Hadronic interactions in Angantyr

Marius Utheim
in collaboration with Ilkka Helenius

Wuppertal, January 22nd, 2024

Outline

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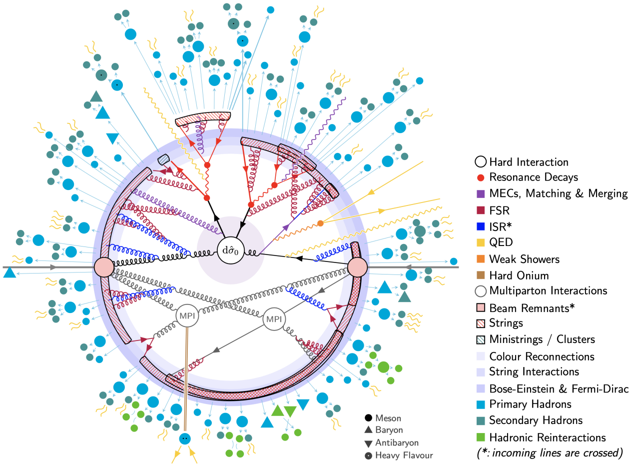
Pythia and Angantyr

PYTHIA is a general-purpose event generator.

- For information about PYTHIA itself, see Torbjörn's talk from earlier
- In this talk, I focus on ANGANTYR, the module for heavy ions.



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Hadron-proton interactions already exist in PYTHIA [arXiv:2108.03481]. In this talk, I will present this framework, then introduce the changes we have made to extend this to ANGANTYR. Finally we look at some results, comparing to HERA and LHC data.

Cosmic rays

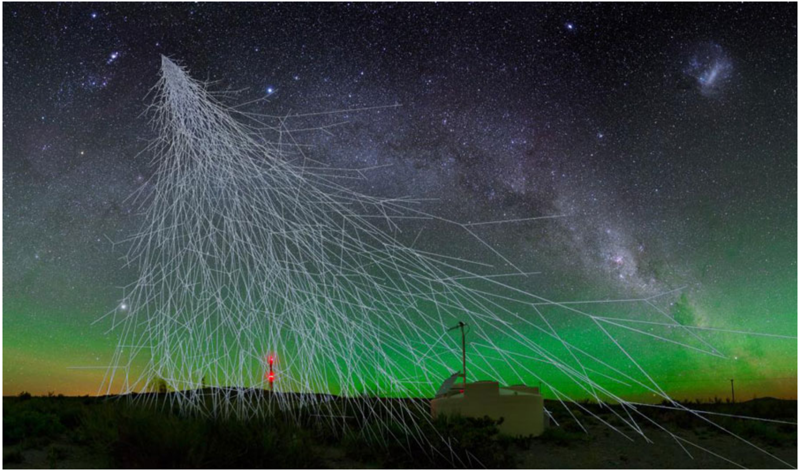
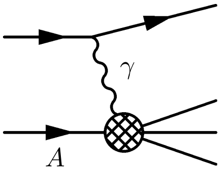
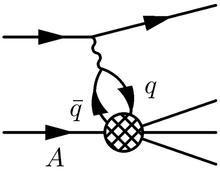


Photo-induced processes

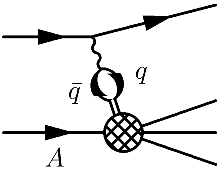
Direct



Anomalous



VMD



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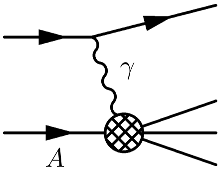

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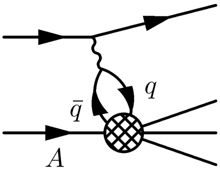

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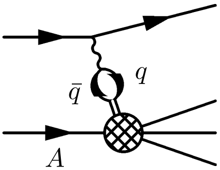

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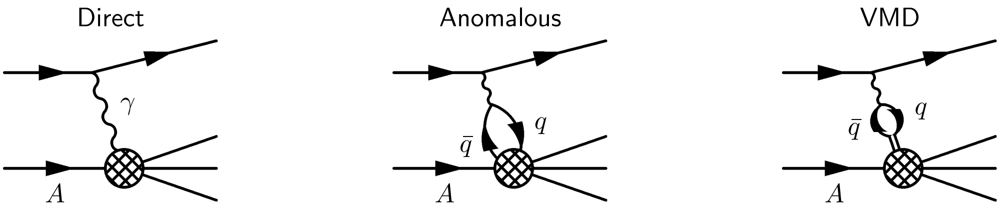

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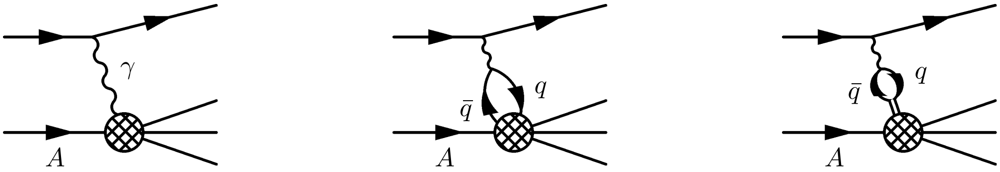
Direct | Anomalous | VMD



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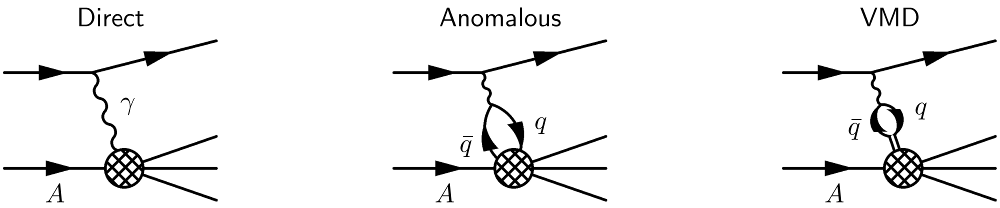

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- The anomalous part is more complicated. The q and $\bar{q}$ can interact with different nucleons in A.
- The VMD part can be described as a hA interaction, analogous to pA. This is the component with highest multiplicity, due to MPIs and multiple subcollisions.

Outline

Total and partial cross sections

Several models for total cross sections are available in Pythia. The most generic is the Donnachie-Landshoff model, which is available for most hadron–nucleon combinations:

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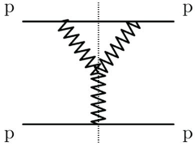

$$d\sigma = \frac{g_{3\mathbb{P}} \beta_{A\mathbb{P}} \beta_{B\mathbb{P}}^2}{16\pi} \frac{dM_X^2}{M_X^2} (e^{B_{XB} t} dt) \, F_{\mathrm{SD}}(M_X^2, s)$$

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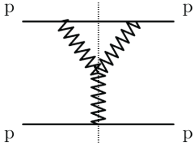

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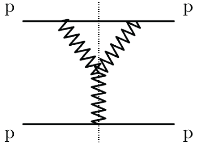

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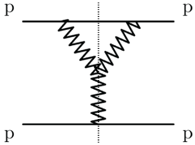

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- F_{SD} is a fudge factor (out of scope for this talk)

Parton distribution functions

PDFs determine the contents of a hadron. For protons, detailed PDFs based on global fits exist, the Pythia default being NNPDF2.3 QCD+QED LO (with $\alpha_S = 0.130$).

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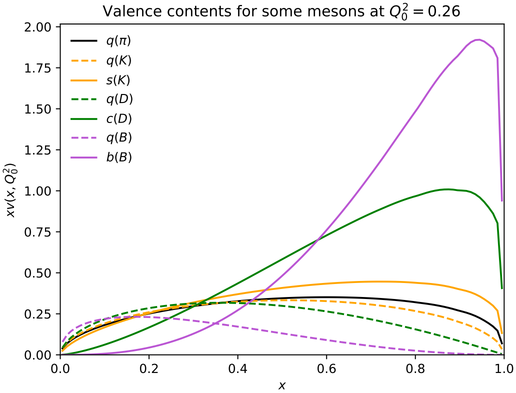
For other species, very little data exists, and we base our valence distributions on an ansatz by Glück, Reya et al. [arXiv:hep-ph/9806404]:

$$f(x, Q_0^2 = 0.26\ \mathrm{GeV}^2) = N x^a (1-x)^b (1 + A\sqrt{x} + Bx)$$

and evolve to higher scales using the QCDNUM program. The parameters are fixed by flavour- and momentum sum relations, and some heuristic guesses. In particular, heavier valence quarks should have larger x, as they must all have similar velocities in order for the hadron to stay intact.

Parton distribution functions



- $\langle x \rangle$ is higher for heavy valence content (solid lines), and correspondingly lower for light content (dashed lines).

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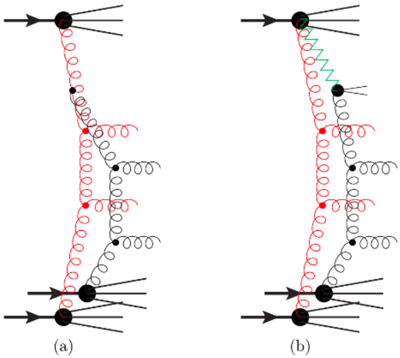

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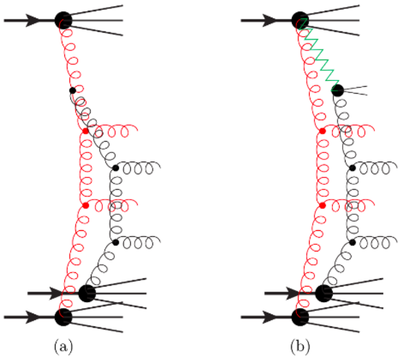

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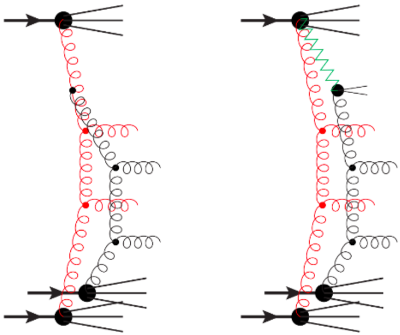

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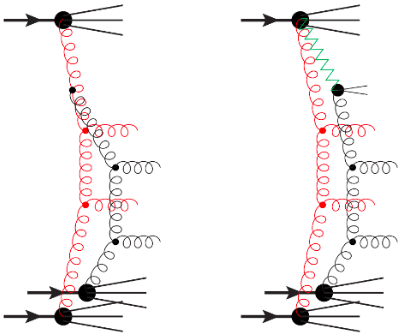

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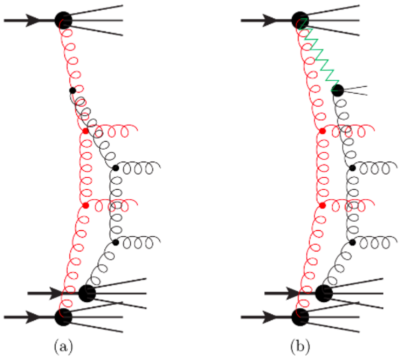
- Combine partons from all subevents, then do color reconnection, string interactions, string hadronization, etc.



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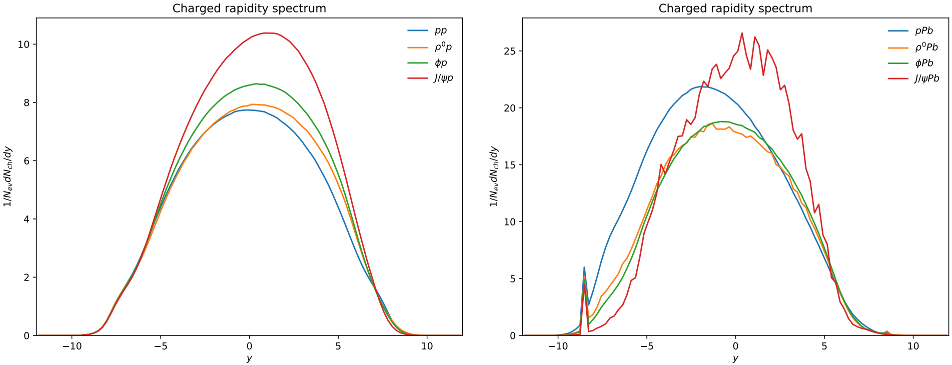
Applying this procedure to the asymmetric meson-nucleon case gives mediocre results. The fitting targets are insensitive to asymmetric fluctuations. Furthermore, the model gives unphysically large fluctuations for J/ψ, which is expected to have a small wavefunction. Clearly there is room for improvement.

Model test: Rapidity spectra at 5.02 TeV



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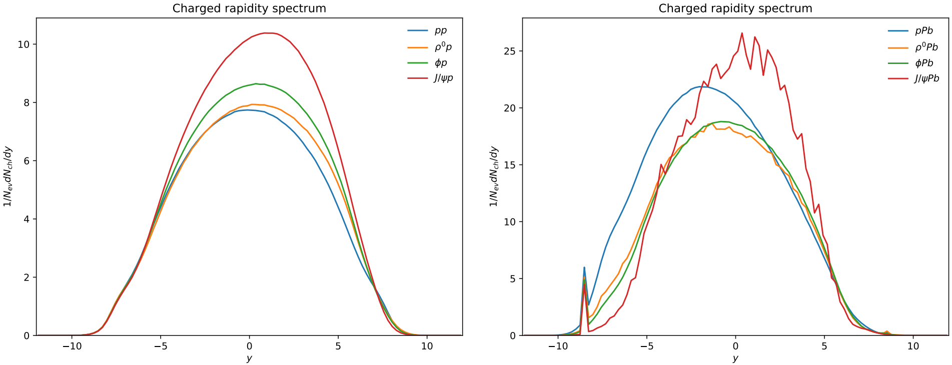

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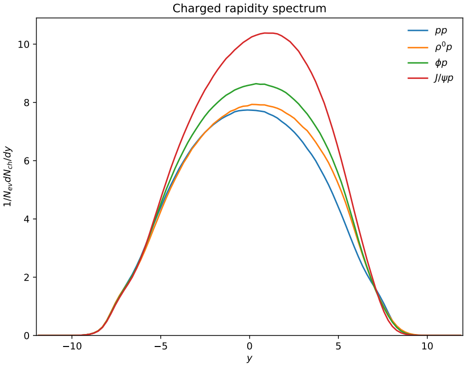

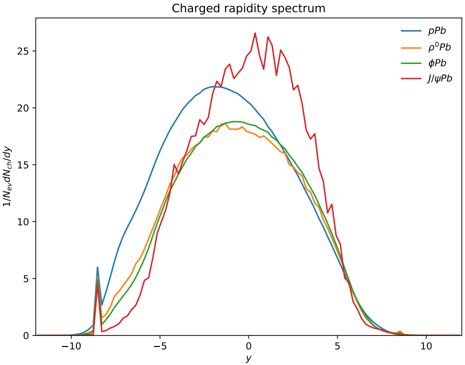

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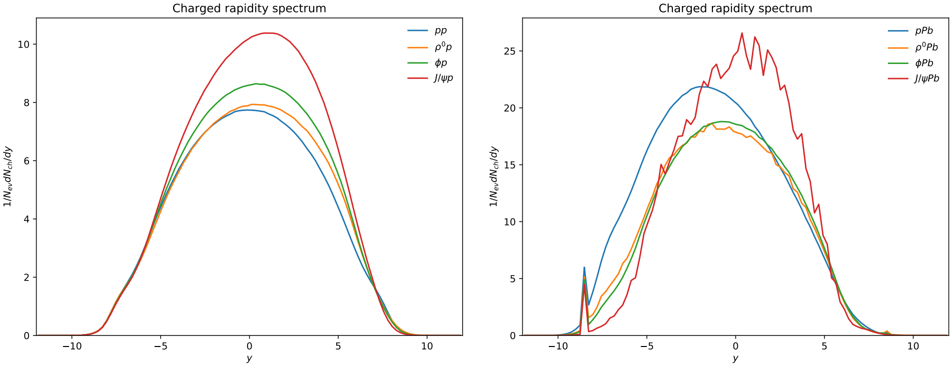

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- Due to fluctuations and impact parameter sampling, J/ψ gets some events with extremely high weight.

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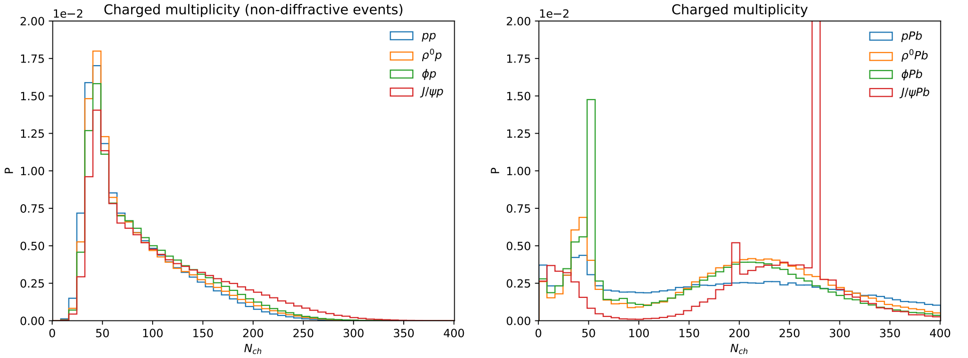

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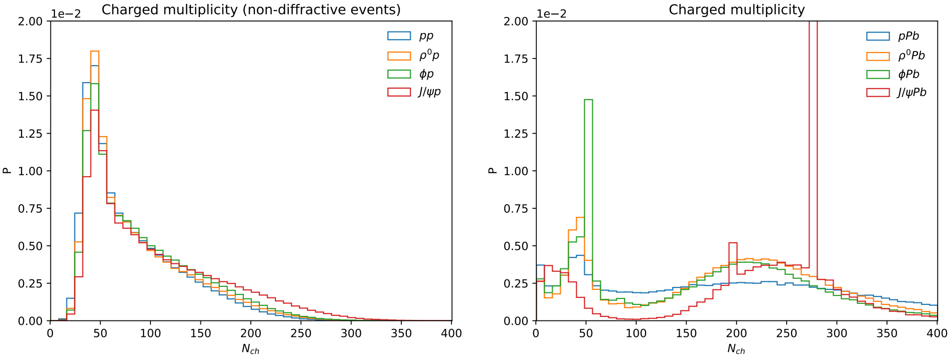

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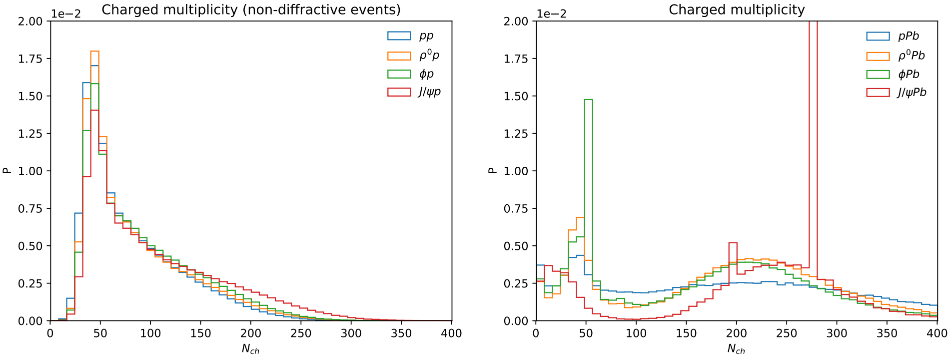

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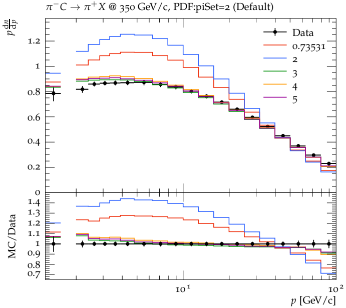
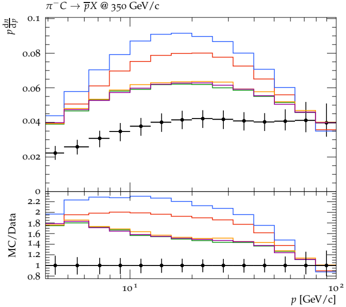
- Heavier mesons produce fewer subcollisions, but each subcollision produces more particles, leading to a non-trivial progression from ρ^0 to ϕ to J/ψ.

Outline

$\pi^- C$ at NA61/SHINE [arXiv:2209.10561v1]

In collaboration with Chloé Gaudu





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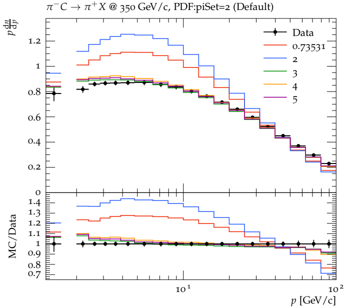

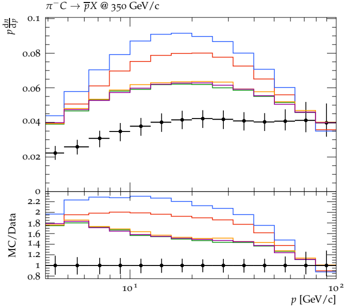

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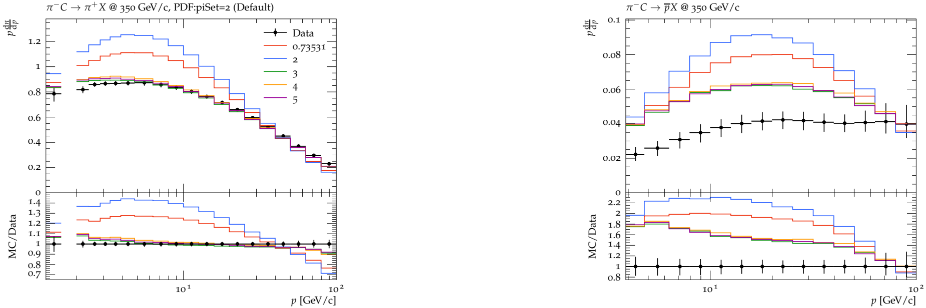

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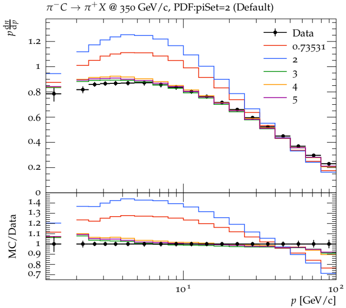

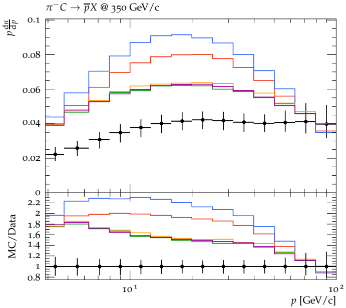

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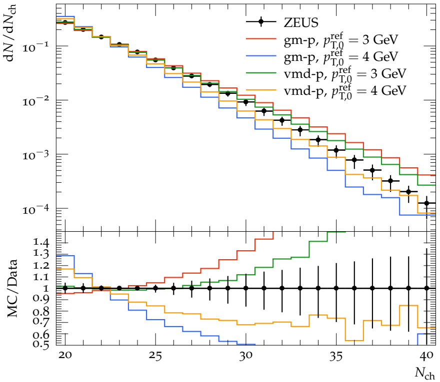
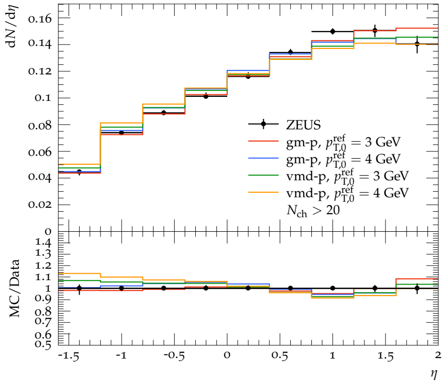
- Baryons are less well described.
- Low energy framework is not applied here.

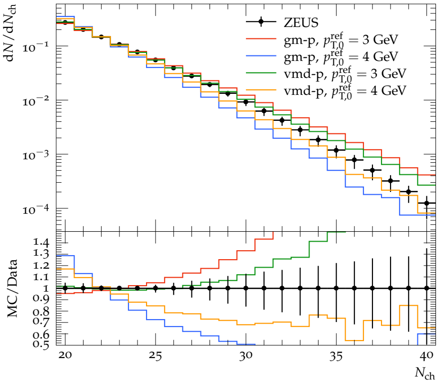
γp at HERA [arXiv:2106.12377]

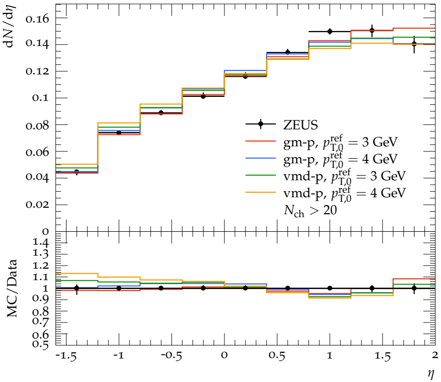




- The $p_{0,\perp}^{\mathrm{ref}}$ variation gives a sense of the model uncertainty.

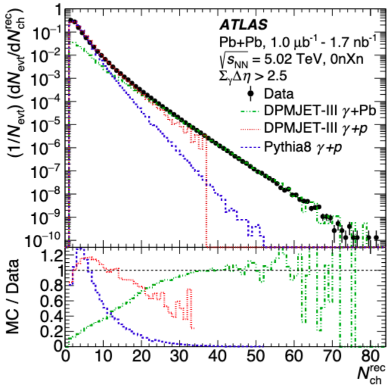
γp at HERA [arXiv:2106.12377]

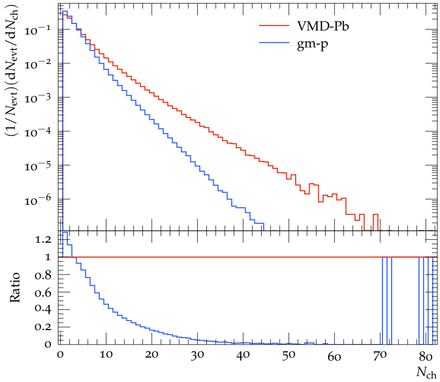




- The $p_{0,\perp}^{ref}$ variation gives a sense of the model uncertainty.
- The shift due to changing $p_{0,\perp}^{ref}$ is larger on average in the full photoproduction than in just the VMD component.

ATLAS γ + Pb multiplicities [arXiv:2101.10771]





- The ATLAS data is not corrected for the limited efficiency, estimated to ~ 80 %.

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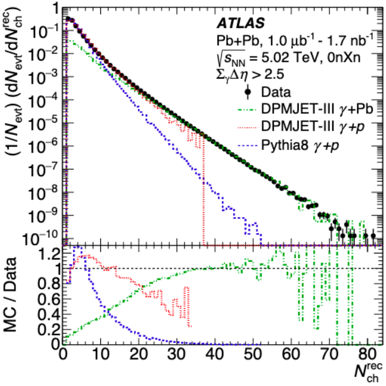

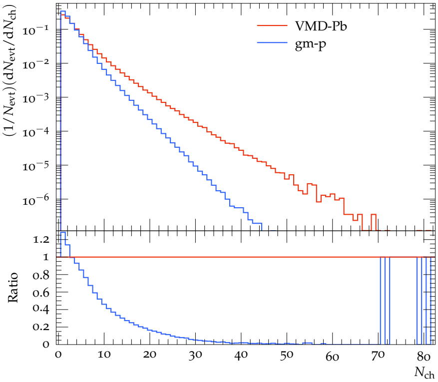

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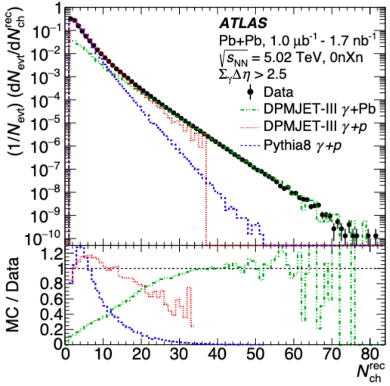
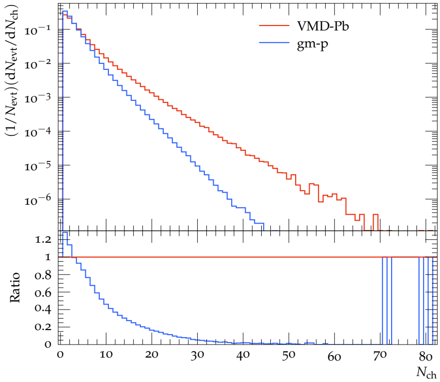
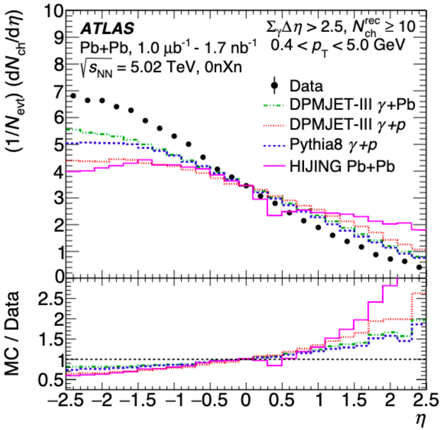
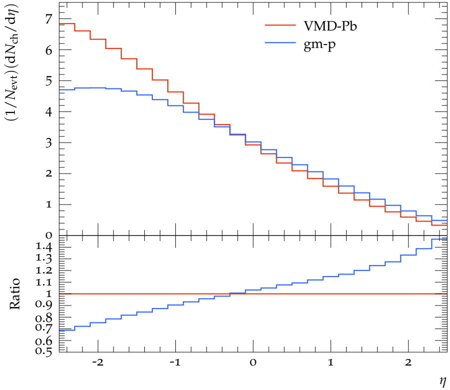




- The ATLAS data is not corrected for the limited efficiency, estimated to ~ 80 %.
- Qualitatively speaking, the shift from γp to γPb is consistent with data.
- In γp, the VMD component has less average multiplicity than in full photoproduction. This could be the other way around for γPb.

ATLAS eta spectrum [arXiv:2101.10771]





- Again, we cannot make a direct comparison, but the fit is still good when accounting for the limited efficiency in the multiplicity cut.

Outline

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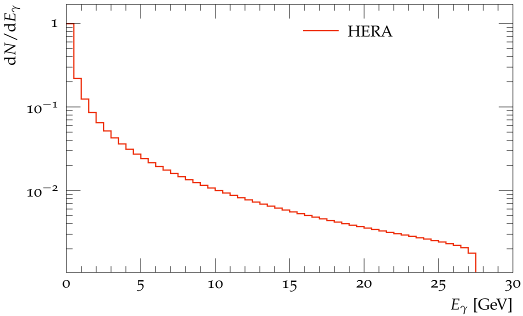
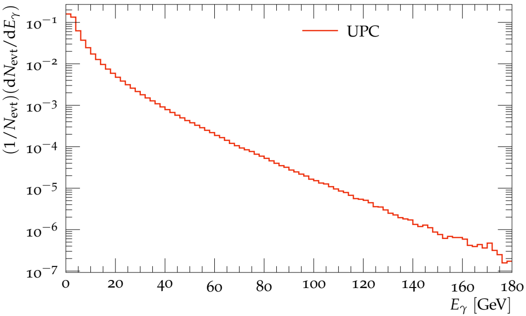
- The work also includes technical features, in particular energy and beam switching.
- Our model shows a good agreement with data from NA61/SHINE, HERA, and ATLAS UPCs.

Outline

Photon flux [arXiv:1901.05261]

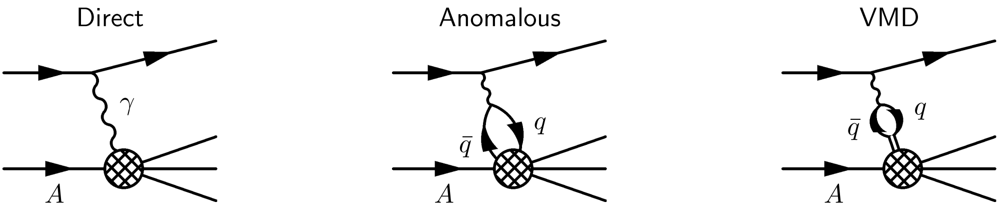




$$f_{\gamma/e}(x) = \frac{\alpha_{EM}}{2\pi}\frac{1+(1-x)^2}{x}\log\left[\frac{Q^2_{\max}(1-x)}{m_2^2x^2}\right]$$

$$f_{\gamma/A}(x) = \frac{\alpha_{EM}Z^2}{\pi x}\left[2\xi K_1(\xi)K_0(\xi) - \xi^2(K_1^2(\xi) - K_0^2(\xi))\right]$$

Photon wavefunction details [arXiv:hep-ph/9403393]



$$|\gamma\rangle = c_{\text{bare}}\,|\gamma_{\text{bare}}\rangle + \sum_q c_q\,|q\bar{q}\rangle + \sum_{V=\rho^0,\omega,\phi,J/\psi} c_V\,|V\rangle$$

$$c_V = \frac{4\pi\alpha_{EM}}{f_V^2}$$

V	$f_V^2/4\pi$
ρ^0	2.20
ω	23.6
ϕ	18.4
J/ψ	11.5

$p_{0,\perp}^{\mathrm{ref}}$ variations