Simulation of muon pairs production at PANDA experiment and the main backgrounds

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Production of lepton pair

(continuum M_{inv} (l^+l^-) case)

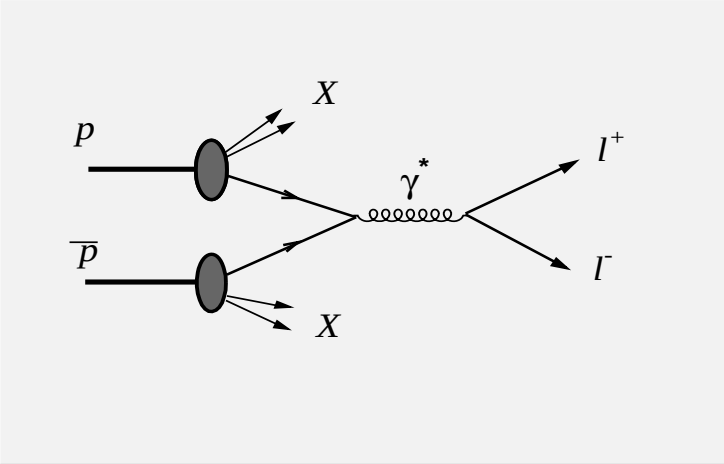
The process of lepton pair production q qbar → γ^* / Z° → l^+l^- is of big physical interest because:

A. The spectrum of final state leptons (e and muons) obviously depends on the form of parton distributions inside colliding protons.

B. The transverse momentum of lepton pair PT (l^+l^-) provides the information about intrinsic transverse momentum < kT> of quark inside the proton (Fermi motion).

C. The results of study of leptons angle and energy spectra distributions, based on Monte-Carlo simulation, was used for a proper "geometrical" design of such important component of PANDA detector as muon system.

MMT-DY process

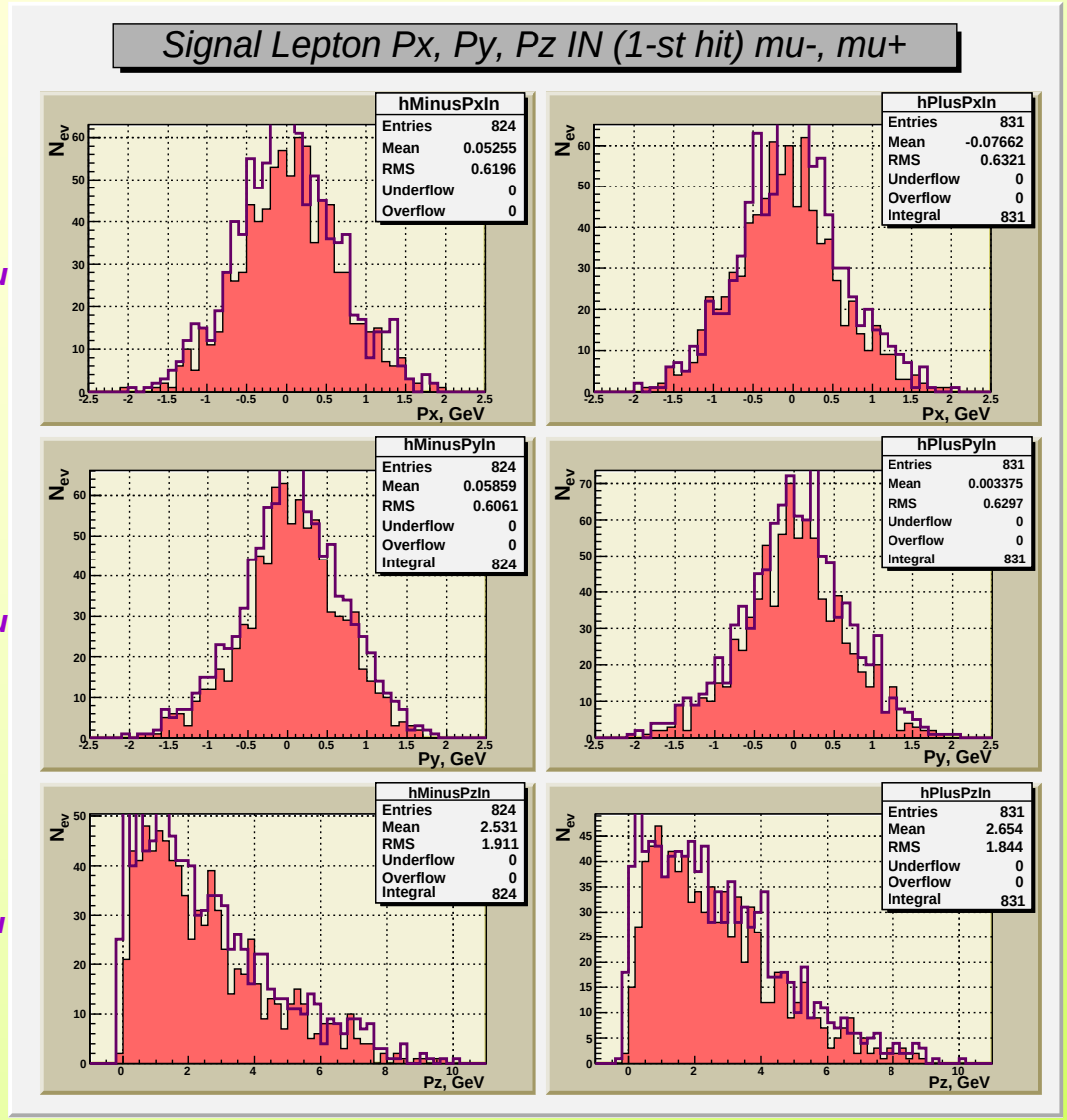


Simulation of muon's kinematical characteristics was done with use of PYTHIA6.4, PandaRoot & Geant 3 (presented by pink histograms) at the level of stand alone muon system.

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

From the statistical numbers (entries) of distributions one can see that the ***total loss of muons in detector*** *is about* ***17.6%*** *for* μ^- *and* ***16.9%*** *for* μ^+.

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

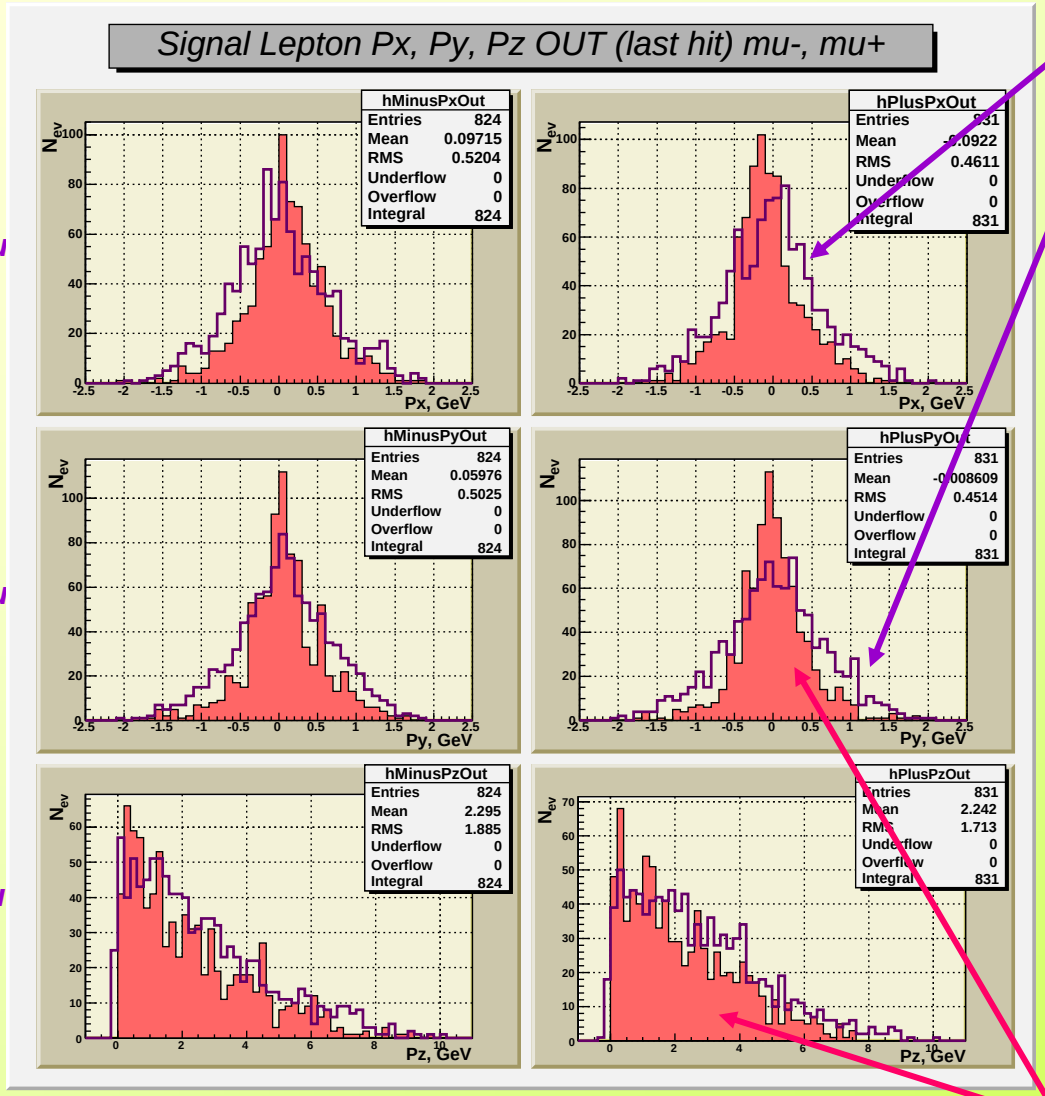


Momenta distributions, obtained in the full simulation,

do not differ significantly from those, simulated in PYTHIA6.4.

The only distinction is in **the small loss of quantity (~17%)**, especially at very low momenta.

Px^{μ}, Py^{μ}, Pz^{μ} from the last hit in muon system



PYTHIA6.4

Momenta distributions, obtained in result of full simulation,

in this case is

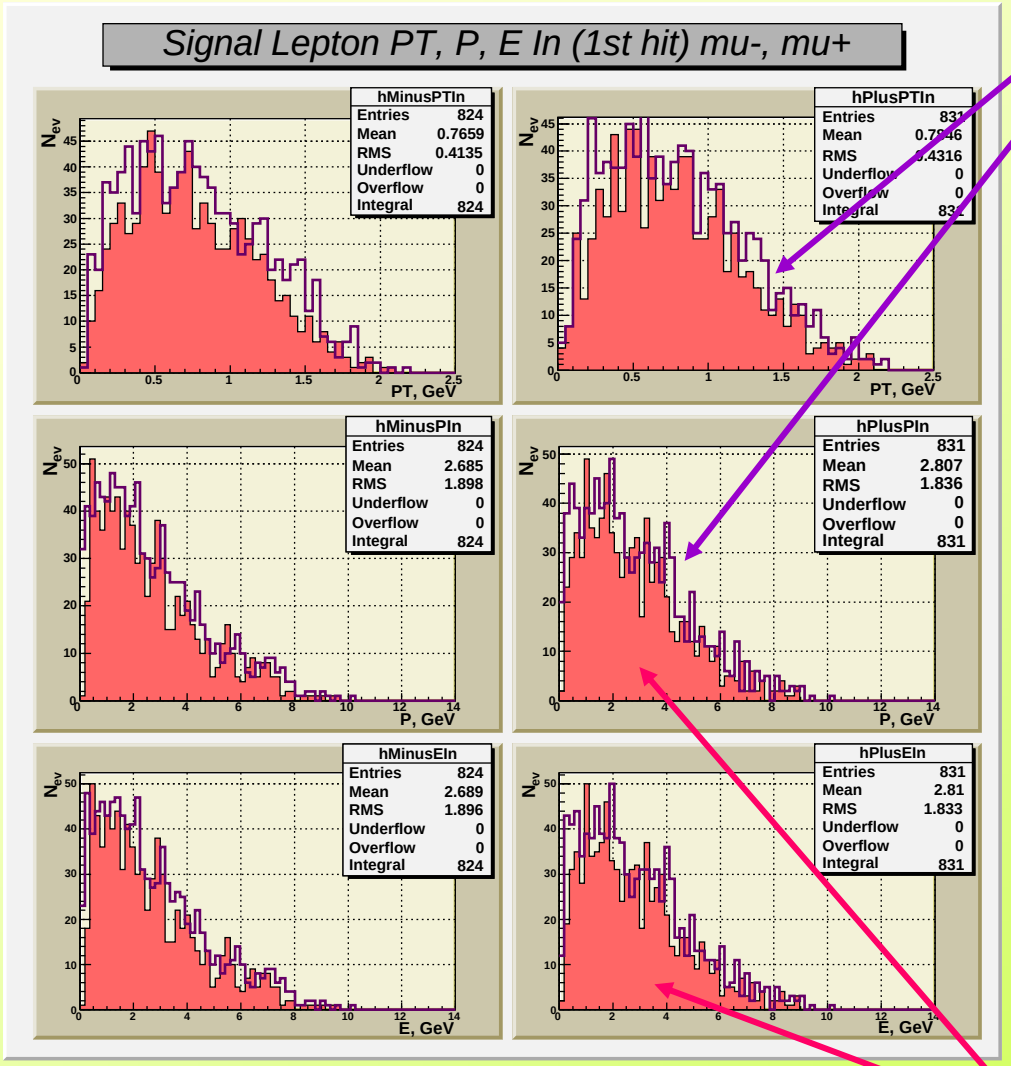
significantly differ from the ones simulated in PYTHIA6.4, and

show noticeable loss of momentum

(about 0.5-1.5 GeV for each component).

PandaRoot & Geant 3

PT^{μ}, P^{μ}, E^{μ} from the 1-st hit in muon system



PT^{μ}

P^{μ}

E^{μ}

μ^{-} μ^{+}

PYTHIA6.4

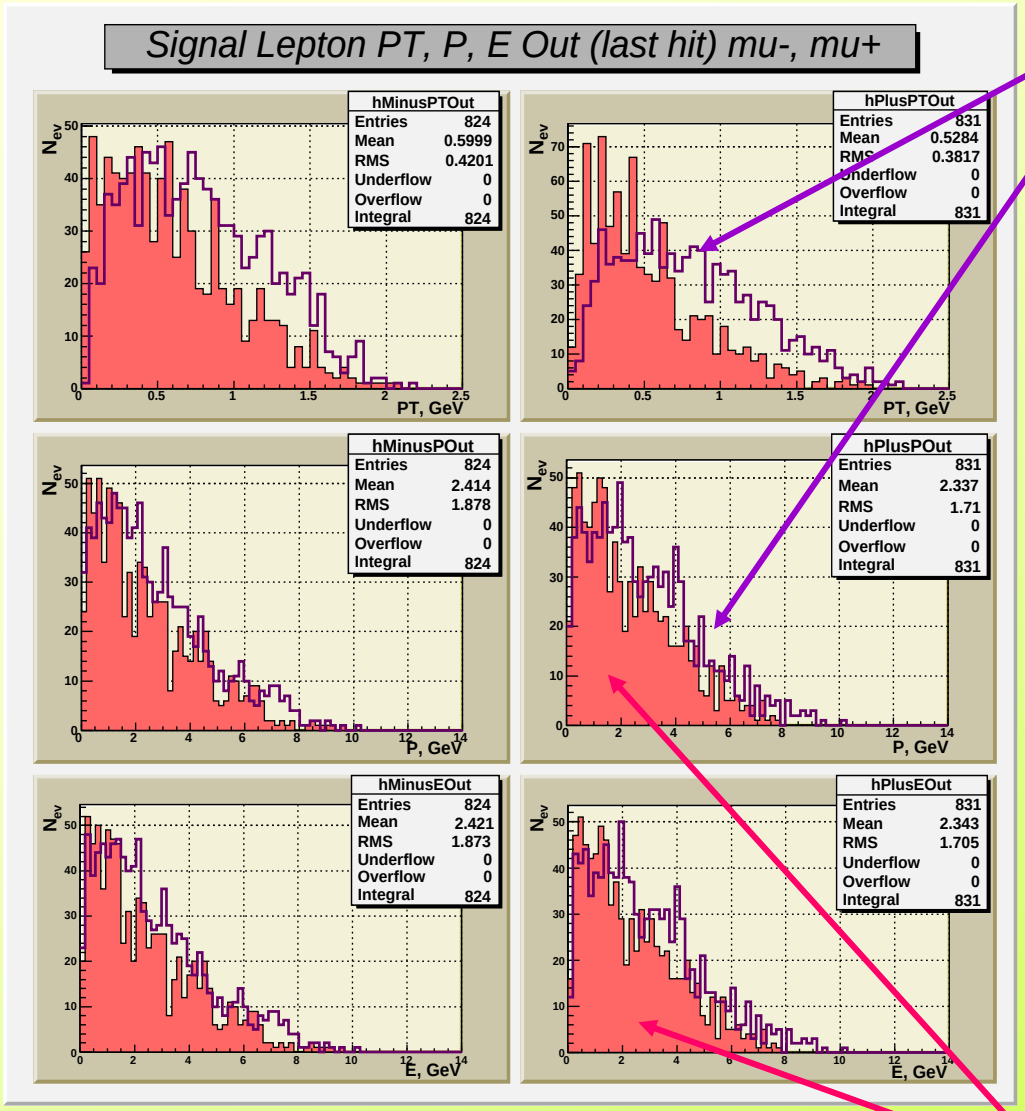
Momenta & Energy distributions, obtained in result of full simulation,

do not differ noticeably from the ones, simulated in PYTHIA6.4,

except **some loss of quantity.**

PandaRoot & Geant 3

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



PT^{μ}

P^{μ}

E^{μ}

μ^- μ^+

PYTHIA6.4

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

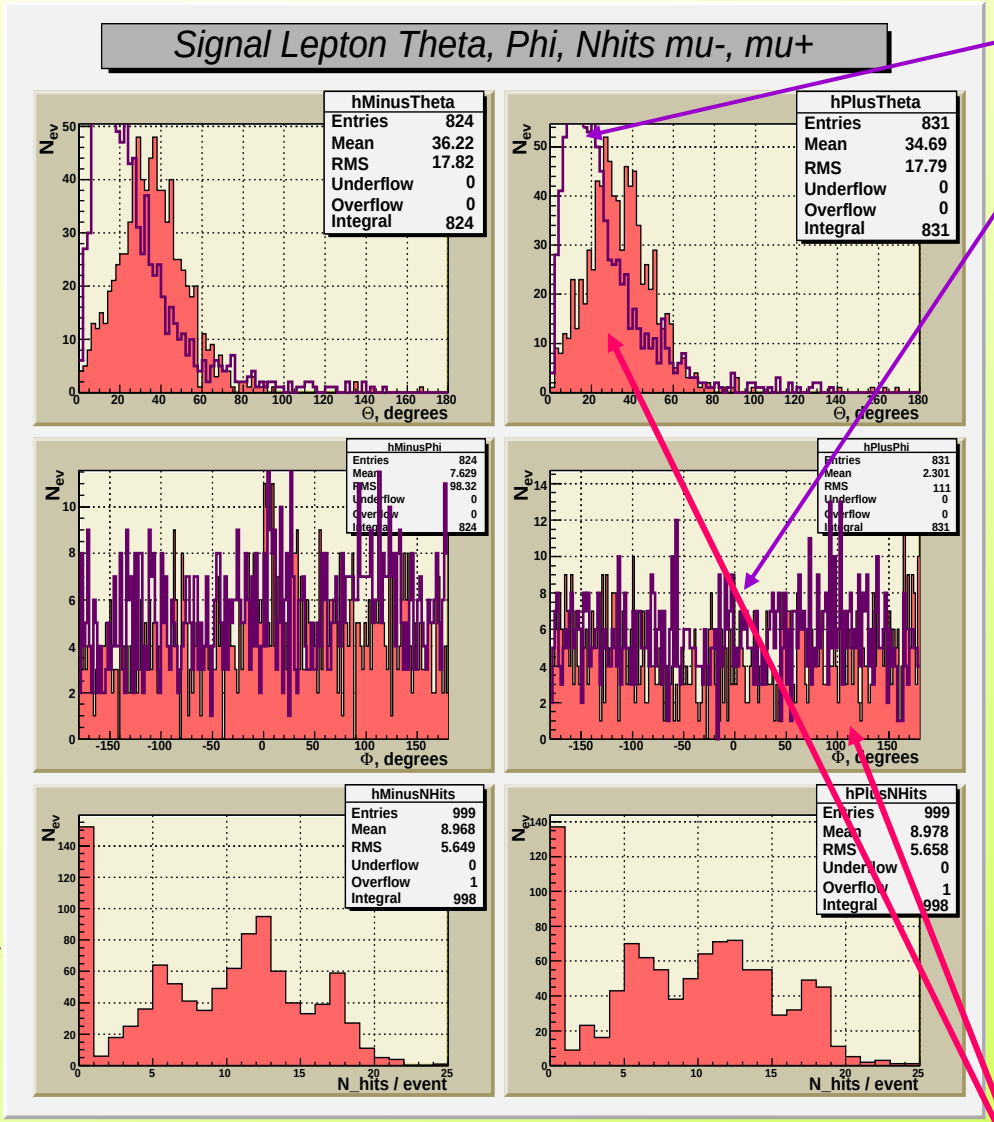
in this case is

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

show noticeable loss of momentum & energy (about 2 GeV) in result of penetrating through the material of the muon system.

PandaRoot & Geant 3

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



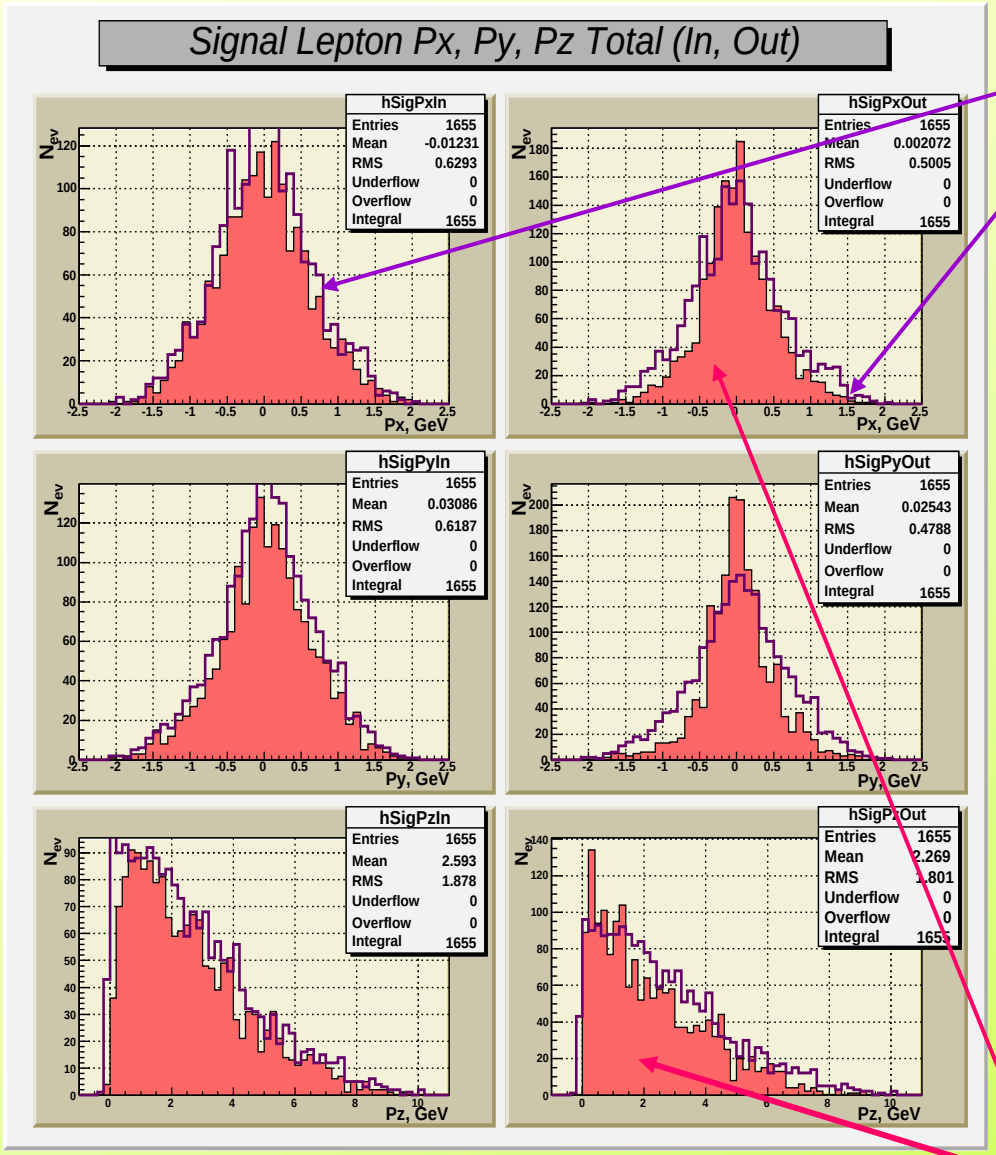
PYTHIA6.4

- 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 muon system



PYTHIA6.4

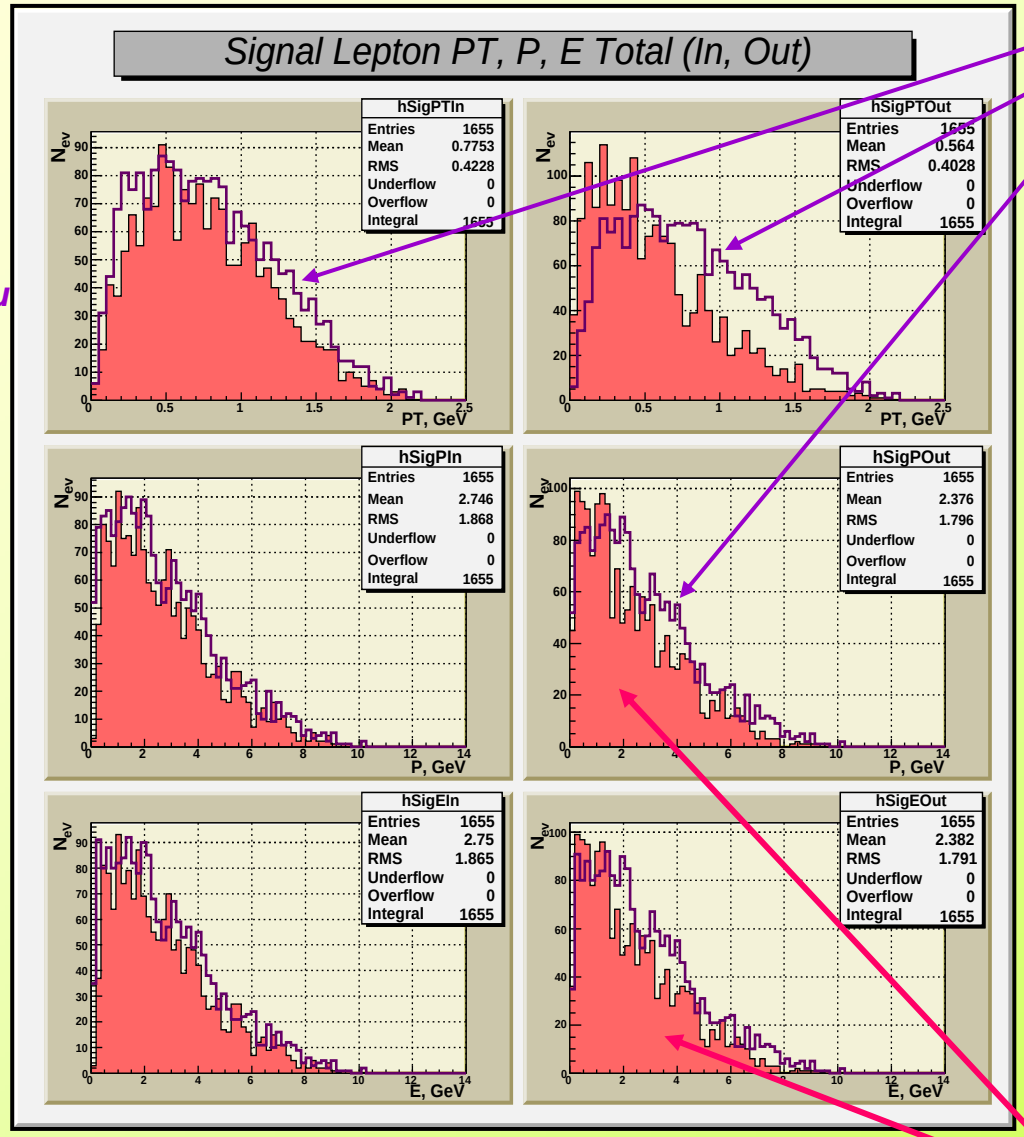
- Like in the case of separate taken muons, the *momenta distributions, obtained in result of full simulation*, **do not much differ** to the ones simulated in PYTHIA6.4 for the **values from the first hit**, exept some loss of quantity, especially at very low momenta,

&

- **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 0.5-1.5 GeV for each components).

PandaRoot & Geant 3

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



PT^{μ}

P^{μ}

E^{μ}

1-st hit *last hit*

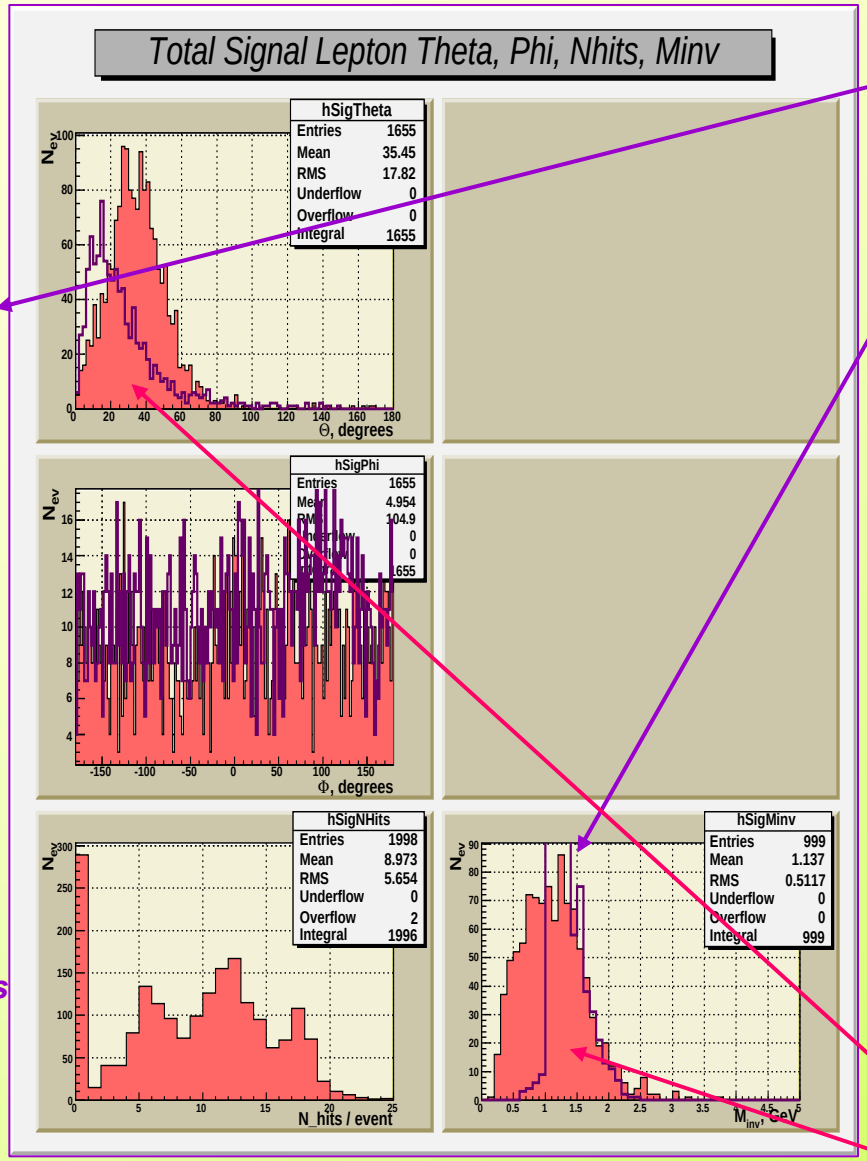
PYTHIA6.4

- 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 small loss of quantity.

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



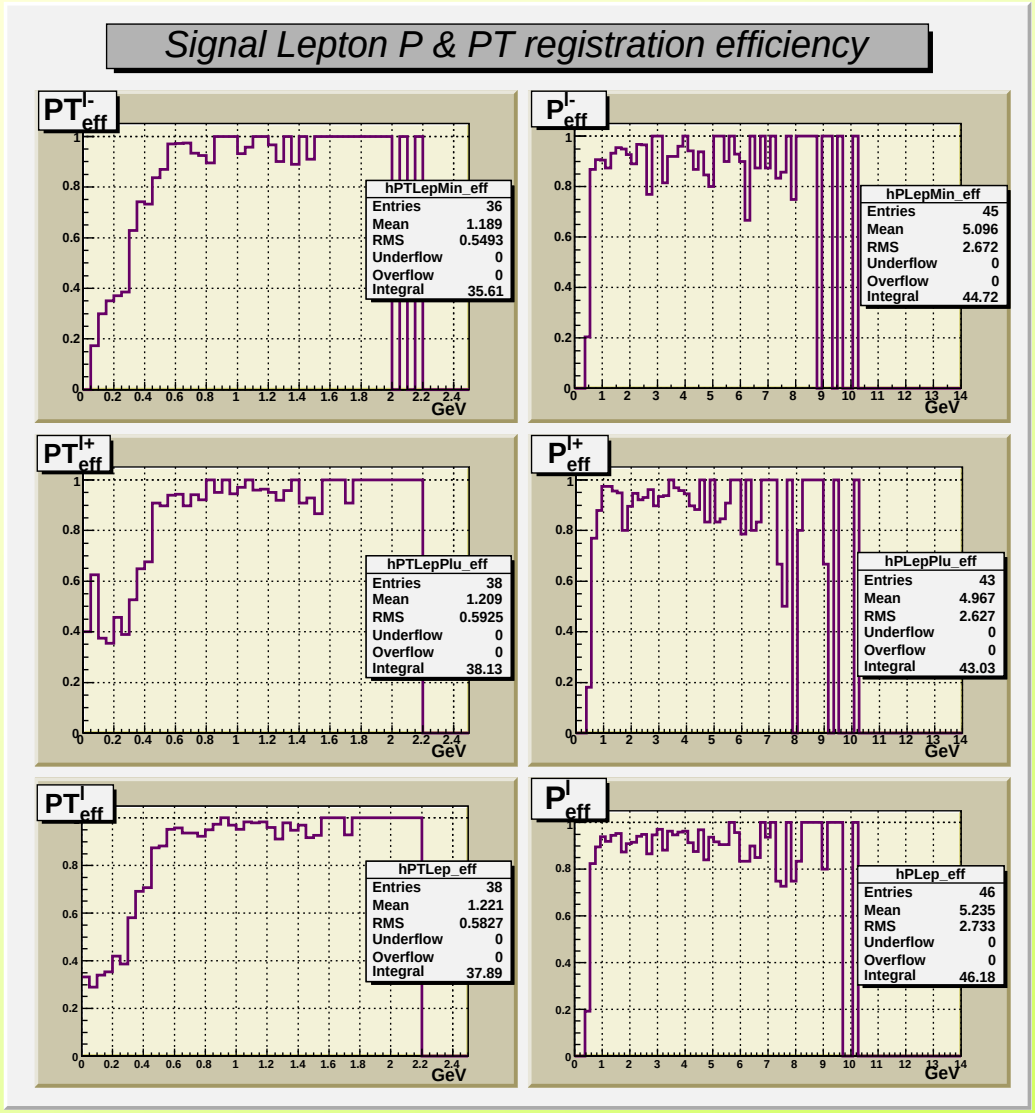
PYTHIA6.4

- θ^{μ} - 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



μ^-

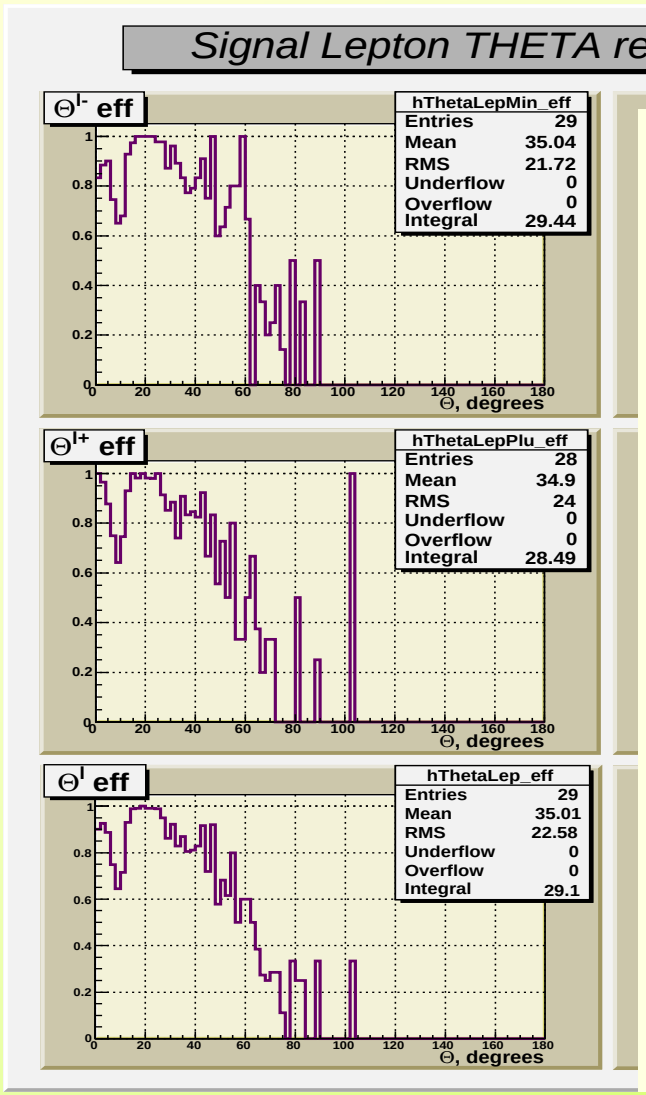
μ^+

$\mu^+ + \mu^-$

PT ***P***

At very low (<0.5 GeV) **initial momentum and transverse momentum, the efficiency of muon registration** is ***noticeably decreasing***.

Signal muon registration efficiency by polar angle θ



μ^-

μ^+

$\mu^+ + \mu^-$

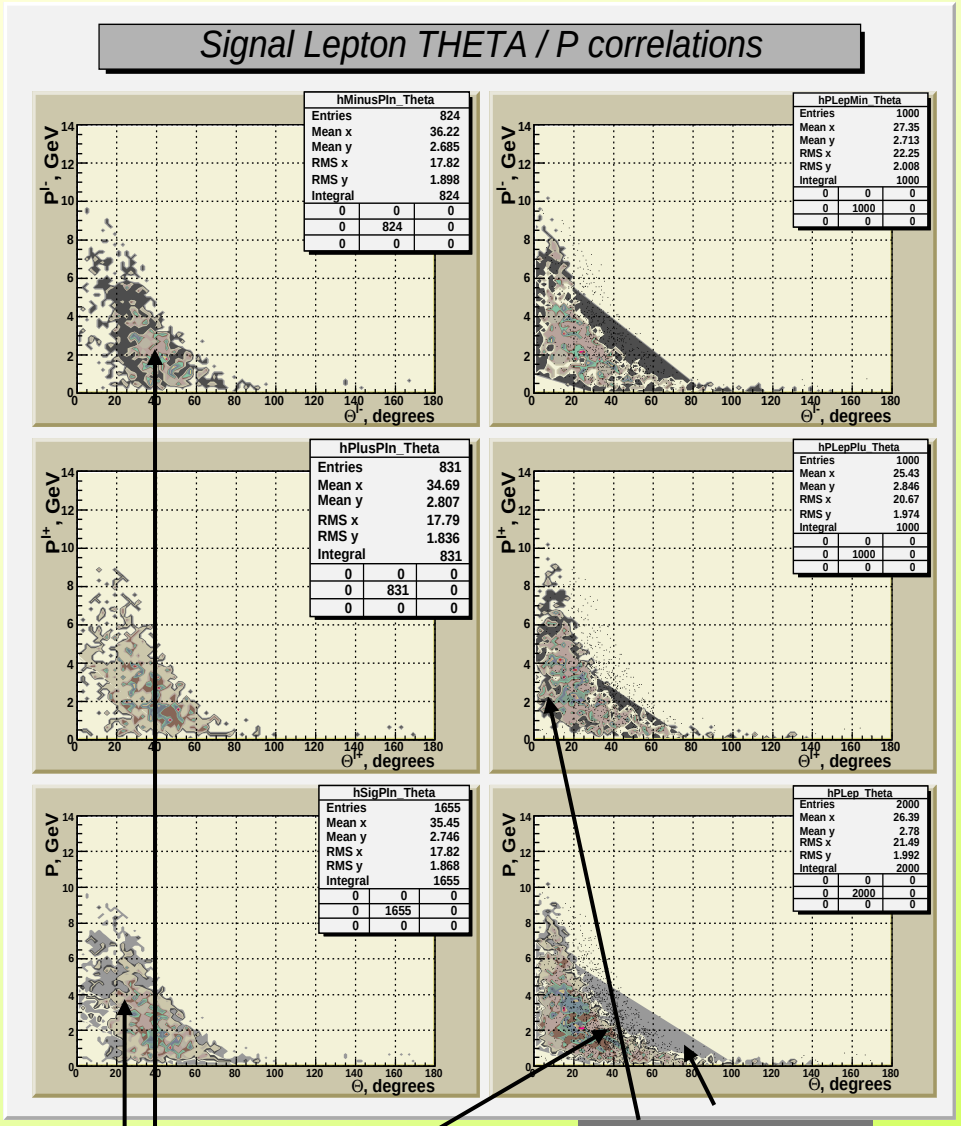
θ

The efficiency of muon registration

is noticeably decreasing

at the angles > 50^0

Correlation distributions of polar angle θ and momentum P

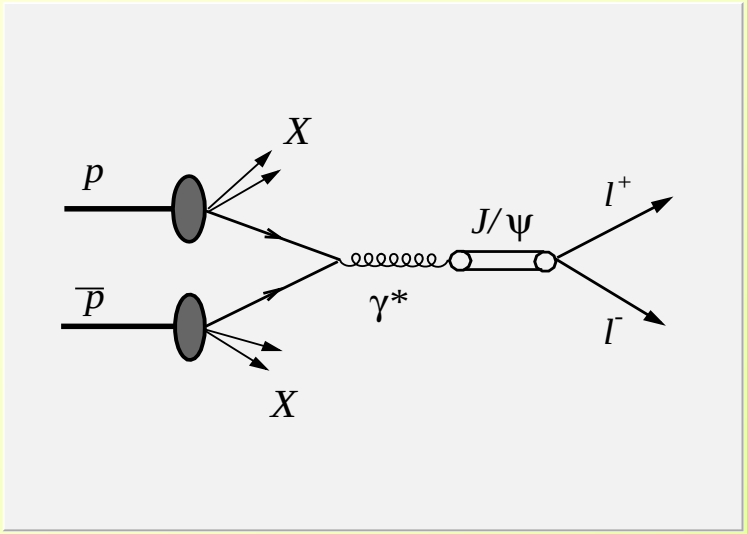


- *The figures are **projections of 3-D signal muons correlation distributions** of polar angle θ and modulus of momentum P(that correspond to the first hit in the muon system):*

- **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 20^0.**

$J/\Psi \rightarrow \mu^+\mu^-$ process



Simulation of muon's kinematical characteristics was done with use of PYTHIA6.4, PandaRoot & Geant 3 (presented by pink histograms) at the level of stand alone muon system.

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

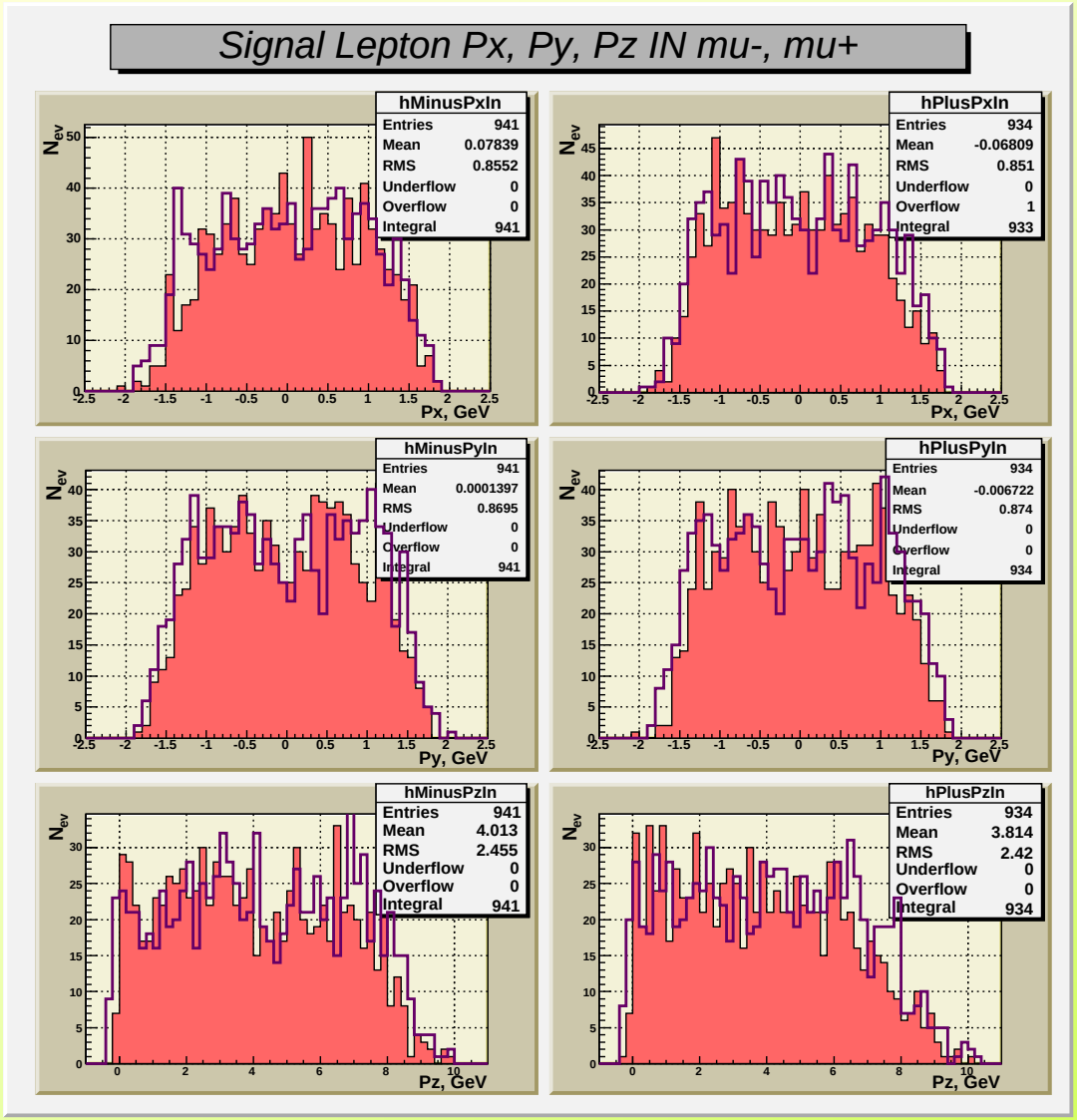
$$q_i\, \bar{q}_i \rightarrow \gamma^* \rightarrow c\, \bar{c} \rightarrow J/\Psi \rightarrow l^+ l^- + X$$

$$q\, \bar{q} \rightarrow c\bar{c}\ [^3S_1^{(8)}]\ g \rightarrow l^+ l^- + X$$

$$q\, \bar{q} \rightarrow c\bar{c}\ [^3P_J^{(8)})]\ g \rightarrow l^+ l^- + X$$

From the statistical numbers (entries) of distributions one can see that the ***total loss of muons in detector*** *is about* ***5.9%*** *for* μ^- *and* ***6.6%*** *for* μ^+.

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

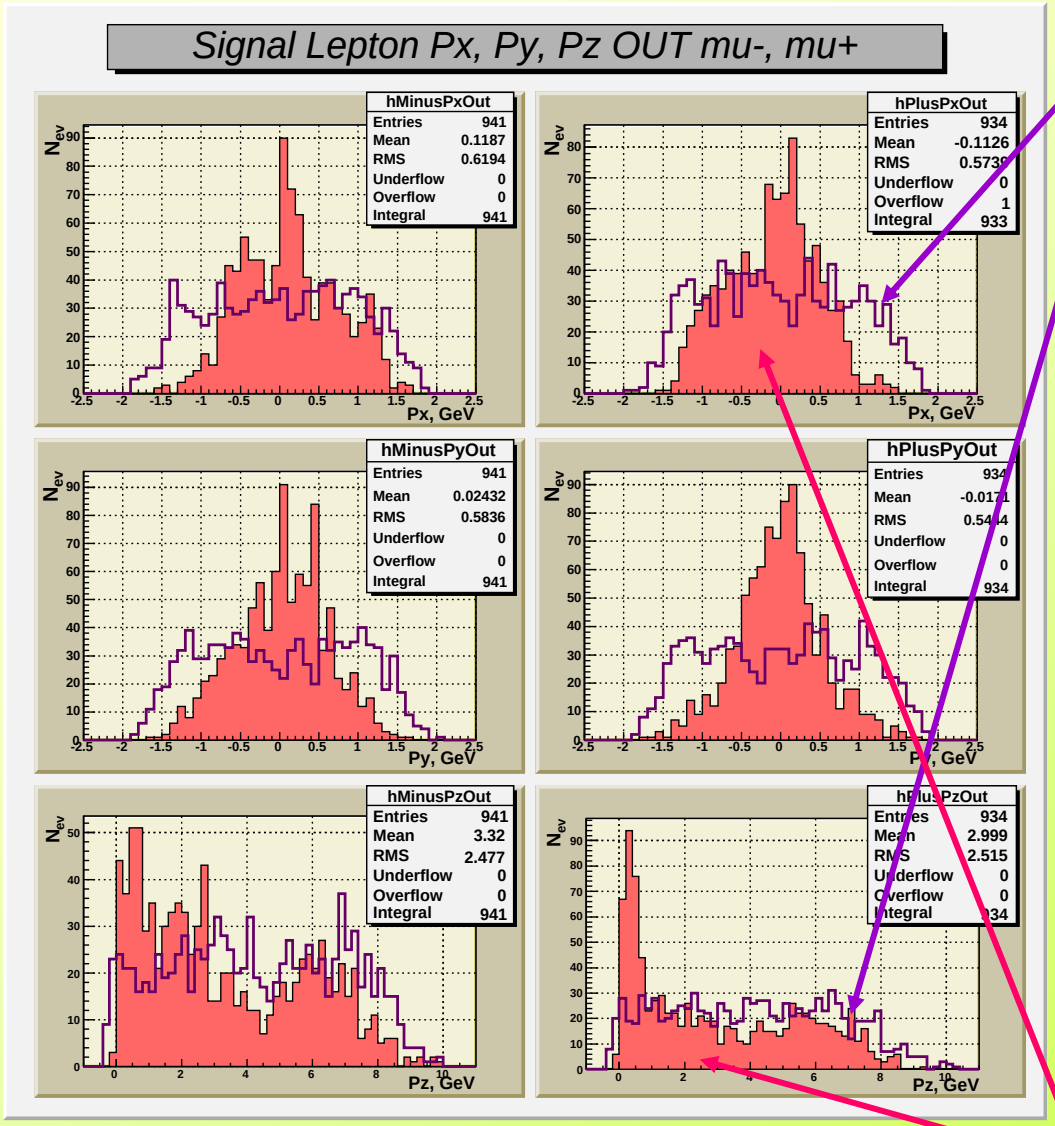


Momenta distributions, obtained in the full simulation,

<u>do not differ</u> significantly from those, simulated in PYTHIA6.4.

The only distinction is in **the small loss of quantity (~6%)**, especially at large momenta.

Px^{μ}, Py^{μ}, Pz^{μ} from the last hit in muon system



PYTHIA6.4

Momenta distributions, obtained in result of full simulation,

in this case is

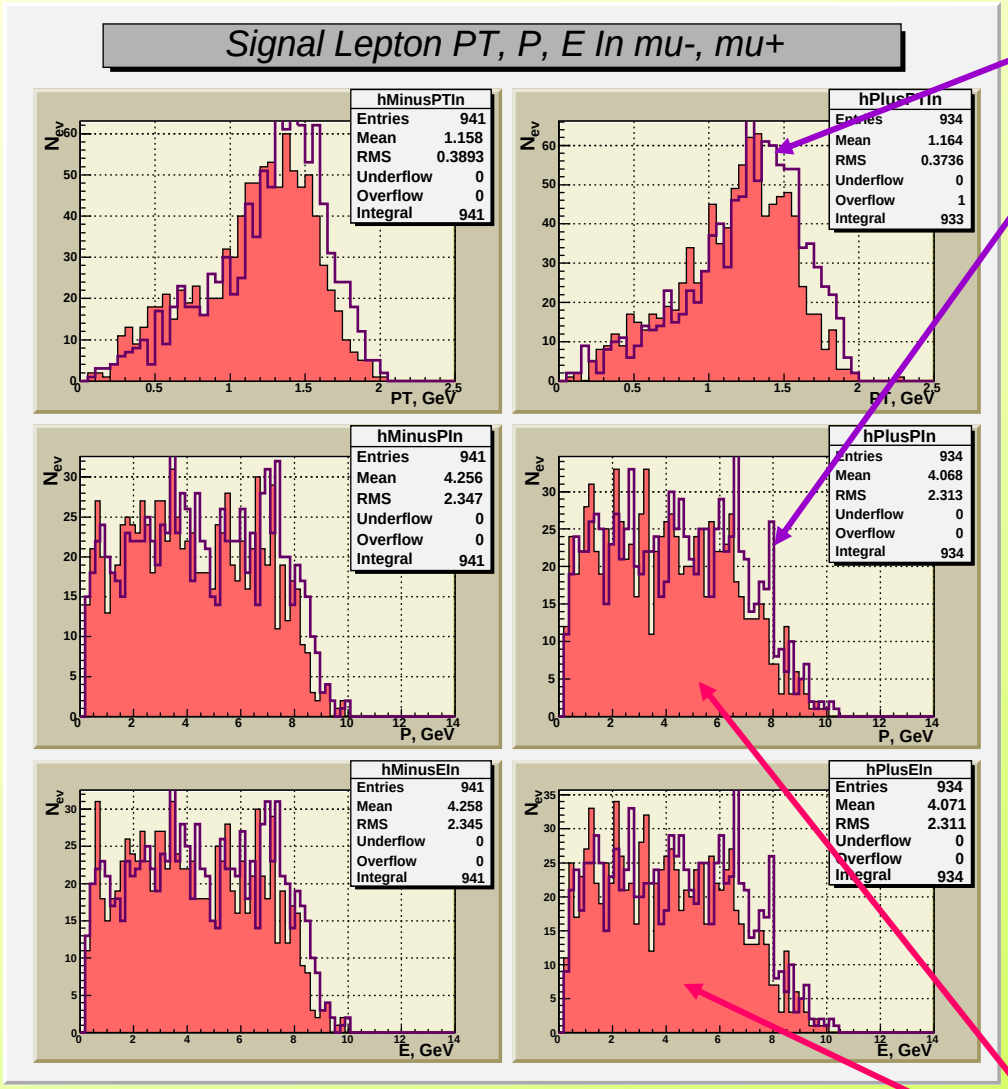
significantly differ in the shape and the values to the ones simulated in PYTHIA6.4, and

show noticeable loss of momentum

(about 0.5-1.5 GeV for each component).

PandaRoot & Geant 3

PT^{μ}, P^{μ}, E^{μ} from the 1-st hit in muon system



PT^{μ}

P^{μ}

E^{μ}

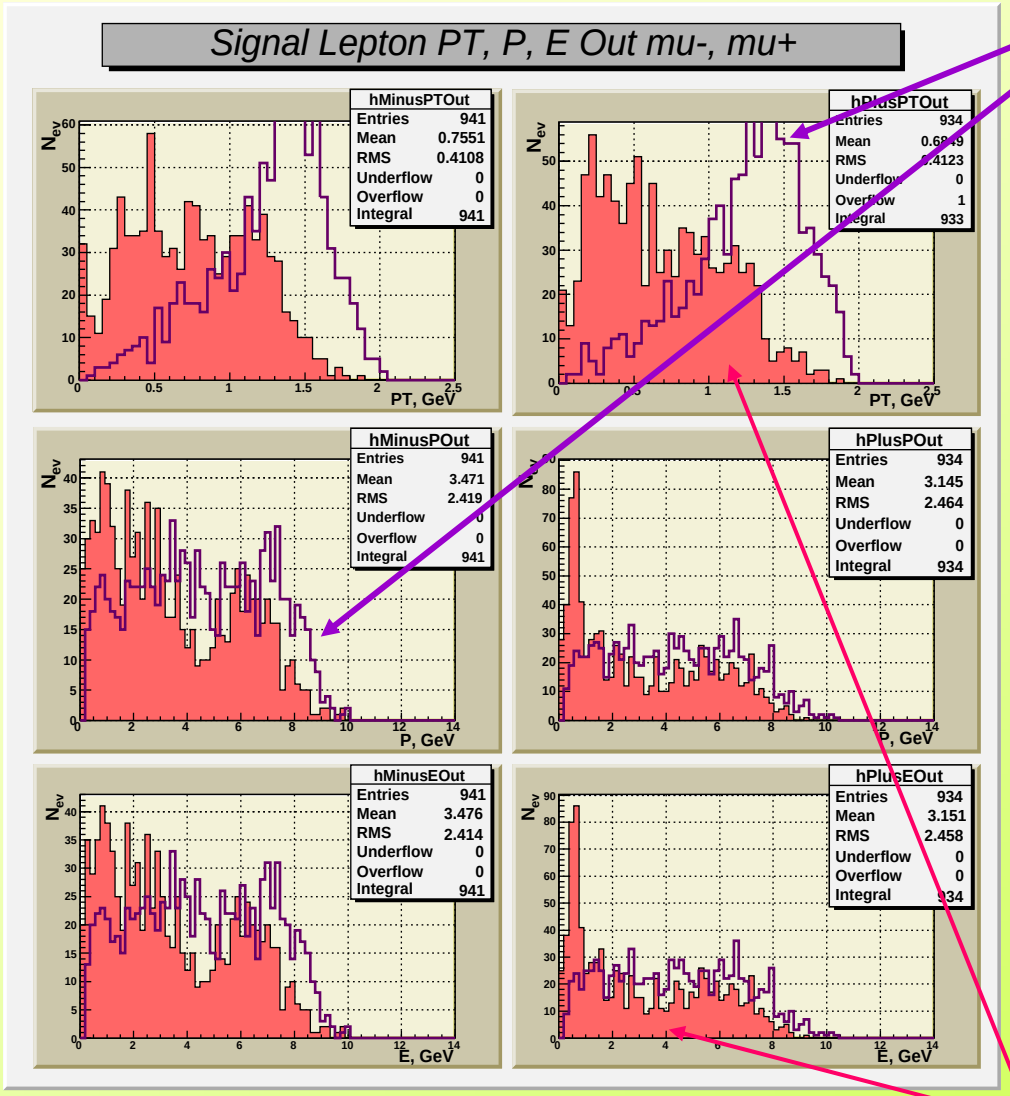
μ^- μ^+

PYTHIA6.4

Momenta & Energy distributions, obtained in result of full simulation, ***insignificantly differ*** from the ones, simulated in PYTHIA6.4 by some ***decrease of the values***, especially at the high edge.

PandaRoot & Geant 3

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



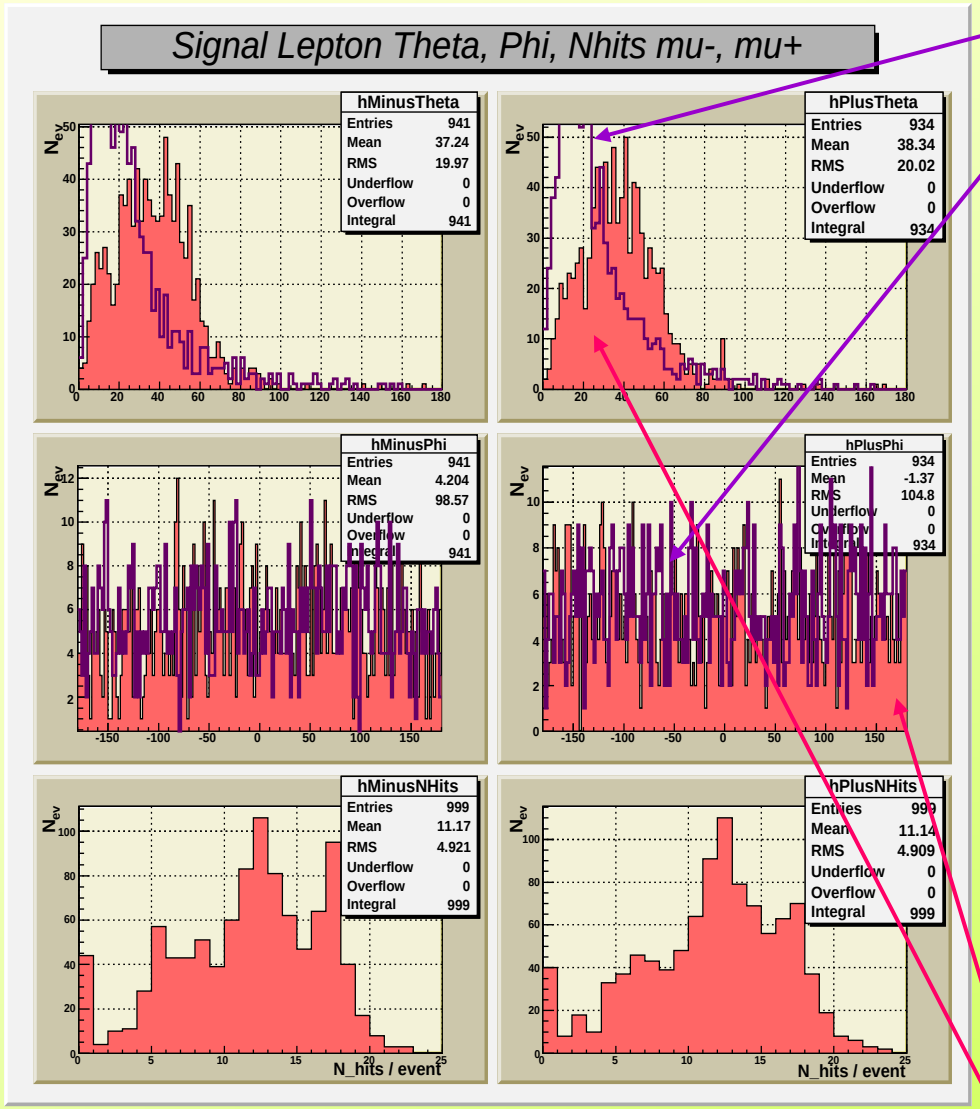
PYTHIA6.4

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** (about 2 GeV) in result of penetrating through the material of the muon system.
- Also, different to PYTHIA, one can see the ***diverse shapes of momentum and energy distributions*** for the cases of positive and negative charges muons.

PandaRoot & Geant 3

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



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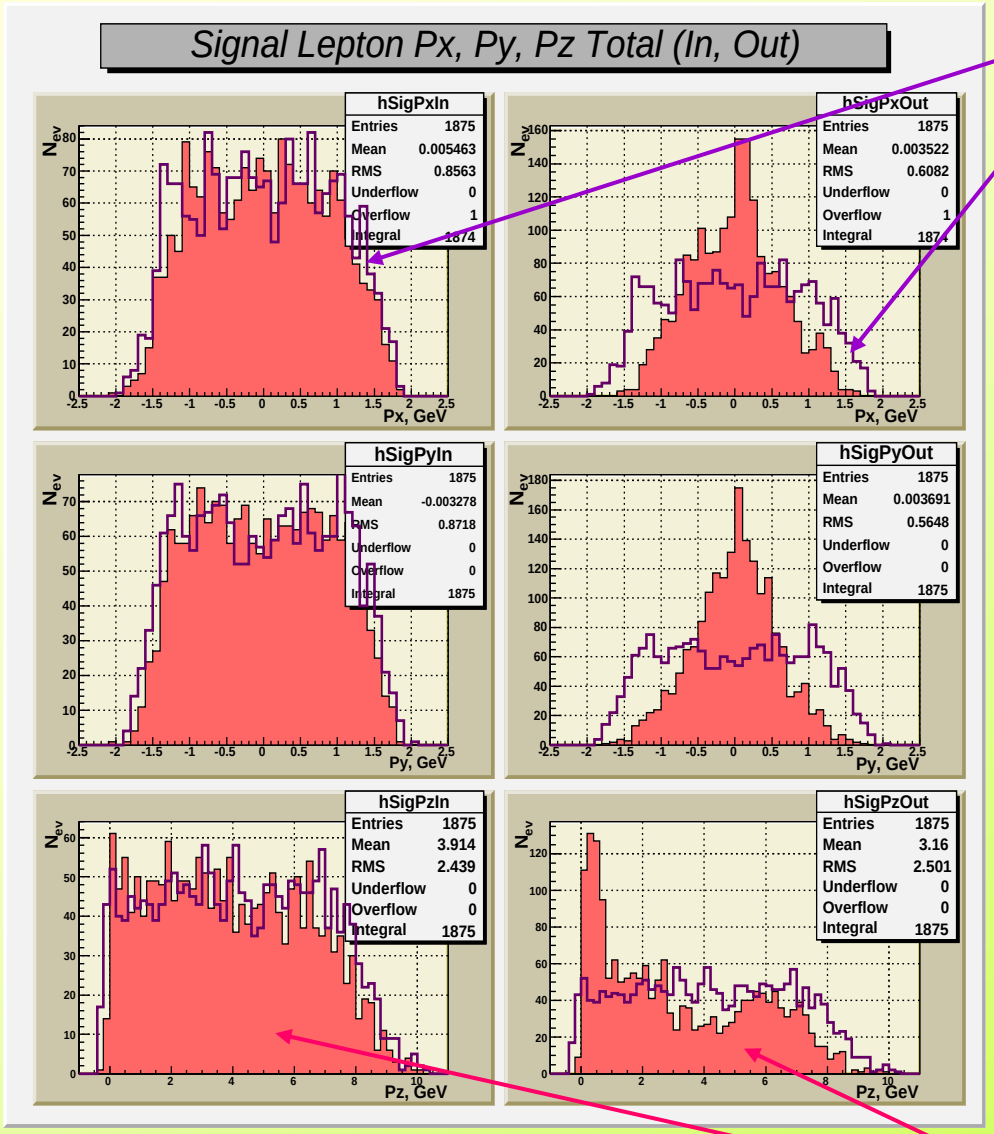
PandaRoot & Geant 3

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



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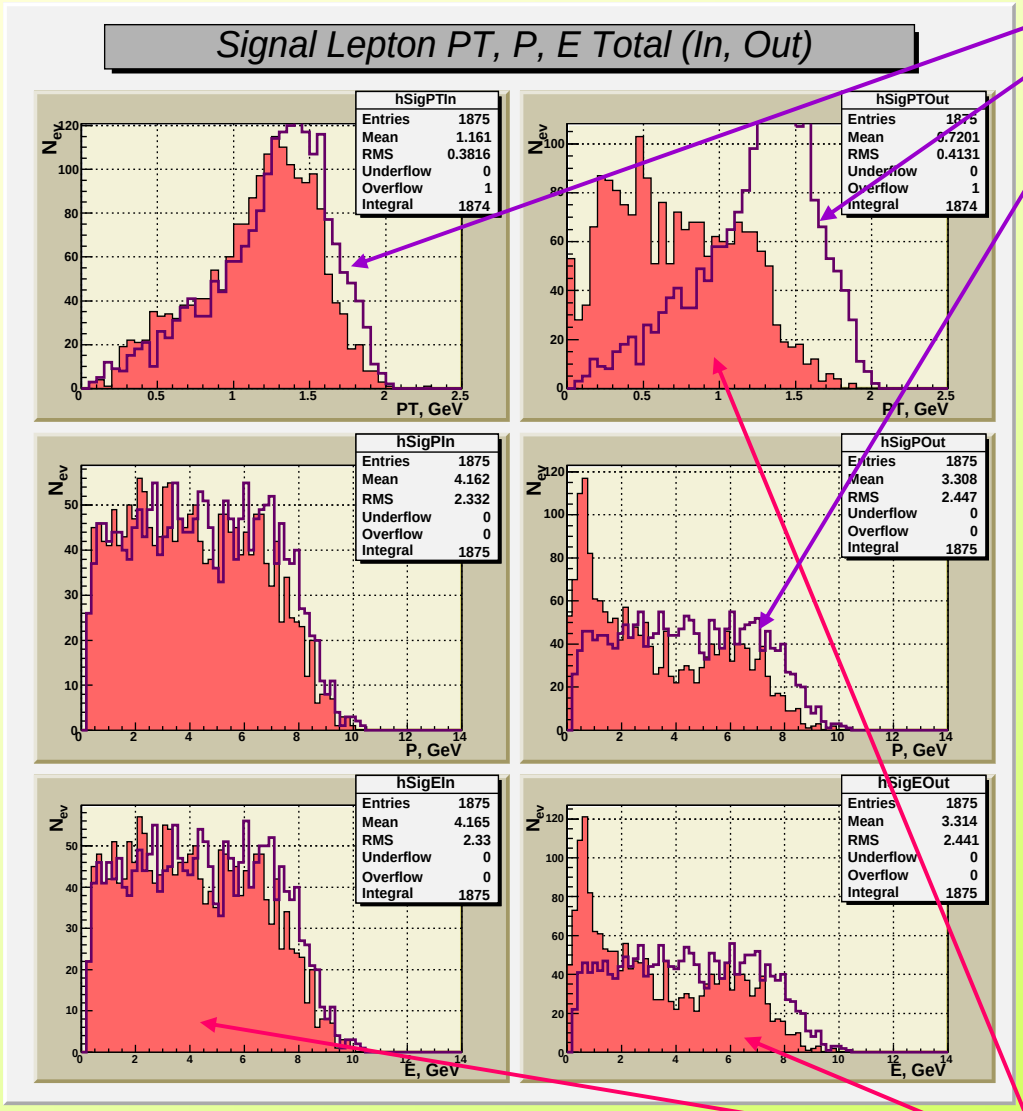


PT^{μ}

P^{μ}

E^{μ}

1-st hit *last hit*

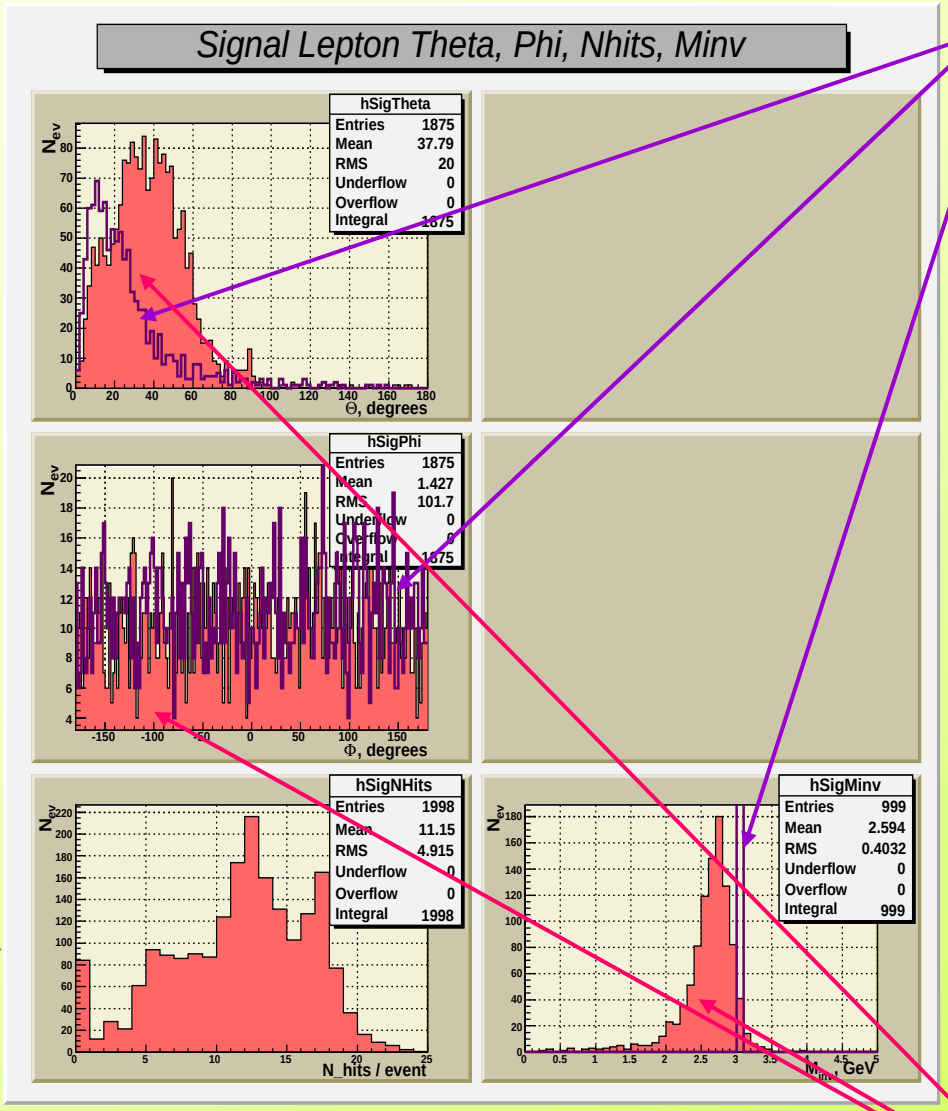
PYTHIA6.4

- 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 are, in general, in a small loss of quantity at higher values.

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



θ^{μ}

φ^{μ}

N_{hits}

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

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.

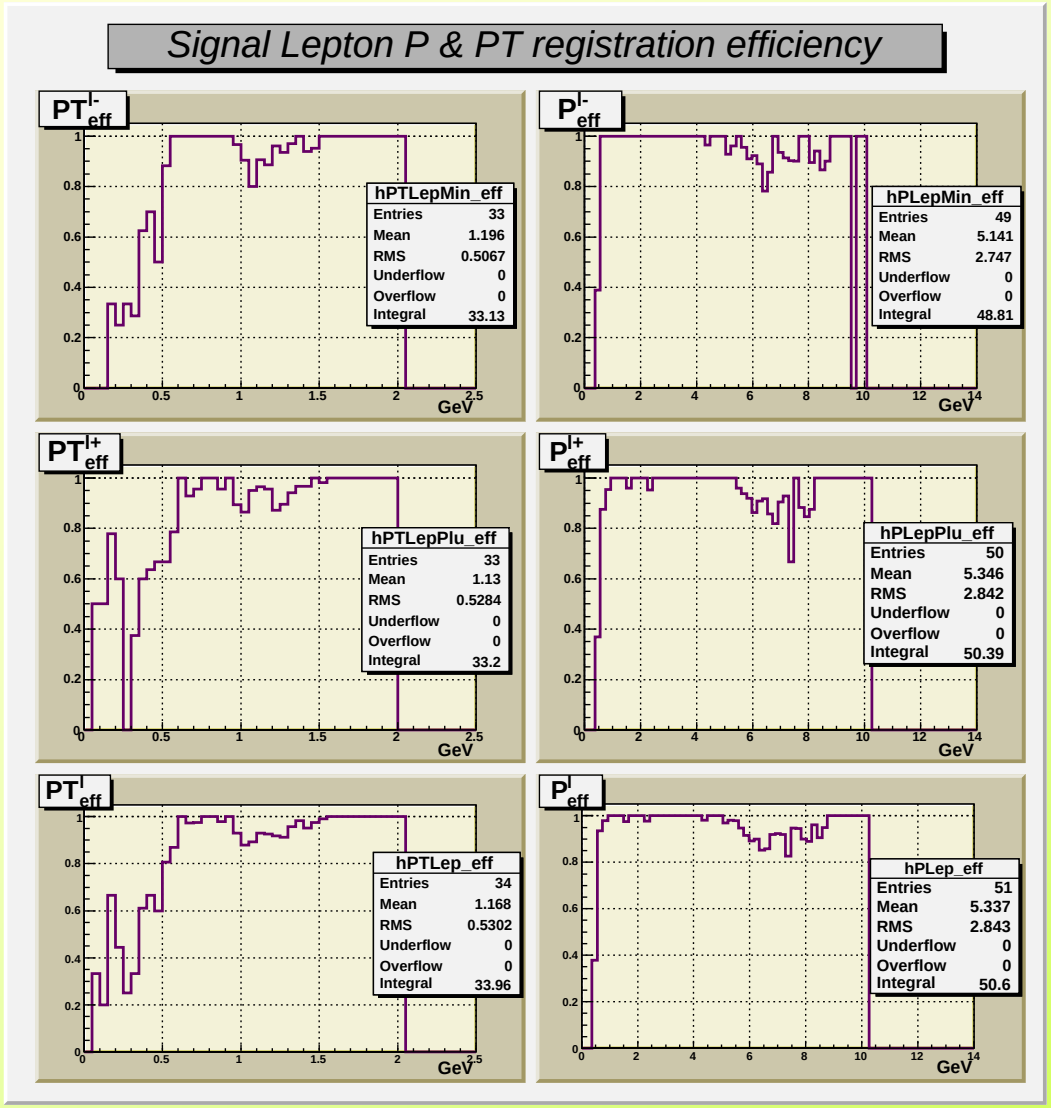
Practically **no difference** in distributions of the azimuth angle φ^{μ}.

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).

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



μ^-

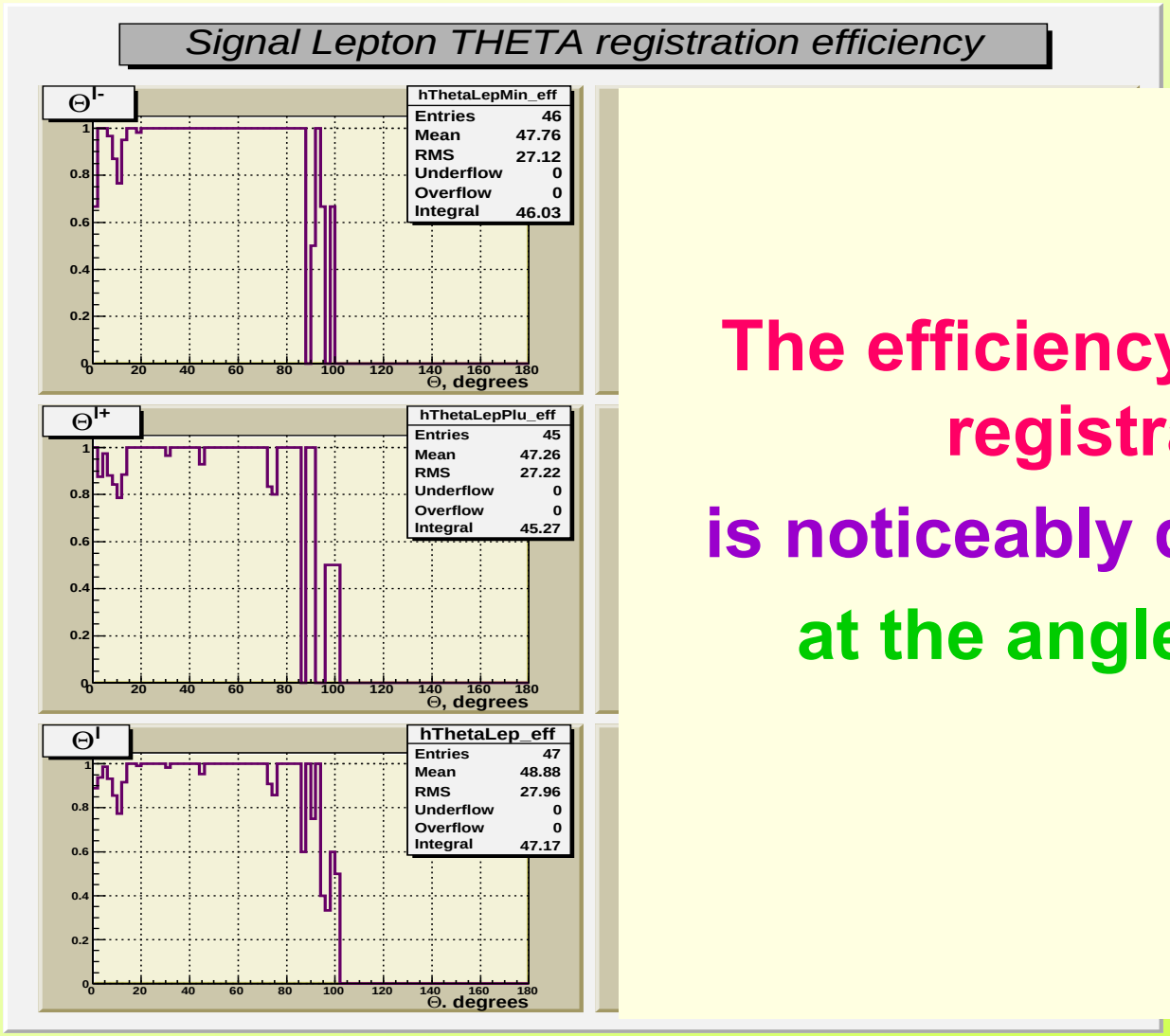
μ^+

$\mu^+ + \mu^-$

PT ***P***

At very low (<0.5 GeV) **initial momentum and transverse momentum, the efficiency of muon registration** is ***noticeably decreasing***.

Signal muon registration efficiency by polar angle θ



μ^-

μ^+

$\mu^+ + \mu^-$

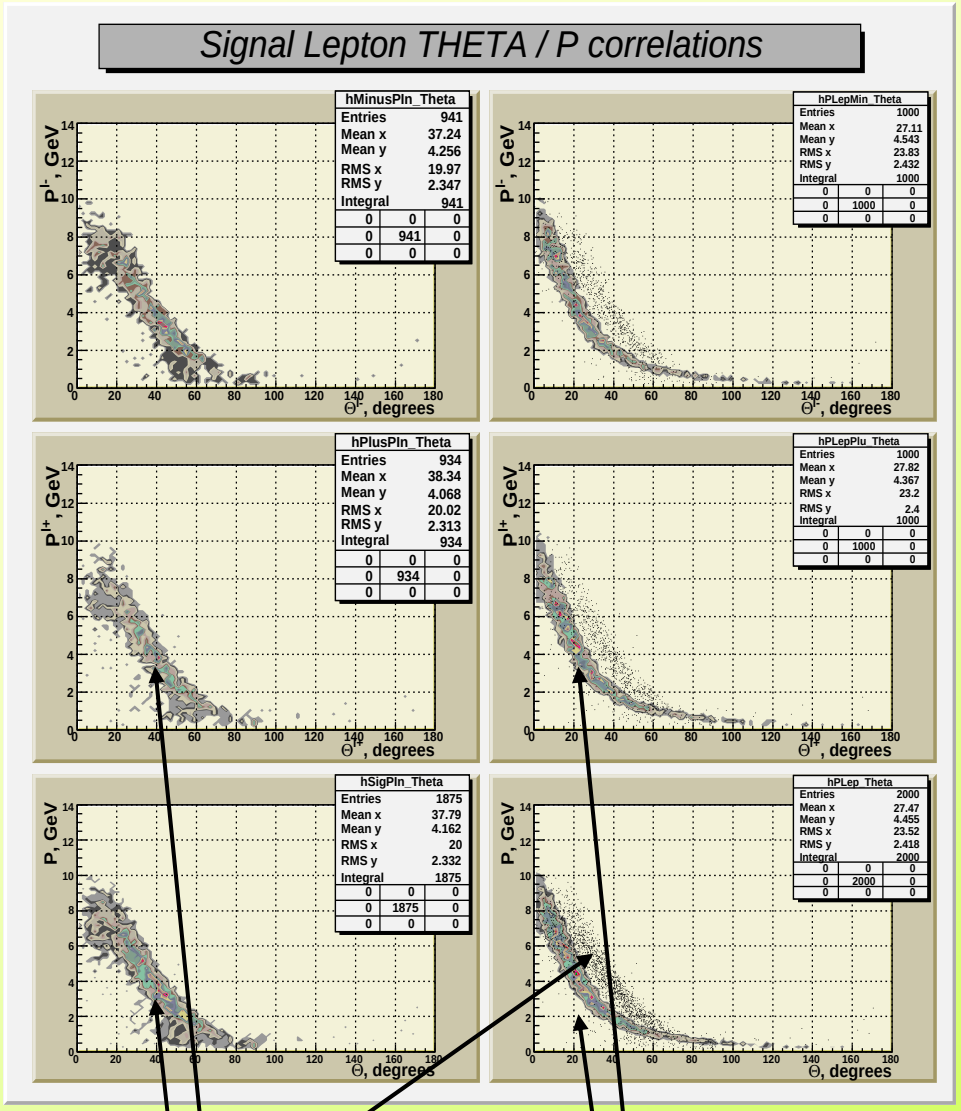
θ

The efficiency of muon registration

is noticeably decreasing

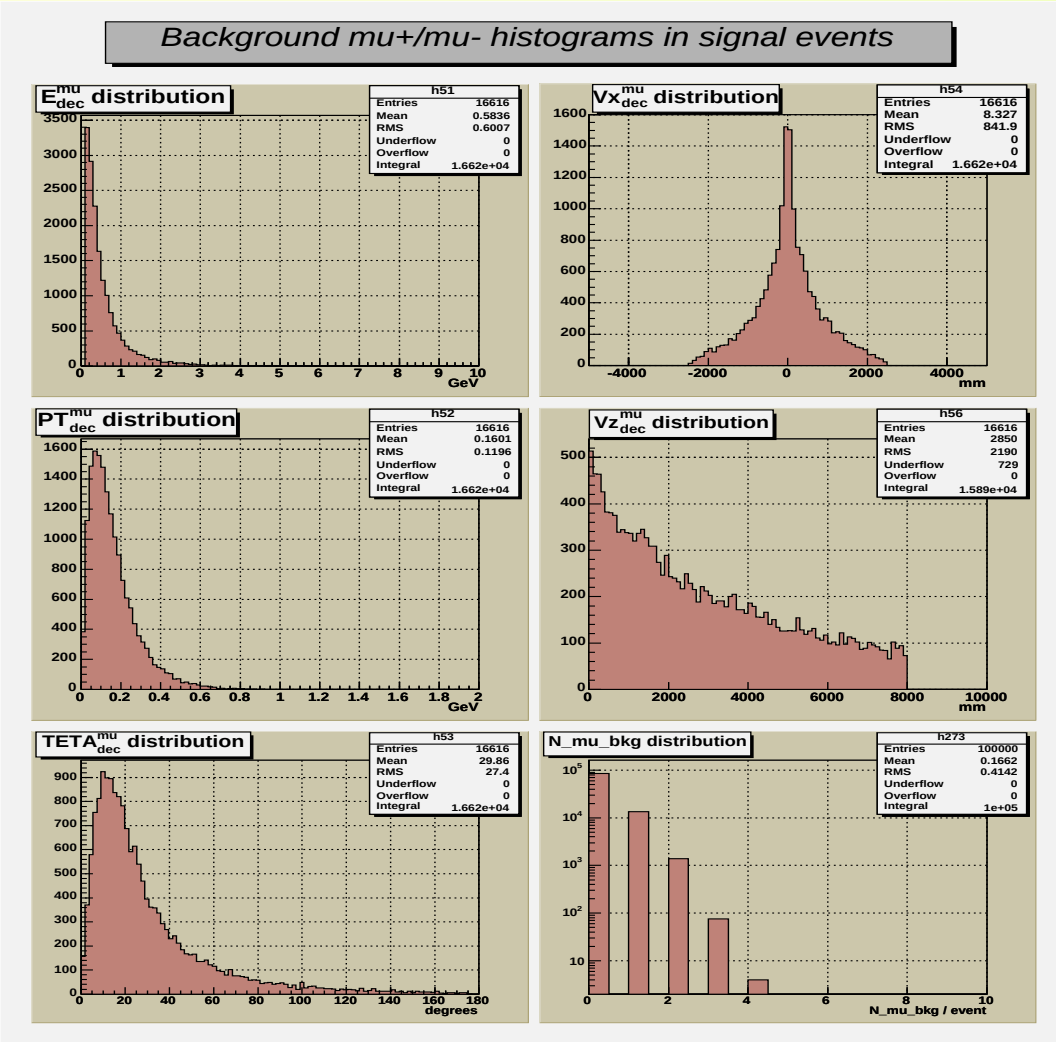
at the angles > 90^0

Correlation distributions of polar angle θ and momentum P



- *The figures are the **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 20^0.**
- Also, ***in the case of the muons from J/Ψ decay, one can observe the clear correlation and the tendency of momentum decrease with increase of a polar angle.***

Fake muons distributions in signal events

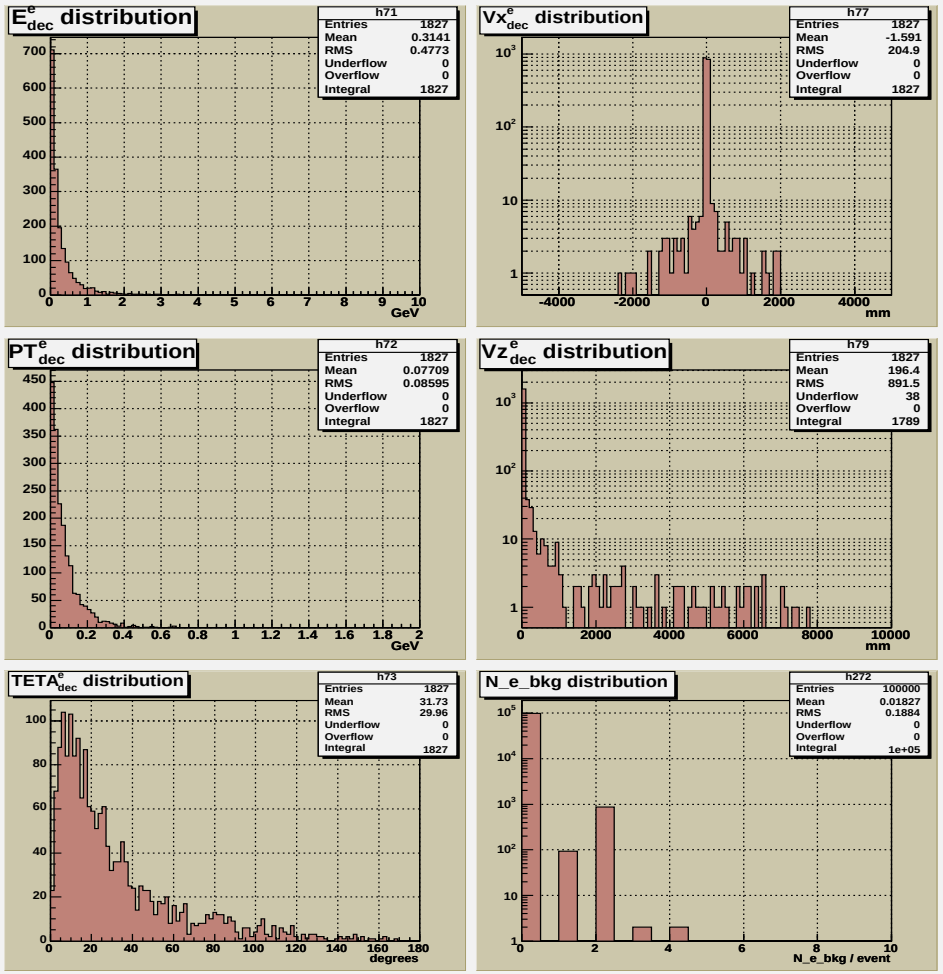


1. The part of signal events which include fake muons is about 16%.
2. Up to 4 fake muons in the final state.
3. Fake **muons production vertices** are distributed within detector volume →

Vertex position information will be useful for Signal / Background separation

Fake electrons distributions in signal events

Background e+/e- histograms in signal events



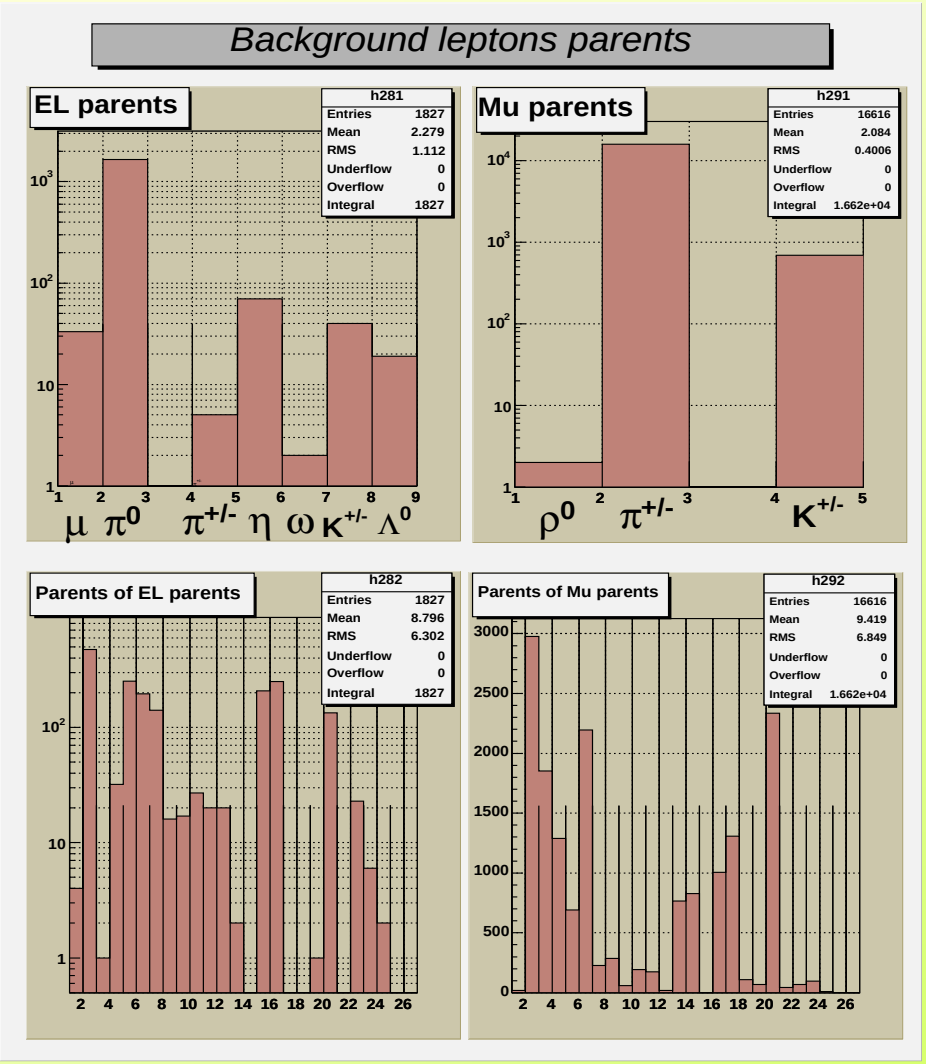
As approximation: particles are allowed to decay in cylinder volume R=2500 x L=8000 mm

The number of events which include fake electrons is about 1 -2% of events

The most of electron pairs do appear as Dalitz pairs ($\pi^0 \rightarrow e^+e^-\gamma$) produced in decays of ***neutral mesons***, which may also appear from **η, ω** or more ***heavy mesons*** or ***barions***, produced in their turn as the resonance states according to the LUND fragmentation model.

The life time of these resonance states is rather short → the electron pairs are produced close to the interaction point → the **vertex position** information will not be efficient for the Signal / Background separation..

Parents of fake leptons



The most probable parents of fake

electrons → are neutral pions (Dalits decay)

muons → are charged pions

The most probable grandparents of fake

electrons → are string (Lund model),

$\rho^+, \eta, \omega, \Delta^0, \Delta^+, \Lambda^0$

muons → are string (Lund model),

$\rho^0, \rho^+, \omega, \Delta^+, \Delta^{++}, \Lambda^0$

Applied cuts for signal events

1. *We select the events with only 2 leptons with* $E_l > 0.2$ GeV, $PT_l > 0.2$ 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*

We suppose the ideal muon system and EM calorimeter covering 180° (PYTHIA simulation)

Cuts influence on signal events

Applying these cuts we have loss of the signal events:

N of cuts	e^+e^- production	$\mu^+\mu^-$ production
1	14.330 %	16.525 %
1 & 2	14.340 %	16.805 %
1 & 2 & 3	14.341 %	17.108 %

The rate of events with left fake leptons is negligible !

0.008 %	0.001 %

Background QCD processes to the $q\,\bar{q} \rightarrow \gamma^* \rightarrow l^+ l^-$ one

The generation was done with the use of more than 20 QCD subprocesses existed in PYTHIA (including the signal one $q\,\bar{q} \rightarrow \gamma^* \rightarrow l^+ l^-$).

The main contributions come from the following partonic subprocesses:

- $q + g \rightarrow q + g$ **(gives 50% of events with the σ = 4.88 mb);**
- $g + g \rightarrow g + g$ **(gives 30% of events with the σ = 2.96 mb);**
- $q + q' \rightarrow q + q'$ **(gives 18% of events with the σ = 1,75 mb);**
- $q + q\ bar \rightarrow g + g$ **(gives 0.6% of events with the σ = 5.89 E- 02 mb);**
- $q + q\ bar \rightarrow l^+ + l^-$ **(signal process gives 0.00005% of bkgd events, due to σ = 5.02 E- 06 mb);**

So, initially there is 1 signal event among 2.000.000 of QCD background

i.e., initially → S/B ≃ $5.5 * 10^{-6}$

The simulation was done with approximation when particles are allowed to decay within cylinder volume of R=2500 and L=8000 mm

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

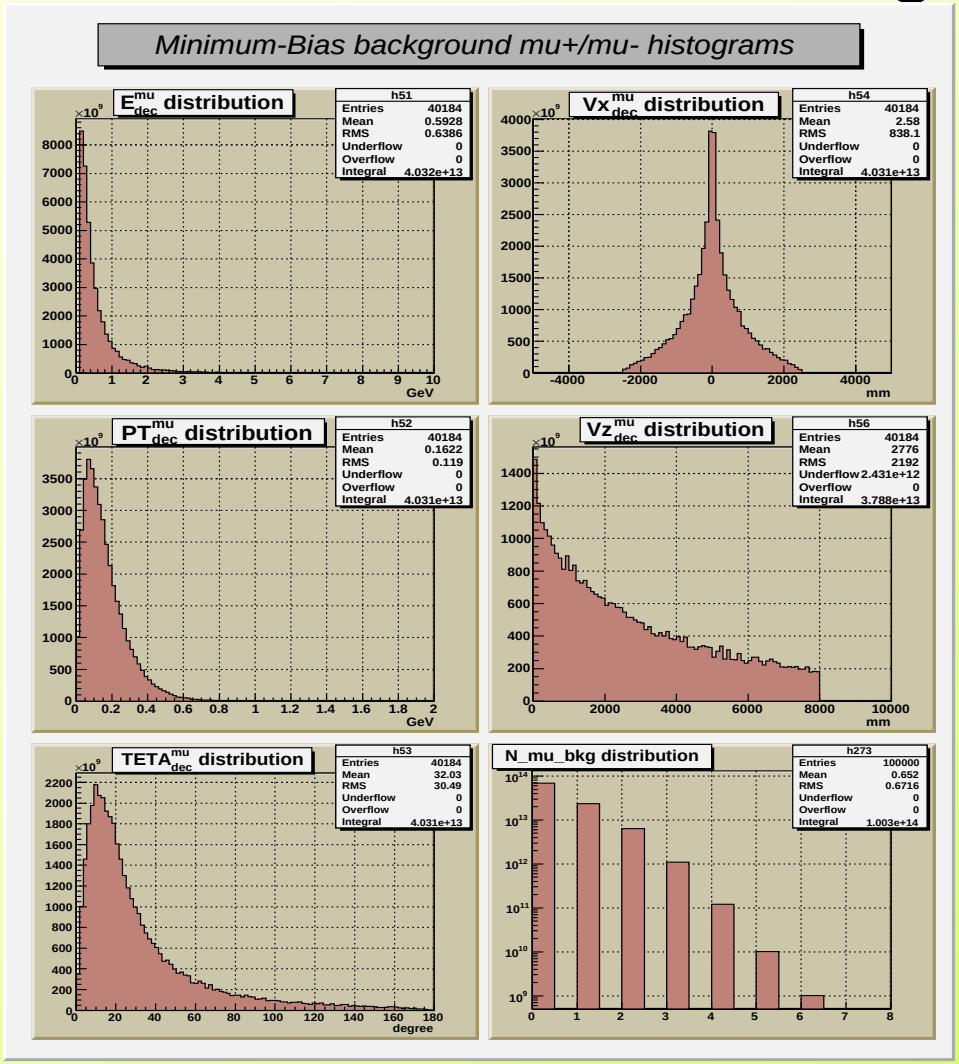
Some examples:

- ***Low - PT scattering*** (gives 68% of events with the **σ** = **34.25** mb);
- ***Single diffractive*** (gives 6% of events with the **σ** = **3.32** mb);
- $qbar + q \rightarrow l^+ + l^-$ (gives **0.000012%** of events, **σ = 5.9 E- 06** mb);

So, we have 1 signal event aginst 8.333.333 of Mini-bias bkgd → **S/B ≃10^{-7}**

Mini-bias background is 5 times harder than QCD background

Muon's distributions from background events

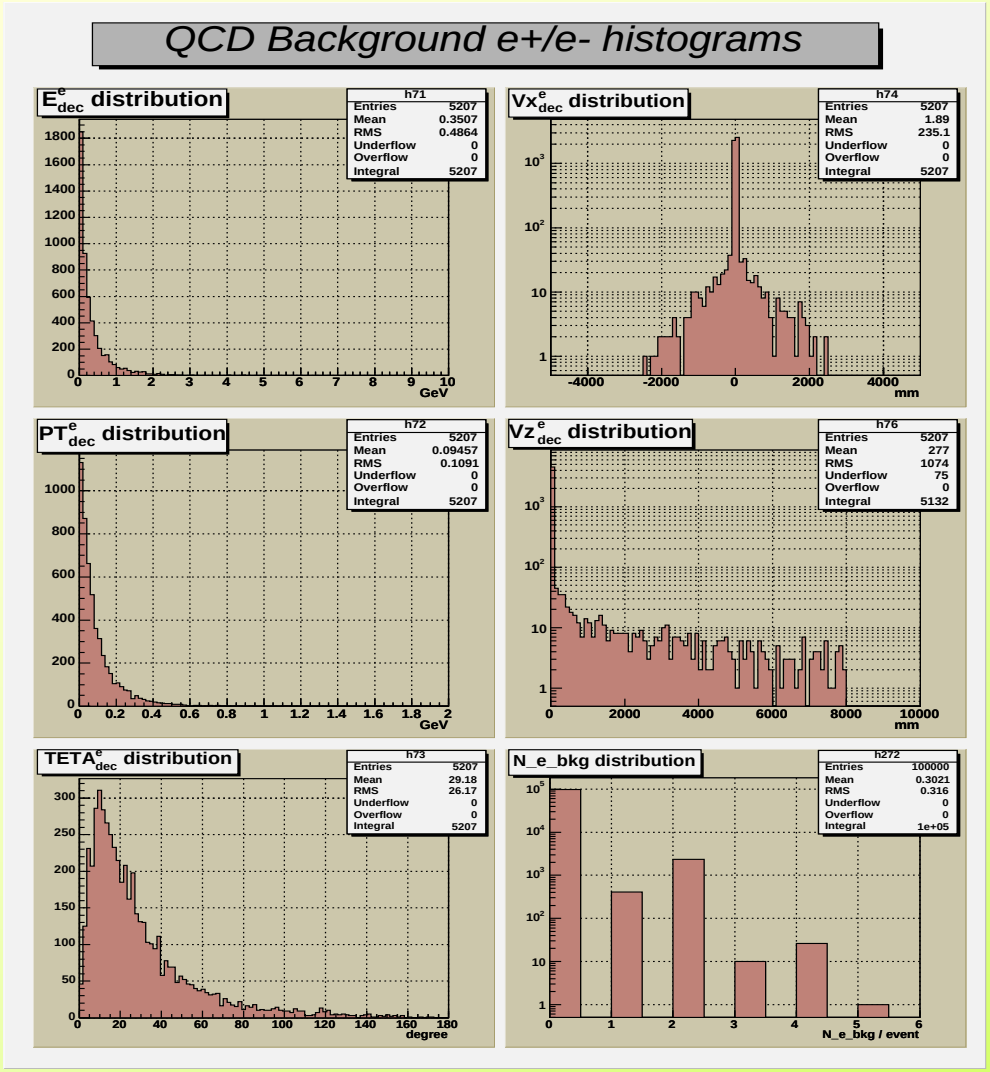


The shape of **muon** distributions, produced in ***background events*** do not differ from those of fake "decay" muons, produced in ***the signal process***

→ 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 e+/e- distributions

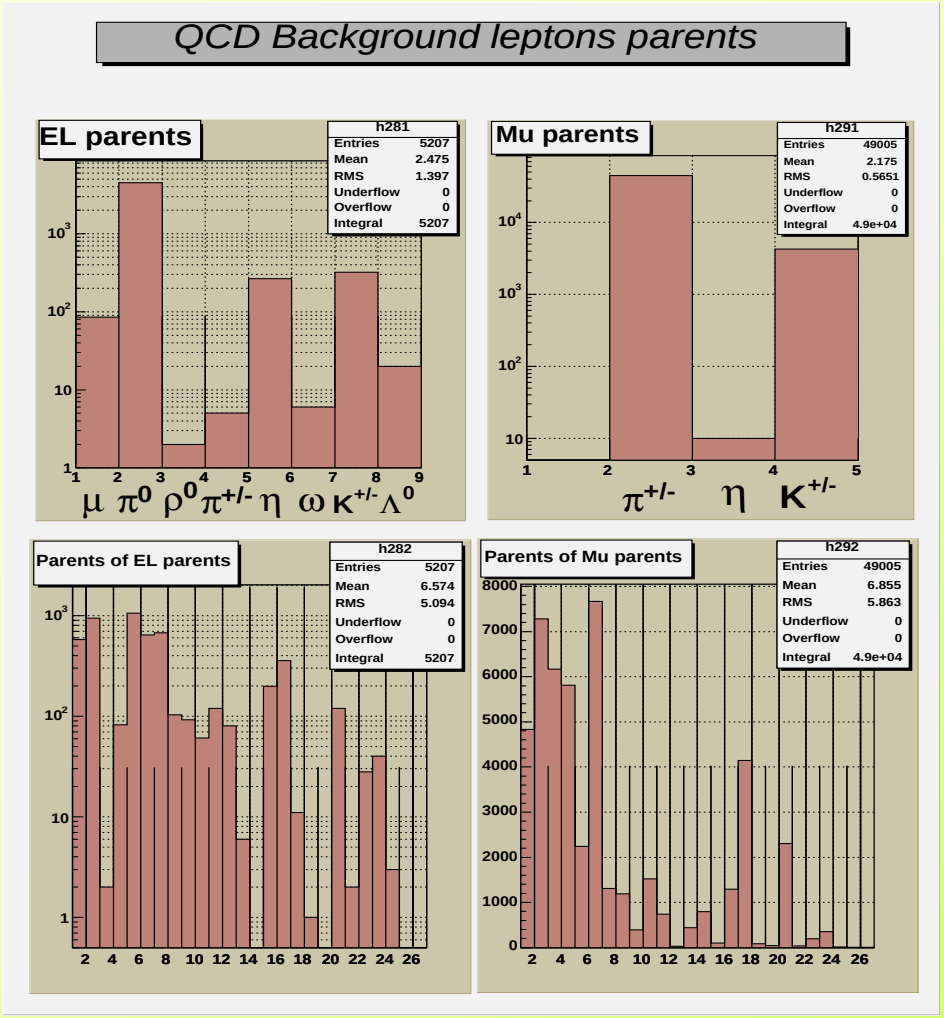


The shape of **background electron's** distributions are identical to the ones, surrounding the signal process.

The most of electron pairs do appear as Dalitz pairs ($\pi^o \rightarrow e^+e^-\gamma$)

The electron pairs are produced close to the interaction point → the vertex position information will not be efficient for the Signal / Background separation..

Parents of background leptons



The most probable parents of fake ***electrons*** *→ are neutral pions* ($\pi^0 \rightarrow e^+e^-\gamma$)

muons *→ are charged pions*

The most probable grandparents of fake ***electrons*** *→ are strings (Lund model),* $\rho^+, \eta, \omega, \Delta^0, \Delta^+$

muons *→ are strings (Lund model),* ρ^0, ρ^+, ω

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

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

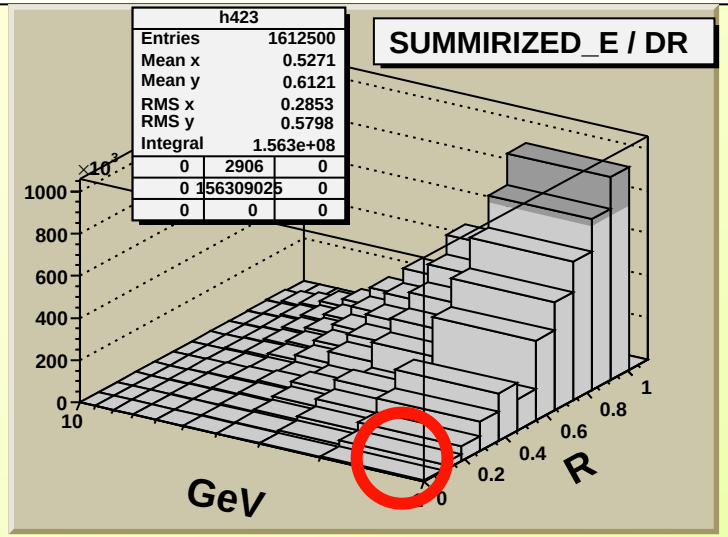
1. selection of events with the only 2 leptons, having $E_l > 0.2$ GeV, $PT_l > 0.2$ GeV;
2. these 2 leptons have charges of the opposite charge;
3. the vertex of lepton origin lies within the R< 15mm from the interaction point;
4. $M_{inv}(l^+l^-) \geq 0.9$ GeV;
5. leptons have to satisfy the isolation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

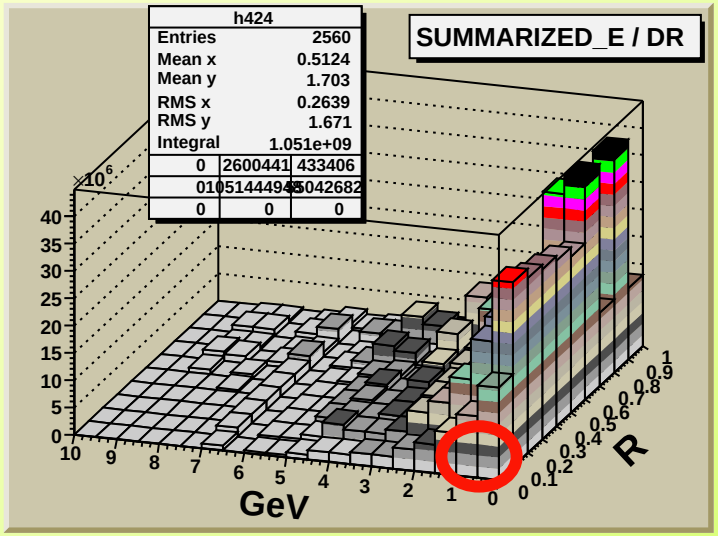
Efficiency of cuts in the presence of mini-bias and QCD bkgd & S/B ratio

N of cuts	S/B for $\mu^+\mu^-$ production	Efficiency	S/B for e^+e^- production	Efficiency
1	$1.41 \cdot 10^{-5}$	0.007	$5.34 \cdot 10^{-4}$	$1.78 \cdot 10^{-4}$
2	$2.12 \cdot 10^{-5}$	0.665	$5.41 \cdot 10^{-4}$	0.98
3	$9.94 \cdot 10^{-5}$	0.002	$5.47 \cdot 10^{-4}$	0.99
4	0.123	0.08	$9.27 \cdot 10^{-2}$	0.006
5	Background = 0	–	3.8	0.024

- The total loss of signal events after application of all five cuts is expected to be about 20%.
- So, we can expect to gain a huge sample of about **7×10^6 signal** dilepton events per 1 year (10^7 sec.)

Lepton (e) 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 → **background events**

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

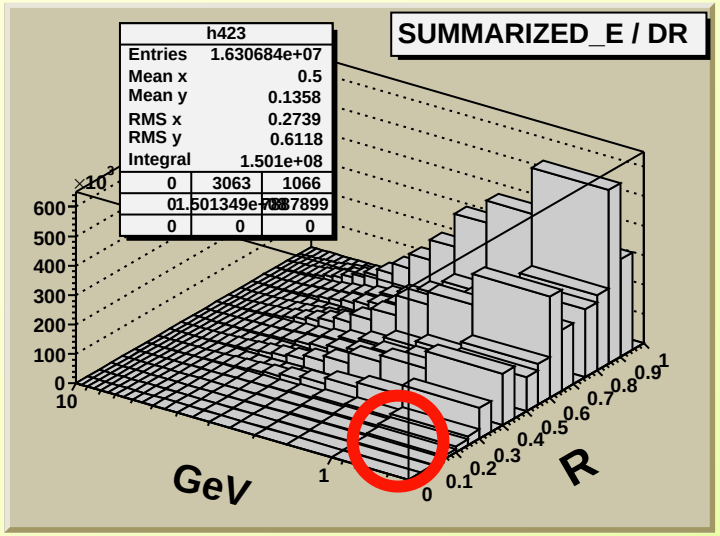
$E^{(of\ particles)}$ = 0.5 GeV

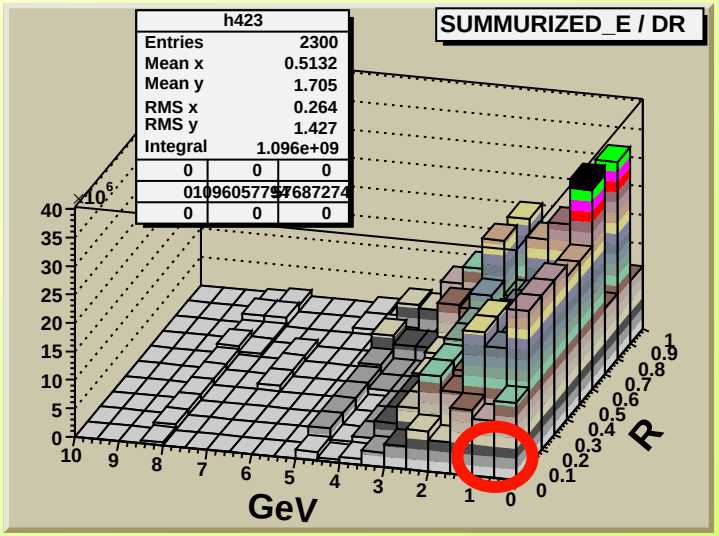
allows to separate 100% of QCD leptons with loss of 8% of signal events

Final ***S/B ratio = 3.6!*** ***M_{inv} (l+,l-) > 0.9***

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

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

allows to separate 100%

of Mini-bias bkg leptons

with the loss of **8%** of signal events

*(after applied 3 cuts discussed above + cut **M inv** (l^+,l^-) > 0.9)*

Conclusion

The proposed cuts:

1. *Events with only 2 leptons having* $E_l > 0.2$ GeV, $PT_l > 0.2$ GeV;
2. *The charges of these 2 leptons have opposite sign;*
3. *The vertex of origin lies within the distance < 15 mm from the interaction point*
4. $M_{inv}(l^+, l^-) > 0.9$ GeV
5. *Isolation criteria* $E_{(R\ isolation = 0.2)} = 0.5$ GeV

allow:

I. To gain about 7×10^6 signal dilepton events per 1 year;

II. To *suppress QCD & Mini-bias bkgd*:

completely for muons *and to*

S/B = 9 for electrons;

III. Next step: full detector MC simulation.