«SIMULATION OF DIRECT PHOTON PRODUCTION PROCESS»

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Previous experiments

First **pp -> γ + X** experiments were done at **CERN**:

at **ISR** (pp - collider, E_{cm} = 31, 45, 53 GeV):

- R412 experiment (Darriulat et. al., 1976);
- R107 (Amaldi et. al., 1978); ….and many others.

Also started at **Fermilab** and **BNL**:

- E557 (Baltrusaitis et. al. 1979, pBe, E_{cm} = 19.4, 23.7 GeV)
- E629 (McLaughlin et. al. 1983, pC, E_{cm} = 19.4 GeV)

... and then continued in many other experiments at higher energies

Dpp has also been studied in pion-proton, pion-nucleus, proton-nucleus and in heavy-ion collisions, also at LEP and HERA

Motivation for studying dpp in hadronic collisions

In addition the direct photon production in the relativistic heavy ions collisions has also played a very important role in finding out of a new form of matter by the experimental confirmation of the existence of a new phase of strongly interacting matter - quark-gluon plasma **QGP**. This kind of measurements of heavy ions collisions was started at **CERN** by ***WA80*** and ***WA98*** collaborations and now is under investigations at **RHIC** and at the **LHC**.

Motivation for studying dpp in hadronic collisions

- Precision test of pQCD;
- Serves to calibrate jet energy;
- Dpp is complementary to DIS and DRELL-YAN for studying the structure of hadrons;
- Dpp contributes significantly to the measurement of the gluon distributions in hadrons.

The energy region $1 < E_{beam} < 15$ GeV which can be covered by antiproton beam at the accelerator center FAIR (GSI, Darmschtadt) is of interest for research because it is much less investigated as compared to those regions which were studied at the accelerators having more higher energies. Also the region of intermediate beam energy is important for searches of expected deviations from the perturbative QCD.

Our interests

Our Physical goal: To estimate the possibility of getting *the information about* ***proton structure functions*** $f(x, Q^2)$.

Main interest: *To estimate the size of the* x-Q^2 *kinematical region in which the* ***structure functions can be measured.***

In ***pbar + p → gamma + X process***

(choosing pbar beam direction as the z-axis)

the role of the ***transferred momentum Q***

plays the ***photon transverse momentum***, i.e.

$$p_T^{\gamma} = Q$$

As it will be shown below, at ***E_{beam} = 15 GeV***

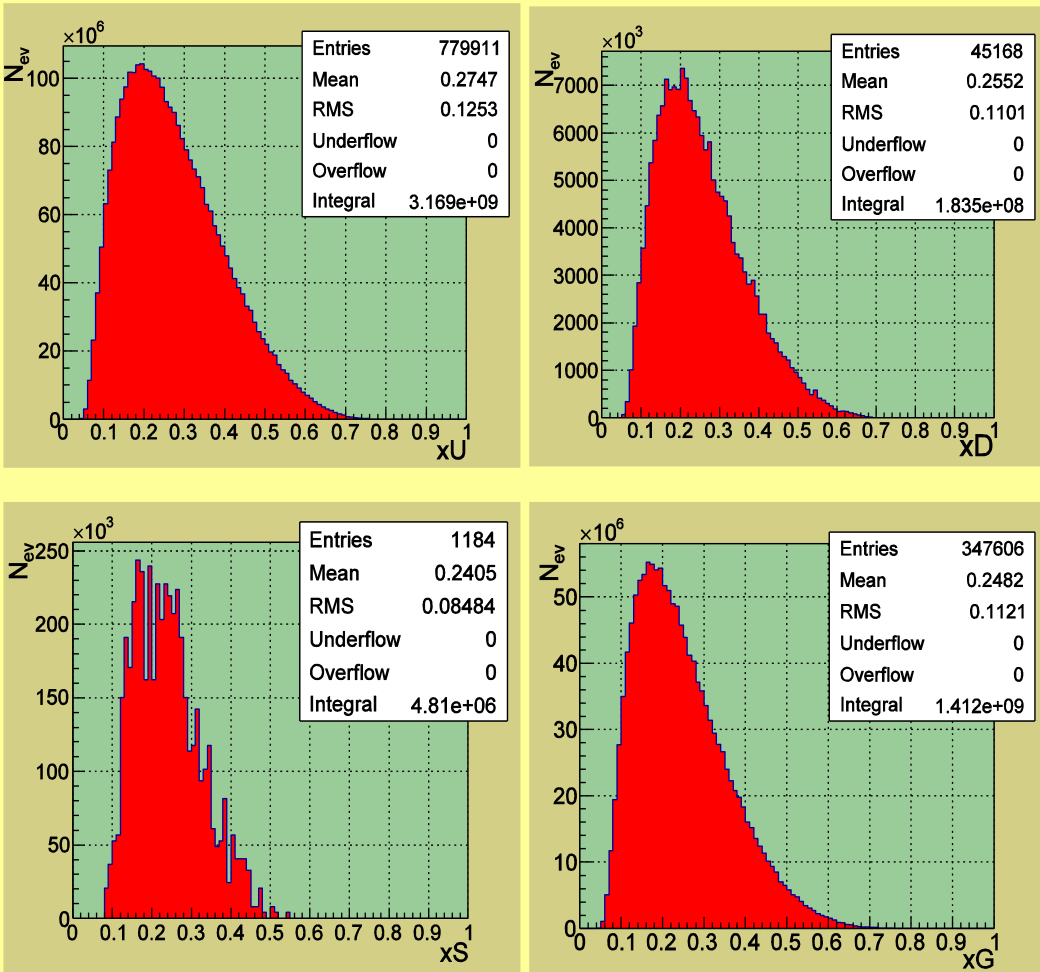
we can expect p_T^{γ} ***< 2.3 GeV, i.e,***

$$Q^2 = (p^{\gamma}_T)^2 < 5.3\ GeV^2$$

This region is under study now at HERA and JLab .

Structure functions distributions

Bjorken x distributions



From these quark distributions we see that at PANDA energy (E_{beam}=15 GeV) PYTHIA (with CTEQ3L parameterization) predicts that the Bjorken x-variable can cover the region

0.05 < x < 0.7

Previous experiments

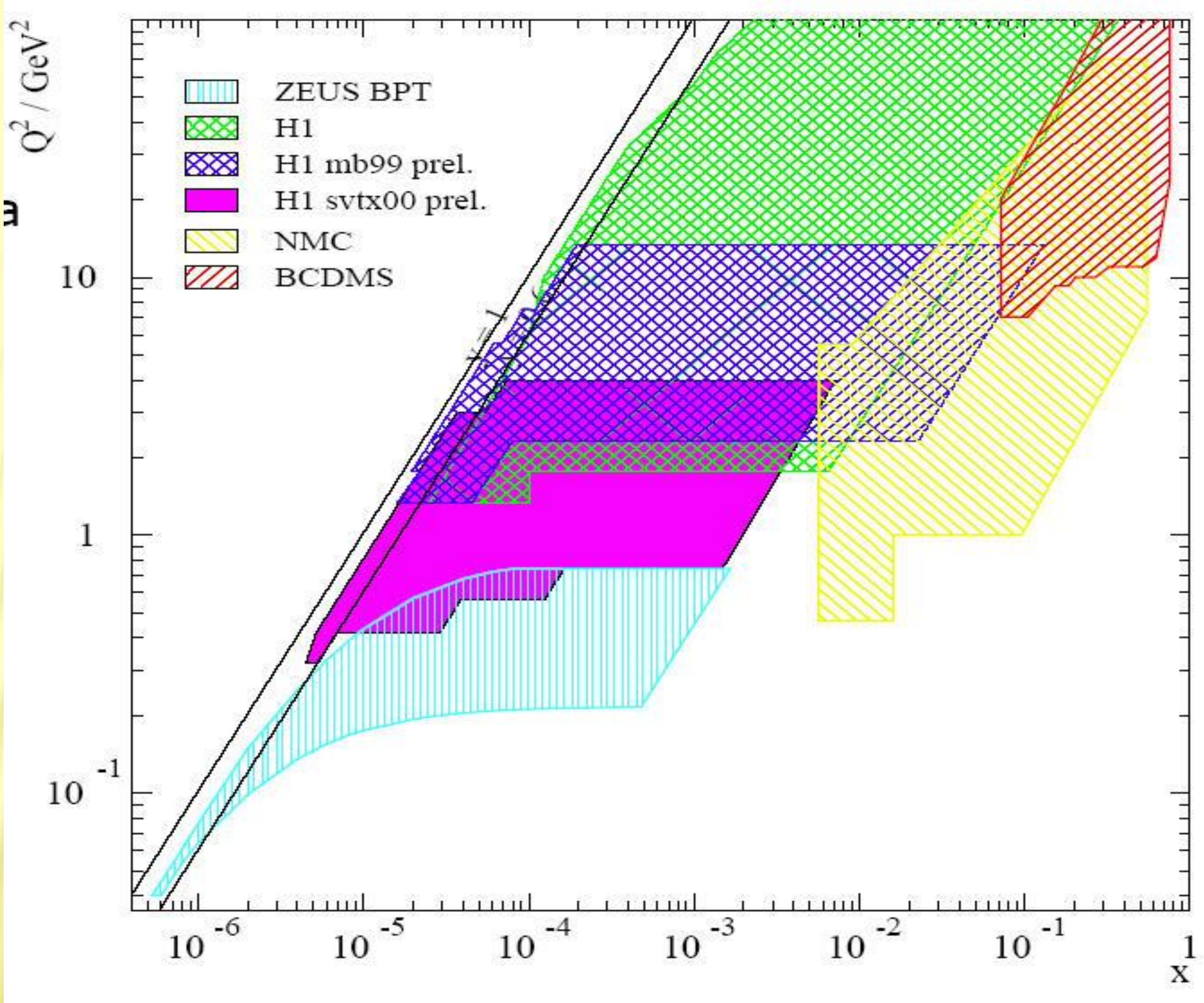
x-Q^2 plane

Regions covered by

Structure Function measurements

in **DIS** experiments

at low Q^2



Previous experiments

Nowadays

there are

new

measurements

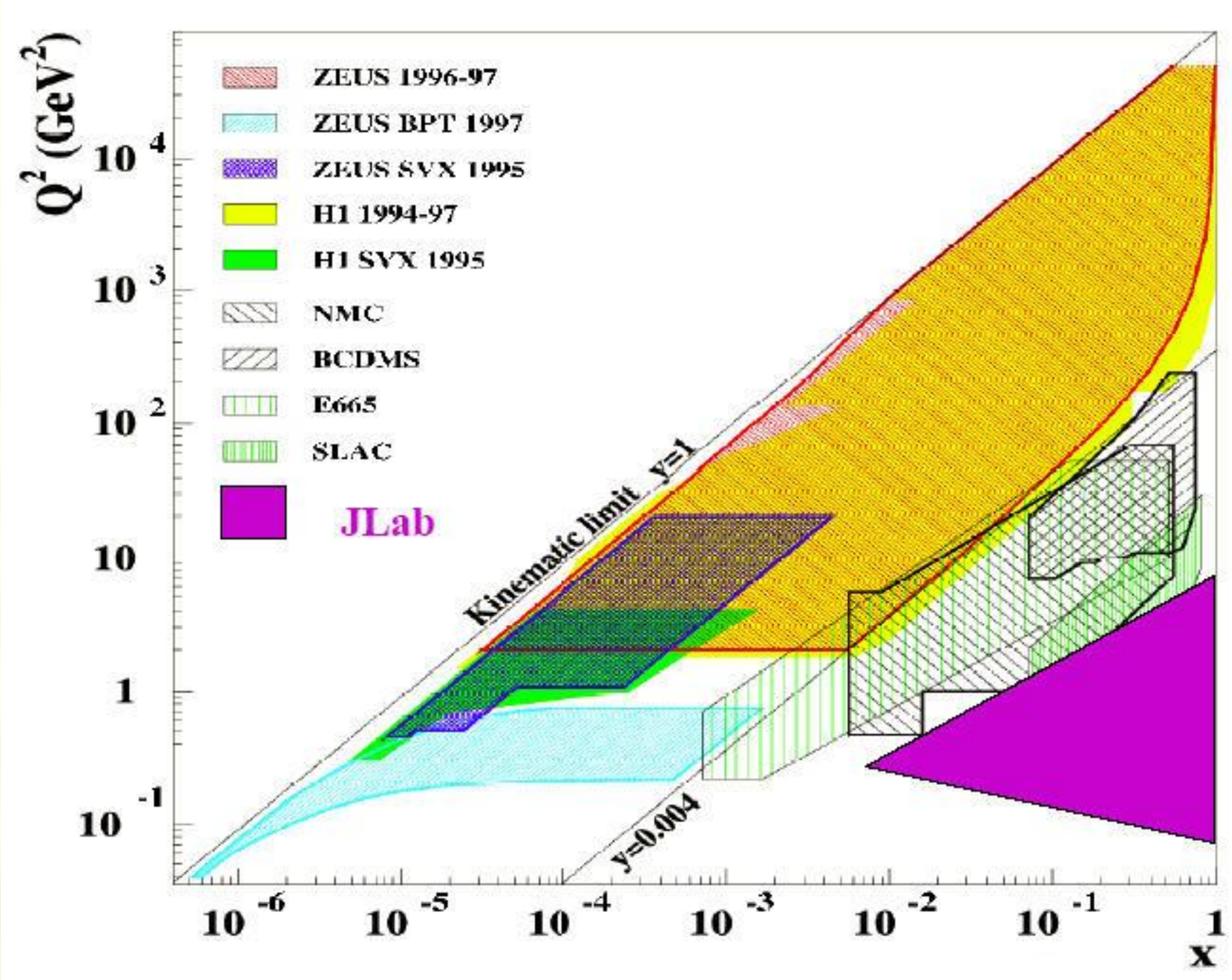
at

low Q^2

at

JLab

$0.1 < Q^2 < 8.0$ GeV^2



Previous experiments

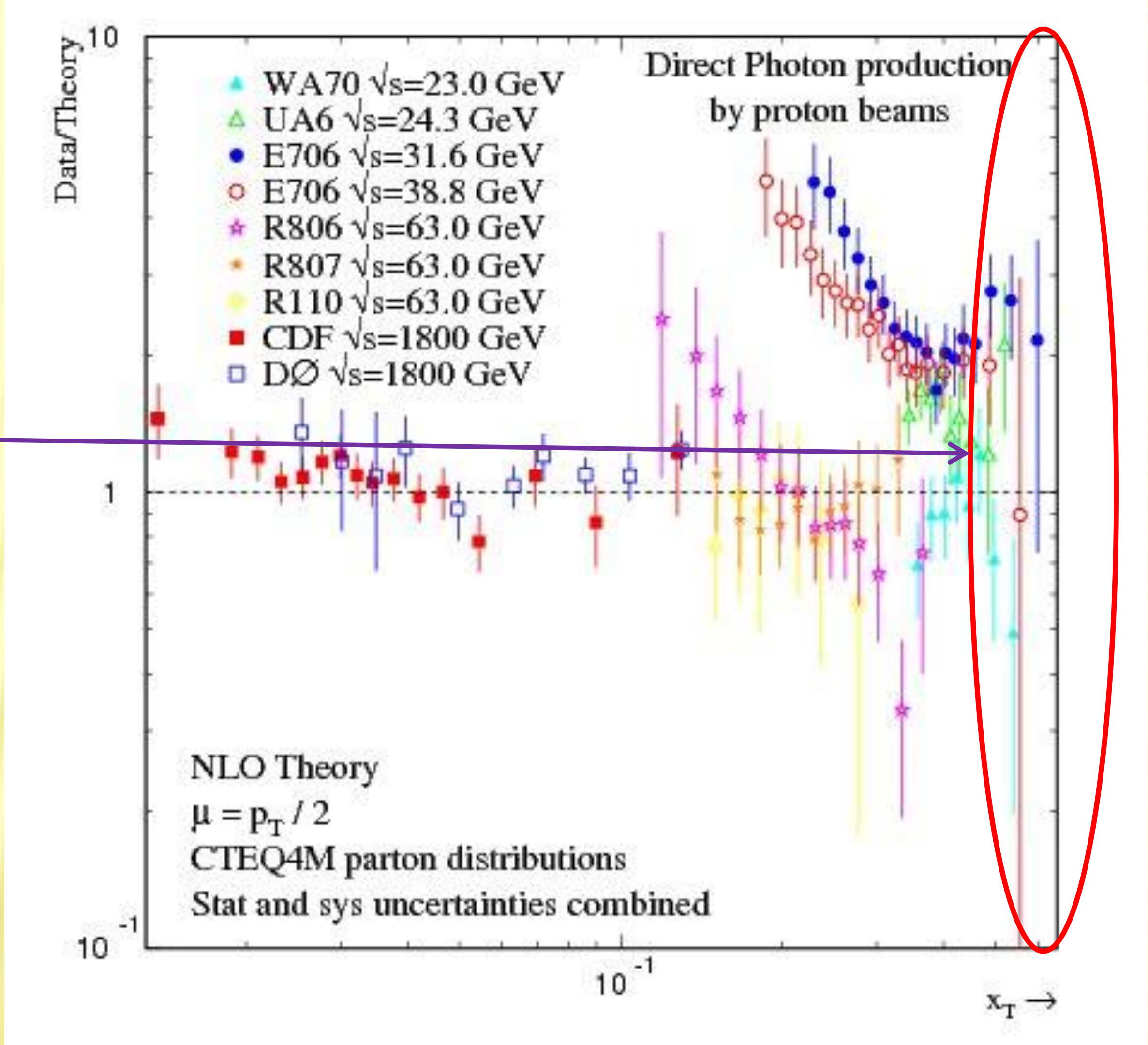
$X_T = 2PT/\sqrt{s}$

for PANDA

$0.39 < X_T < 0.85$

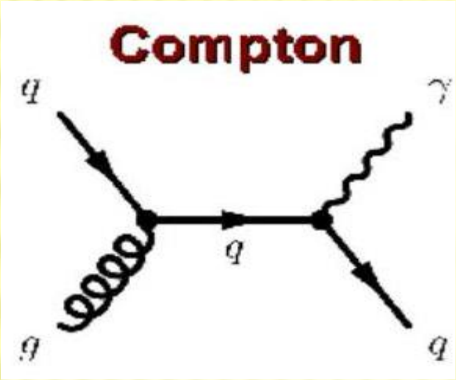
(with account of further background restrictions)

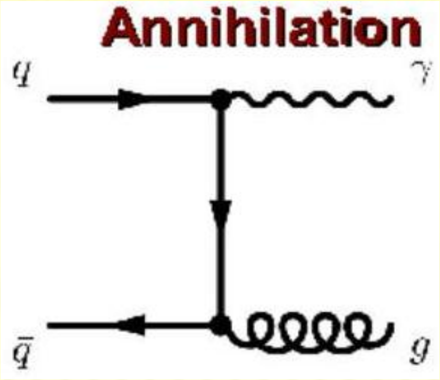
and possibly higher for the smaller E_{beam} (and correspondingly $\sqrt{s}$)



Direct photon production: definition

The ***pbar + p → gamma + X*** process (different to DIS scattering) is mainly defined by ***LO QCD*** diagrams:





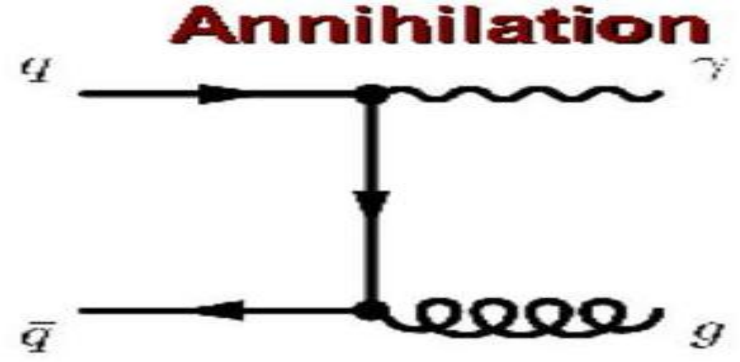
The "***QCD Compton*** " diagram contribution makes ***the cross section of***
pbar + p → gamma + X process to be sensitive to the gluon distribution ***g (x, Q^2).***

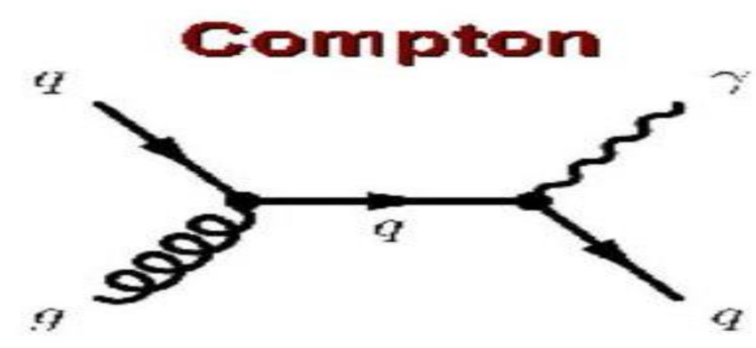
The hadrons are build of quarks which are interconnected by gluons. None of them can be detected as the final states of hadron-hadron or lepton-hadron collisions due to the so called "partons confiement". Nowdays, the physics deals mainly with the structure functions which model the distributions of partons in hadrons.

The information about such structure functions is extracted from the experimentally measured cross sections (defined as the ratio of the Number of events to the beam Luminosity, i.e. Nev /Lum) by fitting the parameters of different models of structure functions to the cross sections data.

The diagrams contribution

The contributions of both diagrams to the total cross section





Cross Sections

Total: $\sigma = 2.34 \times 10^{-3}$ mb

q + qbar → gluon + γ (65%)
$\sigma = 1.53 \times 10^{-3}$ mb

gluon + q → q + γ (35%)
$\sigma = 8.18 \times 10^{-4}$ mb

gluon + gluon → gluon + γ (0.09%)
$\sigma = 2.3 \times 10^{-7}$ mb

At the maximum luminosity one can expect up to 4 x 10^9 signal events per year.

SIMULATION

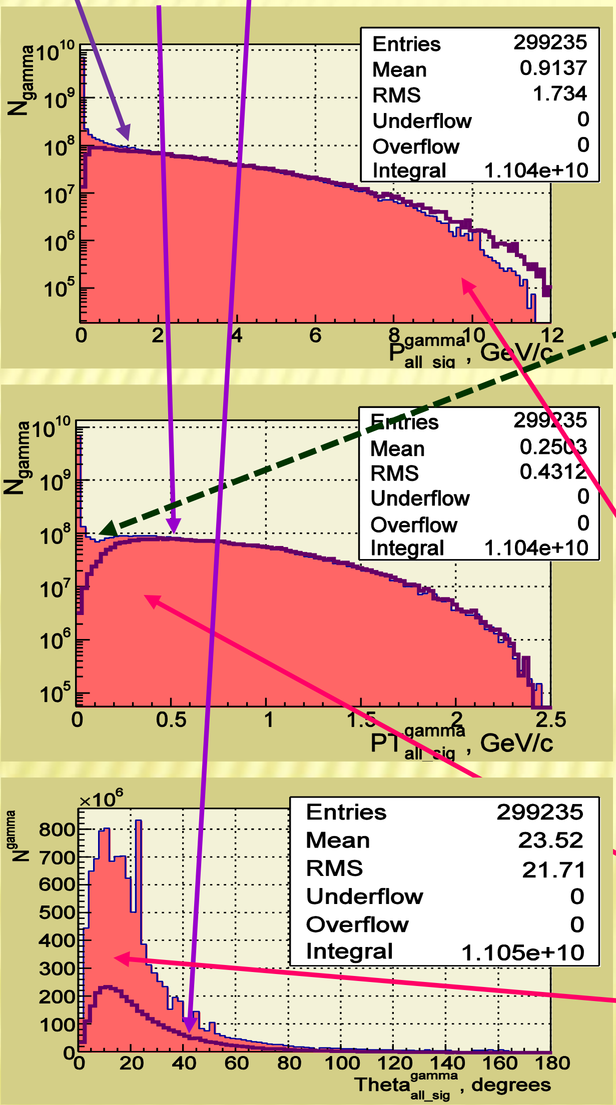
Simulation of photon kinematical characteristics was done with use of PandaRoot & Geant 4 (presented by pink histograms) with the initial set of 100 000 events simulated by PYTHIA6.4 for the case of beam energy E_{beam} = 15 GeV.

The corresponding initial distributions done with use of the PYTHIA6.4 alone are superimposed for comparison (violet line).

The following kinematical distributions over different variables will show the number of produced signal photons per year (supposing the full year of operation with the highest luminosity $2 \cdot 10^{32}$ cm^{-2} s^{-1})

Photons distributions in signal events

PYTHIA6.4



P^{γ}

PT^{γ}

θ^{γ}

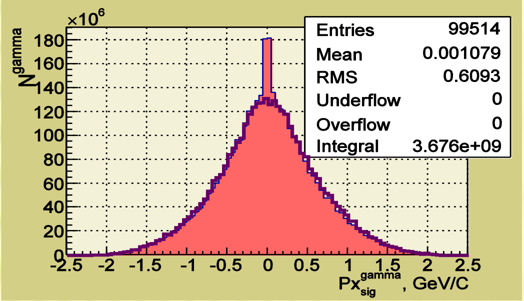
The kinematical distributions in the logarithmic scale of ***<u>all the produced photons</u>*** in signal events show significant excess of their number over initially generated photons in the region <u>of very low momentum</u> components and some loss of events in the region of highest momentum *P > 8 GeV/c*.

The first can be explained by the production of a big amount of secondary photons as a result of interaction of the particles with detector volume and some hadron decays.

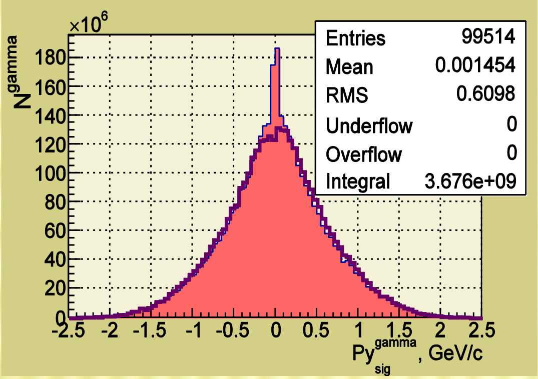
Angle *θ* distribution follows the initial one with the excess in the number of particles.

PANDARoot & Geant4

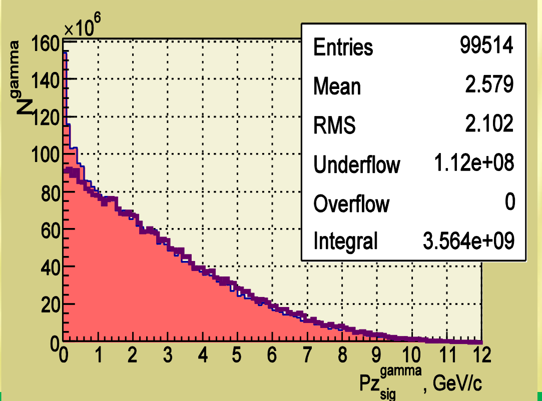
Signal photons Px, Py, Pz distributions



Px$^\gamma$



Py$^\gamma$



Pz$^\gamma$

Here the distributions of the photons with the largest momentum P in the signal events are presented.

The number of such the "registered" photons is 99515 for generated 100000, i.e. 99.514%.

These distributions in general follow the initial distributions of the photon, obtained at the level of PYTHIA simulation, except some excess of the number of the photons in the region of the low momentum components

Px (Py) < 0.3 GeV/c, Pz < 0.9 GeV/c.

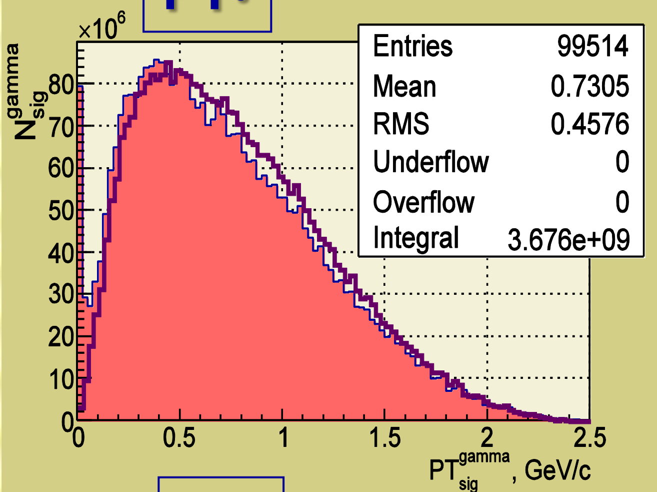
This excess can also be caused by the presence of additional photons, produced in a result of decays of the particles from hadron accompaniment of the signal photon.

$-2.5 \le P^\gamma x, P^\gamma y \le 2.5$ GeV/c

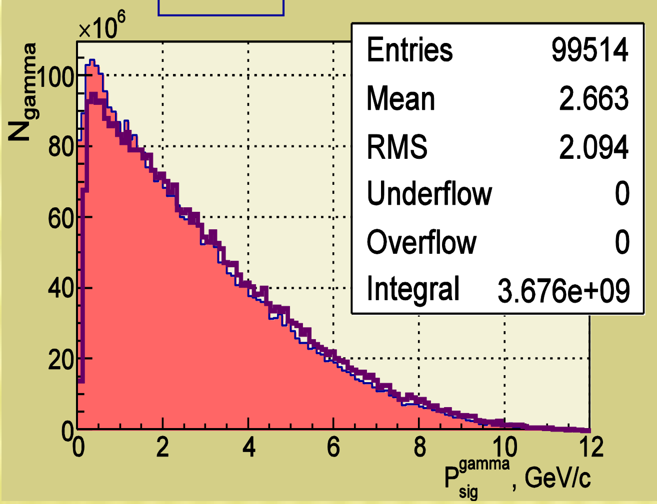
$P^\gamma z \le 11.6$ GeV/c, $\langle P^\gamma z \rangle = 2.58$ GeV/c

Signal photons P & PT distributions

PTɣ



Pɣ



Distributions of the photons with the largest momentum P in the signal events.

PandaRoot distributions practically coincide with Pythia histograms, except

some excess of the number of final photons from PandaRoot simulation in the region of PTɣ < 0.4 GeV/c and P < 1.5 GeV/c, that is caused by the excess of the corresponding values of the momentum components &

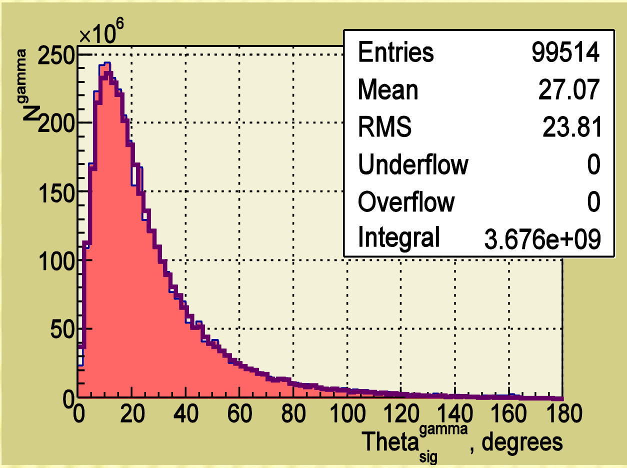
some shift of the final histograms to the left (that corresponds to the momentum loss about 0.05 - 0.1 GeV/c over PT and 0.2 - 0.4 GeV/c over P), that can be caused by the loss of events.

0 ≤ PT γ ≤ 2.4 GeV/c, <PT γ> = 0.73 GeV /c

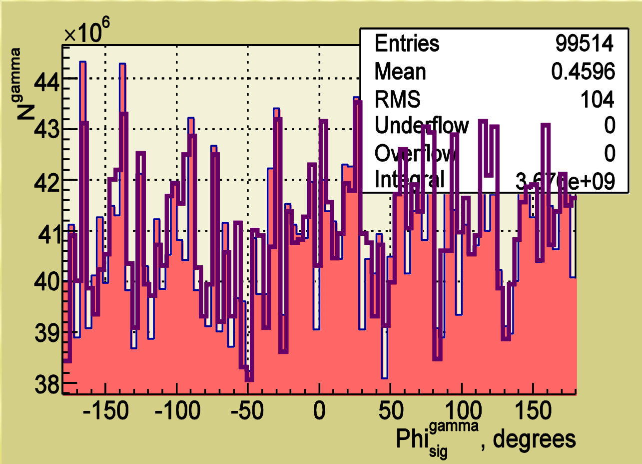
0 ≤ P γ ≤ 11 GeV/c, <P γ> = 2.6 GeV /c

Signal photons θ & φ distributions

Polar angle θ^γ



Azimuth angle φ^γ



Distributions of the photons with the largest momentum P in the signal events over the polar angle θ (top) and azimuth angle φ (bottom).

Both of the distributions mainly repeat the initial distributions, obtained by PYTHIA.

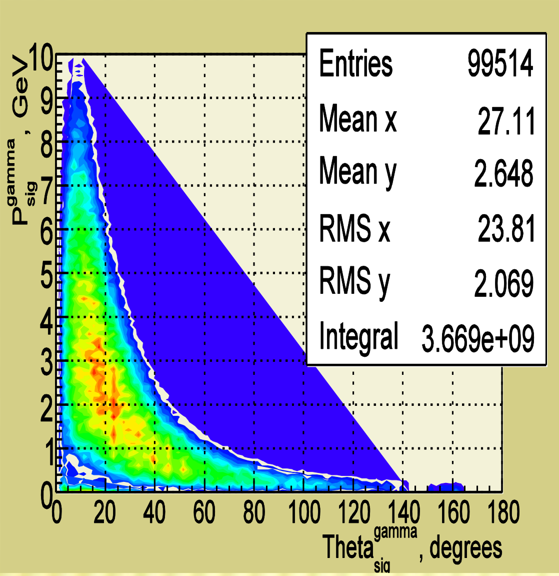
For the polar angle θ the distribution shows

- the evident prevalence in the region of $5^o < \theta < 40^o$ and
- complete loss of the signal in the regions of $142^o < \theta < 148^o$ and $159^o < \theta$.

$0 \leq \theta^\gamma \leq 180$ degrees, $\langle\theta^\gamma\rangle = 27$ degree

With account of the statistical errors the distribution over the azimuth angle φ has the uniform character.

Correlation distributions of polar angle θ and momentum P



The Figure shows the projection of 3-D correlation distribution of the number of the hardest photons over their full momentum P and polar angle θ.

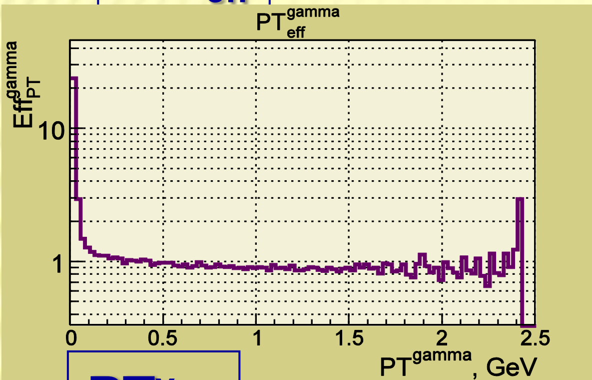
The maximum of the distribution of the number of events belongs to the region of
$0.1 < P < 3.8$ GeV/c over the full momentum and
$10^{o} < \theta < 45^{o}$ over the polar angle.

The next slide will demonstrate the efficiencies of prompt photon registration over different kinematical variables.

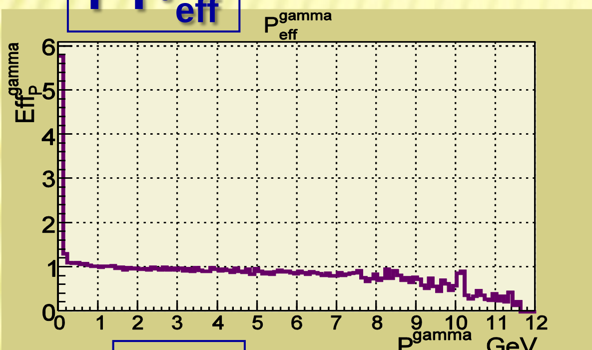
Registration efficiency *Eff* is calculated as **a ratio of the number of the photons "registered"** in a definite momentum and angle region while modeling *in PandaRoot* **to the ones initially generated** in the same momentum region *in PYTHIA* .

P, PT & Θ REGISTRATION EFFICIENCY OF THE SIGNAL γ

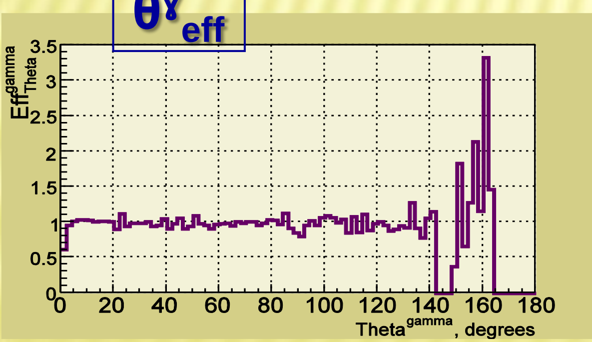
PT^{γ}_{eff}



PT^{γ}_{eff}



θ^{γ}_{eff}



From the upper plot one can see that at the **low values of $PT\gamma < 0.1$ GeV/c**, the registration efficiency over the transverse momentum is $Eff^{\gamma}_{PT} > 1$, that can be caused by the production of some additional low energetic γ in a result of interaction with the detector environment. At the **higher transverse moment values** $0.4 < PT\gamma < 2.4$ GeV/c the registration efficiency with account of the statistical errors is about $Eff^{\gamma}_{PT} \approx 0.9$ and stops at **PT = 2.4 GeV/c**.

The middle plot of the registration efficiency over the full momentum shows that at $P < 0.8$ GeV/c the registration efficiency $Eff^{\gamma}_{P} > 1$, that can be explained by the reason described above. Meanwhile at $0.8 < P\gamma < 7.6$ GeV/c the efficiency of the registration, with taking in account the statistical errors, is about $Eff^{\gamma}_{P} \approx 0.9$, after that it falls practically linearly up to $Eff^{\gamma}_{P} = 0$ at the value of $P\gamma = 11.6$ GeV/c..

The bottom plot of the registration efficiency over the polar angle θ shows the value close to $Eff^{\gamma}_{\theta} \approx 1$ in the region of $\theta < 142^{o}$. In the region of $142^{o} < \theta < 148^{o}$ $Eff^{\gamma}_{\theta} = 0$, after that with the higher statistical errors efficiency is also close to efficiency 1 in the region of $148^{o} < \theta < 164^{o}$, afterwards it is again $Eff^{\gamma}_{\theta} = 0$.

Background processes

Process	Cross section, mb
95 Low-pT scattering	3. 368 E+ 01
92 Single diffractive (XB)	1. 719 E+ 00
93 Single diffractive (AX)	1. 719 E+ 00
94 Double diffractive	2. 479 E- 01
28 f + g -> f + g	1. 670 E- 02
11 f + f' -> f + f' (QCD)	8. 756 E- 03
68 g + g -> g + g	4. 887 E- 03
12 f + fbar -> f' + fbar	1. 111 E- 03
13 f + fbar -> g + g	1. 074 E- 03
53 g + g -> f + fbar	1. 296 E- 04

Signal processes - *total cross section is 4 order less than the cross section of “minimum-bias” processes*

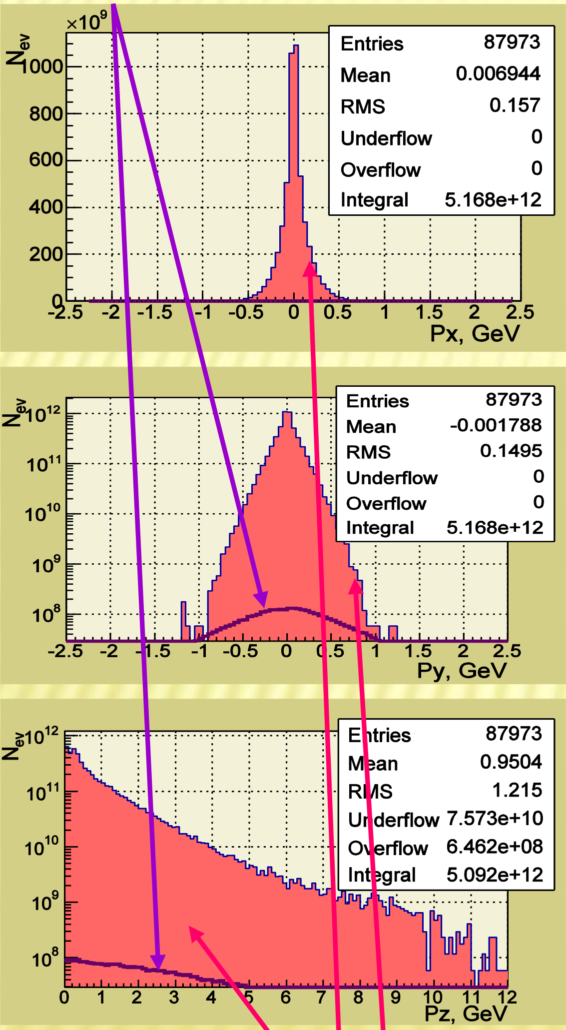
14 f + fbar -> g + gamma	1. 533 E- 03
29 f + g -> f + gamma	8. 181 E- 04
115 g + g -> g + gamma	2. 280 E- 07

According to predictions of Monte-Carlo generator PYTHIA6.4 the total cross section at the energy of antiproton beam E_{beam} = 15 GeV for the processes of the leading photon is 2.35×10^{-3} mb. At the same time the total cross section for the background processes is 37.4 mb.

Thus the initial ratio of the signal to background is $S/B = 6.283 \times 10^{-5}$ and one signal event corresponds to about 16000 background ones.

$P^{\gamma}x$, $P^{\gamma}y$, $P^{\gamma}z$ distributions from 10^5 mini-bias background events

Signal



Background

Pink histograms - photon distributions of the hardest photons from background events.

Px^{γ}

Violet lines on the same pictures for comparison – photons distributions from signal events with account of the corresponding cross sections

As the distributions over *Px* and *Py* are identical to each other, for comparison the distributions over *Px* are done in linear and *Py – in logarithmic* scale.

Py^{γ}

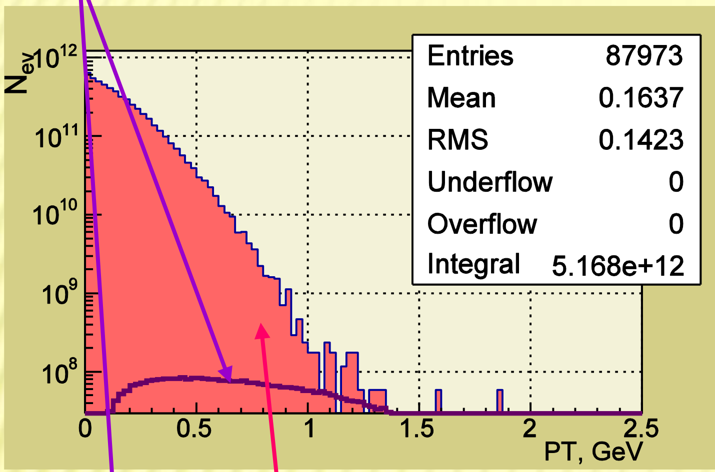
The values of the transverse momenta *Px* and *Py* of the *background photons* coincide with the corresponding values of the *signal photons* with a clear tendency – the lower the value of transverse momentum, - the higher order of magnitude is the suppression of the signal by the background.

Pz^{γ}

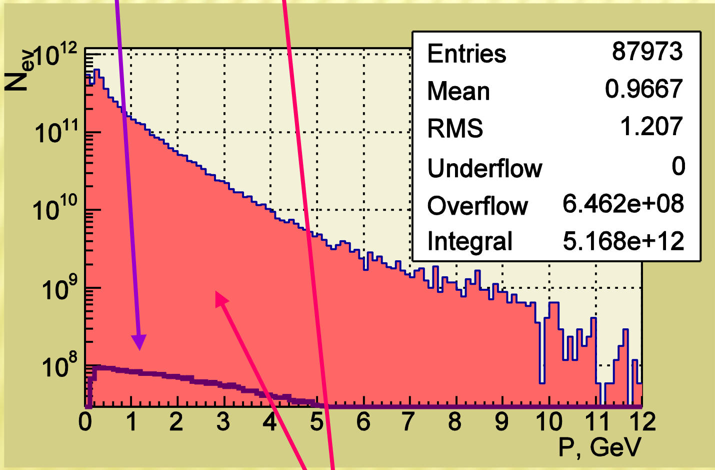
From the distributions over the longitudinal components of momentum *Pz* it is seen that the values of the corresponding components of the background photons strongly overlap the signal ones.

PTɣ, Pɣ DISTRIBUTIONS FROM 10^5 MINI-BIAS BACKGROUND EVENTS

Signal



PTɣ



Pɣ

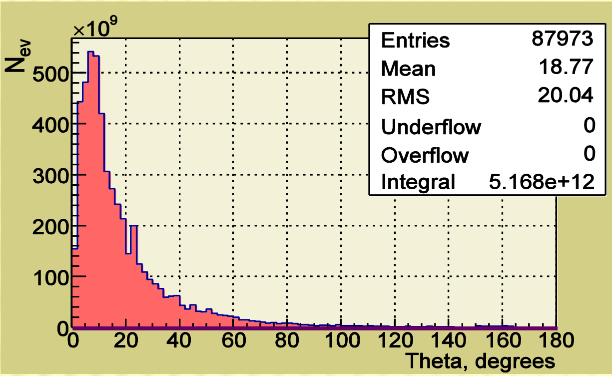
Background

Comparative distributions of the signal and background photons over their transverse momentum PT and full momentum P

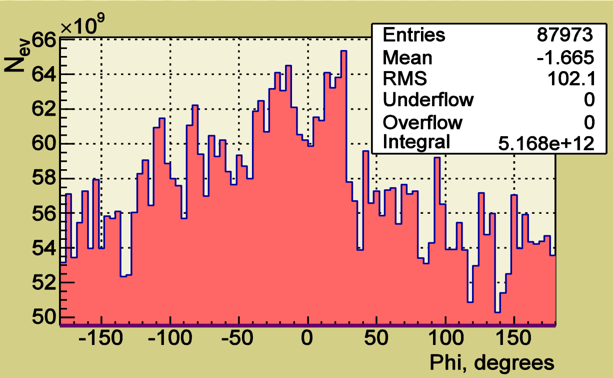
The *values of the transverse momentum PTɣ* of the background photons <u>do coincide</u> with the corresponding ones of the signal photons. Obviously - the lower the value of transverse momentum, the higher order of magnitude is the suppression of the signal by the background.

From the distributions over the *full momentum Pɣ* it is seen that the *values* of the corresponding components of the background photons strongly overlap the signal ones.

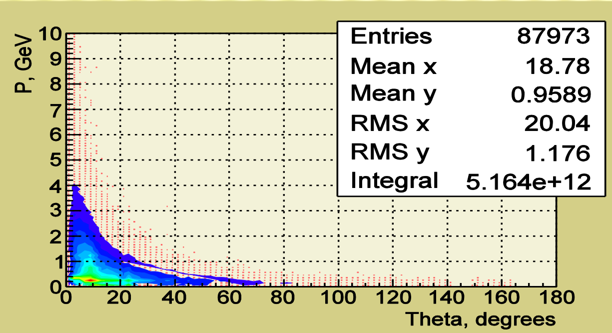
ANGLE AND $P^{\gamma}/\Theta^{\gamma}$ BACKGROUND DISTRIBUTIONS



Distribution of the number of background photons over their polar angle *θ* shows that the most part of the them are produce at the angles $5^o < \theta < 20^o$.



Distribution over the azimuth angle *φ,* with account of statistics, shows relatively uniform character with some prevalence in direction of $-30^o < \varphi < 30^o$.

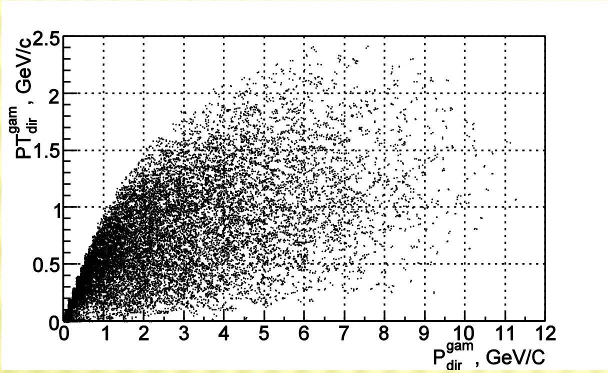


Two- dimensional plot of background photons distributions over their momentum P^{γ} and polar angle *θ* shows that the most energetic photons fly predominantly in the forward direction, while the rest ones are spread at the angles $\theta < 80^o$ and more.

Background elimination

The correlative distributions over transverse momentum PT^{γ} (x axis) and full momentum P^{γ} (y axis) show the influence of kinematical restriction on the leading photon. From these distributions one can see, that the *values of the full photon momentum* P^{γ} are placed at the <u>same range</u> both for the signal and the background. Thus the use of single momentum *P* separation criterion obviously will not help for background suppression, that is shown in the table below.

direct photon



background photon

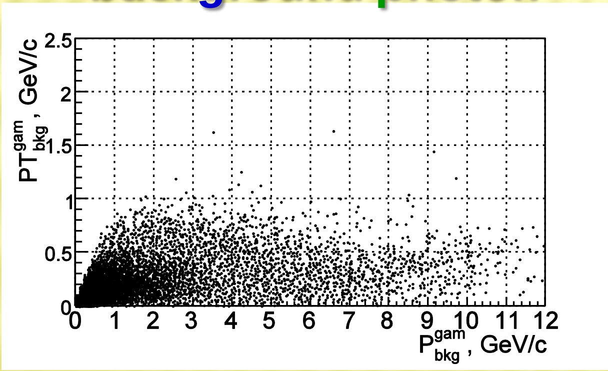


Table 1. Selection by the full momentum P^{γ} together with the transverse momentum criterion $PT^{\gamma} > 0.5$ GeV

Criterion	Efficiency for background, %	Efficiecy for the signal, %	Signal to background ratio S/B
P_{gamma} > **0.5 GeV**	17.76	80.41	**2.845 x 10^{-4}**
P_{gamma} > **1.0 GeV**	12.62	69.44	**3.457 x 10^{-4}**
P_{gamma} > **1.5 GeV**	8.883	59.55	**4.212 x 10^{-4}**
P_{gamma} > **2.0 GeV**	6.292	50.59	**5.046 x 10^{-4}**
P_{gamma} > **2.5 GeV**	4.442	42.45	**6.004 x 10^{-4}**
P_{gamma} > **3.0 GeV**	3.185	35.19	**6.942 x 10^{-4}**
P_{gamma} > **3.5 GeV**	2.321	28.74	**7.780 x 10^{-4}**
P_{gamma} > **4.0 GeV**	1.733	23.31	**8.452 x 10^{-4}**
P_{gamma} > **4.5 GeV**	1.333	18.52	**8.729 x 10^{-4}**
P_{gamma} > **5.0 GeV**	1.041	14.45	**8.722 x 10^{-4}**

But over transverse momentum PT^{γ} they are overlapped not completely that can be used for signal and background separation

Background elimination

Table 3. Selection by the transverse momentum PT_{gamma}

Criterion	Efficiency for background, %	Efficiecy for the signal, %	Signal to background ratio S/B
PT_{gamma} > **0.25 GeV**	19.825	85.19	**2.700 x 10^{-4}**
PT_{gamma} > **0.3 GeV**	13.753	81.01	**3.701 x 10^{-4}**
PT_{gamma} > **0.4 GeV**	6.212	71.94	**7.277 x 10^{-4}**
PT_{gamma} > **0.5 GeV**	2.619	63.01	**1.512 x 10^{-3}**
PT_{gamma} > **0.6 GeV**	1.053	54.47	**3.250 x 10^{-3}**
PT_{gamma} > **0.7 GeV**	0.408	46.55	**7.169 x 10^{-3}**
PT_{gamma} > **0.8 GeV**	0.150	39.06	**1.636 x 10^{-2}**
PT_{gamma} > **0.9 GeV**	0.056	32.46	**3.642 x 10^{-2}**
PT_{gamma} > **1.0 GeV**	0.023	26.42	**7.218 x 10^{-2}**
PT_{gamma} > **1.1 GeV**	0.011	20.94	**1.196 x 10^{-1}**
PT_{gamma} > **1.2 GeV**	0.0055	16.32	**1.864 x 10^{-1}**
PT_{gamma} > **1.3 GeV**	0.00325	12.56	**2.428 x 10^{-1}**
PT_{gamma} > **1.4 GeV**	0.00205	9.46	**2.899 x 10^{-1}**
PT_{gamma} > **1.5 GeV**	0.00155	6.91	**2.801 x 10^{-1}**
PT_{gamma} > **1.6 GeV**	0.00115	4.83	**2.639 x 10^{-1}**
PT_{gamma} > **1.7 GeV**	0.00090	3.26	**2.275 x 10^{-1}**
PT_{gamma} > **1.8 GeV**	0.00065	2.08	**2.011 x 10^{-1}**
PT_{gamma} > **1.9 GeV**	0.00035	1.26	**2.262 x 10^{-1}**
PT_{gamma} > **2.0 GeV**	0.00025	0.73	**1.835x 10^{-1}**

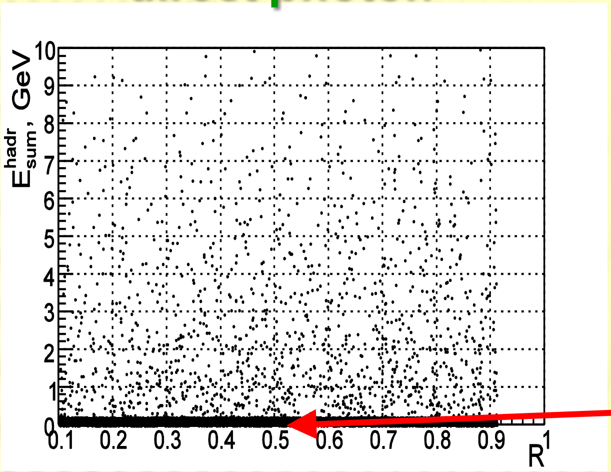
PT_{gamma} cut > 1.1 GeV

doesn‘t influence much on S/B ratio and doesn‘t have physical sense since it rejects strongly the signal.

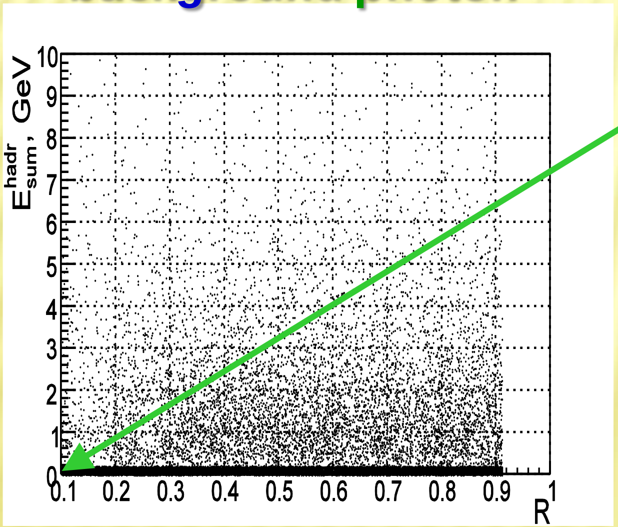
The used statistics is 2000000 events generated in Pandaroot

Gamma isolation criteria

direct photon



background photon



Different kind of taken separately isolation criteria were considered. It was determined that the best suppression of background events gives the criterion of events selection with the summarized energy $E_{sum} < 0.25$ GeV of all the charged particles inside the cone of radius $R = \sqrt{\Delta\eta^2+\Delta\varphi^2} = 0.5$ in $\eta - \varphi$ space around the leading photon momentum direction

(here $\Delta\varphi = \varphi_1 - \varphi_2$ is the difference between the azimuth angles of the photon and the charged particle, $\Delta\eta = \eta_1 - \eta_2$ is the difference of the pseudorapidities of the photon and the charged particles).

Such a criterion allows to suppress 47.8% of background with **the loss of only 6% of the signal**.

Axis ***x***: R (0.1, 0.2…0.9) – radius of the cone around direction of the leading photon momentum.
Axis ***y:*** E_{sum} - summarized energy of all the charged particles inside this cone.

Background elimination

Table 3. Selection by the transverse momentum PT_{gamma} together with the isolation criterion $E_{sum} < 0.25$ GeV in the cone with the radius R=0.5

Criterion	Efficiency for background, %	Efficiency for the signal, %	Signal to background ratio S/B
PT_{gamma} > **0.25 GeV**	13.717	83.41	**3.821×10^{-4}**
PT_{gamma} > **0.3 GeV**	9.774	79.51	**5.111×10^{-4}**
PT_{gamma} > **0.4 GeV**	4.650	70.95	**9.587×10^{-4}**
PT_{gamma} > **0.5 GeV**	2.038	62.34	**1.922×10^{-3}**
PT_{gamma} > **0.6 GeV**	0.848	54.02	**4.003×10^{-3}**
PT_{gamma} > **0.7 GeV**	0.333	46.27	**8.731×10^{-3}**
PT_{gamma} > **0.8 GeV**	0.123	38.86	**1.985×10^{-2}**
PT_{gamma} > **0.9 GeV**	0.048	32.31	**4.229×10^{-2}**
PT_{gamma} > **1.0 GeV**	0.017	26.33	**9.732×10^{-2}**
PT_{gamma} > **1.1 GeV**	0.0085	20.88	**1.543×10^{-1}**
PT_{gamma} > **1.2 GeV**	0.0043	16.28	**2.379×10^{-1}**
PT_{gamma} > **1.3 GeV**	0.0023	12.54	**3.426×10^{-1}**
PT_{gamma} > **1.4 GeV**	0.00155	9.44	**3.827×10^{-1}**
PT_{gamma} > **1.5 GeV**	0.00120	6.89	**3.607×10^{-1}**
PT_{gamma} > **1.6 GeV**	0.00080	4.82	**3.785×10^{-1}**
PT_{gamma} > **1.7 GeV**	0.00060	3.26	**3.414×10^{-1}**
PT_{gamma} > **1.8 GeV**	0.00050	2.08	**2.614×10^{-1}**
PT_{gamma} > **1.9 GeV**	0.00035	1.26	**2.262×10^{-1}**
PT_{gamma} > **2.0 GeV**	0.00005	0.73	**9.174×10^{-1}**

The analysis of the given pictures and tables shows that among all the possible kinematical variables the most effective is the selection of events by the *transverse momentum PT* of the leading photon together with the use of *isolation criterion*. These criteria allow to achieve the *background suppression up to 50000 times* and to get the signal to background ratio at the level of **S/B = 0.36** at the restrictive condition for PT_{gamma} > 1.5 ГэВ, that is nevertheless is not enough for the signal separation

Background elimination

Cut	Rejected events
1. *Events without photons*	12.1 %
2. *PT^{γ} >1.1 GeV of the photon with the largest energy*	99.989 %
&	
Isolation criterion for the photon with the largest energy in event *E_{sum} (of charged particles) > 0.25 GeV in the R=0.5*	99.9915 %

- **Achieved S/B > 0.15**

The rest of the background can be rejected by calculation of invariant masses of the mesons, which can produce those background photons.

Conclusion

The simulation with PYTHIA6.4 & PandaRoot (with Geant4) has shown that at PANDA energy *E_{beam} = 15 GeV*

1. **We can separate the most part of fake and background photons contribution, which comes from decays of neutral pions and other mesons.**

2. **PANDA can make the measurement of proton structure functions in the regions of**

$$1 < Q^2 = (P_T^{\gamma})^2 < 5.3\ \mathrm{GeV}^2 \quad \text{and} \quad 0.05 < x < 0.7$$

3. **This measurement can have an advantage as it is very sensitive to gluon distribution.**

THANKS FOR YOUR ATTENTION

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