ACADEMY
OF FINLAND

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

Pythia, Angantyr, and the path towards a general-purpose electron–ion MC generator

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Pythia overview [`arXiv:2203.11601`]

Pythia is a general-purpose event generator.

- GPEGs tell us what our theoretical models predict at the end of the day.
- Can make future predictions, which may guide e.g. detector design.
- Includes Angantyr module for heavy ions.

(figure by S. Chakraborty and P. Skands)

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Anomalous

q

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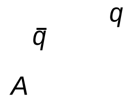

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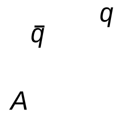

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- The anomalous part is more complicated. The q and $\bar{q}$ can interact with different nucleons in A.
- The VMD part can be described as a hA interaction, analogous to pA. This is the component with highest multiplicity, due to MPIs and multiple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

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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.

Outline

- Background
- Modelling
- Results
- Summary and outlook

From pp to hp

Going from pp to hp requires two changes:

1. Modified cross sections.
2. Parton distribution functions (PDFs) for the new hadrons.

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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$$d \quad = \frac{g_{3P} \quad _{AP} \quad ^{2}_{BP}}{16} \frac{dM_X^2}{M_X^2} (e^{B_{XB} t} dt) \, F_{SD}(M_X^2 ; s)$$

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- $B_{XB} = 2 b_B + 2 {}^{0}_{P} \log(s{=}M_X^2)$ with $b = 1{:}4$ for mesons and 2.3 for baryons

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

Parton distribution functions

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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.:

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

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).

Hadron–proton collisions in Pythia [arXiv:2108.03481]

The following plots are for meson–proton nondiffractive events at 6 TeV

- Hadrons with heavier valence content generally lead to harder interactions and more activity
- Effect is particularly pronounced for $J=$ and , which have no light valence.

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Once we have hp and Angantyr, no further physics modelling is needed.

Hadron-ion collisions in Angantyr

- Heavier quark content implies fewer subcollisions with more activity per collision.
- In hA, there is one or zero absorptive interactions, giving a bimodal spectrum.
- Note that peak is not between ^{0} and J= .

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p at HERA [arXiv:2106.12377]

- $p^{\mathrm{ref}}_{?;0}$ is the regularization scale for MPI evolution. Larger value means fewer MPIs. The variation gives a sense of the model uncertainty.
- The shift due to changing $p^{\mathrm{ref}}_{?;0}$ is larger on average in the full photoproduction than in just the VMD component.

ATLAS + Pb multiplicities [arXiv:2101.10771]

- Our analysis is not exactly the same as in the experimental paper.
- Qualitatively speaking, the shift from p to Pb is consistent with data.
- In p, the VMD component has less average multiplicity than in full photoproduction. This could be the other way around for Pb.

ATLAS eta spectrum [arXiv:2101.10771]

- The ratios between p and Pb is similar for our simulation and in data.
- VMD components have a slight bias in the photon-going direction.

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Code expected to be released in Pythia 8.310.

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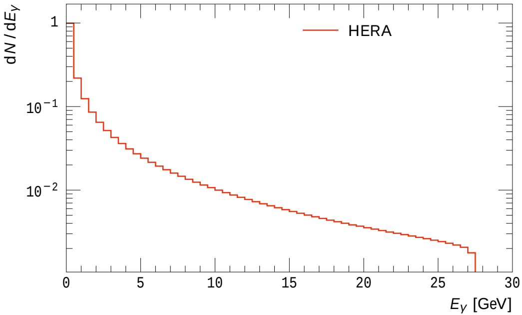
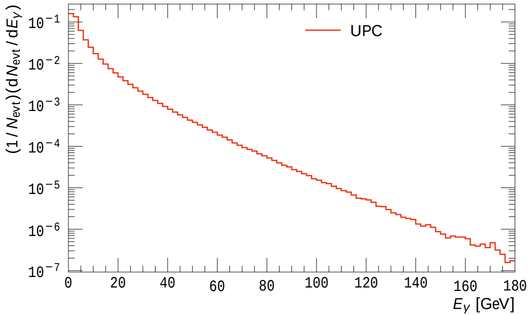
Photon flux [`arXiv:1901.05261`]





$$f_{=e}(x) = \frac{{}_{EM}}{2}\,\frac{1+(1 \quad x)^2}{x}\,\log\,\frac{Q^2_{\mathrm{max}}(1 \quad x)}{m_2^2 x^2}$$

$$f_{=A}(x) = \frac{{}_{EM}Z^2}{x}\;\; 2\;\; K_1(\;)K_0(\;) \qquad {}^2(K_1^2(\;) \quad K_0^2(\;))$$

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

Direct | Anomalous | VMD

A

$\bar{q}$ q

A

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$$j\ \ i = c_{\mathrm{bare}}\, j\ \ {}_{\mathrm{bare}}\, i + \underset{q}{X} c_q\, jq\bar{q}i + \underset{V=\ {}^0;!;\ ;J=}{X} c_V\, jVi$$

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

V	f_V^2=4
^{0}	2.20
!	23.6
	18.4
J=	11.5

$p^{\mathrm{Ref}}_{?;0}$ variations