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

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June 15, 2021

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 $\pm\sigma_{stat} \pm \sigma_{syst}$
$\Upsilon(1S)$	$0.9924 \pm \mathcal{O}(10^{-5})$	$1.005 \pm 0.013 \pm 0.022$
$\Upsilon(2S)$	$0.9940 \pm \mathcal{O}(10^{-5})$	$1.04 \pm 0.04 \pm 0.05$
$\Upsilon(3S)$	$0.9948 \pm \mathcal{O}(10^{-5})$	$1.05 \pm 0.08 \pm 0.05$
$\psi(2S)$	$0.390 \pm \mathcal{O}(10^{-4})$	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

LF Universality Violation

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- new physics only in the τ channel decay

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IDEA: ψ(2S)→ττ

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→ττ decay is affected by NP

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@ BES: hep-ex/0609023v1 (2006)

$$BF(\psi(2S) \to \tau^+\tau^-) = (3.1 \pm 0.21 \pm 0.38) \times 10^{-3}$$

0.21 → 0.03   0.38 → ?

with 550M of psi2S data

Analysis: event and track selection

Study of $\psi(2S) \to \tau\tau \to e\mu 4\nu$ decay

Charged tracks

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

Neutral candidates

- EMC time cut: $0<t_{TDC}<14(/50ns)$
- E_γ >0.025 GeV for the barrel (**$|(\cos(\theta)| < 0.8)$**), and E_γ>0.050 GeV for the endcap (**$0.86<|(\cos(\theta)|<0.92$**)
- Isolated γ: opening angle between photon and its nearest charged tracks $\theta_{\gamma\text{-tr}}> 10°$
- nGamma = 0
- Enel < 0.2 GeV

```
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;
Enddecay

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


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


End
```

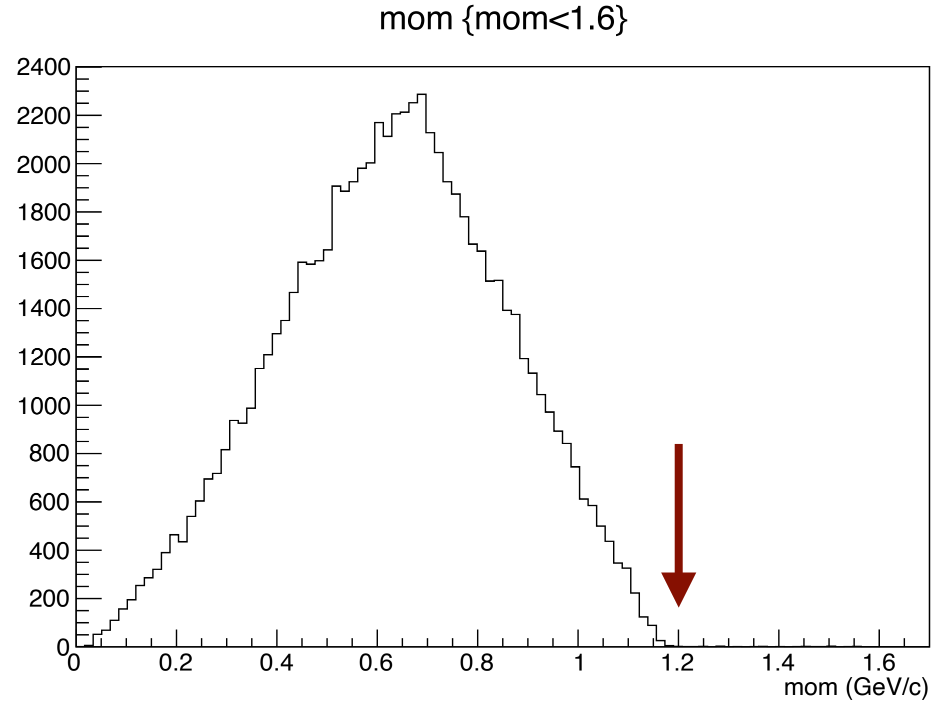
- Release 664p03
- 240000 events simulated: $\psi(2S) \to \tau\tau \to e^{\mp}\mu^{\pm}4\nu$
- 2012 MC inclusive $\psi(2S)$ sample
- 2012 $\psi(2S)$ data sample

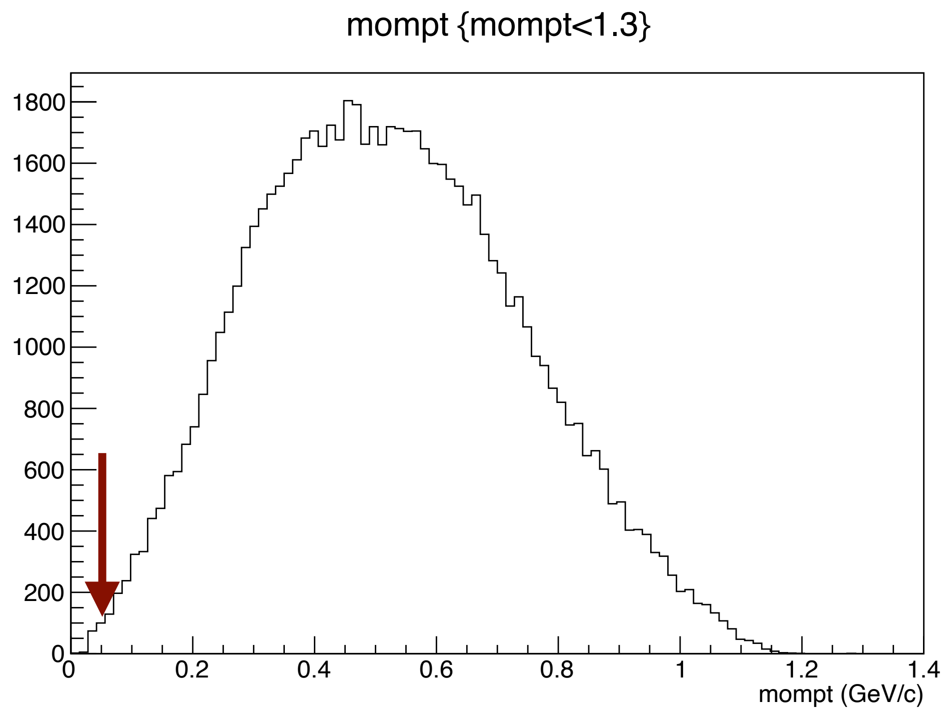
Signal MC: distributions I

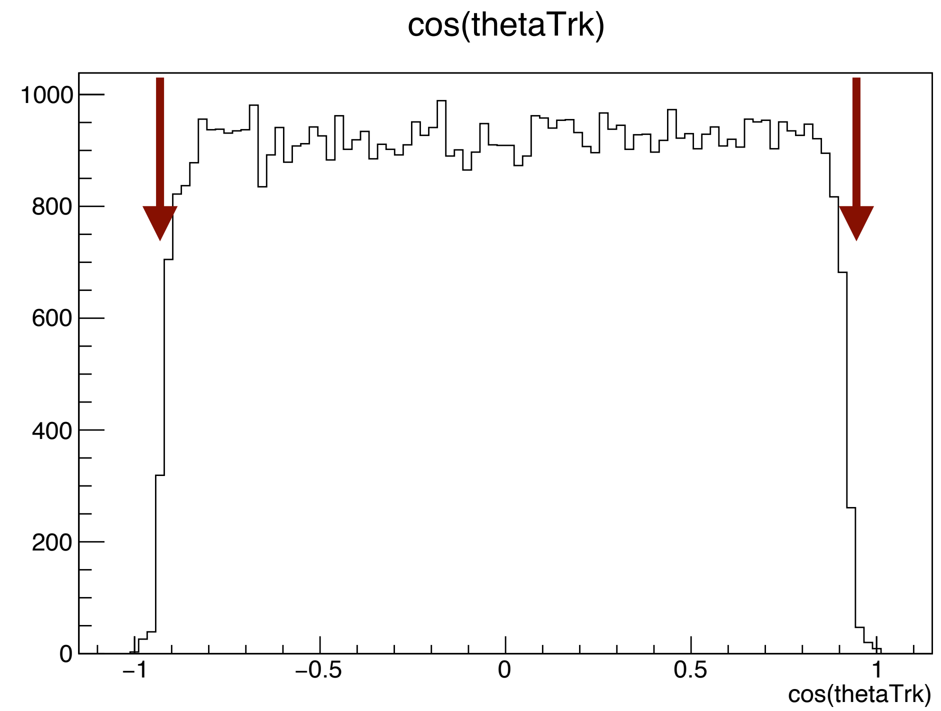
$\psi(2S)\to\tau\tau\to e\mu 4\nu$ signal

Momentum of charged tracks

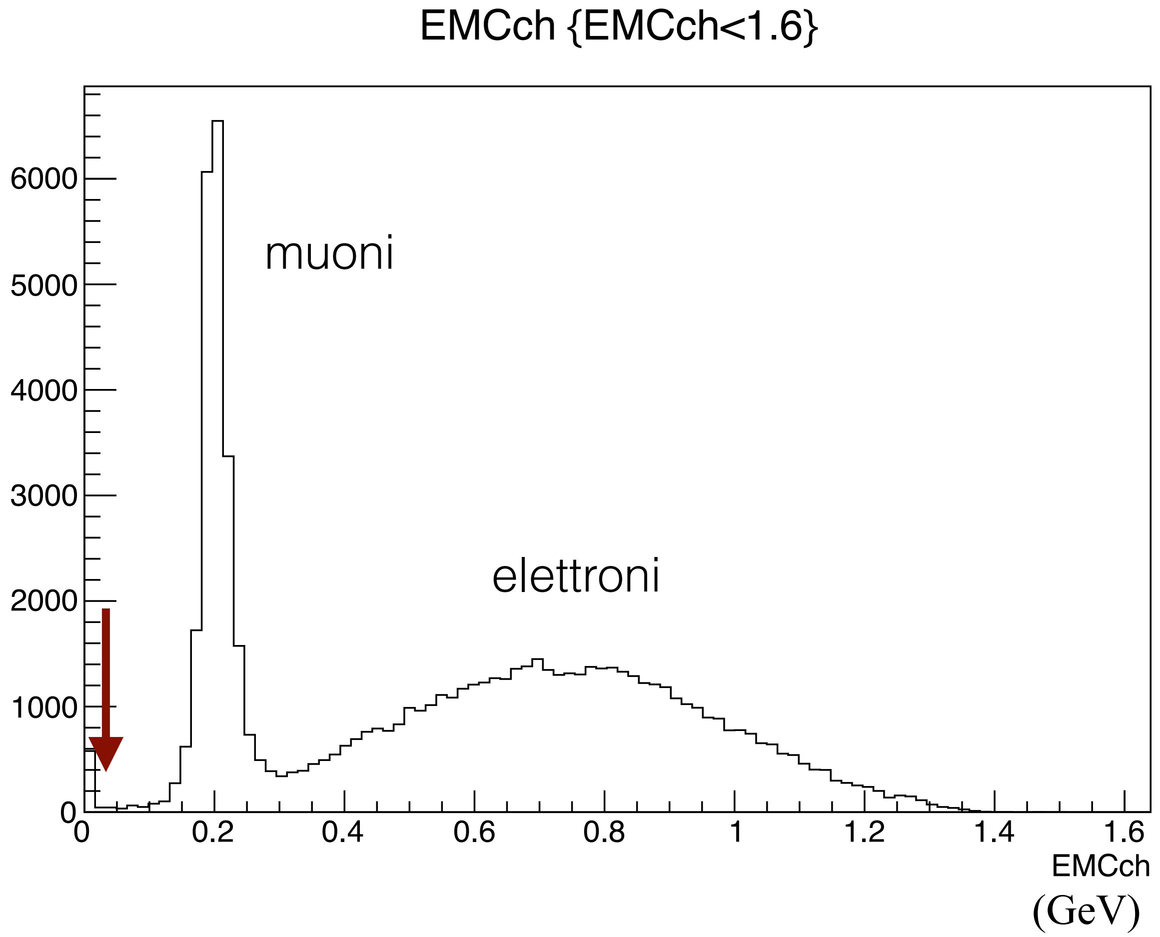
No cuts



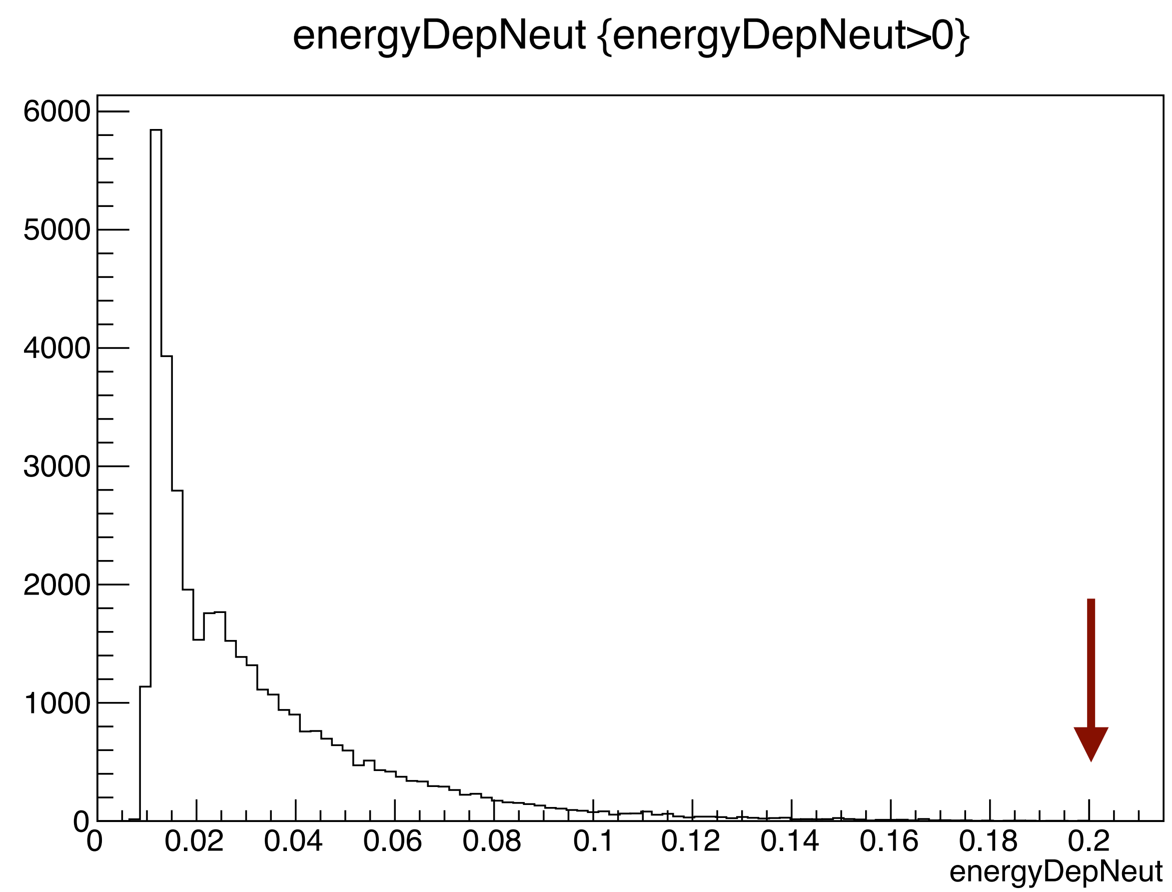




Signal MC: distributions II

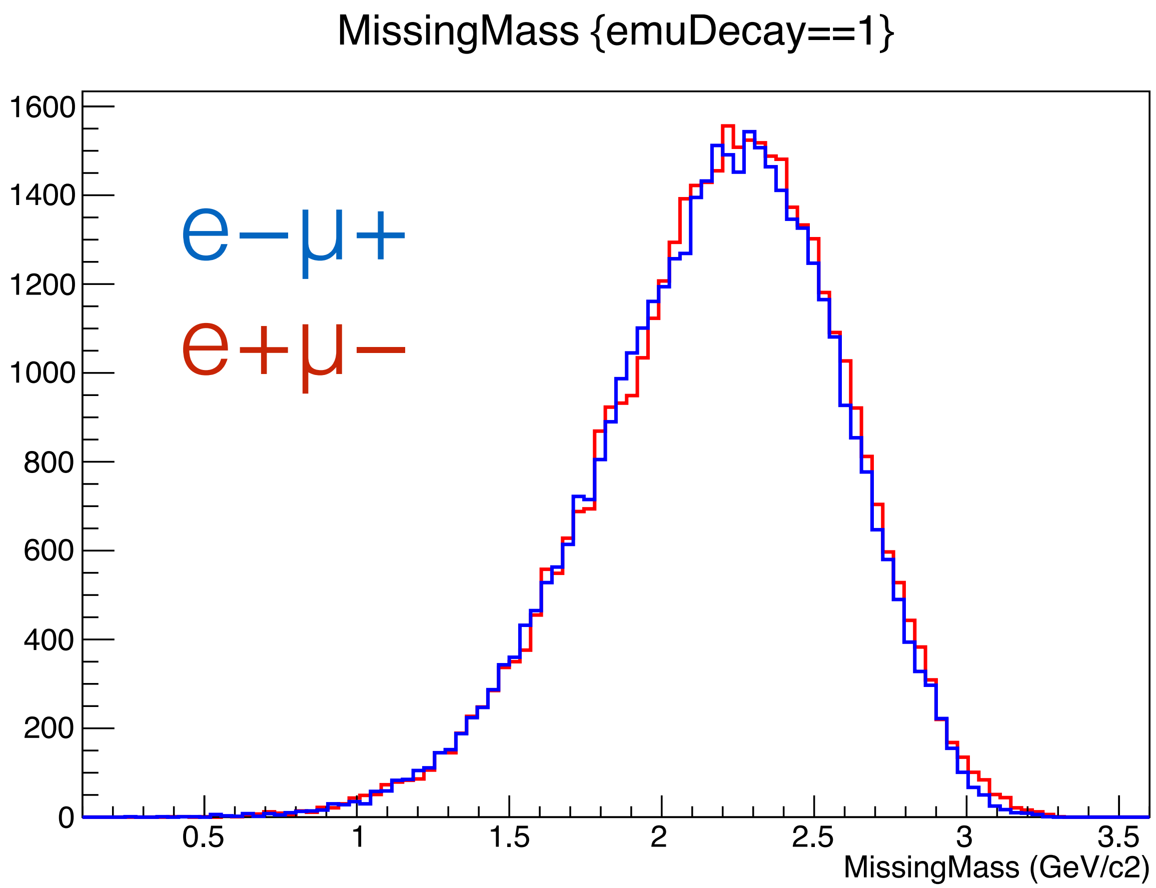


- Charged track energy deposit inside the EMC (total)



- Neutral particle energy deposit inside the EMC (total)

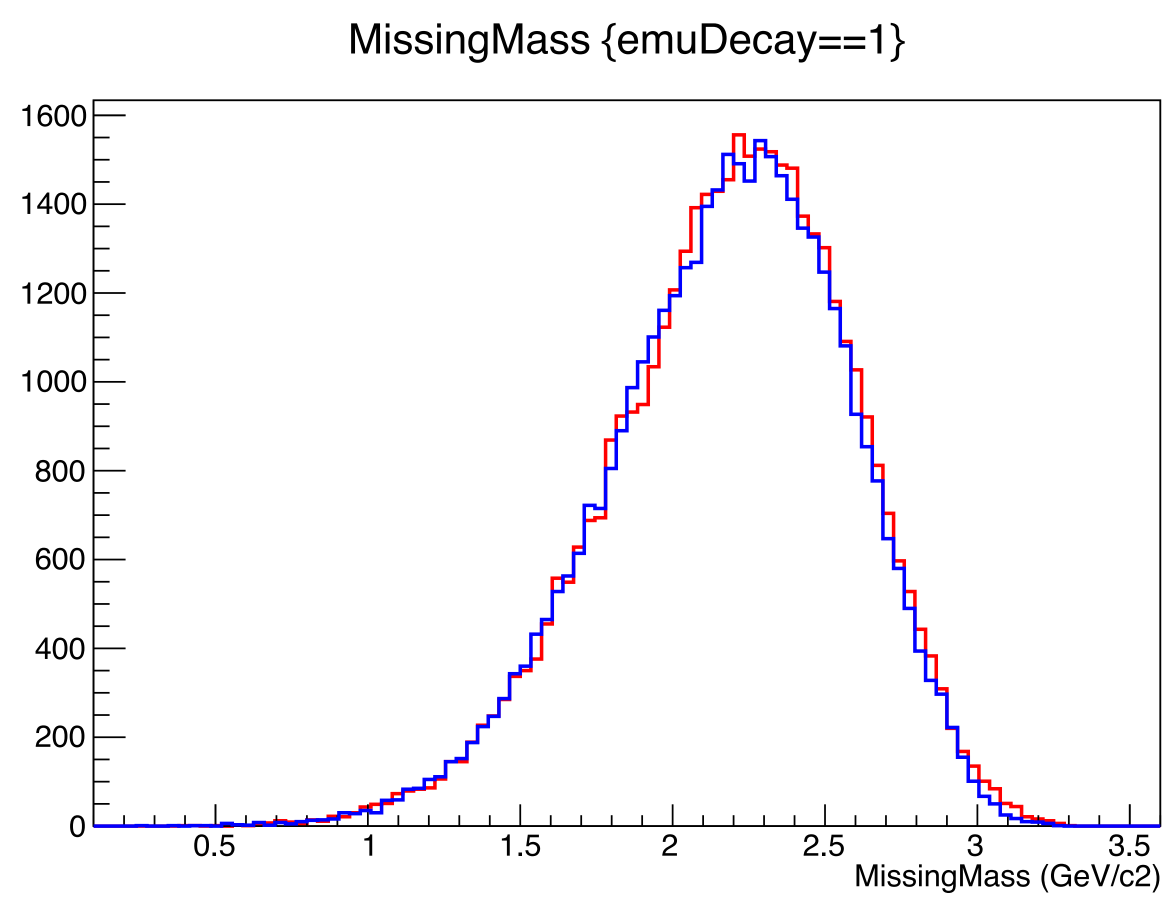
Signal MC: distributions III



Missing energy and missing mass:

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

Distributions after cuts and PID selection



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 $\psi(2S)\to e\mu4\nu$
Tot number	40000	40000	40000	40000	100000	240000
good trk = 2	32368	32531	32744	32750	82762	195993
EMCch > 25 MeV	32336	32499	32703	32712	82647	195847
Ngamma = 0	23505	22618	25732	24870	54505	167455
eμDecay	1005	943	1	1	0	84176
μμDecay	1	0	1119	1074	38	2
eeDecay	4	2	0	0	0	16

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

PID studies

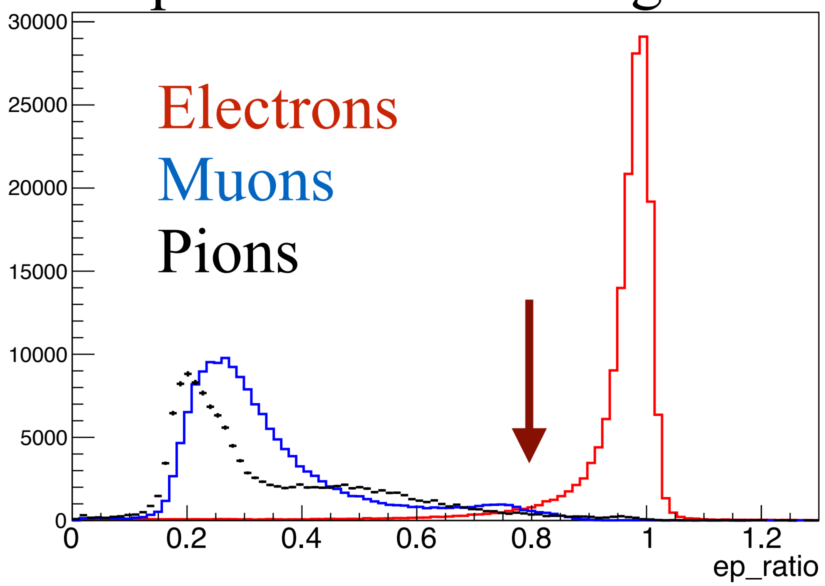
Electron PID

- $0.8 < E/p < 1.2$
- $\chi2_{dE/dx}(e) < 4$
- $|\Delta tof(e)| < 0.3$ ns

Muon PID

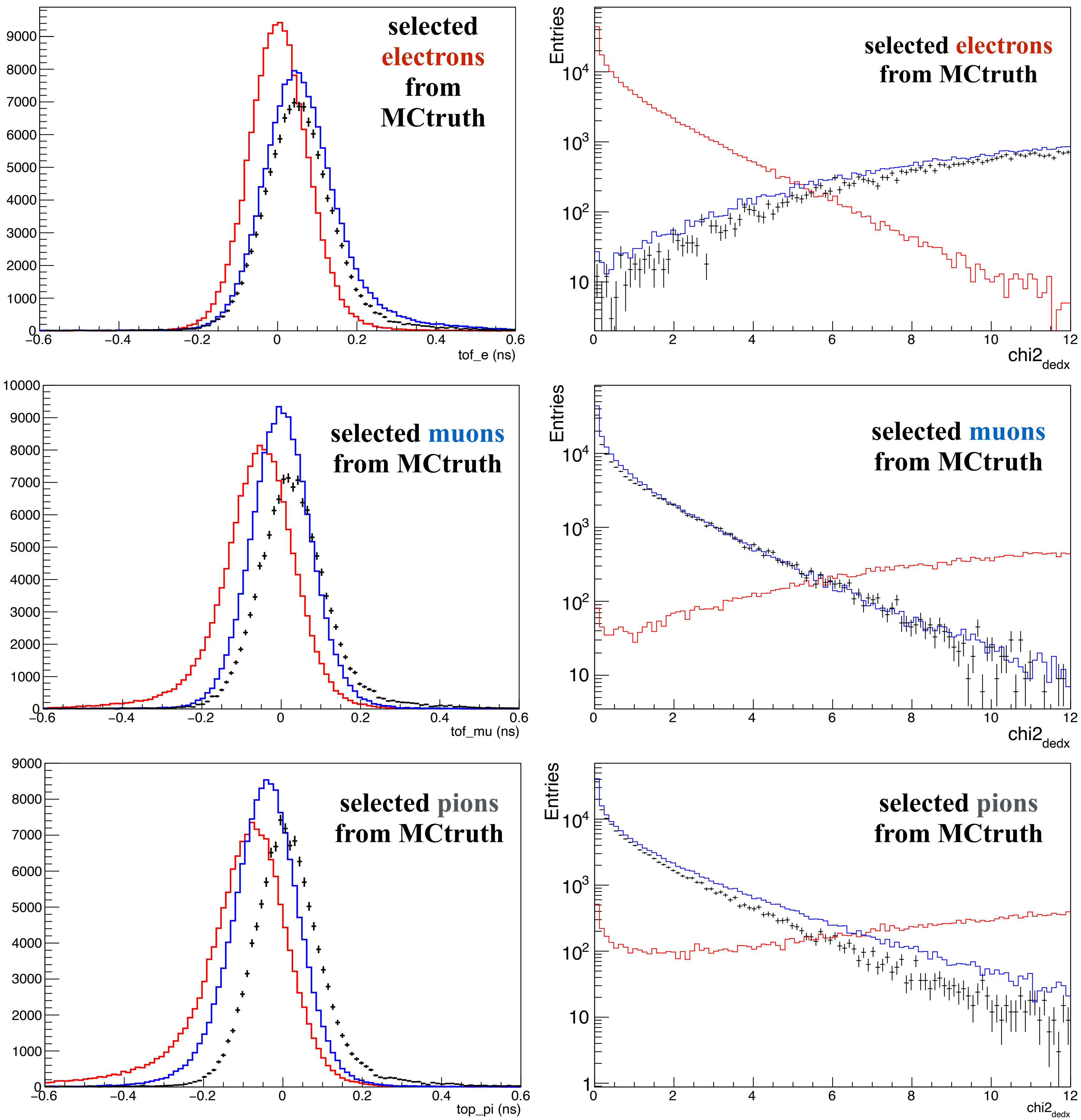
- $E/p < 0.7$
- $\chi2_{dE/dx}(\mu) < 4$
- $|\Delta tof(\mu)| < 0.3$ ns
- **muc_dep>81*(ptrk-0.65)**

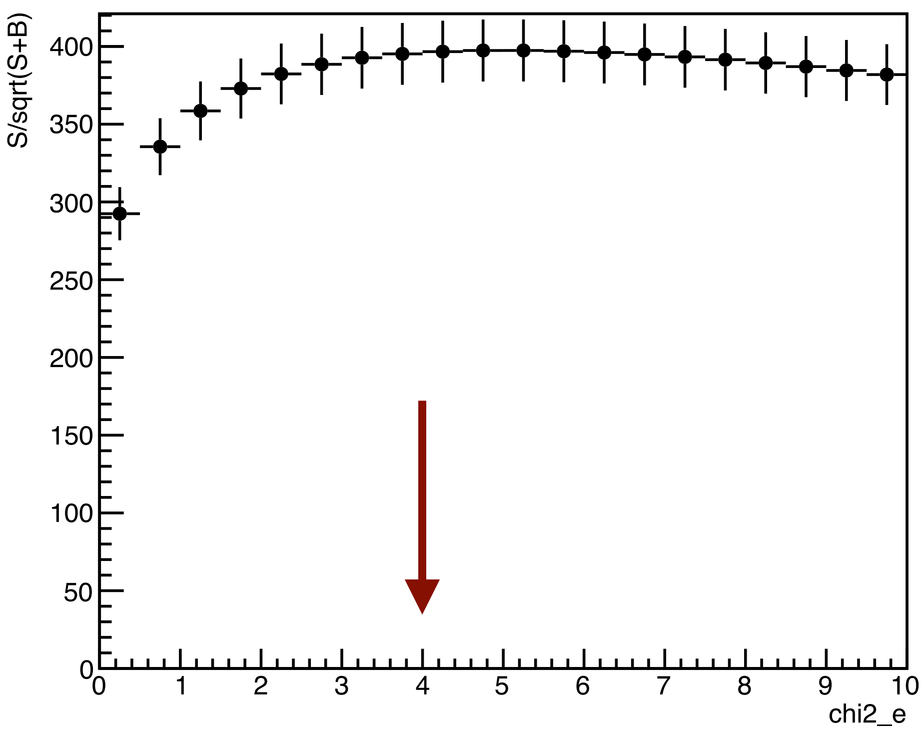
E/p ratio from MC signal

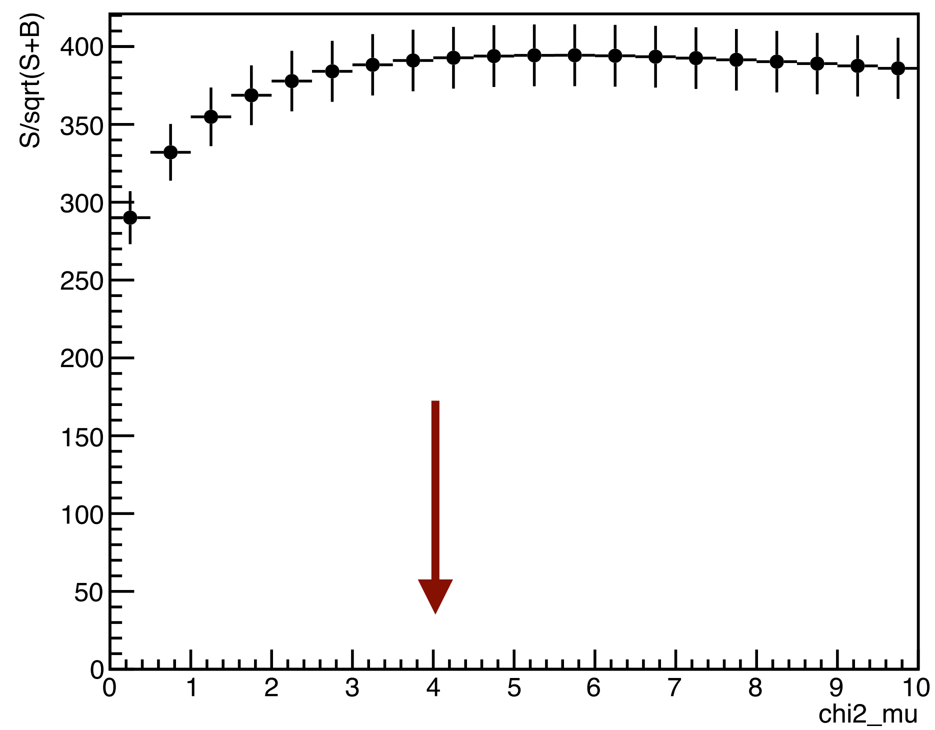


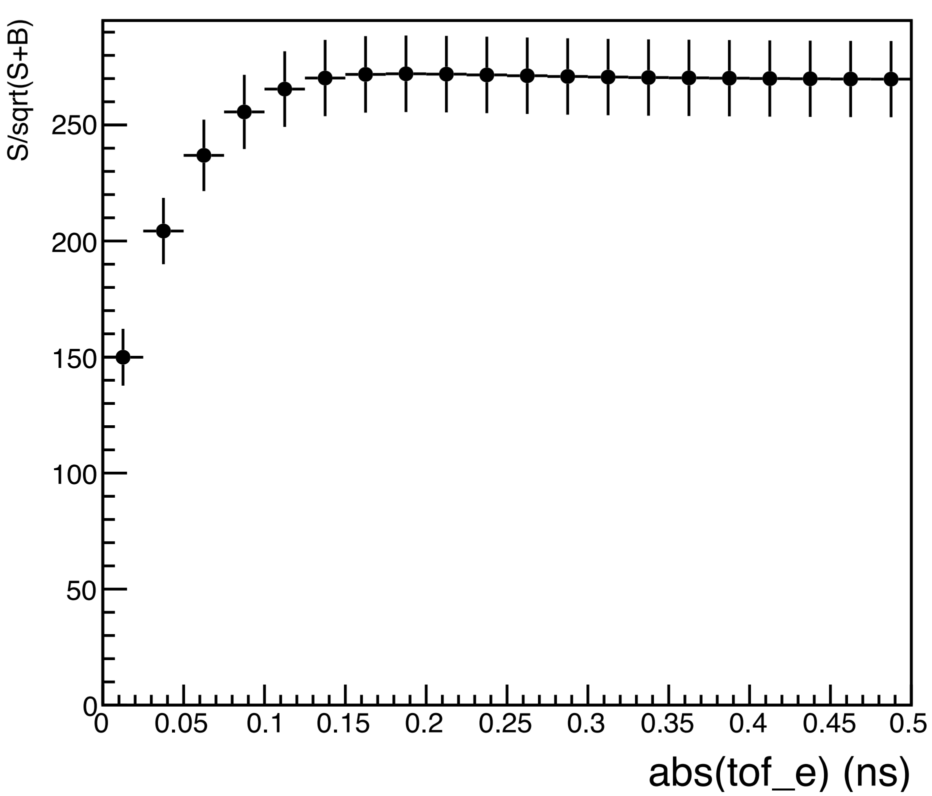
(exp-tof - tof_calc) from MC signal

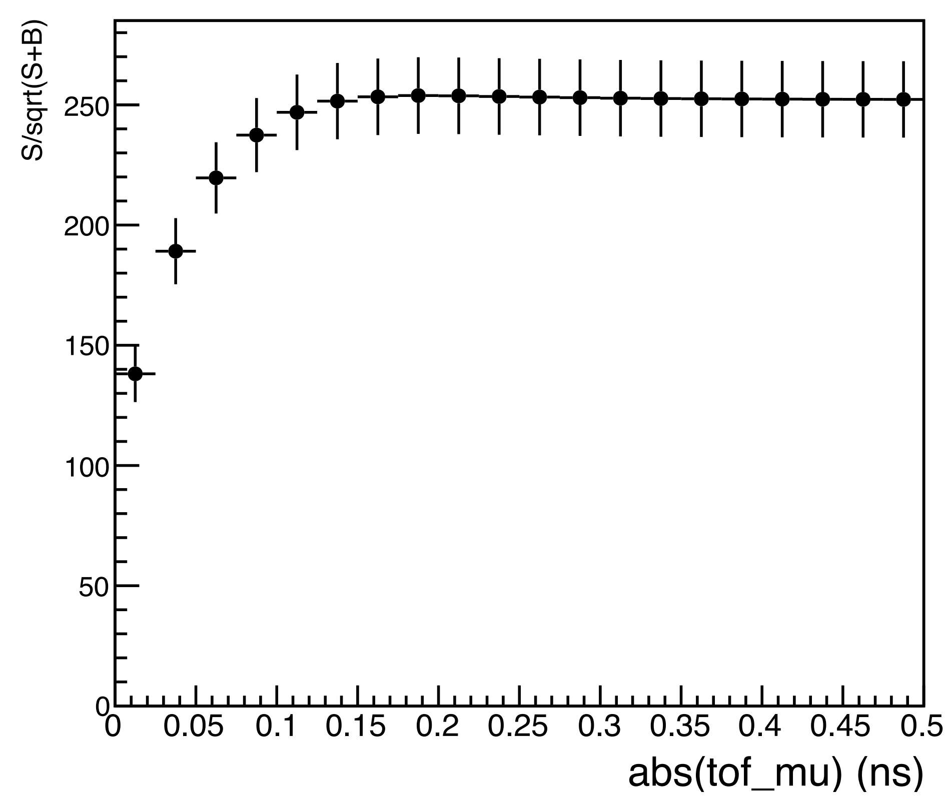
chi2-dEdx from MC signal



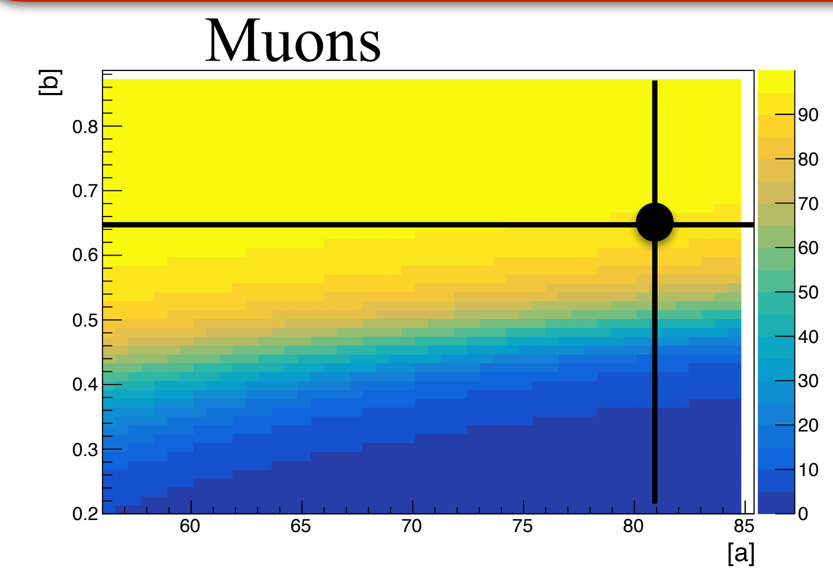

S/sqrt(S+B)
chi2_e


S/sqrt(S+B)
chi2_mu


S/sqrt(S+B)
abs(tof_e) (ns)


S/sqrt(S+B)
abs(tof_mu) (ns)

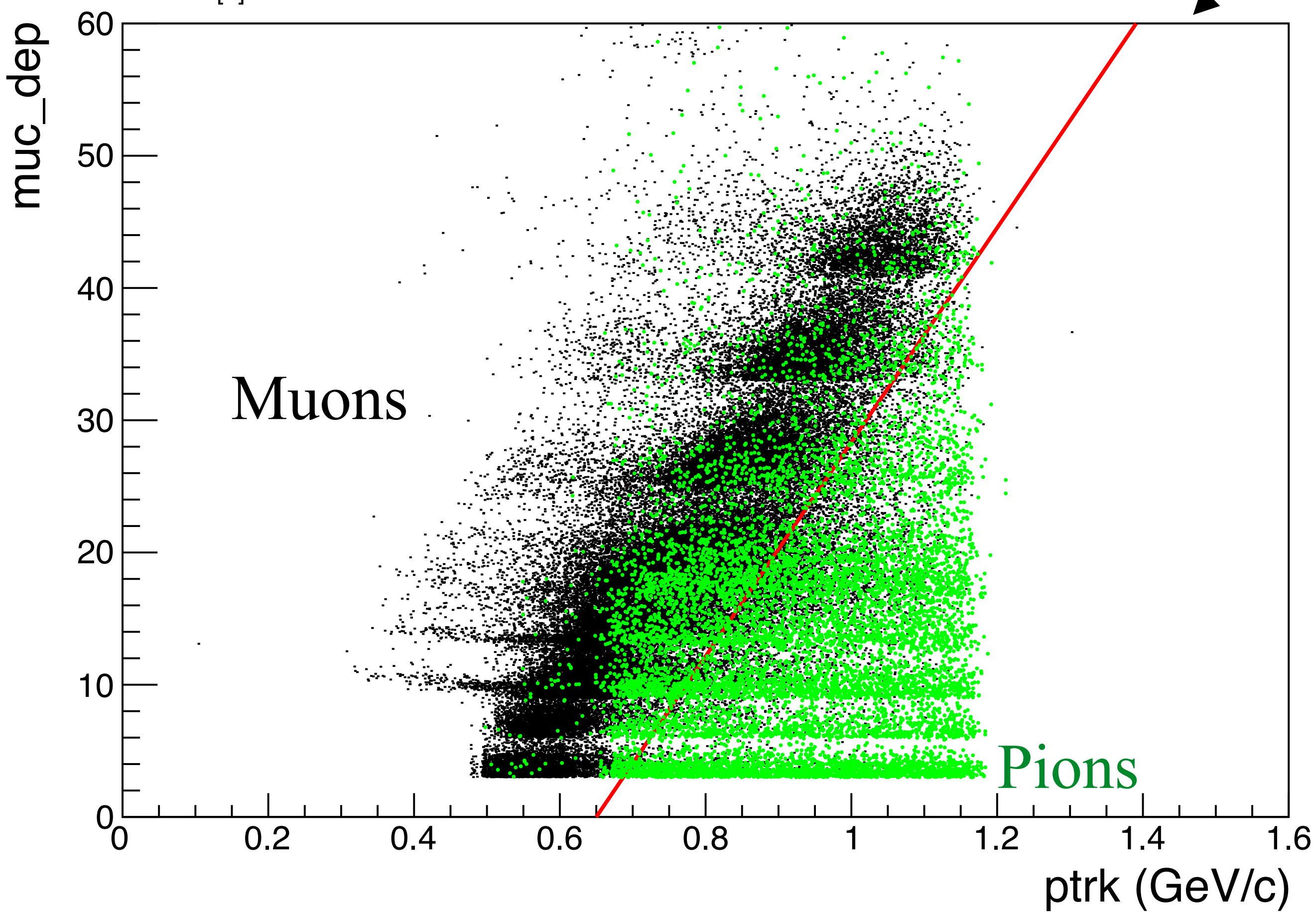
muc vs. ptrk from MC samples



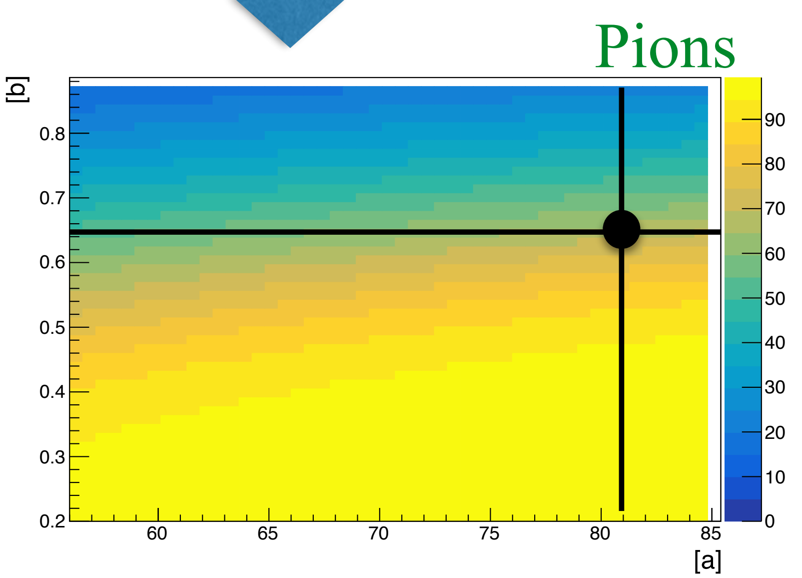
cut efficiency > 90% for muons selection

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

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



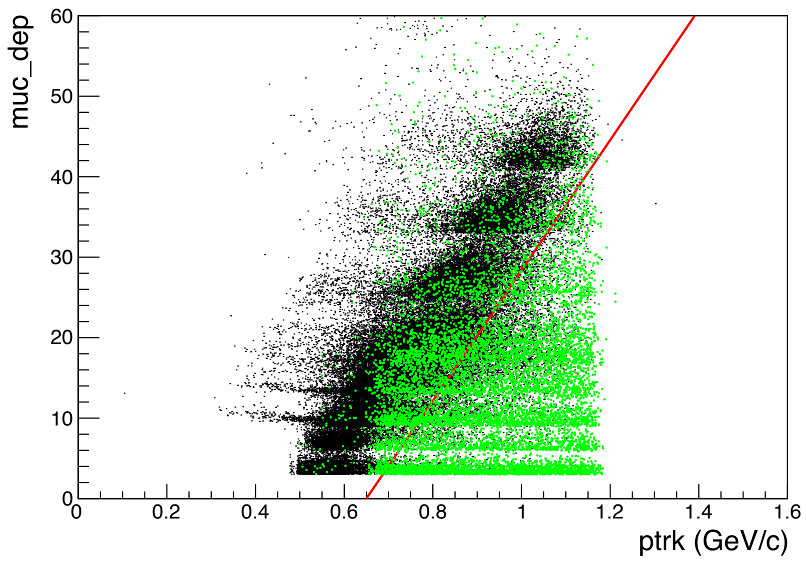
~70% of pions fall below the red line

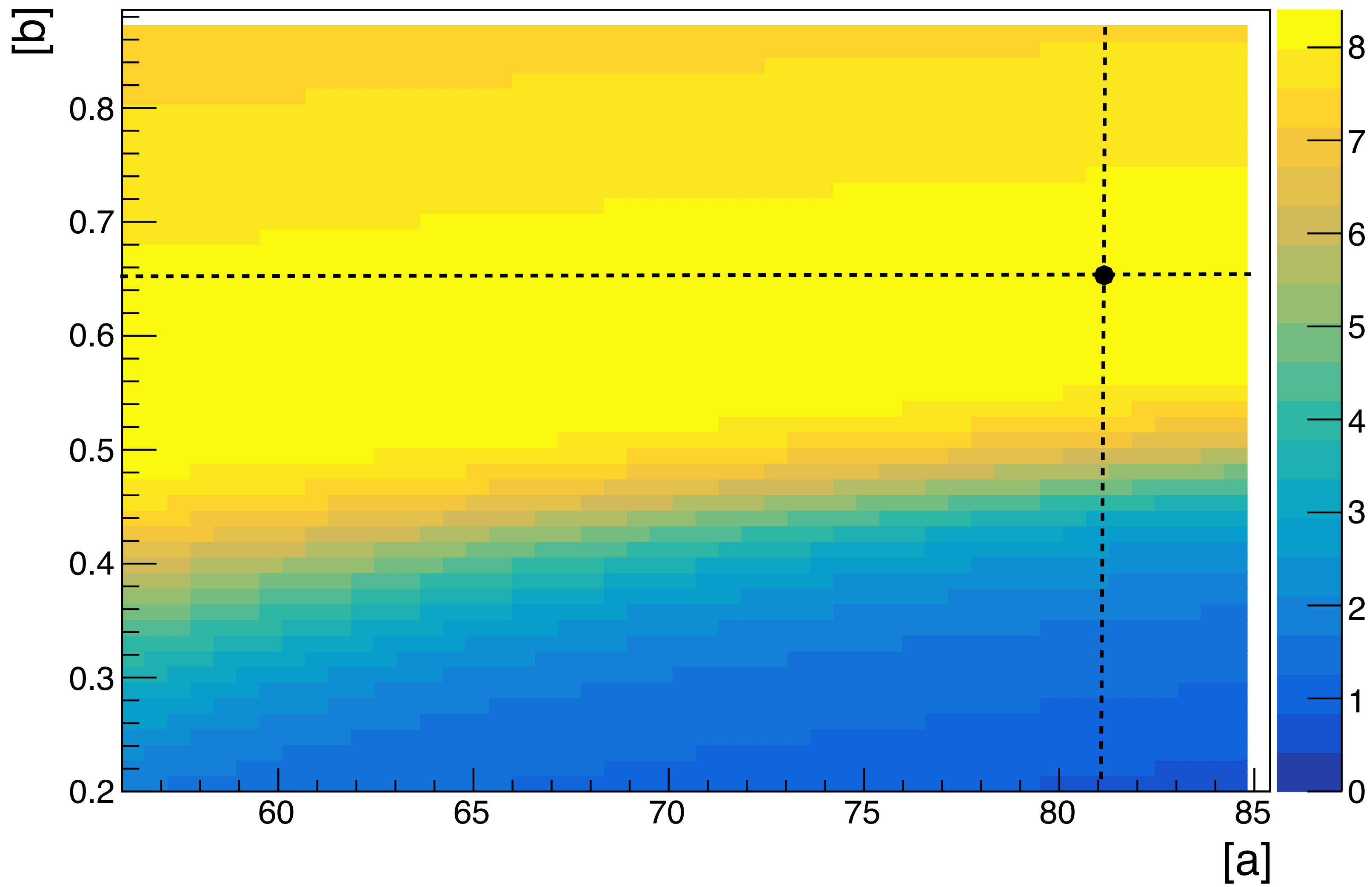


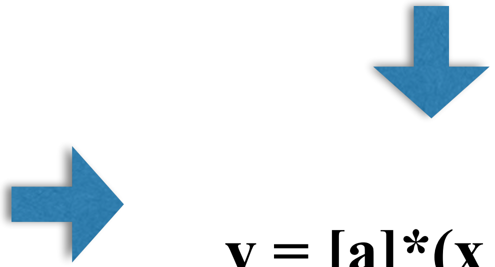
muc vs. ptrk from MC samples

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

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







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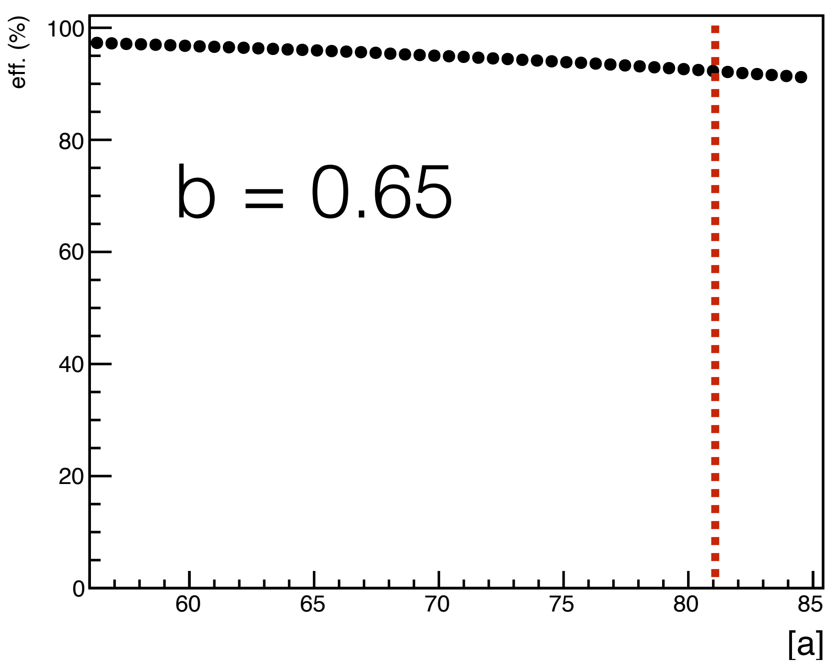
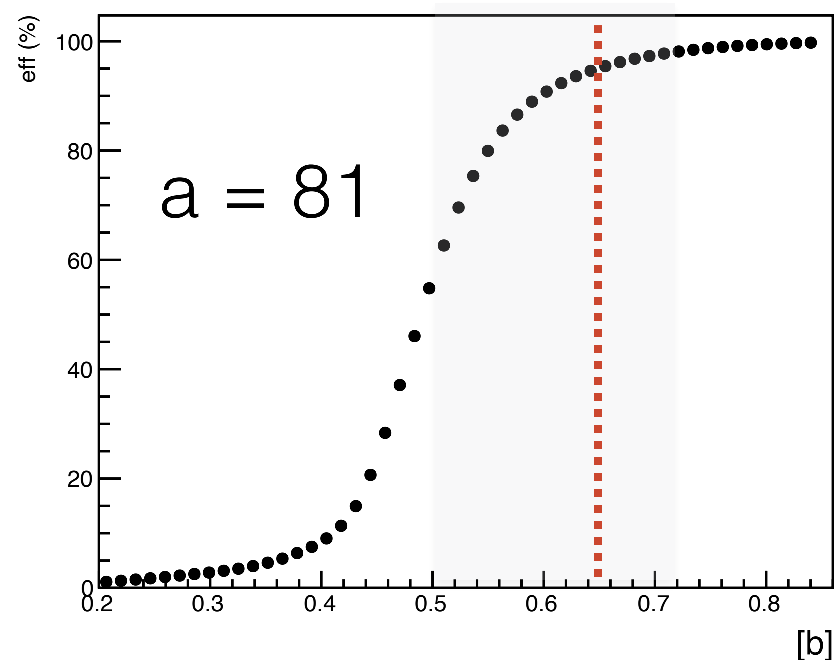
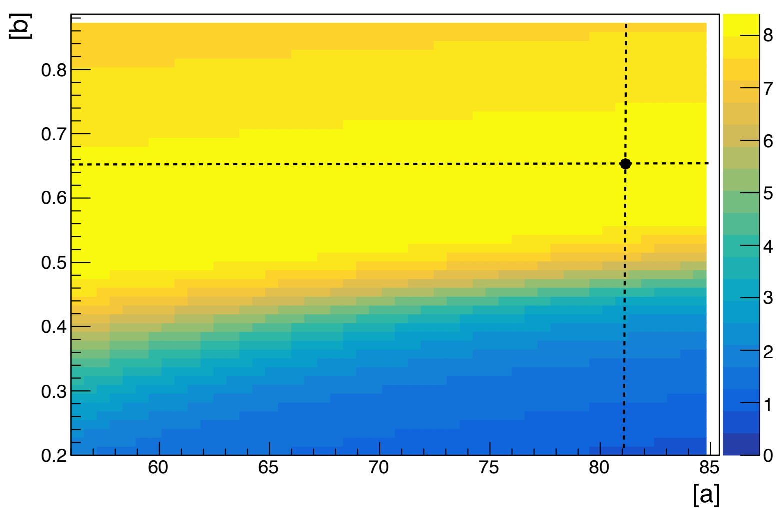
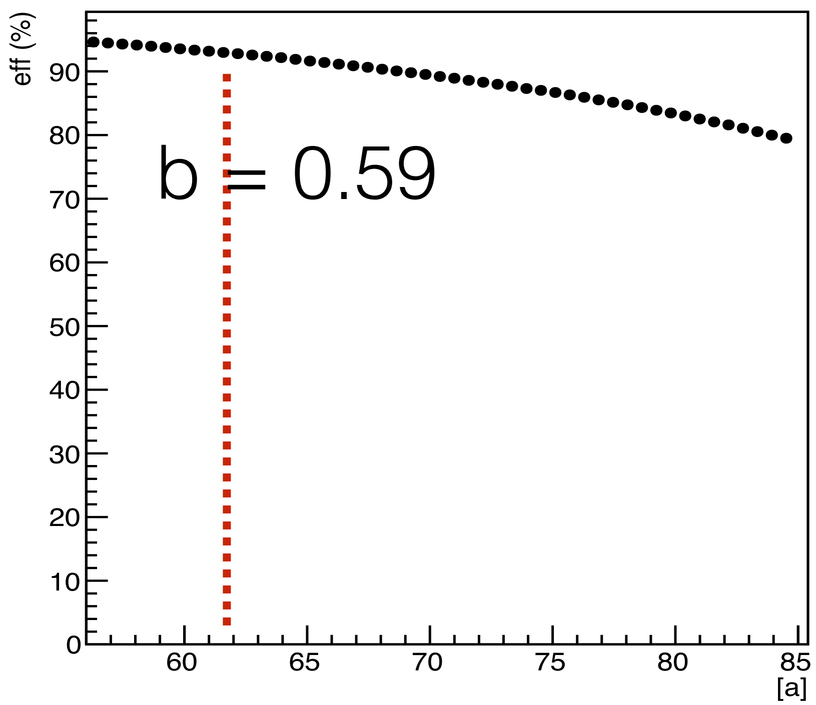
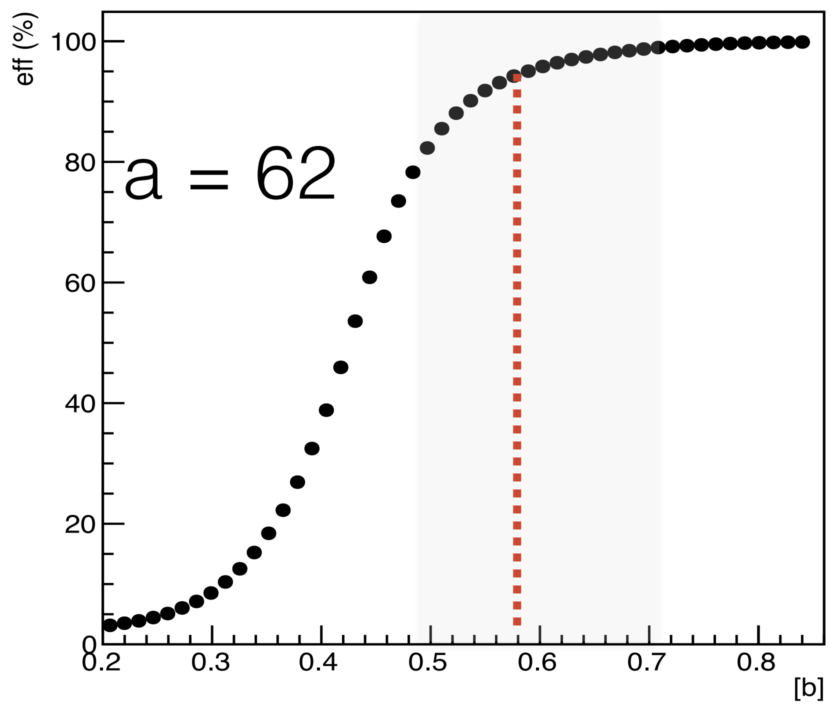
Signal Efficiency

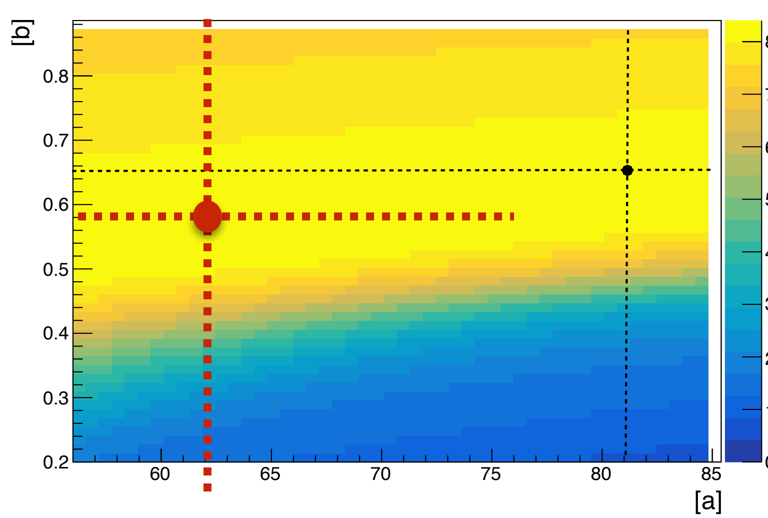




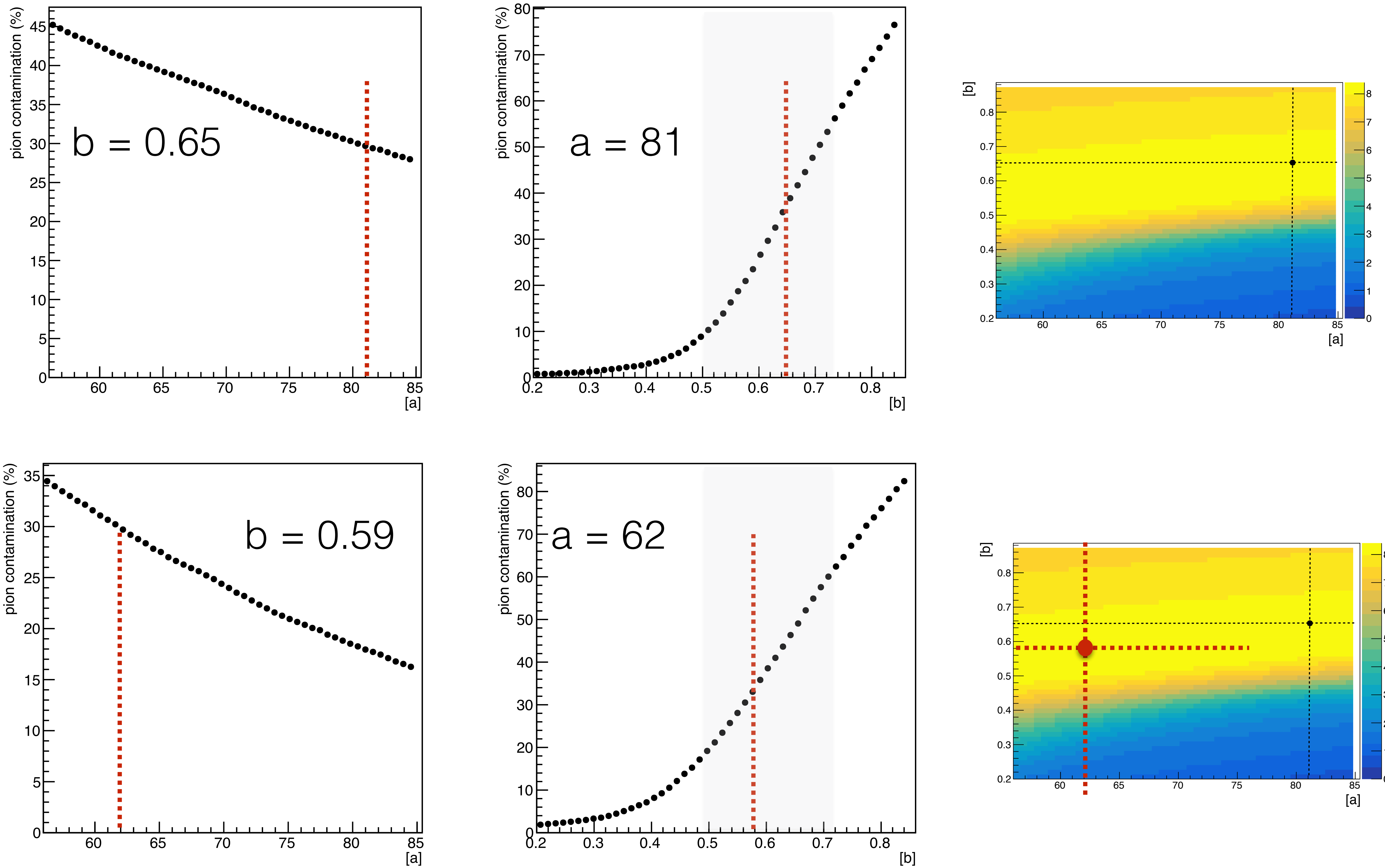






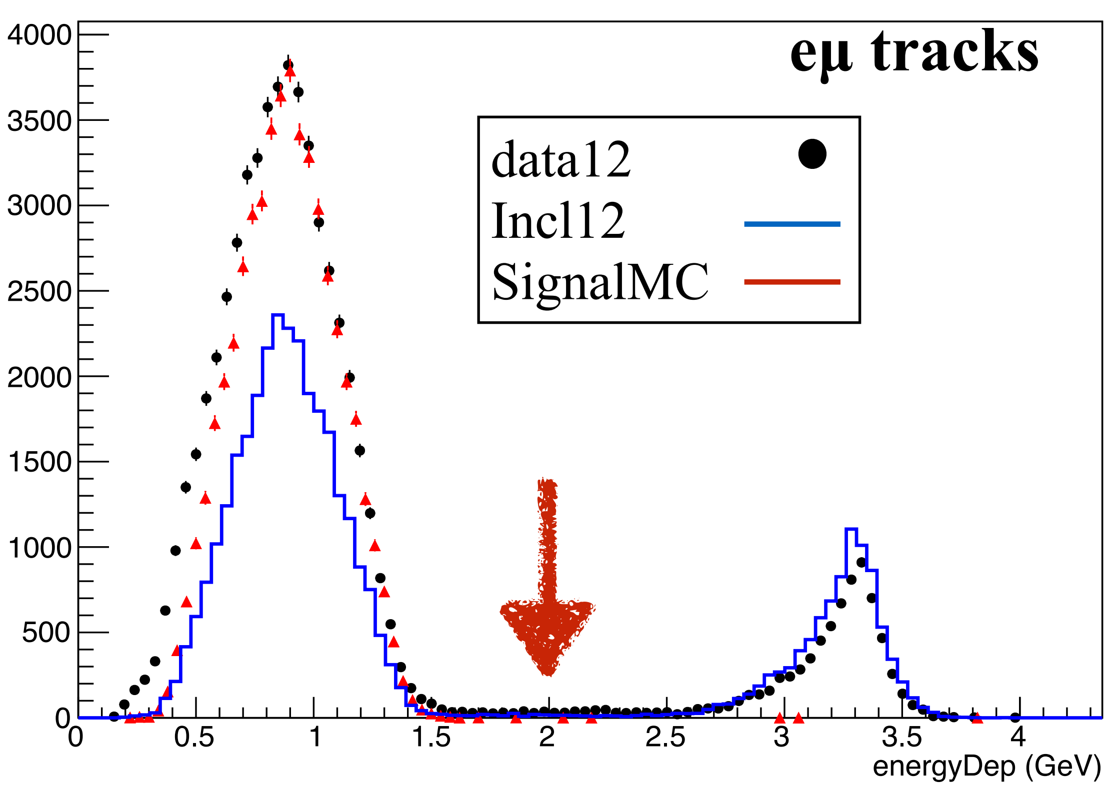


Pions contamination

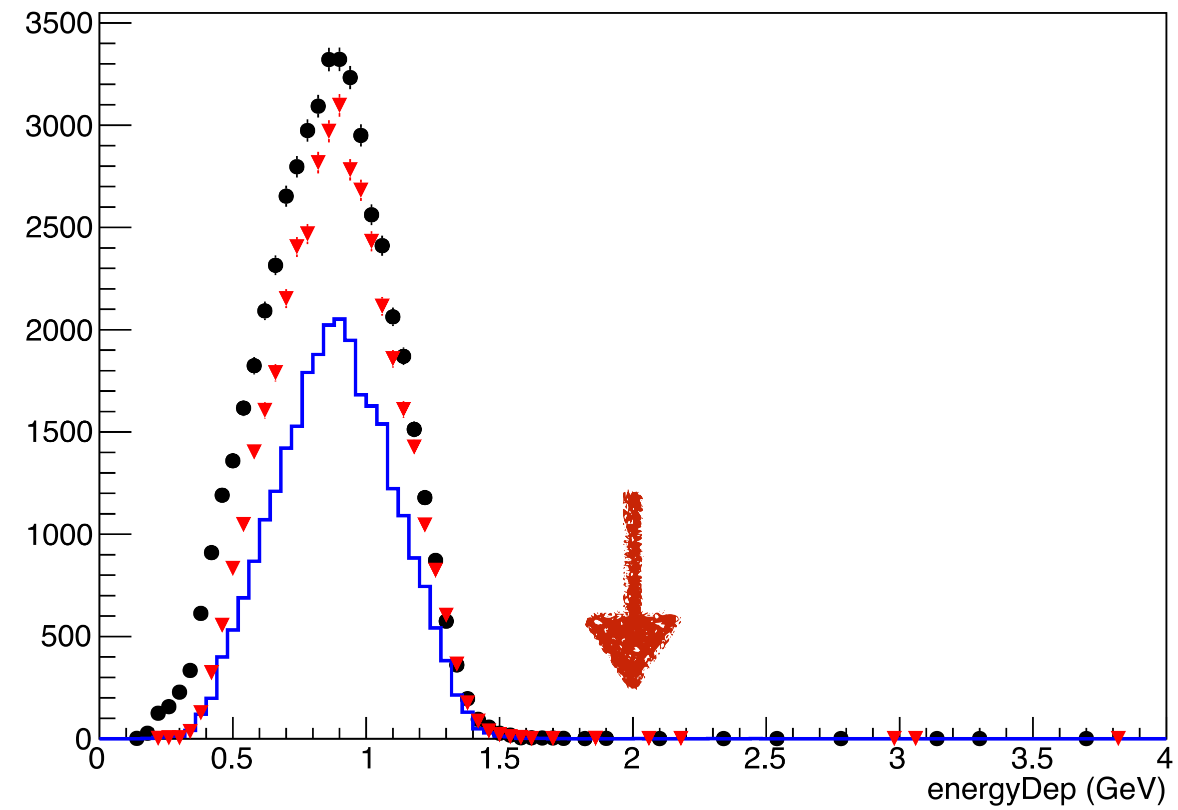


Additional cuts I

*signal arbitrary scale



NgoodTracks ==2



NTracks ==2

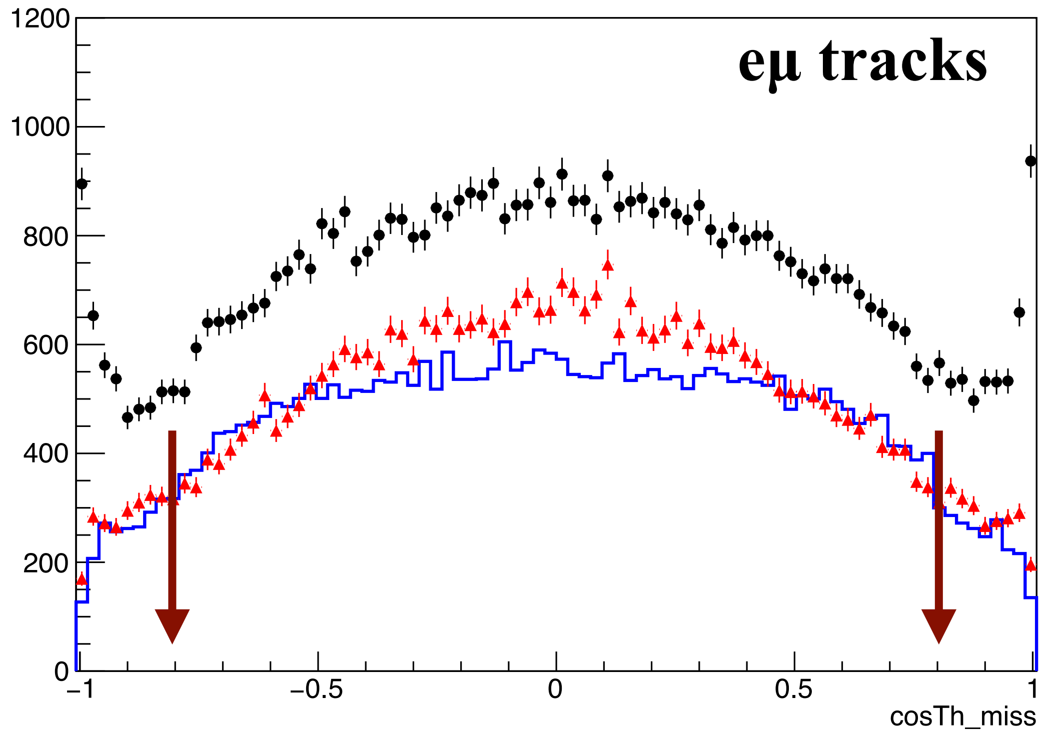
Full data-2012 and inclusive-2012 MC sample analyzed

- evident discrepancy between the two samples in the signal region
- the peak above 3 GeV (due to Psi2S decay to pipiJpsi) is removed after selecting events with charged tracks equal to 2

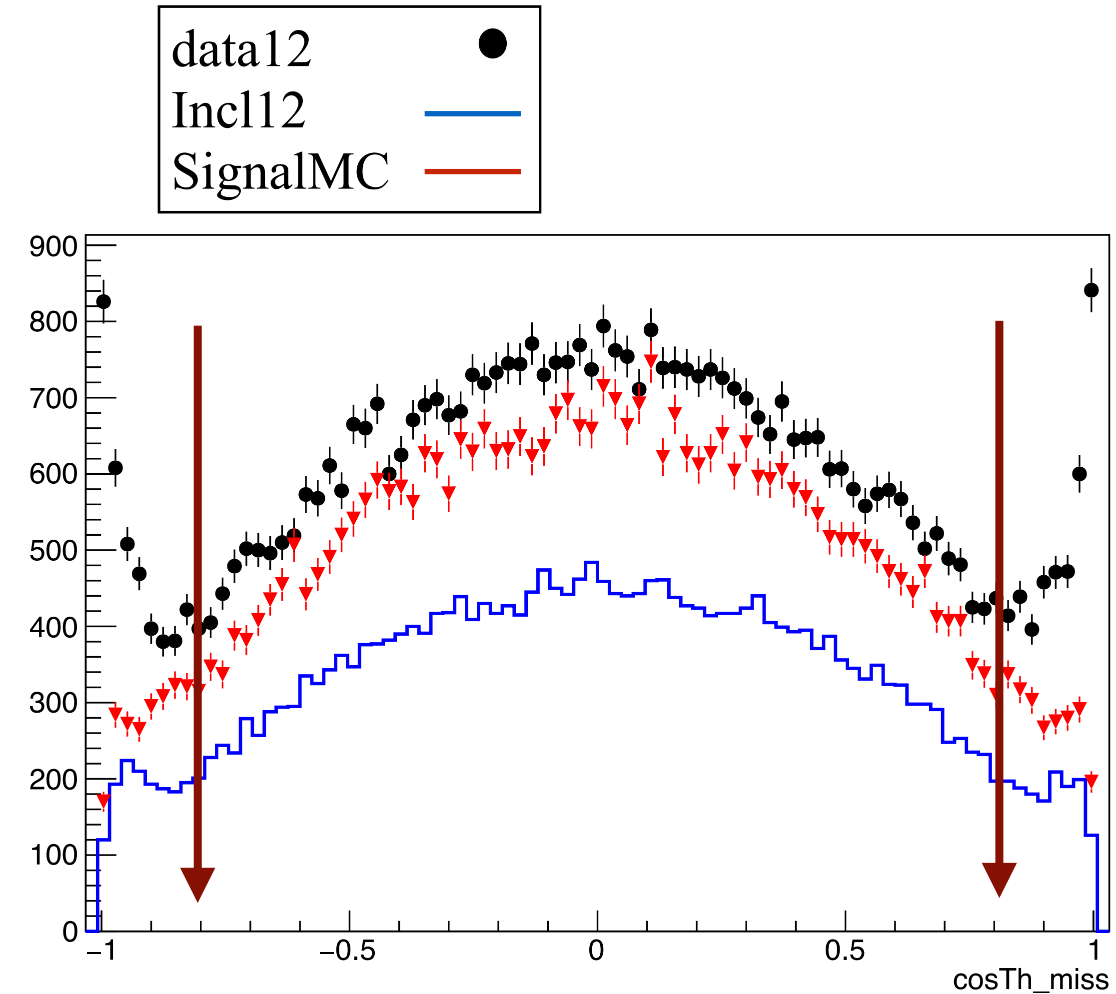
Additional cuts I

*signal arbitrary scale

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



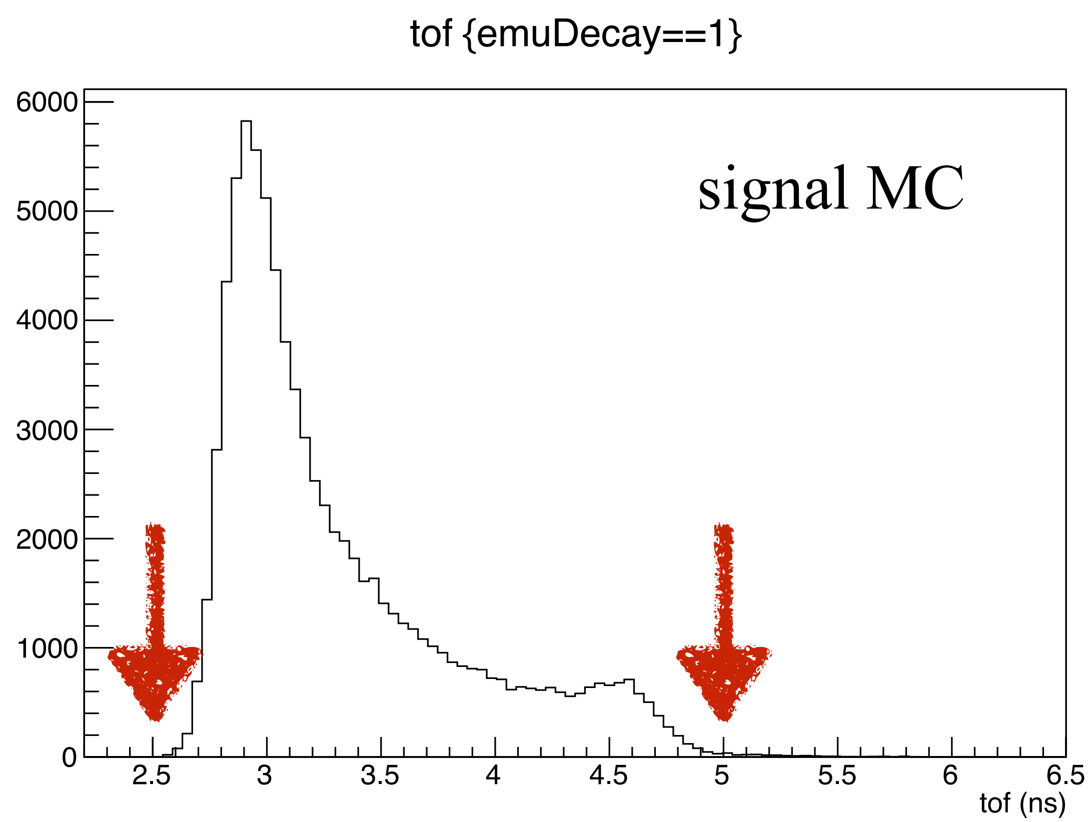
NgoodTracks ==2



NTracks ==2

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

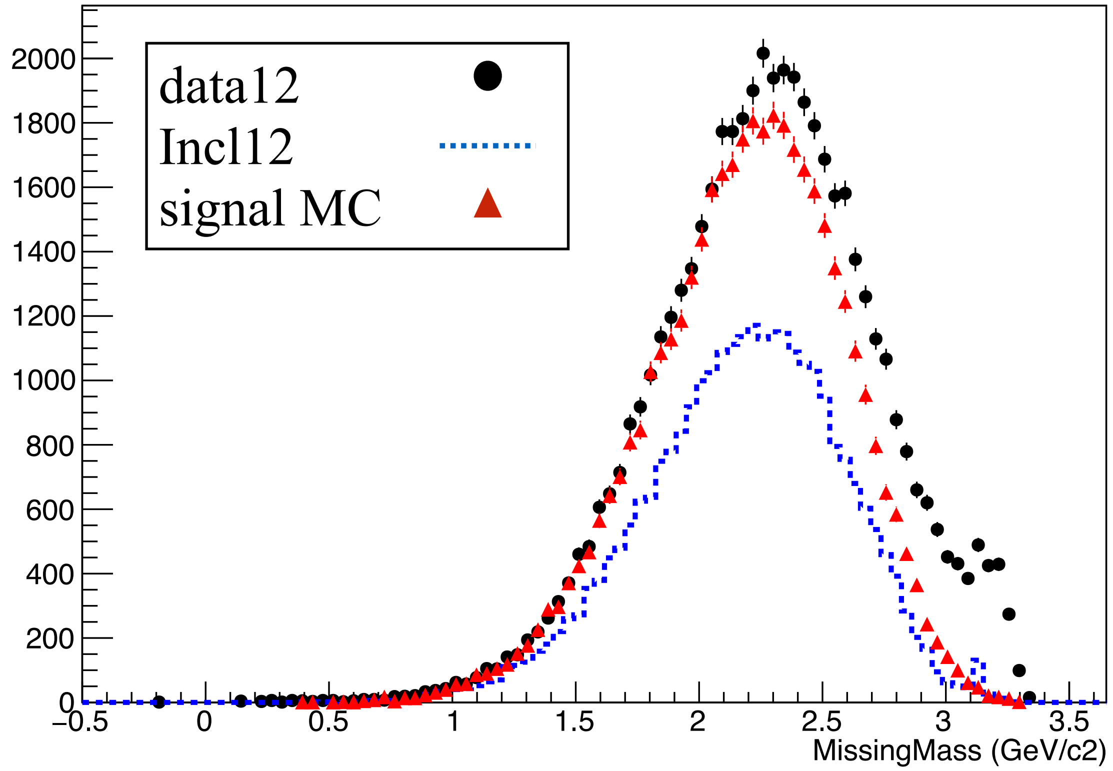
Additional cuts II

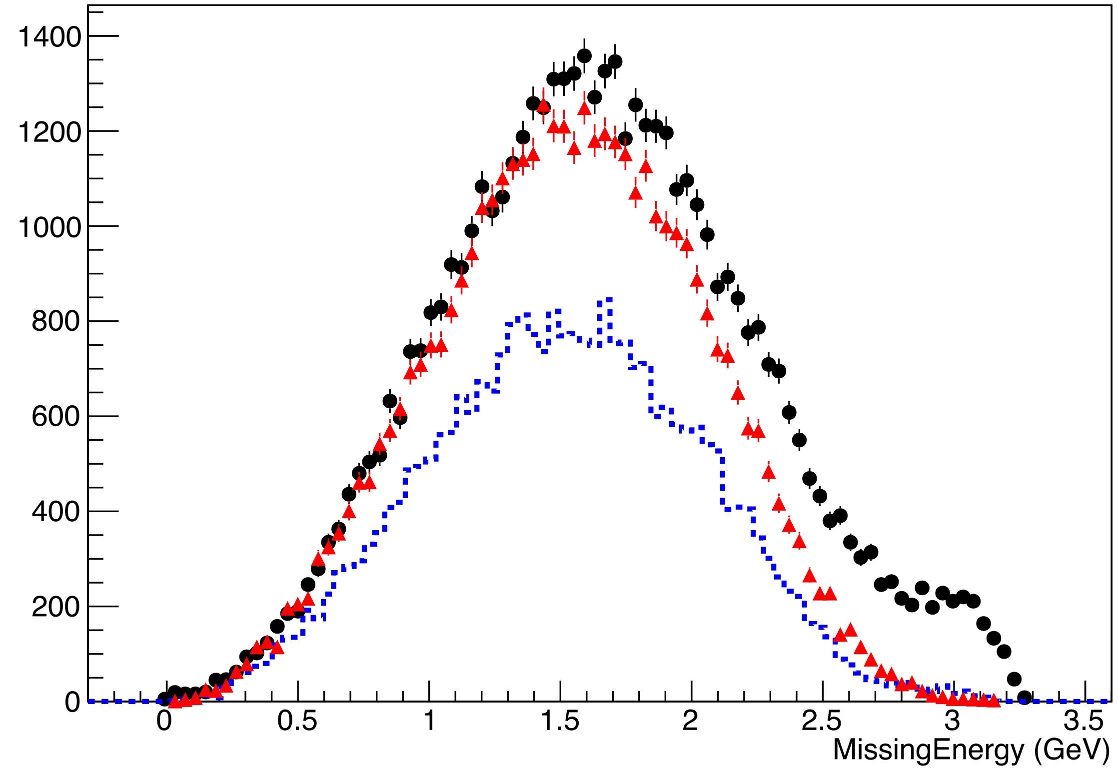


- 2.5<tof < 5 (ns)

Missing mass and missing energy:

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





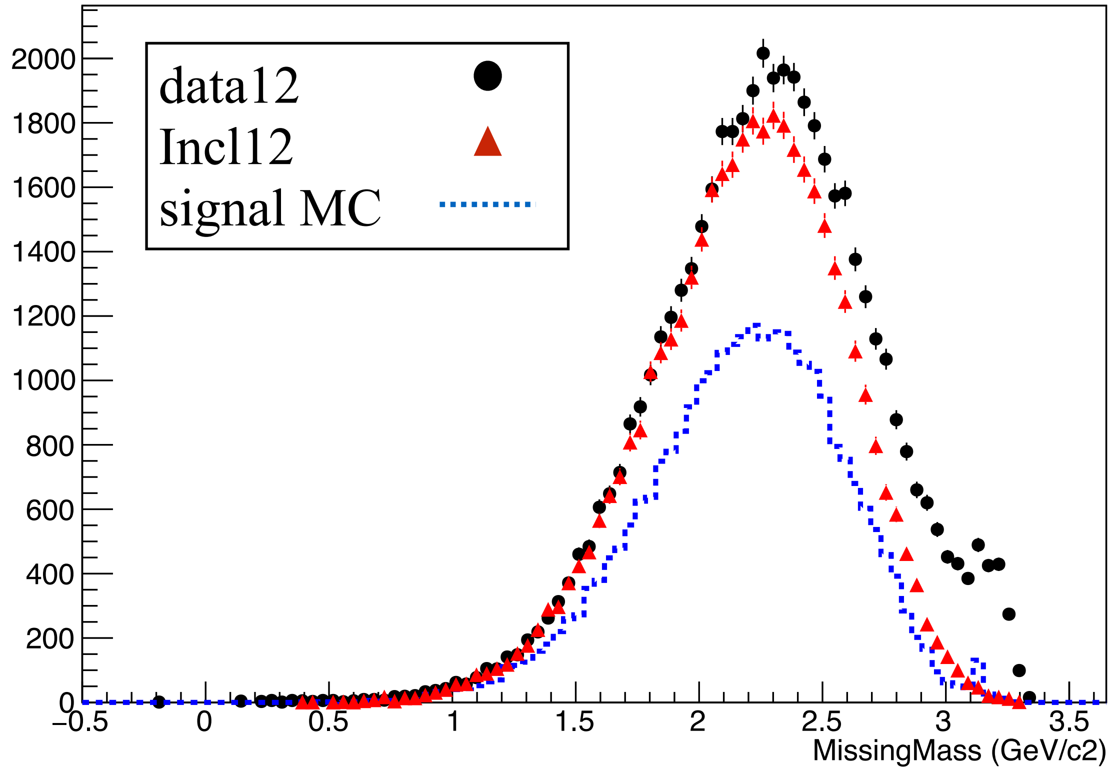
Additional cuts II

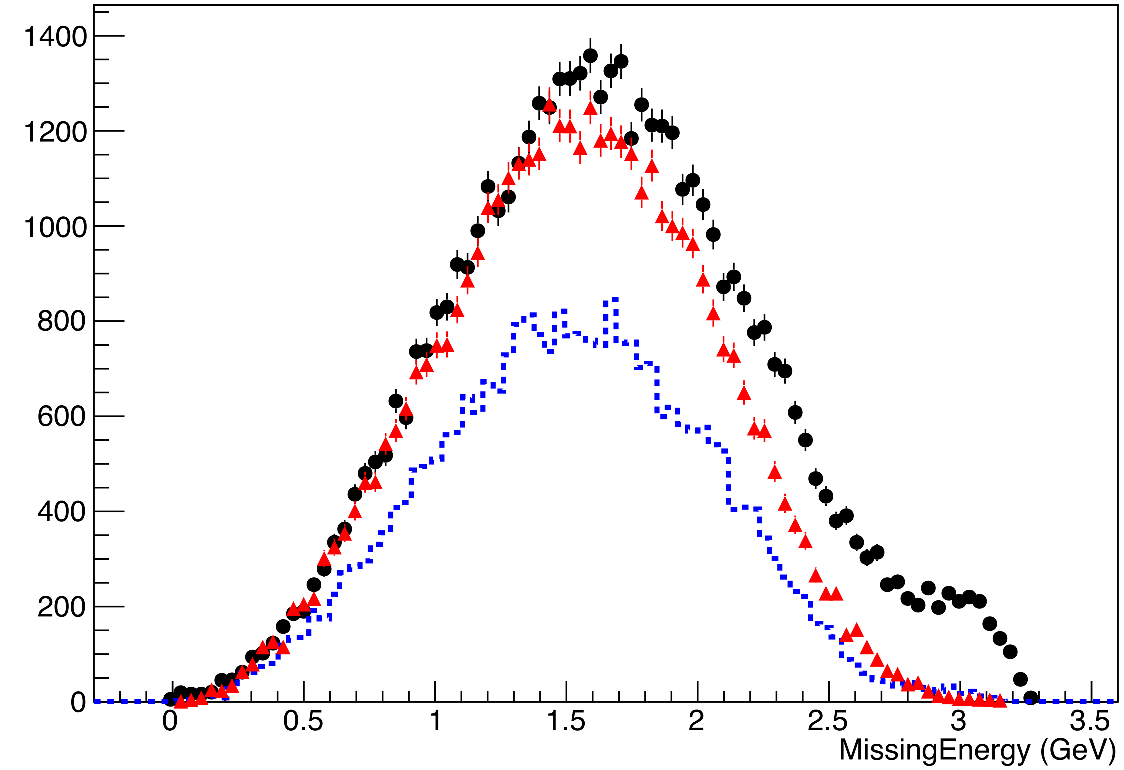
Missing mass and missing energy:

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

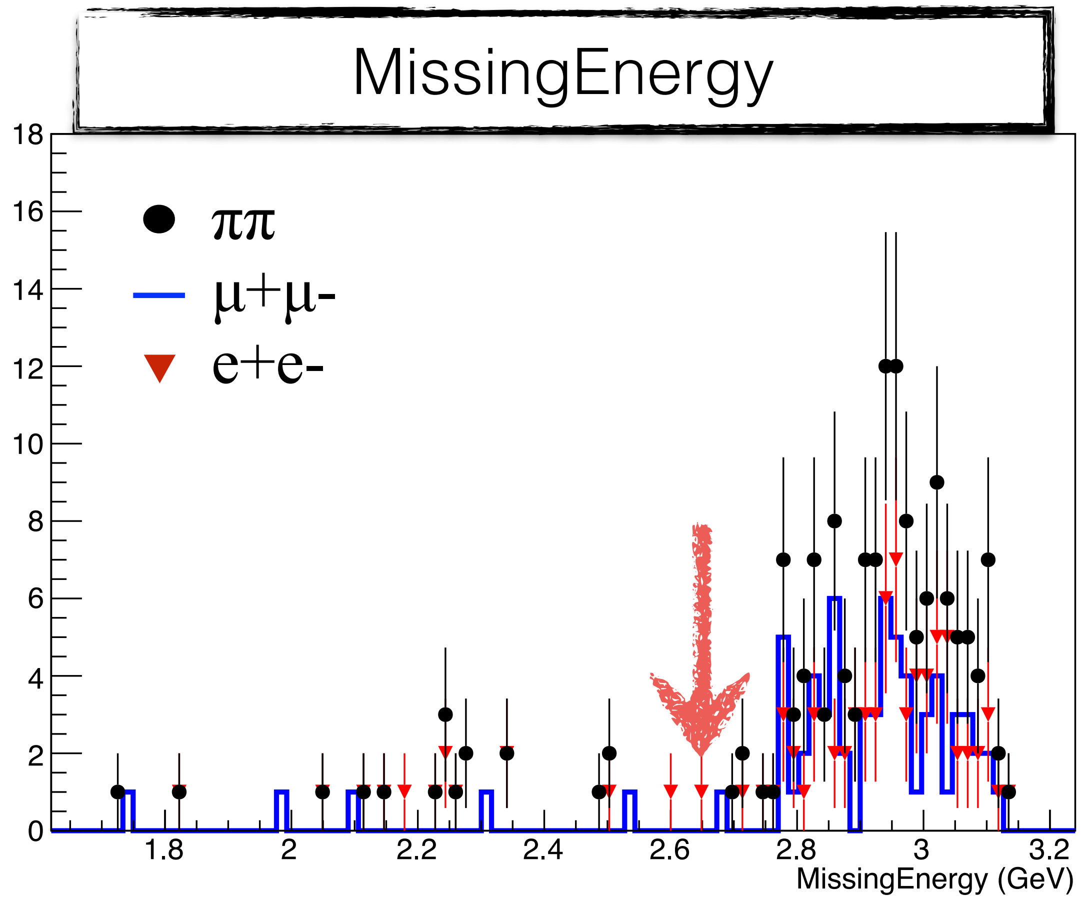
IDEA:

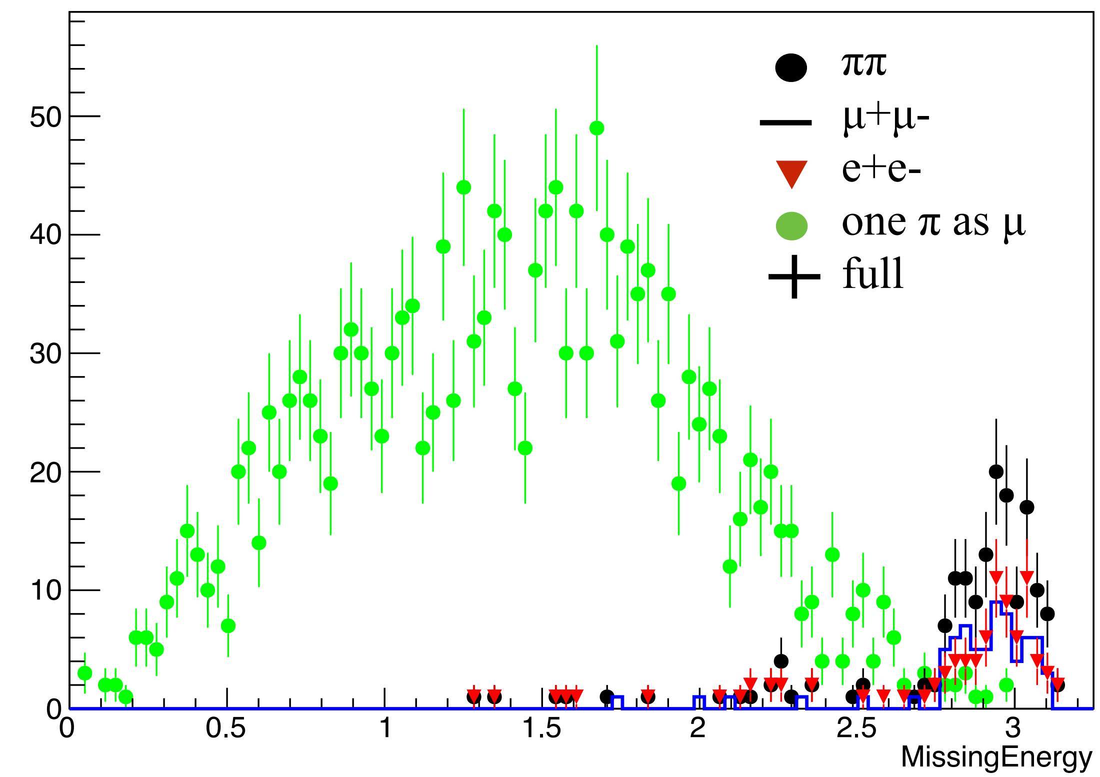
- Check the topology of those events reconstructed as "eμ" (MCtruth info)
  - Jpsi contributions

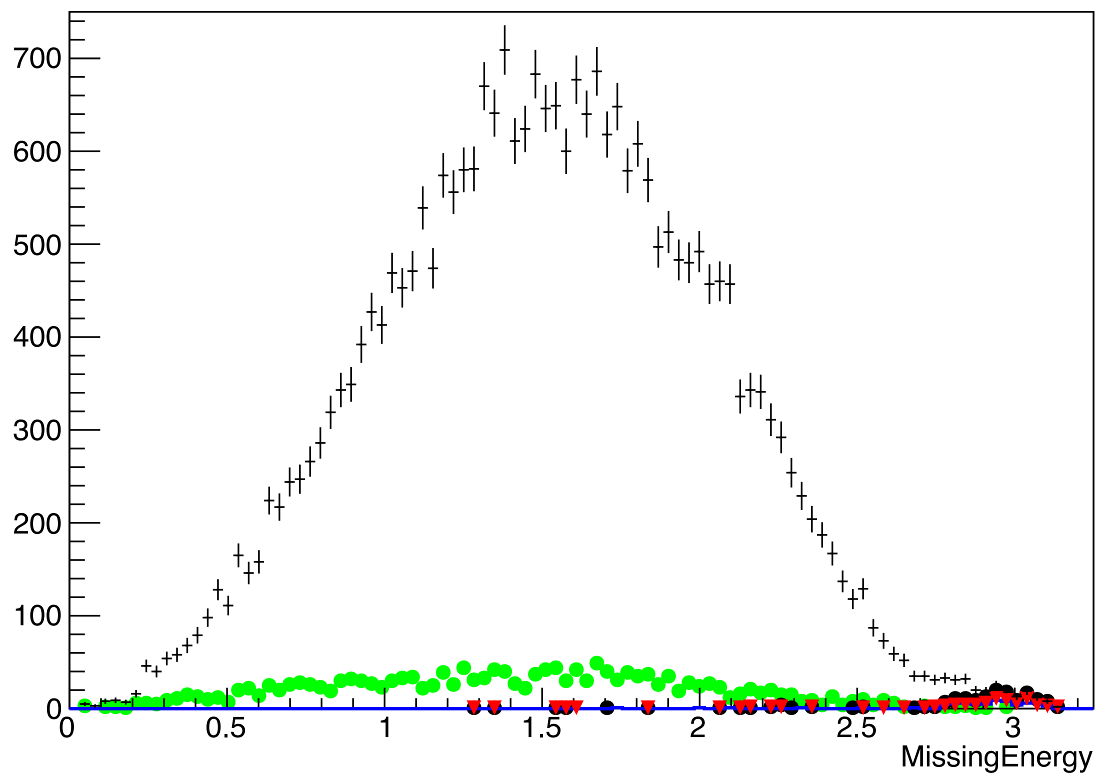




Additional cuts II

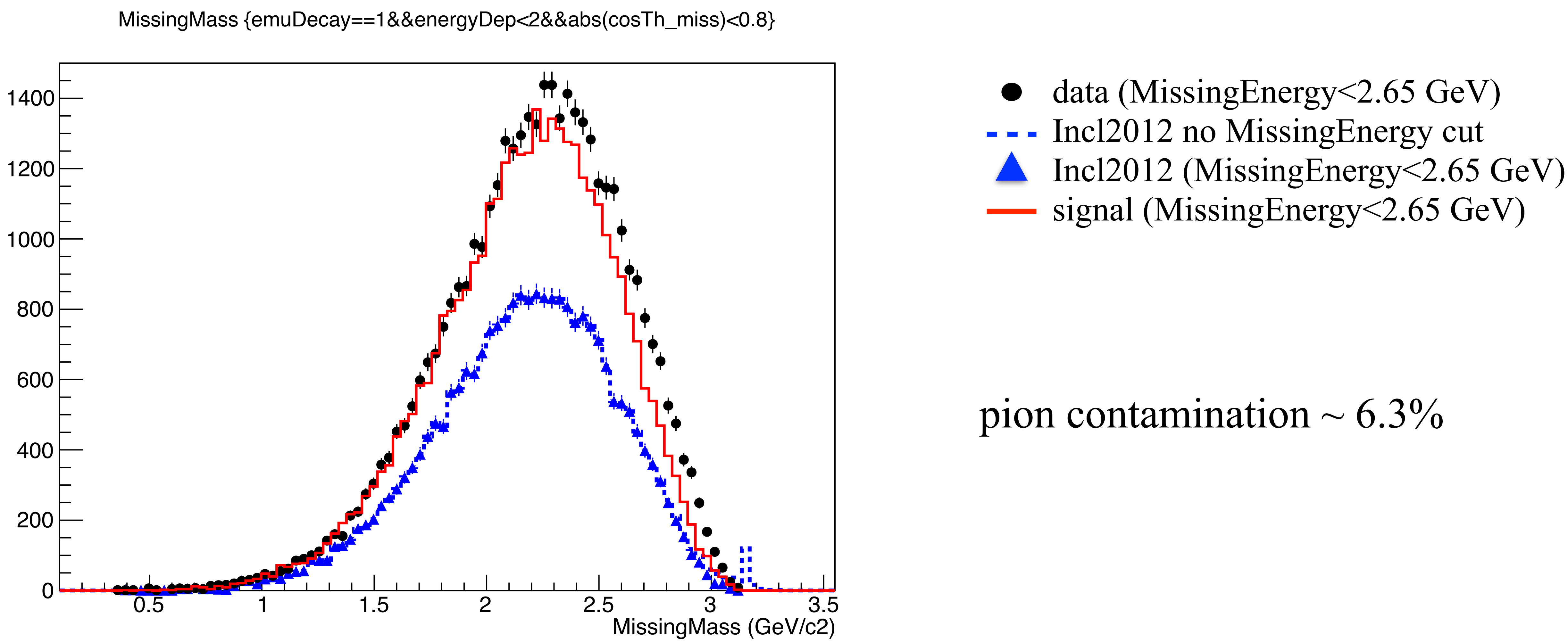






MissingEnergy < 2.65 GeV

Additional cuts II



pion contamination ~ 6.3%

Summary table of cuts

Charged tracks

- **nTracks ==2**
- 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**
- nGood=2
- **Vertex FIT**

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 $\theta_{\gamma\text{-}tr}$> 10°
- 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)**

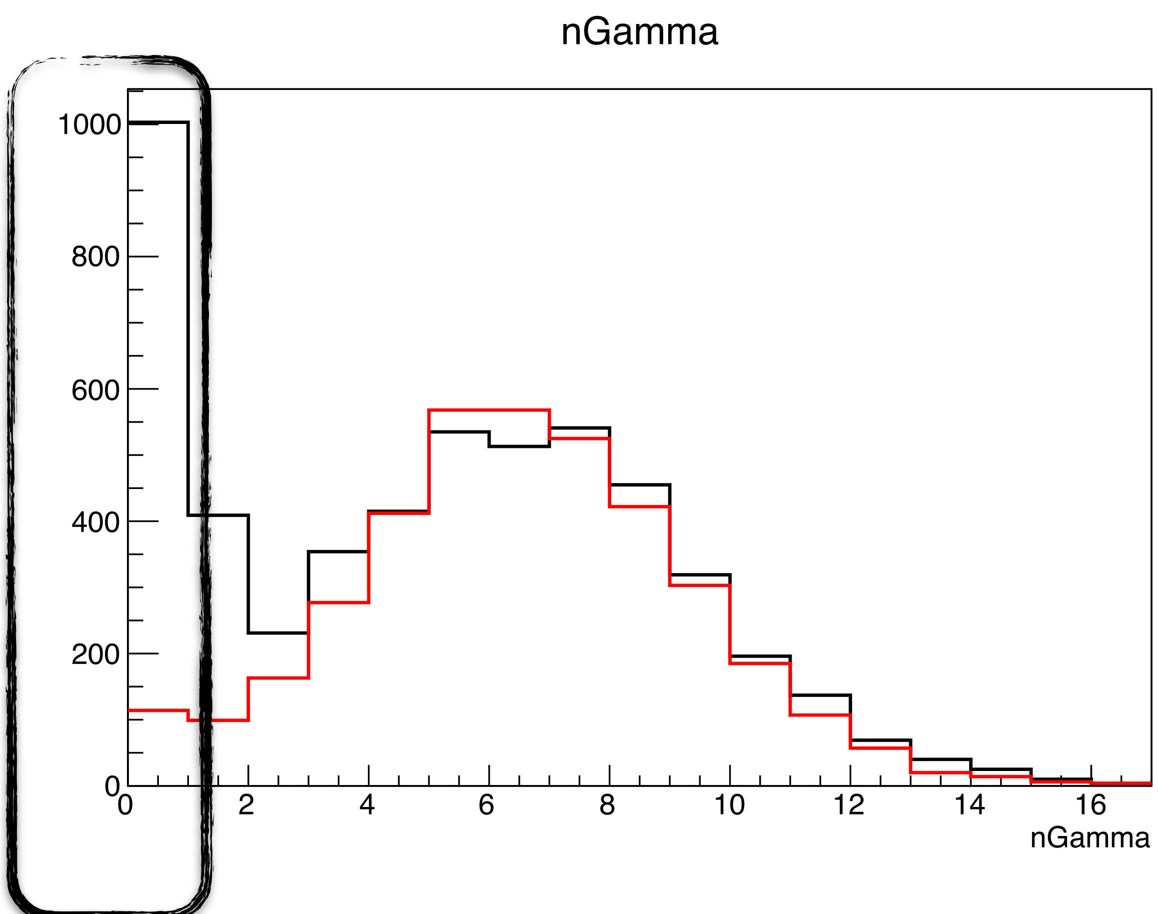
- |cosθ_miss| < 0.8
- energyDep < 2 (sum of deposit energy of the two tracks)

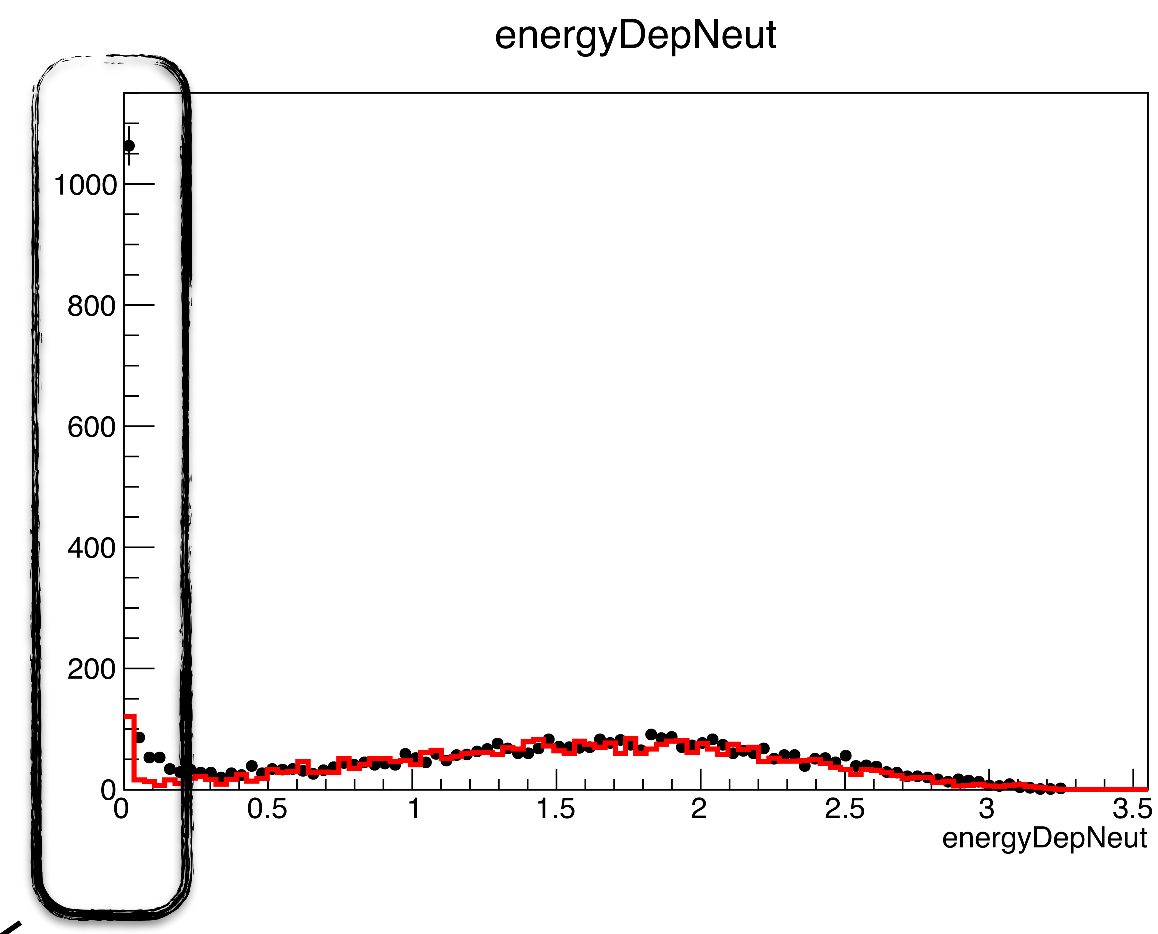
- MissingEnergy<2.65 GeV/c2
- 2.5<tof < 5 (ns)

Check the difference between data and inclusive MC

RUN 25338

- Comparison between data and inclusive MC distributions





Our signal region!!!

Check the difference between data and inclusive MC

RUN 25338

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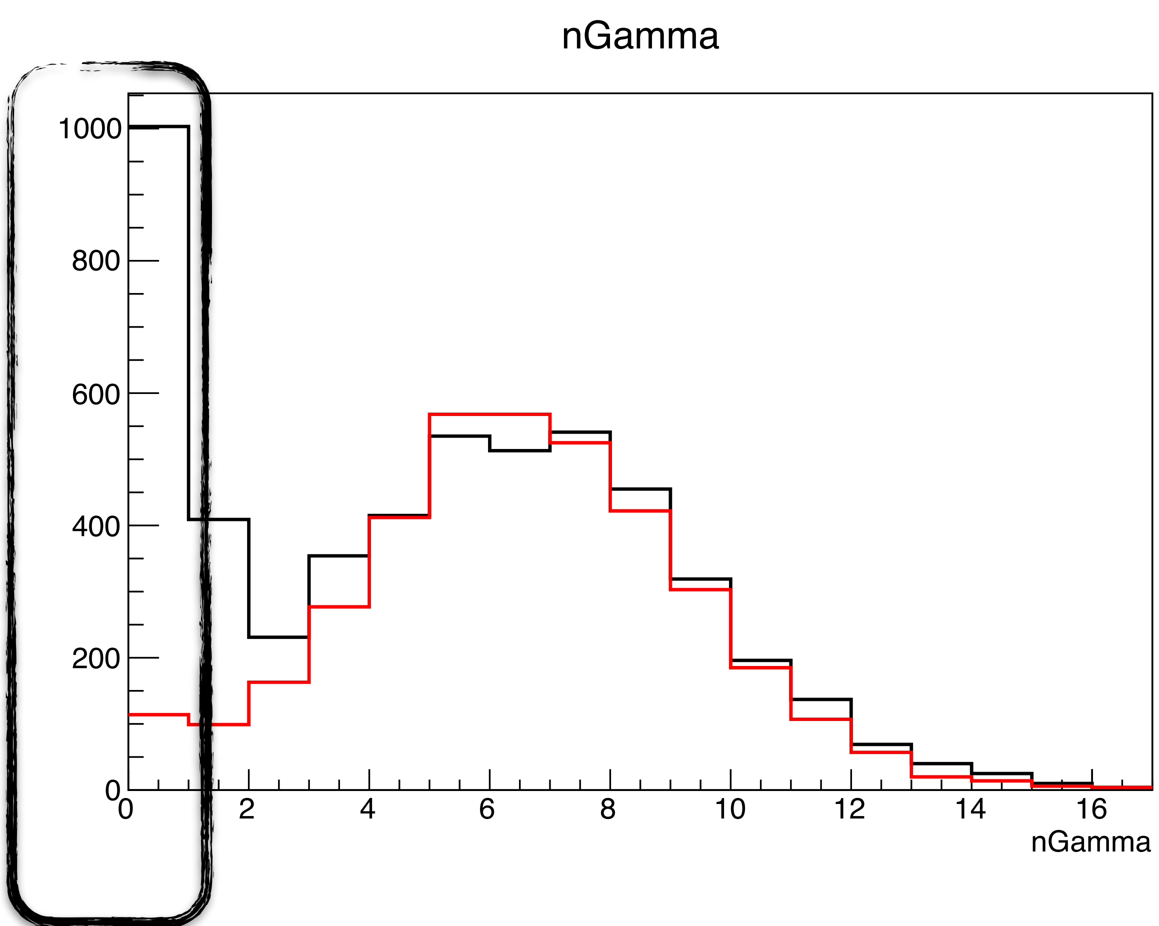
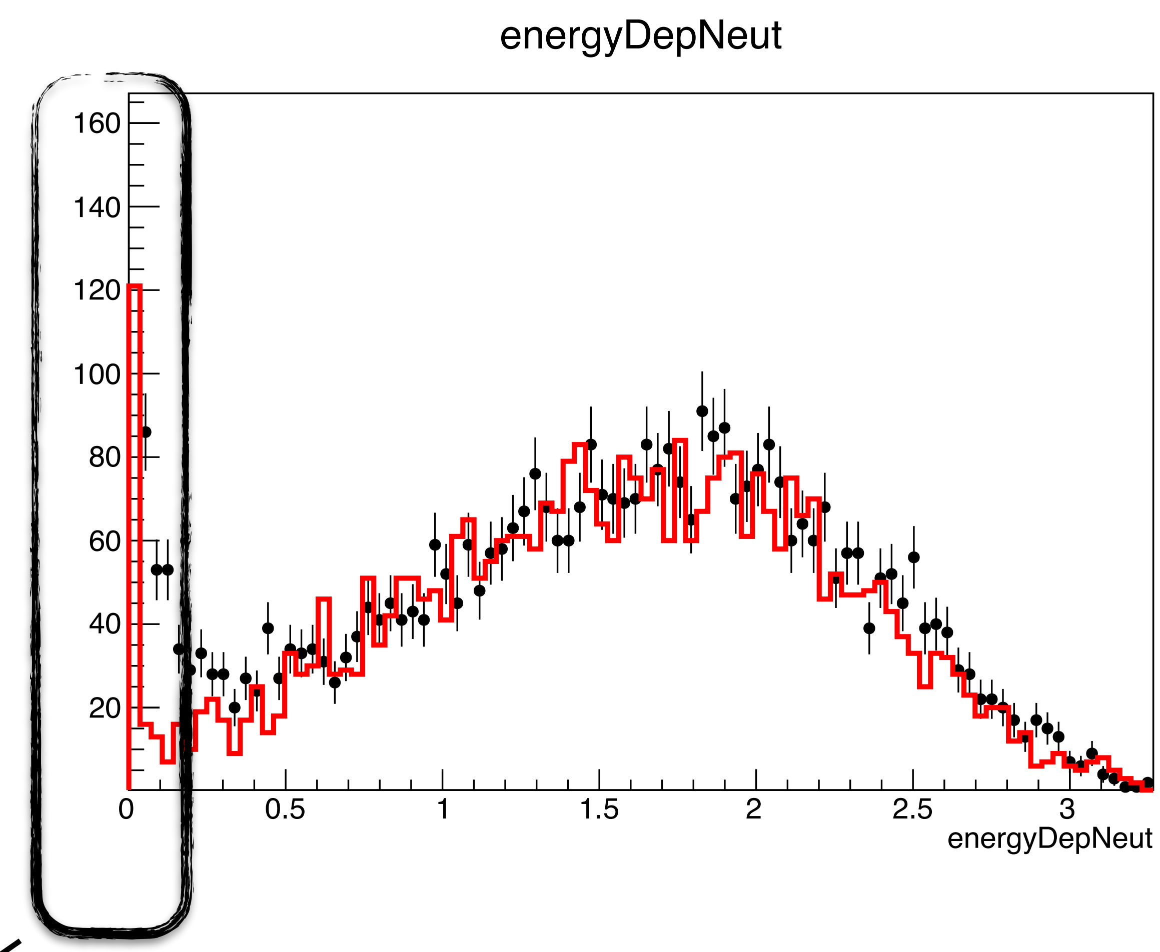


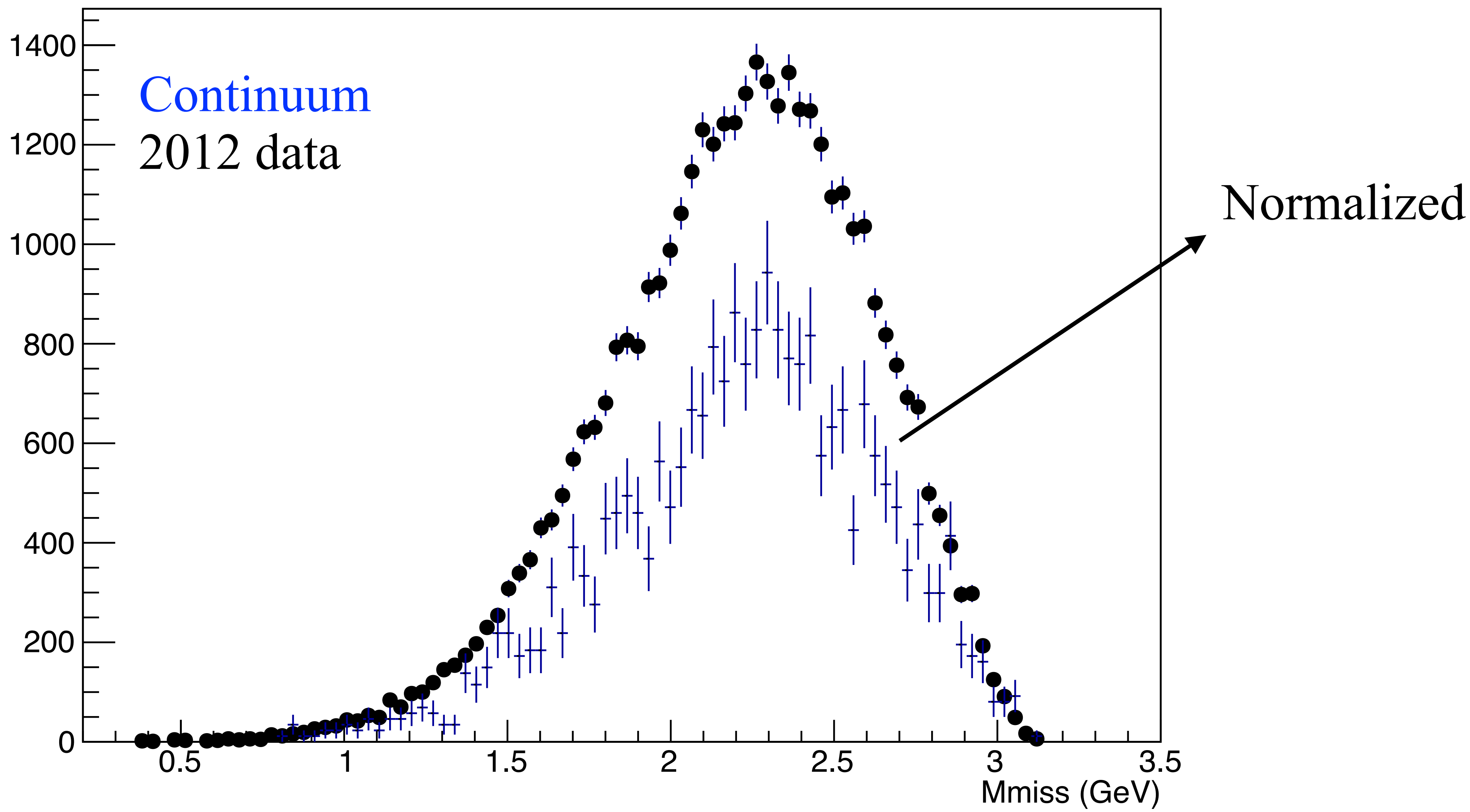


Our signal region!!!

Inclusive MC sample is not reliable

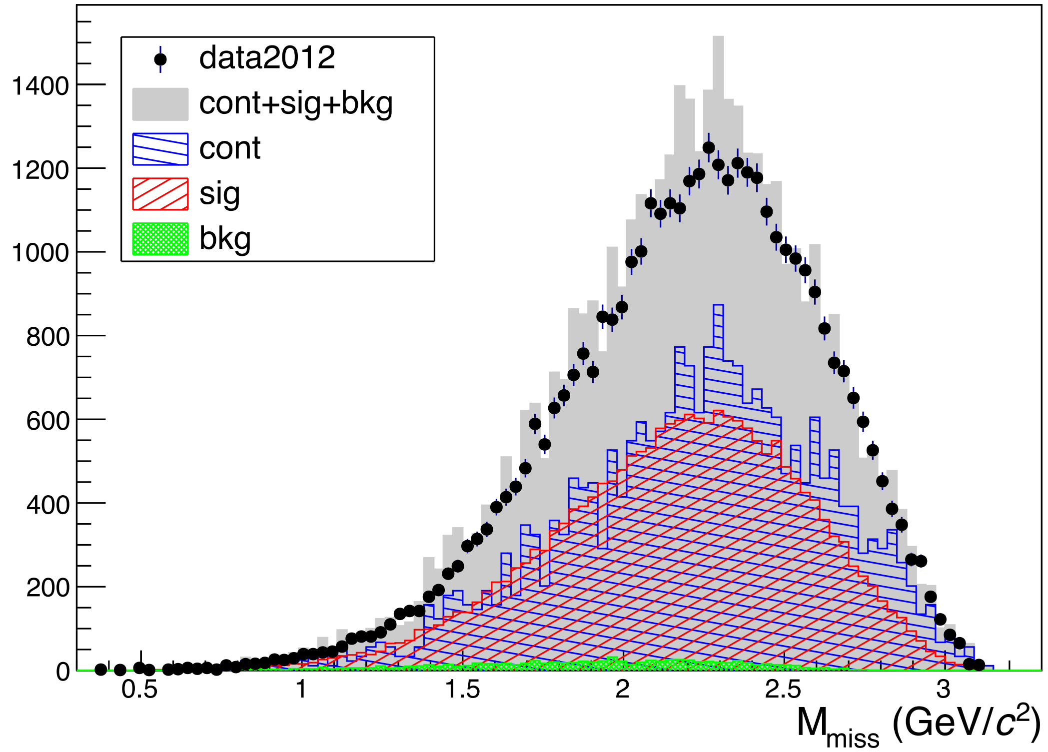
Continuum

@ 3.650 GeV (L ~ 44.5 pb^{-1})

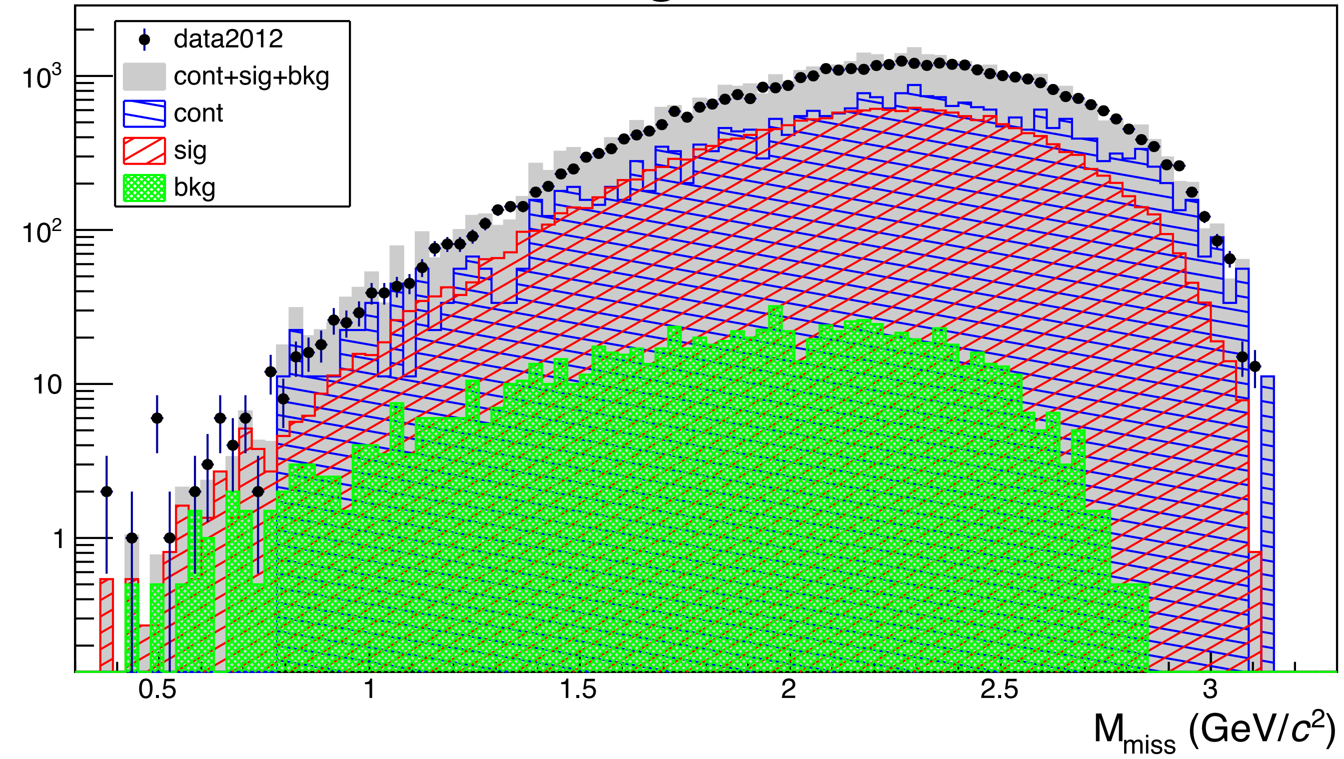


Mmiss Data/MC comparison

Linear Scale



Log Scale



All samples are normalised taking into account the BRs and the total number of data

Plans and Conclusions

- to do list:
  - ✓ update the following additional cuts
  - ✓ inclusive MC topology
  - ✓ 2012 data set
  - ✓ continuum data set
  - ✓ Psi2S —> mumu analysis (ongoing)
  - 2009 data set and consistency check
  - how to estimate background and interference between signal and background
  - Systematic uncertainties

Wednesday 23 @ 15:00 Beijing time: presentation at τ-QCD working group

Thanks for your attention

LFU violation at BESIII?

Rinaldo's suggestion

BR7's talk in Perugia

BESII/BESIII on ψ (2S) -> $\tau\tau$

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

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

6 times lower

- **BESIII:**
  - **550 M ψ (2S)**
  - **BR (ψ (2S) -> $\tau\tau$) ≈ $(3.1 \pm 0.03_{stat} \pm ?) \times 10^{-3}$ [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 ?**

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