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Measuring the tau polarisation at the ILC

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Motivation

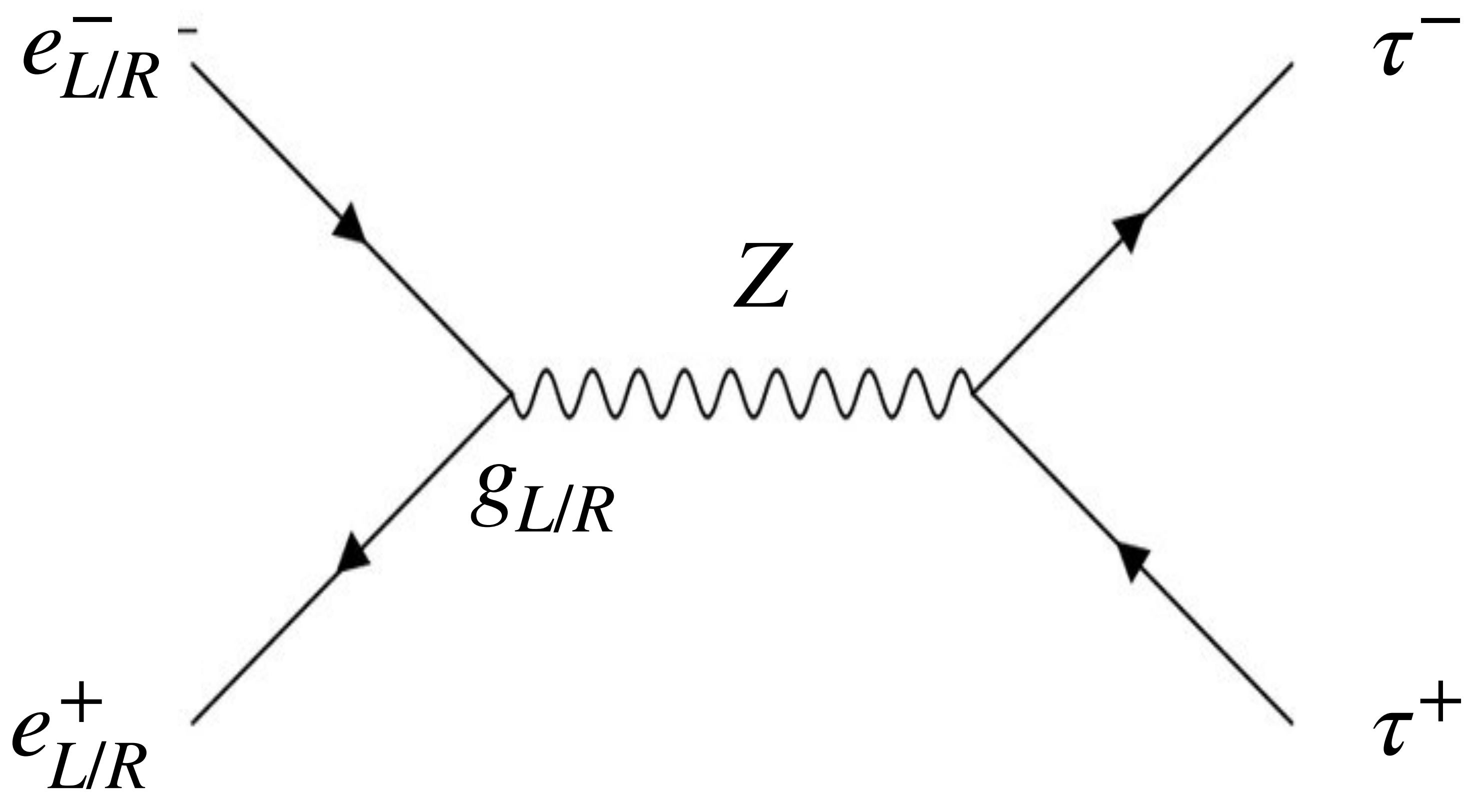
At the ILC, forward-backward asymmetry $A_{FB} = \frac{3}{4} A_e \cdot A_f$ can be measured

Thanks to ILC's polarised beams, A_e can be measured ⇒ A_f can be extracted from A_{FB}

By measuring A_{FB} precisely and looking for deviations from SM predictions, it is possible to search for new physics, such as heavy gauge boson Z'

We can also directly measure A_τ by using tau polarisation $P(\tau)$

$$\frac{dP(\tau)}{d\cos\theta} = \frac{3}{8} A_\tau (1 + \cos^2\theta) + \frac{3}{4} \left(\frac{A_e - P_e}{1 - A_e P_e} \right) \cos\theta$$



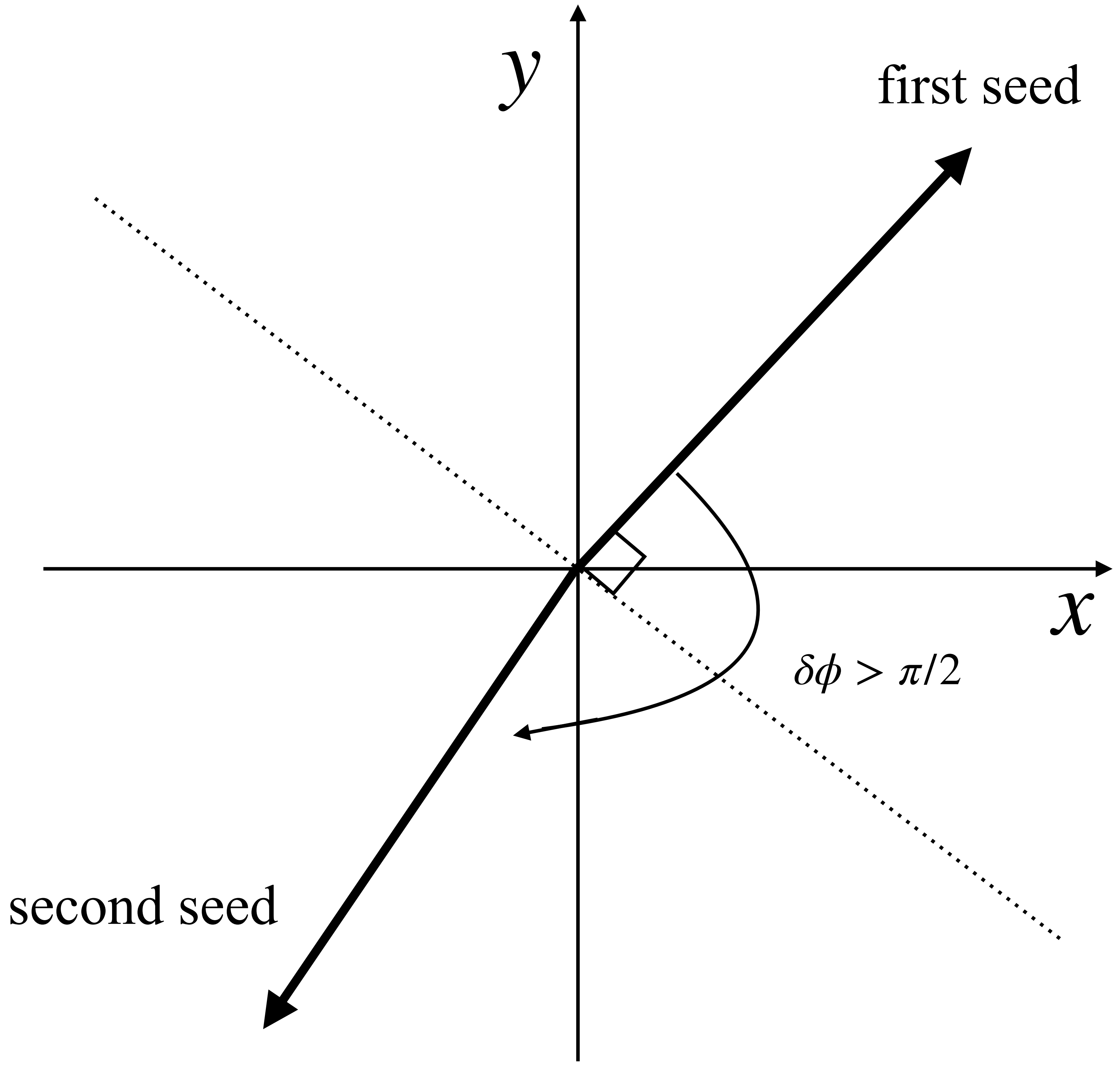
The aim of this study

The reconstruction of tau spin orientation (“**Polarimeter**”) in order to measure polarisation to investigate new physics.

Tau jet reconstruction

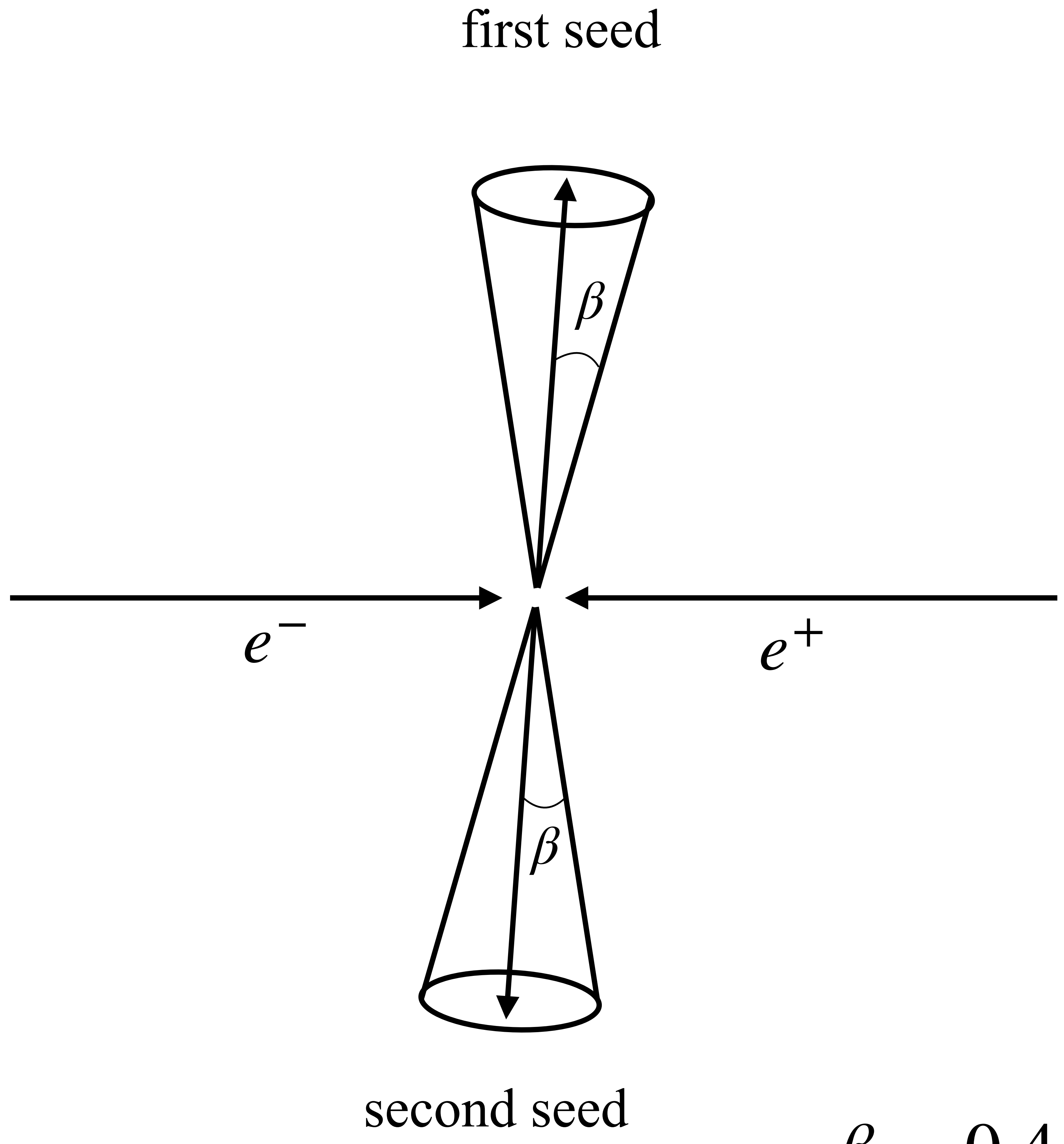
1:Look for two seed direction to build tau jet candidates

first seed : the highest momentum charged PFO



second seed : the highest momentum charged PFO
(separated from the first seed by at least π/2 in the x−y plane (δφ))

2:Make two cones



$\beta = 0.4$ rad

Tau decay mode selection efficiency

Select tau decay mode by looking at $N_{charged}$, N_γ , $m_{\gamma\gamma}$, $m_{\pi\gamma}$

$\tau \to \pi\nu_\tau$ ———— single pi decay

$\tau \to \rho\nu_\tau,\ \rho \to \pi\pi^0$ ———— rho decay

$\tau \to a_1\nu_\tau$ $a_1 \to \pi\pi^0\pi^0$ —— single-prong a1 decay

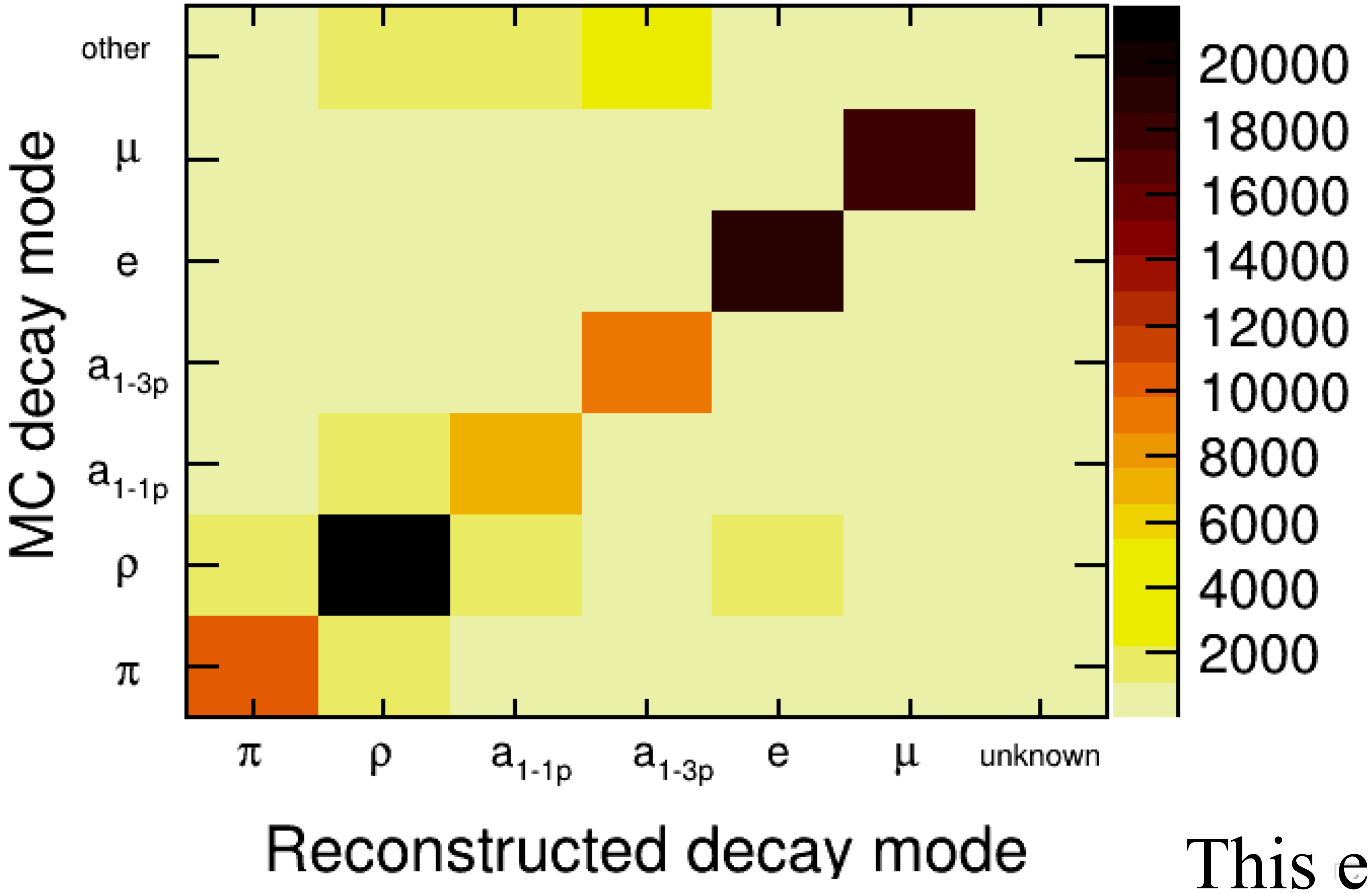
$a_1 \to 3\pi$ —— 3-prong a1 decay

prong: charged particle

IsolatedLeptonTaggingProcessor
was used for leptonic decay

$$\tau \to e\bar{\nu}_e\nu_\tau$$

$$\tau \to \mu\bar{\nu}_\mu\nu_\tau$$



$$\epsilon_{ij} = \frac{N_j}{\Sigma N_{ij}}$$

Reconstructed decay mode

MC decay mode

other	2.87	20	24.5	42	2.18	1.72	6.77
mu	2.97	0.54	0.405	0.0899	0.315	94.7	0.989
e	2.01	1.52	0.0892	0.268	93.4	0.446	2.32
a13p	4.24	3.09	1.59	86.4	0.794	0.177	3.71
a11p	4.04	16.1	68.6	2.15	5.38	2.33	1.35
rho	5.62	77	6.85	1.3	5.94	1.69	1.56
pi	78.9	11.5	0.687	0.153	5.73	1.3	1.68
	pi	rho	a11p	a13p	e	mu	unknown

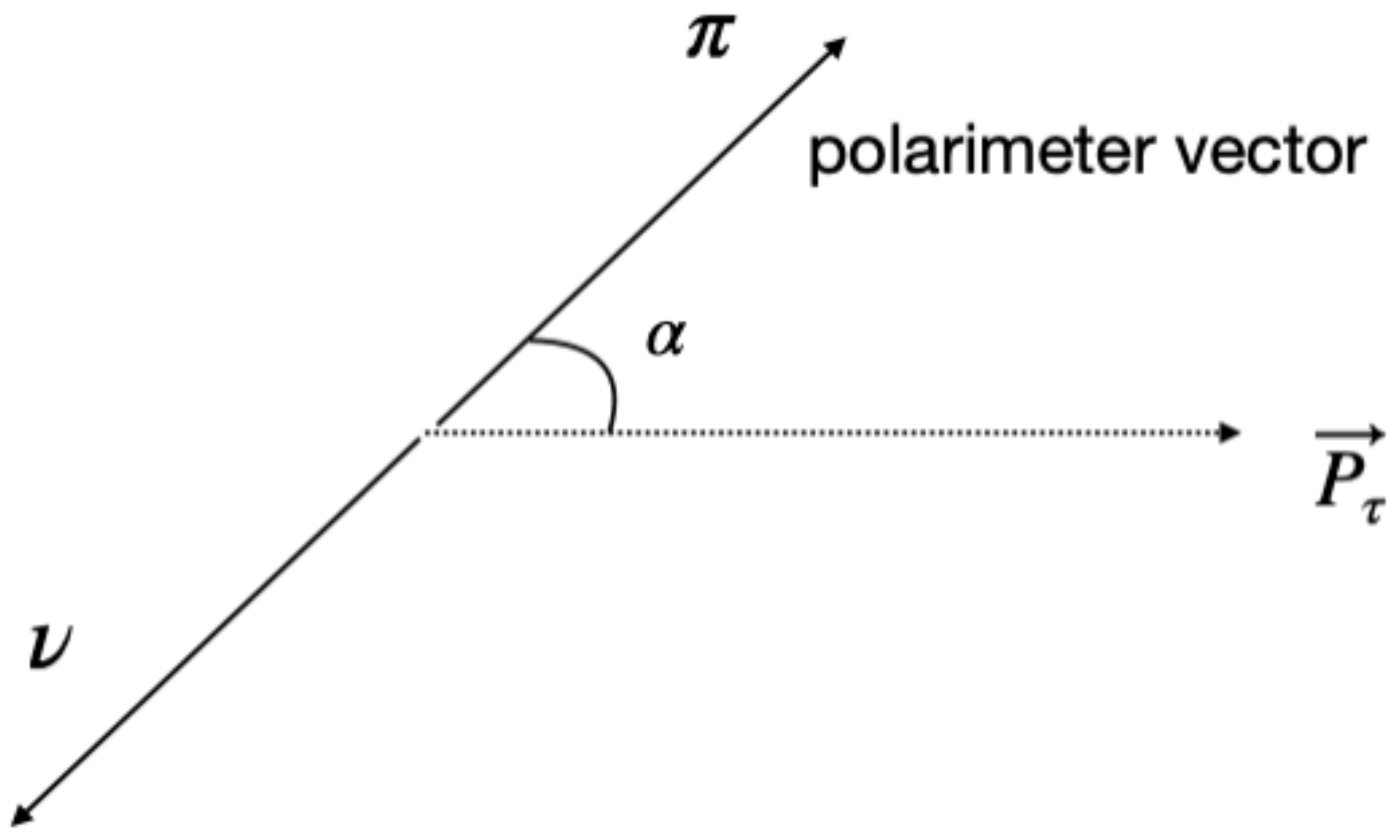
i

j

This efficiency is not very good
→try to improve them using TMVA (on going)

Polarimeter

Reconstruction of tau polarisation $P(\tau)$ depends on tau decay mode.



Polarimeter vectors of $\tau \rightarrow \pi\nu$ in τ rest frame

$$h(\tau^\pm \rightarrow \pi^\pm \nu) \propto p_{\pi^\pm}$$

Polarimeter vectors of $\tau \rightarrow \rho\nu$ in τ rest frame

$$h(\tau^\pm \rightarrow \pi^\pm \pi^0 \nu) \propto m_\tau (E_{\pi^\pm} - E_{\pi^0})(p_{\pi^\pm} - p_{\pi^0}) + \frac{1}{2}(p_{\pi^\pm} + p_{\pi^0})^2 p_\nu$$

“Polarimeter”

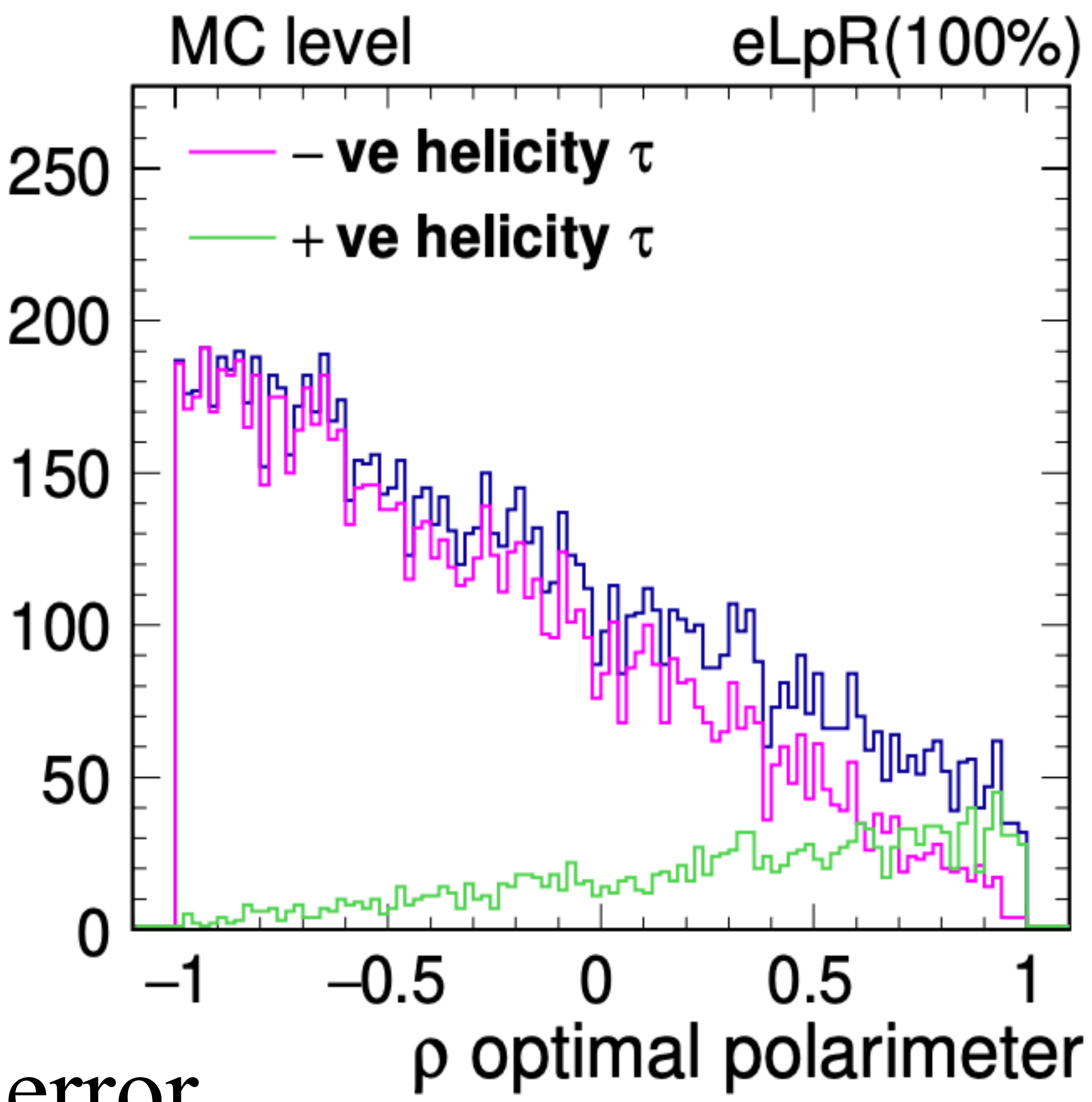
The cosine of the angle this polarimeter vector makes to the tau flight direction

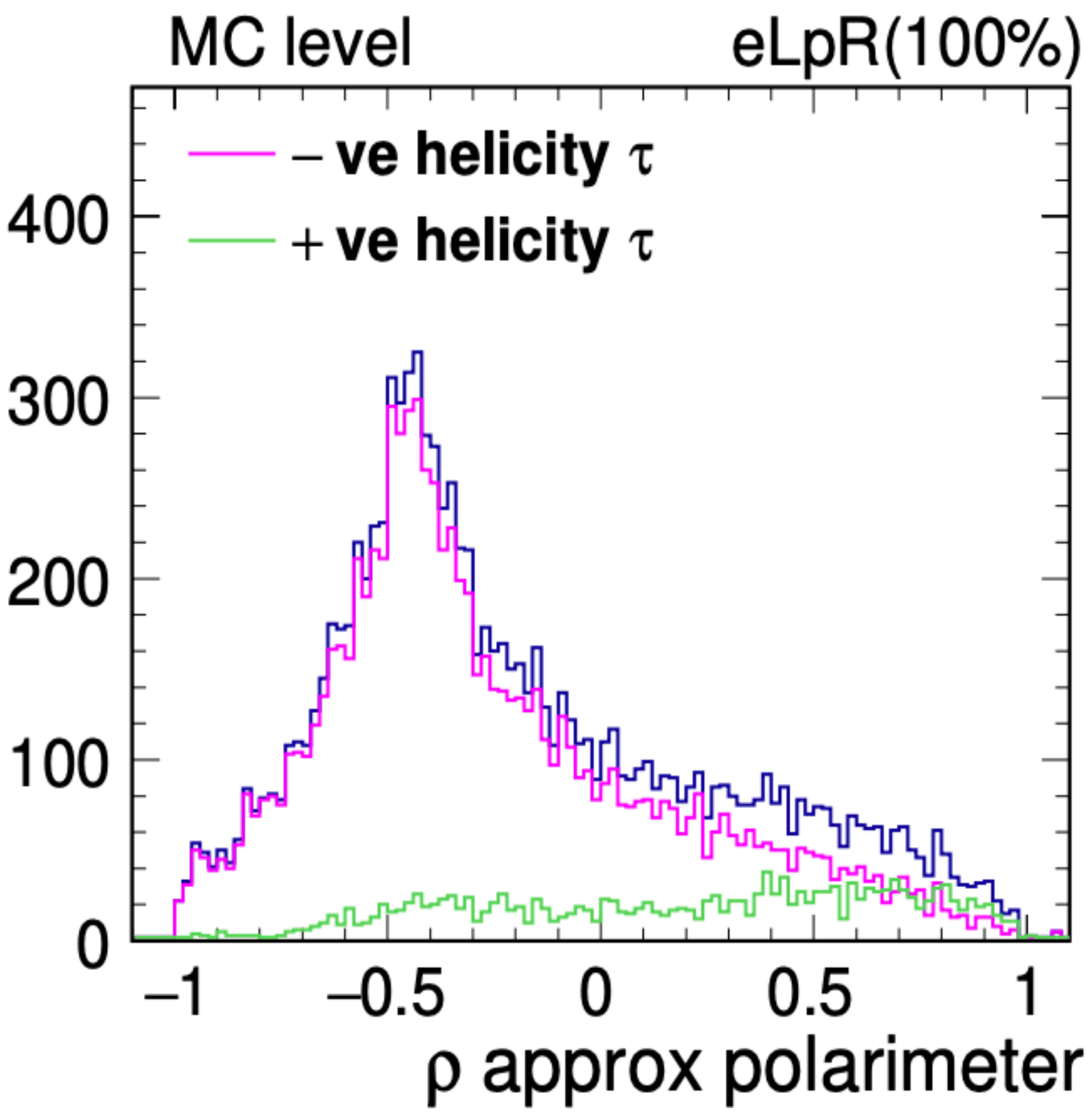
only look at $\tau \rightarrow \pi\nu$ (BR $\sim 10\,\%$)
$\tau \rightarrow \rho\nu$ (BR $\sim 26\,\%$)
in this talk

Previous study

Extract polarimeter without using neutrino information

- "Approximate" polarimeters based only on the momenta of visible tau decay products
- "Optimal" polarimeters including the neutrino component





mean statistical error on tau polarisation

($E_{\mathrm{CM}} = 500$ GeV, $\mathscr{L} = 1.6$ ab^{-1})

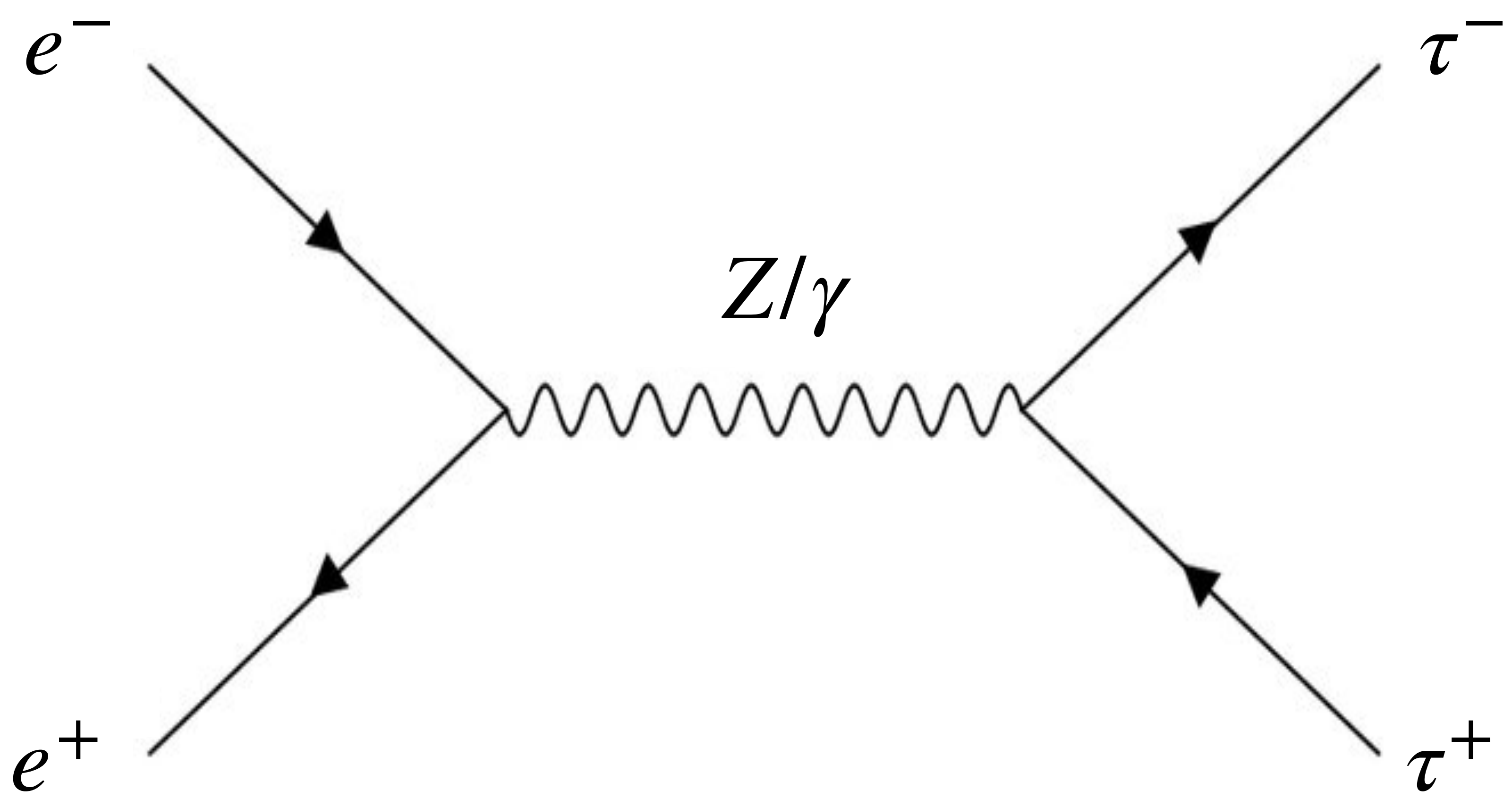
0.30 %

0.40 %

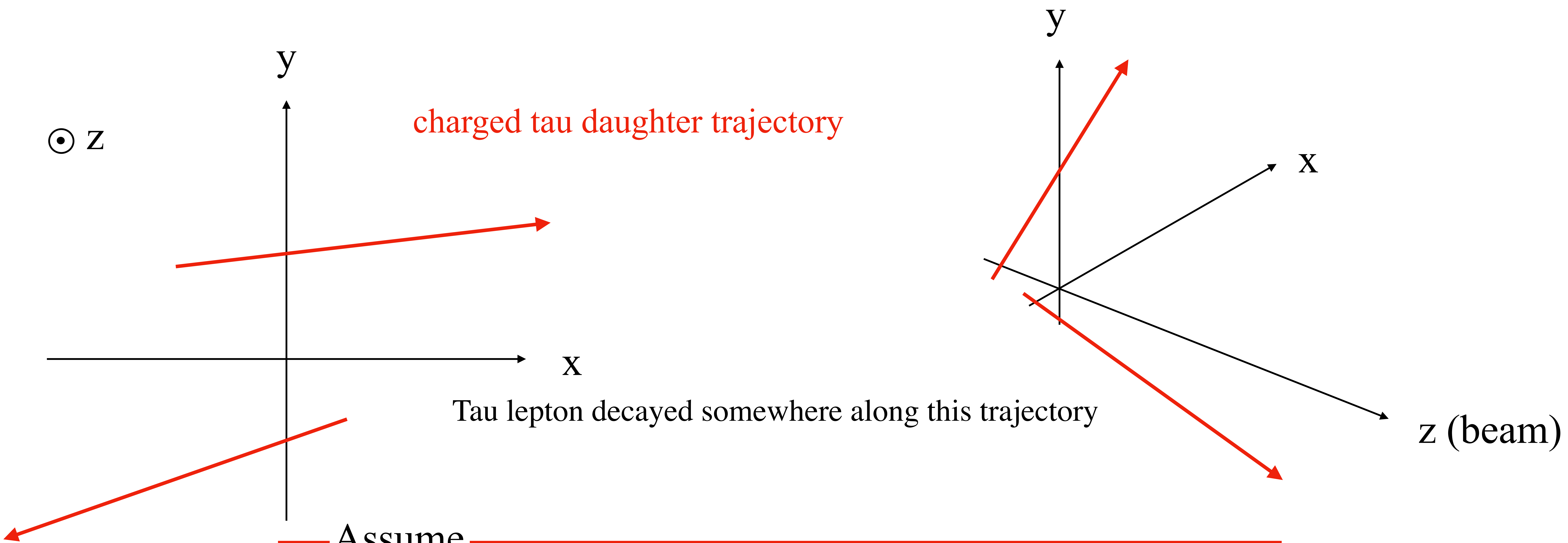
In this talk: reconstruct neutrino momentum → optimal polarimeters

Simulation setup

- Signal event sample with 100 % $e_L^- e_R^+$ beam polarisations were generated using WHIZARD ver 2.8.5.
- The decay of the polarised tau was done using TAUOLA.
- MC truth information was used.



τ reconstruction method



charged tau daughter trajectory

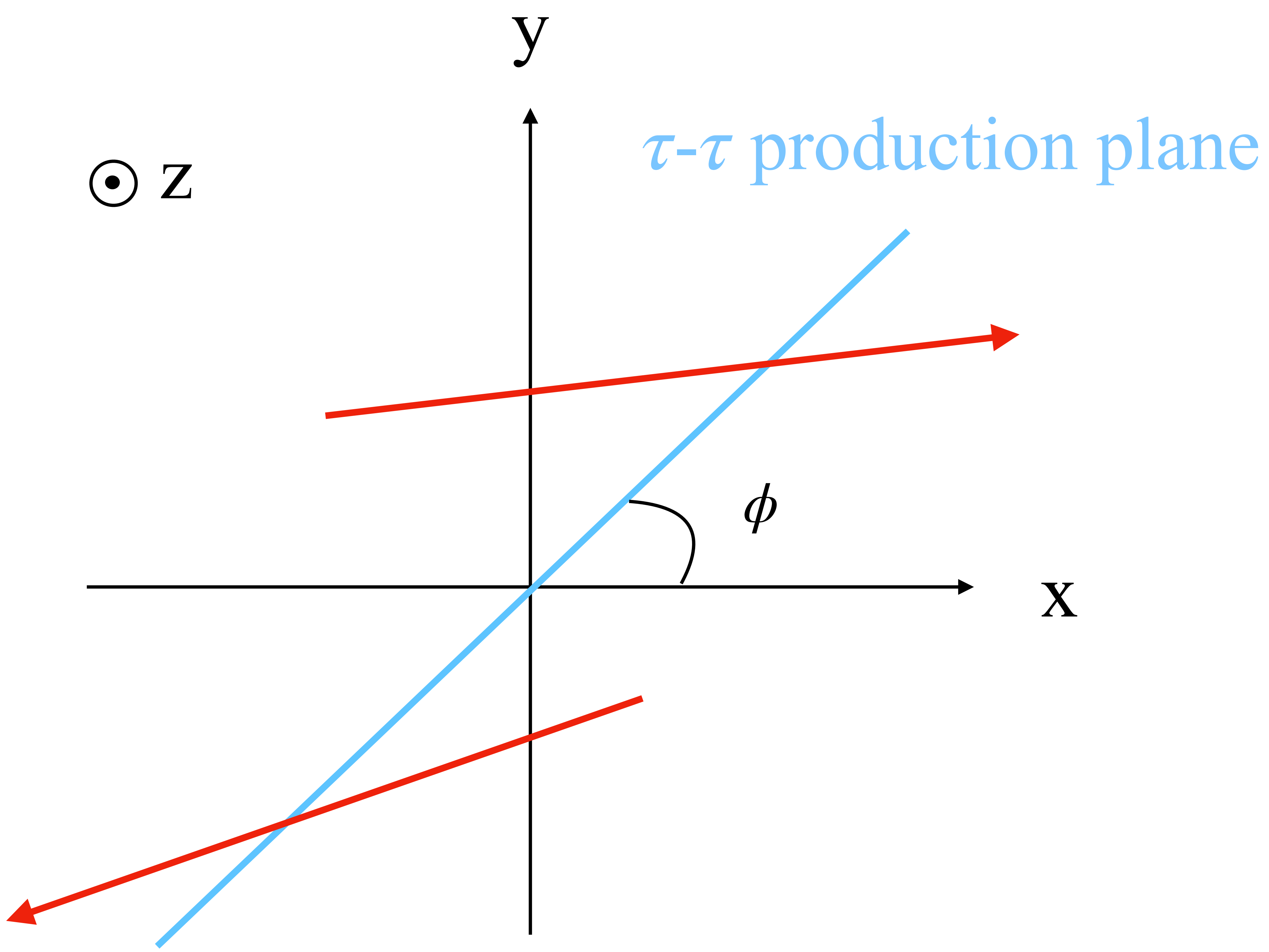
Tau lepton decayed somewhere along this trajectory

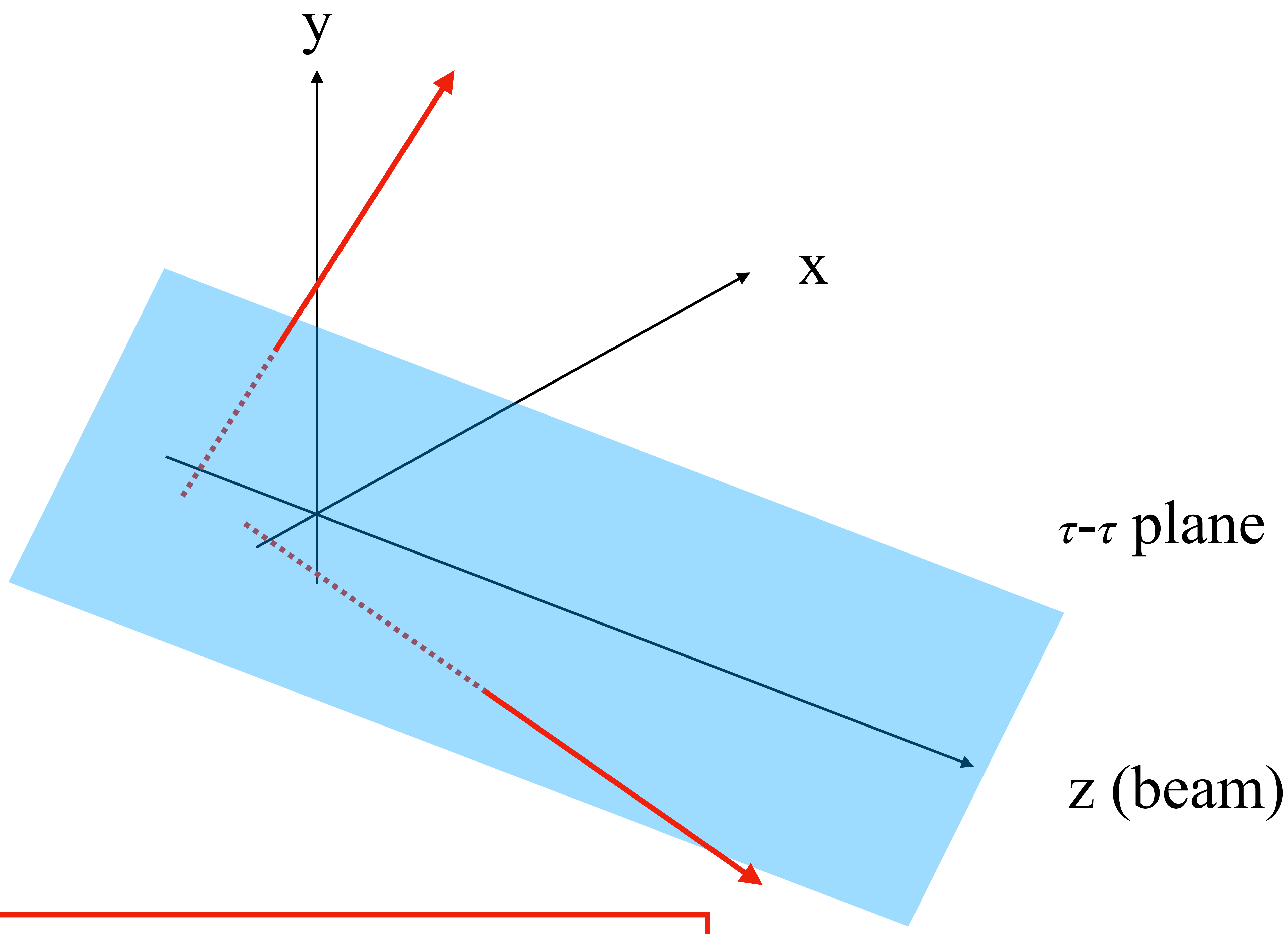
Assume

- Two taus are produced along the beam line($x = y = 0$),
- Two taus are back-to-back in x-y plane,

  — any ISR photons have negligible p_T
- Charged particle travels approximately in a straight line near IP.

τ reconstruction method



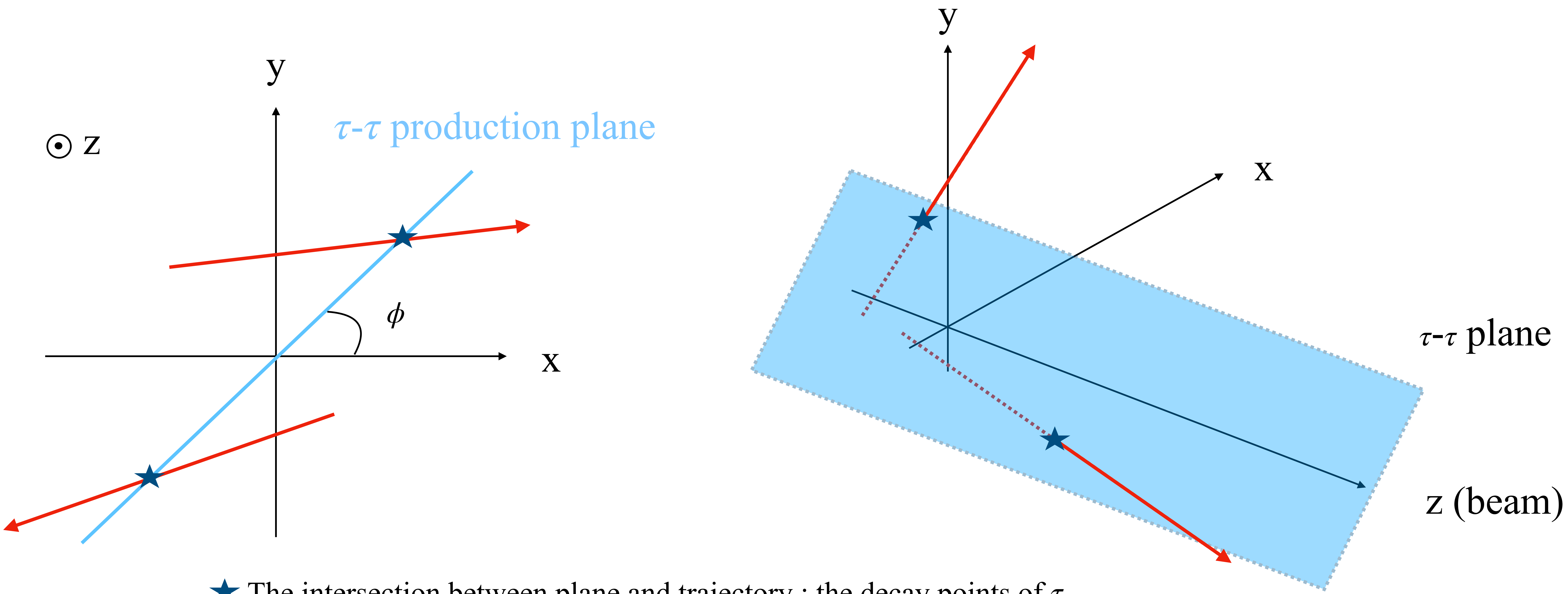


Assume

- Primary interaction occurs along the beam line($x = y = 0$),
- Two taus are back-to-back in x-y plane,
- Charged particle travels approximately in a straight line near IP.

- ○ Two tau momenta lie in a plane containing z-axis, at some azimuthal angle ϕ

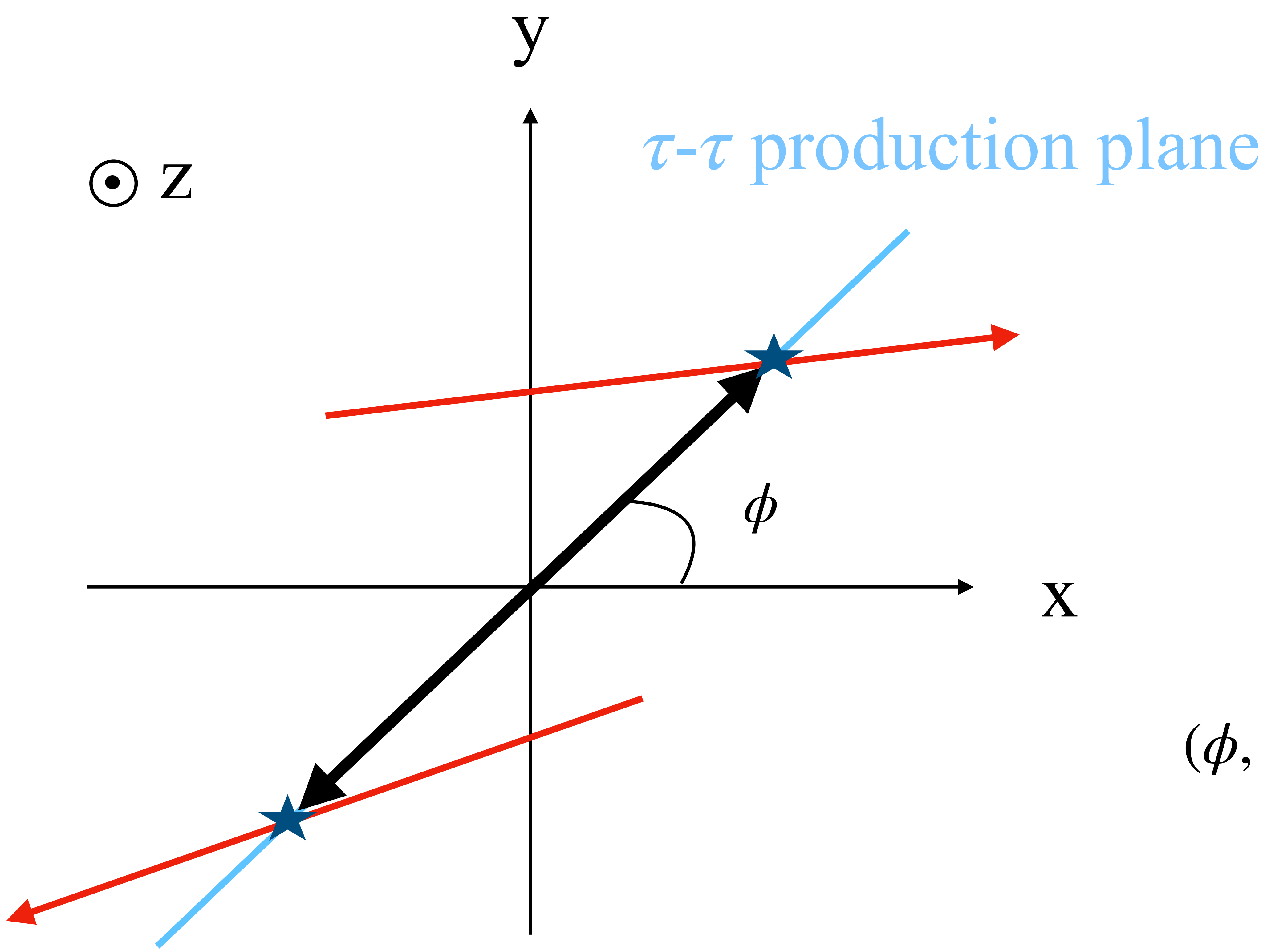
τ reconstruction method



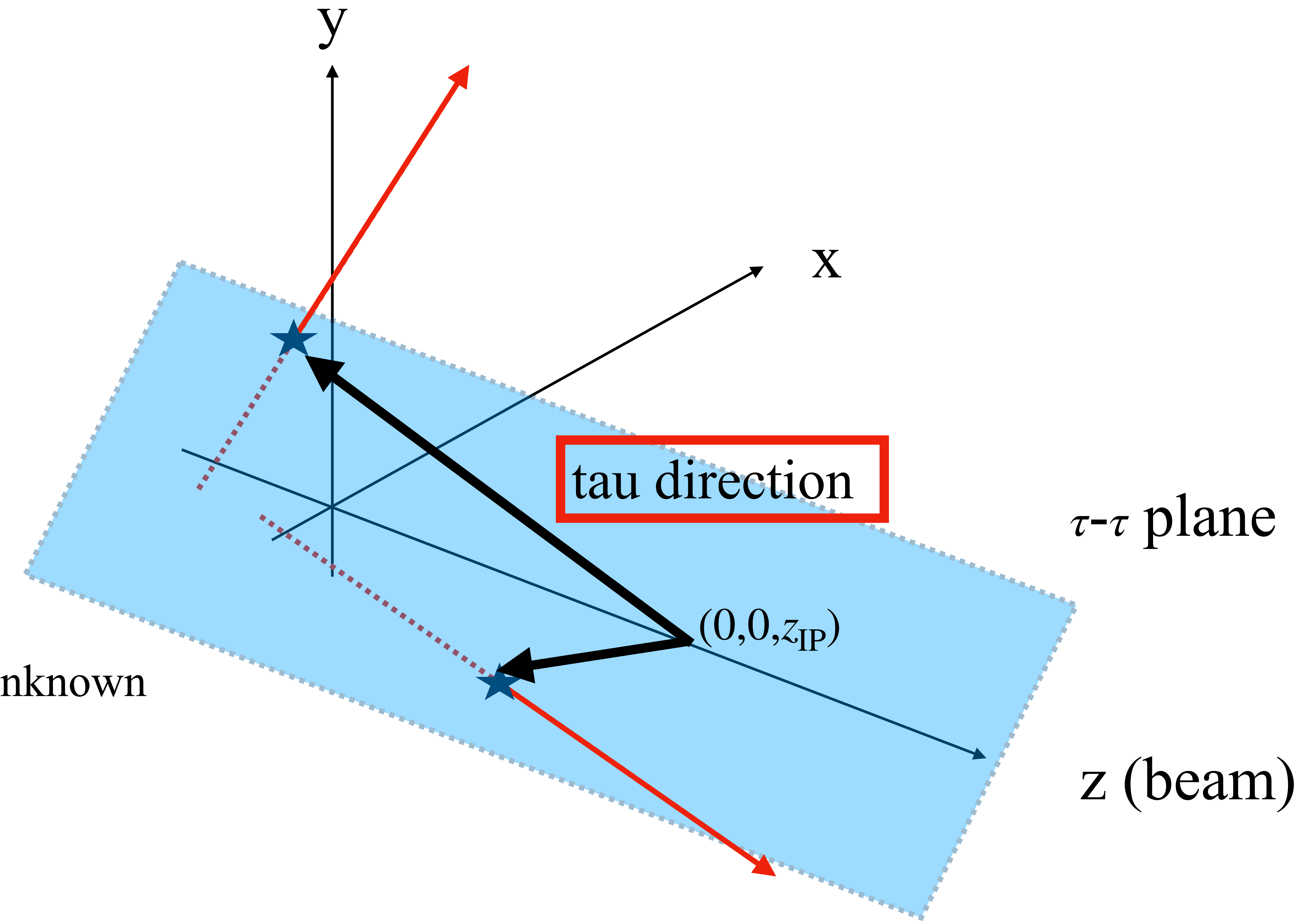
★ The intersection between plane and trajectory : the decay points of τ

For a plane with azimuthal angle ϕ,
the intersection of trajectories with this plane can be calculated.

τ reconstruction method



(ϕ, z_{IP}) : unknown



then choice of z_{IP} gives direction of tau momenta

⇒How can we choose ϕ, z_{IP} ?

τ reconstruction method

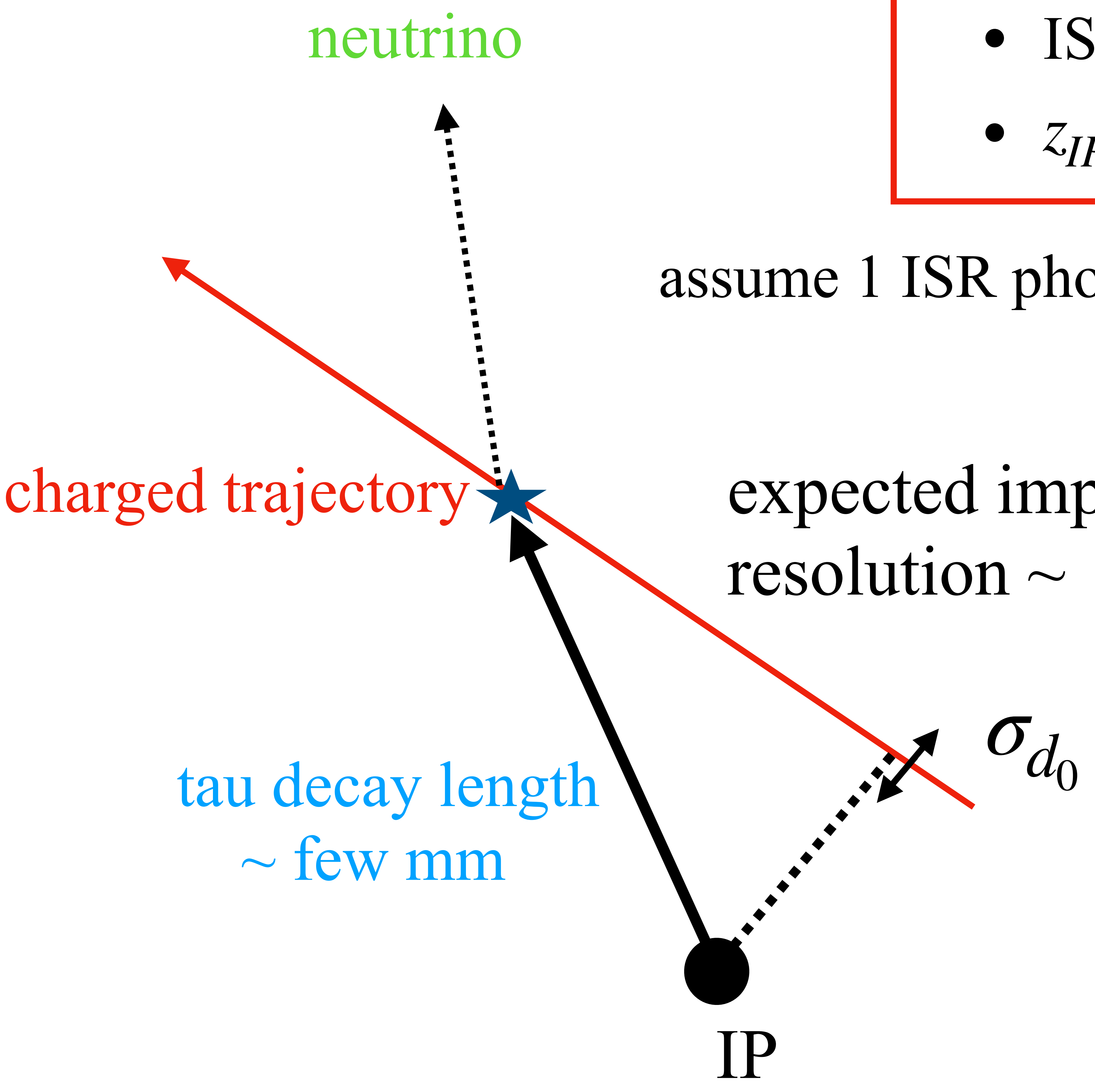
Unknown

- neutrino 3-momentum × 2
- ISR momentum
- z_{IP}

Constraints

- 4-momentum conservation
- tau mass × 2
- Decay point on trajectory × 2

assume 1 ISR photon collinear with beam



expected impact parameter resolution ~ few um

For choice of z_{IP}, ϕ

we can calculate tau 4-momenta P_τ

the invariant mass of the missing (neutrino) momentum for each tau can be calculated

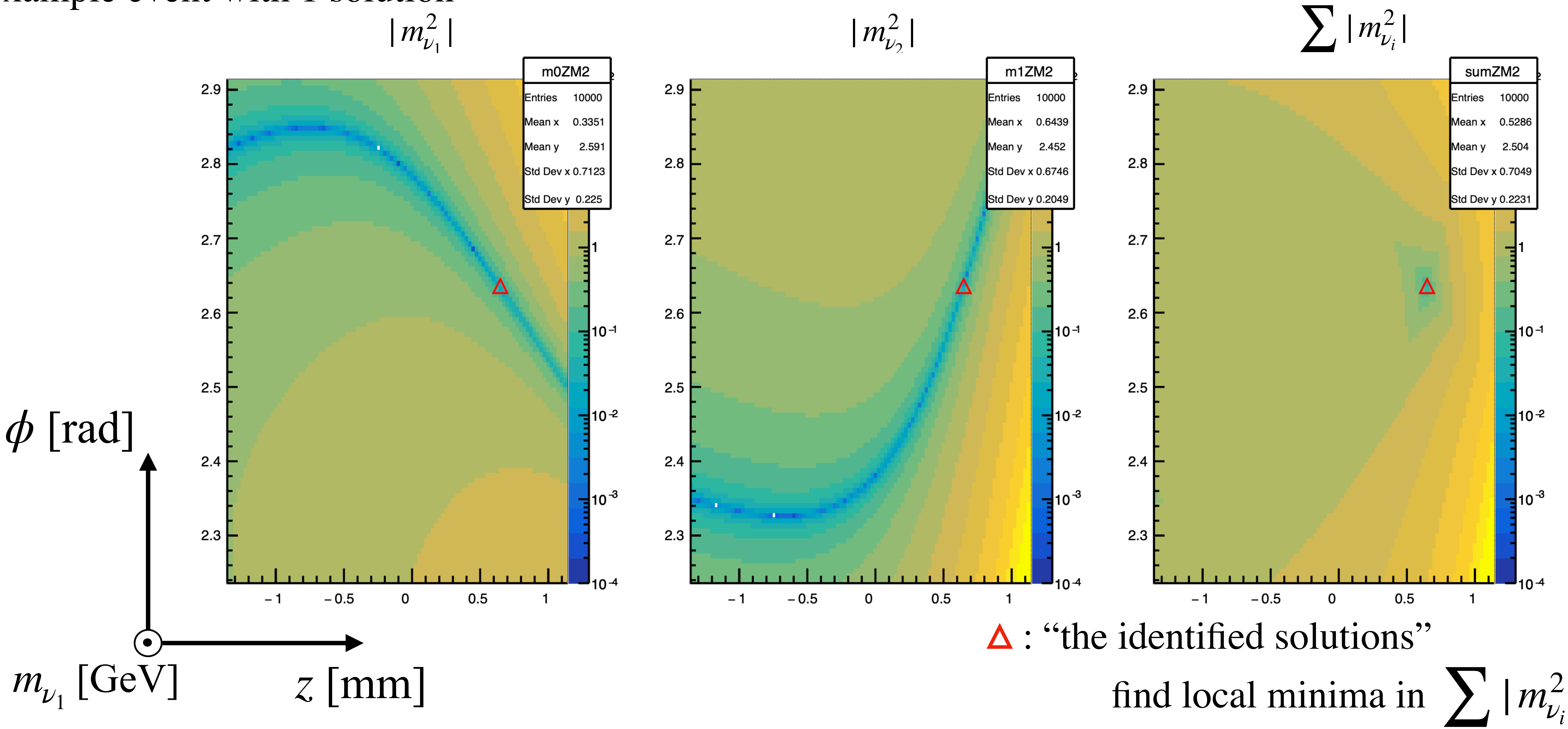
$$P_\nu = P_\tau - P_{vis}$$

We choose the values of z and ϕ which result in neutrino masses closest to zero

Find solutions

We choose the values of z and ϕ which result in neutrino masses closest to zero

example event with 1 solution



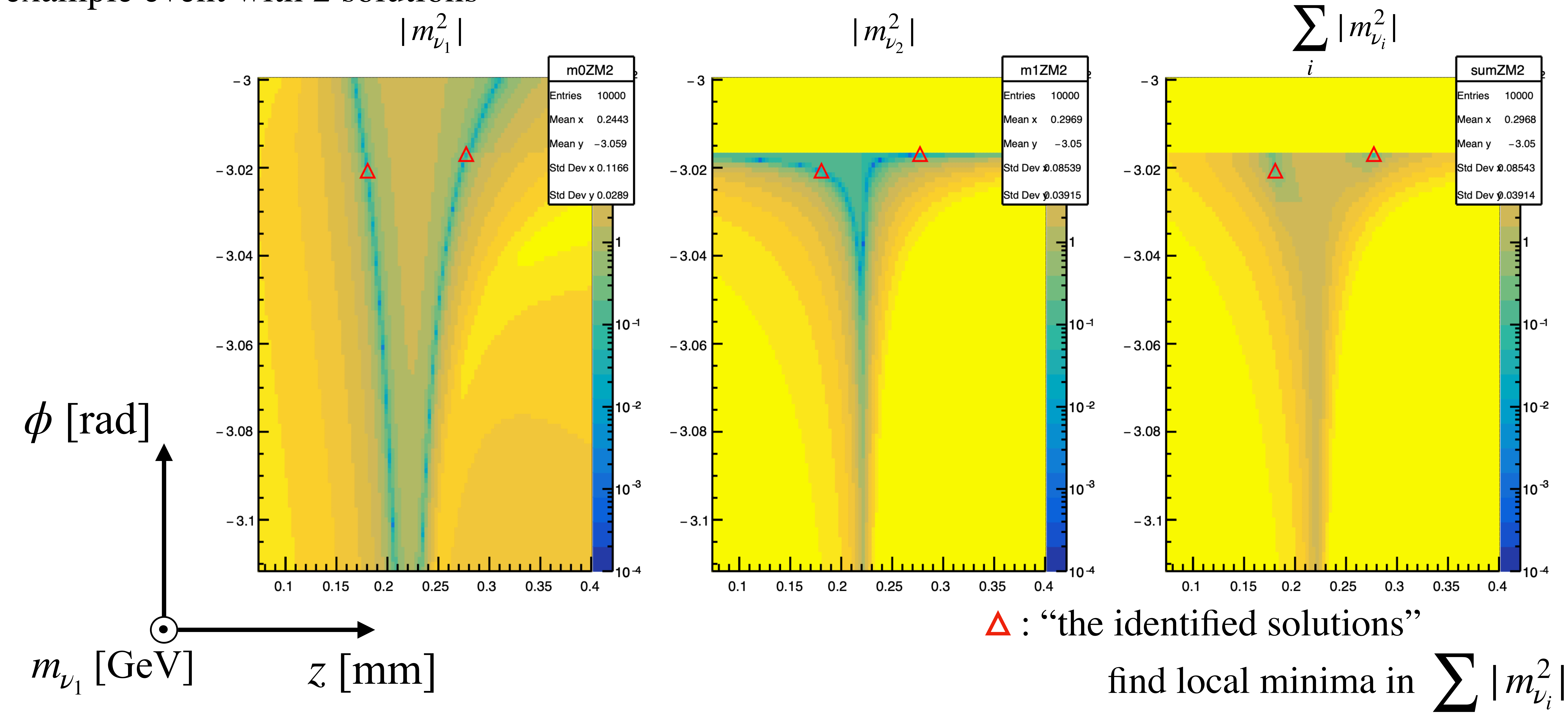
△ : “the identified solutions”

find local minima in $\sum_i |m^2_{\nu_i}|$

Find solutions

We choose the values of z and ϕ which result in neutrino masses closest to zero

example event with 2 solutions



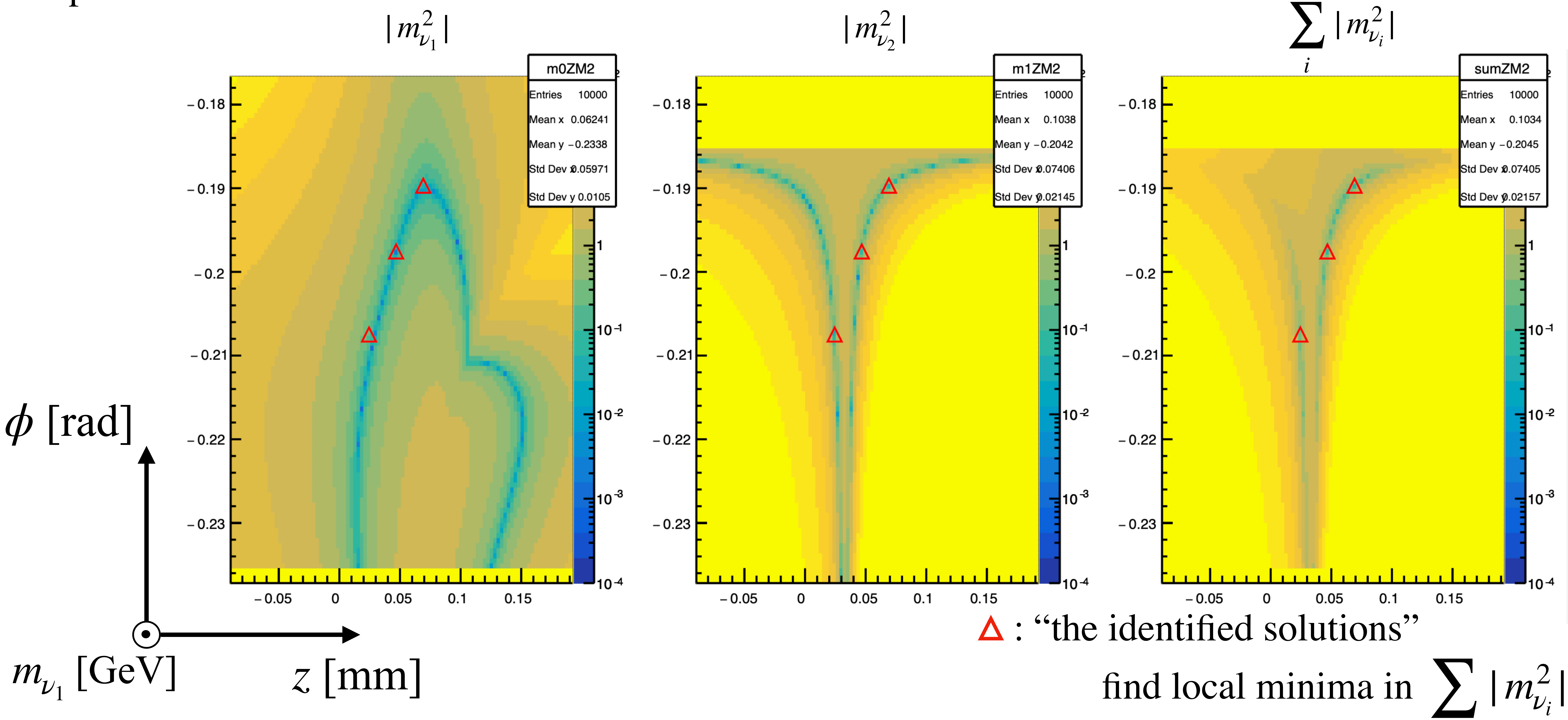
△ : "the identified solutions"

find local minima in $\sum_i |m^2_{\nu_i}|$

Find solutions

We choose the values of z and ϕ which result in neutrino masses closest to zero

example event with 3 solutions



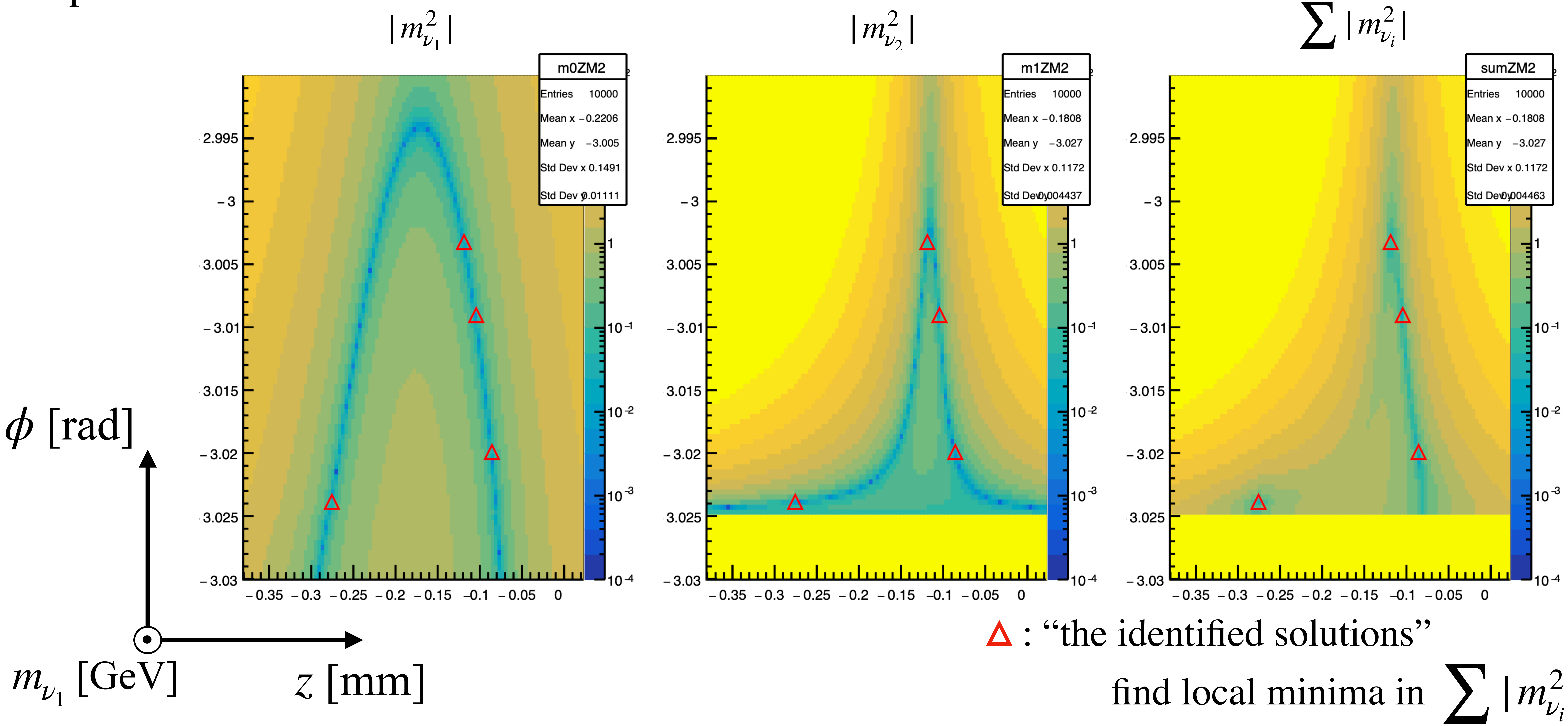
△ : "the identified solutions"

find local minima in $\sum_i |m^2_{\nu_i}|$

Find solutions

We choose the values of z and ϕ which result in neutrino masses closest to zero

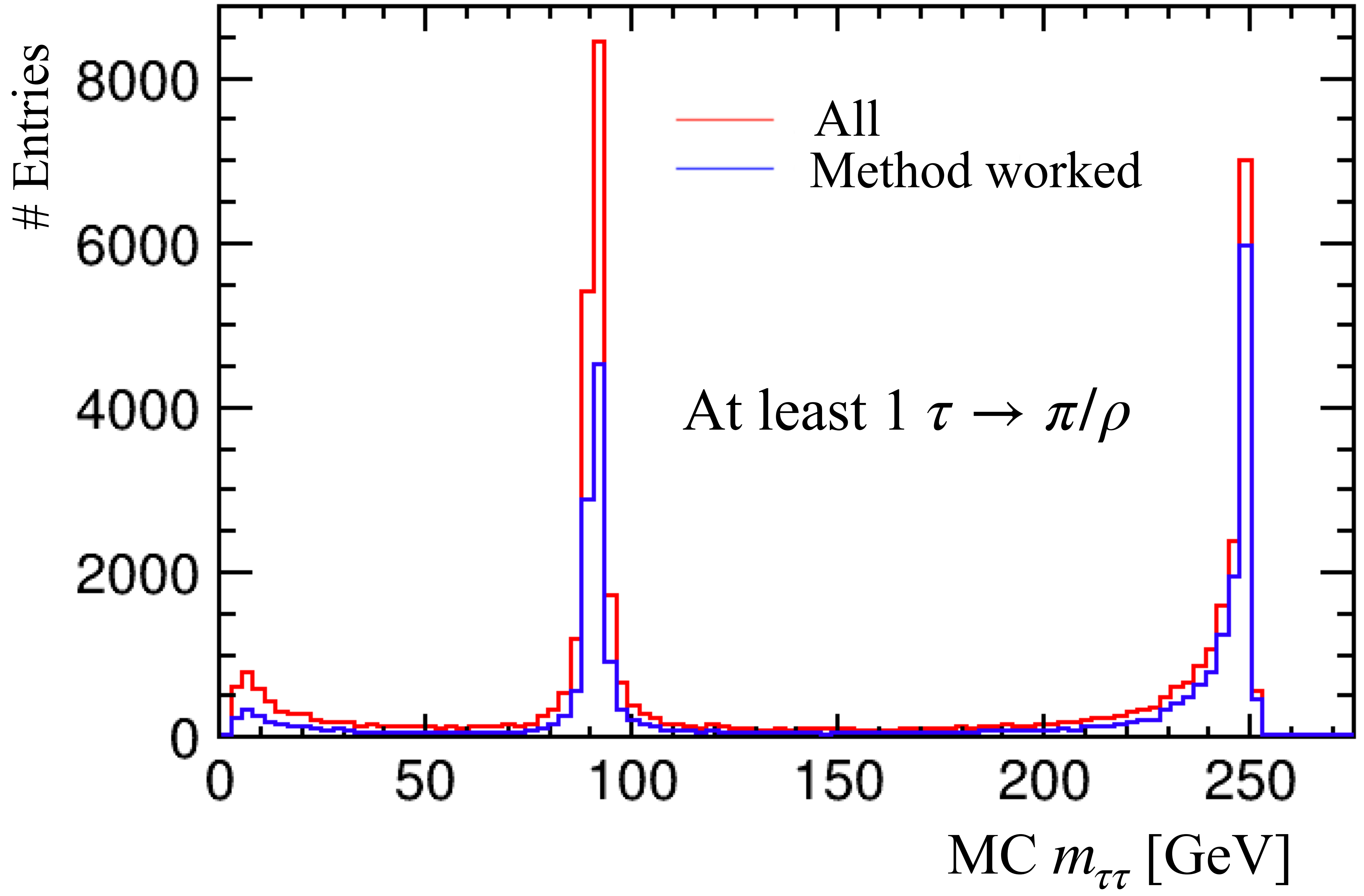
example event with 4 solutions



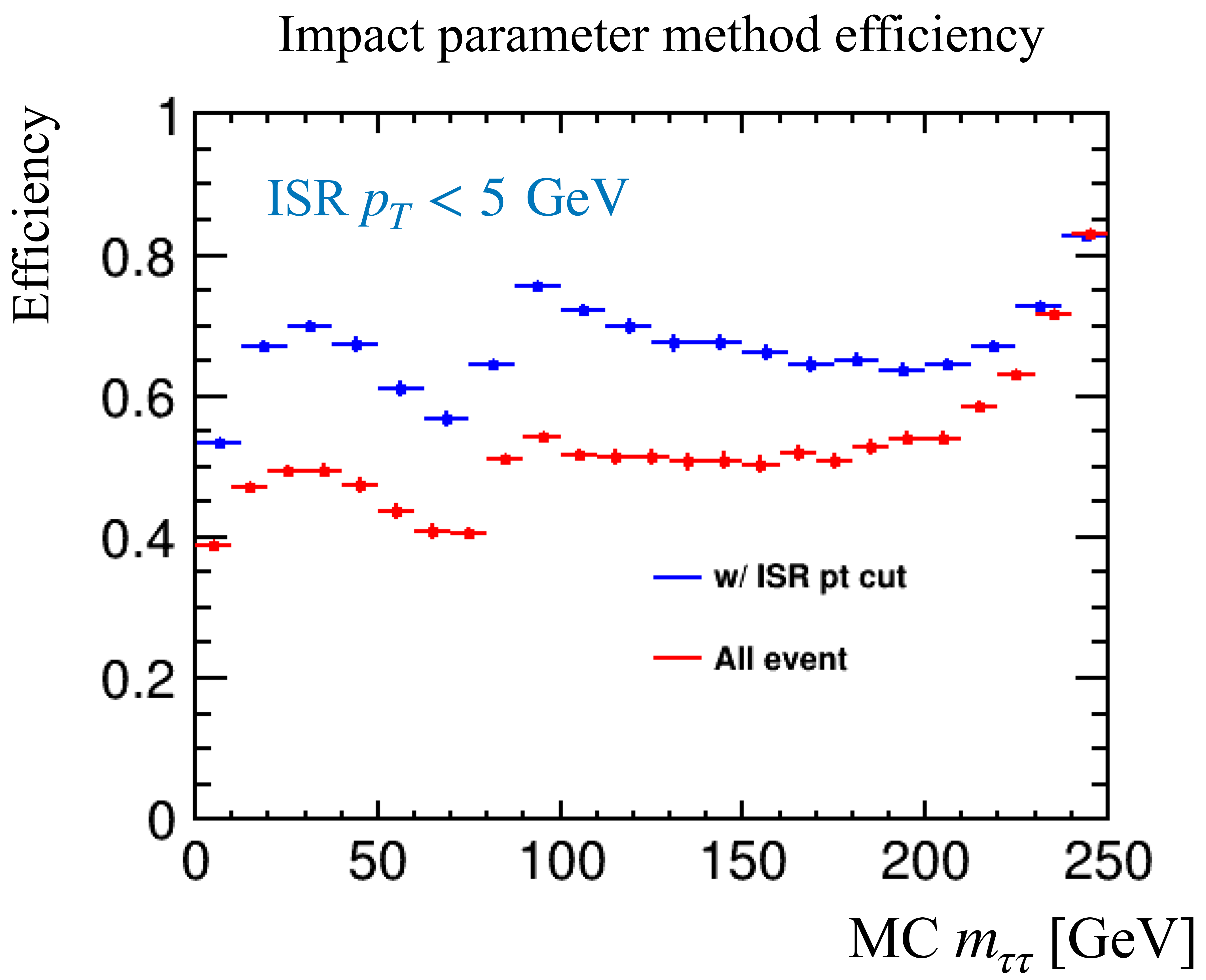
△ : “the identified solutions”

find local minima in $\sum_i |m_{\nu_i}^2|$

Method efficiency



Method worked : at least 1 solution is found

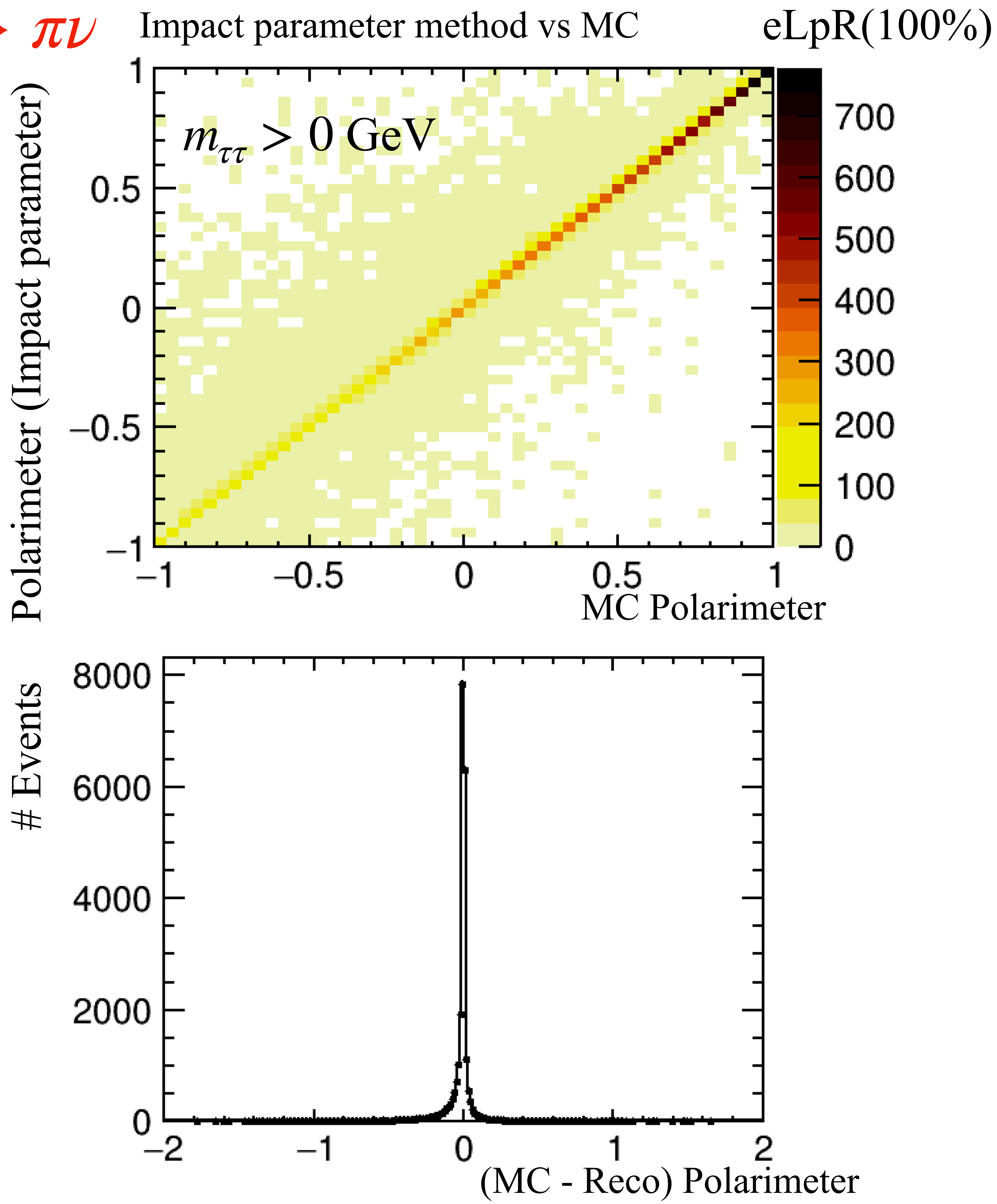


Impact parameter method efficiency is $> 80\,\%$ for events with $m_{\tau\tau} \sim 250$ GeV

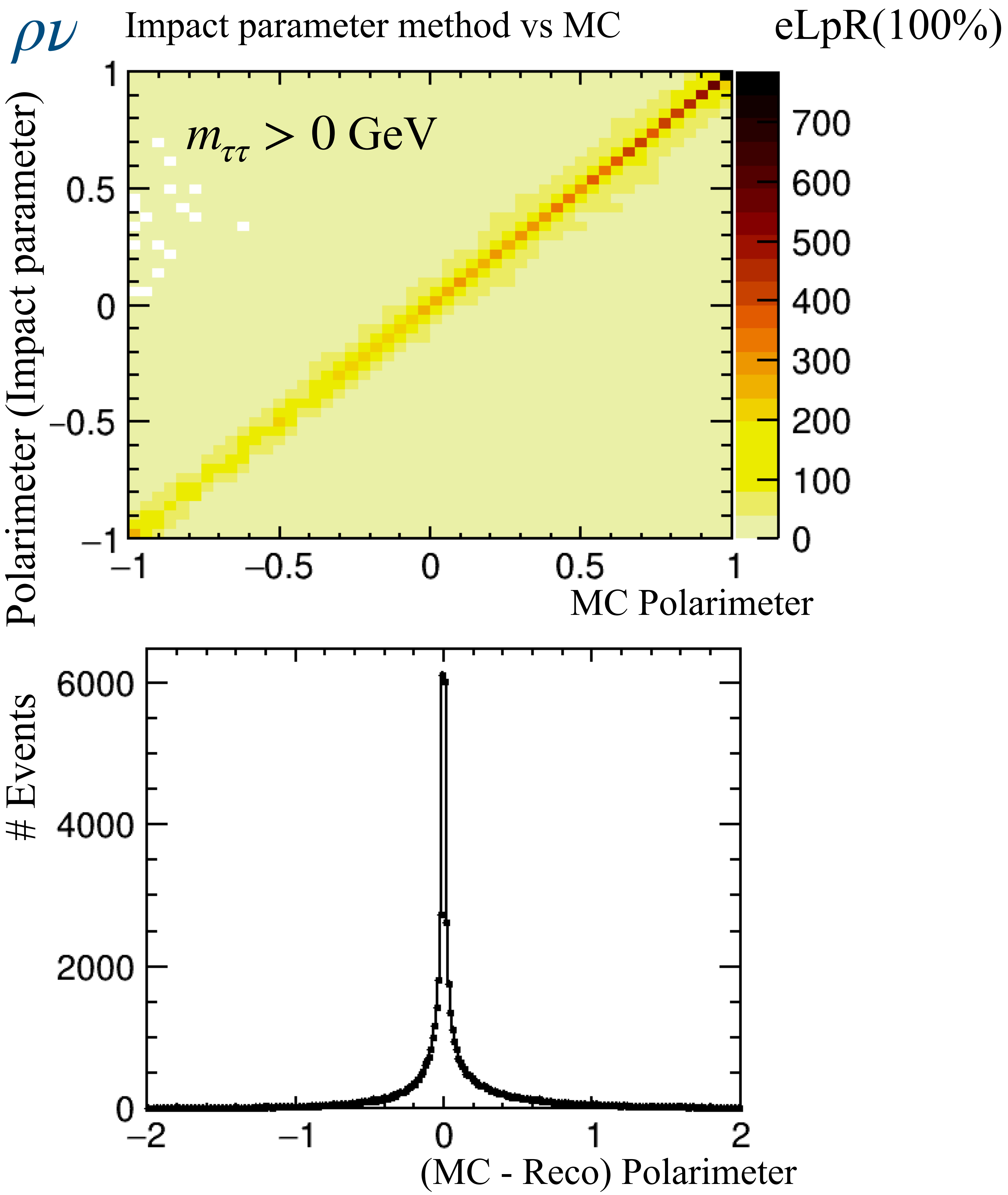
MC

Polarimeter

$\tau \rightarrow \pi\nu$



$\tau \rightarrow \rho\nu$



Polarimeter using reconstructed ν is in reasonable agreement with MC one.

Summary

- Full reconstruction of $e^+e^- \to \tau^+\tau^-$ using impact parameter was investigated.

- For events with $m_{\tau\tau} \sim 250$ GeV, new method efficiency is $> 80\,\%$
  $m_{\tau\tau} \sim 91$ GeV $\sim 75\,\%$

- Polarimeters were reconstructed in the $\tau \to \pi\nu$ and $\tau \to \rho\nu$ decay modes.

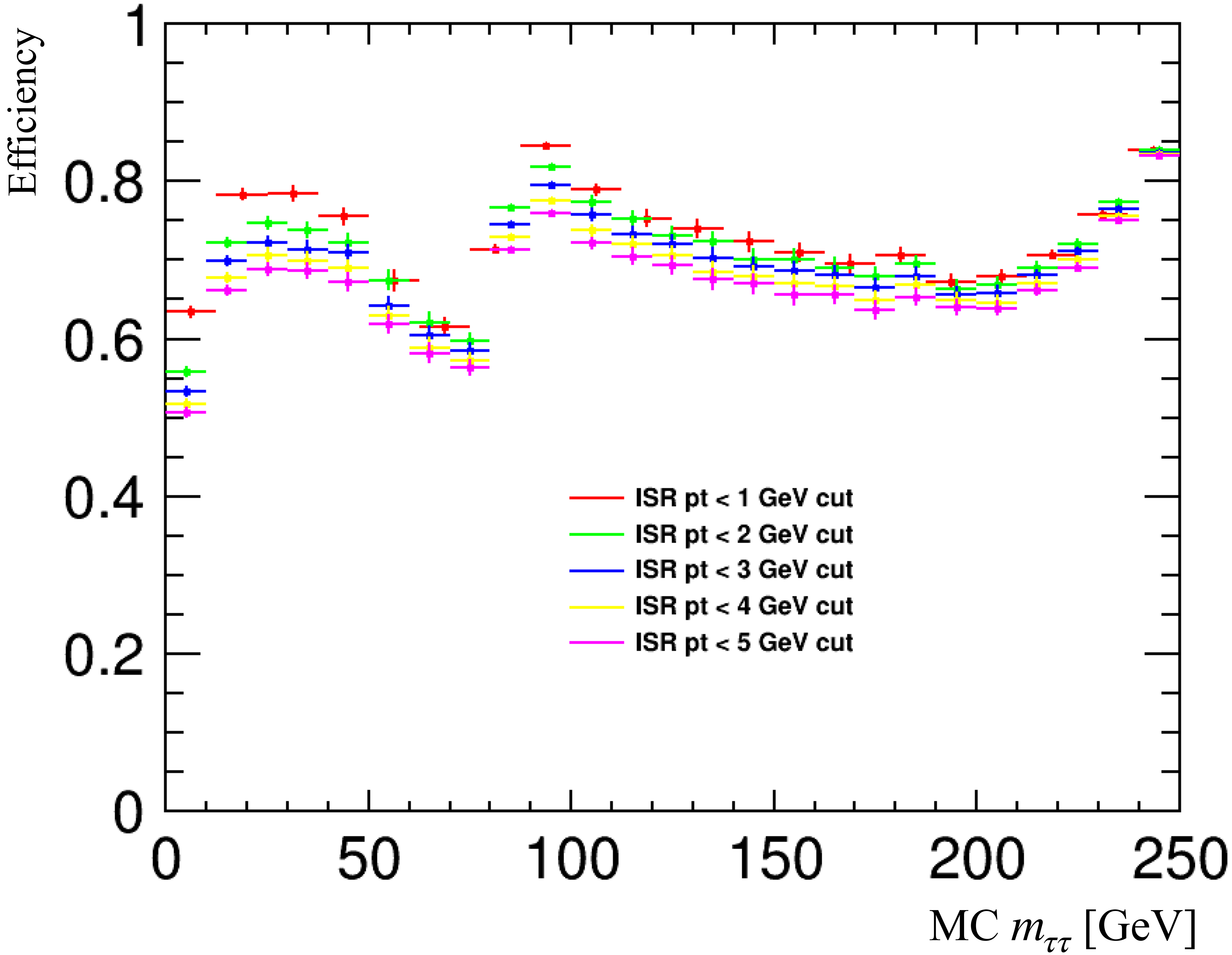
- Reasonable agreement between MC truth polarimeter and the one from "Impact parameter method" for both $\tau \to \pi\nu$ and $\tau \to \rho\nu$ decay were found.

Future plan

- ○ Quantify the precision with which the tau polarisation can be measured at ILC-250.

- ○ Investigate search for new physics by using the tau polarisation.

Effect of ISR photon on method efficiency

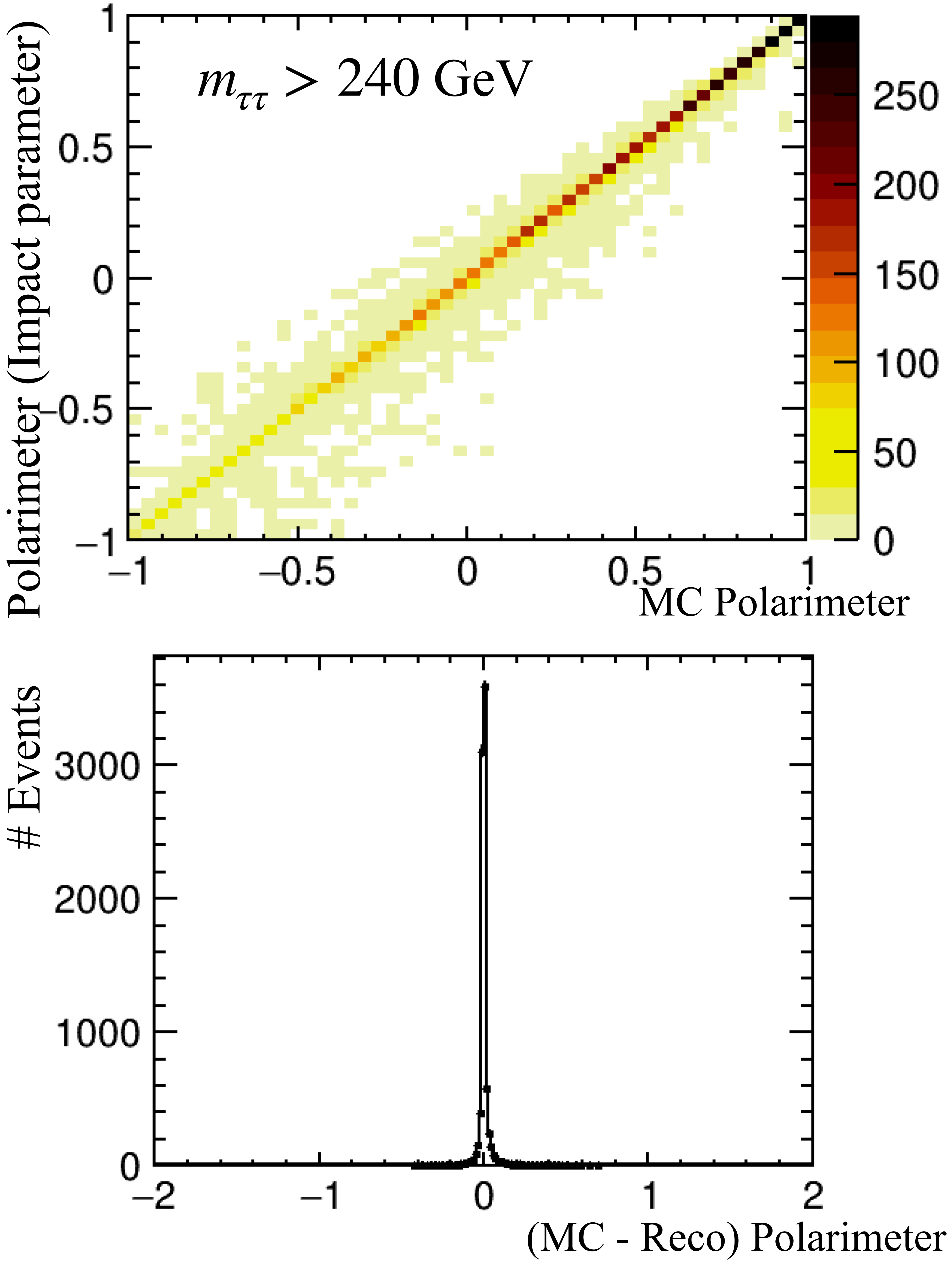


We assumed that ISR photons are collinear with the beams,
Efficiency improves as cut is tightened.

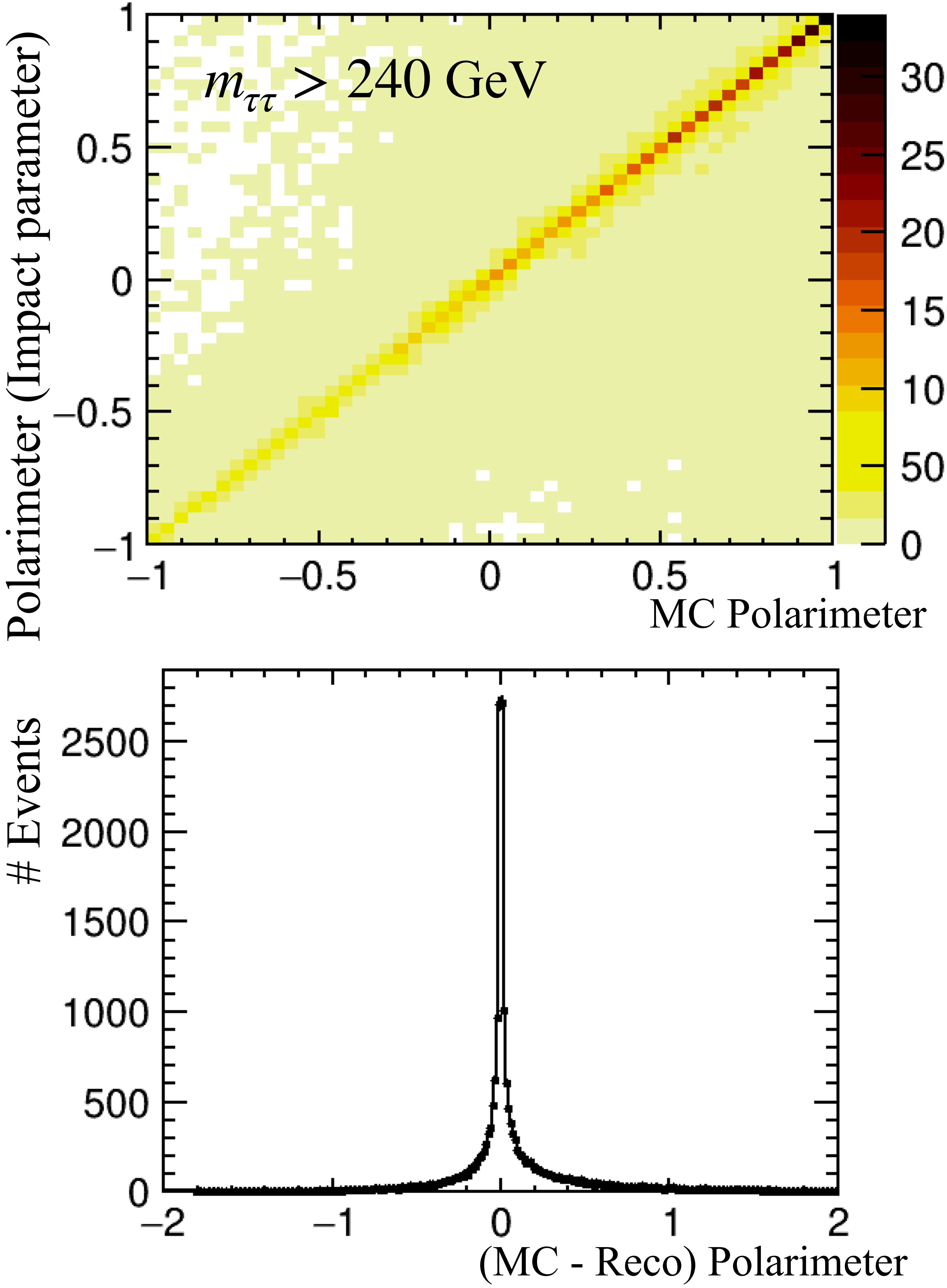
MC

Polarimeter

$\tau \rightarrow \pi\nu$ Impact parameter method vs MC eLpR(100%)



$\tau \rightarrow \rho\nu$ Impact parameter method vs MC eLpR(100%)

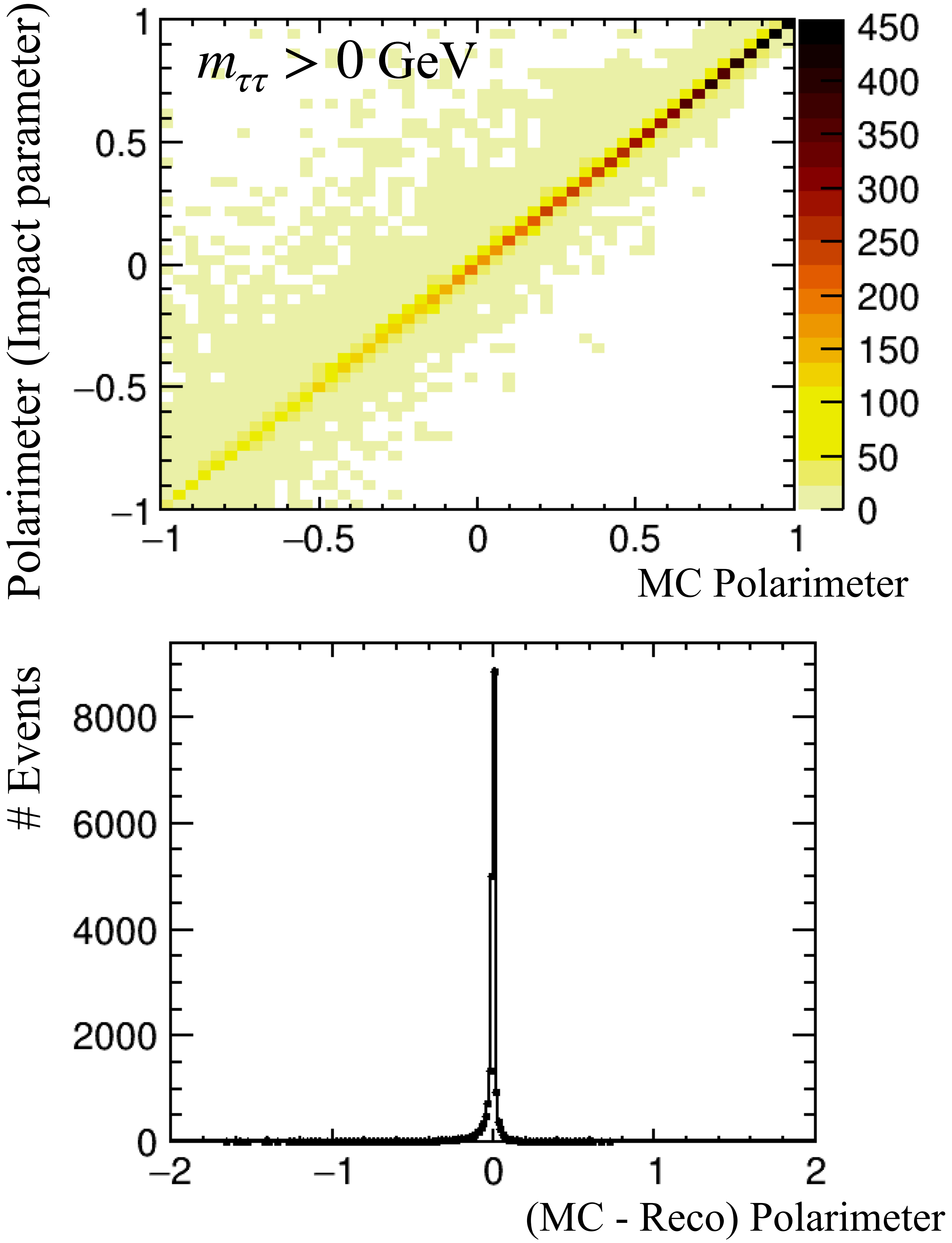


Polarimeter using reconstructed ν is in reasonable agreement with MC one.

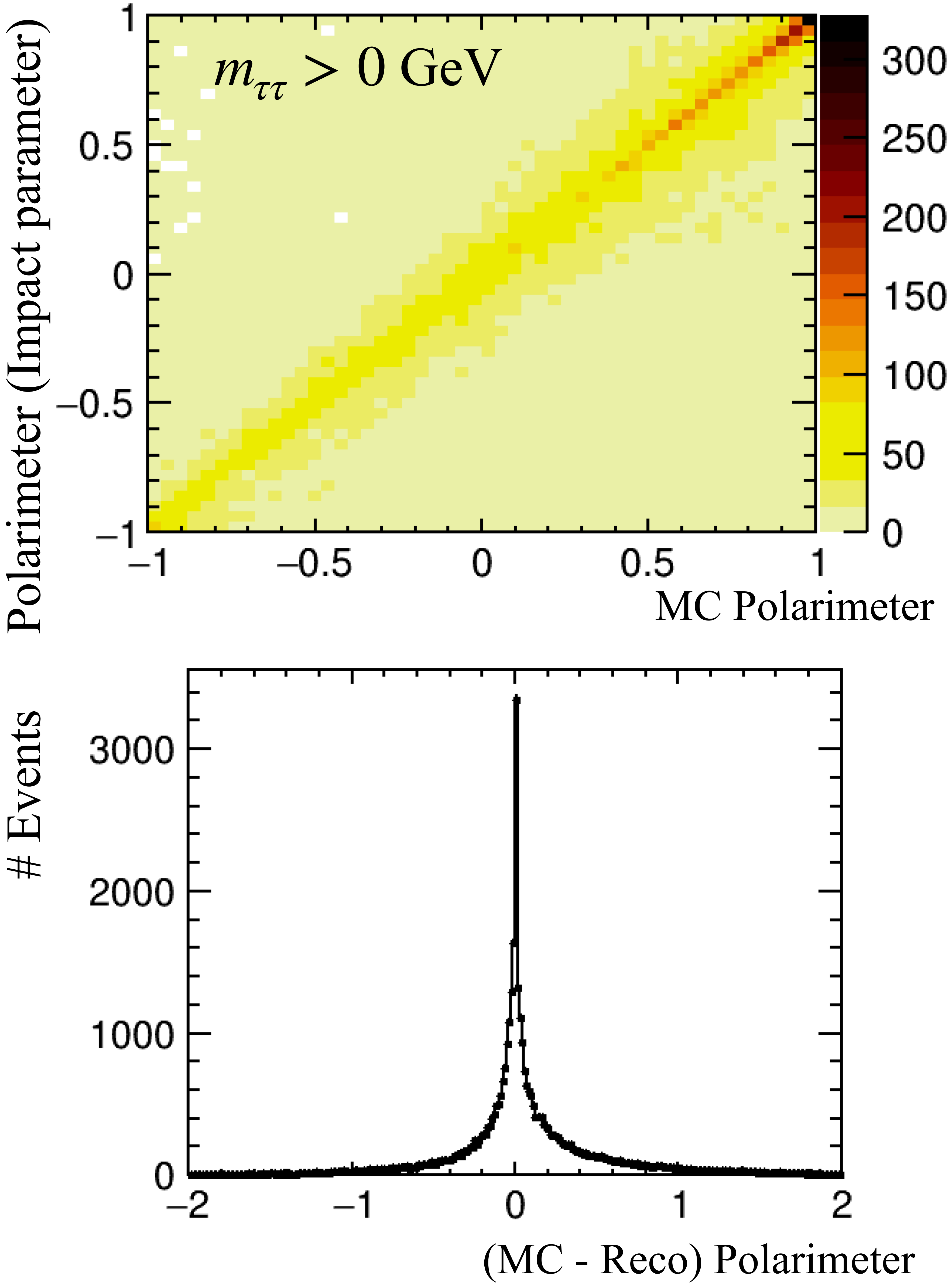
MC linked PFO

Polarimeter

$\tau \to \pi\nu$ Impact parameter method vs MC eLpR(100%)



$\tau \to \rho\nu$ Impact parameter method vs MC eLpR(100%)



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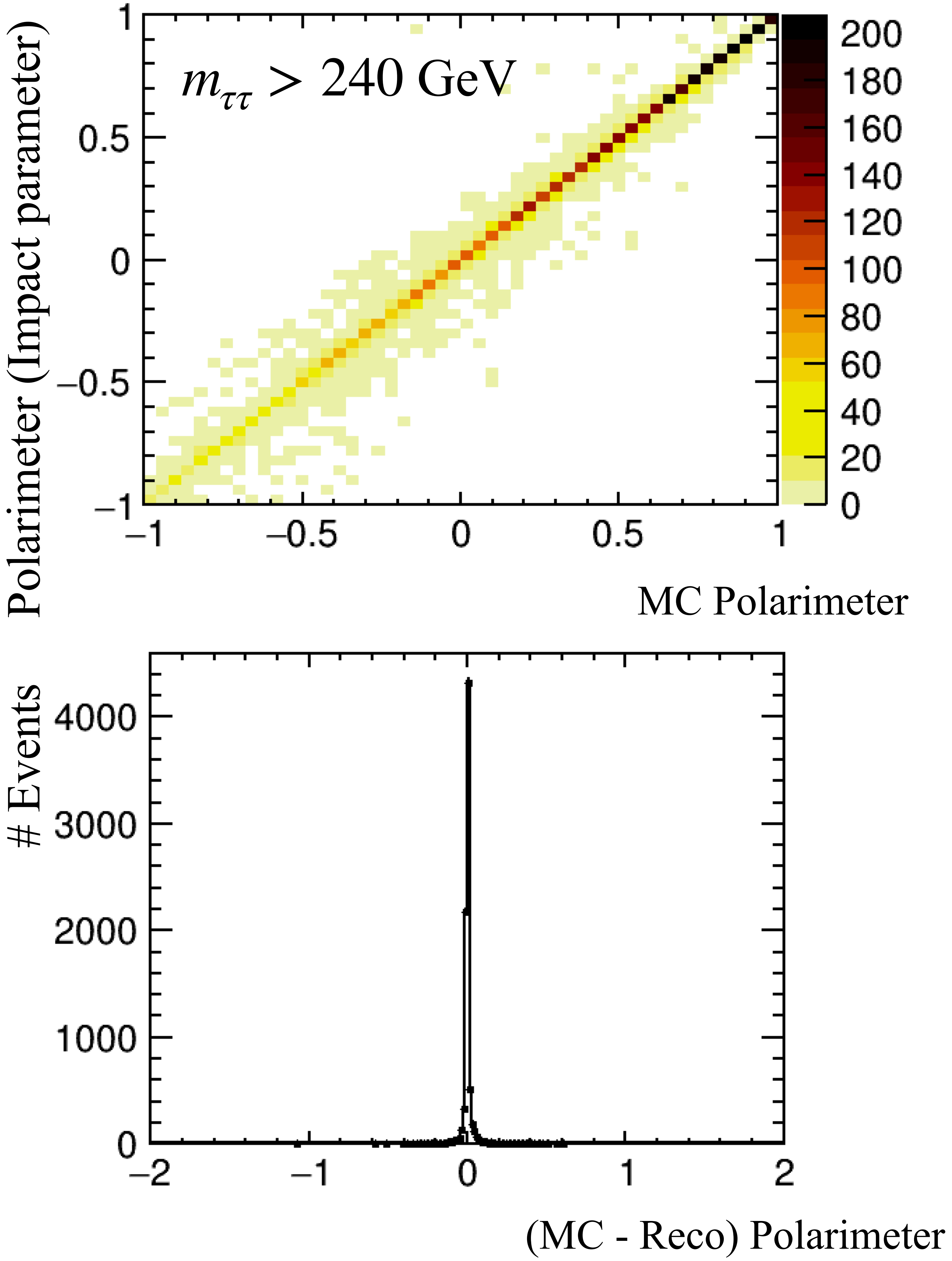
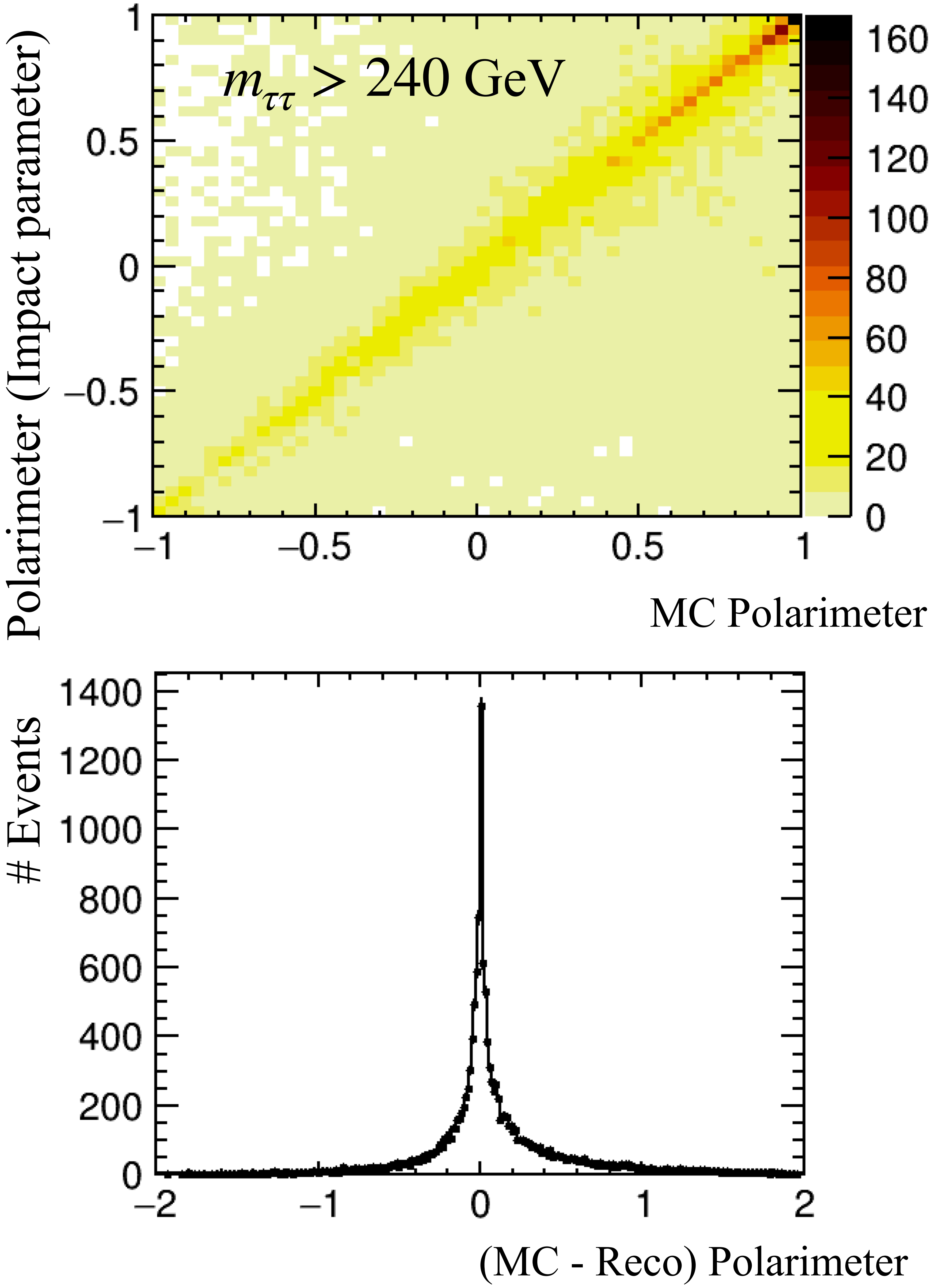
MC linked PFO

Polarimeter

$\tau \rightarrow \pi\nu$ Impact parameter method vs MC eLpR(100%)



$\tau \rightarrow \rho\nu$ Impact parameter method vs MC eLpR(100%)

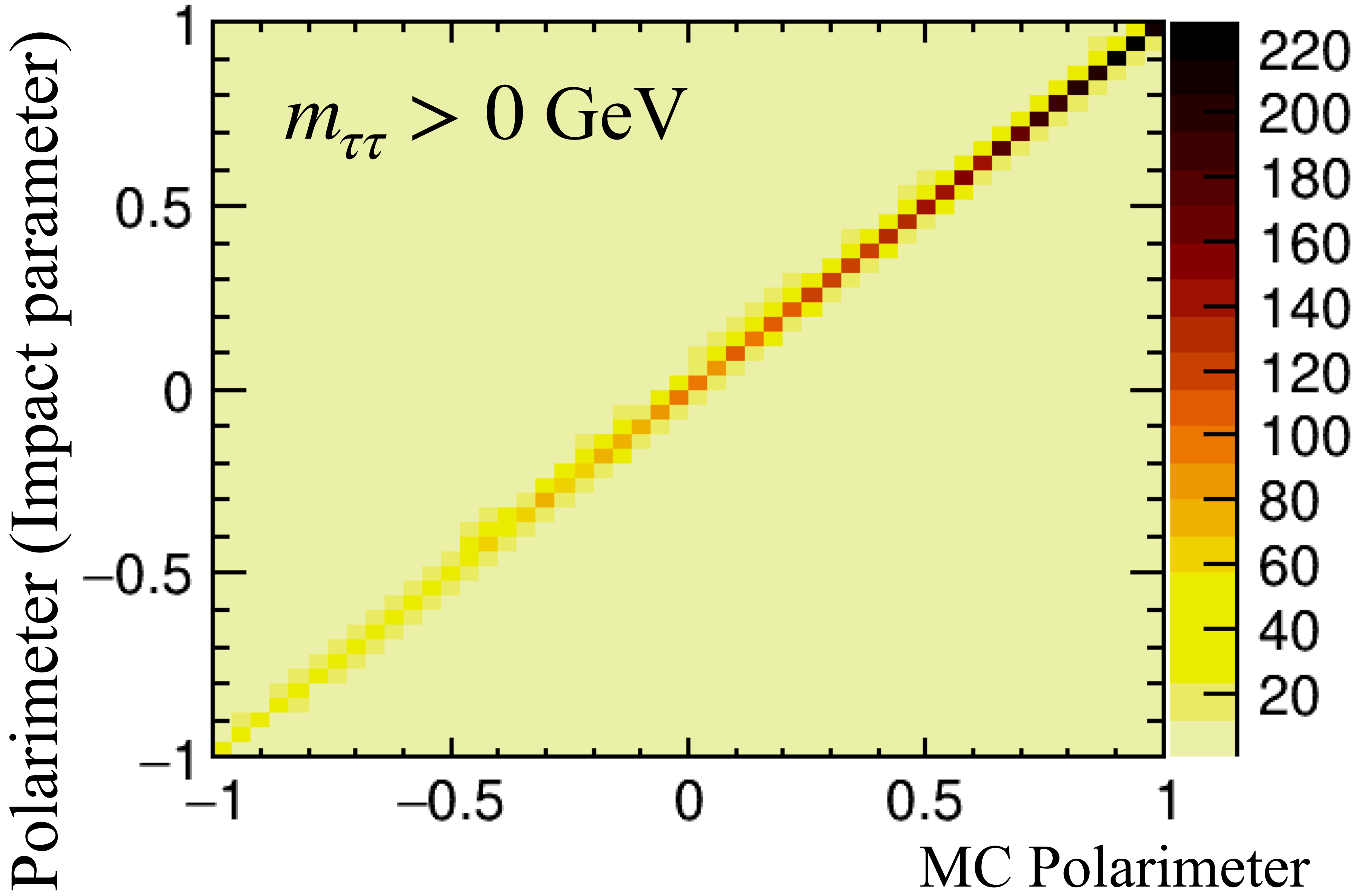


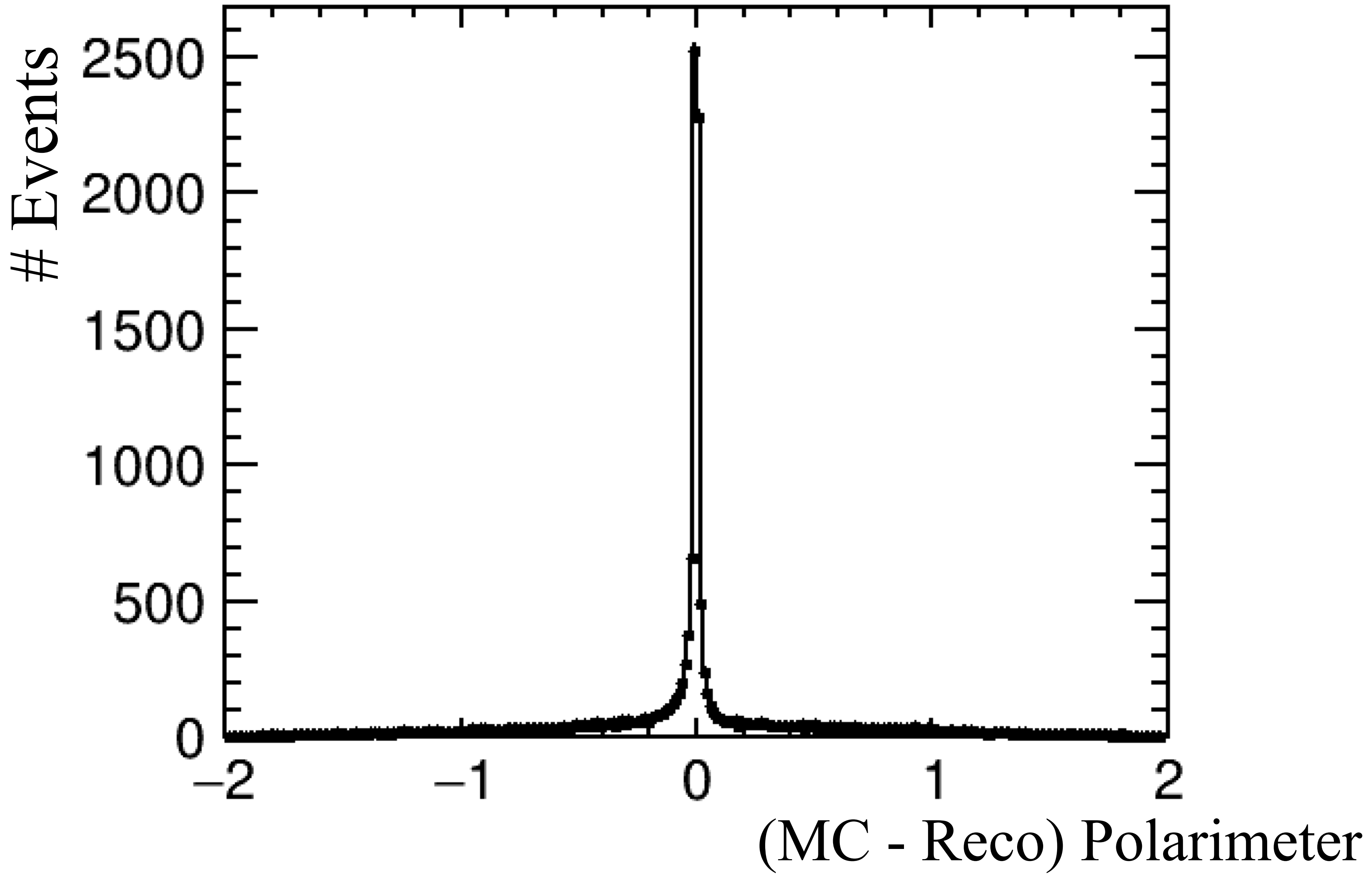
Polarimeter using reconstructed ν is in reasonable agreement with MC one.

PFO

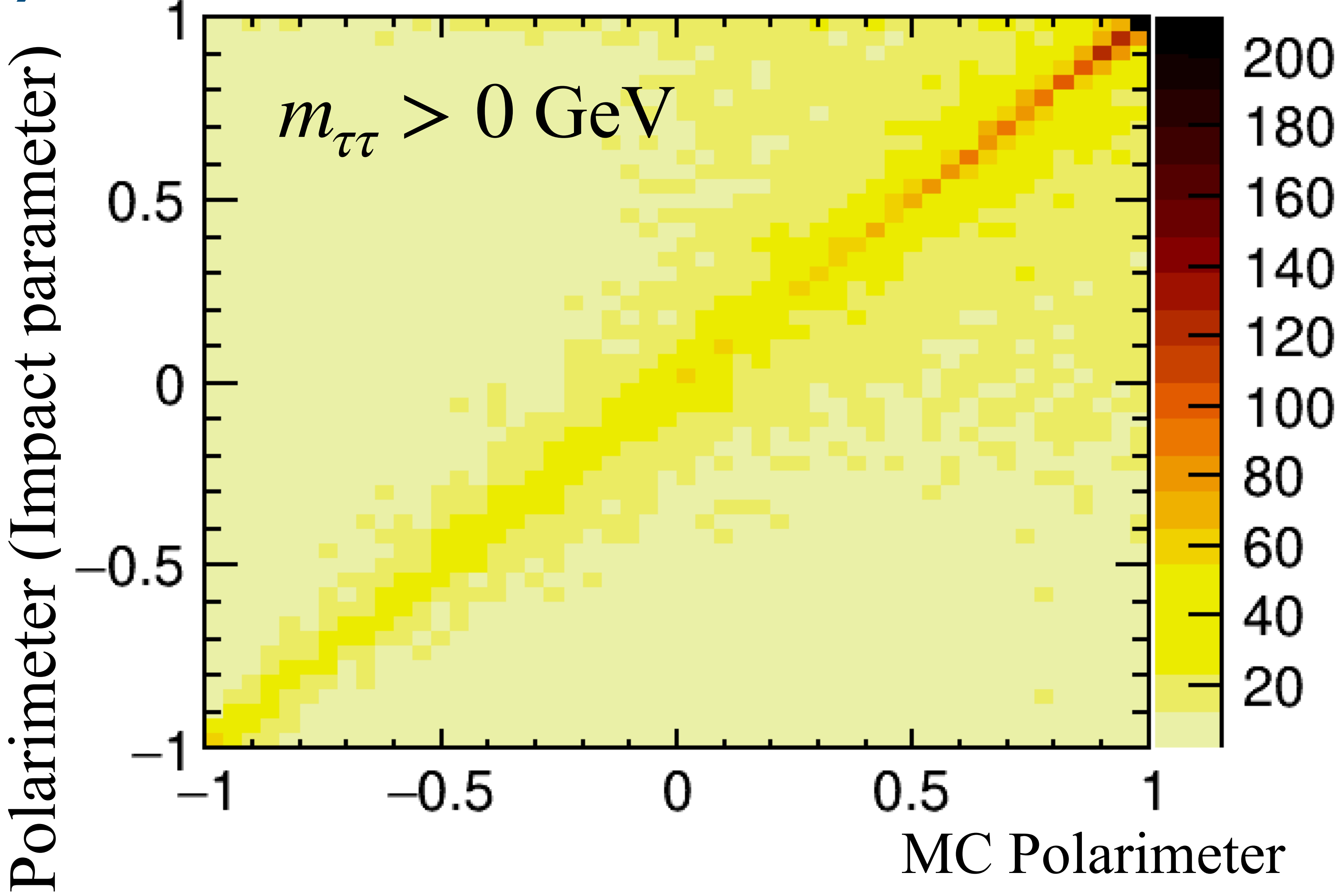
Polarimeter

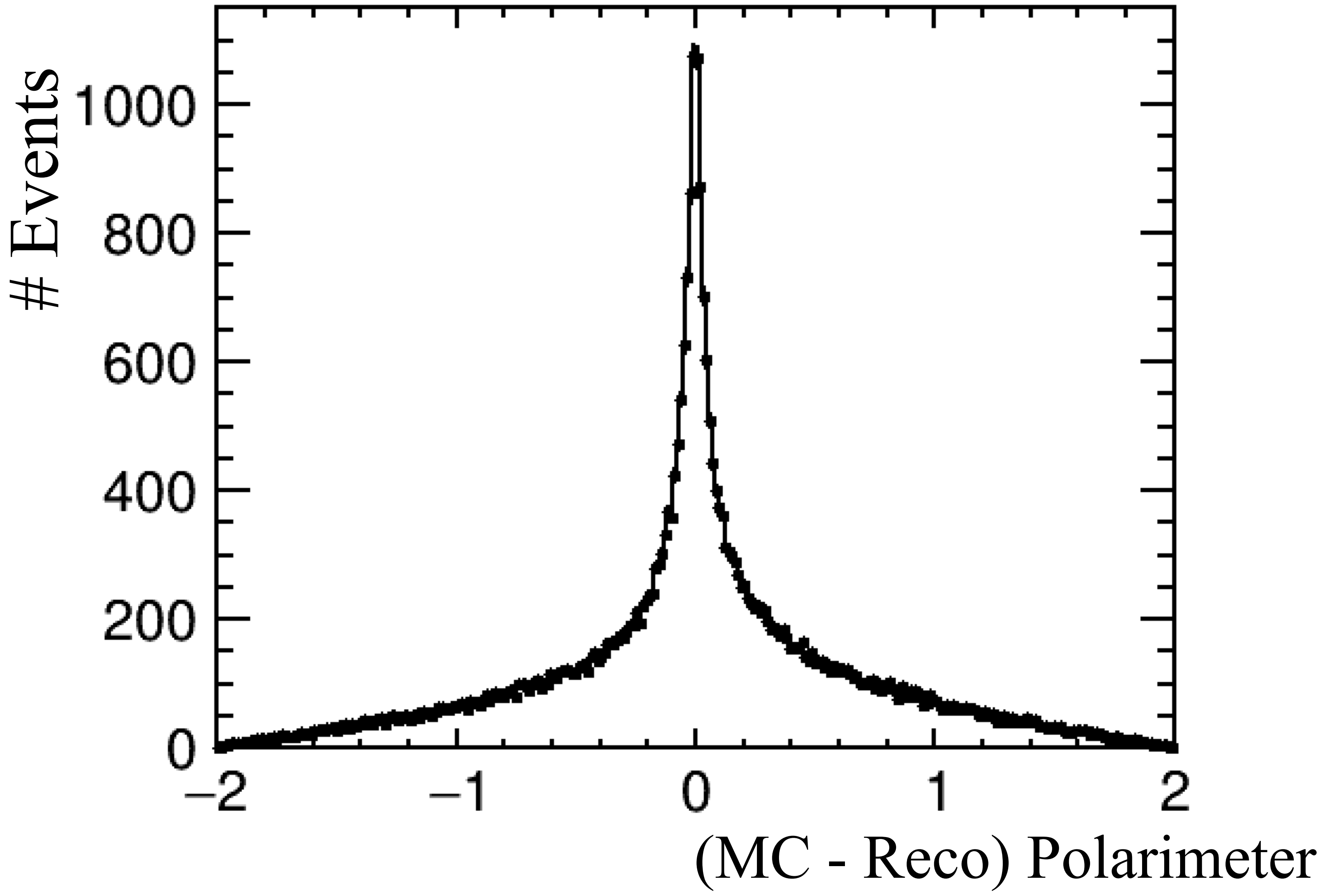
$\tau \to \pi\nu$ Impact parameter method vs MC eLpR(100%)





$\tau \to \rho\nu$ Impact parameter method vs MC eLpR(100%)



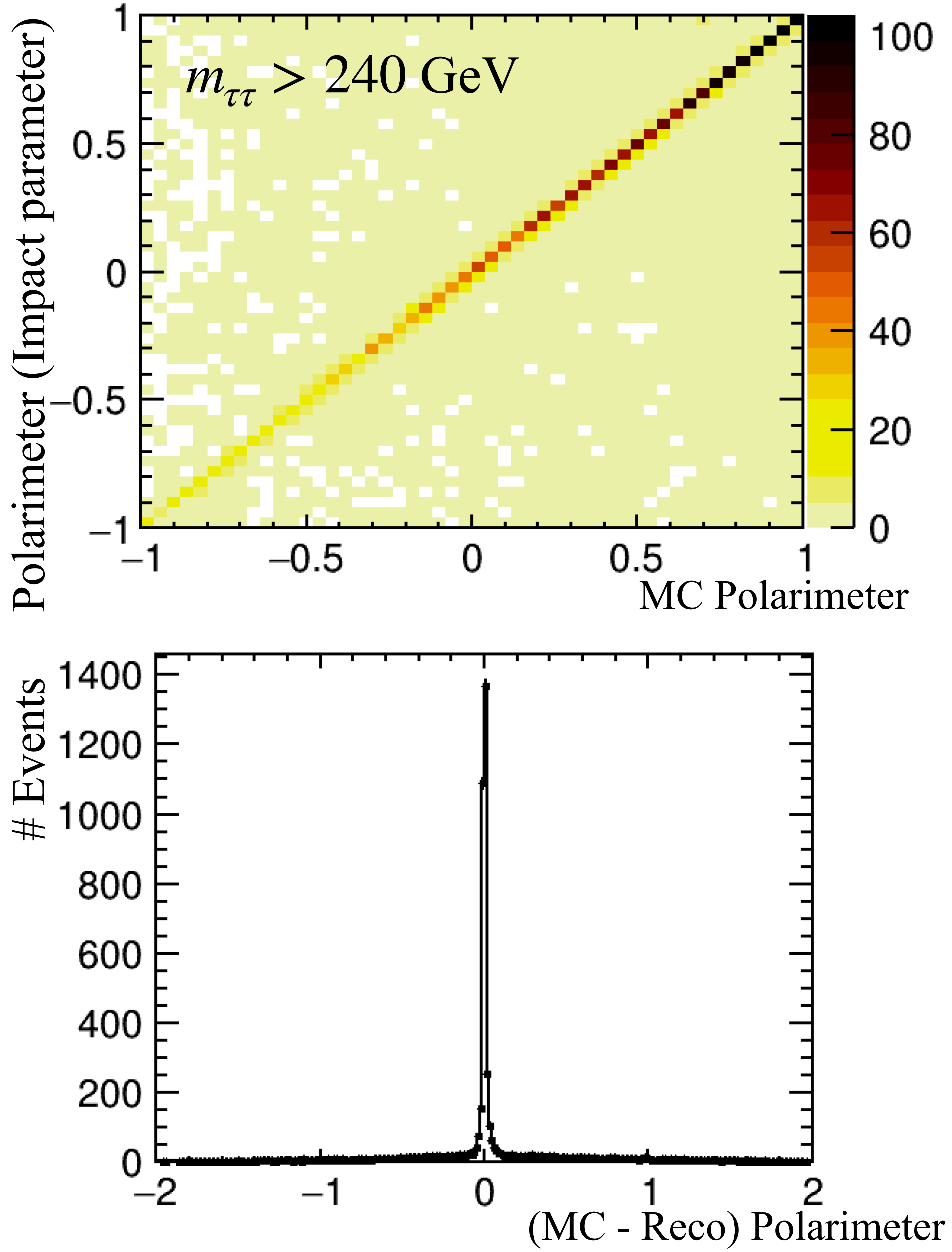


Polarimeter using reconstructed ν is in reasonable agreement with MC one.

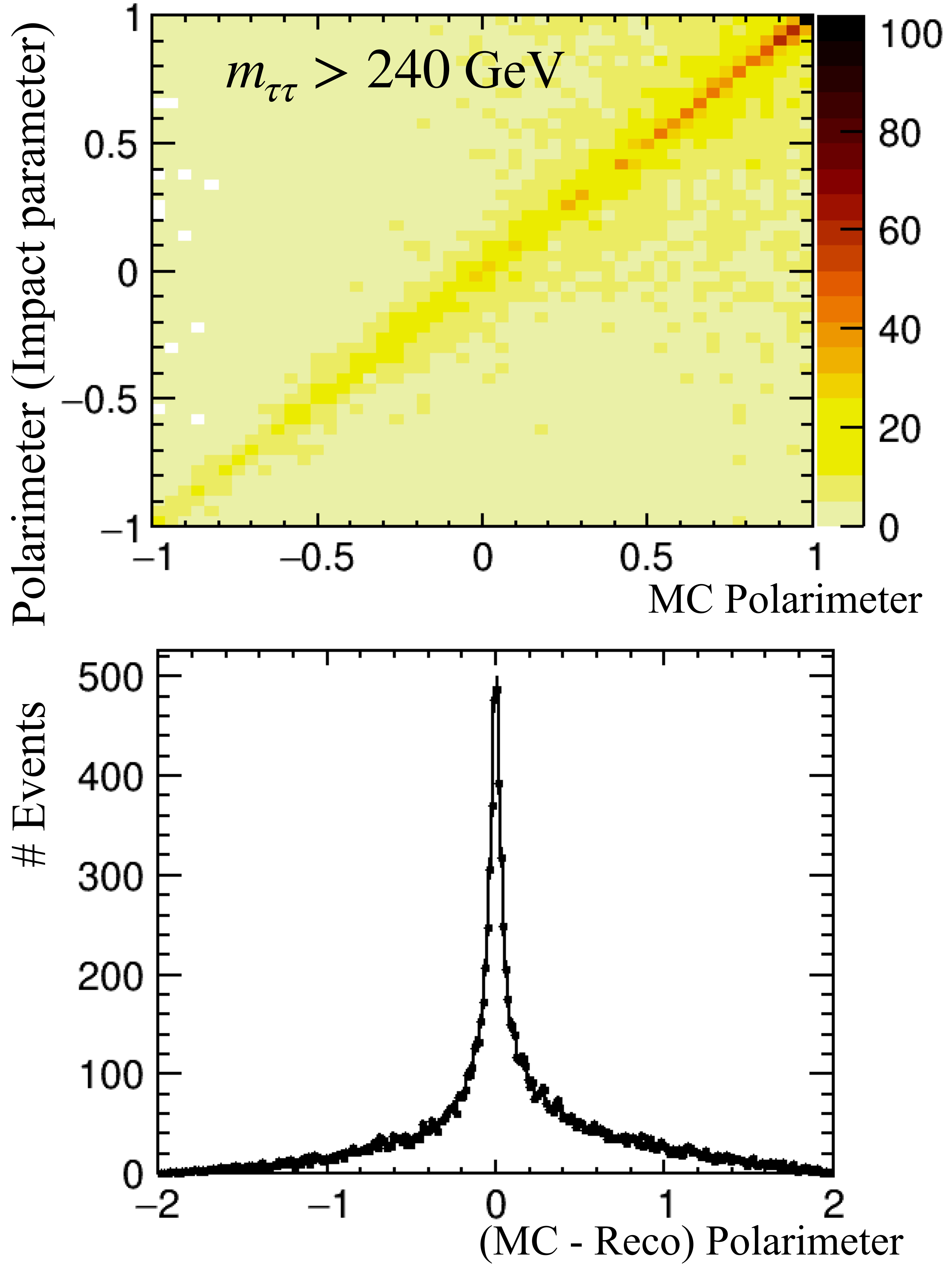
PFO

Polarimeter

$\tau \to \pi\nu$ Impact parameter method vs MC eLpR(100%)

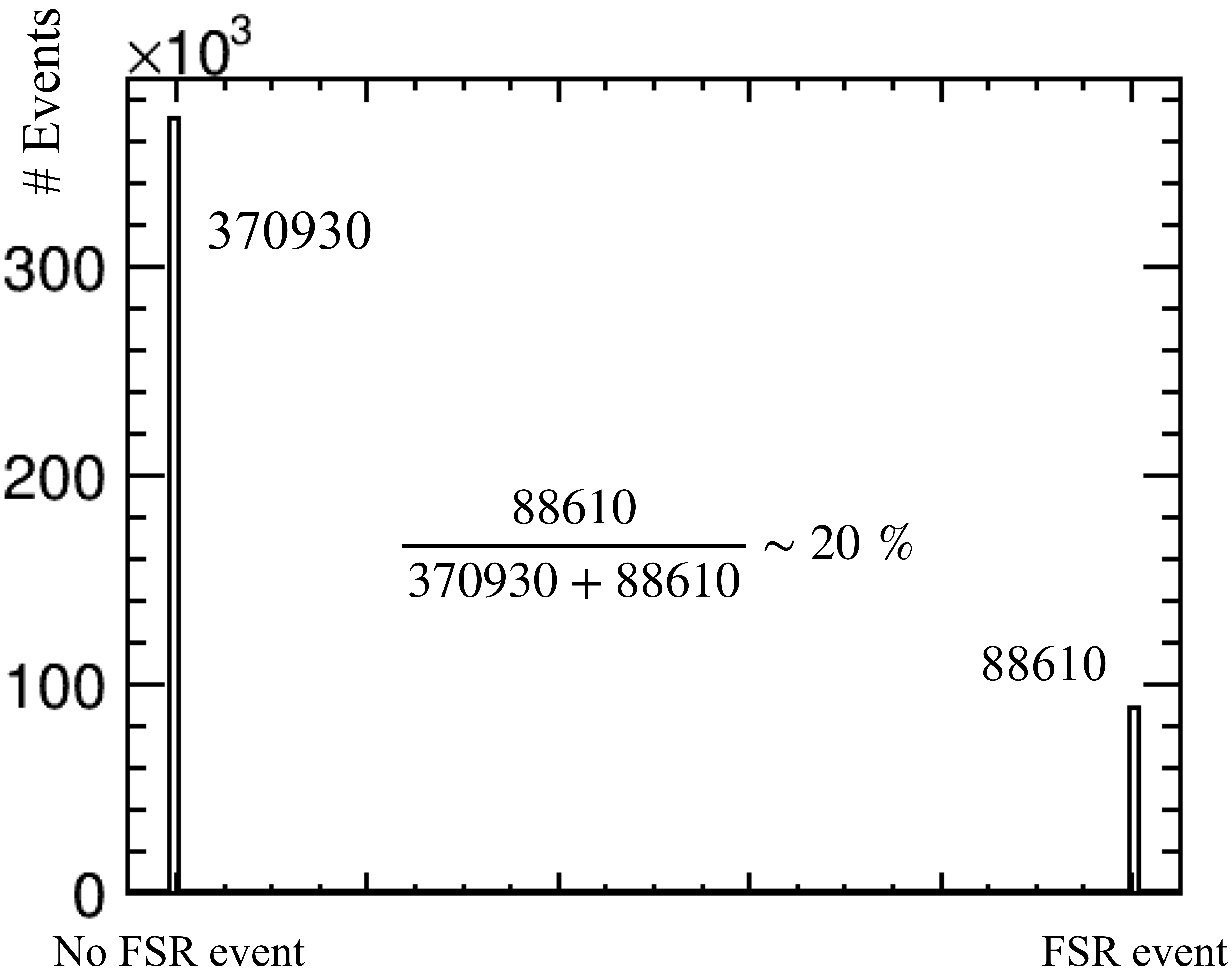


$\tau \to \rho\nu$ Impact parameter method vs MC eLpR(100%)



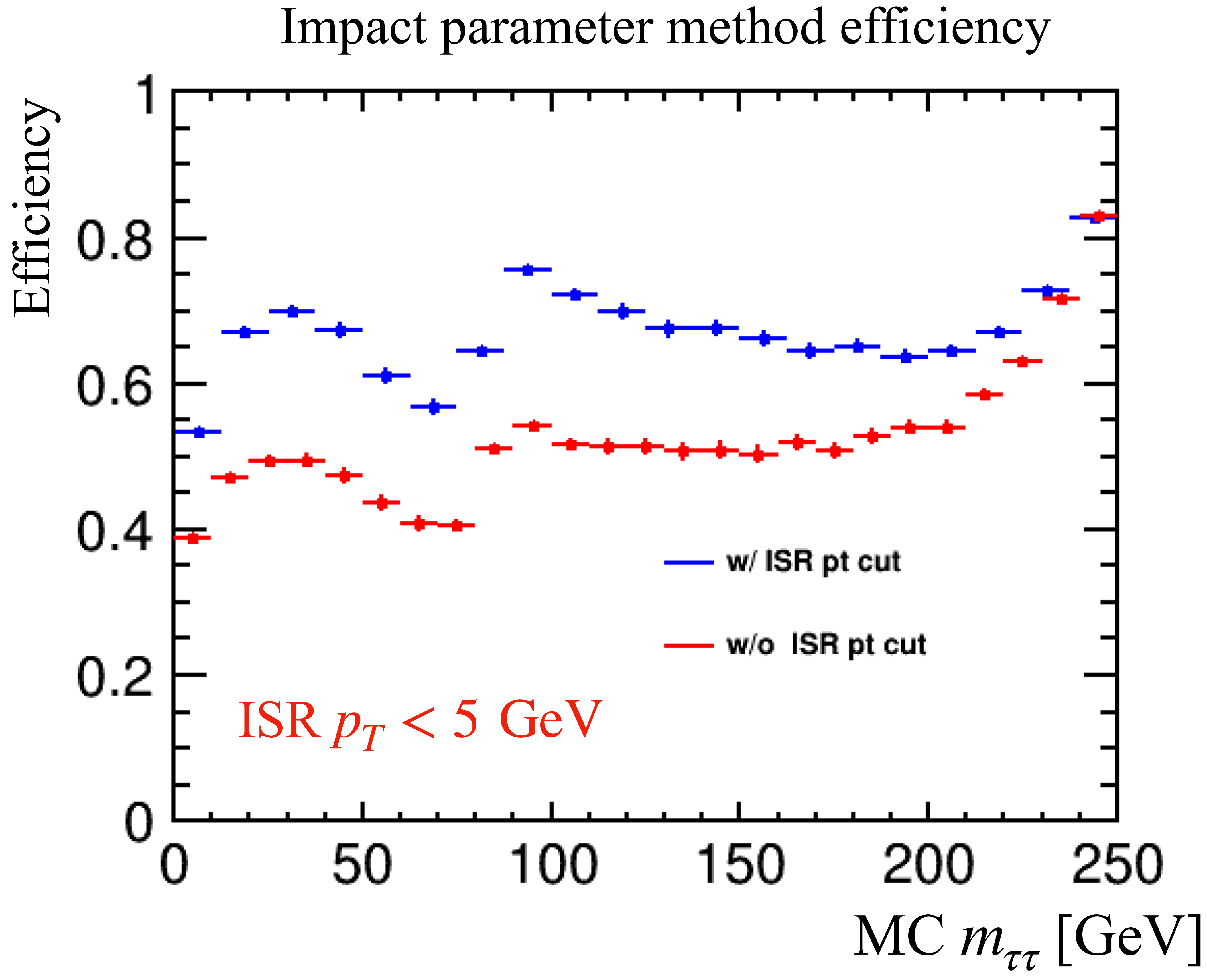
Polarimeter using reconstructed ν is in reasonable agreement with MC one.

FSR event



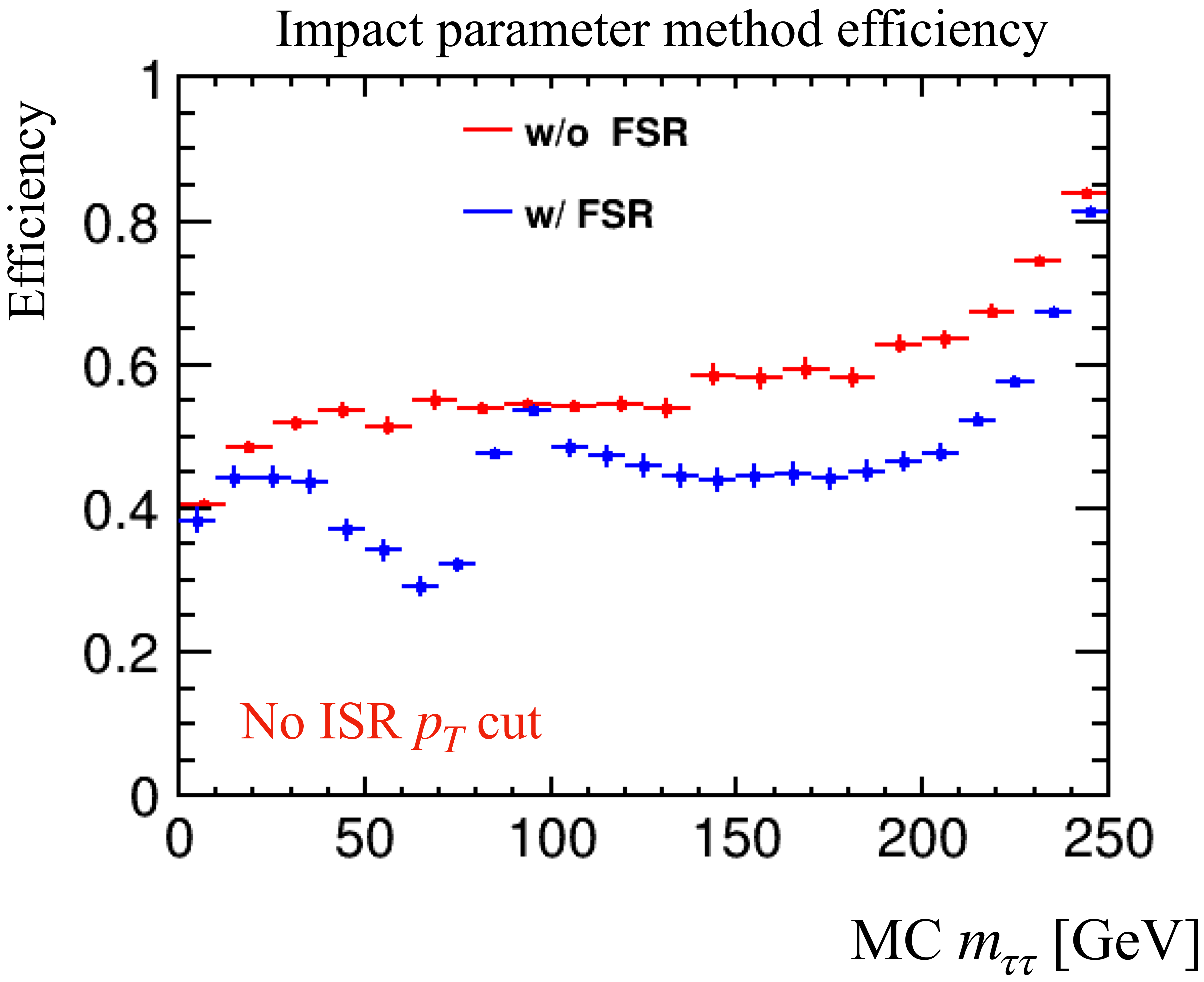
$$\frac{88610}{370930 + 88610} \sim 20\ \%$$

Method efficiency



Impact parameter method efficiency

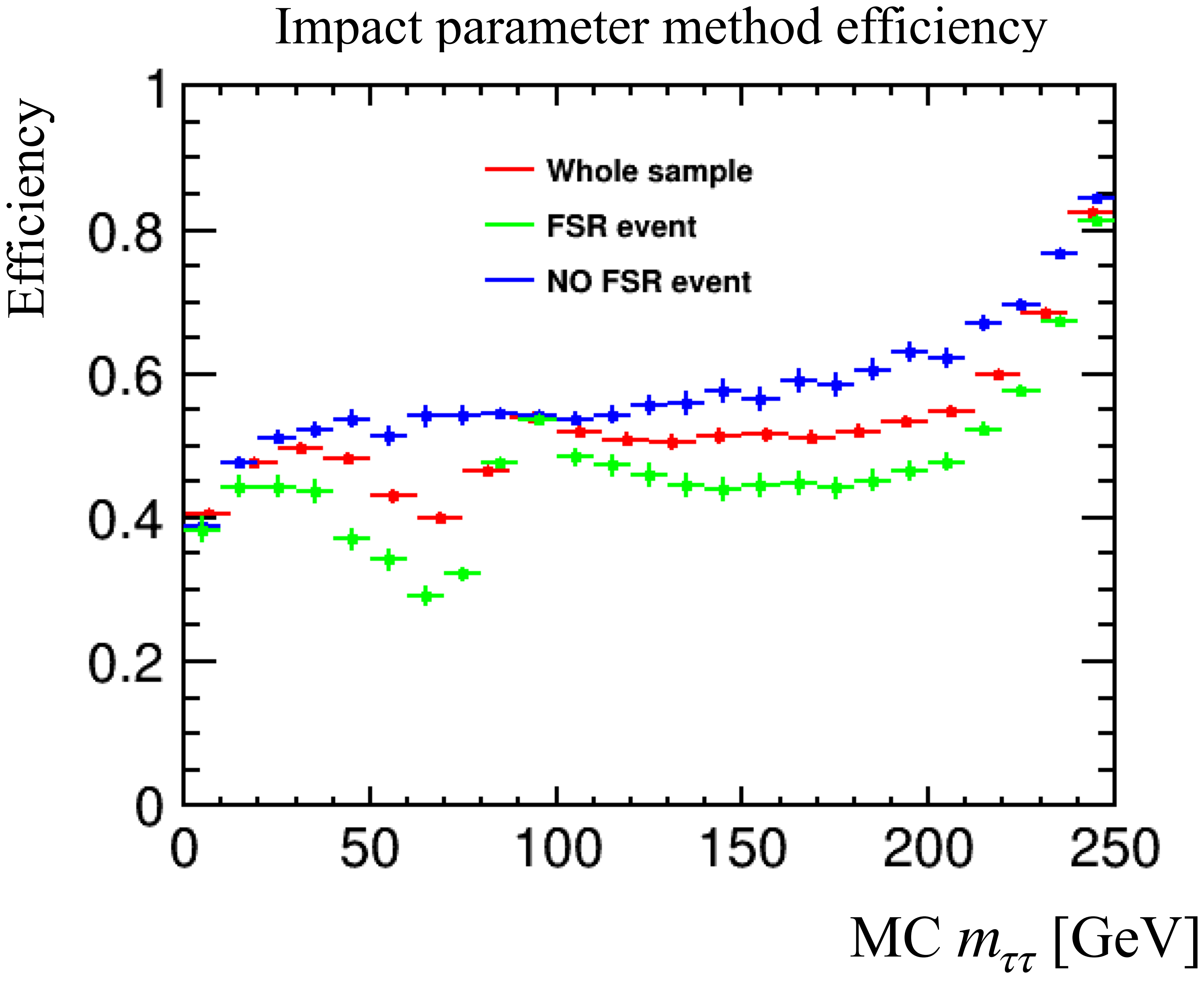
ISR $p_T < 5$ GeV

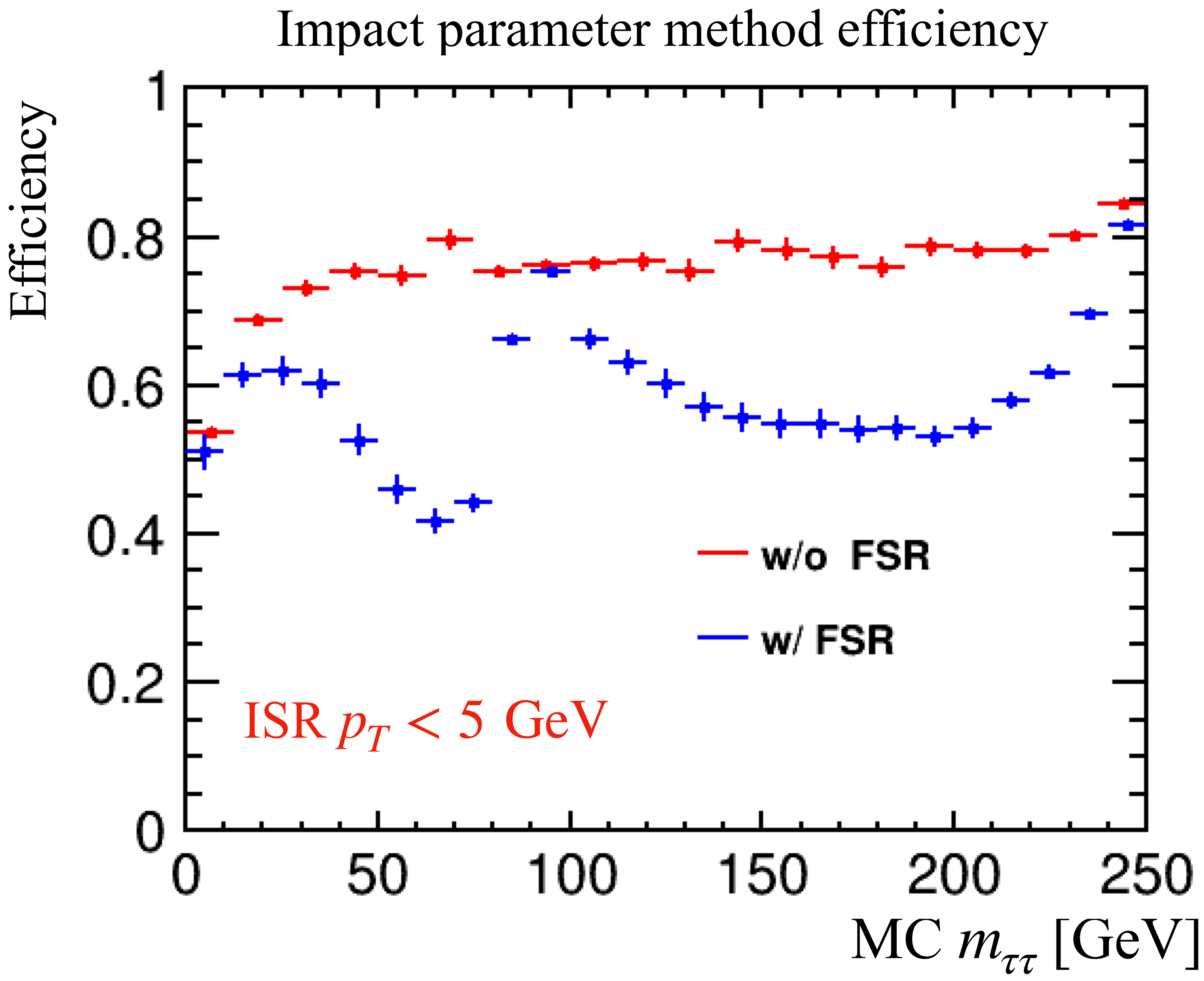


Impact parameter method efficiency

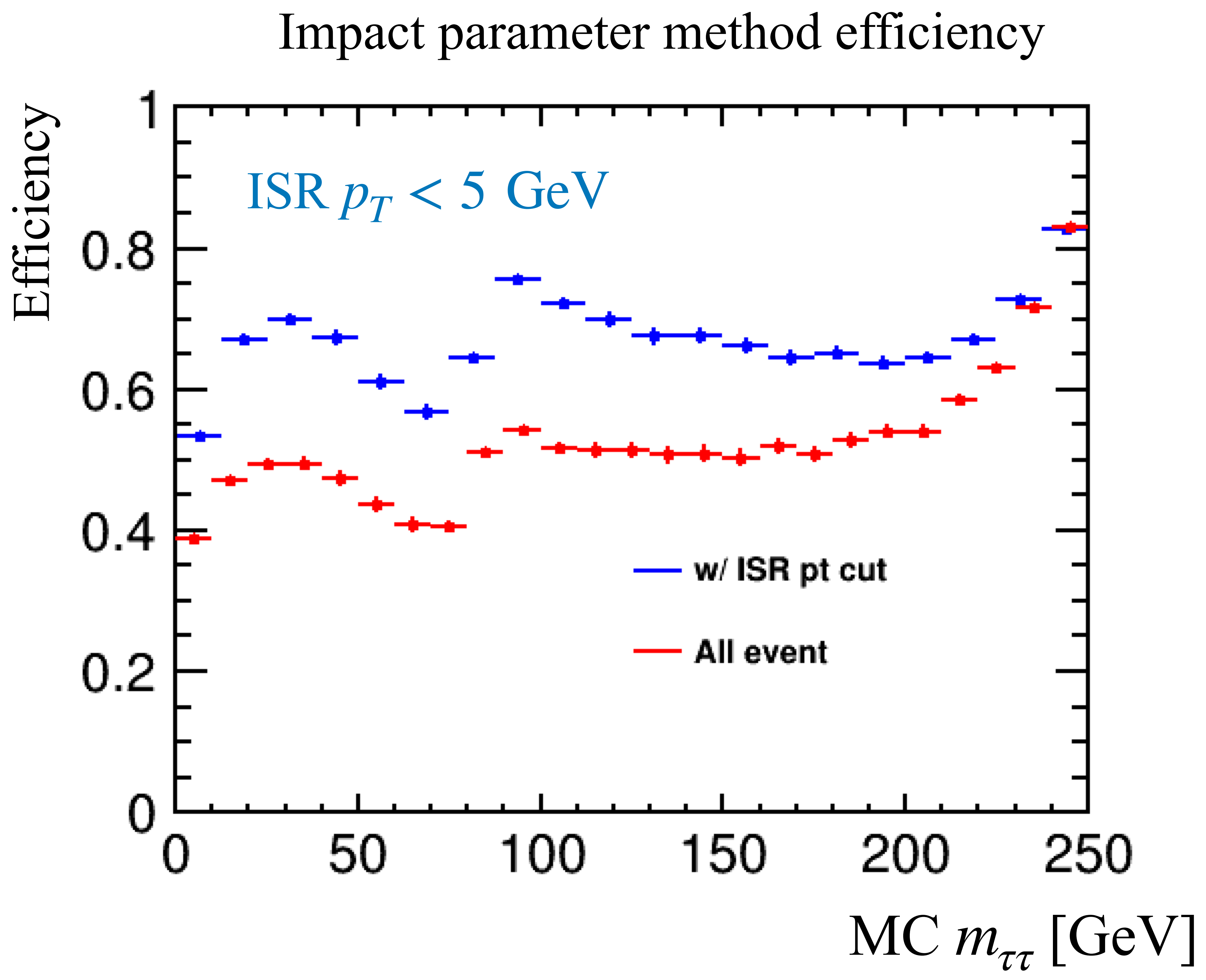
No ISR p_T cut

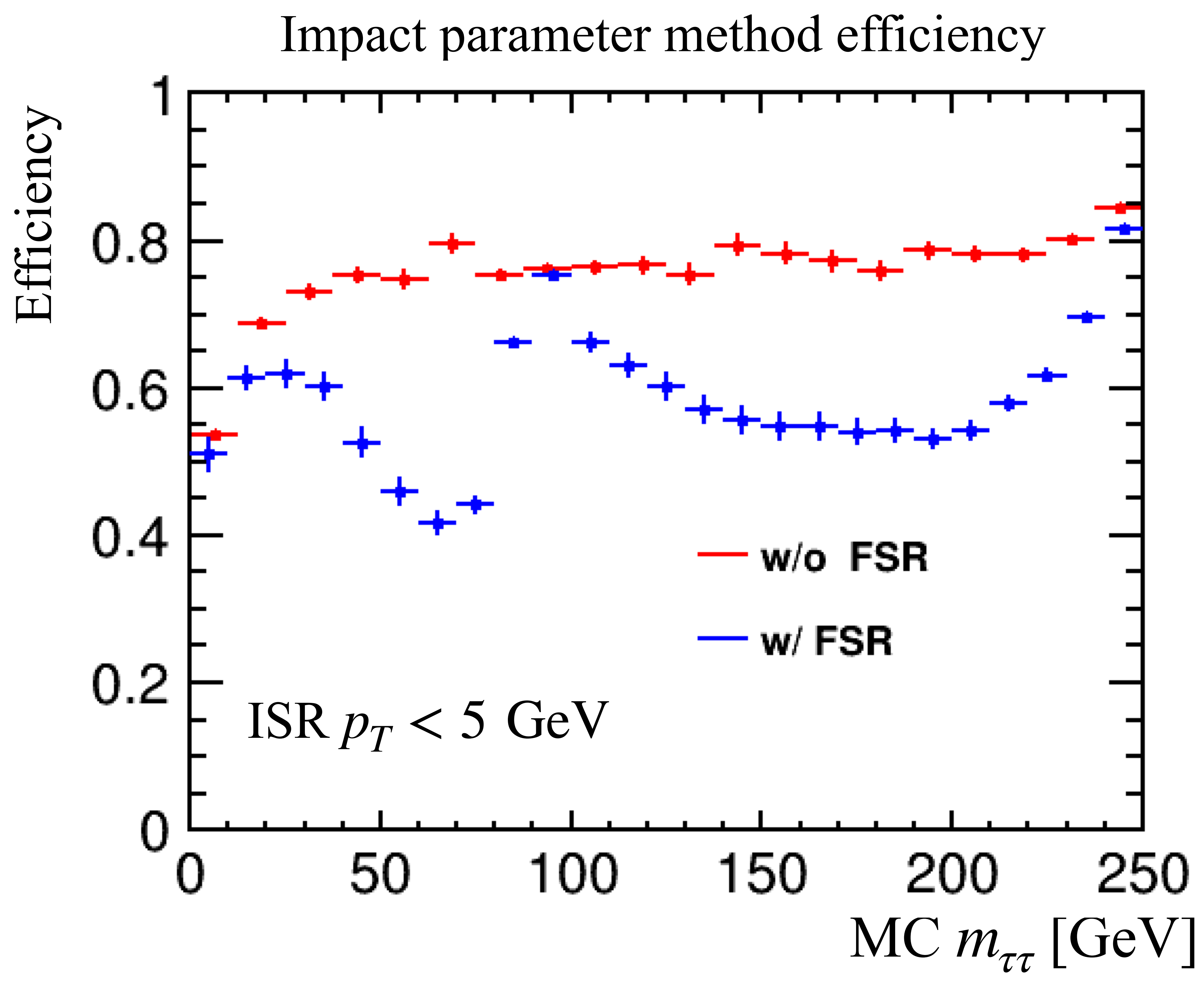
Method efficiency



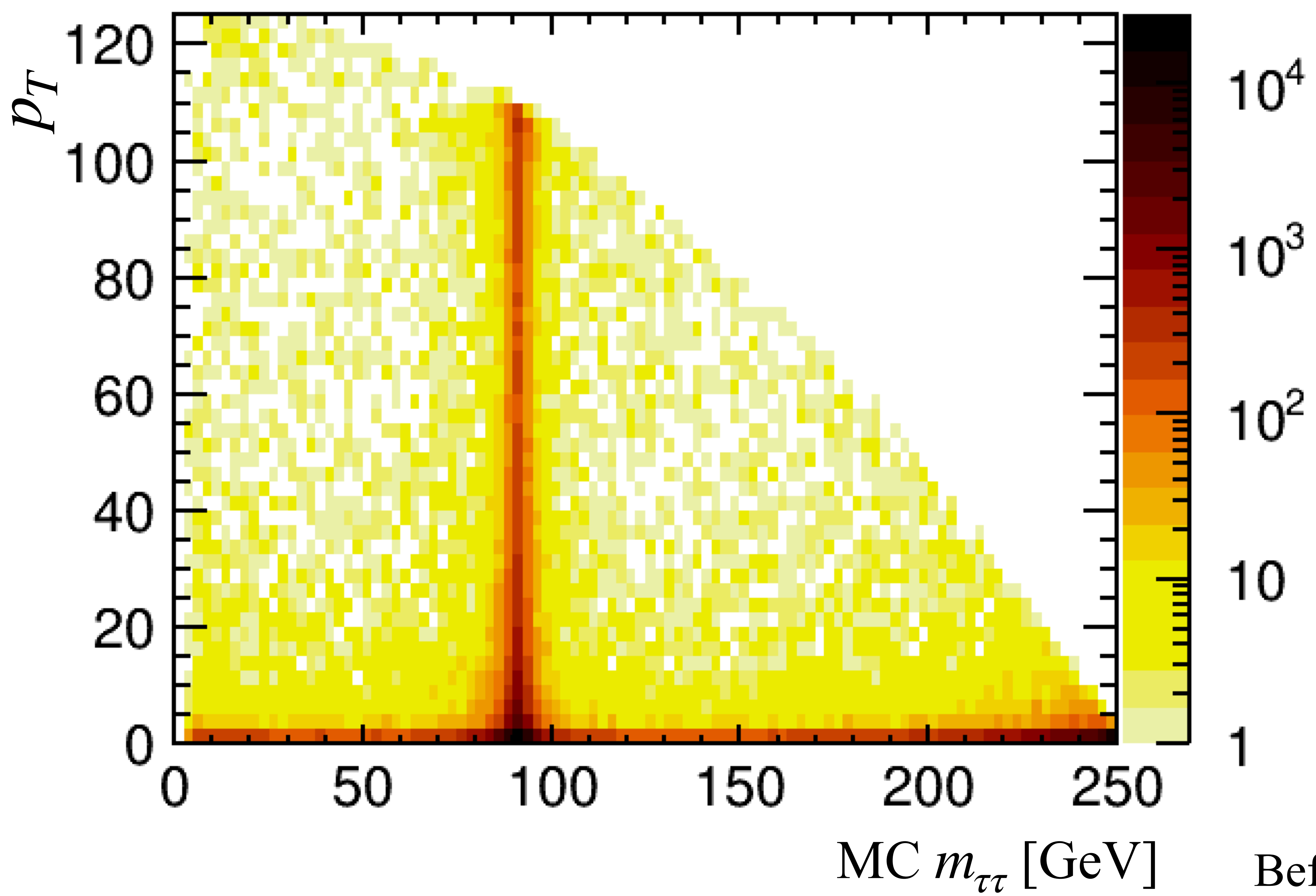


Method efficiency

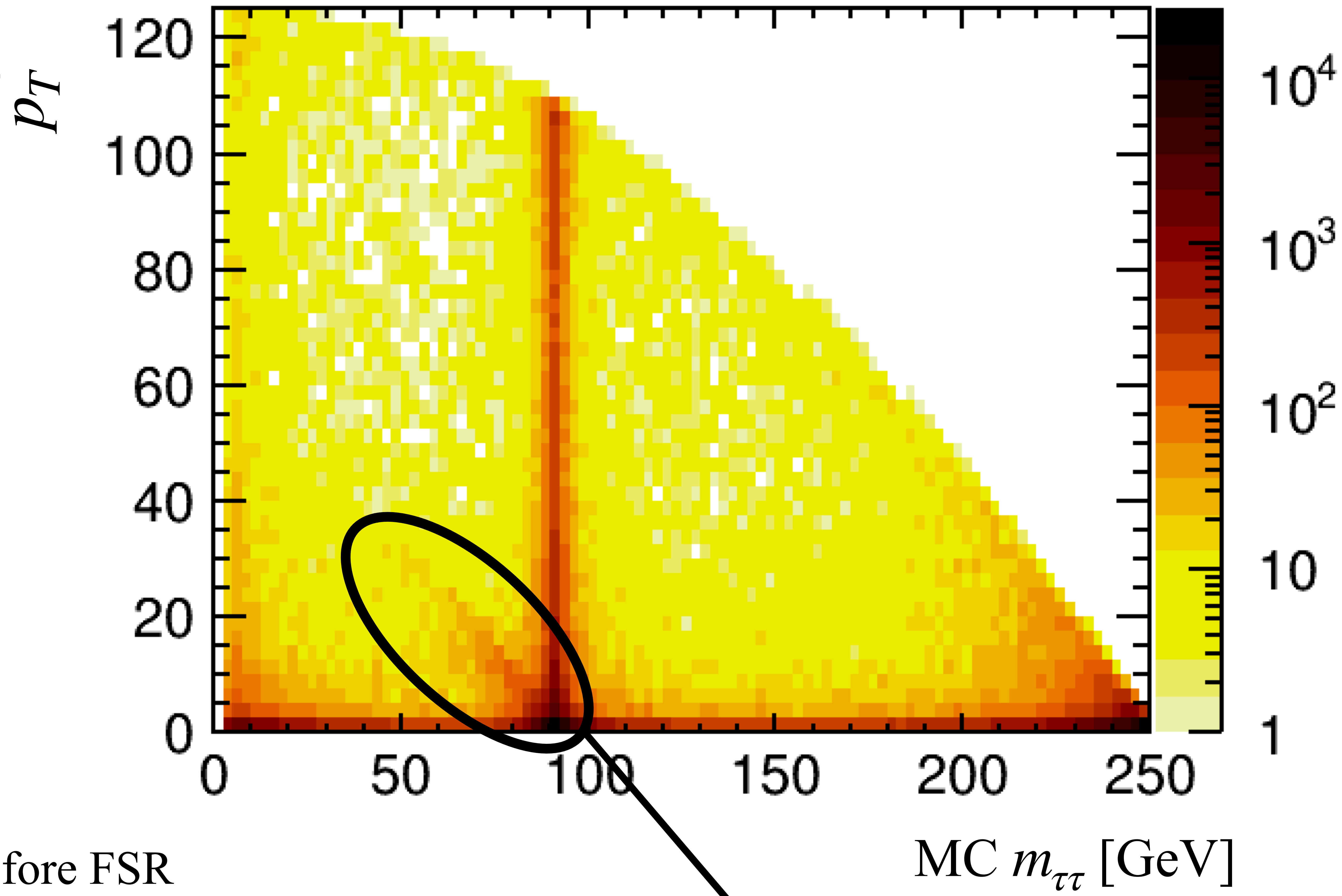


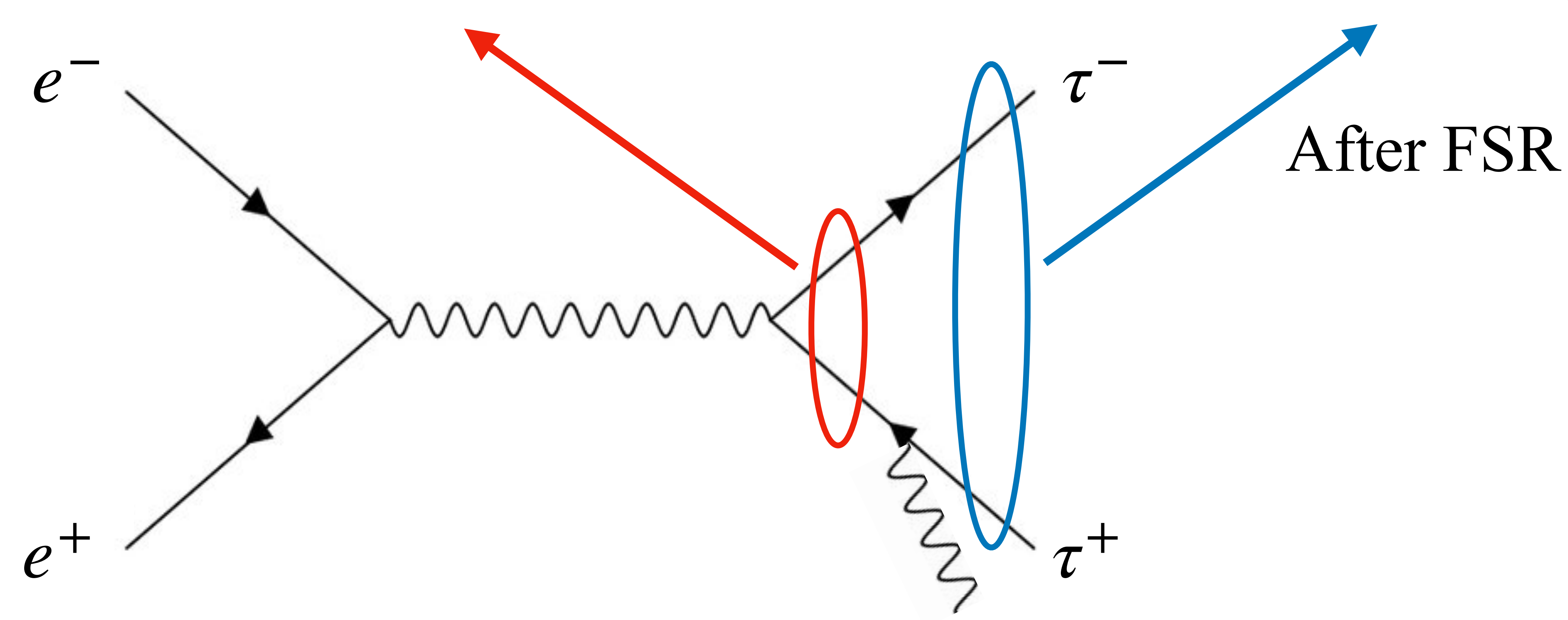


Before FSR



After FSR

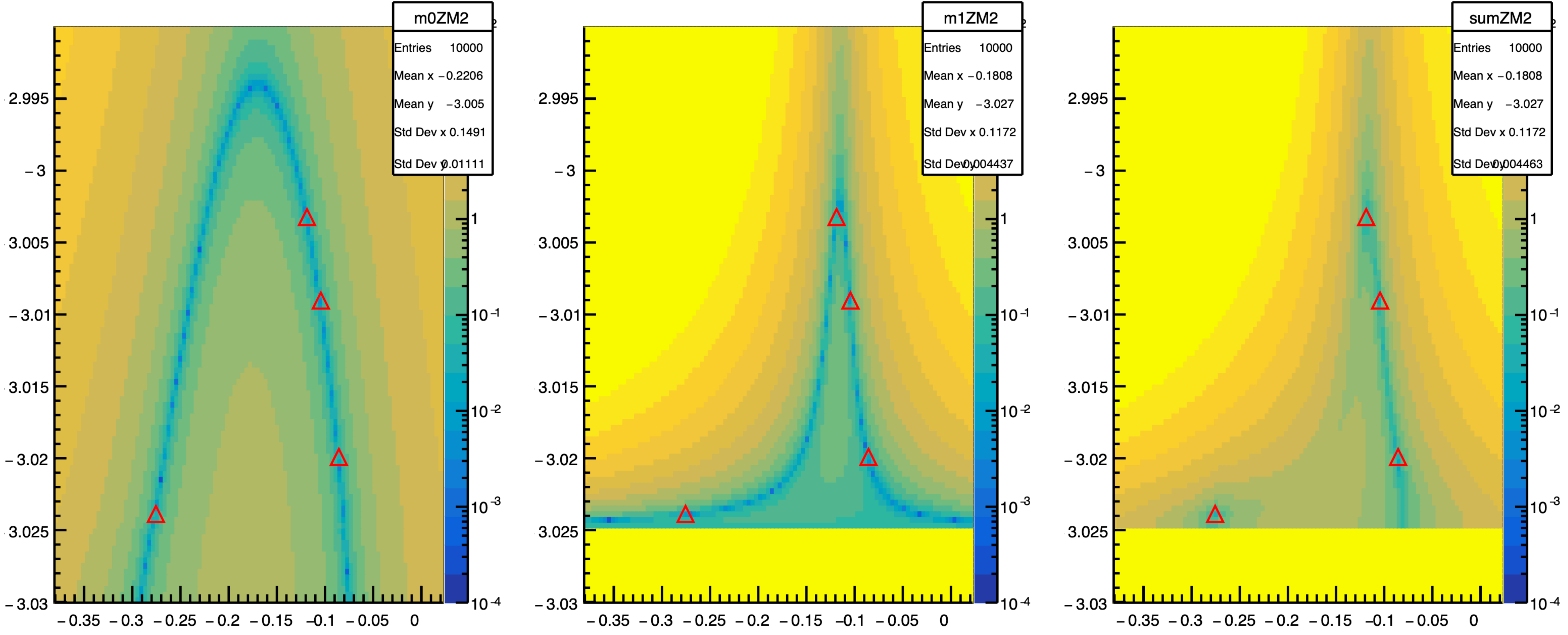




on-shell Z is produced
Significant FSR
$\rightarrow m_{\tau\tau} < m_Z$

example event with 4 solutions

We have up to four solutions



- Tau polarisation precision measurement
  - Jackknife method
  - Pseudo-experiment

Use all solutions as they are. (not good)
Several entries / event → not independent

Take the average of all solutions.
If each tau has several solutions, apply <u>equal</u> weight

$$\text{weight} = \frac{1}{n_\tau \cdot n_{sol}}$$

Tau decay mode selection

500 GeV

Selected 1-prong tau candidates in signal events

$$\epsilon_{ij} = \frac{N_j}{\sum_j N_{ij}}$$

MC truth

i

%	unknown	pi	rho	a11p	a13p	e	mu
pi	1.80	82.3	12.1	0.39	0.37	1.84	1.15
rho	4.99	1.01	79.9	7.40	0.96	5.15	0.58
a11p	8.47	0.87	16.8	64.3	2.16	6.78	0.66
a13p	10.4	2.48	1.87	0.43	84.8	0.05	0.05
e	2.08	0.04	0.38	0.11	0.02	97.1	0.27
mu	0.98	0.64	0.10	0.00	0.02	0.67	97.6
other	21.2	9.95	14.4	13.5	39.0	1.57	0.37

j

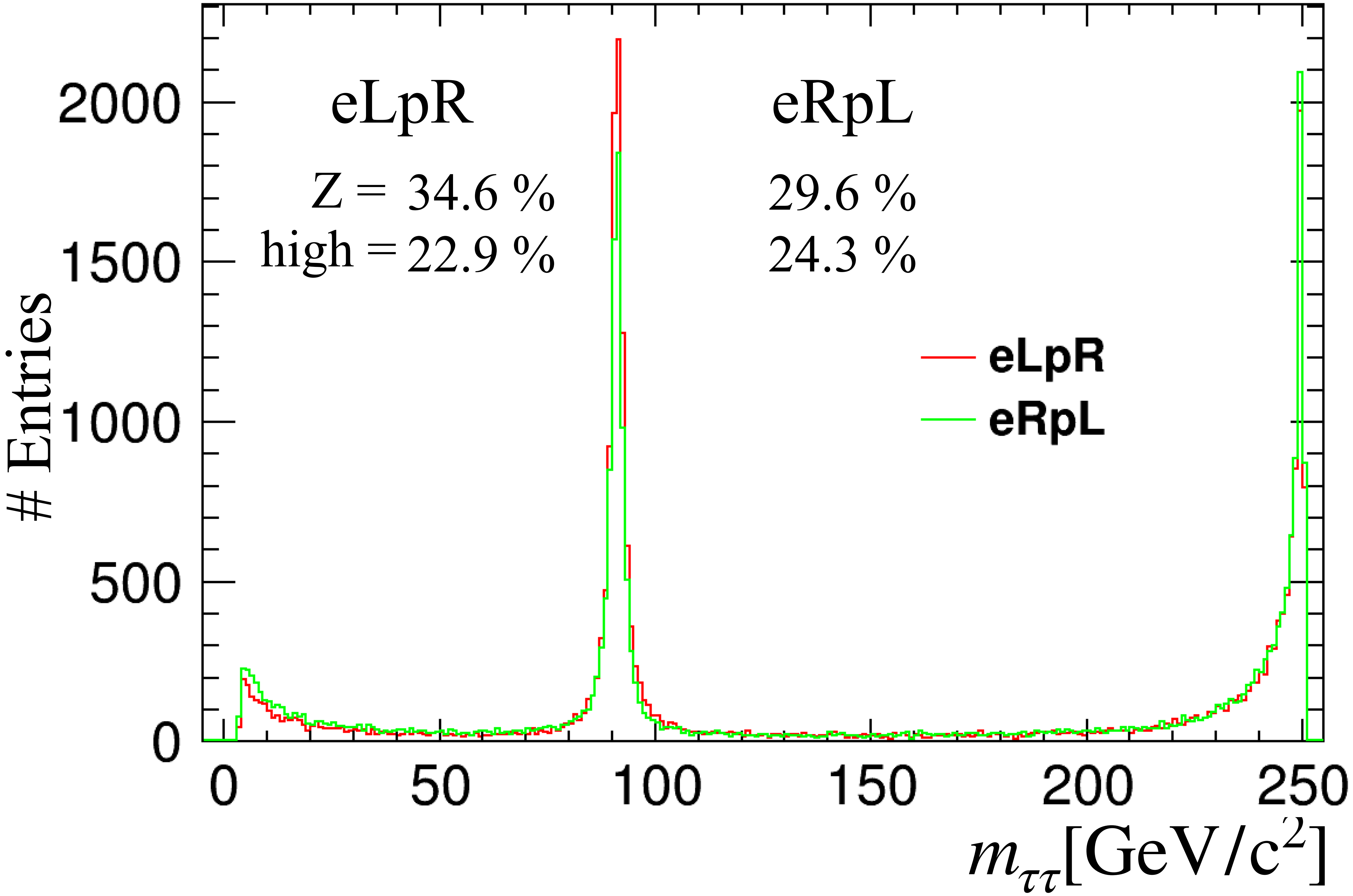
reconstructed tau decay mode

This efficiency is not very good, so we try to improve them using TMVA

Tau statistics @ ILC-250

The 2.0ab^{-1} of integrated luminosity foreseen at ILC-250

beam polarisation	$e^-_{L80}e^+_{R30}$ (- , +)	$e^-_{R80}e^+_{L30}$ (- , +)
integrated luminosity [fb^{-1}]	900	900
e^- (L, R)	(90 % , 10 %)	(10 % , 90 %)
e^+ (L, R)	(35 % , 65 %)	(65 % , 35 %)



$$\sigma_{LR} = 21214.001 \text{ fb}$$

$$\sigma_{RL} = 16363.043 \text{ fb}$$

$$N_{\mathrm{LR}} = 1.2 \times 10^7$$

$$N_{\mathrm{RL}} = 9.3 \times 10^6$$

radiative return (91 ± 5[GeV/c^2])

$$\mathrm{N} = N_{\mathrm{LR}} \times 34.6\% + N_{RL} \times 29.6\%$$

$$\mathrm{N} = 6.8 \times 10^6$$

High mass τ - τ (245 ± 5[GeV/c^2])

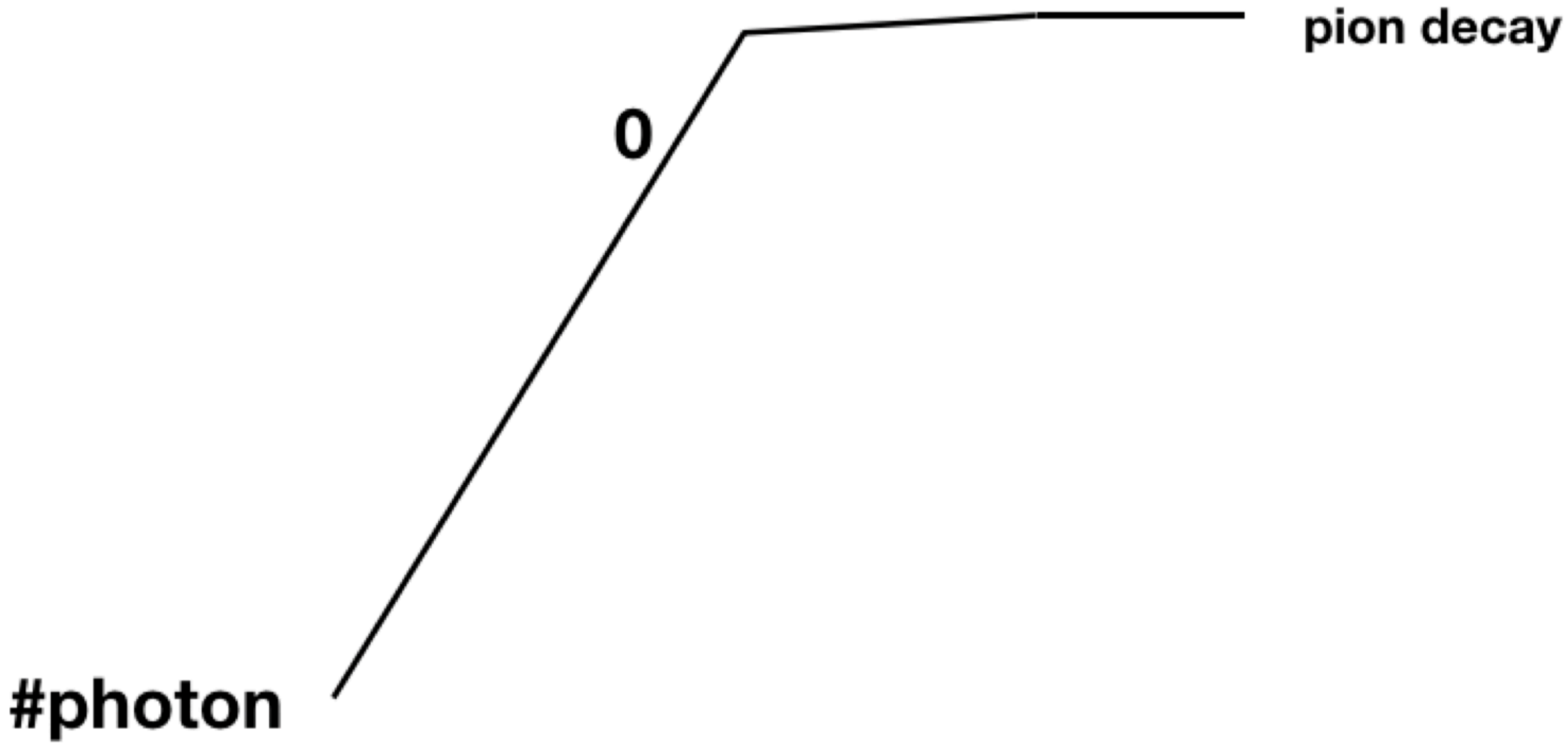
$$\mathrm{N} = N_{\mathrm{LR}} \times 22.9\% + N_{RL} \times 24.3\%$$

$$\mathrm{N} = 4.9 \times 10^6$$

Tau decay mode selection

Select tau decay mode by counting the number of reconstructed photons

Number of charged particle inside cone =1



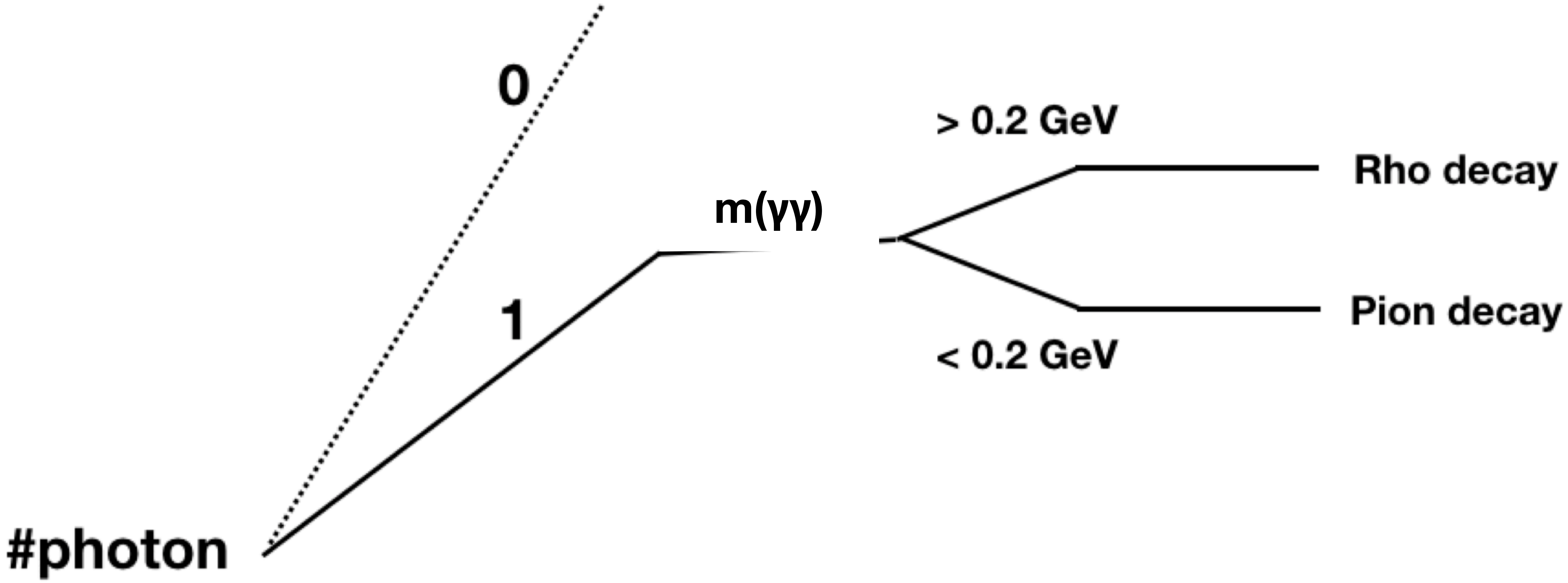
Number of photon = 0 → single pion decay

$\tau \rightarrow \pi\nu_\tau$

Tau decay mode selection

Select tau decay mode by counting the number of reconstructed photons

Number of charged particle inside cone =1



Number of photon = 1
invariant mass of (γγ system) > 0.2 GeV → rho decay

$$\tau \to \rho\nu_\tau$$

Number of photon = 1
invariant mass of (γγ system) < 0.2 GeV → single pion decay

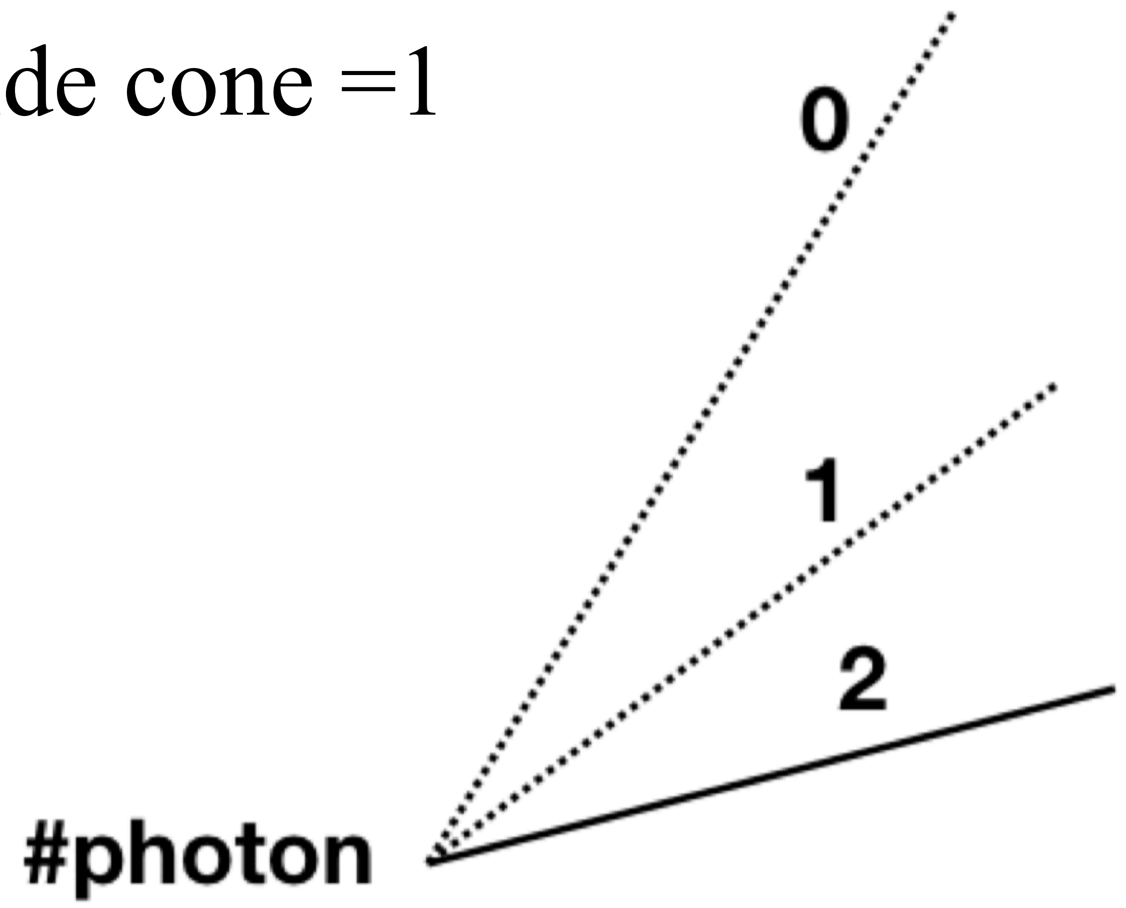
similar procedure number of photon > 1

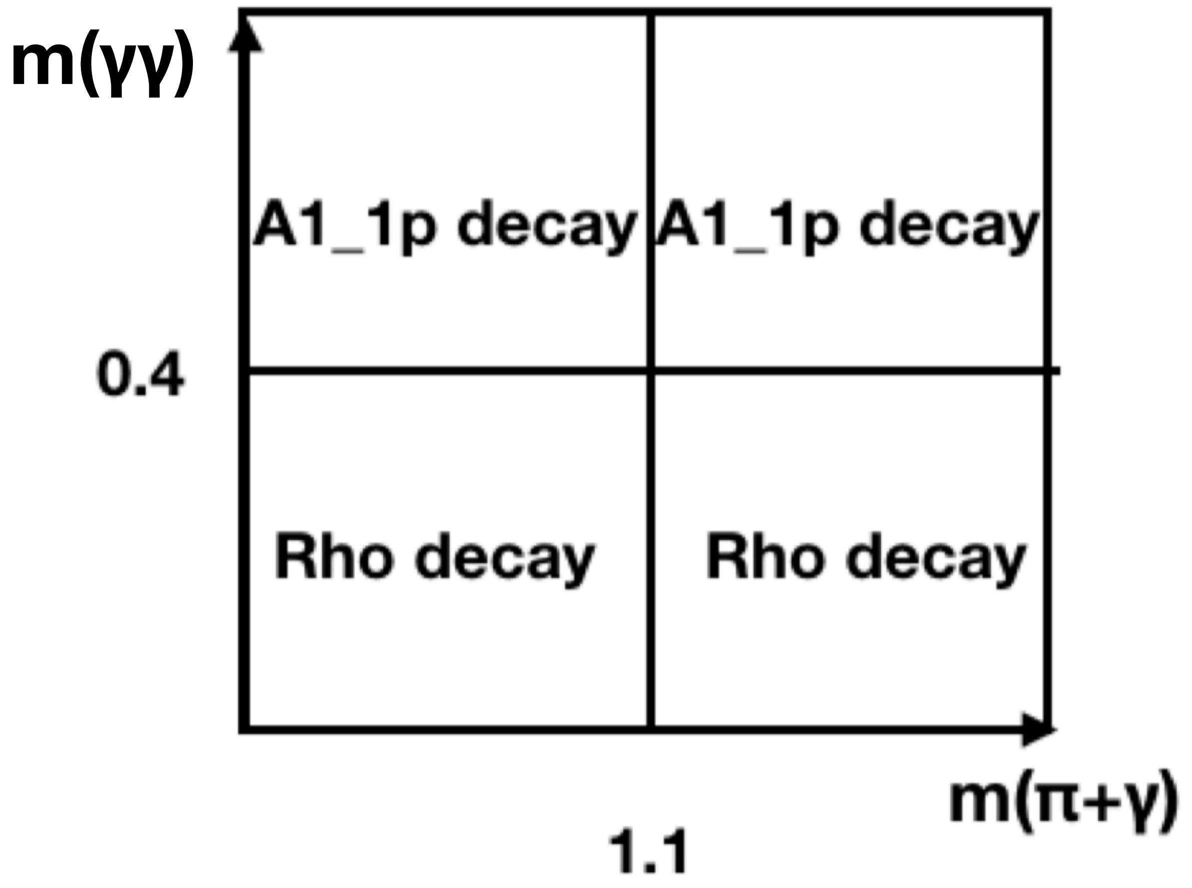
$$\tau \to \pi\nu_\tau$$

Tau decay mode selection

Select tau decay mode by counting the number of reconstructed photons

Number of charged particle inside cone =1





rho decay $\tau \rightarrow \rho\nu_\tau$

Number of photon = 2
invariant mass of (2-photon system + photon) > 1.1 GeV
invariant mass of pion < 0.4 GeV

and

Number of photon = 2
invariant mass of (pion + photon) < 1.1 GeV
invariant mass of pion < 0.4 GeV

single-prong a1 decay $\tau \rightarrow$ single-prong a_1

Number of photon = 2
invariant mass of (pion + photon) > 1.1 GeV
invariant mass of pion> 0.4 GeV

and

Number of photon = 2
invariant mass of (pion + photon) < 1.1 GeV
invariant mass of pion > 0.4 GeV

Tau decay mode selection

Select tau decay mode by counting the number of reconstructed photons

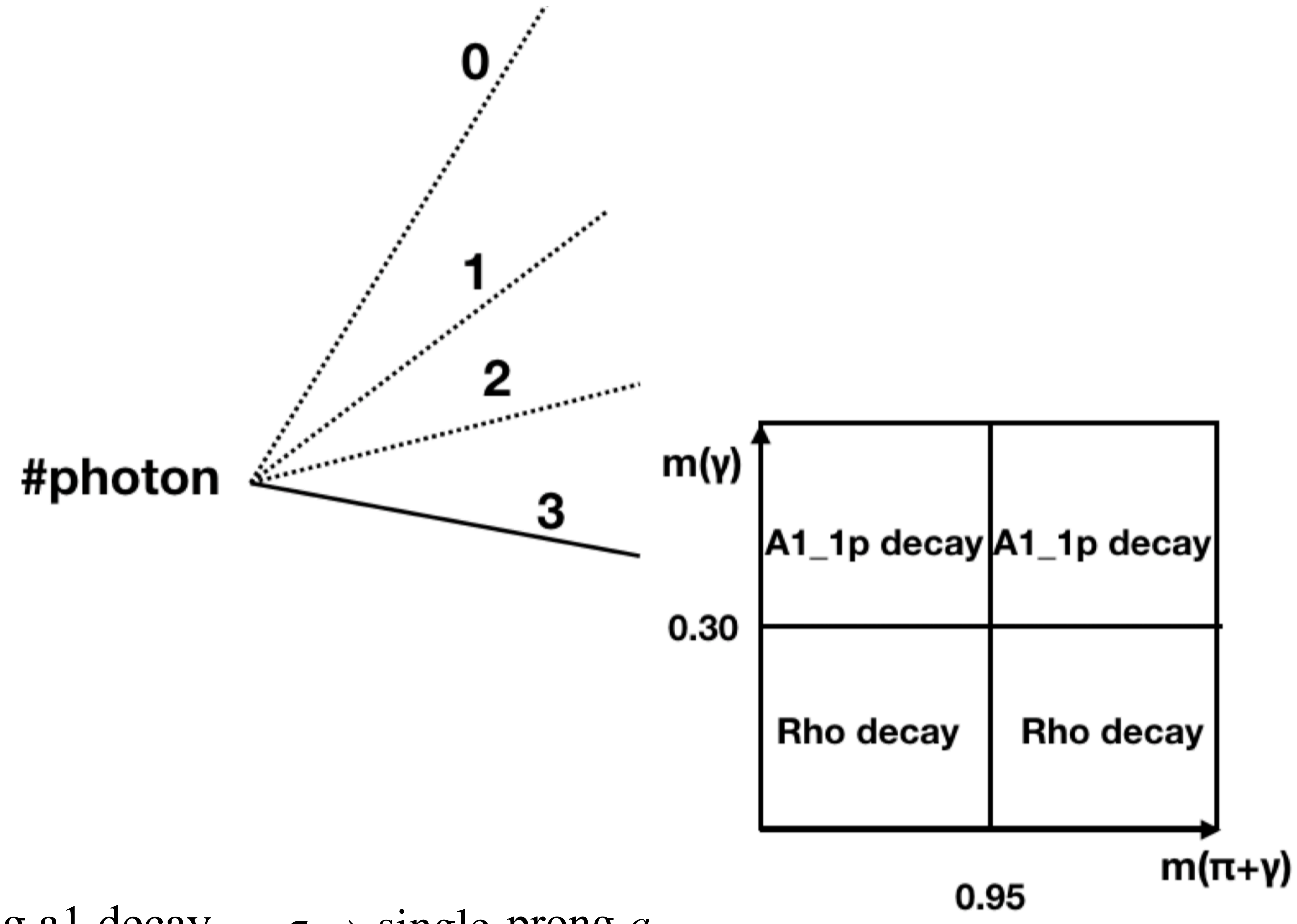
rho decay

Number of charged particle inside cone =1

Number of photon = 2
invariant mass of (pion + photon) > 1.1 GeV
invariant mass of pion < 0.4 GeV

and

Number of photon = 2
invariant mass of (pion + photon) < 1.1 GeV
invariant mass of pion < 0.4 GeV



single-prong a1 decay $\tau \rightarrow$ single-prong a_1

Number of photon = 3
invariant mass of (pion + photon) > 1.1 GeV
invariant mass of pion> 0.4 GeV

and

Number of photon = 2
invariant mass of (pion + photon) < 1.1 GeV
invariant mass of pion > 0.4 GeV