Muon system for the Super c-tau factory

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(LPI RAS)

Outline

- Physics requirements
- Simulation
- Scintillator + WLS fiber + SiPM option (Belle 2 experience)
    - Technology
    - Cost estimation
- Manpower

All information from this talk could be found at Muon system Wiki page
https://ctd.inp.nsk.su/wiki/index.php/Muon_system

Physics requirements

The ***technology choice*** and ***design*** are highly physics-dependent.
The list of critical questions to the physical programme of the detector:

Major:
- Do we need KL registration with muon system?
- Which time and space resolutions for the muon track are desired?

Minor:
- What is desired efficiency for muon reconstruction?
- Which muon ID fake rate is acceptable?
- TBC

All other issues depends on the answers to the above questions.

Feedback from the physical programme people is welcome..

Simulation (I)

One of the most important and urgent tasks for muon system ***technology choice*** and further optimization is to create a ***fast and reliable simulation*** tool. Optimal toolkit in this case is ***pure Geant4 simulation*** with ***simplified geometry*** and physics lists, able to produce fast results and estimate main parameters and characteristics of the detector.

Do not expect too much from this simulation!

Simulation (II)

Tasks for the 0.1 version of the simulation tools:

- Create geant4-based geometry description reflecting all main features influencing muon-related physics. The model are to be extendable to describe muon detector in detail if needed.
- Estimate basic features of the interacting muons (despite of the detector technology choice):
  - Muon smearing due to the multiple scattering (depending of the muon energy, direction and/or specific production process; magnetic field ON/OFF)
  - Desirable thickness of the muon system to reach maximal muon detection efficiency
  - Muon/pion separation: decay point (detector layer) for the muons and pions of the same momentum, feasibility do distinguish processes based on this information
  - Feasibility to distinguish pion kink: distinguish muons originated from the primary vertex and produced in the pion decays.

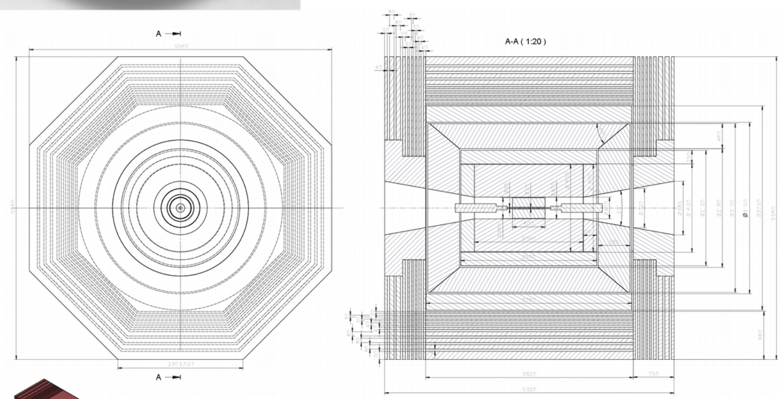
What else? Again: feedback is needed!

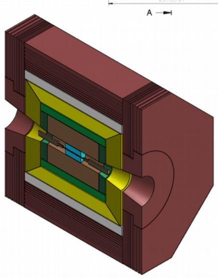
Simulation (III)

For simplicity, ***only the barrel part of the detector*** was simulated. The full simulation is possible, but not urgent for the first estimation.

- ***CsI calorimeter*** (inner radius 1090mm, thickness 297.6 mm, which corresponds to 16 X0)
- ***Magnet coil*** (inner radius 1610mm, thickness 14.4 mm of copper, which corresponds to 1 X0)
- ***9 iron absorber layers*** in octant geometry (see the drawings). The distance to the innermost layer is 1900mm from the beamline, the thickness of the absorber layers 30 mm,30 mm,30 mm,40 mm,40 mm,80 mm,80 mm,80 mm, respectively, which roughly corresponds to 1.7 X0, 1.7 X0, 1.7 X0, 2.3 X0, 2.3 X0, 4.5 X0, 4.5 X0, 4.5 X0.
- The 30 mm ***gaps between the absorber layers*** could be filled with organic scintillator for the energy measurement (not needed for now)
- ***Internal elements*** of the detector are estimated to give from 0.35 X0 to 0.6 X0 and are neglected in this study

Simulation (IV)





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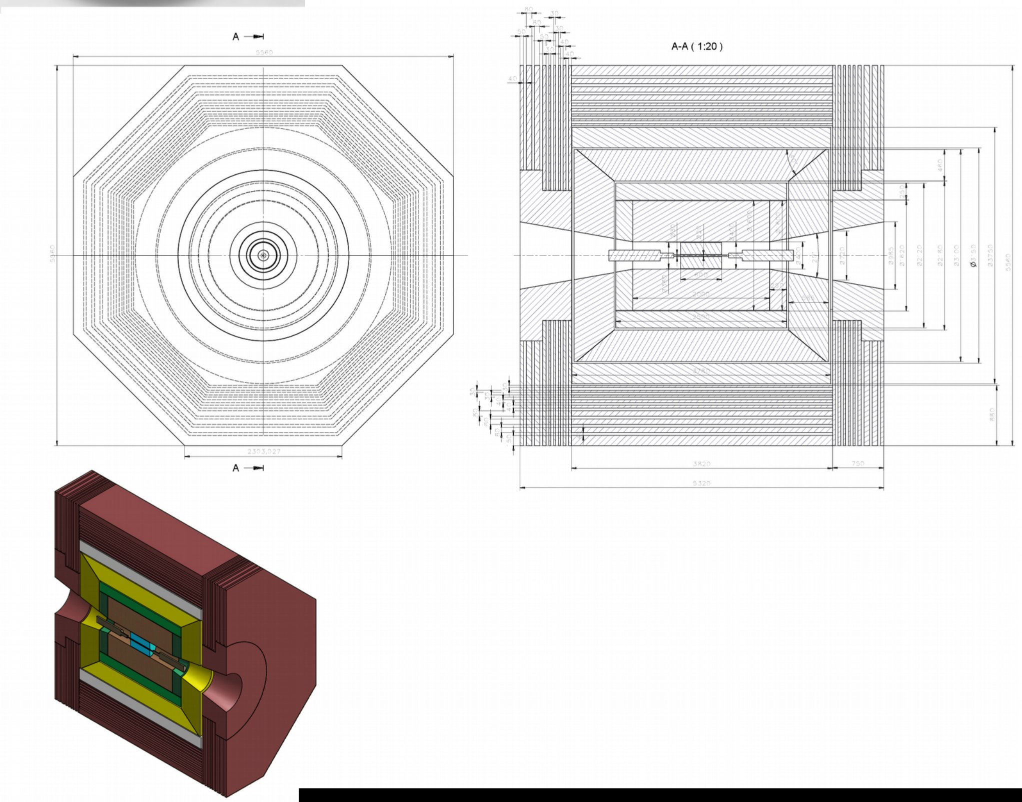
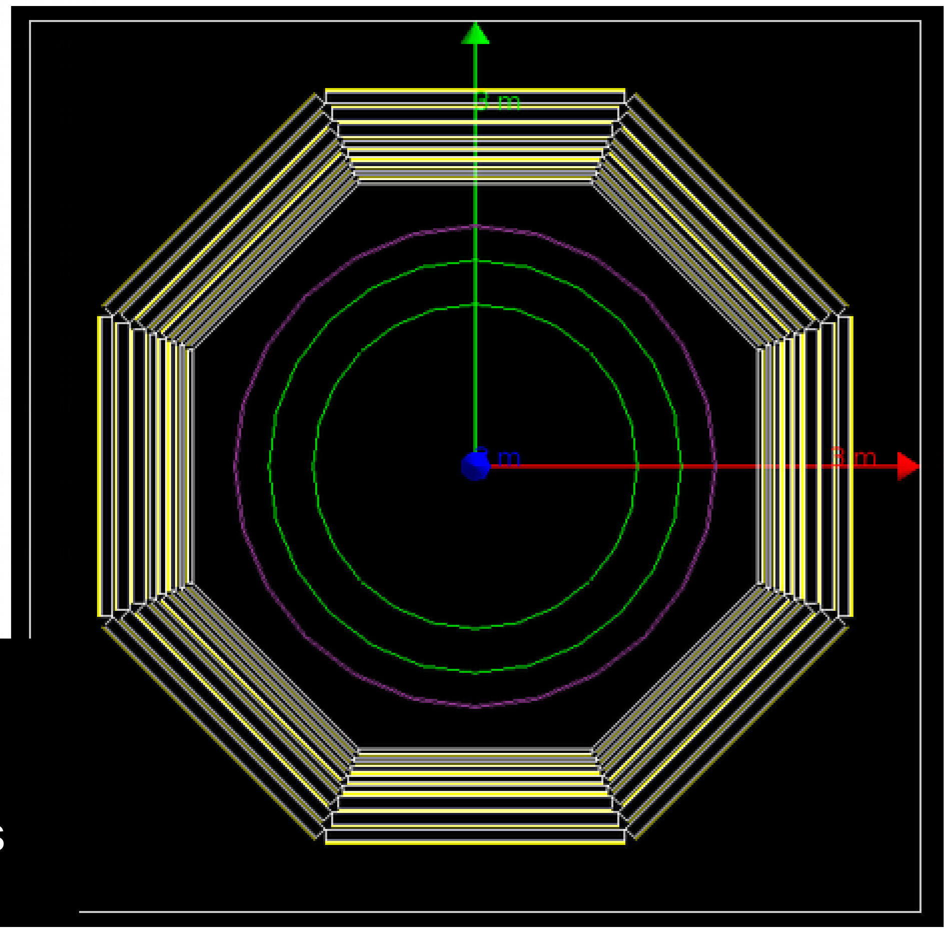
Simulation (V)





Green: CsI calorimeter
Violet: Cu magnet coil
White: Fe absorber layers
Yellow: Organic scintillator gaps

Simulation (VI)

Muons and ***pions*** were simulated as particles originated from the primary vertex according to the various physical distribution, taken from samples, offered by Vitaliy.

To compare detector response in case of pions and muons, pion and muon of the ***same sign*** were generated in the same event with ***identical momenta***.
During the event reconstruction all hits were categorized according to the original particle.

Two samples:

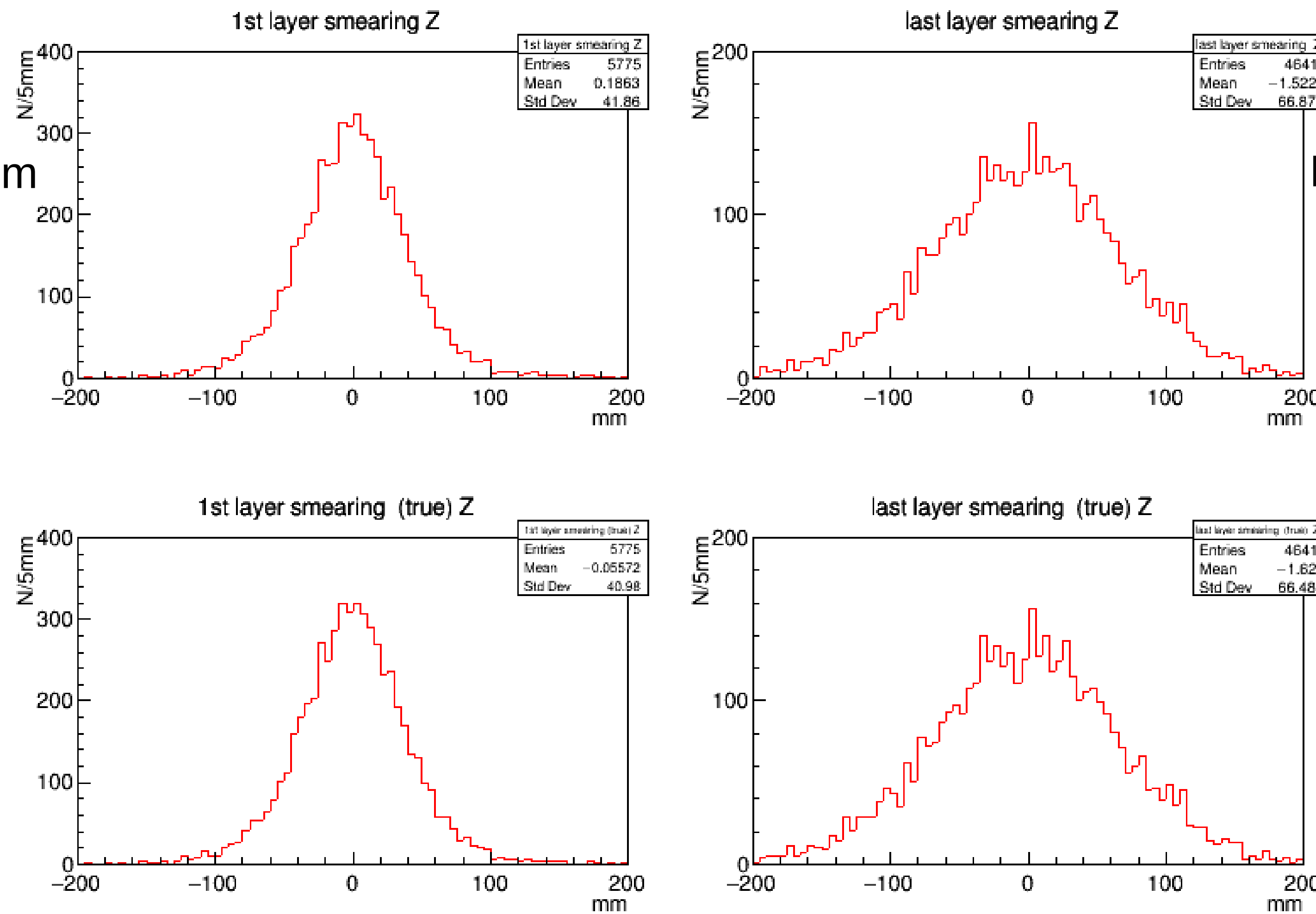
e+ e- → J/Psi → mu+ mu -   E=3.096 GeV

e+ e- → tau+ tau -   E=3.55364 GeV

Simulation (VII)

RMS= 41 mm

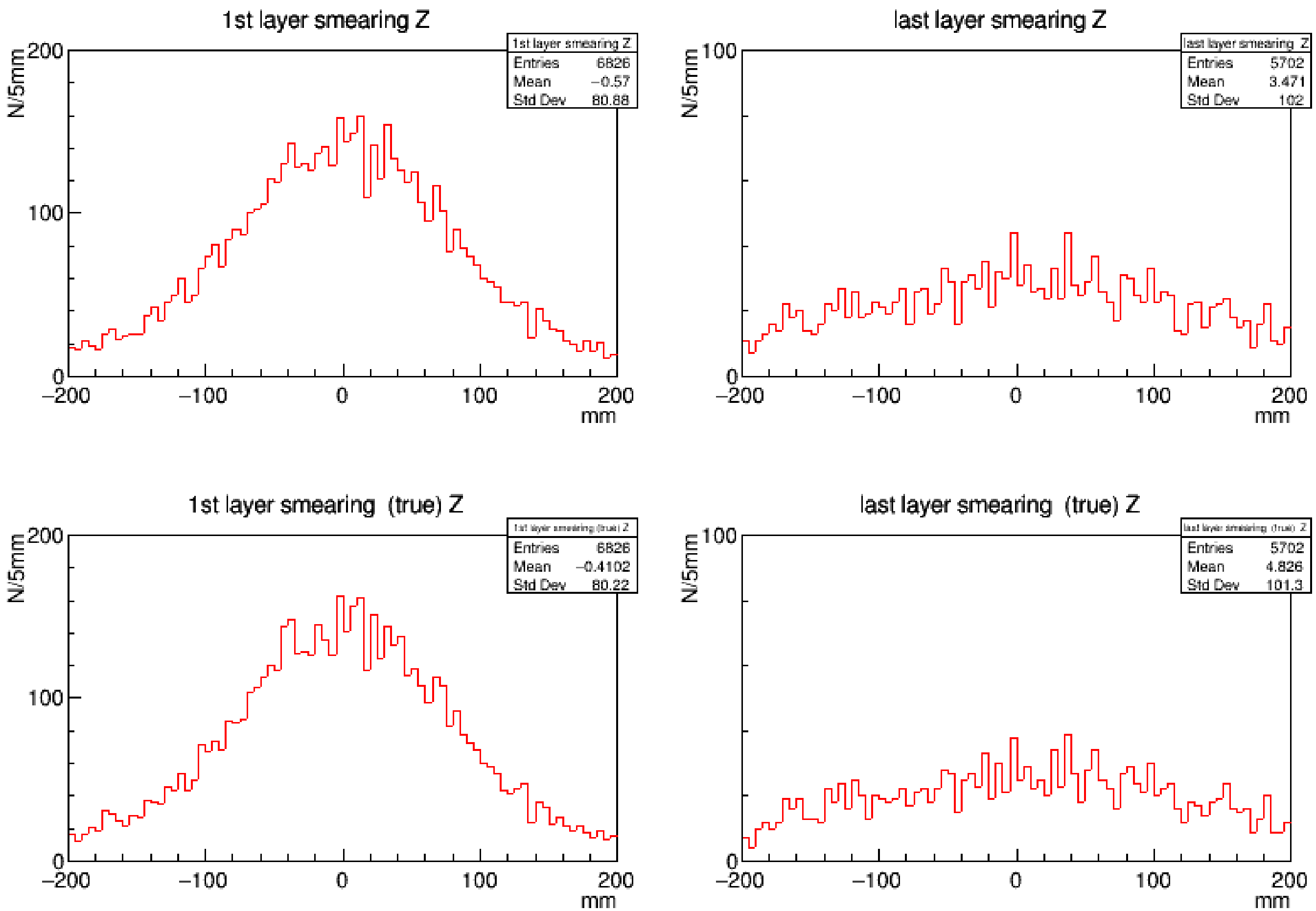
RMS= 67 mm



e+ e- → J/Psi → mu+ mu - E=3.096 GeV

Simulation (VIII)

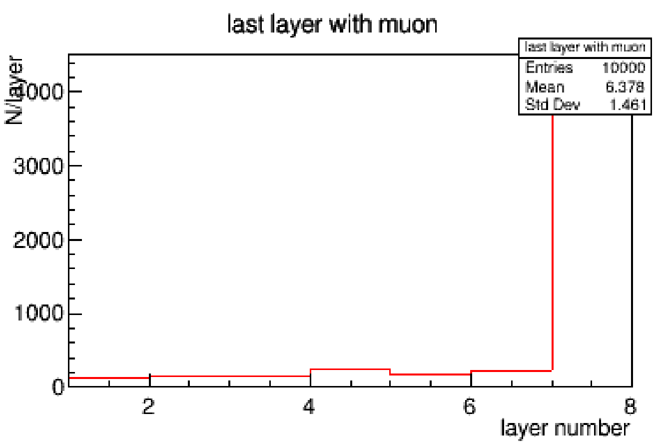
RMS= 80 m

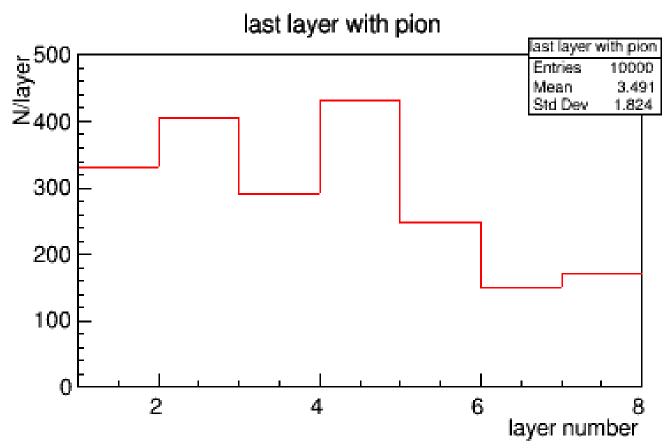


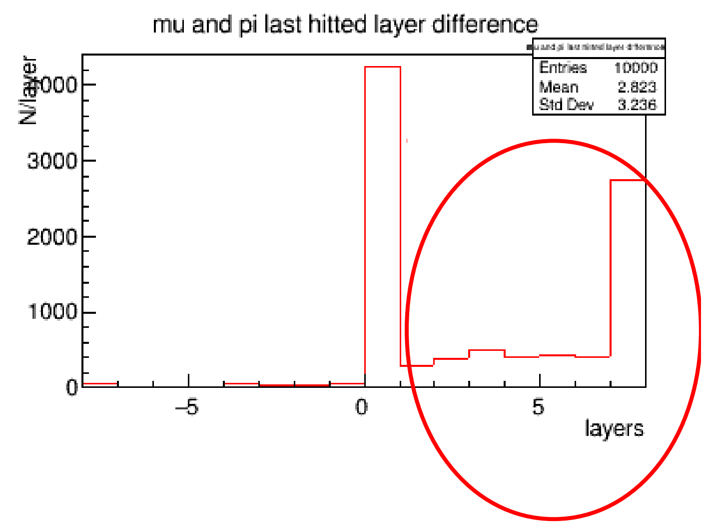
RMS= 102 mm

e+ e- → tau+ tau - E=3.55364 GeV

Simulation (IX)

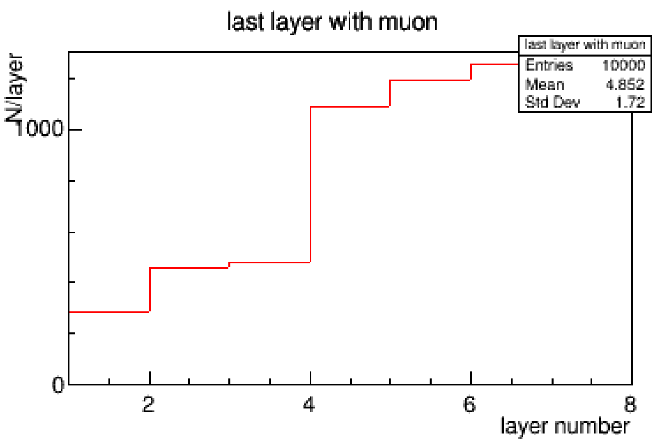


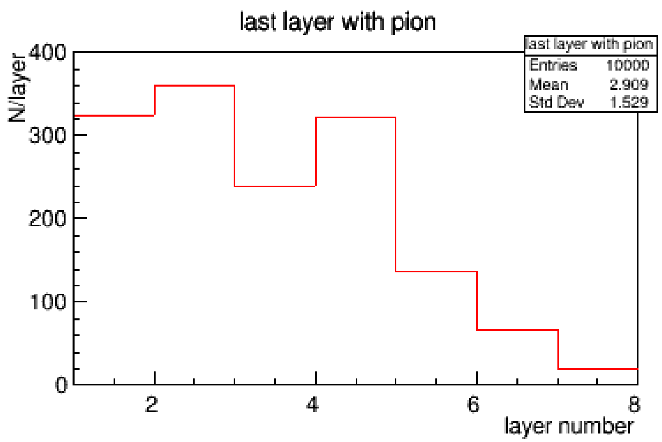


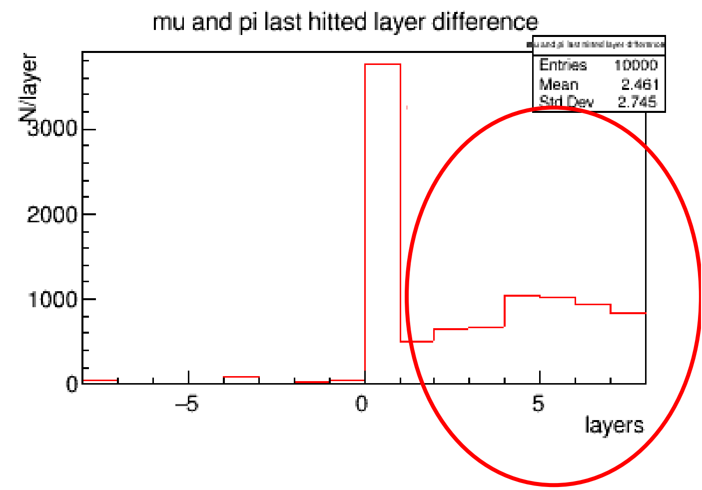


e+ e- → J/Psi → mu+ mu - E=3.096 GeV

Simulation (X)







e+ e- → tau+ tau - E=3.55364 GeV

Simulation: reuslts

- Geometry is almost done (to be tuned)
- Field description is needed
- Due to the multiple scattering smearing at the 1st layer ~5cm
- With magnetic field situation will get worse
- There is a possibility to distinguish muons and pions. The parameters of the yoke to be tuned (in which limits?)

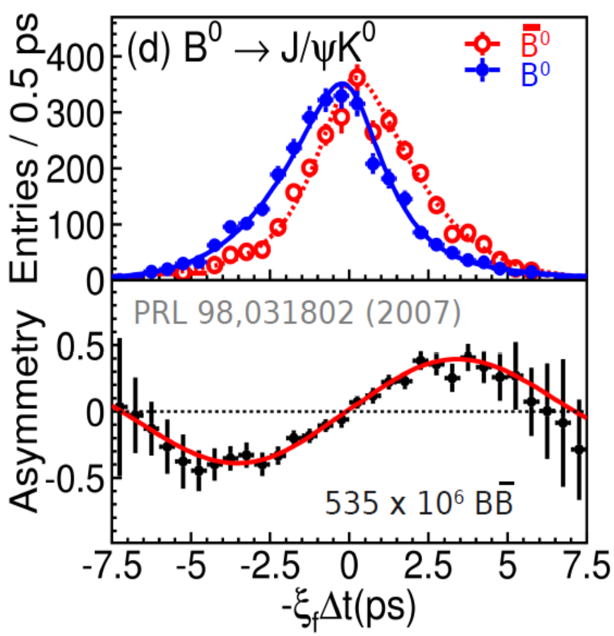
Outline

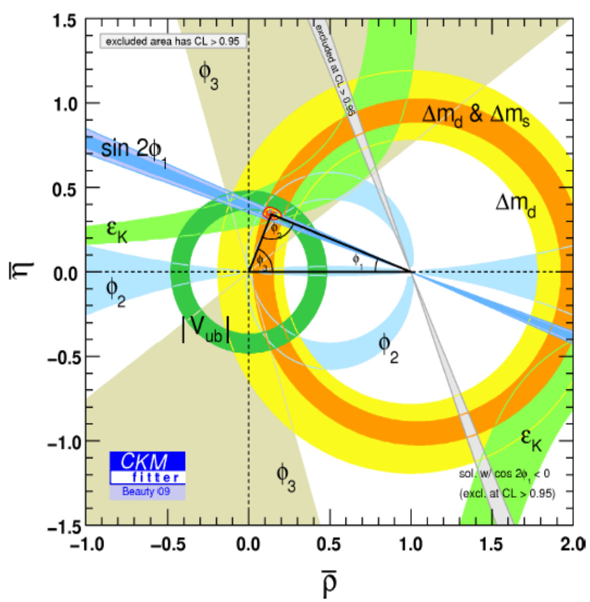
- From Belle to Belle2
  - Belle: RPC option for KL/muon system
  - Belle2: Scintillator option for KL/muon system
- Production, assembly and tests
- Calibration
- Conclusion

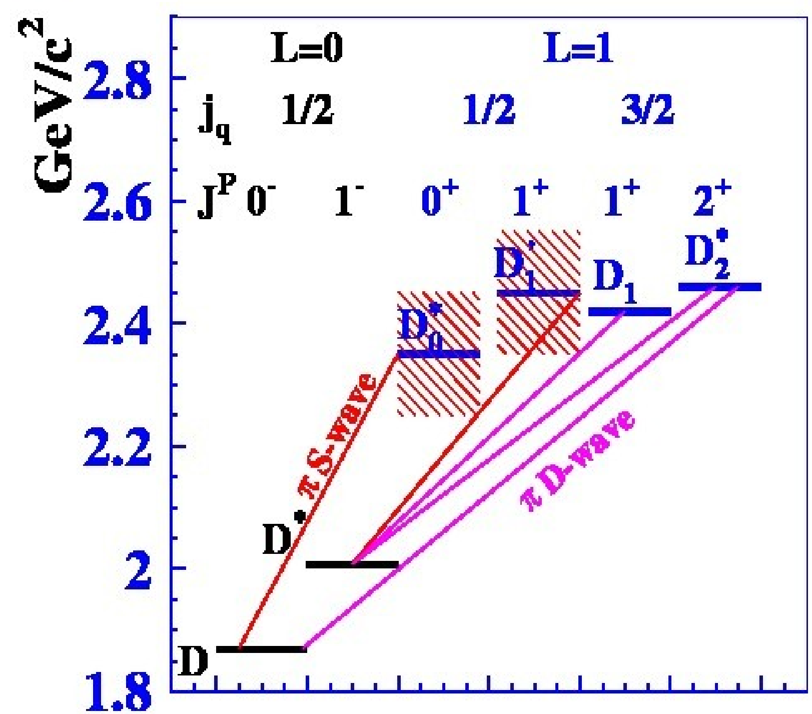
NIM **A 789**, 134–142 (2015)

Belle achievements

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





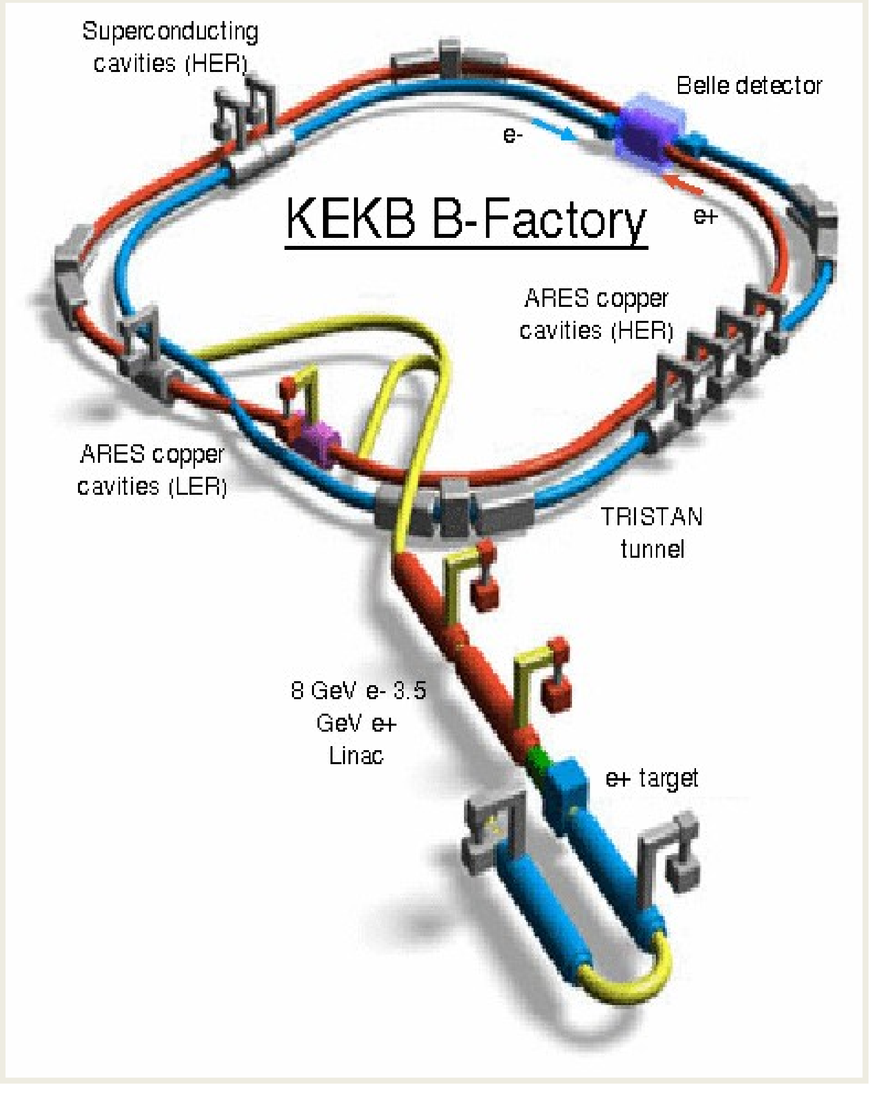


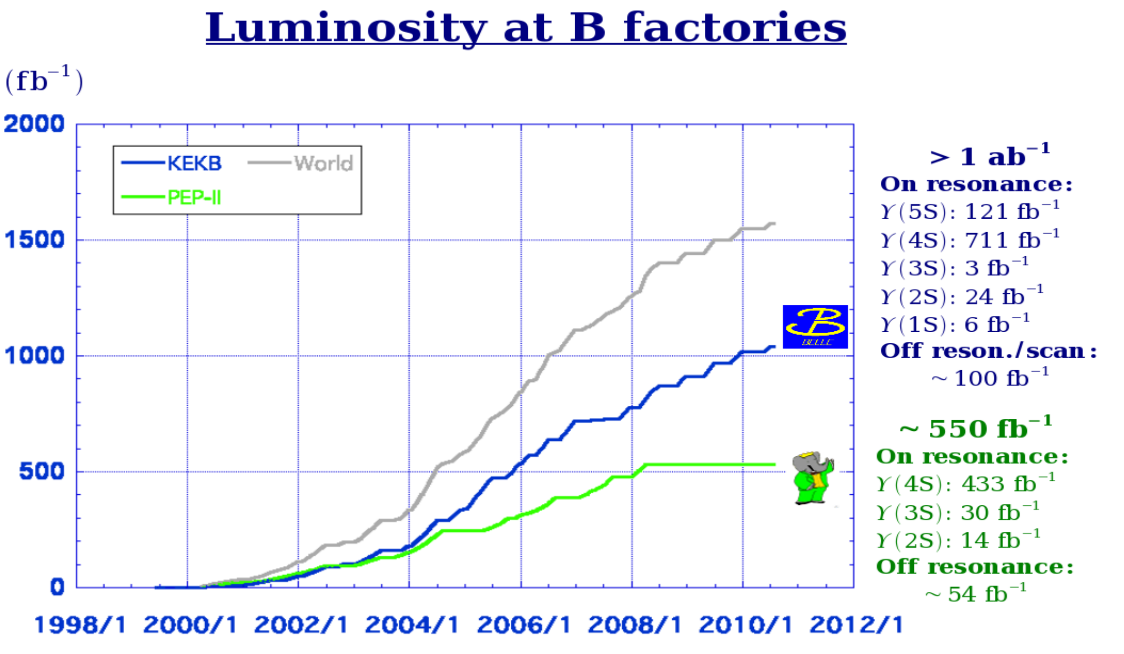
✓ Confirmation of KM mechanism of ~~CP~~ in the Standard Model

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

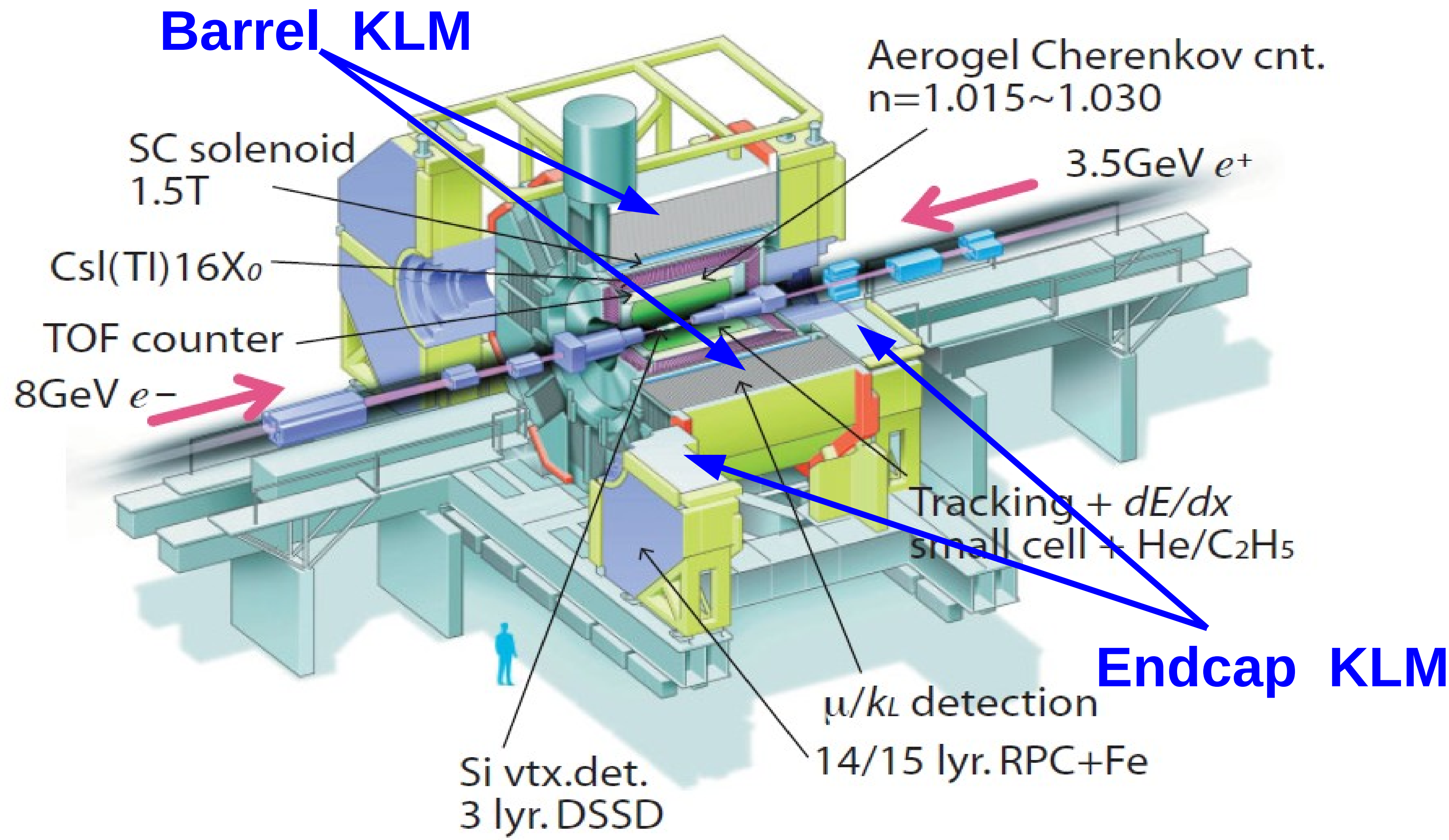
Heavy hadrons spectroscopy

KEKb accelerator

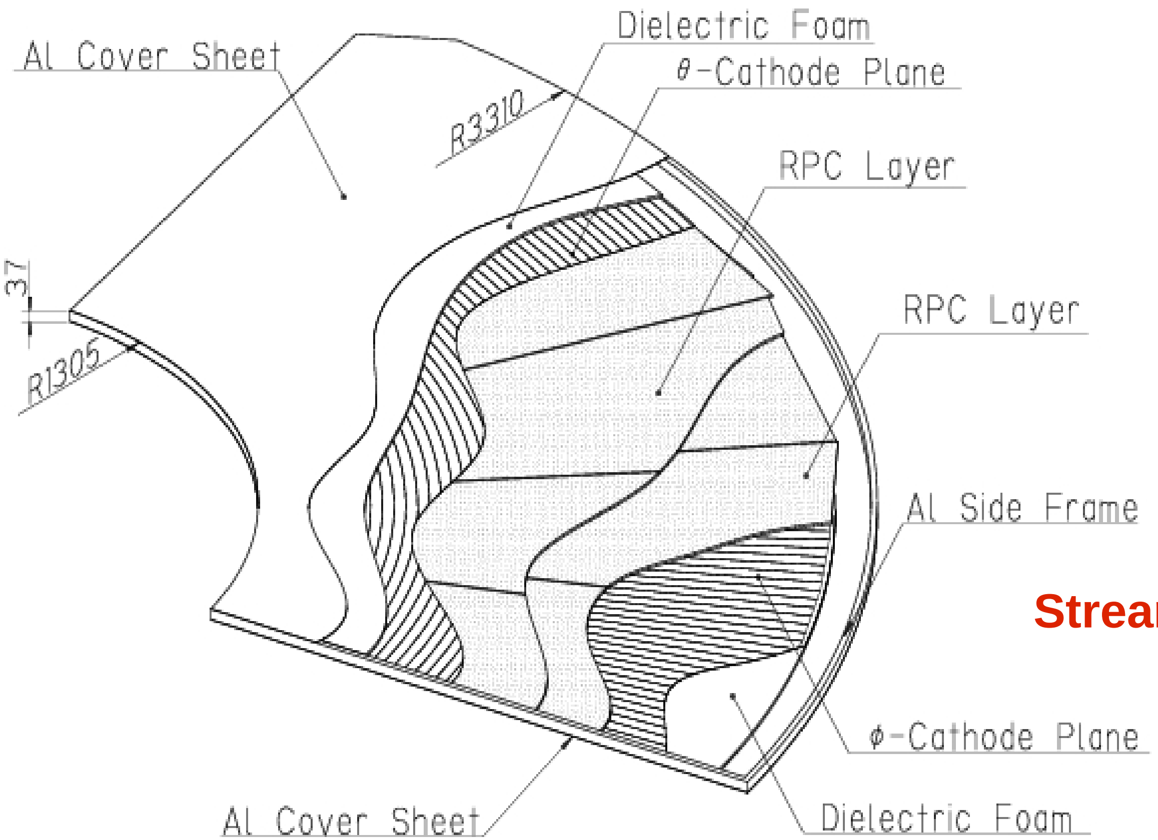


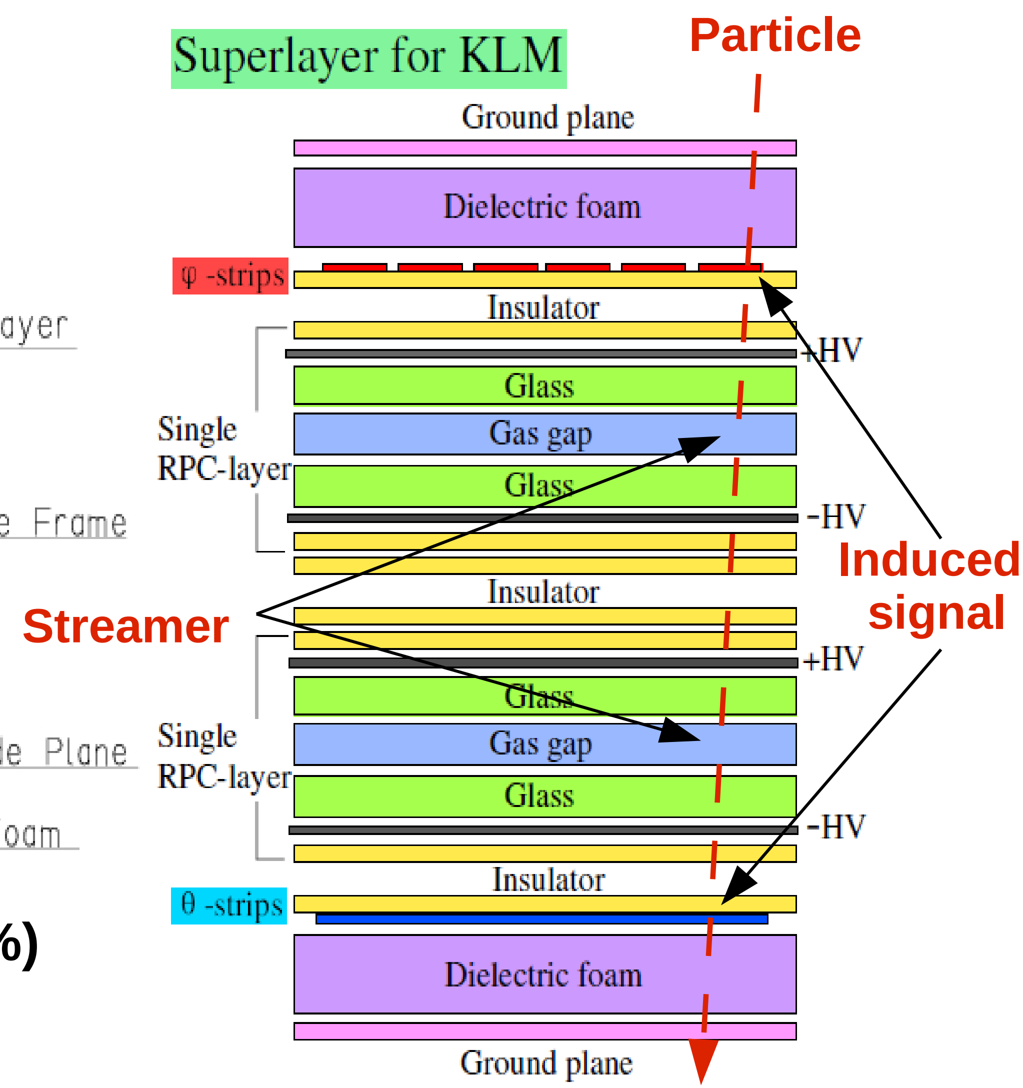


The Belle detector



Belle: Resistive Plate Chambers

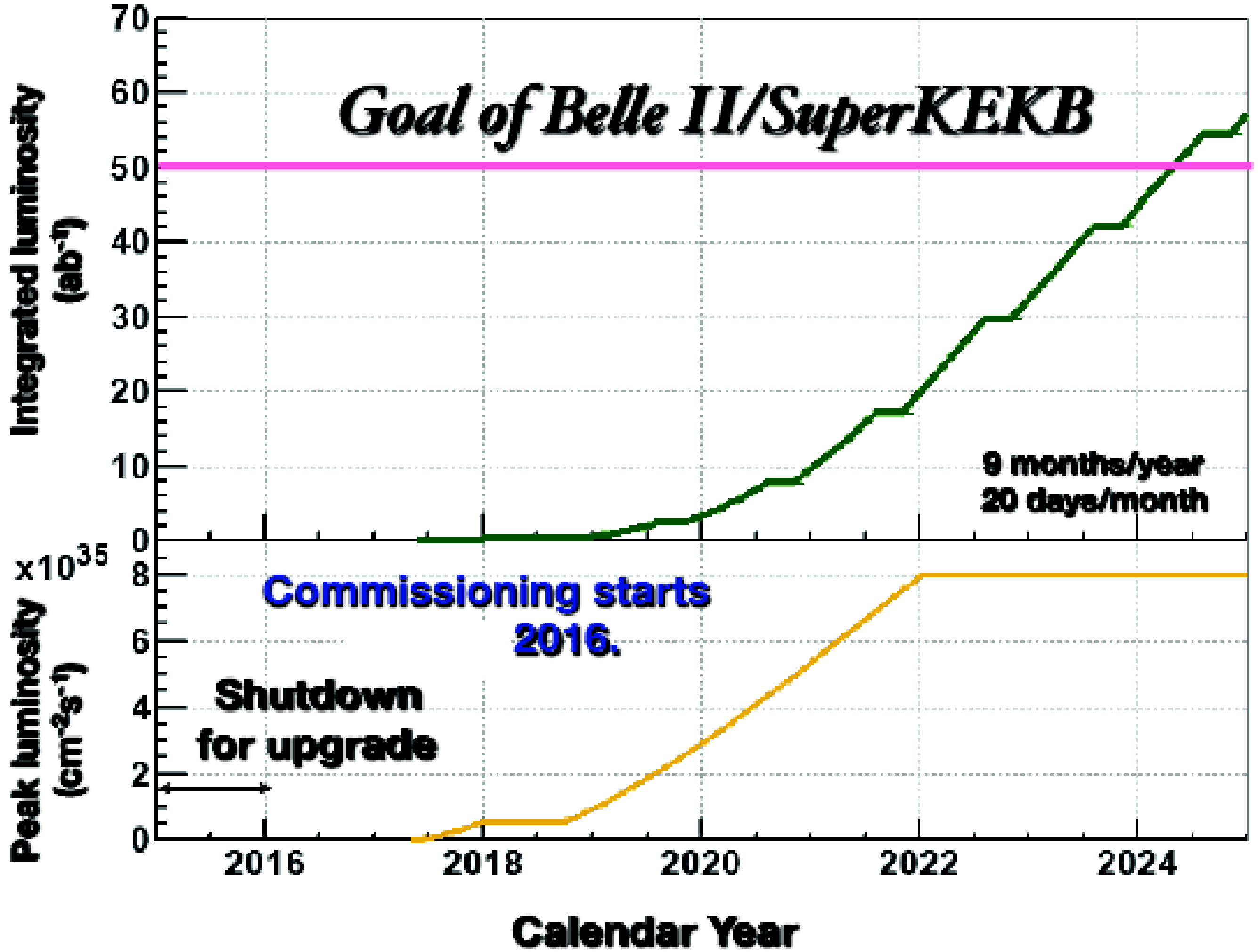




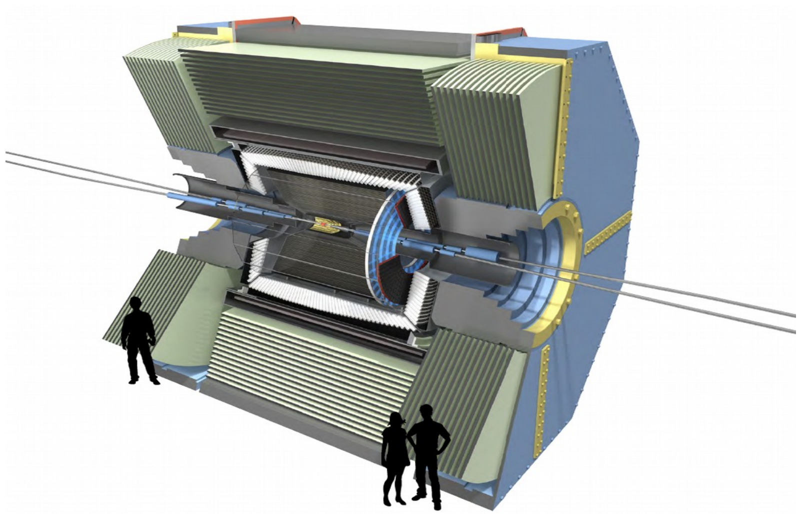
Gas: Ar/C_4H_{10}/HFC-134a = 30/8/62 (%)

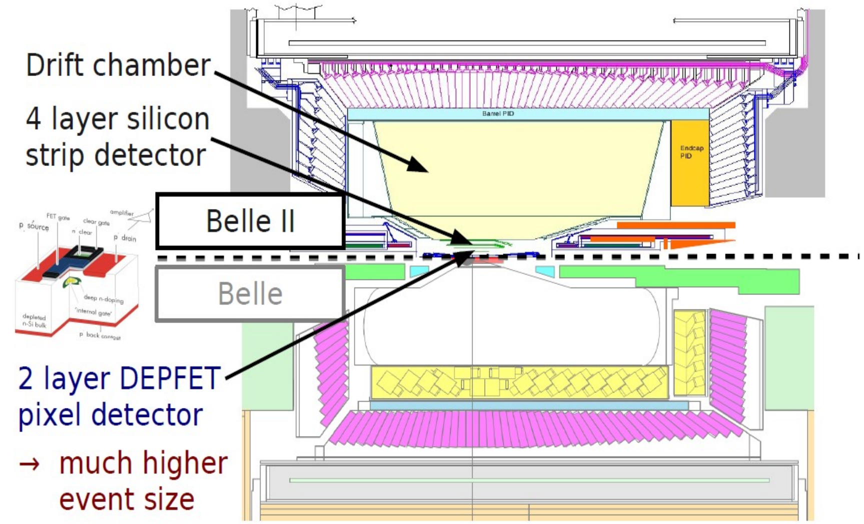
Voltage≈7kV

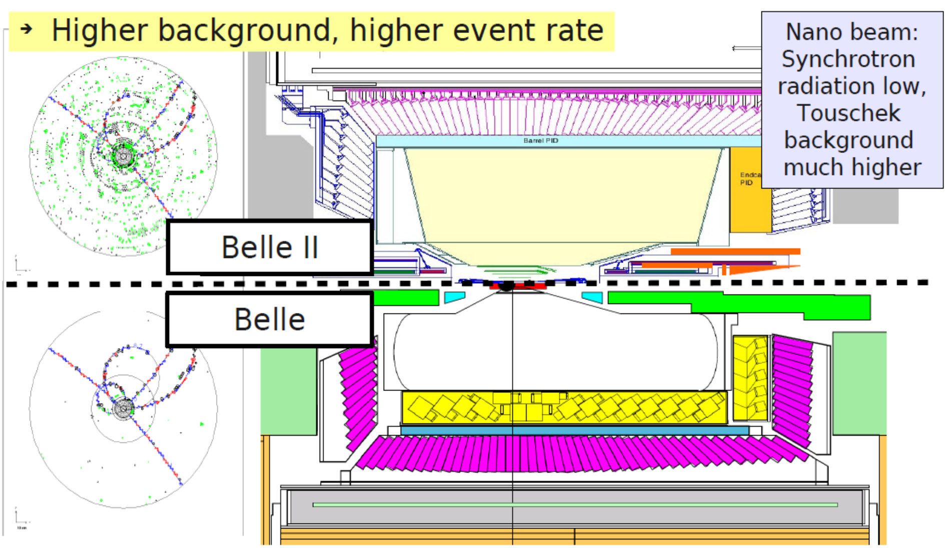
SuperKEKb luminosity plans

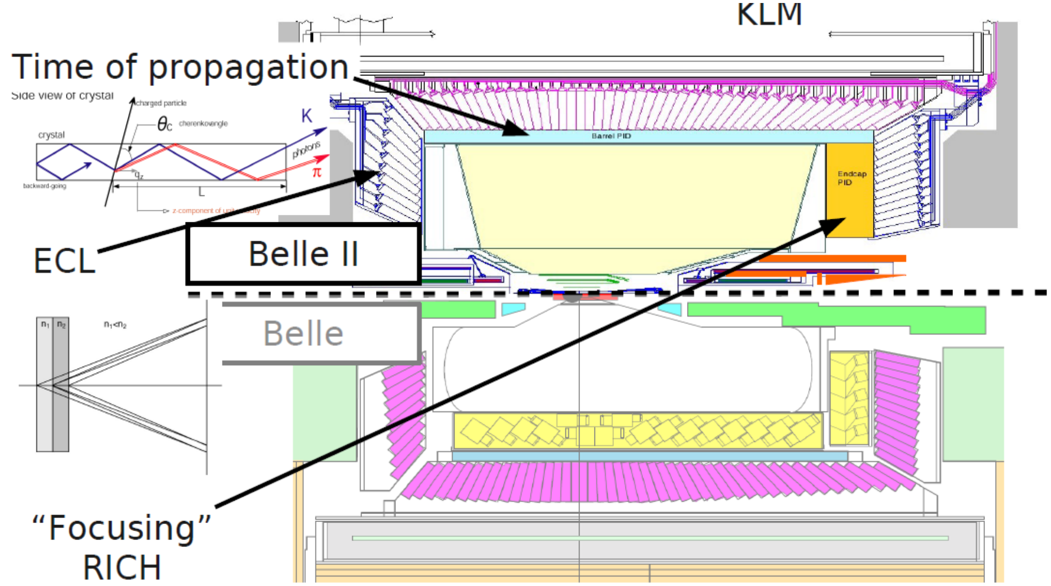


The Belle2 detector









RPC efficiency for Belle2

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

Belle2 TDR

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

Acceptable

Inacceptable

RPC efficiency measured in KEKB and extrapolated to SuperKEKB.

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

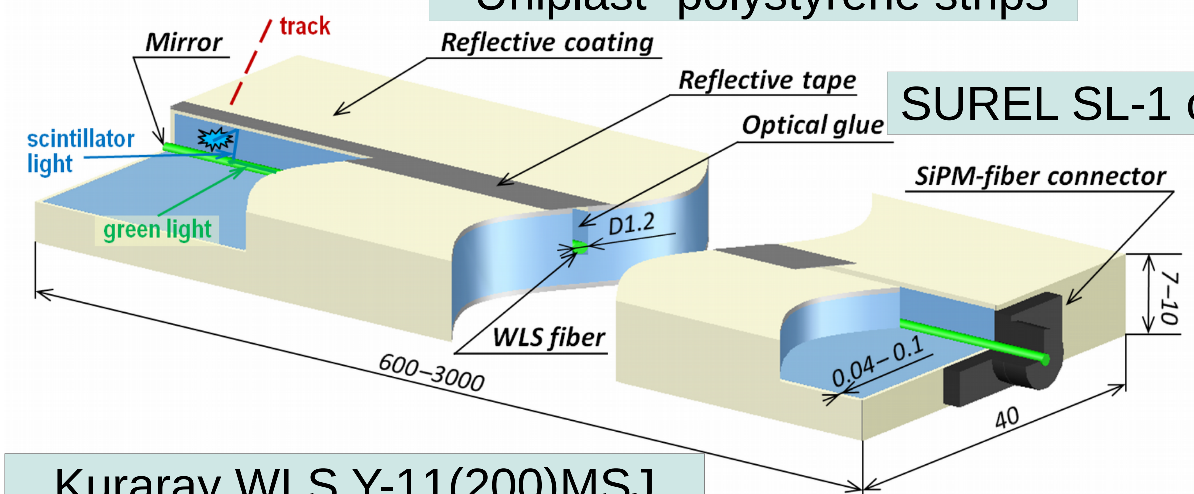
- **REPLACEMENT OF ALL ENDCAP AND 2 INNERMOST BARREL LAYERS**
- Scintillator based detector with WLS readout
- Fast photodector: Si photo diode in Geiger mode (SiPM - Hamamatsu MPPC)
- Independent operation of x-y layers

Scintillator - WLS - SiPM

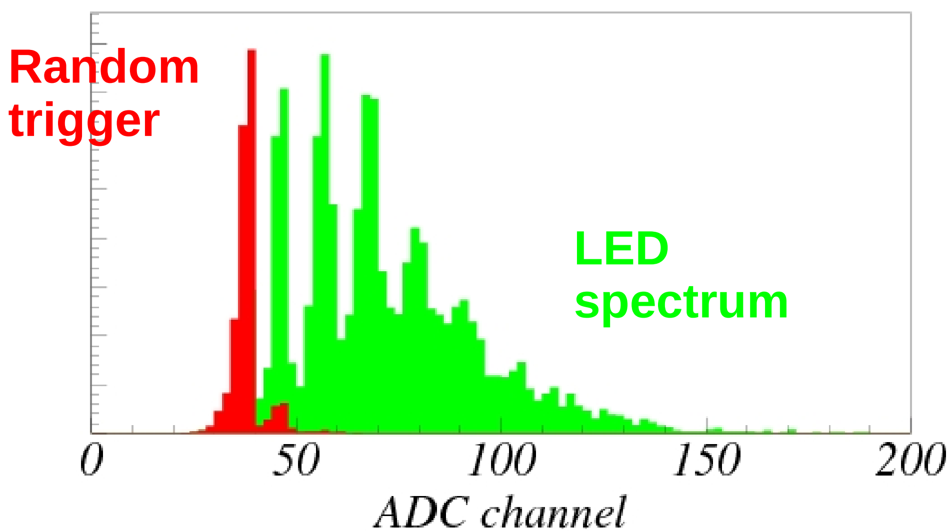
"Uniplast" polystyrene strips

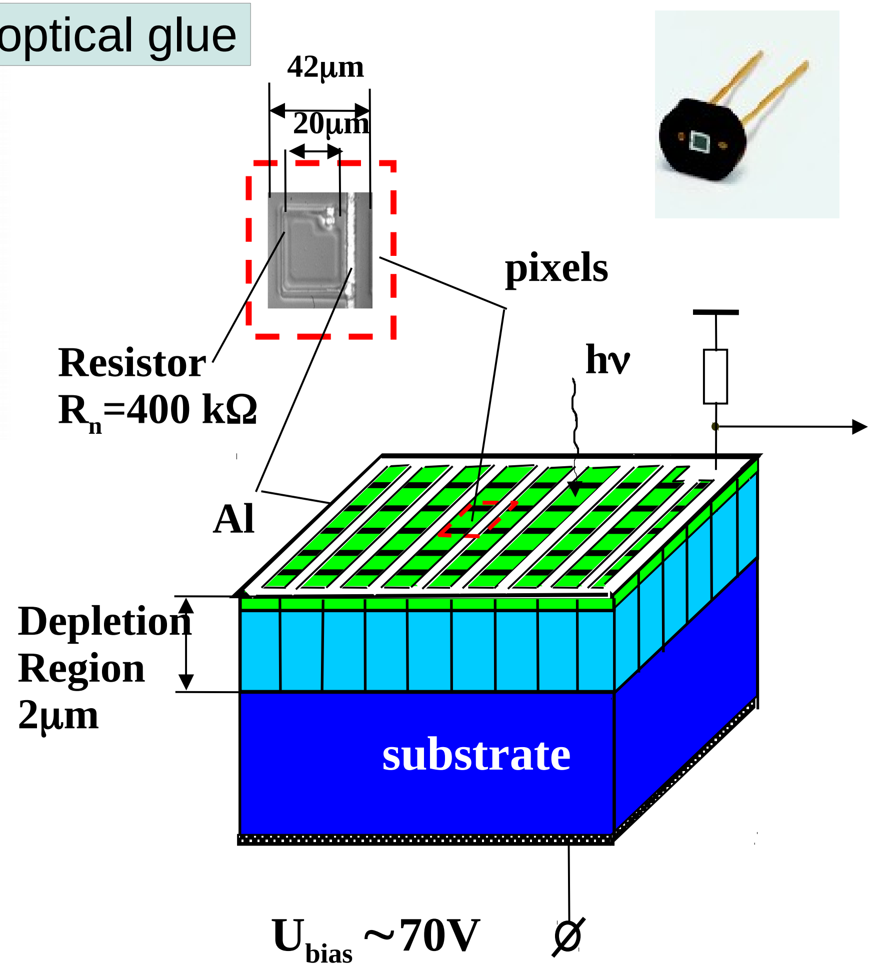
Hamamtsu MPPC S10362-13-050

SUREL SL-1 optical glue



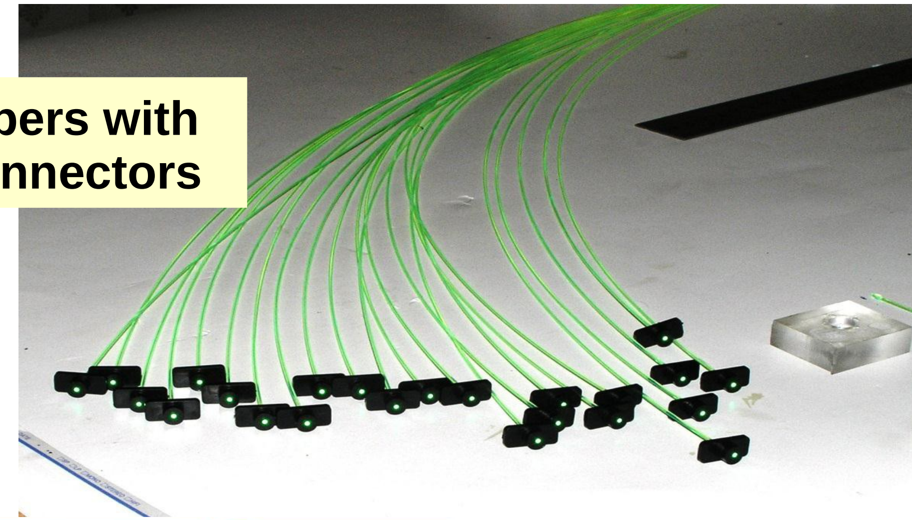
Kuraray WLS Y-11(200)MSJ

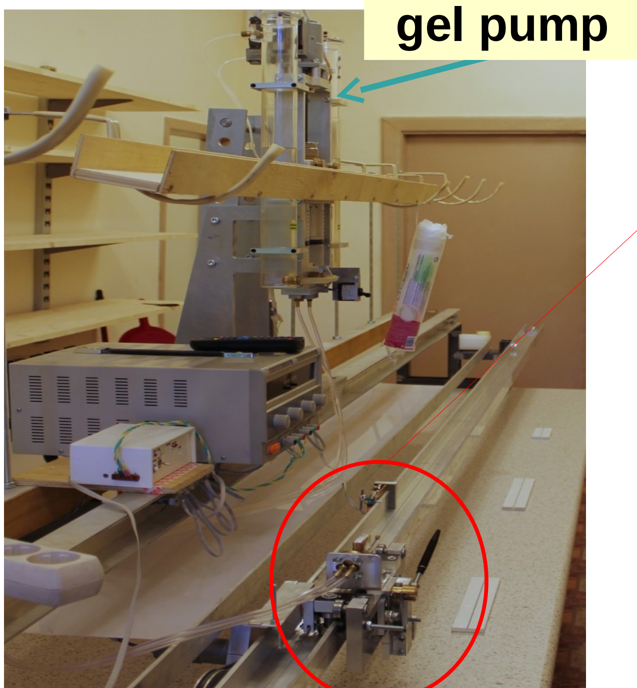


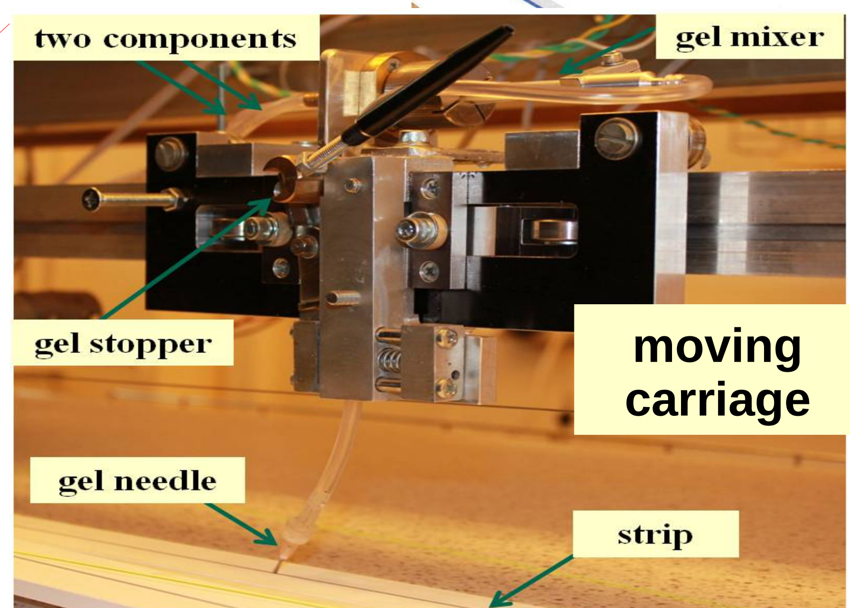


Scintillator strip production

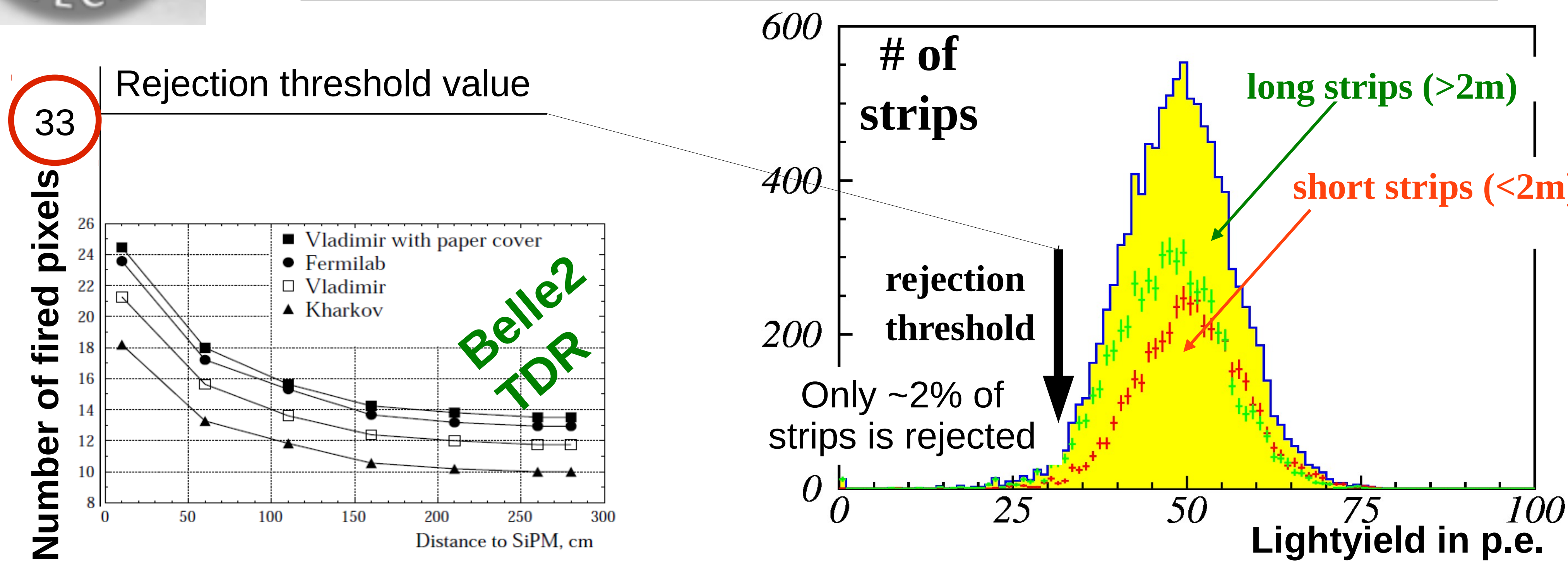
filling the strip groove with optical gel from the top with moving carriage

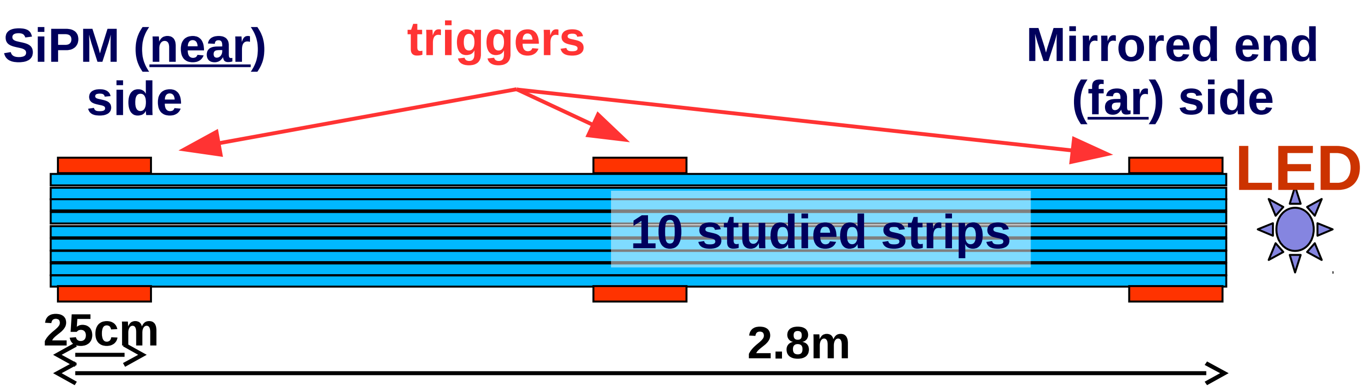






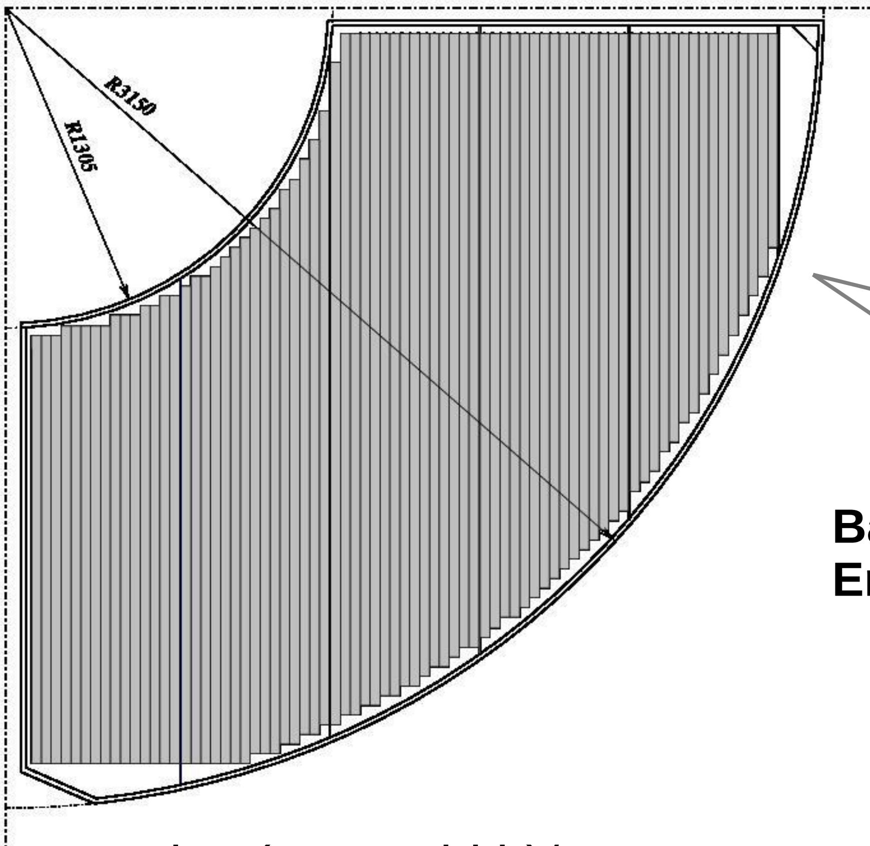
Scintillator strip lightyield



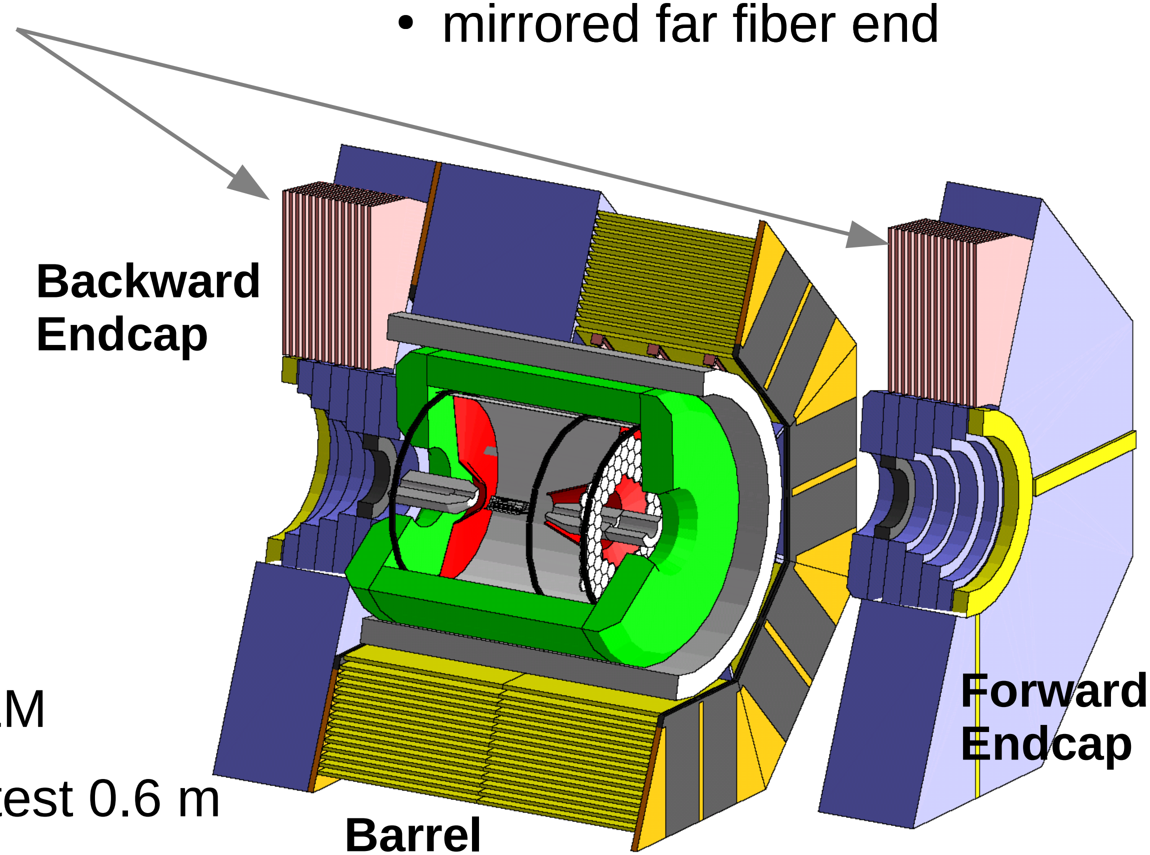


Good Gaussian distribution with a small RMS and perfect (almost twice larger than at TDR) mean value

Endcap sector layer



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



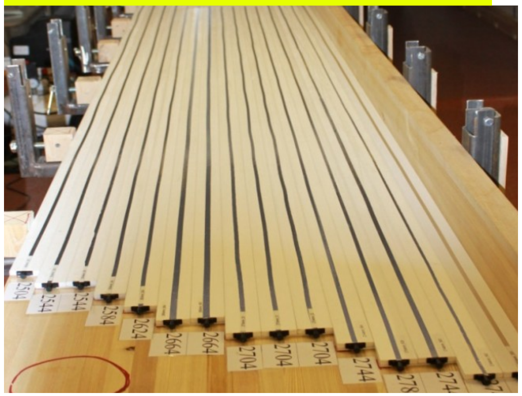
75 strips (4 cm width)/sector

16800 strips for F&B Endcap KLM

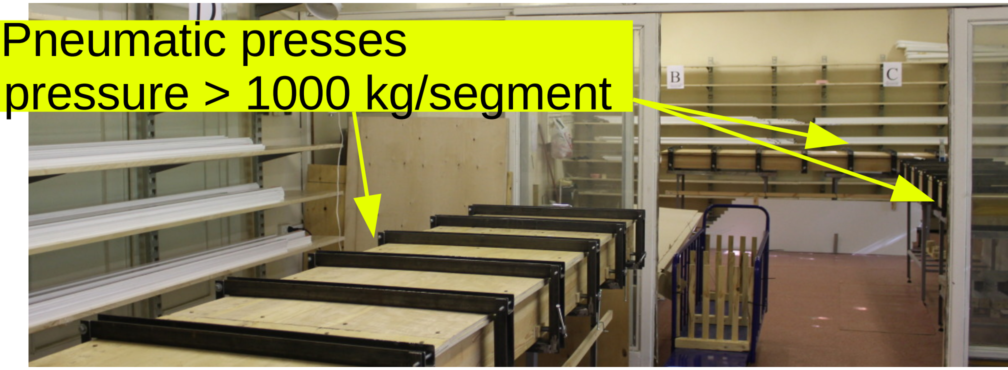
the longest strip 2.8 m; the shortest 0.6 m

Layer assemble

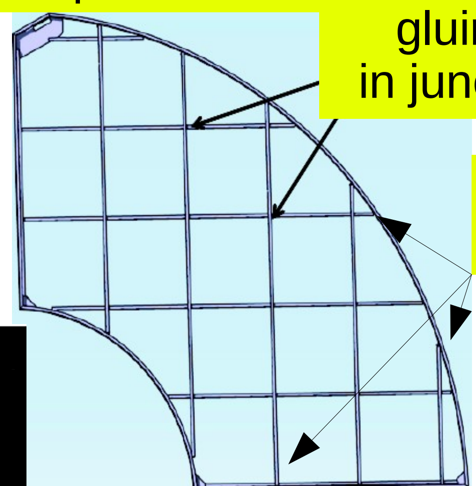
15 strips are glued to polystyrene substrate (1.5mm, both sides)

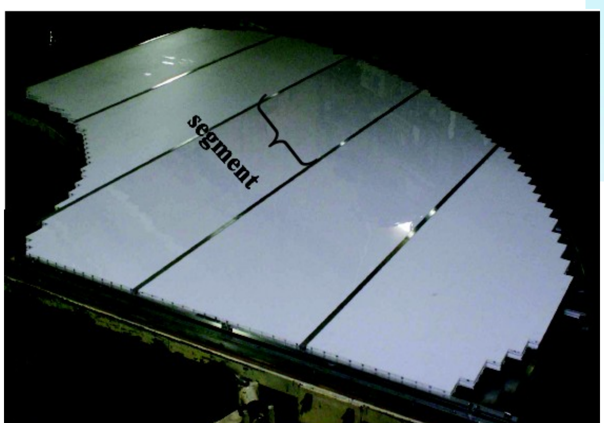


Pneumatic presses
providing pressure > 1000 kg/segment

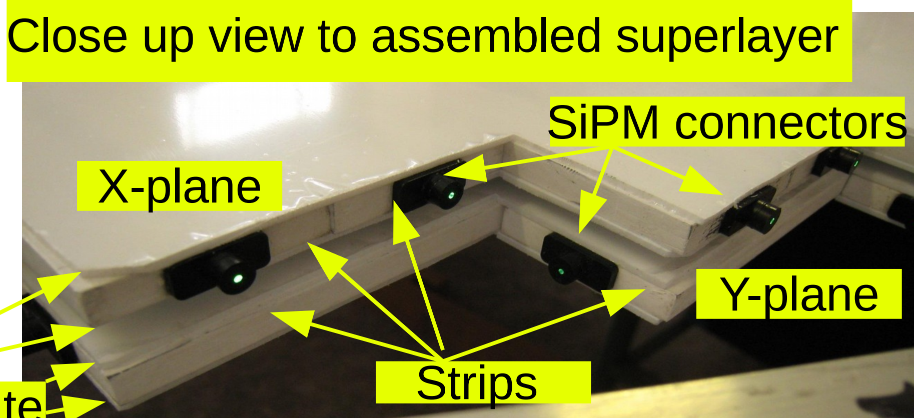


Support structure made of I-beam profiles





Close up view to assembled superlayer

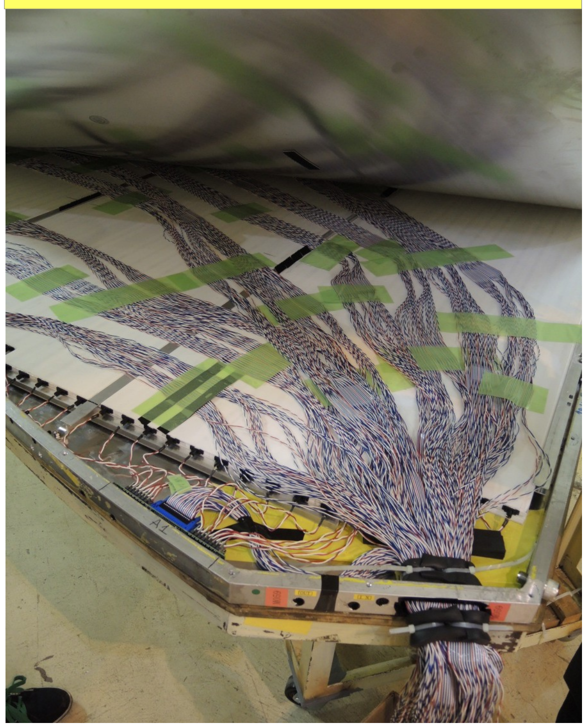


Polystyrene substrate

Modules assemble and installation

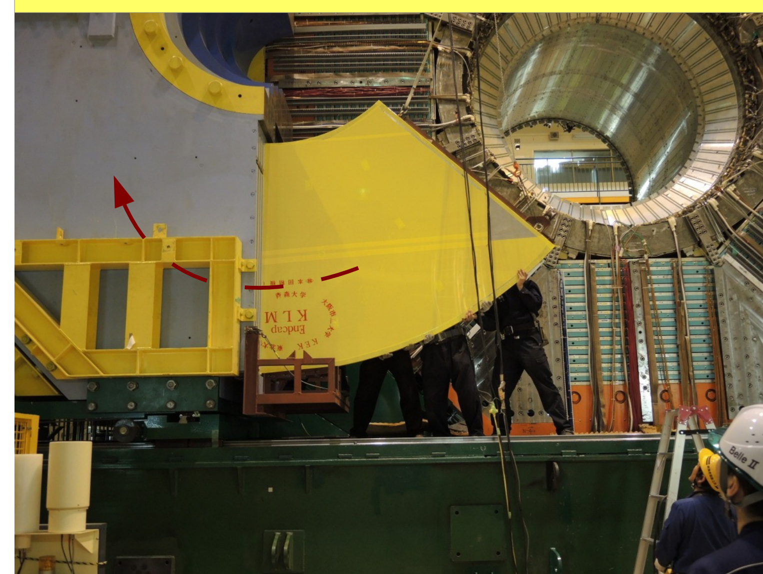
NIM **A 789**, 134–142 (2015)

Assembled module before closing the cover

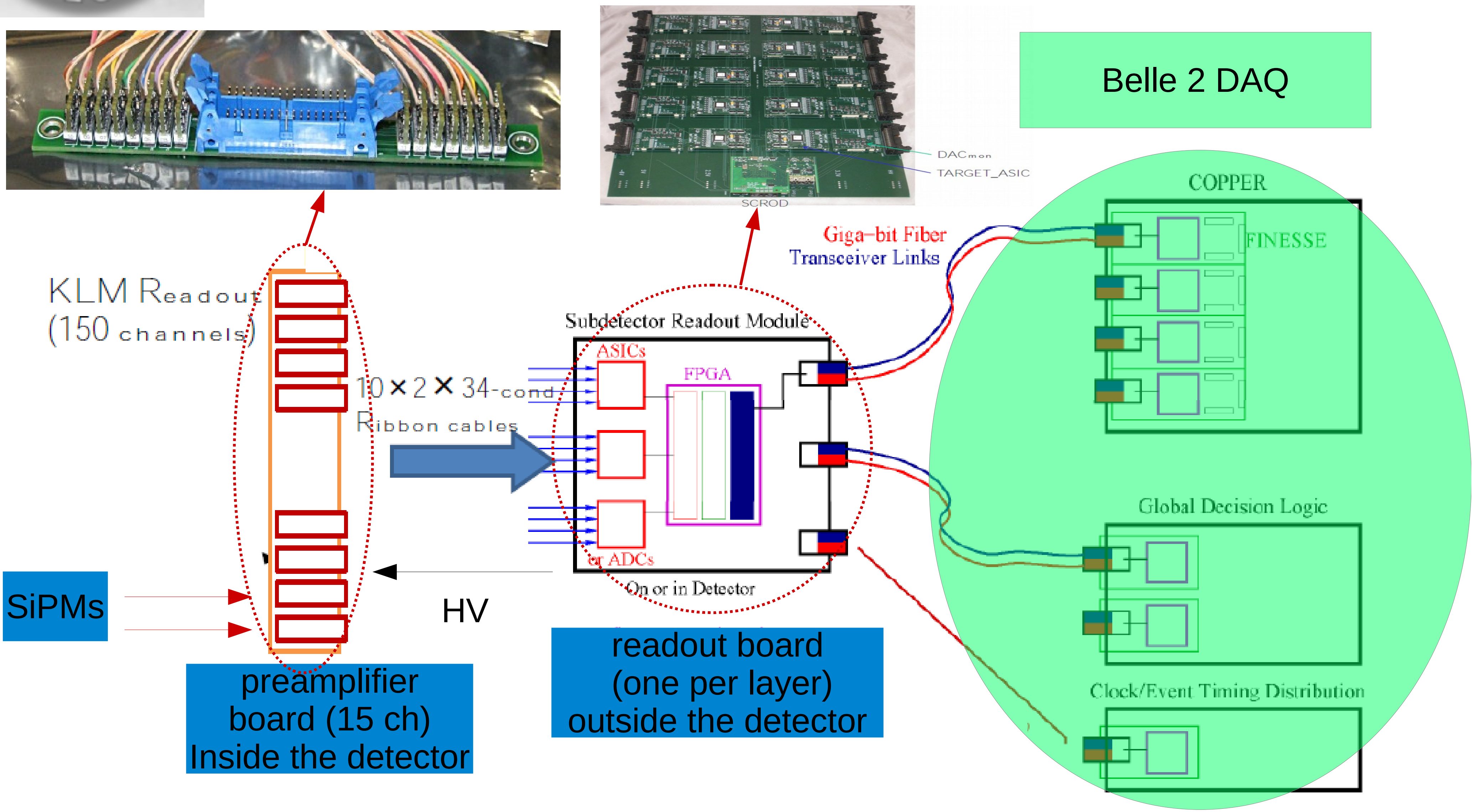


Installation gaps in the magnet flux return

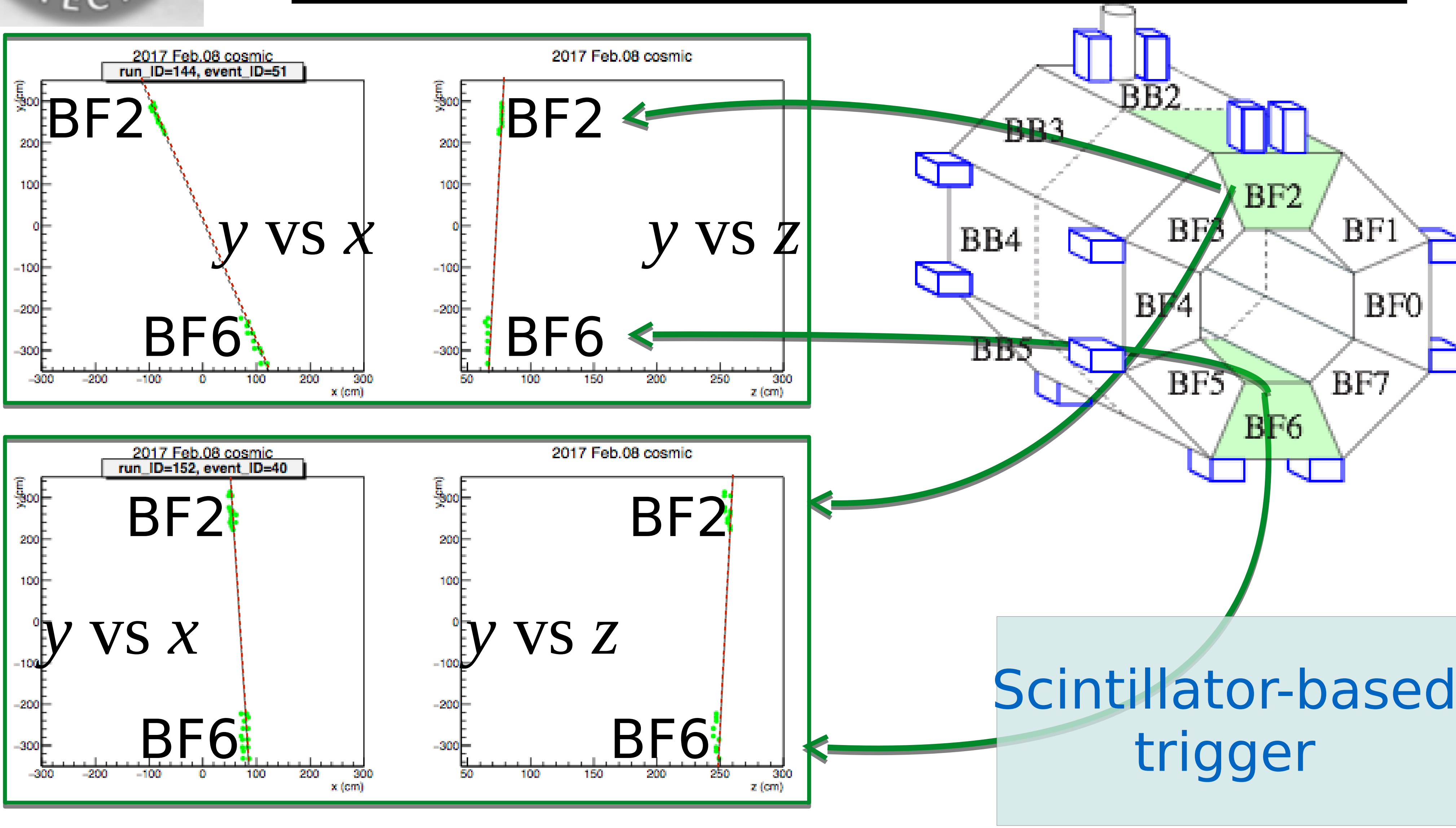
Module installation



Electronics

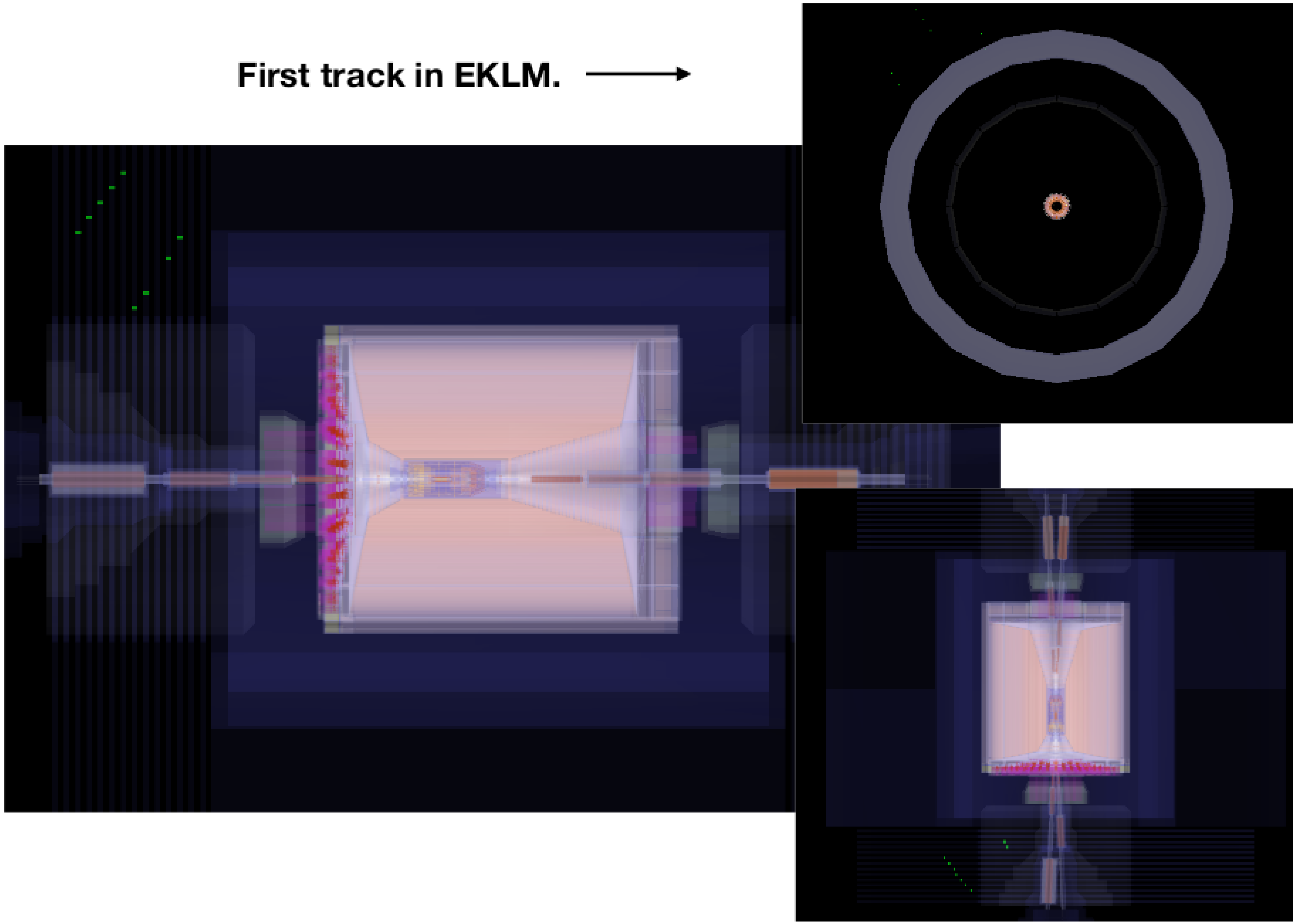


Cosmic tracks with RPC

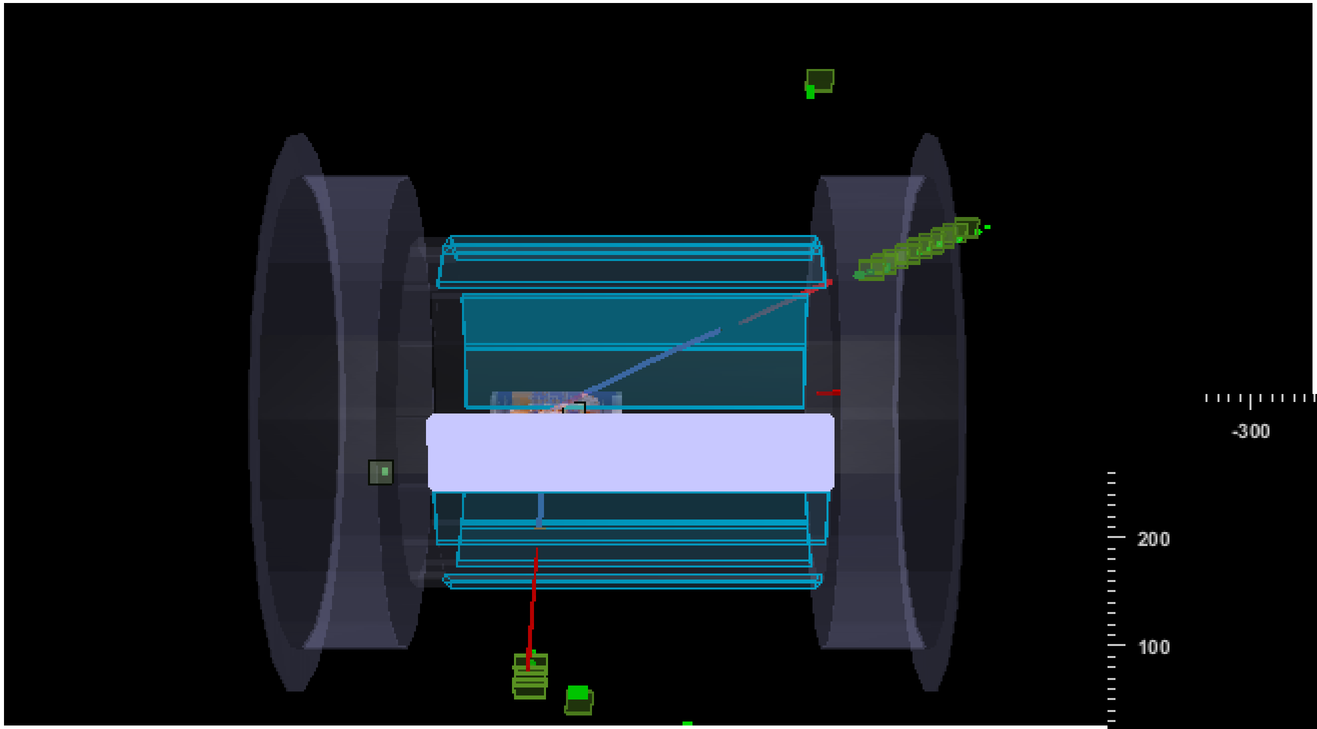


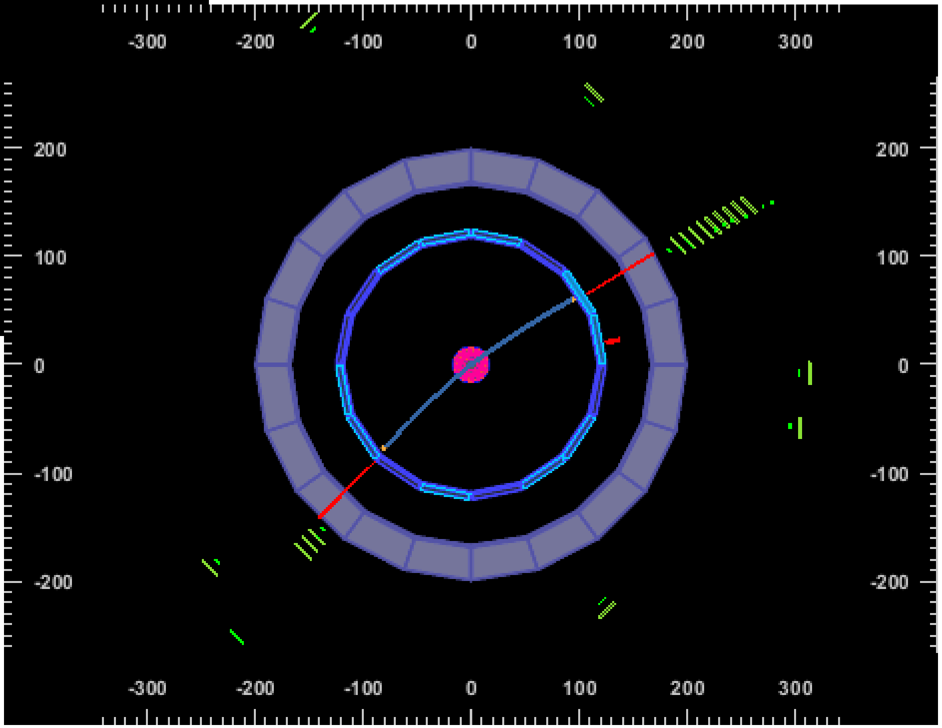
Cosmic tracks with Scintillator

First track in EKLM. →

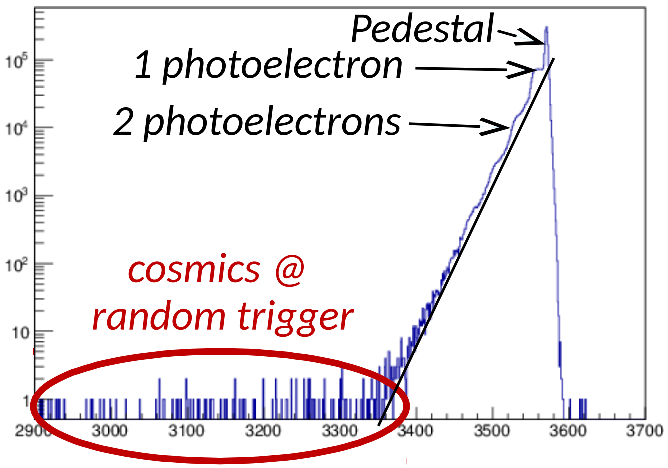


First physics signal





Calibration with SiPM noise

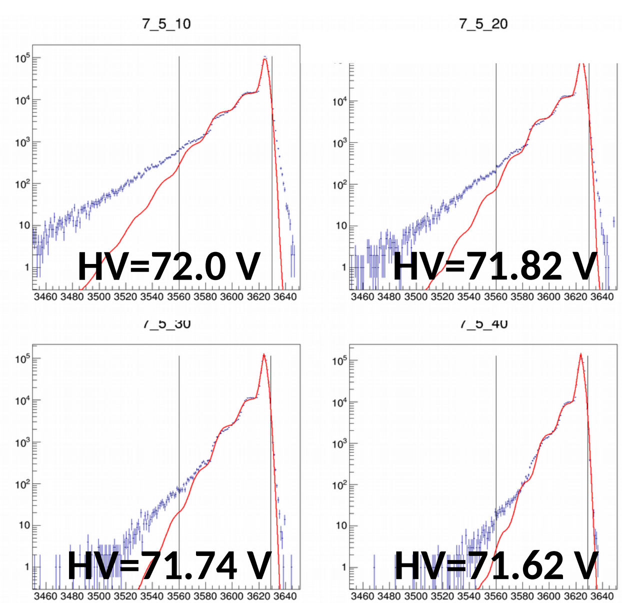


SiPM noise is linear in log scale, as rate for

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

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.

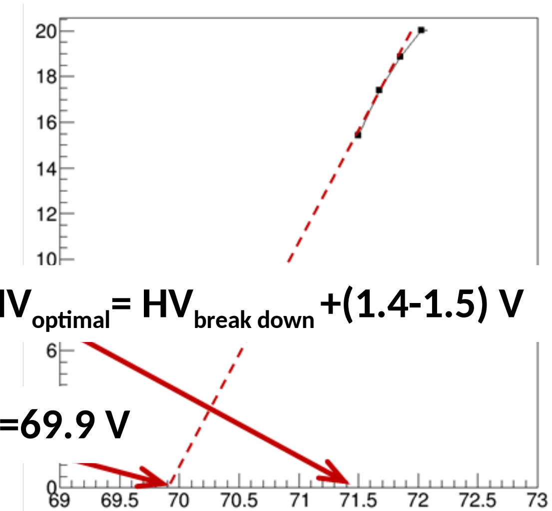
Use SIPM noise spectrum for SiPM calibration and optimal HV tuning: photoelectron peaks are well seen as steps in rate vs threshold distribution



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.

gain = 1 p.e. position - pedestal



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.

Cost estimation (I)

- All prices for 1 m2 (in US dollars): (by Vladimir Rusinov)
- polystyrene scintillating strips (7x40 mm2 x-section with diffusive reflecting coating and milled groove) $240;
- WLS fiber $250;
- SiPM - nobody knows exactly, ~12/m2 (depends on chosen geometry), ~$100 in 2018 prices in case of large purchase;
- labour $70 per day (~ 1 man-day per 1m2);
- other stuff: gel, polystyrene shields, connectors, scotch, silver shine paint etc. ~$10;
- packing, transportation ~$30.

- Total: $700

Cost estimation (II)

- Not included:

- At Belle II aluminium frames taken from the old RPC system were reused.
- Cables, connectors.
- Preamplifiers.
- Read-out electronics.
- Power supply.
- Assembly and installation costs (mostly labour).

Cost estimation (III)

Area estimation: (based on this drawing) *it is very rough estimation, the number of SiPMs and electronics channels highly depends on the exact geometry, while the area is practically superlayer geometry independent*

Geometry:

- Barrel part:
  - 8 octants, each of
    - 8 superlayers, each of
      - 2 independent strip layers of 3820 x (2130+1300)/2 mm2 = 6.55 m2(mean value for the width) size

Total (barrel): 838.40 m2

- Endcaps:
  - 2 endcaps, each of
    - 4 quadrants, each of
      - 8 superlayers, each of
        - 2 independent strip layers of (1/4 of the area of the circle with D=5500 mm MINUS 1/4 of the area of the circle with D=2120 mm) = 1/4*3.14*(5.52-2.122)/4 m2=5.05 m2

Total (endcaps): 646.40 m2

Total area: 1484.8m2

Cost estimation (IV)

Total cost (excluding mechanical support, cabling, installation and electronics)

$1040k=RUB 62M

For a rough estimation of excluded items costs we double the total

Manpower

At LPI:

2 senior researchers (30-50% of working time) Timofey Uglov, Elena Solovieva

(possible) 1-2 students from MIPT and/or MEPhI (inexperienced) ???

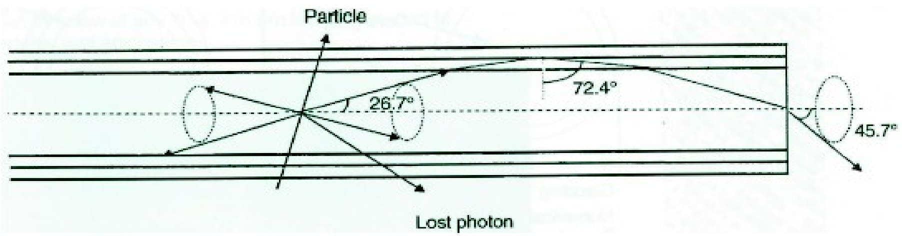
At BINP:

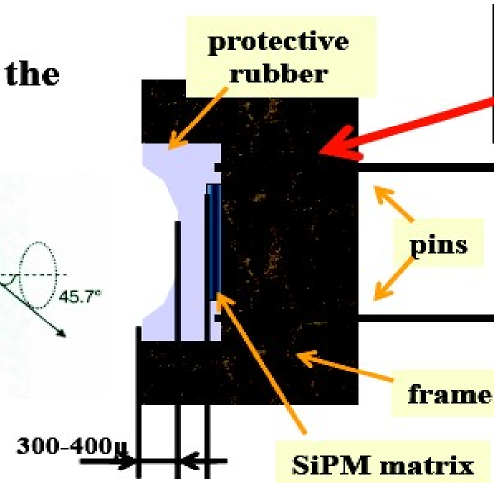
Andrey Sukharev

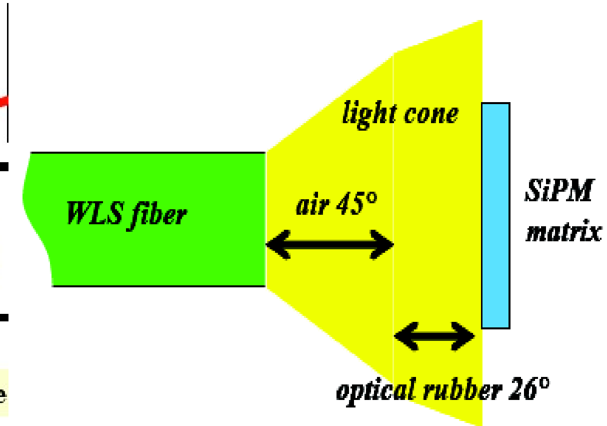
Backup

Lightyield improvement

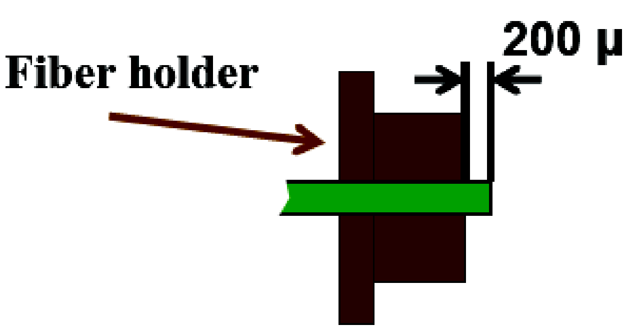
- **Originally (TDR, Module-0) fiber was set at the level of the frame surface**

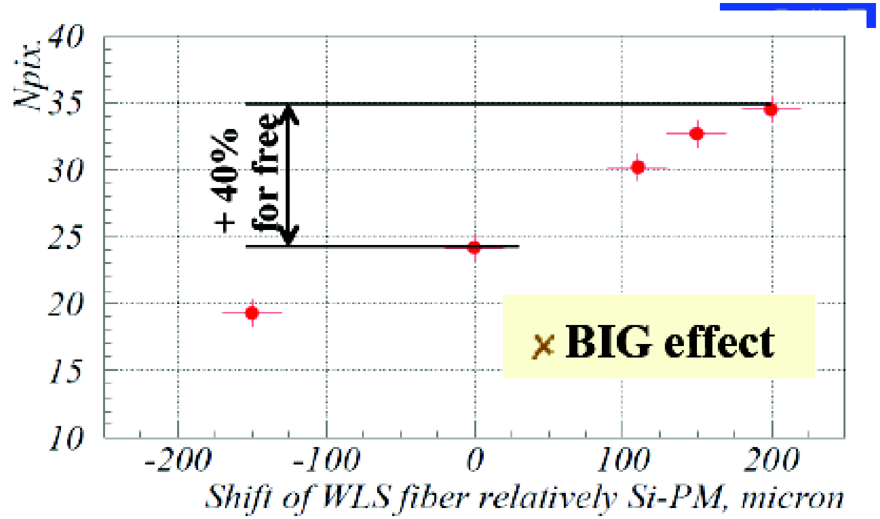




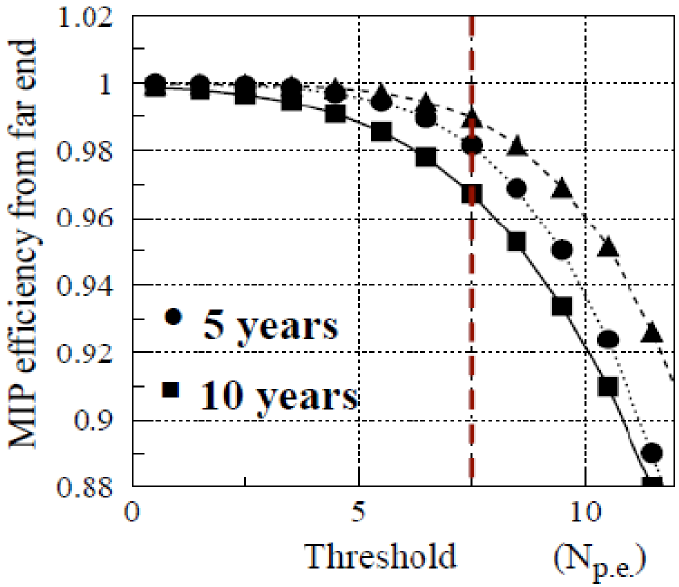


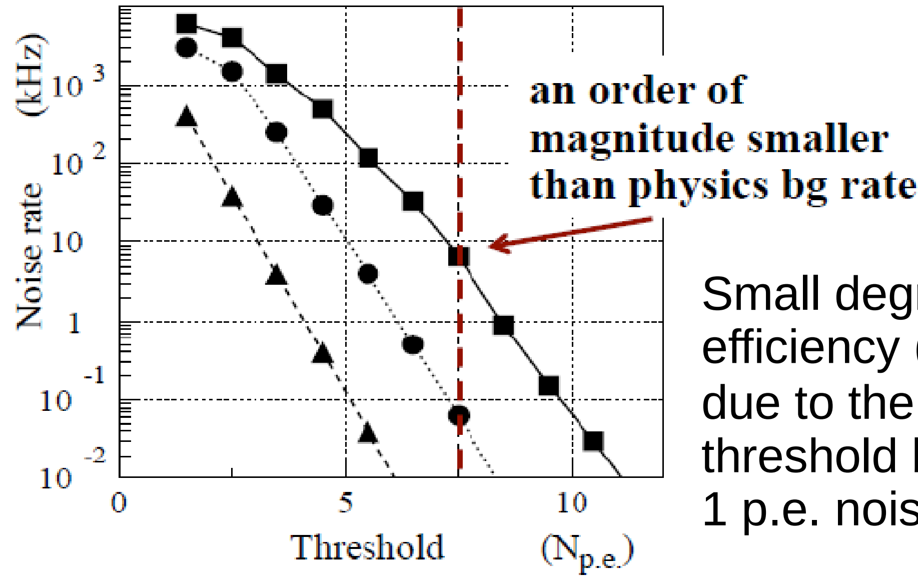
Tests: varying gap –200 ÷ +200µ (without fiber gluing)





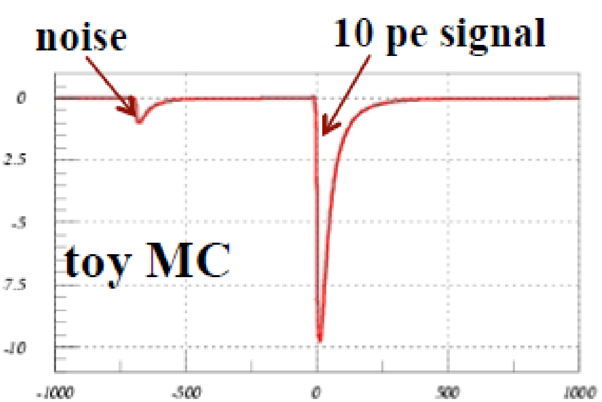
Radiation hardness

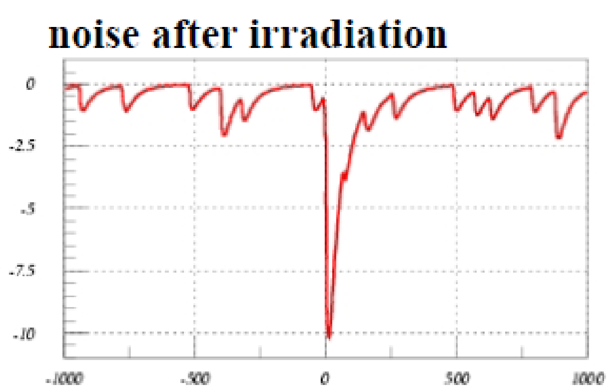




Small degradation of MIP efficiency (99%→97%) is due to the smearing of the threshold by random 1 p.e. noise.

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





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