Challenges and Solutions in Reconstructing Higgs Decays to Heavy Flavour Jets

Leonhard Reichenbach, Yasser Radkhorrami, Jenny List

CERN & University of Bonn, Universität Hamburg, DESY

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Disclaimer:

- Presenting work that was done during my time at DESY (and is still done there)
- Huge thank you to Yasser for kindly supplying me with plots

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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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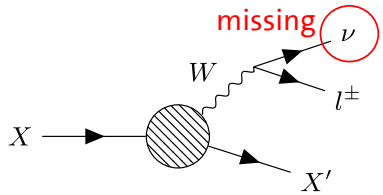
Why are they challenging?



- 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

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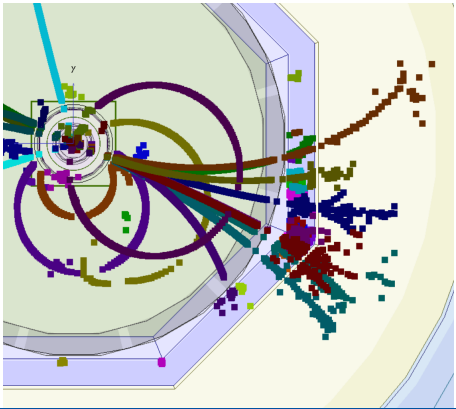
Jets:

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



Particle ID

What?

- Determine correct type of charged PFOs
- Not only for isolated particles but also in dense jets
- Usual focus: $\pi^{\pm}, K^{\pm}, p$ 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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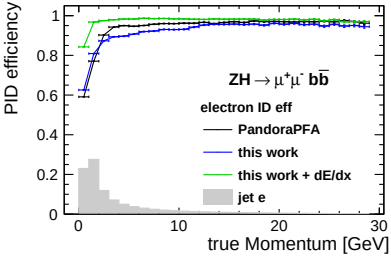
Example: new `MarlinReco/LeptonID`

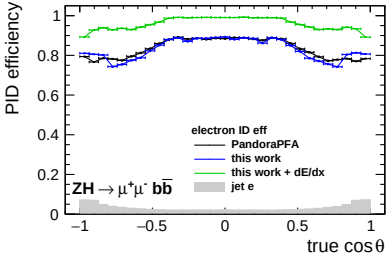
- TMVA based electron and muon identification
- Using detailed calorimeter shower-shape information
- Optionally also uses dE/dx for enhanced electron ID

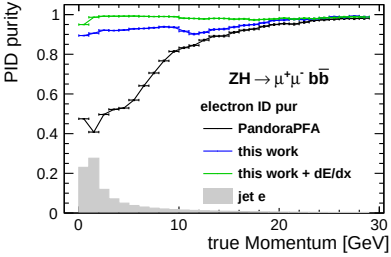
For more details check my recent talk at the **WG2 Reconstruction meeting**

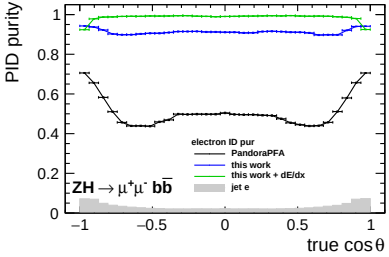
LeptonID: electrons

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



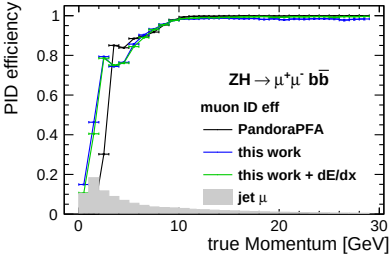


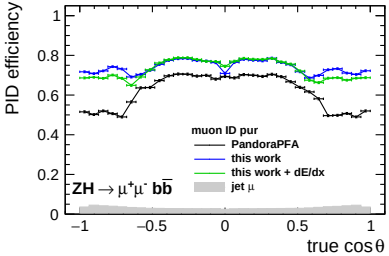


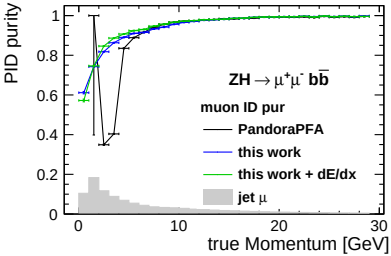


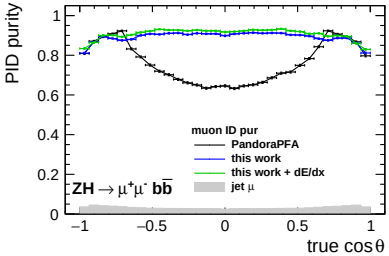
LeptonID: muons

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









Neutrino reconstruction

MarlinReco/SLDCorrection

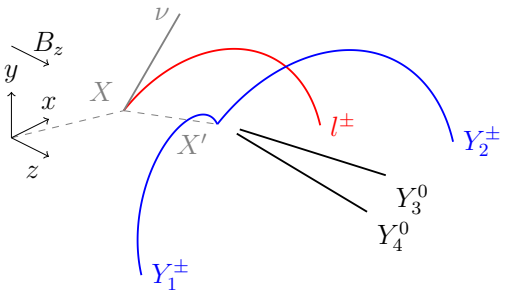
Pre-requisites

- 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]**



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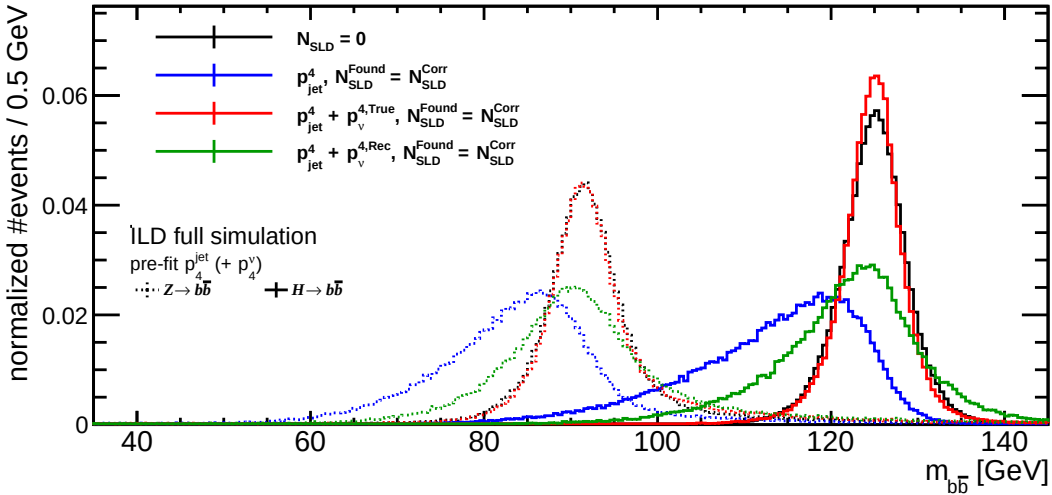
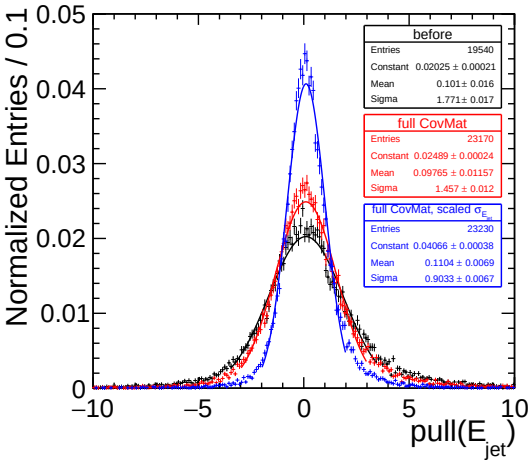


Improved jet error estimation

MarlinReco/ErrorFlow

- 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

For more details check **Yassers talk** at last years ECFA WS



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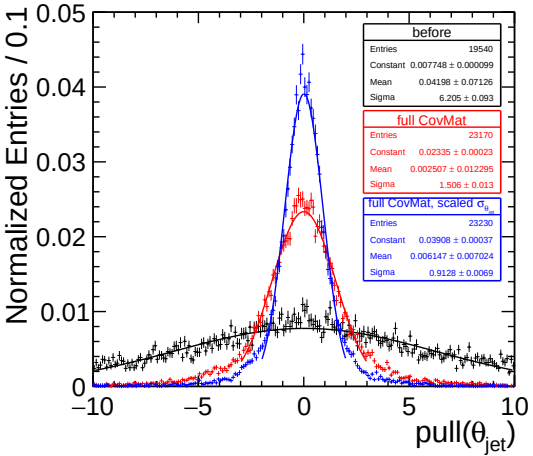

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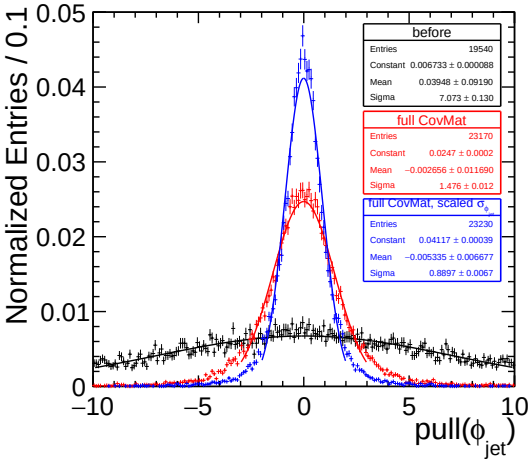


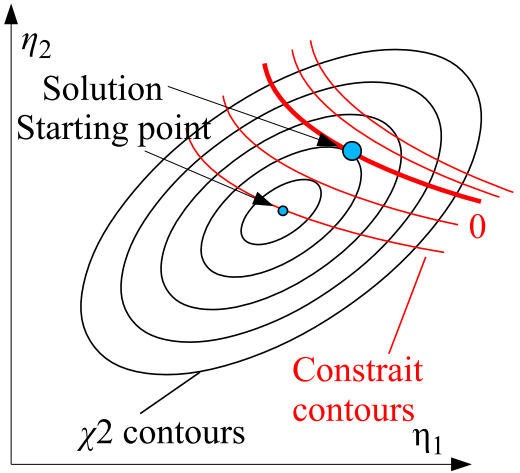
Kinematic fitting

MarlinKinfit (Processors)

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 measurements according to their errors to minimize a χ^2 with additional constraints
- Depends on good error estimation

Reality is a bit more complex (e.g. ISR) but modern kinematic fits can accommodate this. Check out **Jenny's poster** later today!



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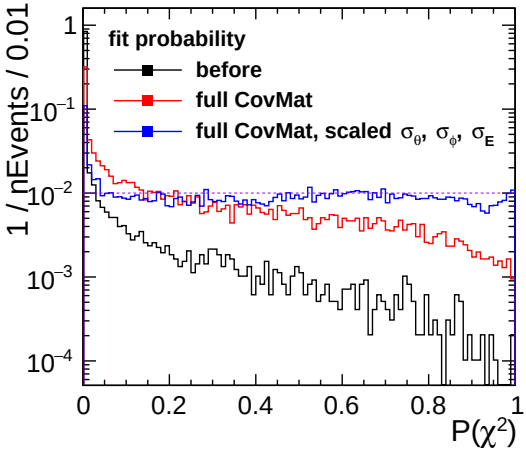

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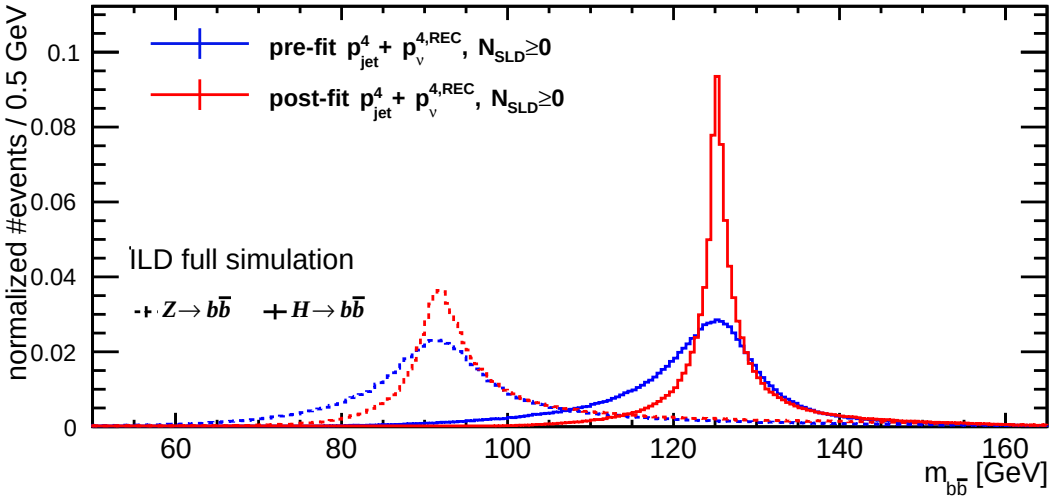

Summary

- 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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