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Measuring the tau polarisation at the ILC

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Motivation

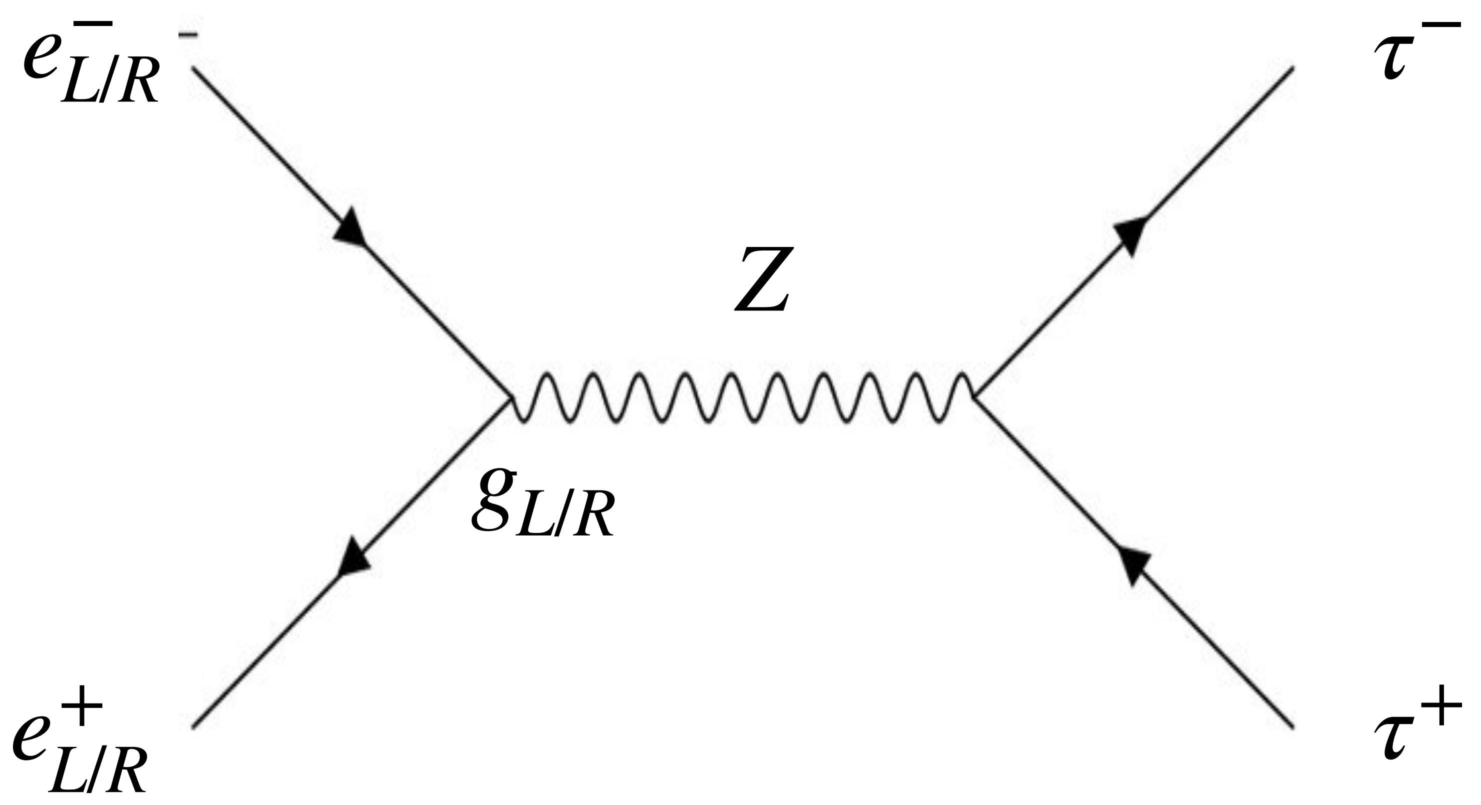
At the ILC, forward-backward asymmetry $A_{FB} = \frac{3}{4} A_e \cdot A_f$ can be measured

Thanks to ILC's polarised beams, A_e can be measured $\Rightarrow$ 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

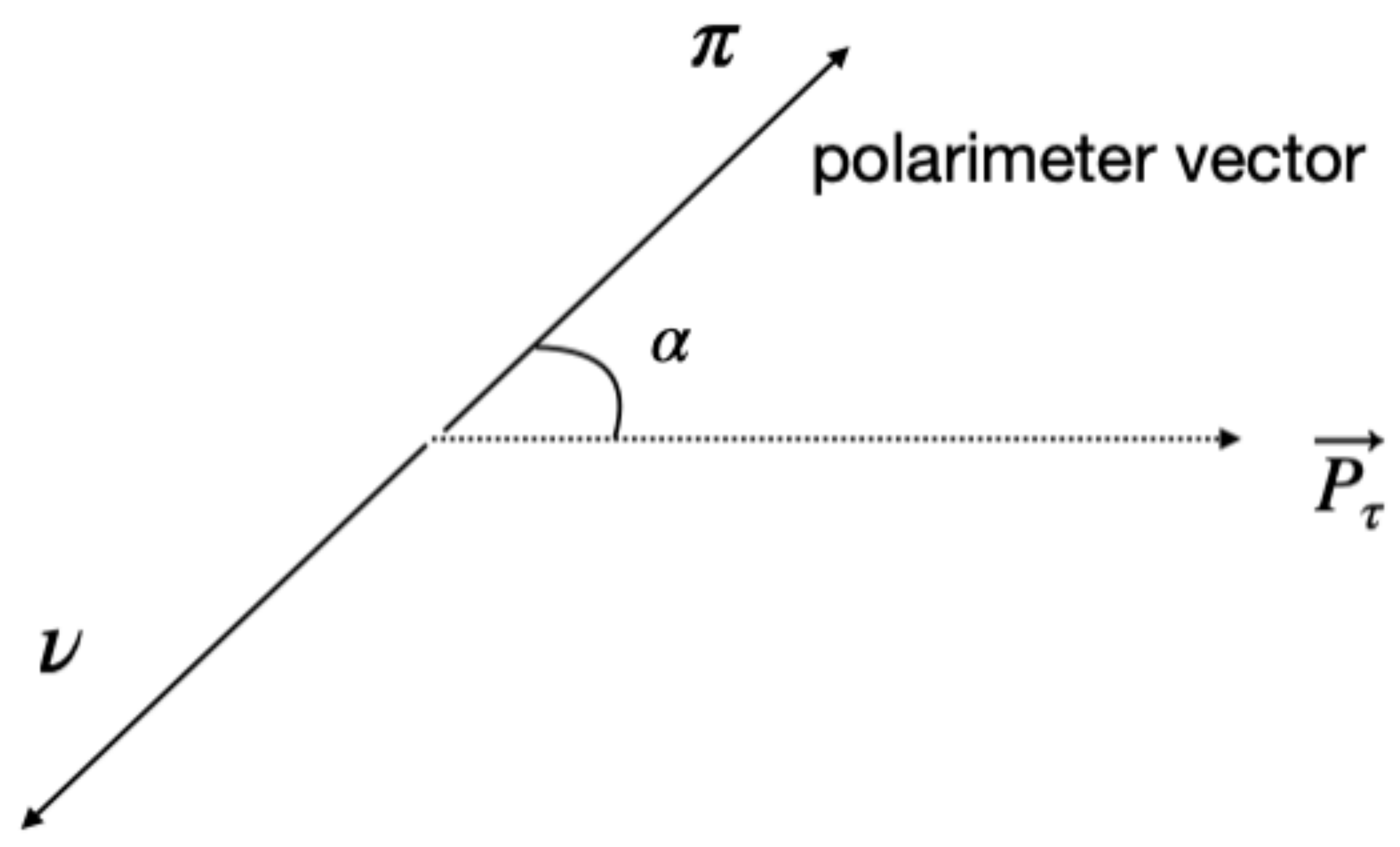
The reconstruction of tau spin orientation ("**Polarimeter**") in order to measure polarisation to investigate new physics.

Polarimeter

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

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

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



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

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

“Polarimeter”

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

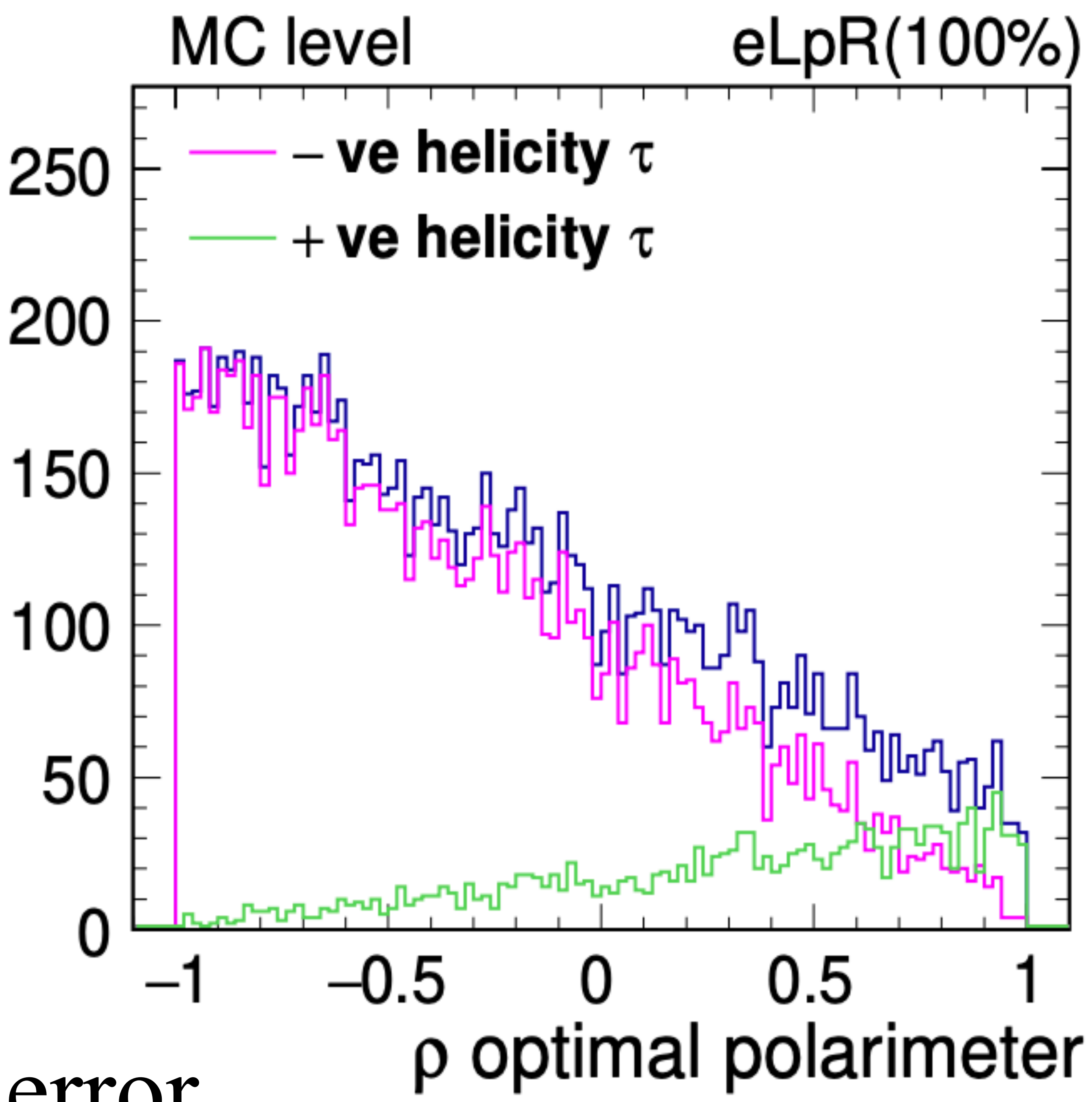
only look at $\tau \to \pi\nu$ (BR ~ 10 %)
$\tau \to \rho\nu$ (BR ~ 26 %) in this talk

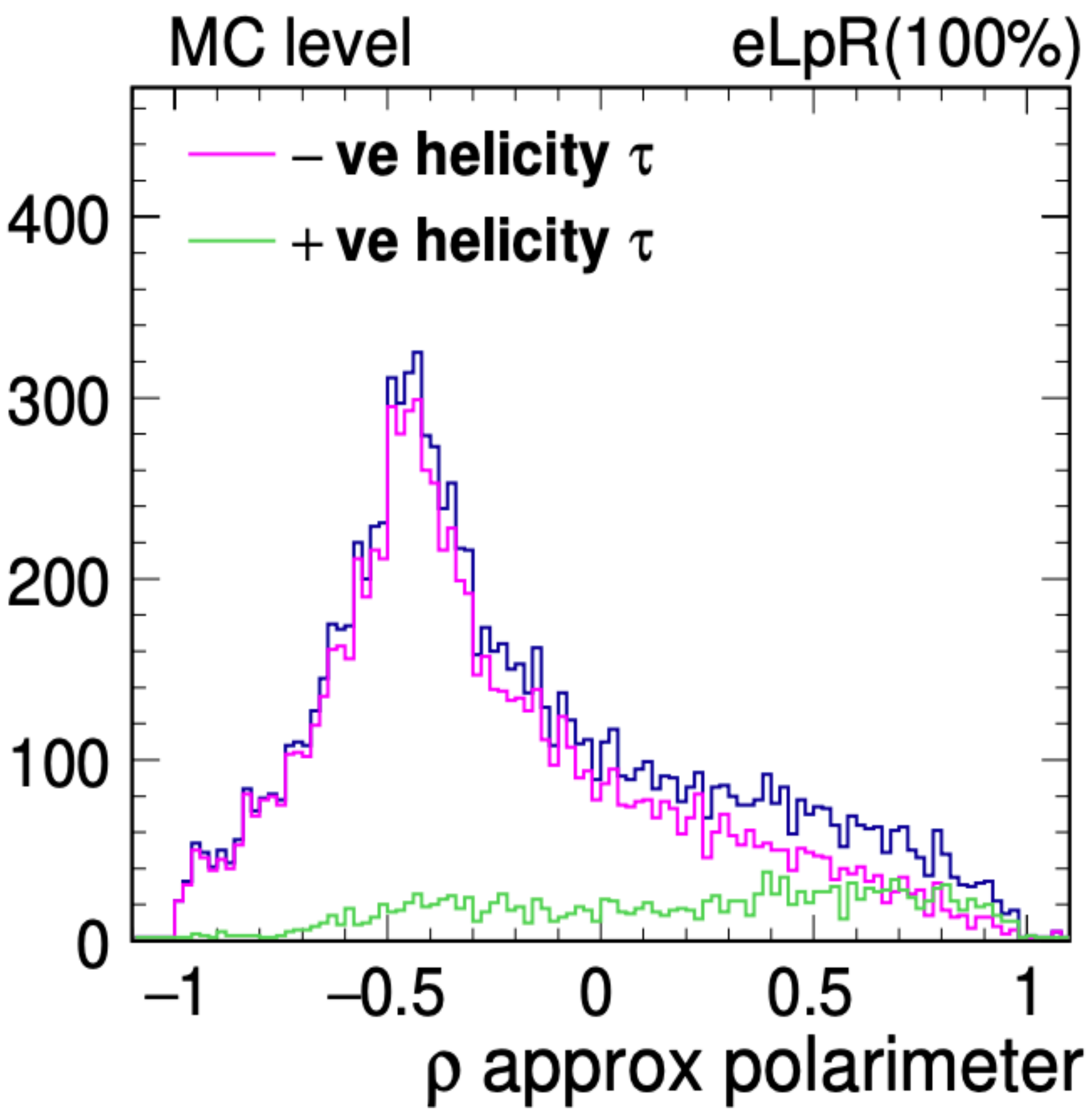
Previous study

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

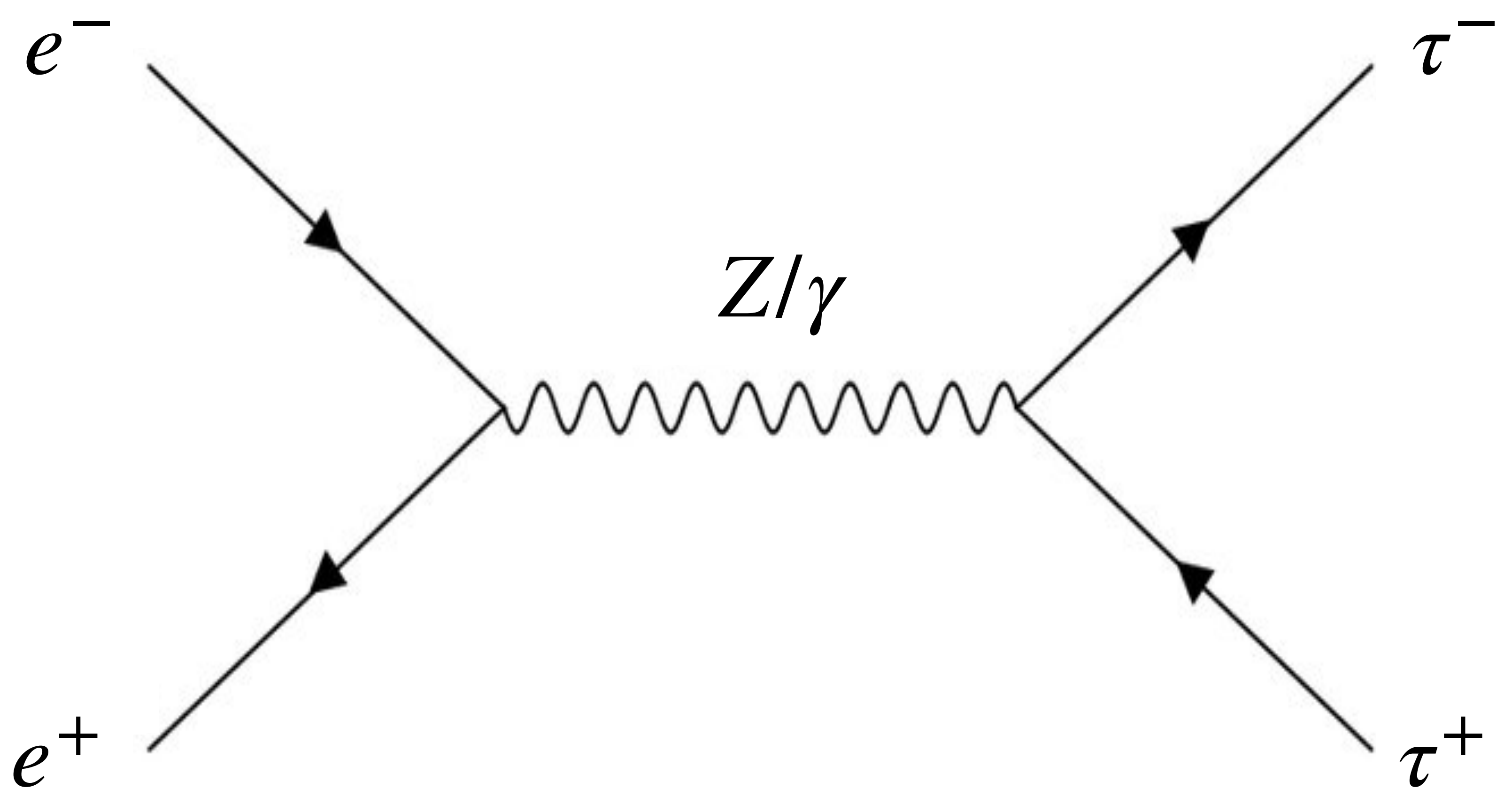
0.30 %

0.40 %

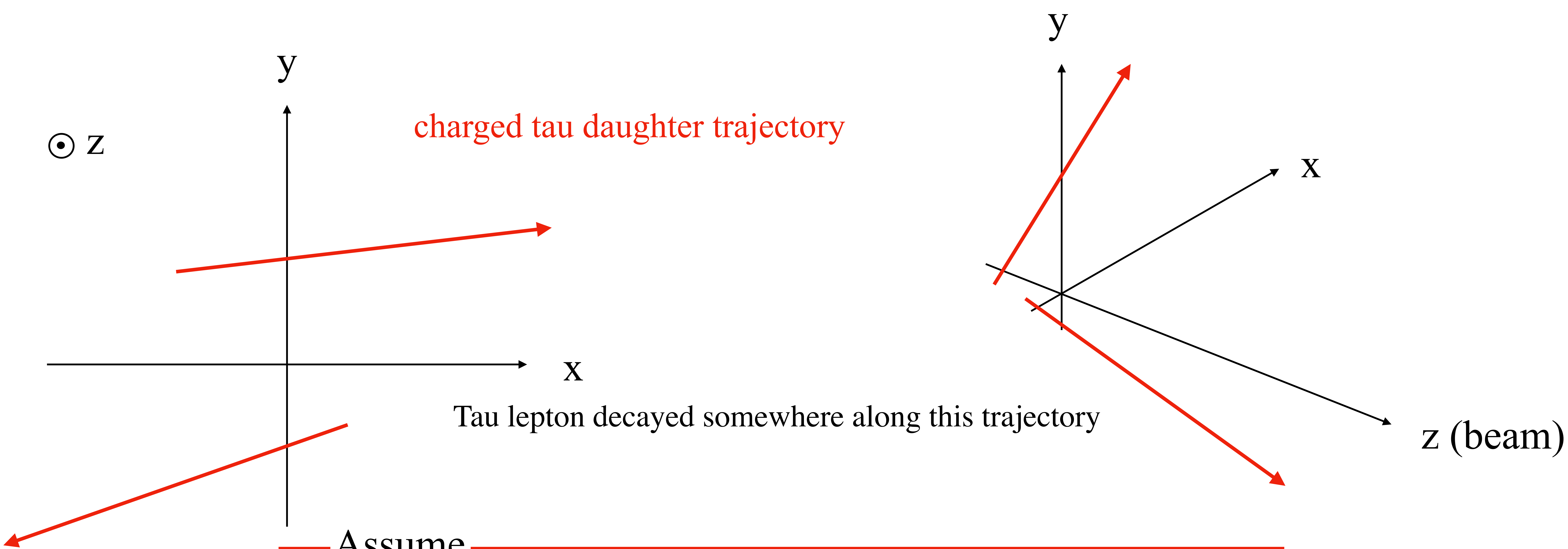
In this talk: reconstruct neutrino momentum → optimal polarimeters

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

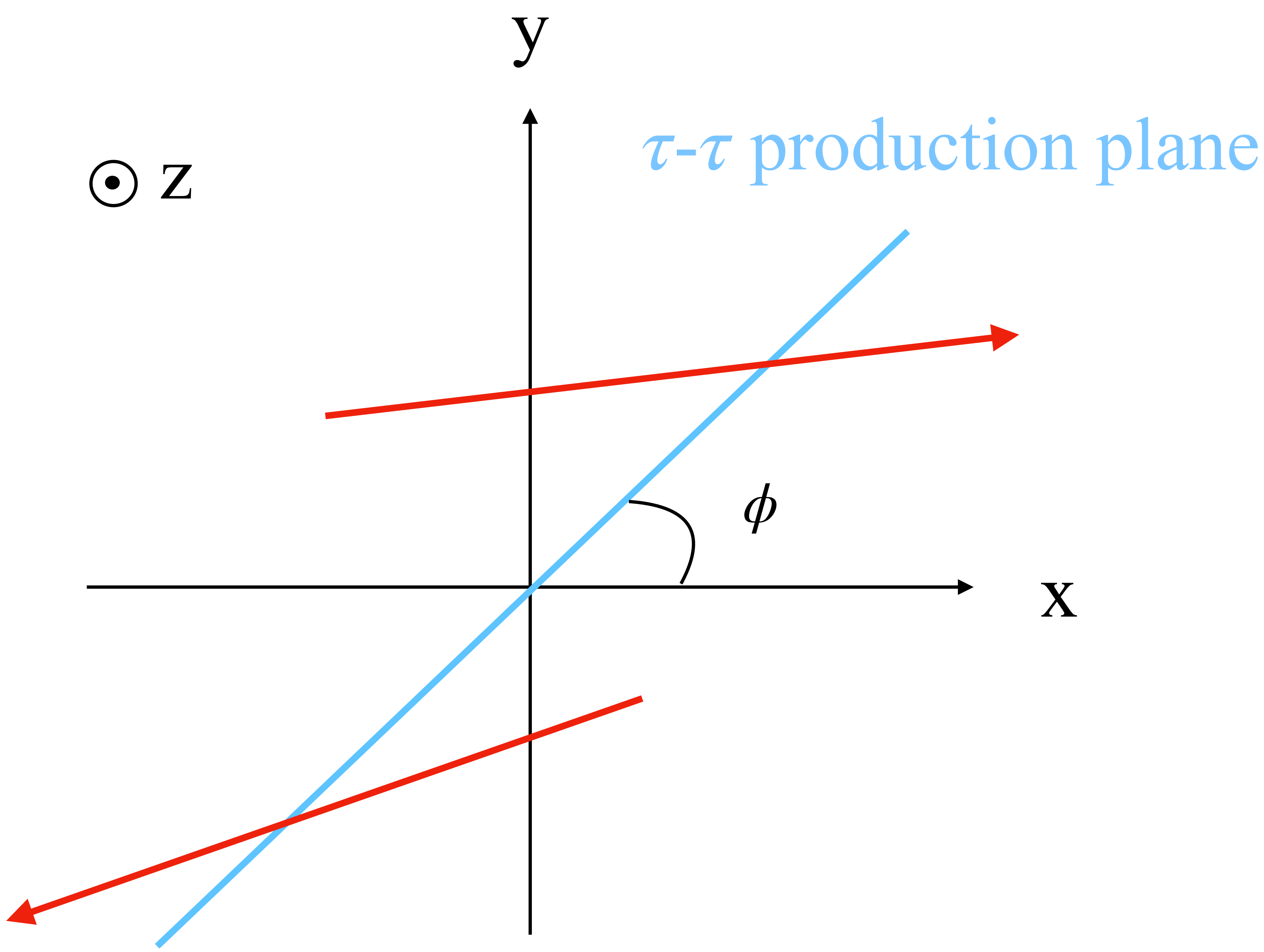


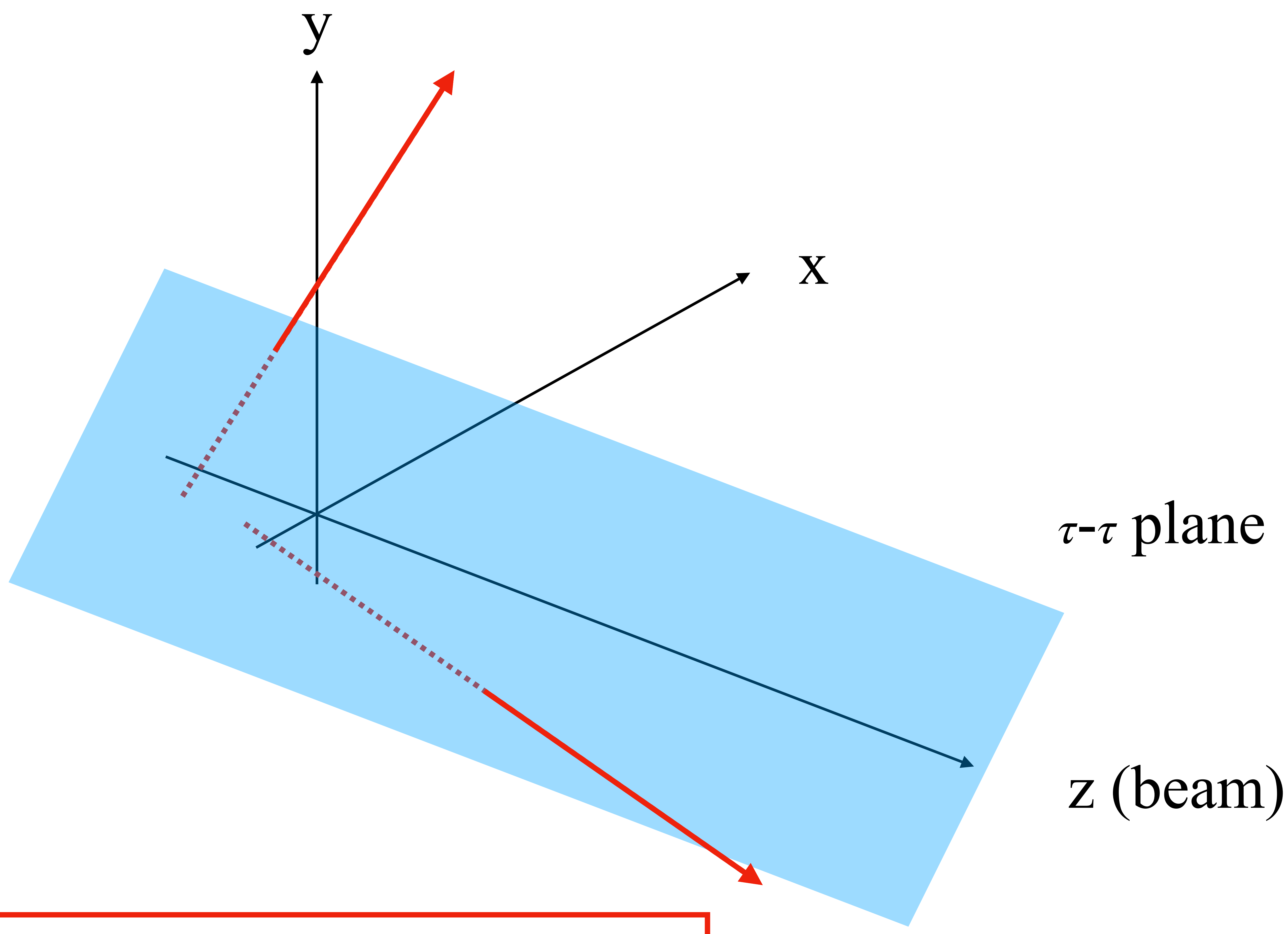
Assume

- 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



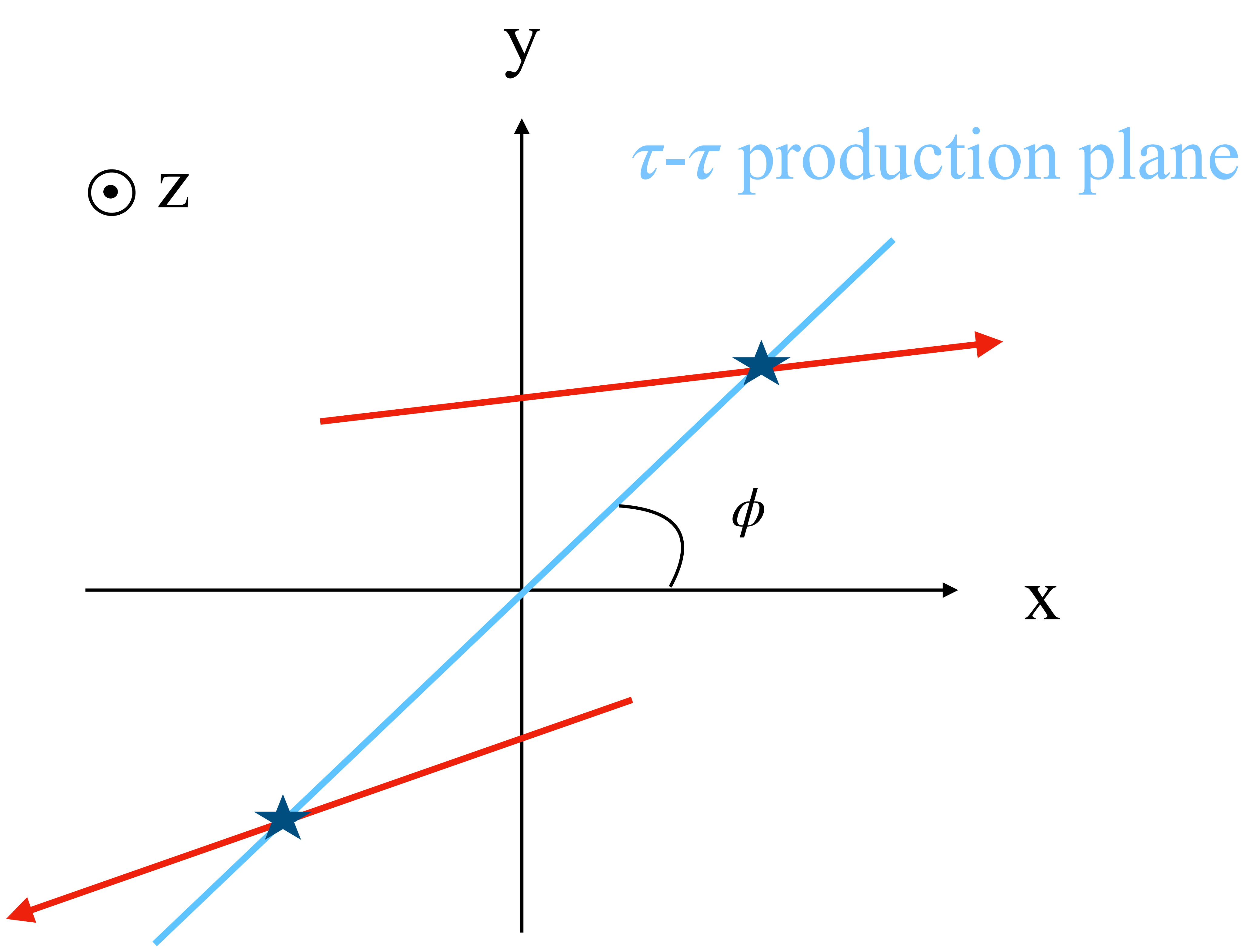


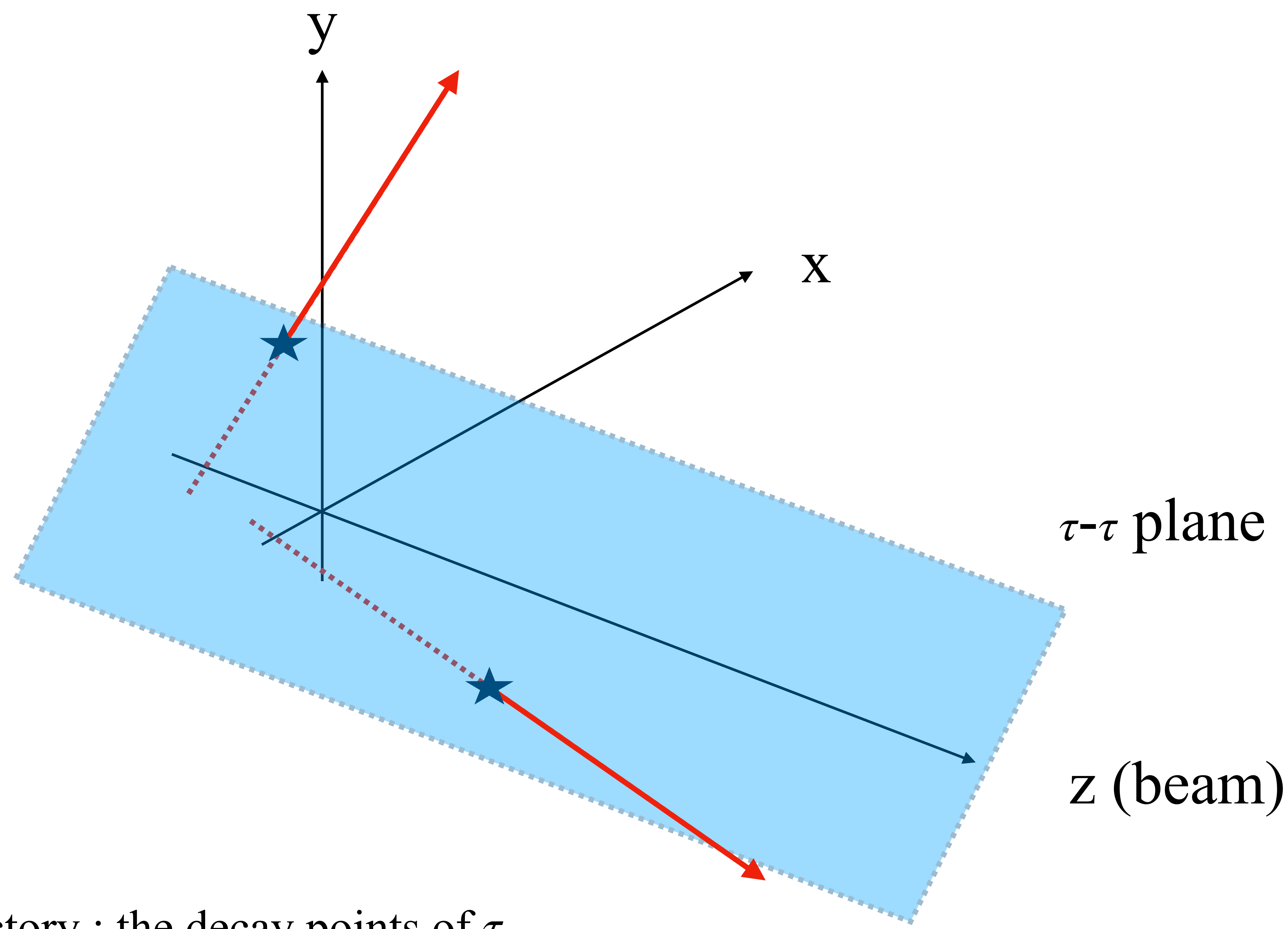
Assume

- 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

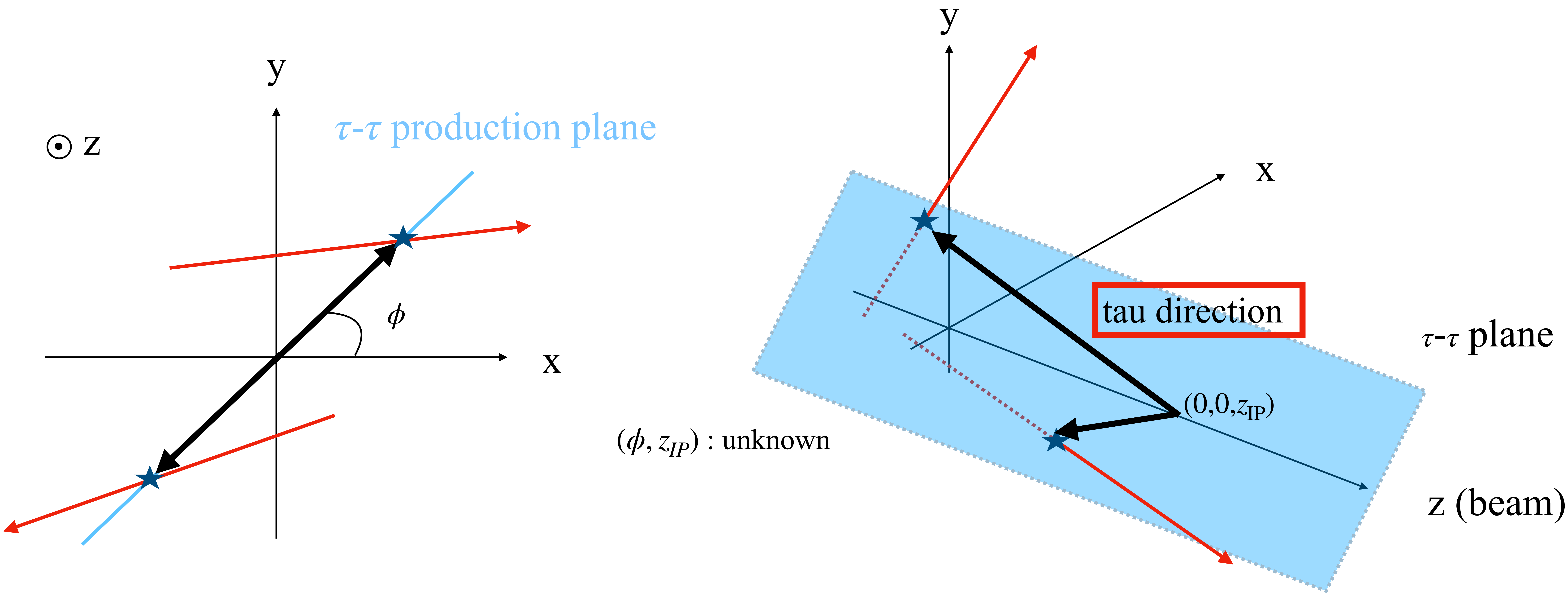




★ The intersection between plane and trajectory : the decay points of τ

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

τ reconstruction method



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

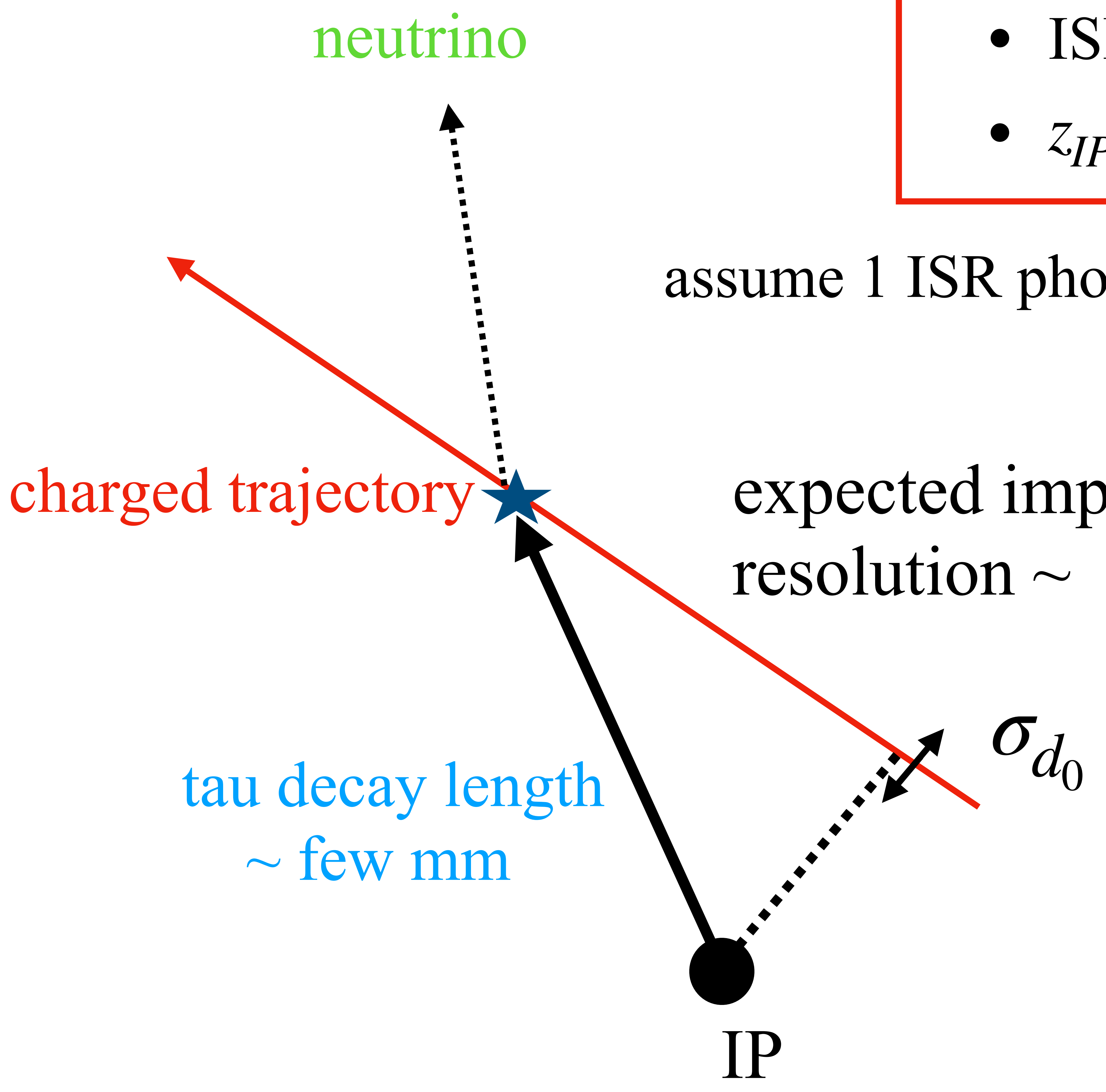
⇒How can we choose ϕ, z_{IP} ?

τ reconstruction method

Unknown
- neutrino 3-momentum $\times 2$
- ISR momentum
- z_{IP}

Constraints
- 4-momentum conservation
- tau mass $\times 2$
- Decay point on trajectory $\times 2$

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

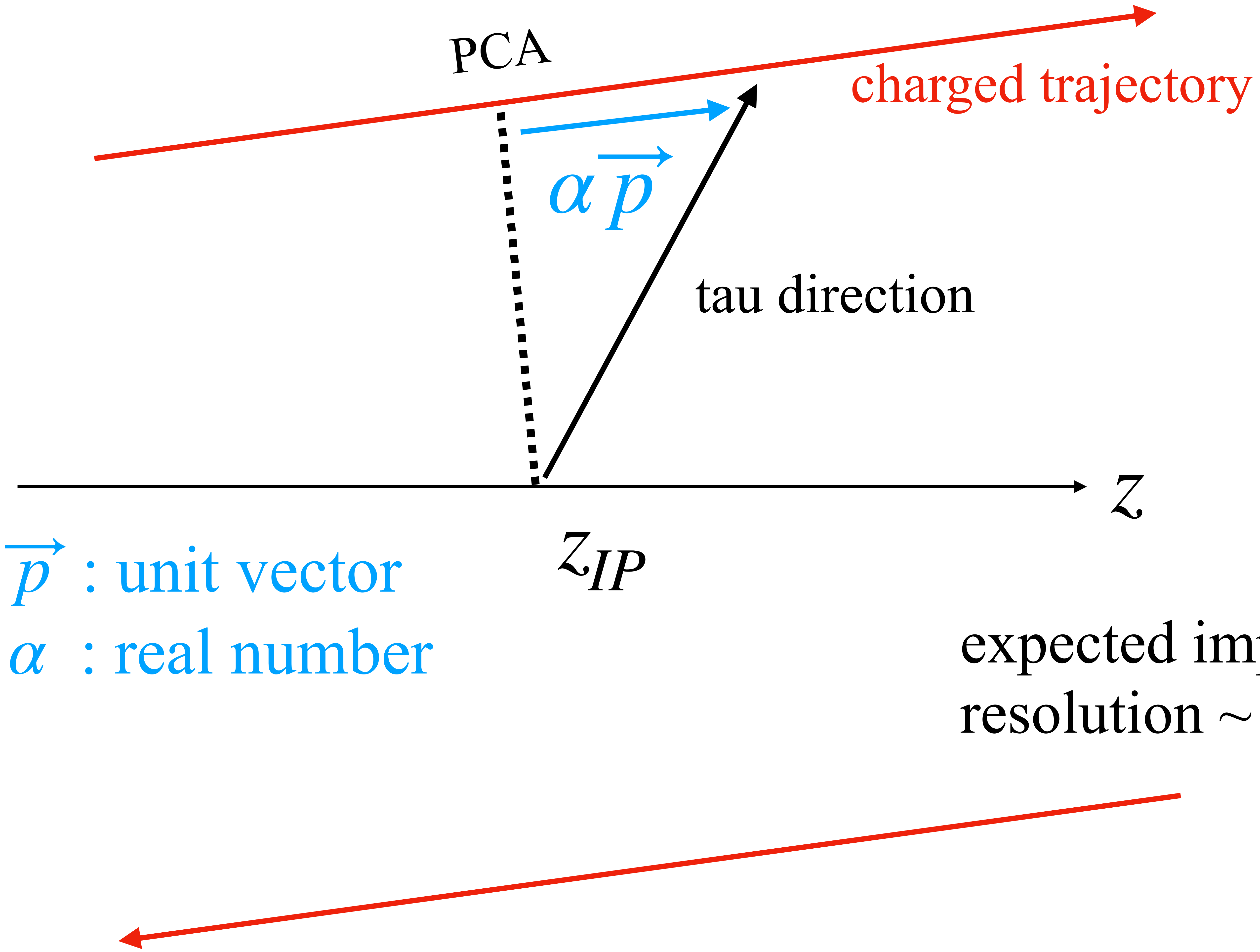
the invariant mass of the missing (neutrino) momentum for each tau can be calculated

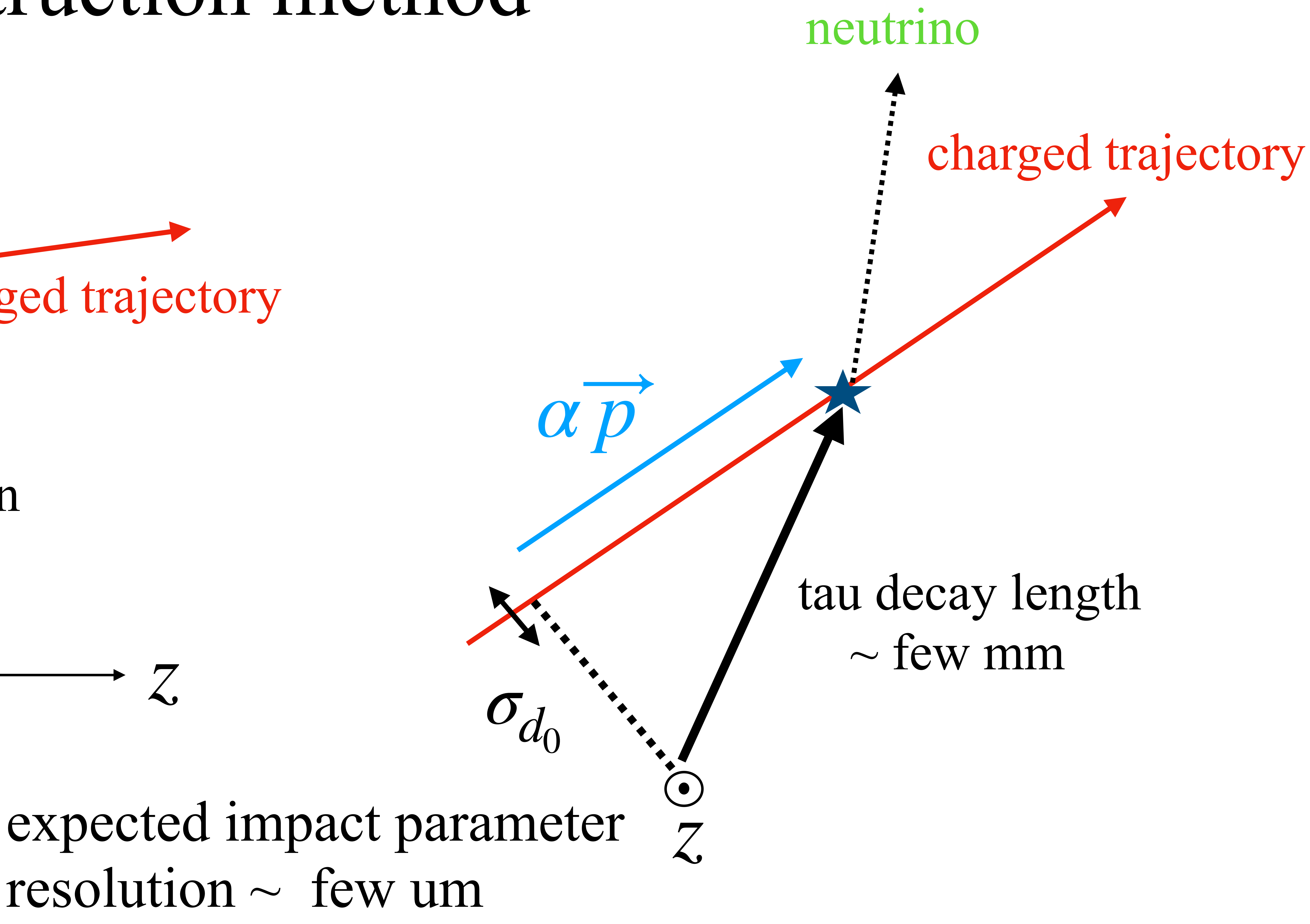
$$P_\nu = P_\tau - P_{vis}$$

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

τ reconstruction method

We have tried another method

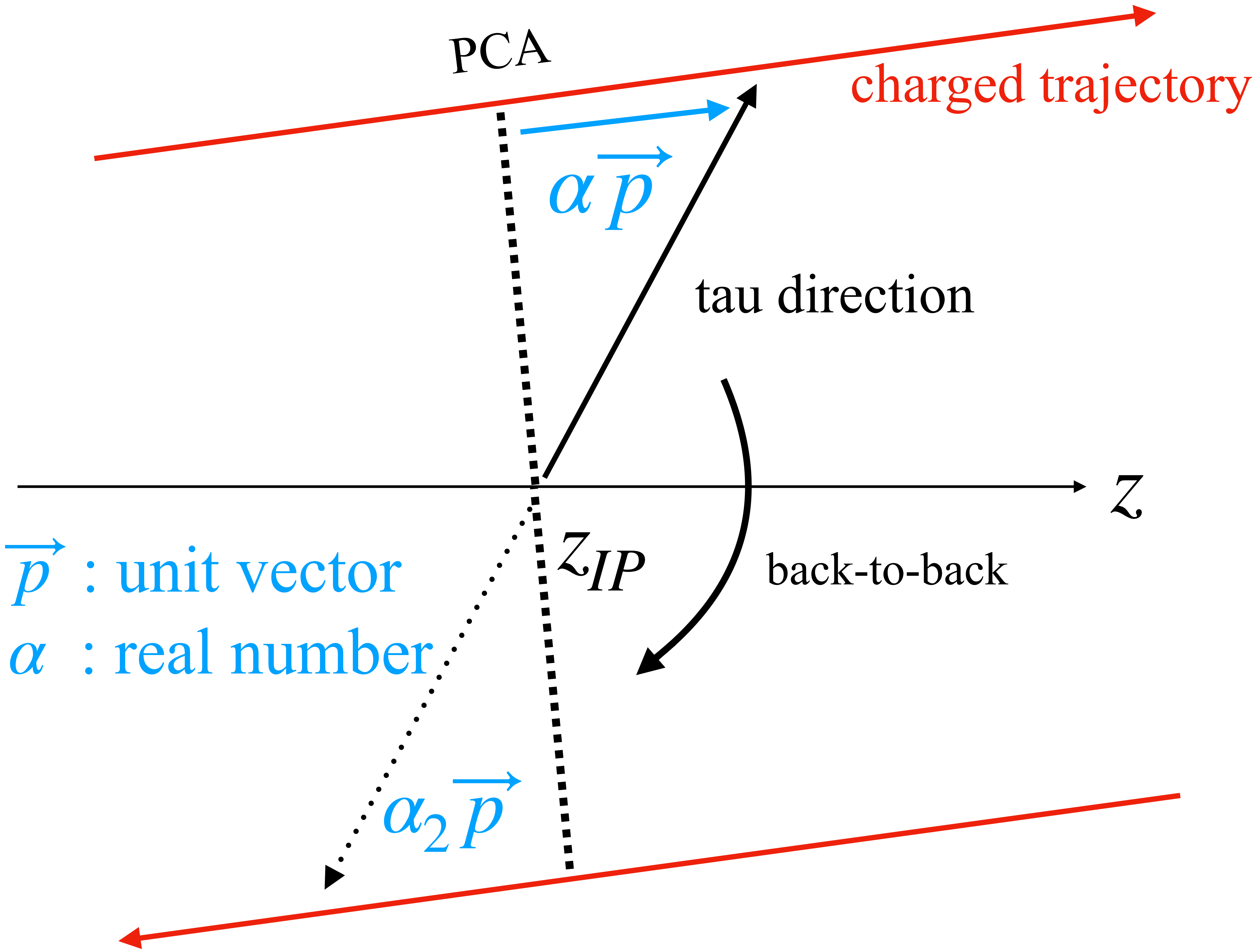


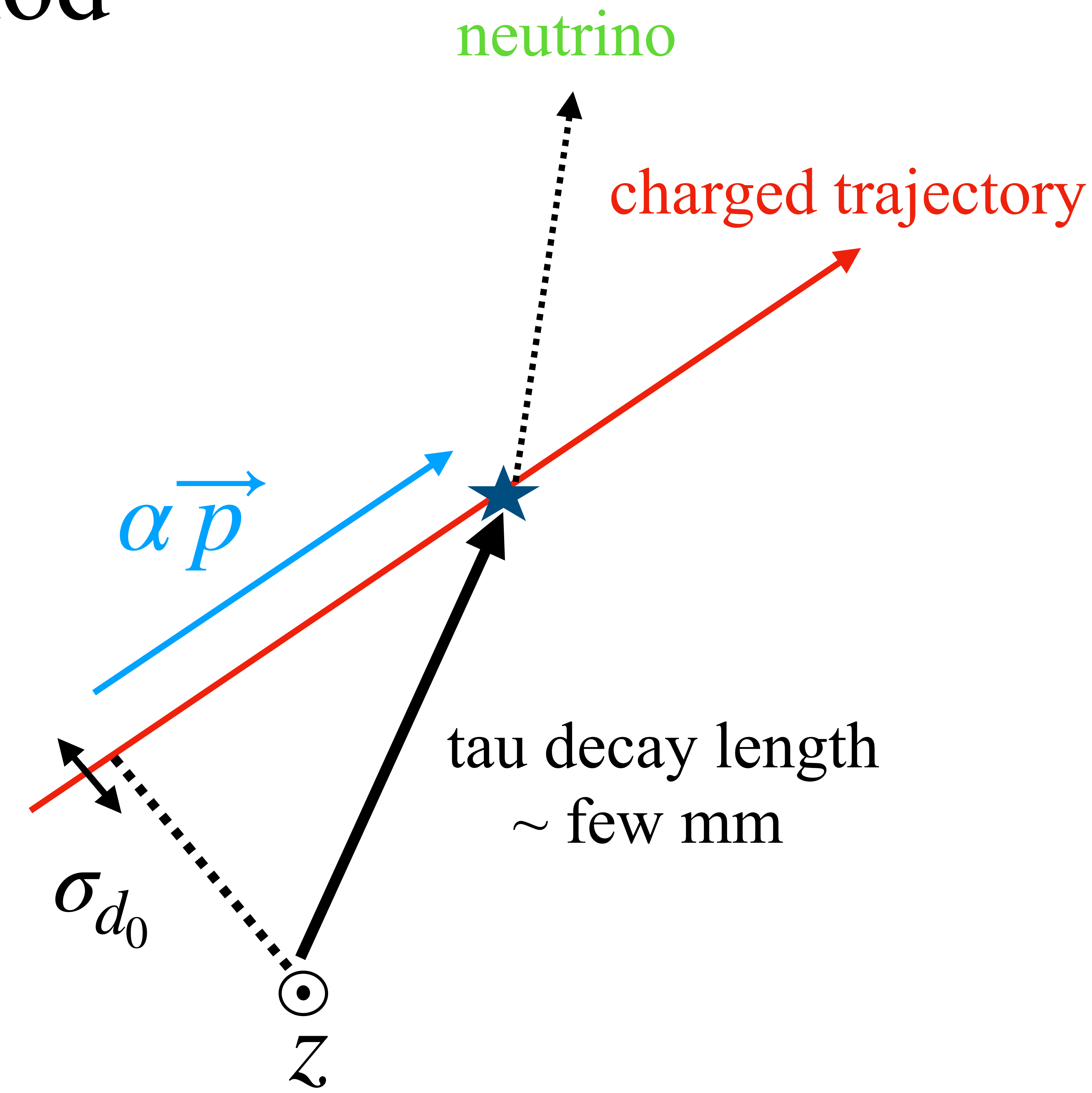


$$(\phi, z_{IP}) \rightarrow (\alpha, z_{IP})$$

τ reconstruction method

We have tried another method

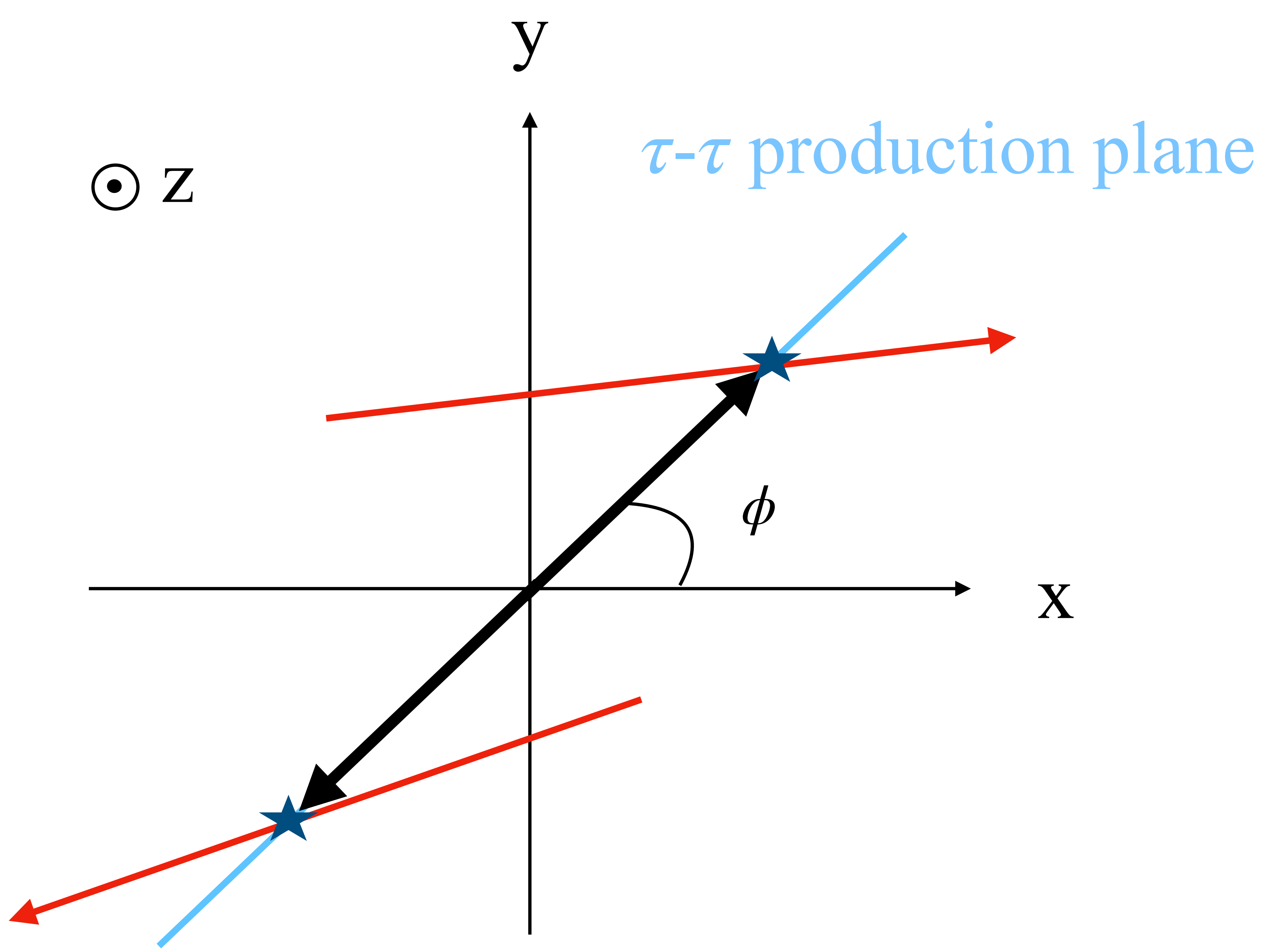


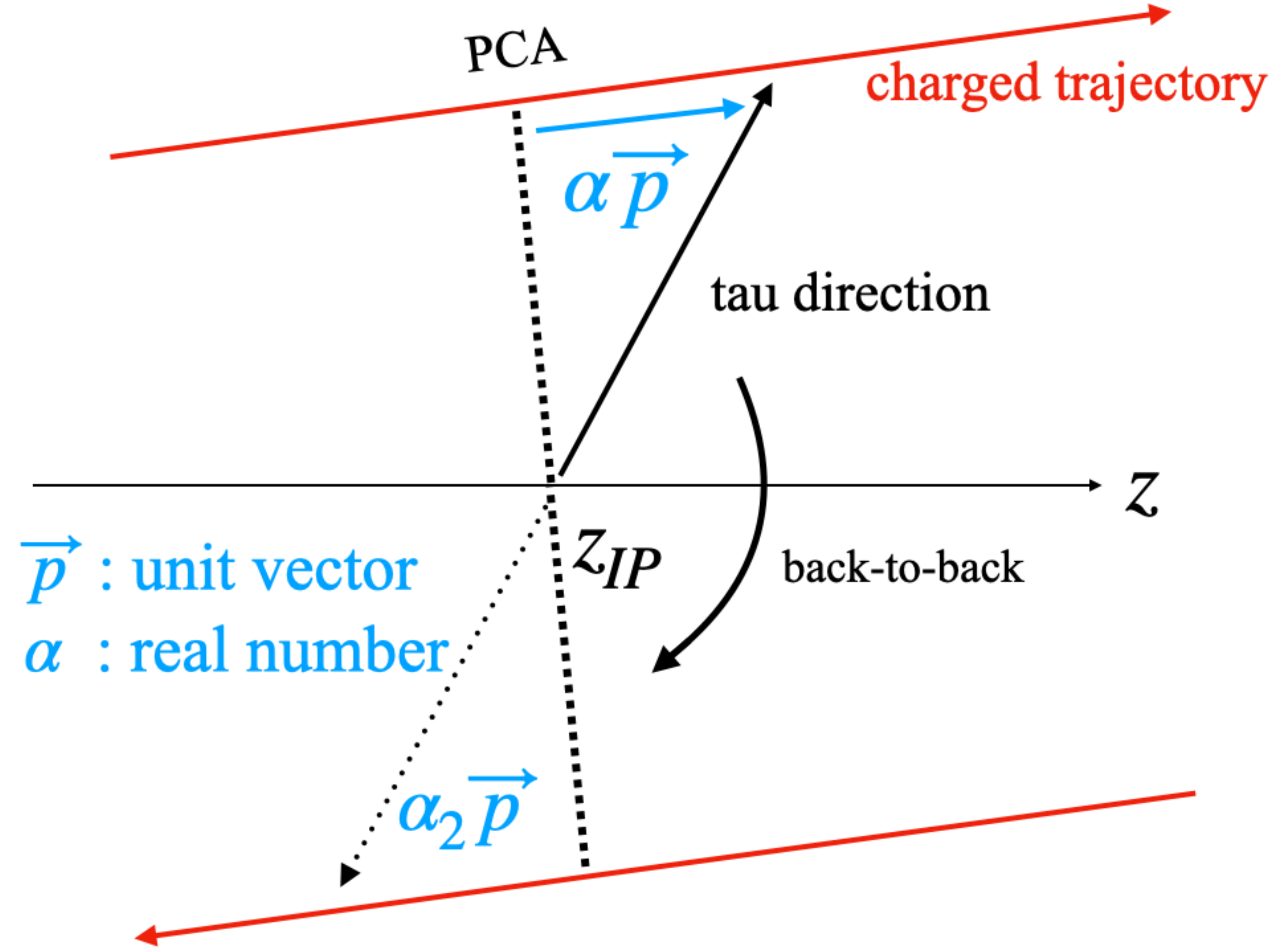


α_2 can be calculated by imposing back-to-back-ness in the x-y projection

τ reconstruction method

Two methods to find solutions





(ϕ, z_{IP}) : unknown

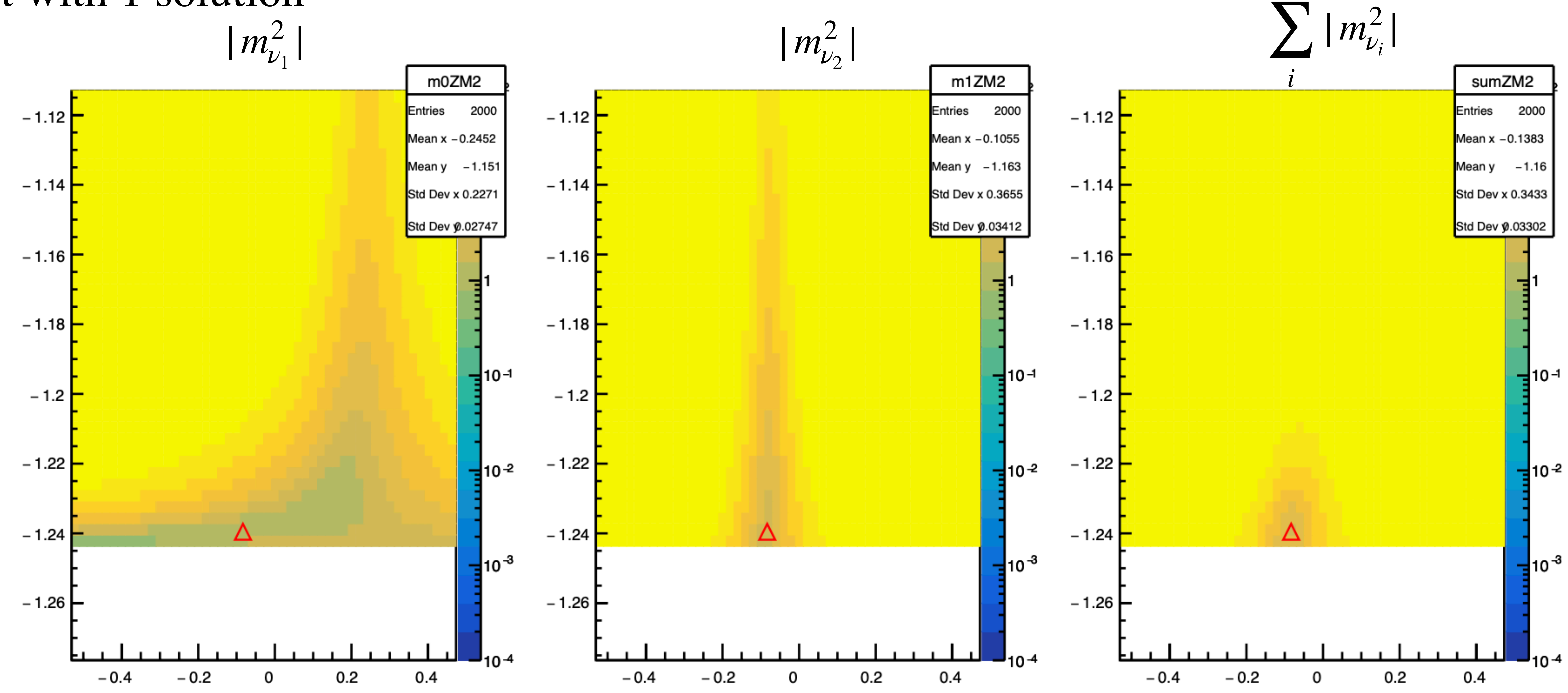
(α, z_{IP}) : unknown

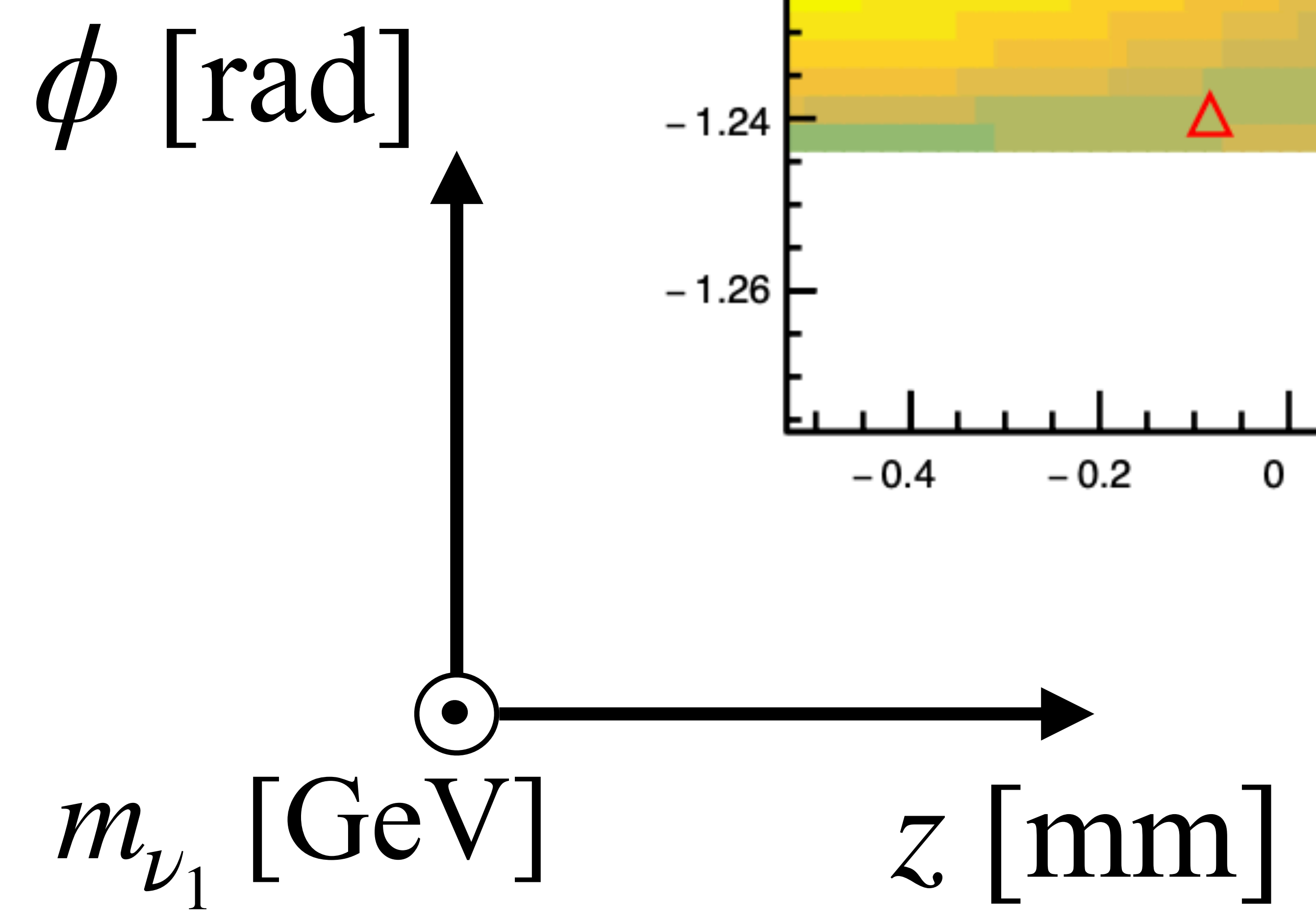
We have combined them

Find solutions

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

example event with 1 solution





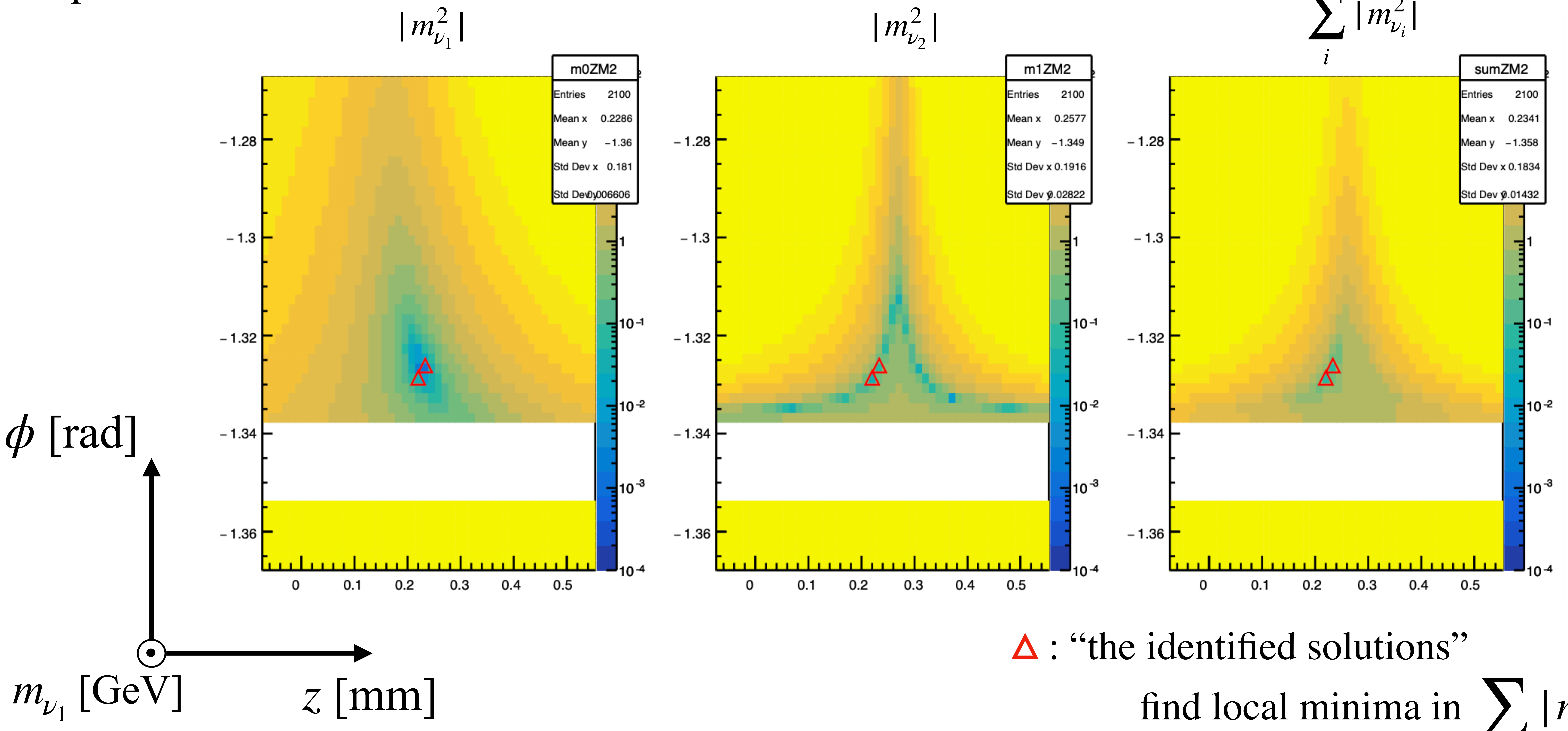
△ : "the identified solutions"

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



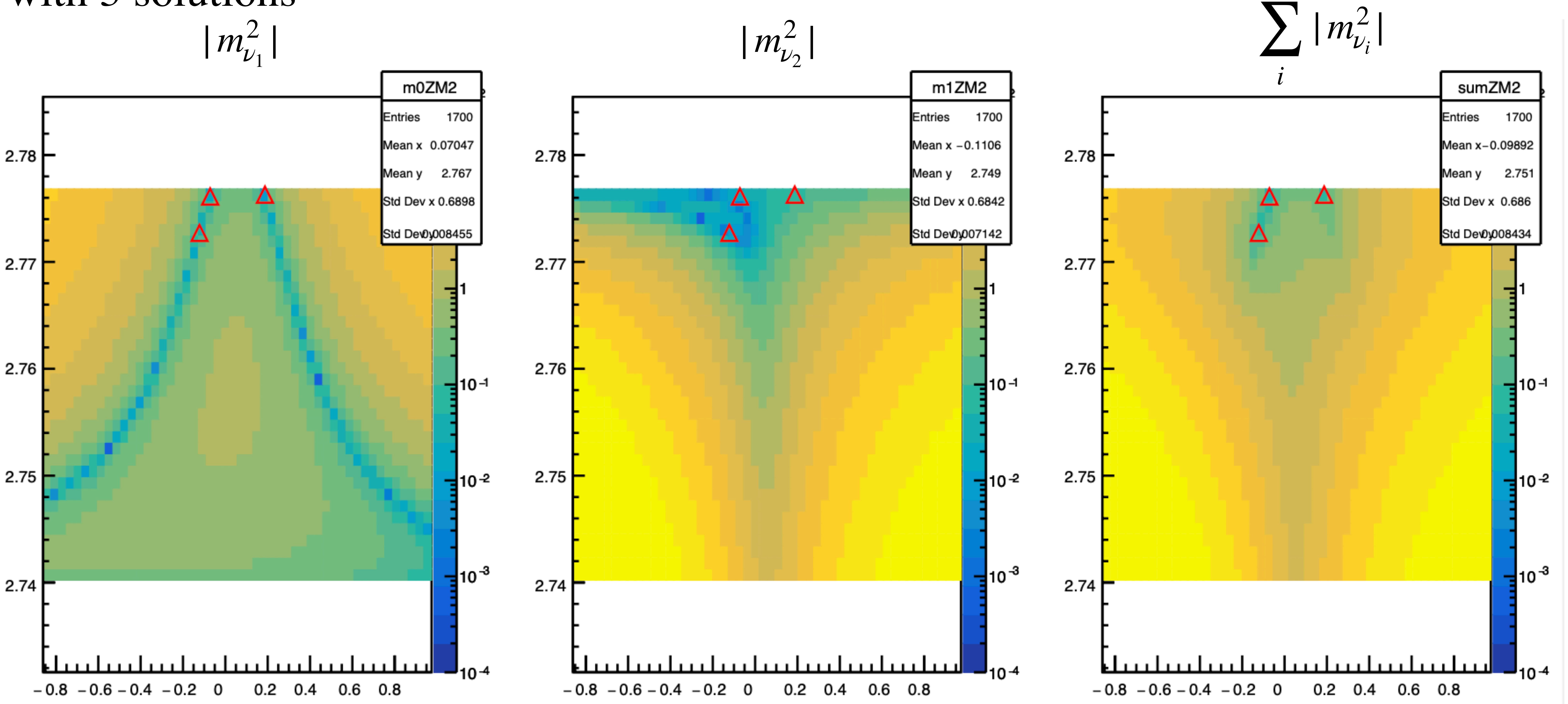
△ : "the identified solutions"

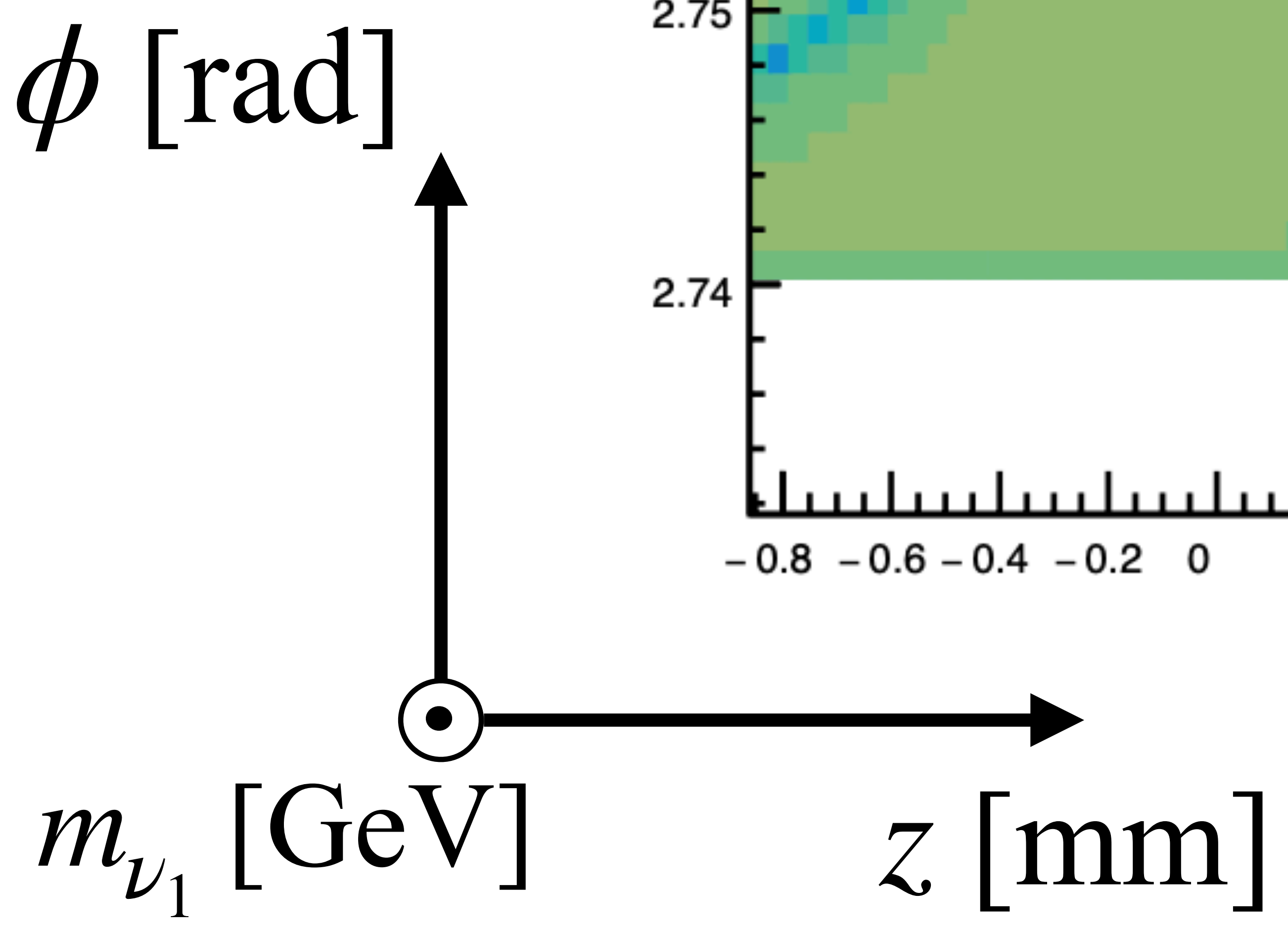
find local minima in $\sum_i |m^2_{\nu_i}|$

Find solutions

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

example event with 3 solutions





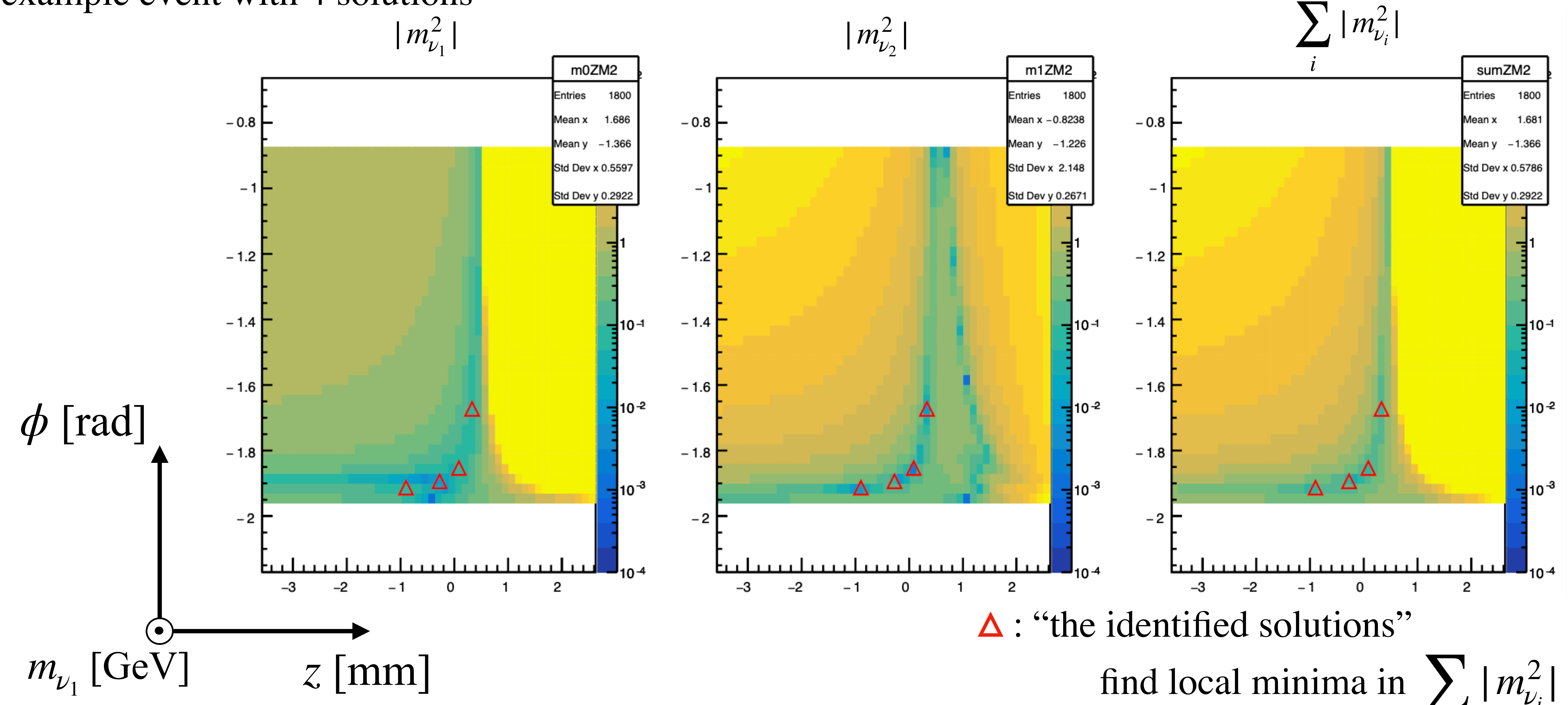
△ : "the identified solutions"

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



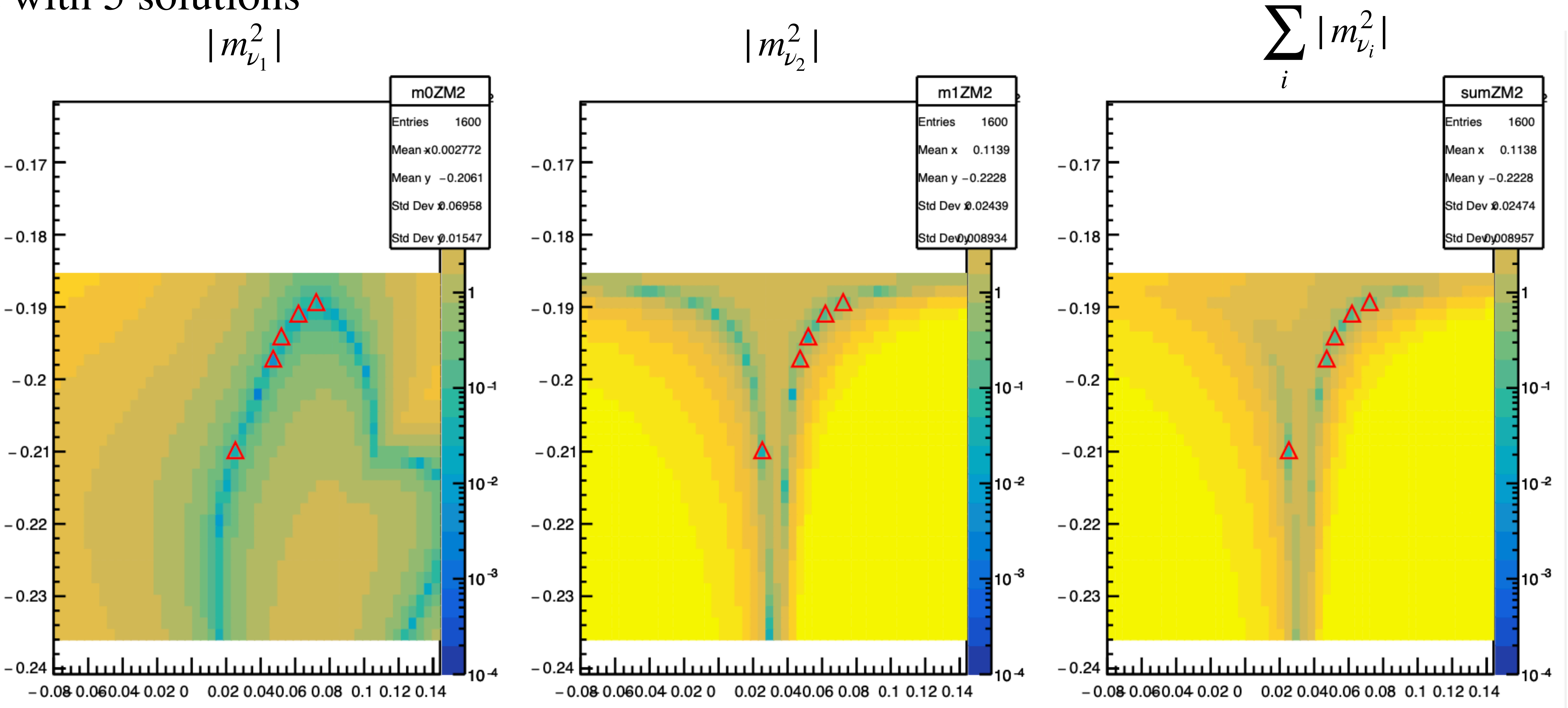
△ : "the identified solutions"

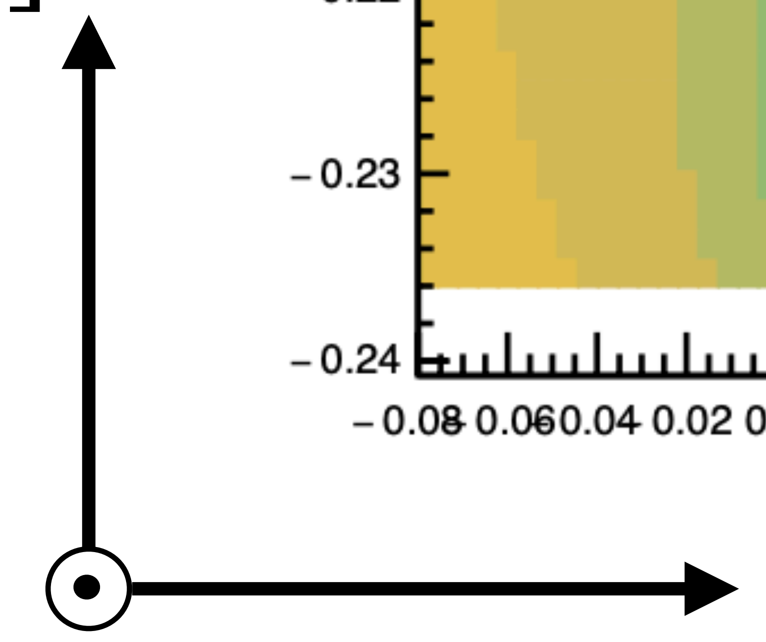
find local minima in $\sum_i |m^2_{\nu_i}|$

Find solutions

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

example event with 5 solutions





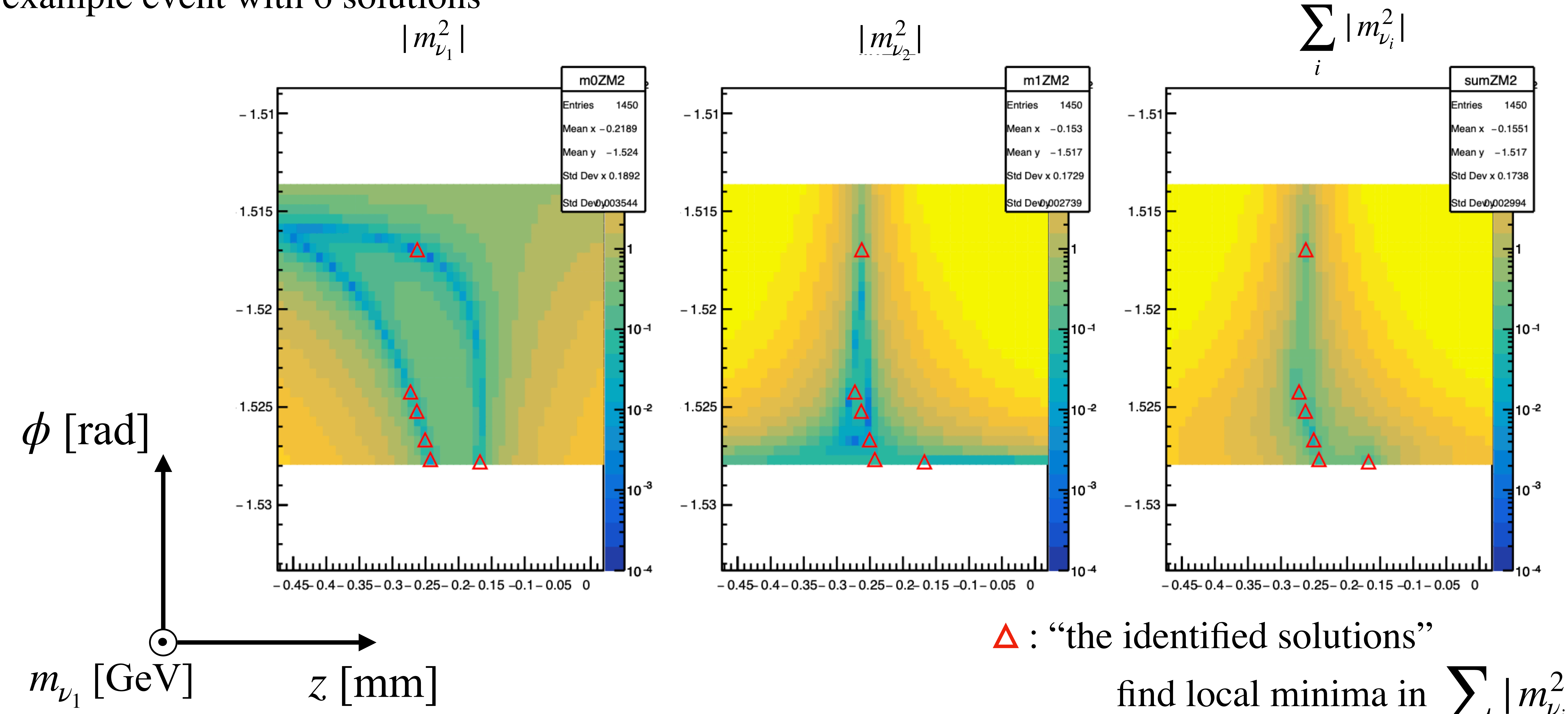
△ : "the identified solutions"

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

Find solutions

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

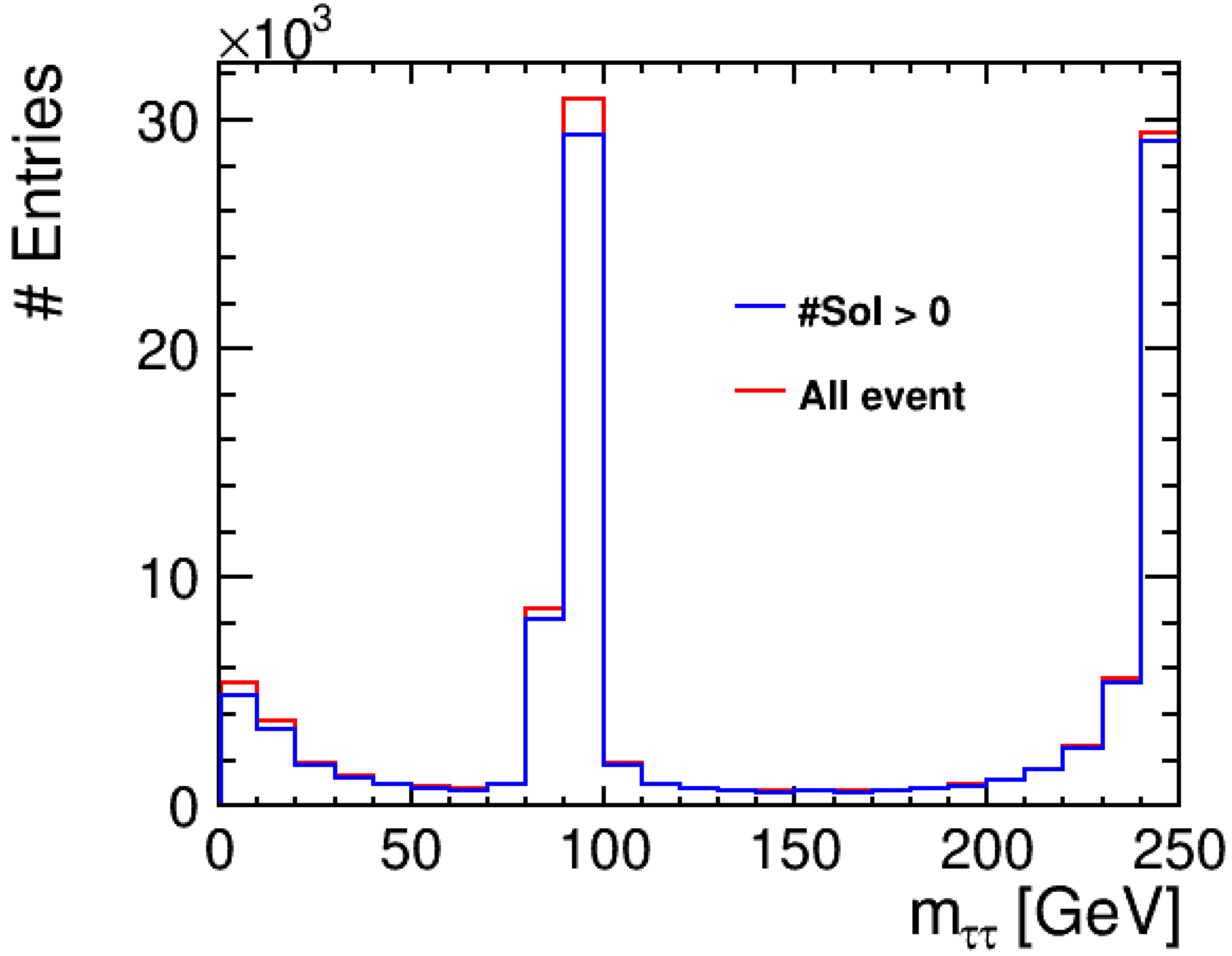
example event with 6 solutions

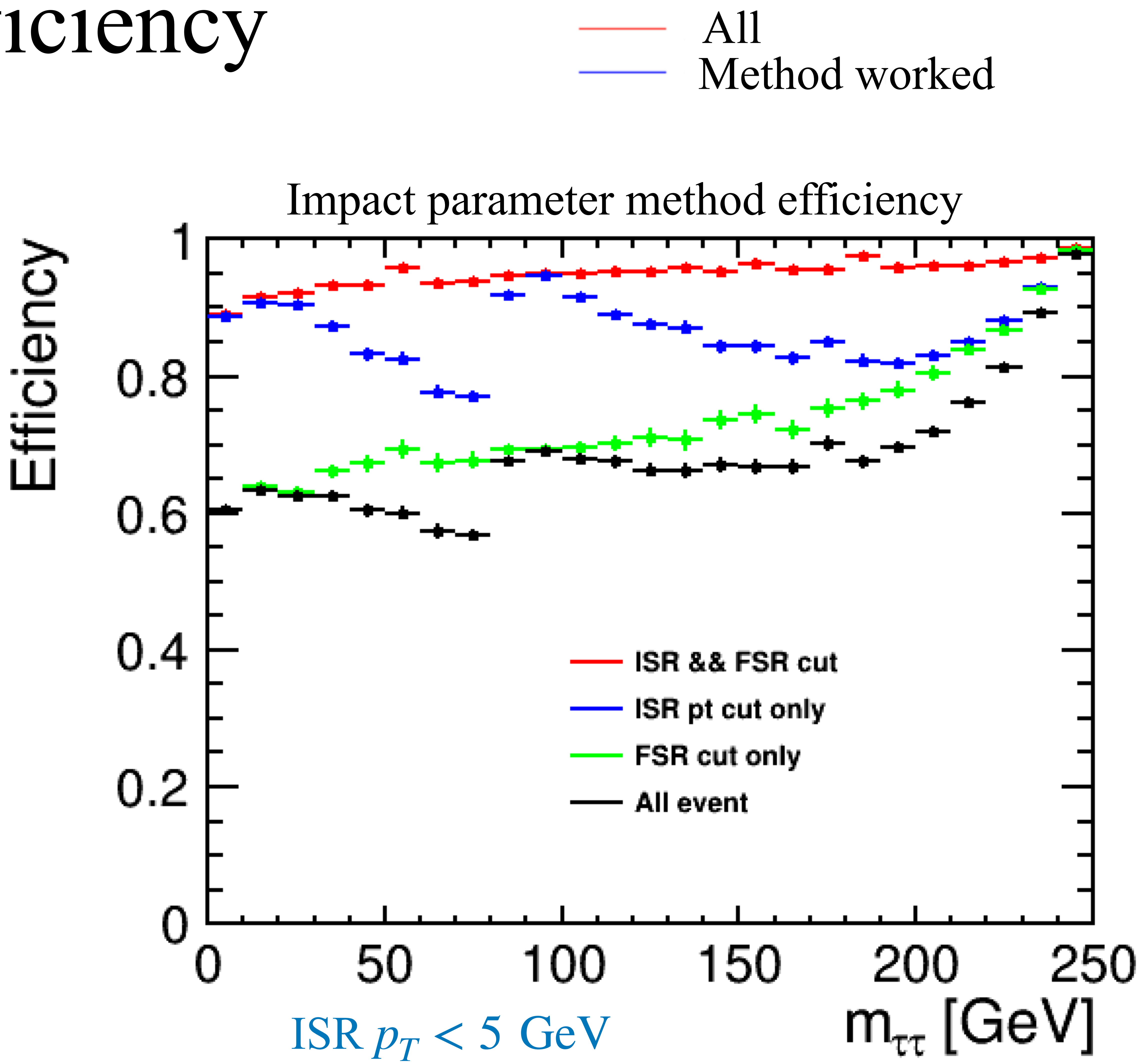


find local minima in $\sum_i |m^2_{\nu_i}|$

Method efficiency

At least 1 $\tau \to \pi/\rho$





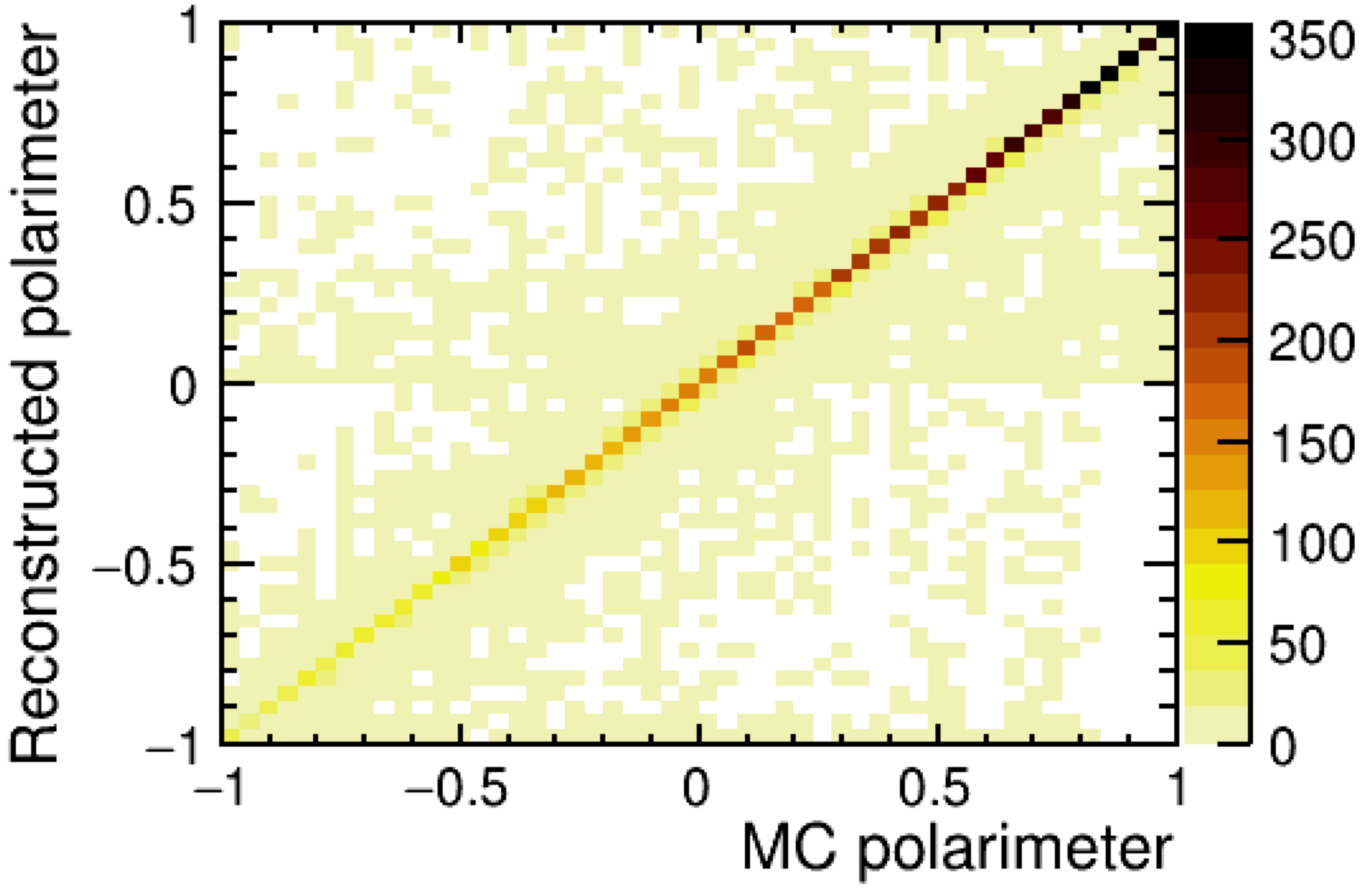
ISR $p_T < 5$ GeV

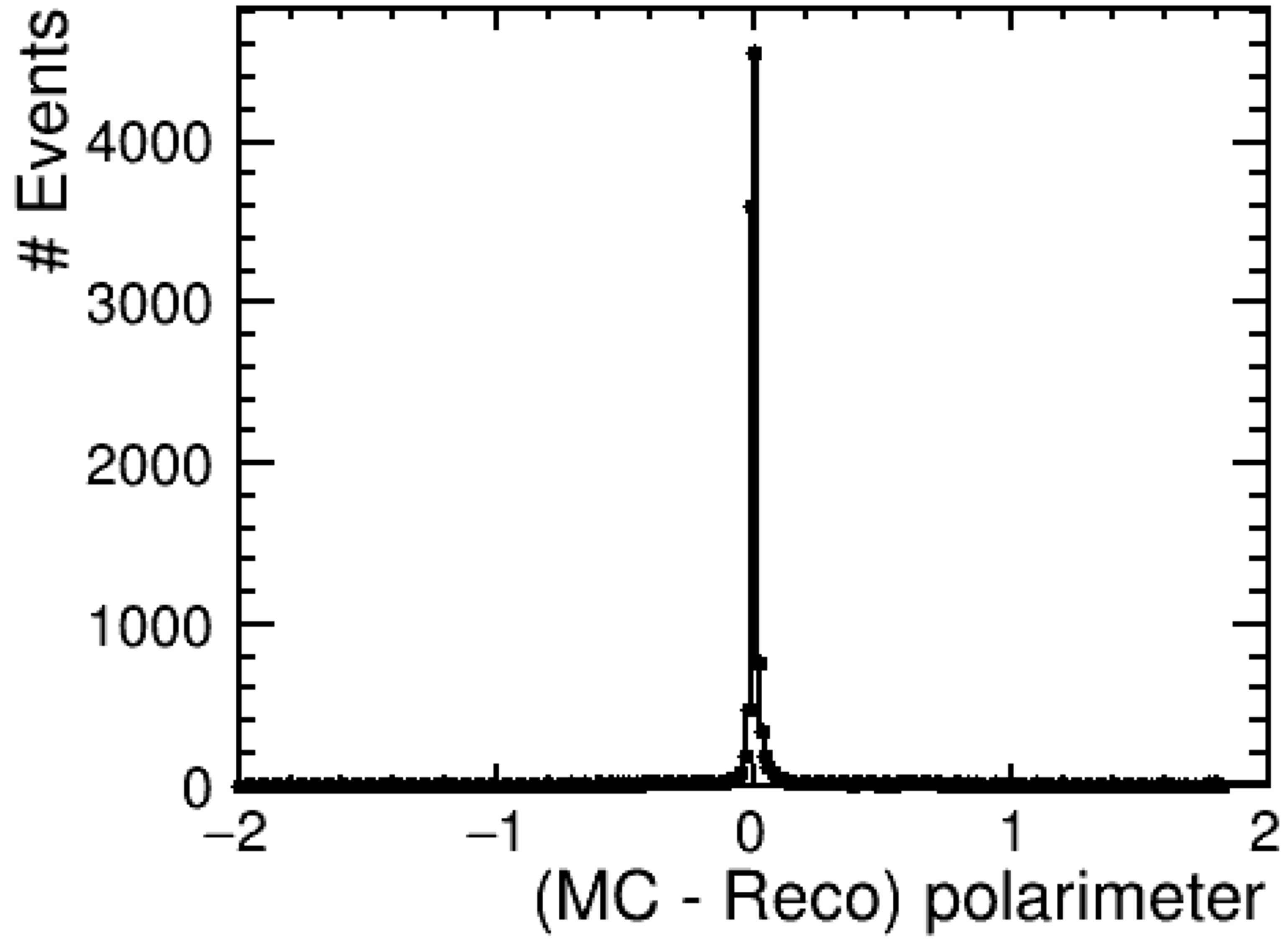
FSR cut : No FSR photon event

Impact parameter method efficiency is > 90 % for events with $m_{\tau\tau} \sim 250$ GeV

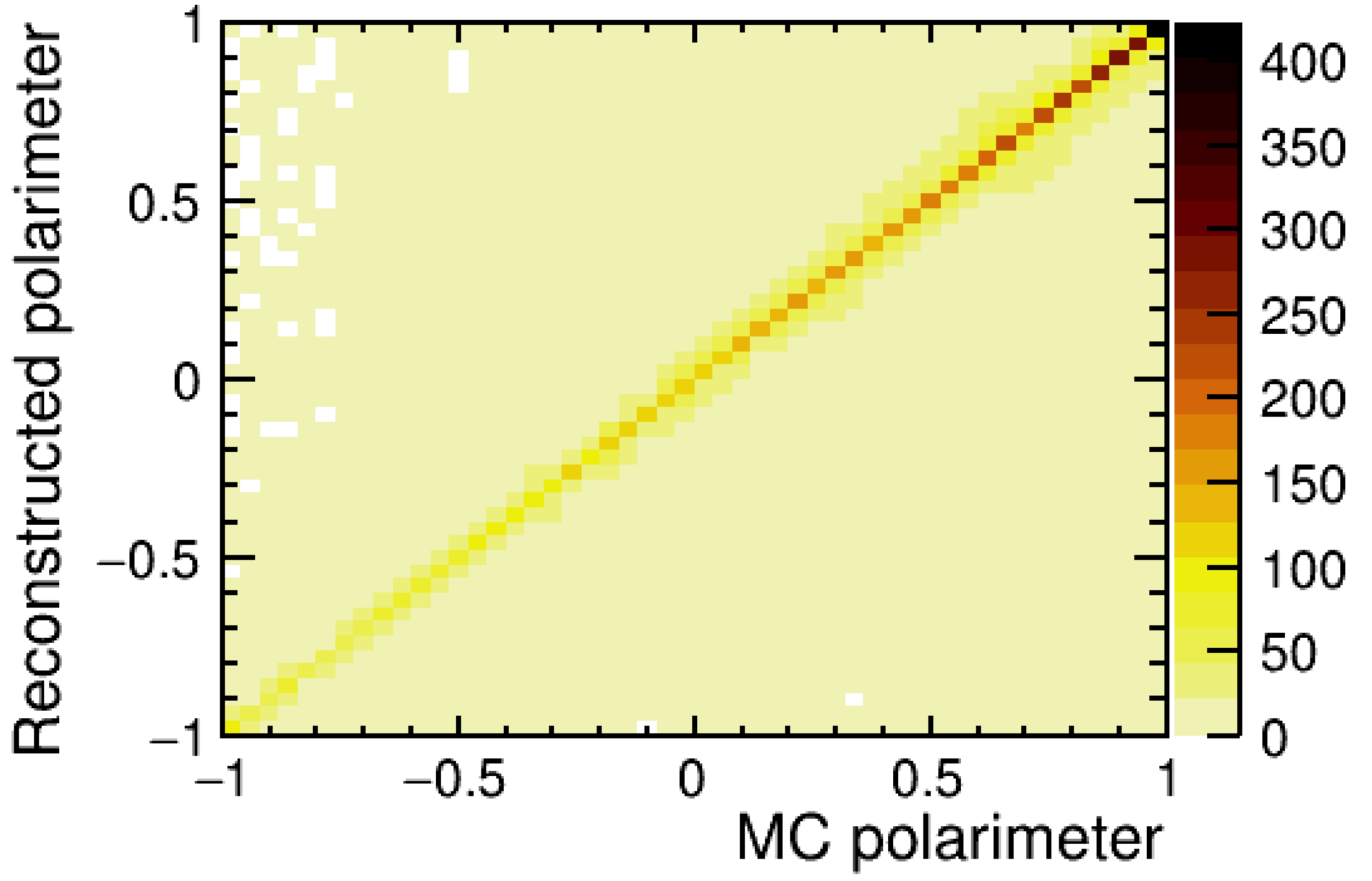
Polarimeter

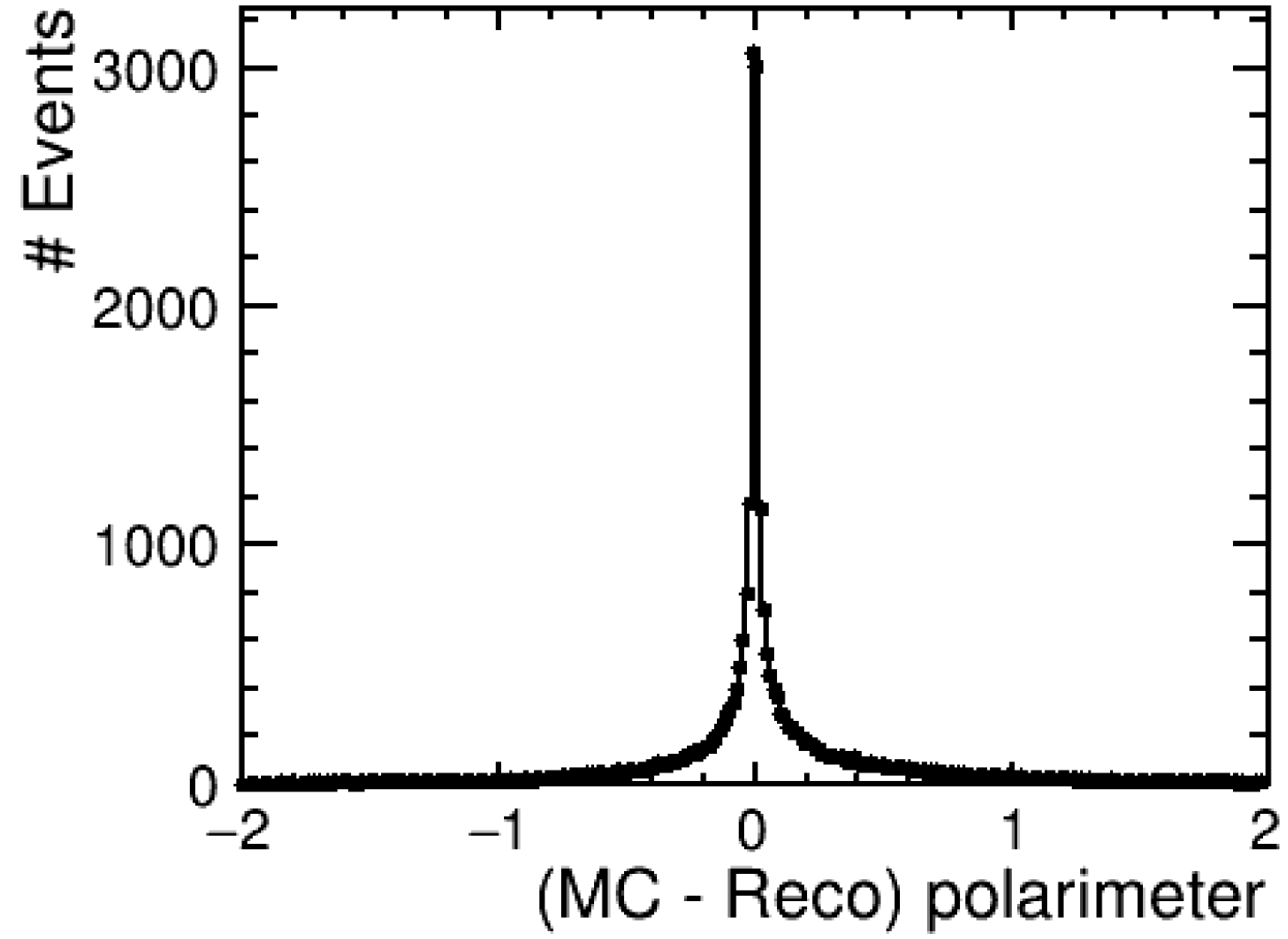
$\tau \rightarrow \pi\nu$ Impact parameter method vs MC eLpR(100%)





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



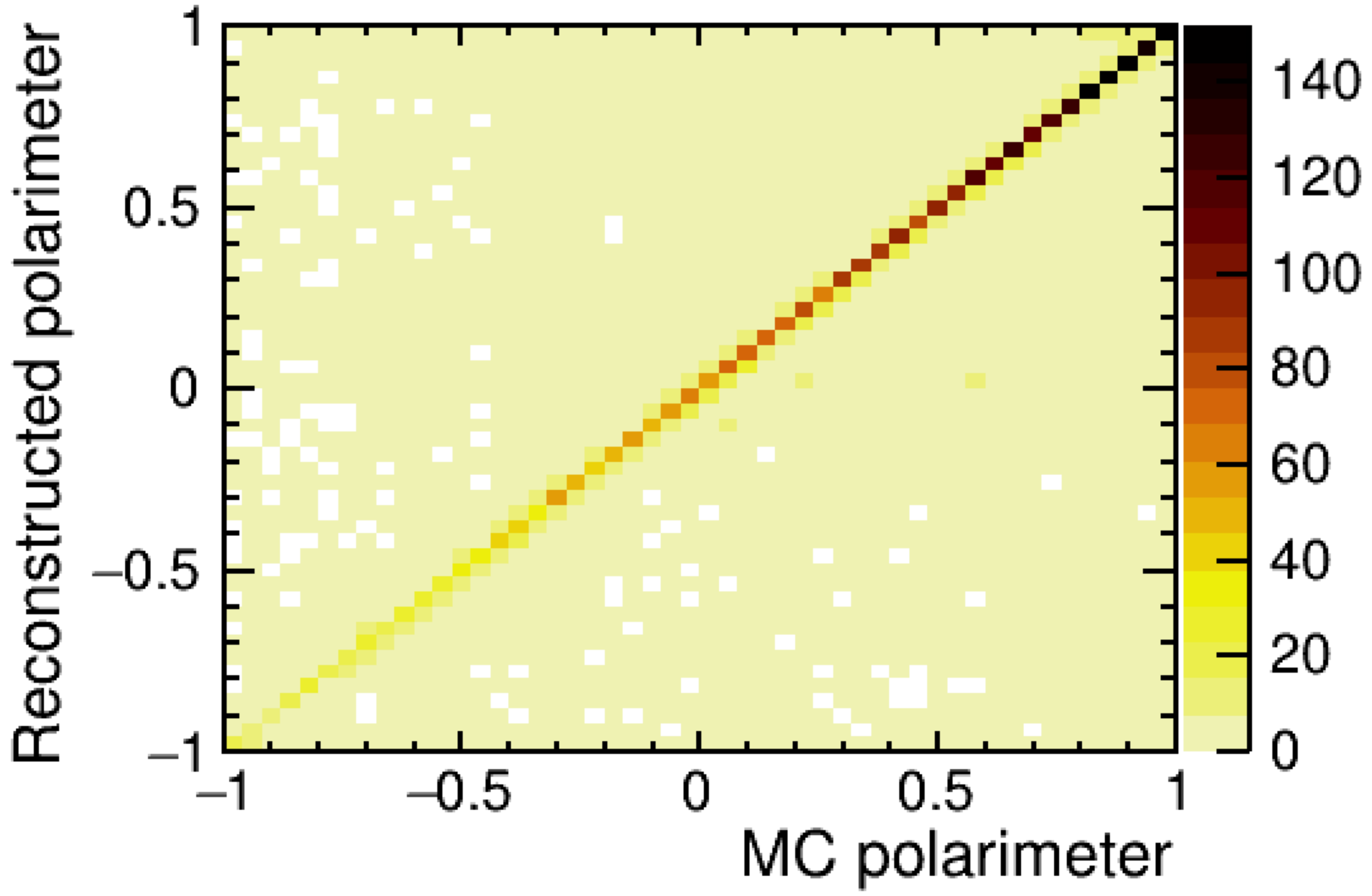


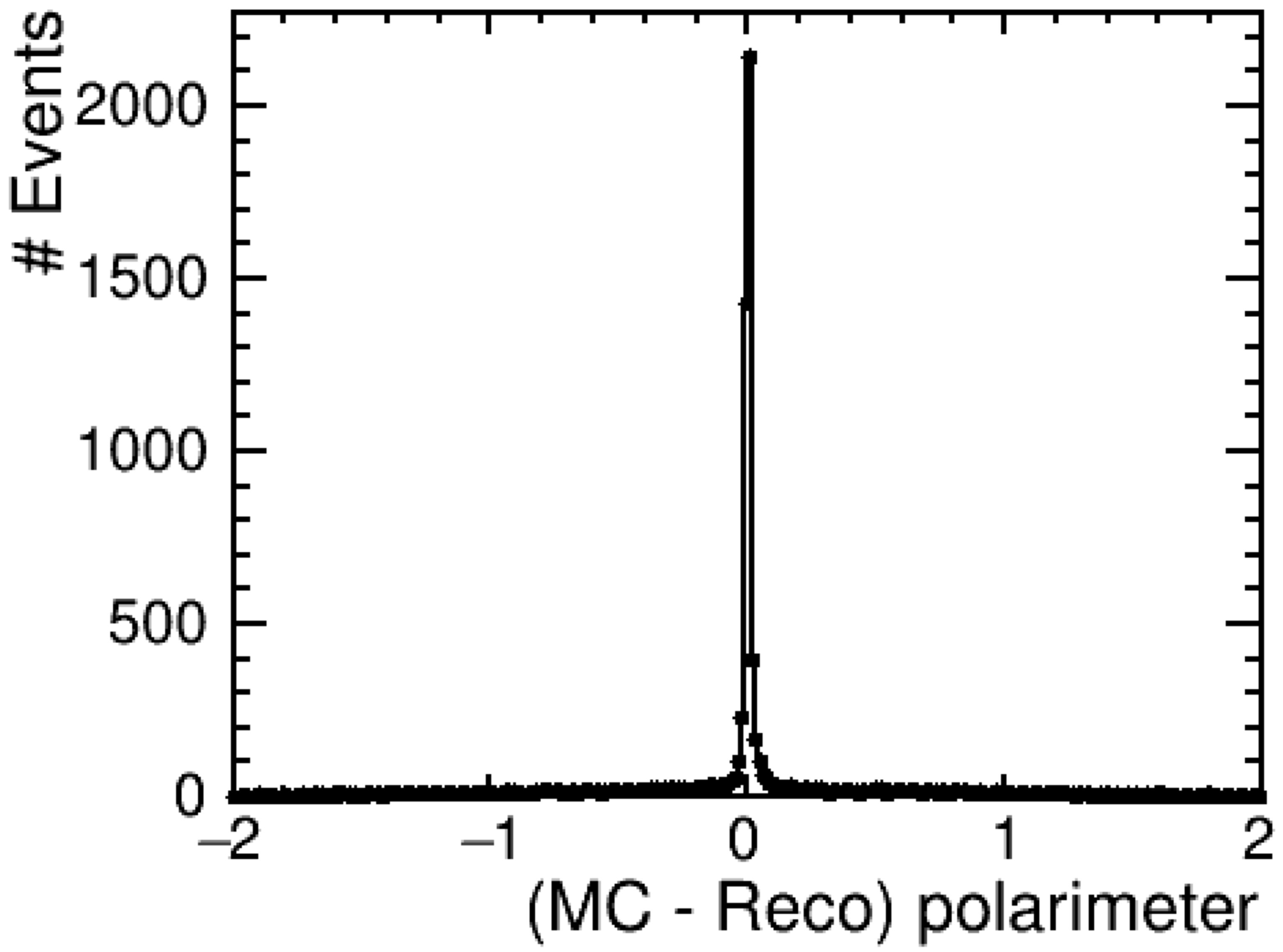
Polarimeter using reconstructed ν is in reasonable agreement with MC one.

PFO

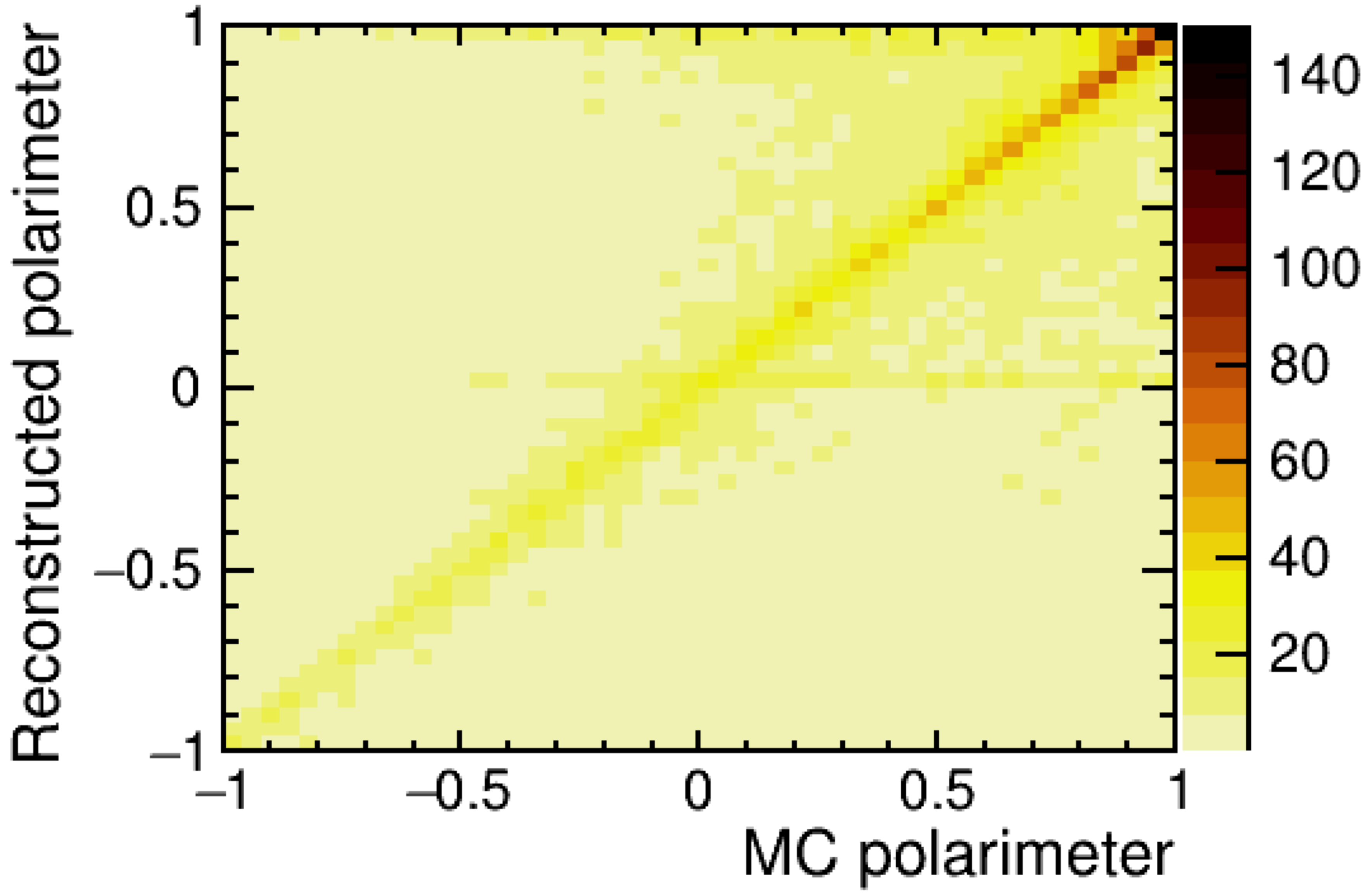
Polarimeter

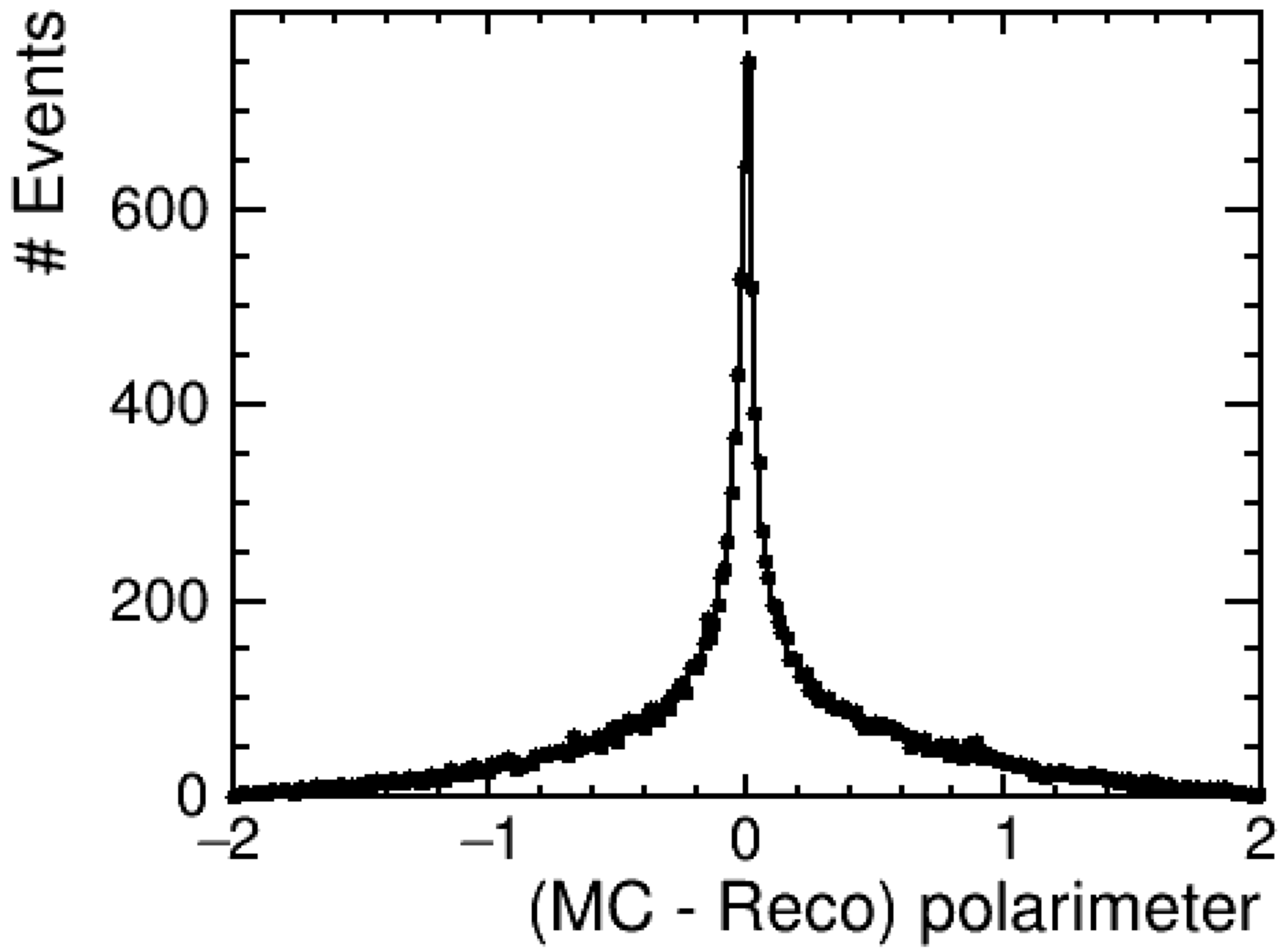
$\tau \rightarrow \pi\nu$ Impact parameter method vs MC eLpR(100%)





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





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

Summary

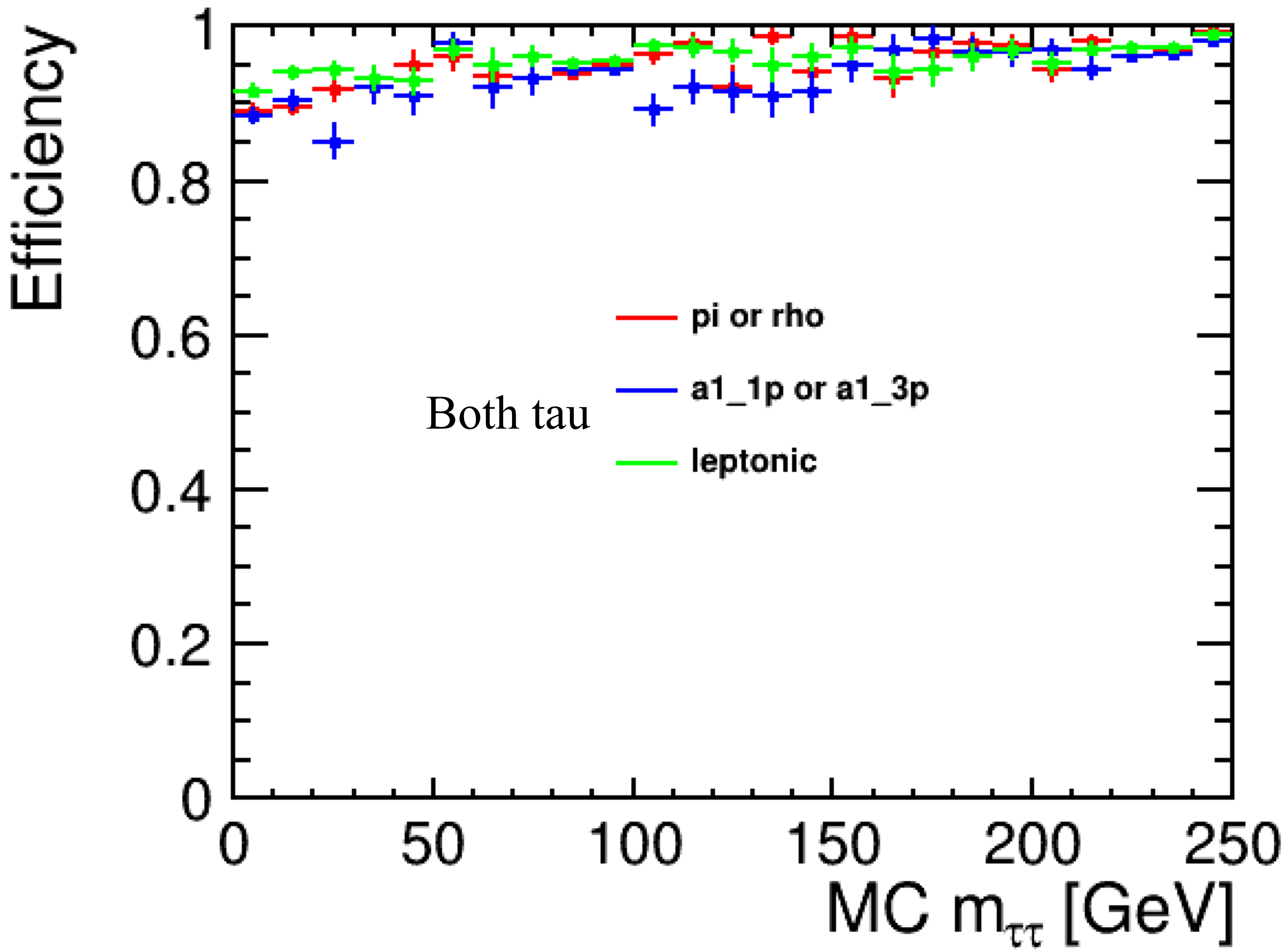
- Full reconstruction of $e^+e^- \to \tau^+\tau^-$ using impact parameter was investigated.
- New method to find solutions was implemented and method efficiency was improved

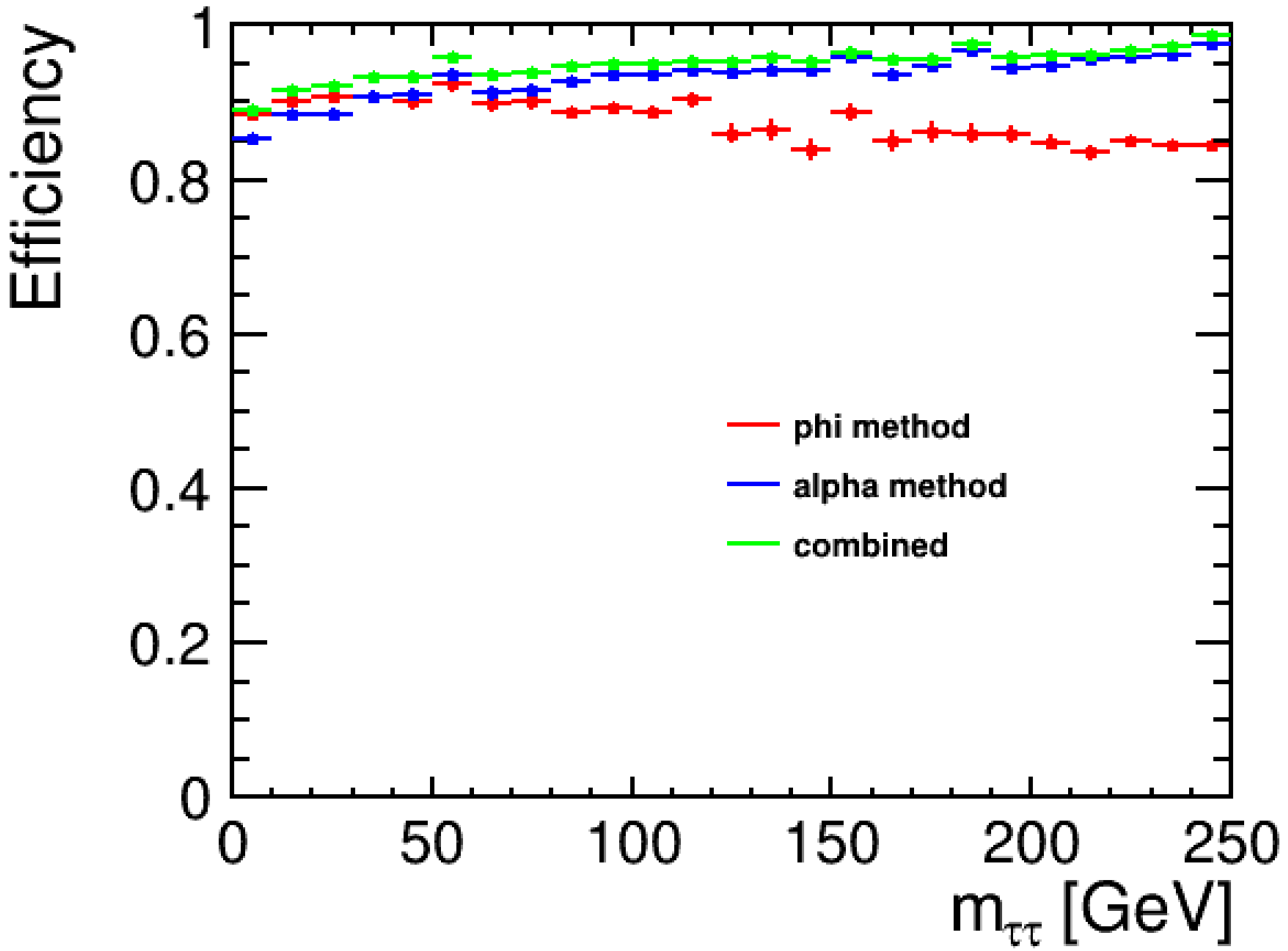
  For events with $m_{\tau\tau} \sim 250$ GeV, new method efficiency is $> 90\,\%$

- 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

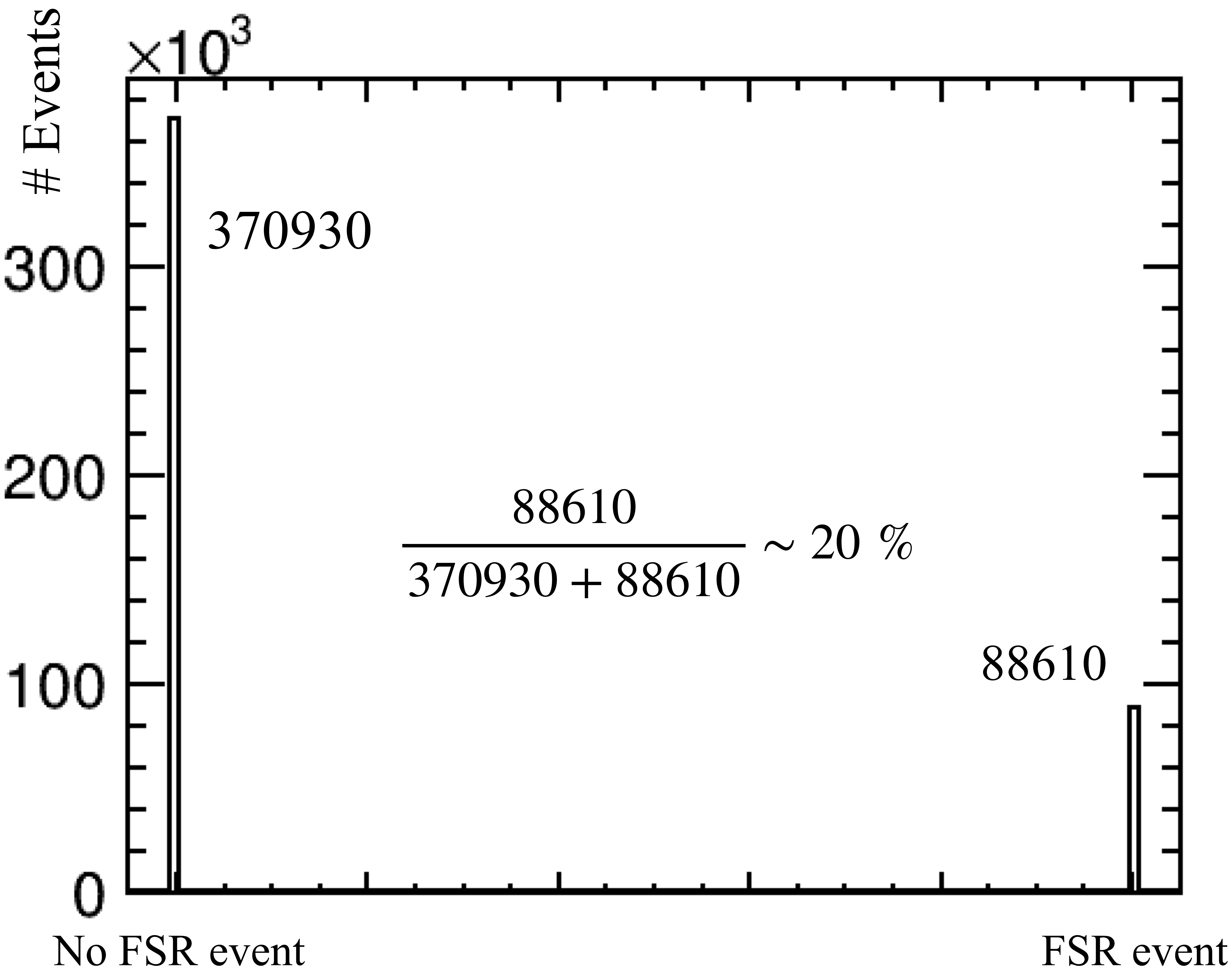
- Quantify the precision with which the tau polarisation can be measured at ILC-250.
- Investigate search for new physics by using the tau polarisation.


Efficiency
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
MC $m_{\tau\tau}$ [GeV]
pi or rho
a1_1p or a1_3p
leptonic
Both tau


Efficiency
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
$m_{\tau\tau}$ [GeV]
phi method
alpha method
combined

Before FSR
After FSR
p_T
MC $m_{\tau\tau}$ [GeV]
e^-
e^+
τ^-
τ^+
on-shell Z is produced
Significant FSR
$\rightarrow m_{\tau\tau} < m_Z$

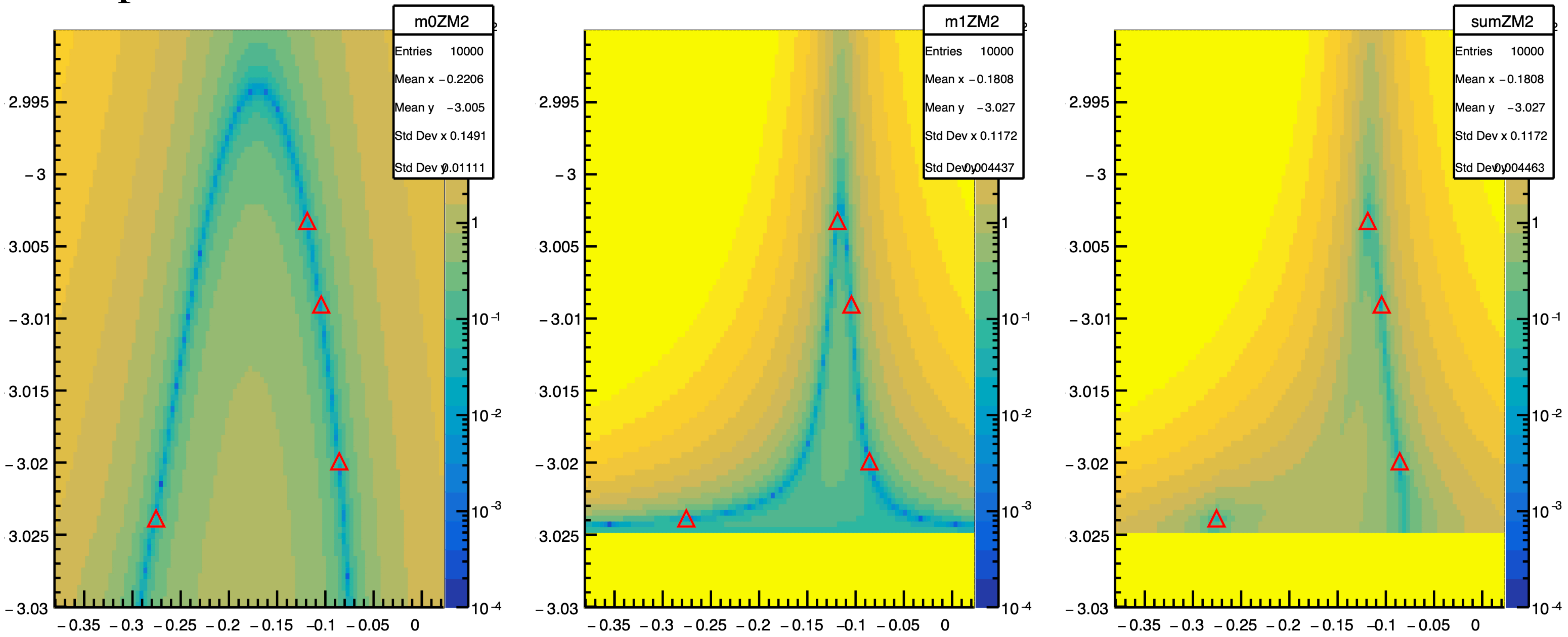
FSR event



Events
×10^3
300
200
100
0
370930
88610
88610 / (370930 + 88610) ~ 20 %
No FSR event
FSR event

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 statistics @ ILC-250

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

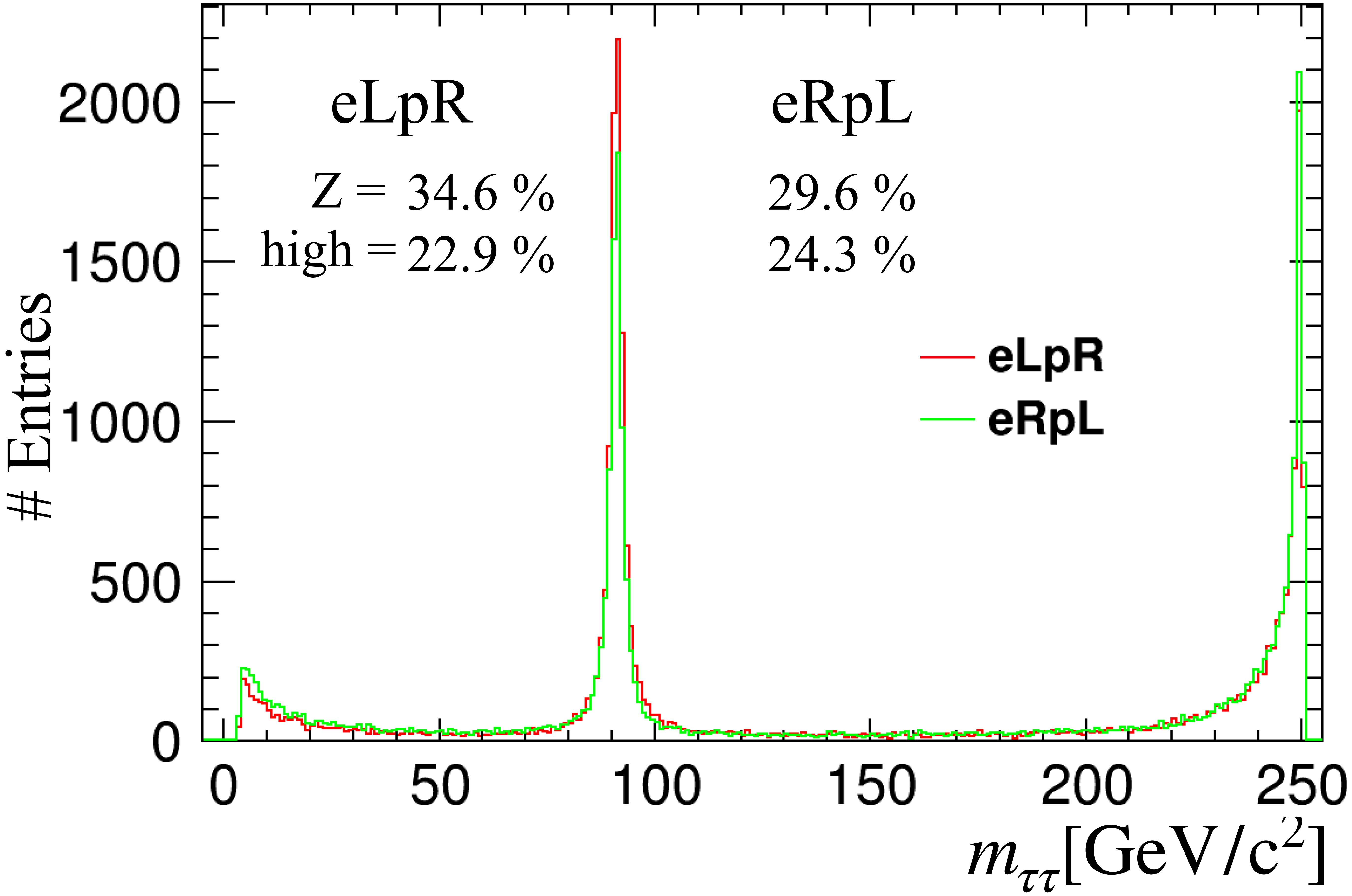
beam polarisation	$e^-_{L80}e^+_{R30}$ (-, +)	$e^-_{R80}e^+_{L30}$ (-, +)
integrated luminosity [fb^{-1}]	900	900
e^- (L, R)	(90 %, 10 %)	(10 %, 90 %)
e^+ (L, R)	(35 %, 65 %)	(65 %, 35 %)

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

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

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

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



radiative return (91 ± 5[GeV/c^2])

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

$$N = 6.8 \times 10^6$$

High mass τ - τ (245 ± 5[GeV/c^2])

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

$$N = 4.9 \times 10^6$$