τ reconstruction using impact parameters

arXiv:1507.01700

motivation

traditional methods

using impact parameters

application to $Z H \to \mu\mu\ \tau\tau$ in ILD

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LCWS
November 2015

Motivation

tau leptons' decay distributions depend on its spin

→ we can use them to probe spin-dependent effects

e.g. in $H \rightarrow \tau\tau$,

different CP states of Higgs induce

different correlations between tau spins

Fully reconstructing tau decay maximises available information

Difficulty:

τ decays to (at least) one neutrino

→ missing information

Tau Decay Mode	Branching Fraction
leptonic	~35%
hadronic single prong	~50%
$\pi^+ \nu$	~11%
$\rho^+ \nu \rightarrow \pi^+ \pi^0 \nu$	~26%
hadronic multiprong	~15%
$a_1^+ \nu \rightarrow \pi^+ \pi^+ \pi^- \nu$	~9%

Leptonic tau decays

involve two neutrinos:

- less available information
- ignore for now

Usually have system of two tau leptons

Each hadronic tau decay has 3 unknown parameters (neutrino 3-mom)

→ 6 unknowns in di-tau system

We can use constraints to induce the value of these unknowns

invariant mass of each tau: 2 constraints

overall p_x, p_y conservation: 2 constraints (if no extra neutrinos in event)

overall p_z, E conservation ← invalidated by forward ISR/beamstrahlung

need 2 more:

invariant mass of tau-tau system ? (assume from H) ← backgrounds

rest frame of tau-tau system ? (e.g. recoil against Z) ← ISR/bs

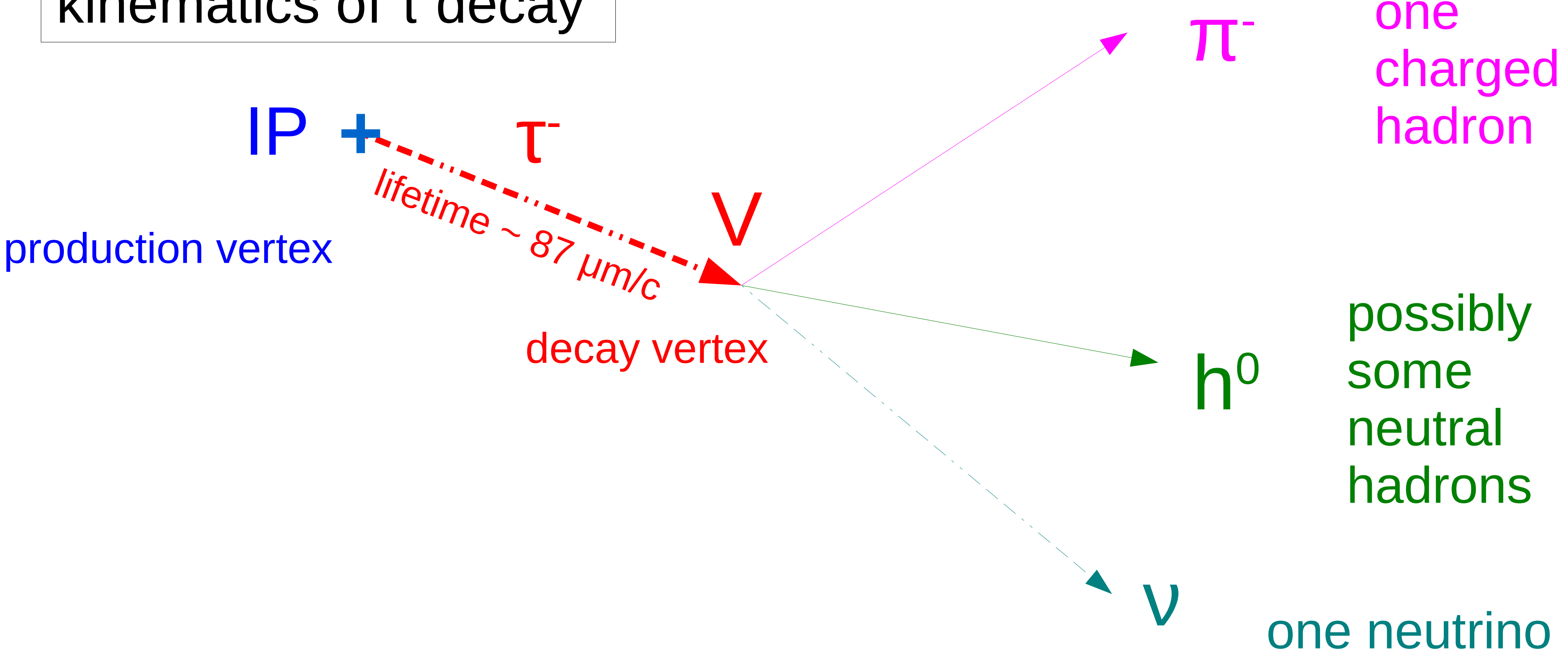
impact parameter information ← if vertex detector is good enough

can consider under-constrained system (e.g. done @ LHC):

scan over solutions allowed by constraints,

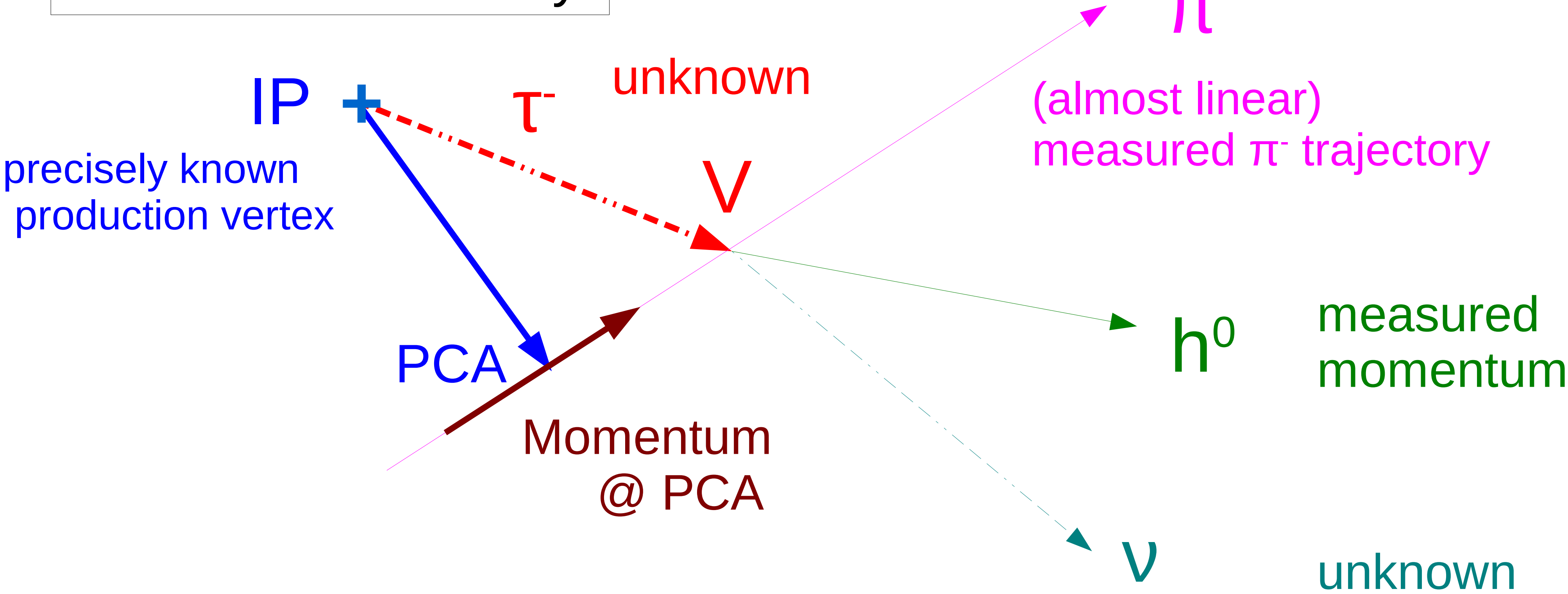
choose most likely one according to known tau decay distributions

kinematics of τ decay



For typical tau energies at ILC,
and for typical experimental B fields,
trajectories of tau and charged hadron ~ linear at this scale

kinematics of τ decay



"track plane" defined by IP-PCA and Momentum@PCA

(these two vectors are perpendicular for 3d PCA)

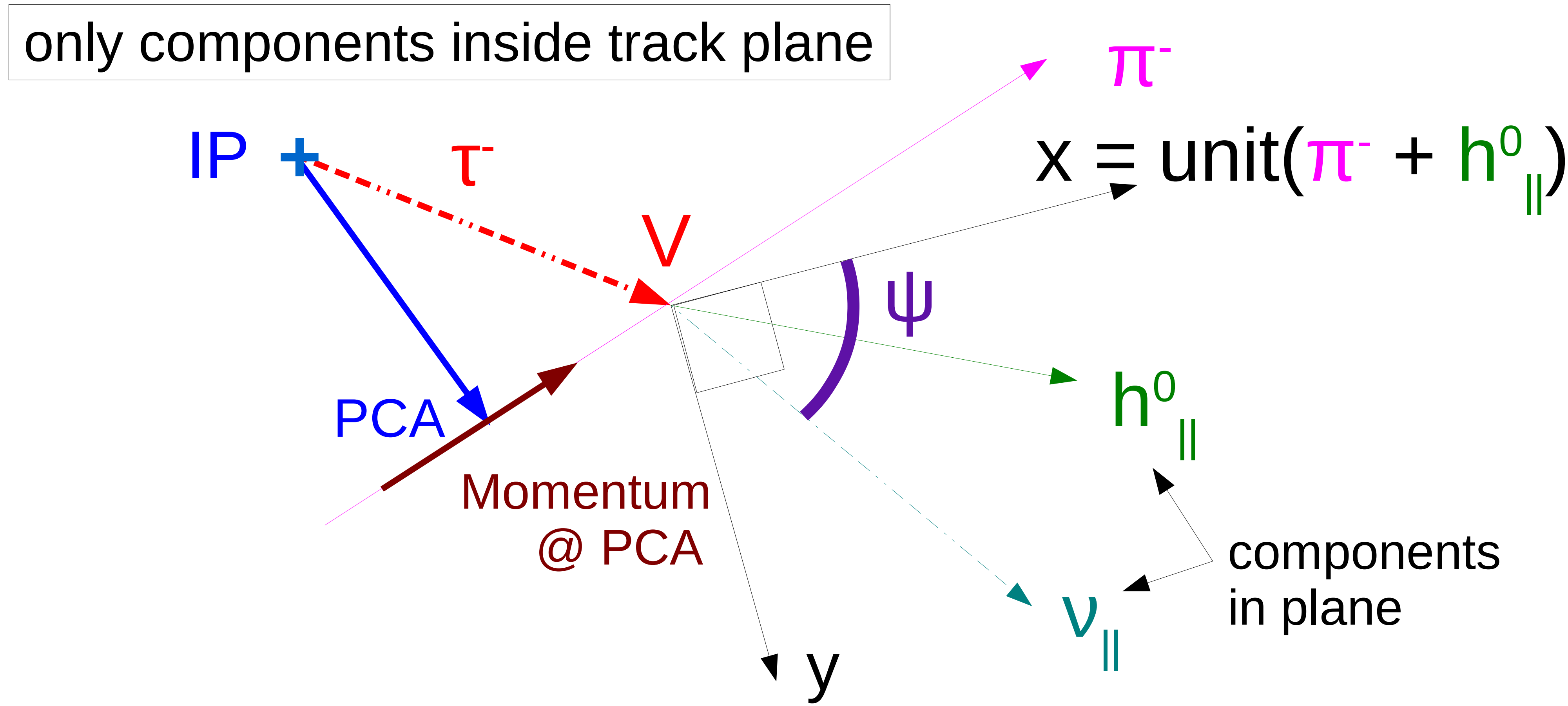
→ requires well measured IP and π^- trajectory

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

→ **we have used the track plane information to infer one component of the neutrino's momentum**



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

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

We can then 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 $\tau = \pi + h^0 + \nu$

Use τ invariant mass to remove one unknown

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

can calculate full kinematics of τ for any assumed ψ : decay length, lifetime

define likelihood of reconstructed lifetime

(in $\pi\nu$ decays, one Q solution gives a negative decay length, can be rejected)

we have reduced unknown ν momentum from

three parameters to one (ψ) + 2-fold ambiguity

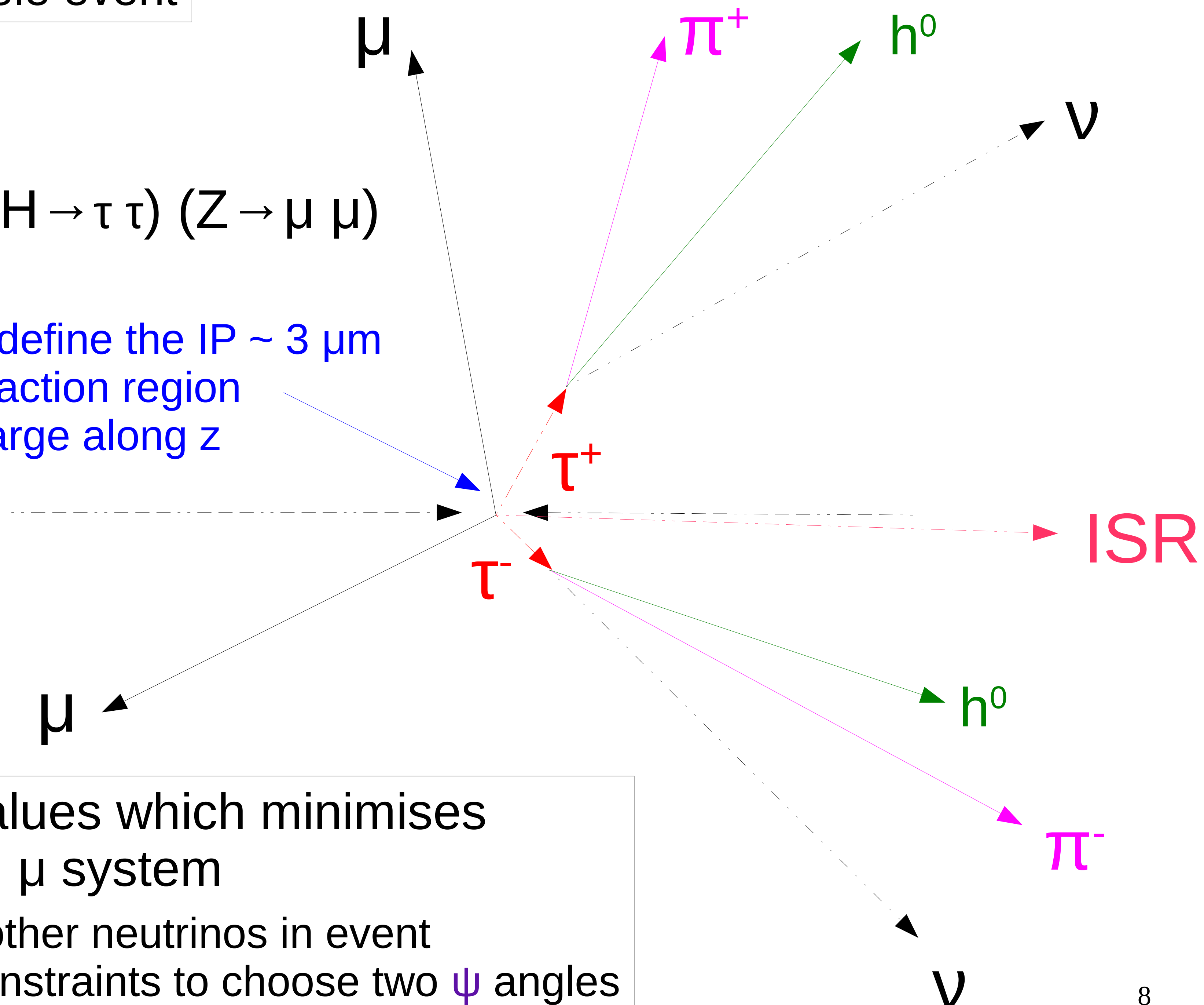
using impact parameter and tau mass constraints

<u>how to determine ψ ?</u>

consider whole event

e.g.

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



choose ψ values which minimises
p_T of τ τ μ μ system

- works if no other neutrinos in event
- use p_x, p_y constraints to choose two ψ angles
  → fully constrained system

...that's the theory

Recap: method needs

- precise measurement of charged prong trajectory
- precise knowledge of IP in all 3 dimensions
  - [“precise” means << typical impact parameters]
- good estimation of neutral hadronic momentum
  - [if present]
- balanced p_T (e.g. no extra neutrinos)

...can it work @ ILC / ILD?

Test the method

$e^+ e^- \to H \mu^+ \mu^-$ events generated @ 250 GeV: Whizard2 with CIRCE1 ISR/BS

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

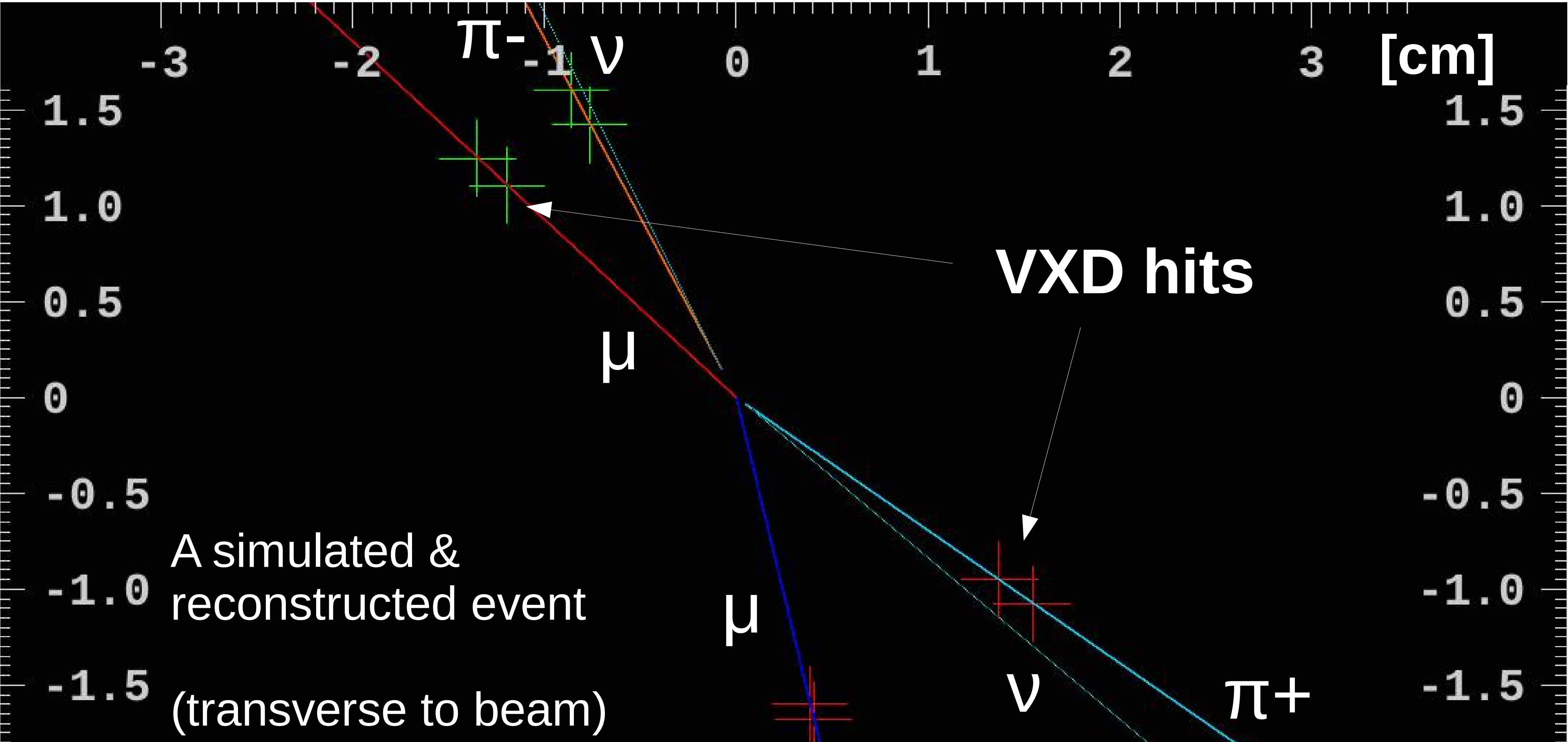
Full ILD simulation, DBD version ILD_v05_o1 [no underlying event]

Usual ILD reconstruction + GARLIC photon reconstruction

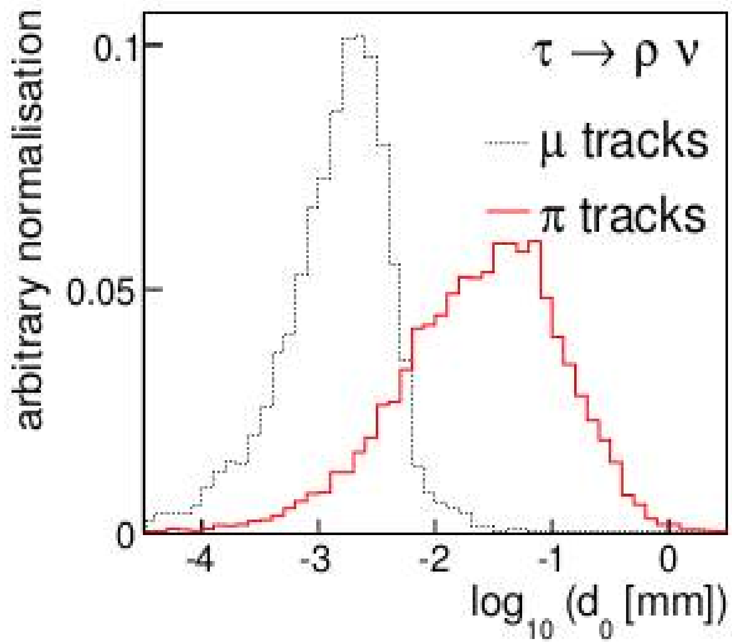
Cheat matching of GARLIC/Pandora clusters to π^0, and of πs to τ

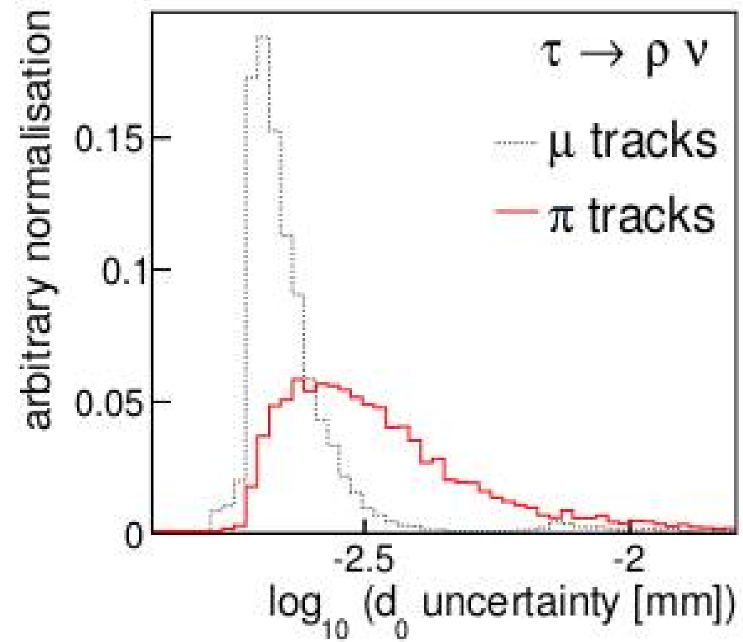
apply π^0 mass constraint to two photon system

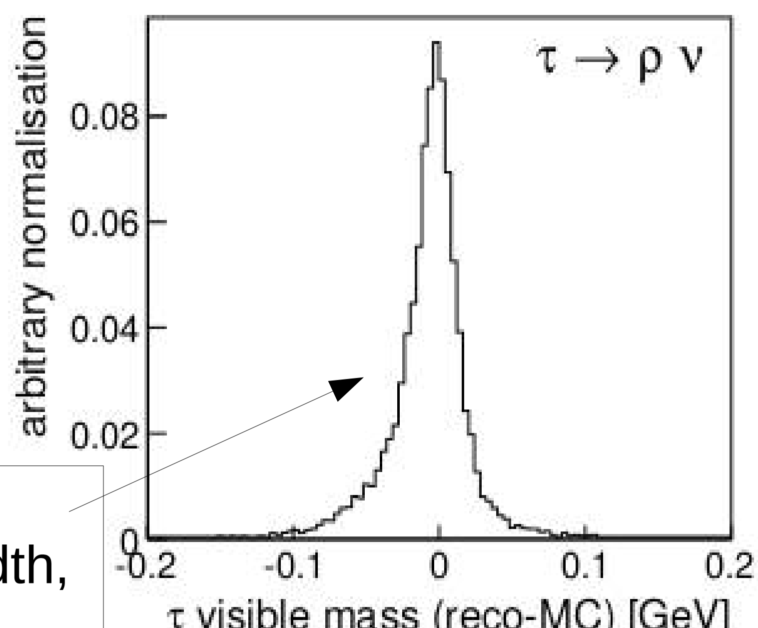
Use $\mu^+ \mu^-$ tracks to reconstruct IP: ~3μm precision



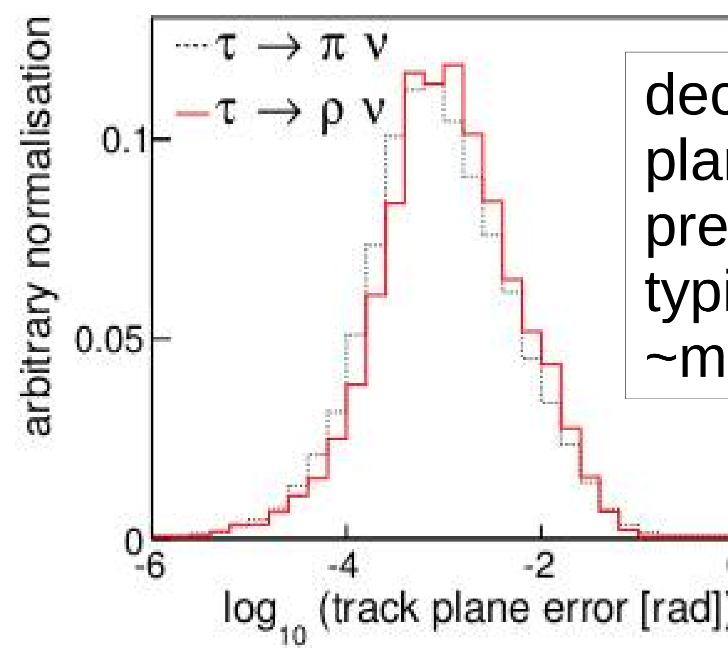
reconstruction of tracks, ρ (π^0)







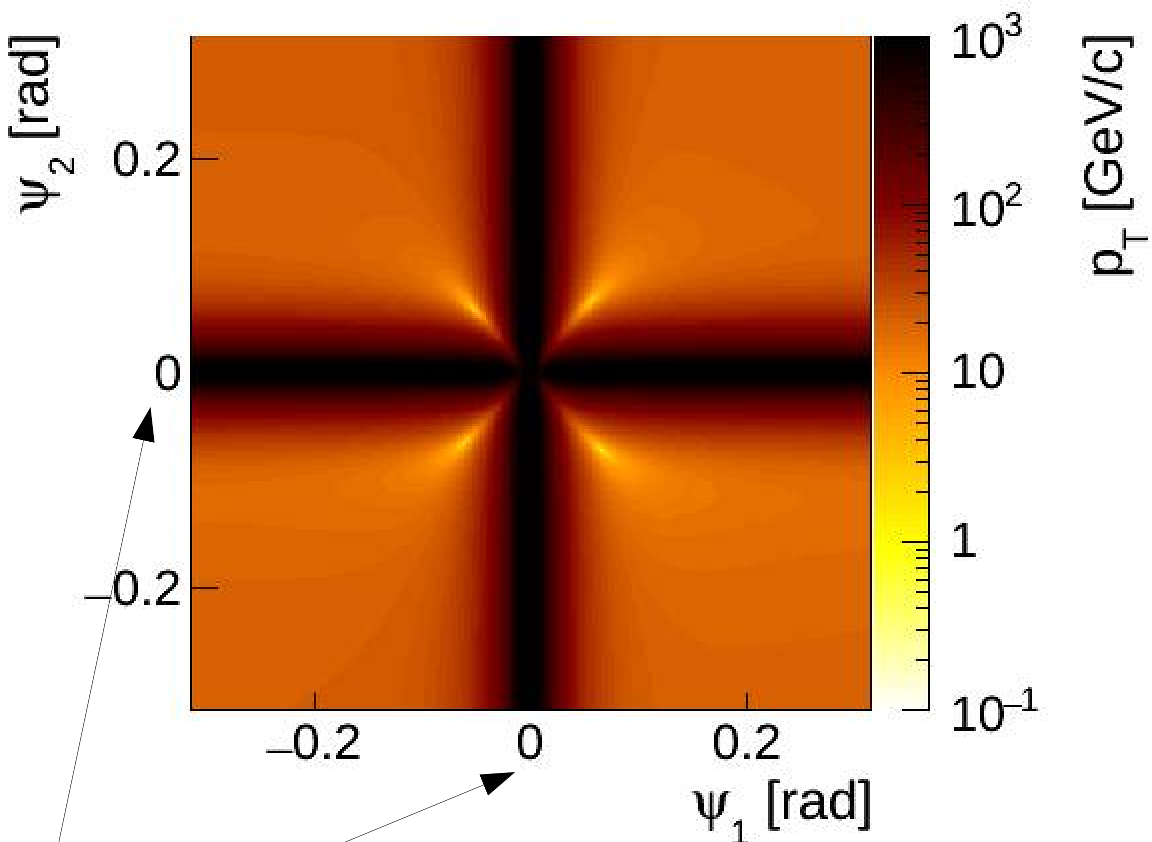
smaller than natural ρ width, small bias



decay plane precision typically ~mrad

angle p_τ makes to reconstructed plane

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



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

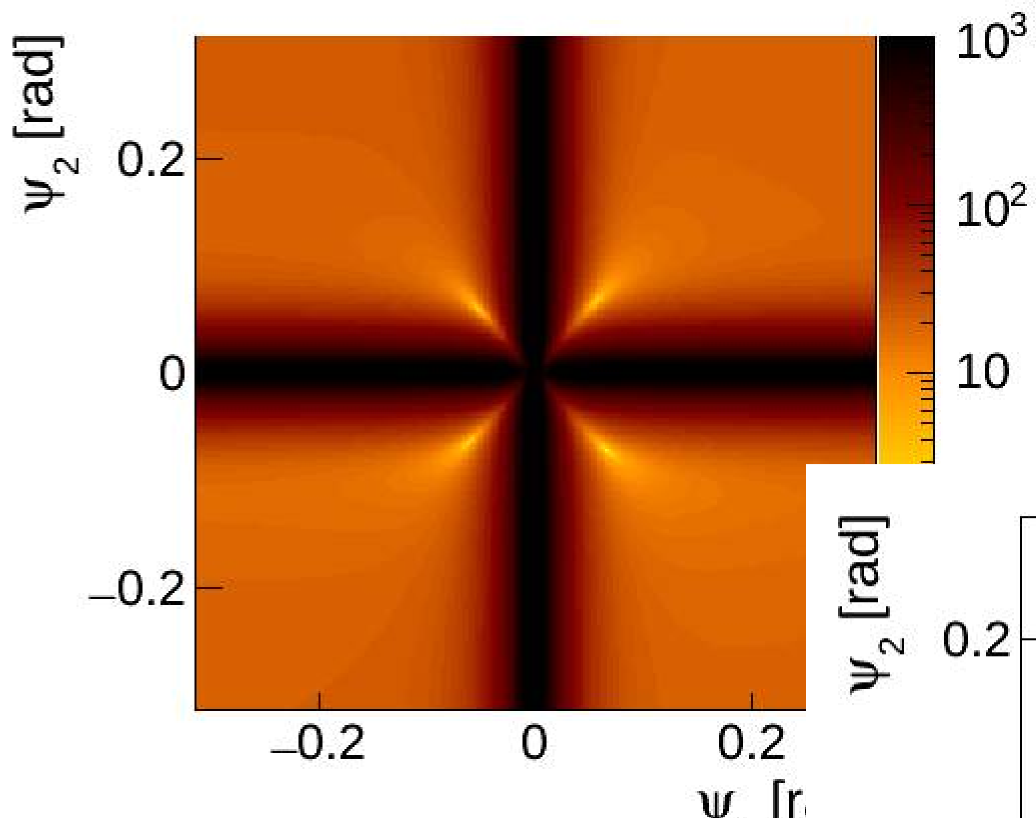
neutrinos collinear with hadron momentum in track plane

Naturally splits into 4 quadrants @ $\psi=0$

Each quadrant has solution with small p_T
easy to find using e.g. MINUIT
rather complicated to do analytically...

how to choose which one?

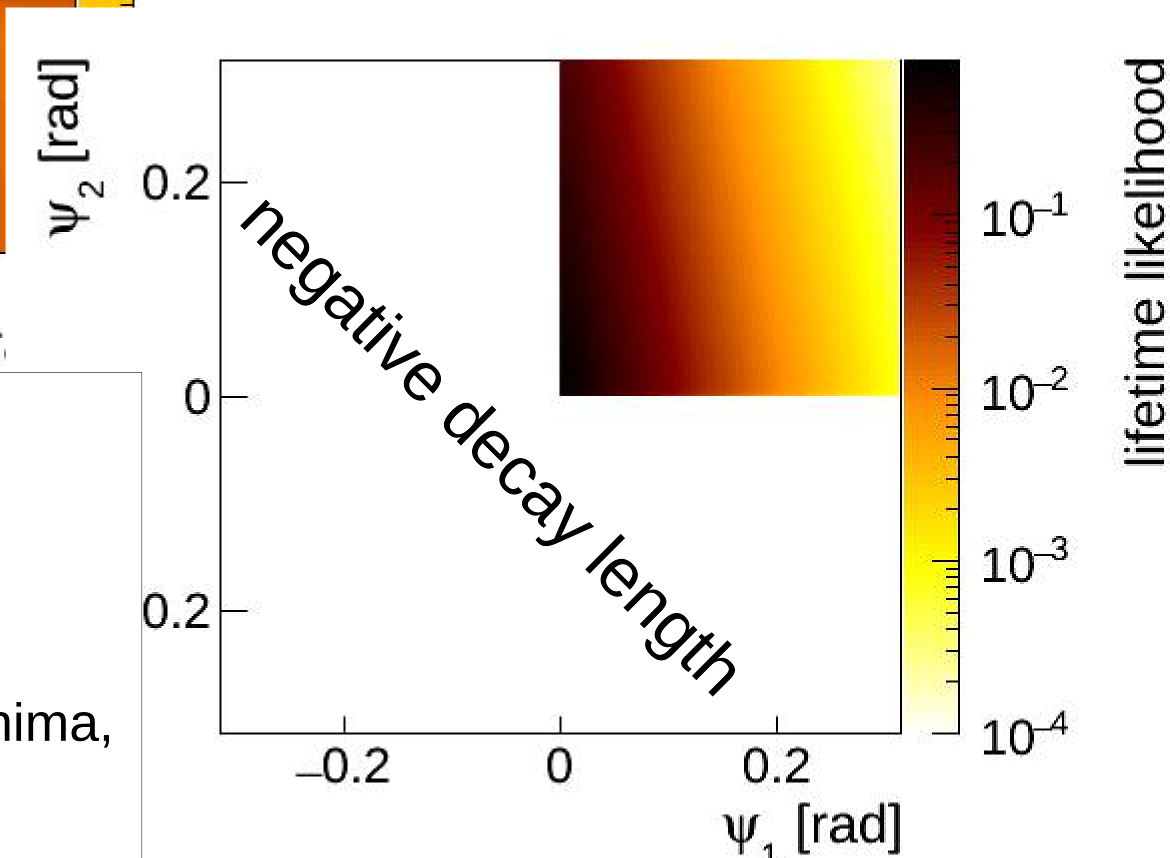
How does event p_T depend on neutrino angle ψ chosen for two taus?



lifetime likelihood =

exp{ - reconstructed lifetime / mean tau lifetime } for +ve candidate decay length,

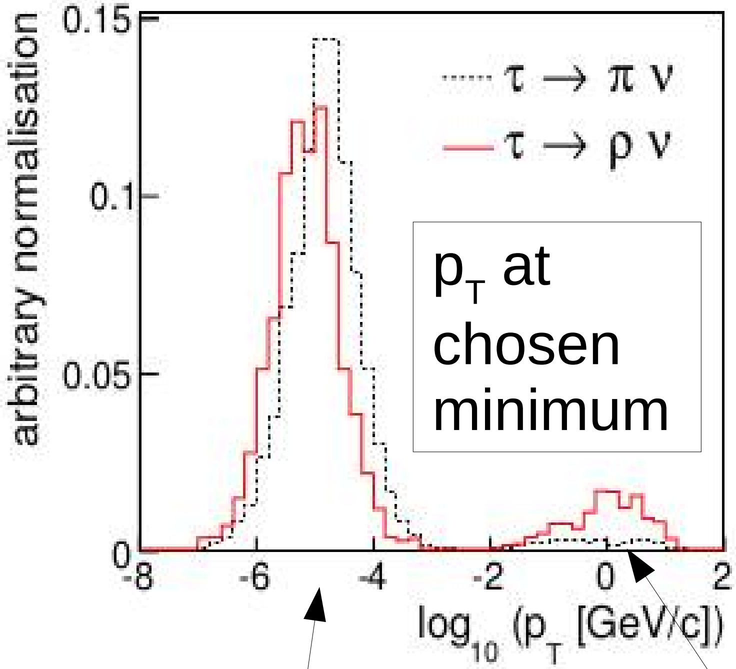
0 for -ve decay length



For each event,
for each combination of
(2-fold) energy solutions

- find p_T minimum in each quadrant
- reconstruct tau decay length @ minima, reject negative decay lengths
- choose minimum with smallest p_T

How well does it work?



a nice minimum is found for most events: p_T ~ 10 keV

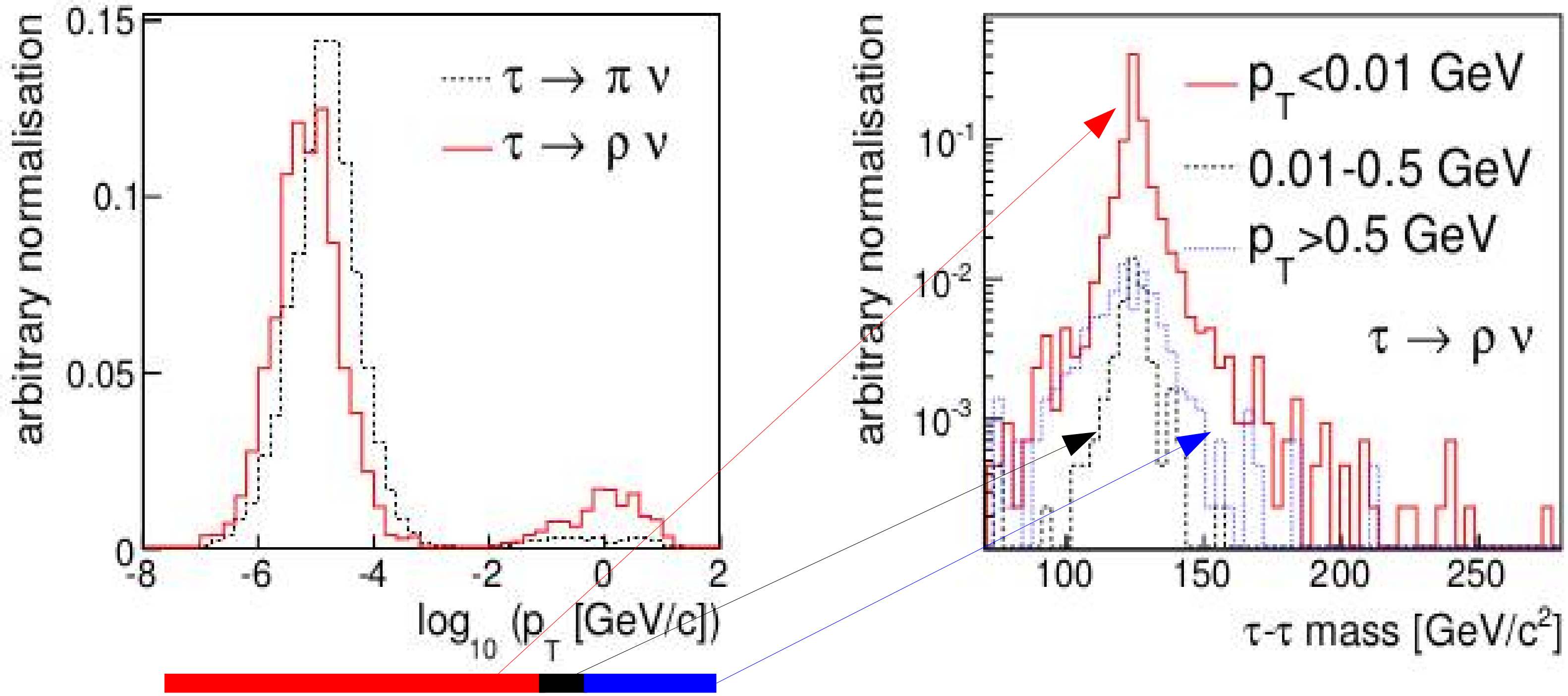
some fraction of mis-reconstructed events

pT ~ 0.1 → 10 GeV

larger fraction for ρ decay mode

(ECAL resolution?)

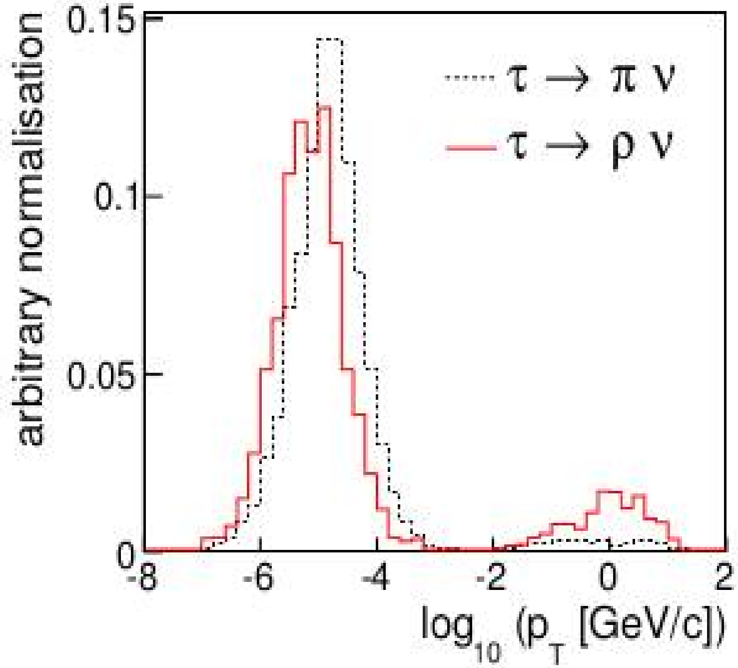
Check the invariant mass of τ τ system: should be 125 GeV

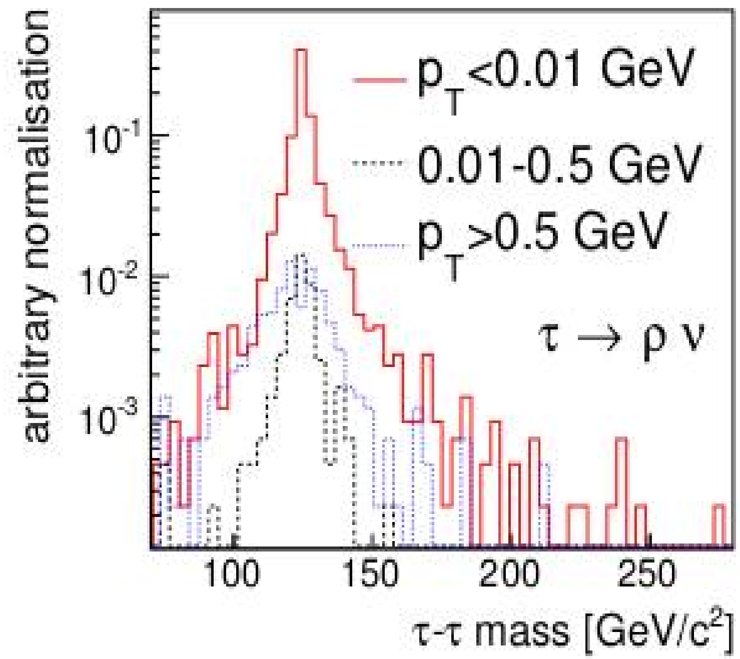


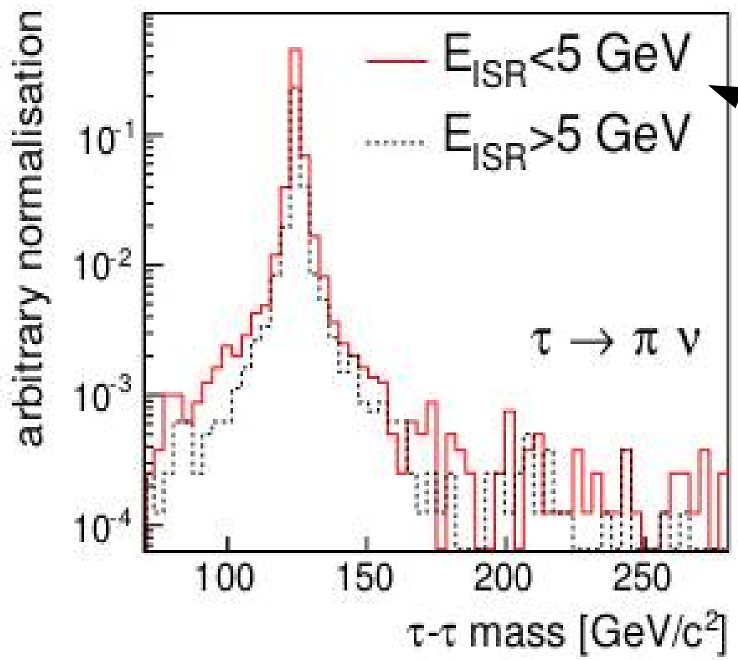
rather sharp mass distribution

even "misreconstructed events" peaked at 125 GeV

Check the invariant mass of τ τ system: should be 125 GeV

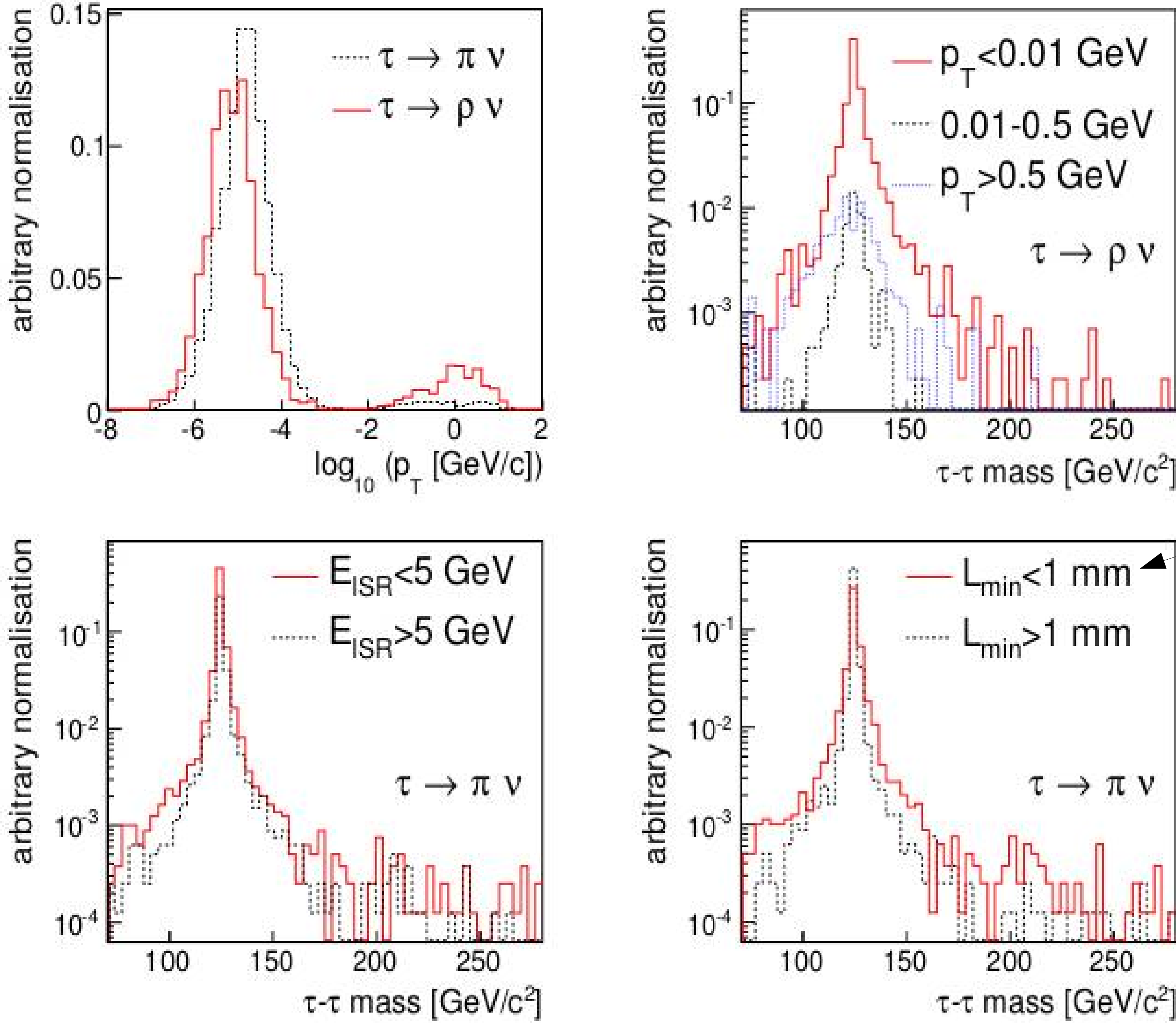




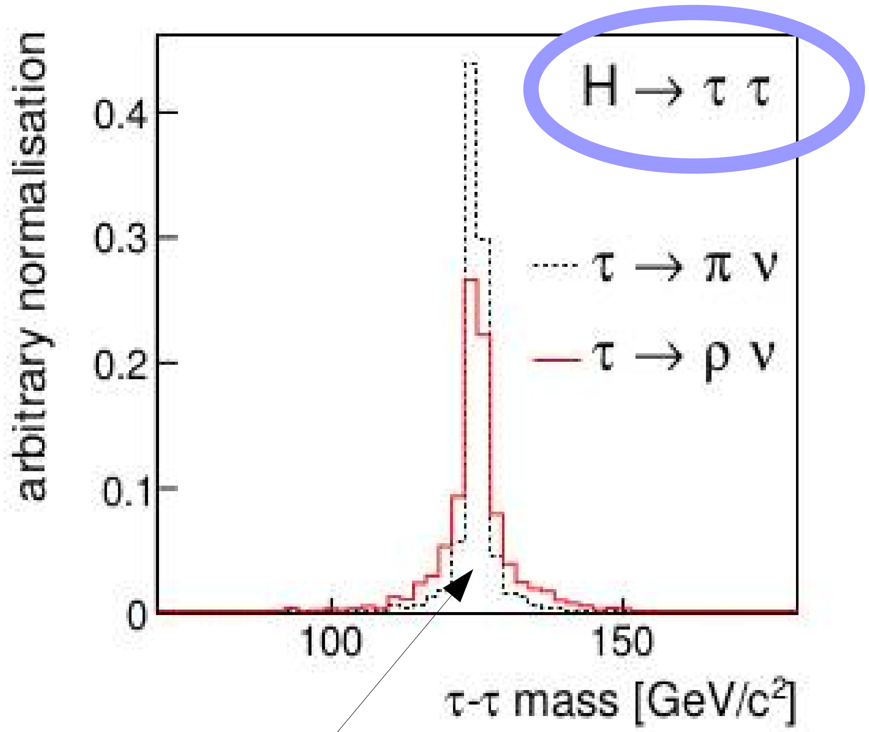


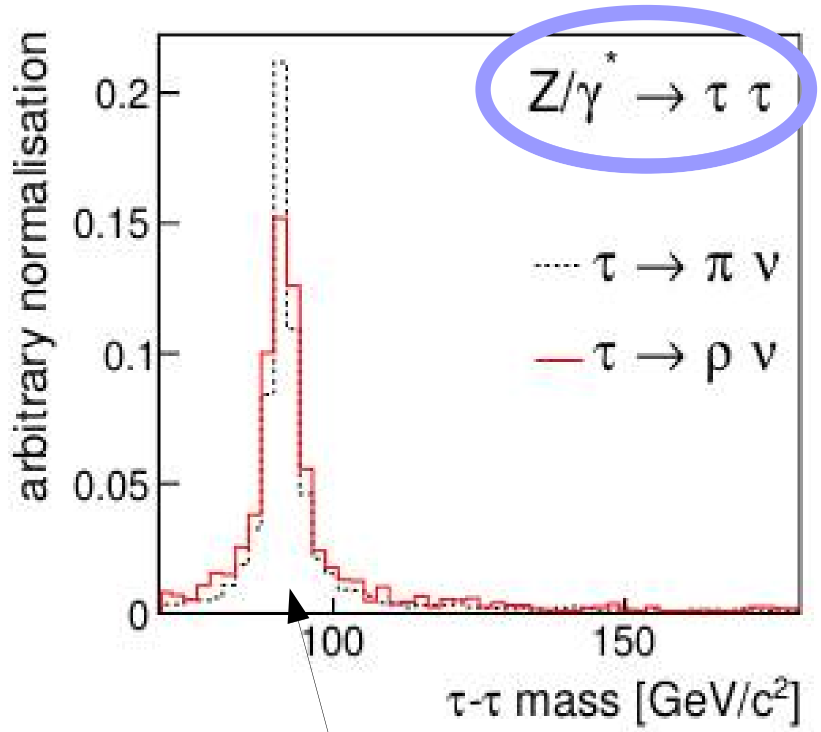
Events with large ISR/bs ~equally well reconstructed

Check the invariant mass of τ τ system: should be 125 GeV



"unlucky" short-lived taus are somewhat less-well measured





Sharp central peak with longer tails

Gaussian width of central peak

~ 0.6 GeV for $\pi^+\nu$

~ 1.1 GeV for $\pi^+\pi^0\nu$

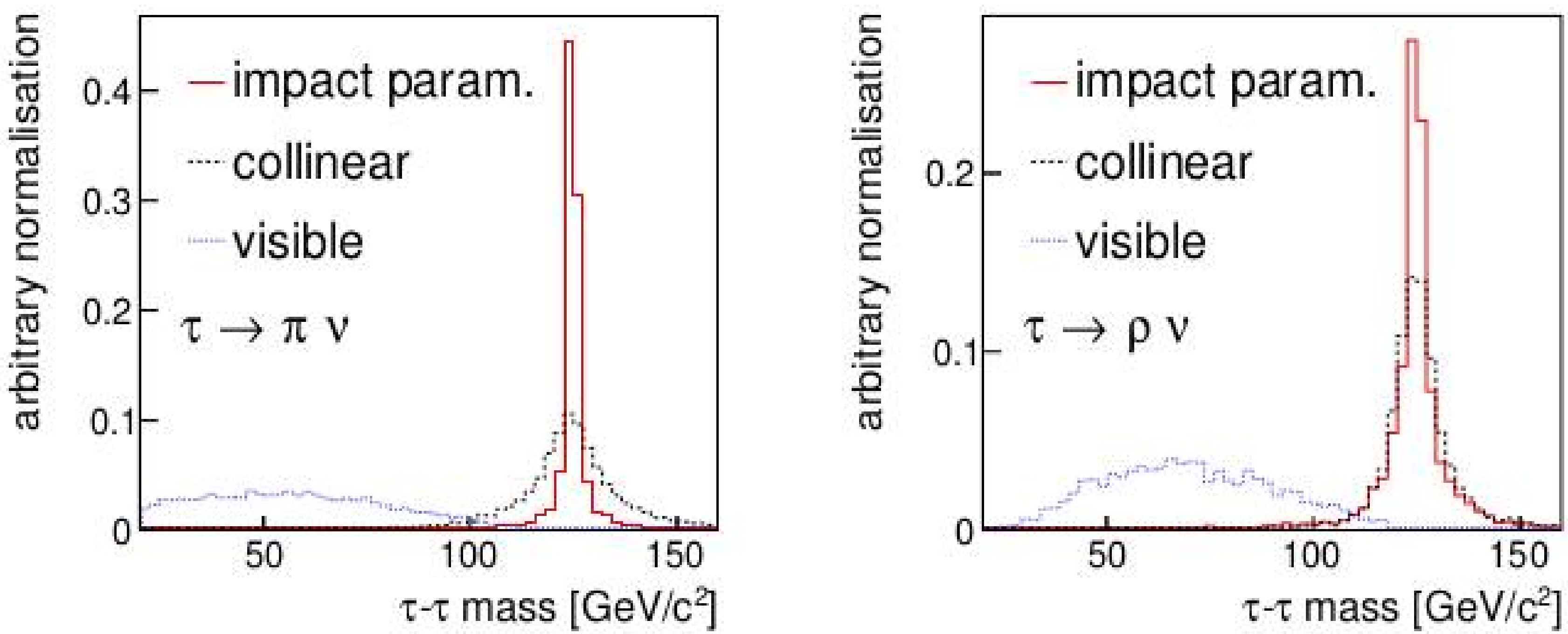
within (125 ± 10) GeV:

~ 95% of $\pi^+\nu$

~ 89% of $\pi^+\pi^0\nu$

H easily distinguished from Z pole

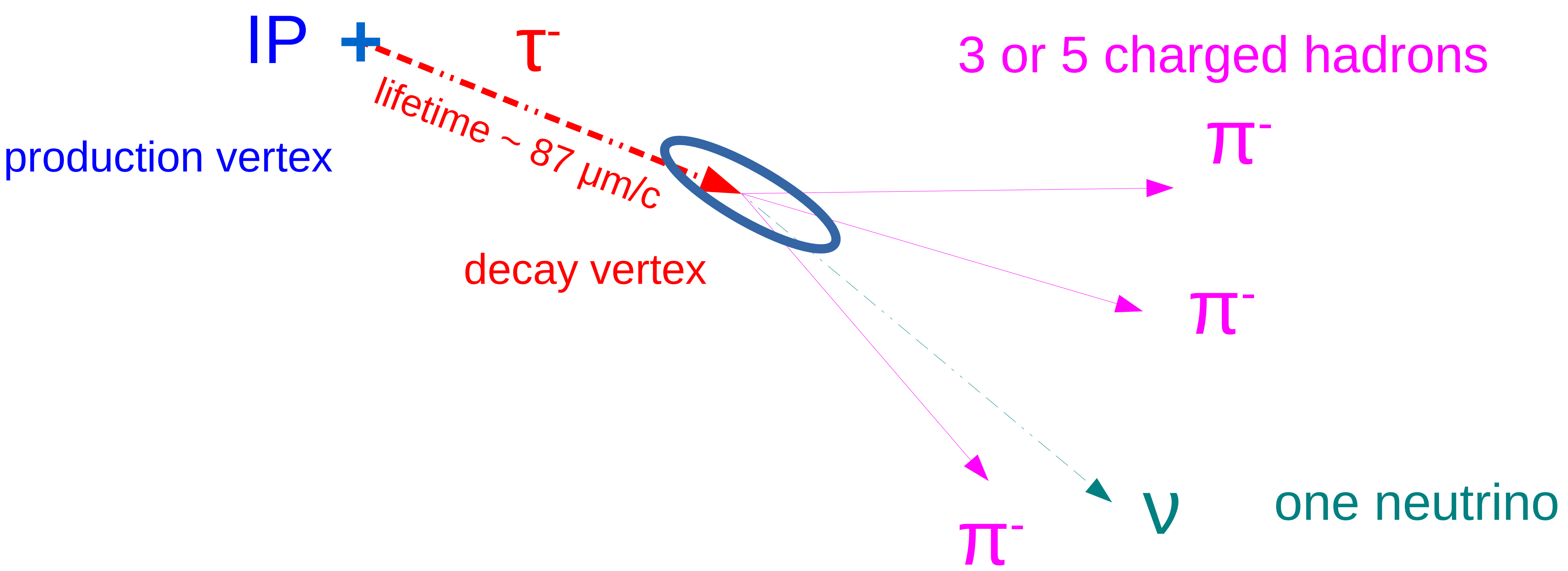
Comparison to other methods



impact param.	method presented in this talk
collinear	assume neutrino collinear with visible tau decay products, balance event pT
visible	consider only visible decay products

Especially in πν channel,
using impact parameters results in much better resolution
Also some improvement in ρν,
but limited (probably) by π^0 energy resolution

Multiprong decays



Multiprong vertex to directly measure tau momentum direction:
applying tau mass constraint gives 2 solutions for neutrino momentum

For taus from Higgs decay, error ellipsoid of
reconstructed tau decay vertex has dimensions ~ 2 x 2 x 100 μm

1) directly use vertex position

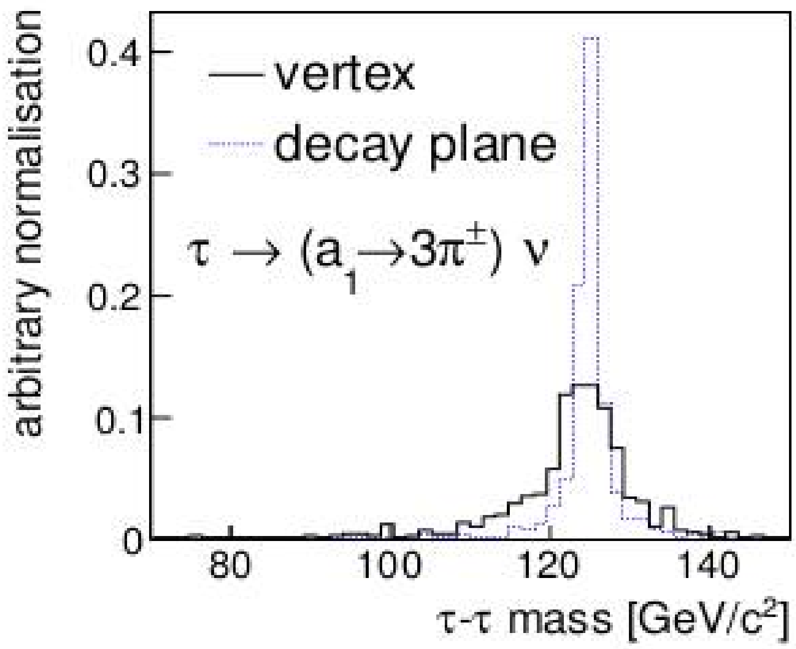
neutrino can be calculated using only tau mass constraint (with 2-fold ambiguity)

event p_T used only to distinguish between possible solutions

2) use major axis of multiprong vertex ellipsoid to

define tau decay plane, then proceed as for single prong

event p_T used to find best solution, check compatibility with measured vertex



Precision of tau decay vertex reconstruction

less good than of event p_T,

at least when recoiling against muons

leptonic tau decays

one more constraint required per leptonic tau decay
(energy of 2-neutrino system)

possible strategies:

assume no ISR ?	+ 2 constraints
assume 1 ISR photon ?	+ 1 constraint
assume $\tau\ \tau$ mass ?	+ 1 constraint

not hopeless, to be studied...

Summary

Impact parameters of tau decay prongs can help reconstruct tau decays

if IP is well-known:

either very small interaction region (smaller than ILC in z)

or tau recoils against prompt charged particles

and vertex detector sufficiently precise

Tau pair events can then be completely reconstructed by assuming only event's p_T balance (if both decay hadronically: ~40% of events)

Works well in ILD: τ τ mass resolution ~ 1 – few GeV when recoiling against muons (hadronic system to be checked)

Since only p_T balance is used,

can work at hadron collider experiments

Powerful tool to measure CP structure of Higgs