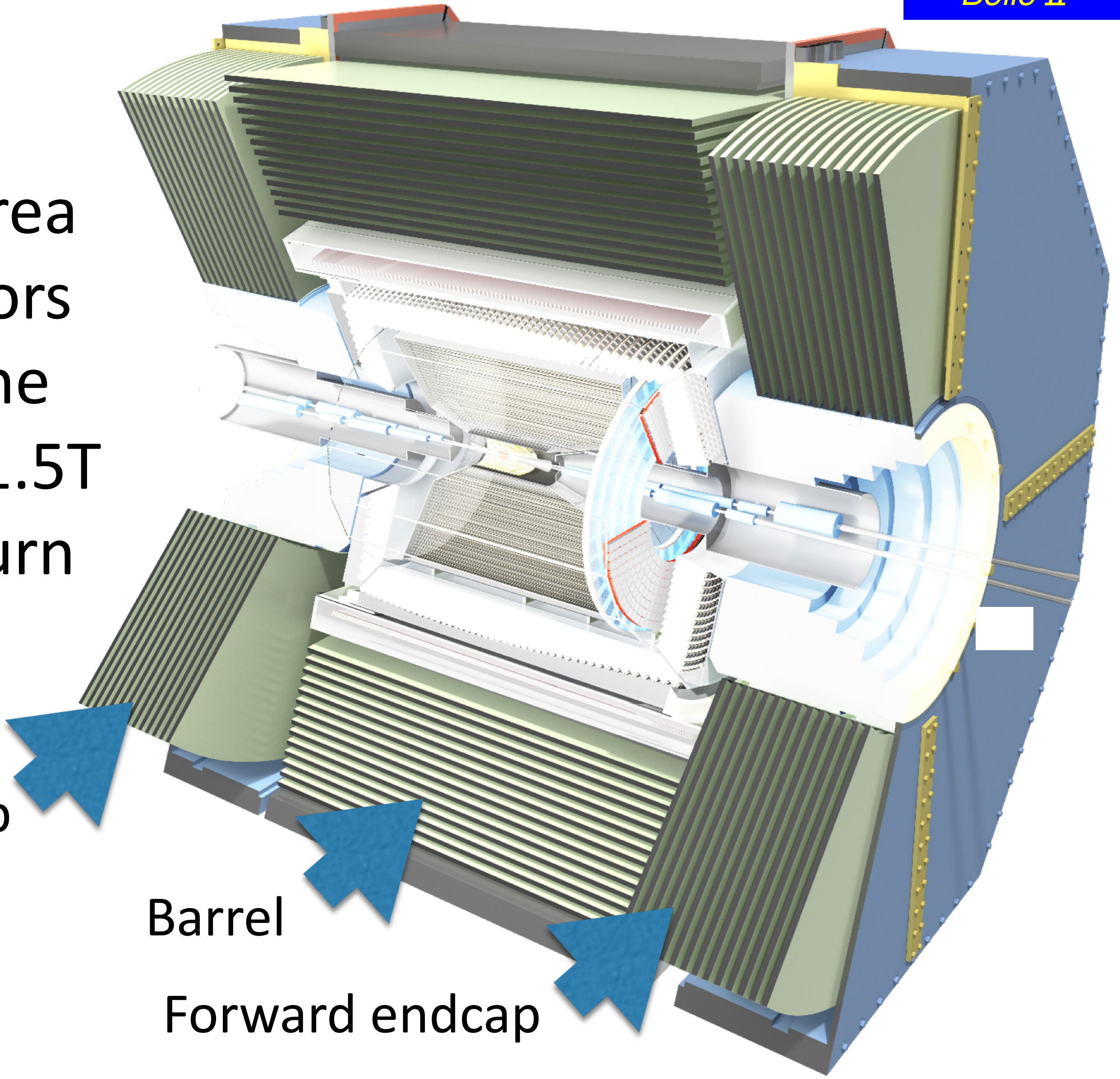
KLM Subsystem Overview

Leo Piilonen
Virginia Tech

The KLM (“K_L–Muon detector”)

Belle II

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



Backward endcap

Barrel

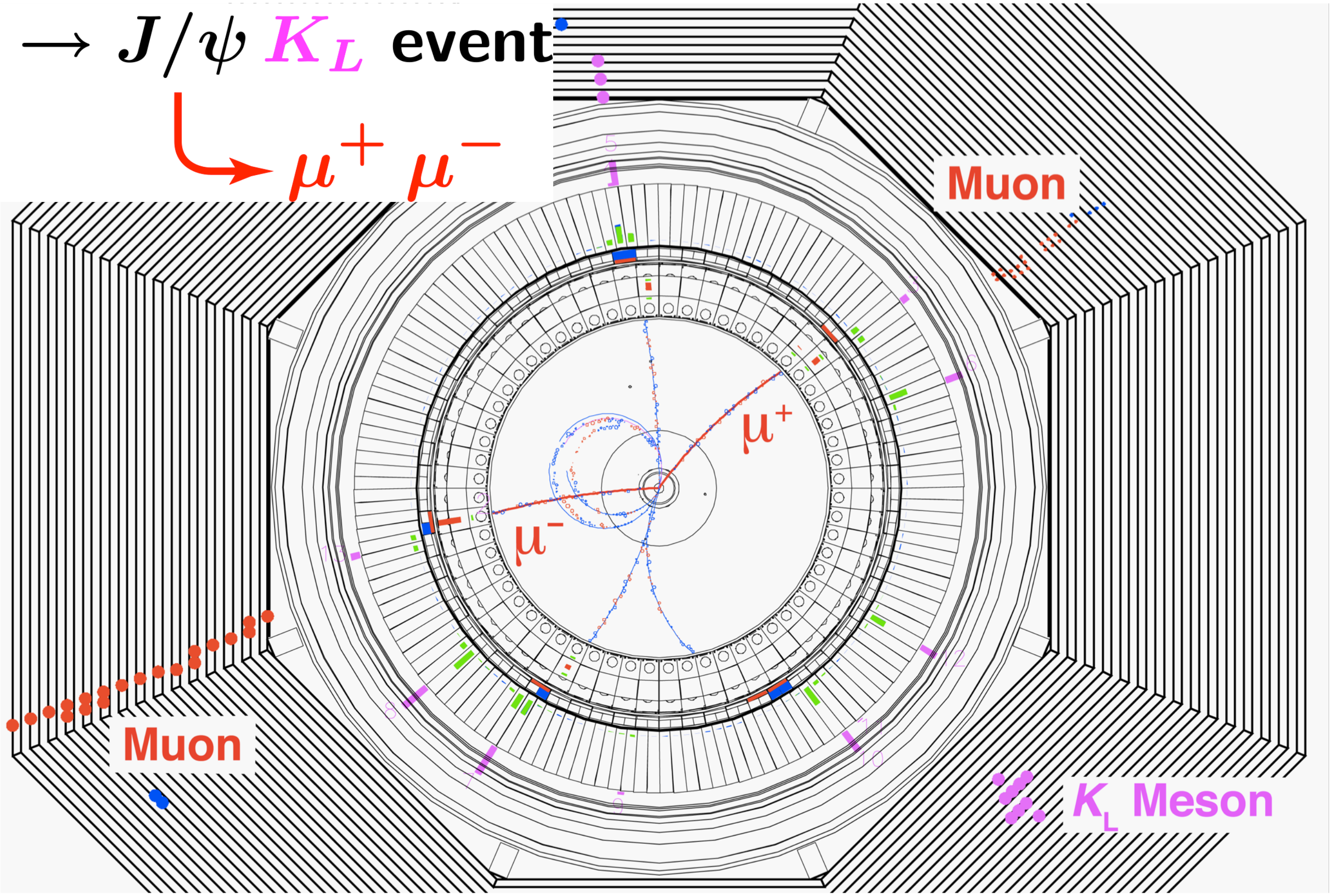
Forward endcap

Performance Requirements (1)

- Detect K_L mesons and muons (≈1 per event)

$B^0 \to J/\psi\, K_L$ event

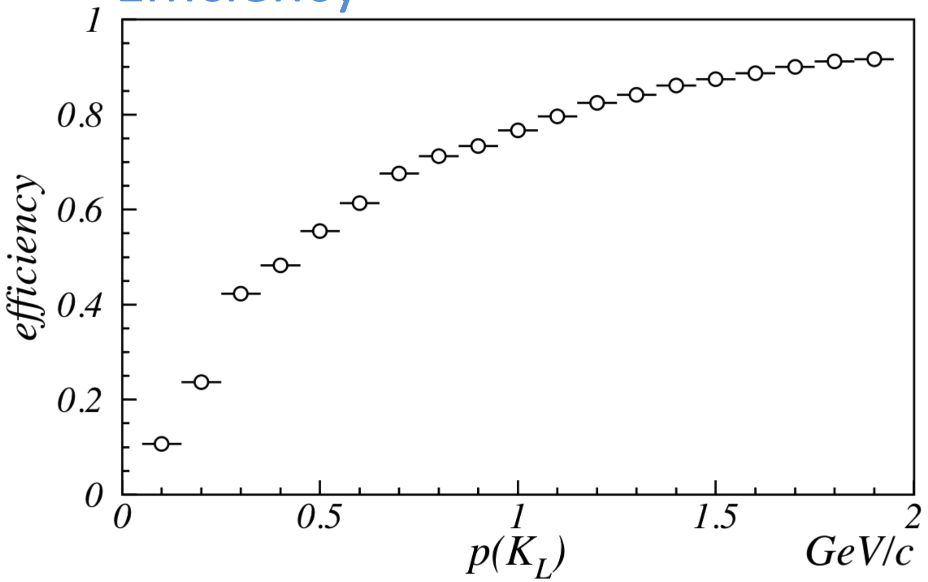
$\hookrightarrow \mu^+ \mu^-$



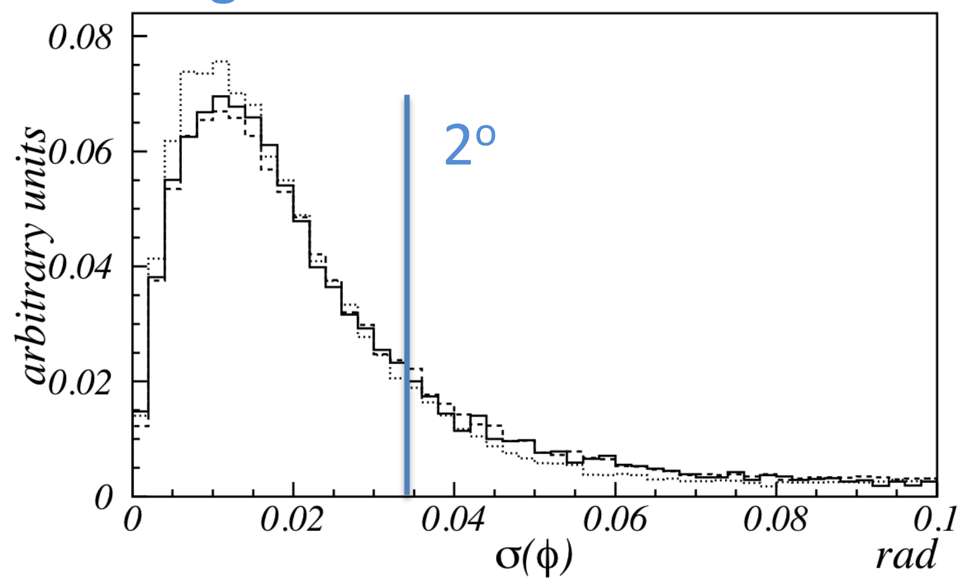
Performance Requirements (2)

- Detect K_L mesons with high efficiency & purity and with good angular resolution
  - For CP-sensitive B decay modes like $B \to J/\psi\, K_L$
  - For K_L veto in missing energy modes like $B \to \tau\, \nu$

Efficiency



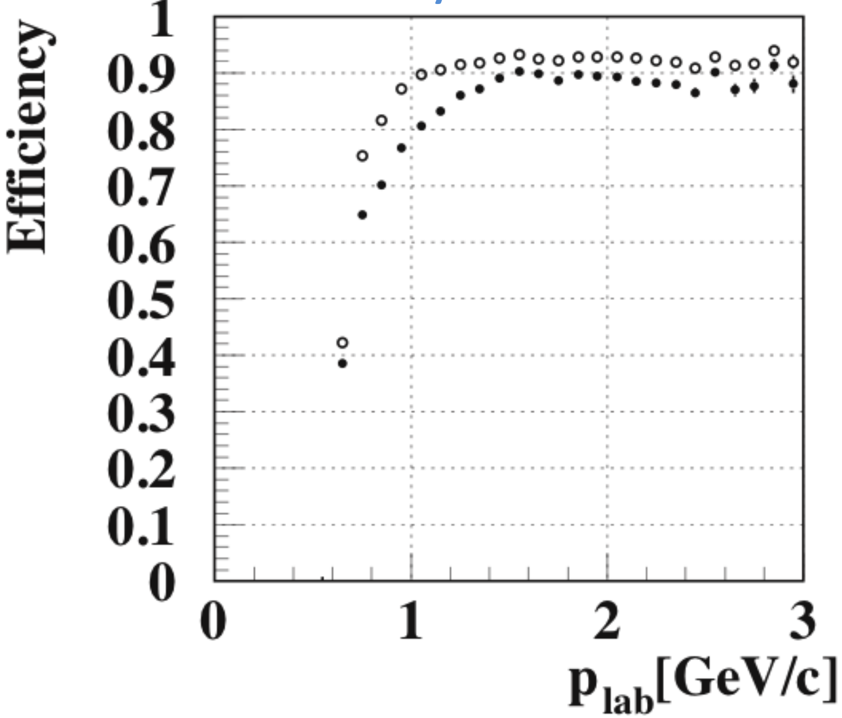
Angular resolution



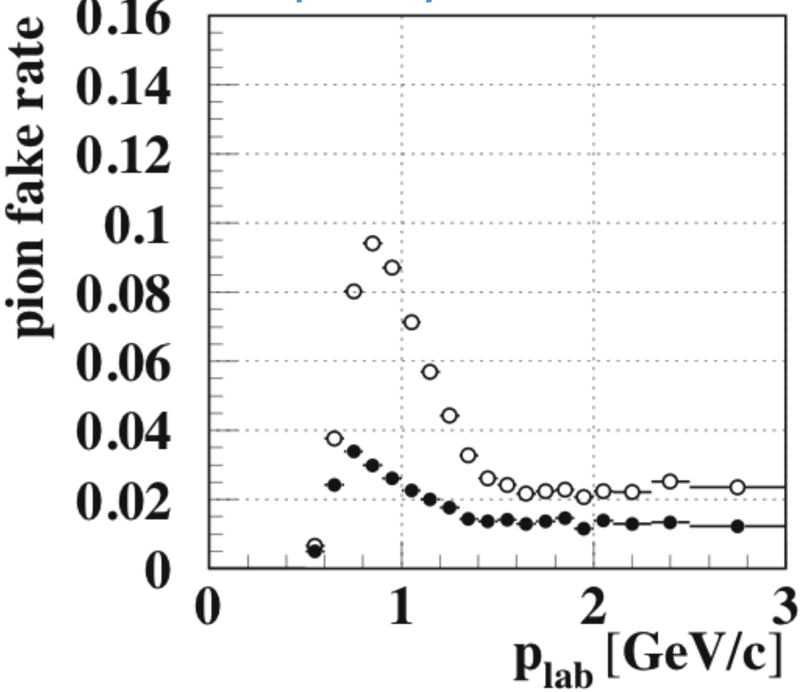
Performance Requirements (3)

- Identify muons with high efficiency & purity for momenta above 0.6 GeV/*c*

Efficiency

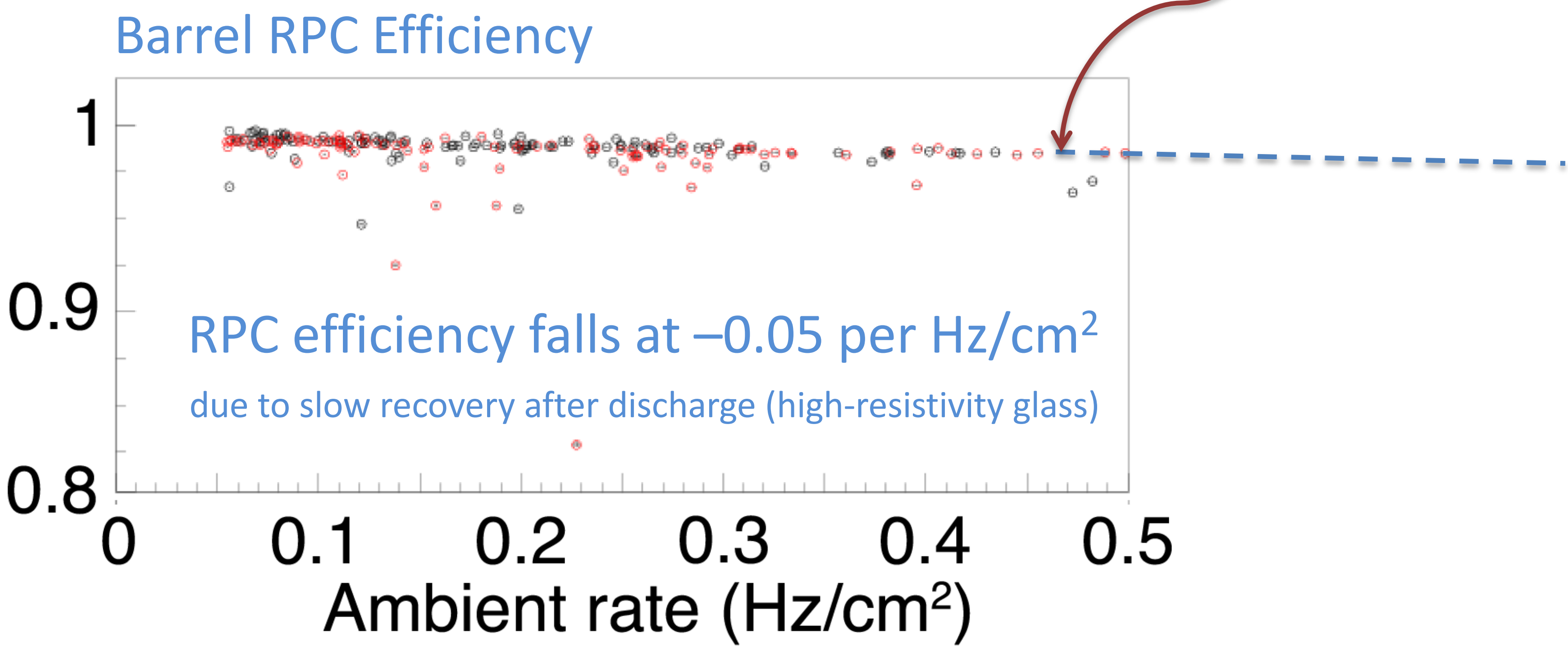


Impurity

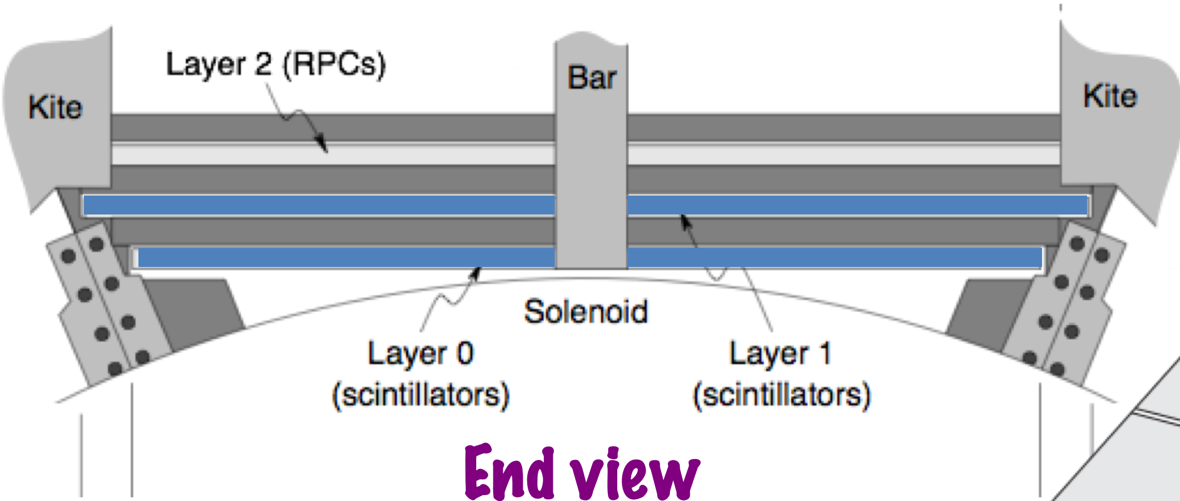


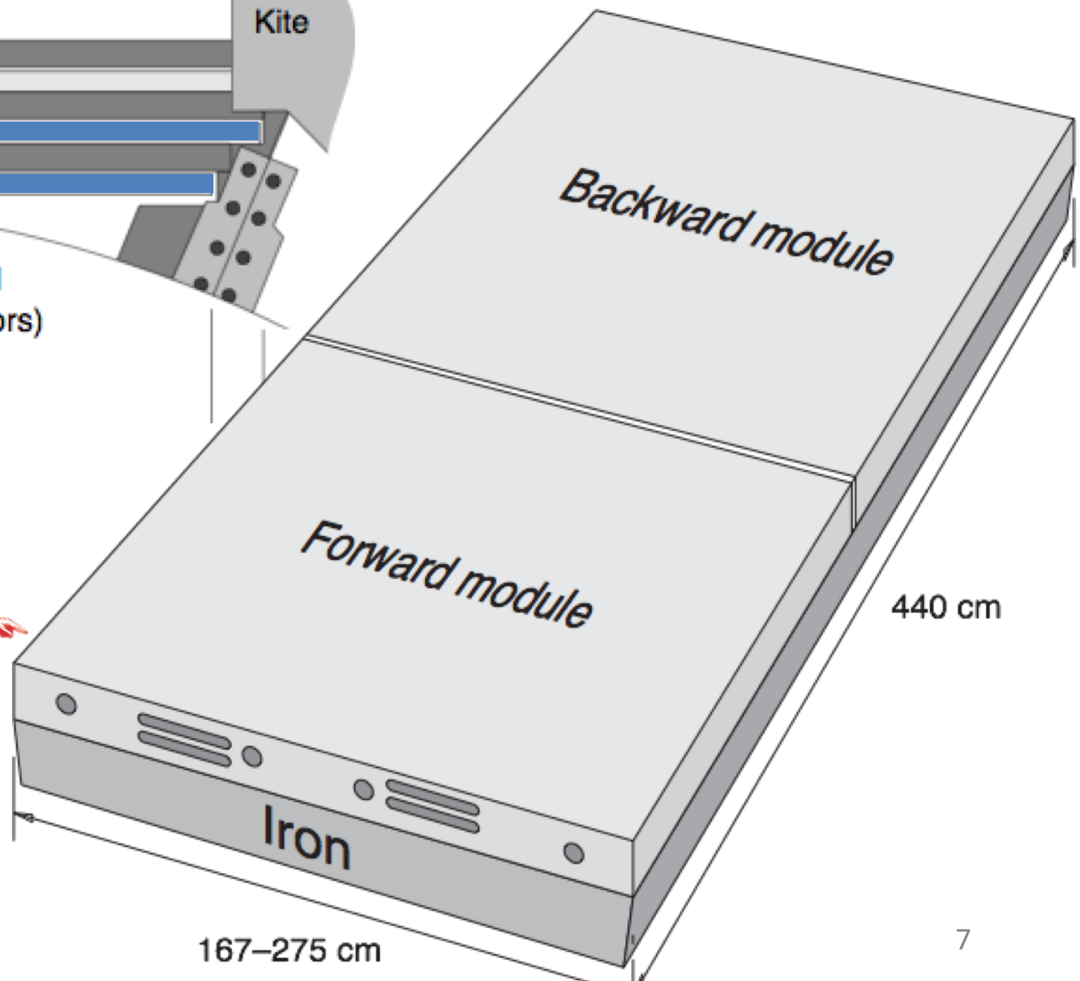
Performance Requirements (4)

- Efficiency & purity not degraded by ≈100 Hz/cm^2 ambient neutron background, *unlike RPCs*
- Scintillators match these requirements



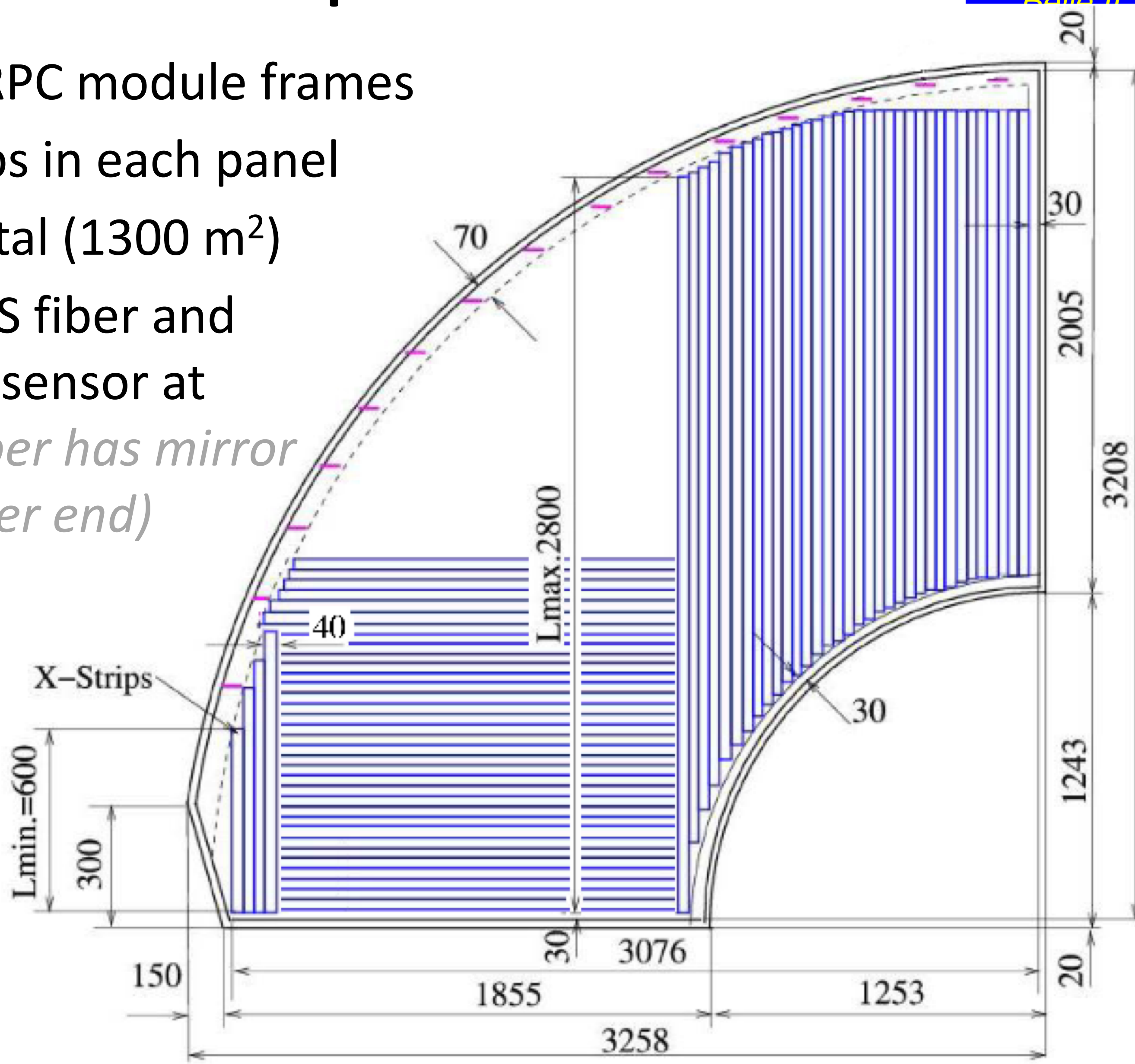
Replace BKLM inner-layer RPCs & all EKLM RPCs with extruded-strip scintillator detectors within the same form-factor panels as the old RPCs





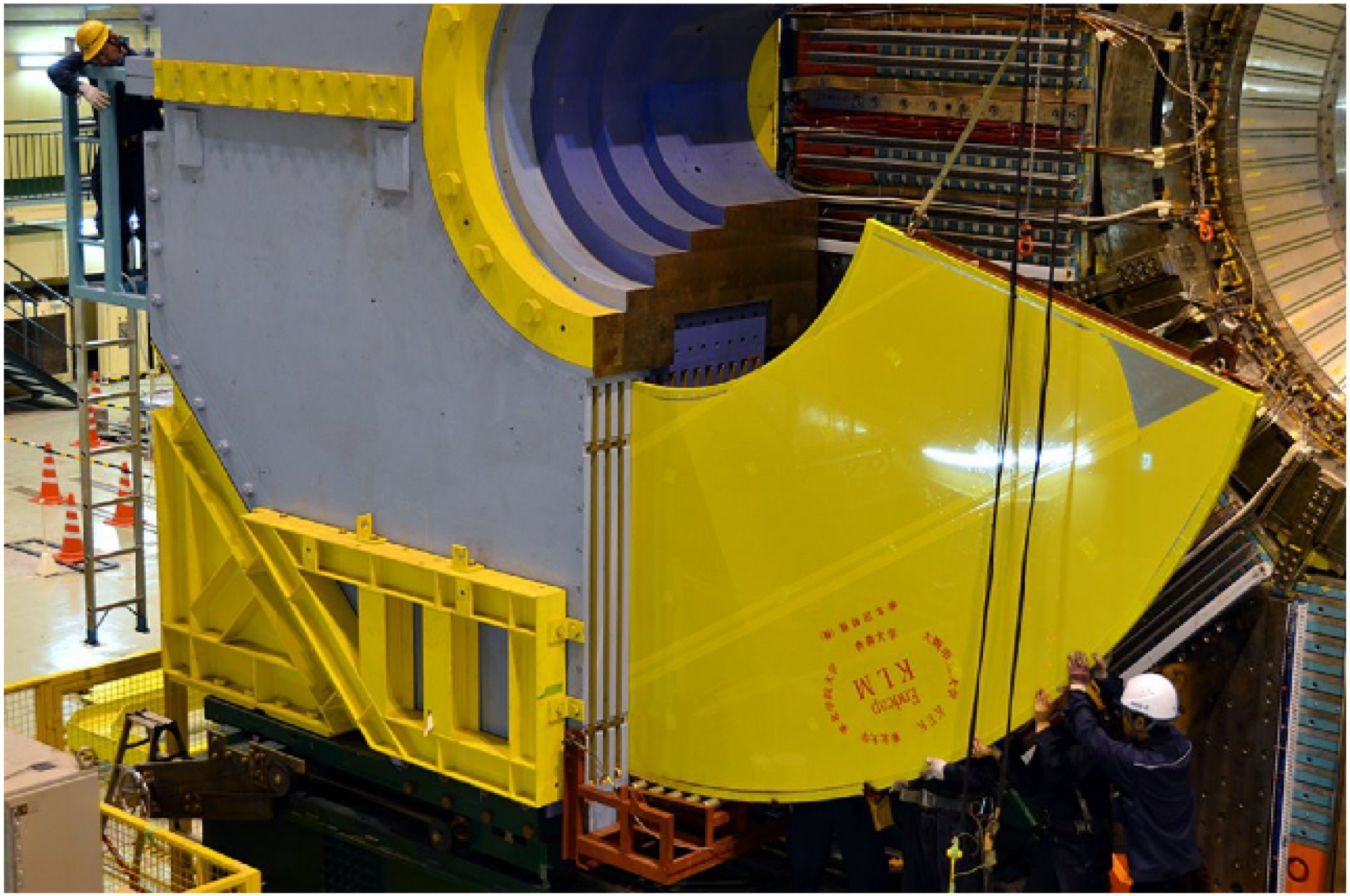
Endcap scintillator panels

- Reuse existing RPC module frames
- 75 X- and Y-strips in each panel
- 15,600 strips total (1300 m^2)
- Readout via WLS fiber and attached MPPC sensor at outer radius *(fiber has mirror paint at the other end)*

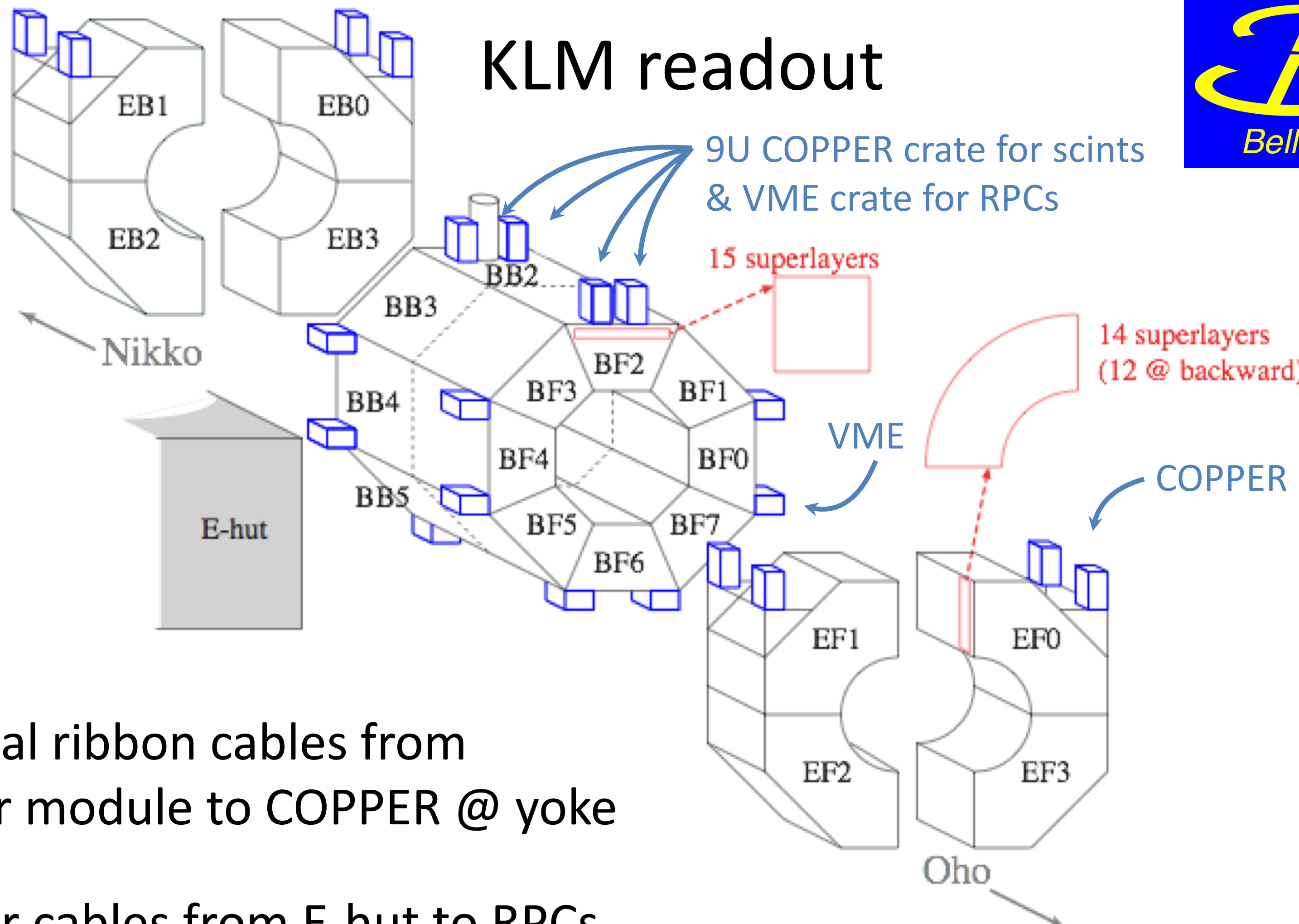


Install Barrel KLM Scintillators (2013)

Install Endcap KLM Scintillators (2014)

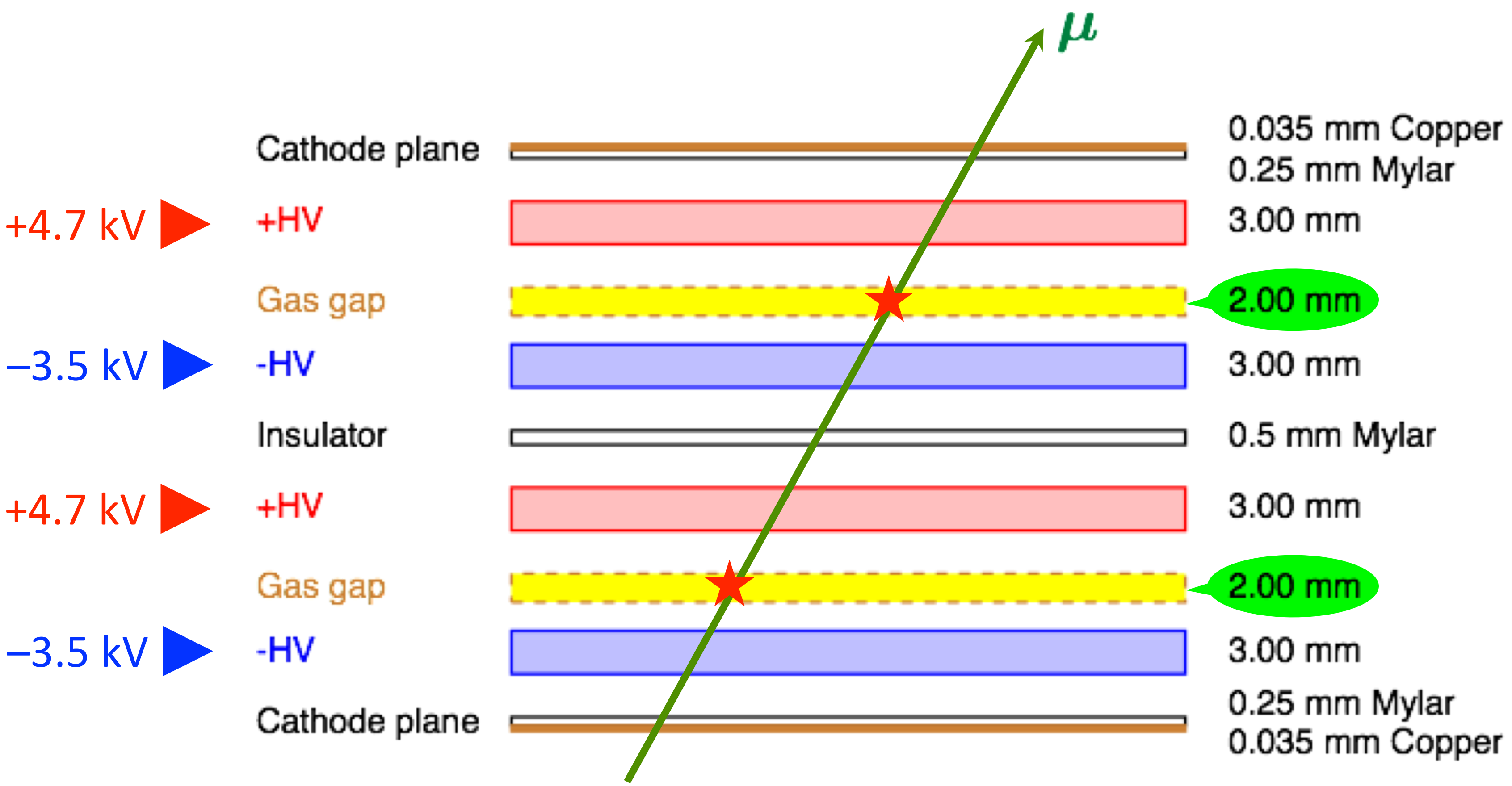


KLM readout



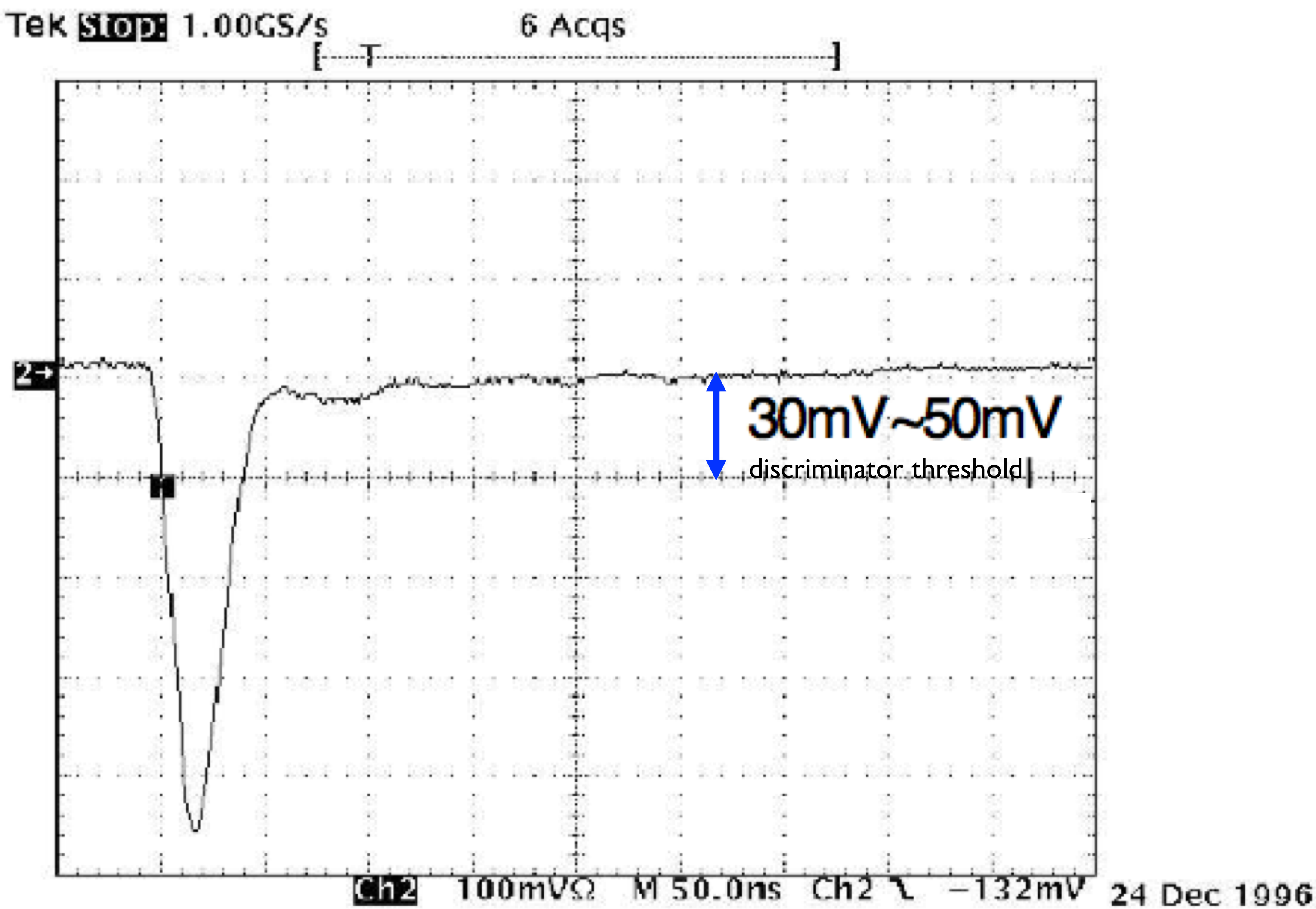
- ✓ Power/signal ribbon cables from scint-detector module to COPPER @ yoke
- ✓ RPC power cables from E-hut to RPCs
- ✓ MPPC power cables from E-hut to COPPER @ yoke
- ✓ Signal/trigger fiber trunks between E-hut and COPPER+VME @ yoke

Barrel KLM Resistive Plate Counter Panel has two independent back-to-back RPCs

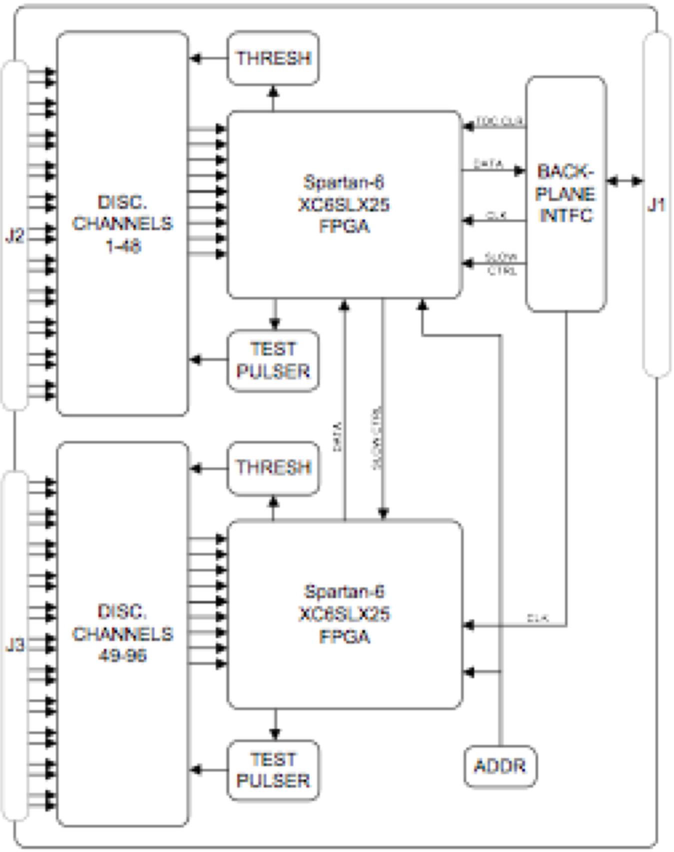


A discharge (=streamer) in *either* gas gap induces an image charge on *both* readout planes.

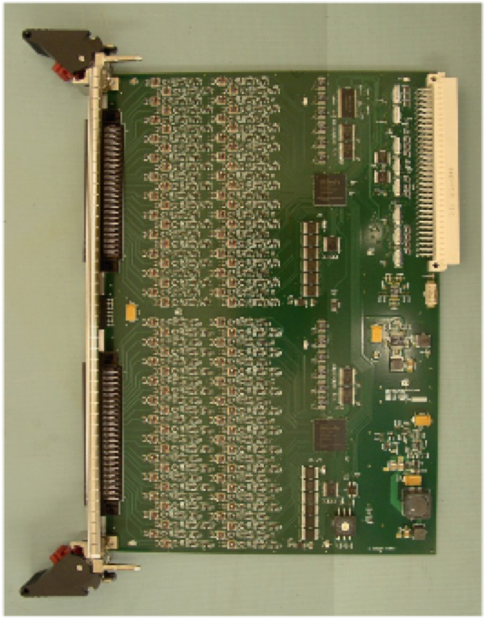
RPC cathode strip delivers ~200 mV signal



Front-End Board for RPC readout



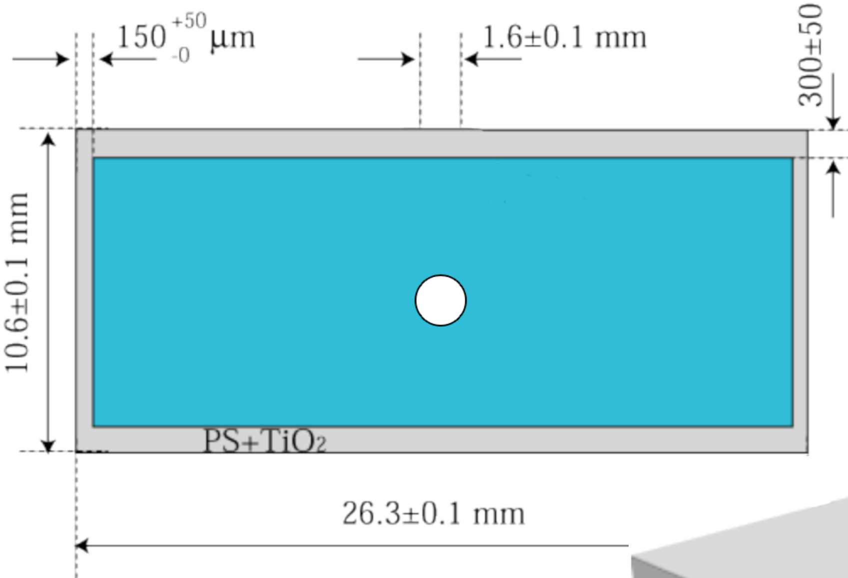
- Contains 96 High performance differential line receivers and discriminator channels.
- Channels 1-48 will connect to negative RPC pulses and channels 49-96 connect to positive RPC pulses.
- Discriminator threshold controlled by DAC.
- Analog test pulser to provide independent built in test of each channel.



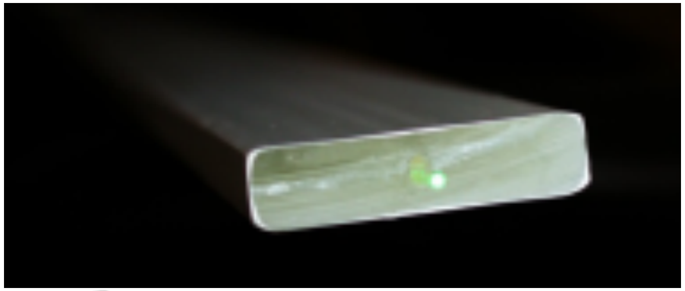
Production 6U VME board

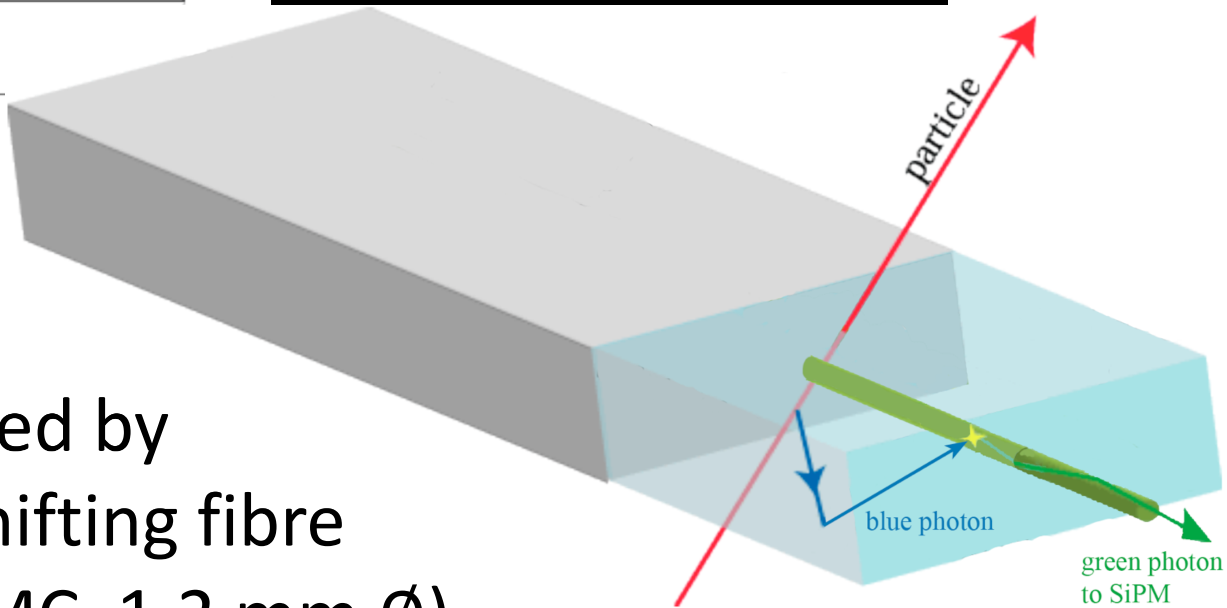
Designed by U. Indiana
Procured by Frascati + Roma3

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



FNAL scintillator for barrel

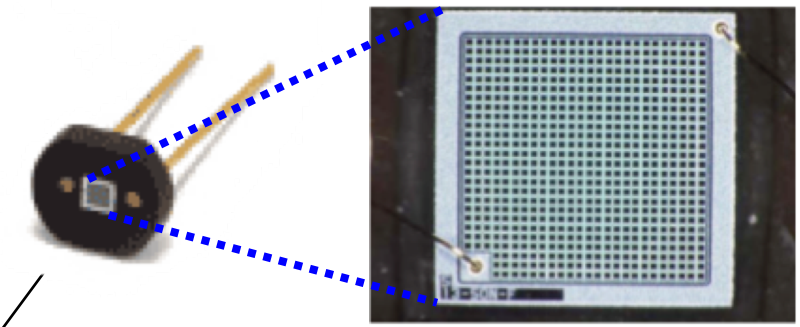




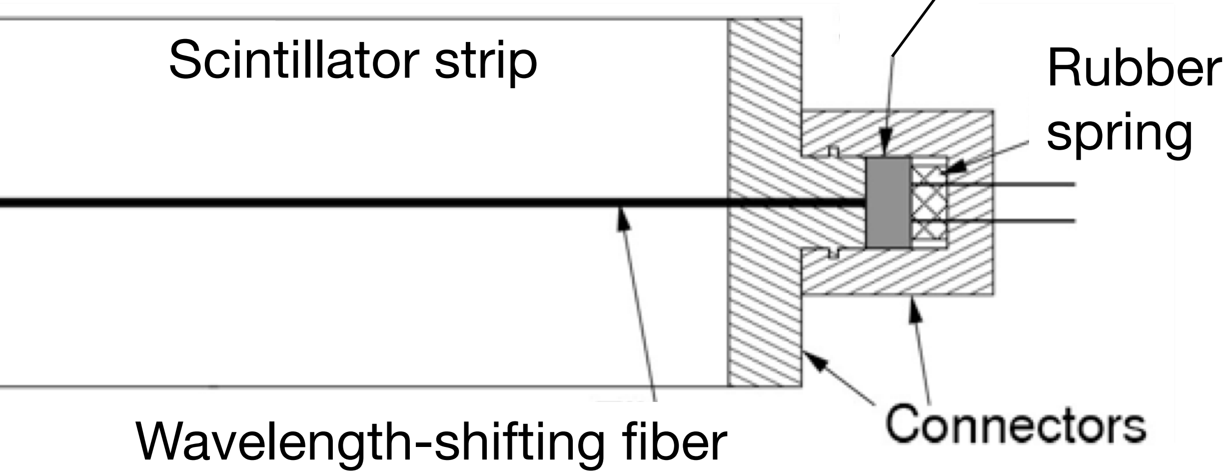
Light is captured by wavelength-shifting fibre (Kuraray Y11 MC, 1.2 mm Ø)

Detect WLS-fiber light with Geiger-mode avalanche photodiode (“SiPM” or “MPPC”)

Hamamatsu S10362-13-050C
attached to one end of fiber
(fiber is mirrored at the other end)



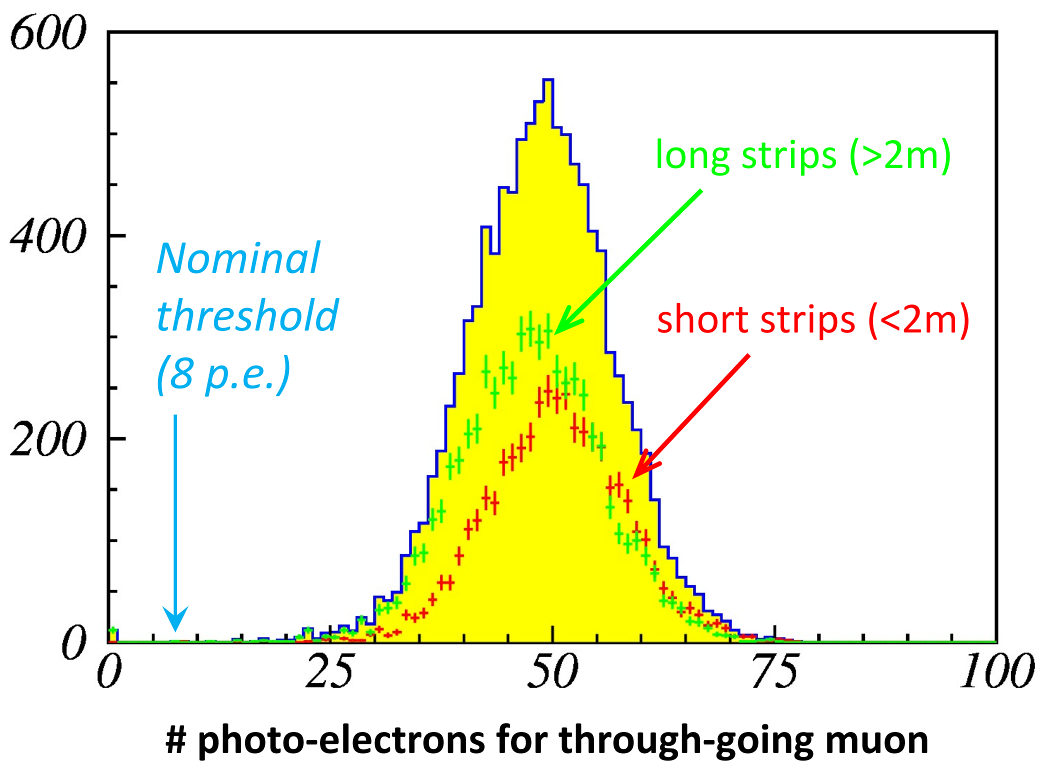
1.3 x 1.3 mm^2
667 pixels

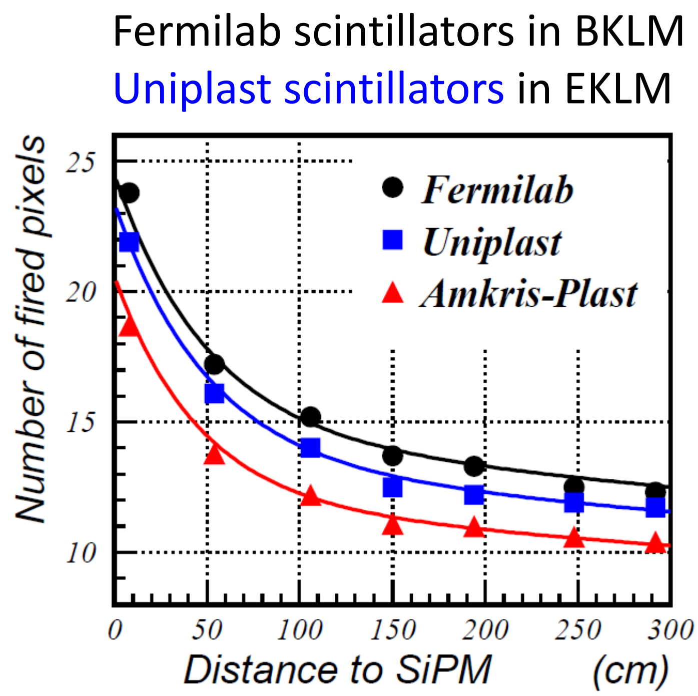


- ☑ developed for T2K near detector
- ☑ operates in 1.5 T magnetic field
- ☑ rad-hard (>10-year lifetime in KLM)
- ☑ **8-pixel** threshold gives >99% efficiency

Scintillators Light-collection Performance

measured with ad hoc standalone readout system

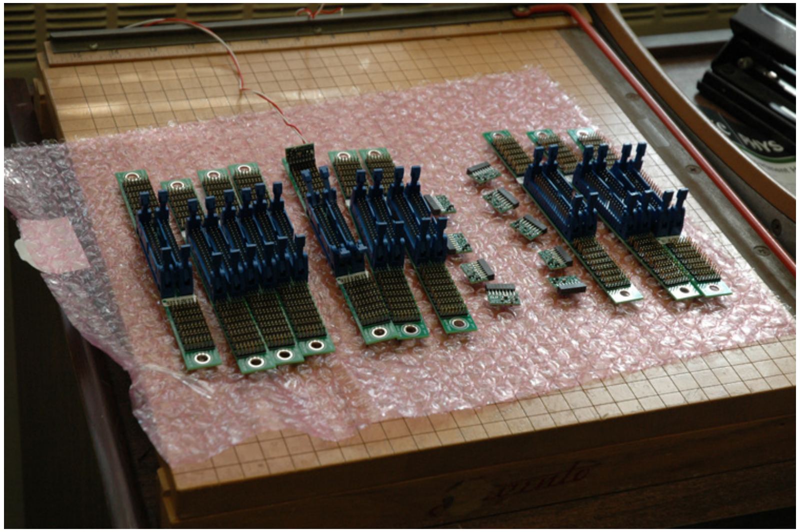




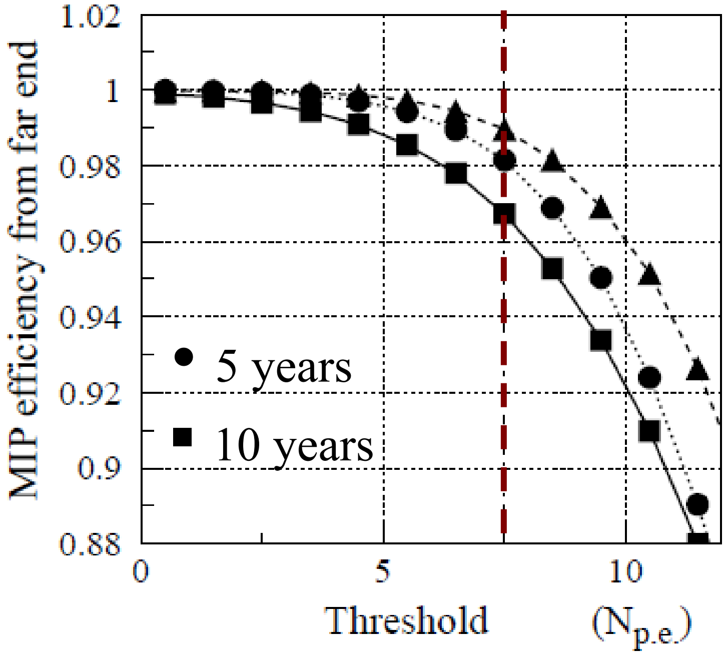
High light-collection performance is a warranty of robustness against radiation damage and high background rate.

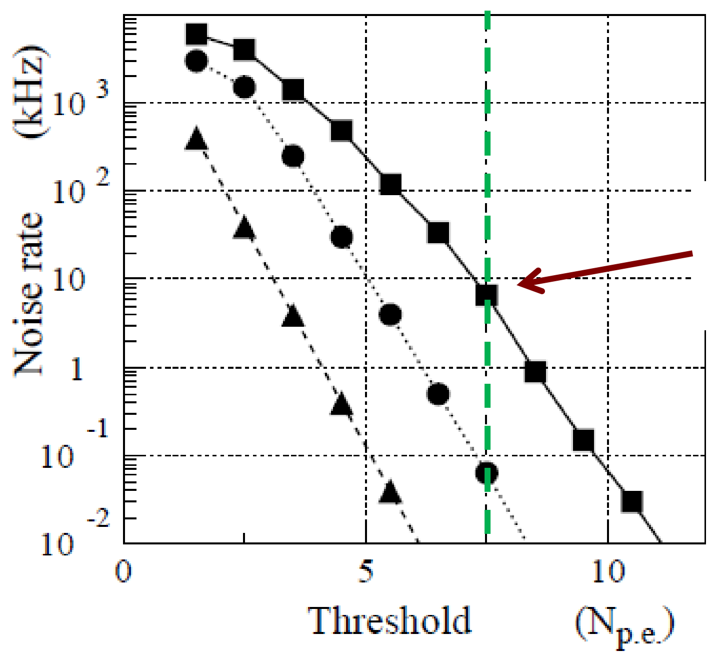
MPPC signals are pre-amplified

- MPPC power and output signal pre-amplification are managed by a custom circuit (on a carrier card, 15 channels/card) designed by U. Hawaii
- 7 (10) of these carrier cards – 105 (150) preamps – are housed in each BKLM (EKLM) detector panel

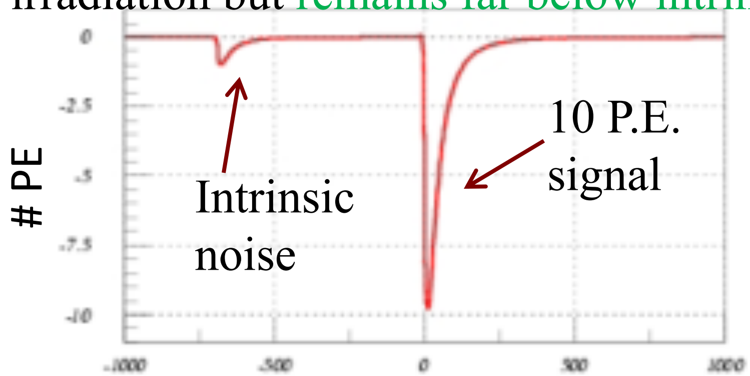


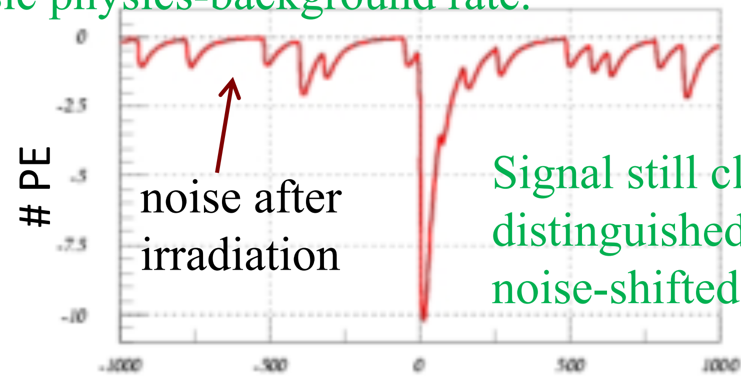
Radiation hardness of photosensors: OK



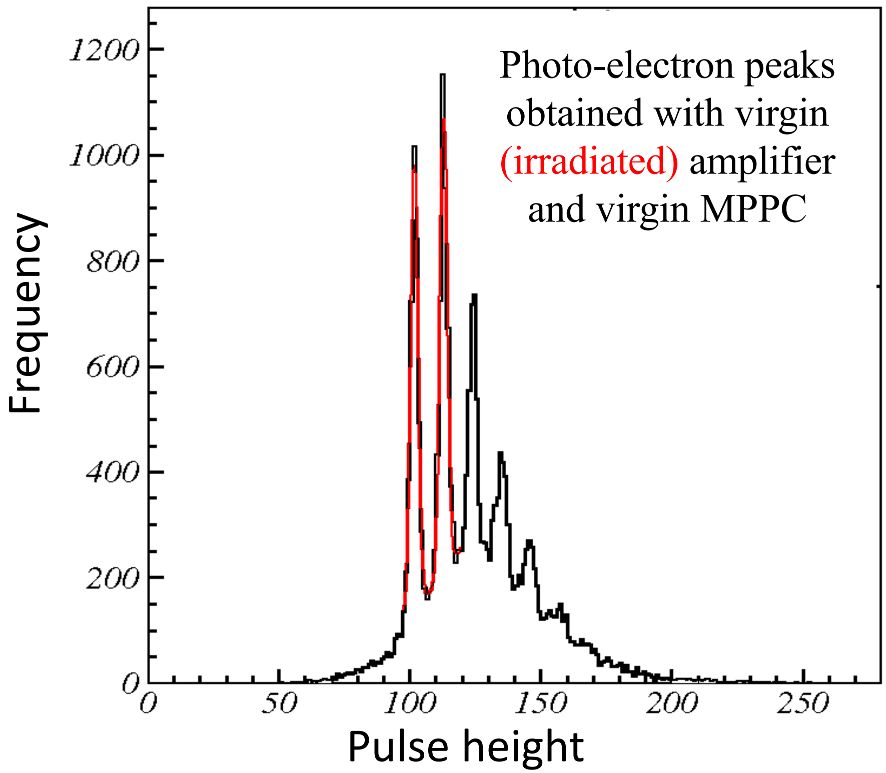


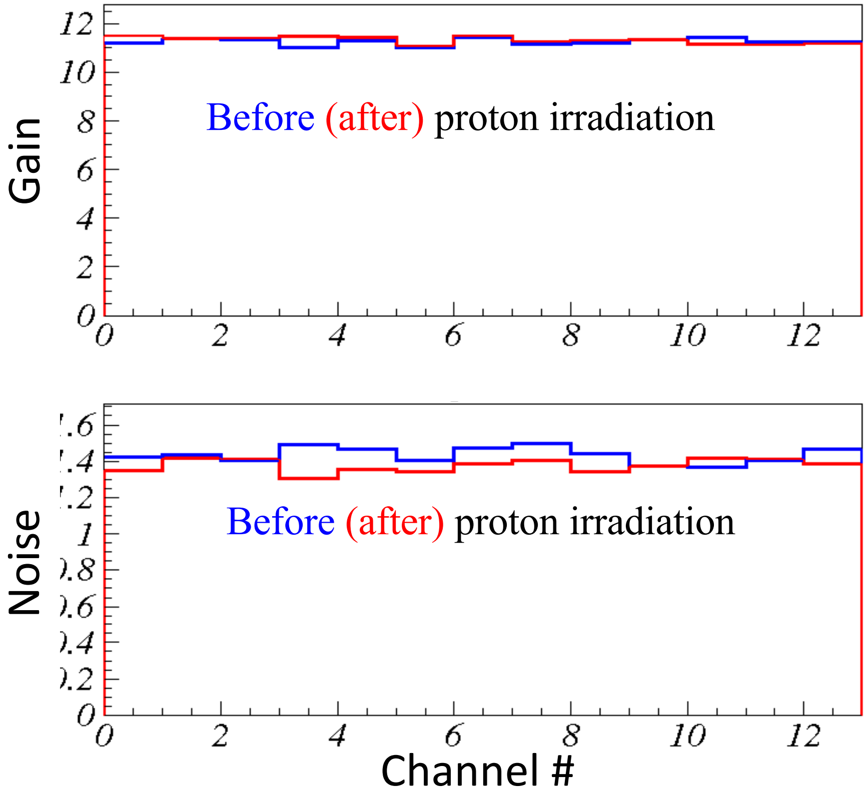
Light collection efficiency is unaffected by irradiation (dose equivalent to 10 years of Belle-II operation); the *apparent* efficiency reduction due to baseline shift may be corrected by more refined pulse-shape fit in future front-end firmware algorithm. MPPC intrinsic noise increases with irradiation but remains far below intrinsic physics-background rate.





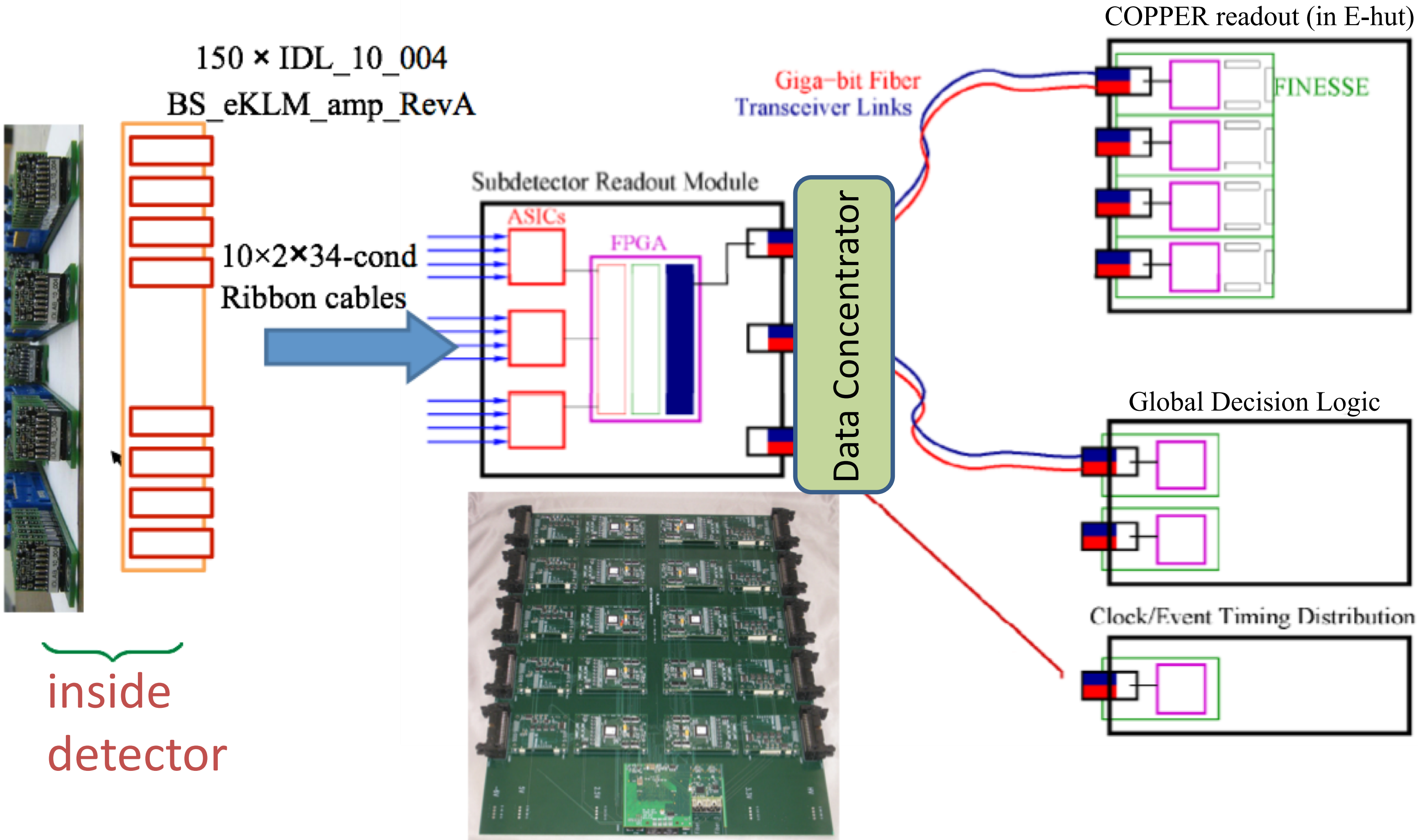
Radiation hardness of preamps: OK





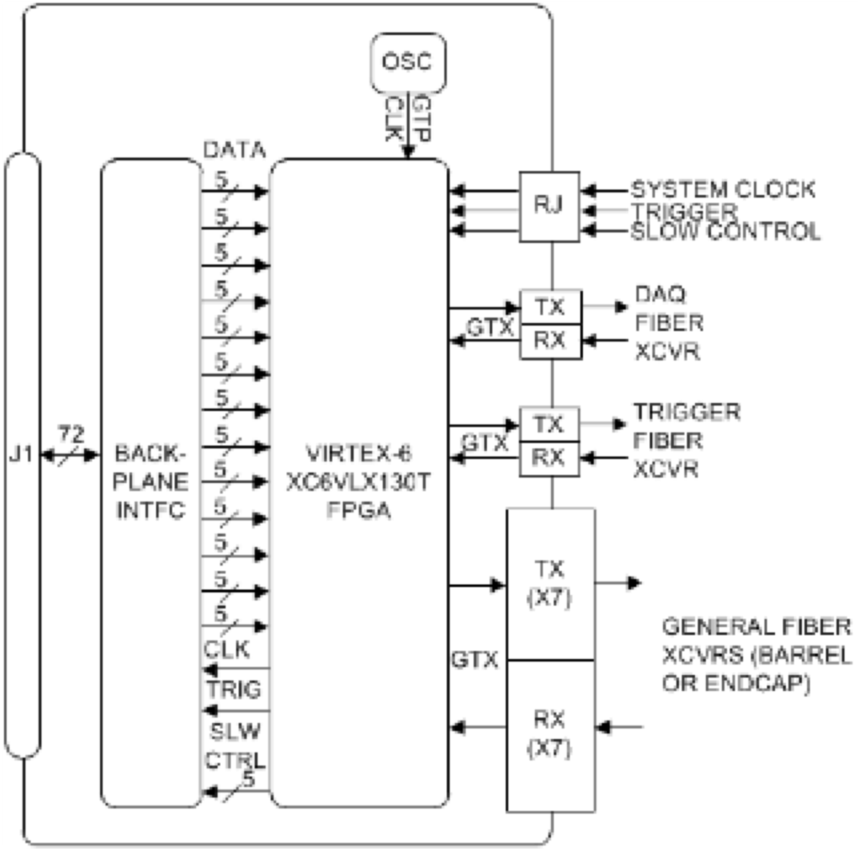
No effect was observed with doses 5x expected at Belle II.

Pre-amplified signals are digitized by Hawaii-developed TARGETX ASIC



at magnet yoke

Concentrator Board collects FEE hits



**eKLM Concentrator Notes:*

- ❑ *Will use different firmware, with bKLM reuse where possible.*
- ❑ *Same board assembly deployed for barrel and end-cap.*
- ❑ *In end-cap B2link remains, but is only used for slow control.*

- One timing and trigger distribution (TTD) interface.
- Two transceivers for "standard" Belle-II links (B2Link and GDL)
- Fourteen transceivers used for data fiber link input from scintillator layers – 2 barrel or 14 endcap.
- Uses ganged/stacked SFP cages for scintillator fibers – will require extra attention to signal integrity issues.
- One FPGA:
  - Implements 16 serial interfaces
  - Finds coincident hits in orthogonal strips and forwards to trigger system
  - Buffers data for >5.2 μs
  - Forwards events in triggered time windows to DAQ system

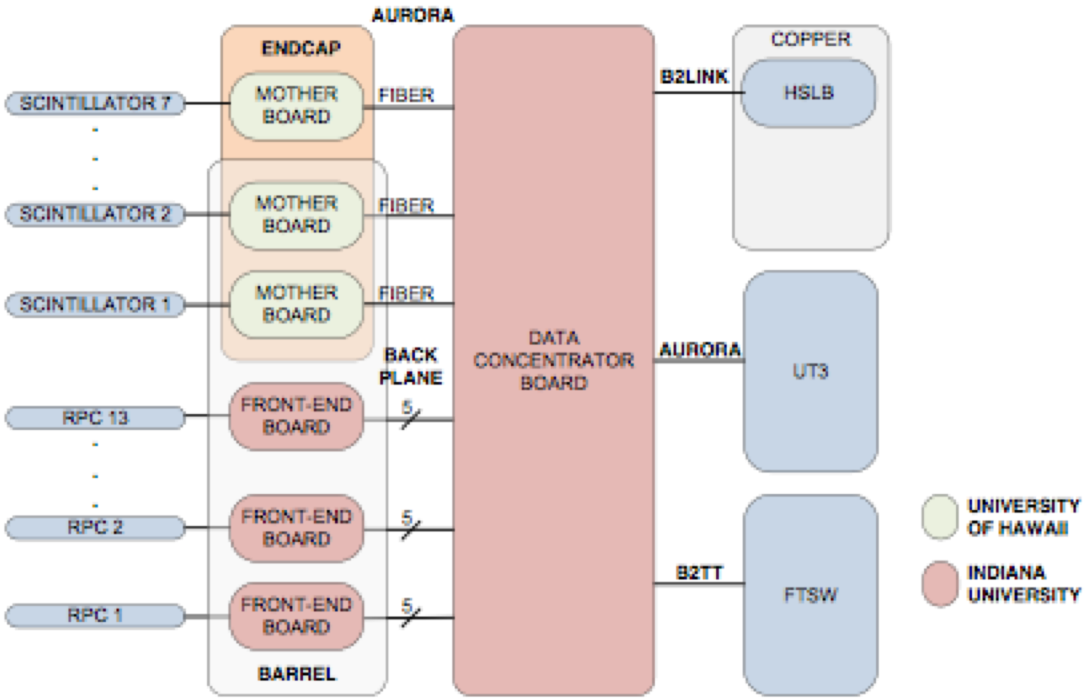
INDIANA UNIVERSITY

Belle II

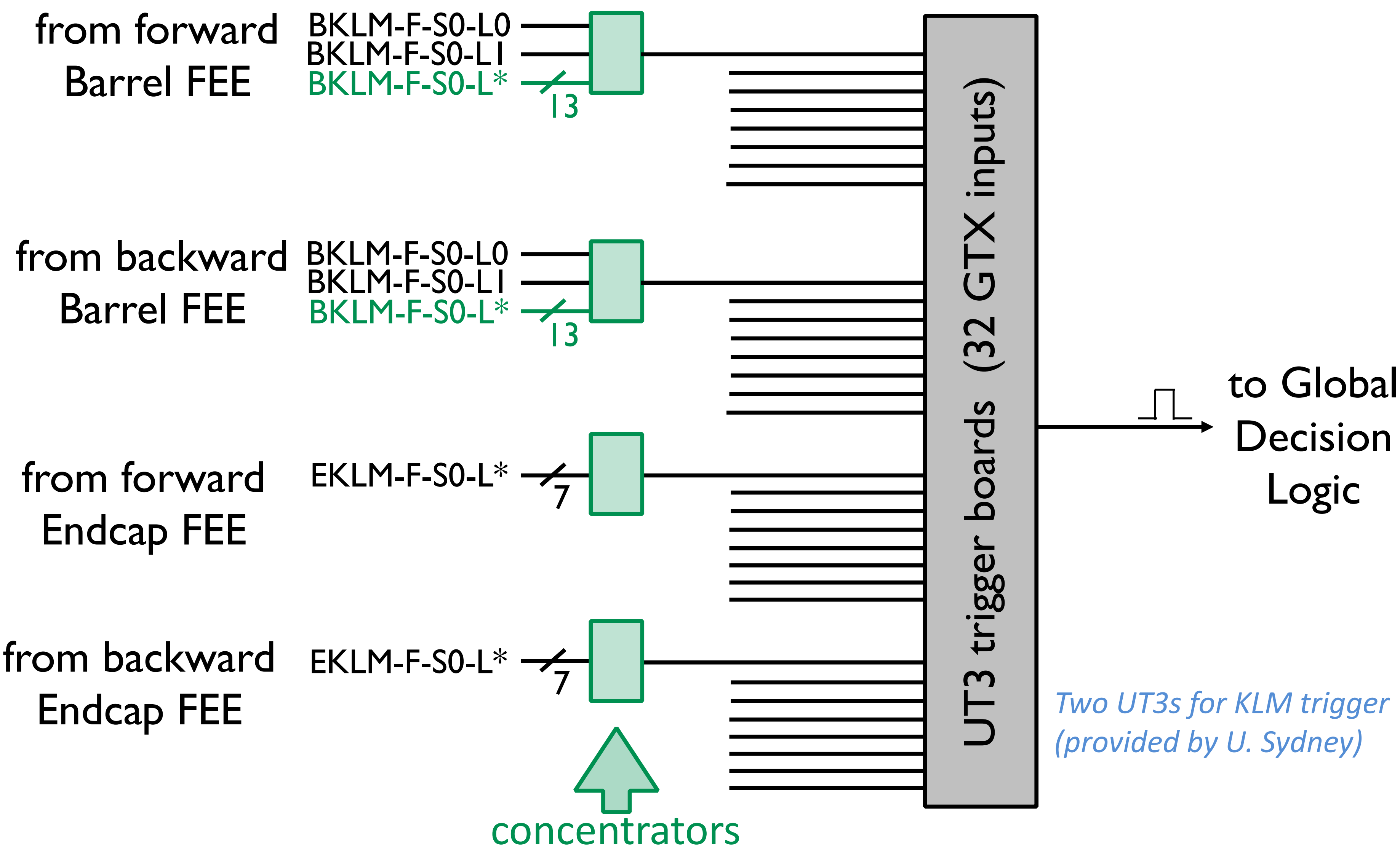
KLM Readout Overview

- 13 RPC Front-End boards connect to a Data Concentrator in the barrel
- 2 Scintillator Motherboards connect to a Data Concentrator in the barrel
- 7 Scintillator Motherboards connect to a Data Concentrator in the end-cap

- The Data Concentrator connects to the detector interface (HSLB, UT3, FTSW)
- Indiana University designed the RPC Front-End and Data Concentrator
- University of Hawaii designed the scintillator Motherboard.



KLM trigger finds muon tracks *and K_L clusters*



Two UT3s for KLM trigger (provided by U. Sydney)

Summary

- Belle II's KLM (K_L–Muon detector) will continue to use the existing RPCs in the outer barrel and new scintillator panels in the inner barrel and endcaps.
- New scintillator-based detectors were installed in 2013–2014 (Virginia Tech for barrel, ITEP for endcaps).
- New front-end RPC readout electronics designed (Indiana) and procured (Frascati + Roma3), installed in Feb–July 2017
- New front-end scint readout electronics designed and procured (Hawaii), installed in early 2016
- Readout commissioning in progress.

Backup

Projected ambient neutron rate in Belle II means that endcap RPCs would never see muons

Efficiency in Belle

Layer	Barrel	Forward Endcap	Backward Endcap
0	0.97	0.91	0.9
1	0.98	0.93	0.9
2	0.99	0.94	0.9
3	0.99	0.94	0.9
4	0.99	0.94	0.89
5	0.99	0.92	0.88
6	0.99	0.93	0.89
7	0.99	0.92	0.87
8	0.99	0.92	0.86
9	0.99	0.9	0.85
10	0.99	0.87	0.82
11	0.99	0.82	0.8
12	0.99	0.78	0.81
13	0.99	0.77	0.76

Efficiency in Belle II

Layer	Barrel	Forward Endcap	Backward Endcap
0	0.13	0	0
1	0.39	0	0
2	0.62	0	0
3	0.78	0	0
4	0.86	0	0
5	0.91	0	0
6	0.94	0	0
7	0.97	0	0
8	0.98	0	0
9	0.99	0	0
10	0.99	0	0
11	0.99	0	0
12	0.99	0	0
13	0.99	0	0

Scintillators in innermost 2 barrel layers mitigate neutron-induced efficiency loss

… ditto for all endcap layers

BKLM Layer	Neutron-induced RPC Rate (Hz/cm^2)	Resulting RPC Efficiency
0	**14.2**	**0.13**
1	**10.2**	**0.39**
2	6.4	0.62
3	3.6	0.78
4	2.2	0.86
5	1.3	0.91
6	0.8	0.94

all RPCs

BKLM Layer	Neutron-induced RPC Rate (Hz/cm^2)	Resulting RPC Efficiency
0	–	–
1	–	–
2	1.9	0.9
3	1	0.94
4	0.6	0.96
5	0.2	0.98
6	0.2	0.98

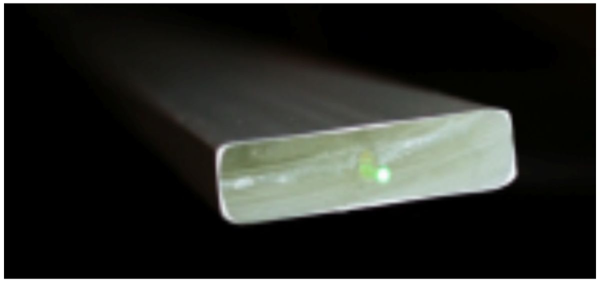
scintillators and polystyrene filler (layers 0–1)

RPCs (layers 2–6)

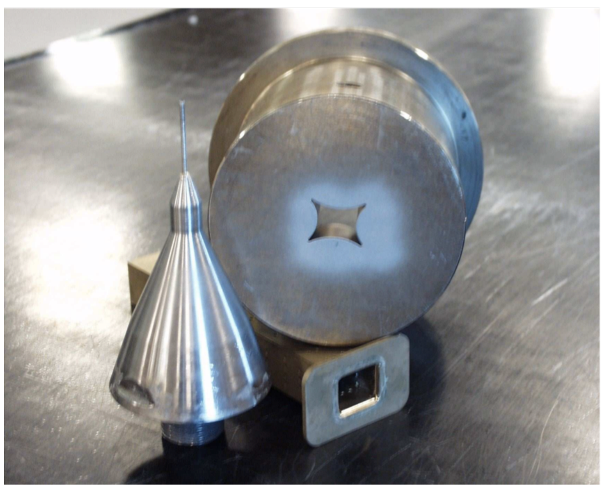
n flux ÷ 3.5

⇒ recovered ε

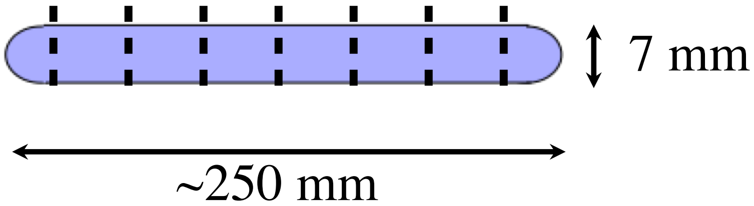
Scintillators were extruded at FNAL–NICADD (October–November 2012)

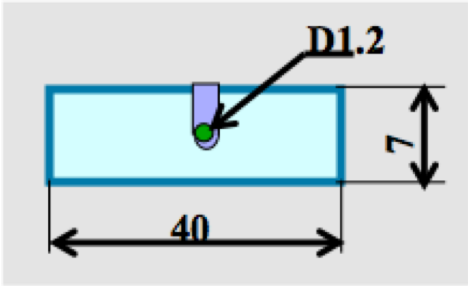


Die for 1.9x1.5 cm^2 extrusion with bore



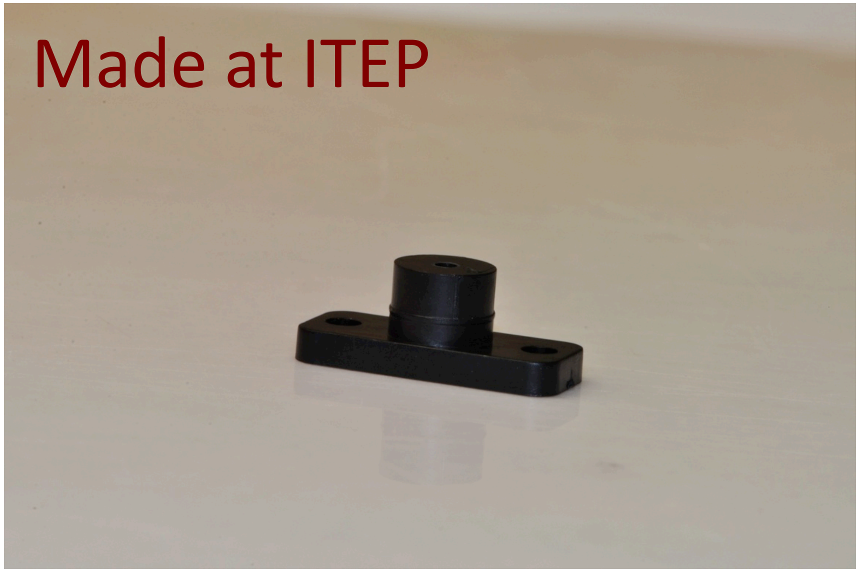
Endcap scintillator strips

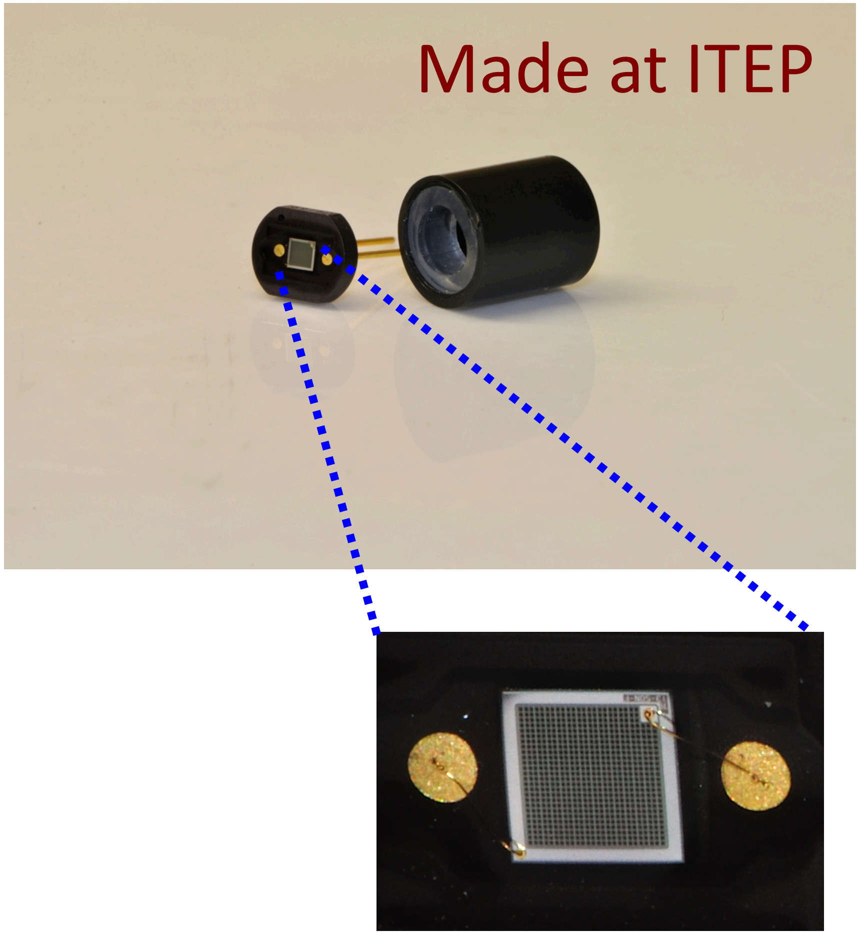


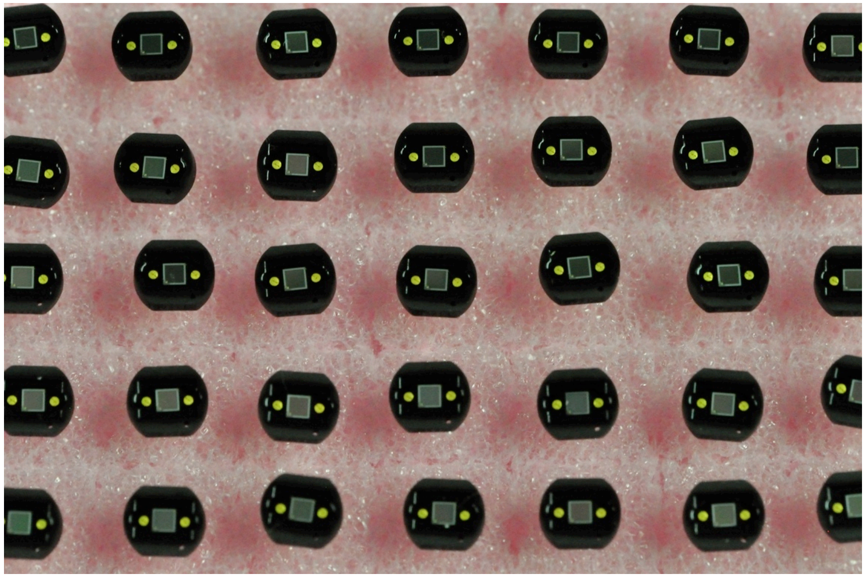


- Fabricated by Uniplast (Russia)
- Slab from extruding machine is sawed into rectangular strips, each 40 mm wide
- Reflective cover is produced by chemical etching of the strip surface (~50 µm)
- Groove for Kuraray Y-11 WLS fiber is sawed into the top surface (3mm deep)

Fiber-and-MPPC holders and MPPCs

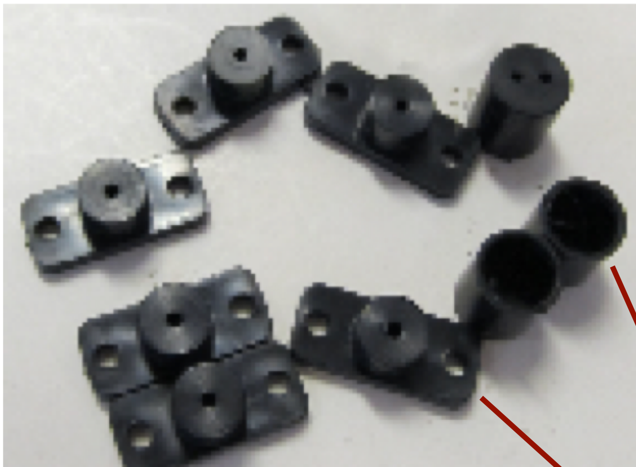


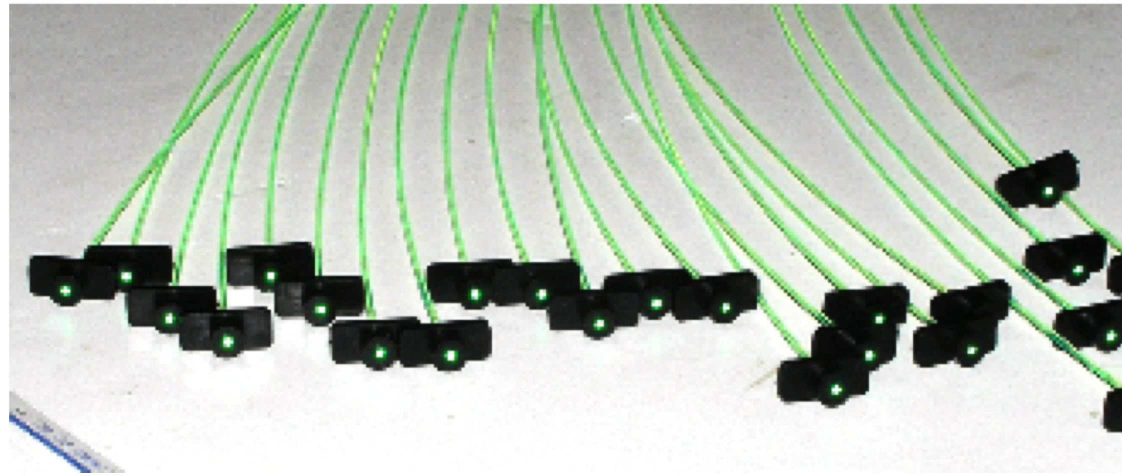


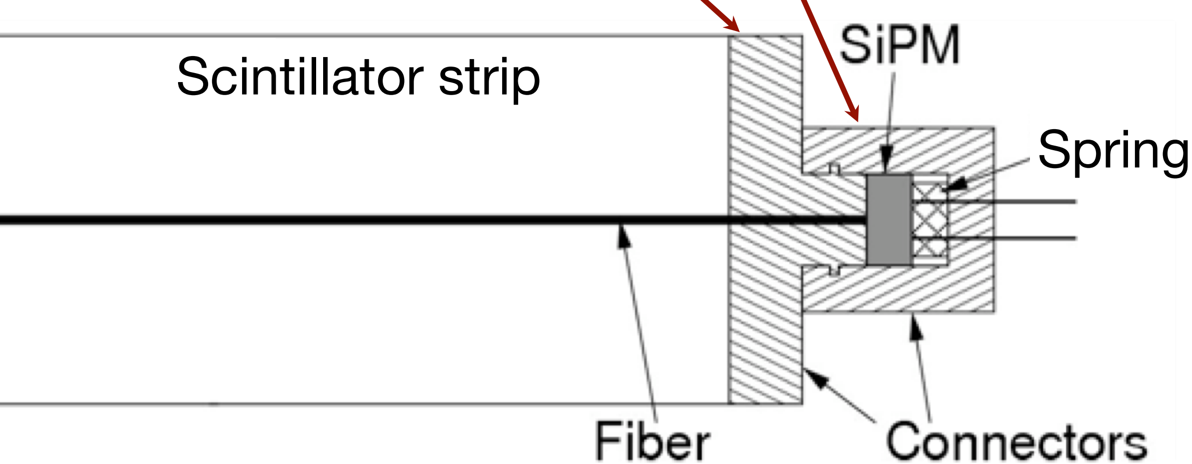


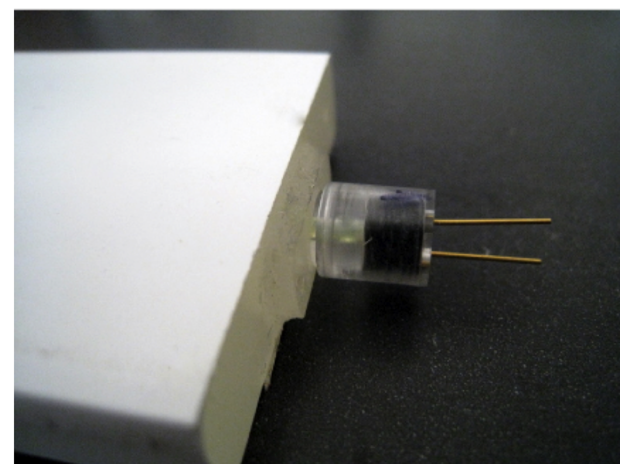
Hamamatsu S10362-13-050C photosensor's active surface

WLS fiber is epoxied to a ferrule that is epoxied to one end of the scintillator strip

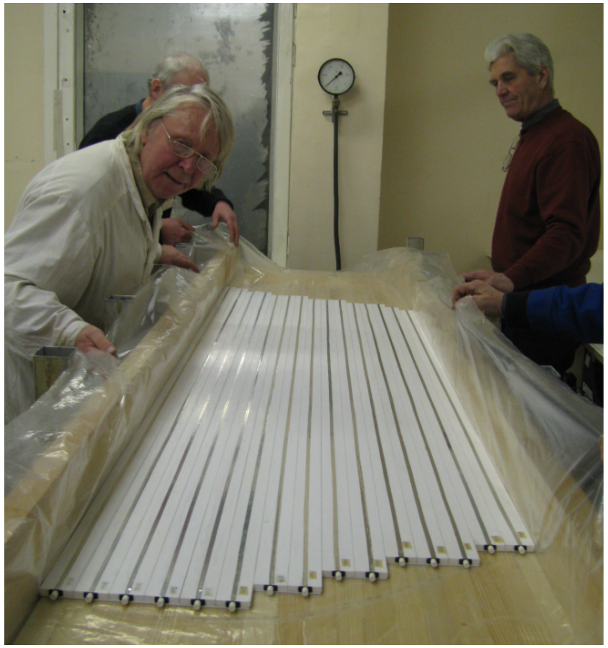


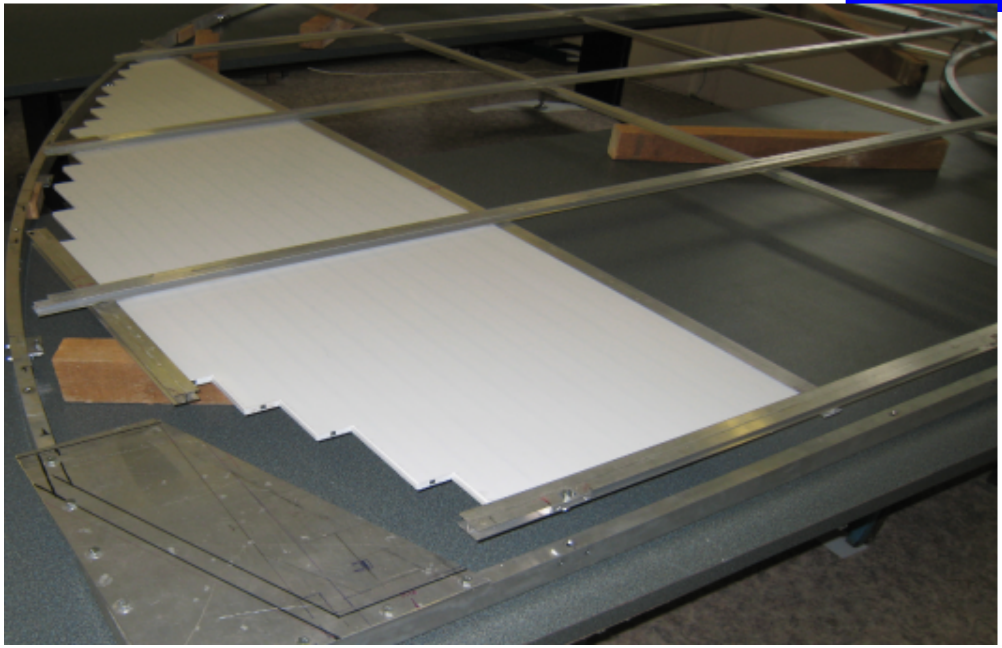


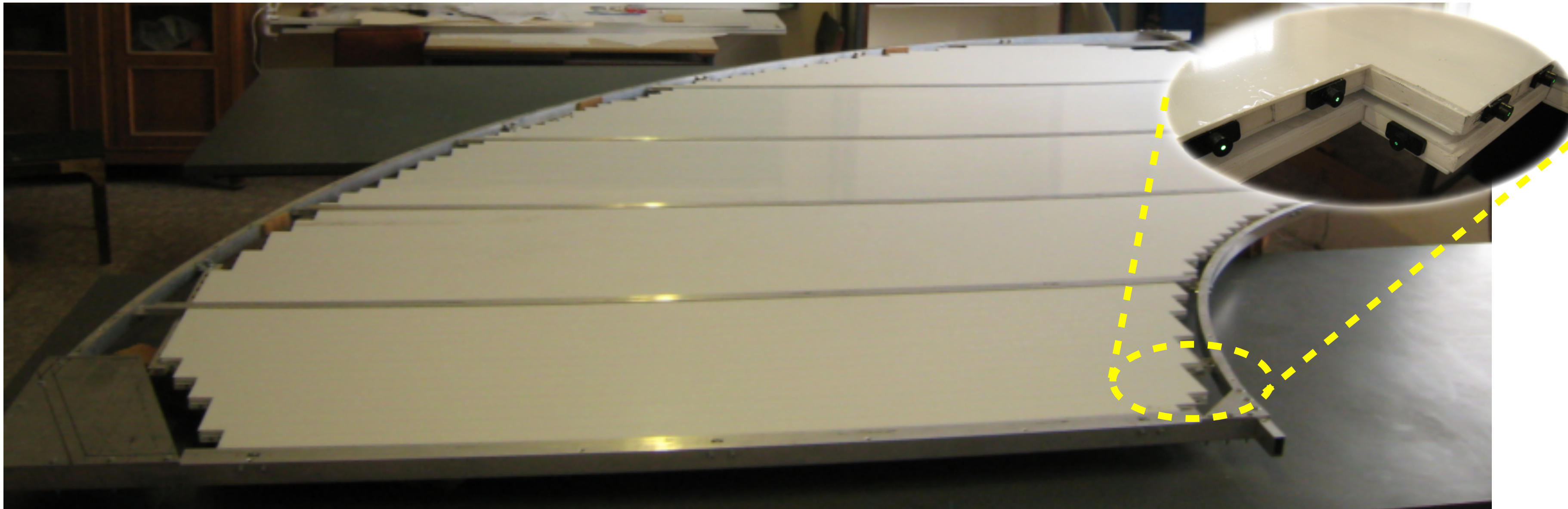




An endcap scintillator superlayer







Pre- and post-installation re-validations at KEK (October–November 2013)

- Use protoboard from VT to deliver HV and power to the preamplifier carrier cards. Use two ganged power supplies (sum ~ 71V). Bring the negative preamp signal through 0.01μF capacitor to TPS 2024 oscilloscope and to LeCroy 623B discriminator. *One channel at a time.*
- Count self-triggered signals less than –70mV (typical pulse height is –200mV: same as at VT).
- Record singles rate, pulse height, tuned operating voltage in spreadsheet for each channel.
- Do this before and after installation of each module.

Post-Installation Cosmic Ray Test at KEK (February 2014)

- ☑ Use pre-production electronics & firmware from Hawaii
- ☑ Attach 2 motherboards to Layer 0 and Layer 1 modules in one of the 8 octants (either forward or backward end)
- ☑ Measure cosmic-ray efficiency in Layer 0 by triggering with Layer 1 – *and vice versa*
- ☑ Repeat 16 times (8 octants; forward & backward ends)

First Batch of RPC Readout has arrived from Italy

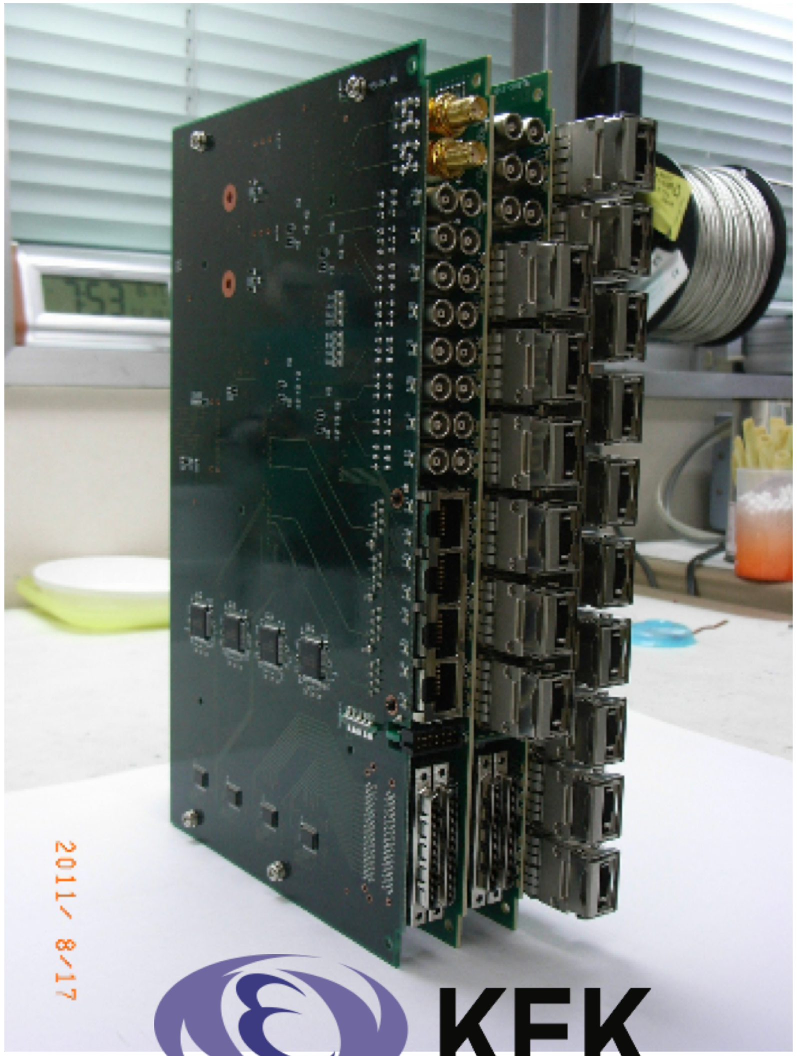
15 pre-production boards produced by Artel were tested in Italy

- ✓ 14 passed the preliminary tests and were shipped to KEK
- ✓ 1 has been reworked and is now in Frascati for re-testing

Board testing is underway to decide whether to give the green light for full production. **Goal: complete production by June** and install at KEK soon thereafter.

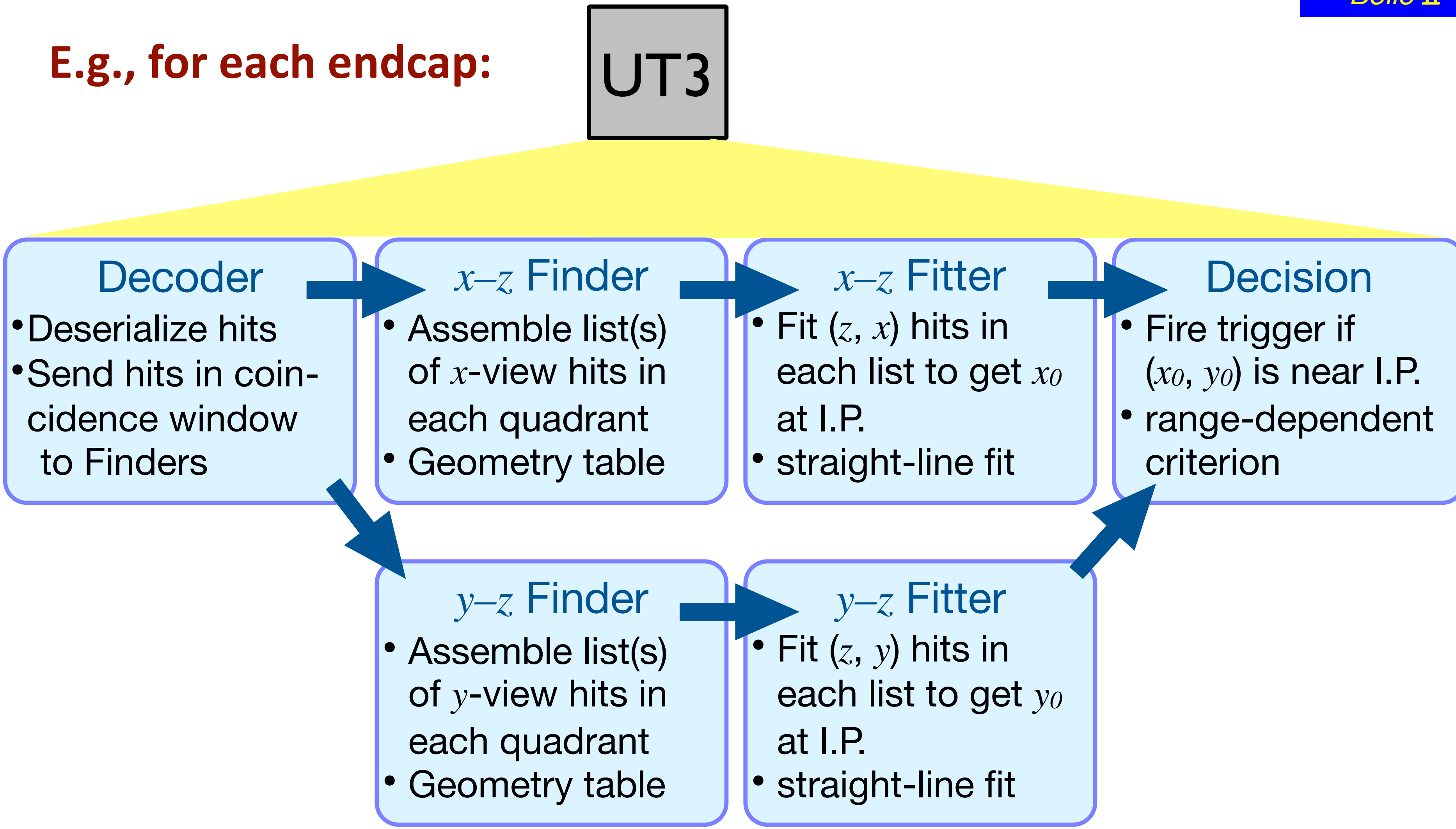
Belle II's Universal Trigger Board (v3) is used for KLM Trigger

- ✓ FPGA = Virtex6 HXT
- ✓ Input/Output:
  - Clock: 1 in, 3 out
  - NIM: 10 in, 10 out
  - 24 GTH (11 Gbps x 24)
  - 40 GTX (6.25 Gbps x 40)
  - LVDS: 32x2 in/out
  - RJ45: 4 (for Belle2Link)



Algorithm finds 2D track(s) in each projection

E.g., for each endcap:



Algorithm finds 2D track(s) in each projection

For barrel: