Accelerating CMS Electron Seeding with Extended Pixel Tracks

Phase-2 Pixel Tracks as GSF Electron Seeds

CERN Openlab Summer Student Programme Lightning Talks

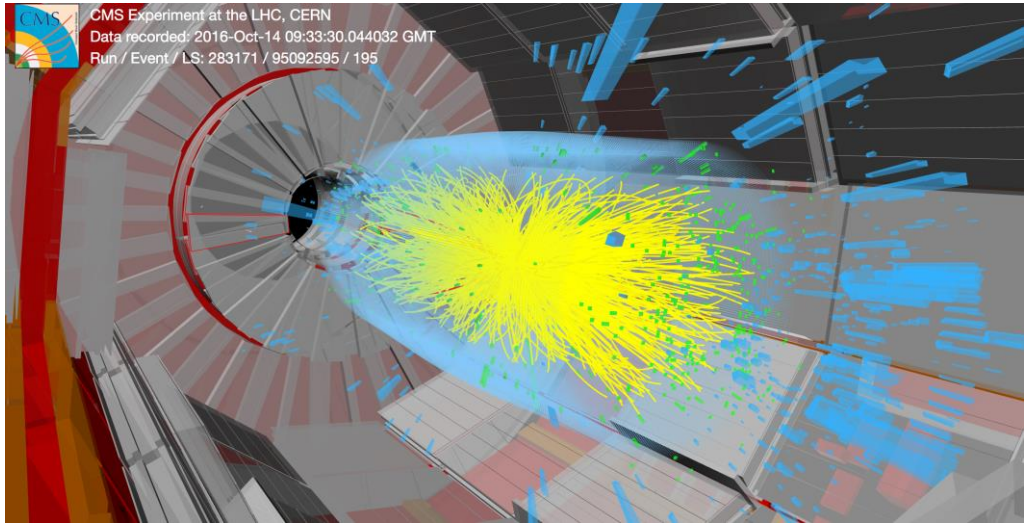
Hannah Havel

Supervisors: Bruno Alves, Wahid Redjeb

18 / 08 / 2026

The Project

The CMS trigger does the same job twice, and Phase-2 makes that expensive



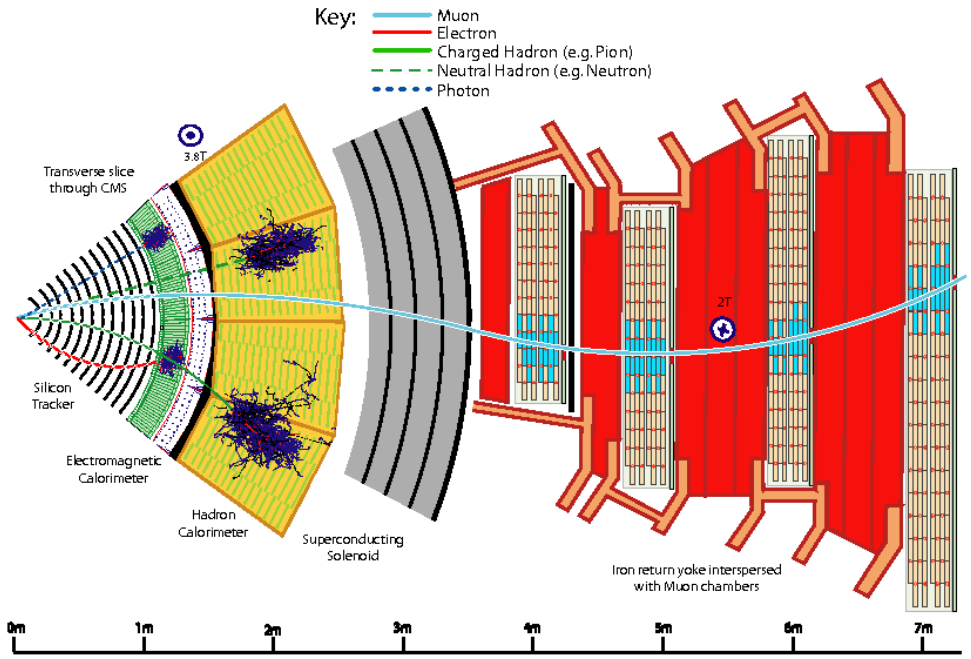
A high pileup collision recorded by CMS in 2016.

- The trigger has milliseconds to decide whether a collision is worth keeping, and finding electrons is part of that decision.
- To follow an electron, the trigger first builds a starting point from raw pixel hits.
- It has already reconstructed the paths of charged particles across the whole collision.
- From 2030 the upgraded LHC will deliver about 200 collisions per bunch crossing on average, so the number of hit combinations to test grows quickly.

Can we reuse the paths that already exist as the starting point?

Electrons in CMS

Two detector layers, two different measurements



Transverse slice through CMS. Particles travel outwards from the beam line.

Tracker

- Silicon layers closest to the beam.
- A charged particle leaves a hit in each layer it crosses.
- The magnetic field bends the path, and the curvature gives momentum and charge.

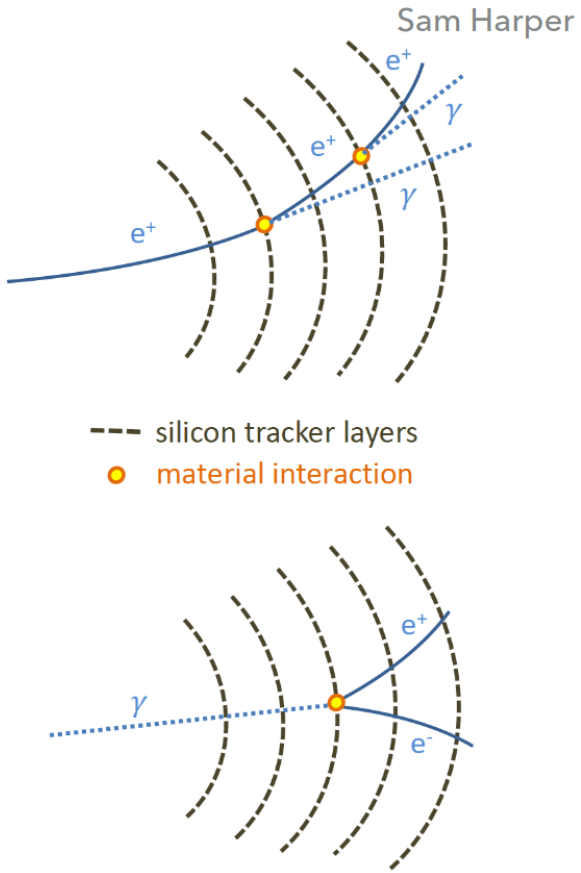
ECAL (Electromagnetic Calorimeter)

- The calorimeter, just outside the tracker.
- Electrons and photons stop here and deposit all of their energy as a cluster.

An electron

- A curved track in the tracker pointing at an energy cluster in ECAL.
- The job is to match the two.

Electrons Radiate

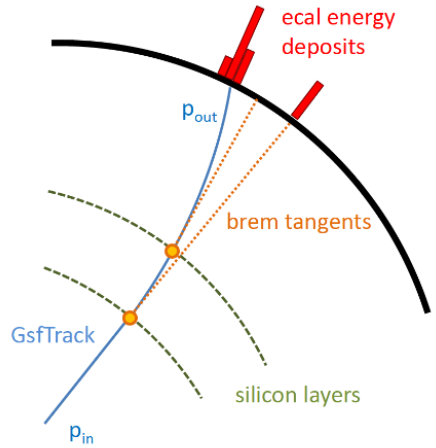


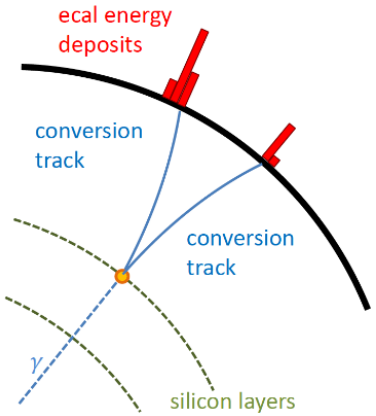
- An electron passing close to a nucleus is deflected and emits a photon. This is bremsstrahlung.
- Each photon carries away part of the electron's energy, so the track bends more sharply after every emission.
- The energy is lost in sudden jumps rather than smoothly.
- Some of those photons convert into electron positron pairs, adding extra tracks that belong to the same original electron.
- A standard track fit assumes small, smooth energy losses, so for electrons it either fails or returns the wrong momentum.

Electrons need their own tracking algorithm!

Gaussian Sum Filter (GSF)

The tracking algorithm built for a particle that keeps losing energy





Benefit

- Models the energy loss as a sum of Gaussians instead of one, so it can follow the sudden changes in curvature.
- Gives the momentum at the start of the track (p_{in}) and again at the calorimeter (p_{out}). The difference is the energy radiated.

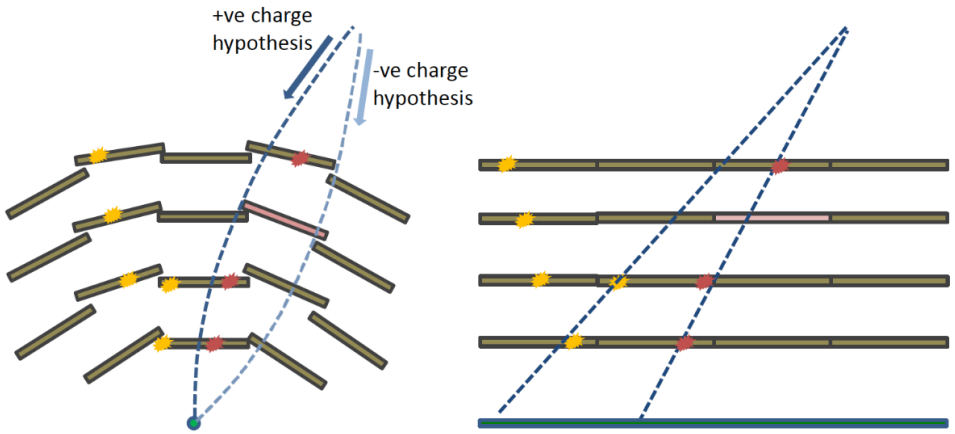
Cost

- Much slower than a standard track fit.
- It cannot start by itself. The fit moves outward hit by hit, so it needs an initial position and direction.
- That starting point is called a seed.

Seeds and the Current Reconstruction

A seed is the starting guess a track fit needs: a few pixel hits and a direction

Sam Harper



- Take an ECAL cluster and extrapolate backwards through the magnetic field.
- Do it twice, once for each possible charge.
- Any pair or triplet of pixel hits close to that path becomes a candidate seed.

Legacy (how CMS builds them now)

`hltElePixelHitDoubletsL1Seeded`

↓

`hltElePixelHitTripletsL1Seeded`

↓

`hltElePixelSeedsCombinedL1Seeded`

↓

`ElectronNHitSeedProducer`

- Runs for every ECAL cluster, in every event.

The doublet and triplet building is the step we want to remove.

Seeding a GSF Electron

LEGACY: build seeds for every cluster

- `hltElePixelHitDoubletsL1Seeded`
- `hltElePixelHitTripletsL1Seeded`
- `hltElePixelSeedsCombinedL1Seeded`

Builds pixel hit combinations for every cluster, in every event.

NEW: reuse Patatrack pixel tracks

- `hltPhase2PixelTracks (already in event)`
- `TrackSelectorByRegion`
- `SeedGeneratorFromProtoTracks`

Picks the pixel tracks that already point into the electron's region and turns them into seeds.

`ElectronNHitSeedProducer` unchanged, only its input changes

Implementation and Testing

ElectronMatchSeedDQM

A monitoring module inside the standard CMS validation chain. For each event it:

- selects the generated electrons from the Z decay
- matches each one to a reconstructed HLT electron within $\Delta R < 0.1$
- counts the seeds produced, per event and per electron
- records which pixel layers and disks the seed hits came from
- divides matched electrons by all generated electrons to build efficiency against η, ϕ and p_T

Setups

- $Z \rightarrow ee$ with and without pileup, each with legacy and pixel-track seeding, so four setups in total
- All four start from the same simulated events, so the seeding is the only thing that changes
- 9,000 events per setup, giving 18,000 generated electrons per point (x2 for each side of endcap)

Results

We get far fewer seeds, with a small loss of efficiency

15× fewer seeds

into the electron seed producer

Seeds per event

legacy 17.96 (no PU) 19.57 (PU200)

pixel tracks 1.21 1.21

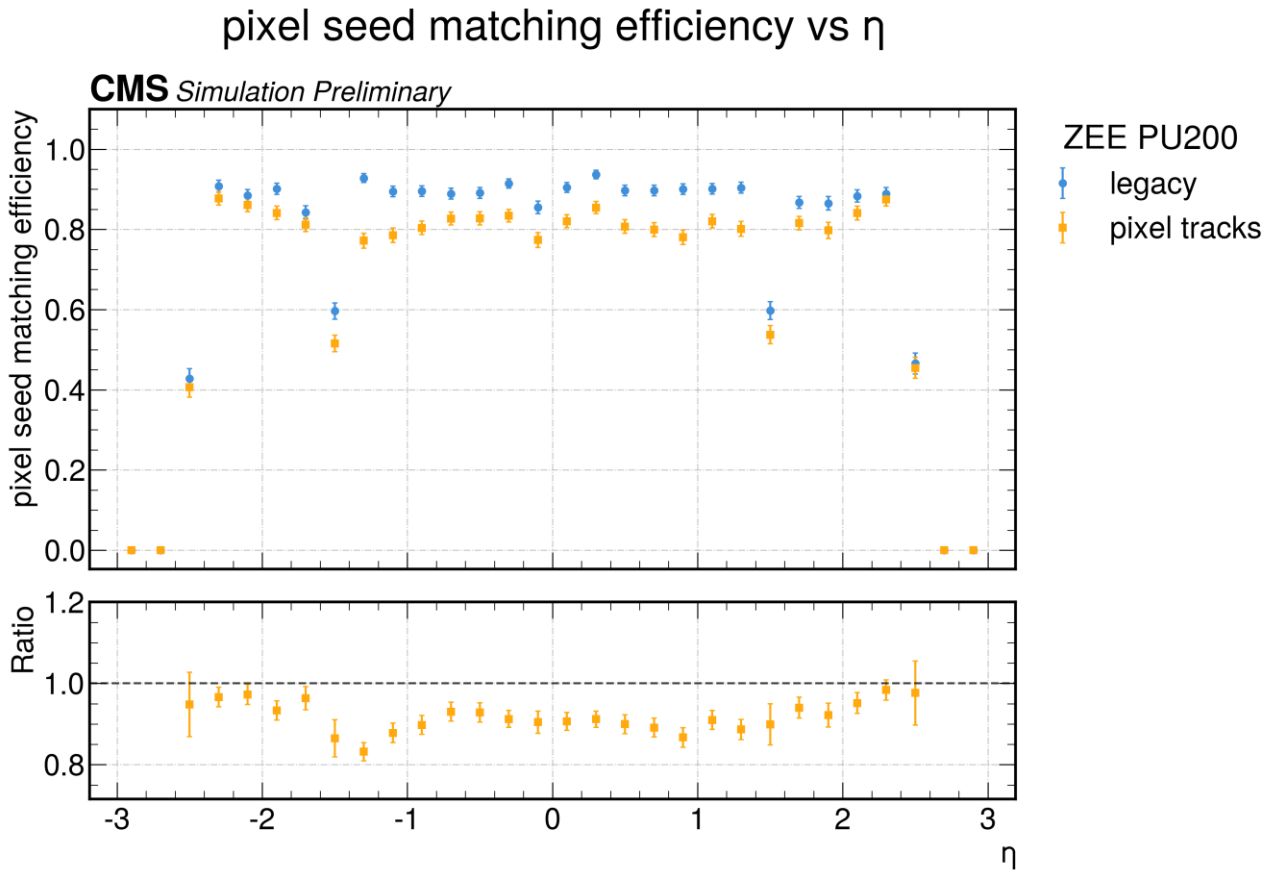
Matching efficiency

no pileup: legacy 59.4 ± 0.4 %, pixel tracks 55.2 ± 0.4 %

gap 4.3%

PU200: legacy 59.3 ± 0.4 %, pixel tracks 54.2 ± 0.4 %

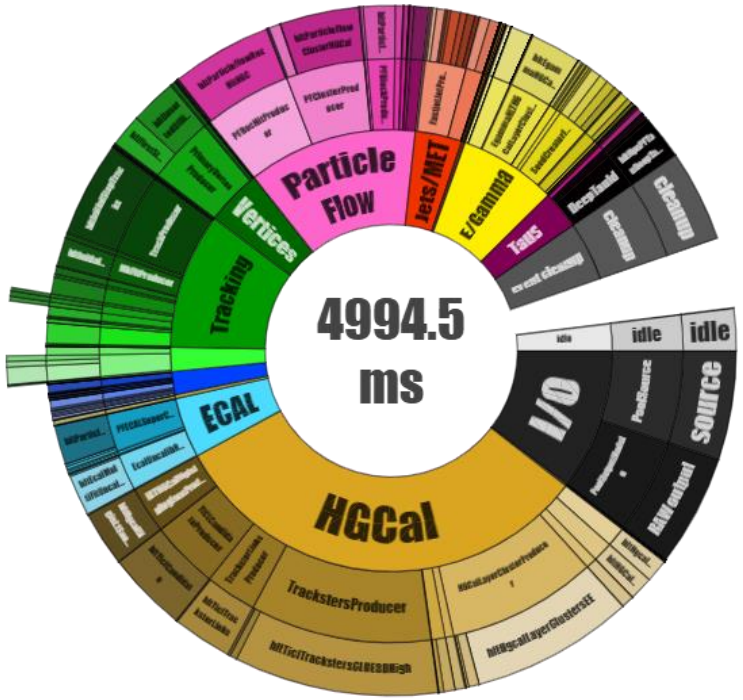
gap 5.0%



Both chains are flat with pileup, and the gap stays around 5%.

Timing

Where the trigger spends its time, per module, **for each event**



Legacy seeding

Pixel-track seeding

The two totals sit within about 5% of each other.

The trigger is dominated by HGCal, particle flow and tracking, so electron seeding is only a small slice of the total. The saving is local to the seeding module.

Summary and Next Steps

The chain works, and the remaining efficiency loss comes from cuts we can tune

What was done:

- The full chain works: pixel tracks are selected, converted to seeds and matched by the unchanged producer.
- The seed load falls by a factor of 15, and the doublet and triplet builders leave the electron path.
- Efficiency is about 5% below legacy, and both chains are flat with pileup – about a ~10% drop of electron efficiency across almost the full pT spectrum.
- A DQM analyzer that can be used across the CMSSW software.

Where the loss comes from, and what is next:

- Quality cuts in the pixel-track builder remove real hit pairs. -- Tomas Sosa's validation shows 97.5% survive in a clean single electron sample but only 83% in Z→ee.
- The matching rule asks for more matched hits from our seeds. Seeds crossing four or more tracker layers need three hits inside the $\Delta\phi$ and $\Delta r/\Delta z$ windows, while legacy seeds crossing fewer layers need only two.
- Next: tune both sets of cuts, re-measure the timing on the same release, and check whether legacy is picking up fake electrons.

If the efficiency can be recovered, an entire reconstruction step disappears from the Phase-2 trigger!

Thank you

Hannah Havel | Supervisors: Bruno Alves, Wahid Redjeb

For more testing and results: hhavel.web.cern.ch

CERN Openlab Summer Student Programme 2026