Belle II KLM
Muon and $K_L$
Particle Identification

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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)
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Installing Endcap KLM Detector Module (2014)
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• KLM detects $K_L$ mesons and muons ($\approx 1$ per event)

For example: $B^0 \rightarrow J/\psi K_L$ event
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
\[ \rho \approx 10^{12} \, \Omega \cdot \text{cm} \]

Non-flammable gas:
- 62% HFC-134a
- 30% argon
- 8% butane-silver

“active volume”
“sensitive volume”

+4.7 kV +HV

Gas gap

-3.5 kV -HV

3.00 mm

2.00 mm

3.00 mm
One panel has two independent RPCs
A discharge ★ (=streamer) from $dE/dx$ in *either* gas gap induces an image charge on *both* readout planes ⇒ $xy$ hit.
Cathode-plane strips are transmission lines ... collect signal at end of strip

Ground plane

Dielectric foam

Cathode plane

+HV

Gas gap

-HV

Insulator

+HV

Gas gap

-HV

Cathode plane

Dielectric foam

Ground plane

0.25 mm Mylar
0.035 mm Copper

7 mm

0.035 mm Copper
0.25 mm Mylar

3.00 mm

0.5 mm Mylar

3.00 mm

0.25 mm Mylar
0.035 mm Copper

7 mm

0.035 mm Copper
0.25 mm Mylar

≈ 50 Ω

~32 mm
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)
Scintillator (with TiO$_2$ reflective coating) delivers **blue light** to central-bore WLS fibre

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
- \( \checkmark \) operates in 1.5 T magnetic field
- \( \checkmark \) 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!\)

- \(\mu\) hits in CDC
- \(\mu\) hits in ECL
- \(\mu\) hits in KLM
- Cherenkov light in TOP
- Escaping muon + stray photons
- Side view of same muon
Electrons suffer EM interactions with ECL nuclei $\Rightarrow$ electromagnetic shower
Pions suffer strong interaction with ECL nuclei \( \Rightarrow \) hadronic shower
... or pions suffer strong interaction with KLM iron nuclei $\Rightarrow$ hadronic shower
For muon identification, each CDC/VXD track is extrapolated outward by Geant4 using $\mu$ 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

From Alberto Martini:

✓ Already better than Belle, due to algorithm improvements
✓ More performance improvements in progress

![Graph showing efficiency-fake rate vs momentum and angle](image)

**Belle II** 2019 data: $\int L dt = 2 \text{ fb}^{-1}$

**Performances for proc10 (new)**
- Efficiency: $\sim 93.5\%$ overall
- Fake rate: $\sim 11\%$ overall

**Performances for proc9 (old)**
- Efficiency: $\sim 92.0\%$ overall
- Fake rate: $\sim 12\%$ overall
Muon Identification Efficiency

- φ [deg]
- θ [deg]

- Forward endcap
- Backward endcap
- Barrel

Solenoid’s liquid-helium chimney
K-long leaves no hits along its path in VXD, CDC, TOP, ...
K-longes suffer strong interaction with ECL nuclei $\Rightarrow$ hadronic shower without a matching CDC track
... or K-longos suffer strong interaction with KLM iron nuclei $\Rightarrow$ hadronic shower

without a matching CDC track

$K_L$ hadronic shower in KLM

NO $K_L$ hits in CDC
... or K-longs suffer strong interaction with KLM iron nuclei \( \Rightarrow \) hadronic shower without a matching CDC track
The **klongID** BDT
(from Giuseppe Finocchiaro)

- The **klongID** is calculated by a fast BDT from the basf2 MVA package, presently using input from KLM and ECL (only in conjunction with KLM)

- Produce official list of KL

KLM Inputs:
- ✓ # 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)
KLM $K_L$ identification Status

From G. Finocchiaro:

➢ Use a trained Boosted Decision Tree to distinguish $K_L$ meson from background

➢ BDT output depends on the event topology.

➢ No universal training sample.

➢ BDT can be done only with run-dependent MC that can be produced only after reprocessing

❖ KLID is still a work in progress. For example, ...
❖ Define $K_L$ clusters at reconstruction stage but defer BDT to analysis stage
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

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