Lancaster University

PandoraModularShower* in the DUNE FD

Dom Brailsford
FD sim/reco meeting
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Shower characterisation

- Shower characterisation == the bit you do after the pattern recognition

- Shower reconstruction is hard, particularly in a LArTPC

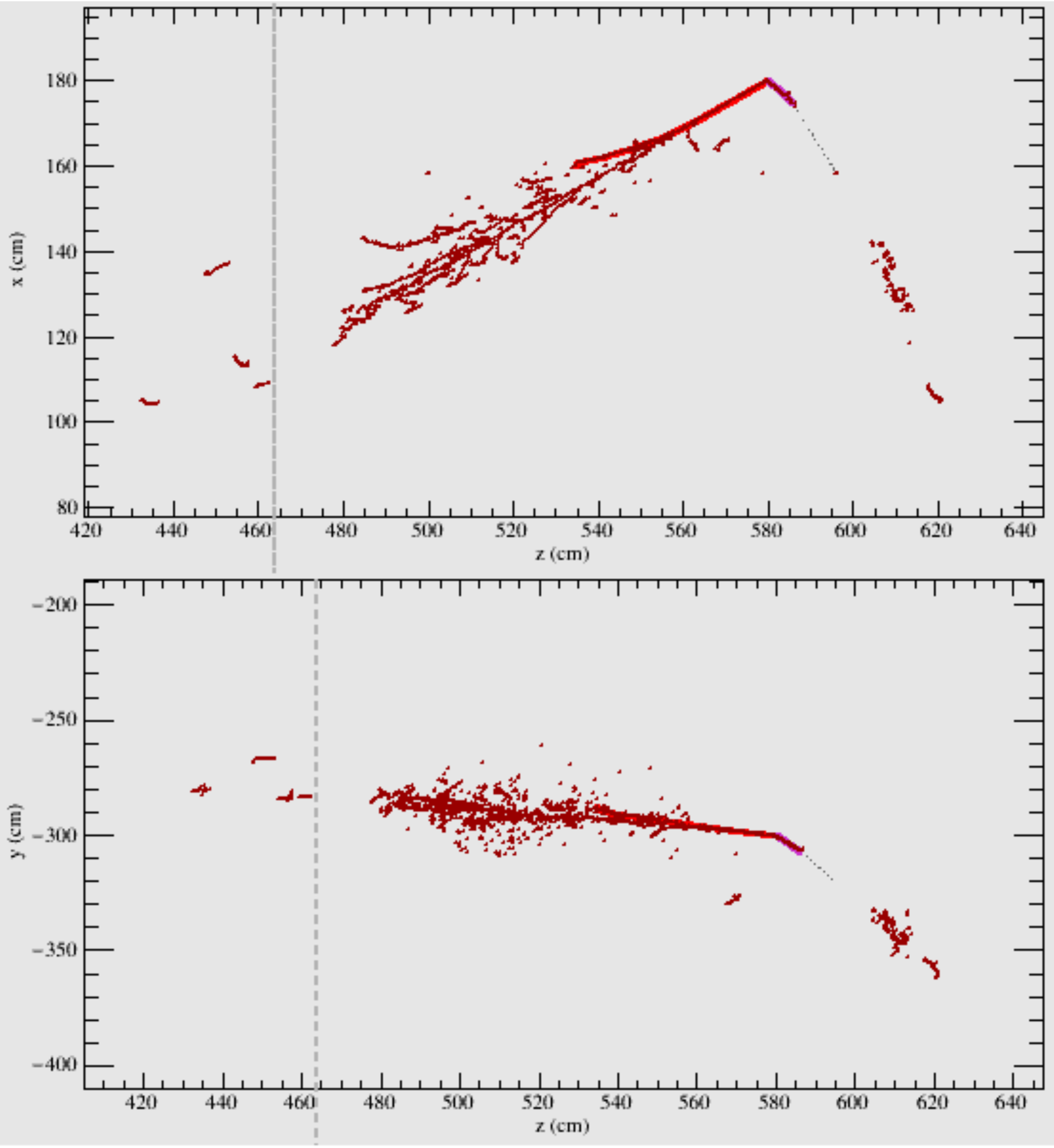
- The difficulty is frustrating because you primarily only need to know a few key pieces of information for physics analyses:

    - **Start position**

    - **Initial direction**

    - **Energy**

    - **dE/dx**



TRACS becomes PandoraModularShower

- I presented a couple of talks on the Tool-Based Reconstruction Algorithm for Characterising Showers (TRACS) in 2019
  - A shower characterisation module
  - Outsources all calculations to hot-swappable ART tools e.g. specific tool for calculating dE/dx, shower direction etc.
  - Incredibly easy to write your own targeted tool for calculating a particular property
  - (As far as I am aware) the only shower characterisation module that is capable of calculating —all— features of a recob::Shower

- After discussion with Pandora, we've come to the agreement that TRACS would:
  1. Be moved from larreco to larpandora
  2. Be rebadged as PandoraModularShower
  3. Replace the old PandoraShower characterisation module, but experiments would need to opt in to this replacement

- The rest of this talk details configuration of PandoraModularShower for the DUNE far detector and, where relevant, compares to the older PandoraShower characterisation module

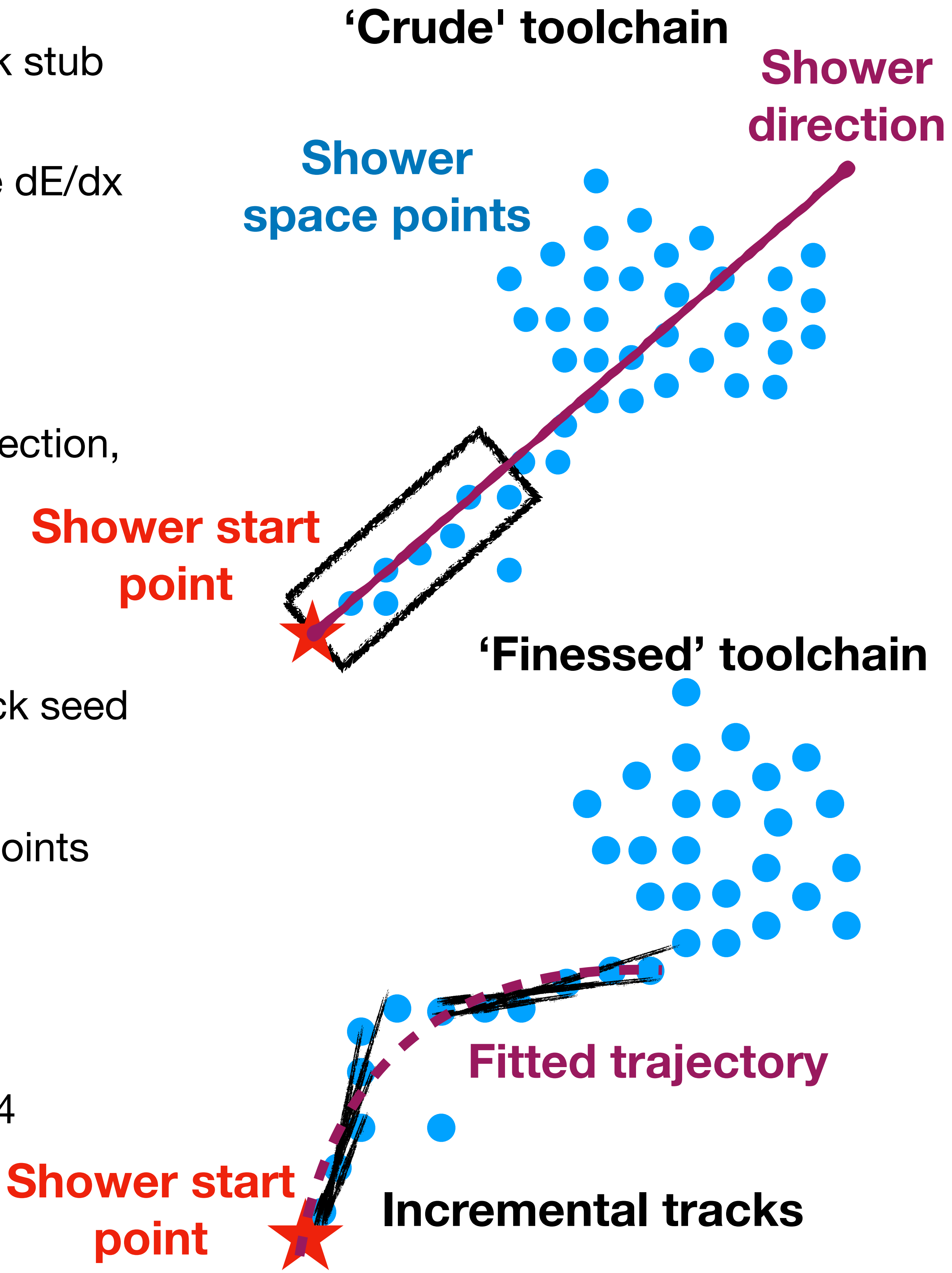
Chosen toolset for calculating dE/dx in PandoraModularShower

- Reconstructing dE/dx from the shower's initial track stub is the hardest feature of a shower to characterise
- I've configured two separate toolchains to estimate dE/dx

1. 'Crude' toolchain
    - Take first X cm of shower to be initial track
    - Calculate median dE/dx using using shower direction, assuming no deviation
    - Returns a dE/dx value almost always
2. 'Finessed' toolchain
    - Find initial track by incrementally growing a track seed
    - Fit a smooth trajectory
    - Calculate median dE/dx using local trajectory points
    - It is more likely that this toolchain fails

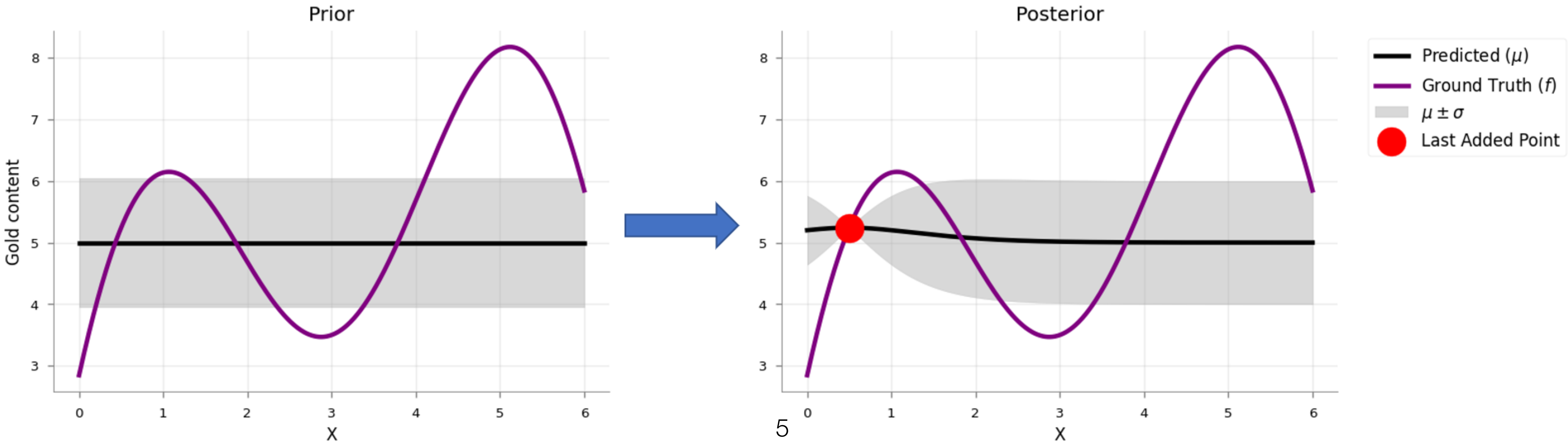
- Finessed dE/dx values takes precedence

- Bayesian optimisation has been used to tune the 14 parameters in the toolchains



Quick aside: Bayesian optimisation

- Bayesian optimisation is a method for finding the global maximum of an N-dimensional function
- The N-dimensional function is modelled as a Gaussian process
- Measurements of the unknown function are made, updating the Gaussian process
- Acquisition function determines where to search after a measurement has been made
- The bottom example, finding peak density in a gold seam, taken from https://distill.pub/2020/bayesian-optimization/



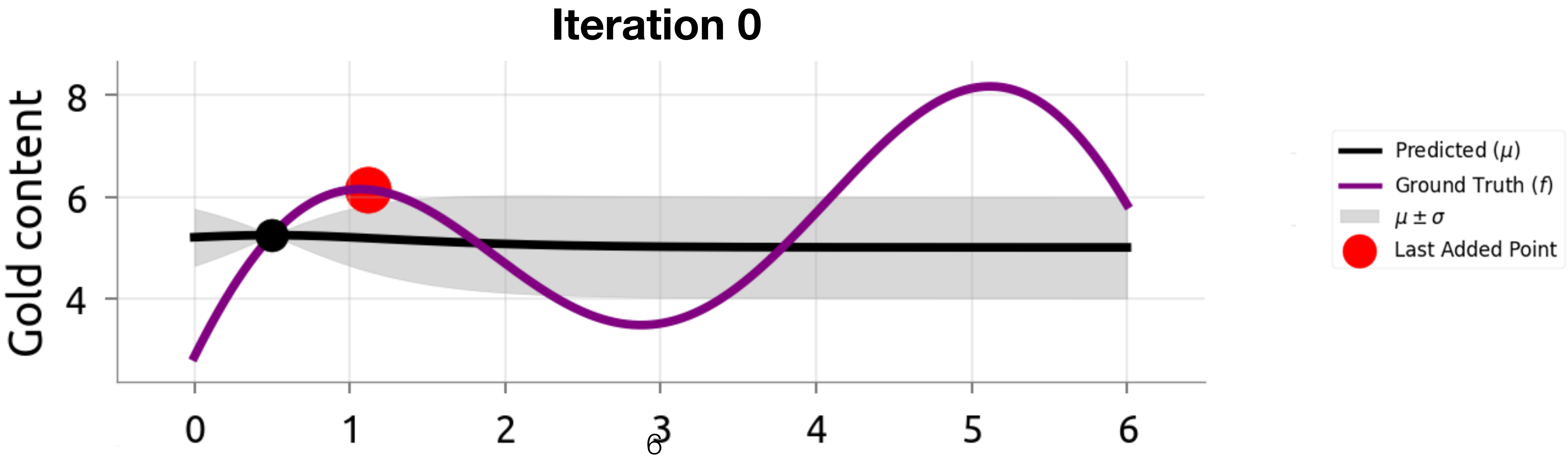
from https://distill.pub/2020/bayesian-optimization/

Quick aside: Bayesian optimisation

- After a measurement is made, (the **black** point), a new measurement needs to follow
- The maximum position of the acquisition function dictates the new measurement position (the **red** point). The acquisition function I've used for tuning the dE/dx reconstruction is:
  - $\alpha(x) = \mu(x) + \lambda\sigma(x)$ ← **Gaussian width**

Gaussian mean

Exploration parameter (hand picked)



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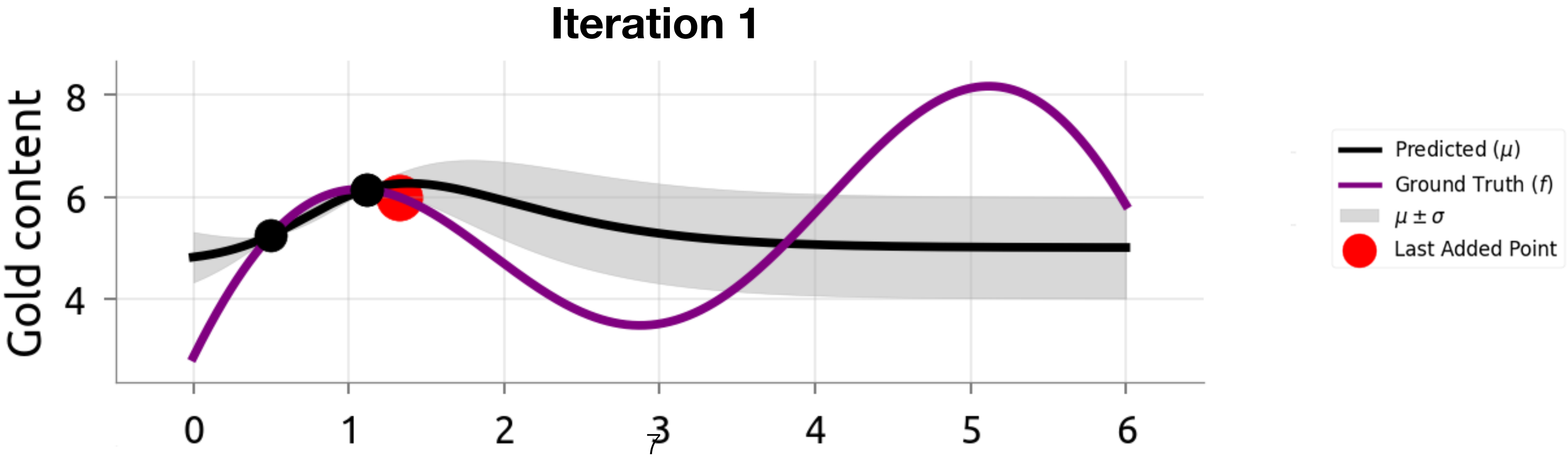

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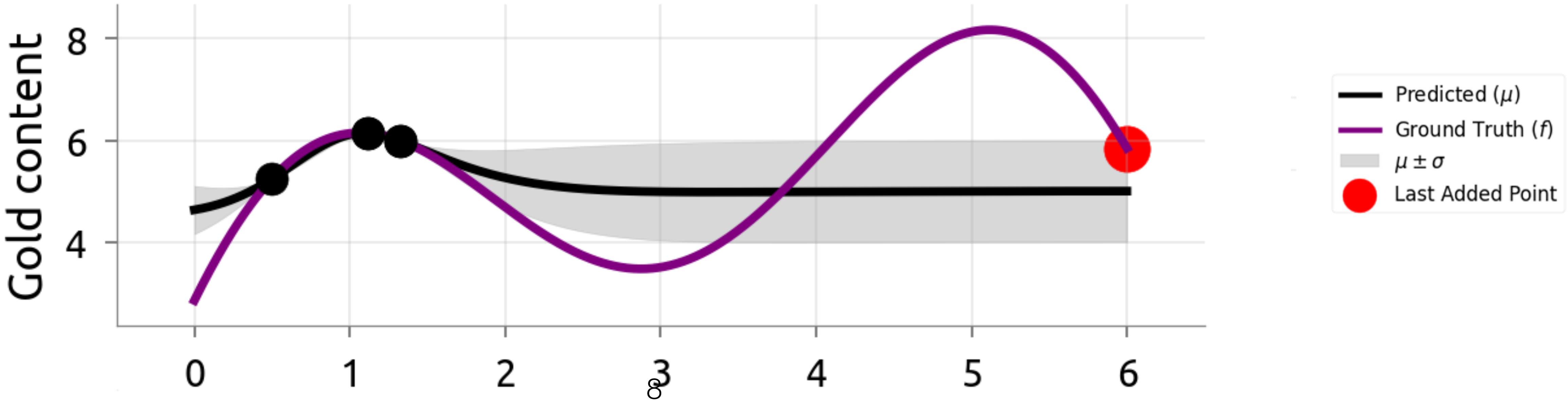
Iteration 2



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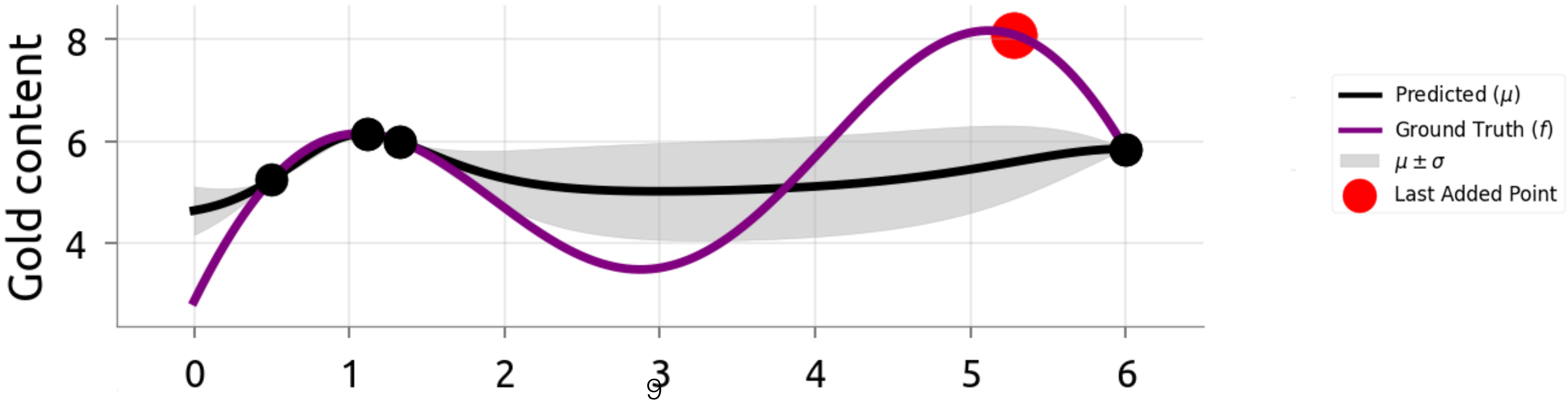
Iteration 3



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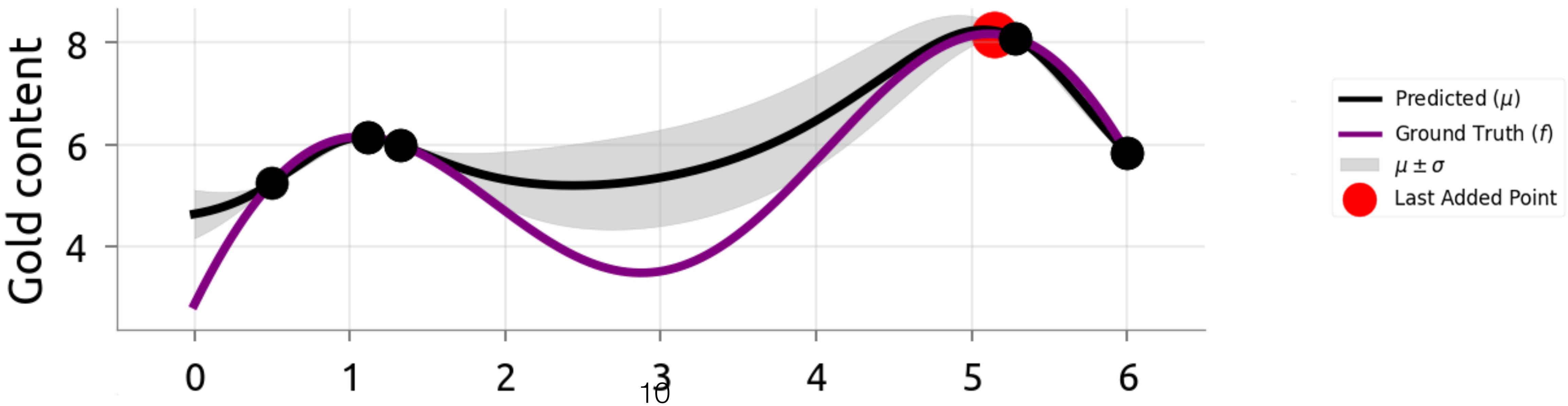
Gaussian mean **Exploration parameter (hand picked)**

Iteration 4



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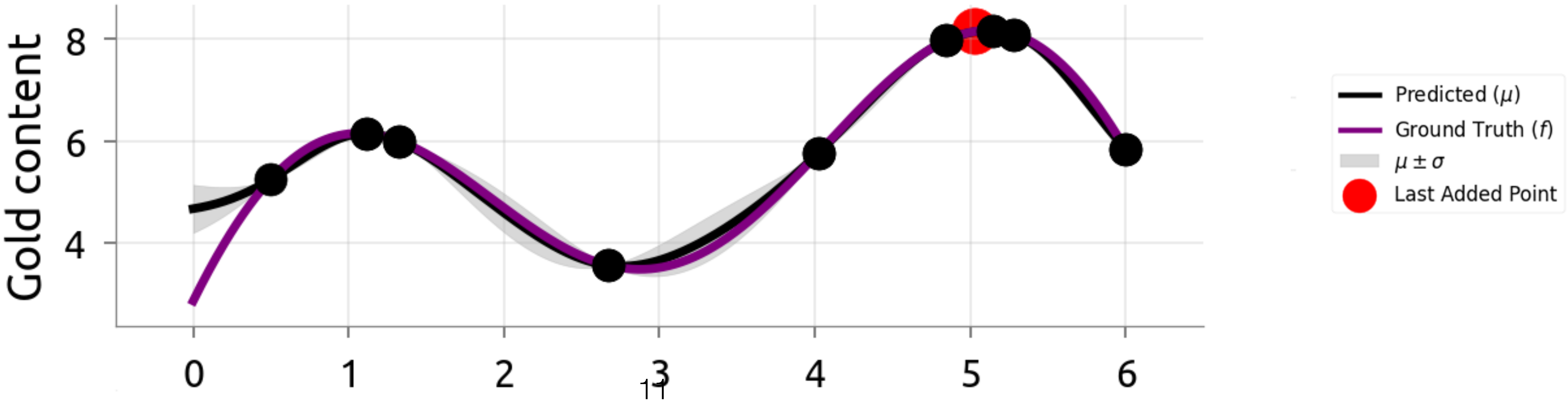
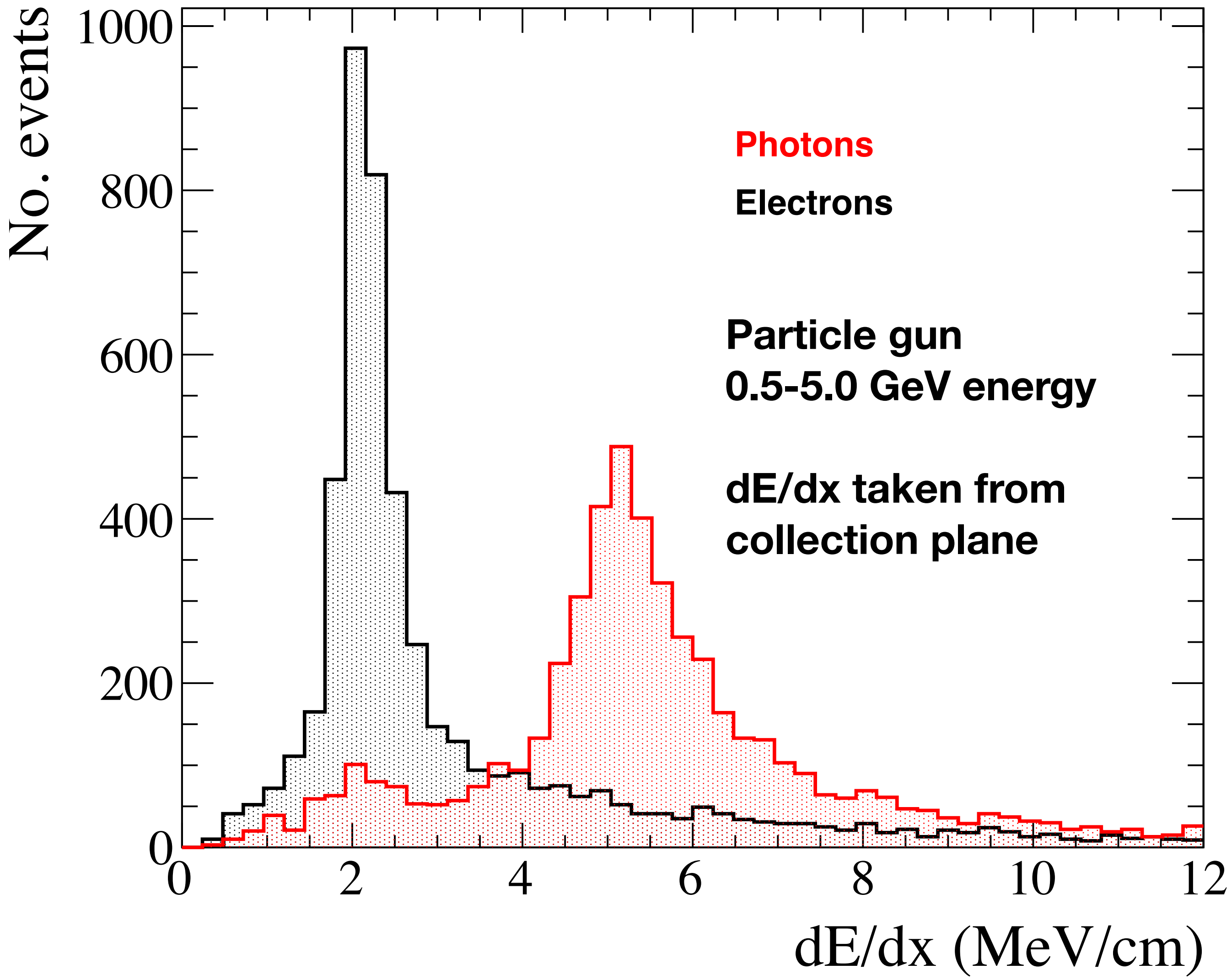
Iteration 8



Tuning the dE/dx reconstruction using Bayesian Optimisation

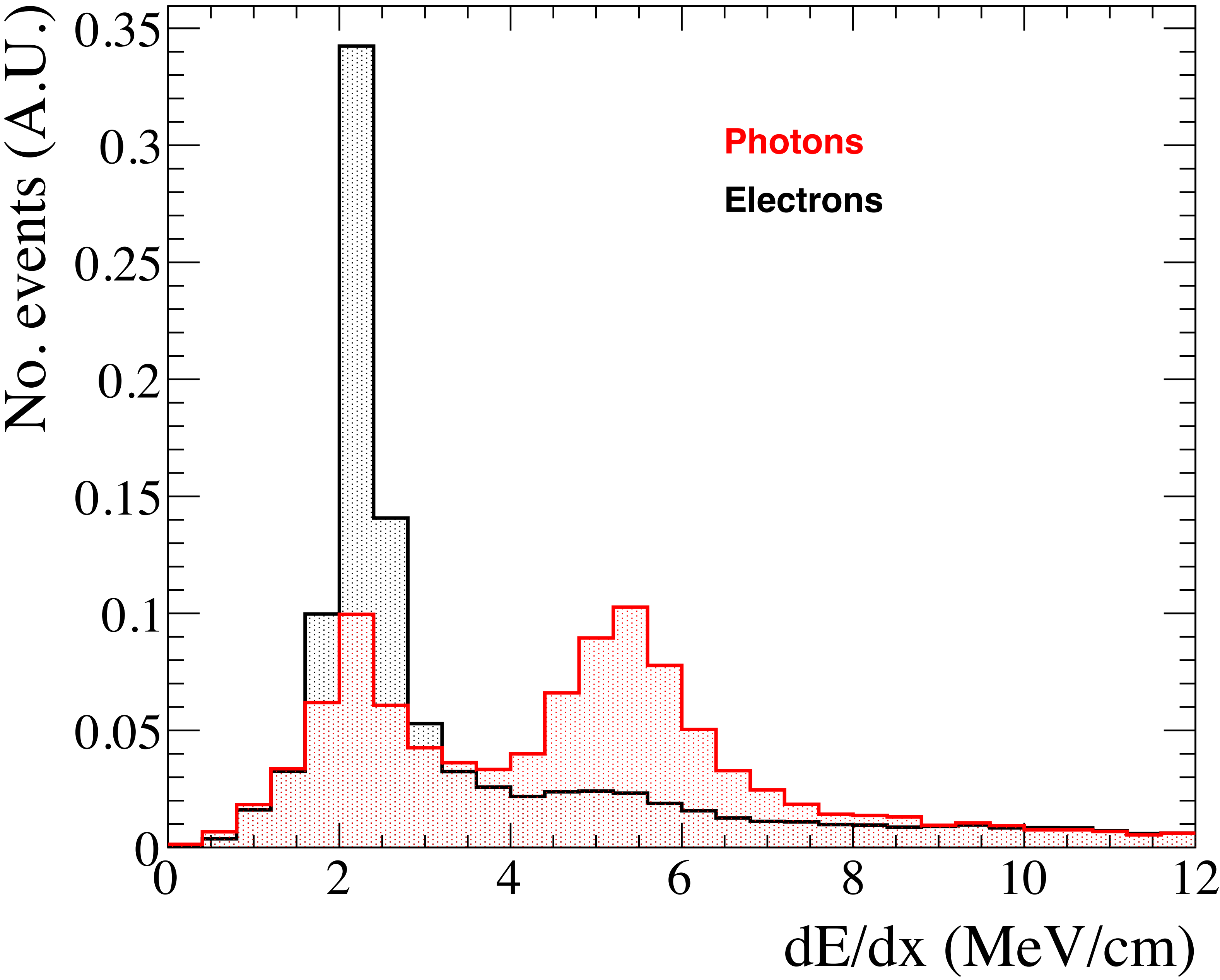
- The main use of a shower's dE/dx is to separate photons and electrons, so the tuning should reflect that
- The tuning metric I am maximising is
  - Num. selected electrons X Num. rejected photons after applying the optimum dE/dx cut
- The general idea is to:
  - Repeatedly run PandoraModularShower over a sample of particle gun electrons and photons (0.5-5.0 GeV energy range)
  - For each reconstruction pass, find the dE/dx cut value that maximises my metric
  - Return that metric to the Bayesian Optimiser and let it decide the new reconstruction parameters for the next reconstruction pass



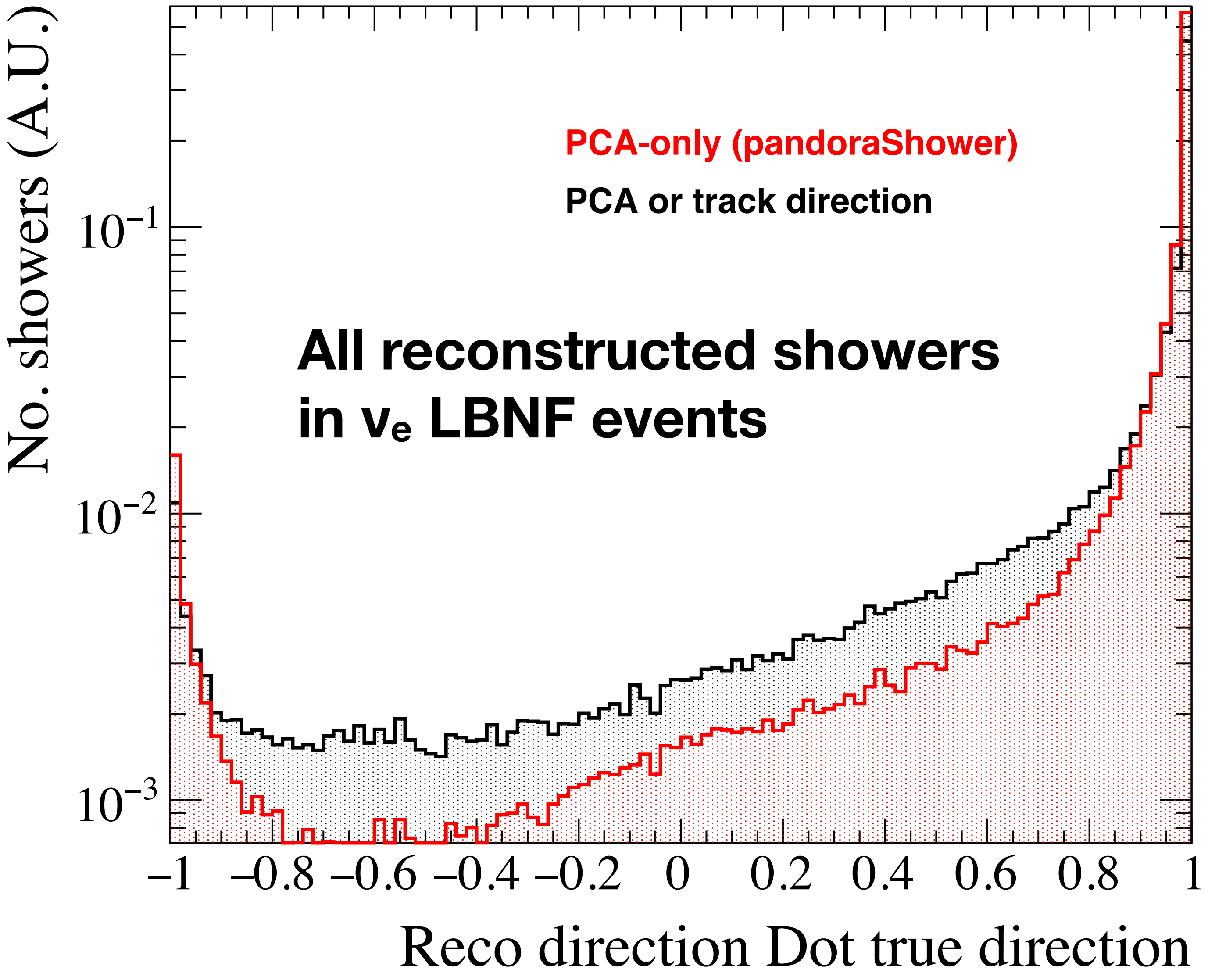
- RHS plot is tuned reconstruction (+ some hand tweaking of the params.)

Running PandoraModularShower's dE/dx reconstruction over fully oscillated ν_e LBNF events

- Separation not as good
- Difference is sculpted by the photon spectrum
- A future tuning iteration would use a different photon spectrum (or just use ν_e events)
- No amount of tuning alone will get rid of the 2 MeV/cm photon peak, however
- Performance is still better than the older PandoraShower module
  - PandoraShower does not reconstruct dE/dx



Shower direction reconstruction



- The old PandoraShower applies a Principal Components Analysis (PCA) to the shower which infers the direction

- I've tested tools in PandoraModularShower that uses either the PCA direction OR the direction of the initial track

  - Which direction is picked depends on the difference between the PCA and track directions

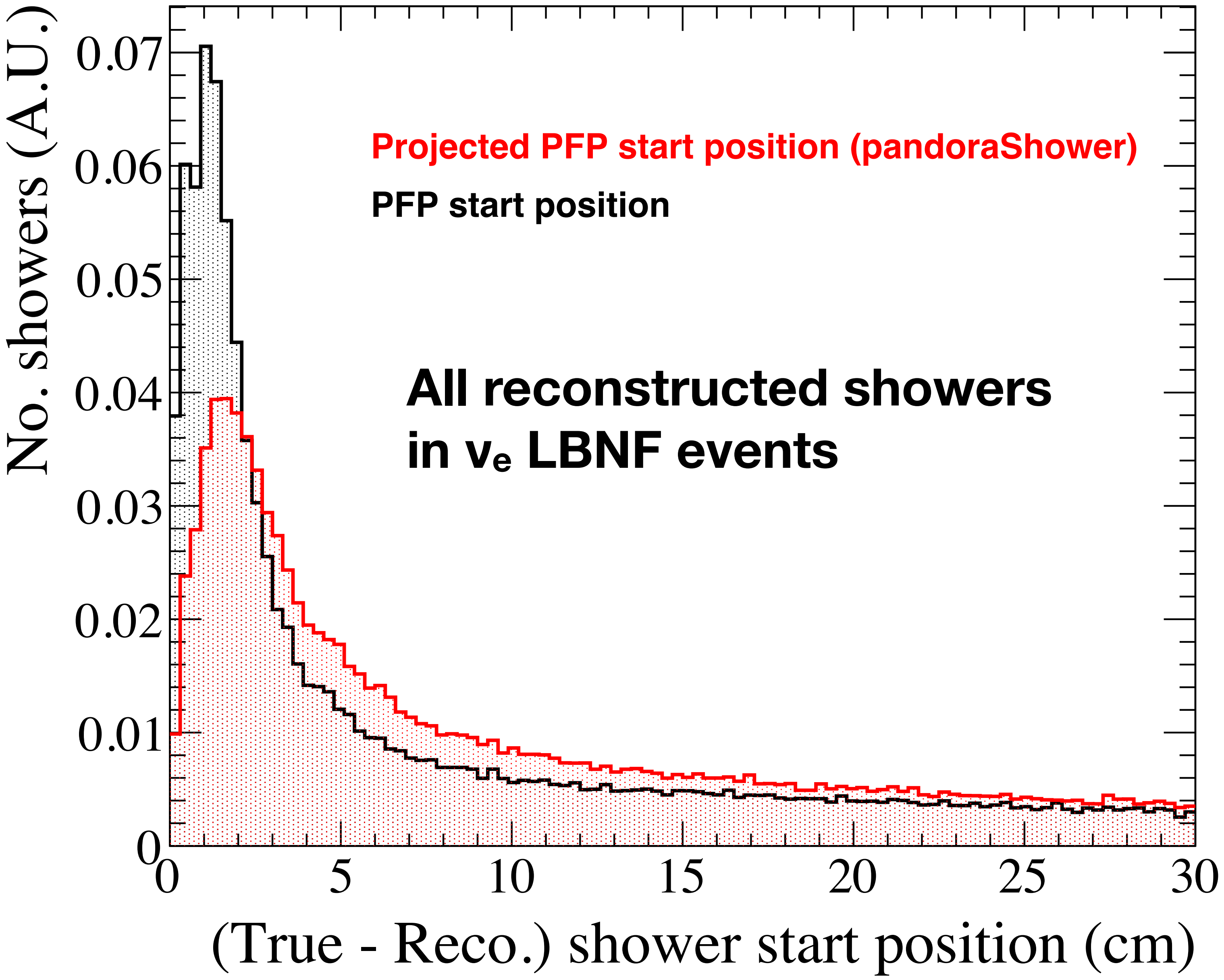
- It seems like using only the PCA wins out here, so we'll go with that for PandoraModularShower's toolset as well…

Shower start position reconstruction

- The old PandoraShower takes the Particle Flow Particle's (PFP) position projected onto the shower direction line as the start position

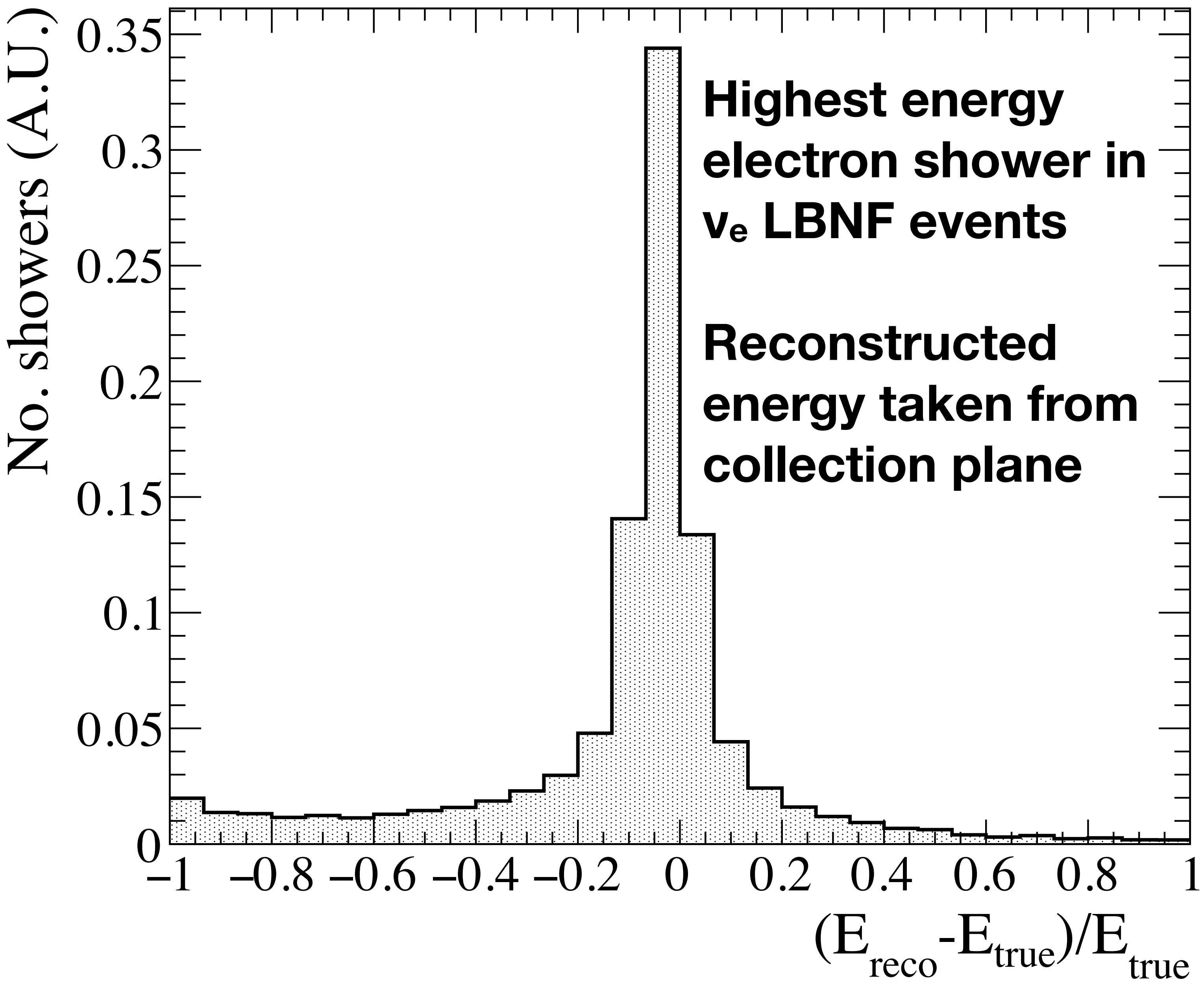
- I've tested tools in PandoraModularShower that takes the PFP position as the start position (no projecting)

- It looks like not projecting the start position has the more optimal performance here, so we'll use that in PandoraModularShower's toolset…



Shower energy reconstruction

- The chosen pandoraModularShower tool sums up hit charge per plane
- Corrects for attenuation and recombination and then converts to energy
- The plot compares reconstructed energy in collection plane to the total energy of the true electron



Highest energy electron shower in ν_e LBNF events

Reconstructed energy taken from collection plane

Proposed toolset for PandoraModularShower

- Direction: calculated using PCA-only
- Start position: the position of the PFP (no projecting)
- Energy: Summed and corrected hit charges
- dE/dx: The crude + ‘finessed’ toolchain described on previous slides

- I propose that we now start to replace the old PandoraShower reconstruction with the new PandoraModularShower reconstruction with the above toolset
- I highly suggest that we keep the data product label as ‘pandoraShower’

Summary

- Highly modular shower characterisation module (PandoraModularShower) now included in the larpandora repo

- I’ve tuned PandoraModularShower using particle gun showers in the DUNE far detector via Bayesian Optimisation

- By comparing performance with the older PandoraShower characterisation module, a toolset for pandoraModularShower has been identified

- The configured PandoraModularShower can now replace the older PandoraShower reconstruction when we’re ready