Lepton pair production at intermediate energies

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XIX INTERNATIONAL BALDIN SEMINAR ON HEP PROBLEMS

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 1069; 27p.)

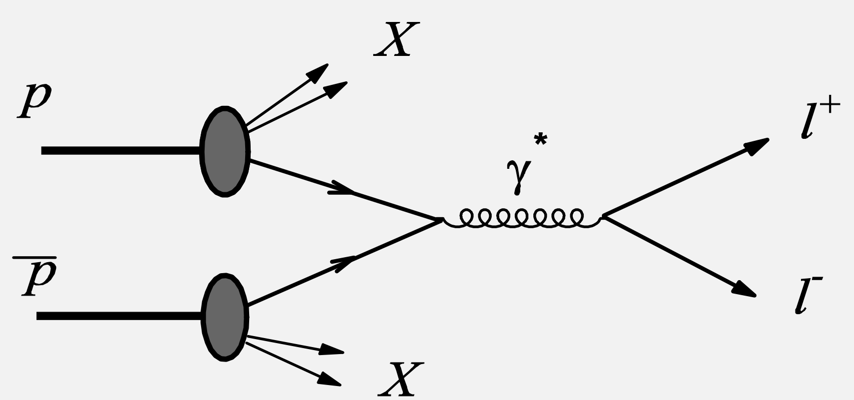
process, called also as Drell-Yan

(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

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

$\sigma = 5.6 * 10^3$ pb



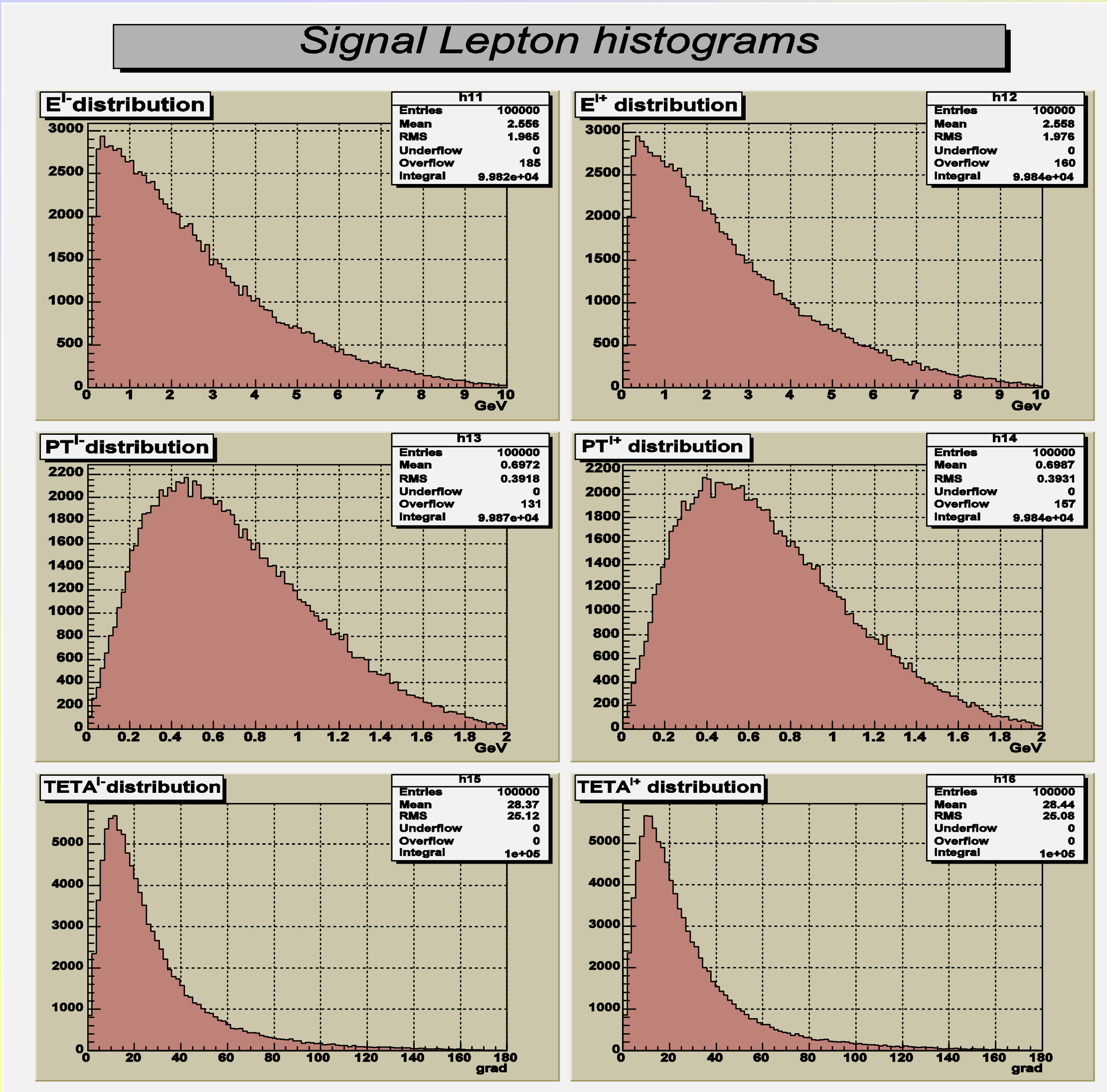
PYTHIA 6 simulation for the $E_{beam} = 14$ GeV

without detector effects (“ideal detector” --> all particles are detected) allows a proper account of the relativistic kinematics during the simulation

- Quark-antiquark annihilation process of hadron-hadron collision may provide an interesting information about the ***quark dynamics inside the hadron***.

- The measurement of the total transverse momentum of a lepton pair as a whole may provide an important information about the ***intrinsic transverse momentum*** ***$\langle k_T \rangle$*** that appears due to the Fermi motion of quarks inside the nucleon.

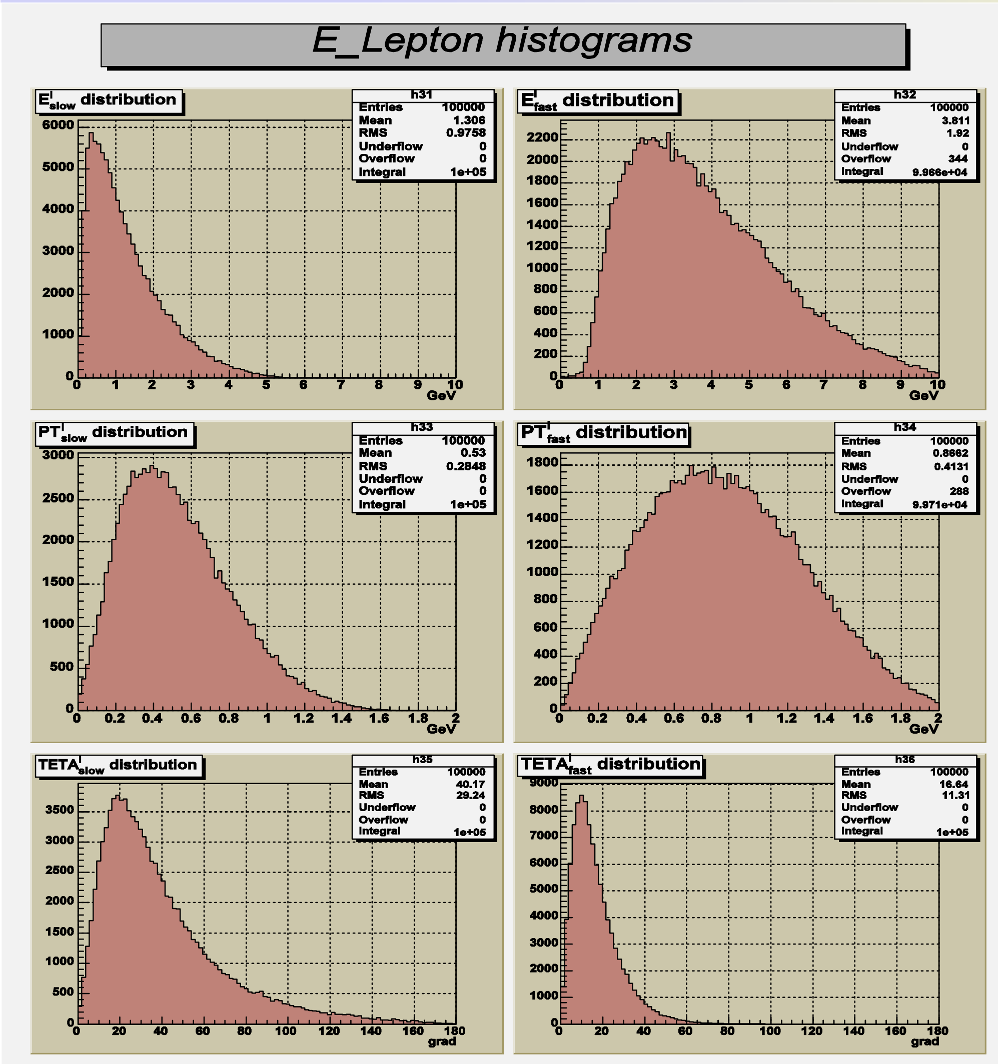
Signal $\ell^{\pm}$:



- $0 \leq E_\ell \leq 10$ GeV, $\langle E_\ell \rangle = 2.6$ GeV, $E_{peak} = 0.4$ GeV
- $0 \leq PT_\ell \leq 2$ GeV, $\langle PT_\ell \rangle = 0.7$ GeV
- $\langle \Theta_\ell \rangle = 27.3°$

  some $\Theta_\ell > 90°$!!!

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



Left column

$0 < E_{\ell\ \text{"slow"}} < 5$ GeV

$0 < \Theta_{\ell\ \text{"slow"}} < 180°$

Less energetic slow leptons some have $\Theta_{\ell\ \text{"slow"}} > 90°$

Right column

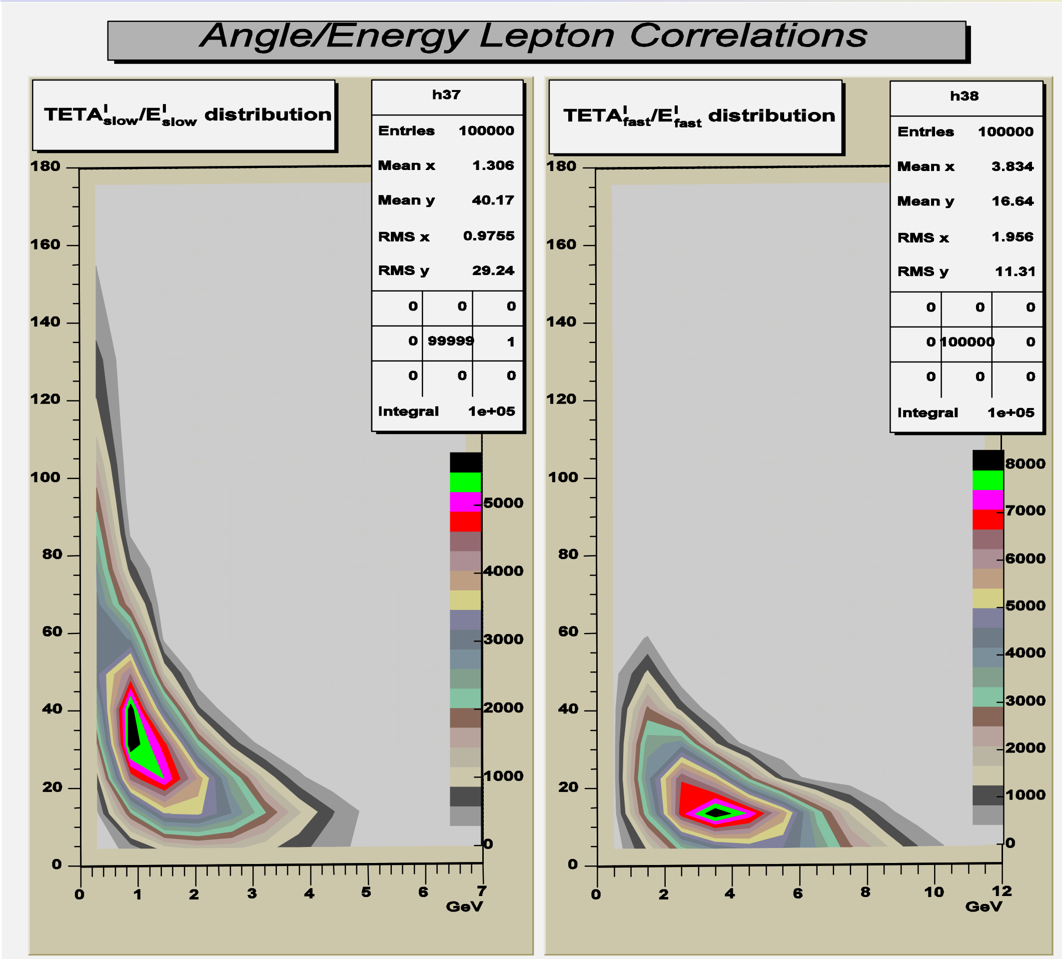
$0.4 < E_{\ell\ \text{"fast"}} < 10$ GeV

$0 < \Theta_{\ell\ \text{"fast"}} < 60°$

High energetic fast leptons fly in a forward direction

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

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



E_ℓ > 0.5 GeV

Nevent ≈ 70% Nevent ≈ 98%

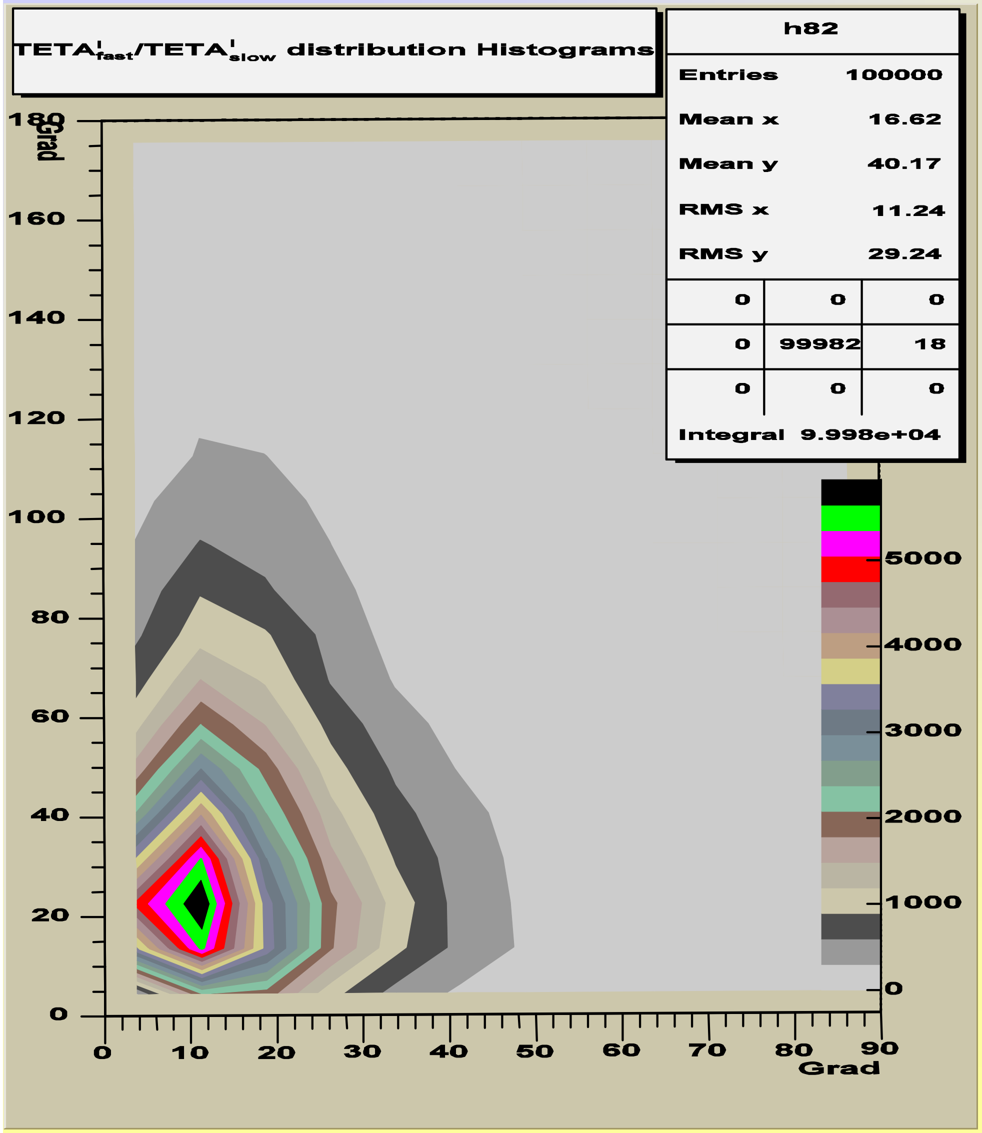
for E_ℓ > 4 GeV "high edge"

Nevent ≈ 2% Nevent ≈ 40%

for Θ_ℓ < 60°

Nevent ≈ 78% Nevent ≈ 99.96%

Θ_{ℓ} "_slow" / Θ_{ℓ} "_fast" correlation

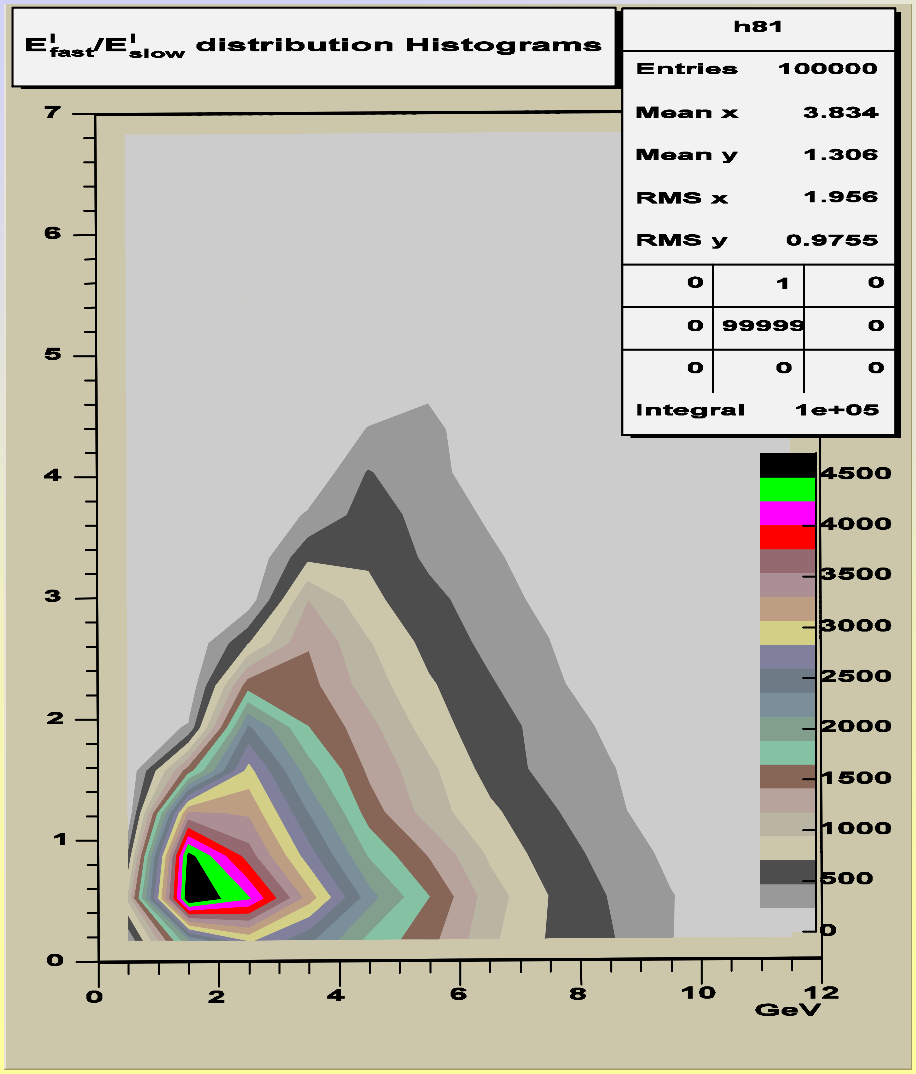


Muon system geometry cuts :

- *Θℓ_"slow" & Θℓ_"fast"* **≤ 20º**
  → ***14% events save***
- *Θℓ_"slow" & Θℓ_"fast"* **≤ 40º**
  → ***50% events save***
- *Θℓ_"slow" & Θℓ_"fast"* **≤ 60º**
  → ***72% events save***
- *Θℓ_"slow" & Θℓ_"fast"* **≤ 90º**
  → ***94% events save***

  (→ 6% of events loss)

E_{ℓ} "slow" / E_{ℓ} "fast" correlation



Applying the Energy cuts:

- E_{ℓ}_"fast" & E_{ℓ}_"slow" > 0.5 GeV

→ get more than 25% events loss

- E_{ℓ}_"fast" & E_{ℓ}_"slow" > 1 GeV

→ get more than 45% events loss

J/Ψ production processes

1) $q_i \bar{q}_i \to \gamma^* \to c\bar{c} \to J/\Psi \to \ell^+\ell^- + X$

86) $g\,g \to J/\Psi + g \to \ell^+\ell^- + X$ — R.Baier and R.Rücke, Z.Phys. C19 (1983) 251

106) $g\,g \to J/\Psi + \gamma \to \ell^+\ell^- + X$ — M.Drees and C.S.Kim, Z.Phys. C53 (1991) 673

421) $g\,g \to c\bar{c}\ [^3S_1{}^{(1)}]\ g \to \ell\ell + X$
422) $g\,g \to c\bar{c}\ [^3S_1{}^{(8)}]\ g \to \ell\ell + X$
423) $g\,g \to c\bar{c}\ [^3S_0{}^{(8)}]\ g \to \ell\ell + X$
424) $g\,g \to c\bar{c}\ [^3P_J{}^{(8)}]\ g \to \ell\ell + X$
425) $g\,q \to c\bar{c}\ [^3S_1{}^{(8)}]\ q \to \ell\ell + X$
426) $g\,q \to c\bar{c}\ [^3P_J{}^{(8)}]\ q \to \ell\ell + X$
427) $g\,g \to c\bar{c}\ [^3S_1{}^{(1)}]\ q \to \ell\ell + X$
428) $q\,\bar{q} \to c\bar{c}\ [^3S_1{}^{(8)}]\ g \to \ell\ell + X$
429) $q\,\bar{q} \to c\bar{c}\ [^1S_0{}^{(8)}]\ g \to \ell\ell + X$
430) $q\,\bar{q} \to c\bar{c}\ [^3P_J{}^{(8)}]\ g \to \ell\ell + X$

431) $g\,g \to c\bar{c}\ [^3P_0\,(^1)]\ g \to \ell\ell + X$
432) $g\,g \to c\bar{c}\ [^3P_1\,(^1)]\ g \to \ell\ell + X$
433) $g\,g \to c\bar{c}\ [^3P_2\,(^1)]\ g \to \ell\ell + X$
434) $g\,q \to c\bar{c}\ [^3P_0\,(^1)]\ q \to \ell\ell + X$
435) $g\,q \to c\bar{c}\ [^3P_1\,(^1)]\ q \to \ell\ell + X$
436) $g\,q \to c\bar{c}\ [^3P_2\,(^1)]\ q \to \ell\ell + X$
437) $q\,q\_ \to c\bar{c}\ [^3P_0\,(^1)]\ g \to \ell\ell + X$
438) $q\,\bar{q} \to c\bar{c}\ [^3P_1\,(^1)]\ g \to \ell\ell + X$
439) $q\,\bar{q} \to c\bar{c}\ [^3P_2\,(^1)]\ g \to \ell\ell + X$

G.T.Badwin, E.Braten and G.P.Lepage, Phys.Rev. **D51** (1995) 1125 [Erratum: *ibid* **D55** (1997) 5883];

M.Beneke, MKrämer and M.Vänttinen, Phys.Rev.**D57** (1998) 4258;

B.A.Kniehl and J.Lee, Phys.Rev. **D62** (2000) 114027

J/Ψ production

The main contributions to the cross section give the next processes:

1) $q_i \bar{q}_i \rightarrow \gamma^* \rightarrow c\bar{c} \rightarrow J/\Psi \rightarrow \ell^+ \ell^- + X$

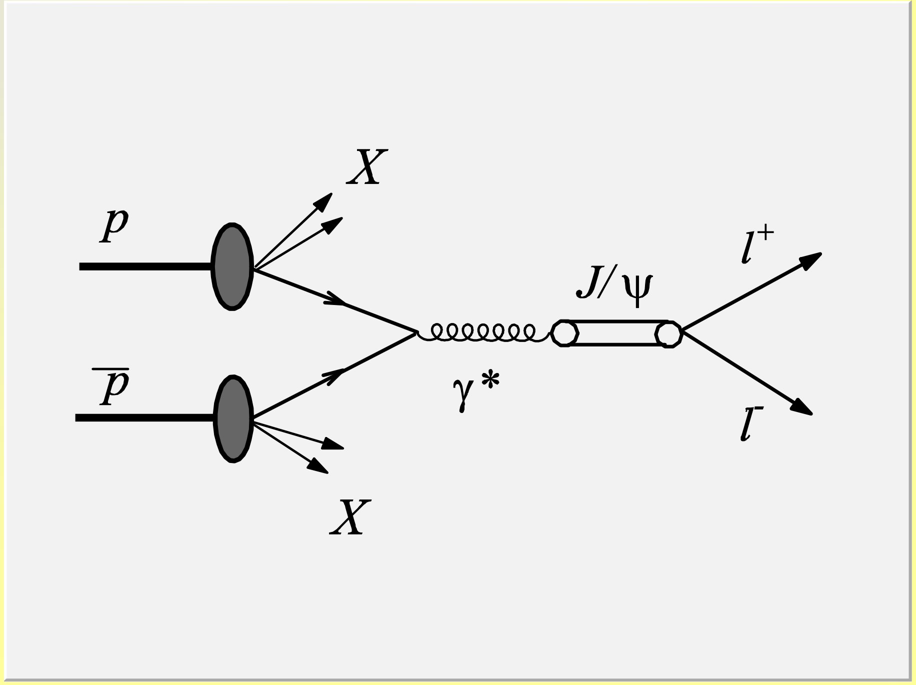
428) $q \bar{q} \rightarrow c\bar{c}\,[{}^3S_1^{(8)}]\, g \rightarrow \ell^+ \ell^- + X$

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

The maximum cross section value (obtained by PYTHIA 6.4 simulation) is

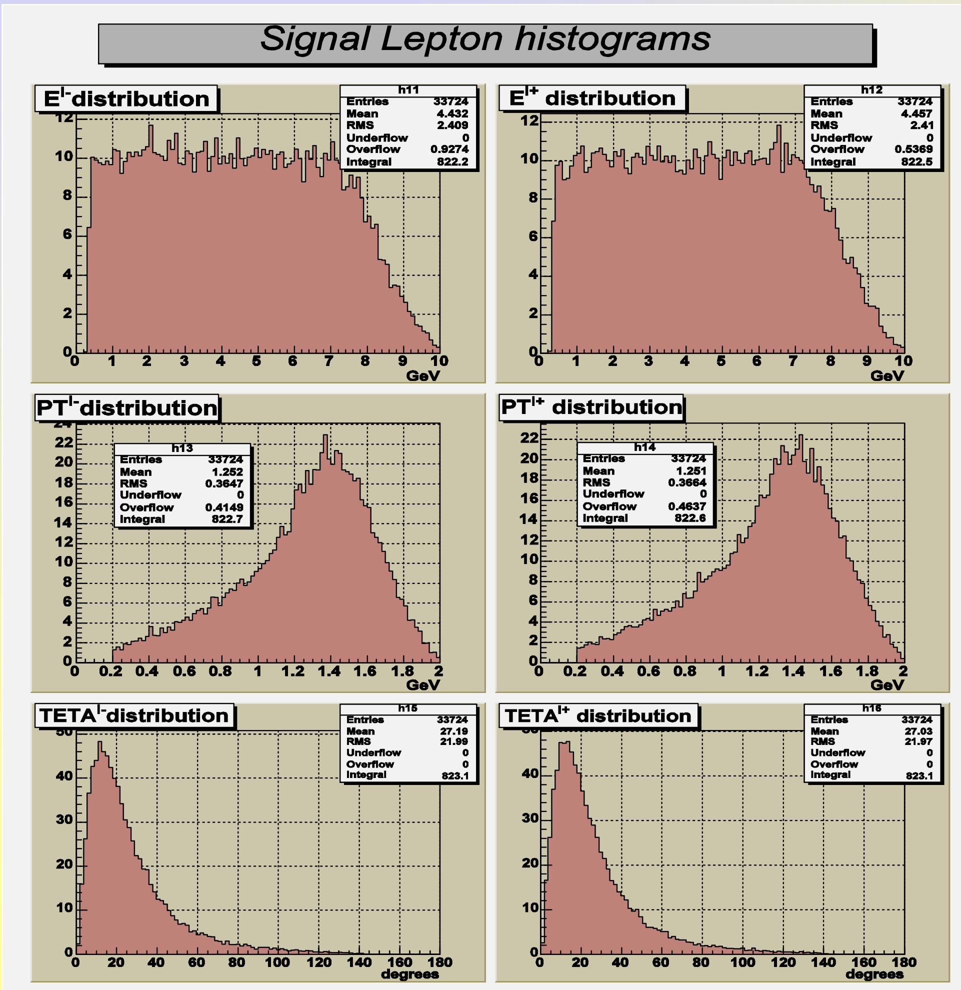
σ = 20.75 pb
that corresponds to
358.5 events / day

for the E beam = 14 GeV
and Luminosity = $2*10^5$ 1/mb*sec
(= $2*10^{32}$ cm^{-2} sec^{-1})



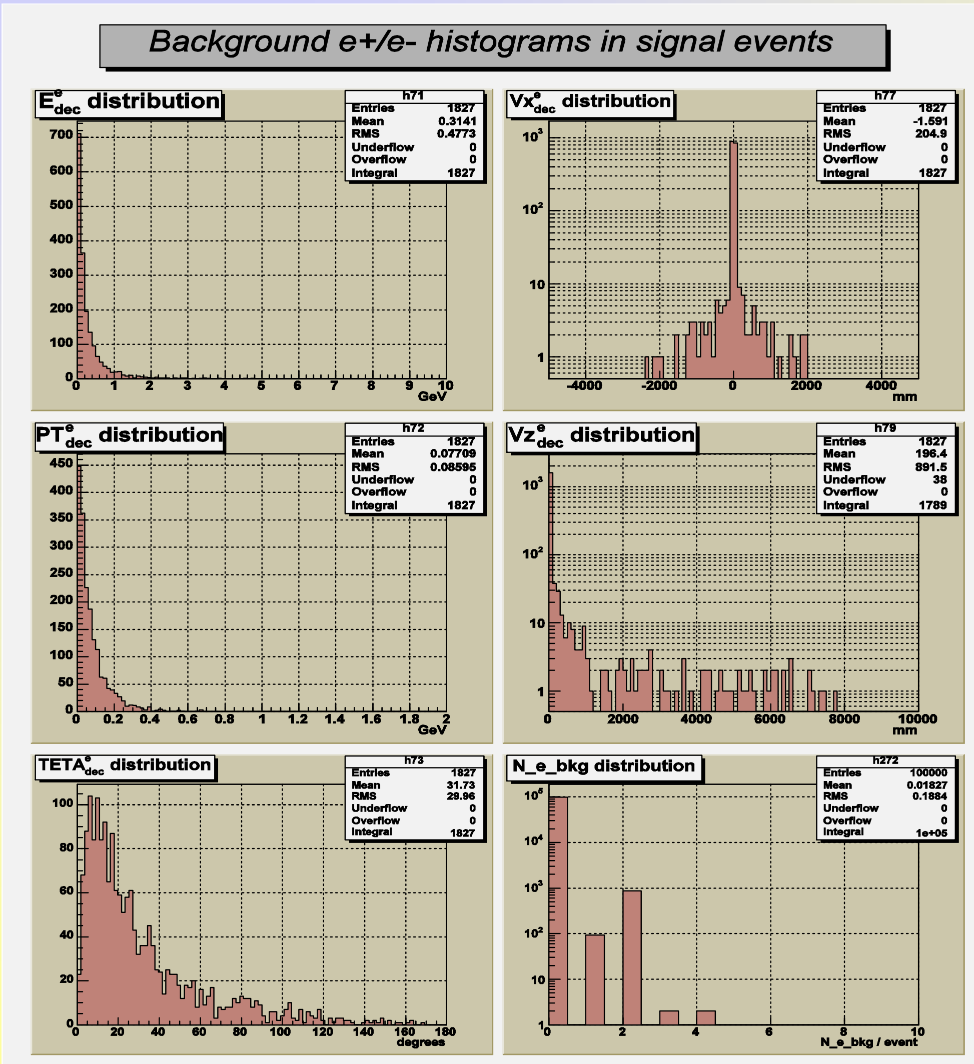
Signal $\ell^{\pm}$: ($\ell = \mu, e$)

ℓ^{-} - left, ℓ^{+} - right:



- **0** ≤ E_ℓ ≤ **10** GeV,
  < E_ℓ > = **4.4** GeV
- **0** ≤ PT_ℓ ≤ **2** GeV,
  < PT_ℓ > = **1.2** GeV
  PT_ℓ^{peak} = **1.4** GeV
- < Θ_ℓ > = **27.2 °**
  some Θ_ℓ **> 90°**

Fake electron distributions



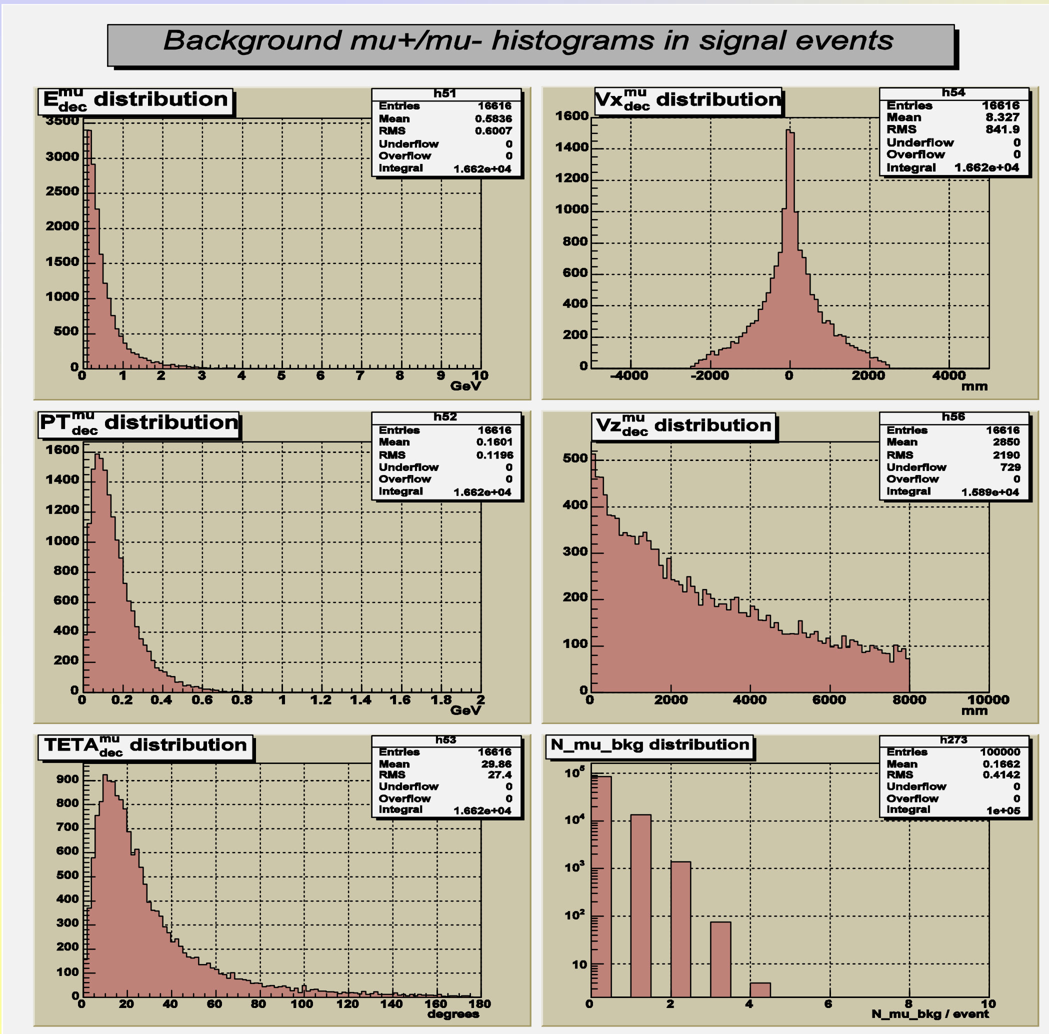
In approximation when particles are allowed to decay in cylinder volume R=2500 x L=8000 mm

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 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..

Fake muon distributions



The number of events which include fake muons is about 16% of events

Up to 4 fake muons in the final state

Fake **muons production vertexes** are distributed within detector volume →

Vertex position information will be useful for Signal / Background separation

Some first estimations were

Published (2006) as PANDA

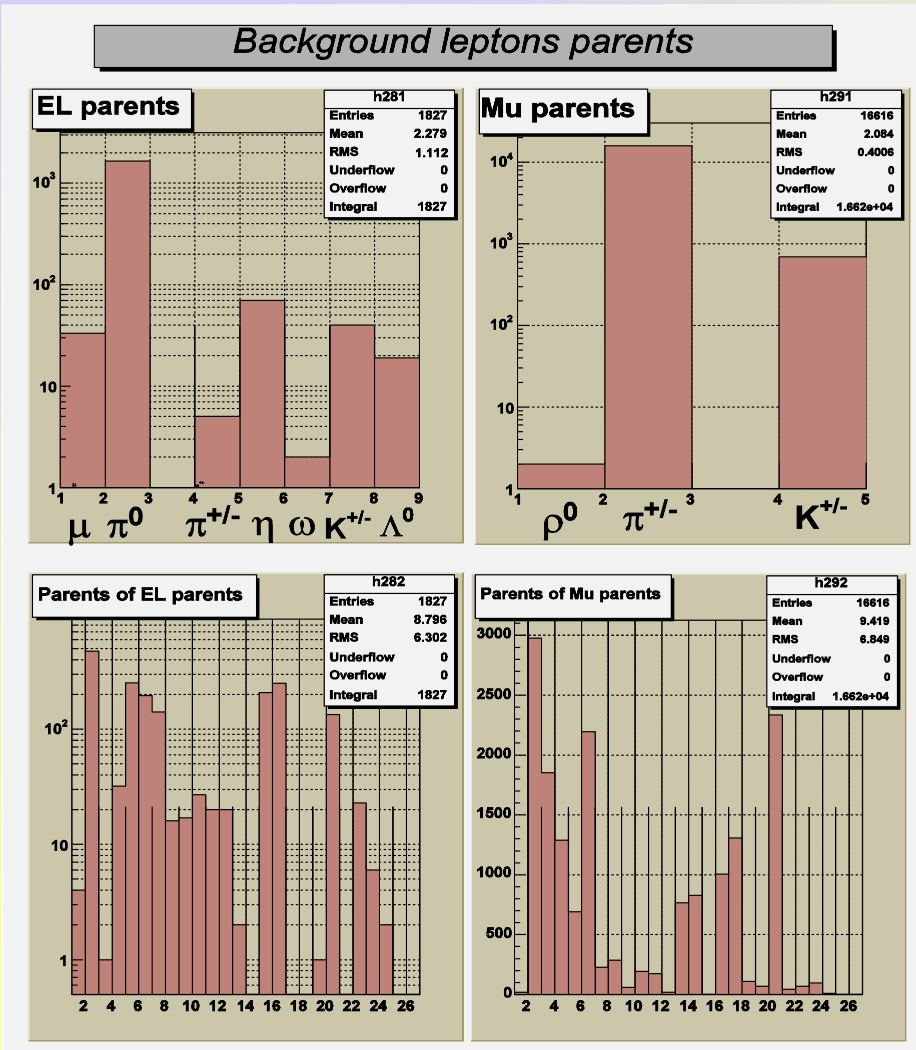
Note PHY-003:

and hep-ph/0506139

A.N.Skachkova, N.B.Skachkov

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

Parents of fake leptons



The most probable parents of fake

electrons → are neutral pions

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),

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

Natural restrictions

Due to apparatus acceptance and electronics features the leptons with the next (at least) parameters will be lost:

$E_\ell < 0.2$ GeV, $PT_\ell < 0.2$ GeV (or like this)

In this situation the lepton from hadronic decays can play the role of the signal one.

We suppose the ideal muon system and EM calorimeter covering 180°

Applied cuts

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*

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 for the $q\bar{q} \to \gamma^* \to \ell^+\ell^-$ one

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

The main contributions come from the following partonic subprocesses:

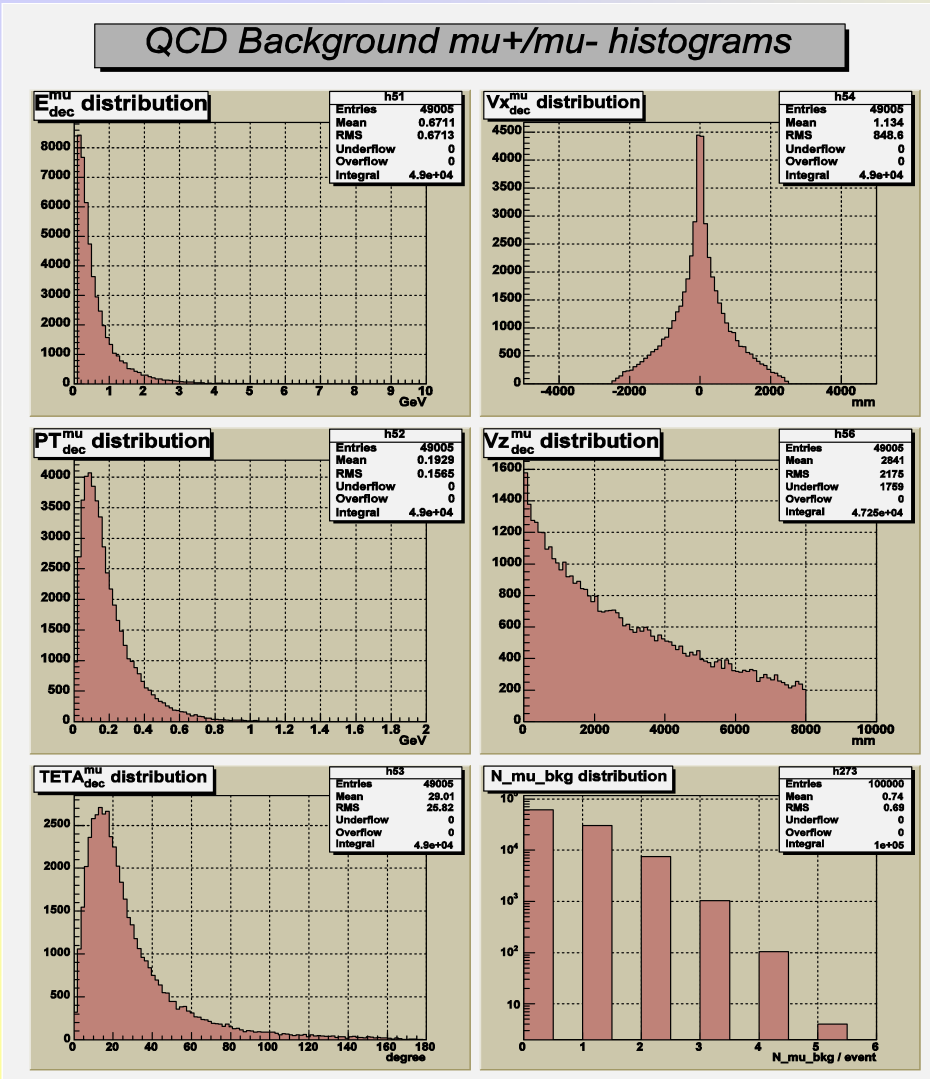
- $q + g \to q + g$ (gives **50%** of events with the **σ** = **4.88** mb);
- $g + g \to g + g$ (gives **30%** of events with the **σ** = **2.96** mb);
- $q + q' \to q + q'$ (gives **18%** of events with the **σ** = **1,75** mb);
- $q + q\,bar \to g + g$ (gives **0.6%** of events with the **σ** = **5.89 E- 02** mb);
- $\bar{q} + q \to \ell^+ + \ell^-$ (has **0.00005%** of events with the **σ = 5.02 E- 06** mb);

So, initially we have 1 signal event among 2.000.000 of QCD background → **$S/B \simeq 5.5 * 10^{-6}$**

The simulation was done within approximation when particles are allowed to decay

in cylinder volume R=2500 x L=8000 mm

QCD Muon background

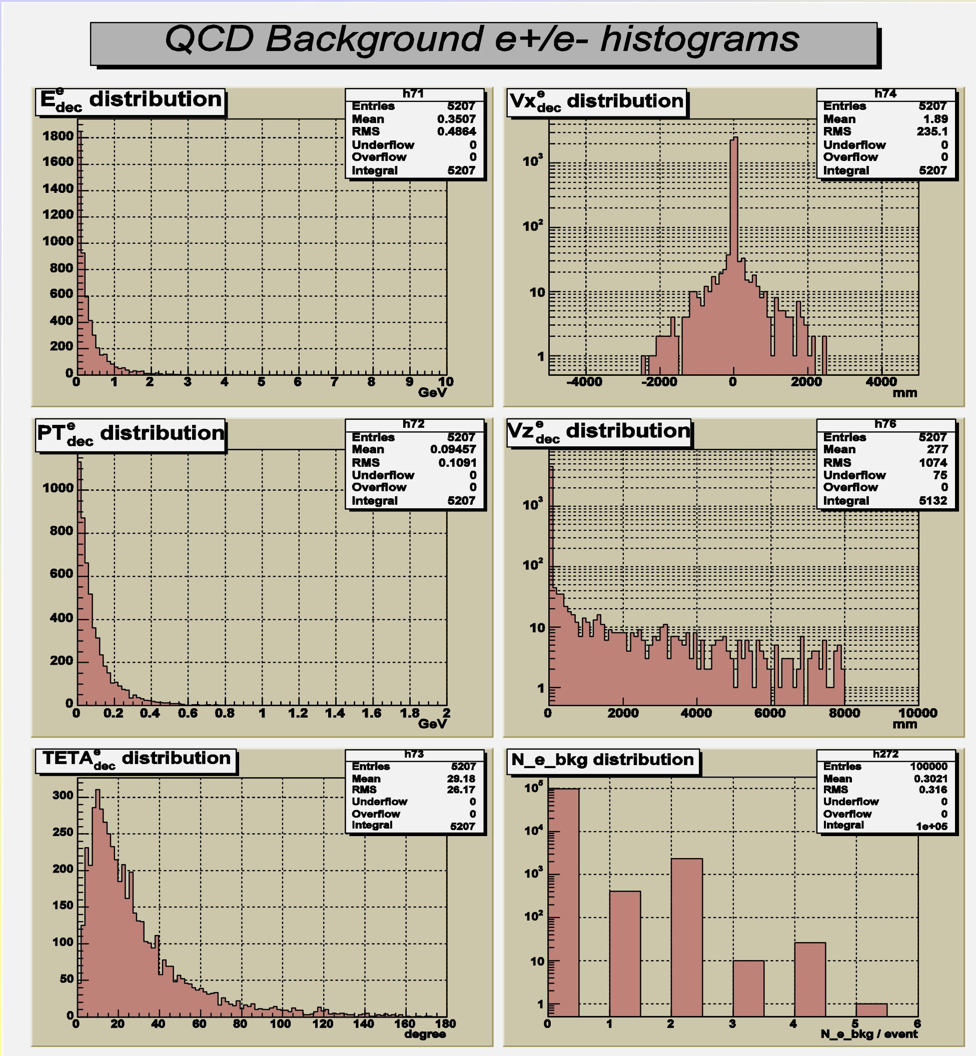


The shape of muon distributions, produced in ***these background events*** do not differ from those of fake “decay” muons, produced in ***the signal process***

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

→ fake pretty good the signal events

QCD background electrons

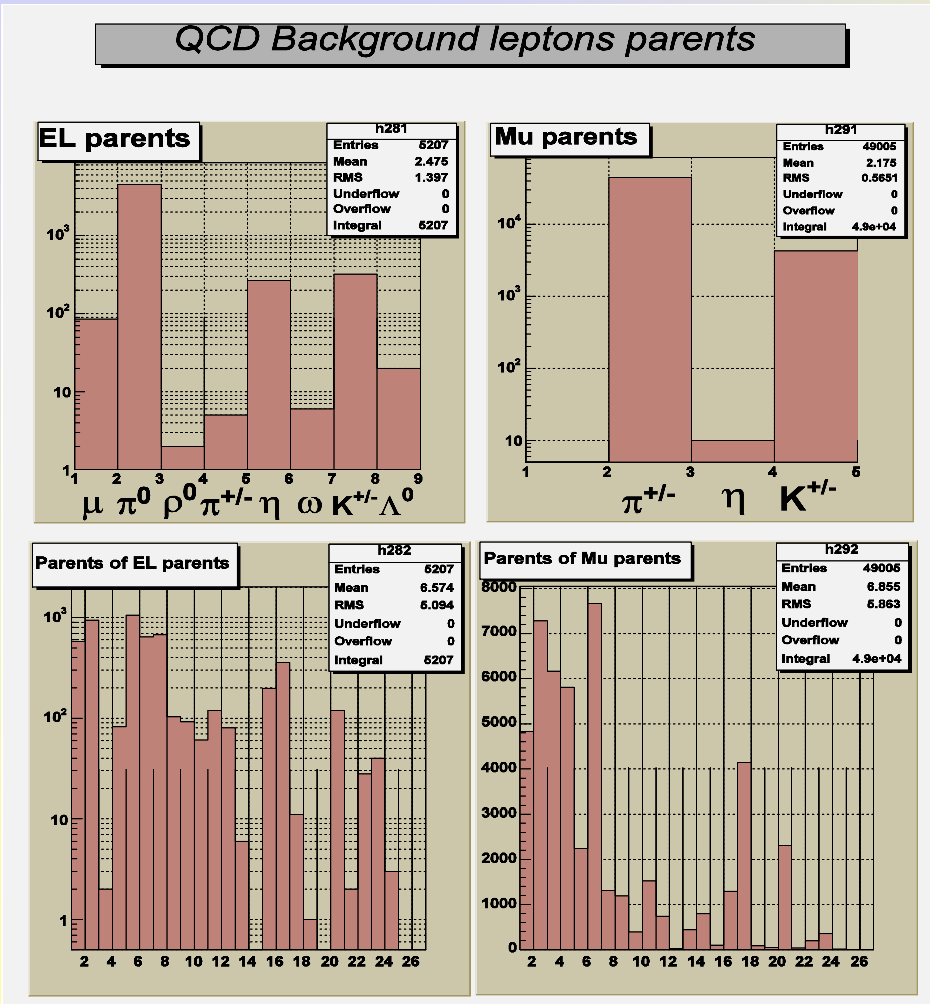


The shape of **QCD background electron's** distributions are <u>identical</u> to the ones, surrounding the signal process.

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

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

Parents of QCD background leptons



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

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

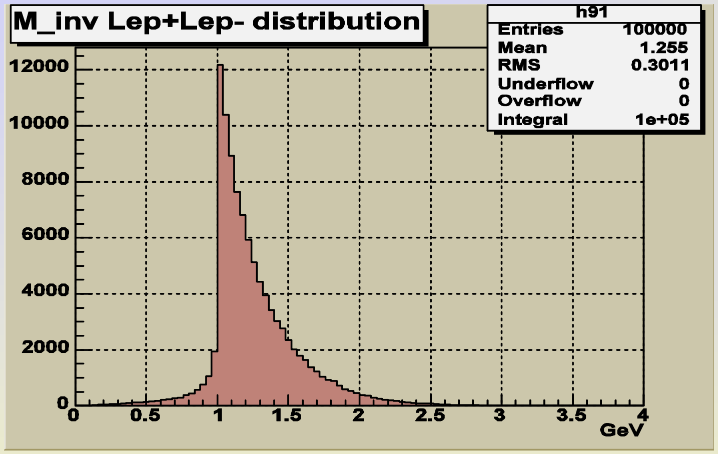
muons → *are strings (Lund model),* *ρ^0, ρ^+, ω*

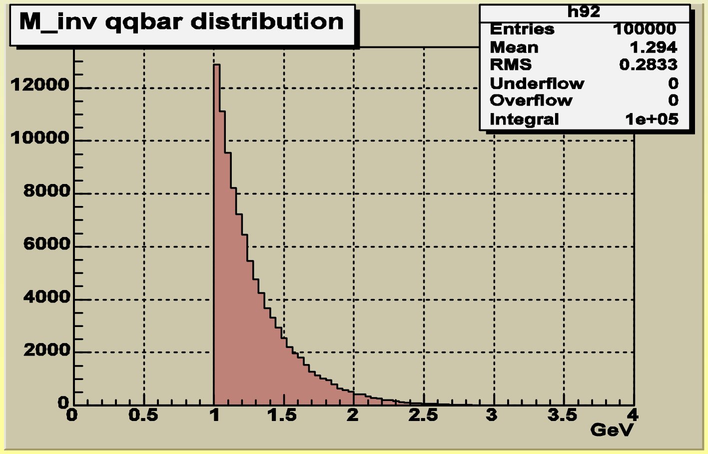
Applied cuts in QCD events

N of cuts	μ+μ- production: S/B ratio	μ+μ- production: Efficiency	e+e- production: S/B ratio	e+e- production: Efficiency
1 *(exactly 2 leptons* with $E_l > 0.2$ GeV, $PT_l > 0.2$ GeV *)*	**3.9 * 10 ⁻ ⁵**	0.011	**7.79 * 10 ⁻ ⁴**	0.006
2 *(2 leptons are of the opposite sign*	**5.7 * 10 ⁻ ⁵**	0.69	**7.88 * 10 ⁻ ⁴**	0.99
3 *(The vertex of origin lies within the R < 15 mm)*	**0.02**	0.002	**0.0008**	0.98

{ The vertex position information is not efficient for the S / B separation for e+e- case }

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**

Efficiency of M_{inv} (ℓ^+, ℓ^-) cut

Muon case

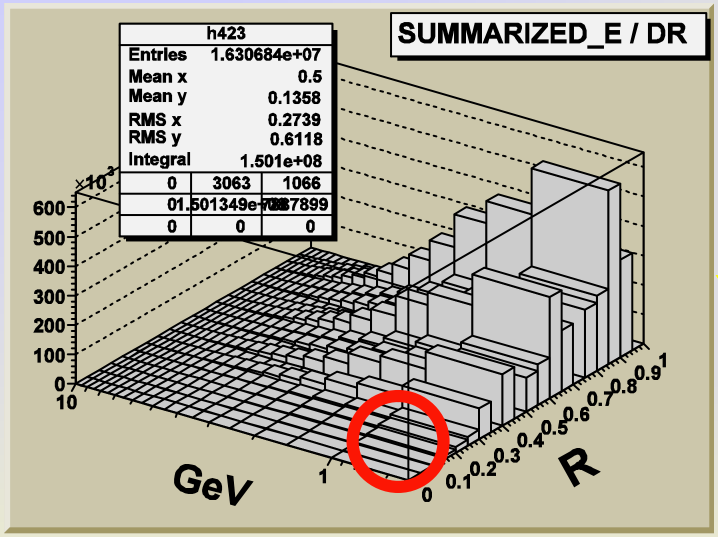
M_{inv} (ℓ^+, ℓ^-) >	S / B	Efficiency	The rest of signal events
0.9	0.50	0.0528	82 %
1.0	1.03	0.0251	81 %
1.03	2.10	0.0112	74 %
1.05	2.31	0.0094	69 %
1.1	3.70	0.0050	59 %
1.2	44	0.0003	43 %

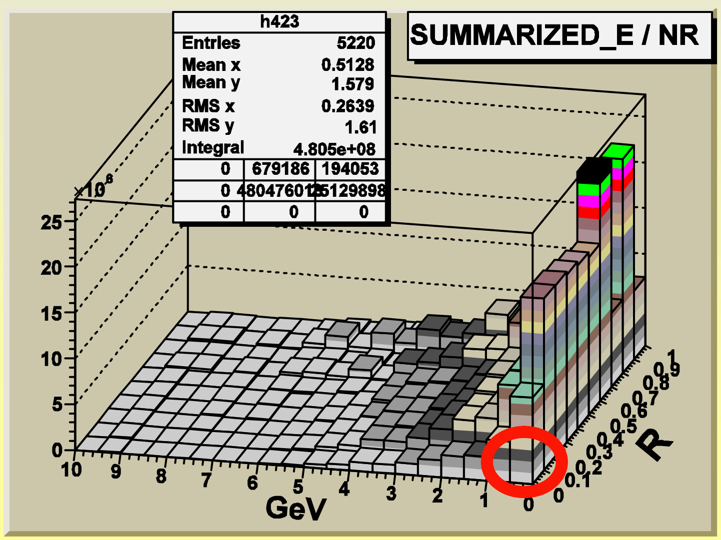
Efficiency of M_{inv} (ℓ^+, ℓ^-) cut

e^+e^- case

$M_{inv}(\ell^+, \ell^-)$ >	S / B	Efficiency	The rest of signal events
0.9	0.36	0.00226	84 %
1.0	0.62	0.00125	81 %
1.03	1.18	0.00057	73 %
1.05	1.37	0.00046	69 %
1.1	1.82	0.00030	58 %
1.2	3.75	0.00010	42 %

Lepton (μ) isolation criteria





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

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

(η – *pseudorapidity)*

upper plot → **signal events**

bottom plot → **QCD background**

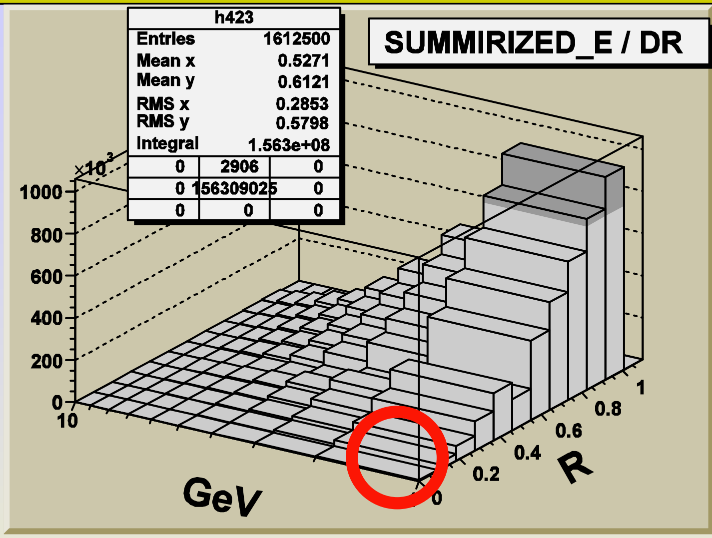
Isolation criteria (**$R_{isolation}$ = 0.2**)

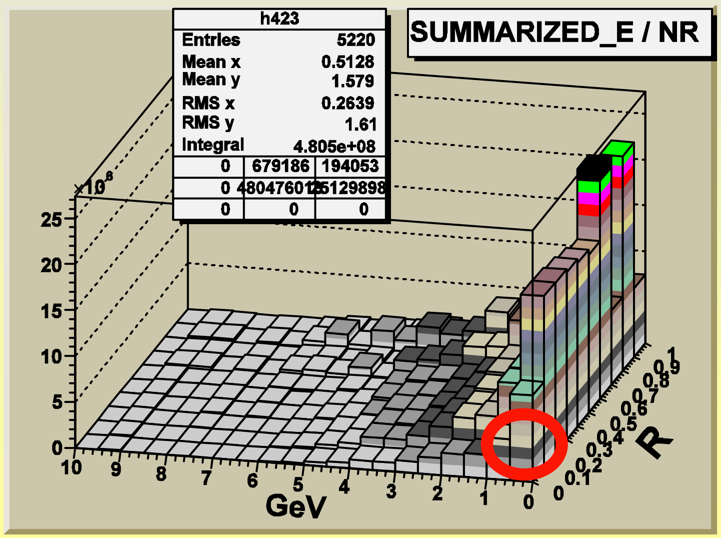
E (of particles) = 0.5 GeV

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

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

Lepton (e) isolation criteria





The plots show the distributions over ***summarized energy*** of the final state particles in the cones of the radius **$R_{isolation} = \sqrt{\eta^2+\varphi^2}$** respect to the (η – *pseudorapidity*)

upper plot → **signal events**

bottom plot → **QCD background**

Isolation criteria (**$R_{isolation}$ = 0.2**)
$E_{(of\ particles)}$ = 0.5 GeV

allows to separate 100% of QCD bkgd leptons with loss of **7%** of signal events

(after applied 3 cuts discussed above + cut $M_{inv}(\ell^+,\ell^-) > 0.9$)

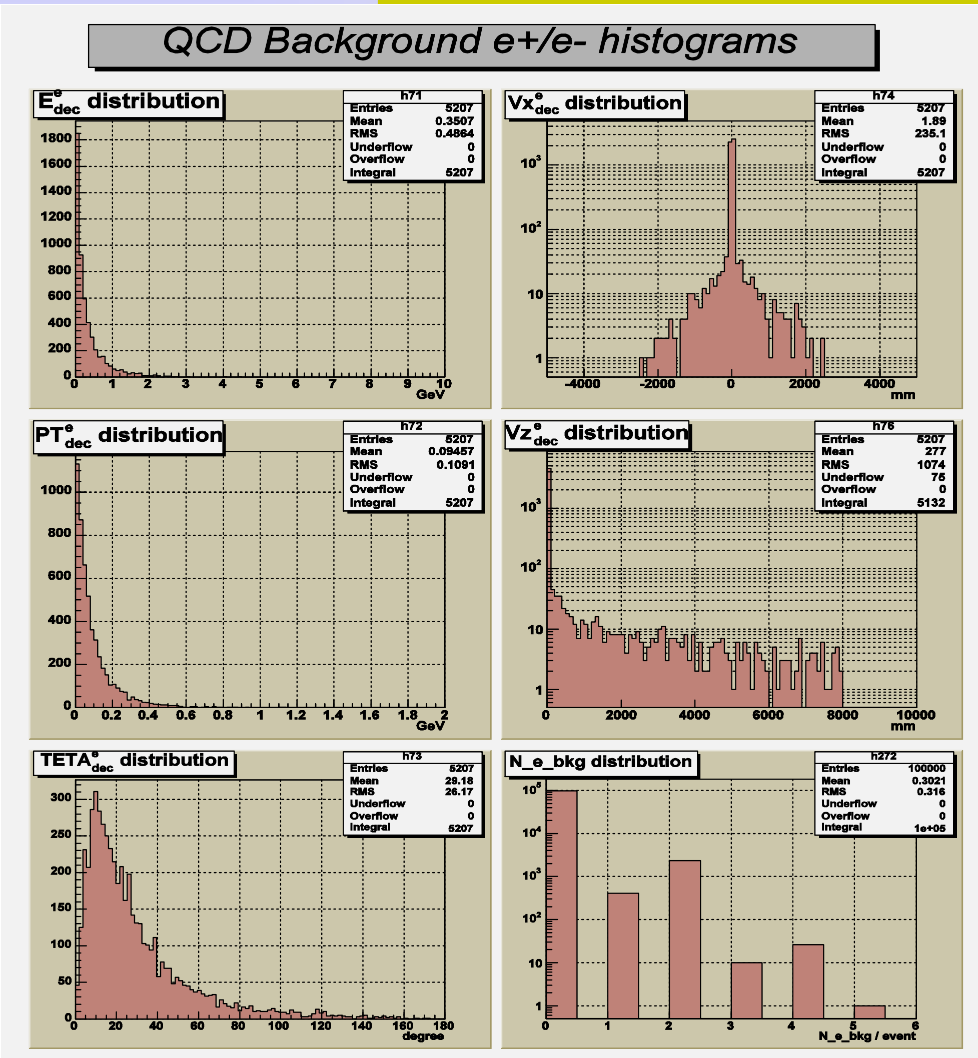
The main source of background for the $\bar{q}q \to \gamma^* \to \ell^+\ell^-$ are the Minimum-Bias processes:

- *Low - PT scattering* (gives 68**%** of events with the **σ** = **34.25** mb);
- *Elastic scattering* (gives 25**%** of events with the **σ** = **12.56** mb);
- *Single diffractive* (gives 6**%** of events with the **σ** = **3.32** mb);
- $\bar{q} + q \to \ell^+ + \ell^-$ (has **0.000012%** of events with the **σ = 5.9 E- 06** mb);

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

This source of background is 5 times harder than QCD background

Minimun-bias background electrons



The shape of
QCD background electron's
distributions are <u>identical</u> to the ones, surrounding the signal process.

The most of electron pairs do appear as Dalitz pairs (**$\pi^0 \rightarrow e^+e^-\gamma$**)

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

Cuts efficiency for Minimum-Bias background events

e^+e^- *production*

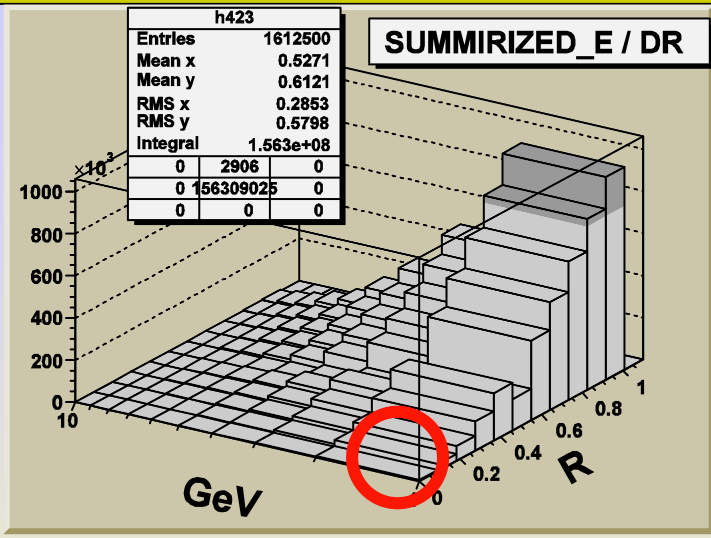
N of cuts	S/B ratio	Efficiency
1 *(exactly 2 leptons* with E_l > 0.2 GeV, PT_l > 0.2 GeV *)*	**$5.3 * 10^{-4}$**	$1.78 * 10^{-4}$
2 *(2 leptons are of the opposite sign)*	**$5.4 * 10^{-4}$**	0.98
3 *(The vertex of origin lies within the R < 15 mm)*	**$5.5 * 10^{-4}$**	0.98
4 *($M_{inv}(l_1,l_2)$ > 0.9)*	**0.09**	0.006

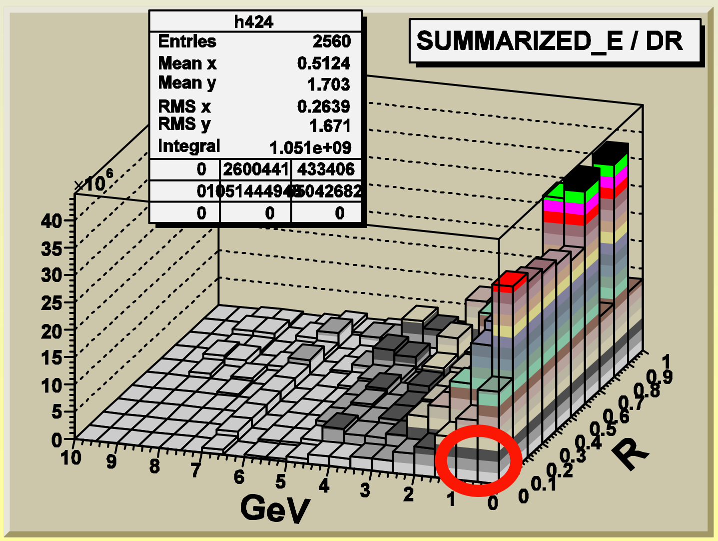
Efficiency of $M_{inv}(l^+,l^-)$ cut

e^+e^- case

$M_{inv}(l^+,l^-)$>	S / B	Efficiency	The rest of signal events
0.9	0.09	0.0057	84 %
1.0	0.15	0.0034	81 %
1.03	0.38	0.0013	73 %
1.05	0.40	0.0012	69 %
1.1	0.83	0.0005	58 %
1.2	2.00	0.0002	42 %

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 → **Mini-bias background**

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

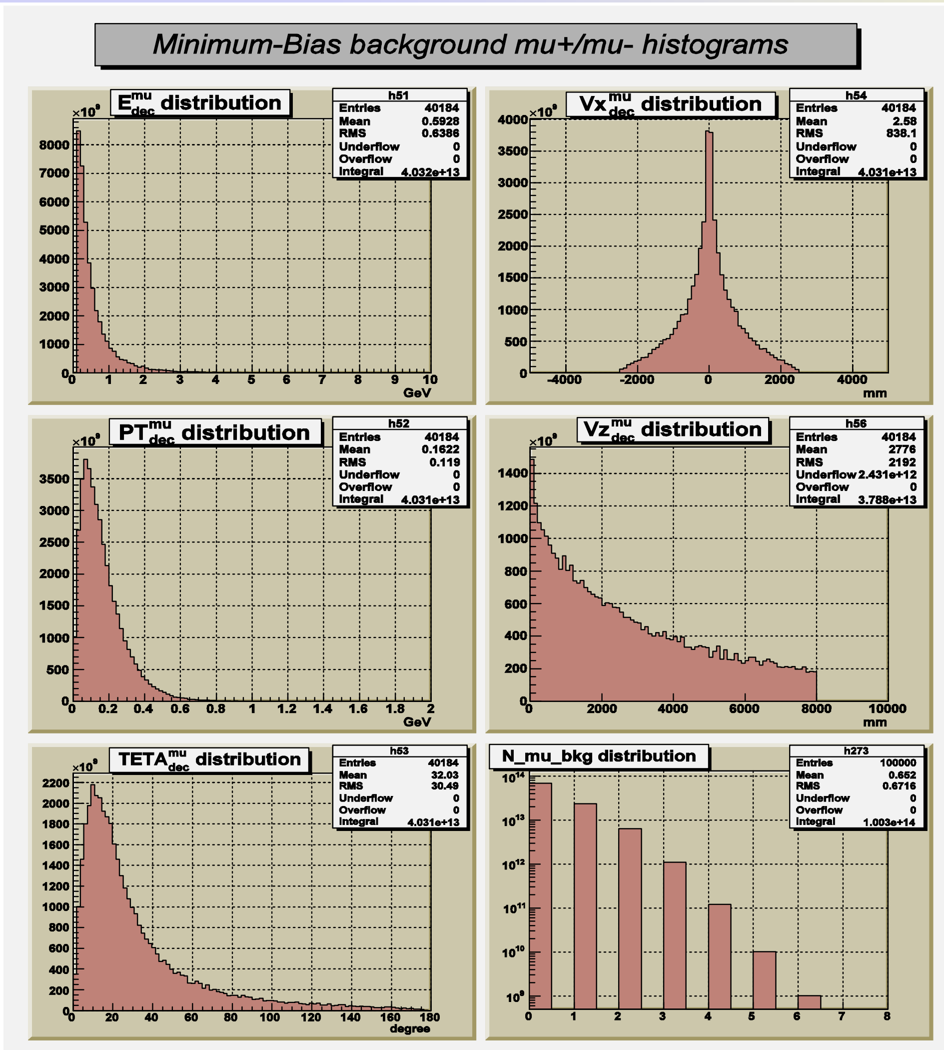
$E_{(of\ particles)}$ = 0.5 GeV

allows to separate **100%** of QCD leptons with loss of **4%** 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***

Minimum-bias muon background



The shape of muon distributions, produced in ***Minimum-bias background events*** do not differ from those, produced in ***QCD background processes***

→ 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 good the signal events

Cuts efficiency for Minimum-Bias background events

$\mu^+\mu^-$ production

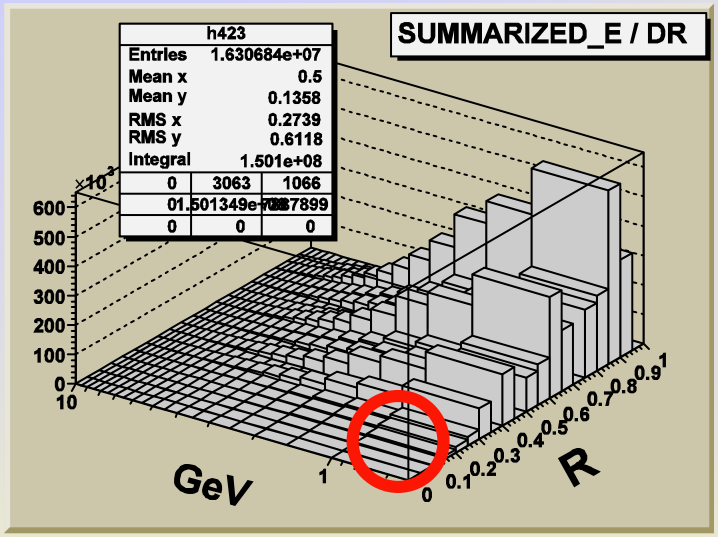
N of cuts	S/B ratio	Efficiency
1 *(exactly 2 leptons* with $E_l > 0.2$ GeV, $PT_l > 0.2$ GeV*)*	$1.3 * 10^{-5}$	0.007
2 *(2 leptons are of the opposite sign)*	$2.0 * 10^{-5}$	0.665
3 *(The vertex of origin lies within the R < 15 mm)*	$9.4 * 10^{-3}$	0.002
4 *($M_{inv}(l_1,l_2) > 0.9$)*	**0.11**	0.086

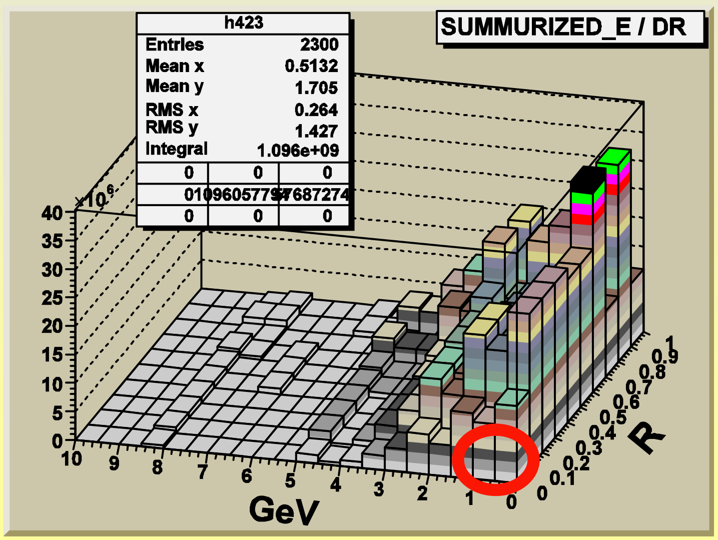
Efficiency of M_{inv} (l^+,l^-) cut

Muon case

M_{inv} (l^+,l^-) >	S / B	Efficiency	The rest of signal events
0.9	0.11	0.0857	82 %
1.0	0.18	0.0507	81 %
1.03	0.43	0.0219	74 %
1.05	0.58	0.0151	69 %
1.1	1.33	0.0063	59 %
1.2	Bkg = 0	0	43 %

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 of the opposite sign and* $E_\ell > 0.2$ GeV, $PT_\ell > 0.2$ GeV
2. *The vertex of origin lies within the distance from the interaction point < 15 mm*
3. *Minv* $(l^+, l^-) > 0.9$ *GeV*
4. *Isolation criteria* $E_{(R\ isolation\ =\ 0.2)} = 0.5$ *GeV*

Allow to suppress QCD & Mini-bias bkgd to:

completely for muons; S/B = 9 for electrons