Intro

While doing the analysis of the test beam data we often have had doubts and questions about the real performance needed for the EMC (forward and barrel), the trigger system and DAQ will need;

In order to get a better comprehension of the EMC situation:

- we collected info about other detectors;
- Riccardo run on the output of the SuperB full-simulation (rad-Bhabha);

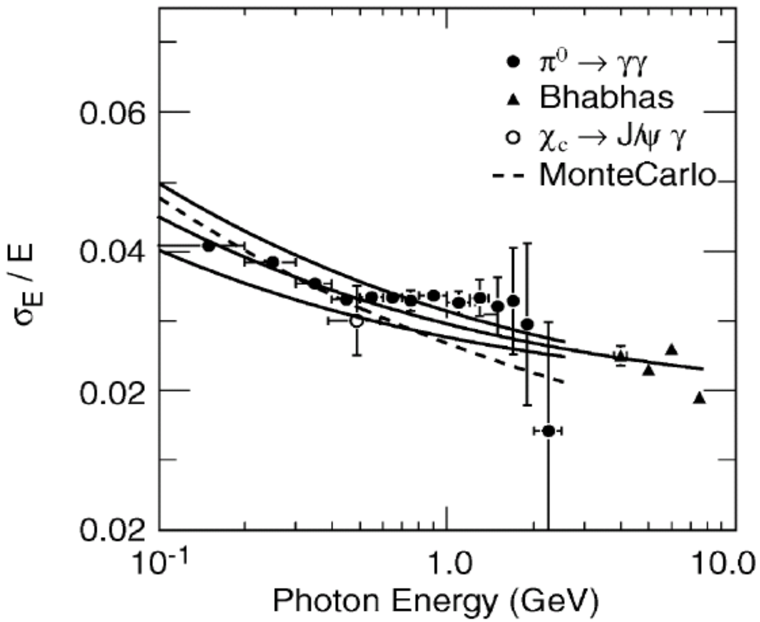
In this presentation we would like to summarize our present understandings about:

- Energy resolution;
- Rad-hardness;
- Background effects and "rate capability";

To share with you our questions in order to fix as many points as possible.

Energy resolution

Babar energy resolution was 4-5% below 100 MeV and 2-3% in the GeV range



$$\frac{\sigma_E}{E} = \frac{(2.32 \pm 0.30)\%}{\sqrt[4]{E(\mathrm{GeV})}} \oplus (1.85 \pm 0.12)\%$$

Are these values reasonables for SuperB?

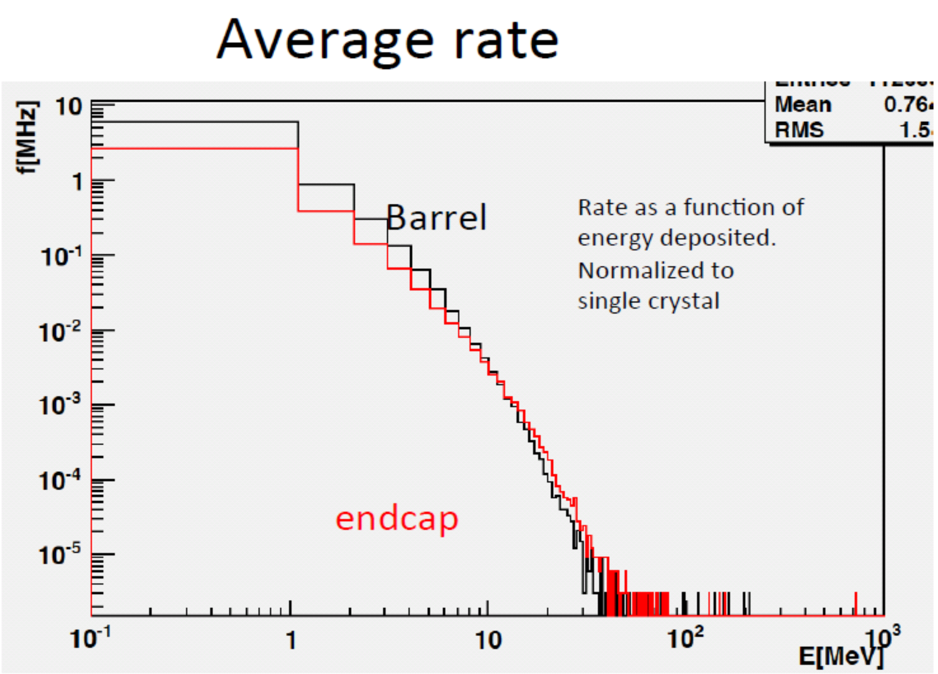
Lyso, for example, has already shown to be able to provide about 3% resolution in the GeV range.

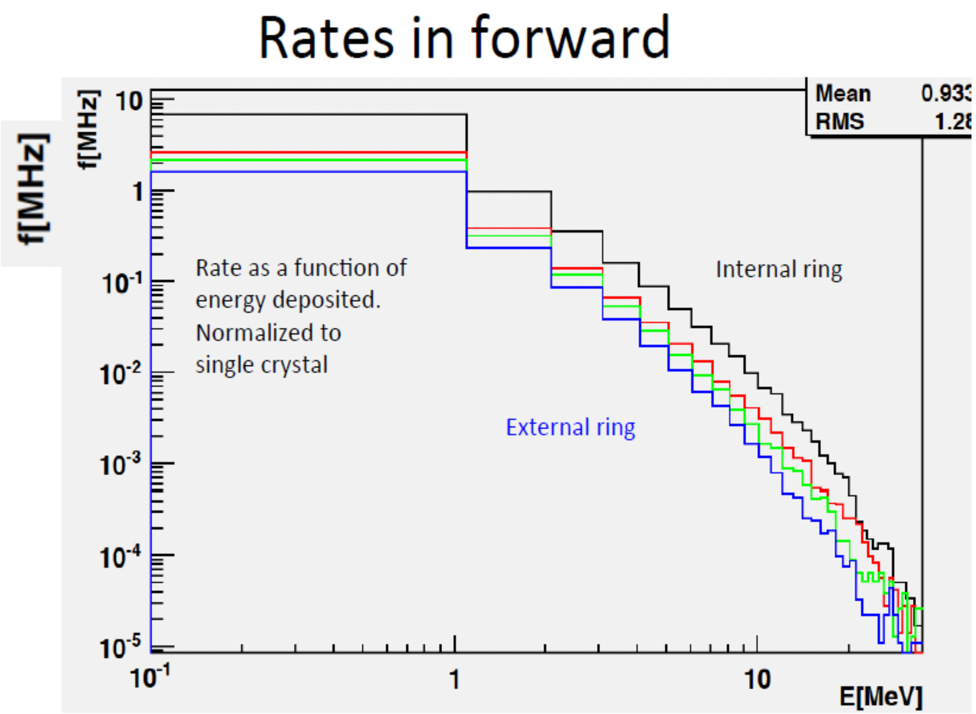
Can we set an upper limit of a 5% value resolution at 100 MeV?

Is it possible to have so good results in the MeV range with the larger background foreseen in SuperB?

Background rate (I)

We evaluated the rate expected in the EMC by using the simulation of radiative Bhabha events





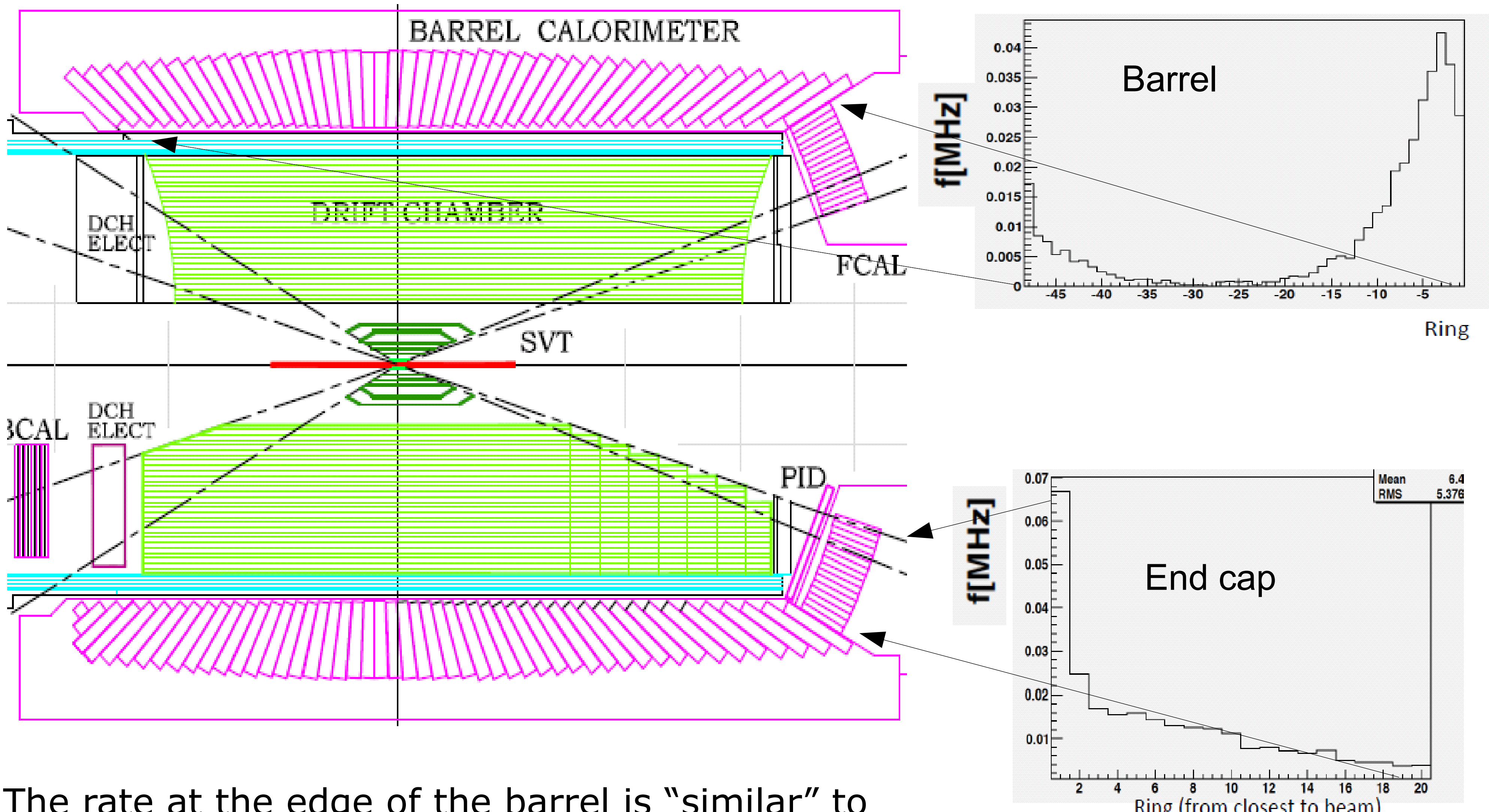
In average we expect:

- up to few MHz per crystal with energy in the MeV range;
- Few Hz per crystal with energy in the 10-100 MeV range;

What about other possible sources of background (e.g. synchrotron radiation...)?

Background rate (II)

Total rate of particle per crystal with energy higher than 10 MeV



The rate at the edge of the barrel is "similar" to the rate at the center of the end-cap

Background (III)

In order to check the "pedestal" stability, the total charge collected in 5x5 crystal matrices was evaluated for several "gates";

The exponential decay of the light output wasn't taken into account;

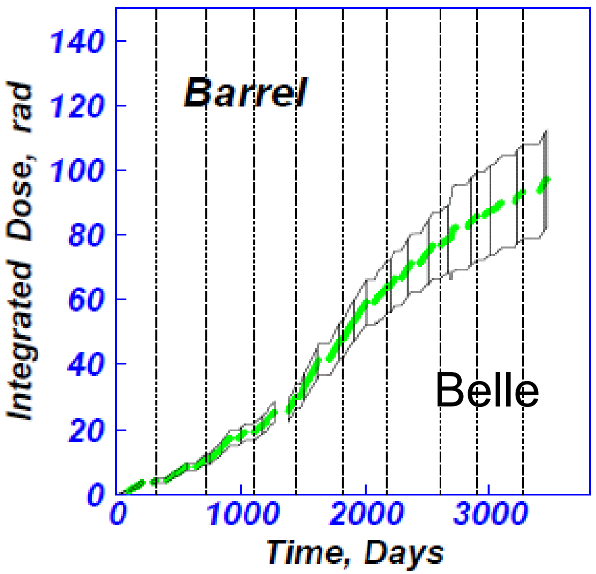
RMS(MeV)	50ns	300ns	1300 ns
central barrel (CsI geom)	2.5	6	12
worst barrel (CsI geom)	6	14	24
external FWD (LYSO geom)	2	5	9
internal FWD (LYSO geom)	5	12	22

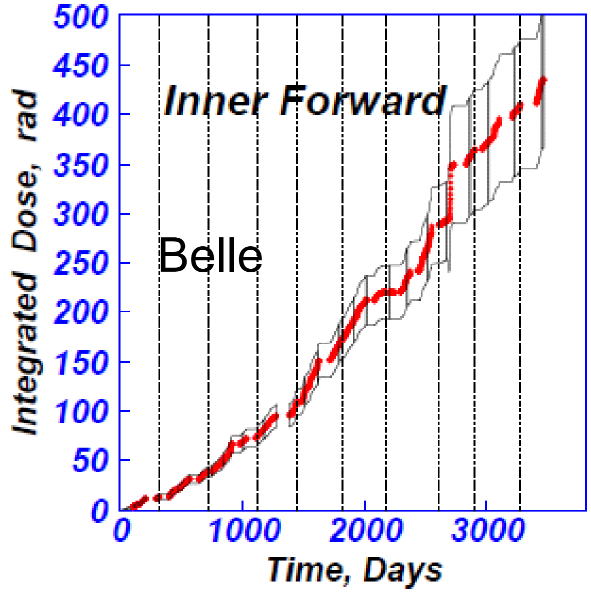
At the first order, these values are per-mill contributions to the 1/E term in the calorimeter resolution;

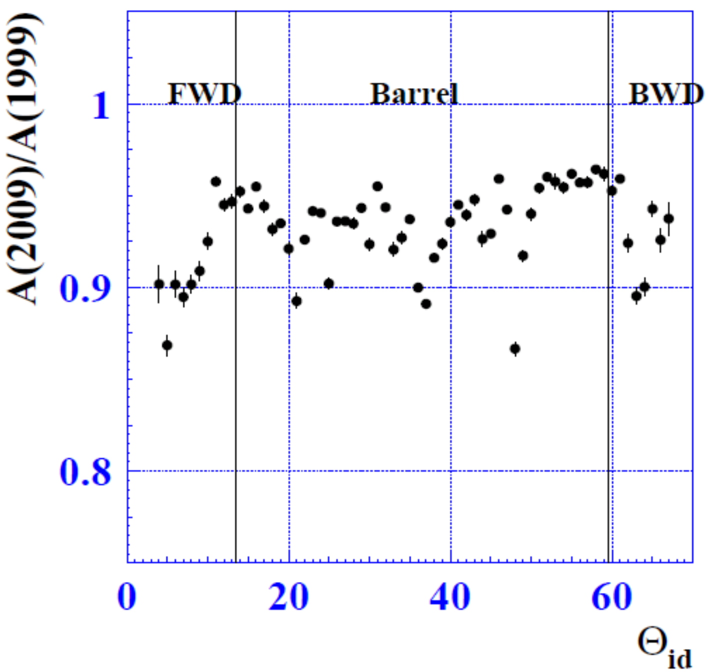
It is important to outline that the worst barrel with the CsI geometry, is always similar to the worst end-cap with the LYSO geometry;

With CsI (Tl) the worst barrel has a pedestal in-stability of 24% at 100 MeV.

Radiation dose







In Belle a dose of 100-500 Rad was accumulated in 10 years of operations

Light yield decreased between 5% and 10% in Belle

By means of a simple extrapolation from Belle data we can expect between 10 kRad and 50 kRad;

What is the expected light output decrease for such an integrated dose?

Summary of the crystals in use in HEP

Table 28.4: Properties of several inorganic crystal scintillators. Most of the notation is defined in Sec. 6 of this *Review*.

Parameter:	ρ	MP	X_0^*	R_M^*	dE^*/dx	λ_I^*	τ_{decay}	λ_{max}	$n^\natural$	Relative output†	Hygro-scopic?	$d(LY)/dT$
Units:	g/cm^3	°C	cm	cm	MeV/cm	cm	ns	nm				%/°C‡
NaI(Tl)	3.67	651	2.59	4.13	4.8	42.9	230	410	1.85	100	yes	−0.2
BGO	7.13	1050	1.12	2.23	9.0	22.8	300	480	2.15	21	no	−0.9
BaF_2	4.89	1280	2.03	3.10	6.5	30.7	630^s	300^s	1.50	36^s	no	-1.3^s
							0.9^f	220^f		3.4^f		$\sim 0^f$
CsI(Tl)	4.51	621	1.86	3.57	5.6	39.3	1300	560	1.79	165	slight	0.3
CsI(pure)	4.51	621	1.86	3.57	5.6	39.3	35^s	420^s	1.95	3.6^s	slight	−1.3
							6^f	310^f		1.1^f		
$PbWO_4$	8.3	1123	0.89	2.00	10.1	20.7	30^s	425^s	2.20	0.083^s	no	−2.7
							10^f	420^f		0.29^f		
LSO(Ce)	7.40	2050	1.14	2.07	9.6	20.9	40	402	1.82	83	no	−0.2
$LaBr_3$(Ce)	5.29	788	1.88	2.85	6.9	30.4	20	356	1.9	130	yes	0.2

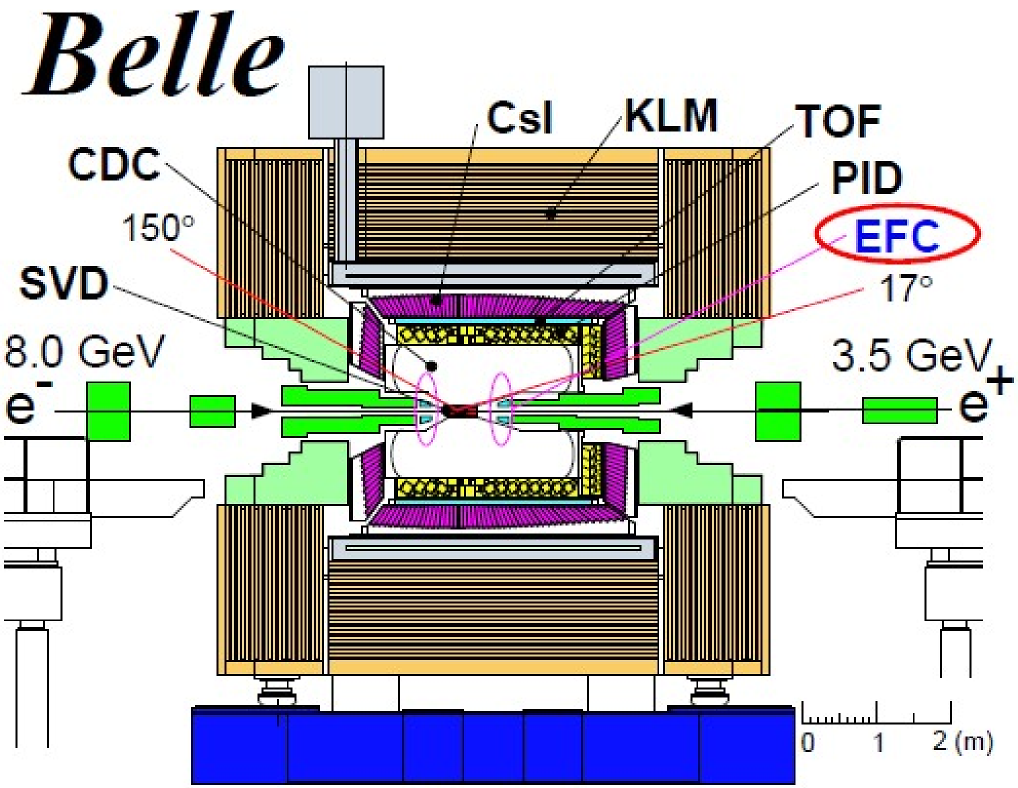
What are the performance and the price we can really afford for the forward EMC?

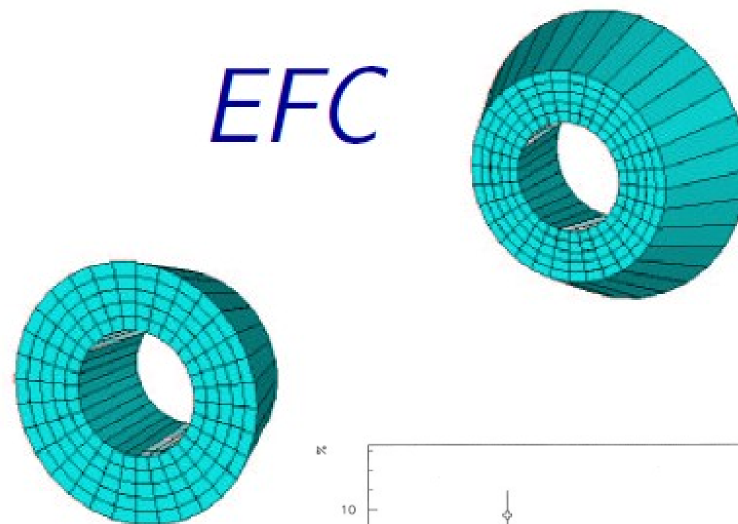
Extreme Forward Calorimeter at Belle

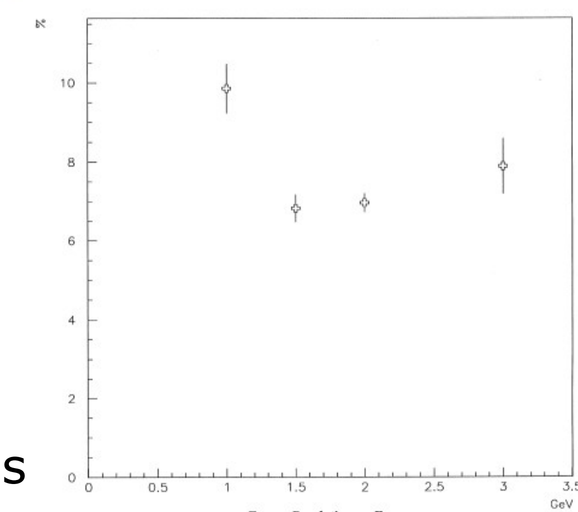
Belle used a "small angle calorimeter" in BGO;

Two endcap BGO calorimeters cover the range of $6.2 < \theta < 11.6$ in forward side and $163.1 < \theta < 171.5$ in backward side.

Typical cross section of a crystal is 2cm x 2cm with 12.0 or 10.5 X_0.







6%-10% resolution obtained because of the short crystals

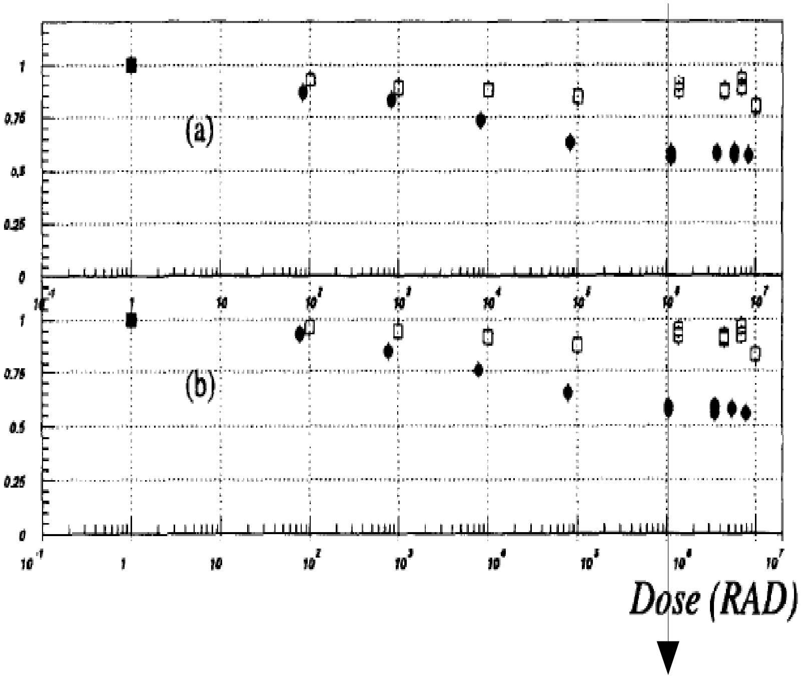
BGO rate capability and radiation hardness

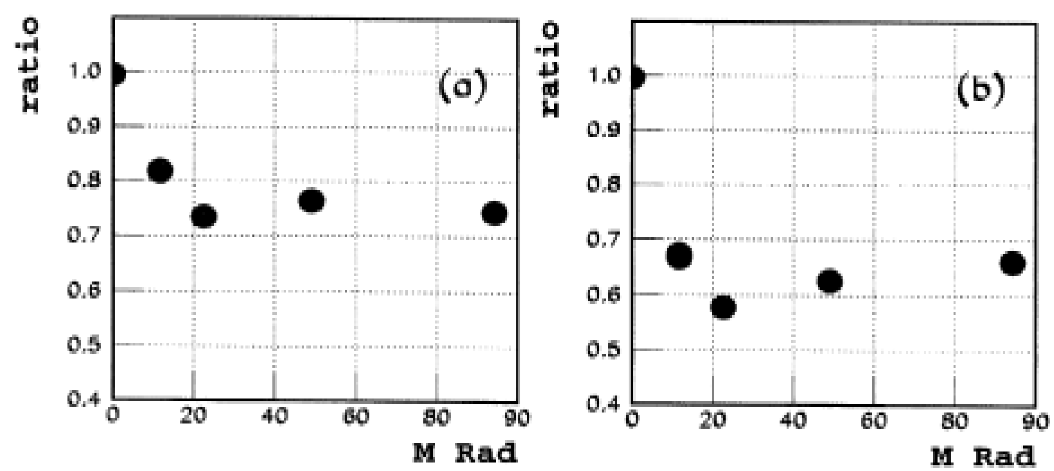
Belle EFC had an expected counting rate for Bhabha events of a few kHz at an ultimate luminosity of 10^{34} cm^{-2} s^{-1};

No problems arose;

SuperB will have 100 times more;

Several measurements were performed on the pure-BGO radiation hardness;

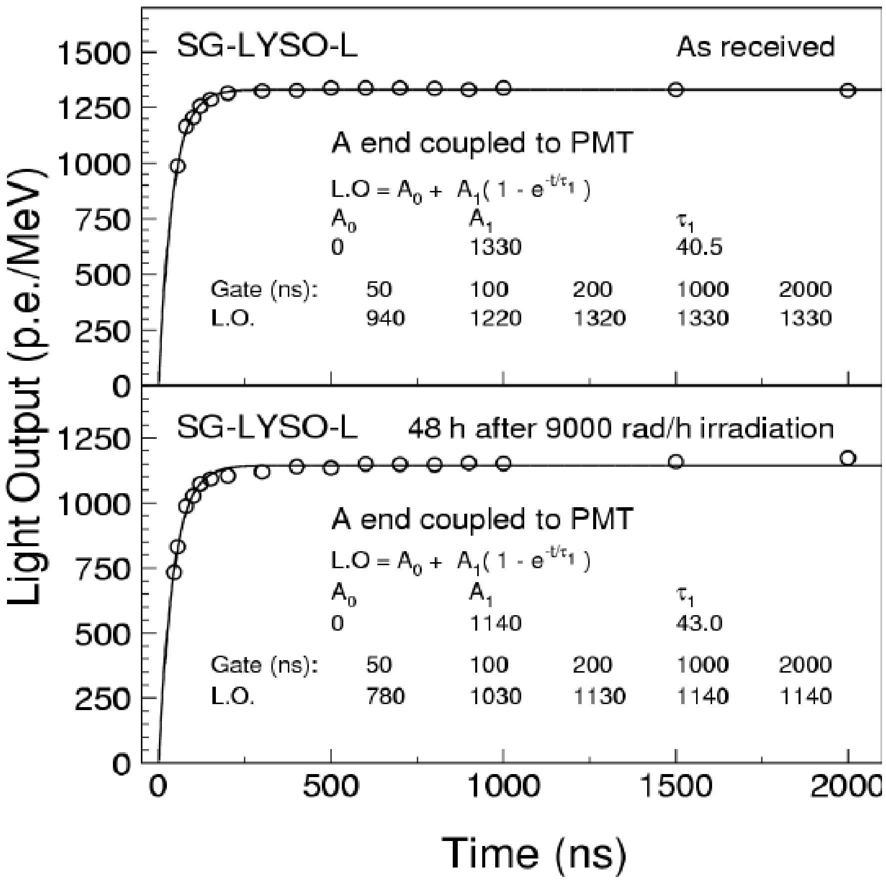




After a drop of 20%-30% for a dose of 10-20 Mrad, the light yield is stable up to 90 Mrad.
Belle decided to pre-irradiate all crystals.

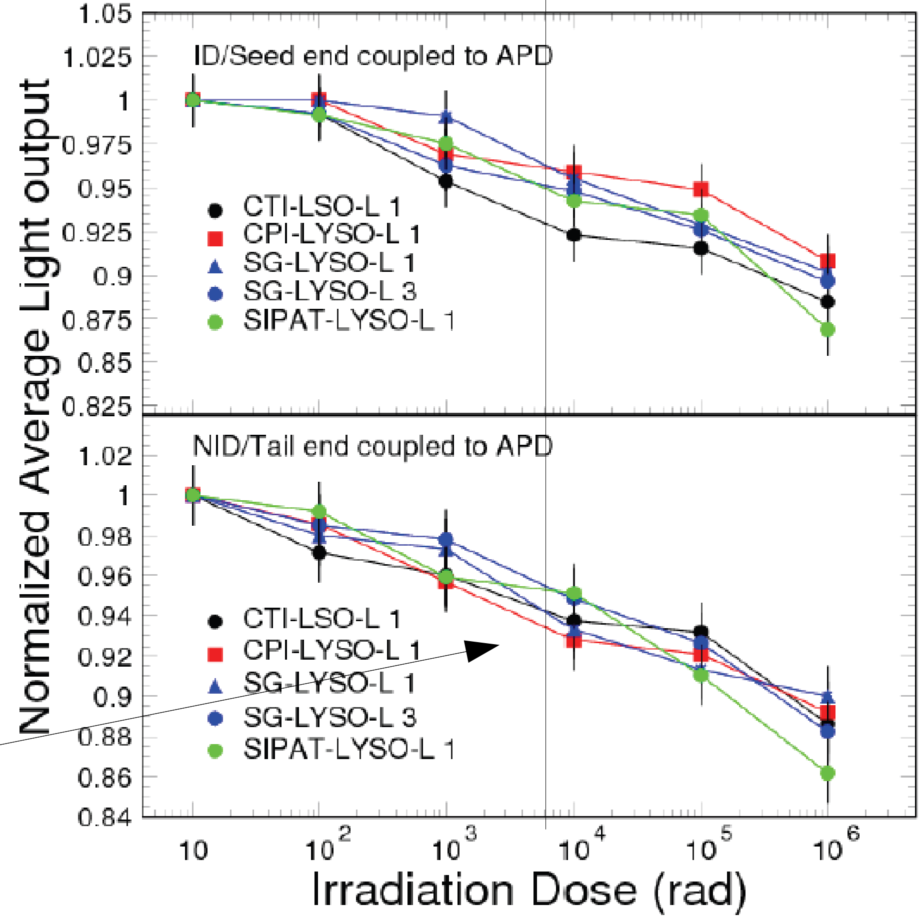
Lyso radiation hardness

Radiation hardness measurements performed by Ren-yuan:



After an irradiation of 9 krad/h x 22h = 0.2 Mrad 86% of light yield (with PMT).

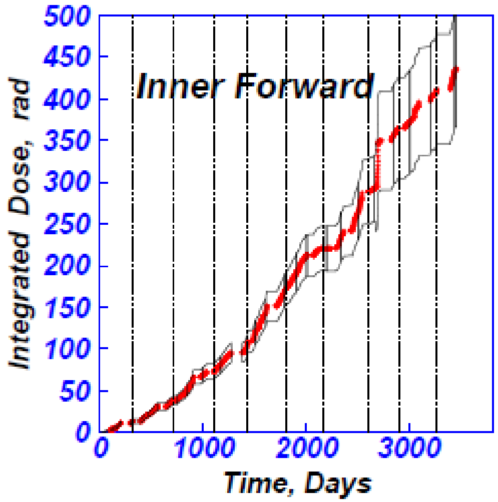
9% - 14% loss by APD

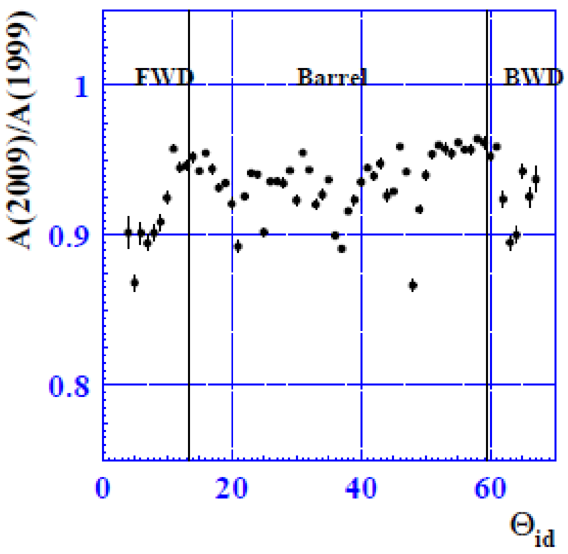


Results confirmed by more detailed tests performed up to 1 Mrad: 10%-15% loss with PMT
5% after 50 kRad

CsI(Tl) at Belle

The total integrated dose in the forward Belle calorimeter is about 100 Rad in the barrel and 400 Rad in the inner forward.





It is known that after 3.6 kRad the light output decreases by a factor 30%.

An increase of the absorbed dose by one order of magnitude will not pose a serious issue.

Main known issues:

1. The dark current of the Photo-diodes reached 200 nA in the end-cap and an increase in the luminosity may cause problems.

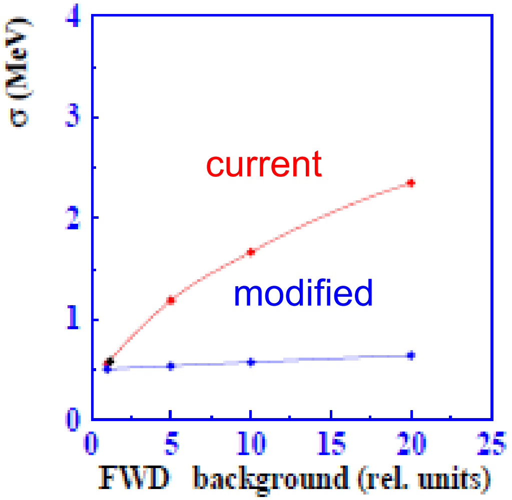
2. Within a 1 μs integration time, a large number of very soft photons (<1 MeV) due to machine background (synchrotron radiation) causes a 1 MeV noise in the end-cap. How does it scale?

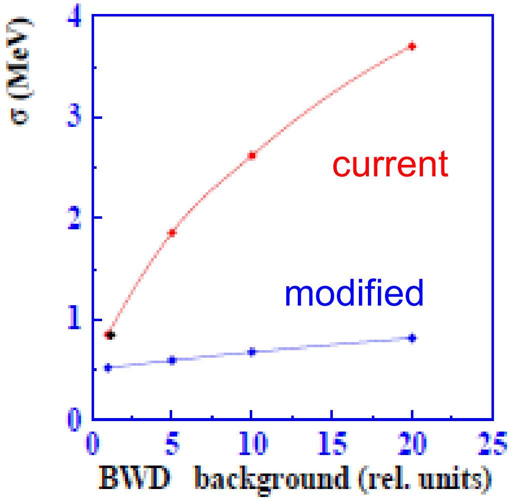
3. High energy photons (Bhabha...) cause 6 clusters/event with E>20 MeV.

Pure CsI and CsI(Tl) at Belle II

The integration time is reduced to 0.5 μs and threshold set to 30 MeV to reduce combinatorial background.

Pure CsI is proposed for the end-caps readout with UV sensitive photo-pentodes (PP): 20% QE, 100-200 gain, expected overall noise of 120-200 keV.



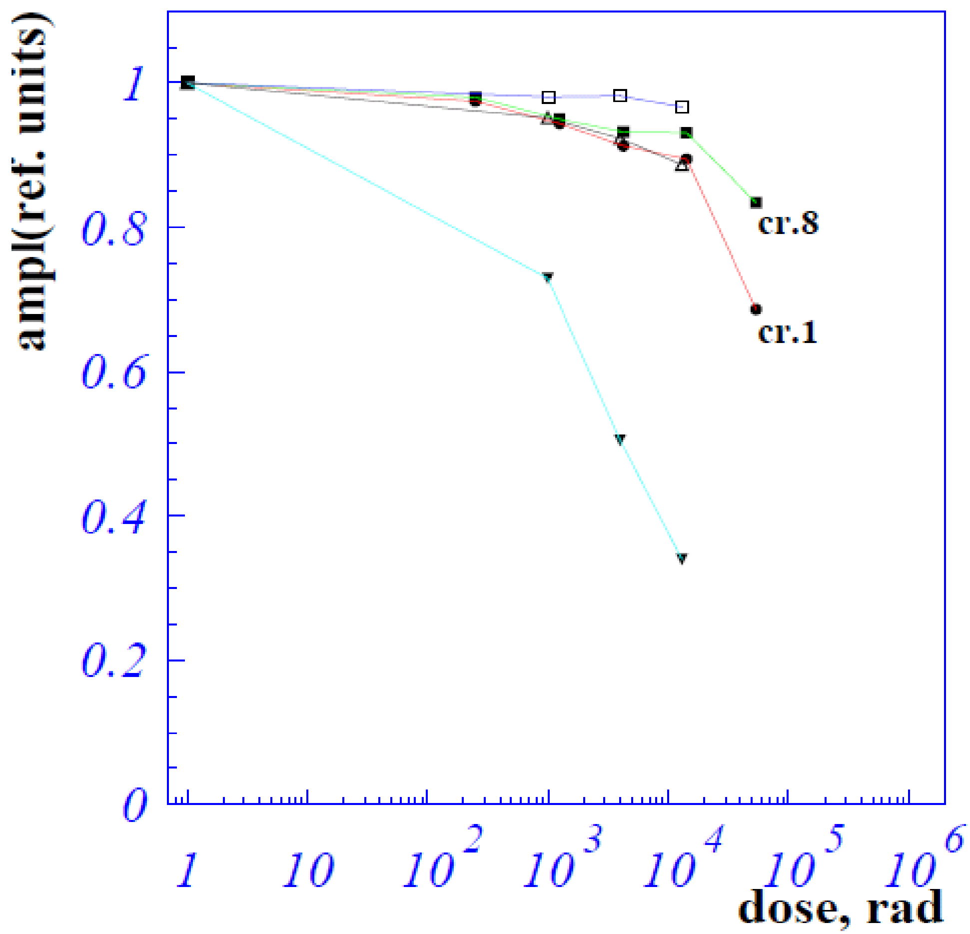


Shorter integration time suppresses pile-up noise of a factor 6.

Usage of a single photo-detector per counter represents a single-point failure and therefore
The PP gain factor depends on the magnetic field and calibration is needed more often.
This gain factor can also vary slightly with background conditions.

Pure CsI radiation hardness

Belle people has measured the radiation hardness of the pure CsI up to a total dose 10^5 Rad.



Except for a very strange crystal, light output losses of about 20%-30% were found.

New tests are foreseen to understand the differences.

Conclusion

Several parameters of different crystal were analyzed:

Crystal	Decay time (ns)	Pedestal "resolution" (MeV)	Radiation hardness 10^5 Rad	Light output
LYSO	40	2 - 6	Good	50
BGO	300	5 - 12	Good	13
Pure CsI	35	2 - 6	?	3 - 1
CsI (Tl)	1300	9 - 24	?	100

For sure LYSO is the best crystal, but are we sure we need it? Also the cost should be taken into account.

Can we think to a different (maybe mixed) solution?

A better understanding of the background effects on the EMC and detailed simulation of some golden channel would help