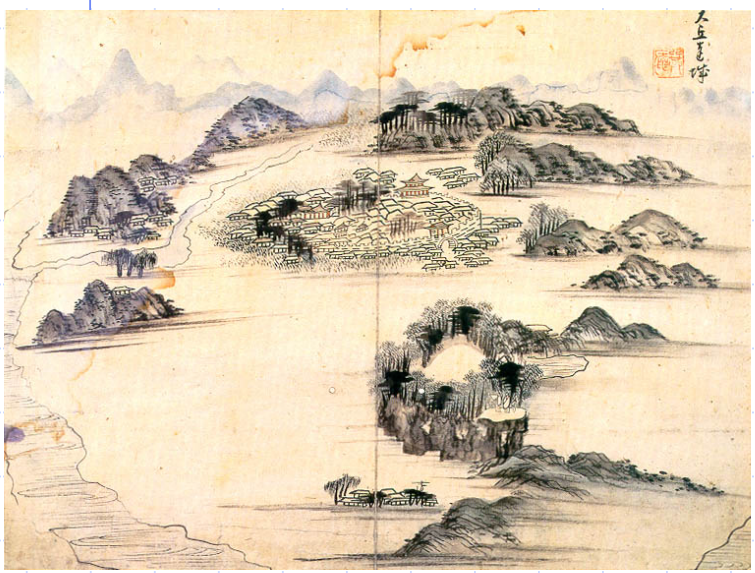
Electromagnetic calorimeter of the Belle II detector



B.Shwartz,

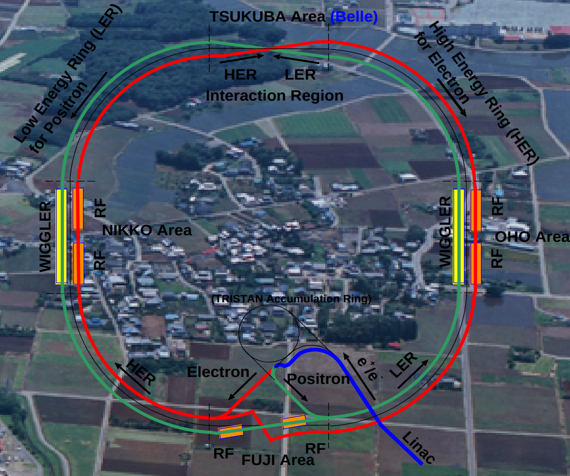
on behalf of BELLE II calorimeter group

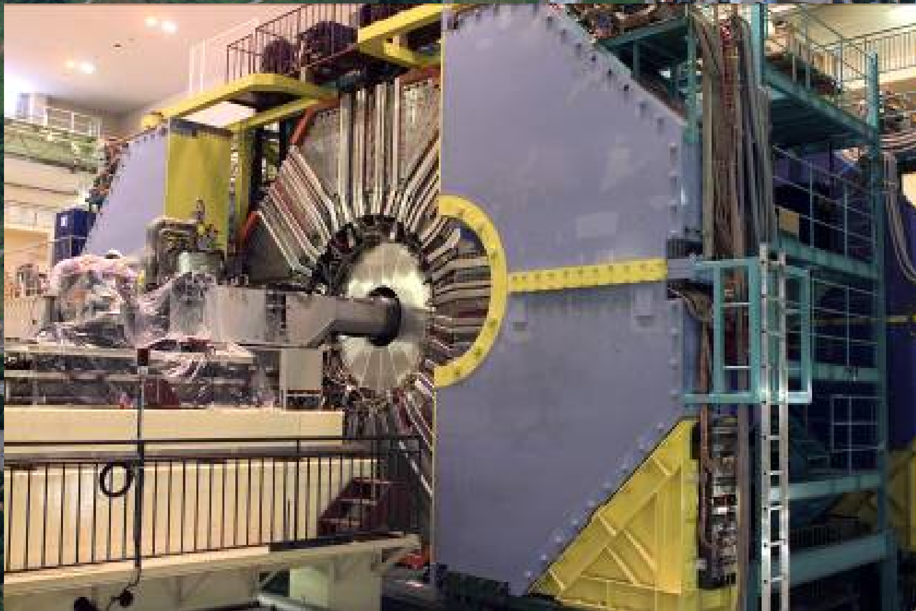
Budker Institute of Nuclear Physics Novosibirsk,

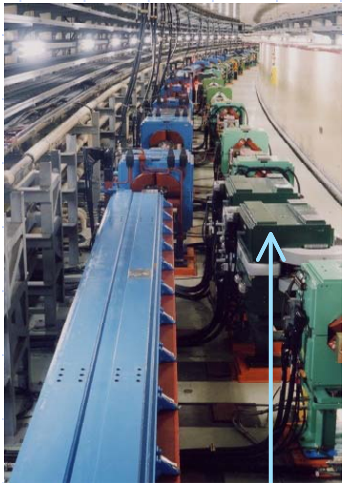
Novosibirsk State University

KEKB and Belle at KEK
From 1999 to 2010

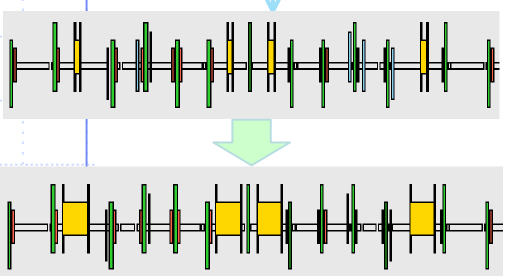
Peak lumi record at KEKB:
L=2.1 x 10^{34}/cm2/sec with crab cavities



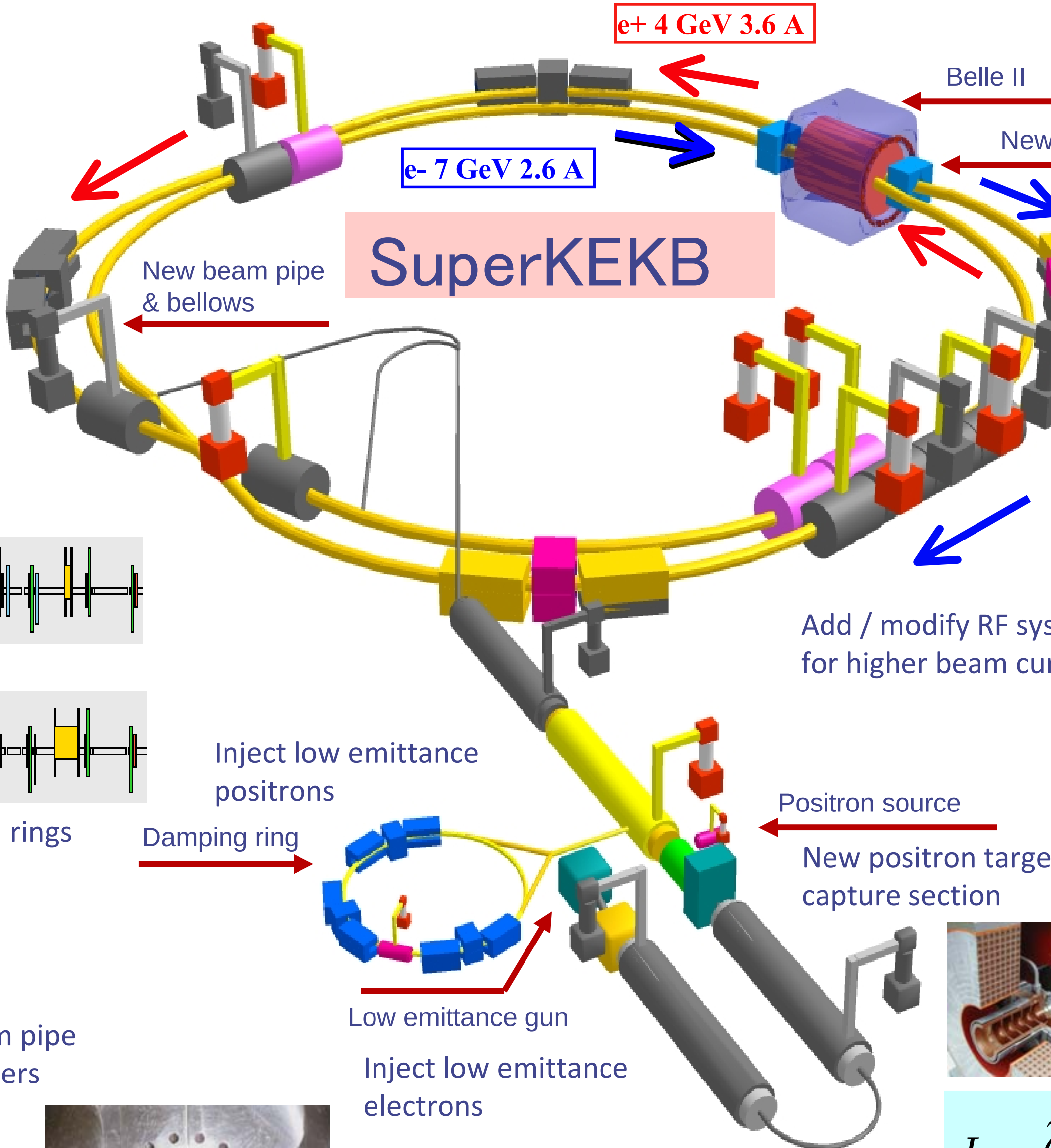


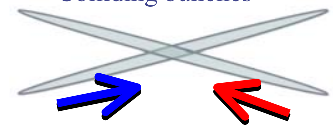


Replace short dipoles with longer ones (LER)



Redesign the lattices of both rings to reduce the emittance

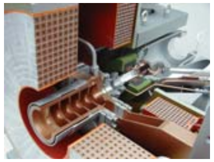




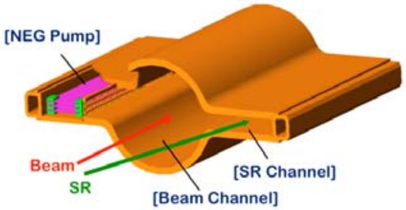
New superconducting /permanent final focusing quads near the IP

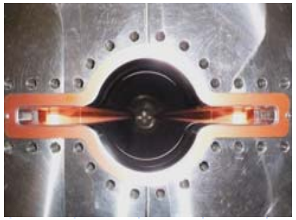
Add / modify RF systems for higher beam current

New positron target / capture section



TiN-coated beam pipe with antechambers





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

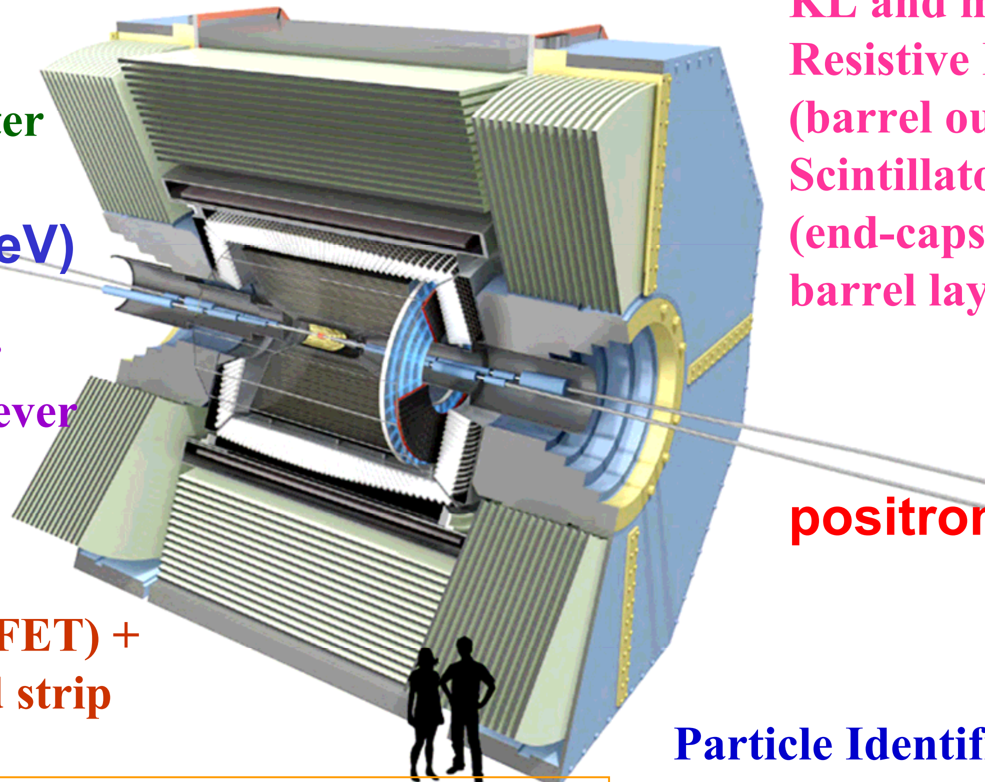
x 40 Increase in Luminosity

Belle II Detector

EM Calorimeter:
CsI(Tl), waveform sampling electronics (barrel)
Pure CsI + waveform sampling (end-caps) later

KL and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps , inner 2 barrel layers)

electrons (7GeV)



positrons (4GeV)

Central Drift Chamber
Smaller cell size, long lever arm

Vertex Detector
2 layers Si Pixels (DEPFET) + 4 layers Si double sided strip DSSD

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (forward)

- \+ New software, improved tracking, ...
- \+ Optimization for low multiplicity trigger
- \+ Improved simulation, generators and GRID

Main tasks of electromagnetic calorimeter

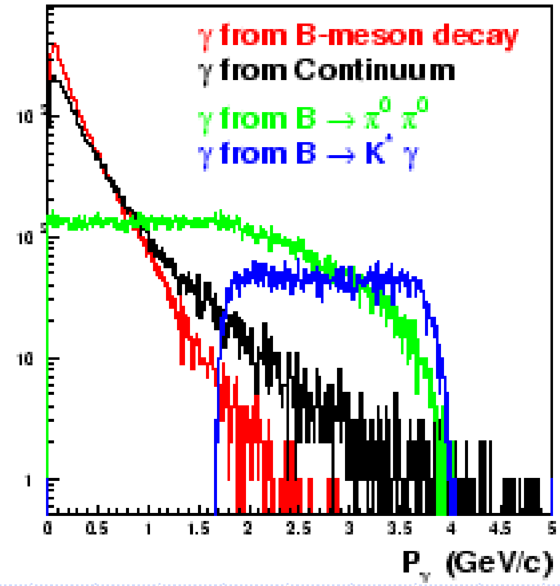
Measurement of

- **Energy/angle of photon (20MeV~8GeV)**
- **Electron identification**
- **K_L detection together with KLM**
- **Redundant trigger**
- **Neutral trigger**

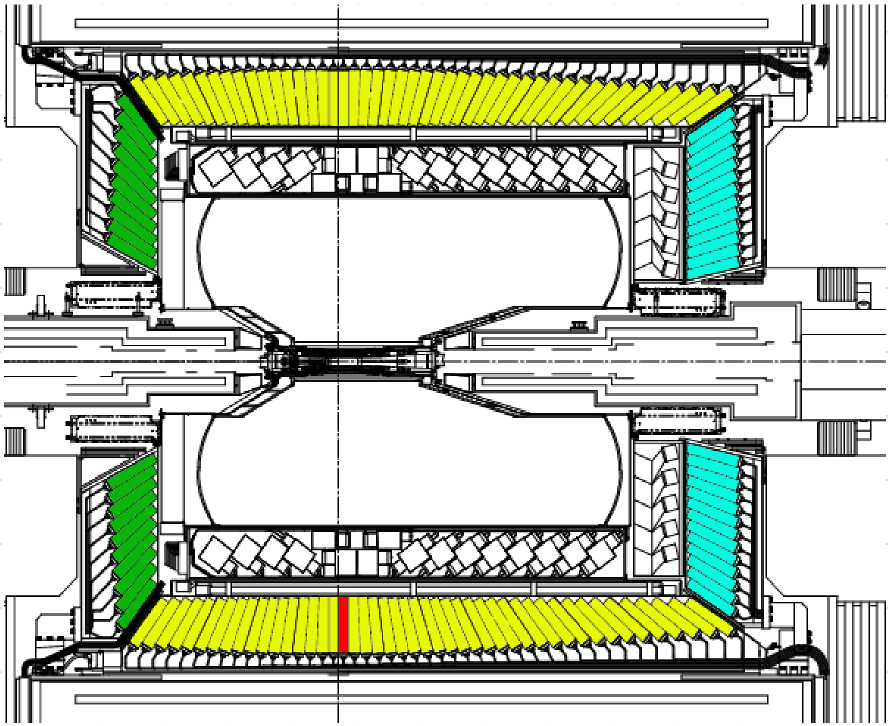
Measurement of the luminosity

- **Online/offline luminosity**

Very important: high resolution for low energy photons are needed



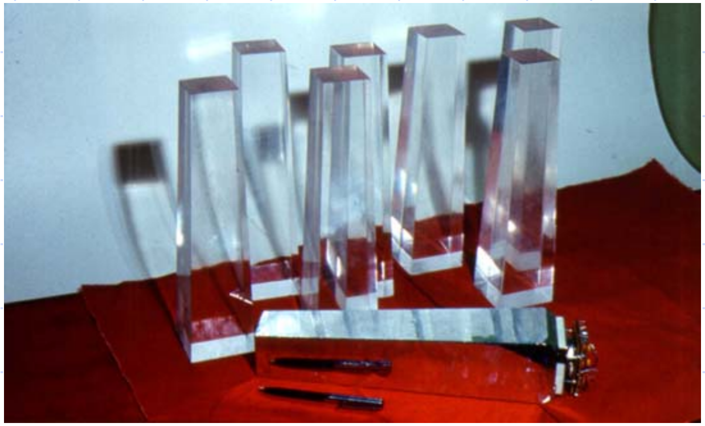
BELLE Electromagnetic Calorimeter for KEKB energy asymmetric B-factory



3 m

CsI(Tl) crystals

L_{cr} = 30 cm = 16.2X_0

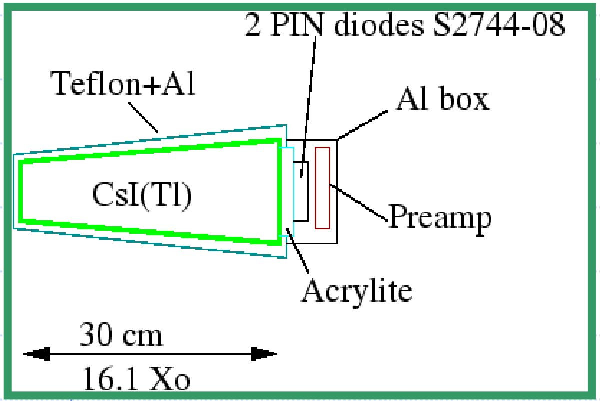


Number of crystal: 8736
Total weight is ~43ton

2/3 of these crystals were provided by the Kharkov&BINP,

Others – Crismatec and Shanghai

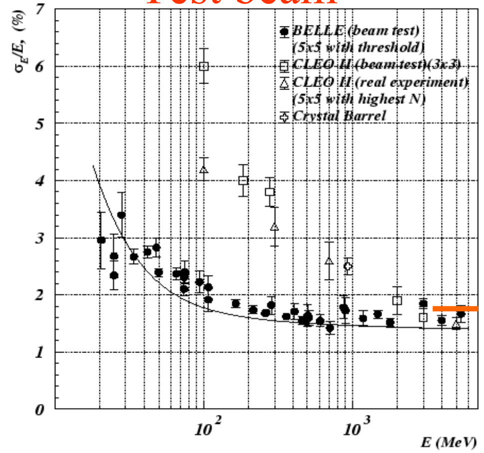
Belle ECL

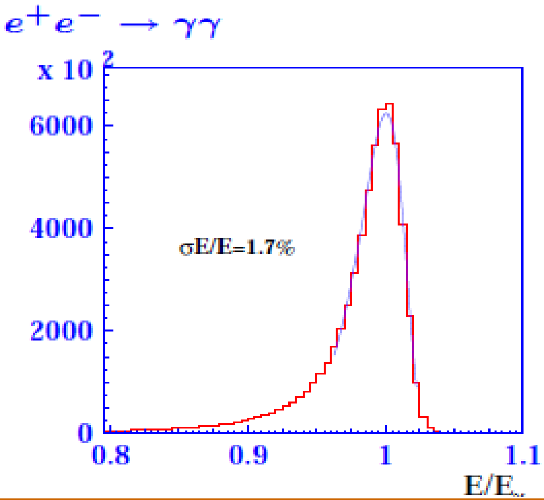


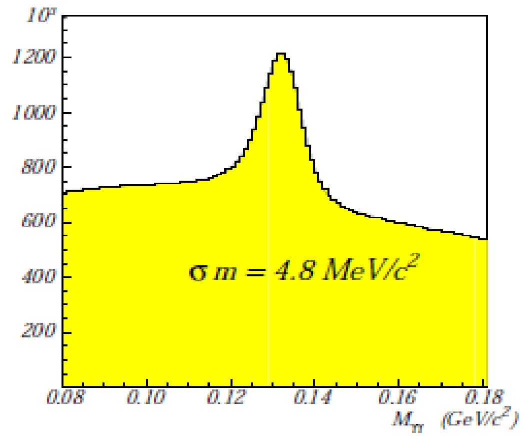
Light output - 5000 ph.el./MeV
electronics noise σ~200 keV

- **Calorimeter successfully worked for more than 10 years since 1999 to 2010**
- **All 8736 channels are operable**
- **It demonstrated high resolution and good performance**

Test beam

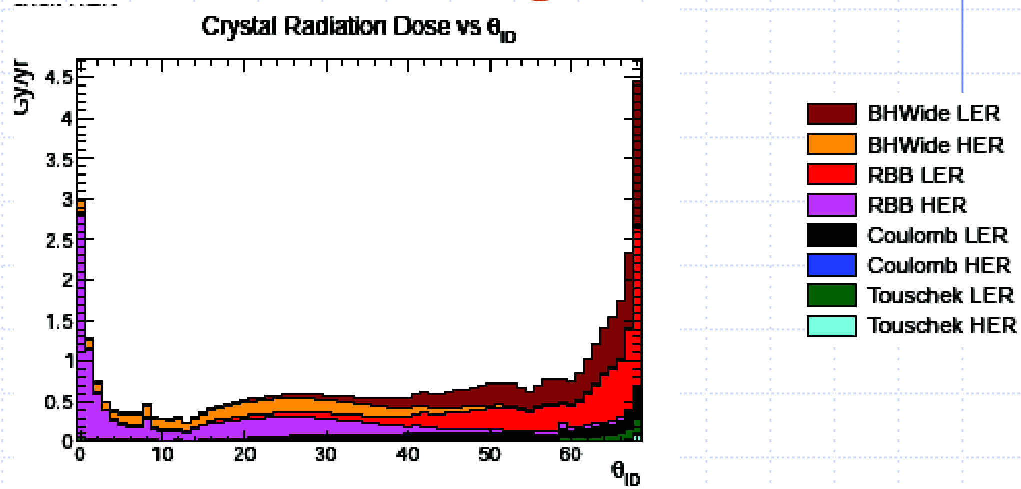




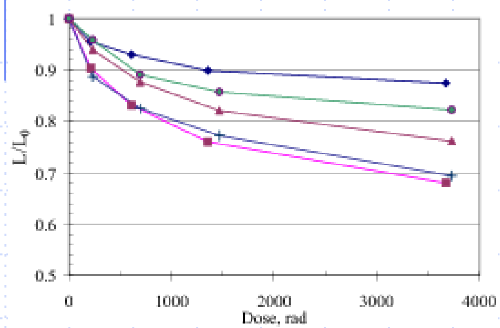


Calorimeter performance in a view of the luminosity increase –radiation background.

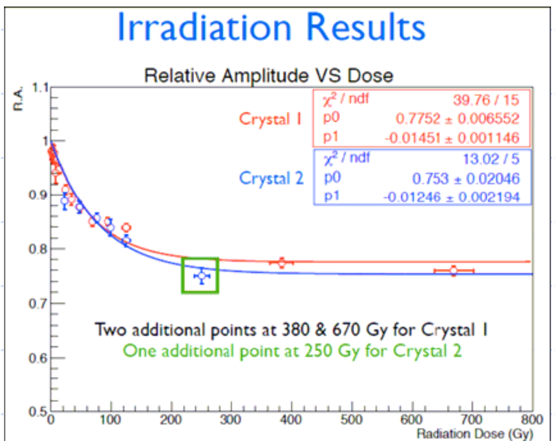
Radiation damage of the crystals: at 1000 fb^{-1} at Belle the absorbed dose reached of about 500 rad in the most irradiated crystals.



In the most loaded part the light output degradation is about 10%



D. Beylin *et al.*, Nucl. Instrum. Meth. A 541, 501 (2005),



study made in collaboration by INFN-Frascati and the ENEA Casaccia Calliope Irradiation Facility *(using two Belle spare endcap crystals)*

Basically – no problem.

Increase of the PD dark current due to neutron background. By the end of the Belle experiments the PD dark current increased up to 200 nA for the most loaded area.

However, according to the simulstion

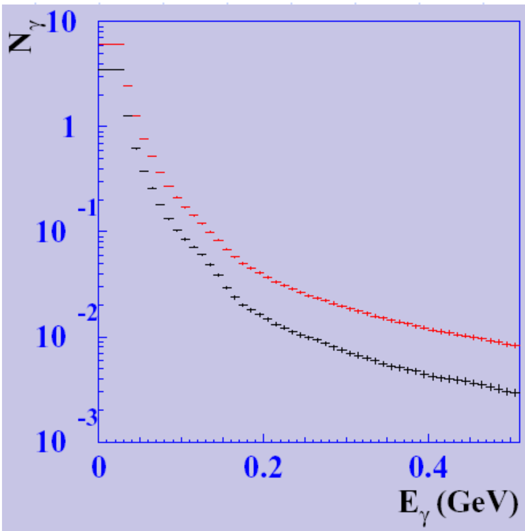
		12th Campaign	11th Campaign	Tolerance
Crystal Radiation Dose (Gy/yr)	Forward	3.0	3.0	
	Barrel	0.8	0.5	10
	Backward	4.5	3.1	
Crystal Neutron Flux ($x10^9 yr^{-1} cm^{-2}$)	Forward	23	24	
	Barrel	5	4	1000
	Backward	14	12.5	
Diode Radiation Dose (Gy/yr)	Forward	0.4	0.7	
	Barrel	<0.2	<0.2	70
	Backward	0.8	0.64	
Diode Neutron Flux ($x10^9 yr^{-1} cm^{-2}$)	Forward	23	24	
	Barrel	5	4	100
	Backward	15	12.5	
Pileup Noise (MeV)	Forward	4.3	3.8	
	Barrel	3.1	2	0.8 for Belle
	Backward	8.2	5.4	
Reconstructed Cluster		3.44	2.57	6 for Belle

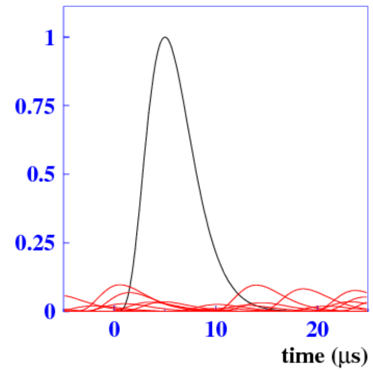
The dark current induced by the expected neutron flux will be still below 1 μA and corresponding noise contribution should be below 1 MeV, still not the most annoying problem.

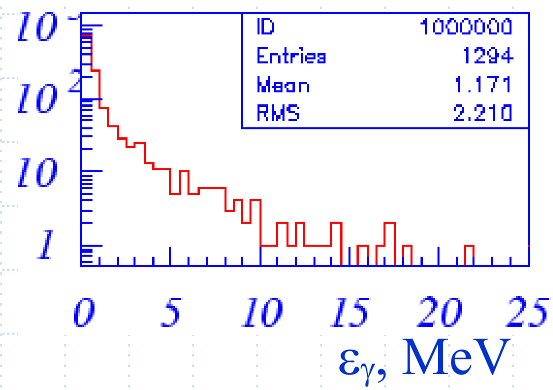
Pile-up noise

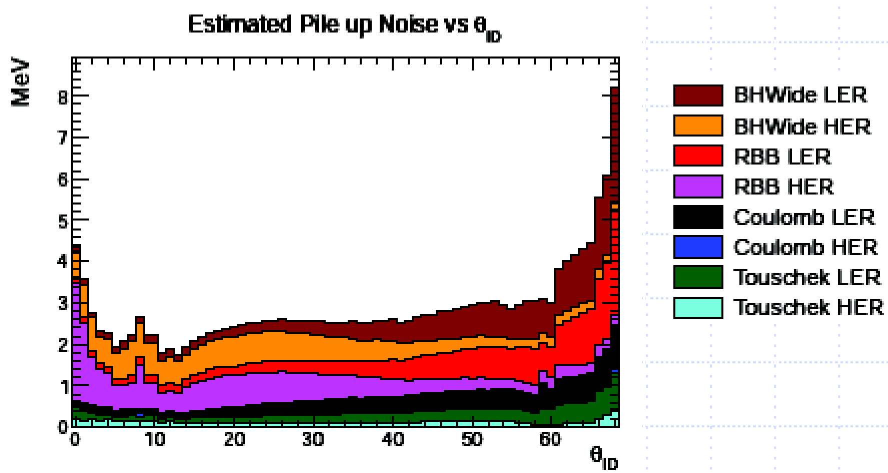
$$\sigma_{pile-up} = \overline{E_\gamma}\sqrt{\overline{f_{bkg}\cdot\tau_{eff}}} \propto \sqrt{\overline{I\cdot P}}$$

Fake clusters



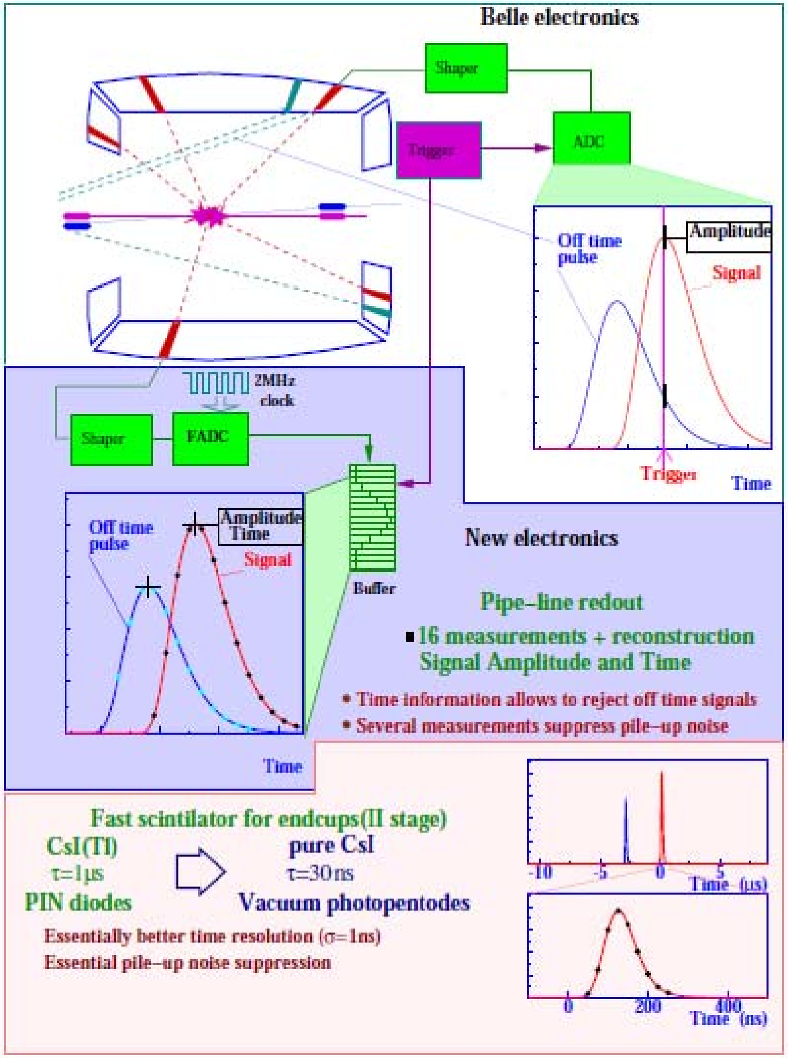






(E>20 MeV) 6 fake clusters, 3 in barrel 3 in endcaps background

New calorimeter electronics



Main upgrade is a replacement of the electronics by the new one with pipe-line readout

- Pipe-line readout with waveform analysis:
- 16 points within the signal are fitted by the signal function $F(t)$:

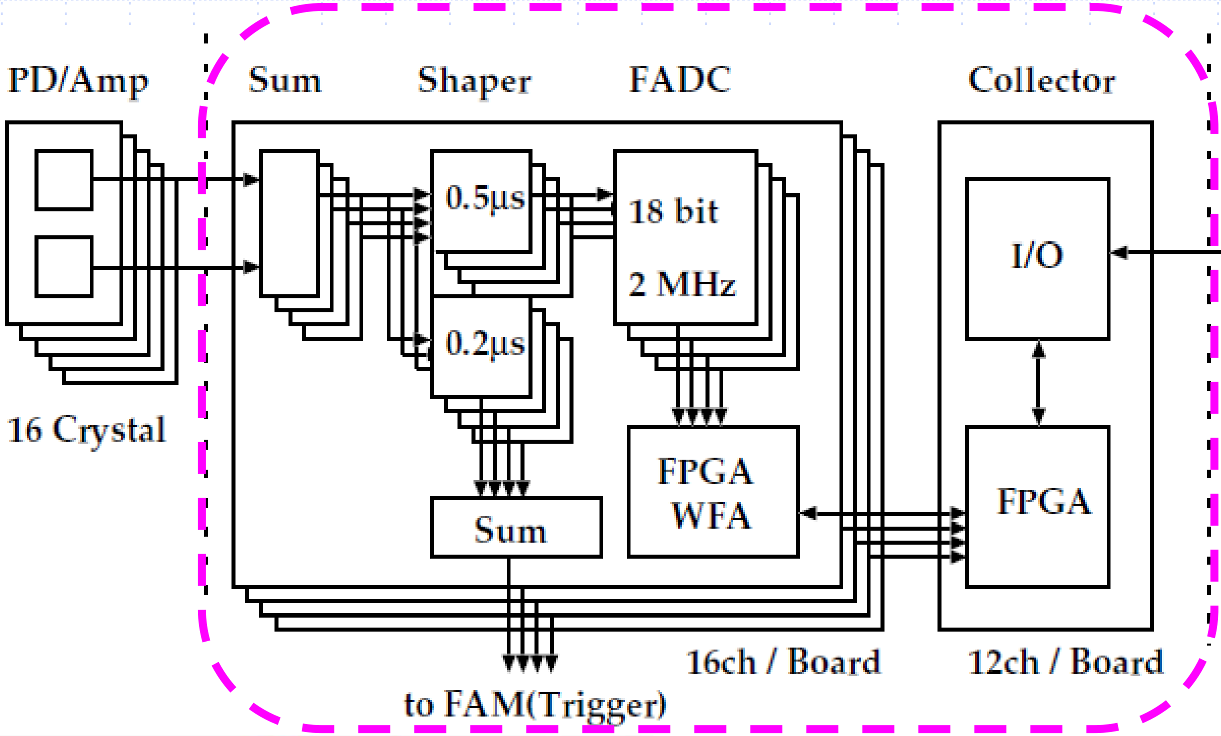
$$F(t) = A\ f(t - t_0)$$

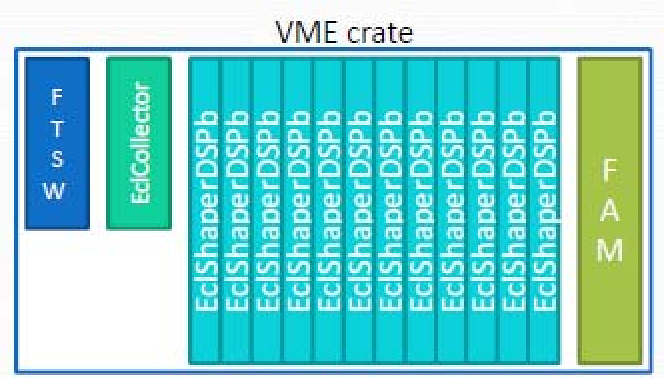
A - amplitude of the signal and
t_0 – time of the signal,

$$\chi^2 = \sum (y_i - A\ f(t_i - t_0)) S_{ij}^{-1} (y_i - A\ f(t_i - t_0))$$

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

Shaper DSP module



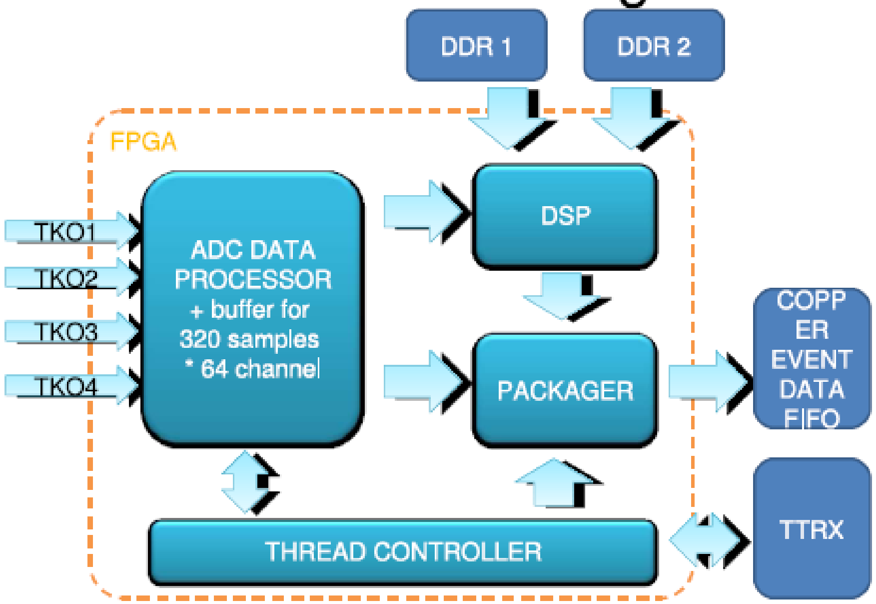


- 52 ECL VME crates
- 12 ShaperDSP boards per crate
- 36 – barrel, 16 – endcap

Shaper DSP algorithm (in FPGA)

- **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

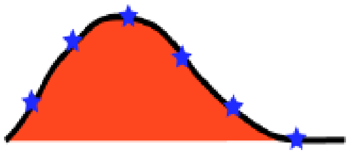


Algorithm details

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

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

$f(t)$ – counter response



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

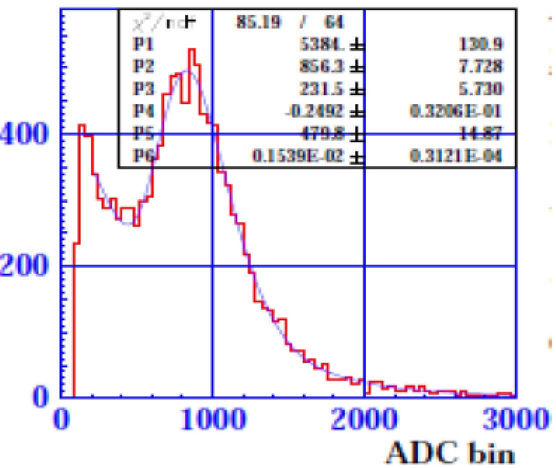
where t_1 – initial time (trigger time)

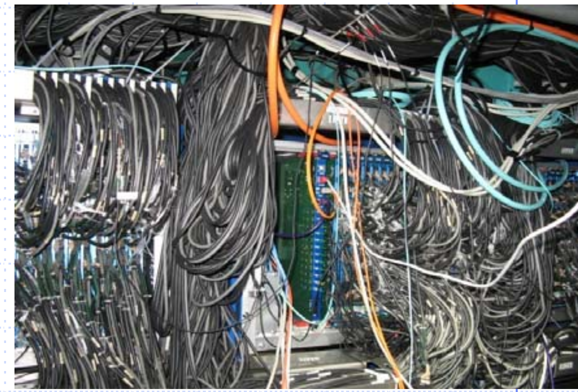
$$\begin{cases} \sum_{i,j} f_i S_{ij}^{-1} (y_j - Af_j - Bf'_j - p) = 0 \\ \sum_{i,j} f'_i S_{ij}^{-1} (y_j - Af_j - Bf'_j - p) = 0 \\ \sum_{i,j} S_{ij}^{-1} (y_j - Af_j - Bf'_j - p) = 0 \end{cases} \Rightarrow \begin{array}{l} A = \sum_i \alpha_i y_i \\ B = \sum_i \beta_i y_i \Rightarrow \Delta t =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

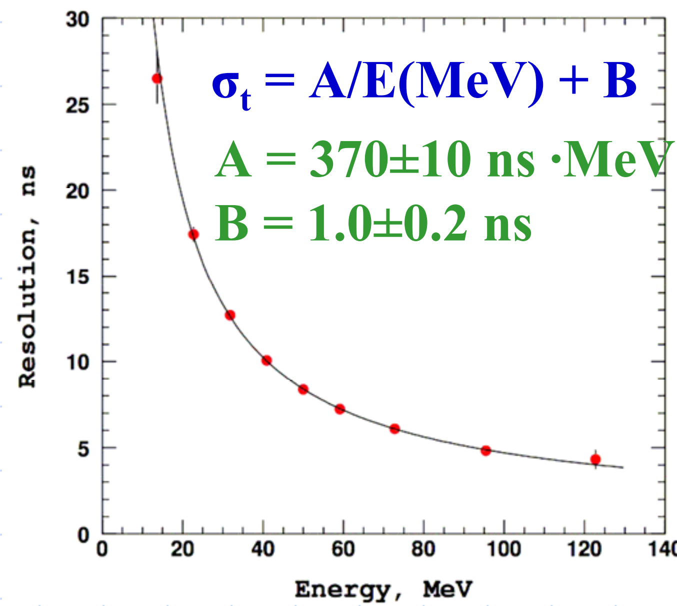
- **For some fraction of data both input and output informations are sent to DAQ for test**

Calorimeter present status

-All barrel counters are connected to DAQ and tested with cosmic rays







Neutral trigger is very important system – next talk by Sung-Hyun Kim

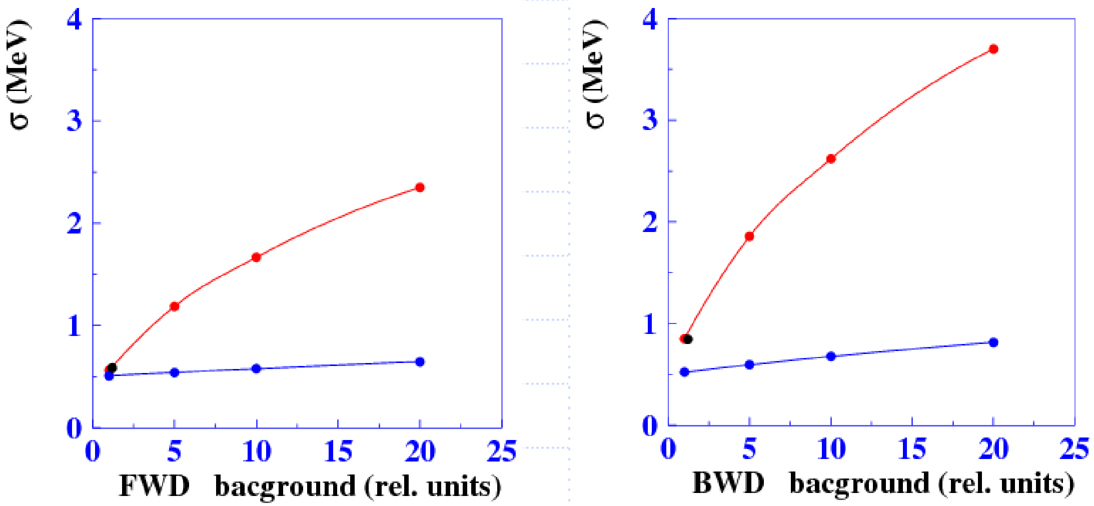
All 6624 channels are operable!

Still performance of the end caps is questionable

Properties of pure CsI and CsI(Tl) scintillation crystals

	ρ, g/cm^3	X_0, cm	λ_{em}, nm	N(λ_{em}, nm)	N_{ph}/MeV	T, ns	dL/dT, %/° @20°C
Pure CsI	4.51	1.85	305	2	2000-5000	20/1000	- 1.3
CsI(Tl)	4.51	1.85	550	1.8	52000	1000	0.4

Expected improvement with pCsI

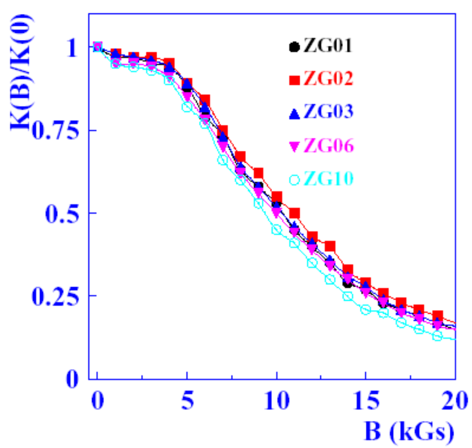


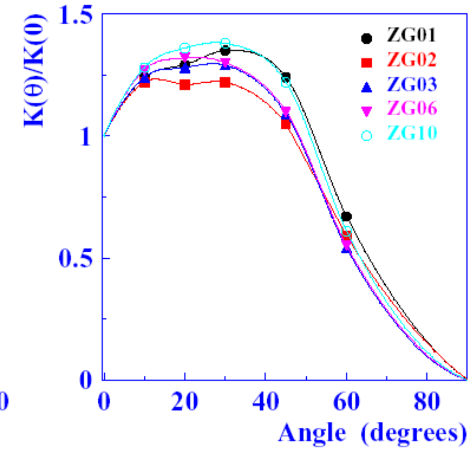
Time information allows to suppress the fake clusters for endcaps by a factor of 7x30=200 by rejecting wrong time clusters due to shorter decay time of the pure CsI

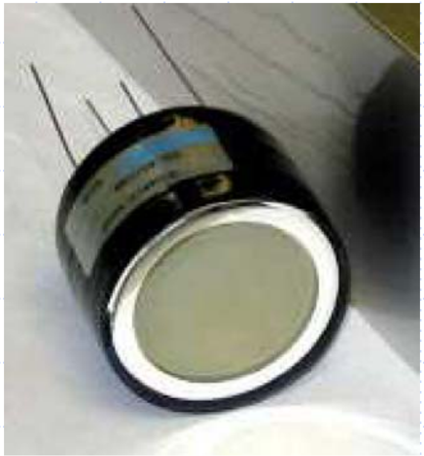
Photodetector

Baseline option:

2" UV sensitive photopentods (PP), Hamamatsu Photonics
Q ~ 20%, C ≈ 10 pF.
PP gain factor 120-240.
(we need > 30 in mag.eld)





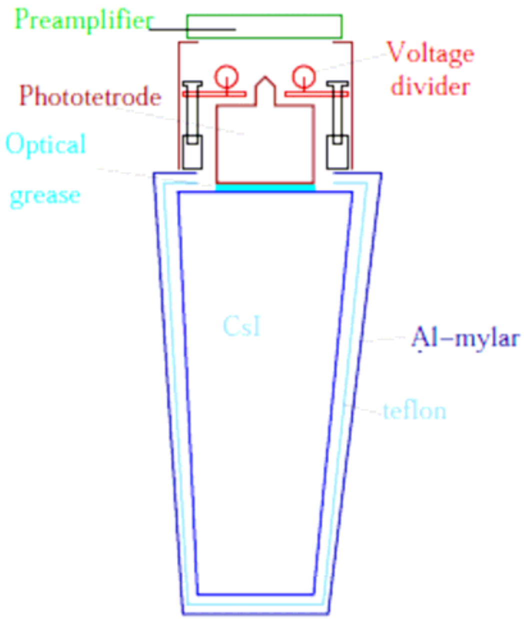


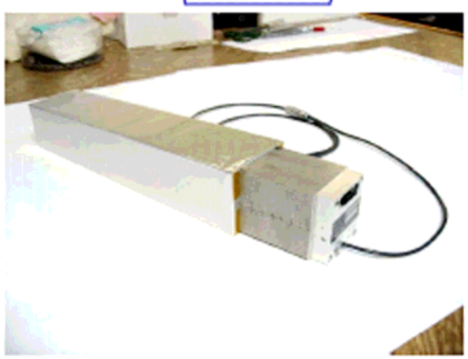
The gain factor drops down 3.5 times for B=15 kGs

About 20-30 % improvement for angle 20-45°

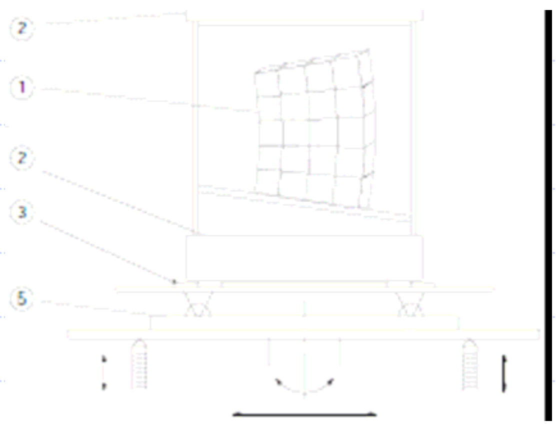
Beam test at BINP back scattered Compton beam

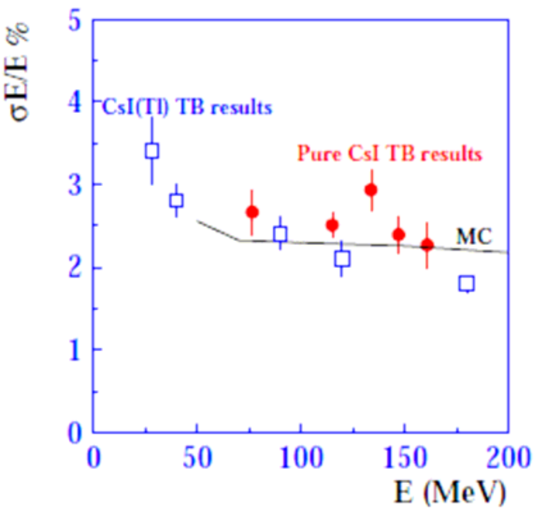
20 crystals of 8 geometrical types(part of FWD) produced in Kharkov, coupled with Hamamatsu phototetrodes.





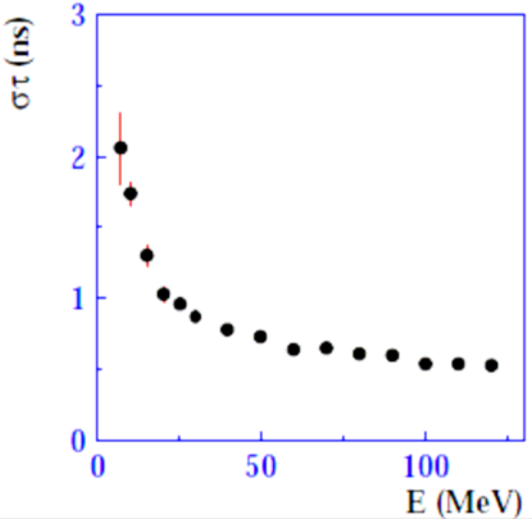
Energy resolution is consistent with MC and previous beam test results.



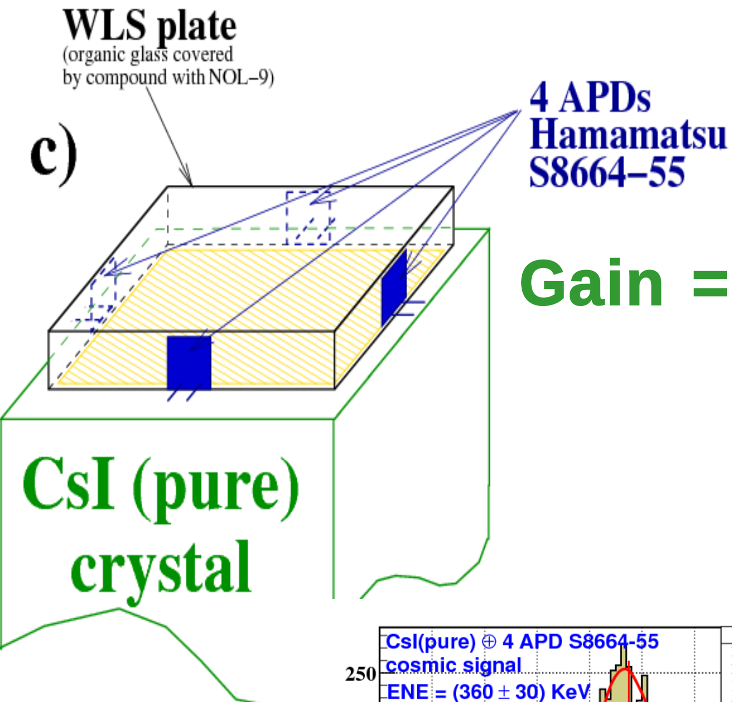


Time resolution

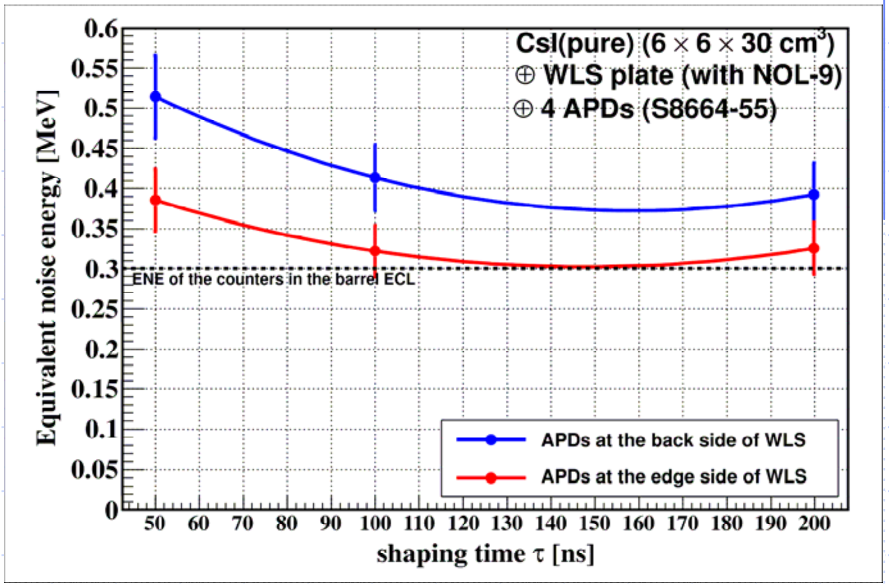
Wave form analysis allows to determine time with accuracy better then 1 ns for $E >$ 20 MeV(60 MeV in magnetic field).

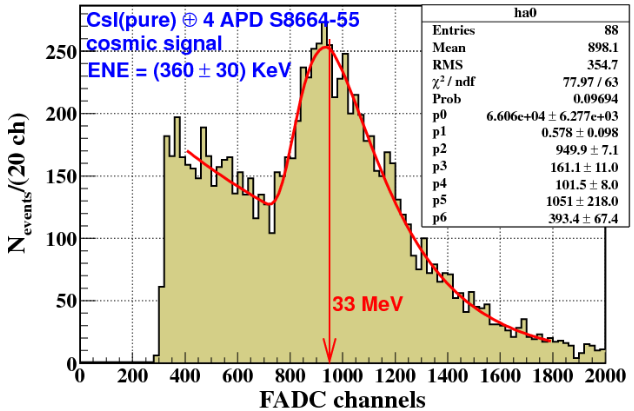


PCsI with APDs option



Gain =50



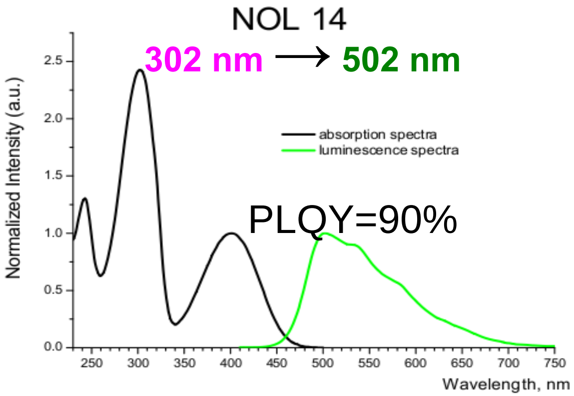


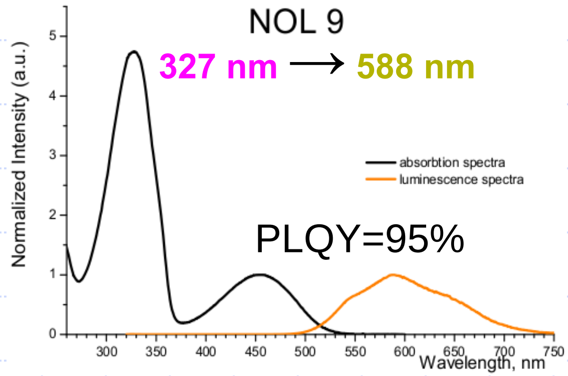
Measured with cosmic rays

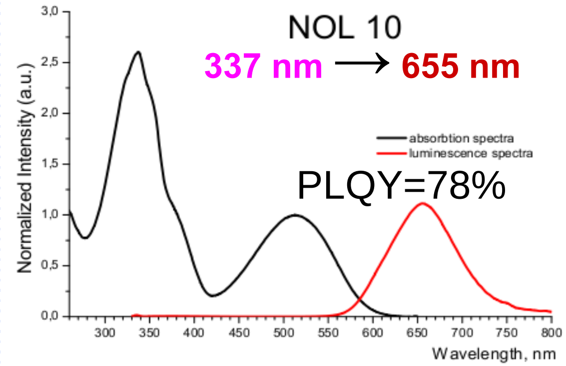
D.Epifanov et al (Univ. of Tokyo and BINP)

Wavelength shifters with organosilicon luminophores

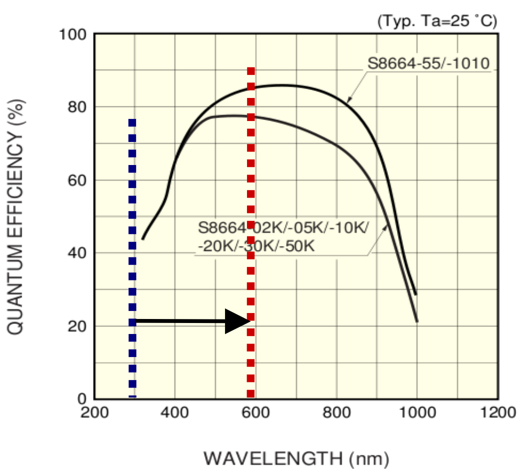
Based on the nanostructured organosilicon luminophores (NOL-9,10,14) from LumInnoTech Co., the WLS plates were developed ((60 x 60 x 2) mm³).

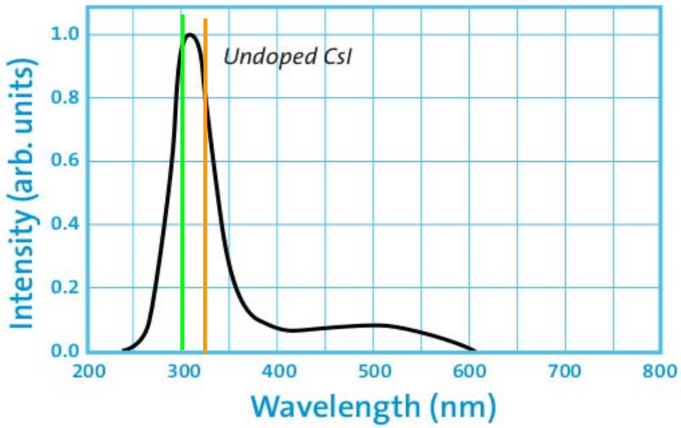


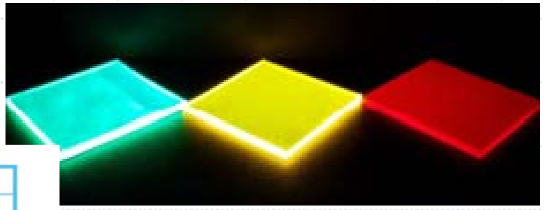




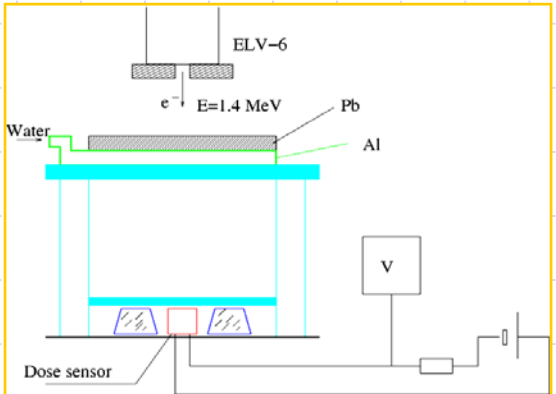
■ Quantum efficiency vs. wavelength



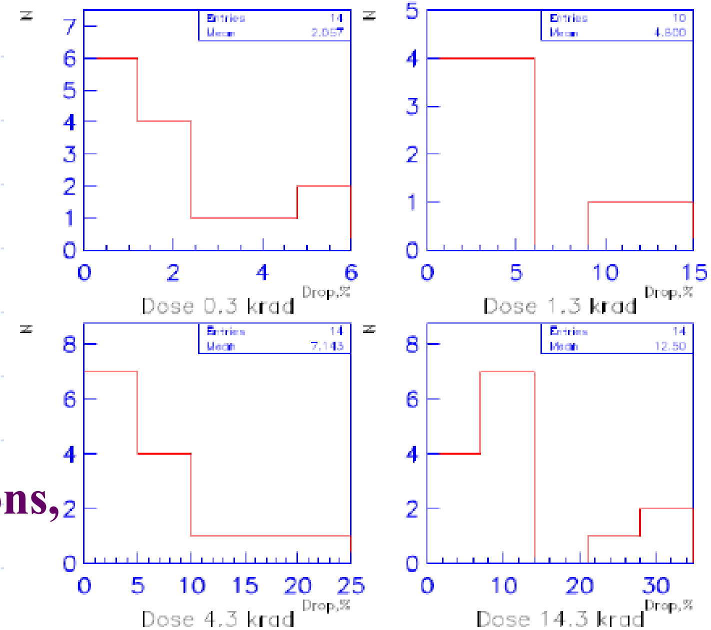




pCsI radiation hardness



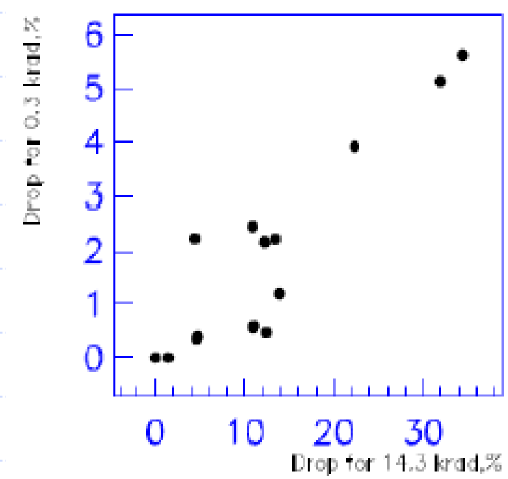
14 full size crystals, produced in Kharkov



Bremsstrahlung photons, $E = 0 \div 1.4$ MeV from ELV-6, BINP

Most of the crystals lost less than 20% of the light output at 14 krad. 3 samples from 14 lost 20-35%.

Clear correlation between deterioration at low and high absorbed dose



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Summary

- **Belle calorimeter worked for more than 10 years and showed good performance**
- **All barrel counters are connected to DAQ All 6624 channels are operable!**
- **Option with pure CsI+PP is well developed and can solve the background problems in end cap parts**
- **Alternative options with silicon APD are under study**
- **Pure CsI crystals produced in Kharkov show good radiation resistance**