

Di-hadron correlations in pp and pA collisions at STAR

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(For the STAR Collaboration)
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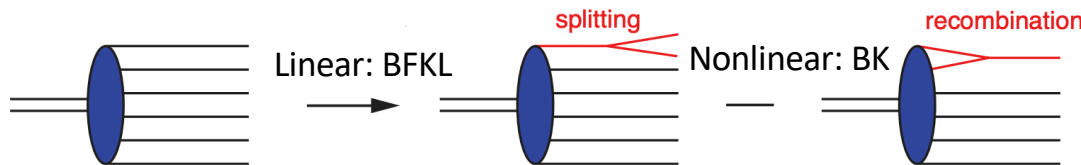


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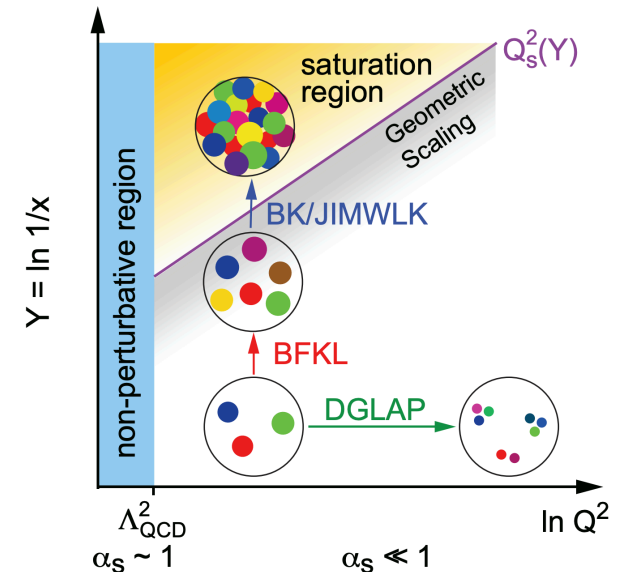
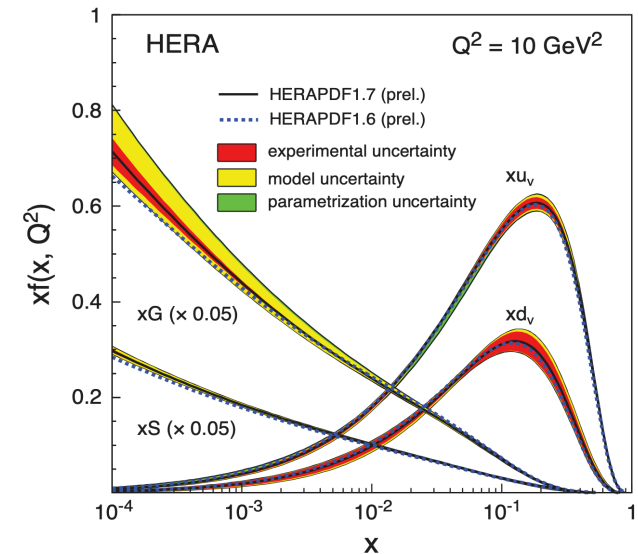
Gluon dynamics at small x

- **Parton Distribution Functions**: at small x, nucleon wave function is dominated by gluons; the rise of gluon density has to stop at some point → saturation
- Saturation scale Q_s^2 : when $Q^2 < Q_s^2$, gluon splitting and recombination reach a balance
- Gluon dynamics changes from linear to **non-linear**: DGLAP/BFKL → BK/JIMWLK
- Large Q: small $\alpha_s \rightarrow$ perturbative QCD calculations under control



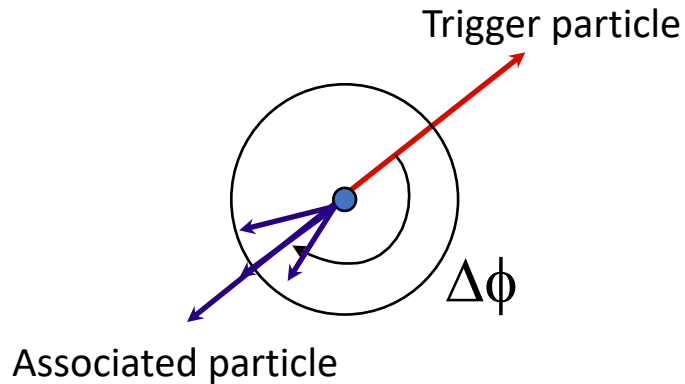
$$\text{BFKL: } \frac{\partial N(x, r_T)}{\partial \ln(1/x)} = \alpha_s K_{\text{BFKL}} \otimes N(x, r_T); \quad N \sim (1/x)^\lambda$$

$$\text{BK: } \frac{\partial N(x, r_T)}{\partial \ln(1/x)} = \alpha_s K_{\text{BFKL}} \otimes N(x, r_T) - \alpha_s [N(x, r_T)]^2$$



Multiple scattering

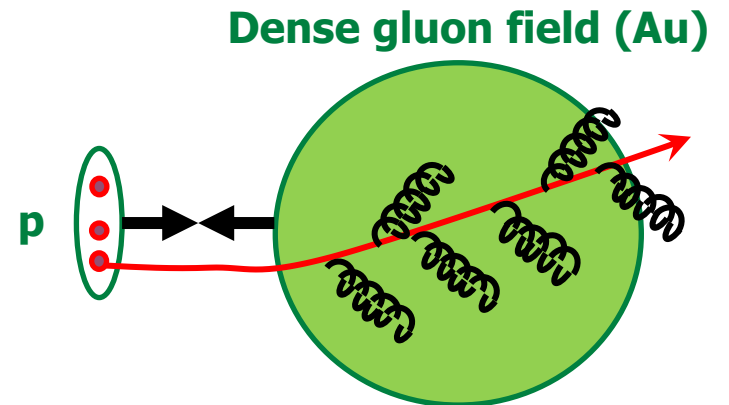
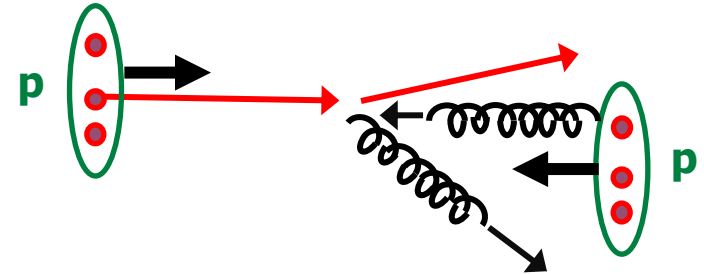
beam-view



$$C(\Delta\phi) = \frac{N_{pair}(\Delta\phi)}{N_{trig} \times \Delta\phi}$$

- **Why forward:** two final state particles at forward rapidity provide access to small x regime
- **Method:** measure the azimuthal correlation between two final hadrons in pp and pA
- **pp:** 2→2 process $\Rightarrow$ back-to-back di-hadron
- **pA:** back-to-back configuration is smeared by multiple gluon interactions

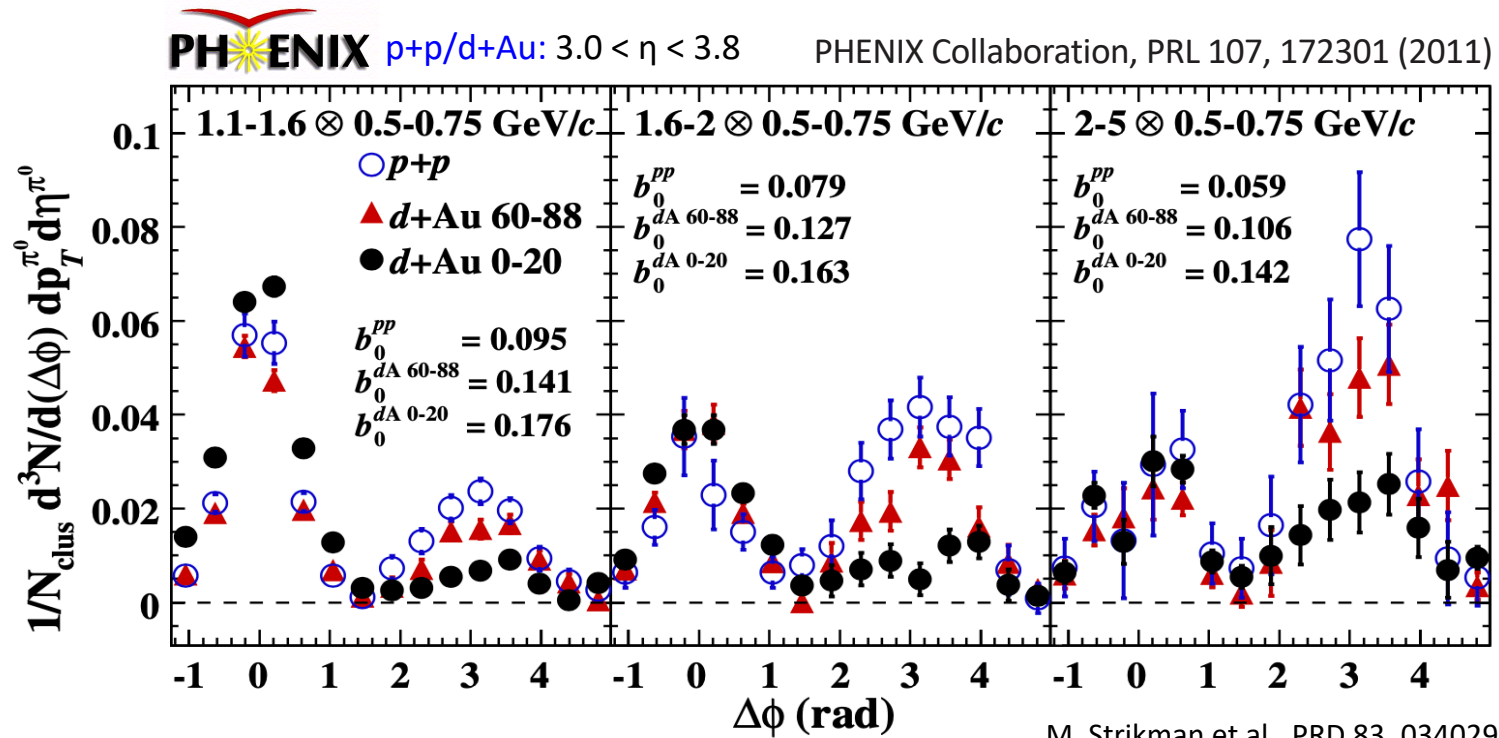
side-view



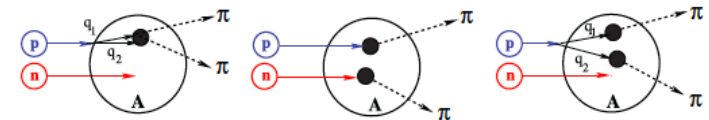
P_T is balanced by many gluons

$$x_1 \sim \frac{p_{T1}e^{\eta_1} + p_{T2}e^{\eta_2}}{\sqrt{s}} \gg x_2 \sim \frac{p_{T1}e^{-\eta_1} + p_{T2}e^{-\eta_2}}{\sqrt{s}}$$

Di- π^0 correlations in dAu



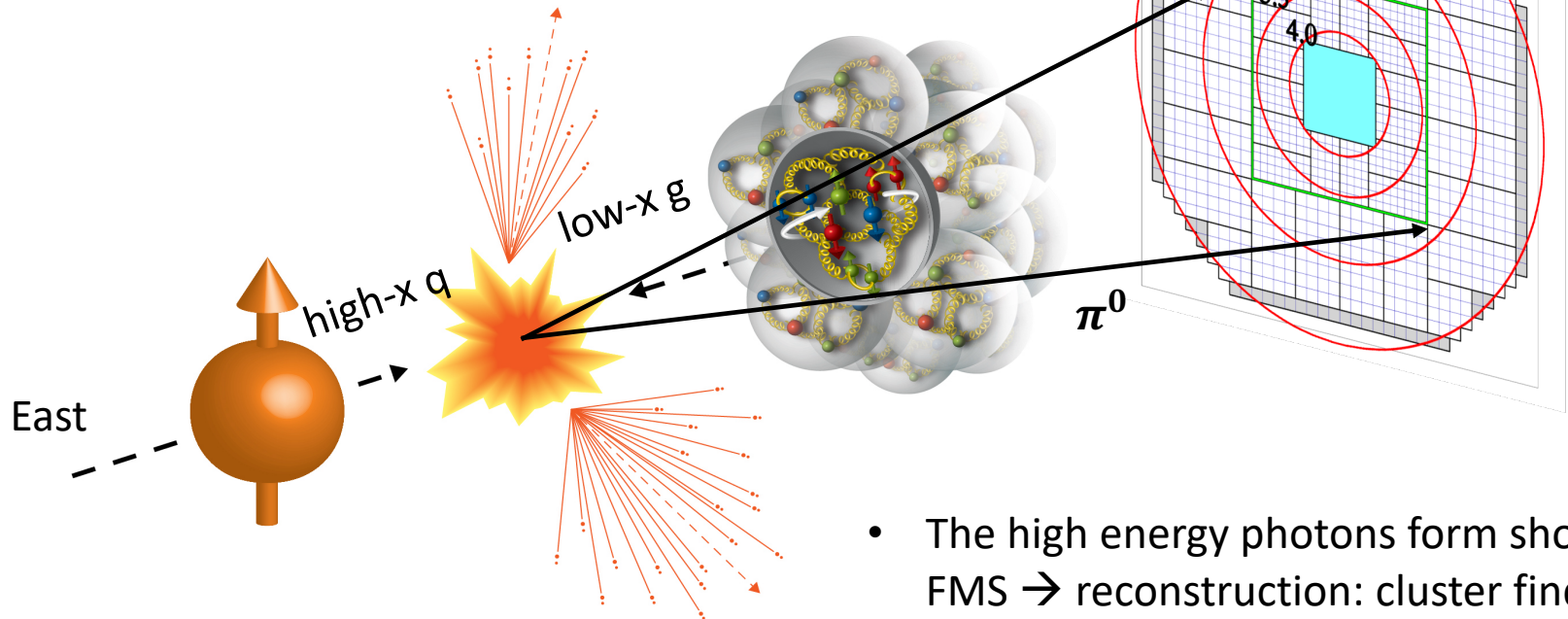
Possible contribution from double parton interaction to the cross section? $\rightarrow$



- dAu: interpretation of the suppression complicated by alternative explanation; much higher pedestal in dAu
- $\rightarrow$ pAu collisions are theoretically and experimentally cleaner

STAR forward detector

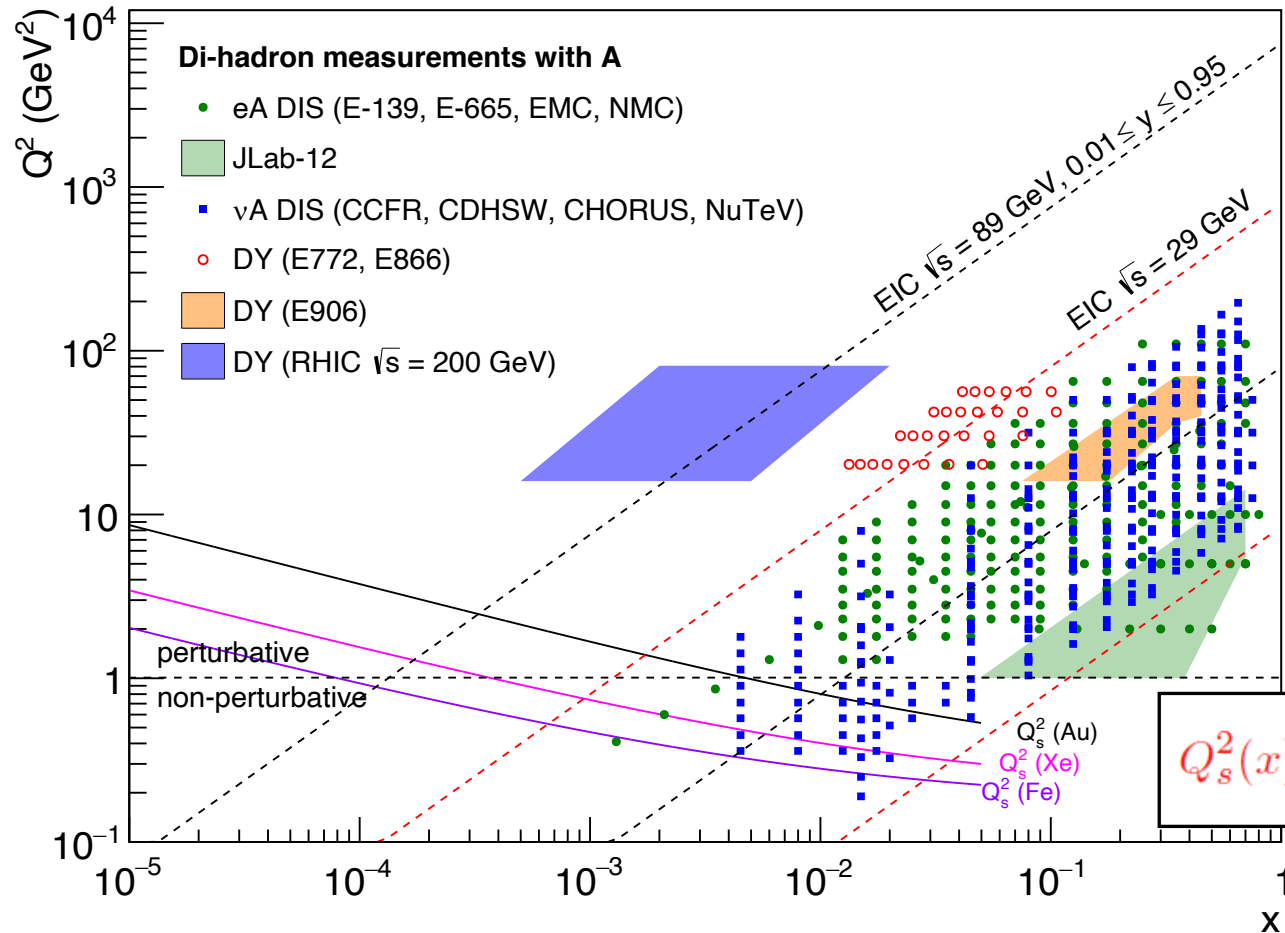
- 2015 p+p and p+A collisions at $\sqrt{s_{NN}} = 200$ GeV
- Forward Meson Spectrometer (FMS) : $2.6 < \eta < 4.1$



- Au, Al beams $\rightarrow$ A dependence
- Forward rapidity hadron production
 - can access low-x gluons with high-x quark probe
- The high energy photons form showers at FMS $\rightarrow$ reconstruction: cluster finding, shower shape fitting
- π^0 , decaying into two photons, is constructed from a pair of photon candidates

Saturation scale Q_s^2

R. Abdul Khalek et al., arXiv:2103.05419

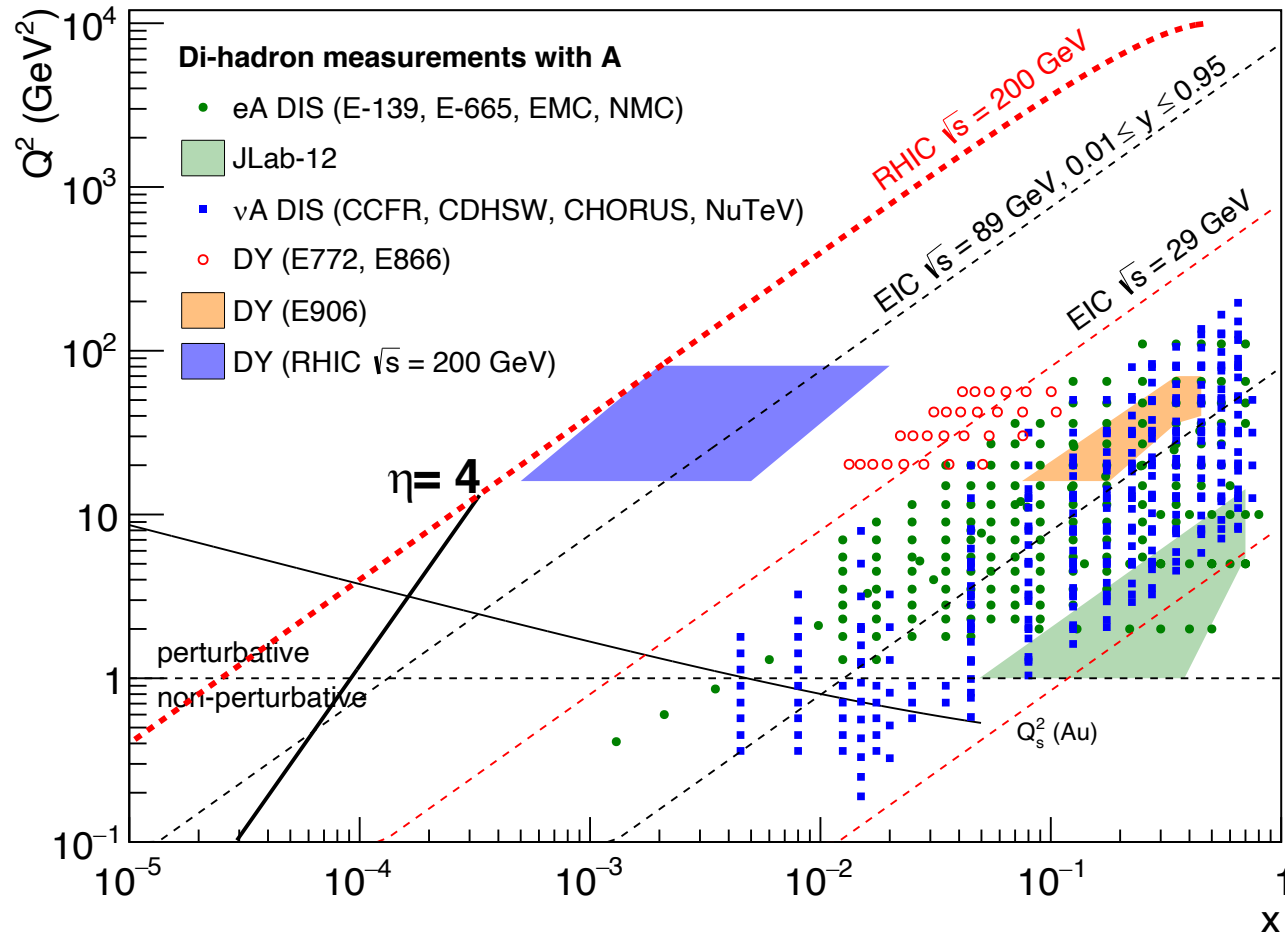


□ Saturation scale Q_s : the inverse of transverse distance between partons; grows with A and decreases with x

$$Q_s^2(x) \sim A^{1/3} \left(\frac{1}{x} \right)^\lambda \sim \left(\frac{A}{x} \right)^{1/3}$$

x-Q² phase space

R. Abdul Khalek et al., arXiv:2103.05419

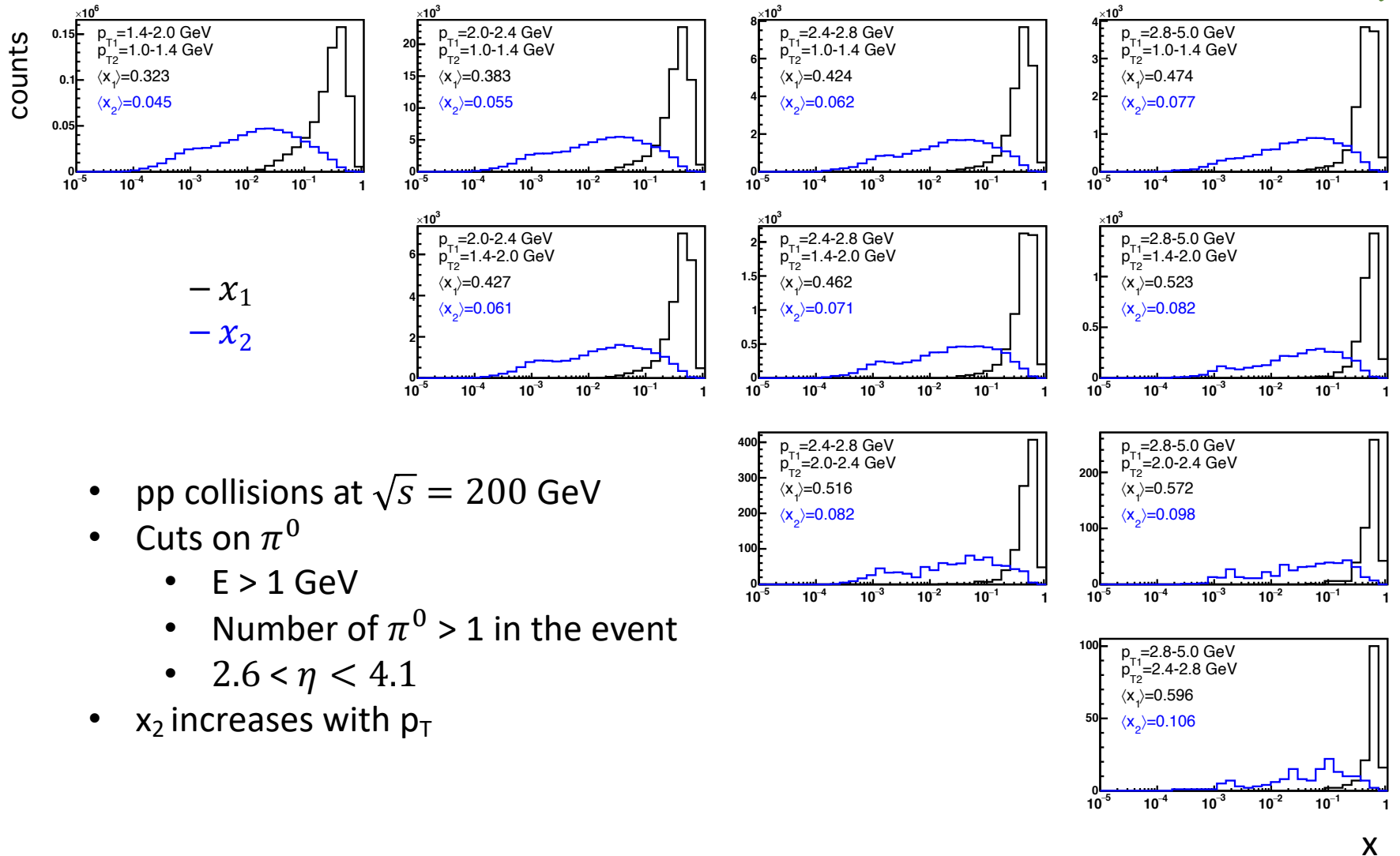


□ STAR FMS data ($\sqrt{s_{NN}} = 200$ GeV) can probe the saturation region

□ One can study the evolution on x and Q^2 through scanning p_T

PYTHIA Kinematics: x_1, x_2

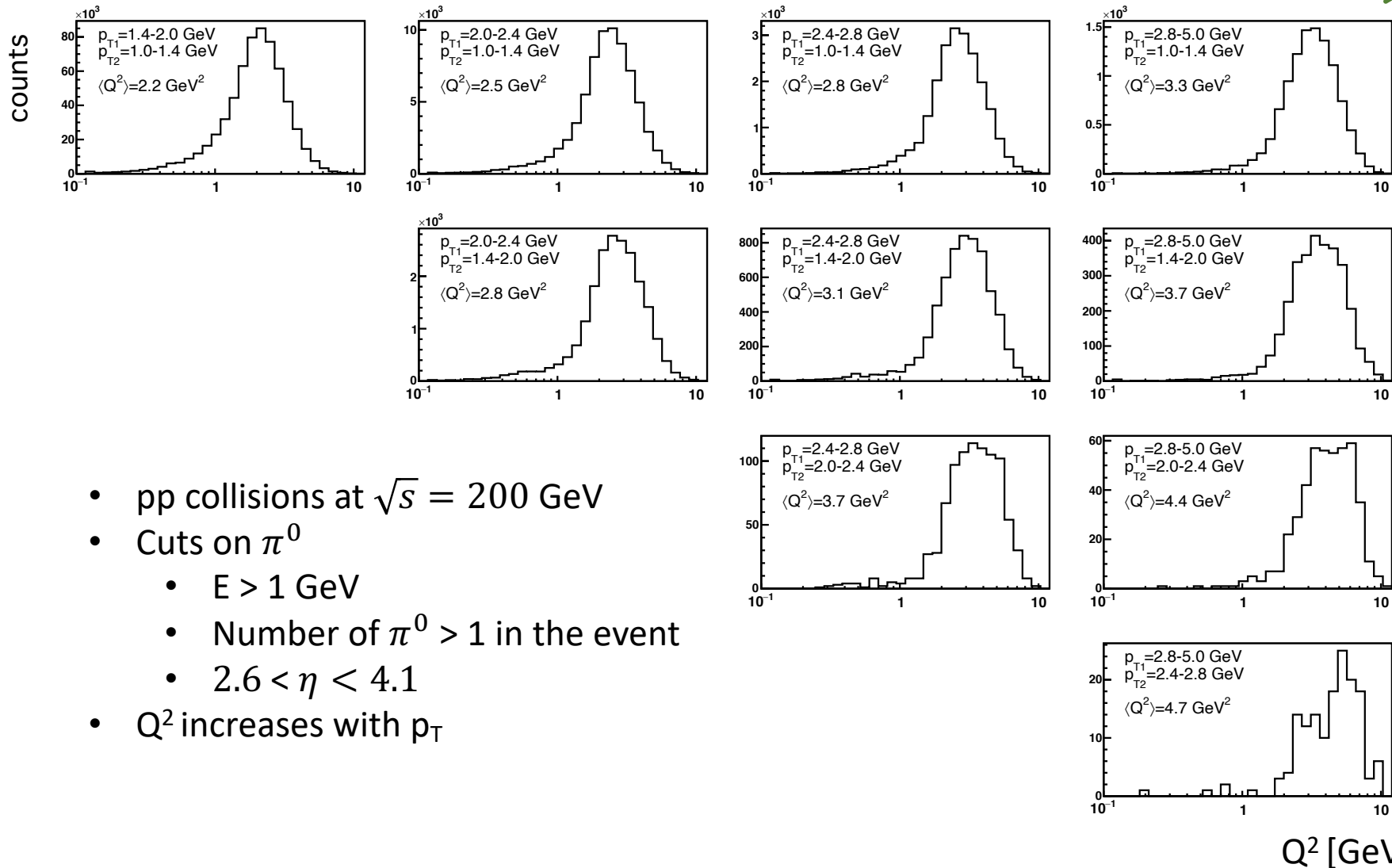
trigger π^0 : p_{T1}



- pp collisions at $\sqrt{s} = 200$ GeV
- Cuts on π^0
 - $E > 1$ GeV
 - Number of $\pi^0 > 1$ in the event
 - $2.6 < \eta < 4.1$
- x_2 increases with p_T

PYTHIA Kinematics: Q^2

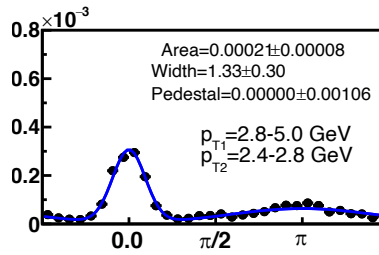
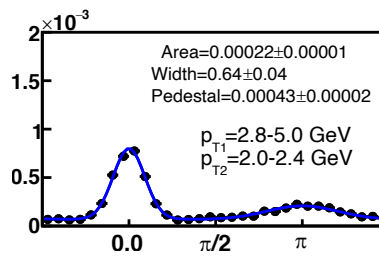
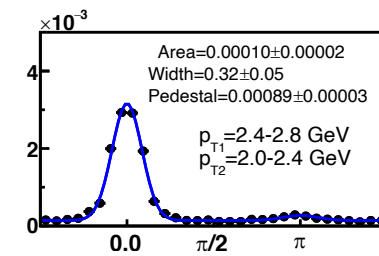
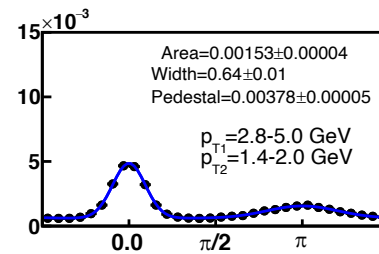
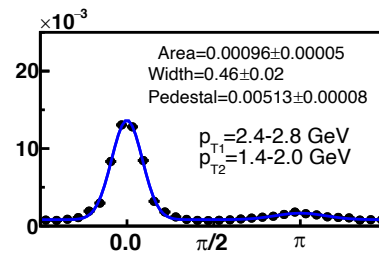
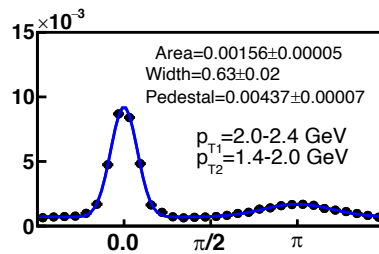
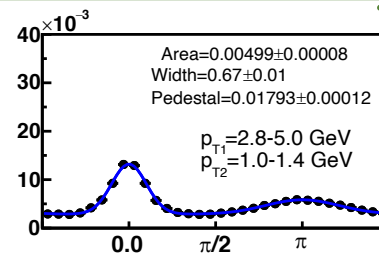
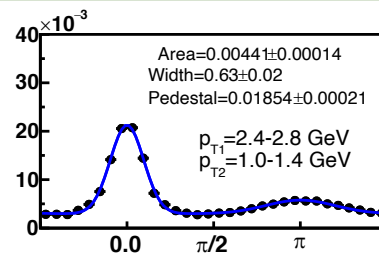
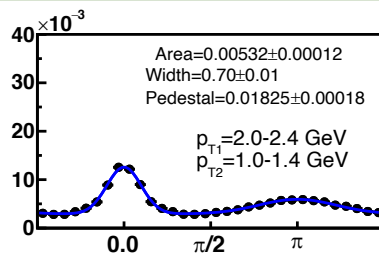
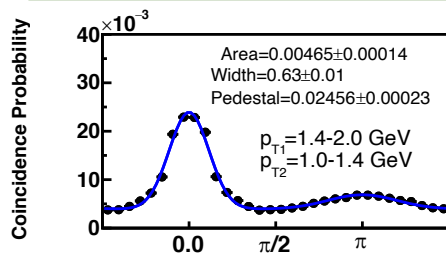
trigger π^0 : p_{T1}



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- Cuts on π^0
 - $E > 1$ GeV
 - Number of $\pi^0 > 1$ in the event
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- Q^2 increases with p_T

Di- π^0 correlations in pp

trigger π^0 : p_{T1}



STAR Preliminary

pp MinBias

$\sqrt{s} = 200$ GeV

$2.6 < \eta < 4.1$

• Data

— Fit

Fit function:

$\Delta\phi = 0$

$\Delta\phi = \pi$

Pedestal/ 2π + Gaussian + Gaussian (Area and width)

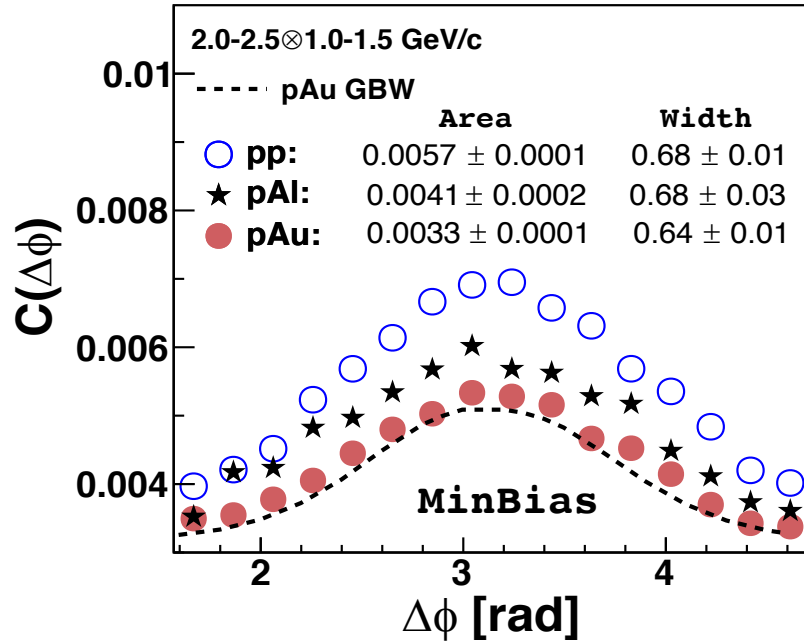
associated π^0 : p_{T2}

$\Delta\phi$ [rad]

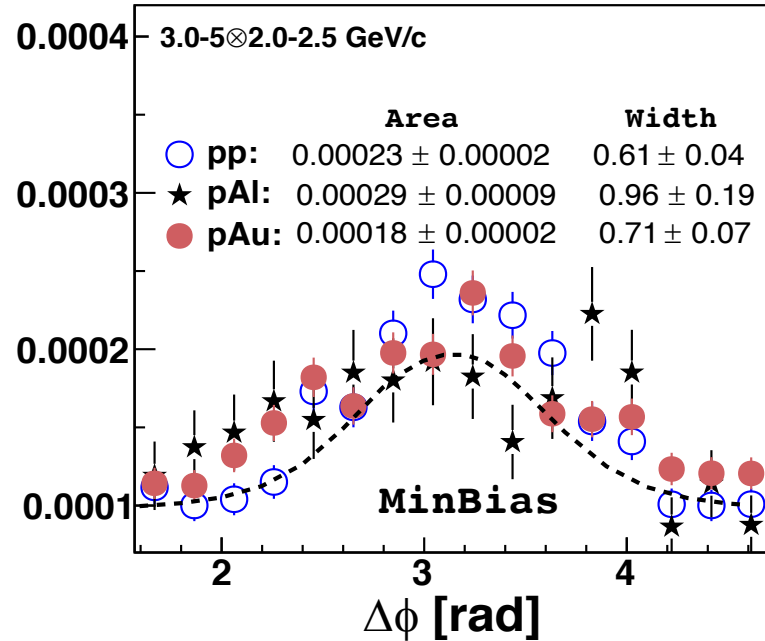
Di- π^0 correlations in pp and pA

pp, pAl and pAu: $\sqrt{s_{NN}} = 200$ GeV, $2.6 < \eta < 4.1$

STAR Preliminary



STAR Preliminary

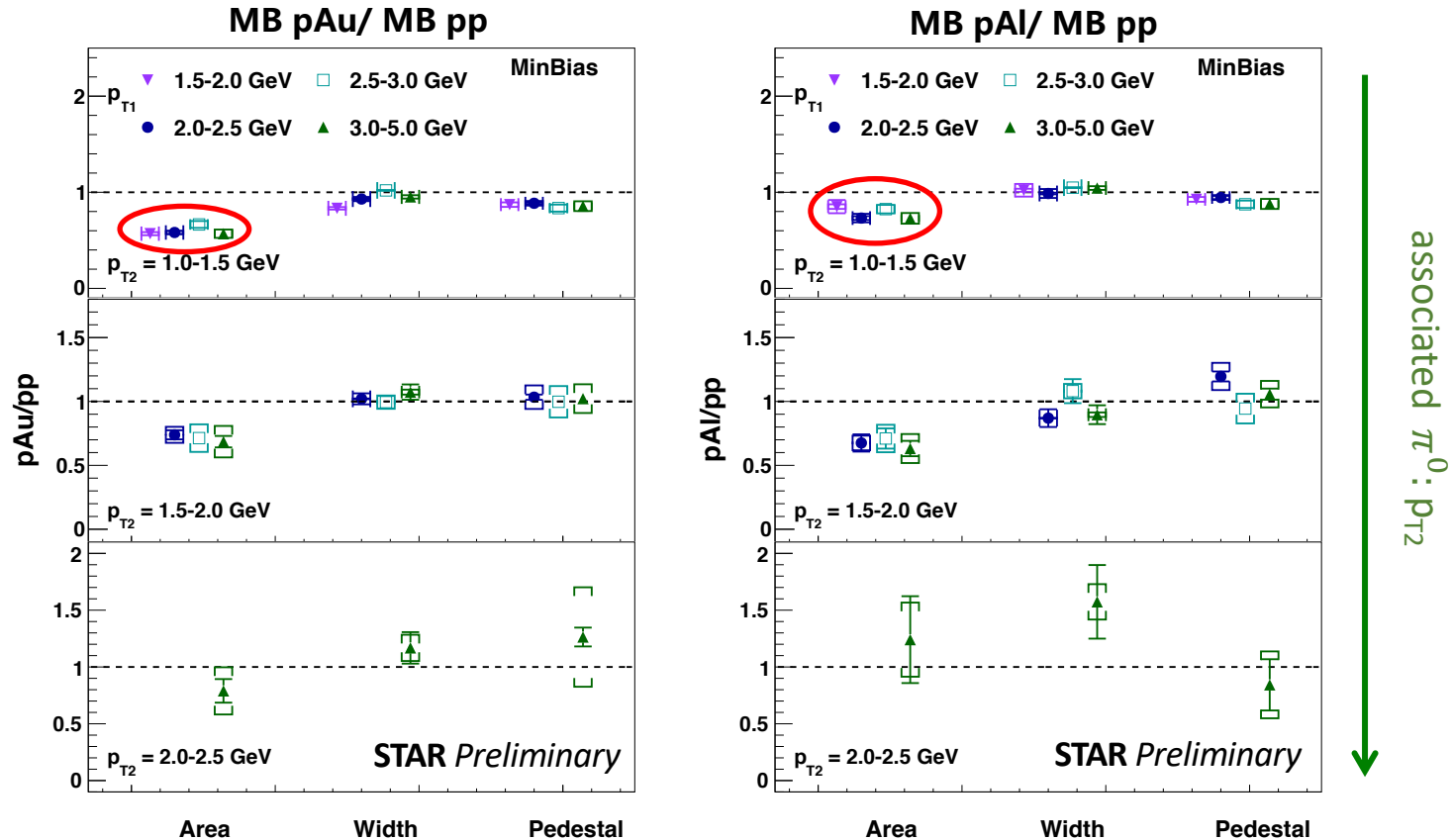


GBW: A. Stasto et al., PLB 716(2012) 430-434

- **A dependence:** at low p_T , more suppression is observed in pAu than pAl in comparison with the reference pp
- **p_T dependence:** less suppression at high p_T (large x and Q^2) in pAu
- Qualitatively agree with predictions: GBW model $\rightarrow$ incorporates gluon saturation

MinBias pA/pp: full p_T range

pp, pAl and pAu: $\sqrt{s_{NN}} = 200$ GeV, $2.6 < \eta < 4.1$



- **Area:** suppression in pA compared to pp. Less suppression in pAl than pAu
- **Width:** no broadening observed in pA compared to pp with FMS resolution
- **Pedestal:** quite stable, previous dAu results show much higher pedestal than pp

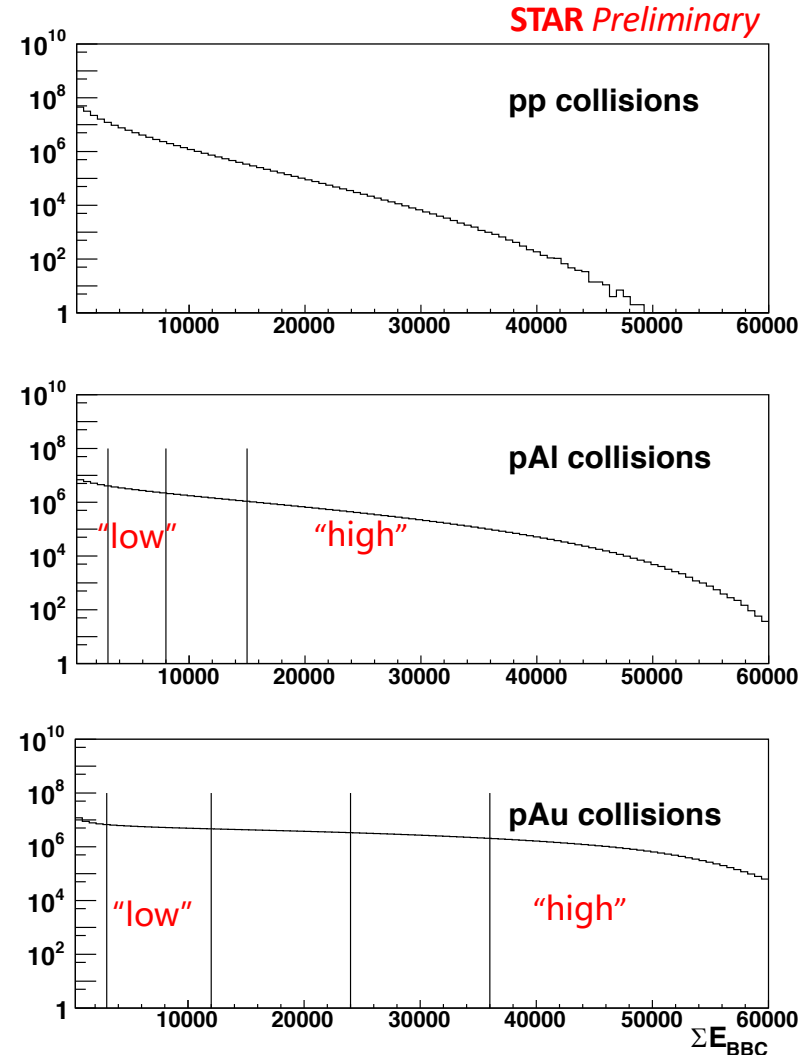
Event activity

Energy deposited at EAST BBC (ΣE_{BBC}) quantifies “event activity”

- East: nucleus beam going direction; backward rapidity
- High energy deposition refers to “high activity” collisions

Event activity in pAl and pAu

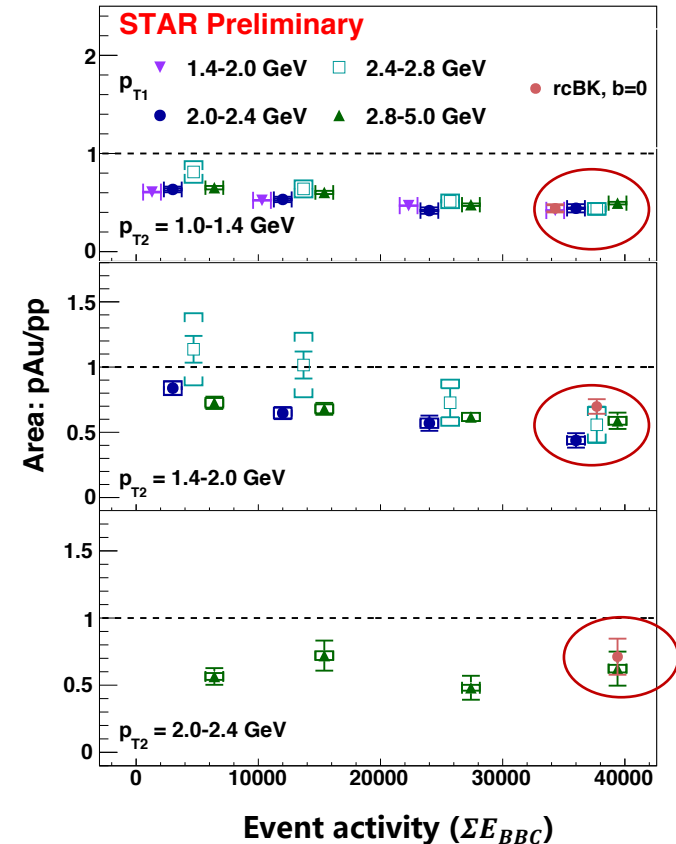
Beam species	Event activity	ΣE_{BBC} range ($\times 10^3$)	Class
$p+\text{Al}$	Lowest	3-8	31%-60%
	Medium	8-15	60%-81%
	Highest	>15	81%-100%
$p+\text{Au}$	Lowest	3-12	15%-43%
	Medium low	12-24	43%-69%
	Medium high	24-36	69%-88%
	Highest	>36	88%-100%



Event activity dependence in pAu

rcBK: Javier L. Albacete et al., PRD 99, 014002 (2019)

pp, pAu: $\sqrt{s_{NN}} = 200 \text{ GeV}, 2.6 < \eta < 4.1$

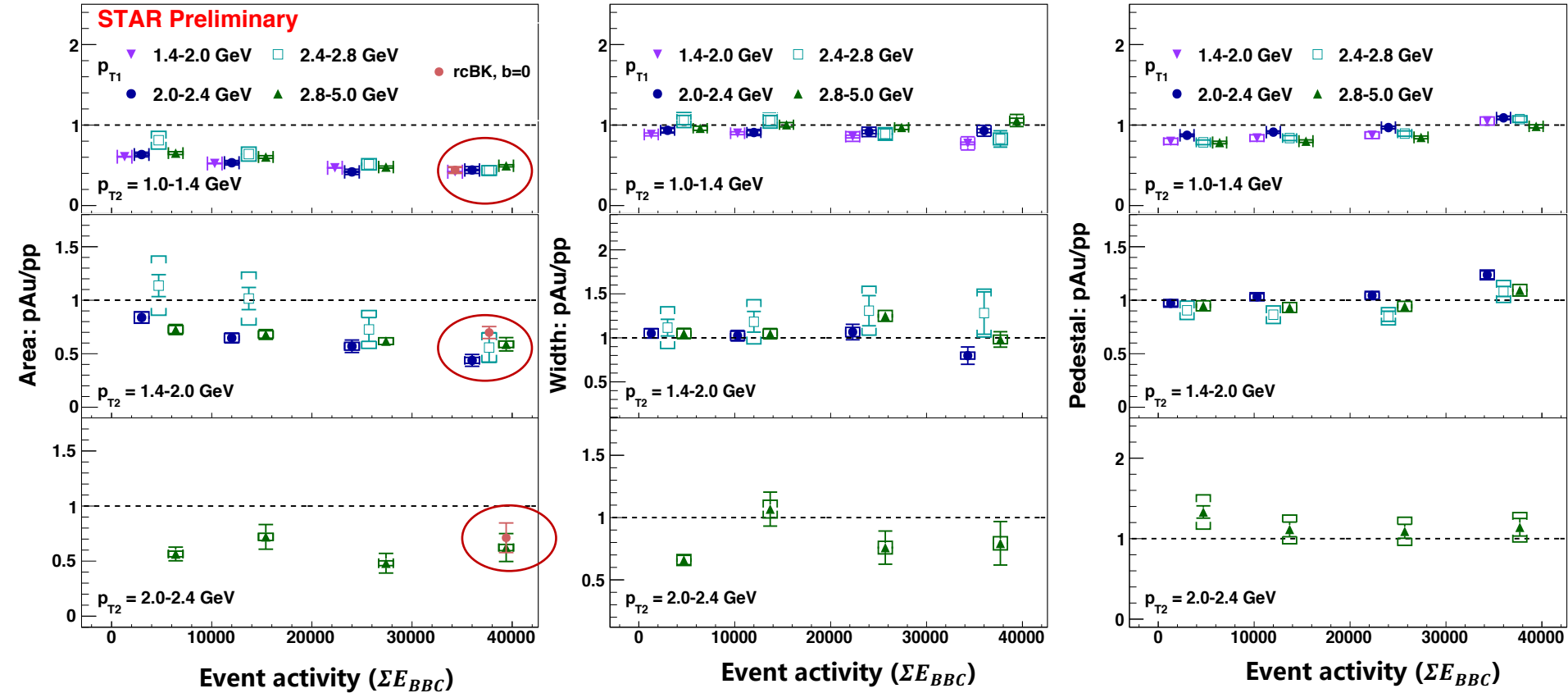


- Suppression depends on event activity $\rightarrow$ enhanced in high activity events at low p_T
- Suppression at highest activity events is consistent with predictions based on gluon saturation model: rcBK at $b=0$

Event activity dependence in pAu

rcBK: Javier L. Albacete et al., PRD 99, 014002 (2019)

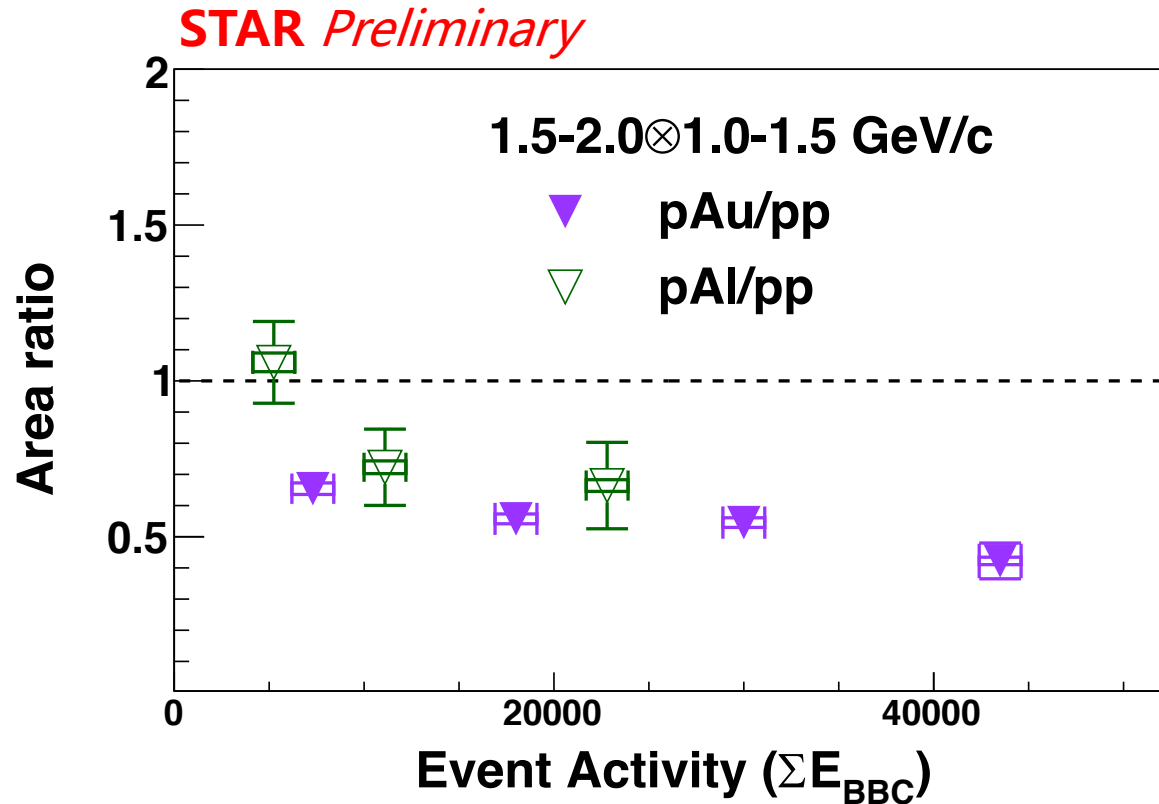
pp, pAu: $\sqrt{s_{NN}} = 200 \text{ GeV}, 2.6 < \eta < 4.1$



- Suppression depends on event activity $\rightarrow$ enhanced in high activity events
- Suppression at highest activity events is consistent with predictions based on gluon saturation model: rcBK at $b=0$
- Width and pedestal are stable in pp and pAu against event activity

Event activity dependence in pAl

pp, pAl and pAu: $\sqrt{s_{NN}} = 200$ GeV
 $2.6 < \eta < 4.1$



- pAl: indication of enhanced suppression in “high activity” events.

Summary and outlook

- ❑ The evidence of a novel universal regime of non-linear gluon dynamics in nuclei is very important to help us understand QCD processes in Cold Nuclear Matter:
 - Understand the collective dynamics of gluons
 - Investigate inner landscape of nuclei: initial state input to eA/pA/AA
- ❑ Di-hadron correlation is a key measurement in the pA physics program at STAR
 - STAR shows a clear signature of non-linear gluon dynamics with di-hadron correlation measurement
 - First measurement of nuclear effect dependence on A: stronger suppression in pAu than pAl
 - Event activity dependence: suppression enhanced in “high activity” collisions at low p_T
- ❑ STAR 2016 dAu results are on the way: the effect from double (multiple) parton interactions?