Monte-Carlo simulation of lepton pairs production in "$p\bar{p} \rightarrow e^+e^- + X$" events at PANDA

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FAIRNESS

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Previous publications

- **Monte-Carlo simulation of lepton pair production in "p pbar → $\ell^+\ell^-$ + X" events at E_{beam} = 14 GeV**

  A.N.Skachkova, N.B.Skachkov, G.D.Alexeev

  arXiv: hep-ph/0506139 PANDA-NOTE PHY-003

- **On Lepton Pair Production in Proton-Antiproton Collisions at Intermediate Energies**

  A.N.Skachkova, N.B.Skachkov

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- **Monte-Carlo simularion of lepton pairs production in ''*pp* ‾ →*mu* + *mu* − +*X*" *events at E (beam) = 5 GeV***

  Anna Skachkova

  J.Phys.Conf.Ser. 426 (2013) 012031, 5 pp

V.A. Matveev, R.M. Muradian, A.N. Tavkhelidze (MMT)

(V.A. Matveev, R.M. Muradian, A.N Tavkhelidze, JINR P2-4543, JINR, Dubna, 1969; SLAC-TRANS-0098, JINR R2-4543, Jun 1969; 27p.)

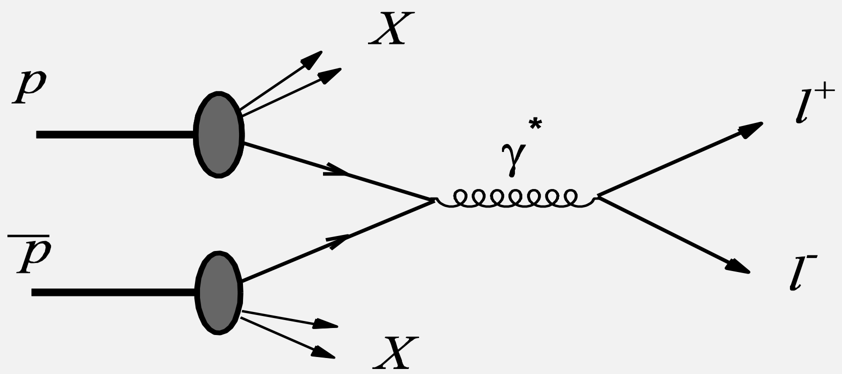
process, called also as Drell-Yan

(S.D. Drell, T.M. Yan, SLAC-PUB-0755, Jun 1970,12p.; Phys.Rev.Lett. 25(1970)316-320, 1970)

The dominant mechanism of the $\ell^+\ell^-$ production is the perturbative QED/QCD partonic 2 → 2 process

$$\bar{q}_i q_i \to \gamma^* / Z^\circ \to e^+ e^-$$

$$\sigma = 4.59 * 10^3 \ \mathrm{pb}$$



We can expect to gain a huge sample of about 7x10⁶ signal di-lepton events per 1 year (10⁷ sec.)

PYTHIA 6 simulation for the E_{beam} = 15 GeV (5.474 GeV center-of-mass energy) without detector effects ("ideal detector" --> all particles are detected) allows a proper account of the relativistic kinematics during the simulation

Lepton pairs production

The process of lepton pairs production q qbar → γ^* / Z° → $\ell^+\ell^-$ is of big physical interest because:

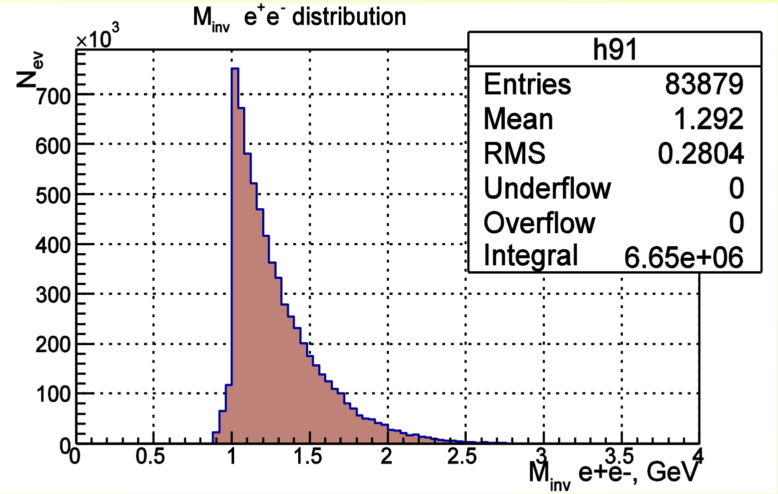
1. The spectrum of final state leptons (*e* and μ) obviously depends on the form of parton distributions inside colliding protons and may provide an interesting information about the *quark dynamics inside the hadron*.

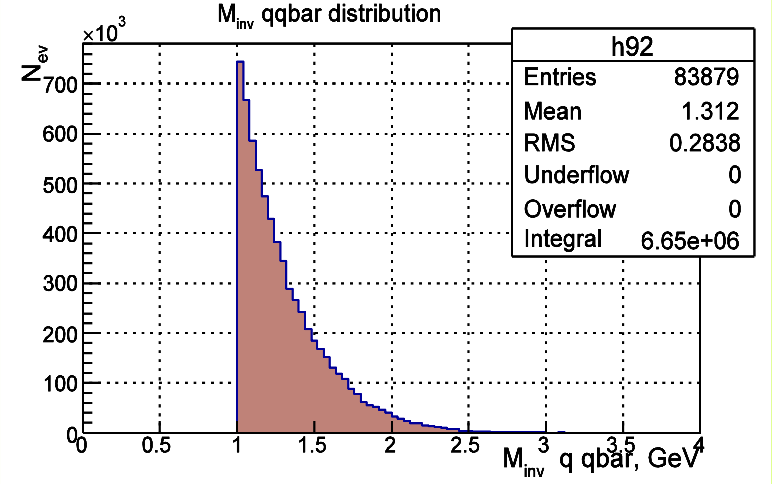
2. The measurement of the total transverse momentum of a lepton pair PT ($\ell^+\ell^-$) as a whole may provide an important information about the *intrinsic transverse momentum* <kT> that appears due to the Fermi motion of quarks inside the nucleon

Different to the electron beams, used for measurements of **proton structure functions** in the region of **!negative!** values of the square of transferred momentum ($q^2 < 0$, **"space-like"** region),

antiproton-proton collisions allow to make measurements of **proton structure functions** in the region of **!positive!** values of the square of the transferred momentum ($q^2 > 0$, **"time-like"** region), which ***is less studied !***

Global variable for $\bar{q}\, q \to \gamma^* \to \ell^+\ell^-$ process - $M_{inv}\ \ell^+\ell^-$





- **$M_{inv}\ \ell^+\ell^- = \sqrt{(P_{\ell^+} + P_{\ell^-})^2}$**

$M_{inv}\ \ell^+\ell^-$ min = $M_{inv}\ \bar{q}q$ = 1 GeV

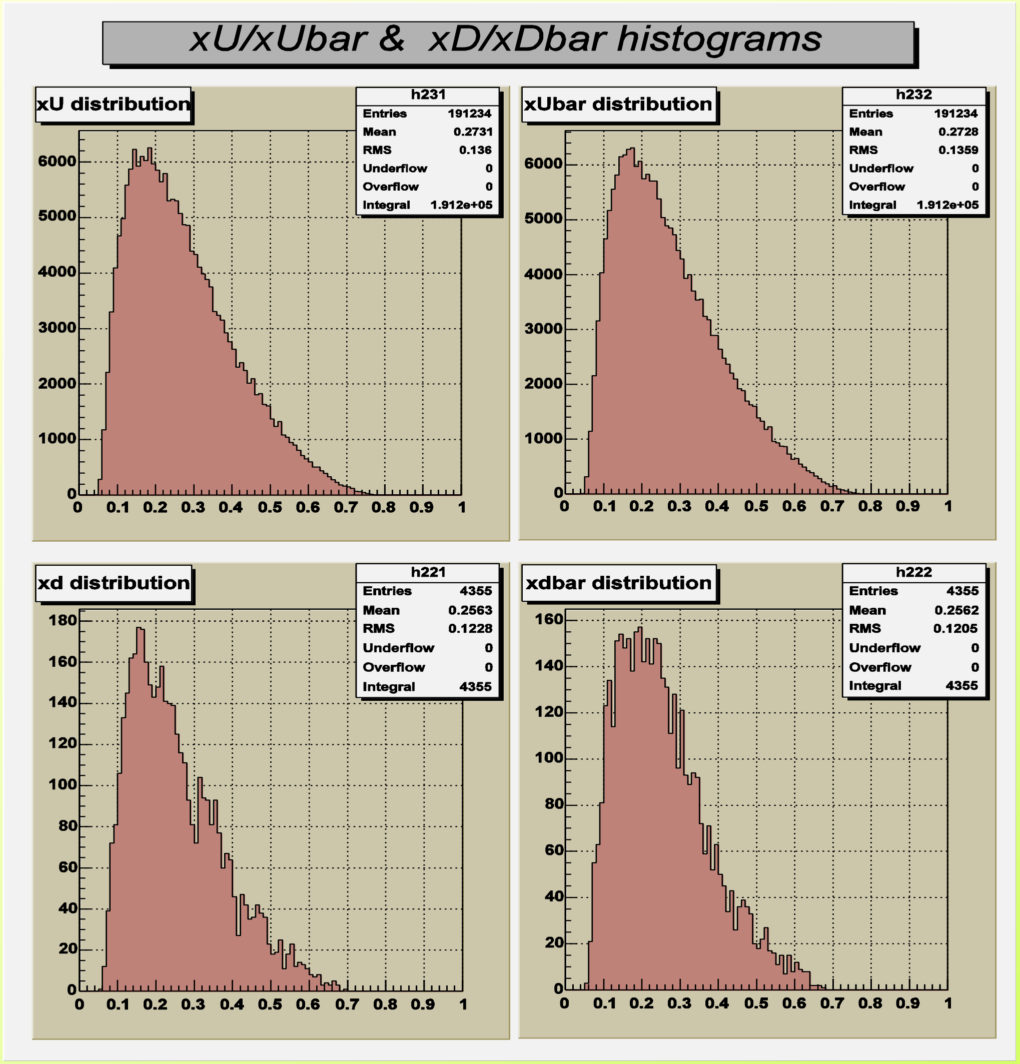
– originates from the internal PYTHIA restriction

- **$M_{inv}\ \bar{q}q = \sqrt{(P_q + P_{\bar{q}})^2}$**

= m_hat ≈ 2.5 GeV

→transferred Q^2 < 6.2 GeV^2

Estimation of the x-Q^2 region, available for the structure functions measurement

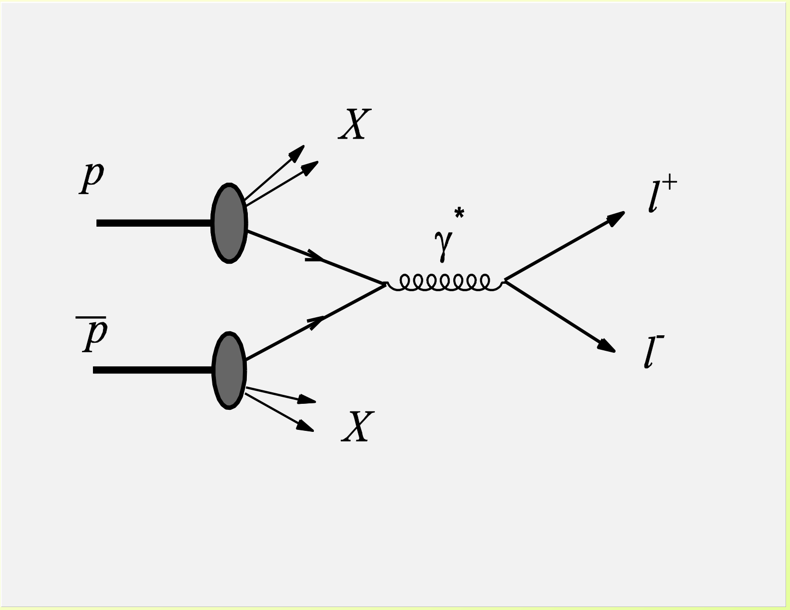


For the PANDA experiment with the E_{beam} = 15 GeV

$0.05 < x < 0.7$

$Q^2 < 6.2\ GeV^2$

MMT-DY process



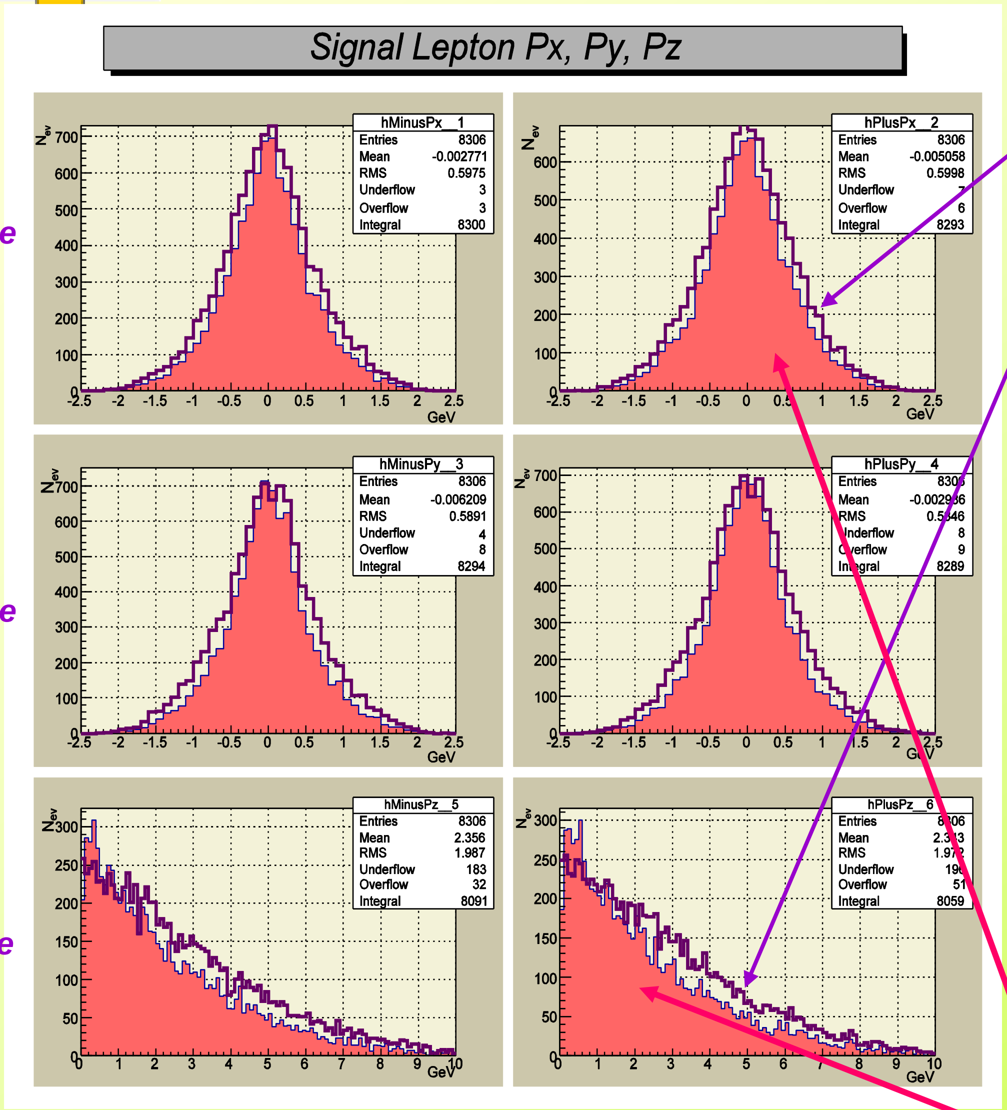
Simulation of electron kinematical characteristics was done with use of PandaRoot & Geant 4 (presented by pink histograms) with the set of 10000 events simulated by PYTHIA6.4.

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

The **number of events** where *one of the signal leptons is not registered in detector* is 1285 for 10000 generated events. There are also 127 events where *no one of signal leptons is registered*. That means **we can expect the registration of only 85.8% of signal events**. The number of signal events where both of the signal leptons satisfy the criteria **Pe >0.2 GeV and PTe > 0.2 GeV is 62.6%.**

Px^e, Py^e, Pz^e of e^+ & e^-

PYTHIA6.4



Px^e

Py^e

Pz^e

e^- e^+

- Distributions of *transverse components* of momentum in PandarRoot follow the ones obtained in PYTHIA except some reduction of number of events.
- Distributions of *longitudinal component* show the **excess** over PYTHIA results in the region of small Pz 0.2 – 0.6 GeV and **some reduction** of number of events at the medium values of Pz 2 – 6 GeV

PandaRoot & Geant 4

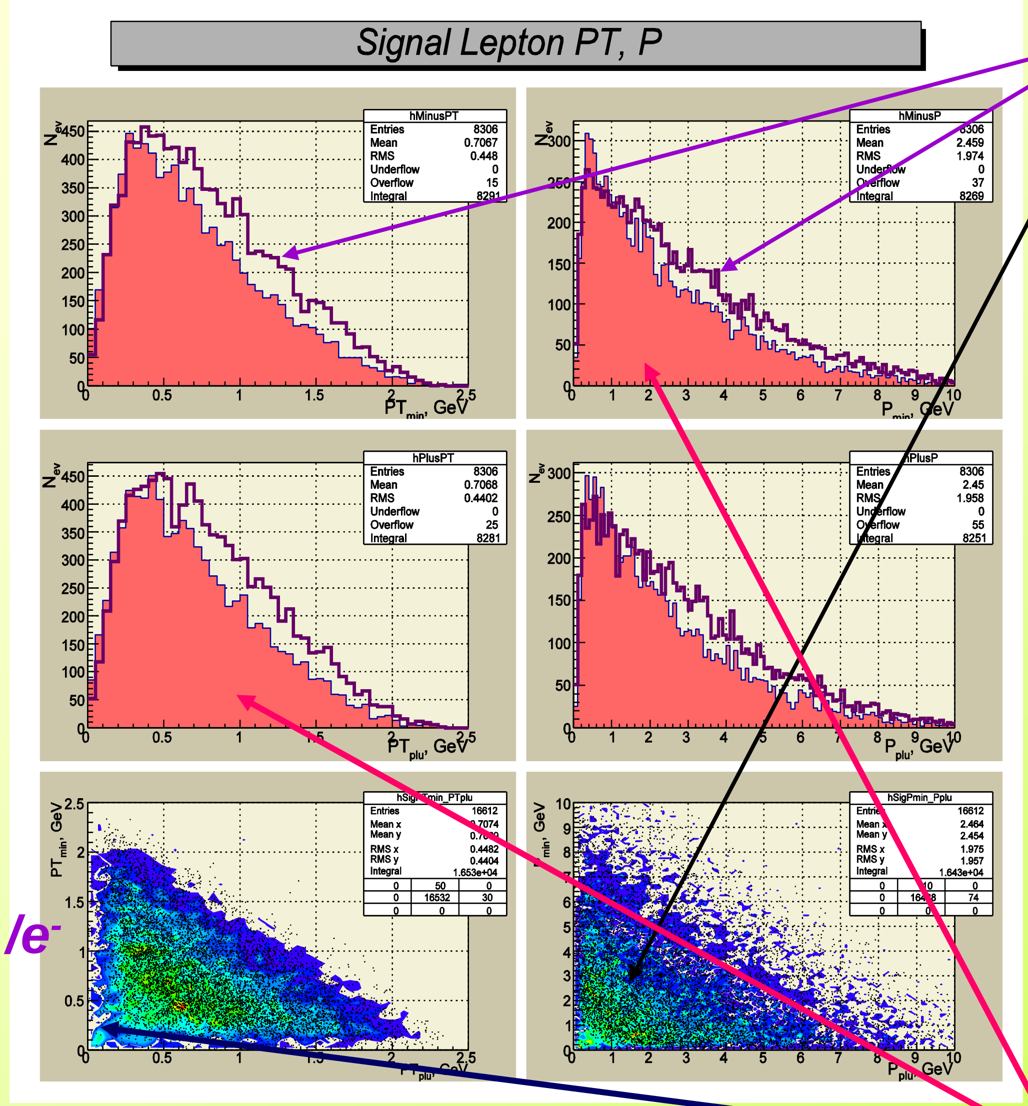
PT^e, P^e, PT^{e+}/PT^{e-}, P^{e+}/P^{e-} of e^+ & e^-

PYTHIA6.4 (black dots)

e^-

e^+

e^+/e^-



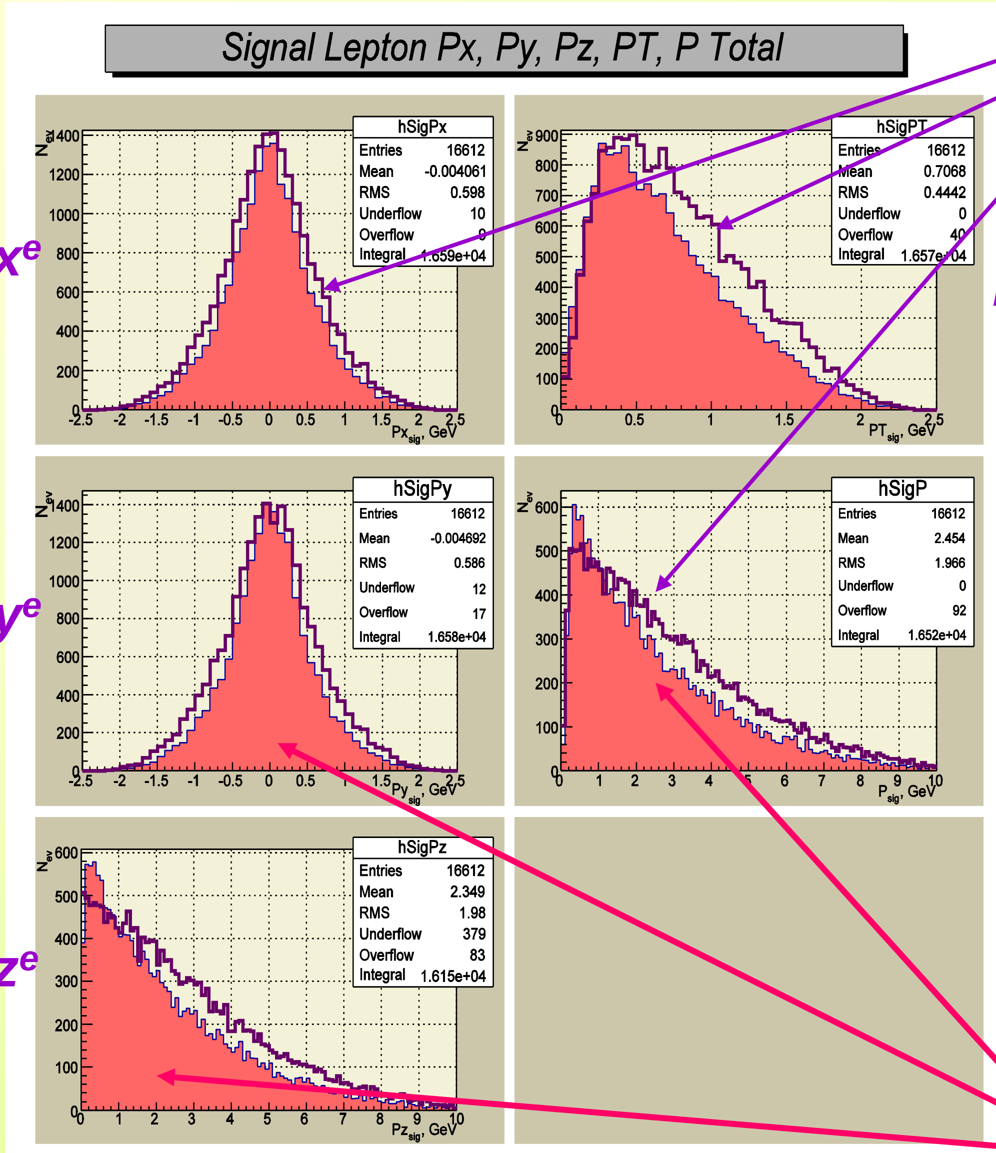
PT^e P^e

- The distributions for e^+ and e^- are practically identical.
- PandaRoot spectra *shift to the* ***region of lower momenta P and PT*** comparing to the PYTHIA ones.
- In the region of **small 0< PT <0.3 GeV** the number of events obtained in PandaRoot **slightly exceed** the initial distributions. At the **higher PT > 0.4 GeV** their **number is reduced** significantly.
- At the region of **smaller values 0.3 < P < 0.8 GeV** one can see the **excess** of PandaRoot events over initial ones simulated in PYTHIA, whereas at the **larger values of P > 2 GeV** their **number is reducing**.

PandaRoot & Geant 4 (blue dots)

Total Px^e, Py^e, Pz^e, PT^e, P^e of $(e^+ + e^-)$

PYTHIA6.4



- Like in the case of the e^+/e^-, taken separately:
- Distributions over **Px and Py** are *identical to each other and follow the initial distributions* at PYTHIA level except ***some loss of events***
- Distributions over **PT** show the **shift** of the spectrum **to the lower values** comparing to PYTHIA one**. At small PT<0.3 GeV** the PandaRoot number of events is **slightly exceed** the initial distributions. At the **higher PT > 0.4 GeV** their number is **reduced significantly**.
- Distributions over the **Pz & P** show the **excess** over PYTHIA results in the region of small **0.2 < Pz < 0.8 GeV** and some **reduction** of number of events at the medium values of **2 < Pz < 8 GeV.**

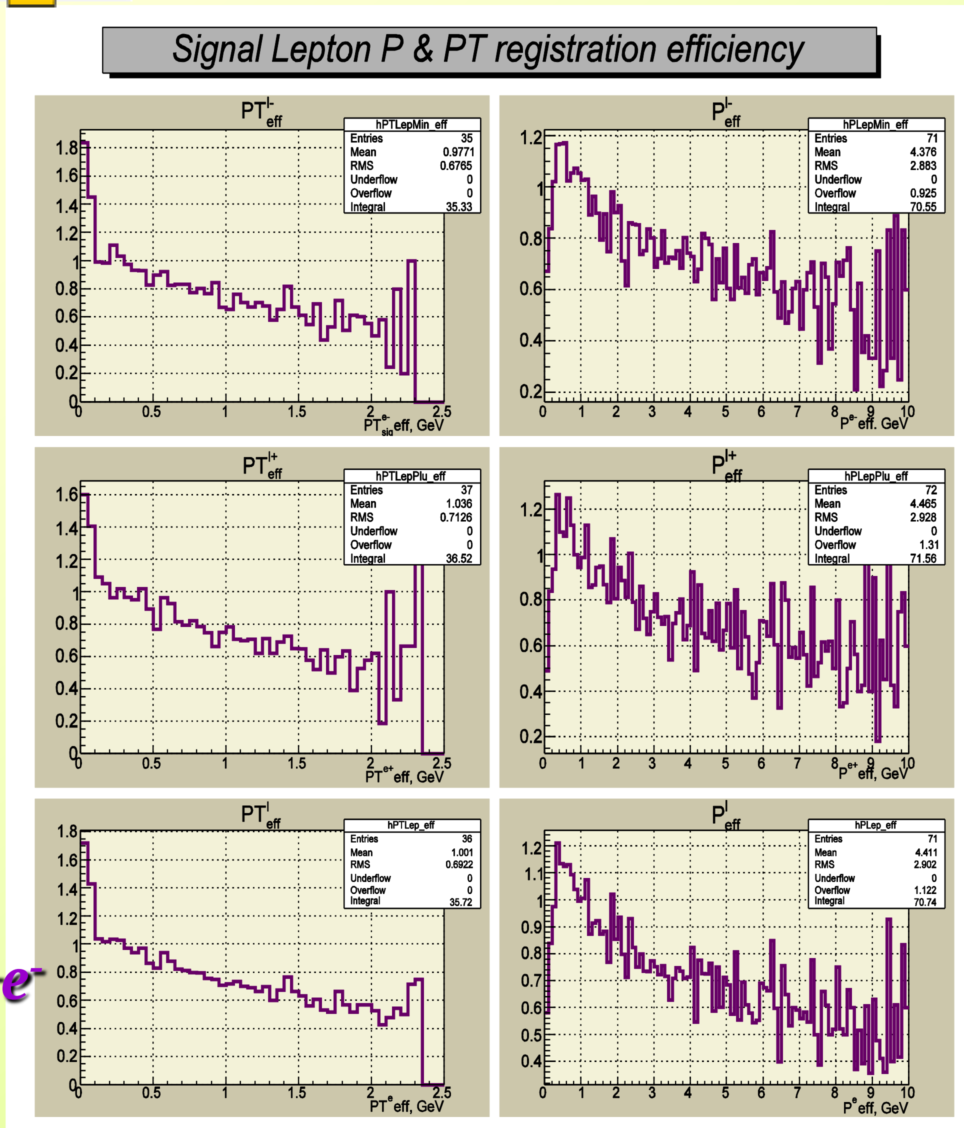
PandaRoot & Geant 4

Signal e^+/e^- P & PT registration efficiency

e^-

e^+

$e^+ + e^-$



PT **P**

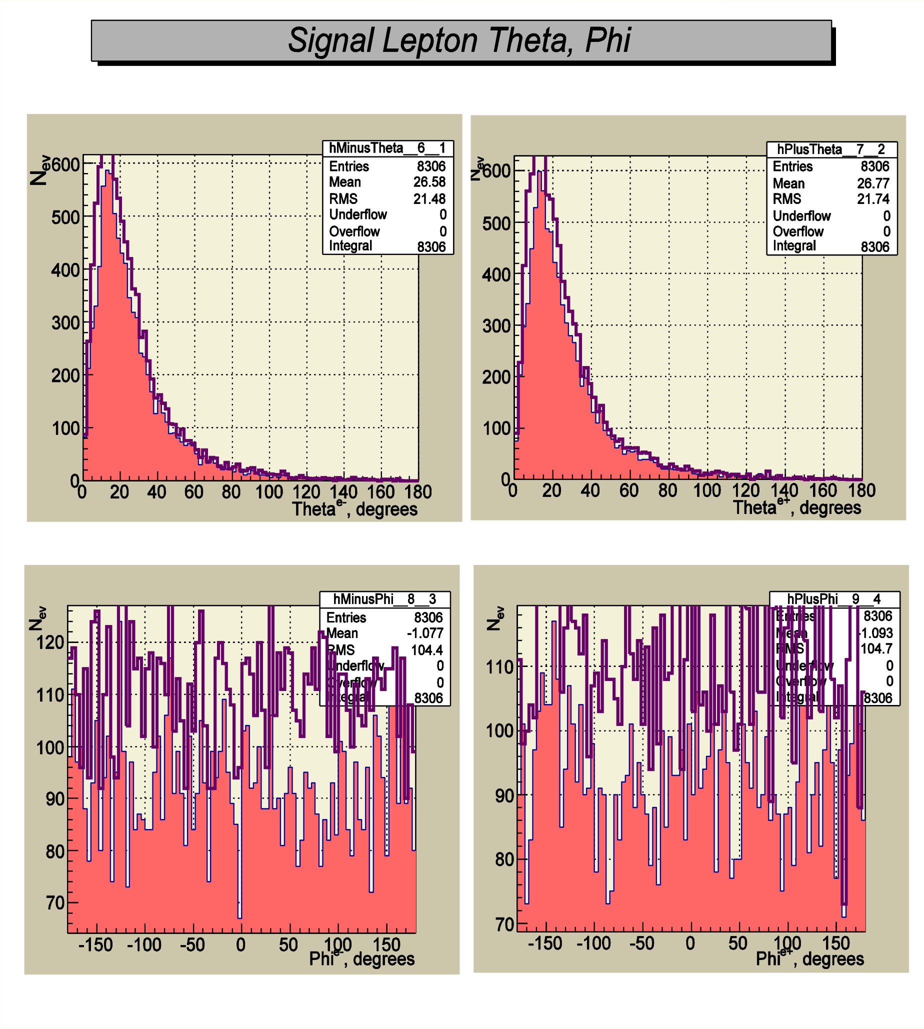
<u>**Efficiency of registration** ***Eff***</u> is calculated as **a ratio of the number of leptons "registered"** in a definite momentum region while modeling *in PandaRoot* **to the ones initially generated** in the same momentum region *in PYTHIA* .

- At the **low values of PT < 0.1 GeV *Eff* >1** may be caused by the production of some additional low energetic e^- in a result of interaction with the detector environment. At the **higher moment values** the registration efficiency <u>*is evenly falls linearly up*</u> to ***Eff* ≈ 0.4-0.6** and the ***Eff*** spectrum stop at **PT = 2.35 GeV**.
- The values of **e^+/e^- full momentum P *Eff*** <u>*sharply grows*</u> at the values **P < 0.4 GeV** from ***Eff* = 0.6 → 1.2**, that can be explained by the reason described above. Then the distribution curve practically <u>*linearly falls*</u> up to the value of ***Eff* = 0.5**.

e^+/e^- *distributions over polar θ and azimuth φ angles*

θ^e

φ^e



e^- e^+

All the distributions, accounting the statistical errors and decrease of the number of “registered” particles, repeat the distributions obtained in PYTHIA.

Namely, distributions over polar angle θ show the maximum at the values about 15 degrees, whereupon sharply fall up to the values about 120 degrees.

Distributions over azimuth angle φ show relatively uniform character.

Total θ^e, φ^e distributions, $M_{inv}(e^+,e^-)$

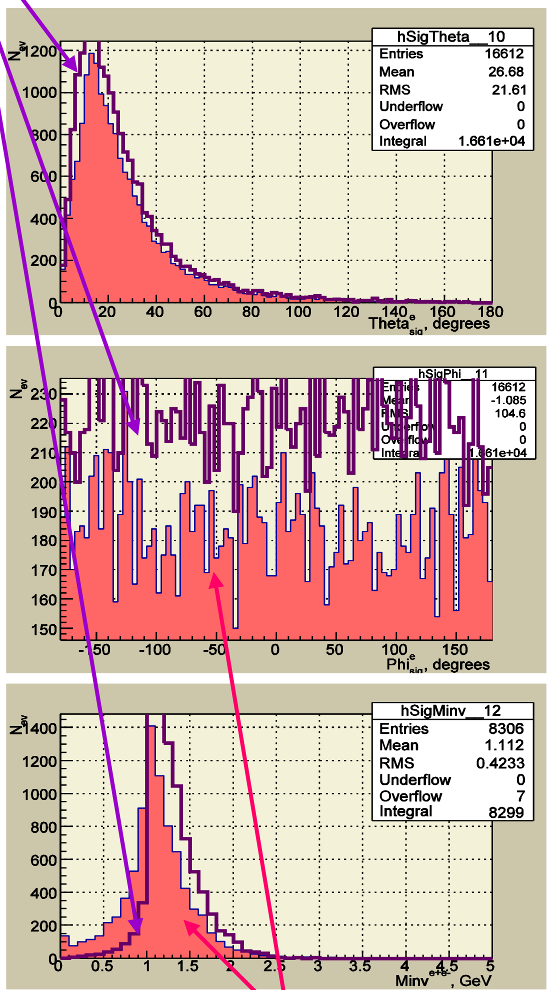
PYTHIA6.4

Signal Lepton Theta, Phi, Minv

θ^e

φ^e

M_{inv}



PandaRoot & Geant 4

- ***θ^e* - polar angle , *φ^e* - azimuth angle**
- *$M_{inv}(e^+,e^-)$* – invariant mass of the e^+,e^- pair
- Both angle distributions repeat the initial distributions obtained in PYTHIA. Distribution over the polar angle θ shows the maximum at the value ≈ 15 º, whereupon sharply falls and goes up to the values ≈120 º. Distribution over the **azimuth angle φ** shows *relatively uniform character* with some gaps at 40º (-40º) and 135 º (-135 º).
- *$M_{inv}(e^+,e^-)$* distribution obtained in PandaRoot is shifted to the left for about 0.25 GeV relatively the PYTHIA one. This fact can be explained by some energy loss of electrons in detector environment, that was demonstrated before, as well as by the presence of some small fraction of additional low energetic electrons that are produced in a result of interaction with the medium of detector.

The current plot needs an additional fitting procedure and more detailed study. Nevertheless the peaks of the both distributions (from PandaRoot and PYTHIA) are rather good coincide.

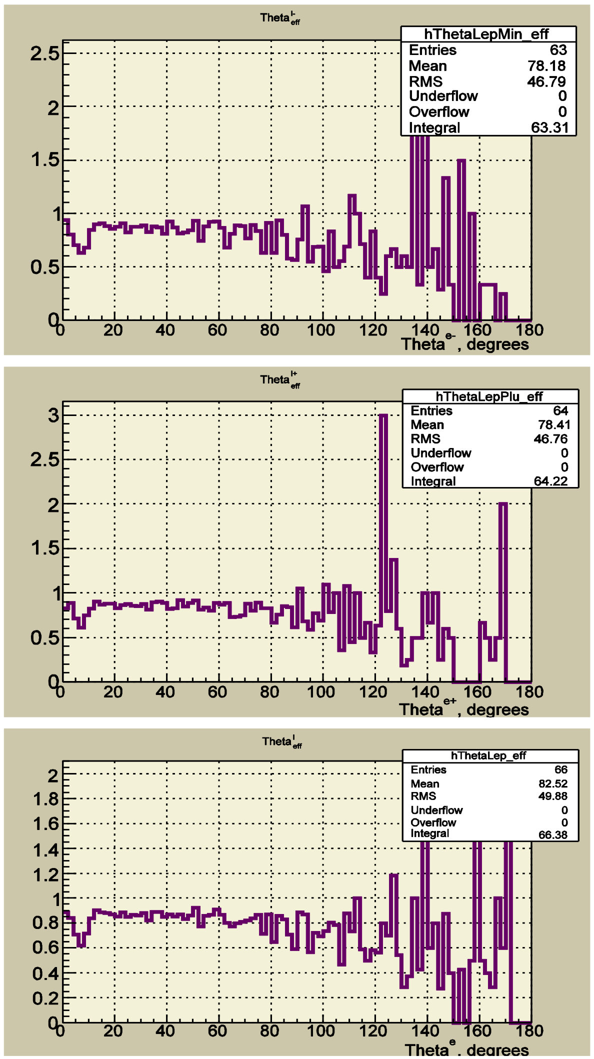
Signal e^+/e^- registration efficiency by polar angle θ

Signal Lepton THETA registration efficiency

e^-

e^+

$e^+ + e^-$



- **Efficiency of registration *Eff***

  is calculated as **a ratio of the number of leptons "registered"** in a definite angle region while modeling *in PandaRoot* **to the ones initially generated** in the same angle region *in PYTHIA*

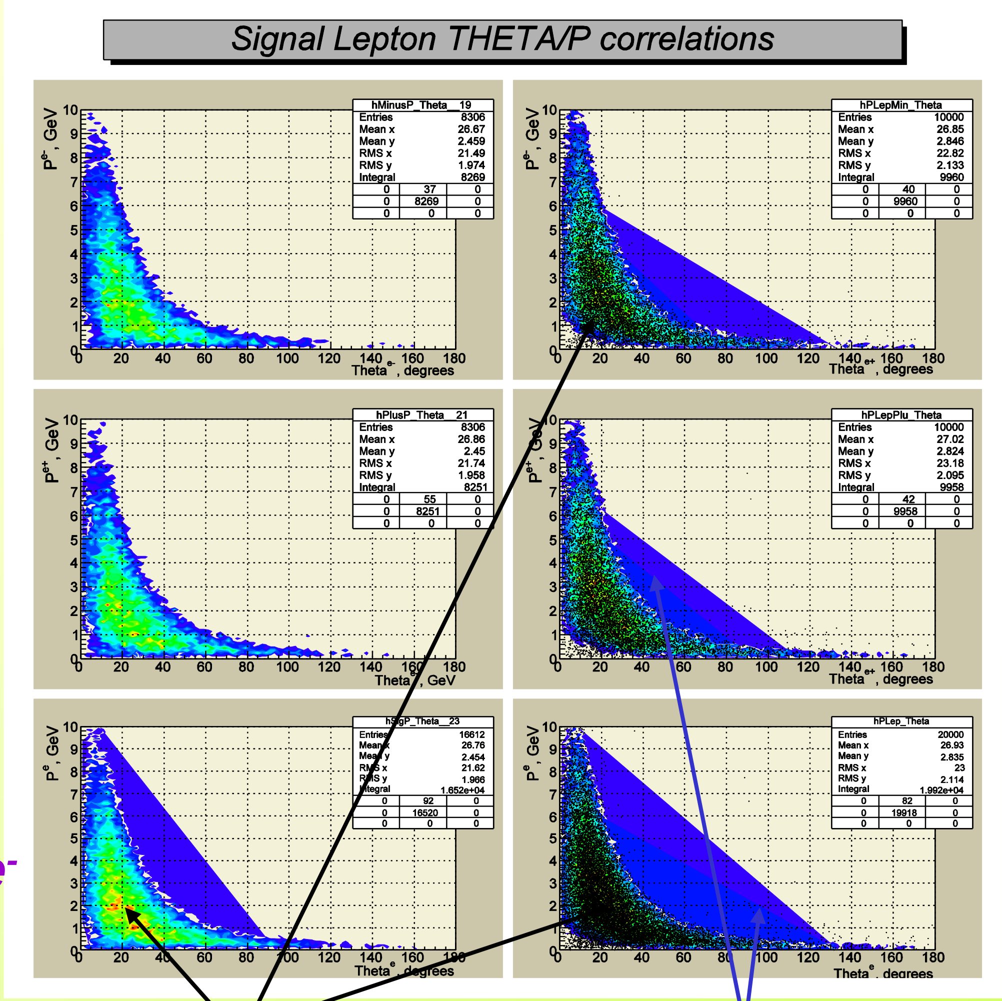
- The values of these efficiencies have almost the same value ***Eff* ≈ 0.83** (that corresponds to the whole loss of the number of signal events) in the polar angle region ***0 < θ < 80º*** with some fall up to the value ***Eff* ≈ 0.6** close to ***θ ≈ 7º***, with the following uniform (with account of statistical errors) fall to ***Eff* ≈ 0.4** at ***θ ≈ 180º*** .

Correlation distributions of polar angle θ and momentum P^e

e^-

e^+

$e^+ + e^-$



PandaRoot & Geant 4

PYTHIA6.4

- *The figures are **projections of 3-D signal e^+/e^- correlation distributions** over polar angle θ and modulus of momentum P*
- **Left coloumn** presents the results, obtained by the full simulation (PANDARoot and GEANT4).
- **Right coloumn** - the color area presents the results of PYTHIA simulation. The black dots, which correspond to the results, shown in the left column, are superimposed for comparison.
- ***Both distributions do not significantly differ from each other.***

The main source of background for $q\ qbar \rightarrow \gamma^* \rightarrow l^+ l^-$ are the Minimum-Bias processes:

Some examples:

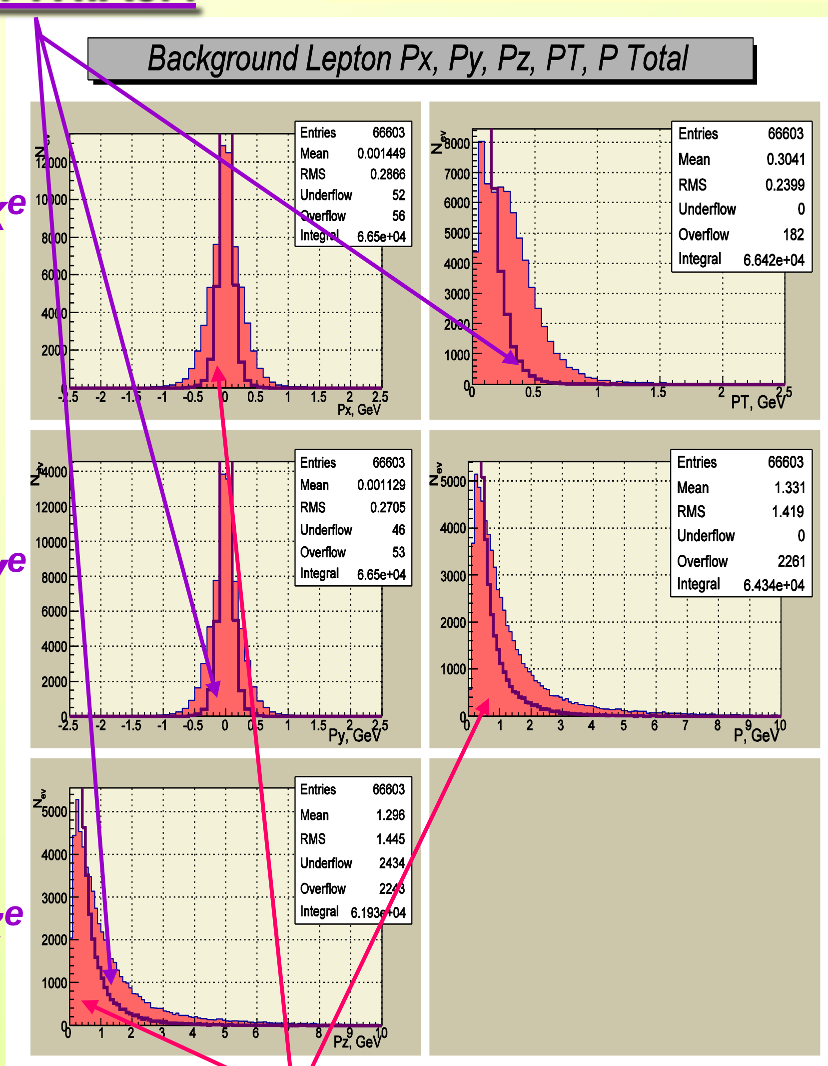
- ***Low - PT scattering*** (gives 68**%** of events with the **σ** = **33.68** mb);
- ***Single diffractive*** (gives 6**%** of events with the **σ** = **3.44** mb);
- ***qbar + q → l⁺ + l⁻*** *(gives* 0.0000015% of events, **σ = 4.59 ·10^{-6}** mb);

So, we have 1 signal event aginst 10.000.000 of Mini-bias bkgd → **S/B ≃10^{-7}**

Mini-bias background is 5 order harder than QCD background

Px^e, Py^e, Pz^e, PT^e, P^e distributions from 10^5 mini-bias BKG events

PYTHIA6.4



Px^e

Py^e

Pz^e

PT^e

P^e

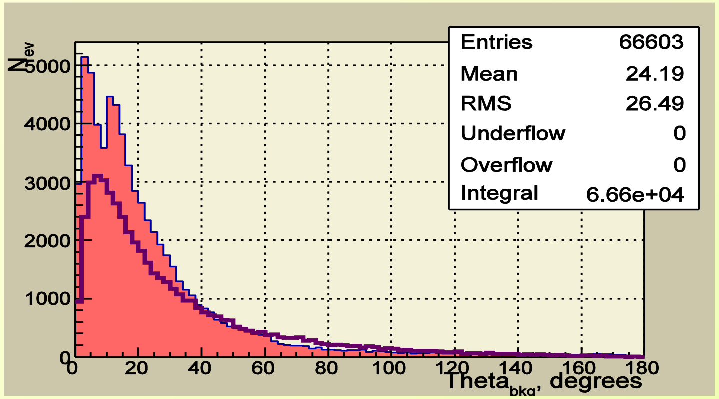
PandaRoot & Geant 4

- The final leptons in background processes
  - in PYTHIA come in a result of hadron and meson decays according to Lund fragmentation model,
  - in PandaRoot they are produced from the analogous decays laid in Geant program.
- e^+/e^- produced *from decays* of different particles in detector volume happen to be **more energetic** in comparison with analogous ones simulated in PYTHIA:

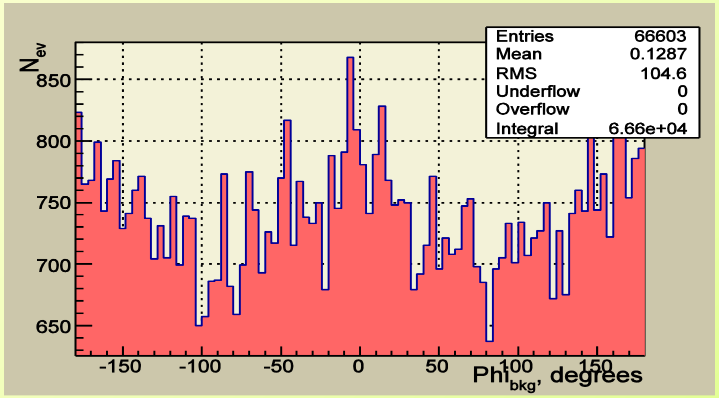
They have ≈ *0.5 GeV higher momentum* in transverse plane (Px, Py and PT),

and ≈ *1 GeV higher momentum in* longitudinal component (Pz and P).

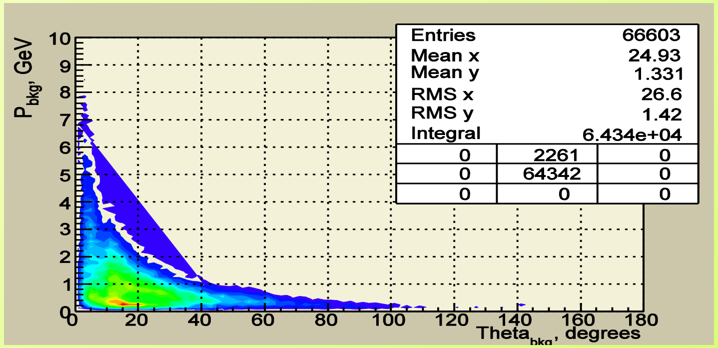
Angle and P^e/θ^e **BKG** distributions



Distributions of the background leptons from PandaRoot over the polar angle θ have the similar shape with electrons/positrons, obtained in PYTHIA simulation, but have some clear excess in direction of 5-35 degrees with the peaks on 3-5 and 9-11 degrees.



Distributions of the background electrons/positrons over the zenith angle ϕ have evidently non uniform character with prevalence in the region of 0 and 180 degrees, as well as with holes close to 80 (-80) and -100 degrees.



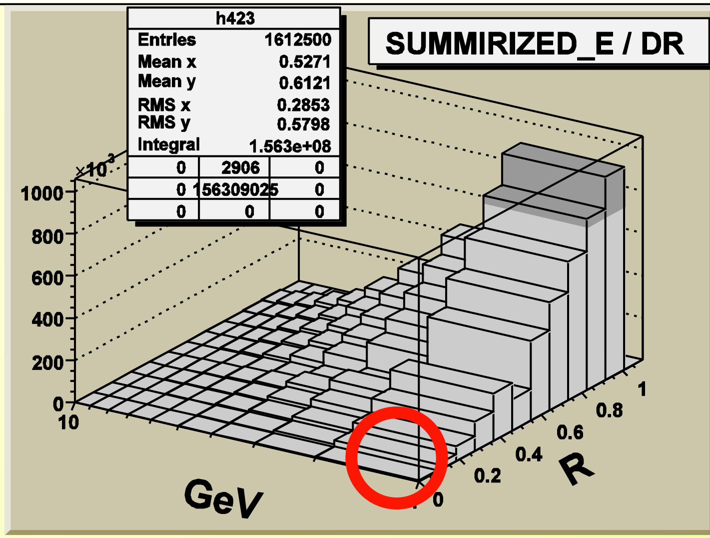
Two- dimensional plot of electron/positron distributions over their momentum P and polar angle θ shows the maximum in the region of 0.3 - 0.4 GeV over momentum and 10-21 degrees over the polar angle.

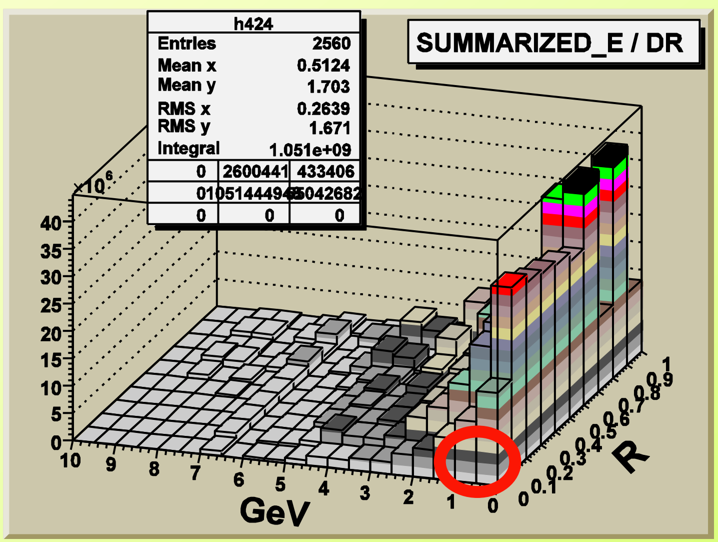
Cuts for mini-bias and QCD processes (including the signal one)

The following cuts were applied to the minimum bias and QCD sample:

1. selection of events with the only 2 leptons, having $E_l > 0.2$ GeV, $PT_l > 0.2$ GeV;
2. these 2 leptons have charges of the opposite sign;
3. the vertex of lepton origin lies within the R< 15 mm from the interaction point;
4. M_{inv} $(\ell^+\ell^-) \geq 0.9$ GeV;
5. leptons have to satisfy the isolation criteria:
   the summed energy of particles **$E_{sum} < 0.5$ GeV** within the **cone** of
   $R_{isolation} = \sqrt{\Delta_\eta^2+\Delta_\varphi^2} = 0.2$.

Lepton (e) isolation criteria





The plots show the distributions over ***summarized energy*** of the final state particles in the cones of radius

R $_{\textbf{isolation}}$ **=** $\sqrt{\eta^2+\varphi^2}$ respect to the (η – *pseudorapidity*)

upper plot → **signal events**

bottom plot → **background events**

Isolation criteria (**R** $_{\textbf{isolation}}$ **= 0.2**)

E $^{\textbf{(of particles)}}$ **= 0.5 GeV**

allows to separate 100% of QCD leptons with loss of 8% of signal events

Final ***S/B ratio = 3.8!*** ***M_{inv} (l+,l-) > 0.9***

S/B ratio = 9! ***For M_{inv} (l+,l-) > 1.0***

Applied cuts & efficiency for Minimum-Bias background events (PYTHIA results)

N of cuts	S/B ratio	Efficiency
1 *(exactly 2 leptons with* $E_l > 0.2$ GeV, $PT_l > 0.2$ GeV *)*	**$5.34 * 10^{-4}$**	$1.78 * 10^{-4}$
2 *(2 leptons are of the opposite sign)*	**$5.41 * 10^{-4}$**	0.98
3 *(The vertex is within the* *R < 15 mm)*	**$5.47 * 10^{-4}$**	0.99
4 $(M_{inv}(l_1,l_2) > 0.9)$	**$9.27 * 10^{-2}$**	0.006
5 *Isolation*	**3.8**	0.024

PandaRoot results

- **<u>100.000 background events</u>** were generated in PandaRoot
- 68.803 **e^+/e^-** were produced per 10^5 events.
- The number of background events were no one **e^+/e^-** was registered is 55.448, i.e. 55.4%.
- The number of background events including only1 **e^+/e^-** is 29.311, i.e. 29.3%.
- Thus the number of events having 2 and more **e^+/e^-** is 15.241, i.e. 15.2%.
- The number of events, which are satisfy to the selection criterion – the presence of exactly 2 leptons of different signs with Pe >0.2 GeV and PTe > 0.2 GeV is zero!

- ***Thus the 1-st proposed selection criterion gives the background suppression at least for the 5 order of magnitude (in 10^5 times), better that as was predicted in the simulation on the level of PYTHIA.***

- …But since the cross section difference of background and signal events is 7 orders of magnitude, the more prolonged and deep study of background events is needed with their simulation at much higher statistic, that demand many terabytes of disk space, which are not yet found...

Summary

- ✓ *Monte-Carlo kinematical distributions of individual **e^+/e^-** from the leptons pair production process were presented on the basis of PandaRoot and compared with the initial ones, simulated in PYTHIA6.4 for the case of $E_{beam} = 15$ GeV*
- ✓ ***e^+/e^-** registration efficiencies over P & PT, polar angle θ were also shown*
- ✓ *Monte-Carlo kinematical distributions of **e^+/e^-** from the minimum-bias process were presented on the basis of PandaRoot and compared with the initial ones, simulated in PYTHIA6.4*
- ✓ *The efficiency of the first proposed criteria for Signal and Background separation was shown on the basis of PandaRoot simulation. A good agreement with the initial PYTHIA estimations was obtained.*
- ✓ *Further study of the backgrounds with in PANDARoot is needed*

ROSATOM

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