Single spin asymmetries of forward neutron production in polarized p+p and p+A collisions at  $\sqrt{s}=200$  GeV

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## Introduction

• Very forward neutron production in pp collision



high-energy, yet pQCD is useless (pT < 0.1 GeV/c)

#### • Mechanism?

- Regge theory?
- Pion exchange?
- Pomeron exchange & decay?
- Other reggeons?



#### Forward n cross section



OPE models seem OK. How about A<sub>N</sub>?

# How $A_N$ is produced?

• Need both helicity flip & non-flip amplitudes

$$|\uparrow/\downarrow\rangle = (|+\rangle \pm i|-\rangle)$$
$$\hat{a}_N = \frac{\hat{\sigma}^{\uparrow} - \hat{\sigma}^{\downarrow}}{\hat{\sigma}^{\uparrow} + \hat{\sigma}^{\downarrow}} \sim \frac{\mathrm{Im}\left(\mathcal{M}^{+*}\mathcal{M}^{-}\right)}{|\mathcal{M}^{+}|^2 + |\mathcal{M}^{-}|^2}$$

- In Regge theory
  - Pion exchange gives spin flip
  - Non flip?Other reggeons?
- Sensitive to mechanism



#### Past PHENIX result

#### **Inclusive neutron**



## **Comparison with model**



#### What's new

The first p<sup>+</sup>+A collision at  $\sqrt{s_{NN}} = 200 \text{ GeV}$ 



#### **PHENIX Experiment**



Pioneering High Energy Nuclear Interaction EXperiment

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## **Shower Maximum Detector**

- Arrays of plastic scintillators
- Position given as shower center
  - position resolution ~1cm @ 50GeV neutron



#### BBC

- Quartz Cherenkov counter
- 2 identical parts (BBC-north and -south)
- 64 segments each.
- Trigger on associated particles





## Result





## **Speculation**

- A<sub>N</sub> is still negative with BBC hits
  Or, large positive A<sub>N</sub> is seen only when there is no hit BBC
- p & A are not (badly) broken
  → Diffraction? common to pp Ultra-Peripheral Collision?



## **Coulomb-Nuclear Interference**



 $\gamma^*$  exchange and Reggeon exchange can interfere  $\rightarrow$  may give positive A<sub>N</sub>  $\gamma^*$  amplitude is proportional to Z  $\rightarrow$  significant for large Z



This gives negative A<sub>N</sub>, and those two do not interfere

## Todos – for further studies

- Cross section
  - Matches with UPC estimation?
  - Small  $p_T$  behavior?
- Sign of A<sub>N</sub>
  - Can γ\*/Reggeon interference produce positive A<sub>N</sub>?



- Any other mechanism?
  - We are discussing with theorists
  - Your inputs are welcome!

## Summary & Perspective

- Single spin asymmetry of forward n
  - The first measurement with (transversely) polarized proton with nuclei (AI and Au), in addition to p+p data.
- Surprising behavior of A<sub>N</sub> with A
  - Inclusive  $A_N(pAu) \sim -3xA_N(pp)$ ; opposite sign
  - Rather small dependence with BBC tagging
- Mechanism?
  - Hint from BBC tagging
  - We are suspecting contribution of Ultra-Peripheral collisions
  - To be quantitative? Other mechanisms?
    We are discussing with theorists
- Your inputs are welcome!

## Backup slides

# Why spin phenomena?

- Let's take single spin asymmetry  $A_N$  for example:
  - Left-right asymmetry (forward = beam direction, up = spin direction)

$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

• Interference of helicity flip & non-flip amplitudes  $|\uparrow / \downarrow\rangle = (|+\rangle \pm i|-\rangle)$ 

 $\hat{a}_N = \frac{\hat{\sigma}^{\uparrow} - \hat{\sigma}^{\downarrow}}{\hat{\sigma}^{\uparrow} + \hat{\sigma}^{\downarrow}} \sim \frac{\operatorname{Im}\left(\mathcal{M}^{+*}\mathcal{M}^{-}\right)}{|\mathcal{M}^+|^2 + |\mathcal{M}^-|^2}$ 

Left  
$$x_F < 0$$
  
 $x_F > 0$ 





#### The Relativistic Heavy Ion Collider accelerator complex at Brookhaven National Laboratory



## RHIC *p*+*p* accelerator complex



## Even more – BBC tagging

