arXiv: https://arxiv.org/abs/2505.00916

Photoproduction and detection of $\rho' \to \pi^+\pi^-\pi^+\pi^-$ decays

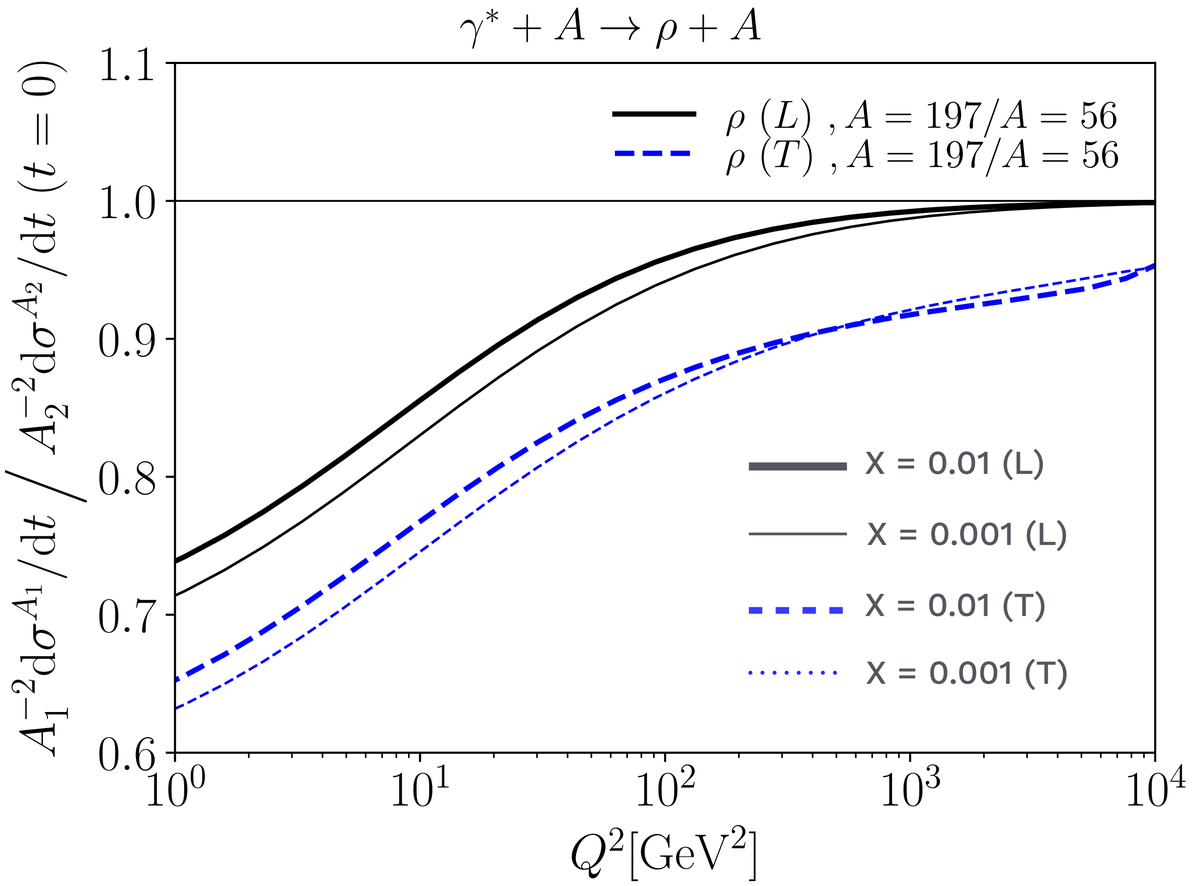
Exclusive/Diffaction and Tagging group meeting

Minjung Kim, UC Berkeley

30 June 2025 (Mon.)

Small-*x* physics via exclusive vector meson photoproduction at the EIC

H. Mäntysaari, R. Venugopalan, PLB 781 (2018) 664-671



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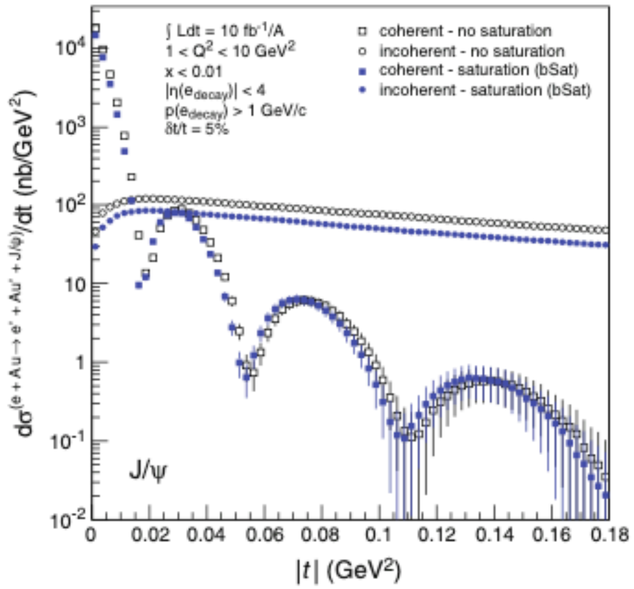
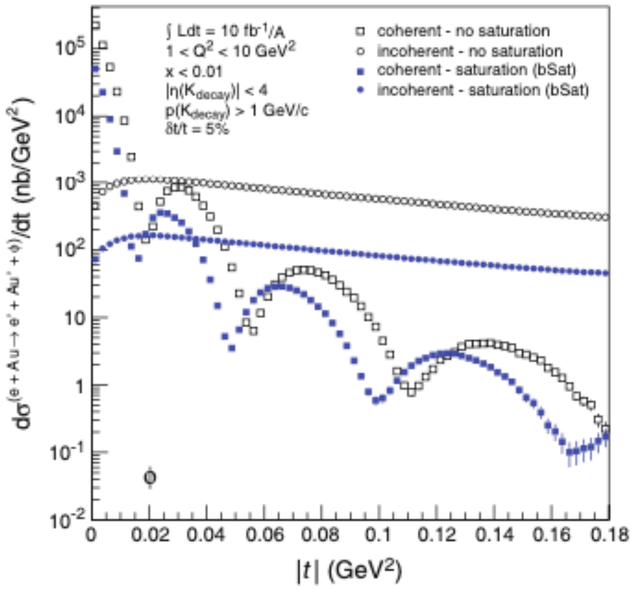
EIC White paper (2016)





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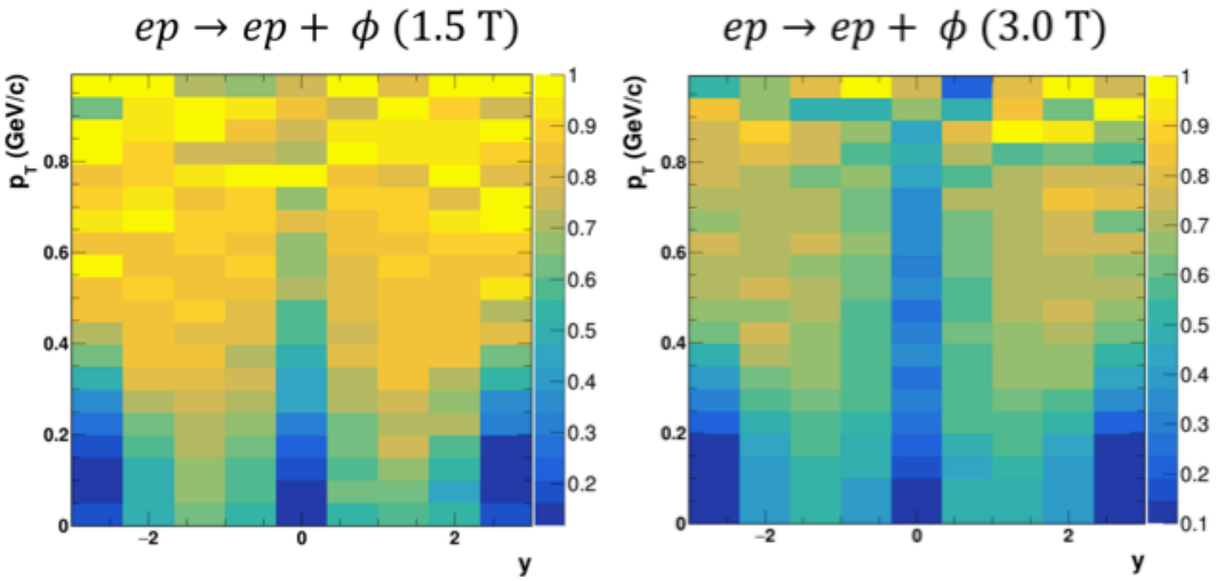
Small-x physics via exclusive vector meson photoproduction at the EIC

J. Arrington et al., arXiv. 2102.08337



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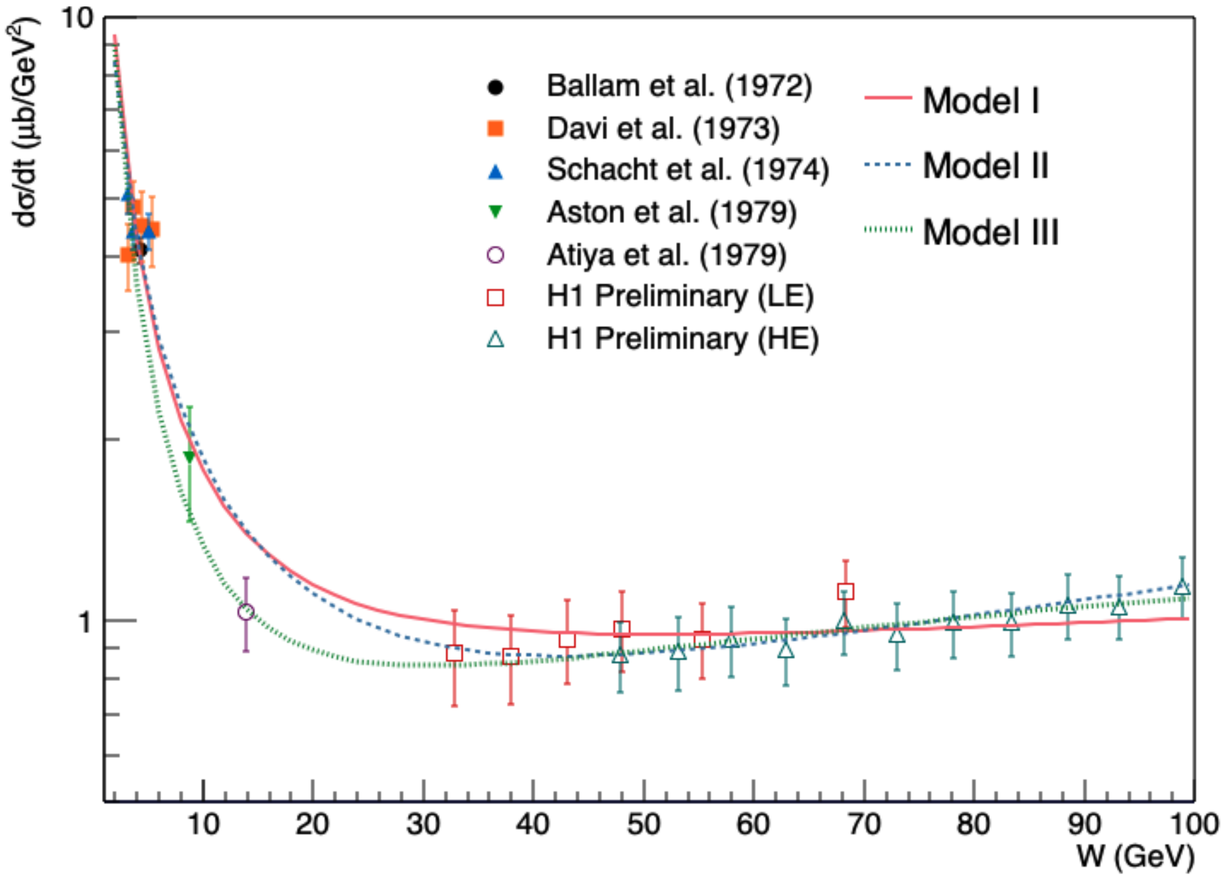
$\rho' \to \pi^+\pi^-\pi^+\pi^-$ production on ion target

1. **Estimate $\gamma p \to \rho' p$ forward cross section $\frac{d\sigma(\gamma p \to \rho' p)}{dt}|_{t=0}$, based on experimental measurements of $\gamma p \to \rho' p \to \pi^+\pi^-\pi^+\pi^- p$, considering branching ratio**



- **Four-pion final states measured in fix-target experiments and HERA**
- **Cross section parameterized using Reggeon-Pomeron model**

$$\sigma(W) = XW^{\epsilon} + YW^{-\eta}$$

- **Different sets of parameters were considered to study the uncertainty from the cross section estimation**

  0 - 10% difference in final cross section depending on collision systems

- $\frac{d\sigma(\gamma p \to \rho' p)}{dt}|_{t=0} = \sigma(W) \times B.R.$

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VM-photon coupling (photon fluctuates into VM)

2. $$\frac{d\sigma(\gamma p \to Vp)}{dt}\Big|_{t=0} = \frac{4\pi\alpha}{f_V^2}\frac{d\sigma(Vp \to Vp)}{dt}\Big|_{t=0}$$ VM-nucleon elastic scattering cross section

3. **Applying optical theorem to get total VM-nucleon cross section**

$$\sigma_{tot}^2(Vp) = 16\pi\frac{d\sigma(Vp \to Vp)}{dt}\Big|_{t=0}$$

4. **VM-A cross section using Quantum Glauber calculation**

nuclear thickness function

$$\sigma_{Tot}(VA) = \int d^3\vec{r}(1 - 2e^{-\sigma_{Tot}(Vp)T_A(\vec{r})/2})$$

➔ γA cross section isn't just a scaled-up version of γp

➔ Effects of the branching ratio and coupling don't entirely cancel

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$$\sigma(\gamma A \to \rho' A \to \pi^+\pi^-\pi^+\pi^- A) = \frac{d\sigma(\gamma A \to \rho' A)}{dt}\Big|_{t=0} \cdot \int_{t_{\min}}^{\infty} dt\,|F(t)|^2 \cdot \mathrm{Br}(\rho' \to \pi^+\pi^-\pi^+\pi^-)\,.$$

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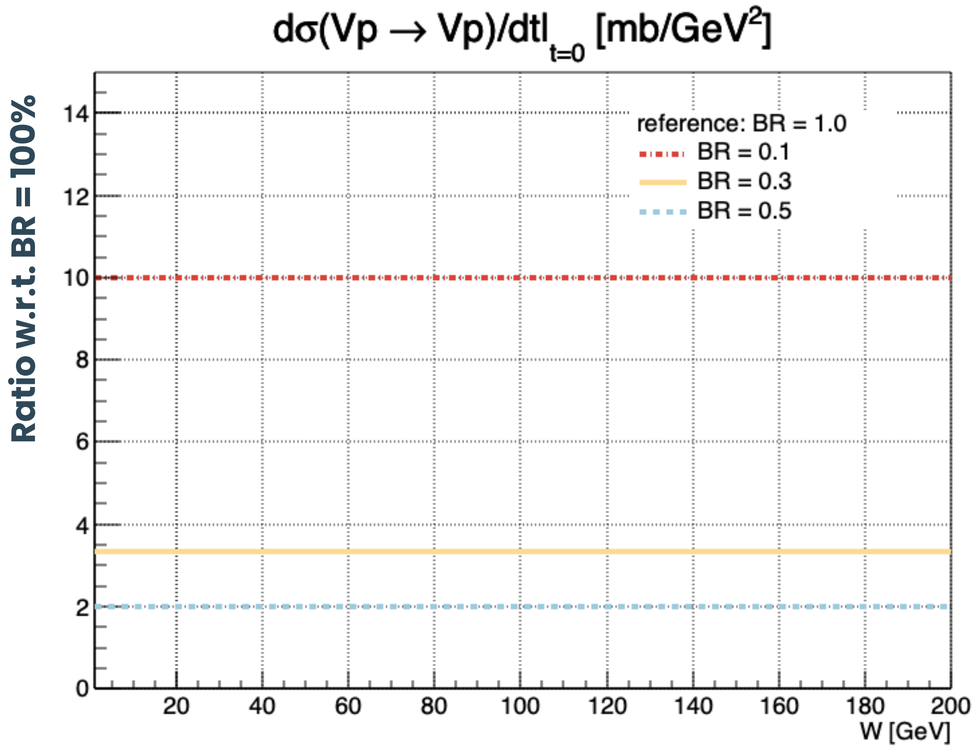
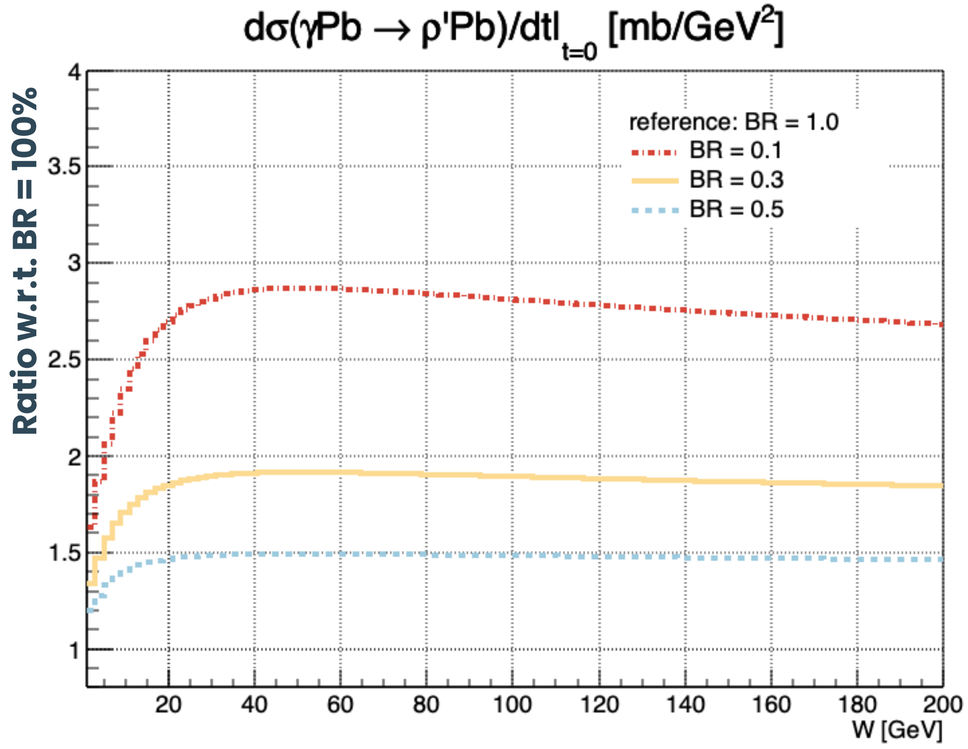
→ step 2 - 5 as well as photon flux defined in (e)STARLight; used for final results

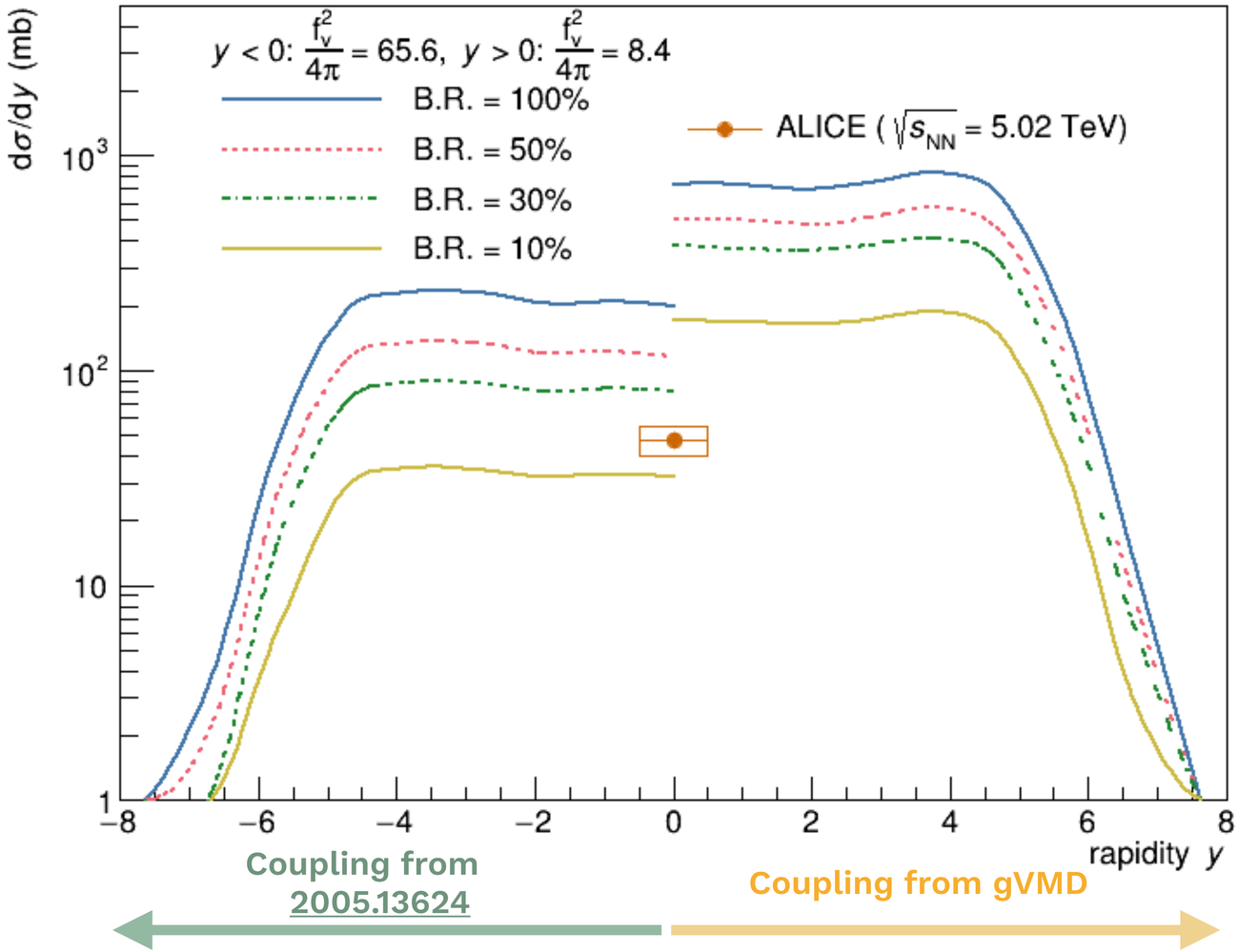
Impact of branching ratio to $\rho' \to \pi^+\pi^-\pi^+\pi^-$

- **Branching ratio of ρ' ($\rho(1450)$, $\rho(1700)$, $\rho(1600)$) to four pion is unknown**
- **Linear scaling of cross section (branching ratio and VM-photon coupling) in γp interaction does not directly translate into γA cross section**





Impact of coupling $\rho' - \gamma$ to $\rho' \to \pi^+\pi^-\pi^+\pi^-$



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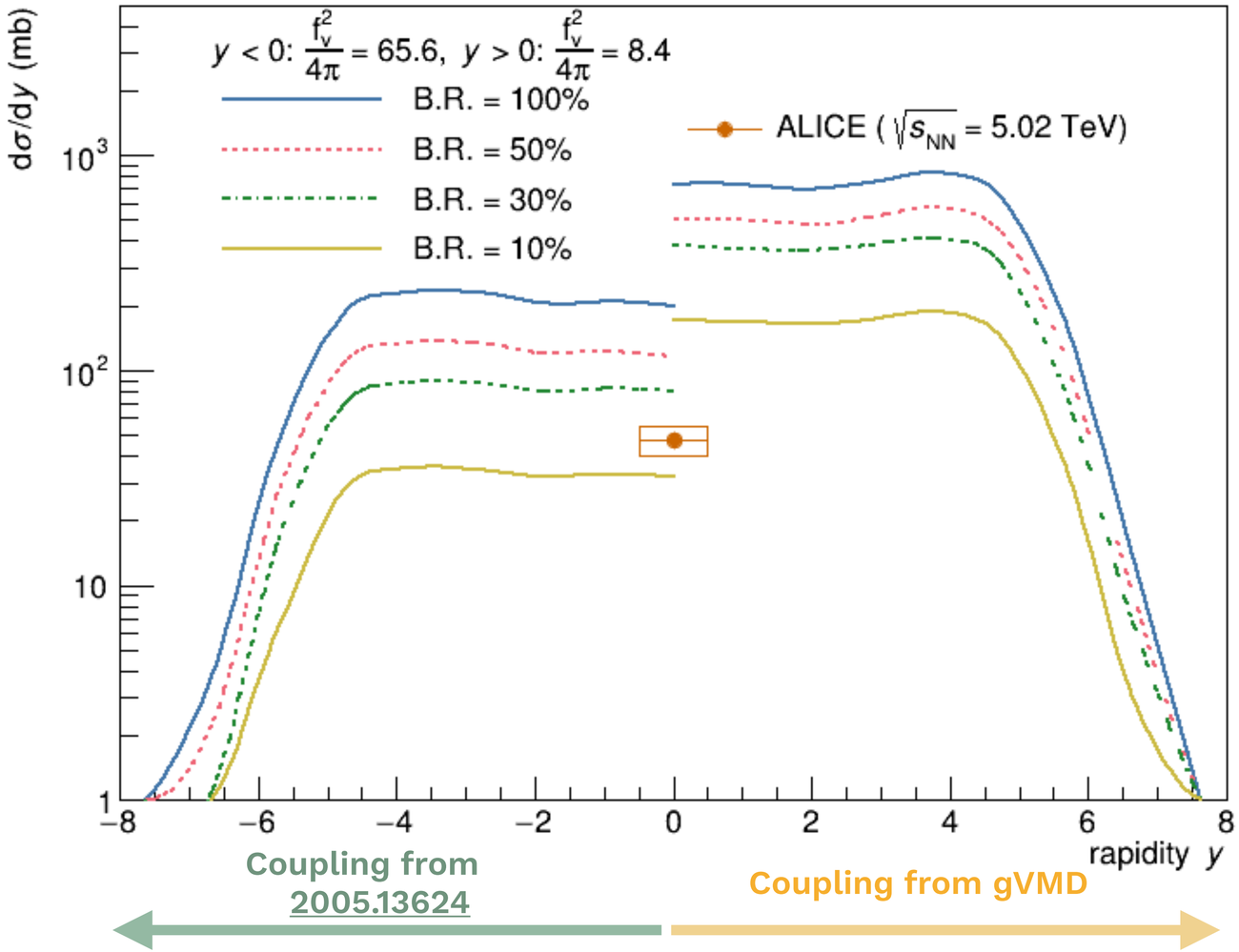

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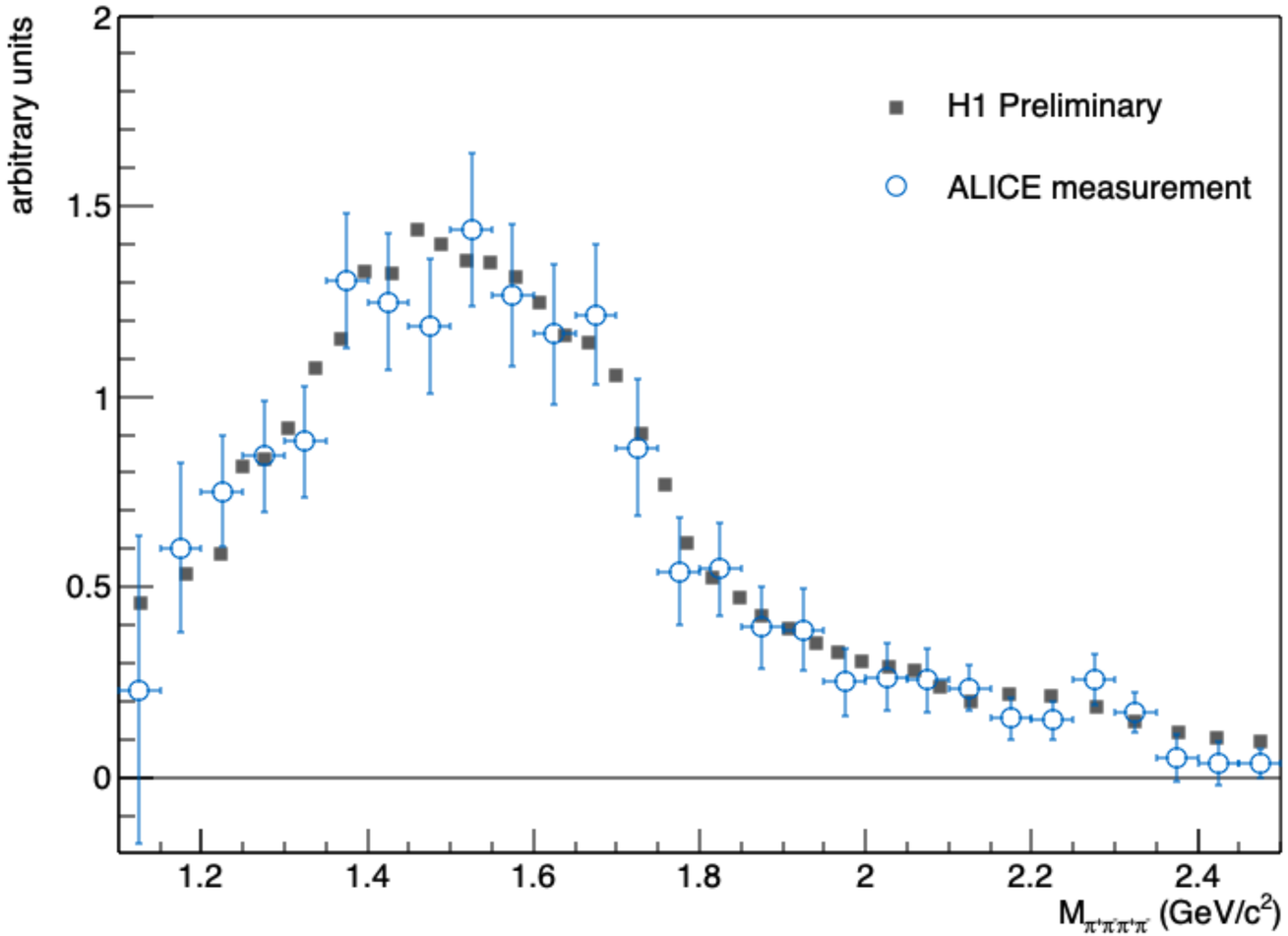
- **Coupling can be determined by $\frac{f_v^2}{4\pi} = \frac{M_v \alpha^2}{3\Gamma_{V\to ee}}$, via ee decay channel**

Impact of non-linear effects in measurements



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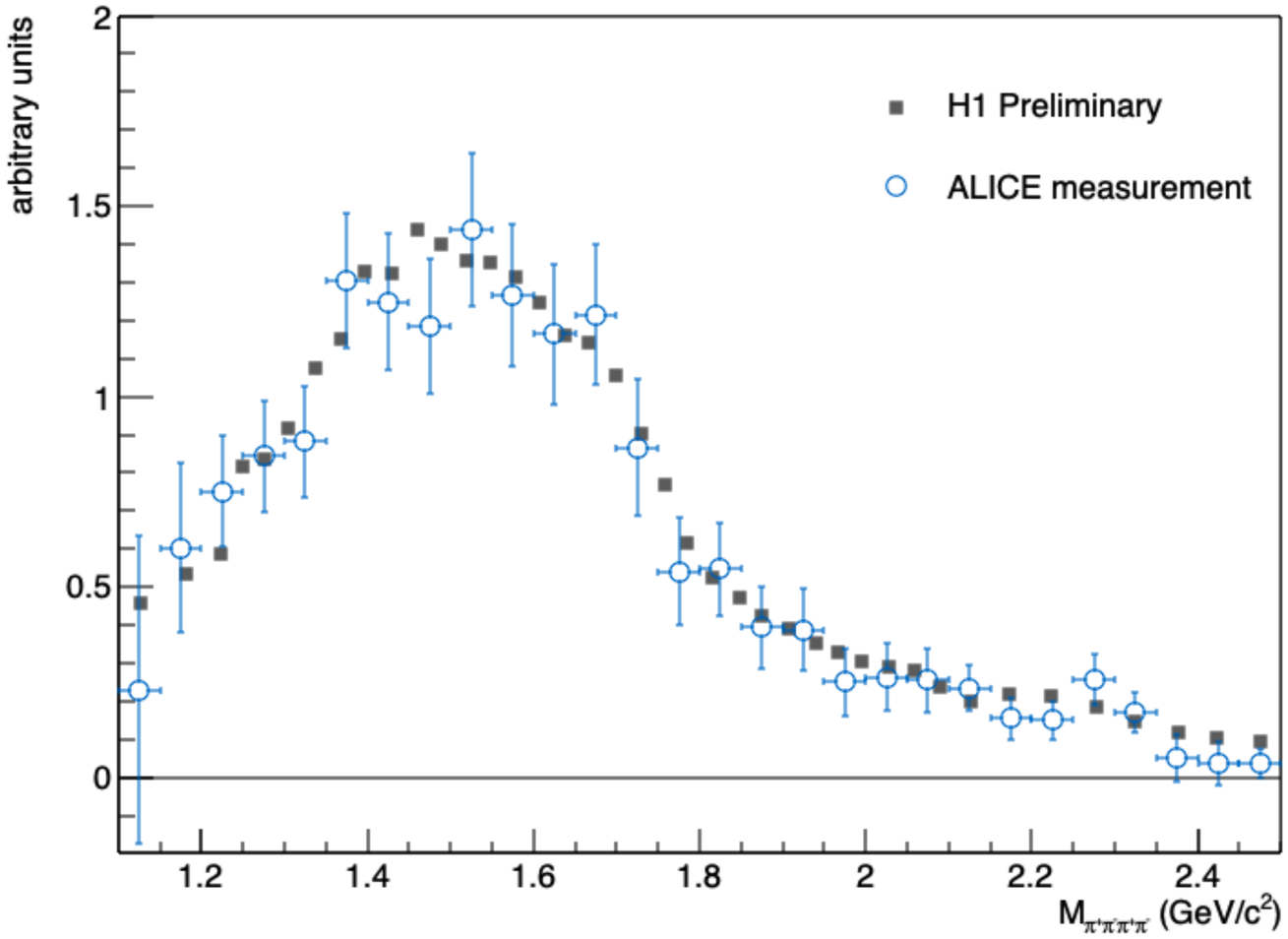

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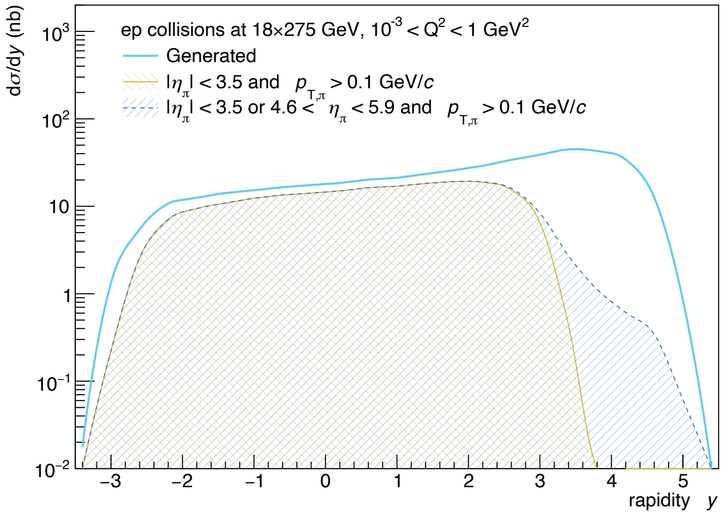
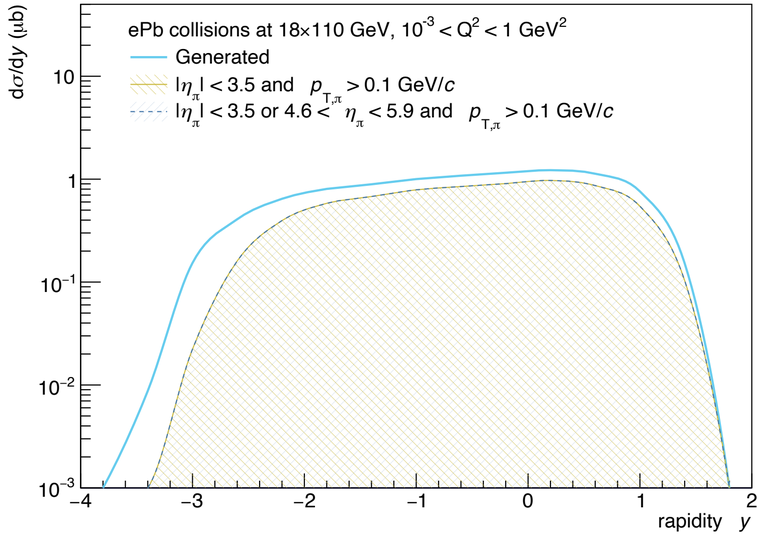
➡**Photon-meson couplings times the branching ratio expected to be similar for the two mesons (Otherwise, the Glauber approach would distort mass spectra for ion targets)**

➡**Total cross section sensitive to the branching ratio due to the Glauber approach**

$\rho' \to \pi^+\pi^-\pi^+\pi^-$ cross section at the EIC





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collision system	Q^2 range (GeV^2)	total cross section	events for $\mathcal{L}$ =10 fb^{-1}	acceptance	acceptance with B0
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	$Q^2 < 1$	681 nb	6.8×10^9	0.39	0.41
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* Tracking efficiency is not considered

- **Large total cross section**
  S. Klein, M. Lomnitz, PRC 99 (2019) 015203
  $\rho^0 \approx 5\ \mu b,\ \phi \approx 0.23\ \mu b$ **in ep**
- **B0 tracker covers large rapidity range in ep collisions probing low-*x***

  $x \propto e^{-y}$
- **Large acceptance (~73%) of $\rho' \to \pi^+\pi^-\pi^+\pi^-$ in ePb collisions covering most of allowed kinematic range**

Summary

- **Exclusive four pion from ρ resonance(s) photoproduction**
  - $\pi^+\pi^-\pi^+\pi^-$ state studied under single resonance scenario with $\rho(1600)$
  - Non-linear scaling of Glauber approach resulting vector meson - photon coupling and branching ratio dependence of total production cross section on ion target
  - $\rho(1450) + \rho(1700)$ or $\rho(1600)$: For two resonances scenario, photon-meson couplings times the branching ratio of $\rho(1450)$ and $\rho(1700)$ is expected to be similar
  - A promising probe for exploring low-*x* and saturation physics: Large luminosity expected in ePIC allow for exploring structure and properties of ρ resonances, which are poorly known, including other decay modes

Backup

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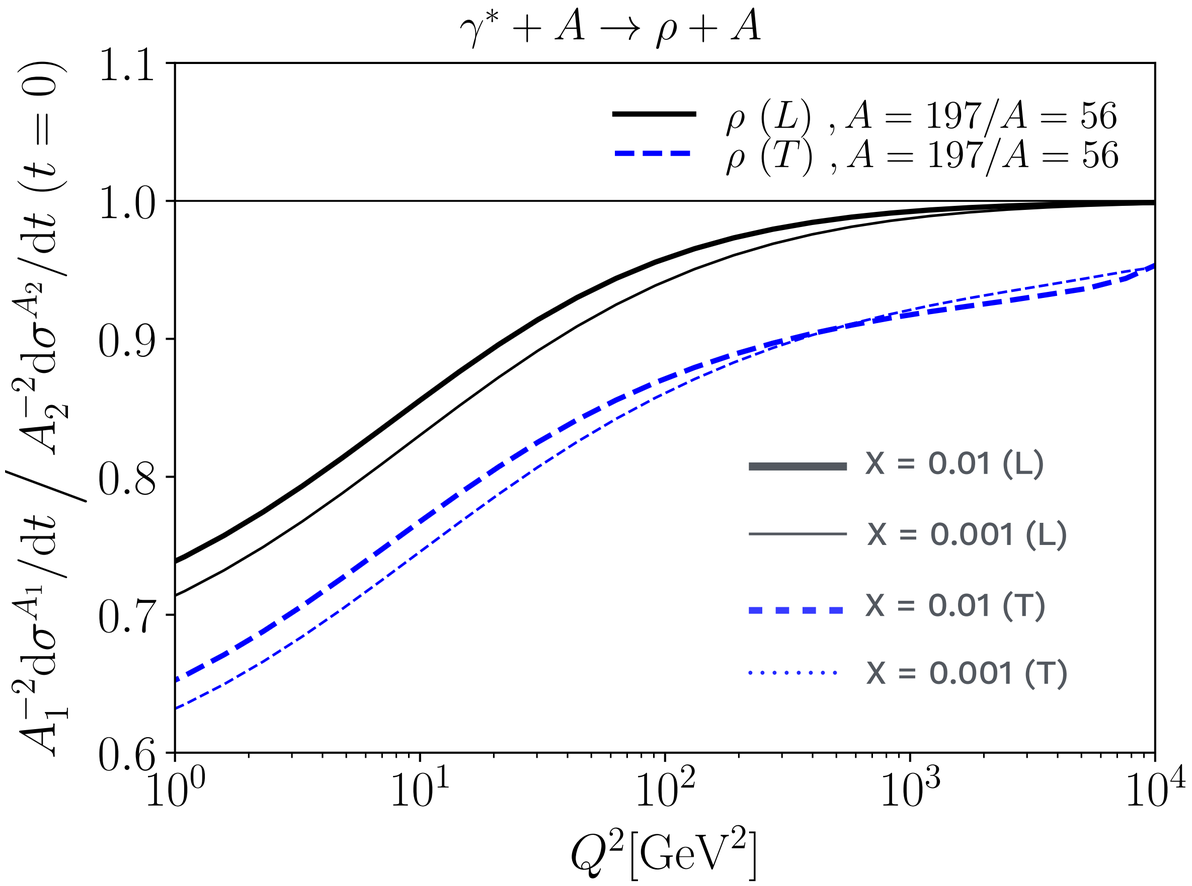

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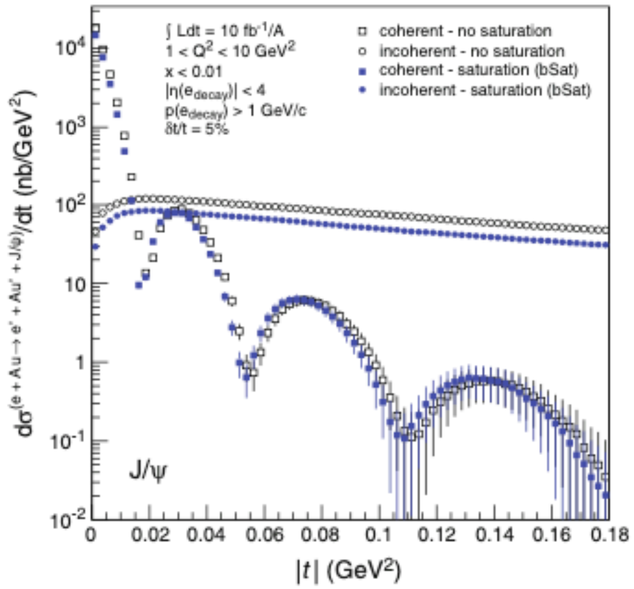

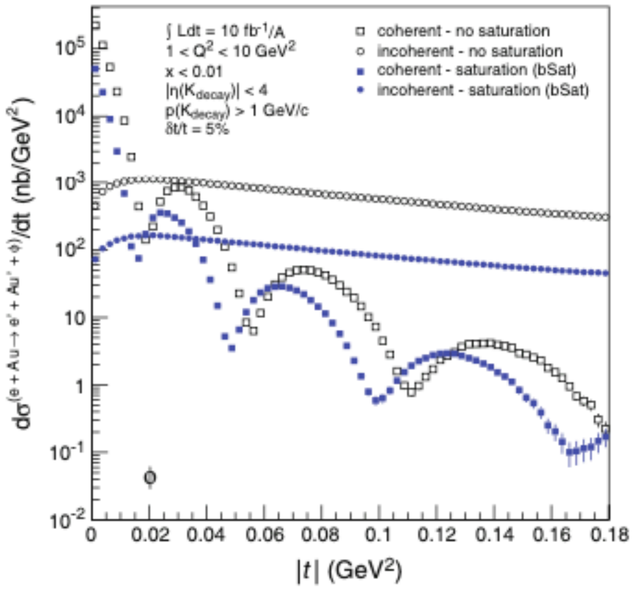

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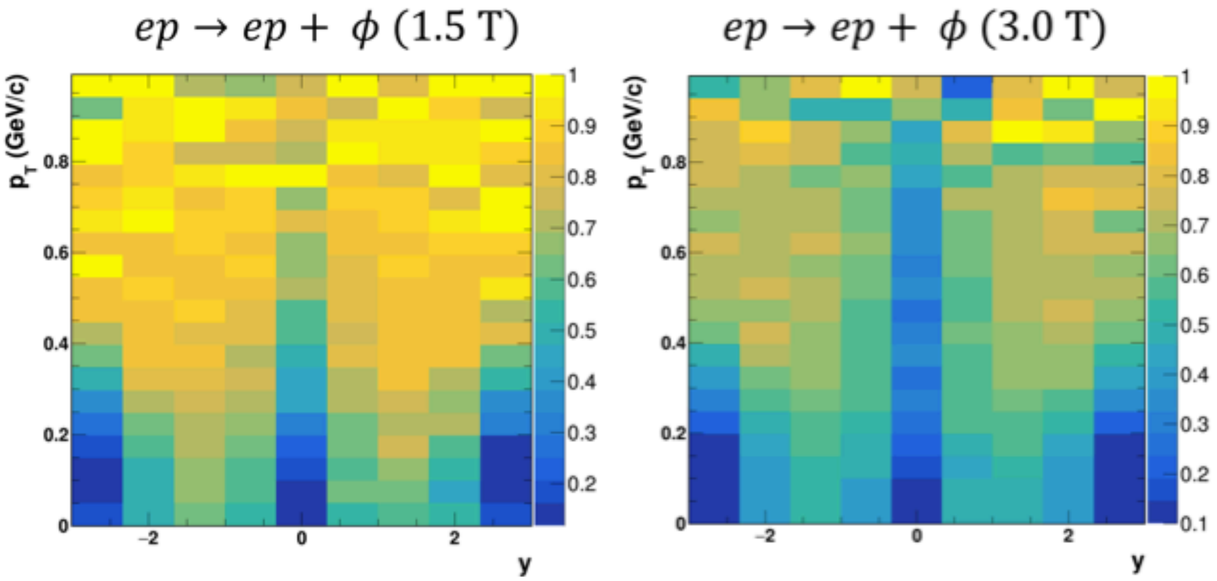

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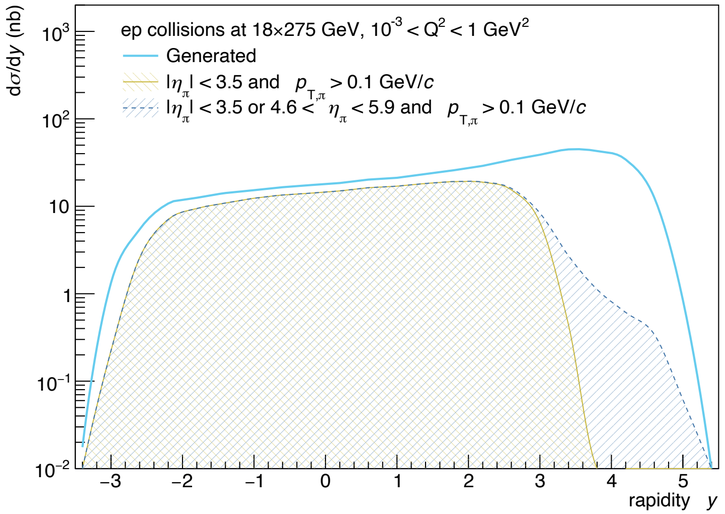

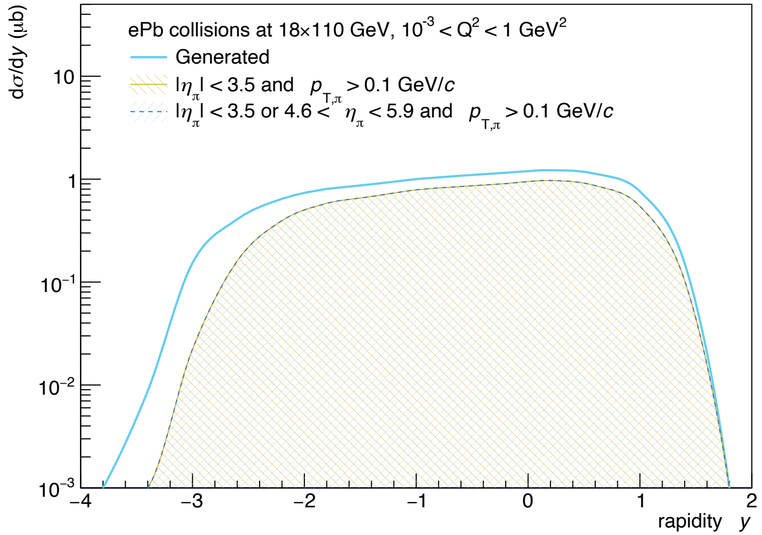

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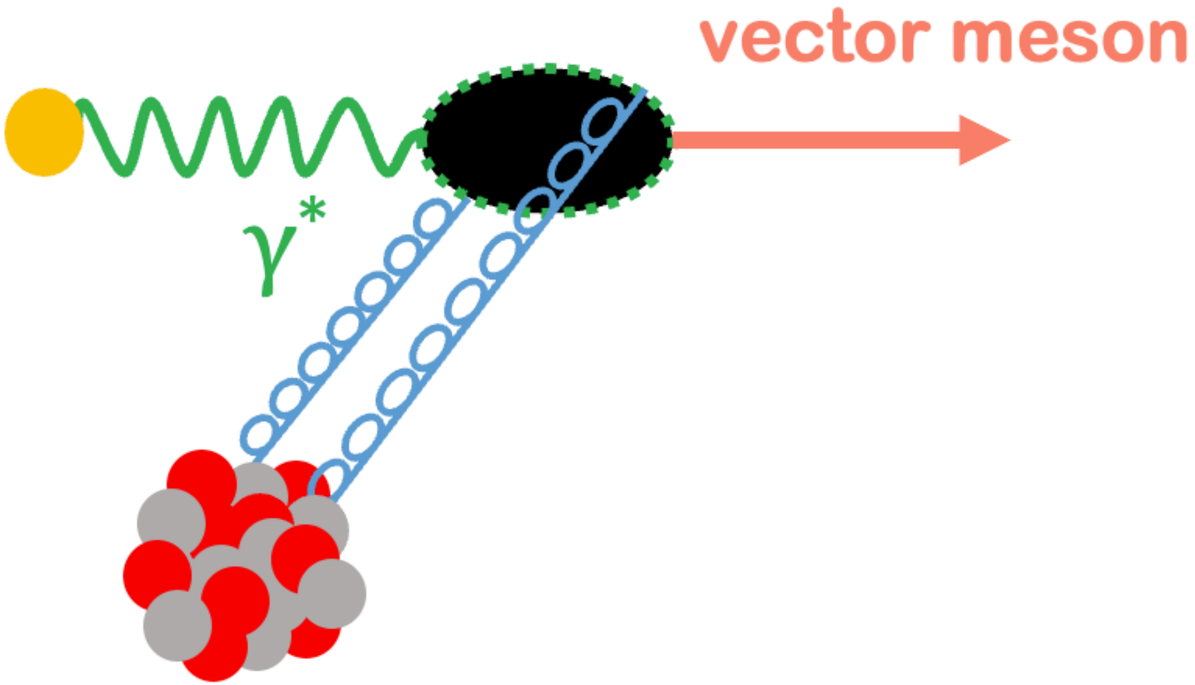
Exclusive vector meson photoproduction



- **Vector meson photoproduction:**

  photon fluctuates to a dipole which then elastically scatters off the nucleus, emerging as vector meson

- **Cannot involve color exchange:**

  must proceed via the exchange of at least two gluons → sensitive to gluon density of the target

- **Exclusivity:**

  Physics variables accessible with final state mass and rapidity