



IS2021

The VIth International Conference on the
INITIAL STAGES
OF HIGH-ENERGY NUCLEAR
COLLISIONS



Di-hadron correlations in pp and pA collisions at STAR

Xiaoxuan Chu
(For the STAR Collaboration)
January 10-15, 2021

Supported by

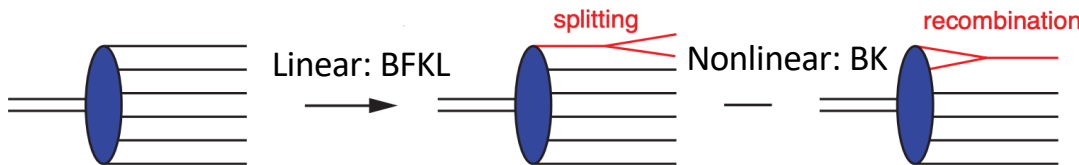


U.S. DEPARTMENT OF
ENERGY

Office of
Science

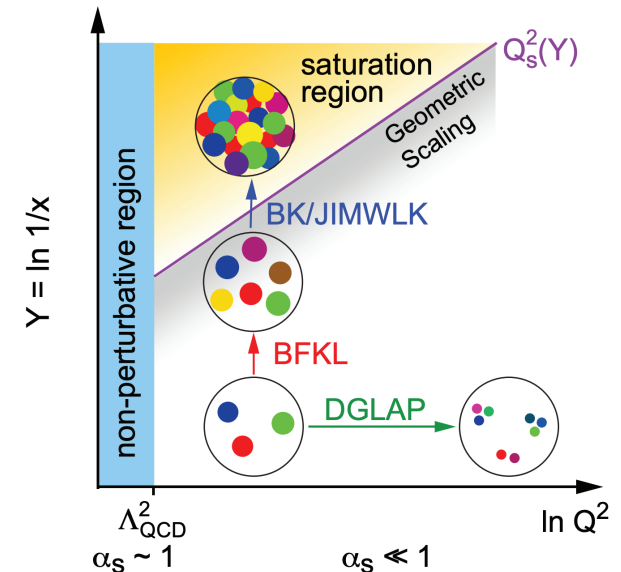
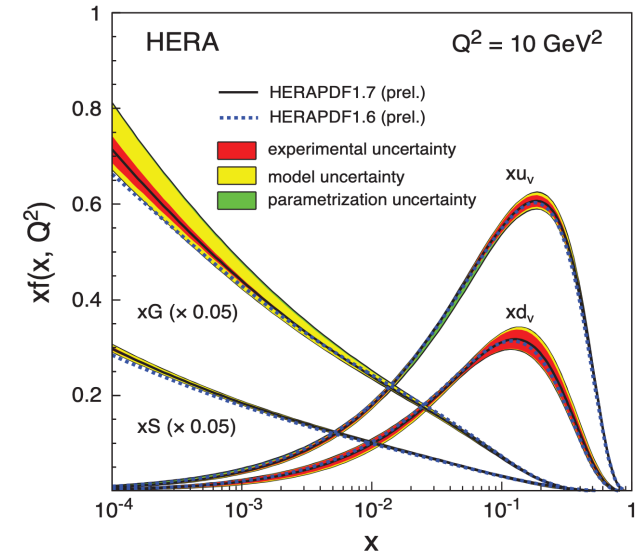
Gluon dynamics at small x

- **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 $Q^2 \leq Q_s^2$, gluon splitting and recombination reach a balance
- Gluon dynamics transfer from linear to **non-linear**: DGLAP/BFKL → BK/JIMWLK
- Large Q: small $\alpha_s \rightarrow$ perturbative QCD calculations under control



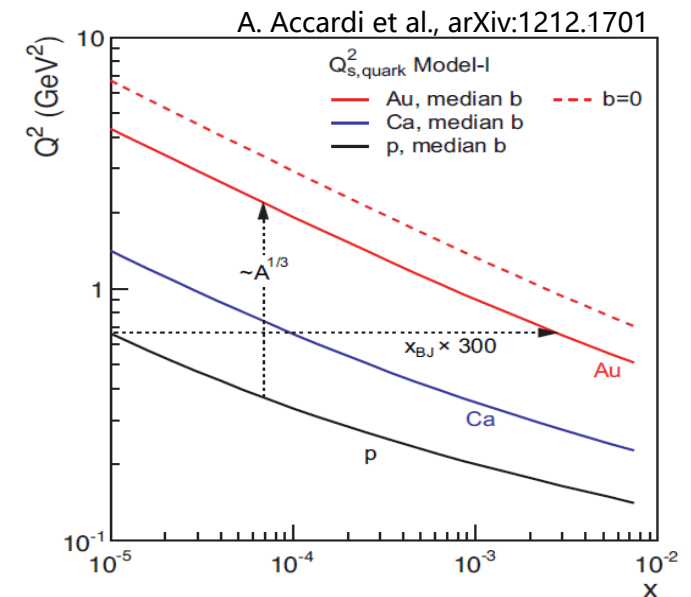
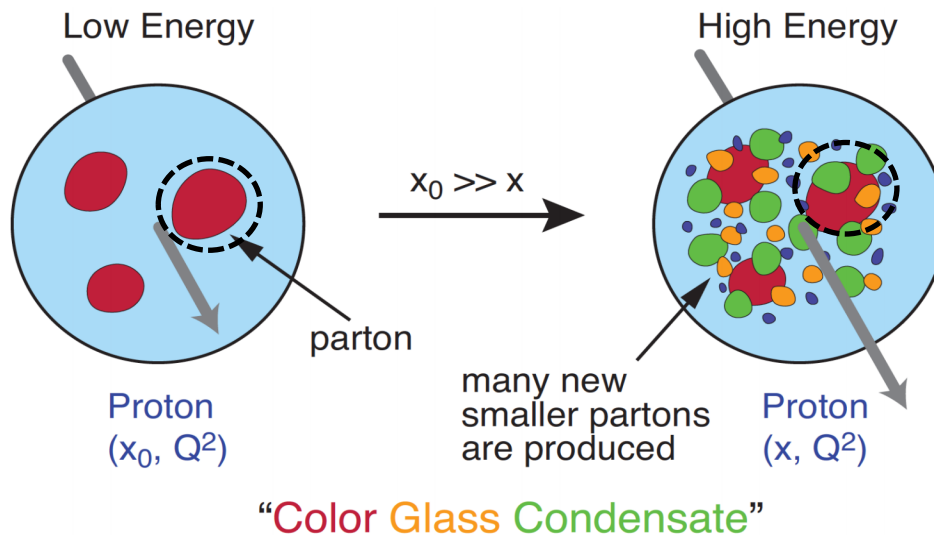
$$\text{BFKL: } \frac{\partial N(x, r_T)}{\partial \ln(1/x)} = \alpha_s K_{\text{BFKL}} \otimes N(x, r_T) \quad N \sim (1/x)^\lambda$$

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



Saturation scale Q_s^2 : x and A dependence

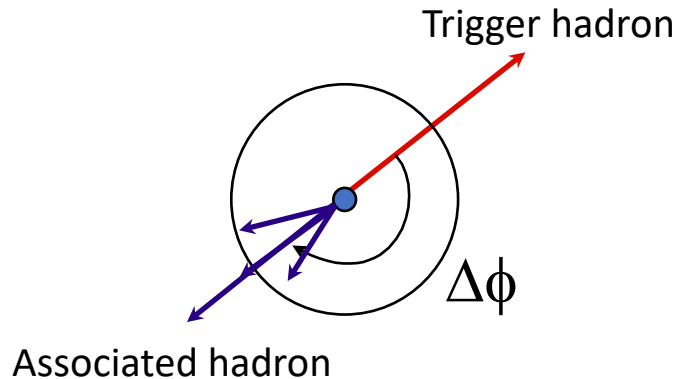
- Transverse distance between partons decreases as the atomic mass number A increases and gets smaller at low-x
- Saturation scale Q_s^2 : the inverse of transverse distance, it grows with A and decreases with x



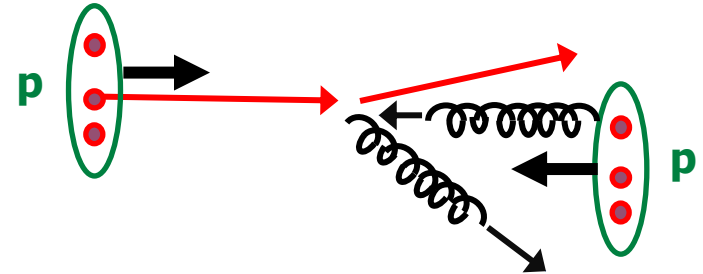
$$Q_s^2(x) \sim A^{1/3} \left(\frac{1}{x} \right)^\lambda \sim \left(\frac{A}{x} \right)^{1/3}$$

Multiple scattering

beam-view



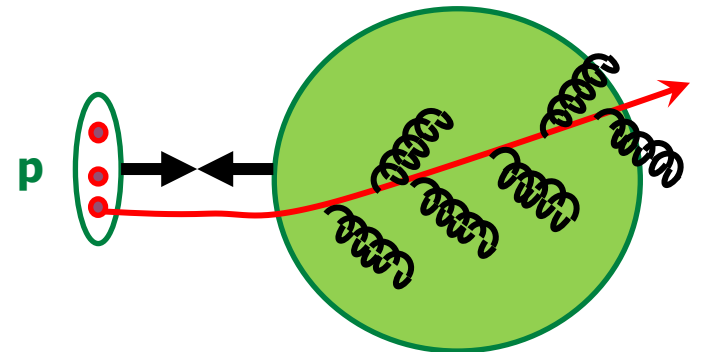
side-view



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

- **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

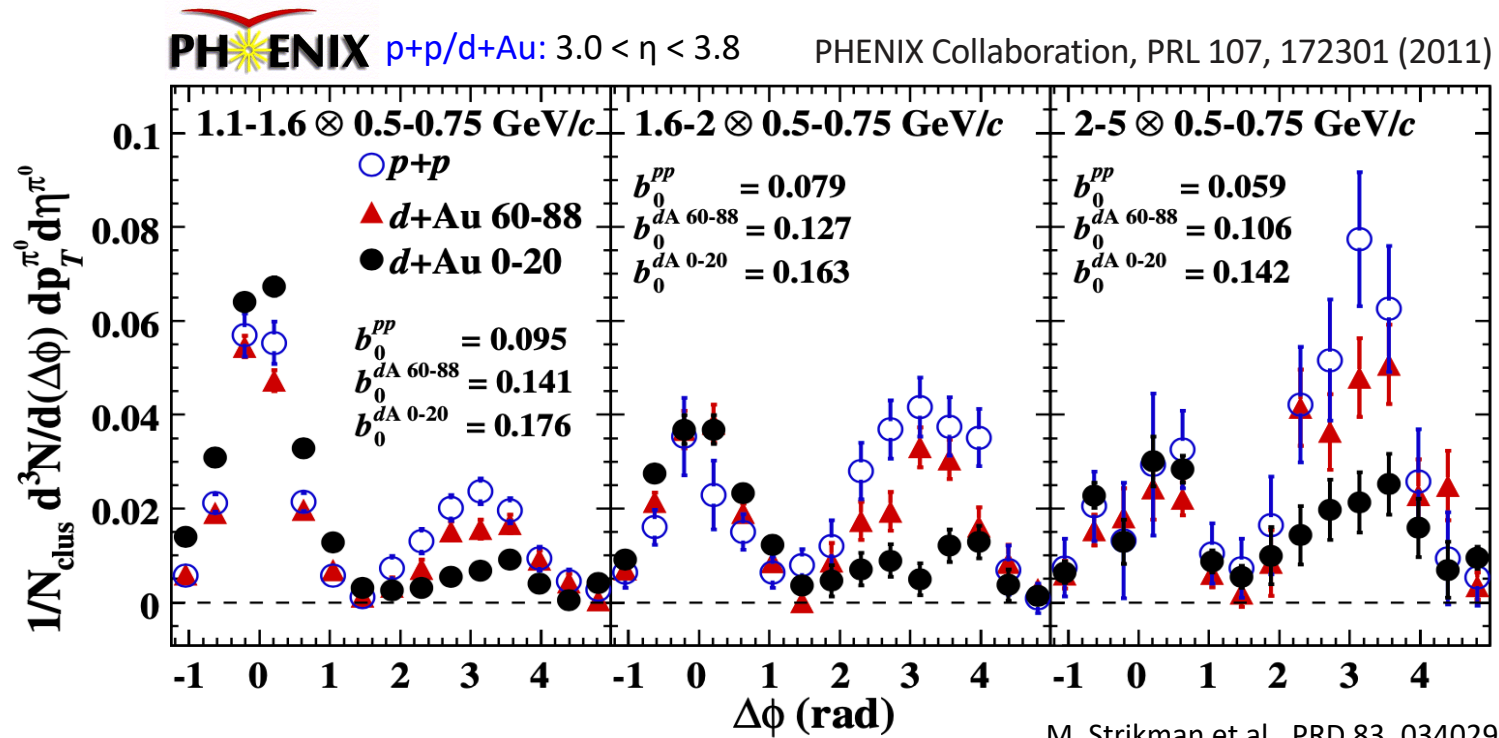
Dense gluon field (Au)



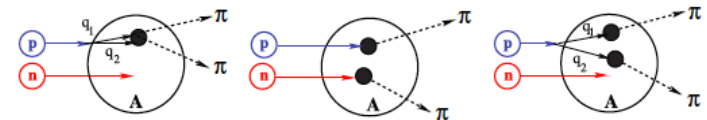
P_T is balanced by many gluons

$$x_A = \frac{p_{T1} e^{-y_1} + p_{T2} e^{-y_2}}{\sqrt{s}} \ll x_p = \frac{p_{T1} e^{y_1} + p_{T2} e^{y_2}}{\sqrt{s}}$$

Di- π^0 correlations in dAu

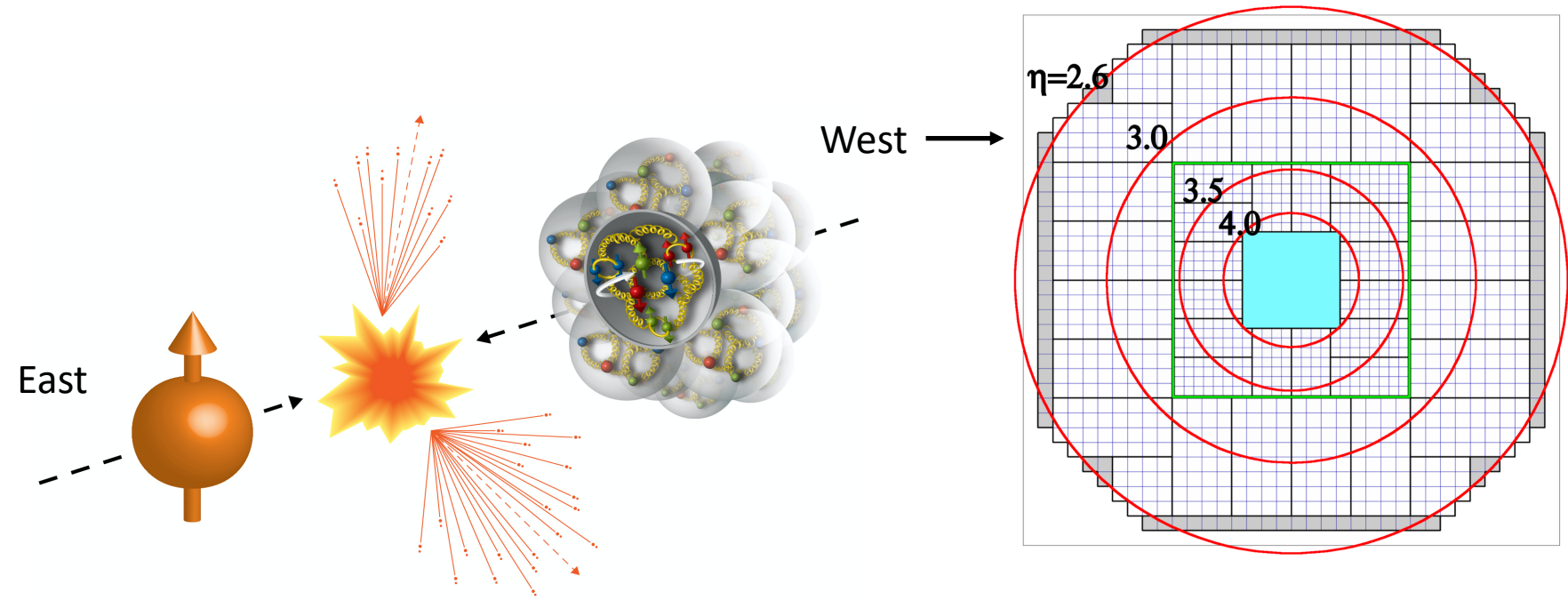


Possible contribution from double parton interaction to the cross section? $\rightarrow$



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

STAR forward detector



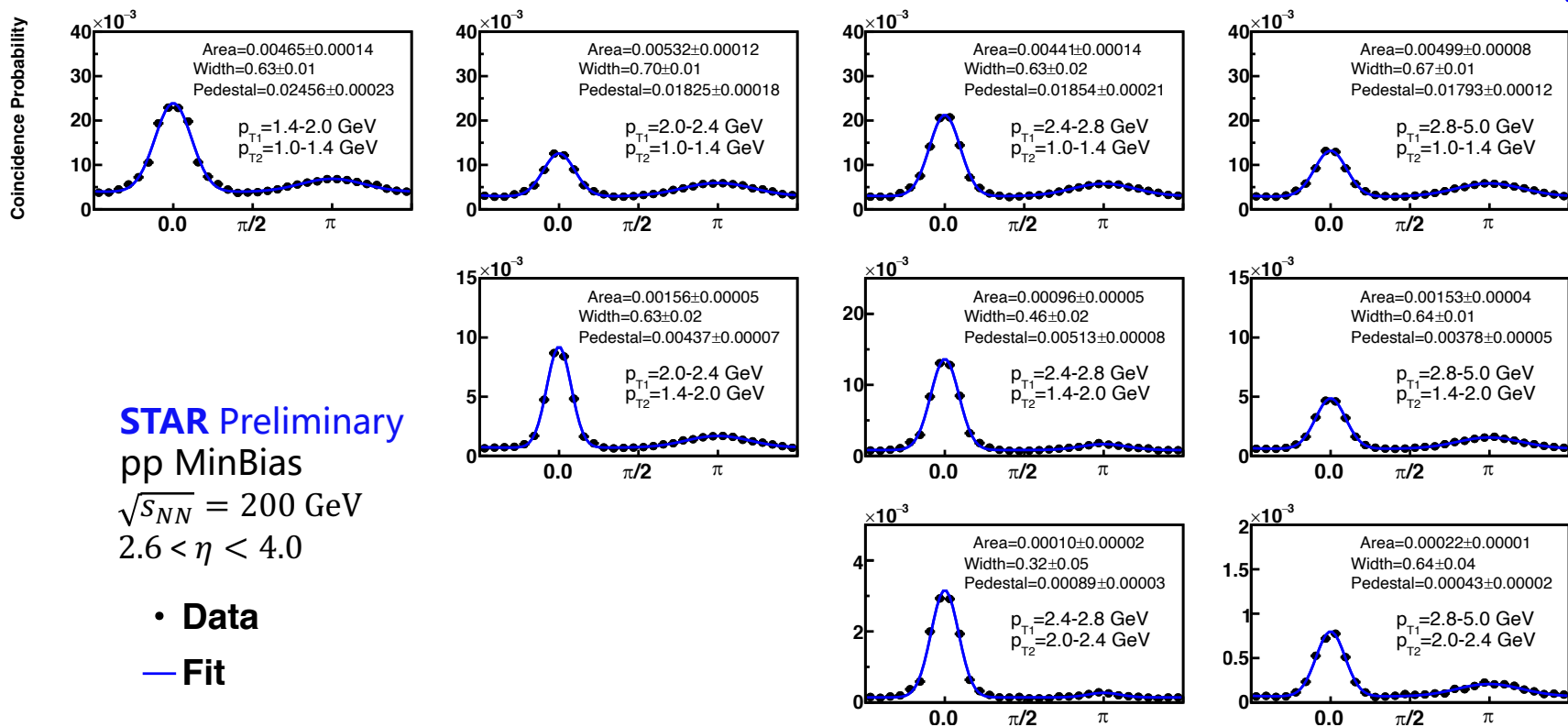
p+p and p+A collisions at $\sqrt{s_{NN}} = 200$ GeV

- Au, Al beams → **A dependence**
- Forward rapidity hadron production
 - can access **low-x gluons** with high-x quark probe

- The high energy photons form showers at Forward Meson Spectrometer (FMS) → reconstruction: cluster finding, shower shape fitting
- π^0 , decaying into two photons, is constructed from a pair of photon candidates

Di- π^0 correlations in pp

trigger π^0 : p_{T1}



associated π^0 : p_{T2}

Fit function:

$$\Delta\phi = 0$$

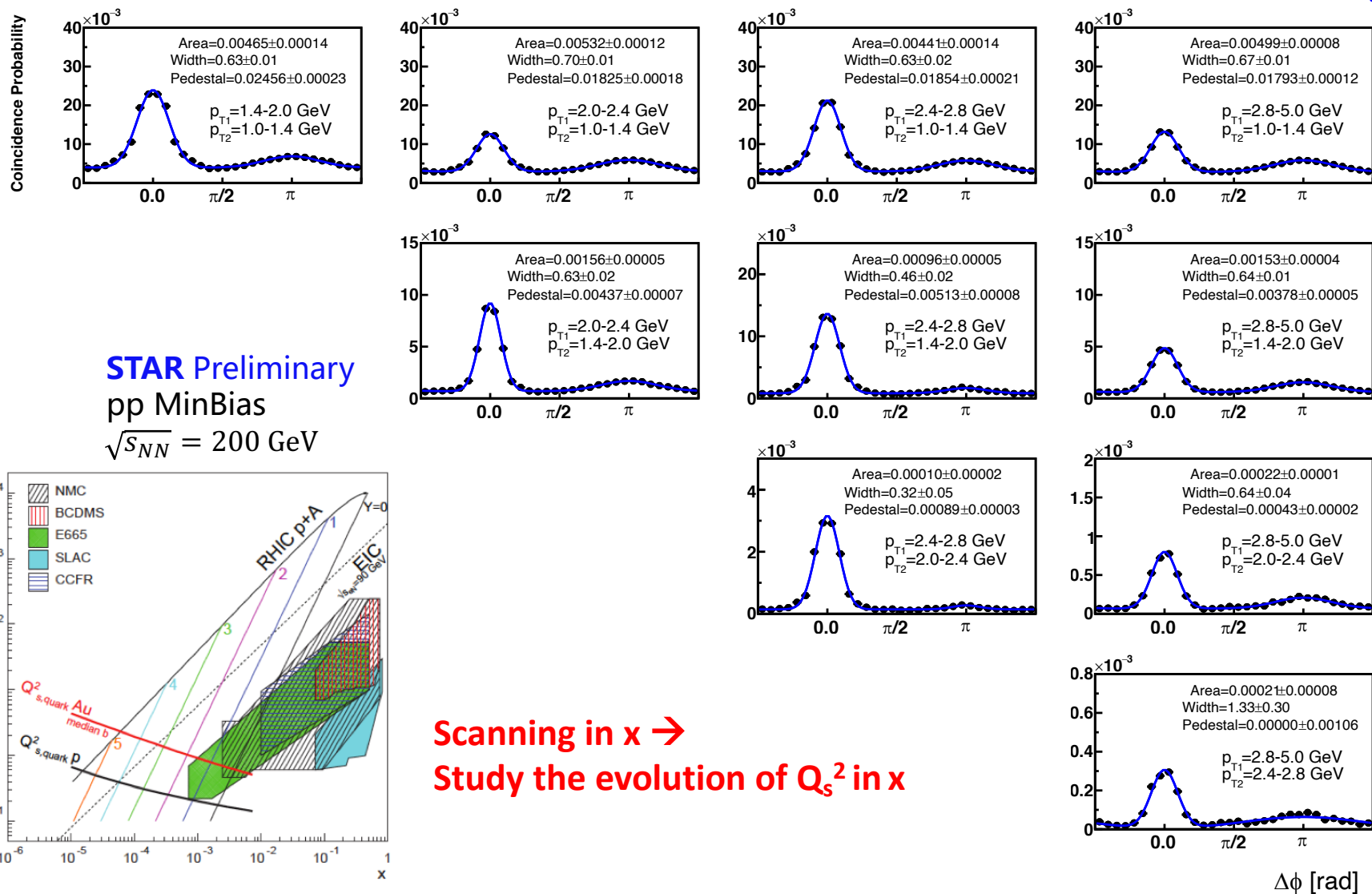
$$\Delta\phi = \pi$$

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

$\Delta\phi$ [rad]

Di- π^0 correlations in pp

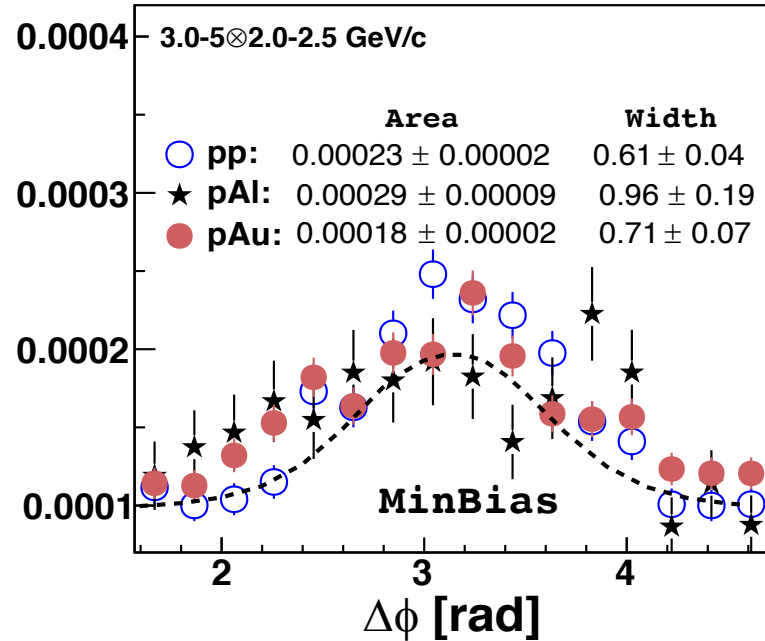
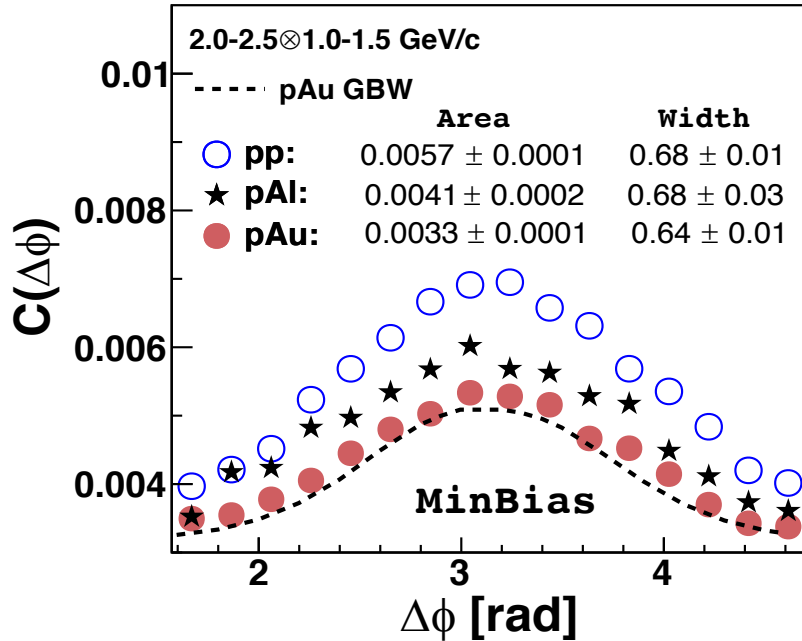
trigger π^0 : p_{T1}



Di- π^0 correlations in pp and pA

pp, pAl and pAu: $\sqrt{s_{NN}} = 200$ GeV, $2.6 < \eta < 4.0$

STAR Preliminary

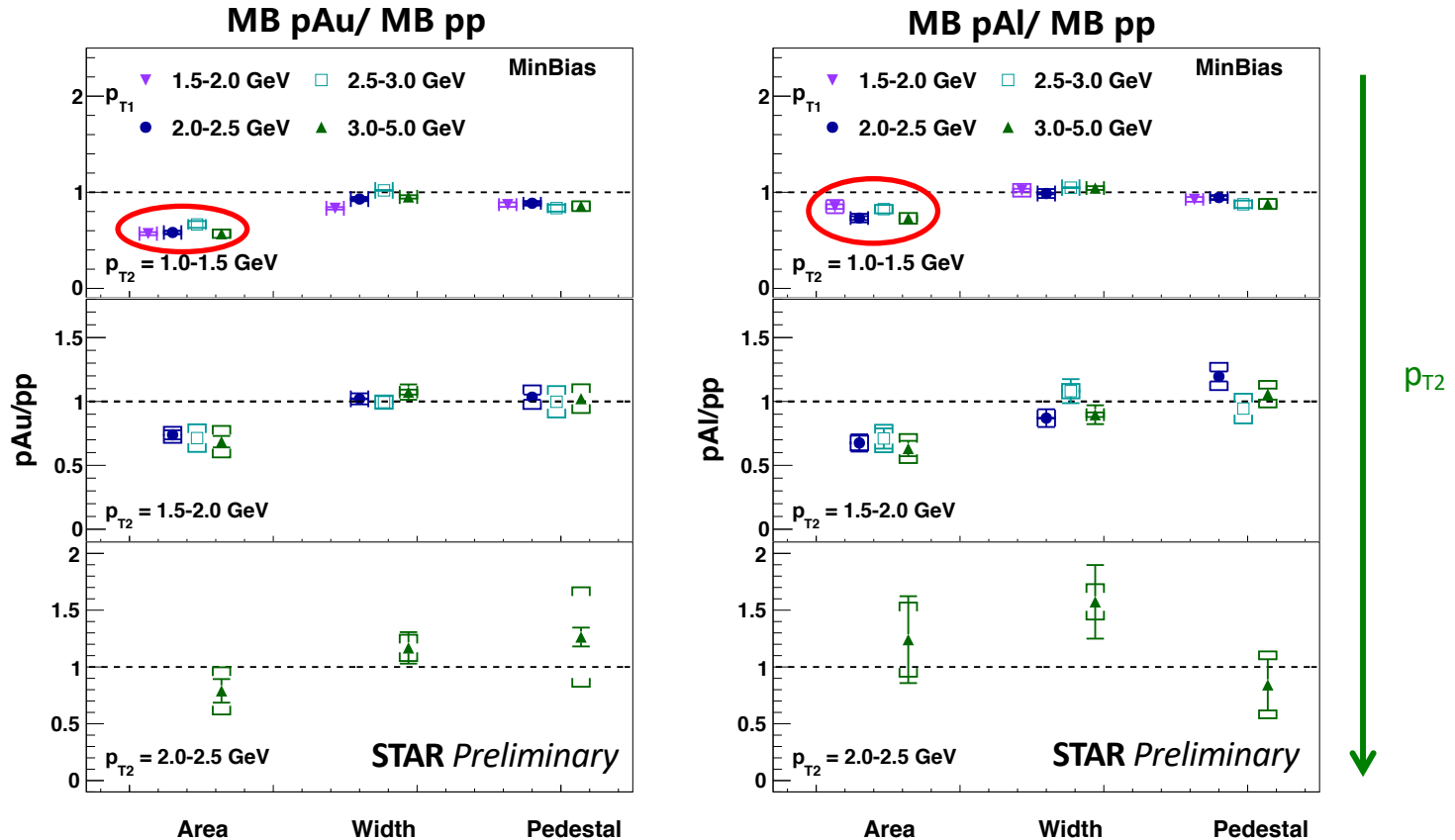


GBW: A. Stasto et al., PLB 716(2012) 430-434

- **A dependence:** at low p_T , more suppression is observed in pAu than pAl in comparison with the reference pp
- **x dependence:** less suppression in pAu at high p_T (large x)
- 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, $2.6 < \eta < 4.0$



- **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”

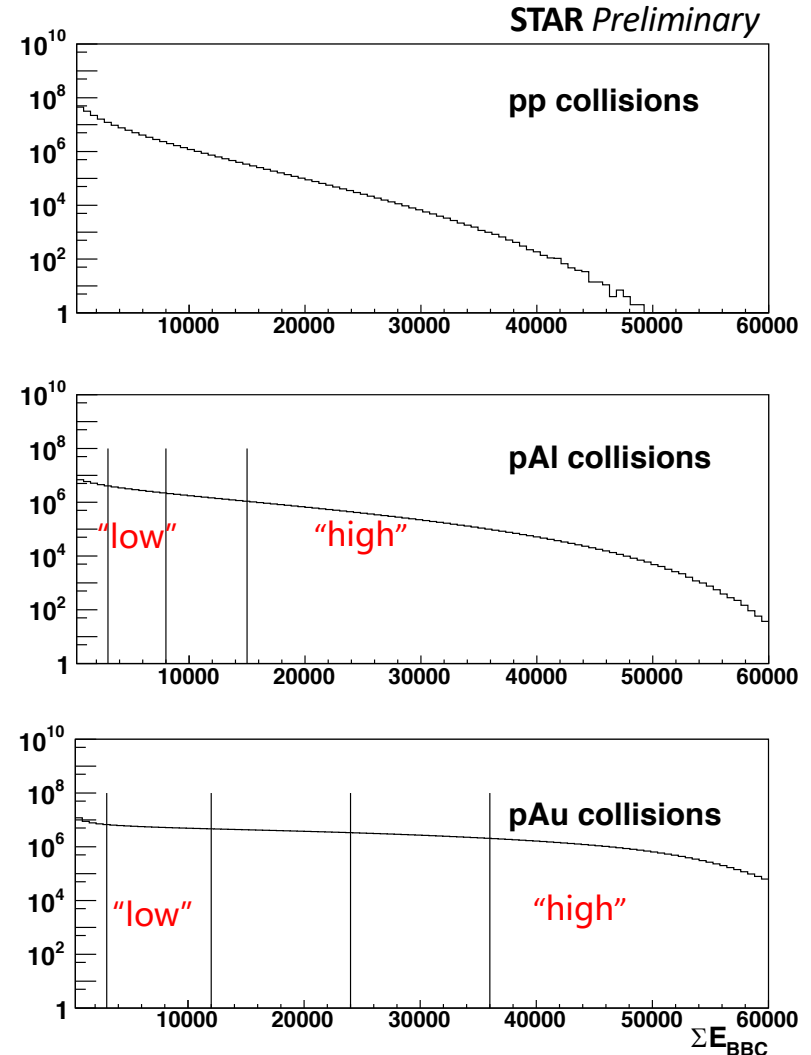
- East: nucleus beam going direction; backward rapidity
- High energy deposition refers to “high activity” collisions

MinBias: No ΣE_{BBC} selection.

Event activity in pAl and pAu

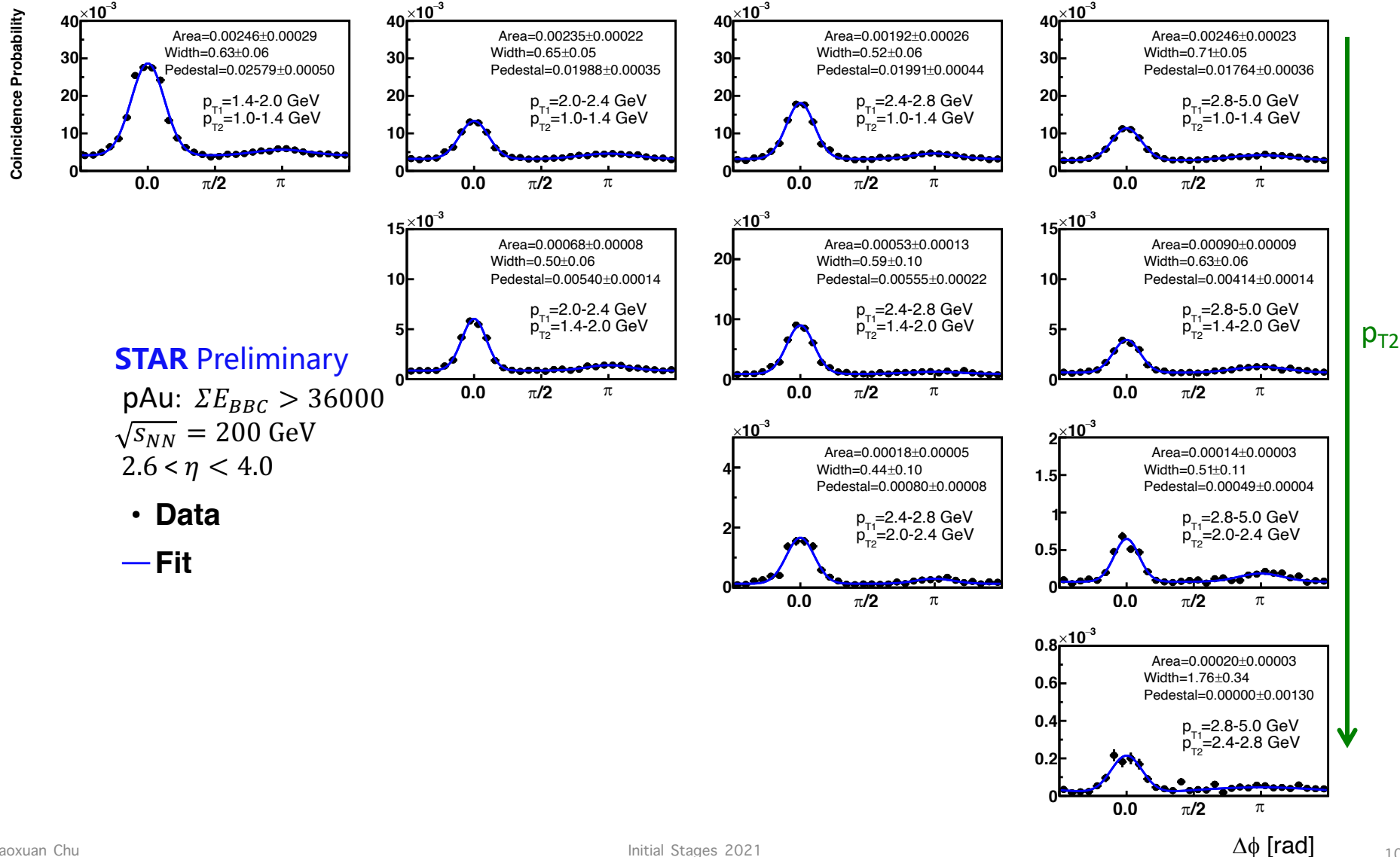
Beam species	Event activity	ΣE_{BBC} range ($\times 10^3$)	Class
p+Al	Lowest	3-8	31%-60%
	Medium	8-15	60%-81%
	Highest	>15	81%-100%
p+Au	Lowest	3-12	15%-43%
	Medium low	12-24	43%-69%
	Medium high	24-36	69%-88%
	Highest	>36	88%-100%

Di- π^0 correlation in 3 ΣE_{BBC} bins in pAl,
4 ΣE_{BBC} bins in pAu.



Di- π^0 correlations in “high activity” pAu

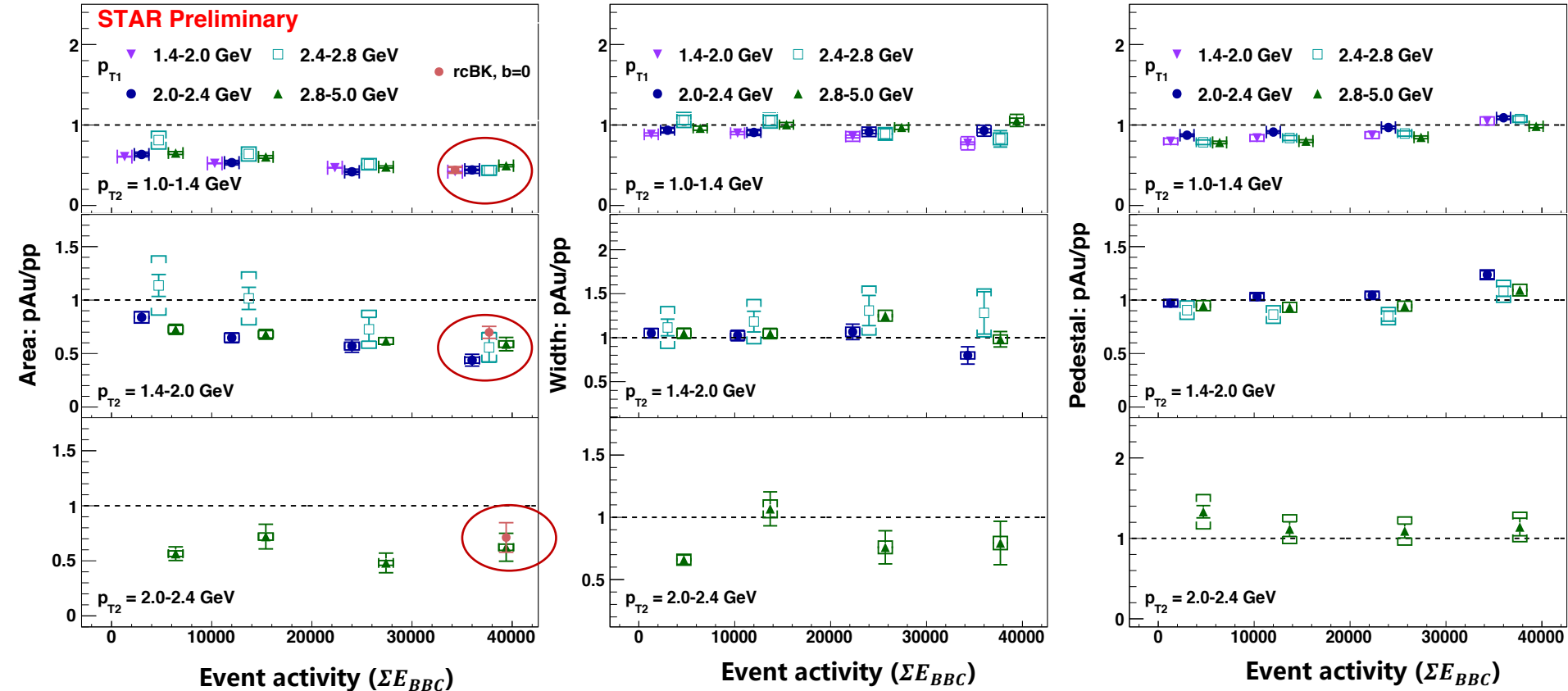
p_{T1}



Event activity dependence in pAu

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

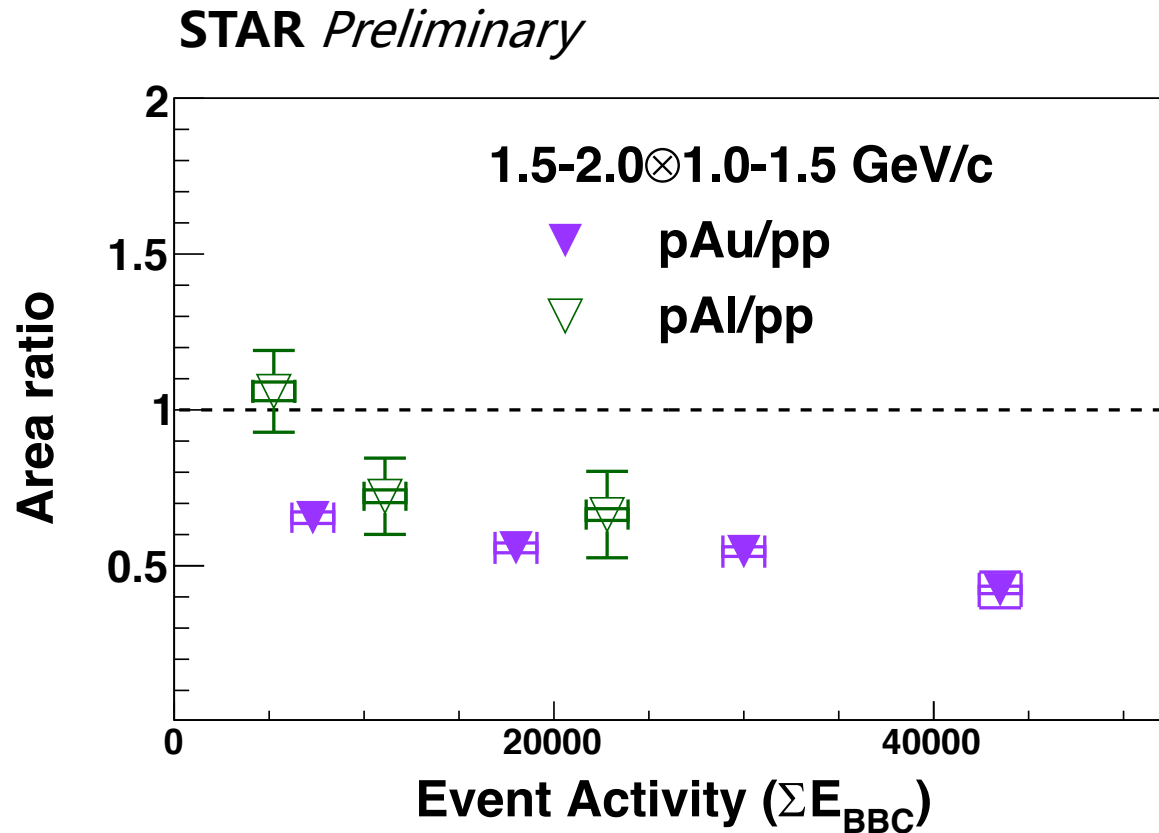
pp, pAu: $\sqrt{s_{NN}} = 200 \text{ GeV}, 2.6 < \eta < 4.0$



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

Event activity dependence in pAl

pp, pAl and pAu: $\sqrt{s_{NN}} = 200$ GeV
 $2.6 < \eta < 4.0$

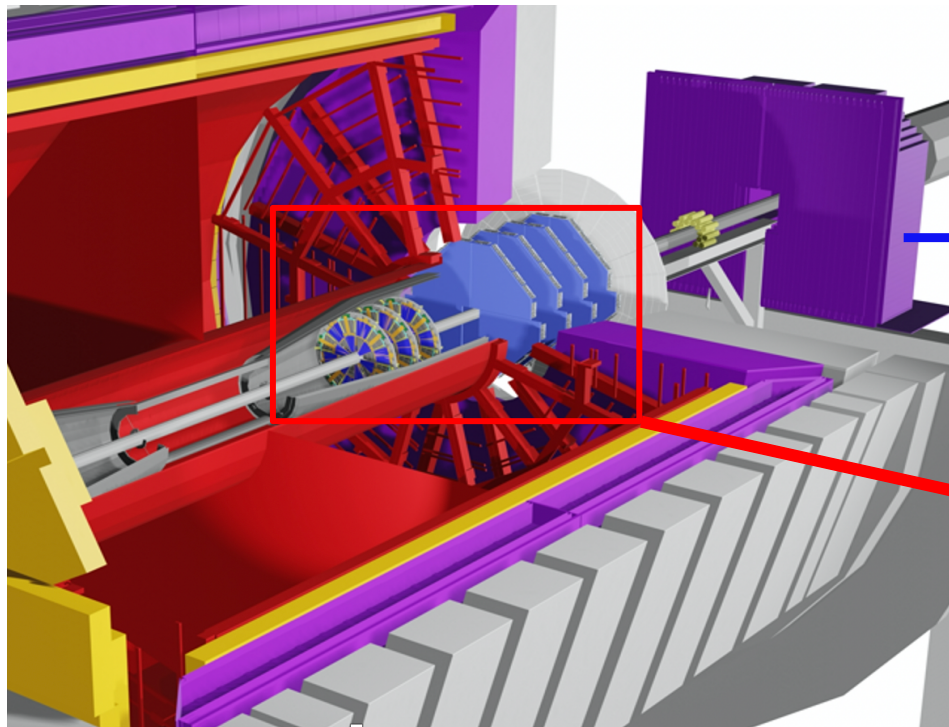


- pAl: indication of enhanced suppression in “high activity” events.

STAR forward upgrade

STAR forward upgrade will be completed in 2022: $2.5 < \eta < 4$

See Ting Lin's talk for details



Forward Calorimeter System

- EMcal and Hcal

Forward Tracking System

- Si disks + Small Thin Gap Chambers (STGC) for tracking

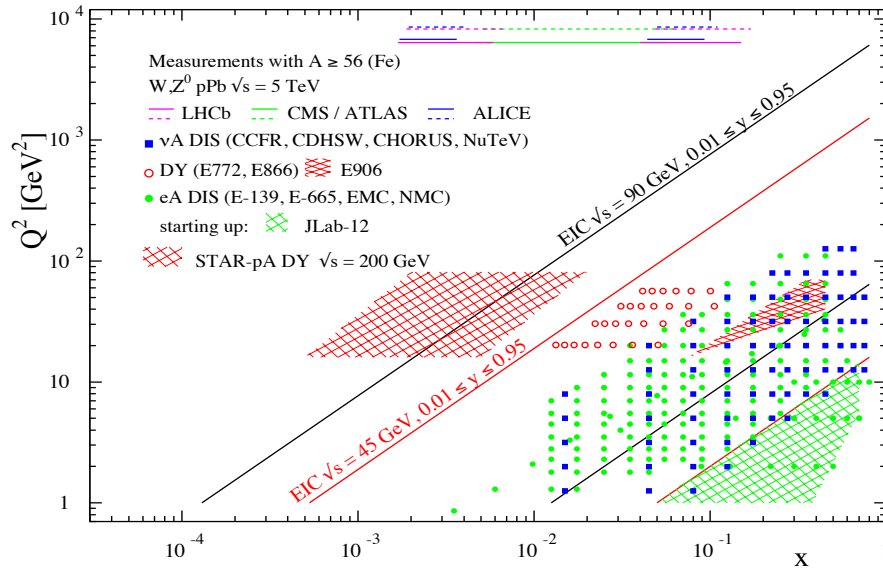
Gluon saturation with forward upgrade

- Provide variety of high precision data to test universality of CGC $\leftrightarrow$ EIC
- Expand observables: charged hadrons, photon-jet, dijet...

R_{pA}^γ @ STAR forward upgrade

E.C. Aschenauer et al., arXiv:1602.03922

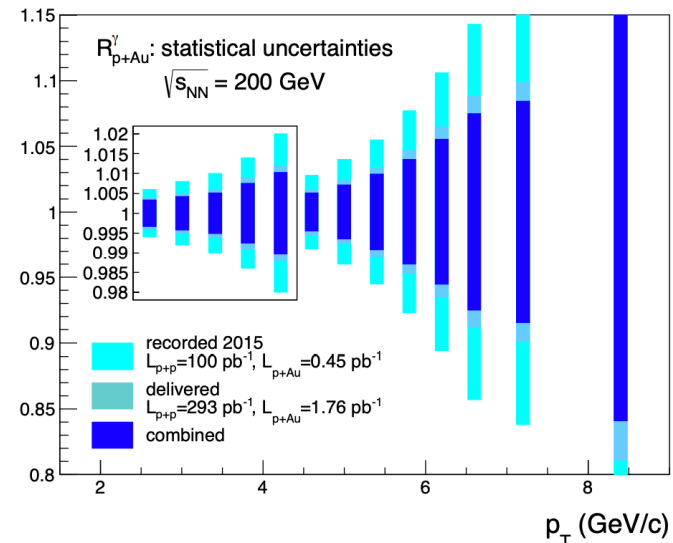
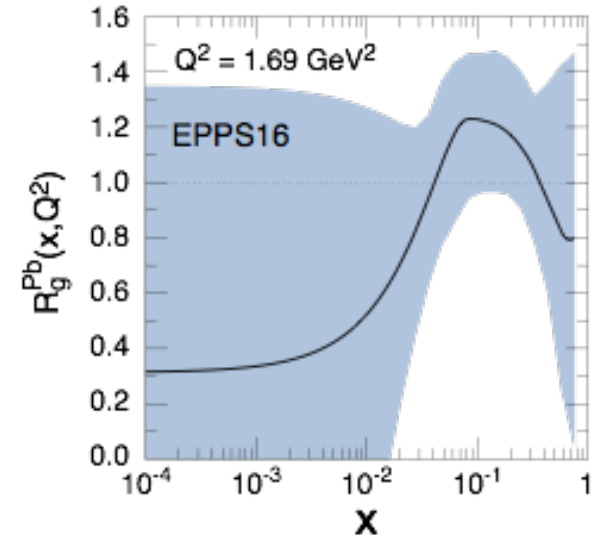
pA@RHIC kinematics range



- **Direct photon measurements:** $g+q \rightarrow \gamma+q$, probes not subject to the strong interaction from the final state
- **STAR forward upgrade:** better constraint on gluon distributions with higher delivered integrated luminosity in pA

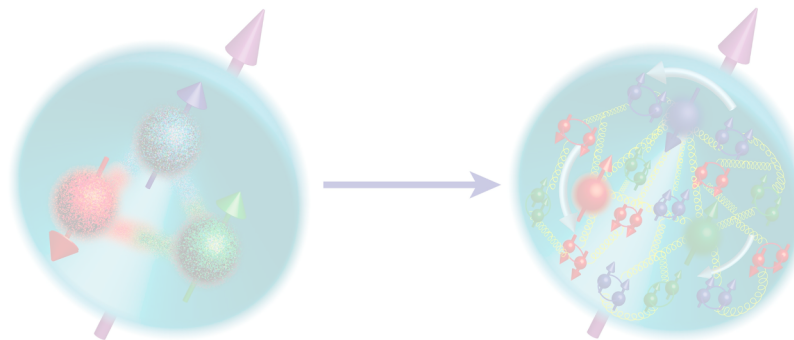
See Ting Lin's talk for details

Current knowledge of nuclear gluon distribution



Summary

- ❑ 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

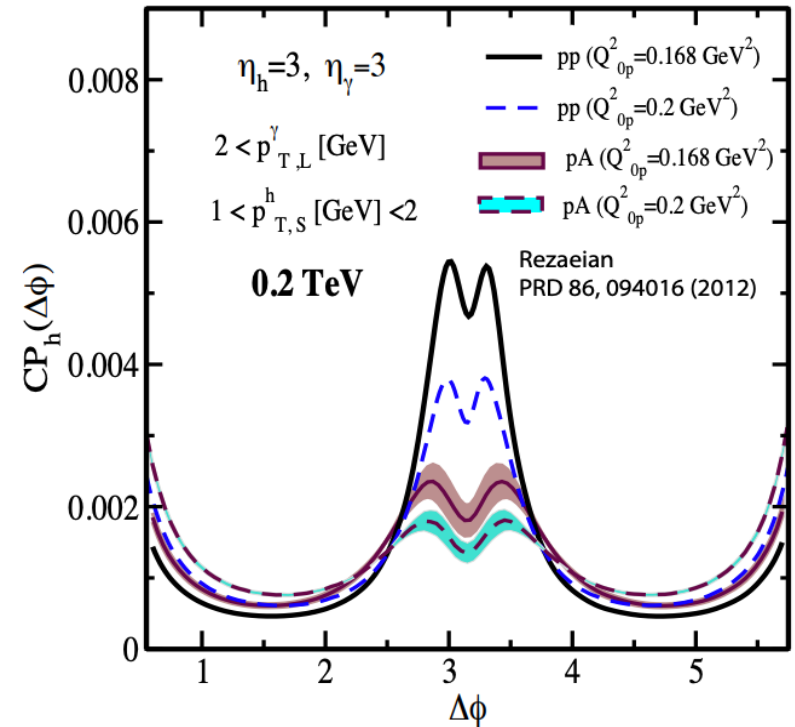
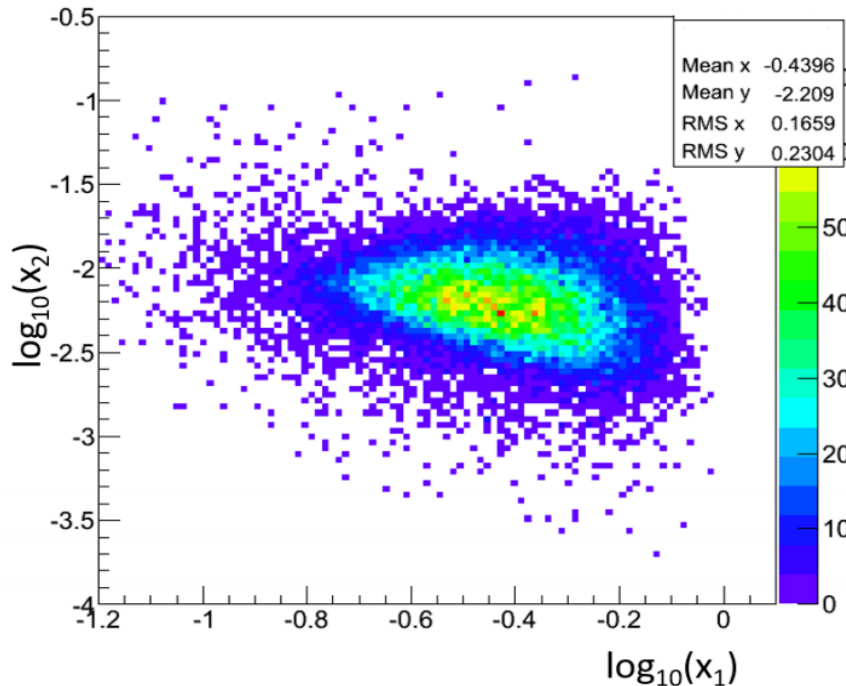


Back up

γ +jet/h @ STAR forward upgrade

1M events with forward upgrade in 2023 pAu

Amir H. Rezaeian, PRD 86, 094016 (2012)



- Forward tracking system: complementary probes to the $\text{di-}\pi^0$ correlations -- charged di-hadron, γ -jet and di-jet
- Challenging due to small cross section; background of di-jet events with photons from fragmentation or hadron decay