Very forward neutron in pp and pA collisions

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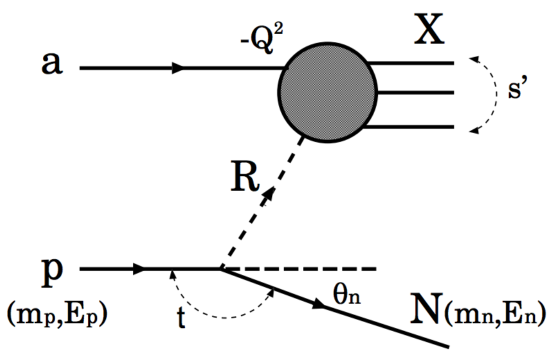
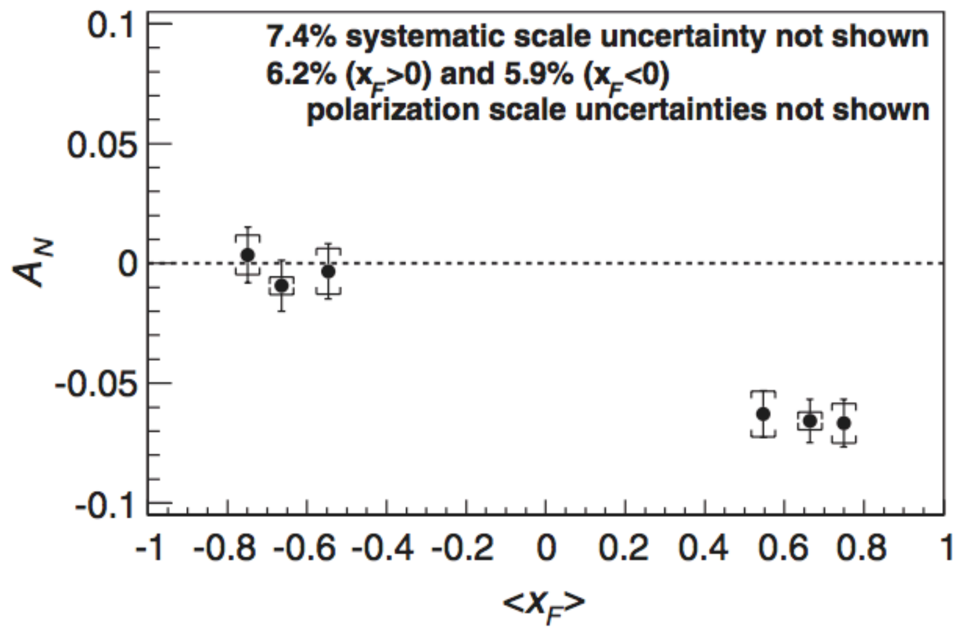
Large A_N for very forward neutron

A_N : Transverse Single Spin Asymmetry

$$A_N \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$





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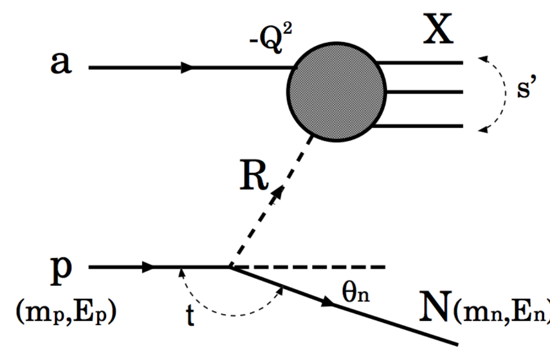
Nonzero A_N

$p^{\uparrow}a \rightarrow nX$



$$A_N \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} = \frac{\sum_X |< nX|T|\uparrow>|^2 - \sum_X |< nX|T|\downarrow>|^2}{\sum_X |< nX|T|\uparrow>|^2 + \sum_X |< nX|T|\downarrow>|^2}$$

Using $|\uparrow> = \frac{1}{\sqrt{2}}(|+> +i|->)$, $|\downarrow> = \frac{1}{\sqrt{2}}(|+> -i|->)$

$$\sum_X |< nX|T|\uparrow>|^2 - \sum_X |< nX|T|\downarrow>|^2 = -2Im \sum_X < nX|T|-><+|T^{+}|nX>$$

$A_N \neq 0$ if there is a nonzero term for

<u>Interference between spin-flip and nonflip interaction with different phase</u>

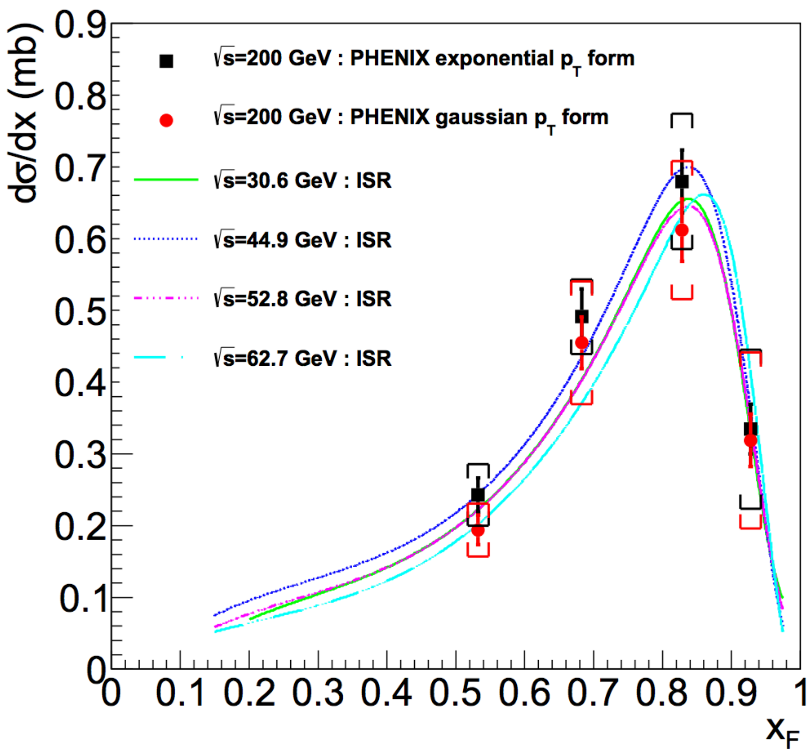
Theory for very forward neutron $p^{\uparrow}a \rightarrow nX$

- Non-perturbative ($p_T < 0.22$GeV at PHENIX Zero Degree) -> pQCD not applicable
- There are theories to describe cross-section, and A_N of very forward neutron production : One Pion Exchange model in Regge framework explain pp collision data well.

One Pion Exchange model

Approach	Cross section description	A_N description	Details
1. π exchange with Born approximation	• Overshoots data • Describe peak at $x_F \cong 0.8$	0	• π pole at wave function $\frac{1}{m_\pi^2 - t}$ -> peak at $x_F \cong 0.8$ (agree with data) • No phase shift
2. π exchange with absorptive correction	• Agree with data	Nonzero, but smaller than observed value	• Survival probability multiplied to final state function -> suppressed cross section
3. π exchange + Interference between π and a_1 Reggeon	• Agree with data	Agree with data	• π vertex : spin-flip & nonflip • a_1 vertex : nonflip • a_1 form factor is not known. A model is applied for this calculation.

Experimental results



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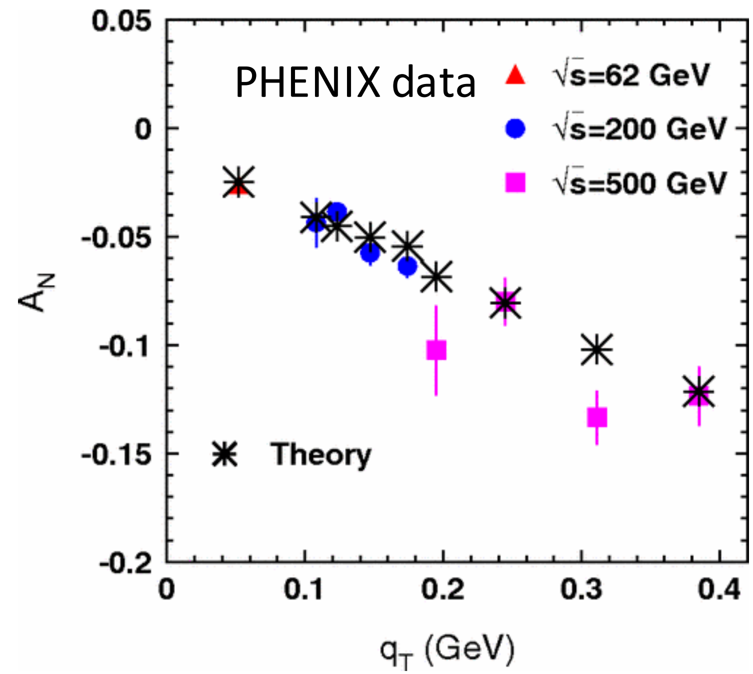
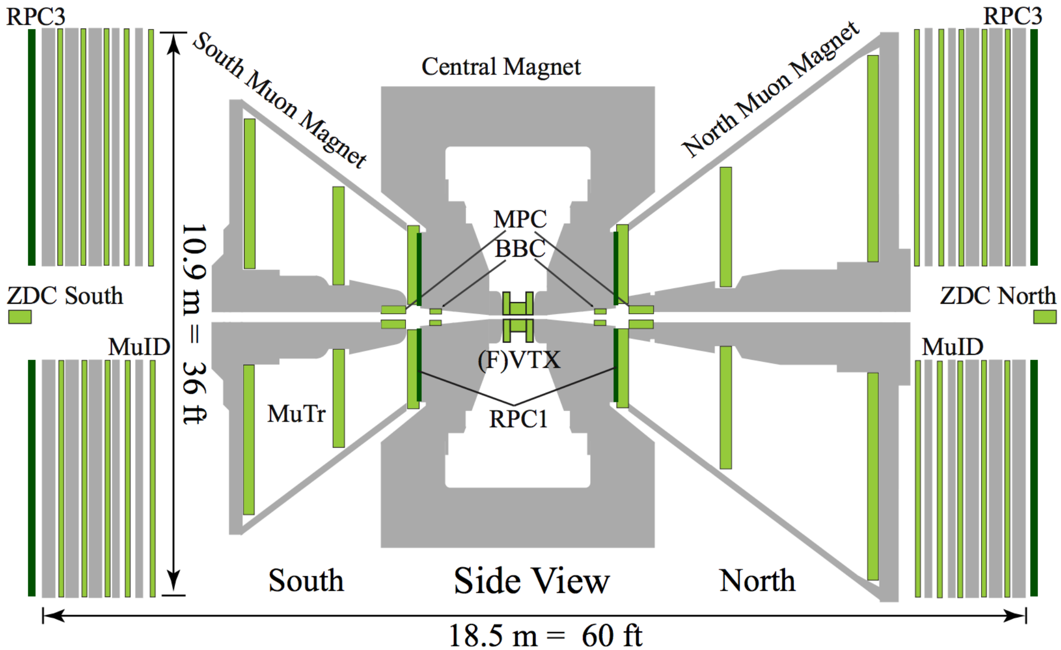
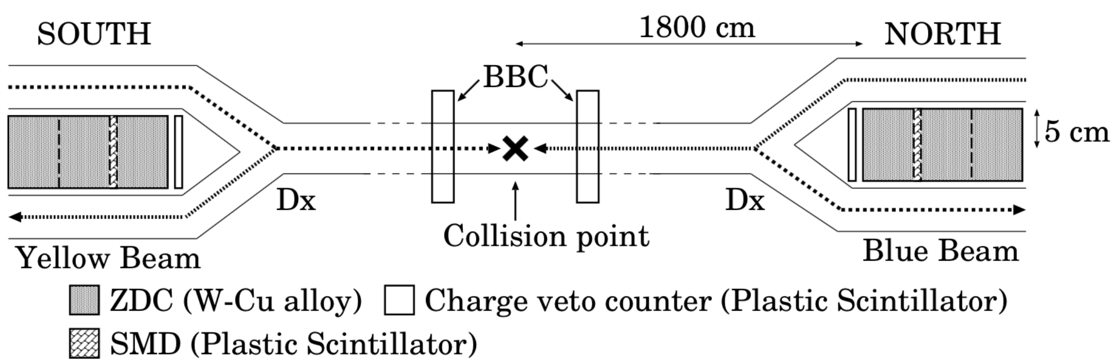
peak at $x_F \cong 0.8$



Phys. Rev. D **84**, 114012 (2011)

A_N measurement - Detectors



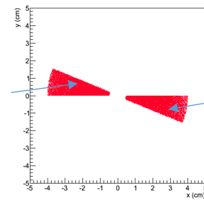


- Zero Degree Calorimeter
- Shower Max Detector
- Charge veto counters

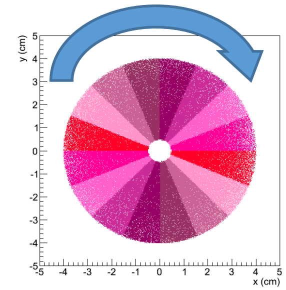
A_N measurement - Analysis

$$A_N = \frac{\sigma_L^{\uparrow} - \sigma_L^{\downarrow}}{\sigma_L^{\uparrow} + \sigma_L^{\downarrow}} = \frac{\sigma_R^{\downarrow} - \sigma_R^{\uparrow}}{\sigma_R^{\downarrow} + \sigma_R^{\uparrow}} = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}} = \frac{\sqrt{\sigma_L^{\uparrow}\sigma_R^{\downarrow}} - \sqrt{\sigma_L^{\downarrow}\sigma_R^{\uparrow}}}{\sqrt{\sigma_L^{\uparrow}\sigma_R^{\downarrow}} + \sqrt{\sigma_L^{\downarrow}\sigma_R^{\uparrow}}}$$

$N_\phi^{\uparrow}, N_\phi^{\downarrow}$



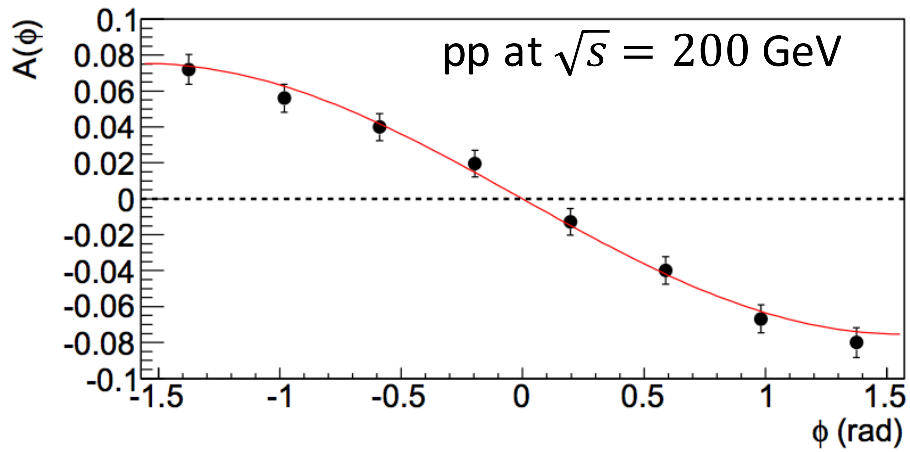
$N_{\pi-\phi}^{\downarrow}, N_{\pi-\phi}^{\uparrow}$



Measured value:

$$e_N(\phi) \equiv \frac{\sqrt{N_\phi^{\uparrow} N_{\pi-\phi}^{\downarrow}} - \sqrt{N_\phi^{\downarrow} N_{\pi-\phi}^{\uparrow}}}{\sqrt{N_\phi^{\uparrow} N_{\pi-\phi}^{\downarrow}} + \sqrt{N_\phi^{\downarrow} N_{\pi-\phi}^{\uparrow}}}$$

$$A_N(\phi) = \frac{e_N(\phi)}{P}\frac{1}{C_\phi}$$



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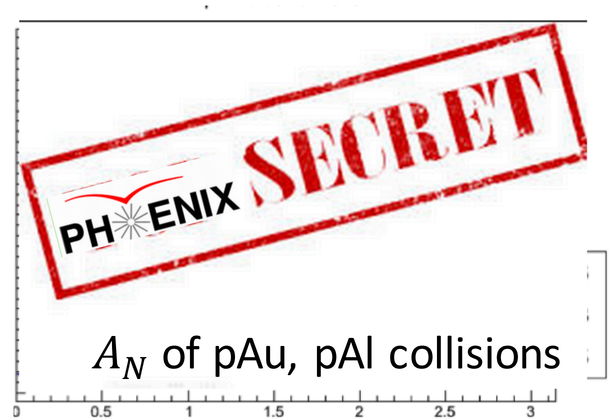
One Pion Exchange model – Does it work for pA?

- pp, pAu, & pAl collisions at $\sqrt{s} = 200$ GeV in RHIC, 2015
- Interesting A dependence of A_N is observed. Analysis for pAu, & pAl data is ongoing.
- No theoretical prediction is made for pAl, pAu before the experiment. Theoretical challenge to apply their framework to pA case has started.

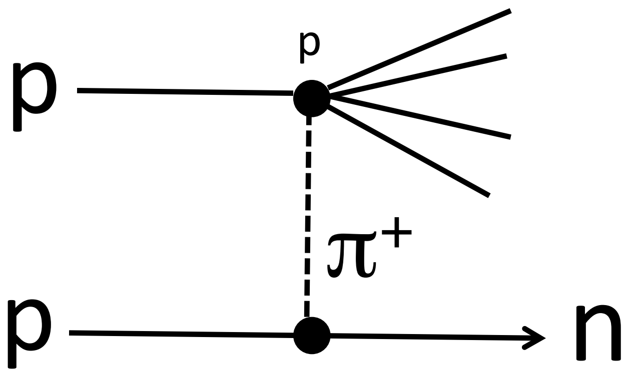


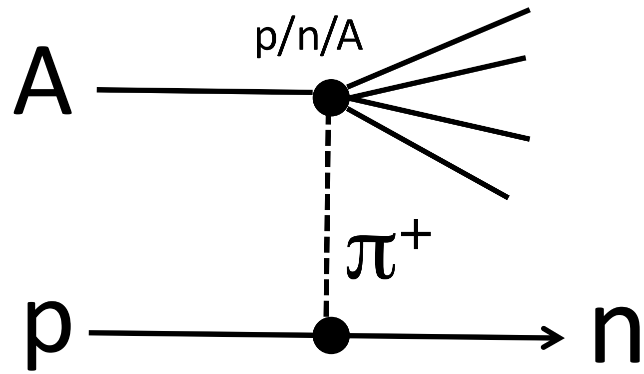
A_N of pAu, pAl collisions

Major theoretical development?

- Any isospin effect taken account for neutron?
- Coherent effect?

What do we learn from pAl, pAu A_N?





	# of proton	# of neutron	A
p	1	0	1
Al	13	14	27
Au	79	118	197

- It is well known interference between π and a_1 Reggeon plays important role in A_N^{pp}.
- Comparing A_N^{pp}, A_N^{pAl} and A_N^{pAu} may give hint if A_N depends on A (coherent effect) or # of neutron (isospin effect).

From Itaru's slide

Summary

- Large A_N of very forward neutron is observed.
- Cross section, and A_N of PHENIX pp collision are well described by π exchange and interference between π and a_1 Reggeon in Regge framework.
- Interesting A dependence of A_N is observed for pAu, & pAl data. Analysis for pAu, & pAl data is ongoing
- No theoretical prediction is made for pAl, pAu before the experiment. Theoretical challenge to apply their framework to pA case has started.