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FINAL REPORT ON THE START PROGRAMME

Validation of Pythia8 for prompt photon and π^0 production

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Abstract

In this paper the signal-to-background ratios for direct photon main production processes were studied at the energies close to the energies from 19.4 GeV to 63 GeV using the Monte-Carlo generator Pythia8. We compare the results of our simulation for the direct photon and π^0 distributions in different intervals of p_T и x_F with the experimental data. We also consider the ratio of experimental cross-sections to cross-sections obtained from simulation.

1 Introduction

The direct photon production in proton-proton collisions, both inclusive and heavy-meson-associated, is an important source of information on gluon distribution function inside the proton. Through the studies of transverse single-spin and double longitudinal asymmetries in polarized-beam collisions one can extract the information on the spin gluon content [1–4]. Since the study of direct photon production is one of the important tasks of the physical program at Spin Physics Detector (SPD) [5] at NICA Collider [6] one faces a problem to recognize the direct photons from the background.

2 Direct photon production

The direct photon production at the energies of ~19-60 GeV is dominated by Compton scattering process $g+q \rightarrow \gamma+q$. Another main process is quark-antiquark annihilation $q+\bar{q} \rightarrow \gamma+g$, where $q=u,s,d$. At first, we performed Pythia8[7] simulation for the experiments at the close to NICA energies of $\sqrt{s}=20$ GeV and $\sqrt{s}=27$ GeV to define a Pythia8 configuration set providing the most convenient description of experimental data. The list of experiments [8–12] considered in the work is presented in Table 1.

Name	$\sqrt{s}$
E704	19.4 GeV
WA70	22.96 GeV
UA6	24.3 GeV
R806	63.0 GeV
R110	63.0 GeV

Tab. 1. List of experiments

As the existing experimental data are presented in the form of invariant cross section distributions, we needed to derive a formula for the normalization of the data obtained from the Pythia.

When p is used as kinematic variable, the triple differential cross section can be written as

$$\sigma_{inv}=E\frac{d^3\sigma}{dp^3}. \tag{1}$$

It is called the invariant differential cross section and also can be written as

$$\sigma_{inv}=\frac{d^3\sigma}{dp_x dp_y dp_z/E}=\frac{d^3\sigma}{dp_x dp_y dy}, \tag{2}$$

and in polar coordinates of p_x, p_y plane this can be transformed to

$$\sigma_{inv}=\frac{d^3\sigma}{p_T dp_T dy\, d\phi}=\frac{d^2\sigma}{2\pi p_T dp_T dy}, \tag{3}$$

if system is azimuthally isotropic.

Finally, we have moved from y to x_F:

$$\begin{gathered} y=\frac{1}{2}\ln\frac{E+p_z}{E-p_z},\ x_F=\frac{2p_z}{\sqrt{S}} \\ dy=\frac{dy}{dx_F}dx_F=\frac{\sqrt{S}}{2}\frac{dy}{dp_z}dx_F \\ \frac{dy}{dp_z}=\frac{1}{E},\ dy=\frac{\sqrt{S}}{2E}dx_F \end{gathered} \tag{4}$$

As a result, we got a formula for invariant cross section:

$$\sigma_{inv}=\frac{E\,d^2\sigma}{\pi p_T\sqrt{S}\,d\,x_F\,d\,p_T}, \tag{5}$$

and its version for averages in p_T and x_F ranges to be calculated with Pythia8:

$$\sigma_{inv}=\frac{\sigma_{total}}{N_{events}}\frac{1}{\pi\sqrt{S}\Delta x_F \Delta p_T}\sum_{i=1}^{N_0}\frac{E_i}{p_{T,i}}, \tag{6}$$

where σ_{total} — full cross-section of the process, N_{events} — number of generated events, $\sqrt{S}$ — beam energy in the CMS, Δx_F — the range of values of x_F in which the cross section is averaged, Δp_T — the range of values of p_T in which the cross section is averaged, N_0 — the number of particles trapped in the bin, $\sum_{i=1}^{N_0}\frac{e_i}{p_{T,i}}$ — the sum of the ratio of energy to transverse momentum for all photons in a bin.
If the experiment specifies the interval by y, normalizing formula is:

$$\sigma_{inv}=\frac{\sigma_{total}}{N_{events}}\frac{1}{2\pi\Delta y \Delta p_T}\sum_{i=1}^{N_0}\frac{1}{p_{T,i}}, \tag{7}$$

To simulate prompt photon production using Pythia were switched on two correspondent process flags: "PromptPhoton:qg2qgamma = on" and "PromptPhoton:qqbar2ggamma = on". Four Pythia configurations were tested: default, with disabled primordial kT, with disabled primordial kT, ISR and FSR, recommended (from SPD wiki). Turning off primordial kT disables Gaussian modeling of initial partonic transverse momentum. Turning off SR and FSR also disables initial and final state radiation.

Direct photon distributions from Pythia and different experiments with $\sqrt{s}$ from 19.4 GeV to 63.0 GeV were compared. x_F spectra were also constructed for the WA70. The statistical and systematic errors are added in quadrature.

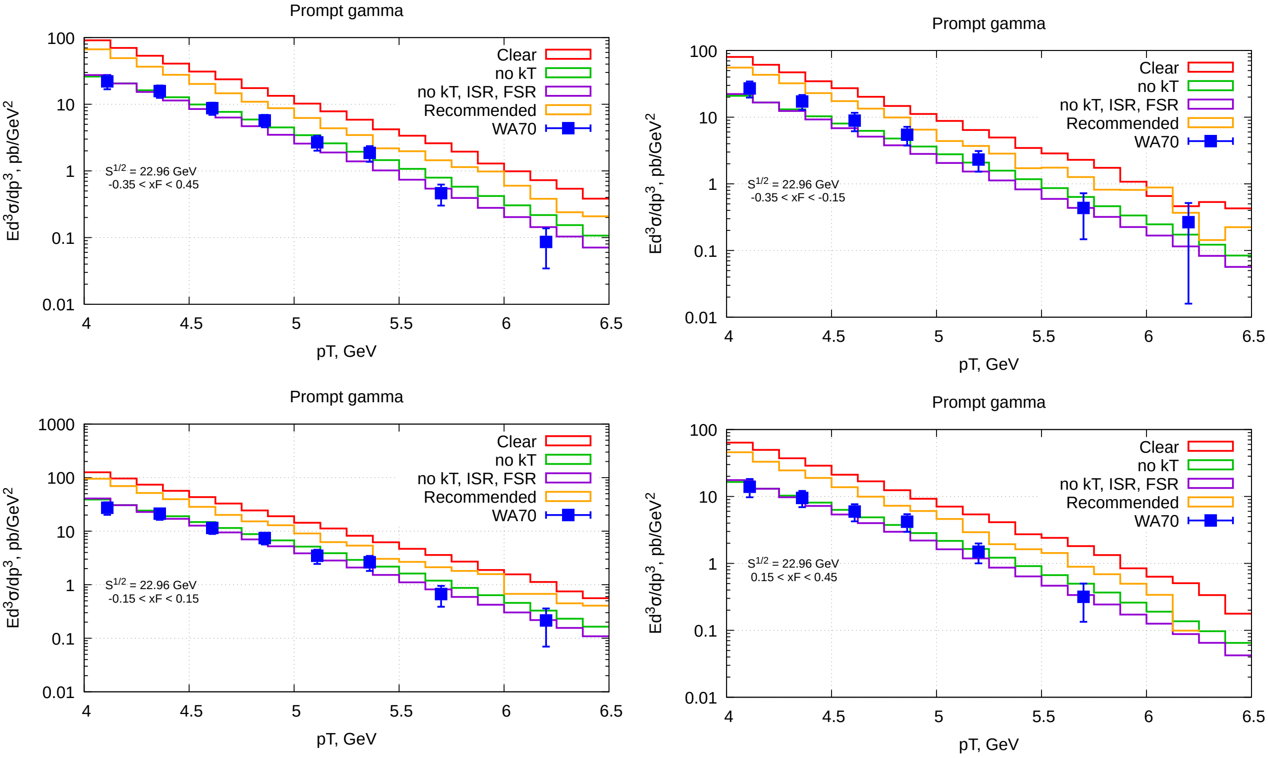

Fig. 1: Distribution of photons by p_T in different x_F intervals

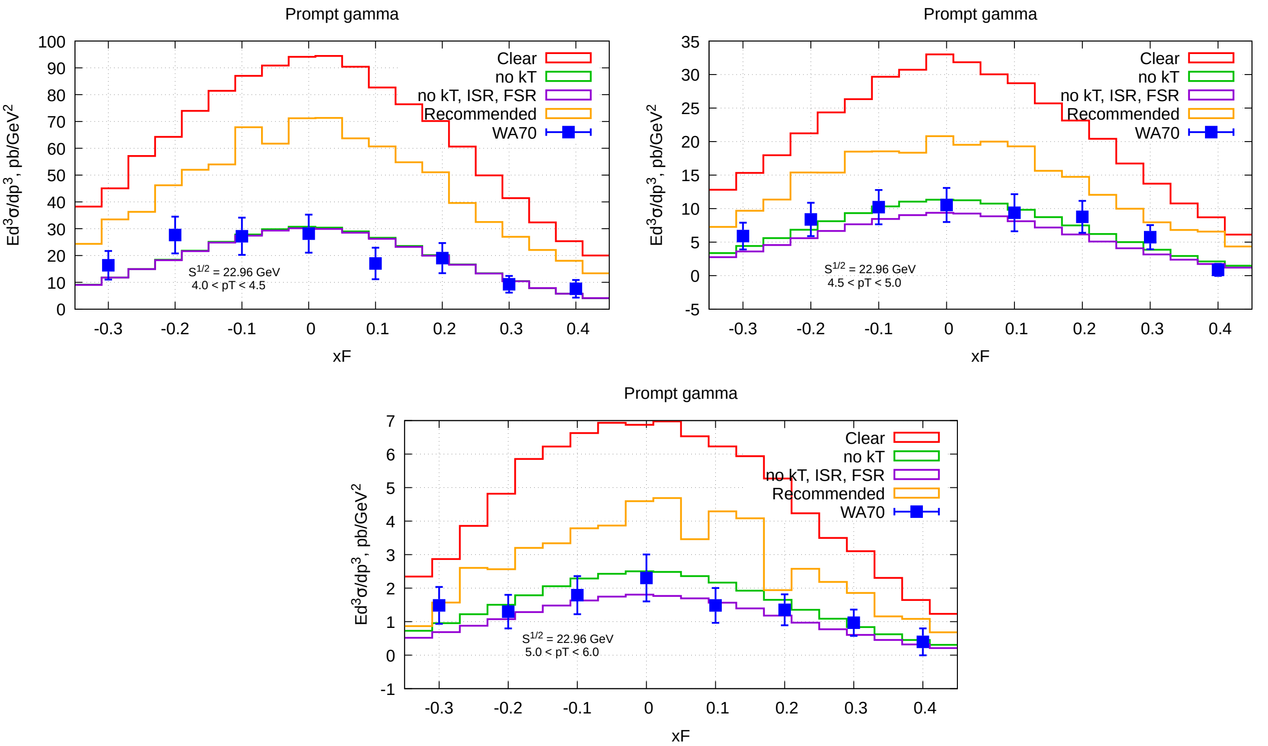

Fig. 2: Distribution of photons by x_F in different p_T intervals

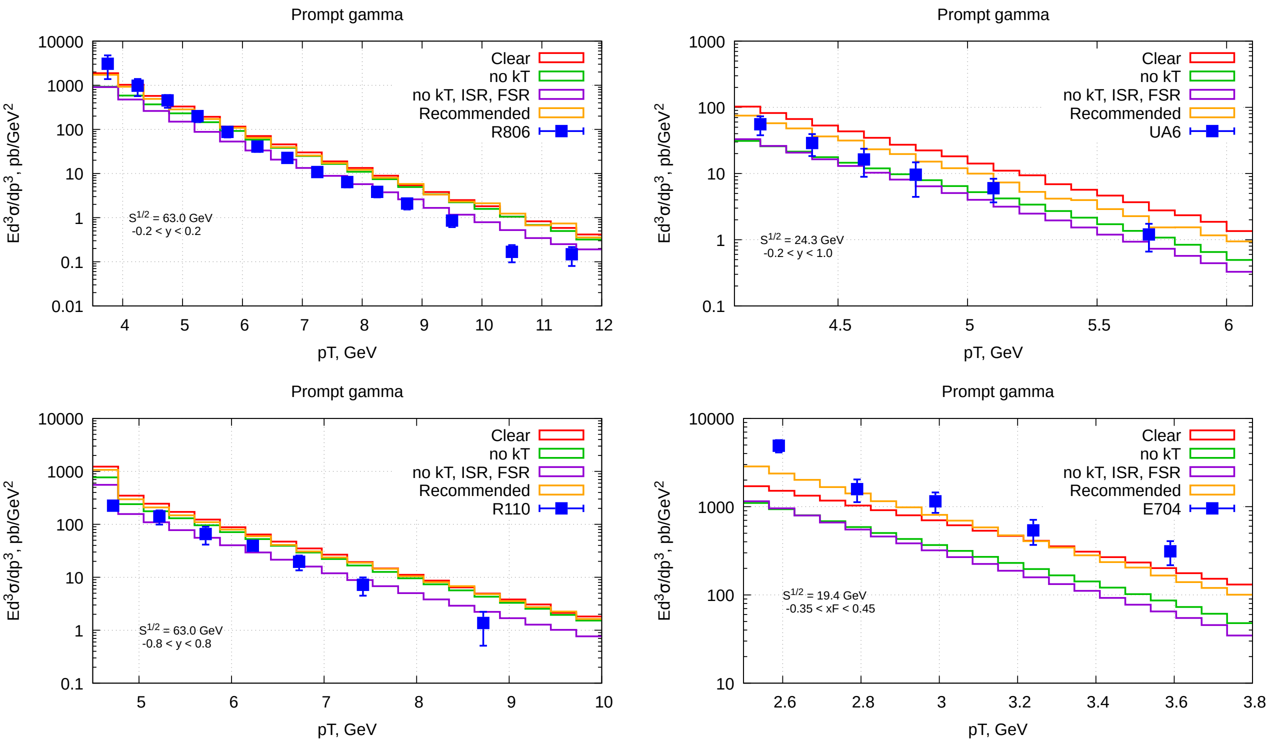

Fig. 3: Distribution of photons by p_T in experiments R806 (up left), UA6 (up right), R110 (down left), E704 (down right)

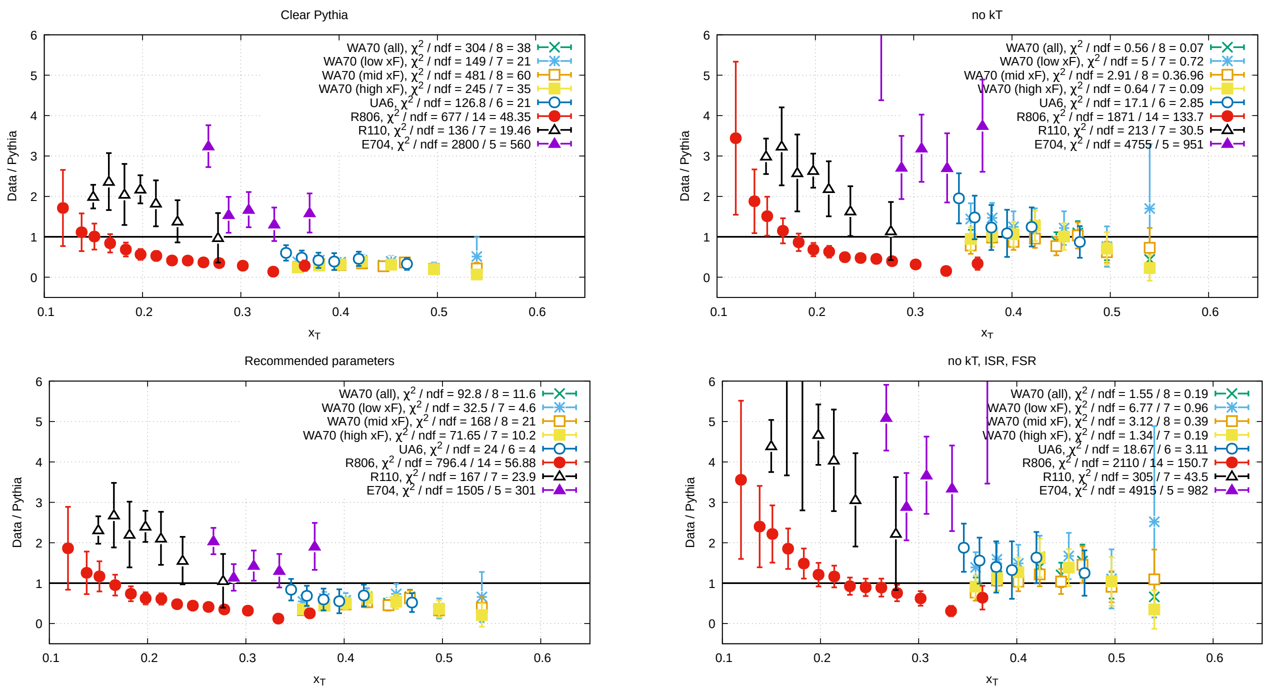

Fig. 4: Graphs of the ratio of experimental data to data from the Pythia for different experiments and Pythia configurations

As a generalization, graphs of the ratio of experimental data to data from the Pythia for different experiments and Pythia configurations are presented in Fig. 4.

3 Pion production

Since the decay of neutral pions into two photons is the main source of the background, we also modeled this process and compared it with the experiment [9]. Pions with primordial kT need way much more time to generate good statistic, then photons, that is the reason why high momentum area is so empty.

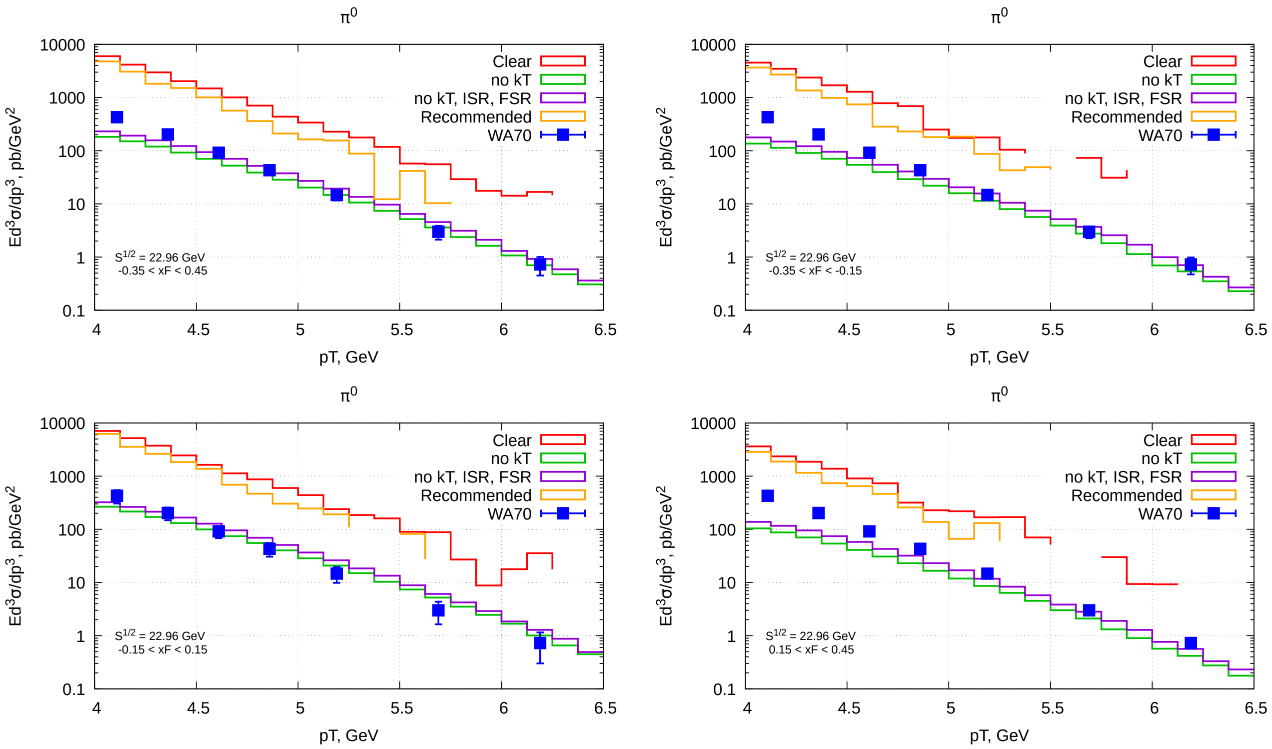

Fig. 5: Distribution of π^0 by p_T

As a next step, we compared the ratio of the cross section for photons to the cross section for pions at an energy of $\sqrt{s}=22.96$ GeV to the parametrization describing experimental data from WA70 [9]. The obtained results are presented in Fig. 6.

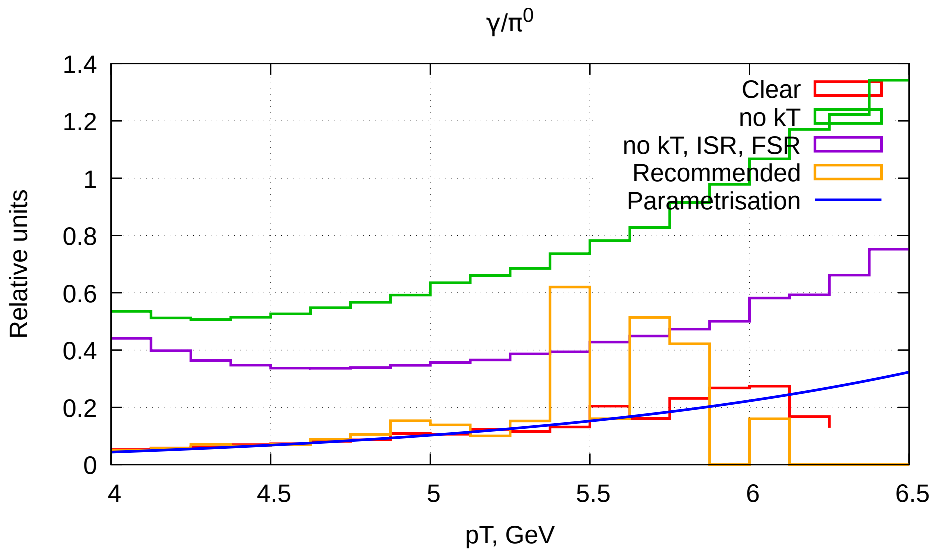

Fig. 6: Graph of the ratio of the invariant section for photons to the invariant cross section for pions

This graph clearly shows that starting from pT=5.4 GeV, in the case of the recommended parameters, modeling should be carried out on more statistics.

4 Conclusions

We studied direct photon production: signal processes and the main source of background photons. We tested four Pythia configurations: by default; with disabled primordial kT; with disabled primordial kT, ISR and FSR; recommended from SPD wiki. We simulated the photon spectra which are in a satisfactory agreement with existing experimental data with the set of c.m. energies close to NICA ones. For these experiments, we plotted a ratio of experimental data to generated data, similar to the graph from the SPD CDR. We simulated the π0 spectra which are in a satisfactory agreement with existing experimental data, but for higher values of pT we need more statistics. We also obtained photon-to-π^0. We are going to continue working on this topic as part of the SPD NICA collaboration. Next step is to check whether disabling primordial kT affects the shape of the spectra for different variables.

5 Acknowledges

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6 References

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