Reconstruction of τ using impact parameters

e.g. e+ e- → (H → τ τ) (Z → μ μ)

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August 2015

Some tau decay modes:

Simplest case

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

Largest BR

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

Leptonic

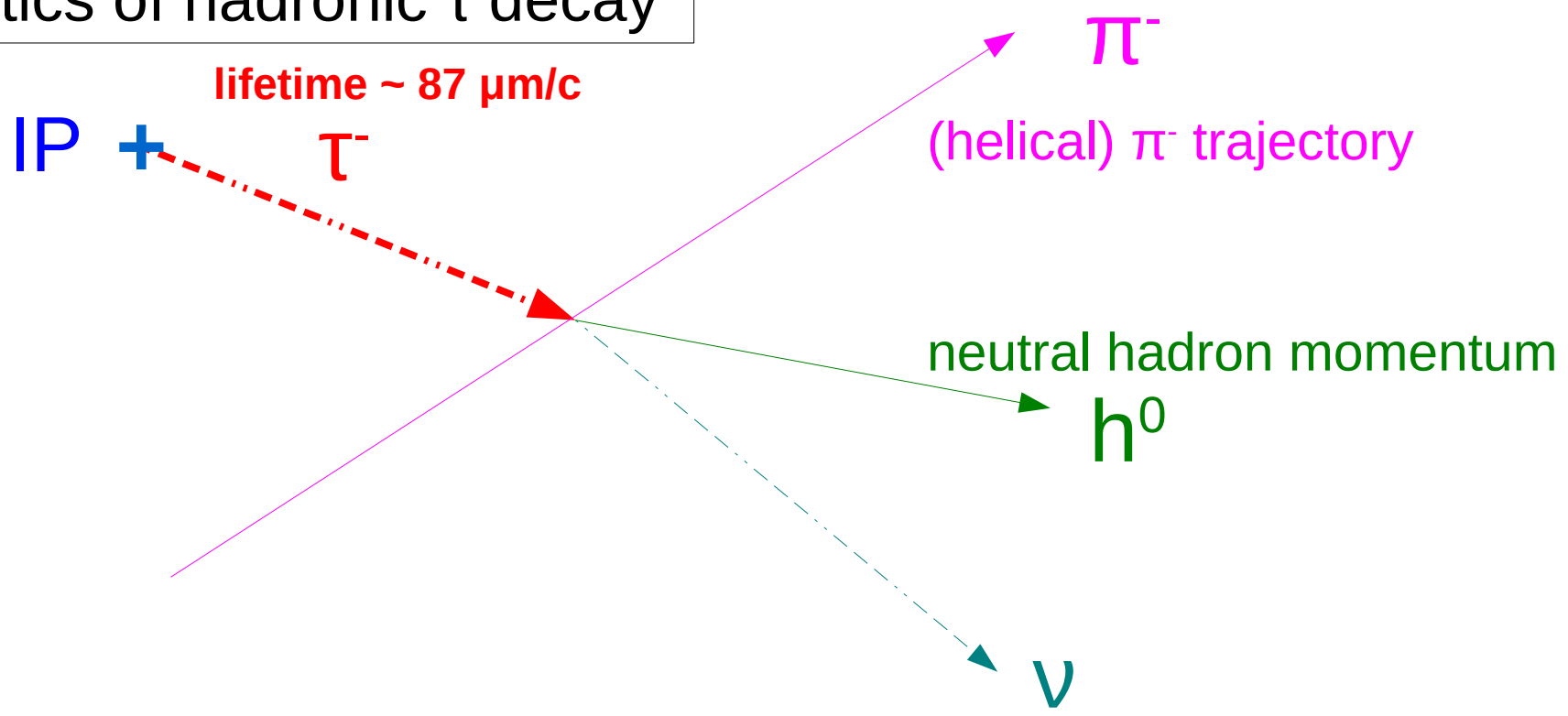
~35% $\tau^+ \rightarrow (e/\mu)^+ \nu \nu$

two missing neutrinos ← limited information, ignore for now

We would ideally like to fully reconstruct the tau momentum and its decay products

However, τ always decays into at least one neutrino

kinematics of hadronic τ decay

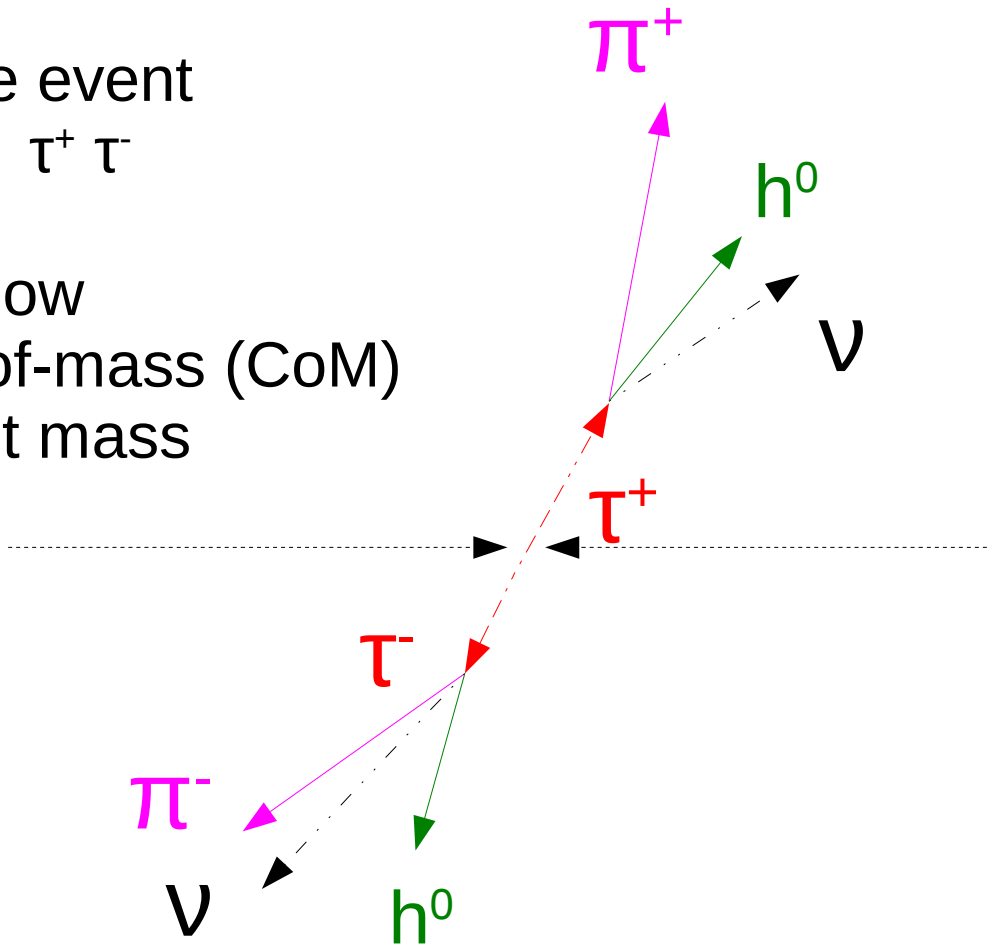


To optimally use events with taus,
want to fully reconstruct the τ
how to reconstruct the invisible neutrino momentum?

<u>traditional method</u>
e.g. LEP, BELLE, …

consider whole event
e.g. $e^+ e^- \rightarrow \tau^+ \tau^-$

<u>assume</u> we know
τ-τ centre-of-mass (CoM)
τ-τ invariant mass



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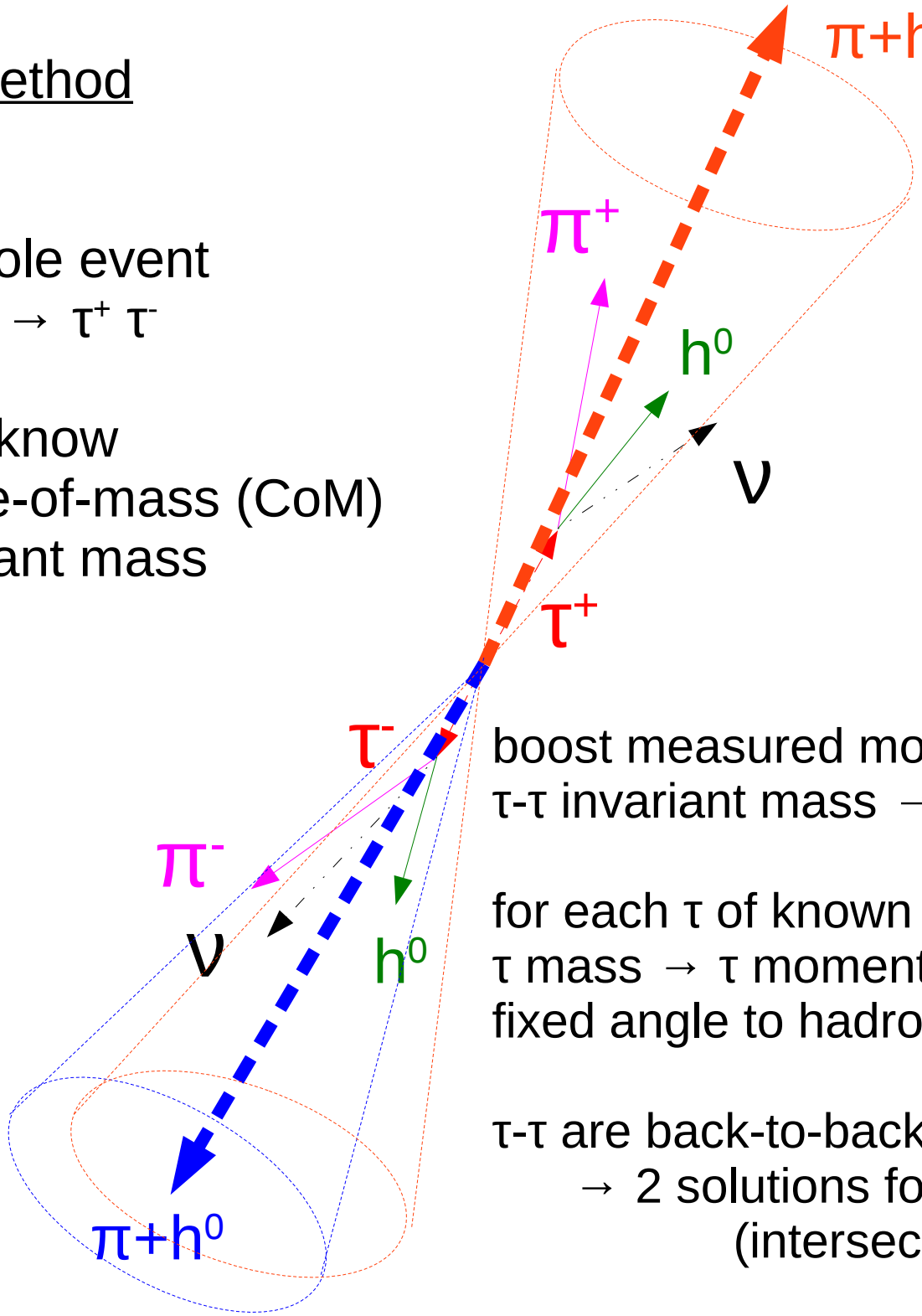


event in τ-τ CoM

cone angle depends
on assumed τ energy

boost measured momenta into CoM
τ-τ invariant mass → τ energy

for each τ of known energy:
τ mass → τ momentum at
fixed angle to hadronic momentum (cone)

τ-τ are back-to-back in CoM:
→ 2 solutions for τ momentum
(intersections of 2 cones)

traditional method

Limitations:

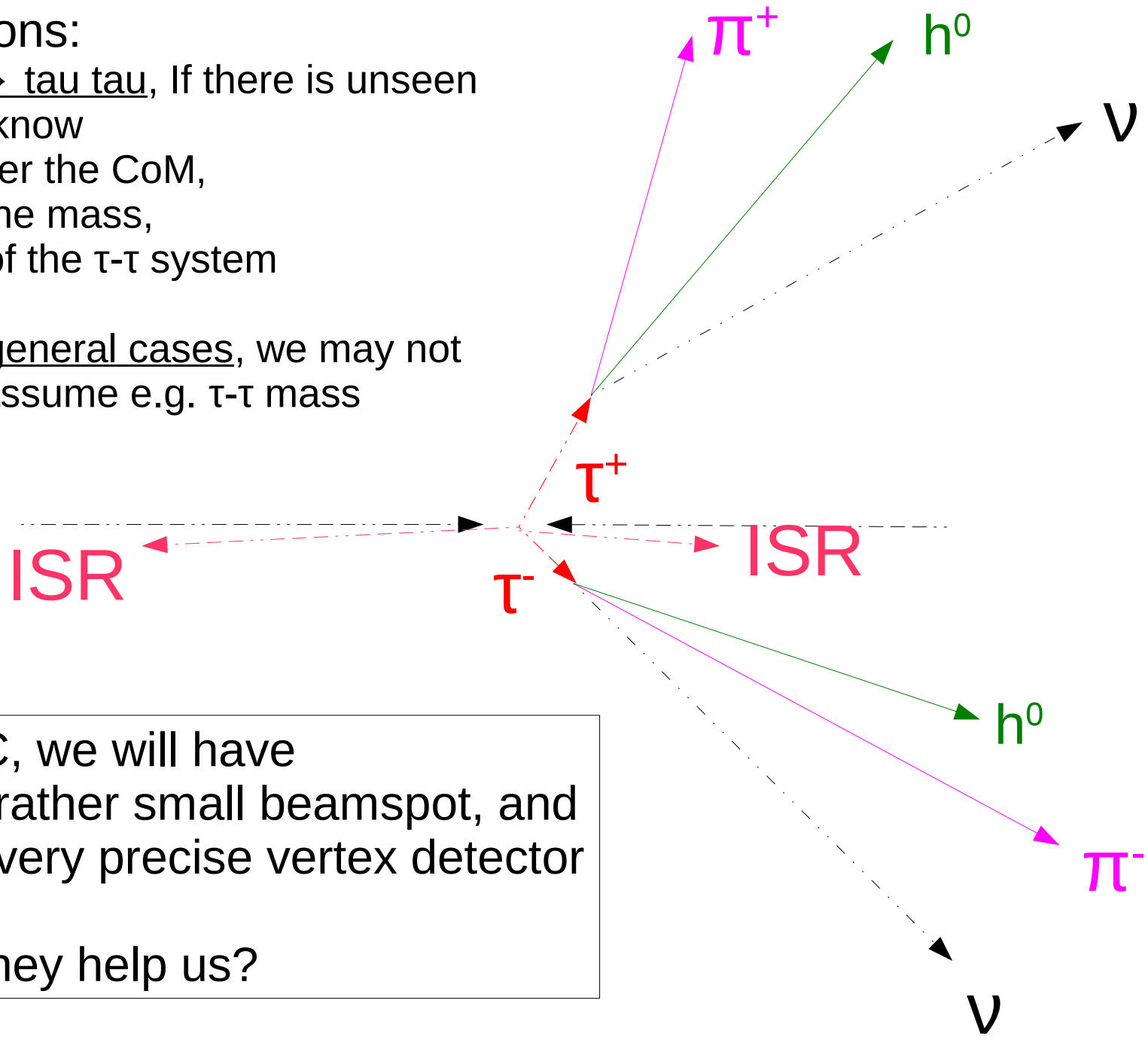
in e+e- → tau tau, If there is unseen ISR, we know

neither the CoM,

nor the mass,

of the τ-τ system

in more general cases, we may not want to assume e.g. τ-τ mass



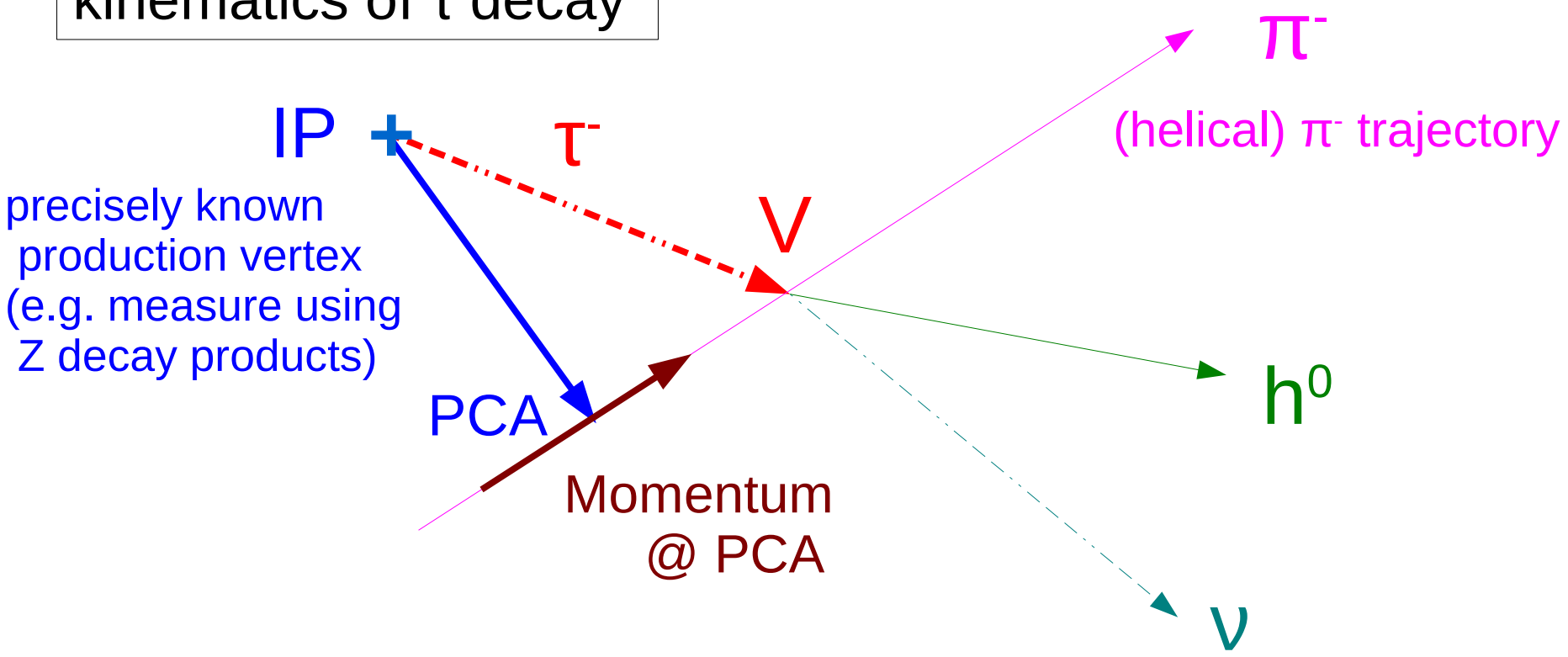
at ILC, we will have

a rather small beamspot, and

a very precise vertex detector

can they help us?

kinematics of τ decay



assume that π/τ trajectory is approx linear between PCA/IP and V

OK since typical radius of curvature >> τ decay length

measured "track plane" defined by IP-PCA and Mom@PCA

(these two vectors are perpendicular)

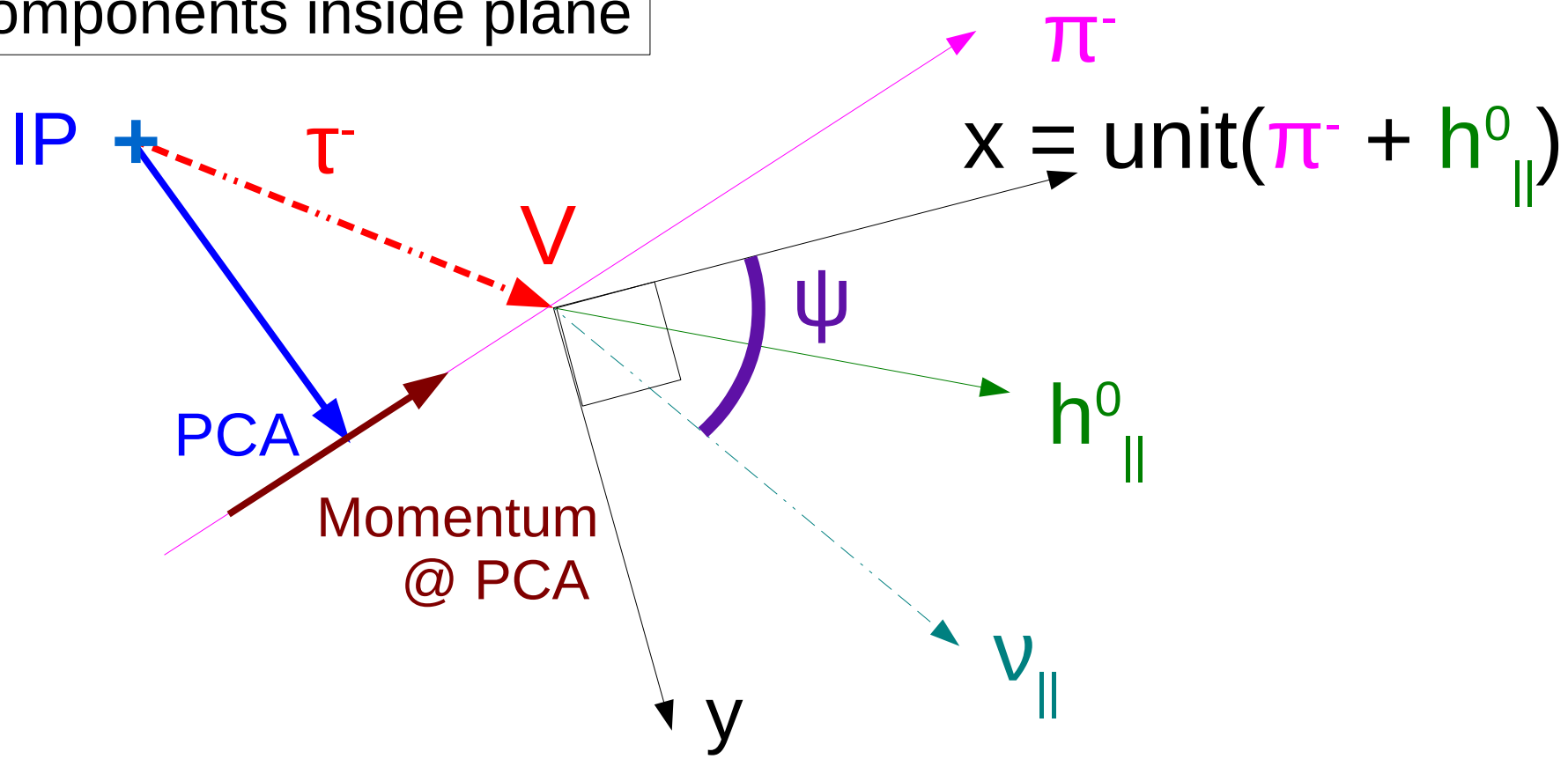
- τ momentum lies inside track plane (linear approx.)

→ (h^0 + ν) momentum lies in track plane

→ ν momentum out of plane = - h^0 momentum out of plane

ν_{perp} = - h^0_{perp}

only components inside plane



parameterise ν momentum inside plane

x is unit vector parallel to hadronic momentum inside plane

y is unit vector in plane, perpendicular to x

Q is magnitude of momentum in plane

$$\nu_{\parallel} = Q\,(\,x \cos\psi + y \sin\psi\,)$$

So we can write the neutrino momentum as

$\nu = Q\,(\,x \cos\psi + y \sin\psi\,) - h^0_{perp}$

two unknown parameters, Q and ψ

4-momentum of $\tau = \pi + h^0 + \nu$

invariant mass of τ is well-known

→ for each choice of ψ can calculate Q (2 solutions)

→ calculate full kinematics of τ for an assumed ψ
including lifetime

often one solution gives a negative lifetime,
and can be rejected

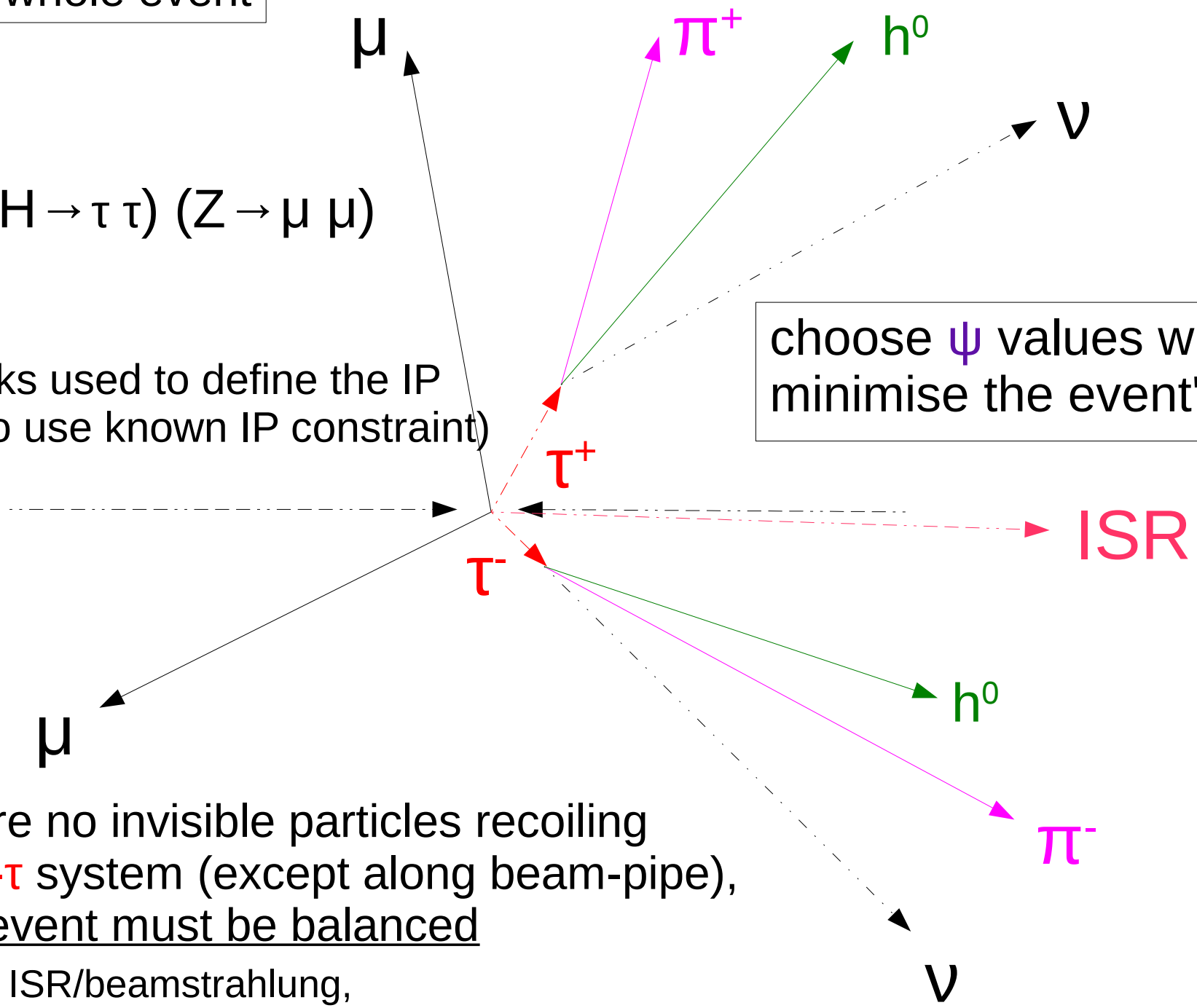
we have reduced the problem of finding ν momentum to:

HOW TO CHOOSE ψ ?

consider whole event

e.g.

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



muon tracks used to define the IP
(could also use known IP constraint)

choose ψ values which minimise the event's p_T

If there are no invisible particles recoiling against τ-τ system (except along beam-pipe),

$\underline{p_T}$ <u>of event must be balanced</u>

because of ISR/beamstrahlung,
don't make requirements on p_z

$e^+ e^- \rightarrow H\ \mu+\ \mu-$ events generated @ 250 GeV Whizard with CIRCE1 ISR/BS

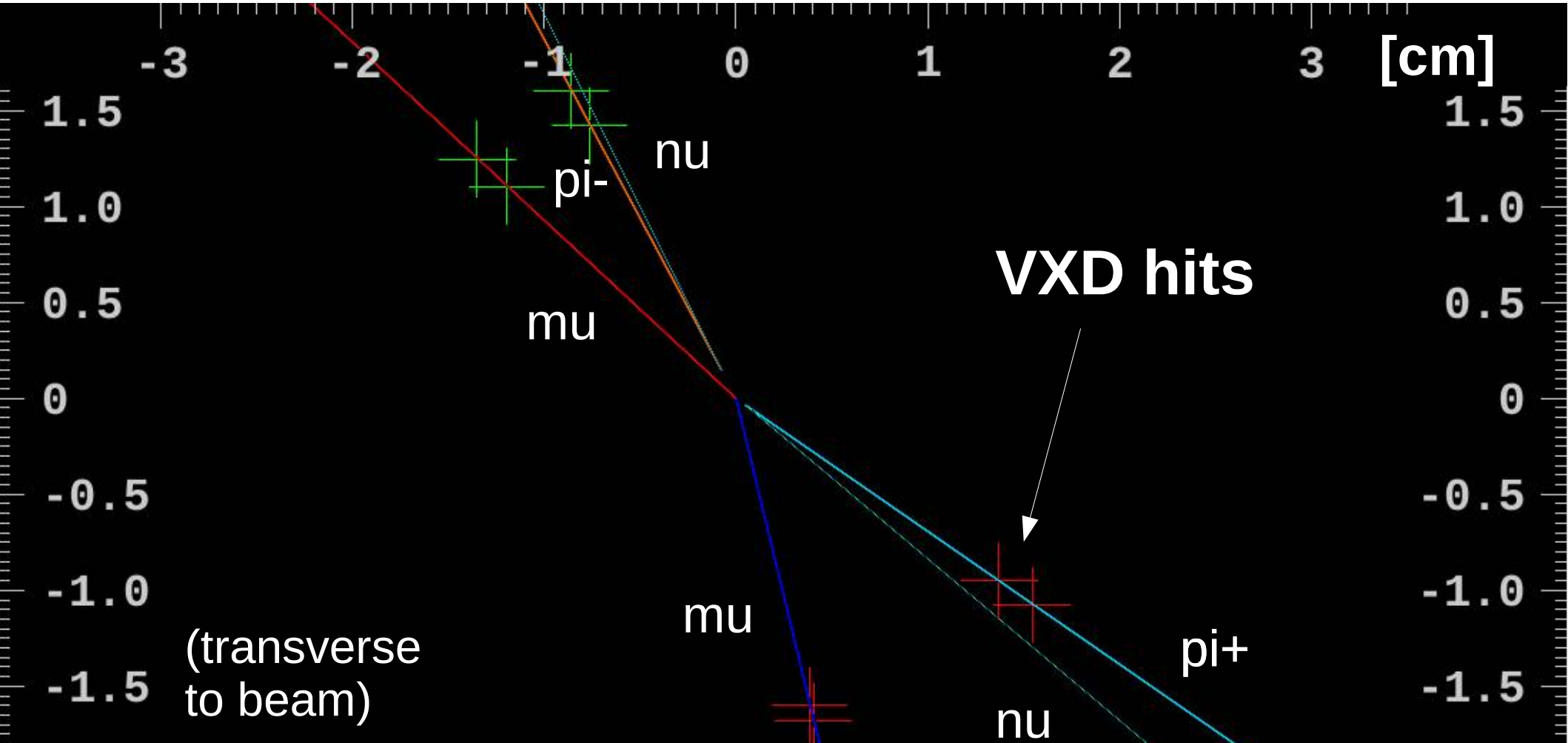
$H \rightarrow \tau\tau$; τ decayed by TAUOLA: either both $\pi^+\nu$ or both $\pi^+\pi^0\nu$ ($\rho\nu$)

Full ILD simulation, DBD version ILD_v05_o1

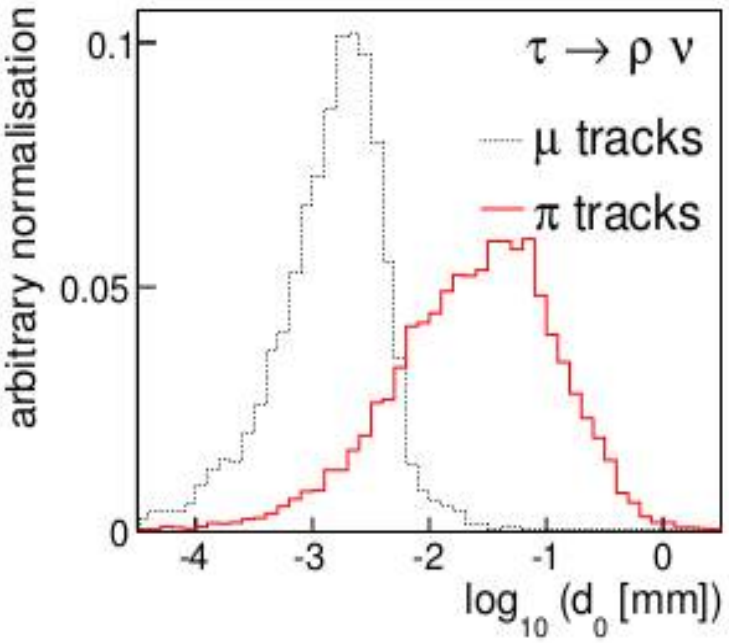
Usual ILD reconstruction + GARLIC, no underlying event overlay

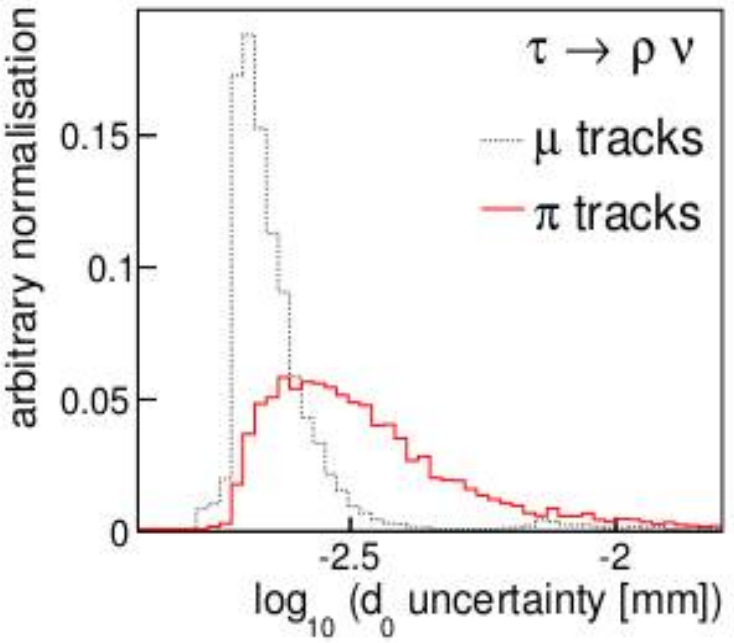
Cheat matching of GARLIC/Pandora clusters to π^0, and of π^0 π^+ to τ

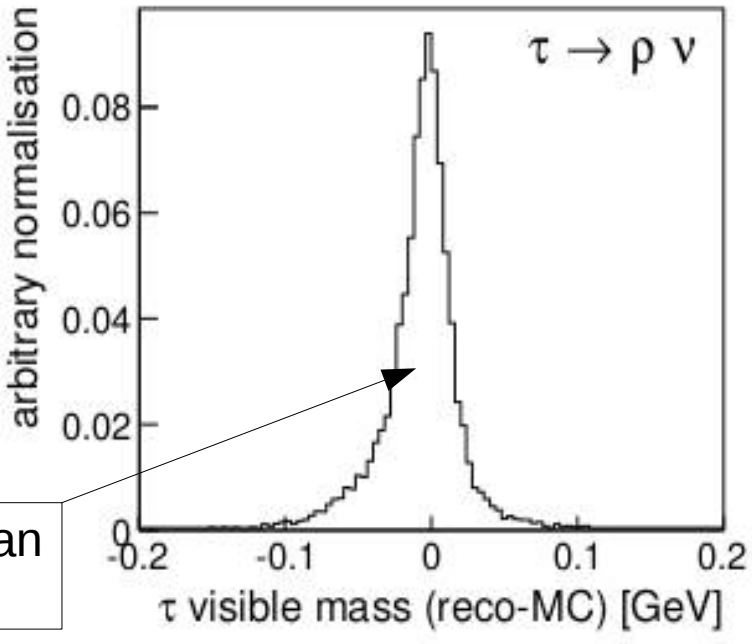
apply π^0 mass constraint to two photon system



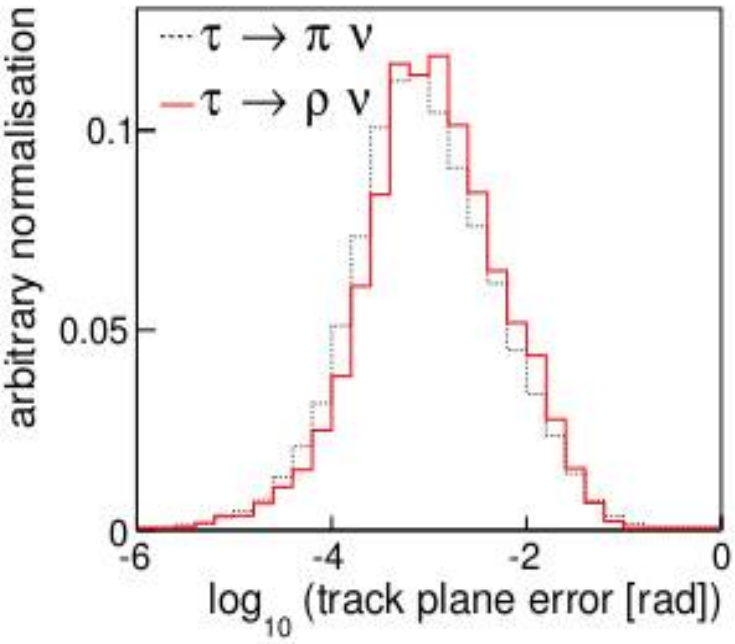
Track and pi0 reconstruction



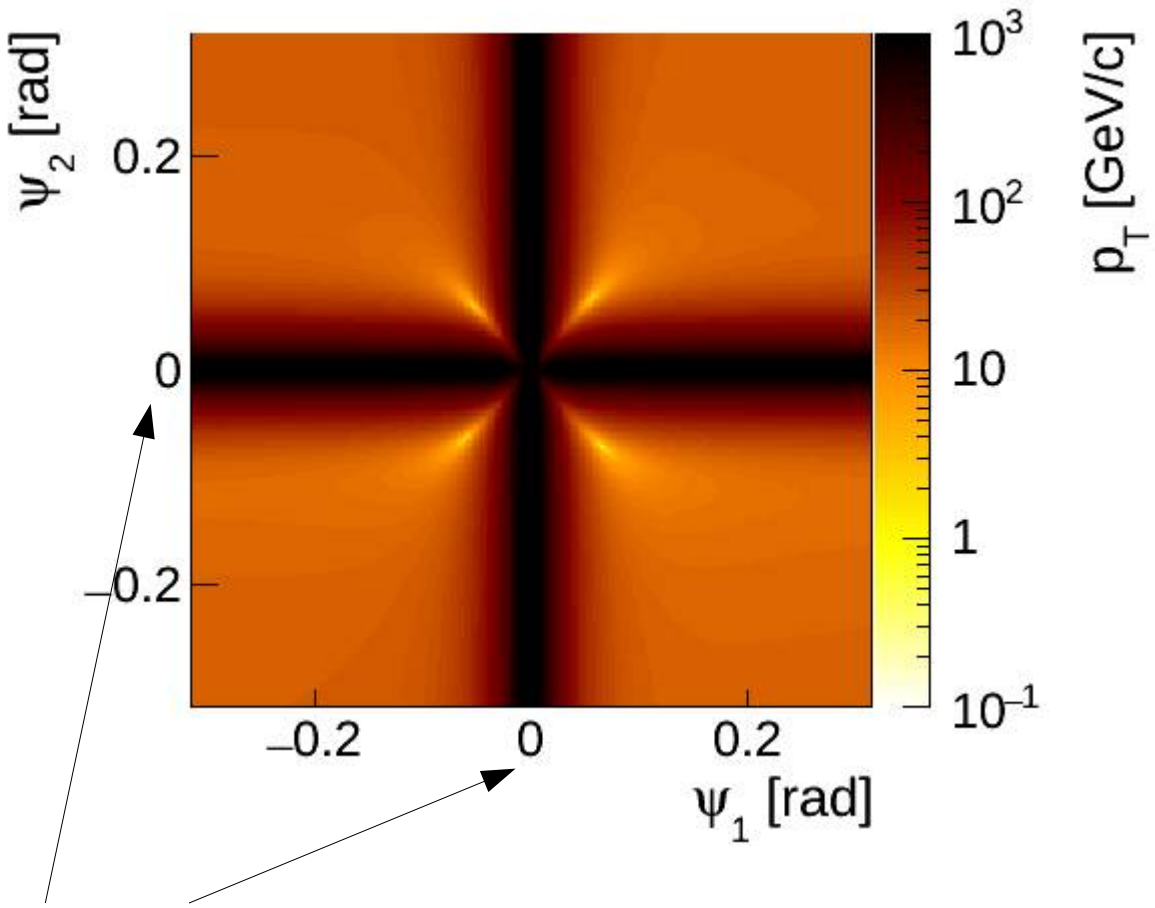




smaller than ρ width



How does event p_T depend on ψ chosen for two taus?



neutrino co-linear with hadrons in track plane

one event @ 250 GeV
$e^+e^- \rightarrow (H \rightarrow \tau\tau)\ (Z \rightarrow \mu\mu)$

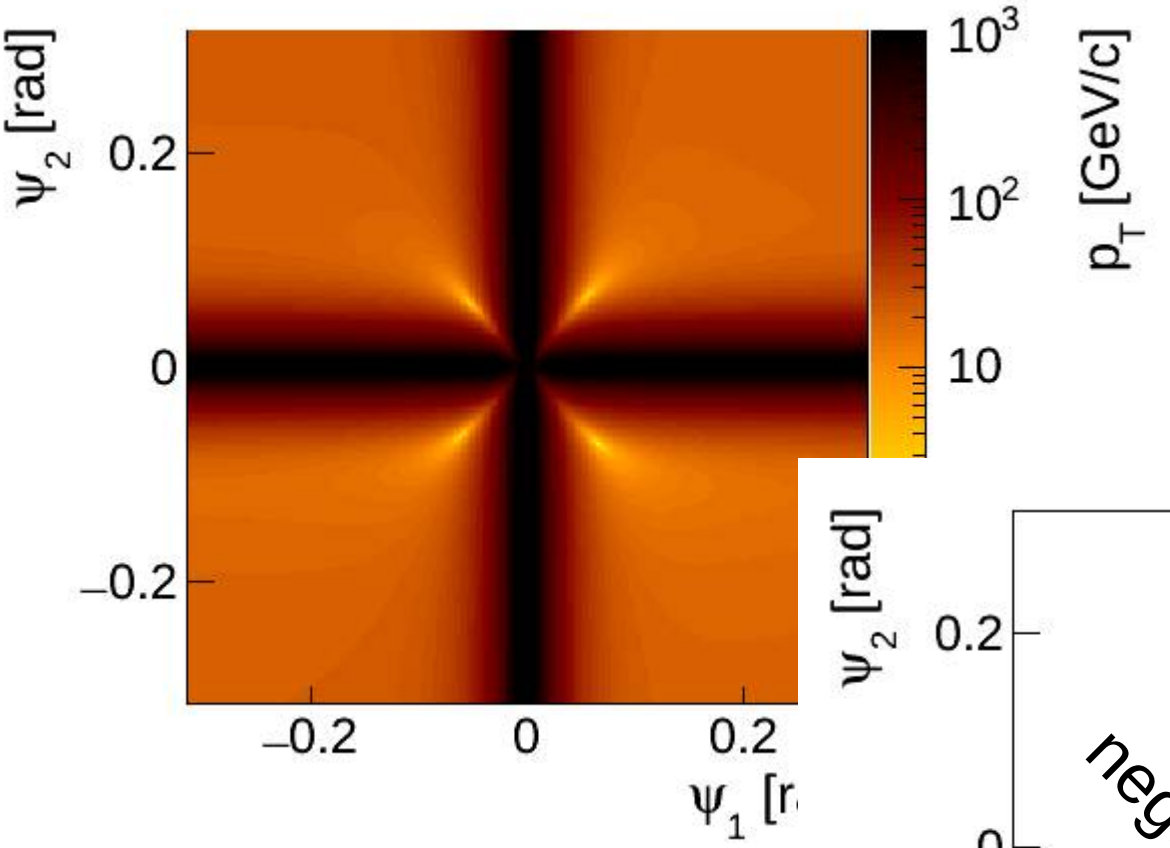
both $\tau \rightarrow \pi\ \nu$

simulated and reconstructed in ILD

Four possible solutions with small p_T
easy to find minima using e.g. MINUIT

how to choose which one?

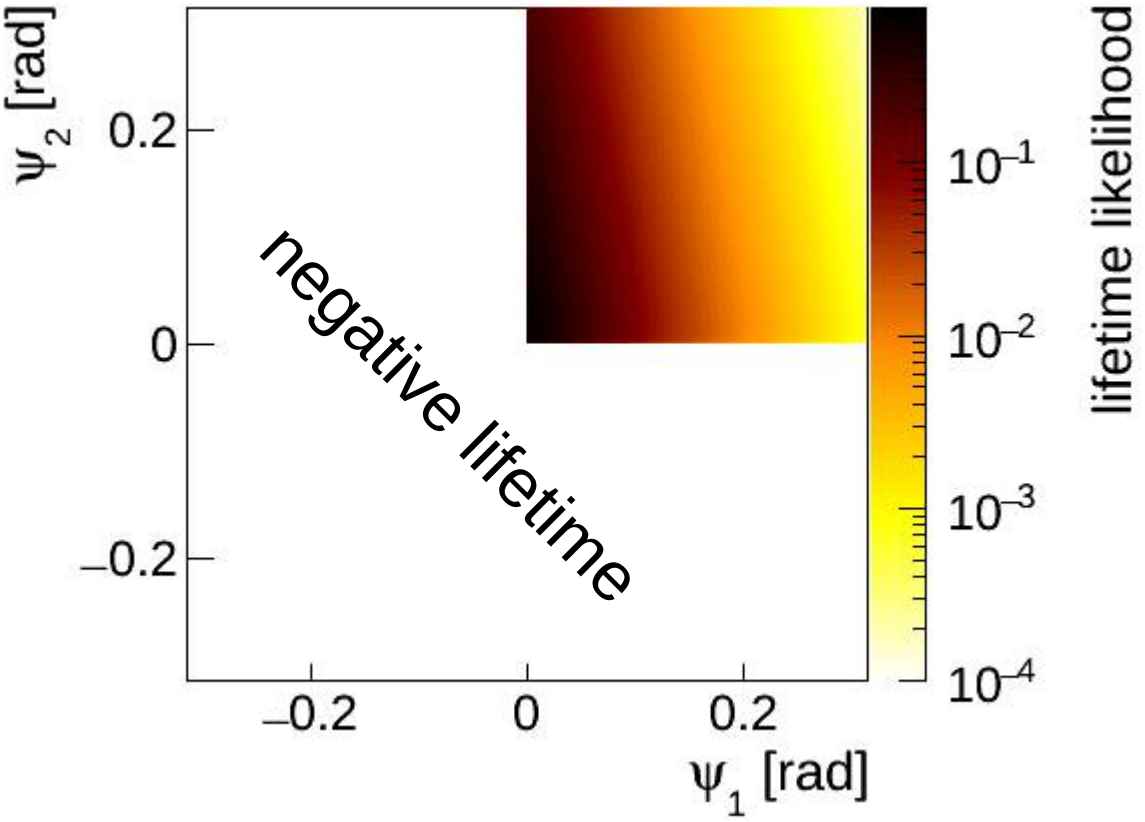
How does event p_T depend on ψ chosen for two taus?



<u>lifetime likelihood</u>

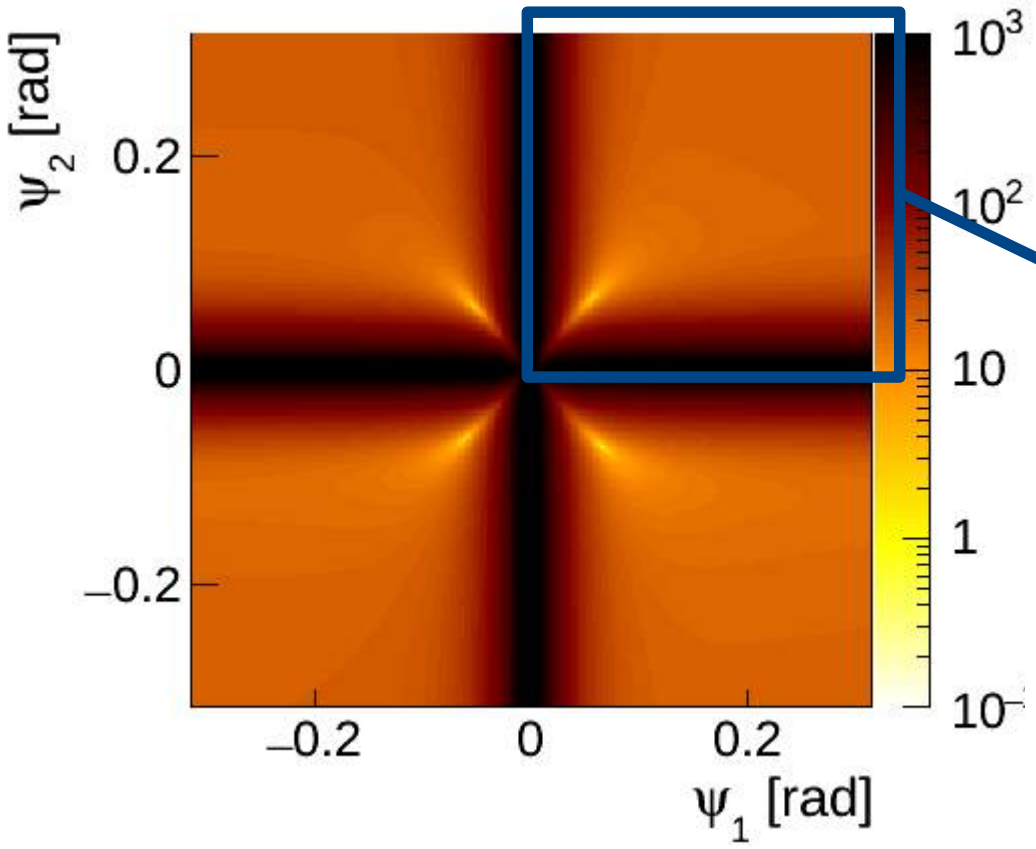
exp{ - candidate lifetime / mean tau lifetime }
for positive candidate lifetime,

0 for negative lifetime

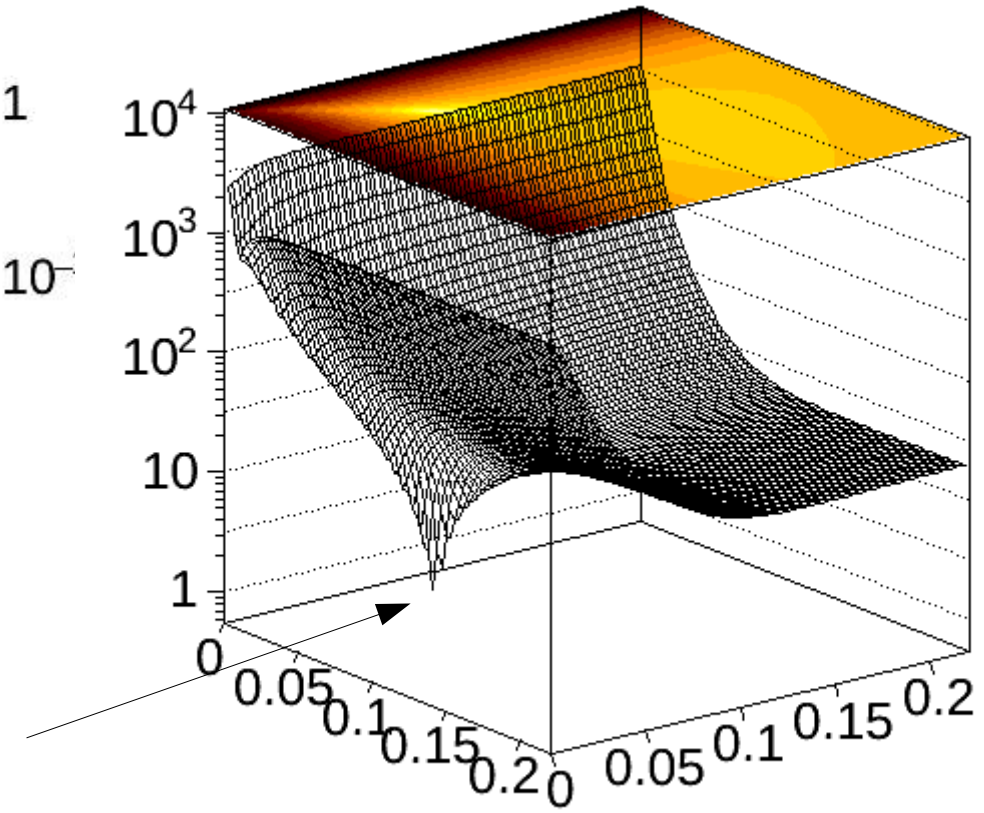


look at reconstructed tau lifetimes of each solution

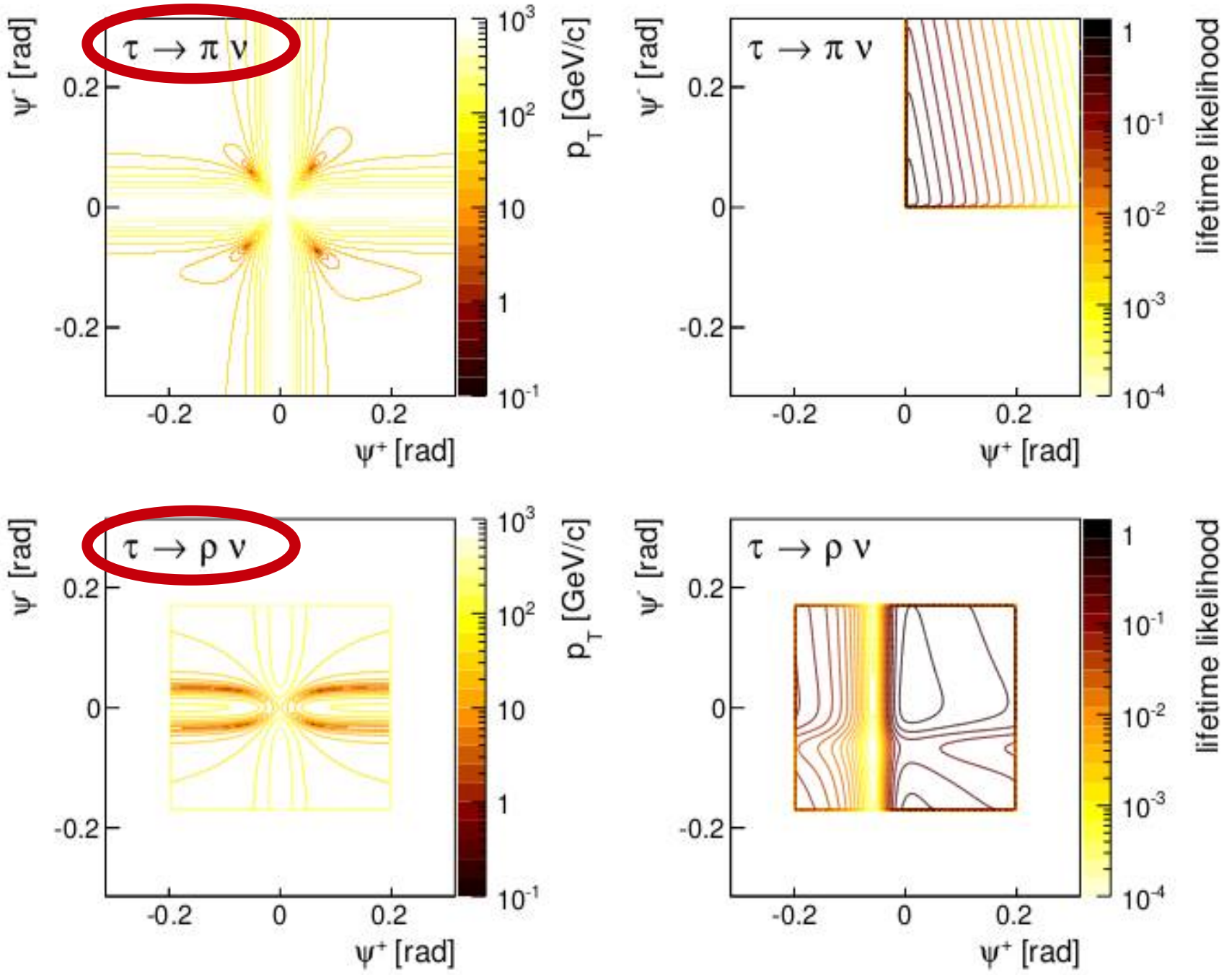
How does event p_T depend on ψ chosen for two taus?



positive lifetime quadrant

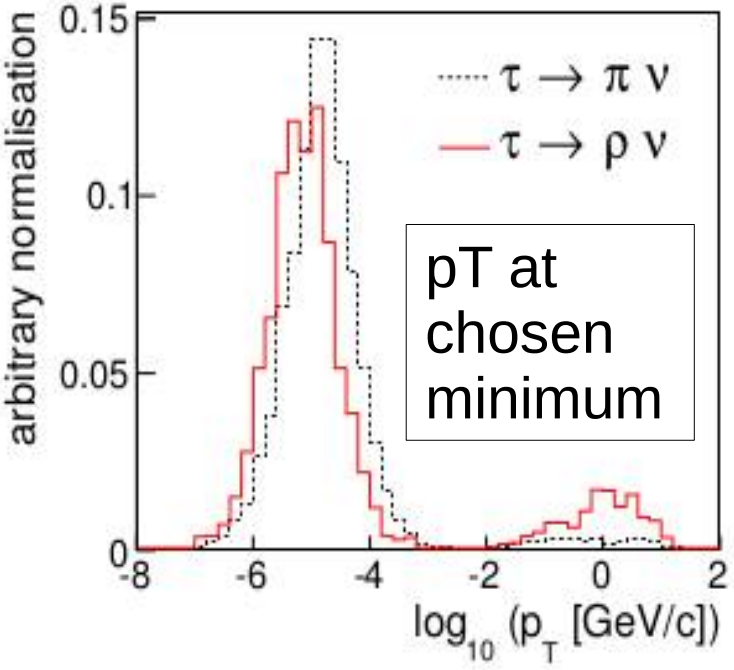


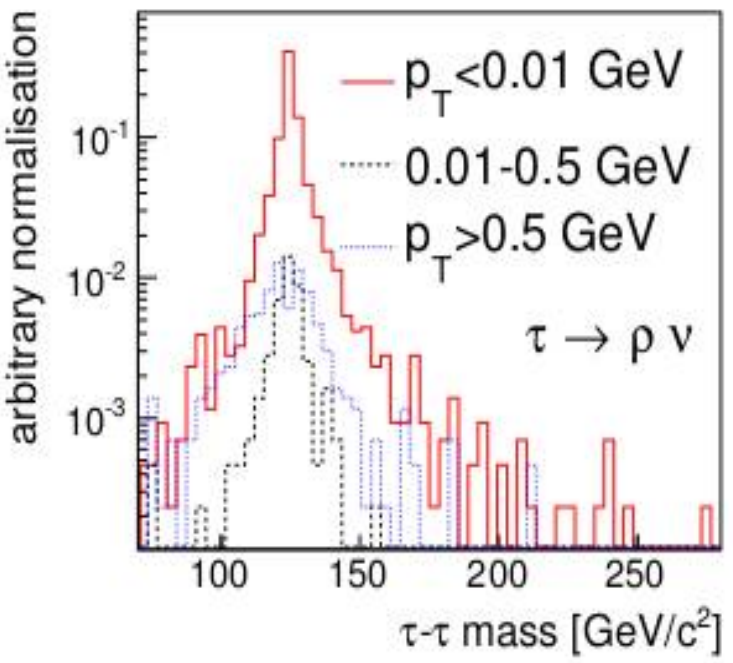
minimum is very sharp



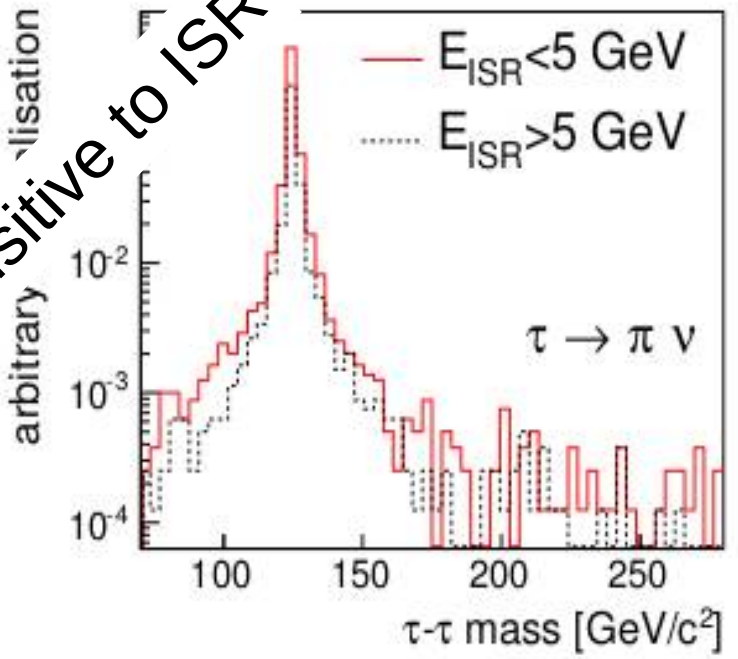
For now, choose smallest p_T minimum with positive decay length

How well does it work?
Check the invariant mass of ττ system: should be 125 GeV

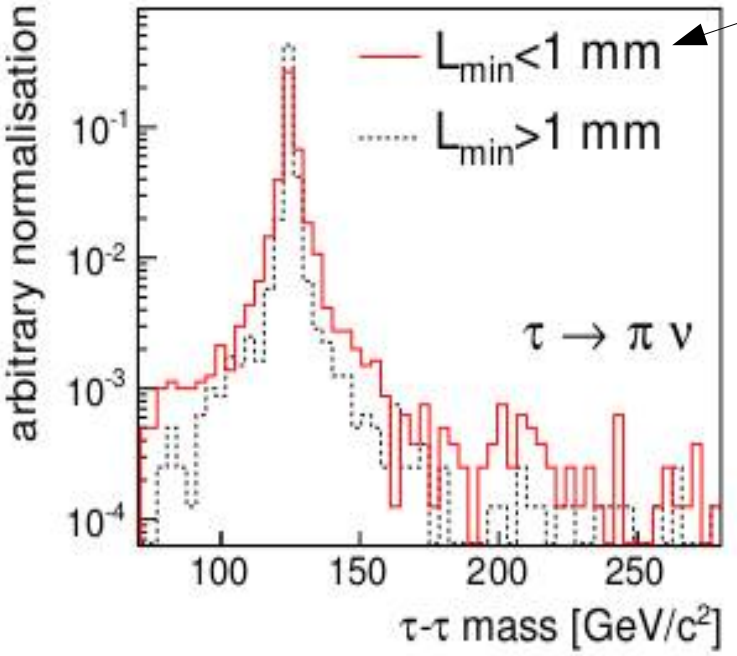


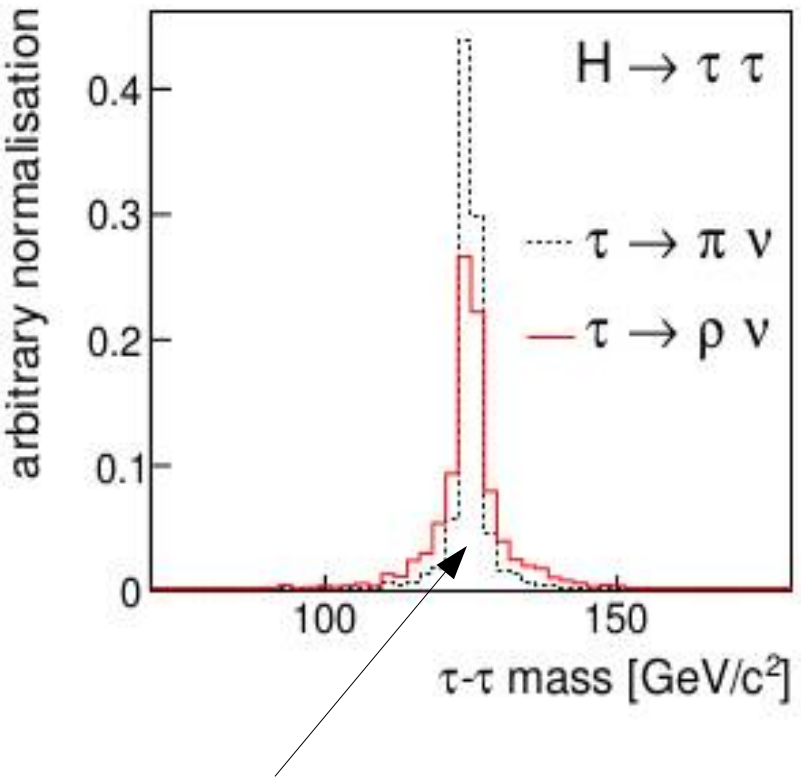


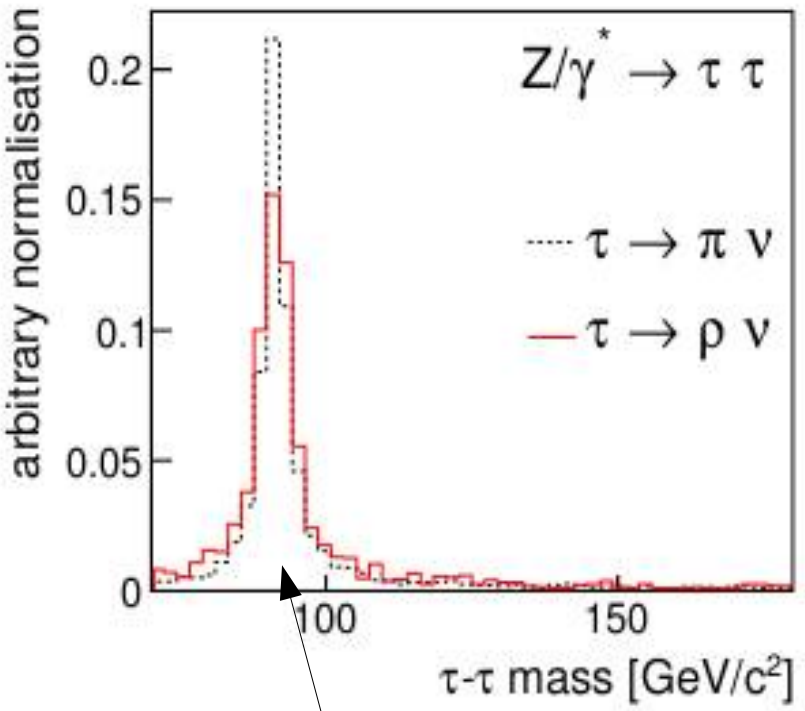
insensitive to ISR



unlucky taus







width of central peak
~ 0.6 GeV for $\pi^+\nu$
~ 1.1 GeV for $\pi^+\pi^0\nu$

95% of $\pi^+\nu$
89% of $\pi^+\pi^0\nu$
within 10 GeV of peak

easily distinguished from Z

Summary

reconstruction method for hadronic tau decays works well @ ILC

requires good IP reconstruction and impact parameter resolution
of order 10 microns (interesting to exactly how good it needs to be)

insensitive boost along beam axis
→ ISR, beamstrahlung OK, HZ above threshold OK
→ in principle, also applicable to hadron collider experiments
if impact parameter resolution sufficiently good
if IP can be measured

Paper submitted to NIM-A (arXiv:1507.01700)

Now working on removing cheating (associating tracks, clusters to taus)
then use tau spins to measure Higgs CP