Belle II KLM

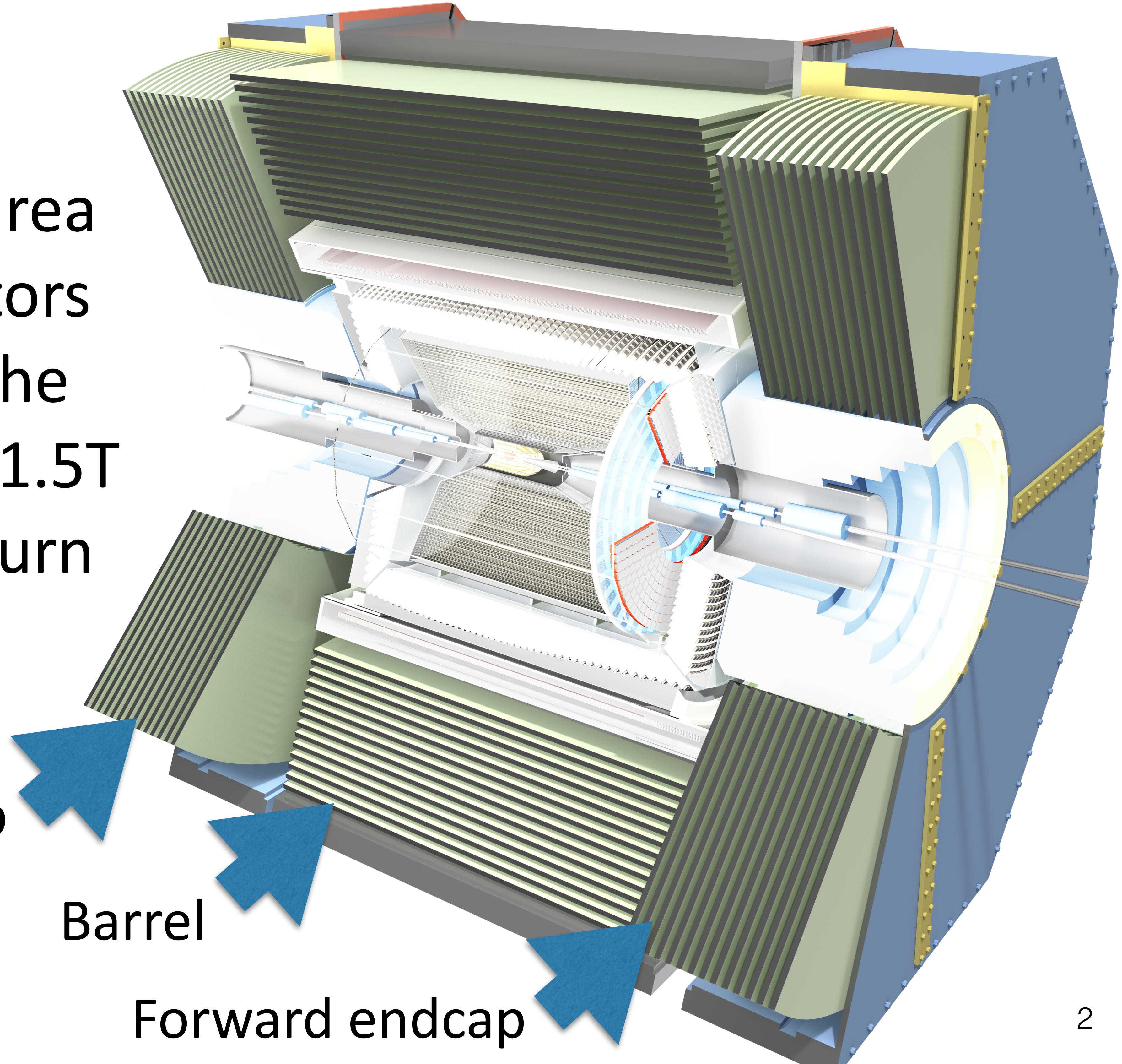
Muon and K_L Particle Identification

Leo Piilonen, Virginia Tech

Belle II Physics Week Valencia November 2022

The KLM (“K_L–Muon detector”)

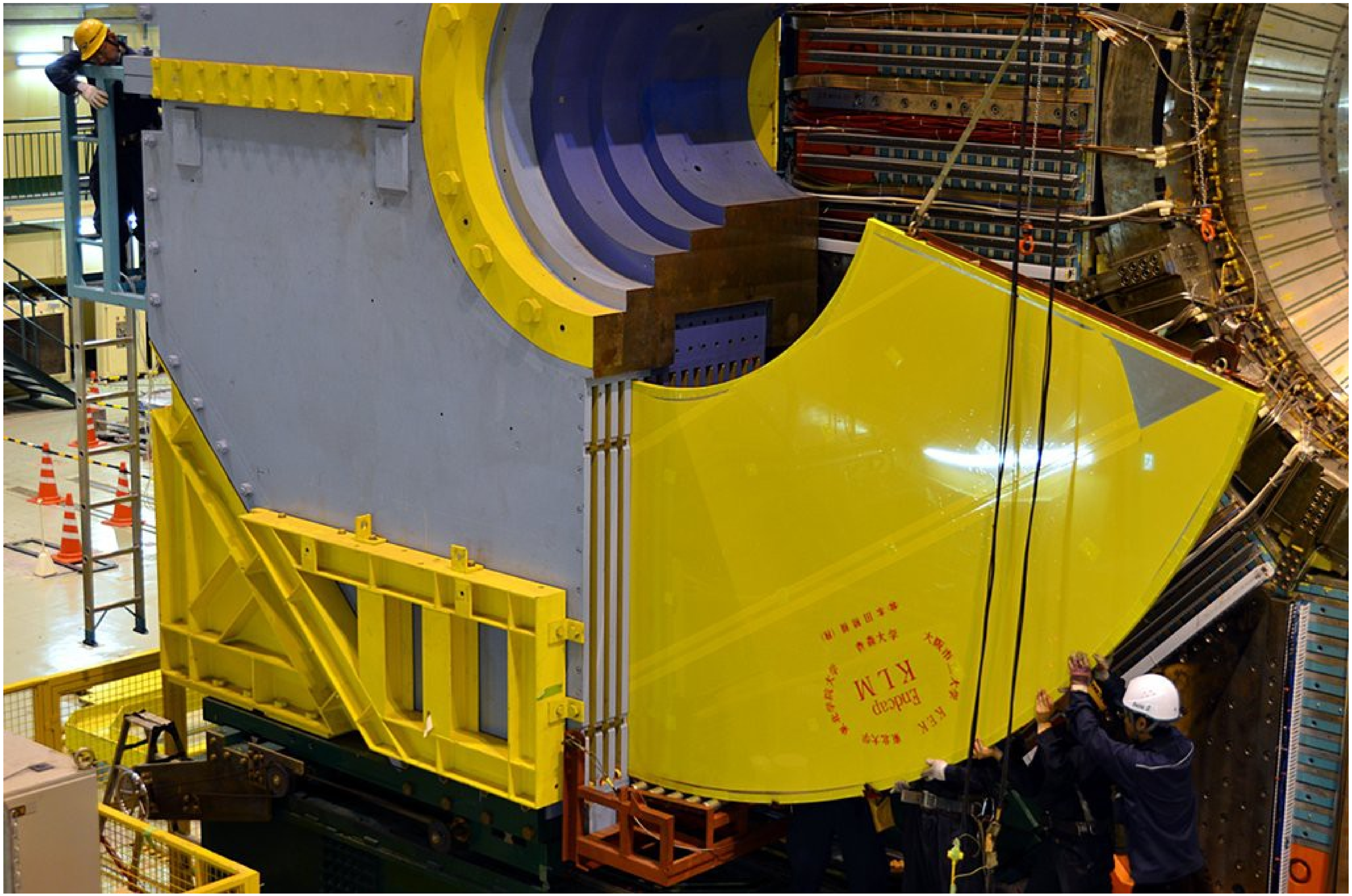
consists of large-area thin planar detectors interleaved with the iron plates of the 1.5T solenoid’s flux return yoke.



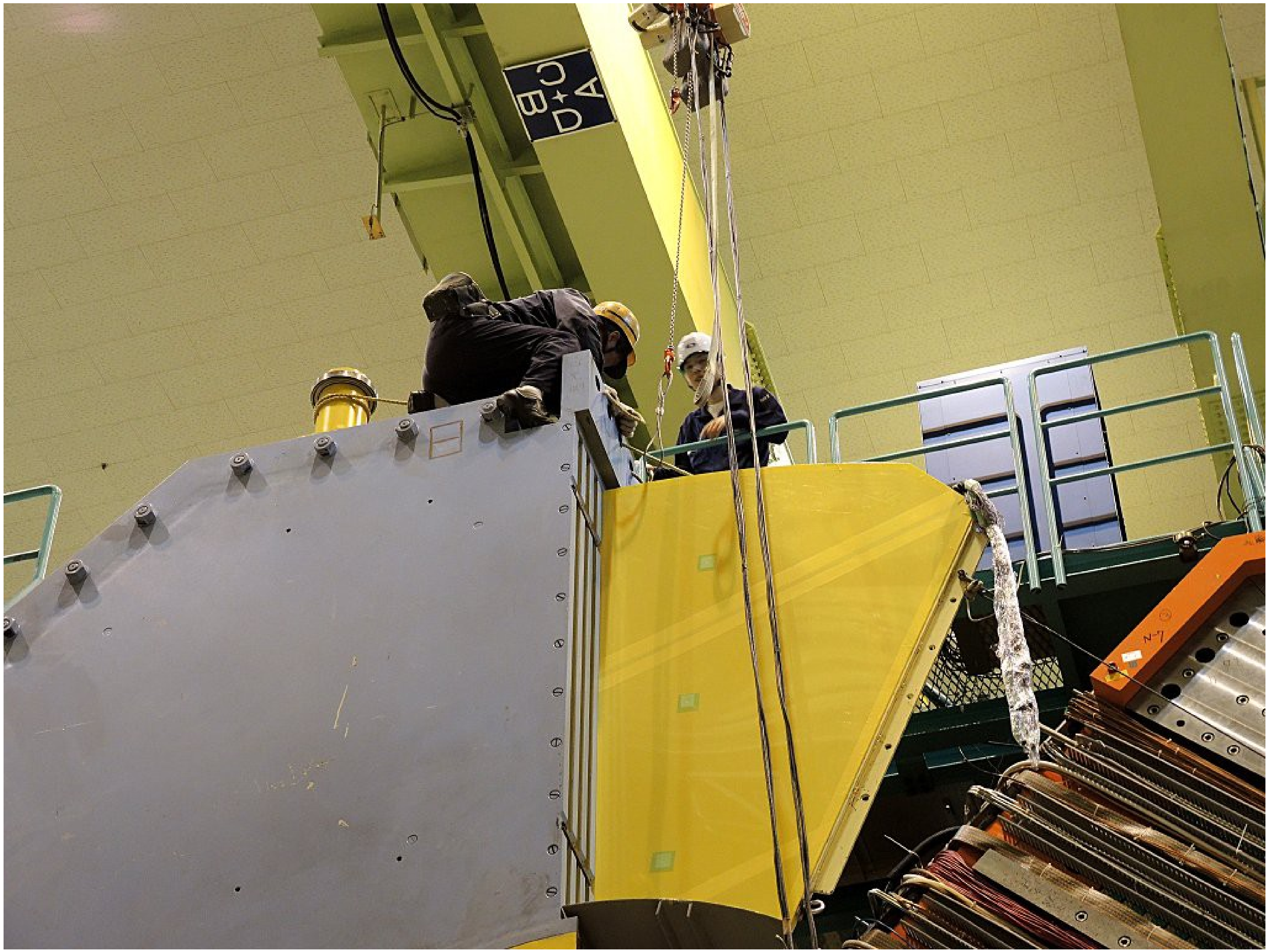
Installing Barrel KLM Detector Module (2013)

Installing Barrel KLM Detector Module (2013)

Installing Endcap KLM Detector Module (2014)



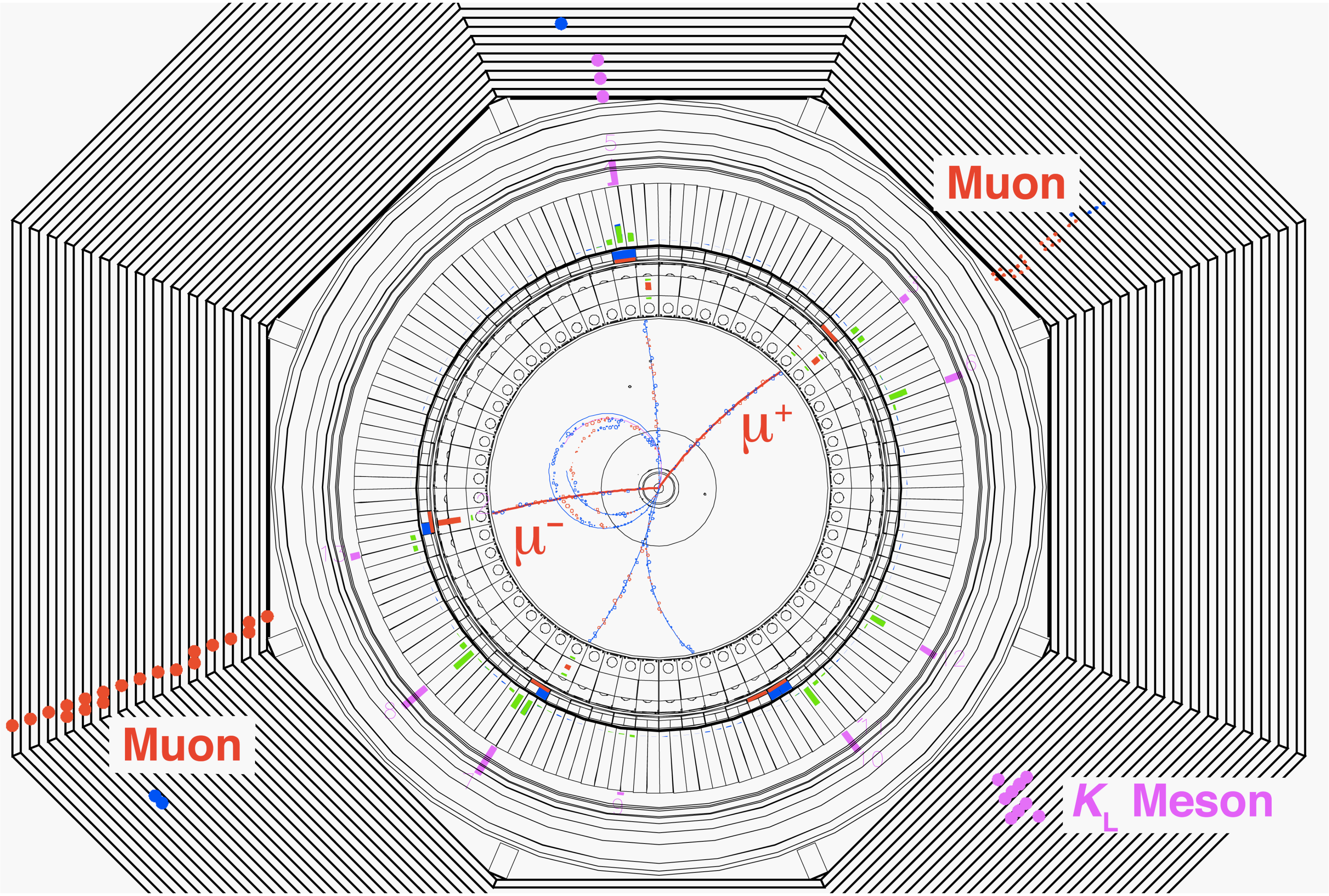
Installing Endcap KLM Detector Module (2014)



- KLM detects K_L mesons and muons (≈1 per event)

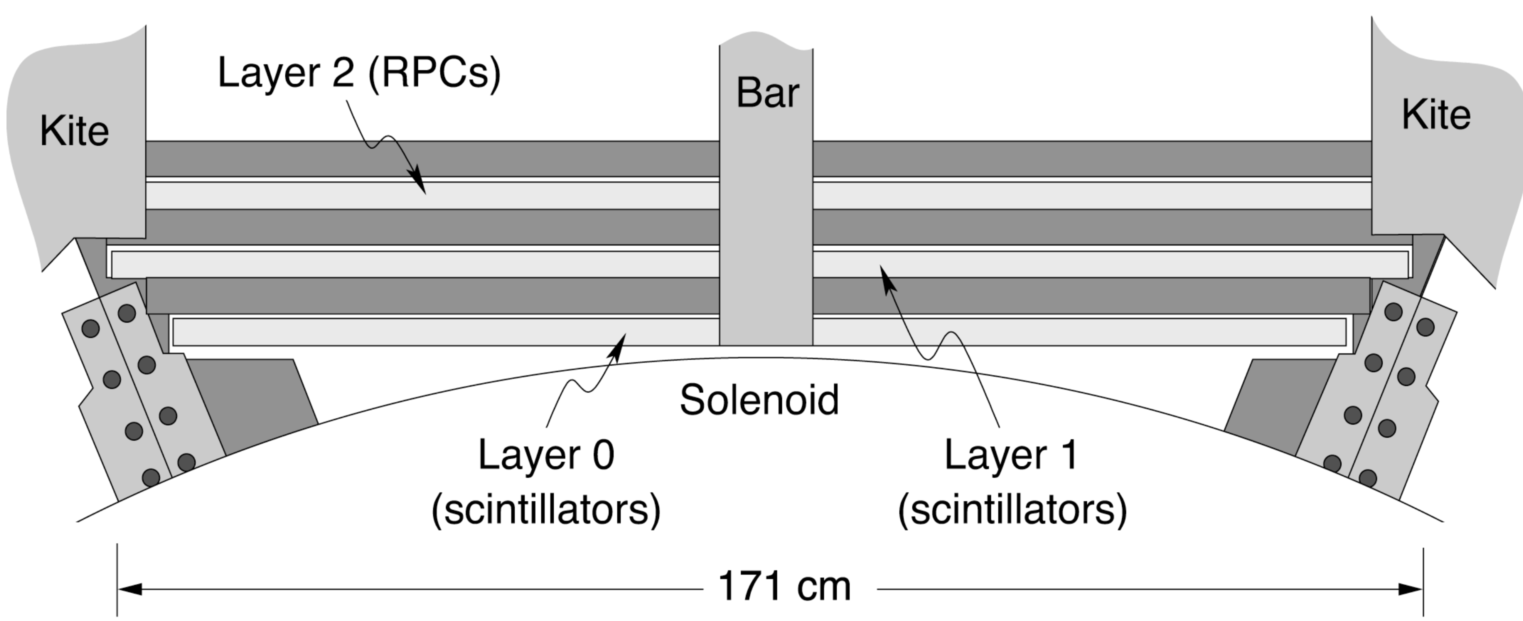
  For example: $B^0 \to J/\psi\, K_L$ **event**

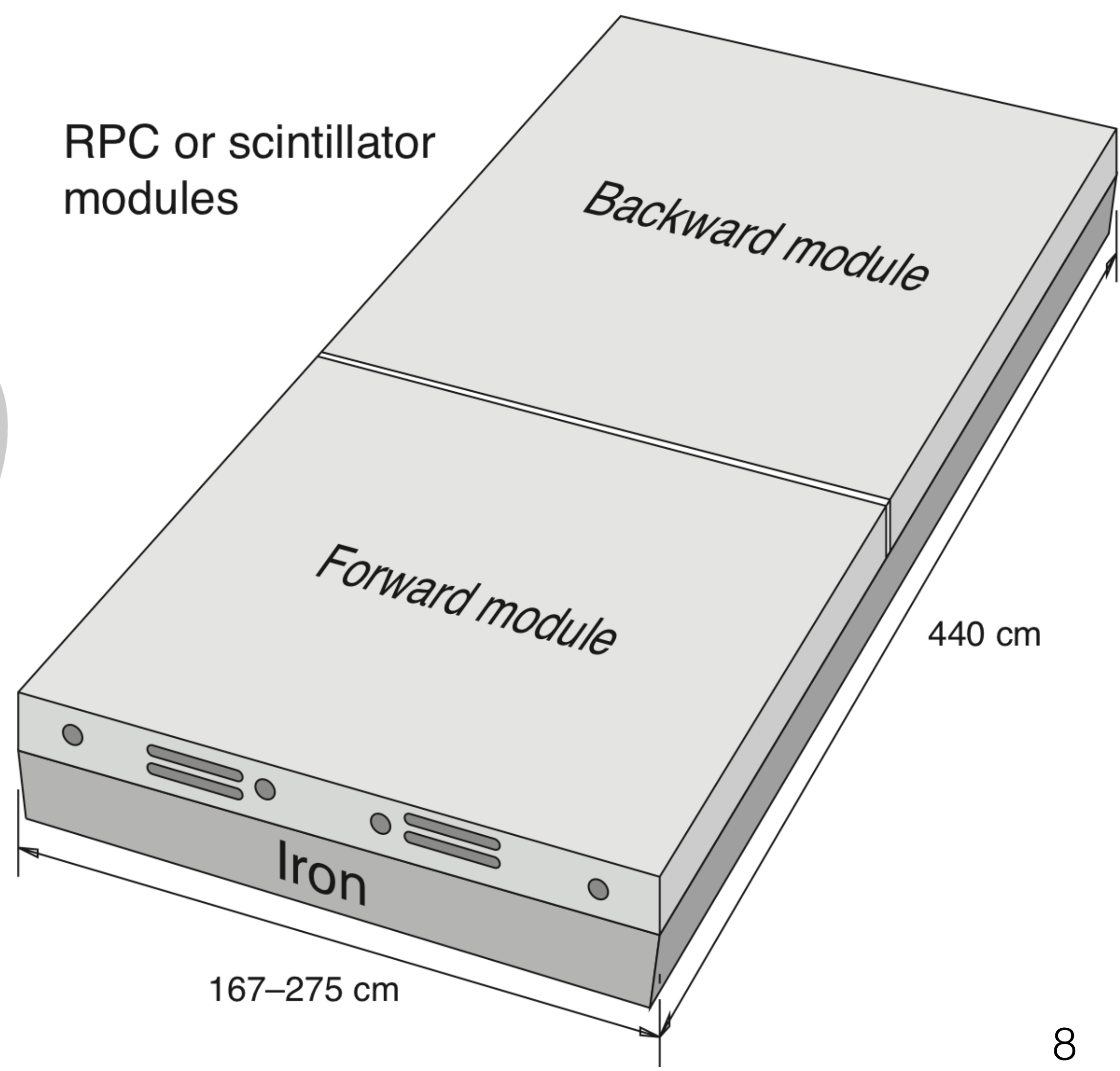
  $\hookrightarrow \mu^+ \mu^-$



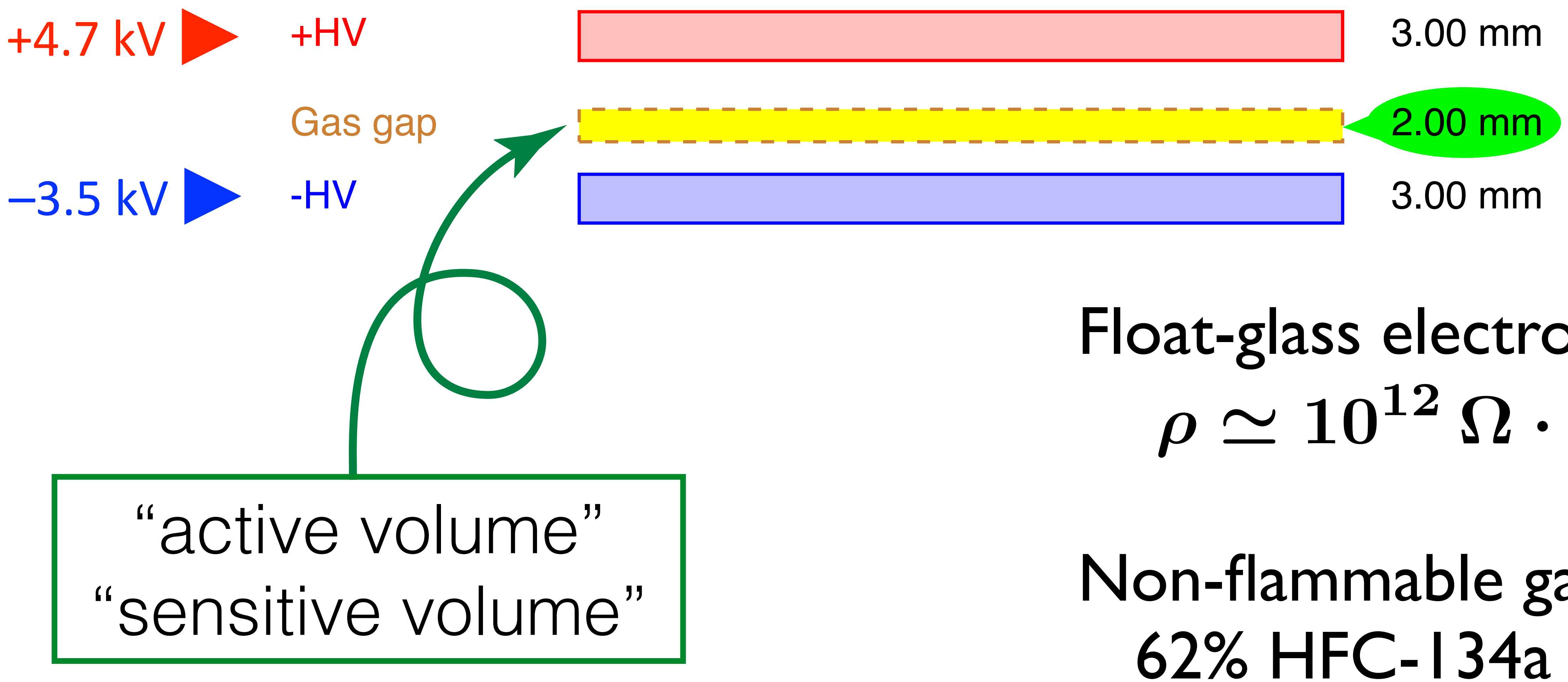
In the barrel KLM …

- Continue to use the Belle-era glass-electrode RPCs in the outer 13 layers
- Install scintillators in the 2 innermost barrel layers





Our Resistive Plate Counter contains …



Float-glass electrodes

$$\rho \simeq 10^{12}\,\Omega\cdot\mathrm{cm}$$

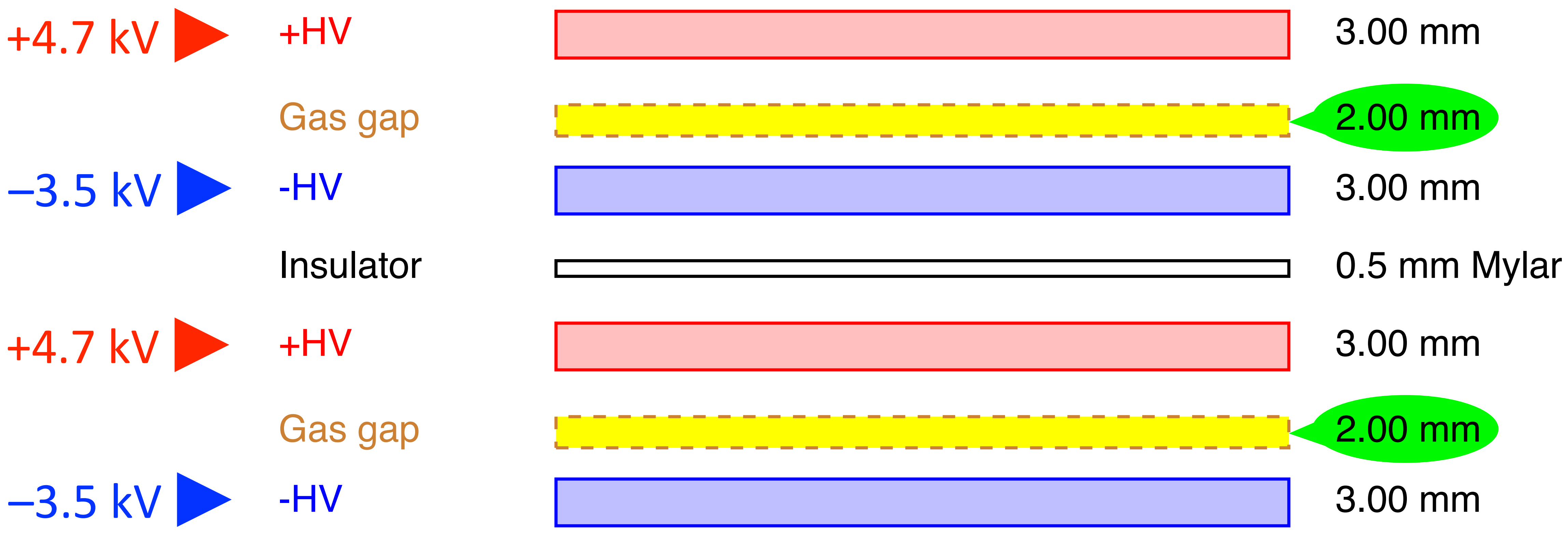
Non-flammable gas:

62% HFC-134a

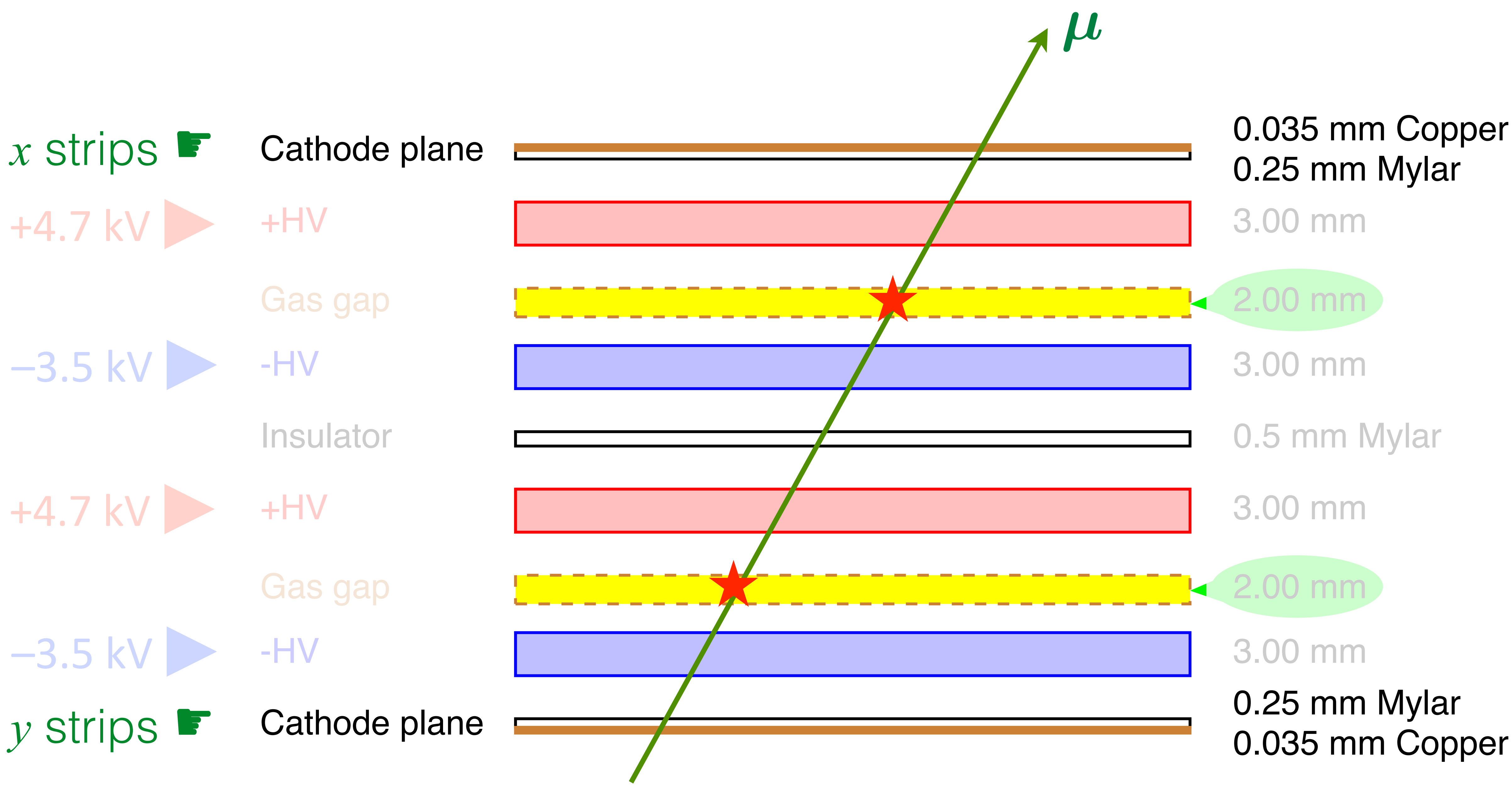
30% argon

8% butane-silver

One panel has two independent RPCs

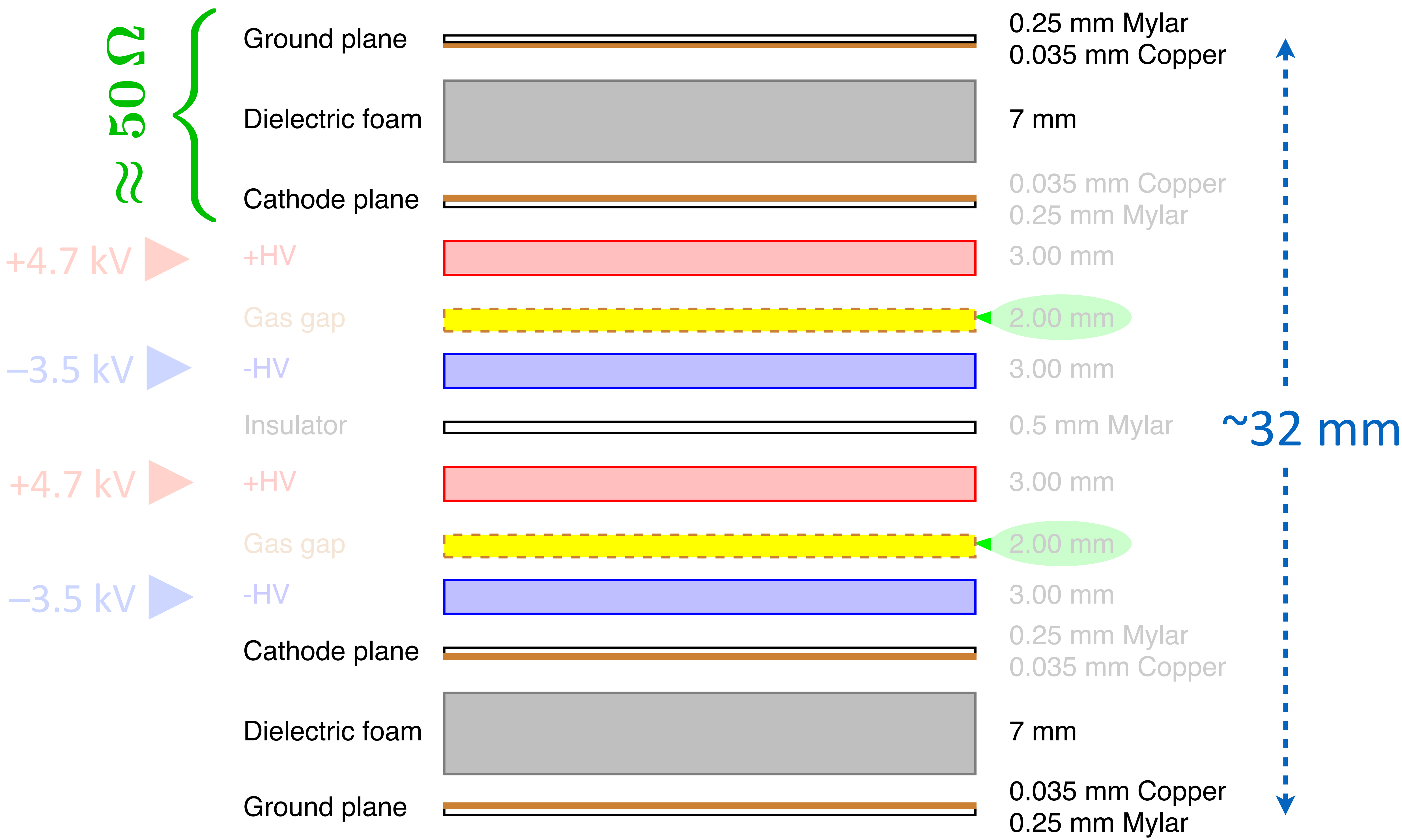


… and orthogonal readout planes.



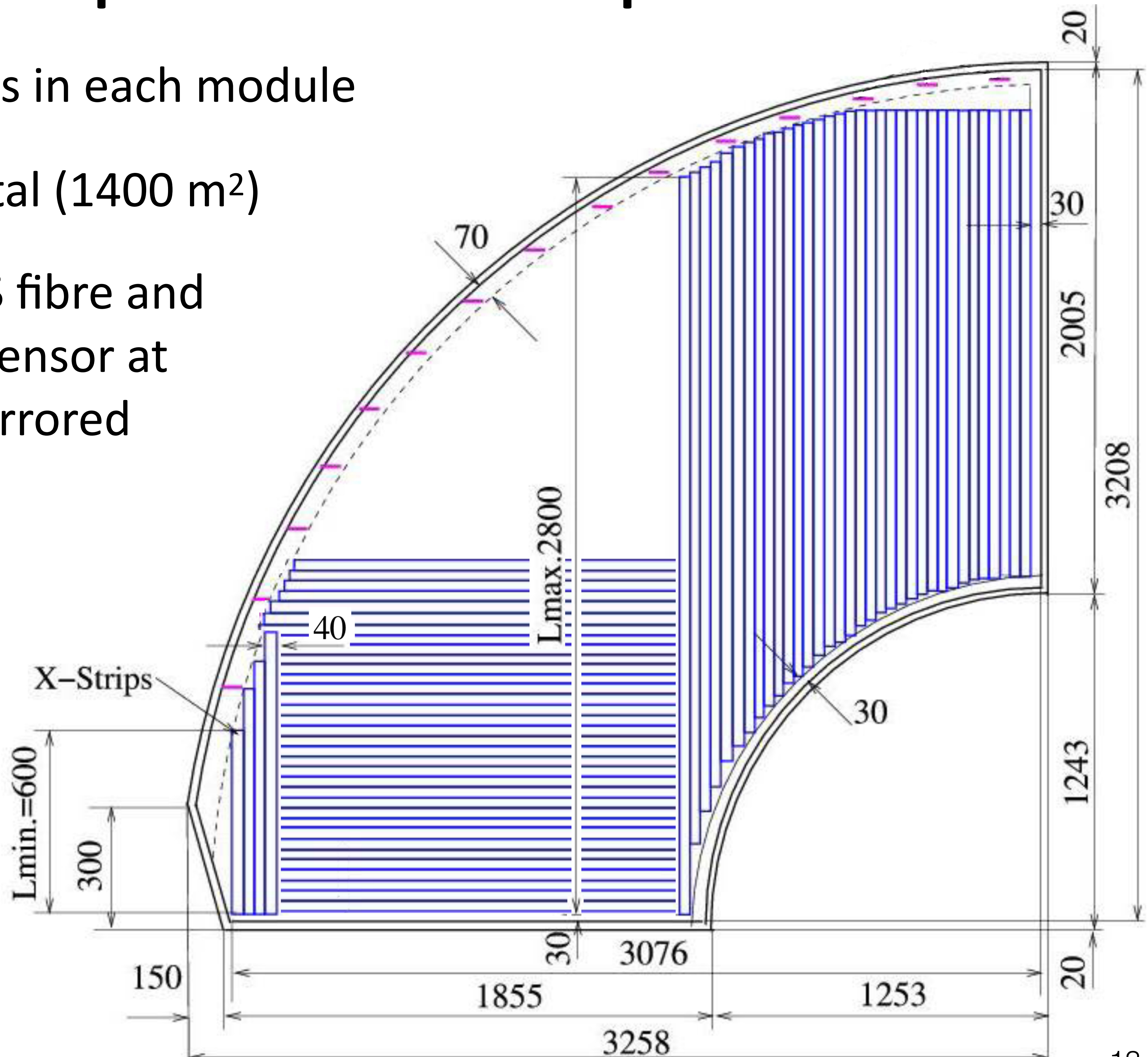
A discharge ★ (=streamer) from dE/dx in *either* gas gap induces an image charge on *both* readout planes $\Rightarrow$ xy hit.

Cathode-plane strips are transmission lines … we collect signal at end of strip

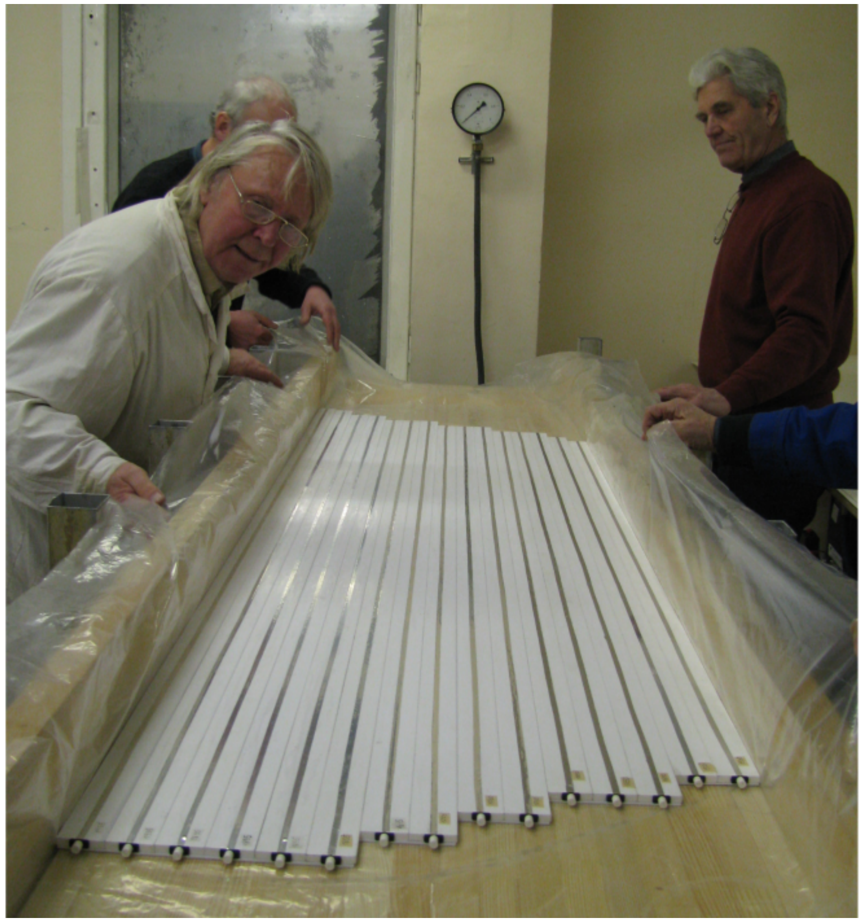


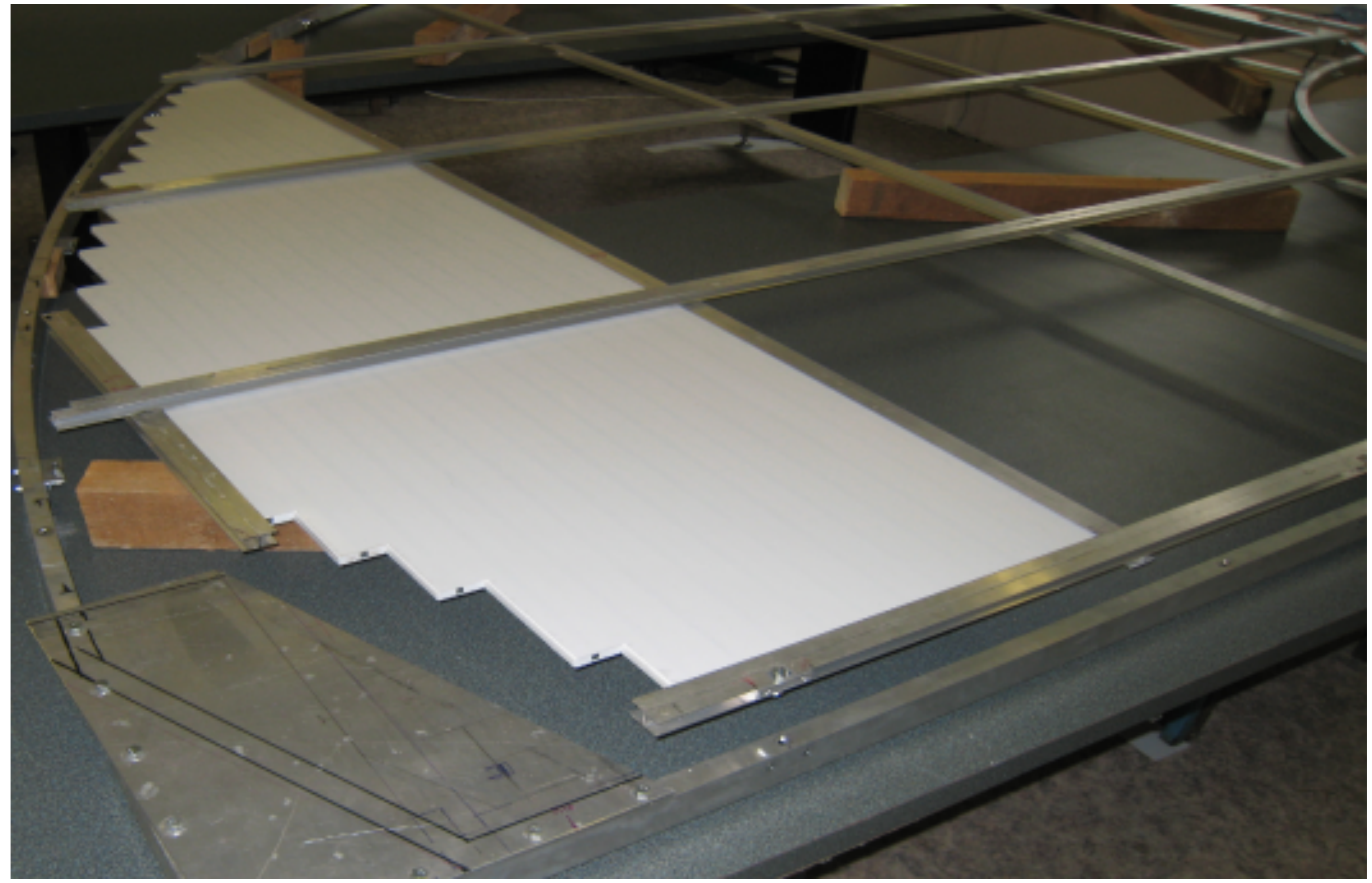
Endcap scintillator panel

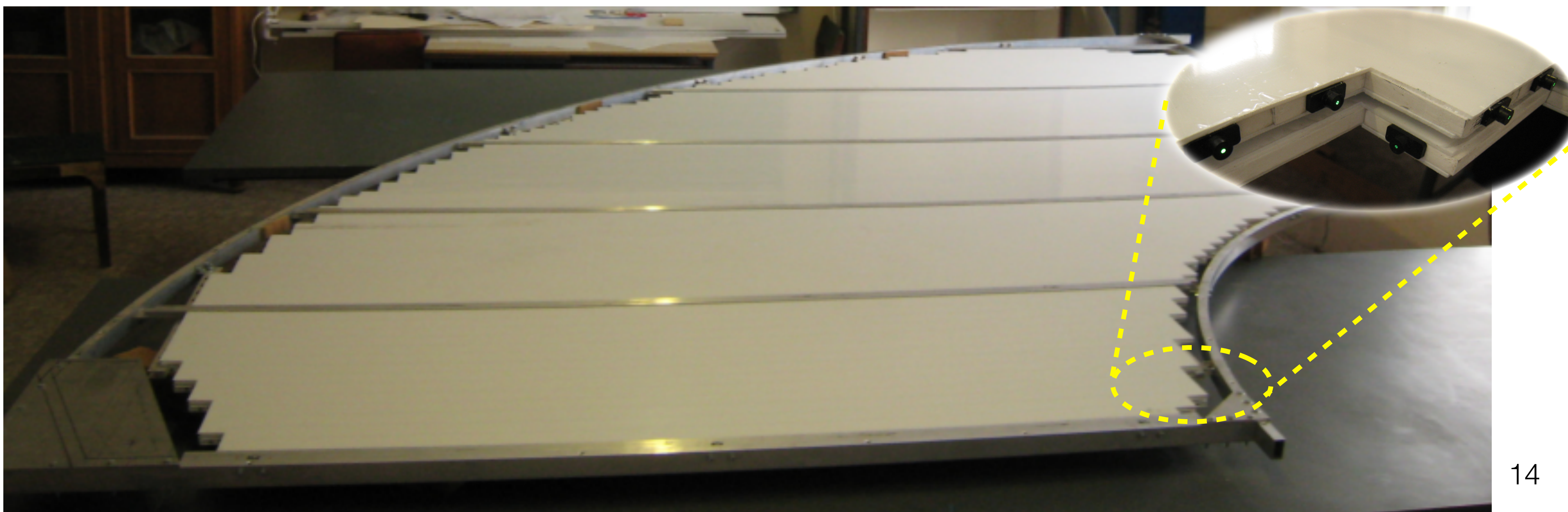
- 75 x- and y-strips in each module
- 16,800 strips total (1400 m^2)
- readout via WLS fibre and attached SiPM sensor at outer radius (mirrored at inner radius)



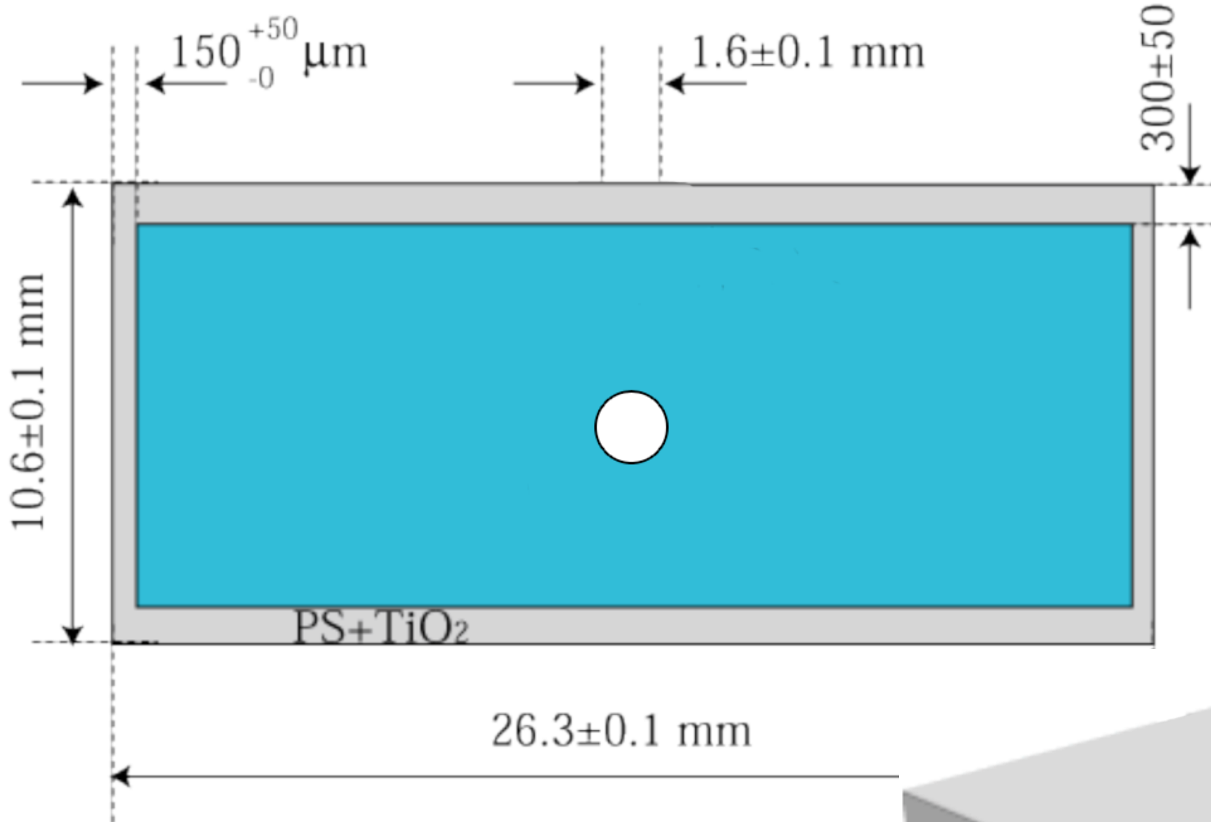
An endcap scintillator panel



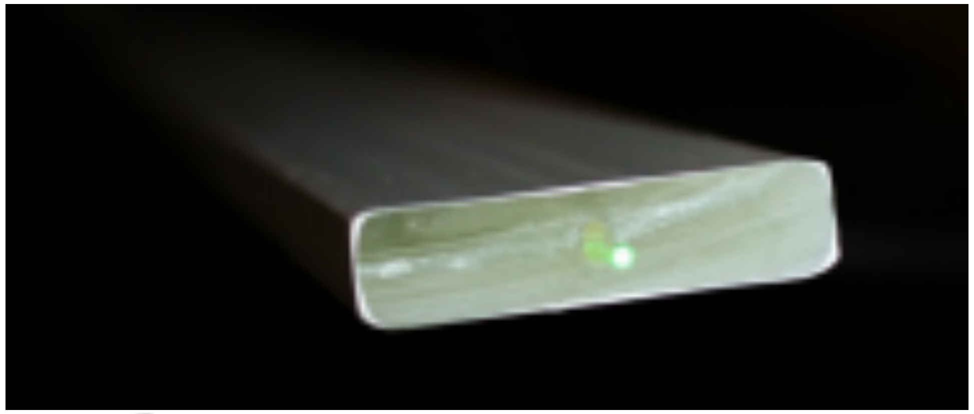


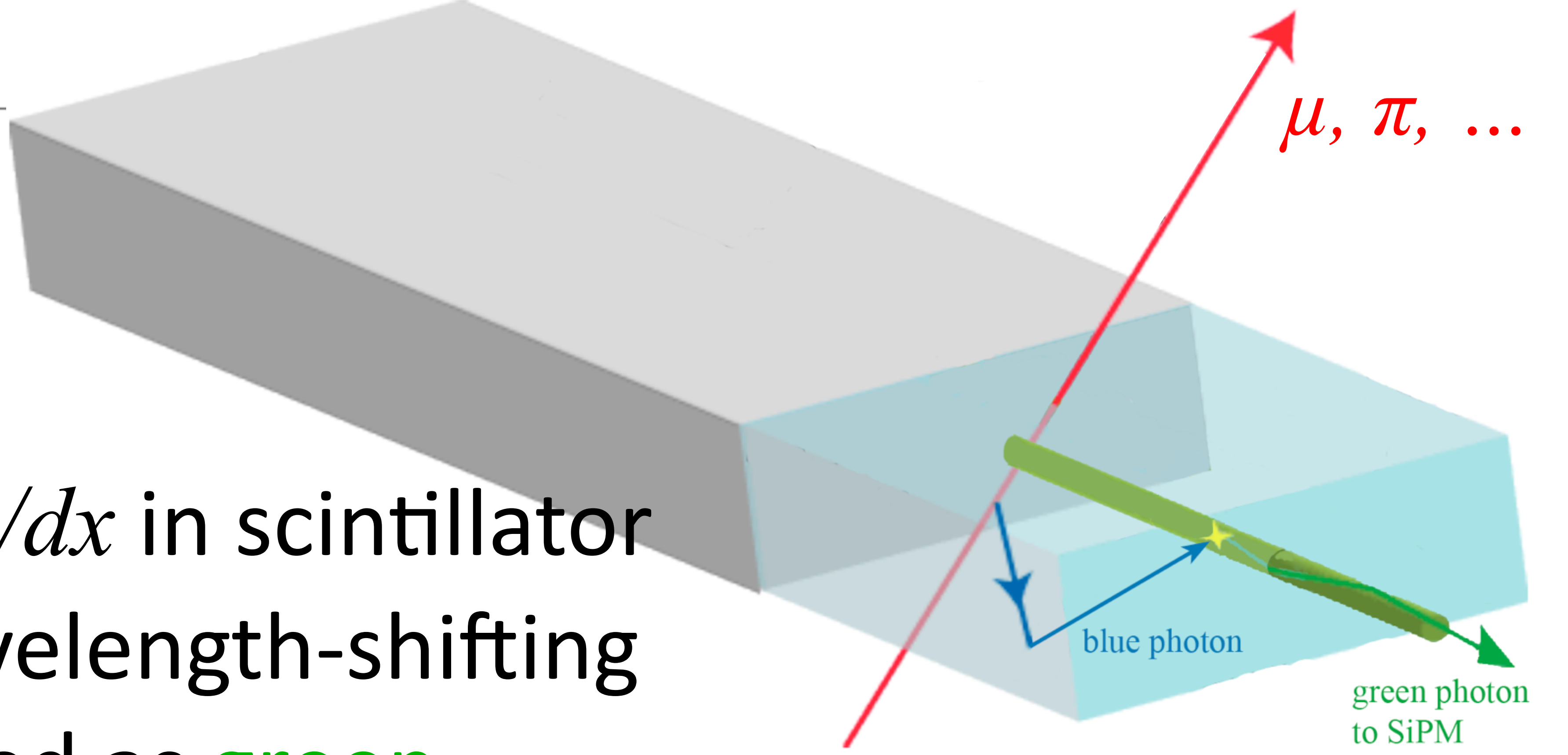


Scintillator (with TiO_2 reflective coating) delivers blue light to central-bore WLS fibre



FNAL scintillator for barrel KLM

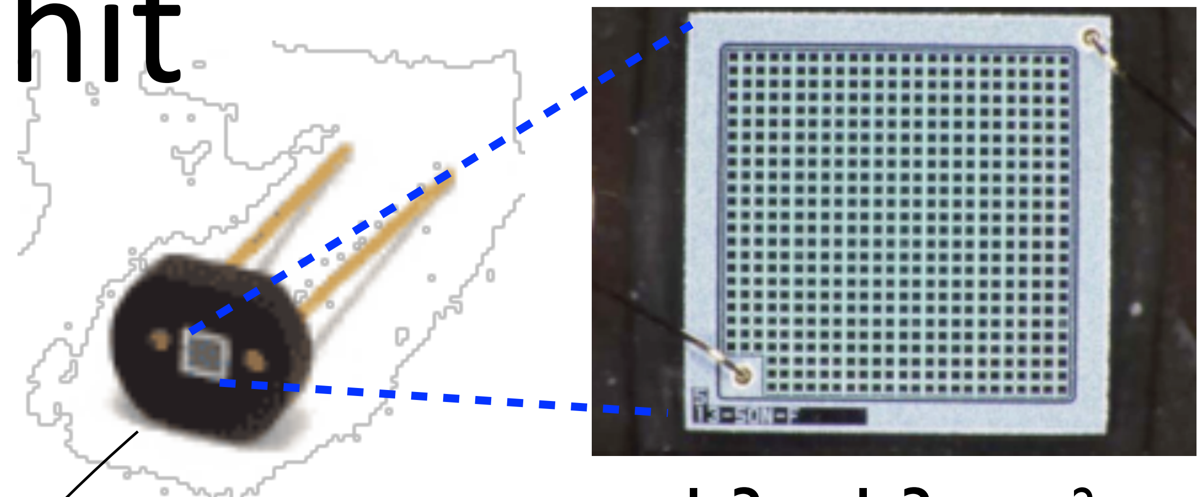




Blue light from dE/dx in scintillator is captured by wavelength-shifting fibre and re-emitted as green

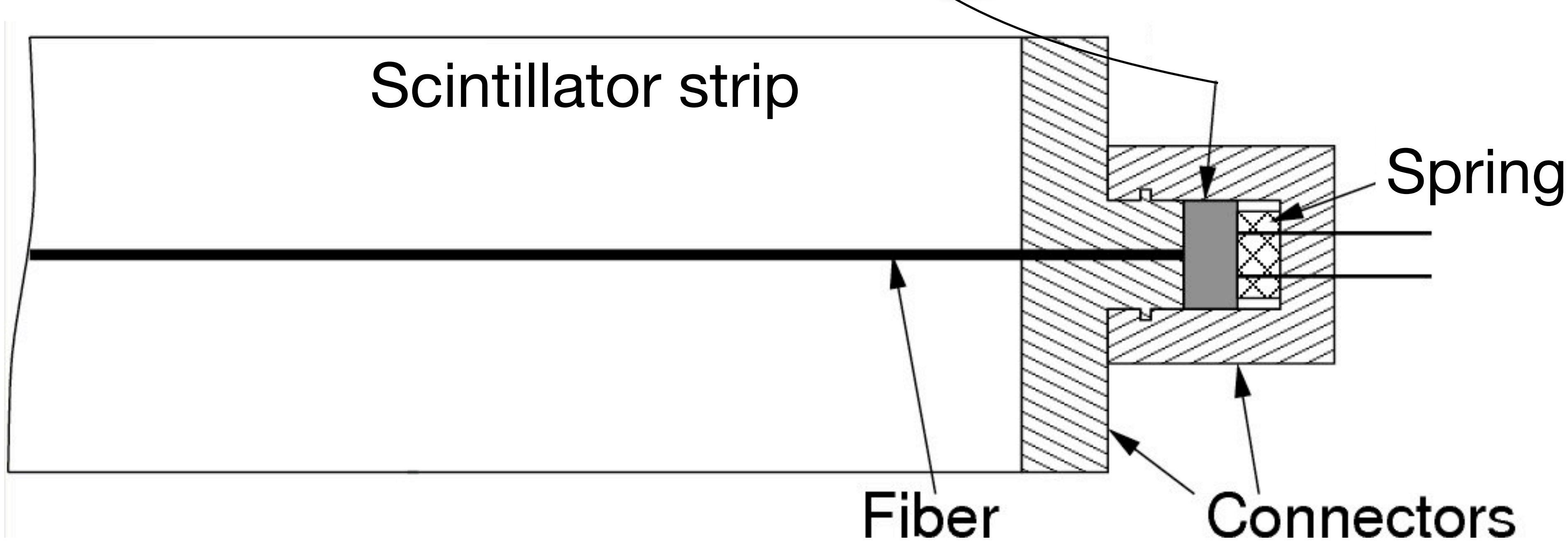
Photosensor detects the fibre's green light $\Rightarrow x$ or y hit

- SiPM ("Silicon photomultiplier") or MPPC ("multipixel photon counter") is a Geiger-mode avalanche photodiode
- Hamamatsu S10362 attached to one end of the scintillator strip
- fibre is mirrored at other end



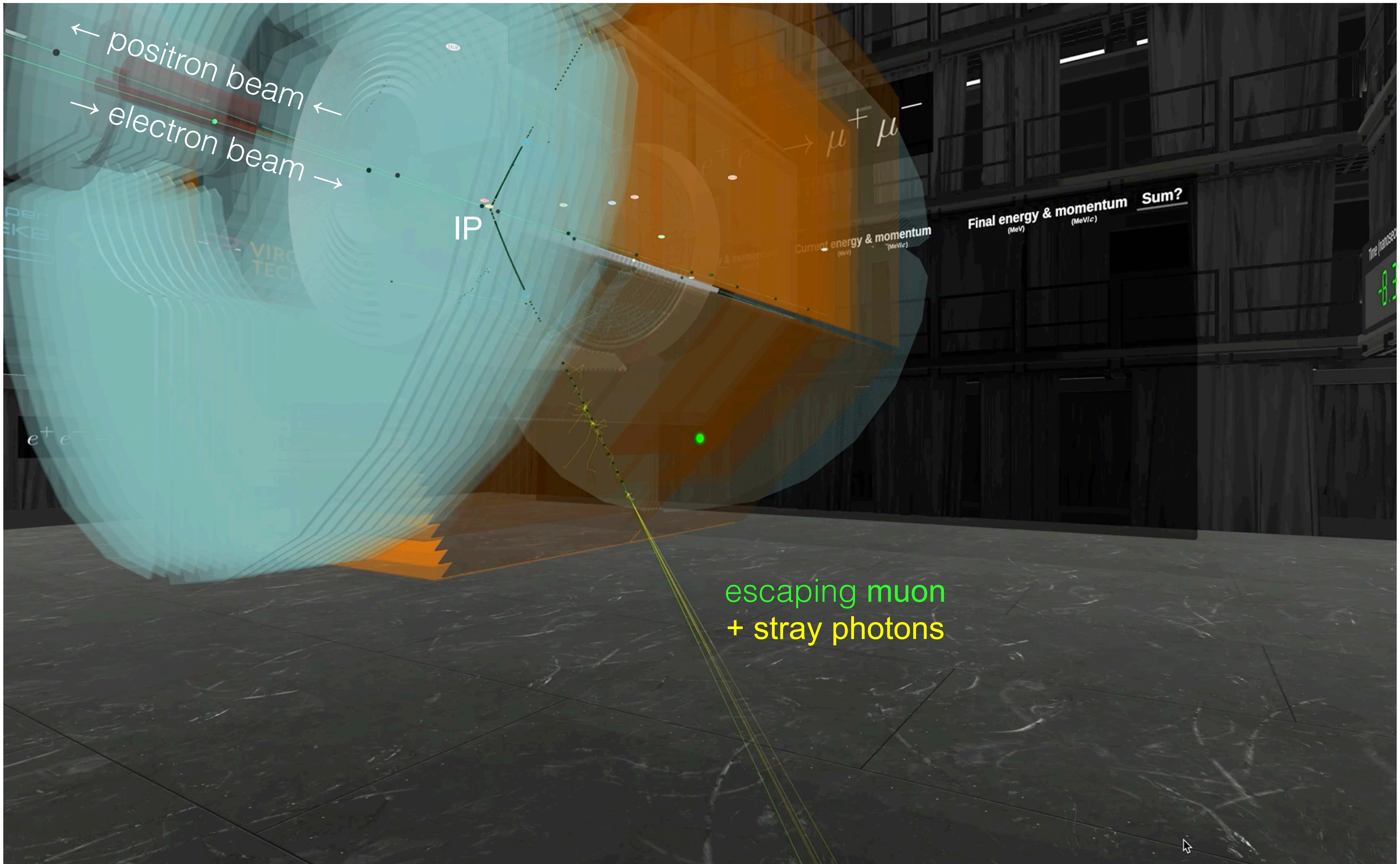
1.3 x 1.3 mm^2
667 pixels

✓ operates in 1.5 T magnetic field
✓ 8-pixel threshold gives $\varepsilon > 99\%$

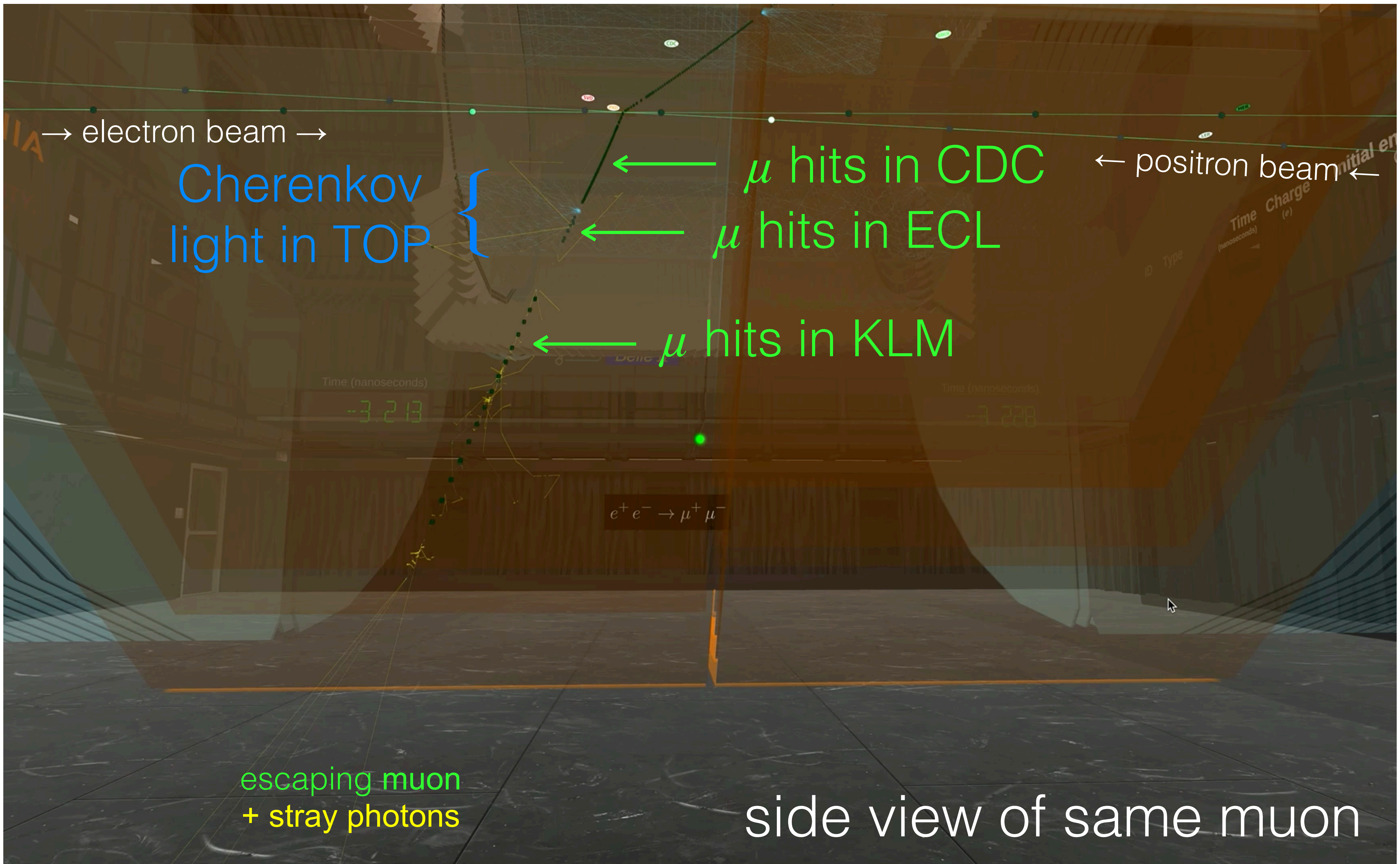


Muons, unlike other charged particles, pass thru **lots** of material (dE/dx only!)

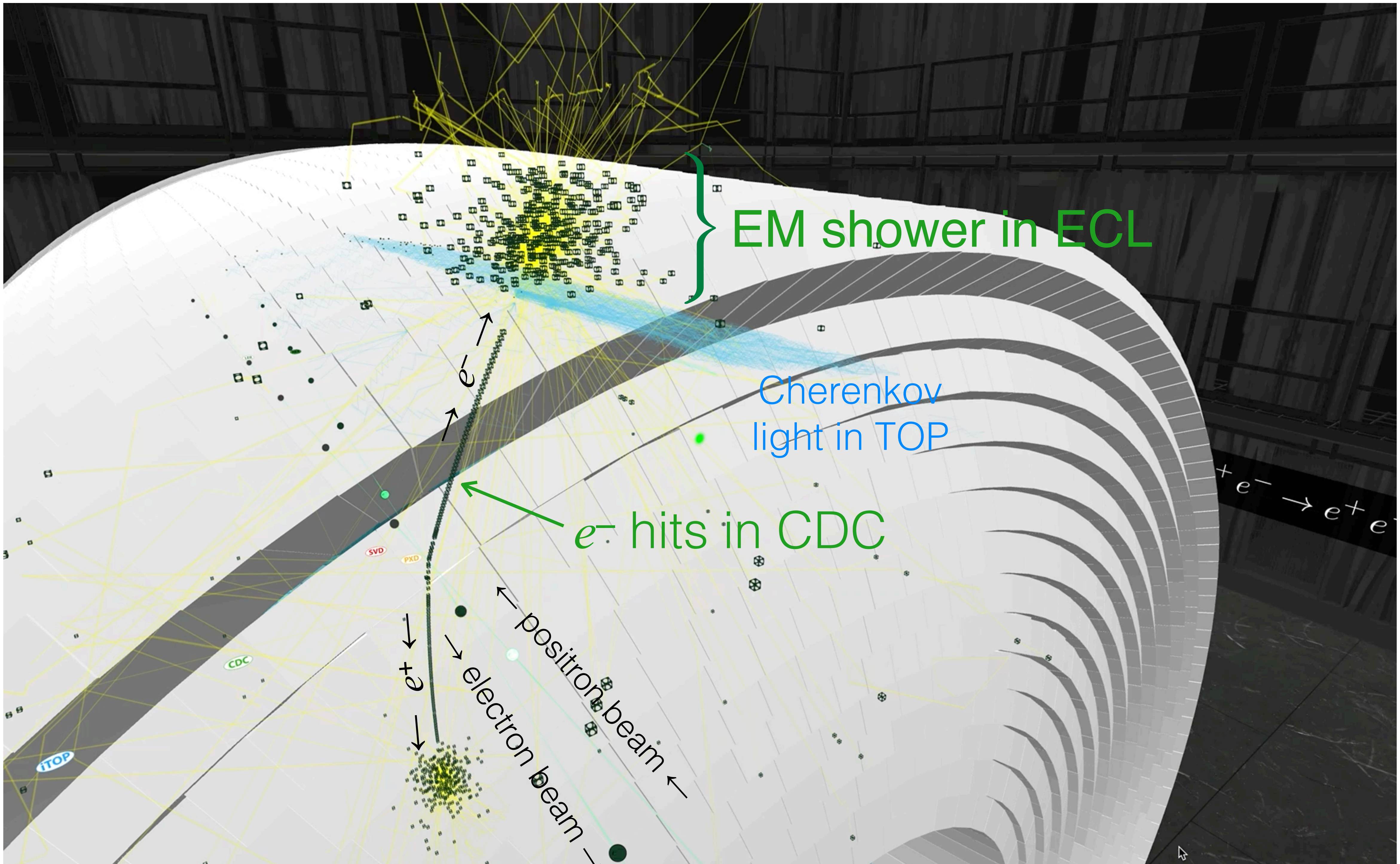
ECL, magnet, yoke, …



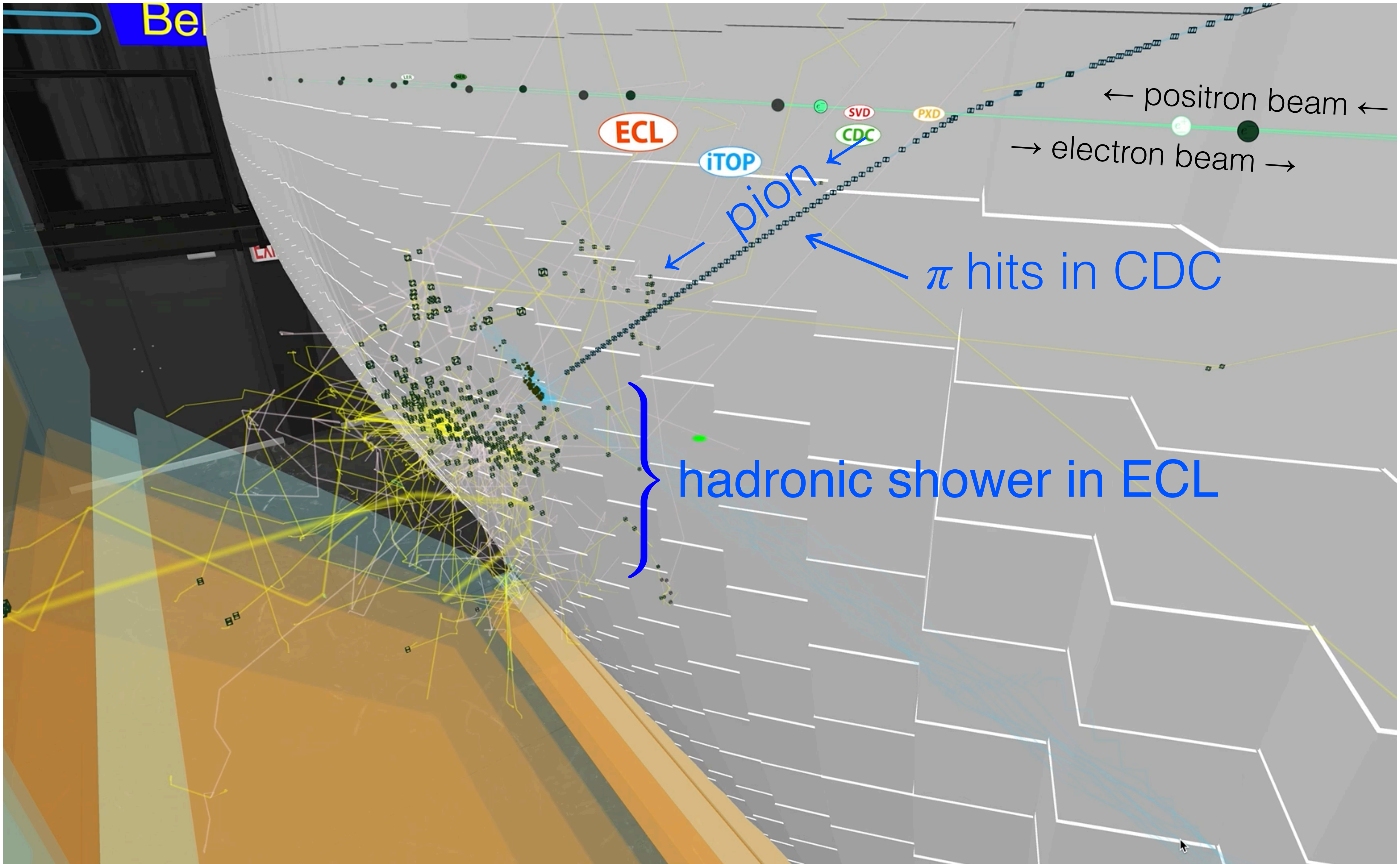
Muons, unlike other charged particles, pass thru lot of material (dE/dx only!)



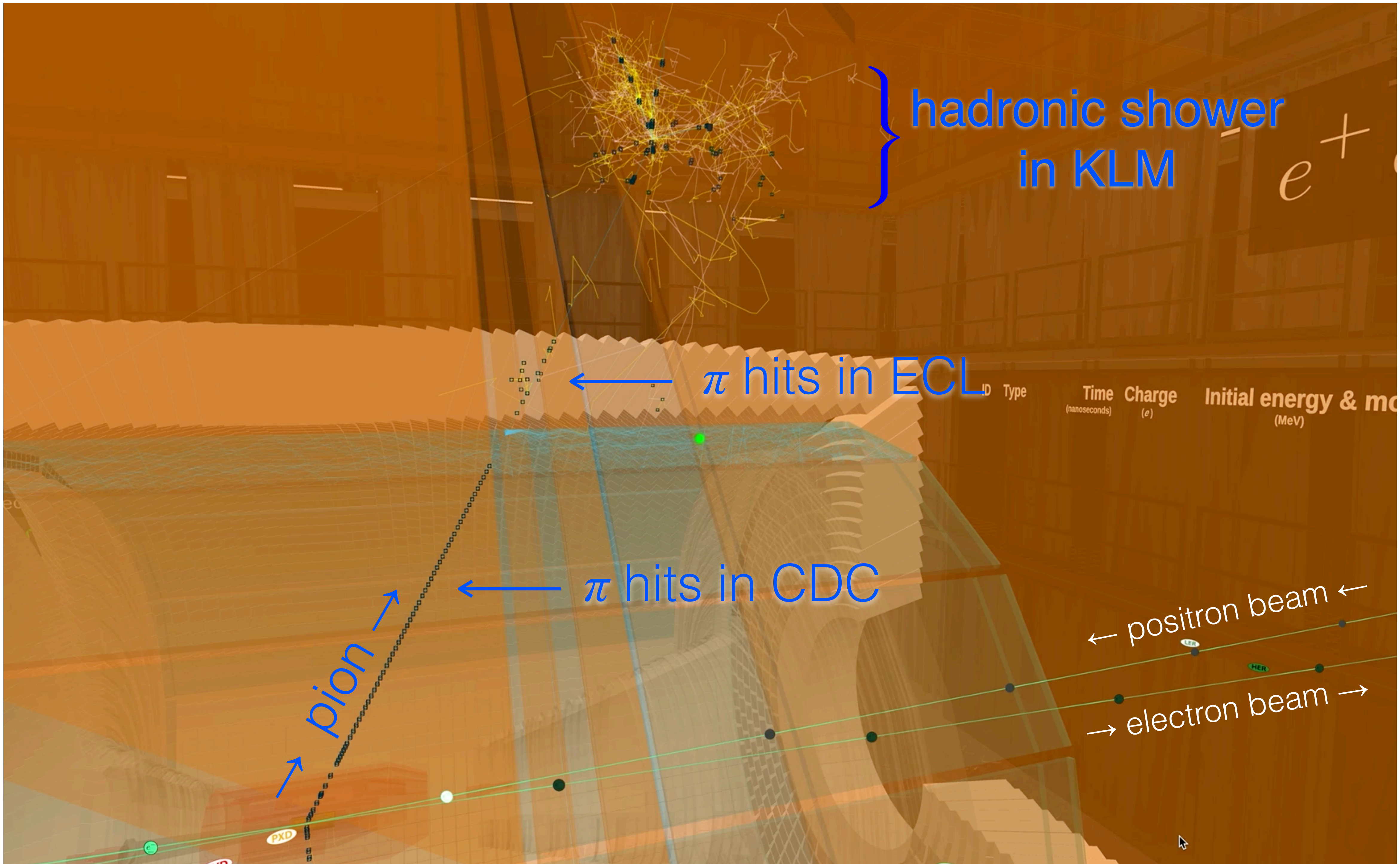
Electrons suffer EM interactions with ECL nuclei ⇒ electromagnetic shower



Pions suffer strong interaction with ECL nuclei ⇒ hadronic shower

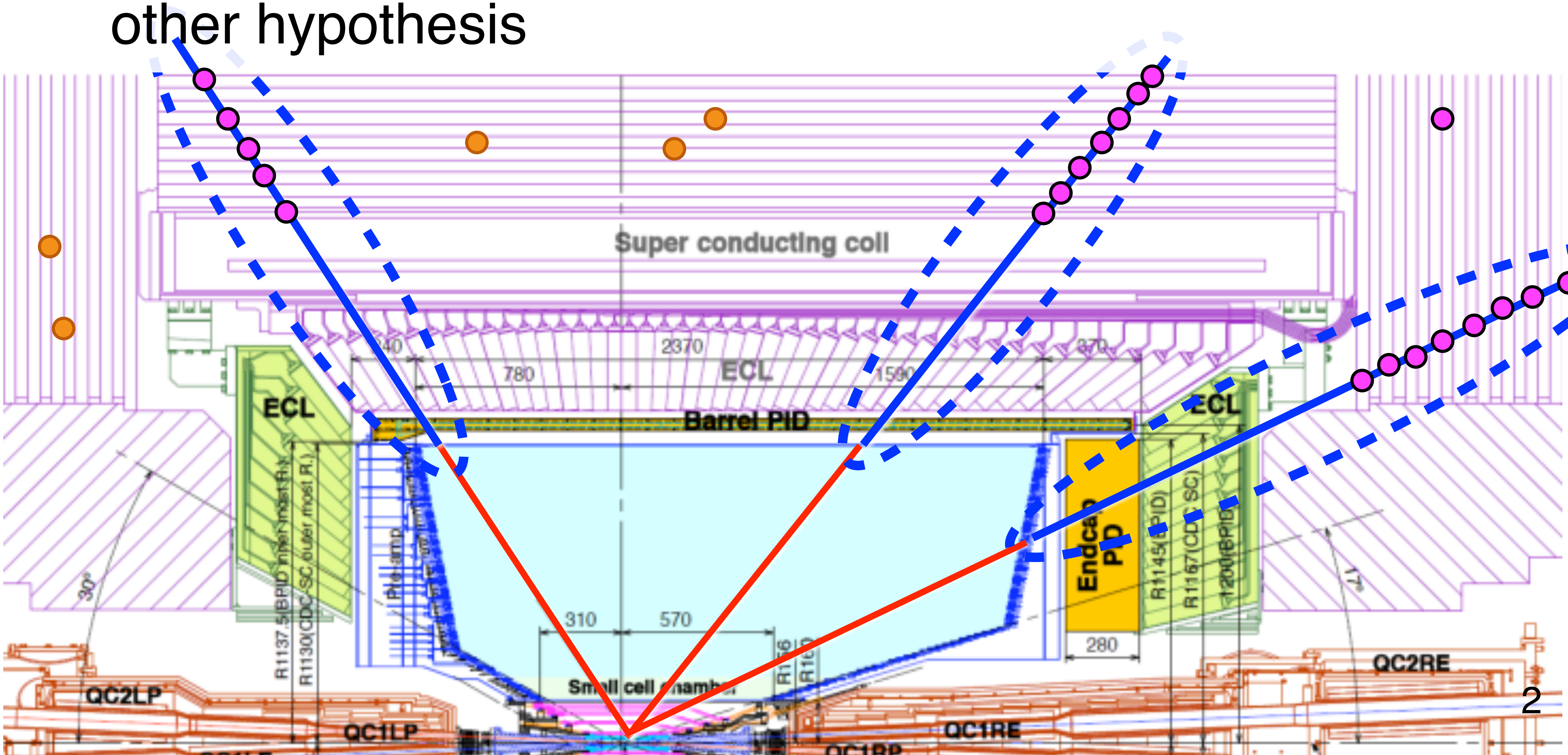


… or pions suffer strong interaction with KLM iron nuclei ⇒ hadronic shower



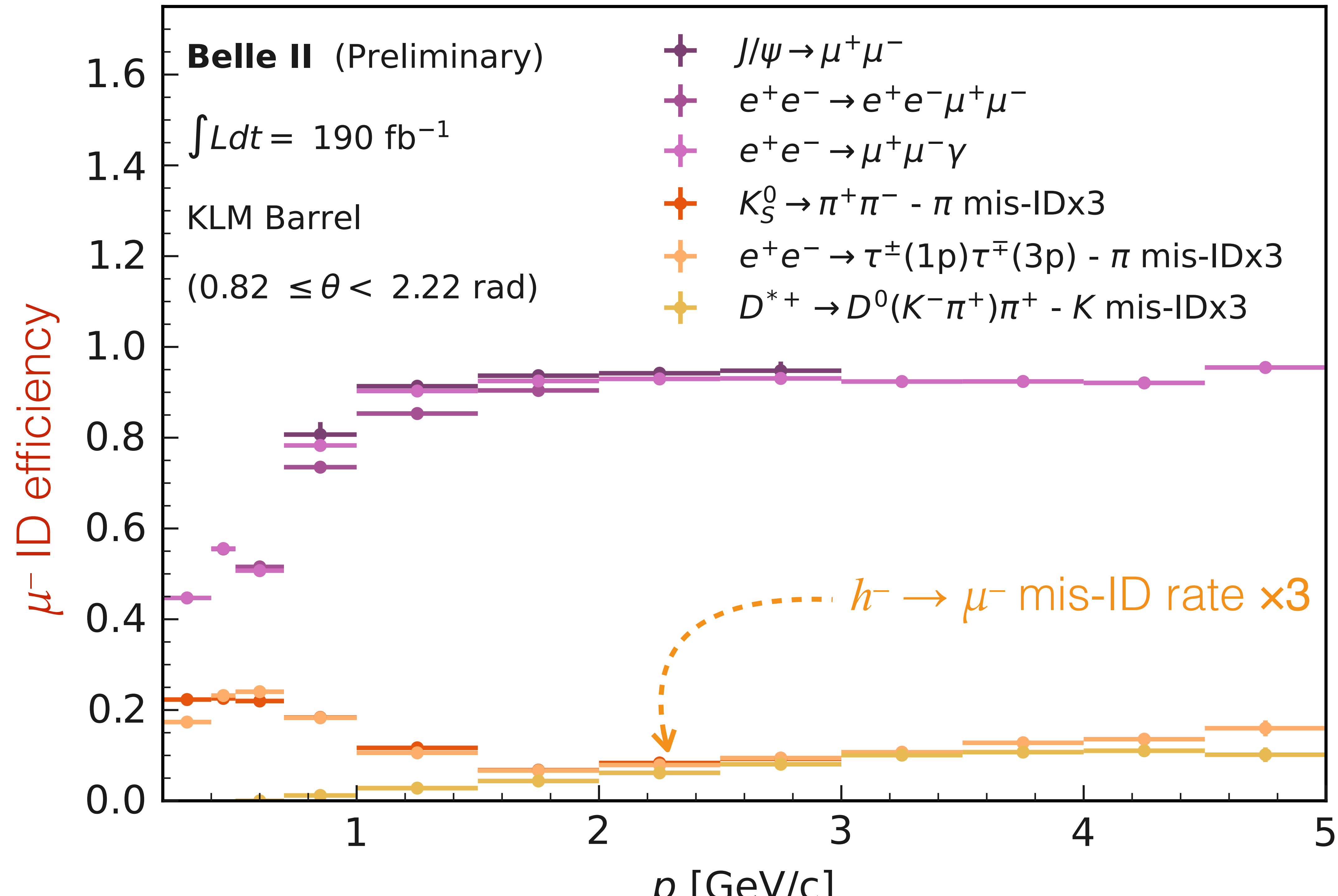
For muon identification, each CDC/VXD track is extrapolated outward by `geant4e` using μ hypothesis

- swim each track through KLM with Kalman fitting to matching hits and track adjustment
- compare measured vs extrapolated range and amount of transverse scattering to distinguish muon from any other hypothesis



KLM μ Identification Performance

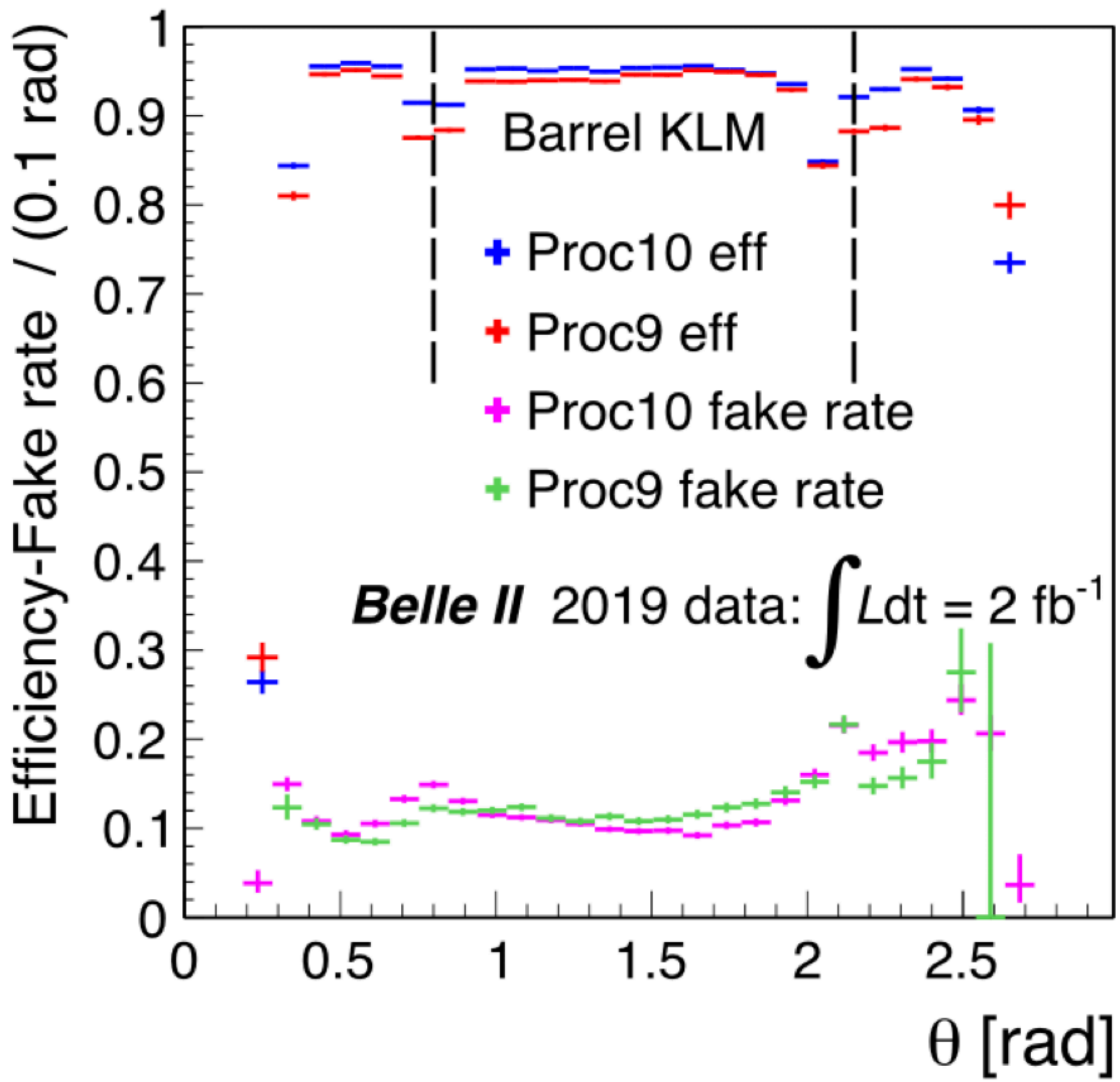
as a function of momentum (in the barrel region only)



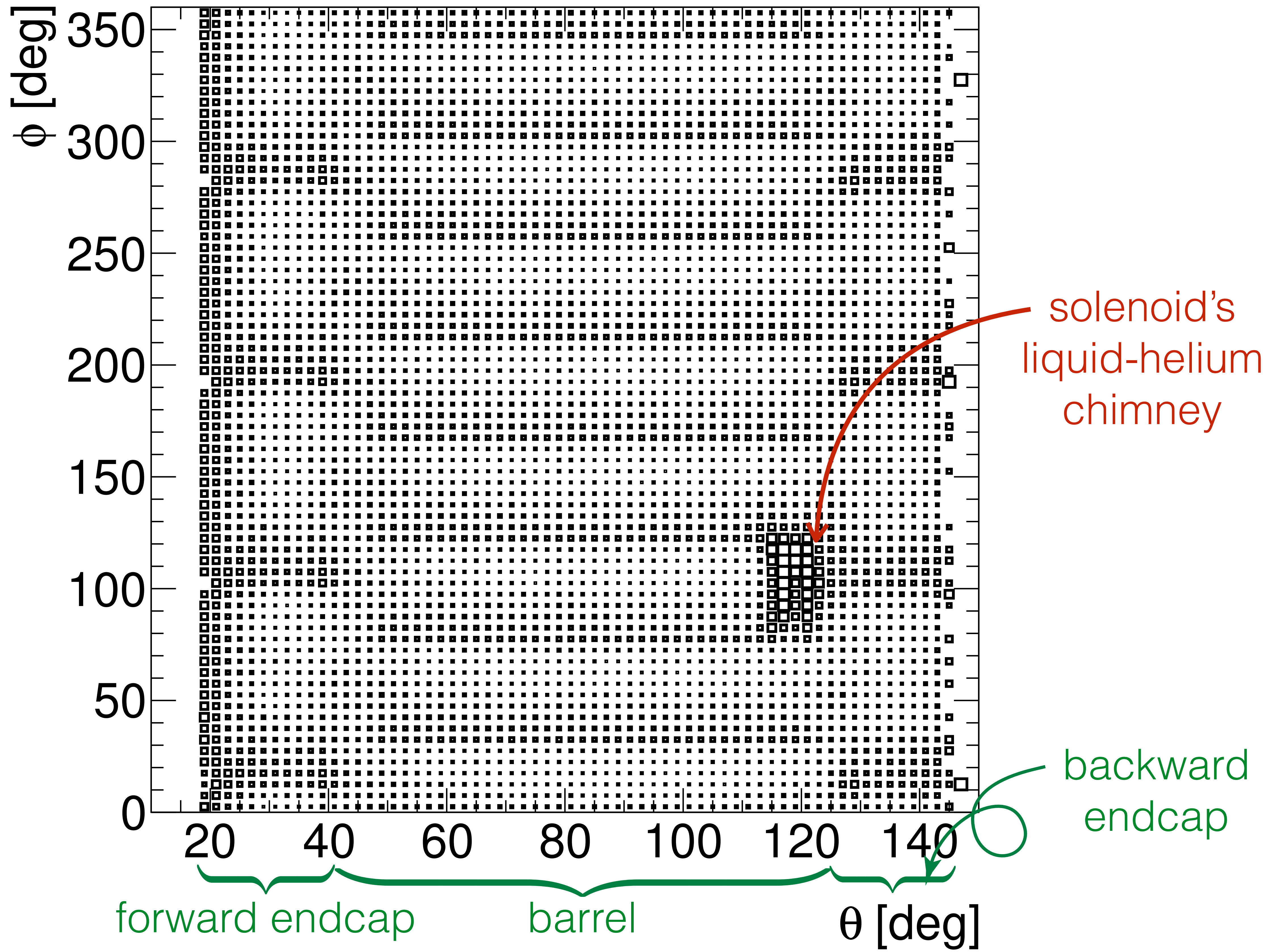
docs.belle2.org/record/2895/

KLM μ Identification Performance

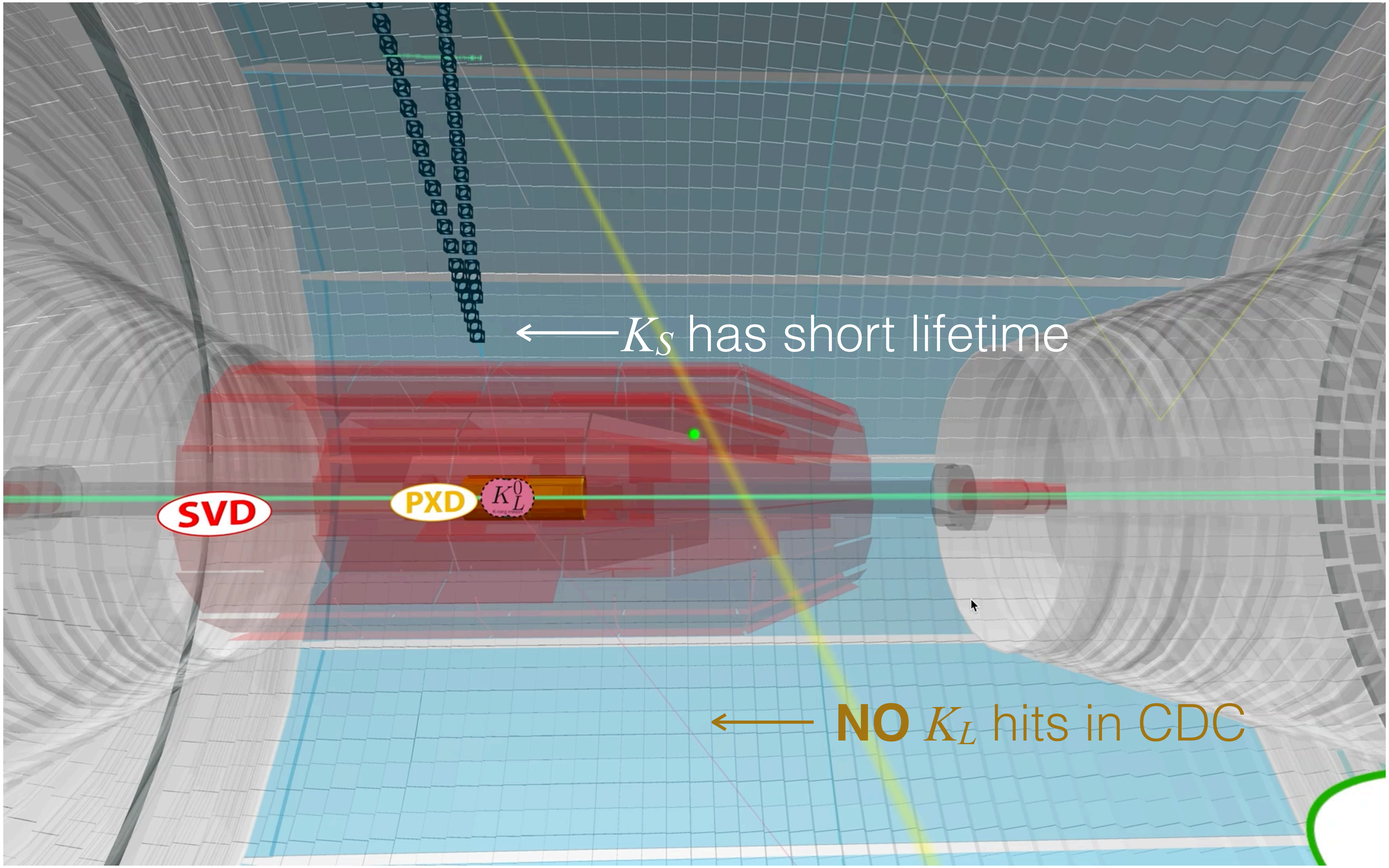
as a function of polar angle



Muon Identification Inefficiency

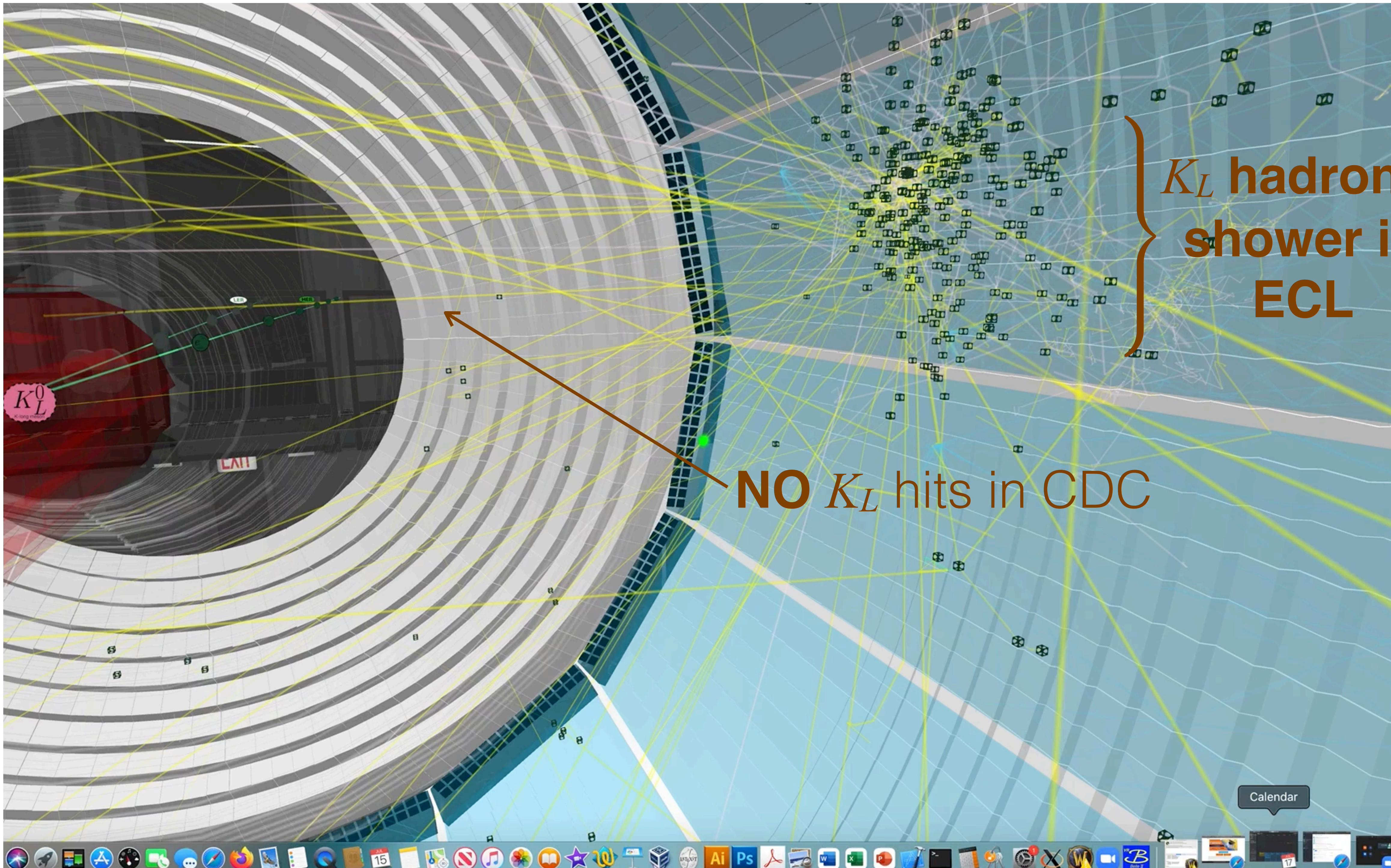


(Neutral) K-long leaves no hits along its path in VXD, CDC, TOP, …



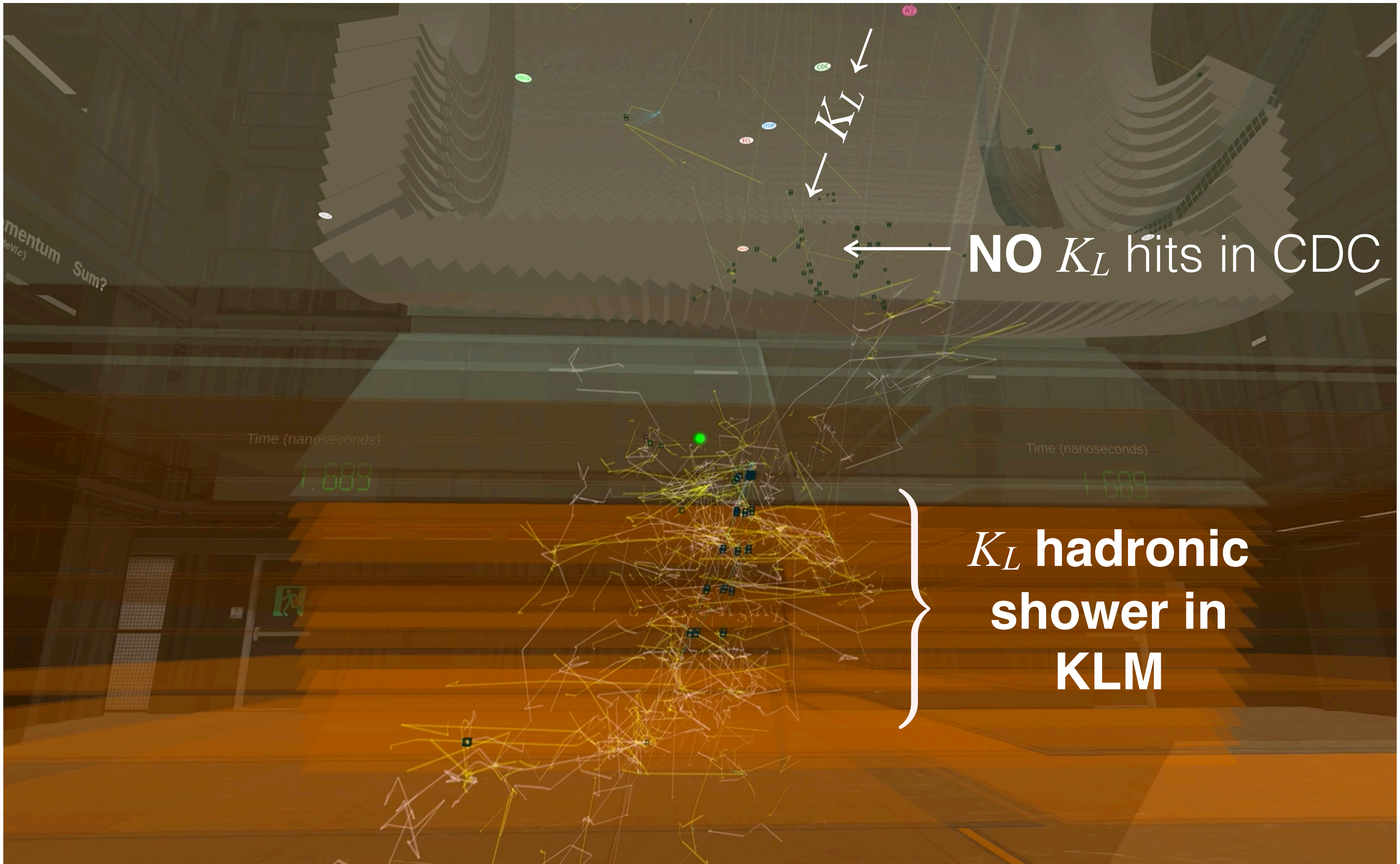
K-longs suffer strong interaction with ECL nuclei ⇒ hadronic shower

without a matching CDC track



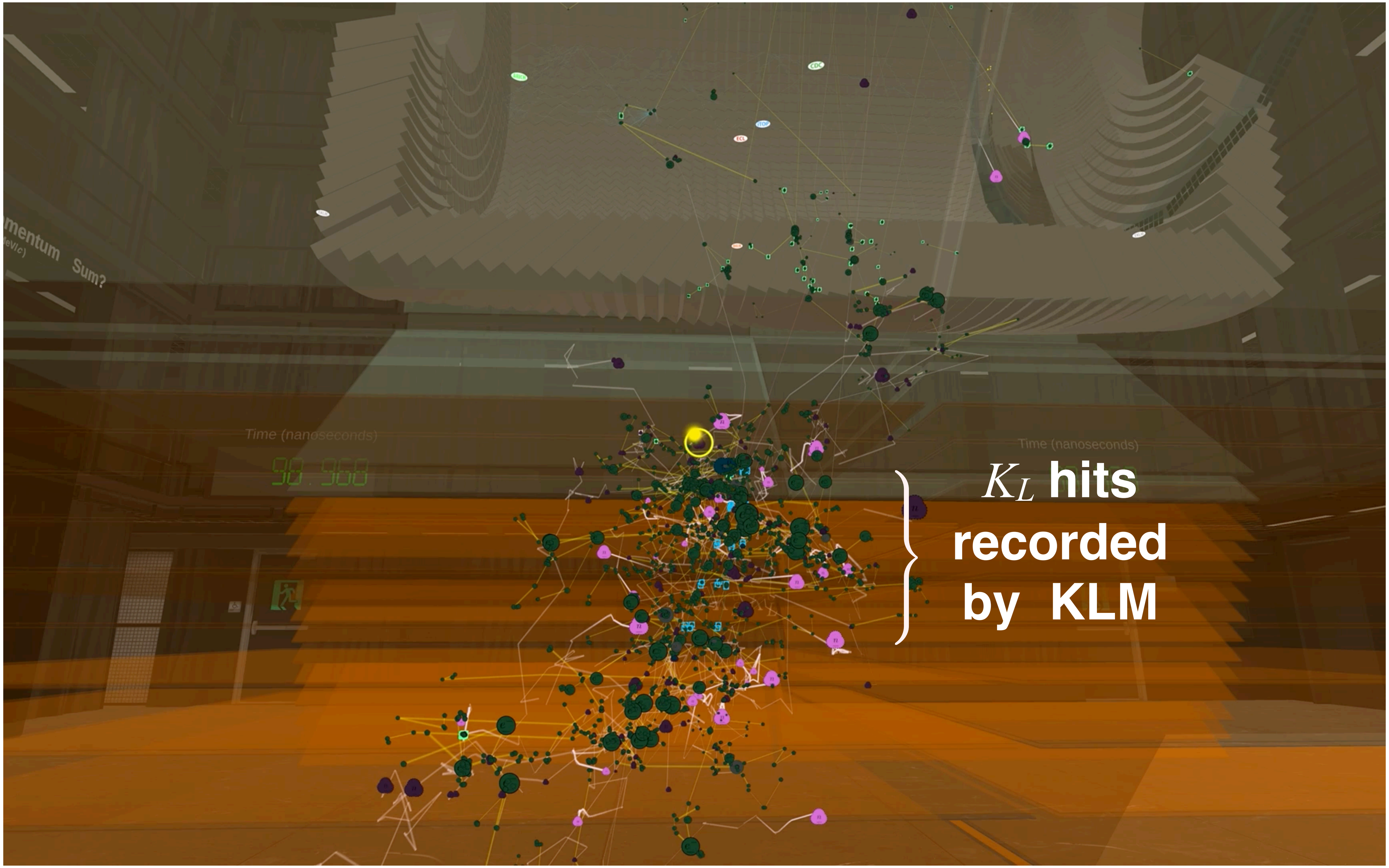
… or K-longs suffer strong interaction with KLM iron nuclei ⇒ hadronic shower

without a matching CDC track



… or K-longs suffer strong interaction with KLM iron nuclei ⇒ hadronic shower

without a matching CDC track



The `klongID` Boosted Decision Tree

- **`klongID`** uses a fast BDT from the basf2 MVA package
- Uses input from (KLM-only) and (KLM+ECL) clusters
- Produces the official list of K_L candidates

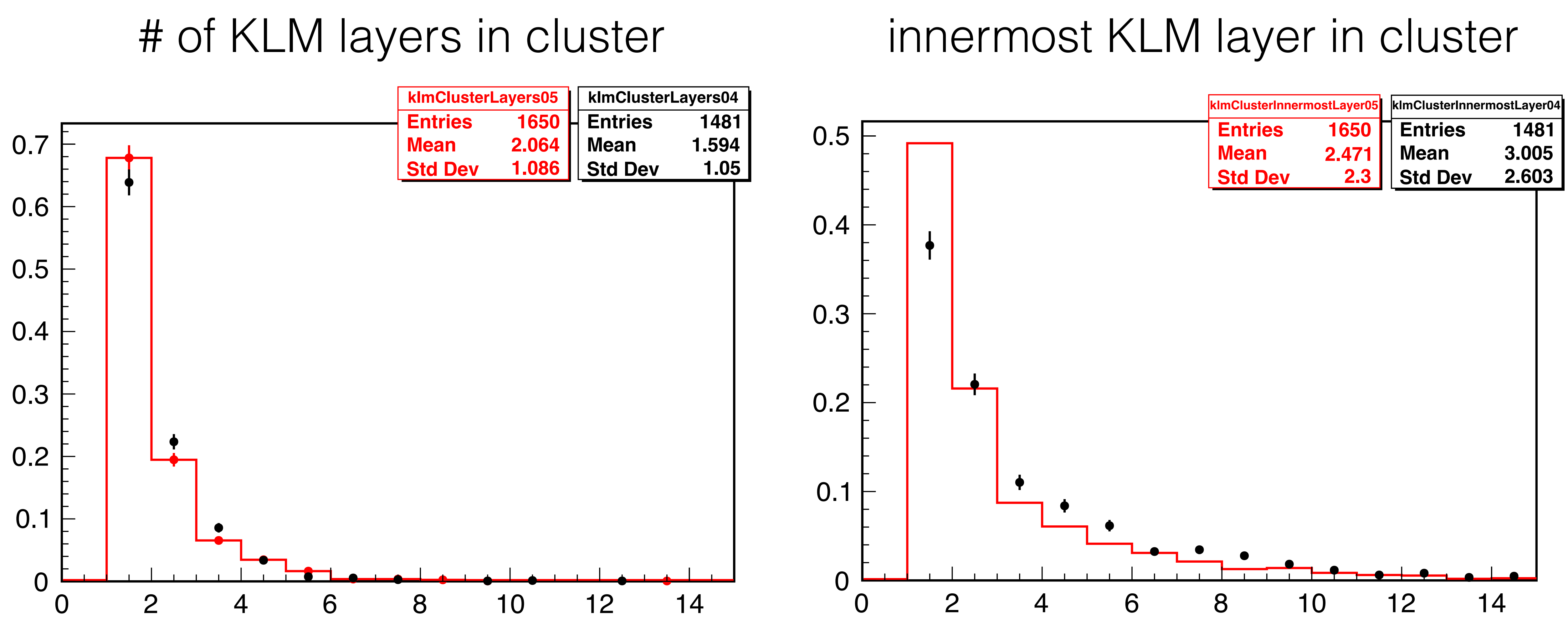
BDT inputs from the KLM:

✓ # of KLM layers in cluster
✓ layer # of first layer in cluster
✓ angular position w.r.t. IP of cluster centroid
✓ 3D distance of nearest track to cluster centroid
✓ (+ other less useful measures)

Caution: BDT must be trained with similar-topology sample (particularly considering # of tracks in event)

The **`klongID`** Boosted Decision Tree

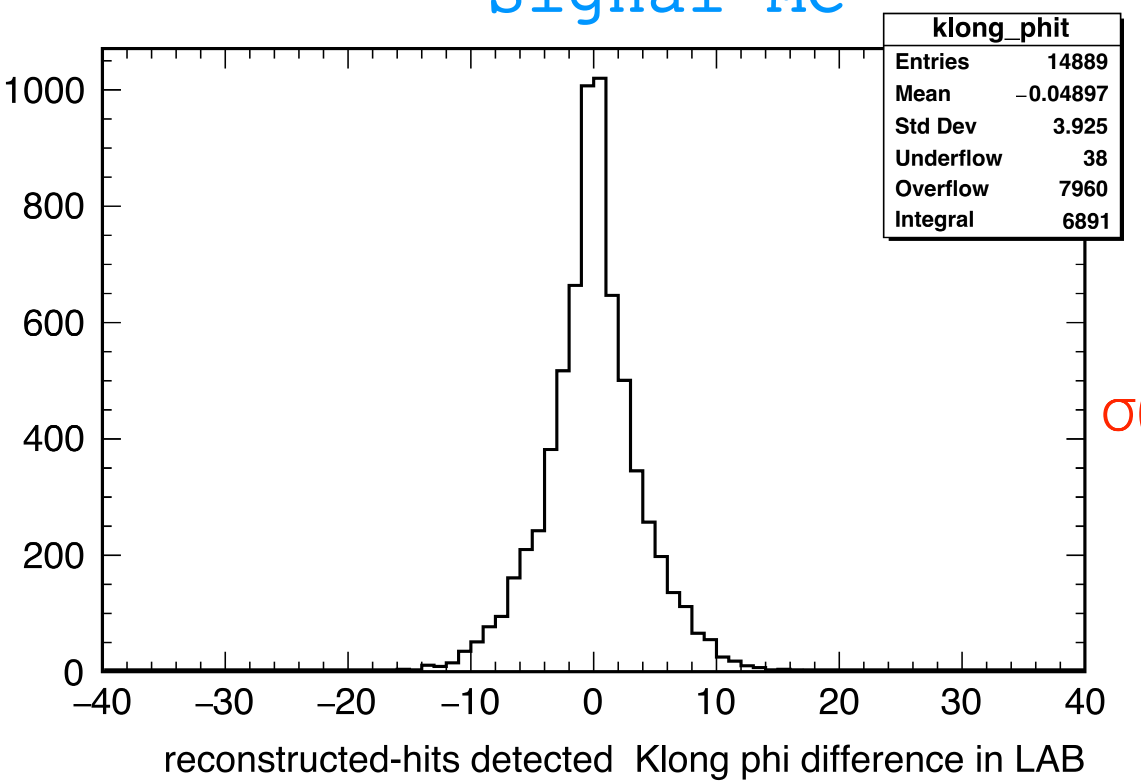
- two of the useful BDT inputs (MC, truth-matched):

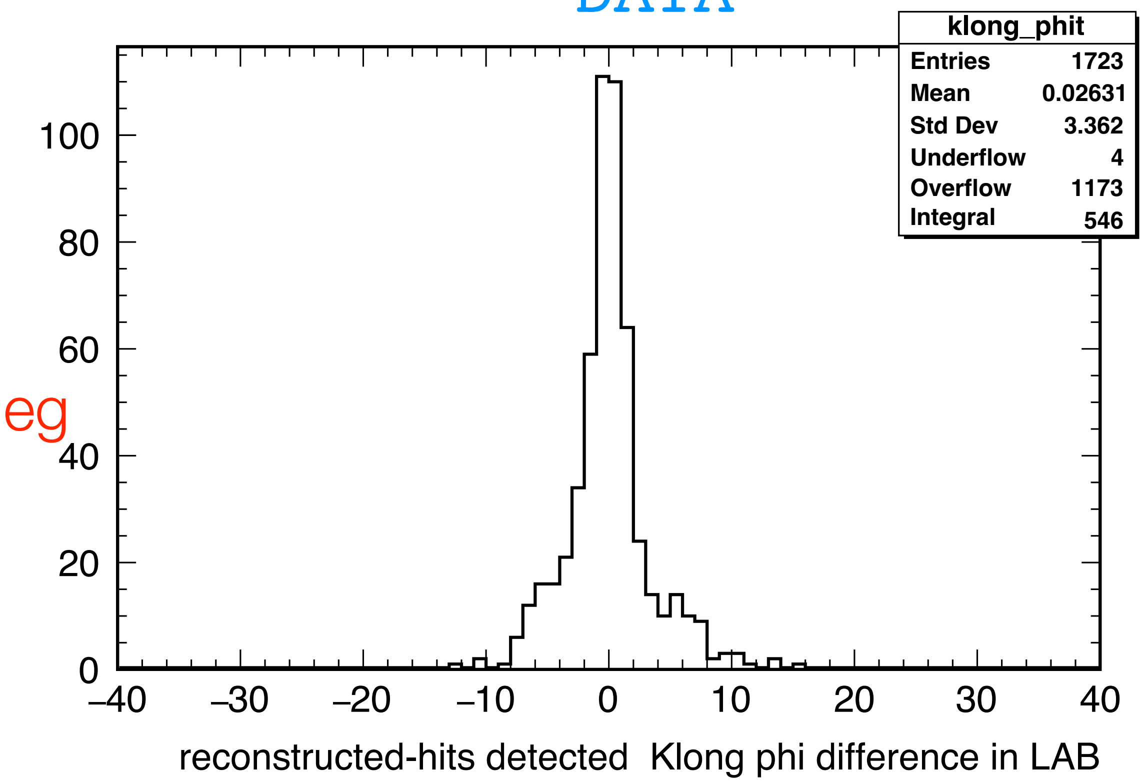


The **klongID** Boosted Decision Tree

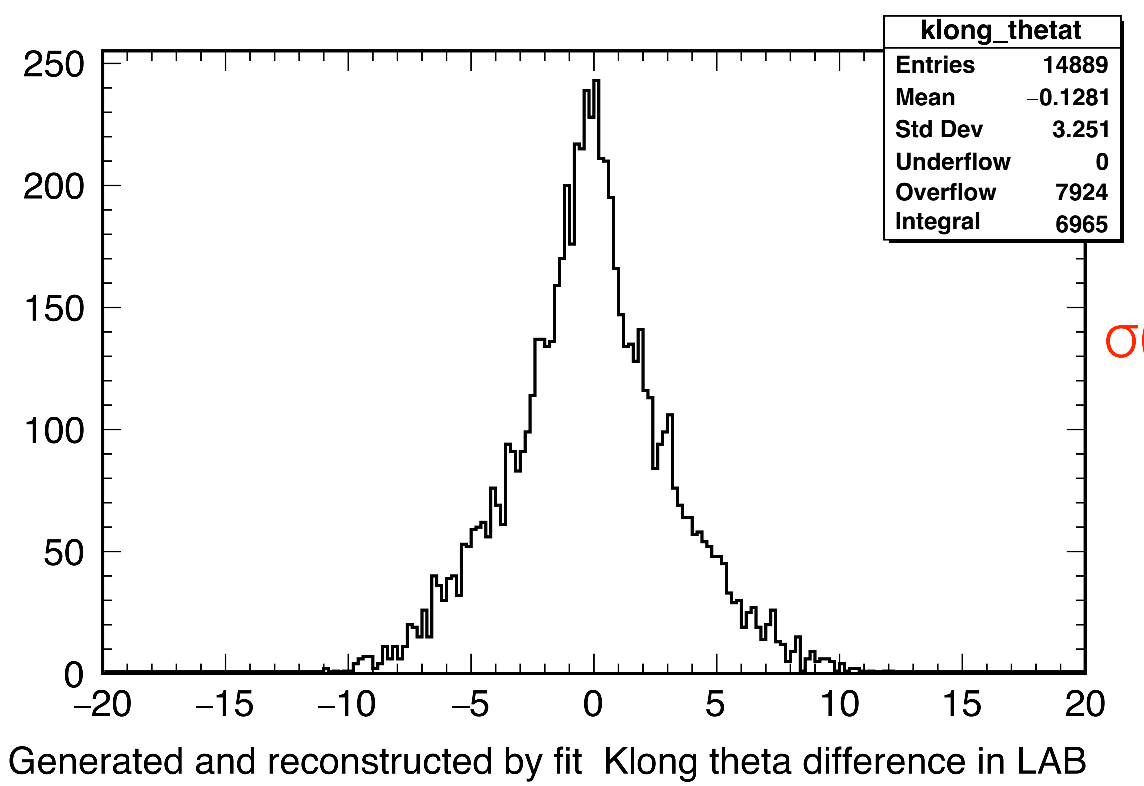
- angular position is an input – resolution is decent

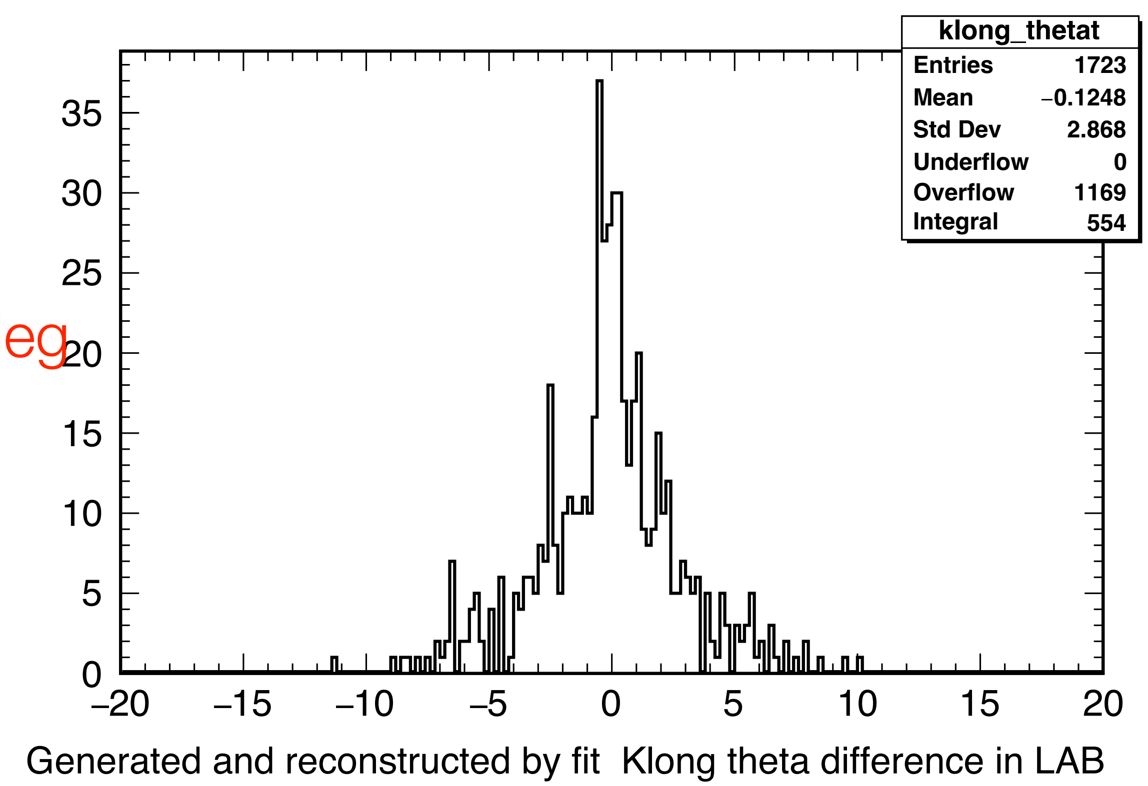
Signal MC | DATA





σ(ϕ)~3 deg

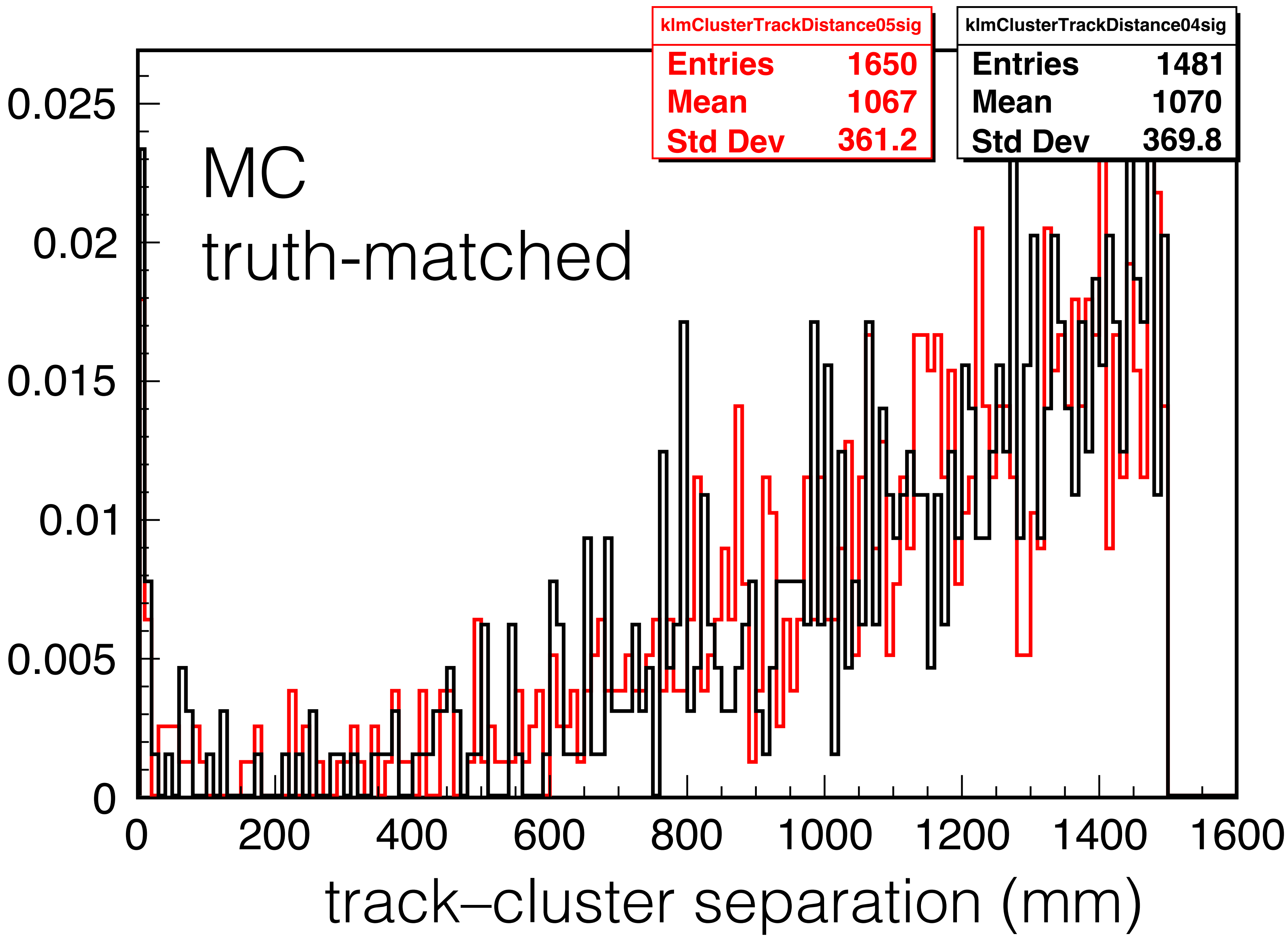




σ(θ)~2 deg

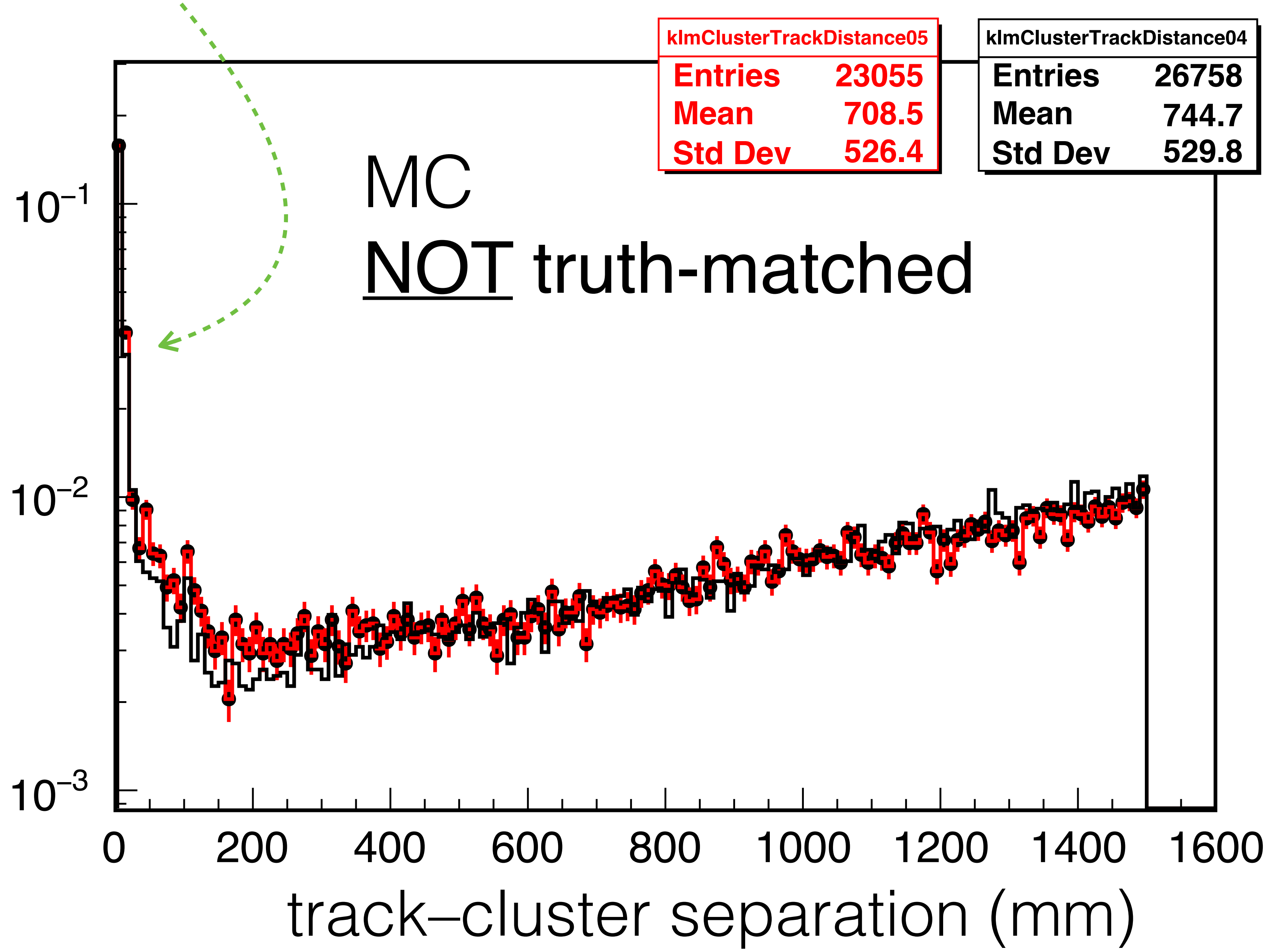
The `klongID` Boosted Decision Tree

- 3D distance between K_L-candidate cluster and nearest [extrapolated] CDC track
- calculated during muID track extrapolation



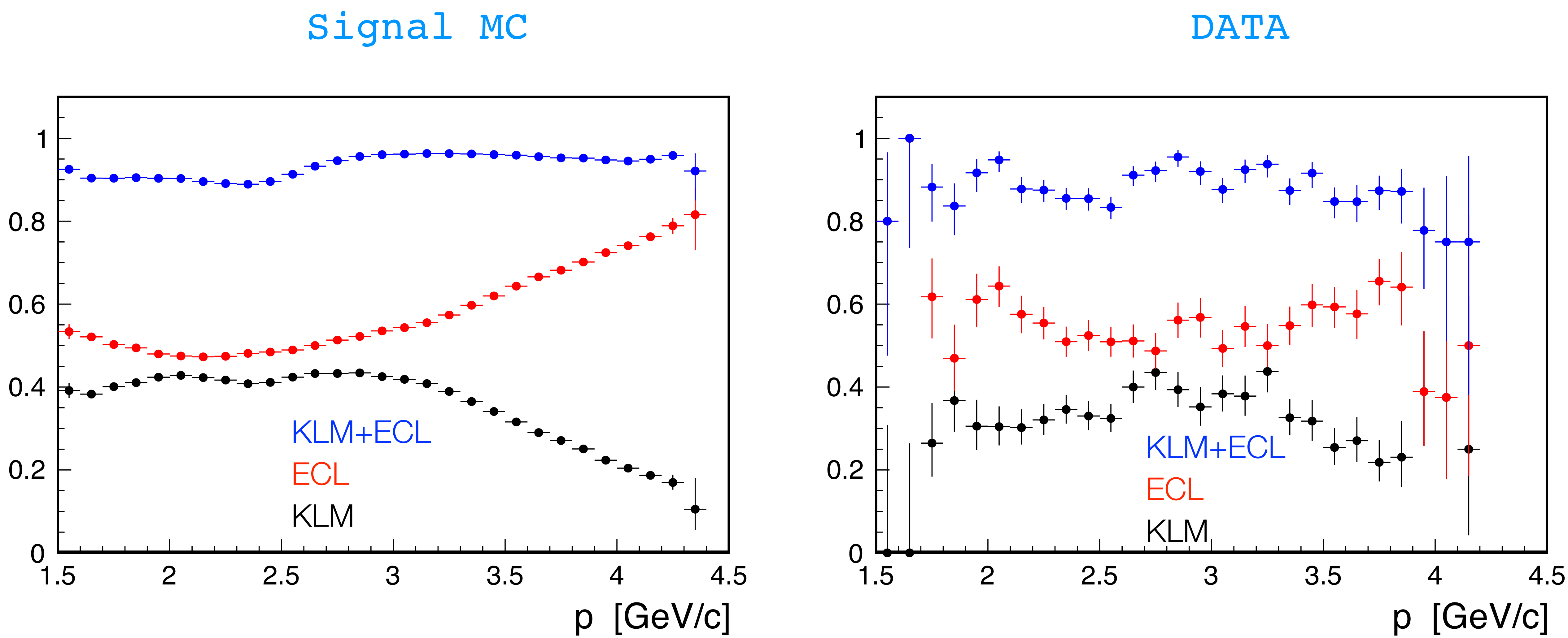
The **klongID** Boosted Decision Tree

- 3D distance between K_L-candidate cluster and nearest [extrapolated] CDC track is very small for “clusters” made by muon tracks



The **klongID** Boosted Decision Tree

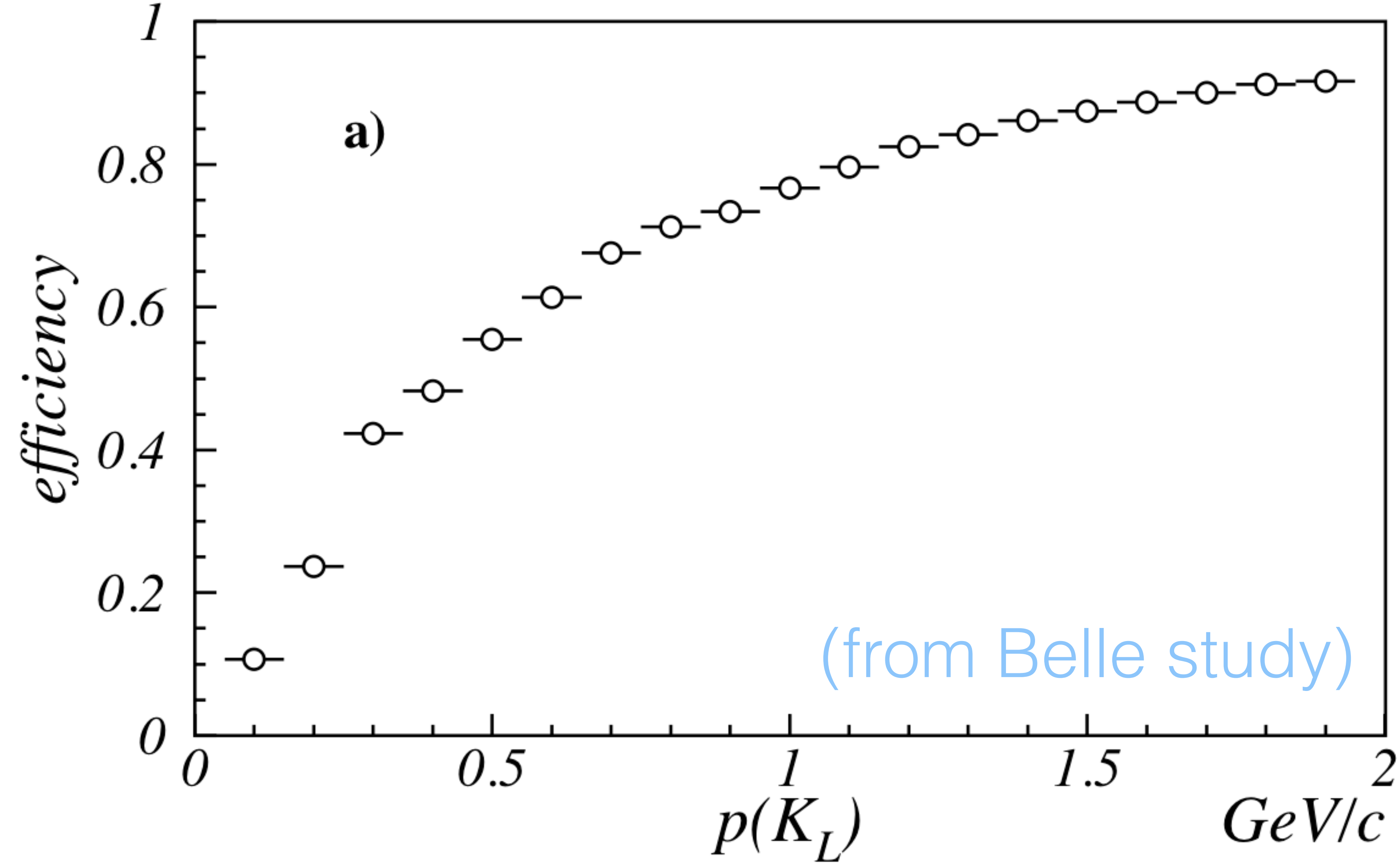
- detection efficiency is good for high-momentum K_L's from $e^+ e^- \to \phi[K_L K_S] \gamma$



- Require KLM cluster with 2 layers
- Require ECL cluster with E>0.4GeV and **ECLclusterPulseShapeDiscriminationMVA**<0.4
- Trend vs. p is due to angular coverage and amount of material

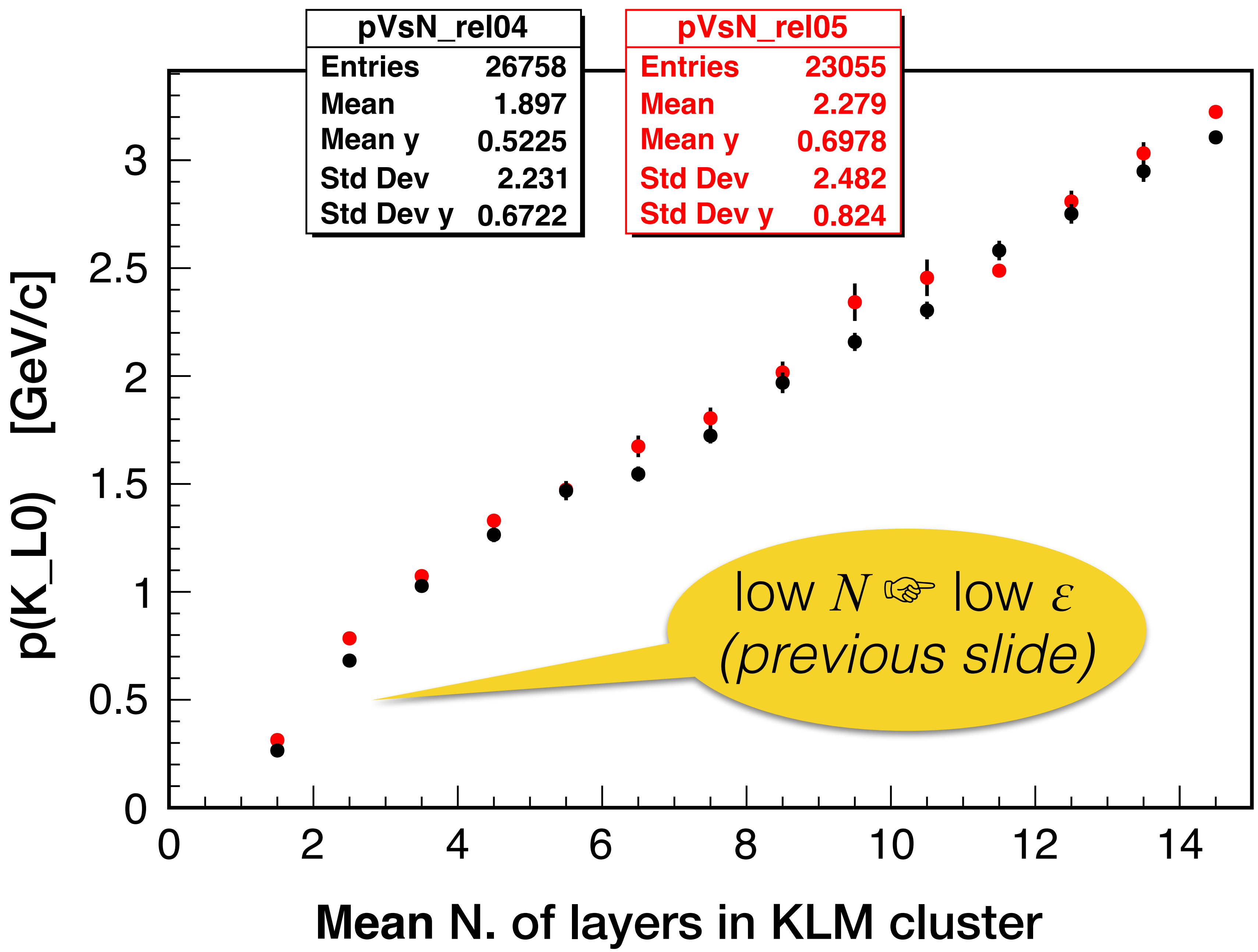
The `klongID` Boosted Decision Tree

- detection efficiency is worse for low-momentum K_L's



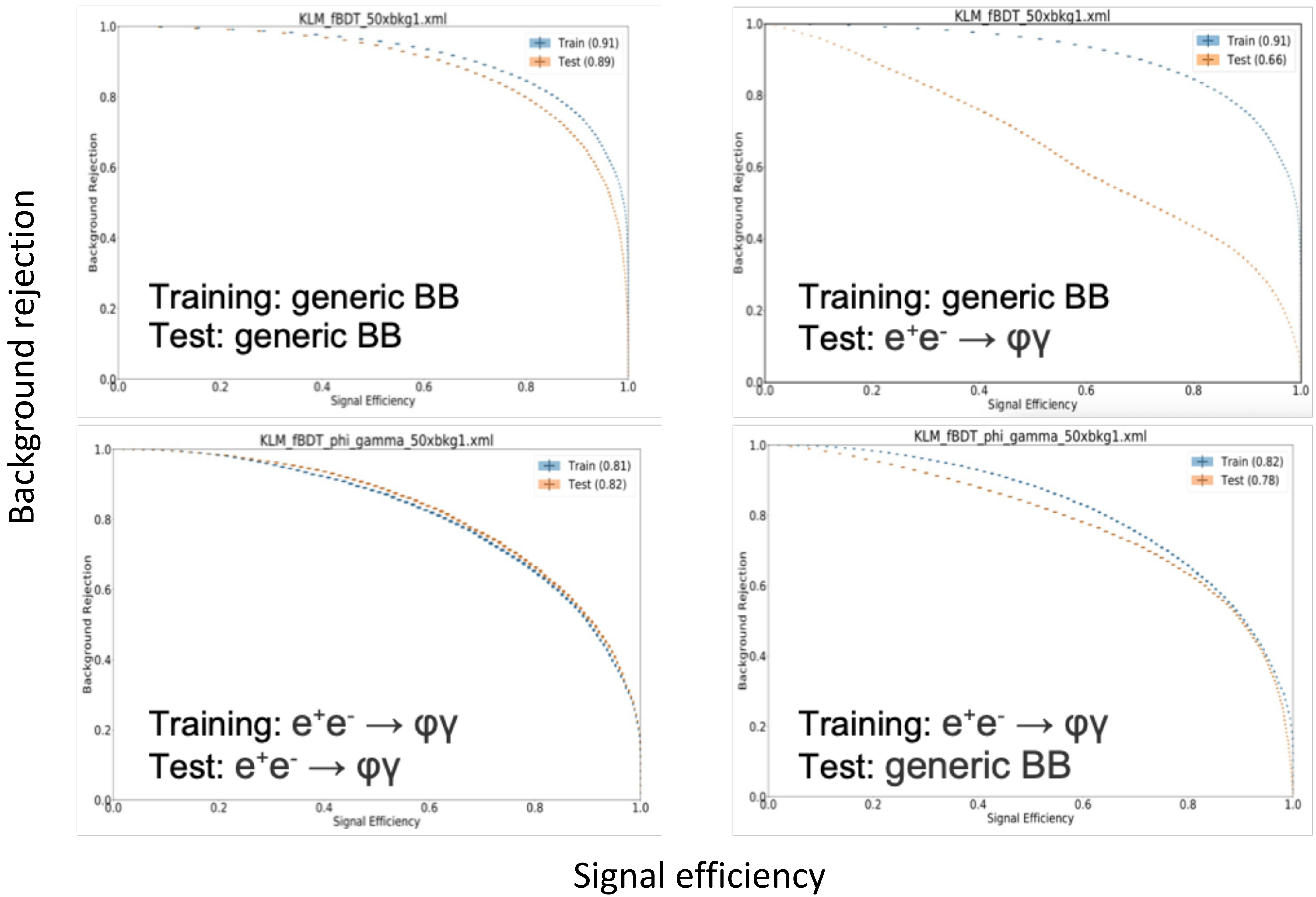
The **klongID** Boosted Decision Tree

- **mean** # of layers is correlated with K_L momentum
- large **spread** ⇒ momentum resolution is poor
- only the K_L direction (from IP) is measured



KLM K_L identification: Training & Test

- *Use a trained Boosted Decision Tree to distinguish K_L meson from background*
- *BDT output depends on the event topology*
- *No universal training sample works for all event topologies*



Summary

✓ Belle II's KLM (K_L–Muon detector) identifies muons and K-long mesons based on their unique signatures in the KLM, combined with info from inner detectors

✓ Muons leave long clean tracks in KLM that match with extrapolation of CDC/VXD tracks

➡ confluence.desy.de/display/BI/Lepton+ID+Performance

✓ K-long mesons deposit a cluster of hits in KLM (and perhaps ECL first) without a matching CDC/VXD track

➡ confluence.desy.de/display/BI/Neutrals+Performance