When exclusivity fails: hadronic effects of *coincident* electromagnetic dissociation in ultraperipheral collisions at the LHC

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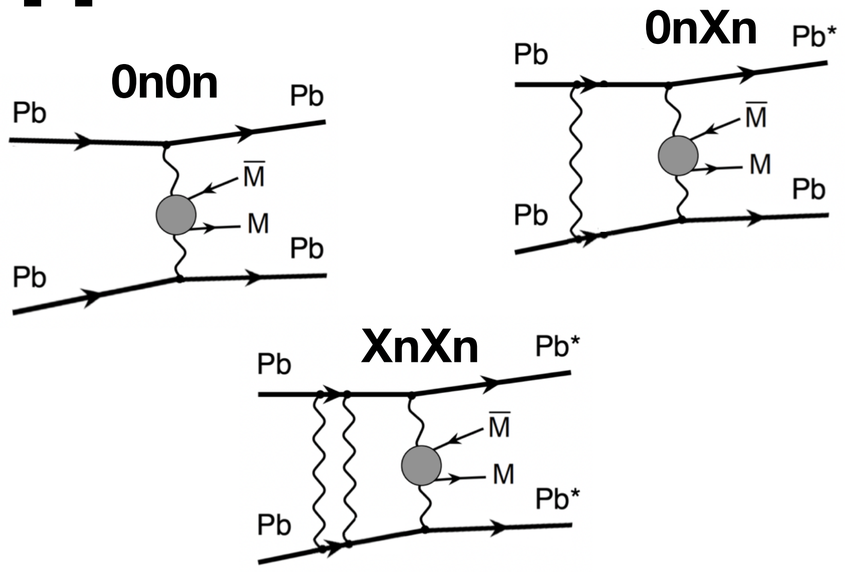
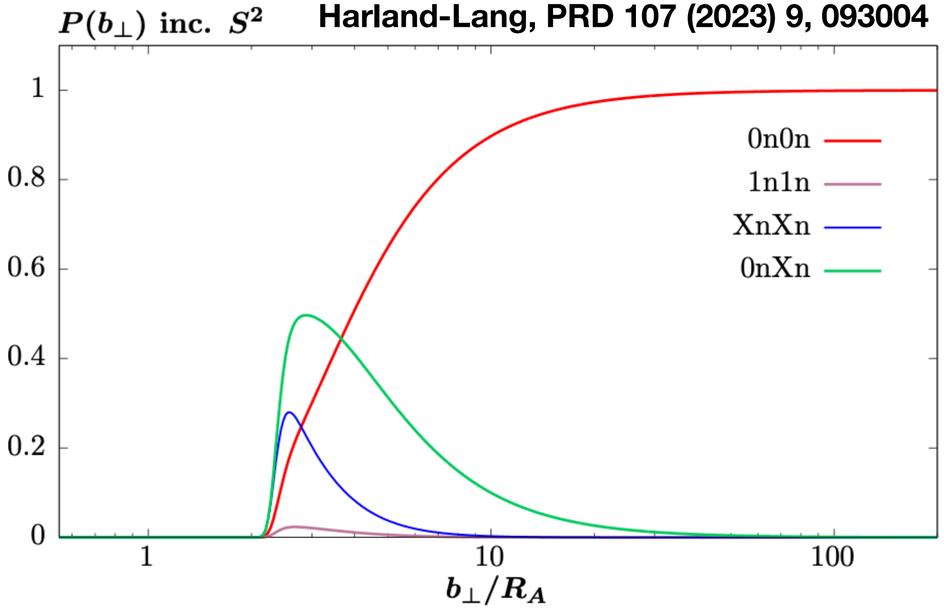
(based on arXiv:2604.19879, in collaboration w/ L. Harland-Lang)

Introduction

- UPC@LHC = enormous EM fields, multi-photon interactions
- Extra photon exchanges leading to **electromagnetic dissociation (EMD)** of **one** or **both** ions
  - Emission of beam-energy neutron(s)
  - Occur typically at smaller impact parameters

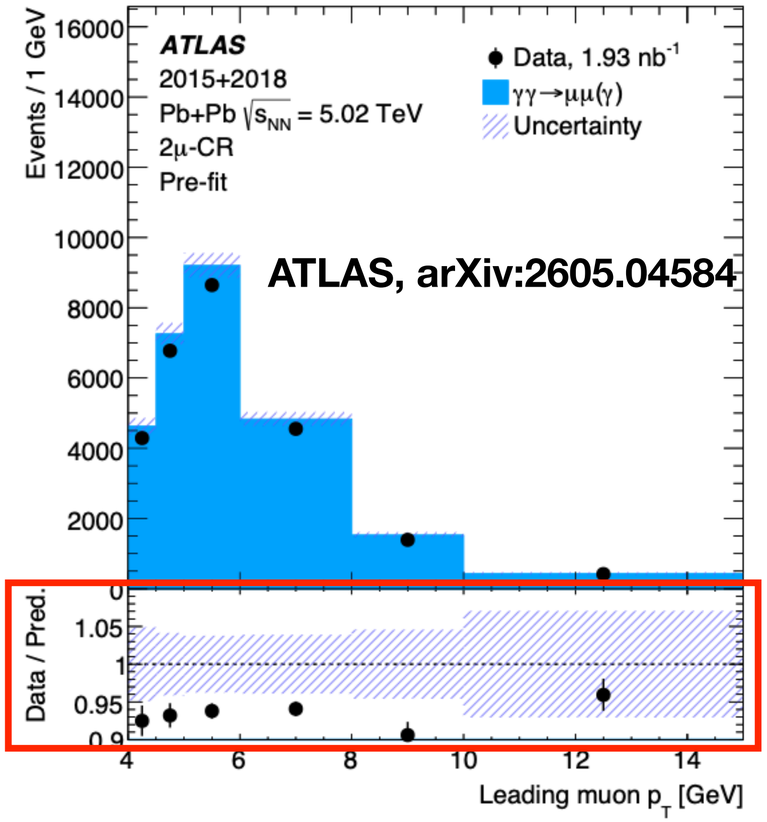


- These interactions can be tagged using far-forward devices called **Zero-Degree Calorimeters (ZDC)**
- Activity classes defined based on the neutron signal in the ZDC detectors:
  - **0n0n**: no neutrons on any side
  - **0nXn**: some neutrons on one side
  - **XnXn**: some neutrons on both sides



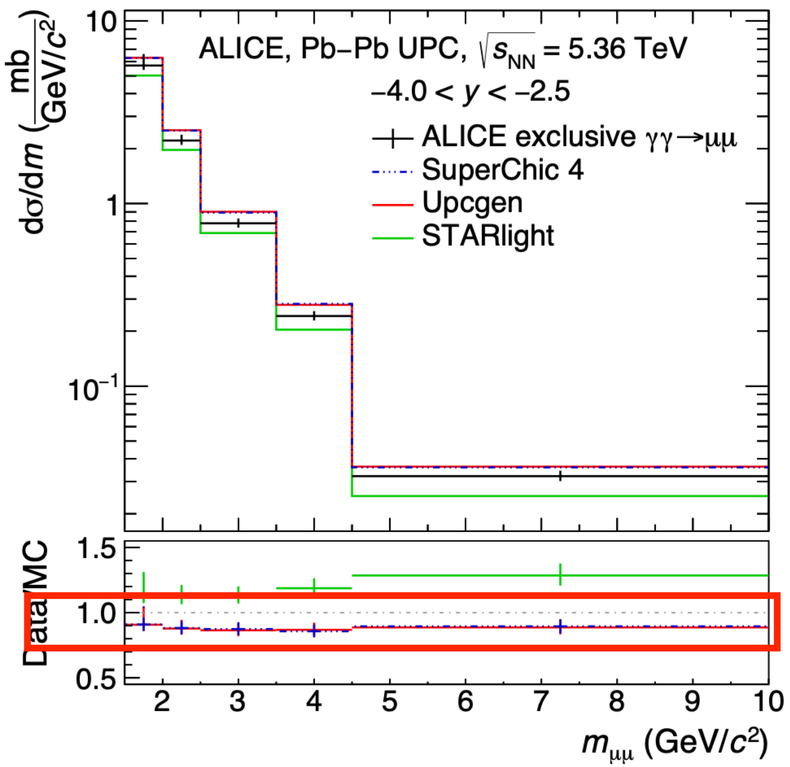
Motivation (I)

- Different analyses, same trends…

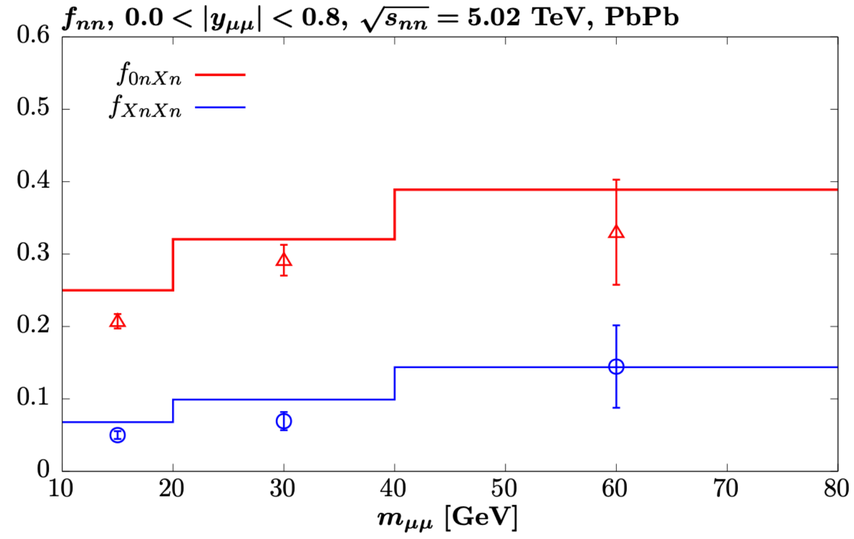


ATLAS, arXiv:2605.04584

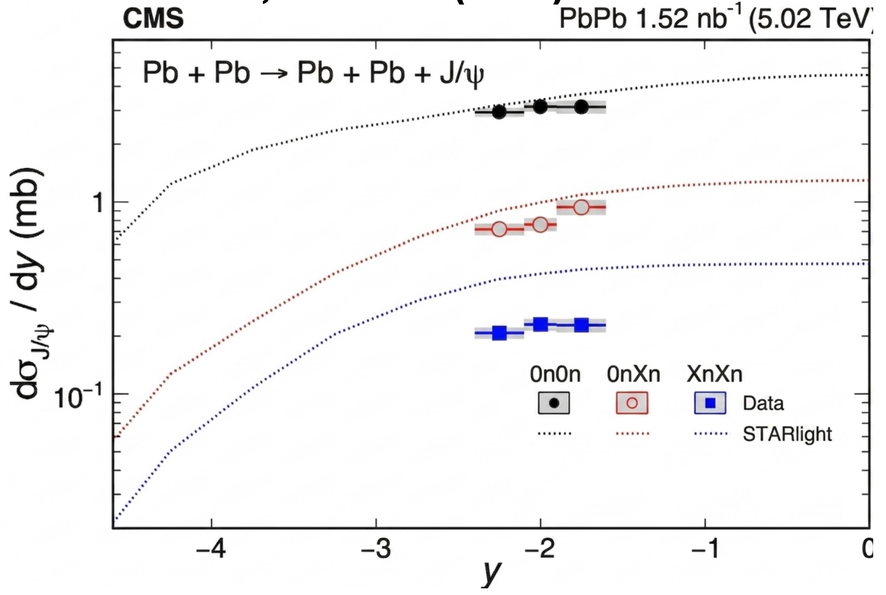
ALICE, arXiv:2605.13569



Harland-Lang, PRD 107 (2023) 9, 093004
+ ATLAS data from PRC 104, 024906 (2021)



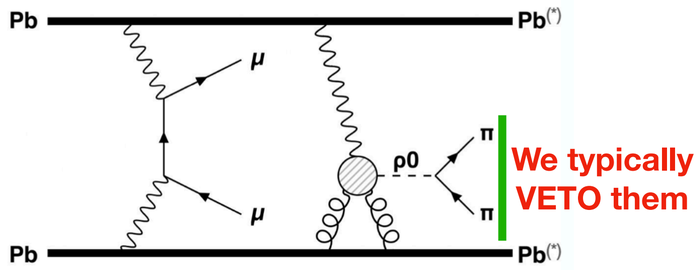
CMS, PRL 131 (2023) 262301

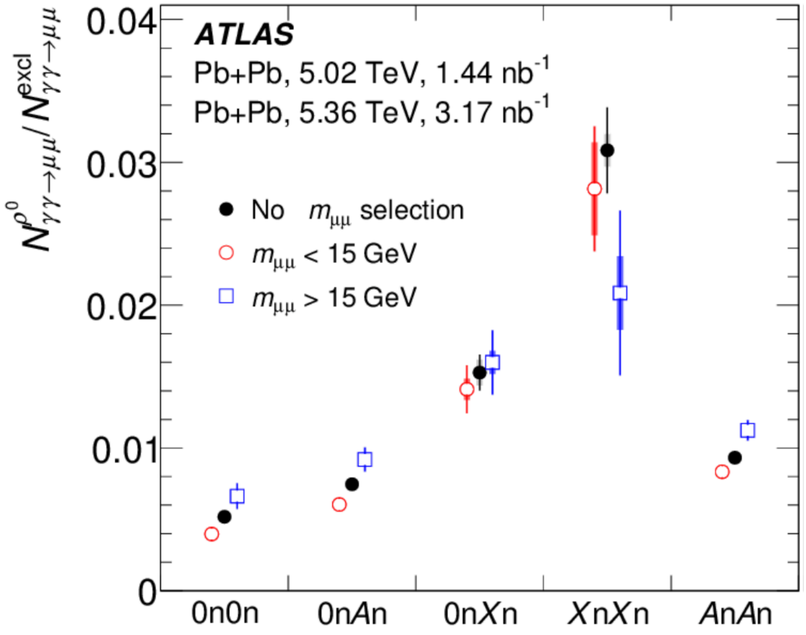


Motivation (II)

- ATLAS data shows that the coincident (elastic) ρ^0 production has some impact on UPC event exclusivity

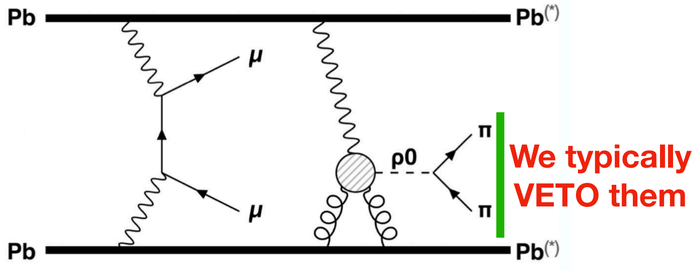
ATLAS, Phys.Lett.B 881 (2026) 140909

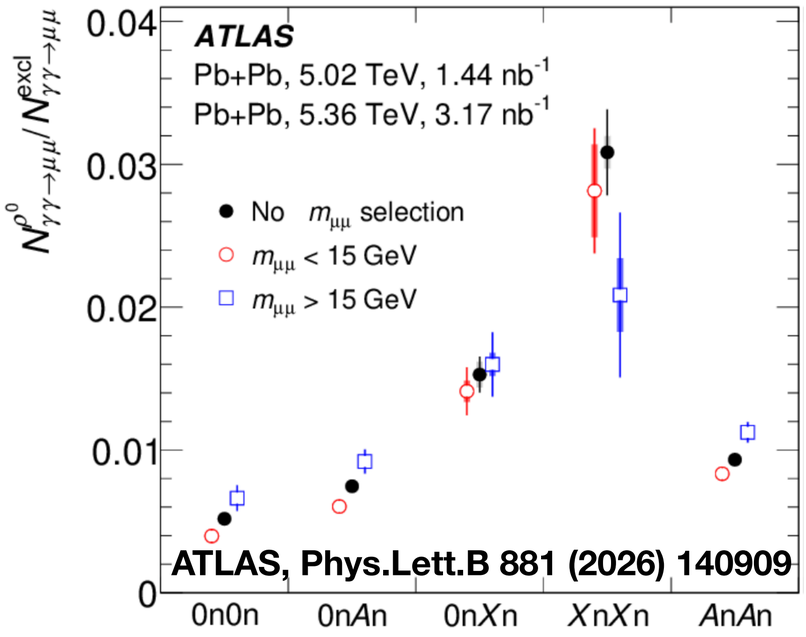




Motivation (II)

- ATLAS data shows that the coincident (elastic) ρ^0 production has some impact on UPC event exclusivity
- BUT: we also know (from HERA) that the elastic contribution to the total γ-p cross section at high energy is sub-dominant





H1 Collaboration, Z. Phys. C 69:27-38,1995

Table 2: Results for partial and total γp cross sections under the assumption that the double dissociation cross section is in the range $0 < \sigma_{DD} < 40$ μb. The first error is statistical, the second one is systematic, and the third error reflects the systematic uncertainty due to the assumption on σ_{DD} . Their sum in quadrature is given as the full error. Note, that due to the error correlation in the partial cross sections the error of the total cross section is relatively smaller.

process	*cross section* (μb)	*full error* (μb)
$\sigma(\gamma p \to XY)$, DD	20 ± 20 (assumed)	—
$\sigma(\gamma p \to Xp)$, GD	23.4 ± 2.6 ± 4.3 ± 10.2	11.3
$\sigma(\gamma p \to VY)$, PD	8.7 ± 1.5 ± 1.5 ± 3.0	3.6
$\sigma(\gamma p \to Vp)$, EL	17.1 ± 1.6 ± 3.7 ± 1.4	4.3
$EL + GD + PD + DD$	69.2 ± 3.4 ± 8.8 ± 9.3	13.2
ND	96.1 ± 3.5 ± 14.7 ± 9.6	17.9
Total	165.3 ± 2.3 ± 10.9 ± 1.3	11.2

sqrt(s) ~200GeV

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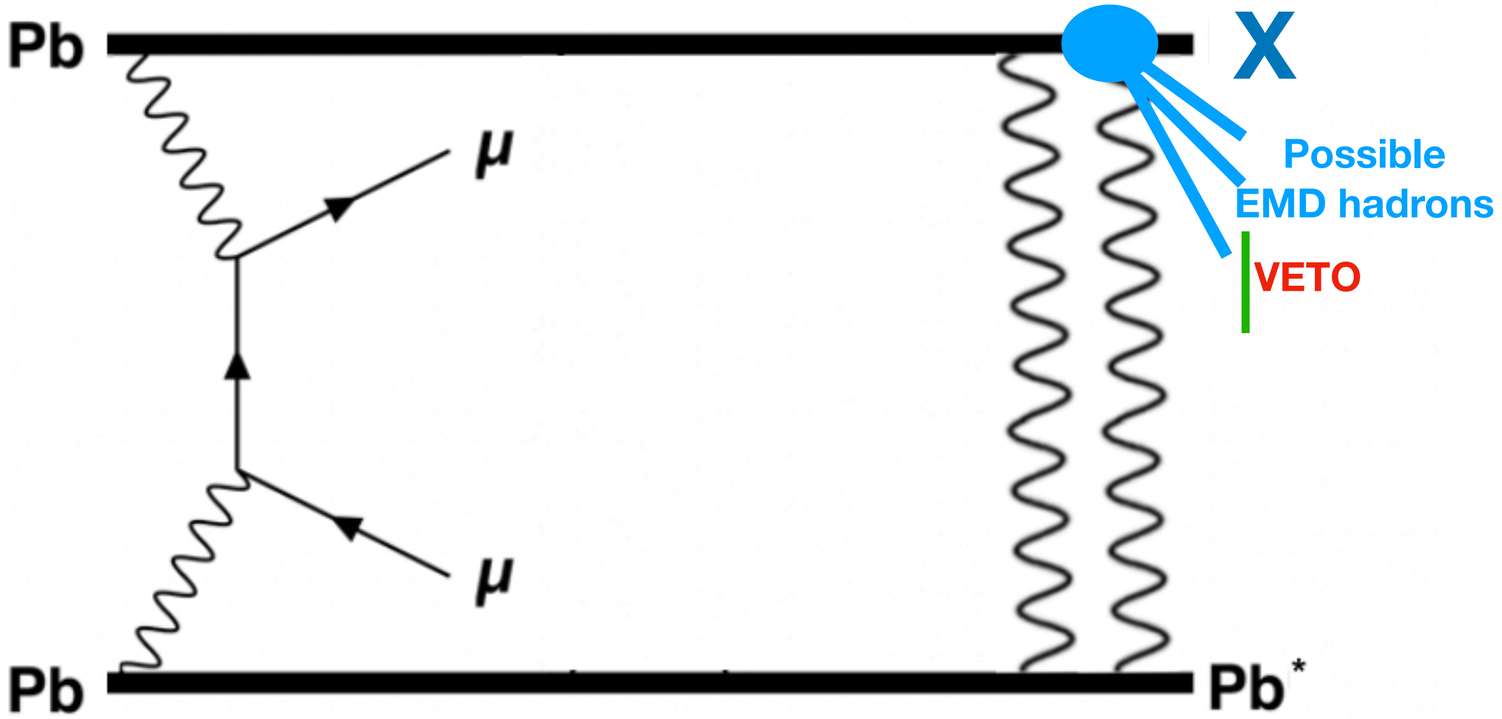
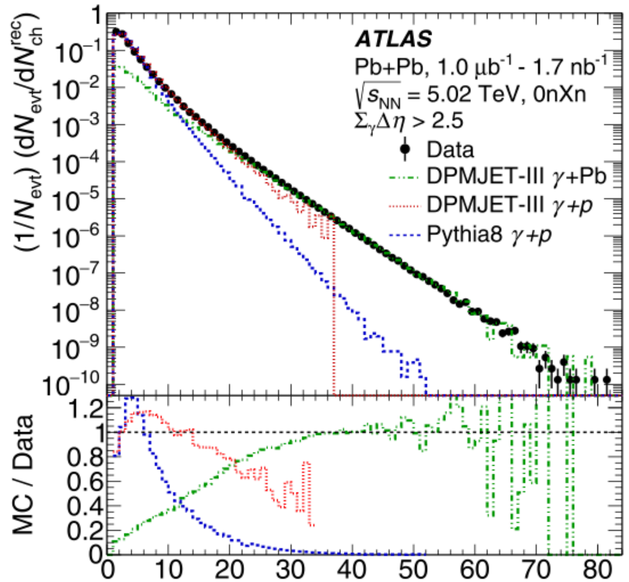
- BUT: we also know (from HERA) that the elastic contribution to the total γ-p cross section at high energy is sub-dominant
  - **Q: What if hadrons from coincident EMD (w/ high-energy photon) can also break the UPC event exclusivity?**



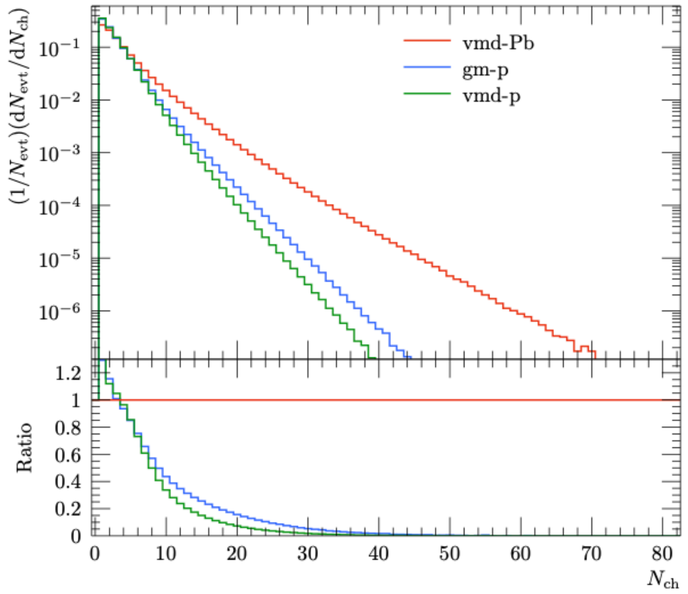
Modeling EMD process (hadrons)

- Using Pythia8+Angantyr setup (γ+Pb collisions)

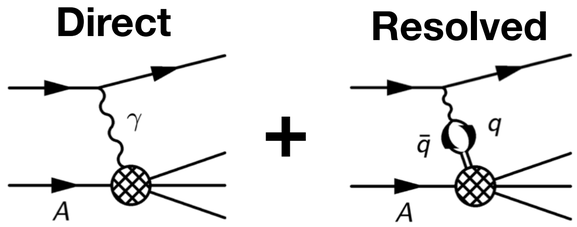
Comparison with data for γ+A (preliminary)



[ATLAS: PRC 104, 014903 (2021)]



- ATLAS data not corrected for efficiency, estimated with $N_{ch}^{rec} \approx 0.8 \cdot N_{ch}$
- Relative increase in multiplicity well in line with the VMD-Pb setup



I. Helenius @ UPC2023 (link)
[see also EPJC 84 (2024) 11, 1155]

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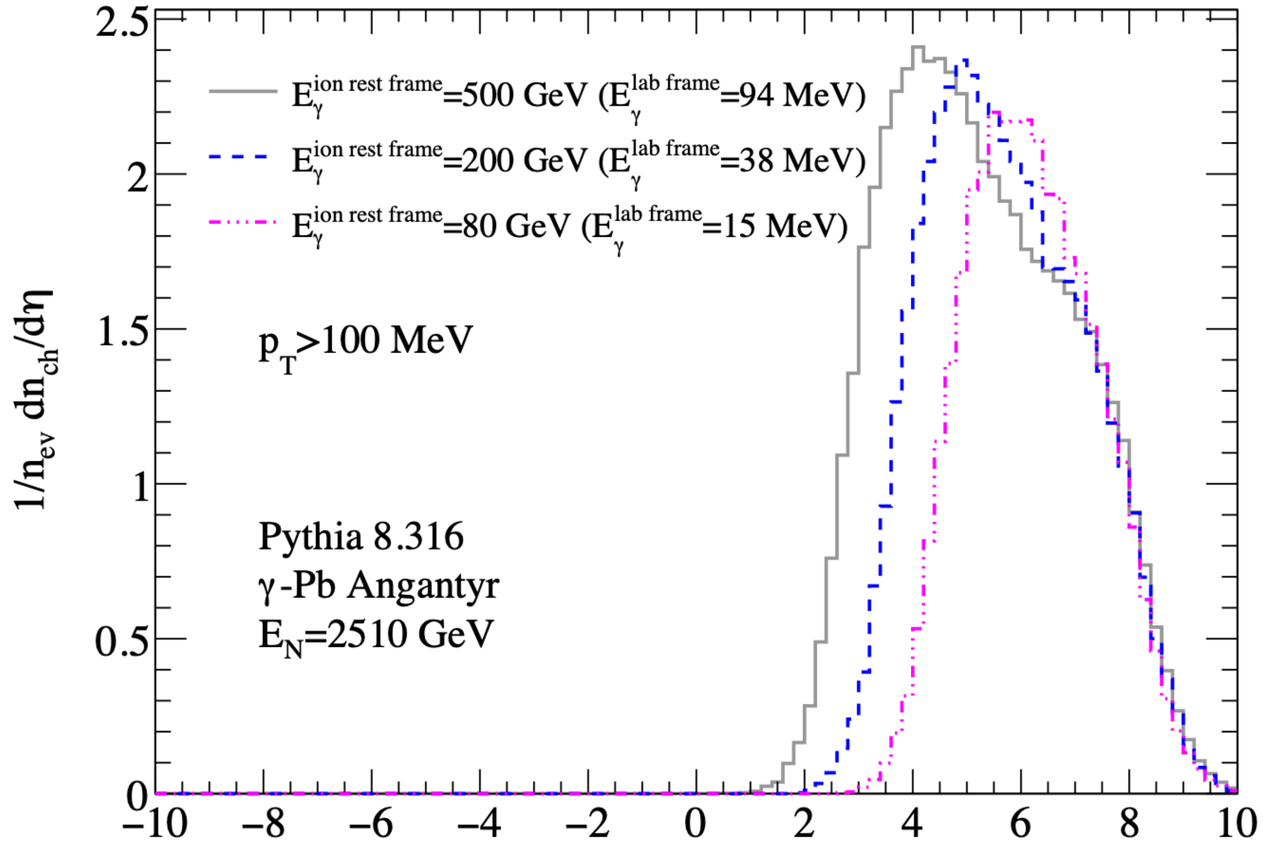


photon-going direction ← → Pb-going direction

Modeling EMD process (cross section)

- Low-energy (up to E_γ = 16 GeV in the ion rest frame) → measurements available
- E_γ > 16 GeV → γ-p cross sections (Regge-based parameterisation) scaled by (**A*S$_g$**)

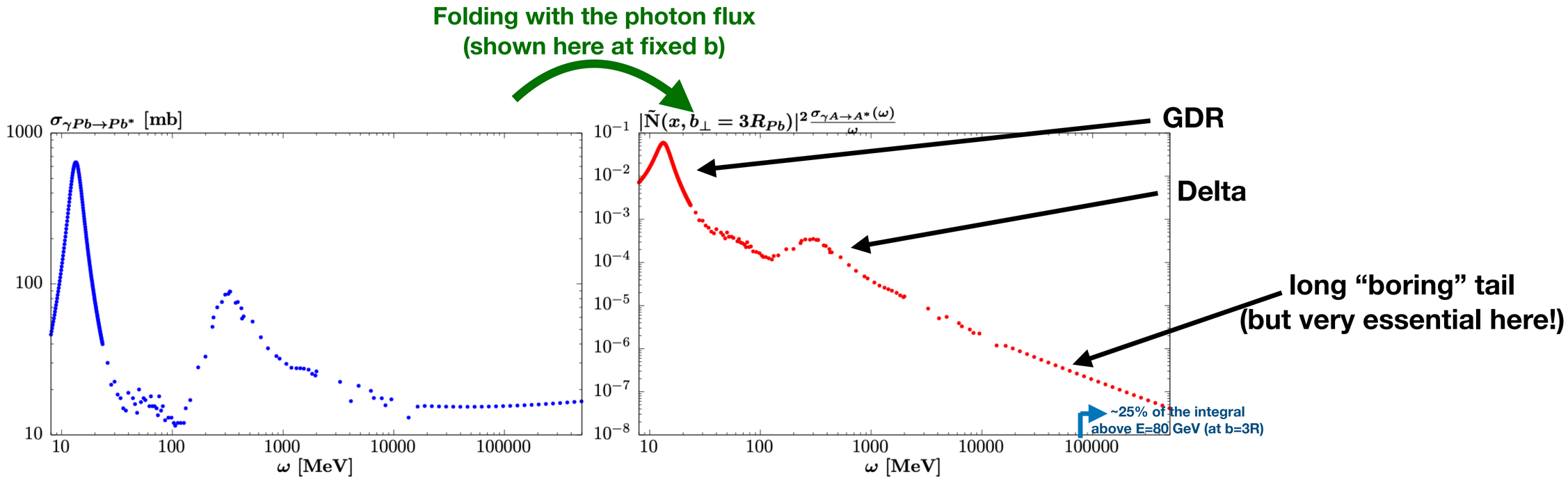


Figure 1: (Left) Photon absorption cross section, $\sigma(\gamma A \to A^*)$, for lead ions, as a function of the photon energy ω in the dissociating ion rest frame. (Right) Photon absorption cross section weighted by corresponding flux factor as in (34) for $b_\perp = 3R_A$, and $\sqrt{s}_{nn} = 5.02$ TeV.

Harland-Lang, PRD 107 (2023) 9, 093004

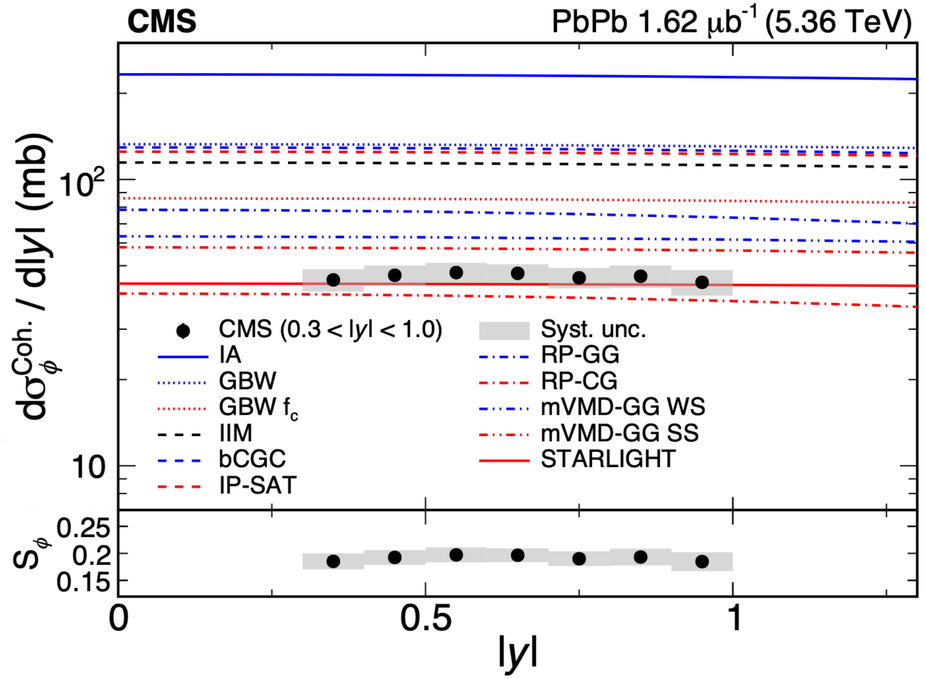
Modeling EMD process (cross section)

- Low-energy (up to E_γ = 16 GeV in the ion rest frame) → measurements available
- E_γ > 16 GeV → γ-p cross sections (Regge-based parameterisation) scaled by (**A*S$_g$**)
- We use **S$_g$** = 0.4 from light VM photoproduction LHC measurements
  - Assign 50% uncertainty to cover **S$_g$**~0.6 typically seen in nPDF analyses for gluons at low-x

LHCb, JHEP 11 (2025) 103

functions is not possible using the nonperturbatively produced ρ meson. A suppression factor of $S_{\mathrm{IA}} = 0.43 \pm 0.05$ is measured at a centre-of-mass energy $W = 5.4\,\mathrm{GeV}$ or equivalently, a fractional parton momentum of $x = 0.018$.

CMS, PRL 135 (2025) 262301



Modeling coincident EMD (in exclusive production)

- Basically all available MC generators use the same approach:

Baltz et al., PRC 80:044902,2009

The lowest order probability for Coulomb breakup of a specific nucleus is

$$P^1_{Xn}(b) = \int_{E_{min}}^{E_{max}} dk \frac{d^3 n_\gamma}{d^2 b dk} \sigma_{\gamma A \to A^*}(k).$$

More precisely, $P^1_{Xn}(b)$ is the mean number of excitations; the probability of having exactly N excitations follows a Poisson distribution, so the probability for at least one Coulomb excitation is

$$P_{Xn}(b) = 1 - \exp\left(-P^1_{Xn}(b)\right). \quad (13)$$

See e.g. STARlight code:

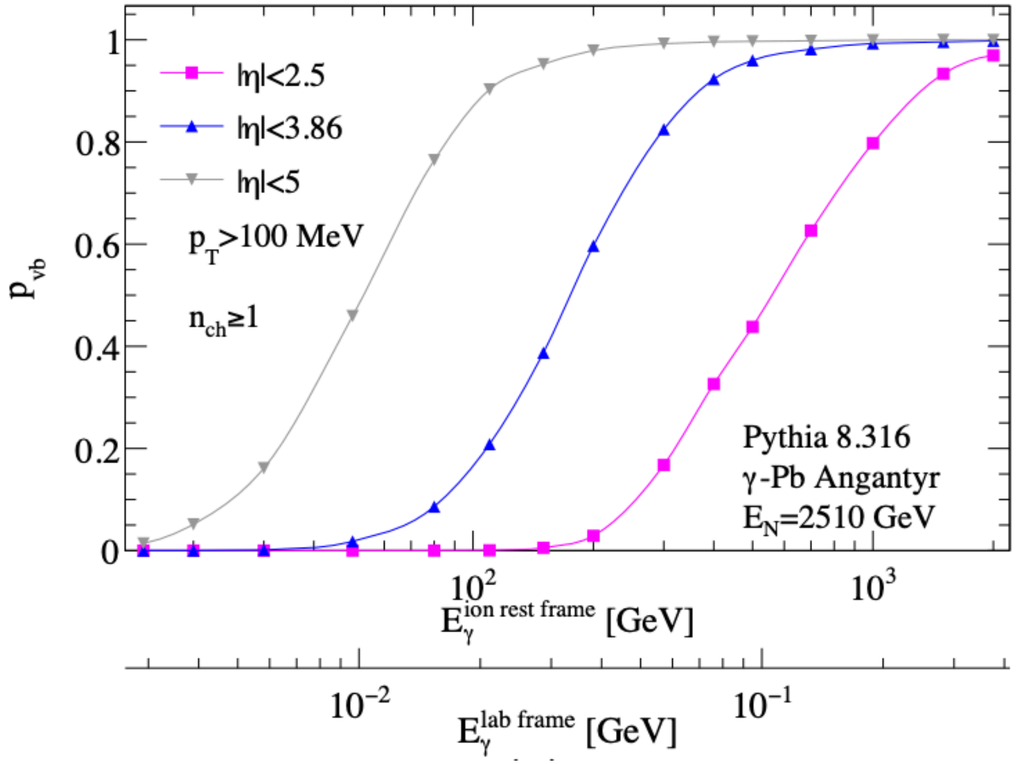
```
if (( mode) == 1) _pPhotonBreakup = 1.;
if (( mode) == 2) _pPhotonBreakup = (1-exp(-1*pxn))*(1-exp(-1*pxn)); -> XnXn
if (( mode) == 3) _pPhotonBreakup = (p1n*exp(-1*pxn))*(p1n*exp(-1*pxn));
if (( mode) == 4) _pPhotonBreakup = exp(-2*pxn); -> 0n0n
if (( mode) == 5) _pPhotonBreakup = 1.;
if (( mode) == 6) _pPhotonBreakup = (1. - exp(-2.*pxn));
if (( mode) == 7) _pPhotonBreakup = 2.*exp(-pxn)*(1.-exp(-pxn)); -> 0nXn
```

Modeling coincident EMD (accounting for EMD hadrons)

- Standard formulas adjusted to:

$$P^{1}_{Xn}(b) = \int dE_\gamma \frac{d^3 n_\gamma}{d^2 b dE_\gamma} \sigma_{\gamma A}(E_\gamma)$$

$$\rightarrow P^{1,\mathrm{v}}_{Xn}(b) = \int dE_\gamma \frac{d^3 n_\gamma}{d^2 b dE_\gamma} \sigma_{\gamma A}(E_\gamma)(1 - p_{\mathrm{vb}}(E_\gamma)) \ ,$$



Ensures at least one "soft" photon exchange

Ensures no additional "high-energy" photon exchanges

$$P^{\mathrm{v}}_{Xn}(b) = \left(1 - \exp\left(-P^{1,\mathrm{v}}_{Xn}\right)\right) \exp\left(-P^{1,\mathrm{vb}}_{Xn}\right)$$

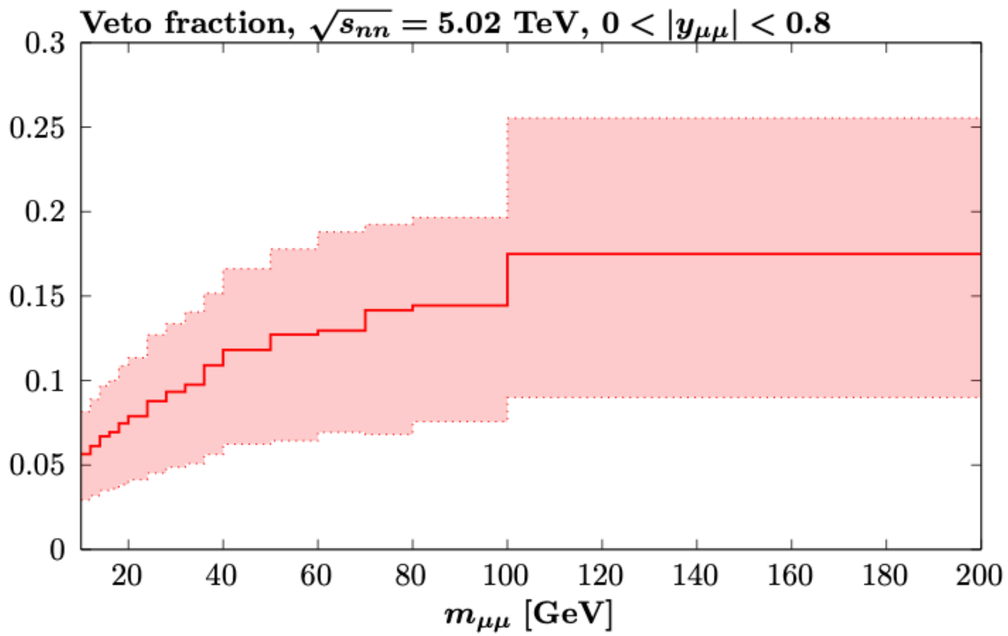
$$P^{1,\mathrm{vb}}_{Xn} = P^{1}_{Xn} - P^{1,\mathrm{v}}_{Xn}$$

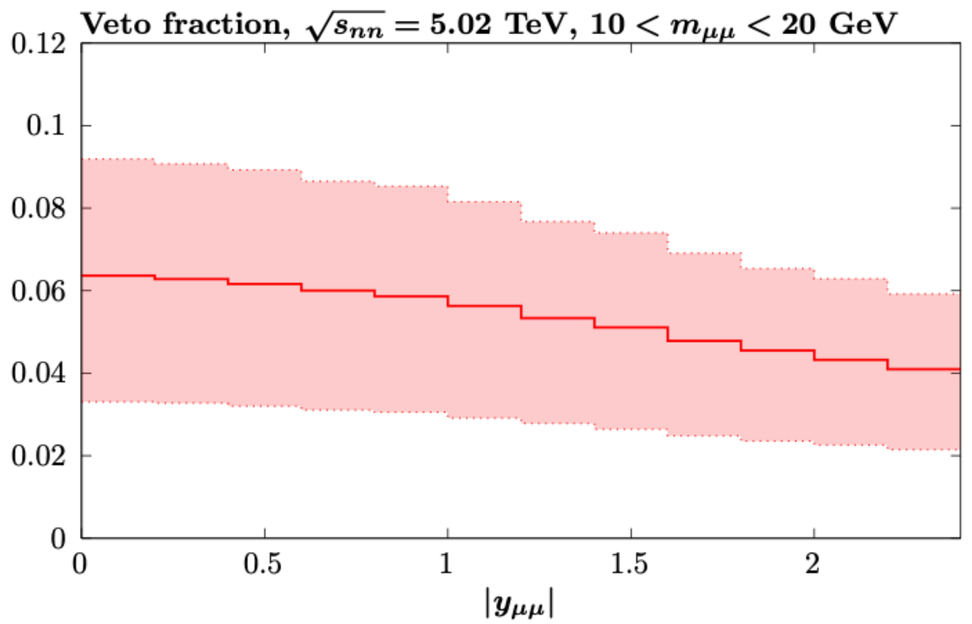
$$P^{\mathrm{v}}_{0n}(b) = \exp\left(-P^{1,\mathrm{v}}_{Xn}\right) \exp\left(-P^{1,\mathrm{vb}}_{Xn}\right) = \exp\left(-P^{1}_{Xn}\right)$$

→ **"no-breakup": unchanged since no particle production here**

Impact on exclusive γγ→l+l- UPC process

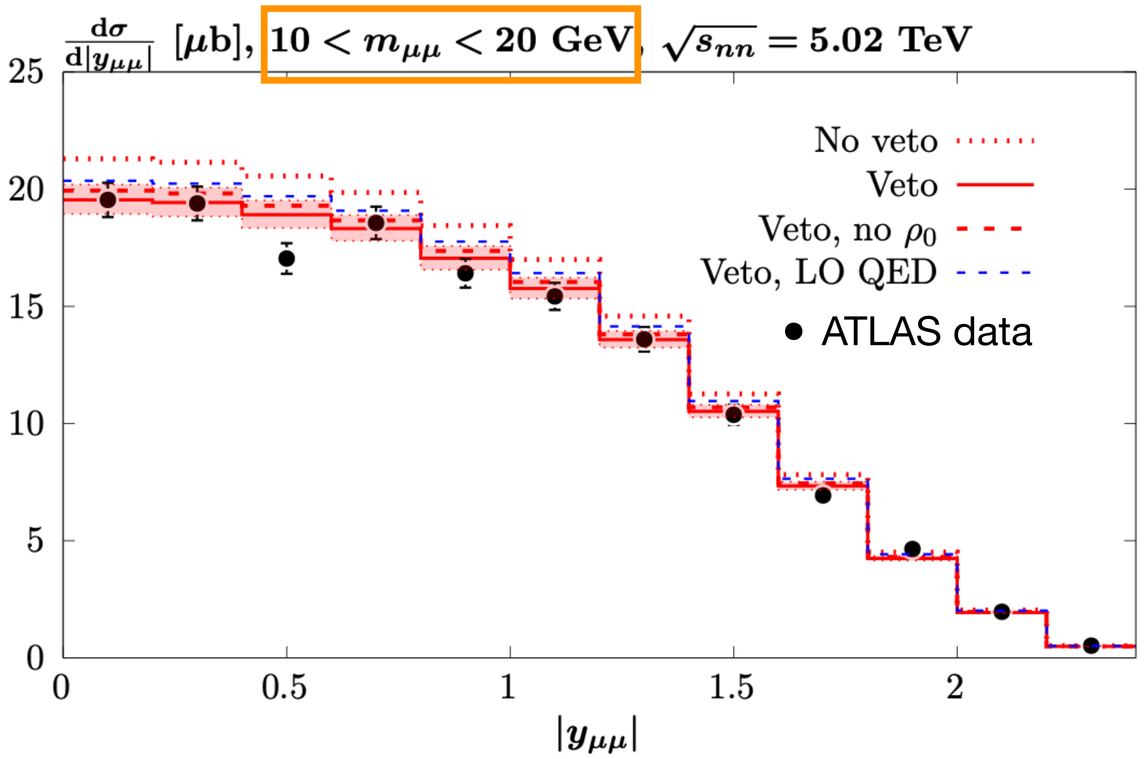
- Impact on ‘standard candle’ high-mass γγ→μμ ATLAS measurement [PRC 104, 024906 (2021)]
  - Veto definition: no extra charged-particles with p_T> 100 MeV and |eta|<3.86
- Shown below are the predicted event fractions that fail exclusivity veto due to coincident EMD hadrons
  - Significant effect!
  - Kinematic trends reflect the impact parameter dependence of the coincident EMD process(es)
  - Model uncertainties dominated by S_g variation

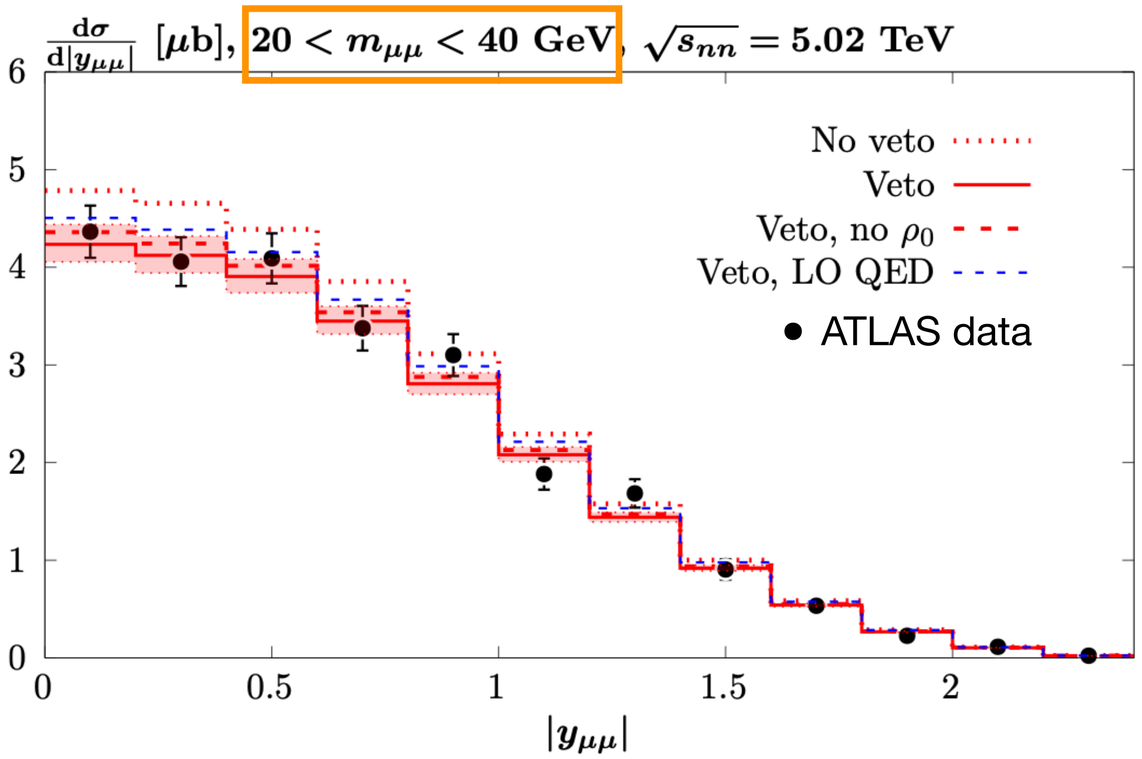




Impact on exclusive γγ→l+l- UPC process

- Impact on ‘standard candle’ high-mass γγ→μμ ATLAS measurement [PRC 104, 024906 (2021)]
  - Good agreement w/ SuperChic (w/ NLO QED k-factors), after including coincident *EMD veto* corrections
  - Resolving long-standing tensions





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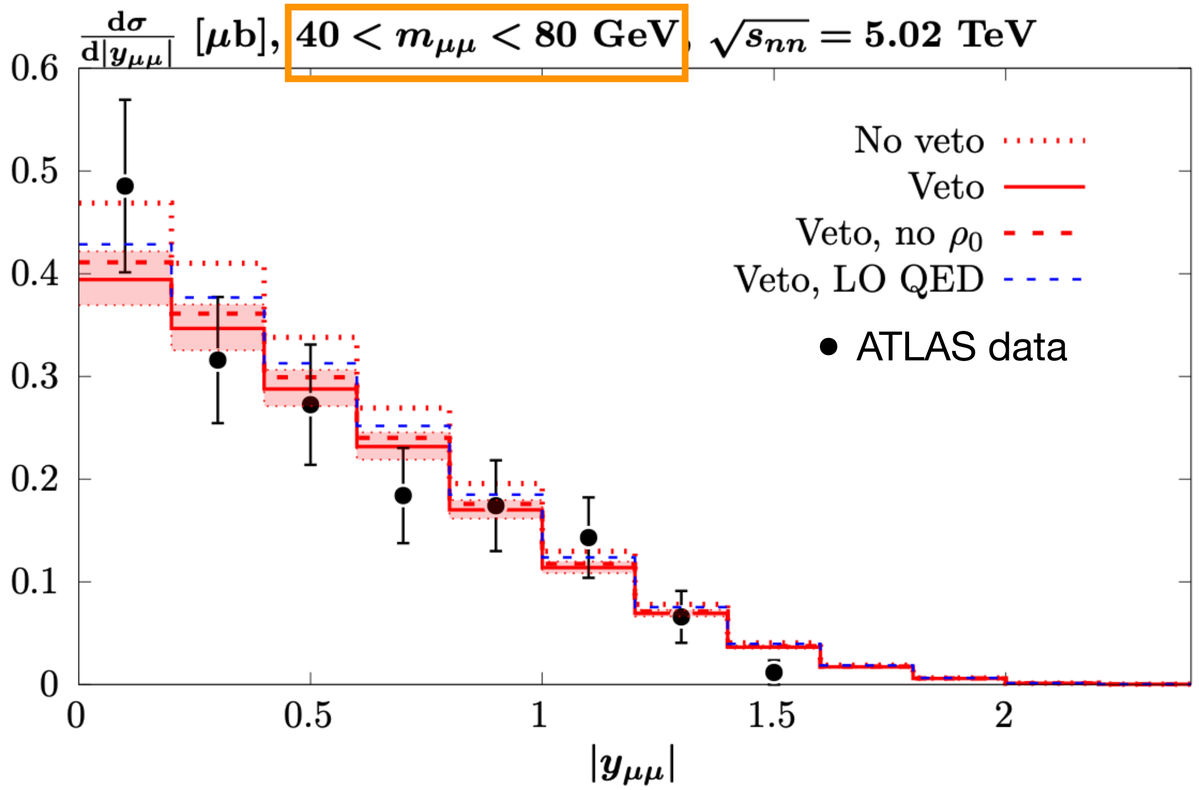
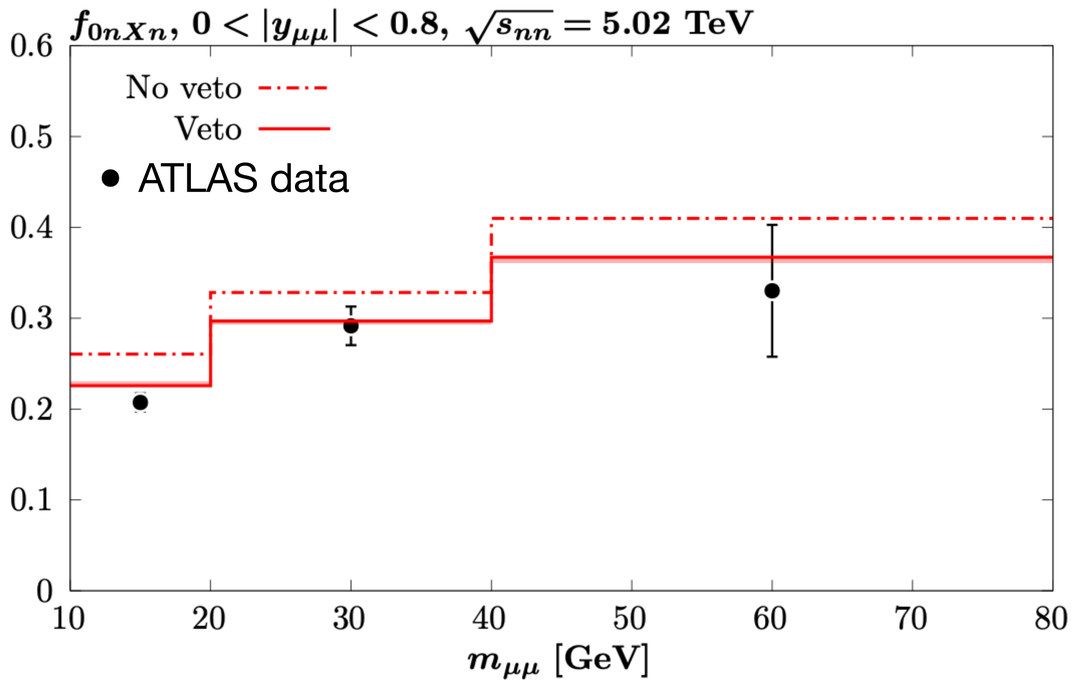
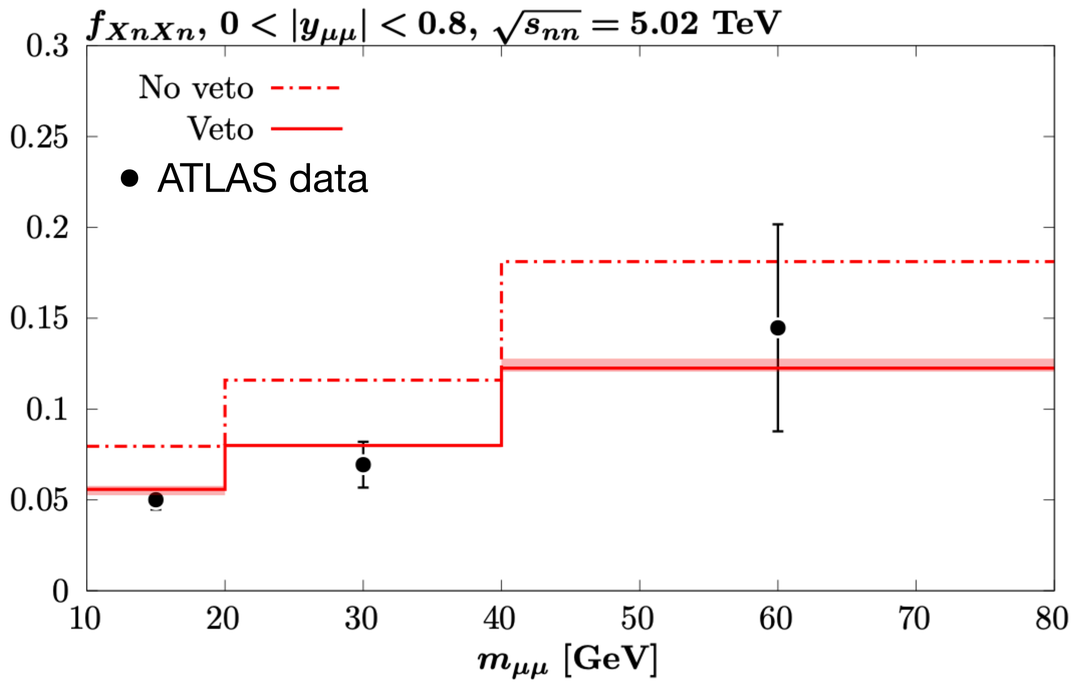


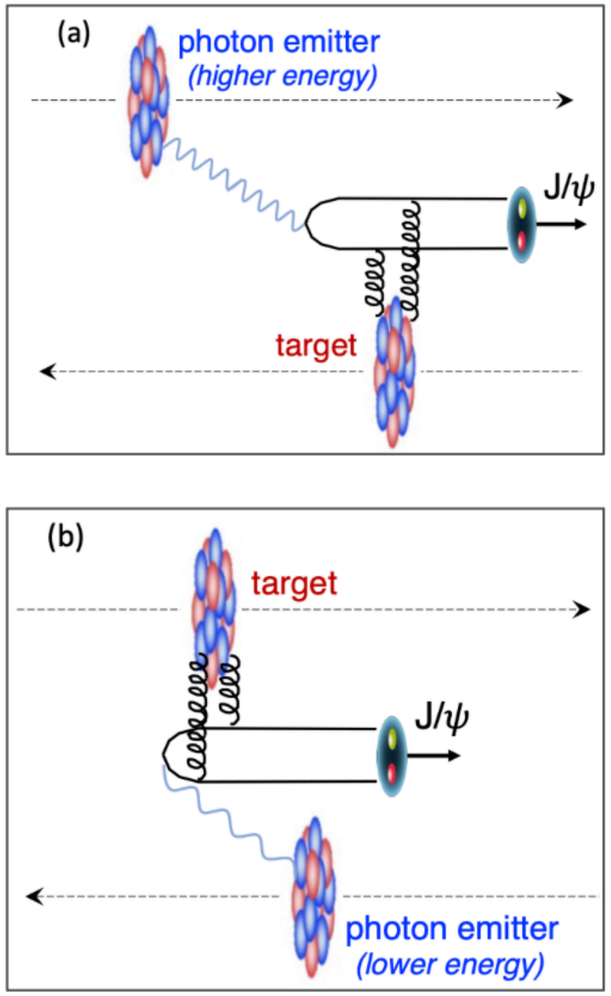
Impact on exclusive γγ→l+l- UPC process

- Impact on ‘standard candle’ high-mass γγ→μμ ATLAS measurement [PRC 104, 024906 (2021)]
  - **EMD breakup fractions**: Good agreement w/ SuperChic after including coincident *EMD veto* corrections
  - Resolving long-standing tensions





Impact on LHC coherent exclusive J/ψ measurements



plots from PRL 131 (2023) 262301

The rapidity-dependent measurements are ignorant to which ion was the photon emitter:

$$d\sigma/dy = N_\gamma(\omega_1)\,\sigma_{\gamma Pb\to J/\psi\,Pb}(\omega_1) + N_\gamma(\omega_2)\,\sigma_{\gamma Pb\to J/\psi\,Pb}(\omega_2)$$

Ambiguity can be resolved by performing the measurement in different ZDC classes:

$$\omega_{1,2} = \frac{1}{2} m_{J/\psi}\, e^{\pm y}$$

[Guzey, Strikman, Zhalov, EPJC (2014) 74:2942]

$$d\sigma^{0n0n}/dy = N_\gamma^{0n0n}(\omega_1)\sigma_{J/\psi}(\omega_1) + N_\gamma^{0n0n}(\omega_2)\sigma_{J/\psi}(\omega_2)$$

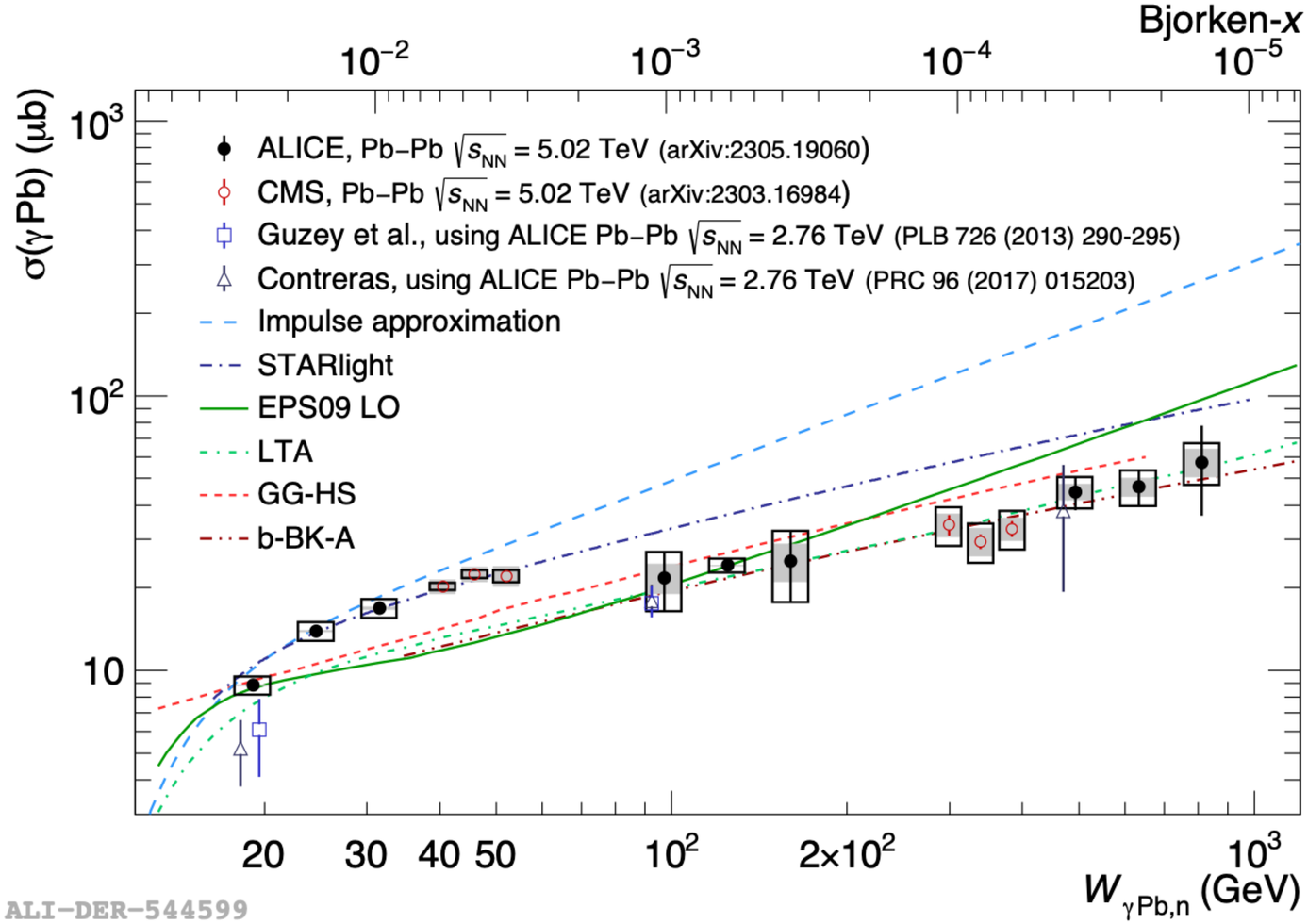
$$d\sigma^{0nXn}/dy = N_\gamma^{0nXn}(\omega_1)\sigma_{J/\psi}(\omega_1) + N_\gamma^{0nXn}(\omega_2)\sigma_{J/\psi}(\omega_2)$$

$$d\sigma^{XnXn}/dy = N_\gamma^{XnXn}(\omega_1)\sigma_{J/\psi}(\omega_1) + N_\gamma^{XnXn}(\omega_2)\sigma_{J/\psi}(\omega_2)$$

(Side remark: this procedure can work only upon a good knowledge of conditional photon fluxes, N_γ^{inj})

Impact on LHC coherent exclusive J/ψ measurements

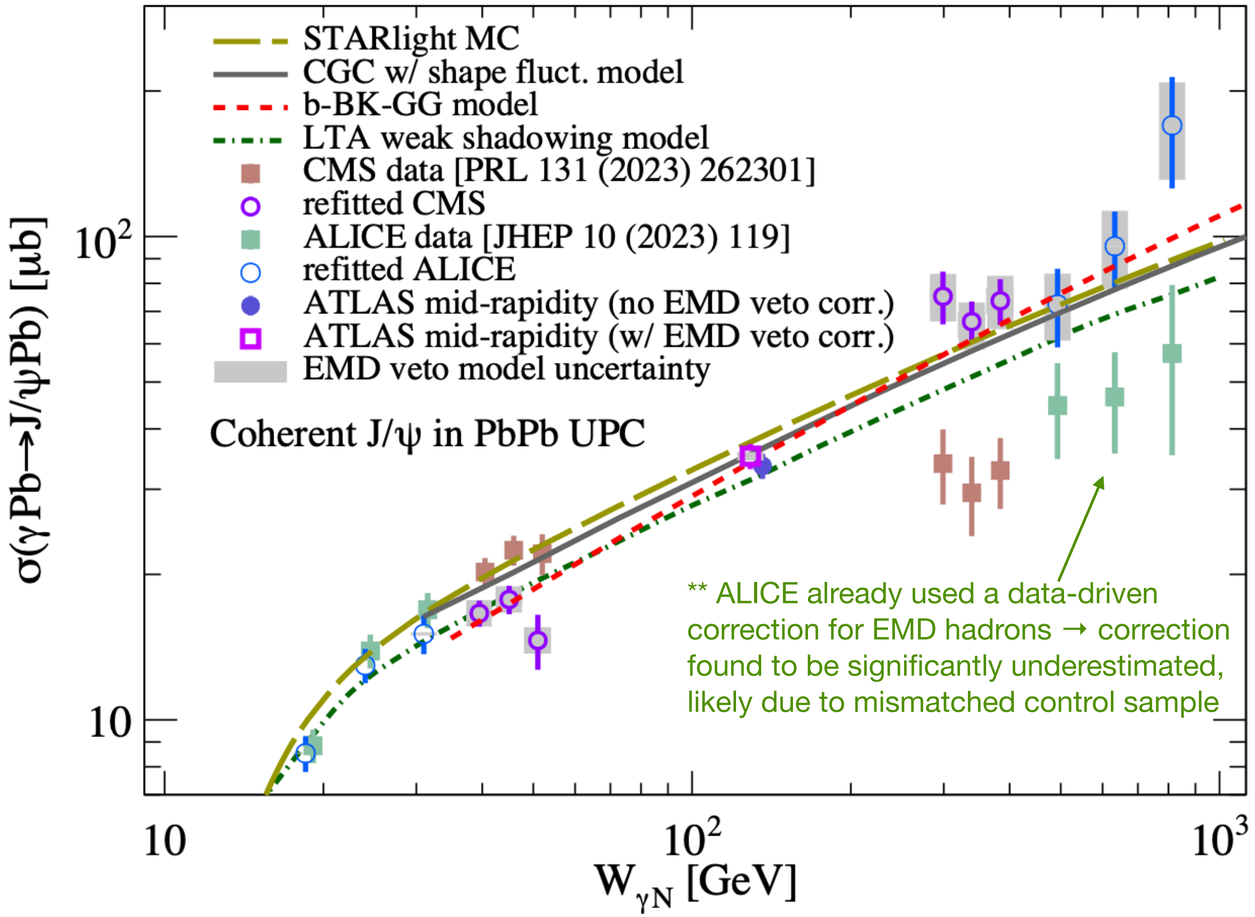
- Original CMS and ALICE trends



$$W_{\gamma\mathrm{N}}^{\mathrm{Pb}} = \sqrt{\sqrt{s_{\mathrm{NN}}}M_{\mathrm{J}/\psi}\exp(\pm y)}$$

Impact on LHC coherent exclusive J/ψ measurements

- CMS and ALICE data re-fitted with modified photon fluxes from STARlight, taking into account exclusivity veto definition of each measurement
  - Large effect, esp. for XnXn fluxes (-50%)
    -> translates directly into high-W behaviour
  - Resolving large data-theory tensions seen w/ the original data
  - Also including y=0 ATLAS measurement (4% effect from EMD veto)
  - ALICE mid-rapidity data not included (likely need extra corrections due to coincident yy->ee that are not currently simulated)
  - Good agreement with Bendova et al. model [*PLB* 817 (2021) 136306] based on b-dependent Balitsky-Kovchegov equation + Glauber-Gribov



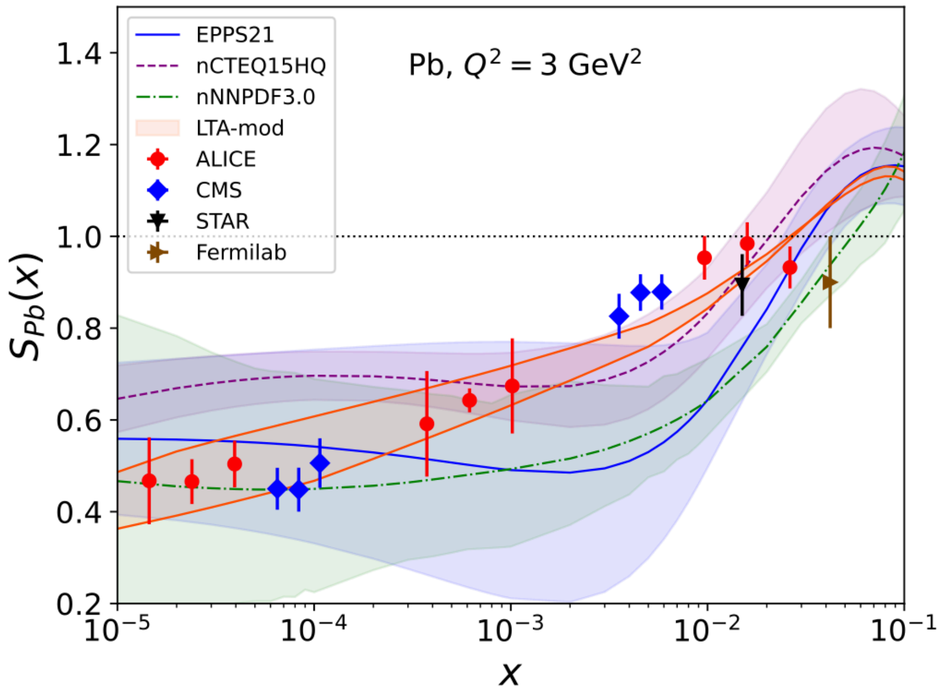
Impact on LHC coherent exclusive J/ψ measurements

- Analysis of nuclear suppression factor

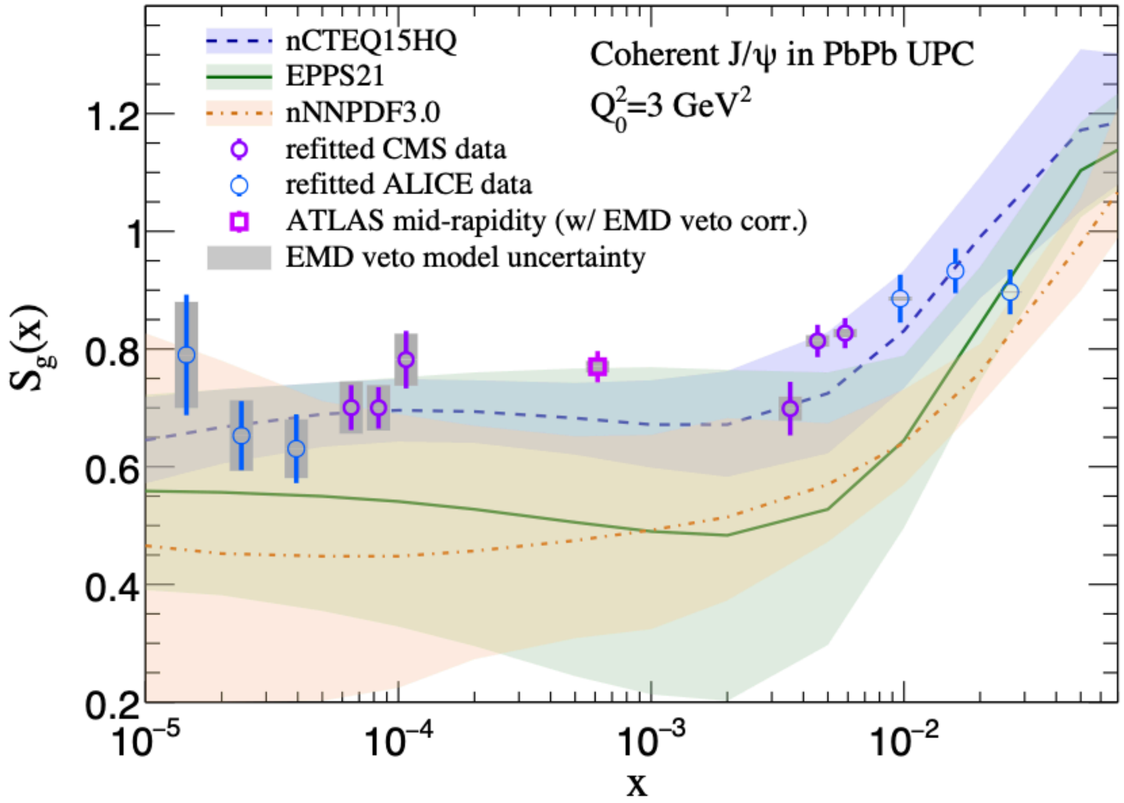
$$S_g(x) = \sqrt{\frac{\sigma(\gamma Pb \to J/\psi Pb)}{\sigma_{IA}(\gamma Pb \to J/\psi Pb)}} \qquad \sigma^{\mathrm{IA}} = \frac{\mathrm{d}\sigma^{\gamma p}}{\mathrm{d}t}(t=0)\int_{-t_{\min}} \mathrm{d}t\,|F(t)|^2$$

  - Excellent agreement w/ nPDF predictions (NLO) after data corrections, in particular within nCTEQ15HQ's "small uncertainties"

Guzey, Strikman, PRC 110 (2024) 4, 045201 (original data trends)



after EMD veto corrections



Impact on LHC coherent exclusive J/ψ measurements

PHYSICAL REVIEW D **114,** L031505 (2026)

Revisiting the role of saturation in diffractive vector meson production

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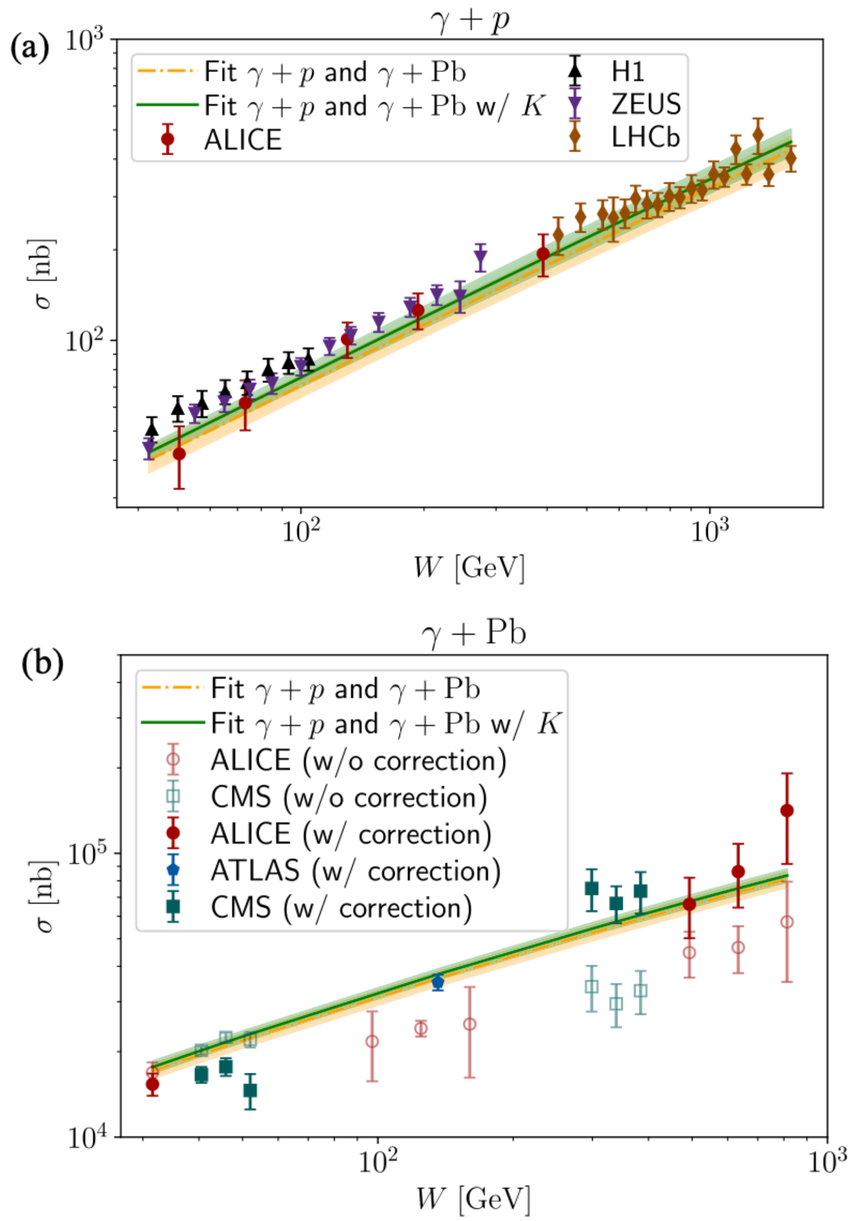
We perform a global Bayesian analysis of coherent and incoherent diffractive J/ψ photoproduction in $\gamma + p$ and $\gamma +$ Pb collisions using a color glass condensate (CGC)-based framework and ultraperipheral collision data from the Large Hadron Collider (LHC), corrected for the expected effect of electromagnetic dissociation (EMD). Using Gaussian-process emulators of the underlying CGC calculations, we infer model parameters from a combined set of HERA and LHC measurements. We find that the $\gamma +$ Pb data with EMD correction substantially reduce the previously observed tension between proton and nuclear datasets, enabling a consistent simultaneous description of diffractive J/ψ production in $\gamma + p$ and $\gamma +$ Pb collisions within the CGC framework.



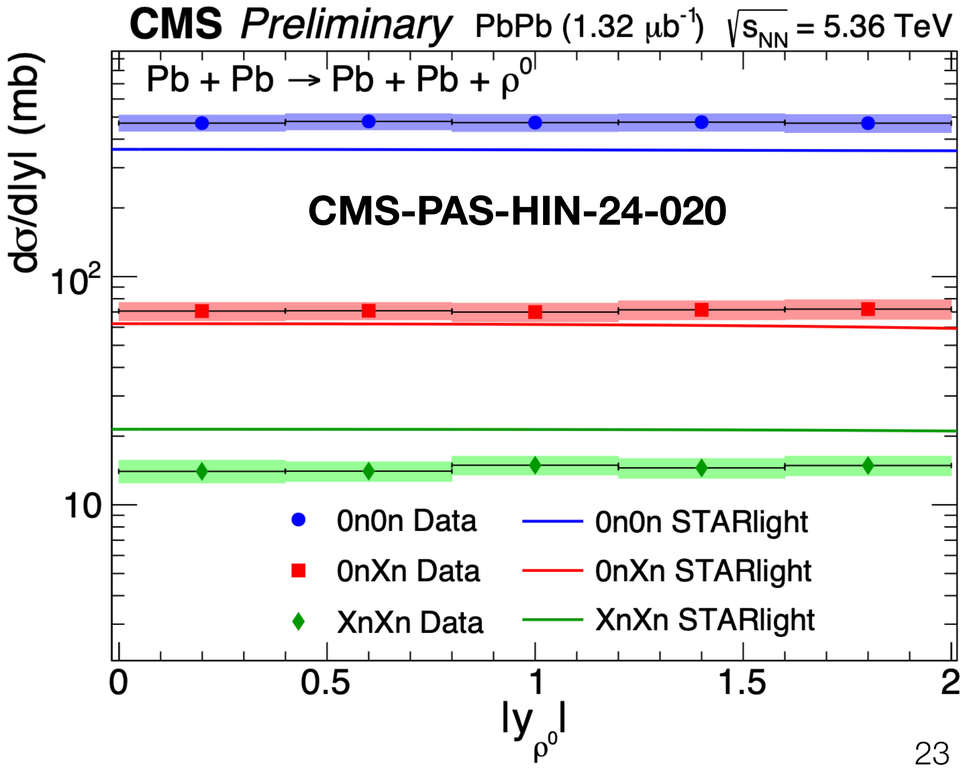
A note on ALICE coherent exclusive ρ^0 measurement

- ALICE measurement of coherent exclusive ρ^0 in Pb+Pb UPC at 5.02 TeV [**JHEP06 (2020) 35**]
  - ALICE data-driven estimation of the corrections due to coincident EMD hadrons, based on ZDC triggers + ρ^0 selection:
    +**(26 ± 4)% for 0nXn** events and +**(43 ± 5)% for XnXn** events
  - STARlight+Pythia8+Angantyr prediction (for $|y(\rho^0)|<0.8$ and ALICE exclusivity vetos):
    +21% for 0nXn and **+43% for XnXn**

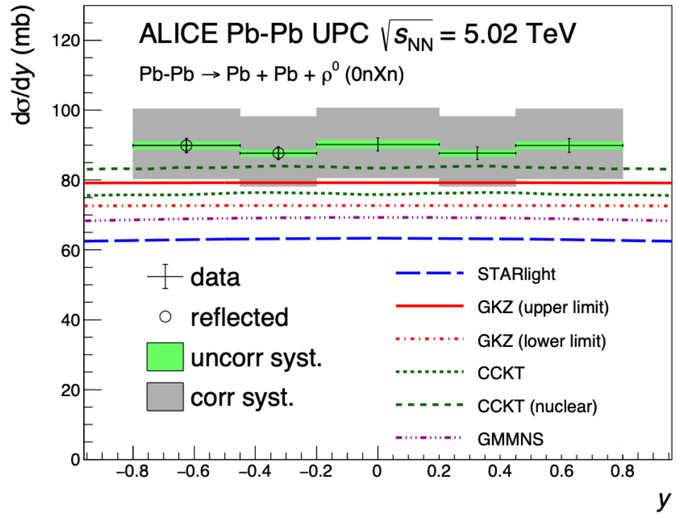
Good events in the 0nXn and XnXn classes are rejected when, in addition to the forward neutrons, other particles are created at large rapidities and leave a signal either in the AD or the V0 detectors. These extra particles come from the different possibilities of dissociation of nuclei, e.g. neutron emission, multi-fragmentation or pion production, and the corresponding cross sections are expected to be large [28]. The amount of good events with neutrons which are lost due to vetoes by AD and V0 is estimated using control triggers. The corrections amount to $(26 \pm 4)\%$ for events with a signal either in ZNA or in ZNC, while it is $(43 \pm 5)\%$ for events with a signal in both ZNA and ZNC.

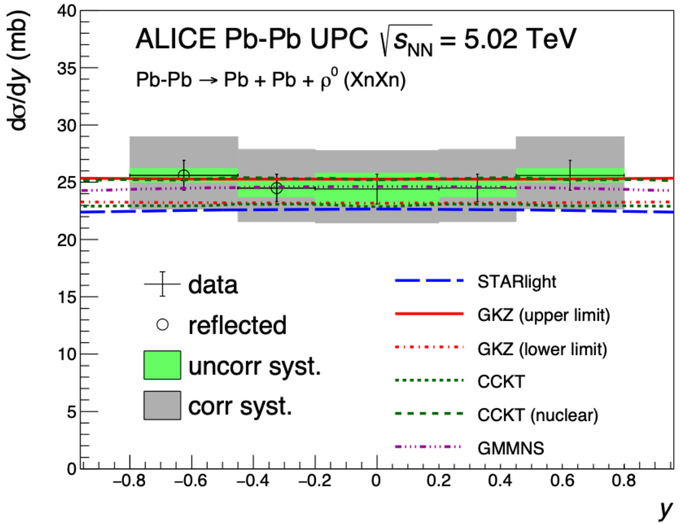
A note on CMS coherent exclusive ρ^0 measurements

- Recent CMS measurement of coherent ρ^0 at 5.36 TeV revealed interesting tensions
  - dsigma/dy (CMS, 0nXn) ~ **70 mb** while dsigma/dy (ALICE, 0nXn) ~ **90 mb**
  - dsigma/dy (CMS, XnXn) ~ **13 mb** while dsigma/dy (ALICE, XnXn) ~ **25 mb**
  - Differences very likely related to EMD hadrons + veto
    (no correction applied for CMS, while ALICE corrects for this using data-driven approach - viz previous slide)



ALICE, JHEP06 (2020) 35





Summary

- Corrections to exclusive LHC UPC measurements due to coincident EMD can be large
  - Depend on process kinematics and the experimental exclusivity definition
  - Resolve long-standing data–theory tensions in exclusive γγ→μμ and coherent J/ψ production
- Percent-level control of UPC photon fluxes at the LHC is achievable
  - Excellent agreement with γγ→μμ data once EMD-induced veto effects are accounted for
- Coincident EMD veto must be consistently treated in UPC phenomenology
  - To avoid large biases, e.g. in the coherent VM energy dependence analyses
  - Different veto definitions → different effective cross sections across experiments

Summary

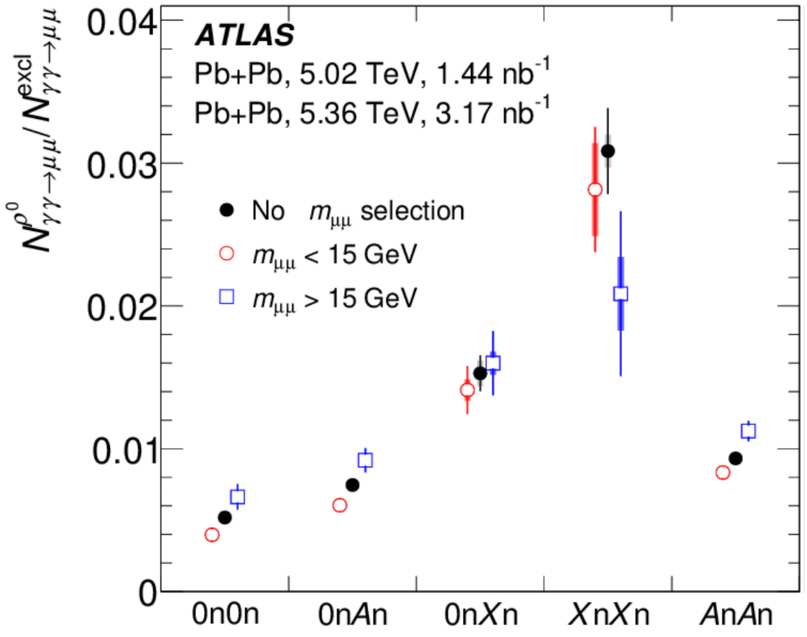
- **Controlling coincident processes (EMD, elastic pairs, …) opens the way to precision LHC UPC phenomenology**

Backup

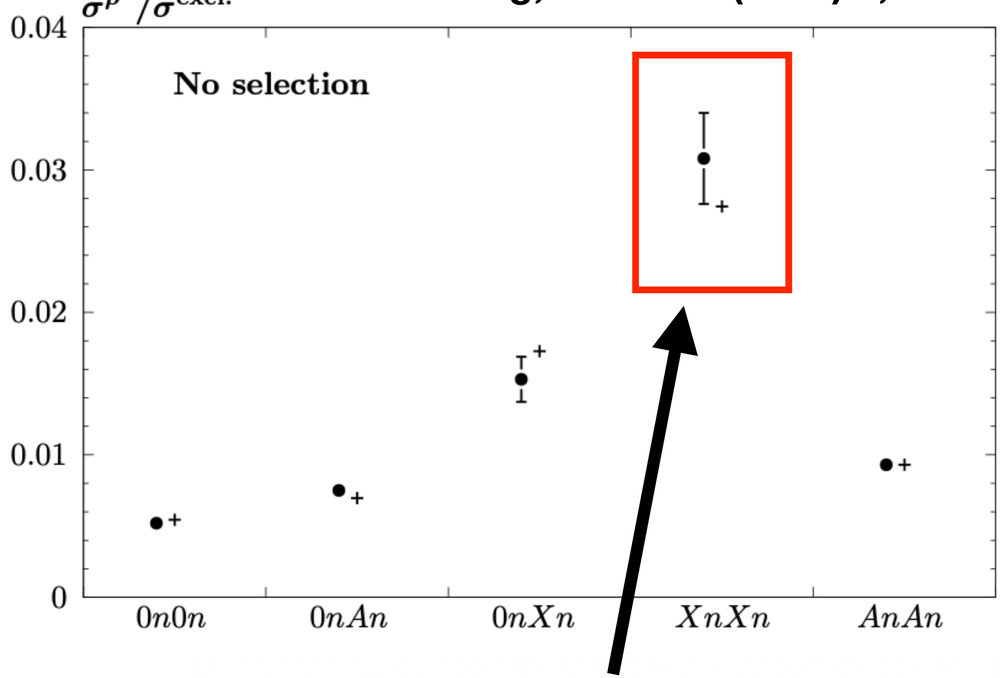
Motivation (II)

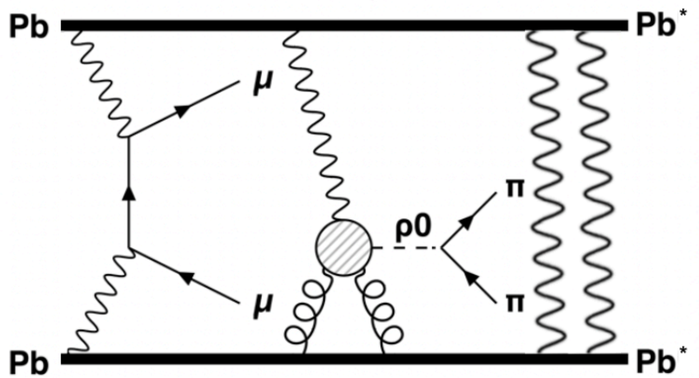
- ATLAS data on the coincident (γγ→μμ) + (ρ^0→pi+pi-) production [aka: **multi-UPC** process]

ATLAS, Phys.Lett.B 881 (2026) 140909



Harland-Lang, PRD 112 (2025) 5, 054049





UPC@LHC = enormous EM fields, multi-photon interactions

SuperChic5.7 implementation

```
.false.  ! [ionbreakup] : set to .true. if include ion breakup, false if inclusive
'AA'     ! [fAA] : if ionbreakup=.true. then specifies breakup type
1d0      ! [fracsigX] : multiply sig_(gamA) by this factor (1d0 - default)
.true.   ! [veto] : impose exclusivity veto in ion-ion case due to EMD
15.9579d0 ! [veto_ecent]
79.5456d0 ! [veto_eden]
0.4d0 ! [rshad]
.false.  ! [wrho] : generate concident rho production in AA collisions
3.86d0    ! [yrho] : maximum rho |y|
1.2d0      ! [accrho] : additional correction factor to account for rho->pipi acceptance, non-
resonant dipions and different beams
```