Measuring Photons with Global Particle Flow in the ATLAS Detector

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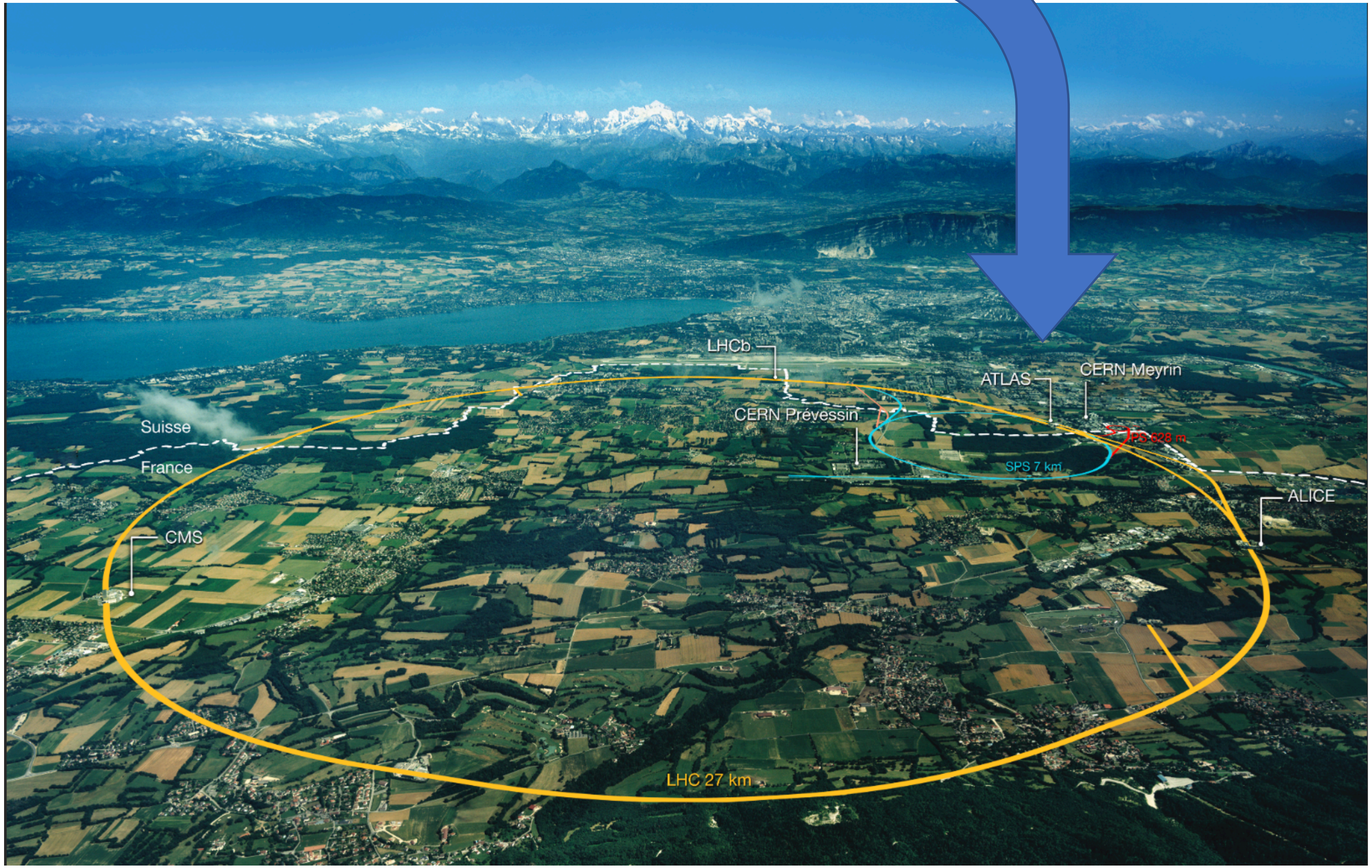
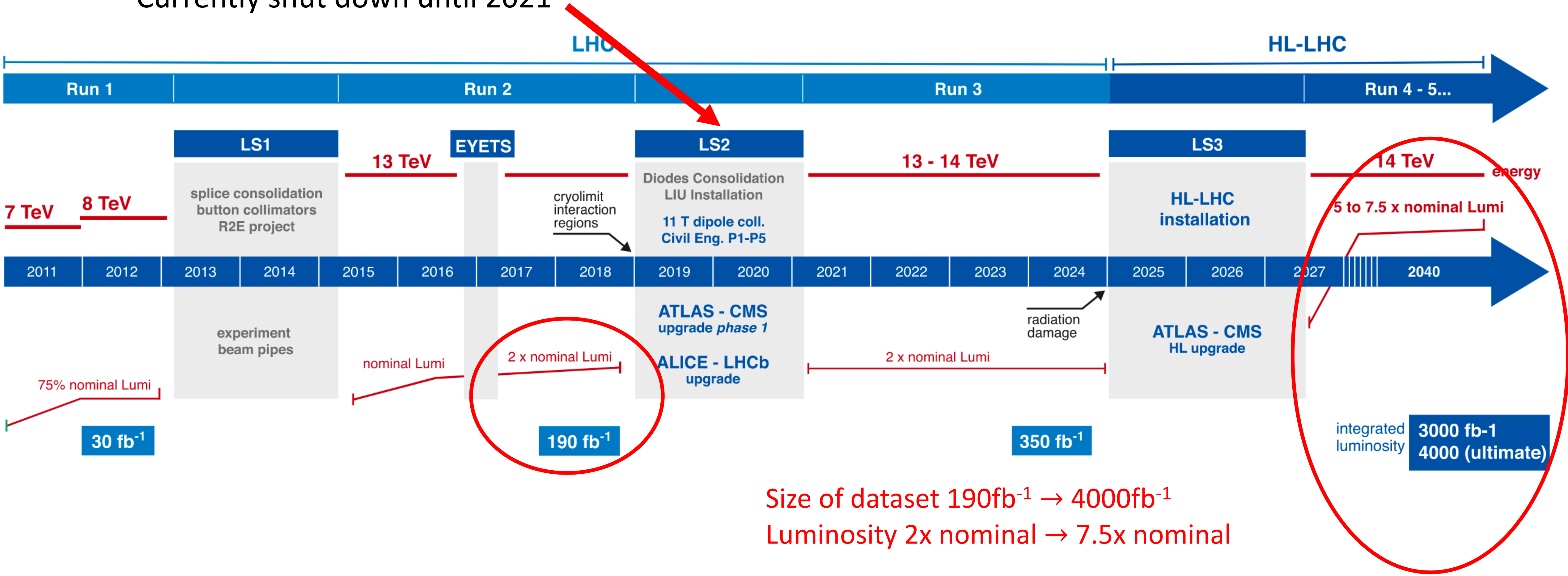
ATLAS Experiment

- One of the experiments located at the Large Hadron Collider (LHC) at CERN
- Major upgrades currently underway to both the LHC and the ATLAS detector
- Later upgrades will massively increase the luminosity
    - Allows more precise studies
    - Could potentially discover new physics
    - Comes at the price of more simultaneous collisions



LHC Upgrades

- Currently shut down until 2021



Size of dataset 190fb^{-1} → 4000fb^{-1}

Luminosity 2x nominal → 7.5x nominal

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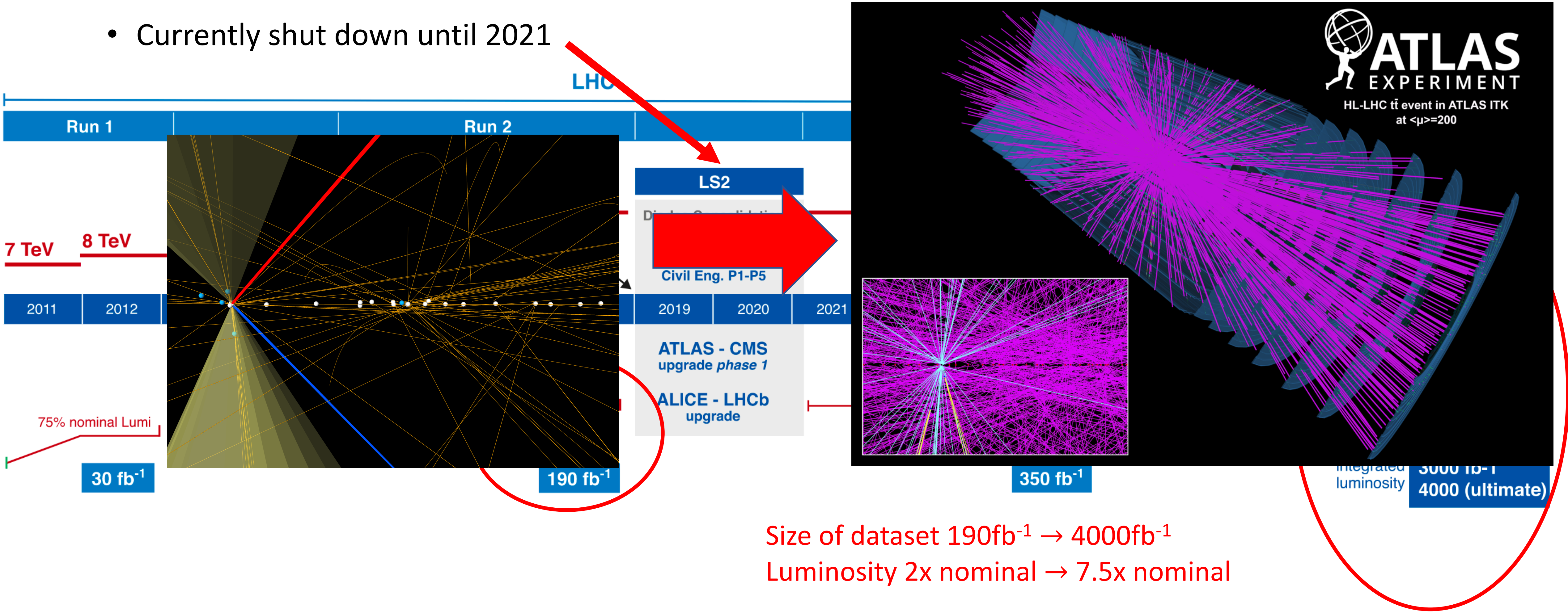

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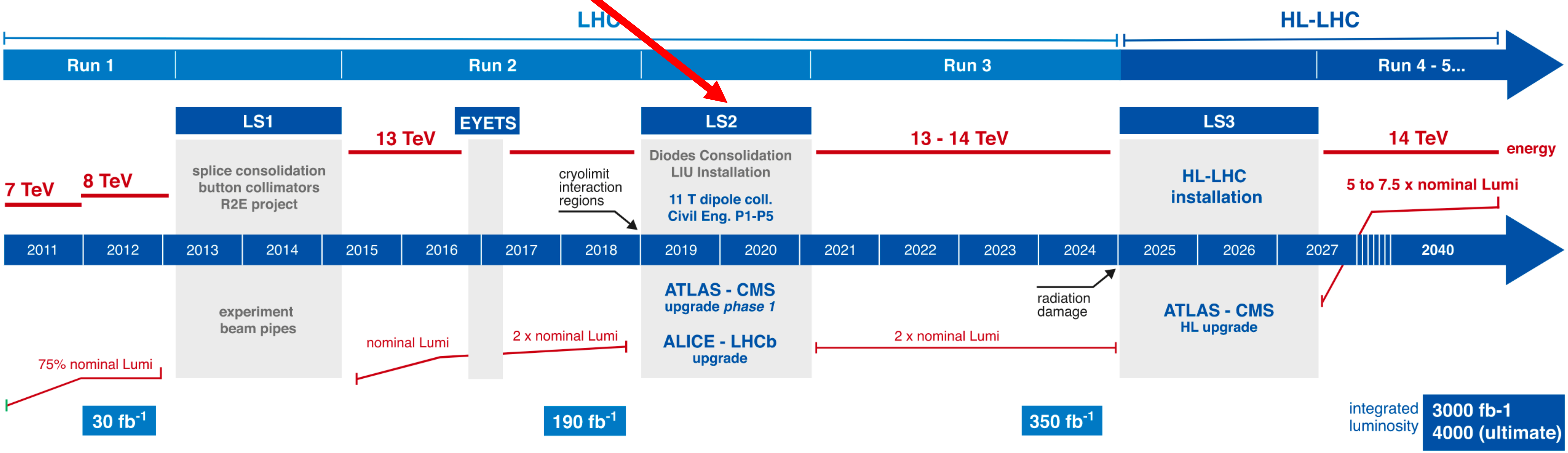
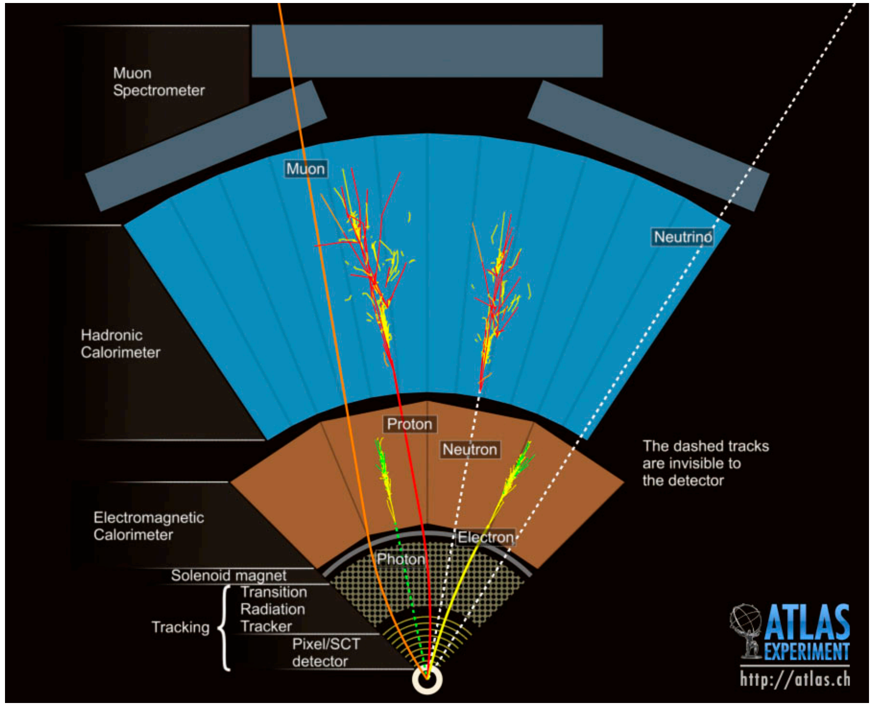
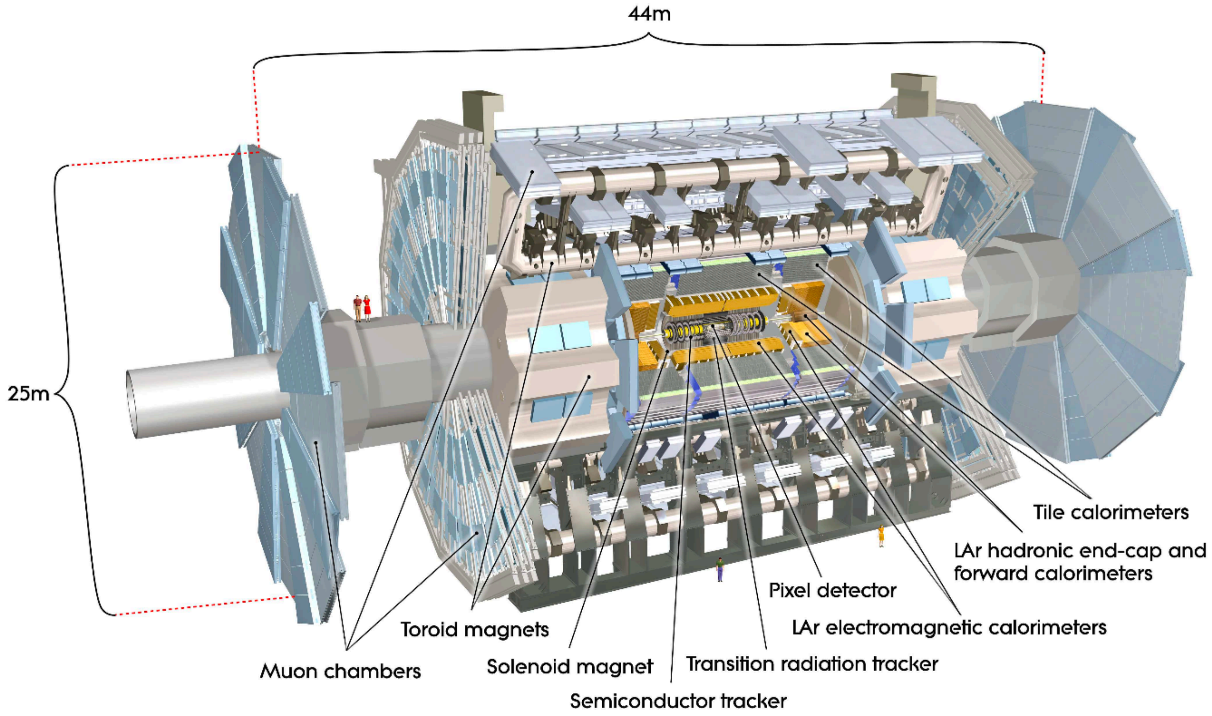


- Great time for software upgrades!

ATLAS Detector

- Main components:
  - Inner Detector
  - Liquid Argon Electromagnetic Calorimeter
  - Hadronic Tile Calorimeter
  - Muon Spectrometer





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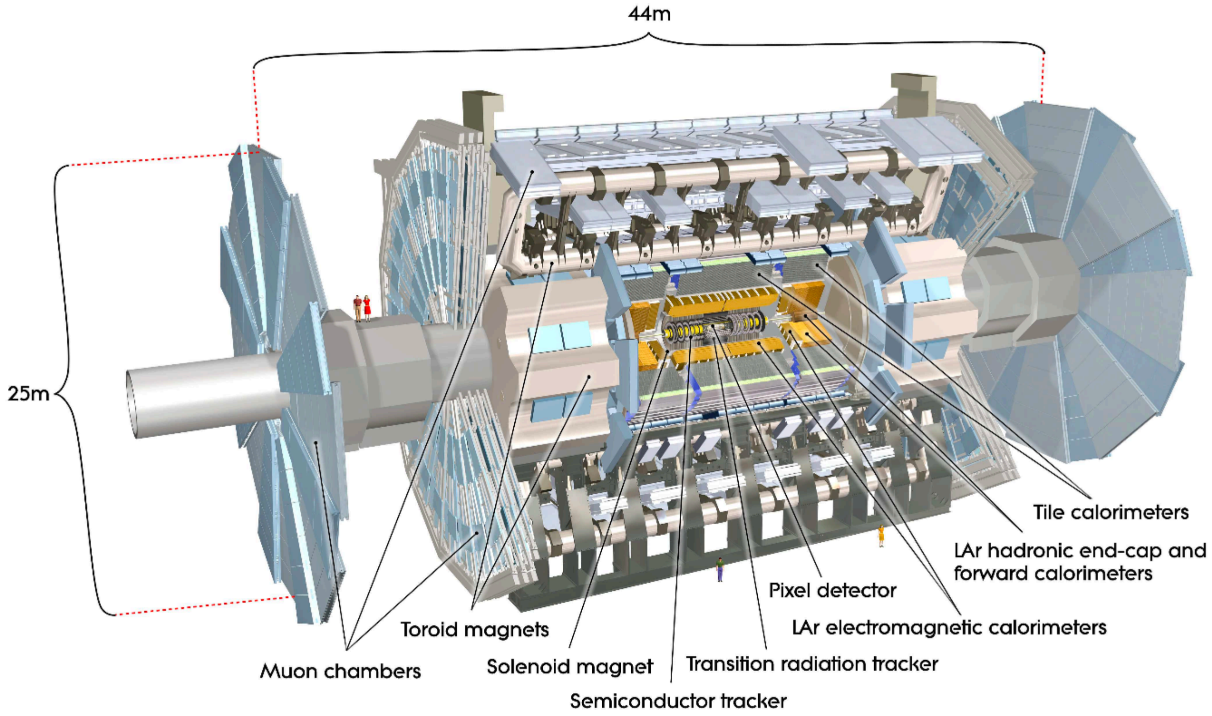

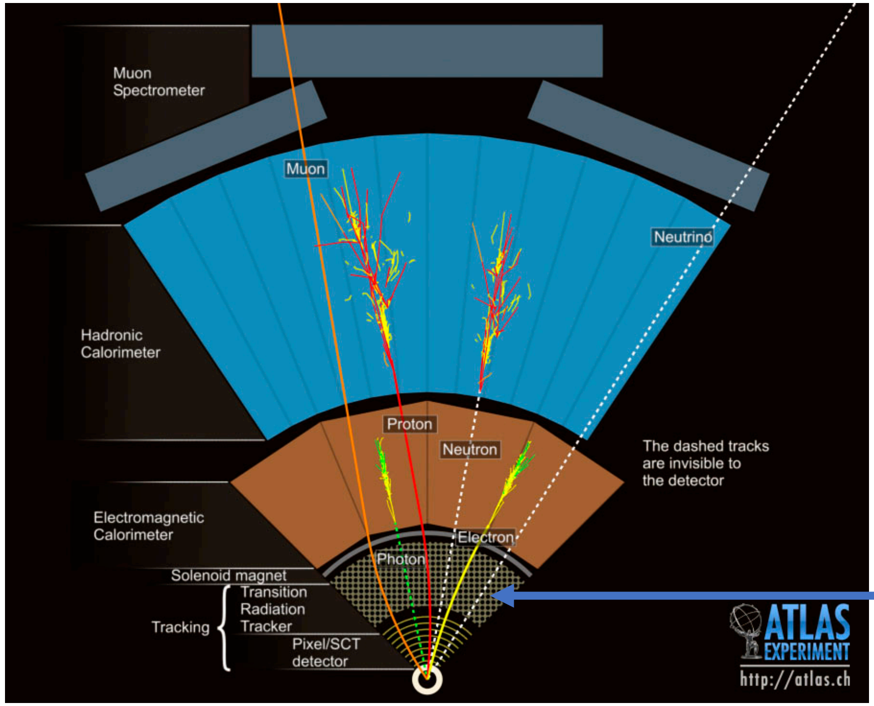

- Charged particles leave "tracks" in the inner detector in the form of hits on various semiconductor and gas detectors
  - Momentum of the particle is measured from the curvature of the track due to the magnets

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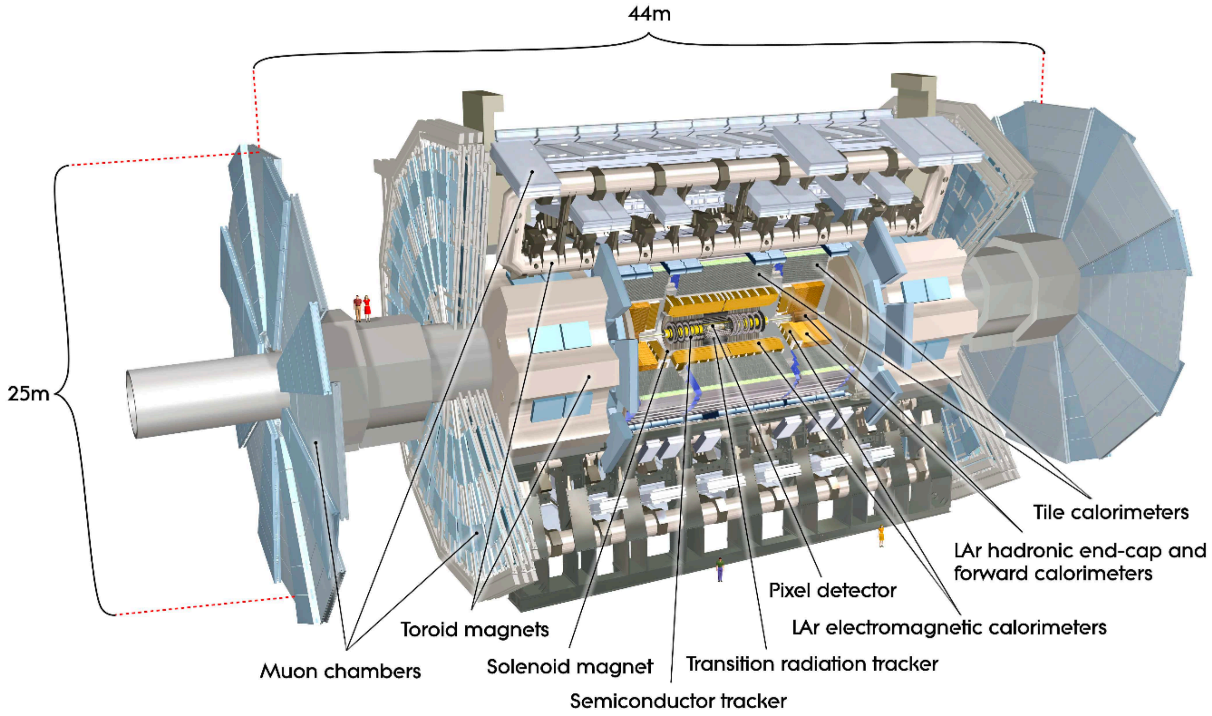
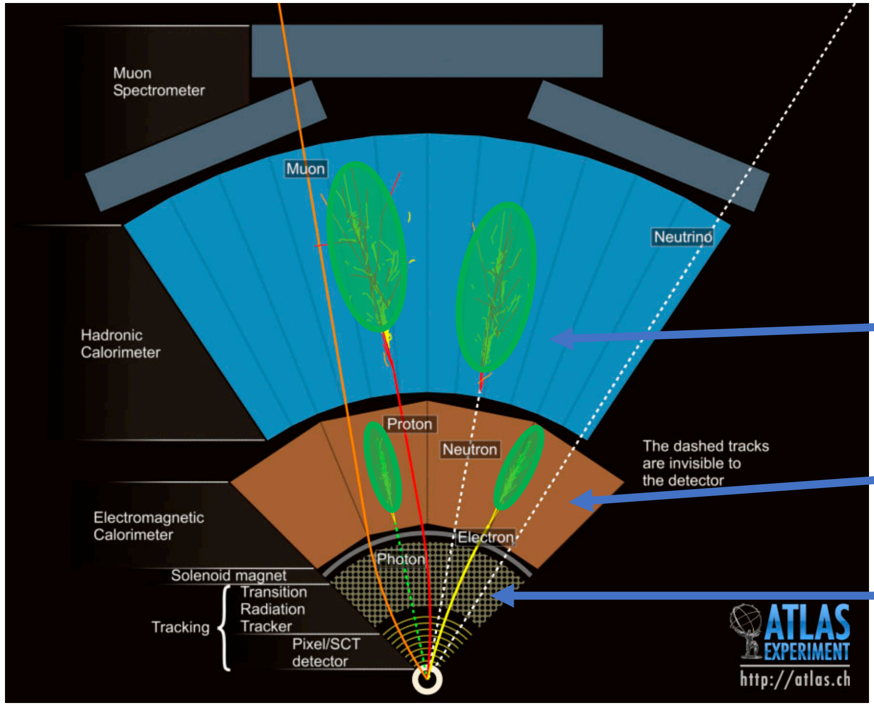
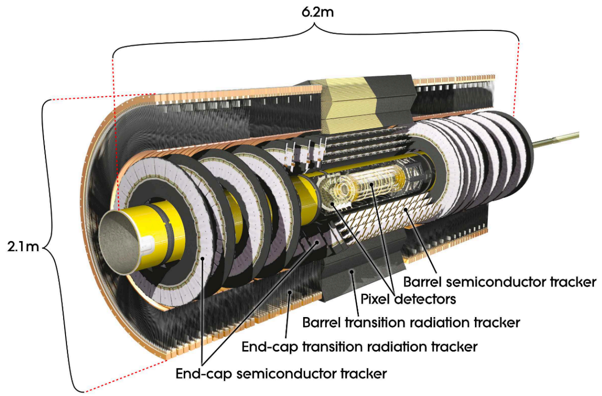




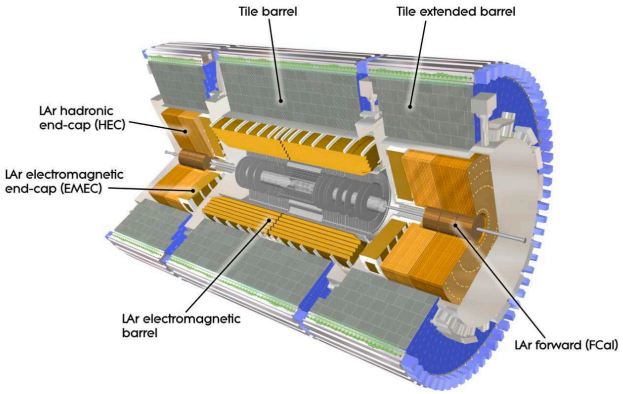
- Electrons and photons deposit their energy in cells in the electromagnetic calorimeter, while hadrons tend to penetrate more deeply and deposit their energy in cells in the hadronic calorimeter. This energy is then measured, and the energy from individual cells is clustered into "topoclusters"
- Charged particles leave "tracks" in the inner detector in the form of hits on various semiconductor and gas detectors

Inner Detector vs. Calorimeters

- Each part of the detector is good at different things



VS

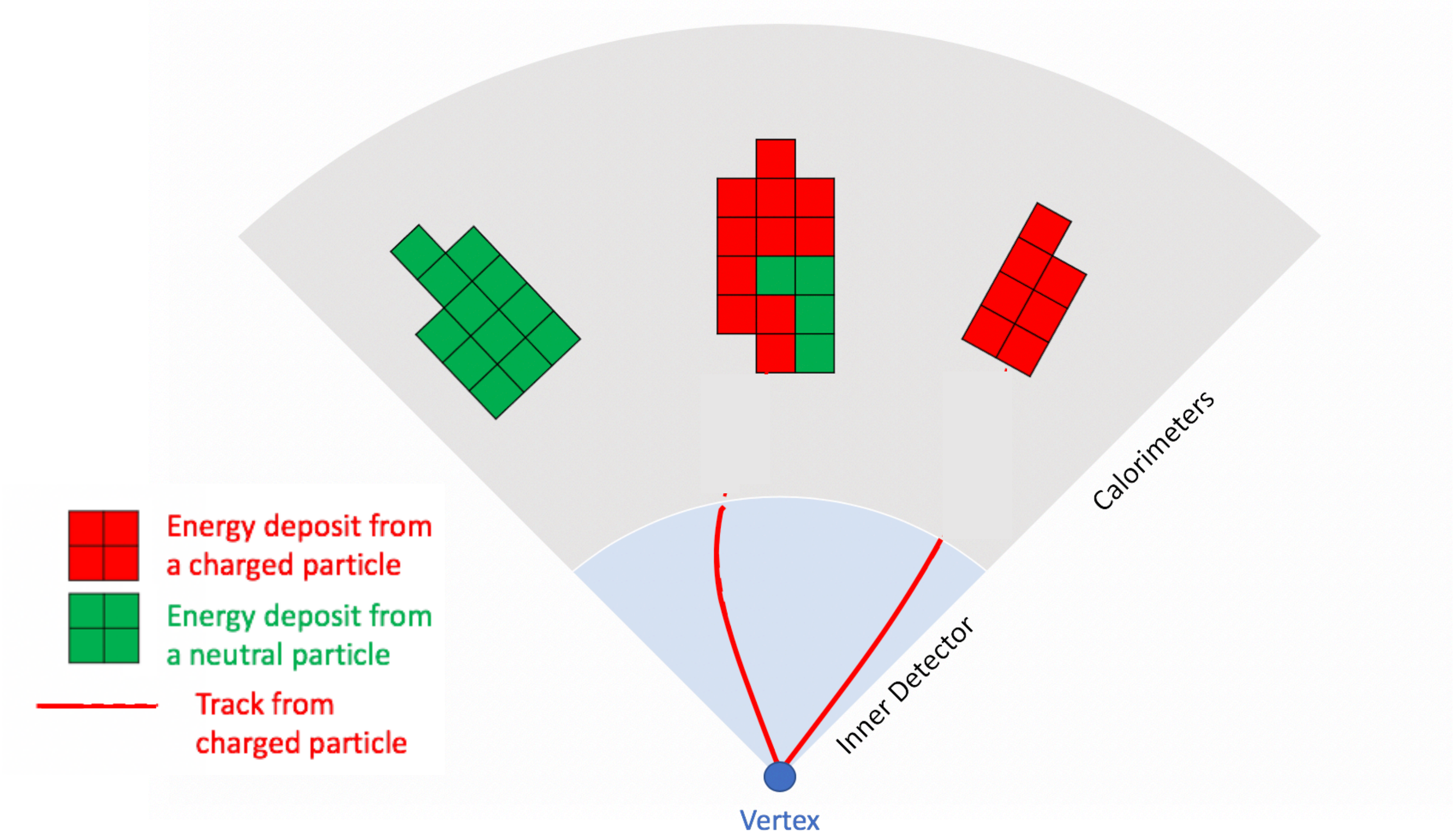


Measurement	Tracker	Calorimeter
Low p_T/E particles	Good ✓	Not as good ✗
High p_T/E particles	Not as good ✗	Good ✓
Neutral Particles	Can't measure ✗	Can measure ✓
Angular Resolution	Very good ✓	Not as good ✗
Vertex Identification	Very good ✓	Poor ✗

- What if we combine information from both of them?

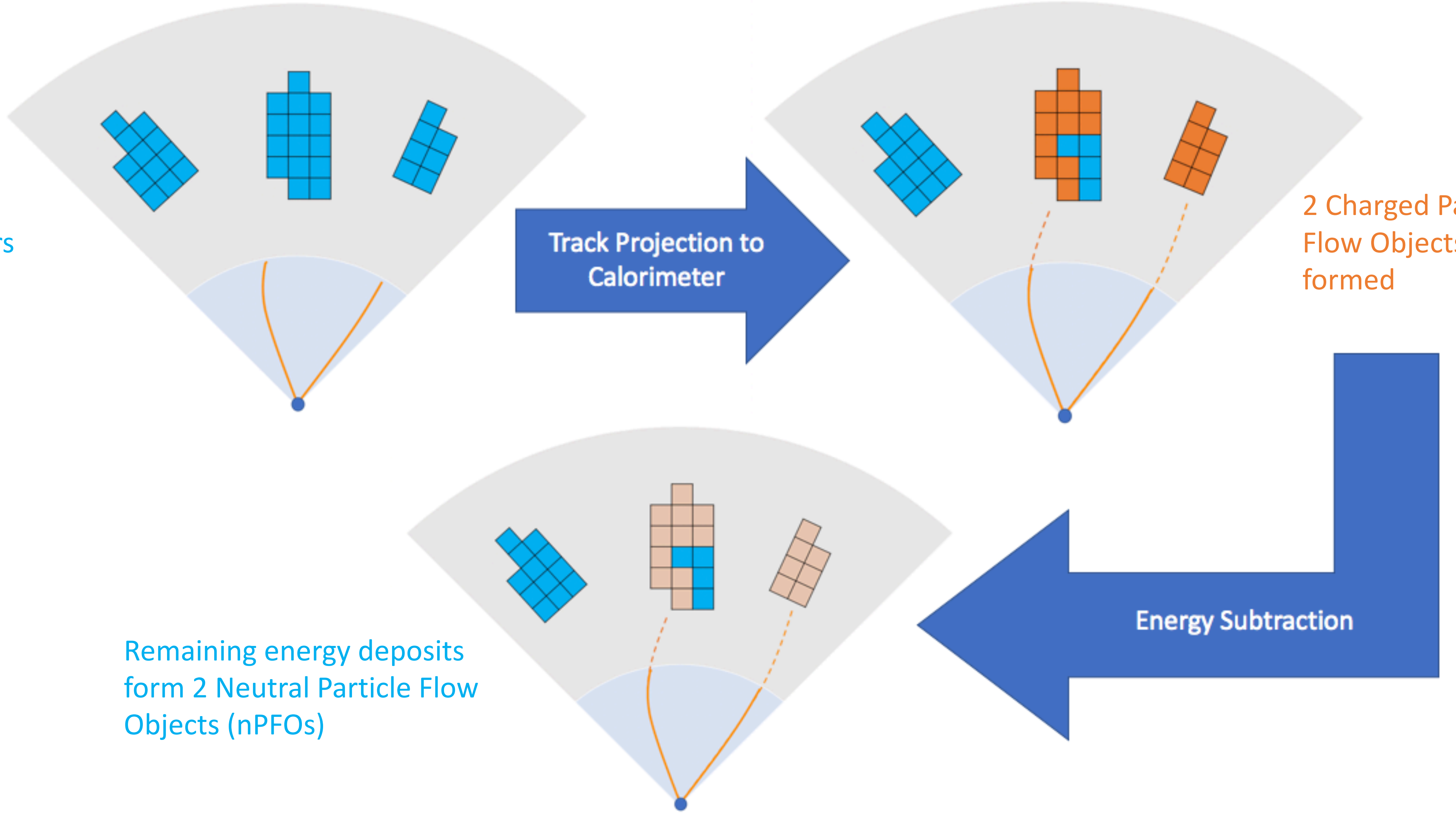
Current Particle Flow Algorithm

- Goal: Reconstruct the energy flow of an event using the different detector technologies



Current Particle Flow Algorithm

Start with:
3 Topoclusters
2 Tracks

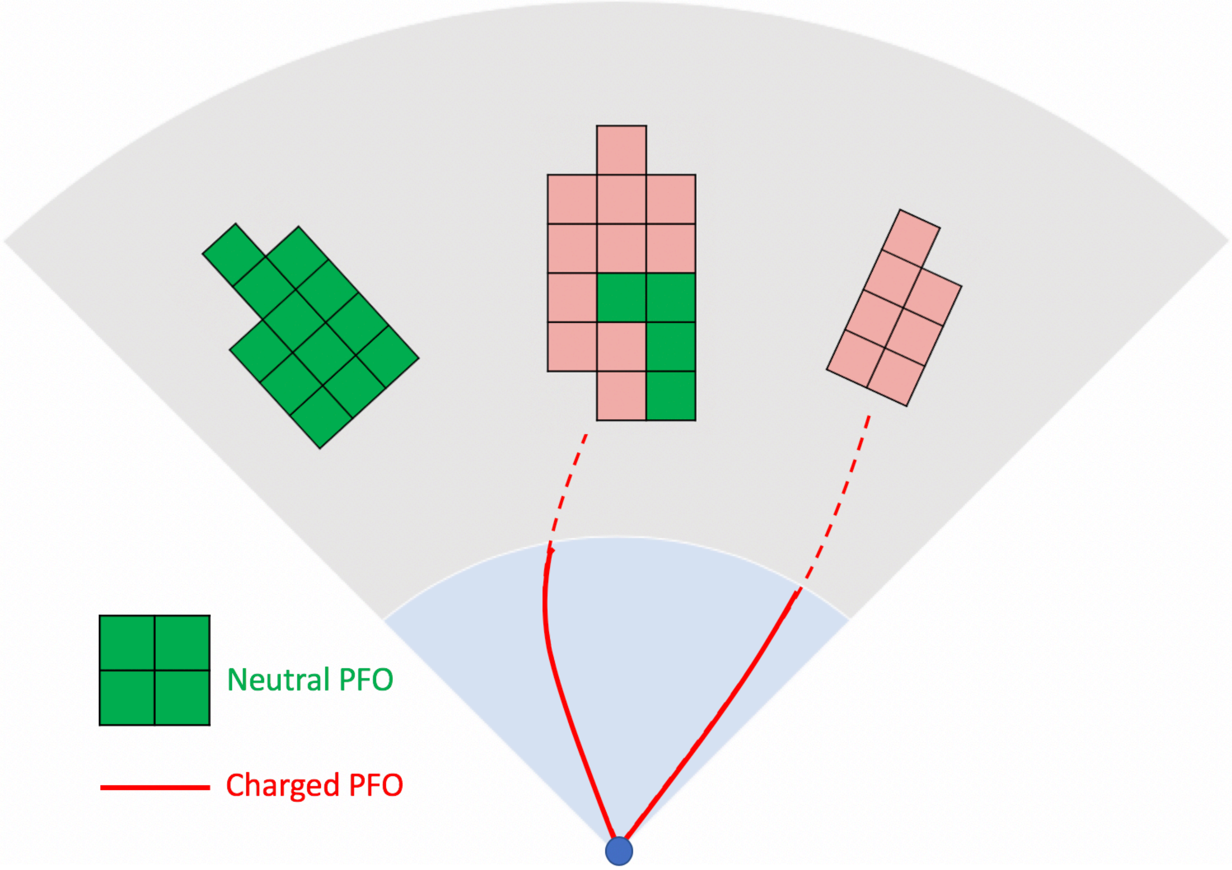


2 Charged Particle Flow Objects (cPFOs) formed

Remaining energy deposits form 2 Neutral Particle Flow Objects (nPFOs)

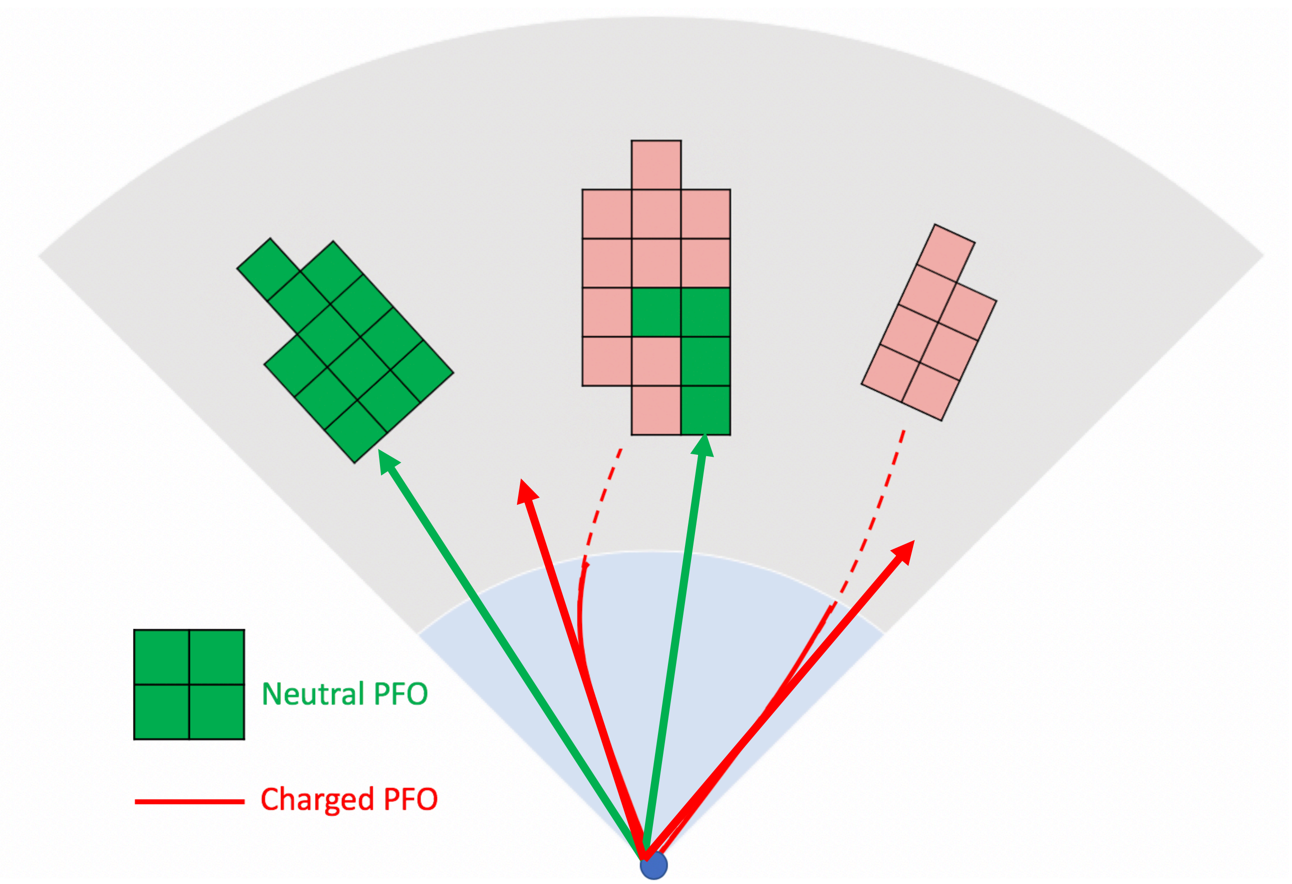
Current Particle Flow – Final Product

- Have reconstructed 2 nPFOs and 2 cPFOs



Current Particle Flow – Final Product

- Have reconstructed 2 nPFOs and 2 cPFOs ⇒ 2 neutral hadrons and 2 charged hadrons

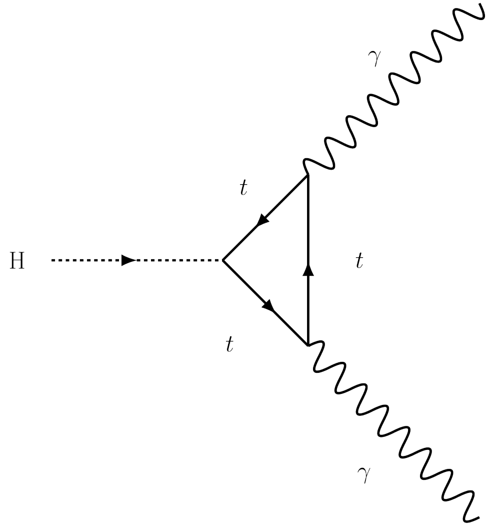


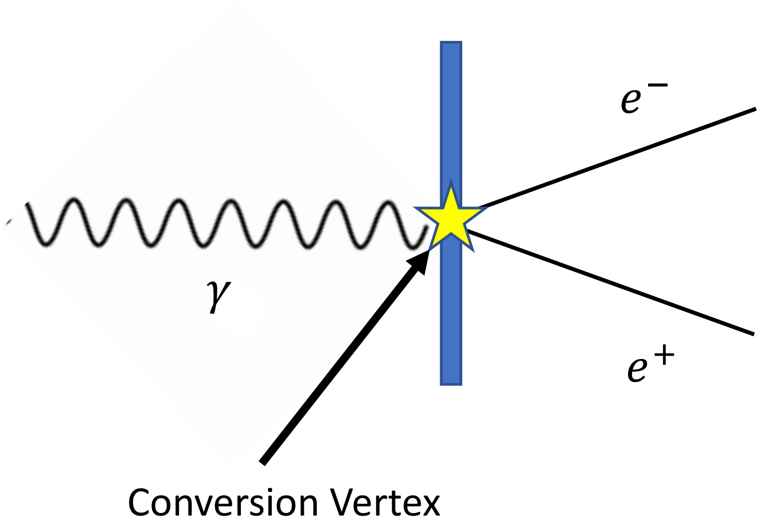
Global Particle Flow

- Currently, particle flow is only used for the reconstruction of hadrons
- Electrons, photons, and muons are reconstructed independently using very carefully optimized algorithms
  - Topoclusters and tracks that are part of these particles will also appear as PFOs
- Main ideas of Global Particle Flow (GPF):
  - Optimally reconstruct energy flow of full event
  - Uniquely classify each particle flow object as a specific particle (e, γ, μ, charged/neutral hadron)
- This means we need a dedicated algorithm to deal with overlap removal between the different reconstruction methods
- The work shown here focuses on integrating photons into GPF
  - Updates to be expected!

Photons in the ATLAS Detector

- High energy photons are produced in many interesting reactions in the LHC
- For example, a Higgs Boson can decay into two photons:
  - The studies that follow are done with 10k $H \rightarrow \gamma\gamma$ events
- When photons interact with material they can undergo pair production





- If a photon's conversion vertex occurs inside the inner detector then it is known as a converted photon

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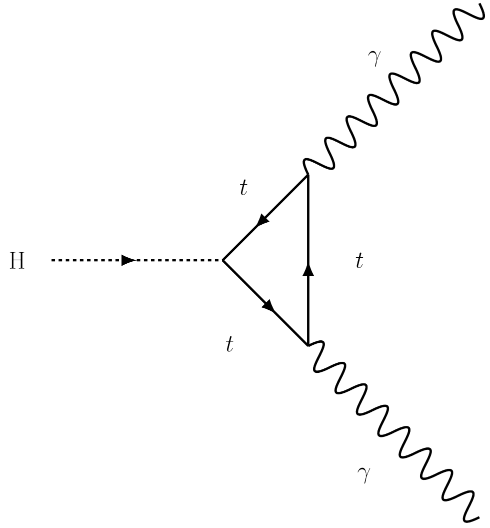

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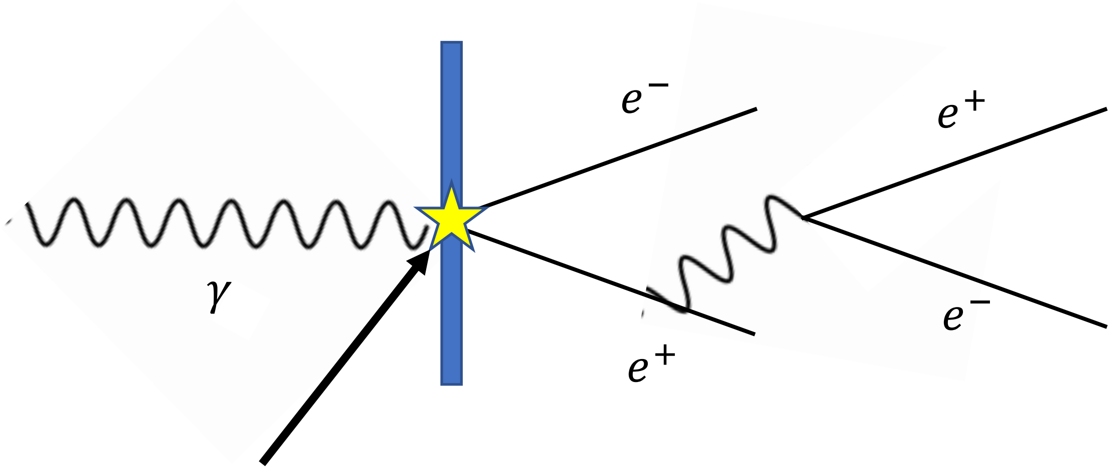

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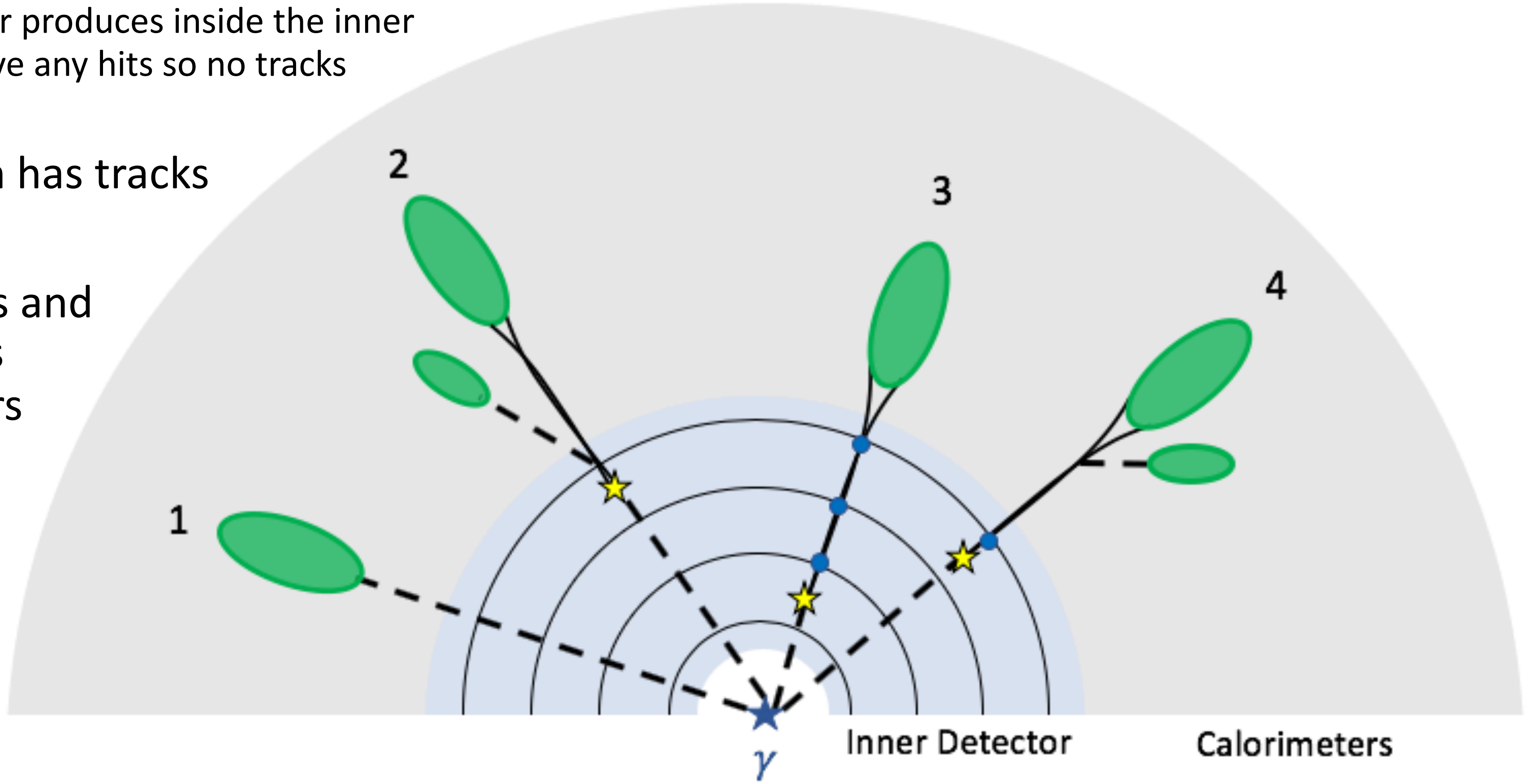
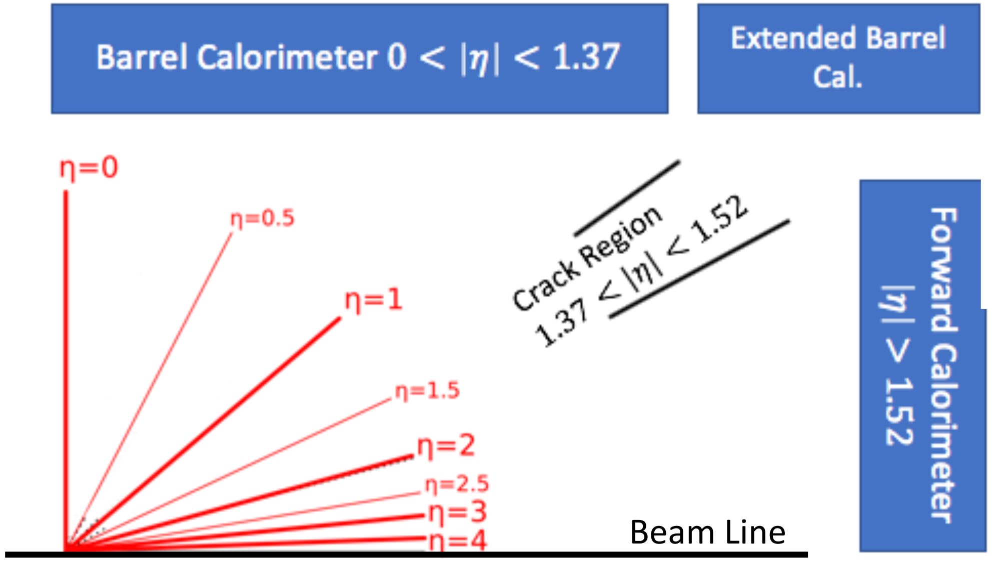
Photons in the ATLAS Detector

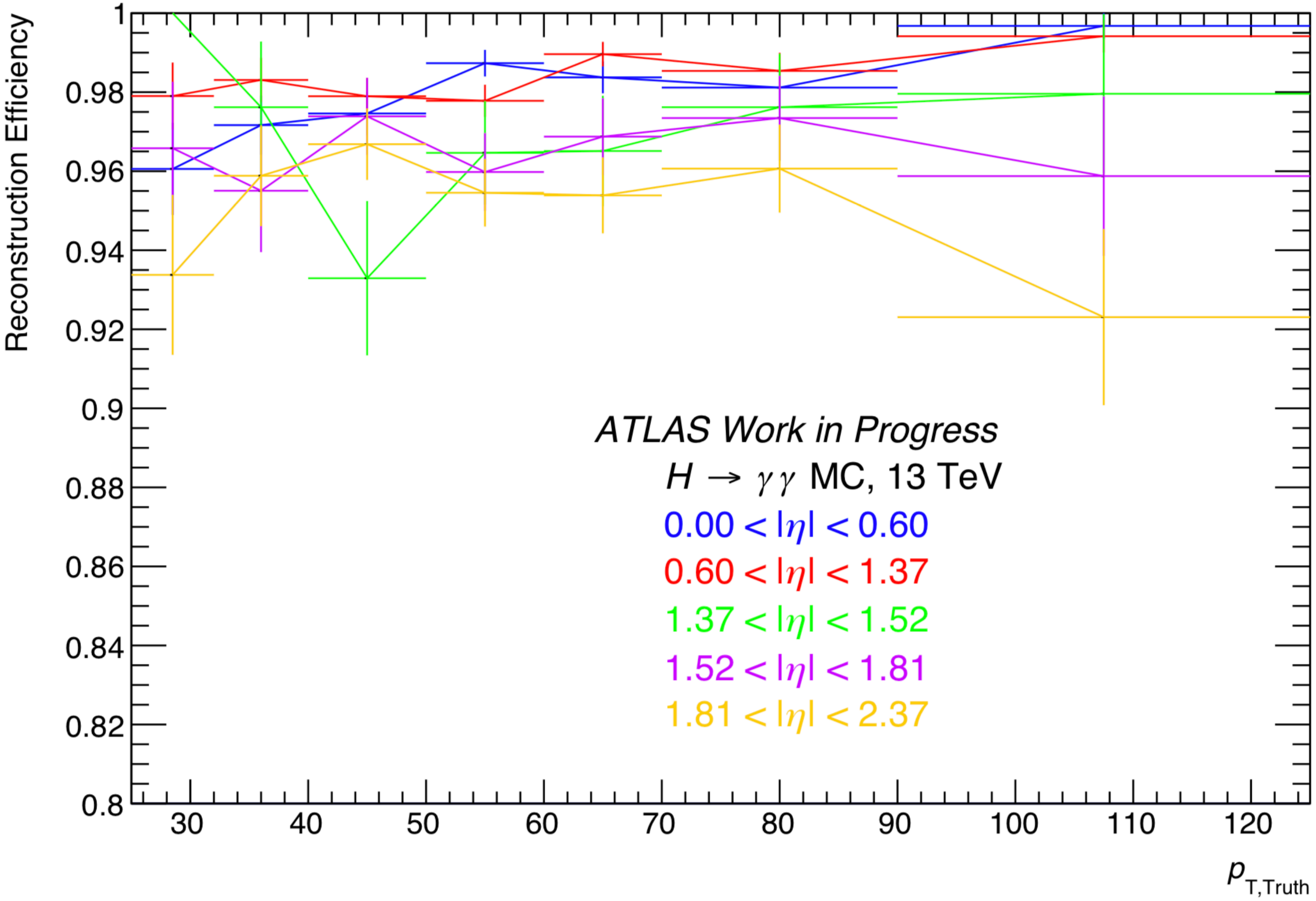
- Case 1: Unconverted photon which deposits energy in one topocluster in the calorimeter
- Case 2: Photon could have one or more satellite clusters in the calorimeter
  - In this case the photon pair produces inside the inner detector, but does not leave any hits so no tracks are reconstructed
- Case 3: Converted photon has tracks and a topocluster
- Case 4: A photon converts and produces tracks as well as additional satellite clusters



Photon Reconstruction

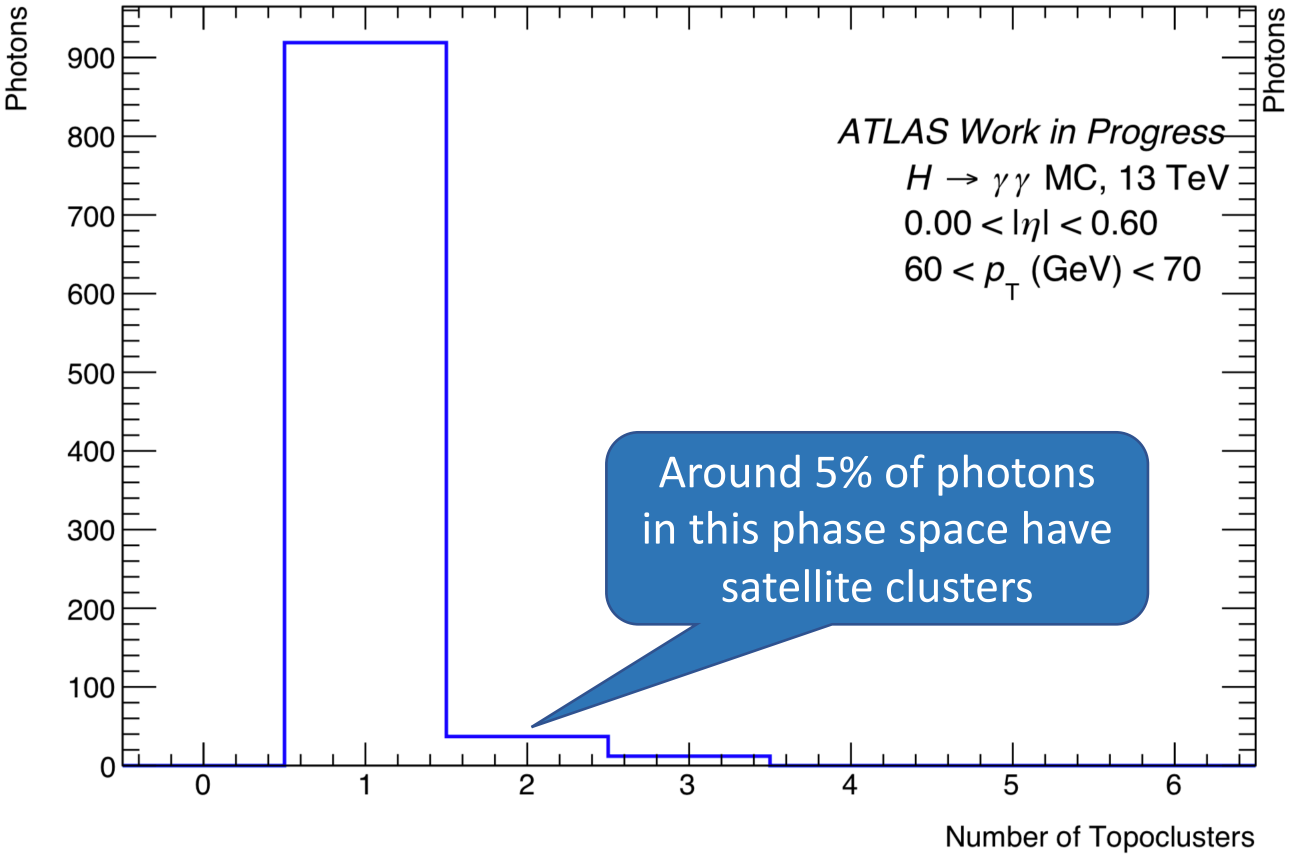
- The reconstruction efficiency is around 97%-99% in the central region, and 95% in the forward region
- Particles in the transition region between the barrel and endcap calorimeter (green) are rarely used in analysis

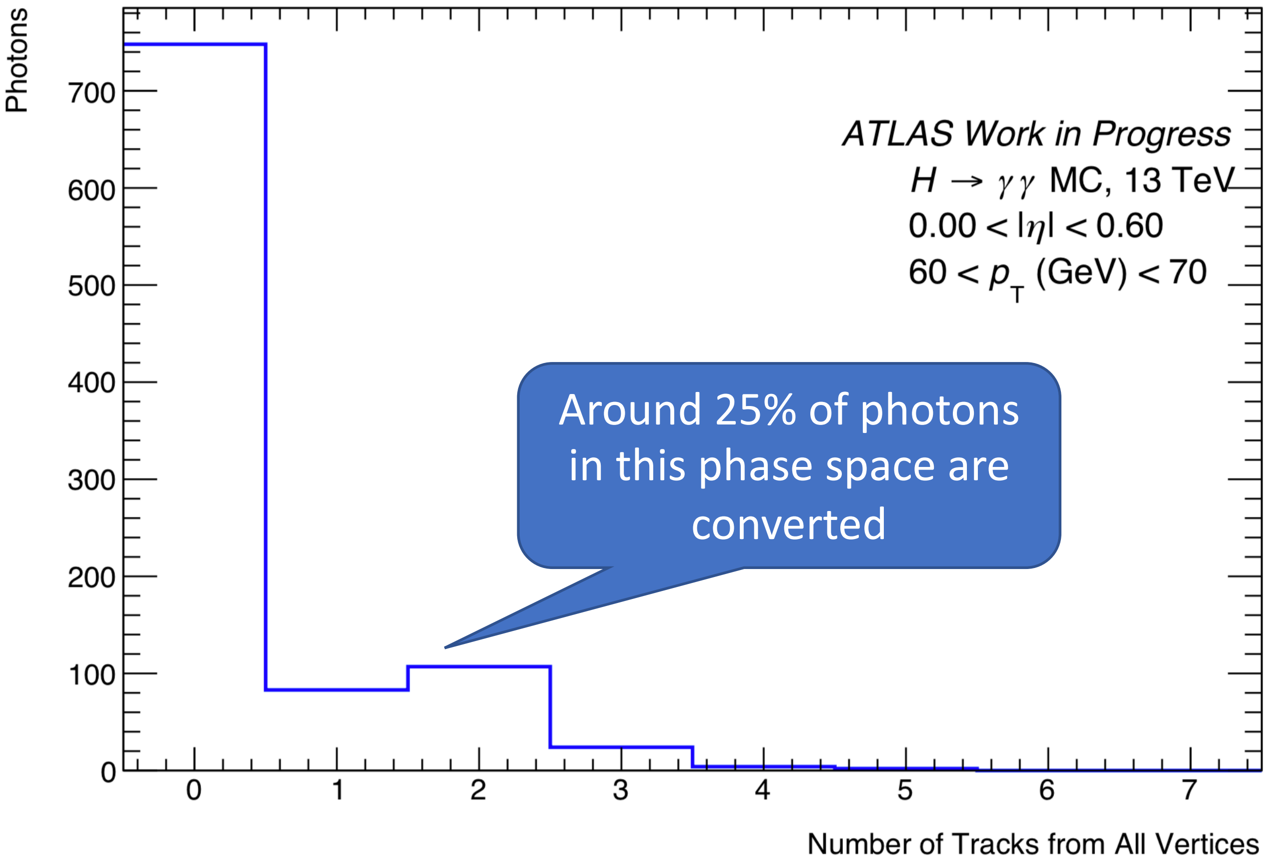




Photon Properties

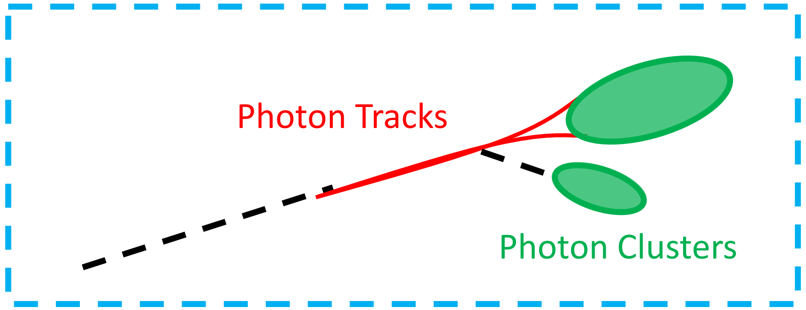
- An example of the number of clusters and tracks per photon





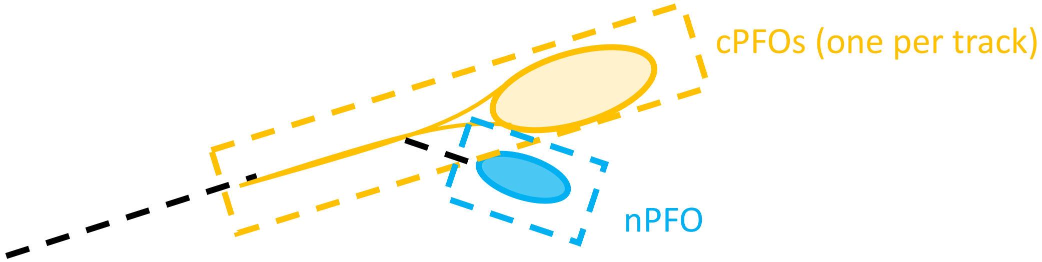
Same Detector Signals, Different Viewpoints

- Photon reconstruction algorithm is heavily optimized for photons



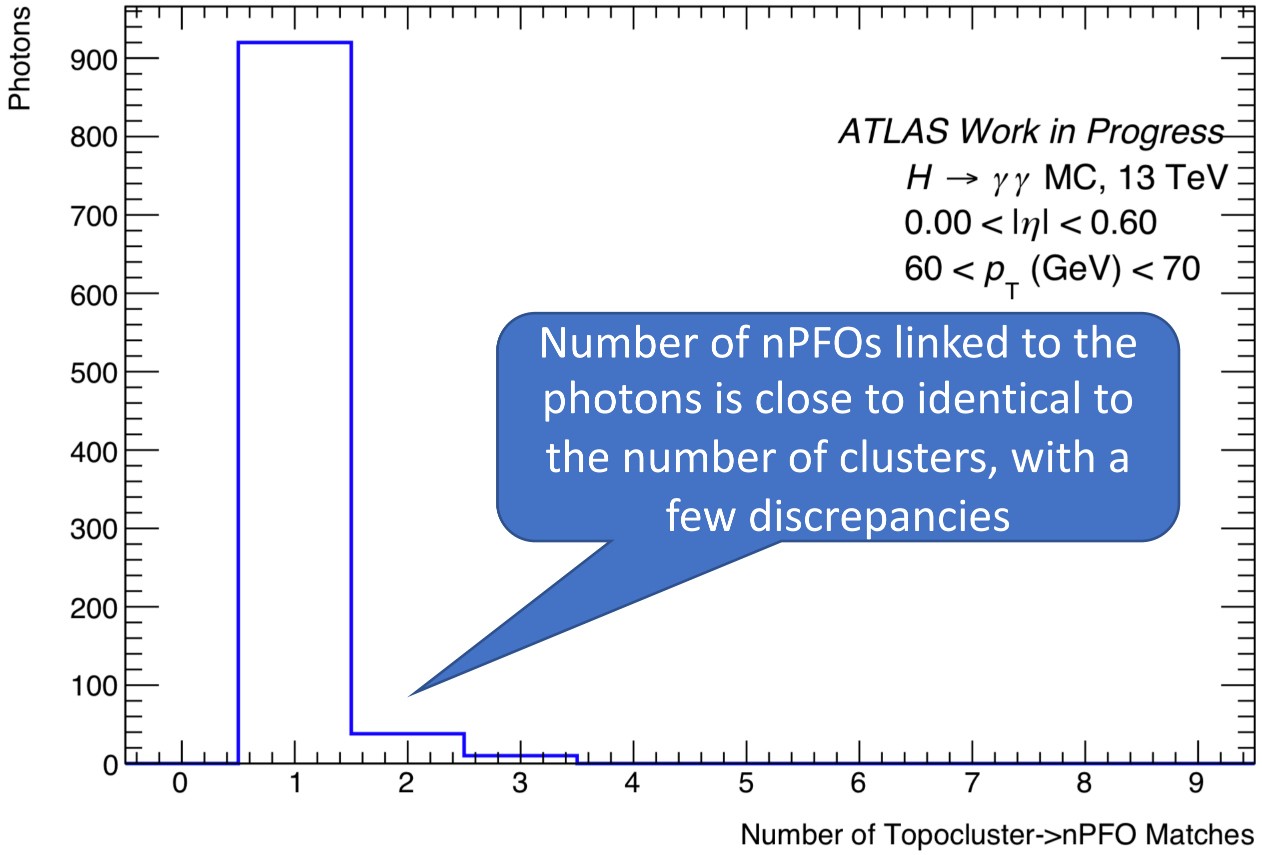
Reconstructed Photon Object

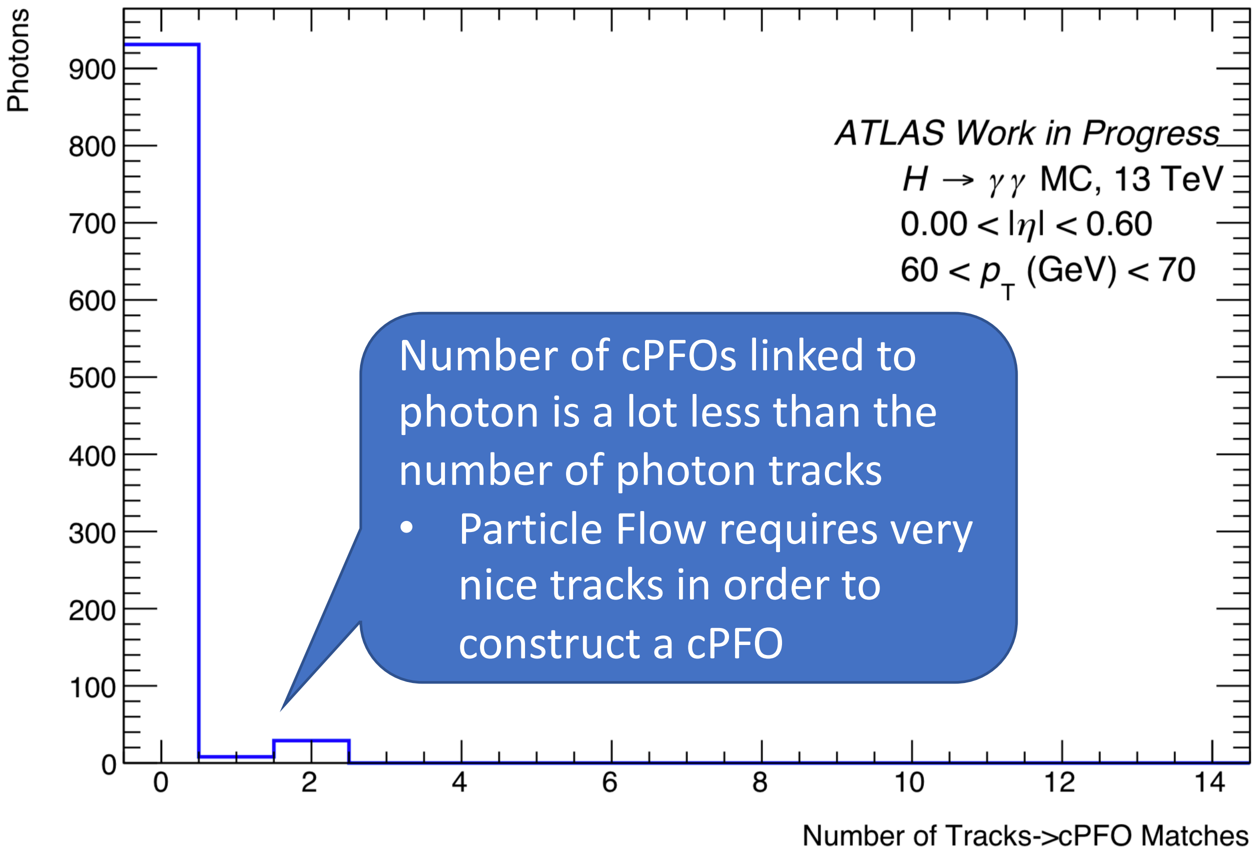
- Particle flow is optimized for hadrons



- Main task is to study overlap between the two
  - This is non-trivial since full or partial overlap can exist between multiple objects of both types
- First step to this is to link the photon components to their corresponding nPFOs and cPFOs (technical links, C++ code)
  - Photon topoclusters can be matched with nPFO objects and photon tracks can be linked to cPFO objects

Links to PFOs

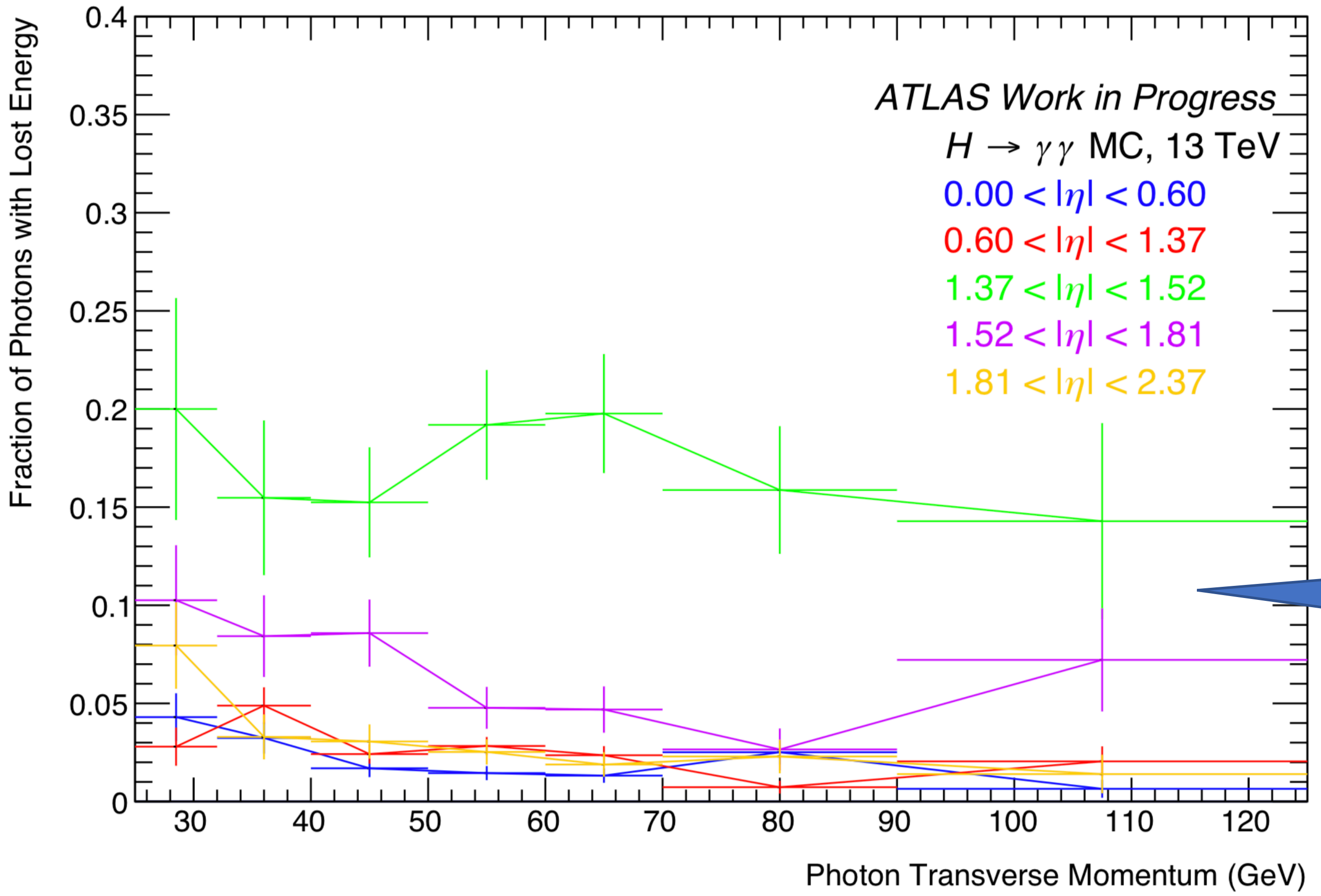


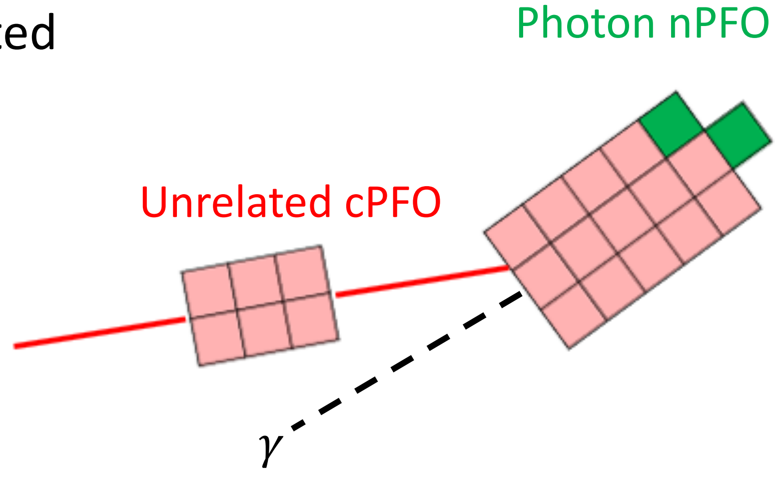


- Now that these technical links are defined, can look at a specific problematic case where an overlap removal procedure will be necessary

Problematic Case – Reduced Cluster Energy

- Can have a cluster from a photon that is fully or partially subtracted due to an overlapping cPFO from a different particle





The largest issue here is in the crack region, which is rarely used in analyses. The other regions have around 5-10% of photons with this problem.

- My goal is to find a treatment to resolve these kinds of ambiguities

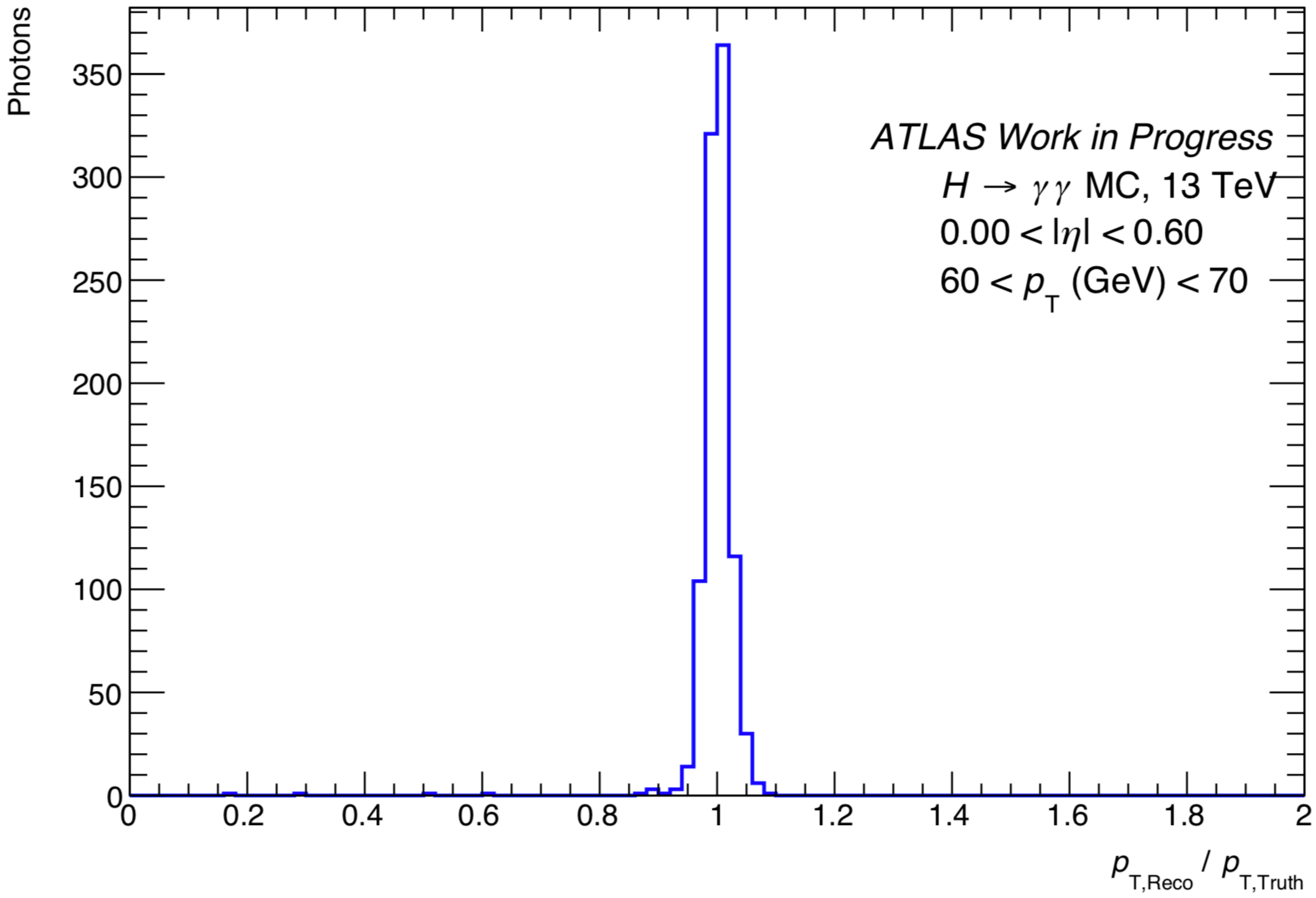
Summary and Next Steps

- Increasing collision intensity at the LHC will create new challenges for physics analyses in the near future
- The particle flow algorithm is developed to cope with such conditions, but is optimized for hardons
- Global Particle Flow aims to integrate particles that are currently reconstructed using separate algorithms into the particle flow algorithm
- My work is to develop an algorithm for overlap removal for photons
- Identified problem cases for photons:
    - Photon nPFO has energy subtracted due to an unrelated cPFO (~5-10% of photons)
- Next steps:
    - Quantifying these problematic cases (what is the effect on the overall energy?)
    - Determining the best way of performing overlap removal in these cases

Thanks for Listening!

Backup

Photon Response Example



nPFO Energy / Cluster Energy