Center for Frontiers in Nuclear Science

My background and plan for CFNS

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Work with : Abhay Deshpande

Stony Brook University

Outline

- My Background : experimental high energy nuclear physics (ALICE@LHC, STAR@RHIC : Texas A&M, Inst. Of Physics, India & NISER, India)
  - Analysis: SPIN physics, cold QCD at RHIC, jet structure studies @ RHIC
  - Detector : Photon Multiplicity Detector, Forward Meson Spectrometer, GEM-detector simulations
- Current experiment attached with
  - RHIC: PHENIX forward neutron transverse spin asymmetries
  - JLab12: Involvement with CREX/PREX
- Other possibilities under consideration next year
  - HERA data analysis for learning about EIC studies,
  - Involvement with forward PID detector RHIC+TOF for EIC, and
  - Physics simulations (probing spin/gluon density) for EIC

Overarching theme:
Transverse Momentum of Partons in hadrons

Transverse momentum distribution of partons seems to play an important role in all aspects of QCD

They affect the jet-correlations/properties and single spin asymmetries

I have studied them in p-p, p-A and polarized p-p scattering. In future I look forward to measuring in e-p and e-A at Jlab12 and the EIC.

Jet properties in pp and pAu at √s=200GeV

(My thesis work from VECC, Kolkata)

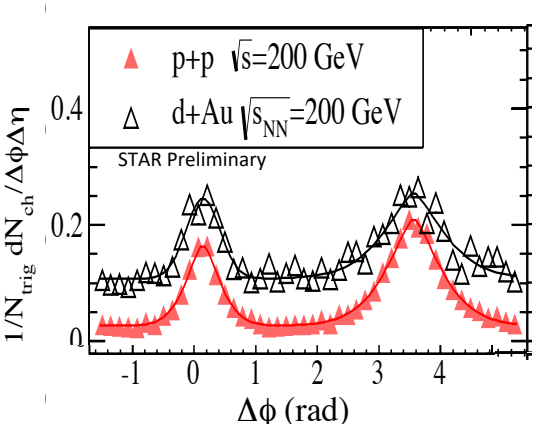
$$\frac{\langle p_T^2 \rangle_{pair}}{2} = \langle k_T^2 \rangle_{intrinsic} + \langle k_T^2 \rangle_{soft} + \langle k_T^2 \rangle_{NLO}$$

(used in event generator like PYTHIA) $f(k_{Ta}) = \frac{e^{-k_T^2/\langle k_T^2 \rangle}}{\pi \langle k_T^2 \rangle}$

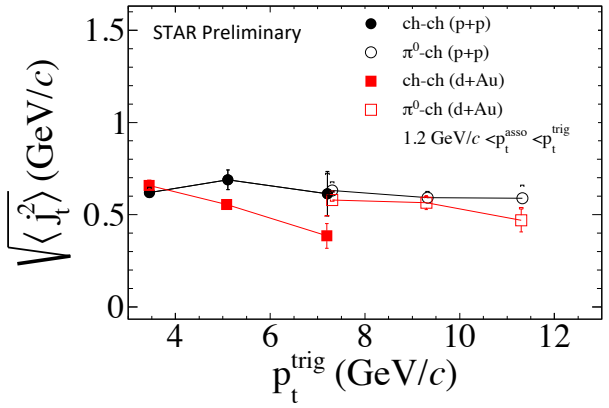
S.S. Adleret al., Phys. Rev. D74, 072002(2006)

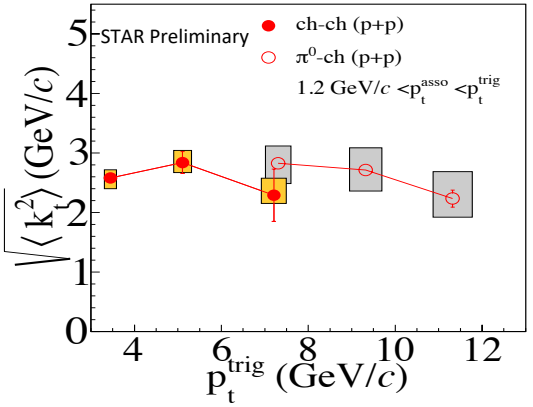
Jet Transverse Momentum : $\sqrt{\langle j_t^2 \rangle} = \sqrt{2}\frac{p_t^{asso} p_t^{trig}}{\sqrt{(p_t^{asso})^2 + (p_t^{trig})^2}}\sigma_N{}^2 \quad \hat{x}_h = \hat{p}_t^{asso}/\hat{p}_t^{trig}, \langle z_t \rangle = \langle p_t/\hat{p}_t \rangle, \text{ and } x_h = p_t^{asso}/p_t^{trig}$

Effective k_T partons : $\sqrt{\langle k^{s2}_t \rangle} = \frac{\langle z_t(k_t, x_h) \rangle \sqrt{\langle k_t^2 \rangle}}{\hat{x}_h(k_t, x_h)} = \frac{1}{x_h}\sqrt{\langle p_{out}^2 \rangle - \langle j_{ty}^2 \rangle (1 + x_h^2)} \quad p_{out} = p_t^{asso} sin\Delta\phi$



p_t (trigger) = 6.5-8.5 GeV/c
p_a (associated) = 1.2-1.7 GeV/c



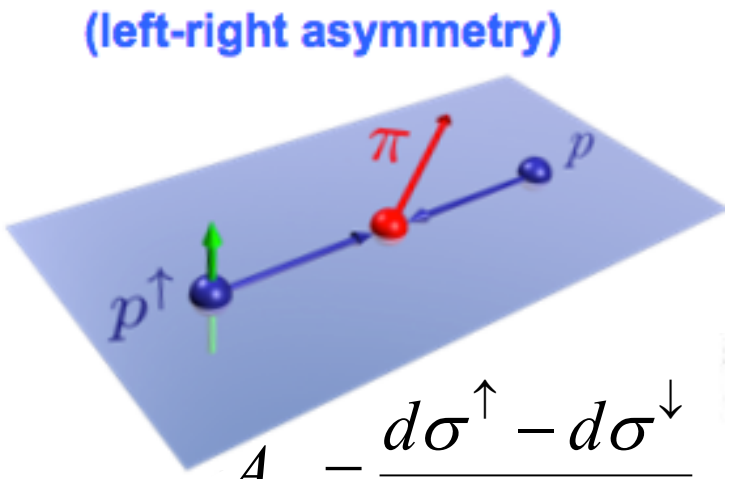


<k_T^2> : 2.77996 +/-0.0337597 [0.273589, -0.0469066] h-h
<k_T^2> : 2.59601 +/-0.084435 [0.119595, -0.0175883] π^0-h

k_T measurement of partons from di-hadron M. M Mondal [for STAR Collaboration] Int. J. Mod. Phys. E 20, 1656 (2011)

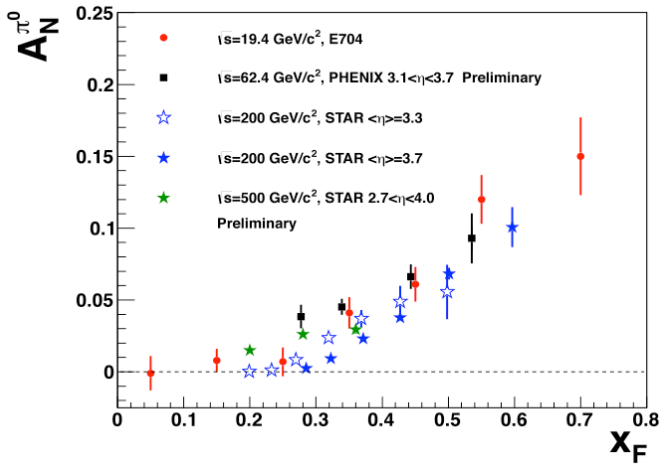
Transverse Single Spin Asymmetry

(My work at Texas A&M)



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

$$p_{\uparrow} + p \rightarrow \pi^0 + \bar{X}$$



- Rising A_N with X_F
- A_N nearly independent of √s
- **No evidence of fall in A_N with increasing P_T**

A standard framework : jets is inevitable for proper understanding

TMD - Sivers and Collins effect

D. Sivers, Phys. Rev. D **41**, 83 (1990)

Sivers effect : the correlation between the **transverse momentum (k_t)** of the struck quark and the **spin (S)** and **momentum (p)** of its parent nucleon

J. C. Collins, Nucl. Phys. **B396**, 161 (1993)

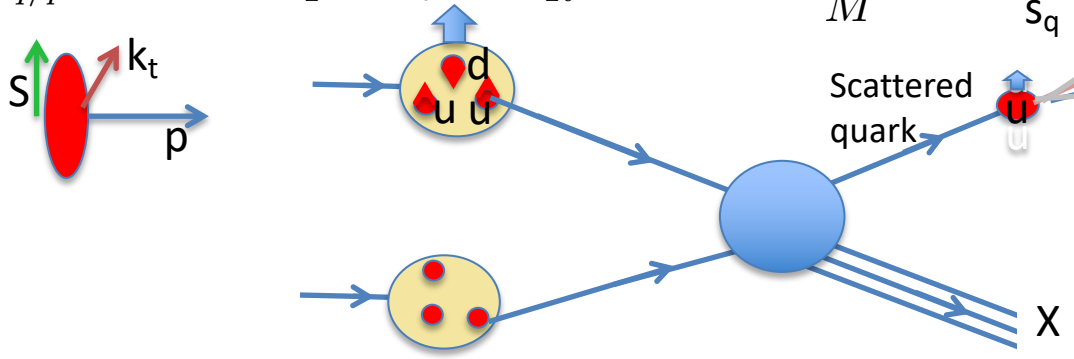
Collins effect :spin-momentum correlation in the hadronization process

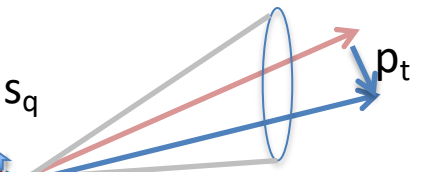
$$\mathbf{s_q} \cdot (\mathbf{k_q} \times \mathbf{p_t})$$

Fragmentation, ΔD^h_q

Sivers distribution

$$f_{q/p^\uparrow}(x, k_t) = f_1^q(x, k_t^2) - f_{1t}^{\perp q}(x, k_t) \frac{\mathbf{S} \cdot (\mathbf{k_t} \times \hat{\mathbf{p}})}{M}$$





s_q = spin fragmenting of quark
k_q = momentum direction of the quark
p_t = transverse momentum of hadron with respect to the direction of the fragmenting quark

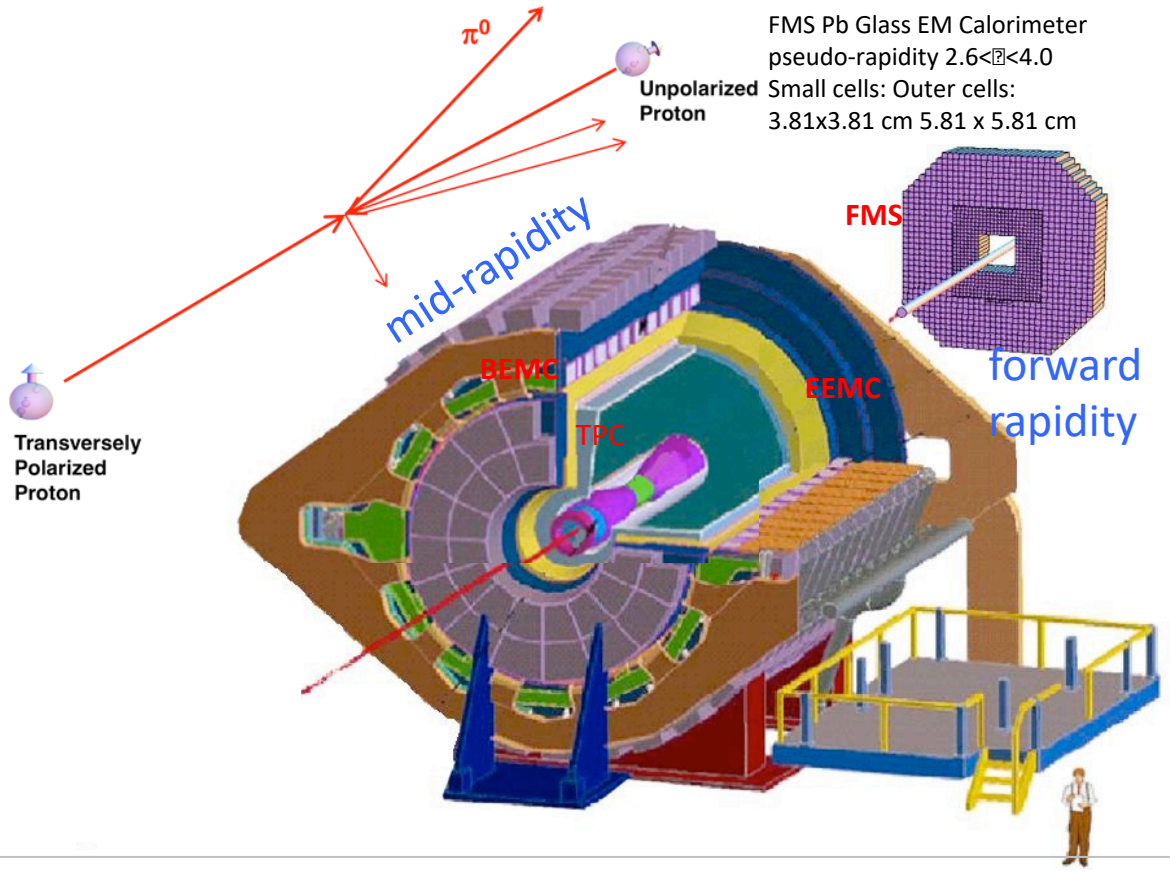
$$A_N = \propto \underbrace{\bar{f}_{1T}^{\perp q}(x, k_\perp^2)}_{\text{Sivers distribution}} \cdot D_q^h(z) \; + \; \propto \underbrace{\delta q(x)}_{\text{Quark transverse spin distribution}} \cdot \underbrace{H_1^\perp(z_2, \bar{k}_\perp^2)}_{\text{Collins FF}}$$

need to move beyond inclusive production

- Sivers effect : Full Jets, Direct photons, Drell-Yan
- Collins effect : azimuthal orientation of particles within a jet
- Separating Sivers and Collins effect

measurements from jets can give an access to Sivers effects

Forward ECAL in STAR

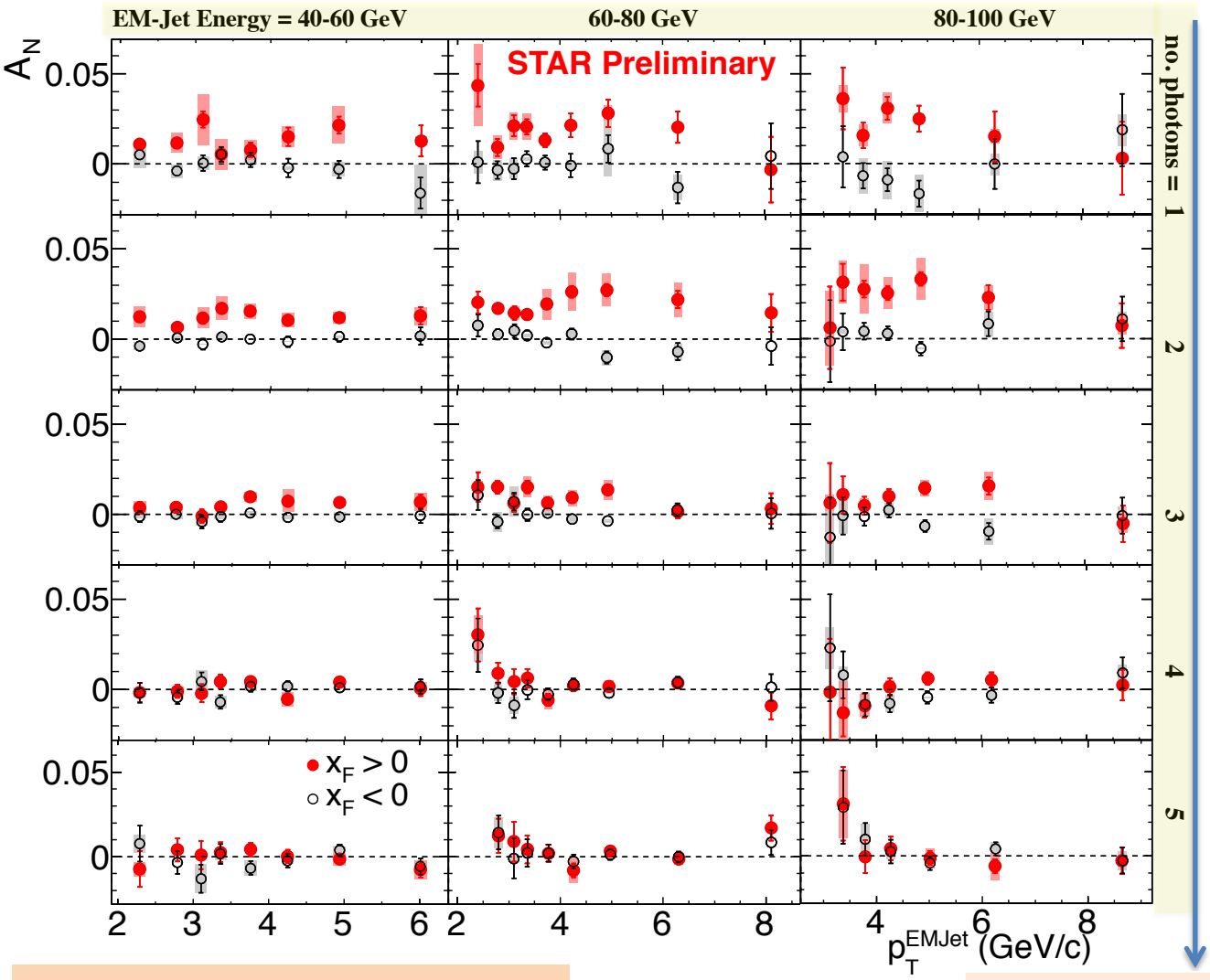


Forward Meson Spectrometer (FMS) :

- Pb glass EM calorimeter covering $2.6<\eta< 4.0$
- Detect π^0,**η, direct photons** and jet-like events in the kinematic region where transverse spin asymmetries are known to be large

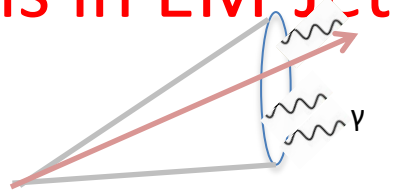
- FMS : A trigger detector : defined for **π^0/Jet-rich, Di-π^0/Jet-rich like triggers**

A_N for different multiplicities of photons in EM-Jets



M. M. Mondal [for STAR Coll.] PoS DIS 2014

Jettier events



- 1-photon events, which include a large π^0 contribution in this analysis, are similar to 2-photon events
- Three-photon jet-like events have a clear non-zero asymmetry, but substantially smaller than that for isolated π^0's
- A_N decreases as the event complexity increases (i.e., the "jettiness"
- A_N for #photons >5 is similar to that for #photons = 5

Conclusions from TSSA for EM jets

(Star publication under preparation)

- Jets with **isolated π^0 have large asymmetry**
- **A_N decreases as the event complexity increases**
- Isolated π^0 **asymmetries are smaller when there is a correlated EM-jet** at mid-rapidity

- **Both of these dependences raise serious question how much of the large forward π^0 A_N comes from 2 → 2 parton scattering**

Diffractive Events ??

Forward upgrade for the STAR experiment - necessary to have better understanding

- Roman pots – tagging diffractive events
- FMS upgrade : with Forward pre-shower detector (direct photons) and post-shower detector (Drell-Yan)
- In 2020's STAR plan to have tracking and full calorimetry to detect full jets in forward rapidity
- **New analysis :** EM-Jet correlations at forward rapidity – small x physics (underway), forward-mid-rapidity correlations - ridge studies

New initiatives since joining CFNS
(since 09/2019)

- PHENIX forward neutron transverse spin asymmetries : how the asymmetries depends on the Center of Mass Energy in p-p collisions
  - Why? Motivation? (p-A showed asymmetries for different A)
    - Mechanism being understood…
  - We provide more data: PHENNIX published 200 GeV: (PRL 120, 022001)
    - Measure asymmetry for 62.4 and 500 GeV. x_F and p_T dependence.

- SBU current activities: CREX/PREX at Jlab
  - electron-proton experiment at JLab12 (see details in Ciprian Gal's talk)

Other studies under consideration:

- HERA data analysis : Jets and understanding final states – What we can learn for the EIC?

- SBU's emerging involvement with forward PID detector RICH+TOF for EIC – One of the difficult unsolved problems for the EIC.

- Physics/detector simulations (probing spin/gluon density/jet structure) for EIC

Summary

- My experience spin physics, jets in p-p, p-A scattering at RHIC. In addition experience with work with detectors for ALICE & RHIC.

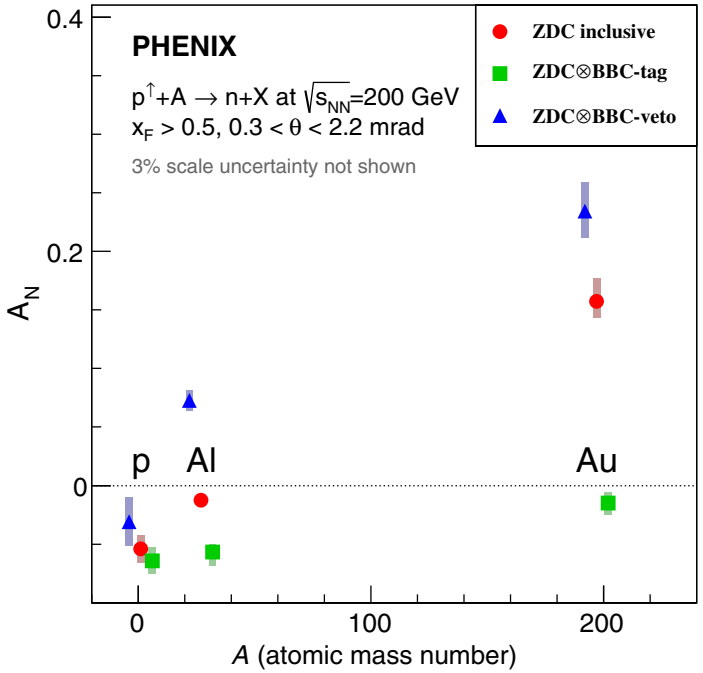
- Current activities include PHENIX data analysis and CREX/PERX -- operations

- Exploring new directions: data from HERA and like to get started with EIC detector and simulations

backup

Nuclear Dependence of the Transverse-Single-Spin Asymmetry for Forward Neutron Production in Polarized p + A Collisions at sNN = 200 GeV

(PRL 120, 022001)



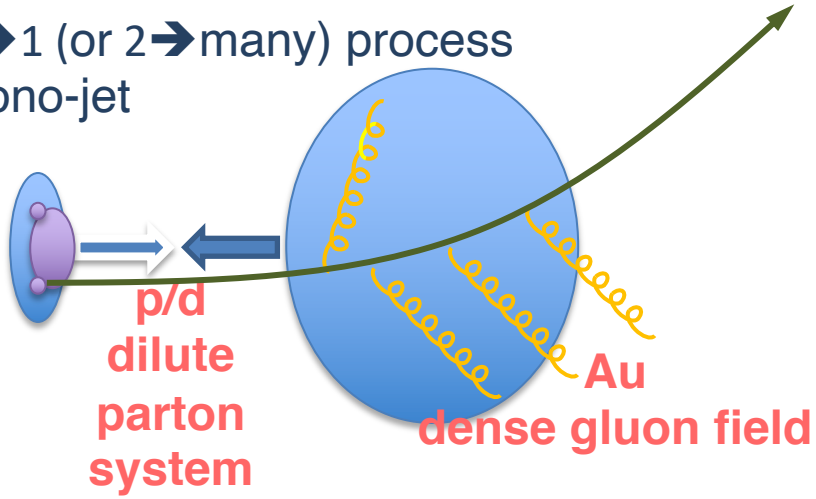
Production cross sections: were successfully explained in terms of one-pion exchange

Asymmetry: an interference between the spin-flip π exchange and a non- spin-flip a1 -Reggeon exchange was necessary

- observed an unexpectedly strong A dependence in A_N of inclusive forward neutron production in polarized p-A
- a distinctly different behavior of AN was observed in two oppositely trigger-enhanced data sets: ZDC ⊗ BBC-tag and ZDC ⊗ BBC-veto
- explained by a contribution of EM interactions, which may be sizable for heavy nuclei

Back-to-back angular correlations at RHIC

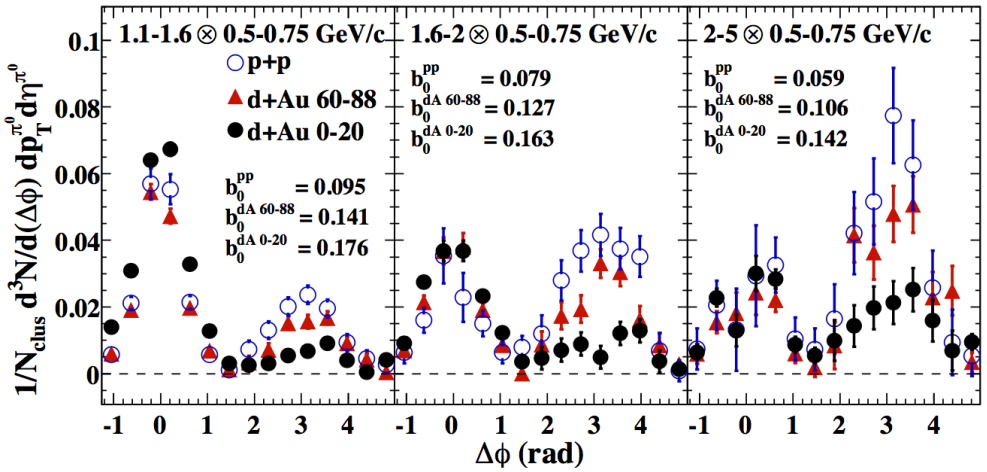
2➔1 (or 2➔many) process
Mono-jet



Kharzeev, Levin, McLerran (NPA748, 627)

Jet Azimuthal Correlation : Suppression

PHENIX, PRL 107, 172301



CGC predicts suppression of the away-side peak.
PHENIX observed suppression of the away-side peak in 0-20% d+Au collisions at (√s = 200 GeV)

STAR 2015 data are being analyzed for π^0- π^0 and EM jet – EM jet azimuthal correlations in p+p, p+Al, p+Au at √s = 200 GeV : Ongoing Working on FMS gain uniformity and stability

Jet-lke azimuthal correlations in p+p and p+Au collisions at forward rapidity with STAR Light Cone 2017 : M. M. Mondal for STAR Collaboration