Measurement of Higgs CP properties in decays to tau leptons

MonteCarlo studies

December 2014

Daniel Jeans,
Inomata, Akitsu (B4 students)

U. Tokyo

Spin of tau leptons produced in Higgs decays are correlated

The transverse spin correlations depend on the
CP nature of the Higgs boson

The spin of the tau lepton is, to some extent,
transmitted to distribution of the tau's decay products

The distribution of tau lepton decay products therefore
contains information about Higgs CP properties

Parameterise:

Higgs = cos (φ) * Higgs (CP_even) +
sin (φ) * Higgs (CP_odd)

φ = 0 => pure CP even => SM Higgs
φ = π/2 => pure CP odd => e.g. A of MSSM

Major Tau decay modes:

17% muon + muon neutrino + tau neutrino

18% electron + electron neutrino + tau neutrino

11% single charged pion + tau neutrino

26% charged pion + neutral pion + tau neutrino
(usually via rho resonance)

15% 3 charged particles + X + tau neutrino

The amount of available information about Higgs depends on the tau decay mode:

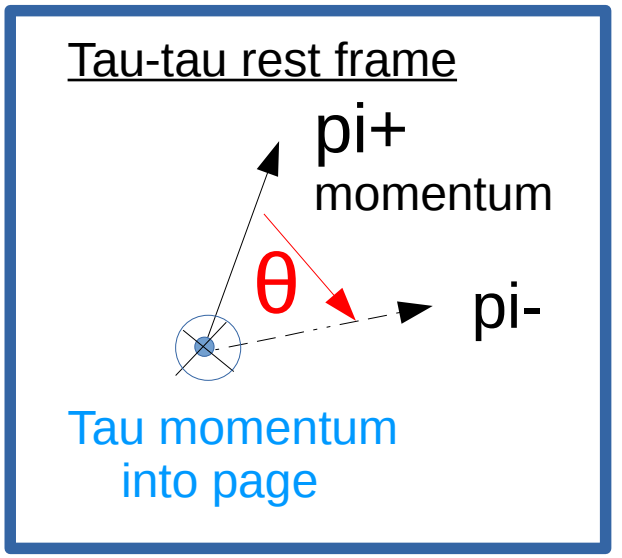
e.g. fully leptonic tau decays contain 2 neutrinos, and therefore less visible information

Simplest case is when both

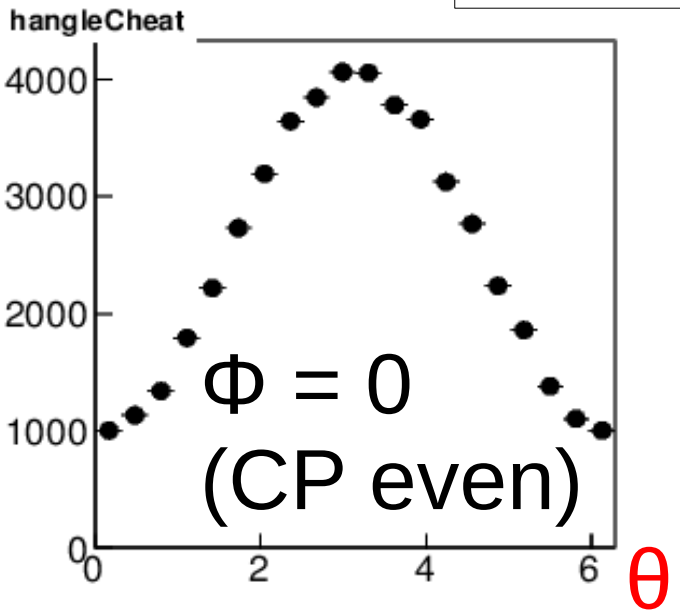
tau(+/-) -> pi(+/-) + tau_neutrino

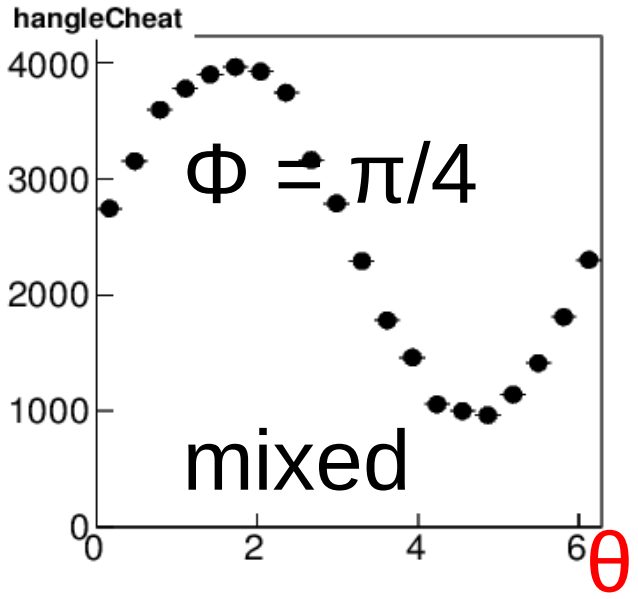
In rest frame of Higgs,

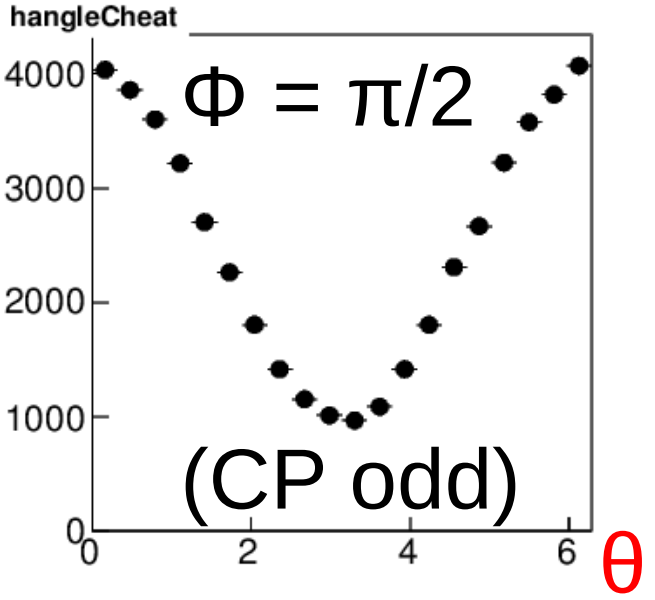
look at angle between pi(+/-)



WHIZARD 2.2.2 + Tauola
e+e- -> ve ve H (-> tau tau) @ 500 GeV
No ISR, beamstrahlung, detector effects

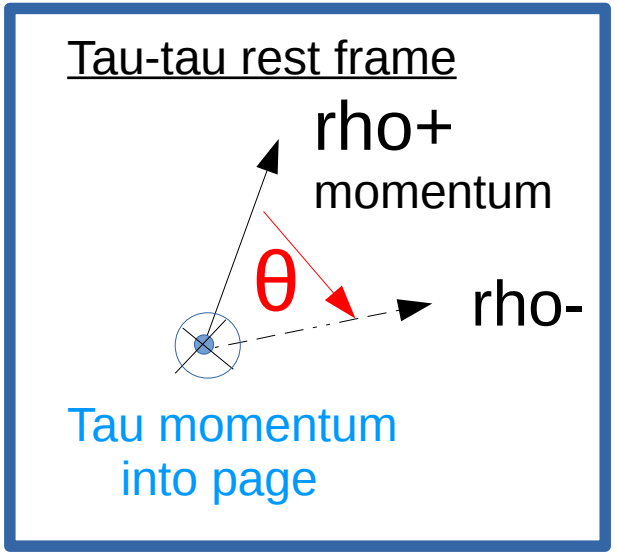


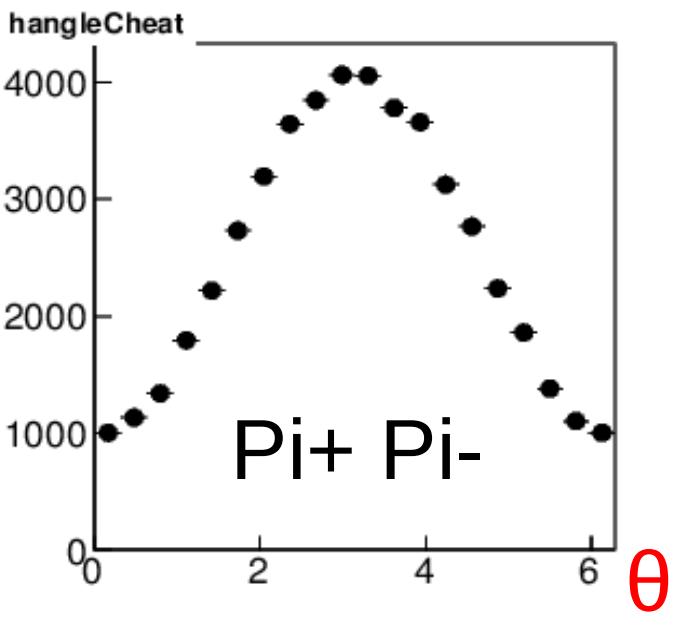


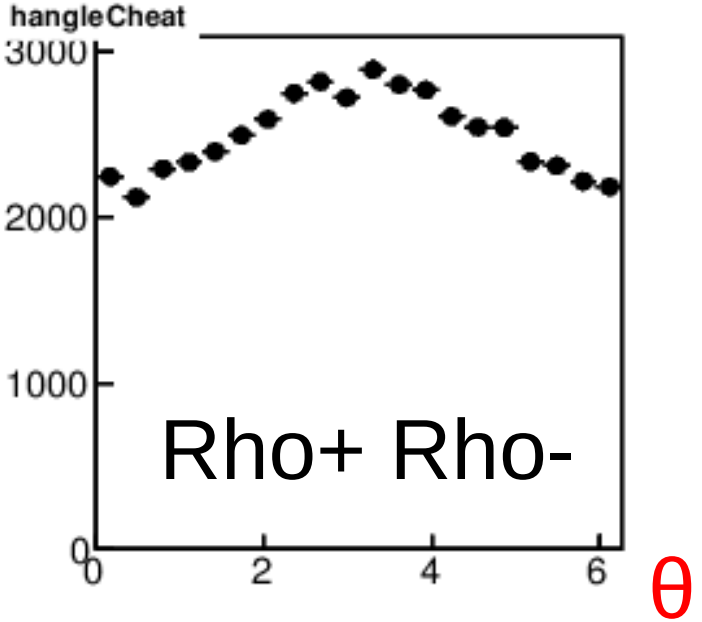


If we consider both taus decaying to rho+/-
(largest branching fraction)

Look at 2d angle between rho mesons
in tau-tau rest frame





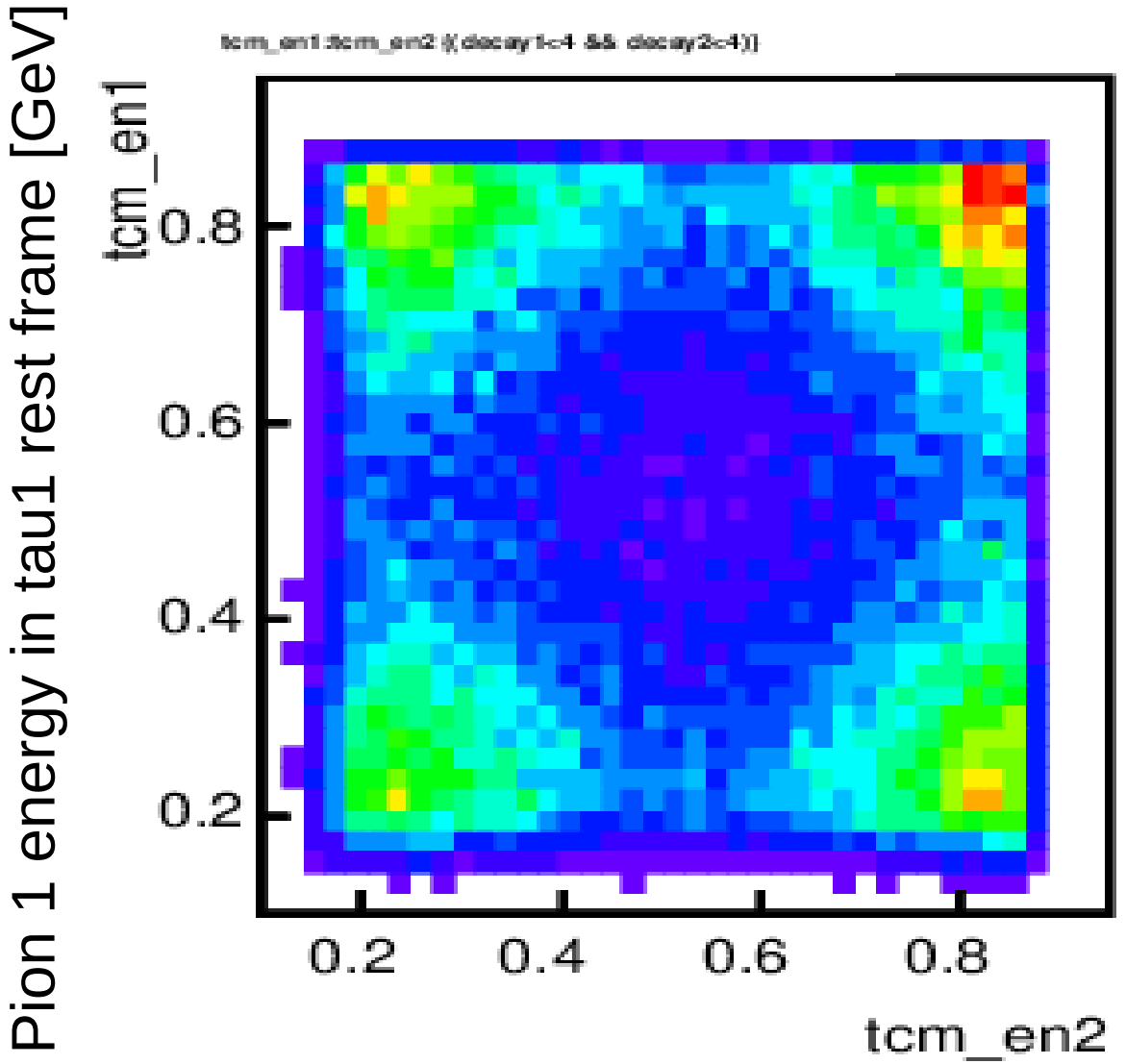


Different decay modes have different sensitivities

Both Φ = 0 (CP even)

Rho+ decays to pi+ pi0

Energy carried by charged pion in rho decay, in tau rest frame:

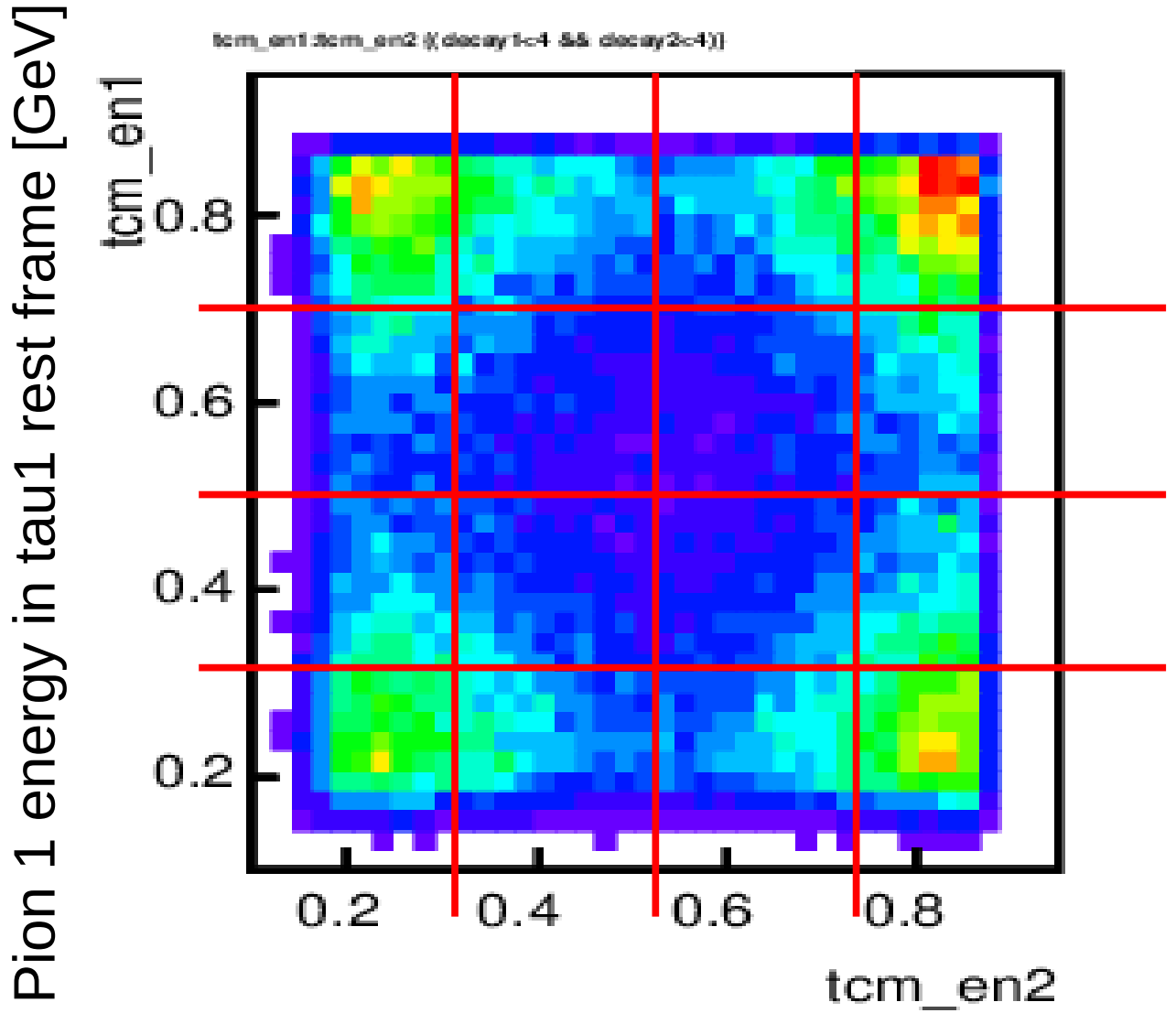


Pion 1 energy in tau1 rest frame [GeV]

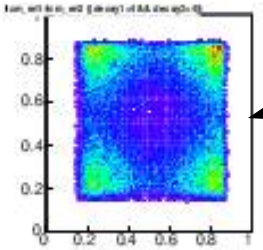
Pion 2 energy in tau2 rest frame [GeV]

Rho+ decays to pi+ pi0

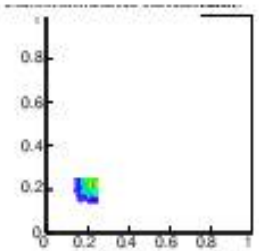
Energy carried by charged pion in rho decay, in tau rest frame:

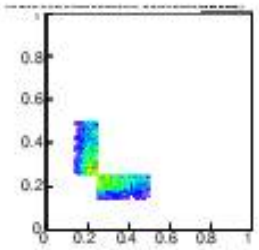


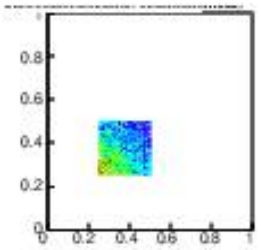
Split into bins according to pi+/- energy



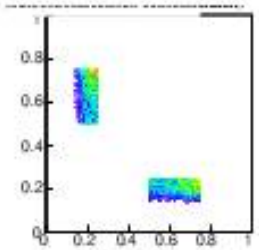
Total energy distribution

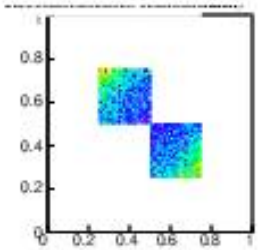


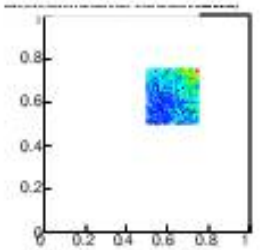


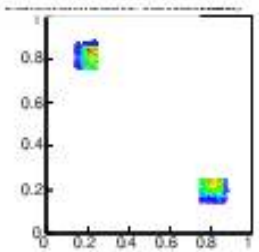


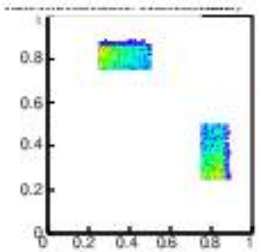
10 energy bins

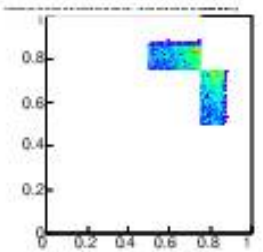


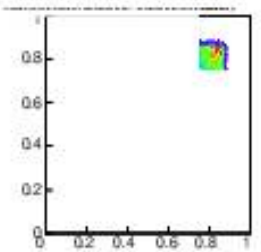


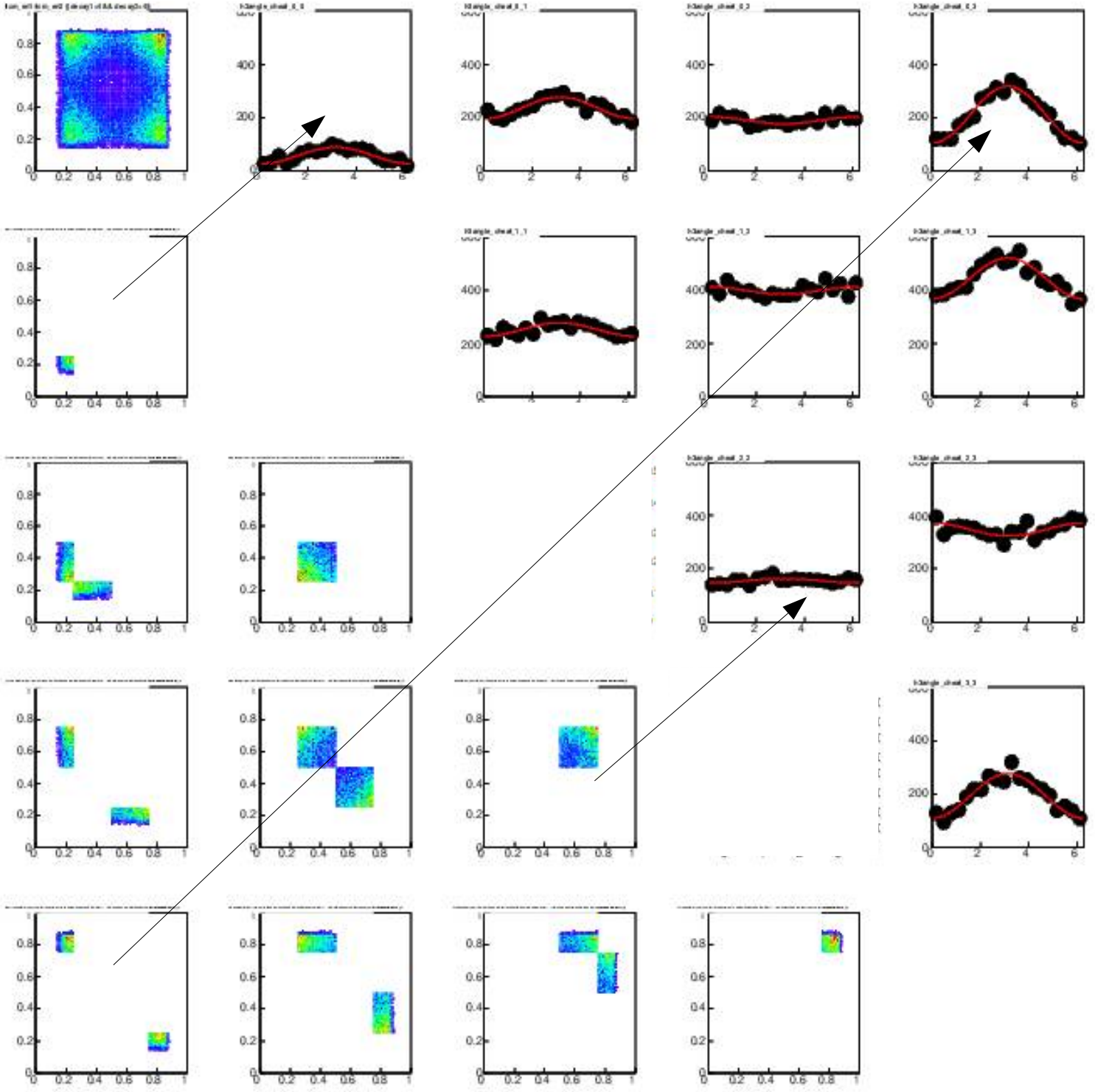












Angular distribution depends strongly on energy of pi+/- in tau rest frame

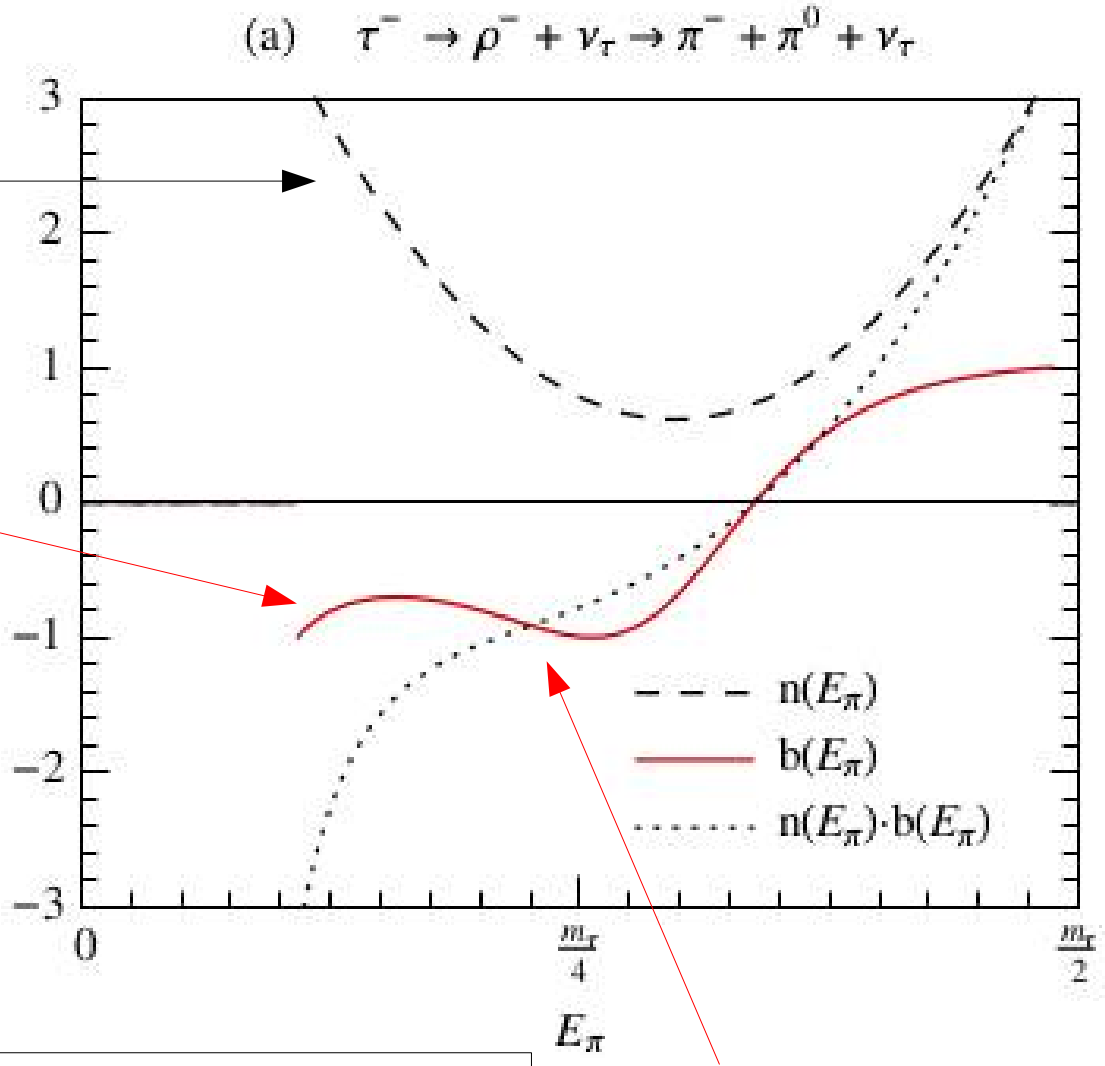
If we integrate over these energies, we dilute the measurement

Estimation of pion energy in tau rest frame is important!

This energy dependence can be encoded in the
"spectral function" of the charged pion in the rho decay

Distribution of pi+ (from rho+) energy in tau rest frame

Tau spin "sensitivity" of the pi+: changes sign



It is crucial to get a "reasonably" good estimate of the charged pion energy in the **tau rest frame**

=>

We need to get a good idea of the **tau rest frame**

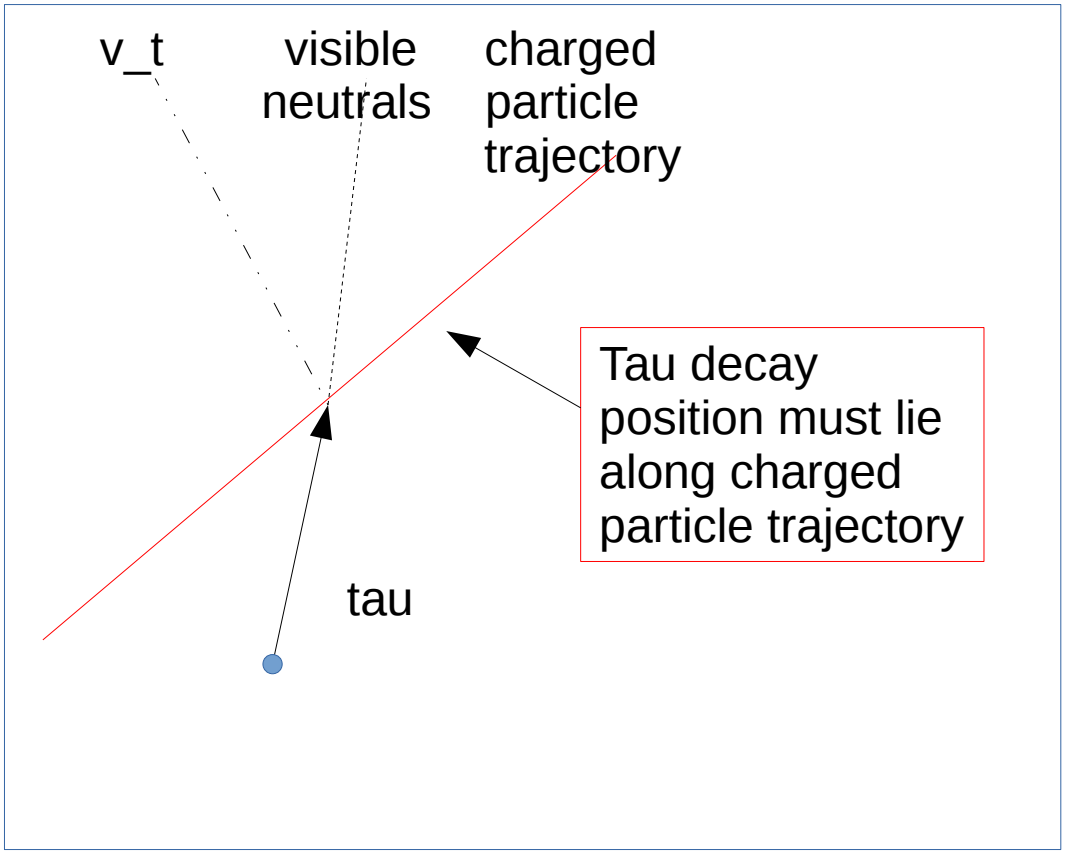
Similar, but not identical, behaviour for leptonic and 3-prong tau decays

Ideally use "sensitivity" to weight events

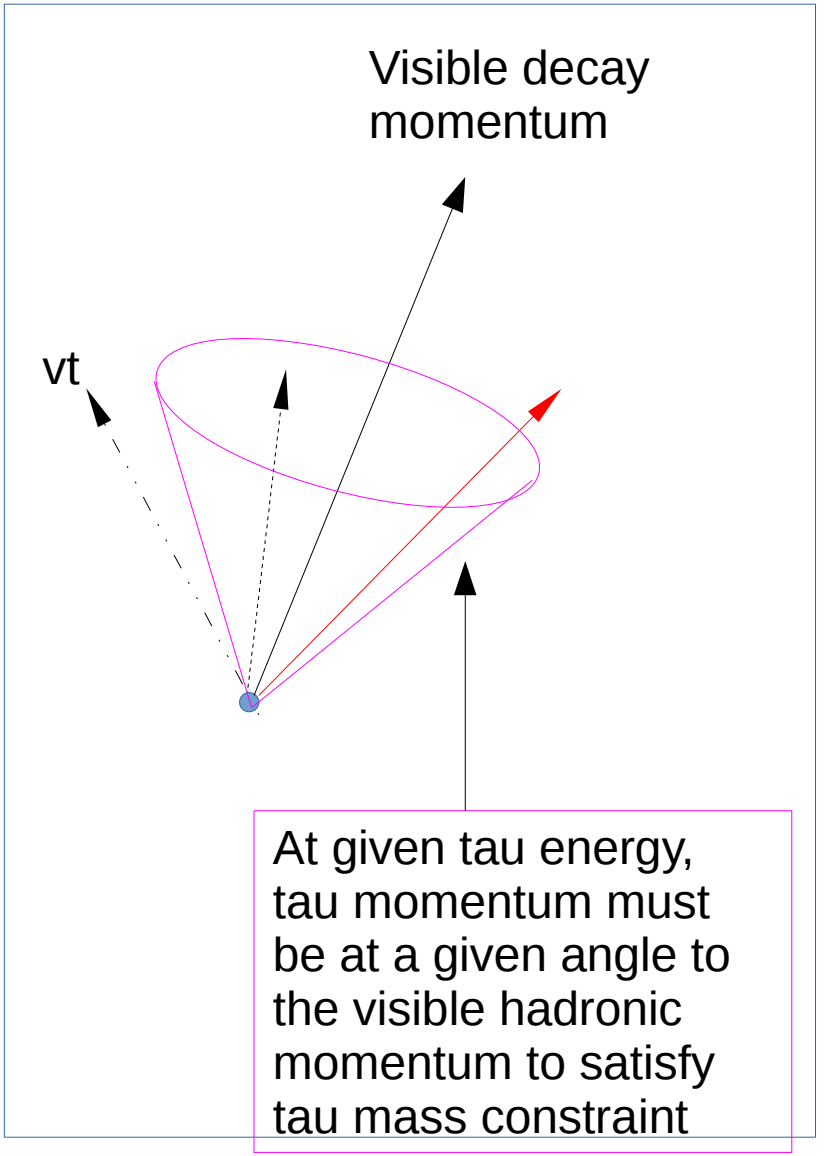
Tau momentum can not be measured directly, but we have some information

constraints on tau momentum

e.g. single prong hadronic decay



Intersection of possible tau trajectories with allowed cone can give (0,) 1 or 2 solutions



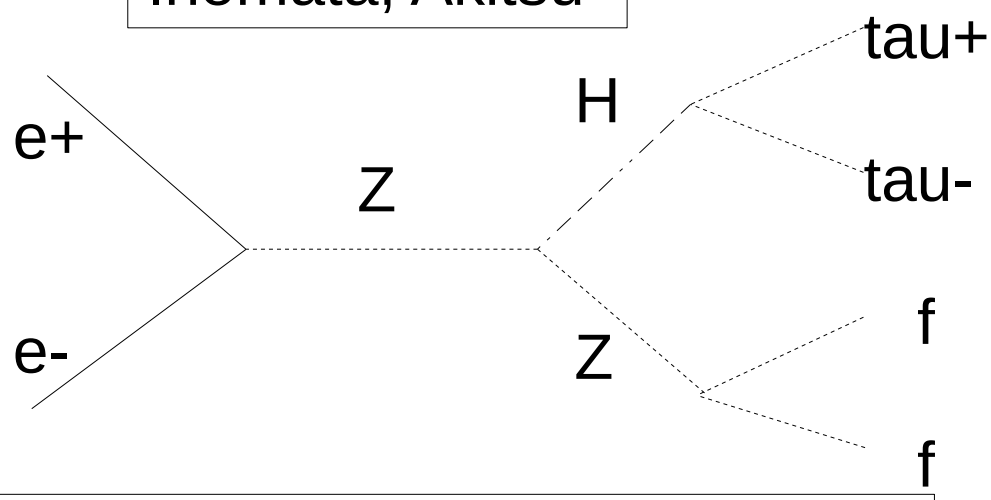
For multi-prong decays, should be able to explicitly reconstruct tau decay vertex

In the Higgs-strahlung process:

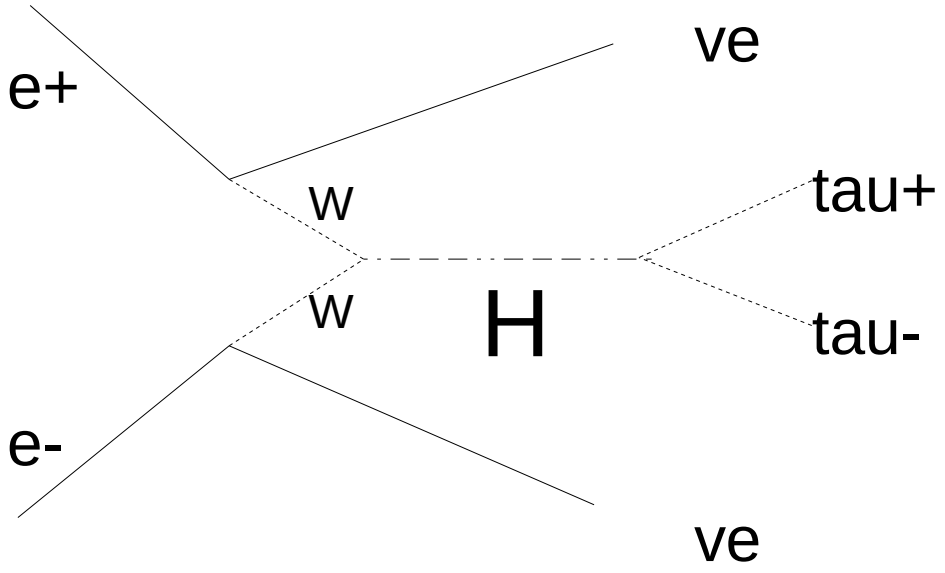
(dominant @ 250,350 GeV)

we also have constaints on the sum of the tau+ tau- mometum

Inomata, Akitsu



If we can measure the Z, we can get partially constrain the Higgs frame
(ISR, beamstrahlung complicate things in the z direction)



Jeans

In WW fusion production process, dominant at 500 GeV, we do not have this information available due to escaping neutrinos

If we have enough contraints (maybe in ZH process),
constrained kinematic fitting will probably give best estimate of tau momenta

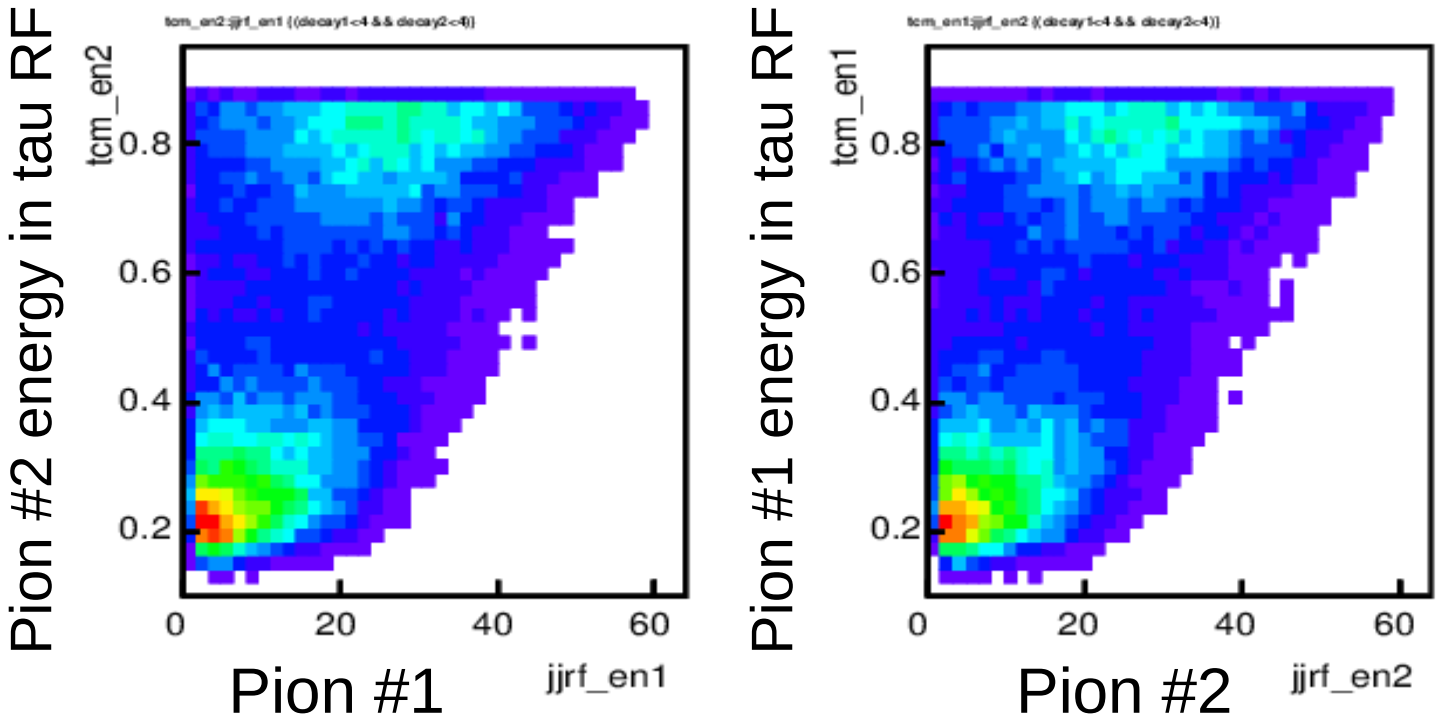
If not, some sort of weighting of different allowed kinematical solutions may be most powerful approach

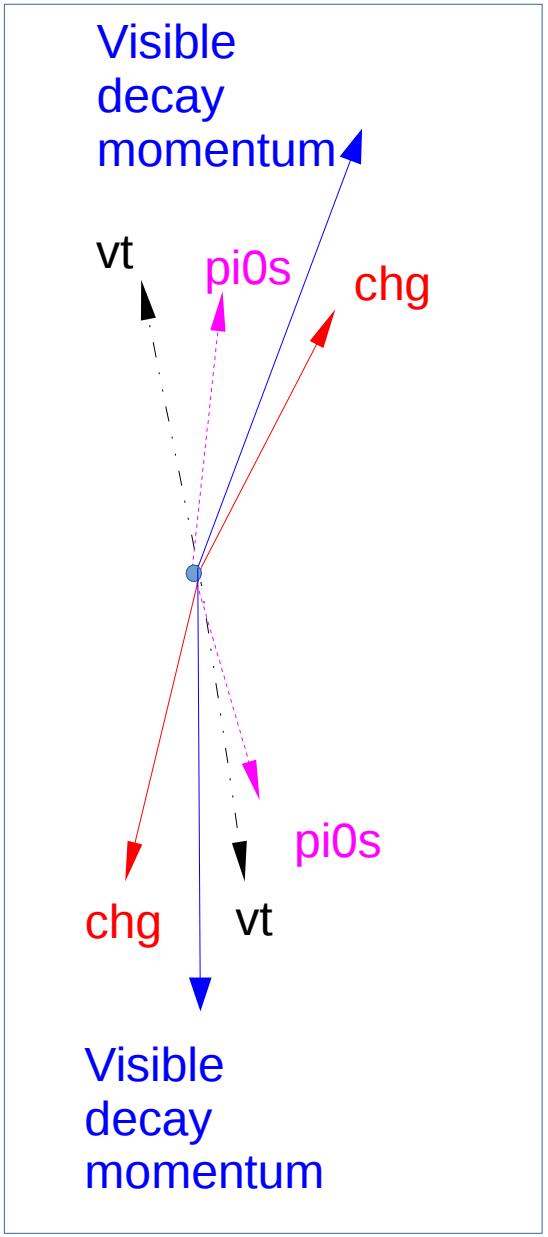
However, first follow a simpler approach:
define approximate reference frames
use correlations between particle energies in
true tau rest frame and
approximate frame

One possibility:
Use rest frame of visible
tau+ and tau- products
(approximates Higgs rest frame)
“jet-jet rest frame”

(This method will work in W-fusion)

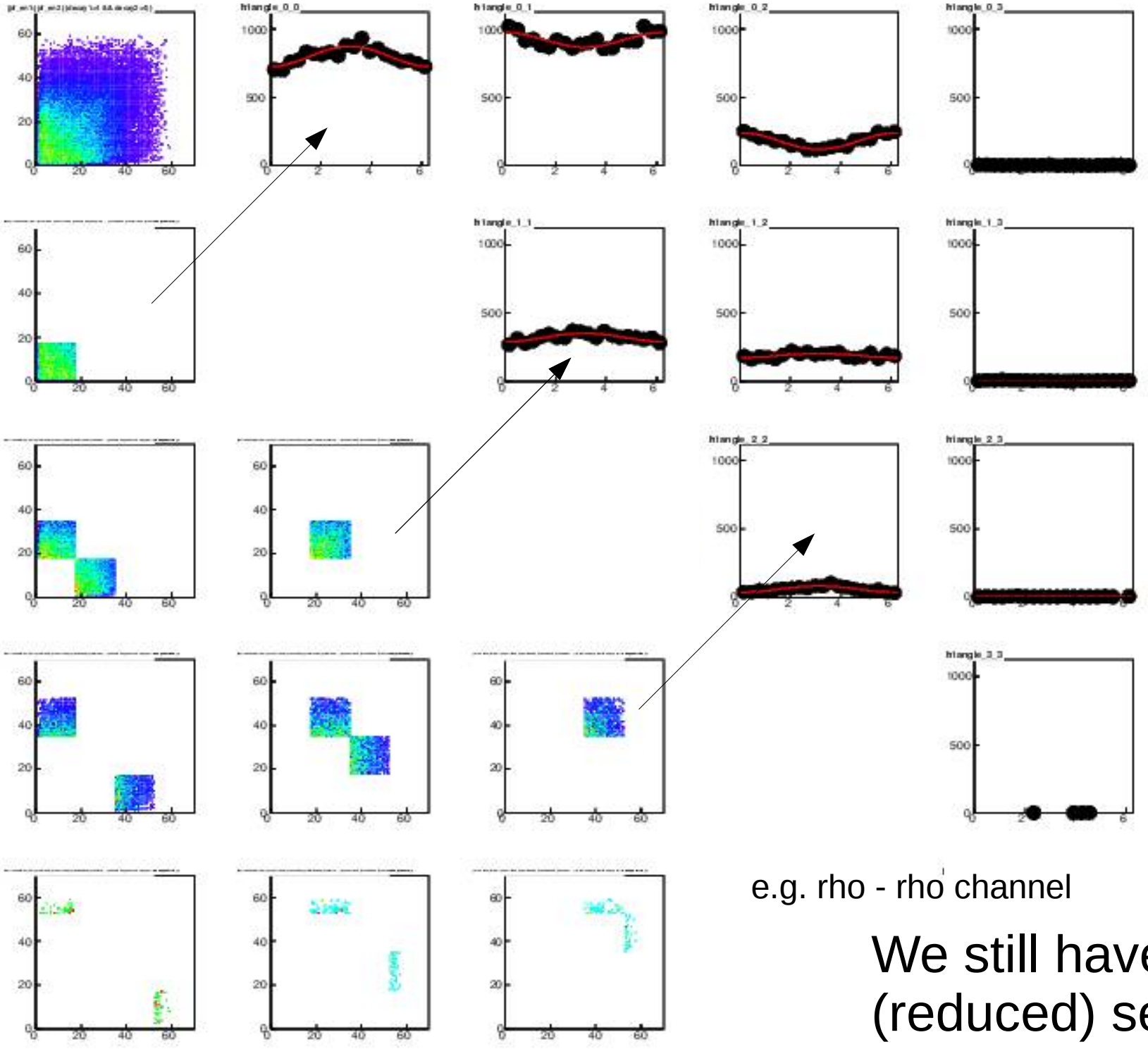
e.g. rho - rho channel





Not-yet understood
correlation to energy
of pion from other tau

Energy of charged pion in jet-jet rest frame



Energy of pi+ in jet-jet rest frame (GeV/c)

Angles measured using impact parameter method

e.g. rho - rho channel

We still have some (reduced) sensitivity

Energy of pi- in jet-jet rest frame (GeV/c)

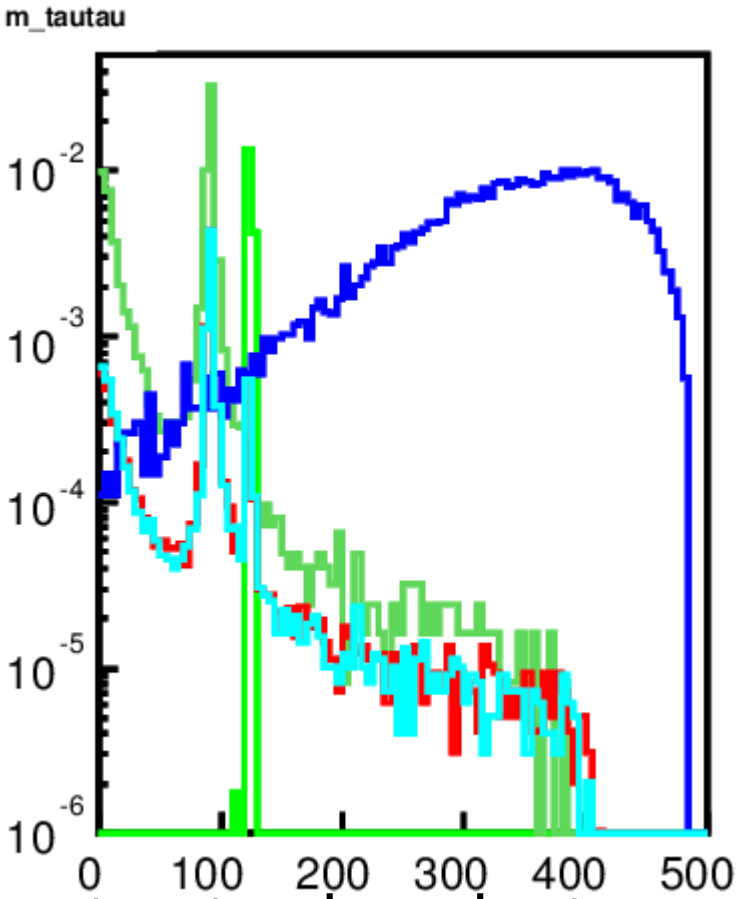
Backgrounds

At 250,350 GeV, using Higgs-strahlung (ee->ZH) process
irreducible background is mostly ZZ
control by use of recoil mass

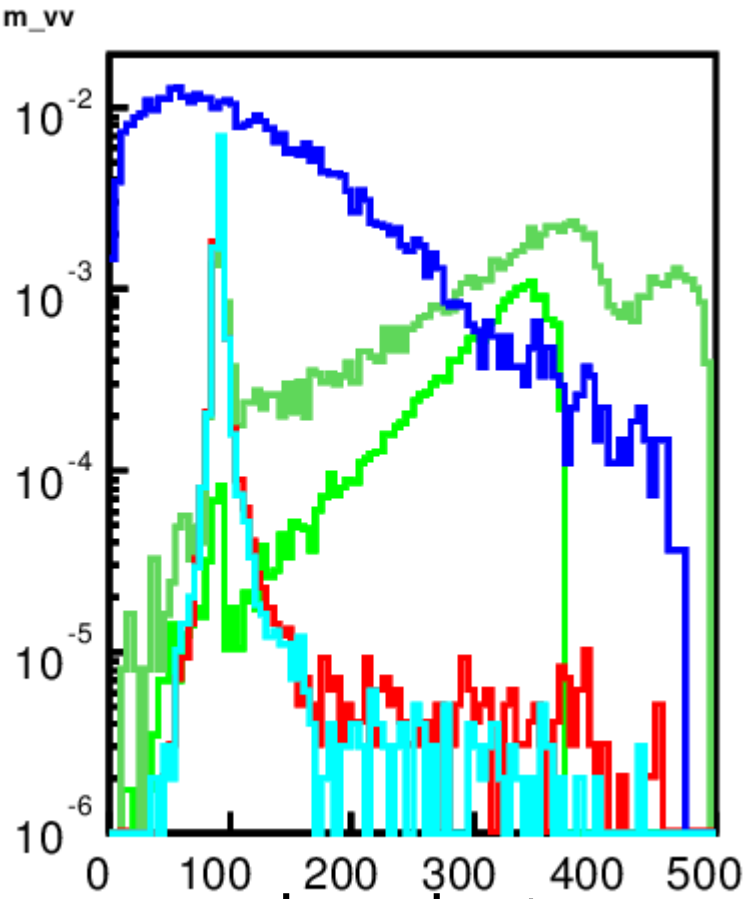
At 500 GeV, (WW fusion process e+e- -> nu nu H),
have many irreducible backgrounds:

ee->WW->(tau vt) (tau vt)
ee->ZZ->(tau tau) (v v)

All tau+ tau- + 2*neutrino final states @ 500 GeV



tau-tau invariant mass



nx-nx invariant mass

No ISR, beam effects

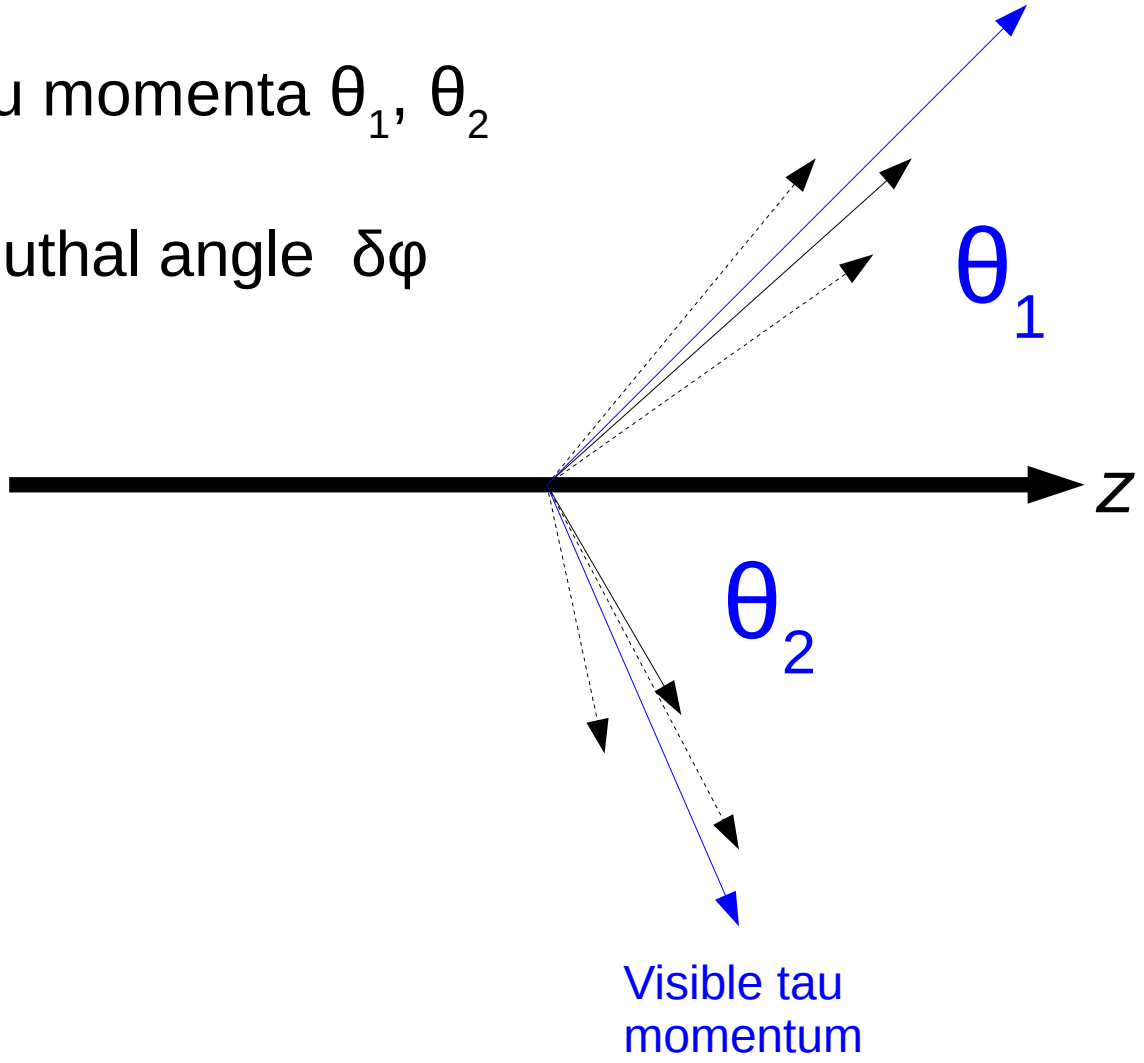
ve ve tau tau (via Higgs: signal)
ve ve tau tau (not Higgs)
vm vm tau tau
vt vt tau tau (WW)
vt vt tau tau (not WW)

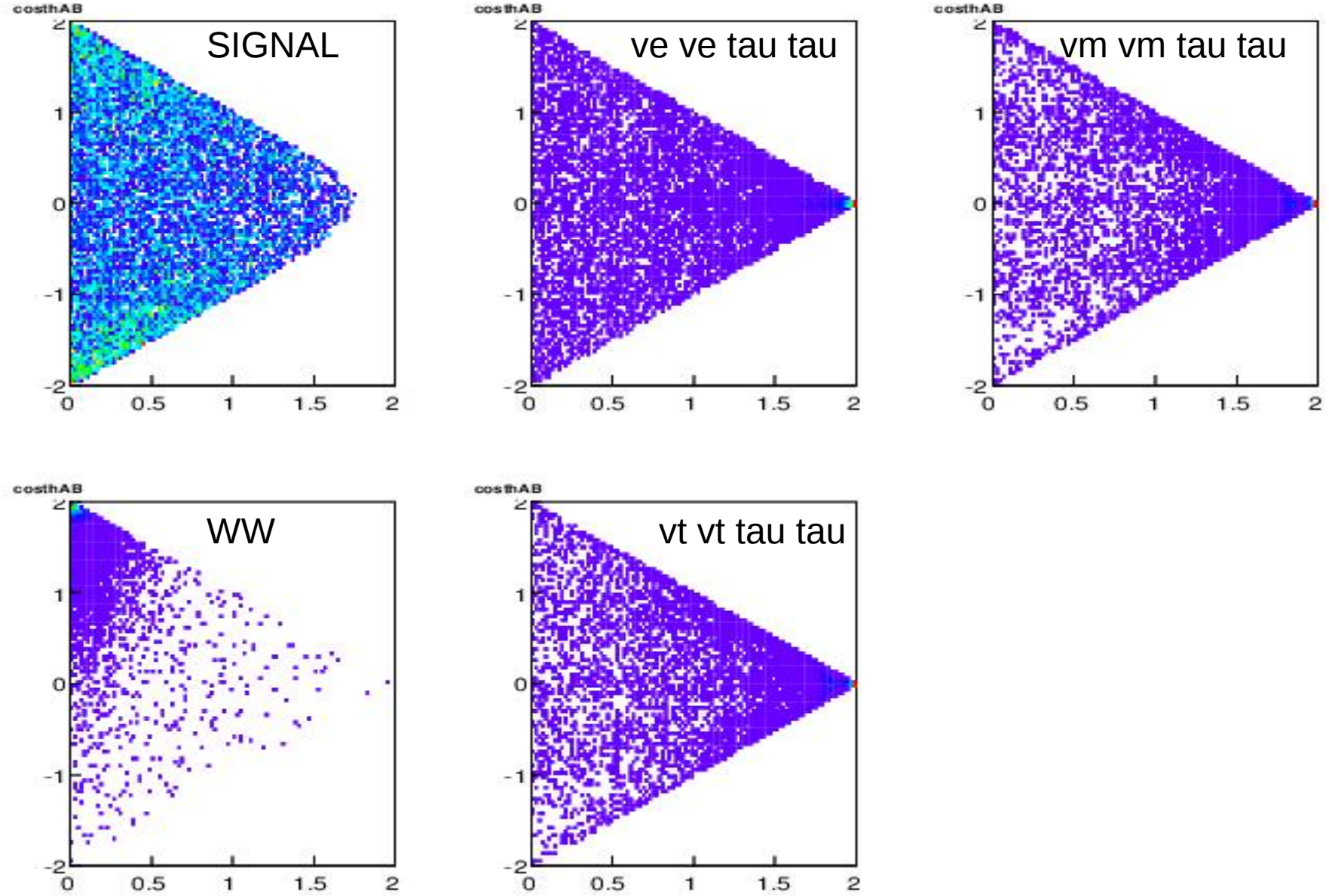
These two variables are ~completely unobservable !

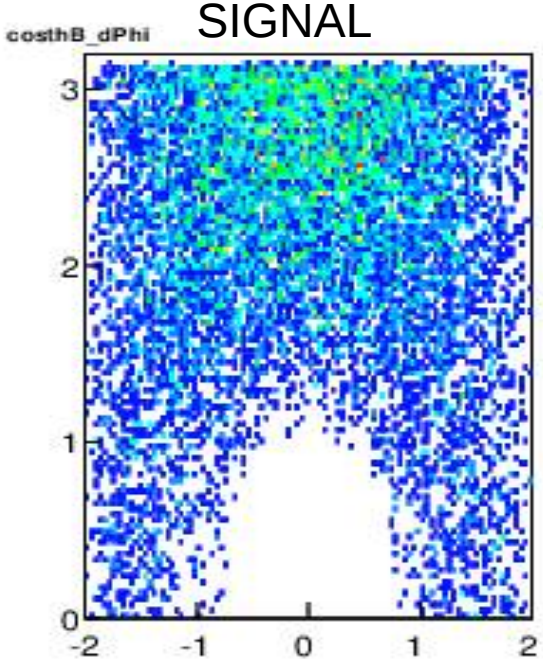
In lab frame, we can probably estimate angles of tau quite well

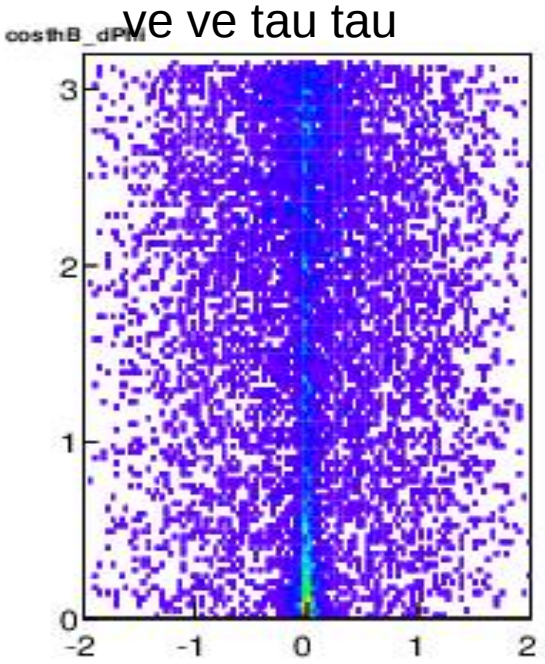
Polar angles of tau momenta θ_1, θ_2

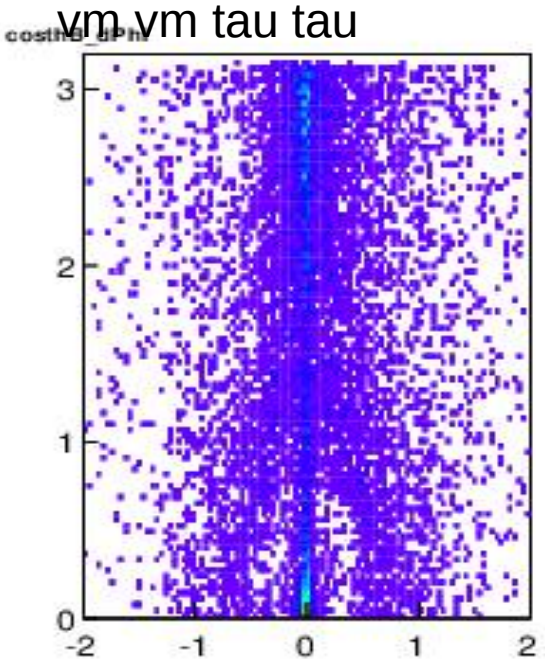
Difference in azimuthal angle $\delta\varphi$

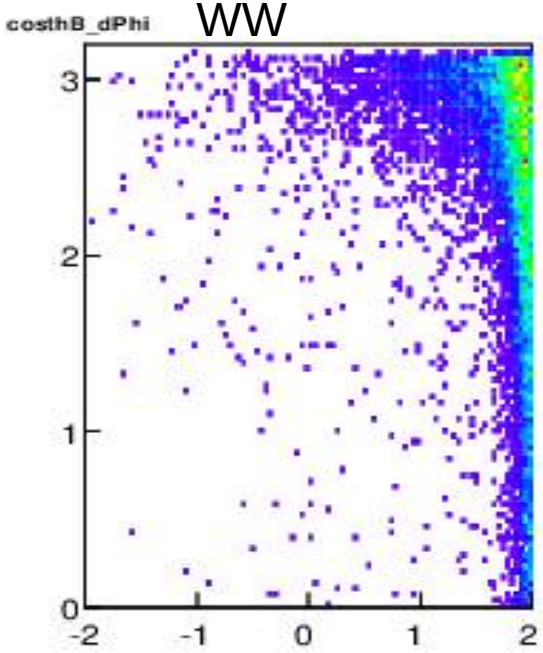


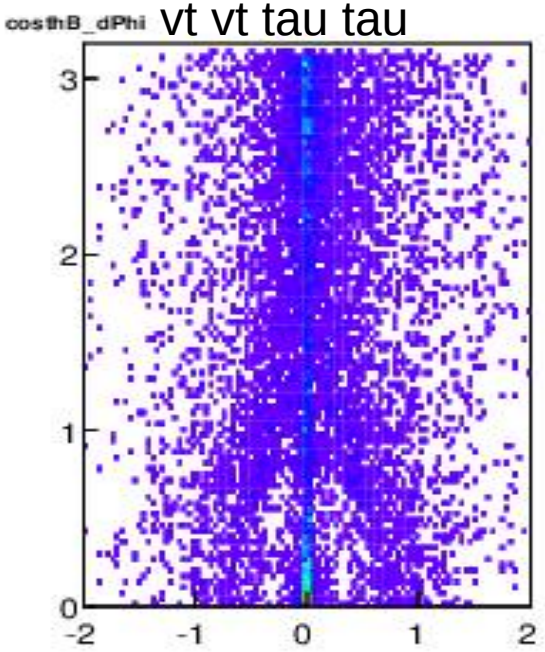

costhAB
SIGNAL
ve ve tau tau
vm vm tau tau
WW
vt vt tau tau
cos (theta_1) + cos(theta_2)
| cos (theta_1) | + | cos(theta_2) |









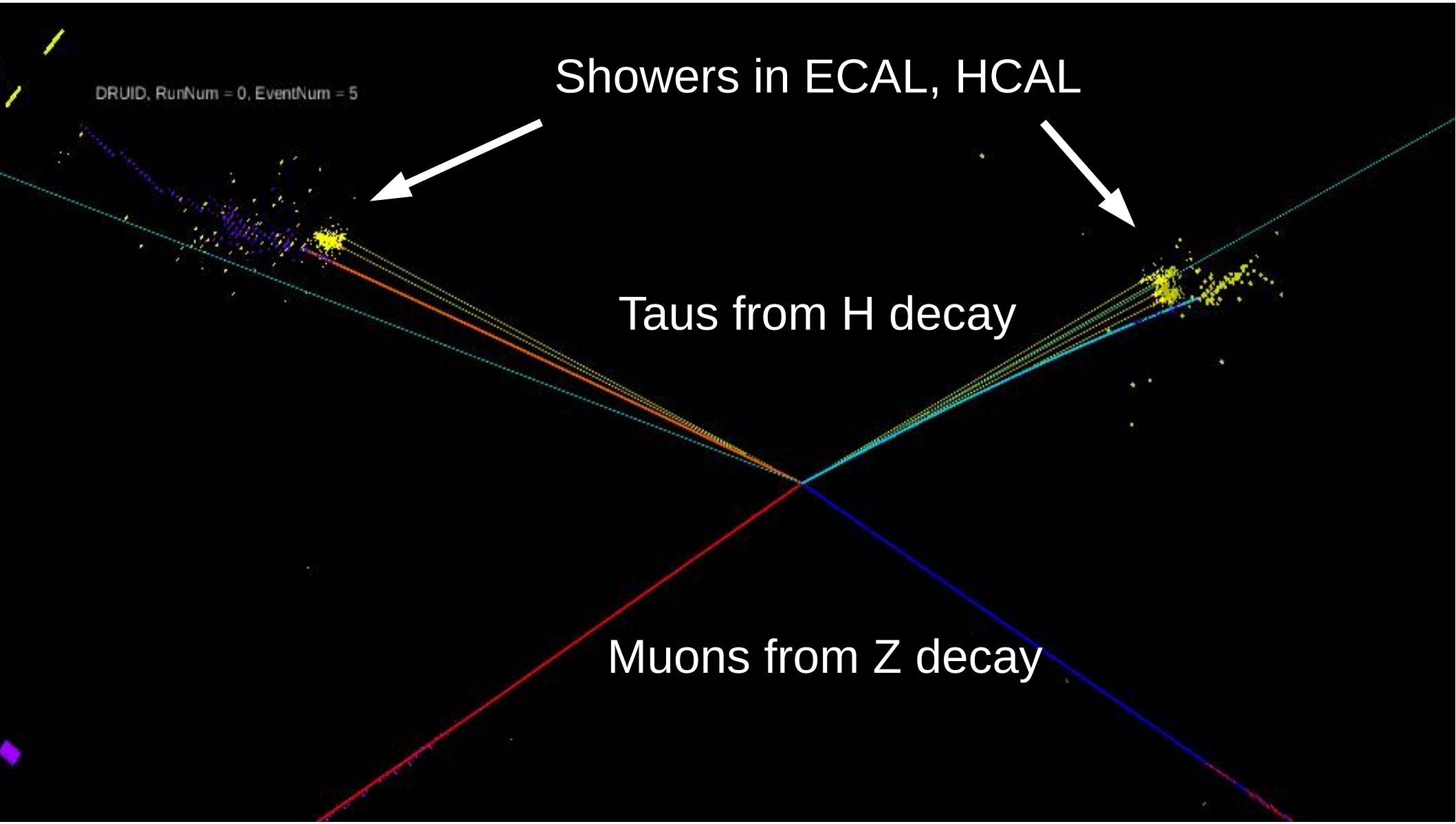


delta phi

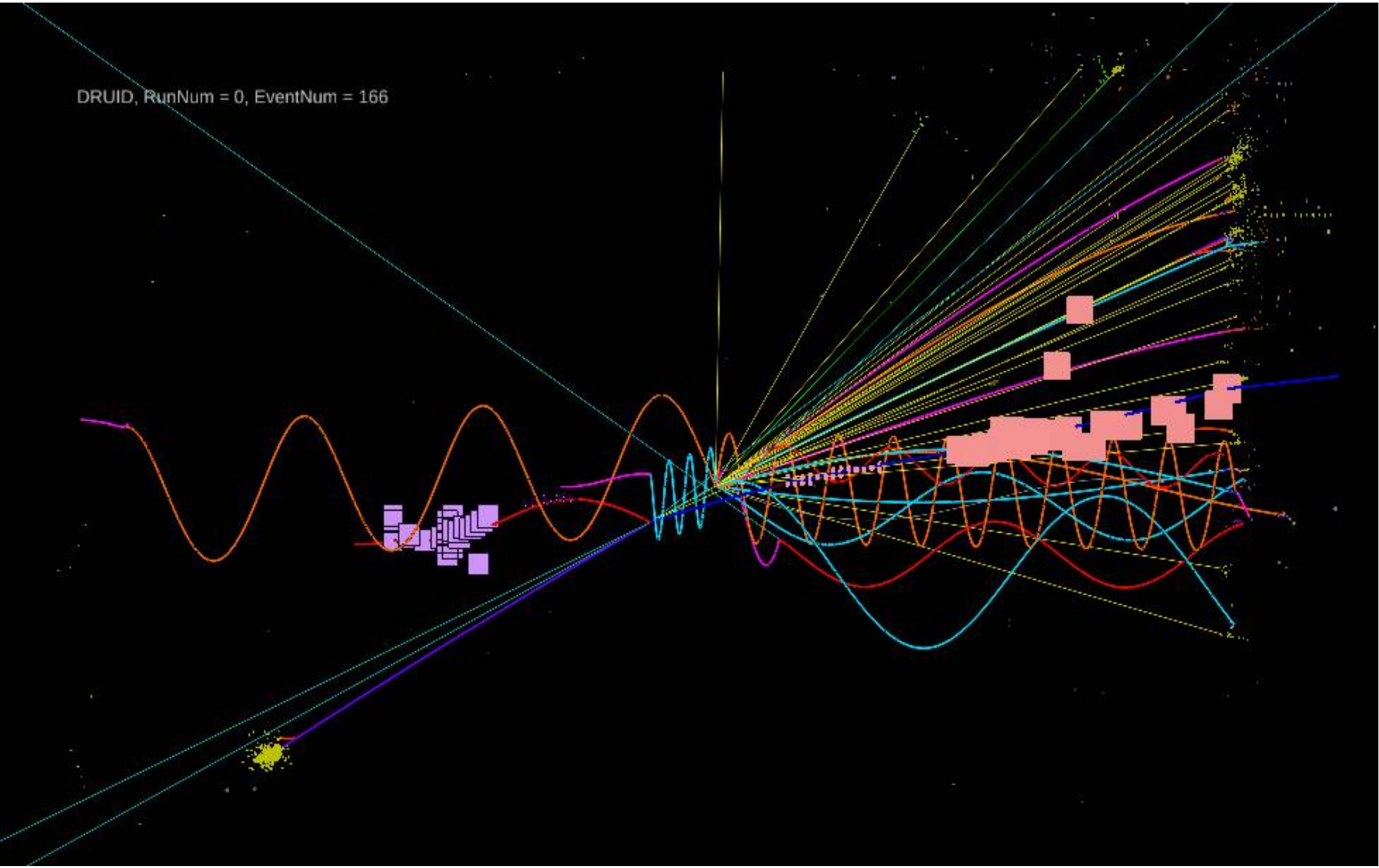
cos (theta_1) + cos(theta_2)

backgrounds can be somewhat reduced using cuts on tau angles, but not eliminated

e+ e- > Z (> mu+ mu-) + H (> tau+ tau-)



The danger of material in the tracker....



e+ e- => mu+ mu- H (=> tau+ tau-)

Summary, plans

Started to look at measurement of CP properties of
Higgs in tau decays

Ultimate goal is a quantitative comparison of measurements in the two production modes:

Higgs-strahlung is certainly easier
Information about H rest frame, backgrounds
W-fusion may be possible...

Plan to continue study, move more to full simulation and reconstruction (using GARLIC)
(Akitsu has started this part)