IS2021

The VI[th] International Conference on the
INITIAL STAGES
OF HIGH-ENERGY NUCLEAR
COLLISIONS

Di-hadron correlations in pp and pA collisions at STAR

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(For the STAR Collaboration)
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STAR

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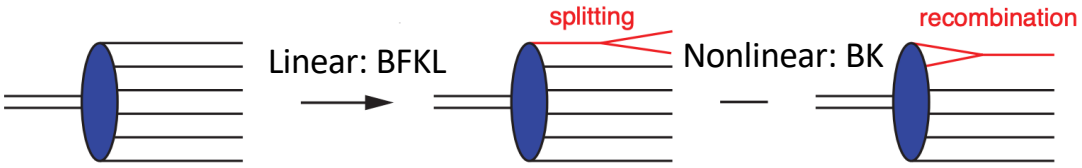
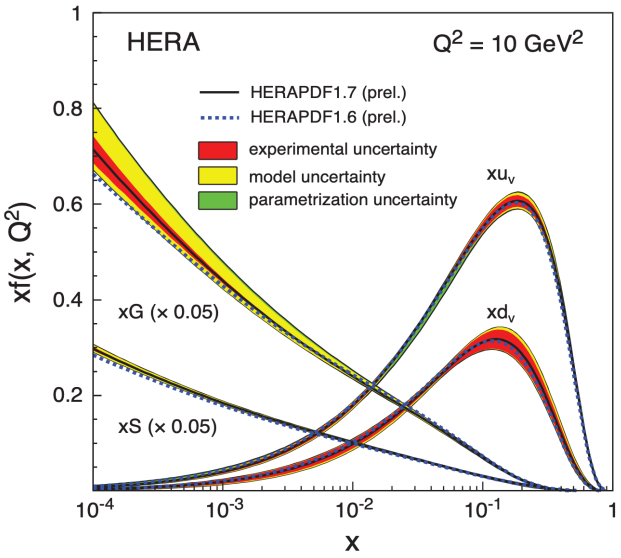
Gluon dynamics at small x

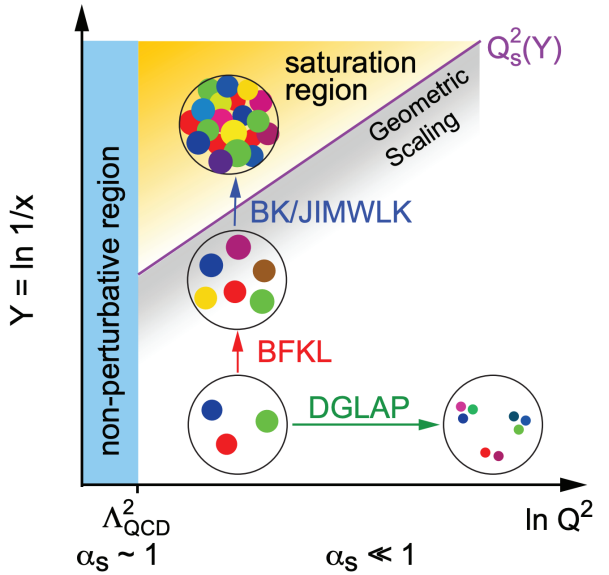
- **P**arton **D**istribution **F**unctions: at small x, nucleon wave function is dominated by gluons; the rise of gluon density has to stop at some point → saturation
- Saturation scale Q_S^2: when $Q^2 < Q_S^2$, gluon splitting and recombination reach a balance
- Gluon dynamics transfer from linear to non-linear: DGLAP/BFKL → BK/JIMWLK
- Large Q: small α_s → perturbative QCD calculations under control



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

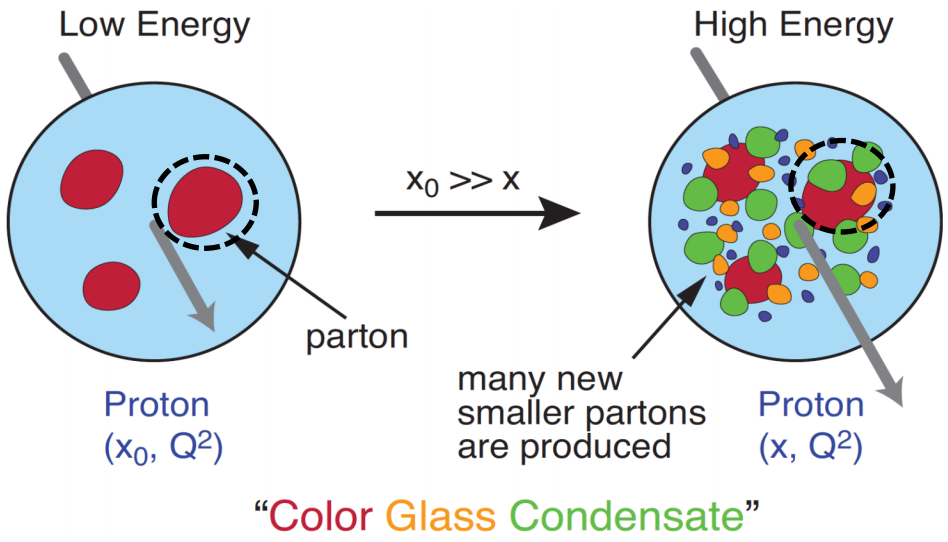
BK: $\frac{\partial N(x,r_T)}{\partial \ln(1/x)} = \alpha_s K_{\mathrm{BFKL}} \otimes N(x,r_T) - \alpha_s [N(x,r_T)]^2$



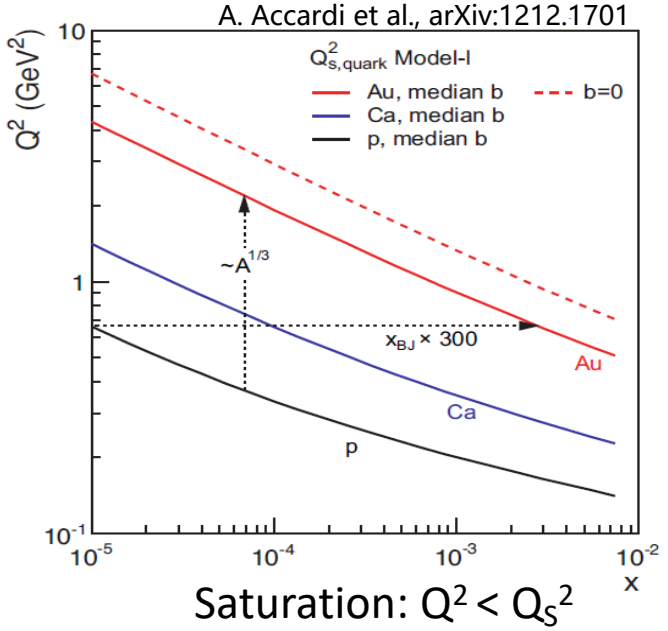


Saturation scale Q_s^2 : x and A dependence

- Transverse distance between partons decreases as the 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



A. Accardi et al., arXiv:1212.1701

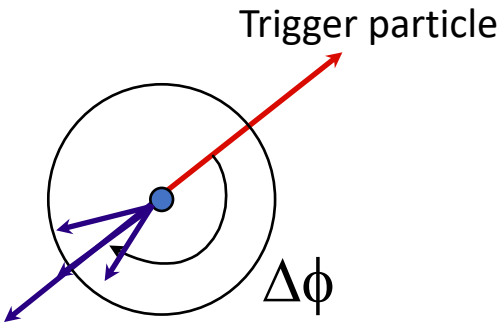


Saturation: $Q^2 < Q_S^2$

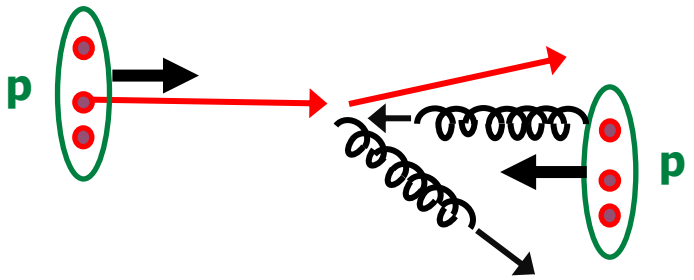
$$Q_s^2(x) \sim A^{1/3}\left(\frac{1}{x}\right)^{\lambda} \sim \left(\frac{A}{x}\right)^{1/3}$$

Multiple scattering

beam-view



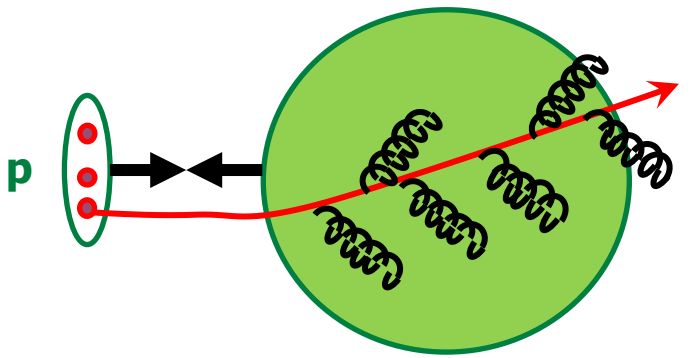
side-view



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

- **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 ⇒ back-to-back di-hadron
- **pA**: back-to-back configuration is smeared by multiple gluon interactions

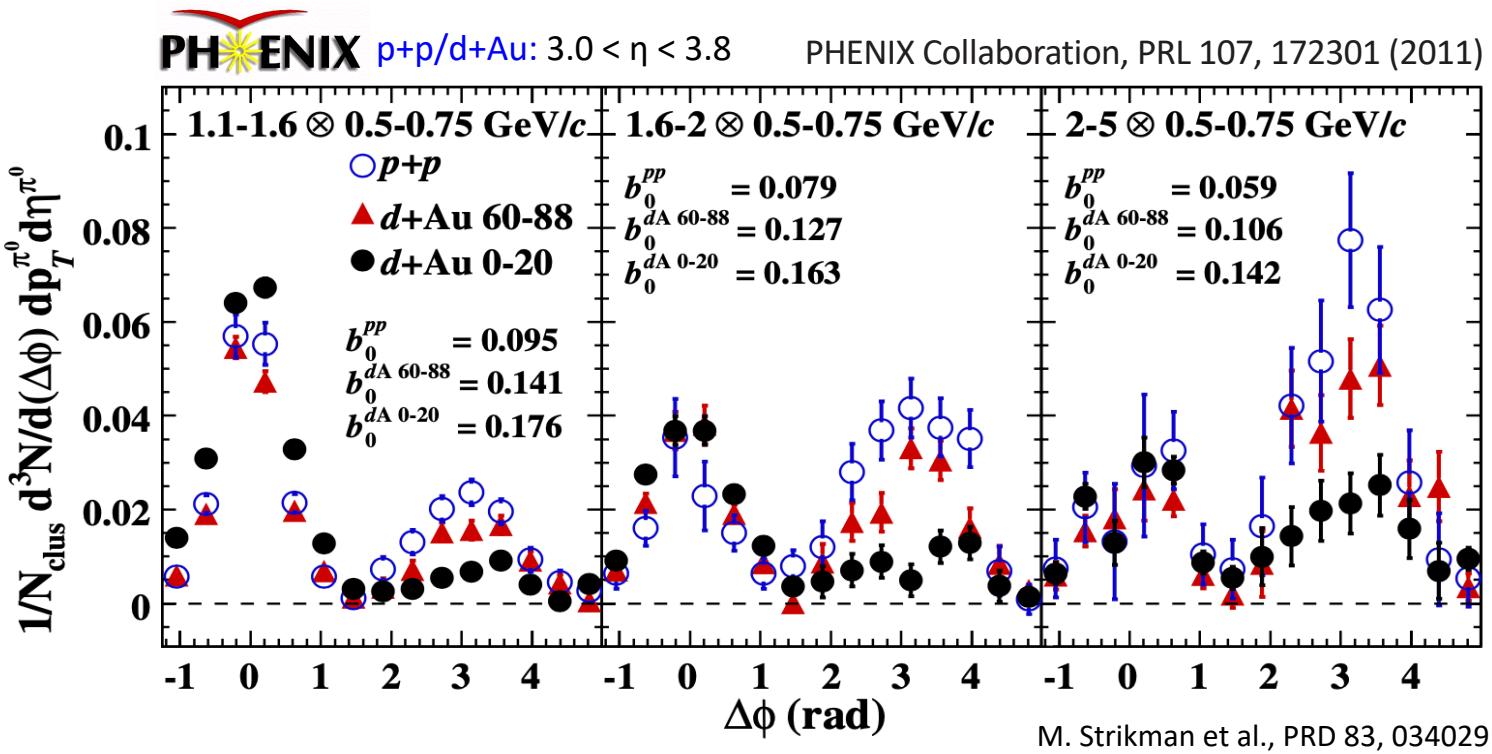
Dense gluon field (Au)



P_T is balanced by many gluons

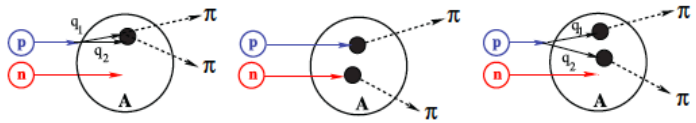
$$x_A = \frac{p_{T1}\, e^{-y_1} + p_{T2} e^{-y_2}}{\sqrt{s}} \ll x_p = \frac{p_{T1}\, e^{y_1} + p_{T2} e^{y_2}}{\sqrt{s}}$$

Di-π^0 correlations in dAu



M. Strikman et al., PRD 83, 034029 (2011)

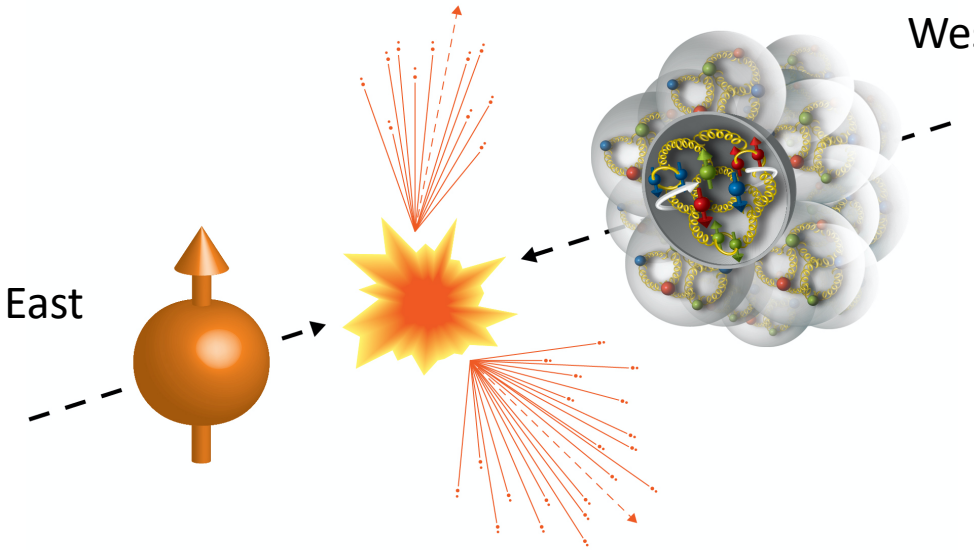
Possible contribution from double parton interaction to the cross section? →



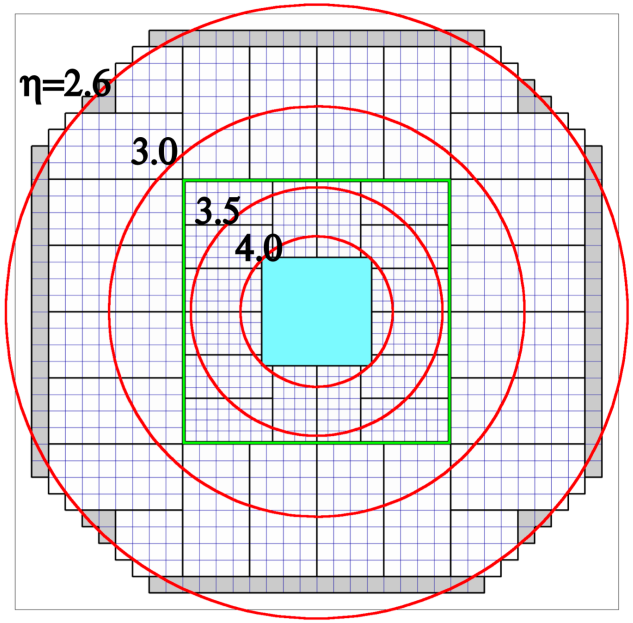
- dAu: complicated interpretation of suppression due to alternative explanation; much higher pedestal in dAu

→ **pAu collisions are theoretically and experimentally cleaner**

STAR forward detector



FMS: $2.6 < \eta < 4.1$

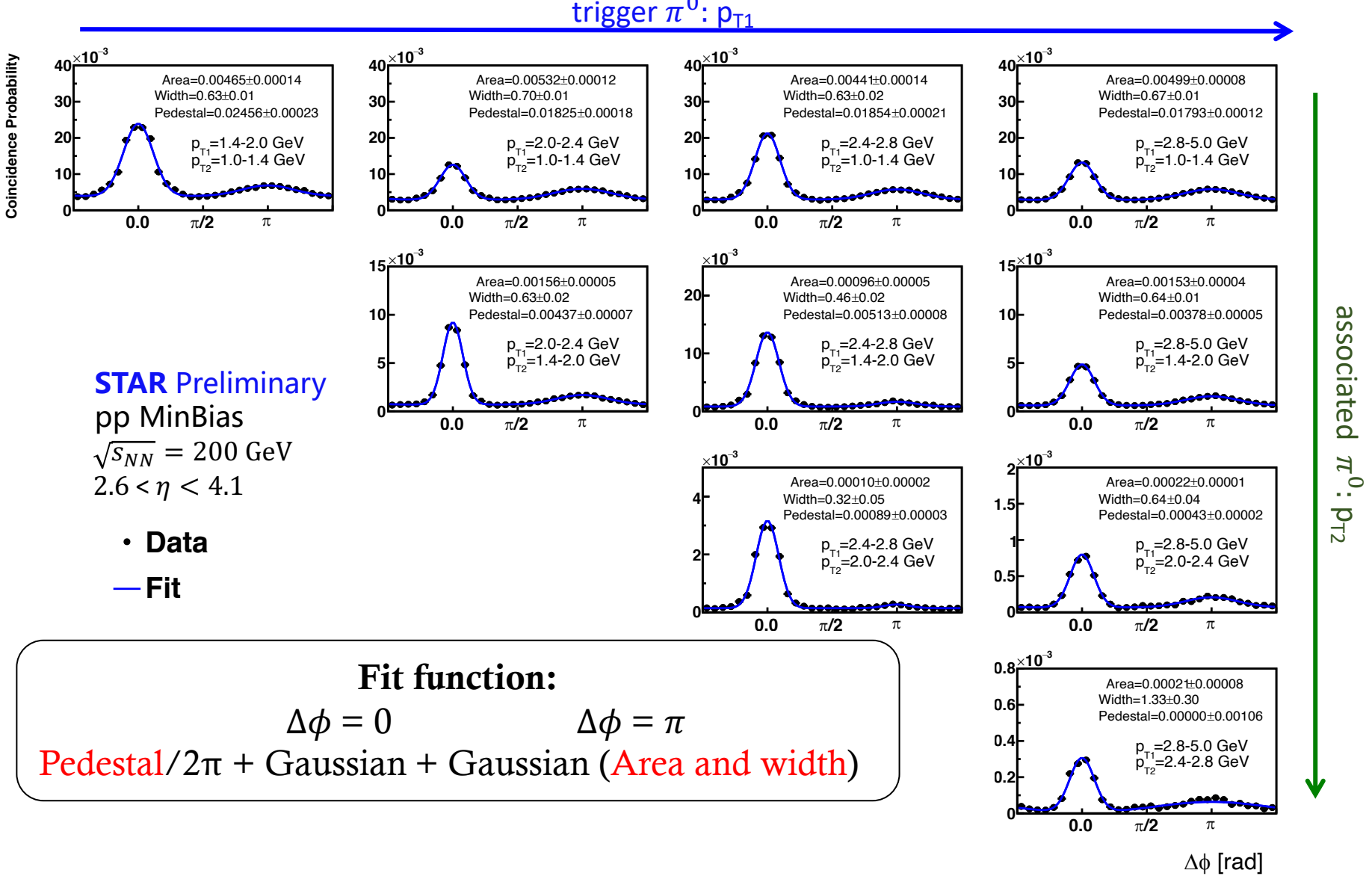


p+p and p+A collisions at $\sqrt{s_{NN}} = 200$ GeV

- 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



STAR Preliminary
pp MinBias
$\sqrt{s_{NN}} = 200$ GeV
$2.6 < \eta < 4.1$

- **Data**
- **Fit**

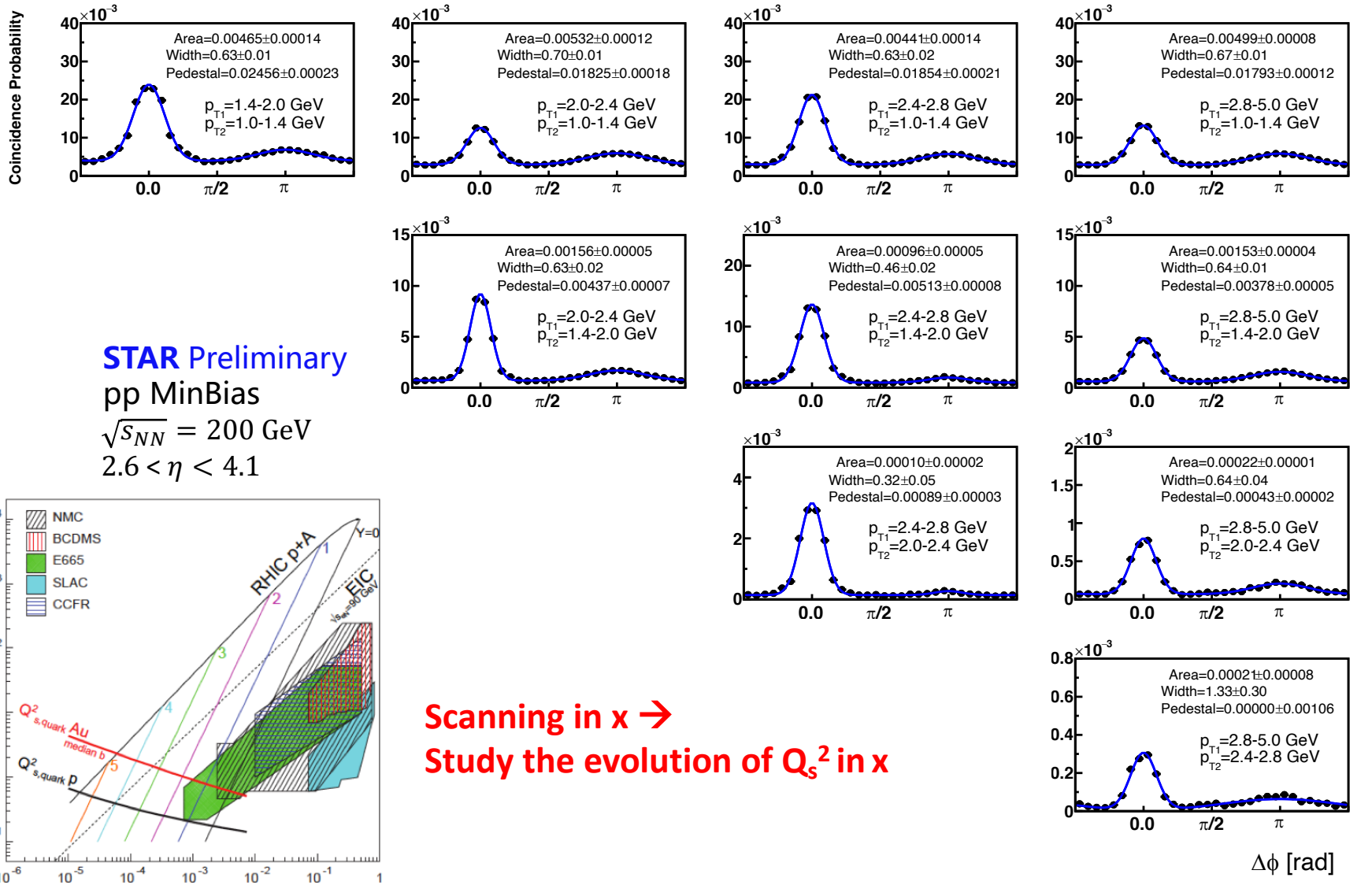
Fit function:

$\Delta\phi = 0$ $\Delta\phi = \pi$

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

Di-π^0 correlations in pp

trigger π^0: p_{T1}



STAR Preliminary
pp MinBias
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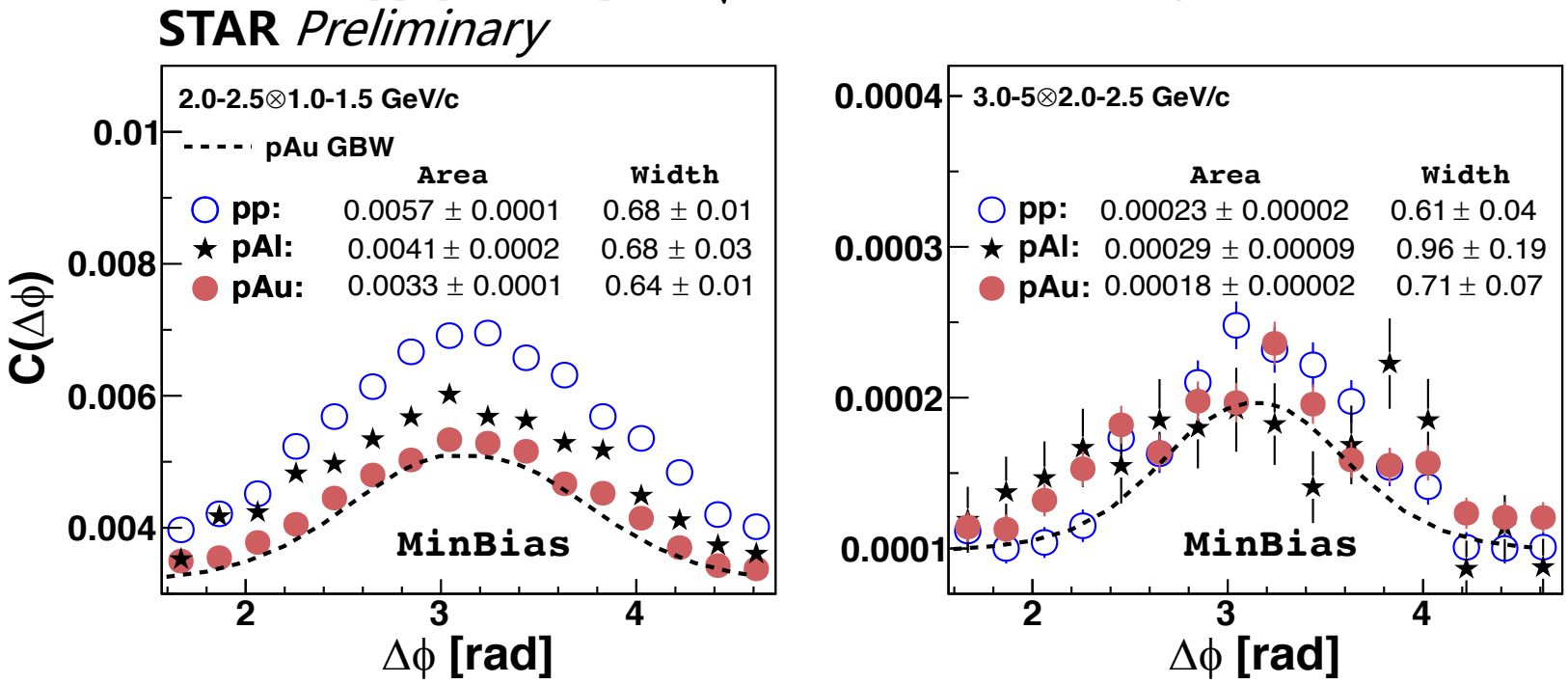
Scanning in x →
Study the evolution of Q_s^2 in x

Di-π^0 correlations in pp and pA

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

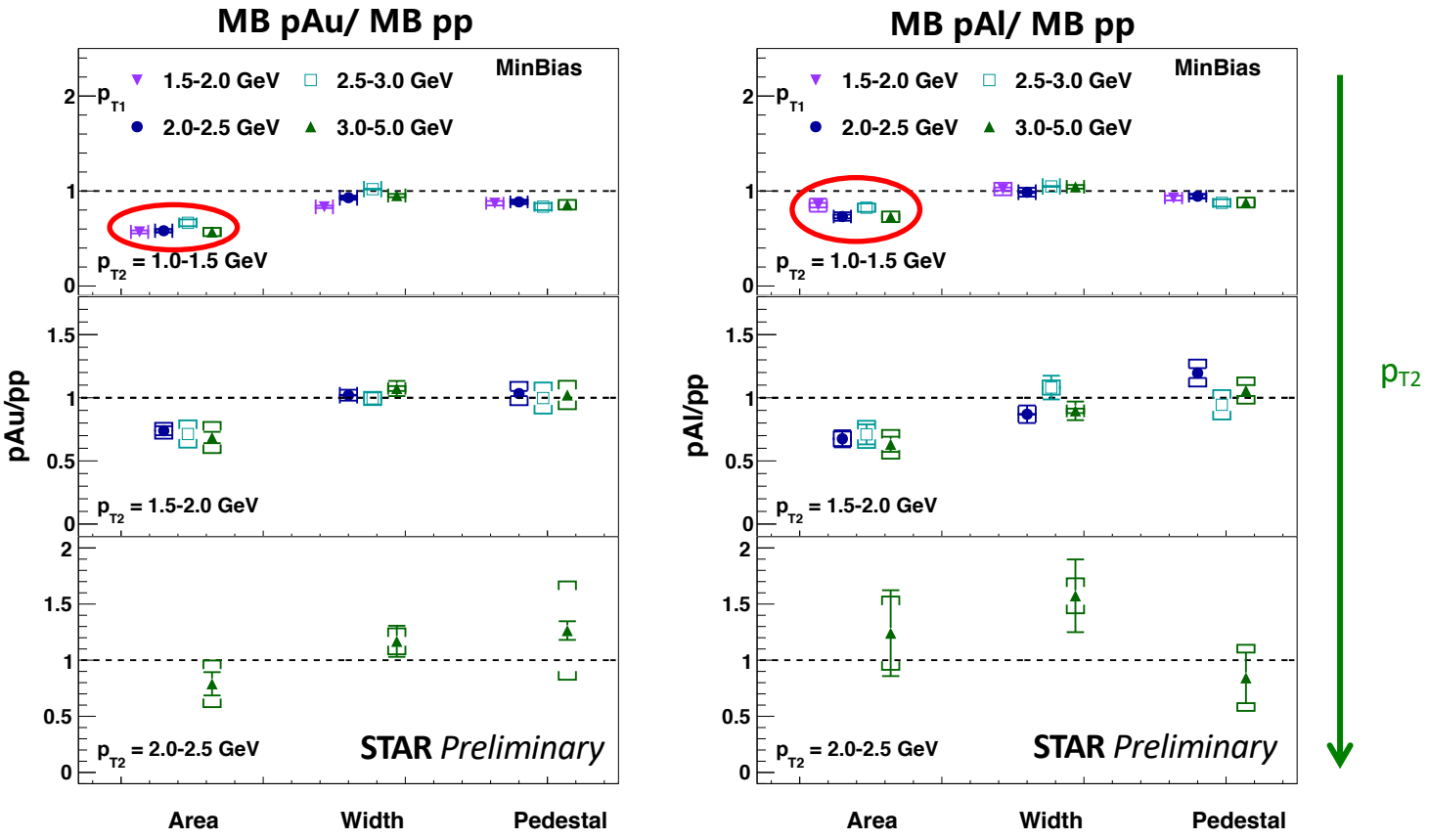


GBW: A. Stasto et al., PLB 716(2012) 430-434

- **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 → 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

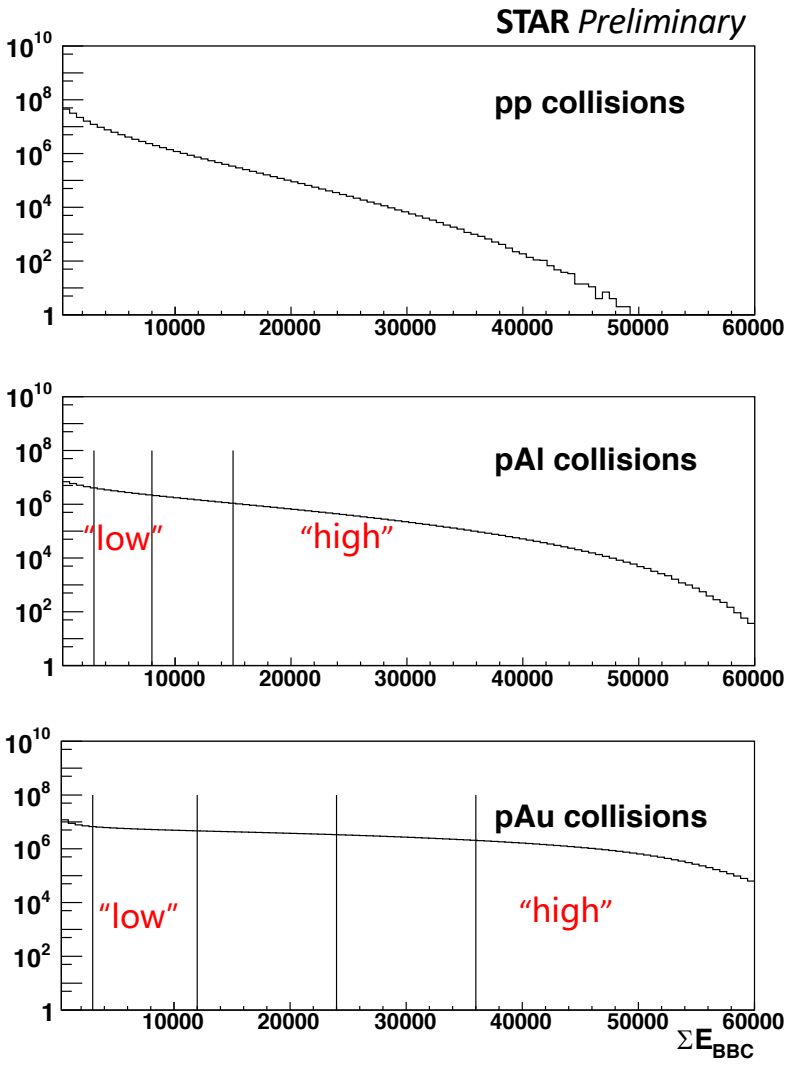
Event activity

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

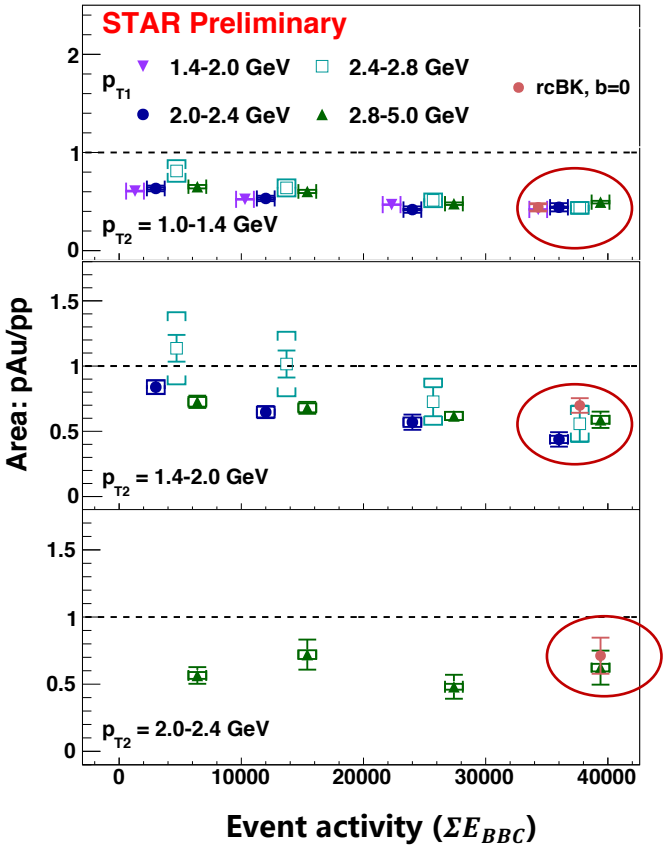
Beam species	Event activity	ΣE_{BBC} range ($\times 10^3$)	Class
p+Al	Lowest	3-8	31%-60%
	Medium	8-15	60%-81%
	Highest	>15	81%-100%
p+Au	Lowest	3-12	15%-43%
	Medium low	12-24	43%-69%
	Medium high	24-36	69%-88%
	Highest	>36	88%-100%



Event activity dependence in pAu

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

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



- Suppression depends on event activity → 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

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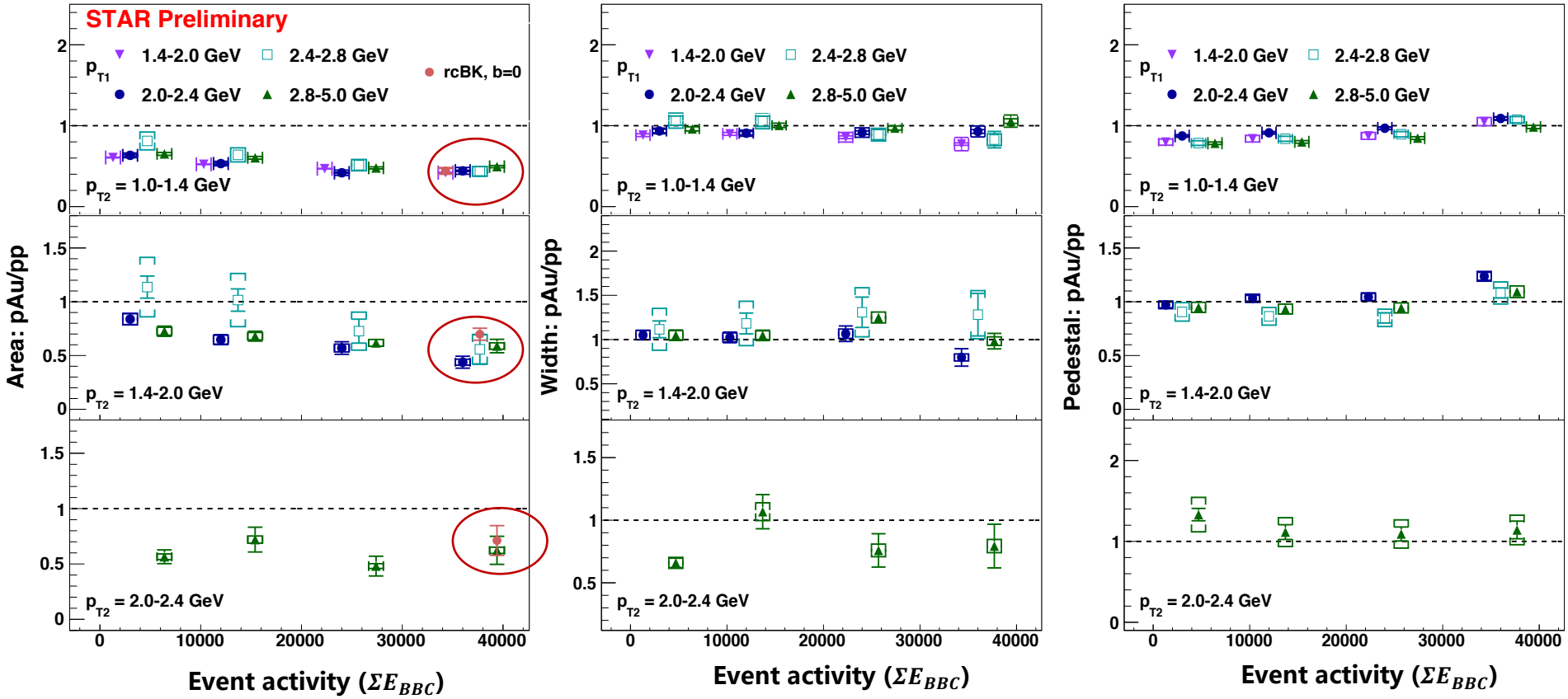
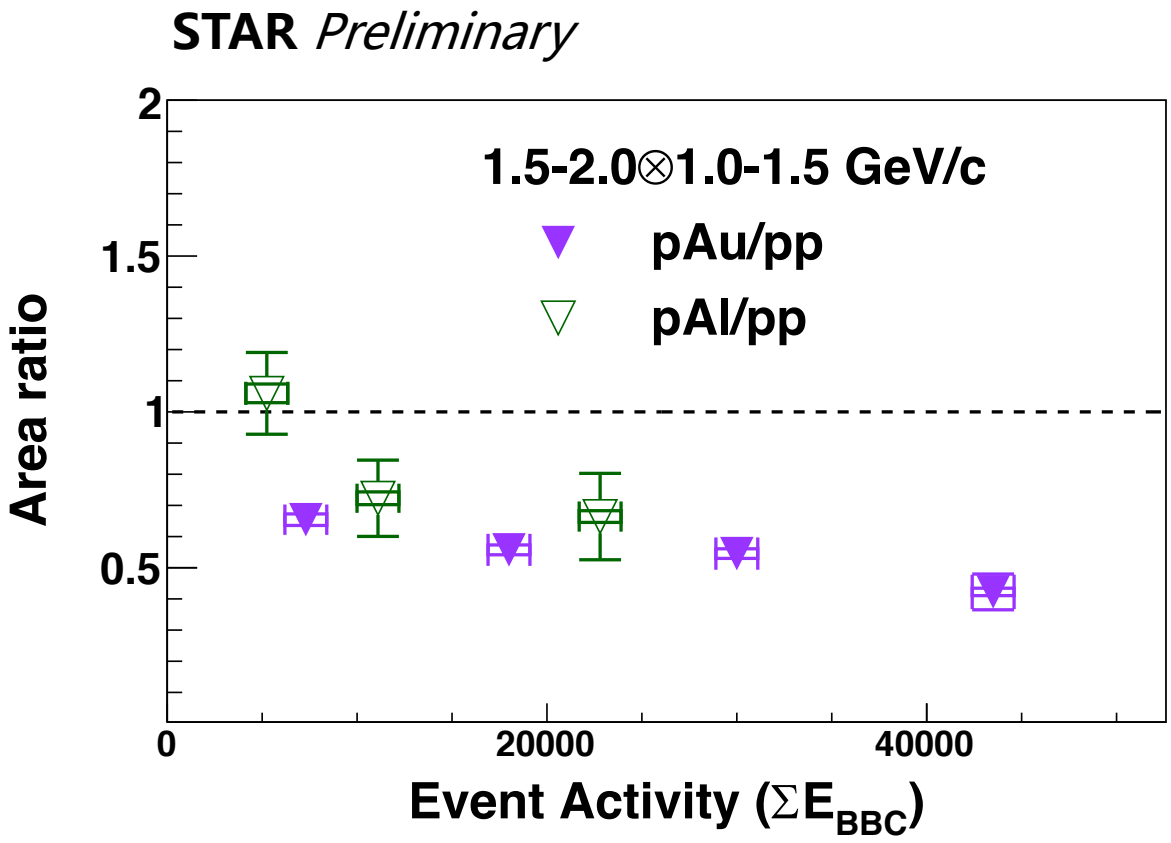


- Suppression depends on event activity → enhanced in high activity events
- Suppression at highest activity events is consistent with predictions based on gluon saturation model: rcBK at b=0
- Width and pedestal are stable in pp and pAu

Event activity dependence in pAl

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

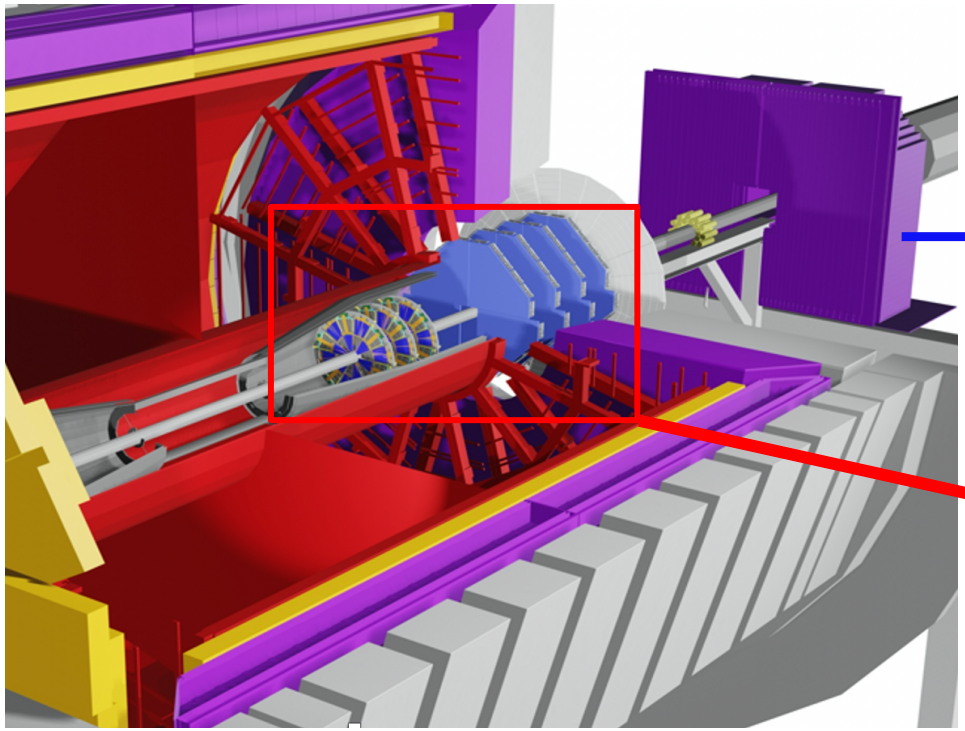


- pAl: indication of enhanced suppression in “high activity” events.

STAR forward upgrade

STAR forward upgrade will be completed in 2022: 2.5 < η < 4

See Ting Lin's talk for details



Forward Calorimeter System
- EMcal and Hcal

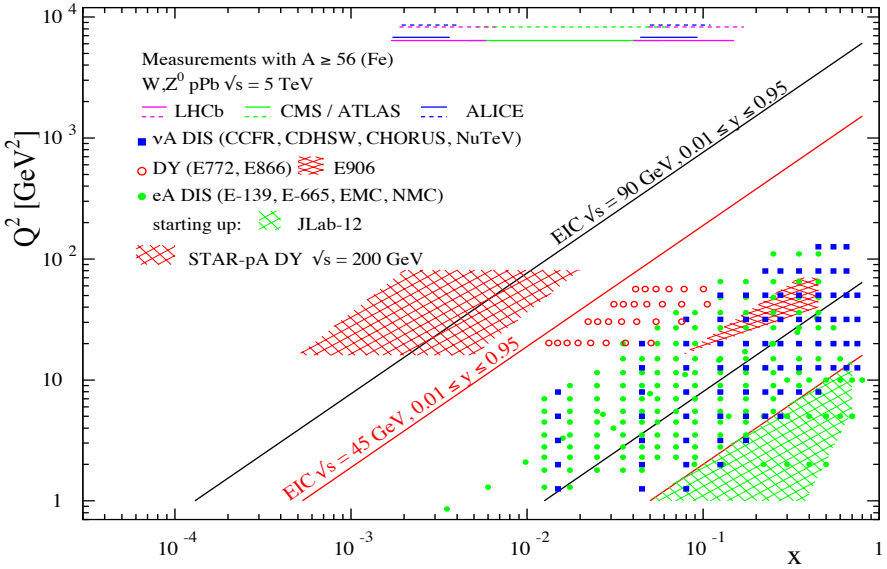
Forward Tracking System
- Si disks + Small Thin Gap Chambers (STGC) for tracking

Gluon saturation with forward upgrade
- Provide variety of high precision data to test universality of CGC ←→ EIC
- Expand observables: charged hadrons, photon-jet, dijet…

R_{pA}^{γ}@ STAR forward upgrade

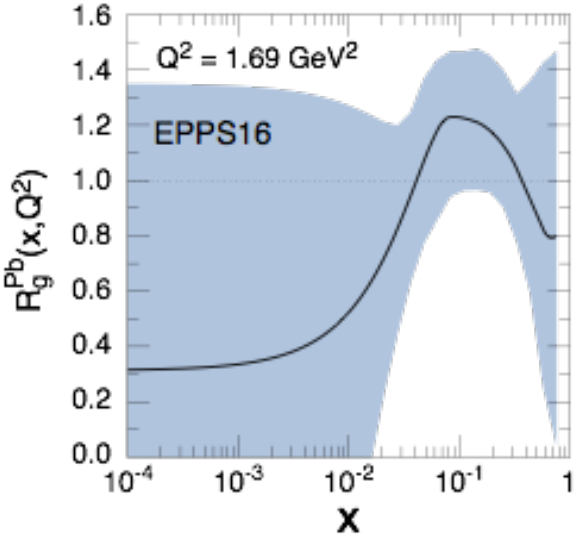
E.C. Aschenauer et al., arXiv:1602.03922

pA@RHIC kinematics range

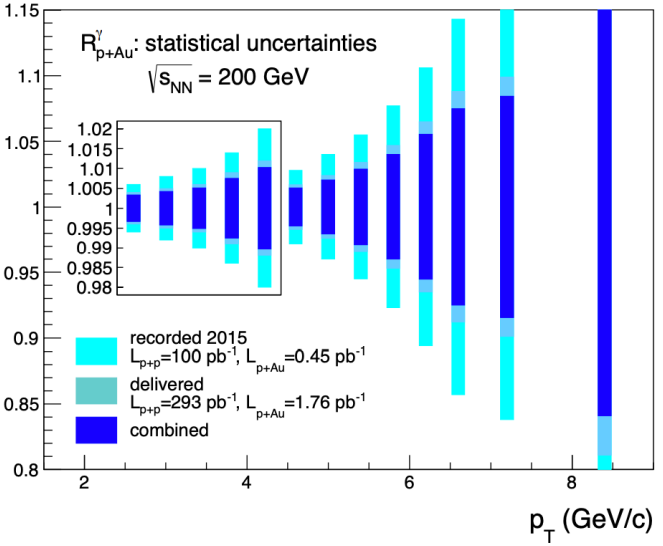


See Ting Lin's talk for details

Current knowledge of nuclear gluon distribution



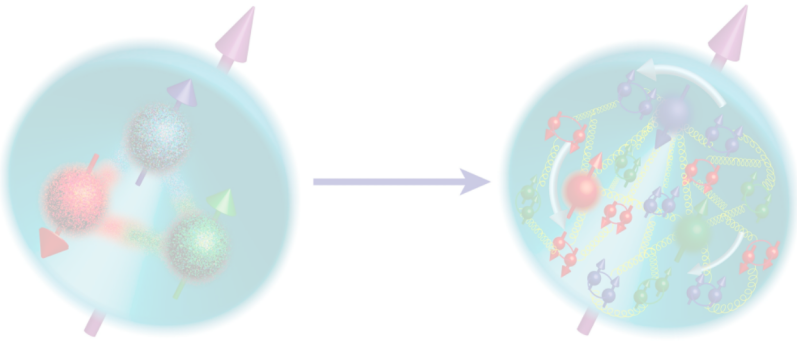
- **Direct photon measurements**: g+q→γ+q, probes not subject to the strong interaction from the final state
- **STAR forward upgrade:** better constraint on gluon distributions with higher delivered integrated luminosity in pA



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

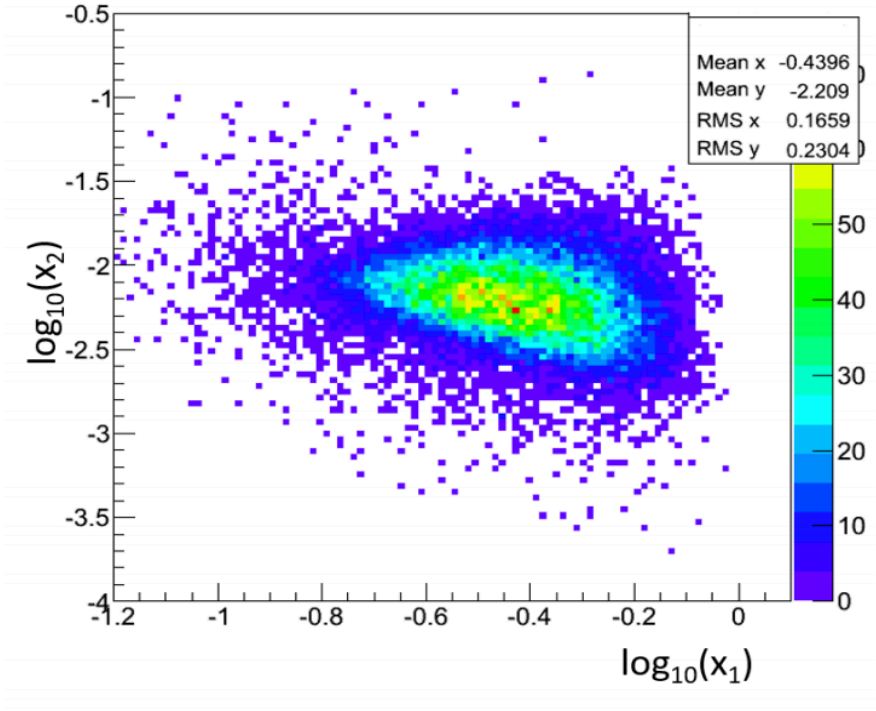
- Di-hadron correlation is a key measurement in the pA physics program at STAR
  - STAR shows a clear signature of non-linear gluon dynamics with di-hadron correlation measurement
  - First measurement of nuclear effect dependence on A: stronger suppression in pAu than pAl
  - Event activity dependence: suppression enhanced in “high activity” collisions at low p_T



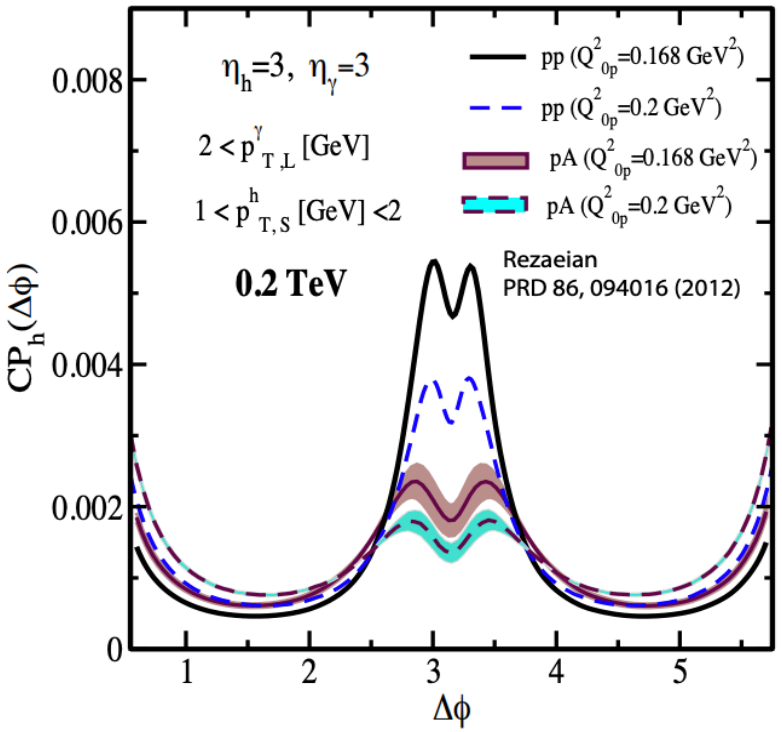
Back up

γ +jet/h @ STAR forward upgrade

1M events with forward upgrade in 2023 pAu

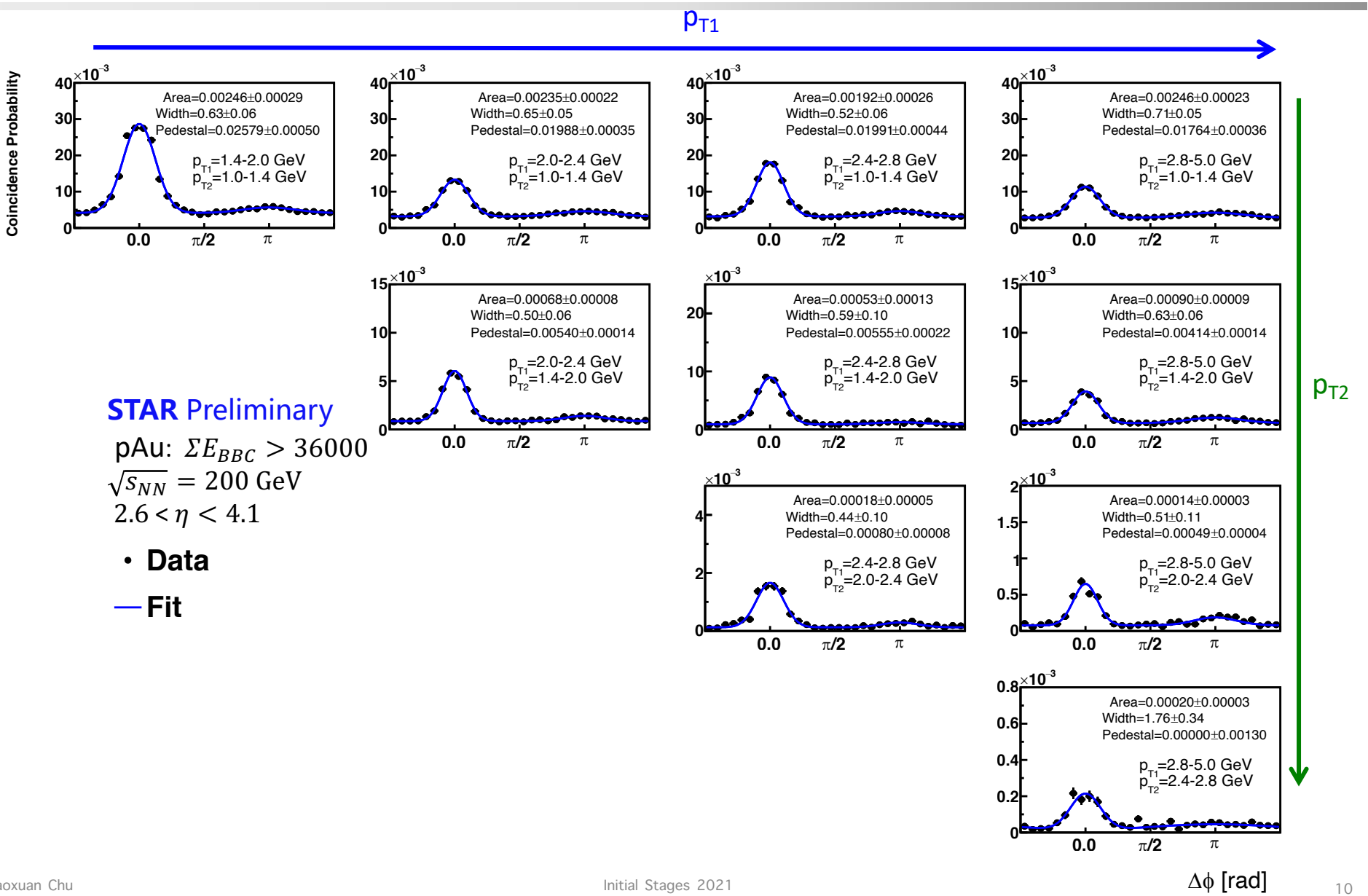


Amir H. Rezaeian, PRD 86, 094016 (2012)



- Forward tracking system: complementary probes to the di-π^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

Di-π^0 correlations in "high activity" pAu



STAR Preliminary

pAu: $\Sigma E_{BBC} > 36000$

$\sqrt{s_{NN}} = 200$ GeV

$2.6 < \eta < 4.1$

- **Data**
- **Fit**