$\psi(2S) \to \tau\tau$
A way to test Lepton Flavor Violation @ BESIII

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LF Universality Violation

Lepton Flavor Universality violation accessed by BaBar and Belle studying the ratio:

$$R(D^{(*)}) \equiv \frac{\Gamma(B \to D^{(*)}\tau\nu)}{\Gamma(B \to D^{(*)}\ell\nu)}, \quad (\ell = e, \mu)$$

EXP: $R(D) = 0.403 \pm 0.047, \quad R(D^*) = 0.310 \pm 0.017,$

SM: $R(D) = 0.300 \pm 0.008, \quad R(D^*) = 0.252 \pm 0.003.$

The combined results show a deviation from SM prediction of a level of 3.9σ

- new physics only in the τ channel decay

*JHEP **06** (2017) 019*

IDEA: $\psi(2S) \to \tau\tau$

New observables for test the LFU violation: non-universality in leptonic decays of ψ and Υ quarkonia

- same mechanism as for the $R(D^{(*)})$
- only the $V \to \tau\tau$ decay is affected by NP

$$R^V_{\tau/\ell} \equiv \frac{\Gamma(V \to \tau^+\tau^-)}{\Gamma(V \to \ell^+\ell^-)}, \quad (V = \psi, \Upsilon; \quad \ell = e, \mu),$$

$V(nS)$	SM prediction	Exp. value $\pm\sigma_{\text{stat}} \pm \sigma_{\text{syst}}$
$\Upsilon(1S)$	$0.9924 \pm \mathcal{O}(10^{-5})$	$1.005 \pm 0.013 \pm 0.022$
$\Upsilon(2S)$	$0.9940 \pm \mathcal{O}(10^{-5})$	$1.04 \pm 0.04 \pm 0.05$
$\Upsilon(3S)$	$0.9948 \pm \mathcal{O}(10^{-5})$	$1.05 \pm 0.08 \pm 0.05$
$\psi(2S)$	$0.390 \pm \mathcal{O}(10^{-4})$	0.39 ± 0.05

new BABAR analysis:
PRL 125,241801 (2020):

$$R^{\Upsilon(3S)}_{\tau\mu} = 0.966 \pm 0.008 \pm 0.014$$

in agreement with SM prediction within 2 standard deviation

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Depending of the model, LFU violation for ψ(2S) at 95% C.L. is predicted to be:

$$R^{\psi(2S)}_{\tau/\ell} = 0.389 - 0.390.$$

LFU violation at BESIII?

Rinaldo's suggestion

BR7's talk in Perugia

BESII/BESIII on ψ (2S) -> ττ

BESII : arXiv:hep-ex/0609023v1 13 Sep 2006 ***(PRD74,112003)***

- BESII:
- 14 M ψ (2S)
- Looking to ττ -> μ e not aligned events
- BR (ψ (2S) -> ττ) = (3.1 ± 0.21_{stat} ± 0.38_{syst}) x 10^{-3}
- Systematic error mostly due to lack of continuum data ***(10%)***

6 times lower

- **BESIII:**
- **550 M ψ (2S)**
- **BR (ψ (2S) -> ττ) ≈ (3.1 ± 0.03_{stat} ± ?) x 10^{-3} [0.03/3.1 ≈ 1 %]**

- **Looking also to other τ decay modes**
- **ψ (2S) scan -> systematic error more under control**
- **can we achieve ≈ 1 % , testing LFU violation ?**

Perugia 2018 April 16th 6

Analysis: event and track selection

Study of ψ(2S)→ττ→eμ4ν decay

Charged tracks

- Vertex cut: R_{xy}<1cm and R_z<10cm
- polar angle of tracks in MDC: |cosθ|<0.93
- ptrk < 1.2 GeV (remove Bhabha and dimuon events)
- **pt>0.05 GeV/c**
- nCharged=2

Neutral candidates

- EMC time cut: 0<t_{TDC}<14(/50*ns*)
- E_γ >0.025 GeV for the barrel (**|(cos(θ)|< 0.8)**, and E_γ>0.050 GeV for the endcap (**0.86<|(cos(θ)|<0.92**)
- Isolated γ: opening angle between photon and its nearest charged tracks $\theta_{\gamma\text{-}tr}$> 20°
- nGamma = 0
- Enel < 0.2 GeV

- Release 664p03
- 240000 events simulated: ψ(2S)→**ττ**→ $e^{\mp}\mu^{\pm}$**4ν**
- 2012 MC inclusive ψ(2S) sample
- 2012 ψ(2S) data sample

```
Decay psi(2S)
  1.0000   tau+  tau-              PHOTOS VLL;
Enddecay

Decay tau+
   1.0000 e+ nu_e anti-nu_tau     PHOTOS TAULNUNU;
Enddecay


Decay tau-
   1.0000 mu- anti-nu_mu nu_tau      PHOTOS TAULNUNU;
Enddecay


End
```

```
Decay psi(2S)
  1.0000   tau+  tau-              PHOTOS VLL;
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   1.0000 e- anti-nu_e nu_tau      PHOTOS TAULNUNU;
Enddecay


End
```
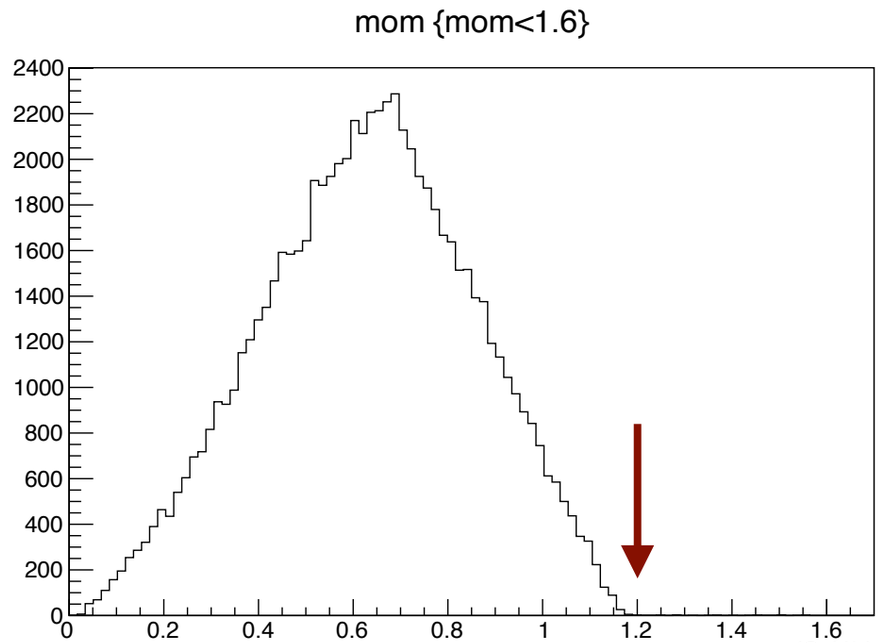
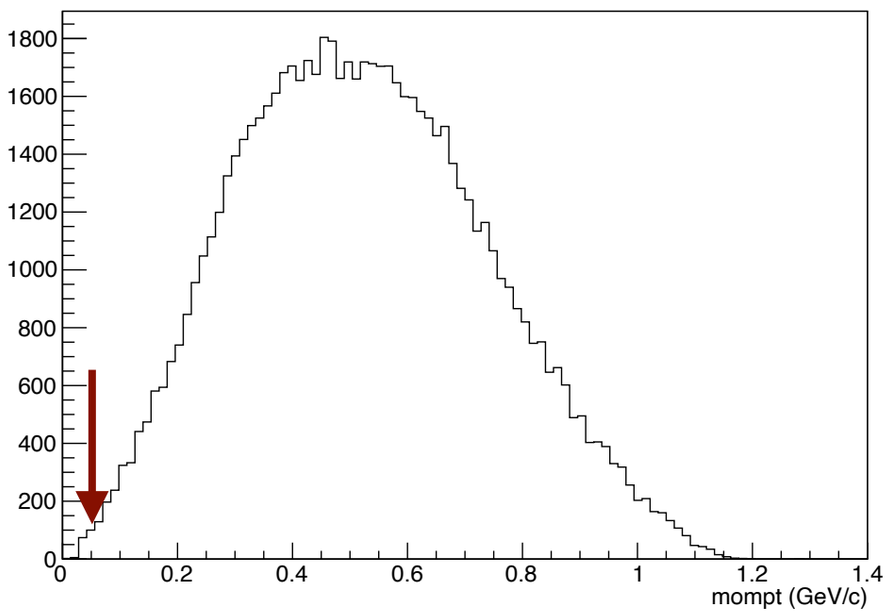

Signal MC: distributions I

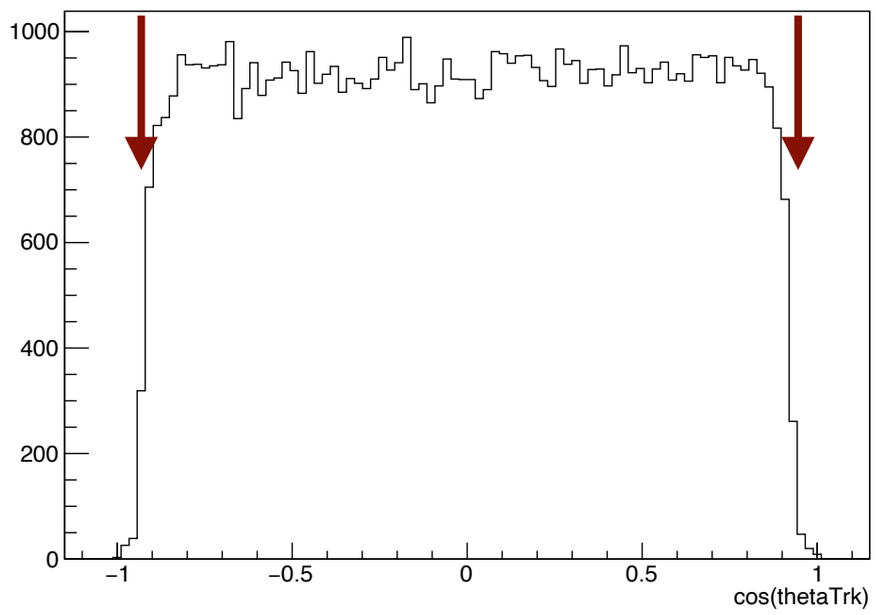
$\psi(2S)\to\tau\tau\to e\mu 4\nu$ signal

Momentum of charged tracks

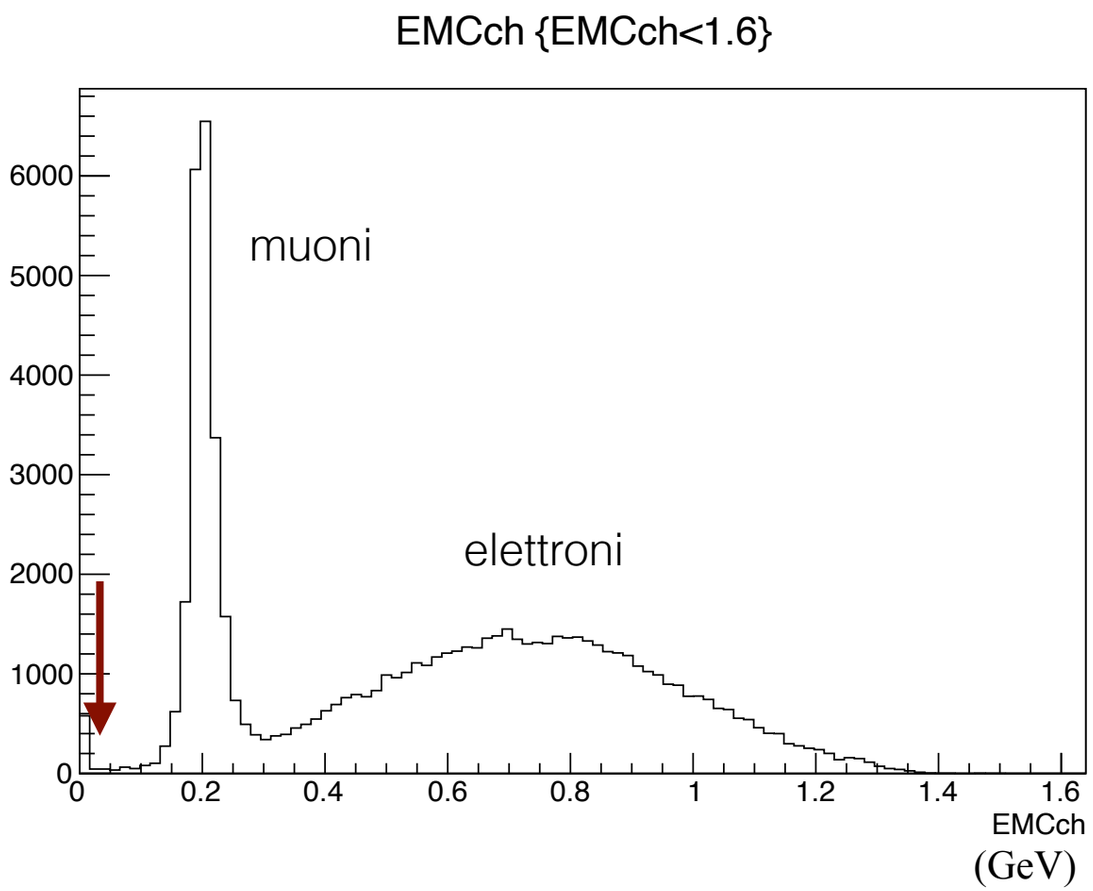


Senza tagli



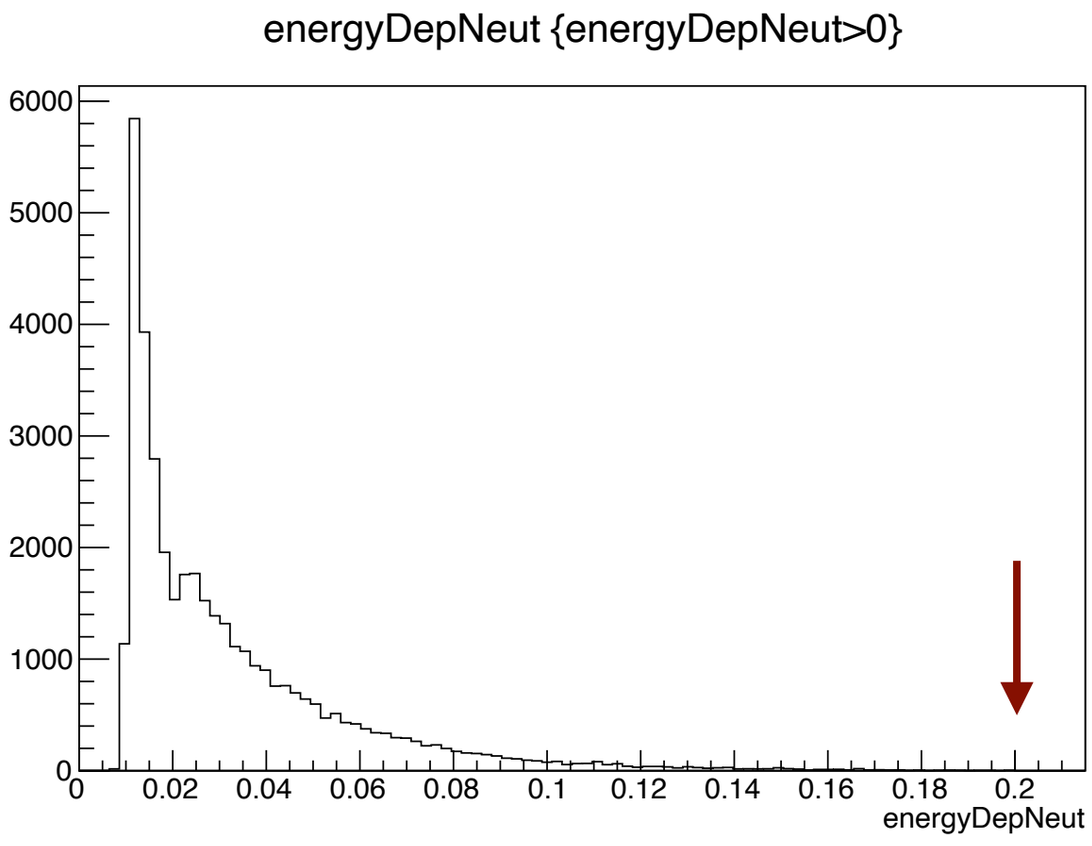


Signal MC: distributions II

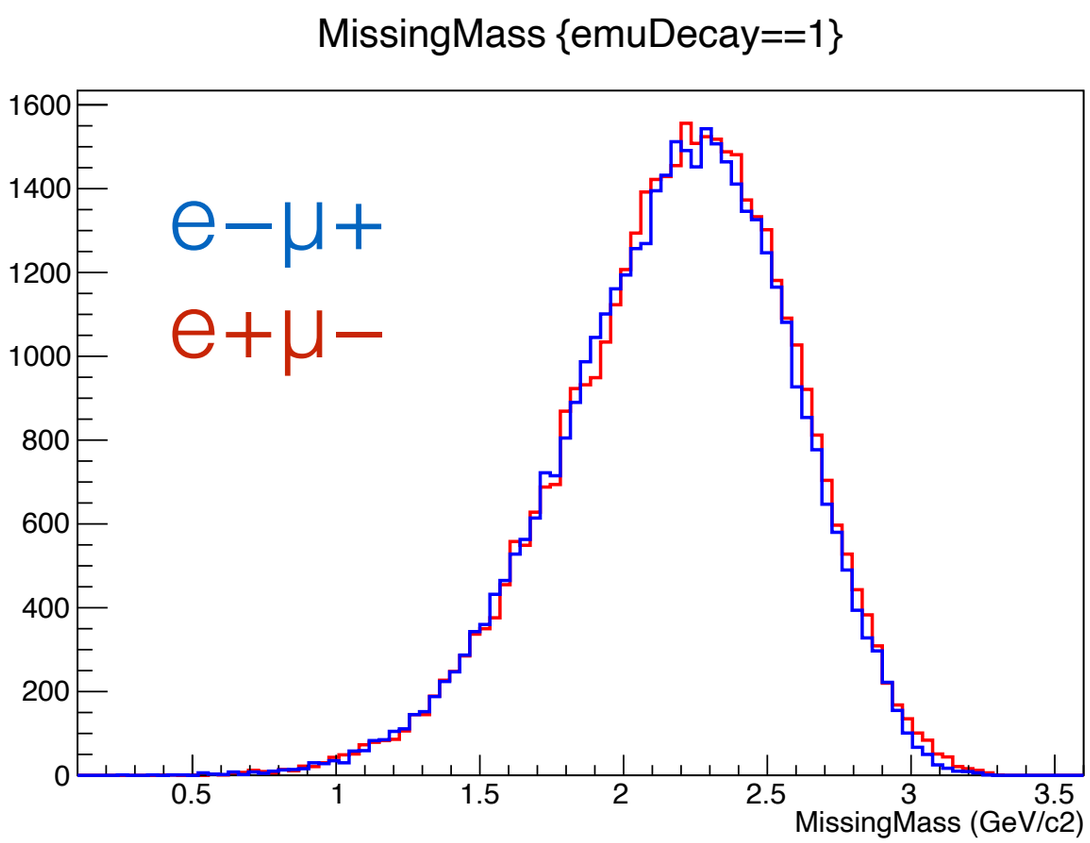


- Charged track energy deposit inside the EMC (total)

- Neutral particle energy deposit inside the EMC (total)



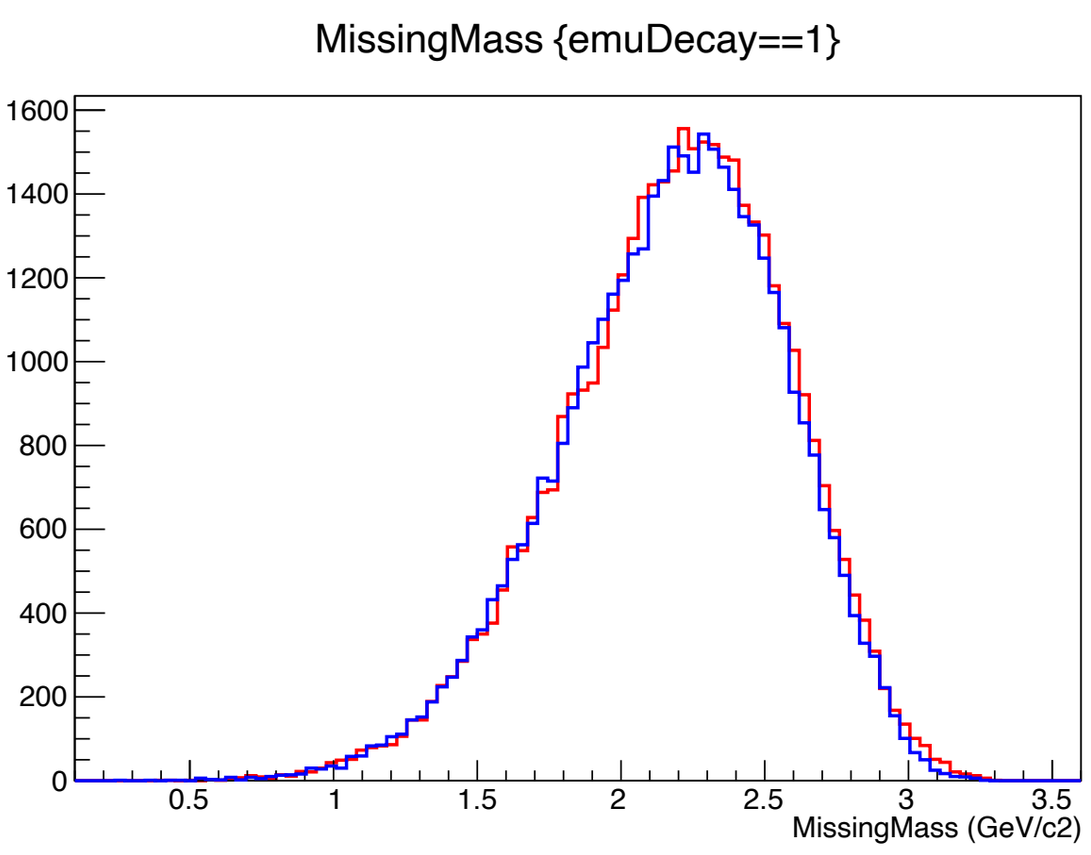
Signal MC: distributions III



Distributions after cuts and PID selection

Missing energy and missing mass:

- *4mom_miss = 4mom_ψ2s - 4mom_ll*
- *U = E_miss = 4mom_miss.e()-| 4mom_miss .p() |*



Background studies

Several background taken into account:

CUTS	$\psi(2S)\to\pi^+e^-3\nu$	$\psi(2S)\to\pi^-e^+3\nu$	$\psi(2S)\to\pi^+\mu^-3\nu$	$\psi(2S)\to\pi^-\mu^+3\nu$	$\psi(2S)\to\pi^-\pi^+3\nu$	SIGNAL $\psi(2S)\to e\mu 4\nu$
Tot number	40000	40000	40000	40000	100000	240000
good trk = 2	32722	32861	33106	33041	84372	196760
EMCch > 25 MeV	32690	32829	33063	32999	84248	196609
Ngamma = 0	23694	22793	25944	25043	55252	167998
eμDecay	1010	948	1	1	0	84290
μμDecay	1	0	1123	1075	38	2
eeDecay	4	2	0	0	0	17

$\psi(2S)\to\pi e3\nu$ non-negligile contribution

PID studies

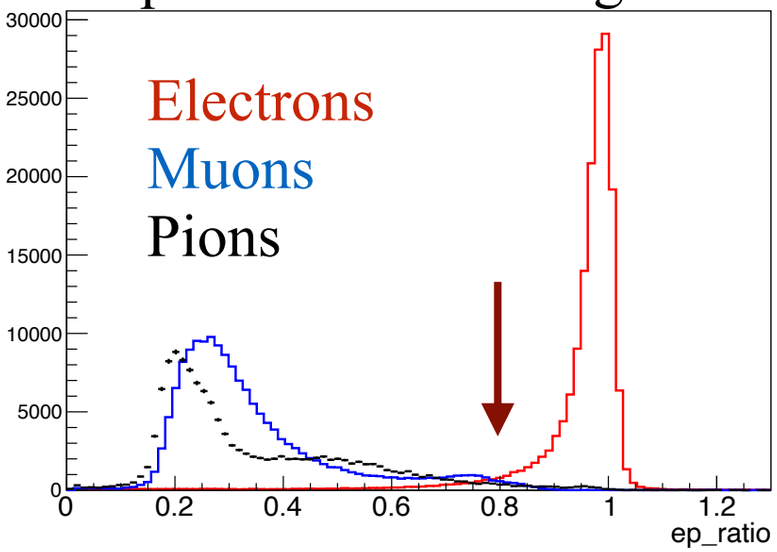
Electron PID

- 0.8 < E/p < 1.2
- $\chi^2_{dE/dx}$ (e)< 4
- |Δtof(e)|<0.3 ns

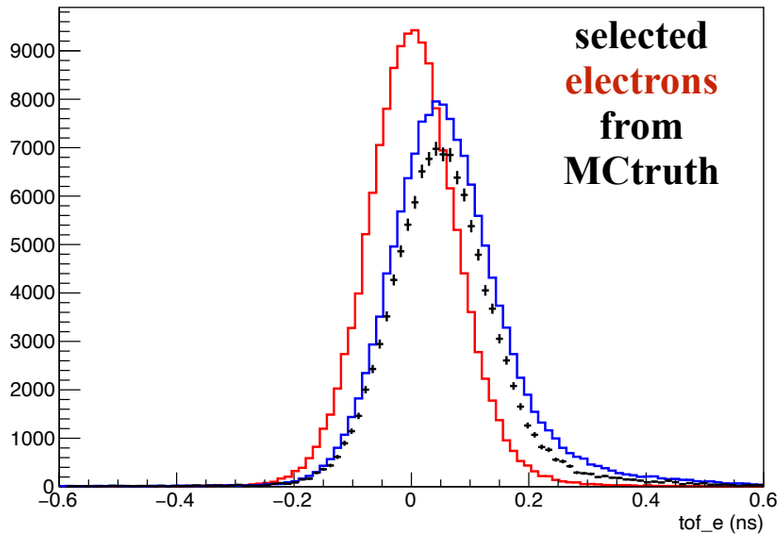
Muon PID

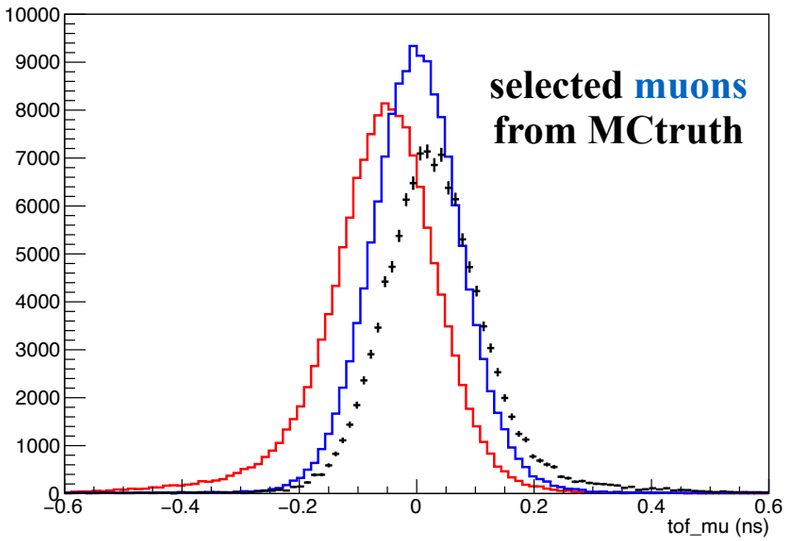
- E/p < 0.7
- $\chi^2_{dE/dx}$ (μ)< 4
- |Δtof(μ)|<0.3 ns
- **muc_dep>81*(ptrk-0.65)**

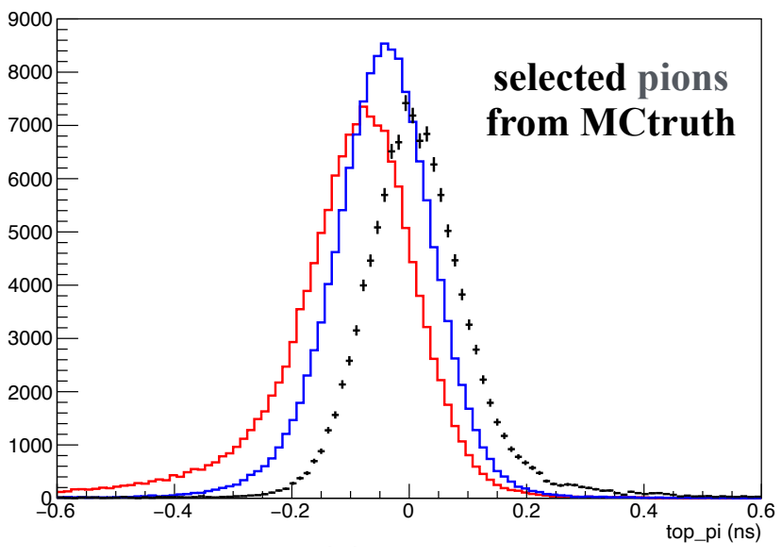
E/p ratio from MC signal



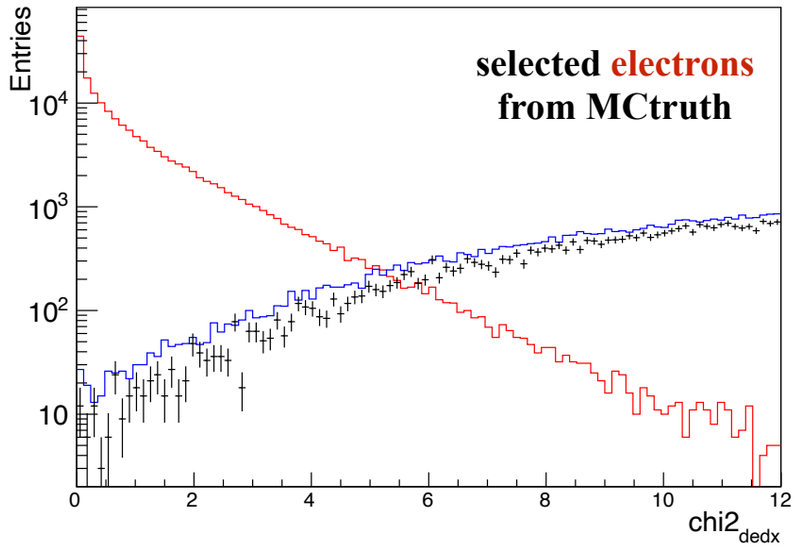
(exp-tof - tof_calc) from MC signal

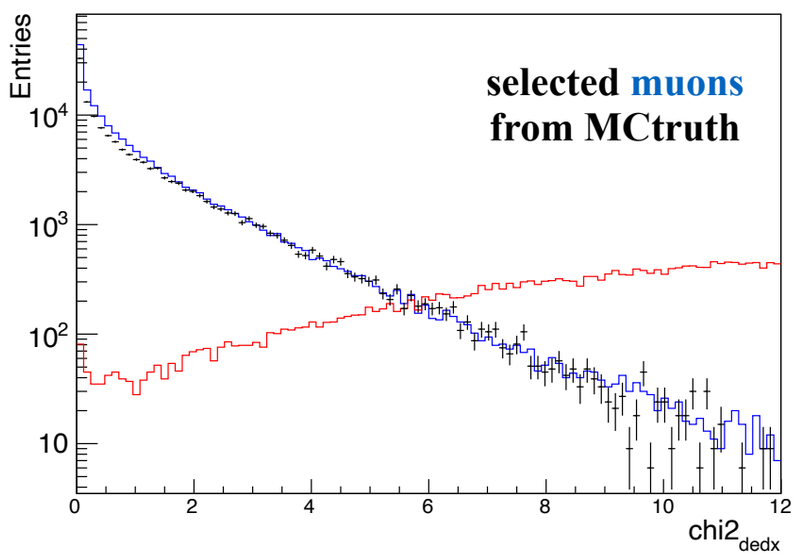


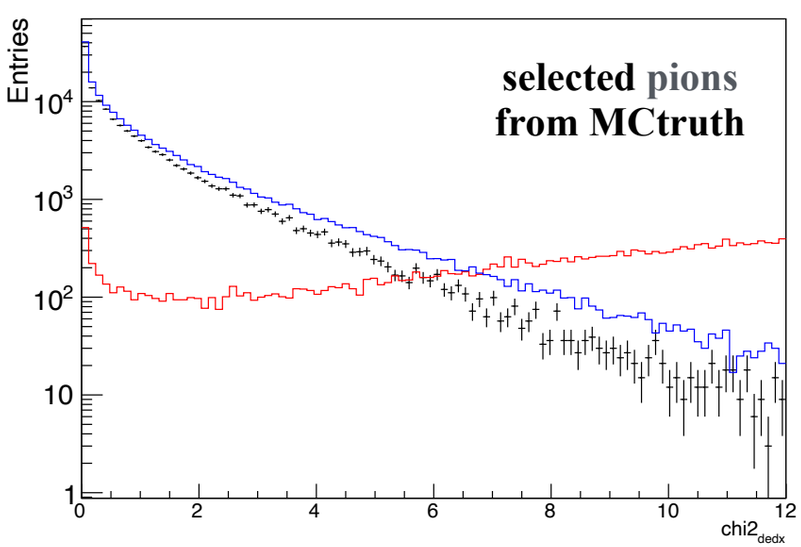


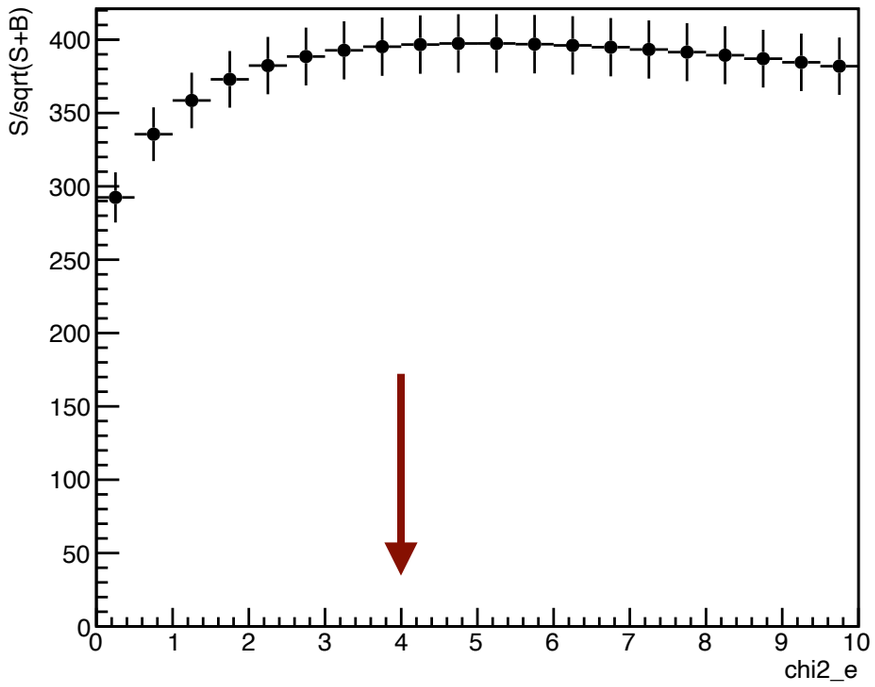


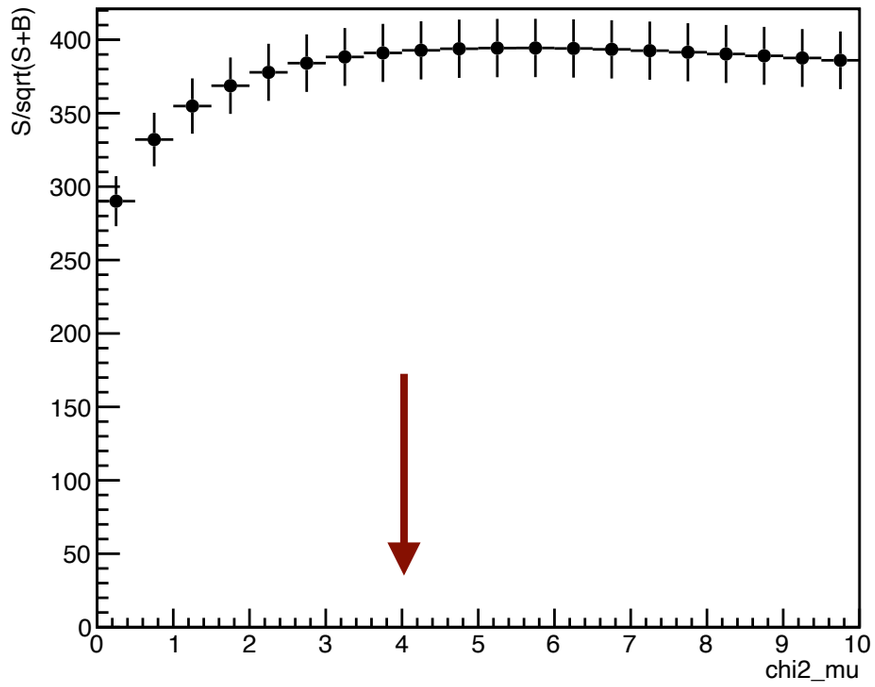
chi2-dEdx from MC signal

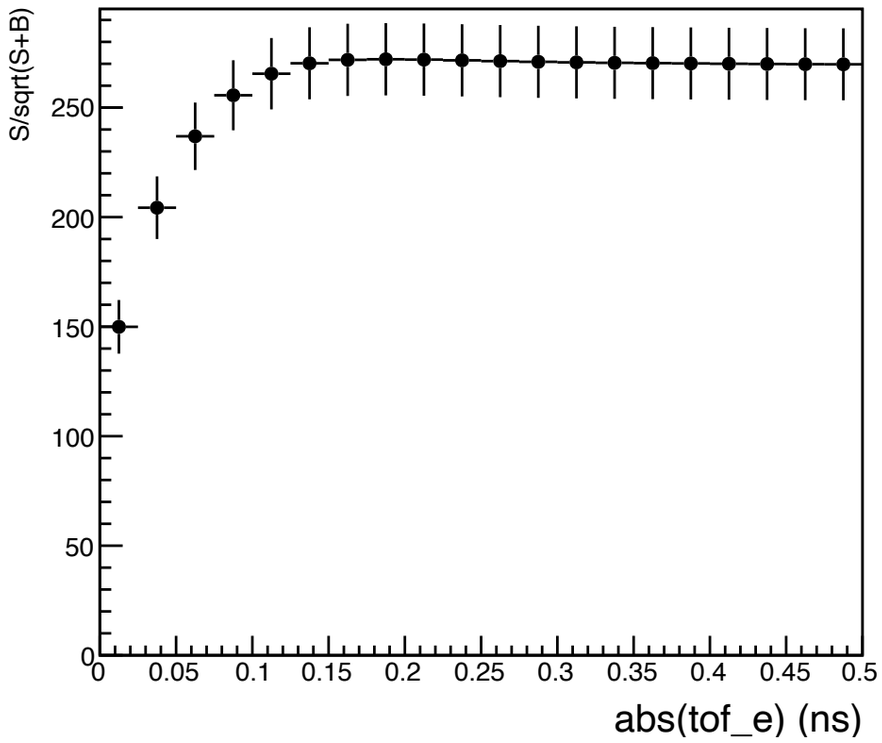


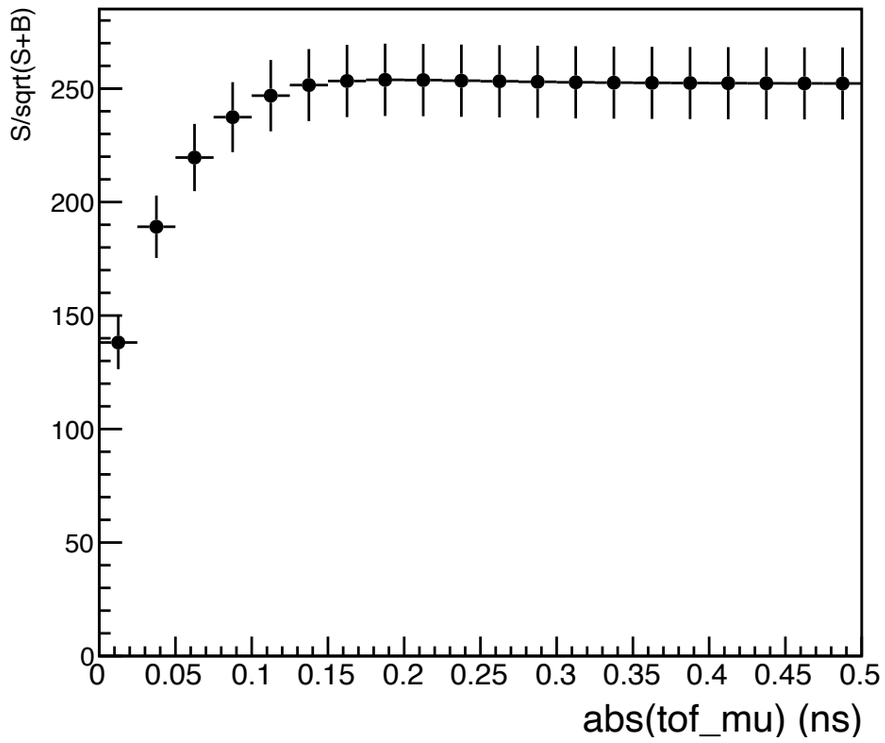





S/sqrt(S+B)
0
50
100
150
200
250
300
350
400
0
1
2
3
4
5
6
7
8
9
10
chi2_e


S/sqrt(S+B)
0
50
100
150
200
250
300
350
400
0
1
2
3
4
5
6
7
8
9
10
chi2_mu


S/sqrt(S+B)
0
50
100
150
200
250
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
abs(tof_e) (ns)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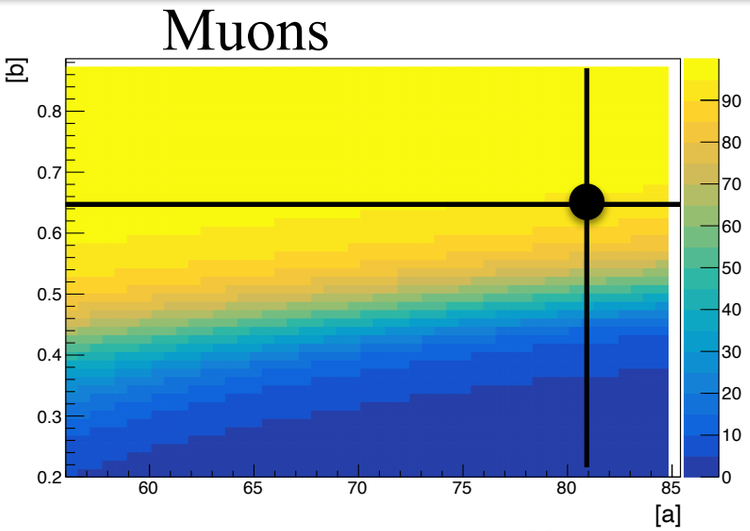
150
200
250
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
abs(tof_mu) (ns)

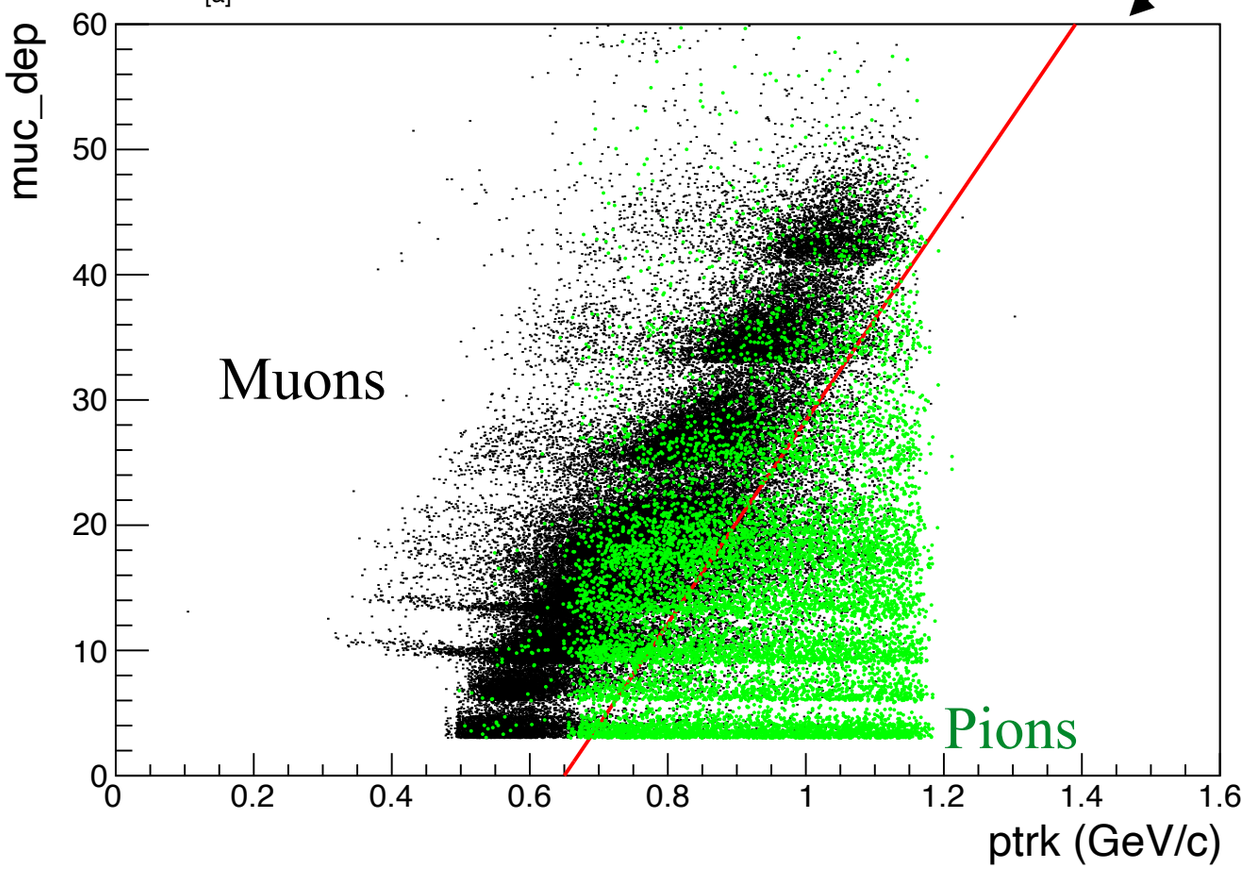
muc vs. ptrk from MC samples



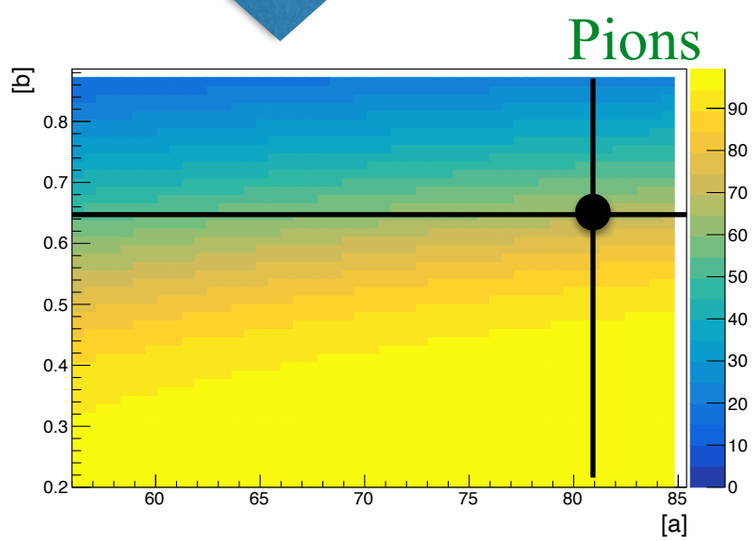
cut efficiency > 90% for muons selection

y = [a]*(x - [b])

y = 81*(x - 0.65) (optimized)



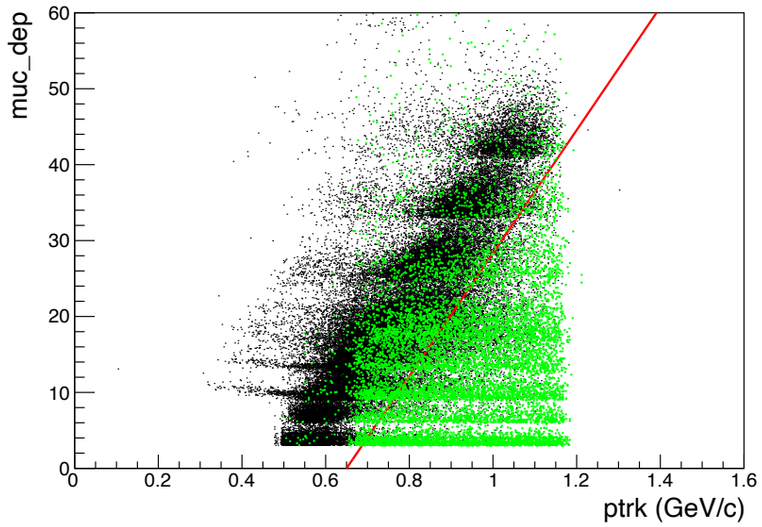
~70% of pions fall below the red line

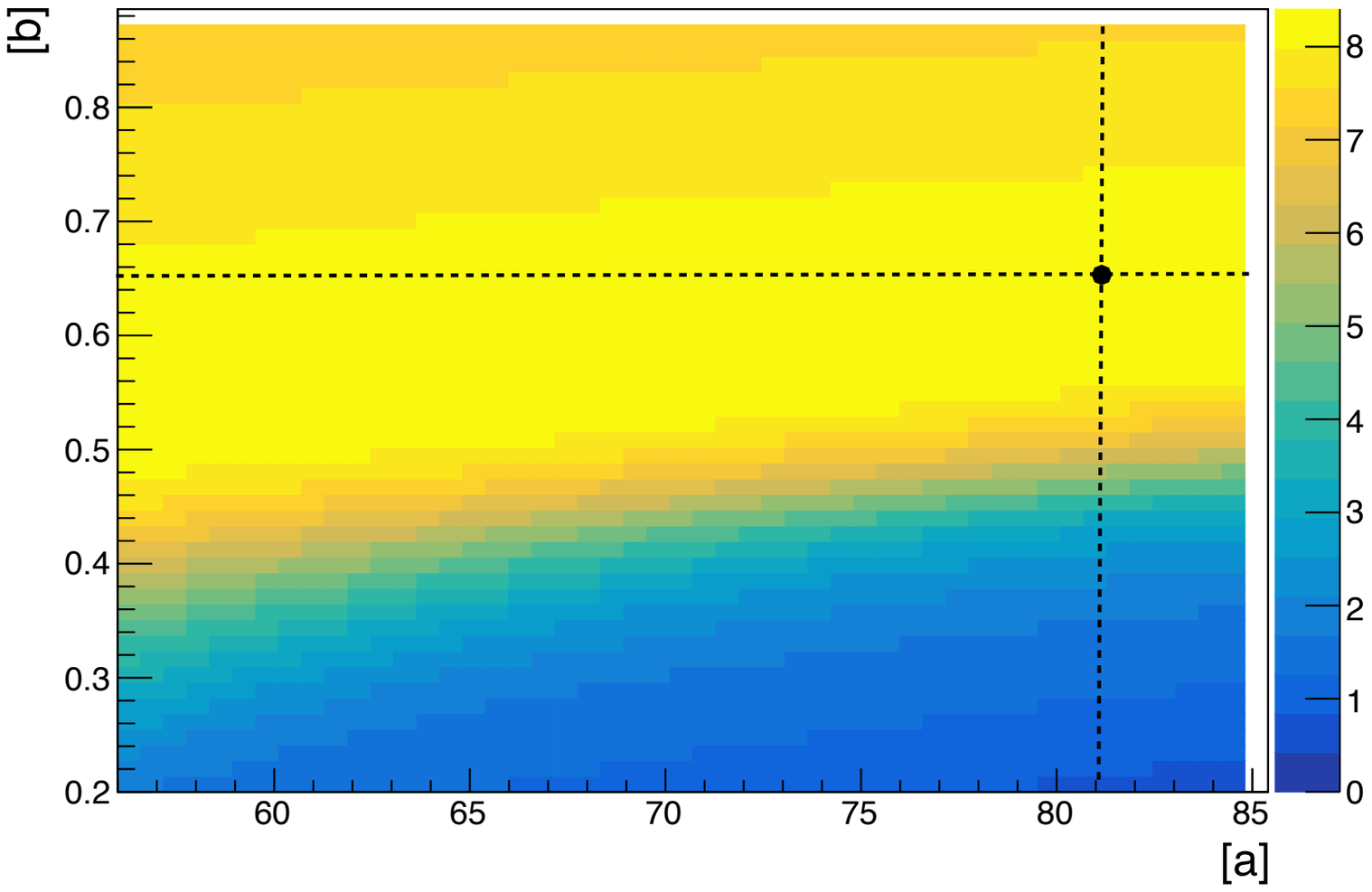


muc vs. ptrk from MC samples

$$\text{f.o.m.} = \frac{S}{\sqrt{S+B}}$$

- Scan for different value of parameters [a] and [b]
- Maximization of f.o.m.





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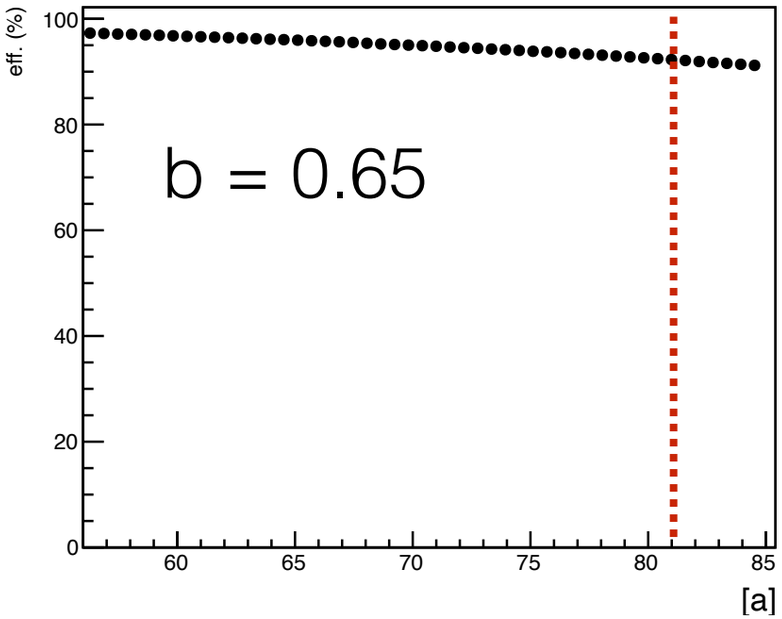
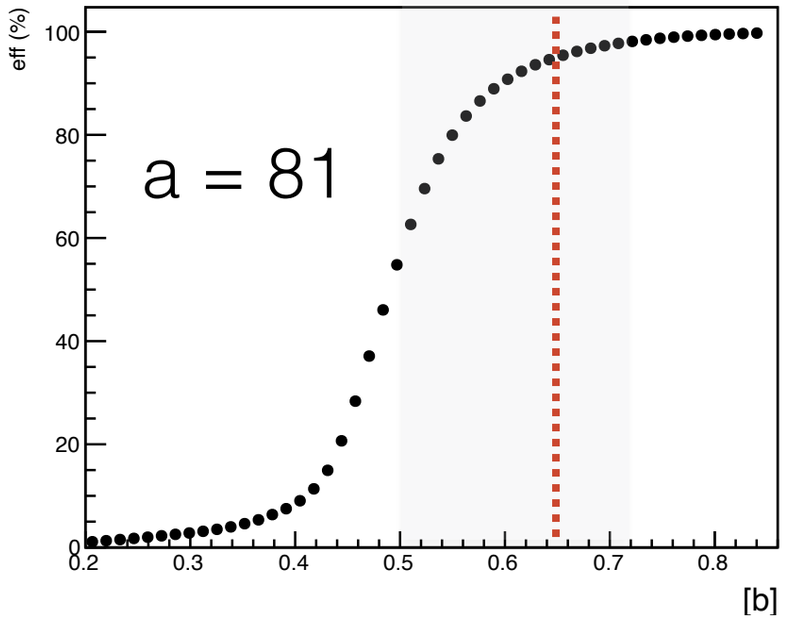
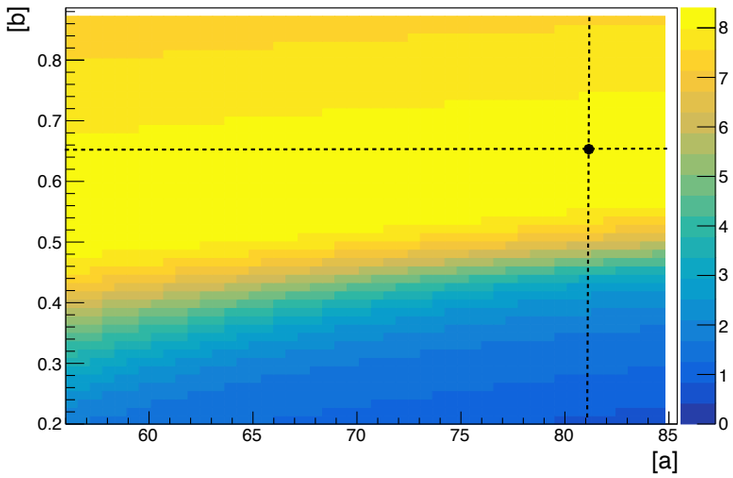
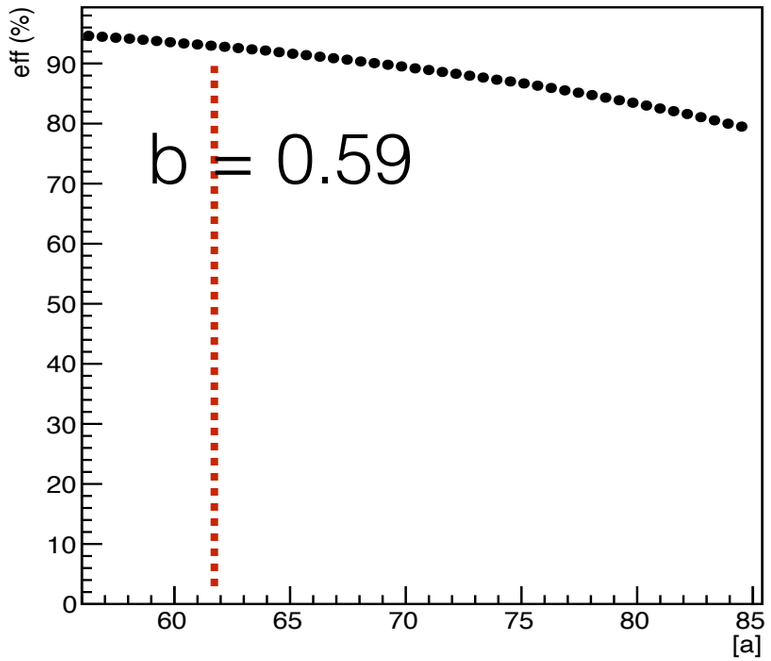
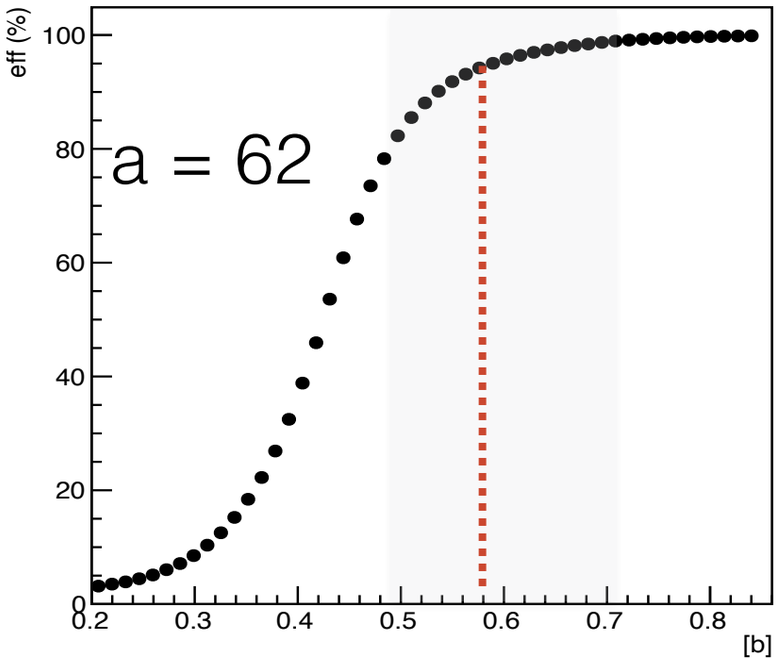
Signal Efficiency

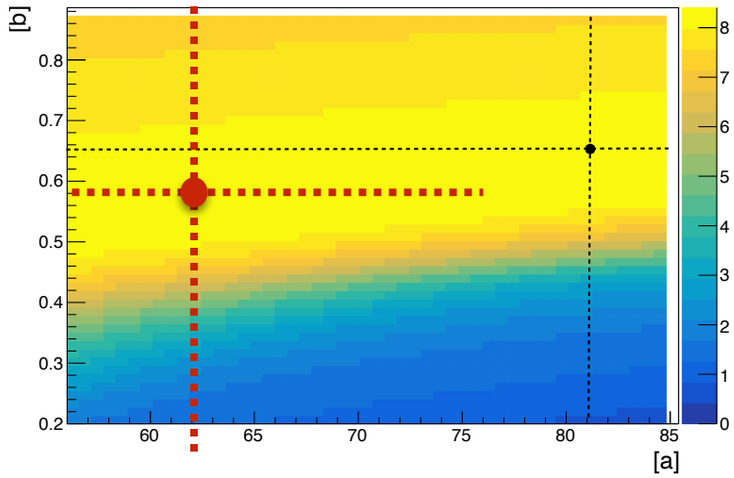




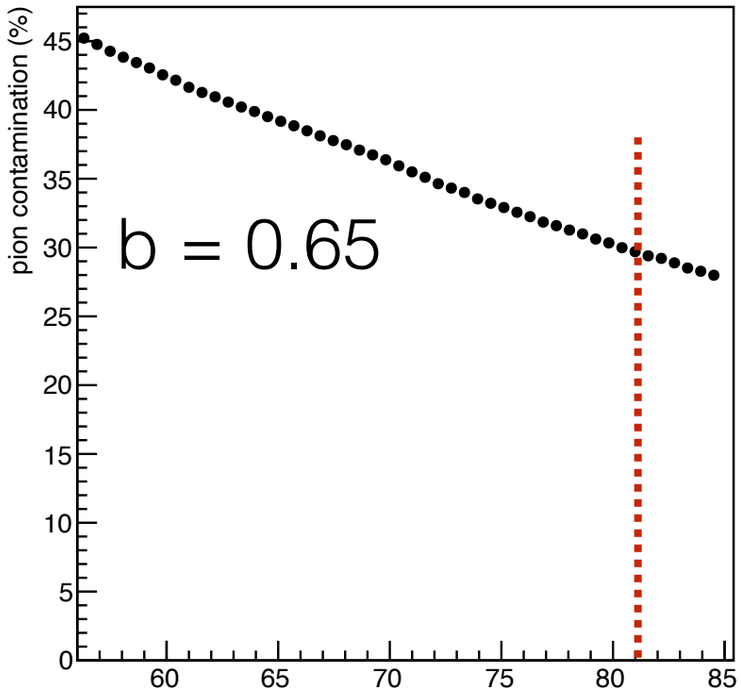


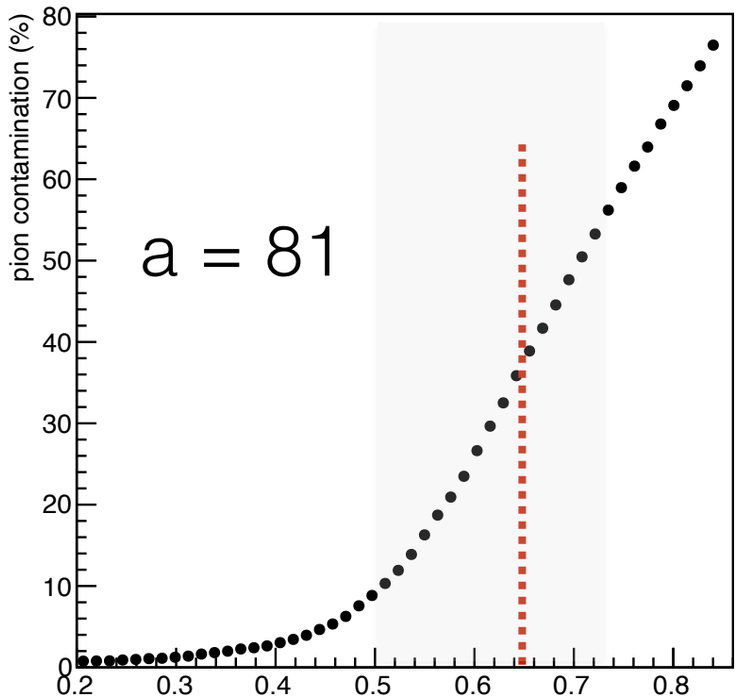


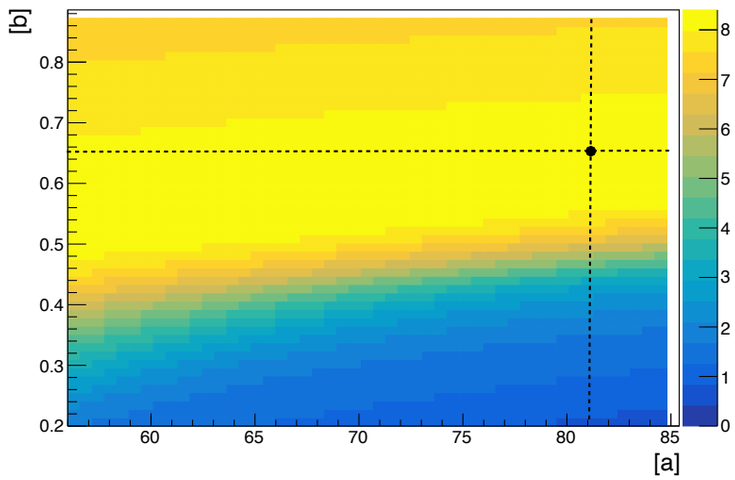


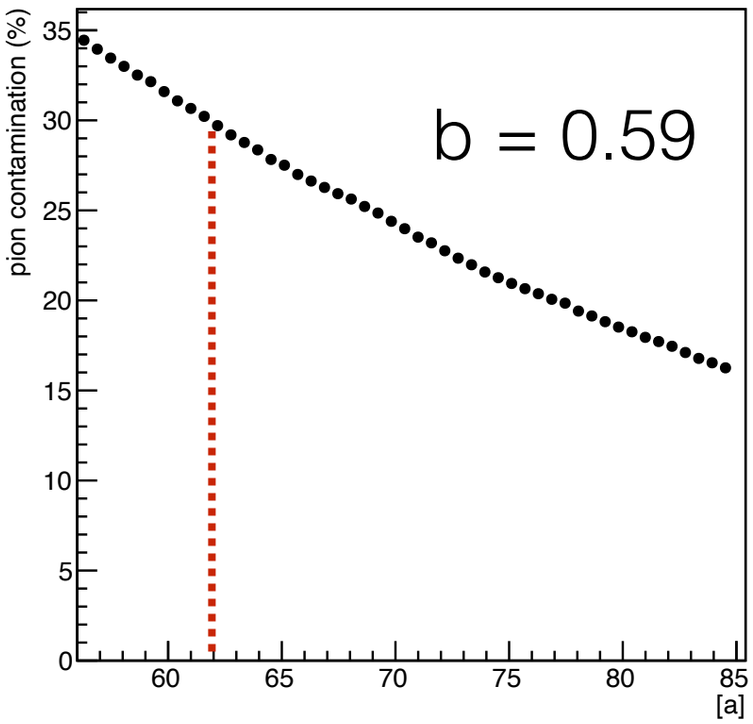


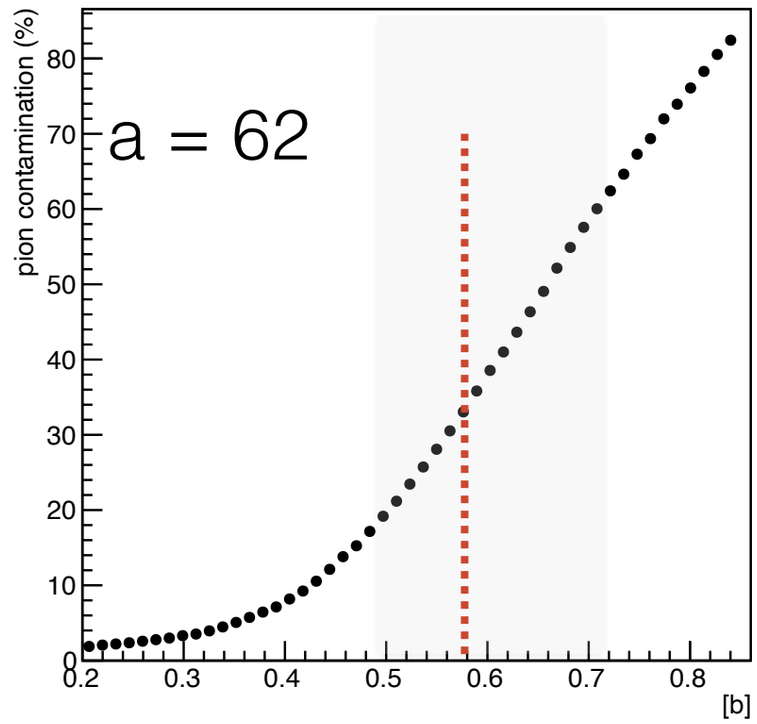
Pions contamination

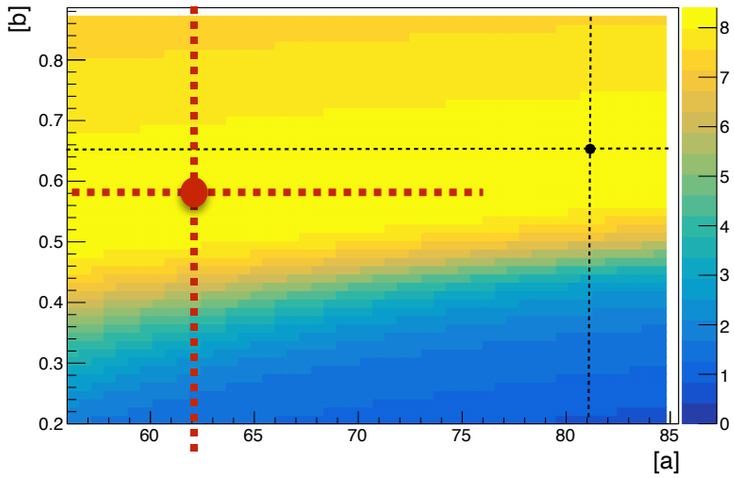








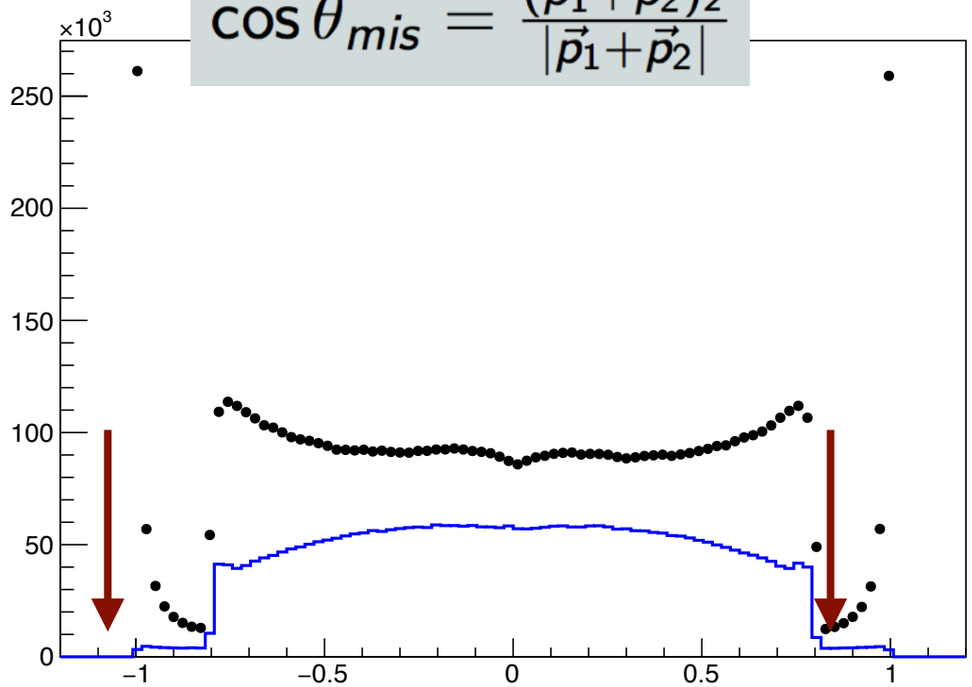


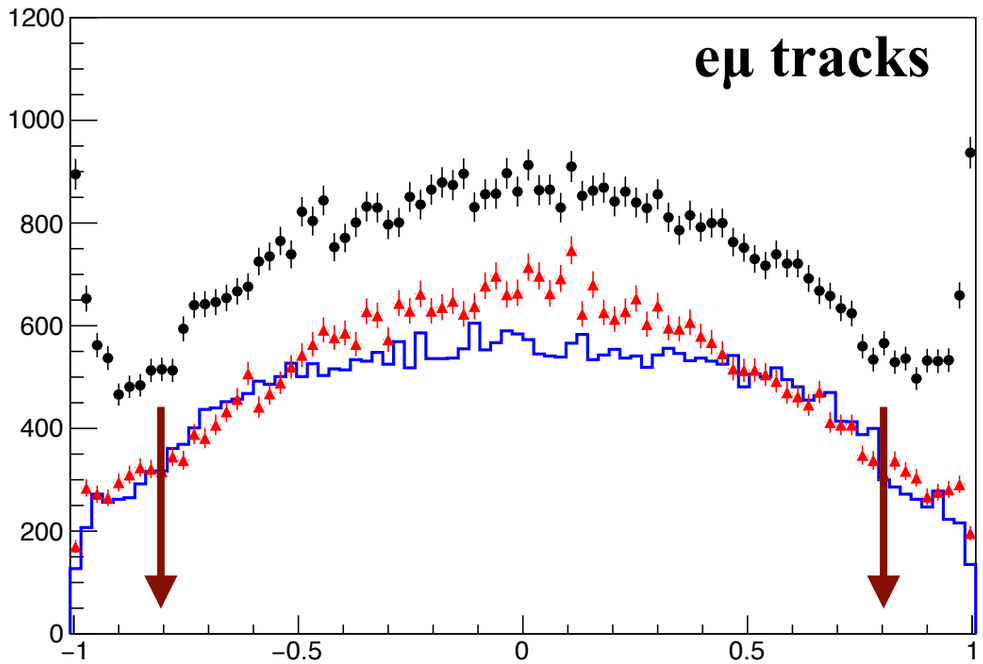


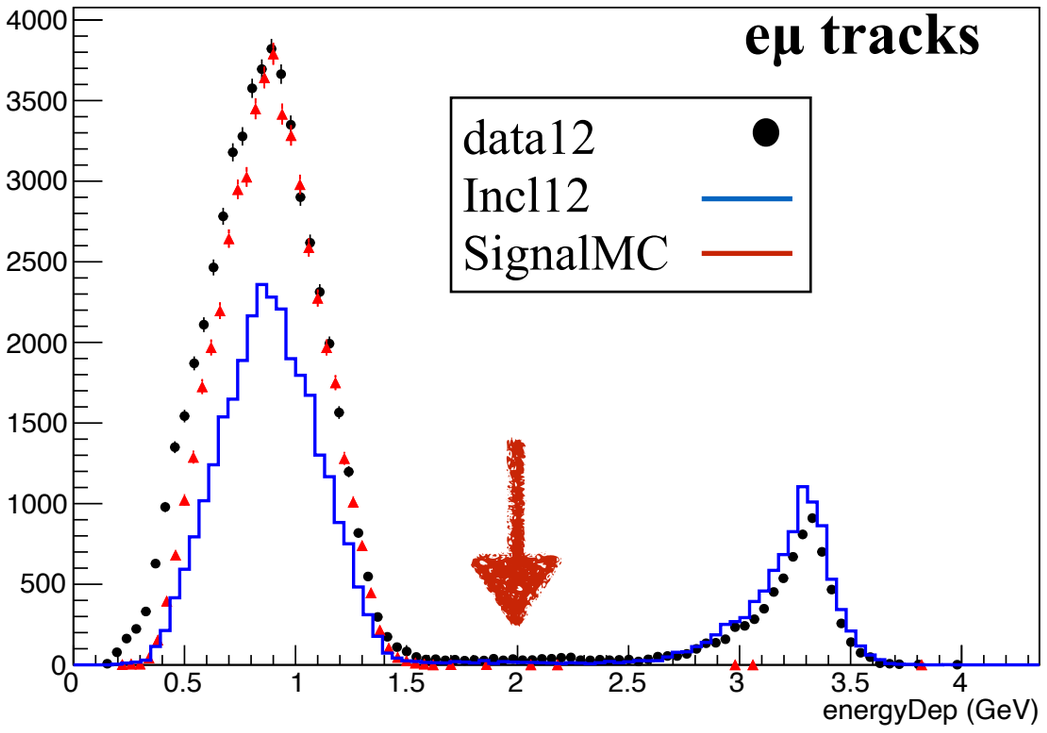
Additional cuts I

*signal arbitrary scale

$$\cos\theta_{mis} = \frac{(\vec{p}_1+\vec{p}_2)_z}{|\vec{p}_1+\vec{p}_2|}$$







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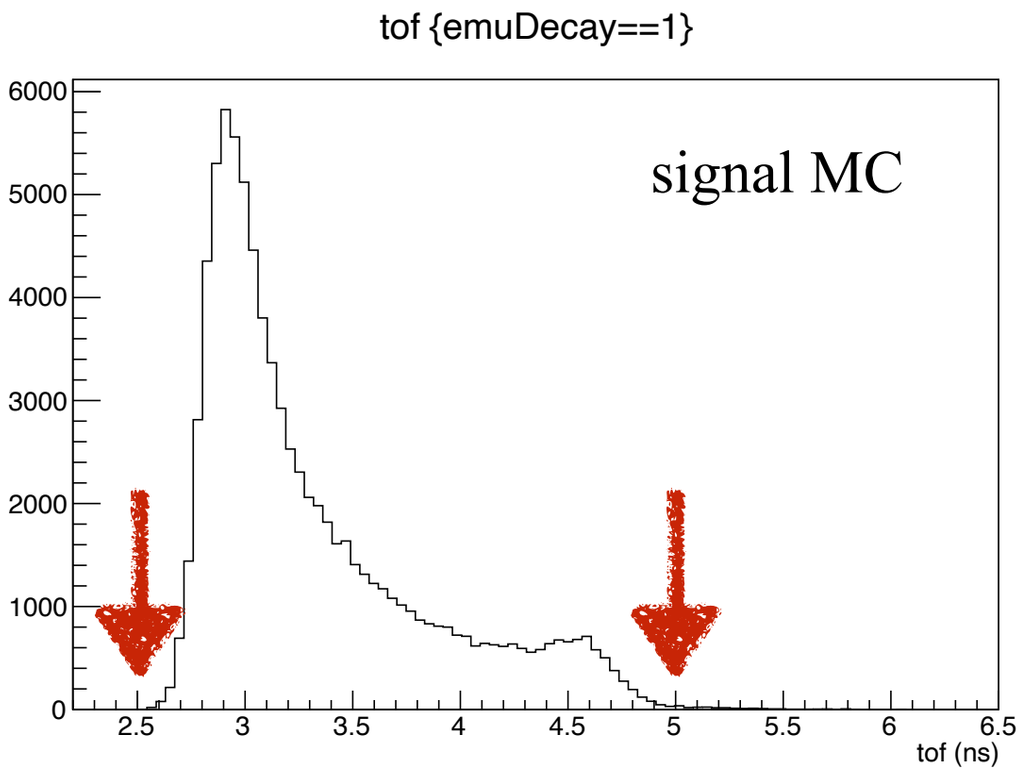
- |cosθ_miss| < 0.8
- energyDep < 2 (sum of deposit energy of the two tracks)

Full data-2012 and inclusive-2012 MC sample analyzed

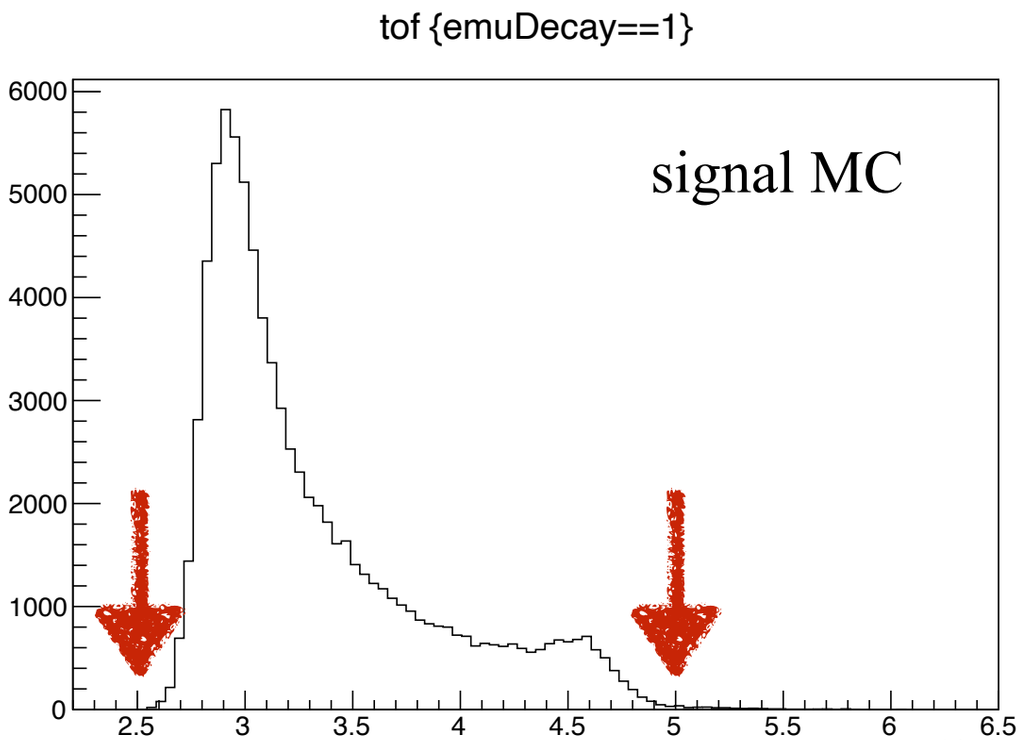
- evident discrepancy between the two samples in the signal region
- **after energyDec cut, pi contamination is about 11% (instead of about 30%)**

Additional cuts II



- 2.5<tof < 5 (ns)

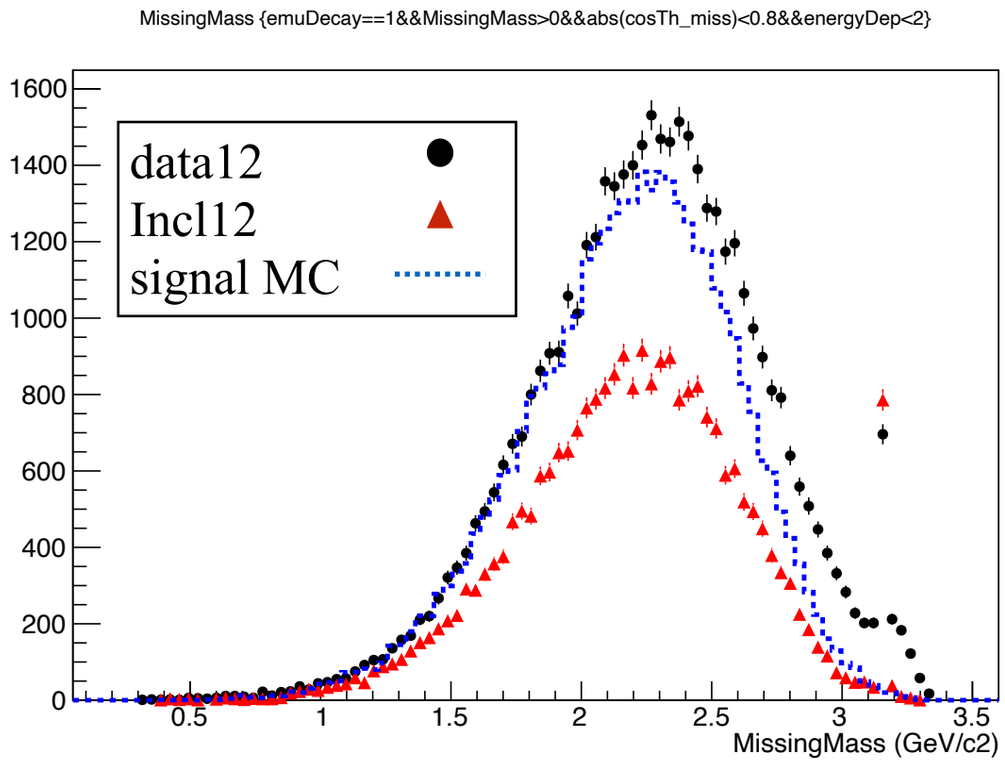
Additional cuts II

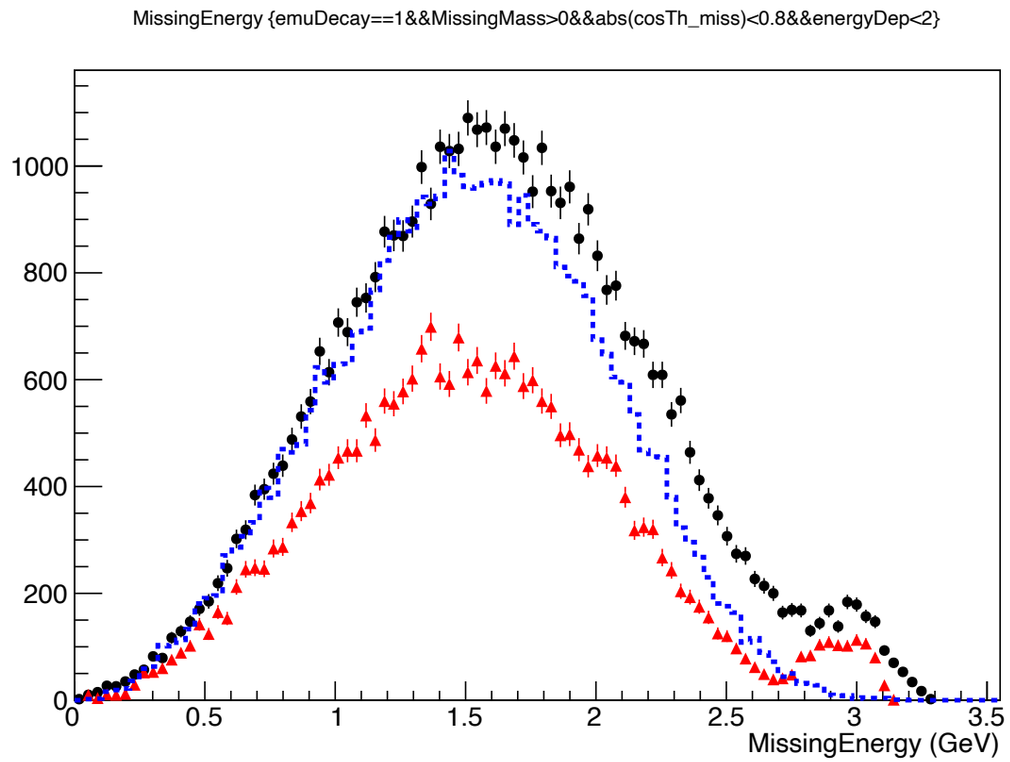


- 2.5<tof < 5 (ns)

Missing mass and missing energy:

- *4mom_miss = 4mom_ψ2s - 4mom_ll*
- *U = E_miss = 4mom_miss.e()-| 4mom_miss .p() |*





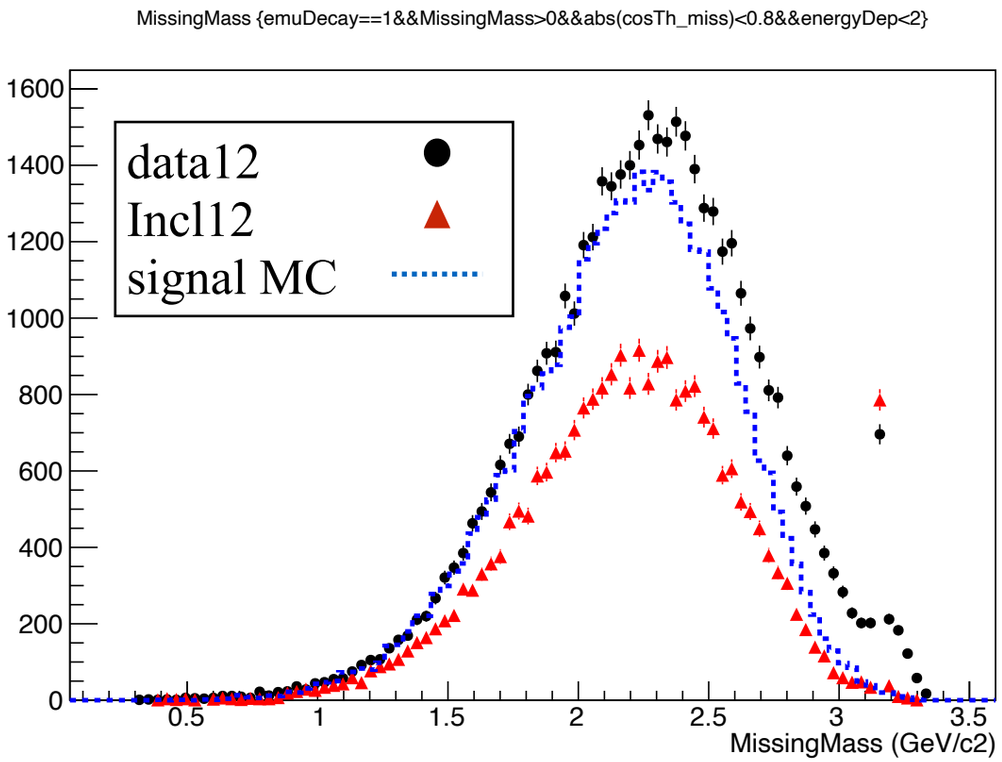
Additional cuts II

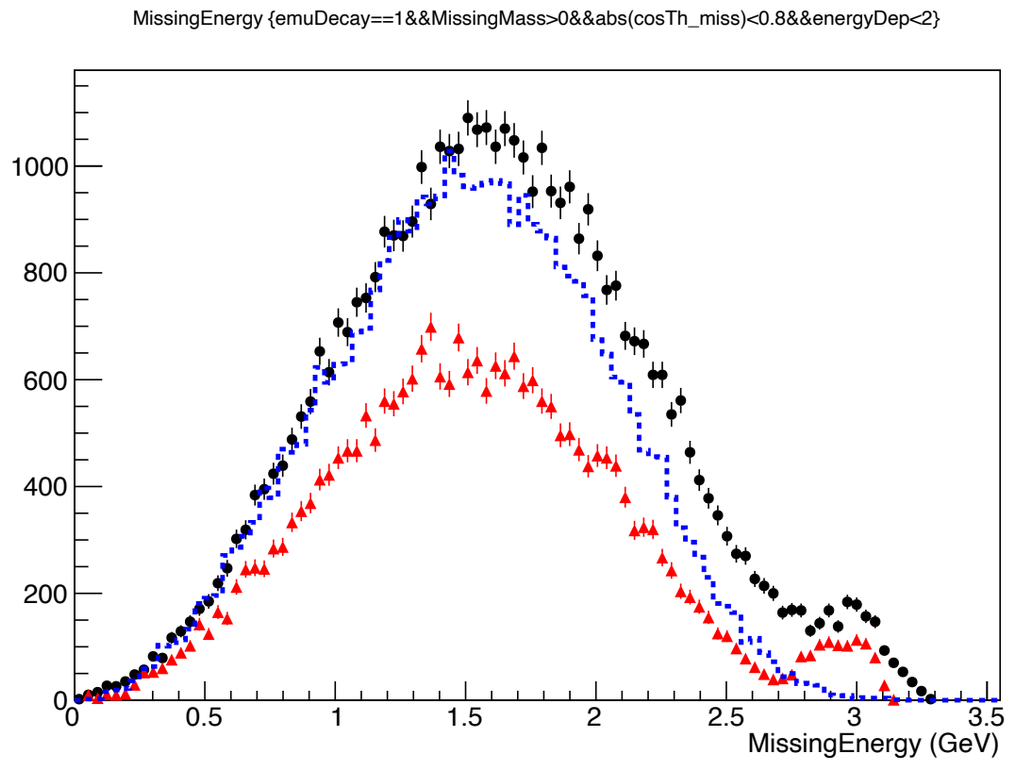
Missing mass and missing energy:

- *4mom_miss = 4mom_ψ2s - 4mom_ll*
- *U = E_miss = 4mom_miss.e()-| 4mom_miss .p() |*

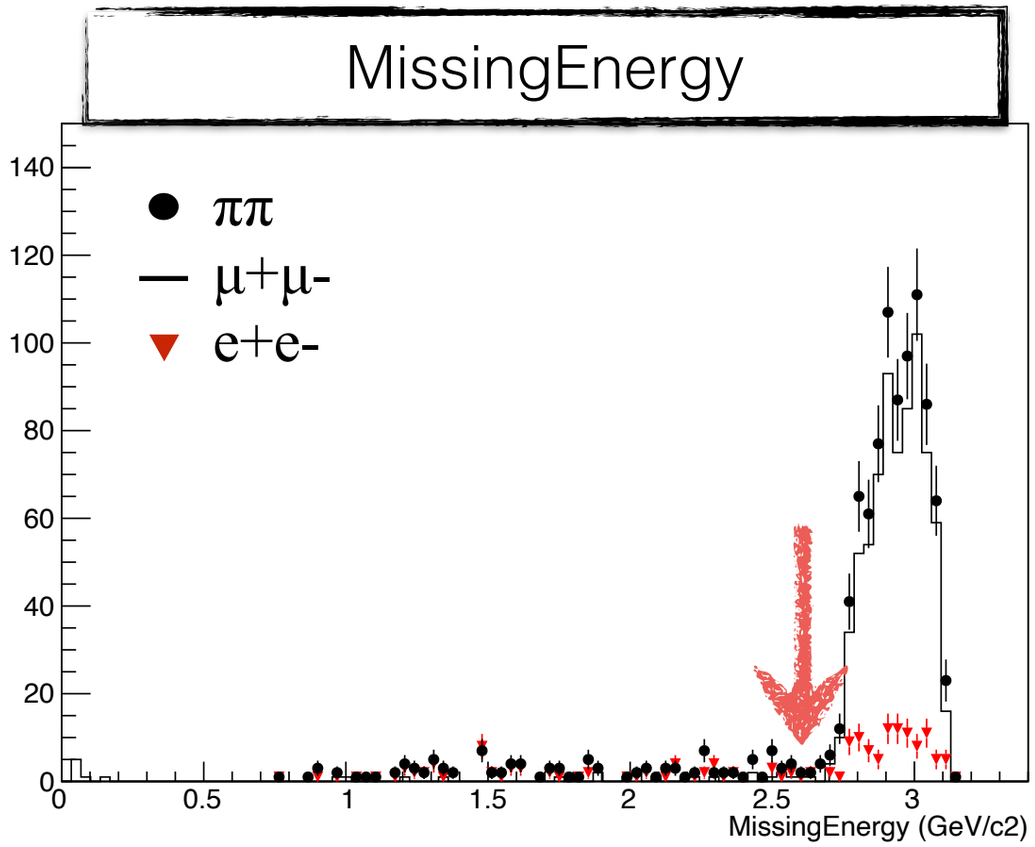
IDEA:

- Check the topology of those events reconstructed as "eμ" (MCtruth info)
  - Jpsi contributions

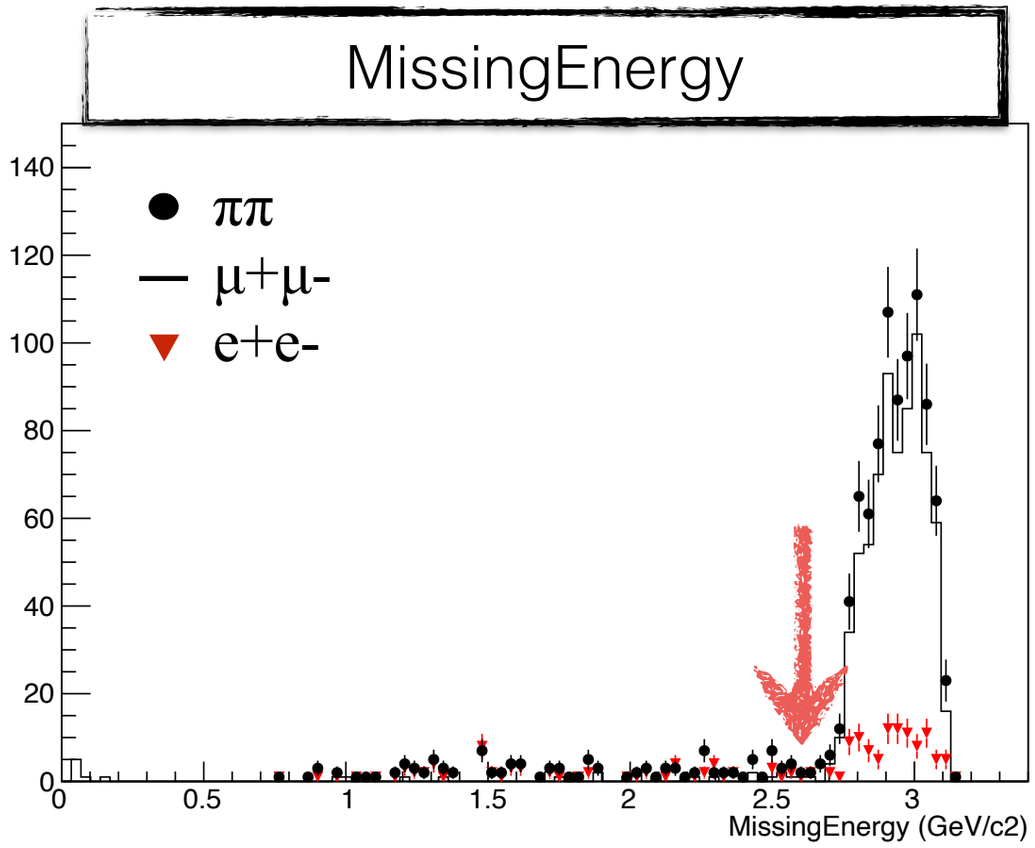


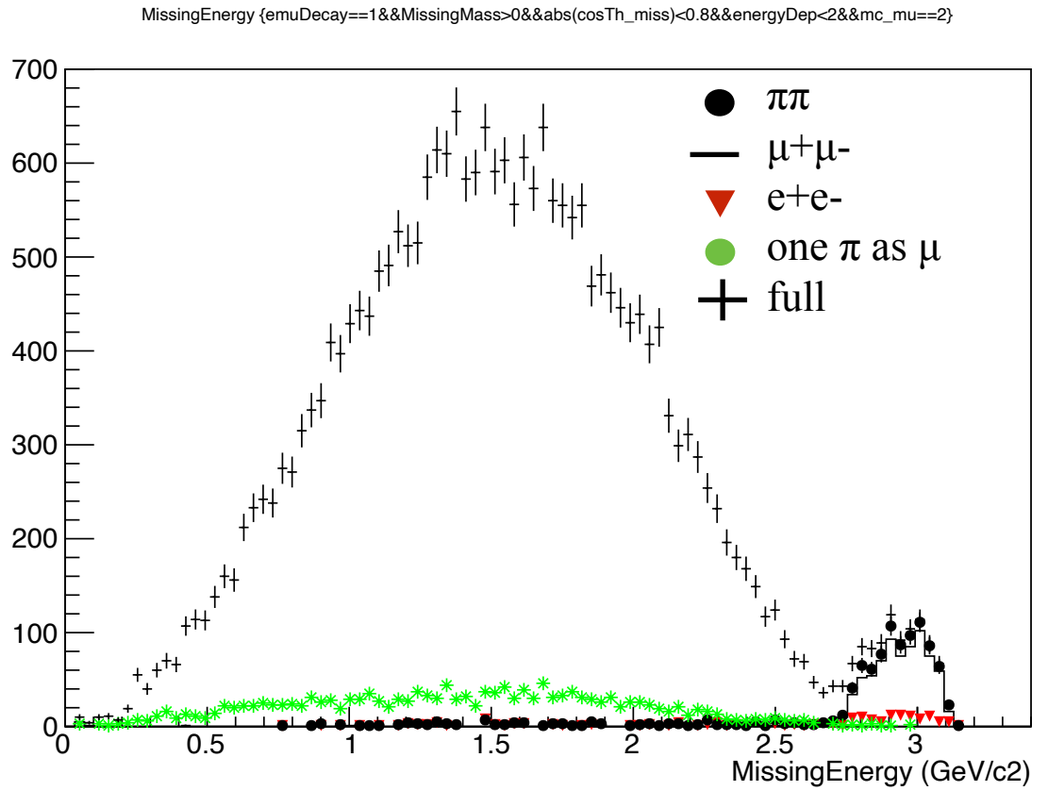


Additional cuts II

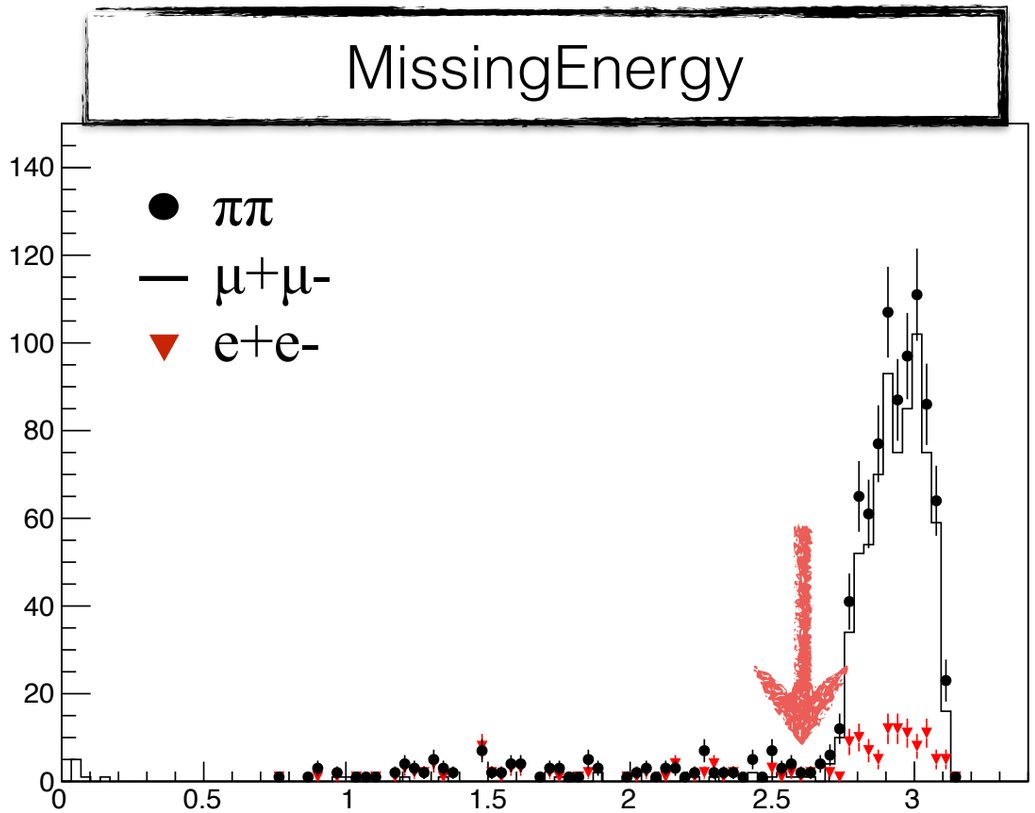


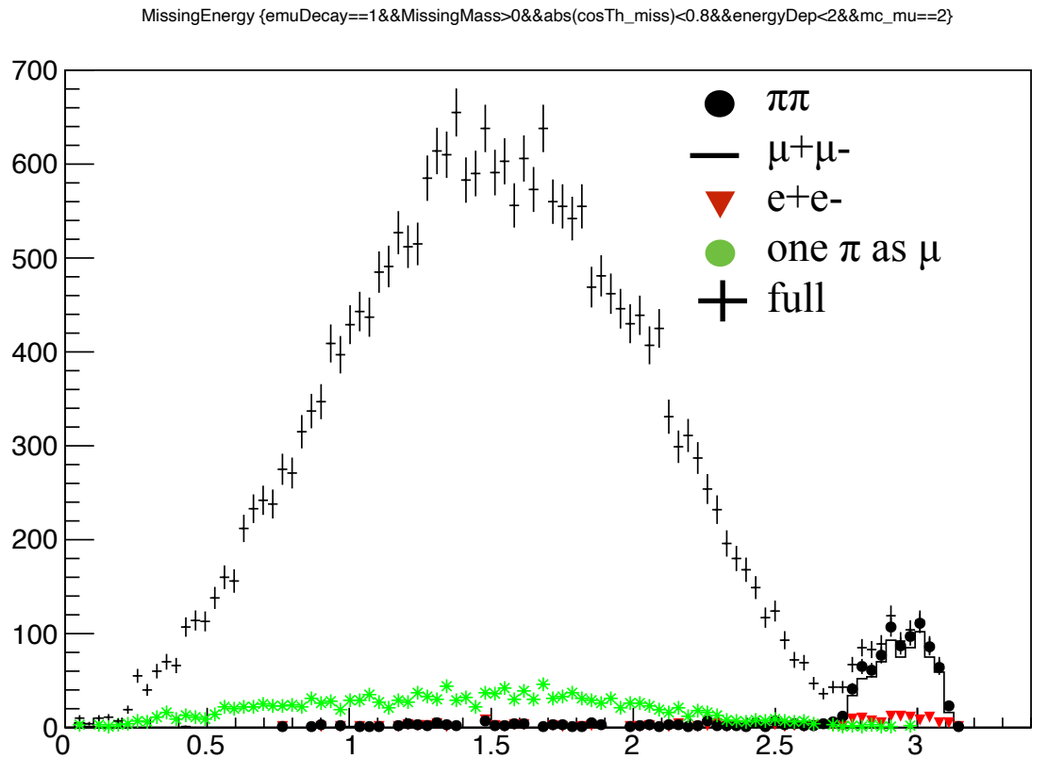
Additional cuts II

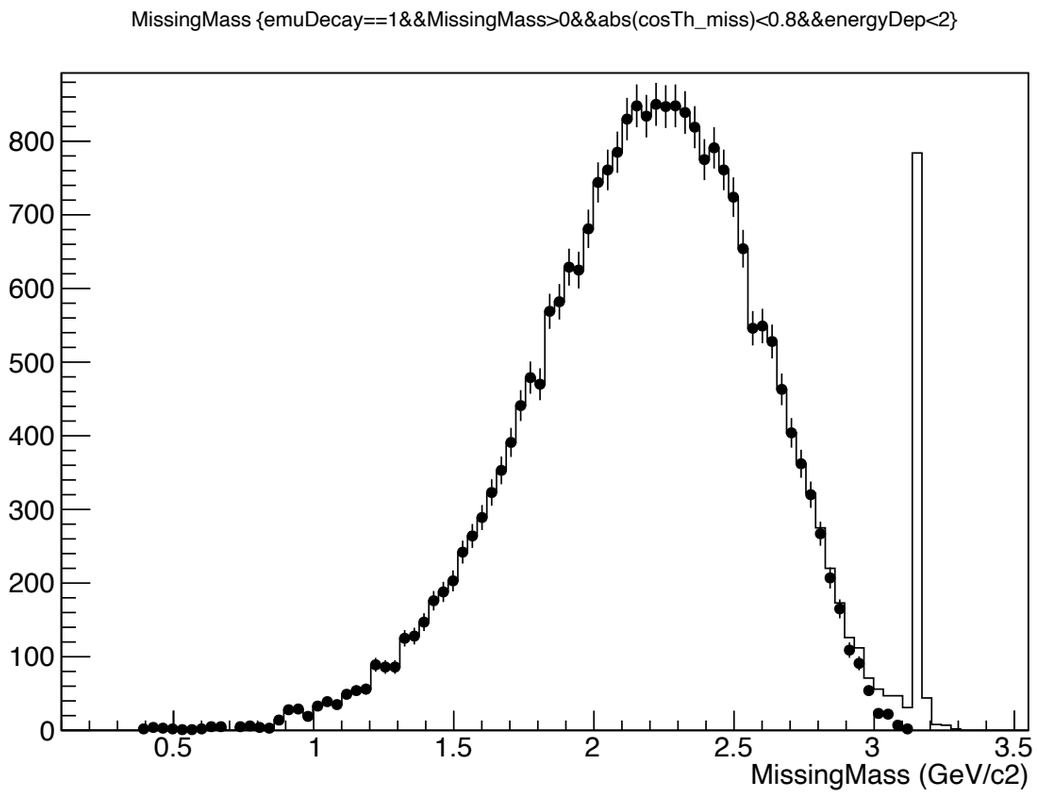




Additional cuts II



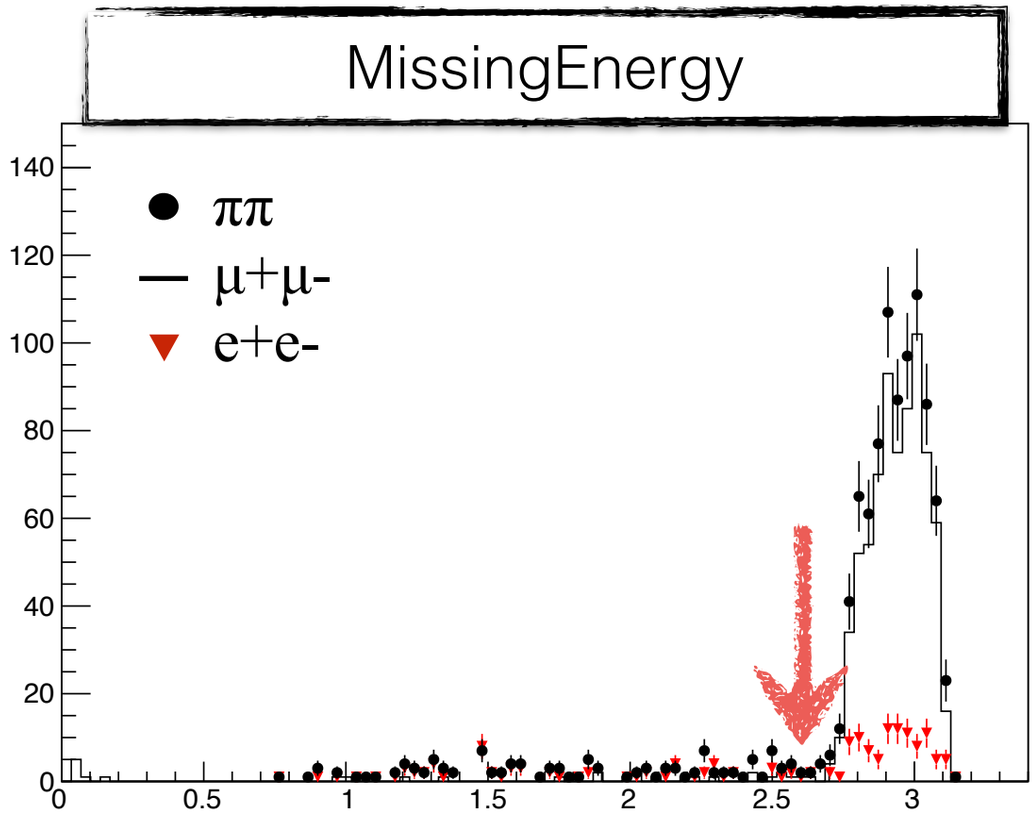


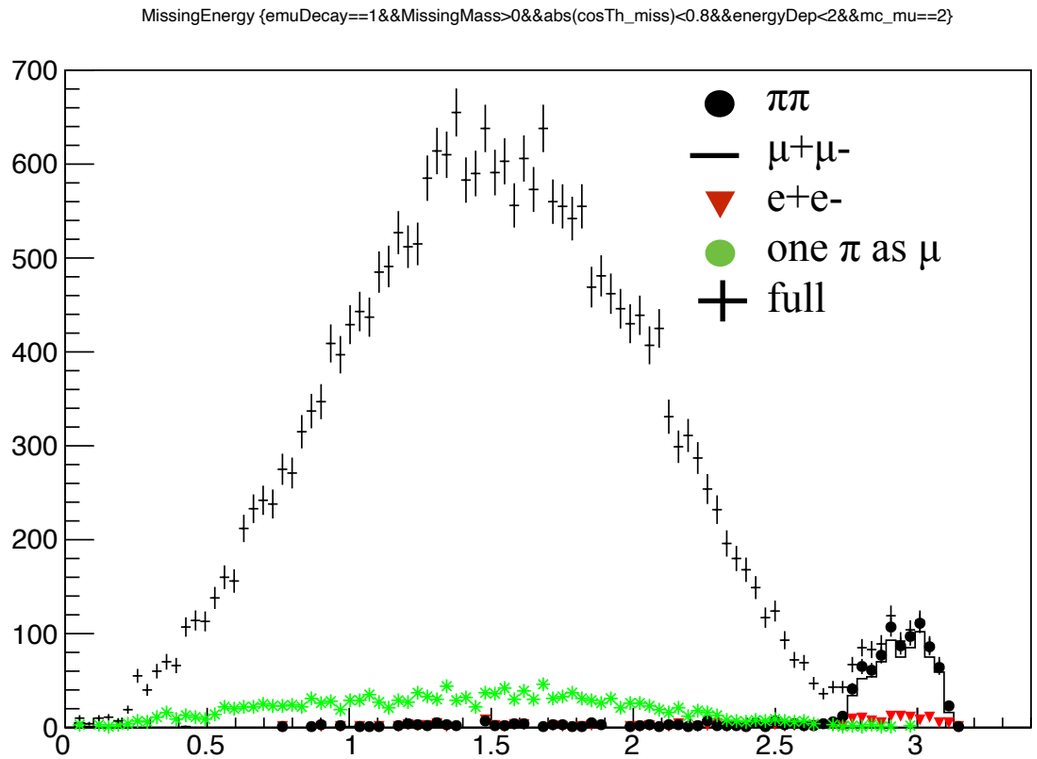


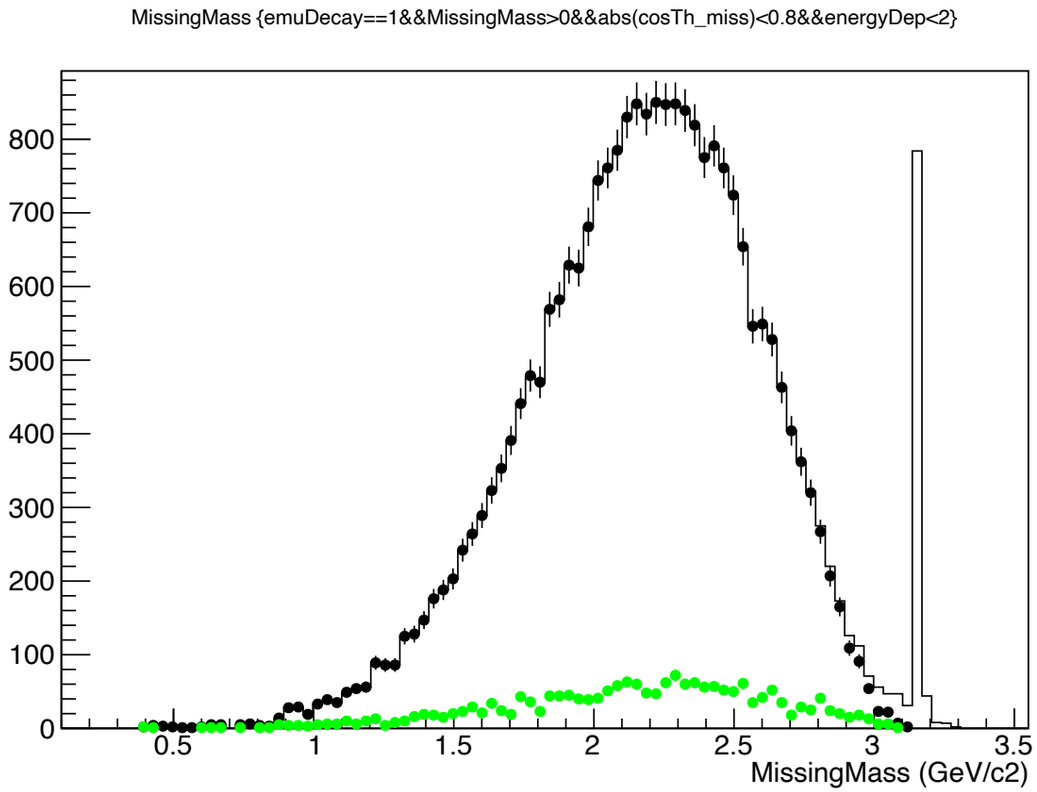
— no cut in MissingEnergy

● MissingEnergy<2.65 GeV

Additional cuts II







- no cut in MissingEnergy
- MissingEnergy<2.65 GeV
- pion contamination

pi contamination ~ 7.8%

Summary table of cuts

Charged tracks

- Vertex cut: R_{xy}<1cm and R_z<10cm
- polar angle of tracks in MDC: |cosθ|<0.93
- ptrk < 1.2 GeV (remove Bhabha and dimuon events)
- **pt>0.05 GeV/c**
- nCharged=2

Neutral candidates

- EMC time cut: 0<t_{TDC}<14(/50ns)
- E_γ >0.025 GeV for the barrel (**|(cos(θ)|< 0.8)**, and E_γ>0.050 GeV for the endcap (**0.86<|(cos(θ)|<0.92**)
- Isolated γ: opening angle between photon and its nearest charged tracks $\theta_{\gamma\text{-}tr}$> 20°
- nGamma = 0
- Enel < 0.2 GeV

Electron PID

- 0.8 < E/p < 1.2
- $\chi^2_{dE/dx}$(e)< 4
- |Δtof(e)|<0.3 ns

Muon PID

- E/p < 0.7
- $\chi^2_{dE/dx}$(μ)< 4
- |Δtof(μ)|<0.3 ns
- **muc_dep>81*(ptrk-0.65)**

- |cosθ_miss| < 0.8
- energyDep < 2 (sum of deposit energy of the two tracks)

- MissingEnergy<2.65 GeV/c2
- 2.5<tof < 5 (ns)

Plans and Conclusions

- to do list:


update the following additional cuts (ongoing)


inclusive MC topology (ongoing)


2012 data set (ongoing)

- continuum data set
- 2009 data set and consistency check
- how to estimate background and interference between signal and background
- Systematic uncertainties

Thanks for your attention

Some numbers

Electron PID

- 0.8 < E/p < 1.2
- $\chi^2_{dE/dx}$ (e)< 4
- |Δtof(e)|<0.3 ns

Muon PID

- E/p < 0.7
- $\chi^2_{dE/dx}$ (μ)< 4
- |Δtof(μ)|<0.3 ns
- muc_dep>81*(ptrk-0.65)

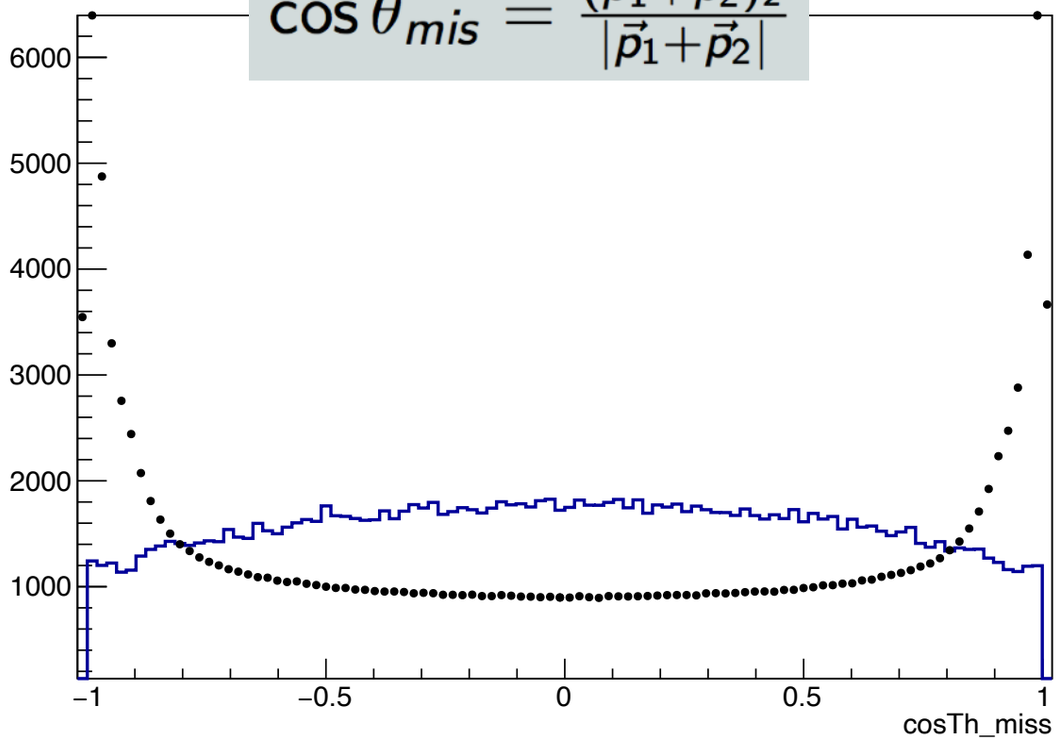
	numbers after each cut: MC signal	numbers after each cut: data09 subsample	numbers after each cut: InclMC09 subsample
total number	80000	16960604	6616952
iGood.size()==2	60390	224222	1142300
EMCch > 25 MeV	60383	222152	1136424
nGamma = 0	54312	26847	41251
n_emu	19975	258	901
n_mumu	0	1367	3186
n_ee	6	2130	288

?

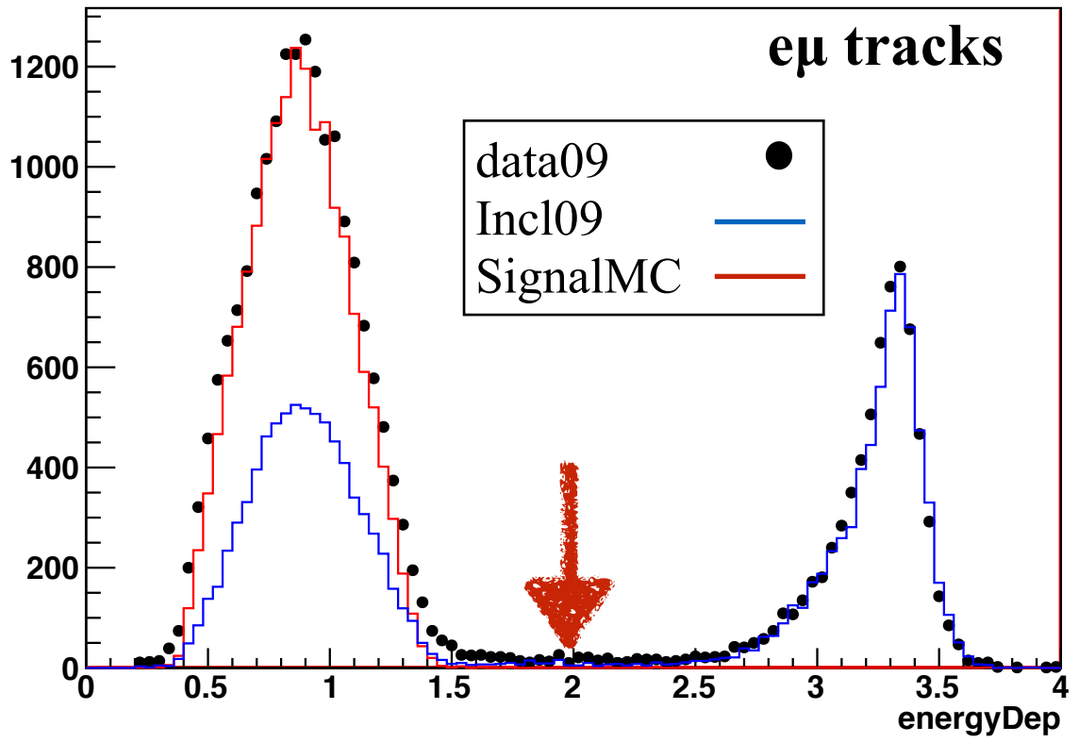
Additional cuts I

To be updated

$$\cos\theta_{mis} = \frac{(\vec{p}_1+\vec{p}_2)_z}{|\vec{p}_1+\vec{p}_2|}$$



- |cosθ_miss| < 0.8 or 0.86<|cosθ_miss| < 0.92
- energyDep < 2 (sum of deposit energy of the two tracks)



Full data09 and incl09 MC sample analyzed

- evident discrepancy between the two samples in the signal region

Signal distributions III