

Recent PYTHIA 8 developments: Hard diffraction, Colour reconnection and $\gamma\gamma$ collisions

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1 Introduction

An overview of recent developments in PYTHIA 8 is given. First the new hard diffraction model, which is implemented as a part of the multiparton interactions (MPI) framework, is discussed. Then the new colour reconnection model, which includes beyond leading colour effects that can become important when MPI are present, is briefly reviewed. As a last topic an introduction is given to our implementation of photon-photon collisions. In particular photon PDFs, required modifications for the initial state radiation algorithm and beam remnant handling with photon beams is discussed.

2 Hard Diffraction

A model for soft diffraction has long been available in PYTHIA 8 and earlier versions [1, 2]. This model allows for $2 \rightarrow 2$ QCD processes at all p_\perp scales, but is primarily intended for lower values of p_\perp . For truly hard diffractive processes, the new model for hard diffraction [3] was developed, not only for high- p_\perp jets, but also allowing for W^\pm, Z^0, H etc.

The model is based on the assumption that the proton PDF can be split into a diffractive and a nondiffractive part,

$$f_{i/p}(x, Q^2) = f_{i/p}^{\text{ND}}(x, Q^2) + f_{i/p}^{\text{D}}(x, Q^2) \quad \text{with} \quad (1)$$

$$f_{i/p}^{\text{D}}(x, Q^2) = \int_x^1 \frac{dx_{\mathbb{P}}}{x_{\mathbb{P}}} f_{\mathbb{P}/p}(x_{\mathbb{P}}) f_{i/\mathbb{P}}\left(\frac{x}{x_{\mathbb{P}}}, Q^2\right), \quad (2)$$

with x and Q^2 the momentum fraction and virtuality of parton i , $x_{\mathbb{P}}$ and t the momentum fraction and virtuality of the Pomeron, and where the Pomeron flux $f_{\mathbb{P}/p}(x_{\mathbb{P}}) = \int_{t_{\min}}^{t_{\max}} dt f_{\mathbb{P}/p}(x_{\mathbb{P}}, t)$, as t for

the most part is not needed. The tentative probability for side A to be diffractive is then given by the ratio of diffractive to inclusive PDFs,

$$\mathcal{P}_A^D = \frac{f_{i/B}^D(x_B, Q^2)}{f_{i/B}(x_B, Q^2)} \quad \text{for } AB \rightarrow XB \quad (3)$$

with a similar equation for side B . The model further implements a dynamical rapidity gap survival, cf. Fig. 1. On an event-by-event basis the possibility for additional MPIs in the pp system is evaluated, and if no such MPIs are found, then the event is diffractive. Only then is the $\mathbb{P}p$ system set up and a full evolution is performed in this subsystem, along with the hadronization of the colour strings in the event.

The dynamical gap survival introduces an additional suppression of the diffractive events, such that the total probability for hard diffraction drops from $\sim 10\%$ to $\sim 1\%$, exact numbers depending on parametrization of \mathbb{P} flux and PDF as well as the free parameters of the MPI framework in PYTHIA 8. The new model is compatible with suppression factors measured at the LHC.

3 Colour Reconnection

The colour reconnection (CR) refers to a phenomenon where the colour strings formed during the hard process and parton shower generation can reconnect and form a different configuration prior to hadronization. A new model for CR in PYTHIA 8 was introduced in Ref. [4]. The model is based on three main principles: use of SU(3) colour rules to determine if the strings are colour compatible, a simplistic space-time picture to check whether the two colour strings can be causally connected, and minimization of string length measure λ to find which colour configurations are preferred. In addition to simple colour strings between a quark and an antiquark, the new model includes also junction structures which can connect three (anti)quarks together. As the junction structures are related to baryons, an enhanced baryon production can be expected.

Natural observables to study the CR effects are baryon-to-meson ratios. The parameters related to the new CR model was fixed using the CMS data for the rapidity dependence of the Λ/K_S^0 ratio, while keeping the rate in e^+e^- collisions unaffected. Without further tuning also the p_\perp dependence of this ratio can be described more accurately than with the old PYTHIA model, although there still exists some discrepancy for $p_\perp > 5$ GeV/c.

A novel way to constrain different CR models is to study the multiplicity dependence of the baryon-to-meson ratios [5]. The old PYTHIA model is more or less flat with multiplicity but – due to the junction structures – the new model predicts an enhancement for baryon production with higher multiplicities. A very interesting observable is the p_\perp dependence of Λ/K ratio in different multiplicities, shown in Fig. 2. In the lowest multiplicity bin the ratio is flat above $p_\perp = 2$ GeV/c, but with higher multiplicities there is a growing enhancement at intermediate p_\perp , flattening again at $p_\perp \gtrsim 8$ GeV/c. Also, the peak of the ratio shifts towards higher values of p_\perp with higher multiplicities – a behaviour that is typically connected to collective flow in heavy-ion collisions. To sort out the physical origin of these kind of observations, further studies are of great interest.

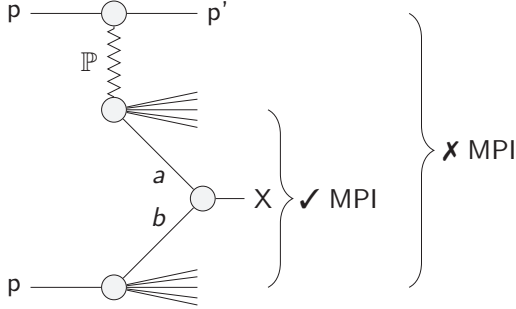


Figure 1: The dynamical gap survival implemented in PYTHIA 8. The model does not allow for MPIs in the pp system, but allows for additional MPIs in the $\mathbb{P}p$ system.

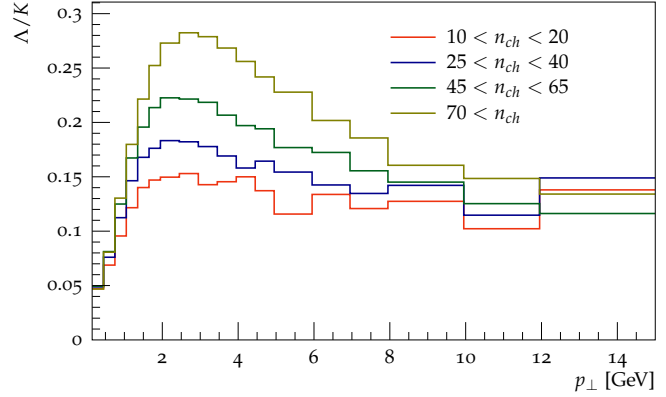


Figure 2: Transverse momentum dependence of the Λ/K ratio for different multiplicities in p+p collisions.

4 Photon-photon Collisions

The $\gamma\gamma$ collisions give access to several interesting hard processes and provide an additional test of QCD factorization. A further motivation to study these collisions is provided by the future e^+e^- experiments, where the $\gamma\gamma$ interactions will generate background processes that influence to the physics potential of future measurements.

An option to simulate $\gamma\gamma$ collisions with PYTHIA 8 have been added with the 8.215 release. The new implementation is not just a repetition of the framework included in PYTHIA 6 [1] but a new – more robust – machinery has been under development [6]. Currently hard processes with parton showers and hadronization of resolved $\gamma\gamma$ interactions can be generated for real photons, but MPIs and soft processes are not included. Here the key differences to the hadronic collisions are briefly described.

4.1 Evolution equations and parton showers

The partonic structure of resolved photons is described by the PDFs in a similar manner as for hadrons. The scale evolution of the photon PDFs is given by

$$\frac{\partial f_i^\gamma(x, Q^2)}{\partial \log(Q^2)} = \frac{\alpha_{\text{EM}}}{2\pi} e_i^2 P_{i\gamma}(x) + \frac{\alpha_s(Q^2)}{2\pi} \sum_j \int_x^1 \frac{dz}{z} P_{ij}(z) f_j(x/z, Q^2), \quad (4)$$

where the first term on the right hand side corresponds to the $\gamma \rightarrow q\bar{q}$ splitting of the beam photon and the second to the usual partonic splittings. Due to the first term, the scale evolution increases the quark PDFs over the whole x region and thus increases the large- x quark PDFs in photons compared to quark PDFs in hadrons.

As the parton shower is generated using the DGLAP equations, the PYTHIA algorithm [7] must be extended accordingly by including a possibility to find the original beam photon during

the generation of the initial state radiation (ISR). If the beam photon is found, no further ISR evolution is allowed for the beam.

4.2 Beam remnants

The beam remnants describe the leftovers of the beam particle after the interaction, for details of PYTHIA 8 implementation see Ref. [8]. Unlike in the case of protons, the valence content of photons is not known beforehand. To fix for the valence content the PDFs are decomposed into sea and valence contributions. These are then used to decide whether the parton taken from the beam was a valence parton or not. If it was a valence quark, the remnant is simply the corresponding (anti)quark and if not, the valence content is sampled according to the PDFs. After the valence content is fixed, a minimal number of partons are added to make sure that the flavour and colour are preserved in an event. If the ISR algorithm ends up at the beam photon, there is no need to add any remnant partons for the given beam.

As the quark PDFs for photons have a large contribution also from large values of x , it may happen that there is no room to add the beam remnants with non-zero masses. Also the parton shower can lead to a situation where the remnants can not be constructed due to the lack of invariant mass available for the remnants. These cases are rejected during the event generation to make sure that only events with appropriate remnants are generated.

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