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AI for calorimetry: Update of recent studies

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Machine-Learning Optimized Design of Experiments

MODE Collaboration

https://mode-collaboration.github.io

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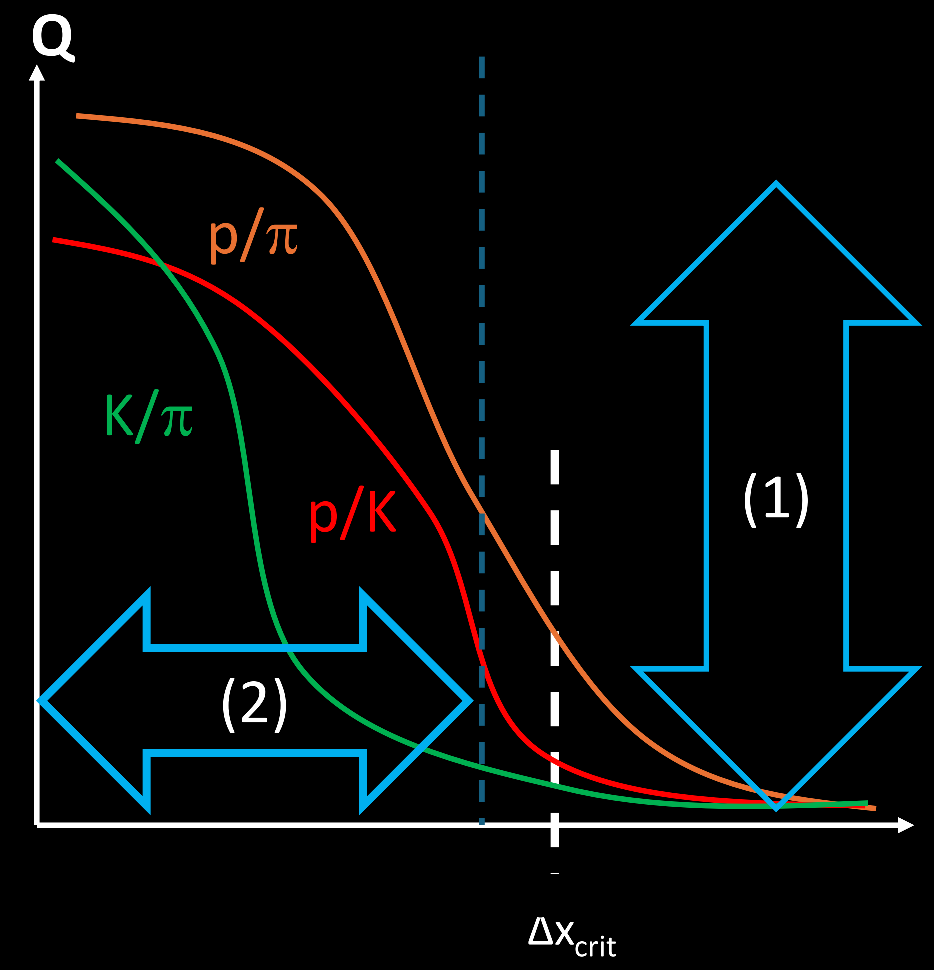
Research Questions and a Money Plot

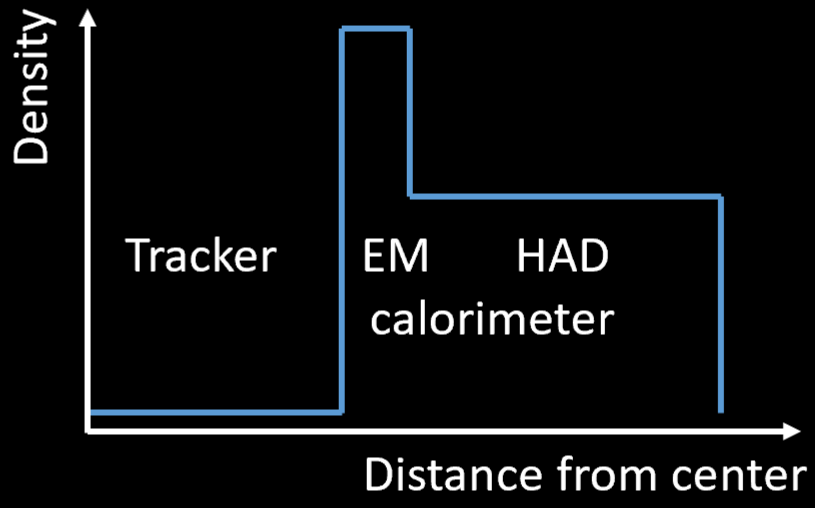
(1) What are the ultimate particle ID capabilities of a granular hadron calorimeter, assuming no limit on size Δx of readout cells?

(2) How does particle ID capability degrade as Δx is increased, and for what value Δx_{crit} does it get lost in conceivable setups?

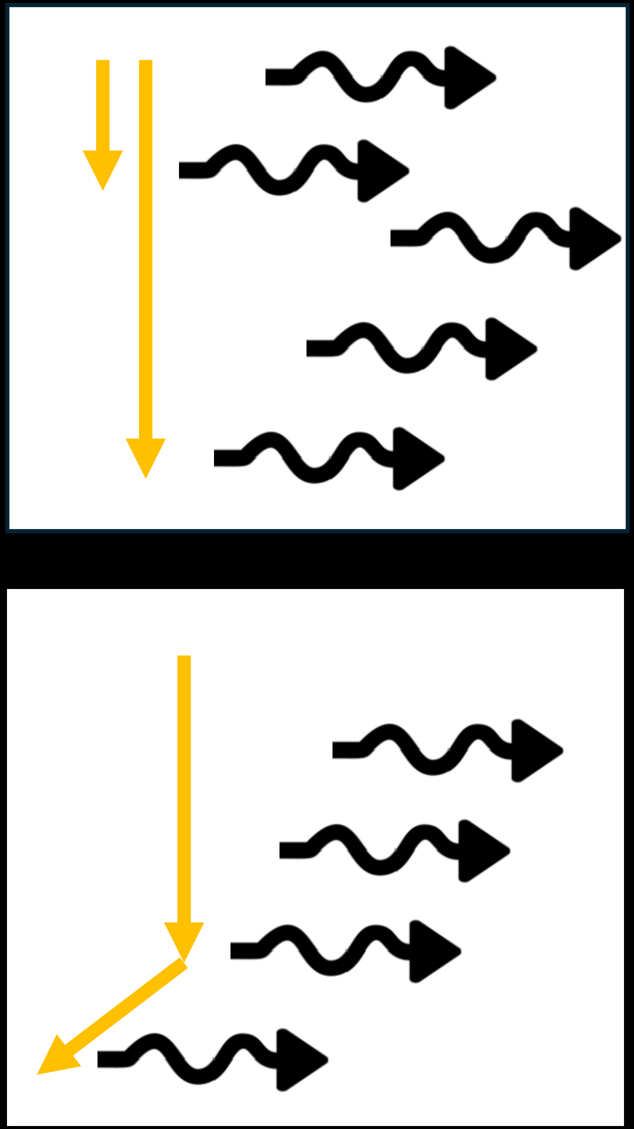


Research Questions and a Money Plot

(3) Is there a better density profile than the dichotomic one we have used in collider experiments for six decades?



Research Questions and a Money Plot



(4) How much further gain is possible by exploiting timing information?

A new idea

In the past the excessive data flow from hadron collider events was handled by reducing information content and/or rate.

Both are suboptimal measures…

A new idea:

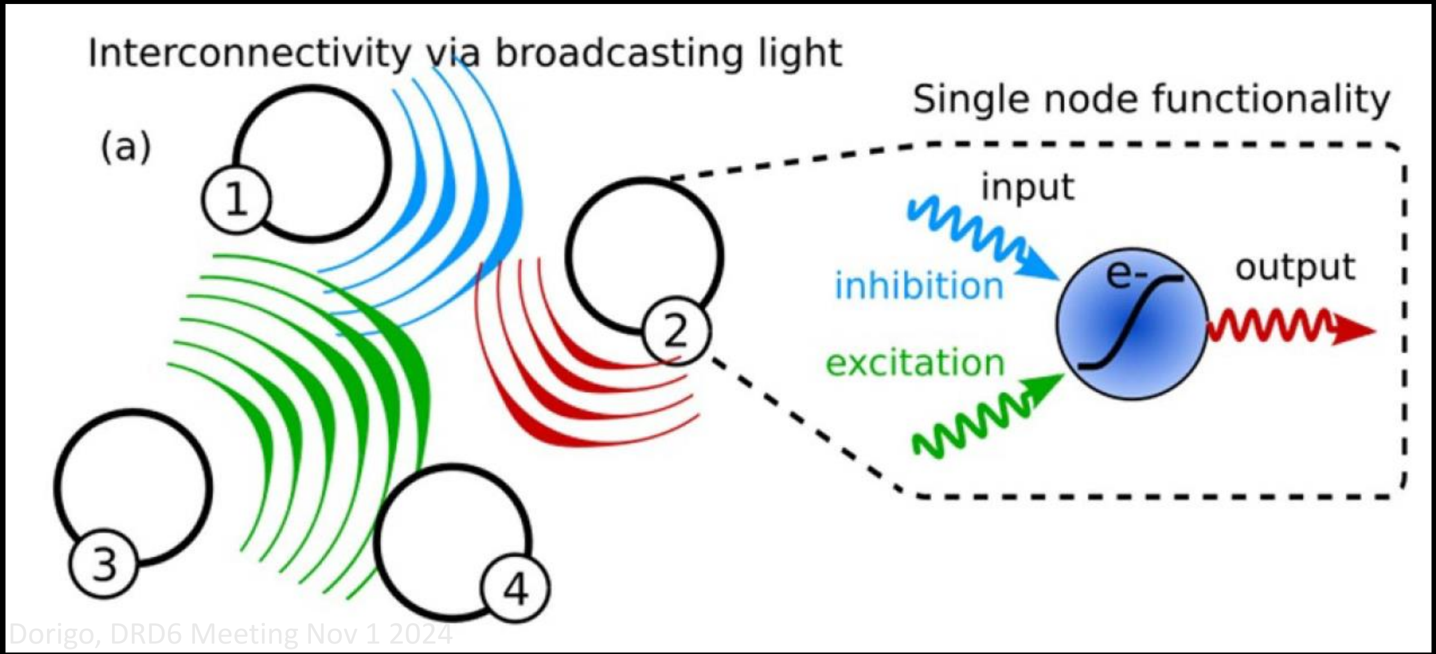
Introduce fast online preprocessing of light signals by nanophotonic devices embedded in the detector

→ exploit timing, transmit to back end higher-level primitives, enable triggering, improve information extraction

Timing with Neuromorphic Computing

Recent developments in nanophotonics: can use light receivers/emitters in micrometric substrates

→ may create neuromorphic network encoding and exploiting time structure of photon signals

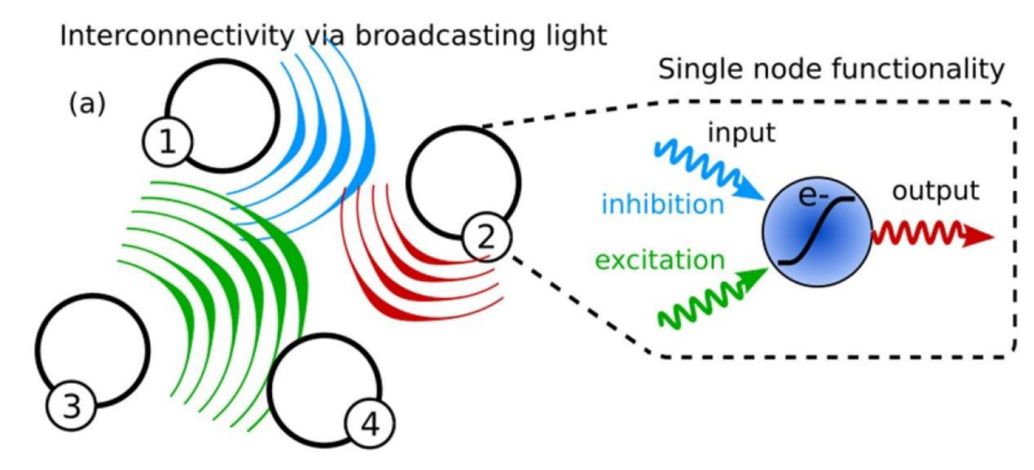


Timing with Neuromorphic Computing

Recent developments in nanophotonics: can use light receivers/emitters in micrometric substrates

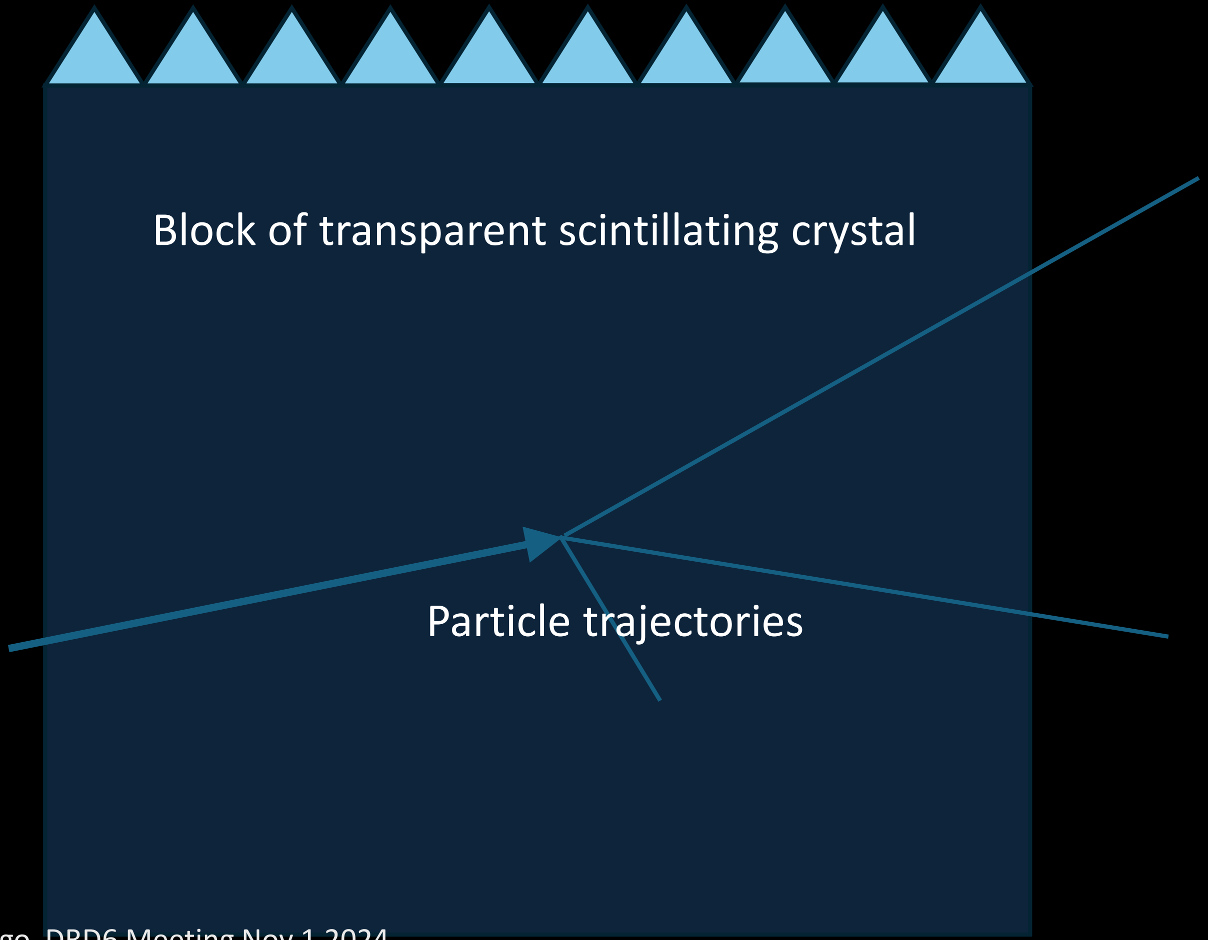
→ may create neuromorphic network encoding and exploiting time structure of photon signals

- No transduction (PMT gone)
- On-site ultrafast computing
- High energy efficiency
- Natural exploitation of time structure



An AI problem to solve (if the rest works)

Use a neuromorphic network to reconstruct trajectories of particles – or simply compress information into useful summaries, given detected photons emitted along the path and their arrival times



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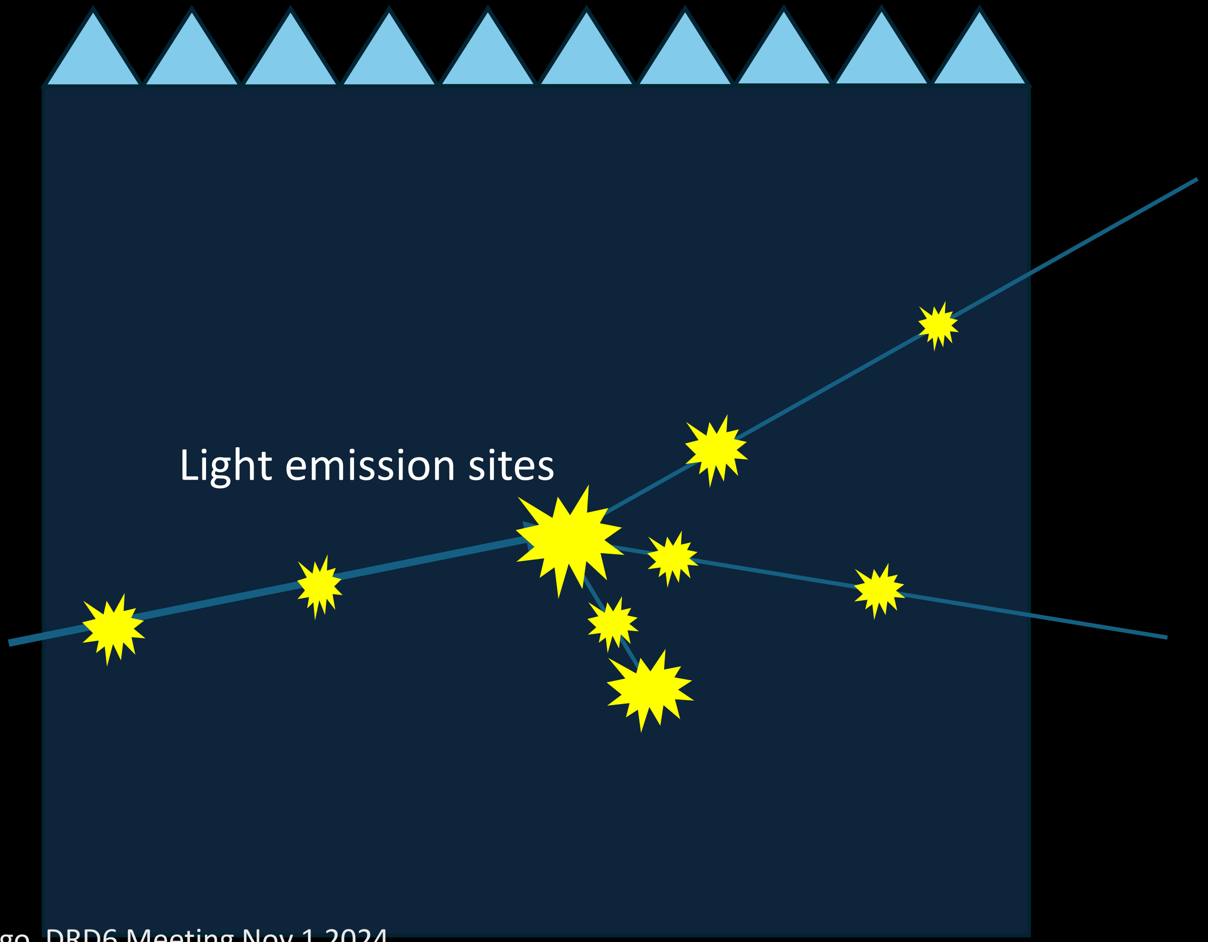

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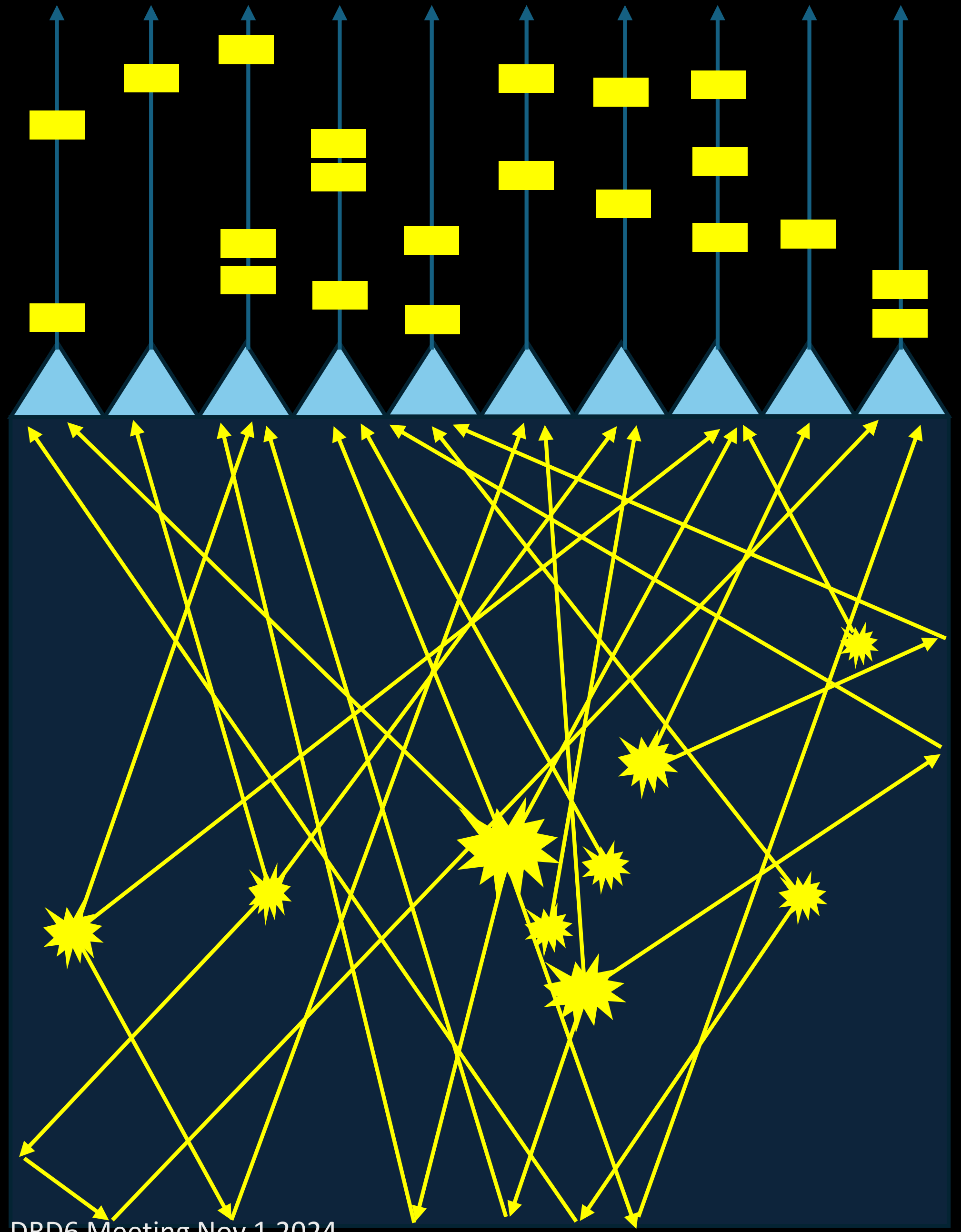


Back to the drawing board

Ultimately, we want to study how to hybridize a tracker and a calorimeter. This can be done the hard way (by including their full modeling in a differentiable programming pipeline), or by taking a shortcut: a generative diffusion model

A tracker measures particles momenta by fitting their curvature in a magnetic field.

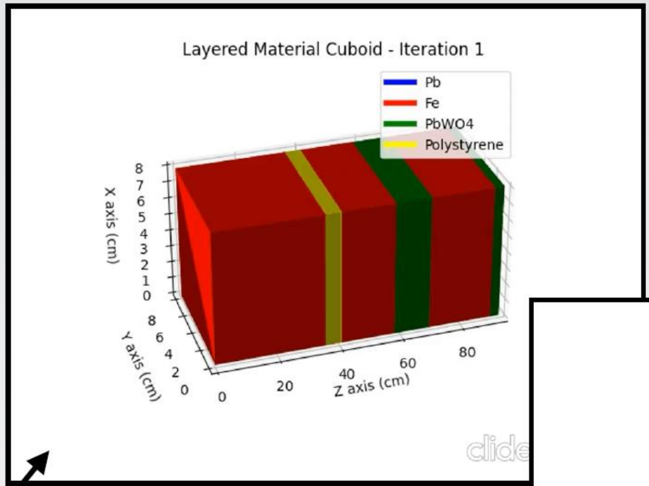
- It requires clean trajectories, not made dirty by scattering and nuclear interactions

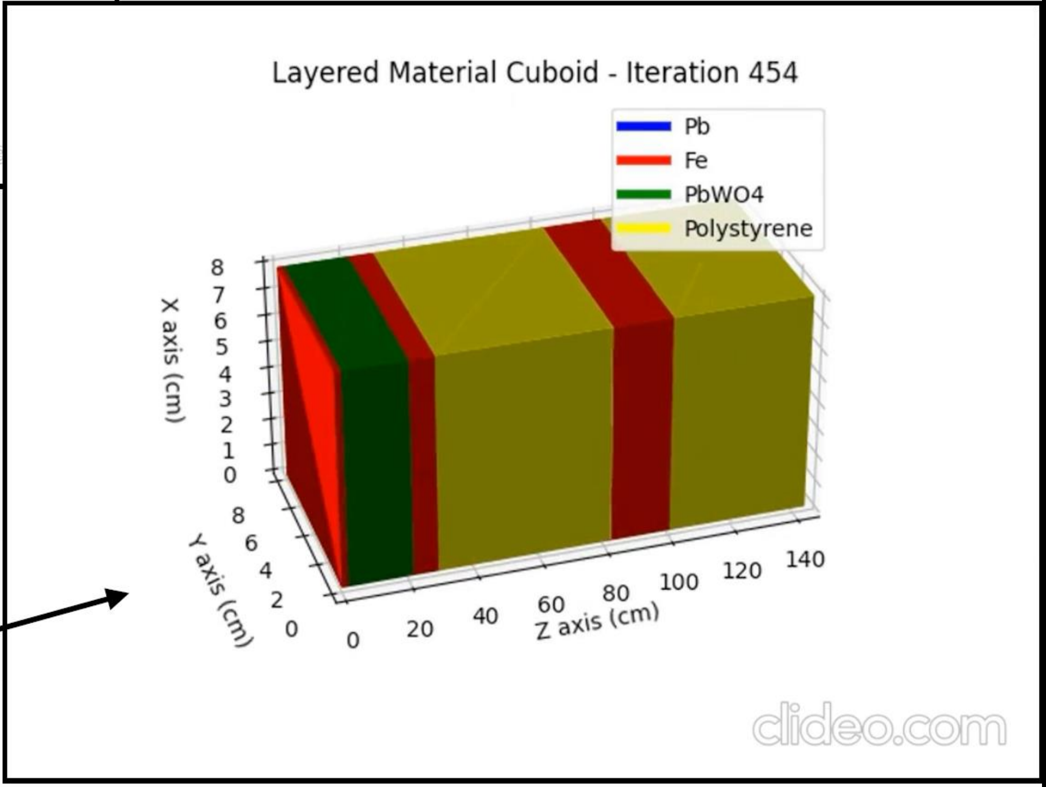
A calorimeter does the opposite – it produces loads of dirty stuff and measures the lump sum of all what happened.

There has to be an optimal point in between!

Yes.

- Different particles (electromagnetic and hadronic)
  - Short showers
  - Deep showers
- All with energies between 1 and 20 GeV
- Material cost <50k CHF
- Length <180 cm
- Start with a ***horrible*** configuration
- After a few hundred iterations: a ***very reasonable*** configuration with significantly better performance (and close to real-world detector designs)





Summary

For serious innovations in calorimetry we must look into AI tools, as they are developing at orders of magnitude more speed than hardware ones.

We are tackling three blue-sky research questions:

- What is the maximum amount of information (on particle ID, used as a proxy) we can extract from high granularity?

  → Informs the design of future instruments

- Can we exploit nanophotonics to perform ultrafast preprocessing of the topology of energy deposition?

  → May be an enabler of better triggering

- What is the optimal profile of material density and detection elements in a tracker + calorimeter, once you consider their collective information output?

  → May change our design paradigm for colliders