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

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IHEP

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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 $V \to \tau\tau$ decay is affected by NP

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

$V(nS)$	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

@ 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

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

BESIII: *By Rinaldo Baldini*

550 M ψ (2S)

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

Analysis: event and track selection

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

Charged tracks
- **nCharged=2**
- Vertex cut: $R_{xy}<1cm$ 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

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

NEW boss709 with 2021 condition

```
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

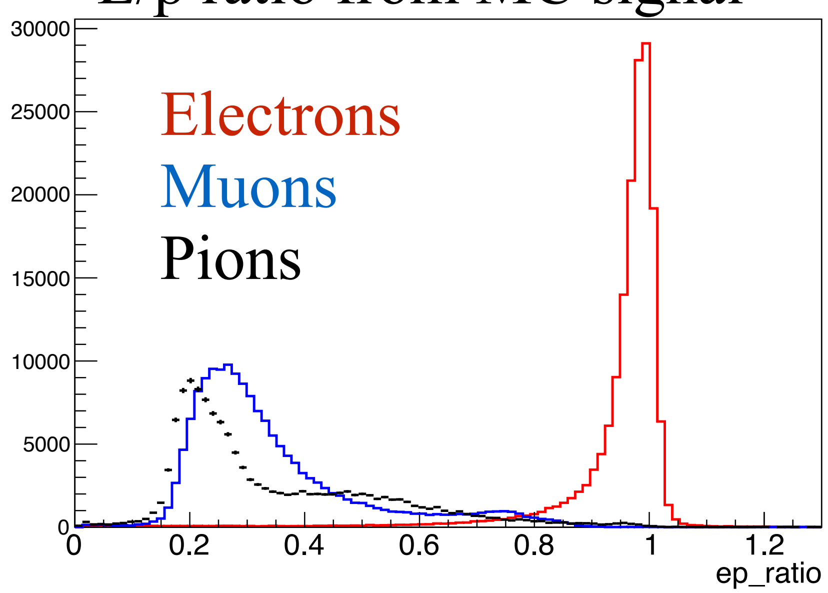
Electron PID

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

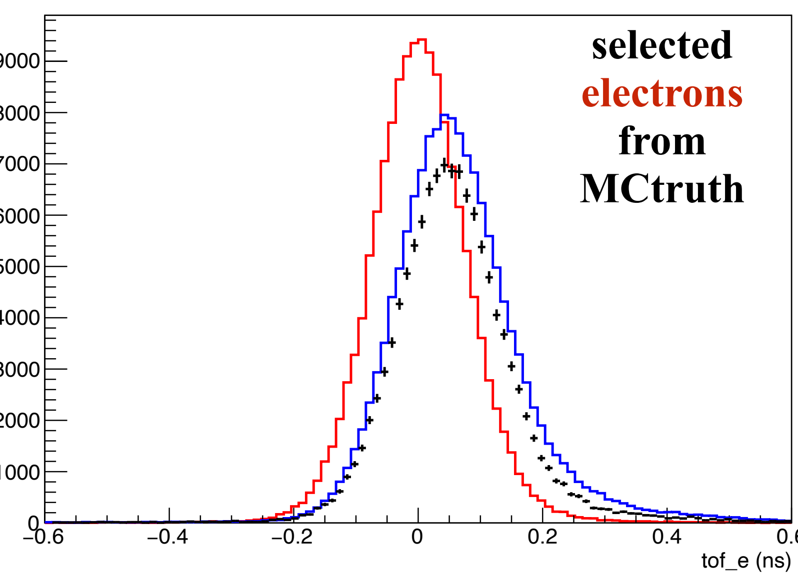
Muon PID

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

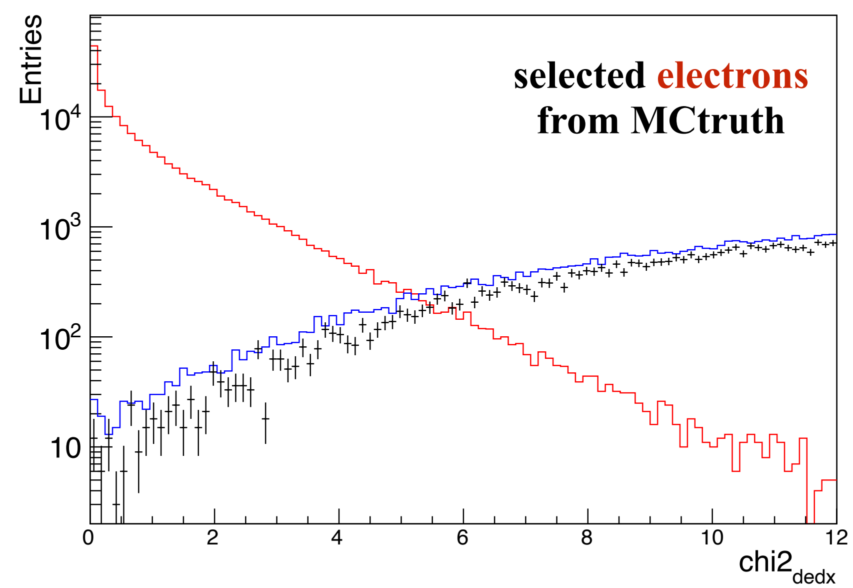
E/p ratio from MC signal



(exp-tof - tof_calc) from MC signal

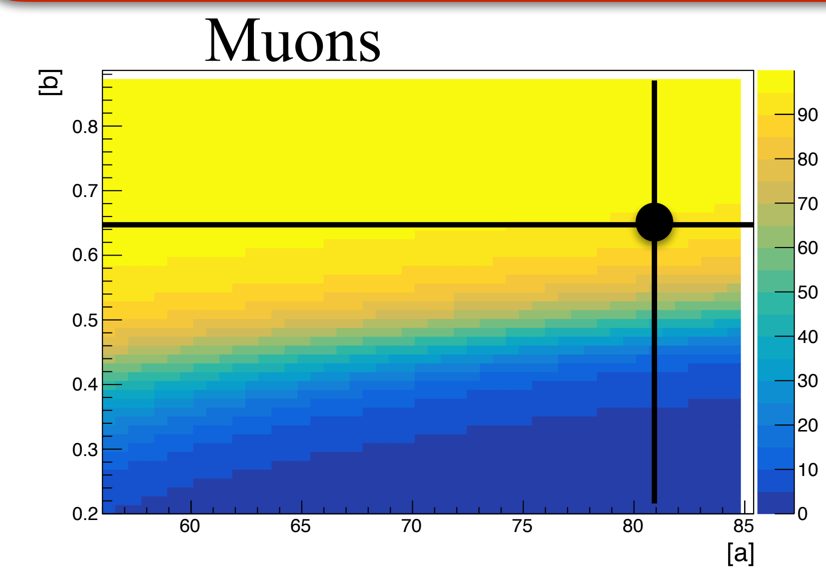


chi2-dEdx from MC signal



similar distributions for selected muons/pions from MC truth

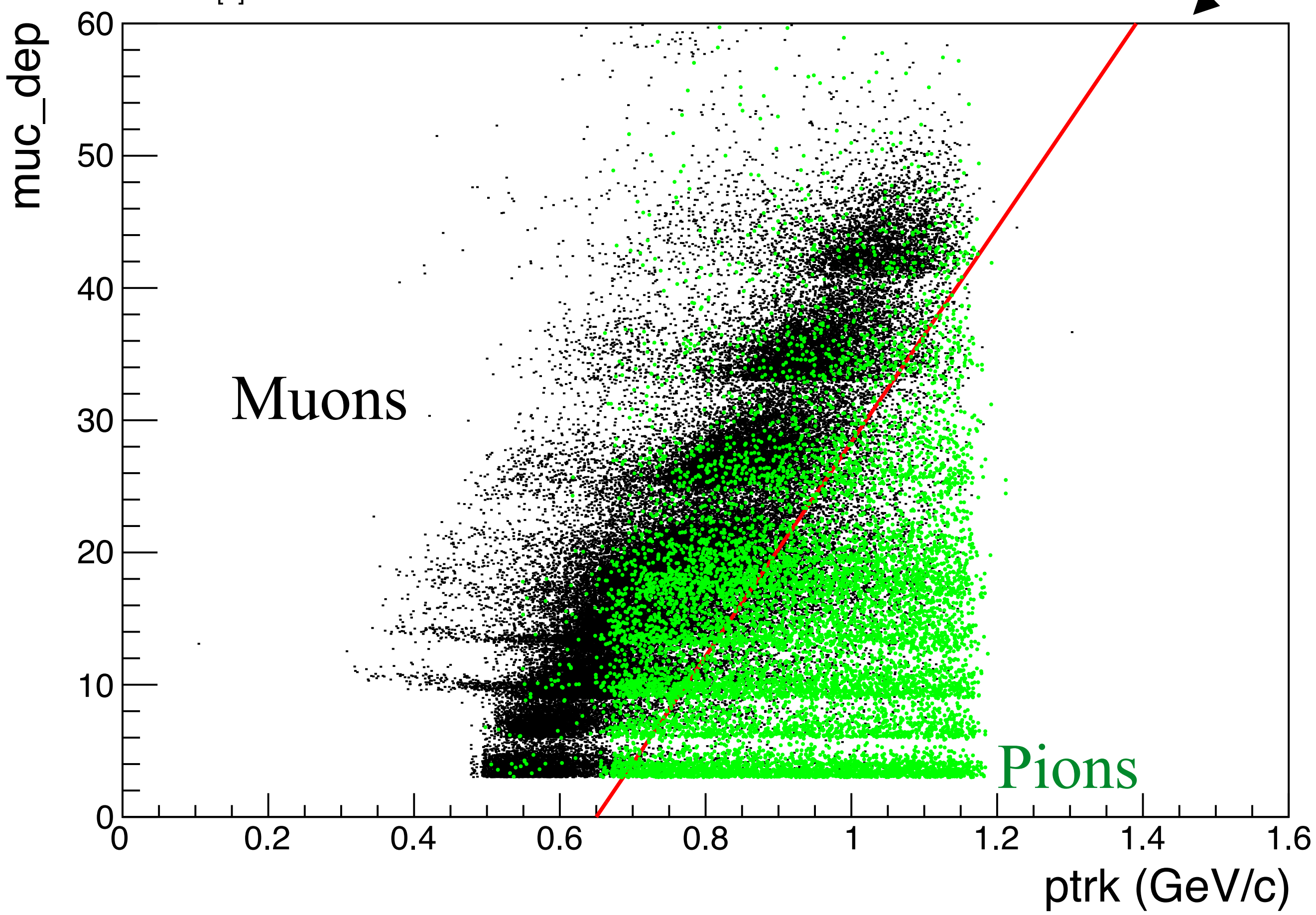
muc vs. ptrk from MC samples



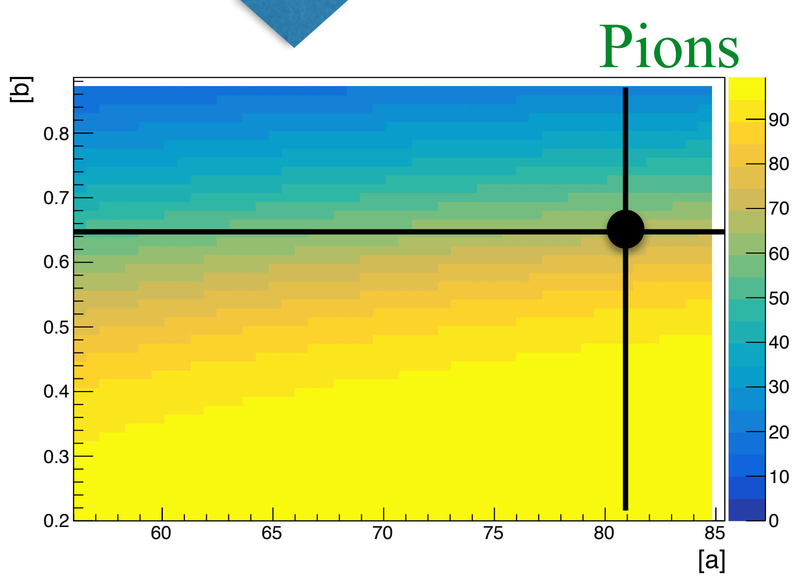
cut efficiency > 90% for muons selection

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

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



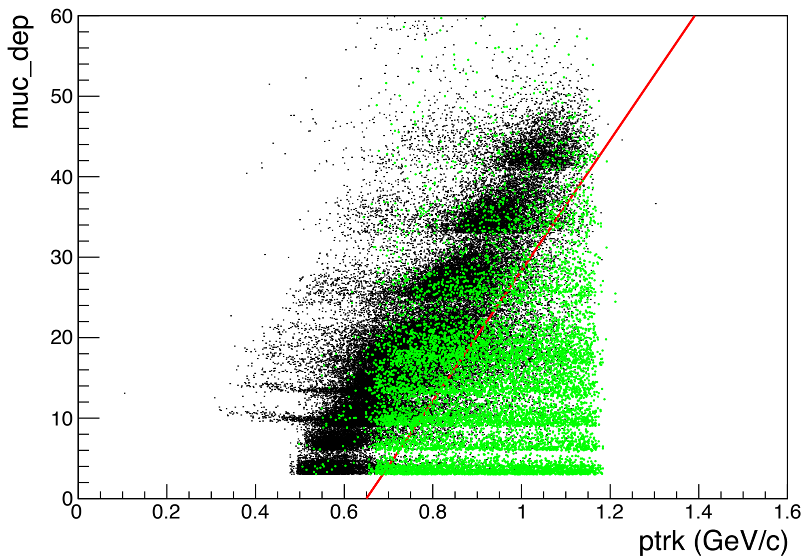
~70% of pions fall below the red line

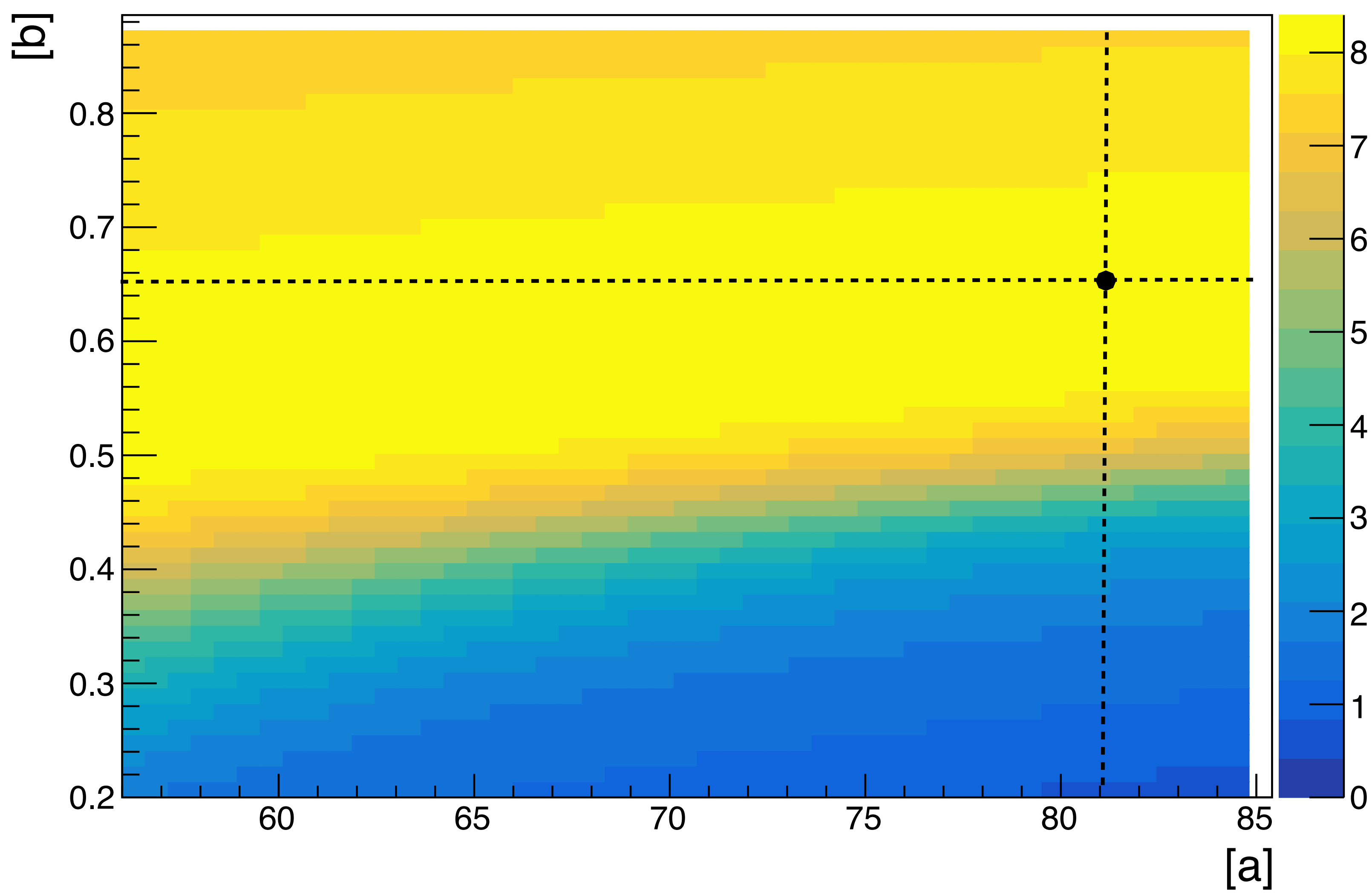


muc vs. ptrk from MC samples

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

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





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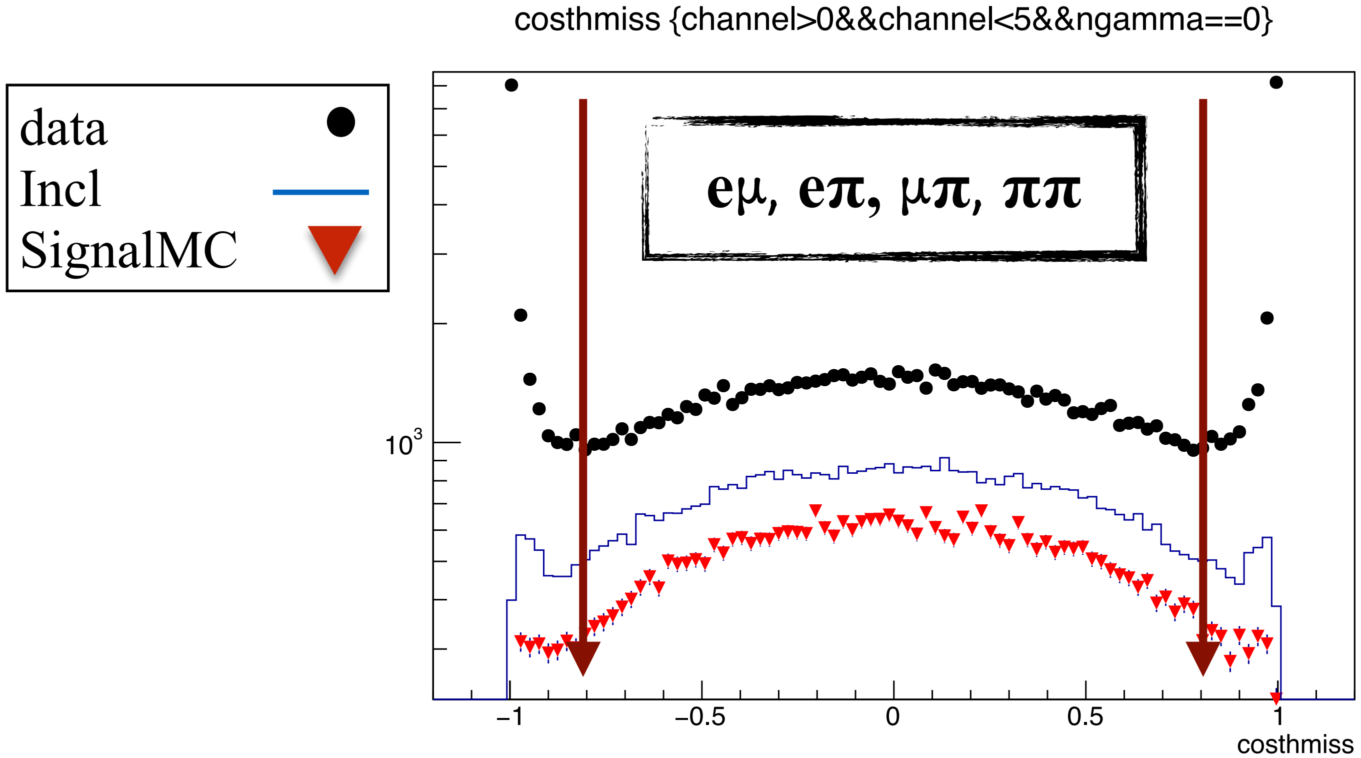
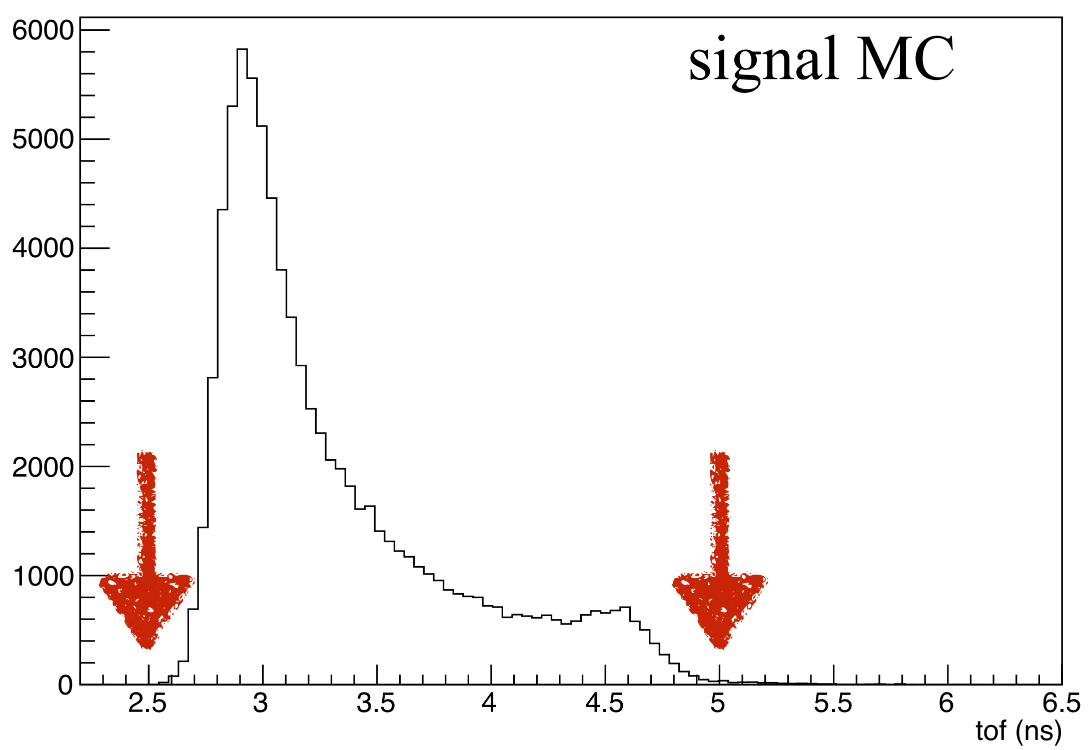
Additional cuts

*signal arbitrary scale



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

- |cosθ_miss| < 0.8

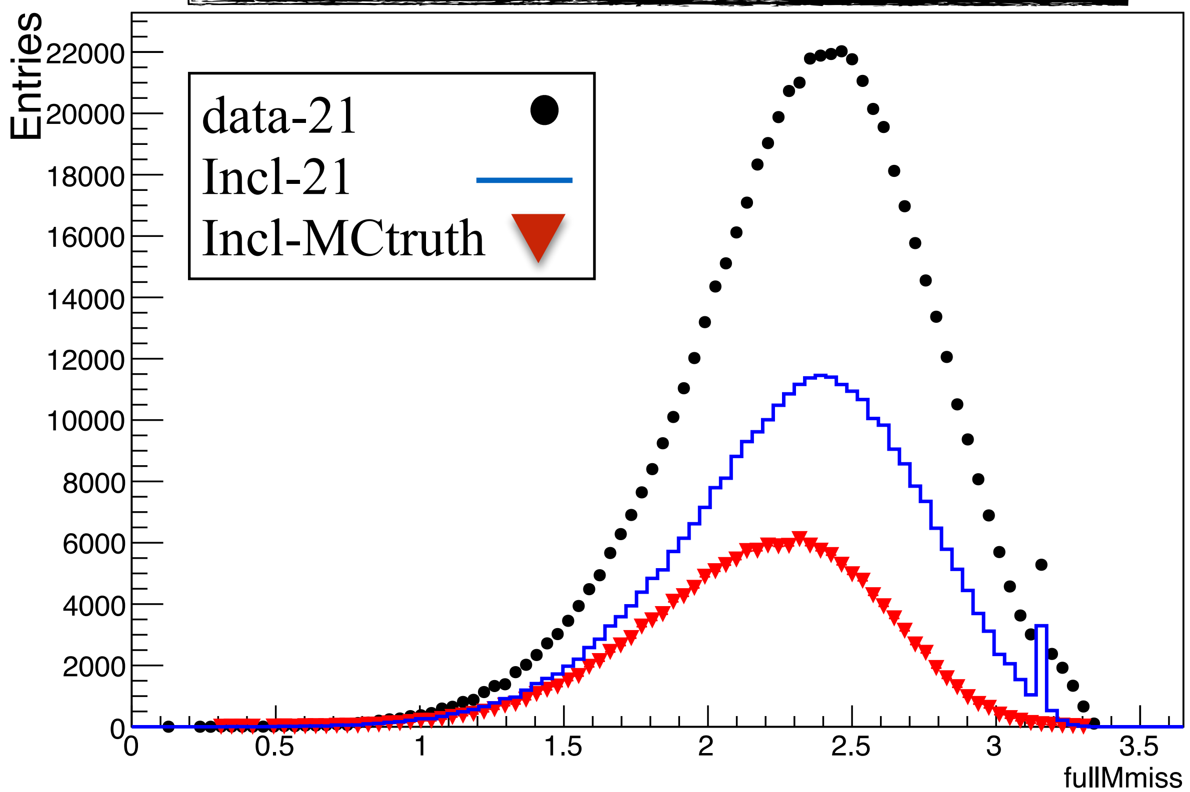


- 2.5<tof < 5 (ns)

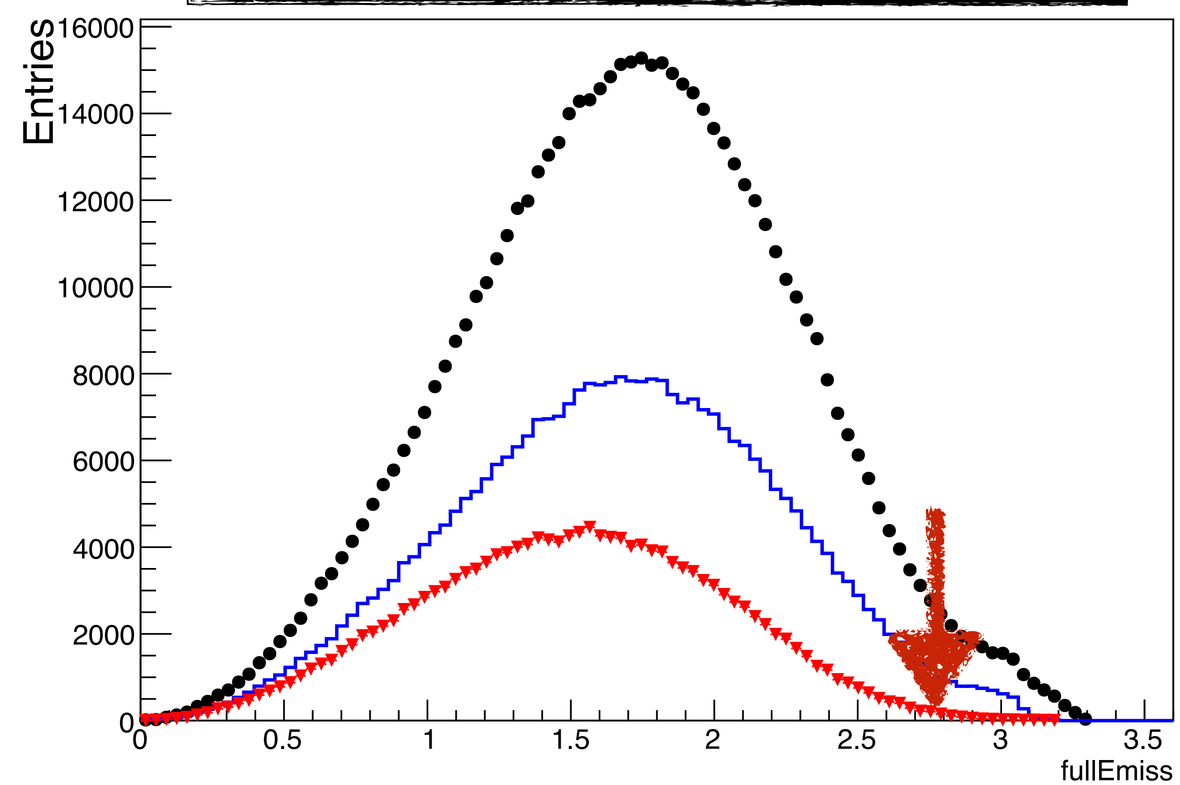
Missing mass and missing energy:

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

Additional cuts II



eμ signal



eμ signal

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

Charged tracks

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- 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)**

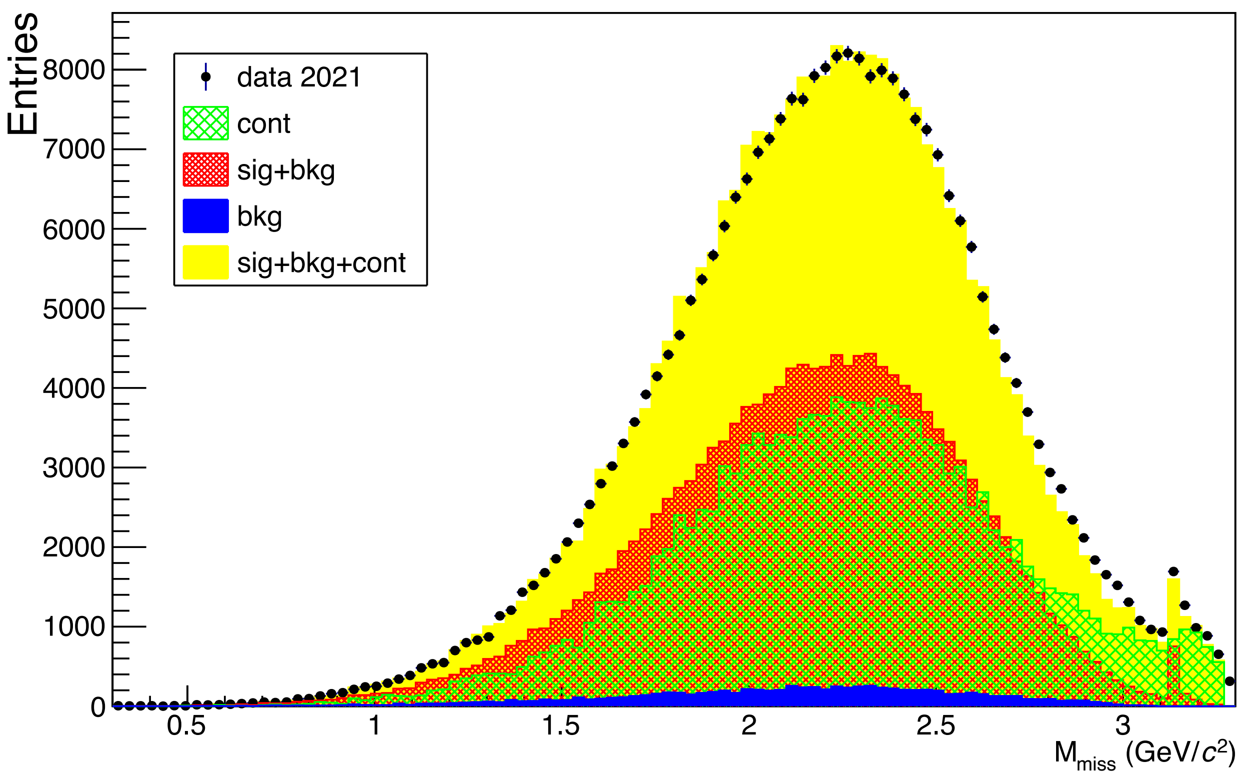
- |cosθ_miss| < 0.8
- energyDep < 2 (sum of deposit energy of the two tracks)

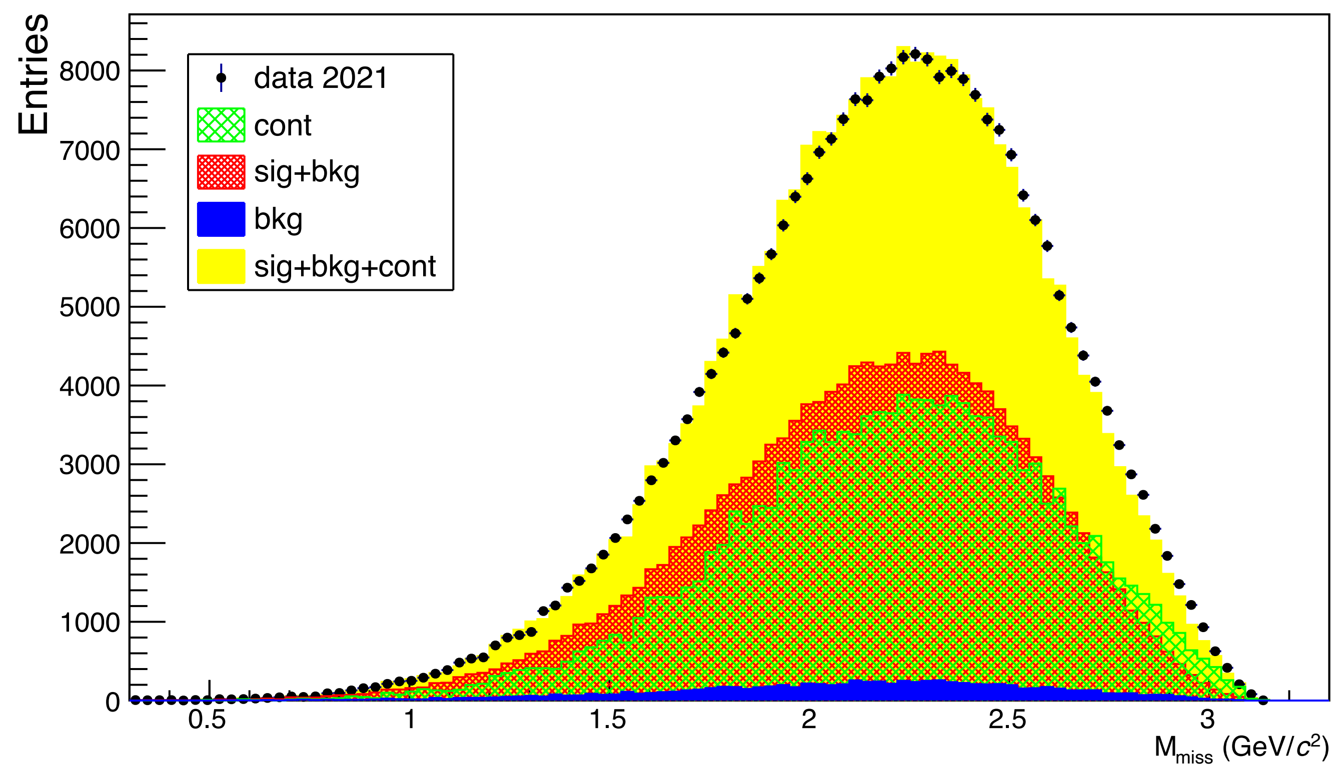
- **MissingEnergy<2.65 GeV/*c*²**
- 2.5<tof < 5 (ns)

Study of inclusive sample

@ 3.650 GeV (L ~ 410 pb^{-1})

Continuum 2021

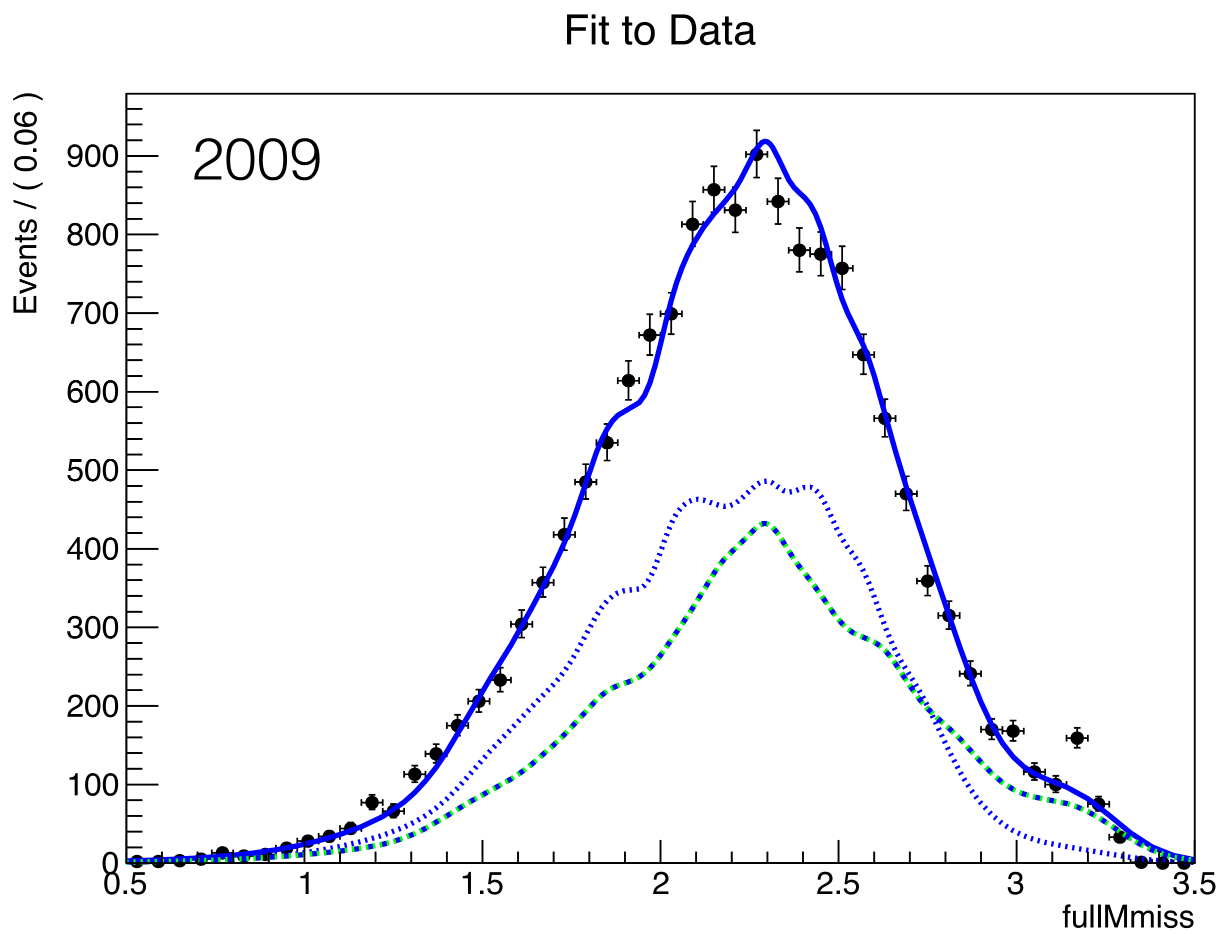


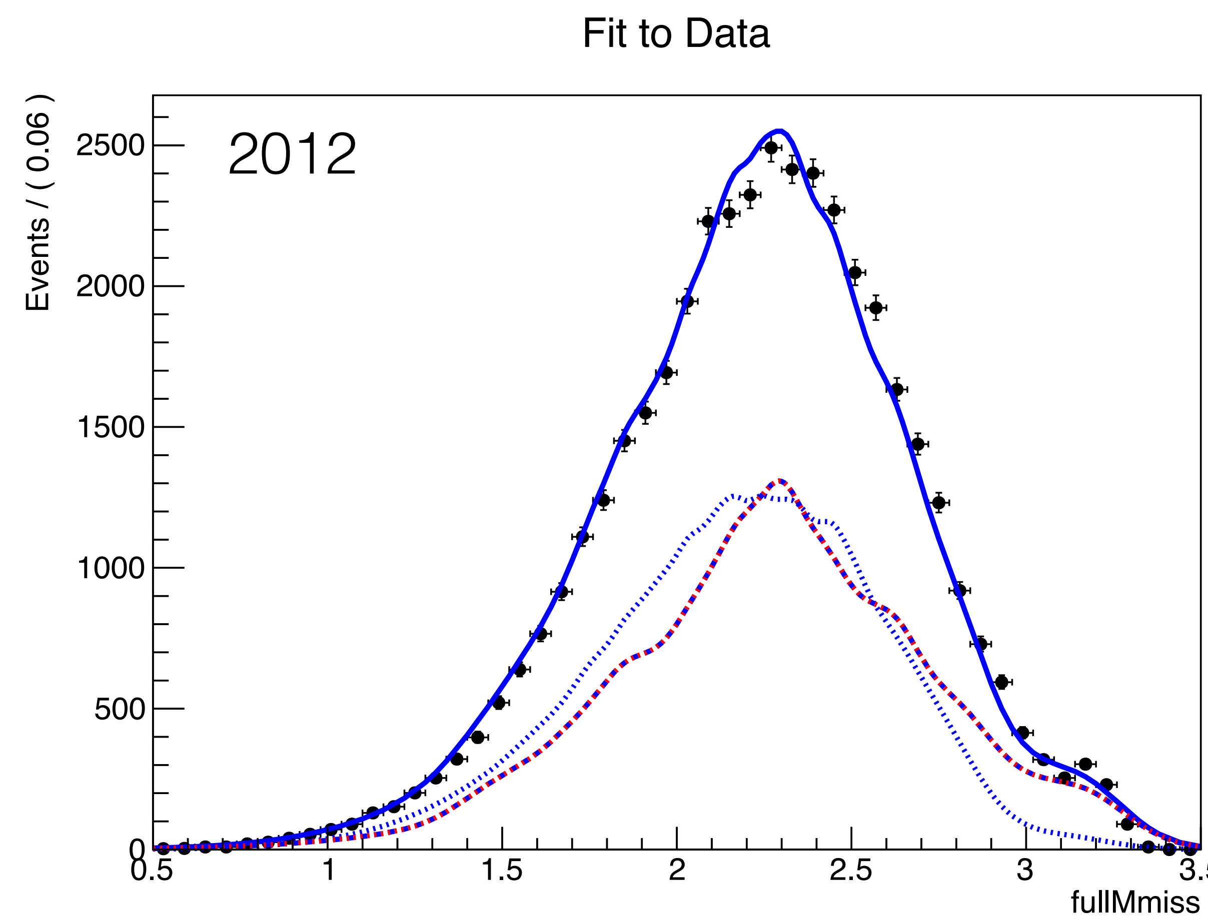


- Comparison with and without Emiss cut: the difference between signal and data in the higher Miss region is due to the continuum contributions
- Signal shape form inclusive MC (it includes bkg)
- Background shape from inclusive MC (check MC truth ID different from emu signal)
  - background fraction ~ 6%
- Continuum from data, rescaled for the right luminosity

$$f = \frac{\mathcal{L}_{\psi(2S)}}{\mathcal{L}_{off}} \cdot \frac{s_{off}}{s_{\psi(2S)}} = 7.6$$

OLD RESULTS (2009 and 2012)





- 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) without Emiss cut

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

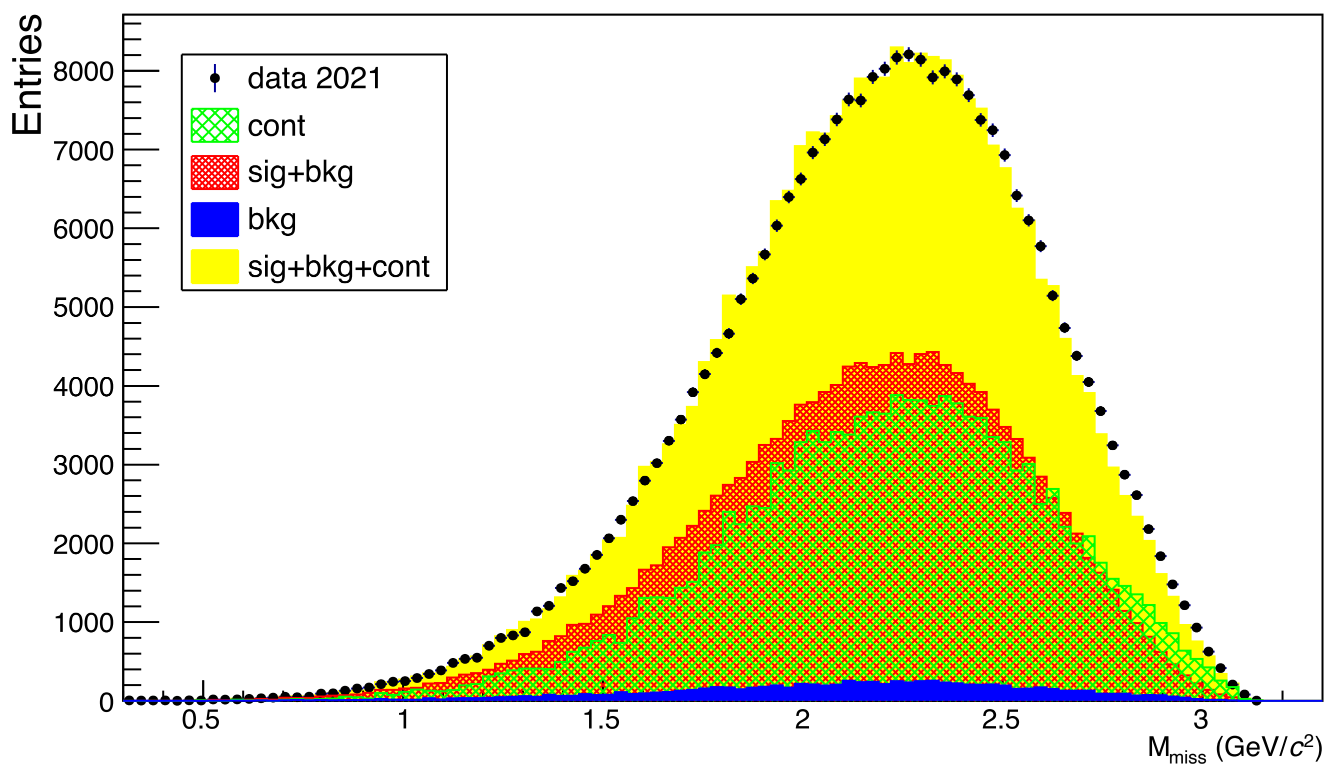
2012 → $=(2.87 \pm 0.09) \times 10^{-3}$

2009 → $=(3.58 \pm 0.16) \times 10^{-3}$

https://doi.org/10.1103/PhysRevD.74.112003

$\sigma_{int} = -66.587 * BR(\tau\tau)\ pb^{-1}$

New result using 2021 dataset



- no fit to data
- Nobs = 276456 ± 526
- Nbkg = 8885 ± 94
- Ncont = 128326 ± 358
- ε = 0.304 (with Emiss cut)

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

$=(3.271 \pm 0.023) \times 10^{-3}$

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$\sigma_{int} = -66.587 * BR(\tau\tau)$ pb^{-1}

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)

From my check
$(3.271\pm0.023)\times10^{-3}$

very good agreement!

Branching fraction calculation

Nobs	Nbkg	Lum. (pb^{-1})	ε	σ(nb)	$N_{\psi'}(10^6)$	$Br(10^{-3})$
280412	11531	3171.64	0.3085	2.125	2260	3.236 ± 0.001 ± 0.104
This work	$(3.236 \pm 0.104)X10^{-3}$					

(3.1 ± 0.4) X 10^{-3} (PDG)

From Zhang Bingxin (IHEP)

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

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

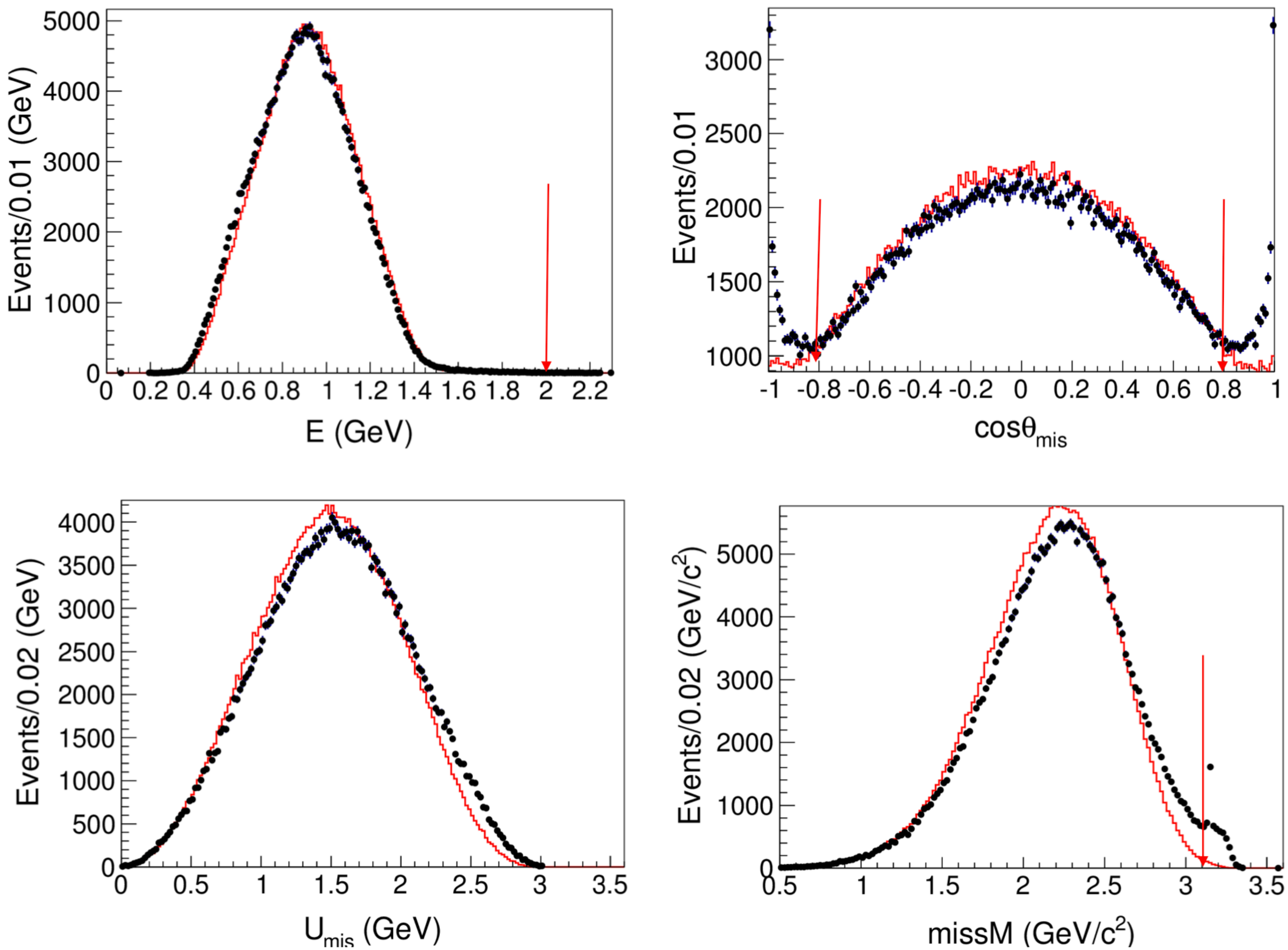
- E/p<0.7
- $\chi2_{dE/dx}<4$
- Δtof(mu) <0.3 ns
- muc_dep>81*(ptrk-0.65)

same event and track selection

From Zhang Bingxin (IHEP)

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

MC & Data distribution comparison (I)



From Zhang Bingxin (IHEP)

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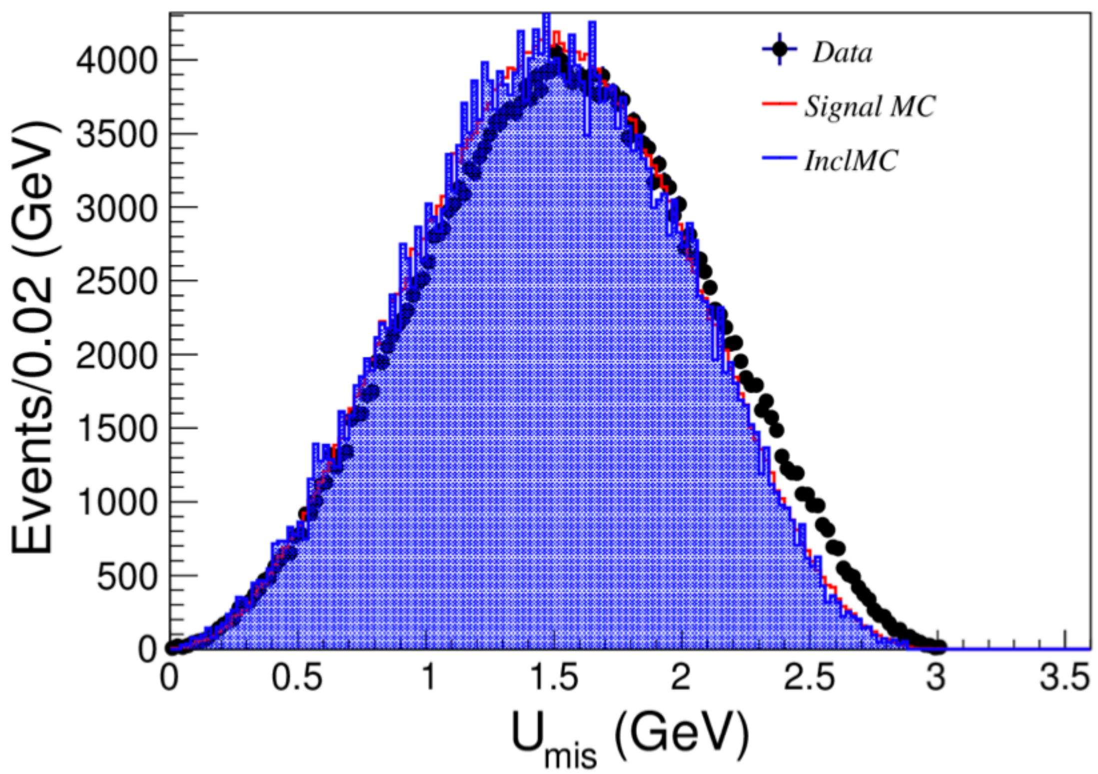
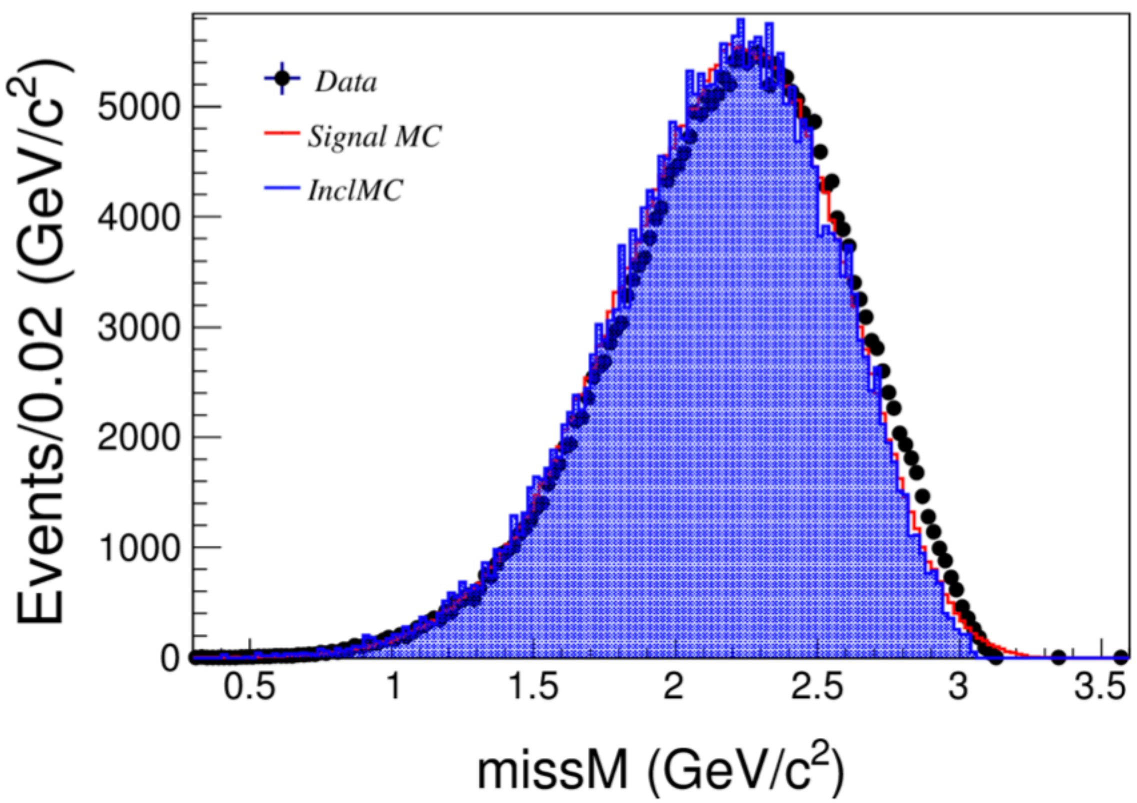
Normalized by number of events





No continuum data included

Cross section calculation (IHEP)

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

$$\sigma(W)=\frac{1}{\sqrt{2\pi}\Delta}\int_0^\infty dW' e^{-(W-W')^2/2\Delta^2}$$
$$\times\int_0^{1-(2m_\tau/W')^2} dx F(x,W')\sigma_1(W'\sqrt{1-x})$$
$$\sigma_1(W)=\frac{4\pi\alpha^2}{3W^2}\frac{\beta(3-\beta^2)}{2}\frac{F_c(\beta)F_r(\beta)}{[1-\Pi(W)]^2}$$
$$\times\left\{1+\frac{3M^3}{\alpha_s}\Gamma_{ee}^2\frac{1}{1+\frac{2m_e^2}{M^2}}\frac{1}{\left(1-\frac{4m_e^2}{M^2}\right)^{1/2}}\right.$$
$$\times\frac{2(W^2-M^2)}{(W^2-M^2)^2+M^2\Gamma^2}$$

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($e^+e^- \to \tau\tau$)

$$+\left(\frac{3M^3}{\alpha_s}\right)^2\Gamma_{ee}^2\frac{1}{\left(1+\frac{2m_e^2}{M^2}\right)^{1/2}}\frac{1}{1-\frac{4m_e^2}{M^2}}$$
$$\left.\times\frac{1}{(W^2-M^2)^2+M^2\Gamma^2}\right\}$$
$$=\sigma_1^{\text{QED}}+\sigma_1^{\text{int}}+\sigma_1^{\psi(2S)}.$$

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

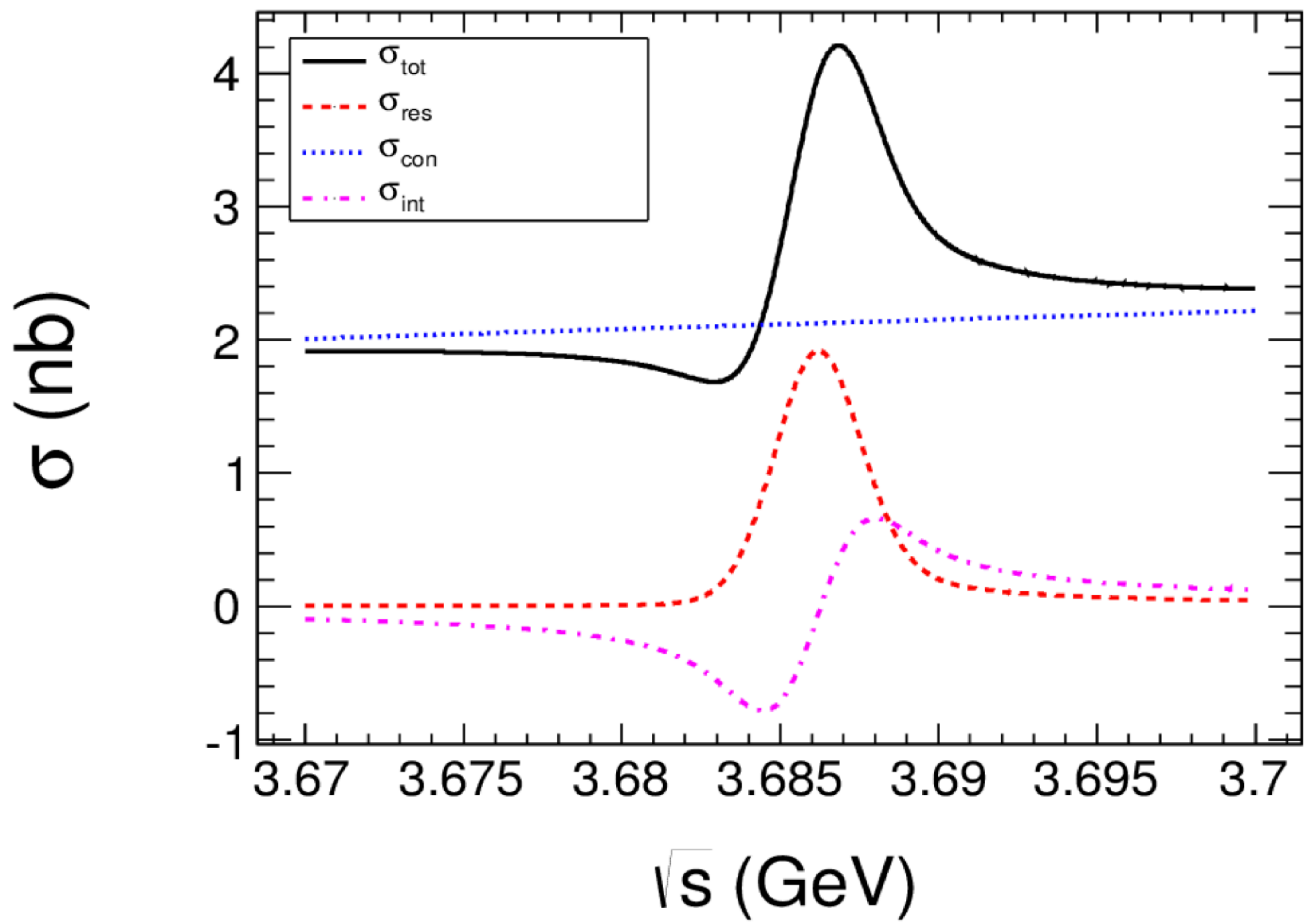
Cross section calculation($e^+e^- \to \tau\tau$)

$$S(v)=\frac{1}{v}\left\{(1+v^2)\left[\frac{\pi^2}{6}+\ln\left(\frac{1+v}{2}\right)\ln\left(\frac{1+v}{1-v}\right)+2\text{Li}_2\left(\frac{1-v}{1+v}\right)+2\text{Li}_2\left(\frac{1+v}{2}\right)\right.\right.$$
$$\left.-2\text{Li}_2\left(\frac{1-v}{2}\right)-4\text{Li}_2(v)+\text{Li}_2(v^2)\right]$$
$$+\left[\frac{11}{8}(1+v^2)-3v+\frac{1}{2}\frac{v^4}{(3-v^2)}\right]\ln\left(\frac{1+v}{1-v}\right)$$
$$\left.+6v\ln\left(\frac{1+v}{2}\right)-4v\ln v+\frac{3}{4}v\frac{(5-3v^2)}{(3-v^2)}\right\}$$

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

From Zhang Bingxin (IHEP)

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



σ_{Q+I} =2.125nb

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

Systematic Uncertainties Zhang Bingxin (IHEP)

Ecm(GeV)	Uncertainty (%)
Track efficiency	0.6
Luminosity	1.4
$\psi(2S)$ total number	0.7
Branching fraction	0.3
PID	1.0
μ and π difference	1.2
M_{mis} requirement	0.8
θ_{mis} requirement	0.1
N_{gamma} requirement	1.7
Background	0.4
Cross section calculation	0.4
MC statistics	0.1
Total	3.1

From Zhang Bingxin (IHEP)

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

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(3.1 ± 0.4) X 10^{-3} (PDG)

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

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- ε detection efficiency
- σ_{Q+I} *QED production* cross section 2.125nb
- L the accumulated luminosity ψ(2S)

very good agreement!

Branching fraction calculation

Nobs	Nbkg	Lum. (pb^{-1})	ε	σ(nb)	$N_{\psi'}$(10^{6})	Br(10^{-3})
280412	11531	3171.64	0.3085	2.125	2260	3.236 ± 0.001 ± 0.104
This work		(3.236 ± 0.104)X10^{-3}				

(3.1 ± 0.4) X 10^{-3} (PDG)

Plans and Conclusions

- Two different approaches give in agreement results
- Review committee started on January 16
  - link of the memo

```
Three referees are :
      Zhiyong Wang,  <wangzy@ihep.ac.cn>,  IHEP (Chair)
      Tao Luo,  <luot@fudan.edu.cn>,  FDU
      Qian Liu,  <liuqian@ucas.ac.cn>,  UCAS
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The Link of HyperNews forum :
     http://hnbes3.ihep.ac.cn/HyperNews/get/paper686.html
The memo in docDB :

https://docbes3.ihep.ac.cn/DocDB/0011/001174/006/Brpsip2TTMeas-memo-v404.pdf
The talk in P&S meeting in Indico :
     https://indico.ihep.ac.cn/event/18523
```

Thanks for your attention

Background analysis (inclusive MC)

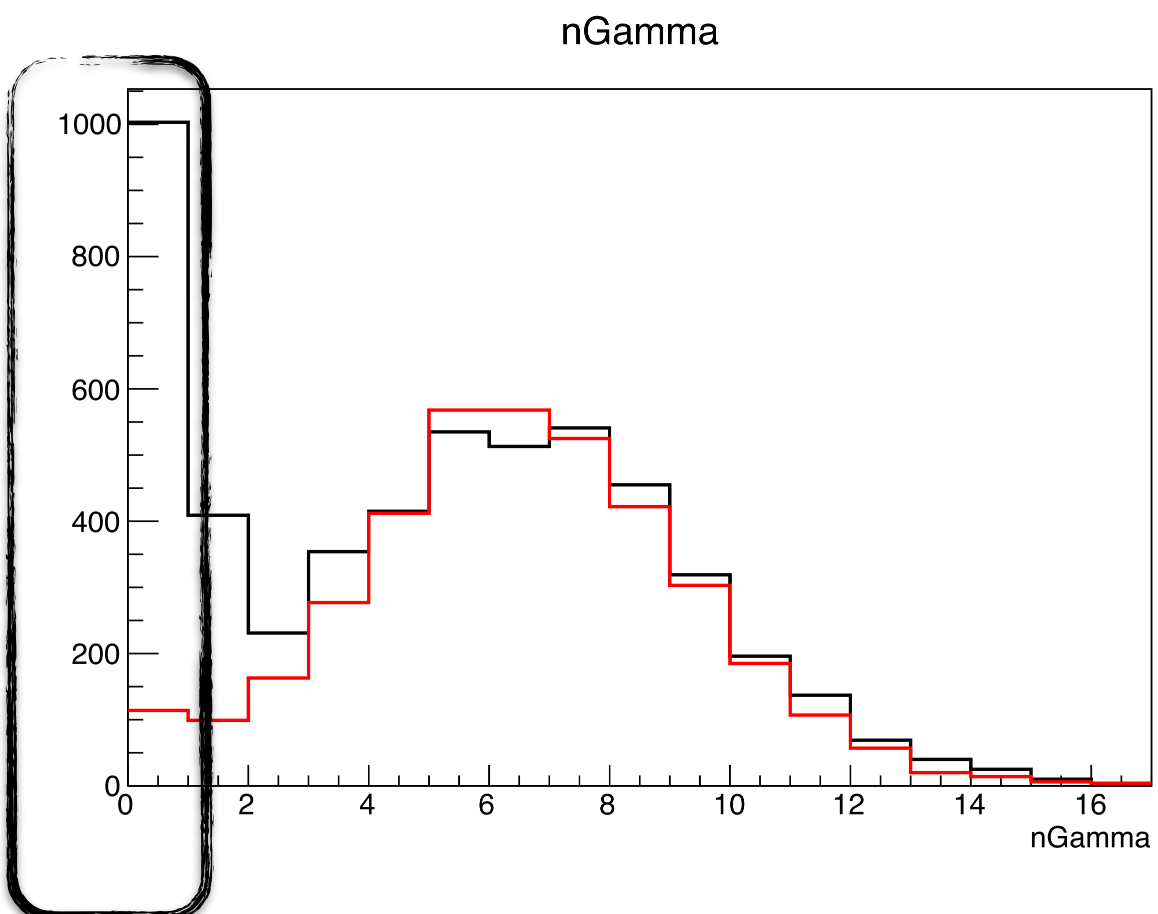
No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	$e^+\bar{\nu}_\mu\bar{\nu}_\tau\nu_e\mu^-\nu_\tau$	0	64245	64245
1	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$\bar{\nu}_e\mu^+\bar{\nu}_\tau e^-\nu_\mu\nu_\tau$	1	63262	127507
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	5045	132552
3	$\psi' \to \tau^+\tau^-, \tau^+ \to \pi^+\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$\bar{\nu}_e\bar{\nu}_\tau e^-\nu_\tau\pi^+$	4	4855	137407
4	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma_{FSR}$	$\bar{\nu}_e\mu^+\bar{\nu}_\tau e^-\nu_\mu\nu_\tau$	5	4166	141573
5	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau\gamma_{FSR}$	$e^+\bar{\nu}_\mu\bar{\nu}_\tau\nu_e\mu^-\nu_\tau$	3	4141	145714
6	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \pi^-\nu_\tau\gamma_{FSR}$	$e^+\bar{\nu}_\tau\pi^-\nu_e\nu_\tau$	10	382	146096
7	$\psi' \to \tau^+\tau^-, \tau^+ \to \pi^+\pi^0\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma_{FSR}$	$\bar{\nu}_e\bar{\nu}_\tau e^-\pi^0\nu_\tau\pi^+$	18	325	146421
8	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \nu_\tau\pi^-K^0, K^0 \to K_L$	$e^+\bar{\nu}_\tau\pi^-\nu_e K_L\nu_\tau$	14	191	146612
9	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau\gamma_{FSR}, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma_{FSR}$	$\bar{\nu}_e\mu^+\bar{\nu}_\tau e^-\nu_\mu\nu_\tau$	12	163	146775
10	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau\gamma_{FSR}\gamma_{FSR}, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	$e^+\bar{\nu}_\mu\bar{\nu}_\tau\nu_e\mu^-\nu_\tau$	11	153	146928
11	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \pi^-\pi^-\pi^+\nu_\tau$	$e^+\bar{\nu}_\tau\pi^-\pi^-\nu_e\nu_\tau\pi^+$	13	141	147069
12	$\psi' \to \tau^+\tau^-, \tau^+ \to \bar{\nu}_\tau\pi^+K^0, \tau^- \to e^-\bar{\nu}_e\nu_\tau, K^0 \to K_L$	$\bar{\nu}_e\bar{\nu}_\tau e^-K_L\nu_\tau\pi^+$	19	132	147201
13	$\psi' \to \tau^+\tau^-, \tau^+ \to \pi^+\pi^+\pi^-\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$\bar{\nu}_e\bar{\nu}_\tau\pi^-e^-\nu_\tau\pi^+\pi^+$	22	124	147325
14	$\psi' \to \tau^+\tau^-\gamma_{FSR}, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	$e^+\bar{\nu}_\mu\bar{\nu}_\tau\nu_e\mu^-\nu_\tau$	17	52	147377
15	$\psi' \to \tau^+\tau^-\gamma_{FSR}, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$\bar{\nu}_e\mu^+\bar{\nu}_\tau e^-\nu_\mu\nu_\tau$	24	52	147429
16	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	$\mu^+\bar{\nu}_\mu\bar{\nu}_\tau\mu^-\nu_\mu\nu_\tau$	20	51	147480
17	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to e^+e^-\gamma_{FSR}$	$e^+\pi^-e^-\pi^+$	8	43	147523
18	$\psi' \to \tau^+\tau^-, \tau^+ \to \pi^+\pi^0\bar{\nu}_\tau, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	$\bar{\nu}_\mu\bar{\nu}_\tau\pi^0\mu^-\nu_\tau\pi^+$	40	34	147557
19	$\psi' \to \tau^+\tau^-, \tau^+ \to K^+\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$\bar{\nu}_e\bar{\nu}_\tau e^-\nu_\tau K^+$	9	31	147588
20	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to K^-\nu_\tau$	$e^+\bar{\nu}_\tau K^-\nu_e\nu_\tau$	63	24	147612
21	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to \pi^-\nu_\tau$	$\mu^+\bar{\nu}_\tau\pi^-\nu_\mu\nu_\tau$	16	22	147634
22	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau\gamma_{FSR}\gamma_{FSR}, \tau^- \to \pi^-\nu_\tau$	$e^+\bar{\nu}_\tau\pi^-\nu_e\nu_\tau$	21	16	147650
23	$\psi' \to \tau^+\tau^-, \tau^+ \to \bar{\nu}_\tau\pi^+K^0\pi^0, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma_{FSR}, K^0 \to K_L$	$\bar{\nu}_e\bar{\nu}_\tau e^-\pi^0K_L\nu_\tau\pi^+$	56	13	147663
24	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$e^+\bar{\nu}_e\bar{\nu}_\tau e^-\nu_e\nu_\tau$	41	11	147674
25	$\psi' \to \tau^+\tau^-, \tau^+ \to \bar{\nu}_\tau\pi^+\pi^-\pi^+\pi^0, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma_{FSR}$	$\bar{\nu}_e\bar{\nu}_\tau\pi^-e^-\pi^0\nu_\tau\pi^+\pi^+$	54	11	147685
26	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau\gamma_{FSR}, \tau^- \to \pi^-\pi^-\pi^+\nu_\tau$	$e^+\bar{\nu}_\tau\pi^-\pi^-\nu_e\nu_\tau\pi^+$	15	9	147694
27	$\psi' \to \tau^+\tau^-, \tau^+ \to \pi^+\pi^0\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma_{FSR}\gamma_{FSR}$	$\bar{\nu}_e\bar{\nu}_\tau e^-\pi^0\nu_\tau\pi^+$	64	9	147703
28	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau\gamma_{FSR}, \tau^- \to \nu_\tau\pi^-\bar{K}^0, \bar{K}^0 \to K_L$	$e^+\bar{\nu}_\tau\pi^-\nu_e K_L\nu_\tau$	55	7	147710
29	$\psi' \to J/\psi\pi^+\pi^-, J/\psi \to e^+e^-\gamma_{FSR}\gamma_{FSR}$	$e^+\pi^-e^-\pi^+$	42	7	147717

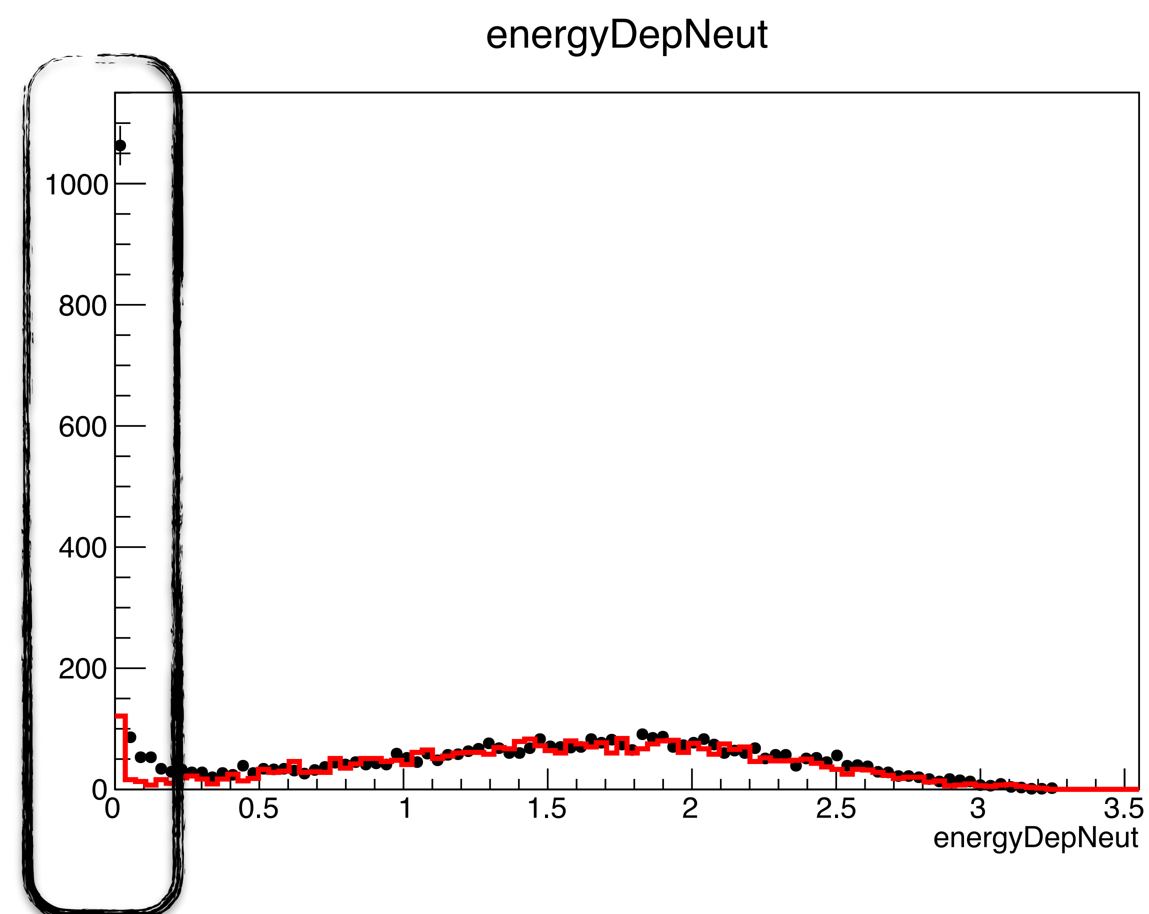
Mainly background come from eπ(π^0) events with same intermediate states ττ and few ππJ/ψ (J/ψ to electron pairs) events

Check the difference between data and inclusive MC

RUN 25338

- Comparison between data and inclusive MC distributions



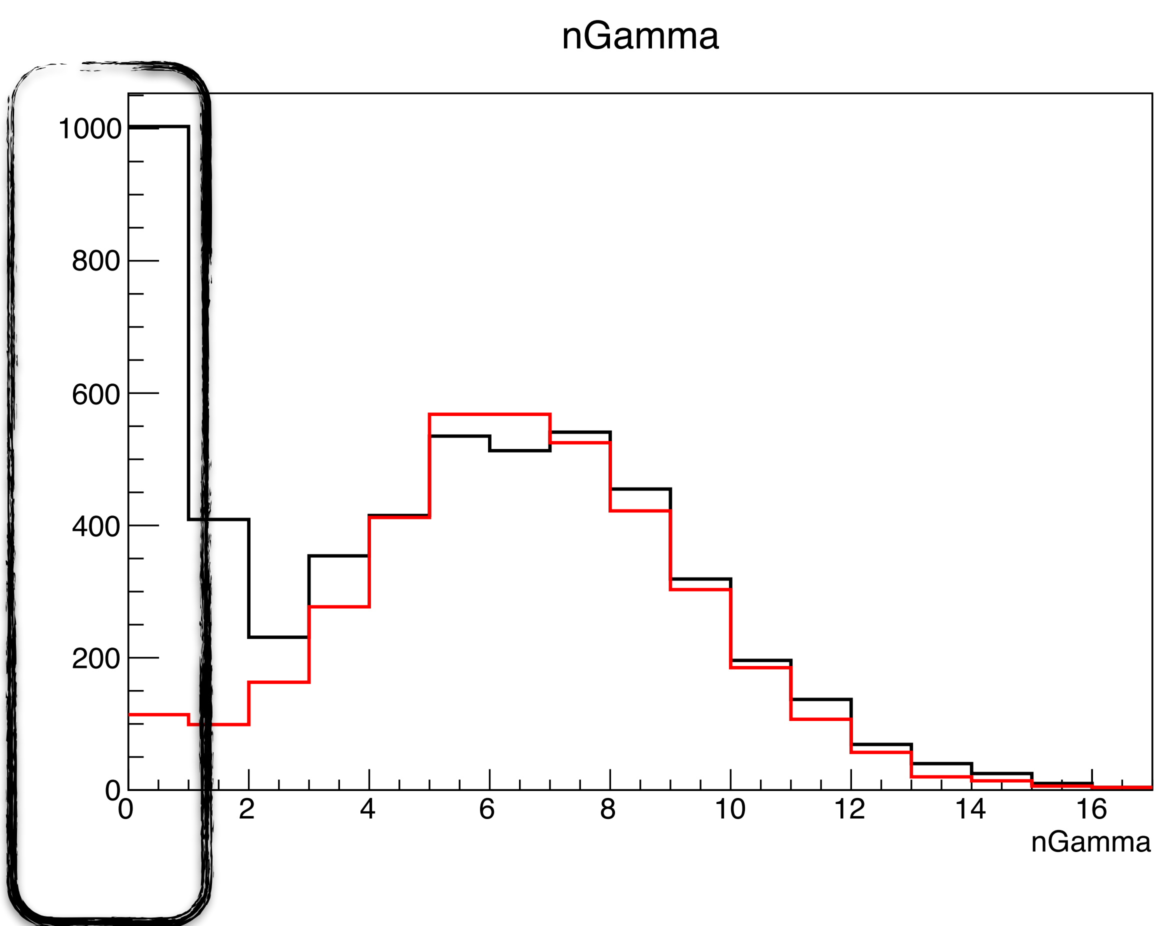


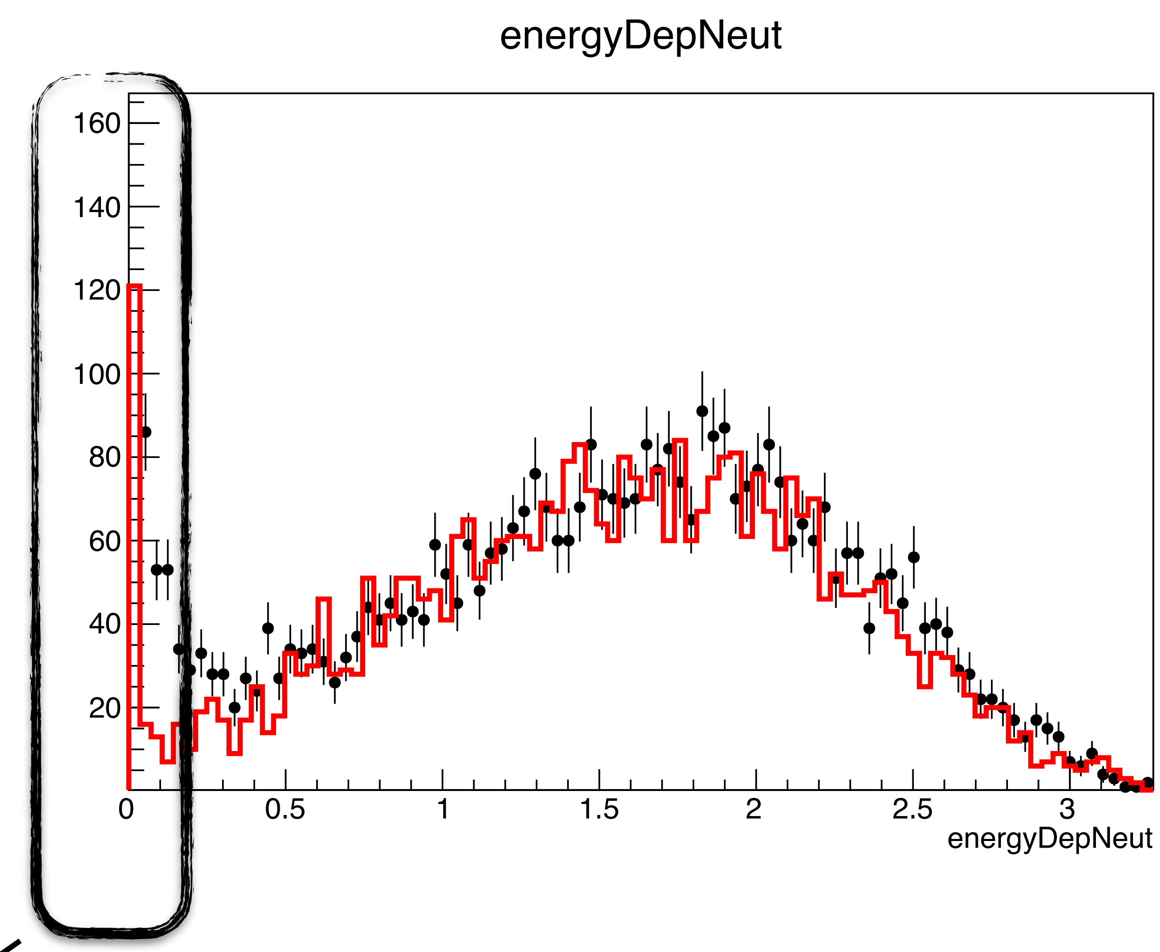
Our signal region!!!

Check the difference between data and inclusive MC

RUN 25338

- Comparison between data and inclusive MC distributions

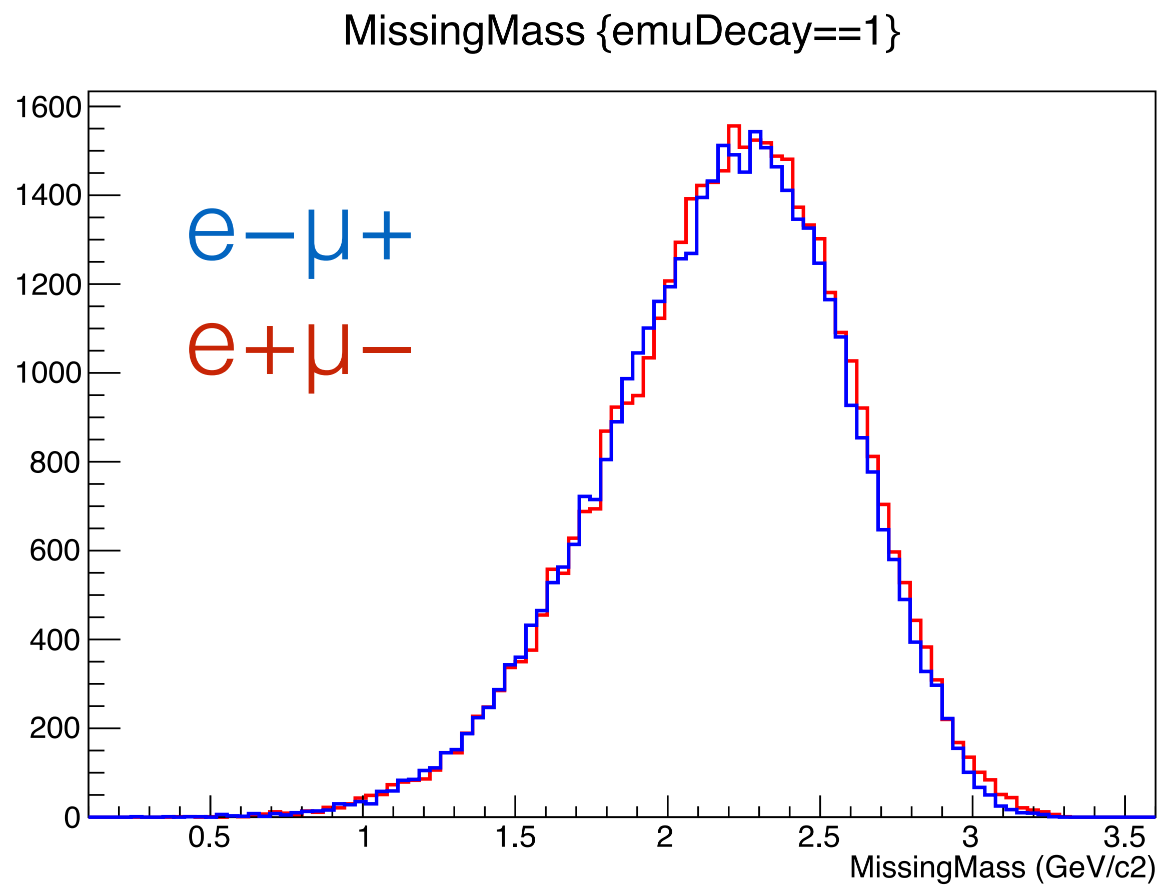




Our signal region!!!

Inclusive MC sample is not reliable

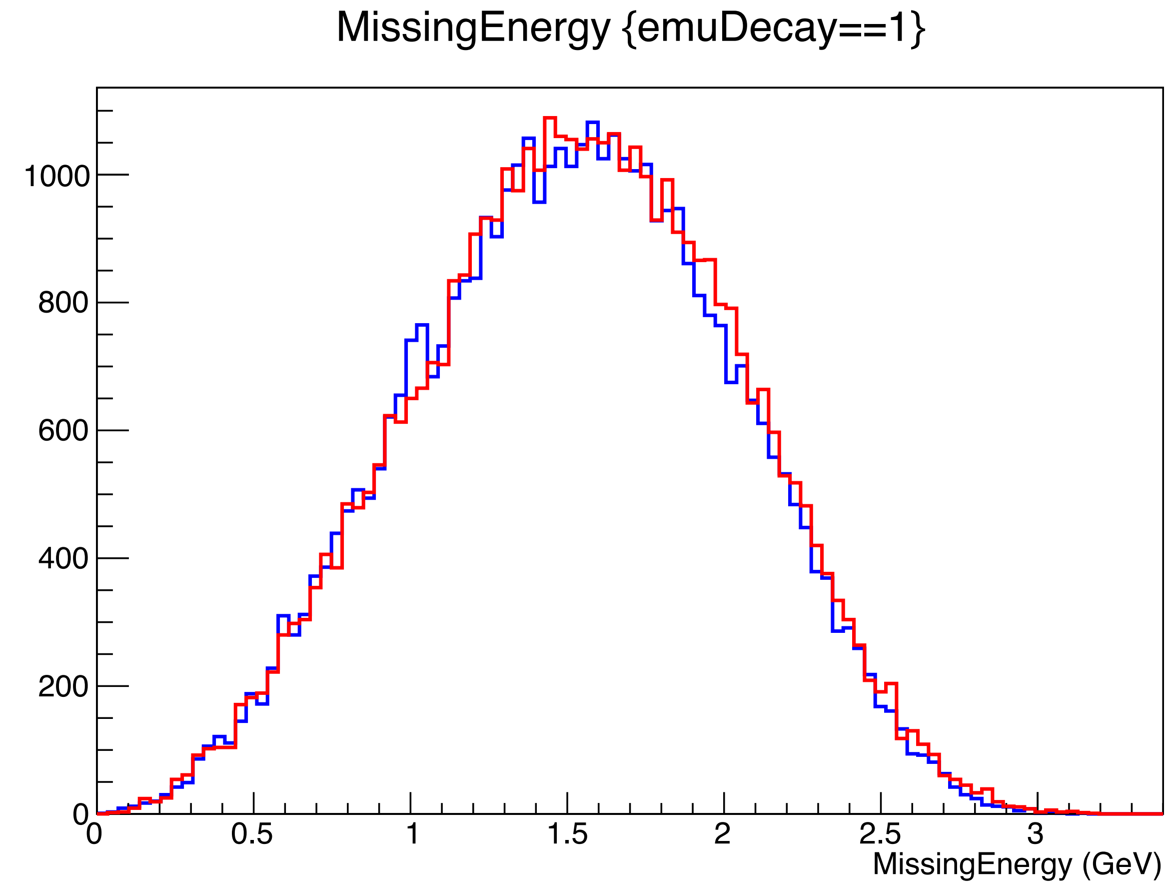
Signal MC: distributions III



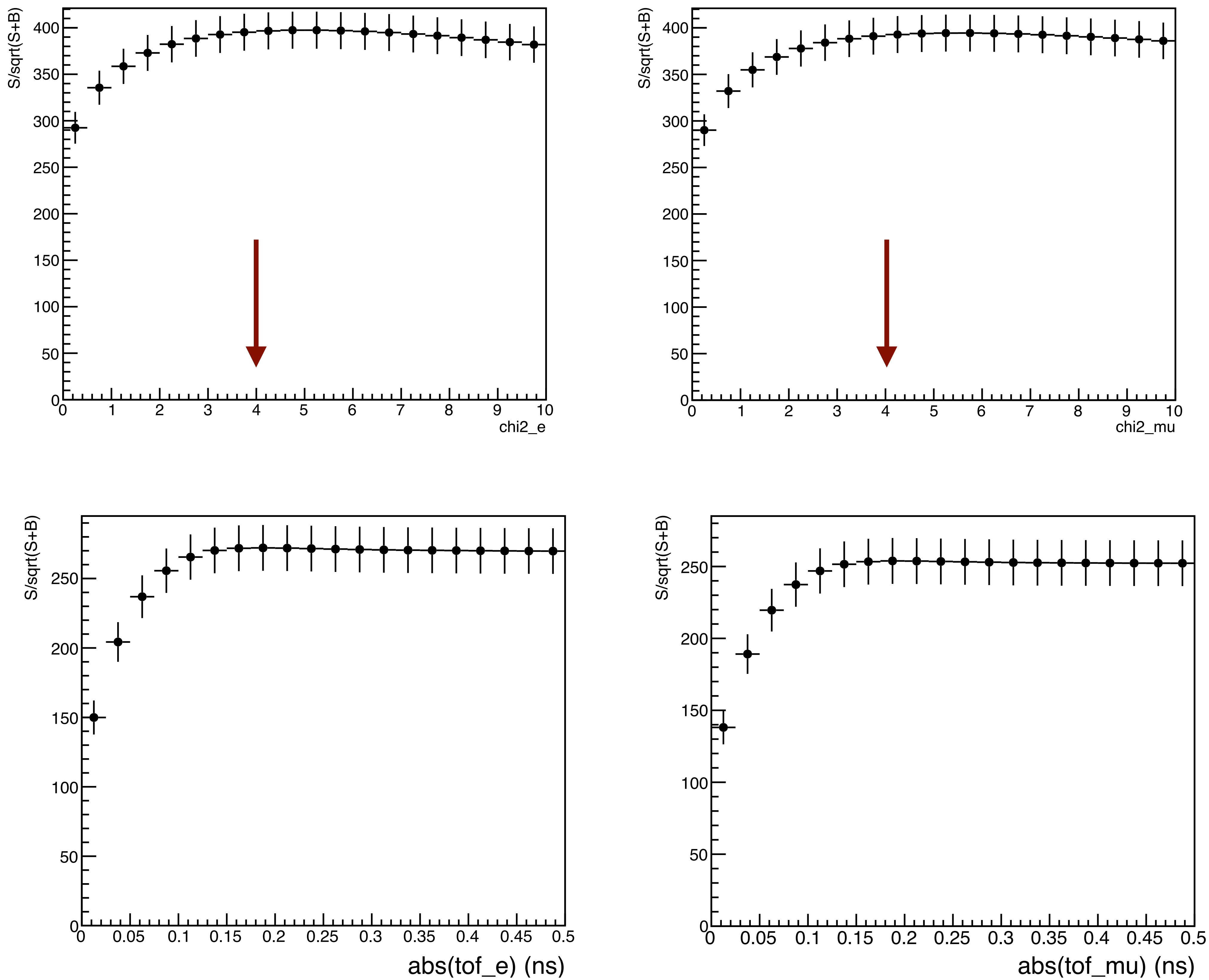
Missing energy and missing mass:

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

Distributions after cuts and PID selection



Cuts Optimization



OLD Background studies

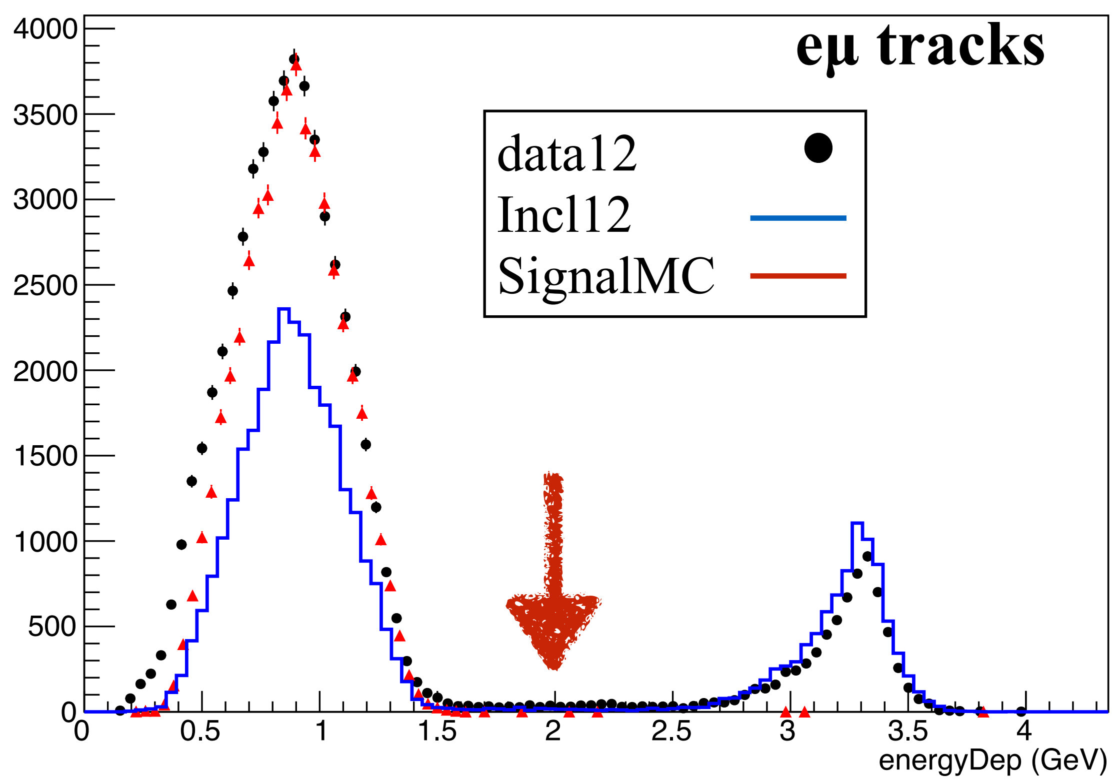
Several background taken into account:

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	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

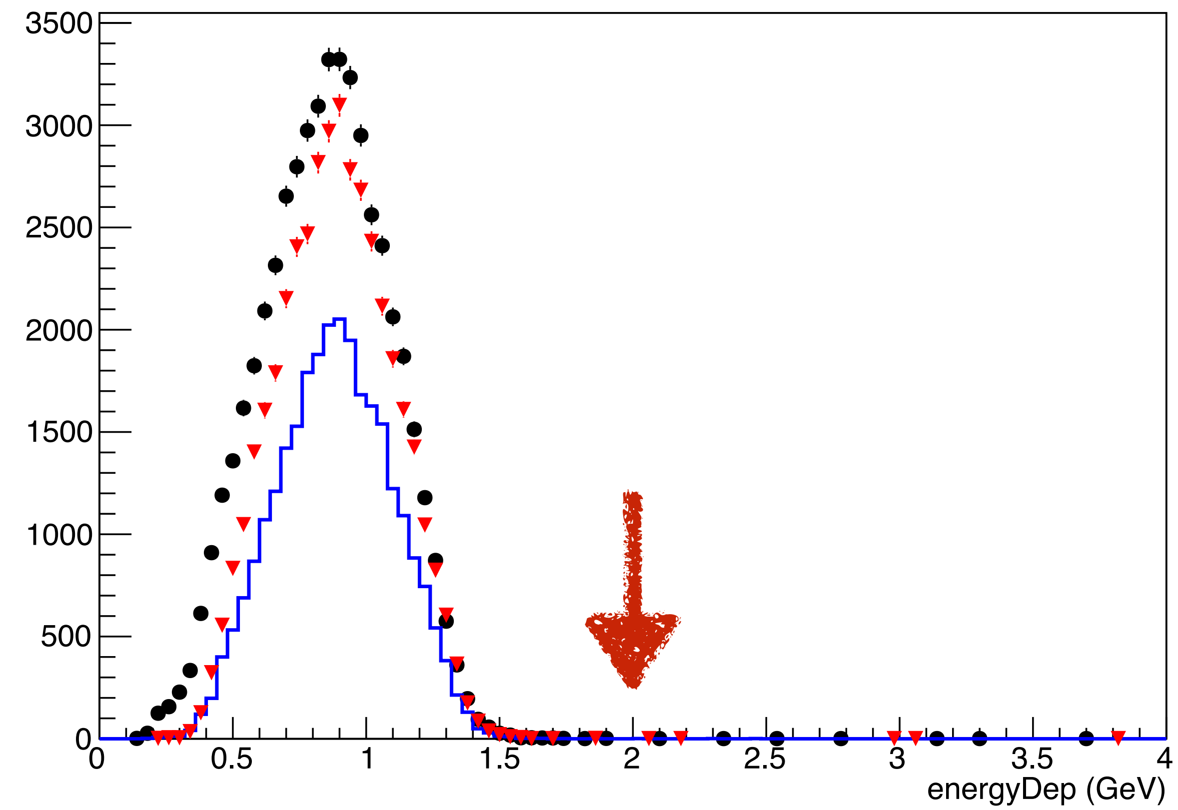
$\psi(2S)\to\pi e 3\nu$ non-negligile contribution

Additional cuts I

*signal arbitrary scale



NgoodTracks ==2

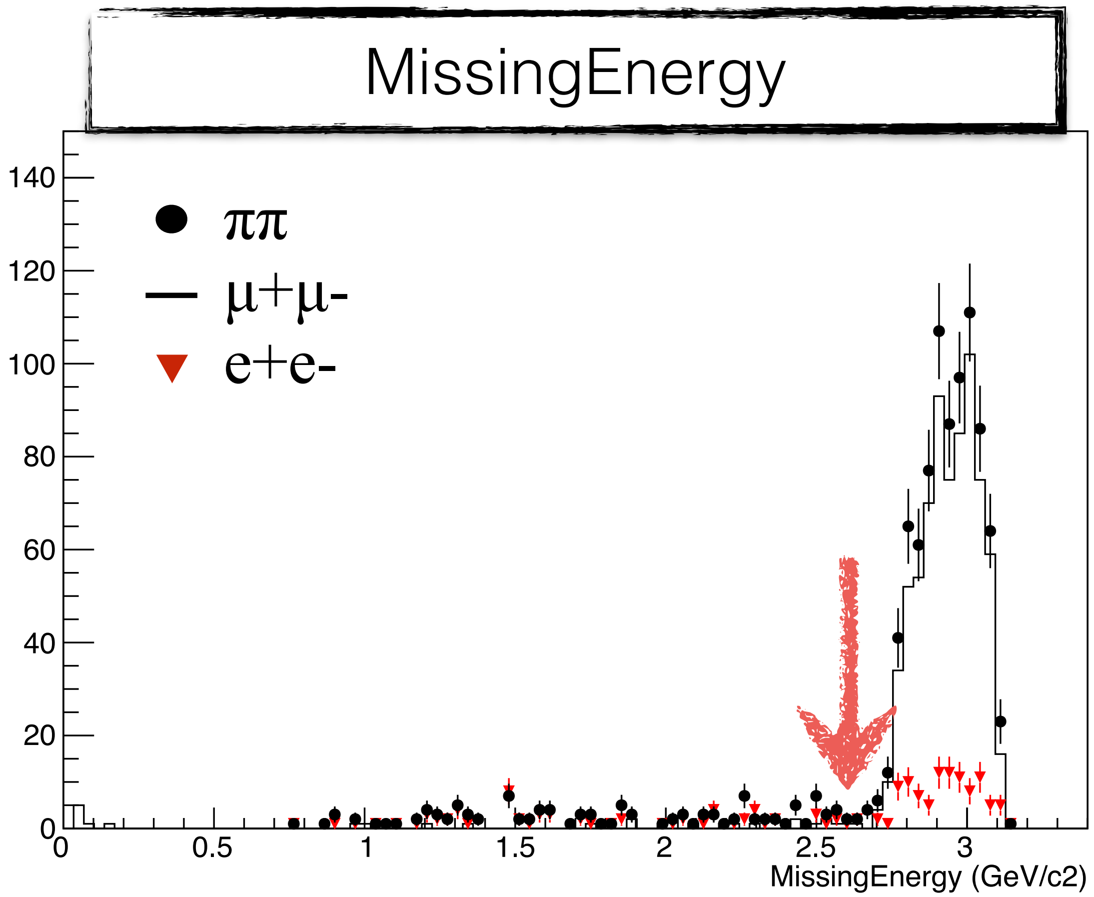


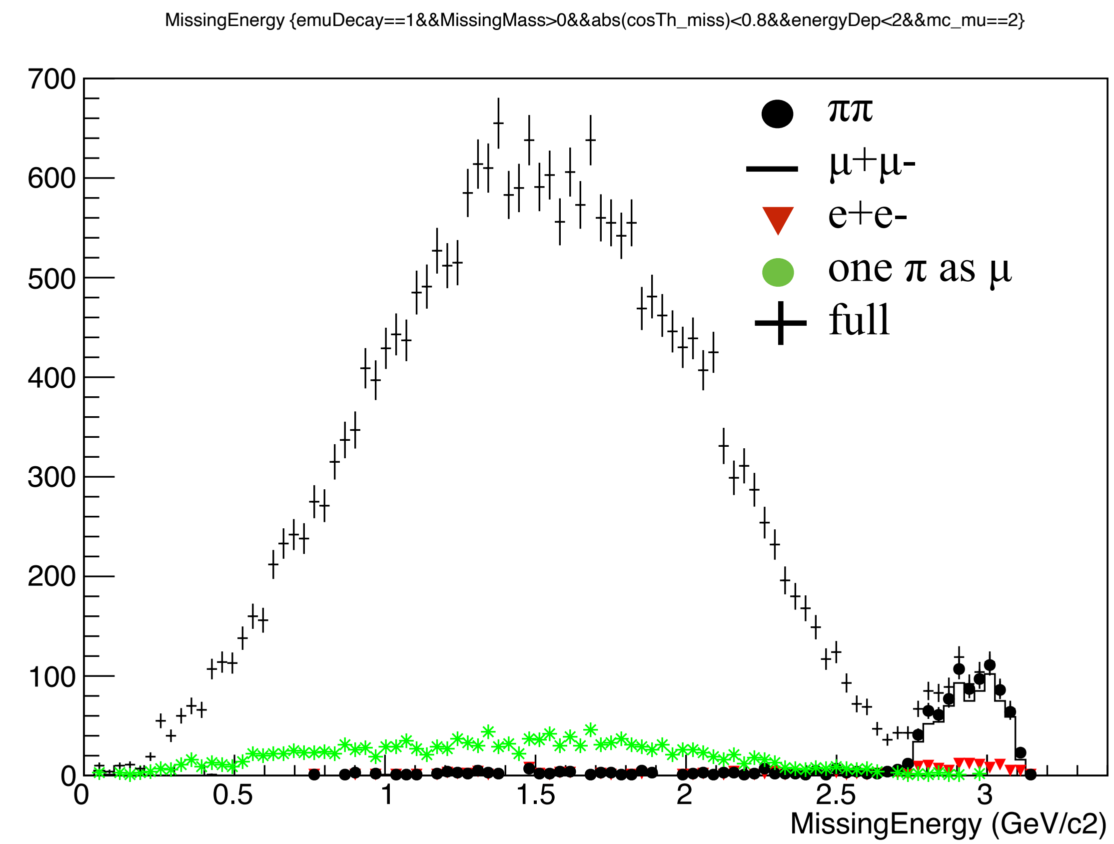
NTracks ==2

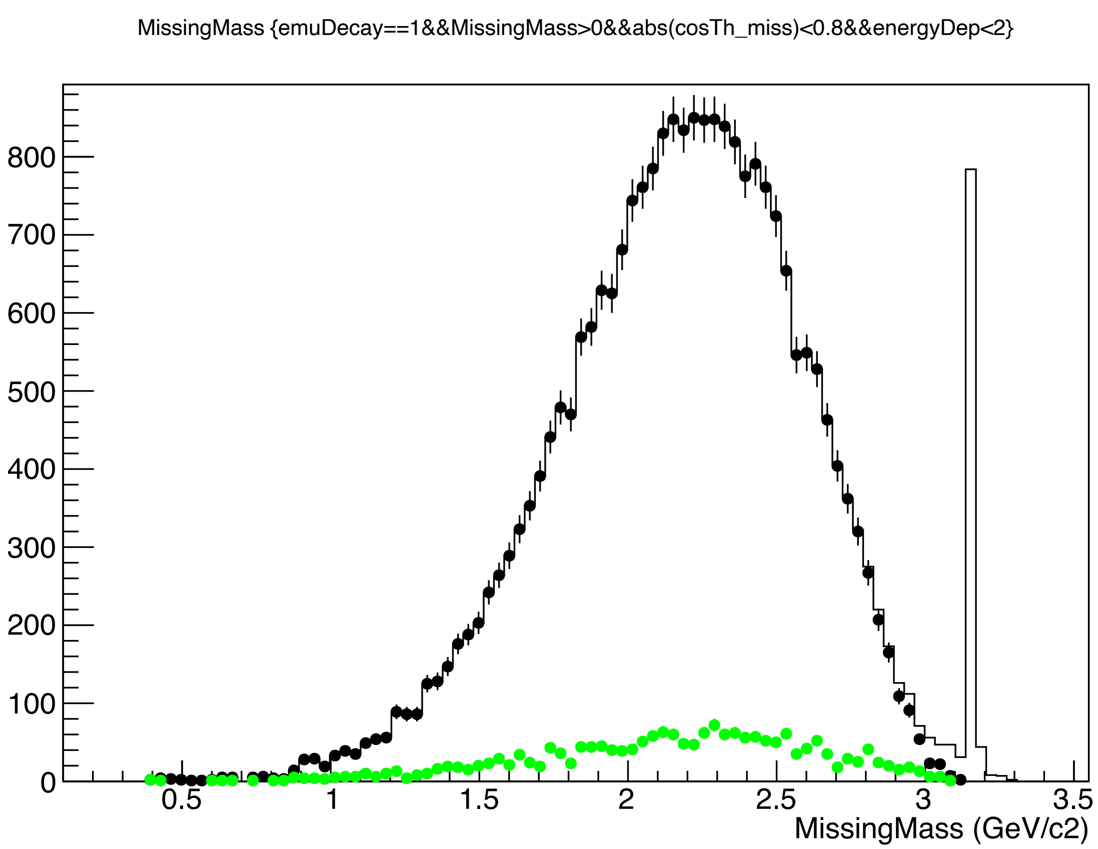
Full data-2012 and inclusive-2012 MC sample analyzed

- 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





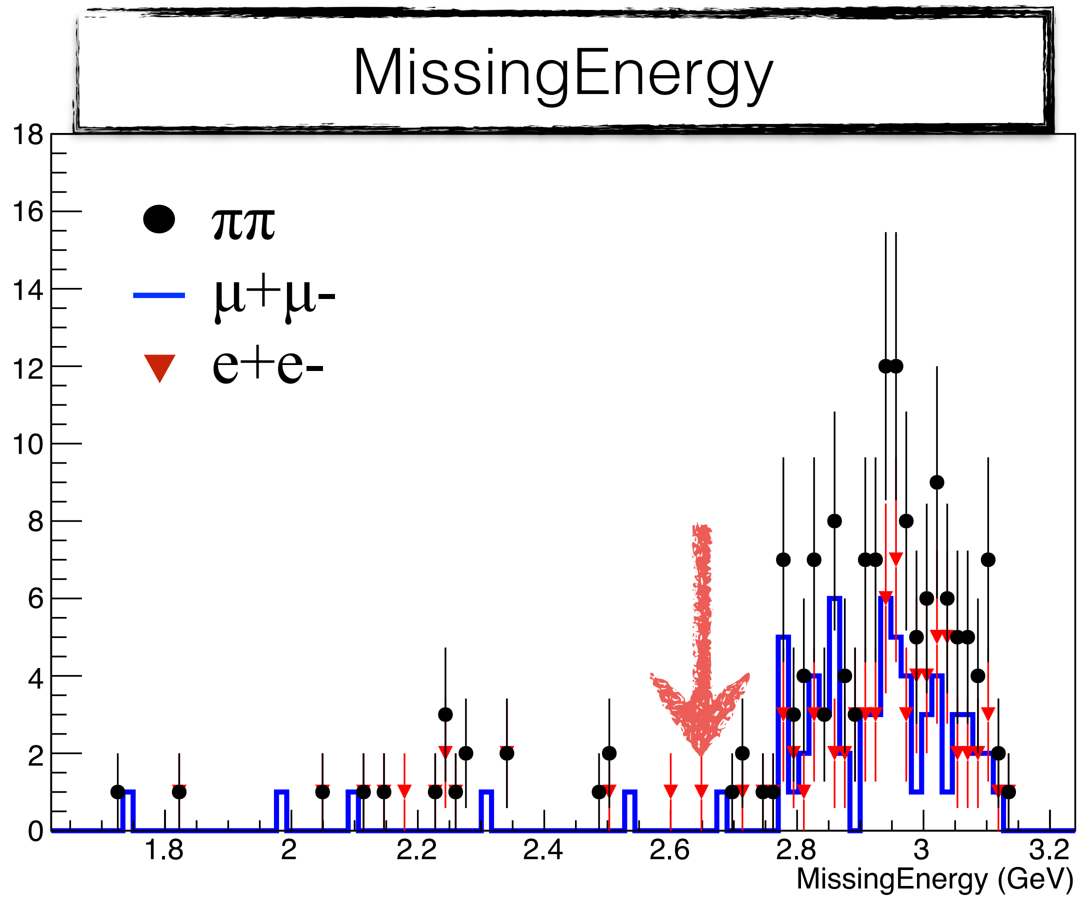


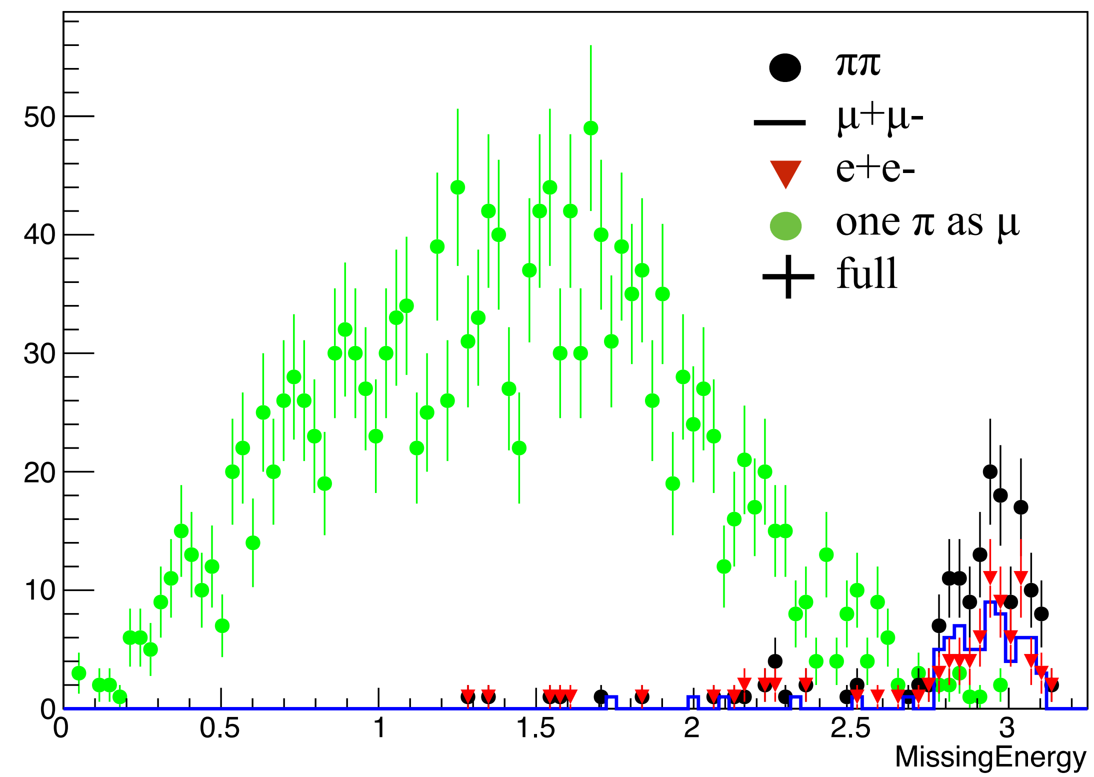
— no cut in MissingEnergy

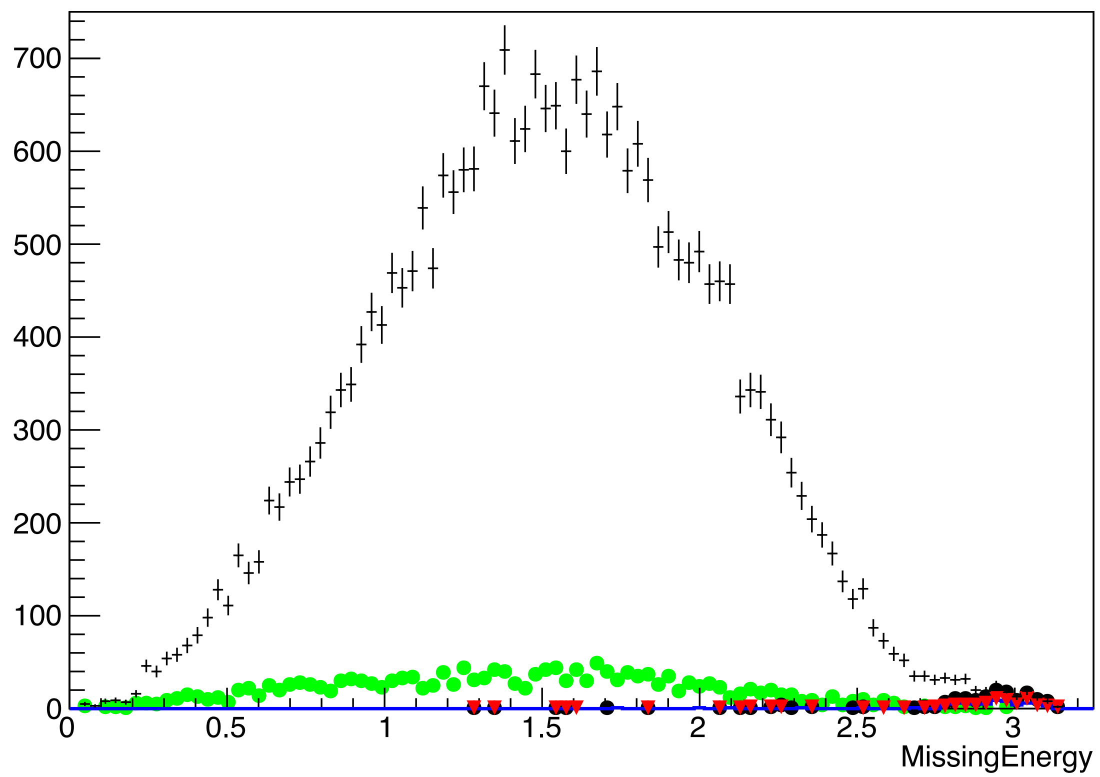
● MissingEnergy<2.65 GeV

● pion contamination

Additional cuts II



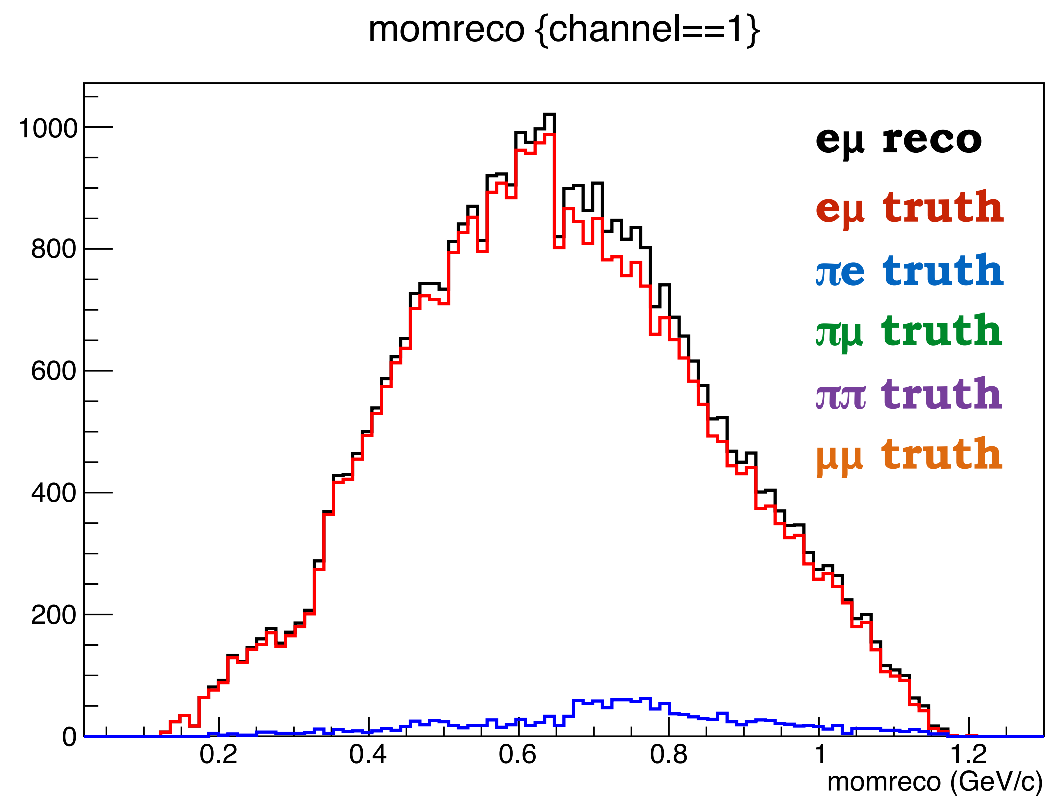


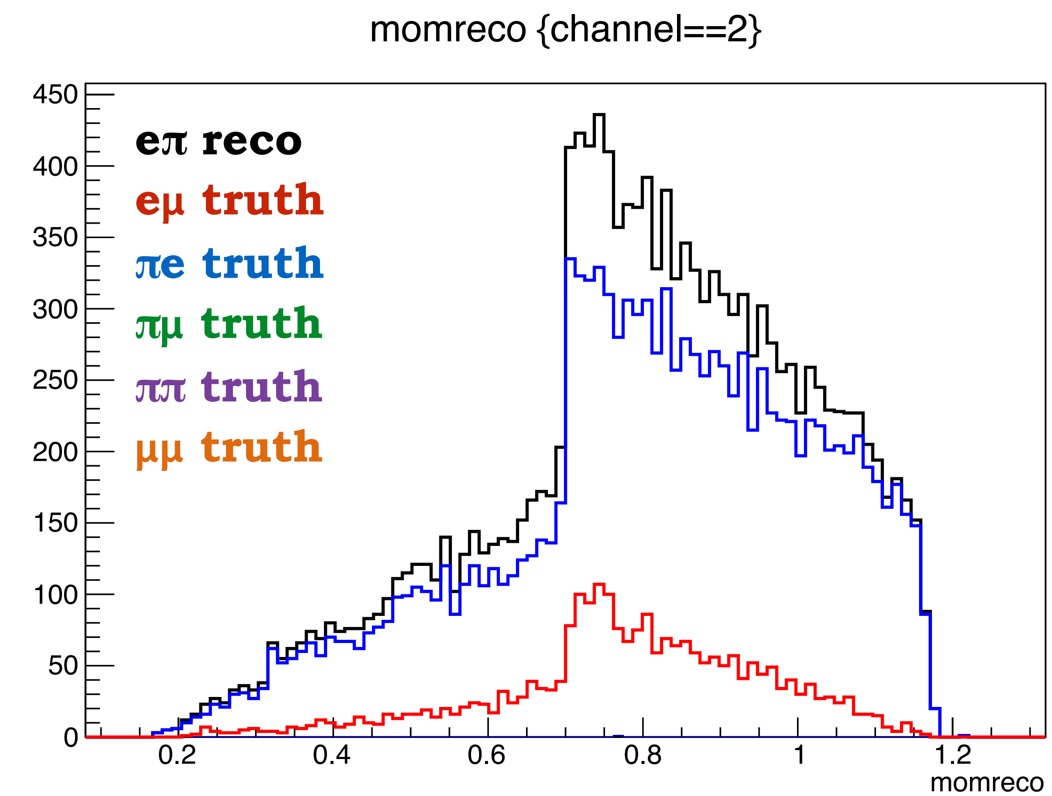


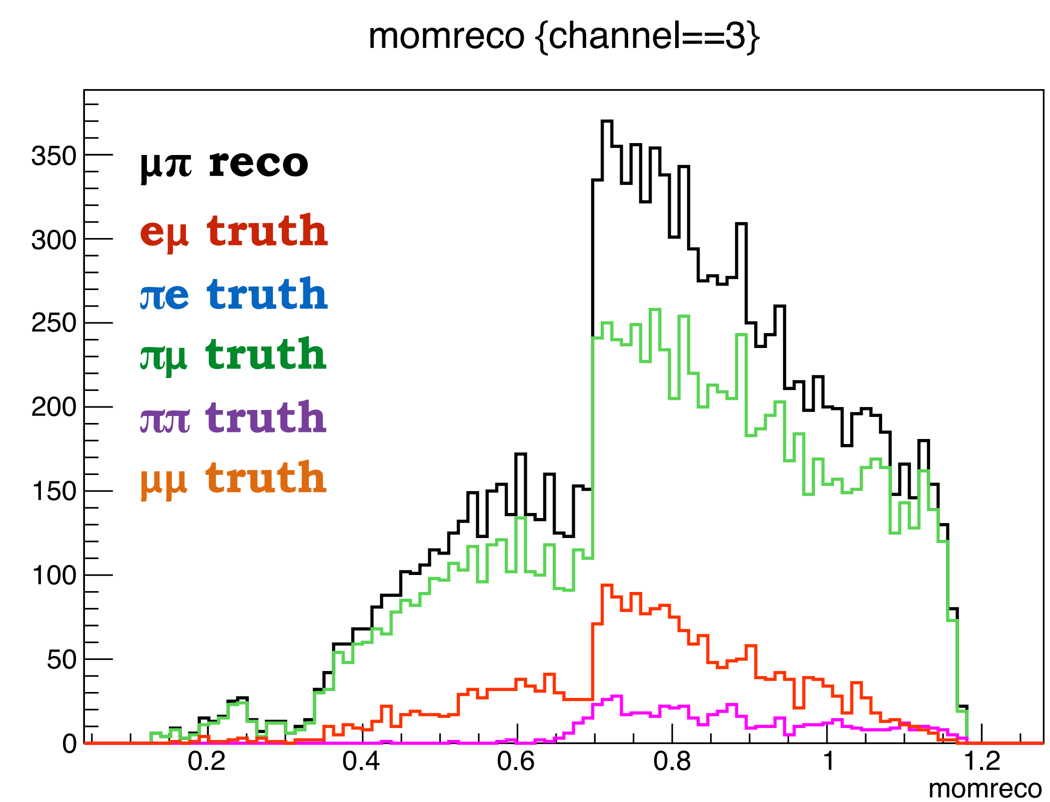
MissingEnergy < 2.65 GeV

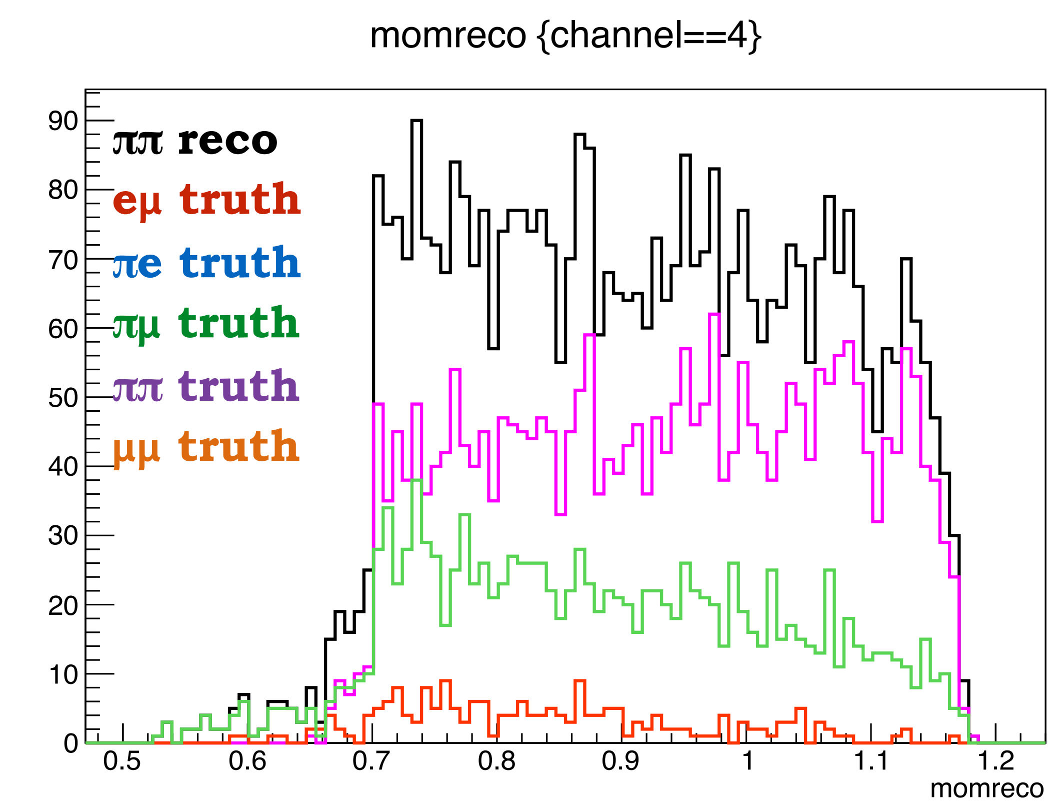
Signal MC: distributions I

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



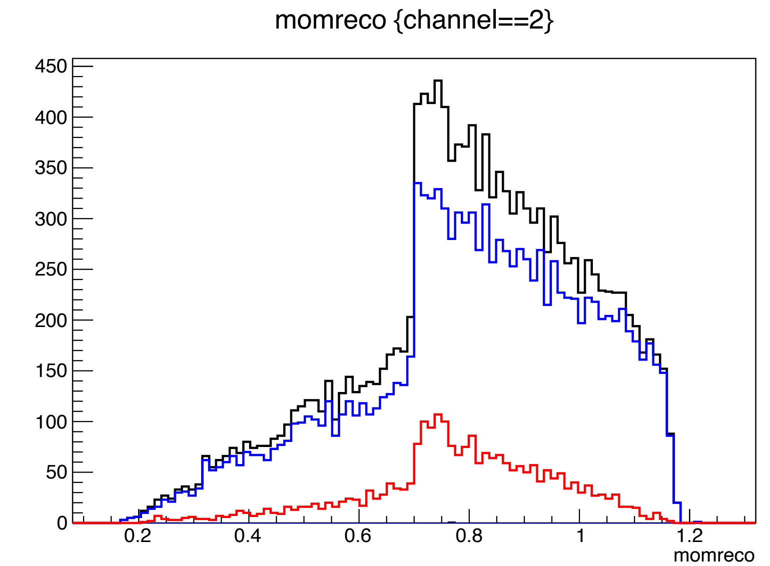


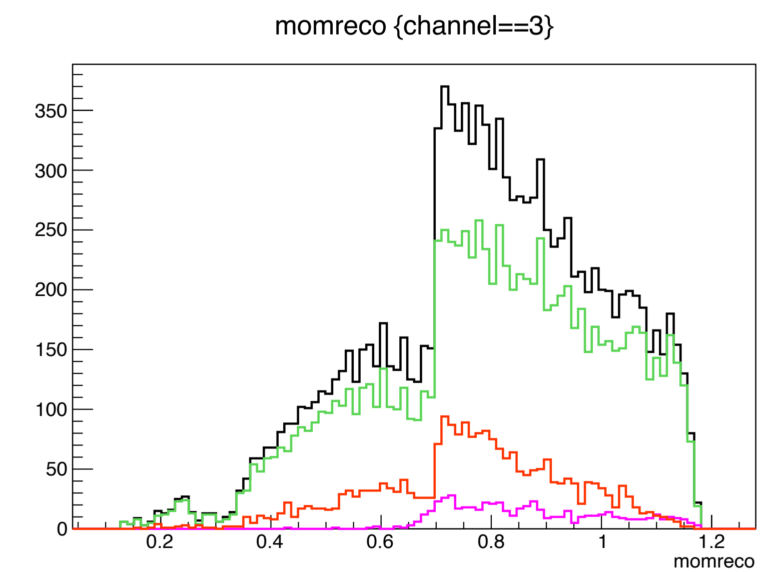


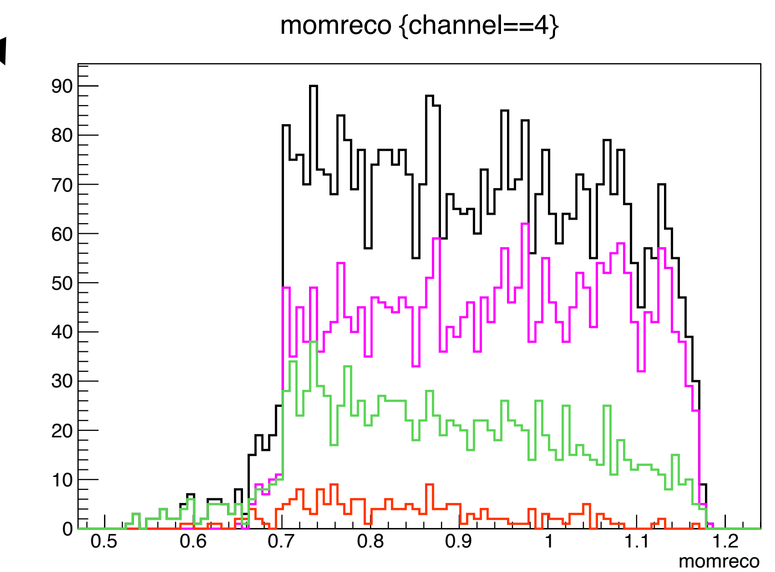


Conclusion from this new event and track selection

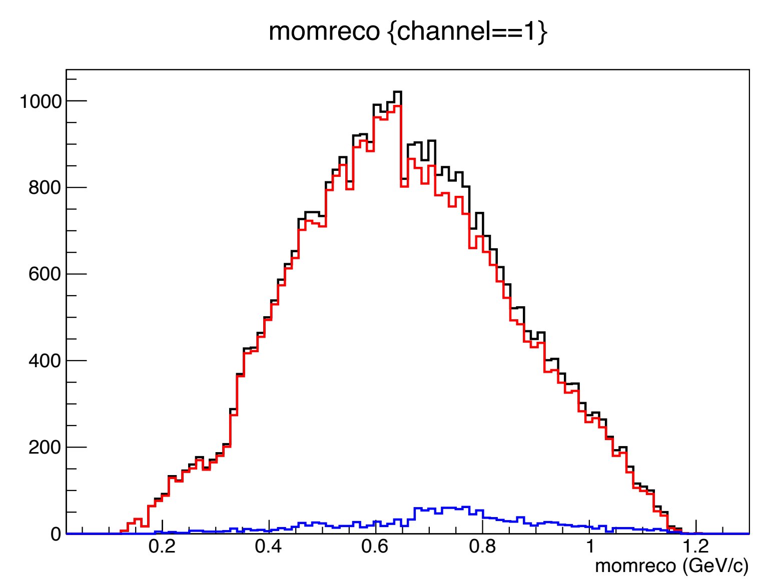
$\psi(2S) \to \tau\tau \to e\mu4\nu / \pi e3\nu / \pi\mu3\nu / \pi\pi2\nu$







- 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)

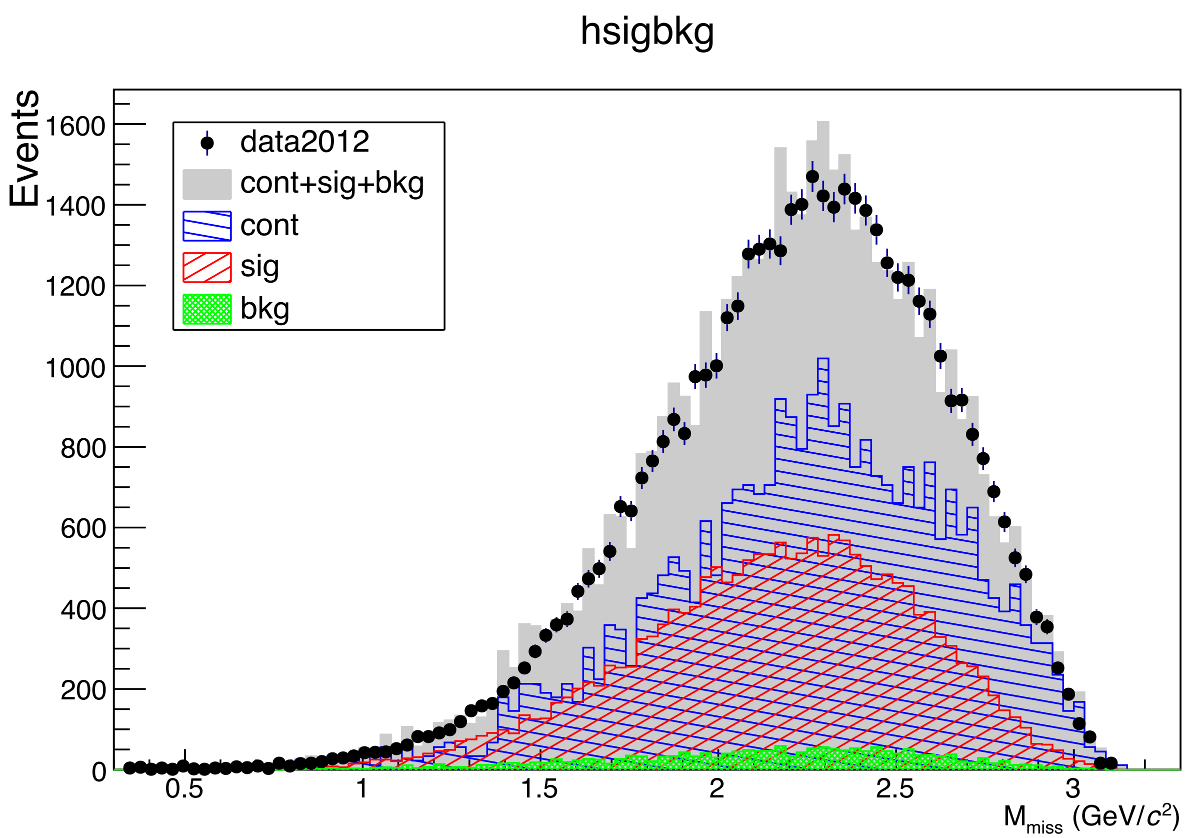


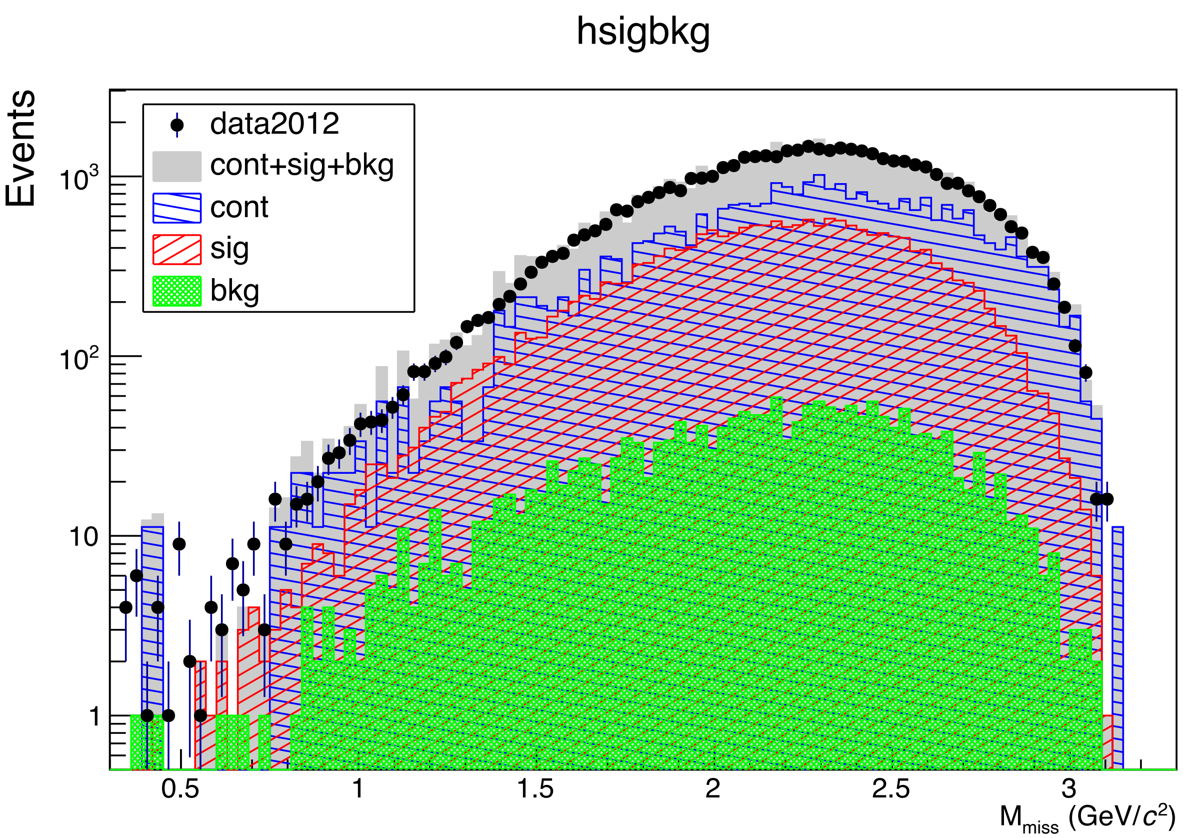
eμ reco
πe truth
~4/5% of background contamination

Study of inclusive sample

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

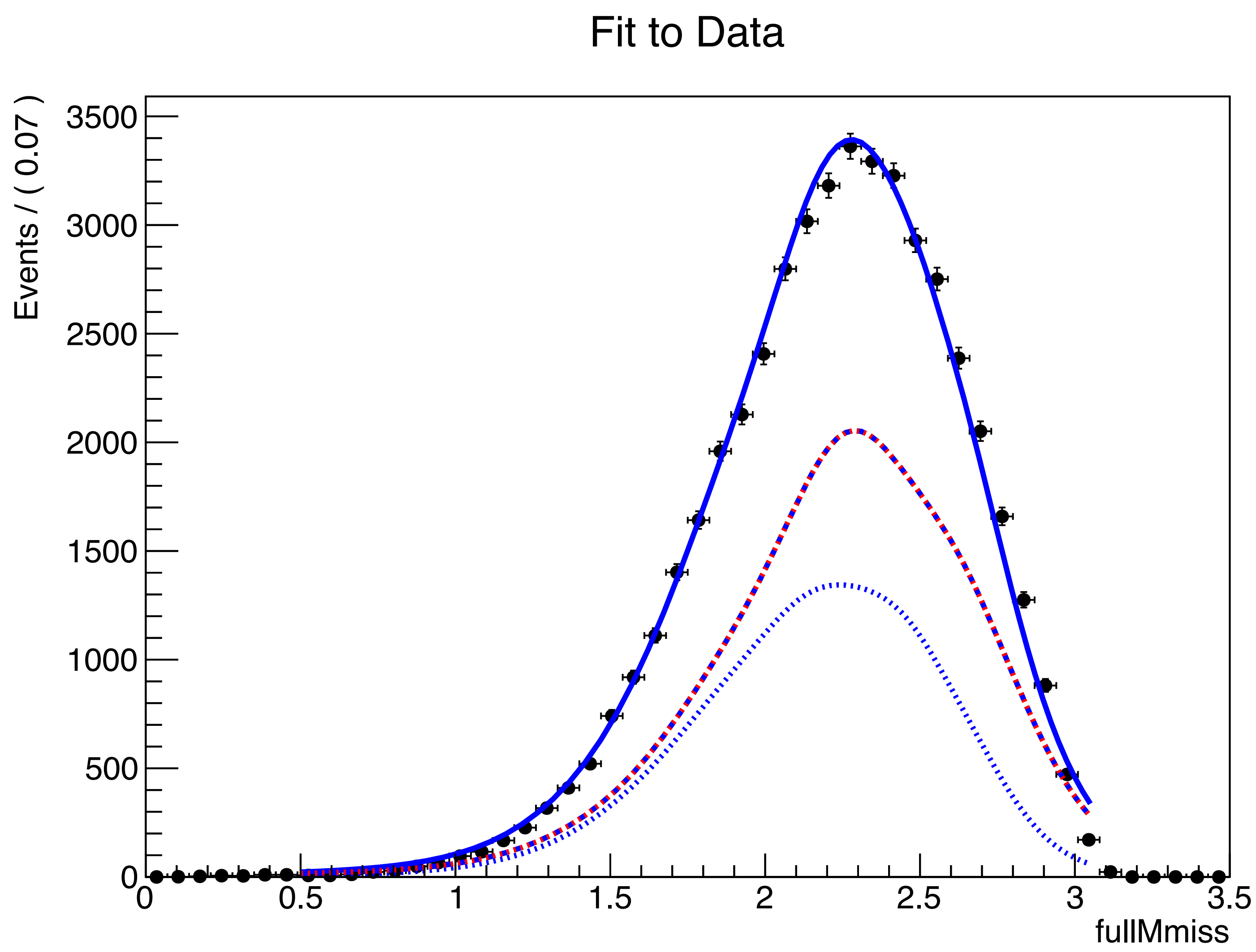
Continuum
2012 data





- 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

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

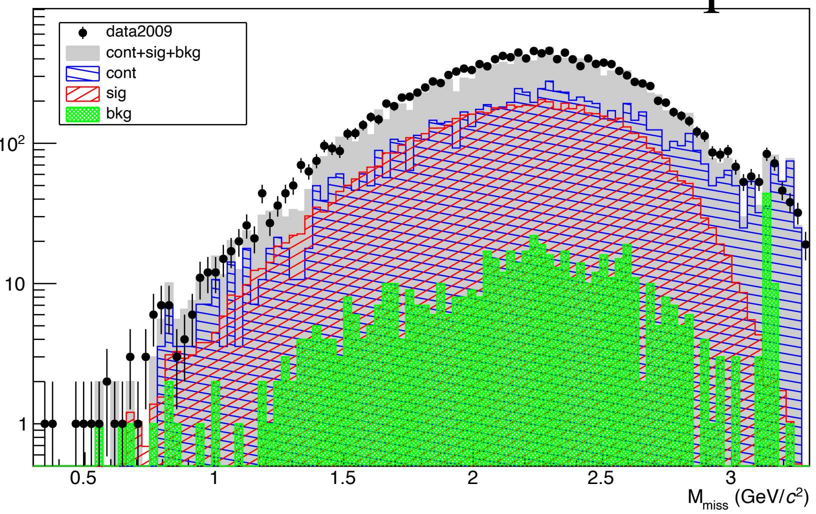
$=(2.72 \pm 0.05) \times 10^{-3}$

Additional tests

2009 DATA SET

- Check consistency of continuum
  - data set collected in 2009

2009 data sample



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

~3.56×10^{-3}

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

This term is estimated by QED calculation

~3.41×10^{-3}

2012 DATA SET

- Check consistency of continuum
  - data set collected in 2009

https://doi.org/10.1103/PhysRevD.74.112003

σ_{int} = -66.587*BR(ττ) pb^{-1}

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

~2.87×10^{-3}

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

This term is estimated by QED calculation

~2.64×10^{-3}

https://arxiv.org/pdf/hep-ex/0010072.pdf

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)