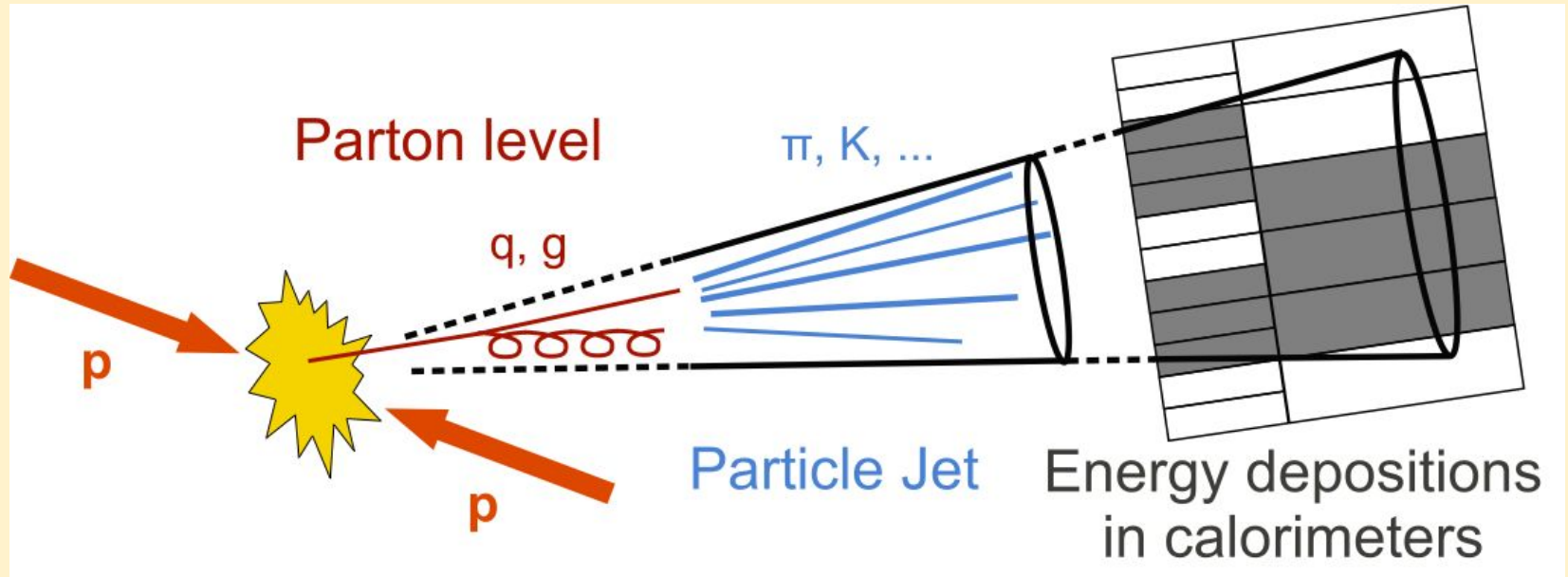# Improving ATLAS Jet Measurements and Searches with Particle Information
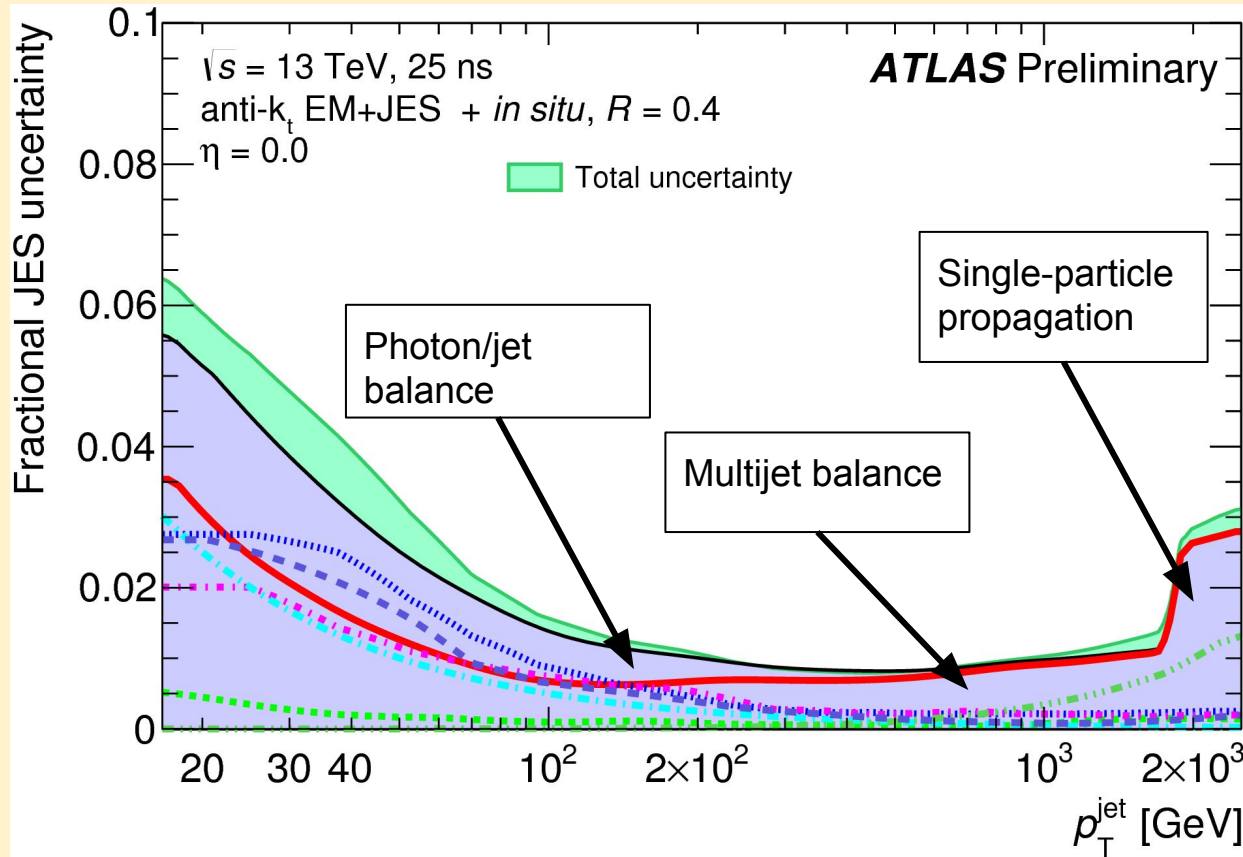
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UM CERN REU
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Hadronic Jets

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."

Jet Energy Scale Uncertainties

√s = 13 TeV, 25 ns
anti-k$_t$ EM+JES + *in situ*, R = 0.4
η = 0.0

ATLAS Preliminary

Total uncertainty

Photon/jet balance

Multijet balance

Single-particle propagation

Fractional JES uncertainty

p_T^{jet} [GeV]

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
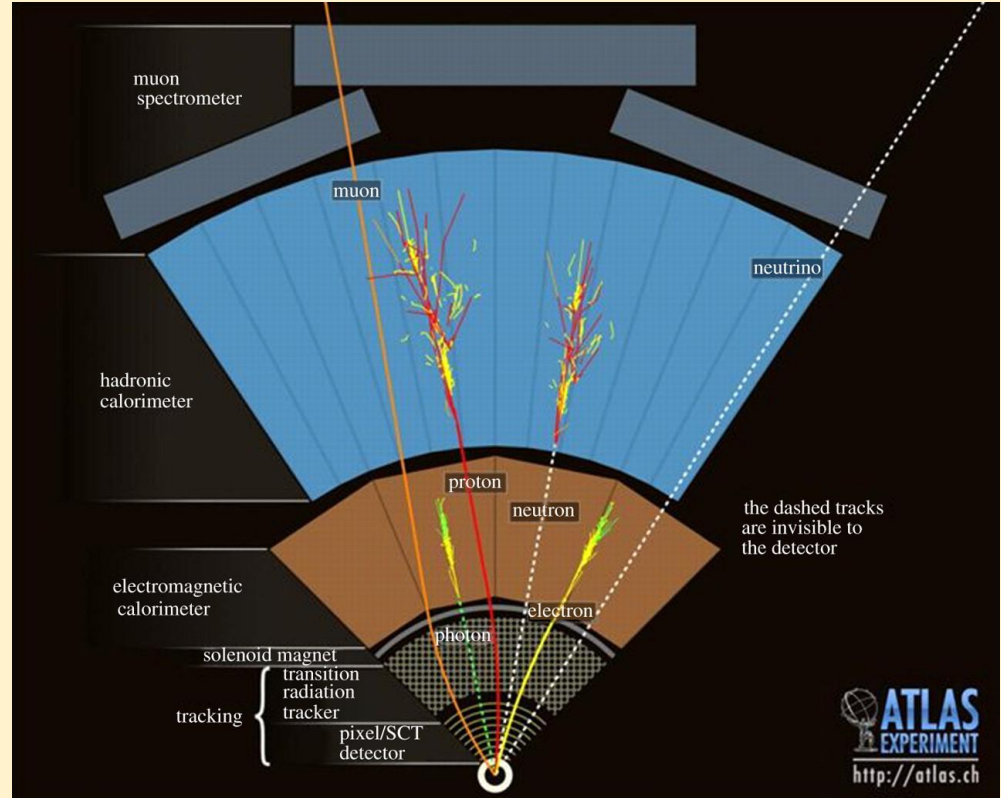
Moving Forward with my Project

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
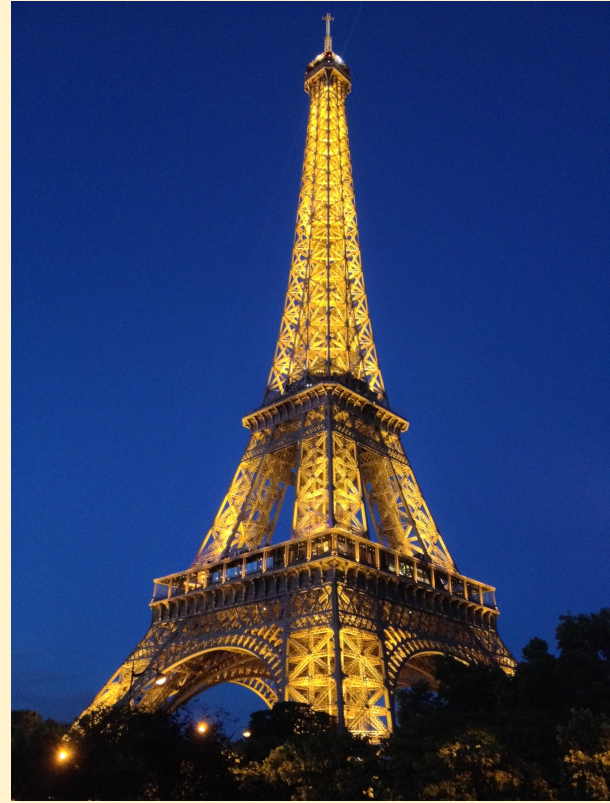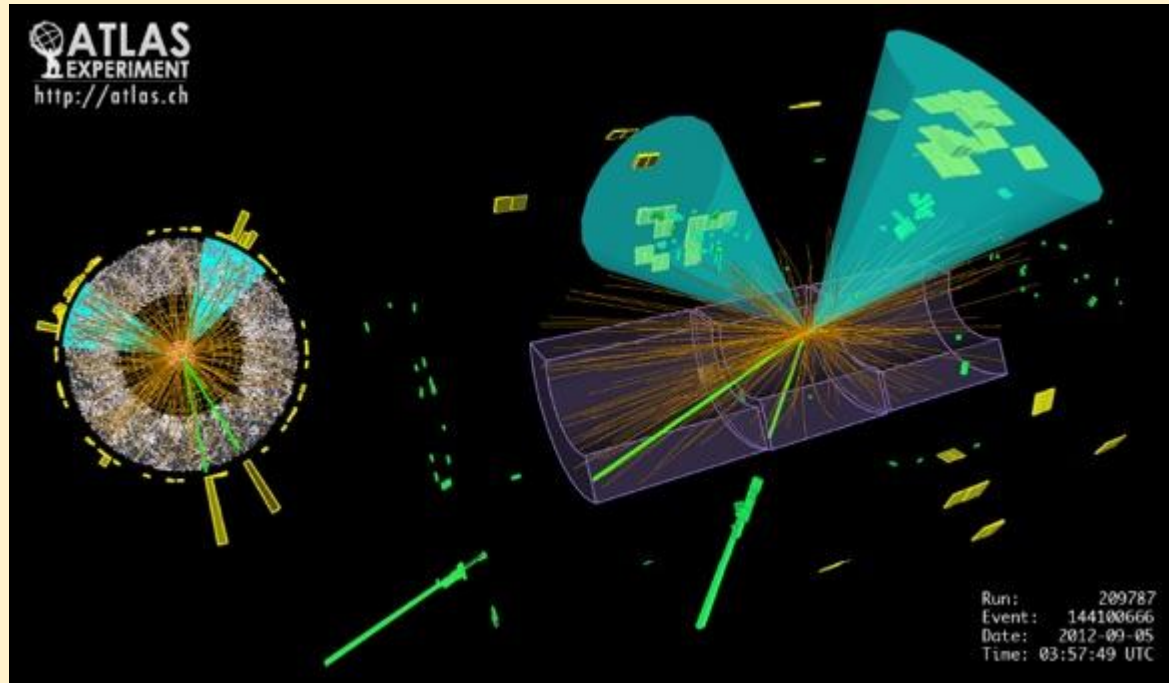
Backup Slides

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)
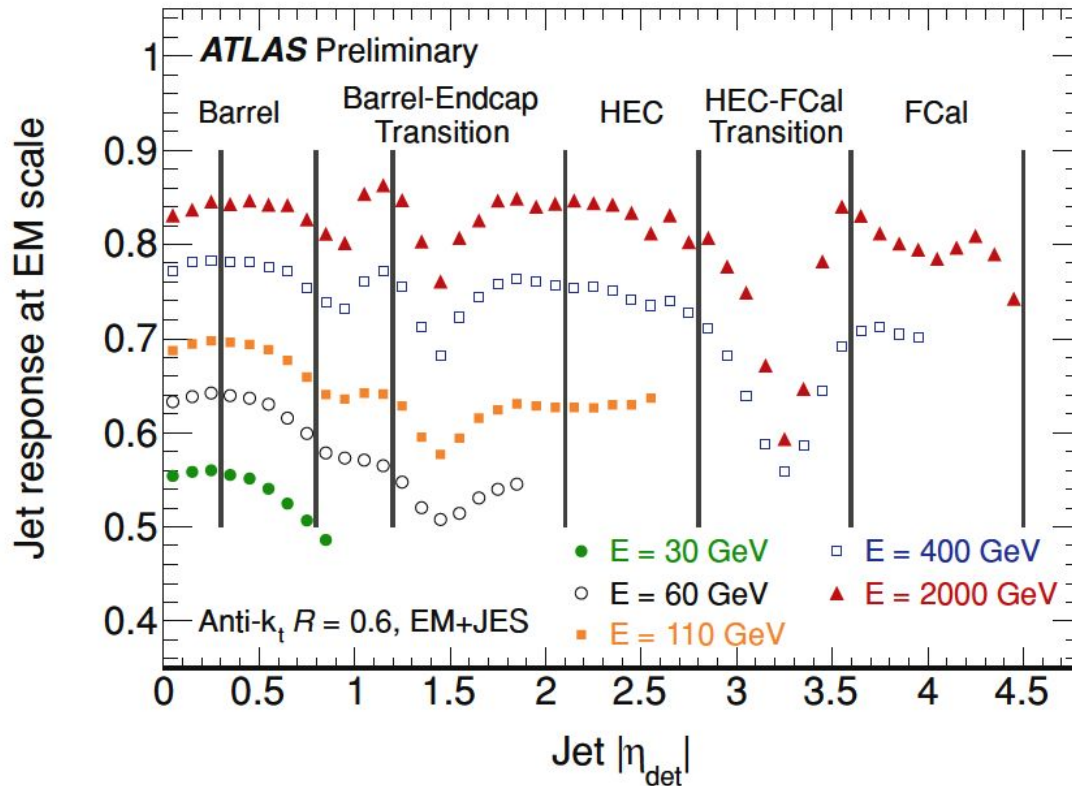
Jet Calibration

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 $\langle \mathcal{R} \rangle$.

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

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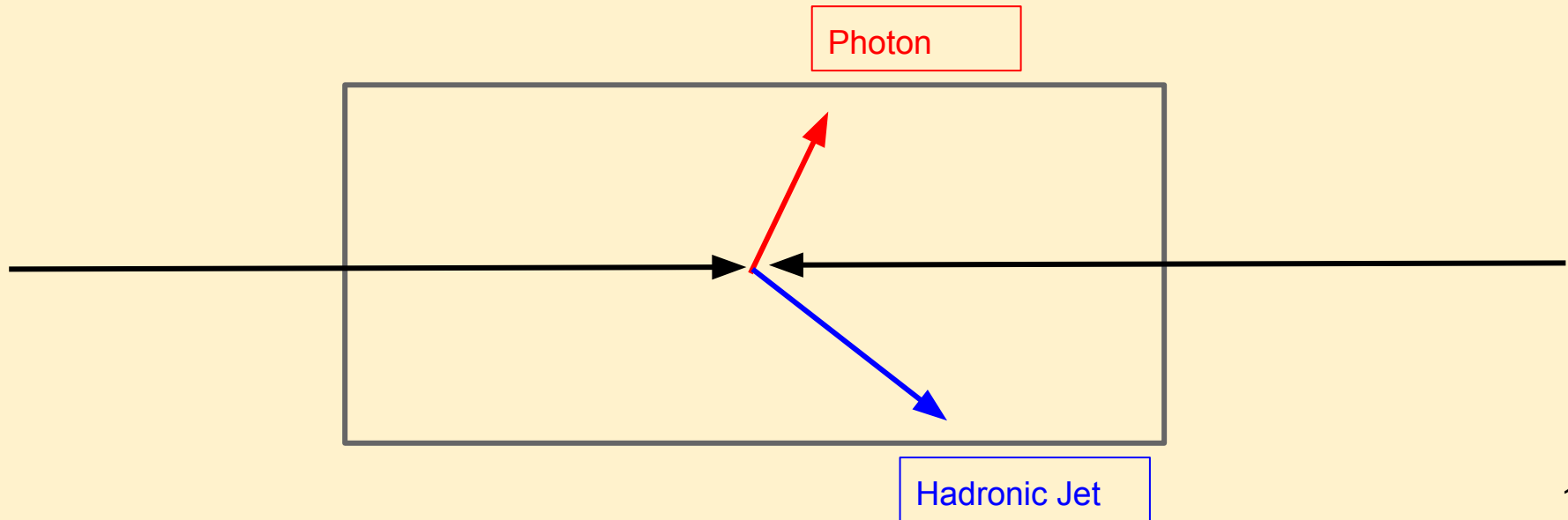
1) The Dijet Balance calibration uses central jets to calibrate jets in the detector endcap:
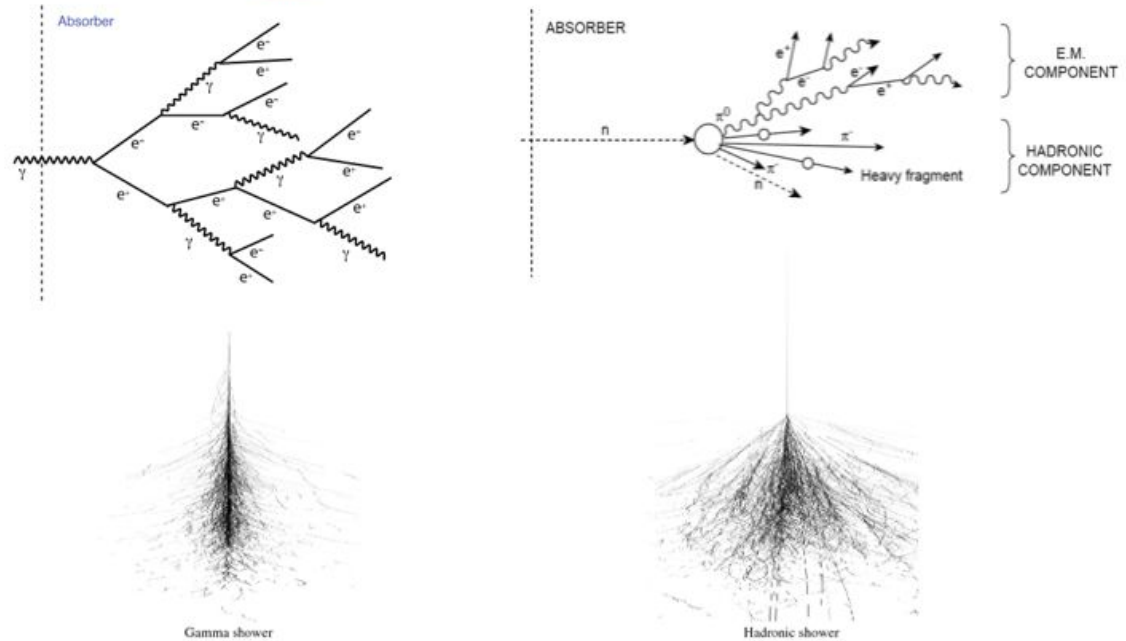
Central Jet

Endcap Jet
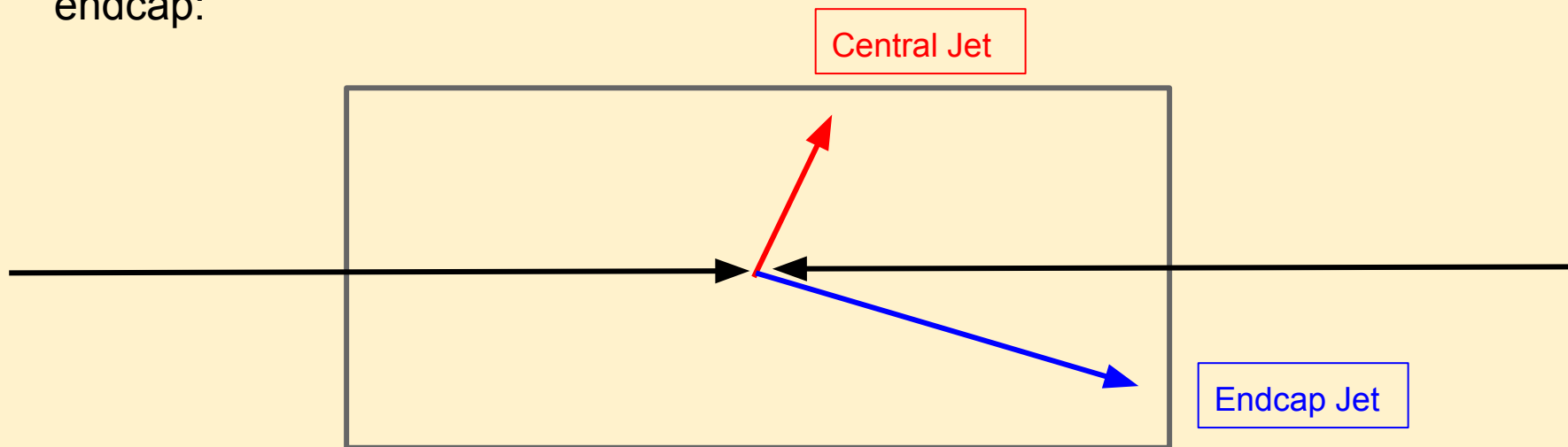
Photon-Jet Calibration Method

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

Hadronic Jet

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.

Electromagnetic showers vs hadronic showers

T. Ferbel, Experimental Techniques in High Energy Physics.

Gamma shower

Hadronic shower

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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.

Low p_T jets

High p_T Jet
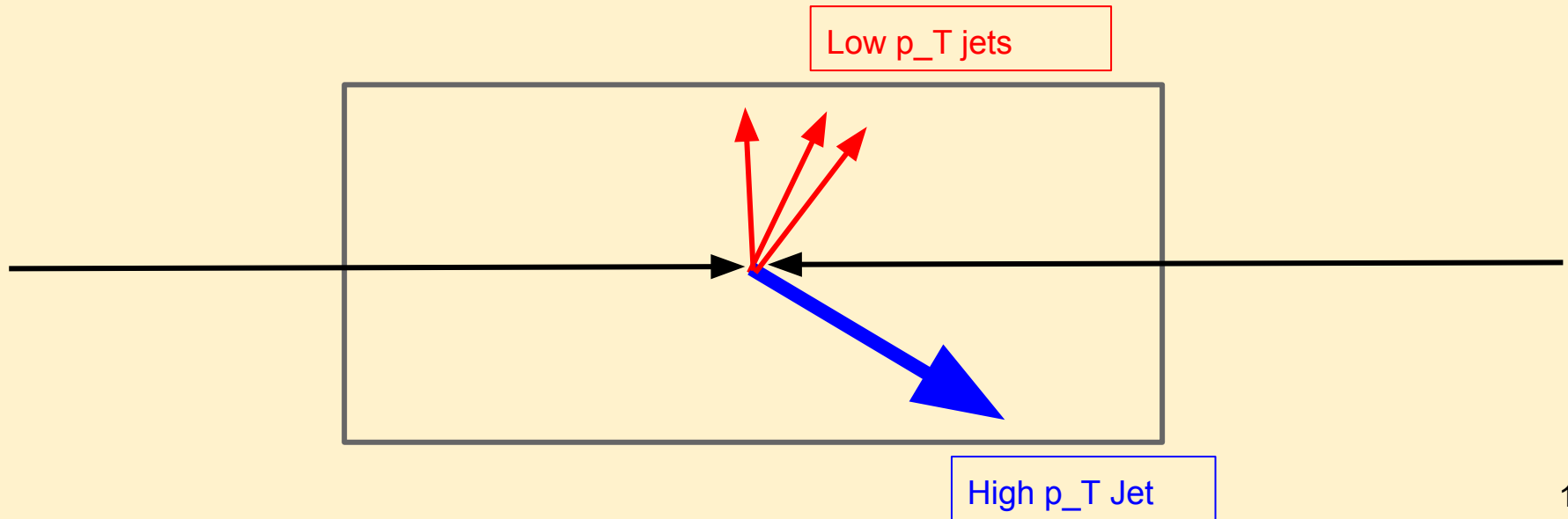
Dijet Balance for Jet Energy Resolution

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).

Jet1

Jet 2
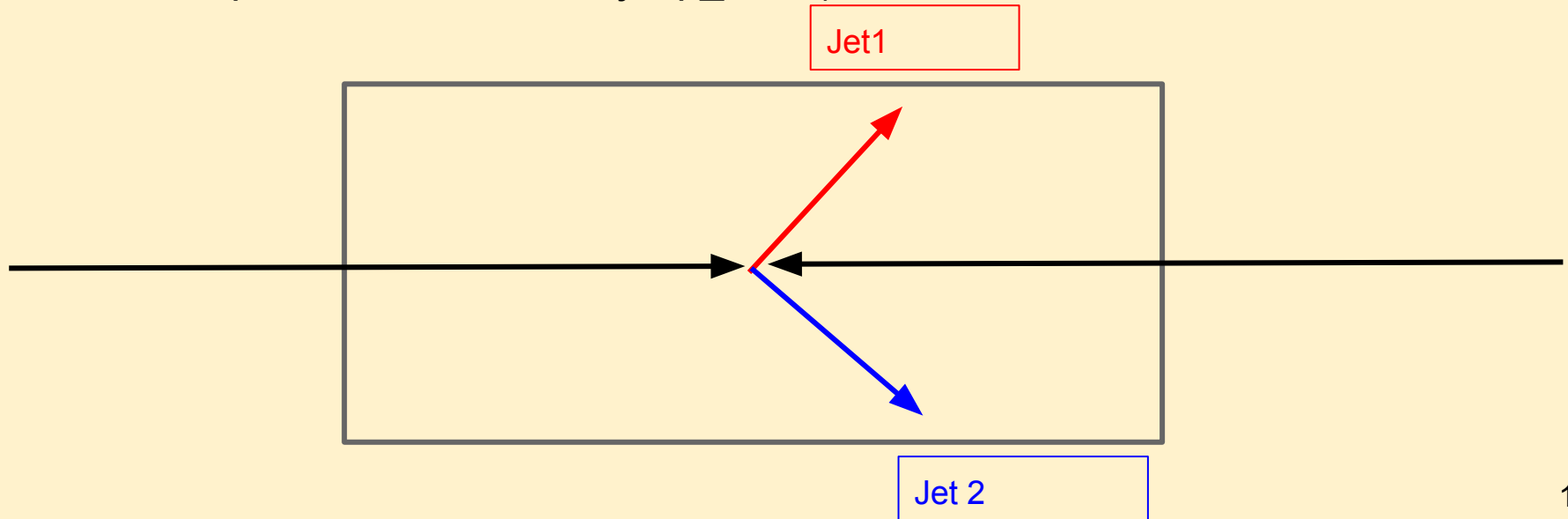
PFlow

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
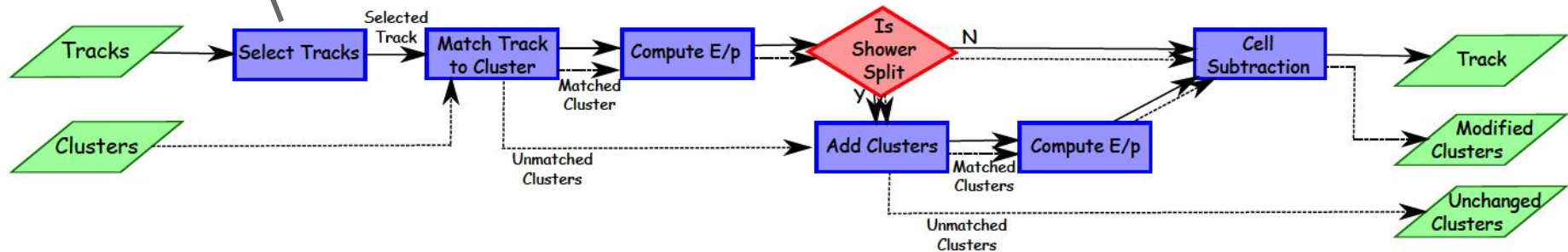
Sources

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