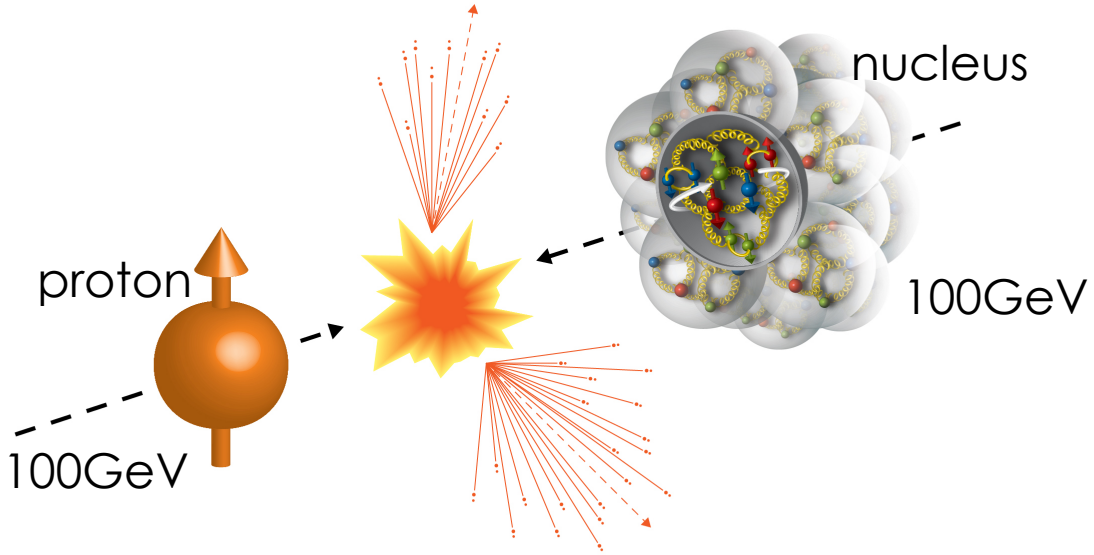
The First Asymmetry Measurements in High Energy Polarized Proton-Nucleus Collisions at PHENIX-RHIC



RIKEN/RBRC

Itaru Nakagawa

Outline

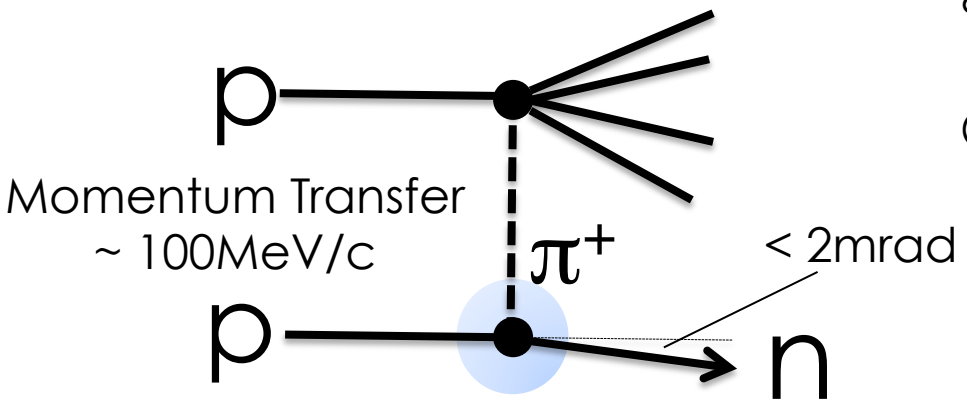
- Introduction
  - Forward Neutron Detector
  - Forward Neutron Single Spin Asymmetry in **p+p**
- New measurements of **p+A** in Run15
  - Inclusive Measurement
  - Neutron + charged particle measurements to separate competing effects
  - Theoretical interpretation
- Summary

known

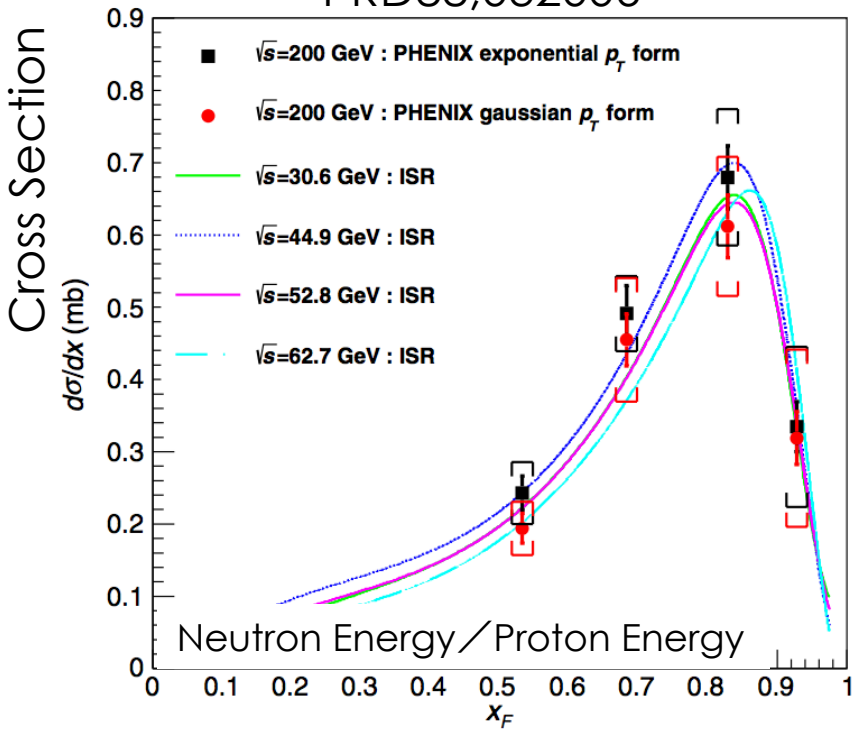
new

Production Mechanism of Forward Neutron @ E_p=100GeV

Cross Section

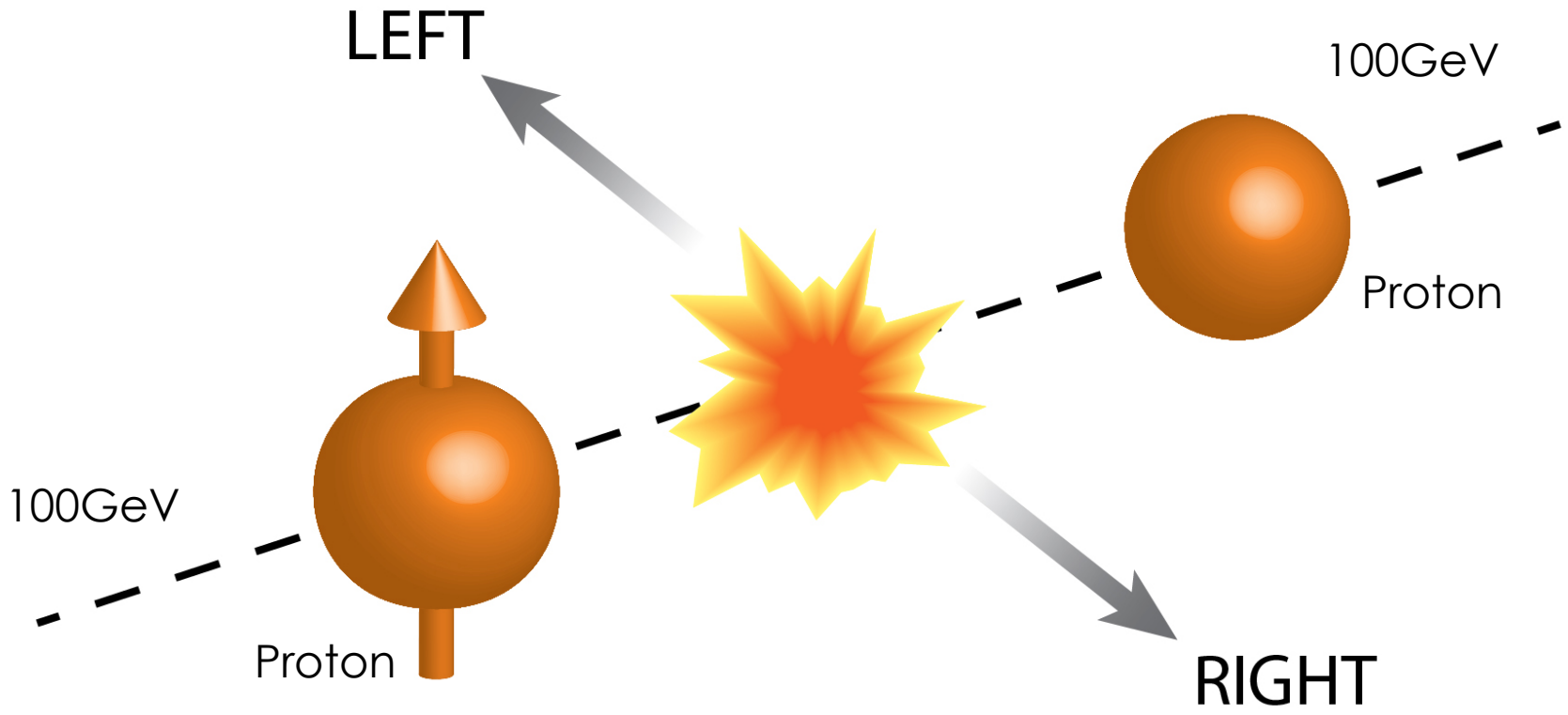


PRD88,032006

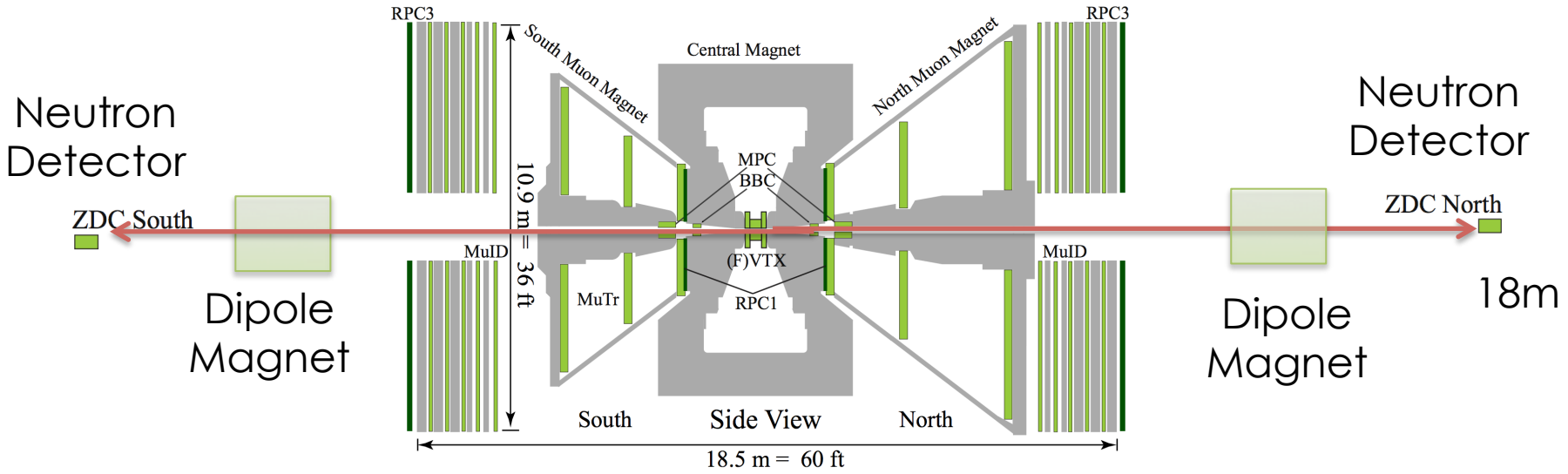


Well Explained by One-Pion Exchange

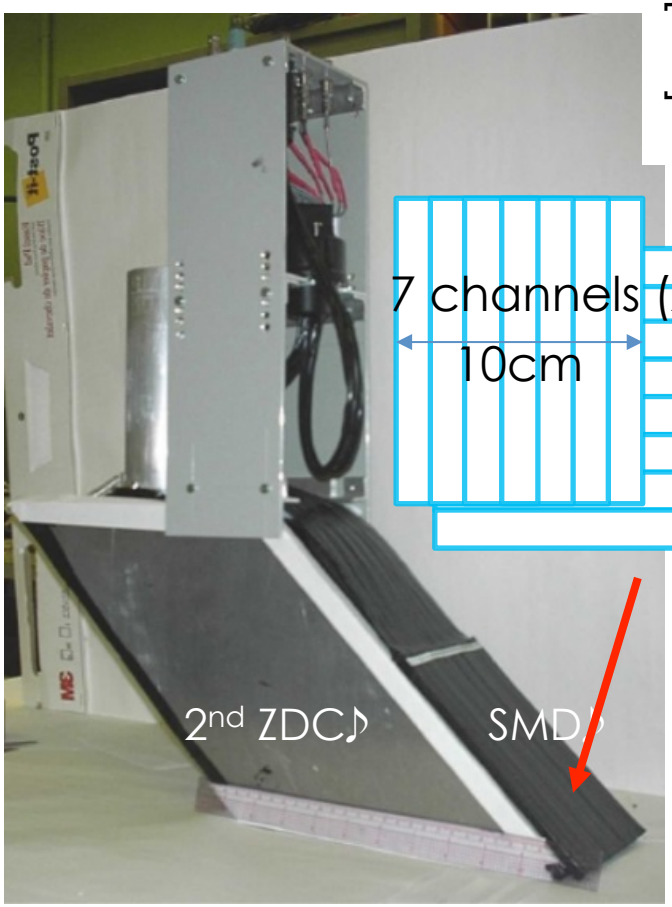
Transverse Single Spin Asymmetry

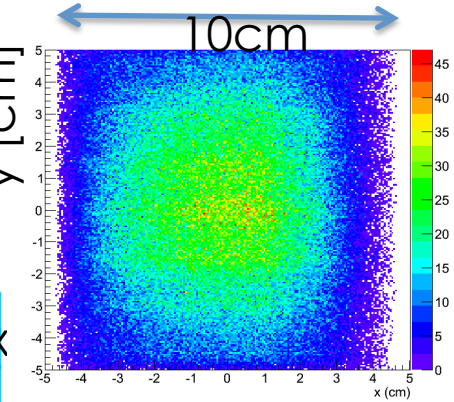


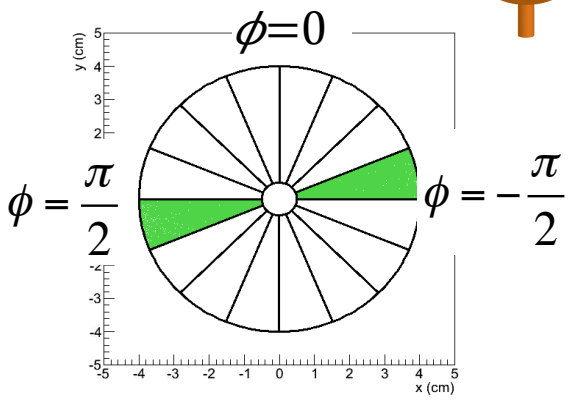
Zero **D**egree **C**ounter (ZDC)

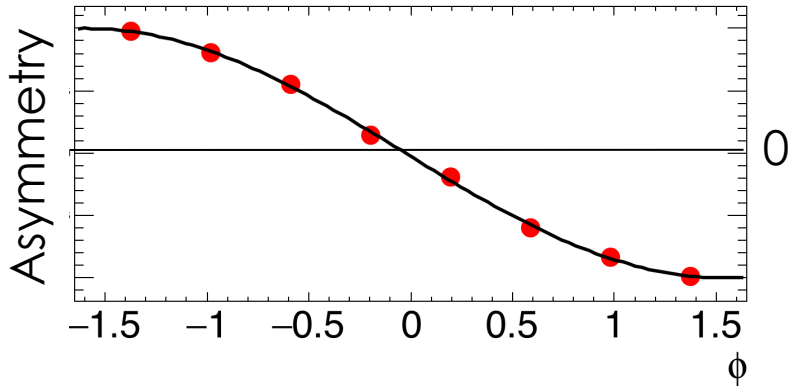


Asymmetry Measurements using Shower Max Detectors



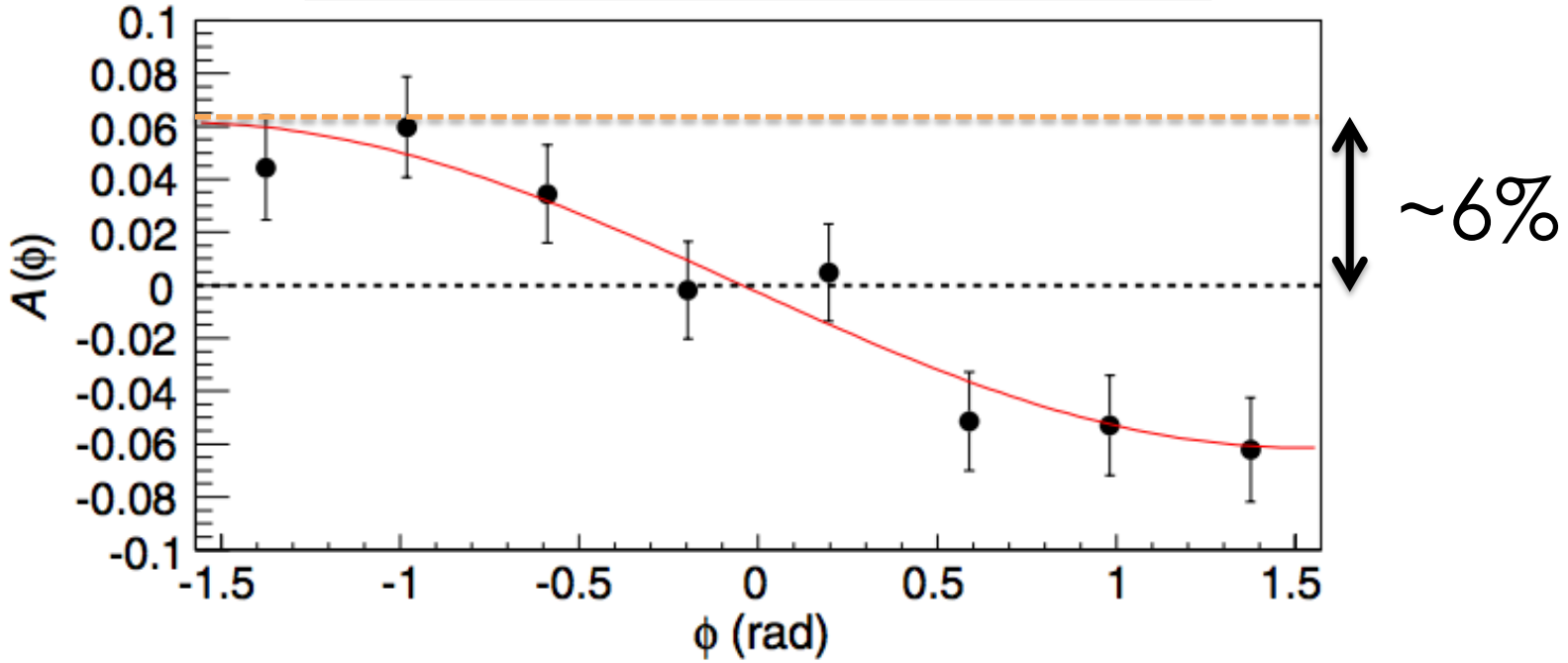






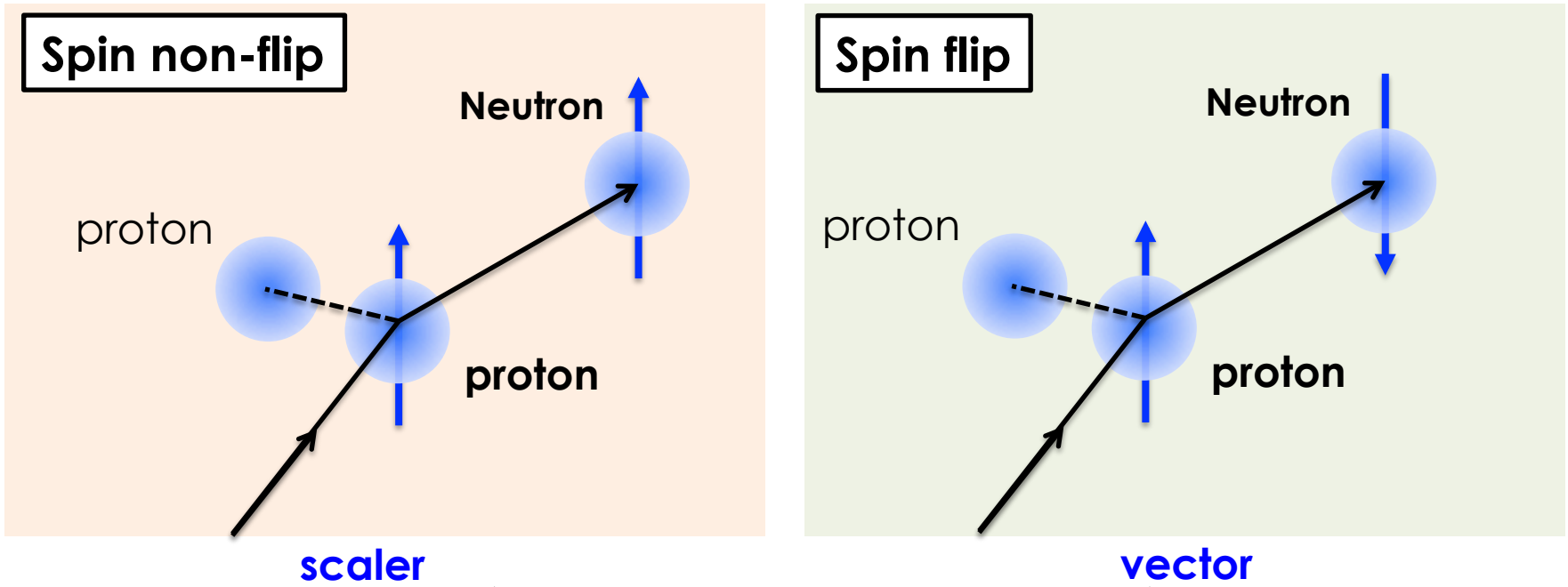
Transverse Single Spin Asymmetry

Published: PRD 88, 032006 (2013)



Observed at PHENIX in Run6

$p^{\uparrow}$+p Forward Neutron A_N

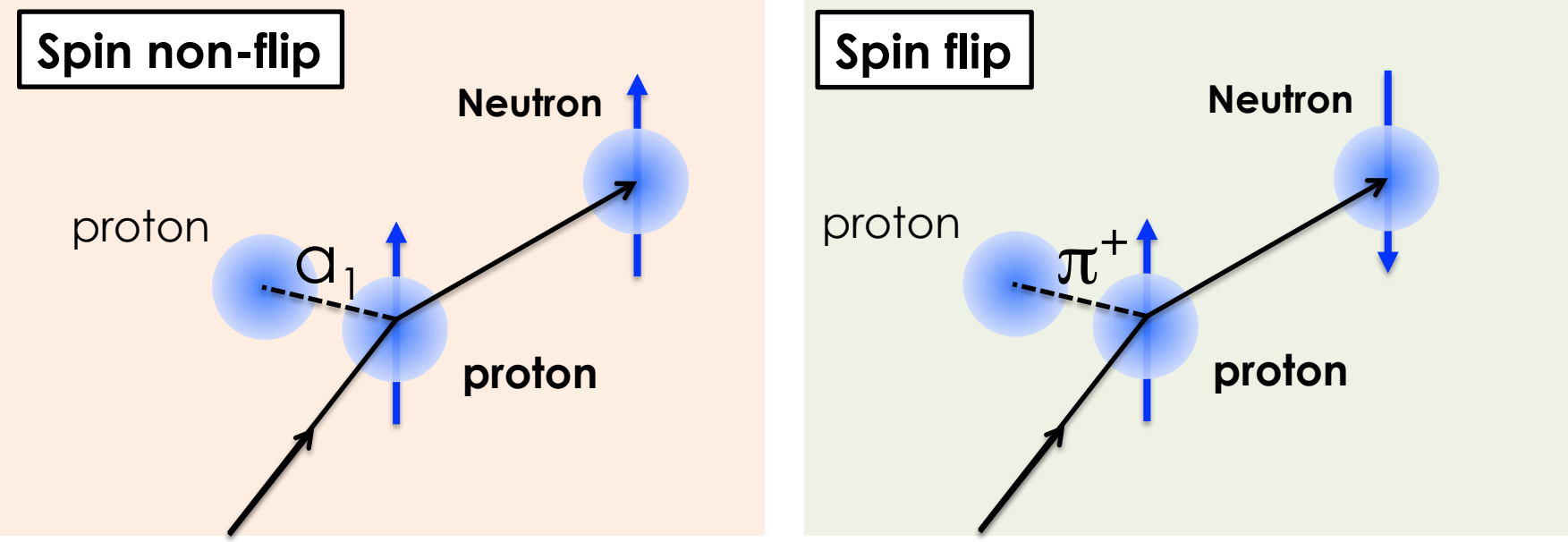


$$A_N \approx \frac{\left(\phi^{*}_{non-flip}\,\phi_{flip}\,\sin\delta\right)}{\left|\phi_{non-flip}\right|^2 + \left|\phi_{flip}\right|^2}$$

Unpolarized Cross Section

δ : phase shift

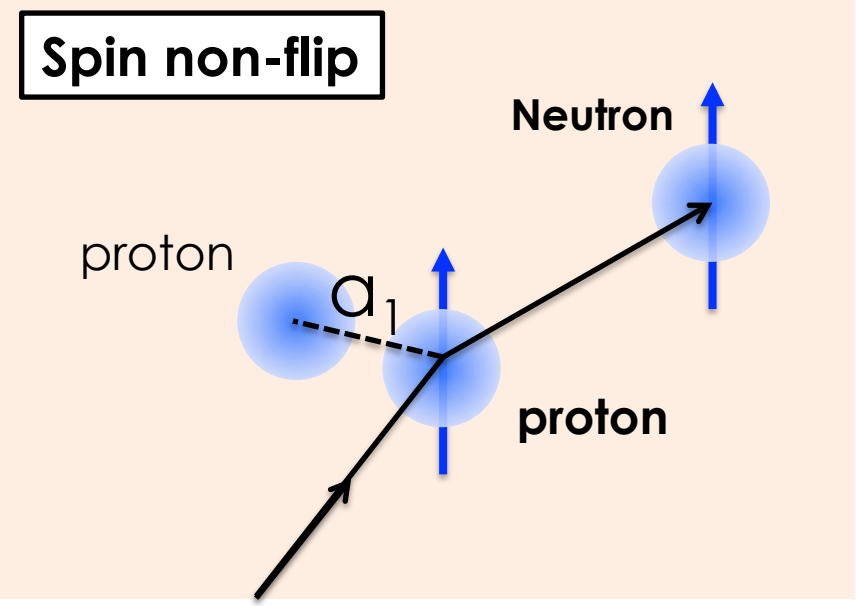
$p^{\uparrow}$+p Forward Neutron A_N

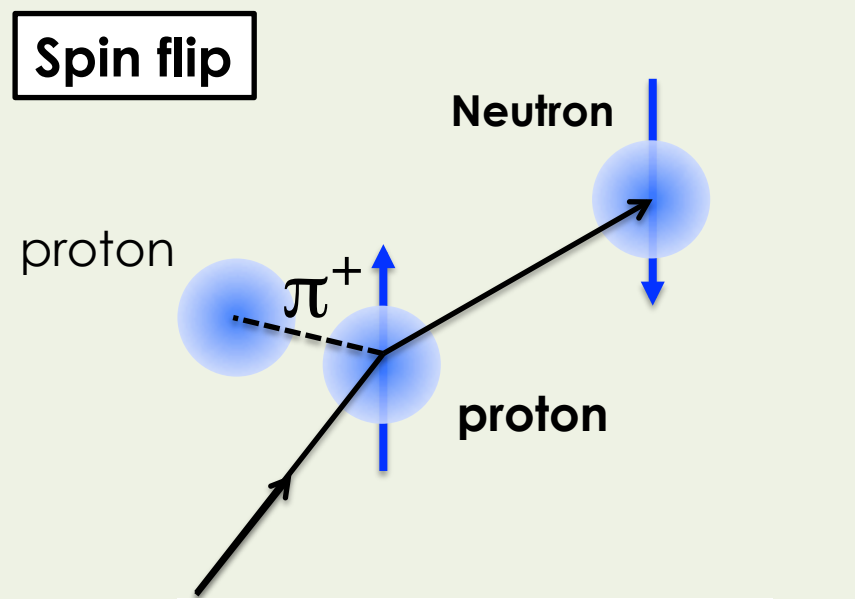


$$A_N \approx \frac{\left(\phi^*_{non-flip}\,\phi_{flip}\,\sin\delta\right)}{\left|\phi_{non-flip}\right|^2 + \left|\phi_{flip}\right|^2}$$

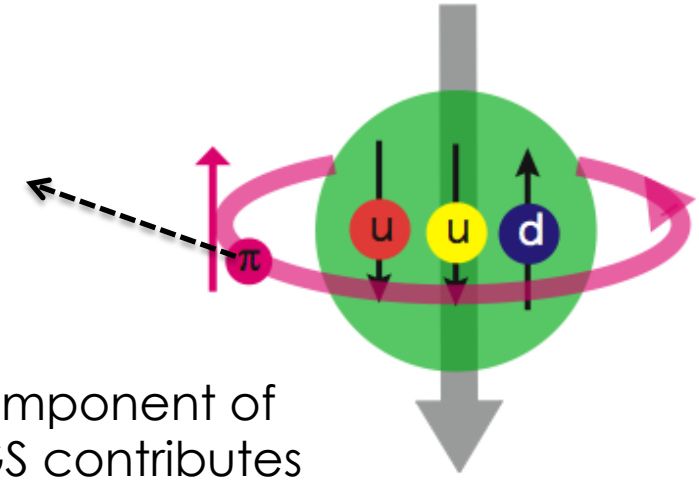
δ : phase shift

$p^{\uparrow}+p$ Forward Neutron A_N



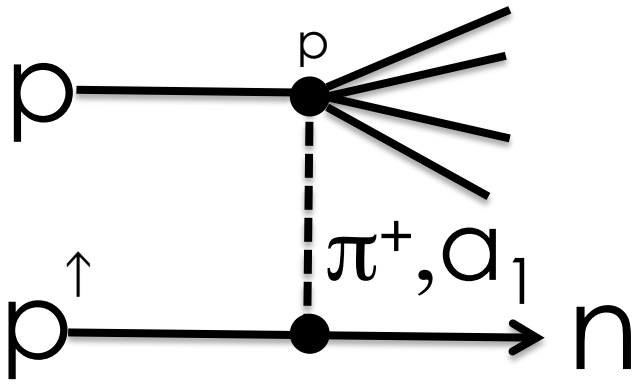


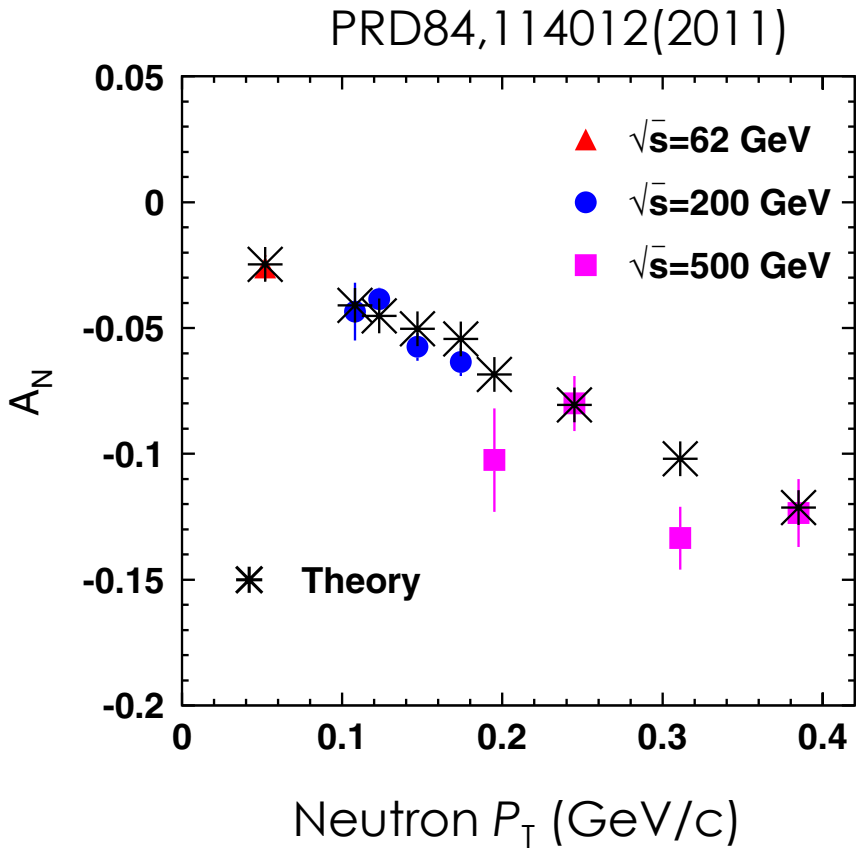
a_1 (1260) Reggeon
Spin Parity = 1^+



n + π^+ component of
proton GS contributes

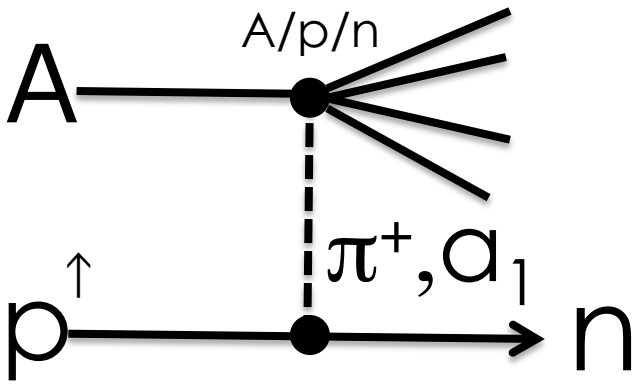
$p^{\uparrow}+p$ Forward Neutron A_N

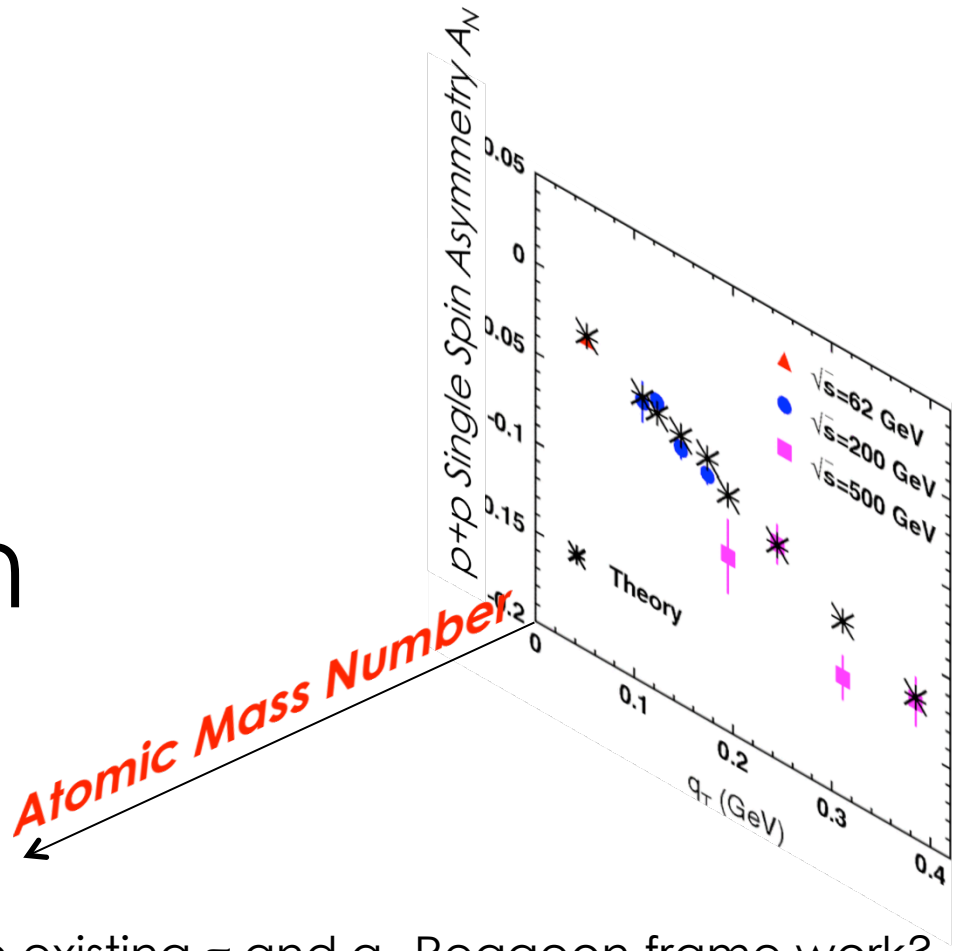




Data are well reproduced by the interference between π and a_1 Reggeon

Atomic Mass Dependence of A_N

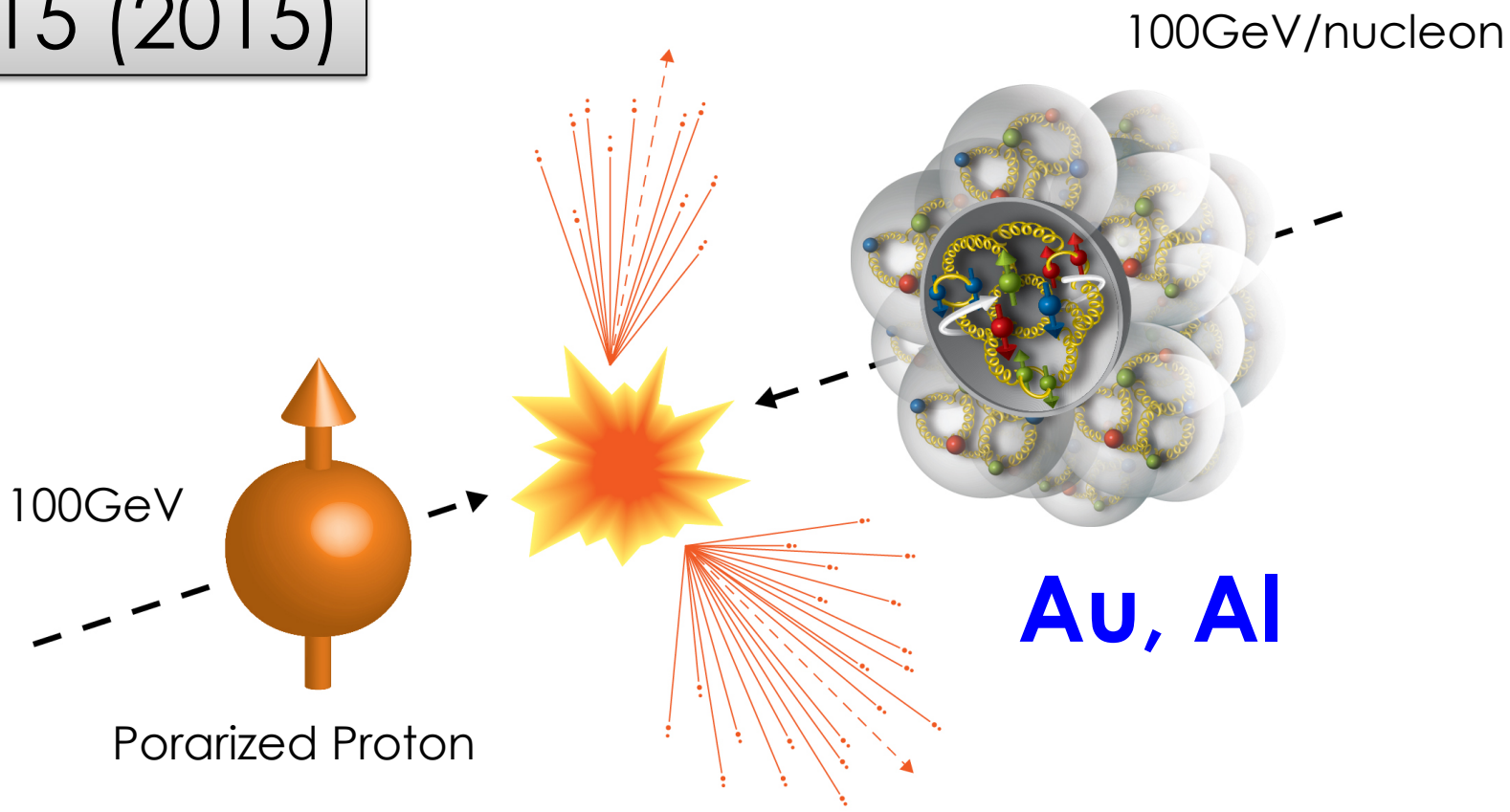




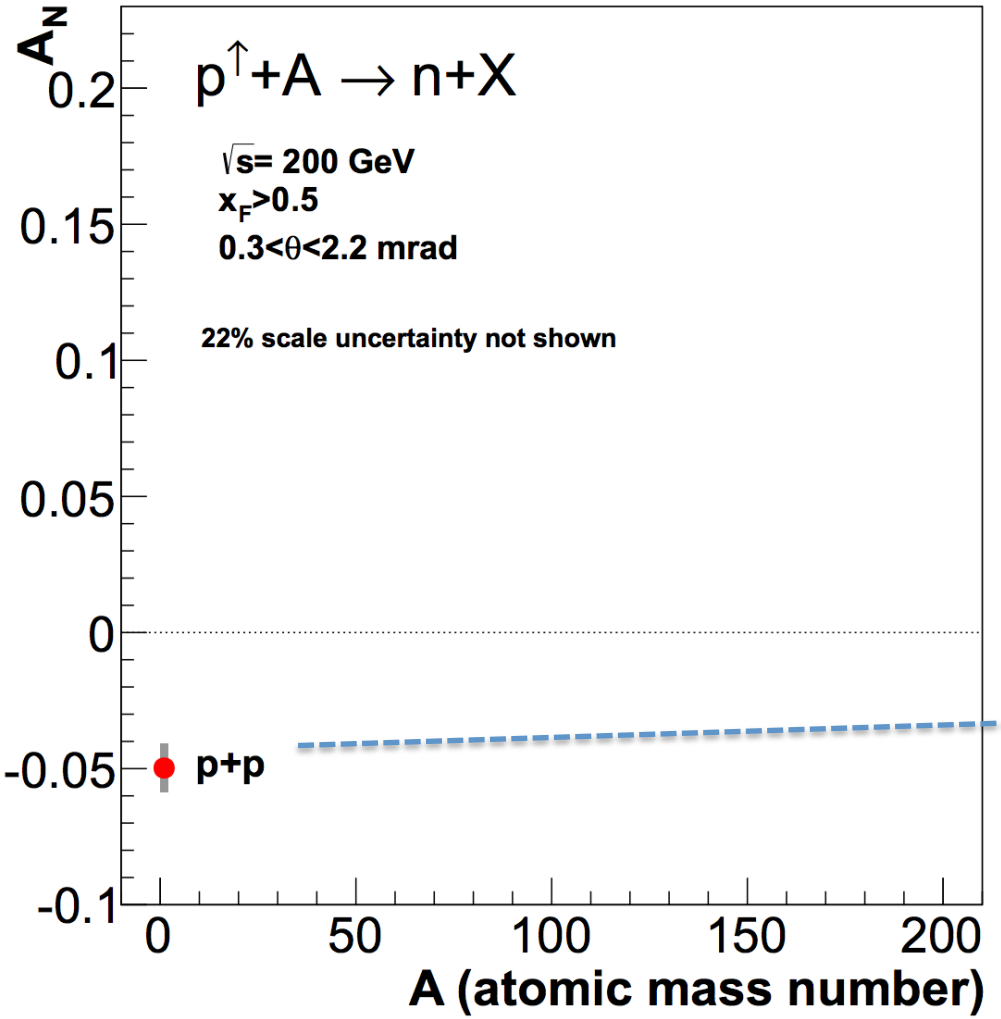
Can it be explained by the existing π and a_1 Reggeon frame work?

The First Time Ever High Energy $p^{\uparrow} + A$ Collisions

Run15 (2015)

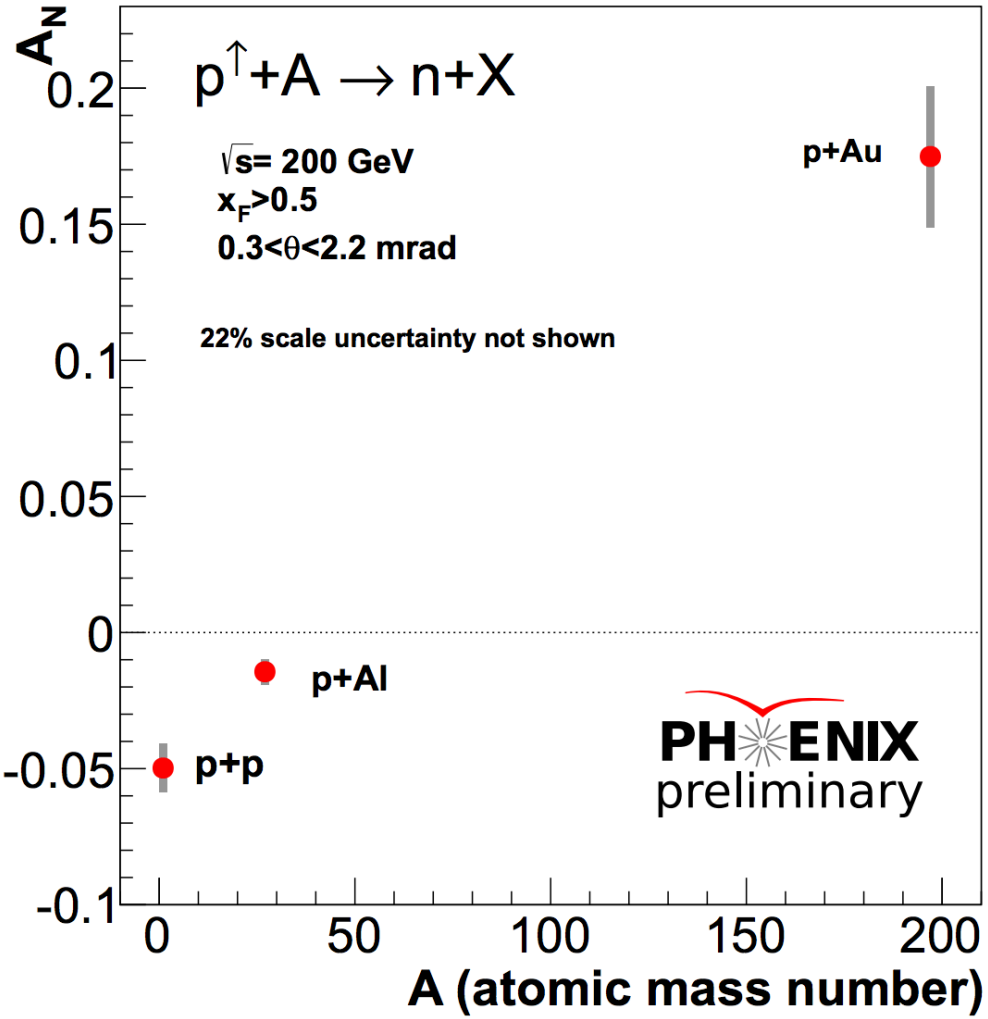


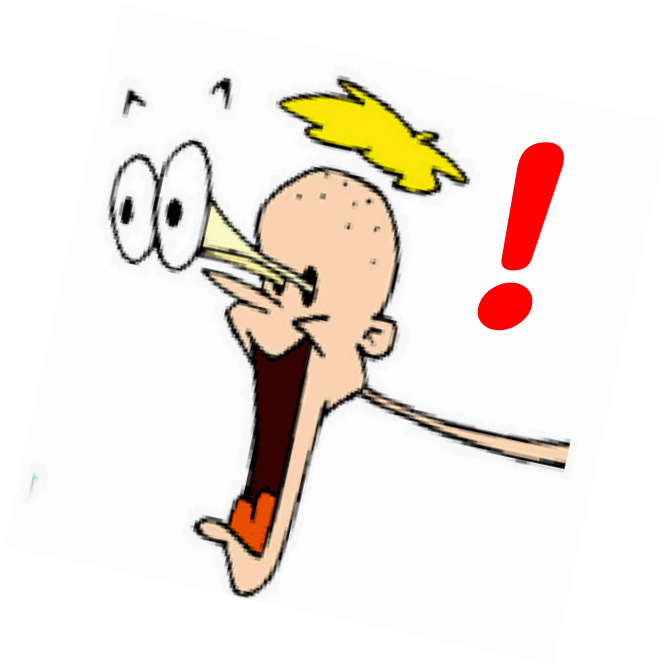
A-Dependent A_N (inclusive)



Present Frame Work

A-Dependent A_N (inclusive)

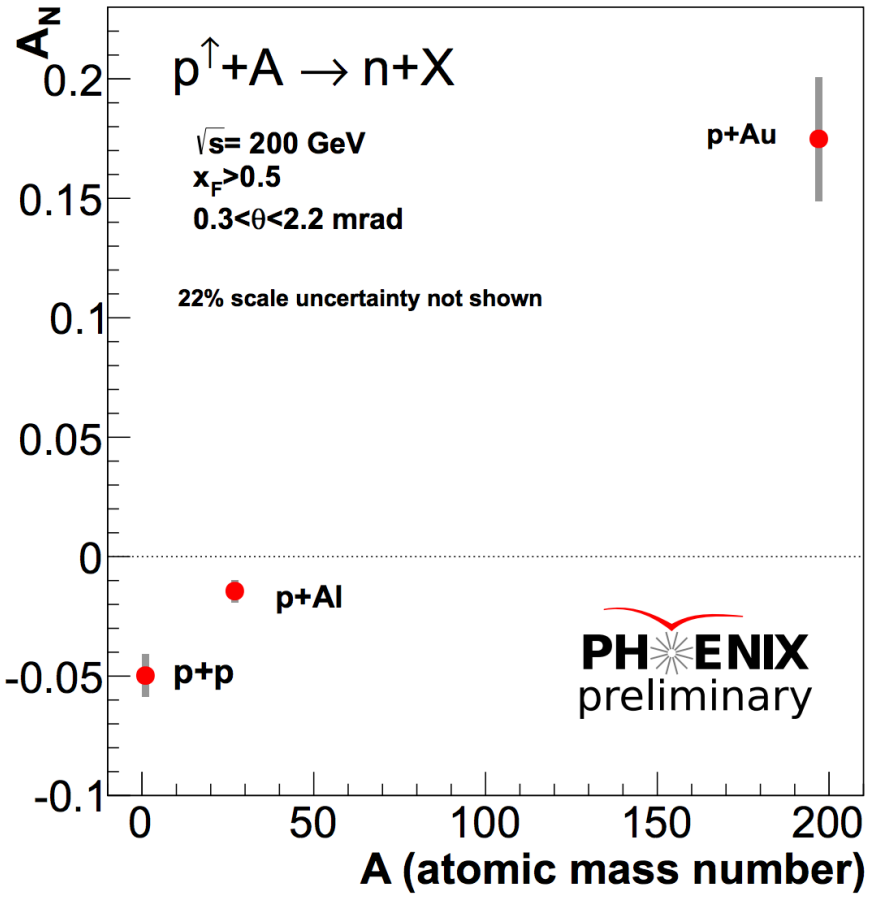




Absolutely Unexpected!

Analysis by
Minjung Kim (SNU/RIKEN)

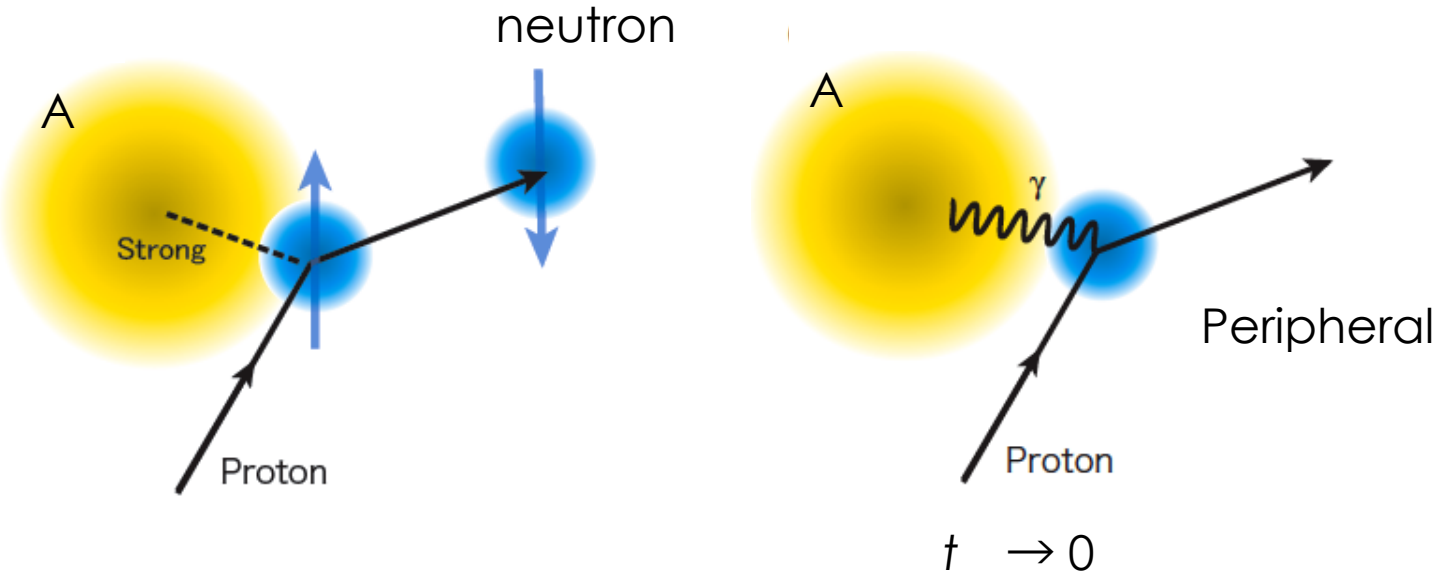
What is going on ?

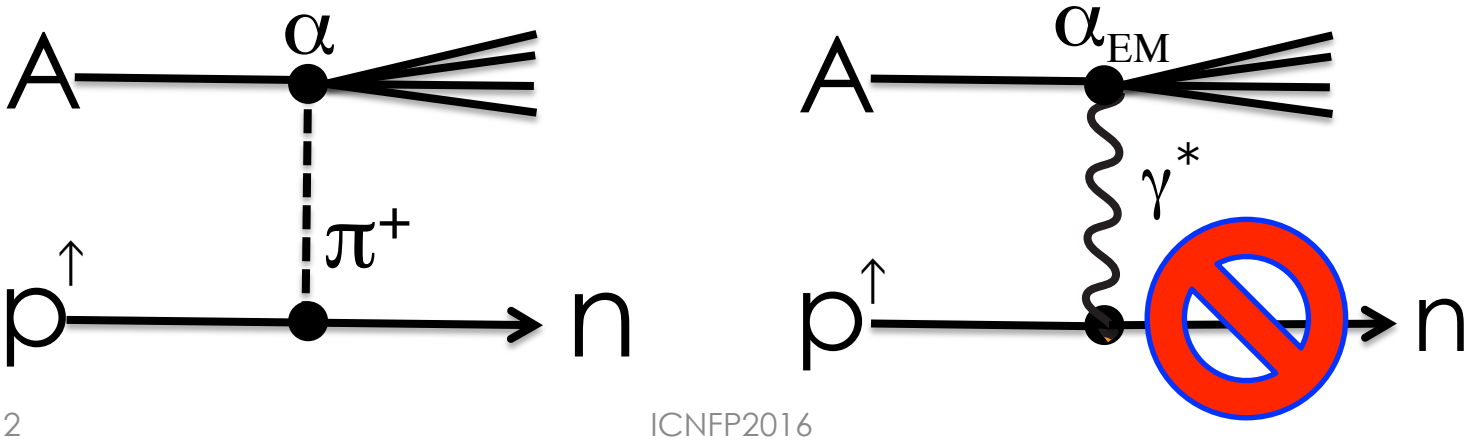


	# of proton	# of neutron
p	1	0
Al	13	14
Au	79	118

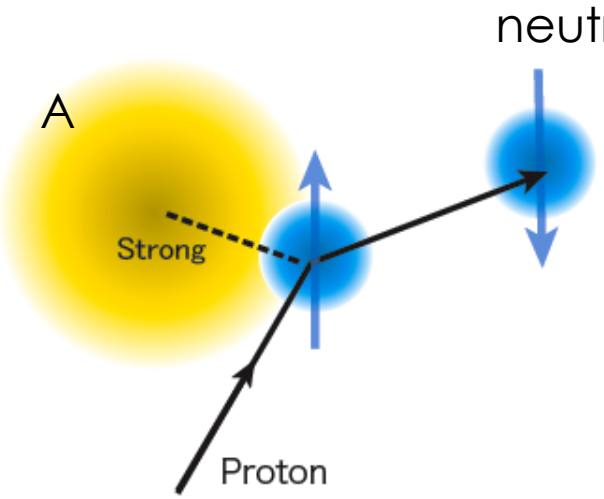
- Isospin Symmetry
- Surface Structure of Nucleus
- QED Process
- Gluon Saturation
- Else…

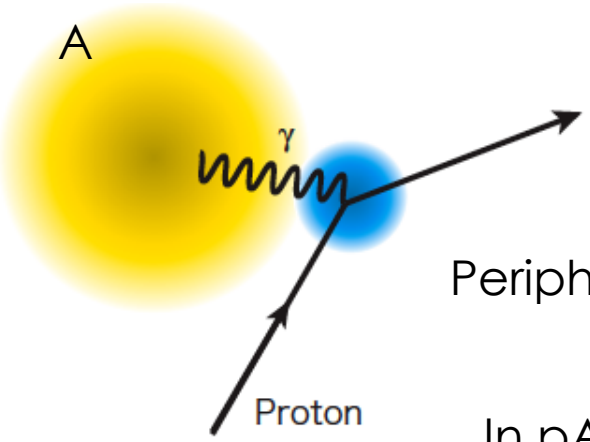
Electro-Magnetic Ultra Peripheral Collision (UPC)





Electro-Magnetic Ultra Peripheral Collision (UPC)



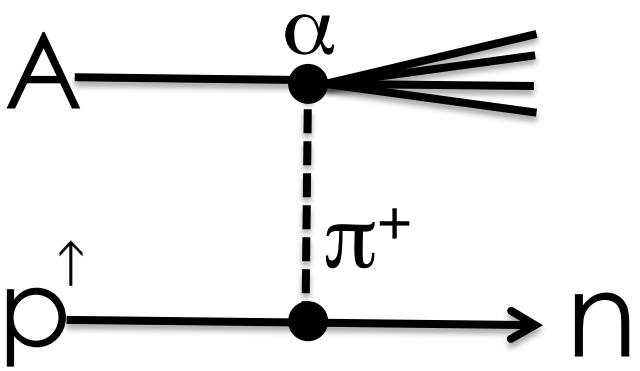


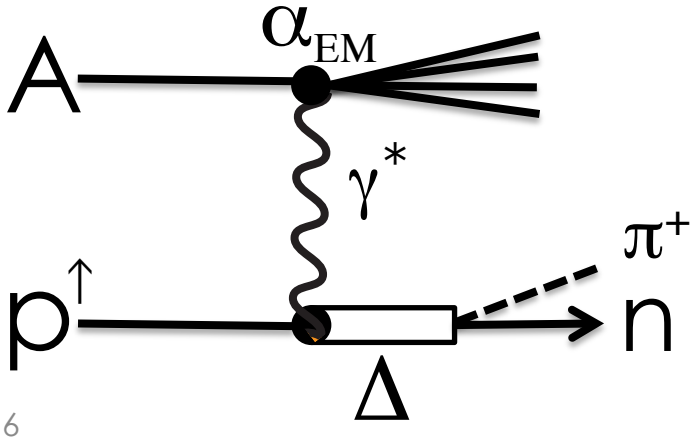
Peripheral

In pAu case

$t \rightarrow 0$

$Z \bullet \alpha_{EM} \sim 79/137$





Full Description of A_N

$$A_N \propto 2\,\mathrm{Im}\left\{\phi^*_{non-flip}\phi_{flip}\sin\delta\right\}$$

$$\phi_{flip} = \phi^{had}_{flip} + \phi^{EM}_{flip}$$

$$\phi_{non-flip} = \phi^{had}_{non-flip} + \phi^{EM}_{non-flip}$$

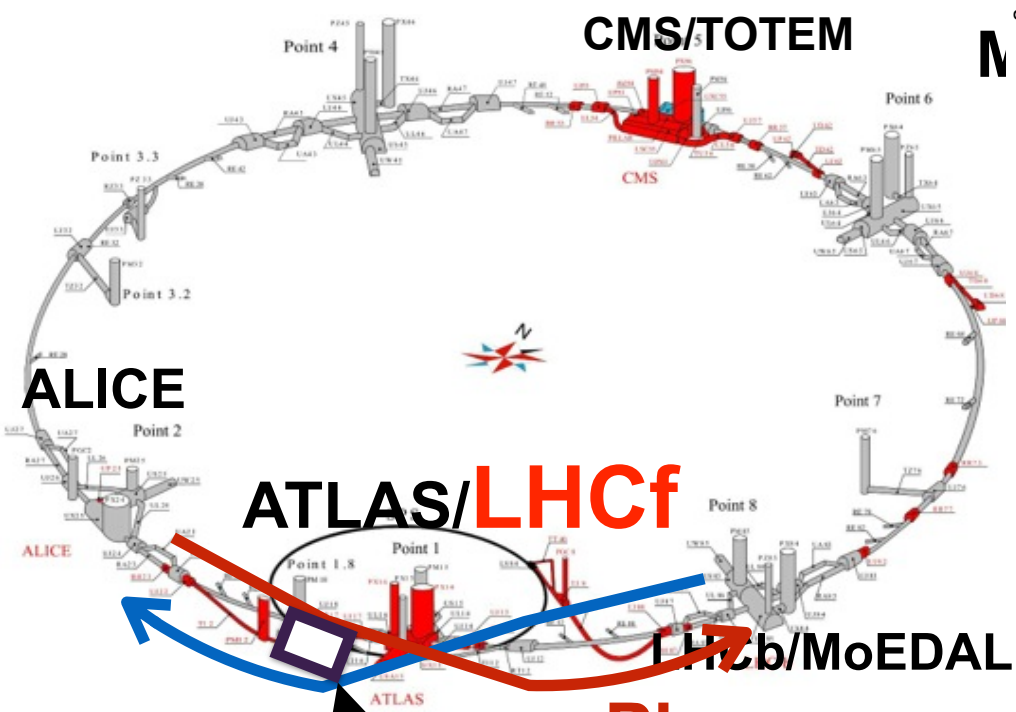
$\Delta_{1\sim4}$: relative phase of amplitudes

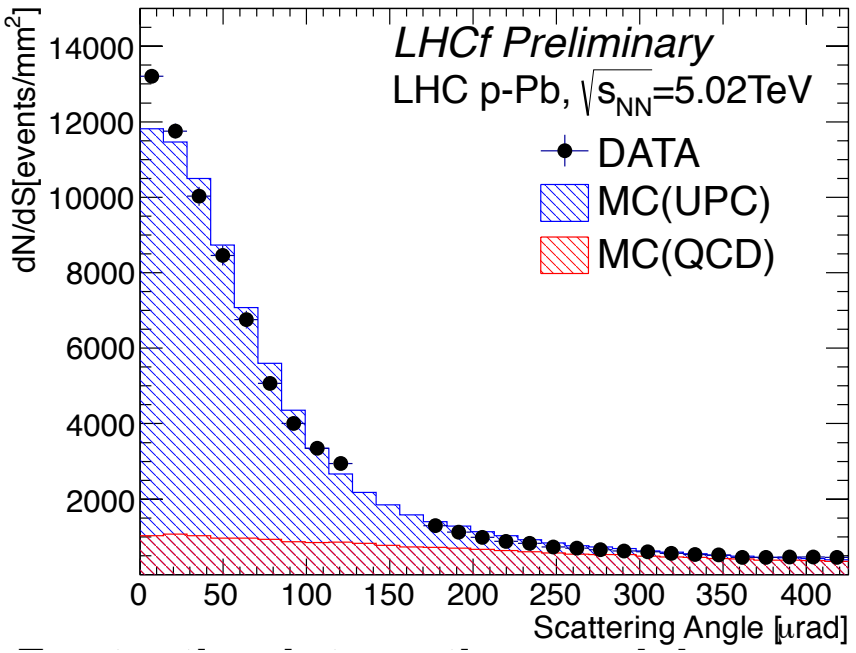
$$A_N \propto 2\,\mathrm{Im}\left(\phi^{had}_{non-flip} + \phi^{EM}_{non-flip}\right)\left(\phi^{had*}_{flip} + \phi^{EM*}_{flip}\right)$$

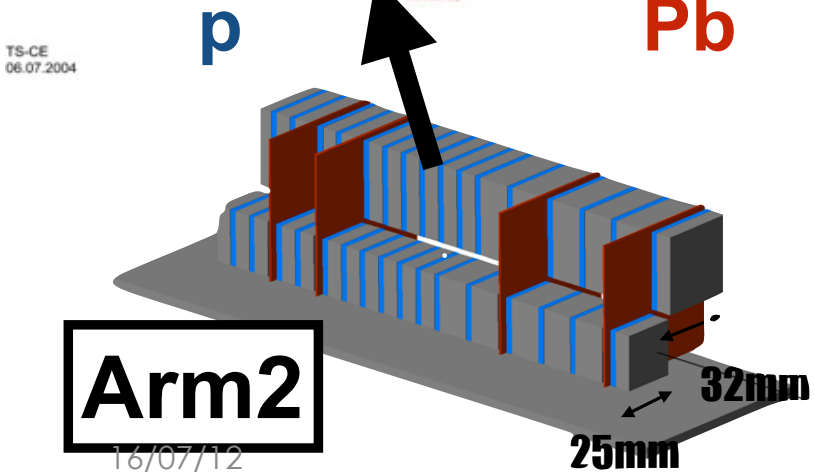
$$= 2\left(\phi^{had}_{non-flip}\phi^{had}_{flip}\sin\delta_1 + \phi^{EM}_{non-flip}\phi^{had}_{flip}\sin\delta_2 + \phi^{had}_{non-flip}\phi^{EM}_{flip}\sin\delta_3 + \phi^{EM}_{non-flip}\phi^{EM}_{flip}\sin\delta_4\right)$$

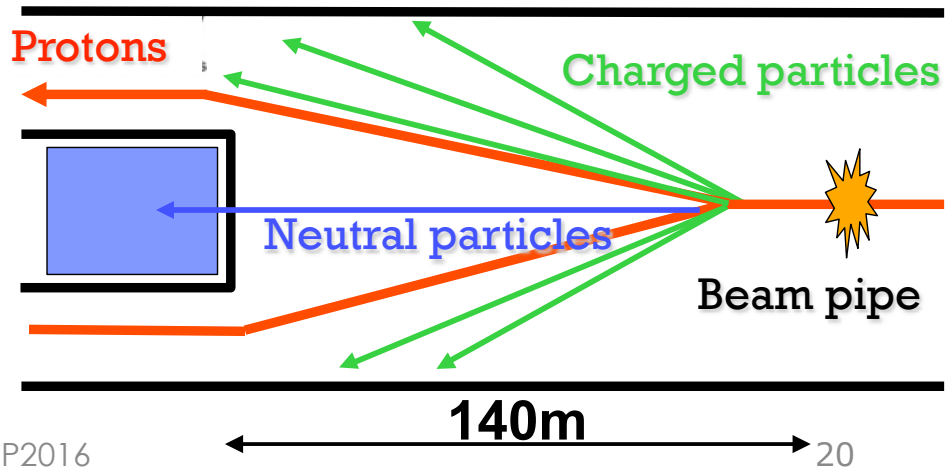
$\rightarrow 0$ (For pp)

The LHCf experiment









UPC Monte Carlo

Eur. Phys. J. C (2015) 75:614
DOI 10.1140/epjc/s10052-015-3848-0

THE EUROPEAN PHYSICAL JOURNAL C

Special Article - Tools for Experiment and Theory

Forward hadron production in ultra-peripheral proton–heavy-ion collisions at the LHC and RHIC

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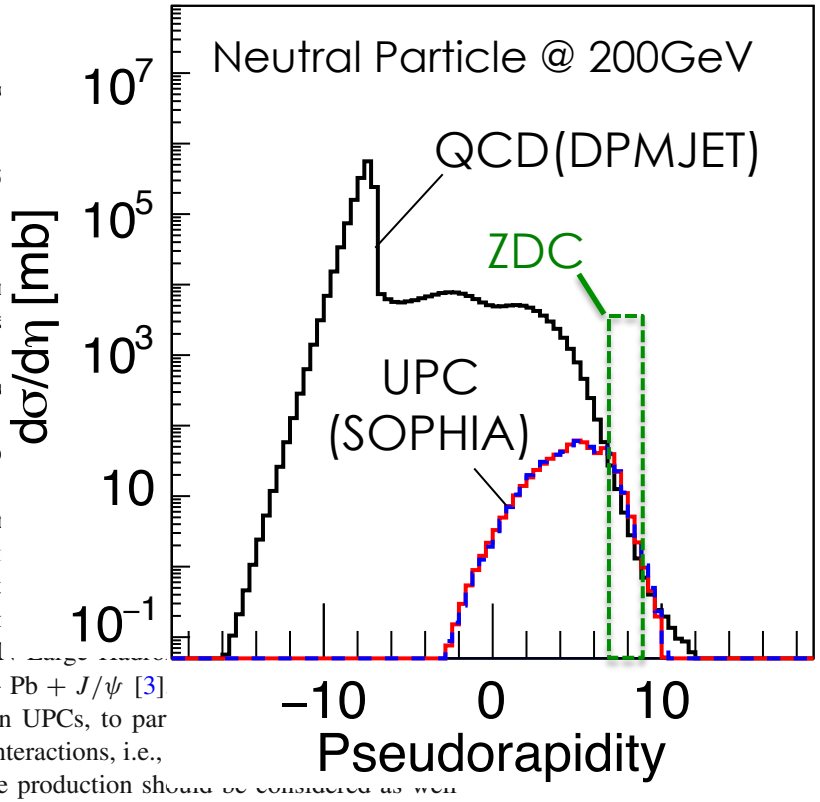
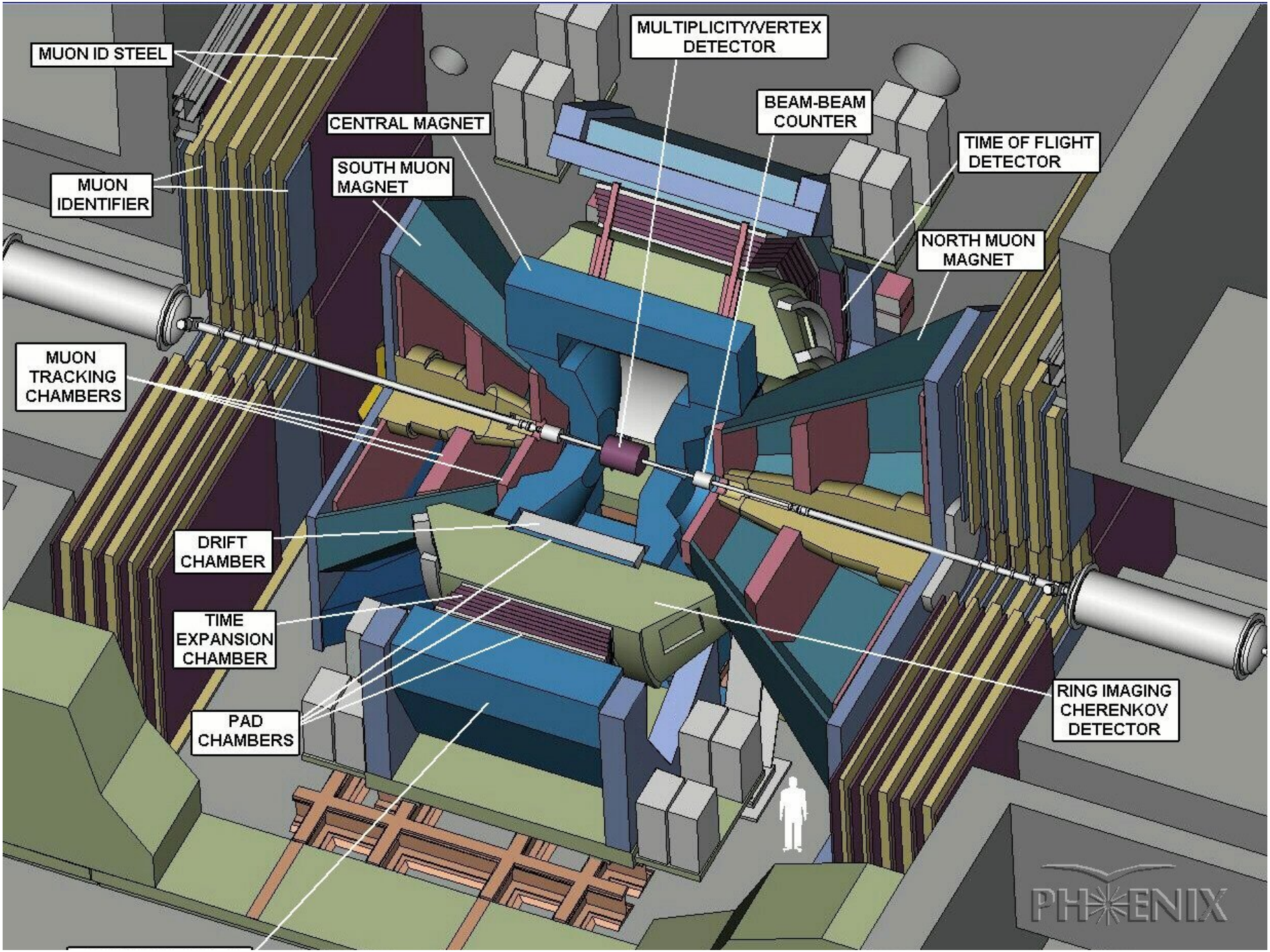
Abstract We present a hadron production study in the forward rapidity region in ultra-peripheral proton–lead (p+Pb) collisions at the LHC and proton–gold (p + Au) collisions at RHIC. The present paper is based on the Monte Carlo simulations of the interactions of a virtual photon emitted by a fast moving nucleus with a proton beam. The simulation consists of two stages: the STARLIGHT event generator simulates the virtual photon flux, which is then coupled to the SOPHIA, DPMJET, and PYTHIA event generators for the simulation of particle production. According to these Monte Carlo simulations, we find large cross sections for ultra-peripheral collisions particle production, especially in the very forward region. We show the rapidity distributions for charged and neutral particles, and the momentum distributions for neutral pions and neutrons at high rapidities. These processes lead to substantial background contributions to the investigations of

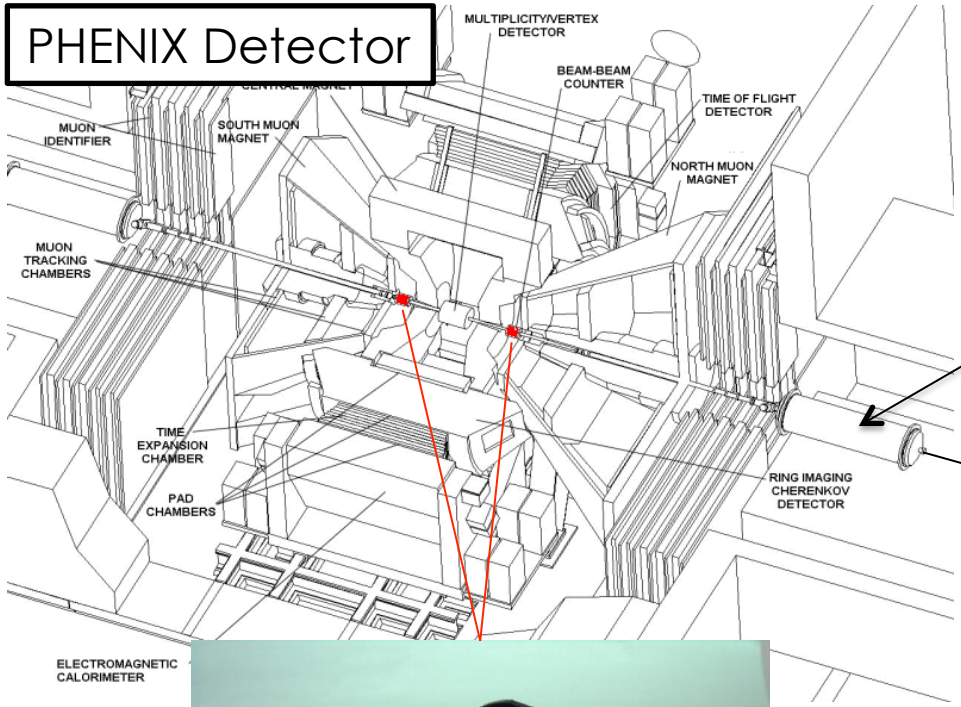


Predicts comparable yields between QCD and UPC processes


MUON ID STEEL
MULTIPLICITY/VERTEX DETECTOR
BEAM-BEAM COUNTER
CENTRAL MAGNET
TIME OF FLIGHT DETECTOR
SOUTH MUON MAGNET
MUON IDENTIFIER
NORTH MUON MAGNET
MUON TRACKING CHAMBERS
DRIFT CHAMBER
TIME EXPANSION CHAMBER
RING IMAGING CHERENKOV DETECTOR
PAD CHAMBERS
PHENIX

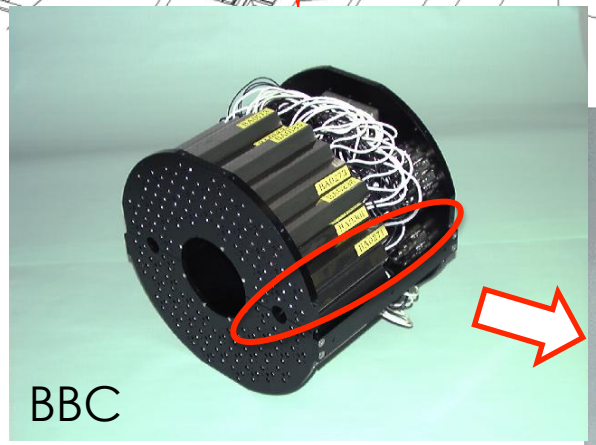
Beam-Beam Counter

PHENIX Detector



Dipole Bending Magnet

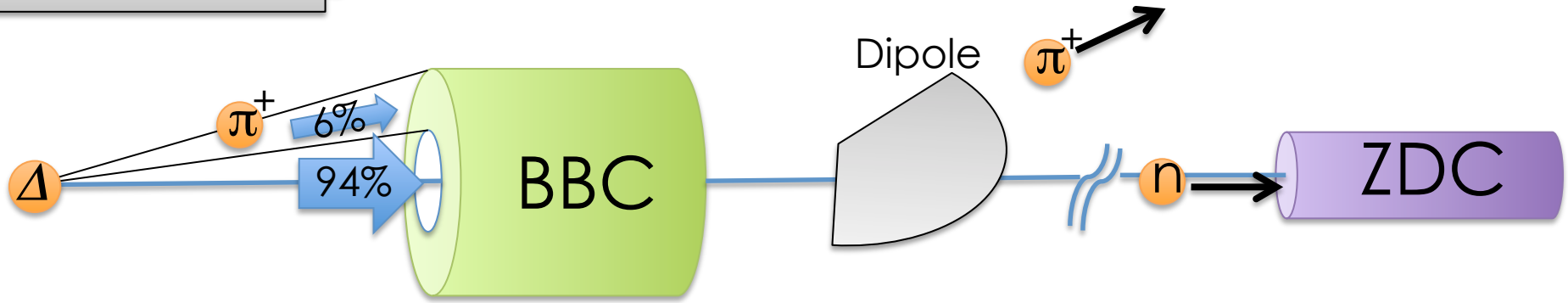
ZDC



Quartz Cherenkov radiator

Can we identify UPC events?

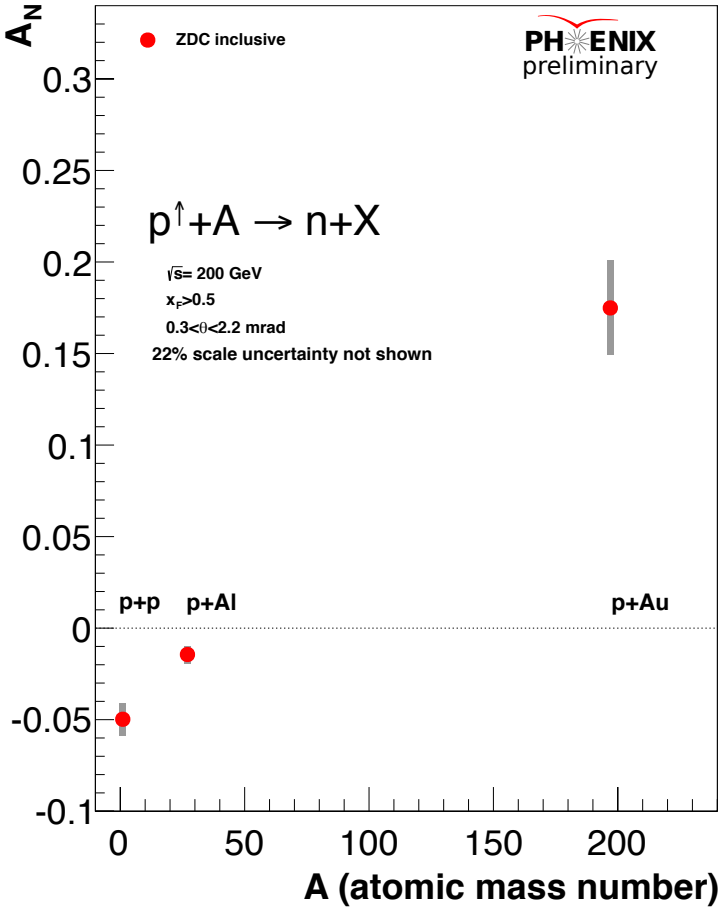
Semi-Inclusive



UPC MC : SOPHIA
G. Mitsuka, Eur. Phys. J.C. (2015) 75:614

BBC	tag	veto
UPC	Small	Large

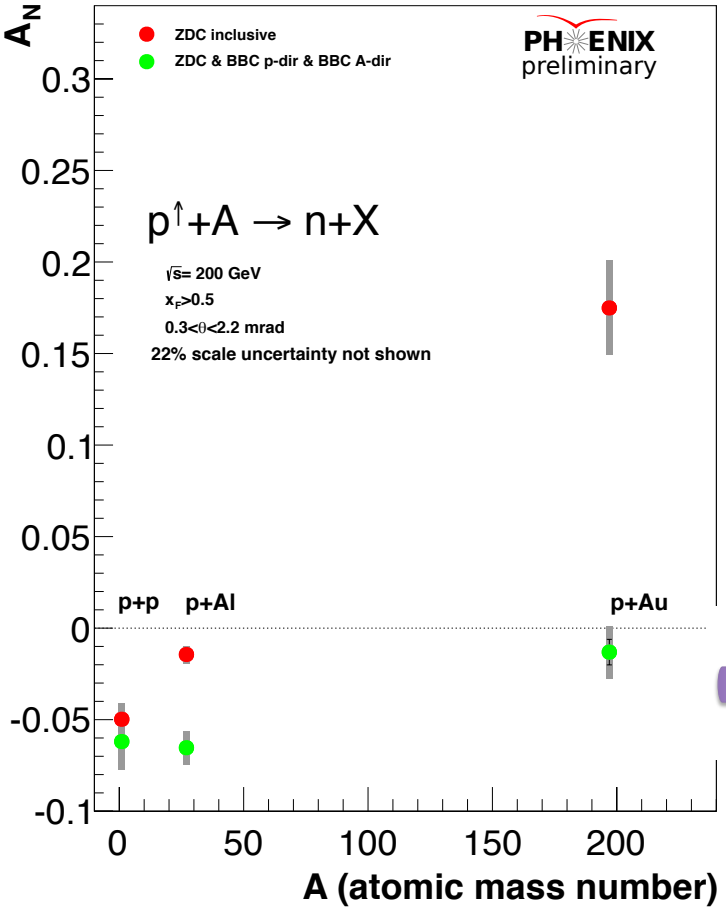
BBC Tagging and Vetoing

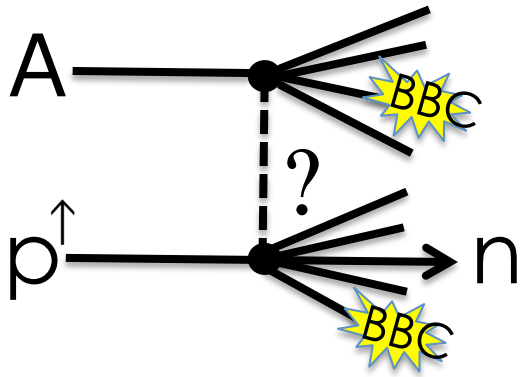


Inclusive

$$A_N \sim had * had + had * EM + EM * had + EM * EM$$

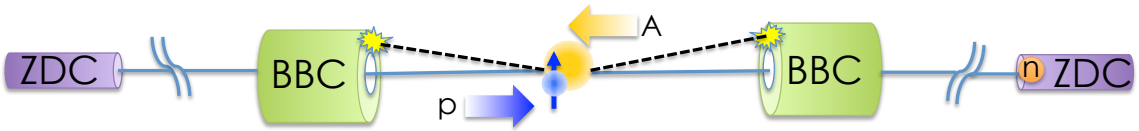
BBC Tagging and Vetoing





Non-diffractive

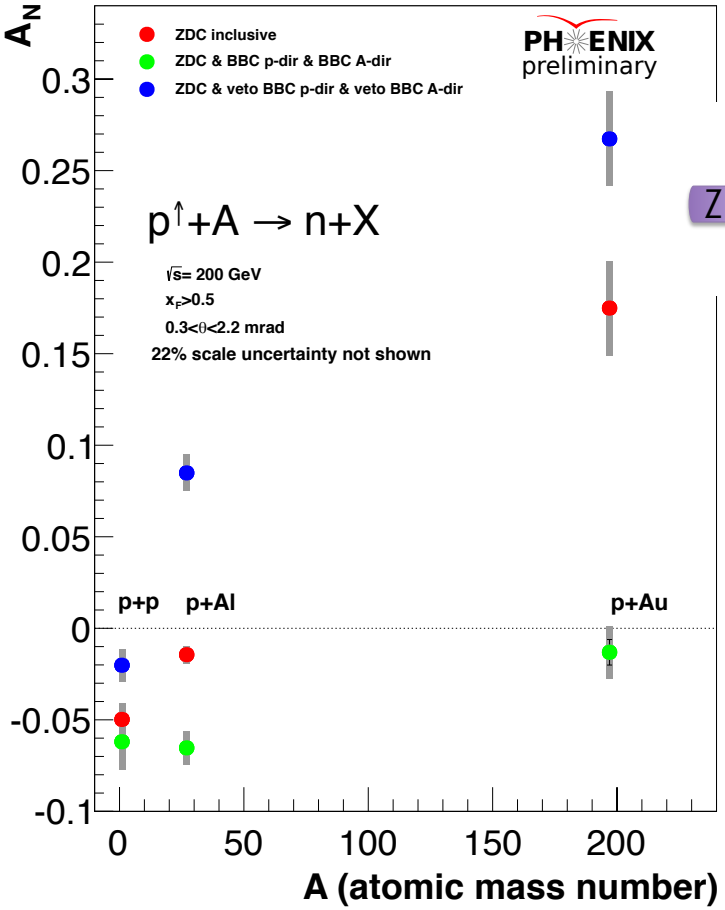
BBC Tagging



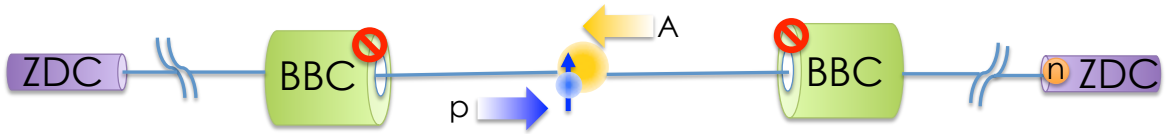
EM surpressed

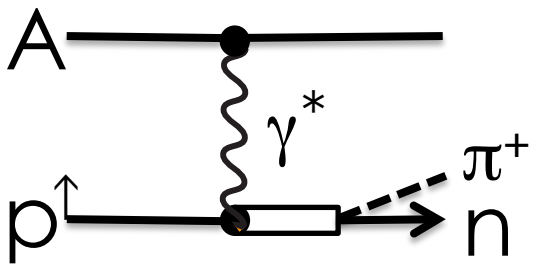
$$A_N \sim \boxed{had * had} + had * EM + EM * had + EM * EM$$

BBC Tagging and Vetoing



BBC Vetoing





Diffractive

EM enhanced

$$A_N \sim had * had + \underbrace{had * EM + EM * had + EM * EM}$$

Summary

- Diffractiveness seems to play a key role in A(Z)-dependent A_N.
- EM process tends to be diffractive due to large impact parameter.
- interaction or/and EM*hadronic interference may cause large positive A_N in large A.
- Hadronic Interaction likely to keep negative A_N between p+p and p+A.