Reconstruction algorithms dealing with electrons

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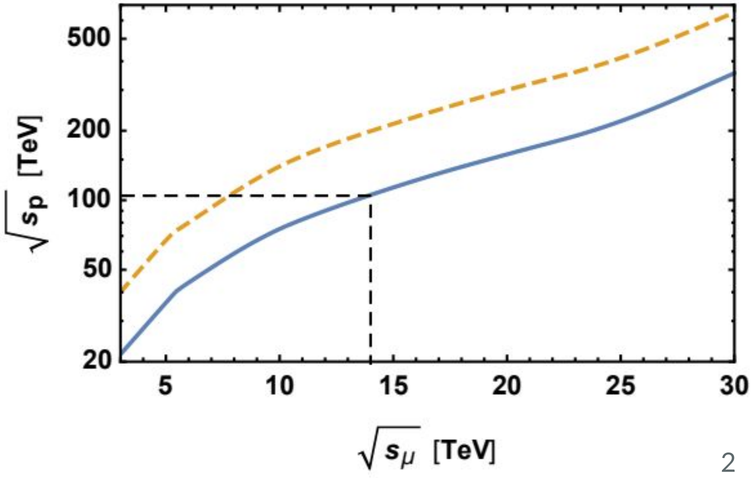
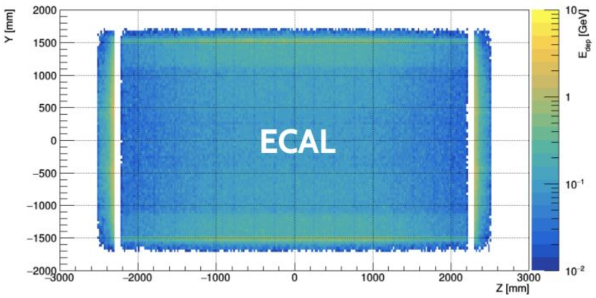
Muon collider: The good

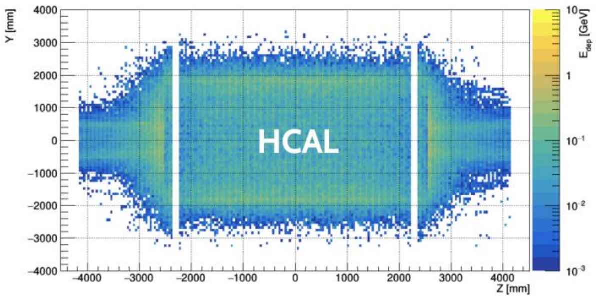
- Discussions have begun on how to create the next high energy collider
  - A more compact choice is a muon collider
- Compared to protons, muons:
  - Are fundamental particles:
    - Lets all the energy be used in the collision
    - Known initial momentum
- Compared to electrons, muons:
  - Have a large mass:
    - Less energy is lost when they are accelerated

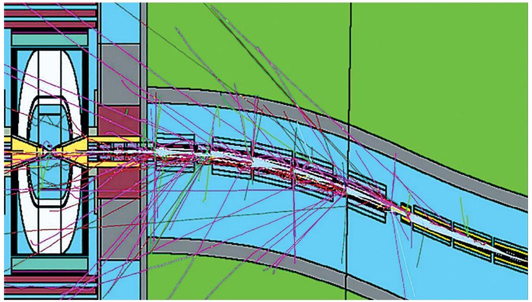


Muon collider: The bad

- Muons are harder to collimate than the previously mentioned particles
- Muons **rapidly decay** inside of the particle accelerator → causes **beam induced background** (BIB) inside of the detector
  - Special relativity increases lifetime in lab frame→can be used in the accelerator
  - Initial decays and secondary particles light up detector
  - Decays into electrons and other particles



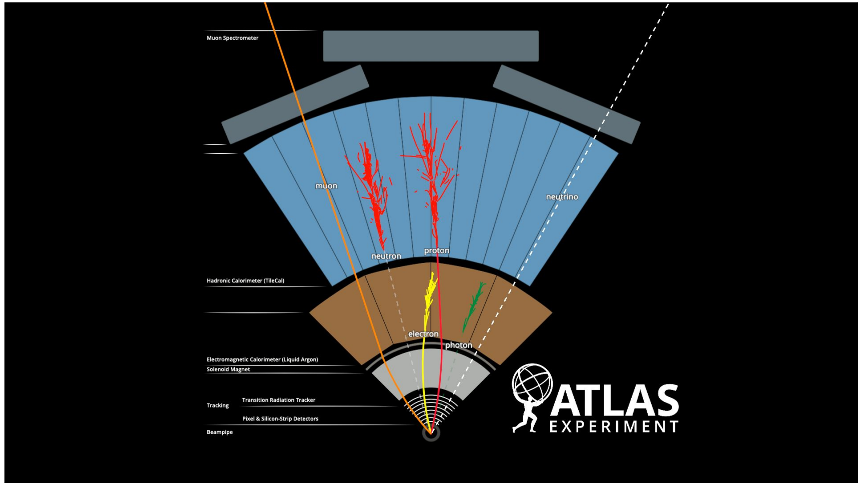


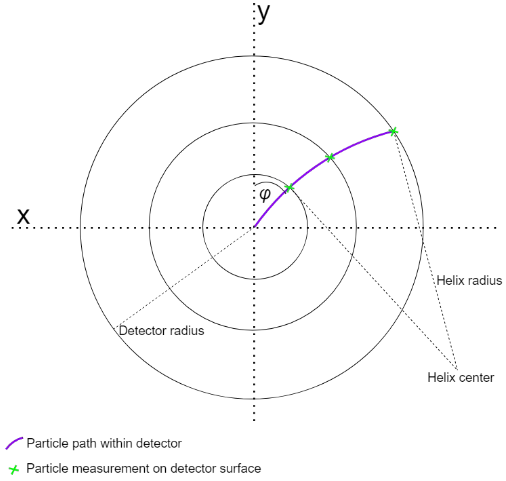


The goal

Study electron reconstruction algorithms and identify necessary improvements

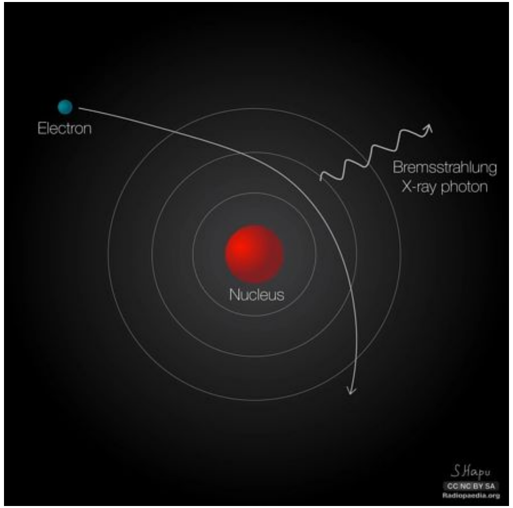
- Particle ID is done by:
  - Analyzing tracks created in the inner detector through chains of hits
  - Measuring energy deposition and depth of particle into calorimeters





The ugly truth about electrons

- Electrons undergo bremsstrahlung and multiple scattering
  - Changing their trajectory whilst in the detector → makes it difficult to track them
- Bremsstrahlung: electrons emit a photon in the presence of a magnetic field
  - This **changes their course** due to momentum of emitted photon
- Confuses reconstruction algorithm:
  - **Misidentifies electrons** as other particles
  - Sometimes **unable to reconstruct** any particles

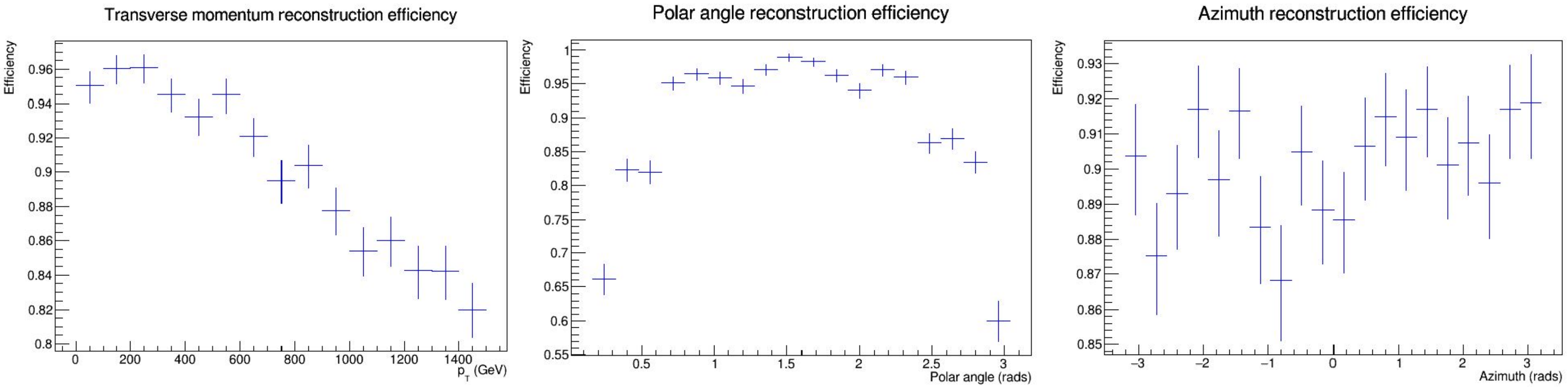


True particle data

Initial electron values	
$p_{T.}$	1-1500 GeV
Polar angle	10°-170°
Azimuth	0-360°

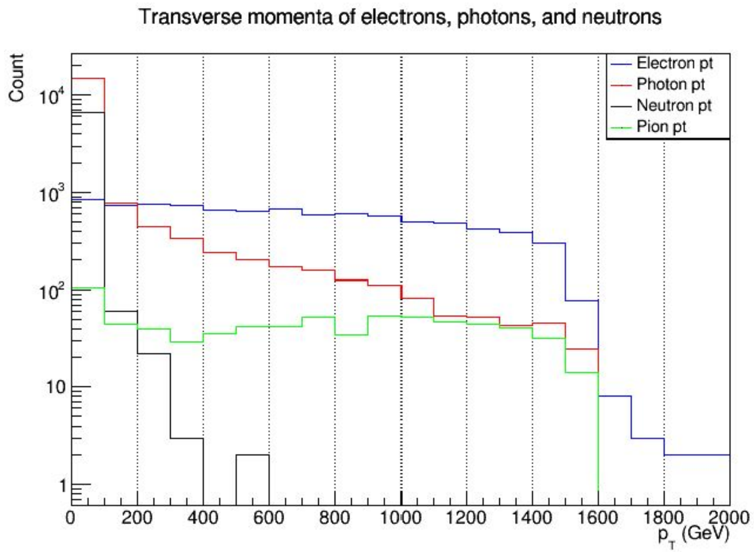
- 10000 particles
- No BIB included in events
- I will be using the data from the **conformal tracking** unless otherwise specified
- Particle ID will be done by **Pandora**

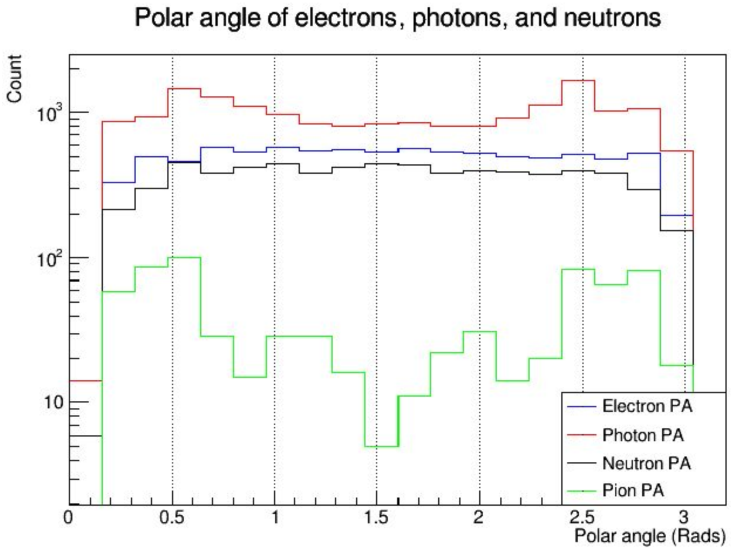
Comparing the true particle data to the reconstructed electrons:



Types of reconstructed particles

- With perfect reconstruction, there should **only be photons and electrons**
  - Photons could be the result of bremsstrahlung
  - Additional electrons and positions can appear due to pair production
- All neutrons and pions are incorrectly identified



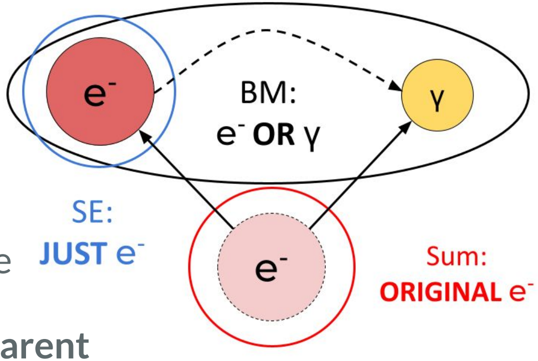


Particle matching methods

- Particle linking compares the number of track/calorimeter hits and energies between the reconstructed and truth particle to get a weight

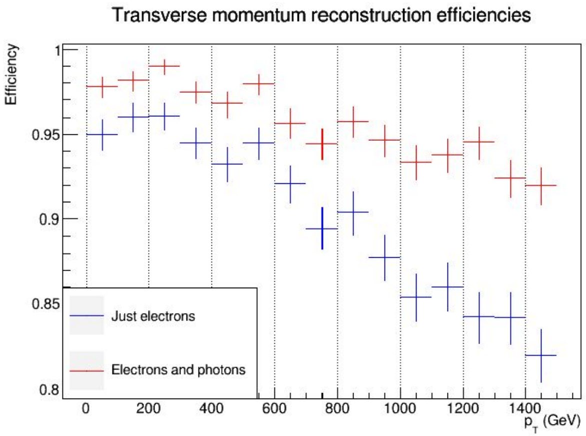
Three matching methods:

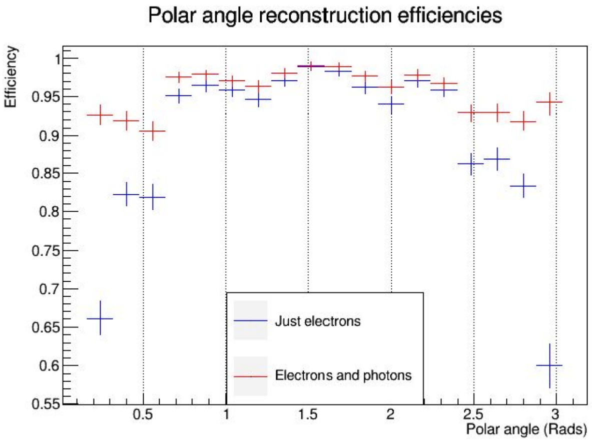
1. Simple electron (SE) linking:
   a. The reconstructed electron with the **highest weight** is treated as the truth particle
2. Best match (BM) linking:
   a. Finds the particle that has the **highest weight** out of reconstructed electrons, if none exist, search photons
3. Sum matching:
   a. Takes **sum of momentum** for all electrons and photons and treats the result as a singular particle
   b. Accounts for any pair production/ionization by **reconstructing the parent particle**



Transverse momentum between SE & BM

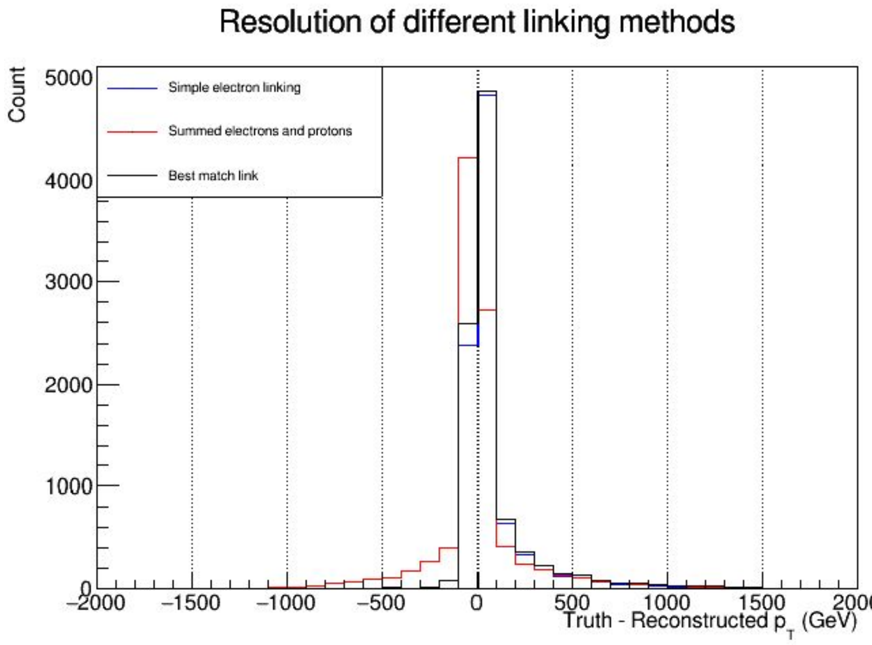
- Including photons recovered efficiency at high p_T, misidentification?
- Gap in high energy range due to:
    - Bremsstrahlung occurring less frequently→track may not exhibit traditional electron behavior
    - Punch through is higher in the electromagnetic calorimeter resulting in a larger deposition in the hadronic calorimeter→problem for both photons and electrons





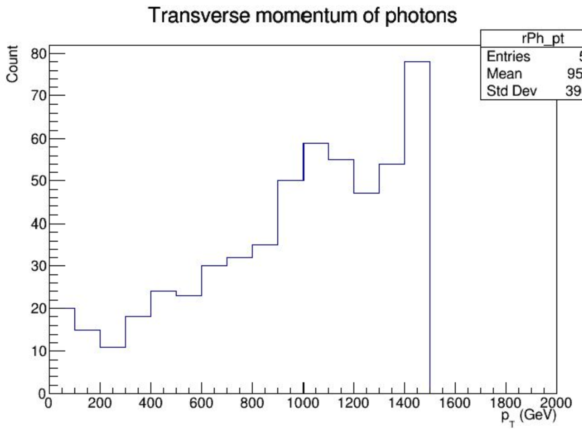
Resolution of matching methods

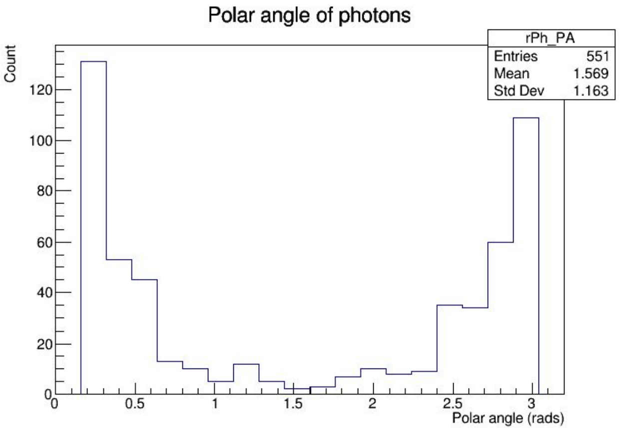
- Simple electron:
  - Large high tail→particle missing energy, std dev: 165.3
- Best match:
  - Worst mean: 80.8 GeV
  - Another high tail, std dev: 204.3
- Sum method:
  - Best mean: 4.675 GeV (double-ended tail)
  - Adding photon restores gaussian→bremsstrahlung?
  - Double sided tail causes larger std dev: 229.7 GeV

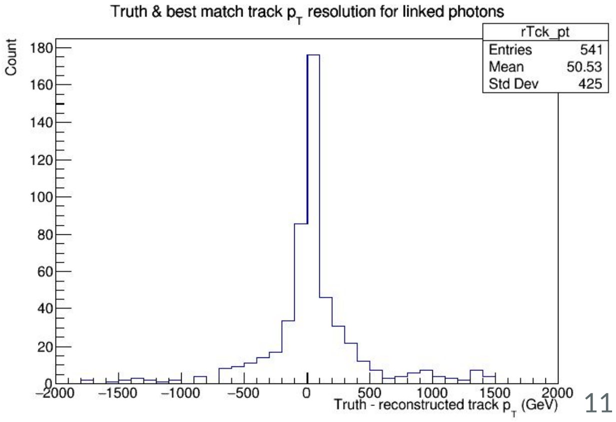


Track data of photons

- Most of the time, tracks are accurately calculated, particle ID is failing here
- Photons are commonly ID'd as the highest energy particles
- High p_T and polar angle on extremes→Larger total energy→More punch through
- Curve in polar angle graph is close to inverse sinusoidal
- Track found for nearly all identified linked photons

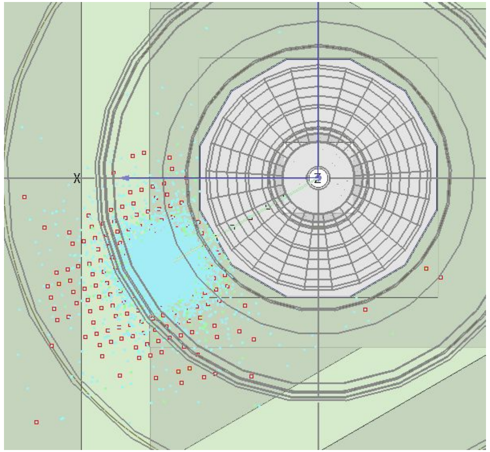


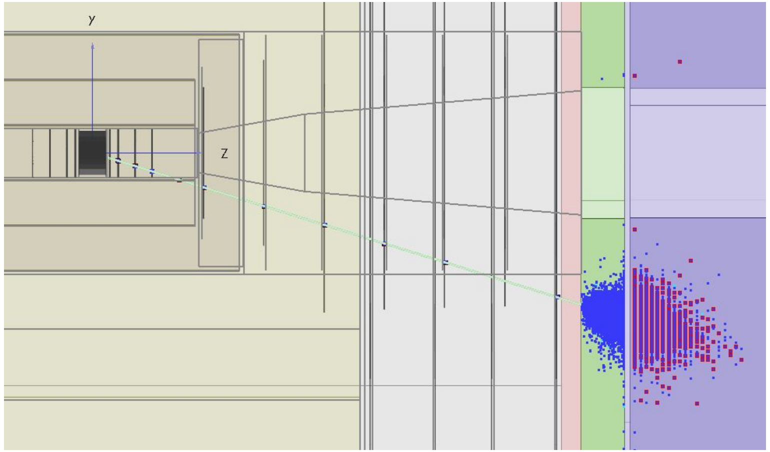


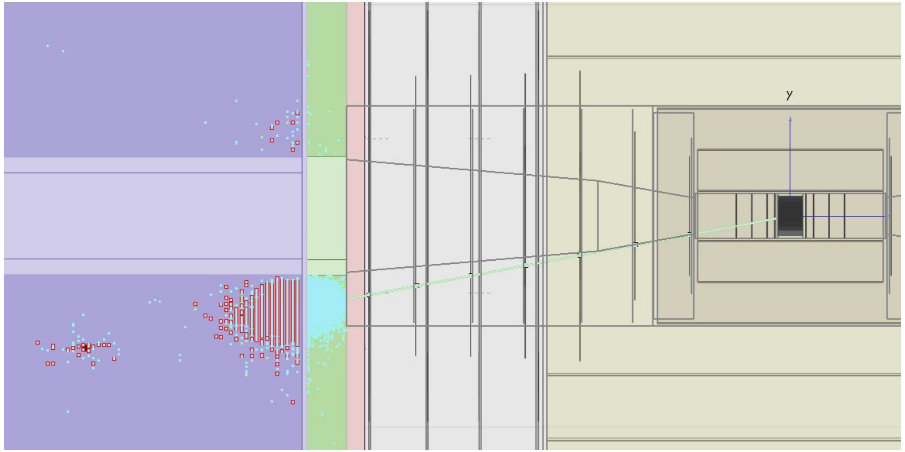


Photon ID visuals

- As a sanity check: visuals do confirm an angle on the extremes
- Punch through is quite large
    - Punches through the electromagnetic calorimeter (where electrons are designed to stop)
    - Particle shower continues into the hadronic calorimeter

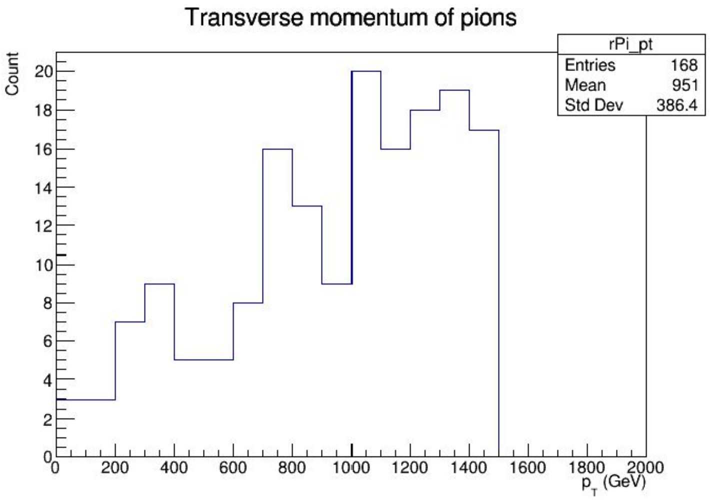


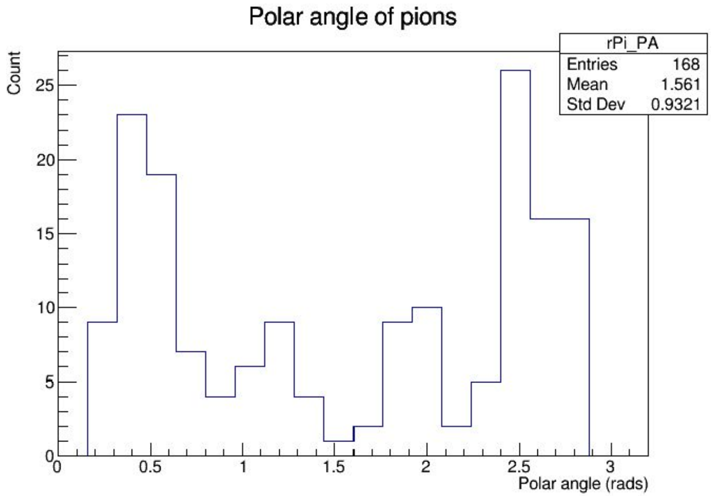




Pion occurrences

- Pions are commonly reconstructed at higher energies due to their punch-through and large energy deposits in the hadronic calorimeter
- Two “mountains” in polar angle are where the electromagnetic barrel and endcap overlap→pattern recognition is failing in transition region





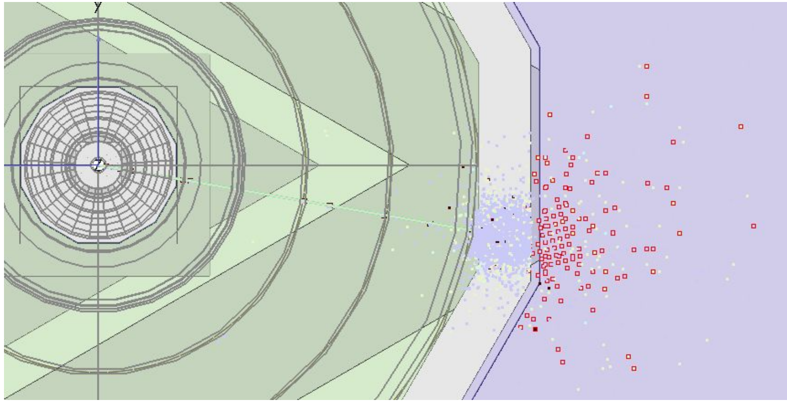
Pion visual patterns

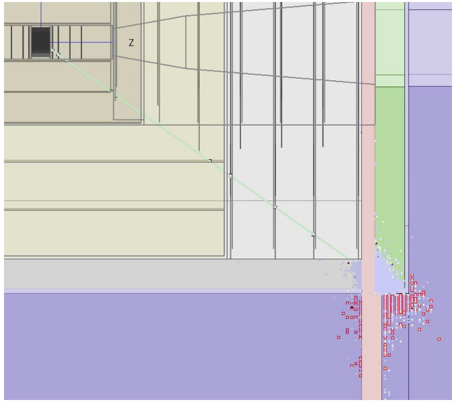
- Check the visuals as a sanity check
- For electromagnetic calorimeter:
  - Critical energy = 9.64 MeV
  - Radiation length = 0.8903 cm
  - Assuming particle has the maximum 1500 GeV
  - Shower depth should be 15.355 cm

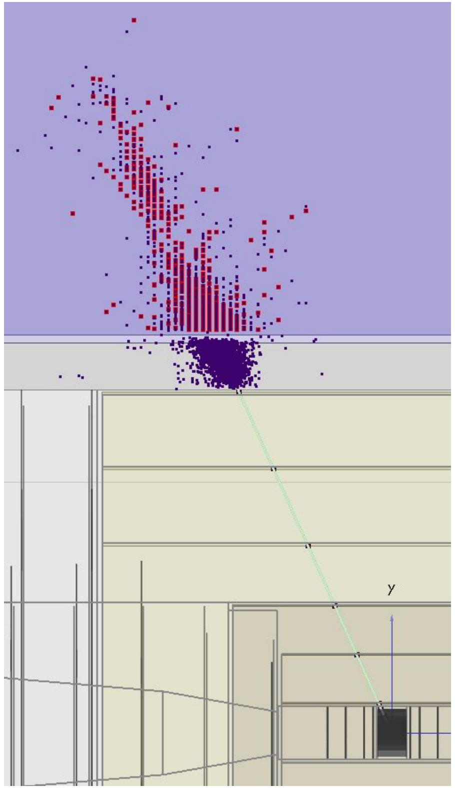
$$t = x/X_0$$

$$E_c = E_0 2^{-t}$$

$$x = \frac{X_0 ln(\frac{E_0}{E_c})}{ln(2)}$$





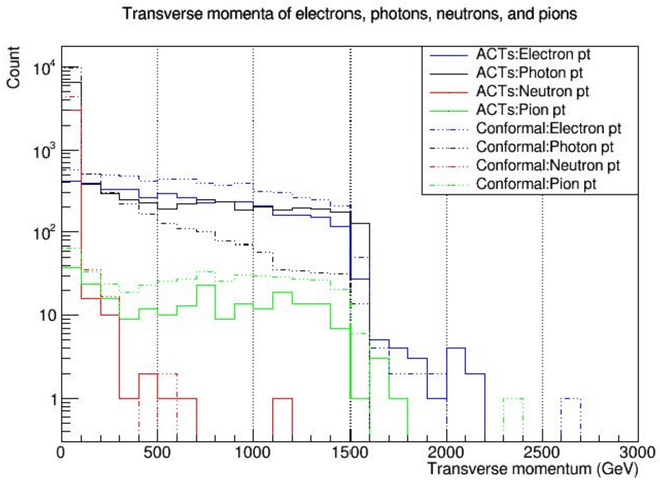


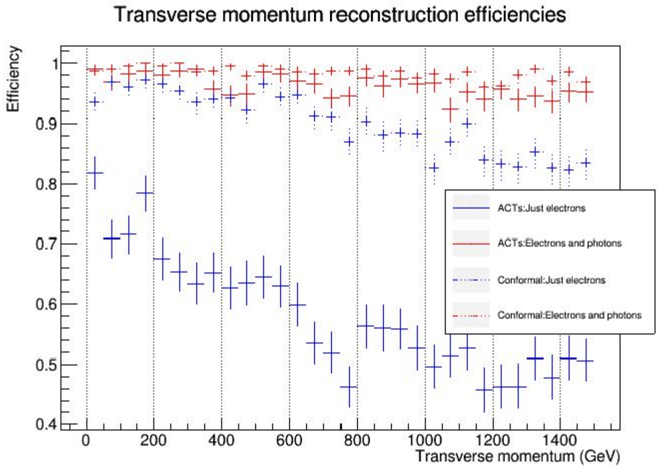
Conformal vs. ACTS(CKF)

ACTS find tracks by:

1. Finds seed from 2-3 hits, propagate track
2. Using least squares estimation adds hits along estimated trajectory to track

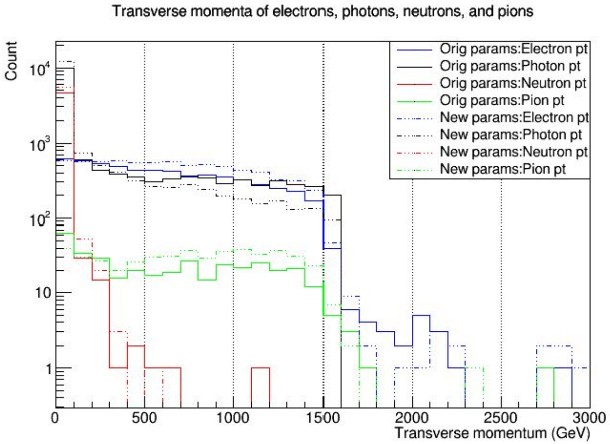
- Compared to conformal, ACTS:
  - Finds more photons, less electrons and pions
  - Worse reconstruction of particles
    - SE matches goes from ~90% →~60%

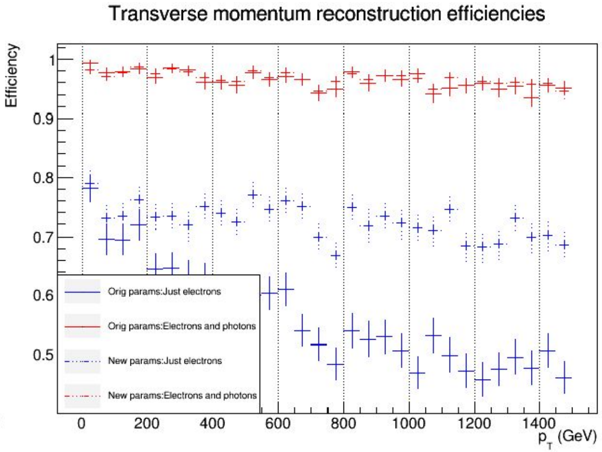




Altering ACTS: Efficiency

- Changed parameters:
  - chi2cutoff: 10→15, broadens selection of hits per layer
  - NumMeasurementsCutoff: 1→2, follows two separate seeds per layer
- Changing parameters:
  - Removes issue with efficiency falloff at high p_T region for SE matching
  - Does not affect BM efficiency→photons identified with old params now identified as electrons
  - More electrons & pions
  - Fewer photons





Conclusions

- Track finding is quite accurate, but ID needs work
  - Electrons most likely to be misidentified as photons, then pions
  - Particle ID algorithms need help with:
    - High energy particles that enter hadronic calorimeter
    - Particles with energy depositions in the transition region
- ACTS helps with dealing with electrons at the high end of energies
- ACTS increases decreases efficiency
  - ID of pions and photons is less tied to polar angle
  - At the end of the day, changing ACTS parameters is about optimizing what data you want
- Algorithms in programs (e.g Pandora and ACTS), can be optimized by machine learning

Thank you

Code used to generate graphs:

https://github.com/Benzillaist/MuC-BIB-electron-tracking

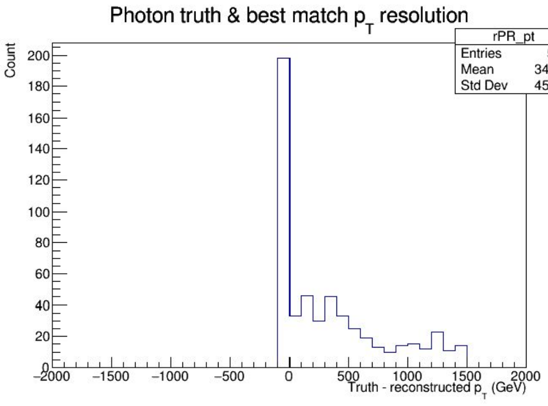
Backup slides

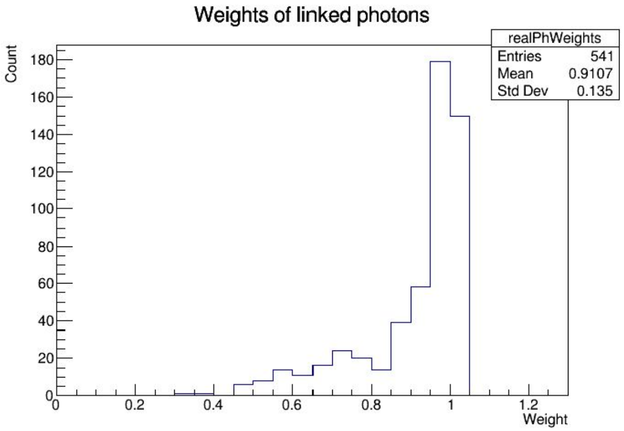
The process

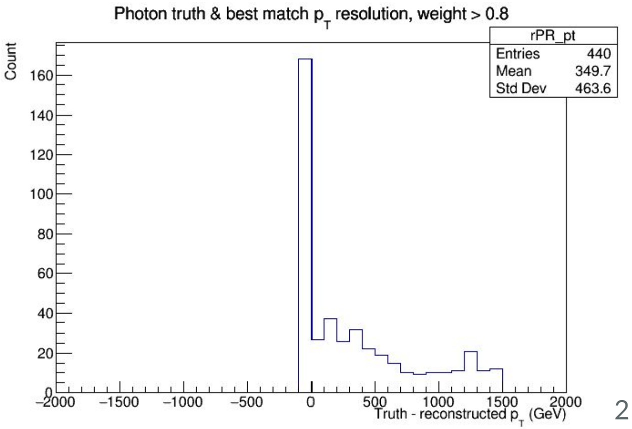
1. Simulate single electrons using **ddsim** (detector simulator tool)
2. Using a reconstruction tool called **Marlin**, I am testing out two different reconstruction algorithms, **Conformal tracking** and **ACTS**
    - The **pandora** package was used for electron identification
3. Output files contain collections of events and particles
    - Most importantly: initial angle and momentum, track momentum, and particle linking data
4. From the output files, look through collections of events & identify where Conformal tracking and ACTS can be improved

Resolution of photons

- Isolating the photons→Similar pattern to the three methods
  - Means many of the electrons are misidentified as photons
- Higher tail means that photons accuracy is worse
  - Still valuable to search through photons
  - Applying a weight minimum does **not** give a better selection of particles
    - Due to weight not mattering, photons are essentially just mis-ID’d electrons

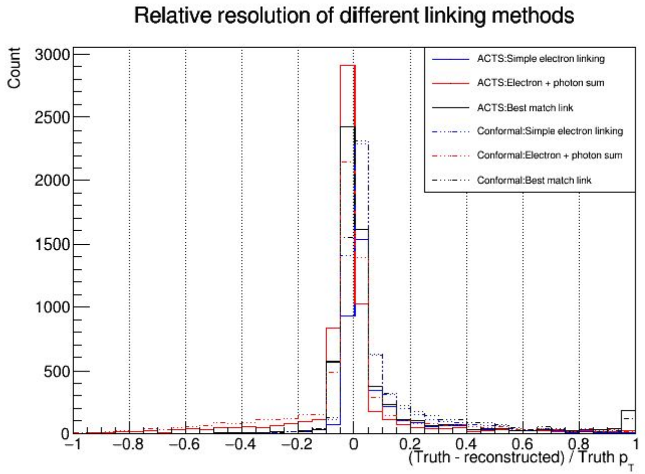


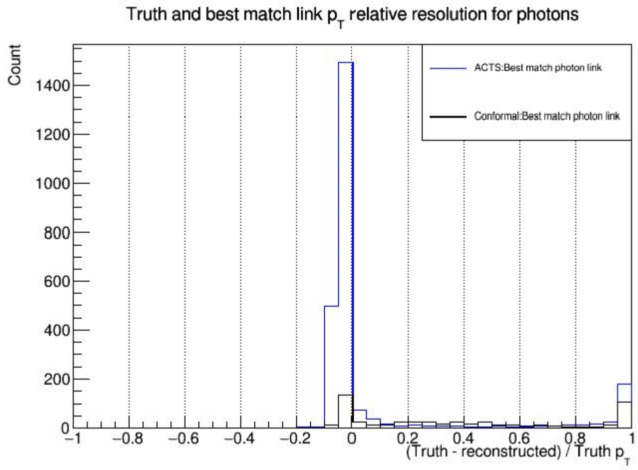




Conformal vs. ACTS(CKF)

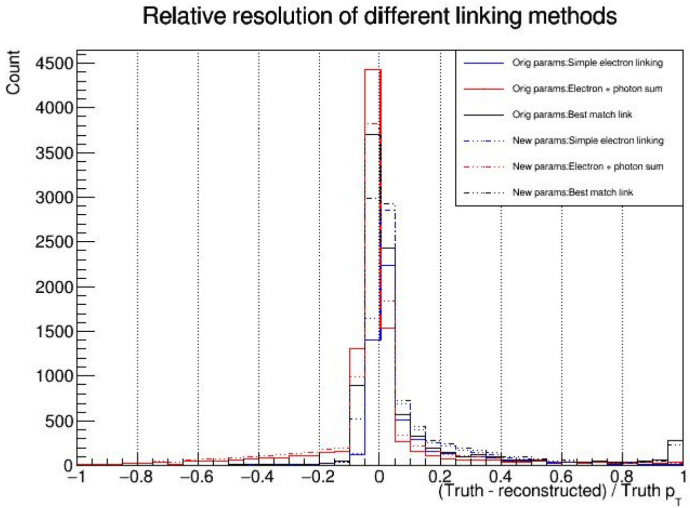
- ACTS accuracy has gone up, even with the increase in electrons
- Point of weakness is spike in relative resolution at ~1 by BM method
  - Caused by increase in photons being selected by BM
  - Means some events have no accurate tracks found for electrons
- Additional photons reconstructed by ACTS are commonly electrons→Jump in photons used in BM

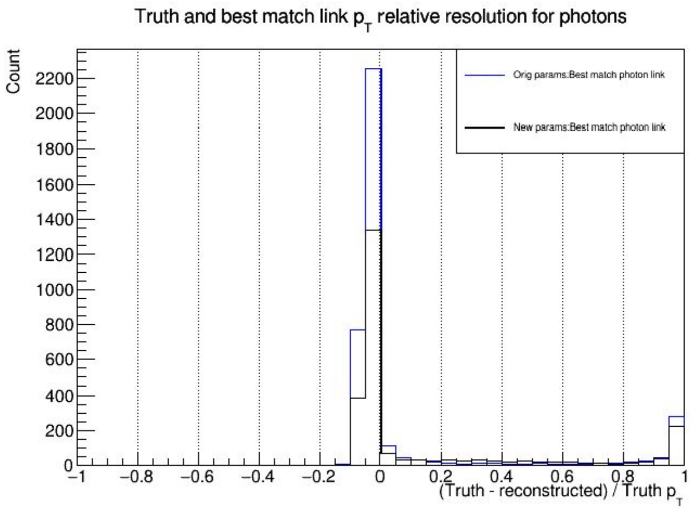




Altering ACTS: Resolution

- Increase in SE matching resolution at center compared to tail
- Sum method gets a tiny bit worse everywhere
- BM gets worse→change in types of reconstructed particles is positive
  - Many reconstructed photons with high accuracy are now correctly being identified as electrons





Photon and pion ties to p_T and polar angle