Simulation of muon pairs production in "$p\bar{p} \rightarrow \mu^+\mu^- + X$" events at E_{beam} = 5 GeV and backgrounds

A.N.Skachkova

(JINR, Dubna)

PANDA XLIII. Collaboration Meeting

10 – 14 December 2012, GSI

Publications

for the higher energy E_{beam} = 14 GeV

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

  Authors: 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 "***

  Authors: A.N.Skachkova, N.B.Skachkov

  PepanLetters: JINR,

  ISSN:1814-5957, eISSN:1814-5973,

  V.6 №:4 (153) – 2009. - Pp.504-518

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.)

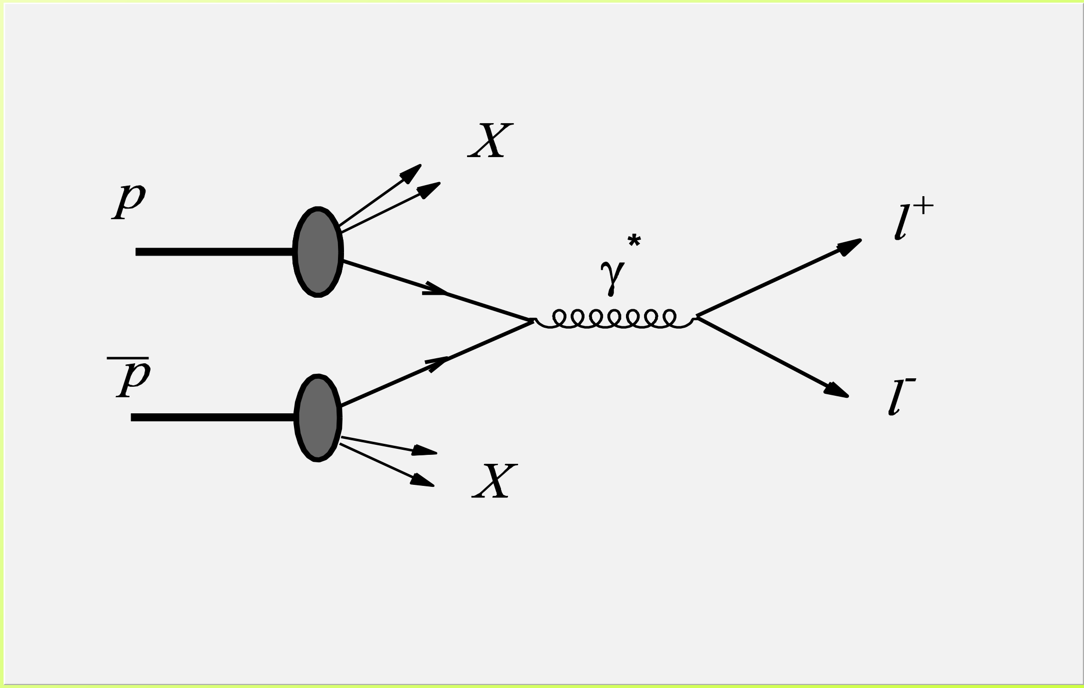
process, called also as Drell-Yan

(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

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

$$\sigma = 1.6 * 10^2 \ pb$$



PYTHIA 6 simulation for the E_{beam} = 5 GeV (3.3 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

I. Antiproton beam with **E_{beam} < 15 GeV** may provide an interesting information about ***quark dynamics inside the hadron*** and ***proton structure*** in the **energy region where** the **Perturbative QCD** comes into **interplay with** a reach **resonance (i.e., Nonperturbative) physics*.***

II. Different to 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 !).

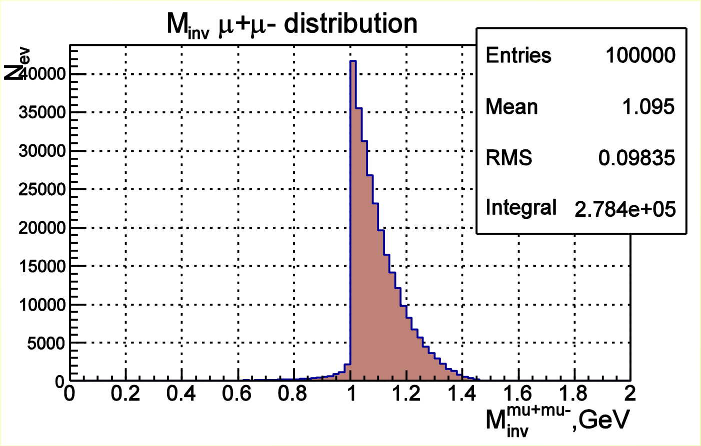
Production of lepton pair

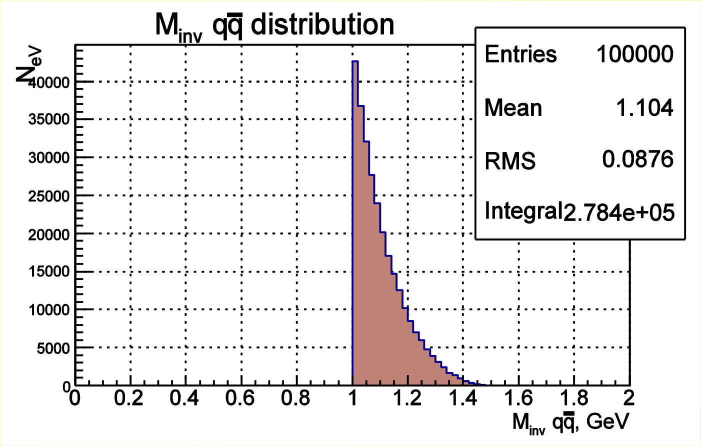
The process of lepton pair production q qbar → γ^* / Z° → $\ell^+\ell^-$ is of big physical interest because:

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

B. **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**

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





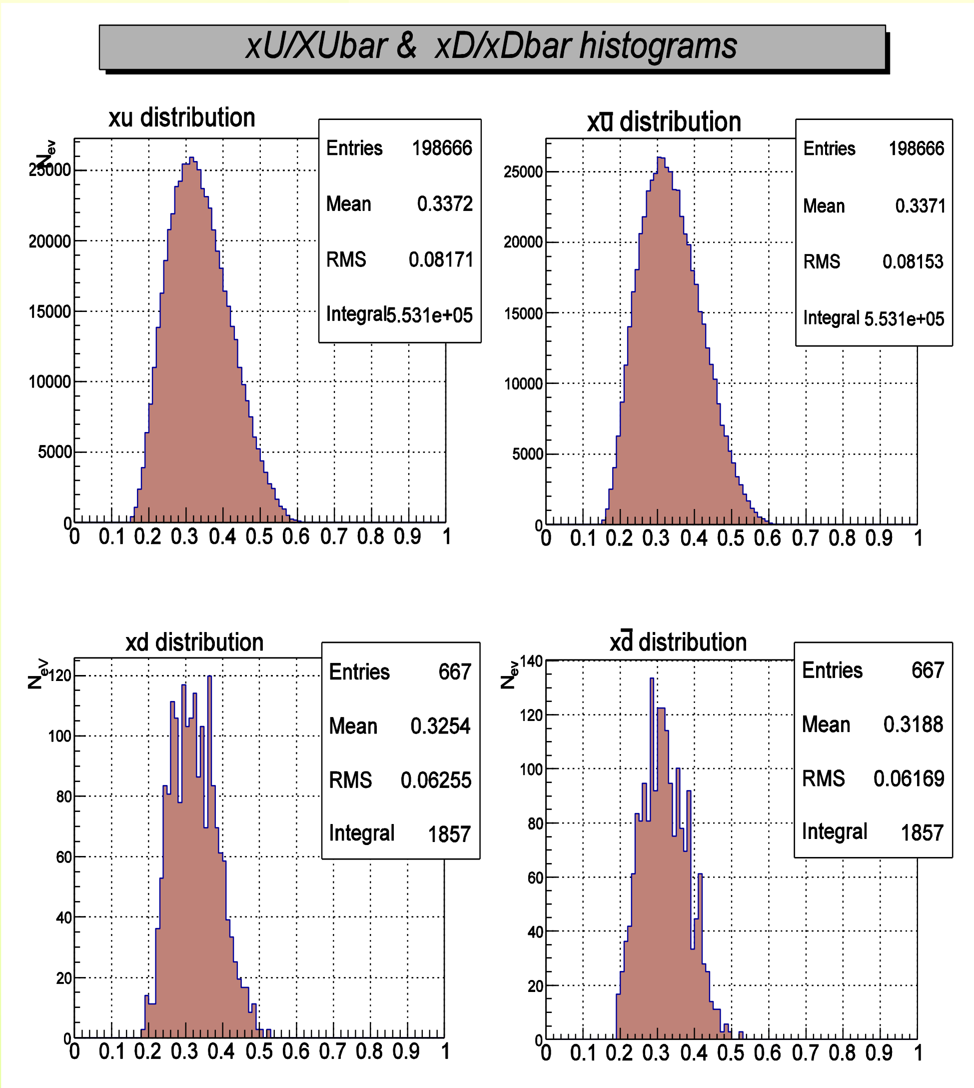
- **$M_{inv}\ \ell^+\ell^- = \sqrt{(P_{\ell^+} + P_{\ell^-})^2}$**

$M_{inv}\ \ell^+\ell^-$ 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 ≈ 1.45 GeV

→ $Q^2 < 2.1\ GeV^2$

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

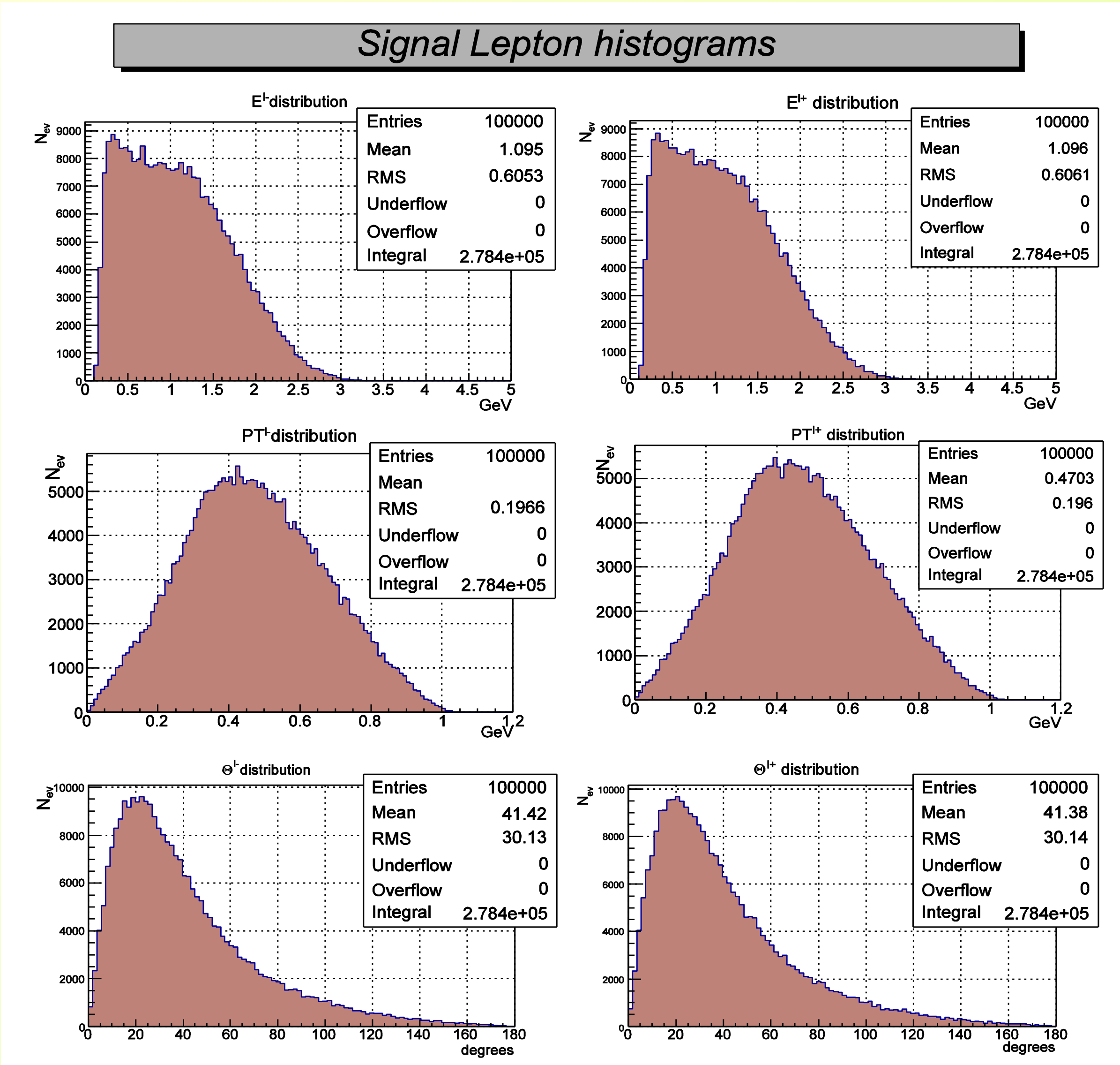


For the PANDA experiment with the $E_{beam} = 5$ GeV

$0.15 < x < 0.6$

$Q^2 < 2.1$ GeV^2

Signal $\ell^{\pm}$:



$0 \leq E_{\ell} \leq 3$ GeV,

$\langle E_{\ell} \rangle = 1.09$ GeV,

$E_{peak} = 0.3$ GeV

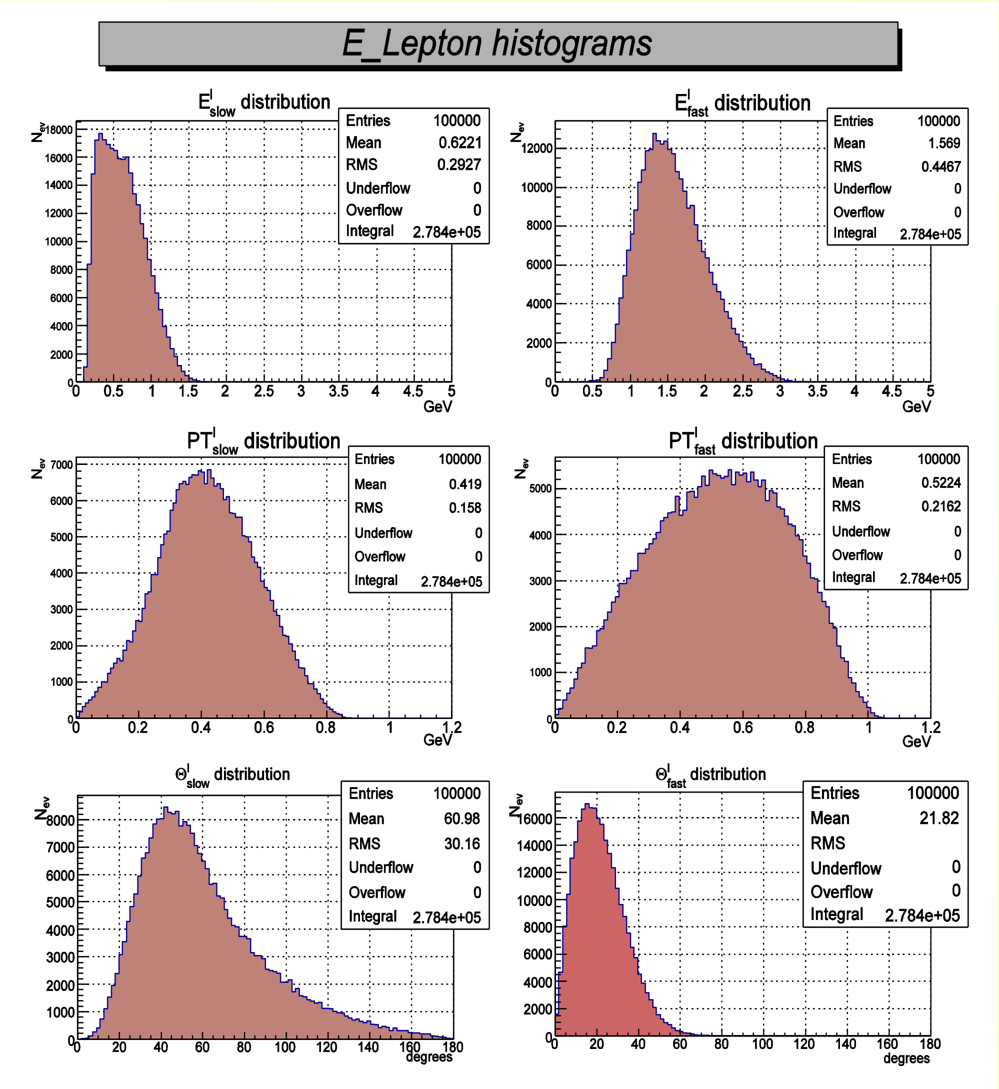
$0 \leq PT_{\ell} \leq 1$ GeV,

$\langle PT_{\ell} \rangle = 0.47$ GeV

$\langle \Theta_{\ell} \rangle = 41.4$ °

some $\Theta_{\ell} > 90°$!!!

In each signal $\ell^{\pm}$ event: $E_{\ell\ \text{"fast"}} > E_{\ell\ \text{"slow"}}$



Left column

$0.2 < E^{\mu}_{slow} < 1.6$ GeV

$E^{\mu\_peak}_{slow} \approx 0.3$ GeV,

$< E^{\mu}_{slow} > = 0.62$ GeV

$0 < \Theta^{\mu}_{slow} < 180°$

Less energetic slow leptons some have $\Theta^{\mu}_{slow"} > 90°$

Right column

$0.6 < E^{\mu}_{fast} < 3.1$ GeV

$E^{\mu\_peak}_{fast} \approx 1.3$ GeV,

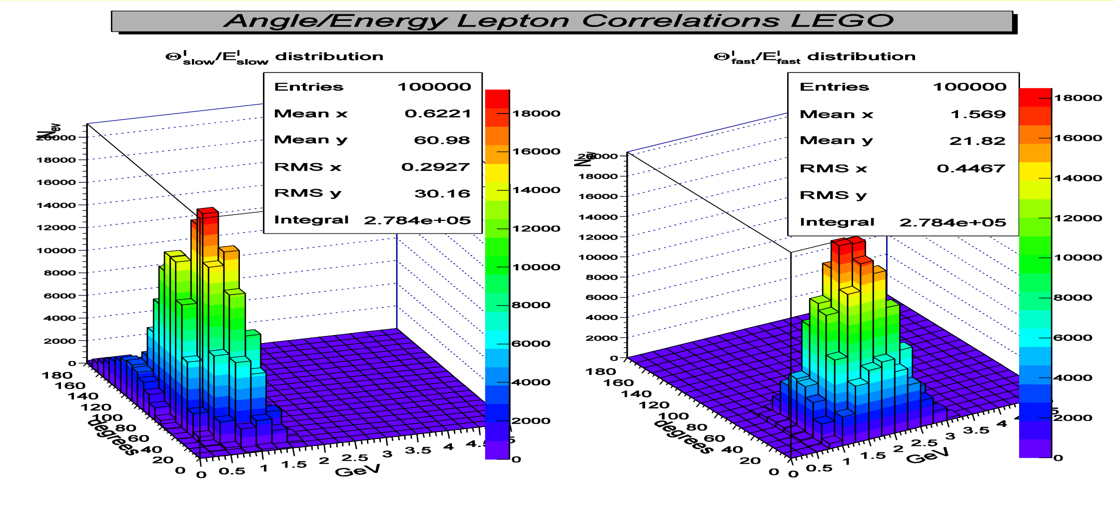
$< E^{\mu}_{fast} > = 1.57$ GeV

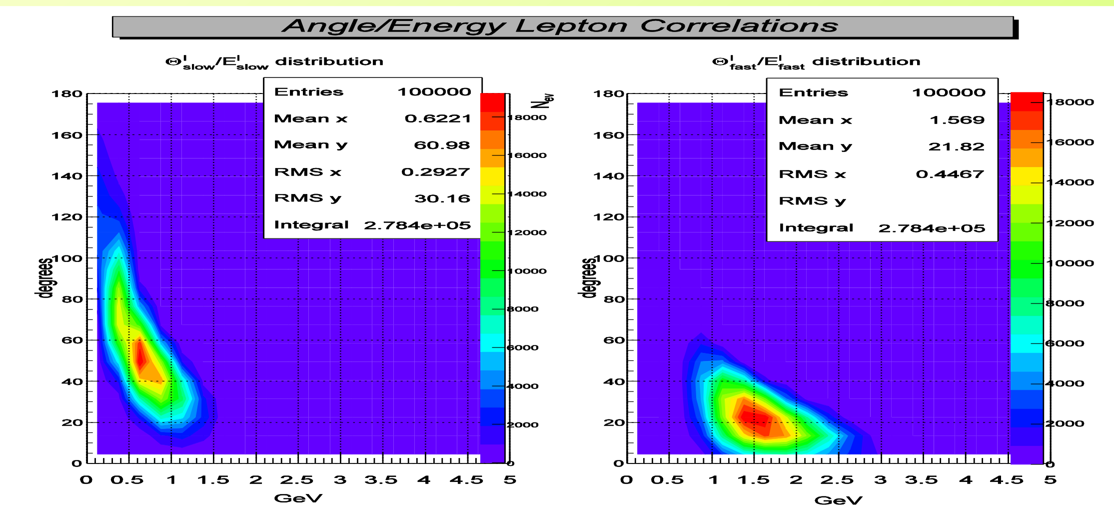
$0 < \Theta^{\mu}_{fast} < 70°$

High energetic fast leptons fly in a forward direction

Θ_ℓ/E_ℓ correlation for signal $\ell^\pm$

$\Theta_{\ell\text{"slow"}}$ / $E_{\ell\text{"slow"}}$ $\Theta_{\ell\text{"fast"}}$ / $E_{\ell\text{"fast"}}$





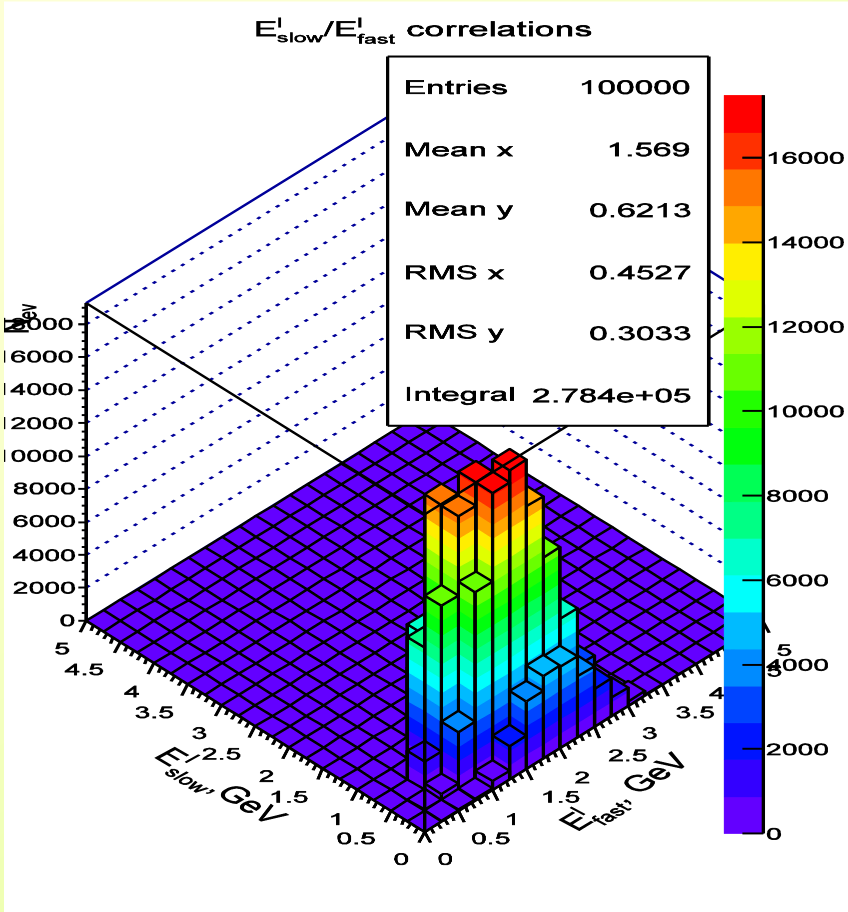
Left column – "slow" μ,

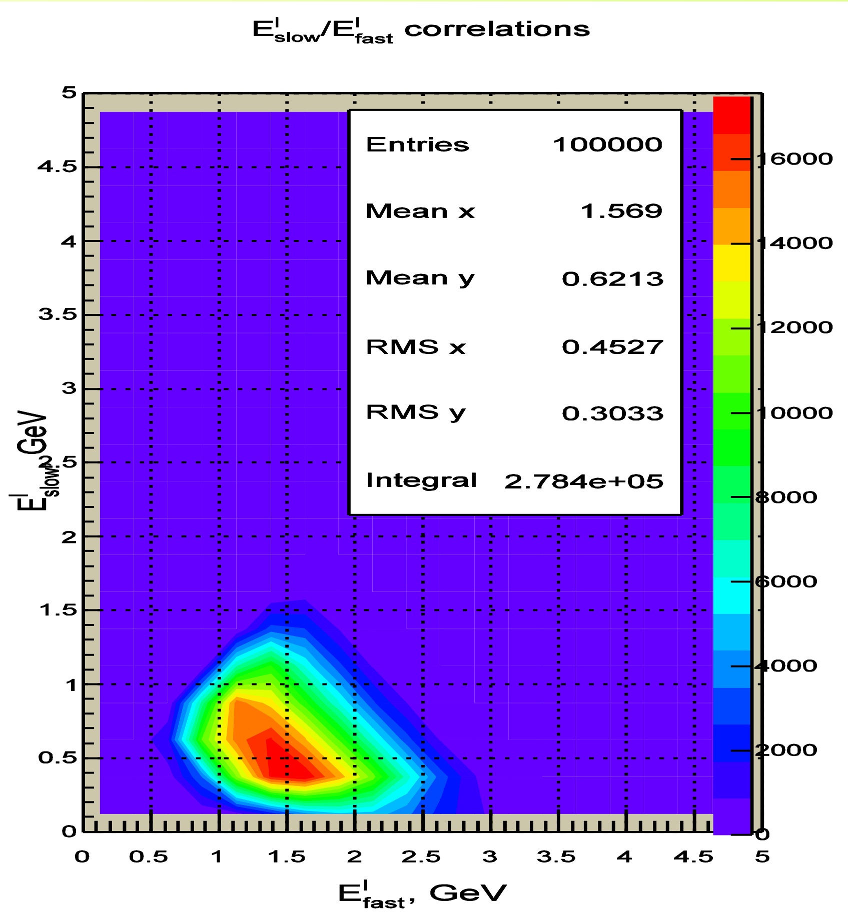
Right column – "fast" μ

Tendency:

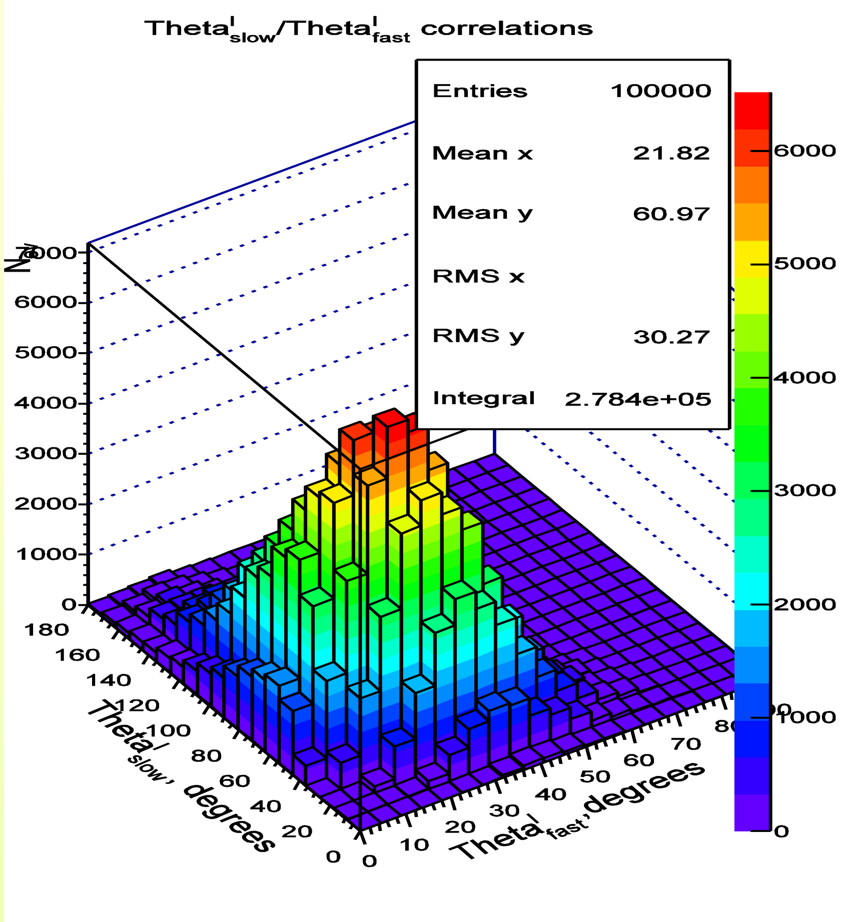
the higher is energy – the less is angle

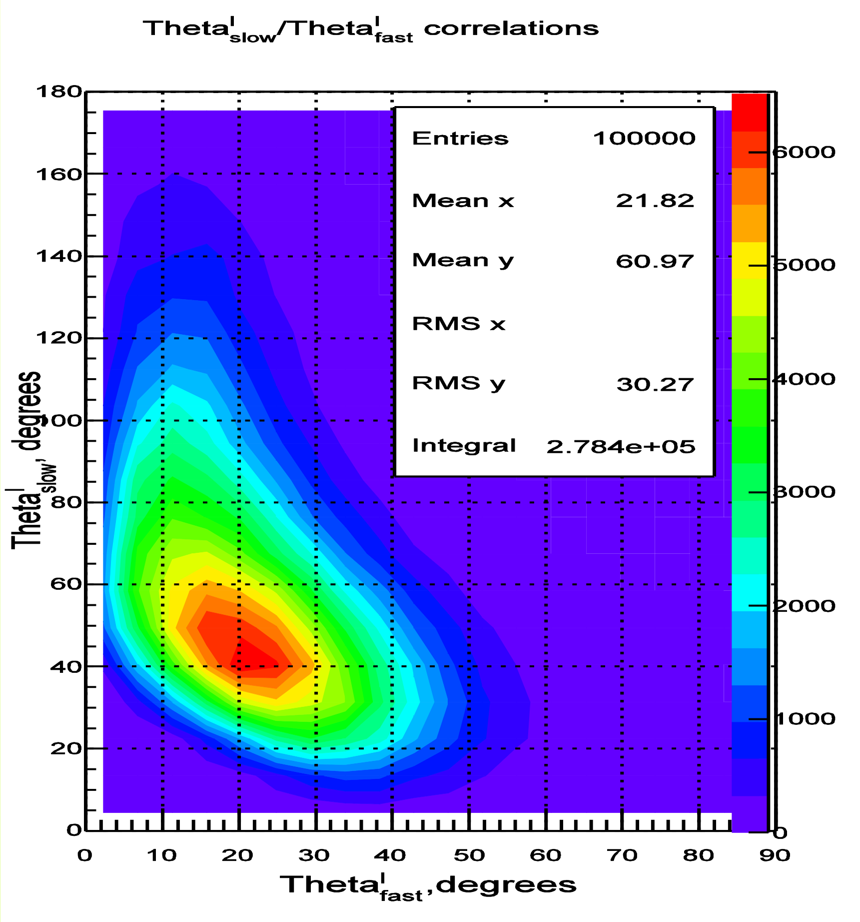
E^{μ}_{slow} / E^{μ}_{fast} correlation



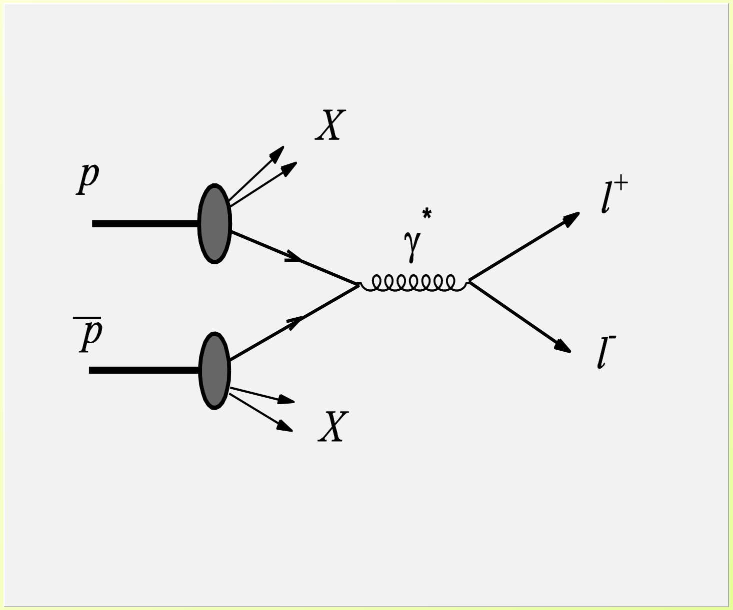


Θ^{μ}_{slow} / Θ^{μ}_{fast} correlation





MMT-DY process



Simulation of muon's kinematical characteristics was done with use of PandaRoot & Geant 3 (presented by pink histograms) at the level of stand alone muon system 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).

From the statistical numbers (entries) of distributions one can see that the ***total loss of muons in detector*** *is about* ***34.61%*** *for* μ^- *and* ***34.2%*** *for* μ^+.

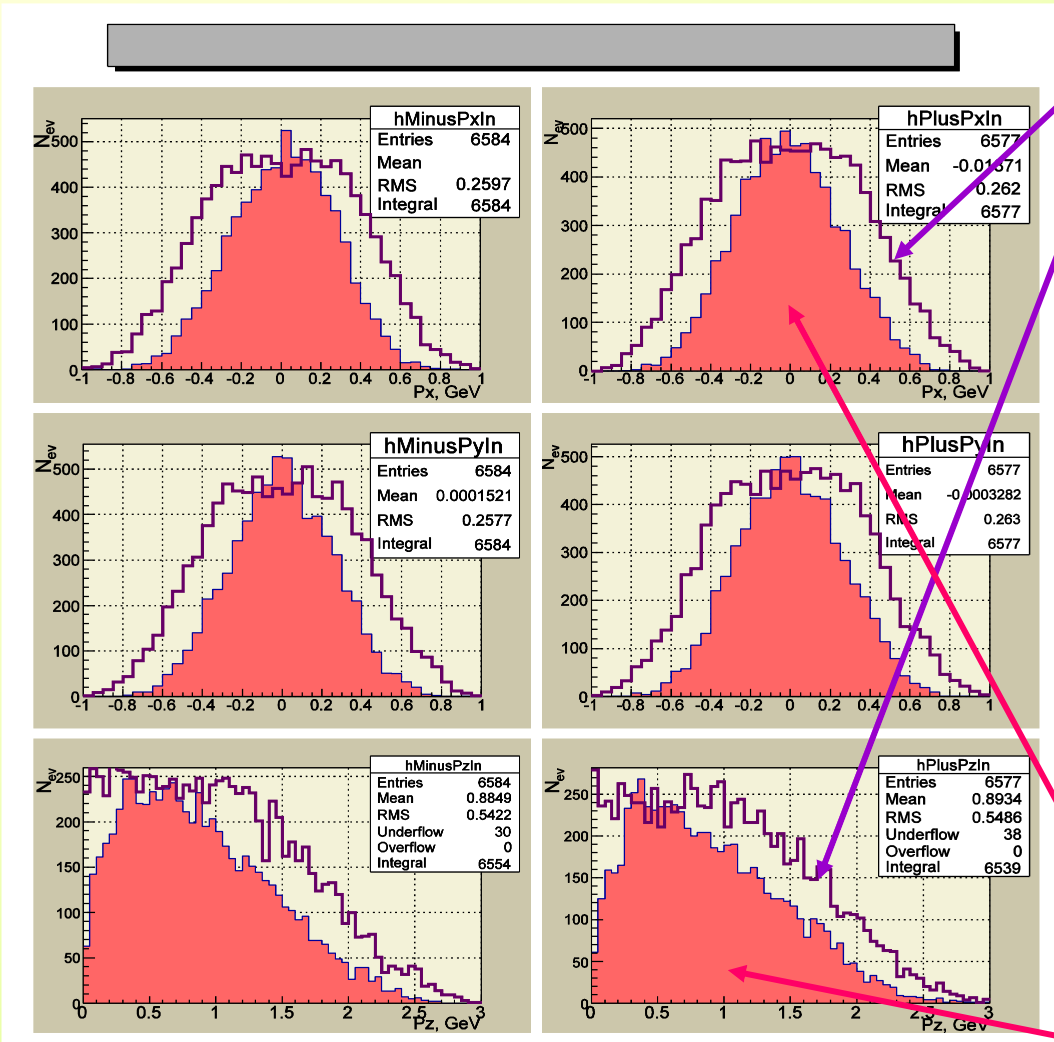
Px^{μ}, Py^{μ}, Pz^{μ} from the 1-st hit in the muon system

PYTHIA6.4

Px^{μ}

Py^{μ}

Pz^{μ}



μ^- *μ^+*

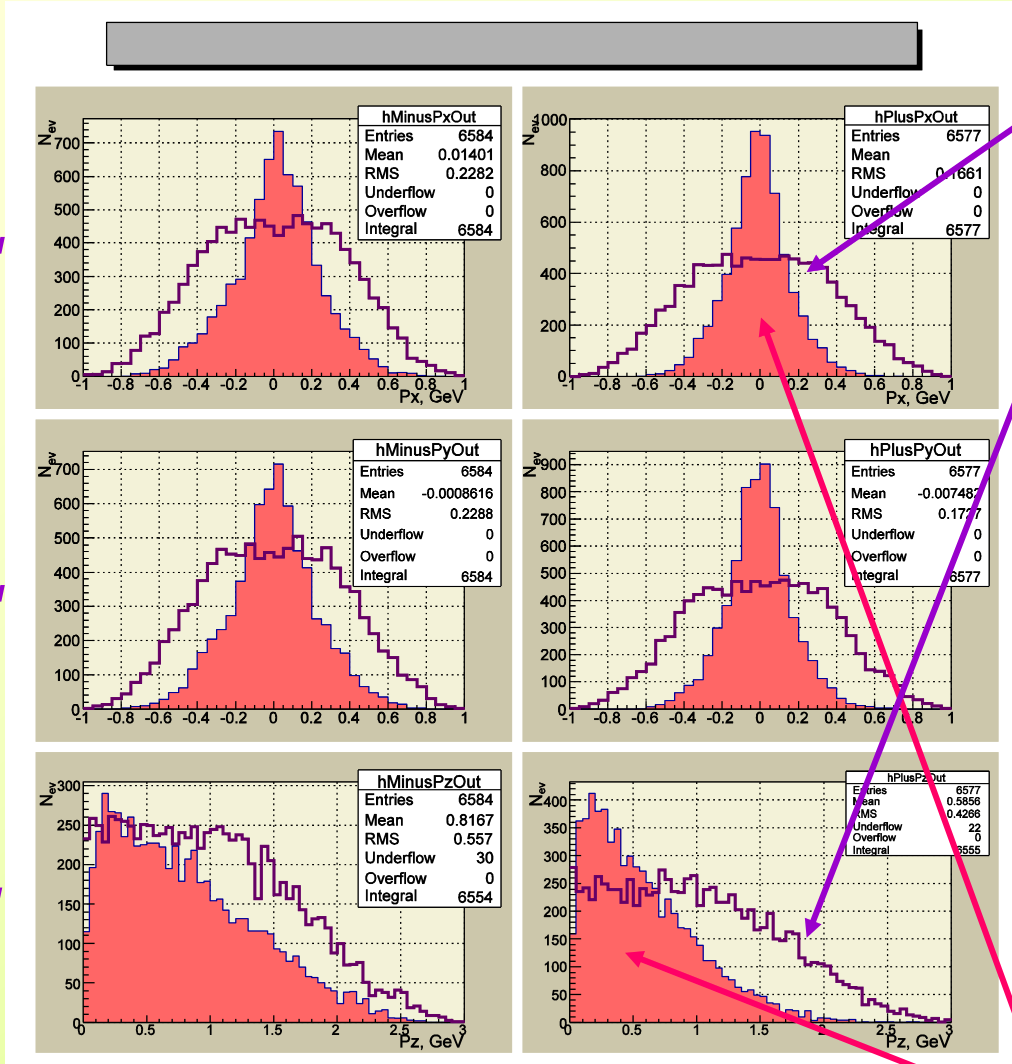
PandaRoot & Geant 3

Momenta distributions, obtained in the full simulation,

differ from those, simulated in PYTHIA6.4,

by the loss of quantity and some loss in momenta ~ 0,25 GeV for each component.

Px$^{\mu}$, Py$^{\mu}$, Pz$^{\mu}$ from the last hit in the muon system



Px$^{\mu}$

Py$^{\mu}$

Pz$^{\mu}$

μ^- μ^+

PYTHIA6.4

Momenta distributions, obtained in result of full simulation, in this case is **significantly differ** from the ones simulated in PYTHIA6.4, and **show noticeable loss of momentum** (about 0.3-0.6 GeV for each component).

Let us mention that for the positive charged muons the momentum losses are higher.

PandaRoot & Geant 3

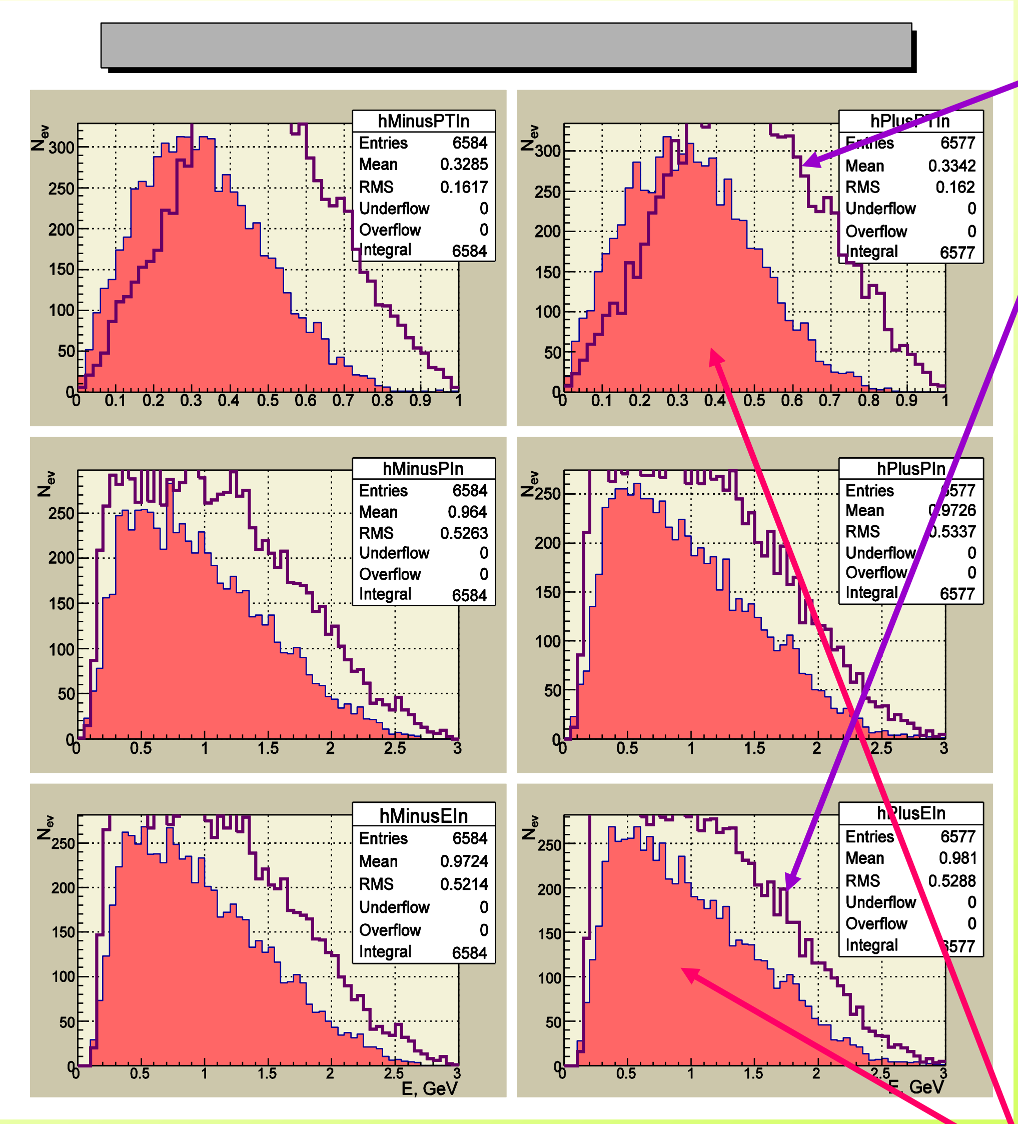
PT$^\mu$, P$^\mu$, E$^\mu$ from the 1-st hit in the muon system

PYTHIA6.4

PT$^\mu$

P$^\mu$

E$^\mu$



μ^- μ^+

Momenta & Energy distributions, obtained in result of full simulation,

differ from the ones, simulated in PYTHIA6.4 by

some loss of quantity and by the loss of E (PT) ~ 0.2 GeV

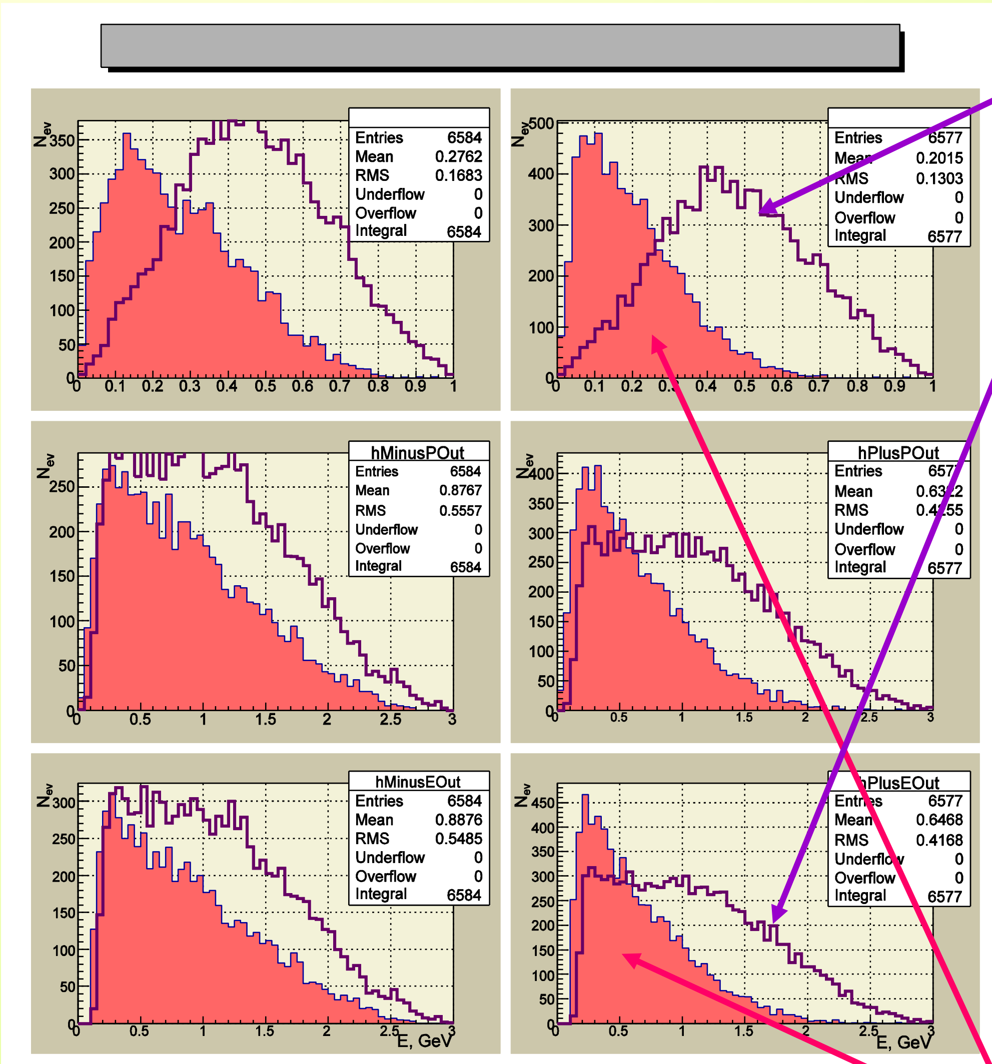
PandaRoot & Geant 3

PT^{μ}, P^{μ}, E^{μ} from the last hit in the muon system

PT^{μ}

P^{μ}

E^{μ}



μ^- ***μ^+***

PYTHIA6.4

Momenta & Energy distributions, obtained in result of full simulation,

in this case is

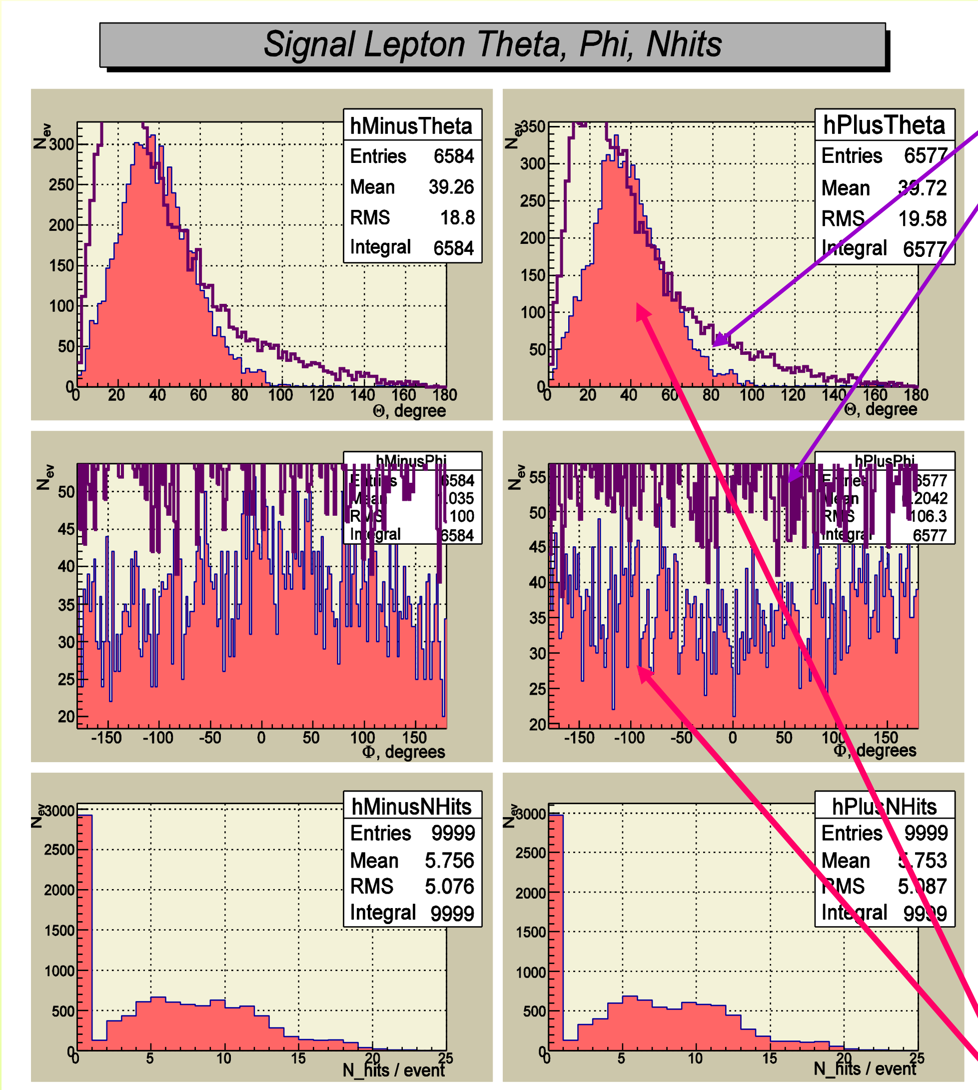
differ significantly from the ones, simulated in PYTHIA6.4, and

show noticeable loss of momentum & energy (up to 0.7 GeV) in result of penetrating through the material of the muon system.

Positive charged muons show higher loss of momentum.

PandaRoot & Geant 3

Angle θ^{μ}, φ^{μ} distributions and N_{hits} in the muon system



θ^{μ}

φ^{μ}

N_{hits}

μ^- μ^+

PYTHIA6.4

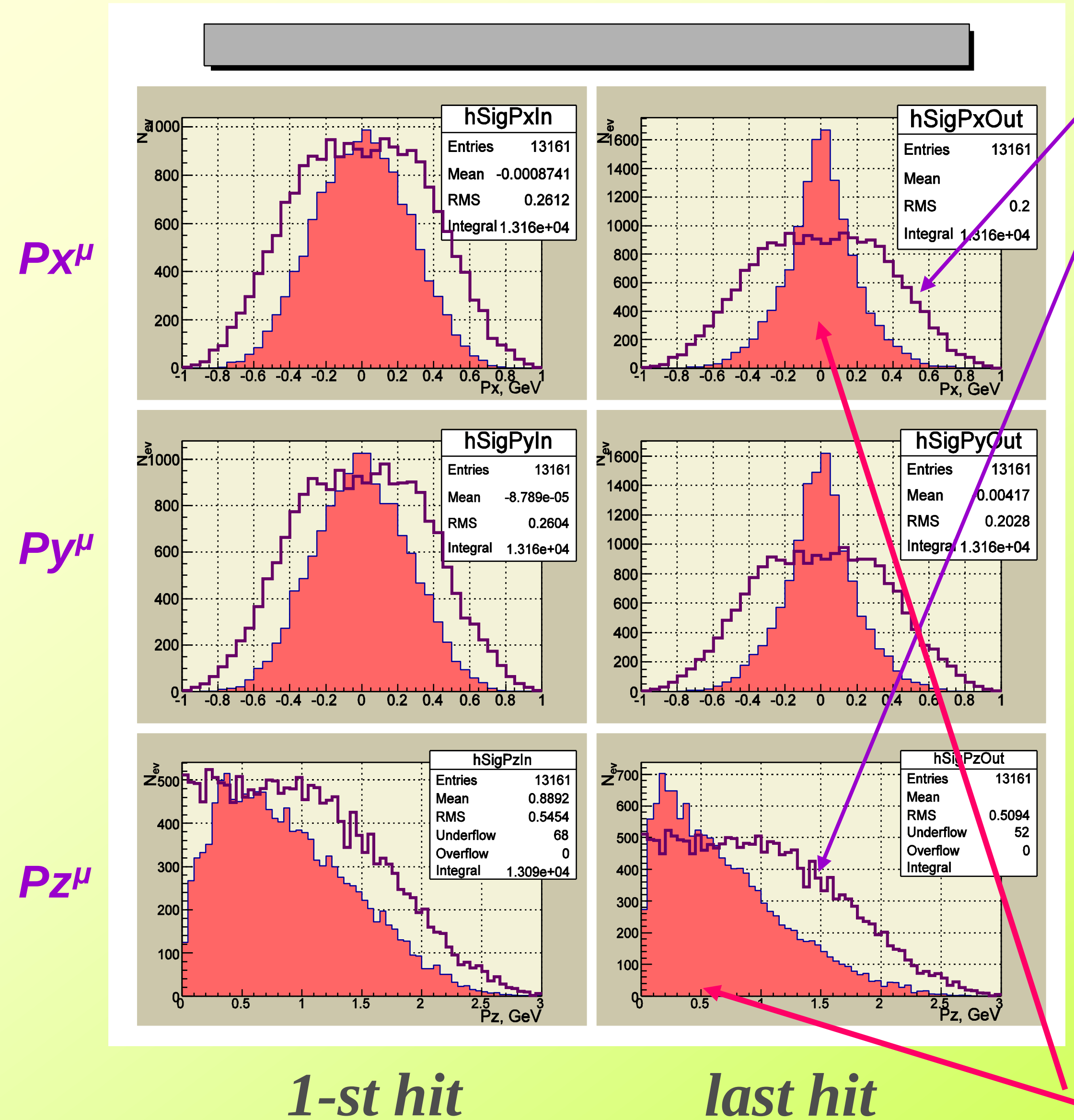
- θ^{μ} - polar angle
- φ^{μ} - azimuth angle
- N_{hits} - number of hits, made by muon in muon system per event

- The **significant difference in distributions of polar angle θ^{μ}** can be explaned by deviation in magnetic field.
- Practically no difference in distributions of the azimuth angle φ^{μ}.
- The first column in muon hits distributions shows the number of events, in which the corresponding muons gave no hits in the muon system (lost muons).

PandaRoot & Geant 3

Px^{μ}, Py^{μ}, Pz^{μ} of ($\mu^+ + \mu^-$) from the 1-st & last hit in the muon system

PYTHIA6.4



- Like in the case of separate taken muons, the *momenta distributions, obtained in result of full simulation*, **do not much differ** to the ones simulated in PYTHIA6.4 for the **values from the first hit**, exept some loss of quantity

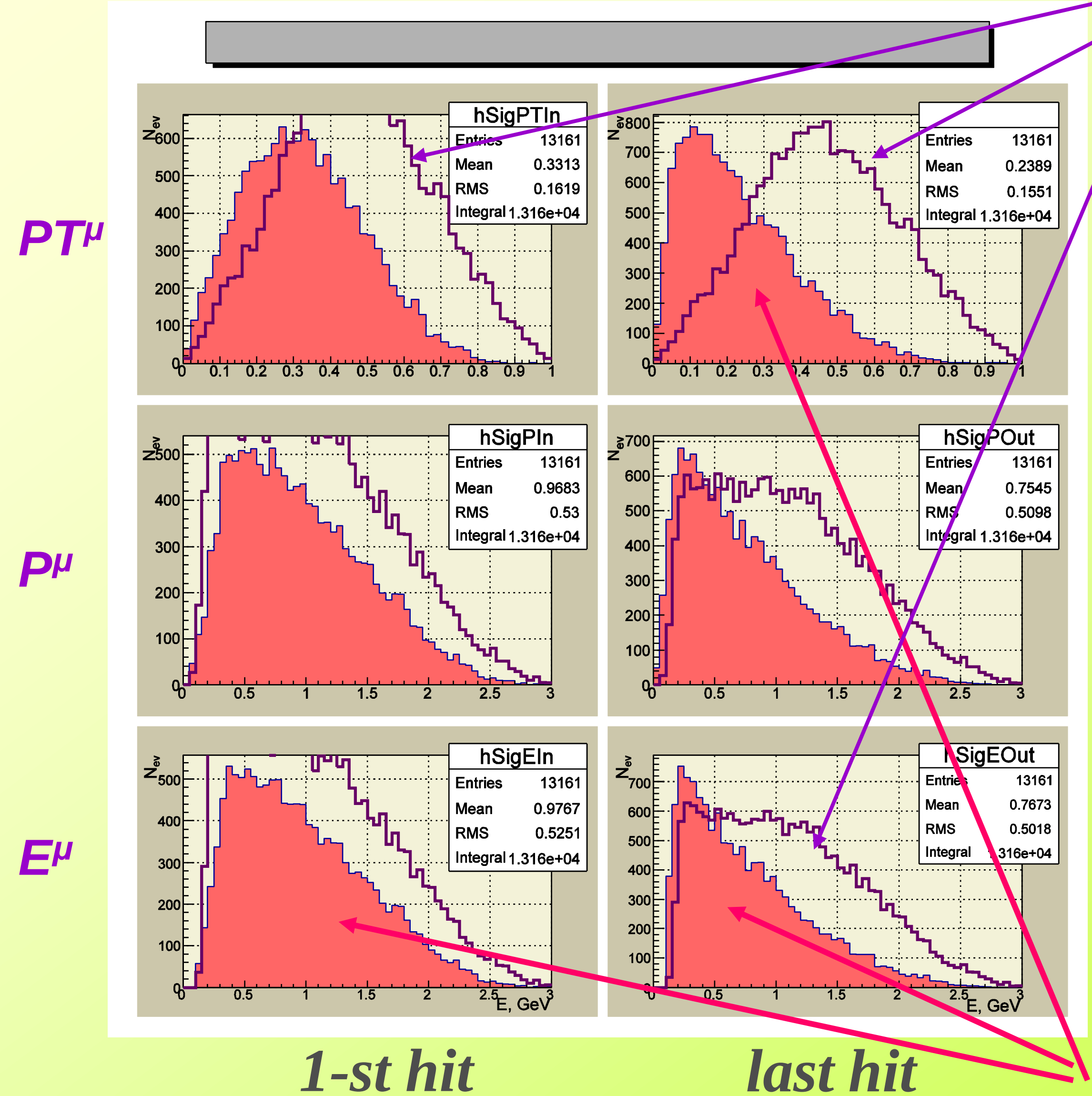
&

- **noticeably differ** to the ones simulated in PYTHIA6.4 in the **case of the last hit**, and show here the noticeable loss of momentum (about 0.4-0.5 GeV for each components).

PandaRoot & Geant 3

PT$^\mu$, P$^\mu$, E$^\mu$ of (μ^++μ^-) from the 1-st & last hit in the muon system

PYTHIA6.4



- Like in the case of the muons, taken separately, the ***momenta and energetical distributions*** of the **first hit**, obtained during a full simulation, **do not differ significantly** from the ones simulated in PYTHIA6.4. The differences is, in general, in a loss of quantity and E&PT ~0.2 GeV.

- In the **case of a last hit**, they are **noticeably differ** from the ones, simulated in PYTHIA6.4, and ***show significant loss of momentusm and energy*** (about 0.2-0.5 GeV) as a result of penetrating through the material of the muon system

PandaRoot & Geant 3

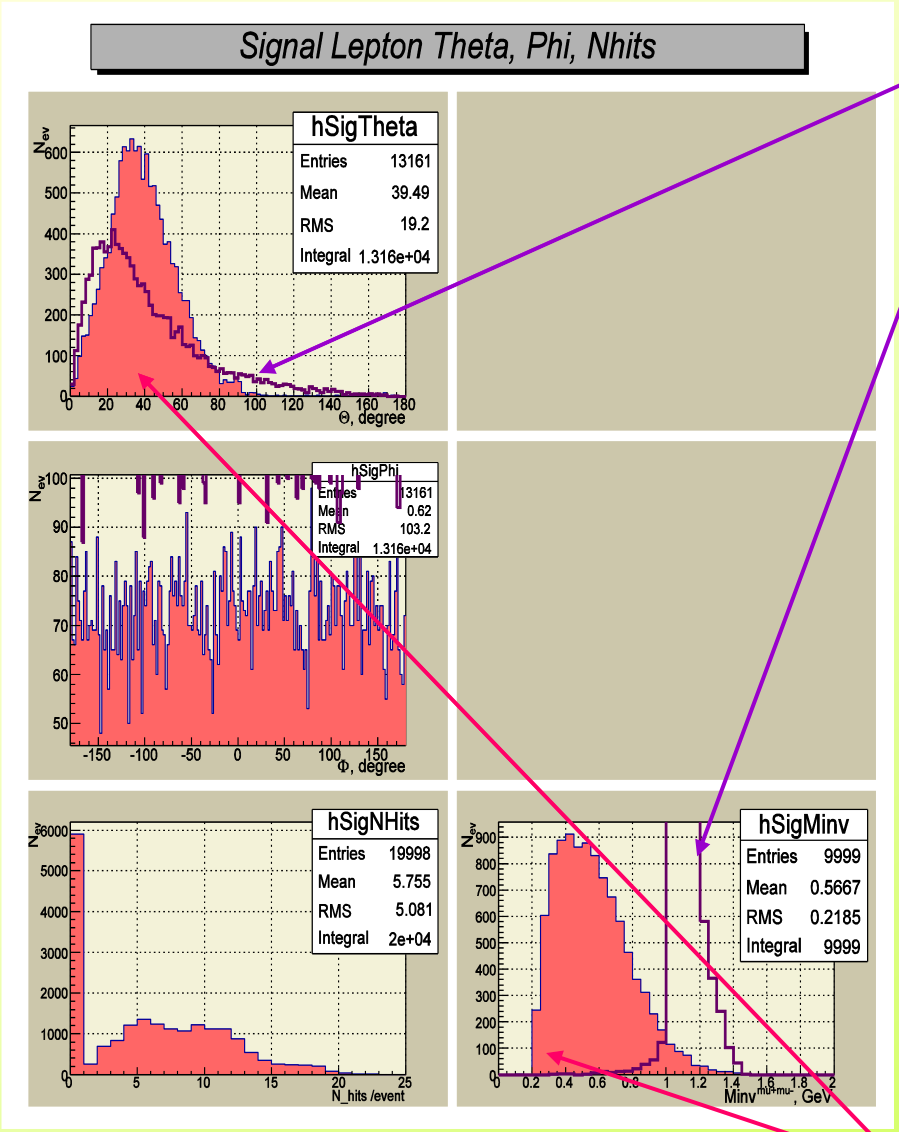
Total θ^{μ}, φ^{μ} distributions & N_{hits} in muon system, $M_{inv}(\mu^{+},\mu^{-})$

PYTHIA6.4

θ^{μ}

φ^{μ}

N_{hits}



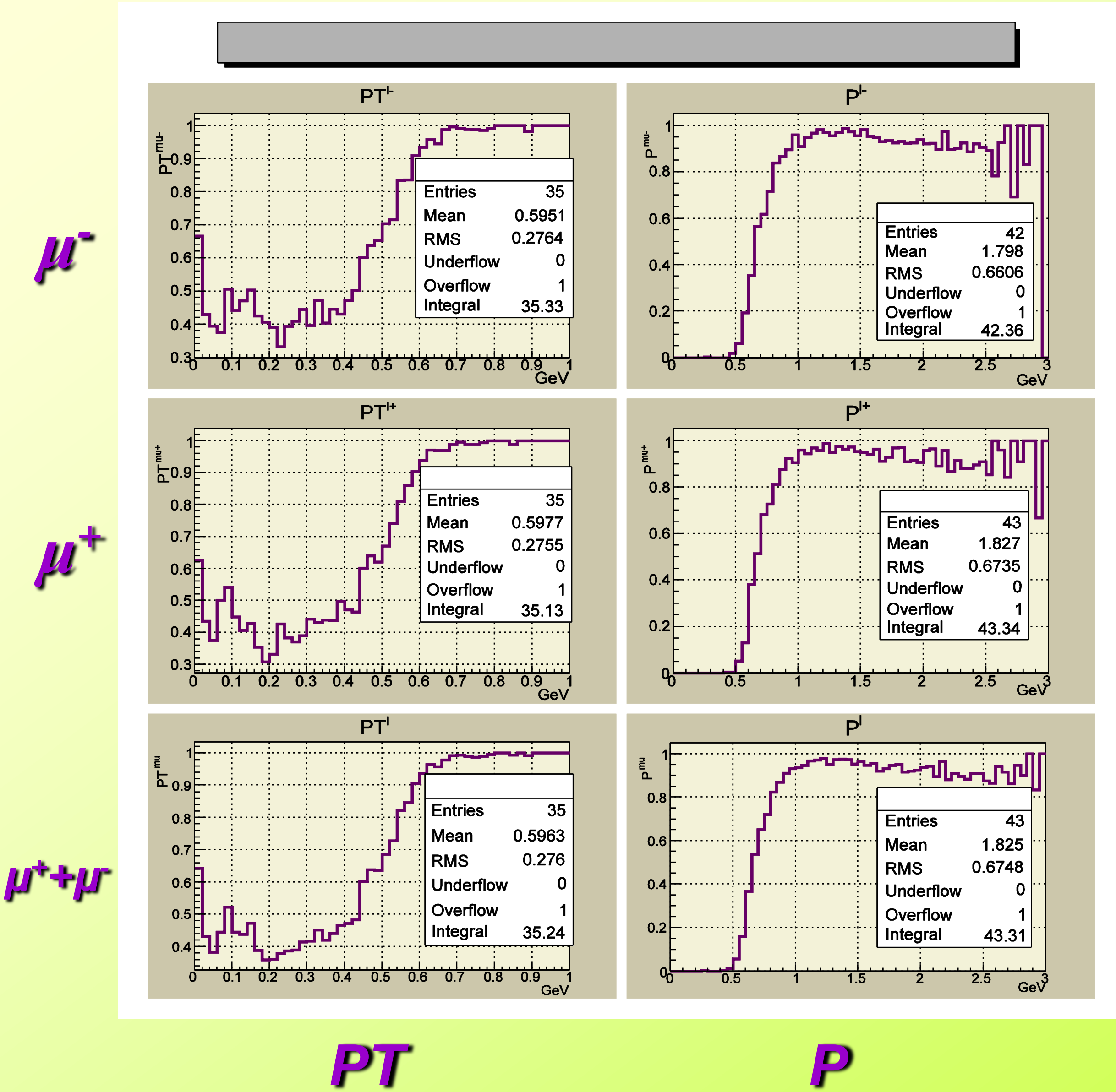
$M_{inv}(\mu^{+},\mu^{-})$

- θ^{μ} - polar angle
- φ^{μ} - azimuth angle
- N_{hits} - number of hits, made by muon in muon system per event

- The **significant difference in distributions of polar angle θ^{μ}** can be explaned by deviation in magnetic field.
- Practically **no difference** in distributions of the azimuth angle φ^{μ}.
- The first column in muon hits distributions shows the number of events, in which the corresponding muons gave no hits in the muon system (lost muons).
- Distribution of invariant mass $M^{inv}(\mu^{+},\mu^{-})$ also **differ** from the initial one, simulated by PYTHIA.

PandaRoot & Geant 3

Signal muon P & PT registration efficiency



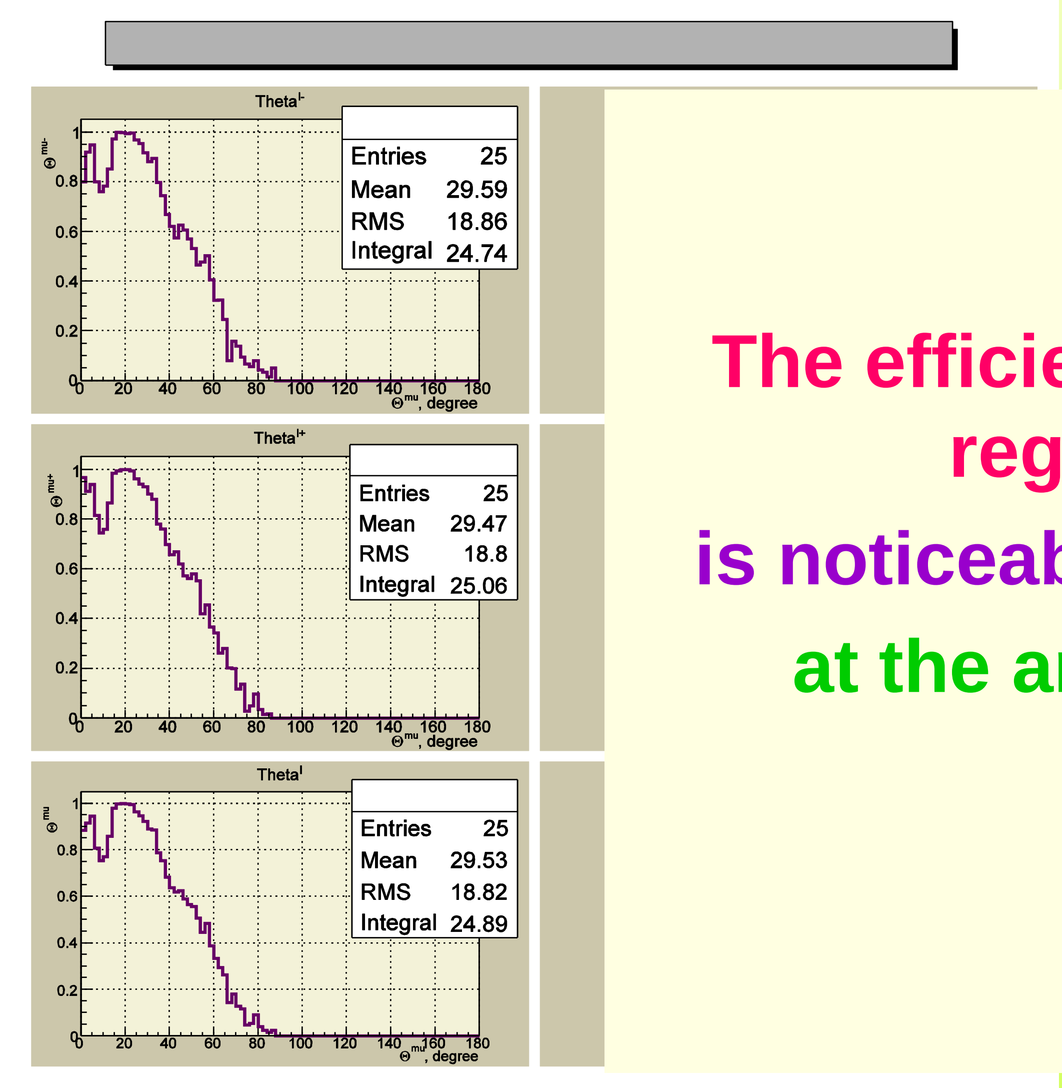
At very low (< 0.5 GeV) **full momentum and transverse momentum, the efficiency of muon registration** is ***noticeably decreasing***. **At the momenta > 0.8 GeV the efficiency goes to 1.**

Signal muon registration efficiency by polar angle θ

μ^-

μ^+

$\mu^+ + \mu^-$



θ

The efficiency of muon registration

is noticeably decreasing

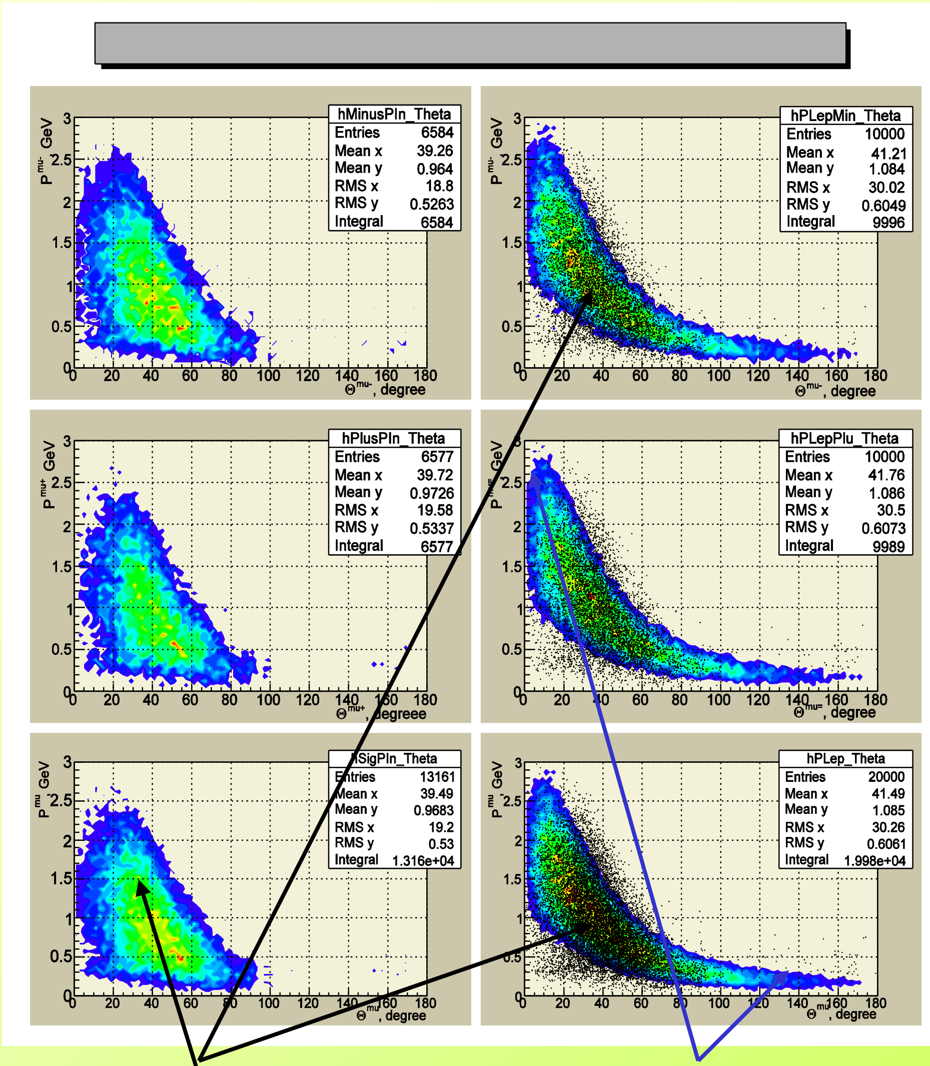
at the angles > 40^0

Correlation distributions of polar angle θ and momentum P

μ^-

μ^+

$\mu^+ + \mu^-$

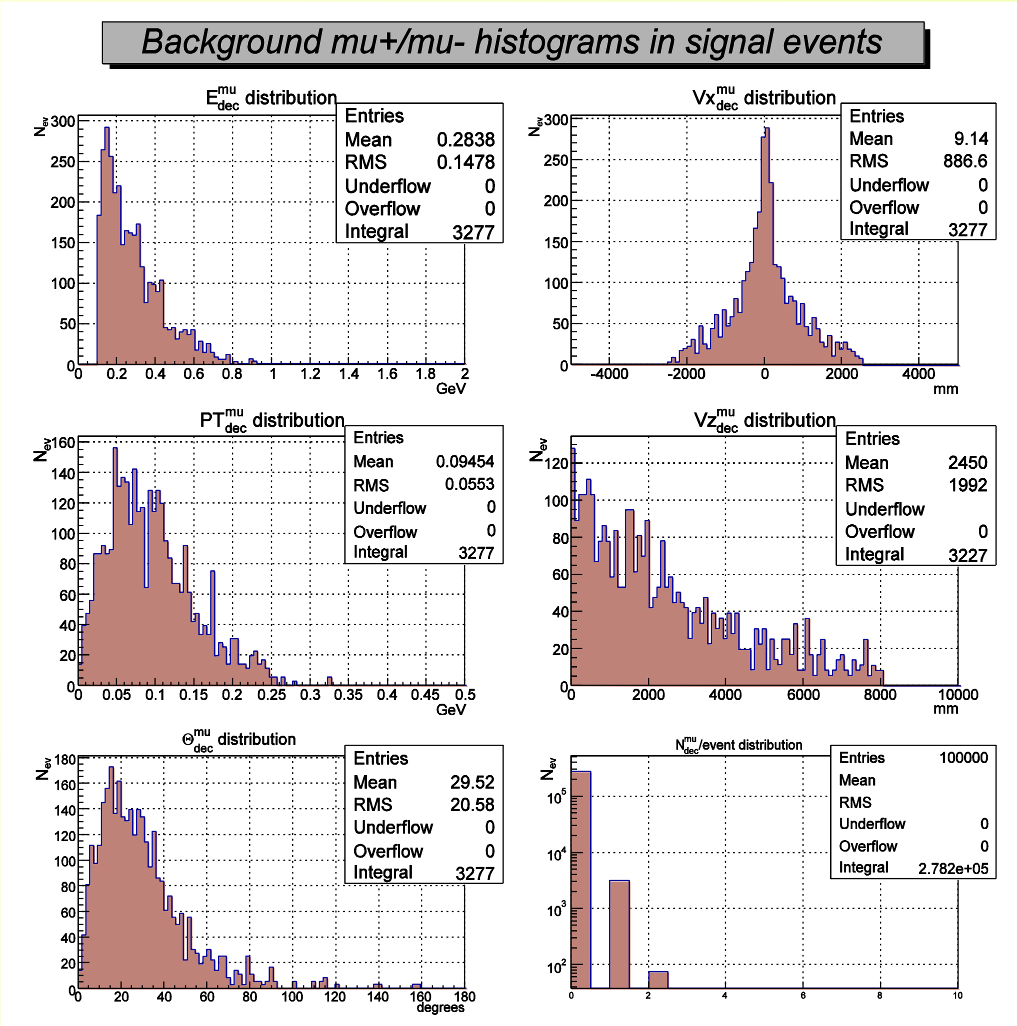


PandaRoot & Geant 3

PYTHIA6.4

- *The figures are **projections of 3-D signal muons correlation distributions** of polar angle θ and modulus of momentum P(that correspond to the first hit in the muon system):*
- **Left coloumn** presents the results, obtained by the full simulation (PANDARoot and GEANT3).
- **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.
- **As it was already shown before in 2-D figures,**
  due to the magnetic field influence,
  muons are moving aside to an angle of about 40^0.

Fake muons distributions in signal events



- The part of signal events which include fake muons is about 1.2%.
- Up to 2 fake muons in the final state.
- Fake **muons production vertices** are distributed within detector volume →

Vertex position information will be useful

for Signal / Background separation

Fake muons are less energetic than the signal ones

Applied cuts for signal events

1. *We select the events with only 2 leptons with* $E_\ell > 0.2$ GeV, $PT_\ell > 0.2$ GeV
2. *These 2 leptons must be of the opposite sign*
3. *The vertex of origin lies within the R < 15 mm from the interaction point*

These criteria allow to discriminate completely events with the fake decay muons

with the loss of 15.8% signal events

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

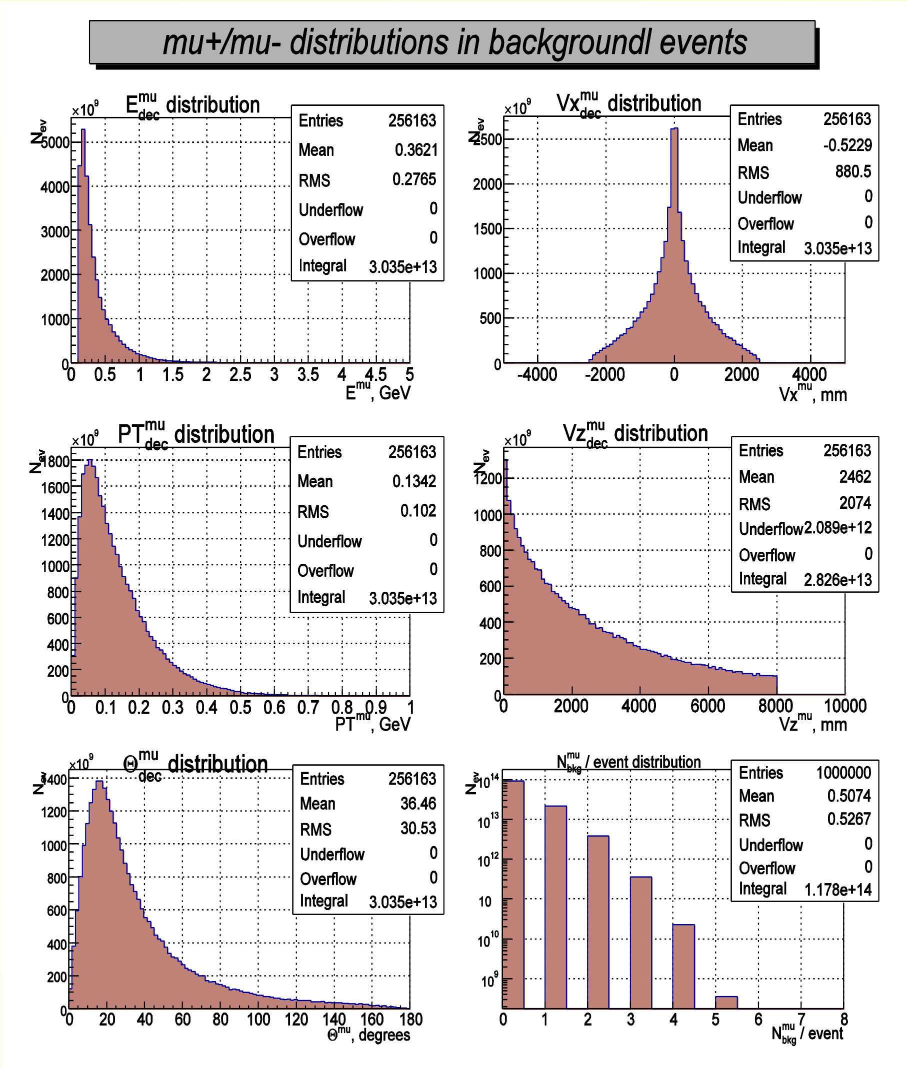
Some examples:

- ***Low - PT scattering*** (gives 68**%** of events with the **σ** = **39.48** mb);
- ***Single diffractive*** (gives 6**%** of events with the **σ** = **1.58** mb);
- ***qbar + q → l⁺ + l⁻*** *(gives* 0.0000015% of events, **σ = 5.09 ·10^{-7}** mb);

So, we have 3 signal event aginst 200.000.000 of Mini-bias bkgd → **S/B ≃10^{-8}**

Mini-bias background is 5 order harder than QCD background

Muon's distributions from background events



Up to 6 μ per event →

→ a rather high probability of appearing the muon pair with the different signs of their charges in "*Minimum_bias*" events (which are other than the signal one)

→ fake pretty well the signal events

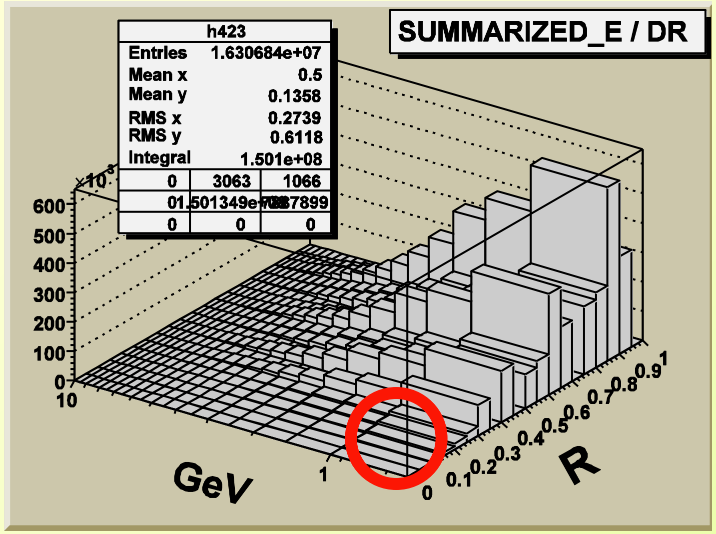
Background muons are less energetic than the signal ones

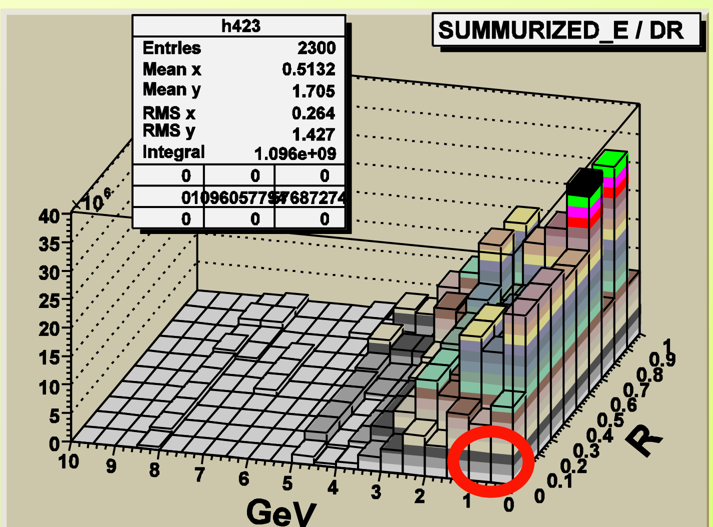
Cuts for mini-bias and QCD processes (including the signal one)

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 charge;
3. the vertex of lepton origin lies within the R< 15mm 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 (μ) isolation criteria





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

$R_{isolation} = \sqrt{\eta^2+\varphi^2}$ respect to the

(η – pseudorapidity)

upper plot → **signal events**

bottom plot → **Mini-bias background**

Isolation criteria **($R_{isolation}$ = 0.2)**

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

Applied cuts & efficiency for Minimum-Bias background events

	$E_l > 0.2$ GeV	$PT_l > 0.2$ GeV		$PT_l > 0.5$ GeV	
N of cuts		**S/B ratio**	***Efficiency***	**S/B ratio**	***Efficiency***
1 *(exactly 2 leptons with $E_l > 0.2$ GeV, $PT_l > 0.2$ GeV)*		**$1.02 * 10^{-6}$**	$1.47 * 10^{-3}$	**$2.37 * 10^{-6}$**	$4.22 * 10^{-4}$
2 *(2 leptons are of the opposite sign*		**$1.13 * 10^{-6}$**	0.906	**$2.57 * 10^{-6}$**	0.921
3 *(The vertex is within the R < 15 mm)*		**$3.70 * 10^{-4}$**	$3.04 * 10^{-3}$	**$6.09 * 10^{-4}$**	$4.21 * 10^{-3}$
4 *($M_{inv}(l_1,l_2) > 0.9$)*		**$6.58 * 10^{-2}$**	0.056	**$7.04 * 10^{-3}$**	0.086
5 *Isolation*		**1.5**	0.004	**2**	0.003
Loss of signal events		**16.9 %**		**88.5 %**	

Applied cuts & efficiency for Minimum-Bias background events

E_l > 0.5 GeV PT_l > 0.2 & 0.5 GeV

N of cuts	S/B ratio	Efficiency
1 *(exactly 2 leptons with E_l > 0.5 GeV, PT_l > 0.2 GeV)*	0.0012	4.15 * 10^{-7}
2 *(2 leptons are of the opposite sign*	0.0012	0.998
3 *(The vertex is within the R < 15 mm)*	0.0833	1.45 * 10^{-2}
4 *($M_{inv}(l_1,l_2)$ > 0.9)*	0.0909	0.916
5 *Isolation*	Bkg = 0	---

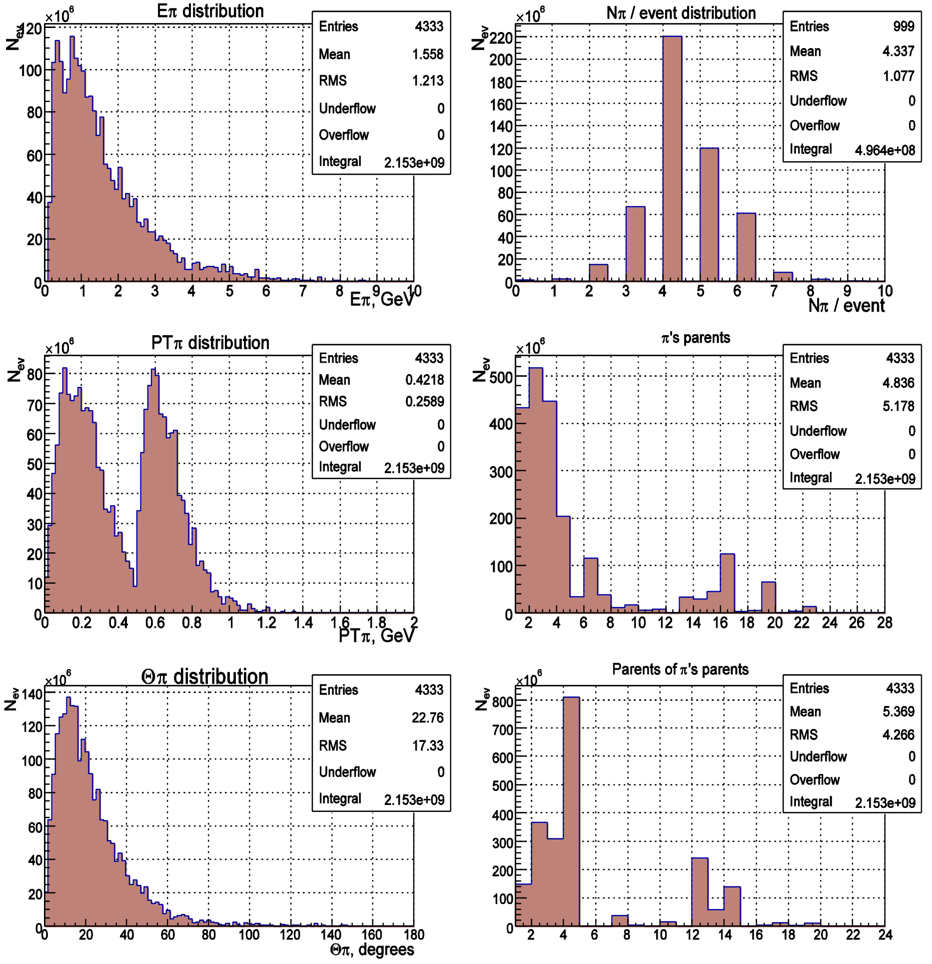
As the muon registration efficiency is equal 0 at P (E) < 0.5 GeV – the cut **P (E) > 0.5 GeV is preferable**

The muon registration efficiency at PT < 0.5 GeV is rather small and comes to 40%. But with the cut PT > 0.5 GeV the loss of signal events became too high – up to 90%. And the value of this cut doesn't influence much on the final S/B ratio. **So it's better to use PT > 0.2 GeV**

Loss of signal events PT_l > 0.2 GeV - **44.3 %**, PT_l > 0.5 GeV - **88.5 %**,

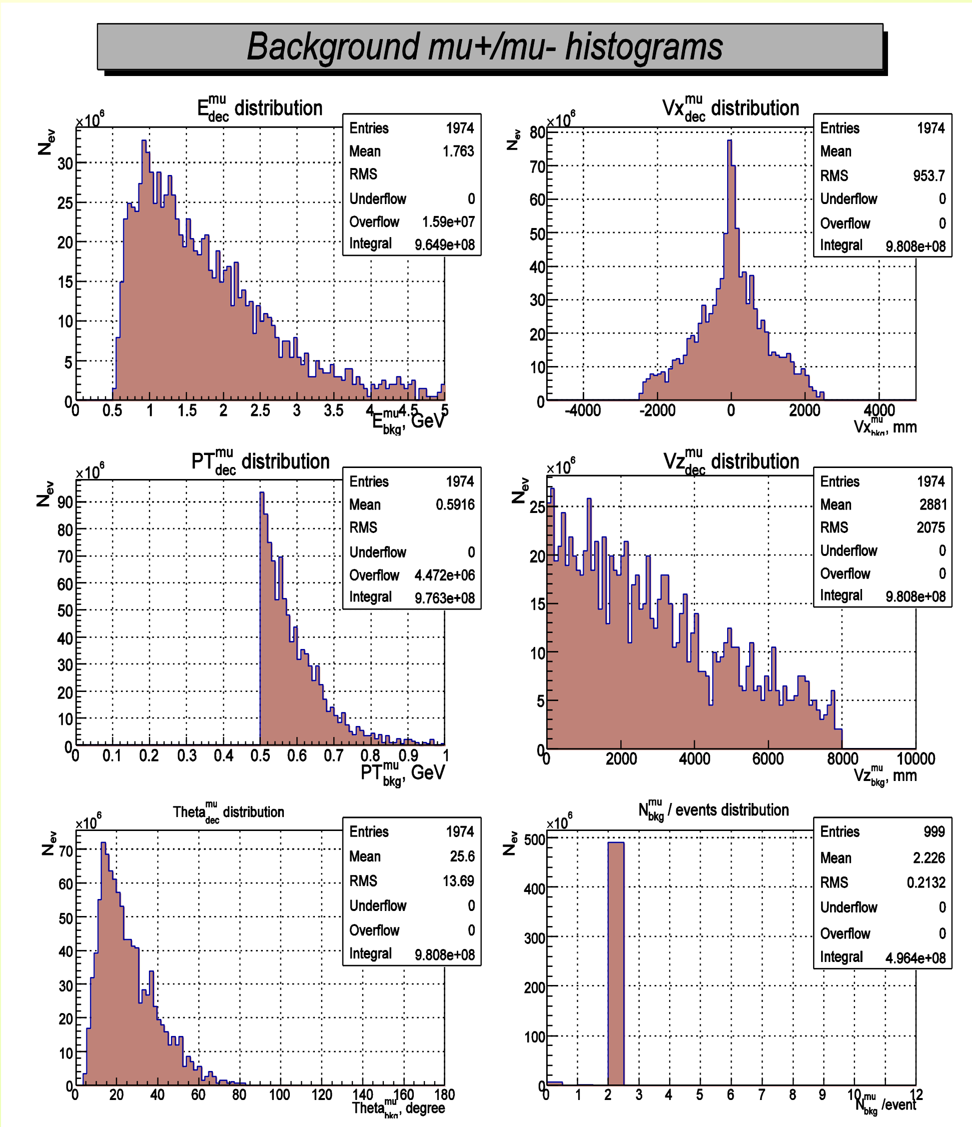
Estimation of the background contribution of the "$p\bar{p} \rightarrow \pi^+\pi^- + X$" to the signal process of muon pairs production "$p\bar{p} \rightarrow \mu^+\mu^- + X$" ($E_{beam}$ = 15 GeV)

PI - distribution histograms



- π with the probability 99.9% decay into μ. So, such a process can give us a muon pair.
- Among $2{\cdot}10^8$ generated QCD and minimum-bias the fraction of charged pion pairs production is **25.8%**
- We consider only the events with only 2 muons in the fiinal state with the opposite charges and E, PT > 0.5 GeV. Their fraction among generated is **$4.94 \cdot 10^{-4}$ %**.
- Up to 8 pions in the background event.
- Eπ < 9 GeV, PTπ < 1.4 GeV. The first left peak is caused by the pions which do not produce hard muons (the additional pions in the same events where the pion pairs are produced).

Muon's distributions from the "$p\,\bar{p} \rightarrow \pi^+\pi^- + X$" process ($E_{beam}$ = 15 GeV)



- Fake **muons production vertices** are distributed <u>within detector volume</u> →

  Vertex position information <u>will be useful</u>

  for Signal / Background separation

The proposed cuts are the same as before:

0. Selection of events with at least 2 charged pions from the same production vertex;
1. We choose the events with exactly 2 muons in the final state with E^{μ}_{dec} > 0.5 GeV, PT^{μ}_{dec} > 0.5 GeV;
2. These muons should have different signs;
3. Their production vertex is close to the interaction point;
4. Their invariant mass $Minv^{\mu+\mu-}$ >0.9 GeV;
5. Muons are isolated (summarized energy of the charged particles around the axes of the muons movement is less than 0.5 GeV in the radius R = 0.2)

Applied cuts & efficiency for $\pi^+\pi^-$ + X background events

	E_{beam} = 15 GeV		E_{beam} = 5 GeV	
N of cuts	S/B ratio	Efficiency	S/B ratio	Efficiency
0. At least 1 pair of $\pi^+\pi^-$ from the same interaction point	$4.83 * 10^{-7}$	0.259	$3.94 * 10^{-9}$	0.127
1. Exactly 2 μ's with $E_l > 0.5$ GeV, $PT_l > 0.5$ GeV	$6.84 * 10^{-7}$	$3.04 * 10^{-3}$	0.0127	$4.73 * 10^{-8}$
2. 2 μ's are of the opposite sign	$1.11 * 10^{-2}$	0.615	0.083	1
3. The vertex is within the R < 15 mm	5.5	0.002	Bkg = 0	---
4. $M_{inv}(l_1,l_2) > 0.9$	11	0.5	Bkg = 0	---
5. Isolation	Bkg = 0	----	Bkg = 0	---

Conclusion

- ✓ *“Theoretical” Monte-Carlo distrbutions of individual muons from the leptons pair production process were presented on the basis of PYTHIA6.4 for the case of E_{beam} = 5 GeV*

- ✓ *Final distributions of these muons after propagation through the detector volume were obtained by use of PANDARoot program*

- ✓ *Preliminary set of criteria for Signal and Background separation was shown on the basis of PYTHIA simulation*

- ✓ *Futher study of the backgrounds with a full simulation in PANDARoot is needed.*

- ✓ ***To perform the full simulation the integration of the muon sistem into the whole detector PANDARoot description is needed URGENTLY !!!***

This work was generously supported by the Helmholtz Association under grant agreement IK-RU-002