https://indico.bnl.gov/event/10155/overview

Center for Frontiers in Nuclear Science

Summary of CFNS workshop

Open Questions *in Photon-induced Interactions from Relativistic Nuclear Collisions to the Future Electron-Ion Collider*

Wei Li[1], Bjoern Schenke[2], Kong Tu[2], and Thomas Ullrich[2]

1. Rice University
2. BNL

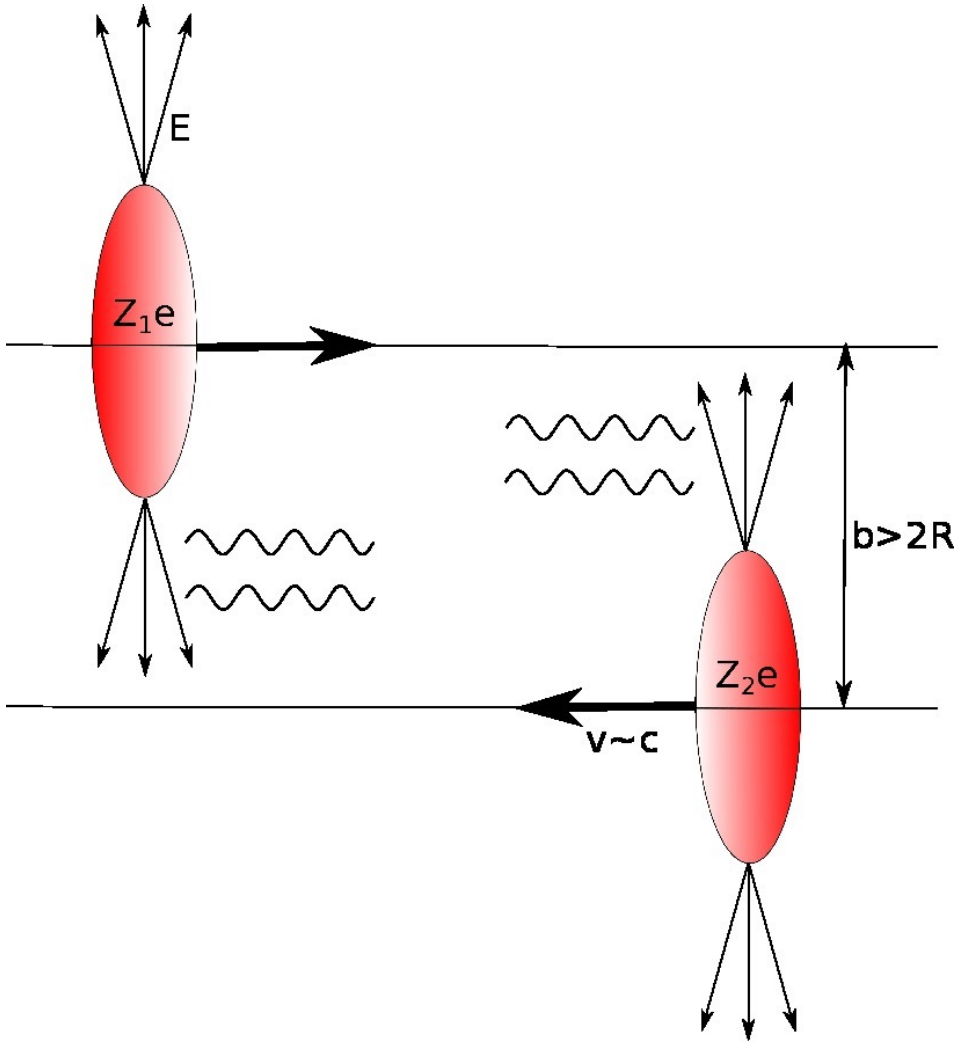
05.24.2021

Introduction – photon-induced interactions

Exclusivity

1. Photon-photon interactions
2. Diffractive VM productions
3. Collectivity

Main topics of the April workshop



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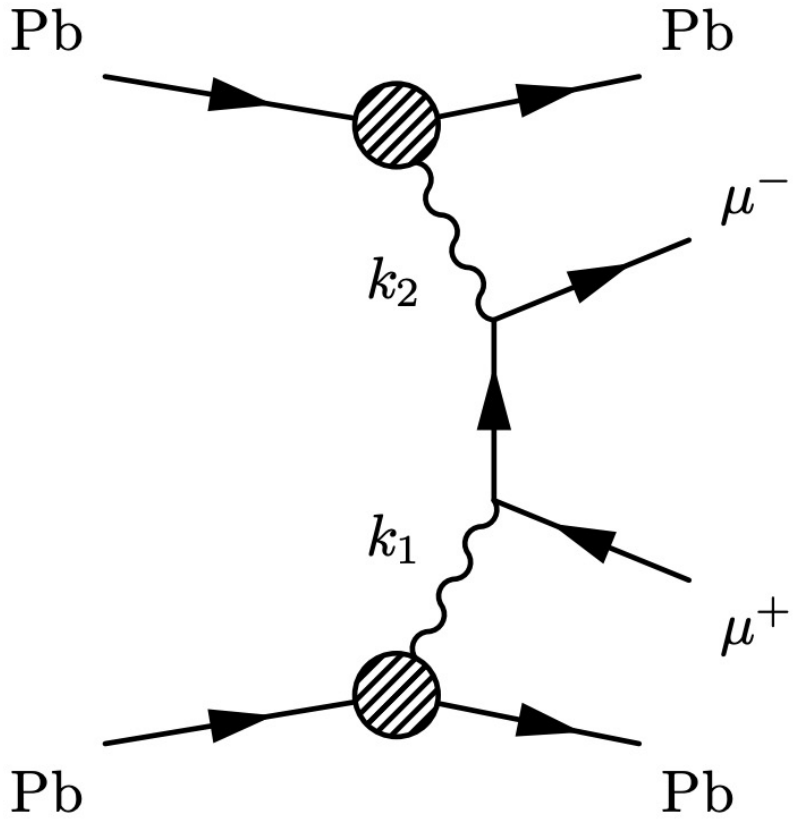

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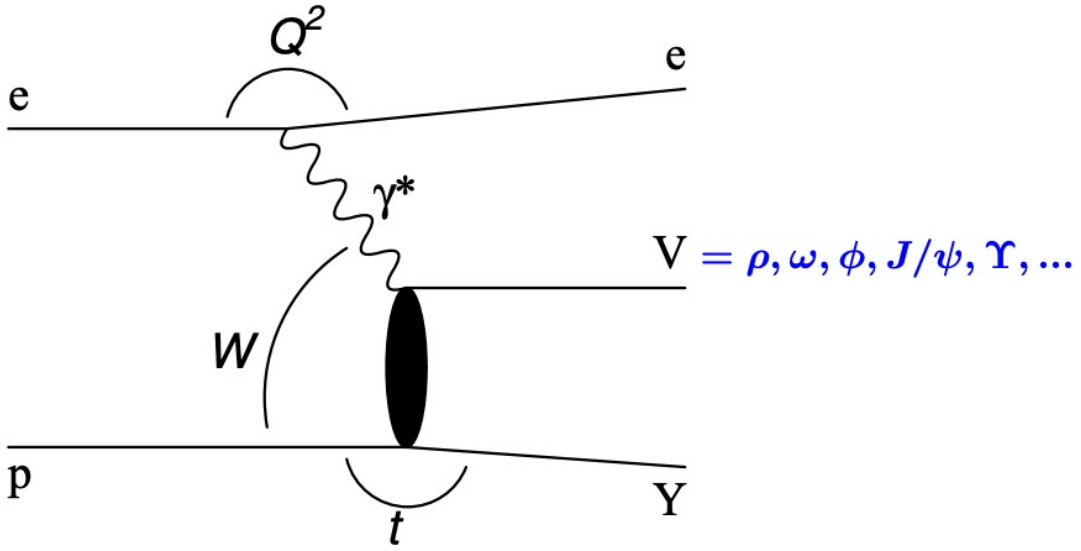

Target source density distributions

Introduction – photon-induced interactions

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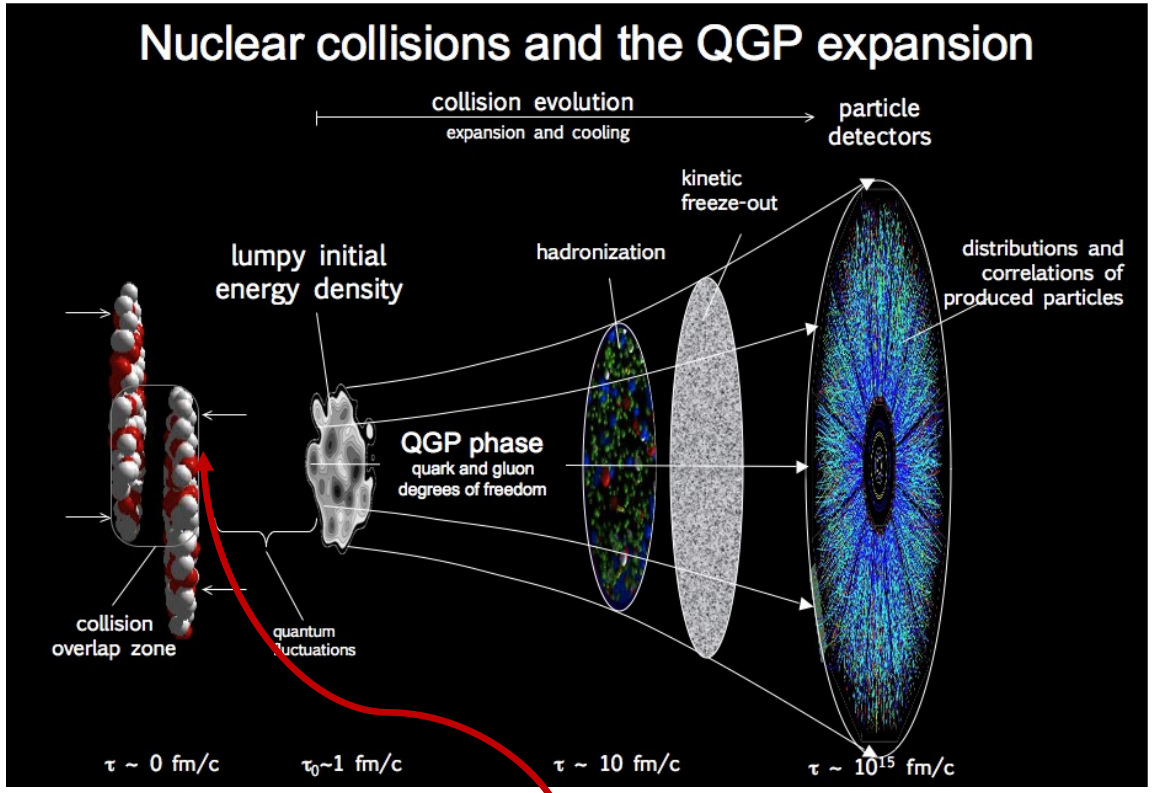


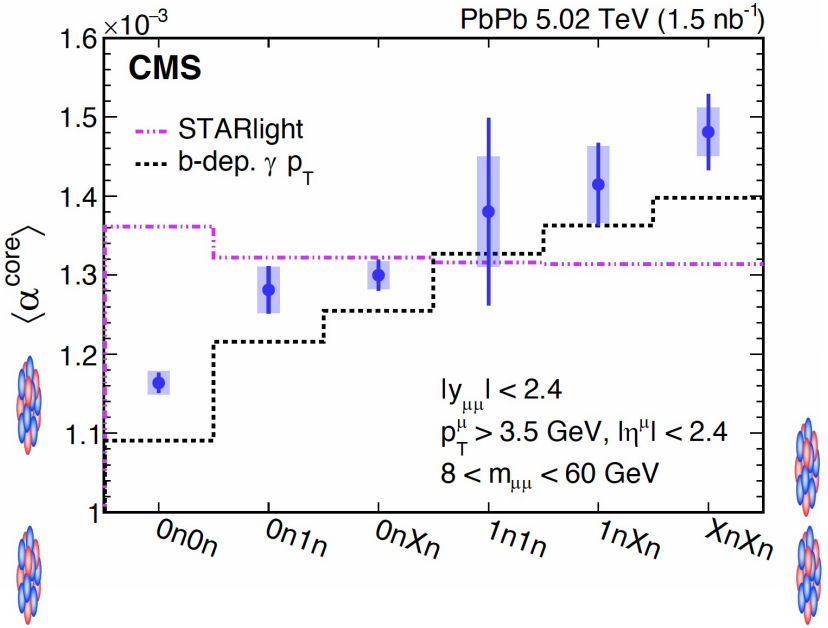
One or both sides replaced by a photon

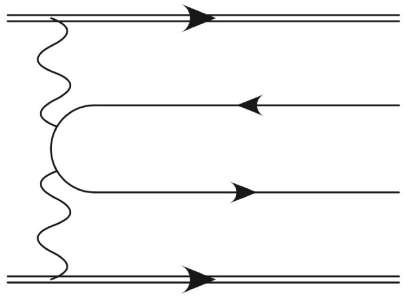
What would happen?

Photon-Photon interactions

Light-sabers in UPCs?

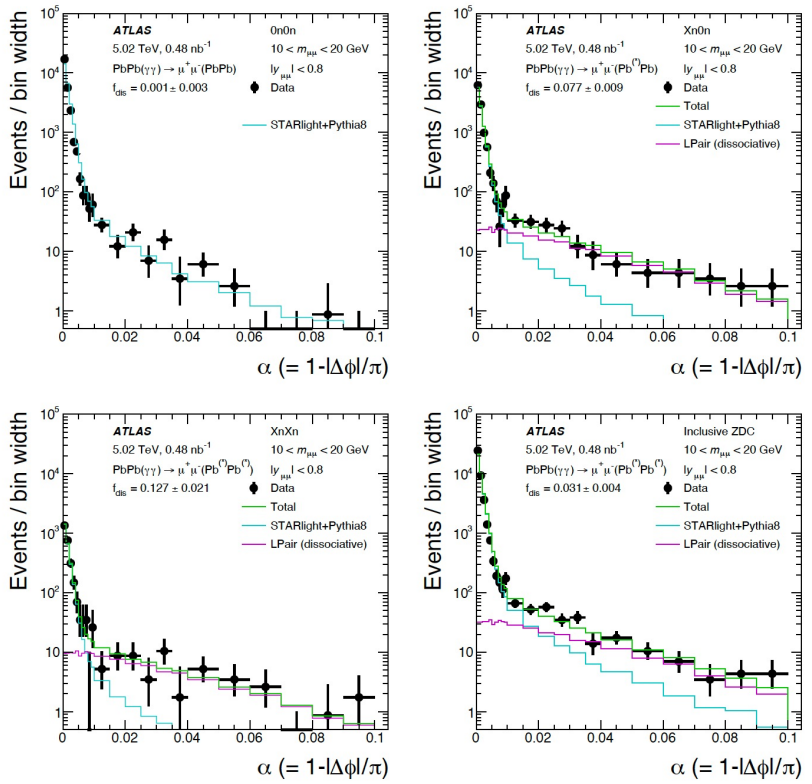
Photon-photon interactions – recent data on acoplanarity, $\alpha = 1 - |\Delta\phi|/\pi$





S. Yang

NEW arXiv:2011.12211



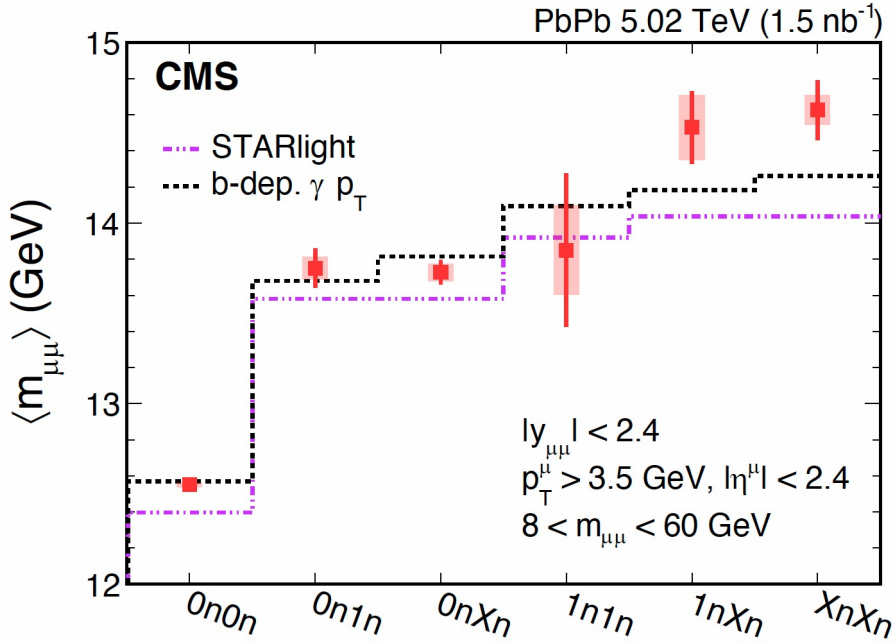
P. Steinberg

b dependence of photon flux p_T well established by new experimental results in neutron multiplicity classes (CMS and ATLAS data appear to be consistent)

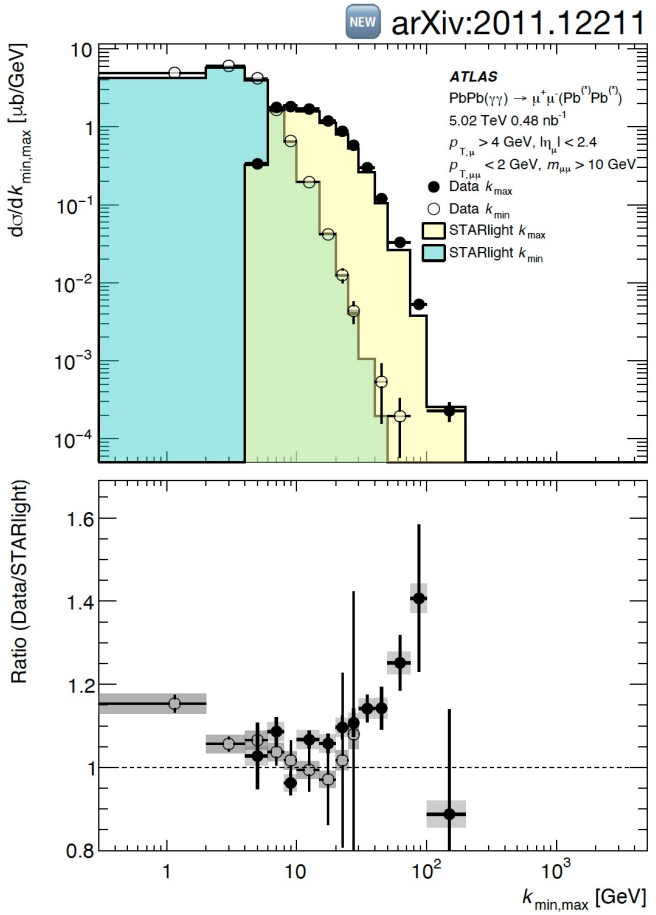
Open question:

- Is empirical fitting to separate LO and HO contributions robust?
- What contributes to the HO (tail of α dist.) and how to properly describe them?

Photon energy spectrum in the data harder than STARLight



S. Yang



P. Steinberg

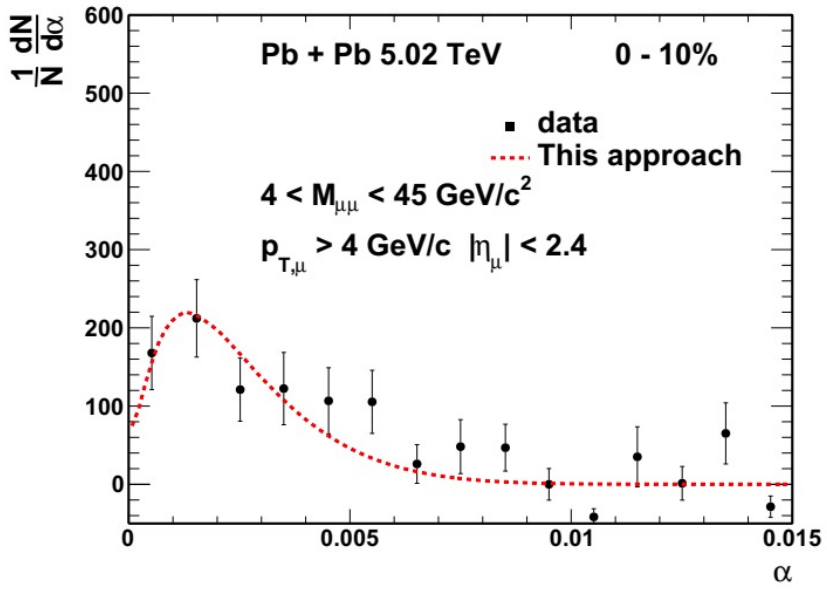
Open question:

- Is it also related to initial photon p_T?
- Requirement of b>R in STARLight? Sensitivity to charge distribution inside nucleus event-by-event?
- HO contribution missing?

Theoretical development

QED

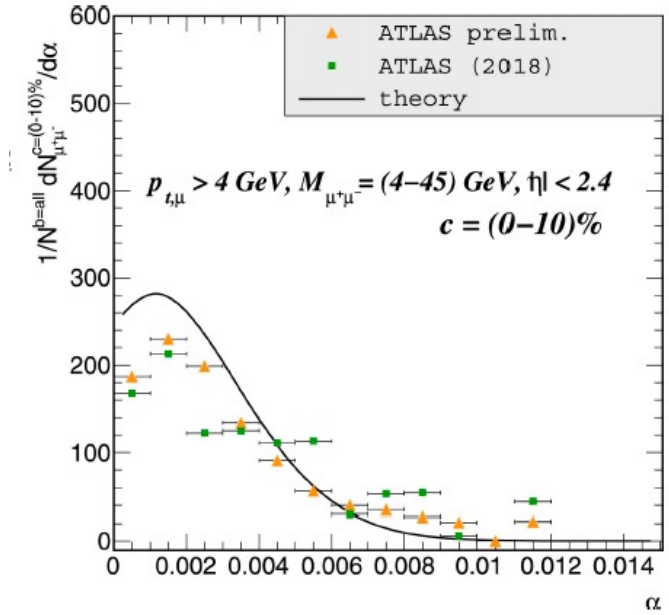
W. Zha



vs.

Wigner function

B. Xiao



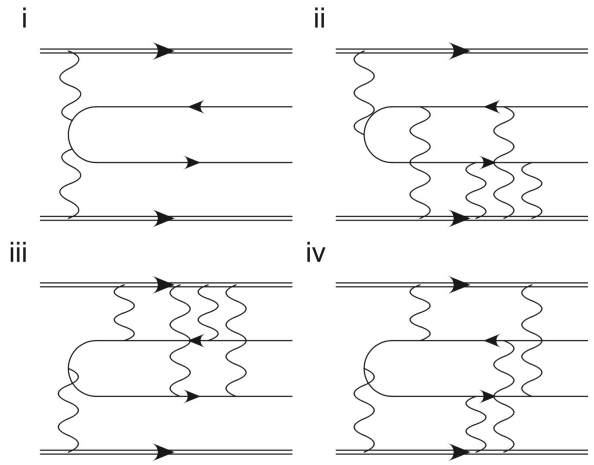
Open question:

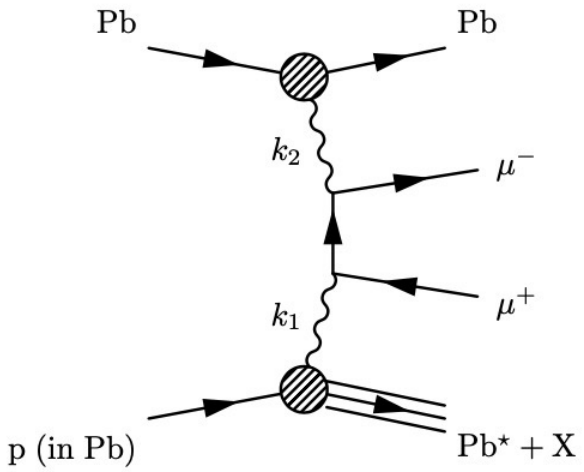
- Are two approaches equivalent? While they both predict b dependent photon flux pT, they appear to be different quantitatively
- What is the advantage/benefit of Wigner function approach if the process can be calculated by QED?

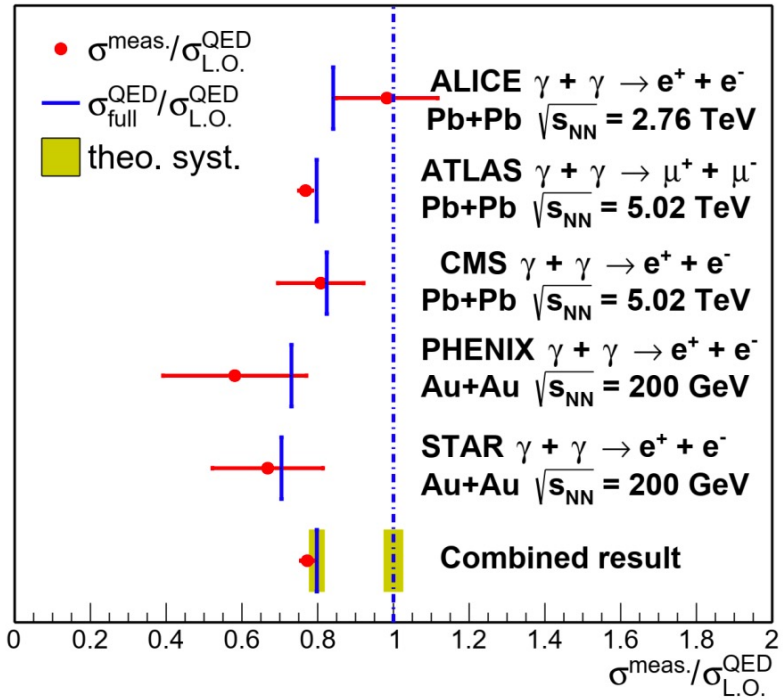
Crucial to understand for the most robust baseline prediction

Higher-order QED contribution

$Z\alpha$ ~0.6 for Au and Pb







W. Zha

Cross section data require HO QED

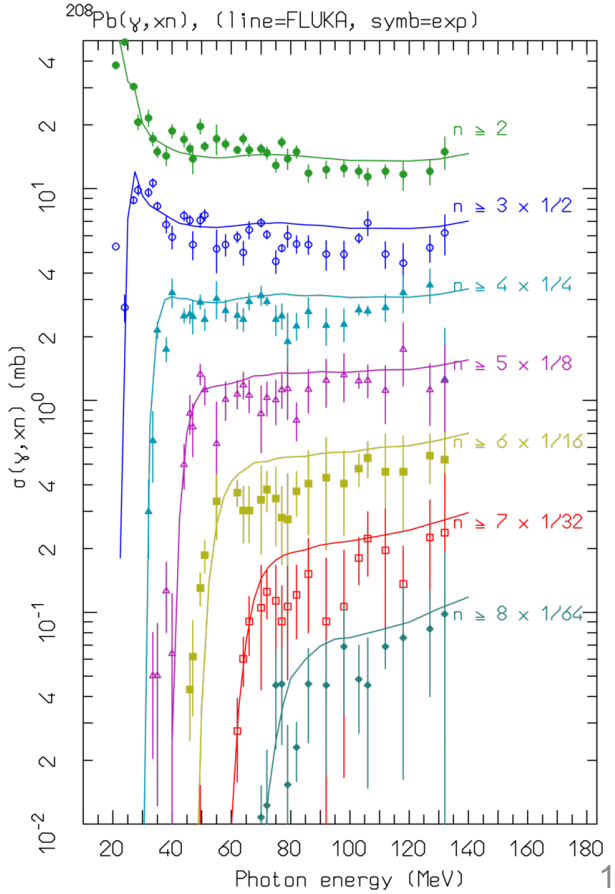
Open question:

- Do other contributions, such as semi-coherent, need to be considered?
- What is the effect on alpha distribution?

Need a serious (collaborative) effort to establish a new, state-of-the-art MC generator for photon-photon interactions, which includes:

- *b*-dependent photon flux p_T
- all major backgrounds: semi-coherent, high-order QED
- Integration for b<R
- modeling of nuclear break up (FLUKA and others)

A. Ferrari

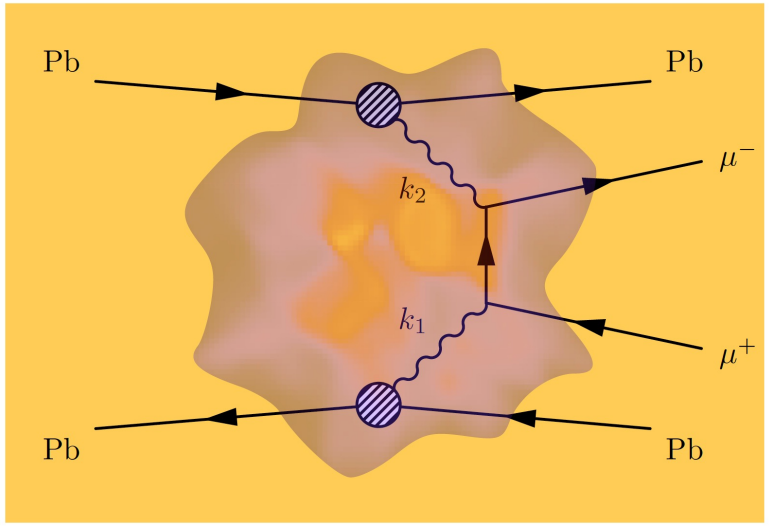


Open question:

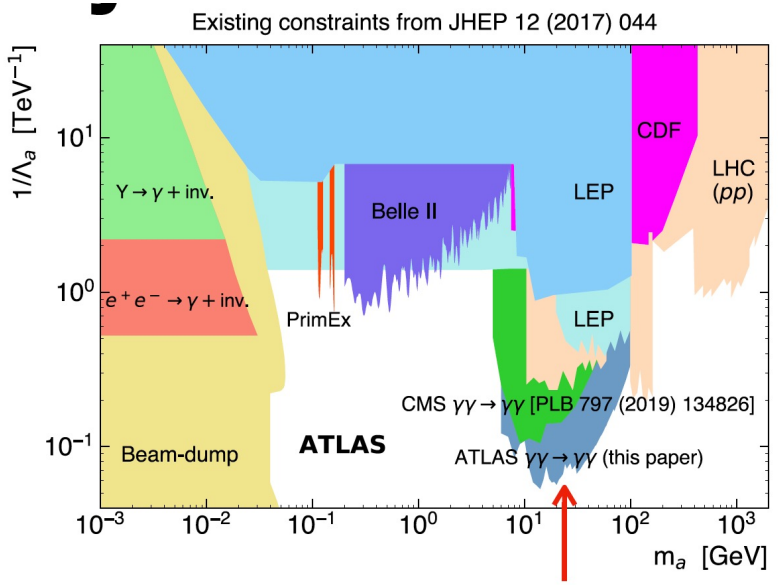
- What's the best way to coordinate and proceed?

- Collaboration with BeAGLE?

Are there EM effects from QGP Medium?



Are there physics beyond standard model in photon-photon?



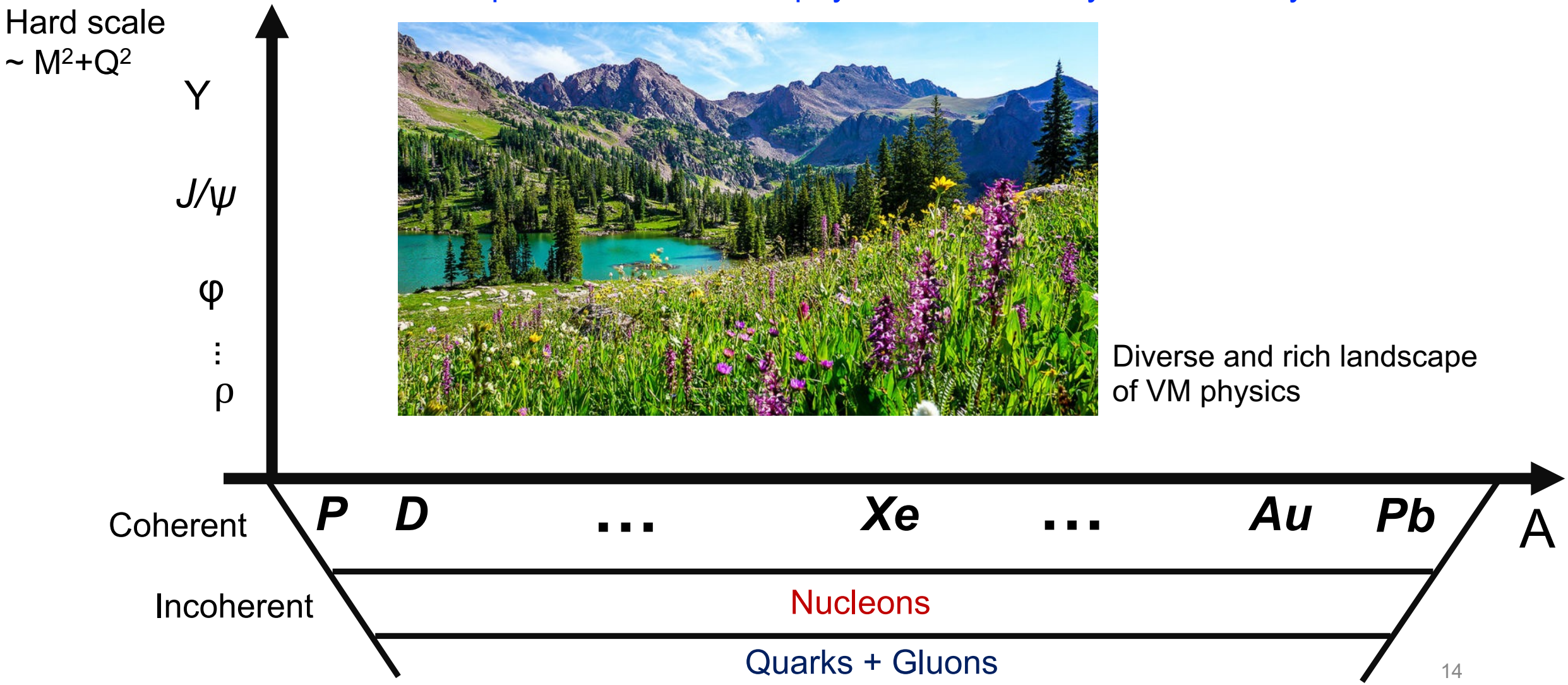
We have to first answer the **open questions** earlier

Vector Meson

Vector Meson productions

where particle and nuclear physics meets nicely and naturally…

Diverse and rich landscape of VM physics



Vector Meson productions

Hard scale
~ M^2+Q^2

Y

J/ψ

φ

⋮

ρ

S. Levonian

9

t—dependence. Elastic slope vs Universal scale

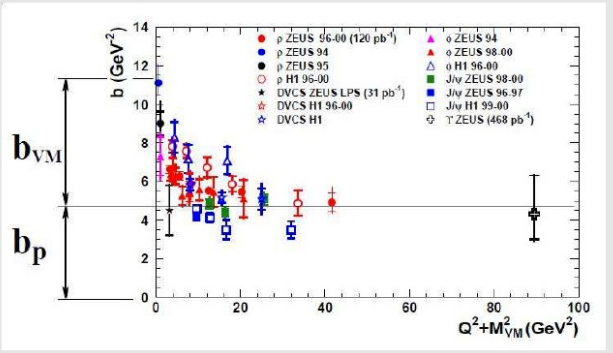
Dipole picture interpretation:

$b = b_{VM} + b_p$

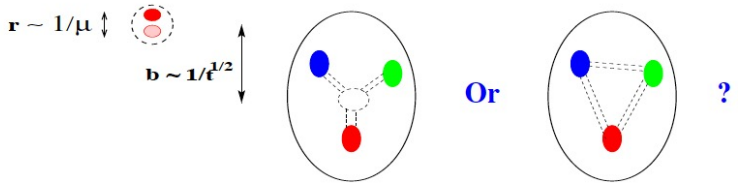
$b_{VM} \sim 1/(Q^2 + M_{VM}^2)$

$b_p \rightarrow$ size of the gluons area:

$\langle r^2 \rangle = 2b_p \cdot (\hbar c)^2 \simeq 0.6$ fm



Gluons confinement area (0.6 fm) is smaller than the proton size (0.8 fm)



VM productions off protons

- Differential cross section –***t***
  → spatial distributions

(gluon radius vs charge radius)

Open questions:

- Precision on protons ?
- Smaller gluon-radius ?

Coherent

Incoherent

P D … Xe … Au Pb

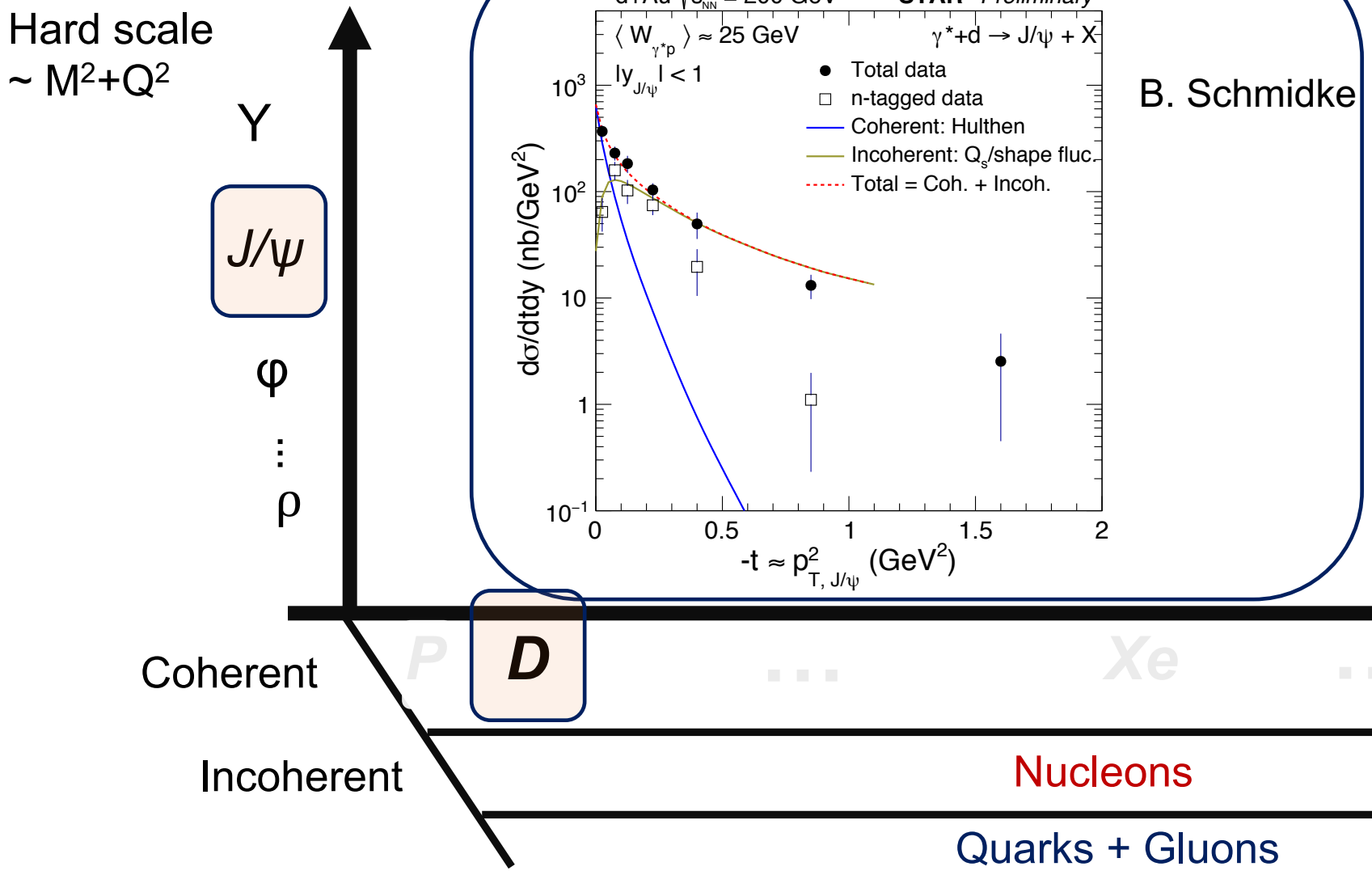
A

Nucleons

Quarks + Gluons

Vector Meson productions

Hard scale
~ M^2+Q^2



B. Schmidke

VM productions off deuterons

- Differential cross section $-t$
  → spatial distributions

(gluon radius vs charge radius)

Open questions:

- **What about nucleus?**
- Modification?

Vector Meson productions

Hard scale
~ M^2+Q^2

Y

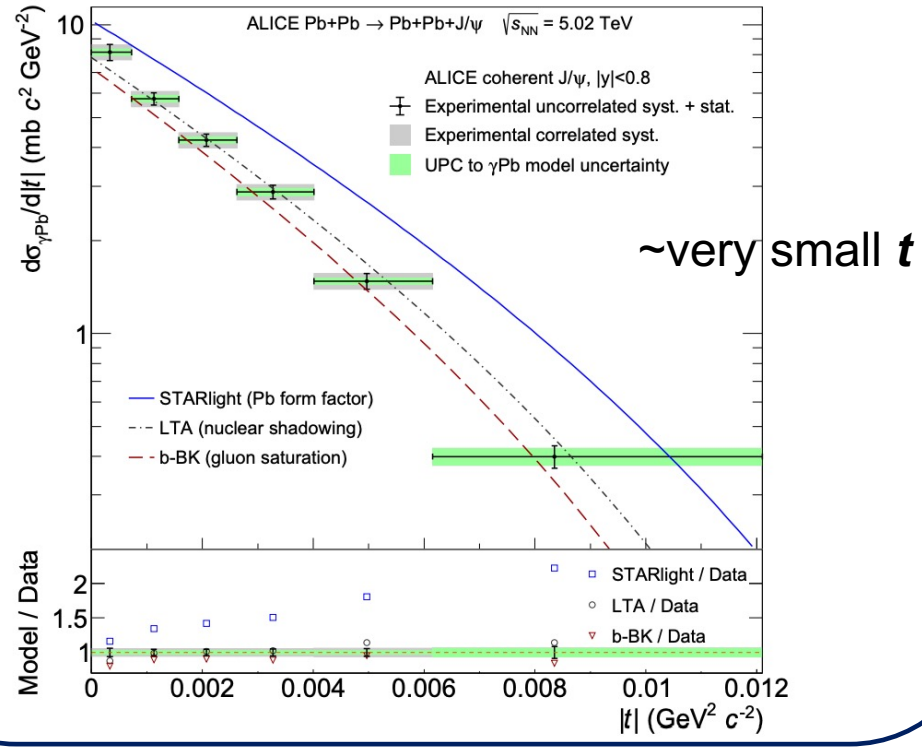
J/ψ

φ

⋮

ρ

G. Contreras



~very small ***t***

Coherent

Incoherent

P D … Xe … Au **Pb**

A

Nucleons

Quarks + Gluons

VM productions off heavy nucleus

- Differential cross section –***t***
  → spatial distributions

Open questions:

- Shadowing and/or saturation?
- Initial-state photon & final-state particles smearing.

Vector Meson productions

Hard scale
~ M^2+Q^2

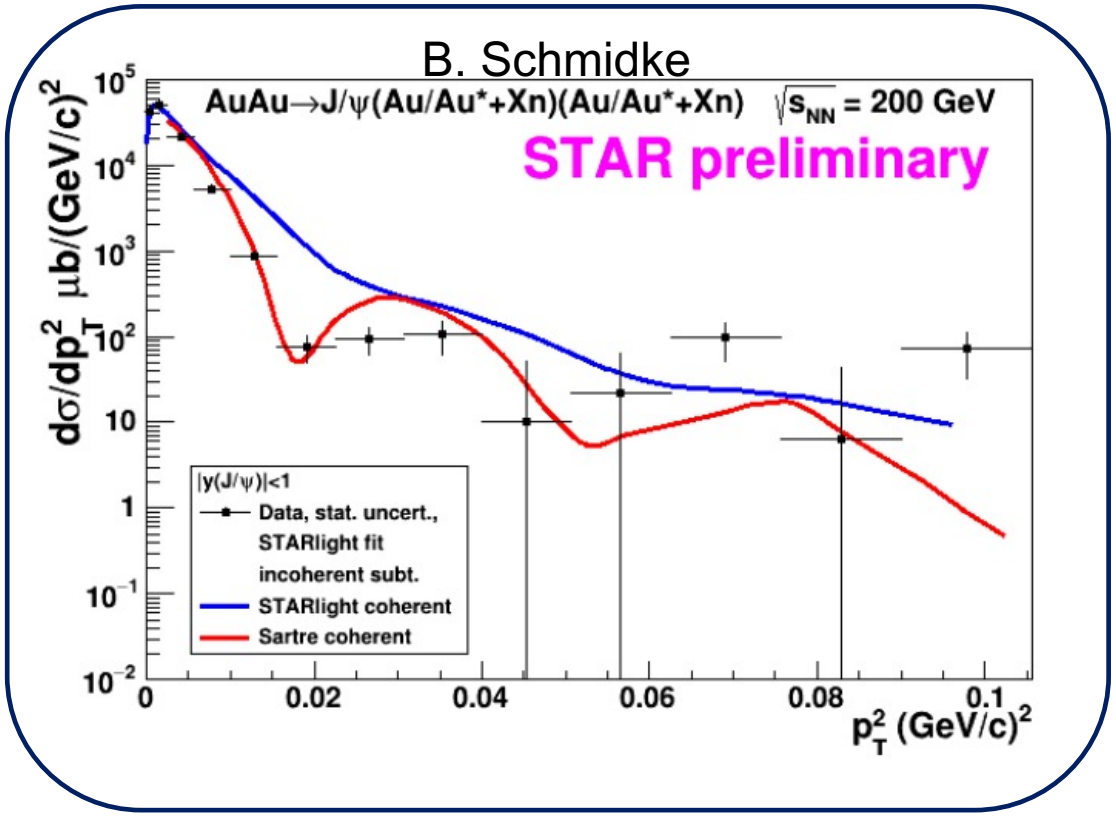
Y

J/ψ

φ

⋮

ρ



VM productions off heavy nucleus

- Differential cross section –***t***
  → spatial distributions

Open questions:

- Initial-state photon smearing (lessons learned from photon-photon physics?)
- **Diffractive pattern → b_T**

Coherent

Incoherent

P D … Xe … ***Au*** Pb

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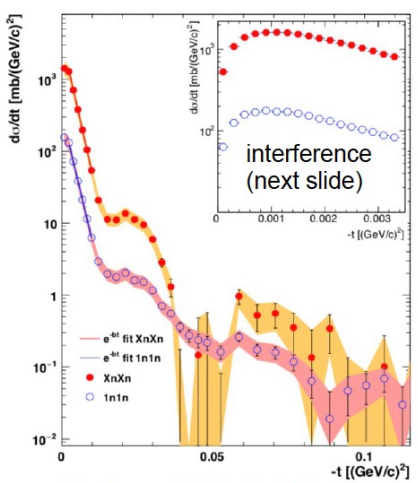
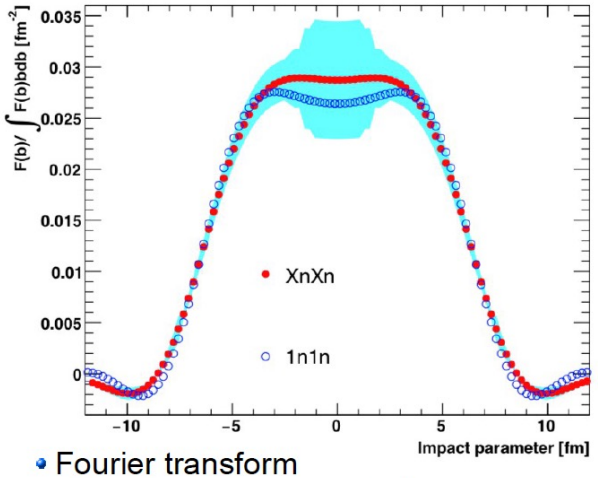


- Coherent |t| distribution, diffractive features clear:
  - 0th & 1st order peaks
  - 1st & 2nd order minima



- Fourier transform
  |t| → impact parameter b:
  - uncertainty b~0 ↔ cutoff high |t|
  - sharp edges
  - negative high b ↔

VM productions off heavy nucleus

- Differential cross section –***t***
  → spatial distributions

Open questions:

- **Diffractive pattern → b_T**
- Best from rho but not good enough (Why is it so hard?)
- Separation of coh. and incoh.

Coherent

Incoherent

P D … Xe … **Au** Pb

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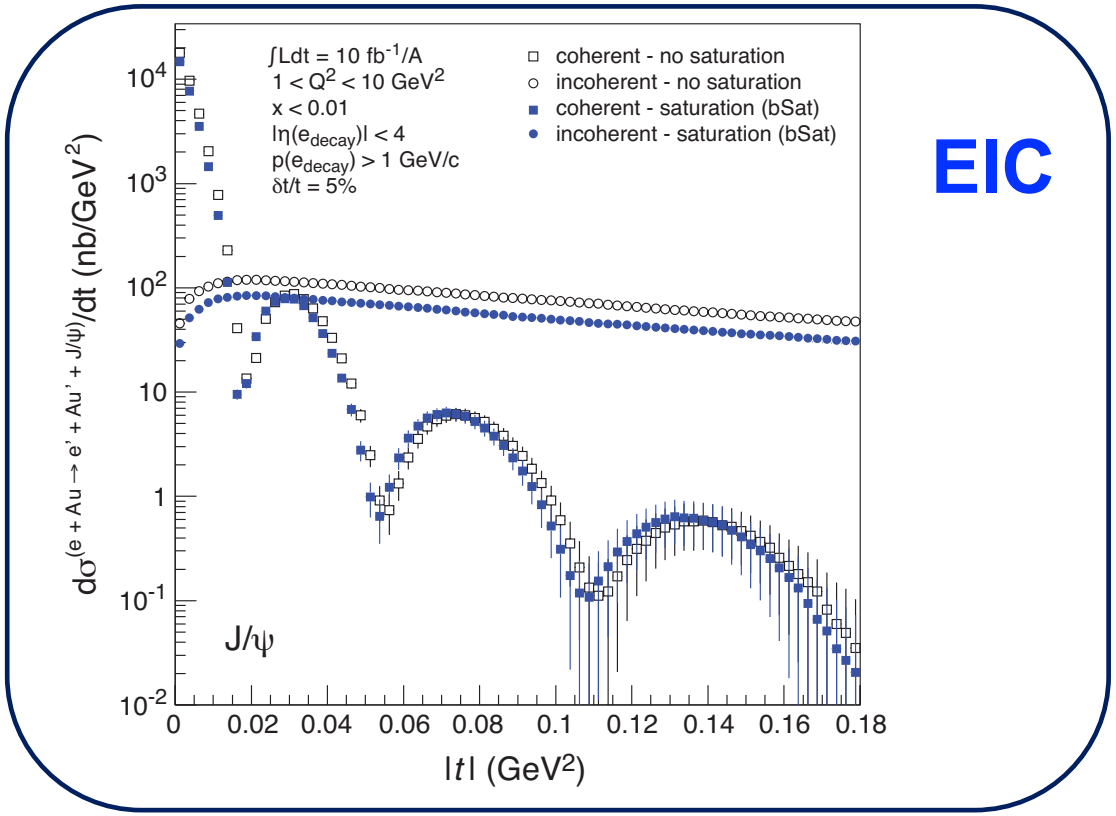

EIC

VM productions off heavy nucleus

Open questions:

- **Diffractive pattern → b_T**

- Can EIC do this?

Coherent

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Incoherent

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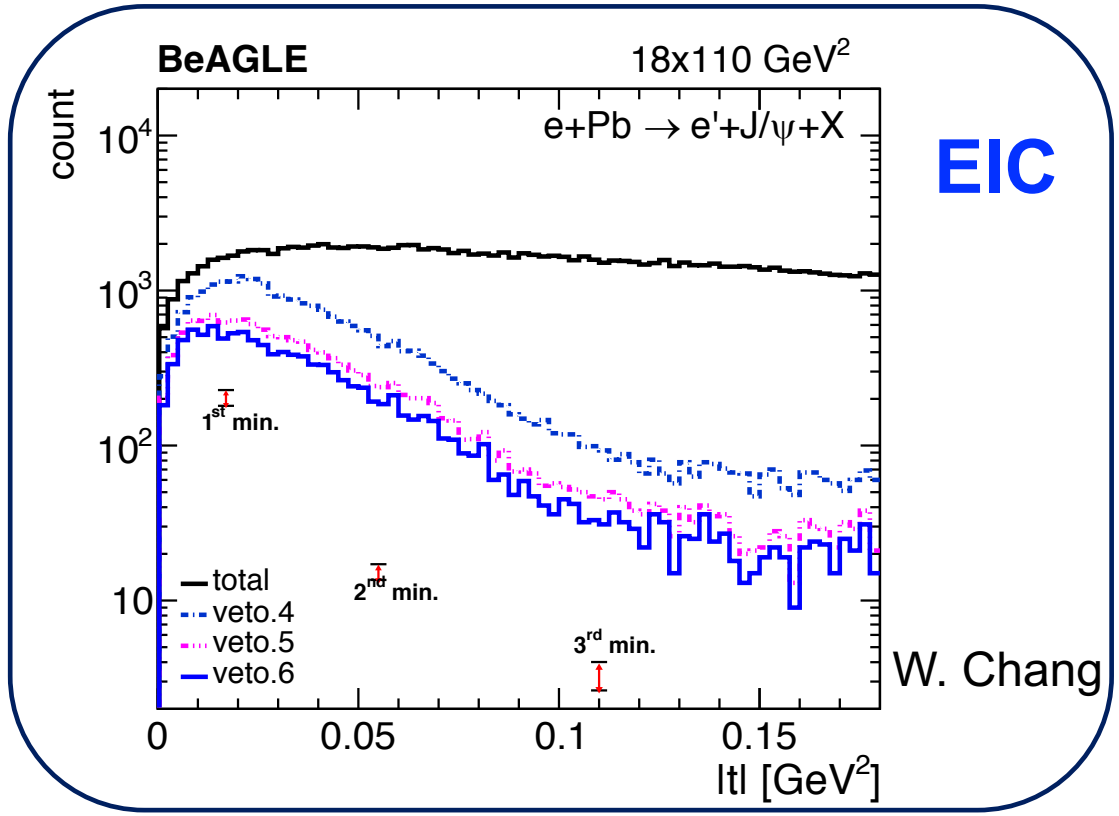

VM productions off heavy nucleus

Open questions:

- **Diffractive pattern → b_T**
- Veto on nuclear breakups – protons, neutrons, photons. (bottleneck – beam pipe, photons, etc…)
- Forward detections are absolutely critical

Coherent

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Pb

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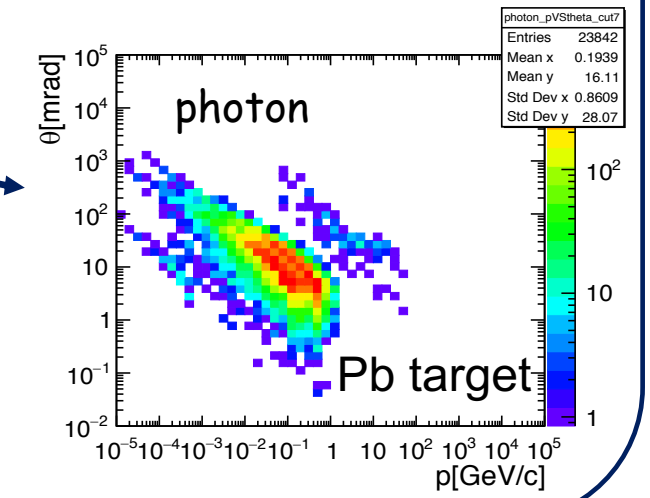
Observing nuclear deexcitation via photon emission is tough

- For lead, it requires good acceptance for ~ 100 MeV photons
- Gold may deexcite via 77 keV photons with a 1.9 nsec lifetime
  - Impossible to see.
- Can we reliably calculate the rates for unseen excitations as a function of |t|?

S. Klein

SK, Phys. Rev. ST Accel. Beams 17, 121003 (2014) 16



W. Chang

VM productions off heavy nucleus

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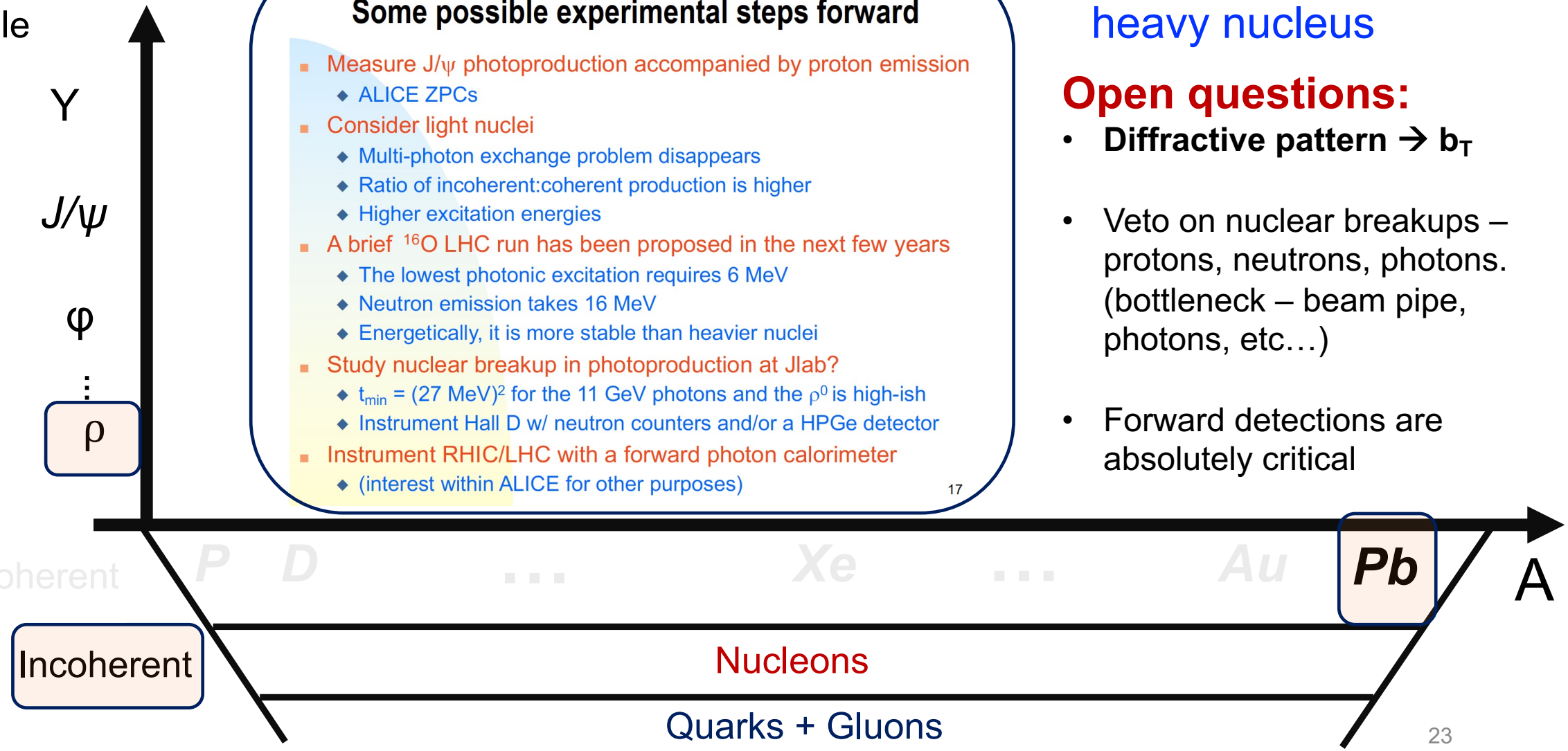

S. Klein
Some possible experimental steps forward

- Measure J/ψ photoproduction accompanied by proton emission
  - ALICE ZPCs
- Consider light nuclei
  - Multi-photon exchange problem disappears
  - Ratio of incoherent:coherent production is higher
  - Higher excitation energies
- A brief ^{16}O LHC run has been proposed in the next few years
  - The lowest photonic excitation requires 6 MeV
  - Neutron emission takes 16 MeV
  - Energetically, it is more stable than heavier nuclei
- Study nuclear breakup in photoproduction at Jlab?
  - t_{min} = (27 MeV)^2 for the 11 GeV photons and the ρ^0 is high-ish
  - Instrument Hall D w/ neutron counters and/or a HPGe detector
- Instrument RHIC/LHC with a forward photon calorimeter
  - (interest within ALICE for other purposes)

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VM productions off heavy nucleus

Open questions:

- **Diffractive pattern → b_T**
- Veto on nuclear breakups – protons, neutrons, photons. (bottleneck – beam pipe, photons, etc…)
- Forward detections are absolutely critical

Vector Meson productions

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Y

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⋮

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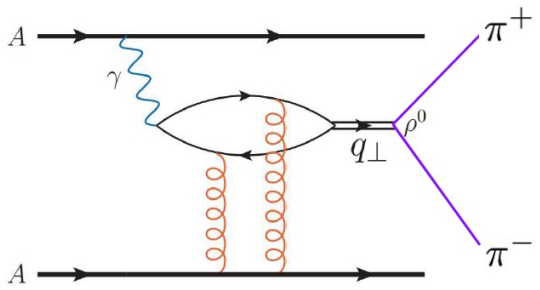
J. Zhou



A $\cos(2\phi)$ azimuthal asymmetry is induced by linearly polarized photons.

ϕ is the angle between $q_\perp$ and $p_\perp^\pi$

$q_\perp$: ρ^0 transverse momentum

$p_\perp^\pi$: pion's transverse momentum.

VM productions off heavy nucleus

Open questions:

- **Diffractive pattern → b_T**
- A new observable?
- J. Zhou provides a bunch, cos(phi), cos(2phi), cos(3phi), cos(4phi)…

Coherent

Incoherent

P D … Xe … **Au** Pb

A

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Vector Meson productions

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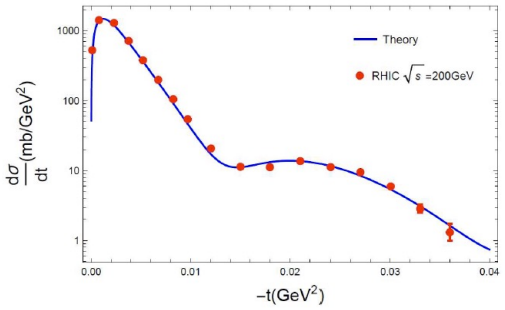
⋮

ρ

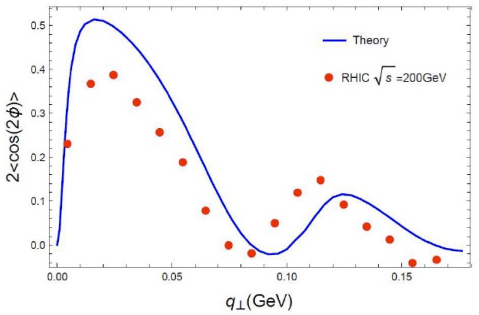
J. Zhou

ρ^0 production in UPCs

Unpolarized cross section



Cos2ϕ azimuthal asymmetry



Daniel Brandenburg, QM 2019

➢ Incoherent production doesn't contribute to the asymmetry

$\Delta_\perp$ distribution is very flat

$$\int d^2k_\perp x f(x,k_\perp)\left[2(\hat{q}_\perp\cdot\hat{k}_\perp)^2-1\right]=0$$

VM productions off heavy nucleus

Open questions:

- **Diffractive pattern → b_T**
- A new observable?
- How does this observable relate to the **b_T** distributions**?**

Coherent

Incoherent

P D … Xe … **Au** Pb

A

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Vector Meson productions

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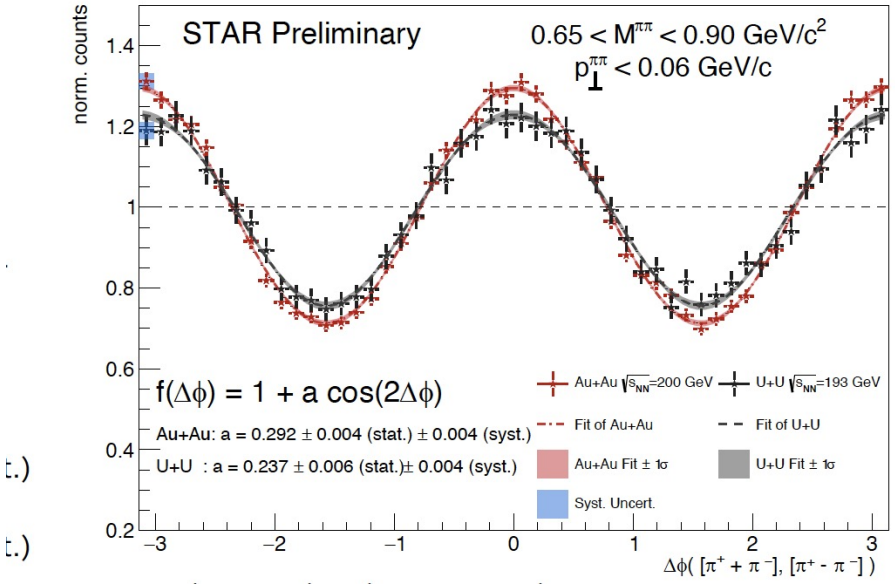
D. Brandenburg

$\gamma\mathbb{P} \rightarrow \rho^0 \rightarrow \pi^+\pi^-$



VM productions off heavy nucleus

Open questions:

- **Diffractive pattern → b_T**
- Sensitive to nuclear geometry.
- Polarization sensitive meas. at the LHC. (ALICE?)
- Odd harmonics at STAR?

Coherent

Incoherent

P D … Xe … **Au** Pb

A

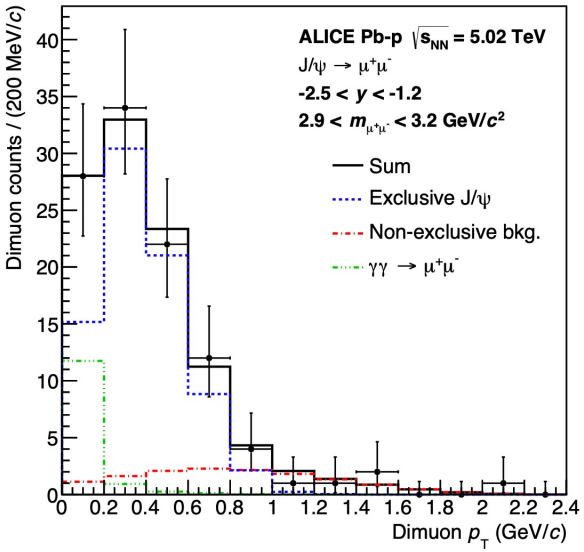
Nucleons

Quarks + Gluons

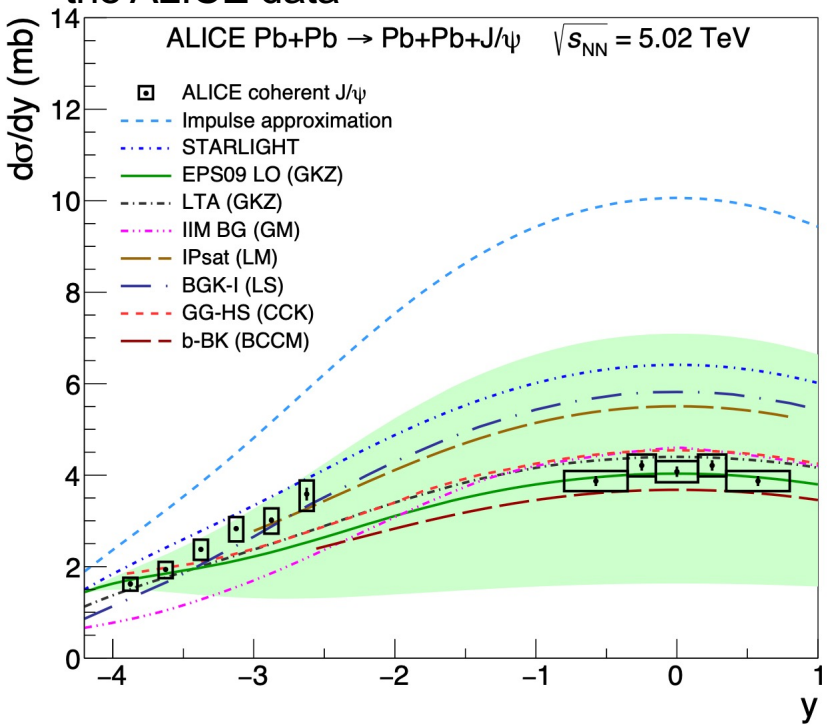
VM Theory/Model

- Guzey: Leading twist model of nuclear shadowing (Glauber Gribov shadowing + QCD factorization theorems) - also dijet production
  Mäntysaari: Dipole picture, CGC framework
- What exactly do the two approaches have in common and what distinguishes them?
- Gluon nPDF constrained by diffractive VM measurements - included in PDF analysis?

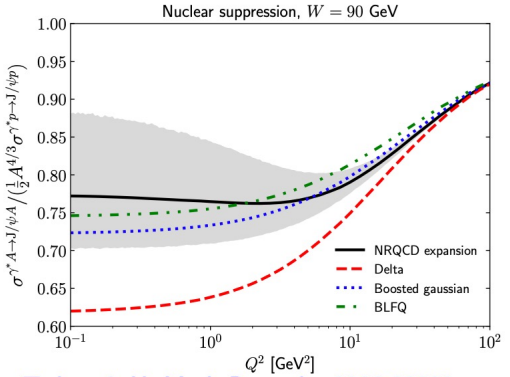
ALICE data at the cross section level?
Also for Pb-Pb



No model predicts the entire y dependence of the ALICE data

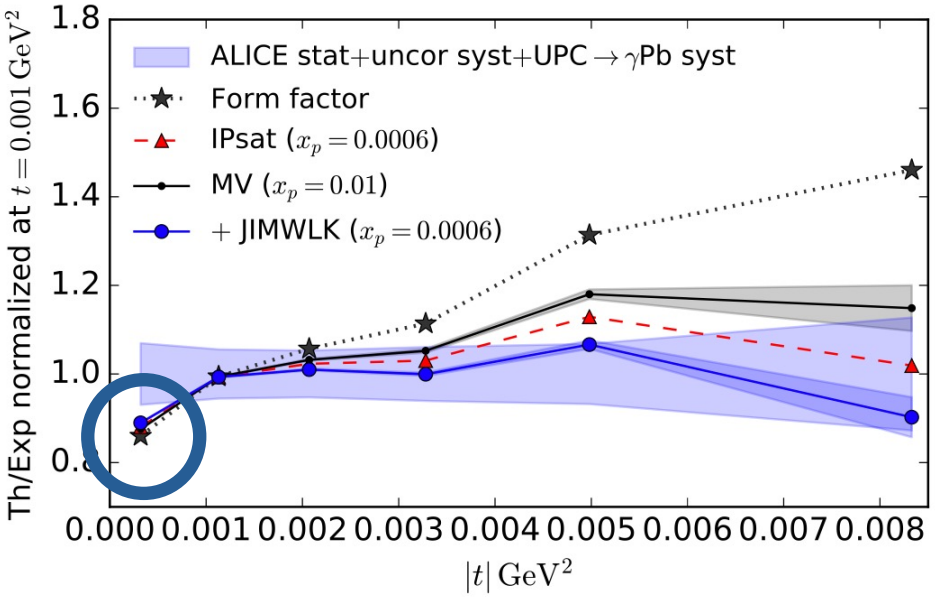


Also: normalization uncertainty from J/ψ wf, does not completely cancel in nuclear suppression ratio (=ratio to imp. approx.)



T. Lappi, H. M, J. Penttala, 2006.02830

VM Theory/Model



|t| spectra steeper in the data than any model
Especially lowest |t| point cannot be described

Interference important for that point?
Removed in the data - ALICE paper gives correction factor

Missing: y and $\sqrt{s}$ dependence of the incoherent cross section
How do the incoherent cross section and e-b-e fluctuations depend on x_P?

Measurements at high |t| (to uncover substructure).
Problems at LHC? Up to 1 GeV^2 feasible soon.

PHOTOPRODUCTION OF J/ψ AT THRESHOLD

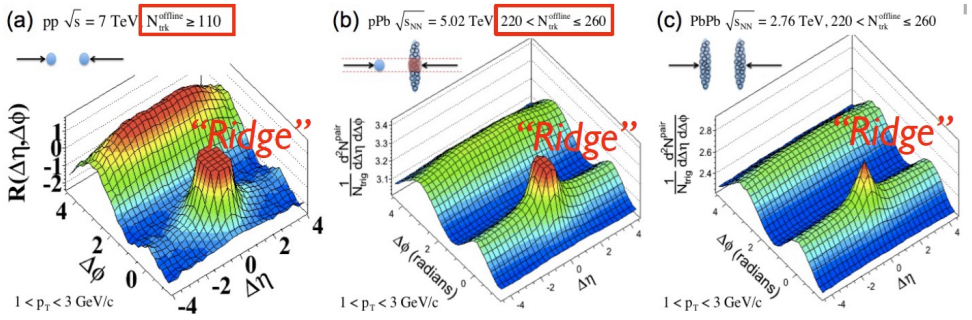
Y. Hatta

Unique opportunity to probe gluon gravitational form factors, D-term and trace anomaly.

Measurement: high Q^2, W=4.4 GeV (J/Psi) (Possible at EIC)

Collectivity

Ridge and collectivity



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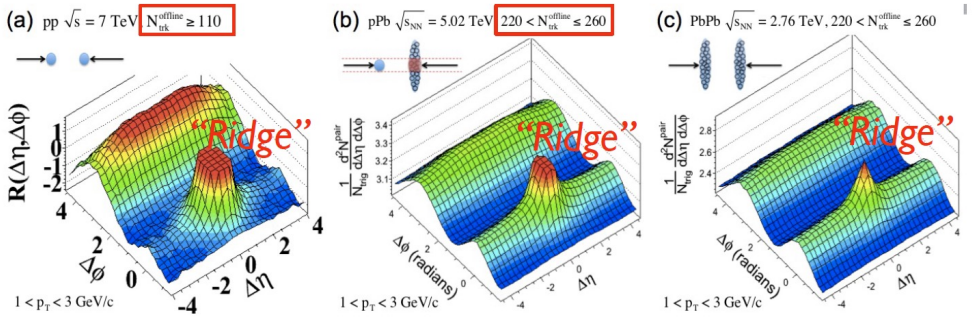
Collectivity in all hadronic collisions at sufficient high multiplicity

Ridge and collectivity



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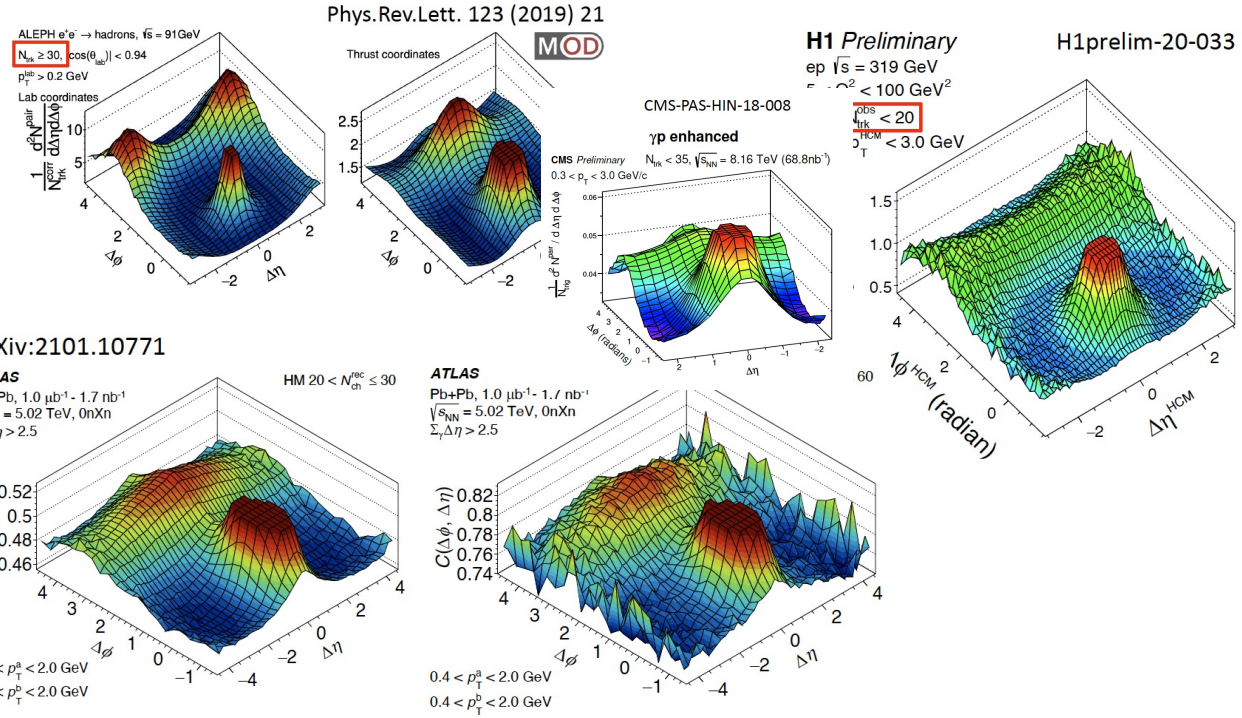
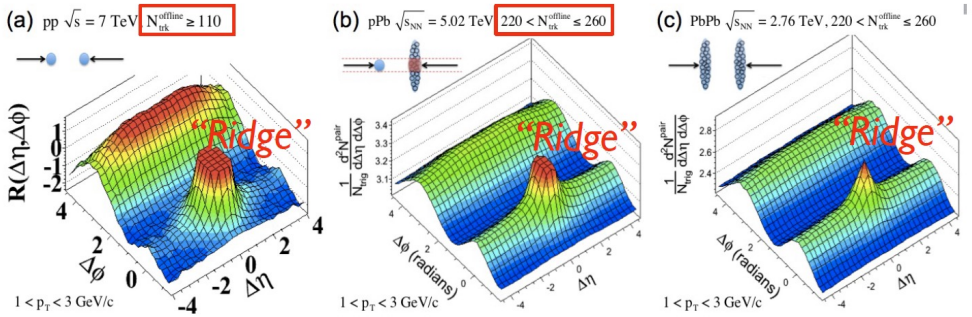
Collectivity in all hadronic collisions at sufficient high multiplicity



Ridge and collectivity



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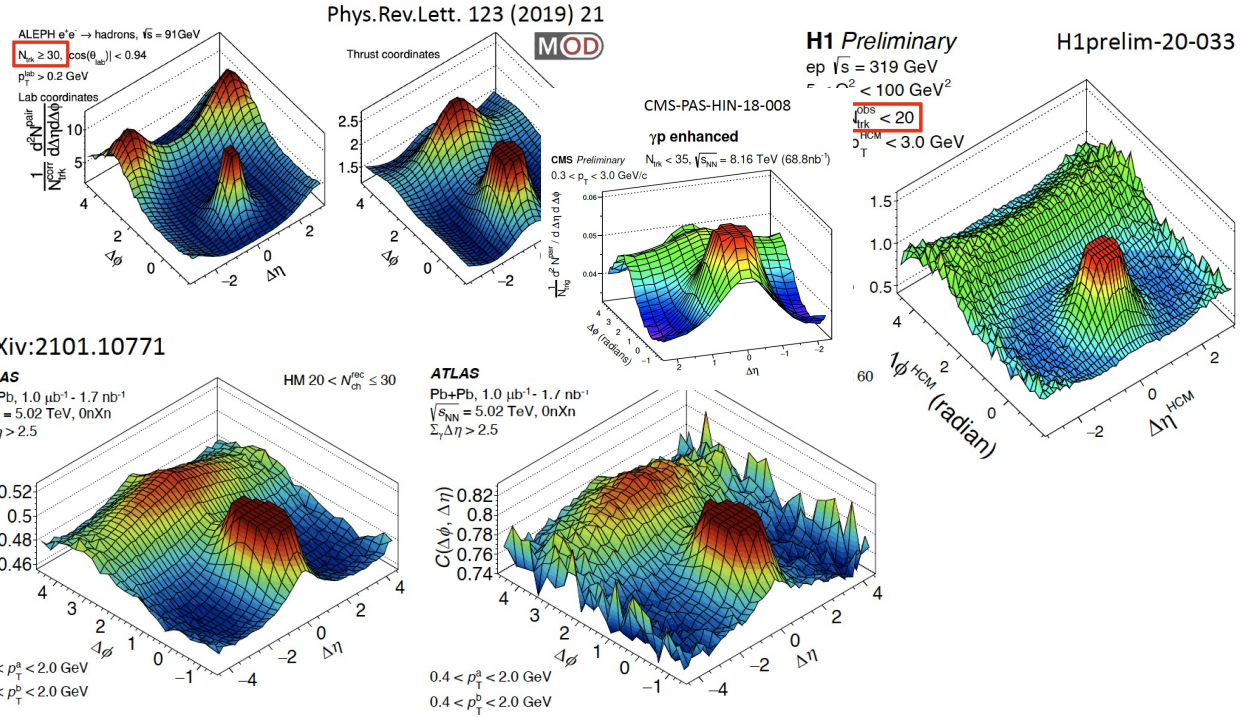
Collectivity in all hadronic collisions at sufficient high multiplicity



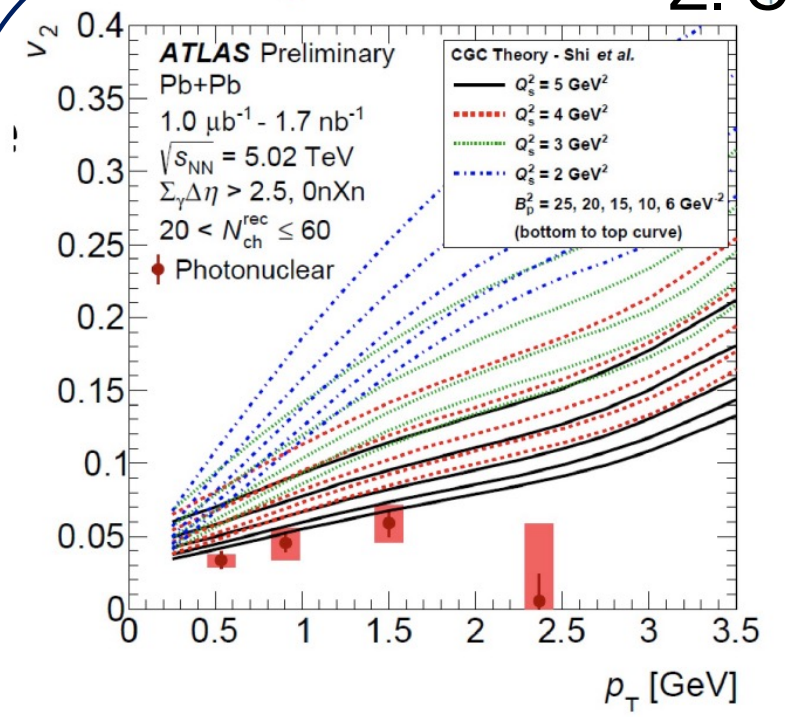
Collectivity "LOOK-UP" table

	e^+e^-	ep (DIS)	γp	γA	pp,pA,AA
N_{trk} reach	30	30	30	60	>100
Ridge	X	X	X	X	✓
Collective v_n	?	X	?	✓	✓
$C_n\{4\} < 0$	?	X	X	?	✓
PID flow	?	?	?	?	✓
Heavy flavor	?	?	?	?	✓
…	?	?	?	?	✓
Current Model	PYTHIA	RAPGAP LEPTO	PYTHIA +Delphes	CGC	Hydro/CGC

No sign of collectivity except γA
Electron Ion Colliders will provide more data for further exploration
A chance to seek out what exactly are beyond/beneath hydro

Photon-induced collectivity?

Z. Chen



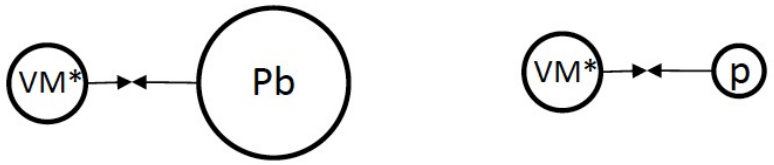
CGC $v_2 \propto 1/B_p \propto \max[Q^2, \Lambda_{QCD}^2]$

Collective v_2 -> 0 in DIS

A rising and following trend vs Q^2?
Key measurement at EICs

With current interpretation γA vs γp should be like VM*+A vs VM*+p

- Collectivity in sufficient high multiplicity γp?



Open Questions

- High multiplicity in photon-A and photon-p?
- How high it needs to go?
- EIC with level-arm in Q^2 ?
- **What is the origin of collectivity?**

Summary of summary

- Diverse and rich physics in photon-induced interactions

→A bridge between the UPCs and the EIC.

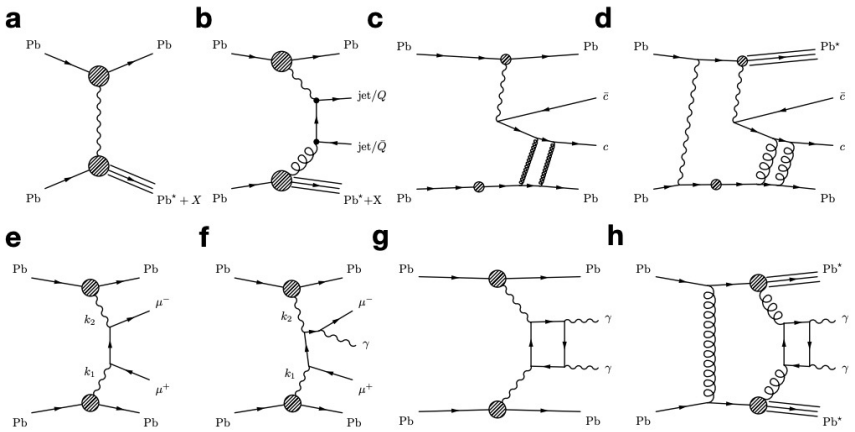
Summary of summary

- Diverse and rich physics in photon-induced interactions

→A bridge between the UPCs and the EIC.

- Many lessons can be learned from current and near-term experiments, theory/model developments, etc…

Ultra-peripheral Collisions



"BACK TO THE FUTURE"