Search for $\psi(2S) \to e\mu + invisible$ at BESIII

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OUTLINE

- Motivation
- Data set and event selection
- Background analysis

Motivation

Motivation----Physical background

- **Neutrino Oscillation**

In vacuum, the neutrino oscillation is totally determined by the neutrino mass matrix. However, the oscillation pattern can receive environmental effect if neutrinos propagate through matter . Even without mass term, neutrino oscillation can happen in matter [1].

- **Dark Matter**

If DM is a fundamental particle, our universe is immersed in a sea of DM particles. With small enough mass, there would be a plenty of DM particles surrounding us. Due to the Pauli exclusion principle, the light DM (< 100 eV) can only be bosons, either scalar or vector particles.

- **The dark non-standard interaction (Dark NSI)**

If the scalar DM particle has interaction with neutrinos, the relevant Lagrangian is

$$-\mathcal{L} = \frac{1}{2} m_\phi^2 \phi^2 + \frac{1}{2} M_{\alpha\beta} \bar{\nu}_\alpha \nu_\beta + y_{\alpha\beta} \phi \bar{\nu}_\alpha \nu_\beta + h.c.$$

with a Yukawa coupling between the light DM φ (≡ χ) and neutrinos.

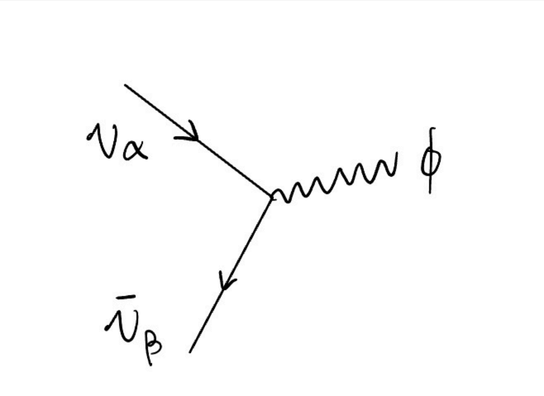
$\alpha,\beta = e, \mu, \tau$

Motivation---- $\psi(2S) \rightarrow e\mu$ +*invisible*

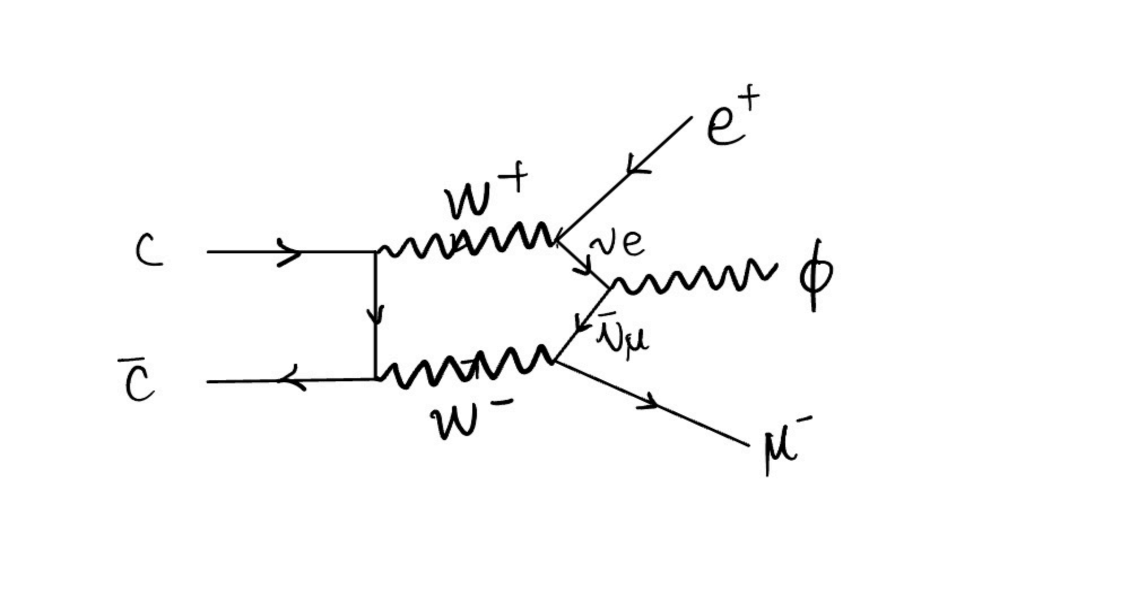
- **The dark non-standard interaction (Dark NSI)**

$$-\mathcal{L} = \frac{1}{2} m_\phi^2 \phi^2 + \frac{1}{2} M_{\alpha\beta} \bar{\nu}_\alpha \nu_\beta + \mathcal{Y}_{\alpha\beta} \phi \bar{\nu}_\alpha \nu_\beta + h.c.$$

If $\mathcal{Y}_{\alpha\beta} \neq 0, when\ \alpha \neq \beta$ we have this kind of vertex of interaction :



The Feynman diagram of $\psi(2S) \rightarrow e\mu$ +*invisible*



Data set and event selection

Single MC

We define a stable particle with a mass of 500MeV/c^2 in pdt.table ,named X500. X500 stands for the invisible particle, which is boson.

We use phase space to generate the single MC.

decayDIY.dec

```
Decay psi(2S)
0.5000    e+ mu- X500                  PHSP;
0.5000    mu+ e- X500                  PHSP;
Enddecay


End
```

pdt.table

```
add   p Meson       X500                 500  0.5000         0         0       0       2        0 0

*       |           |                     |  |              |        |       |       |         | + KC=Lund internal code
*       |           |                     |  |              |        |       |       |         + T=c*lifetime (mm, alternative to
W)
*       |           |                     |  |              |        |       |       + S=2*spin
*       |           |                     |  |              |        |       + Q=3*charge
*       |           |                     |  |              |        + WM=max deviation from mass
*       |           |                     |  |              + W=width in GeV
*       |           |                     |  + M=mass in GeV
*       |           |                     + ID=STDHEP-ID
*       |           + NAME=name to be used in printout or as char string to identify particle
*       + TYPE
```

```
sets   p  X500      isStable 1
```

Primary selection

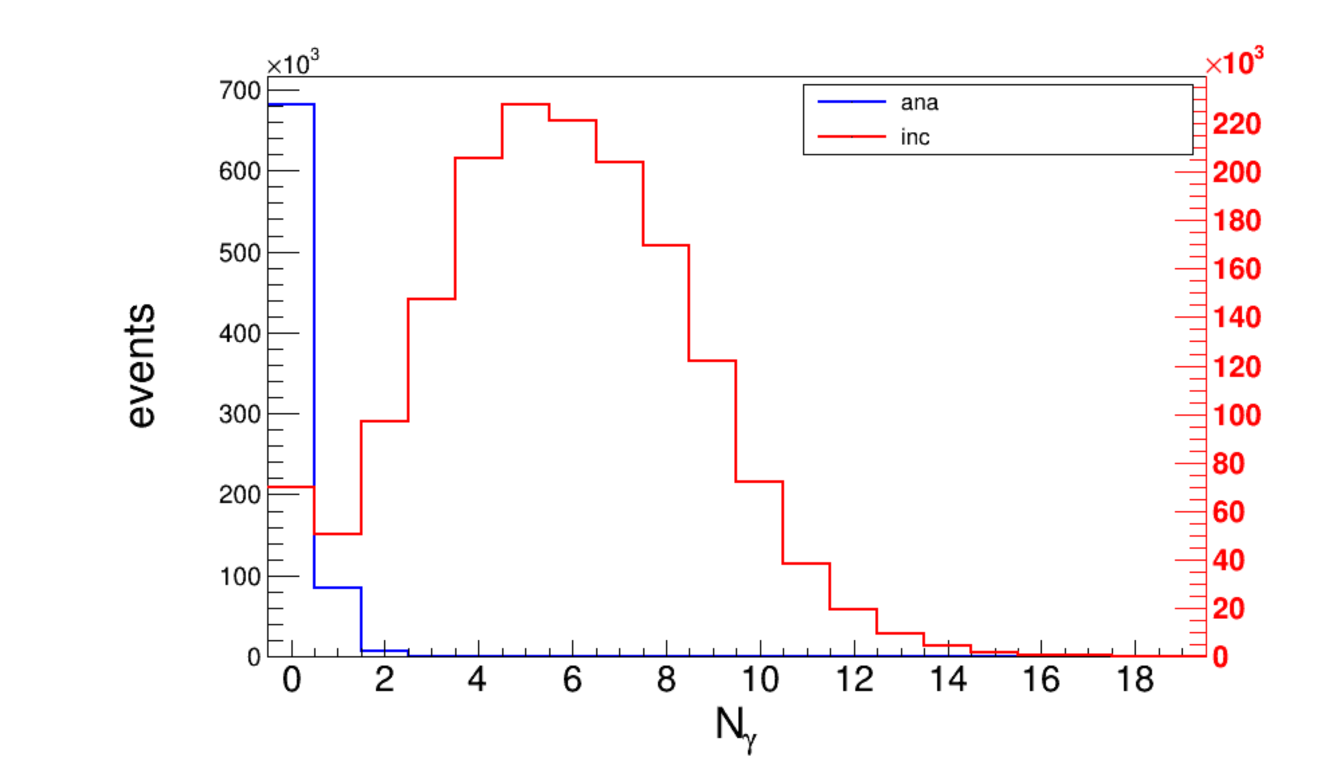
Boss:709 Data set:2009 1.07x10^8 ψ(2S) data samples Blind Analysis

- **Good charged track selection**
  - $|cos\theta| < 0.93$, $|V_z| < 20$cm, nGood = 2, ΣQ=0
  - from interaction point: $|V_z| < 10$cm, $|V_r| < 1$cm

- **Good photons**
  - $E_\gamma > 25MeV$ for barrel ($|cos\theta| < 0.80$)
  - $E_\gamma > 50MeV$ for gap ($0.80 < |cos\theta| < 0.86$)
  - $E_\gamma > 50MeV$ for endcap ($0.86 < |cos\theta| < 0.92$)
  - TDC time window: [0, 700] ns
  - $\theta_{c\gamma} > 10^\circ$

- **Particle identification**
  - e $E_{EMC}/P_{MDC} > 0.8$
  - μ $E_{EMC}/P_{MDC} < 0.8$
  - $N_e = N_\mu = 1$

Further selection



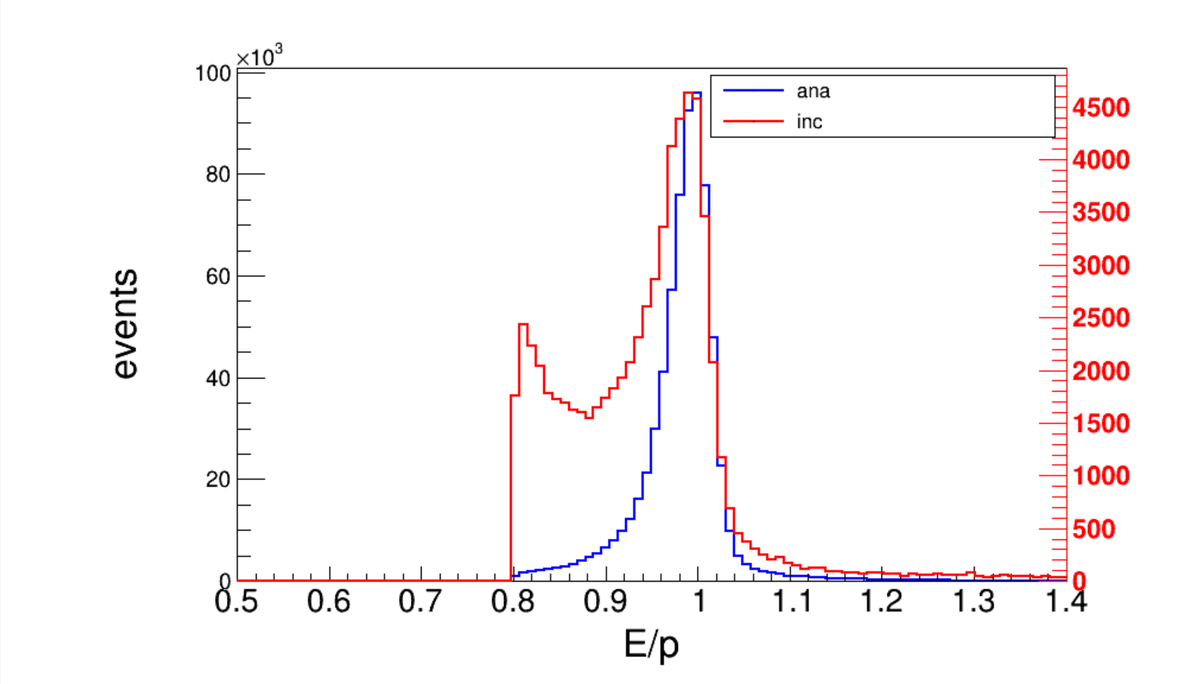
$N_\gamma = 0$

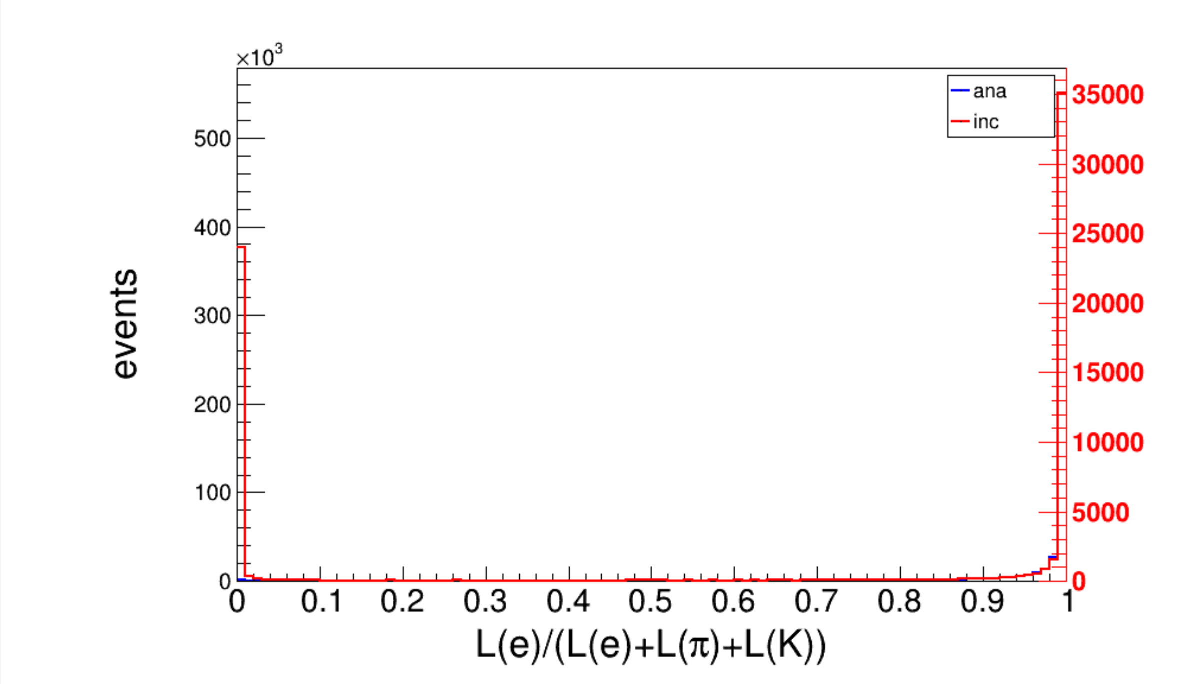
Further selection

- **Electron identification**

➢ $E_{EMC}/P_{MDC} > 0.9$

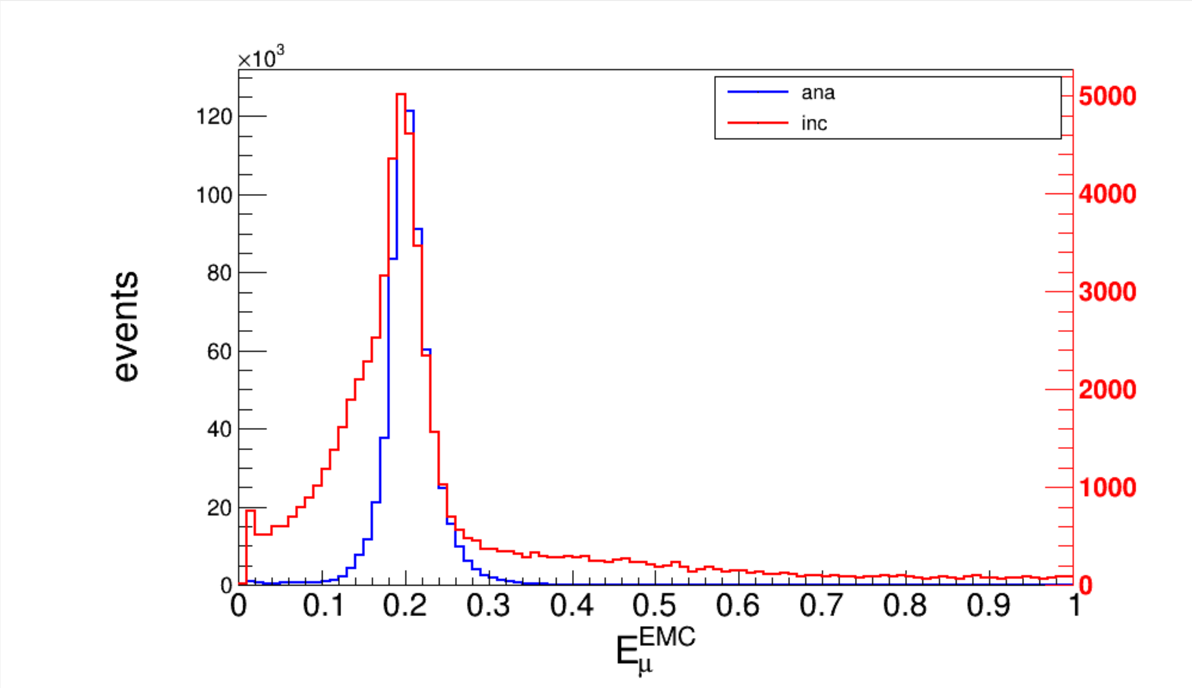
➢ Prob(e)/(Prob(e)+prob(π)+prob(K)) > 0.8

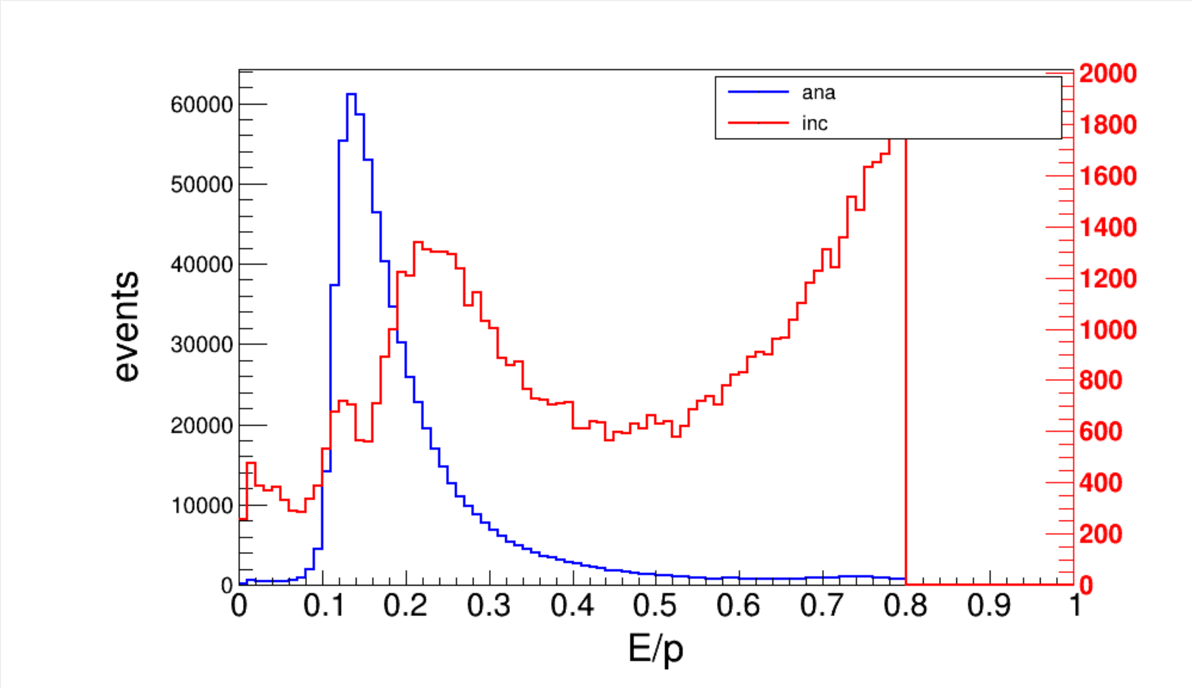




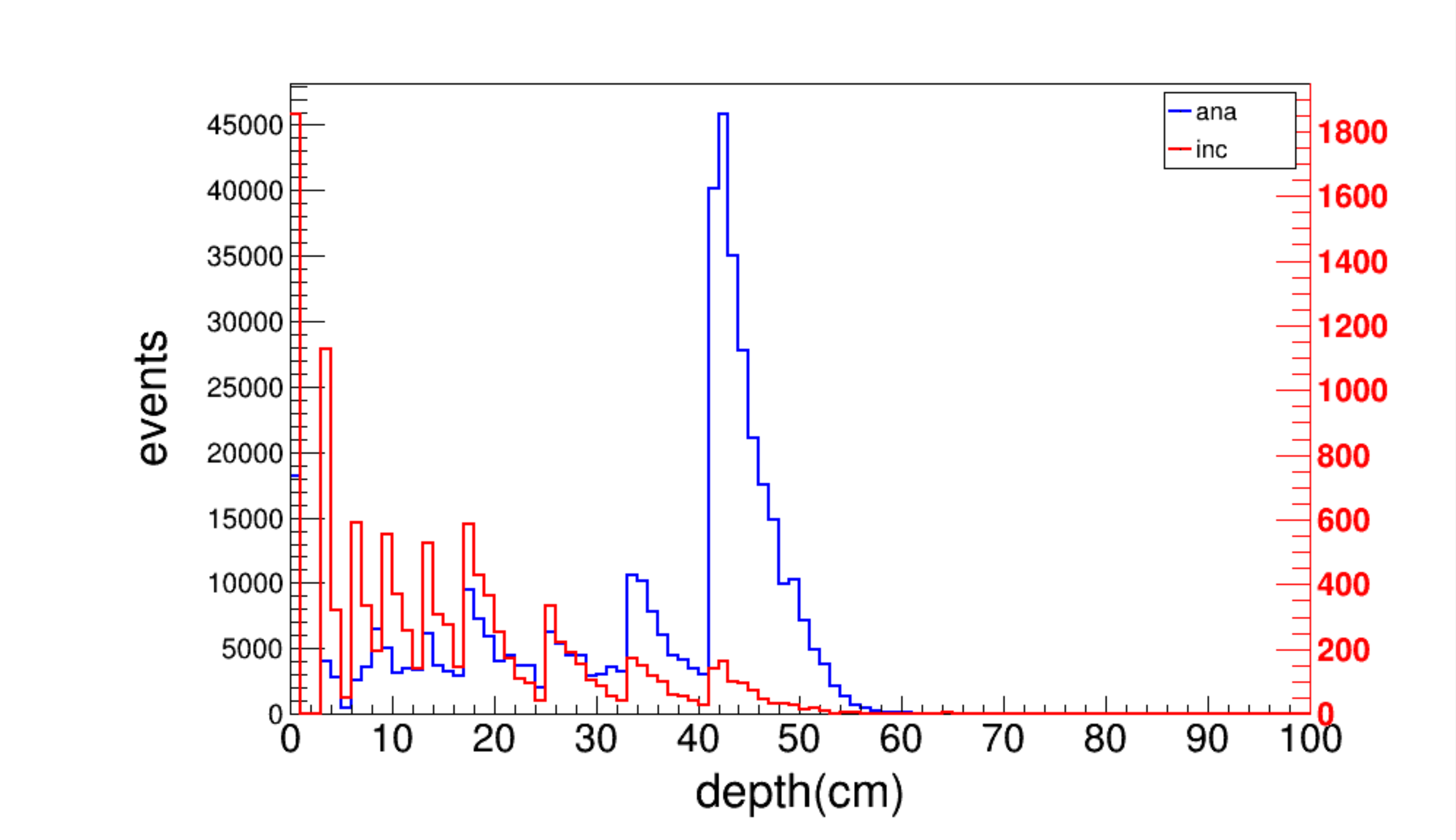
Further selection

- **Muon identification**
  - 0.1 < E(EMC) <0.3
  - $0.1 < E_{EMC}/P_{MDC} < 0.3$
  - Prob(μ) > Prob(e),Prob(μ) > Prob (K)
  - MUC depth > 40cm





Further selection



MUC depth > 40 cm

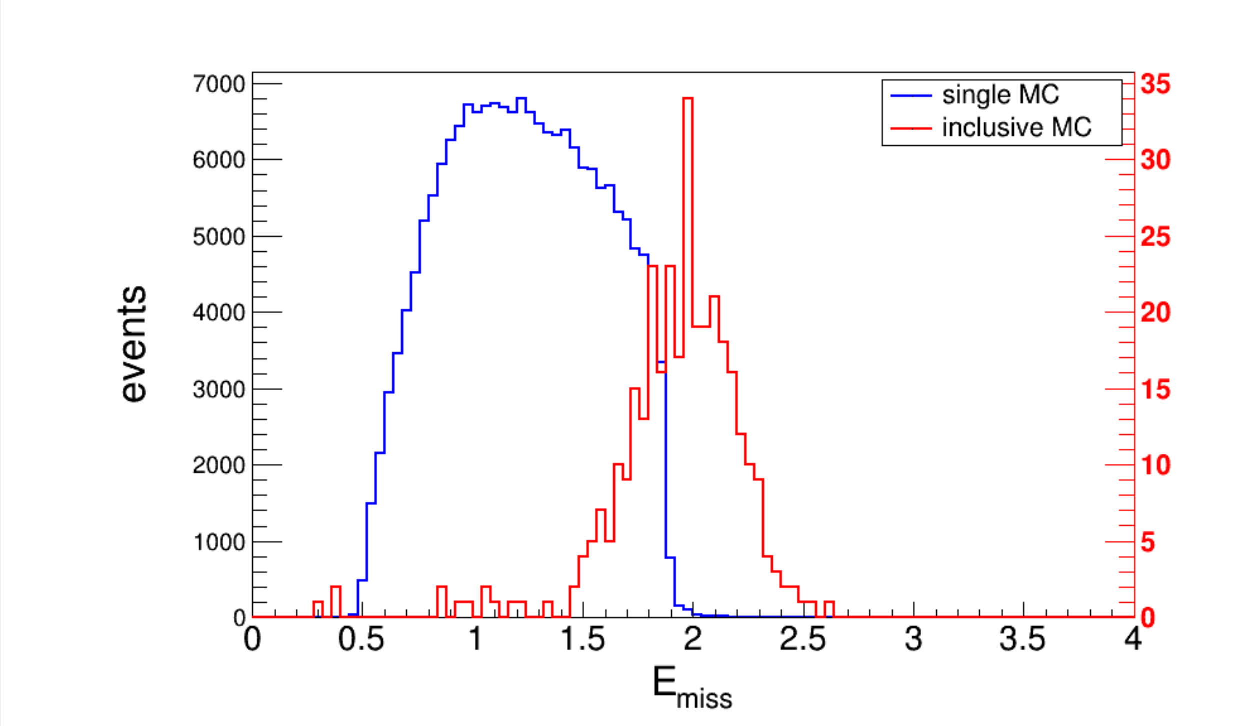
Cut Flow

	Cut flow for ψ(2S)	
	relative ε	Inclusive MC
no cut	100.00%	1.070E+08
Ntrack = 2,Q =0	85.00%	1.521E+07
e e/p>0.8,mu e/p<0.8	91.16%	1.662E+06
N光子=0	88.04%	69916
e;e/p>0.9	94.95%	49067
e:prob(e)/(prob(e)+prob(pi)+prob(k)) > 0.8	95.06%	35928
mu:0.1<E<0.3	98.26%	18386
mu:0.1<E/p<0.3	85.64%	9991
mu:prob(mu)>prob(e),prob(mu)>prob(k)	86.97%	8577
mudepth > 40	41.24%	334
All	18.58%	

Background analysis

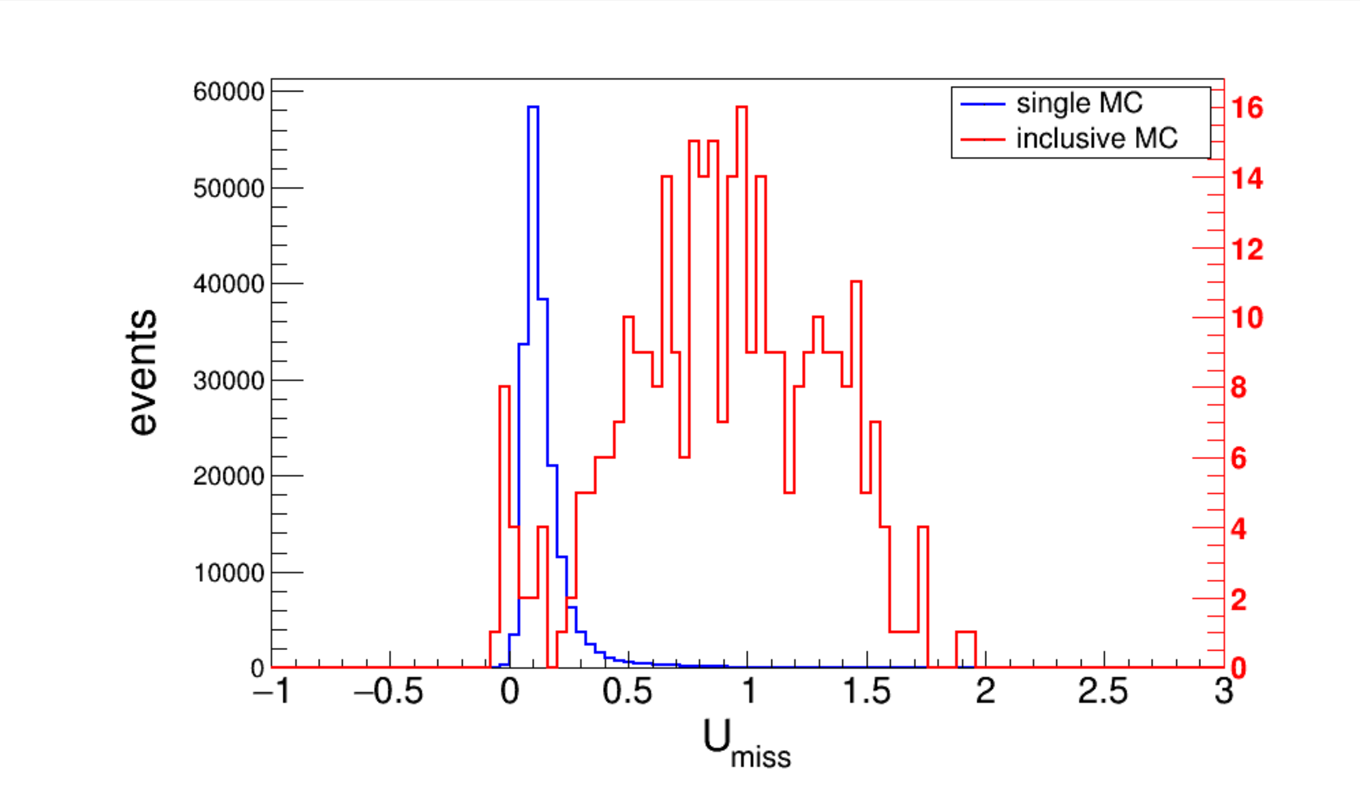
rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$e^-\bar{\nu}_e\mu^+\nu_\mu\nu_\tau\bar{\nu}_\tau$	0	123	123
2	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	$e^+\nu_e\mu^-\bar{\nu}_\mu\nu_\tau\bar{\nu}_\tau$	1	121	244
3	$\psi' \to \tau^+\tau^-, \tau^+ \to \bar{\nu}_\tau\pi^+, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$e^-\bar{\nu}_e\nu_\tau\bar{\nu}_\tau\pi^+$	6	13	257
4	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \nu_\tau\pi^-$	$e^+\nu_e\nu_\tau\bar{\nu}_\tau\pi^-$	3	11	268
5	$\psi' \to \mu^+\mu^-$	$\mu^+\mu^-$	2	11	279
6	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau, \tau^- \to e^-\bar{\nu}_e\nu_\tau\gamma^f$	$e^-\bar{\nu}_e\mu^+\nu_\mu\nu_\tau\bar{\nu}_\tau\gamma^f$	5	9	288
7	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau\gamma^f, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	$e^+\nu_e\mu^-\bar{\nu}_\mu\nu_\tau\bar{\nu}_\tau\gamma^f$	4	5	293
8	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau\gamma^f, \tau^- \to \nu_\tau\pi^-$	$e^+\nu_e\nu_\tau\bar{\nu}_\tau\pi^-\gamma^f$	7	1	294
9	$\psi' \to \mu^+\mu^-\gamma^f$	$\mu^+\mu^-\gamma^f$	8	1	295
10	$\psi' \to \tau^+\tau^-, \tau^+ \to e^+\nu_e\bar{\nu}_\tau, \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau\gamma^f$	$e^+\nu_e\mu^-\bar{\nu}_\mu\nu_\tau\bar{\nu}_\tau\gamma^f$	9	1	296
11	$\psi' \to \tau^+\tau^-, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau\gamma^f, \tau^- \to e^-\bar{\nu}_e\nu_\tau$	$e^-\bar{\nu}_e\mu^+\nu_\mu\nu_\tau\bar{\nu}_\tau\gamma^f$	10	1	297

Background analysis



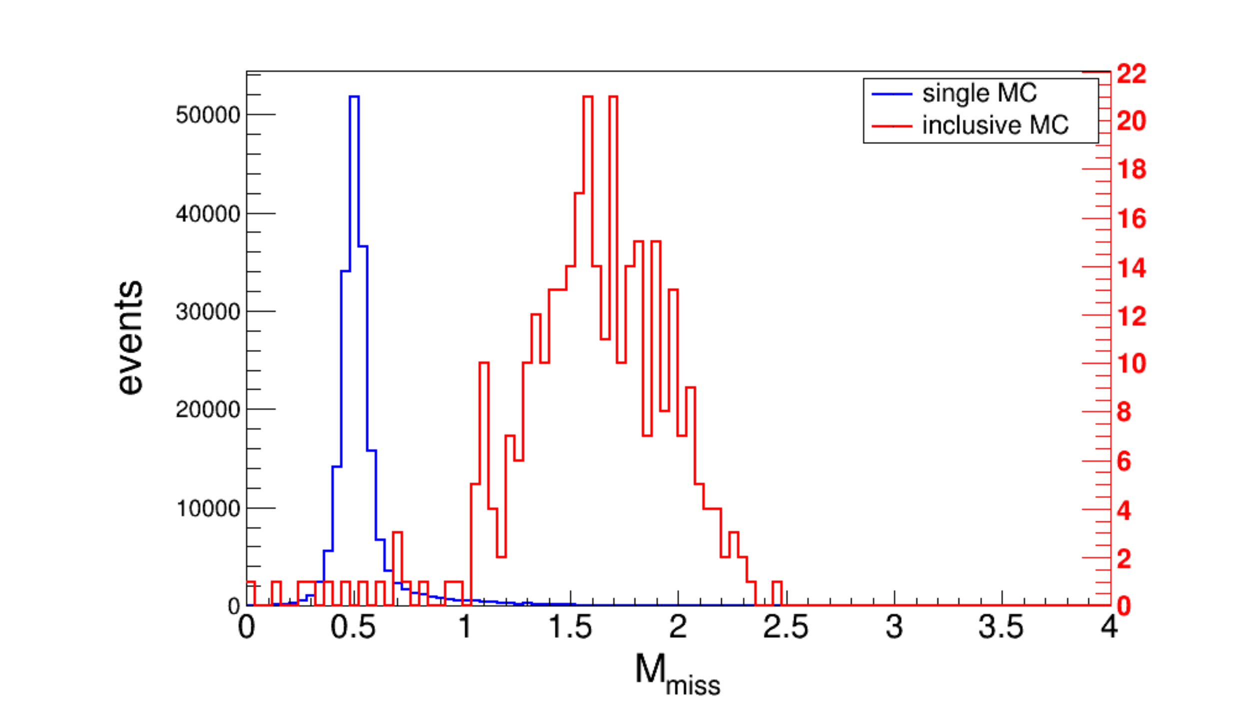
$$E_{miss} = E_{tot} - E_e - E_\mu$$

Background analysis



$$U_{miss} = E_{miss} - P_{miss}$$

Background analysis



$$M_{miss} = \sqrt{E_{miss}^2 - P_{miss}^2}$$

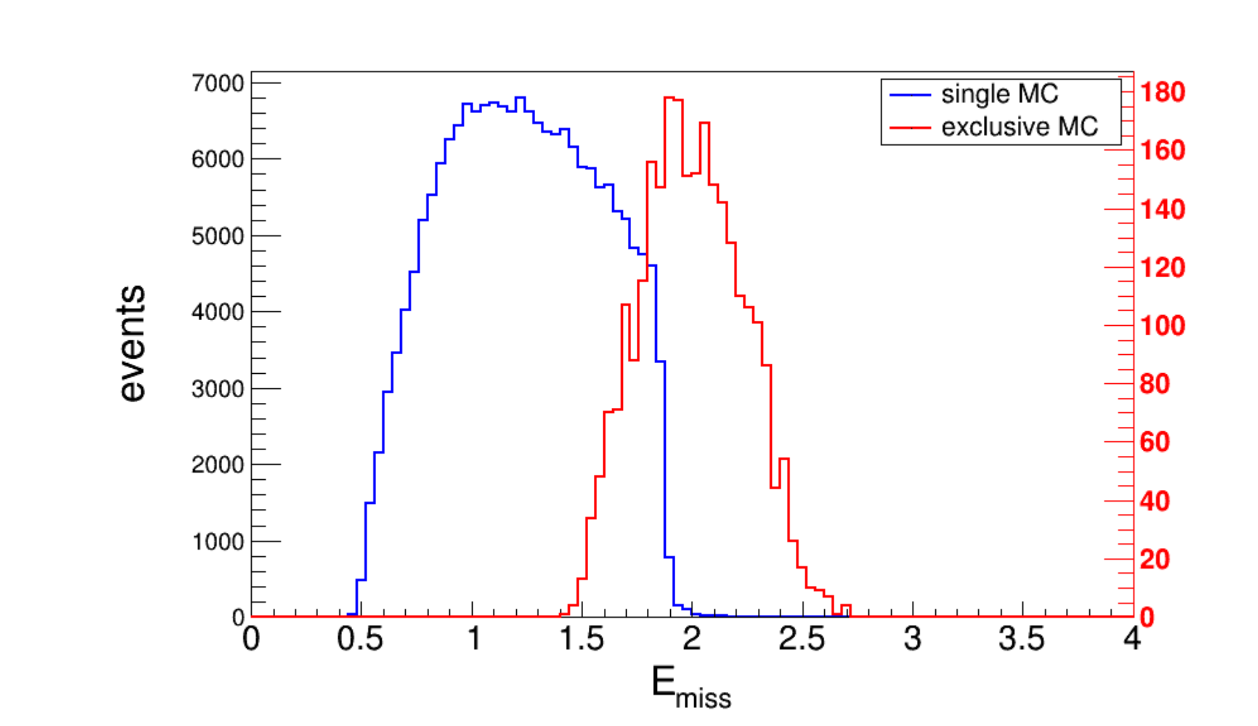
Exclusive MC

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

Decay tau+
1.0000     mu+  nu_mu anti-nu_tau            PHSP;
Enddecay

Decay tau-
1.0000     e- anti-nu_e nu_tau            PHSP;
Enddecay

End
```

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

Decay tau+
1.0000     e+   nu_e anti-nu_tau            PHSP;
Enddecay

Decay tau-
1.0000     mu- anti-nu_mu nu_tau            PHSP;
Enddecay

End
```

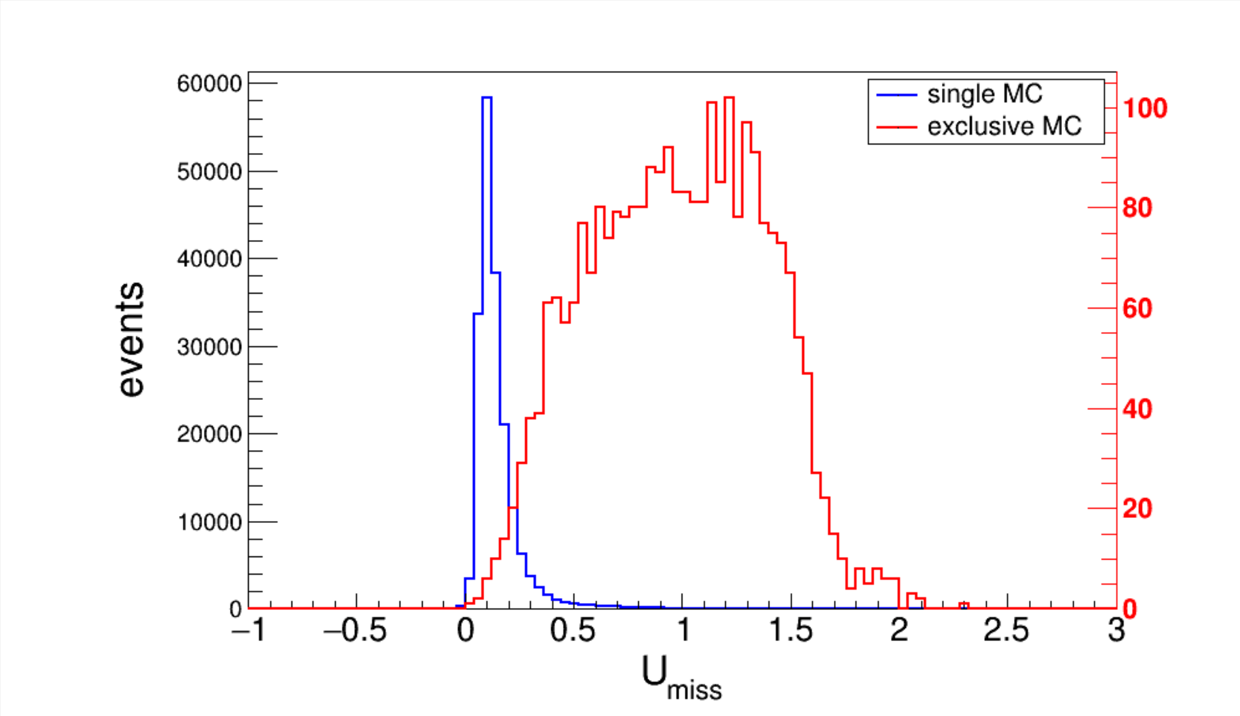
100,000 event for each

Background analysis



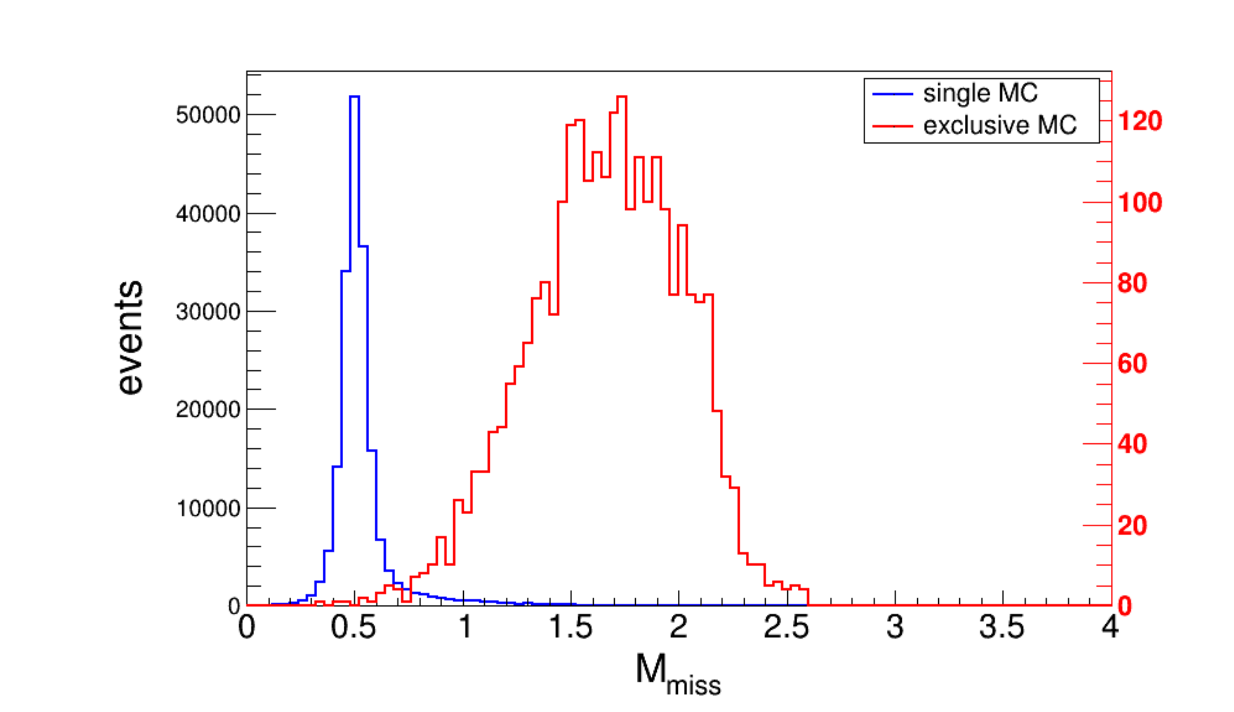
$$E_{miss} = E_{tot} - E_e - E_\mu$$

Background analysis



$$U_{miss} = E_{miss} - P_{miss}$$

Background analysis



$$M_{miss} = \sqrt{E_{miss}^2 - P_{miss}^2}$$