Study of backgrounds for Drell-Yan process ($\mu^+\mu^-$ case)

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

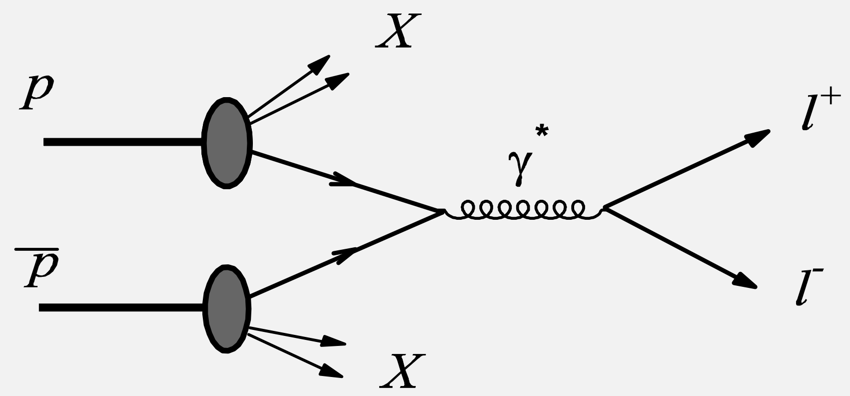
process, called also as Drell-Yan

(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 l^+l^- production is the perturbative QED/QCD partonic 2 -> 2 process

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

$\sigma = 4.6 * 10^3$ pb



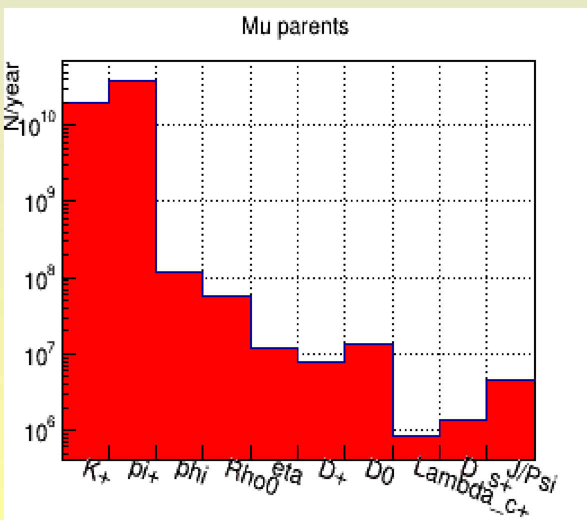
PYTHIA 6.4 simulation for the $E_{cms} = 5.474$ GeV

For the Luminosity L = 2×10^{32} $cm^{-2}s^{-1}$ with assumption of the 10^7 sec/year beam operation we expect up to 9.2×10^7 Drell-Yan events/year

Background muons

We allow particles decay (and produce muons) in the volume before Muon (Range) System :
cylinder radius **R = 1440 mm**,
size from the centre along Z axis **L = 2505 mm**
and we do search for muons in the angle region **5º< Θ < 137º.**

We assume also 100% π/μ rejection in muon system.



The most probable parents of bkg muons - are charged π and K

The most probable grandparents of bkg muons - are «string» (Lund model),
ρ^0, ρ^+, K^0_s, K^{*0}, K^+, η'

Here we consider 2 kinds of backgrounds: hard QCD and Minimun-bias events

Hard QCD subprocesses are:

The main contributions come from the following partonic subprocesses:

- ***q + q' --> q + q'*** (gives 19.1**%** of QCD events with the **σ = 1.39** mb);
- ***q + g --> q + g*** (gives 51.1**%** of QCD events with the **σ = 3.73** mb);
- ***g + g --> g + g*** (gives 28.6**%** of QCD events with the **σ = 2.09** mb);
- **&**

q + qbar --> q + qbar (σ = 0.016 mb);
q + qbar --> g + g (σ = 0.052 mb);
g + g --> q + qbar (σ = 0.018 mb);

For QCD background

S/B ≃ 6.5*10^-7^ $S/B \simeq 6.5 \times 10^{-7}$

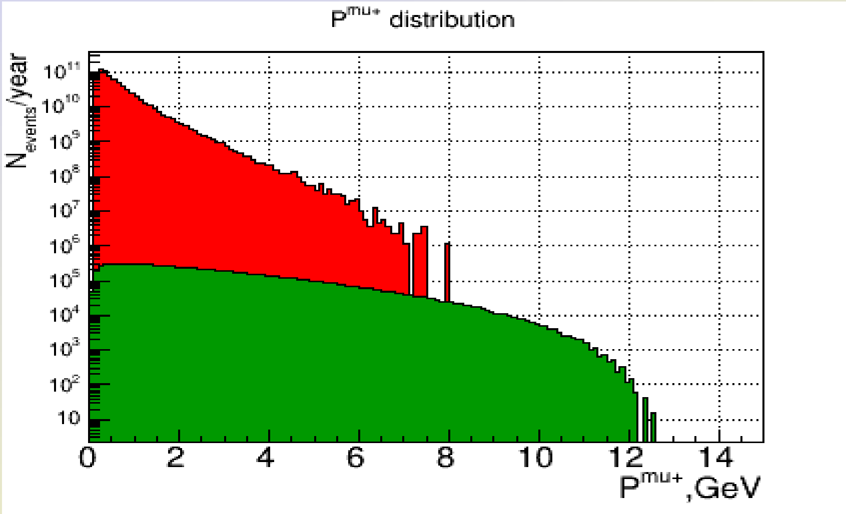
The main source of background for the $\bar{q} q \rightarrow \gamma^* \rightarrow \mu^+\mu^-$ are the Minimum-Bias processes:

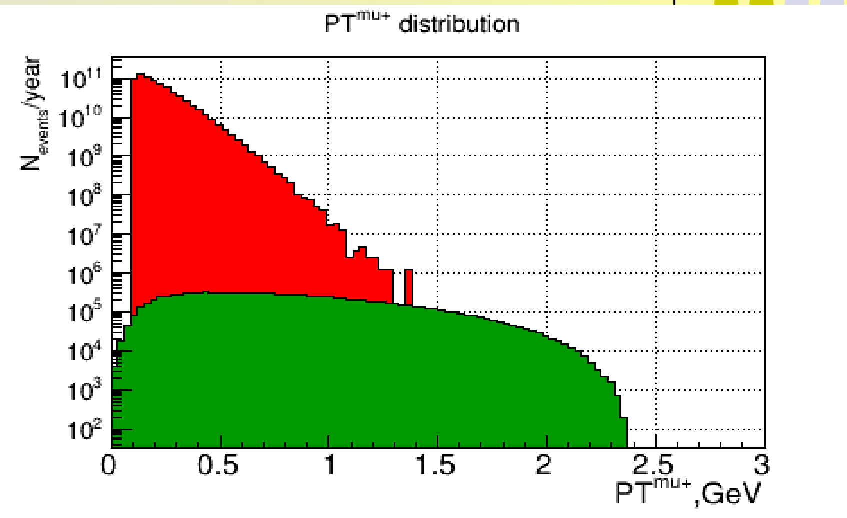
- ***Low - PT scattering*** (gives 90**%** of events with the **σ** = **33.68** mb);
- *Single diffractive* (gives 9.2**%** of events with the **σ** = **3.44** mb);
- *Double diffractive* (gives 2.7**%** of events with the **σ** = **0.25** mb);

For Mini-bias background

S/B ≃ 1.2 x 10^{-7}

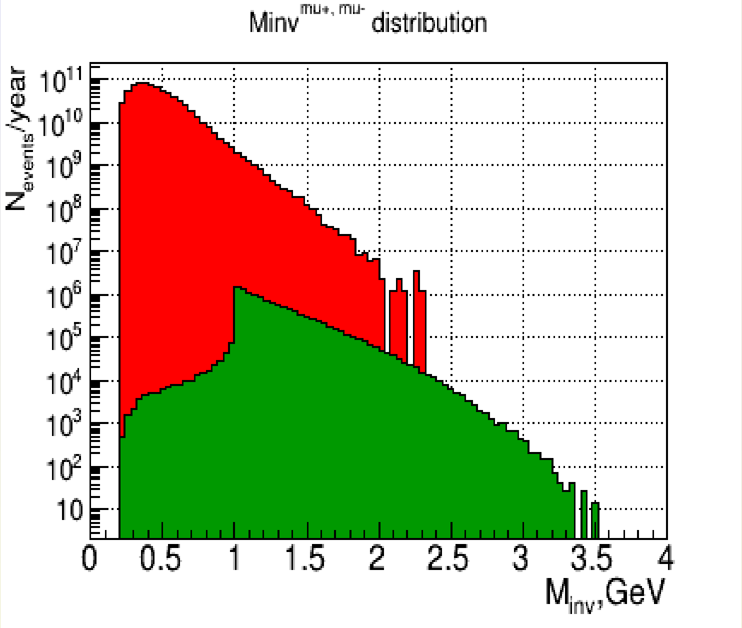
First cuts — on E(P) and PT





Effective cut off on E(P) is in the region **$E(P)^{\mu}_{bkg}$ < ~2 GeV** where is the maximum gradient in $E(P)^{\mu}_{bkg}$ distribution	The most effective cuts off are in the region **PT^{μ}_{bkg} < 1.0 GeV** **(PT^{μ}_{bkg} = 0.7 GeV)**

Invariant mass cut



Together with (after) the cut
E > 0.5, PT > 0.3 GeV
Supposing 100 % - without Minv cut

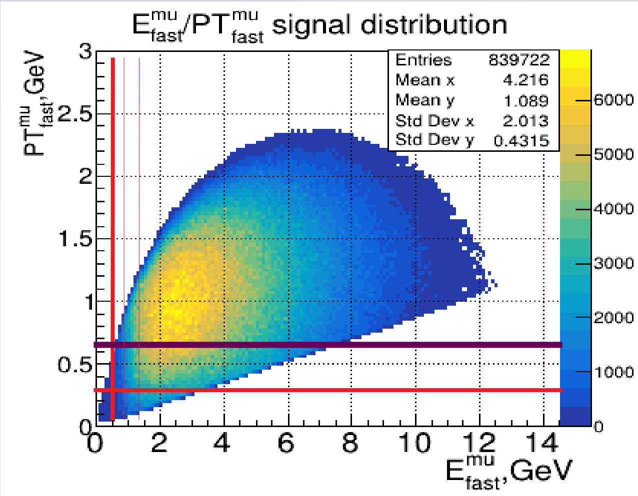
Cut on $M^{\mu\mu}_{inv}$ >	Rest of BKG	Cut efficiency	Rest of sig	Cut efficiency	S/B
1.0 GeV	13.3 %	7.48	97.5 %	1.02	0.0035
1.5 GeV	0.66 %	150.9	18.0 %	5.0	0.014
2.0 GeV	0.02 %	4483	3.70 %	27	0.078

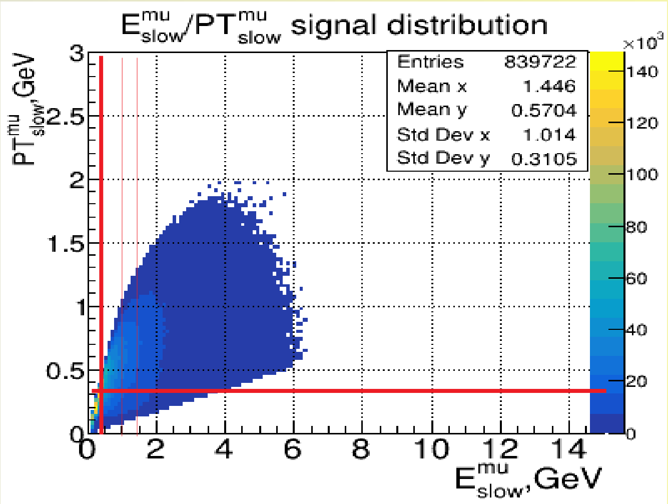
The most effective cut is in the region **~ 1 GeV.**
The peak at 1 GeV for DY is caused by some internal PYTHIA restrictions.

Further increase of Minv cut has no sense for Minimum-bias background events (it leads to significant loss of signal events without real improvement of S/B ratio).

E^{μ}/PT^{μ} correlations for muons with max(fast)/min(slow) E^{μ} in the pair

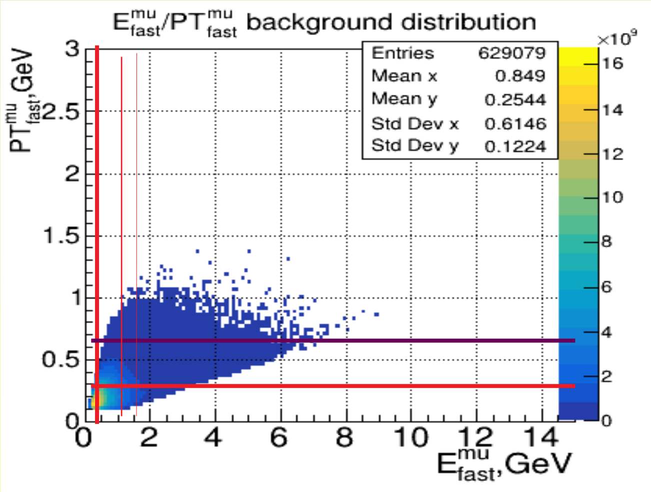
S I G

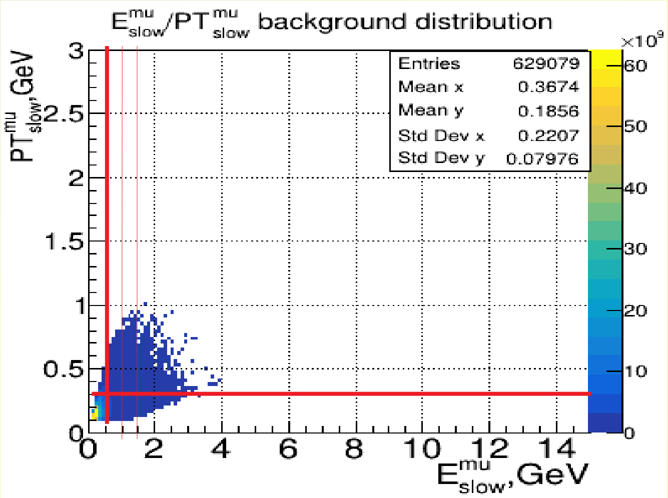




PT^{μ}_{Emax} > 0.7 GeV can also be considered

B K G

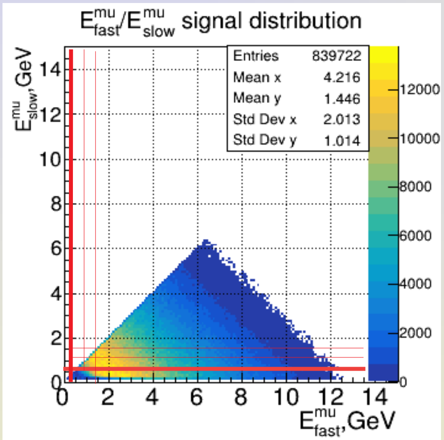


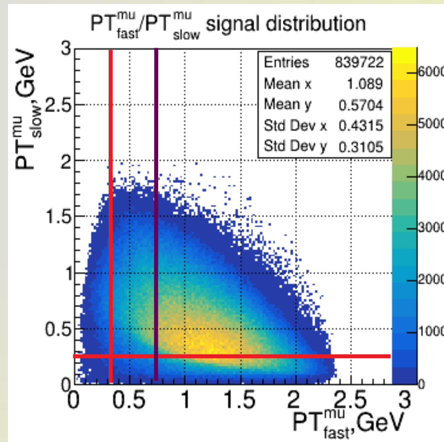


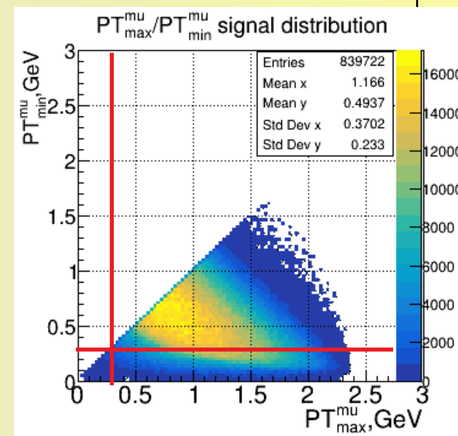
Cut on PTμ > 0.3 GeV and E(P)μ > 0.5 (1.0, 1.5) GeV

E_{max}(fast) /E_{min}(slow), PT_{fast}/PT_{slow}, PT_{max}/PT_{min} distributions

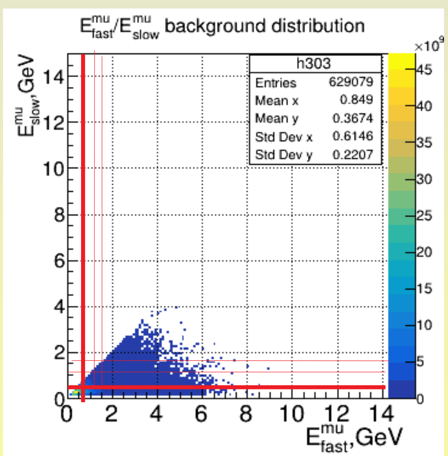
S I G

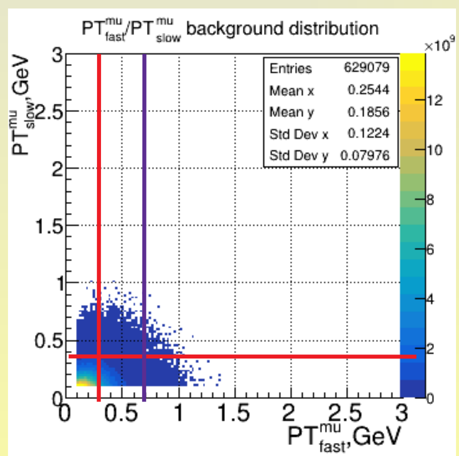


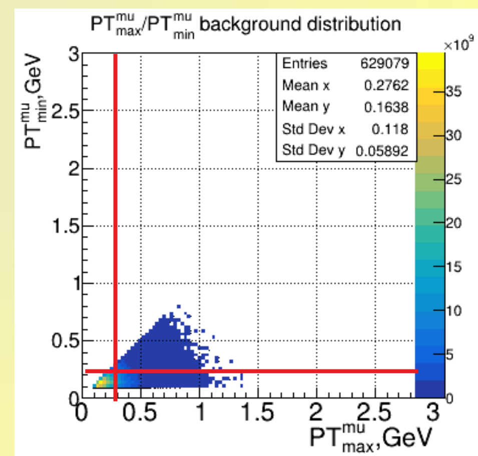




B K G







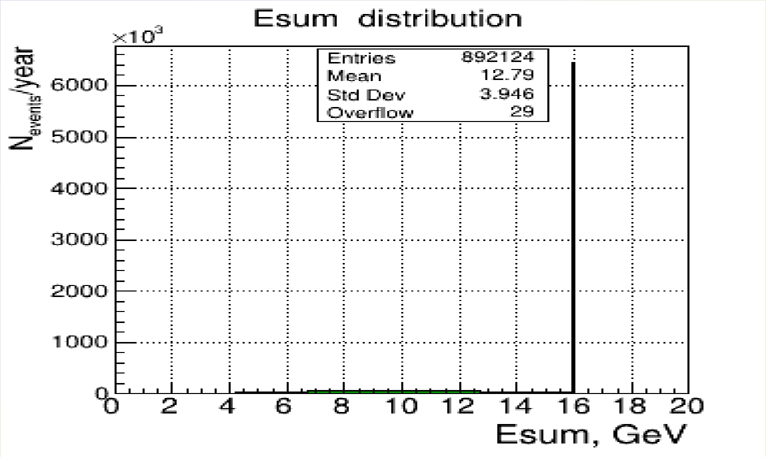
E(P) > 0.5 GeV
E(P) > 1.0, 1.5 GeV

PT > 0.3 GeV,
PT_{fast} > 0.7 GeV

PT > 0.3 GeV

Cut on E_{sum} - summarized energy of all particles in event

S I G



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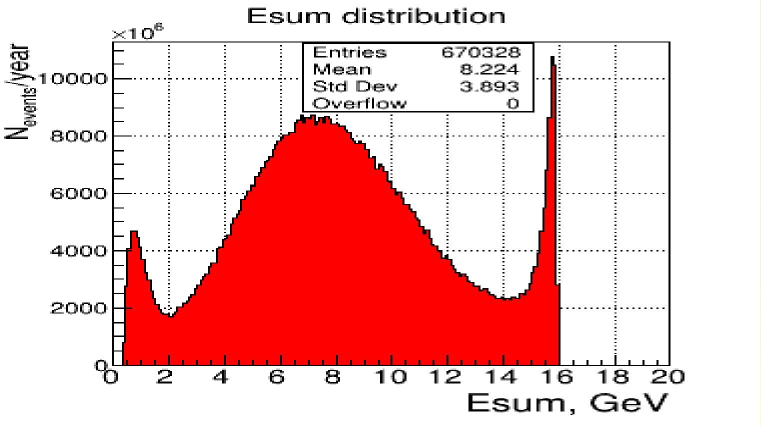
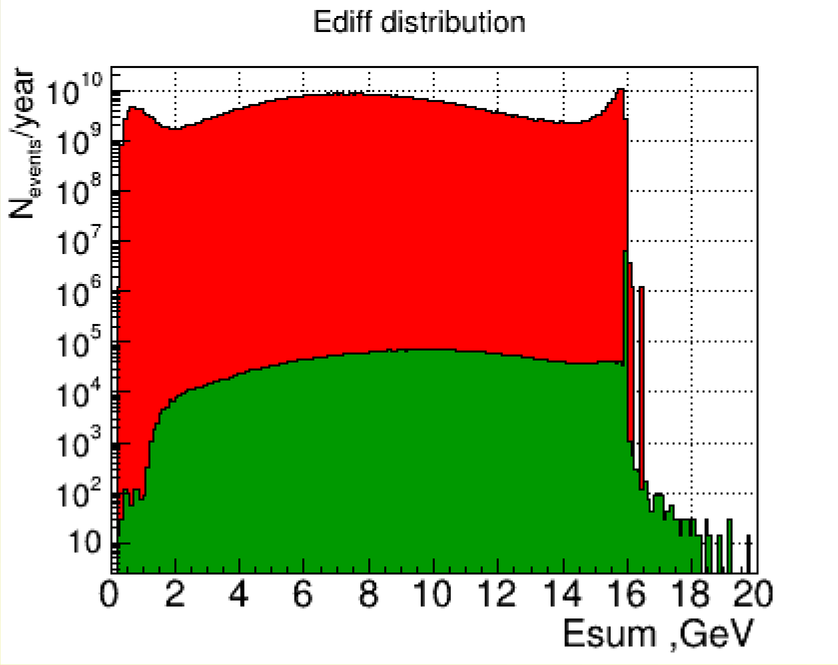


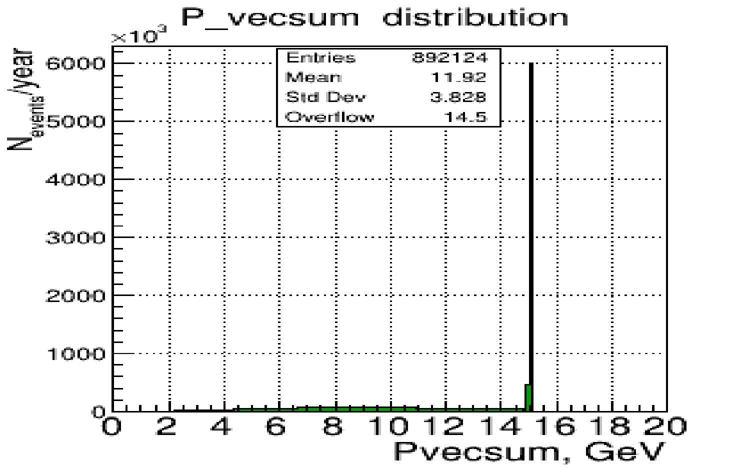
E_{sum} > 15.8 GeV

Sig & BKG
in log scale



Analogous cut on P_{vecsum} - vector summa of all particles momenta in an event

S
I
G



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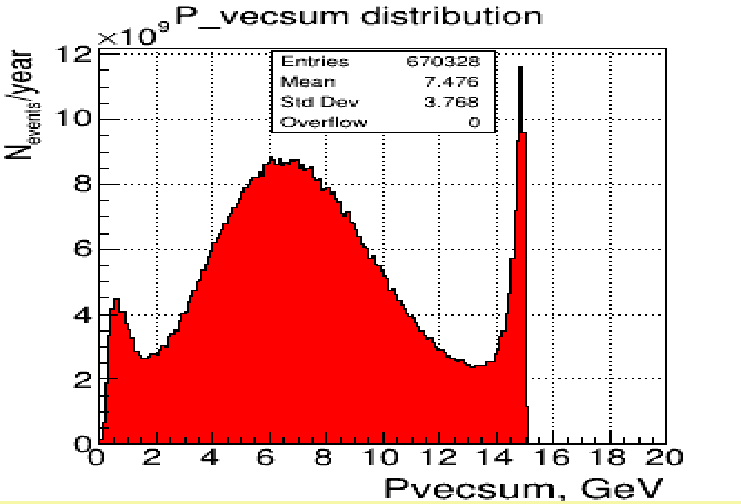
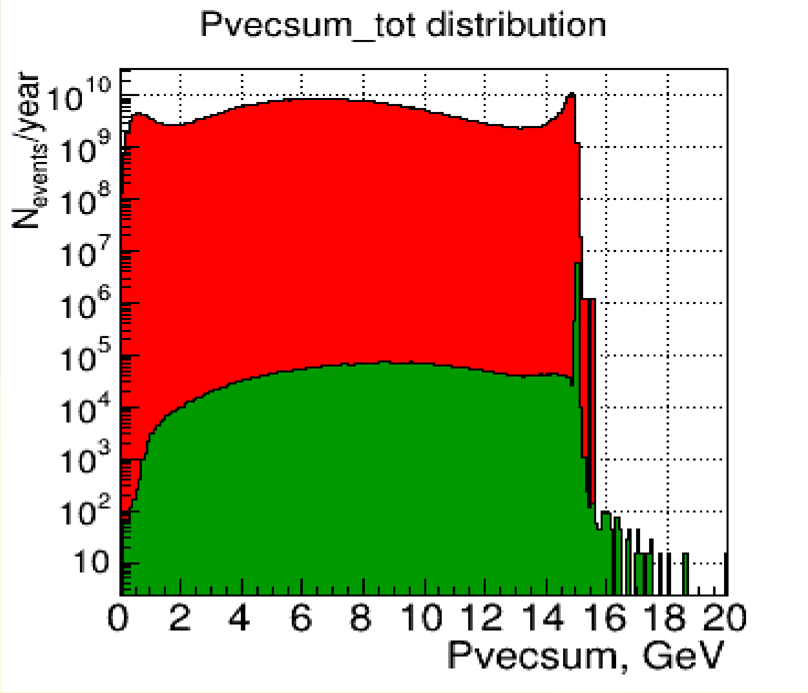


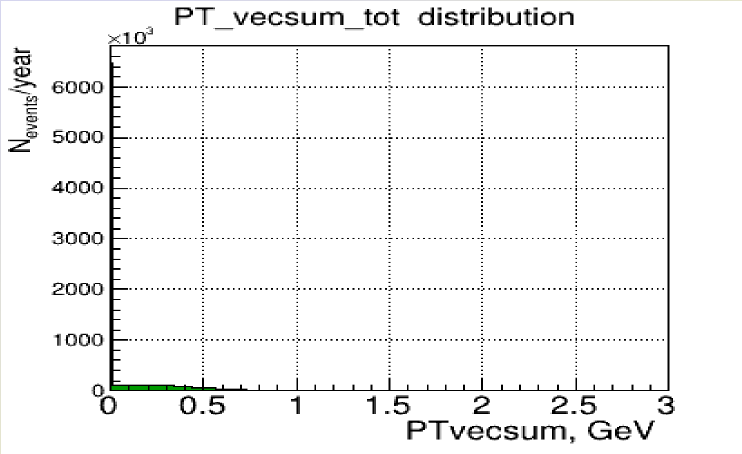
Sig & BKG
in log scale



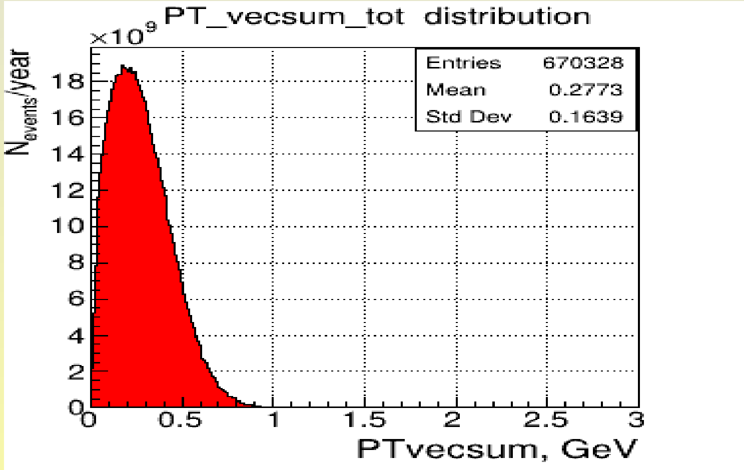
P_{vecsum} > 14.8 GeV

Cut on PT_{vecsum} - vector summa of all particles transverse momenta in event

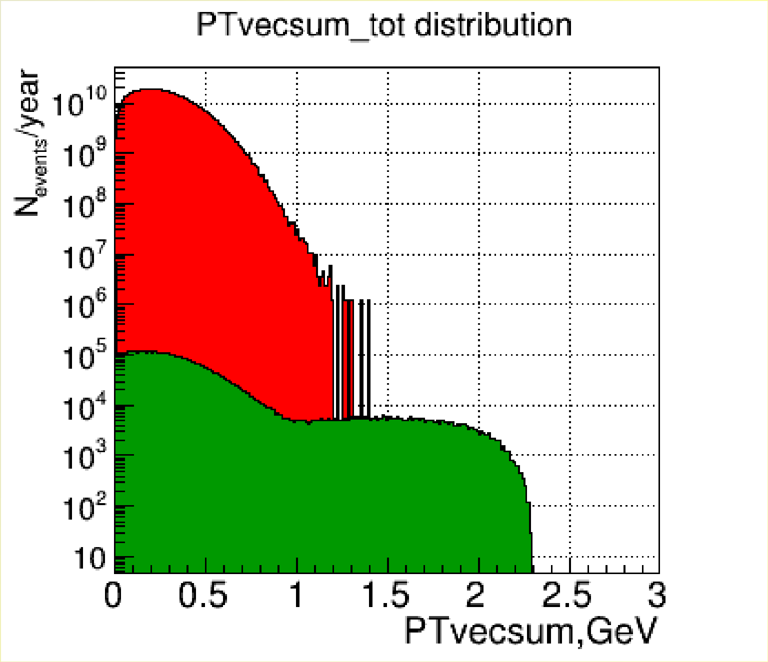
S I G



B K G



Sig & BKG
in log scale



PT_{vecsum} < 0.2 GeV

Proposed cuts

1. *Events with only 2 muons with*

$PT_l > 0.3$ GeV, $E(P)_l > 0.5$ GeV

2. *Muons are of the opposite sign*

3. *Minv* $(l^+, l^-) > 1.0$ *GeV*

4. $PT^{\mu}_{Emax} > 0.7$ GeV

5. $E_{sum} > 15.8$ GeV, $P_{vecsum} > 14.8$ GeV, $PT_{vecsum} < 0.2$ GeV

6. *Isolation criteria* $E^{sum}_{(R\ isolation\ =\ 0.2)} > 0.5$ *GeV*

7. *The vertex of origin lies within the distance from the interaction point < 1 (25) mm*

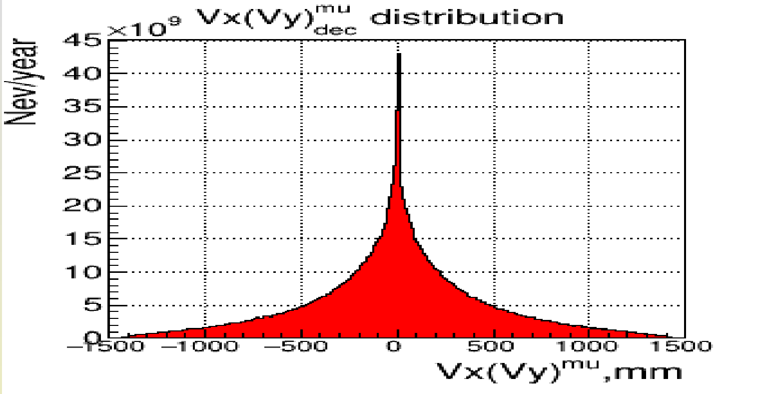
Cuts separate efficiency for minimum-bias background events (10^9)

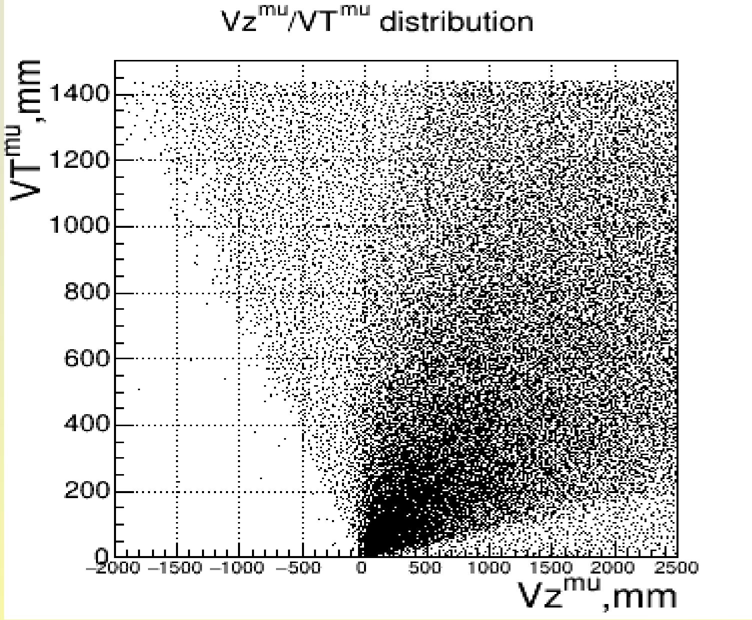
Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

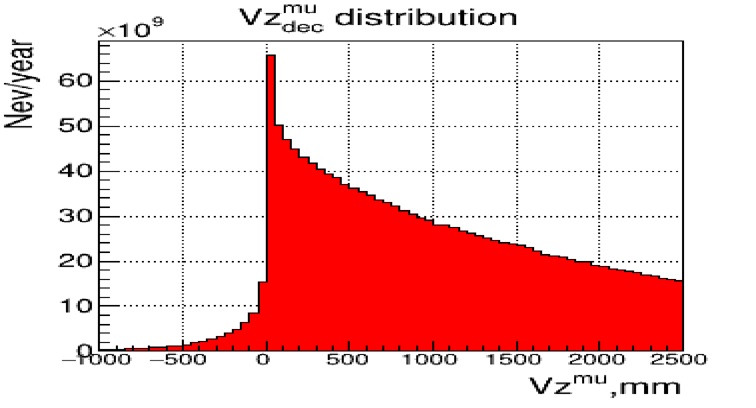
N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 ***Exactly 2μ*** with **PT_l > 0.3 GeV, $E(P)_l$ > 0.5 GeV**	**$3.14 * 10^{-4}$**	Eff (1,init) = **3879**	2.6×10^{-2} %	1.6	62.3 %
2^{+1} ***2μ*** *are of the* ***opposite sign***	**$4.75 * 10^{-4}$**	Eff (2,1) = **1.52**	1.7×10^{-2} %	1.6	62.3 %
3^{+2+1} ***$M_{inv}(\mu^+,\mu^-)$ > 1.0 GeV***	**$3.47 * 10^{-3}$**	Eff (3,2) = **7.48**	2.3×10^{-3} %	1.02	60.8 %
4^{+3+2+1} ***PT^{μ}_{Emax} > 0.7 GeV***	**$2.01 * 10^{-2}$**	Eff (4,3) = **6.92**	3.3×10^{-4} %	1.2	50.7 %
5^{+3+2+1} ***E^{all}_{sum} > 15.8 GeV***	**$1.94 * 10^{-1}$**	Eff (5,3) = **105.4**	2.2×10^{-5} %	1.9	46.1 %
6^{+3+2+1} ***PT^{all}_{vecsum} < 0.2 GeV***	**$6.49 * 10^{-3}$**	Eff (6,3) = **2.59**	8.8×10^{-4} %	1.4	32.3 %
7^{+3+2+1} ***P^{all}_{vecsum} > 14.8 GeV***	**$1.10 * 10^{-1}$**	Eff (7,3) = **58.23**	3.9×10^{-5} %	1.8	43.8 %
8^{+3+2+1} ***Isolation criterium***	**2.78**	Eff (8,3) = **813.4**	2.8×10^{-6} %	1.01	**33.1 %**
9^{+3+2+1} ***R_{vertex} < 1 mm***	**$1.89 * 10^{-1}$**	Eff (9,3) = **55.13**	4.1×10^{-5} %	1.01	60 %
10^{+3+2+1} ***R_{vertex} < 25 mm***	**$1.72 * 10^{-1}$**	Eff (10,3) = **50.37**	4.5×10^{-5} %	1.01	60 %

Vertex distributions

Still under big question the possibility of kink resolution in π→μν decay trajectory **(which is ~ 1-3 degrees)** *(no manpower)*.
Most probable it will be very hard due to the Straw detector geometry, thus the **criterium of muon vertex production point is very effective, but not realistic.**







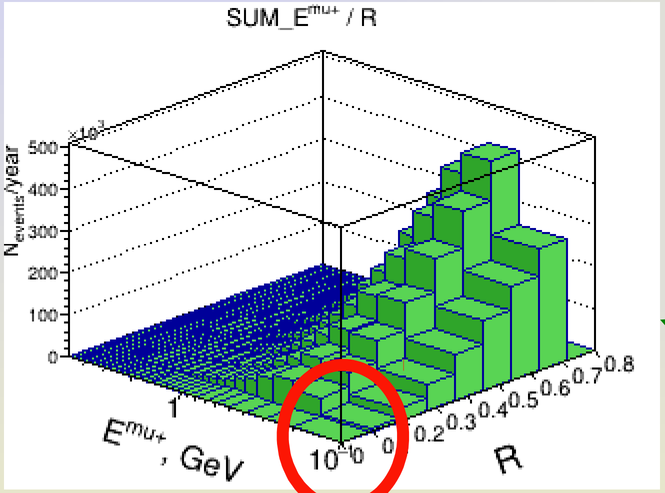
Summarized efficiency of subsequent cuts for minimum-bias background events (10^9)

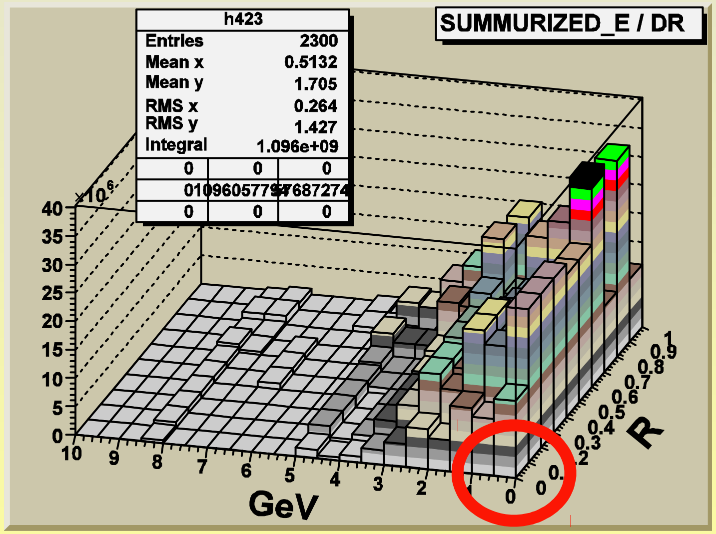
Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 ***Exactly 2μ*** with **PT_l > 0.3 GeV, $E(P)_l$ > 0.5 GeV**	**$3.14 * 10^{-4}$**	Eff (1,init) = **3879**	2.6×10^{-2} %	1.6	62.3 %
2^{+1} ***2μ*** *are of the* ***opposite sign***	**$4.75 * 10^{-4}$**	Eff (2,1) = **1.52**	1.7×10^{-2} %	1.6	62.3 %
3^{+2+1} ***$M_{inv}(\mu^+,\mu^-)$ > 1.0 GeV***	**$3.47 * 10^{-3}$**	Eff (3,2) = **7.48**	2.3×10^{-3} %	1.02	60.8 %
4^{+3+2+1} ***PT^{μ}_{Emax} > 0.7 GeV***	**$2.01 * 10^{-2}$**	Eff (4,3) = **6.92**	3.3×10^{-4} %	1.2	50.7 %
$5^{+4+3+2+1}$ **E^{all}_{sum} > 15.8 GeV**	**1.0**	Eff (5,4) = **86.5**	1.0×10^{-7} %	1.7	**29.2 %**
$6^{+5+4+3+2+1}$ **PT^{all}_{vecsum} < 0.2 GeV**	**---==---**	Eff (6,5) = **1**	---==---	1	**---==---**
$7^{+5+4+3+2+1}$ **P^{all}_{vecsum} > 14.8 GeV**	**---==---**	Eff (7,5) = **1**	---==---	1	**---==---**
$8^{+4+3+2+1}$ **Isolation criterium**	**> 65**	Eff (8,4) > **3288**	< 1.0×10^{-7} %	1.01	**50.0 %**
$8^{+5+4+3+2+1}$ **Isolation criterium**	**> 38**	Eff (8,5) > **216**	< 1.0×10^{-7} %	1	**29.2 %**

PT^{all}_{vecsum} and P^{all}_{vecsum} cuts are correlated with the cut on E^{all}_{sum}

Lepton (μ) isolation criteria





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

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

(η - pseudorapidity, φ — azimuthal angle)

upper plot **signal events**

bottom plot **Mini-bias background**

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

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

allows to separate most part

of Mini-bias & QCD bkg muons

with the loss of < **0.7 %** of signal events

after applied cuts discussed above

But! In PandaRoot shows tentatively worse results

π/μ rejection

Particle momentum	**π/μ rejection**
0.5 — 1 GeV	~ 80 % (experiment with MS prototype)
1 — 1.5 GeV	~ 90 % (assumption)
> 1.5 GeV	~ 99 % (assumption)

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For 5λ of path length in iron.

In PANDA detector we have only **~3λ** path length (EMC+MS) in barrel (+ ~5% muon misidentification)
and > 5λ (~0.7% misidentification) in forward region.

Cuts separate and summarized efficiency for Minimum-bias background events (10^9)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 ***Exactly 2μ*** with **PT_l > 0.3 GeV, P_l > 1.0 GeV**	**$1.01 * 10^{-3}$**	Eff (1,init) = **17417**	5.7×10^{-3} %	2.1	47.1 %
2^{+1} ***2μ*** *are of the* ***opposite sign***	**$1.5 * 10^{-3}$**	Eff (2,1) = **1.49**	3.8×10^{-3} %	1.0	47.0 %
3^{+2+1} ***$M_{inv}(\mu^+,\mu^-)$ > 1.0 GeV***	**$9.0 * 10^{-3}$**	Eff (3,2) = **6.08**	6.3×10^{-4} %	1.0	46.4 %
4^{+3+2+1} ***PT^{μ}_{Emax} > 0.7 GeV***	**$3.84 * 10^{-2}$**	Eff (4,3) = **4.96**	1.3×10^{-4} %	1.3	36.1 %
5^{+3+2+1} ***E^{all}_{sum} > 15.8 GeV***	**$5.2 * 10^{-1}$**	Eff (5,3) = **103.7**	6.1×10^{-6} %	1.9	24.6 %
6^{+3+2+1} ***PT^{all}_{vecsum} < 0.2 GeV***	**$1.6 * 10^{-2}$**	Eff (6,3) = **2.42**	2.7×10^{-4} %	1.4	33.1 %
7^{+3+2+1} ***P^{all}_{vecsum} > 14.8 GeV***	**$3.1 * 10^{-1}$**	Eff (7,3) = **12.14**	1.0×10^{-5} %	1.8	25.4 %
8^{+3+2+1} ***Isolation criterium***	**9.5**	Eff (8,3) = **212.5**	6.0×10^{-7} %	1.0	**43.8 %**
9^{+3+2+1} ***R_{vertex} < 1 mm***	**$2.8 * 10^{-1}$**	Eff (9,3) = **33.3**	2.0×10^{-5} %	1.0	43.8 %
10^{+3+2+1} ***R_{vertex} < 25 mm***	**$2.7 * 10^{-1}$**	Eff (10,3) = **30.1**	2.1×10^{-5} %	1.0	43.8 %
$5^{+4+3+2+1}$ E^{all}_{sum} > 15.8 GeV	**1.76**	Eff (5,4) = **75**	7.0×10^{-7} %	1.6	**22.7 %**
$8^{+4+3+2+1}$ Isolation criterium	**> 49**	Eff (8,4) > **1275**	< 1.0×10^{-7} %	1.0	**36.0 %**
$8^{+5+4+3+2+1}$ Isolation criterium	**> 32**	Eff (8,5) > **61**	< 1.0×10^{-7} %	1.1	**22.4 %**

Cuts separate and summarized efficiency for Minimum-bias background events (10^9)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 *Exactly 2μ* with **PT_l > 0.3 GeV, P_l > 1.5 GeV**	**$2.73 * 10^{-3}$**	Eff (1,init) = **71772**	1.4×10^{-3} %	3.0	32.7 %
2^{+1} *2μ are of the **opposite sign***	**$3.99 * 10^{-3}$**	Eff (2,1) = **1.46**	9.5×10^{-4} %	1.0	32.6 %
3^{+2+1} $M_{inv}(\mu^+,\mu^-)$ > 1.0 GeV	**$2.08 * 10^{-2}$**	Eff (3,2) = **5.35**	1.8×10^{-4} %	1.0	32.2 %
4^{+3+2+1} PT^{μ}_{Emax} > 0.7 GeV	**$8.37 * 10^{-2}$**	Eff (4,3) = **4.26**	4.2×10^{-5} %	1.3	25.2 %
5^{+3+2+1} E^{all}_{sum} > 15.8 GeV	**$9.54 * 10^{-1}$**	Eff (5,3) = **80.9**	2.2×10^{-6} %	2.0	16.1 %
6^{+3+2+1} PT^{all}_{vecsum} < 0.2 GeV	**$3.37 * 10^{-2}$**	Eff (6,3) = **2.14**	8.3×10^{-5} %	1.6	21.5 %
7^{+3+2+1} P^{all}_{vecsum} > 14.8 GeV	**$6.66 * 10^{-1}$**	Eff (7,3) = **53.9**	3.3×10^{-6} %	1.9	16.9 %
8^{+3+2+1} *Isolation criterium*	**12.3**	Eff (8,3) = **593**	3.0×10^{-7} %	1.0	**32.2 %**
9^{+3+2+1} R_{vertex} < 1 mm	**$3.42 * 10^{-1}$**	Eff (9,3) = **16.5**	1.08×10^{-5} %	1.0	32.2 %
10^{+3+2+1} R_{vertex} < 25 mm	**$3.33 * 10^{-1}$**	Eff (10,3) = **16.0**	1.11×10^{-5} %	1.0	32.2 %
$5^{+4+3+2+1}$ E^{all}_{sum} > 15.8 GeV	**2.85**	Eff (5,4) = **59.7**	7.0×10^{-7} %	1.5	**16.7 %**
$8^{+4+3+2+1}$ **Isolation criterium**	**> 35**	Eff (8,4) > **418**	< 1.0×10^{-7} %	1.0	**25.2 %**
$8^{+5+4+3+2+1}$ **Isolation criterium**	**> 20**	Eff (8,5) > **22**	< 1.0×10^{-7} %	1.0	**15.4 %**

Cuts separate and summarized efficiency for QCD background events (10^9)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	Rest of BKG	*Efficiency for SIG*	Rest of SIG
1 ***Exactly 2μ*** with **PT_l > 0.3 GeV, P_l > 1.5 GeV**	**3.67 * 10^{-3}**	Eff (1,init) = **20198**	4.9 x 10^{-3} %	3.0	32.7 %
2^{+1} ***2μ*** *are of the* ***opposite sign***	**4.90 * 10^{-3}**	Eff (2,1) = **1.33**	3.71 x 10^{-3} %	1.0	32.6 %
3^{+2+1} ***$M_{inv}(\mu^+,\mu^-)$ > 1.0 GeV***	**1.19 * 10^{-2}**	Eff (3,2) = **2.45**	1.51 x 10^{-3} %	1.0	32.2 %
4^{+3+2+1} ***PT^{μ}_{Emax} > 0.7 GeV***	**1.85 * 10^{-2}**	Eff (4,3) = **2.06**	7.3 x 10^{-4} %	1.3	25.2 %
5^{+3+2+1} ***E^{all}_{sum} > 15.8 GeV***	**6.76 * 10^{-1}**	Eff (5,3) = **87.5**	1.7 x 10^{-5} %	2.0	16.1 %
6^{+3+2+1} ***PT^{all}_{vecsum} < 0.2 GeV***	**2.51* 10^{-2}**	Eff (6,3) = **2.45**	6.2 x 10^{-4} %	1.6	21.5 %
7^{+3+2+1} ***P^{all}_{vecsum} > 14.8 GeV***	**3.76 * 10^{-1}**	Eff (7,3) = **48.2**	3.1 x 10^{-5} %	1.9	16.9 %
8^{+3+2+1} ***Isolation criterium***	**> 178**	Eff (8,3) **> 15141**	< 1.0 x 10^{-7} %	1.0	**32.2 %**
9^{+3+2+1} ***R_{vertex} < 1 mm***	**1.52**	Eff (9,3) = **128.3**	1.2 x 10^{-5} %	1.0	32.2 %
10^{+3+2+1} ***R_{vertex} < 25 mm***	**1.27**	Eff (10,3) = **107.4**	1.4 x 10^{-5} %	1.0	32.2 %
$5^{+4+3+2+1}$ **E^{all}_{sum} > 15.8 GeV**	**0.94**	Eff (5,4) = **77.1**	9.5 x 10^{-6} %	1.5	**16.7 %**
$8^{+4+3+2+1}$ **Isolation criterium**	**> 136**	Eff (8,4) > **7328**	< 1.0 x 10^{-7} %	1.0	**25.2 %**
$8^{+5+4+3+2+1}$ **Isolation criterium**	**> 116**	Eff (8,5) > **173**	< 1.0 x 10^{-7} %	1.0	**15.4 %**

Cuts summarized efficiency for DPM&PandaRoot background events ($2*10^7$)

(A.Semenov - preliminary)

Efficiency Eff (K,N) = Nev(cutN) / Nev(cutK)

N of cuts	S/B ratio	*Efficiency for BKG*	S/B ratio	*Efficiency for BKG*
	P_l > 1.0 GeV	P_l > 1.0 GeV	P_l > 1.5 GeV	P_l > 1.5 GeV
1 ***Exactly 2μ*** with **PT_l > 0.3 GeV, P_l >**	**$1.11 * 10^{-4}$**	Eff (1,init) = **2248**	**$1.18 * 10^{-4}$**	**5330**
2^{+1} ***2μ*** *are of the* ***opposite sign***	**$1.98 * 10^{-4}$**	Eff (2,1) = **1.80**	**$3.49 * 10^{-4}$**	**1.93**
3^{+2+1} ***$M_{inv}(\mu^+,\mu^-)$ > 1.0 GeV***	**$1.31 * 10^{-3}$**	Eff (3,2) = **6.61**	**$2.35 * 10^{-3}$**	**6.73**
4^{+3+2+1} ***PT^{μ}_{Emax} > 0.7 GeV***	**$1.79 * 10^{-3}$**	Eff (4,3) = **1.37**	**$2.76 * 10^{-3}$**	**1.17**
$5^{+4+3+2+1}$ ***E^{all}_{sum} > 15.8 GeV***	**$1.46 * 10^{-2}$**	Eff (5,3) = **8.16**	**$1.58 * 10^{-2}$**	**5.72**

Cross section of DPM BKG δ = 44.23 mb → S/B = $1.04 * 10^{-7}$.
DPM&PandaRoot full generation shows for the moment >1 order worse BKG suppresion result than pure PYTHIA.

To study isolation criterium influence increase of statistics is needed. Study of PYTHIA modeling together with PandaRoot is also planned.

Conclusion

The proposed cuts:

1. Events with only 2 muons with

$PT_l > 0.3$ GeV, $E(P)_l > 1.5$ GeV

2. Muons are of the opposite sign

3. Minv $(l^+, l^-) > 1.0$ GeV

4. $PT^{\mu}_{Emax} > 0.7$ GeV

5. $E_{sum} > 15.8$ GeV, $P_{vecsum} > 14.8$ GeV, $PT_{vecsum} < 0.2$ GeV

6. Isolation criteria $E^{sum}_{(R\ isolation\ =\ 0.2)} > 0.5$ GeV

Pure PYTHIA simulation estimates ***for DY (muon channel)***

QCD & Mini-bias bkgd suppresion up to

S/B > 20-50 *with the* ***loss of signal ~ 70-85% ,***

While DPM full generation for the moment shows at least 1 order worse result.

Further study and increase of statistics with PANDARoot (for DPM & PYTHIA generators) is needed

Drell-Yan process study at PANDA is still questionable