

2026 RHIC/AGS ANNUAL USERS' MEETING
AND RHIC SCIENCE SYMPOSIUM

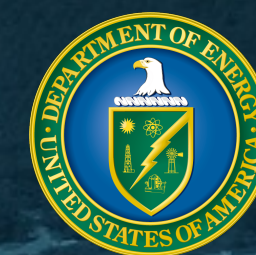
The Apex of RHIC Physics

Resolving the Strong Force

May 11–15, 2026



Brookhaven[™]
National Laboratory



U.S. DEPARTMENT OF
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KENT STATE
UNIVERSITY



THE OHIO STATE UNIVERSITY

Workshop Report: UPC & Electromagnetic Processes

Ashik Ikbal Sheikh & Daniel Brandenburg

RHIC-AGS User's Meeting 2026

May 11-15, 2026

Interesting talks

☰ Contribution list 🕒 Timetable	
⏪ Tue 12/05	
🖨️ Print 📄 PDF	
09:00	Session Introduction : Ultra-Peripheral Collisions <i>Gian Michele Innocenti</i> 09:00 - 09:30
	Measurements of EM-probes at PHENIX and sPHENIX <i>Mariia Mitrankova</i>
10:00	Measurements of Vector mesons in Ultra-Peripheral Collisions at STAR <i>Xihe Han</i>
	Coffee Break 10:30 - 11:00
11:00	Mirror Quantum Tomography for UPC and beyond <i>Daniel Tapia Takaki</i>
	Nuclear imaging efforts at EIC <i>Rongrong Ma</i> 11:30 - 12:00
12:00	

2026 RHIC/AGS Annual Users' Meeting
 PHENIX sPHENIX
 Measurements of EM-probes at PHENIX/sPHENIX
 Mariia Mitrankova
 Stony Brook University
 2026 RHIC/AGS annual users' meeting and symposium

Supported in Part By
 U.S. DEPARTMENT OF ENERGY
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Measurements of Vector Mesons in Ultra-Peripheral Collisions at STAR
 Xihe Han
 The Ohio State University
 2026 RHIC/AGS User's Meeting
 Sincerely apologize in advance for any omissions or misinterpretations ☹️

Ultraperipheral collisions as probes for nuclear matter
 2026 RHIC/AGS Annual Users' Meeting,
 May 11-15, 2026.
 Gian Michele Innocenti
 Massachusetts Institute of Technology

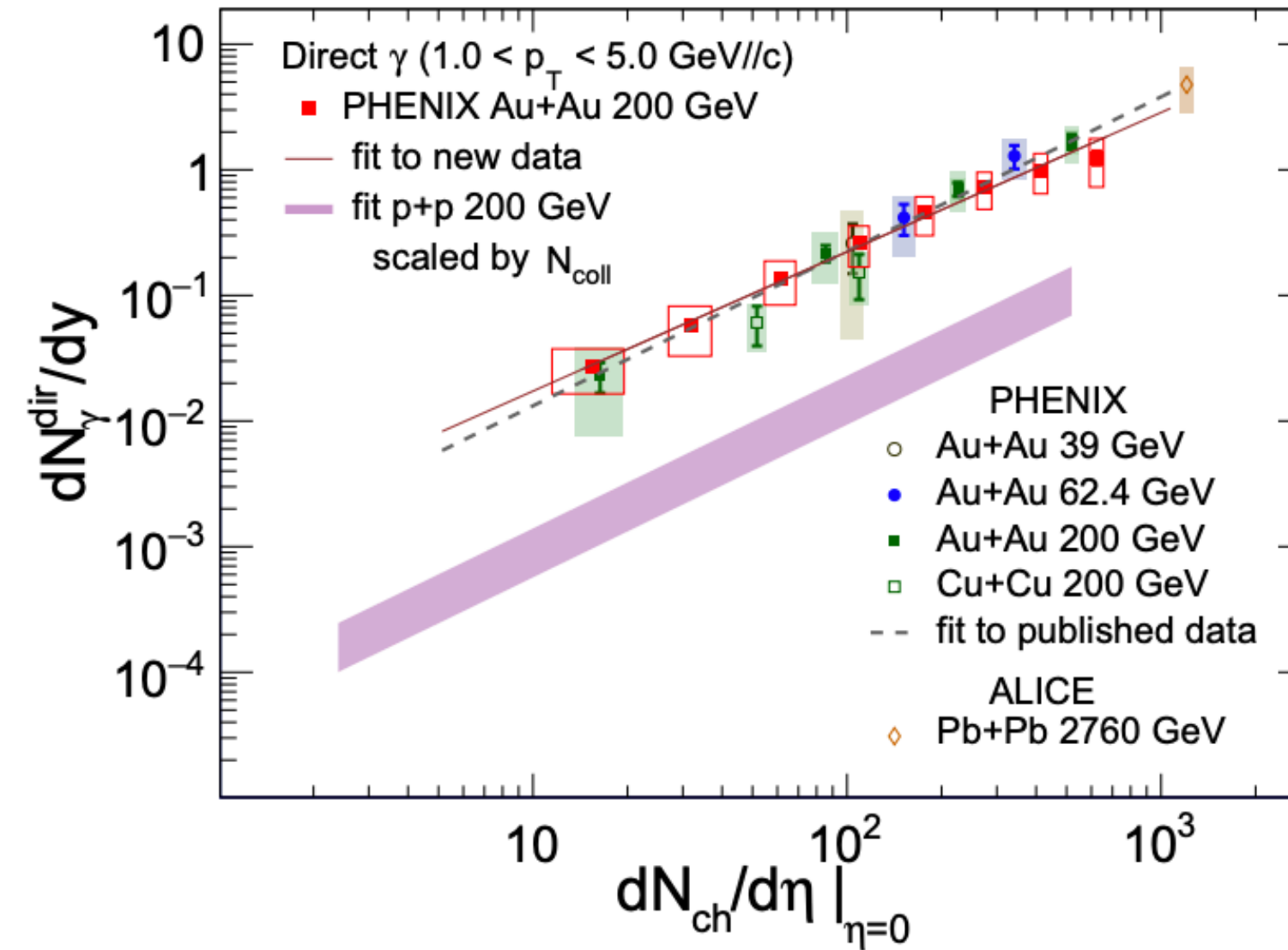
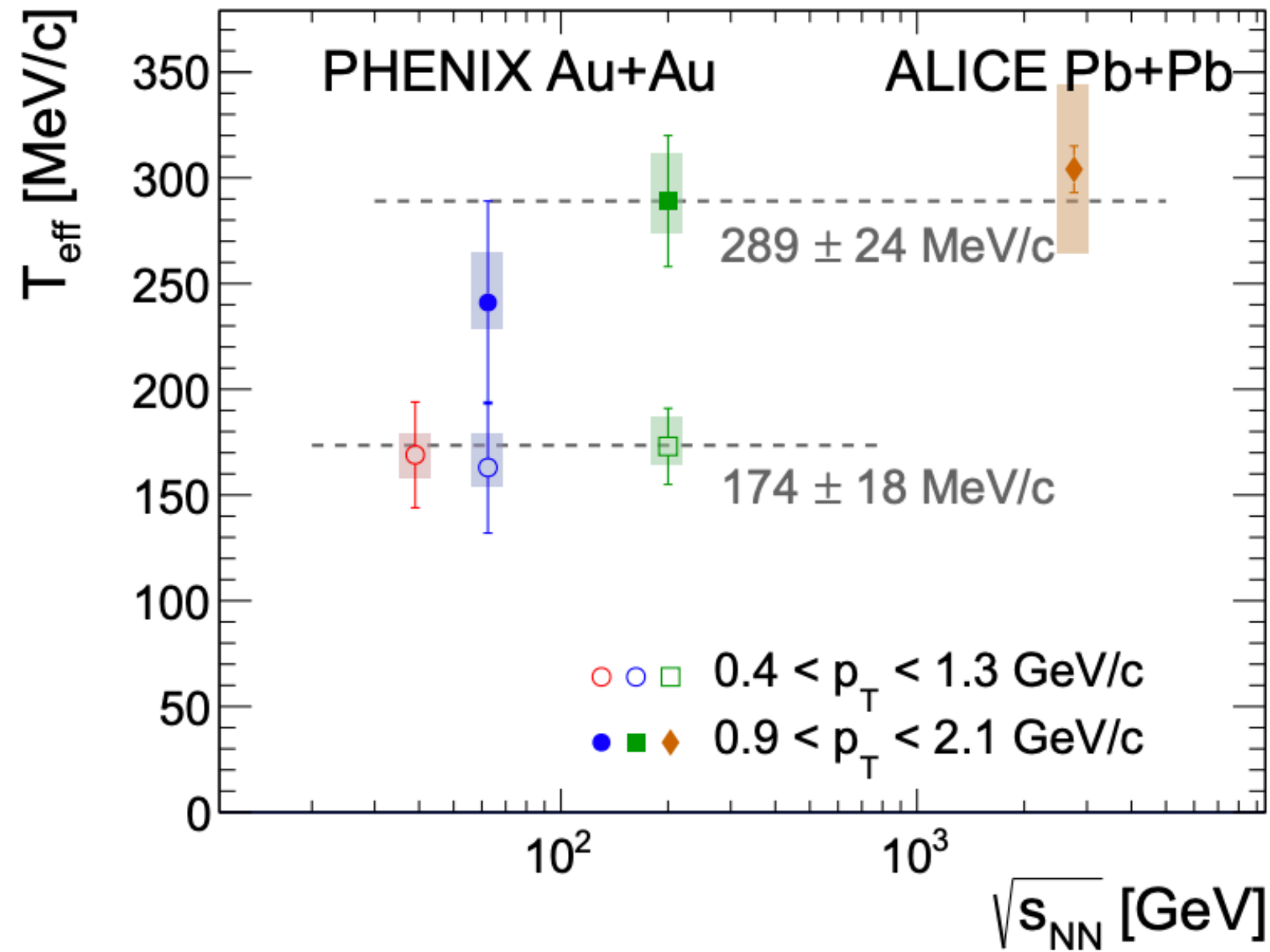
2026 RHIC/AGS ANNUAL USERS' MEETING AND RHIC SCIENCE SYMPOSIUM
The Apex of RHIC Physics
 Resolving the Strong Force
 May 11-15, 2026

Mirror Quantum Tomography : For UPC and beyond
 Daniel Tapia Takaki
 work with John Ralston
 The University of Kansas
 AGS&RHIC users meeting
 May 12, 2026

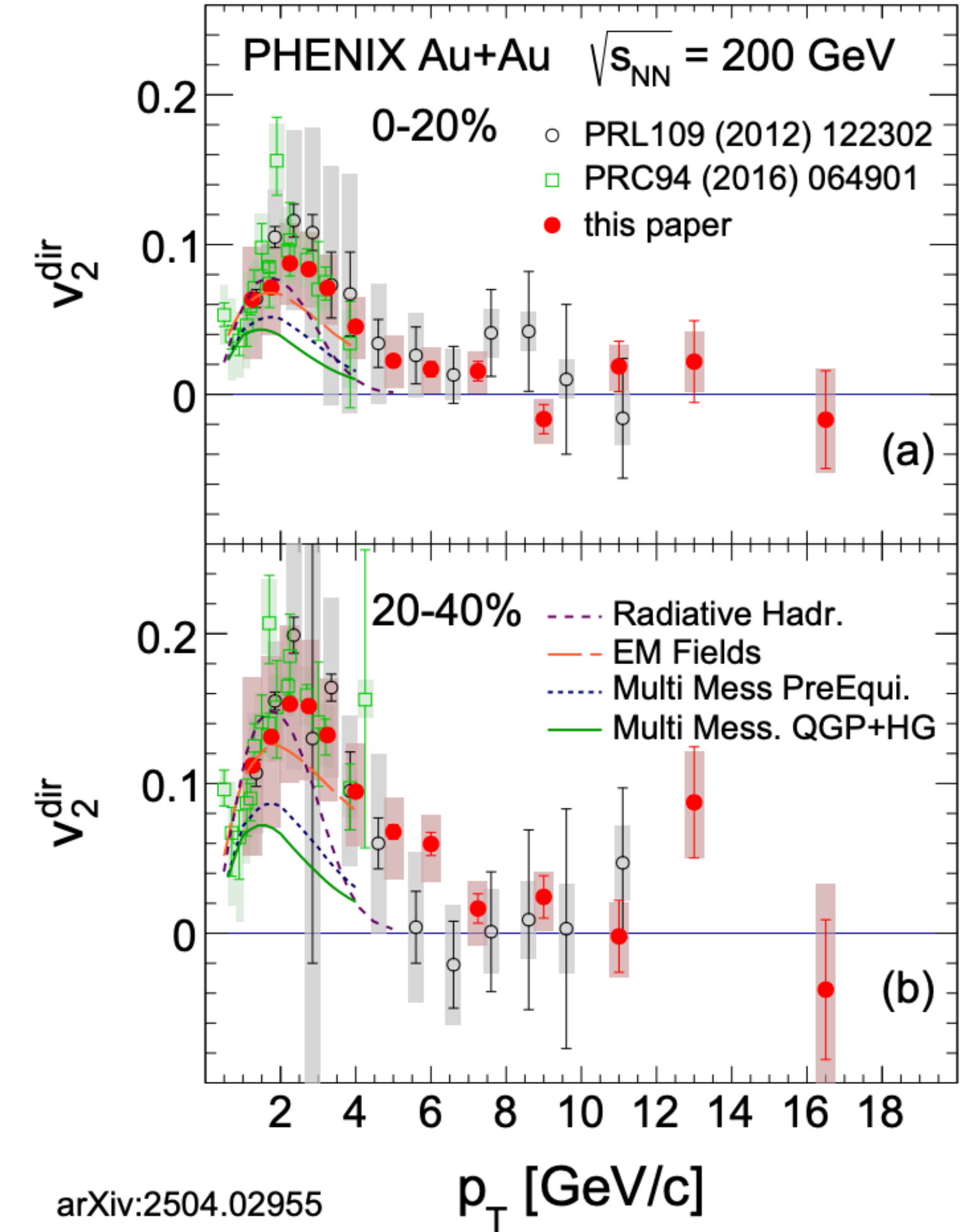
Nuclear imaging efforts at EIC
 Rongrong Ma
 Brookhaven National Laboratory
 2026 RHIC/AGS Annual Users' Meeting & RHIC Science Symposium
 May 11-15, 2026, BNL

Electromagnetic probes

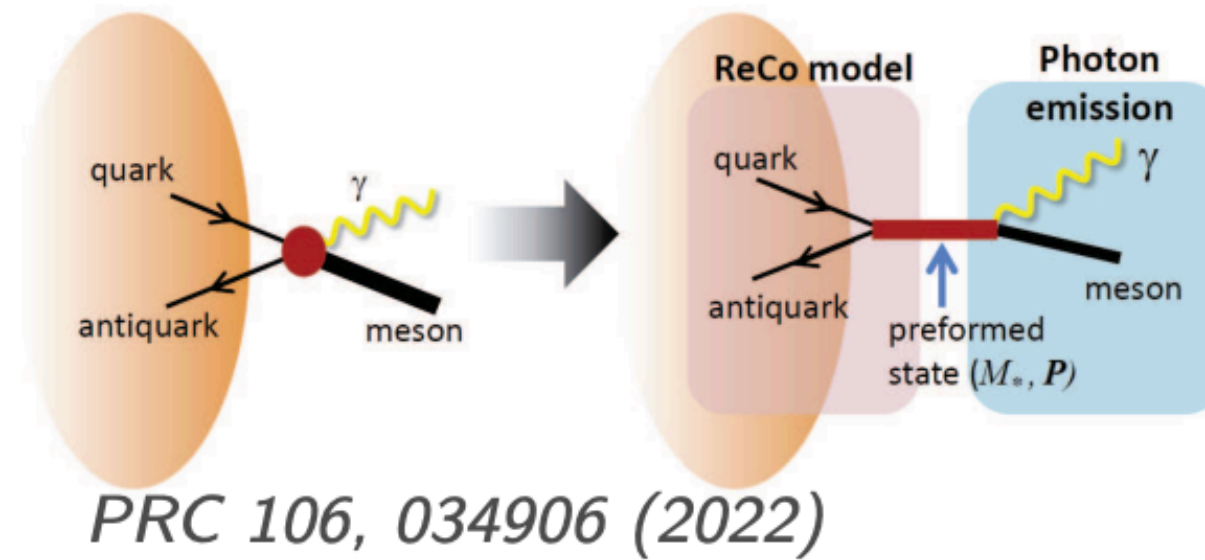
PRC 109, 044912 (2024)



arXiv:2504.02955



No dependence on $\sqrt{s_{NN}}$
Composition and relative weight
of different sources always the
same?

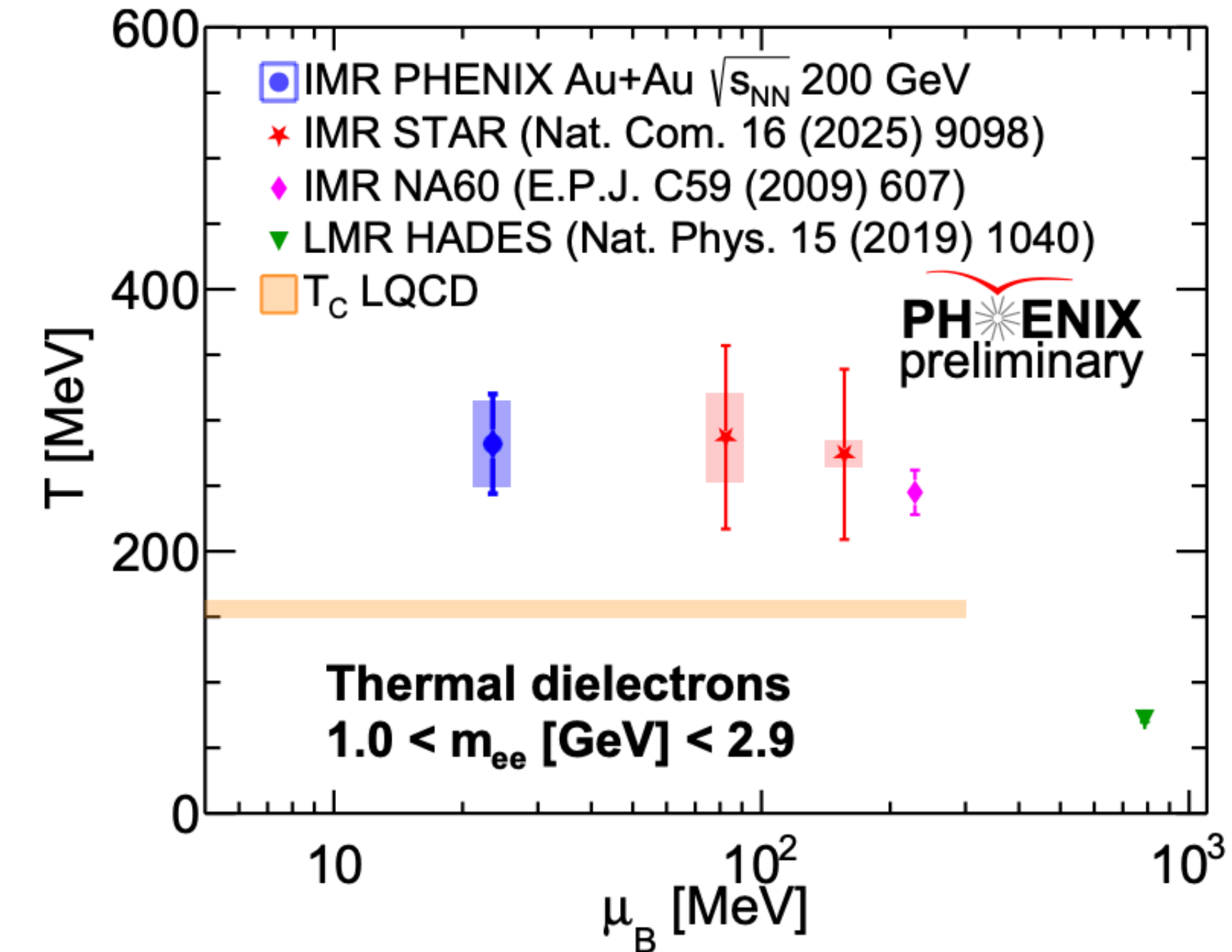
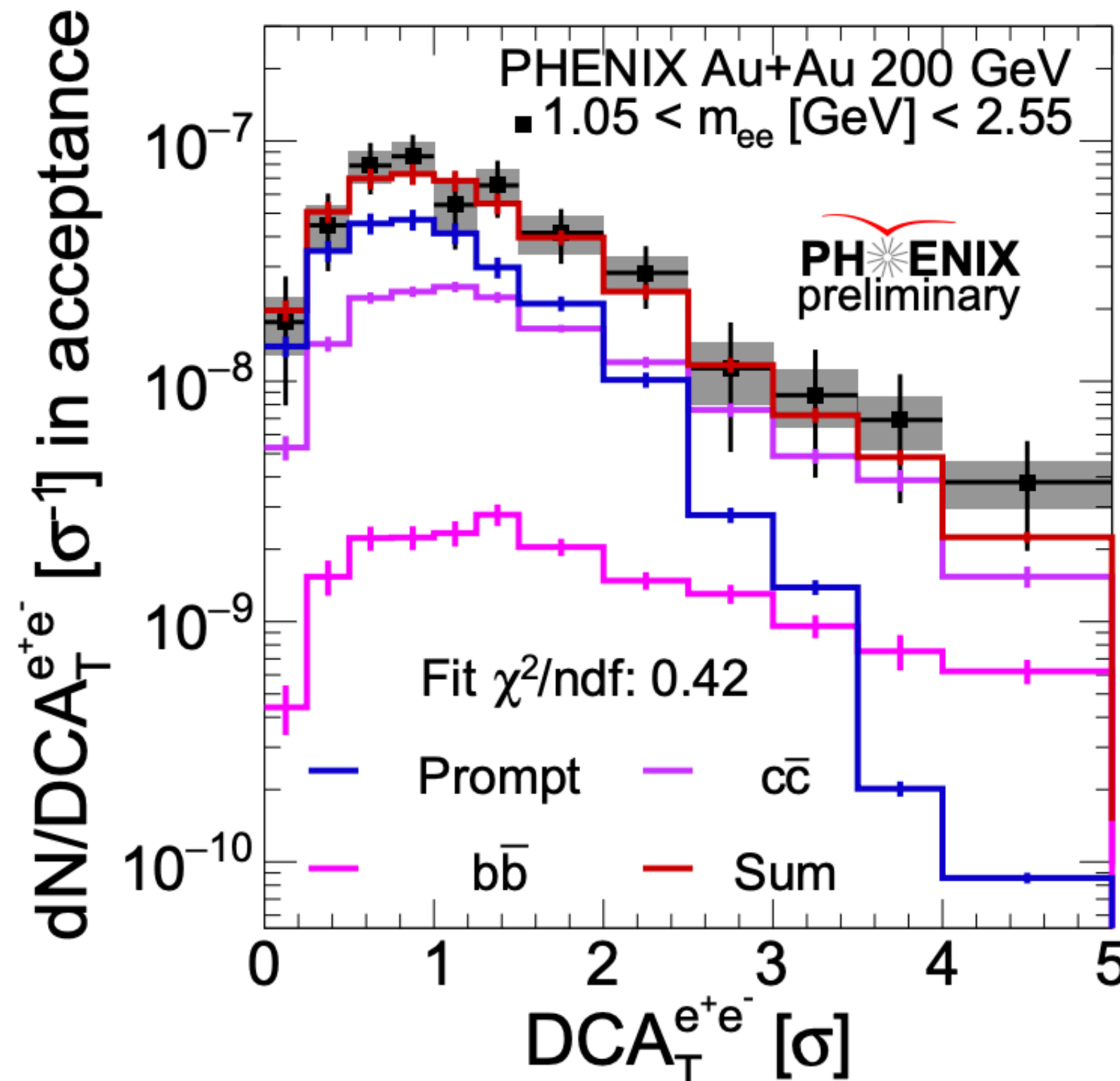
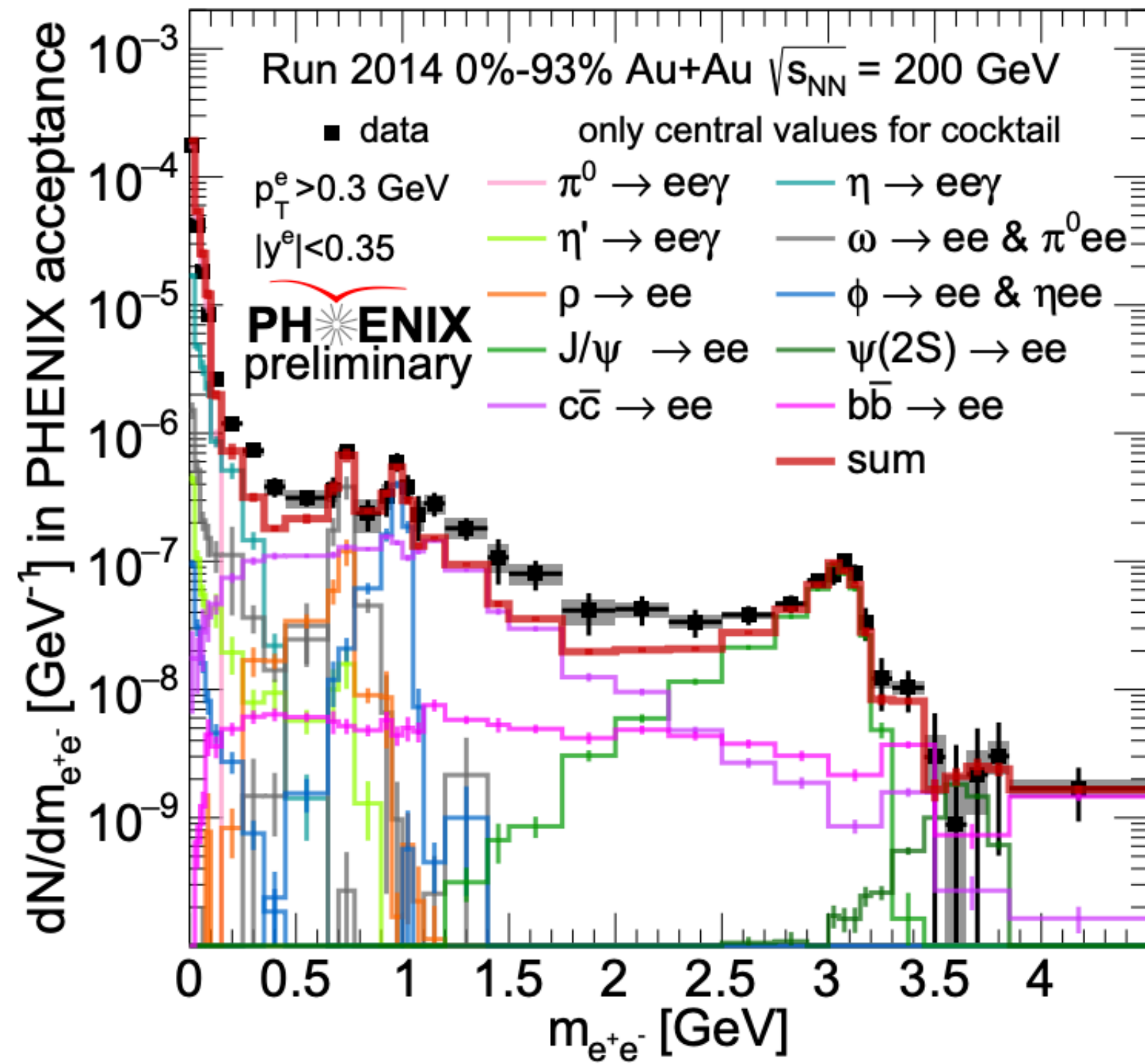


PRC 106, 034906 (2022)

$$dN_\gamma/dy \sim (dN_{ch}/d\eta)^\alpha$$

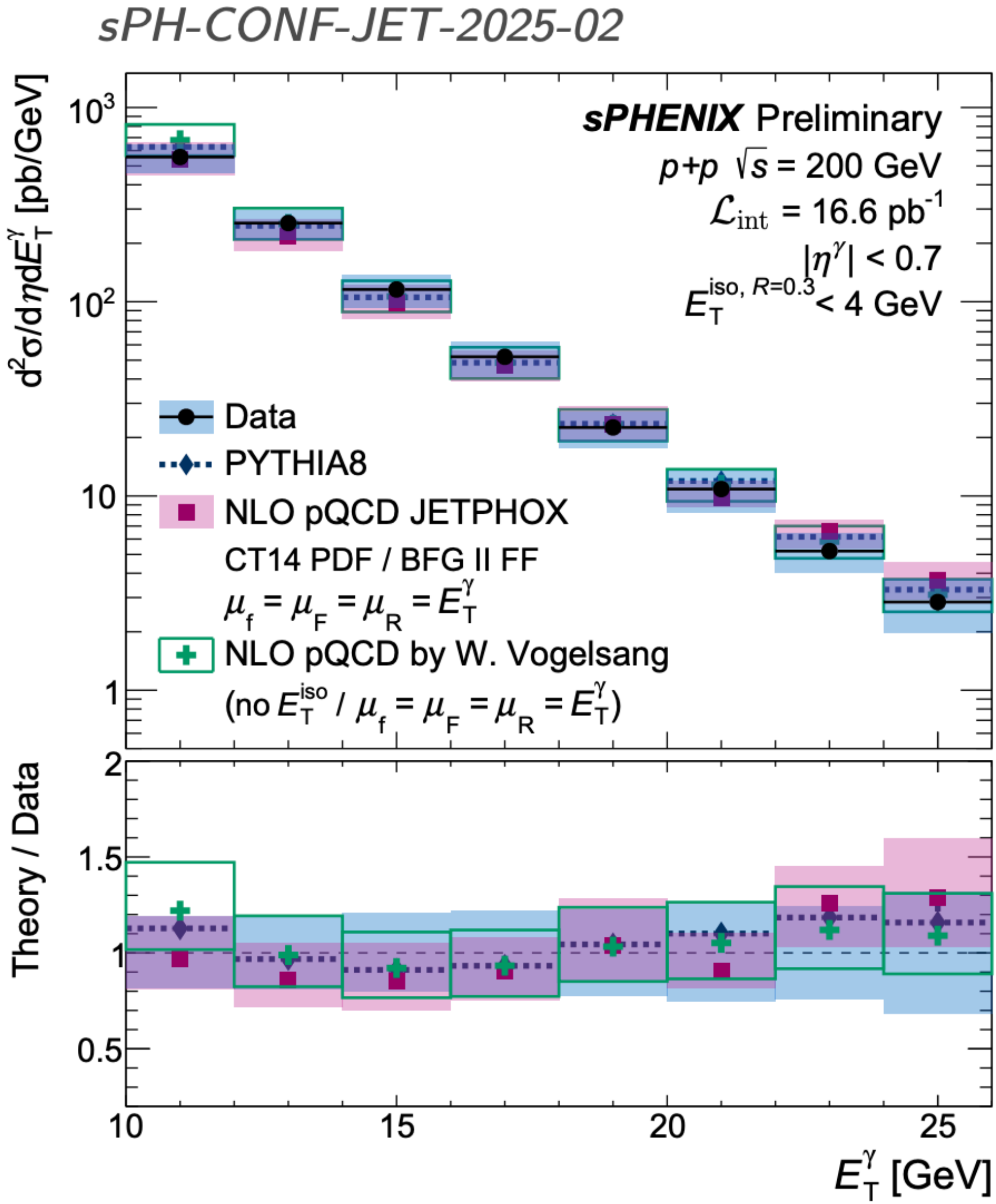
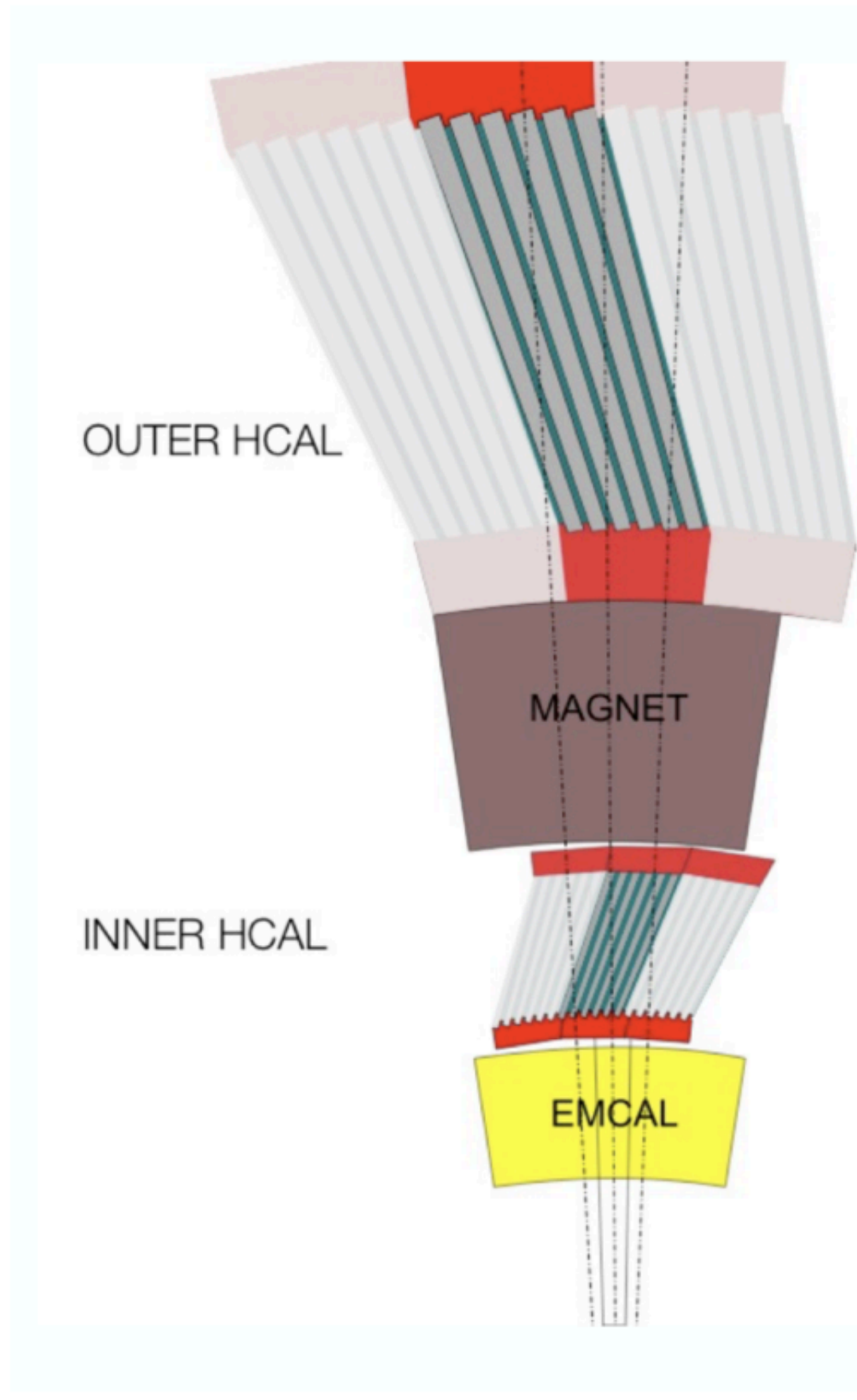
α measured ~ 1.11
(QGP ~ 1.85 , HG ~ 1.25)

$v_2^{dir} > 0$ at high- p_T



First precision measurement of thermal dielectrons in the IMR at top RHIC energy, **with HF separation!**

Only slight increase in $T_{\text{eff}}^{\text{IMR}}$ from SPS to RHIC.



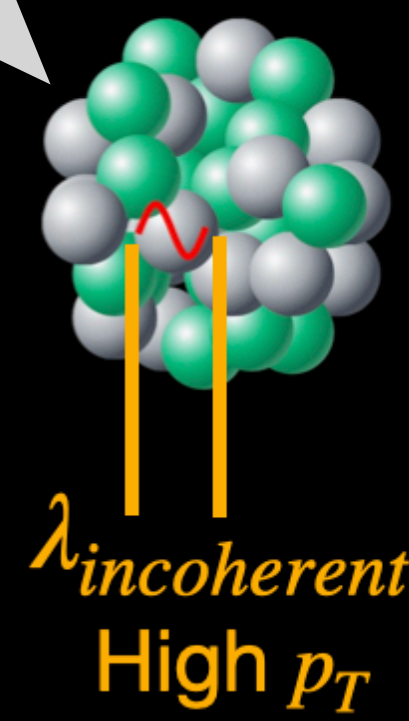
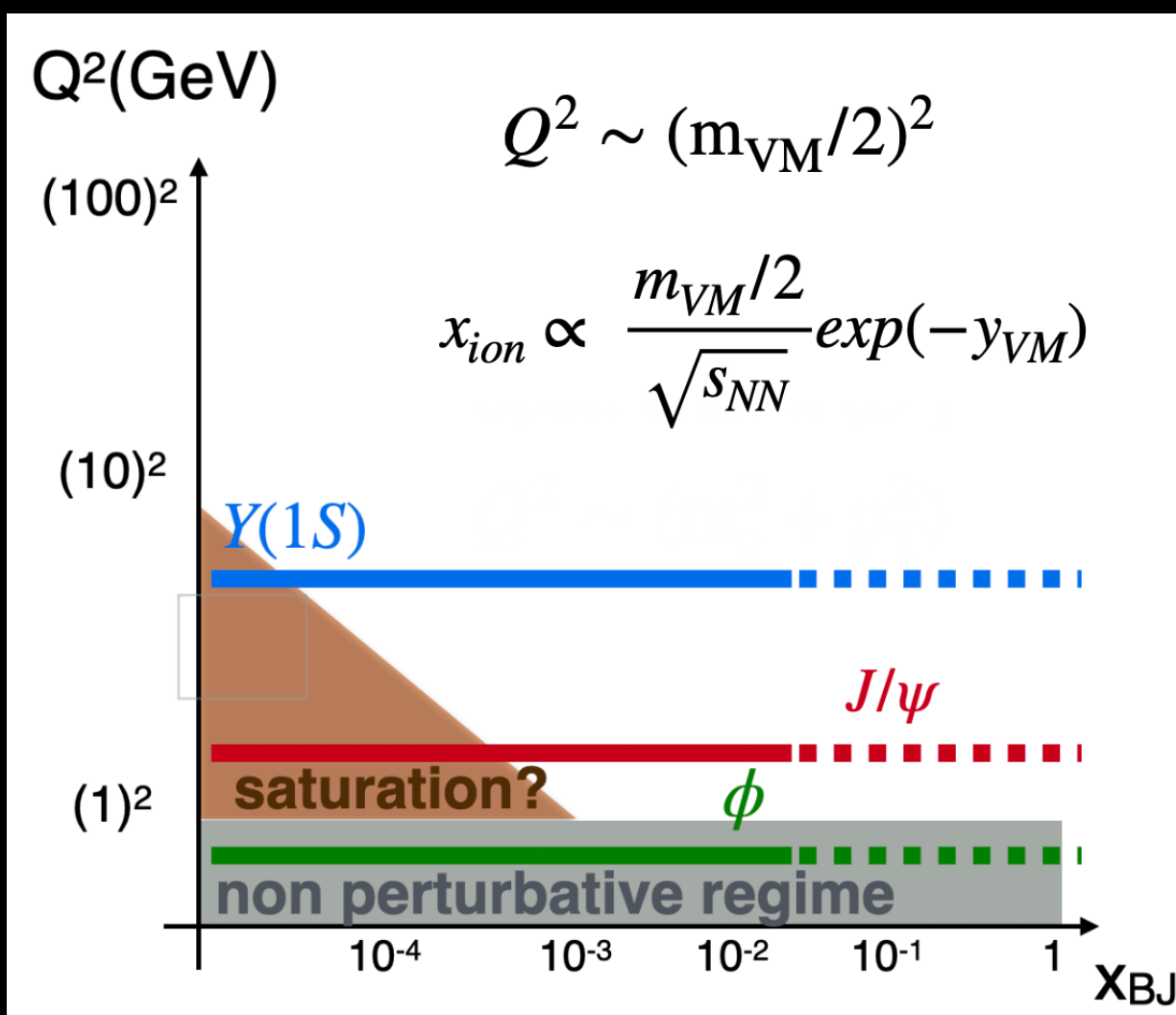
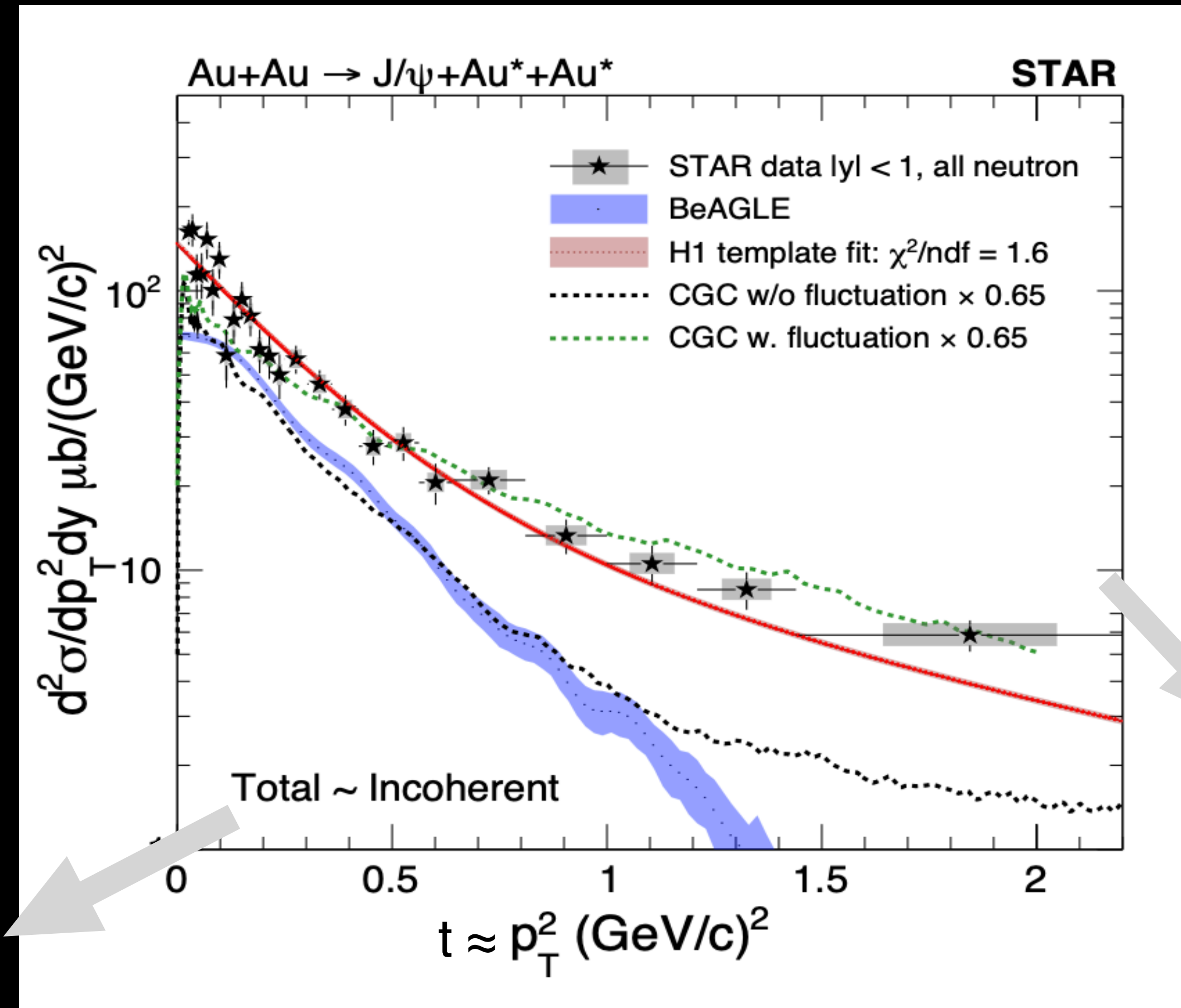
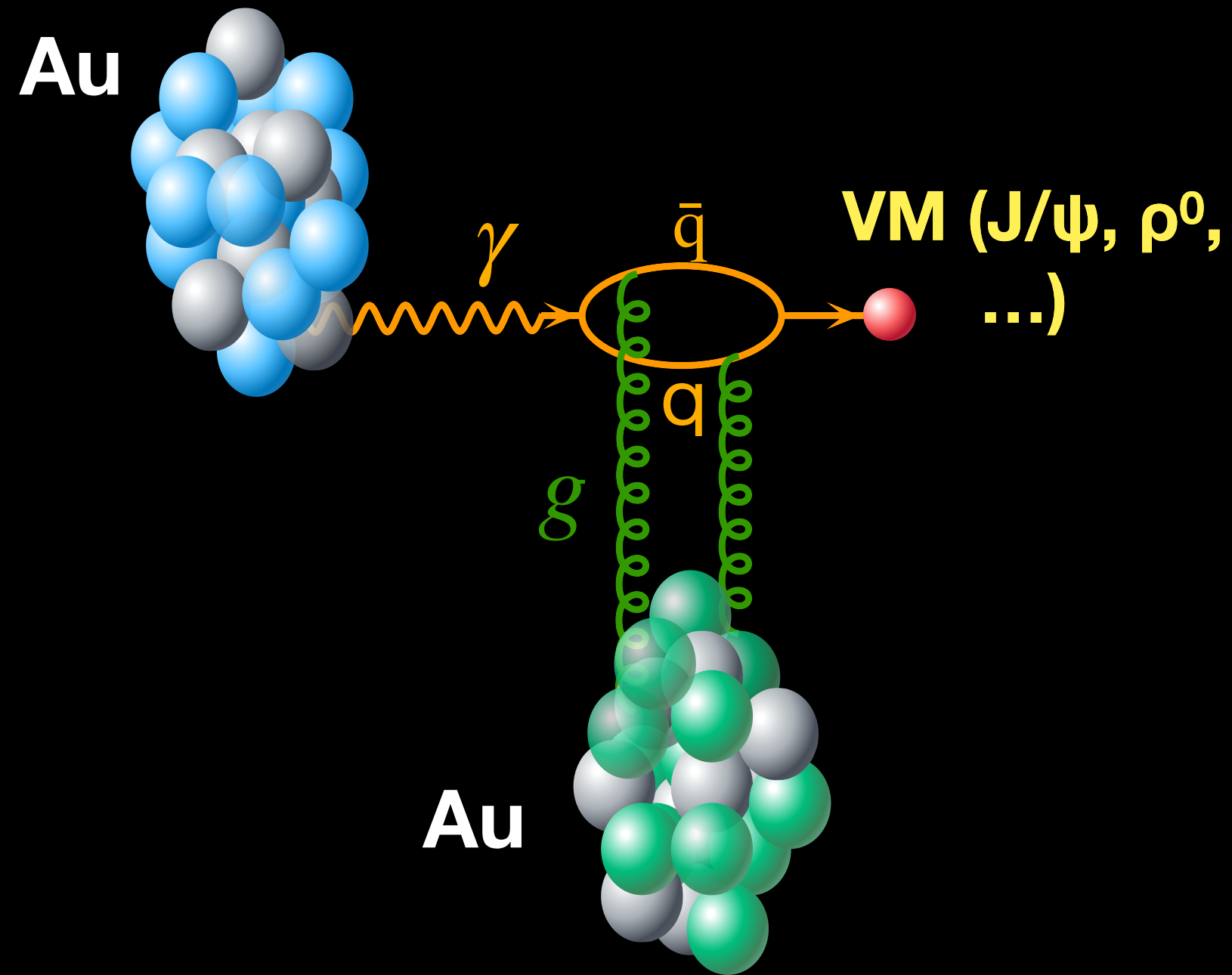
- Results unfolded for detector effect / energy resolution
- Only small fraction of the full p+p dataset used
- EM energy scale dominant source for systematic unc.
 - Expect to be improved with the full dataset
- All predictions consistent with data within uncertainties

Ultra-peripheral collisions and nuclear imaging

Ultra-peripheral collisions and nuclear imaging

UPCs: Photoproduction of VM

STAR Collab., Phys. Rev. Lett. 133, 052301 (2024)



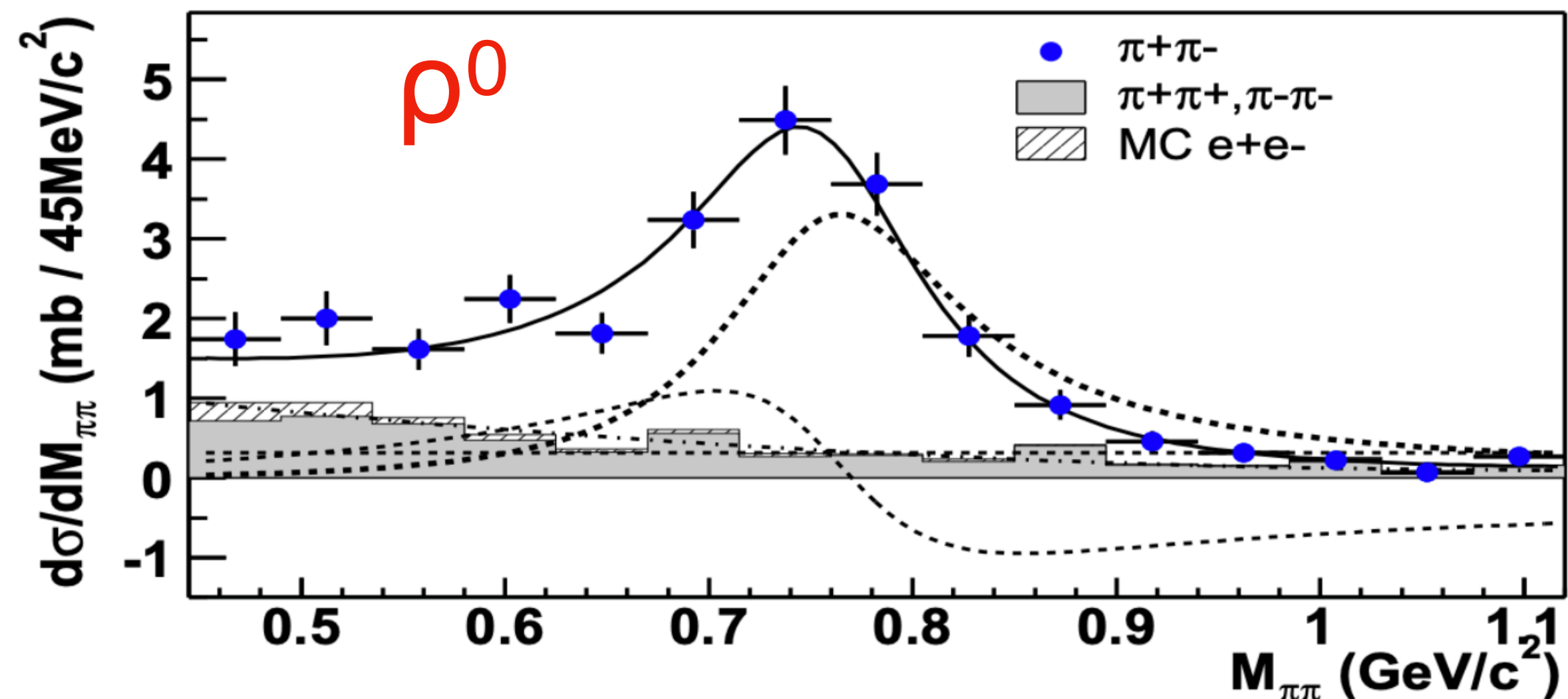
Low $t \rightarrow$ coherent \rightarrow nuclear scale
 High $t \rightarrow$ incoherent \rightarrow sub-nucleon structure

Standard observable $t \approx p_T^2 \rightarrow$ spatial imaging

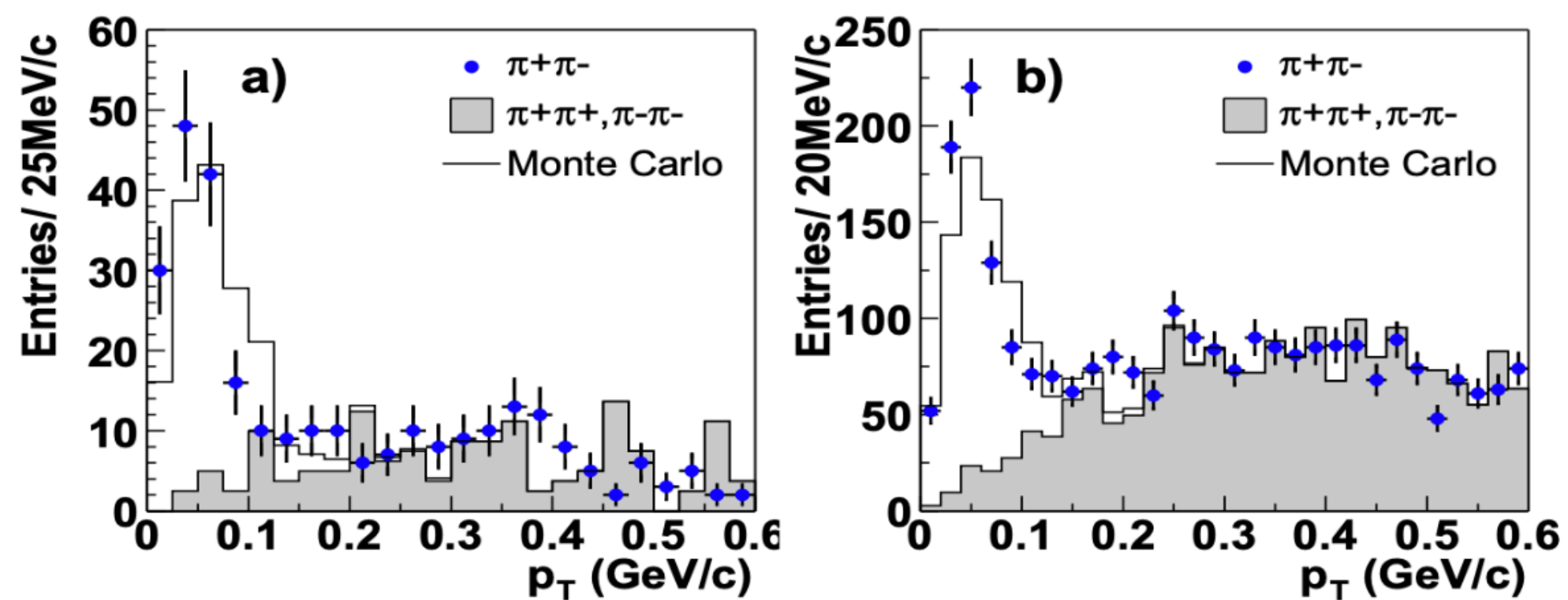
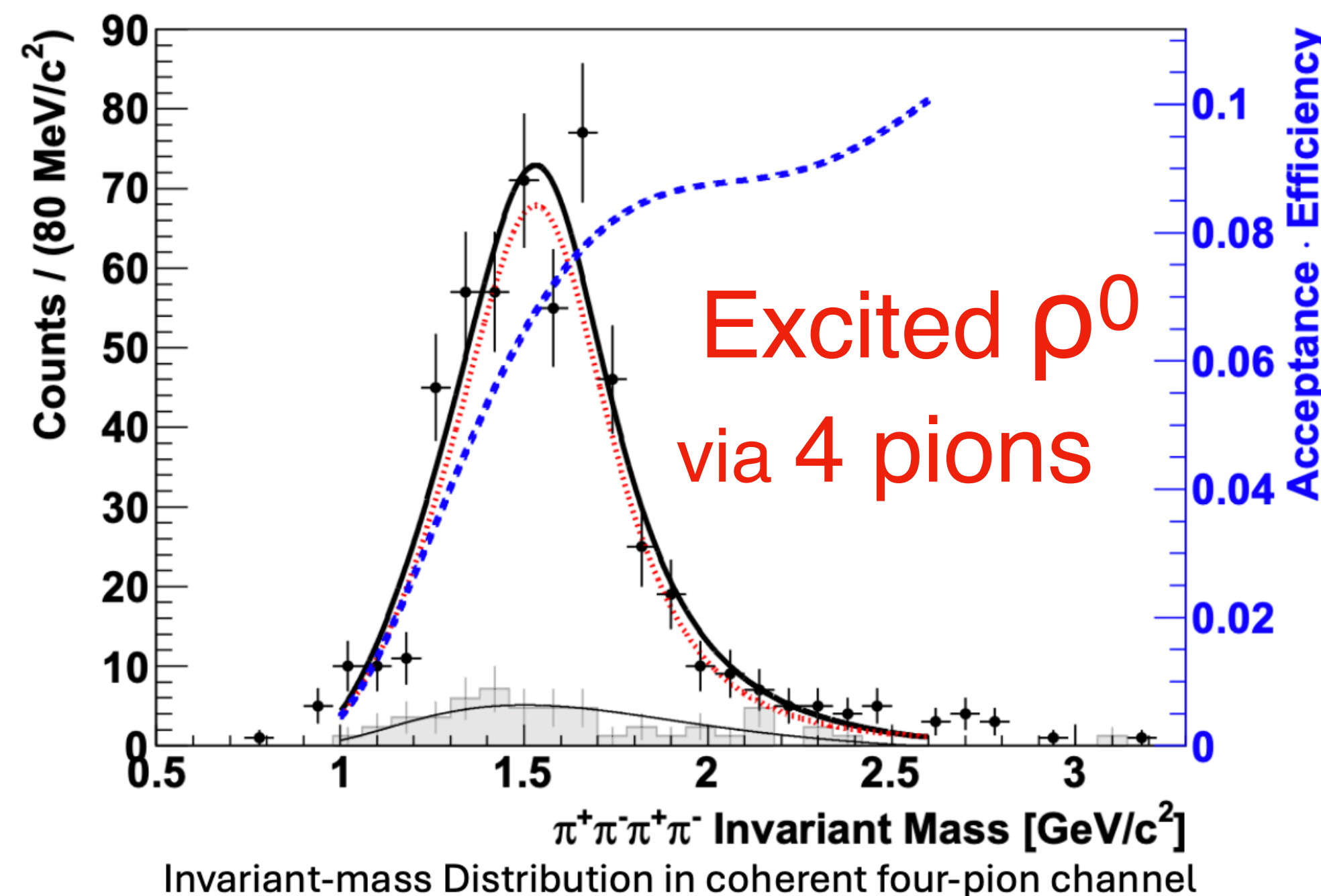
UPC light vector meson production at STAR

Xihe Han

STAR, Phys. Rev. Lett. 89 (2002) 272302



First UPC $\frac{d\sigma_{\rho^0}}{dM_{\pi\pi}}$ measurement with pair $p_T < 150$ MeV/c in ZDCMB data at STAR



p_T spectra demonstrating coherent peak by (a) topological trigger and (b) ZDCMB

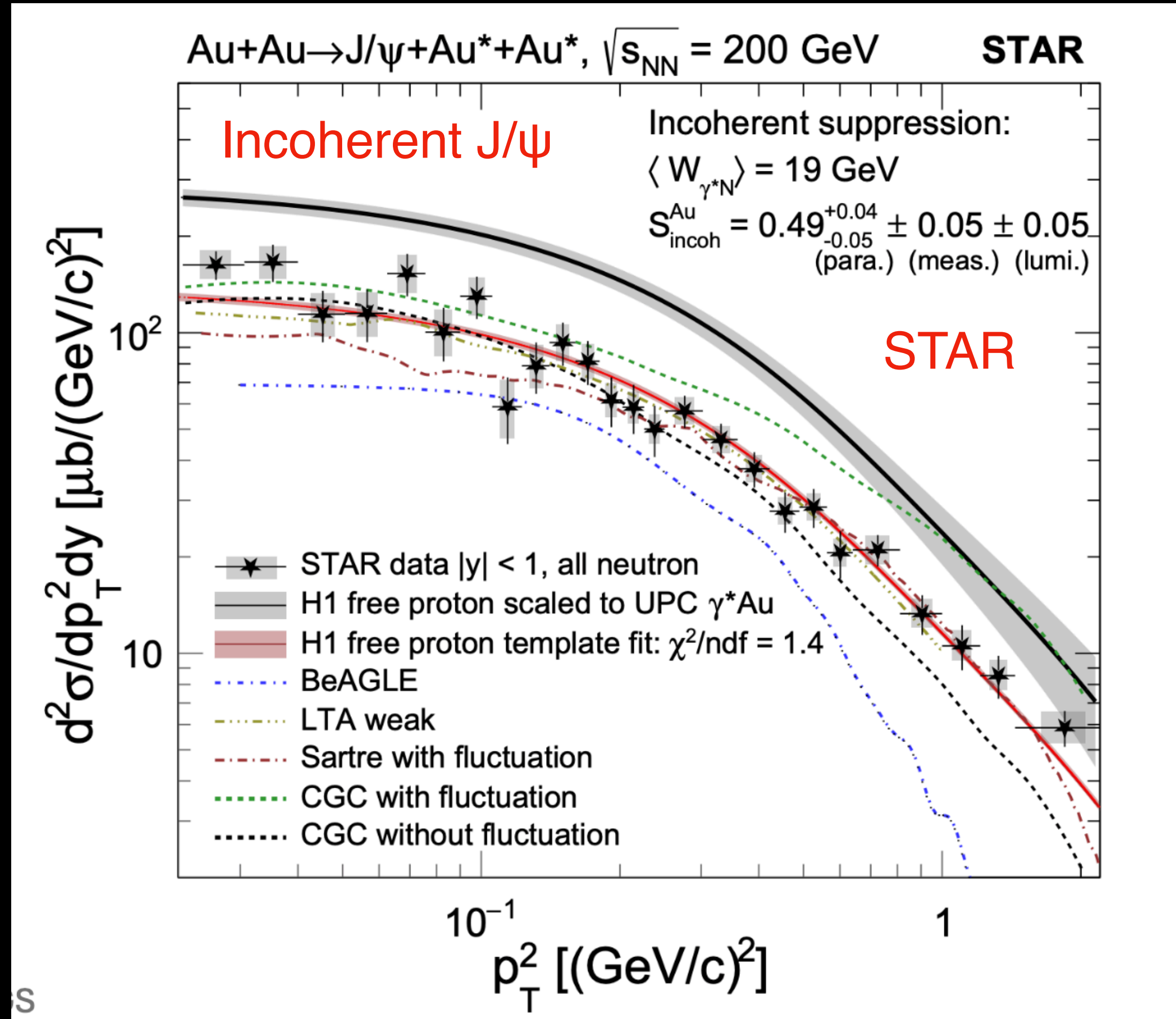
RHIC/AGS

— Early STAR UPC measurements in early 2000

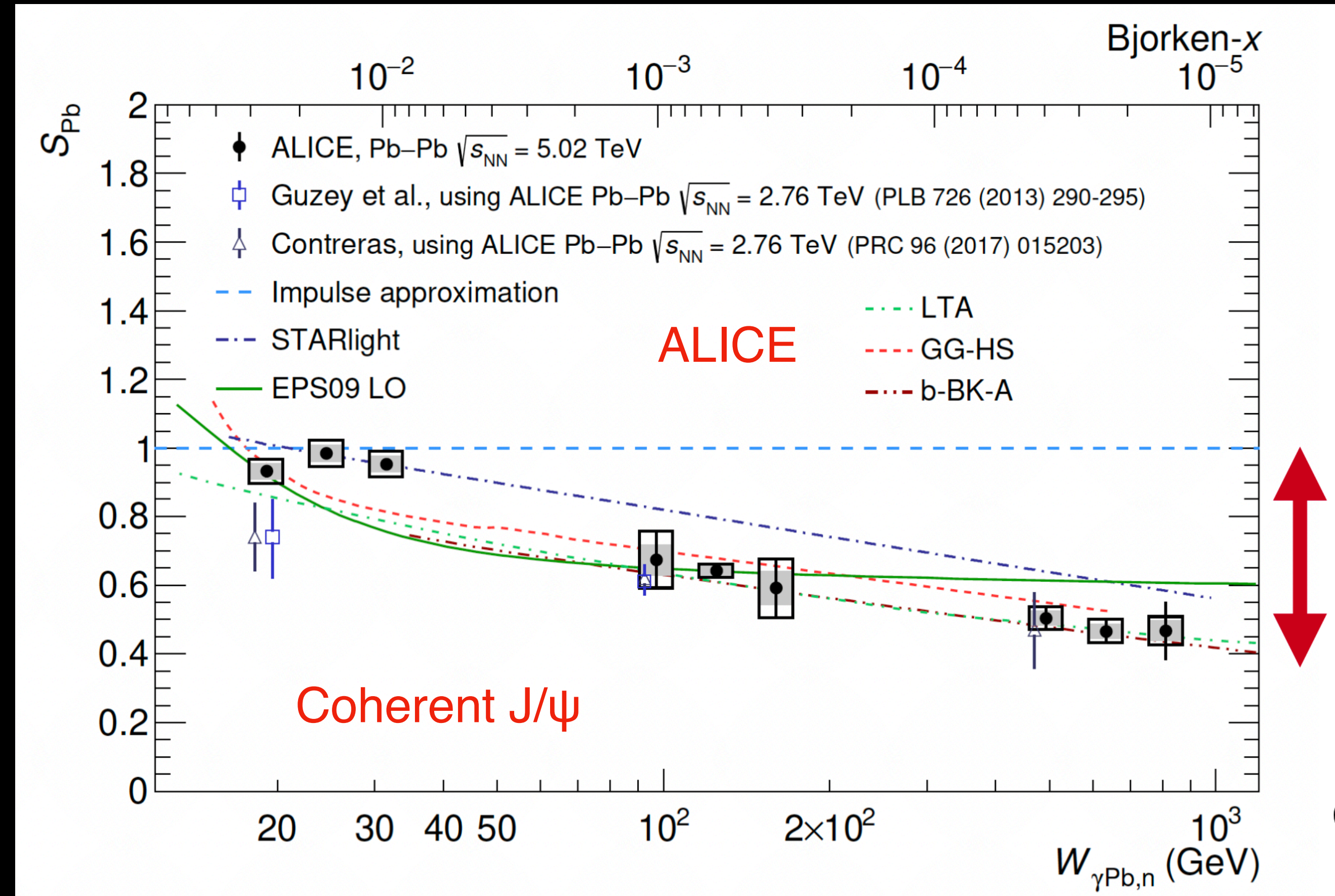
— UPC events can be triggered experimentally

UPC J/ψ production

STAR, Phys. Rev. Lett. 133 (2024) 052301



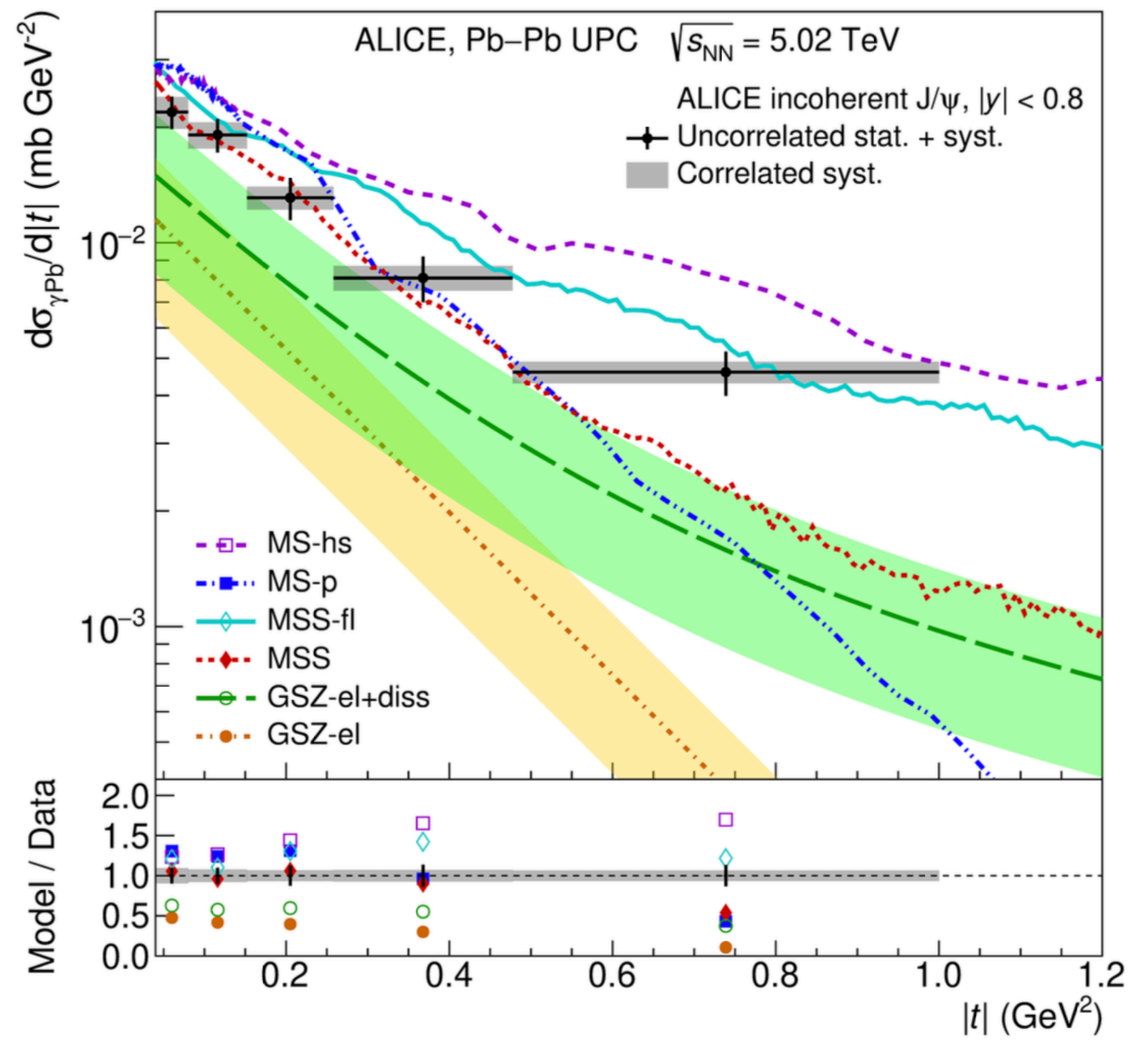
Gian Innocenti & Xihe Han



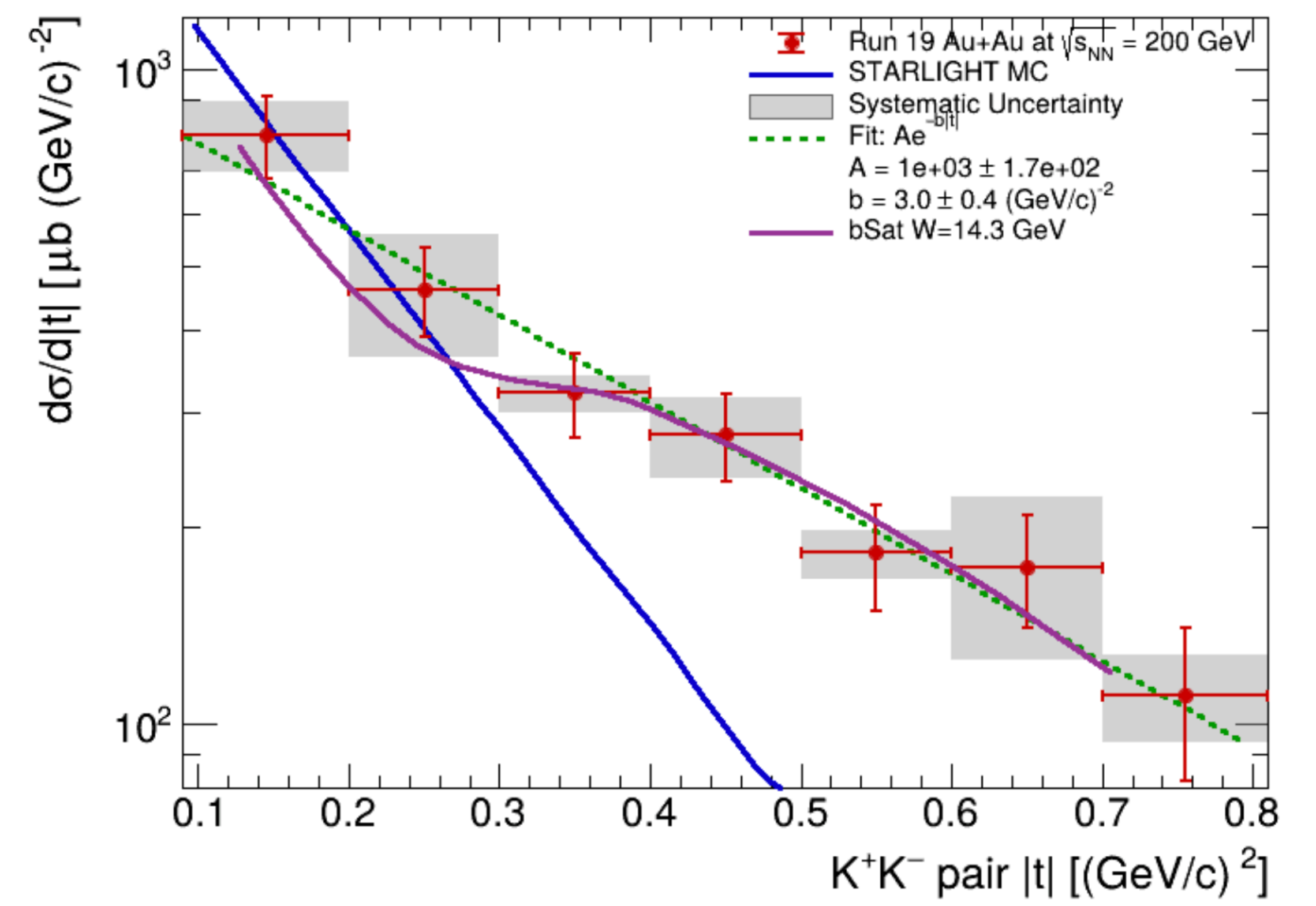
- Strong nuclear suppression (~49%) seen
- Bound nucleon's shape similar to free proton
- Sub-nucleonic fluctuations

- J/ψ as a function of $W_{\gamma N}$
- Strong suppression at small x

Incoherent J/ψ production at the LHC (ALICE)



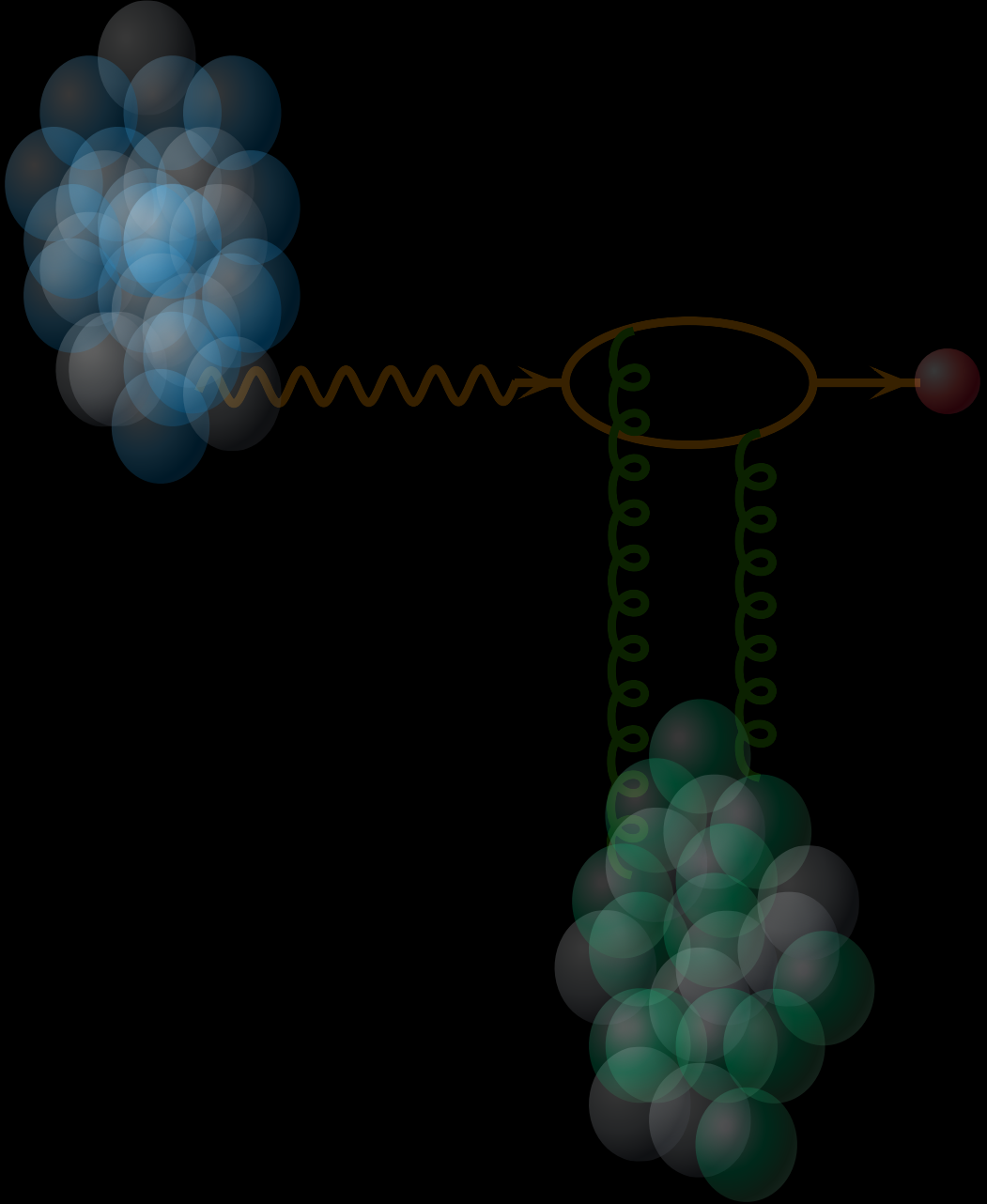
Incoherent ϕ production at RHIC (STAR)



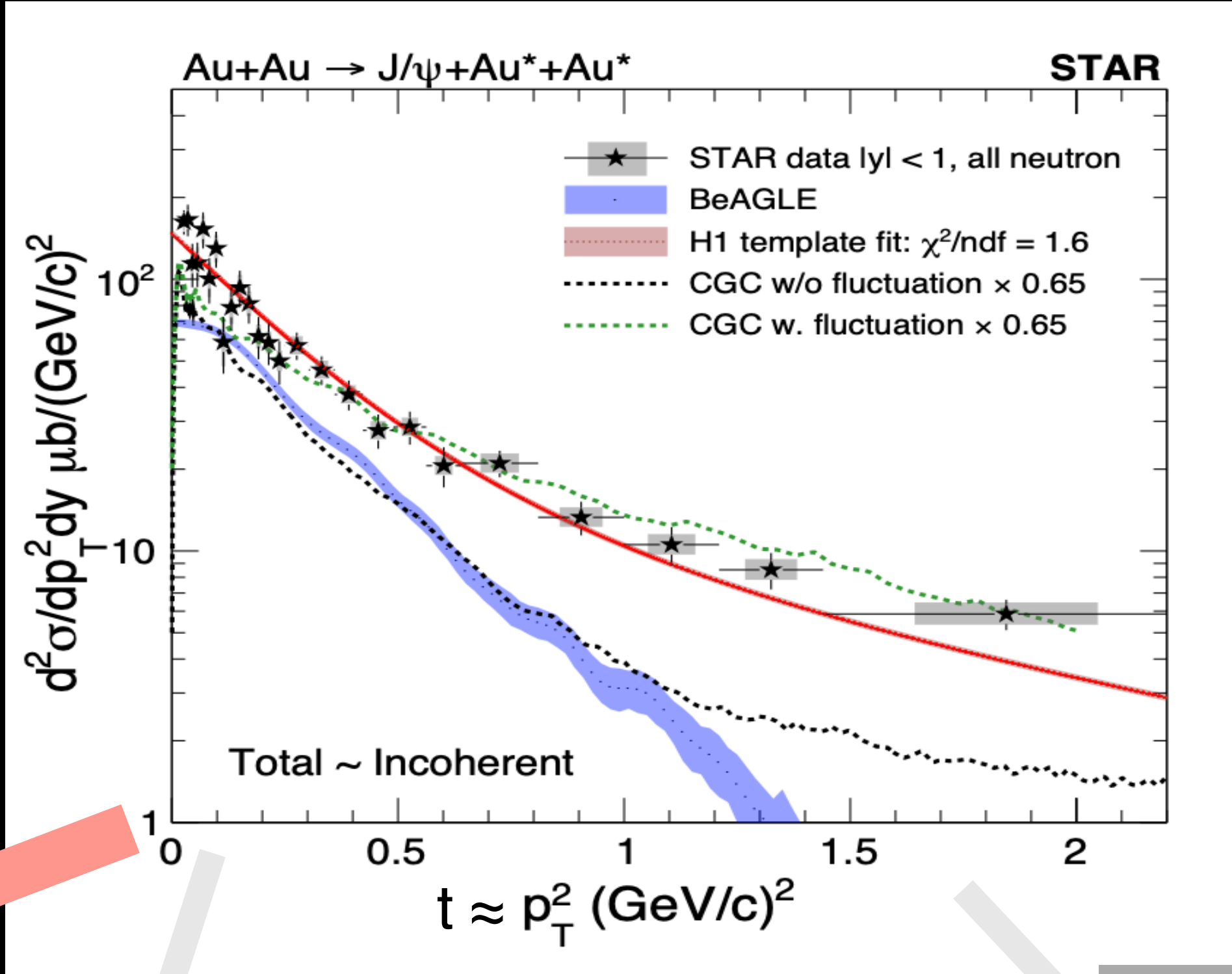
- Incoherent probes event-by-event gluon-density fluctuations
- t -dependence is sensitive to the transverse scale of gluon-density fluctuations
- Models without gluon-density fluctuations predict a much steeper t -dependence than observed

Adding a new dimension to UPC imaging

UPCs: Photon-induced nuclear imaging



Add orientation-dependent information



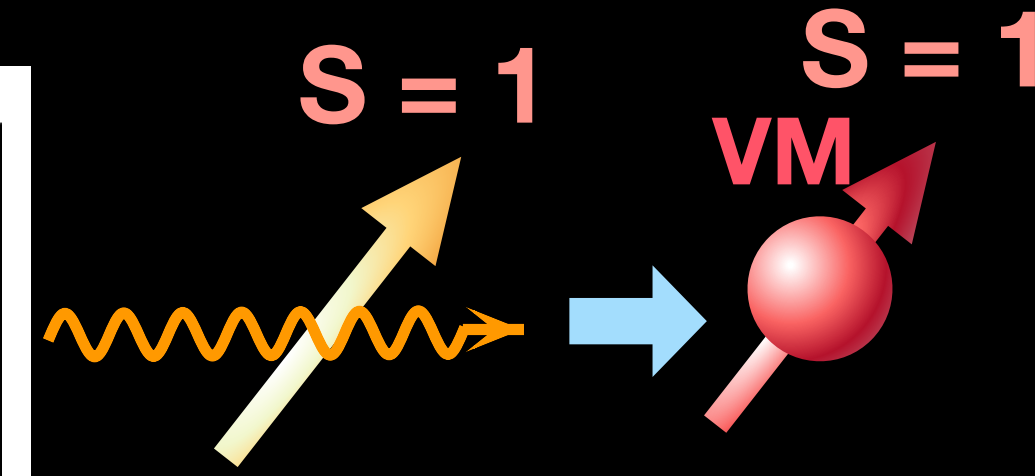
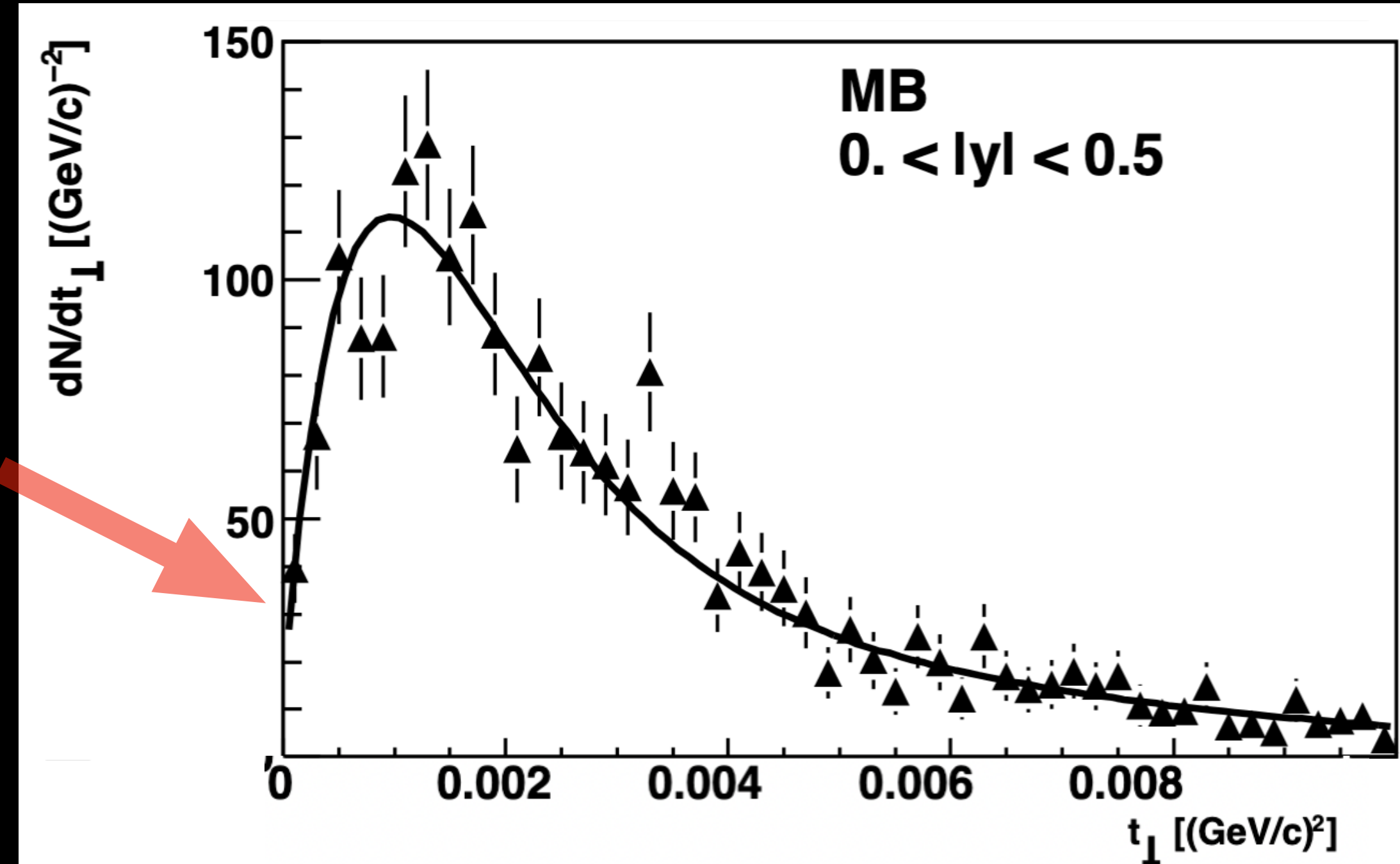
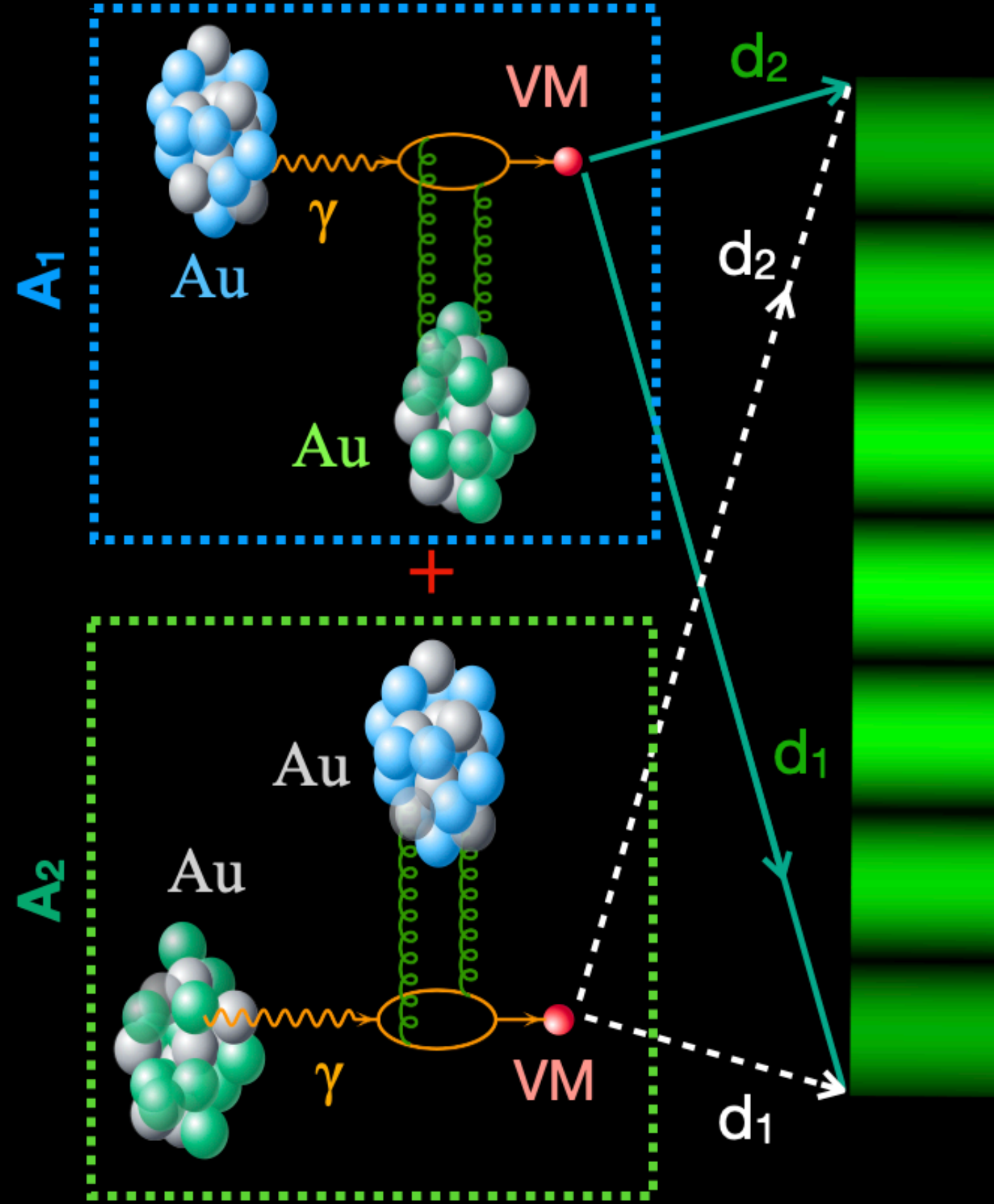
$\vec{p}_T \cdot \vec{p}_T = p_T^2$
(Magnitude only)



Can we go beyond t ?

Evidence of Two-source Interference in UPC events

STAR collab., Phys. Rev. Lett. 102: 112301, 2009



Orientation dependence is built-in

$$\frac{\hbar d\sigma}{dy dp_T} = \int_{b>2R} |A_1 \pm A_2|^2 d^2b$$

$$|A_1 \pm A_2|^2 = 2A_0^2 \left(1 \pm \cos\left(\frac{\vec{p} \cdot \vec{b}}{\hbar}\right) \right)$$

Interference link VM momentum (\vec{p}) and impact parameter (\vec{b}) between two nuclei

UPC VM production contains orientation-dependent physics through $\vec{p} \cdot \vec{b}$

Spin interference with ρ^0

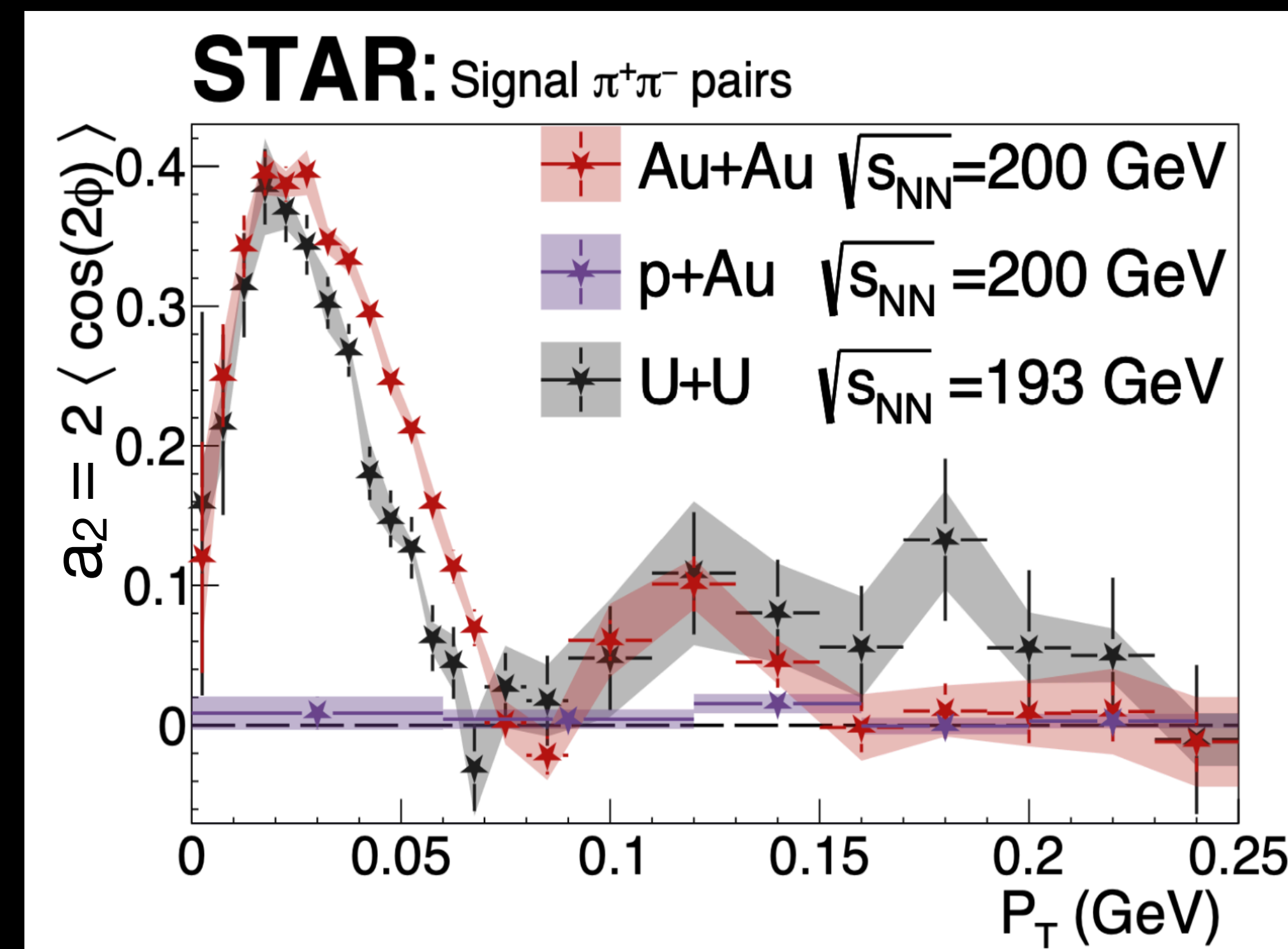
Xihe Han

STAR collab., *Sci. Adv.* 9, eabq 3903 (2023)

Interference + polarization \rightarrow
spin-momentum correlation

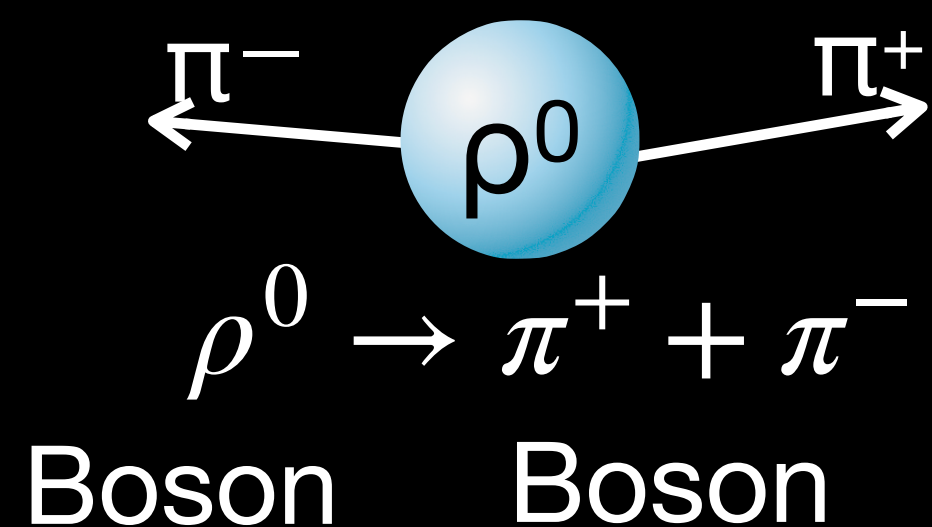
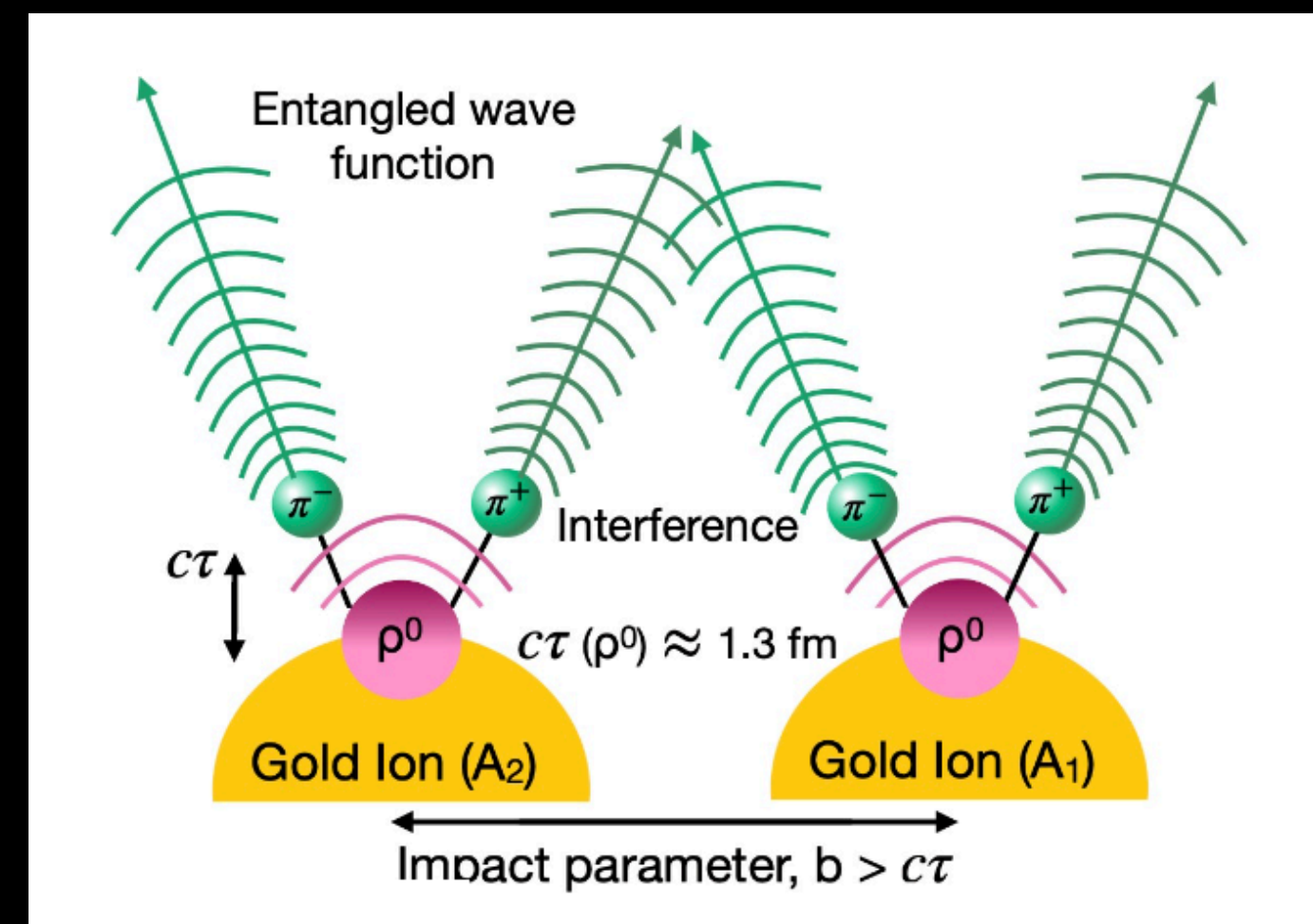
Observable:
 $a_2 = 2 \langle \cos 2\phi \rangle$ vs. p_T

ϕ : angle between VM
momentum & π decay axis

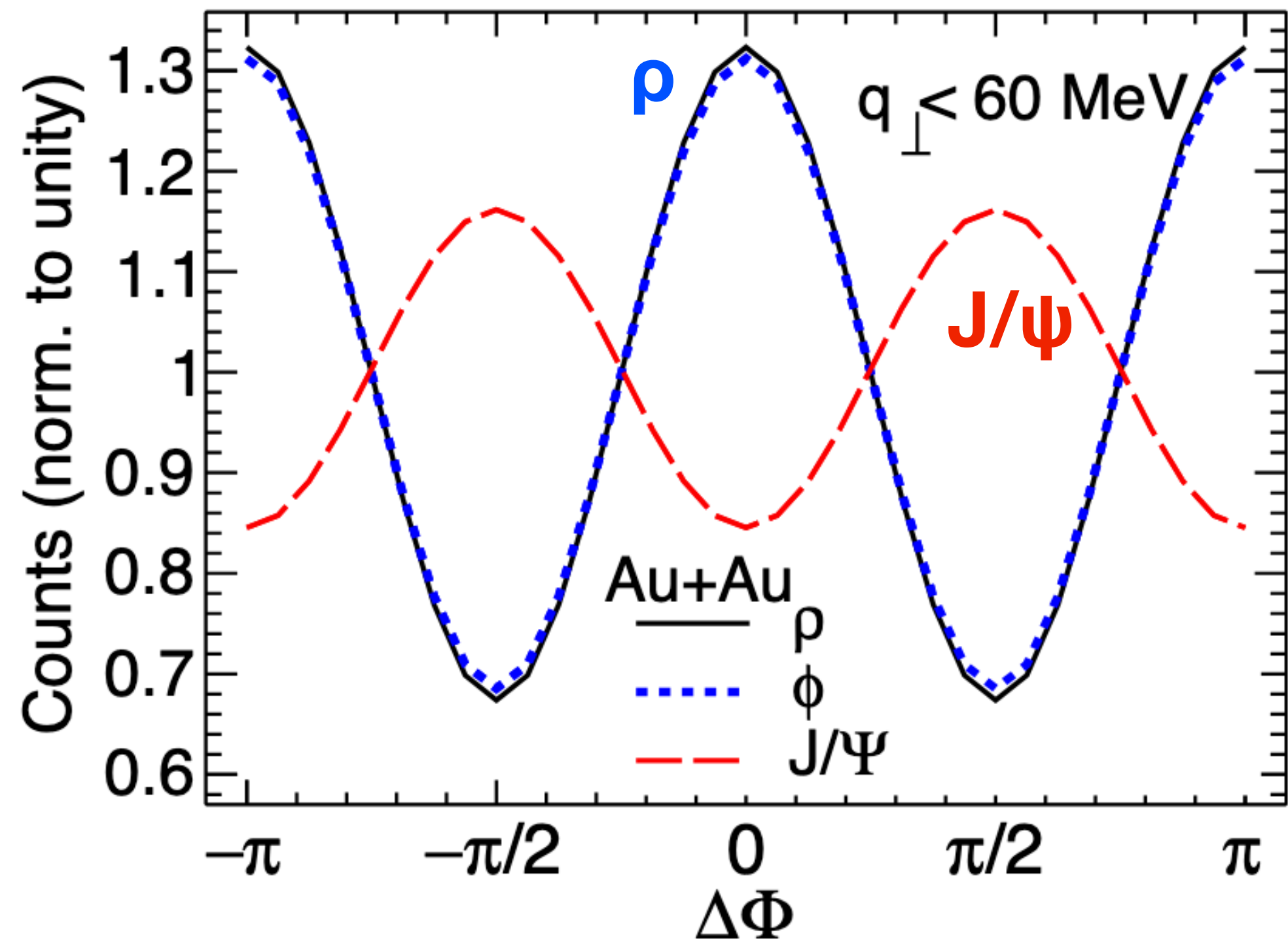


Nonzero in A+A \rightarrow spin-momentum correlation
Vanishing in p+A \rightarrow no 2-source interference

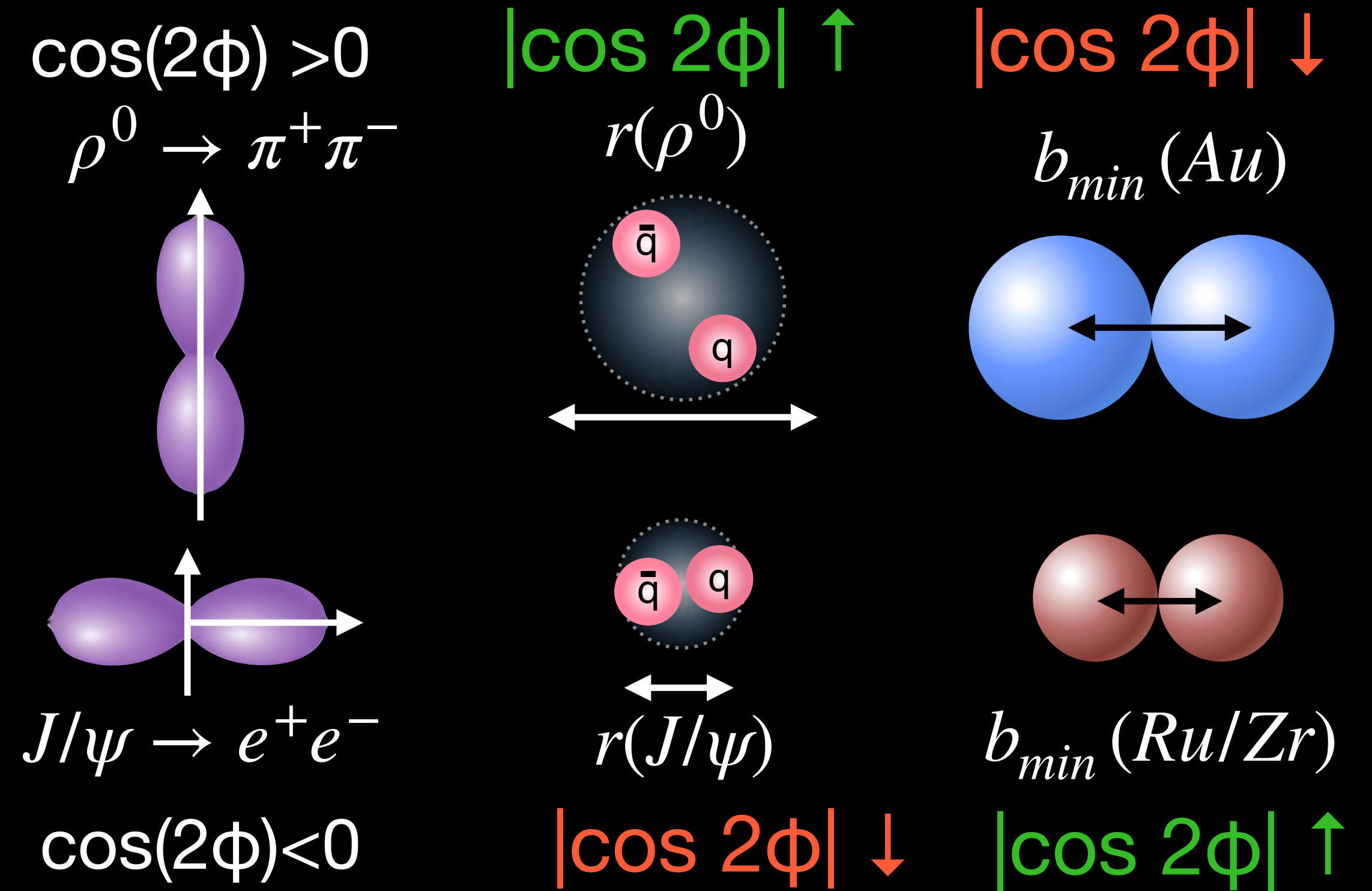
Interference + polarization + decay \rightarrow measurable spin-momentum correlation



ρ^0 vs J/ψ : dipole size and model comparison



Available saturation model predictions:



Key tests: Sign flip, $|\cos 2\phi| \rightarrow \rho > J/\psi$ (compact dipole), Au > Isobars (closer centers)

J/ψ introduces a harder scale enabling a more controlled data-model comparison

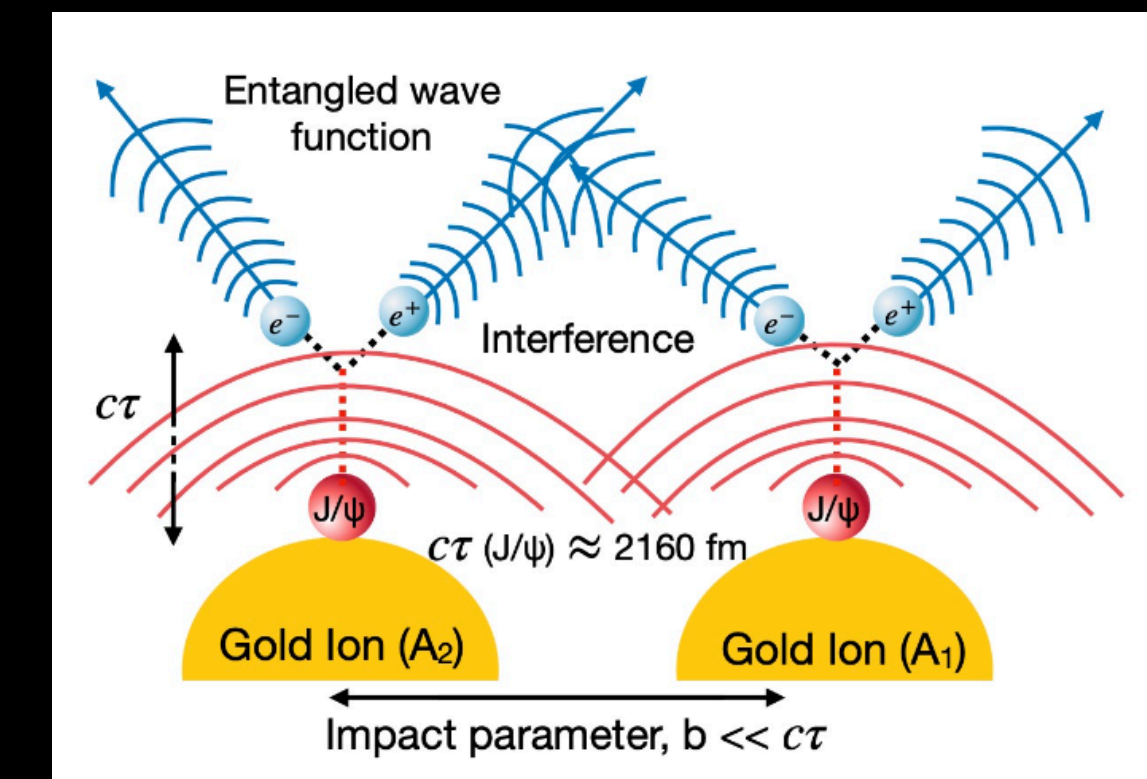
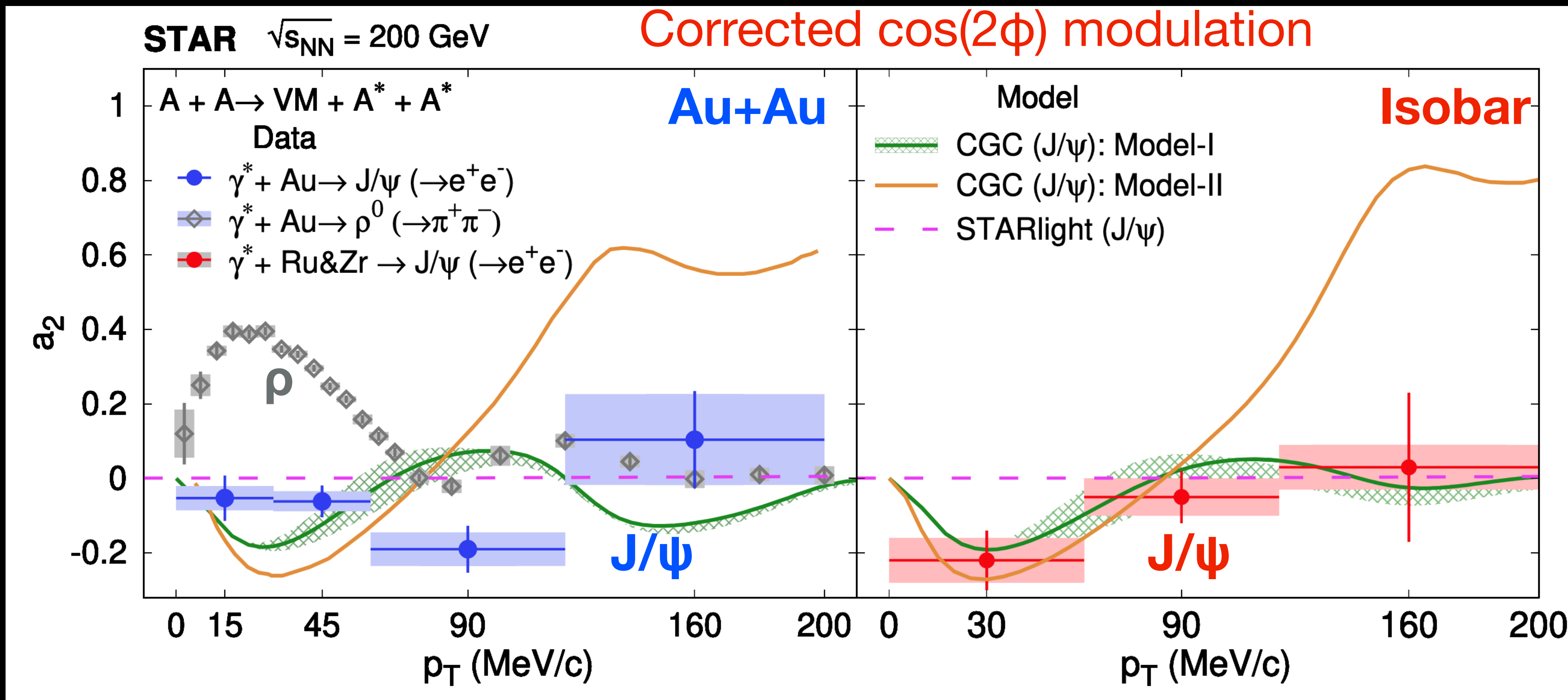
Spin interference with J/ψ : New Measurements at STAR

Xihe Han

STAR collab, arXiv: 2512.02865, to appear in PRL

CGC Model-I:
Mäntysaari, Salazar,
Schenke, Shen, and
Zhao, *Phys. Rev. C* 109,
024908 (2024).

CGC Model-II:
Brandenburg, Xu, Zha,
Zhang, Zhou,
and Zhou, *Phys. Rev. D*
106, 074008 (2022).

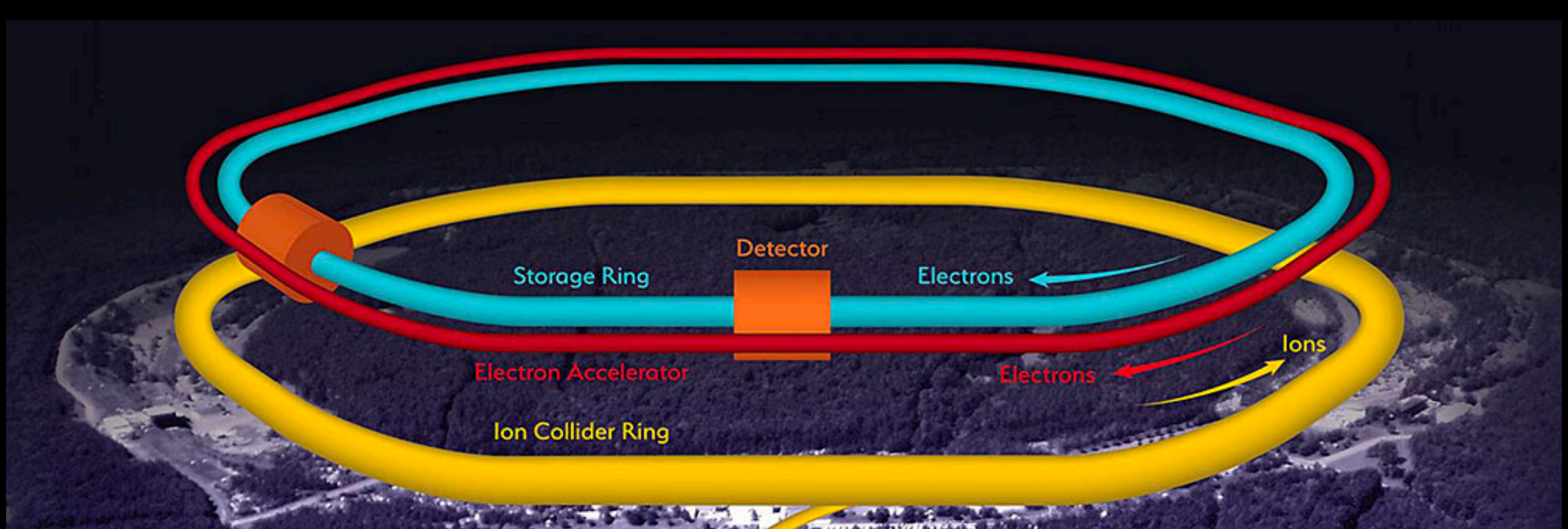


Negative modulation at $p_T < 100$ MeV for Au+Au ($>3\sigma$) for J/ψ , weaker than ρ

Qualitatively consistent with spin-interference expectation from available saturation models

Magnitude and p_T dependence help discriminate between model scenarios

Spin interference opens a new, orientation-sensitive observable, constraint on models

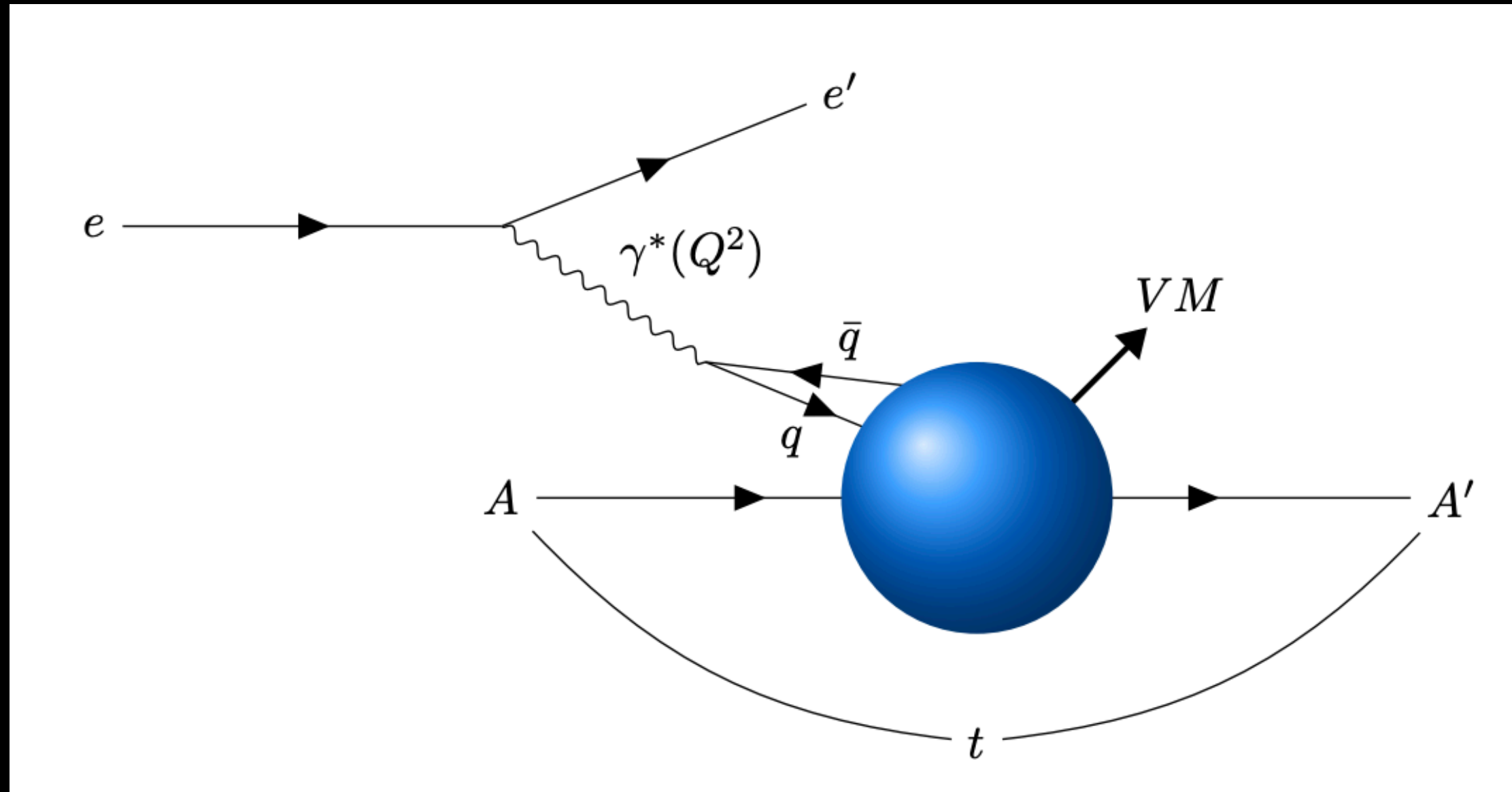


Nuclear Imaging at EIC



Gluon imaging via exclusive vector meson production in e+A collisions

Rongrong Ma



- $|t|$ -distribution sensitive to gluon distribution at high energy (low x)

$$t = - (p_{A'} - p_A)^2$$

Energy-momentum conservation:

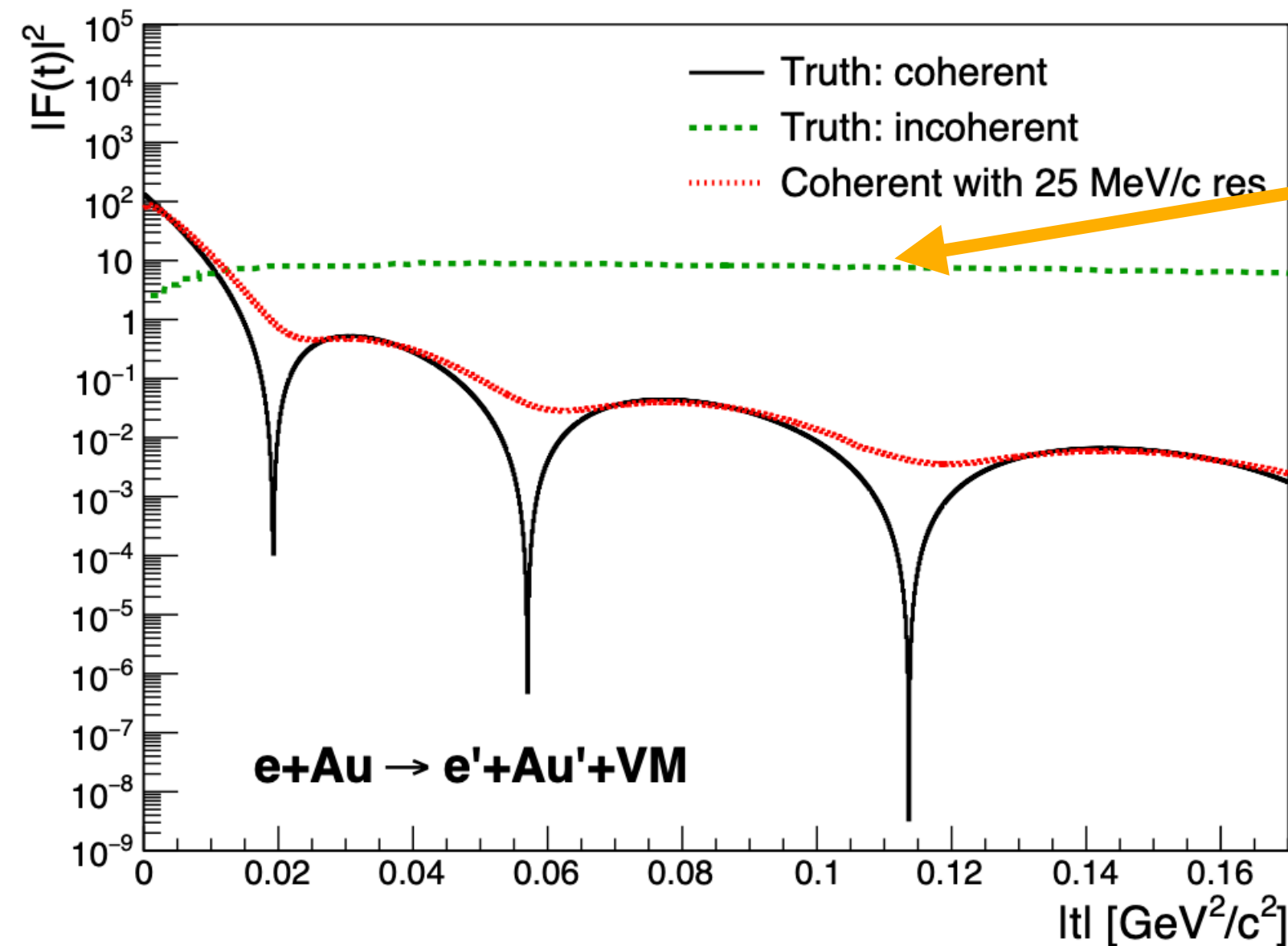
$$p_e + p_A = p_{VM} + p_{A'} + p_{e'}$$

$$t = - (p_e - p_{e'} - p_{VM})^2$$

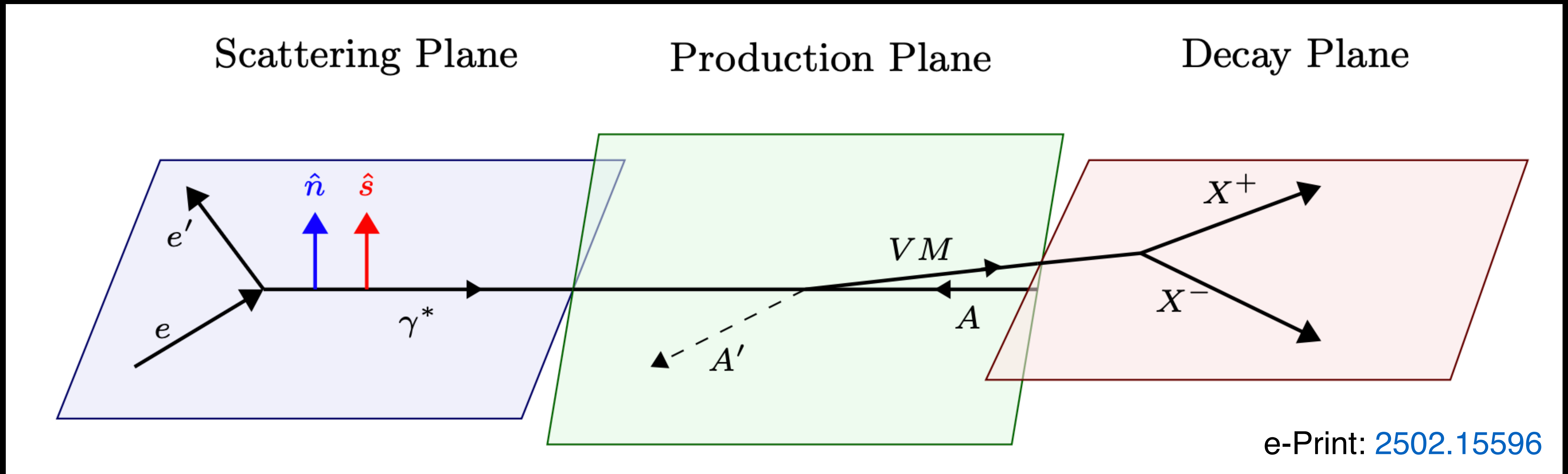
↑
scattered e momentum

—> limited by the resolution

- Challenges to get precise $|t|$:
 - a. momentum resolution
 - b. Incoherent background



Incoherent background



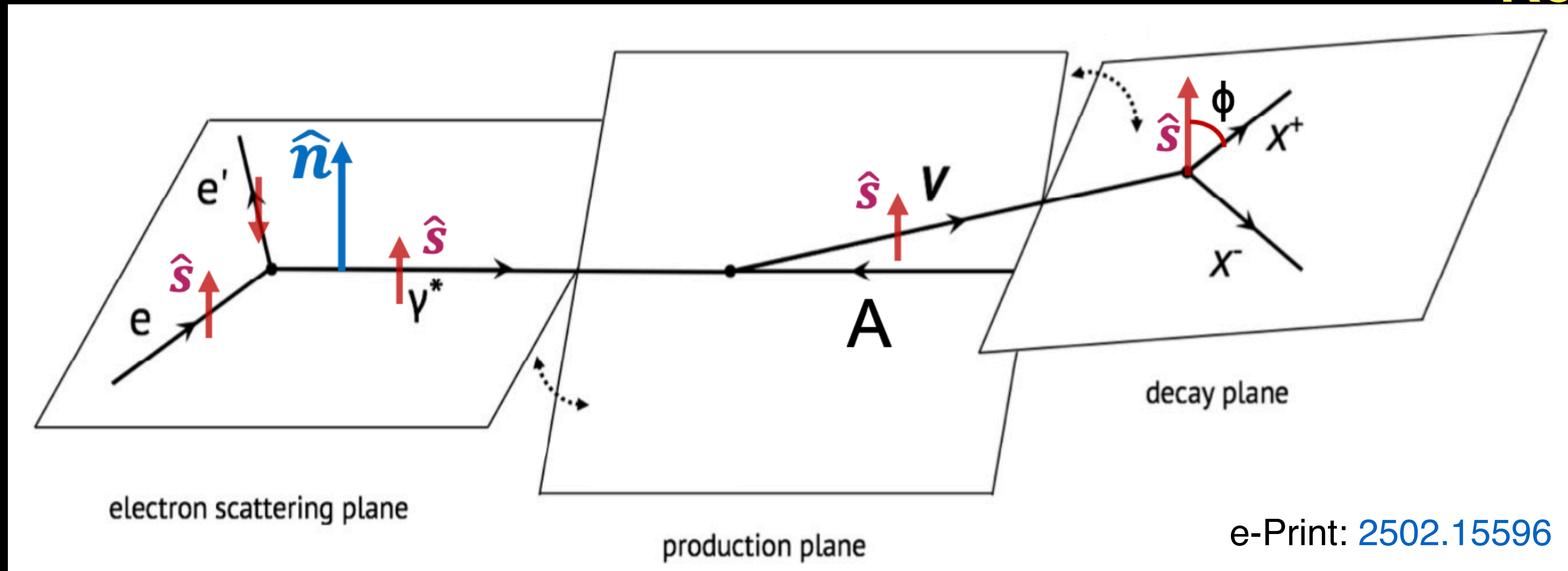
Project $t \perp e$ scattering plane

$$- t \cdot \hat{n} = (P_{VM} \cdot \hat{n} - p' \cdot \hat{n} + p \cdot \hat{n})^2 = (P_{VM} \cdot \hat{n})^2$$

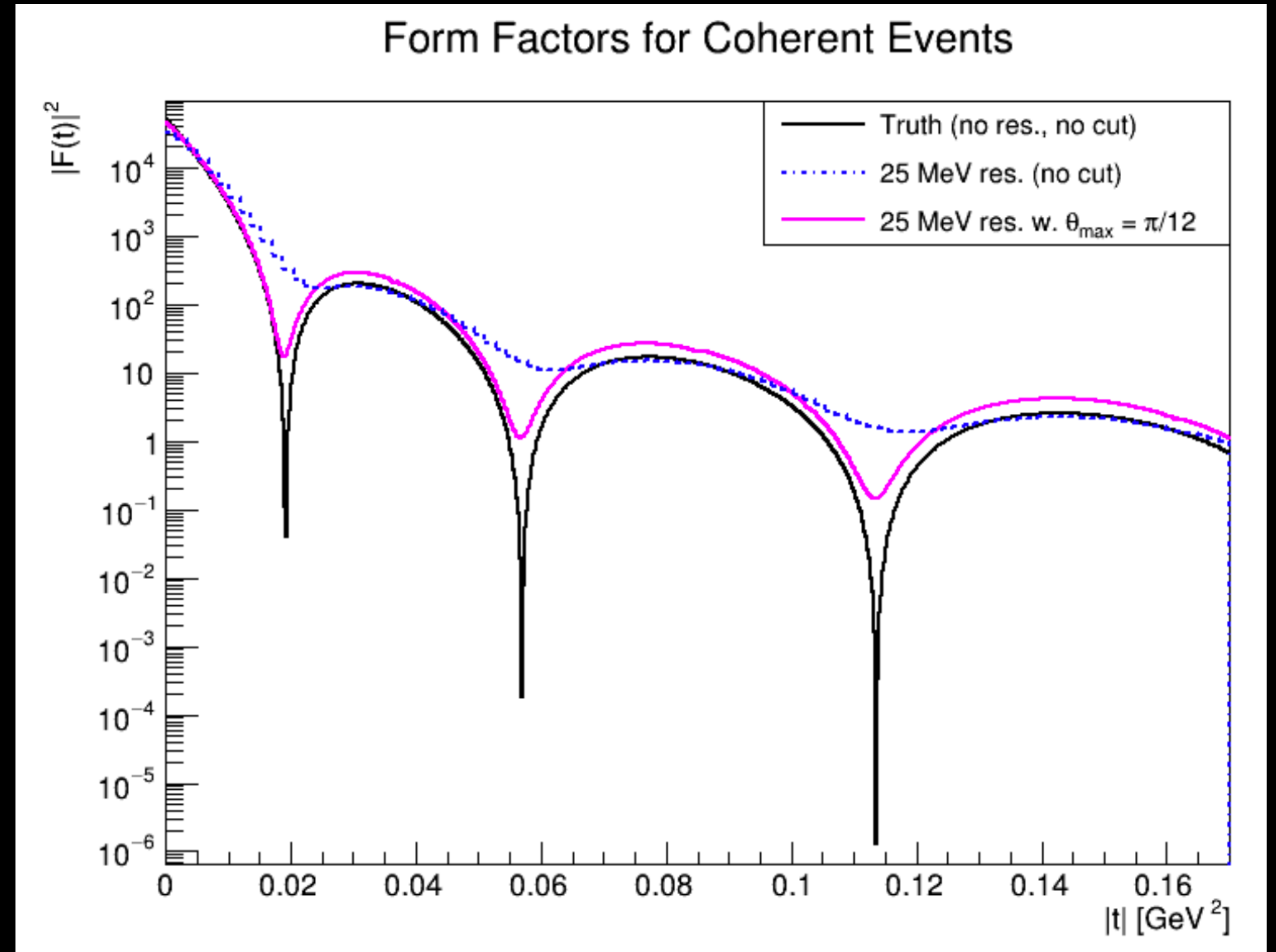
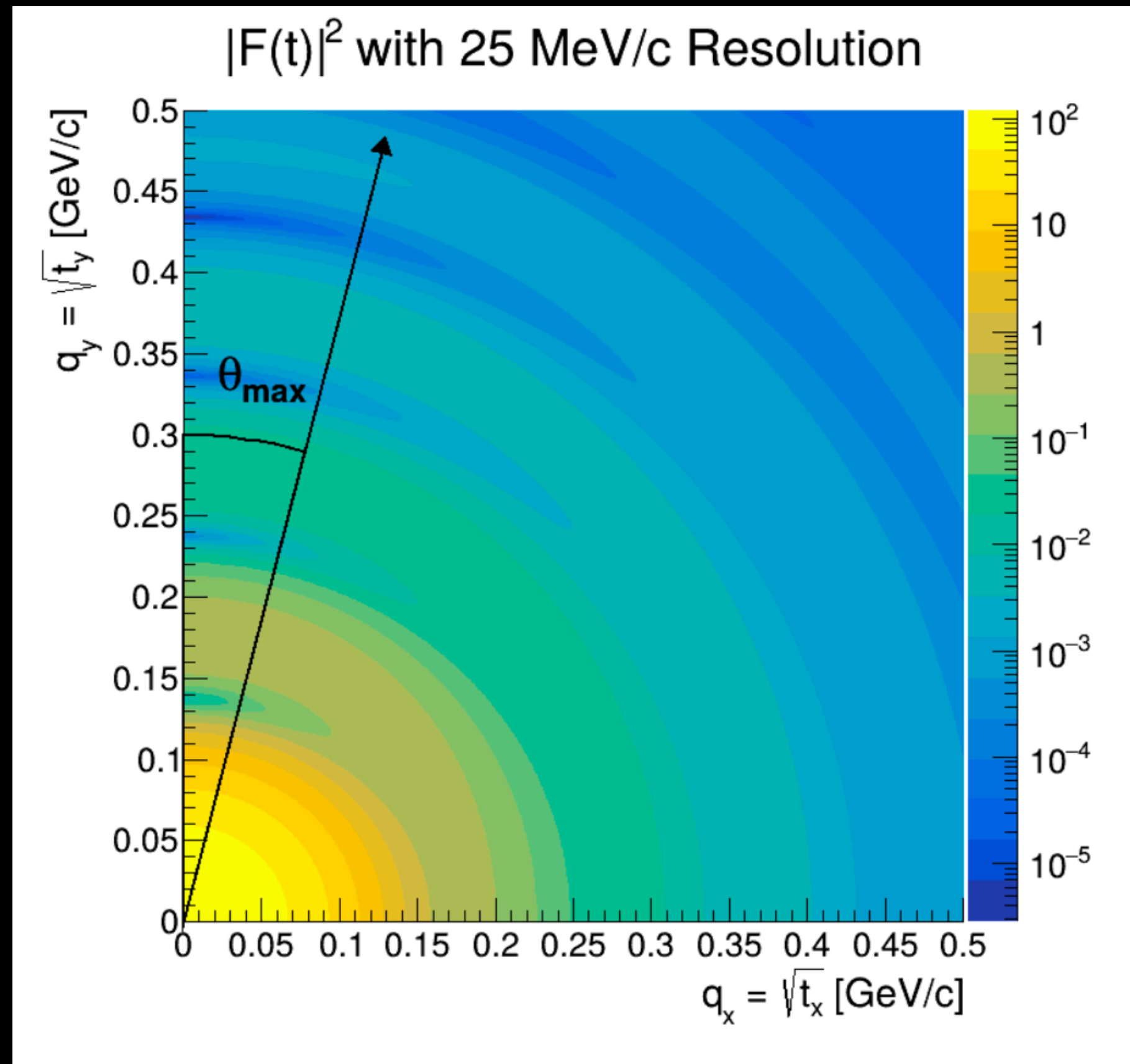
—> Only need to measure the electron directions, not their momenta

Suppressing incoherent background with polarized e beam

Rongrong Ma



- Use transversely polarized e beam, $\hat{s} \perp \vec{p}_e$
- If \hat{s} flips sign after scattering (exchanged pompon spin 0), virtual photon spin aligns with $\hat{s} \Rightarrow$ VM spin aligns with $\hat{s} \parallel \hat{n}$
 - Correlation of VM daughters with $\hat{s} \Rightarrow$ echoes STAR lesson
- Incoherent event (nucleus breaks up), VM spin is random \Rightarrow no correlation



— Specific selection of wedge along \hat{n} minimizes detector resolution

— Diffractive pattern largely restored (magenta curve)

Quantum tomography

Quantum tomography

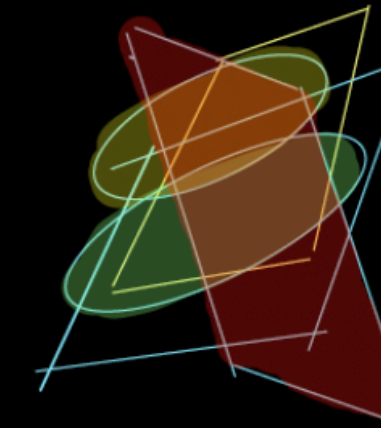
Daniel Takaki

QUANTUM TOMOGRAPHY
IN ONE PAGE

$A=A^\dagger, \rho=\rho^\dagger$ "PROBE- l "

$$\langle A_l \rangle = \text{tr}(A_l \rho) = \langle A_l | \rho \rangle$$

A PROJECTION, AN
INNER PRODUCT
OF OPERATORS



COMPLETENESS ;
GENERATORS of $U(N)$

$$1 = \sum_l |A_l \rangle \langle A_l|$$

$$\rho = \sum_l |A_l \rangle \langle A_l| \rho$$

EXPANSION

"OBSERVABLE"

NO MODEL
OF THE TARGET

QUANTUM TOMOGRAPHY

$$\rho = \sum_l |A_l \rangle \langle A_l|$$

"OBSERVABLE"

— Based on
Quantum Mechanics

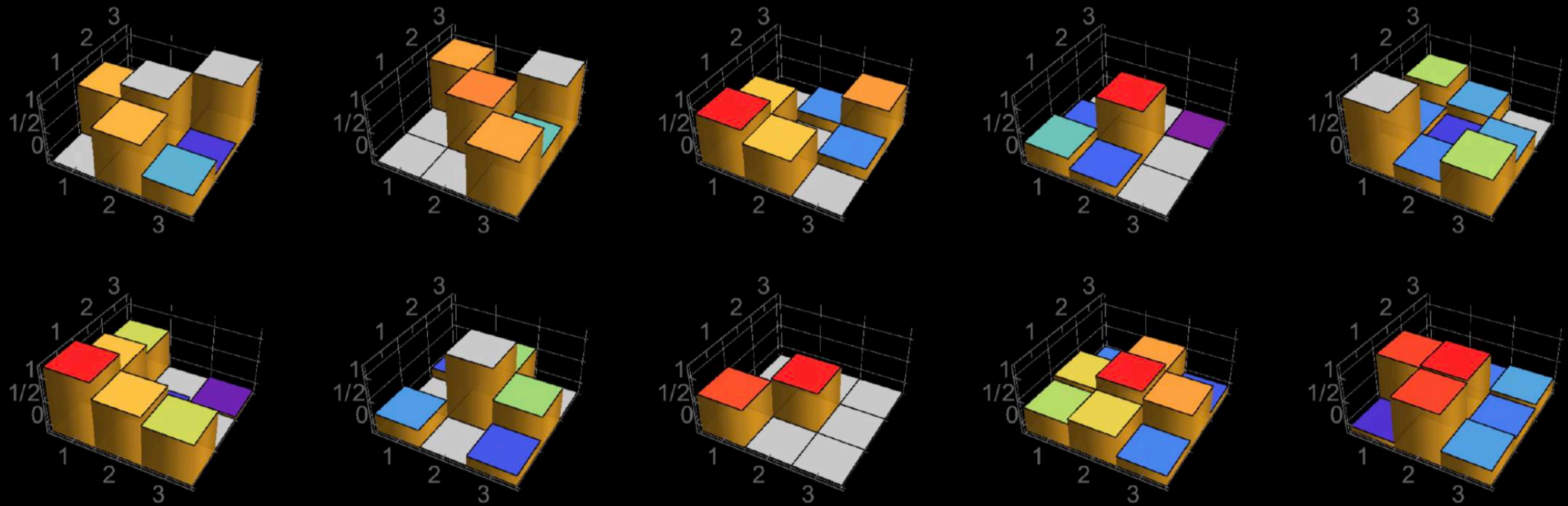
— Goal: Obtain
density matrix
elements in model
independent way

— Density matrix
elements can be
measured

Regular Article - Theoretical Physics
Quantum tomography for collider physics: illustrations
with lepton-pair production
John C. Martens^a, John P. Ralston^a, J. D. Tapia Takaki^b
Department of Physics and Astronomy, The University of Kansas, Lawrence, KS 66045, USA

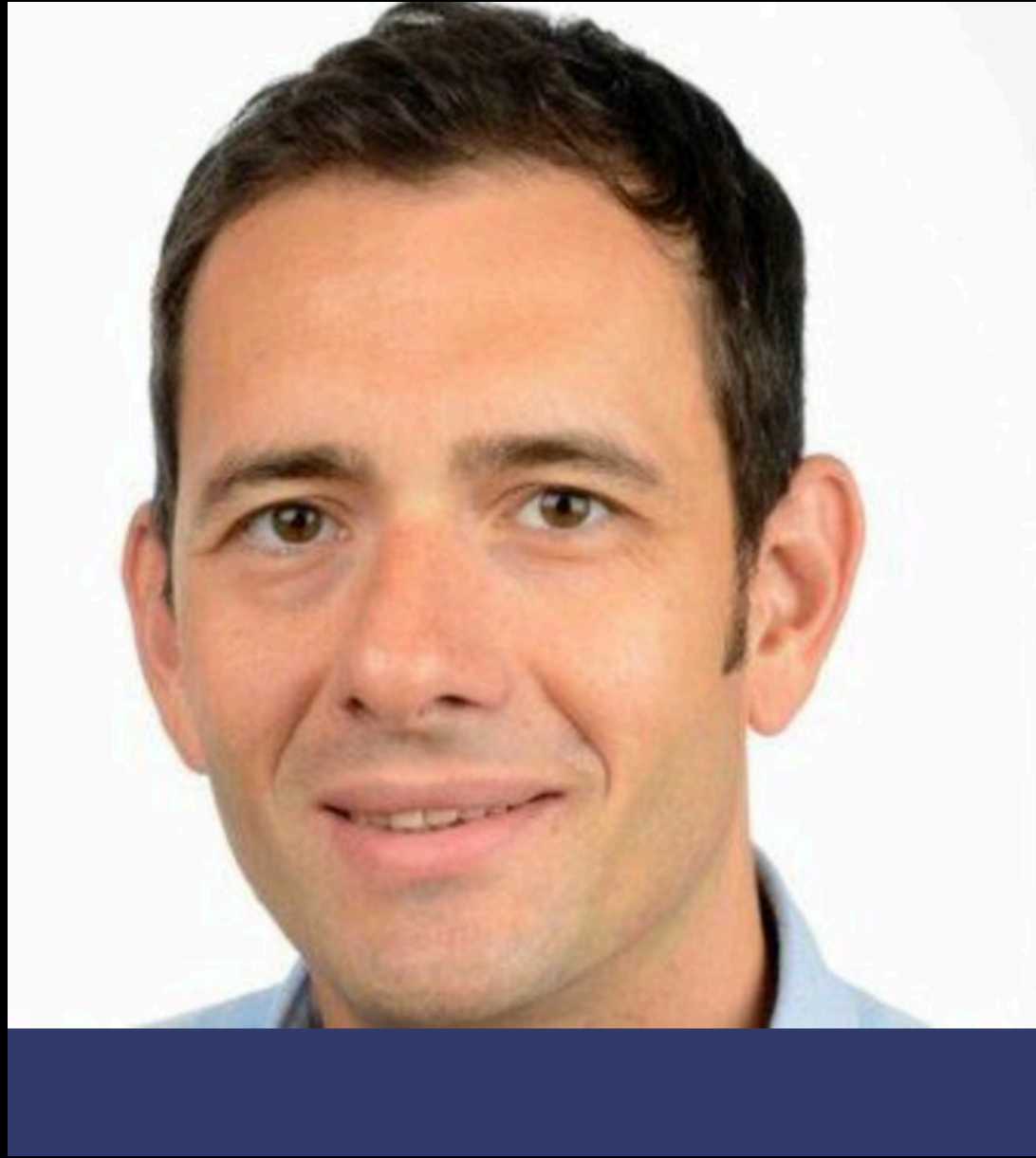
Martens, Ralston, Tapia Takaki Eur. Phys. J. C78, 5, 2018

10 EVENTS, 10 DENSITY MATRICES



- Density matrix elements in each events
- More to follow on observable reconstruction from density matrix elements

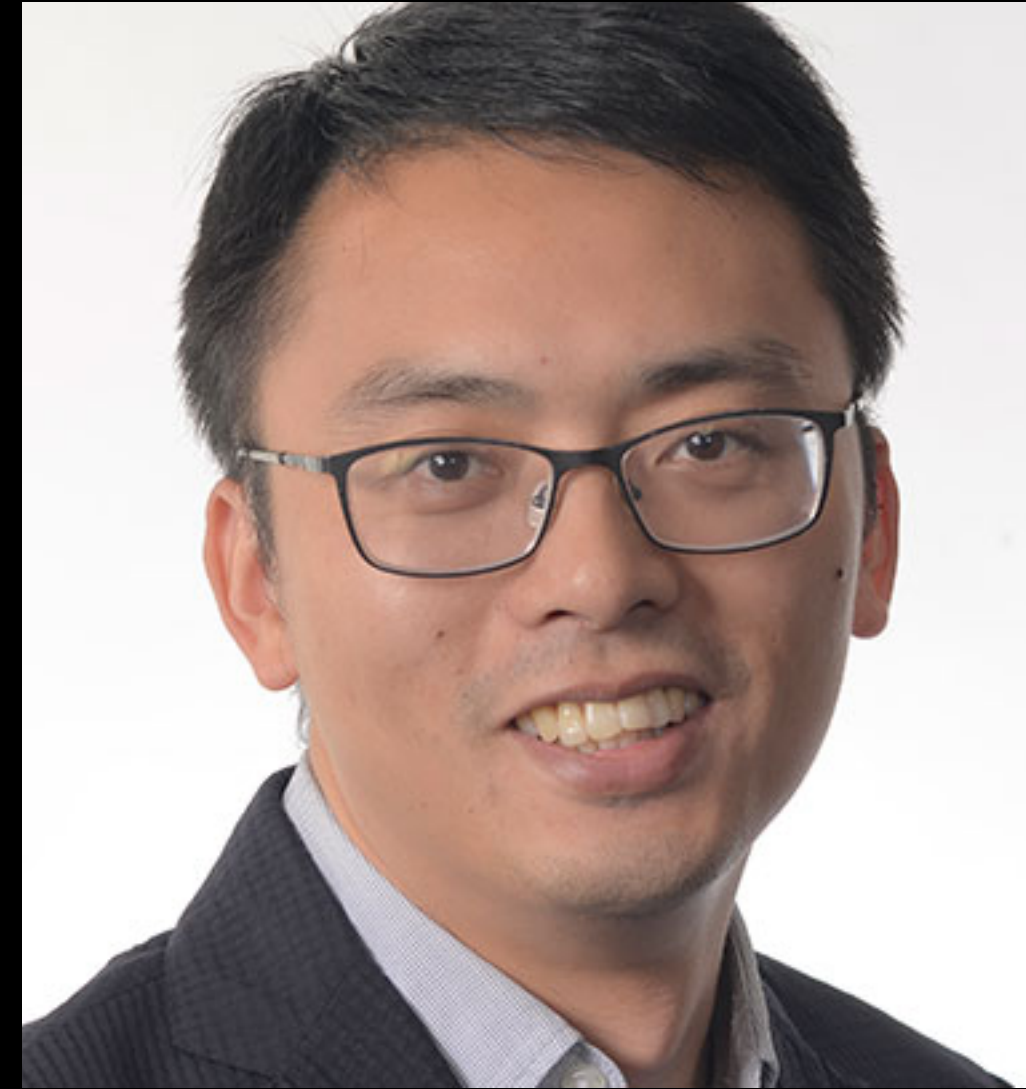
Big thanks to our speakers



Gian Michele Innocenti



Mariia Mitrankova



Rongrong Ma



Daniel Tapia Takaki



Xihe Han

Thank You!