Improving ATLAS Jet Measurements and Searches with Particle Information

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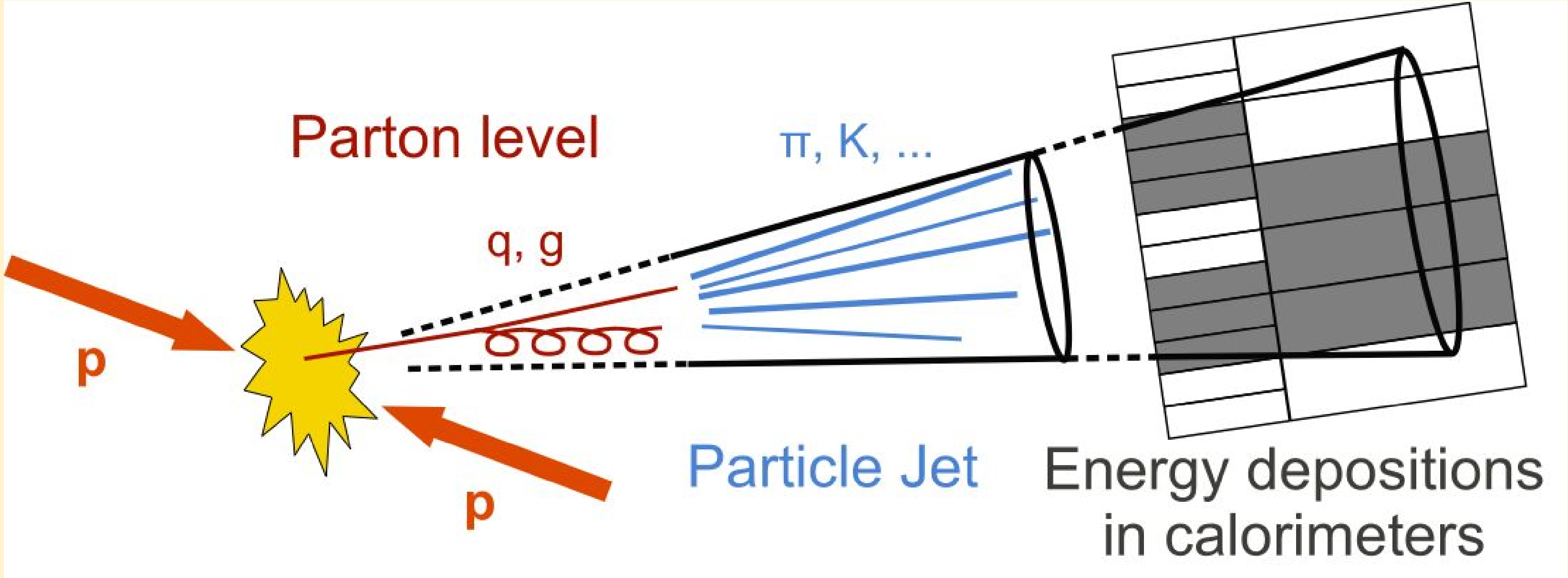
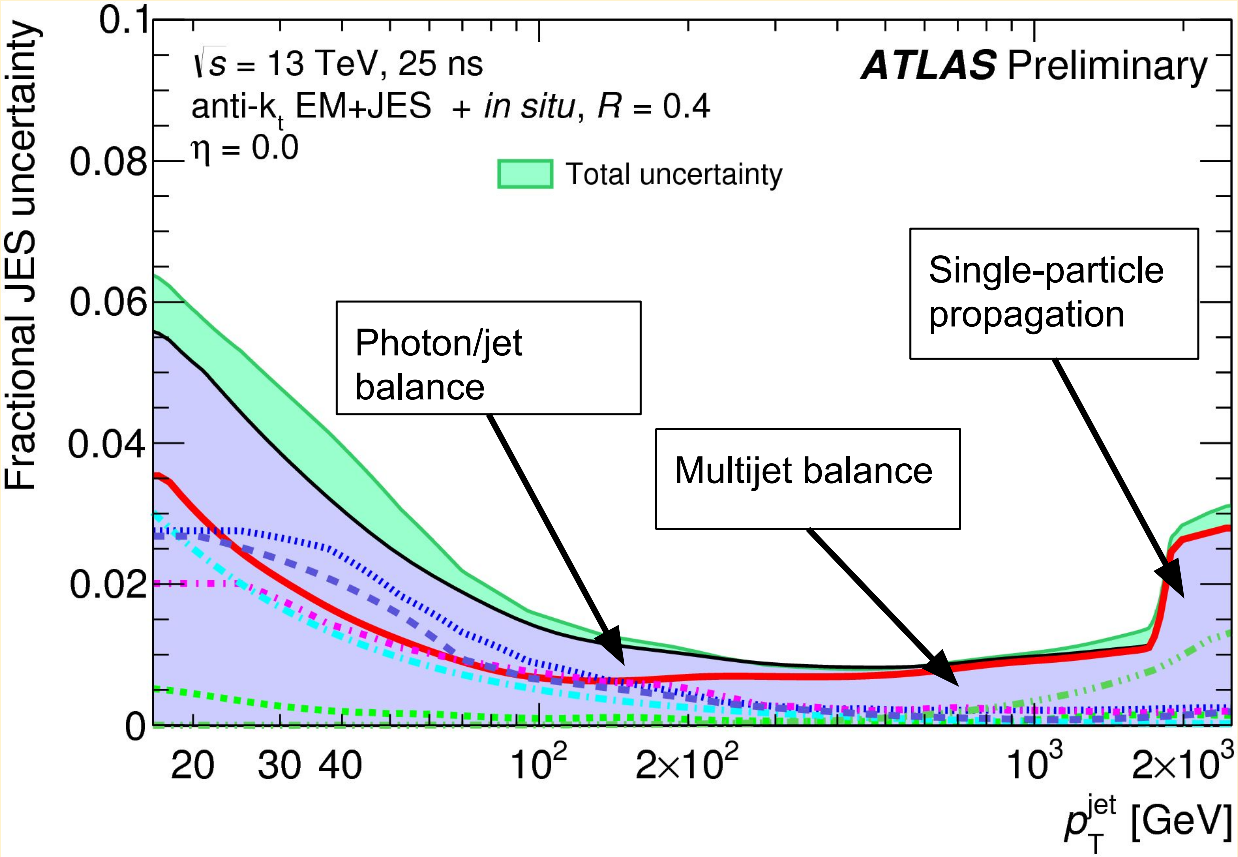
Hadronic Jets

Jets originate as free (colored) partons leave a hard scattering event. Due to confinement, colored partons immediately pull other particles out of the vacuum in a process called “hadronization”, resulting in a stream of colorless hadrons which we refer to as a “jet.”



http://cms.web.cern.ch/news/jets-cms-and-determination-their-energy-scale

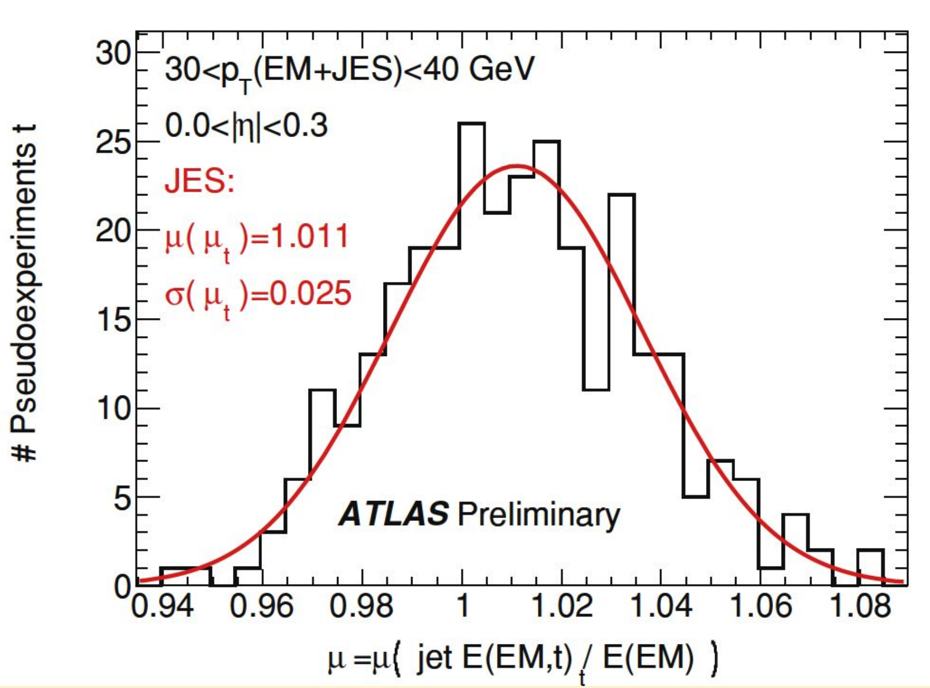
Jet Energy Scale Uncertainties



http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2015-015/fig_13a.png

Single Particle Propagation Uncertainty

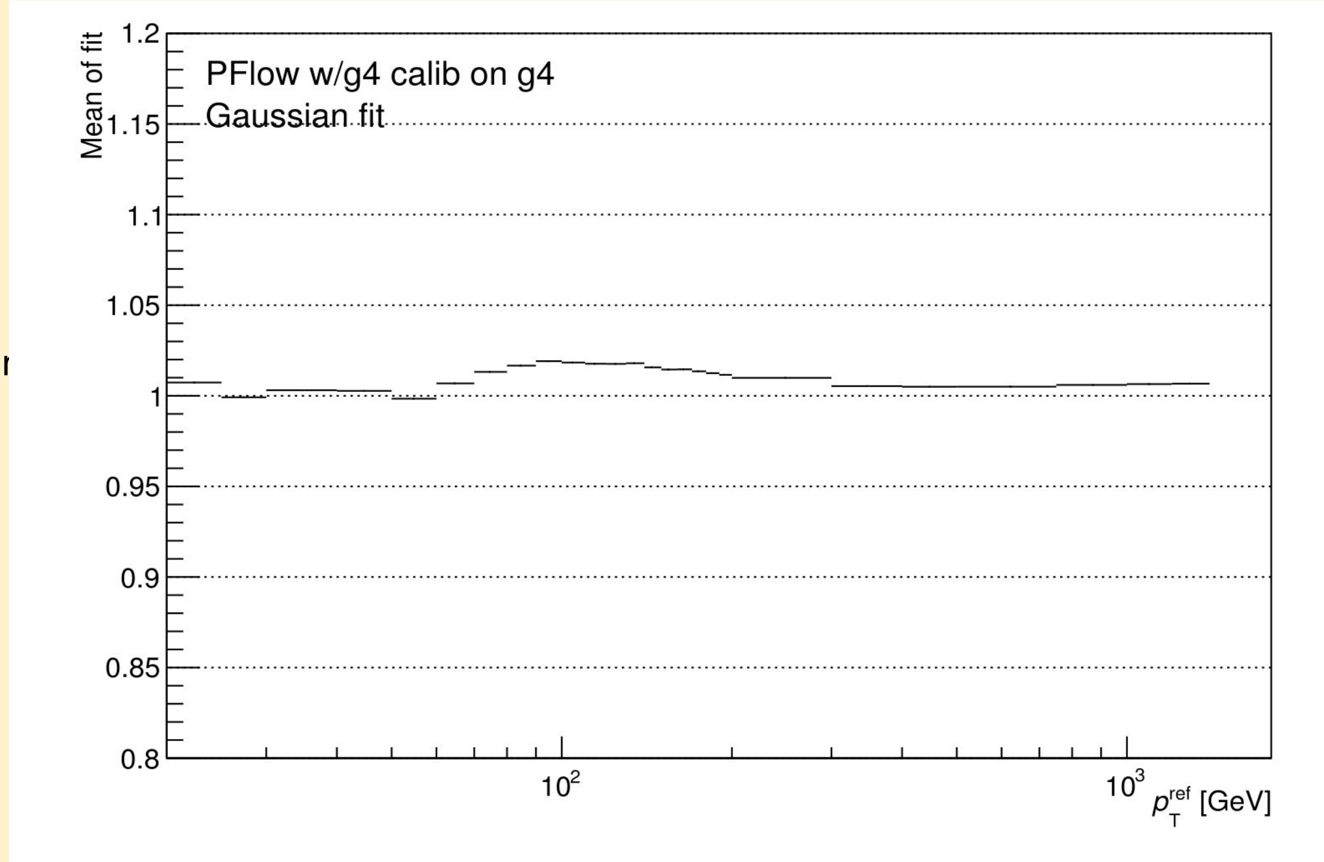
- Catalog each particle in each simulated (truth) jet
- For different kinds of particles and different p_T ranges, assign different uncertainties (for example, use combined test beam uncertainty for charged pions up to 350 GeV)
- For each truth jet, combine the uncertainties from all the different particles to get a mean p_T shift for the entire jet, and take the ratio between this quantity and the truth level p_T of the jet
- For a given truth p_T bin, plot the distribution of the mean p_T shifts and derive the overall uncertainty from a gaussian fit to this distribution



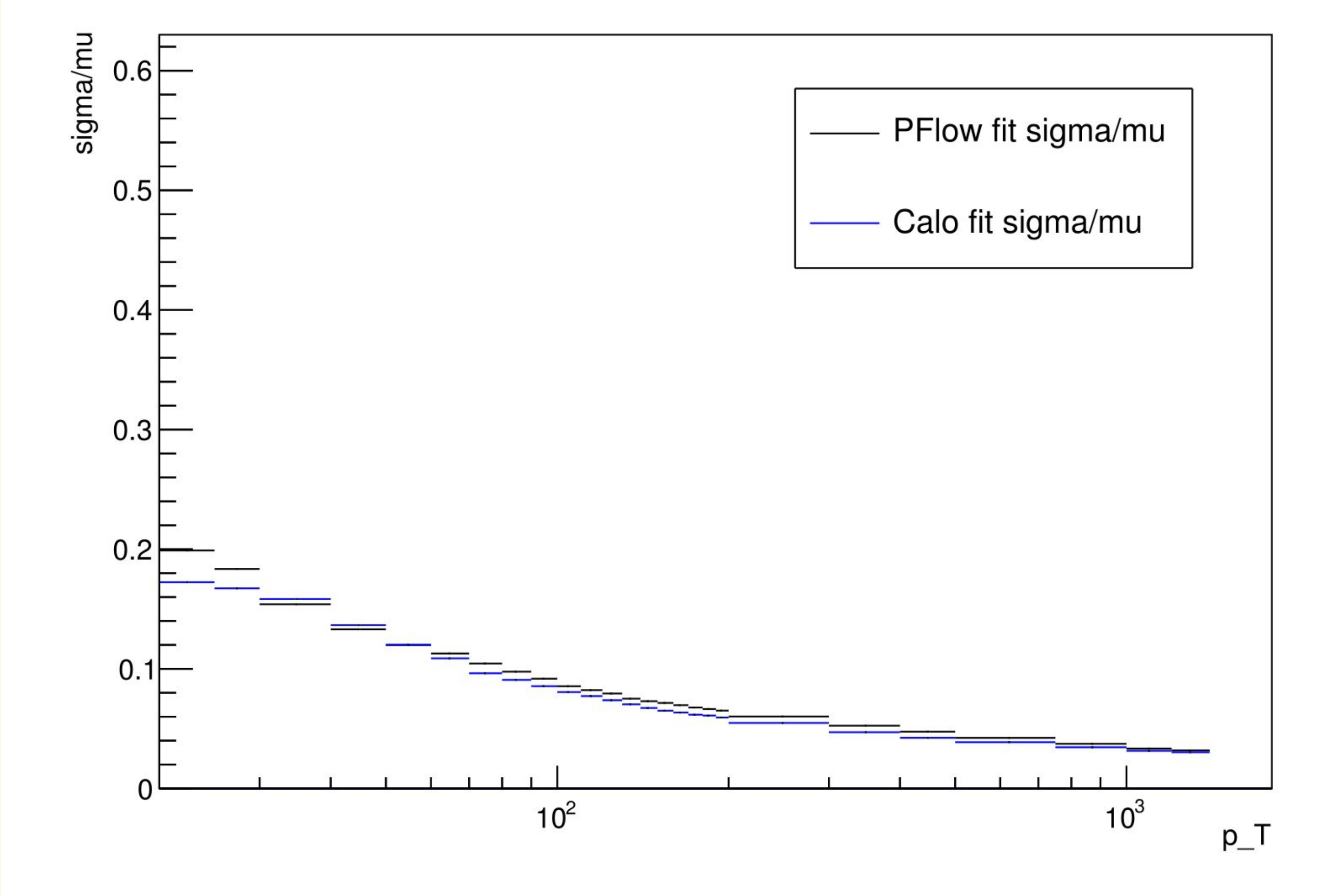
Thesis, Caterina Doglioni (2010 plot)

Particle Flow Calibration Evaluation

20.7 Monte Carlo samples
E_reco/E_truth compared
using 20.1 calibration constar
values



Particle Flow Performance

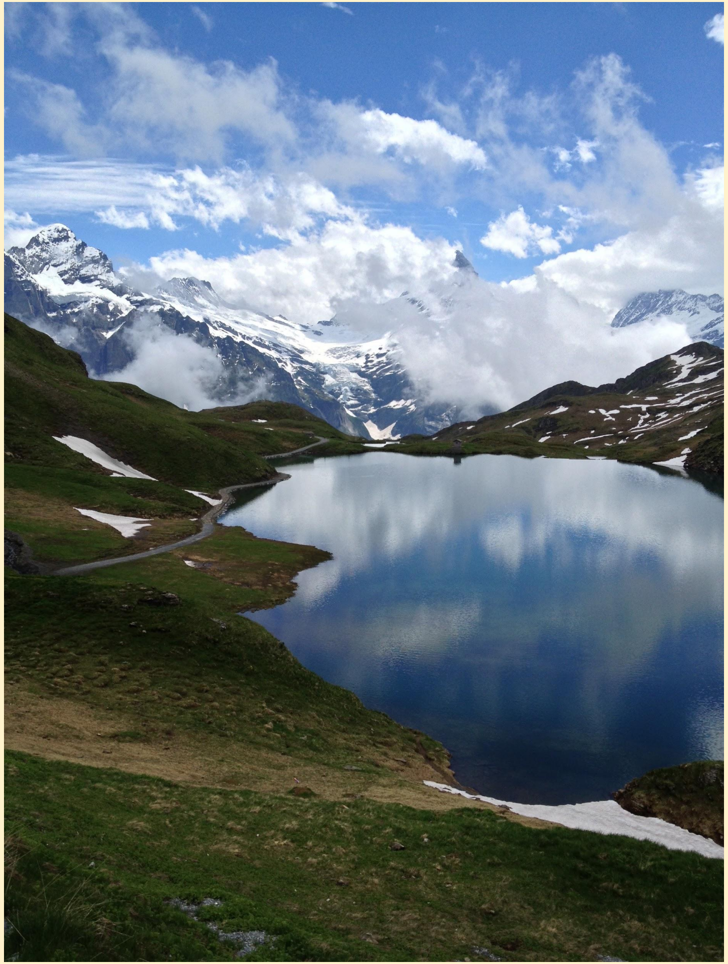


Multijet Balance

Current work (need the calibration finished first for actual results, but working through the Multijet Balance software first with old calibration then swap when new calibration available):

- Investigate multijet balance using PFlow jets
- Determine the calibration dependence on charged/neutral particle fraction by varying the fraction of charged/neutral particles in PFlow jets in the multijet balance
- Compare the calibration and uncertainties for the different charged/neutral particle fraction PFlow jets with the single particle propagation technique to observe what uncertainties dominate in single particle propagation





Backup Slides


22
21
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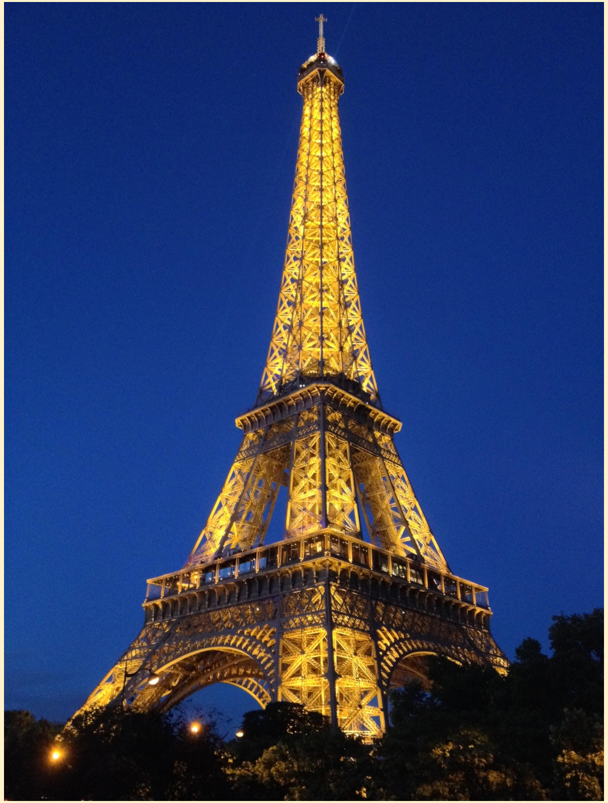
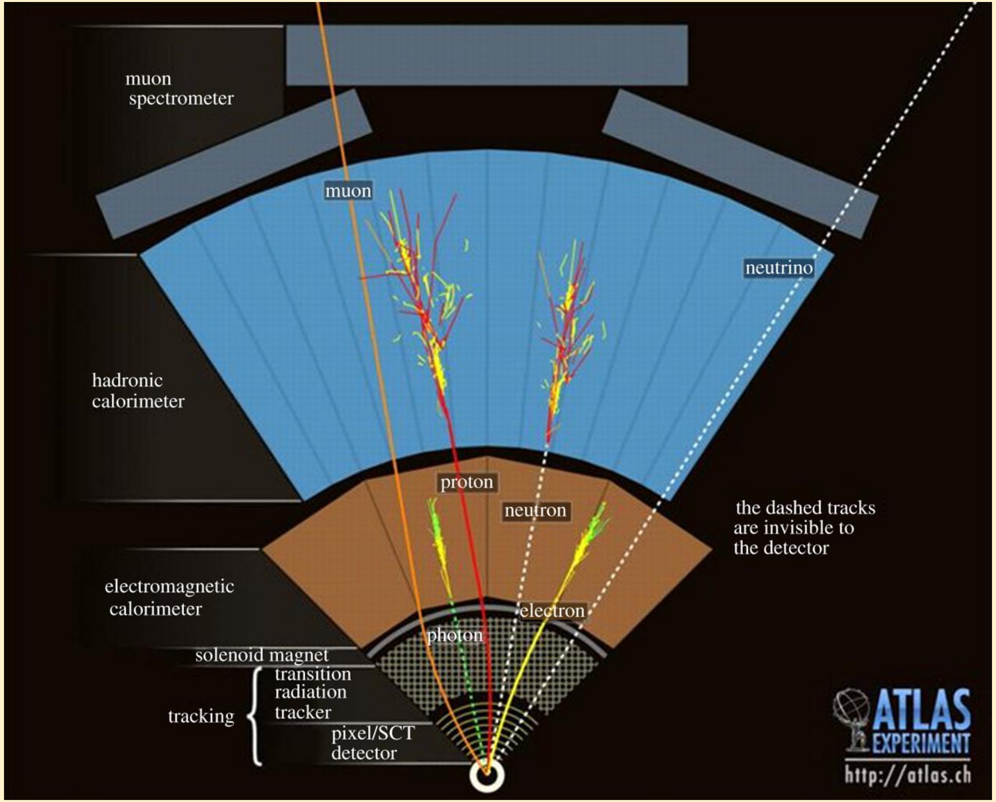


Particle Flow Jet Algorithm

- Inner Detector tracker: better resolution for low p_T charged particles
- Calorimeter: better resolution for high p_T particles

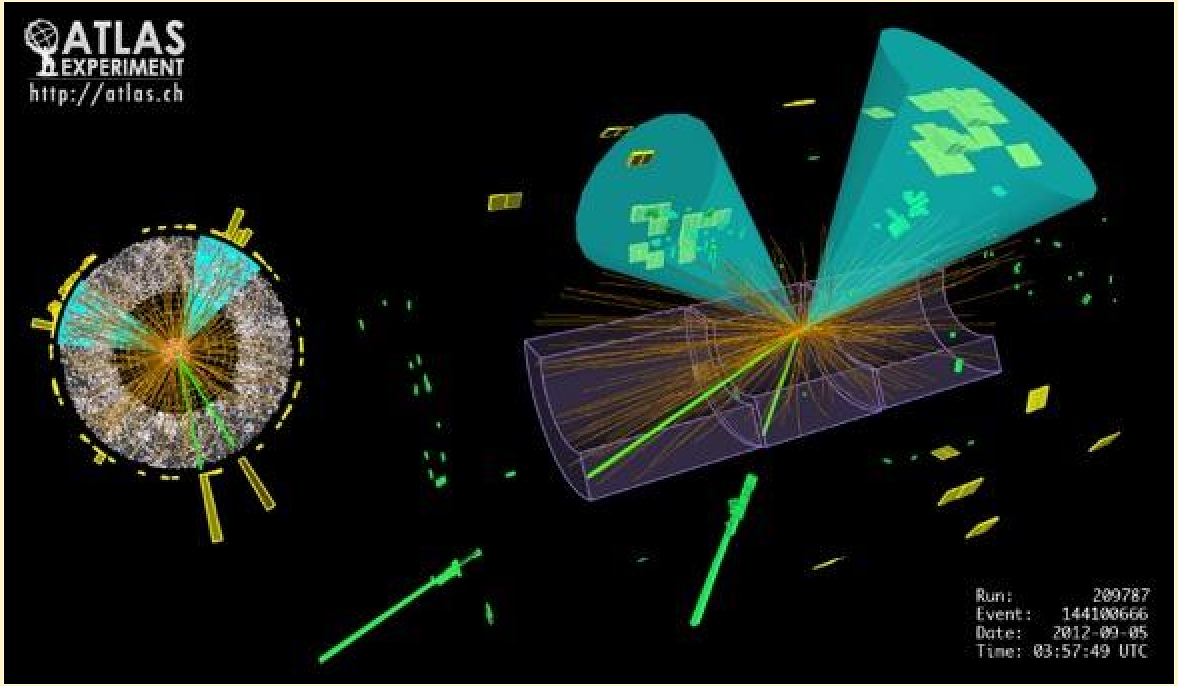
Particle flow algorithm: incorporates information from both tracker and calorimeter to improve overall jet energy resolution



http://rsta.royalsocietypublishing.org/content/370/1961/876

Hadronic Jets Overview

Particles in jets can be detected in both the ATLAS Inner Detector tracker and the calorimeters, and sophisticated algorithms determine the way in which detector cells should be clustered into jets.



http://users.physics.harvard.edu/~dlopez/Research.html

Jet Algorithm

- The “topocluster formation” algorithm takes “seed” cells (4X the RMS signal to noise) and groups them together with their surrounding high signal cells, forming “topological clusters.”
- Topoclusters are 3-dimensional objects that use multiple calorimeter layers to capture the hadronic showers, generated by particles interacting with the calorimeter material to produce streams of photons and other particles
- Topological clusters are then fed into the “anti-k_t” jet recombination algorithm, which groups them into jets based partly upon their proximity in η-ϕ space

Jet Calibration

Jet Energy Scale (JES) Calibration calibrates the calorimeters for a range of energy and pseudorapidity regions.

JES accounts for several sources of uncertainty:

- Pile-up (more than one collision per bunch crossing)
- Jet Origin uncertainty (uses jet kinematics to determine the primary vertex, which need not be perfectly centered in the ATLAS detector, improves angular resolution)
- Final Correction uses a comparison to Monte Carlo simulations to determine the actual particle energy corresponding to a given calorimeter signal, and for the hadronic calorimeter especially to correct for the non-compensation effects (the fact that the hadronic calorimeter can’t capture the entire particle signal because of energy lost to nuclear excitation and breakdown and the creation of muons and neutrinos that aren’t detected in the calorimeter)
- Global Sequential Calibration (improves resolution, helps equalize response to quark and gluon originated jets)

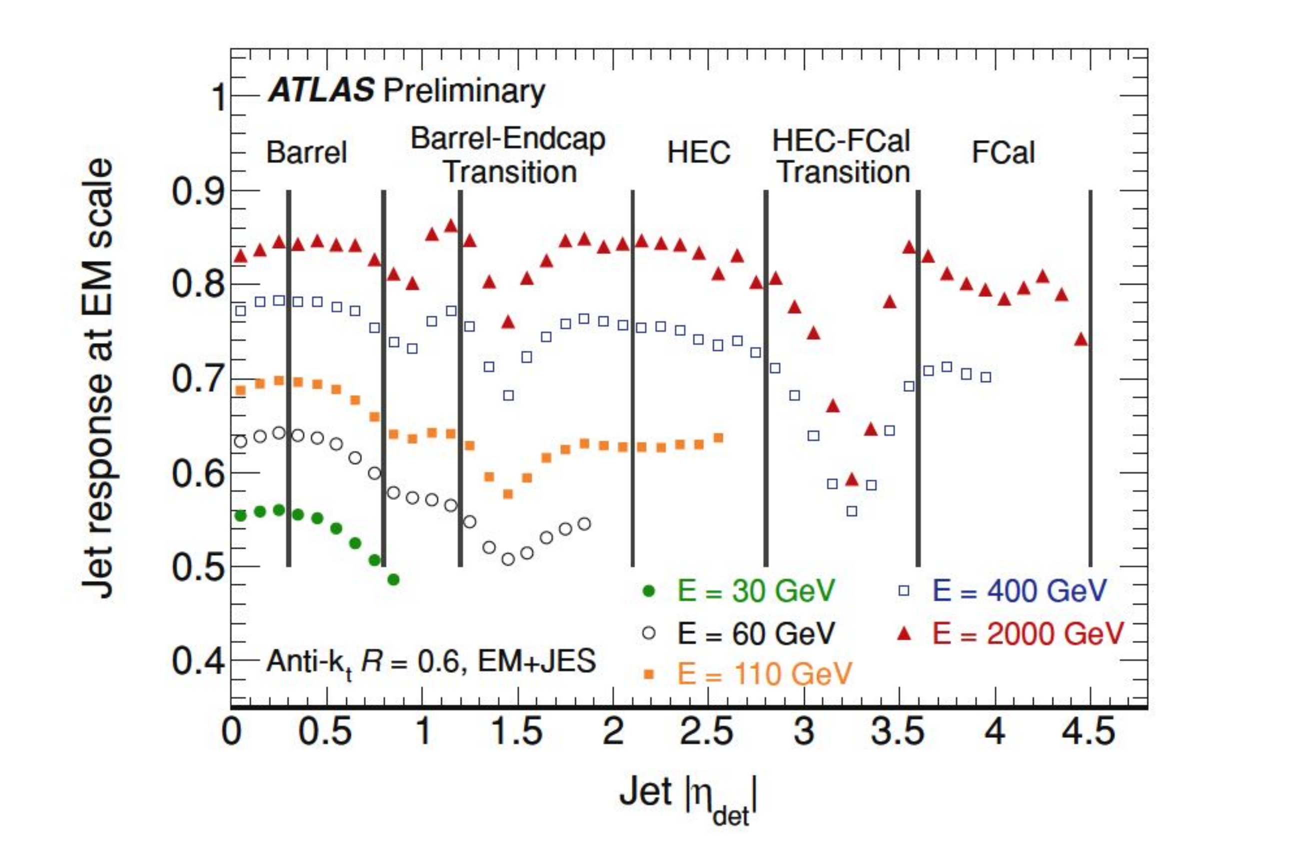
Jet Calibration

The JES final calibration compares isolated jets in the data to Monte Carlo simulated “truth jets.”

For a series of energy and pseudorapidity bins, the “jet energy response” $\mathcal{R}$ is calculated as the ratio between measured and simulated energies. For each bin, many isolated jet events from data are matched to Monte Carlo truth jets. The jet energy responses for each of these events form a gaussian distribution which we can fit to determine the average jet energy response $\langle\mathcal{R}\rangle$.

$$\mathcal{R} = E_{\mathrm{calo}}/E_{\mathrm{truth}}$$

Jet Response vs Pseudorapidity

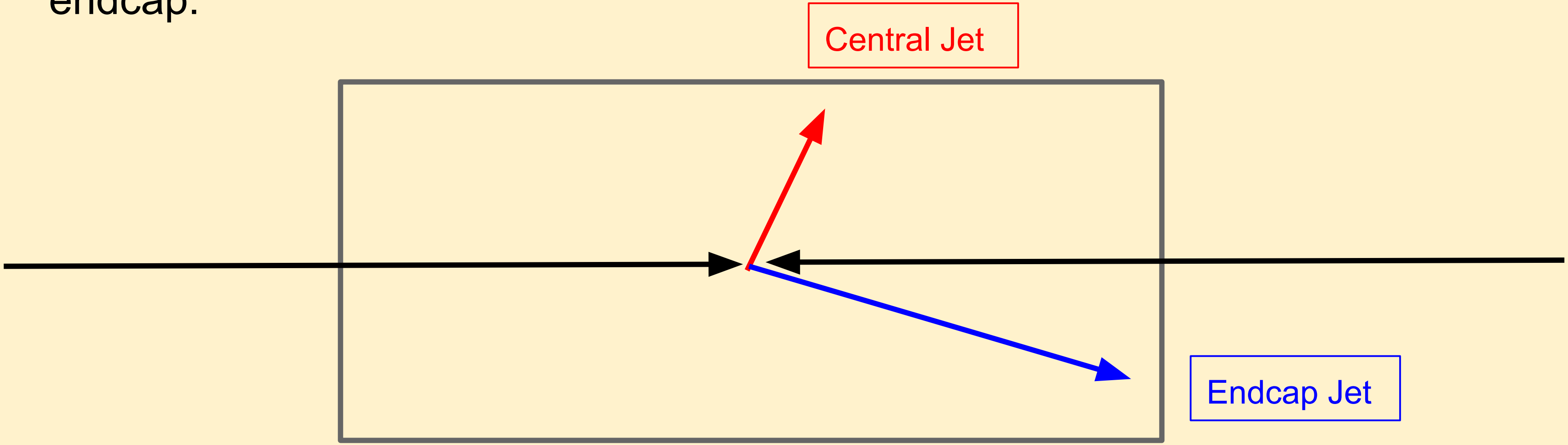


Caterina's Thesis (2010 plot)

Dijet Calibration Method

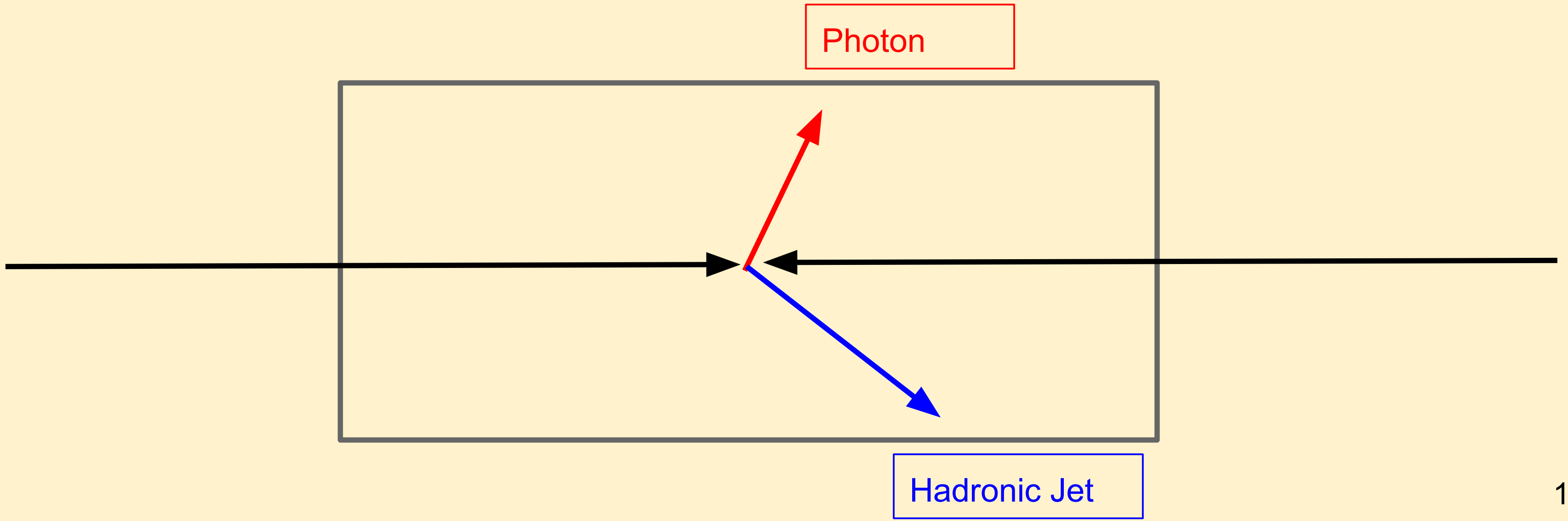
To correct for any mismodelling by the Monte Carlos in the JES calibration, we also use several additional calibration methods that rely upon transverse momentum conservation, looking at the p_T of dijet, jet-photon, and jet-multijet events.

1) The Dijet Balance calibration uses central jets to calibrate jets in the detector endcap:

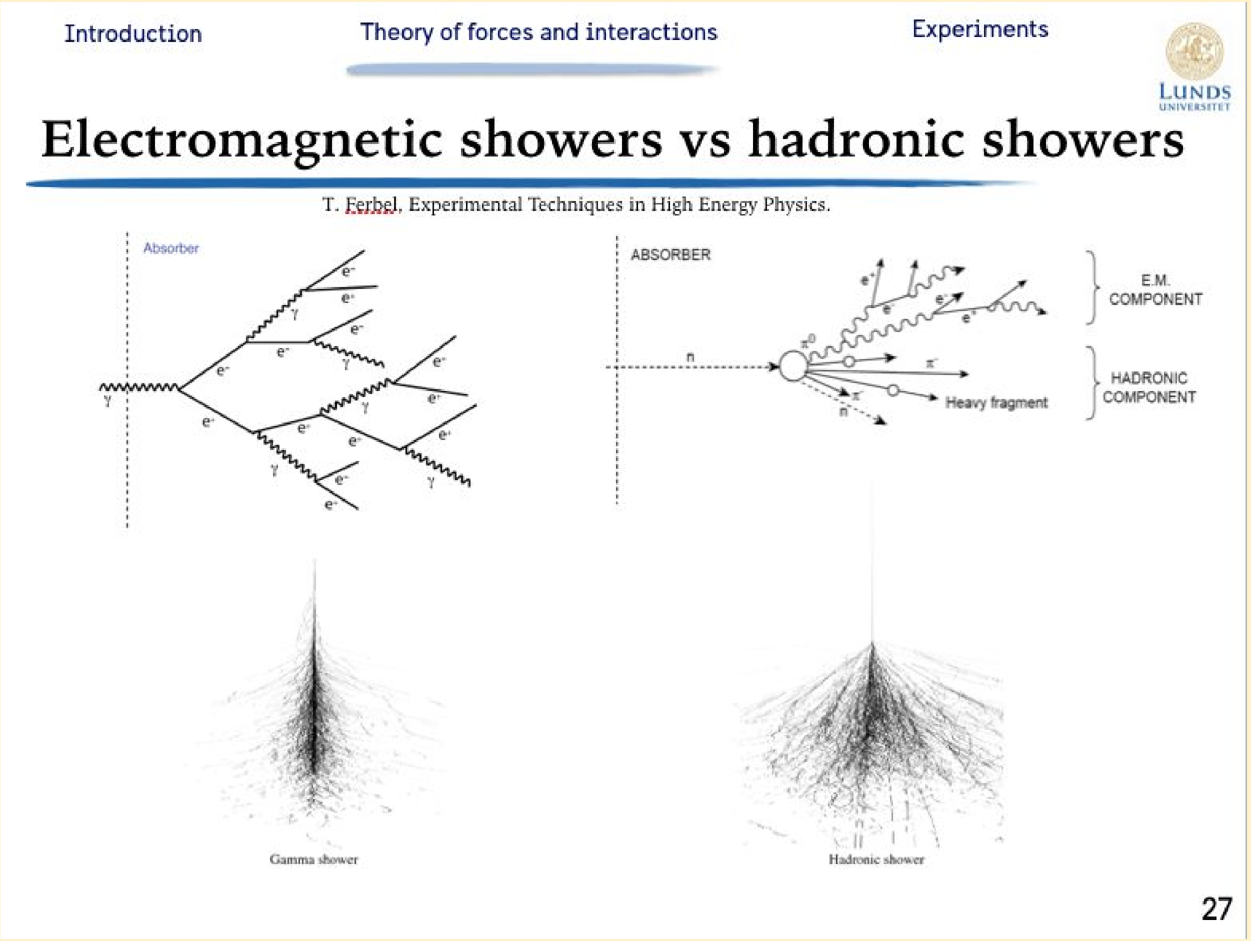


Photon-Jet Calibration Method

2) The Photon-Jet Balance calibration uses events with one photon balanced against a hadronic jet (other methods for in situ calibration exist as well):

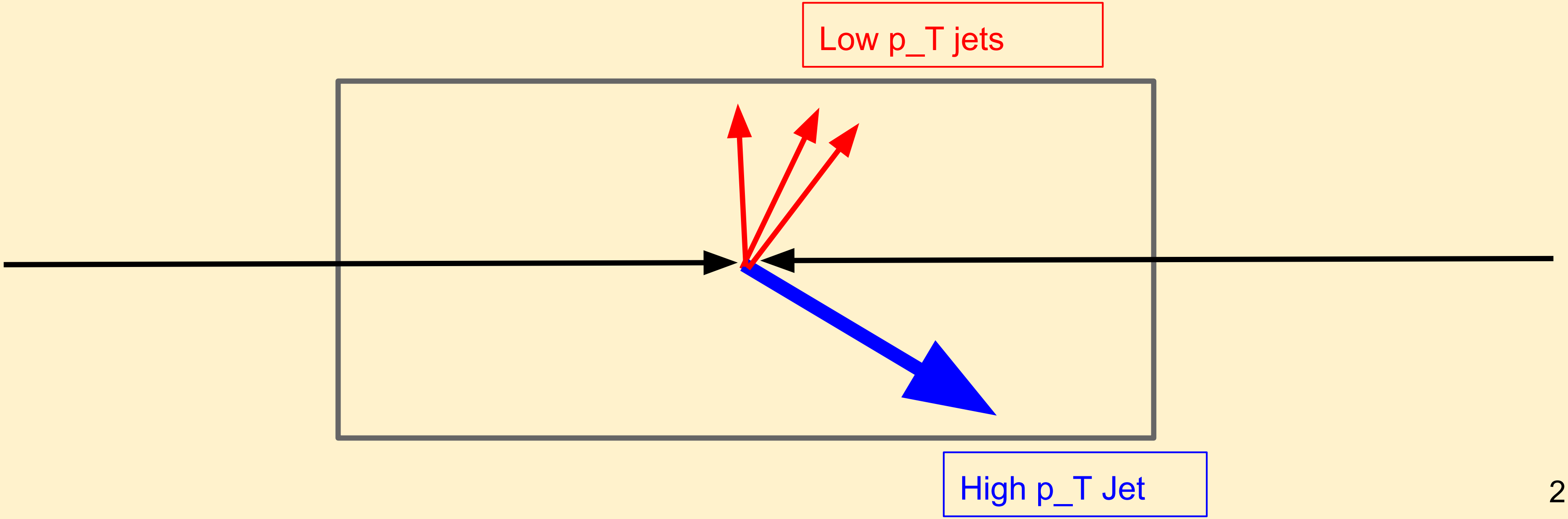


Photon calibration improves measurements of P_T since EM calorimeter achieves superior resolution due to the fact that EM showers consist of photons + electrons/positrons, allowing us to capture a greater fraction of the shower energy than with hadronic showers.



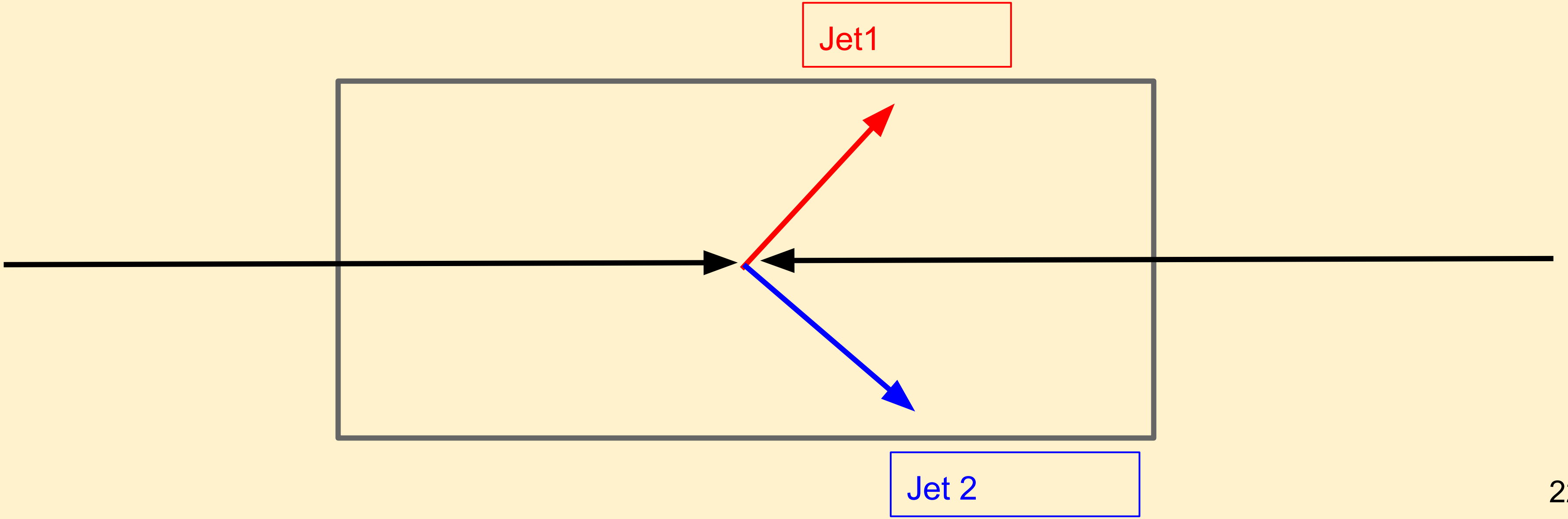
Multijet Calibration Method

3) At high p_T, we get low statistics for photon-jet balance events, so the Multijet Balance calibration balances multiple low-p_T jets against one high-p_T jet to calibrate at high p_T. As part of my project I plan to perform a multijet balance to improve the calibration at high p_T.



Dijet Balance for Jet Energy Resolution

We can also use dijet events to measure the detector resolution. Using only events that have a third jet $p_T < 10$ GeV, momentum conservation implies that the two remaining jets should have approximately equal p_T, and we can use asymmetries in our measurements of the two jets in each event to evaluate the detector resolution. (To correct for additional low-p_T jets, a series of third jet p_T cuts are used and a linear fit extrapolates back to third jet $p_T = 0$).



PFlow

Particle Flow combines momentum measurements from both the Inner Detector tracker and the calorimeter to improve measurement precision

- Inner Detector tracker provides better momentum resolution for low momentum charged particles, measured by the particle path curvature in the solenoidal field
- Calorimeter provides better resolution for high momentum particles since ID tracks become asymptotically straight as momentum increases

The PFlow algorithm attempts to match particle trajectories from the tracker with calorimeter topoclusters. Successful matching allows us to modify the clusters by subtracting out the energy contributions from particles we already measure using the tracker.

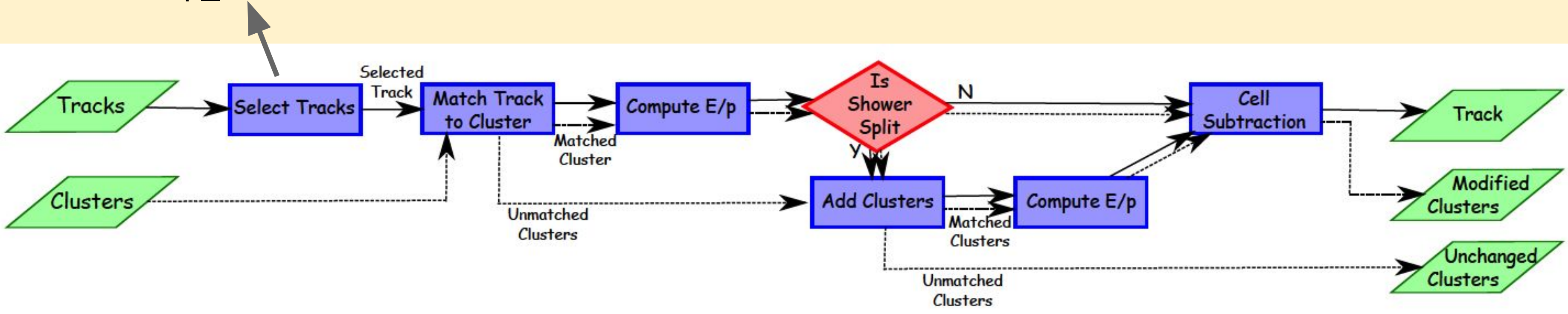
IDEA: Use tracker for low momentum particles, calorimeter for high momentum particles.

Particle Flow Jet Algorithm

Particle flow algorithm: use tracker for low momentum particles, calorimeter for high momentum particles to improve overall jet energy resolution

Problem: Particles measured in tracker also deposit energy in calorimeters, so if we wish to measure the momentum of low-p_T particles with the tracker, we must subtract their energy contributions from the calorimeter jets

0.5 GeV < p_T < 40 GeV



Moving Forward with my Project

1) Check current Particle Flow jet calibration against the new R20.7 Monte Carlo sample
2) Test the multijet balance method with pflow jets with the R20.7 sample
3) Develop an understanding of the performance of multijet balance methods with pflow jets as a function of variables available in particle flow jets, such as fraction of neutrals, to determine which uncertainties dominate single particle propagation, ultimately to further improve the calibration at high p_T

Sources

Caterina Doglioni -- Measurement of the Inclusive Jet Cross Section with the ATLAS Detector at the Large Hadron Collider

The ATLAS Collaboration -- Jet Reconstruction and Performance Using Particle Flow with the ATLAS Detector