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

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

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

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

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

? ?

with 550M of psi2S data

Analysis: event and track selection

Study of $\psi(2S)\rightarrow\tau\tau\rightarrow e\mu 4\nu/\pi e 3\nu/\pi\mu 3\nu/\pi\pi 2\nu$ decays

Charged tracks

- **nCharged=2**
- Vertex cut: $R_{xy}<1$cm and $R_z<10$cm
- 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

- Release 664p03
- 240000 events simulated: $\psi(2S)\rightarrow\tau\tau\rightarrow e^{\mp}\mu^{\pm}4\nu$
  - 2009+2012 conditions
- 2009+2012 MC inclusive $\psi(2S)$ sample
- 2009+2012 $\psi(2S)$ data sample

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

Decay tau+
   0.3900 e+ nu_e anti-nu_tau          PHOTOS TAULNUNU;
   0.3900 mu+ nu_mu anti-nu_tau        PHOTOS TAULNUNU;
   0.2200 pi+  nu_tau                  TAUSCALARNU;
Enddecay


Decay tau-
   0.3900 e- anti-nu_e nu_tau          PHOTOS TAULNUNU;
   0.3900 mu- anti-nu_mu nu_tau        PHOTOS TAULNUNU;
   0.2200 pi-  nu_tau                  TAUSCALARNU;
Enddecay


End
```

PID studies

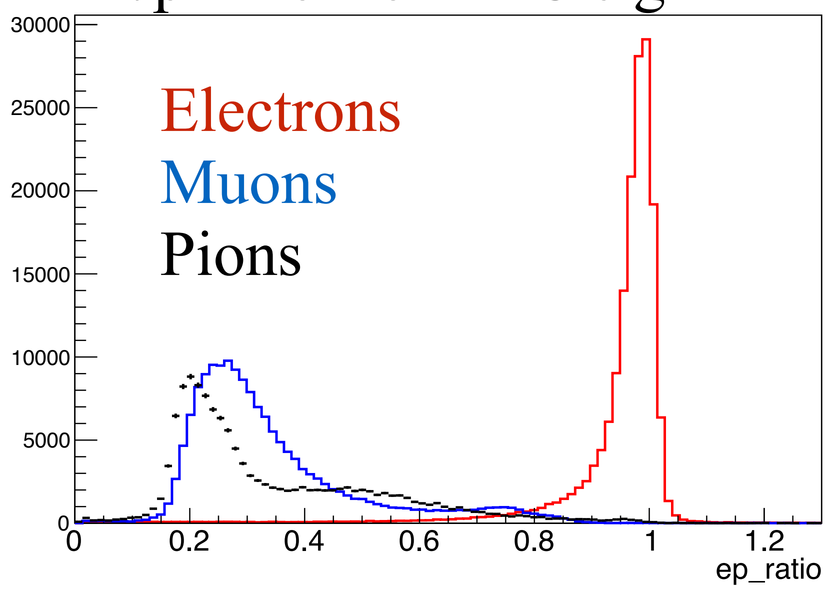
Electron PID

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

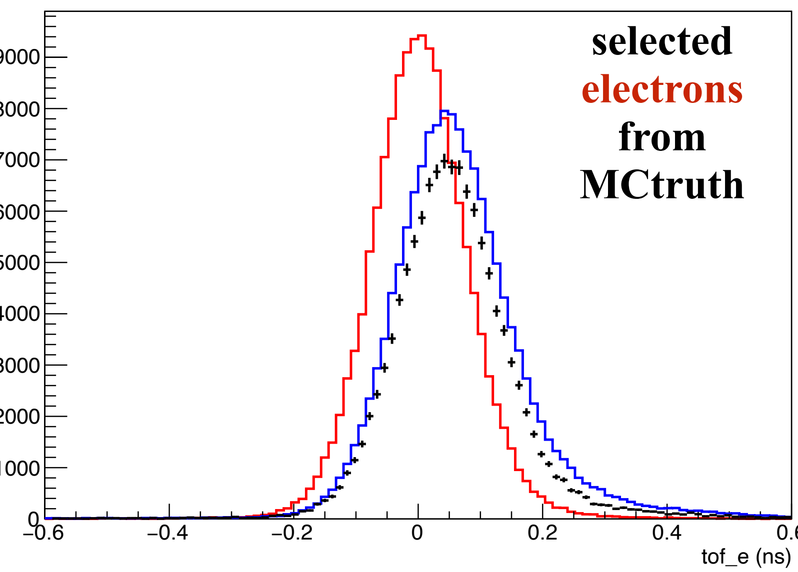
Muon PID

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

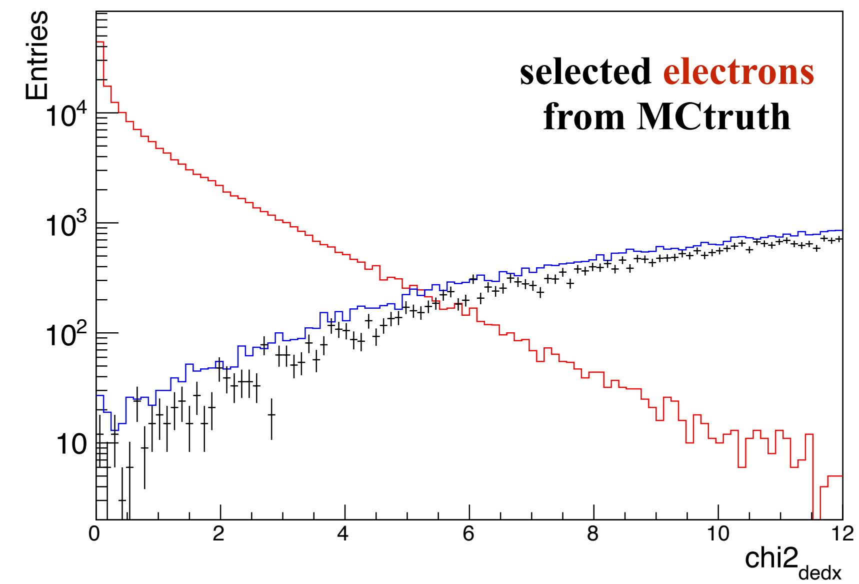
E/p ratio from MC signal



(exp-tof - tof_calc) from MC signal

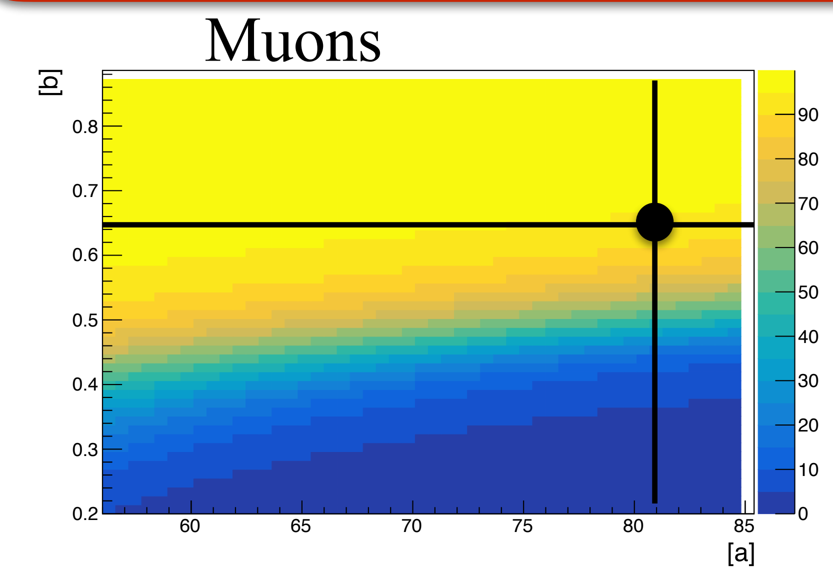


chi2-dEdx from MC signal



similar distributions for selected muons/pions from MC truth

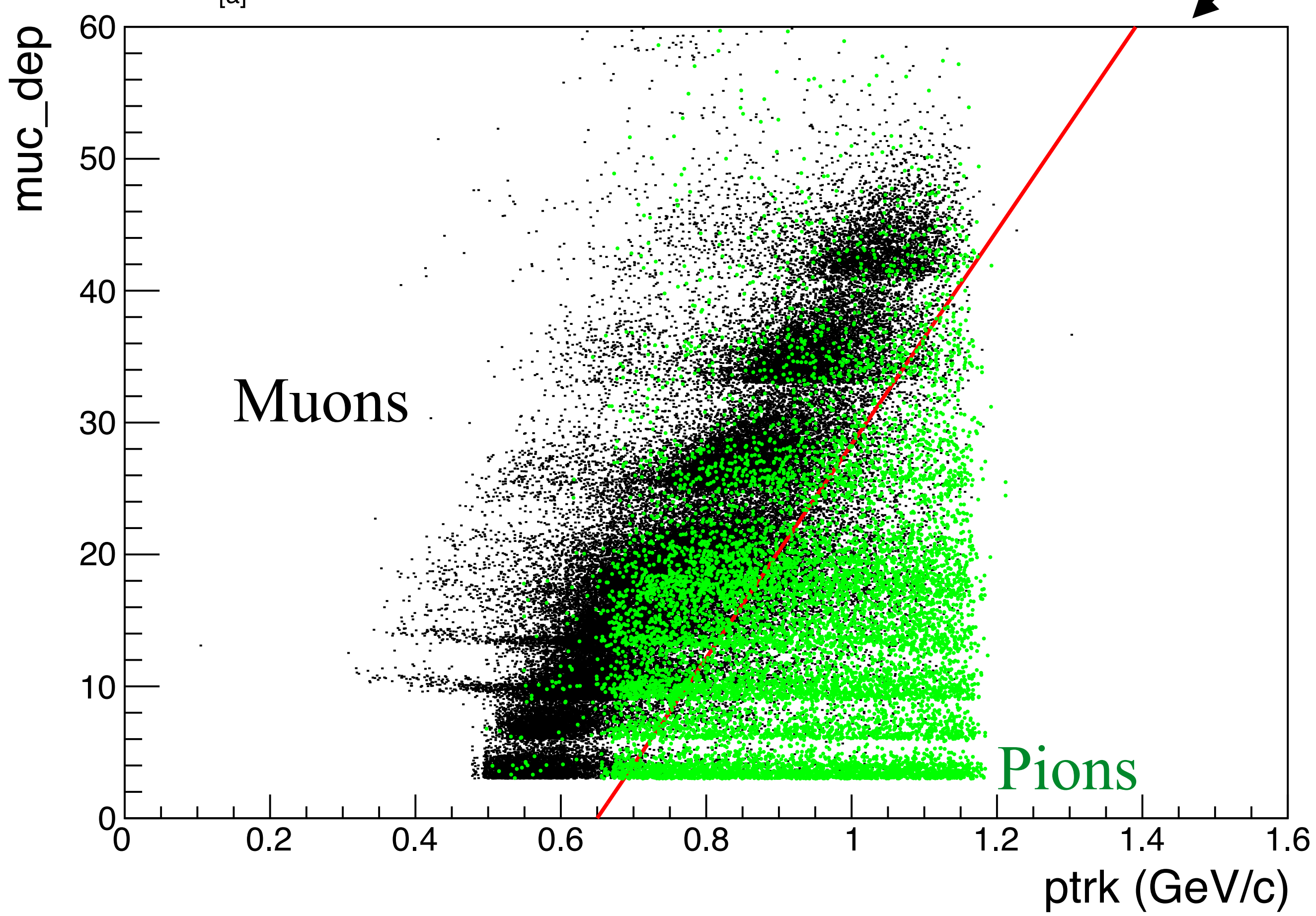
muc vs. ptrk from MC samples



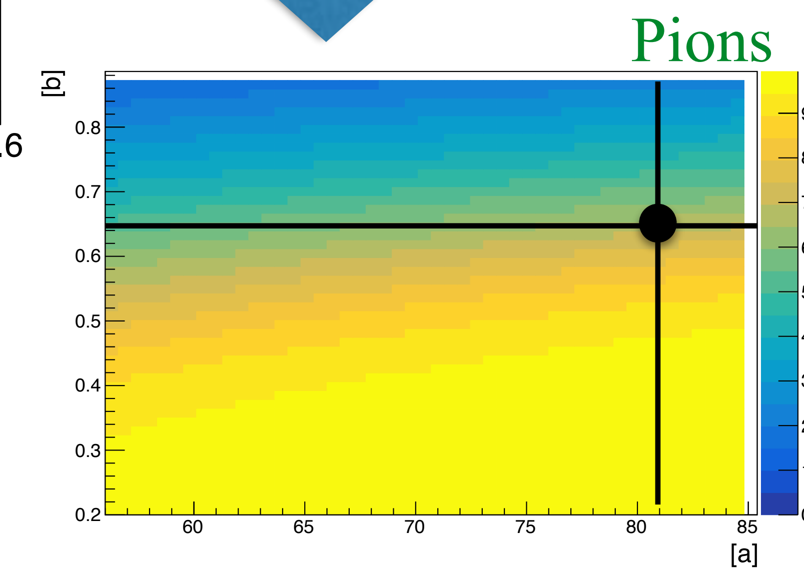
cut efficiency > 90% for muons selection

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

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



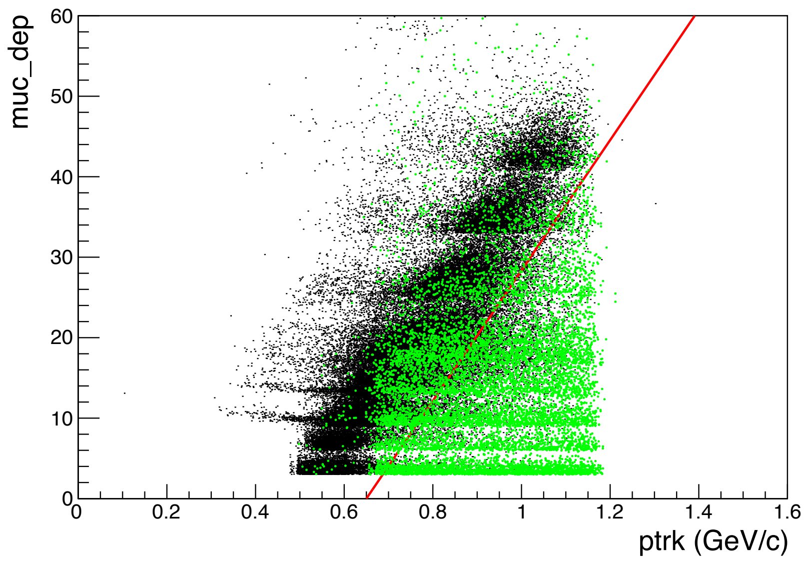
~70% of pions fall below the red line

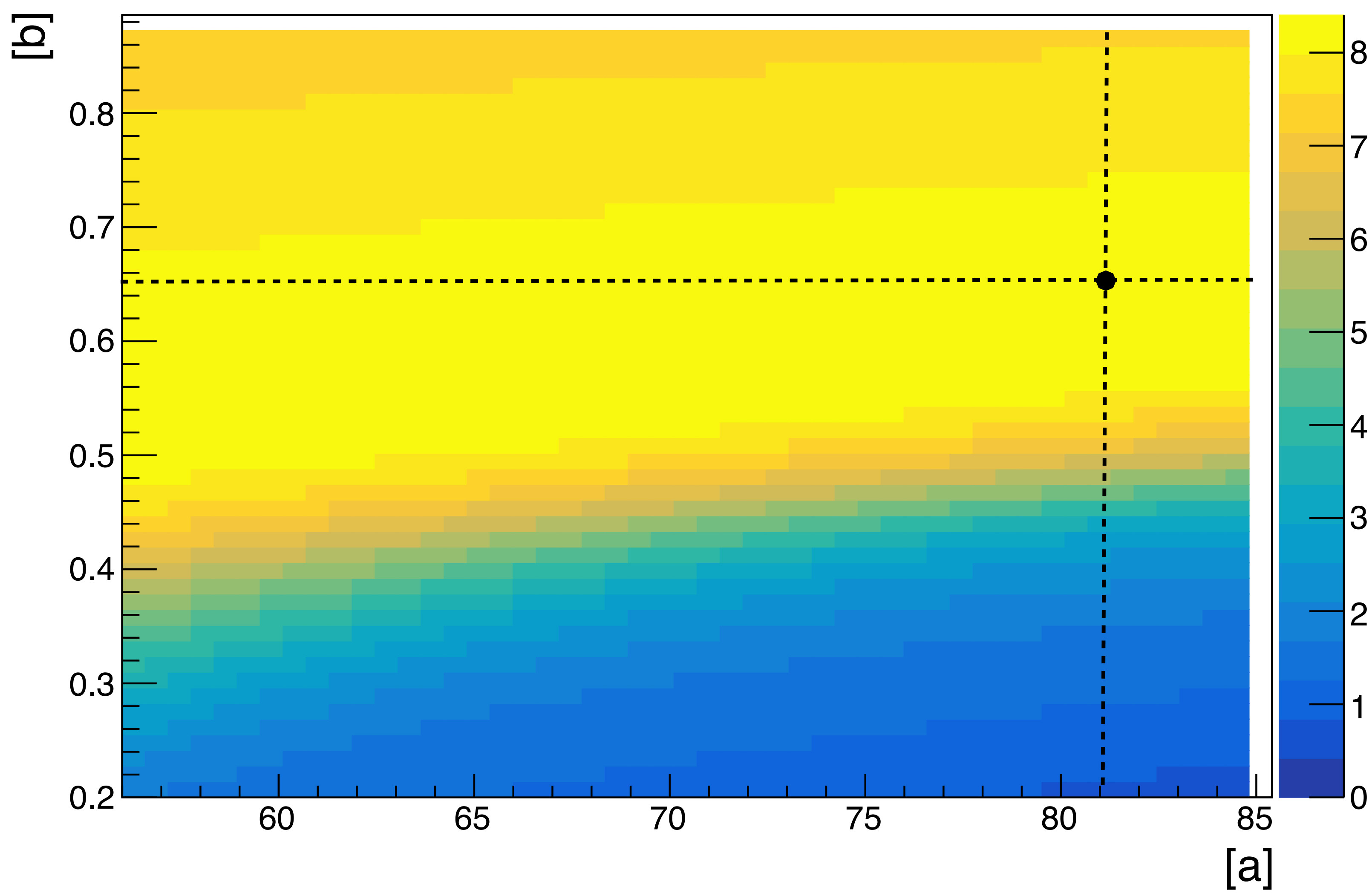


muc vs. ptrk from MC samples

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

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



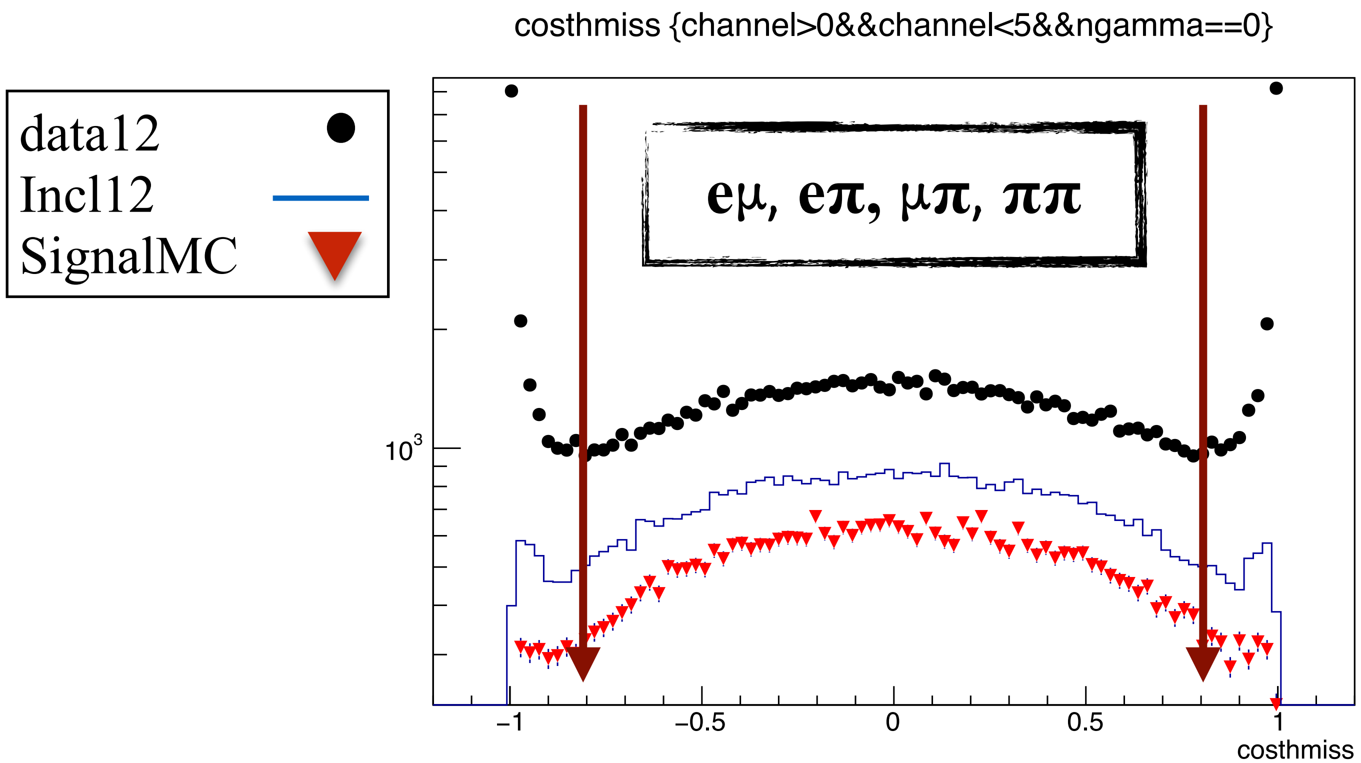


y = [a]*(x - [b])

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

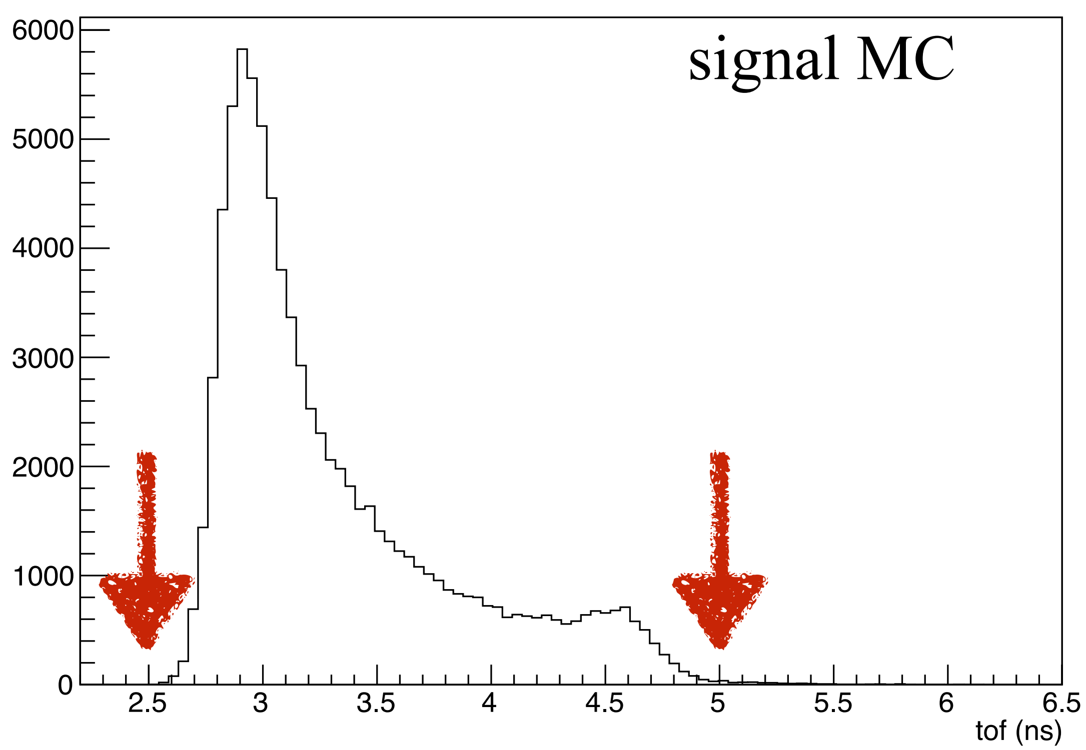
Additional cuts

*signal arbitrary scale



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

- |cosθ_miss| < 0.8

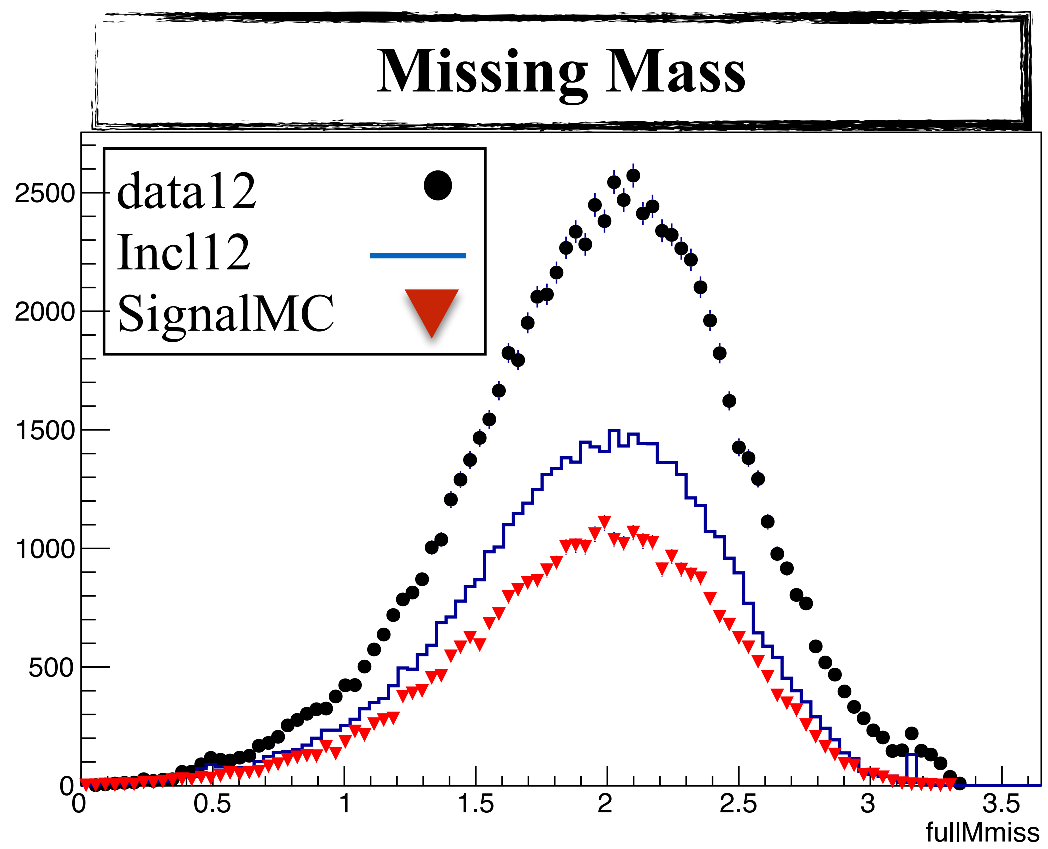


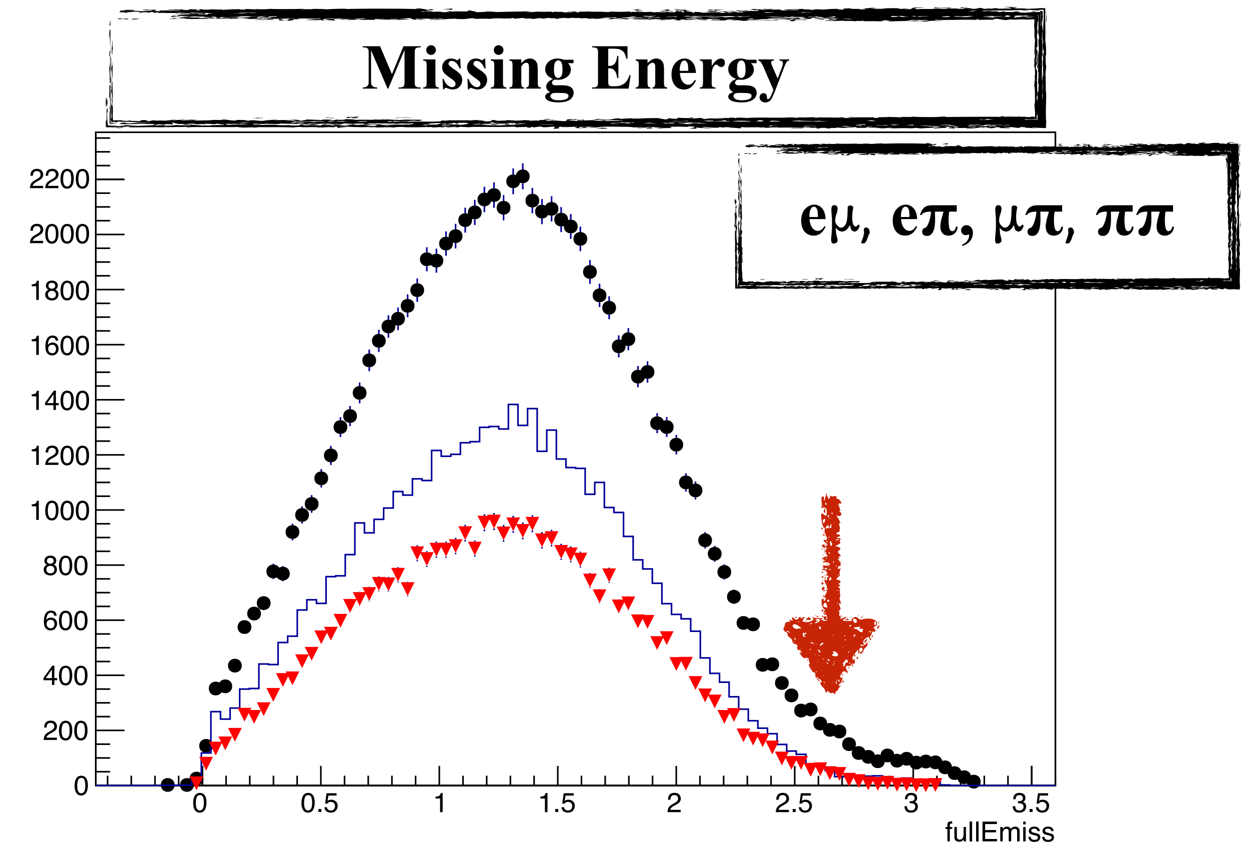
- 2.5<tof < 5 (ns)

Missing mass and missing energy:

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

Additional cuts II





Summary table of cuts $\psi(2S) \to \tau\tau \to e\mu 4\nu$

Charged tracks

- **nCharged=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)
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Neutral candidates

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- nGamma = 0

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)

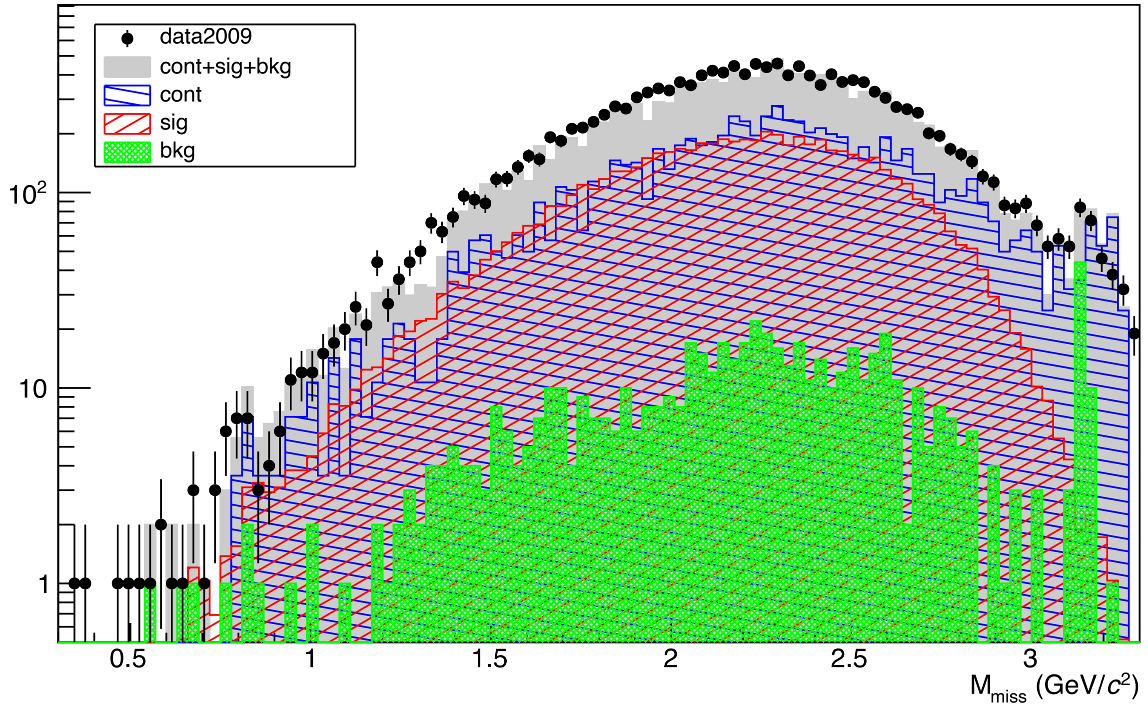
- ~~MissingEnergy<2.65 GeV/c2~~
- 2.5<tof < 5 (ns)

Study of inclusive sample

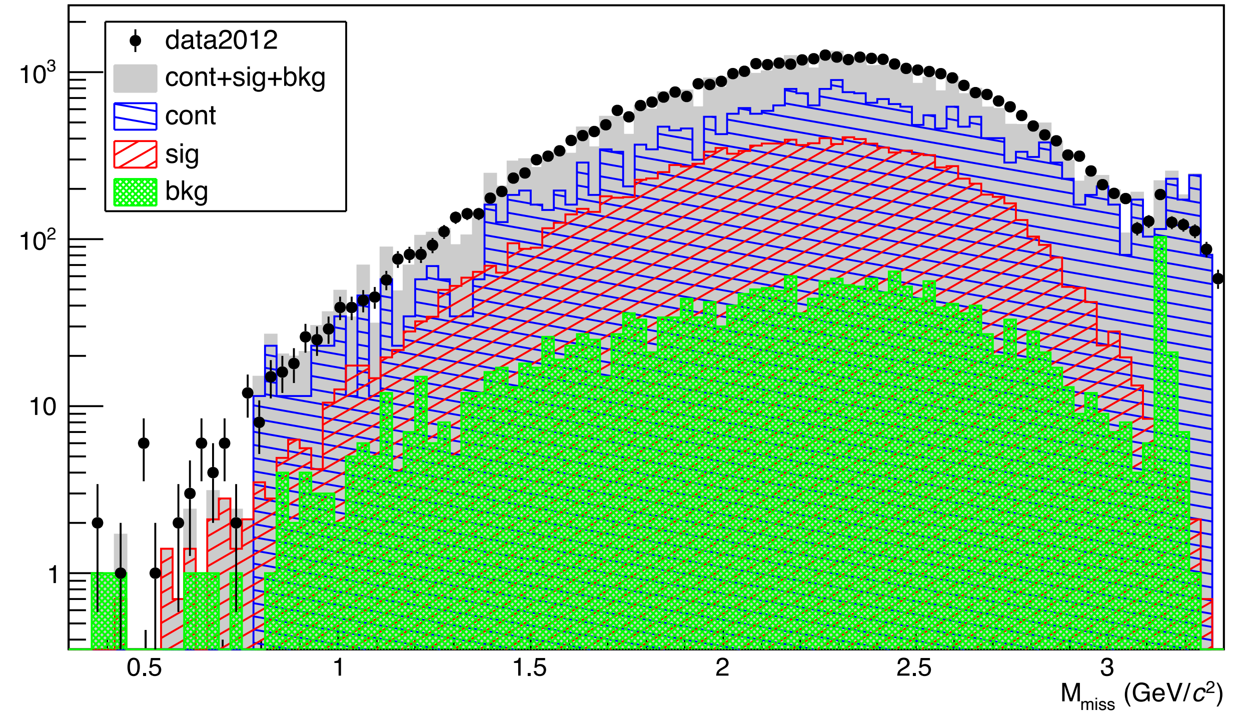
@ 3.650 GeV (L ~ 44.5 pb^{-1})

Continuum
2009 and 2012 data

2009 data sample

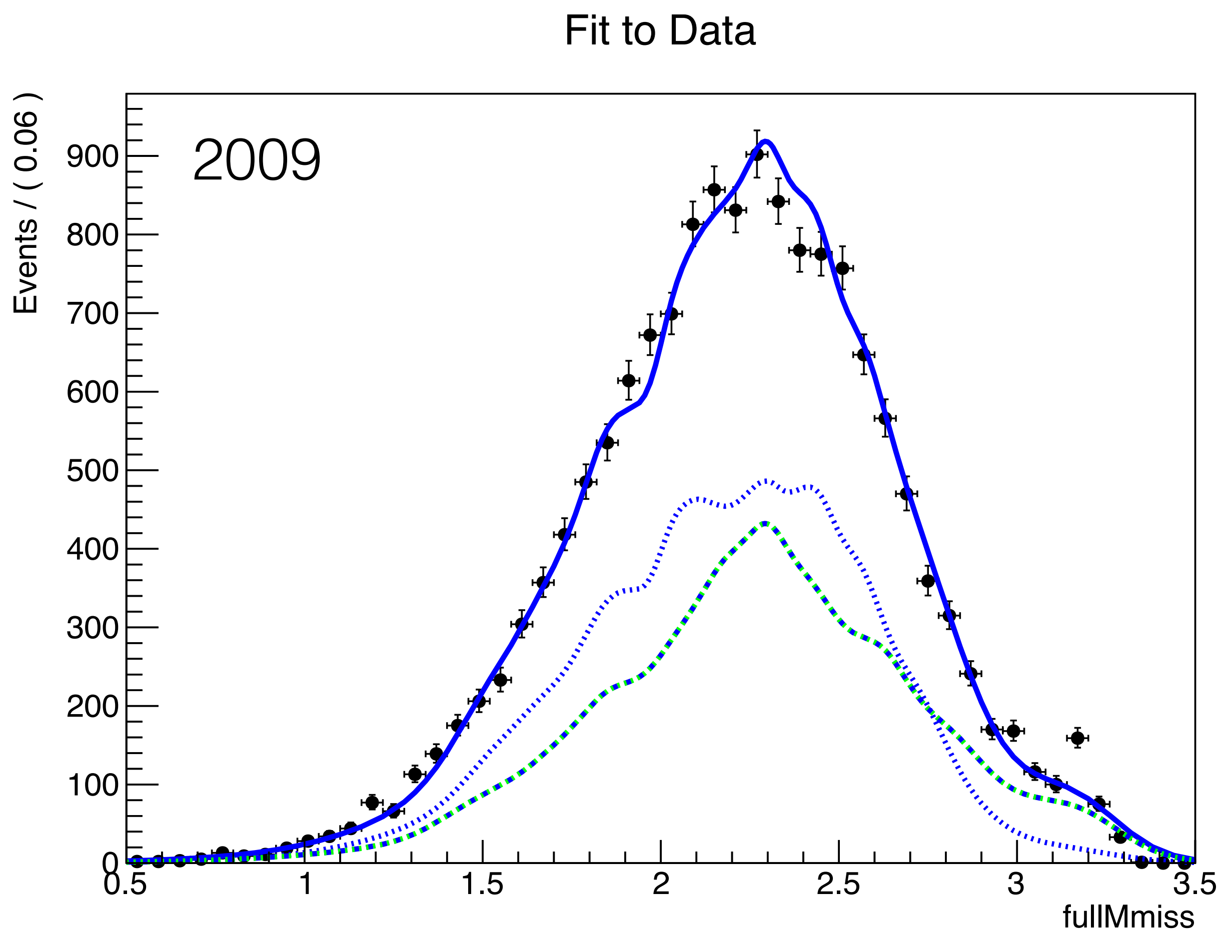


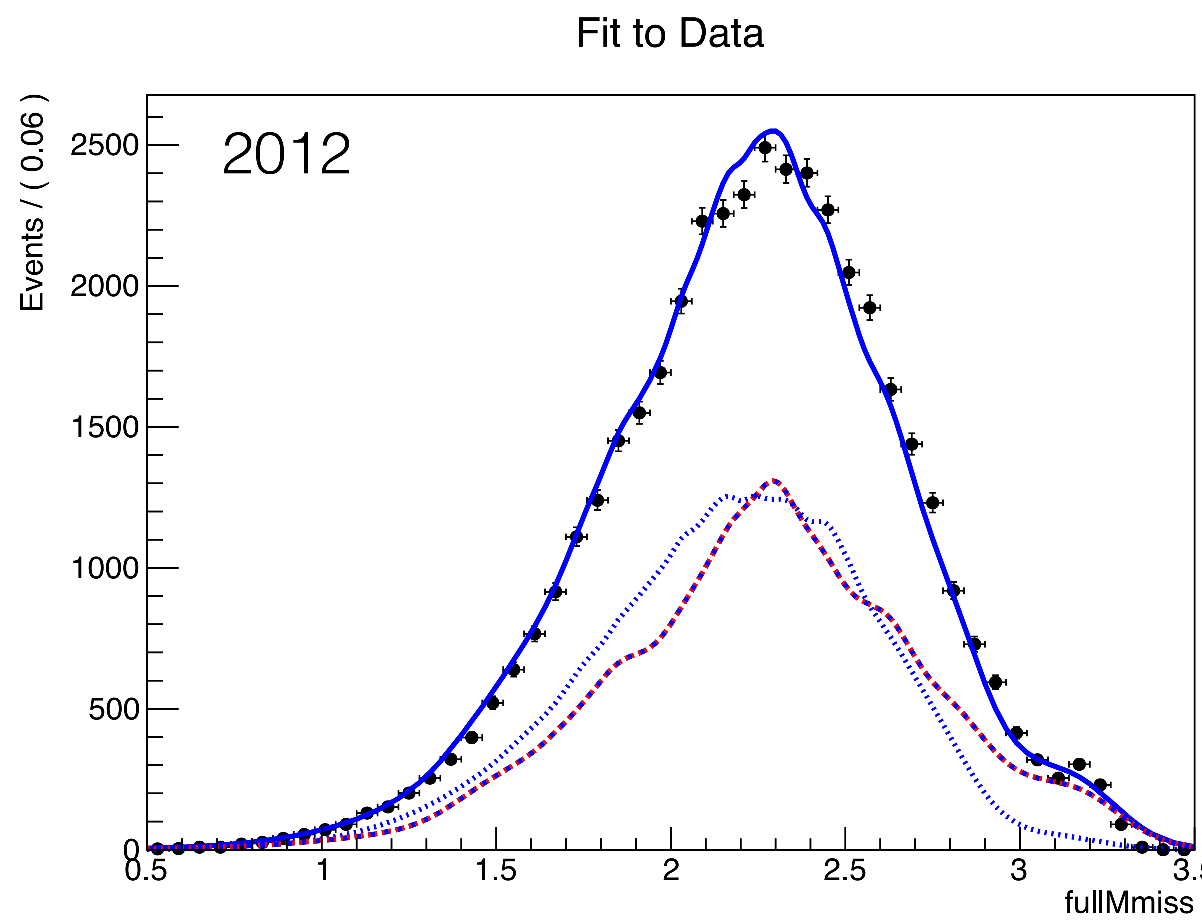
2012 data sample



- No cut on the Emiss
- Signal shape form inclusive MC (MCtruth)
- Background shape from inclusive MC (check MC truth ID different from emu signal)
  - background fraction ~ 8.5% (8.9%) from 2012(2009) inclusive MC sample
- Continuum from data, rescaled for the right luminosity factor for each data taking period

Extraction of number of signal





- Signal+background shape form inclusive MC
  - background fraction ~ 8.5% (8.9%) from 2012(2009) inclusive MC sample
- Continuum shape from data
- Nsig2012 = 18796 ± 668
- Nsig2009 = 7370 ± 365
- ε = 0.31 (the same for 2009 and 2012)

$$Br_{\tau\tau} = \frac{\frac{N^{obs} - N^{obs}_{cont} - N^{norm}_{bg}(Br_{\tau\tau})}{\varepsilon_{e\mu} \cdot Br(e\mu)} - \sigma^{\tau\tau}_{Int}(Br_{\tau\tau}) \cdot L_{3.686}}{N_{\psi(2S)}}$$

2012 → $=(2.77 \pm 0.09) \times 10^{-3}$

2009 → $=(3.48 \pm 0.16) \times 10^{-3}$

From Zhang Bingxin (IHEP)

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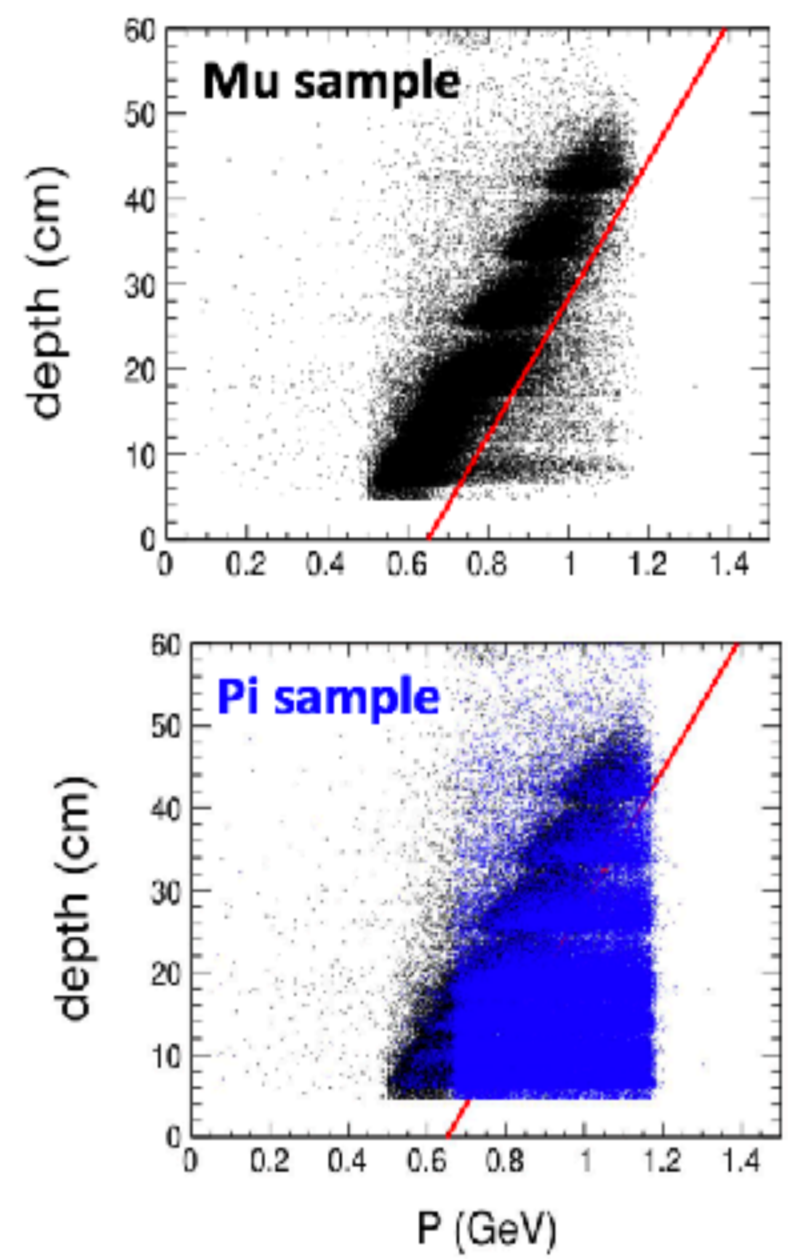
Events selection

◆ **Charged track**
- nCharged=2
- Vr<1cm, |Vz|<10cm
- |cosθ|<0.93
- ptrk<1.2 GeV
- Vertex Fit

◆ **Neutral track**
- Emc>0.025GeV(barrel), Emc>0.050 GeV(Endcap)
- $0<T_{EMC}<14$(x50ns)
- $\theta(\gamma,trk)>10^0$

◆ PID electron
- 0.8<E/p<1.2
- $\chi2_{dE/dx}<4$
- Δtof(e) <0.3 ns

◆ PID muon
- E/p<0.7
- $\chi2_{dE/dx}<4$
- Δtof(mu) <0.3 ns
- muc_dep>81*(ptrk-0.65)



same event and track selection

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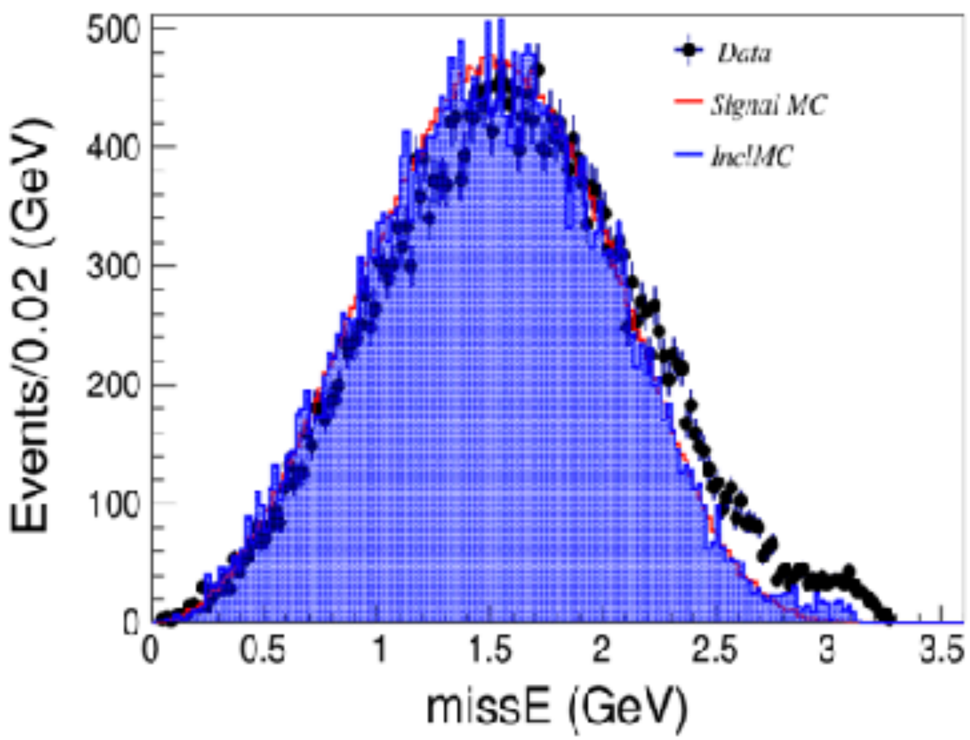
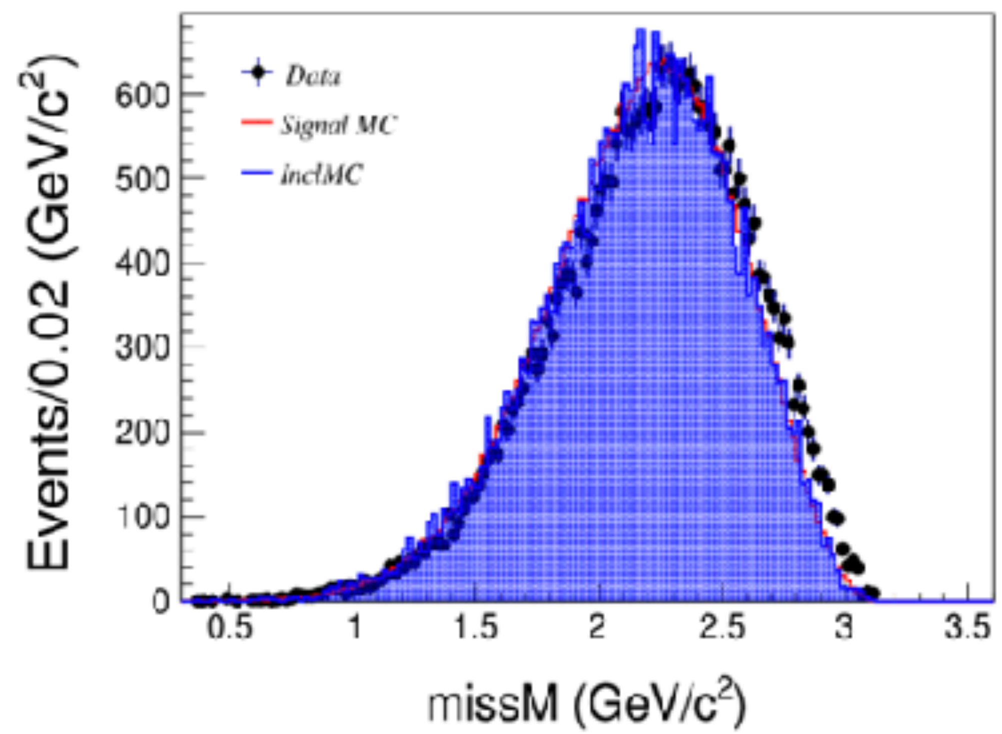
MC & Data distribution comparison(IV)

Normalized by number of events





Cross section calculation (IHEP)

Cross section calculation($e^+e^- \to \tau\tau$)

$$\sigma(W) = \frac{1}{\sqrt{2\pi}\Delta}\int_0^\infty dW' e^{-(W-W')^2/2\Delta^2}$$

$$\times \int_0^{1-(2m_\tau/W')^2} dx F(x,W')\sigma_1(W'\sqrt{1-x})$$

$$\sigma_1(W) = \frac{4\pi\alpha^2}{3W^2}\frac{\beta(3-\beta^2)}{2}\frac{F_c(\beta)F_r(\beta)}{[1-\Pi(W)]^2}$$

$$\times \Bigg\{ 1 + \frac{3M^3}{\alpha_s}\Gamma_{ee}^2 \frac{1}{1+\frac{2m_e^2}{M^2}} \frac{1}{\left(1-\frac{4m_e^2}{M^2}\right)^{1/2}}$$

$$\times \frac{2(W^2-M^2)}{(W^2-M^2)^2+M^2\Gamma^2}$$

Δ Energy spread
W the c.m. energy
$F_c(\beta)$ Coulomb factor
$F_r(\beta)$ radiative and spin correction factor

$$\beta = \sqrt{1-\left(\frac{2m_\tau}{W}\right)}$$

Cross section calculation($e^+e^- \to \tau\tau$)

$$+\left(\frac{3M^3}{\alpha_s}\right)^2 \Gamma_{ee}^2 \frac{1}{\left(1+\frac{2m_e^2}{M^2}\right)^{1/2}} \frac{1}{1-\frac{4m_e^2}{M^2}}$$

$$\times \frac{1}{(W^2-M^2)^2+M^2\Gamma^2}\Bigg\}$$

$$= \sigma_1^{\mathrm{QED}} + \sigma_1^{\mathrm{int}} + \sigma_1^{\psi(2S)}.$$

$$F_c(v) = \frac{\pi\alpha/v}{1-\exp(-\pi\alpha/v)}$$

$$F_r(v) = 1 + \frac{\alpha}{\pi}S(v) - \frac{\alpha\pi}{2v} - \frac{\alpha\pi v}{2}$$

Cross section calculation($e^+e^- \to \tau\tau$)

$$S(v) = \frac{1}{v}\Bigg\{(1+v^2)\Bigg[\frac{\pi^2}{6} + \ln\left(\frac{1+v}{2}\right)\ln\left(\frac{1+v}{1-v}\right) + 2\mathrm{Li}_2\left(\frac{1-v}{1+v}\right) + 2\mathrm{Li}_2\left(\frac{1+v}{2}\right)$$

$$-2\mathrm{Li}_2\left(\frac{1-v}{2}\right) - 4\mathrm{Li}_2(v) + \mathrm{Li}_2(v^2)\Bigg]$$

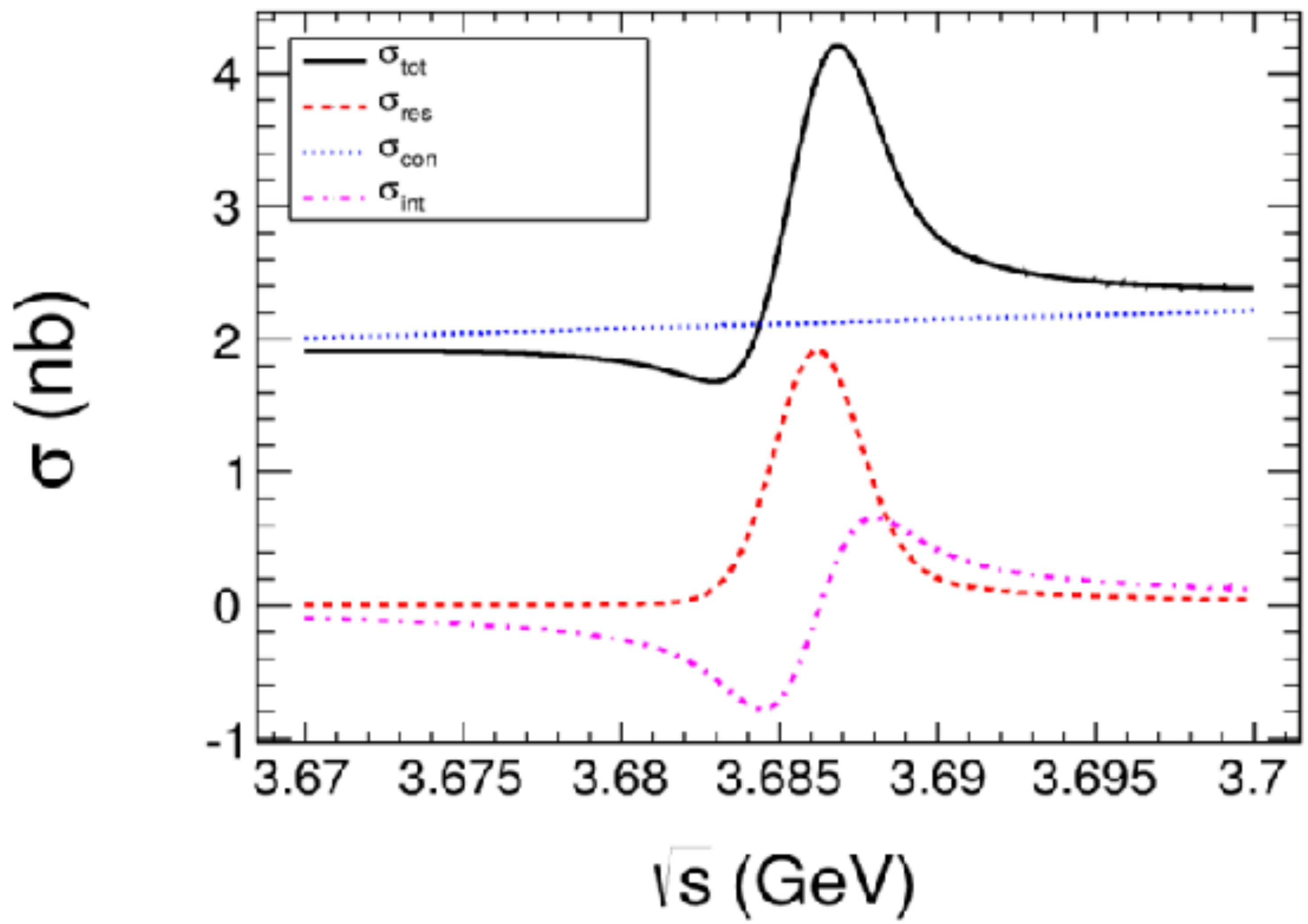
$$+\left[\frac{11}{8}(1+v^2) - 3v + \frac{1}{2}\frac{v^4}{(3-v^2)}\right]\ln\left(\frac{1+v}{1-v}\right)$$

$$+6v\ln\left(\frac{1+v}{2}\right) - 4v\ln v + \frac{3}{4}v\frac{(5-3v^2)}{(3-v^2)}\Bigg\}$$

$$\mathrm{Li}_2(x) = -\int_0^x \ln(1-t)dt/t = \sum_{n=1}^\infty x^n/n^2$$

From Zhang Bingxin (IHEP)

Cross section calculation($e^+e^- \to \tau\tau$)



σ_{Q+I} =2.125nb

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Systematic Uncertainties Zhang Bingxin (IHEP)

- tracking efficiency 2%
- luminosity 0.90%
- $\psi(2S)$ total number 0.65%

Chin. Phys. C 42 (2018) 023001

- MC statistic $\frac{1}{\sqrt{N}}\frac{\sqrt{(1-\varepsilon)}}{\sqrt{\varepsilon}}$ 0.2%
- Tau branching fraction 0.3% (PDG)

Source	Uncertainty(%)
Track efficiency	2
luminosity	0.9
Ψ(2S) total number	0.7
Branching fraction	0.3
MC statistic	0.2
* PID	2.8
Emis requirement	0.8
Θmis requirement	0.1
Background	0.4
Cross section calculation	0.4
Total	3.8

R-QCD group meeting

➢ E_{mis}, θ_{mis} cuts and cross section calculation

- E_{mis} cuts from 2.65 to 2.70 GeV 0.8%
- $\cos\theta_{mis}$ cuts from 0.80 to 0.75 0.1%
- Background evets change 1σ error. 0.4%
- QED cross section calculation changing mass of $\psi(2s)$ mass 1MeV and energy spread 0.4MeV 0.4%

* ➢ PID

- E/p requirement for electron from 0.8 to 0.9 0.8%
- E/p requirement for muon from 0.7 to 0.65 2.0%
- dE/dx requirement from 4 to 5 0.8%
- Δ (tof) requirement from 0.3 to 0.2 1.3%
- identity of muon and pion slope from 0.81 to 0.90 and intercept from 0.65 to 0.7 0.8%

From Zhang Bingxin (IHEP)

$$B(\tau\tau) = \frac{\frac{N_{e\mu} - N_{bg}}{B\varepsilon} - \sigma_{Q+I}L}{N_{\psi(2S)}}$$

This term is estimated by QED calculation

- B fraction of τ+τ- events yielding the eμ topology. 0.6190（PDG）
- $N_{e\mu}$, N_{bg} , $N_{\psi(2S)}$ Events number of eu, background and ψ(2S)
- ε detection efficiency
- σ_{Q+I} *QED production* cross section 2.125nb
- L the accumulated luminosity ψ(2S)

Branching fraction calculation

Item/ Year	Nobs	Nbkg	Lum. (pb^{-1})	ε	$N_{\psi'}(10^6)$	$Br(10^{-3})$
09+12	53637	3659	668.55	0.3065	481.1	2.70±0.01±0.11
This work	$(2.70\pm0.11)\times10^{-3}$					

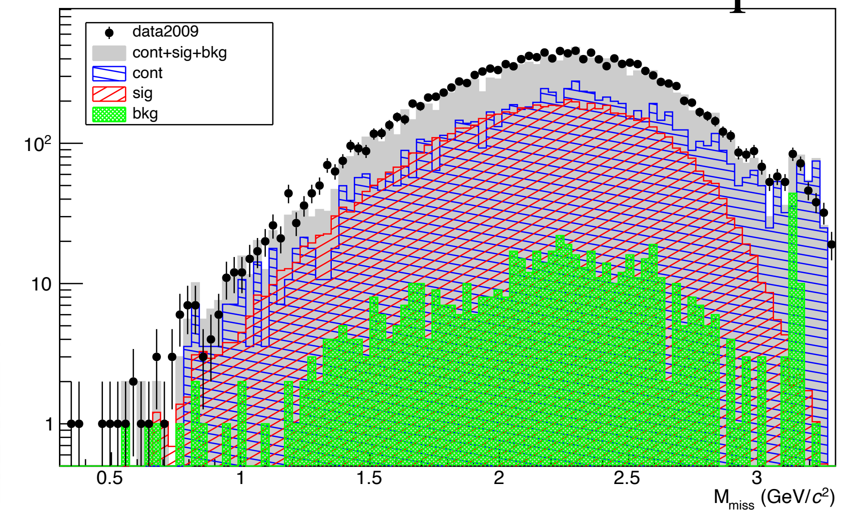
$(3.1 \pm 0.4) \times 10^{-3}$ (PDG)

Additional tests

2009 DATA SET

- Check consistency of continuum
  - data set collected in 2009

2009 data sample



$$Br_{\tau\tau} = \frac{\frac{N^{obs}-N^{obs}_{cont}-N^{norm}_{bg}(Br_{\tau\tau})}{\varepsilon_{e\mu}\cdot Br(e\mu)} - \sigma^{\tau\tau}_{Int}(Br_{\tau\tau})\cdot L_{3.686}}{N_{\psi(2S)}}$$

~3.46×10^{-3}

$$B(\tau\tau) = \frac{\frac{N_{e\mu}-N_{bg}}{B\varepsilon} - \sigma_{Q+I}L}{N_{\psi(2S)}}$$

This term is estimated by QED calculation

~3.41×10^{-3}

2012 DATA SET

- Check consistency of continuum
  - data set collected in 2009

σ_{int} = -66.587 pb^{-1}

$$Br_{\tau\tau} = \frac{\frac{N^{obs}-N^{obs}_{cont}-N^{norm}_{bg}(Br_{\tau\tau})}{\varepsilon_{e\mu}\cdot Br(e\mu)} - \sigma^{\tau\tau}_{Int}(Br_{\tau\tau})\cdot L_{3.686}}{N_{\psi(2S)}}$$

~2.77×10^{-3}

$$B(\tau\tau) = \frac{\frac{N_{e\mu}-N_{bg}}{B\varepsilon} - \sigma_{Q+I}L}{N_{\psi(2S)}}$$

This term is estimated by QED calculation

~2.64×10^{-3}

Plans and Conclusions

- First very preliminary results obtained
  - BR = $(2.70 \pm 0.11) \times 10^{-3}$
- to do list:
  - understand the difference between 2009 and 2012 data set
  - Systematic uncertainties to be improved
  - Use the new Psi(2S) data set collected in 2021

Thanks for your attention

Background analysis (inclusive MC)

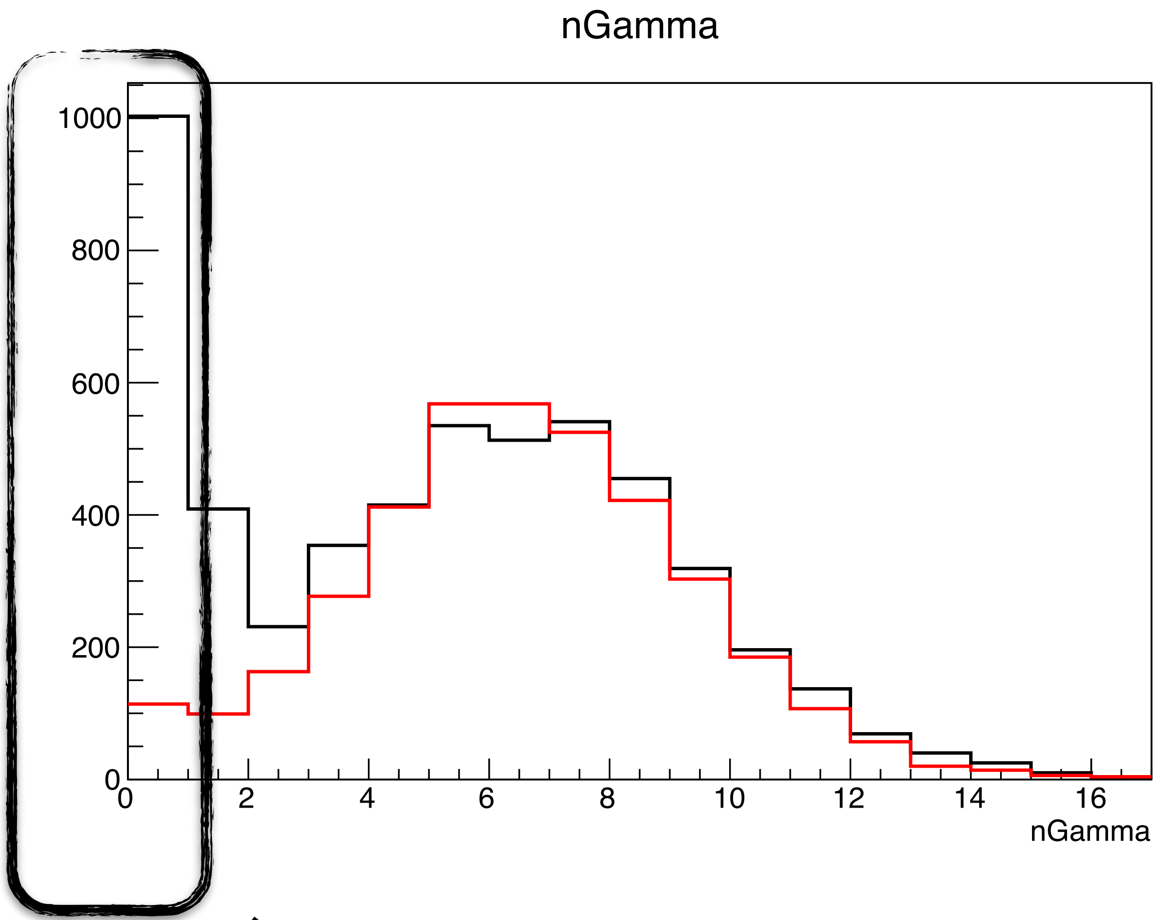
No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	$e^+\bar{\nu}_\mu\bar{\nu}_\tau\nu_e\mu^-\nu_\tau$	0	8018	8018
1	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$\bar{\nu}_e\mu^+\bar{\nu}_\tau e^-\nu_\mu\nu_\tau$	1	7939	15957
2	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \pi^-\nu_\tau$	$e^+\bar{\nu}_\tau\pi^-\nu_e\nu_\tau$	2	735	16692
3	$\psi' \to \tau^+\tau^-, \tau^+ \to \pi^+\pi^0\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$\bar{\nu}_e\bar{\nu}_\tau e^-\pi^0\nu_\tau\pi^+$	7	664	17356
4	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau\gamma_{FSR}$	$e^+\bar{\nu}_\mu\bar{\nu}_\tau\nu_e\mu^-\nu_\tau$	3	568	17924
5	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma_{FSR}$	$\bar{\nu}_e\mu^+\bar{\nu}_\tau e^-\nu_\mu\nu_\tau$	4	556	18480
6	$\psi' \to \tau^+\tau^-, \tau^+ \to \pi^+\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma_{FSR}$	$\bar{\nu}_e\bar{\nu}_\tau e^-\nu_\tau\pi^+$	12	55	18535
7	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau\gamma_{FSR}, \tau^- \to \pi^-\pi^0\nu_\tau$	$e^+\bar{\nu}_\tau\pi^-\pi^0\nu_e\nu_\tau$	13	40	18575
8	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \pi^-\pi^-\pi^+\nu_\tau$	$e^+\bar{\nu}_\tau\pi^-\pi^-\nu_e\nu_\tau\pi^+$	16	25	18600
9	$\psi' \to \tau^+\tau^-, \tau^+ \to \pi^+\pi^+\pi^-\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$\bar{\nu}_e\bar{\nu}_\tau\pi^- e^-\nu_\tau\pi^+\pi^+$	5	24	18624
10	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma_{FSR}\gamma_{FSR}$	$\bar{\nu}_e\mu^+\bar{\nu}_\tau e^-\nu_\mu\nu_\tau$	15	23	18647
11	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to K^{*-}\nu_\tau, K^{*-} \to \bar{K}^0\pi^-, \bar{K}^0 \to K_L$	$e^+\bar{\nu}_\tau\pi^-\nu_e K_L\nu_\tau$	14	23	18670
12	$\psi' \to \tau^+\tau^-, \tau^+ \to K^{*+}\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau, K^{*+} \to K^0\pi^+, K^0 \to K_L$	$\bar{\nu}_e\bar{\nu}_\tau e^- K_L\nu_\tau\pi^+$	17	23	18693
13	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau\gamma_{FSR}\gamma_{FSR}, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	$e^+\bar{\nu}_\mu\bar{\nu}_\tau\nu_e\mu^-\nu_\tau$	9	19	18712
14	$\psi' \to \tau^+\tau^-\gamma_{FSR}, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	$e^+\bar{\nu}_\mu\bar{\nu}_\tau\nu_e\mu^-\nu_\tau$	8	8	18720
15	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to e^+e^-\gamma_{FSR}$	$e^+\pi^-e^-\pi^+$	28	7	18727
16	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	$\mu^+\bar{\nu}_\mu\bar{\nu}_\tau\mu^-\nu_\mu\nu_\tau$	11	4	18731
17	$\psi' \to \tau^+\tau^-, \tau^+ \to \pi^+\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma_{FSR}\gamma_{FSR}$	$\bar{\nu}_e\bar{\nu}_\tau e^-\nu_\tau\pi^+$	35	4	18735
18	$\psi' \to \tau^+\tau^-, \tau^+ \to K^{*+}\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma_{FSR}, K^{*+} \to K^0\pi^+, K^0 \to K_L$	$\bar{\nu}_e\bar{\nu}_\tau e^- K_L\nu_\tau\pi^+$	21	3	18738
19	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to K^{*-}\nu_\tau, K^{*-} \to \bar{K}^0\pi^-, \bar{K}^0 \to K_S, K_S \to \pi^+\pi^-$	$e^+\bar{\nu}_\tau\pi^-\pi^-\nu_e\nu_\tau\pi^+$	33	3	18741
20	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to K^-\nu_\tau$	$e^+\bar{\nu}_\tau K^-\nu_e\nu_\tau$	24	3	18744
21	$\psi' \to \tau^+\tau^-\gamma_{FSR}, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$\bar{\nu}_e\mu^+\bar{\nu}_\tau e^-\nu_\mu\nu_\tau$	44	3	18747
22	$\psi' \to \tau^+\tau^-, \tau^+ \to \pi^+\pi^0\bar{\nu}_\tau, \tau^- \to \pi^-\pi^0\nu_\tau$	$\bar{\nu}_\tau\pi^-\pi^0\pi^0\nu_\tau\pi^+$	29	2	18749
23	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau\gamma_{FSR}, \tau^- \to \pi^-\pi^-\pi^+\nu_\tau$	$e^+\bar{\nu}_\tau\pi^-\pi^-\nu_e\nu_\tau\pi^+$	18	2	18751
24	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau\gamma_{FSR}\gamma_{FSR}, \tau^- \to \pi^0\pi^0\pi^-\nu_\tau$	$e^+\bar{\nu}_\tau\pi^-\pi^0\pi^0\nu_e\nu_\tau$	25	2	18753
25	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to \pi^-\pi^0\nu_\tau$	$\mu^+\bar{\nu}_\tau\pi^-\pi^0\nu_\mu\nu_\tau$	37	2	18755
26	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to e^+e^-\gamma_{FSR}\gamma_{FSR}$	$e^+\pi^-e^-\pi^+$	6	2	18757
27	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau\gamma_{FSR}, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma_{FSR}\gamma_{FSR}$	$\bar{\nu}_e\mu^+\bar{\nu}_\tau e^-\nu_\mu\nu_\tau$	27	1	18758
28	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau\gamma_{FSR}, \tau^- \to K^{*-}\nu_\tau, K^{*-} \to \bar{K}^0\pi^-, \bar{K}^0 \to K_L$	$e^+\bar{\nu}_\tau\pi^-\nu_e K_L\nu_\tau$	10	1	18759
29	$\psi' \to \pi^0\pi^0\omega, \omega \to \pi^-\pi^+\pi^0$	$\pi^-\pi^0\pi^0\pi^0\pi^+$	22	1	18760

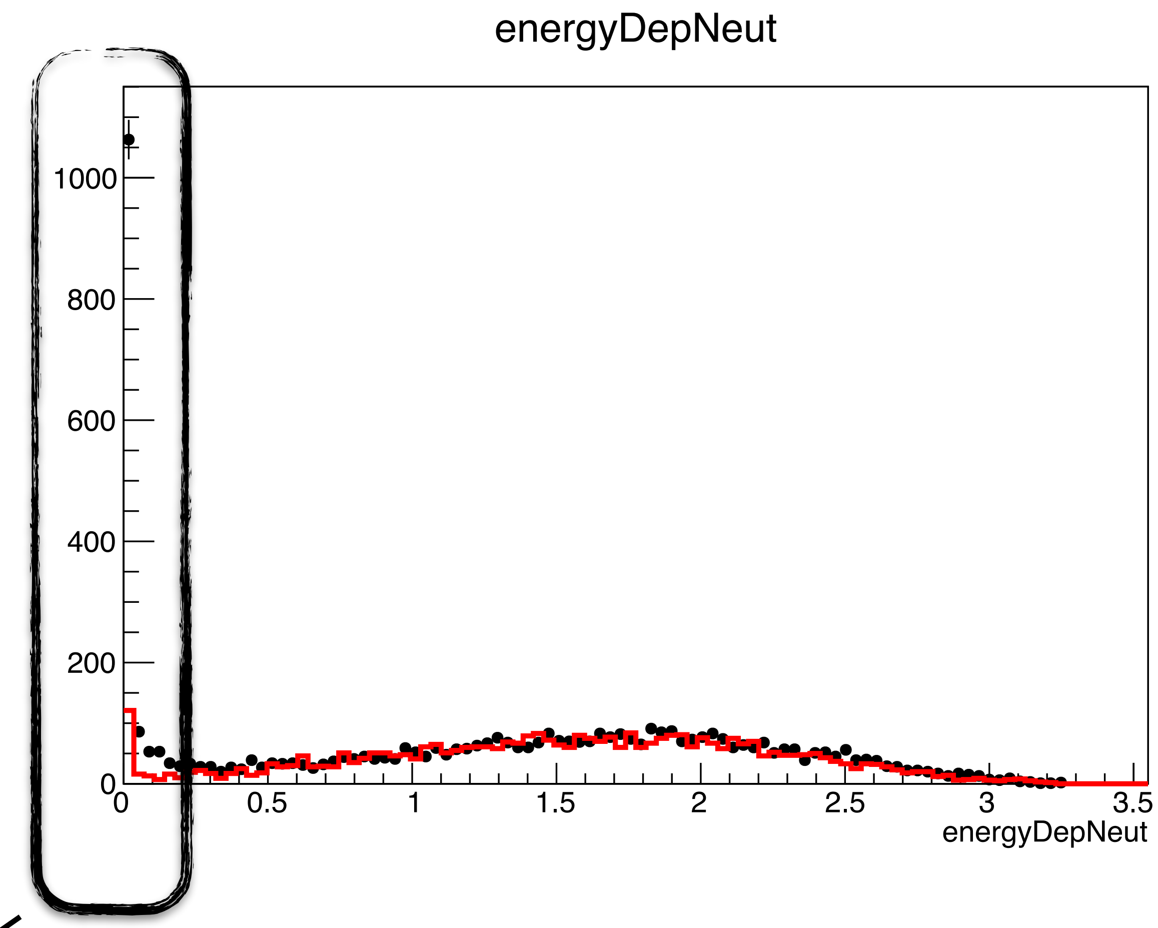
Mainly background come from eπ and eK events with same intermediate state ττ and ππJ/ψ (J/ψ to electron pairs)

Check the difference between data and inclusive MC

RUN 25338

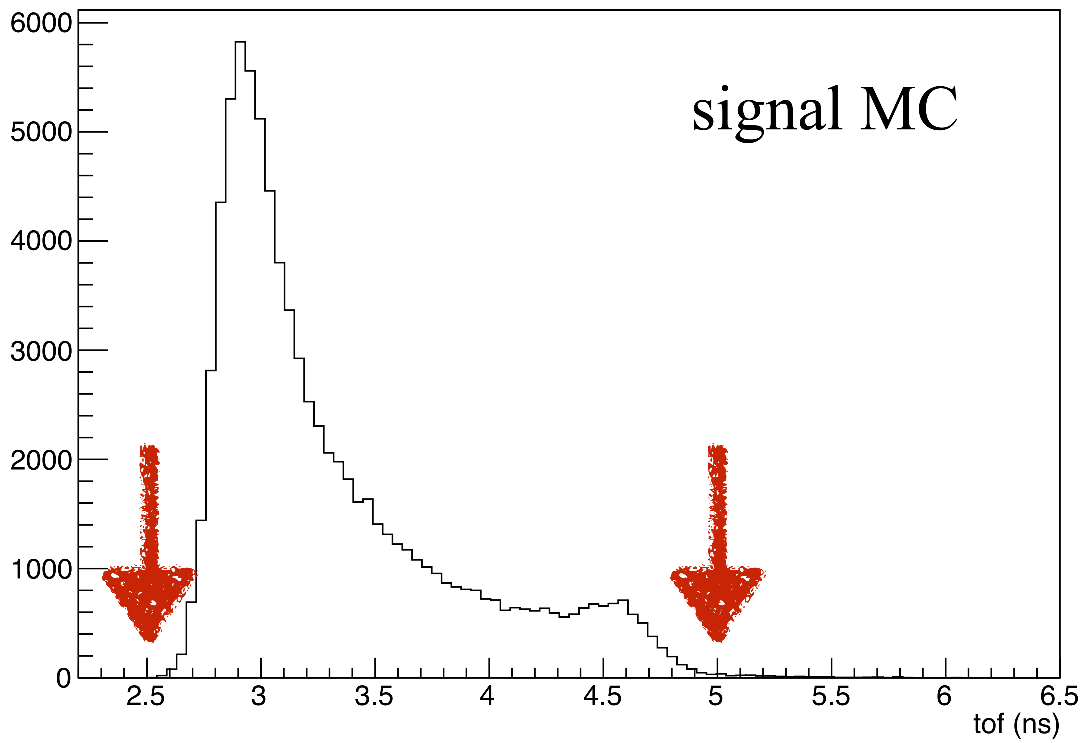
- Comparison between data and inclusive MC distributions





Our signal region!!!

Additional cuts II



- 2.5<tof < 5 (ns)

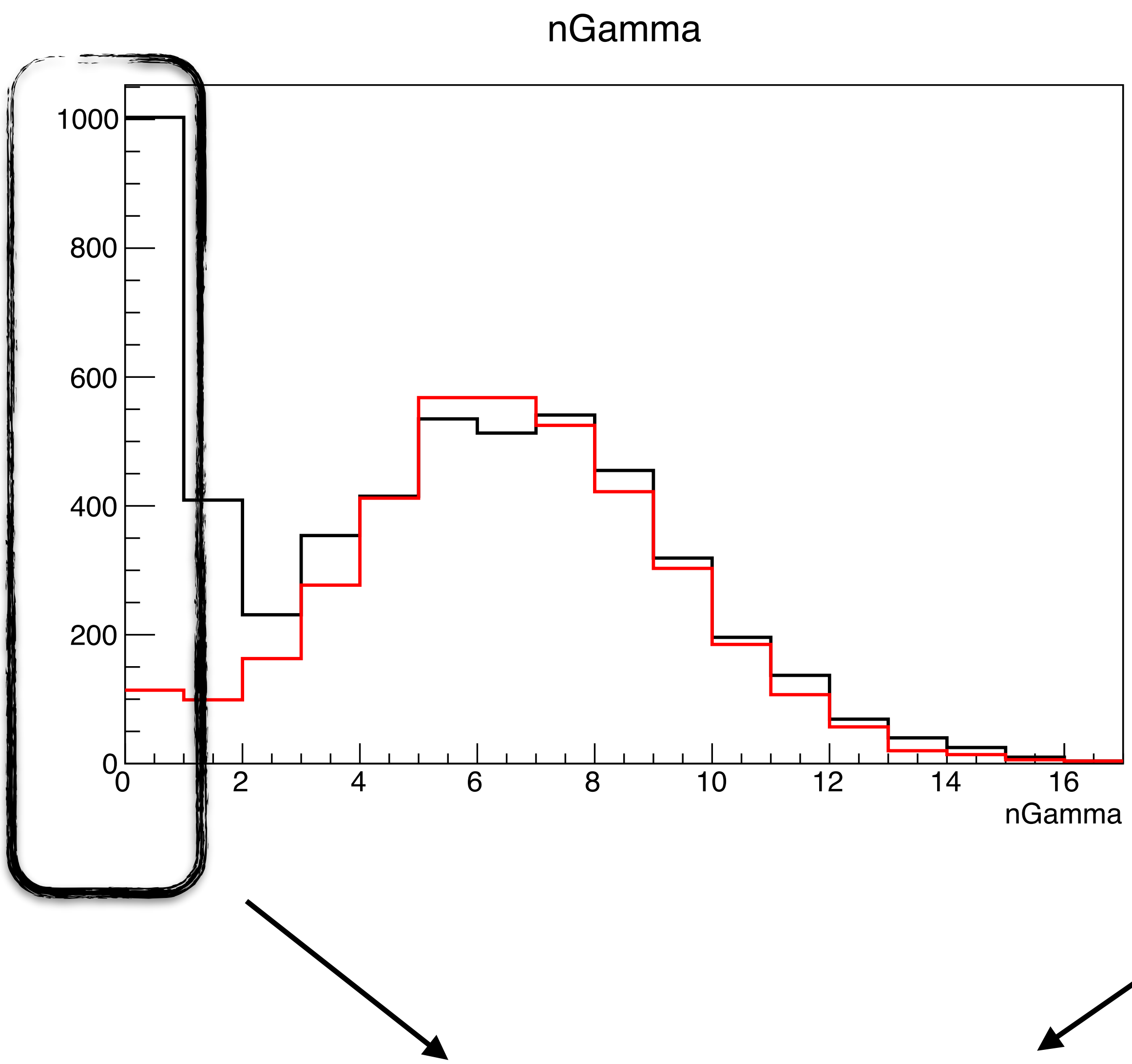
Missing mass and missing energy:

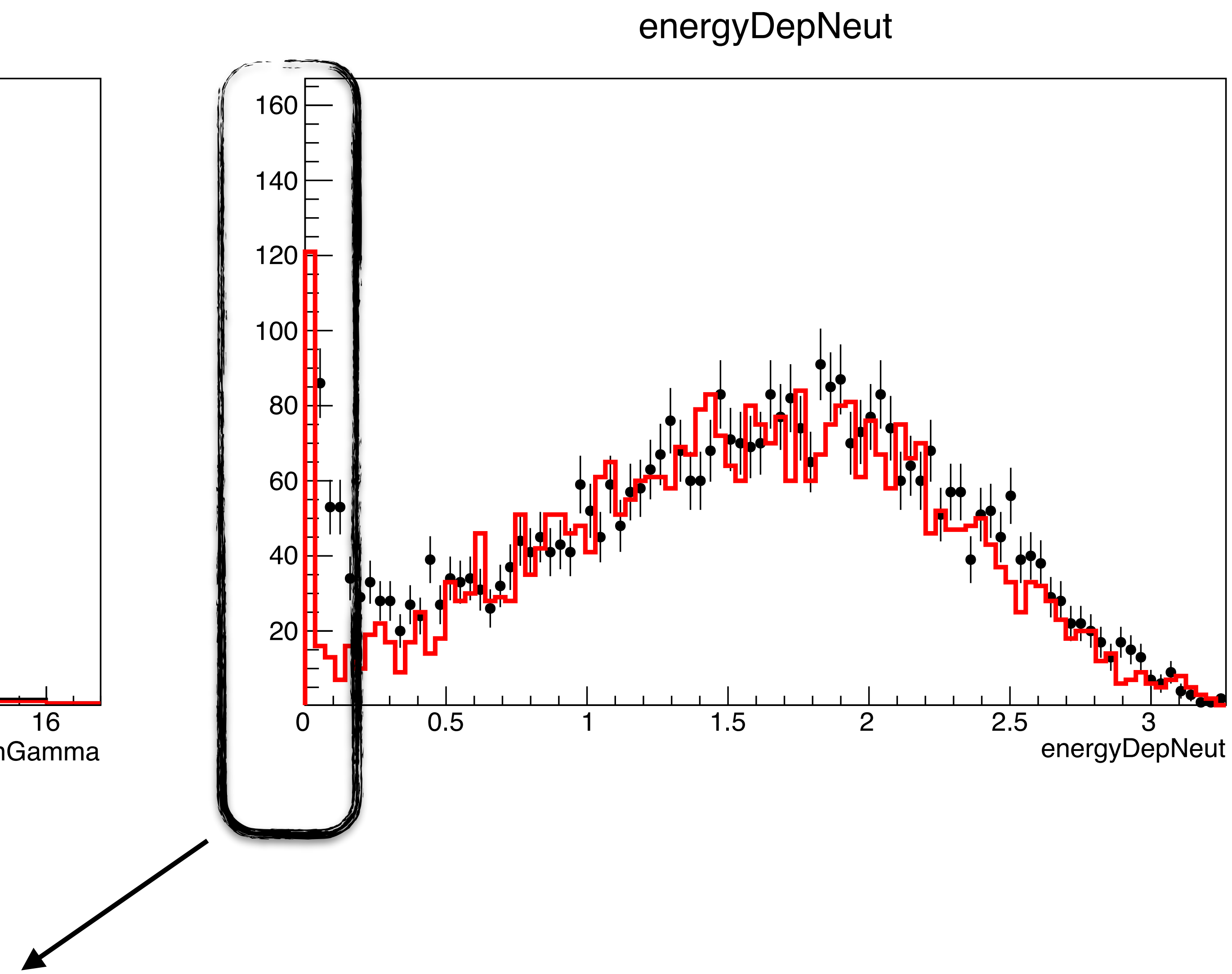
- *4mom_miss = 4mom_ψ2s - 4mom_ll*
- *U = E_miss = 4mom_miss.e()-|4mom_miss .p()|*

Check the difference between data and inclusive MC

RUN 25338

- Comparison between data and inclusive MC distributions

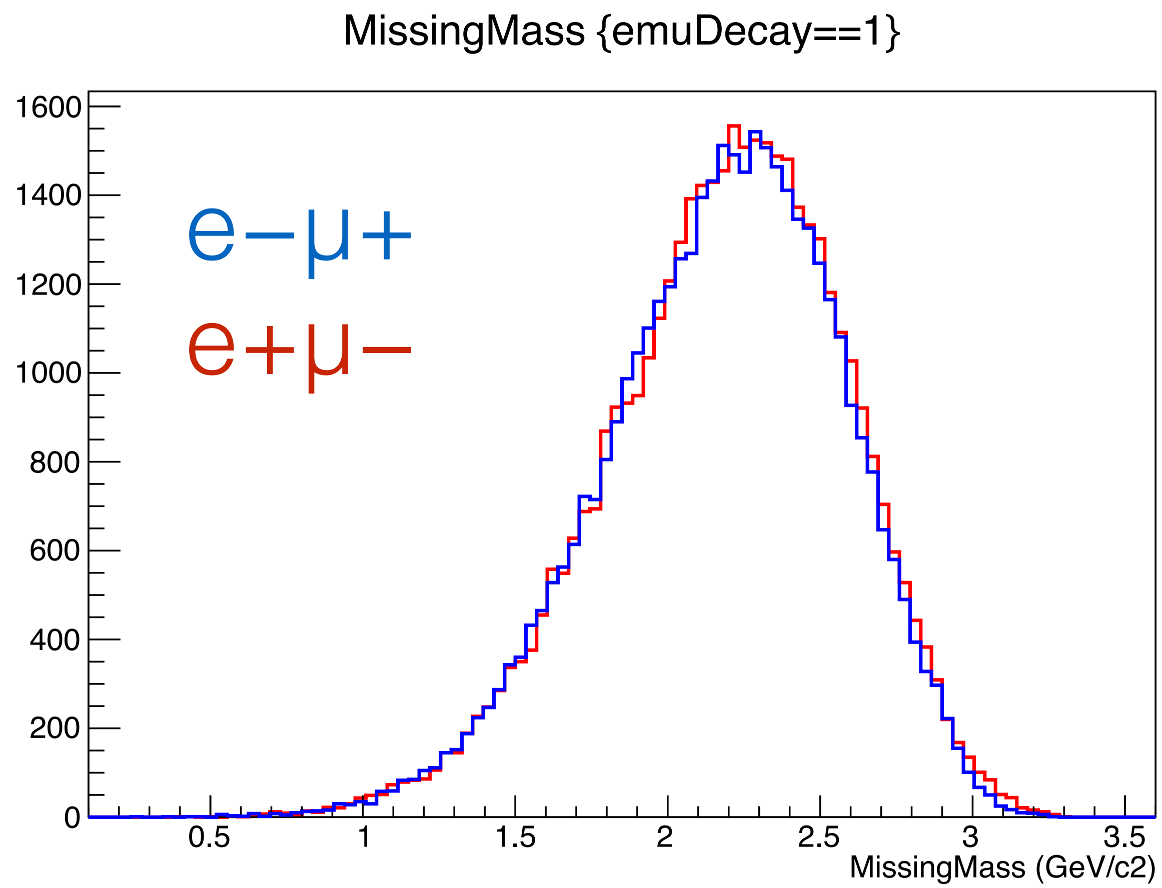




Our signal region!!!

Inclusive MC sample is not reliable

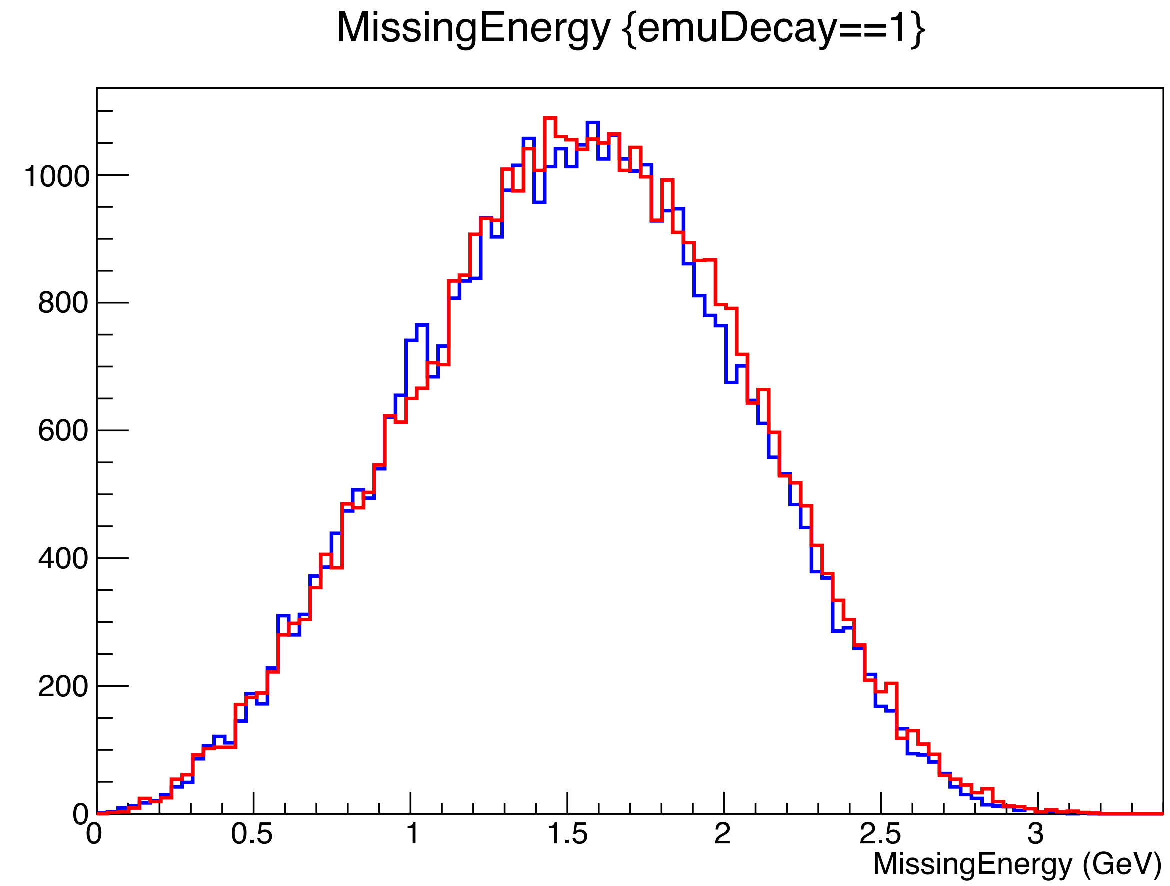
Signal MC: distributions III



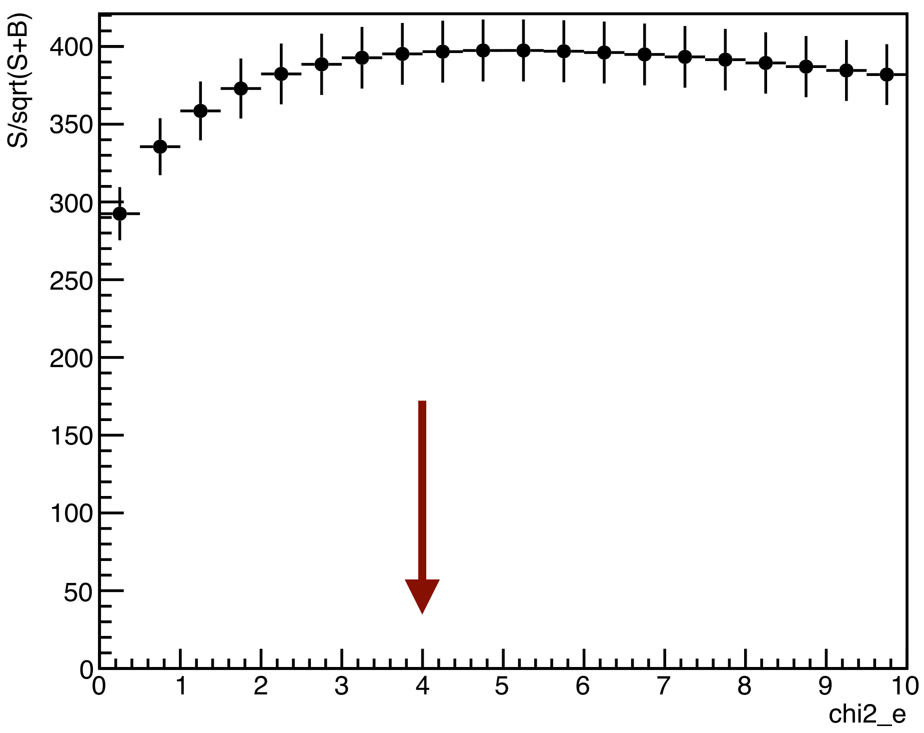
Missing energy and missing mass:

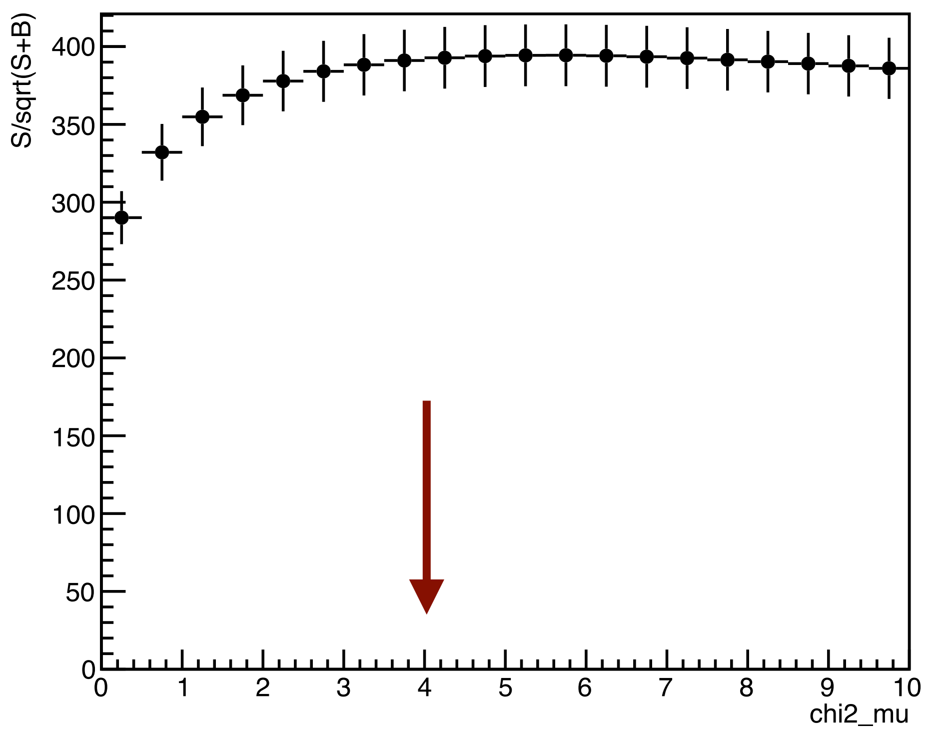
- *4mom_miss = 4mom_ψ2s - 4mom_ll*
- *U = E_miss = 4mom_miss.e()-|4mom_miss .p()|*

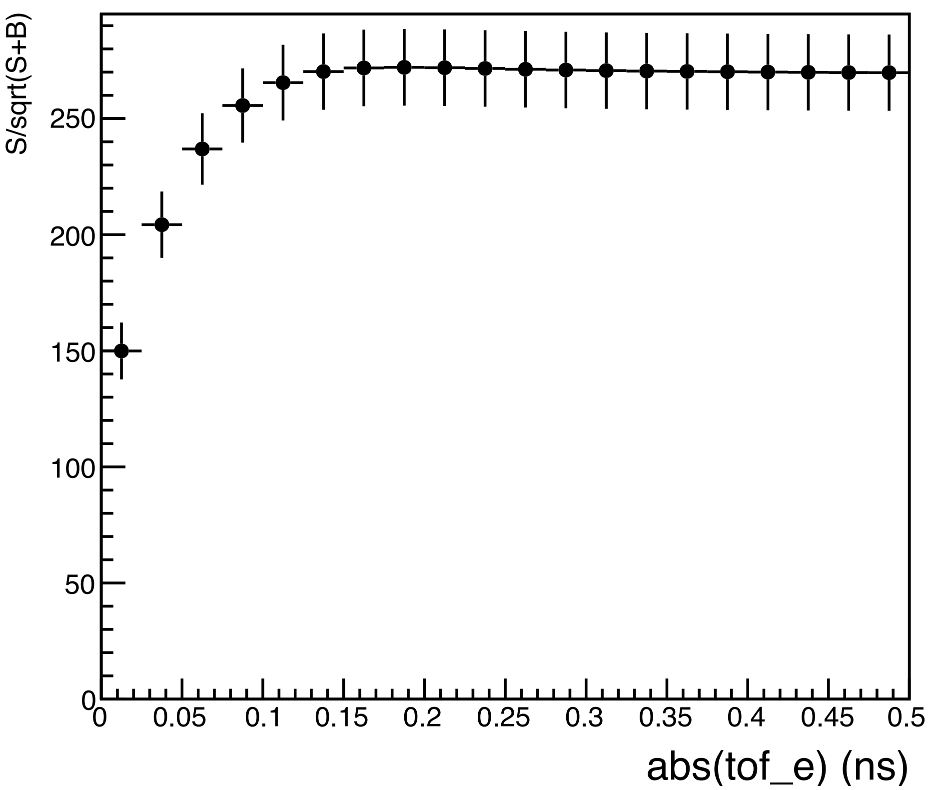
Distributions after cuts and PID selection

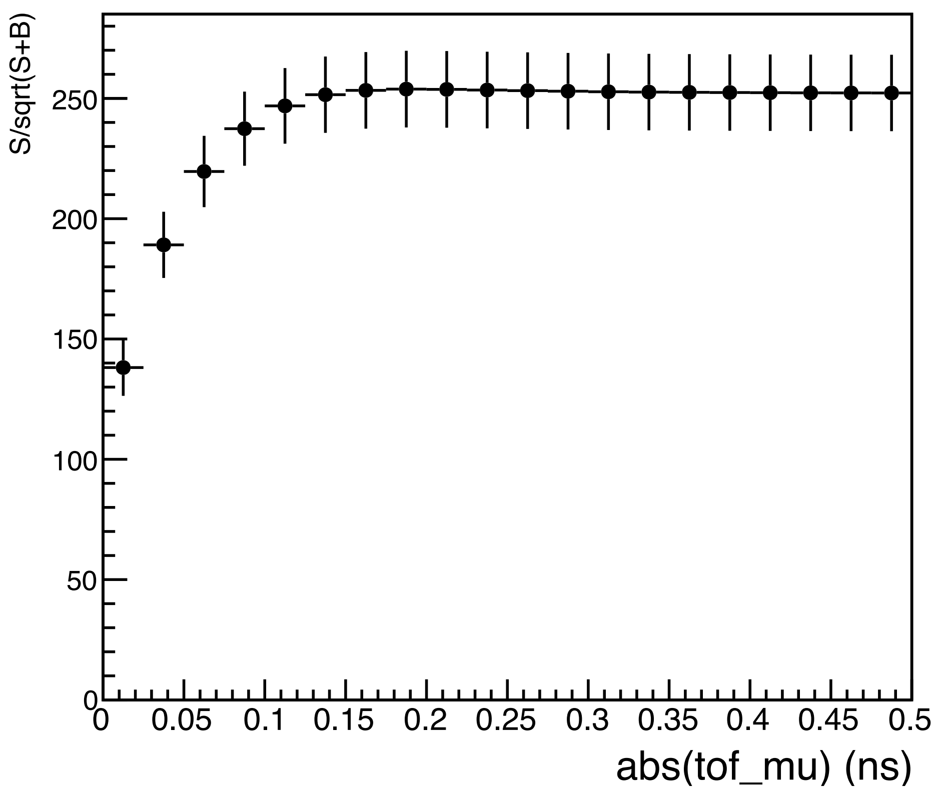


Cuts Optimization









Background studies

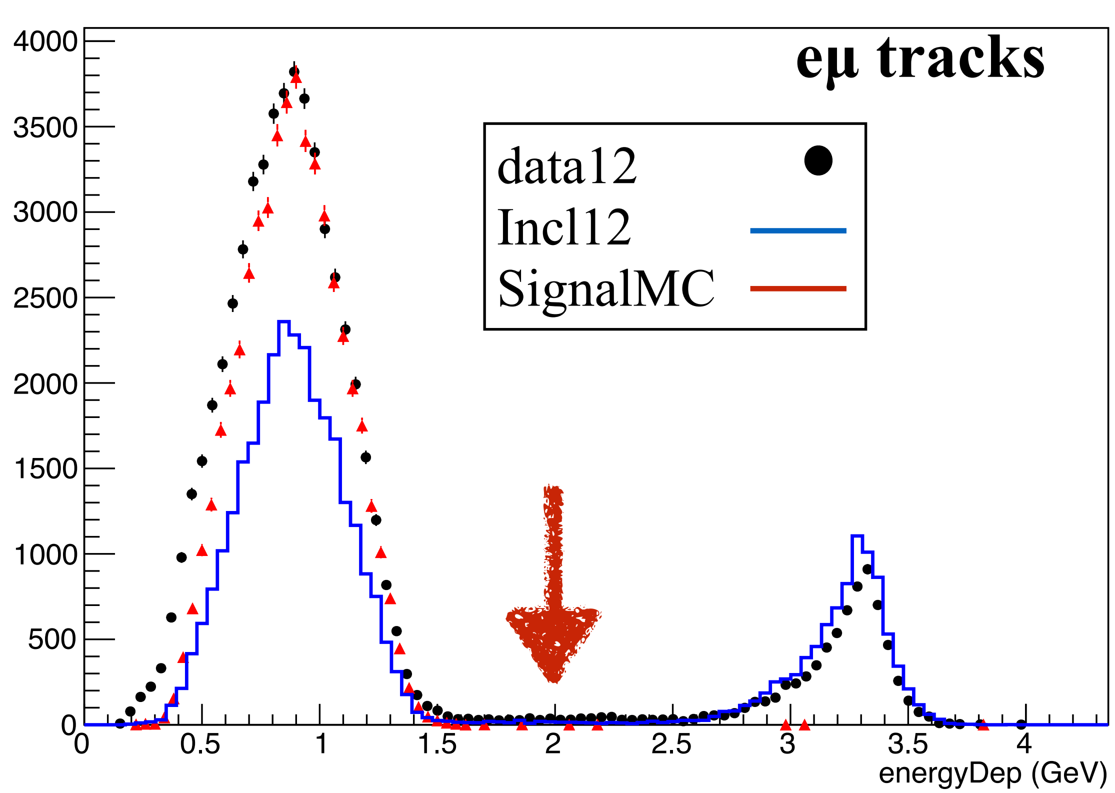
Several background taken into account:

CUTS	$\psi(2S)\rightarrow\pi^+e^-3\nu$	$\psi(2S)\rightarrow\pi^-e^+3\nu$	$\psi(2S)\rightarrow\pi^+\mu^-3\nu$	$\psi(2S)\rightarrow\pi^-\mu^+3\nu$	$\psi(2S)\rightarrow\pi^-\pi^+3\nu$	SIGNAL $\psi(2S)\rightarrow e\mu 4\nu$
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

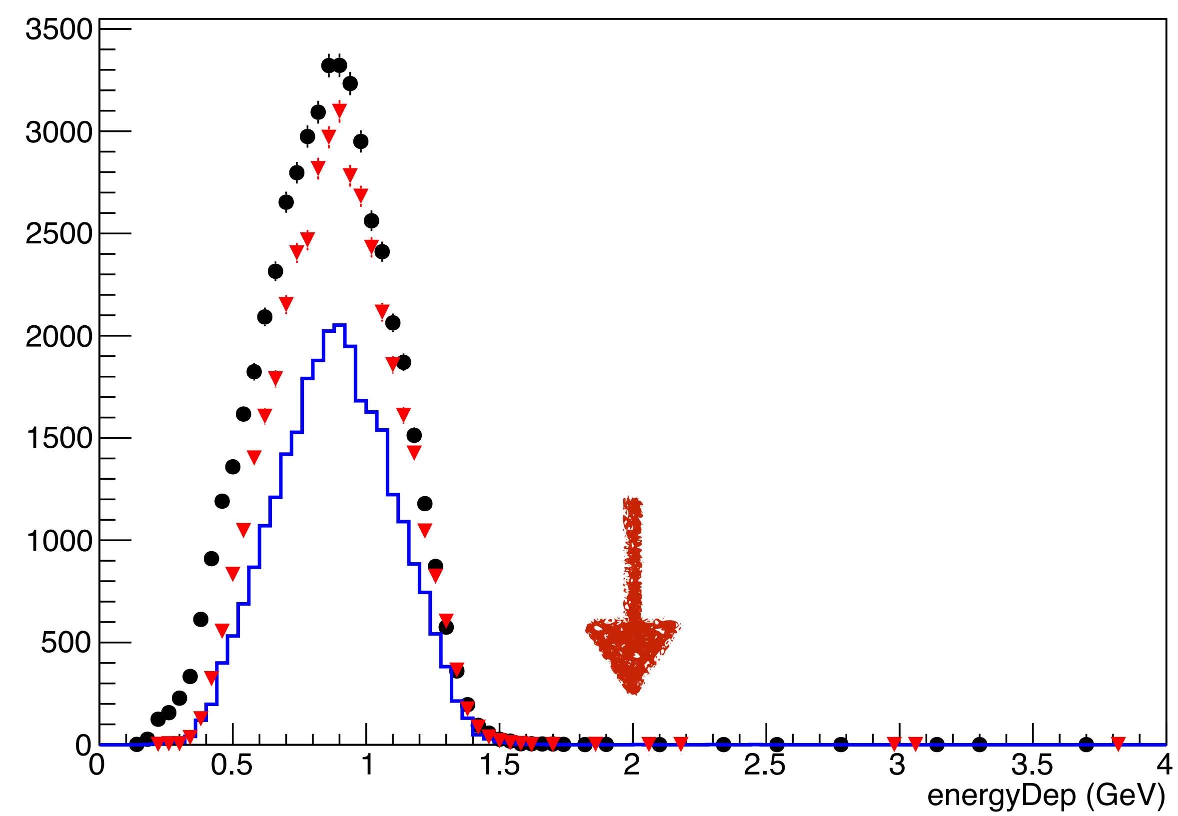
$\psi(2S)\rightarrow\pi e 3\nu$ non-negligile contribution

Additional cuts I

*signal arbitrary scale



NgoodTracks ==2

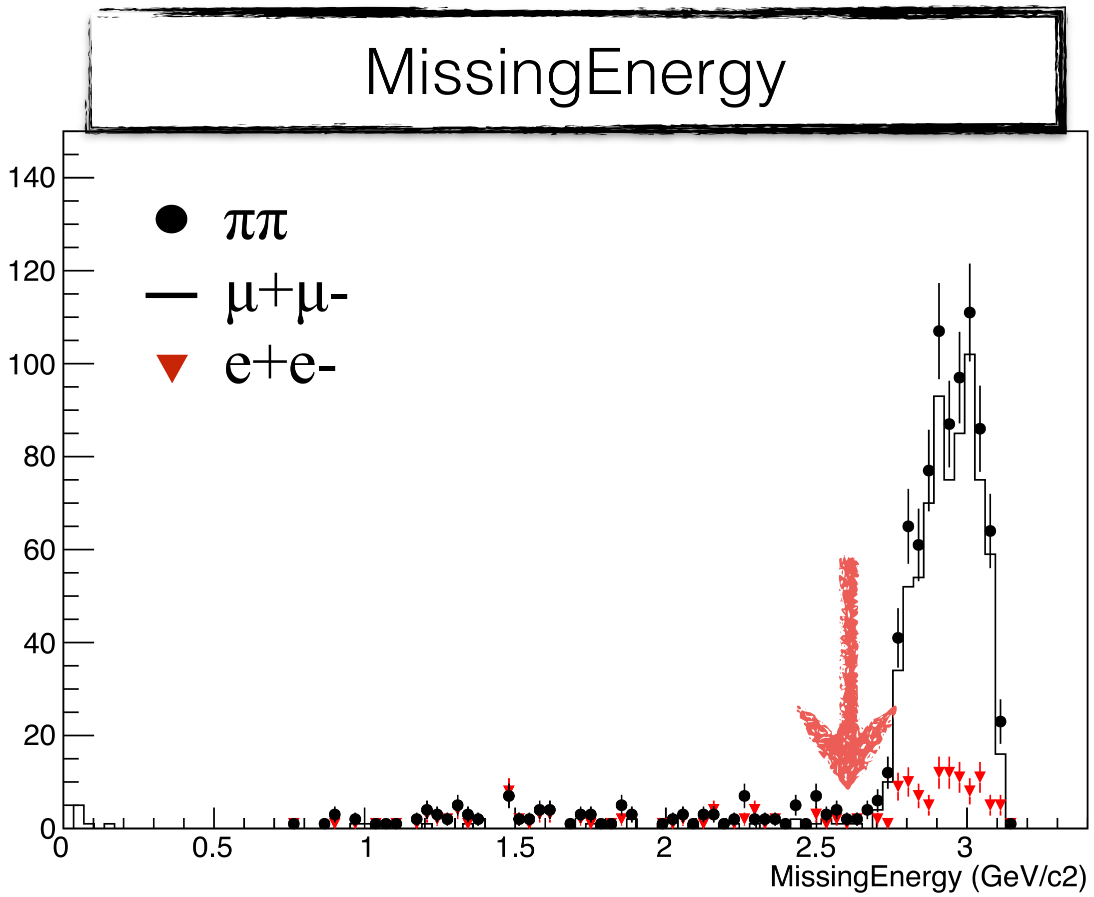


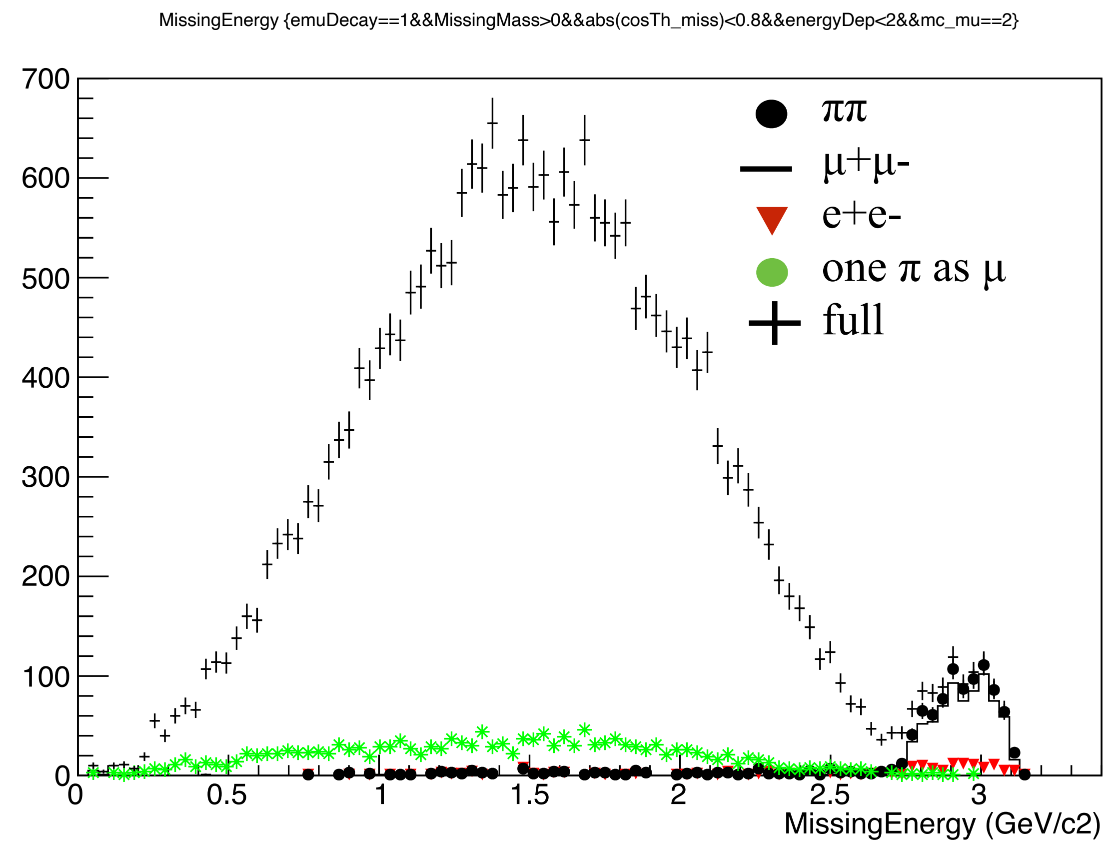
NTracks ==2

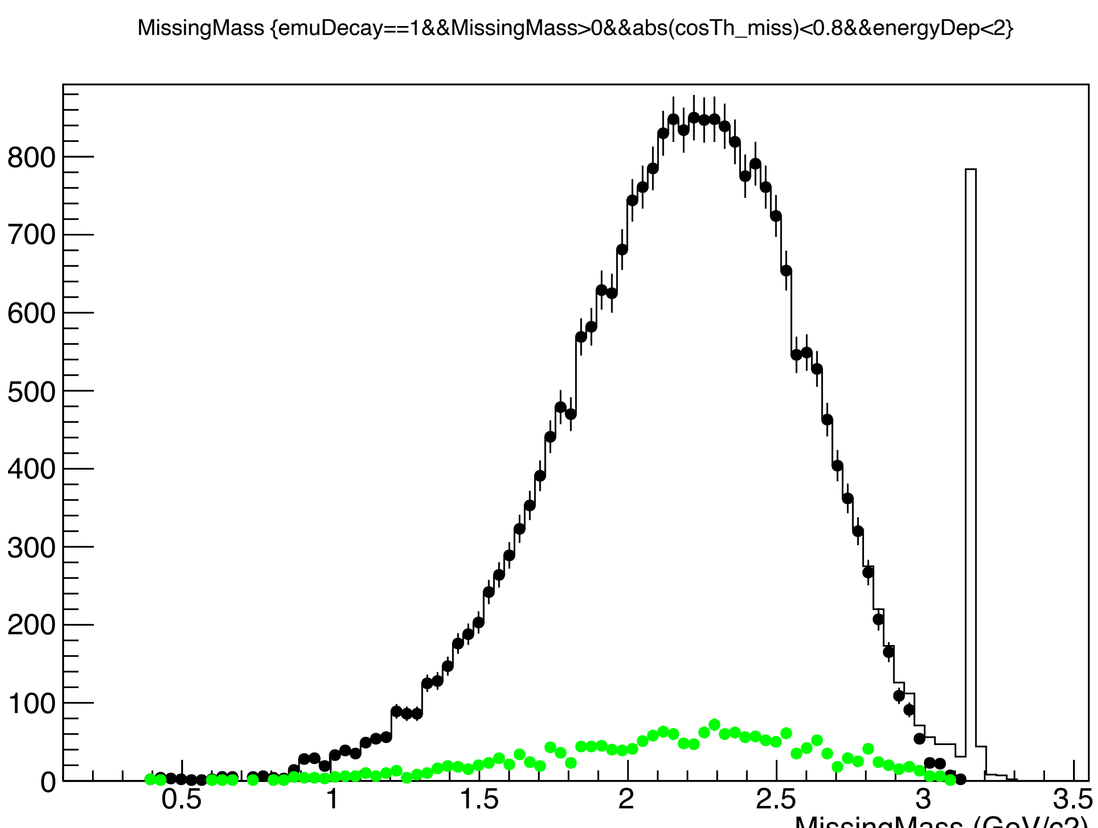
Full data-2012 and inclusive-2012 MC sample analyzed

- 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 II





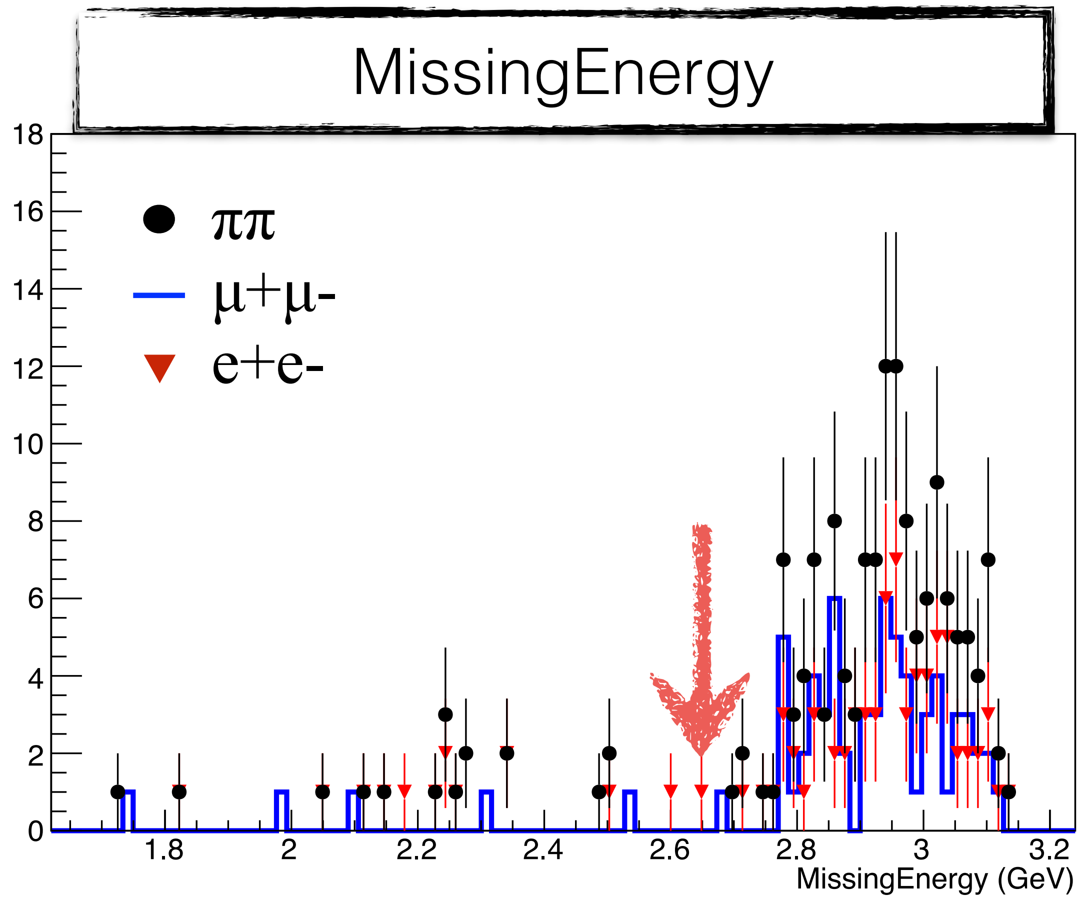


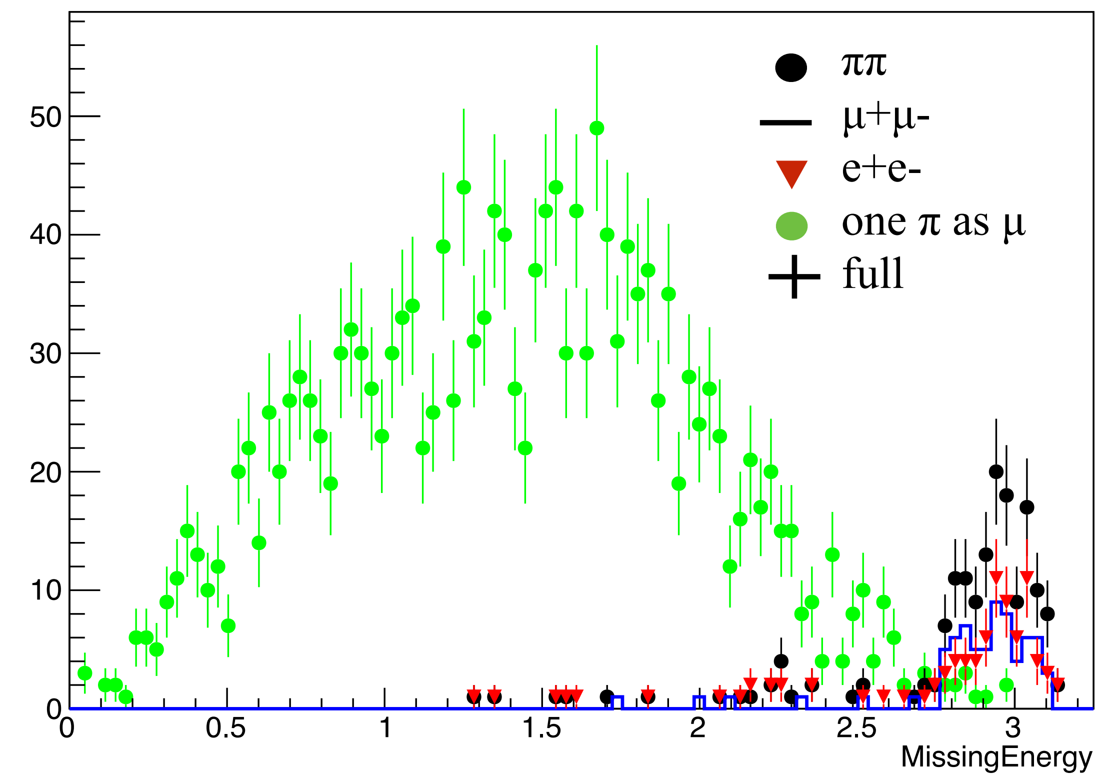
— no cut in MissingEnergy

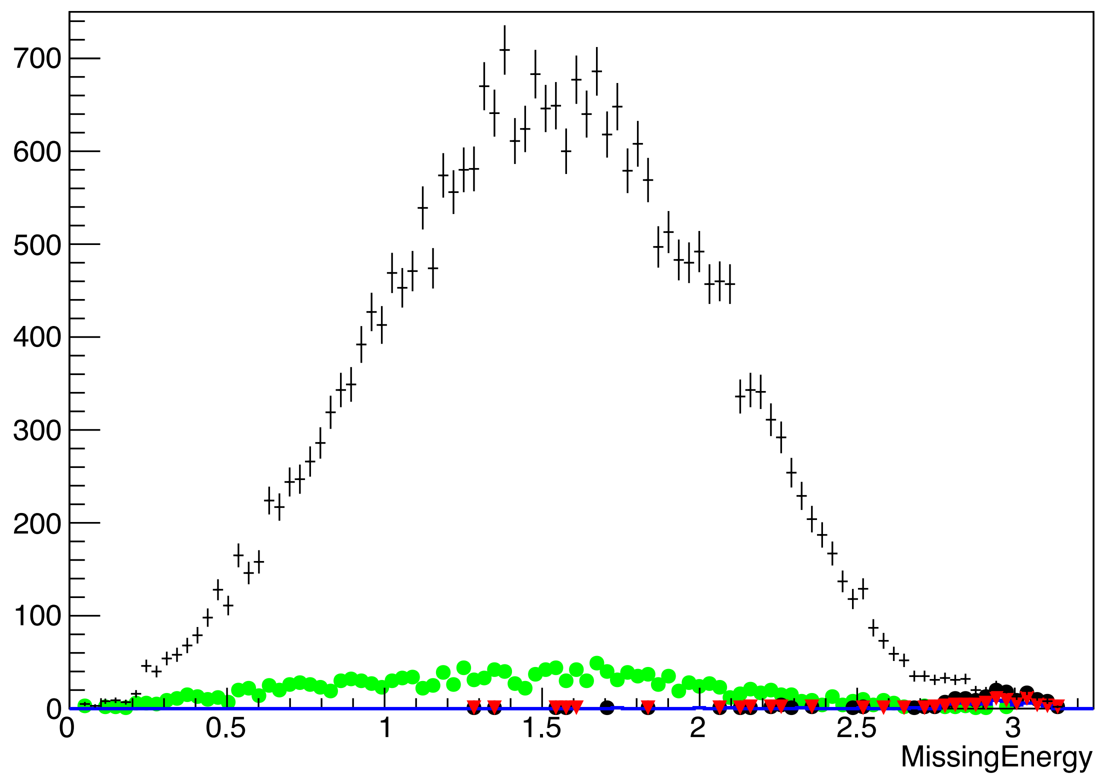
● MissingEnergy<2.65 GeV

● pion contamination

Additional cuts II

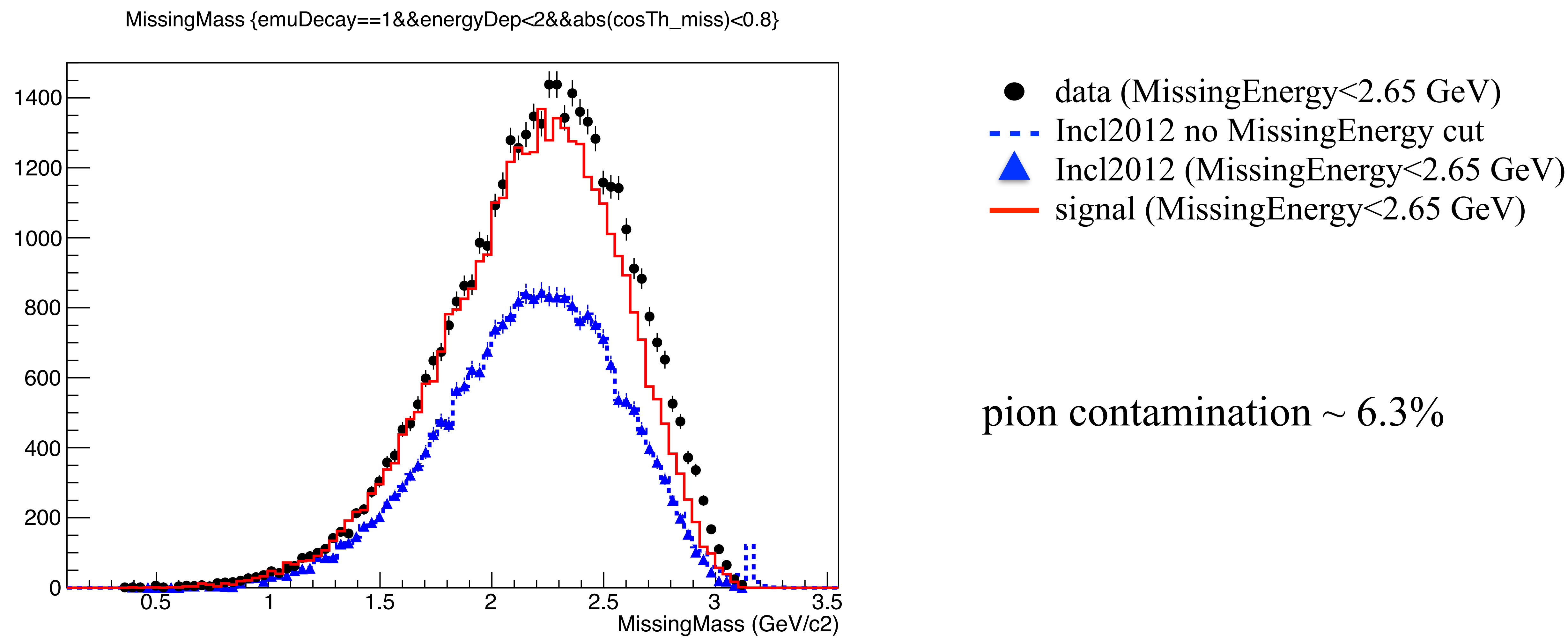






MissingEnergy < 2.65 GeV

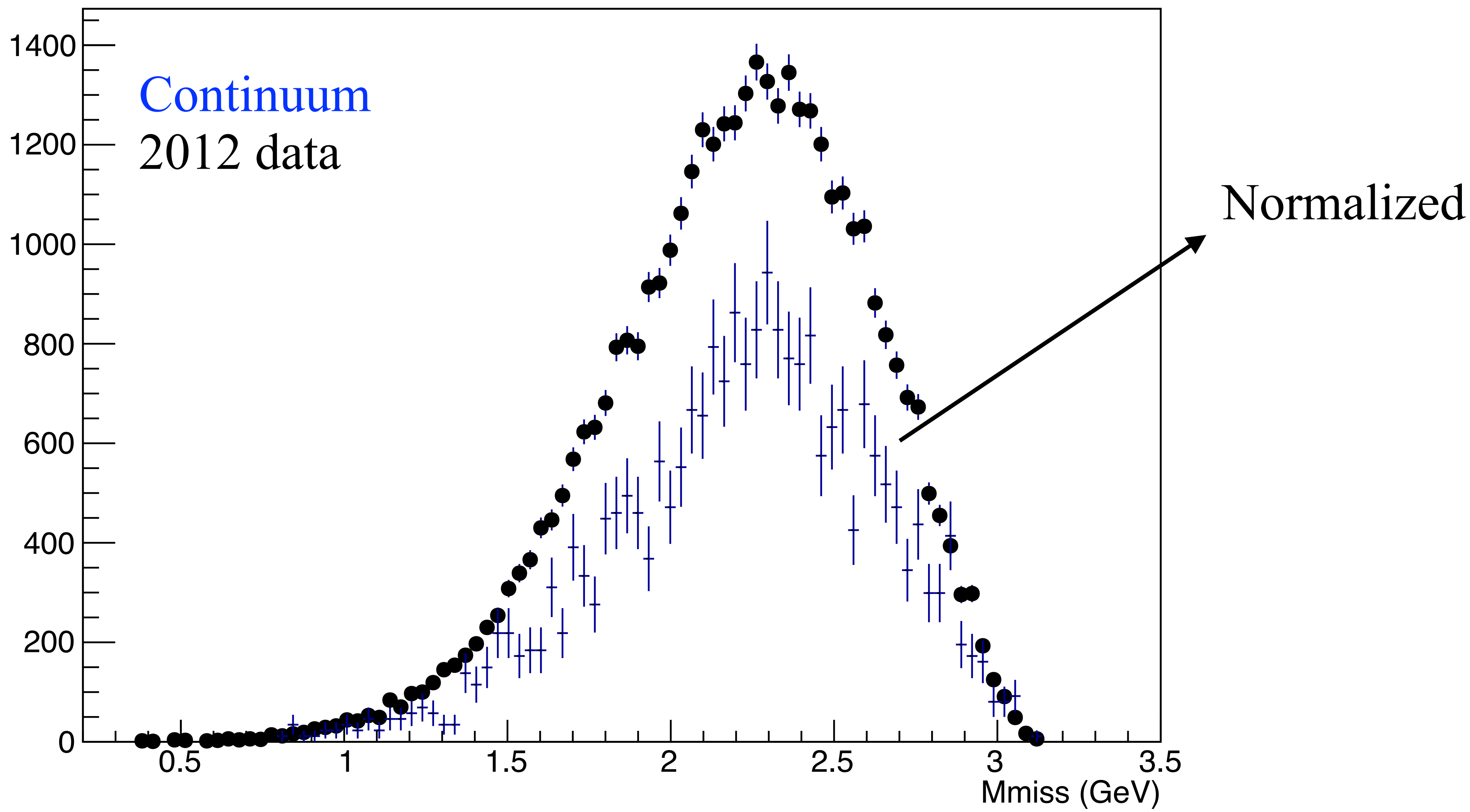
Additional cuts II



pion contamination ~ 6.3%

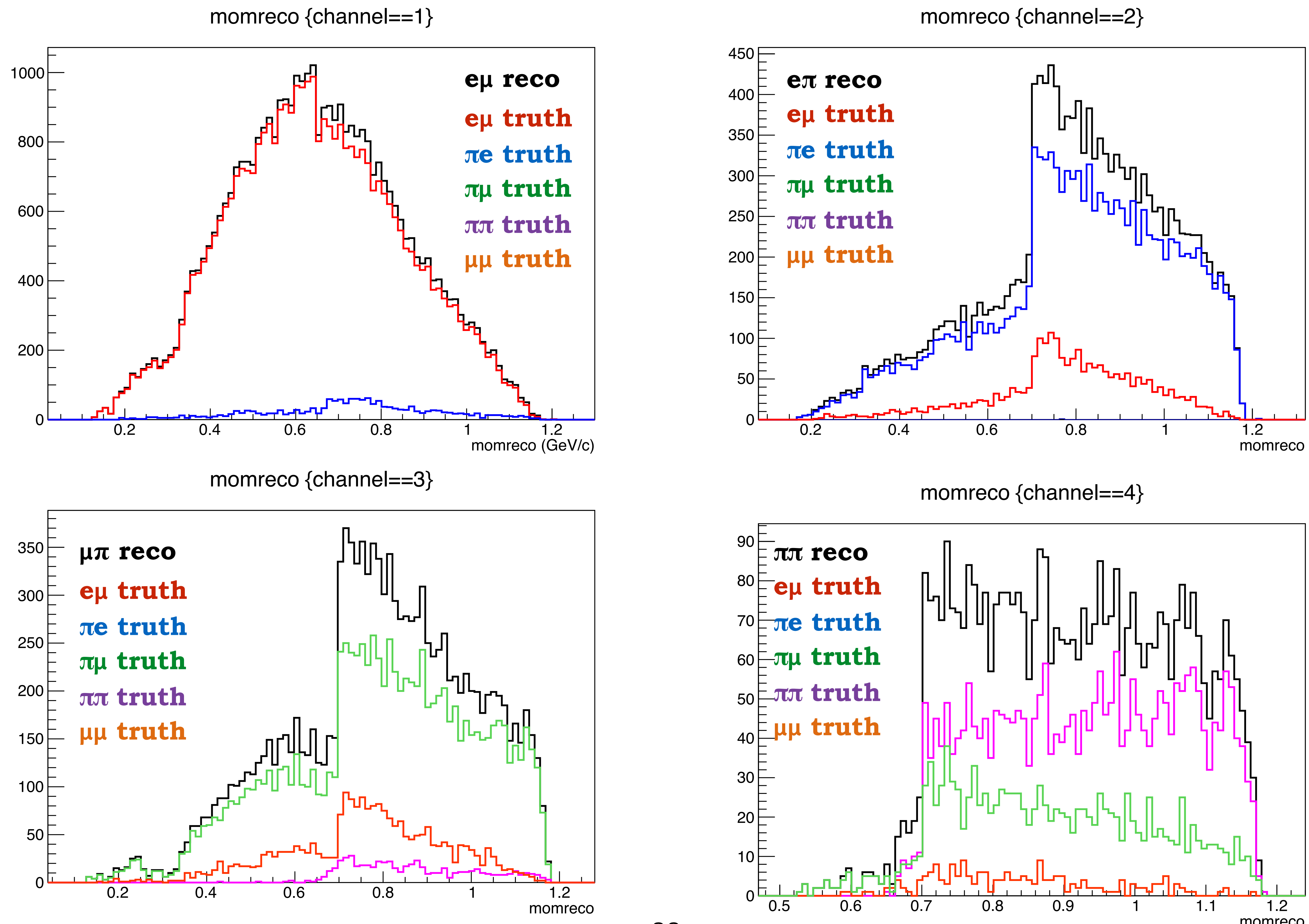
Continuum

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



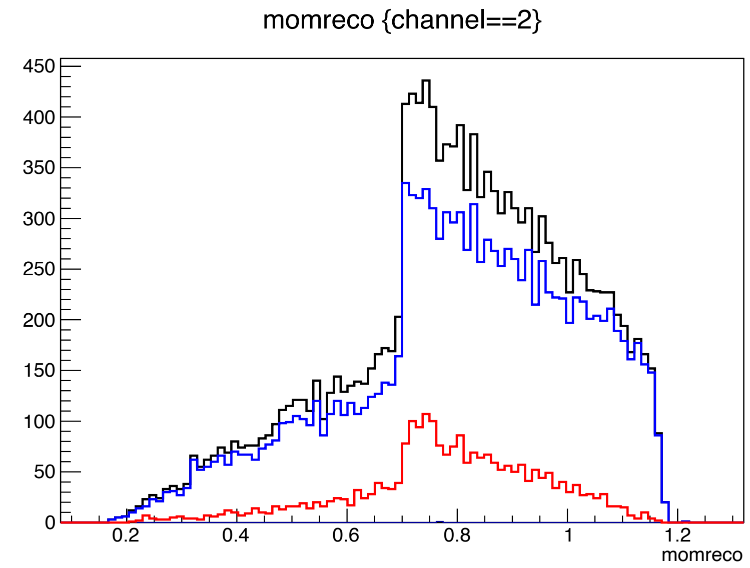
Signal MC: distributions I

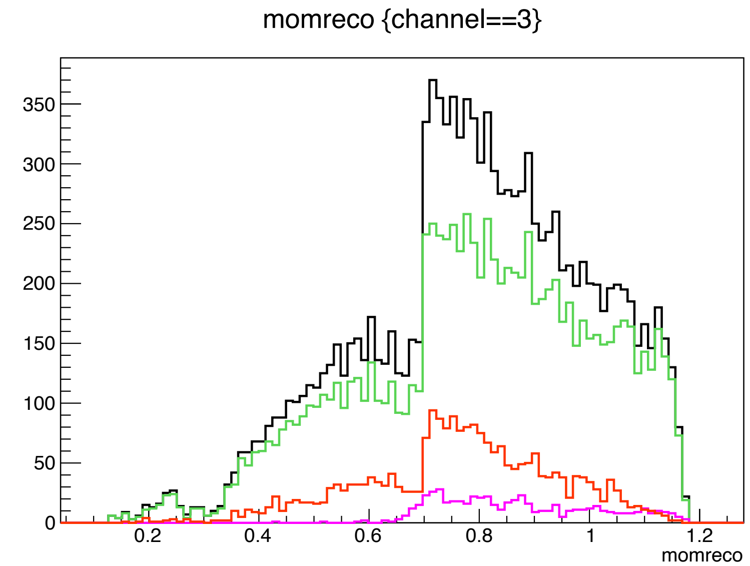
ψ(2S)→ττ→eμ4ν/πe3ν/πμ3ν/ππ2ν signal

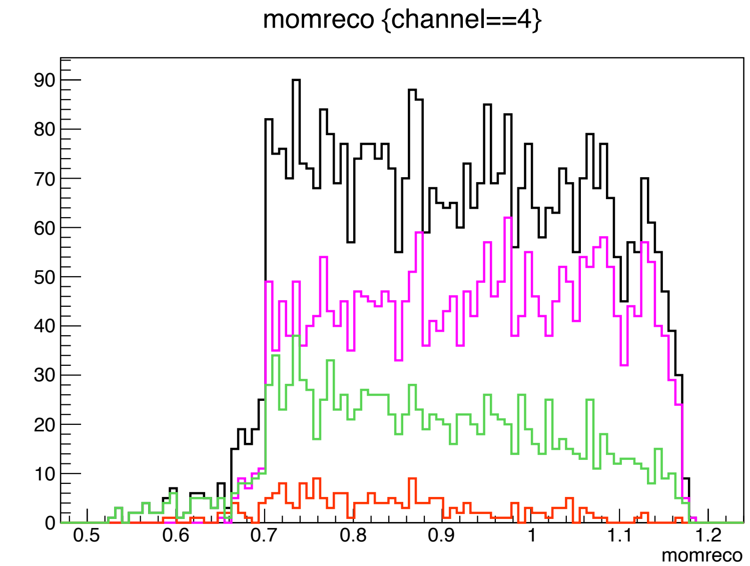


Conclusion from this new event and track selection

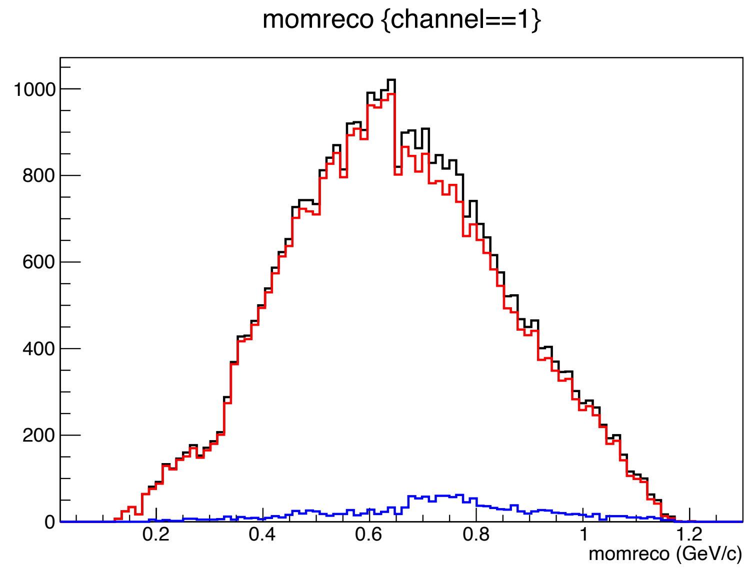
$\psi(2S) \to \tau\tau \to e\mu 4\nu$ / $\pi e 3\nu$ / $\pi\mu 3\nu$ / $\pi\pi 2\nu$







- Huge contamination form other signal channels
- Unfolding procedure should be necessary to disentangle each channel
  - increase the uncertainties
- We decide to use only **eμ4ν** channel as “signal" (cleanest channel)



eμ reco

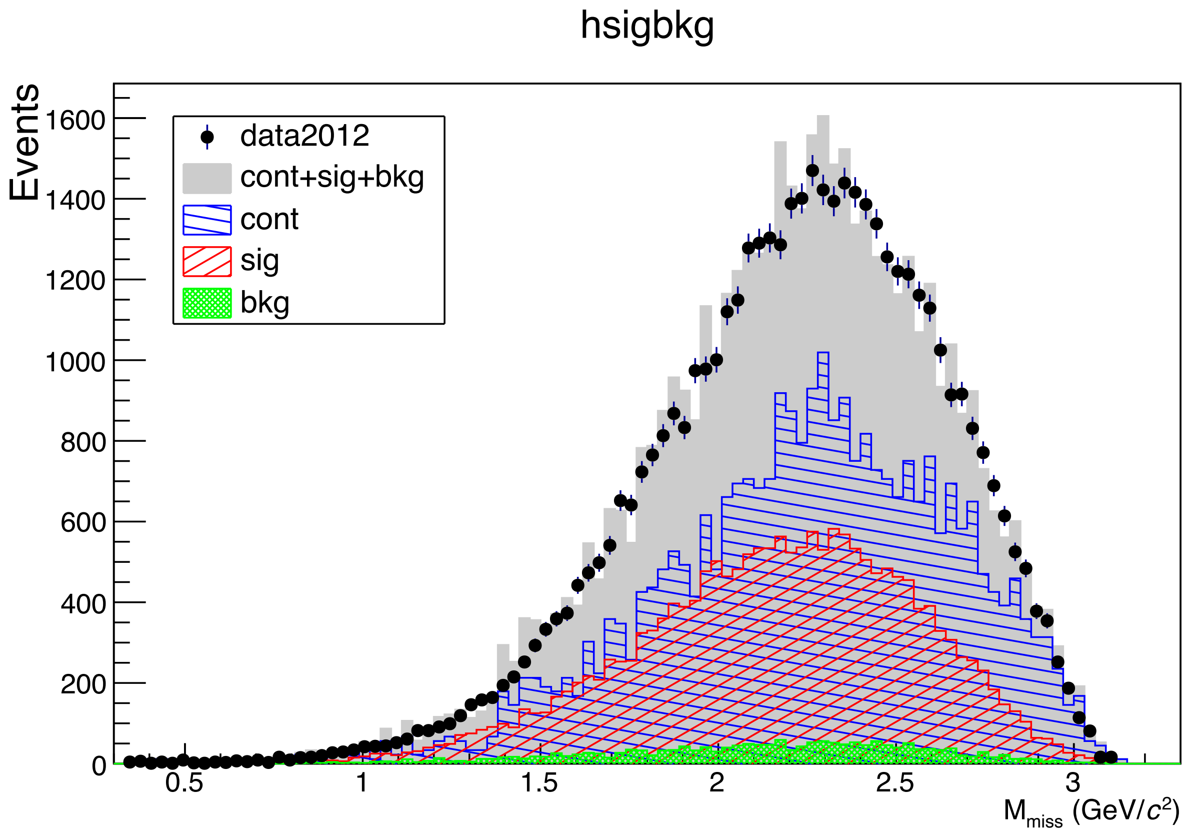
πe truth

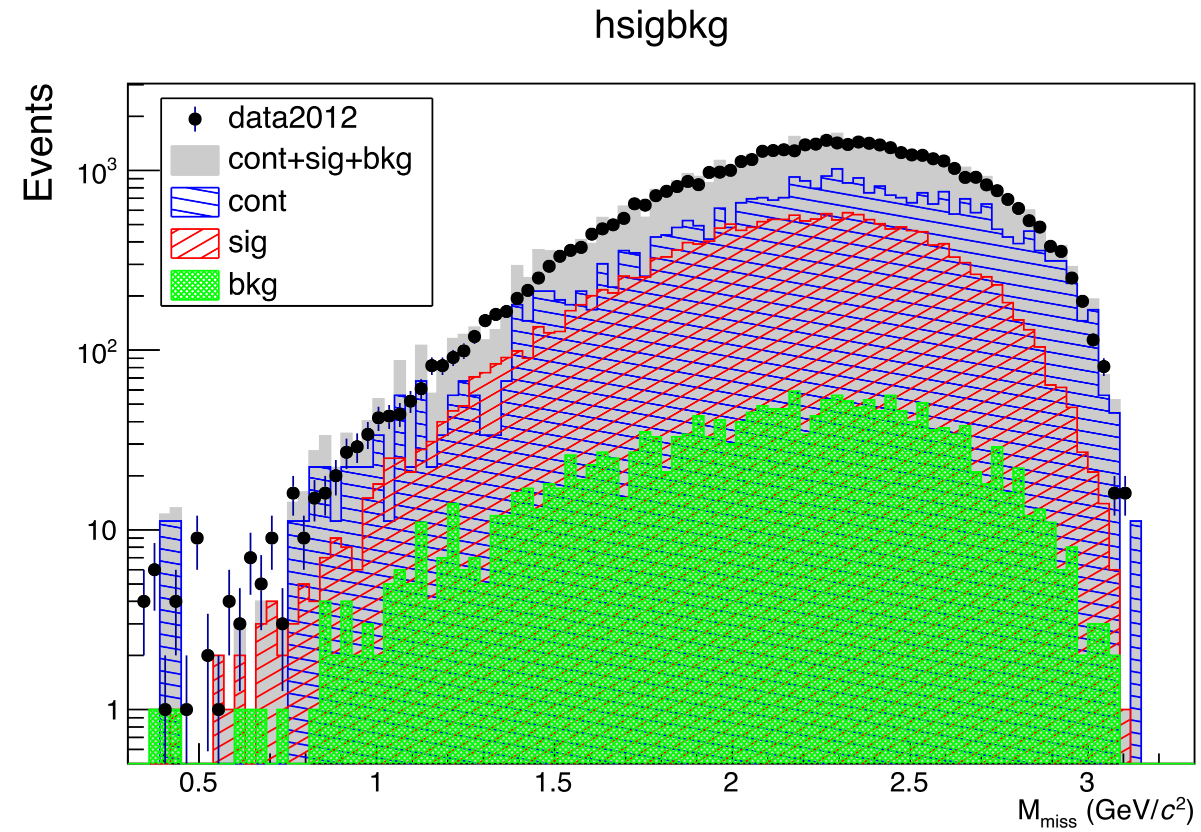
~4/5% of background contamination

Study of inclusive sample

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

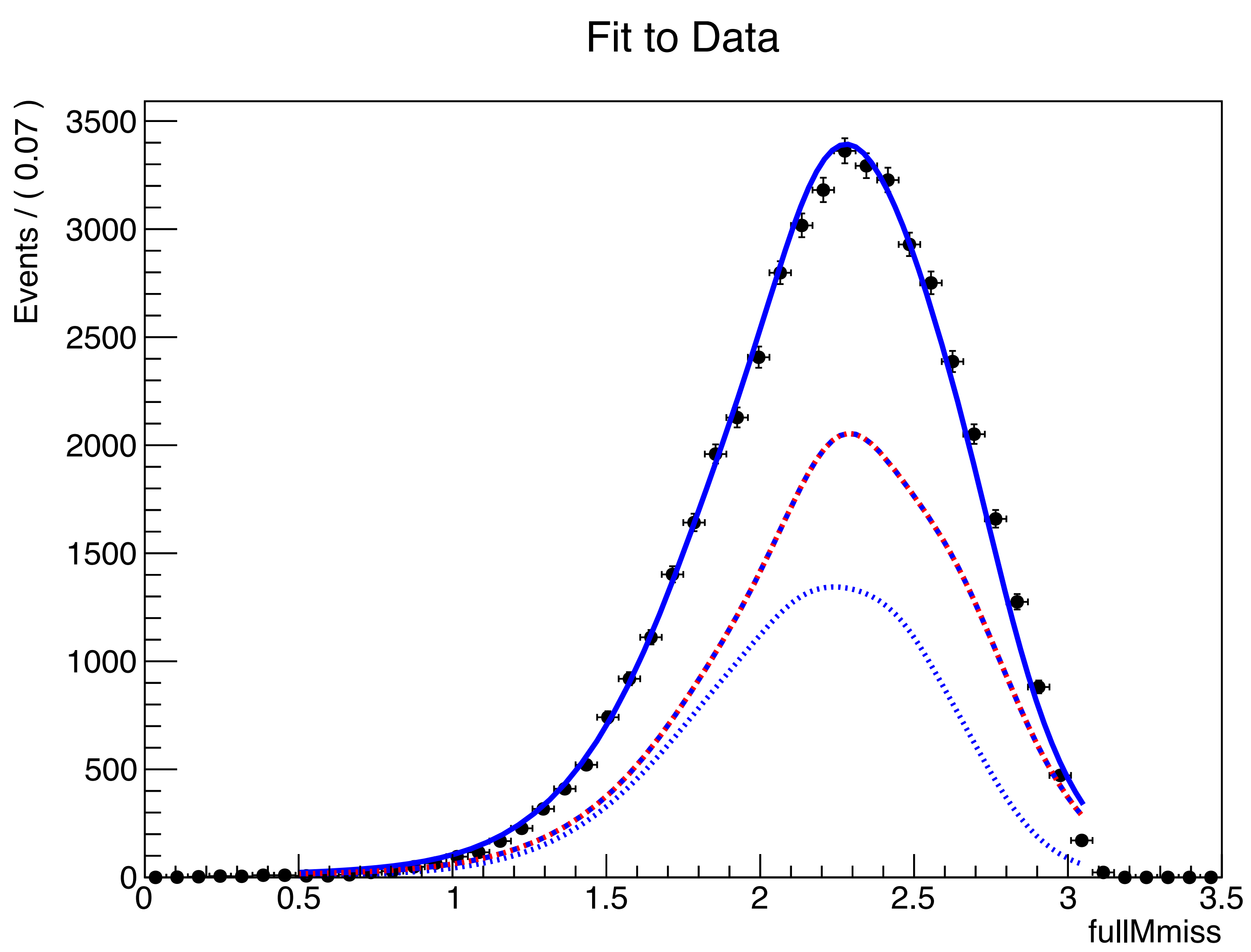
Continuum
2012 data





- Signal shape form inclusive MC (MCtruth)
- Background shape from inclusive MC (check MC truth info different from emu signal)
- Continuum from data, rescaled for the right luminosity factor

Extraction of number of signal



- Signal+background shape form inclusive MC
  - background fraction ~ 10% from inclusive MC sample
- Continuum from data, rescaled for the right luminosity factor (fixed)
- Nsig = 17237 ± 195
- ε = 0.30

$$Br_{\tau\tau} = \frac{\frac{N^{obs} - N^{obs}_{cont} - N^{norm}_{bg}(Br_{\tau\tau})}{\varepsilon_{e\mu} \cdot Br(e\mu)} - \sigma^{\tau\tau}_{Int}(Br_{\tau\tau}) \cdot L_{3.686}}{N_{\psi(2S)}} = (2.72 \pm 0.05) \times 10^{-3}$$

From Zhang Bingxin (IHEP)

X. H. Mo, J. Y. Zhang, B.X. Zhang (IHEP)

$$B(\tau\tau) = \frac{\frac{N_{e\mu} - N_{bg}}{B\varepsilon} - \sigma_{Q+I}L}{N_{\psi(2S)}}$$

This term is estimated by continuum data at energy point （3.65 GeV）

- B fraction of τ+τ- events yielding the eμ topology. 0.6190（PDG）
- $N_{e\mu}$, N_{bg} , $N_{\psi(2S)}$ Events number of eu, background and ψ(2S)
- ε detection efficiency
- σ_{Q+I} *QED production* cross section 2.230nb
- L the accumulated luminosity ψ(2S)

Branching fraction calculation

Item/ Year	Nobs	Nbkg	Lum.	ε	$N_{\psi'}(10^6)$	$Br(10^{-3})$
2009	11535	835	161.63	0.2304	107.0	3.63±0.006
2012	31006	2821	506.92	0.2433	341.1	2.17±0.003 IT: $(2.72\pm0.05)\times10^{-3}$
Combine	$(2.40\pm0.006)\mathrm{X}10^{-3}$					

(3.1 ± 0.4) X 10^{-3} (PDG)