K-long and muon system for the Belle II experiment

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Outline

- From Belle to Belle2
  - Belle: RPC option for KL/muon system
  - Belle2: Scintillator option for KL/muon system
- Production, assembly and tests
- Calibration
- Conclusion

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B-factory motivation

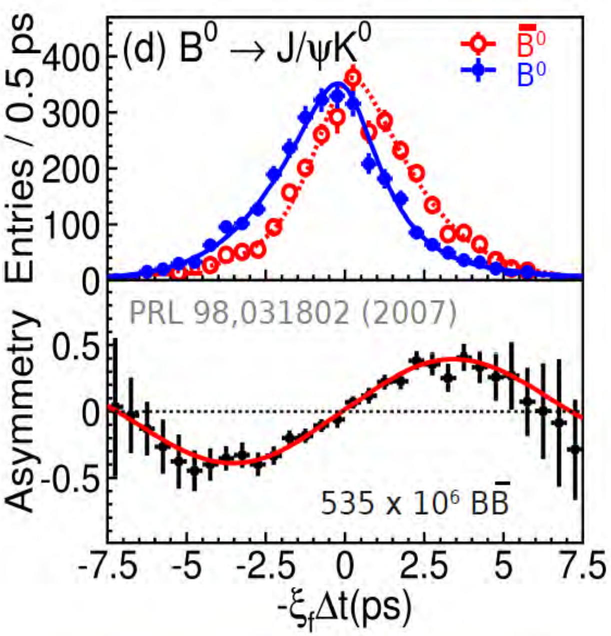
- 1964, Cronin, Fitch: Discovery of CP violation in K^0 system, small effect $O(10^{-3})$

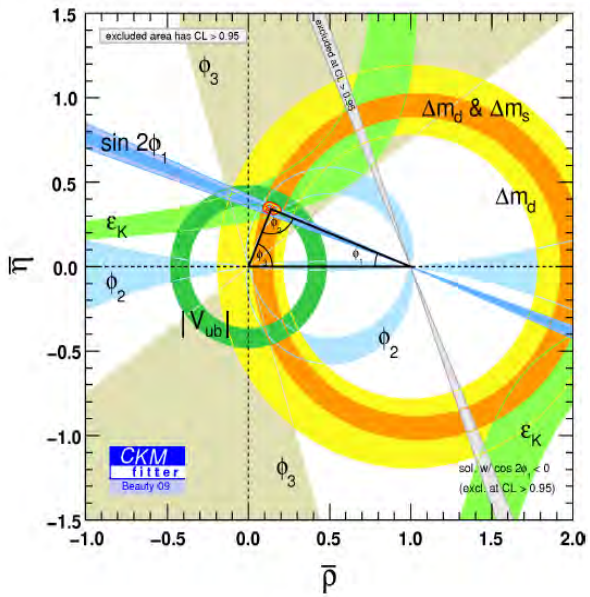

- 1972, Kobayashi, Maskawa:
  - CP violation possible, if there are 6 quark flavors
- ✔ 1974, Burton, Richter: Discovery of charm quark
- ✔ 1977, E288: Discovery of bottom quark
- ✔ 1995, CDF, D0: Discovery of top quark

→ CP violation?

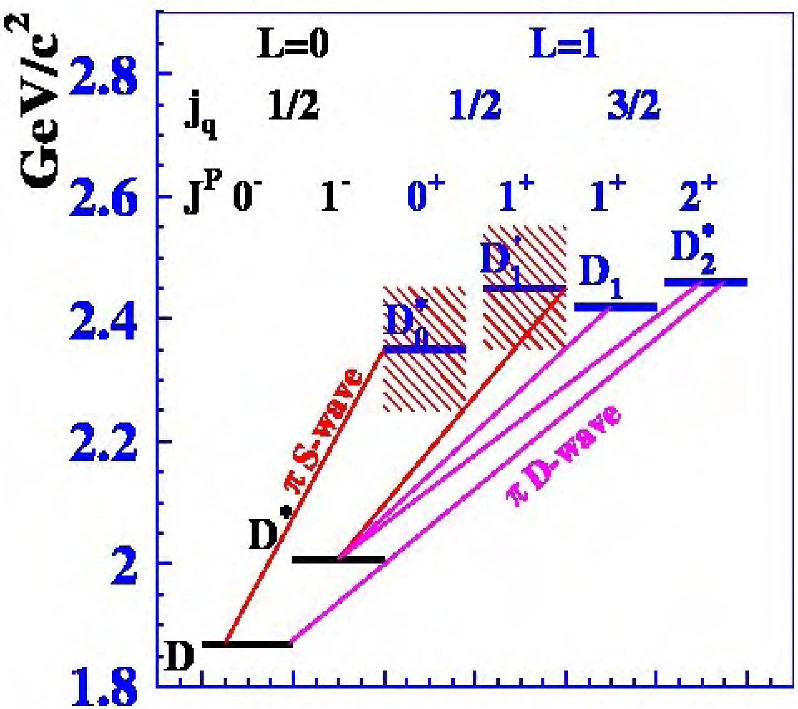
Belle achievements

$\int \mathbf{L} dt > 1000\ fb^{-1} = \sim 10^{9}\ BB$





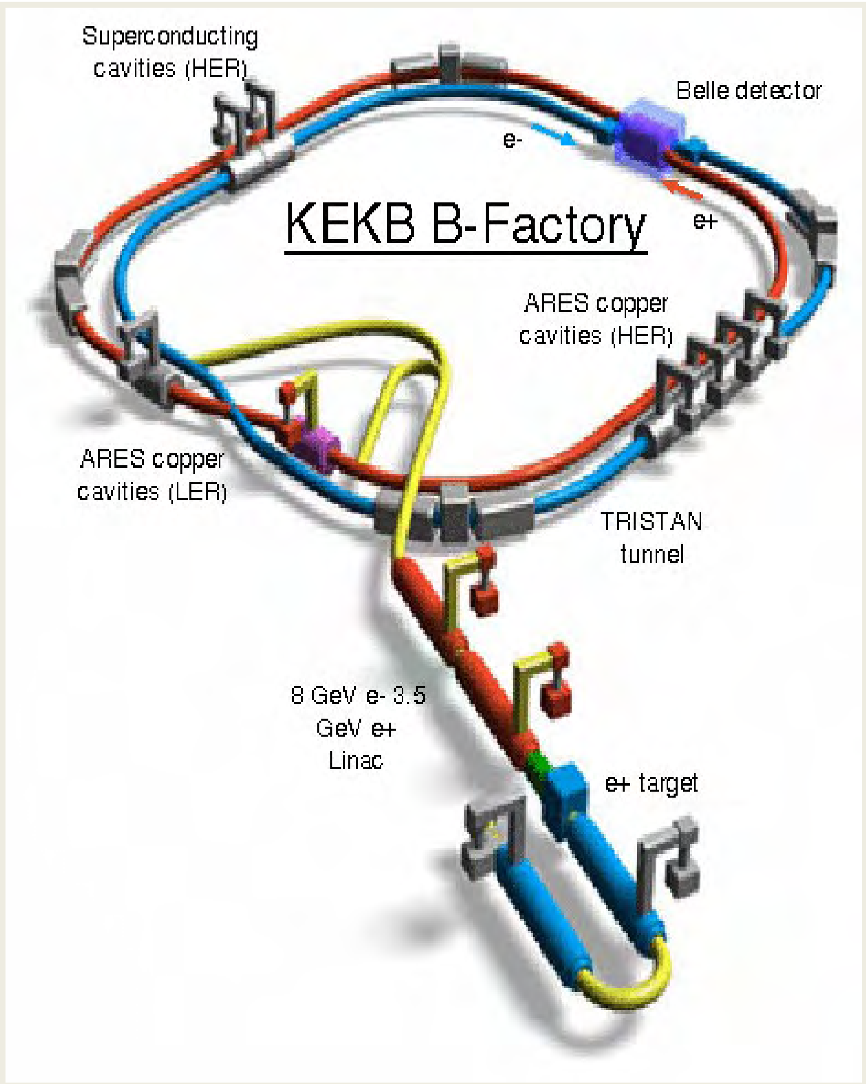
✓ Confirmation of KM mechanism of CP in the Standard Model

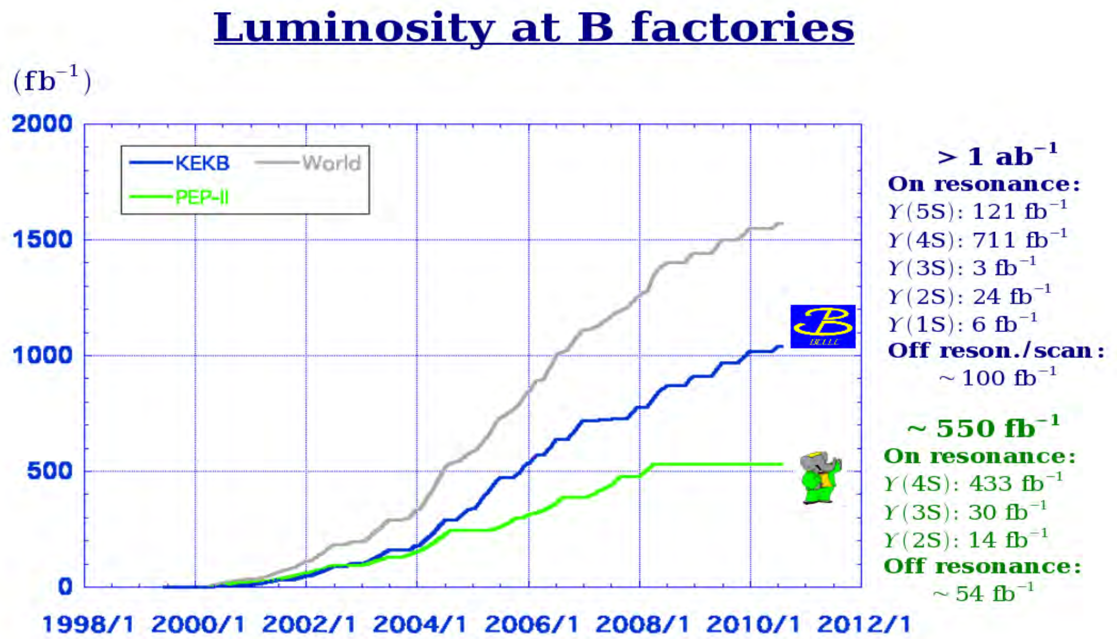


New charmonium-like states: X, Y, Z ...

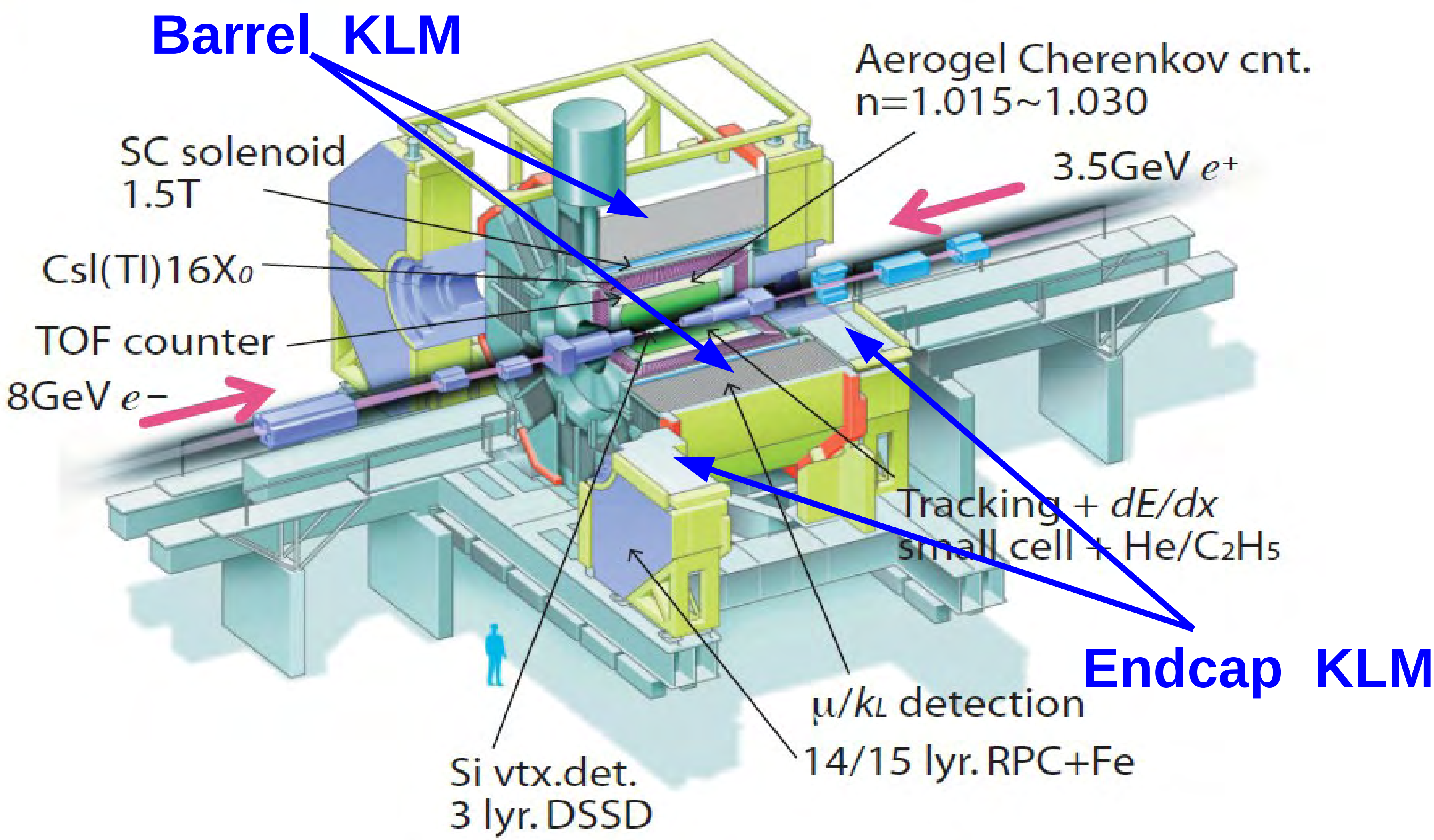
Heavy hadrons spectroscopy

KEKb accelerator

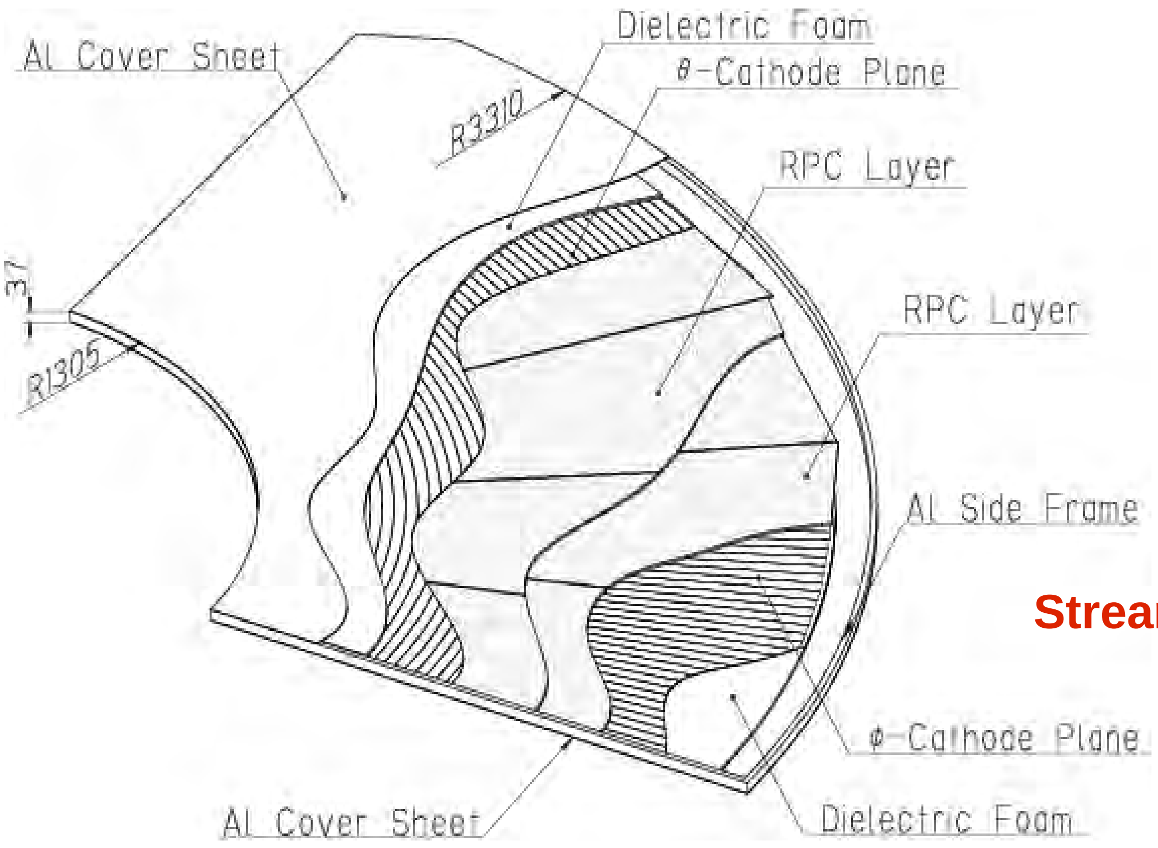


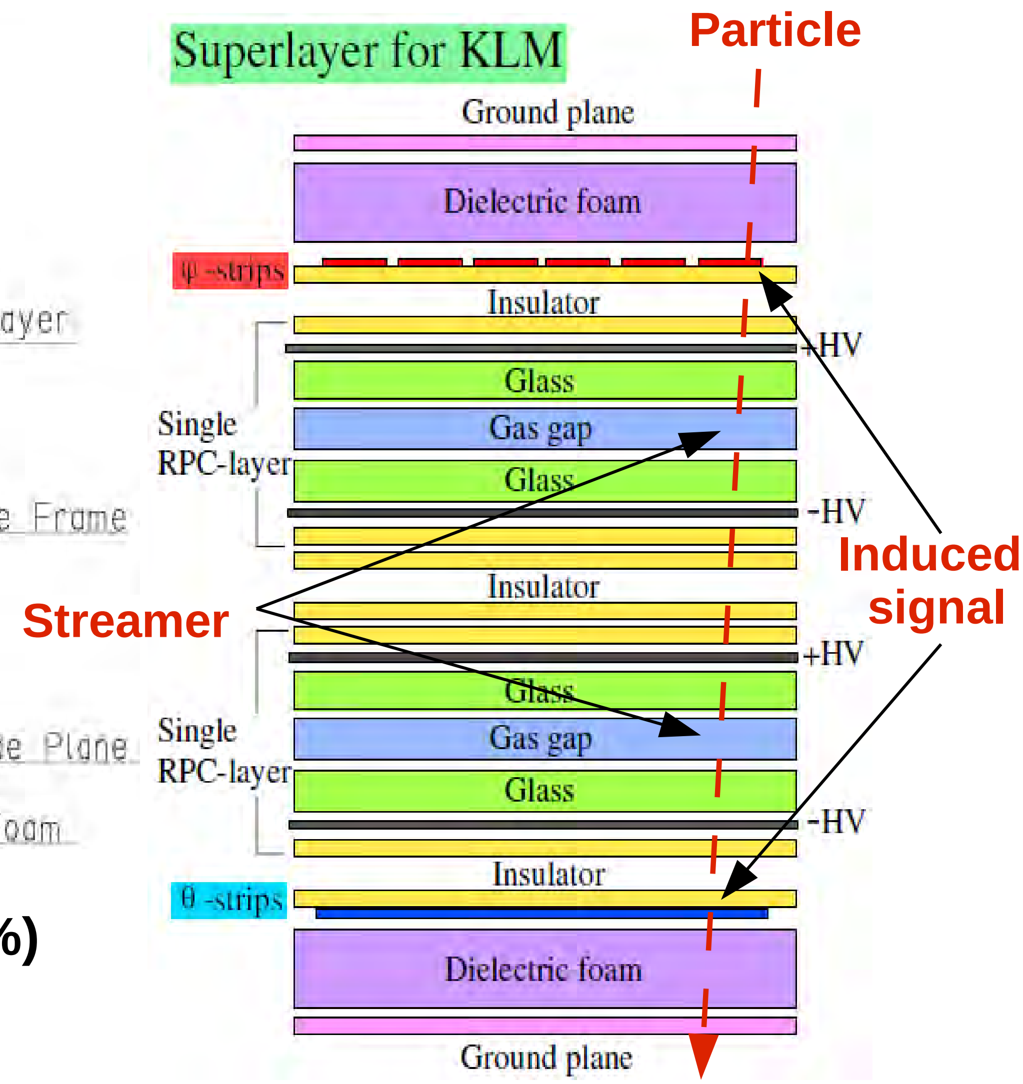


The Belle detector



Belle: Resistive Plate Chambers

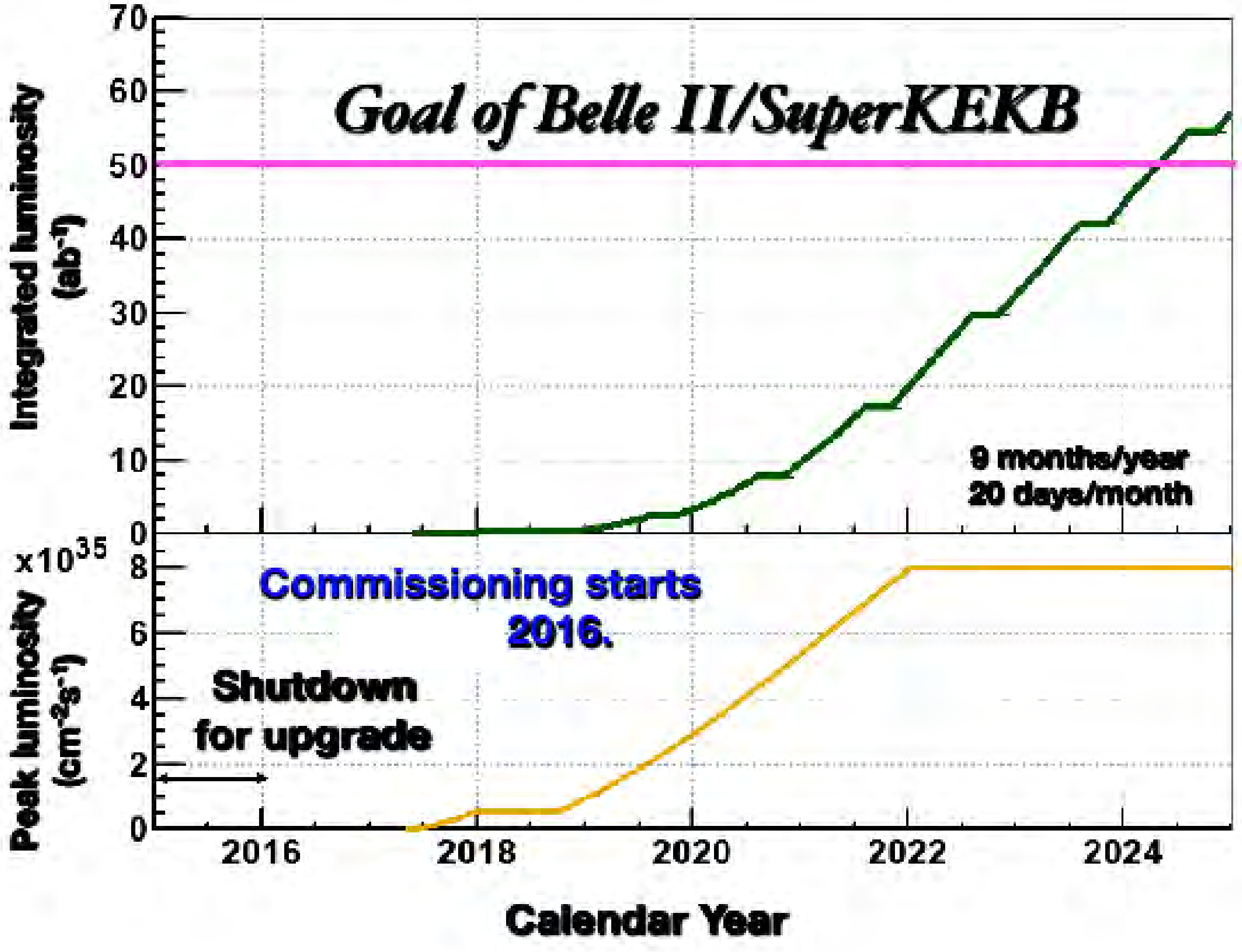




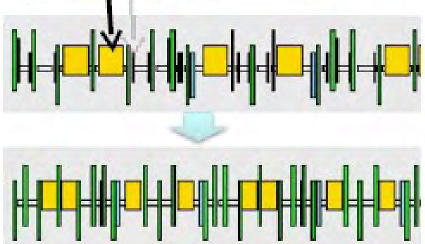
Gas: Ar/C_4H_{10}/HFC-134a = 30/8/62 (%)

Voltage≈7kV

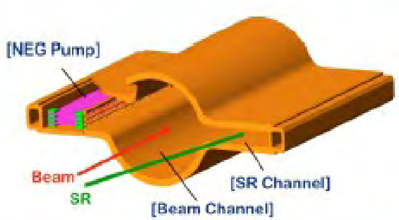
SuperKEKb luminosity plans



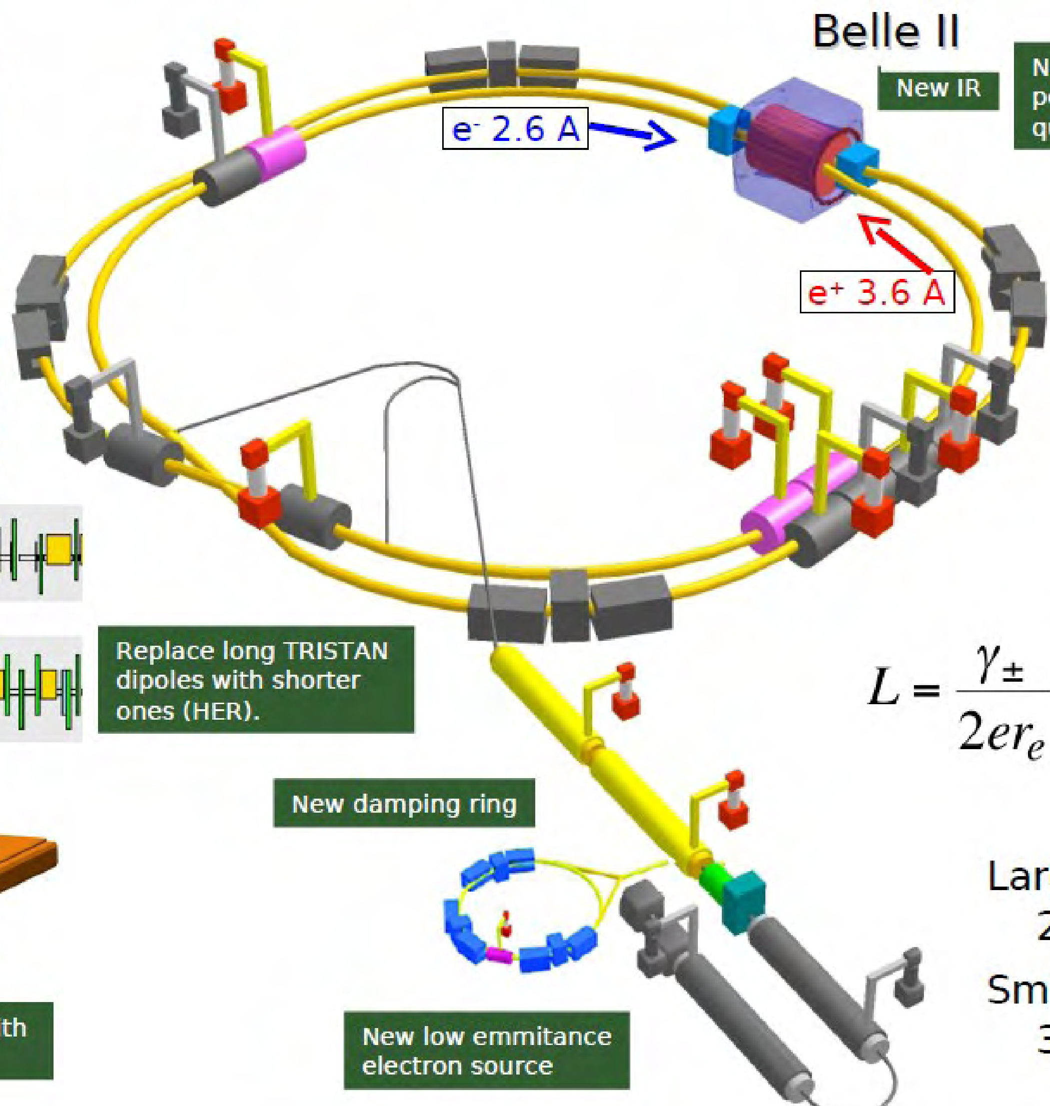
SuperKEKb



Replace long TRISTAN dipoles with shorter ones (HER).



TiN coated beam pipe with antechambers



New IR

New Superconducting / permanent final focusing quads near the IP

New damping ring

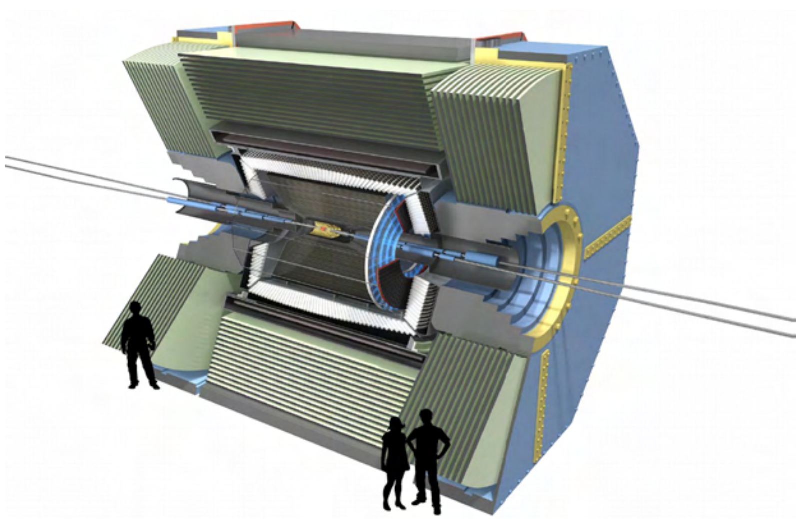
New low emmitance electron source

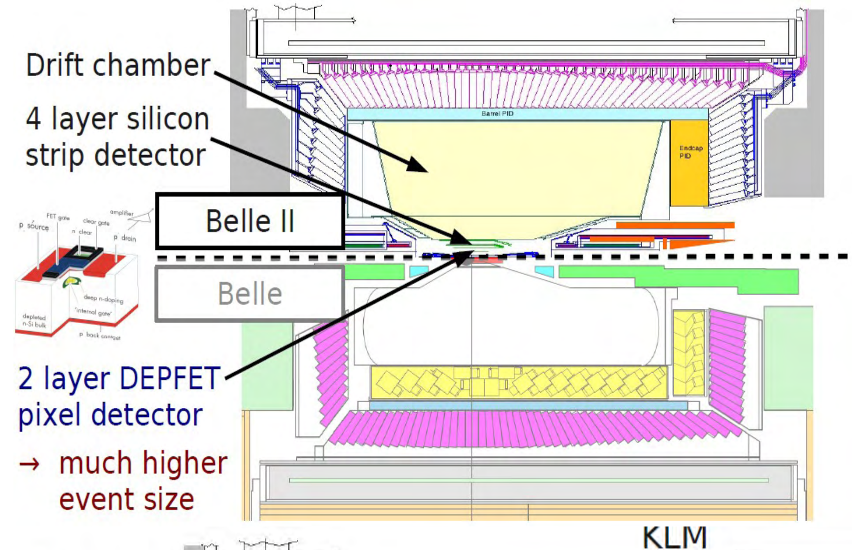
$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

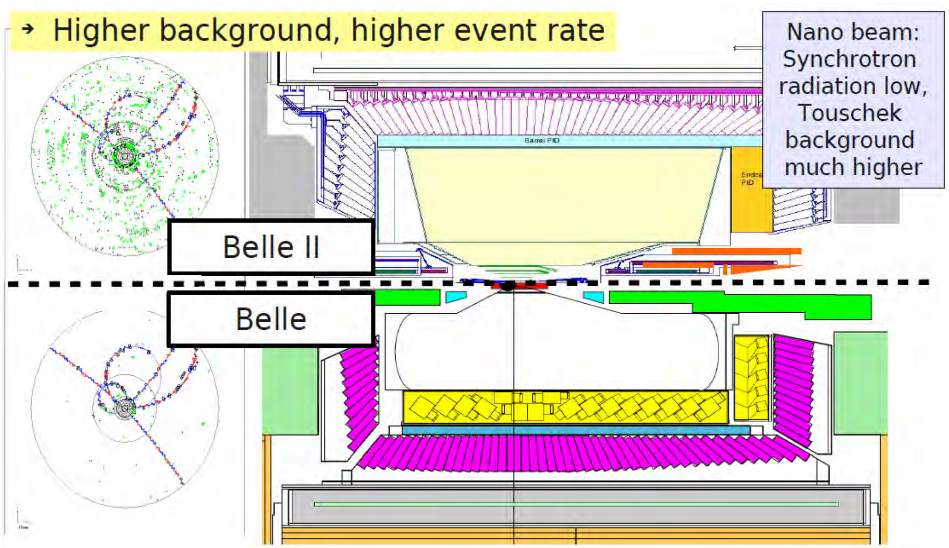
Larger crossing angle
2ϕ = 22 mrad → 83 mrad

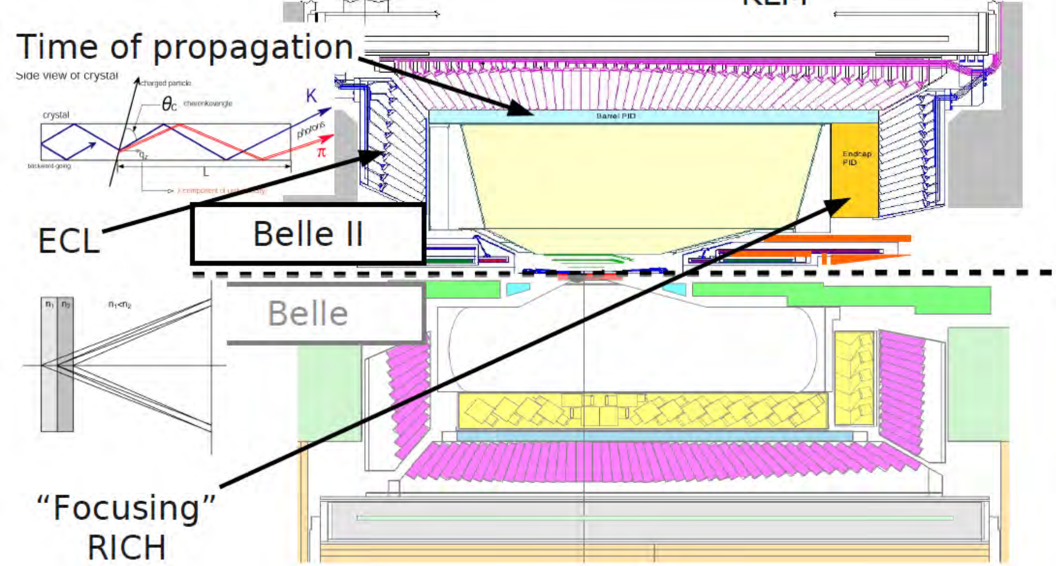
Smaller asymmetry
3.5 / 8 GeV → 4 / 7 Gev

The Belle2 detector









RPC efficiency for Belle2

Higher luminosity → Higher background → Larger dead time → Lower efficiency

Belle2 TDR

Moderate

Layer	Barrel KEKB	Barrel SuperKEKB	Endcap forward KEKB	Endcap forward SuperKEKB	Endcap backward KEKB	Endcap backward SuperKEKB
0	0.91	0.70	0.91	0.0	0.90	0.0
1	0.94	0.81	0.93	0.0	0.90	0.0
2	0.96	0.87	0.94	0.0	0.90	0.0
3	0.98	0.91	0.94	0.0	0.90	0.0
4	0.98	0.94	0.94	0.0	0.89	0.0
5	0.99	0.95	0.92	0.0	0.88	0.0
6	0.99	0.95	0.93	0.0	0.89	0.0
7	0.99	0.96	0.92	0.0	0.87	0.0
8	0.99	0.94	0.92	0.0	0.86	0.0
9	0.99	0.96	0.90	0.0	0.85	0.0
10	0.99	0.98	0.87	0.0	0.82	0.0
11	0.99	0.97	0.82	0.0	0.80	0.0
12	0.99	0.96	0.78	0.0	0.81	0.0
13	0.99	0.97	0.77	0.0	0.76	0.0
14	0.99	0.96	N/A	N/A	N/A	N/A

RPC efficiency measured in KEKB and extrapolated to SuperKEKB.

Acceptable

Inacceptable

Scintillator option for KLM

Requirements for a new KLM system designed for operation at SuperKEKb luminosity:

- Low dead time: << μsec for a typical channel (strip) area 1000 cm^2
- Large geometrical acceptance: > 95%
- High detection efficiency: ~99% for MIP
- Low bg (neutron bg + electronic noise)

Solution

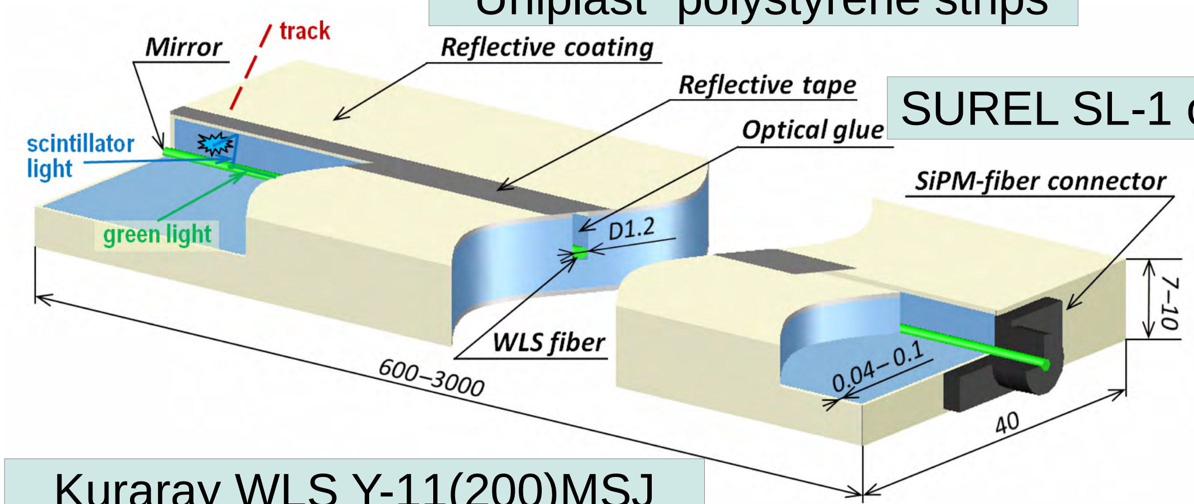
- **REPLACEMENT OF ALL ENDCAP AND 2 INNERMOST BARREL LAYERS**
- Scintillator based detector with WLS readout
- Fast photodector: Si photo diode in Geiger mode (SiPM - Hamamatsu MPPC)
- Independent operation of x-y layers

Scintillator - WLS - SiPM

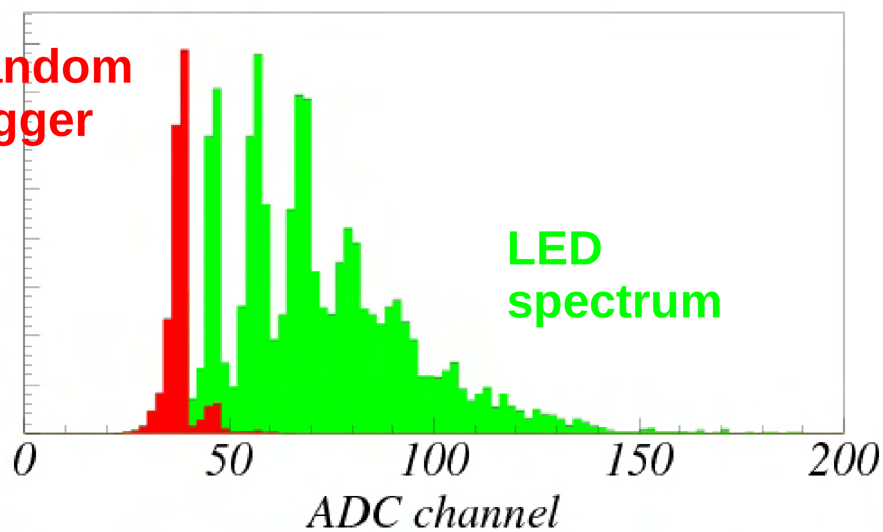
“Uniplast” polystyrene strips

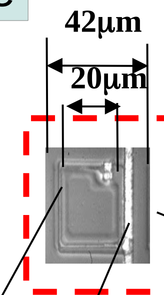
Hamamtsu MPPC S10362-13-050

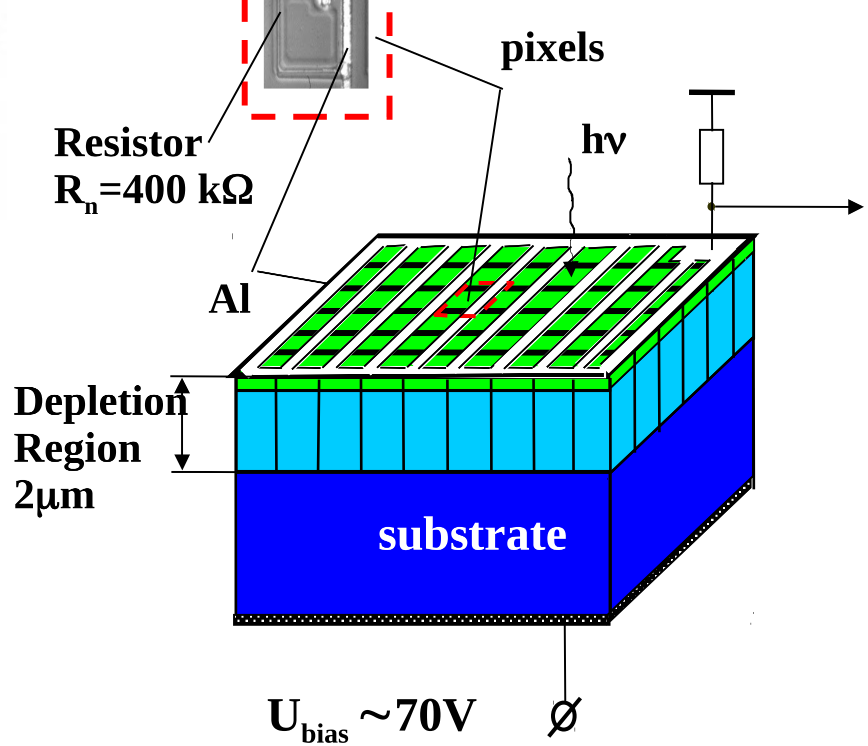
SUREL SL-1 optical glue



Kuraray WLS Y-11(200)MSJ

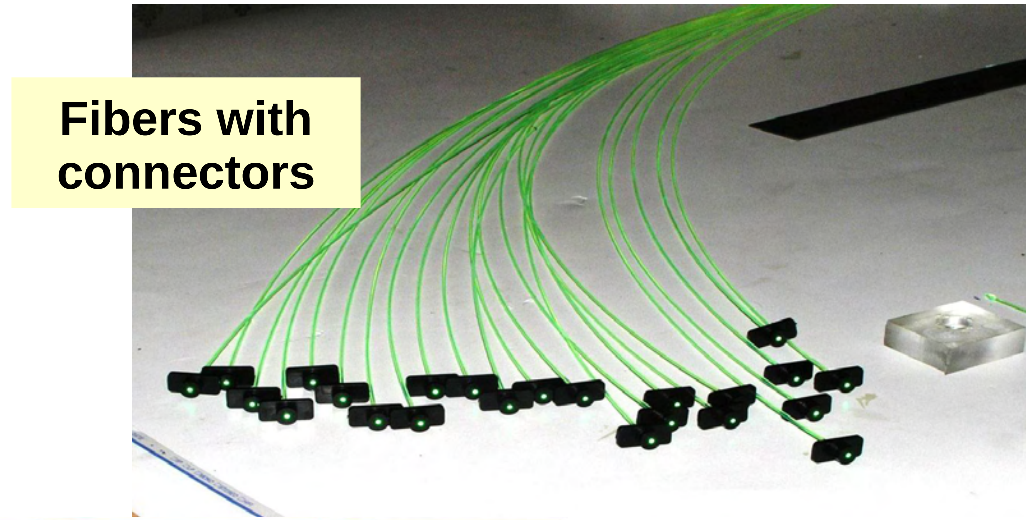


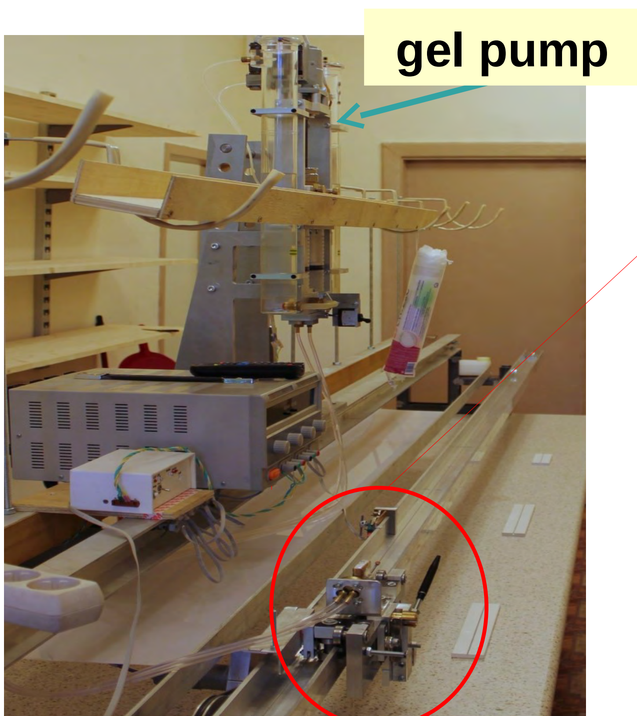


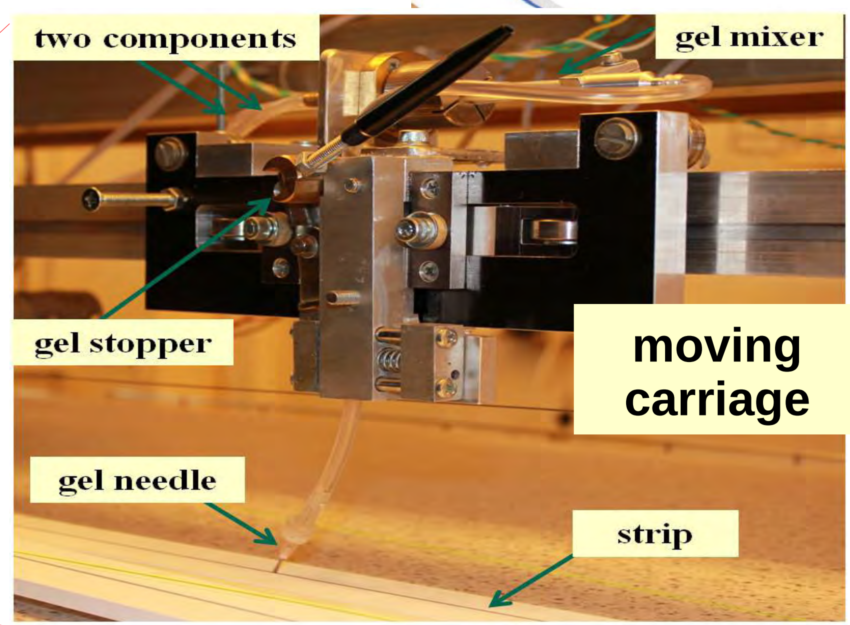


Scintillator strip production

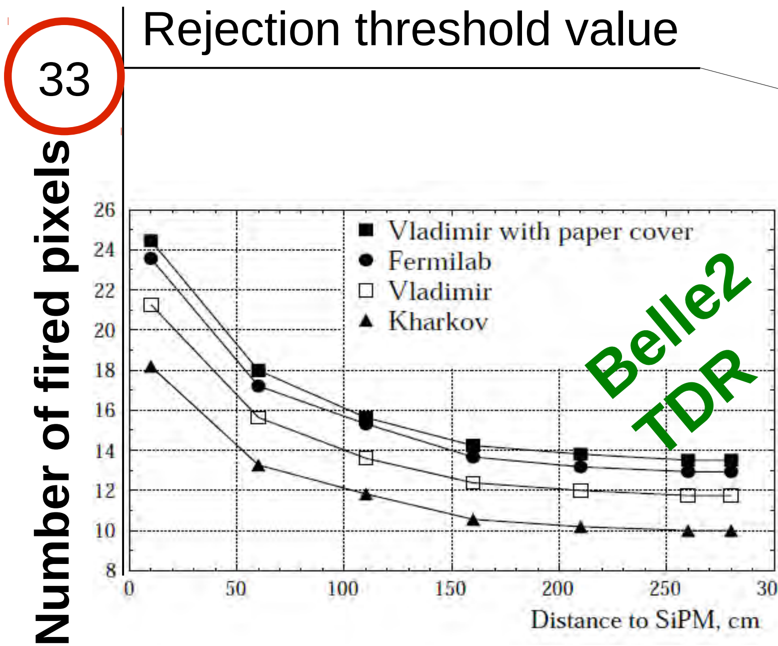
filling the strip groove with optical gel from the top with moving carriage

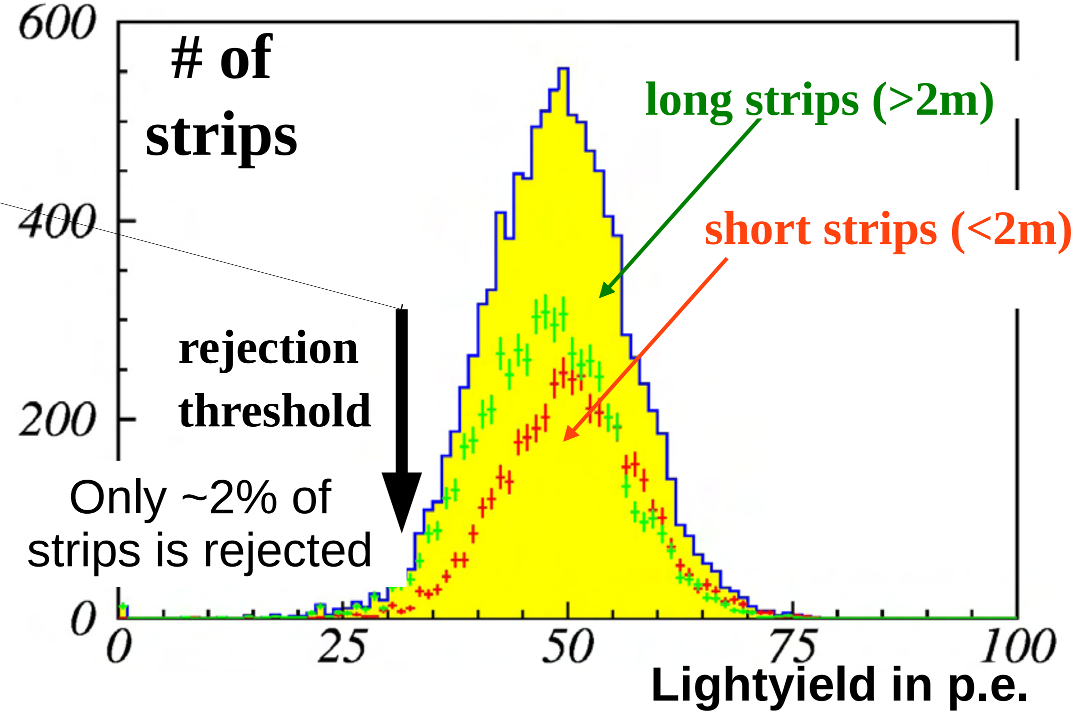


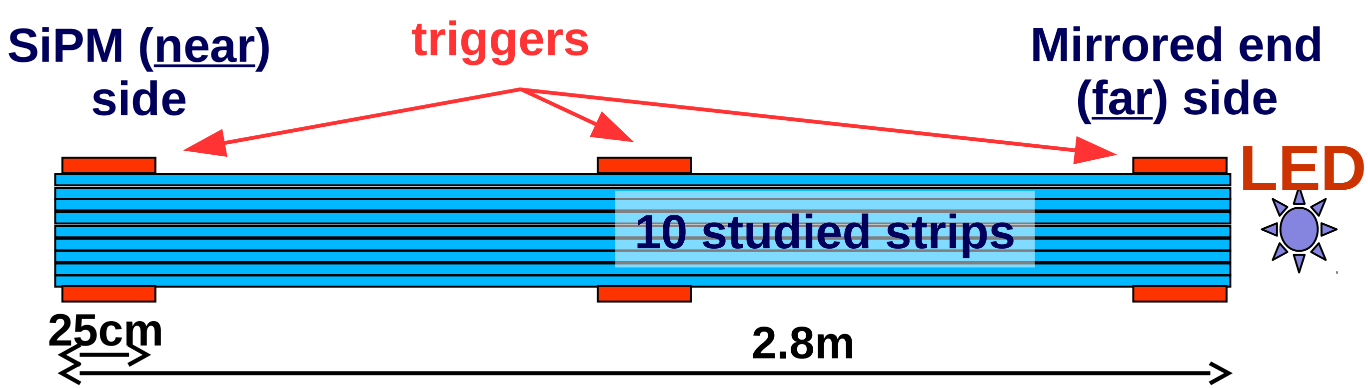




Scintillator strip lightyield

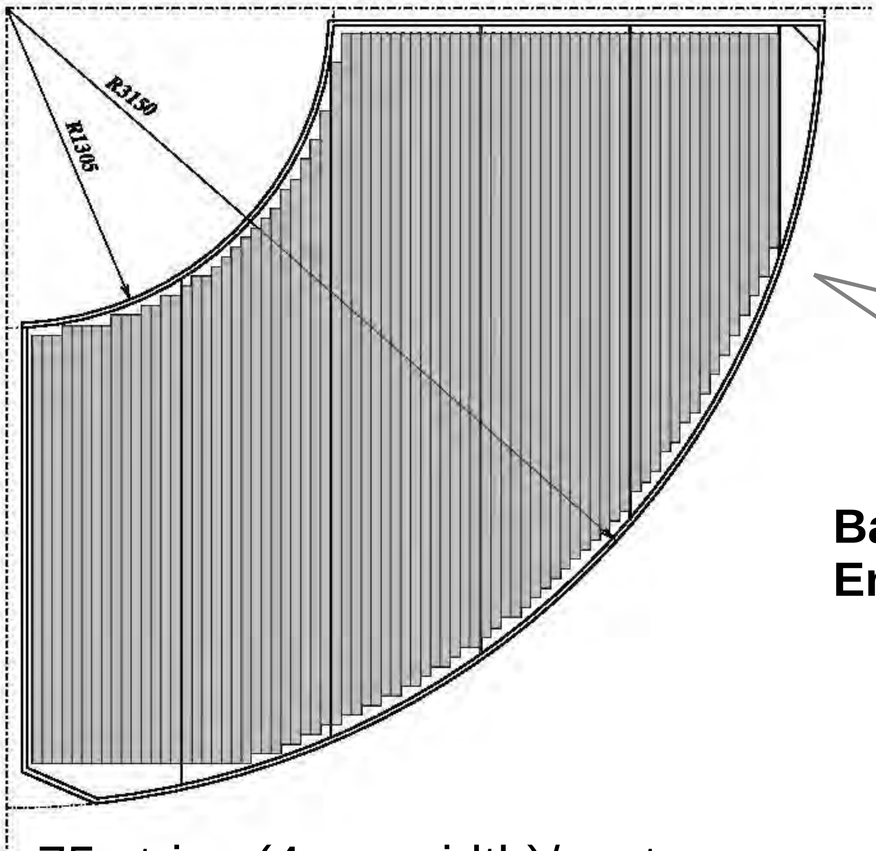




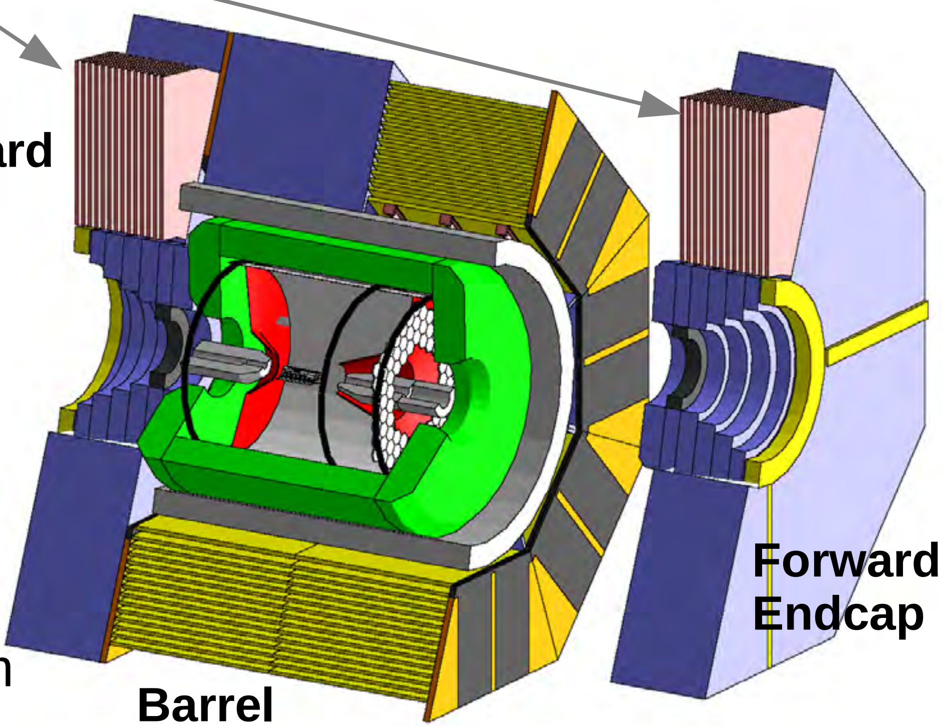


Good Gaussian distribution with a small RMS and perfect (almost twice larger than at TDR) mean value

Endcap sector layer



- WLS fiber in each strip
- SiPM at one fiber end
- mirrored far fiber end



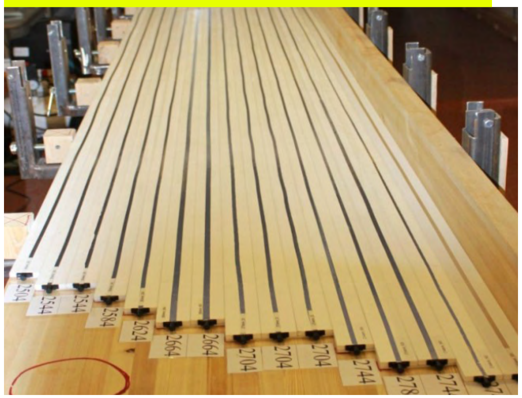
75 strips (4 cm width)/sector

16800 strips for F&B Endcap KLM

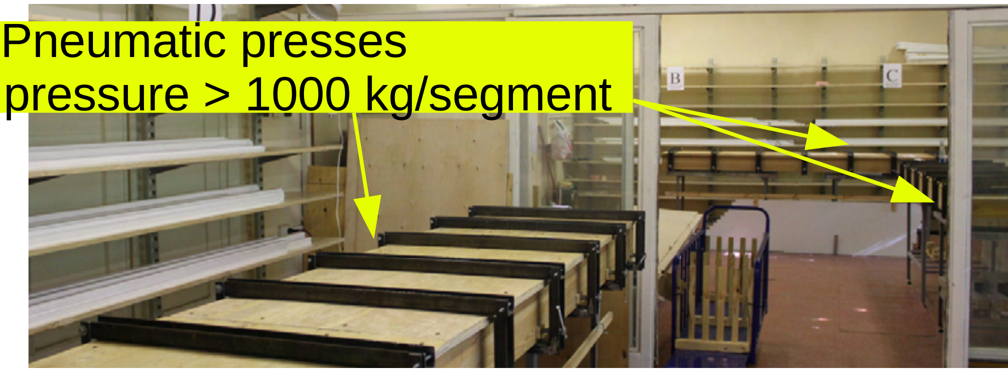
the longest strip 2.8 m; the shortest 0.6 m

Layer assemble

15 strips are glued to polystyrene substrate (1.5mm, both sides)



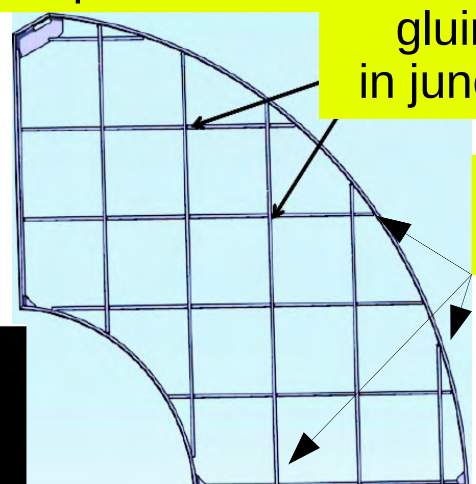
Pneumatic presses providing pressure > 1000 kg/segment



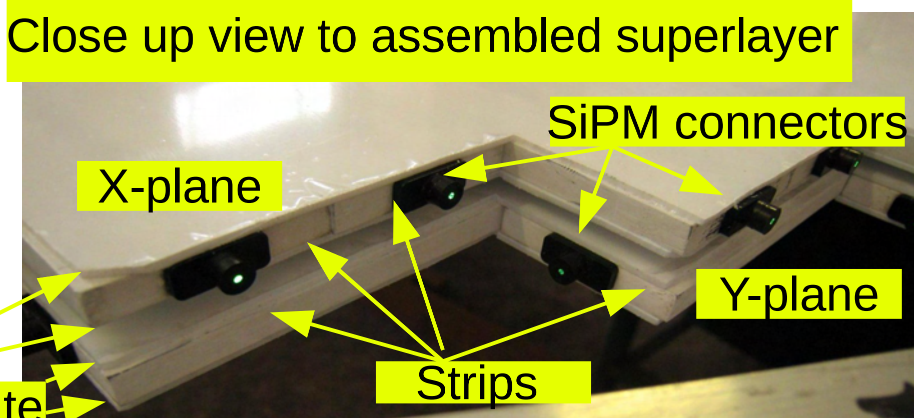
Support structure made of I-beam profiles

gluing in junction

screwing to the net



Close up view to assembled superlayer



SiPM connectors

X-plane

Y-plane

Strips

Polystyrene substrate

Modules assemble and installation

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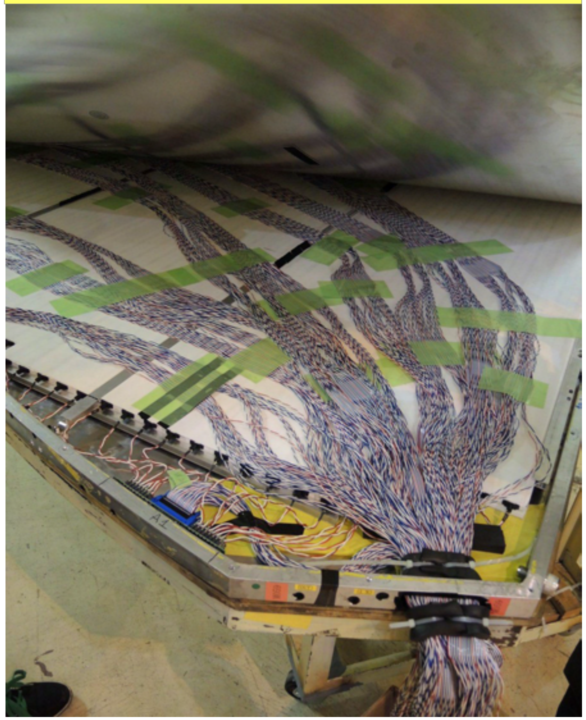
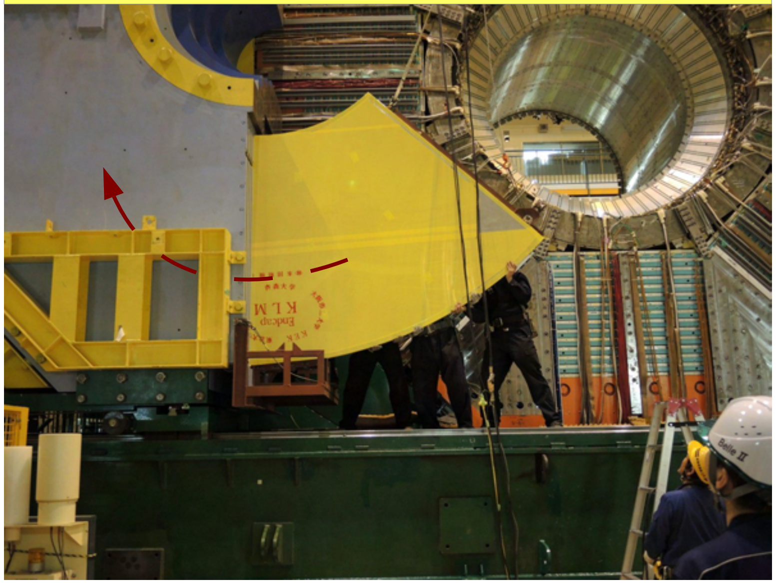
Assembled module before closing the cover

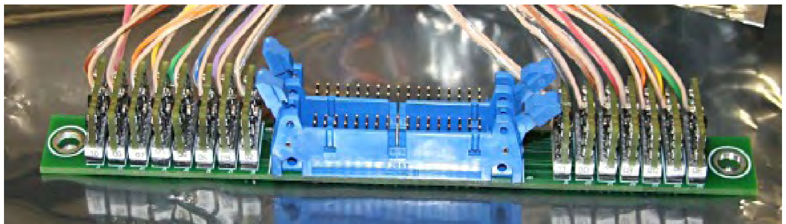


Installation gaps in the magnet flux return

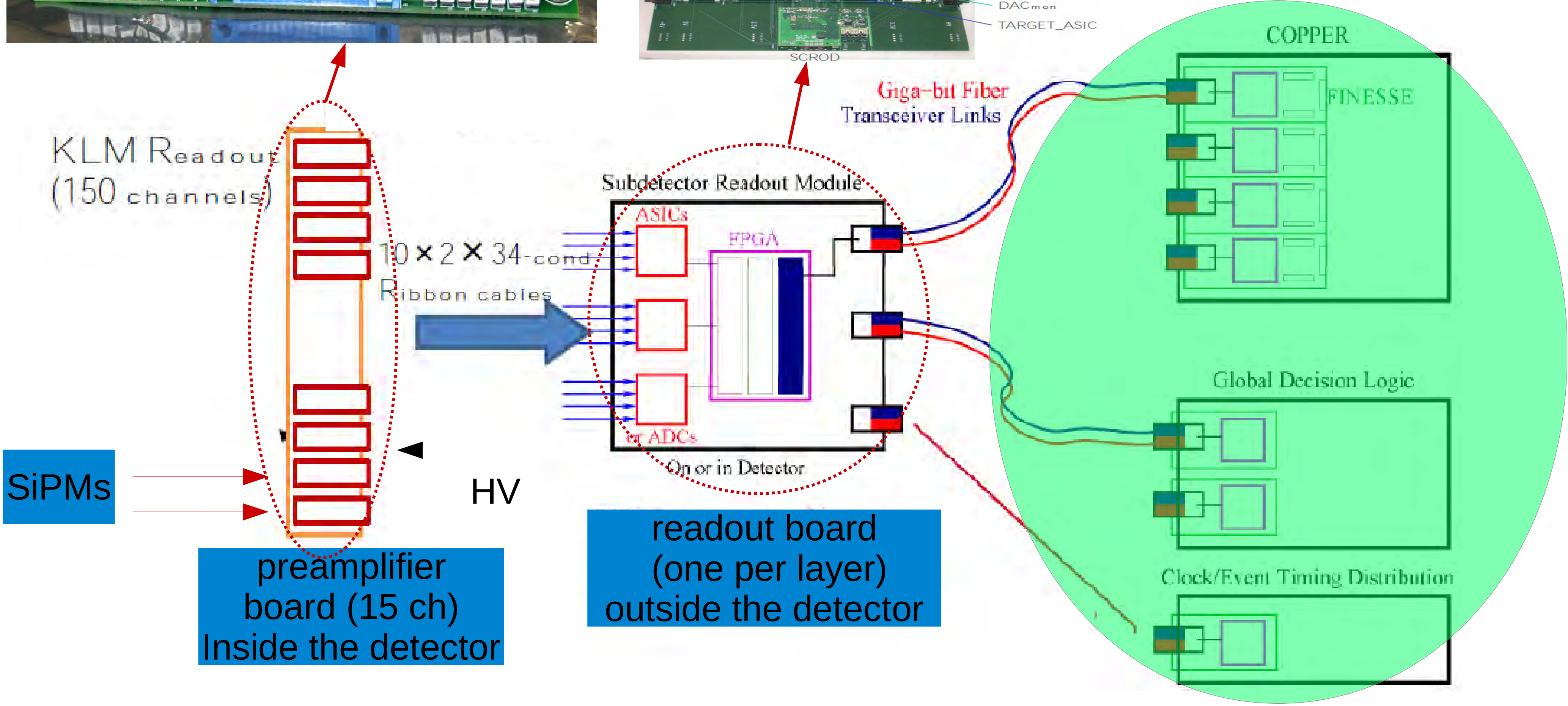
Module installation



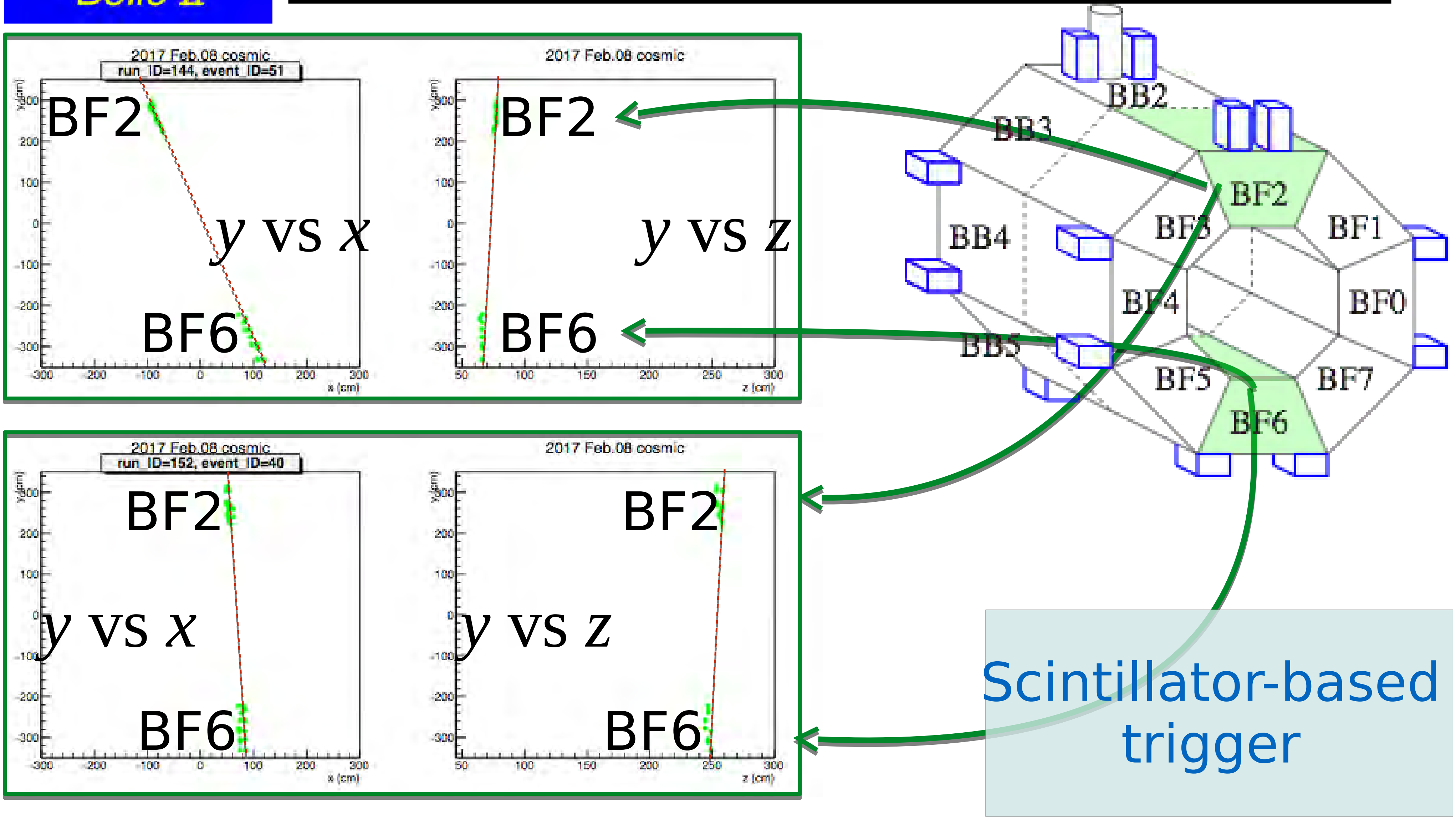
Electronics



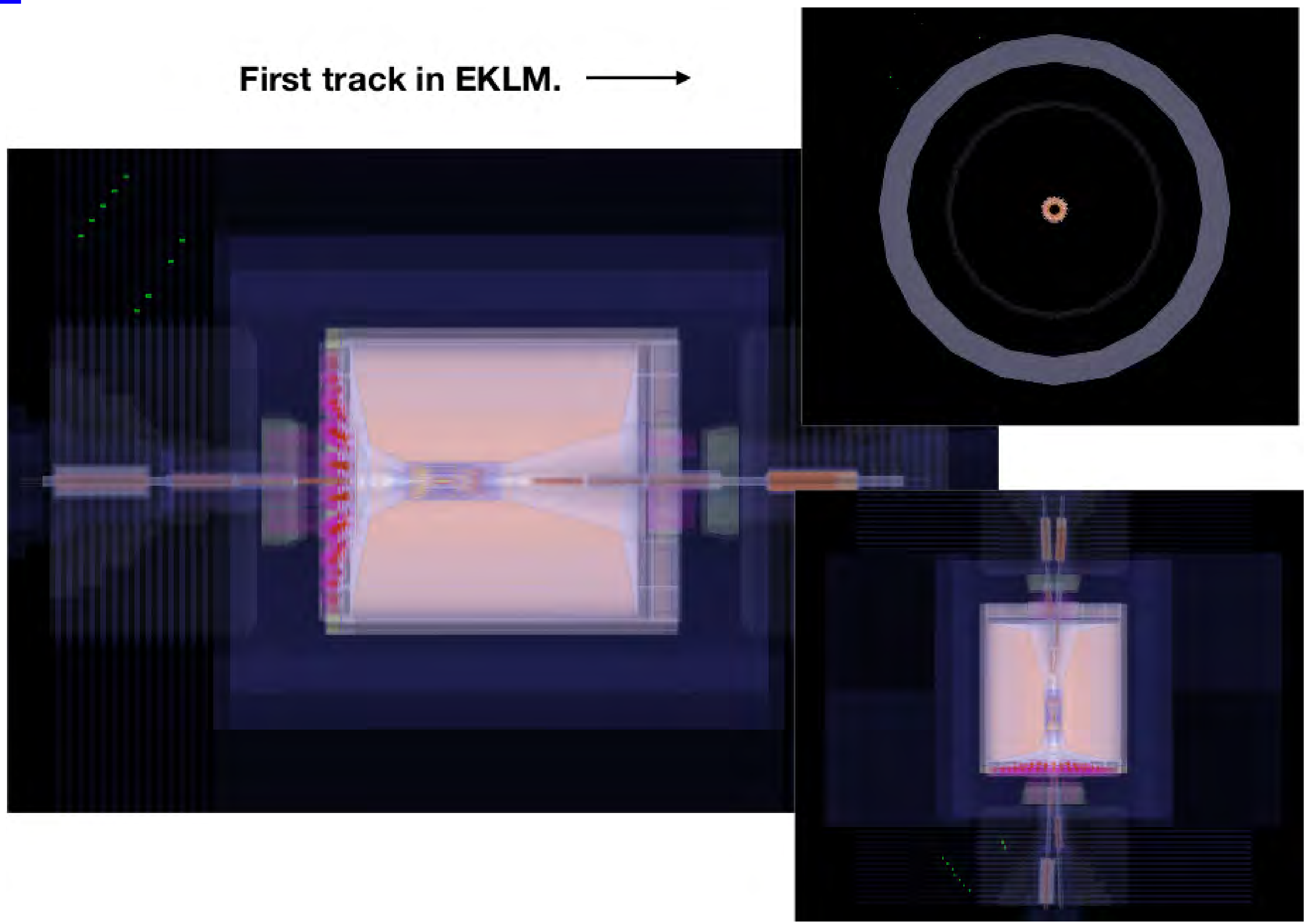
Belle 2 DAQ



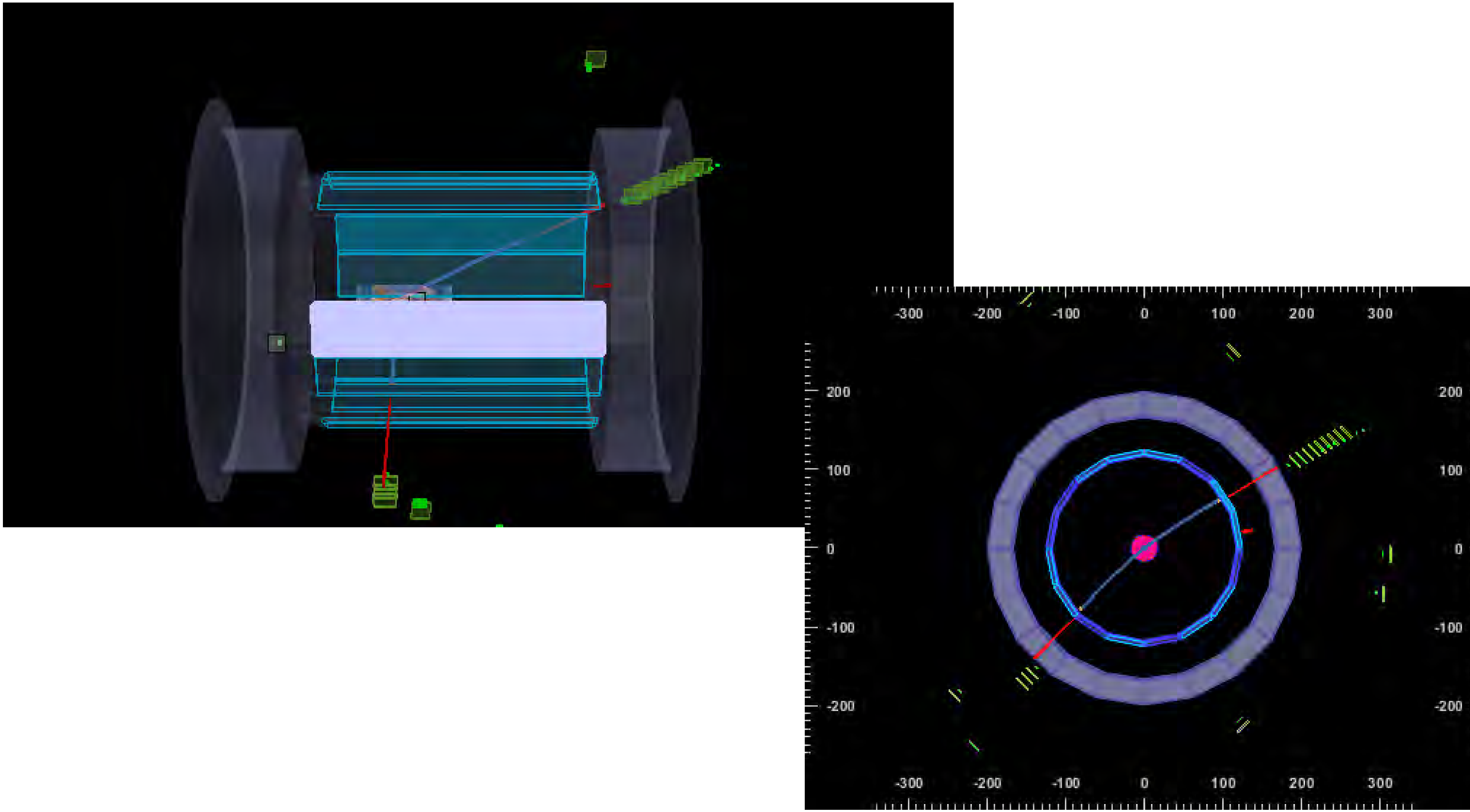
Cosmic tracks with RPC



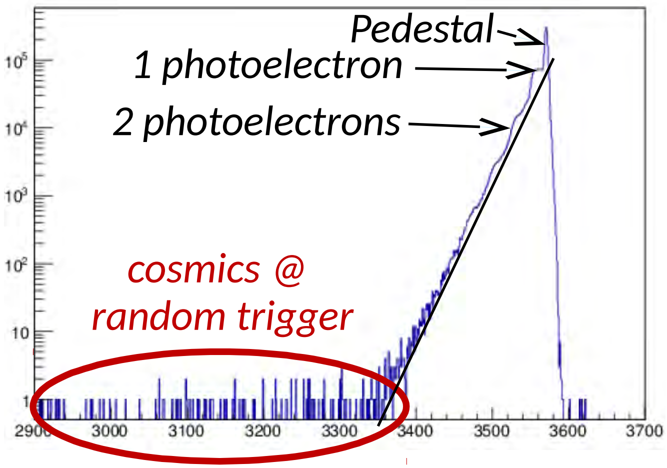
Cosmic tracks with Scintillator



First physics signal



Calibration with SiPM noise

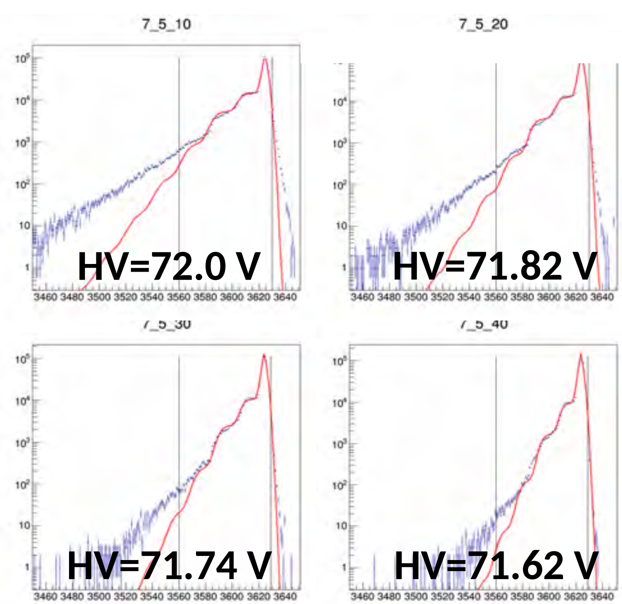


SiPM noise is linear in log scale, as rate for

$N_{Photoelectrons} \sim (xtalk)^{(N-1)}$

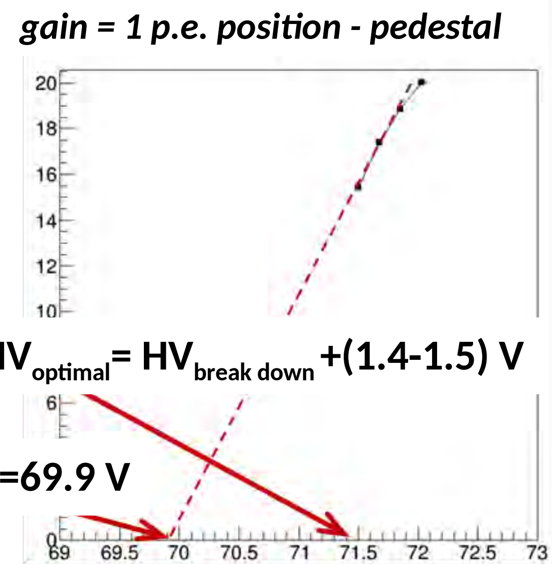
Cross talk (xtalk~ 0.1-0.2) is due to after pulses, when photons from Geiger discharge in one pixel hit the neighboring pixels at SiPM.

Use SIPM noise spectrum for SiPM calibration and optimal HV tuning: photoelectron peaks are well seen as steps in rate vs threshold distributio



Naive fit model of SiPM noise: G(pedestal)+∑erf(p.e. peak position)

position of the 1 p.e. peak is determined with reasonable precision, and this is the only required information (gain vs HV) to tune HV and set threshold for trigger.



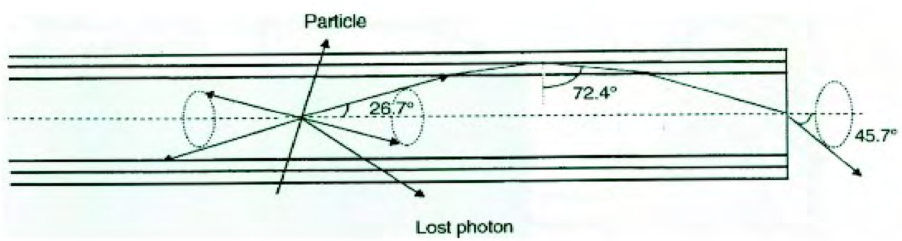
Conclusion

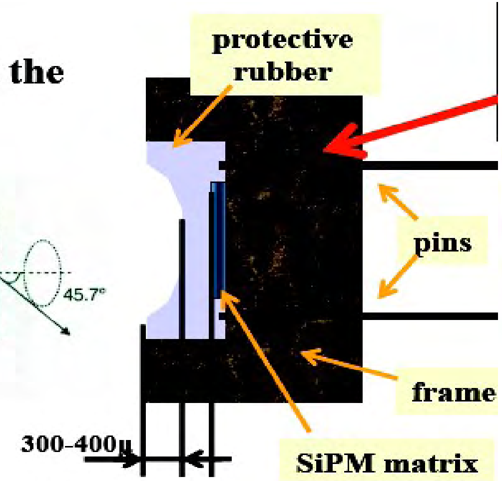
- RPC-based KLM system worked fine in the Belle environment, but its efficiency vanishes in SuperKEKb conditions.
- New endcap KLM system for Belle2 is based on the mixed technique: scintillator+WLS+SiPM for endcaps and 2 innermost barrel layers, RPC for others.
- Good time resolution, tiny dead time and ability to measure signal amplitudes allows to cope with higher background and be efficient in new conditions.
- All components of the system were successfully produced, tested and installed to the Belle 2 detector.
- Calibration, slow control etc software is developed and integrated into the Belle 2 DAQ.
- See muon tracks both in standalone mode and from the collisions.
- New KLM system for Belle2 is ready for data taking.

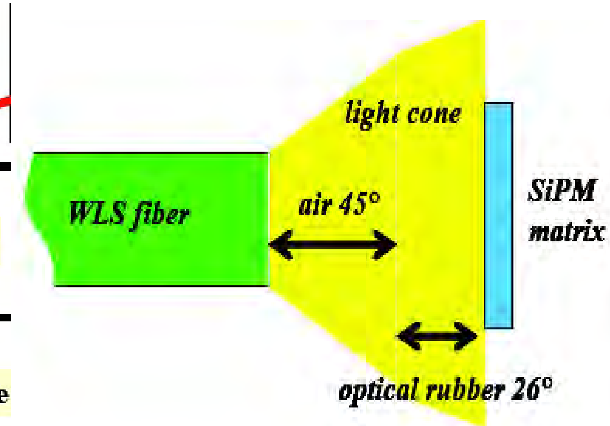
Backup

Lightyield improvement

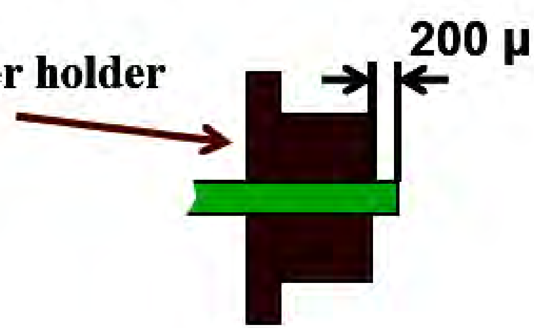
- Originally (TDR, Module-0) fiber was set at the level of the frame surface

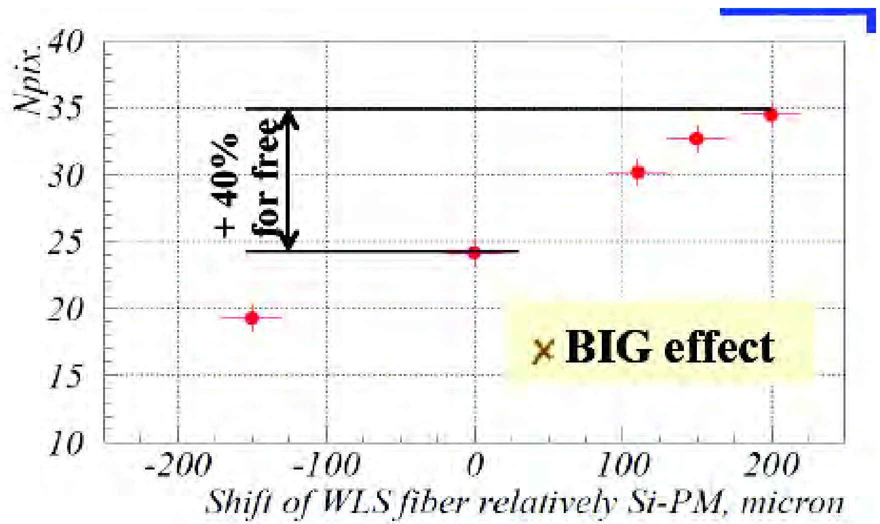






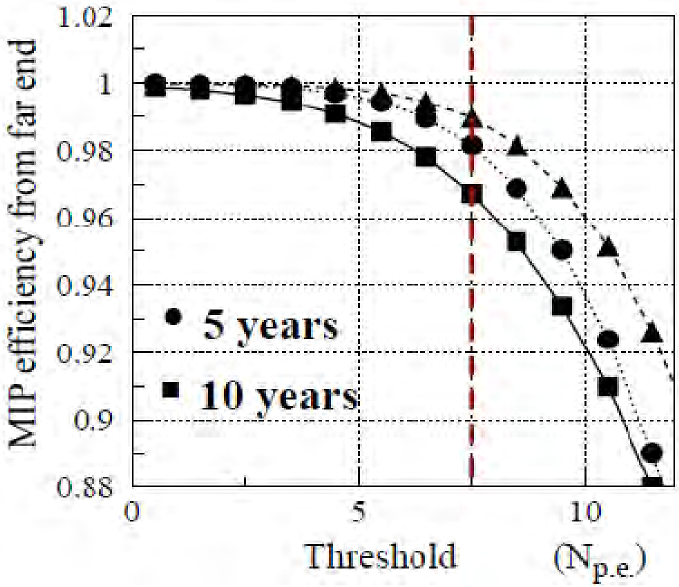
Tests: varying gap –200 ÷ +200μ (without fiber gluing)

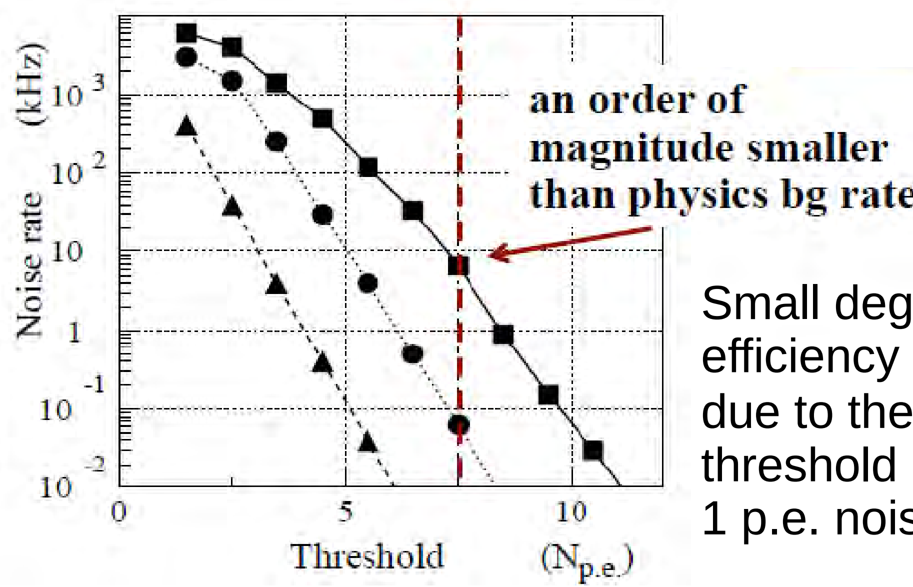




- **BIG effect**

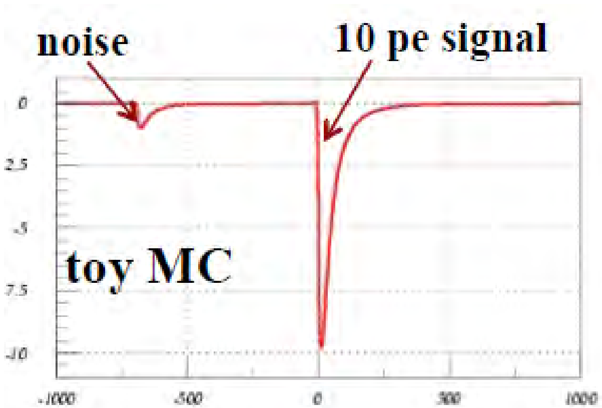
Radiation hardness





Small degradation of MIP efficiency (99%→97%) is due to the smearing of the threshold by random 1 p.e. noise.

SiPM: Irradiation at a dose equivalent to 10 years of Belle2 operation



Strips, fibers, glue etc do not degrade at estimated radiation dose