Reconstruction of X → tau tau

e.g.

e+ e- → (H → tau tau) (Z → mu mu)

an intermediate status report

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Motivation:

the Higgs decay modes
ZZ WW tau tau (converted photons)

are particularly interesting, because spin state of W, Z, tau
are to some extent reflected in the
distribution of their decay products

Allows measurement of e.g. Higgs CP properties
H(125) = cos(phi) CP(+1) + sin(phi) CP(-1)

H → tau tau ~ 6% @ 125 GeV
~2 * larger than ZZ
fermionic

Some tau decay modes:

~11% $tau^+ \rightarrow pi^+$ tau_neutrino

Simplest case ← this talk

~25% $tau^+ \rightarrow pi^+ pi^0$ tau_neutrino

Large BR, also useful

~35% $tau^+ \rightarrow lepton^+$ tau_neutrino l_neutrino

two missing neutrinos ← limited information

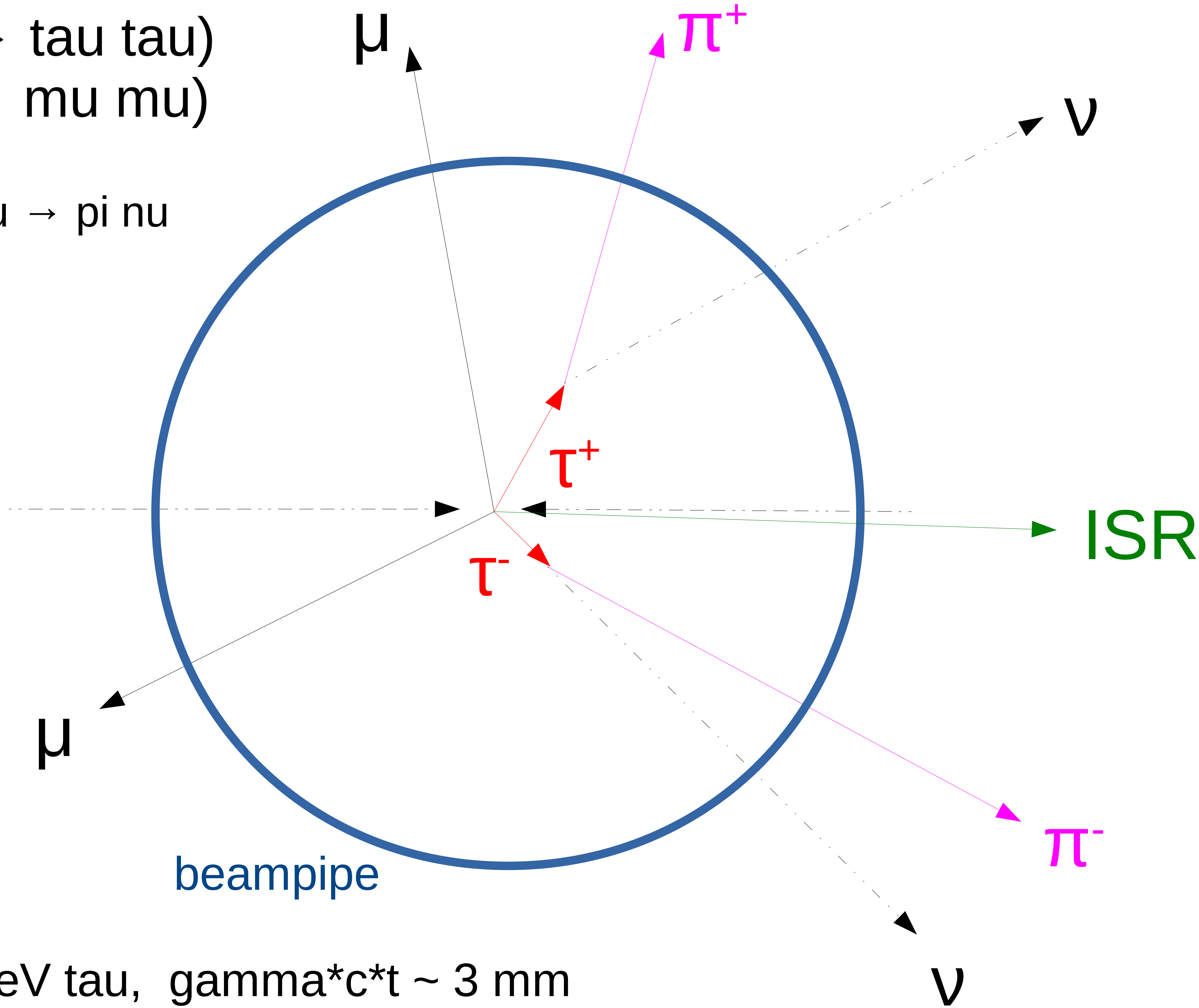
We would ideally like to fully reconstruct the
tau momentum and its decay products
to get as much information as possible

$e^+ e^- \rightarrow$

($H \rightarrow$ tau tau)

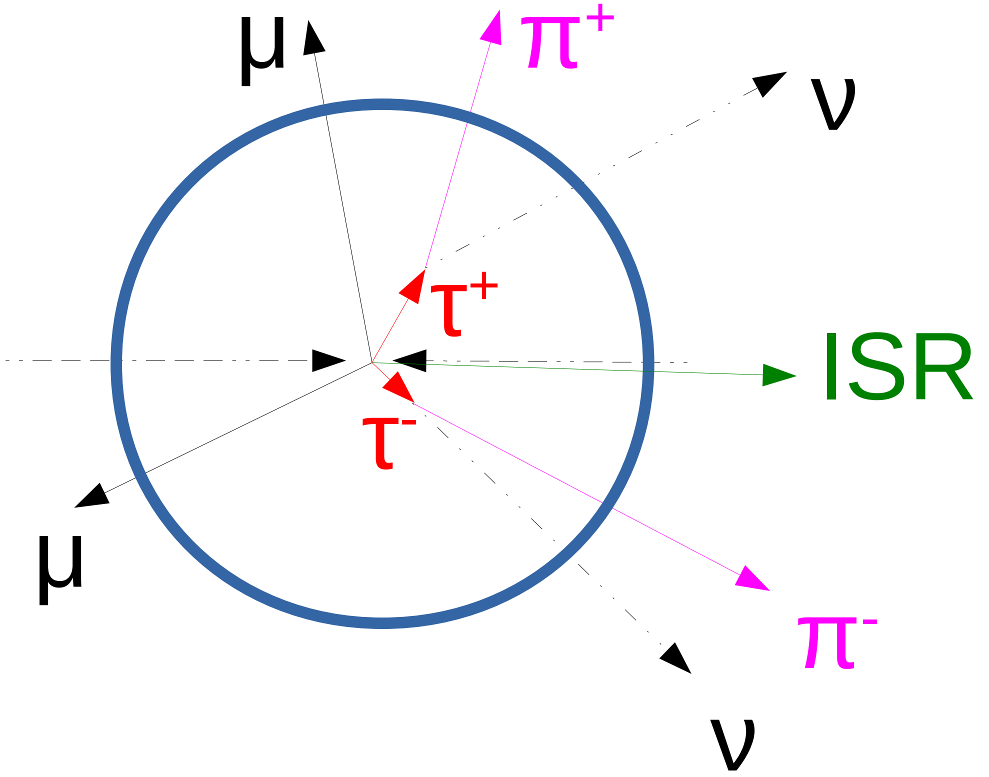
($Z \rightarrow$ mu mu)

both tau → pi nu



For 60 GeV tau, gamma*c*t ~ 3 mm

ILD impact parameter resolution ~5 microns



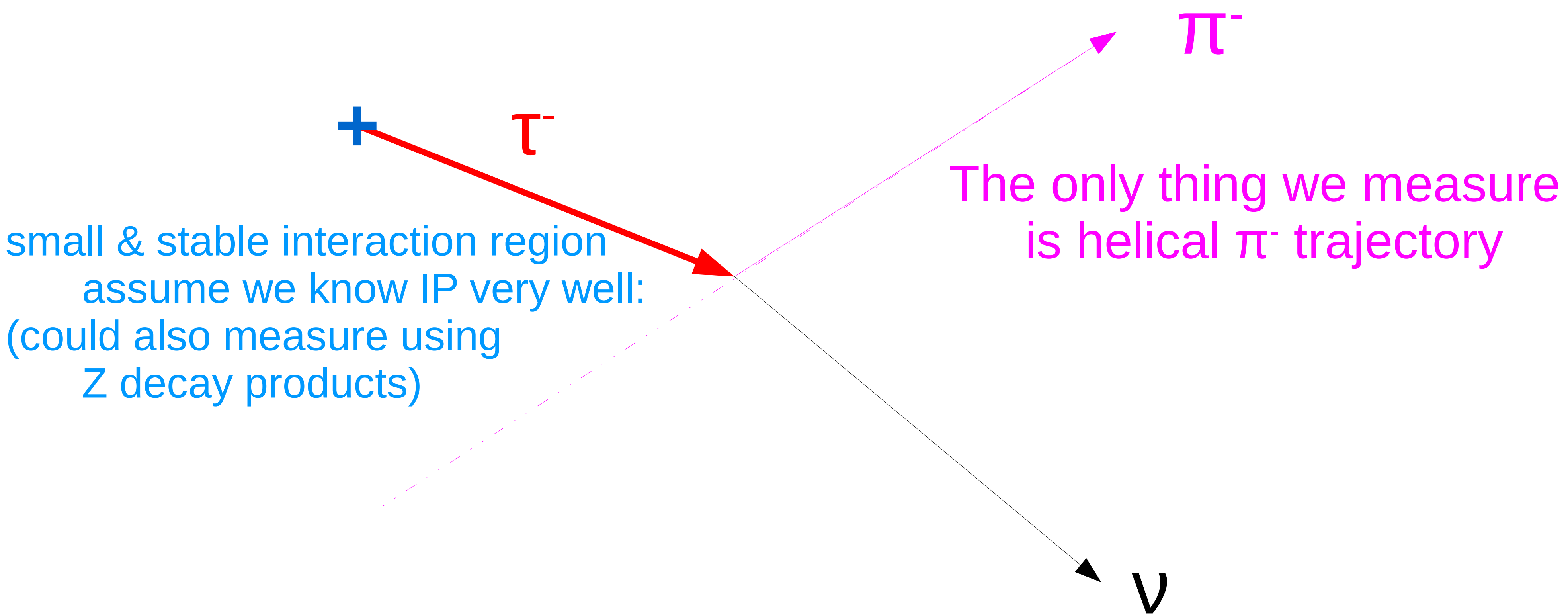
Unmeasured quantities

2 x neutrino 3-momenta
lost ISR photons

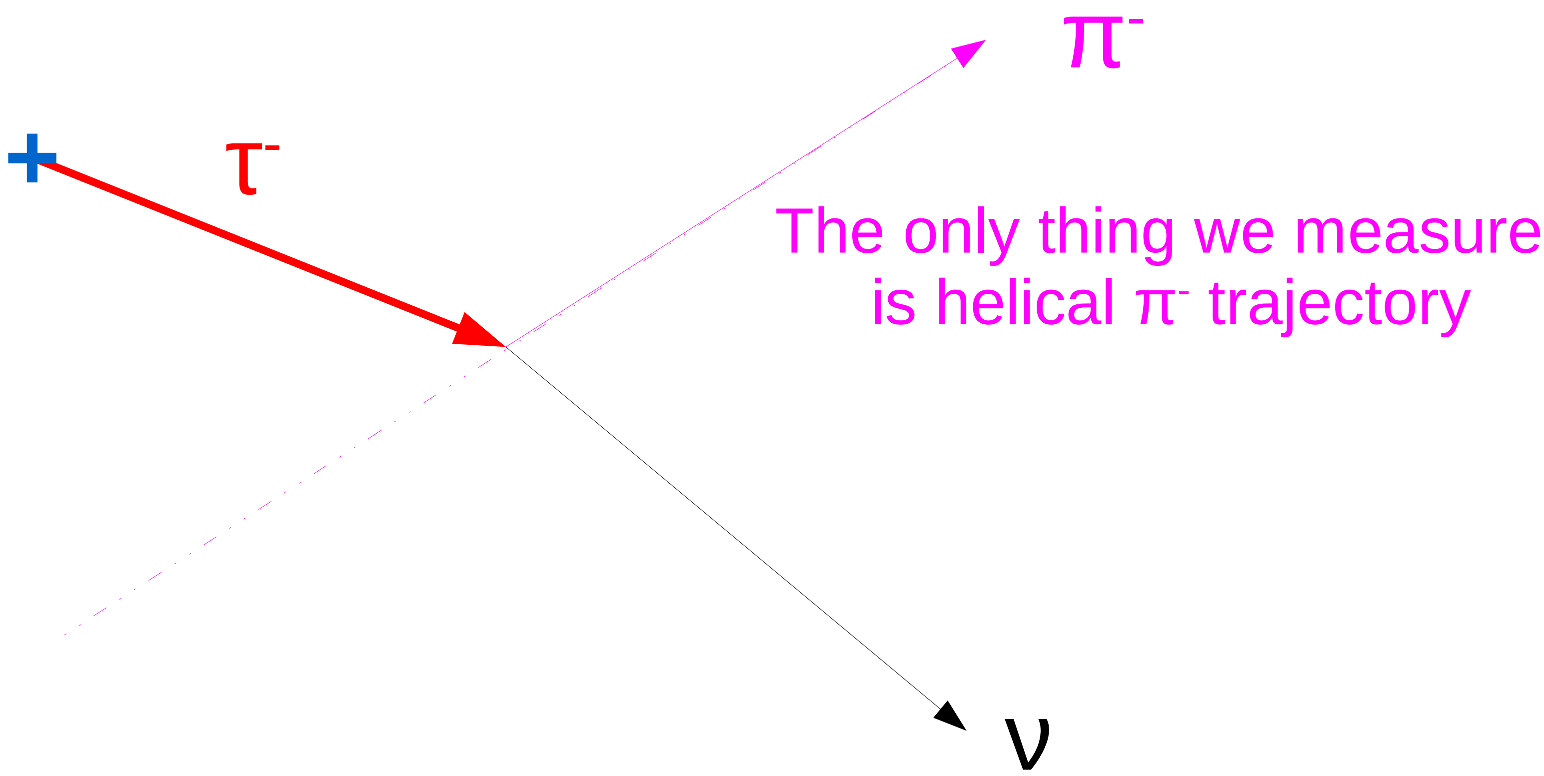
Kinematic constraints

overall 4-momentum conservation
2 x tau decay kinematics ← more details next

tau-tau mass (if we assume H->tau tau)
mu-mu mass not useful: resolution much better than Z width

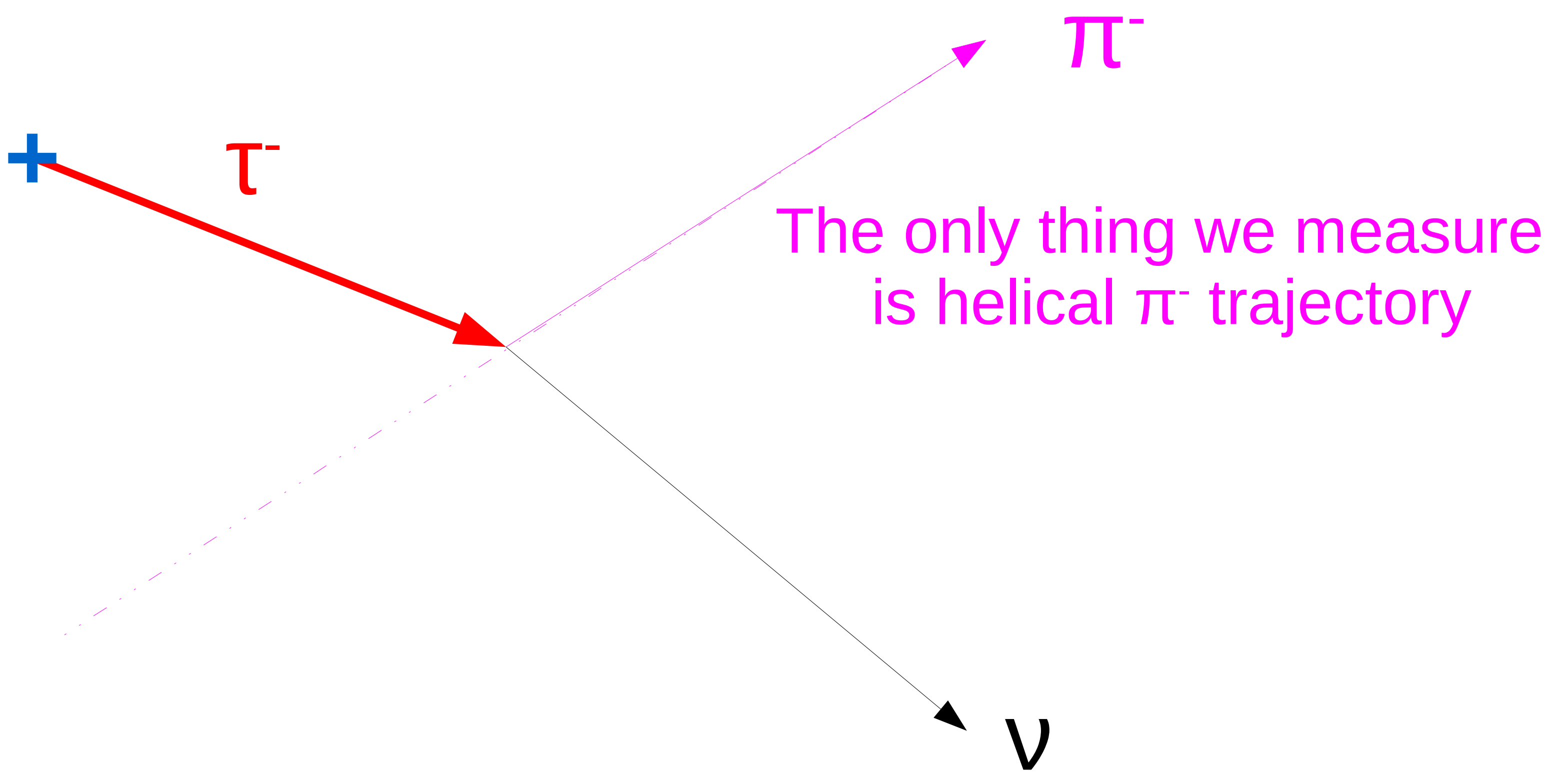


π⁻
τ⁻
The only thing we measure
is helical π⁻ trajectory
small & stable interaction region
assume we know IP very well:
(could also measure using
Z decay products)
ν



We know that:

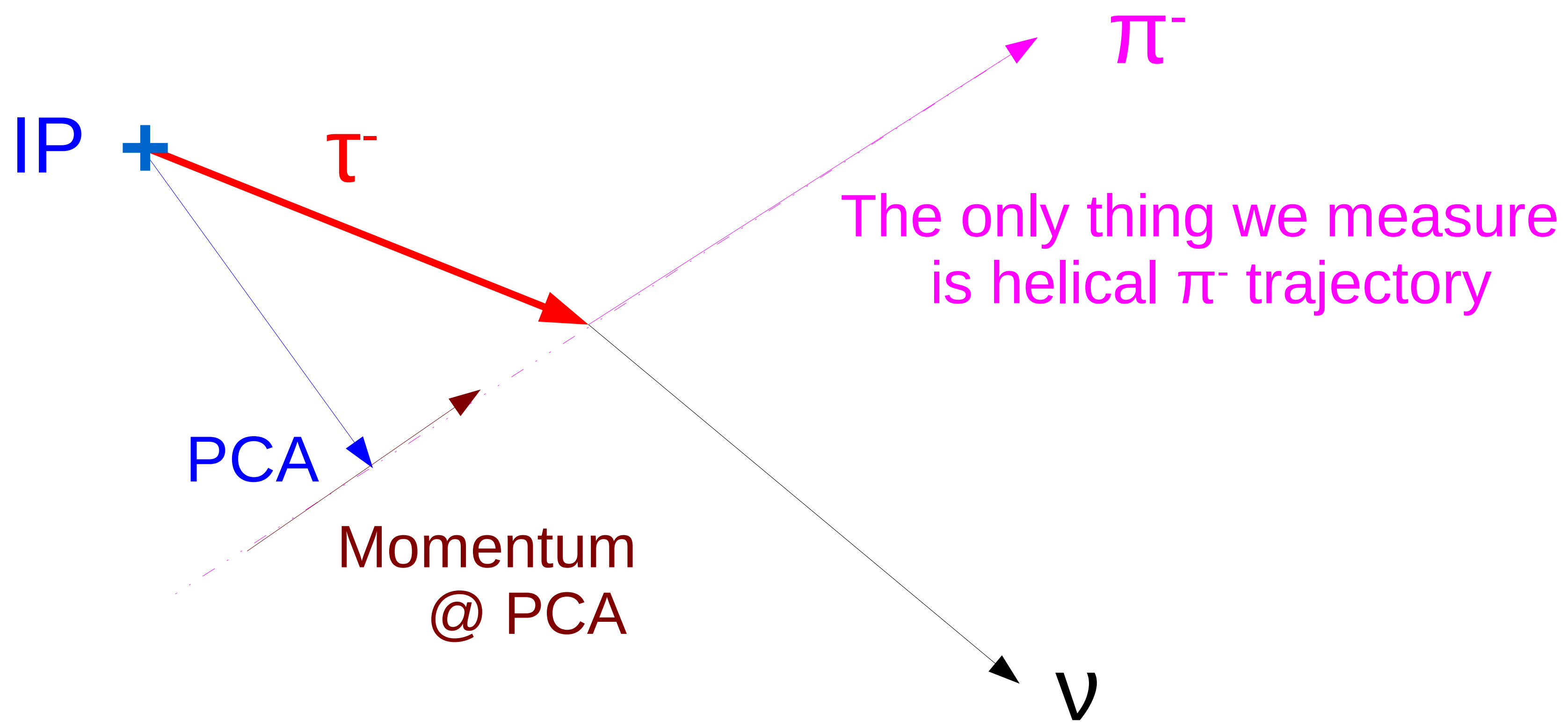
- endpoint of tau lies on pi- trajectory



We know that:

- endpoint of tau lies on pi- trajectory

→ neutrino momentum lies in plane
defined by tau- and pi- momenta



If we assume that pi- trajectory is linear,

OK since track radius of curvature >> tau decay length

neutrino momentum is in plane defined by

IP-PCA vector and

momentum @ PCA

2 constraints from each tau decay

invariant mass of

4-momentum @ PCA and neutrino 4-momentum = tau mass

Let's test these ideas:

private production of

- $e^+e^- \rightarrow Z\,H \rightarrow$ mu mu tau tau events

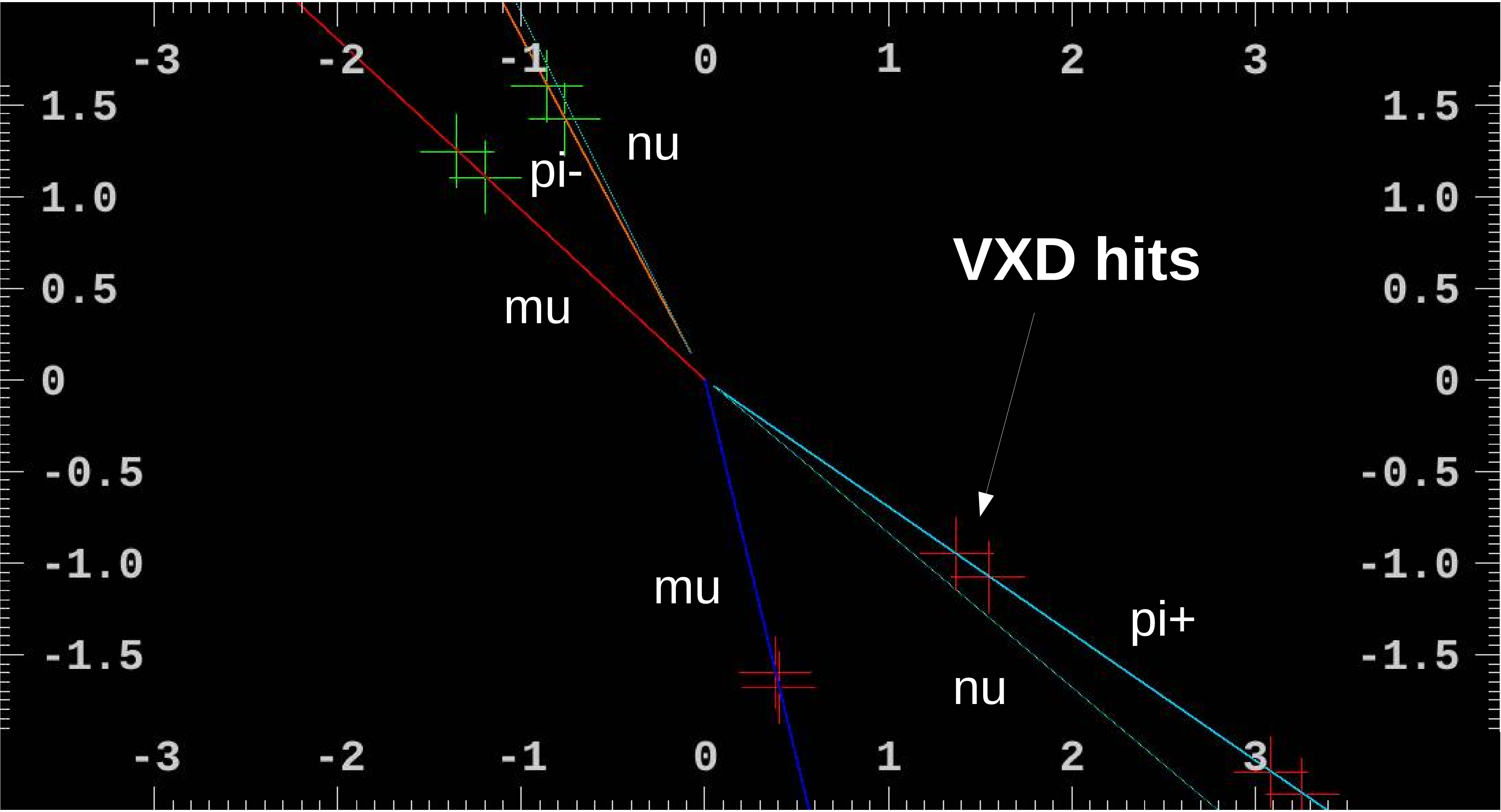
- Whizard 2.2.2,
  - with ISR, beamstrahlung (also samples without)
  - 250 GeV centre-of-mass
  - eL pR beam polarisation

- Tau decay to pi-neutrino only
  - Tauola 1.1.4,
    - with correct spin correlations

- simulated in ILD detector (Mokka)
  - ILD_o1_v06 detector model

- ilcsoft v01-17-04 reconstruction
  - use tracks from MarlinTrkTracks collection
  - PID by MC cheating (for now)

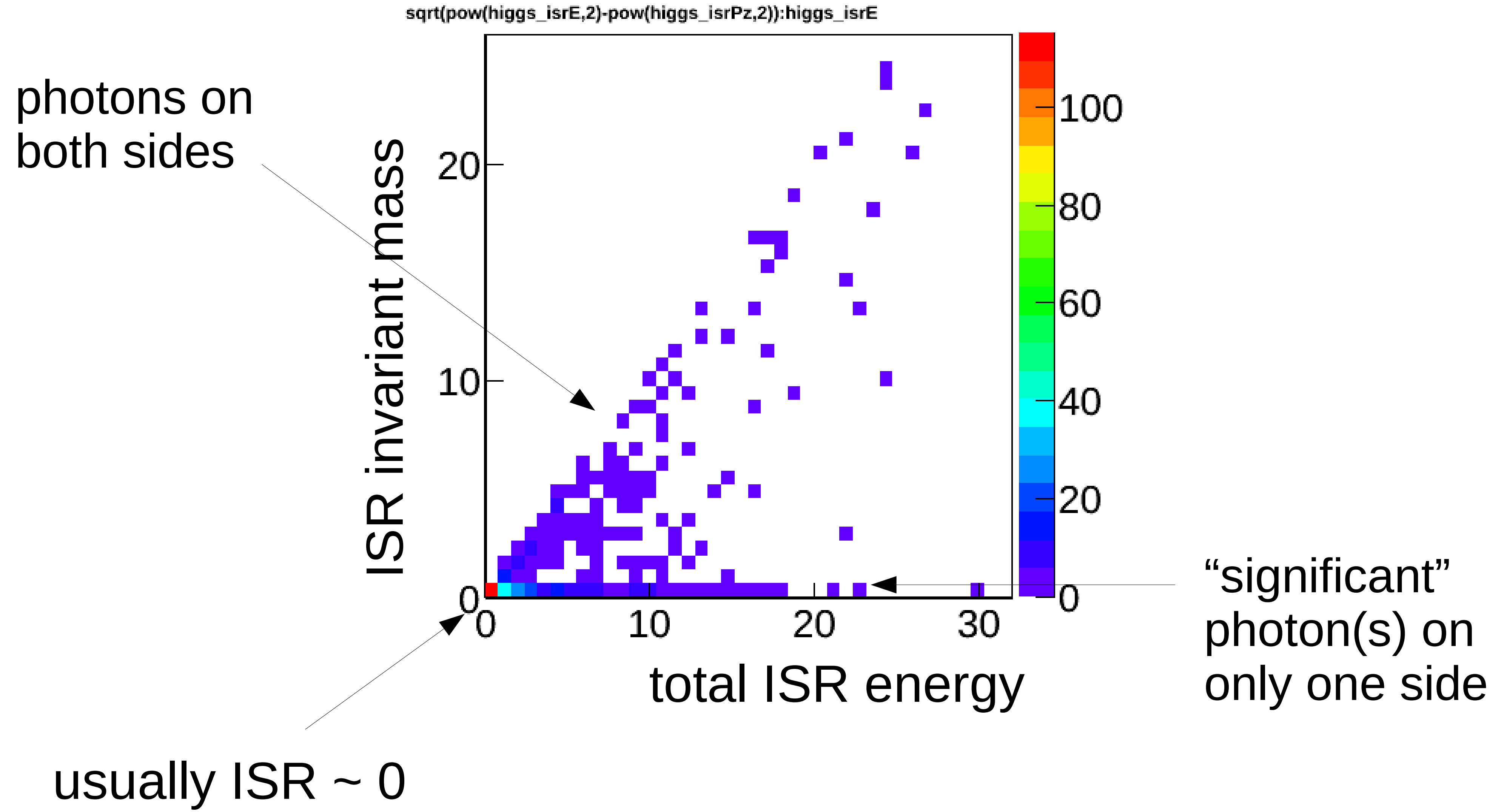
an event



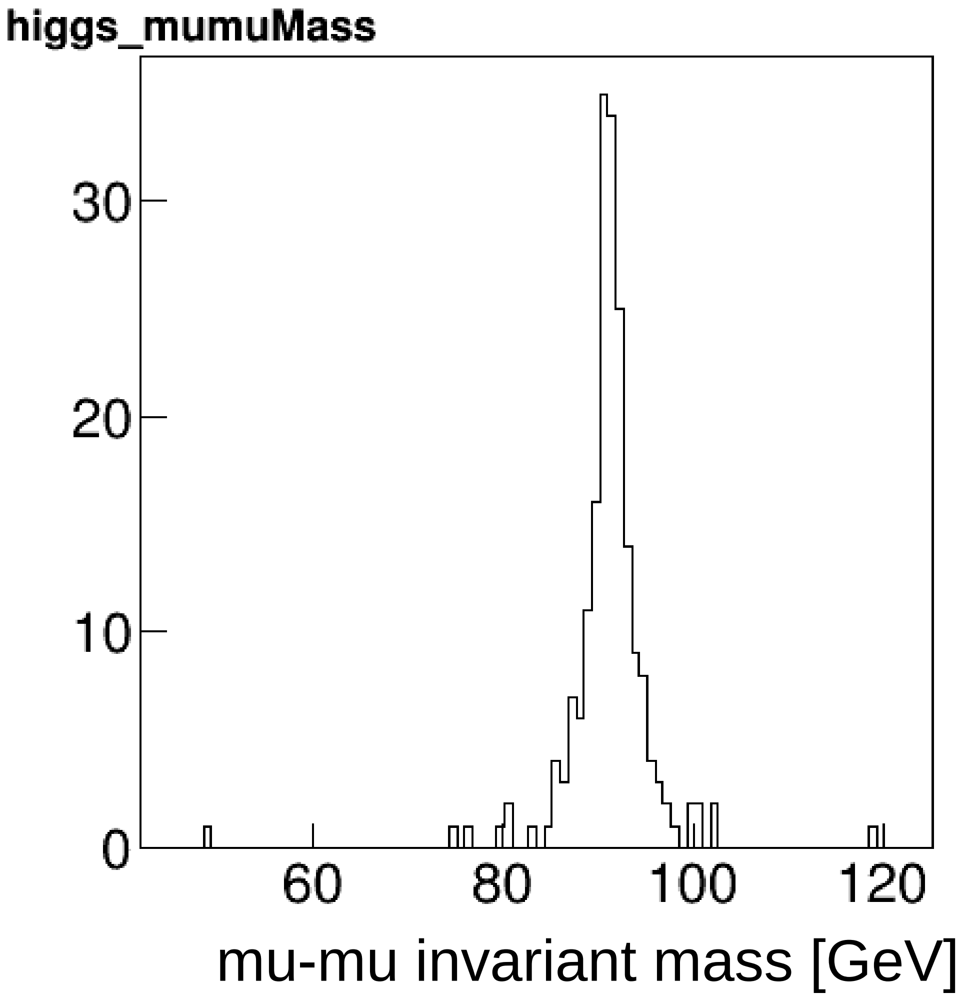
ISR properties

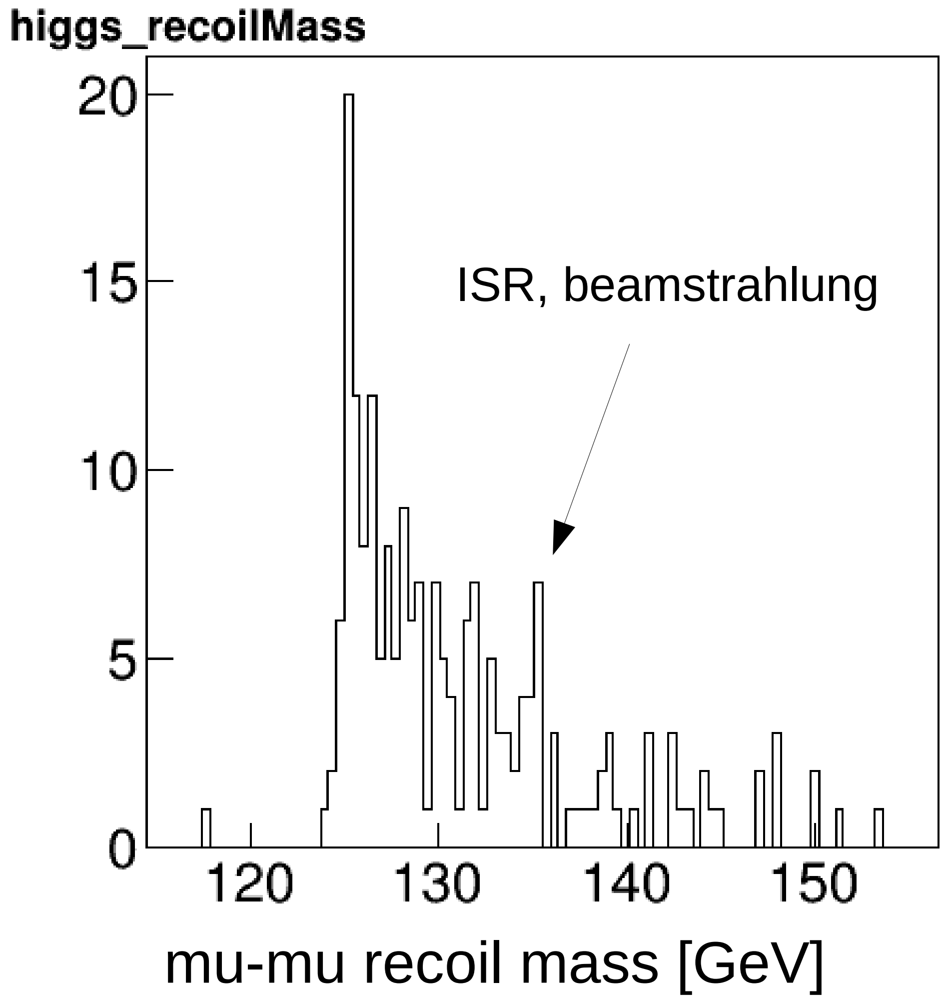
actually ISR + beamstrahlung

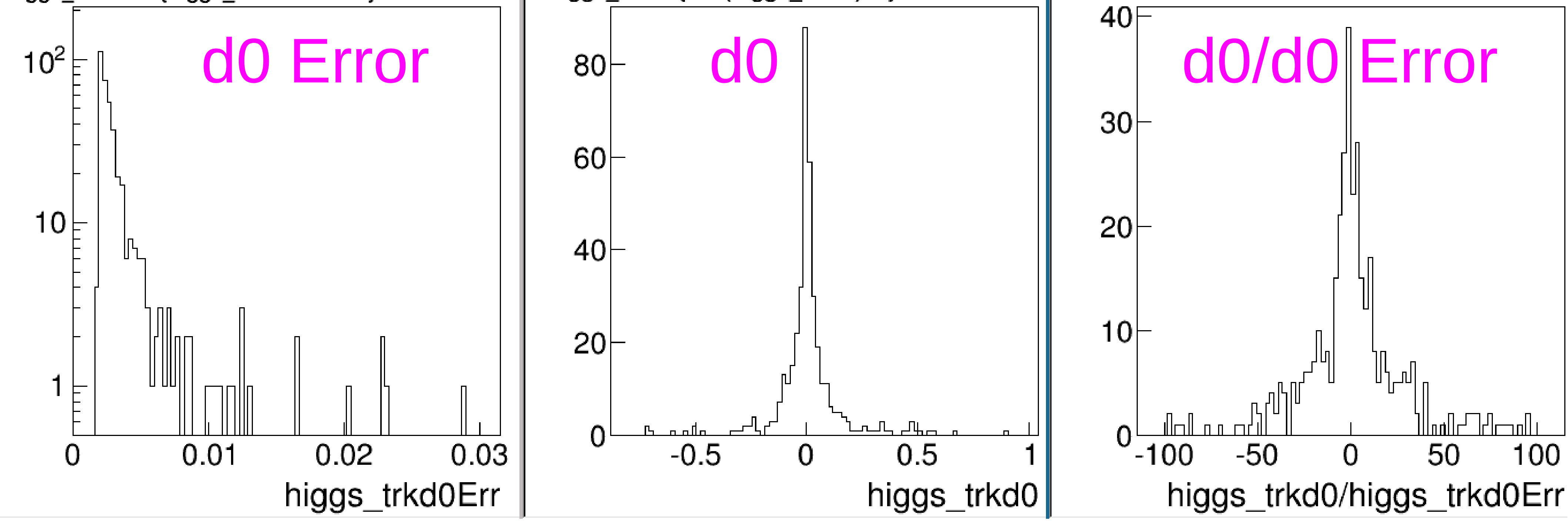
- total Energy
- invariant mass of sum of all ISR/BS photons ← zero if only on one side e.g. single ISR photon



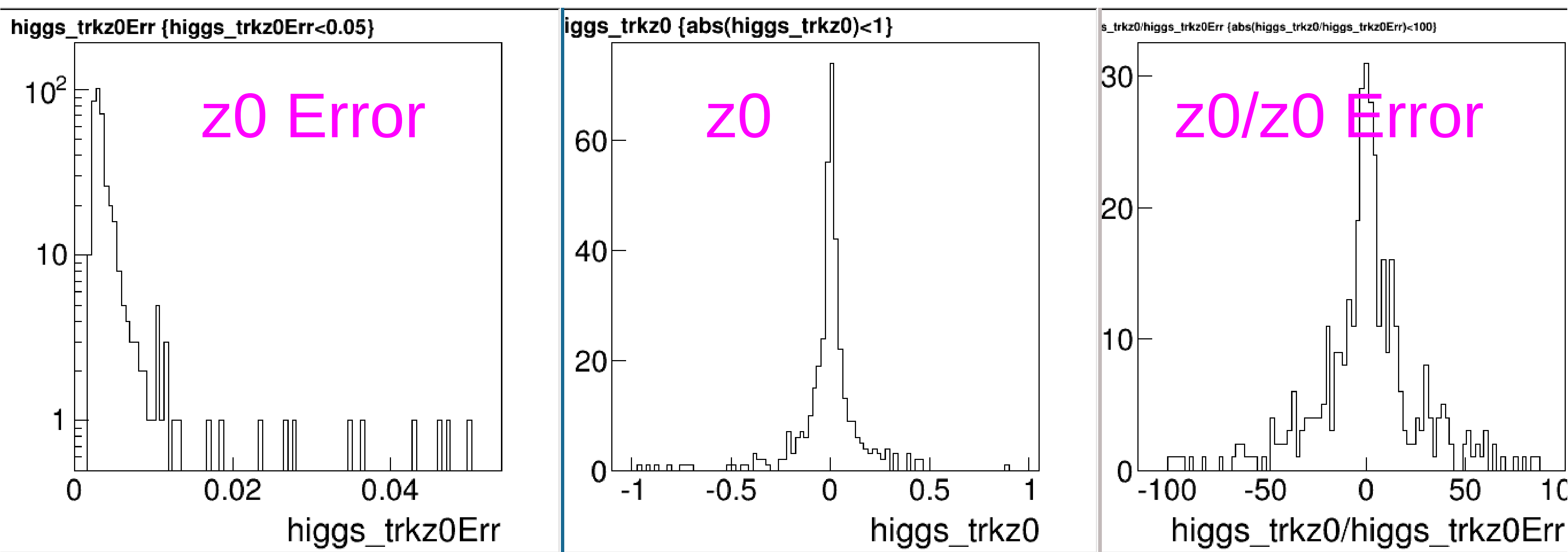
the reconstructed muon tracks

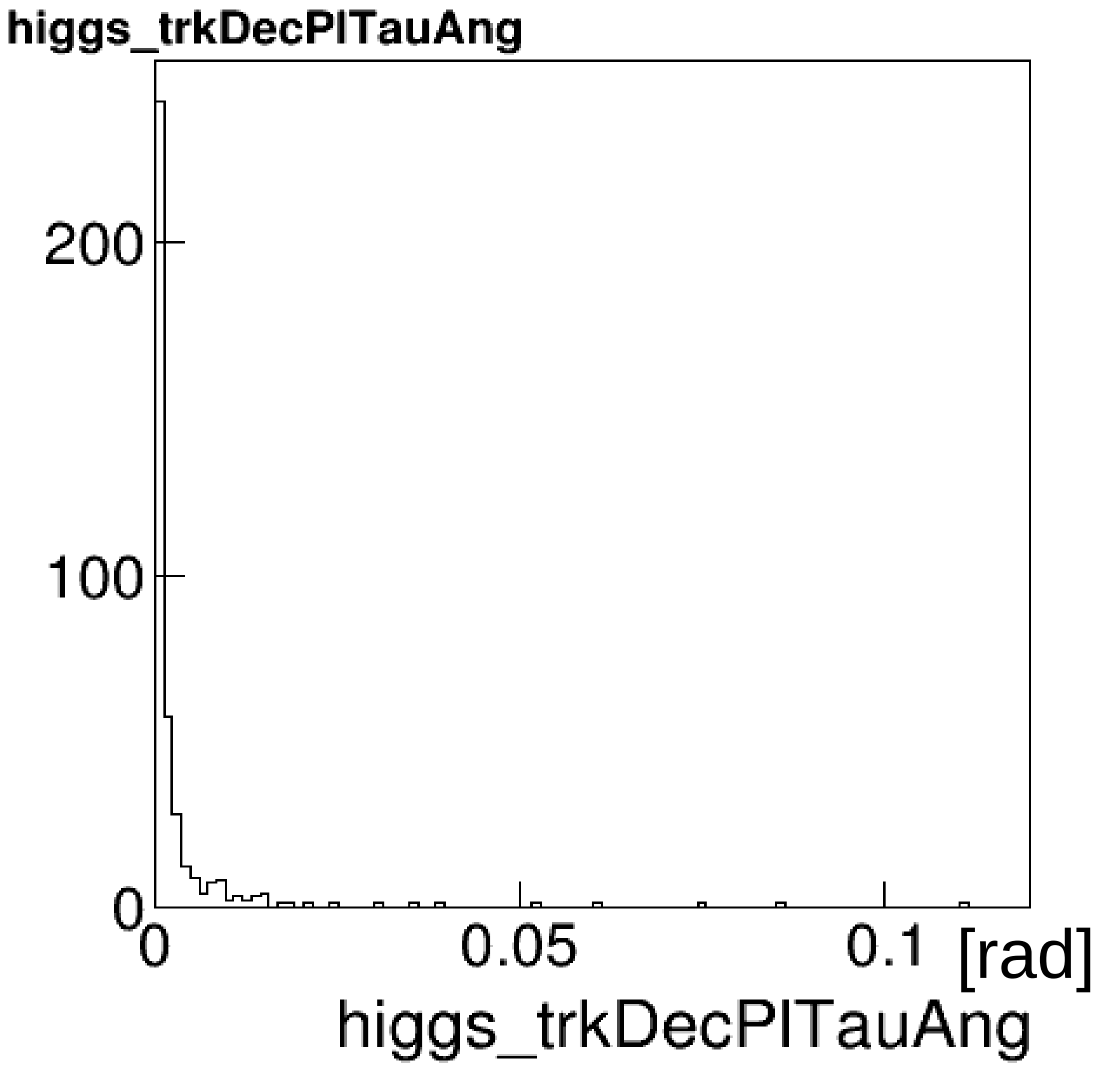






Charged pion track parameters [in mm]

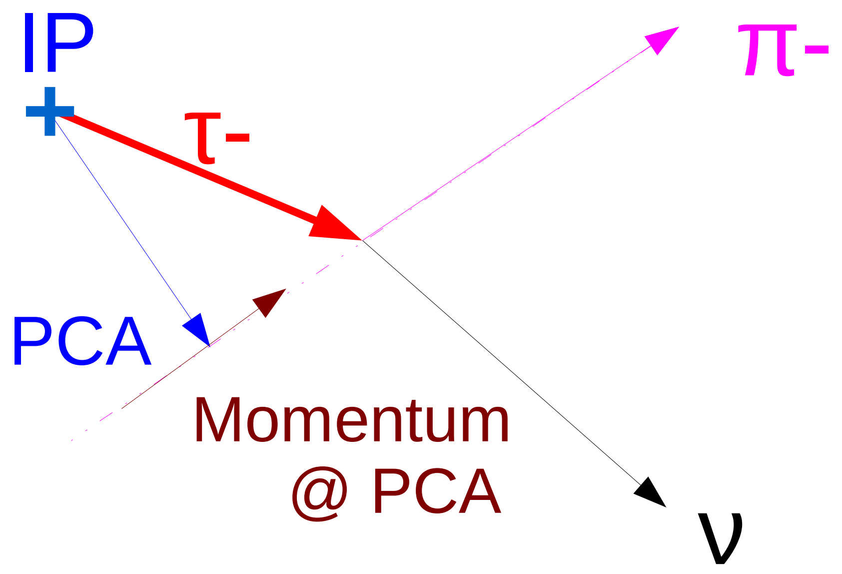




Cross-check

Angle between
MC tau momentum
and
reconstructed plane of
pion track

(should ideally be 0)



First approach:

Constrained kinematic fitting

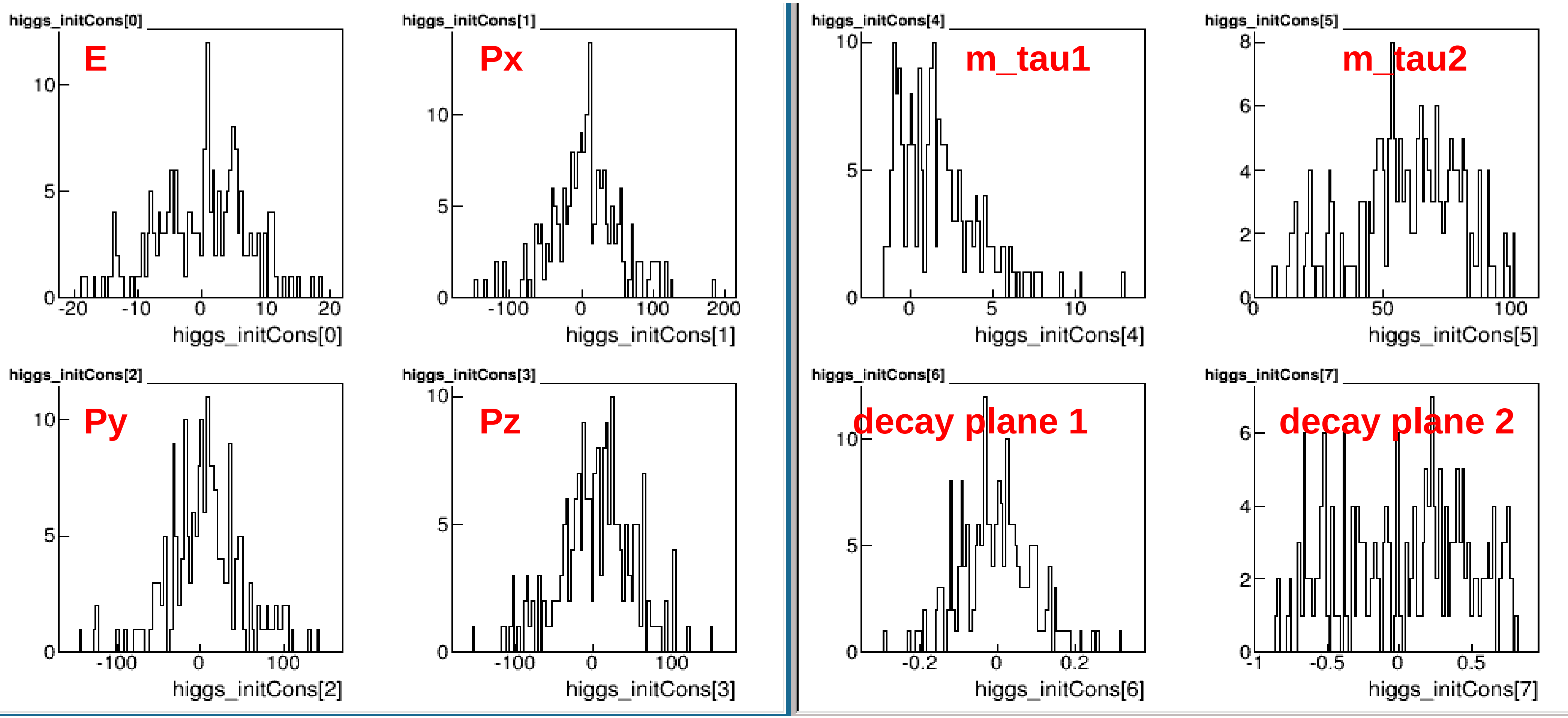
Using MarlinKinFit package
extended to use LCIO tracks (with full covariance matrix)
a lot of patient help from Jenny & Benno List

neutrino momenta: unknown parameters
muon & charged pion tracks: measured parameters
(ISR treatment also possible, using expected ISR distribution)

Overall 4-momentum constraint
Tau mass constraints
Tau decay plane constraints

Adjust measured and un-measured paramteters to satisfy constraints,
while minimising the “chisq” (deviations from measured values)

Choice of starting position for neutrino momentum
turns out to be rather important
here use randomly smeared direction around charged pion track

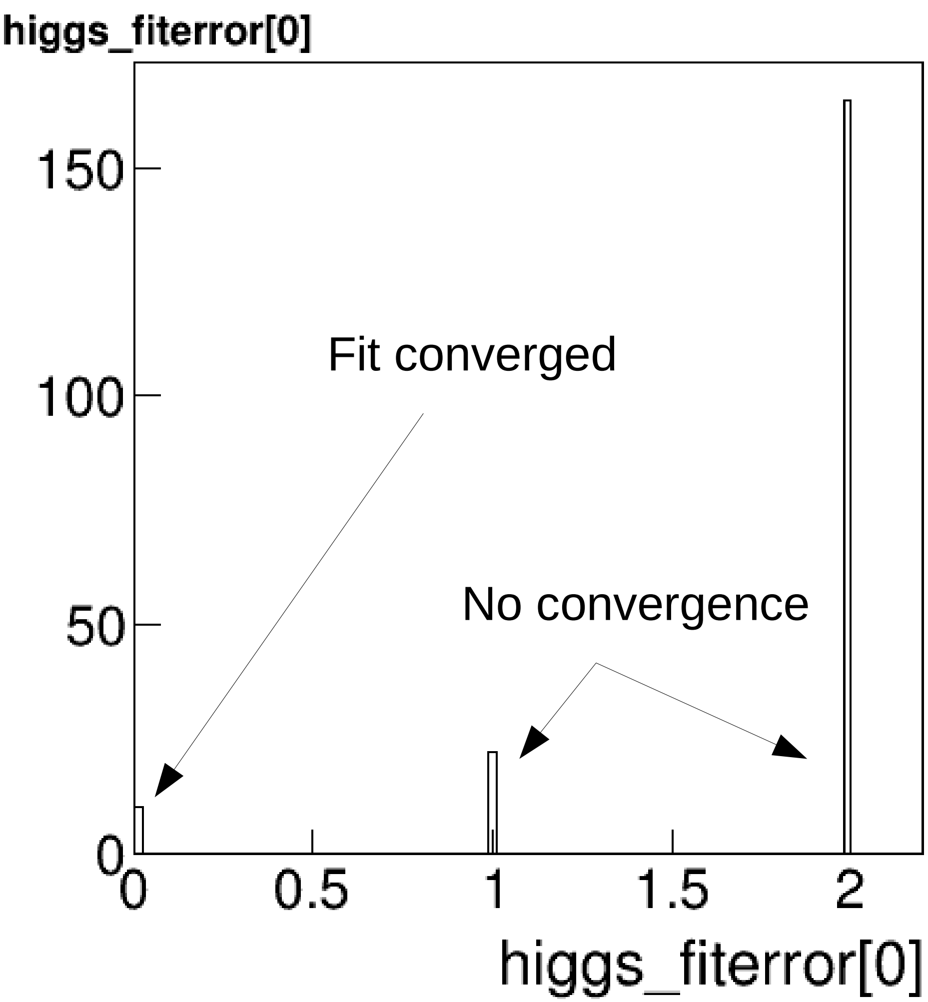


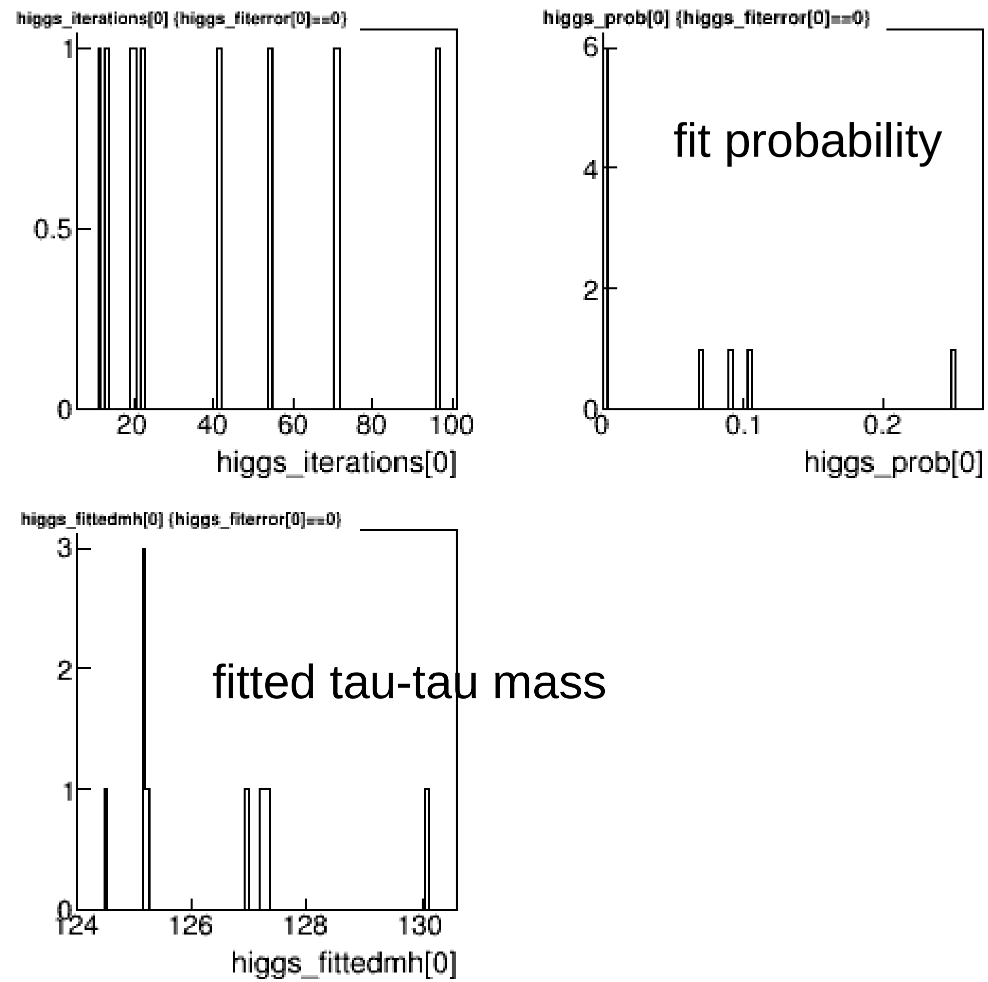
Value of constraints before fitting

far from being satisfied

Units are
GeV for momenta/masses
cos(angle) for decay plane

Fit results



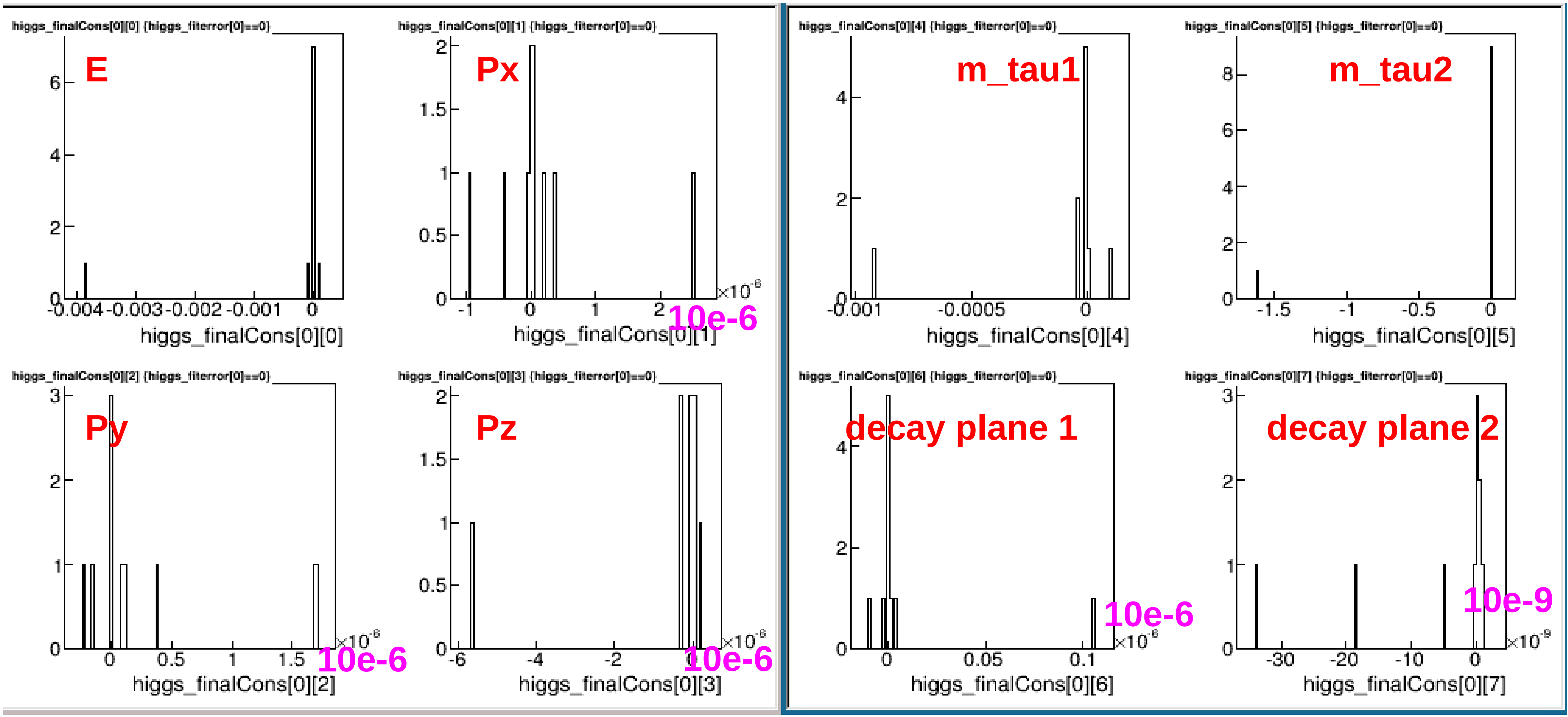


Only very small fraction of fits converge

Those that do look somewhat OK, but not great...

If initial guess for neutrino momenta are smeared around MC value, it works <u>much</u> better ← need better initial estimates

Value of constraints after converged fitting



Constraints well satisfied:
Fitter itself is working ~OK

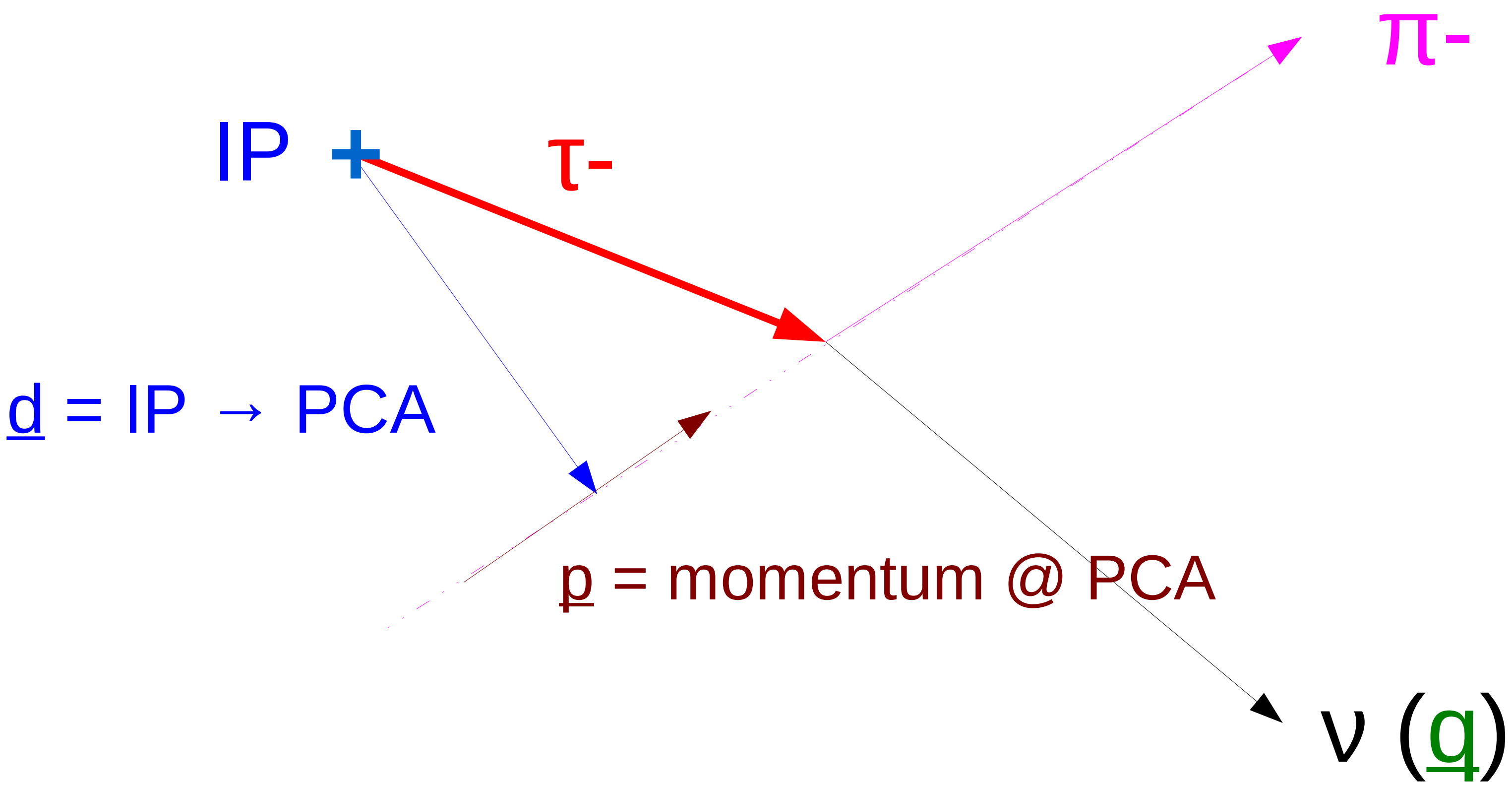
Units are
GeV for momenta/masses
cos(angle) for decay plane

It seems essential to have a good initial estimate of unknown quantities (neutrino momenta) before applying a constrained kinematic fit

Second approach:

Try to calculate the unknown quantities

Ignore uncertainties on measured quantities



d and p are perpendicular in x-y, but not in 3d

define d' = p x (d x p) ← inside p-d plane, perpendicular to p

neutrino momentum q lies in plane of d and p

so we can write: q = |q| (cosψ p* + sinψ d'*)

where x* is a unit vector: x / |x|

We know that the invariant mass of (p + q) is m_{tau}

so we can calculate the neutrino energy |q| for each value of ψ

For a given event, we can then see how the

total event **pT** (muons, pions, neutrinos)

should be ~0, even with lost ISR

depends on the

angles **ψ1, ψ2** (for the 2 taus)

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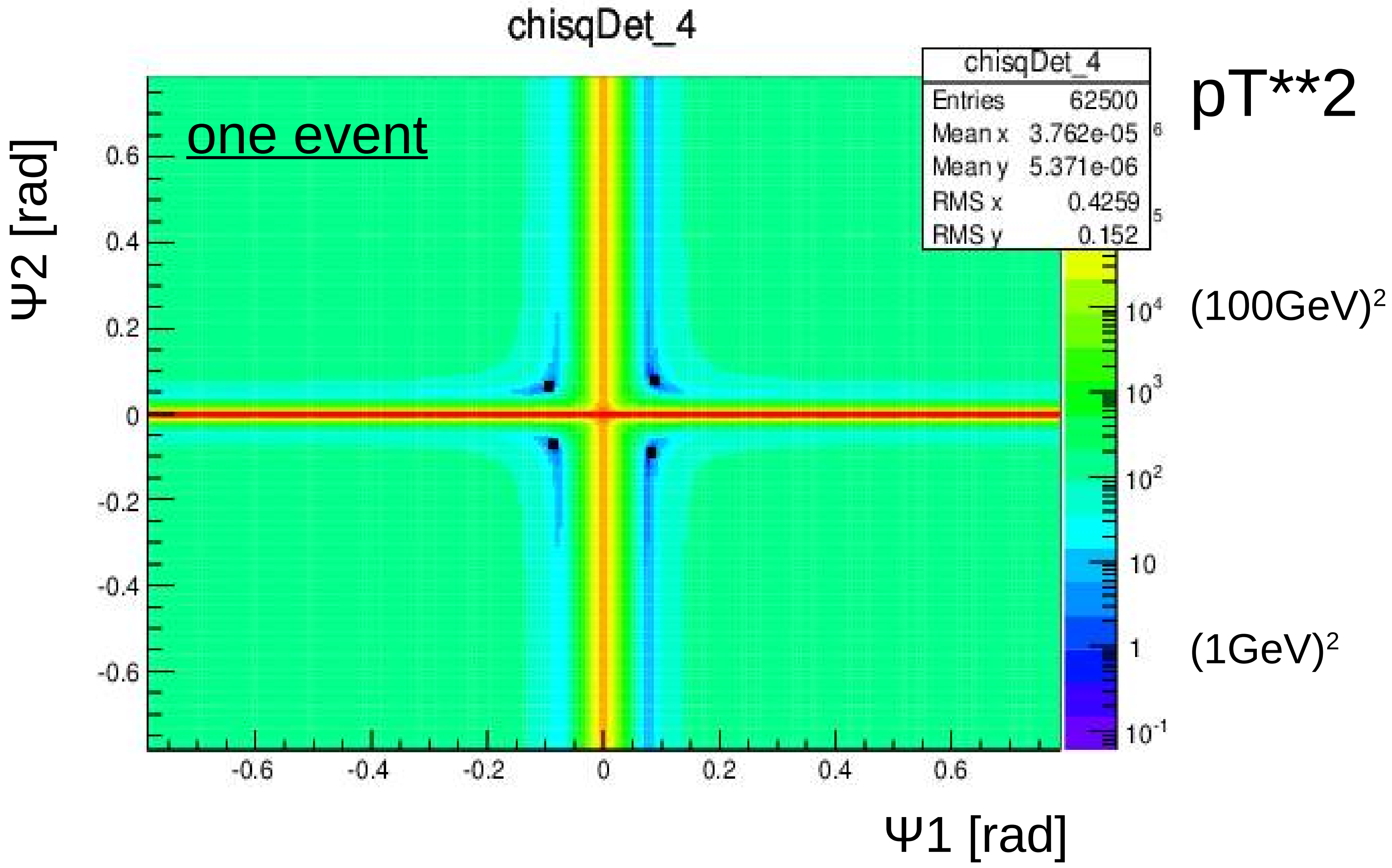
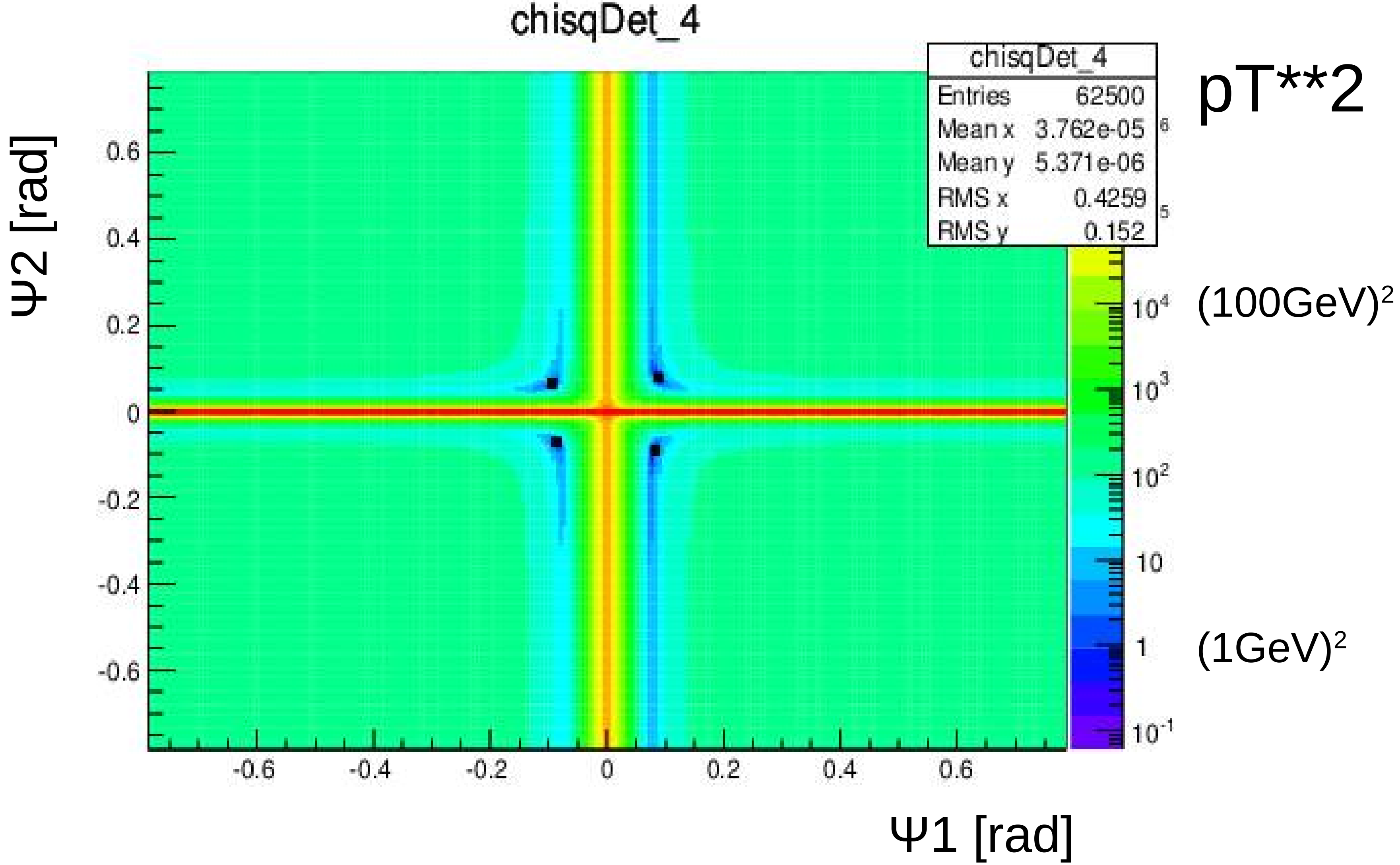


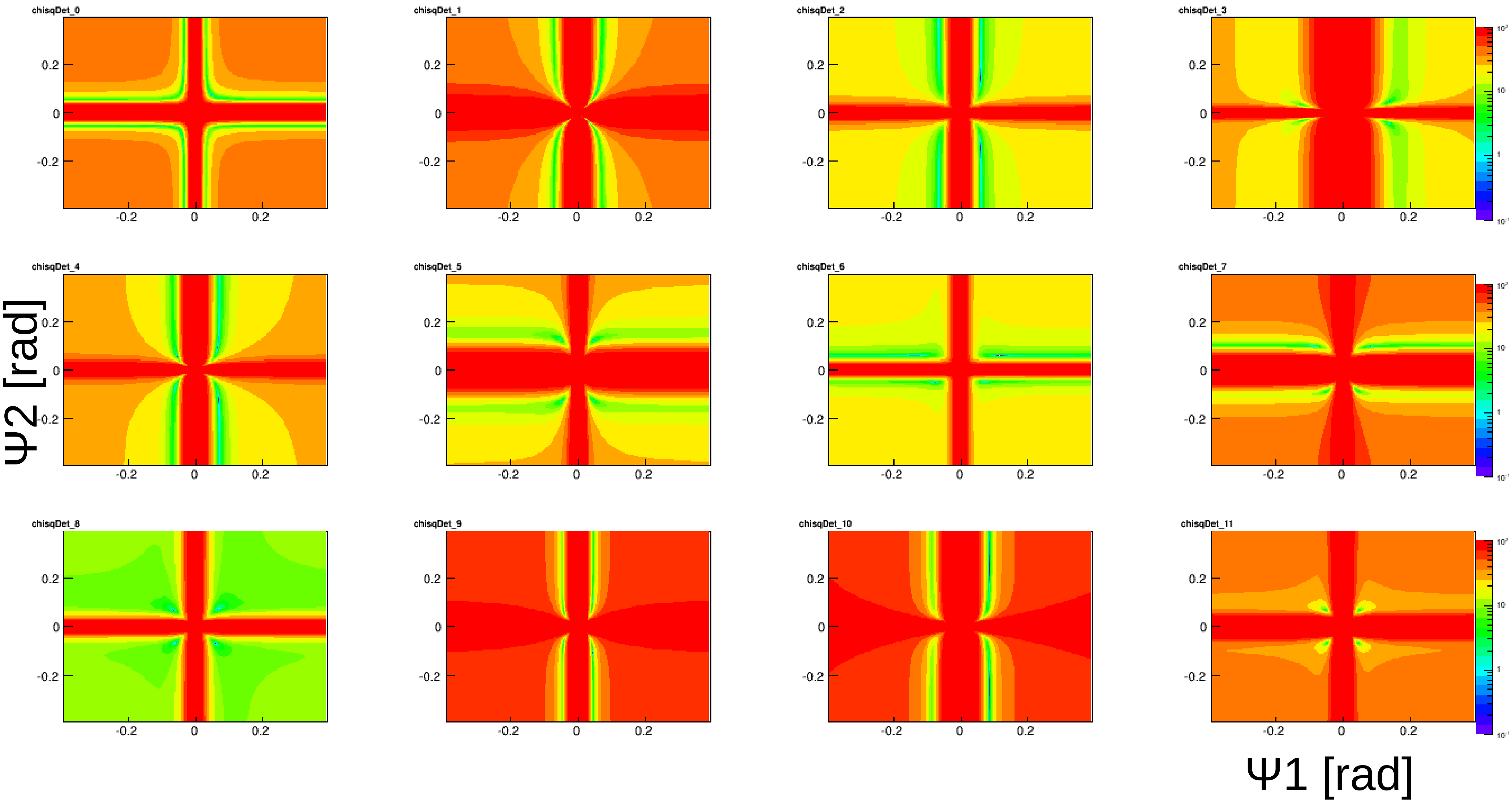
Ψ = 0 corresponds to neutrino colinear with pion
needs large energy to make tau mass
gives very large pt imbalance

$q = |q| (\cos\psi\, p^* + \sin\psi\, d^*)$

We can see local minima in each of the 4 quadrants
Is the nu momentum on the d = +ve or -ve side of the pion momentum



A few more events:



color = pT (0.1 1 10 100) GeV

by requiring pt-balance in the event [sum px = sum py = 0]

it is possible (but somewhat messy) to calculate the angles Ψ

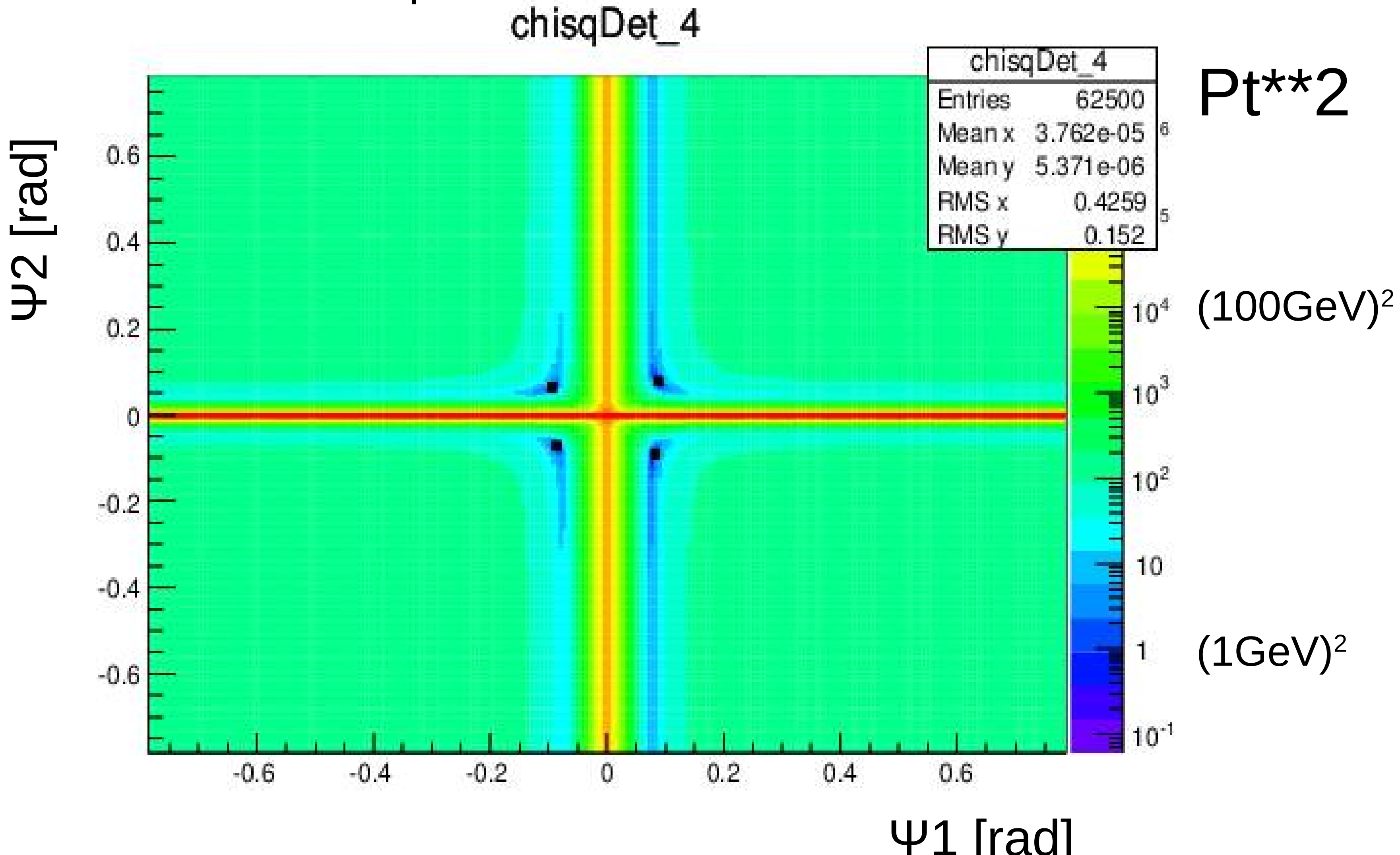
due to finite resolution of measured quantities,

a real solution is not always possible

More robust approach is to do a

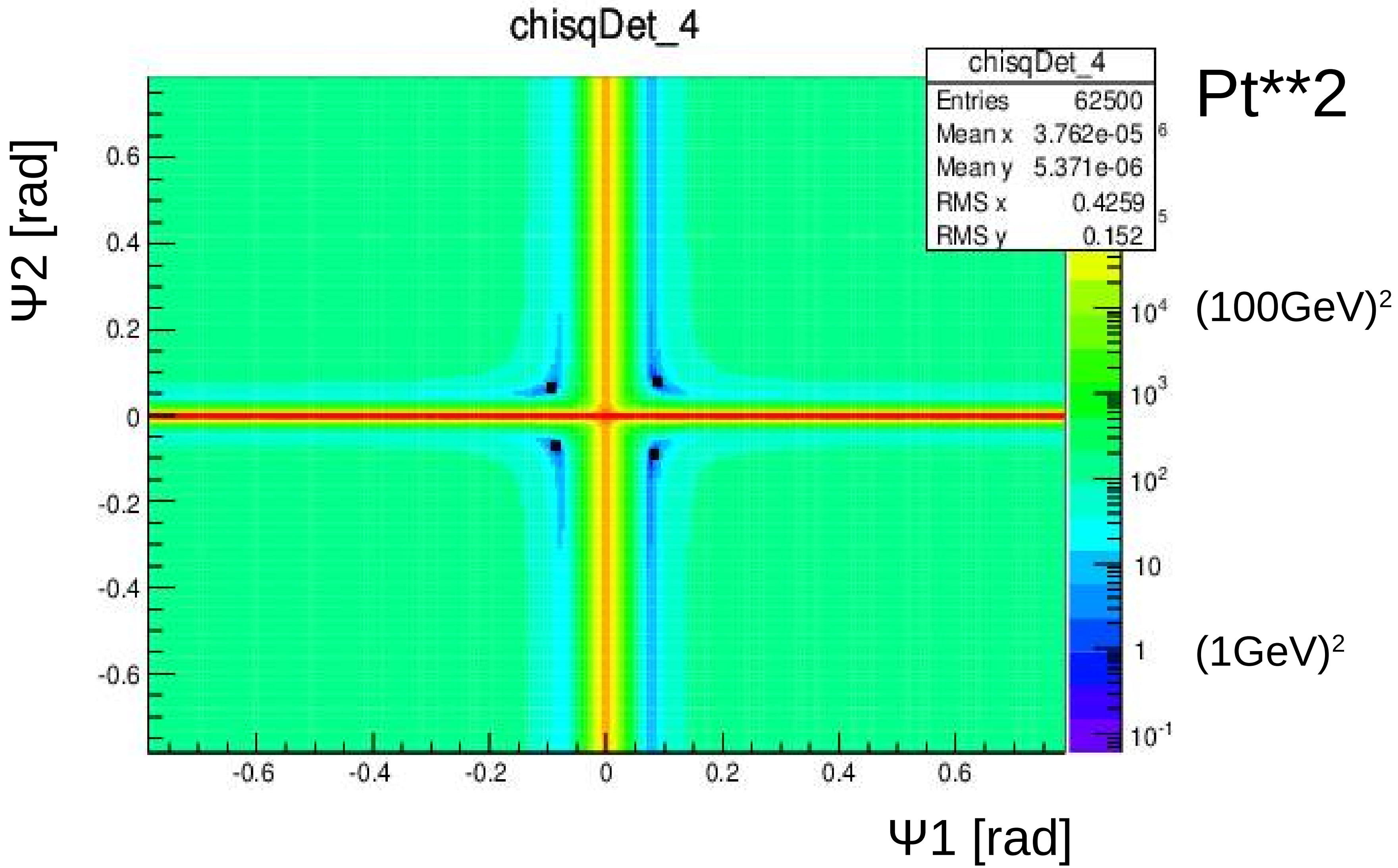
standard minimisation [i.e. not a constrained fit]

to minimise the event pT



Minuit minimisation separately in each quadrant (no constraints needed)
→ Four solutions

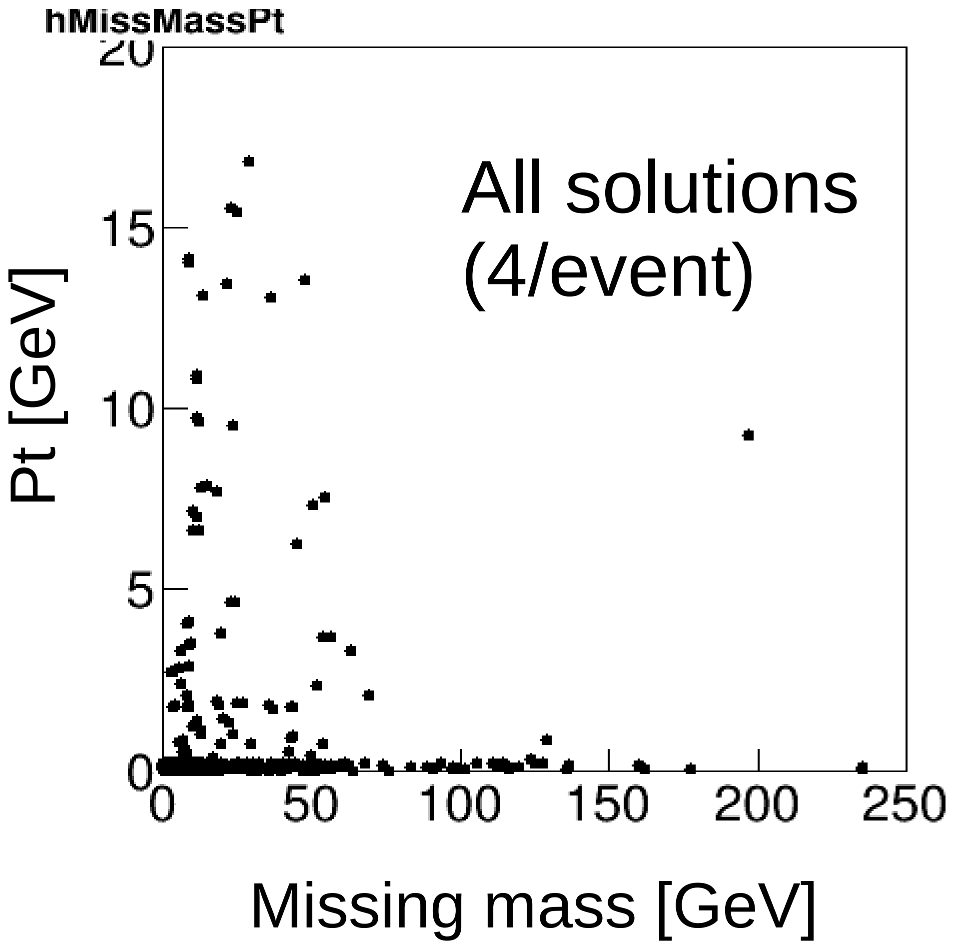
How to choose which one is the best?
- Value at minimum ← pt as small as possible
- Comparison of |pz| and missing energy ← same, if 1 ISR photon
- invariant mass of 2 taus (if we assume presence of Higgs)

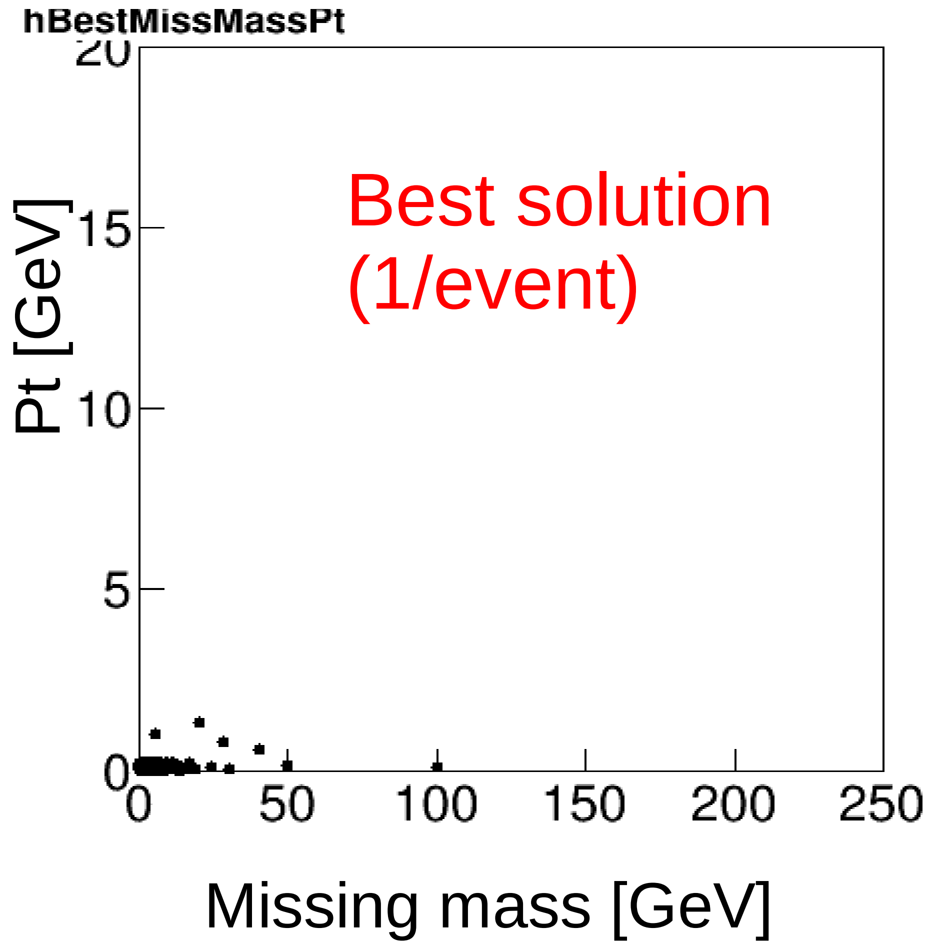


For now, define “best” solution as one with smallest value of

pT + missing mass

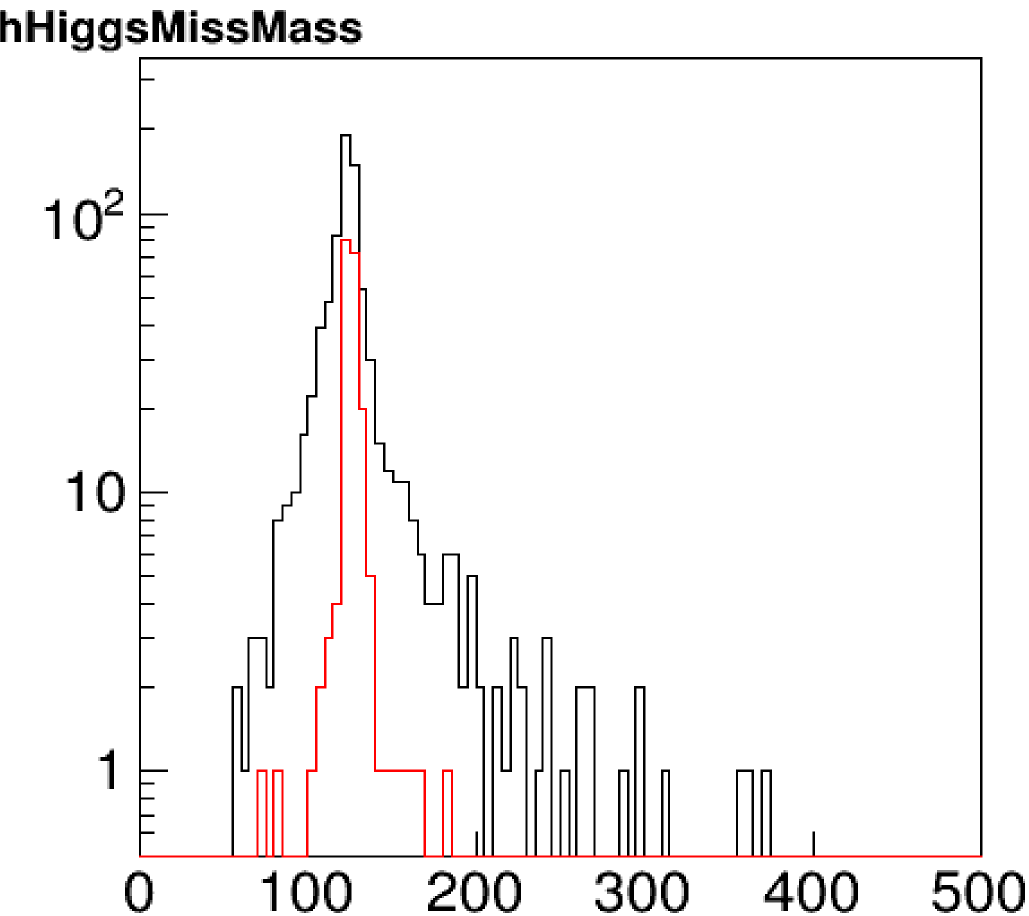
If we have zero or one ISR photon, missing mass = 0



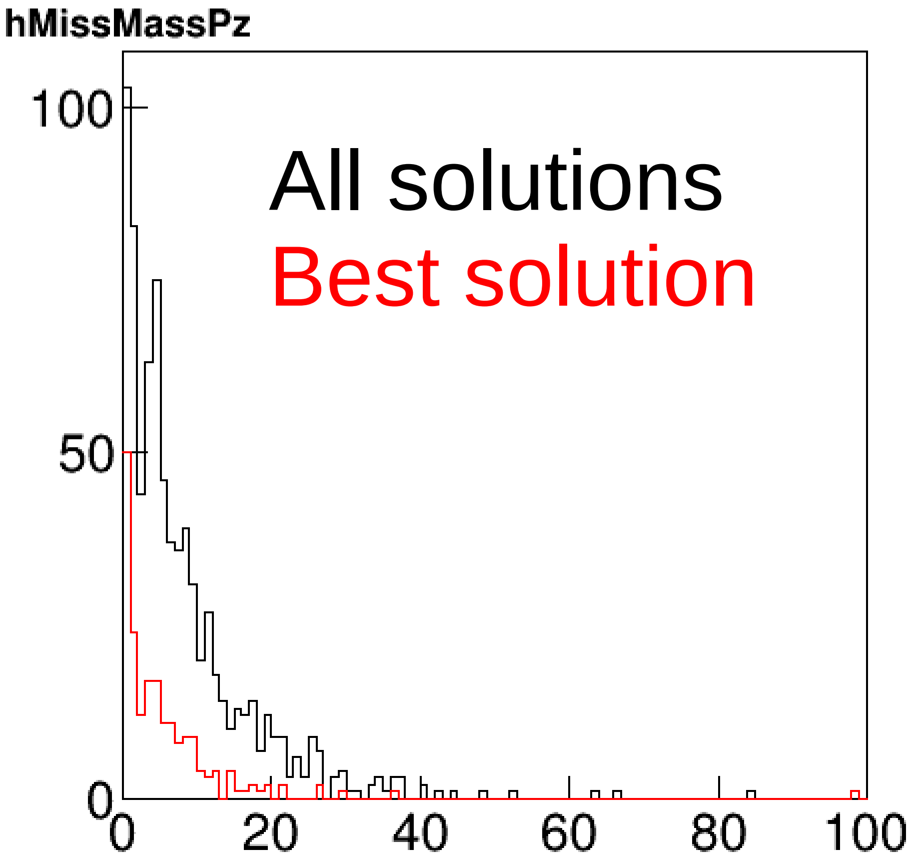


Check: Invariant mass of two taus, total pz (*e.g.* of ISR)

n.b. we have not used these in any part of the analysis



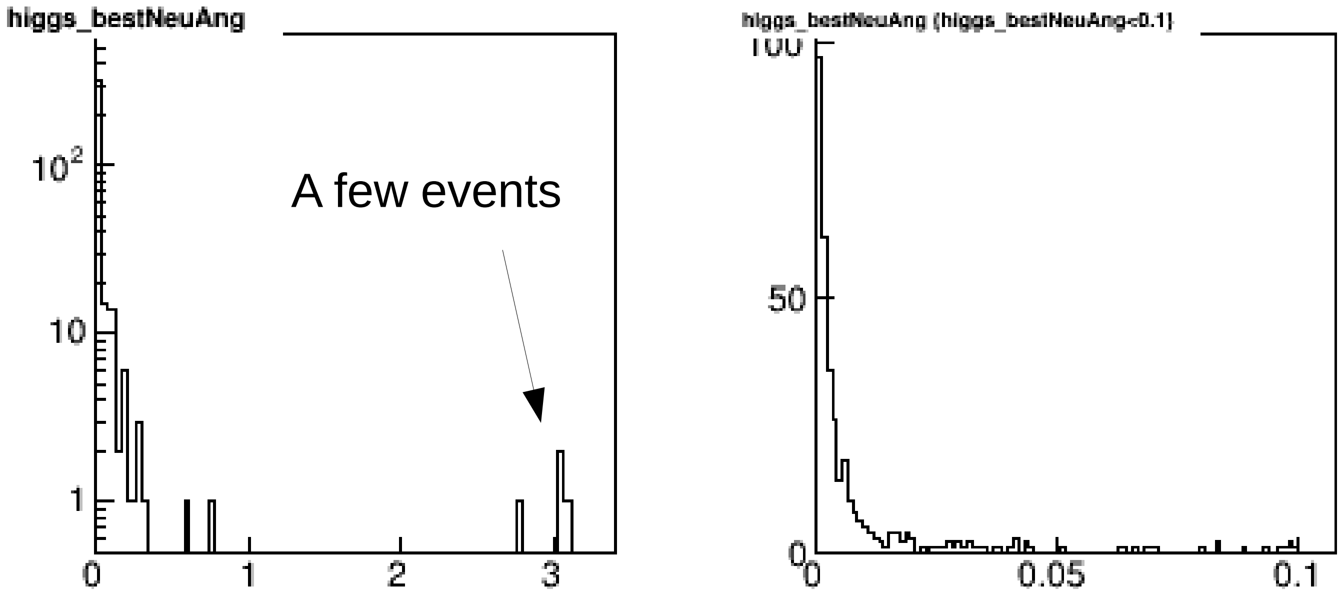
tau-tau mass [GeV]



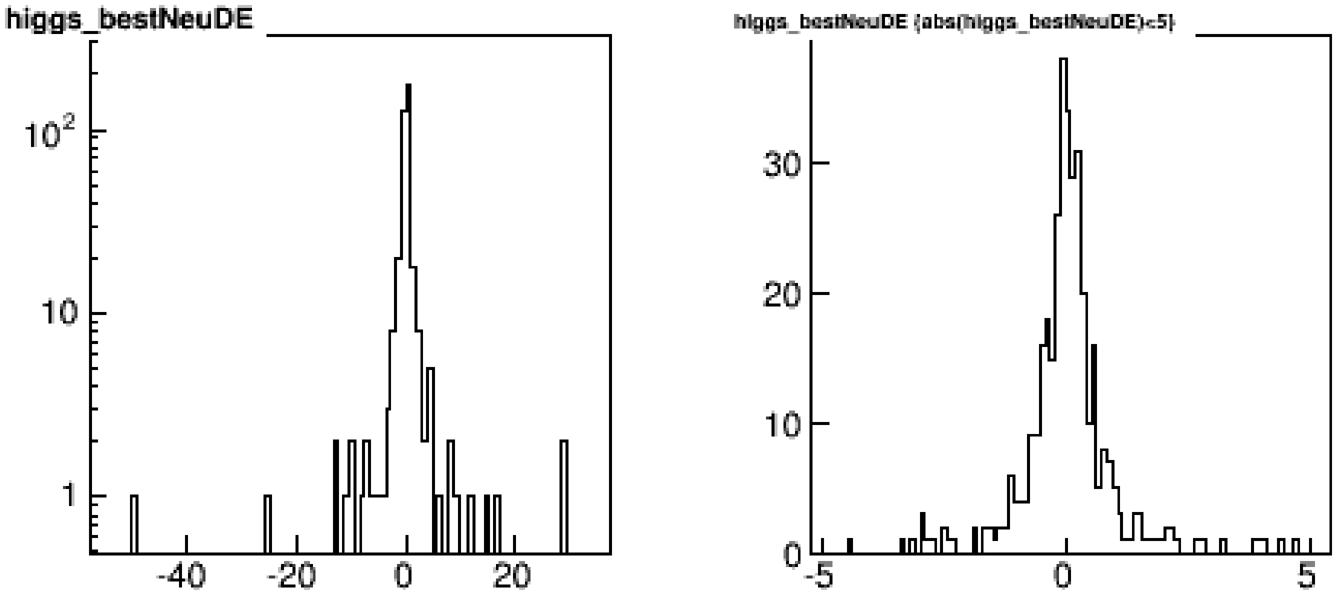
|pz| [GeV]

Compare fitted and true neutrino energies and directions

Only best solution



Angle between MC and fitted neutrinos [rad]

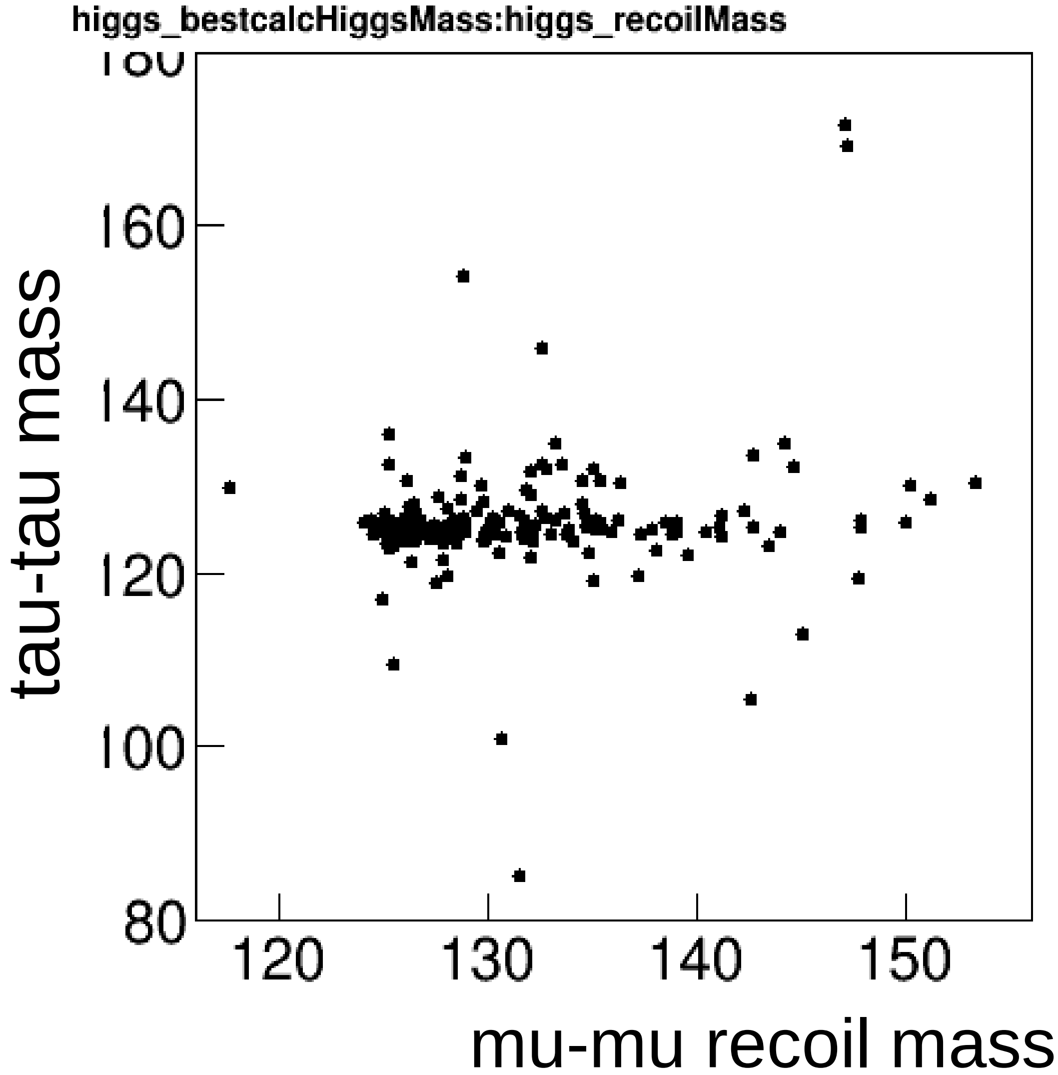


MC – fitted neutrino energy [GeV]

Precision typically
< ~ 10 mrad
< ~ GeV

recoil mass (from muons) vs. reconstructed tau-tau mass

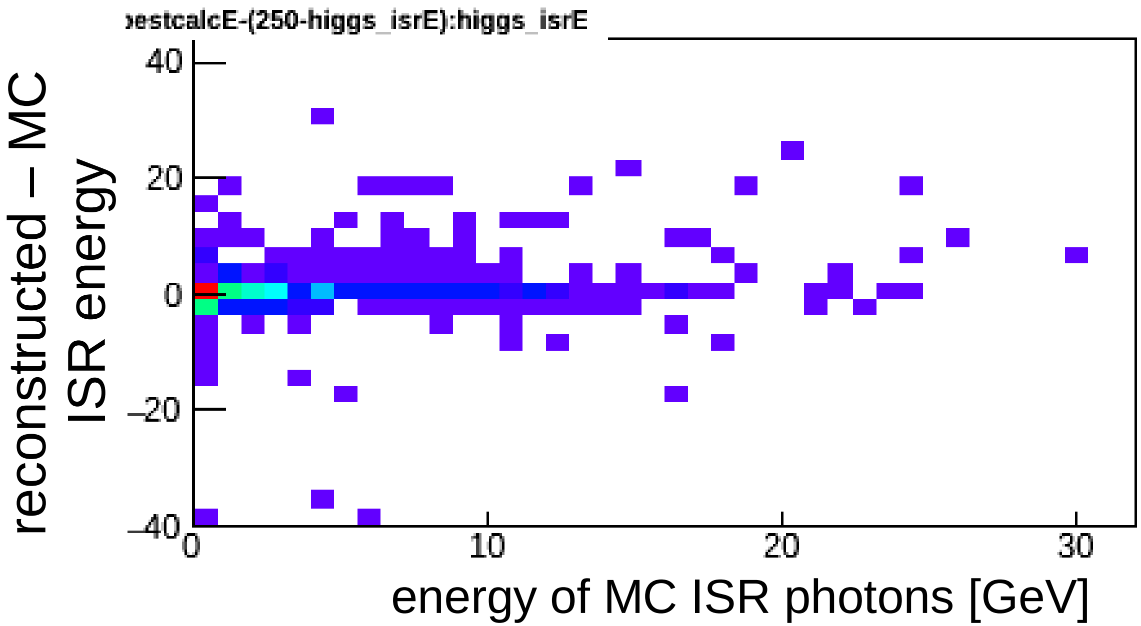
Only best solution

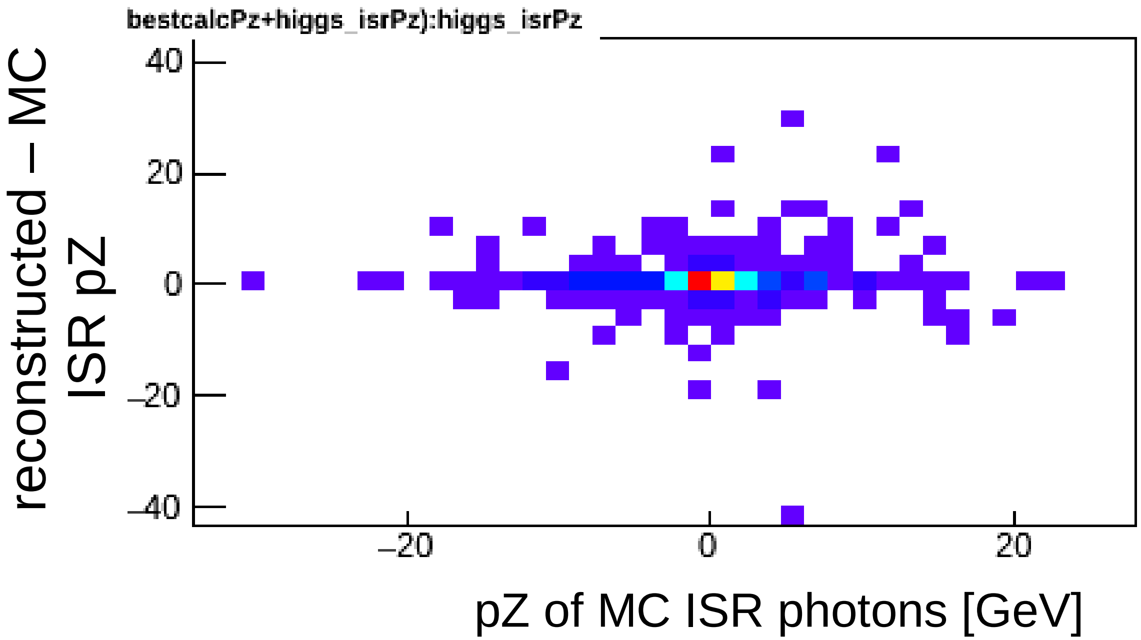


As expected, this method of mass reco not affected by ISR

unlike recoil mass

How well is ISR/BS energy and pZ reconstructed?





Summary

It's interesting to try to fully reconstruct taus:

- they can act as “polarimeters”
  - → can reconstruct their spin state by looking at their decay products

The ILC machine and detectors have great potential for tau reco:

- tiny beam spot
- high precision vertex detector

In hadronic tau decays of (tau tau + “X”) processes

- we can calculate the tau neutrino momenta with good precision
  - if we can measure pT of “X”
    - If this is not possible, other approaches may be possible
      - → make different assumptions about event

Kinematic fitting should give some improvements in precision

- take account of uncertainties in measured quantities
  - tools are ~in hand

Things to do next:

- apply kinematic fit on the identified (best) solutions
  - may improve the resolution

- apply to tau → rho nu decay mode
  - I think (almost) same method can be used

    Multi-prong decays should be easier
      - Identify vertex → tau momentum direction

    Leptonic decays need more constraints
      - maybe if only one tau decays leptonically,
        - something can still be done with some extra assumptions

- apply to Higgs CP measurement