



Challenges and Solutions in Reconstructing Higgs Decays to Heavy Flavour Jets

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Disclaimer:

- ▶ Presenting work that was done during my time at DESY (and is still done there)
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Questions to answer:

- ▶ What are the challenges when reconstructing heavy flavour jets?
- ▶ Can we exploit the clean e^+e^- environment and our highly-detailed detector information to solve them?
- ▶ Is this ready to be used for analyses?

Heavy flavor jets



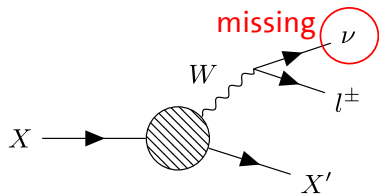
Why do we care about heavy flavor jets?

- ▶ Higgs predominantly decays to $b\bar{b}$ ($\sim 60\%$)
- ▶ Z-bosons also decay to $b\bar{b}$ and $c\bar{c}$ often ($\sim 15\%$, $\sim 12\%$)
- ▶ We will have lots of Z, ZZ, ZH events at a Higgs factory

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Why are they challenging?



- ▶ Semi-leptonic decays (SLDs), ≥ 1 SLD in $\sim 2/3$ of $b\bar{b}$ decays

Challenges in (heavy flavor) jet reconstruction



Challenges

- ▶ Missing neutrino energy
- ▶ Incorrectly identified charged particles
- ▶ Correct jet-error estimations

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Solutions?

- ▶ Reconstruct every single particle
- ▶ Determine errors from first principles on a jet-by-jet basis
- ▶ Kinematic fitting

Reconstruction and jets at particle flow detectors



Particle flow reconstruction:

- ▶ Reconstruct every single particle thanks to high granularity
- ▶ Charged particles: track + calorimeter cluster
- ▶ Neutral particles: calorimeter cluster only
- ▶ We call these particle flow objects (PFOs)

Idea: use the preciser momentum measurement to determine the energy of charged PFOs

Reconstruction and jets at particle flow detectors



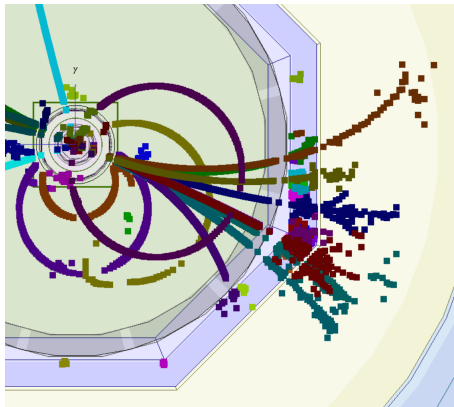
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Jets:

- ▶ Just a collection of particle flow objects
- ▶ Jet energy/momentum: sum over all jet constituents





What?

- ▶ Determine correct type of charged PFOs
- ▶ Not only for isolated particles but also in dense jets
- ▶ Usual focus: π^\pm , K^\pm , p separation
- ▶ Also interesting: electron and muon identification



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- ▶ Identify semi-leptonic heavy flavour decays
- ▶ Improve flavour tagging
- ▶ Choose correct mass hypothesis for better track fit and energy measurement

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Example: new MarlinReco/LeptonID

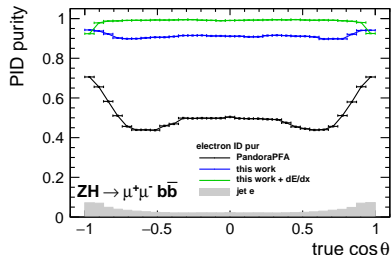
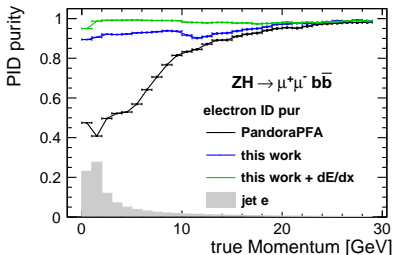
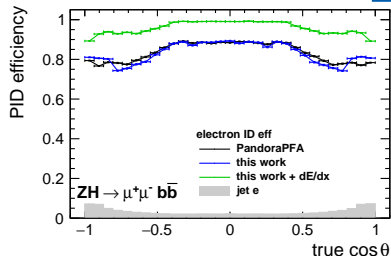
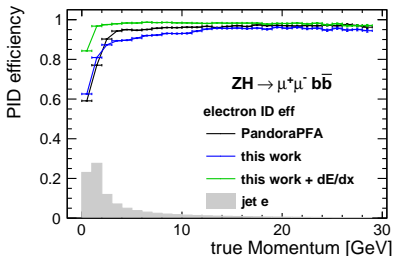
- ▶ TMVA based electron and muon identification
- ▶ Using detailed calorimeter shower-shape information
- ▶ Optionally also uses dE/dx for enhanced electron ID

For more details check my recent talk at the [WG2 Reconstruction meeting](#)

LeptonID: electrons



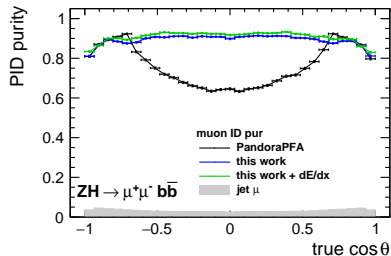
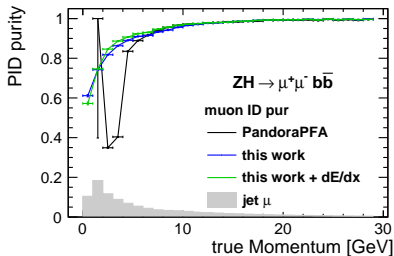
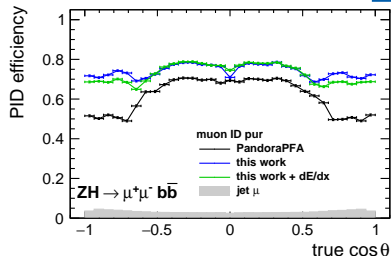
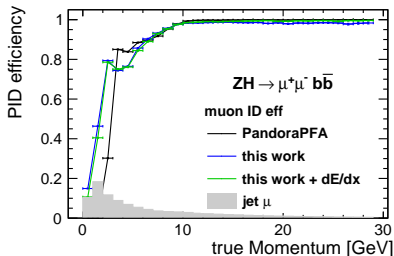
- ▶ Efficiency is similar to Pandora PFA
- ▶ Purity at low momenta is much better
- ▶ Highlight: dE/dx significantly improves performance for electrons at low momenta



LeptonID: muons



- ▶ Overall better efficiency, especially in forward region
- ▶ Better purity in barrel region
- ▶ Pandora PFA muon tag too dirty at low momenta



Neutrino reconstruction



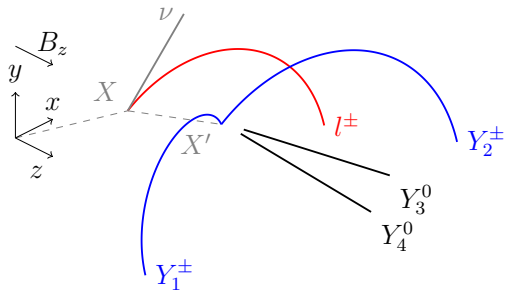
Pre-requisites

- ▶ Find SLD-associated lepton in jet
- ▶ Reconstruct flight direction of the parent hadron
- ▶ I.e. have a jet with electron or muon and a secondary vertex

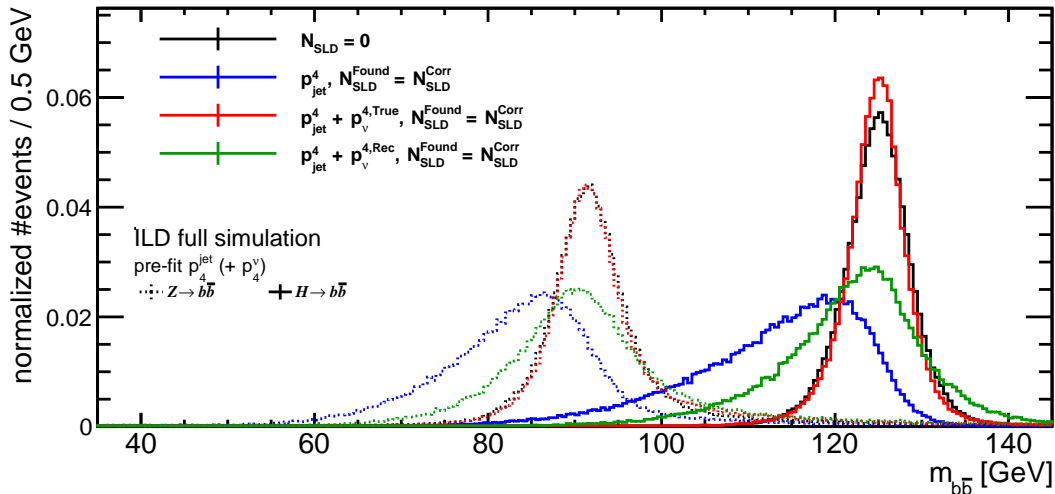
Obtain:

- ▶ Missing neutrino four momentum up to a sign ambiguity!

Details: [\[arXiv:2105.08480\]](https://arxiv.org/abs/2105.08480)



Neutrino reconstruction



Improved jet error estimation



For more details check [Yassers talk](#) at last years ECFA WS

- ▶ We need to know the errors of our specific measurements
- ▶ Especially important to do fits
- ▶ Combine errors of jet constituents to estimate jet error
- ▶ Also includes particle flow confusion
- ▶ Ongoing work to include errors from jet assignment, particle shower and $\gamma\gamma \rightarrow$ hadrons

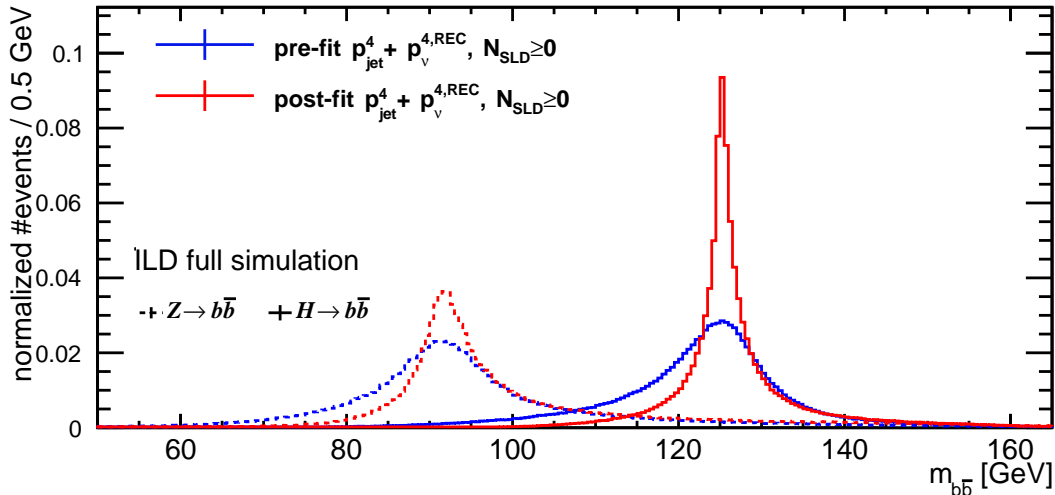
Simple (and well tested) concept:

- ▶ Use knowledge of physics to establish constraints
- ▶ E.g. energy and momentum conservation, equal masses in decay into pair
- ▶ Vary measured values according to their errors to better fulfill constraints
- ▶ Depends on good error estimation

Reality is a bit more complex (e.g. ISR) but modern kinematic fits can accommodate this

Cf. e.g. [\[arXiv:0901.4656\]](#)

Kinematic fitting



Summary



- ▶ Reconstructing heavy flavor jets is challenging
- ▶ Techniques like neutrino reconstruction and kinematic fitting can improve reconstruction significantly
- ▶ Advertisement: all the shown techniques are available in Key4hep

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