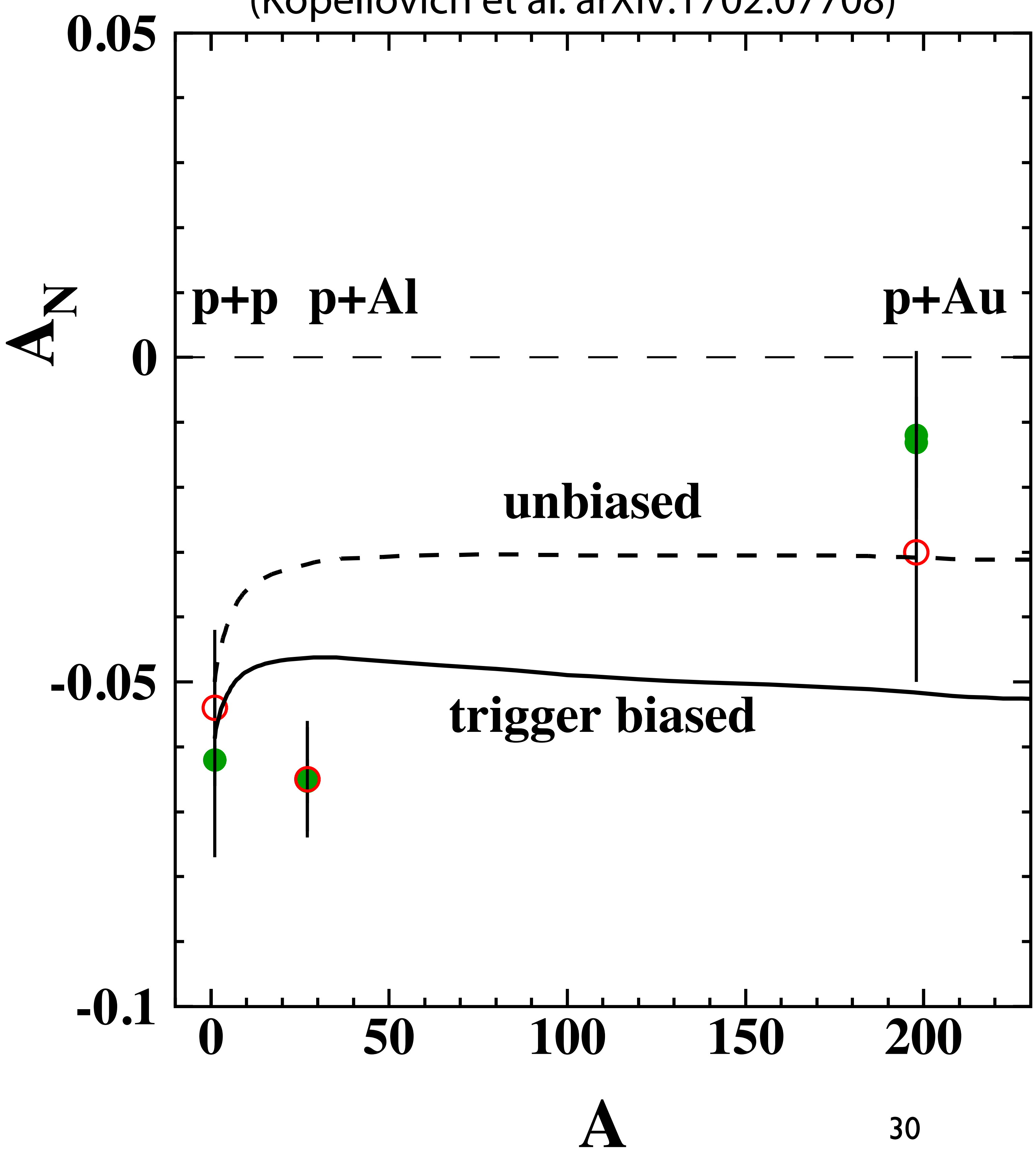
Target asymmetry as a function of W

z axis: T(θ)



Hadronic interactions (one-π exchange)

(Kopeliovich et al. arXiv:1702.07708)



$$A_N^{(\pi-\tilde{a}_1)}(q_T, z) = q_T \, \frac{4 m_N \, q_L}{|t|^{3/2}} \, (1-z)^{\alpha_\pi(t)-\alpha_{\tilde{a}_1}(t)} \quad (12)$$

$$\times \; \frac{\mathrm{Im}\; \eta_\pi^*(t)\, \eta_{\tilde{a}_1}(t)}{|\eta_\pi(t)|^2} \left(\frac{d\sigma_{\pi p \to \tilde{a}_1 p}(M_X^2)/dt|_{t=0}}{d\sigma_{\pi p \to \pi p}(M_X^2)/dt|_{t=0}} \right)^{1/2} \frac{g_{\tilde{a}_1^+ pn}}{g_{\pi^+ pn}}.$$

$$A_N^{pA \to nX} = A_N^{pp \to nX} \times \frac{R_1}{R_2} R_3$$

Nuclear effects:
no significant effect to A_N

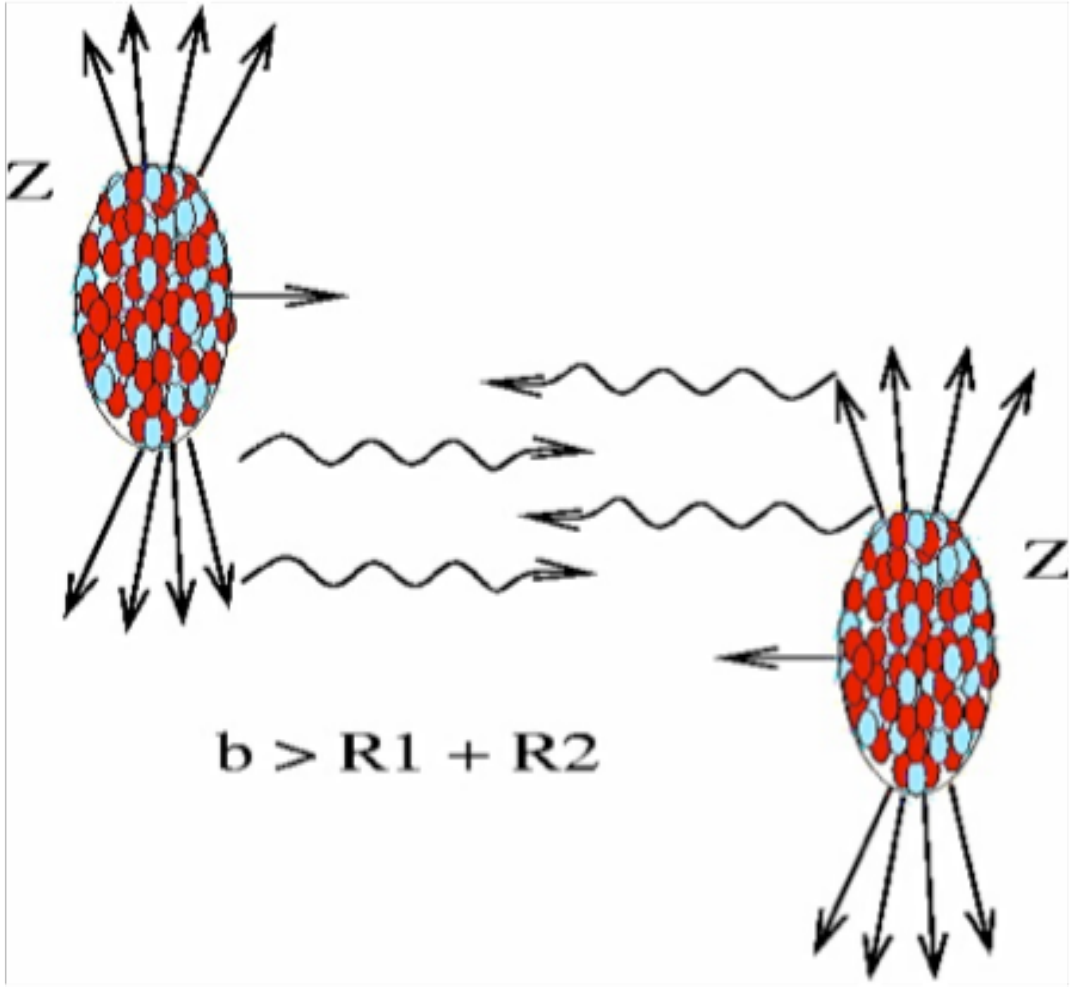
What are ultraperipheral collisions?

Heavy-ions (with the charge Z) produce strong electromagnetic fields due to the coherent action of all proton charges.

Equivalent photon approximation formula for the photon flux in ultraperipheral (p)A+A collisions at $b>b_{min}\sim R_1+R_2$:

$$n(\omega) = \frac{2Z^2\alpha}{\pi\beta^2}\left[\xi K_0(\xi)K_1(\xi) - \frac{\xi^2}{2}\left(K_1^2(\xi) - K_0^2(\xi)\right)\right]$$

where $\xi = \omega b_{min}/\gamma\beta\hbar c = 2\,\omega\,R_A/\gamma\beta\hbar c$.



Characteristics of photon beams:

Photon flux$\sim Z^2$ ($\sim 6\times10^3$ for Au) and $\sigma(\gamma\gamma)\sim Z^4$ (i.e.$\sim 4\times10^7$)

γ wavelength > nucleus size → very low photon virtuality