KLM detector for SuperB

P. Pakhlov
(ITEP)

1st Open meeting of the SuperKEKB Collaboration

Motivation for a new KLM design

- The present RPC design for KLM demonstrated nice performance at Belle
- However, the efficiency decrease is observed due to high neutron background and large RPC dead time. The effect is not significant at barrel, but large for the endcap KLM.

- With SuperKEKB luminosity, it is still possible to use RPC in the barrel with moderate modification: streamer/avalanche mode, faster gas mixture, shield in the innermost gap

• Barrel : try to recover efficiency

efficiency at KEKB

Layer	Barrel	E fwd	E bwd
0	0.91	0.91	0.90
1	0.94	0.93	0.90
2	0.96	0.94	0.90
3	0.98	0.94	0.90
4	0.98	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	0.90	0.85
10	0.99	0.87	0.82
11	0.99	0.82	0.80
12	0.99	0.78	0.81
13	0.99	0.77	0.76
14	0.99	N/A	N/A

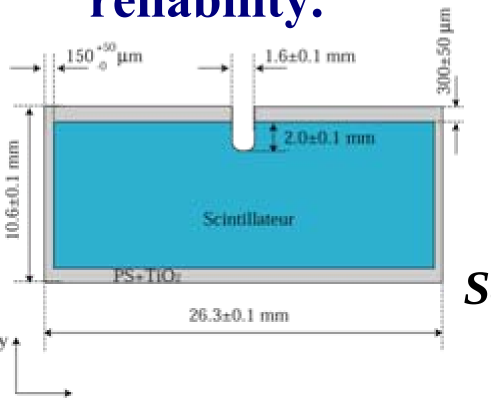
efficiency at SuperKEKB

Layer	Barrel	E fwd	E bwd
0	0.70	0.0	0.0
1	0.81	0.0	0.0
2	0.87	0.0	0.0
3	0.91	0.0	0.0
4	0.94	0.0	0.0
5	0.95	0.0	0.0
6	0.95	0.0	0.0
7	0.96	0.0	0.0
8	0.94	0.0	0.0
9	0.96	0.0	0.0
10	0.98	0.0	0.0
11	0.97	0.0	0.0
12	0.96	0.0	0.0
13	0.97	0.0	0.0
14	0.96	N/A	N/A

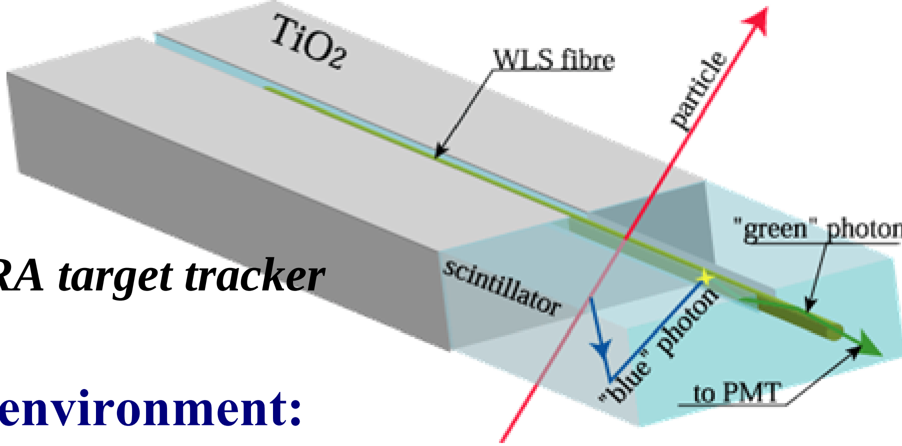
- However, the efficiency of endcap KLM becomes unacceptably low and new fast detector is required.

Scintillator option for endcap KLM

- Plastic scintillator + WLS fiber read out successful in many neutrino experiments (MINOS, MINERva etc) and very popular in the new neutrino experiments (OPERA, T2K near detector), because of relatively low price, high reliability.

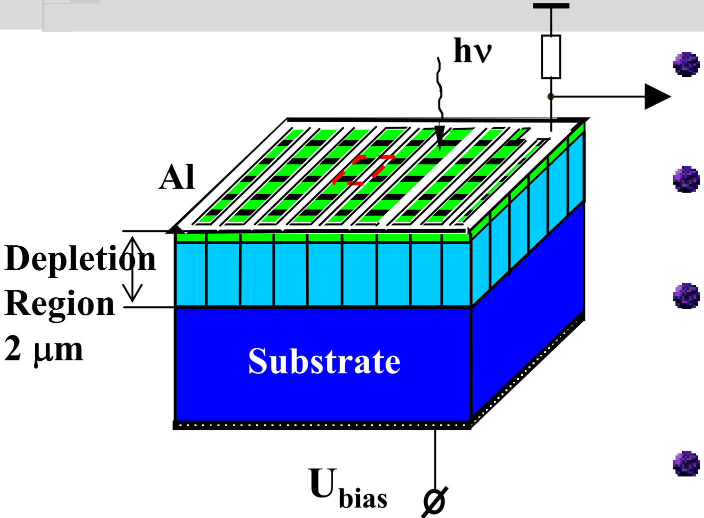


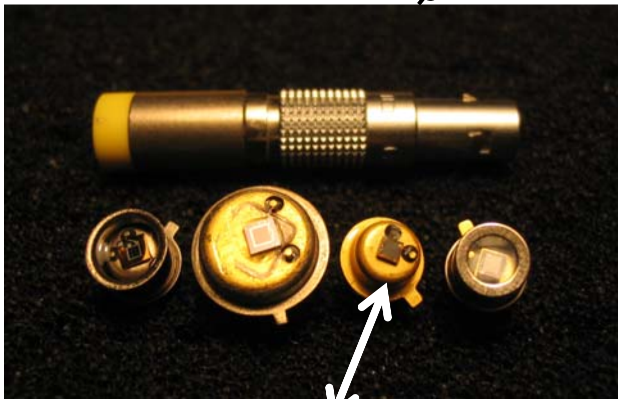
Scintillator strips for OPERA target tracker

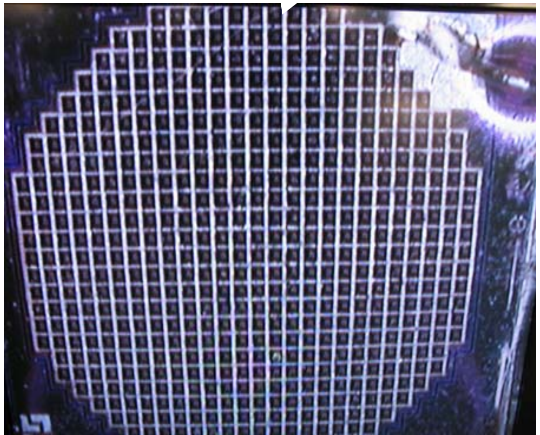


- e^+e^- experiments has (slightly) different environment:
  - ☐ Higher occupancies
  - ☐ Radiation
  - ☐ (Huge) magnetic field
  - ☐ Limited space
- The extra requirements due to these new environments are ok for scintillator and WLS fiber;
- The choice of photodetector is the key question:
  - ☐ Photomulitpliers are not compact and poorly operates in the magnetic field.
  - ☐ New multipixel Si photo diodes operating in Geiger mode are tiny and insensitive to the magnetic field.

Geiger Photo Diodes



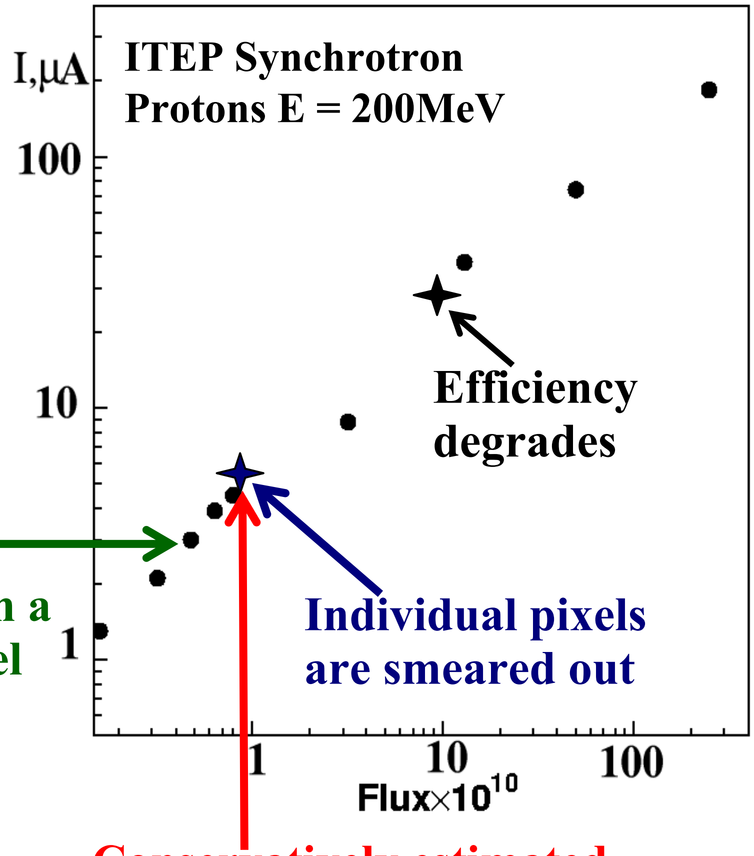




- Matrix of independent tiny pixels arranged on a common substrate (200−2000 pixels).
- Each pixel operates in a self-quenching Geiger mode: gain is ~10^6.
- Each pixel produces a standard response independent on number of incident photons. *GPD* at whole integrates over all fired pixels.
- Efficiency (including geometrical) to detect photon ~30%, higher than typical efficiency of photomultiplier.
- Compact: typical matrix size ~ 1 × 1 mm^2.
- Cheap: 20−30$; cheaper or comparable to one channel of multychannel photomultiplier.
- Not sensitive to magnetic fields.
- Radiation hardness is sufficient for our purposes.
- Internal GPD (one pixel) noise is 100kHz − 2MHz is not a problem: setting threshold at 5 fired pixels reduces the internal noise to < 1kHz and keep the efficiency to MIP 99%.
- Produced by many companies in Russia, Japan, Switzerland, Italy. The russian company CPTA has experience of moderate mass production of few thousand pieces working in real experiment.

Radiation hardness

- **Dark current increases linearly with flux Φ as in other Si devices: $\Delta I = \alpha \Phi V_{eff}$ Gain, where $\alpha = 6 \times 10^{-17}$ A/cm, $V_{eff} \sim 0.004$ mm^3 determined fr observed ΔI**
- **Since initial *GAPD* resolution of ~ 0.15 p.e. is mu better than in other Si detectors it suffers sooner:**
- **After Φ ~ 10^{10} n/cm^2 individual p.e. signals are smeared out, while MIP efficiency is not affected**
- **MIP signal are seen even after Φ ~ 10^{11} n/cm^2 but efficiency degrades**



Efficiency degrades

Individual pixels are smeared out

Extrapolated for 5 years at SuperB increase of noise from a measurement in KEKB tunnel

Conservatively estimated neutron flux in 5 years at SuperB assuming neutron energy spectrum causing maximal damage

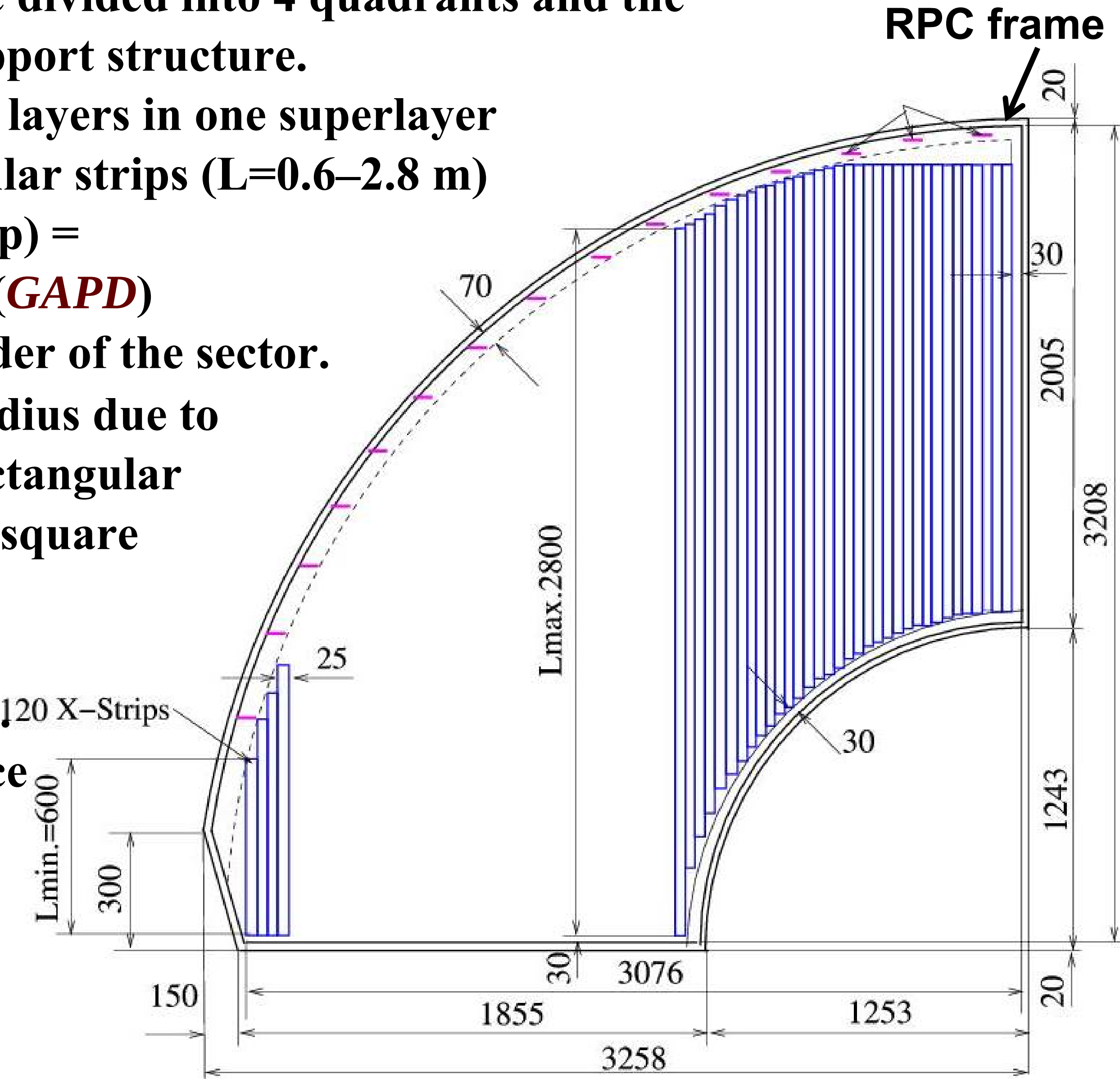
- **Measurements at KEKB in almost real conditions demonstrate ~3 times smaller dam than estimated**

Radiation hardness of *GAPD* is sufficient for SuperBelle, but we do not have a large safety margin for more ambitious luminosity plans

Now we perform another radiation hardness test (including MPPC)

Scintillator KLM set up

- The geometry is fixed by the requirement to use the existing 4cm gaps in the iron magnet flux return yoke divided into 4 quadrants and the existing RPC frames as a support structure.
- Two independent (x and y) layers in one superlayer made of orthogonal rectangular strips (L=0.6–2.8 m)
- Photodetector (one per strip) = photo diode in Geiger mode (*GAPD*) placed around the outer border of the sector.
- Dead zone around inner radius due to circle circumscribed with rectangular strips is ~ 0.2% of the sector square
- Outer dead zone is ~ 3% and may be reduced by adding few extra short strips. However the outer acceptance is not so much important.

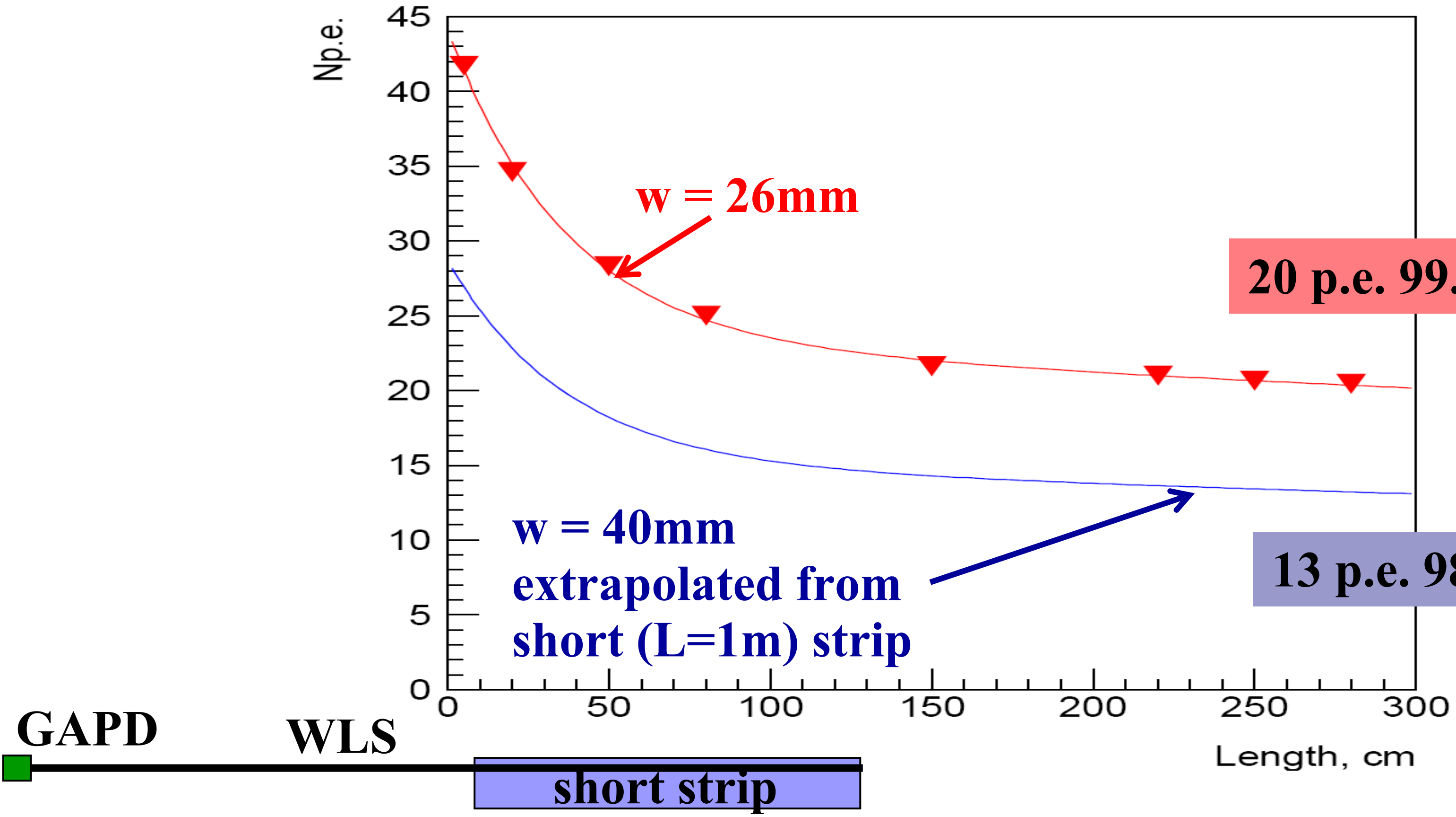


Strip geometry

We consider now two options of strip width:

economic option (w=40mm) ≈ present RPC granularity (17k read out channels)
- 30% cheaper

"improved" granularity (w=26mm) ≡ OPERA strips (27k read out channels)
Advantages:
- 30% more light;
- better muon ID (how better is to be confirmed with GEANT MC)



Far end:

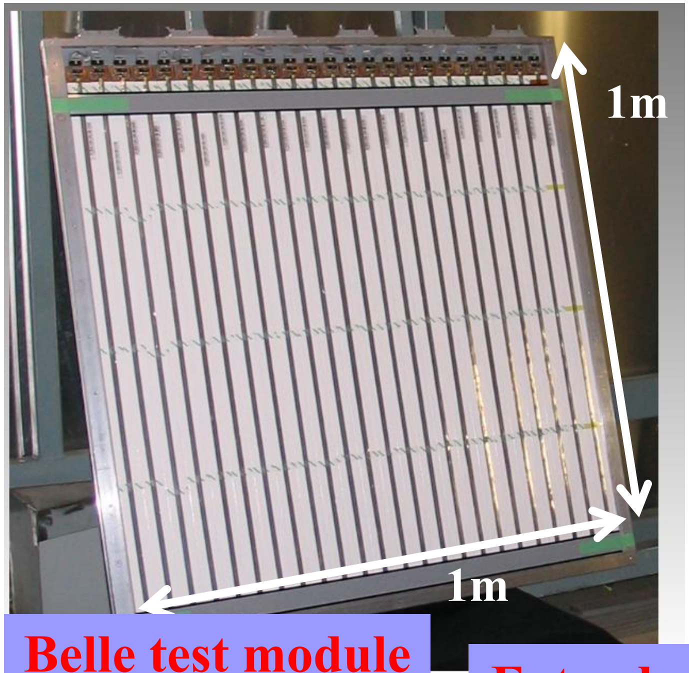
20 p.e. 99.9% efficiency

13 p.e. 98% efficiency

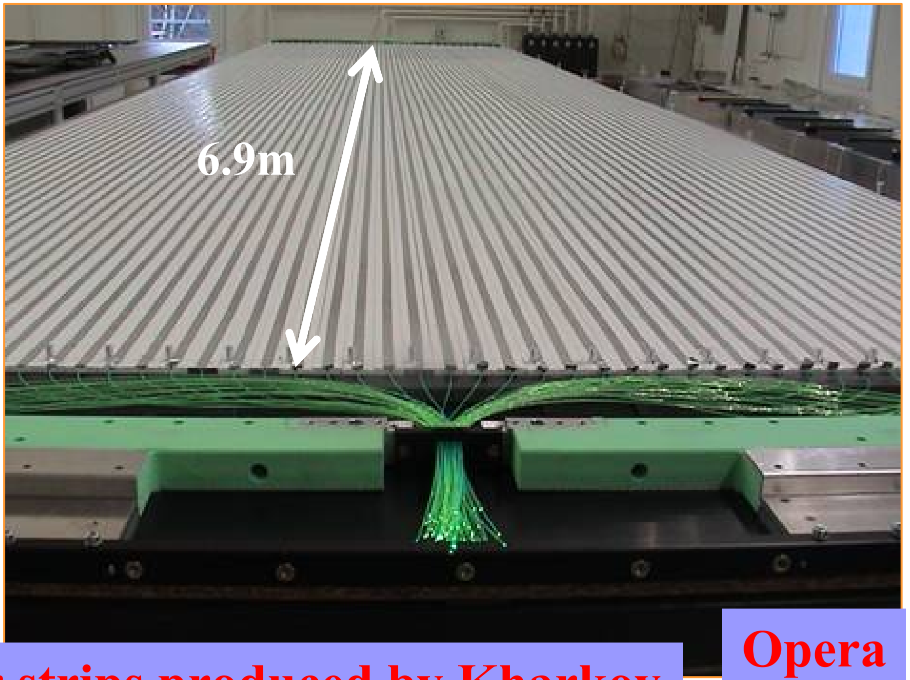
with 6 p.e. threshold

Producers

- There are several producers for scintillator strips and photodetectors that meet our conditions and have an experience for mass production:
- Scintillator strips:
  - ☐ <u>Kharkov (Ukraine)</u> *produced scintillator strips for OPERA*
  - ☐ <u>Fermilab</u> *produced scintillator strips for T2K*
- Photodetectors:
  - ☐ CPTA (Russia)
  - ☐ Hamamtsu
- WLS fiber: Kurarai Y11 (no better option)
- Optical glue: St. Petersburg (Russia) or Bicron



Belle test module

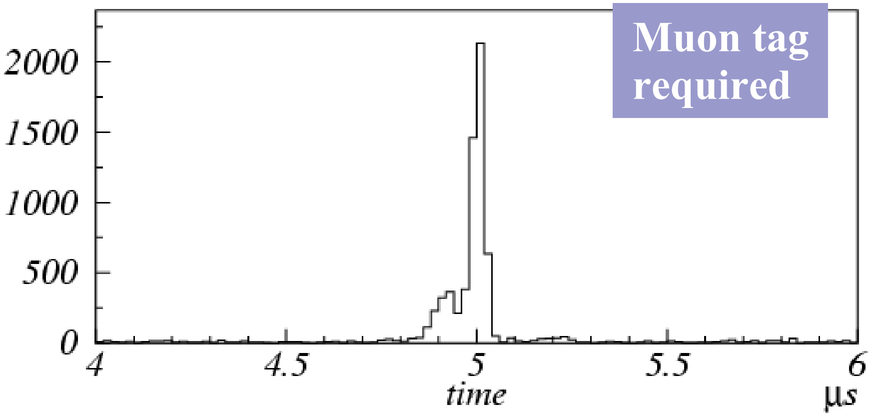


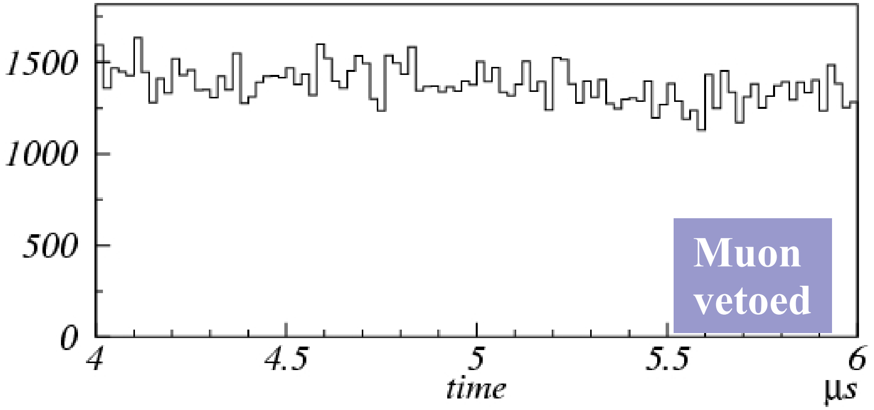
Opera

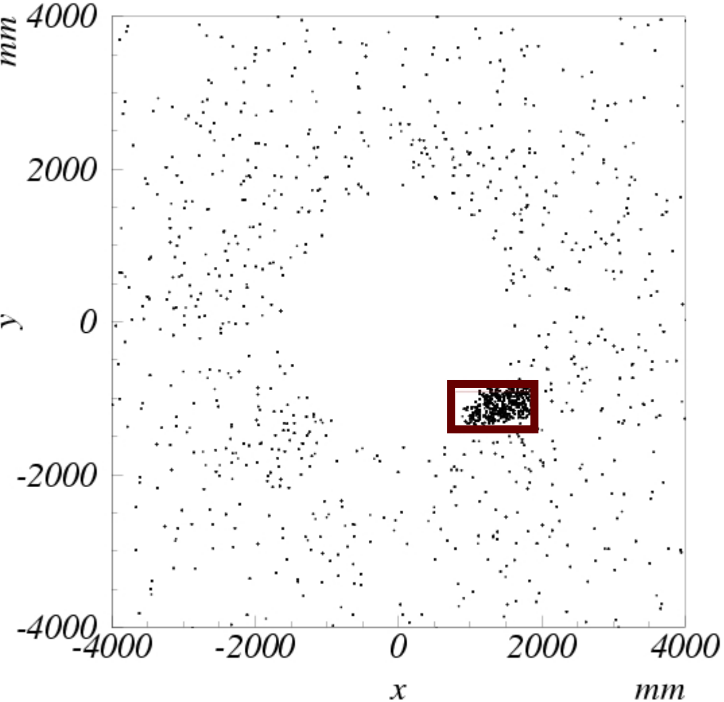
Extruded scintillator strips produced by Kharkov

Test module in KEKB tunnel

- Sc-KLM hits are stored in the data tapes: the raw hit rate is ~10 times higher than RPC hits.
- Muons from ee →μμ are seen with proper time off line.
- Proper time hits show the position of the test module in the tunnel.







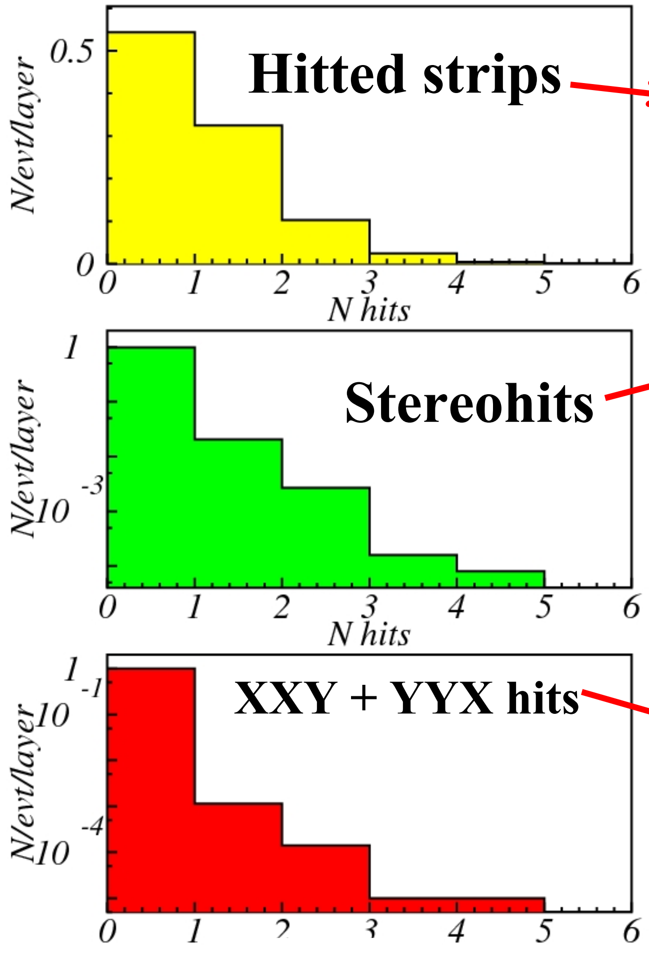
The distribution of the muons hits (x%y) extrapolated from CDC to $z = z_{\text{test module}}$ with the proper time sc-KLM module hits.

Physics performance

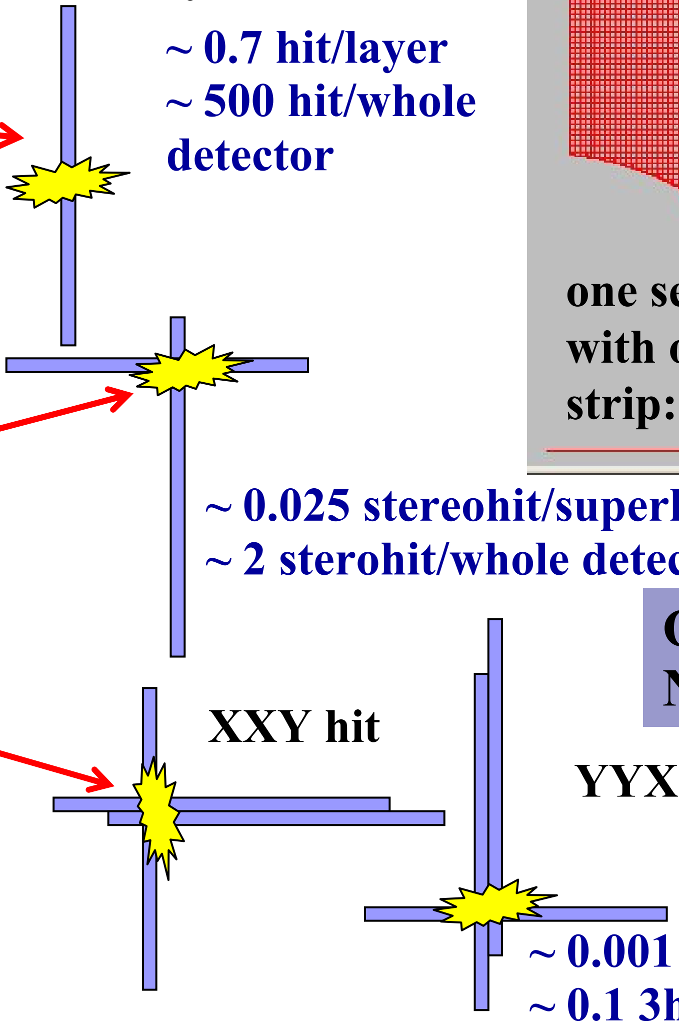
- **Scintillator detectors are more sensitive to neutrons (due to hydrogen in plastic). The tests in the KEKB tunnels show that neutron rate at scintillator strips is 5 Hz/cm^2 now; ⇒ 70 Hz/cm^2 at L=2×10^{35} /cm^2/s**
- **Background neutron can produce hits in one strip only (no correlated hits in x and y plane). This allows to have stereohit background rate smaller than at RPC in spite of increased single hit rate.**
- **Additional suppression is due to good time resolution (measured Strip+GAPD time resolution is ~1 ns), therefore x-y coincidence time can be cut at ±5ns.**
- **K_L detection ⇒ now two different tasks:**
  - ☐ **for reconstruction finals states including K_L (e.g. $B \to J/\psi\ (\varphi)\ K_L$; $D \to K_L\pi$): the time gate can be set at ±5ns from the expected (calculated time of flight using the known K_L momentum)**
  - ☐ **for K_L veto ($B \to \tau\upsilon$; $B \to h\upsilon\upsilon$): the time gate have to be as large as 50ns from the bunch crossing to accept all K_L momenta (for p~0.2GeV t~40ns)**
- **Muon identification should be better due to better spatial resolution (with 26mm strips) and higher MIP detection efficiency.**

Neutron background estimate

- Neutron hit rate: 100 Hz/cm^2
- Cross-talk between neighboring strips 1%
- Gate 50 ns
- Coincidence time between x and y hits 10 ns



N hits



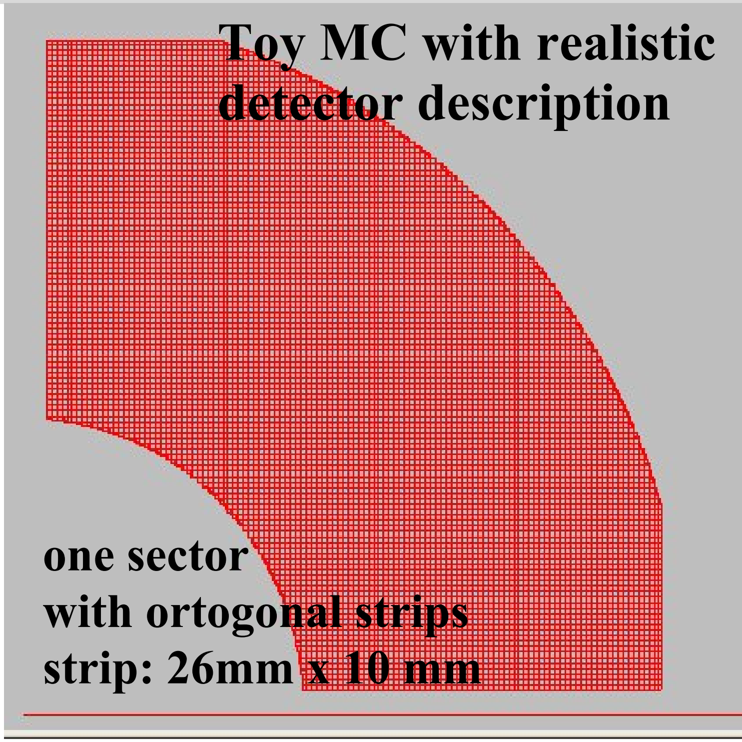
~ 0.7 hit/layer
~ 500 hit/whole detector

~ 0.025 stereohit/superlayer
~ 2 sterohit/whole detector

OK for K_L reconstruction
Not OK for K_L veto

OK for K_L veto

~ 0.001 3hit-cluster/superlayer
~ 0.1 3hit-cluster/whole detector

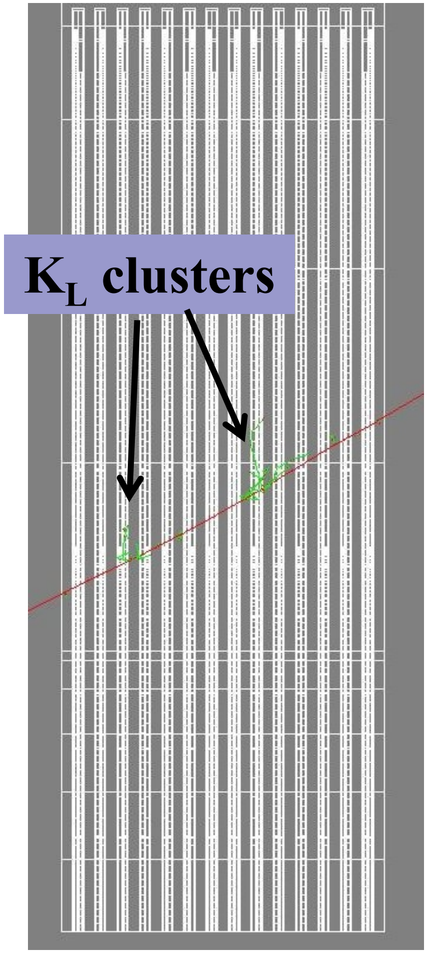


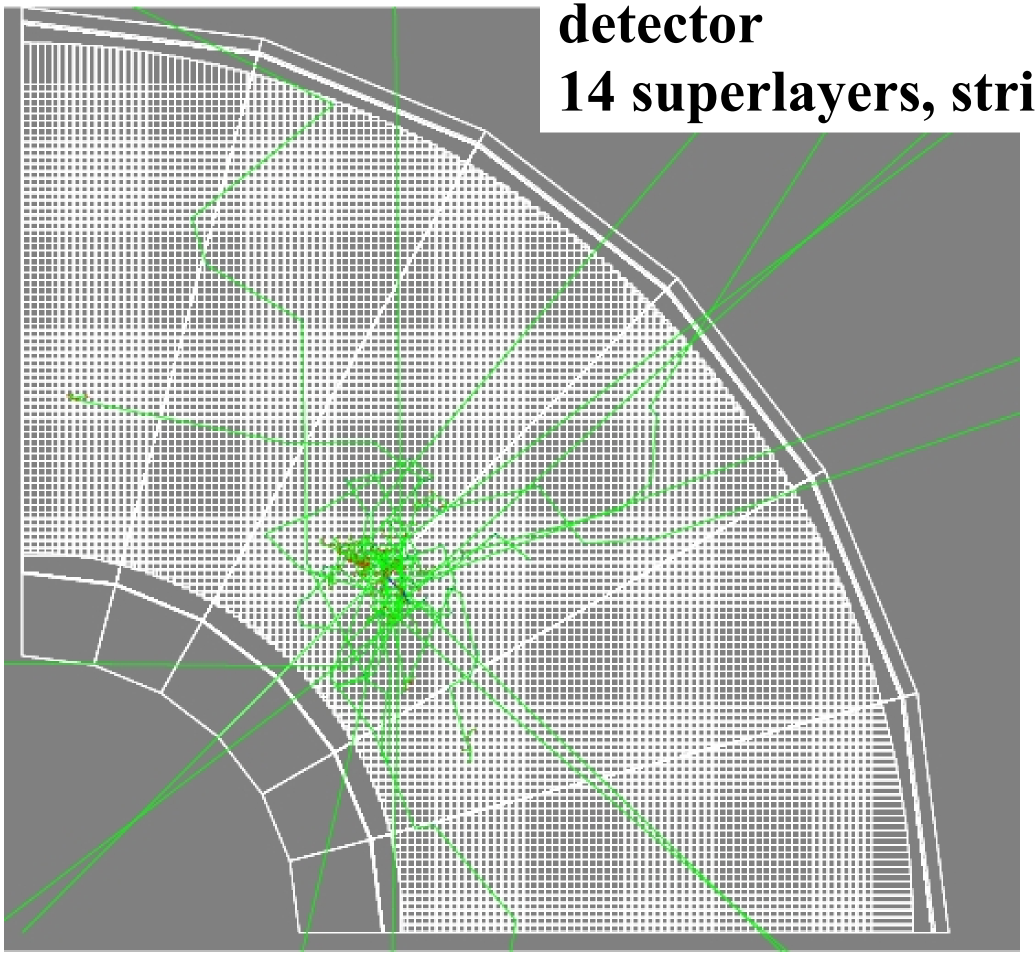
Toy MC with realistic detector description

one sector
with ortogonal strips
strip: 26mm x 10 mm

Realistic G4-based prototype

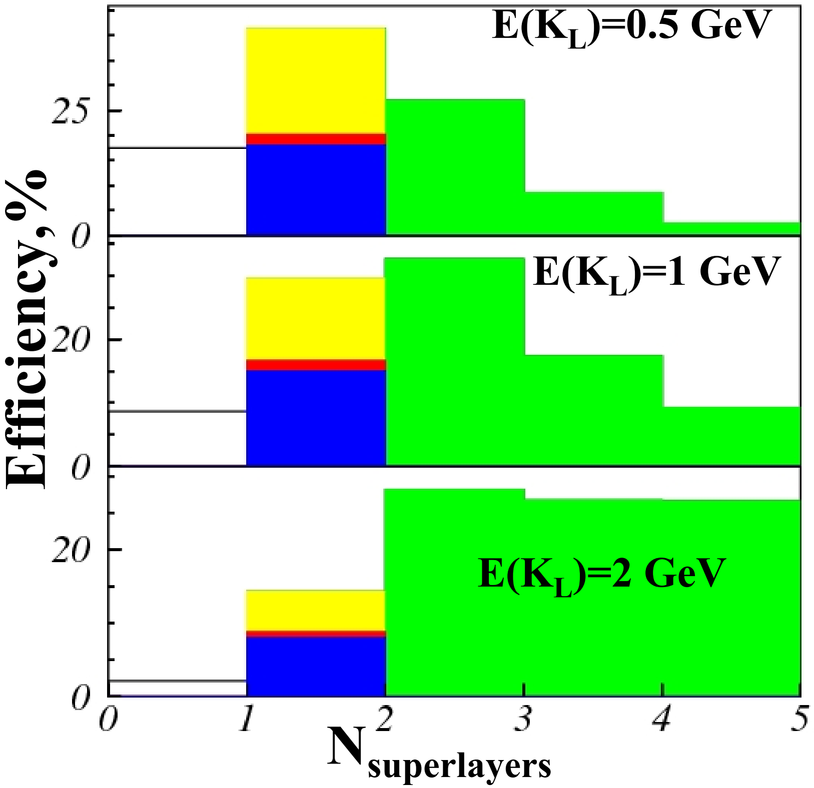
Geant4 standalone endcap KlM detector
14 superlayers, strip width 26mm





K_L efficiency study

- **GEANT-4 simulation for standalone KLM detector; still no correction for**
  - **geometrical efficiency/ light collection efficiency**
  - **ECL**

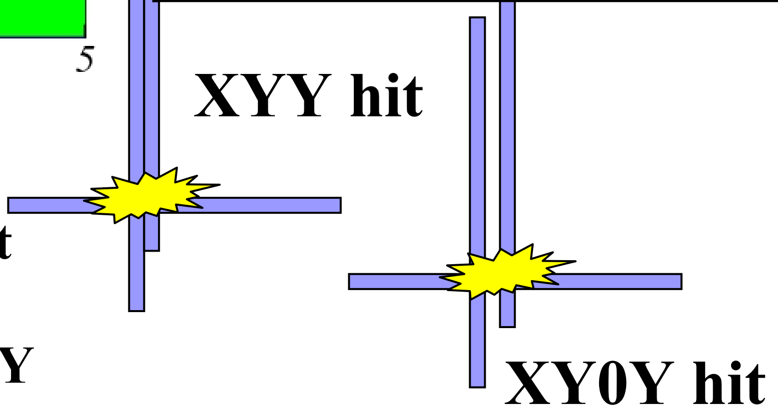


- **Present algorithm: require two superlayers hits or ECL cluster + one superlayer**

$E(K_L)$, GeV	0.5	1.0	2.0
Present efficiency	**38%**	**59%**	**81%**
Addition			
K_L reconstrution	**+40%**	**+30%**	**+16%**
Veto (option 1)	**+18%**	**+15%**	**+10%**
Veto (option 2)	**+20%**	**+17%**	**+11%**

Options to increase efficiency in the case of one superlayer hit

1. **use 3hit-cluster XXY+XYY**
2. **use 3hit-cluster X0XY+XY0Y**



Recent progress

- Another radiation ageing tests is now under way with 10 GAPD(Russia) and 10 MPPC(Hamamtsu). November 6 – December 22, 2008.
- Both Fermilab and Kharkov confirmed that they can produce required amount of strpis. Their prices are similar (~20$/kg). November'08 – strips from Fermilab arrived to ITEP for tests.
- Electronics: readout electronics is common for all other subdetectors: 16-channels (flashADC/2.5GHz + FPGA – "oscilloscope on chip"), developed and produced at Hawaii. It has been given us for tests in November.
- HV and slow control/local run electronics still need to be developed.
- Geant4 MC for geometry optimization: the progress is slow. Leo decribed endcap scKLM in new GEANT MC, with RPC strip geometry. Besides description of new geometry, new reconstruction is required.

Summary

- **Scintillator KLM design is OK for SuperBelle:**
  - ☐ **the efficiency of MIP detection can be kept at high level (>99% geometrical; thresholds: compromise between efficiency and neutron bg rate)**
  - ☐ **K_L reconstruction: The reconstruction efficiencies can be improved**
- **Radiation hardness of *GAPD* is sufficient for SuperBelle for endcap and barrel parts, but we do not have a large safety margin for $L=10^{36}$.**
- **The final optimization of the strip size is to be done with a full GEANT simulation of the whole SuperBelle detector (in progress now).**
- **The negations with producers started; Their products have similar characteristics, that are ok for us, and the prices from different producers are similar.**
- **The test with a real prototype in the KEKB tunnel allowed to measure neutron background rate and estimate the radiation hardness of GAPD in real conditions.**

Cost estimate for endcap KLM

Item		price	cost
Scintillator strips	28, 000 pc. (14,000 kg)	20 $/kg	280 k$
WLS fiber	56 km	1.4 $/km	80 k$
Photo-detectors CPTA	28, 000 pc.	20 $/pc.	560 k$
Optical glue	300 kg		30 k$
Electronics	28, 000 ch.	? $/ch.	? k$
Miscellaneous			70 k$
Transportation			40 k$
Total			1060 k$

* Cost estimate for electronics will be made after the electronics design

** Cost does not include electronics, labor and R&D

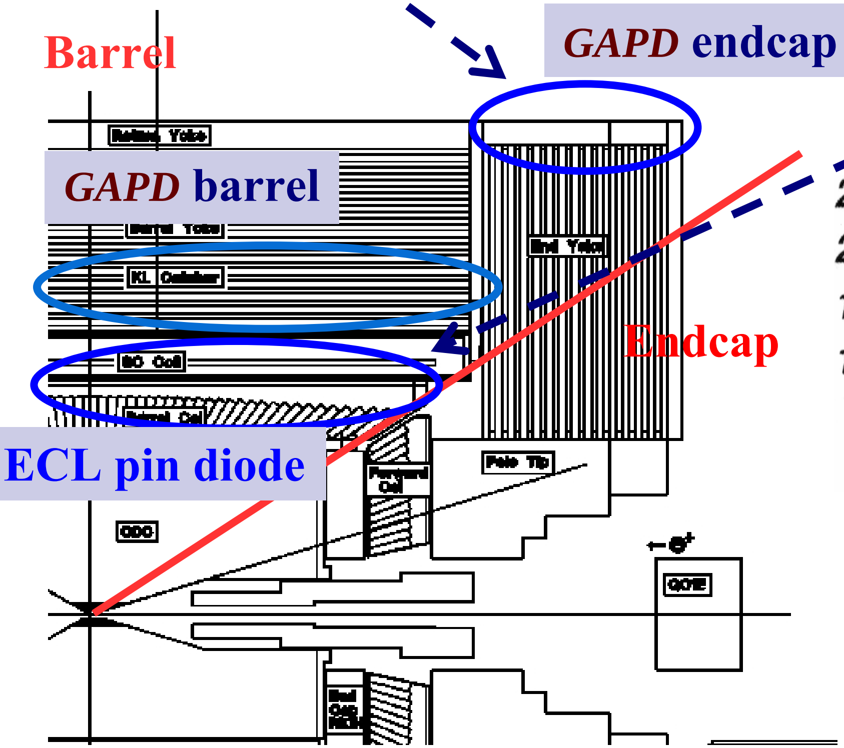
*** Changes in $ exchange rate can influence the cost

Estimate of neutron dose at SuperB

Now ($L=1.4\times10^{34}$) ~ 1mSv/week → 15mSv/week at SuperB ($L=2\times10^{35}$)
→ 3Sv/5 years → conservatively → 9×10^{9} n/cm^2/5years

Luxel budges (J type) measure fast neutron dose

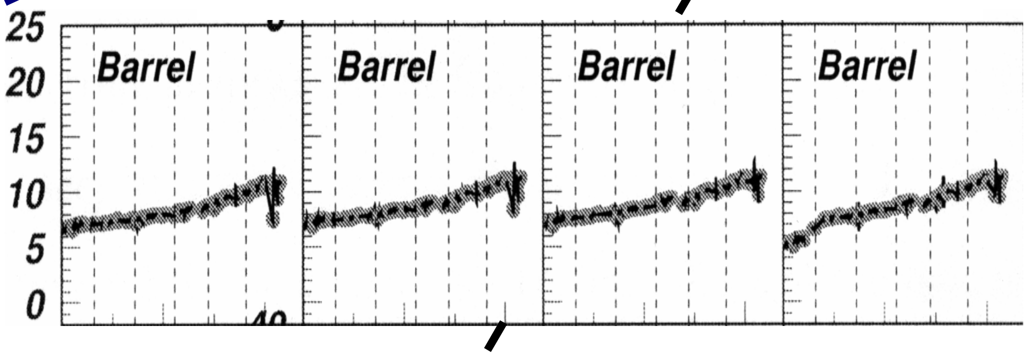
Independent method: neutron dose has been measured at ECL via observed increase of the pin-diod dark current: ΔI ~ 5nA



GAPD endcap

GAPD barrel

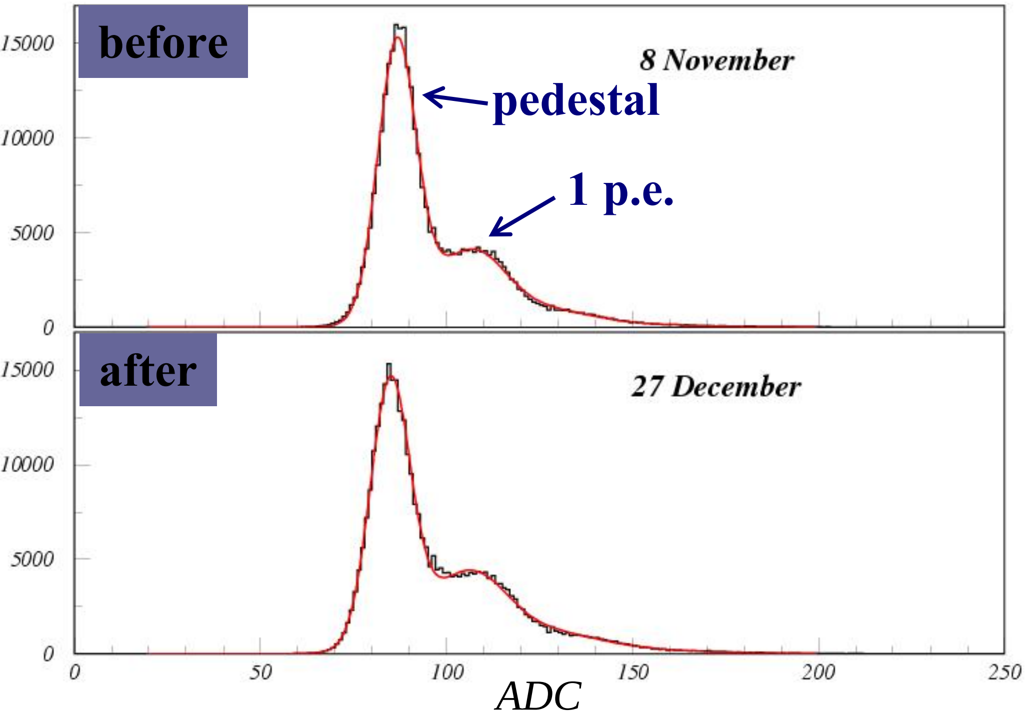
ECL pin diode



Conservatively: 5×10^{8} n/cm^2/500fb^{-1}
assuming dose ~ 1/r → 10^{10} n/cm^2/5years

Both methods are conservative and give consistent estimates of 10^{10} n/cm^2/5years
Neutron dose at barrel KLM can be 1.5 times higher

Radiation damage measurements at KEKB tunnel



The GAPDs have been exposed to neutron radiation in KEKB tunnel during 40 days. The measured neutron dose is 0.3 Sv, corresponding to half year of Super KEKB operation

- Increase of dark currents after 40 days in KEKB tunnel

  $I_{after} - I_{before} \sim 0.1\ \mu A$ (within the accuracy of the measurement)
- More accurate estimate of *GAPD* degradation is done using fit to ADC spectra: the 1 p.e. noise has increased by 10% only after 40 days in KEKB tunnel for the *GAPD*s irradiated with the highest dose 0.3 Sv.

Extrapolation to 5 years of operation: I_{dark} will increase by 1 μA;
1 p.e. noise rate will increase twice

The tests go on. By the summer shut down the dose will be equivalent to 2.5 years.