Di-hadron correlations in pp and pA collisions at STAR

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STAR

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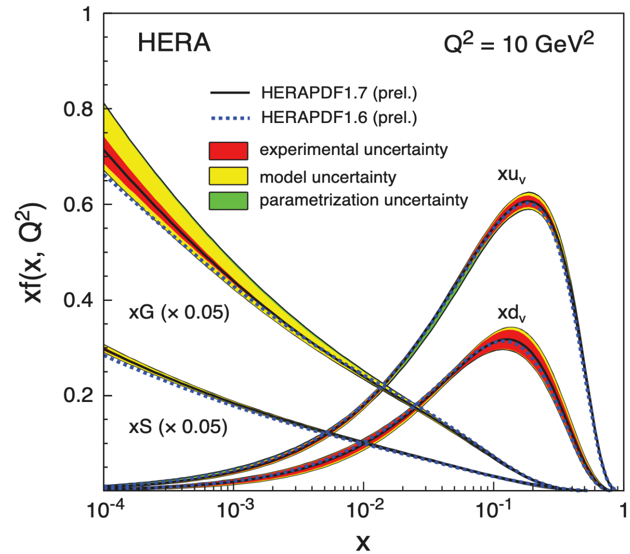
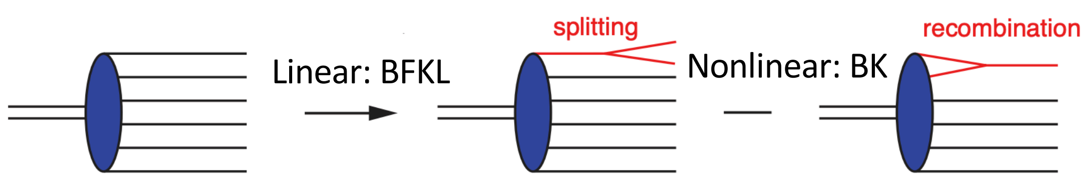
Gluon dynamics at small x

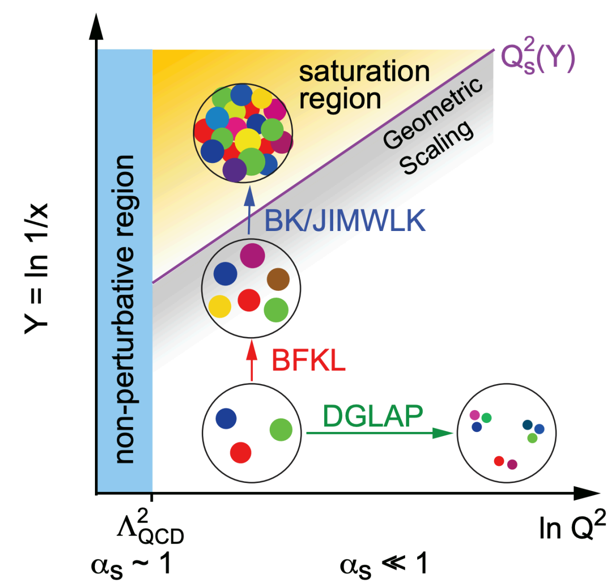
- **Parton Distribution Functions**: at small x, nucleon wave function is dominated by gluons; the rise of gluon density has to stop at some point → saturation
- Saturation scale Q_s^2: when $Q^2 < Q_s^2$, gluon splitting and recombination reach a balance
- Gluon dynamics changes from linear to non-linear: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





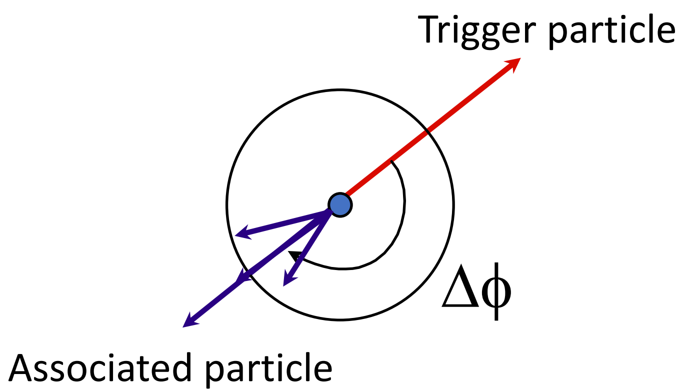
$$\text{BFKL:}\quad \frac{\partial N(x,r_T)}{\partial \ln(1/x)} = \alpha_s K_{\mathrm{BFKL}} \otimes N(x,r_T). \qquad N \sim (1/x)^{\lambda}$$

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



Multiple scattering

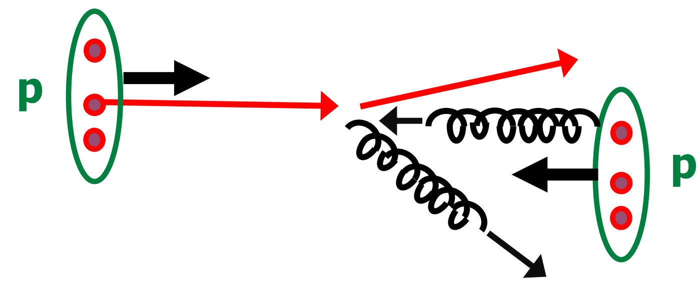
beam-view



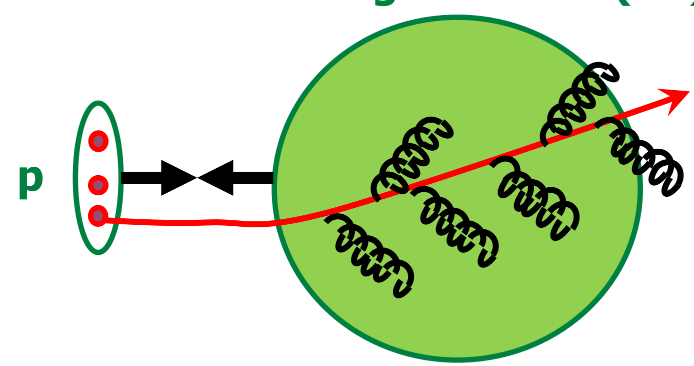
$$C(\Delta\phi) = \frac{N_{pair}(\Delta\phi)}{N_{trig} \times \Delta\phi}$$

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

side-view



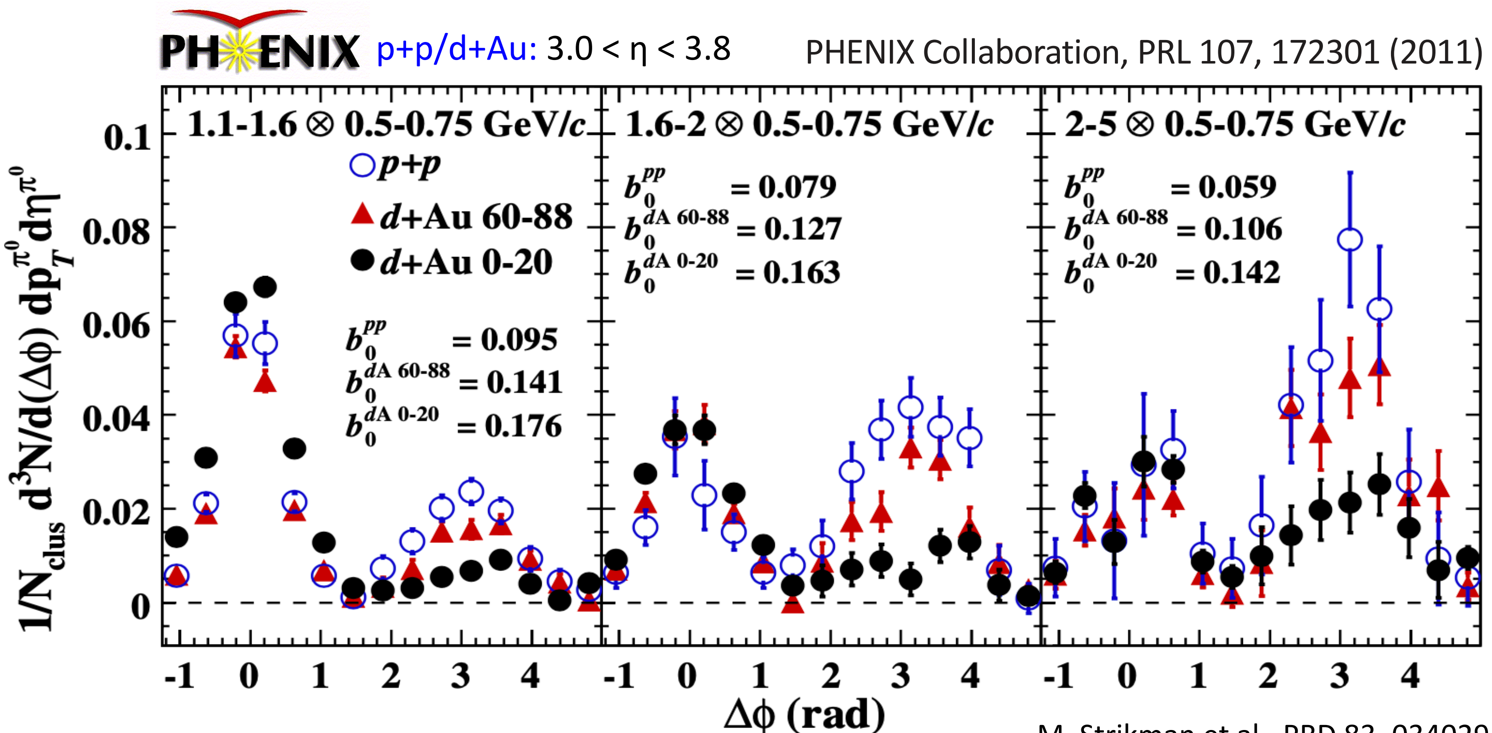
Dense gluon field (Au)



P_T is balanced by many gluons

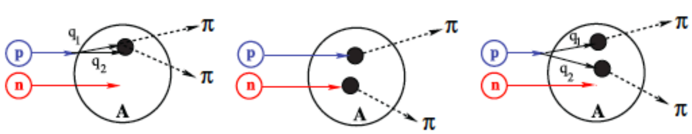
$$x_1 \sim \frac{p_{T1}e^{\eta_1} + p_{T2}e^{\eta_2}}{\sqrt{s}} \gg x_2 \sim \frac{p_{T1}e^{-\eta_1} + p_{T2}e^{-\eta_2}}{\sqrt{s}}$$

Di-π^0 correlations in dAu



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

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

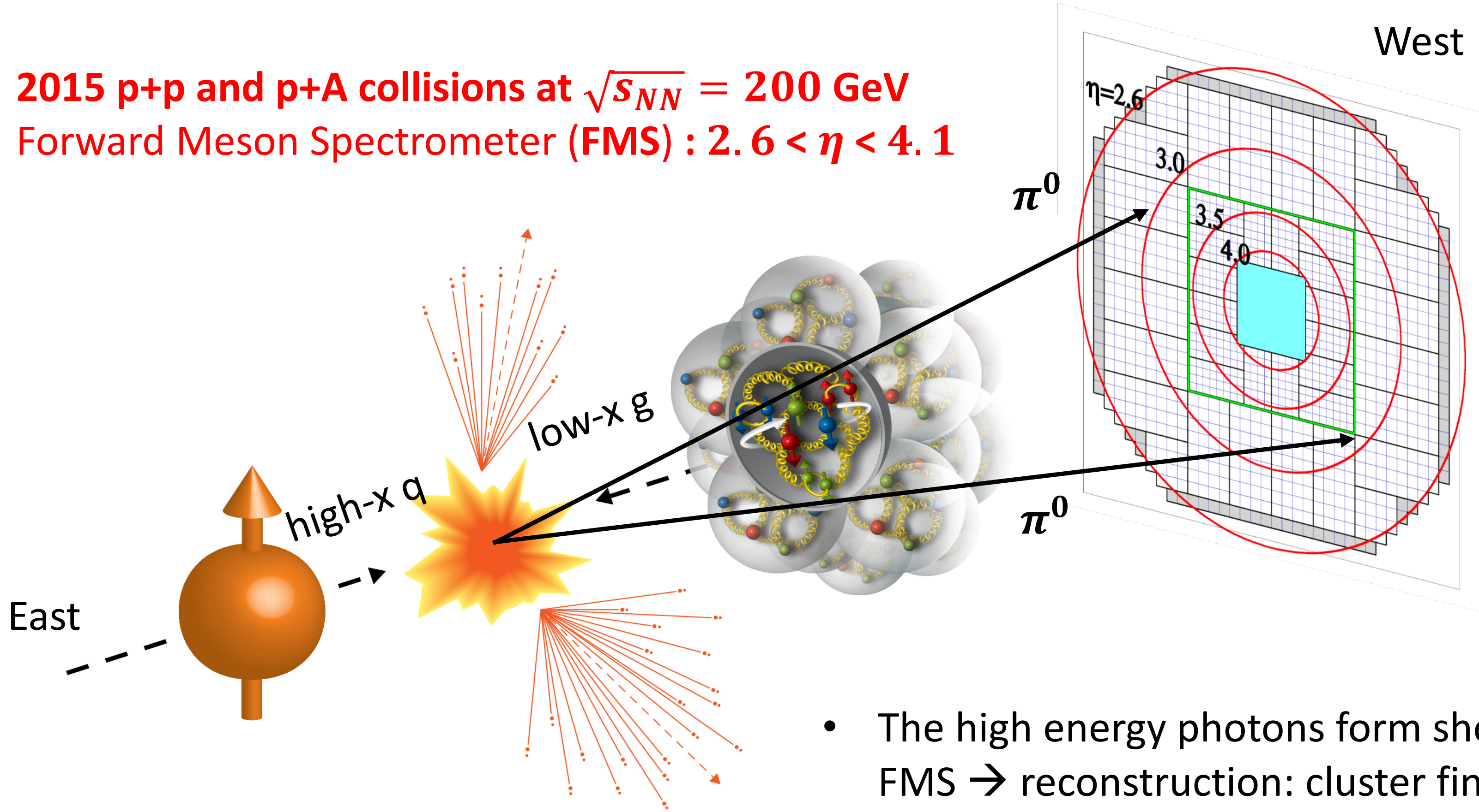


- dAu: interpretation of the suppression complicated by alternative explanation; much higher pedestal in dAu

→ **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**) : $2.6 < \eta < 4.1$

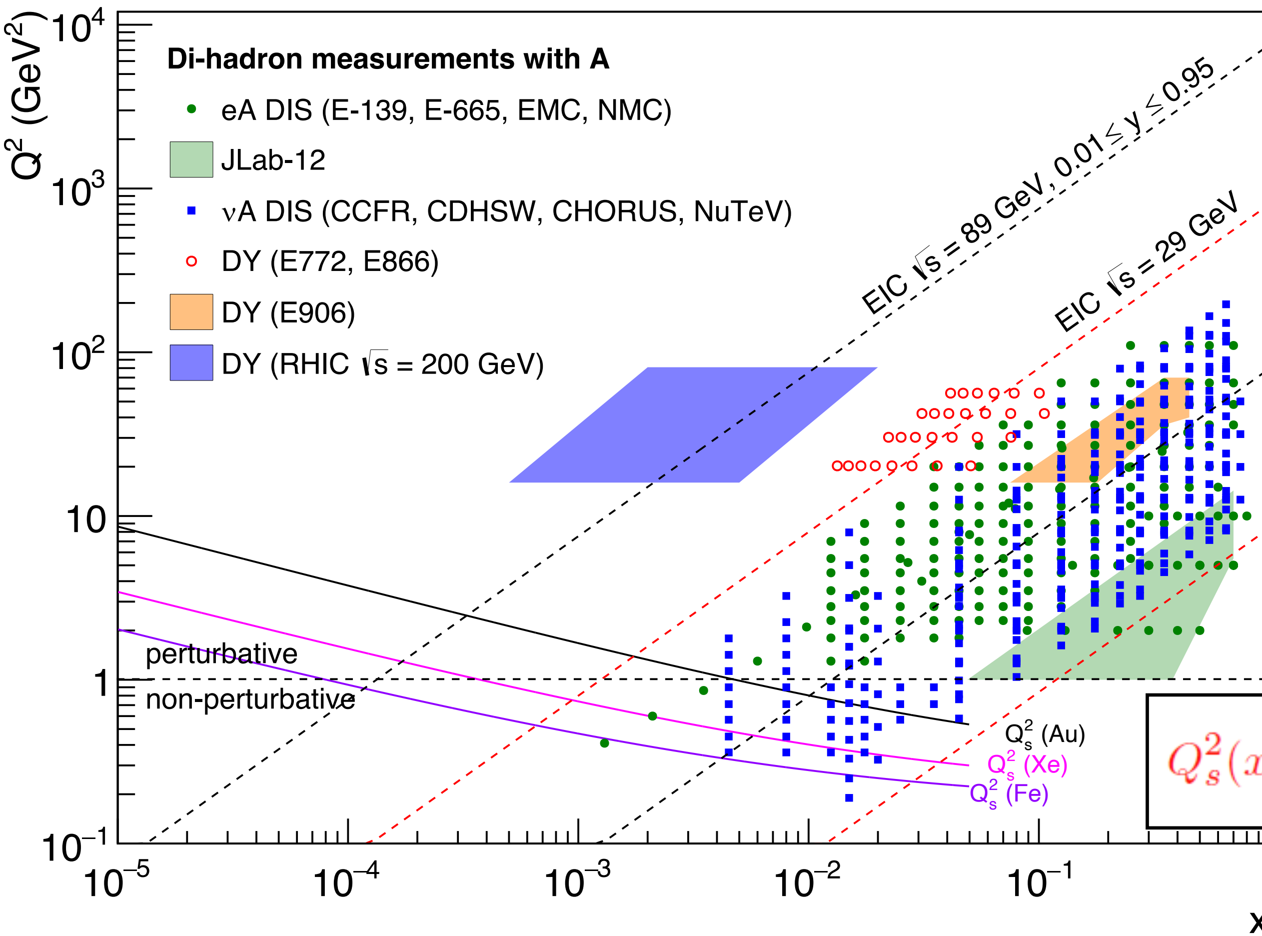


- Au, Al beams → A dependence
- Forward rapidity hadron production
  - can access low-x gluons with high-x quark probe

- The high energy photons form showers at FMS → 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

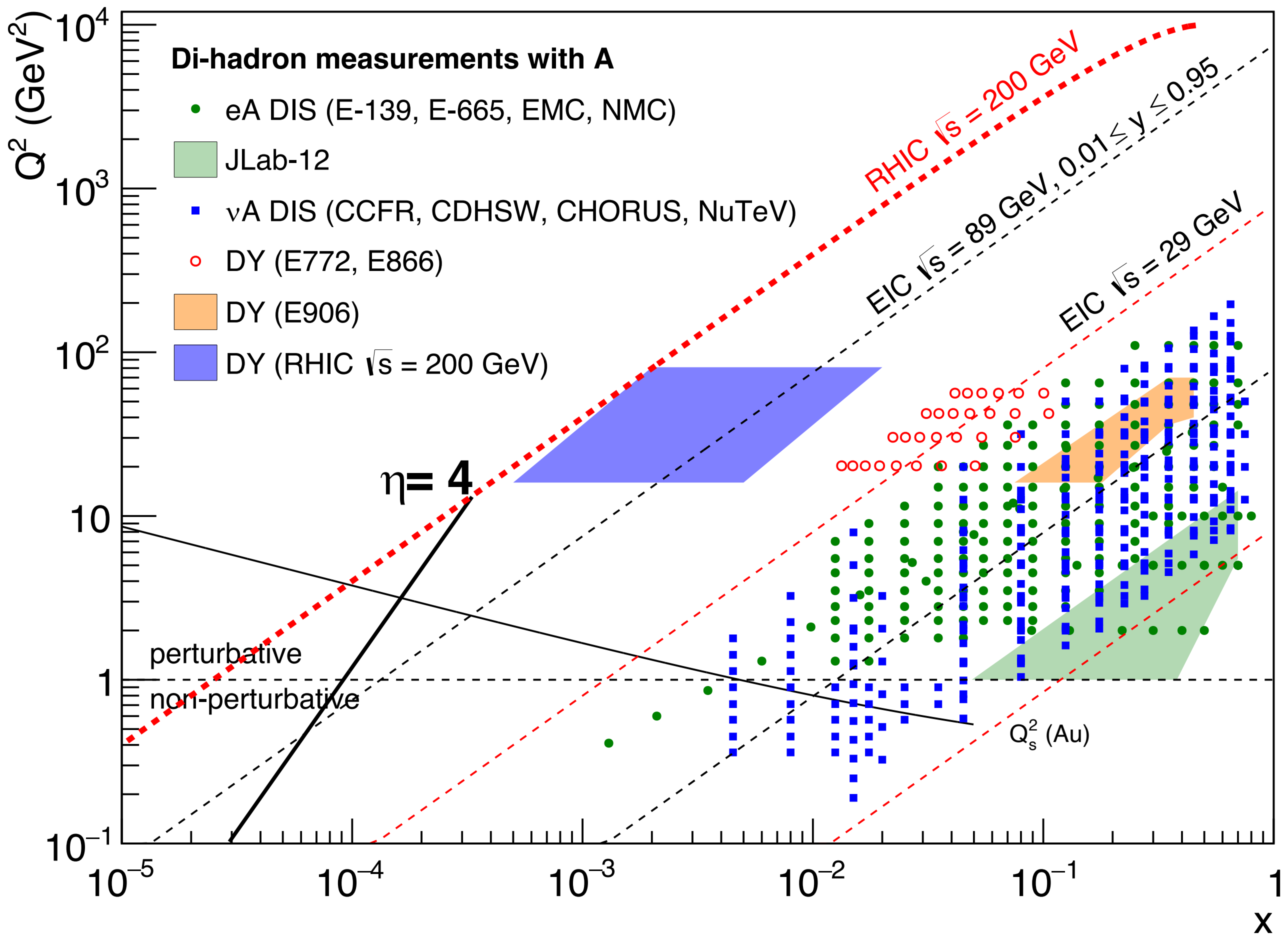
R. Abdul Khalek et al., arXiv:2103.05419



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

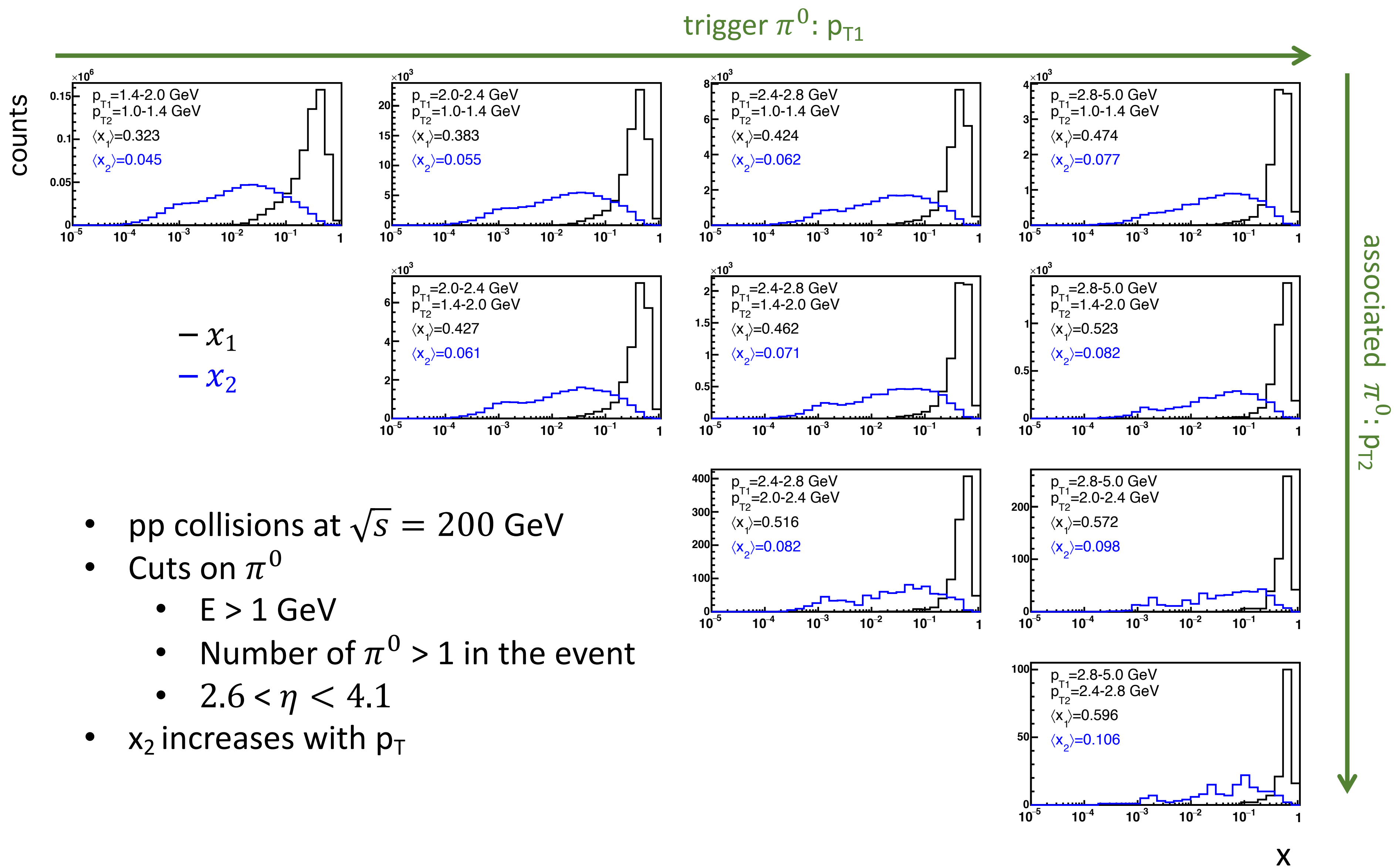
$$Q_s^2(x) \sim A^{1/3}\left(\frac{1}{x}\right)^{\lambda} \sim \left(\frac{A}{x}\right)^{1/3}$$

x-Q^2 phase space



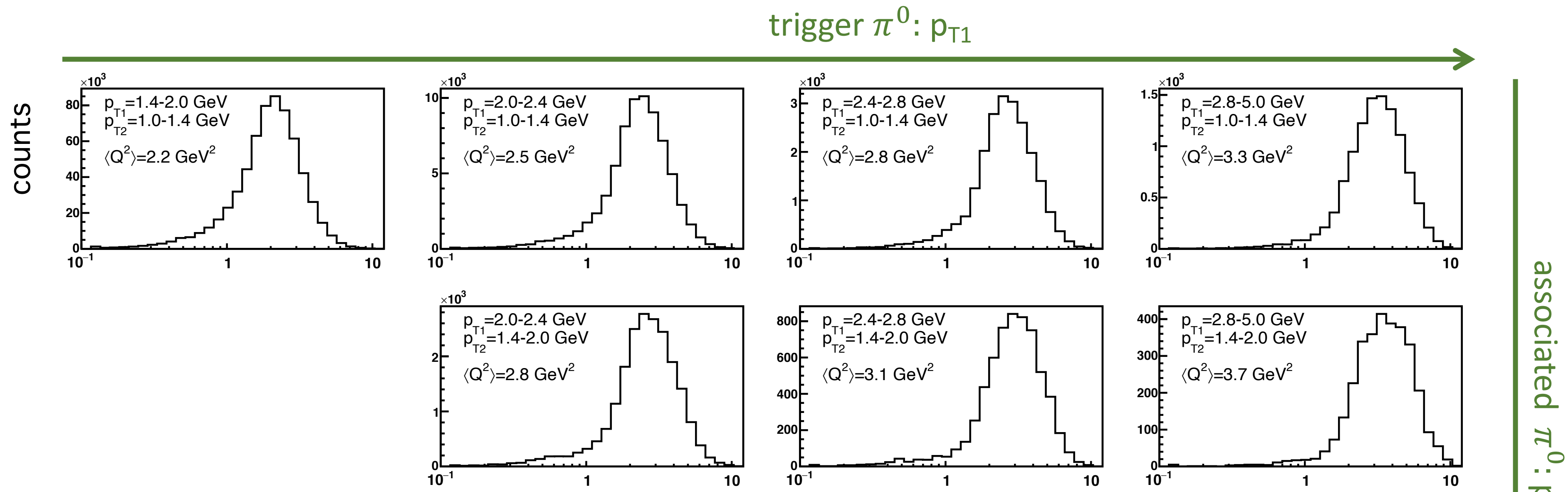
- STAR FMS data ($\sqrt{s_{NN}} = 200$ GeV) can probe the saturation region
- One can study the evolution on x and Q^2 through scanning p_T

PYTHIA Kinematics: x_1, x_2

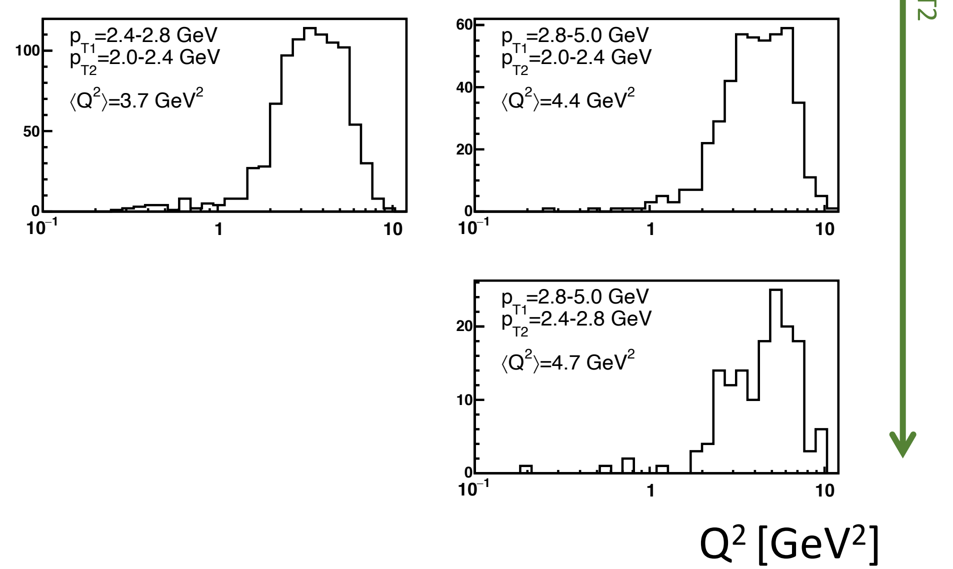


- pp collisions at $\sqrt{s} = 200$ GeV
- Cuts on π^0
  - E > 1 GeV
  - Number of π^0 > 1 in the event
  - $2.6 < \eta < 4.1$
- x_2 increases with p_T

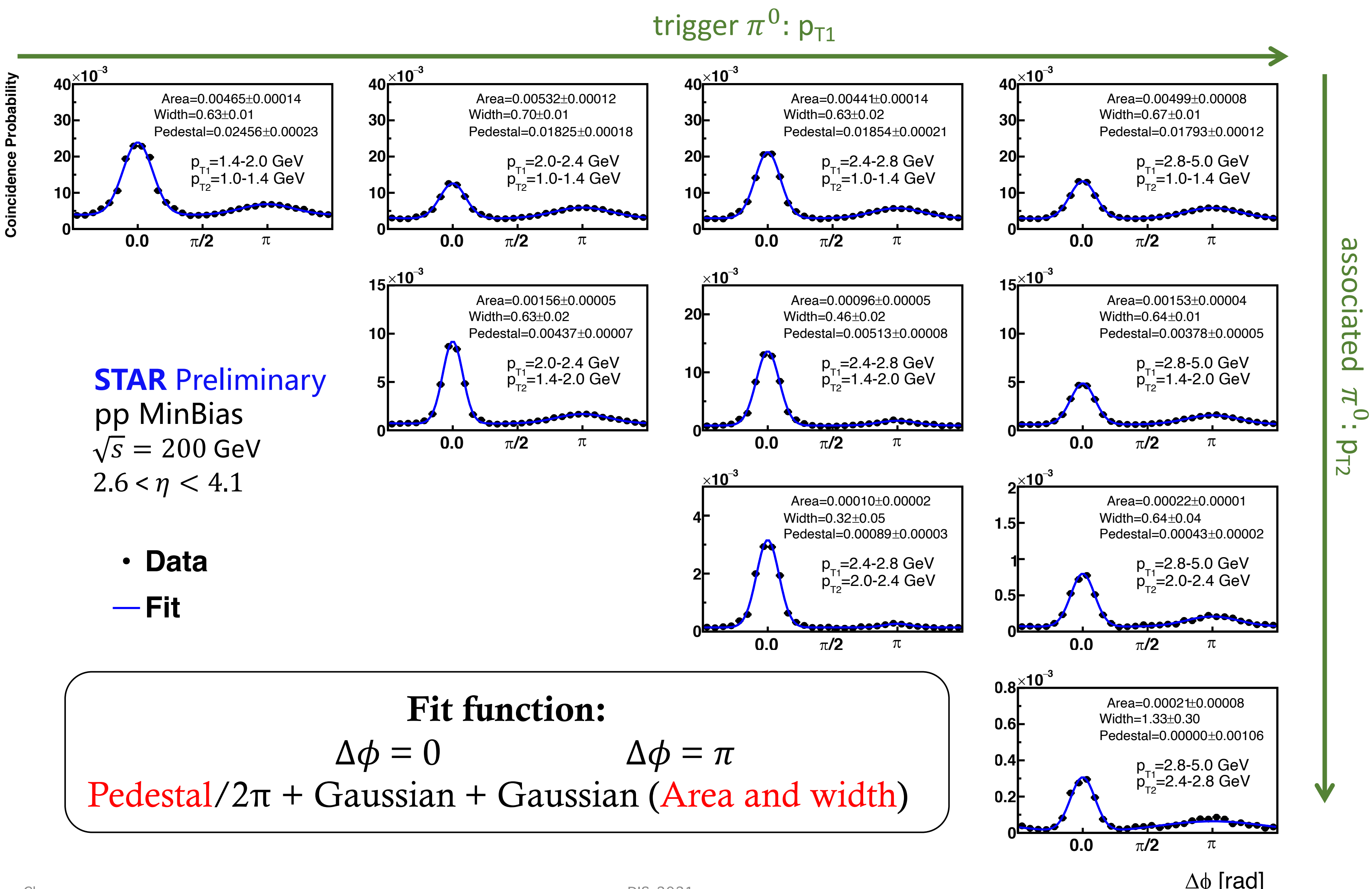
PYTHIA Kinematics: Q^2



- pp collisions at $\sqrt{s} = 200$ GeV
- Cuts on π^0
  - E > 1 GeV
  - Number of π^0 > 1 in the event
  - $2.6 < \eta < 4.1$
- Q^2 increases with p_T



Di-π^0 correlations in pp



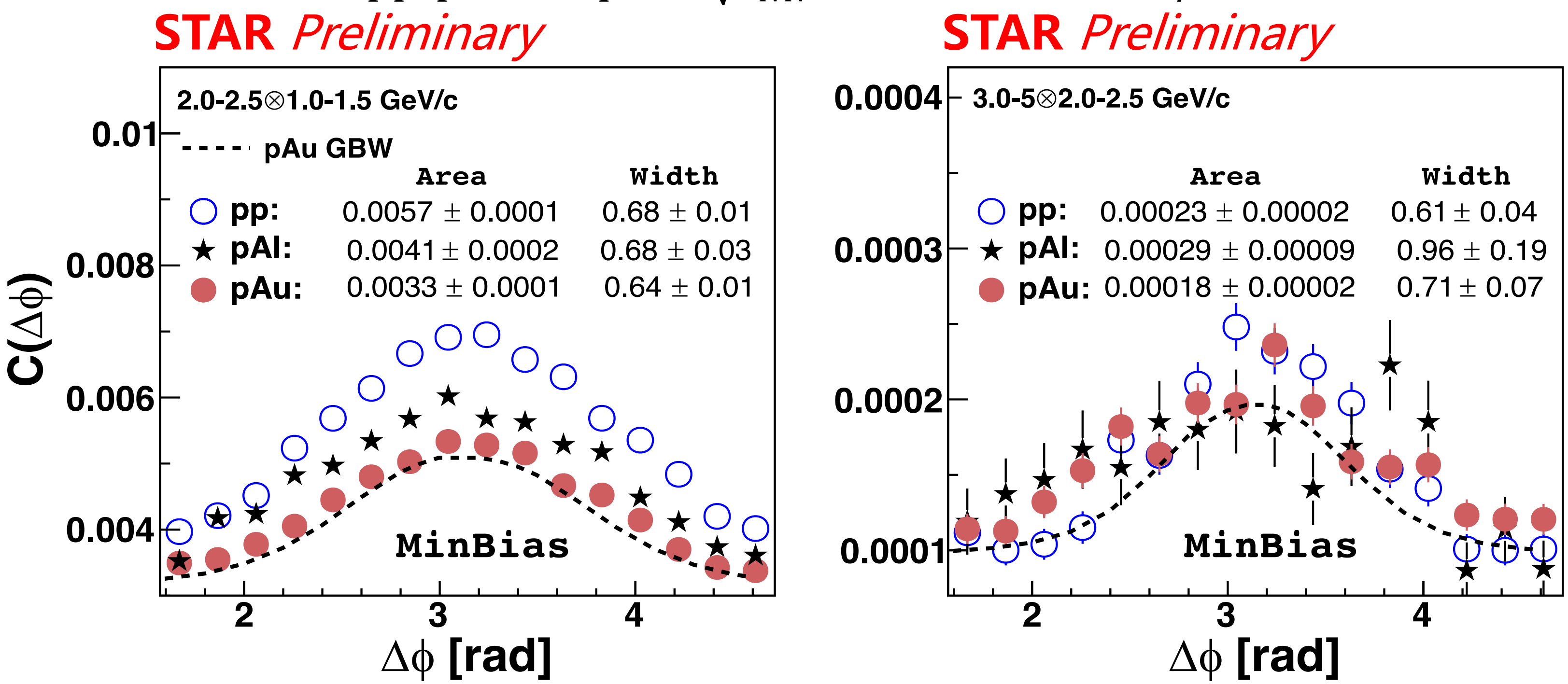
Fit function:

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

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

Di-π^0 correlations in pp and pA

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

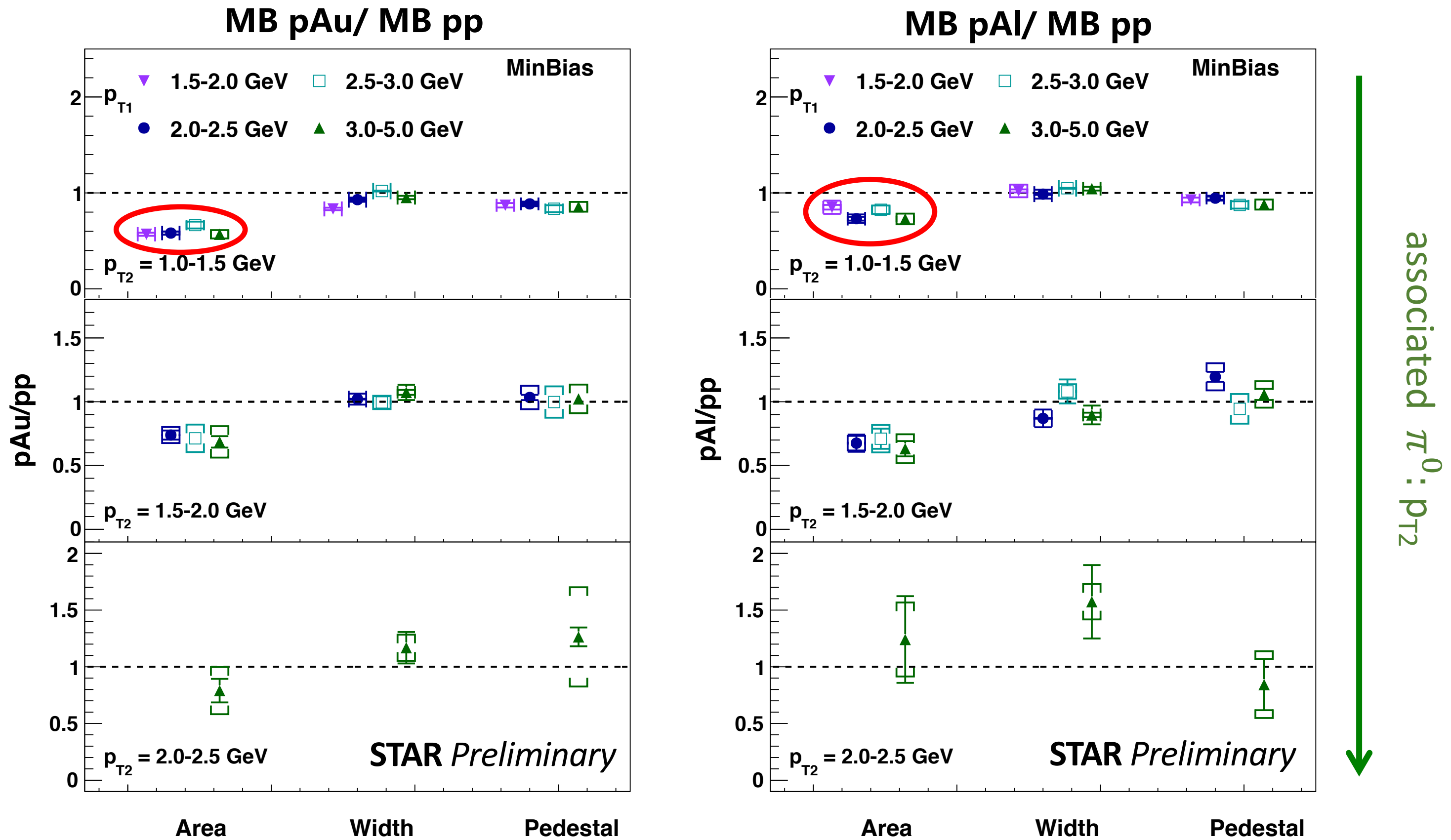


GBW: A. Stasto et al., PLB 716(2012) 430-434

- **A dependence**: at low p_T, more suppression is observed in pAu than pAl in comparison with the reference pp
- **p_T dependence**: less suppression at high p_T (large x and Q^2) in pAu
- 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

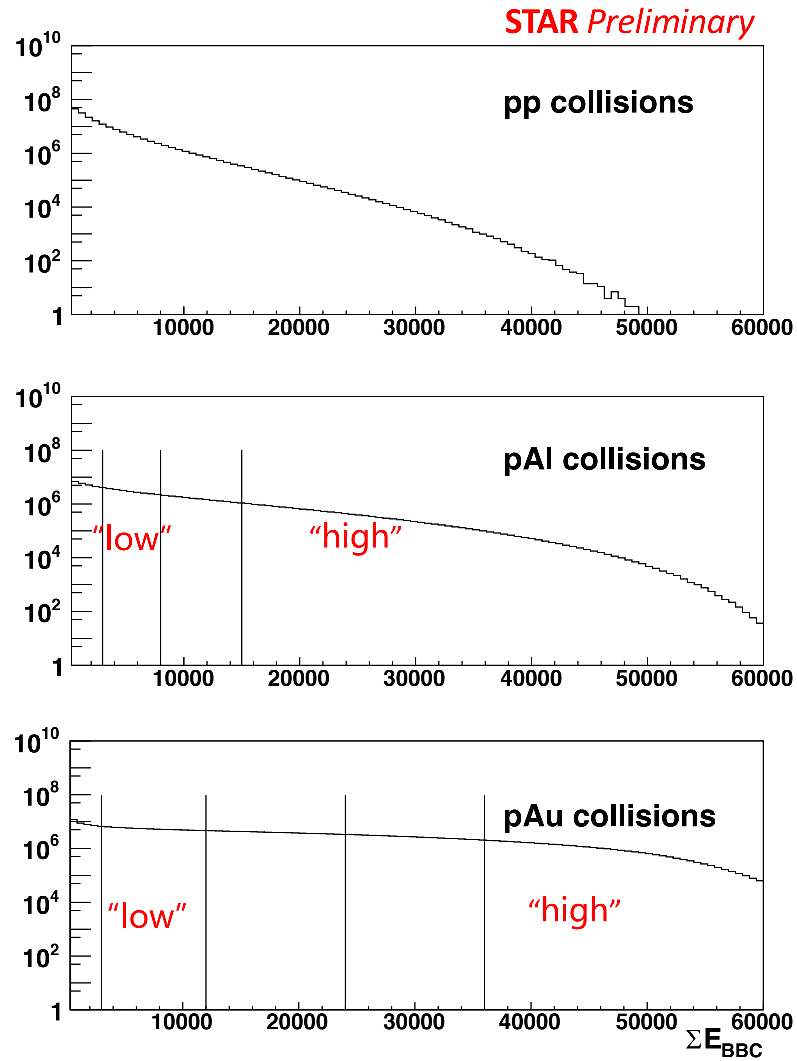
Event activity

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

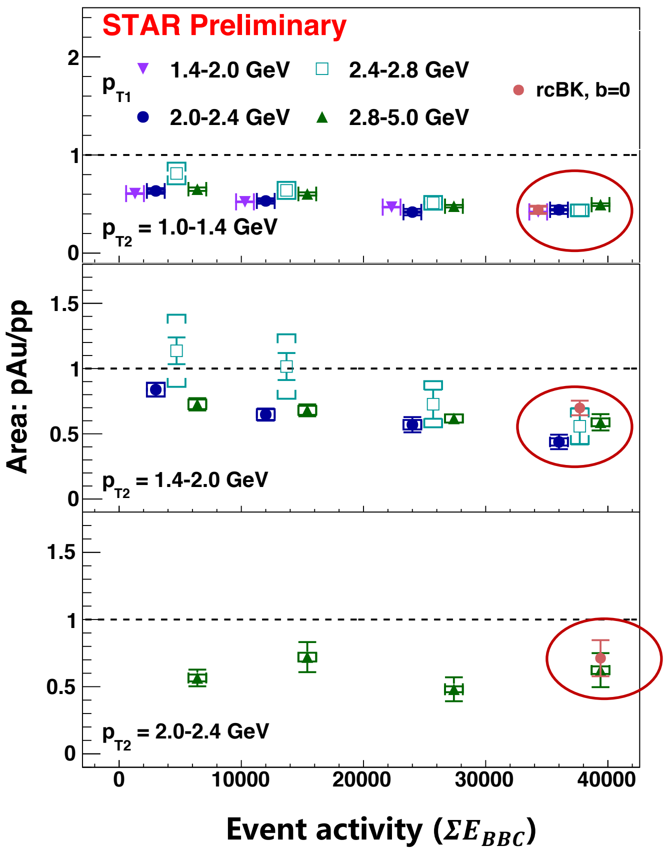
Beam species	Event activity	ΣE_{BBC} range ($\times 10^3$)	Class
p+**Al**	Lowest	3-8	31%-60%
	Medium	8-15	60%-81%
	Highest	>15	81%-100%
p+**Au**	Lowest	3-12	15%-43%
	Medium low	12-24	43%-69%
	Medium high	24-36	69%-88%
	Highest	>36	88%-100%



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

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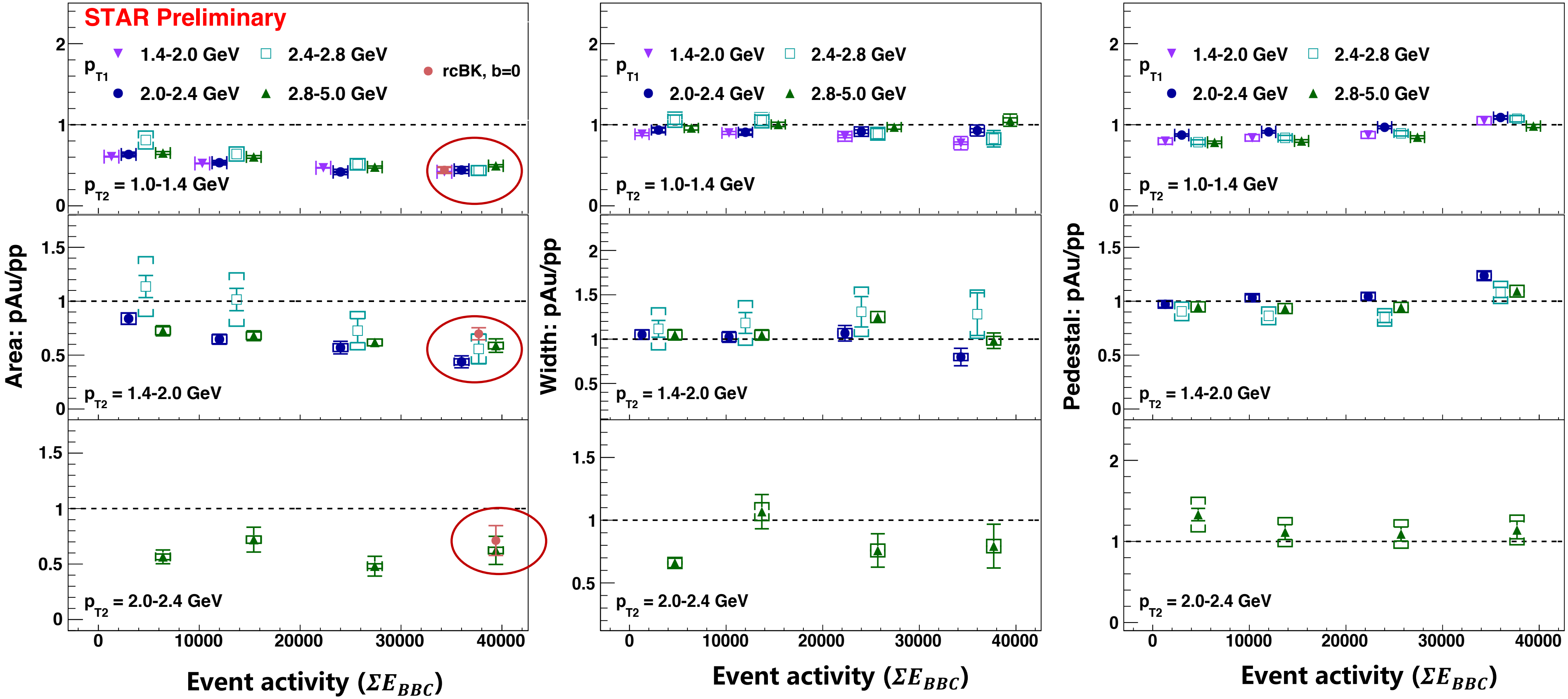
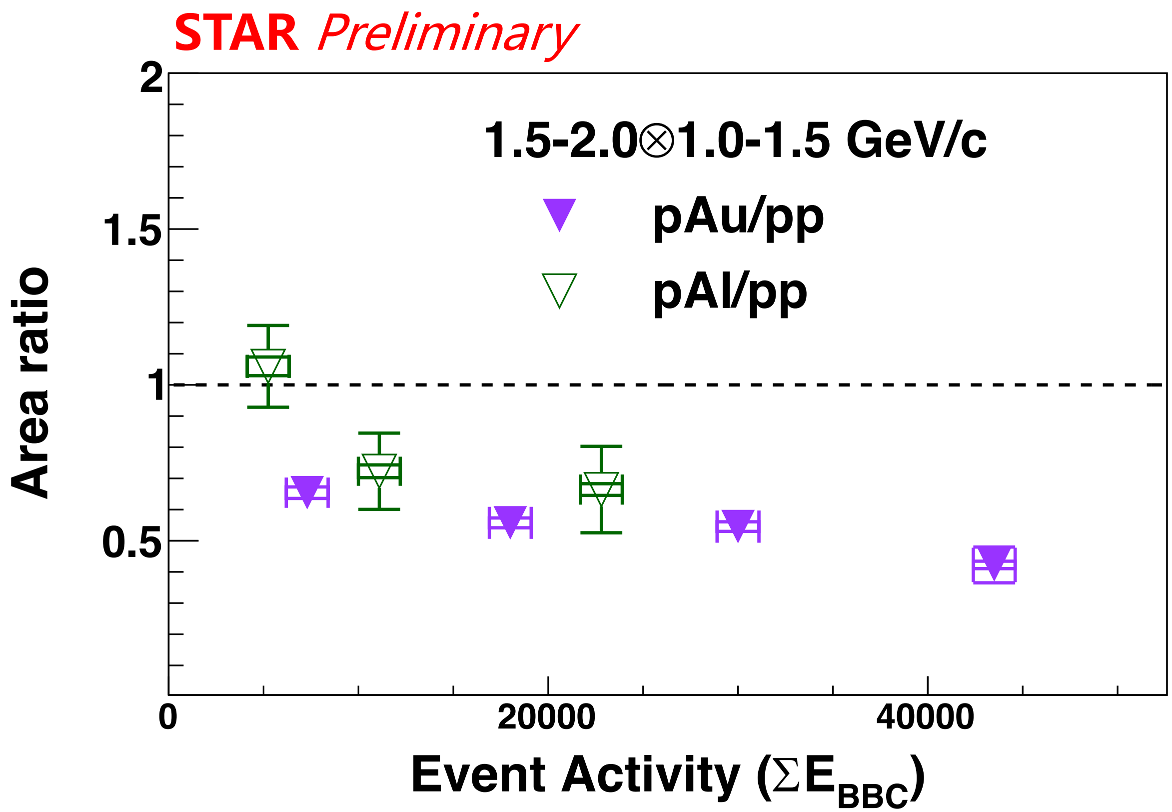


- Suppression depends on event activity → enhanced in high activity events
- Suppression at highest activity events is consistent with predictions based on gluon saturation model: rcBK at b=0
- Width and pedestal are stable in pp and pAu against event activity

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?