Upgrade of the electromagnetic calorimeter for Belle II

CHEF2013

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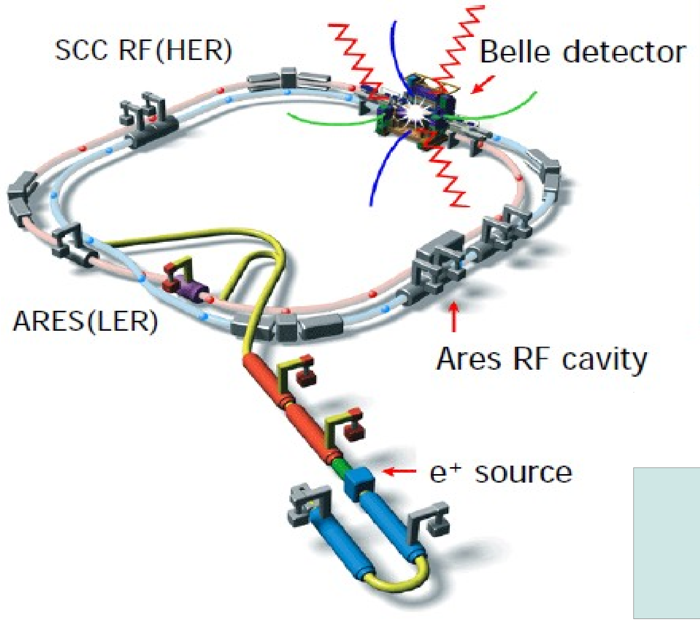
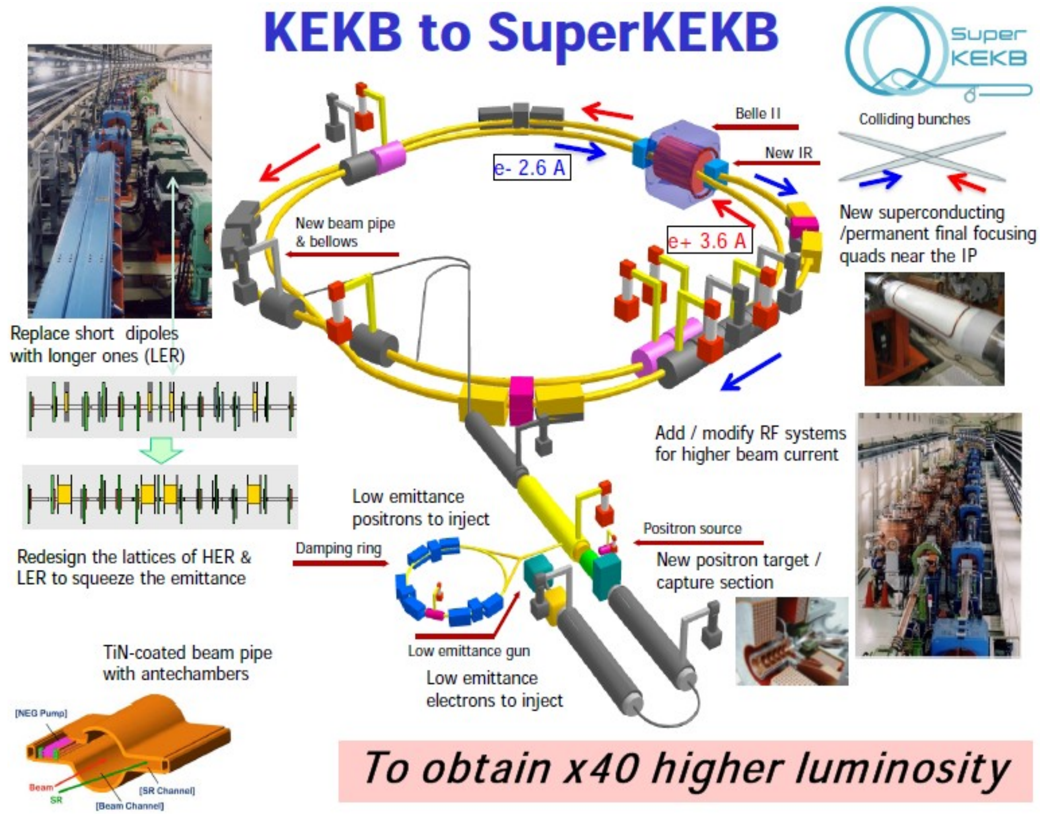
(For BelleII ECL)

KEKB upgrade



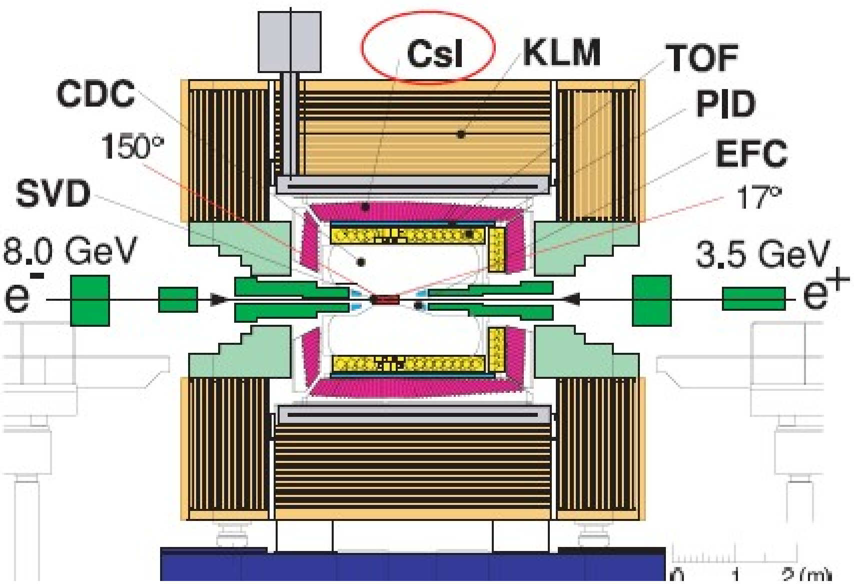


Energy: 3.5 GeV (e+) 8 GeV (e-)
Current: 1.6 A 1.2 A
Crossing angle/2: 11 mrad
Luminosity: $2.1x0^{34}$ cm^{-2}s^{-1}

Energy: 4 GeV (e+) 7 GeV (e-)
Current: 3.6 A 2.6 A
Crossing angle/2: 41 mrad
Luminosity: $8x10^{35}$ cm^{-2}s^{-1}

Belle calorimeter

- Crystals 300x(50-80)x(50-80) mm
- Wrapping 200μm teflon+50 μm Al mylar
- Readout 2 10x20 mm PIN diodes
- 2 charge sensitive preamplifiers
- Shaper CR-(RC)^4, τ=1μs
- Lightoutput 5000 p.e./MeV
- Electronic noise $1000e \approx 200$ keV



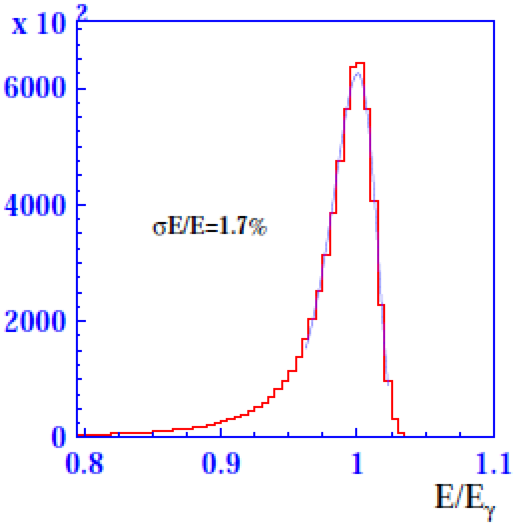
- Calorimeter based on CsI(Tl) scintillating crystals
- Thickness – 16.1 X_0(30 cm)
- Calorimeter is inside magnetic coil
- CDC+ACC is about 0.3 X_0
- 8736 counters (40 tons of CsI(Tl))

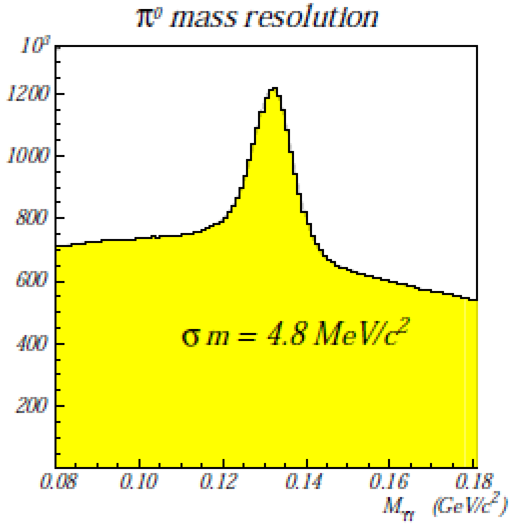
Belle calorimeter

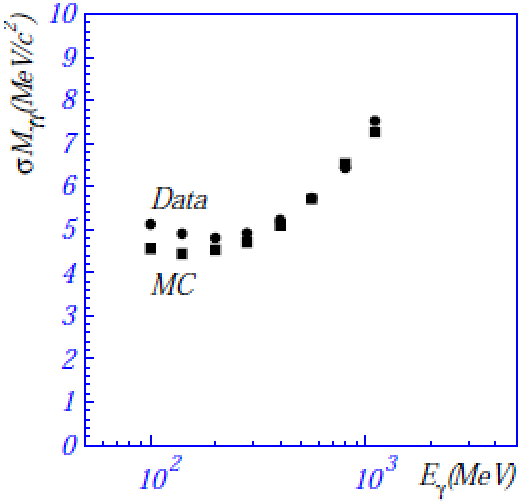
π^0 mass resolution

$m^2 = 2E_{\gamma 1}E_{\gamma 2}(1 - \cos\psi)$

$e^+e^- \rightarrow \gamma\gamma$







-Calorimeter successfully worked for more than 10 years

-All 8736 channels are workable, no dead channels!

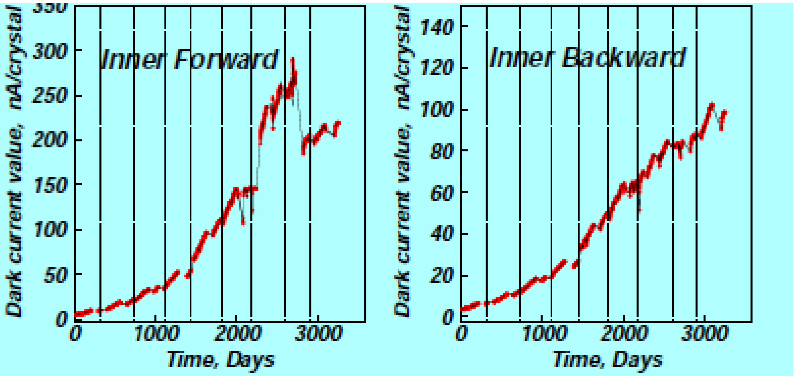
-Good performance

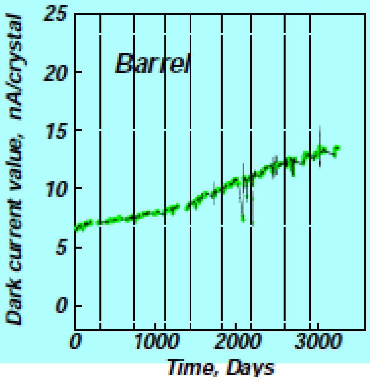
-We would like to have the same or better performance for BelleII

The problems revealed during Belle operation

Radiation damages of the crystals

Radiation damages of PIN photodiodes





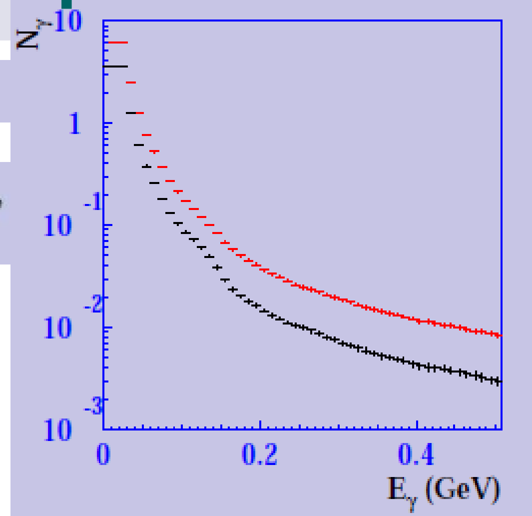
Small increase of the dark current in barrel

Essential increase of the dark current in the endcaps

Caused by neutron flux

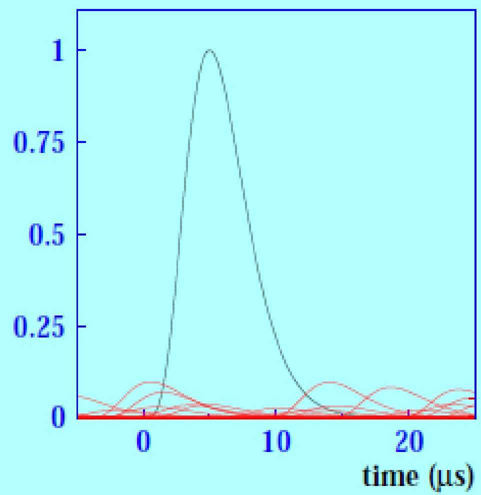
Fake clusters

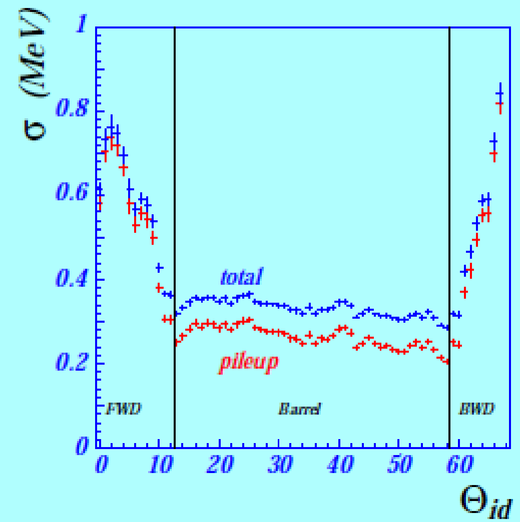
(E>20 MeV) 6 fake clusters, 3 in barrel 3 in endcaps



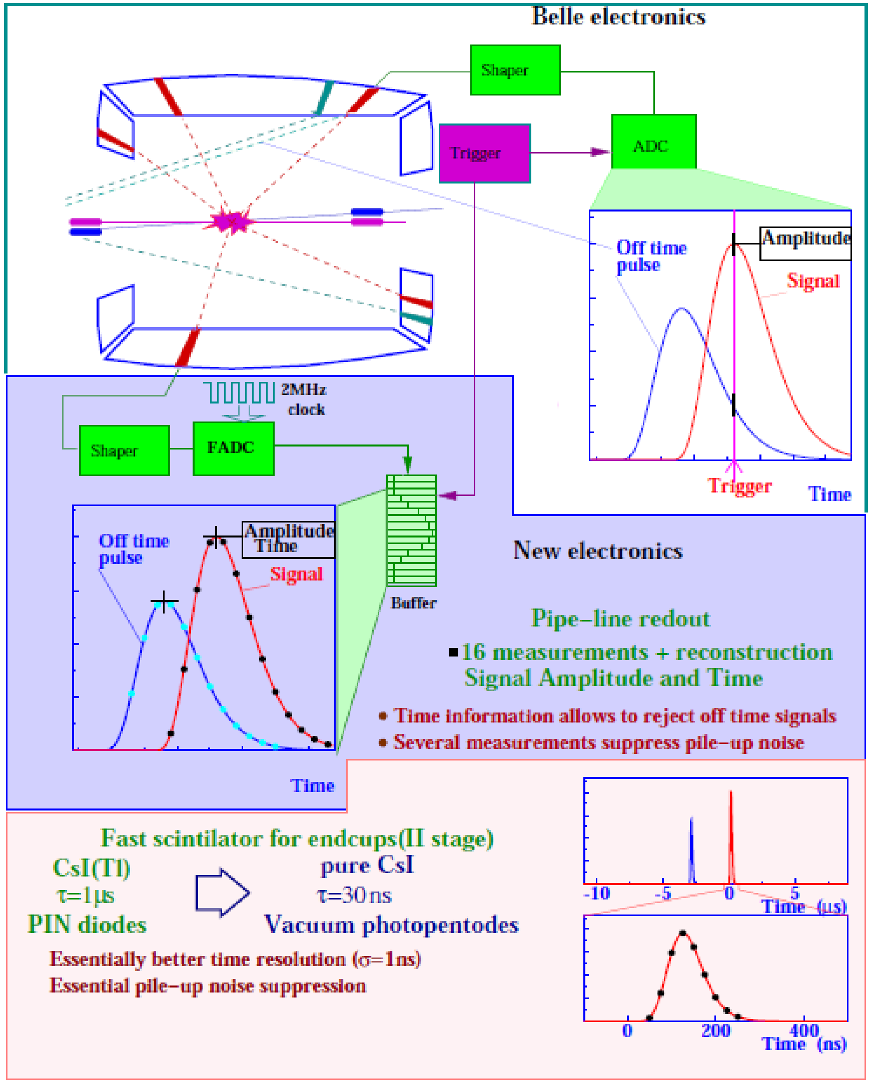
Pileup noise

$$\sigma = \overline{E_\gamma}\sqrt{\nu\tau_{eff}} \sim \sqrt{IP}$$





Strategy of upgrade



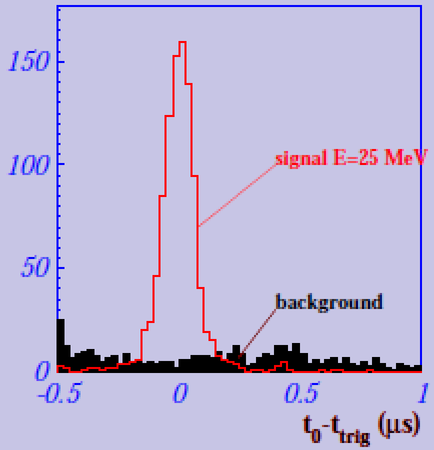
- Belle II can get advantage in π^0 and soft photon-detection efficiency and resolution in comparison with LHCb experiment
- Modify electronics for the barrel.
- Pipe-line readout with waveform analysis:
- 16 points within the signal are fitted by the signal function $F(t)$:

$$F(t) = A\ f(t - t_0)$$

A - amplitude of the signal and
t_0 – time of the signal,

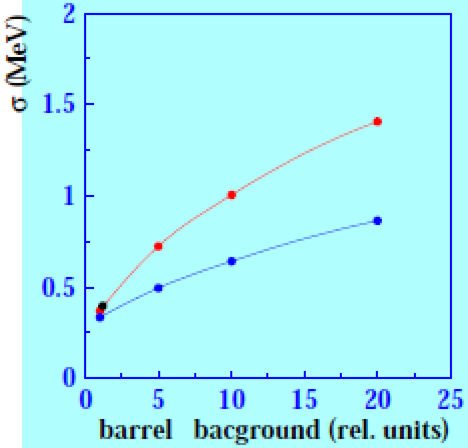
- Both amplitude and time information are reconstructed:
- Next stage: Replace the CsI(Tl) by the pure CsI crystals in endcaps.

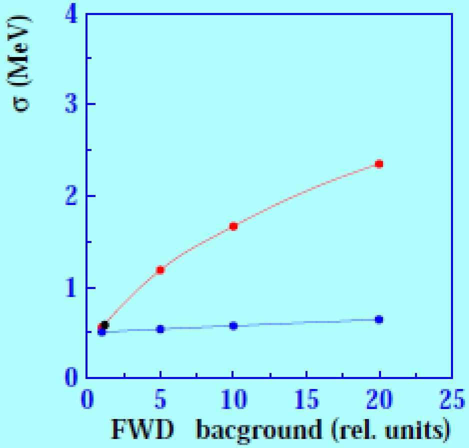
Expected improvement

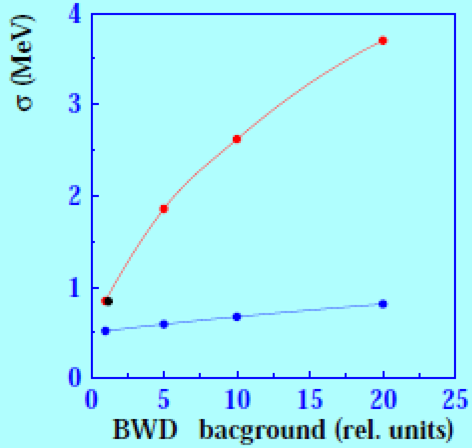


- **Time information allows to suppress the fake clusters by a factor of 7 for the barrel by rejecting wrong time clusters**
- **For endcaps the suppression is by a factor of 7x30=200 due to shorter decay time of the pure CsI**

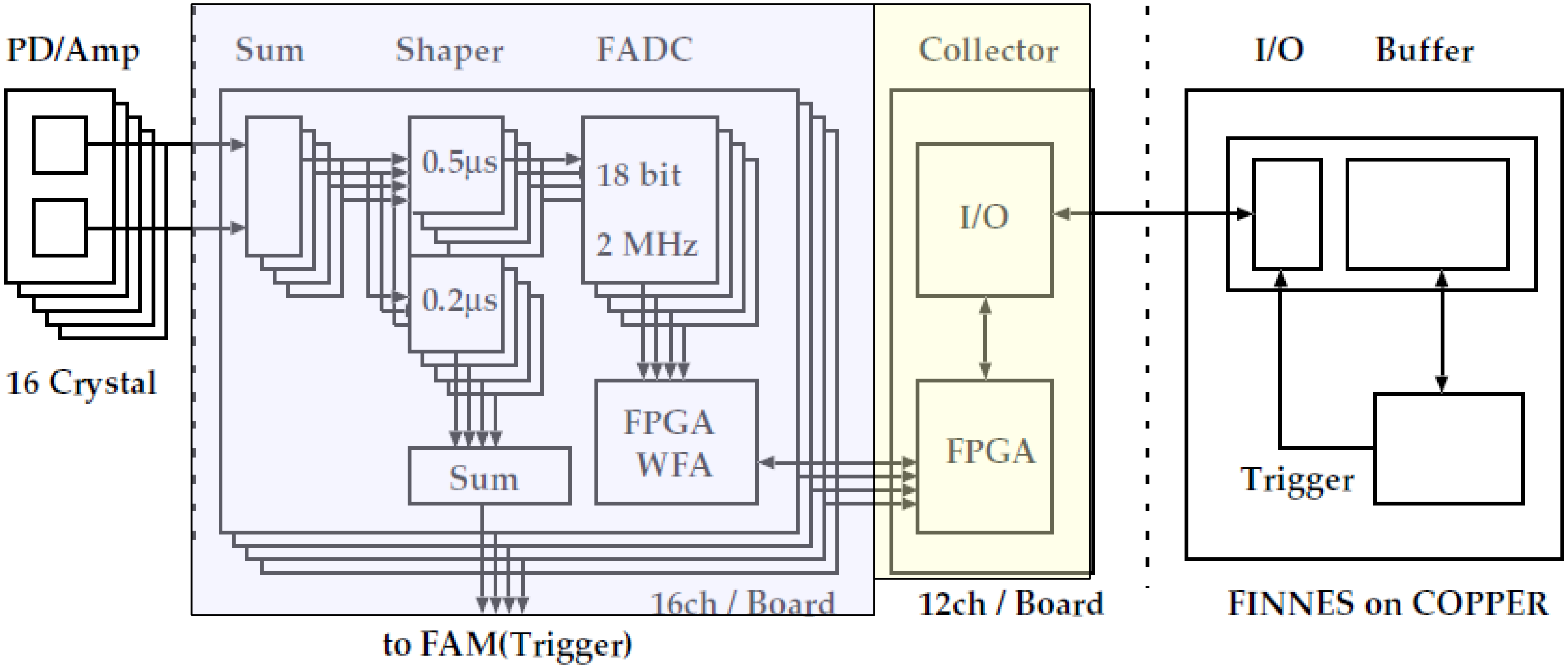
- The pileup noise will be reduced factor ~ 1.5 for barrel and factor 5 for endcaps:

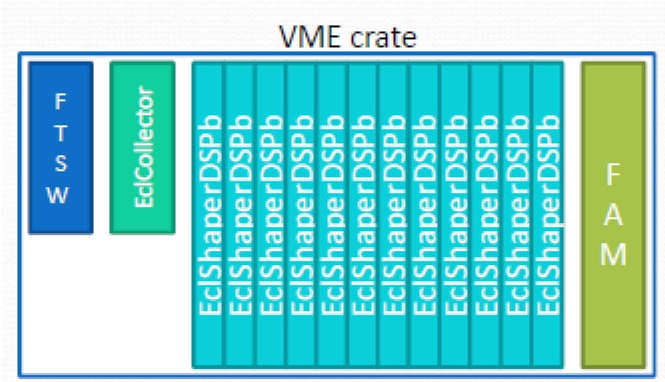






New electronics





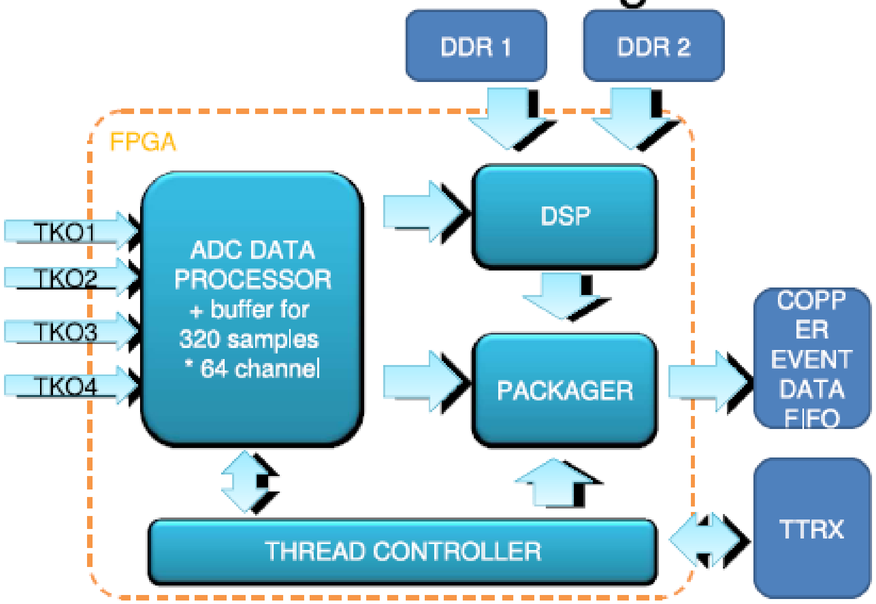
There are 52 ECL VME crates
We don't plan to install VME controller at the crates

The crates have non-standard power supplies!
7.5 V (instead of 5.0V)
15 V (instead of 12V)

FPGA algorithm

- **Fit of several measurements to response function taking into account correlation between measurements ->A,T, Quality**
- **Correlation matrix is obtained from the data**

FPGA overall design

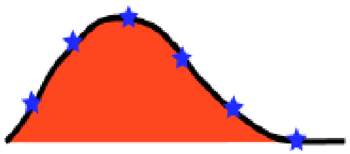


Algorithm details

$$\chi^2(A,p,t_0)=\sum_{i,j}\left(y_i-Af(t_i-t_0)-p\right)S_{ij}^{-1}\left(y_j-Af(t_j-t_0)-p\right)\rightarrow \min$$

$$S_{ij}=\overline{\left(y_i-\overline{y}\right)\left(y_j-\overline{y}\right)}$$

$f(t)$ — counter response



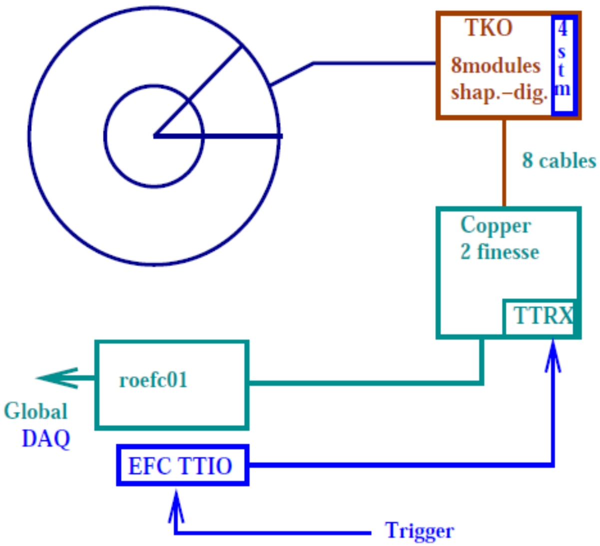
$$Af(t_i-t_1-\Delta t)=Af(t_i-t_1)-A\Delta t f'(t_i-t_1)=Af(t_i-t_1)+Bf'(t_i-t_1)$$

where t_1 — initial time (trigger time)

$$\left\{\begin{array}{l}\sum_{i,j} f_i S_{ij}^{-1}\left(y_j-Af_j-Bf_j'-p\right)=0\\ \sum_{i,j} f_i' S_{ij}^{-1}\left(y_j-Af_j-Bf_j'-p\right)=0\\ \sum_{i,j} S_{ij}^{-1}\left(y_j-Af_j-Bf_j'-p\right)=0\end{array}\right. \Rightarrow \begin{array}{l}A=\sum_i \alpha_i y_i\\ B=\sum_i \beta_i y_i \Rightarrow \Delta t=-B/A\\ p=\sum_i \gamma_i y_i\end{array}$$

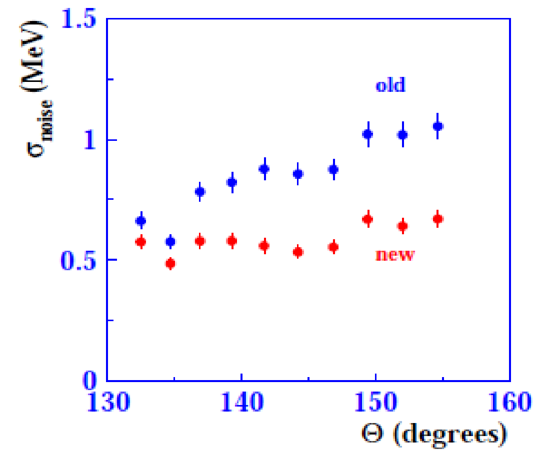
- **For some fraction of data both input and output informations are sent to DAQ for test**

Test of the electronics with Belle detector



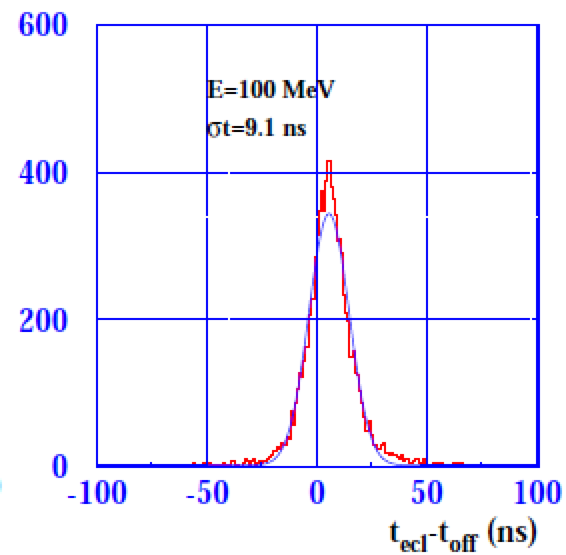
- **In 2008 and in 2010**

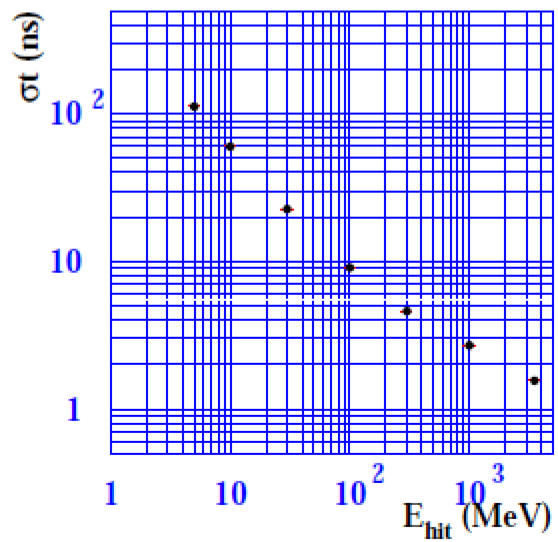
  1/8 of backward endcap of Belle calorimeter was switched to new electronics



- **The expected pile-up noise suppression was observed**
- **Time resolution gives possibility to suppress**

  fake clusters with E>20Mev by factor 7





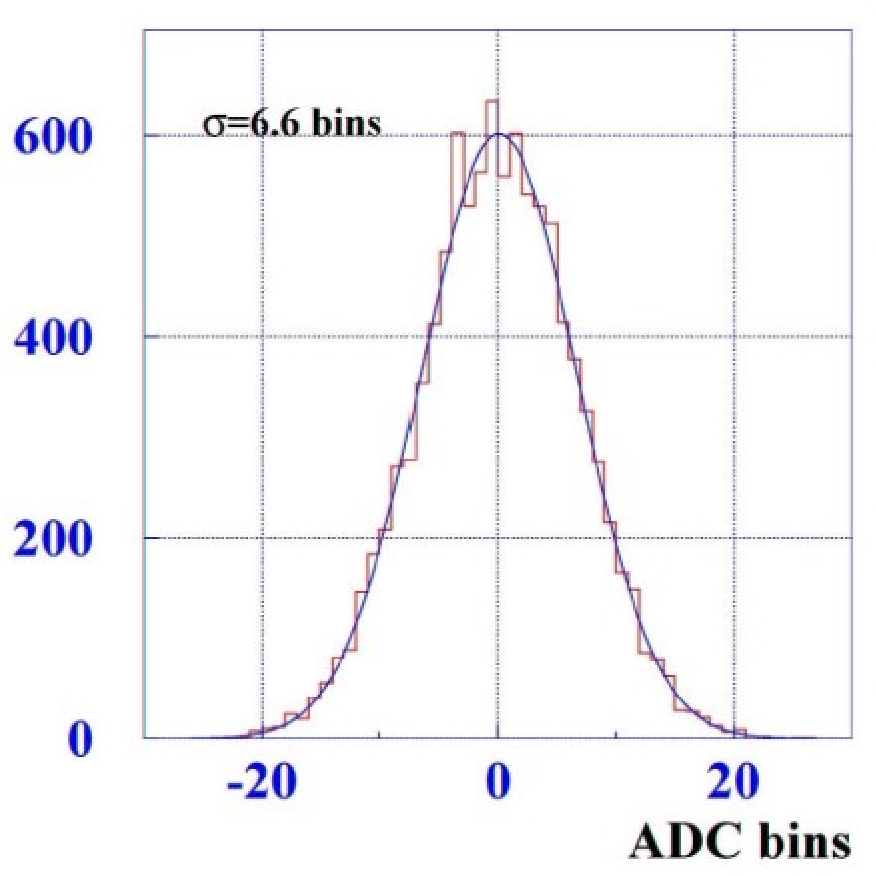
Shaper DSP module

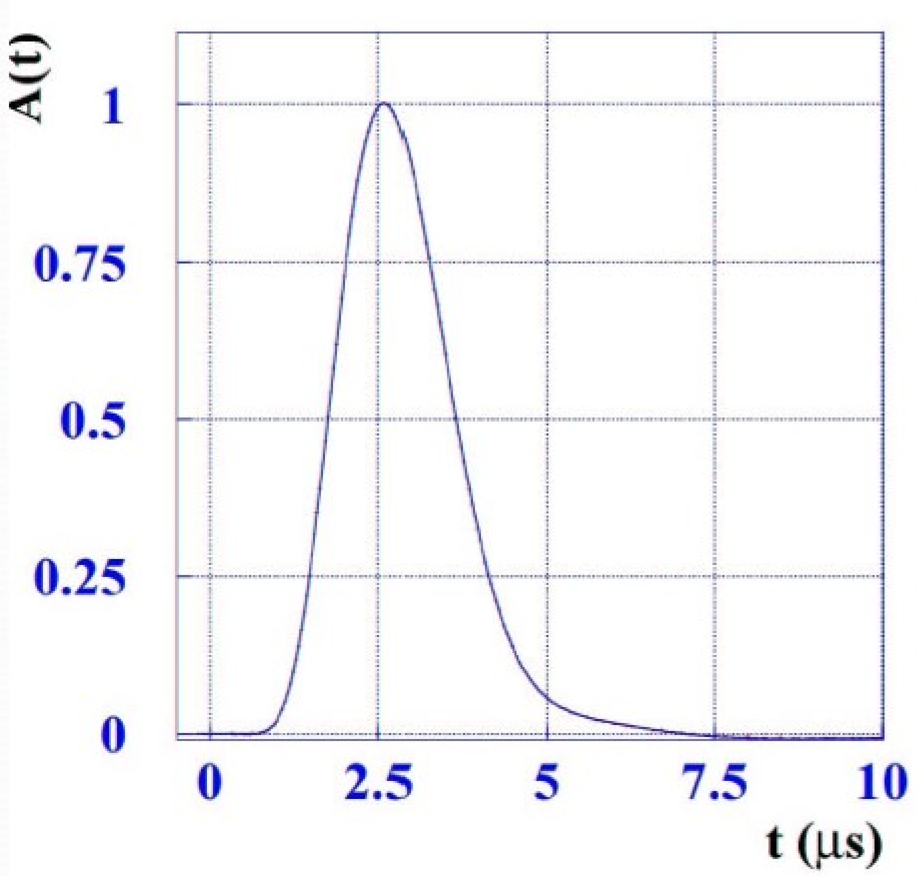
- Shaping of the signal with time 0.5 μs
- Waveform sampling with 2 MHz
- Waveform fitting in FPGA => A,T
- Providing fast sum signal for trigger (FAM)

- 9U VME module
- 16 channels/per module

- **In total we need 432 barrel and 144 endcap modules**
- **Development of the module completed and mass production has been started.**

Noise and shape



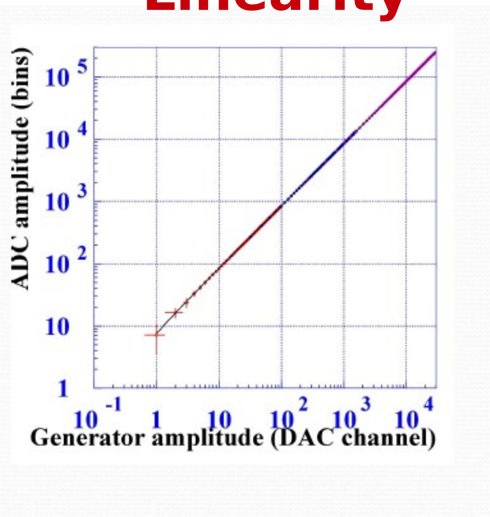


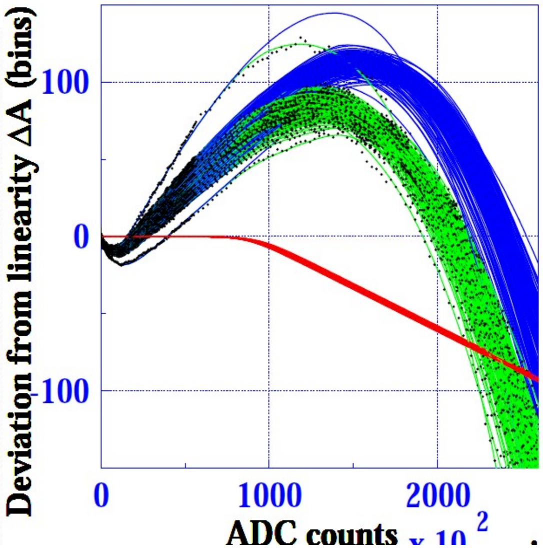
Noise: Incoherent noise - 6.6 bins (~300 keV)

Coherent noise - 0.45 bins (~20 keV)

Linearity and fast shaping for trigger

Linearity



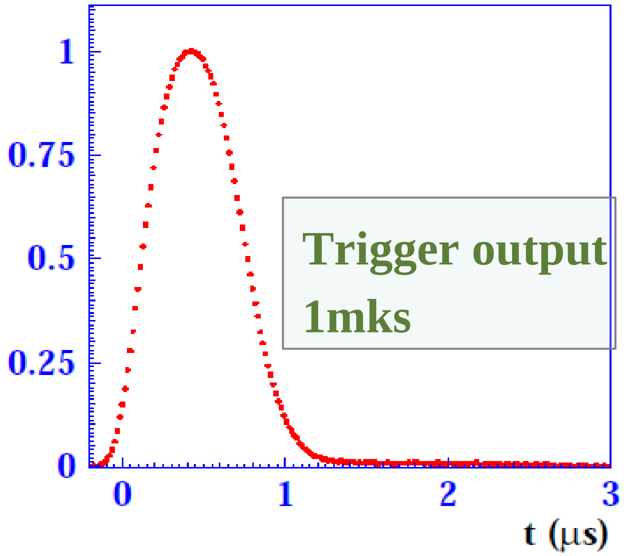


In full range ~260 000 bins

nonlinearity < 2 10^{-3}

Fast trigger output:

- Sum of 16 channels
- Short signal with suppressed tail
- Noise in the trigger output <10MeV



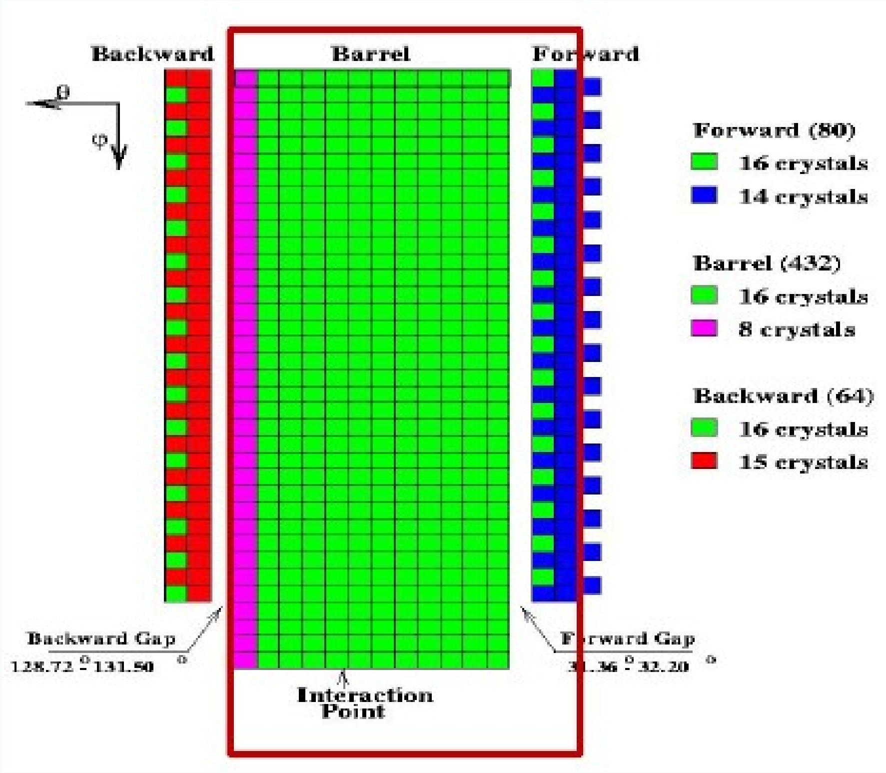
Trigger output

1mks

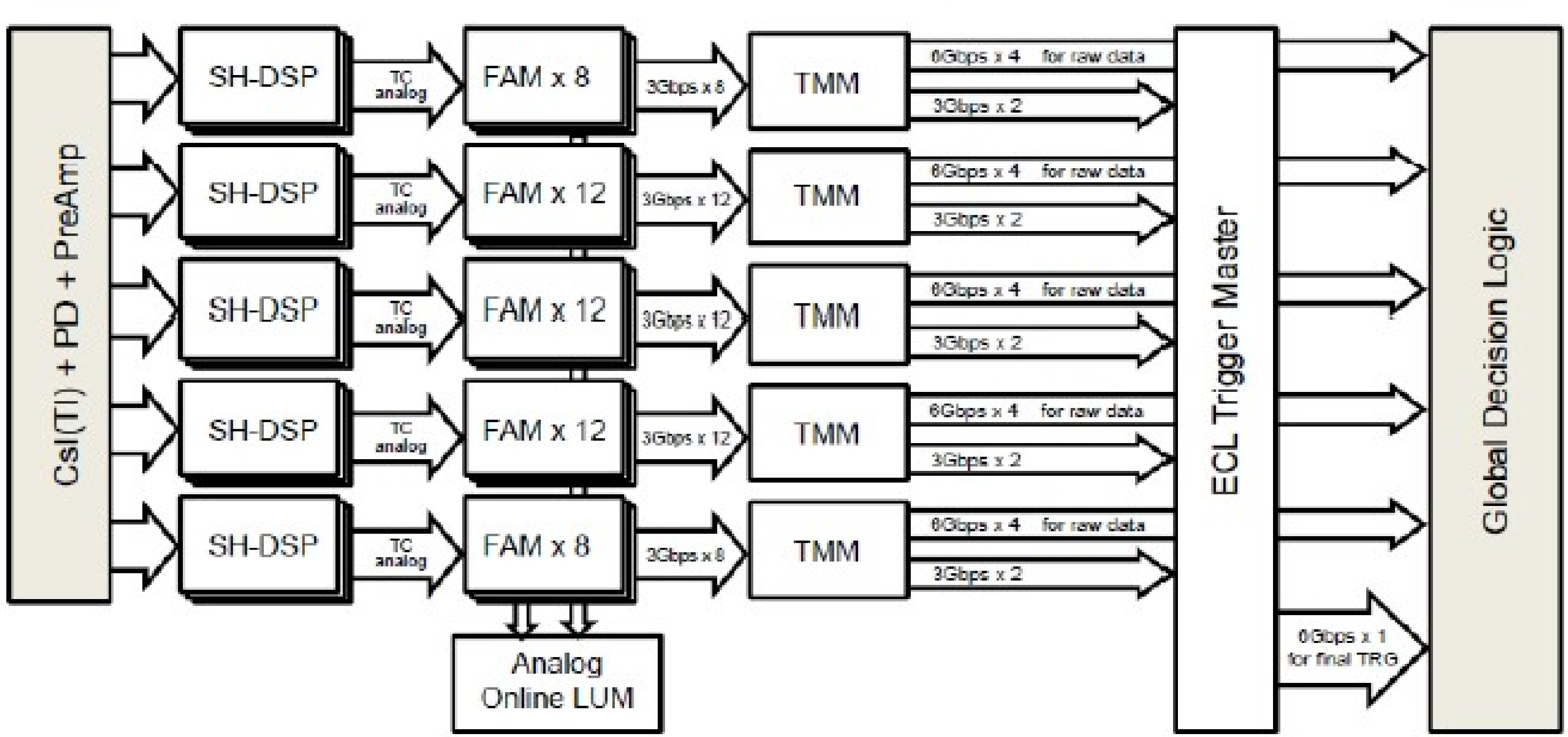
Neutral trigger

- Basic element(576): Trigger Cell (4x4 crystal sum)
- Main physics event triggers
  - Energy trigger : E_{TOT} > 1GeV & $\overline{\text{Bhabha}}$
  - Cluster trigger : ICN > 3
- ECL TRG output to GDL

Item	Number of bits
Trigger timing (Final, Fwd, Barrel, Bwd)	4
Total Energy (>0.5, 1.0, 3.0 GeV)	3
Isolated cluster	4
Bhabha-type	11
OR ed Bhabha	1
Barrel Bhabha	1
Prescale Bhabha	1
Cosmic veto	1
TC hit pattern	576
Total	26+576



Neutral trigger



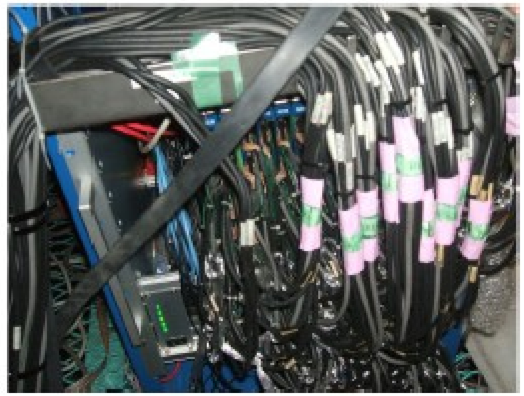
The fast trigger output is digitized in FAM module with 10 MHz. TMM module generates flexible logic by FPGA using FAM outputs in order for neutral trigger as well as luminosity measurement.

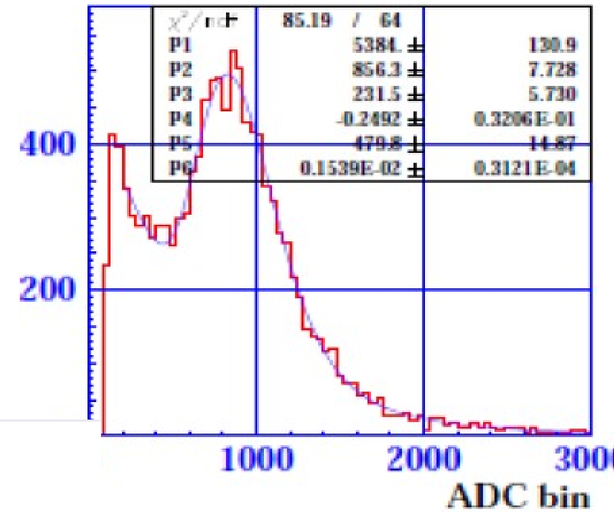
Electronics test with barrel counters

- -VME crate
  - +12 Shaper DSP
  - +collector
  - +FAM
- -Computer

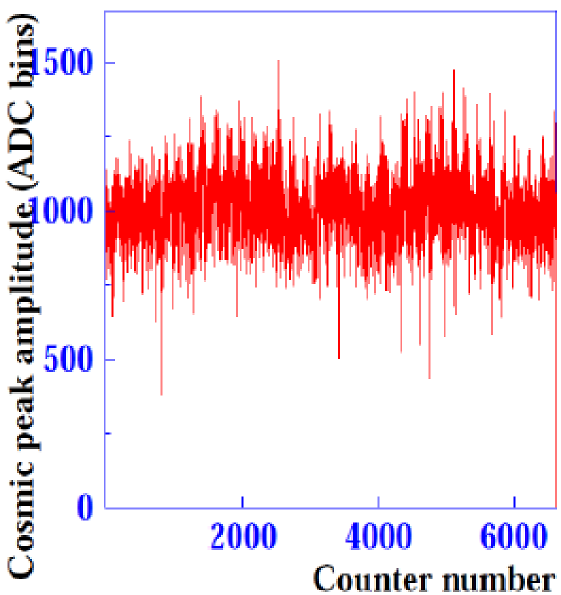
--Test of barrel counters

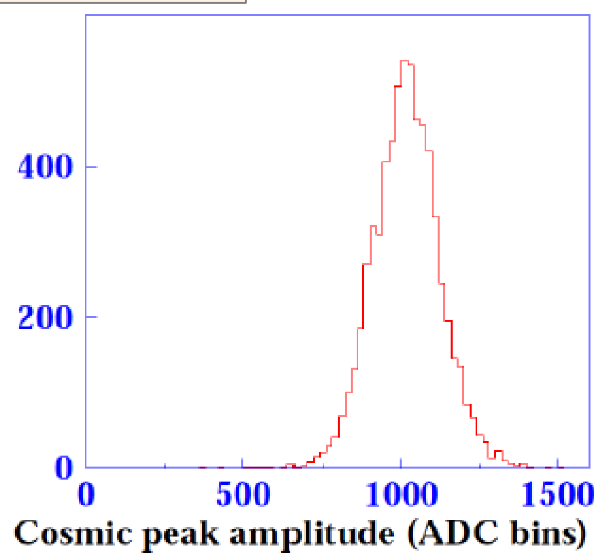
--Test of electronics





-All 6624 counters are workable!





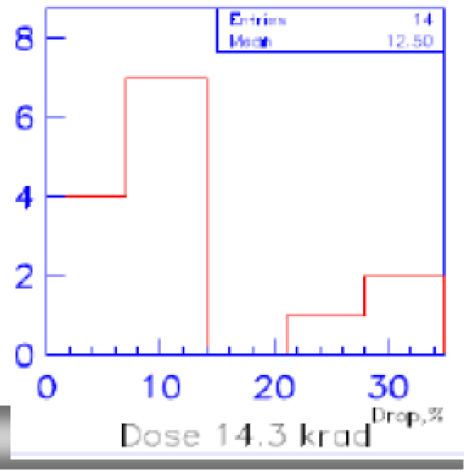
All modules showed no problem during ~4 months measurement

Pure CsI

crystal	ρ, g/cm^3	X_0, cm	λ_{em}, nm	n	N_{ph}/MeV	τ, ns
CsI(Tl)	4.51	1.86	550	1.8	52000	1000
CsI	4.51	1.86	305/400	2	5000	30/1000
BaF_2	4.89	2.03	220/310	1.56	2500/6500	0.6/620
CeF_3	6.16	1.65	310	1.62	600	3
$PbWO_4$	8.28	0.89	430	2.2	25	10
$LuAlO_3$(Ce)	8.34	1.08	365	1.94	20500	18
$Lu_3Al_5O_{12}$(Ce)	7.13	1.37	510	1.8	5600	60
Lu_2SiO_5(Ce)	7.41	1.2	420	1.82	26000	12/40

- **Pure CsI is a good candidate for fast scintillator in endcap**
  It has relatively high lightoutput, short decay component
- **There are several producers who can provide crystal production**

- **Radiation hardness of 14 pure CsI crystals were tested up to 14 krad (expected dose less than 10 krad)**
- **In most of the crystals the drop of the light output is less than 20%**



Photodetectors for pure CsI

CsI(Tl) → pure CsI

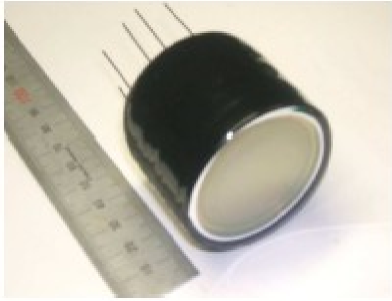
- Lightoutput ten times less
- Decay time 30 ns
- 300 nm – UV-light

Requirements for photodetectors

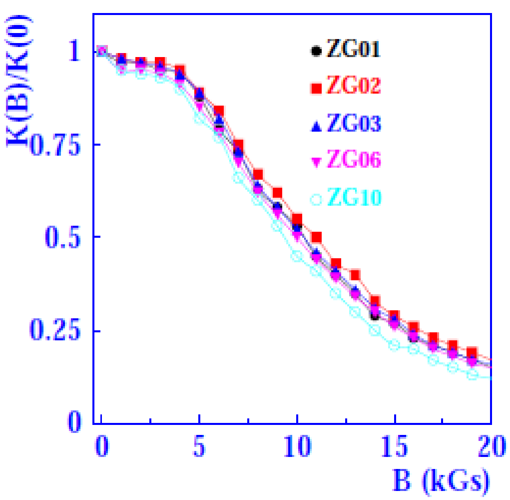
- UV-sensitive
- large sensitive area
- low capacity($\sigma_{noise} \sim \frac{C}{\sqrt{\tau}}$)
- gain factor more than 30 in magnetic field
- good stability, compact, not expensive...

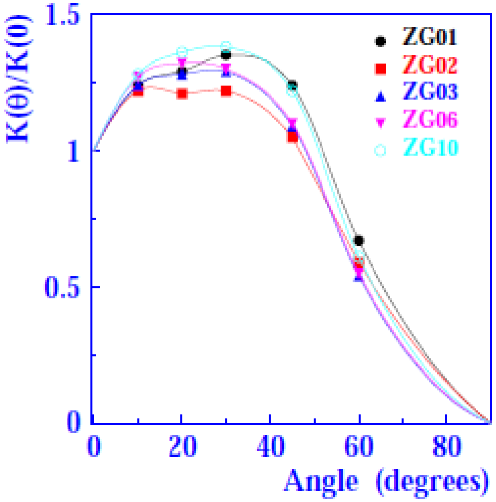
PIN diode - large noise/signal
APD - large noise/signal due to capacity

Hamamatsu developed the 2" UV sensitive phototriodes, phototetrodes, photopentodes $C \approx 10$ pF.
Dependence of gain factor on voltage is close to linear.



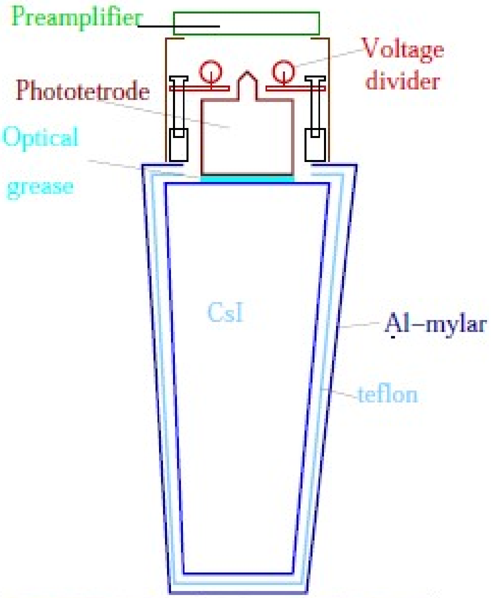
- Gain factor without magnetic field is 150-250
- The gain factor drops down ~3.5 times for B=15 kGs
- About 20-30 % improvement for angle 20-45°

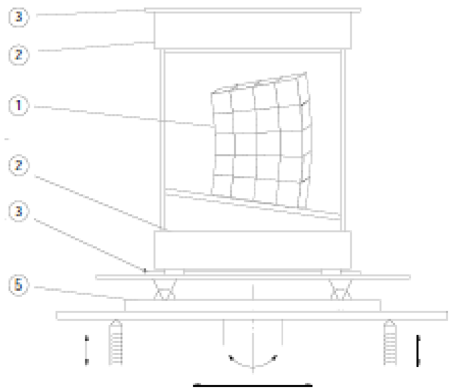




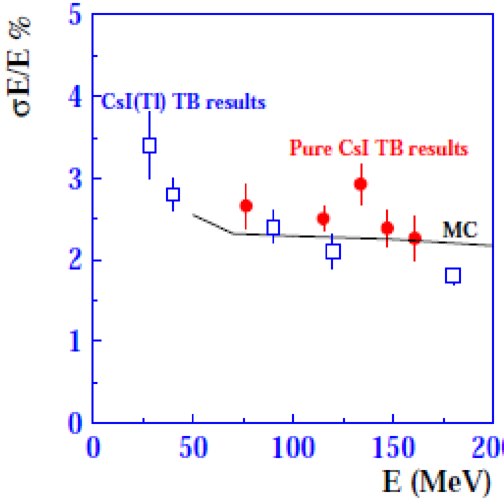
Beam test

20 crystals of 8 geometrical types(part of FWD) produced in Kharkov, coupled with Hamamatsu phototetrodes.



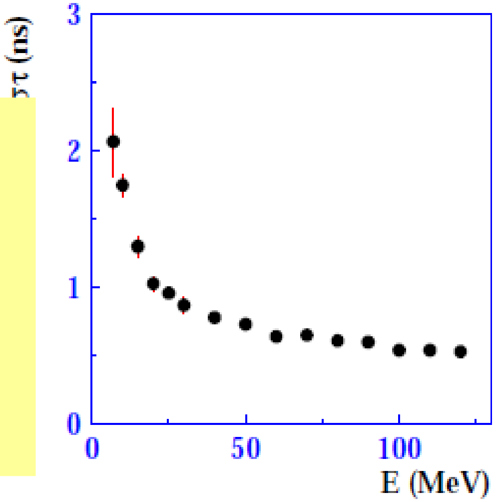


Energy resolution is consistent with MC and previous beam test results.



Time resolution

Wave form analysis allows to determine time with accuracy better than 1 ns for E> 20 MeV(60 MeV in magnetic field).



Summary

-Belle calorimeter worked for more than 10 years and showed good performance

-Modification of the electronics allows to suppress pile-up noise and reject fake clusters keeping the good performance of the calorimeter

-Electronics has been developed and production started

-For endcap region the second stage - replacement of CsI(Tl) to pure CsI crystals with PP readout allows an essential improvement of beam-background immunity to keep performance