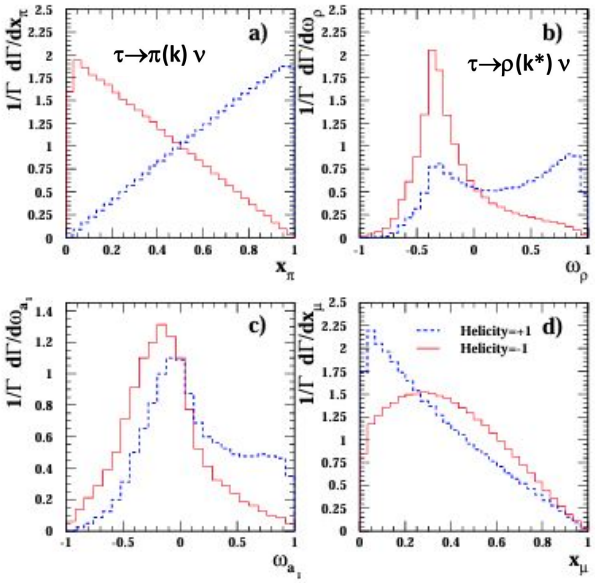
Tau Polarization Discussion

Dolores Garcia, Michele Selvaggi, María Cepeda

Polarization Task force: Juan Alcaraz, Patrizia Azzi, Jean-Claude Brient, M.C, D.G, Jan Eysermans, Emmanuel Perez, M.S, Roberto Tenchini

Overview (I)

Request by SPC to perform **tau polarisation study at the Z** by looking at **full simulation** of the hadronic showers.



Z pole LEP+SLD paper: Physics Reports 427:257-454,2006

Figure 4.2: Monte Carlo simulated distributions of polarisation sensitive kinematic variables defined in the text for (a) $\tau \to \pi\nu$, (b) $\tau \to \rho\nu$, (c) $\tau \to a_1\nu$ and (d) $\tau \to \mu\bar{\nu}\nu$ decays for positive and negative helicity τ leptons excluding the effects of selection and detector response.

$$\mathcal{P}_\tau \equiv (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$$

$$\mathcal{P}_\tau(\cos\theta_{\tau^-}) = -\frac{\mathcal{A}_\tau(1+\cos^2\theta_{\tau^-}) + 2\mathcal{A}_e\cos\theta_{\tau^-}}{(1+\cos^2\theta_{\tau^-}) + \frac{8}{3}A_{\rm FB}^\tau\cos\theta_{\tau^-}}$$

The polarisation measurements rely on the dependence of kinematic distributions of the observed τ decay products on the helicity of the parent τ lepton. $P_\tau(\cos\theta_{\tau^-})$ allows for the nearly independent determination of A_τ and A_e .. See Physics Reports 427:257-454,2006 for details.

Plan for this study:

➔ Check performance in full sim samples: impact of reconstruction in identification of decay channels and associated systematics

➔ Once understood, propagate to a physics analysis (in Delphes) through parametrization of performance ➔ effect on templates! (note the full analysis cannot be done in fullsim) ➔ sensitivity

Overview (II)

First target: Aτ . Focus on π vs ρ channels, photon&π0 identification / rejection

Second target: muon/electron vs tau discrimination (Ae)

Starting point: full simulation of single particles (pi+-, pi0, rho, muons, electrons) in CLD

Two approaches: ML (based on hits, Graph and heuristic (based on PFO candidates)

Decay mode	Resonance	$\mathcal{B}$ (%)
Leptonic decays		35.2
$\tau^- \to e^- \overline{\nu}_e \nu_\tau$		17.8
$\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau$		17.4
Hadronic decays		64.8
$\tau^- \to h^- \nu_\tau$		11.5
$\tau^- \to h^- \pi^0 \nu_\tau$	$\rho(770)$	25.9
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	9.5
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a_1(1260)$	9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$		4.8
Other		3.3

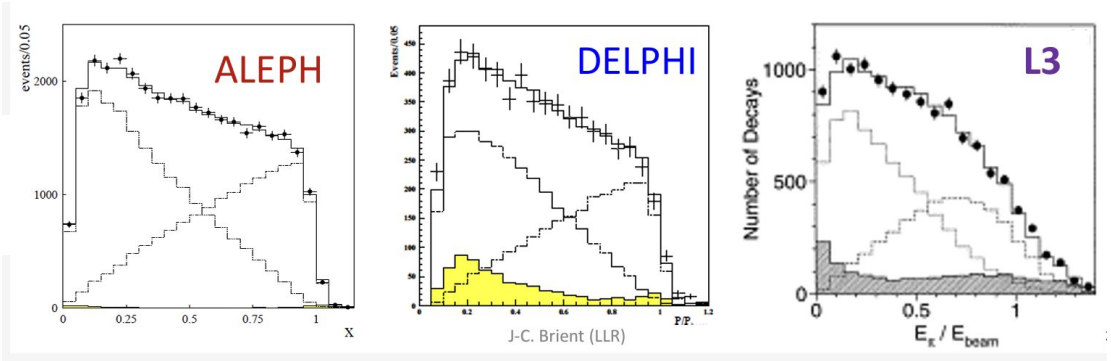
➡ From LEP we know we can focus on the pion and rho decays

Notes from LEP

See J-C. Brient's presentation in Krakow Physics Workshop for a detailed discussion

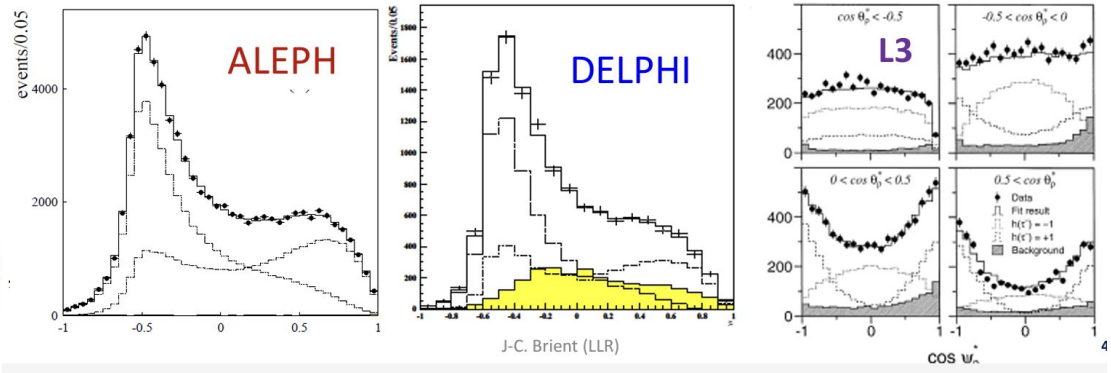
$\tau \rightarrow \pi(k)\, \nu$

$x_\pi = E_\pi / E_\tau$



$\tau \rightarrow \rho(k^*)\, \nu$

$\omega_\rho = \frac{W_+(\theta^*, \psi) - W_-(\theta^*, \psi)}{W_+(\theta^*, \psi) + W_-(\theta^*, \psi)}$



Effect of reconstruction on the templates?

Discrimination pion vs rho

Notes from LEP

ALEPH

Systematics errors estimation as a function of the source of the uncertainties

A_τ

Source	h	ρ	$3h$	$h2\pi^0$	e	μ	Incl. h
selection	-	0.01	-	-	0.14	0.02	0.08
tracking	0.06	-	0.22	-	-	0.10	-
ECAL scale	0.15	0.11	0.21	1.10	0.47	-	-
PID	0.15	0.06	0.04	0.01	0.07	0.07	0.18
misid.	0.05	-	-	-	0.08	0.03	0.05
photon	0.22	0.24	0.37	0.22	-	-	-
non-τ back.	0.19	0.08	0.05	0.18	0.54	0.67	0.15
τ BR	0.09	0.04	0.10	0.26	0.03	0.03	0.78
modelling	-	-	0.70	0.70	-	-	0.09
MC stat	0.30	0.26	0.49	0.63	0.61	0.63	0.26
TOTAL	0.49	0.38	1.00	1.52	0.96	0.93	0.87

A_e

Source	h	ρ	$3h$	$h2\pi^0$	e	μ	Incl. h
tracking	0.04	-	-	-	-	0.05	-
non-τ back.	0.11	0.09	0.04	0.22	0.91	0.24	0.17
modelling	-	-	0.40	0.40	-	-	-
TOTAL	0.12	0.09	0.40	0.47	0.91	0.25	0.17

Krakow Physics Workshop

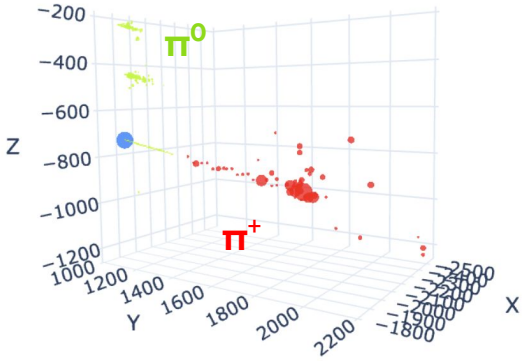
experiments	$\mathcal{A}\tau$ (x100)
ALEPH	14.51 ± 0.52 ± 0.29
DELPHI	13.59 ± 0.79 ± 0.55
L3	14.76 ± 0.88 ± 0.62
OPAL	14.56 ± 0.76 ± 0.57
Combined	**14. 39 ± 0.35 ± 0.26**

At FCC Dominated by systematics

Full simulation of CLD samples

Data available @ /eos/experiment/fcc/ee/datasets/mlpf/condor/train/single_particles_flat/*_1/

- Gun hepmc
  - 0-50 GeV (uniformly distributed in energy)
  - 1 particle per event (π or ρ)
  - Random angle in the detector
- CLD simulation and reconstruction [1]
- Inputs to the ML approach:
  - All ECAL and HCAL hits and the track state at calorimeter (4)
    - Hits inputs are (x,y,z) coordinates in the detector, energy
    - Track inputs (x,y,z), p
- Input to heuristic analysis: particle flow reconstruction (with pandora)

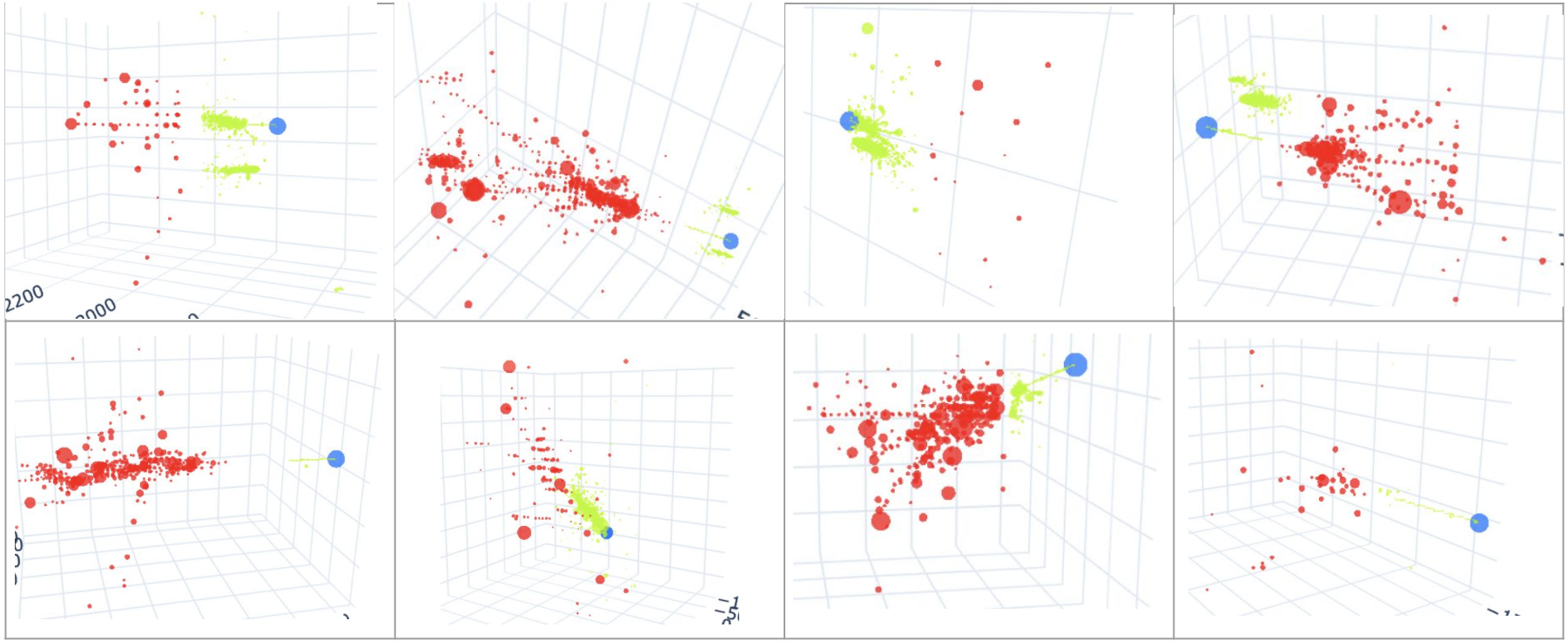


Example rho event. Track (blue), ECAL hits (green) HCAL hit (red). The size of the hits represents the energy deposit.

[1] https://github.com/key4hep/CLDConfig/tree/main/CLDConfig

Example events

Track (blue), ECAL hits (green) HCAL hit (red). The size of the hits represents the energy deposit.



Heuristic approach: Decay reconstruction

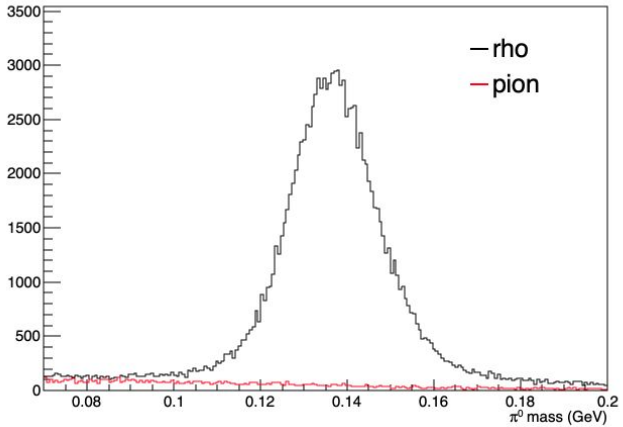
Target specific decays of the tau: identify the decay by looking at the particle flow candidates in the event (similar to the simple reconstruction presented last year, designed using Delphes)

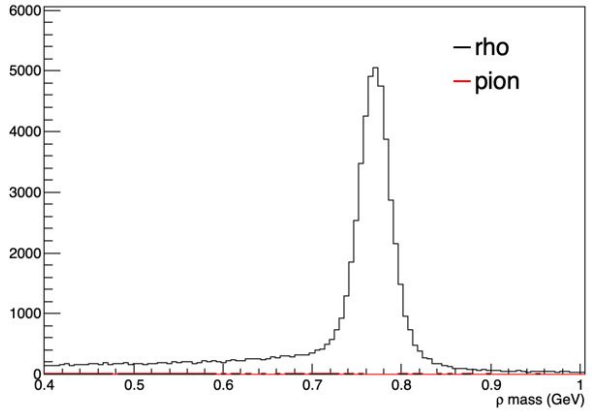
Start directly from charged and neutral PFOs: charged pions and photons as elements for building the tau decay:

- Reconstruct Pi0 (from pairs of photons) and Rho (clustering photons around the pion - allowing for only one photon to recover events in which either the two photons are very collimated or we have lost one photon)
- For now no pt/energy requirements on PFO candidates, and maximum distance photons and photon/pion dR=0.1

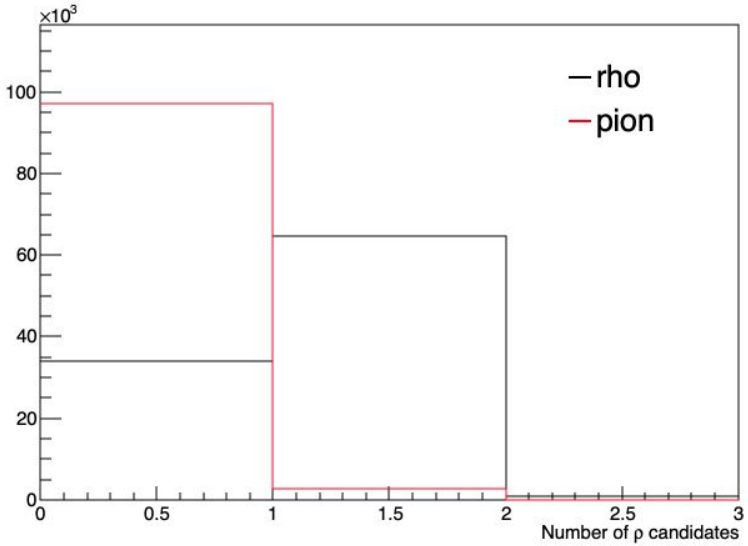
Exclusive samples of rho, pion+-

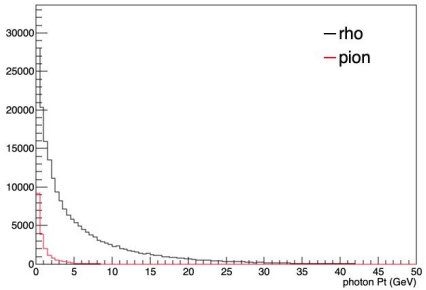
Careful: arbitrary normalization (~100k events in each samples)

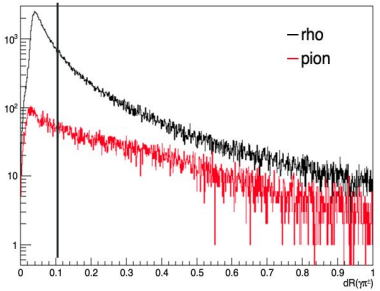


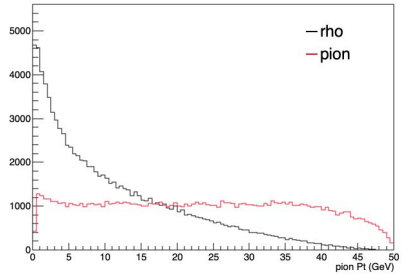


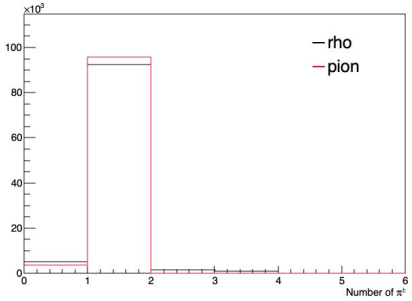
Migration rho ⇔ pion?





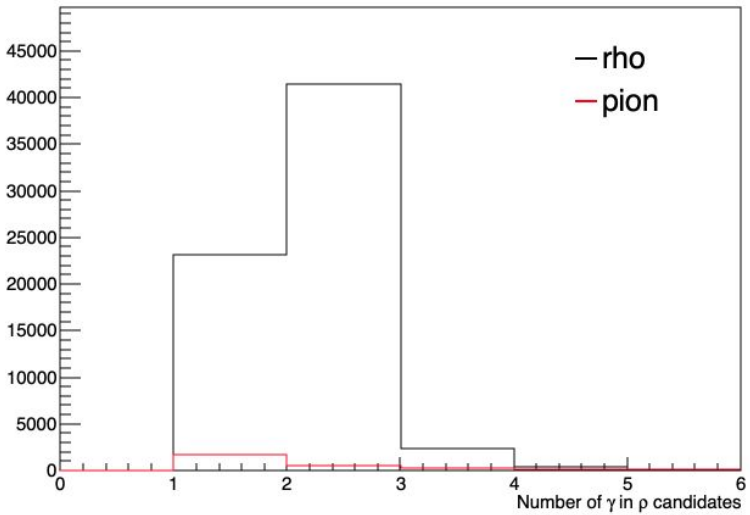


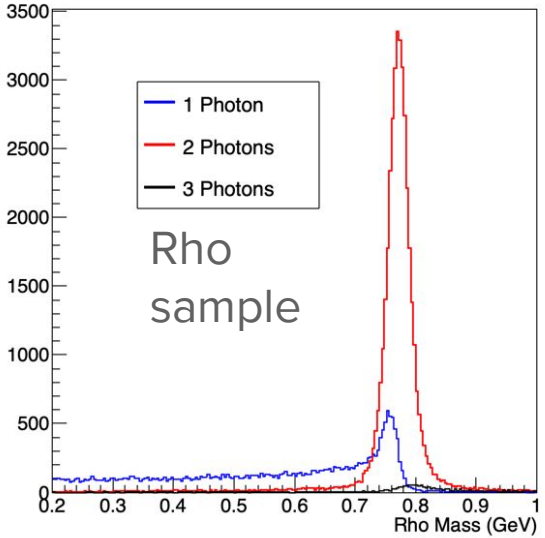




Negligible migration from pion->rho.
Migration from rho->pion sizeable, under study (pt, dR ?).

Rho: Pion+1 Photon vs Pion+2 Photons



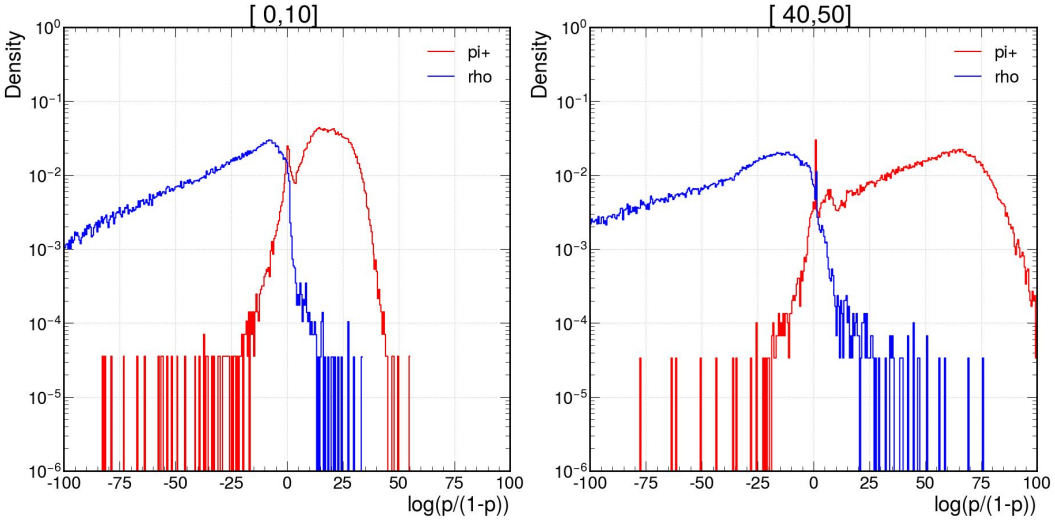


To build the rho:

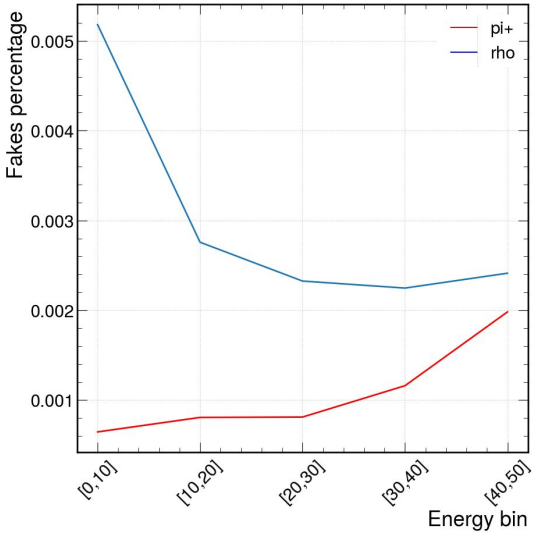
- Starting from pion
- Incorporating all photons found within dR=0.1 of the pion to build the rho candidate
  - ➡ If only 1 photon is found, this is still incorporated in the rho. Tail at lower mass
- Events with only 1 photon will be studied in more detail

ML approach and results

- The GNN takes hits as inputs and outputs a score for rho and pi+



P= probability to be classified as pi+



Mistag rate at 99% efficiency for pi+ (red), rho (blue)
Fakes percentage < 1% !

Reminder: Inputs to the ML approach: All ECAL and HCAL hits and the track state at calorimeter , Hits inputs are (x,y,z) coordinates in the detector, energy , Track inputs (x,y,z), p

Summary / Outlook

- First look at rho reconstruction in full sim. Next steps:
  - Study the impact of selection cuts on the photon on the migration between rho/pion categories
  - Compare to gen and study behaviour as a function of the pt of the pion/rho
  - Compute efficiencies / resolution on full tau samples and Z->tautau decays

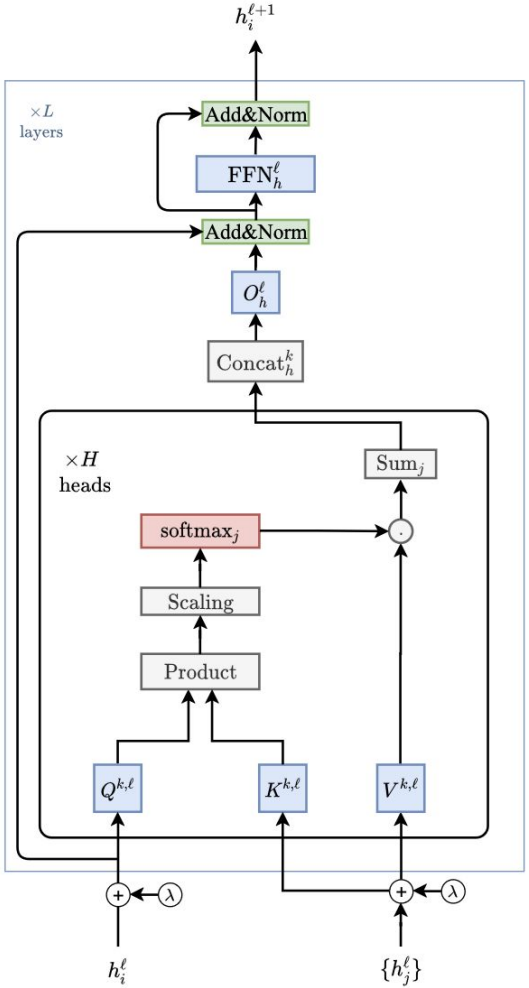
- Possible improvements ML:
  - Weight events with different number of tracks (corresponding to different decays, nuclear interactions)
  - Add e, muon, pi0, to the classification task

backup

Architecture

Graph Neural Network transformer

- Each hit attends to all other hits
- Graph is consider fully connected

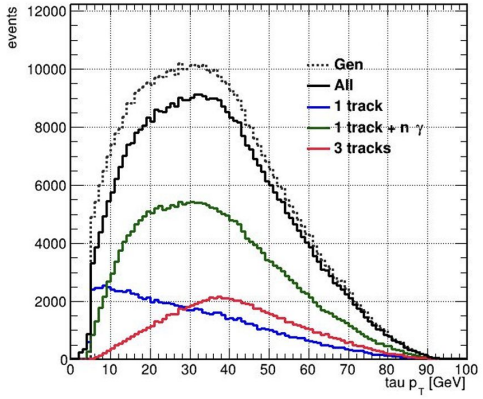


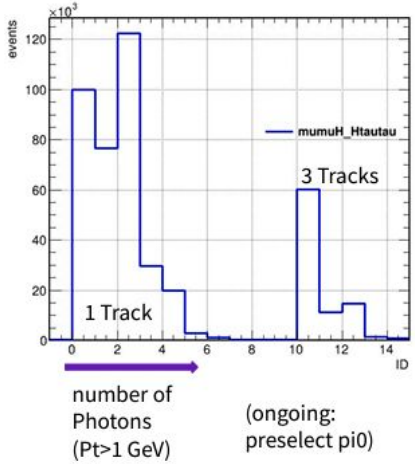
Graph Transformer layer

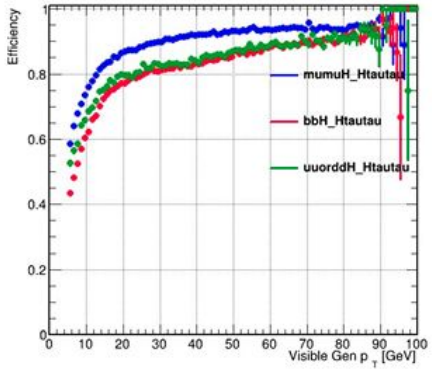
l] https://arxiv.org/pdf/2012.09699

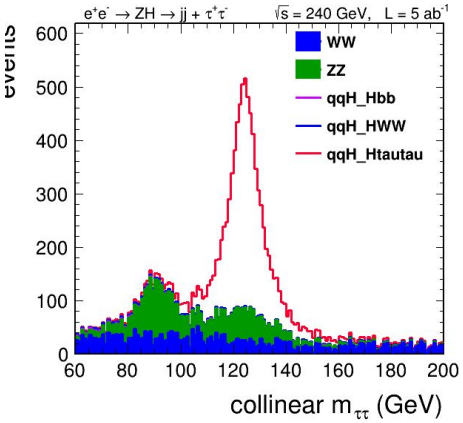
Recap: Decay reconstruction in Delphes

The ‘heuristic approach’ is conceptually equivalent to the simple reconstruction designed with Delphes last year, then applied to ZH, now using PFO candidates



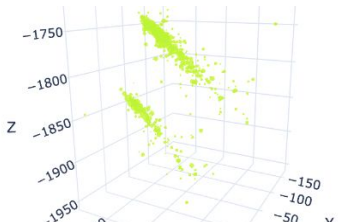
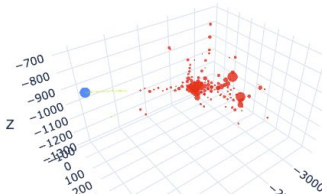
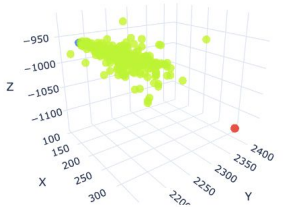
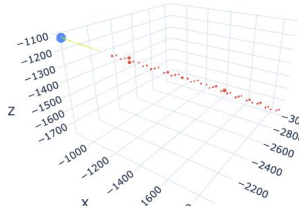
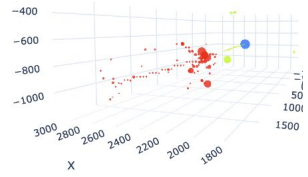
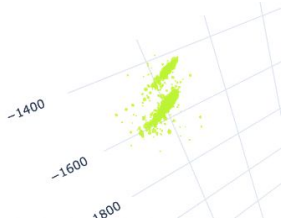
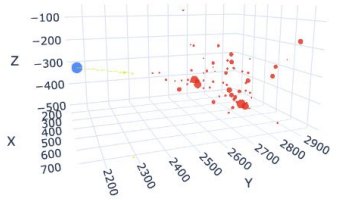
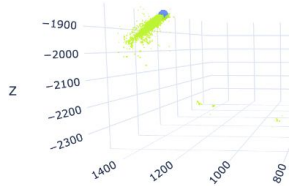
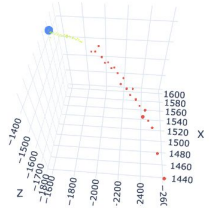
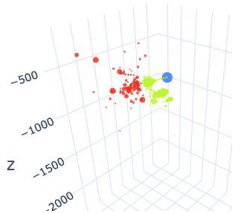
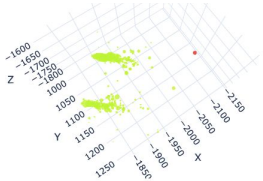
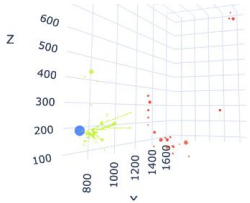
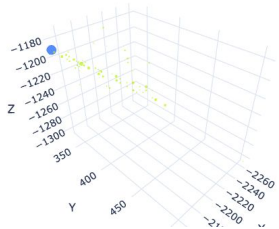
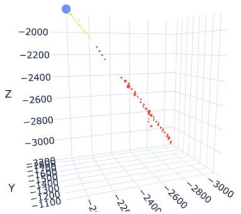
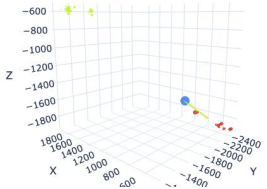
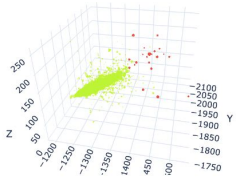
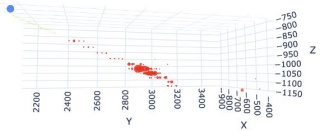
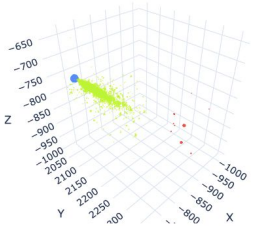
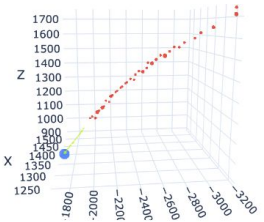
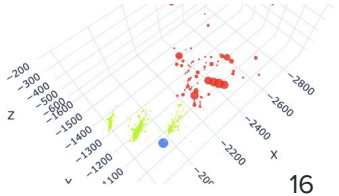






Details on the delphes study: PERFORMANCE and HIGGS (ZH, H->tautau)

pi0 | pi+ | e+ | muon | rho

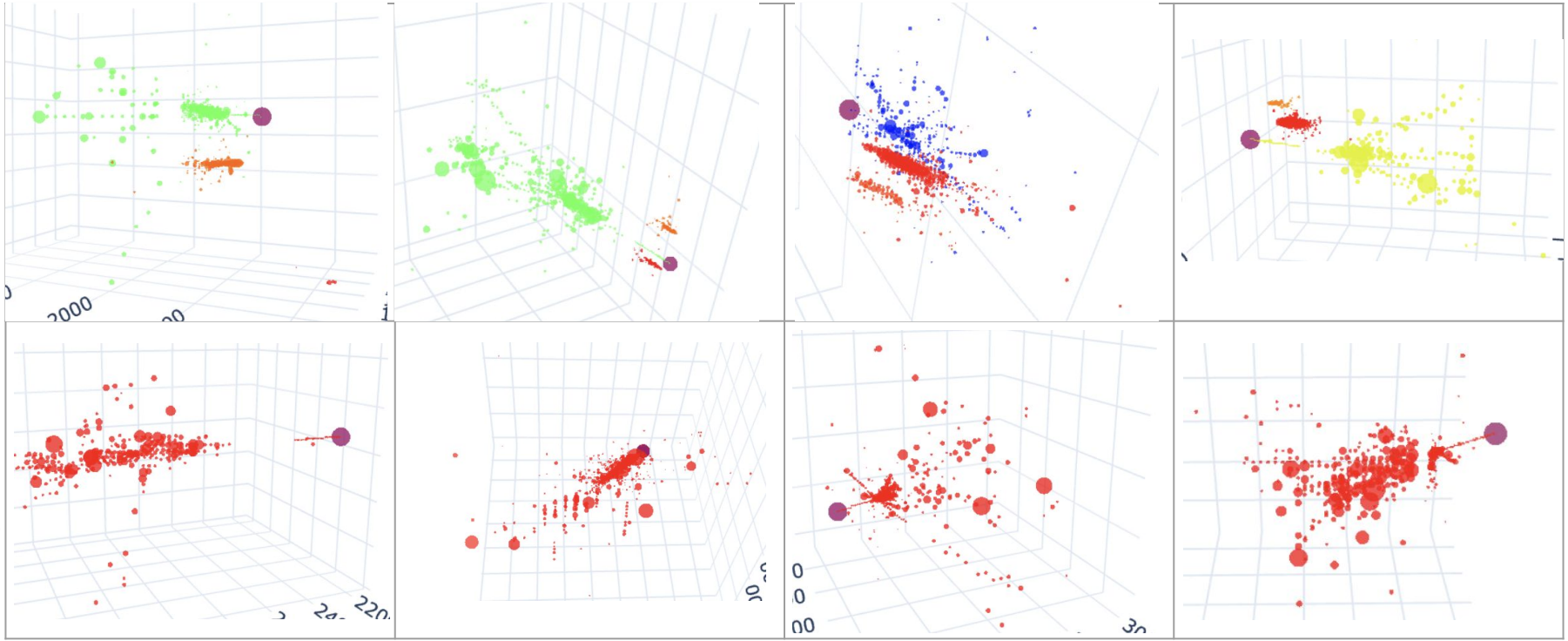





















Example events

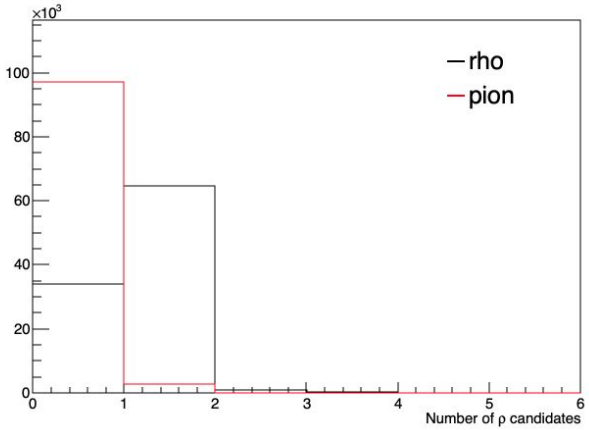
Different MC particles are in different colours

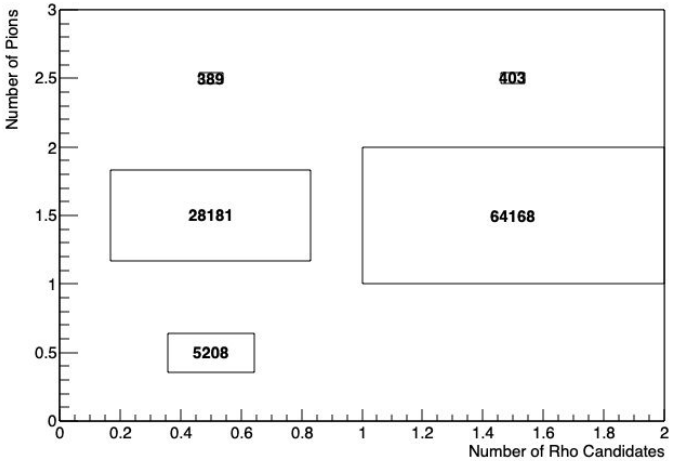
rho

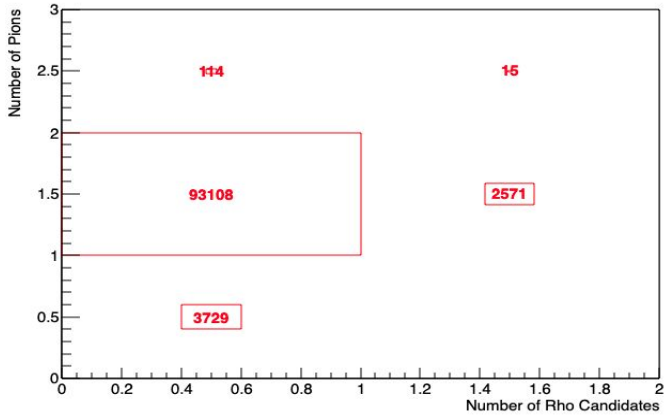
pi+



Migration rho ⇔ pion?



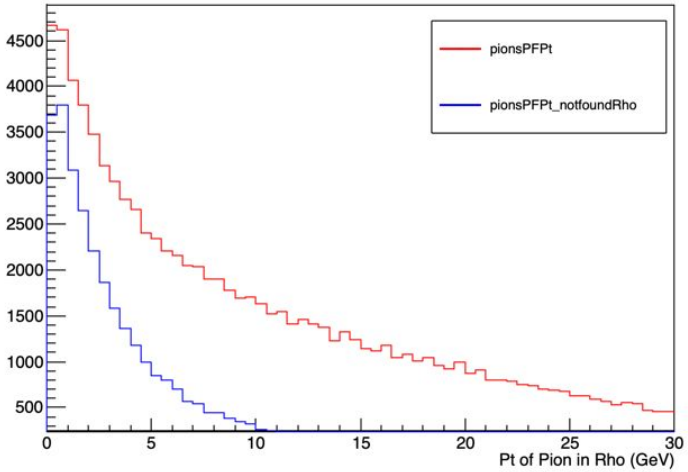




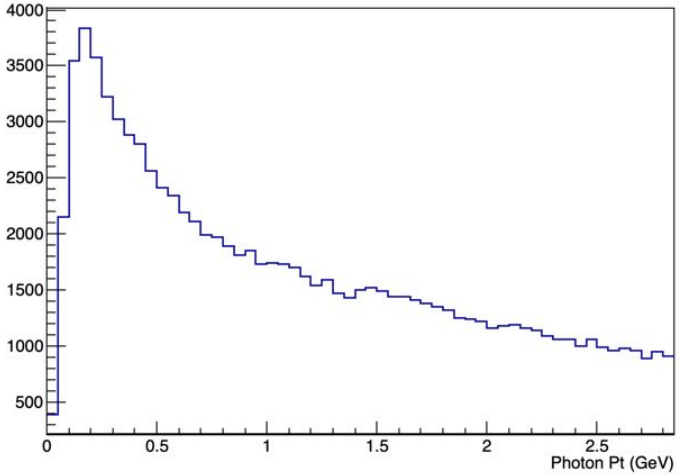
Negligible migration from pion->rho.
Migration from rho->pion under study.

Note: incorporating all photons found within dR=0.1 of the pion to build the rho. If only 1 photon is found, this is still incorporated in the rho. This will be studied more carefully.

Checks on Rho->Pion Migration



Typically lower Pion Pt
Next: check true Rho Pt (Gen)



Photon Pt/Energy: how low can we go?