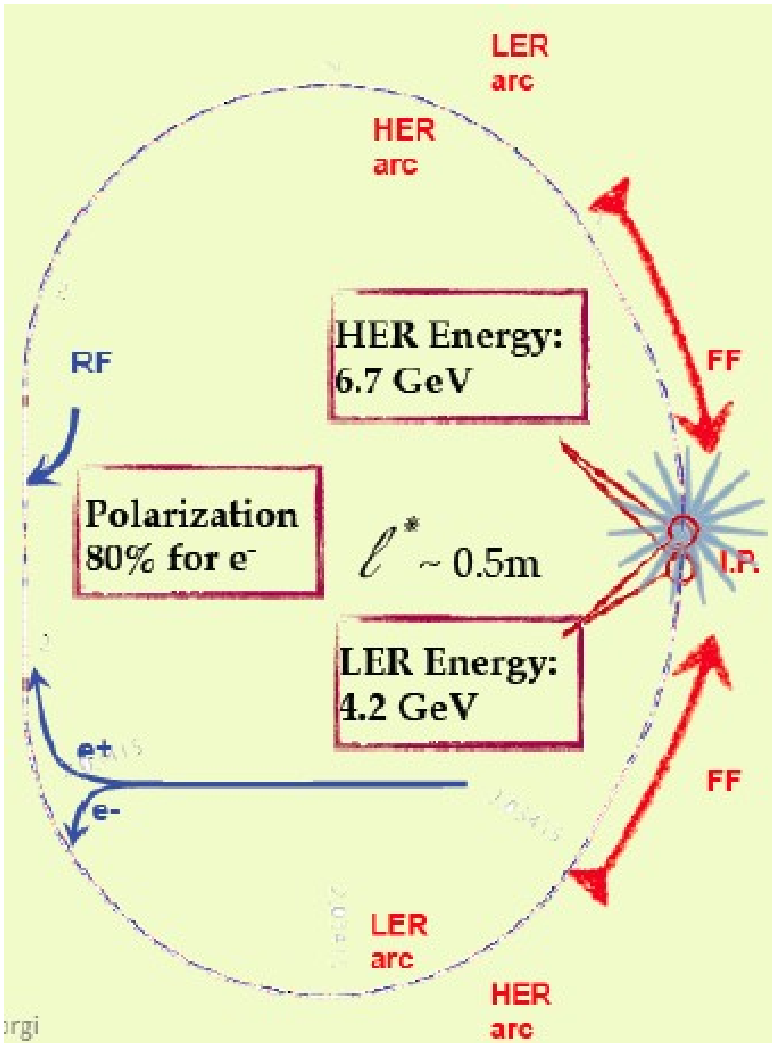
The Electromagnetic Calorimeter of the SuperB Detector

Davide Pinci – INFN - Italy

The SuperB project

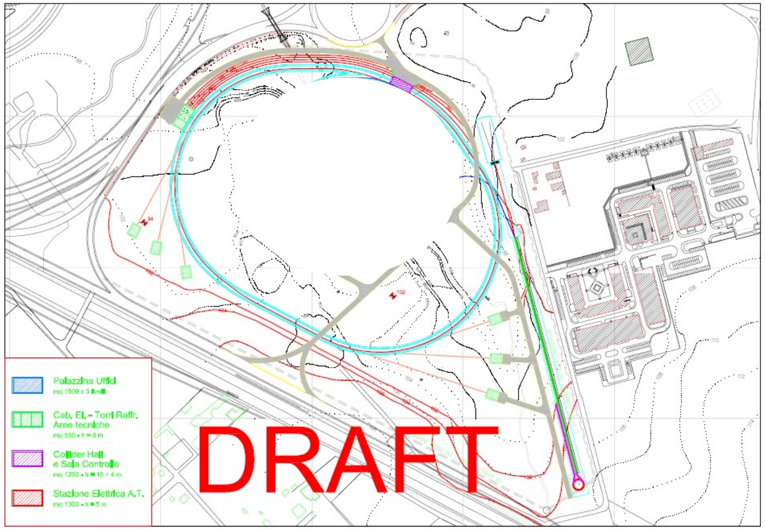
SuperB is a project aiming to study with great precision CP violating and rare processes of heavy quarks (c and b) and leptons ( );

It will be based on a asymmetric e^+ - e^- machine designed to provide a luminosity of 10^{36} $cm^{-2}s^{-1}$;



The high luminosity will be reached by exploiting the crab waist mechanism developed by P. Raimondi and successfully tested on the Dafne machine in Frascati.

The machine will be built near to Roma (Tor Vergata).

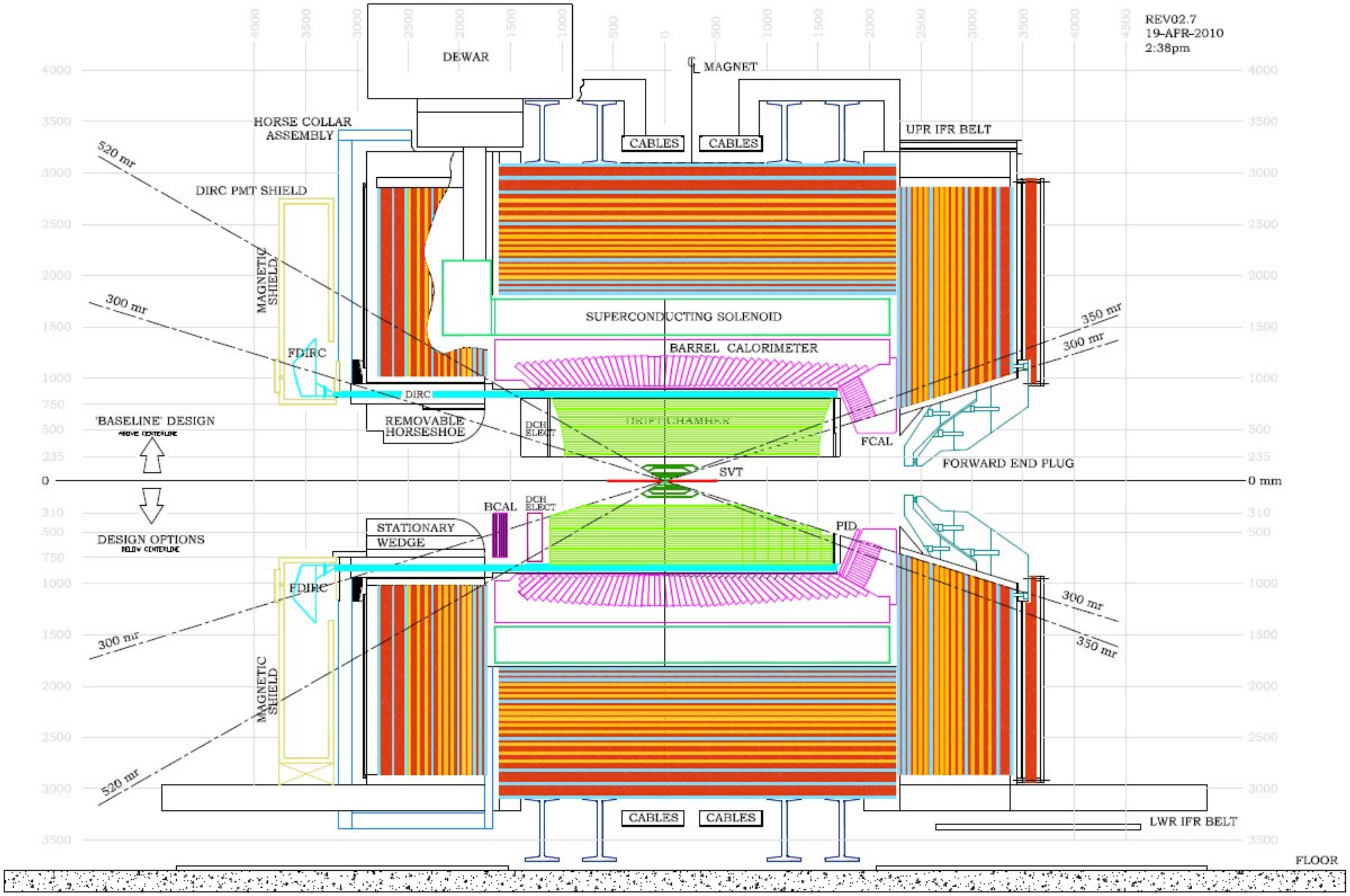


	PEP-II (SLAC)	SuperB (Italy)	SuperKEKB (KEK)
Luminosity (10^{30} $cm^{-2}s^{-1}$)	12069 (design: 3000)	1.0×10^6	8×10^5
Injection energy (GeV)	2.5–12	$e^-/e^+ : 4.2/6.7$	$e^-/e^+ : 7/4$

The SuperB Detector

Main part is based on the Babar apparatus;

Remaining Generic Detector Options to be decided;



Background simulation and R&D ongoing across detector systems;

Primary Background Rates

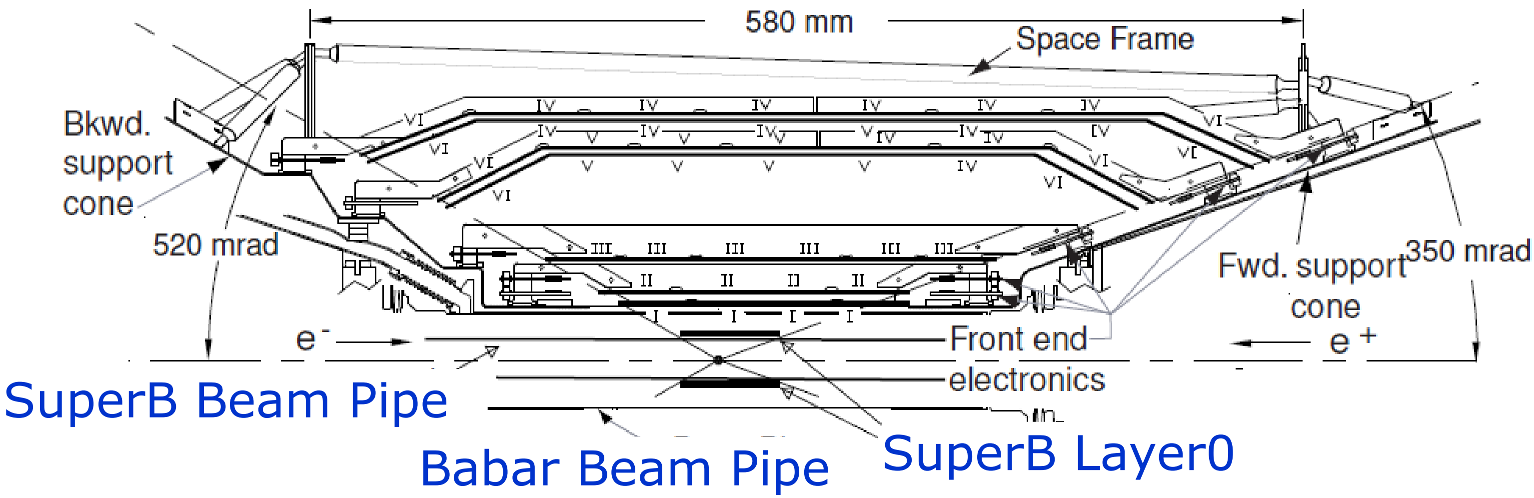
	Cross section	Event per bunch crossing	Rate
Radiative Bhabha	~340 mbarn (Eγ/Ebeam > 1%)	850	300 GHz
e+e- pair production	7.3 mbarn	18	7 GHz
e+e- pair (seen by L0)	0.3 mbarn	1	0.3 GHz
Elastic Bhabha	10^{-4} mbarn	2.5 10^{-4}	100 KHz
Y (4S)	10^{-6} mbarn	2.6 10^{-6}	1 KHz

Primary Background Particle will eventually hit the beam pipe showering in the surrounding material;

Ad hoc Monte Carlo generator for primary particles;

Geant4 Based full simulation code for the simulation of the interaction of primary particles with the material;

Silicon Vertex Detector



SVT Baseline:

5 layers of silicon strip modules (extended coverage w.r.t BaBar) 3-15 cm

Striplets in Layer0 at a distance of about 1.5 cm:

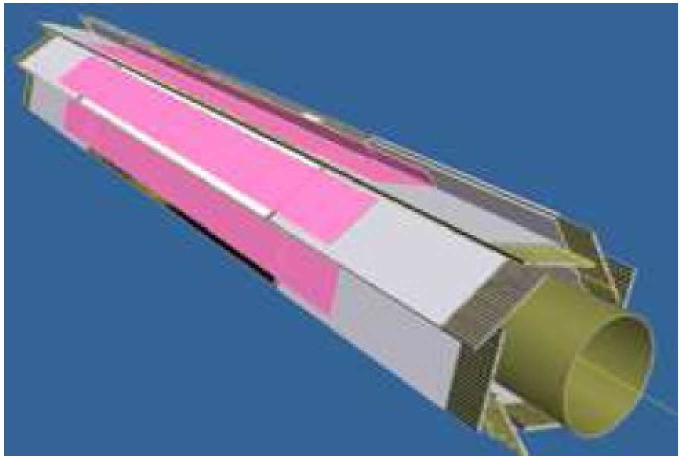
Resolution of 10-15 μm in both coordinates;

Total material budget lesser than 1% X_0;

Particle rate of 100-300 MHz/cm^2 depends strongly on radius and sensor thickness

Total Integrated Dose of 15Mrad/yr

Equivalent neutron fluence: 2.5 10^{13} n/cm^2/yr

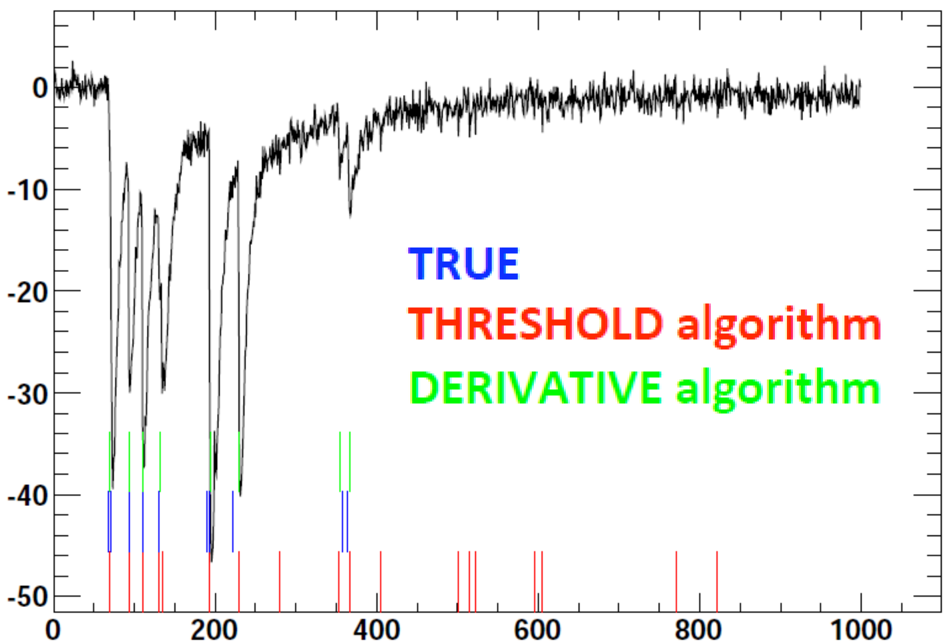


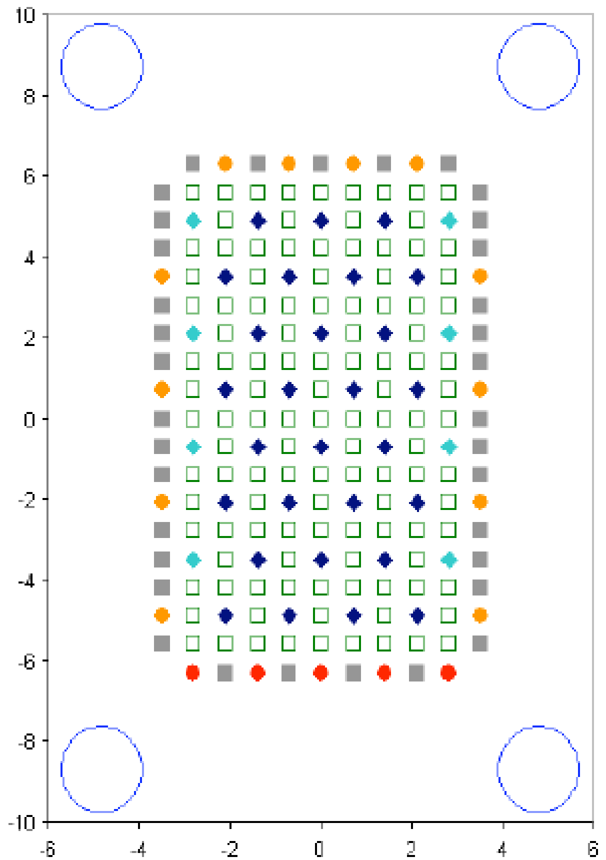
Drift Chamber

The gas mixture for SuperB should satisfy the requirements which already concurred to the definition of the BABAR gas mixture (80%He-20%iC_4H_{10}): low density, small diffusion and Lorentz angle.

Rectangular cells arranged in concentric layers with one 20 μm diameter gold coated sense wire surrounded by a rectangular grid eight field wires.

If the individual ionization cluster can be detected with high efficiency, it could in principle be possible to measure the track specific ionization by counting the clusters.
Studies on algorithms and data bandwidth are ongoing



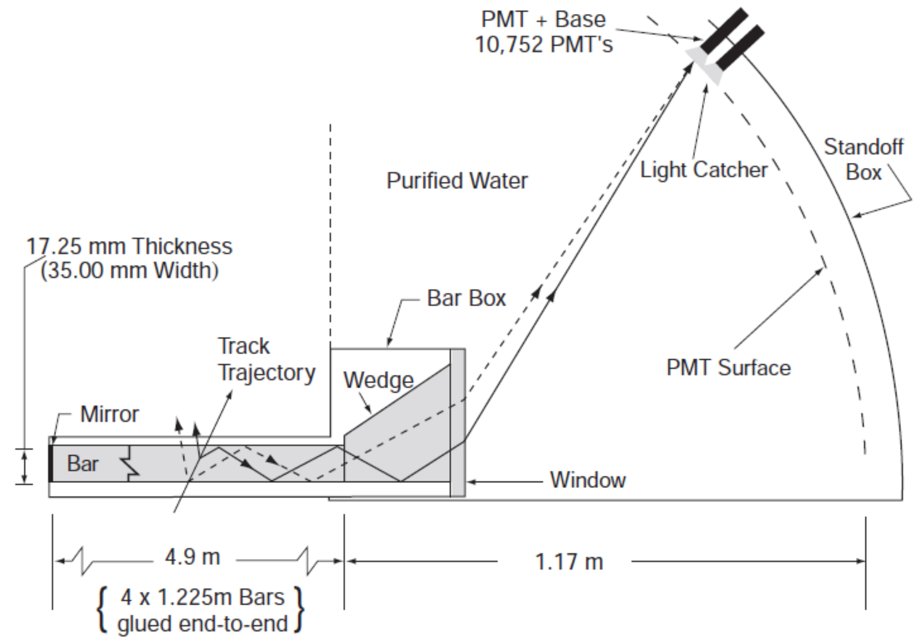


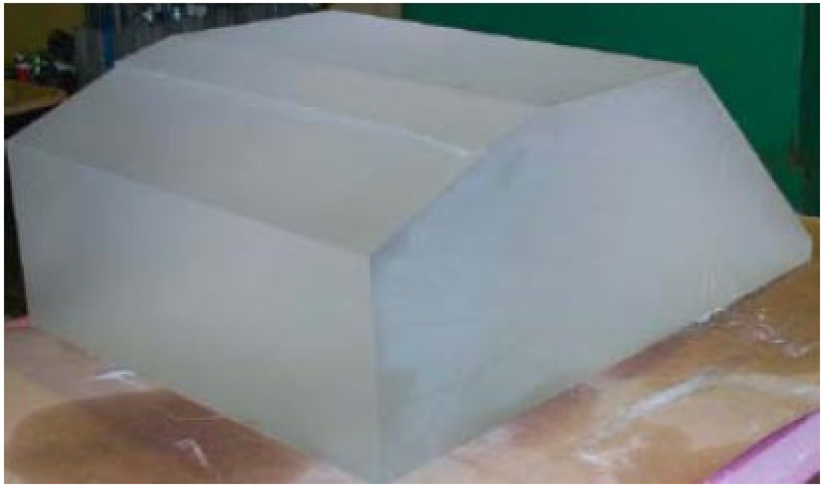
Particle Identification

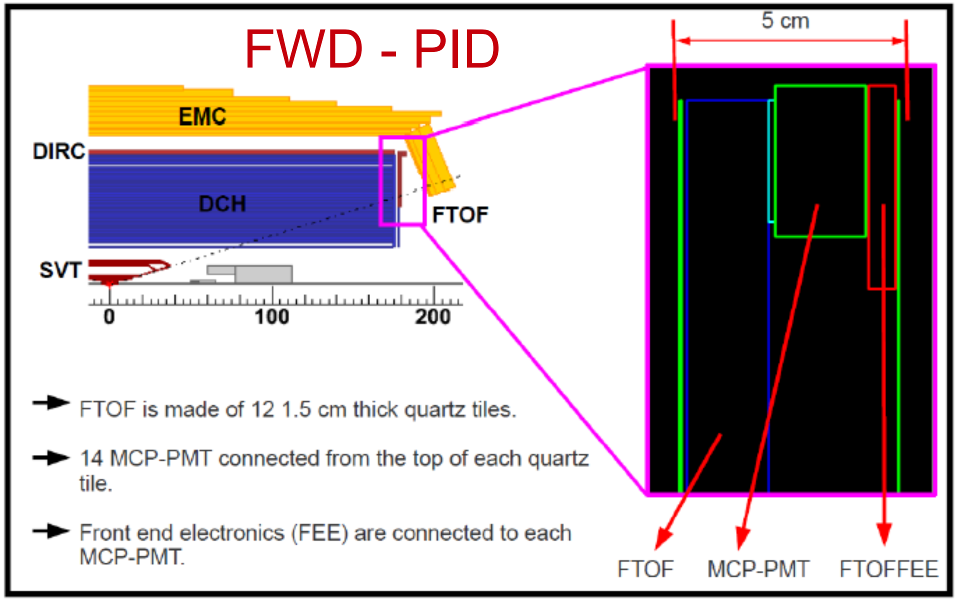
Excellent flavor tagging will continue to be essential for the program of physics anticipated at SuperB.

The PID system must cope with much higher luminosity.

A new photon camera imaging concept, based on focusing blocks (FBLOCK), responsible for imaging the Cherenkov photons onto a focal plane instrumented with very fast, highly pixelated, photon detectors (PMTs).







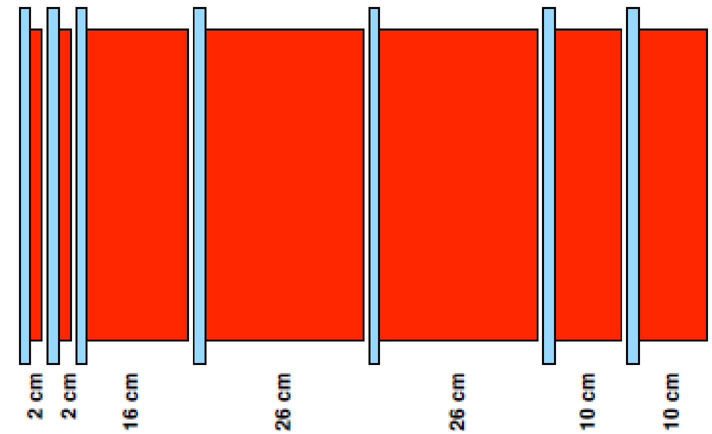
Instrumented Flux Return

Plan to re-use BaBar IFR structure, adding iron to improve μ-ID

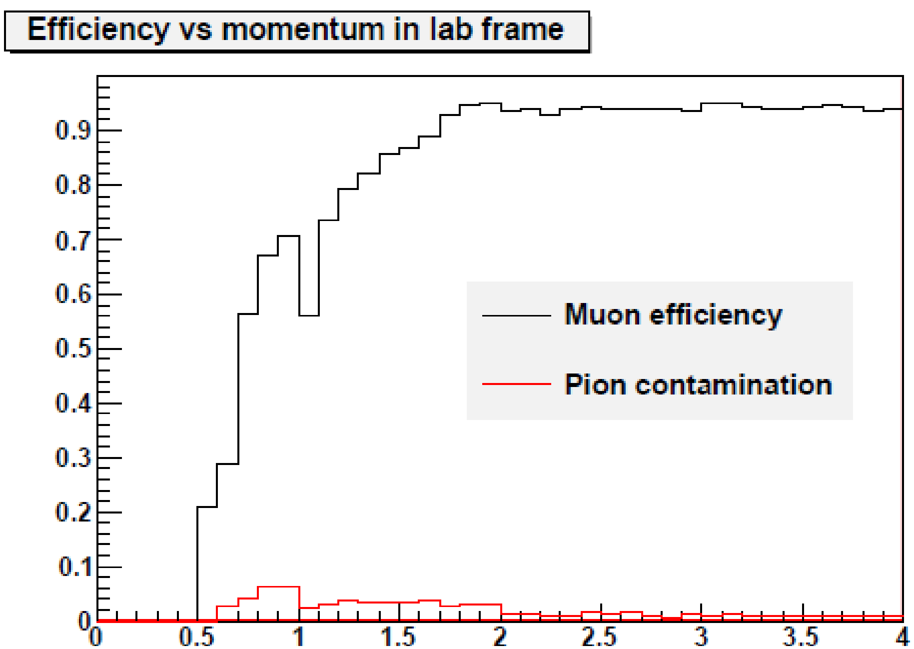
Extruded Scintillator as active material to cope with higher flux of particles

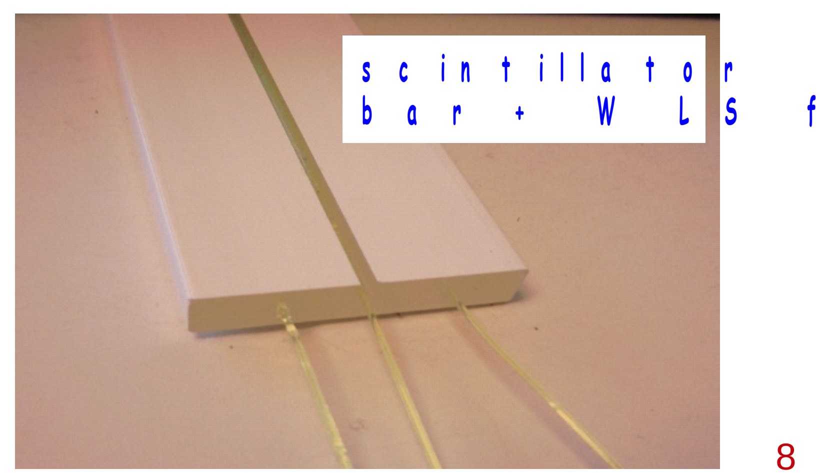
Scintillator bars readout through 3 WLS fibers and Silicon Photo-Multipliers (SiPM)

Iron layers (~80 cm) interleaved by 8-9 active layers:



Preliminary results give an average muon efficiency of 87% with a pion contamination of 2.1% over the entire momentum range.



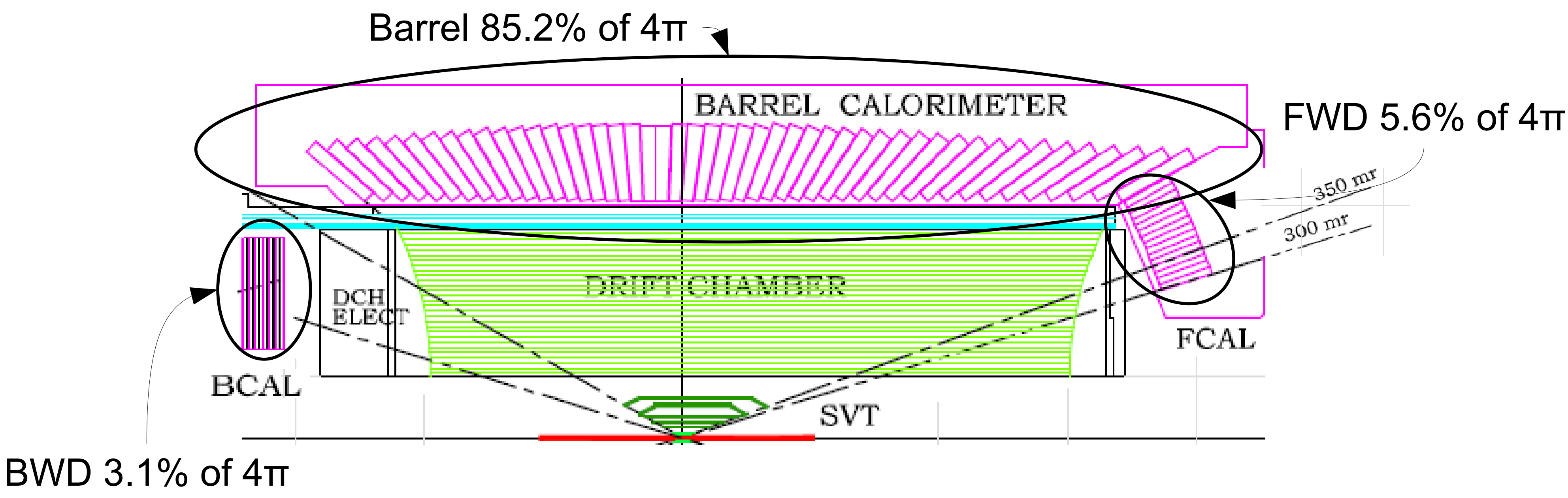


The Electromagnetic Calorimeter

The electromagnetic calorimeter (EMC) provides energy and direction measurement of photons and electrons;

It is an important component in the identification of electrons versus other charged particles.

The system is made by three components:

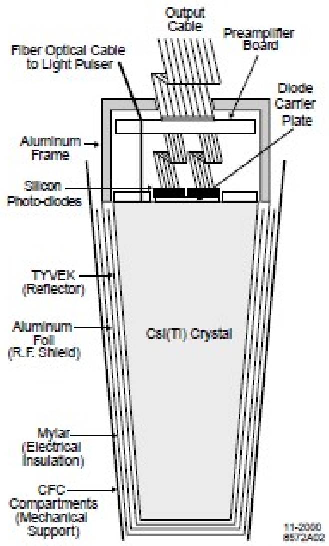


The total solid angle covered for a massless particle in the center-of-mass is 94.1% of 4π

Barrel Calorimeter

The barrel calorimeter is the existing BABAR CsI(Tl) crystal calorimeter;

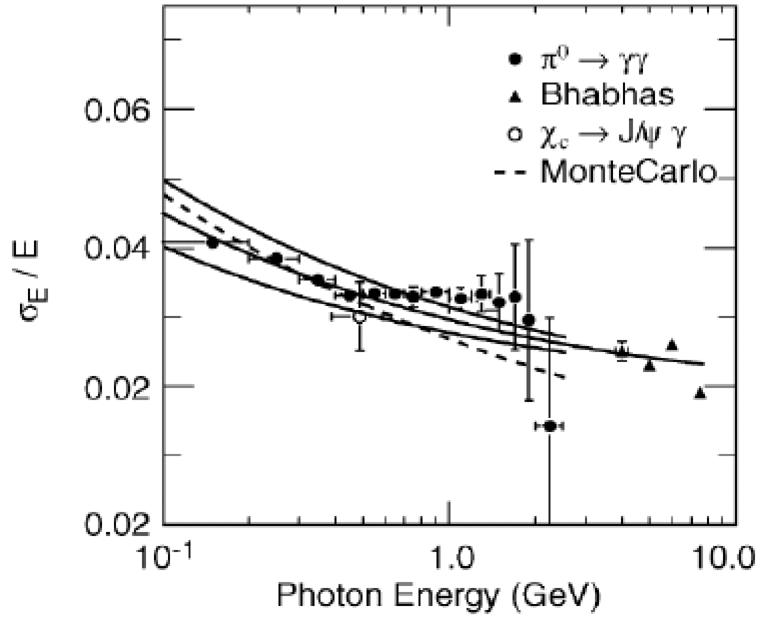
It is made of 5,760 CsI (Tl), 16.0 X_0– 17.5 X_0 long crystals, arranged in 48 rings with 120 crystals each;



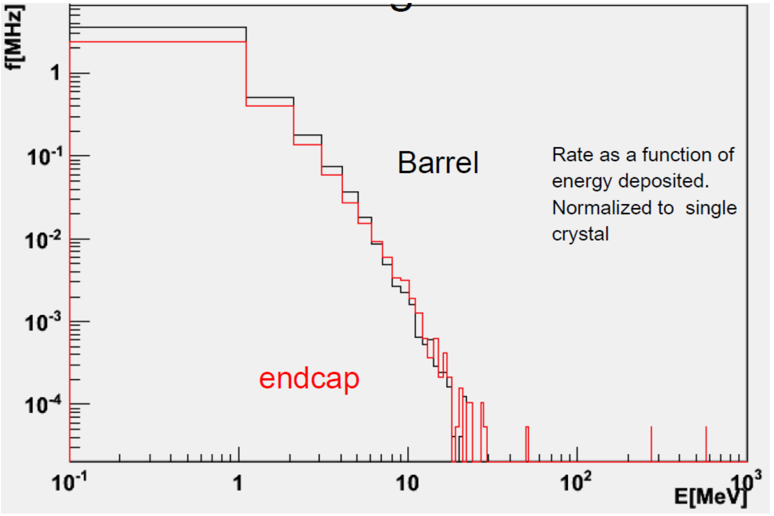
Energy resolution was 4-5% below 100 MeV and 2-3% in the GeV range

$$\frac{\sigma_E}{E} = \frac{(2.30 \pm 0.03 \pm 0.3)\%}{\sqrt[4]{E(\mathrm{GeV})}} \oplus (1.35 \pm 0.08 \pm 0.2)\%$$

This is the requirement for the SuperB EMC

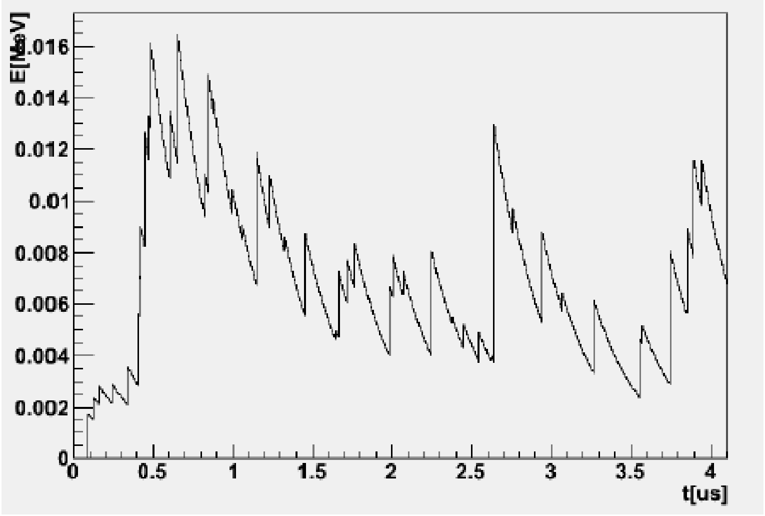


Background rate



The particle rate foreseen on the Calorimeter will be quite large;

Mainly due to radiative Bhabha events, up to few MHz of photons per crystal are expected;

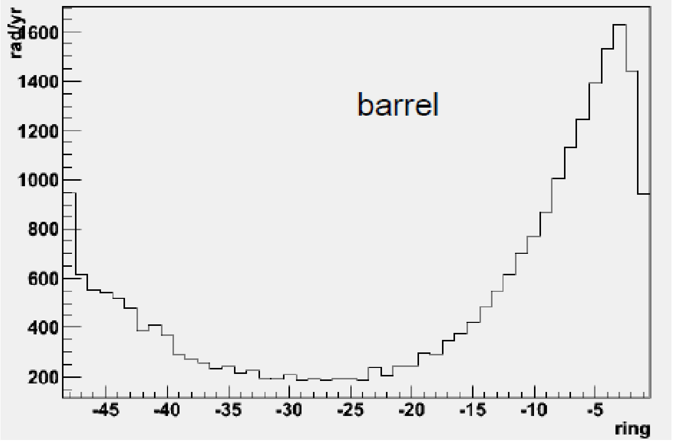


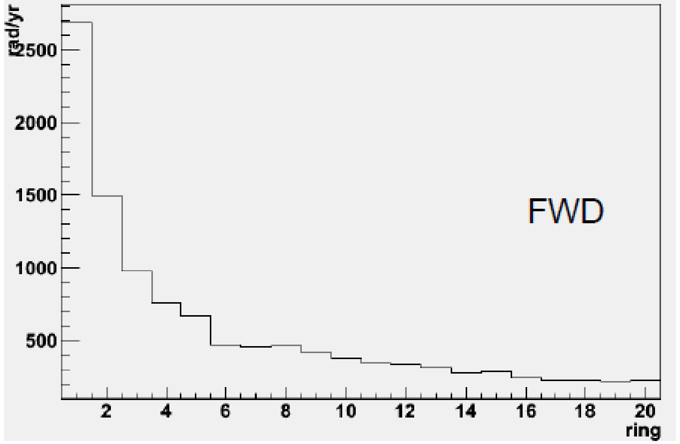
These will cause a fluctuating background under the main signals we want to measure.

The main value and the jitter of the level have to be taken into account

The background is also responsible for the radiation dose integrated by the crystals.

A max dose of 1.6/2.5 kRad/year is expected





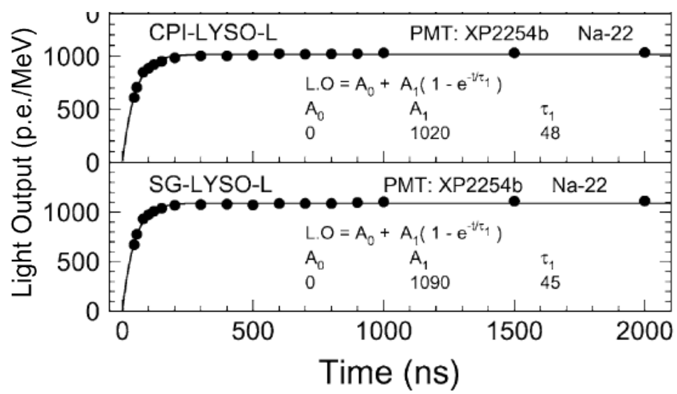
The LYSO studies

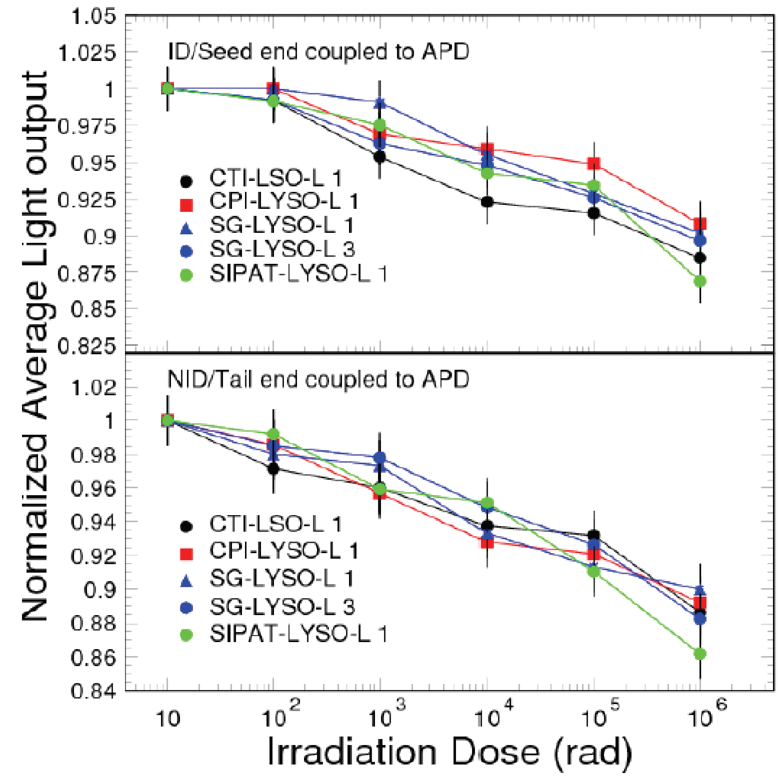
LYSO crystals are the baseline solution for equipping the FWD EMC:

Parameter:	ρ	MP	X_0^*	R_M^*	dE^*/dx	λ_I^*	τ_{decay}	$\lambda_{\max}$	$n^\natural$	Relative output†	Hygro-scopic?	$d(LY)/dT$
Units:	g/cm^3	°C	cm	cm	MeV/cm	cm	ns	nm				%/°C‡
LSO(Ce)	7.40	2050	1.14	2.07	9.6	20.9	40	402	1.82	83	no	−0.2

high mass density | very fast | large amount of light

Very good scintillating properties;





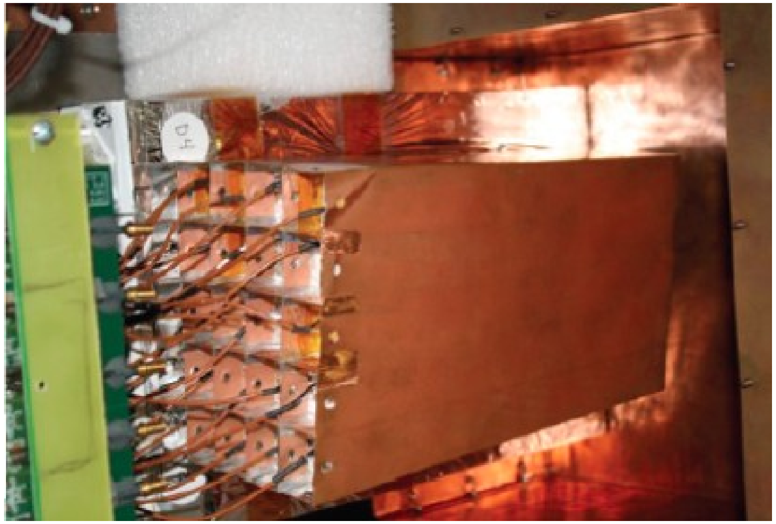
It have already demonstrated to be radiation resistant, with a light yield loss of about 10% for an integrated dose of 1 Mrad.

A 25 crystal matrix, readout by APD was built and tested on beam at CERN (T10) and Frascati (BTF)

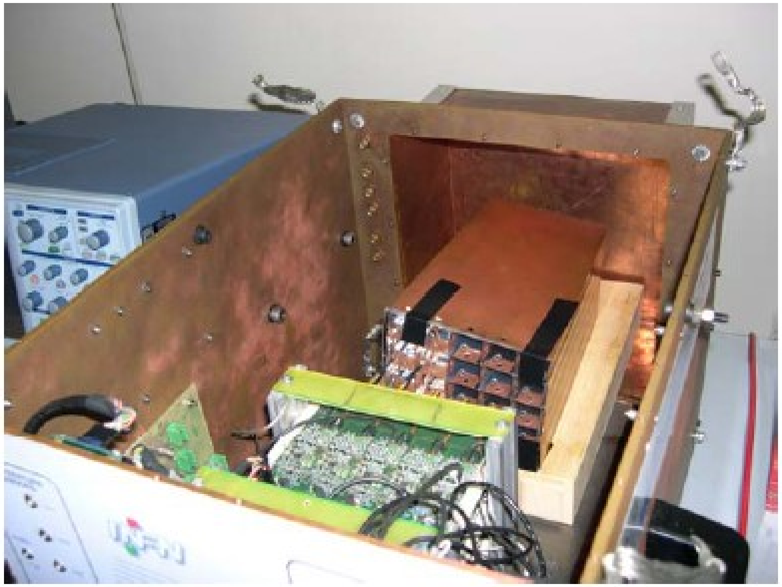
Beam test set-up

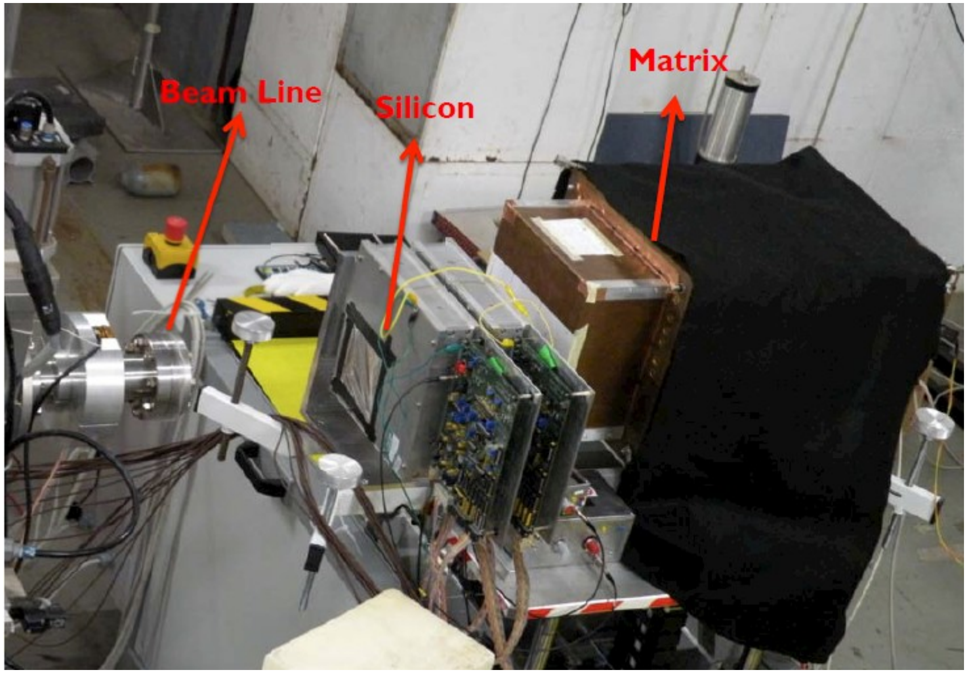
One APD per crystal

The carbon structure with 25 crystals



The copper box with the front-end electronics

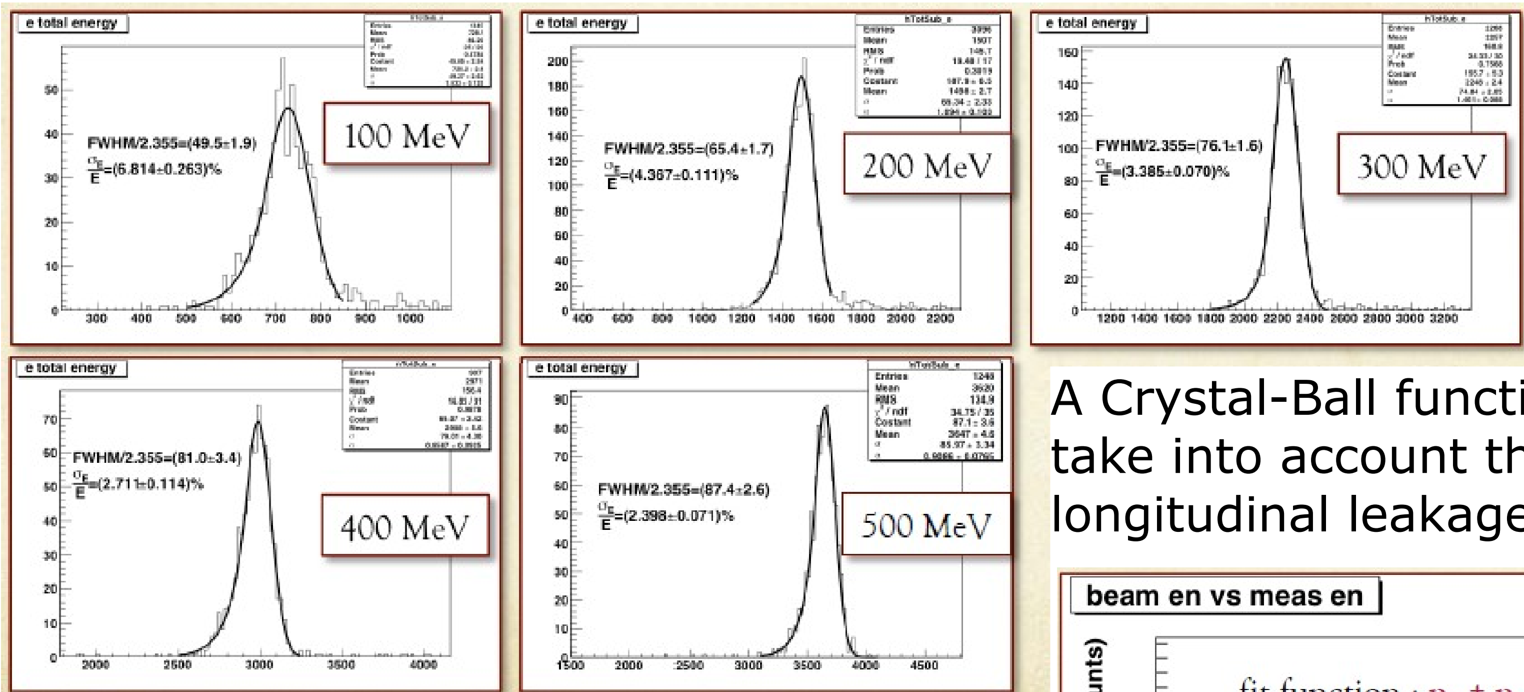




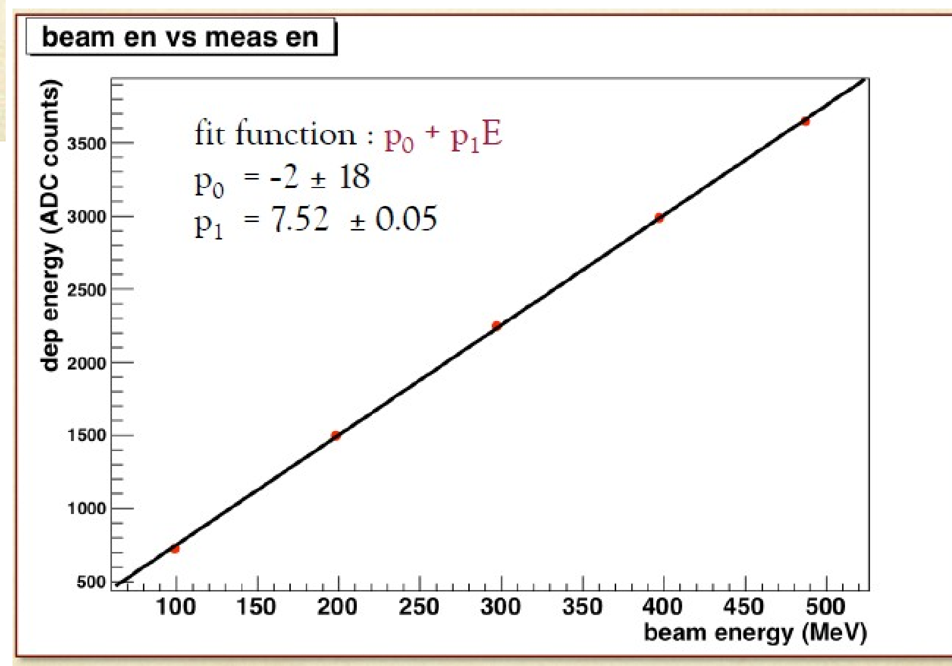
The box on the beam line

BTF - Results

At the BTF the matrix was tested with electrons in the 100 MeV – 500 GeV range;



A Crystal-Ball function was used to take into account the effect of the longitudinal leakages while fitting;



A very good linearity was found in the studied energy range

Energy resolution

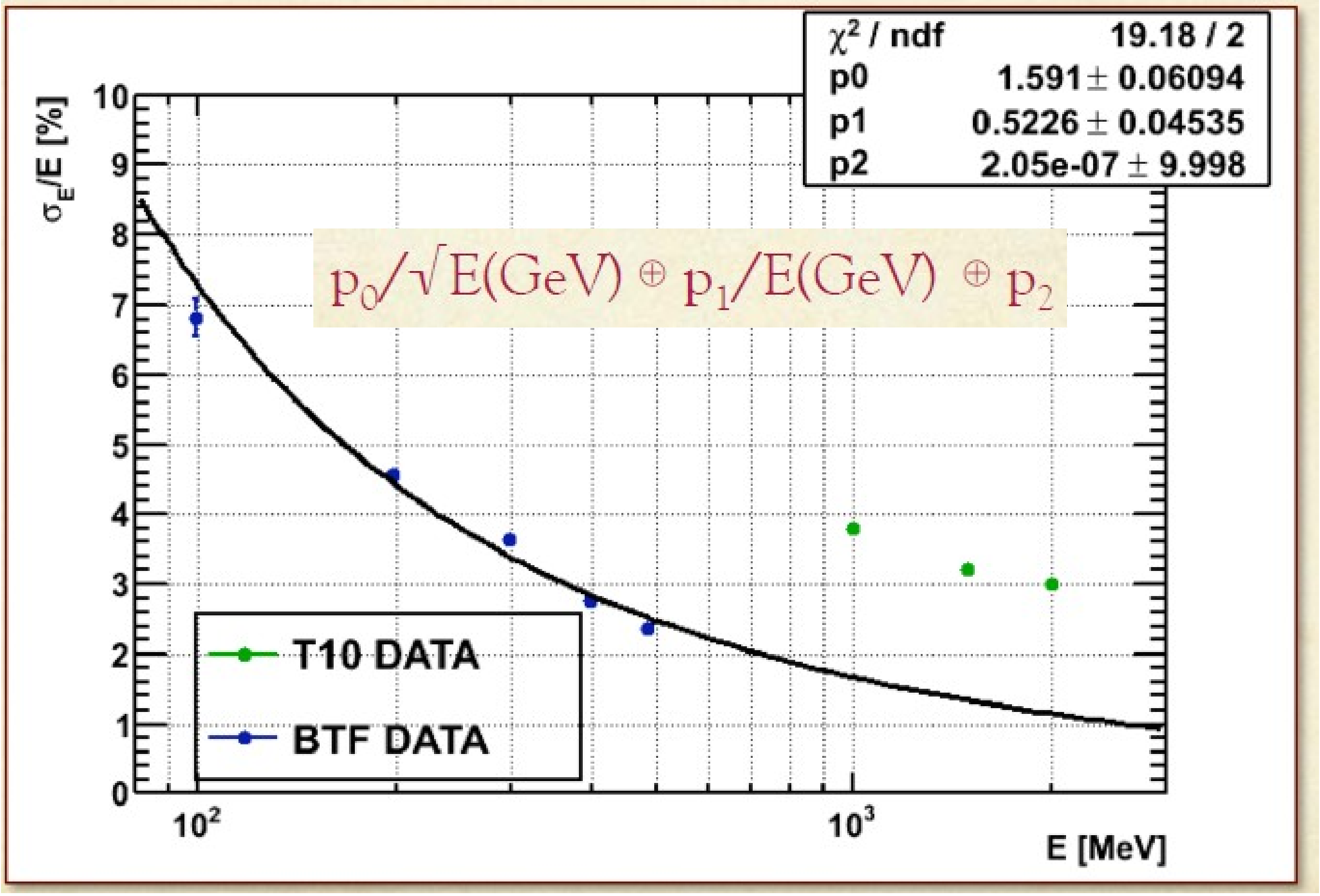
The results obtained on two different beams are shown;

A resolution of 2.3% was obtained at 500 MeV;

A different behavior was found on the CERN test beam, very likely due to an energy spread of the beam;

For lower values, the energy spread of the beam becomes important also in the BTF case.

Next TB foreseen at Mainz able to provide a precision on the beam of 1% down to 100 MeV.



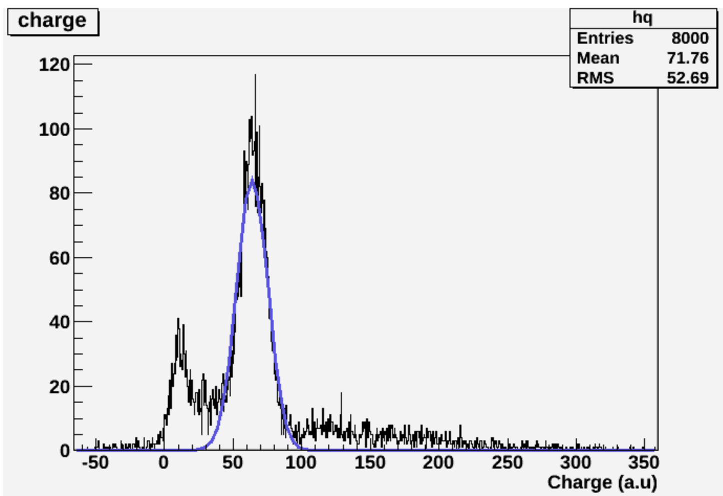
The BGO alternative

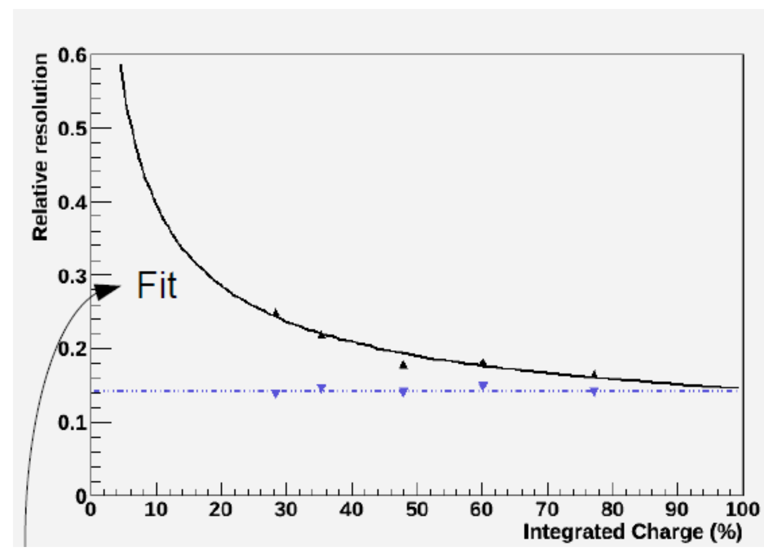
LYSO has already shown to fulfill the requirements for SuperB;

It is anyway a quite expansive material and some possible alternative is taken into account;

BGO is able to provide a good enough resolution. In lab we obtained 14% with a ^{137}Cs source.

That is 75 p.e./MeV → 1.6% statistical term at 50 MeV





The long decay time (300 ns) can be cured by integrating a fraction *f* of the total charge;
It has been demonstrated that the resolution downgrade as the square root of the total charge.

$$\frac{\sigma_A}{A} = 8\% \oplus \frac{12.6\%}{\sqrt{f}}$$

The EMC Rad-Bhabha background

With the latest results on the expected background at SuperB, we evaluated the effect of soft photons (rad-Bhabha) on the energy resolution.

The crystal density has an important impact on the calculated rates;

The total charge collected in 5x5 crystal matrices was evaluated for several “gates”:

RMS(MeV)	$T_{dec}=T_{shaper}$ =50ns	T_{dec}=300ns T_{shaper}=100	$T_{dec}=T_{shaper}$ =300ns	T_{dec}=1300ns T_{shaper}=600ns	$T_{dec}=T_{shaper}$ =1300 ns
central barrel (CsI geom)	N/A	N/A	N/A	0.5	1.0
worst barrel (CsI geom)	N/A	N/A	N/A	2.7	4.9
external FWD (LYSO geom)	0.1	0.2	0.3	N/A	N/A
internal FWD (LYSO geom)	0.7	0.7	1.2	N/A	N/A

The situation in the barrel is quite worst than in the FWD, also for a BGO solution with a shaping time of 300 ns.

BGO radiation hardness

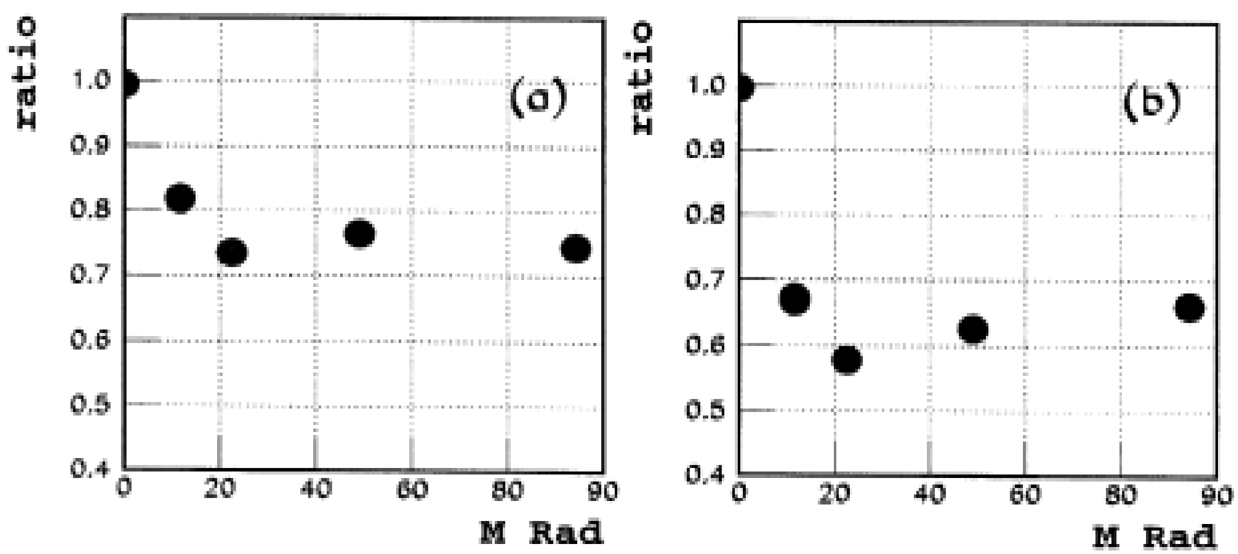
Babar accumulated 750-1200 Rad with a light yield loss between 10% and 15%;

According to the latest simulation, a dose of 1600/2500 Rad/year is expected in the barrel/FWD;

BGO rad-hardness was tested up to 90 MRad.

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 and pure CsI showed good behavior after 20 kRad;

Some more aging tests on crystal samples can be carried out at the ENEA-Casaccia Calliope irradiation facility (800 TBq ^{60}Co source);

Conclusion

The SuperB project is started:

(1) The site was decided;

(2) The machine design is proceeding;

(3) Work on detector R&D is going on;

The barrel part of Electromagnetic Calorimeter will be based on the Babar one: CsI[Tl] crystals, with a new readout scheme.

For the FWD part LYSO crystals have already shown to fulfill the experiment requirements.

We are investigating BGO as a possible cheaper alternative.

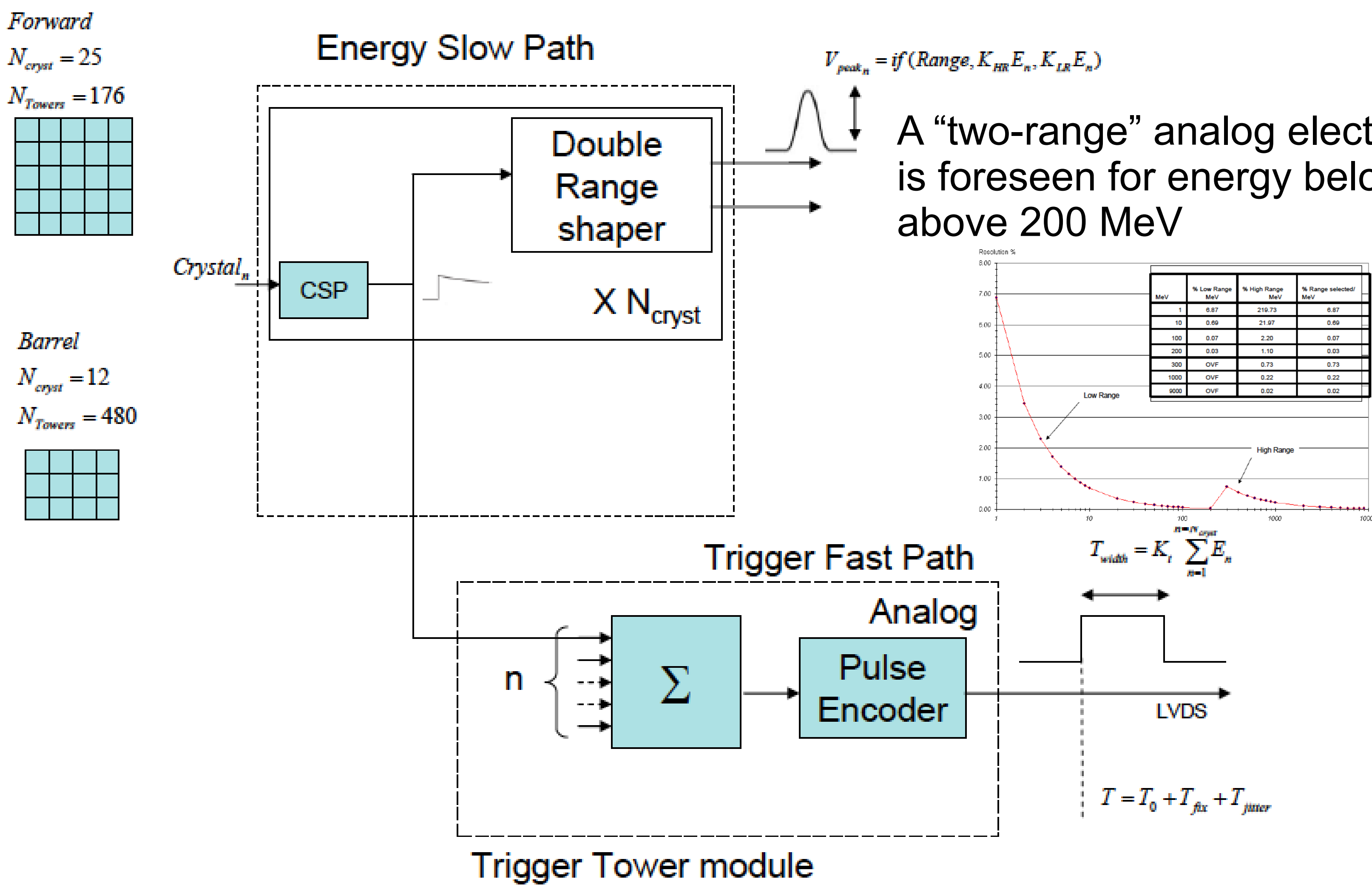
Lab tests demonstrated very good results. Extensive tests foreseen for the Fall/Winter 2011.

Last decision to be taken for the TDR expected at the beginning of 2012.

DAQ and trigger system

A fast path is foreseen for the trigger and a slower one for the analog DAQ

A "two-range" analog electronics is foreseen for energy below or above 200 MeV



MeV	% Low Range MeV	% High Range MeV	% Range selected/ MeV
1	6.87	219.73	6.87
10	0.69	21.97	0.69
100	0.07	2.20	0.07
200	0.03	1.10	0.03
300	OVF	0.73	0.73
1000	OVF	0.22	0.22
9000	OVF	0.02	0.02

Golden measurements: General

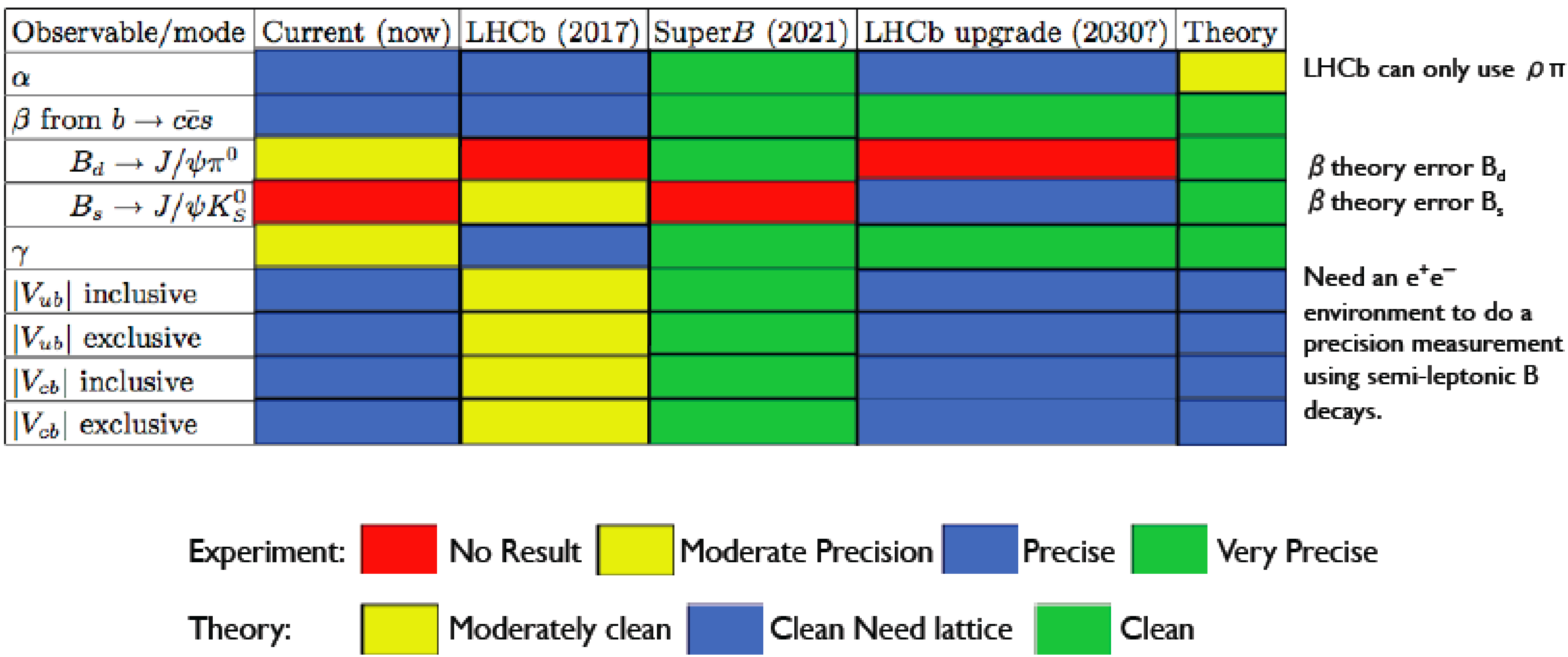
Experiment: Red = No Result, Yellow = Moderate Precision, Blue = Precise, Green = Very Precise

Theory: Yellow = Moderately clean, Blue = Clean Need lattice, Green = Clean

Observable/mode	Current (now)	LHCb (2017)	Super$B$ (2021)	LHCb upgrade (2030?)	theory	
τ Decays						
$\tau \to \mu\gamma$	Yellow	Yellow	Green	Yellow	Green	Benefit from polarised e⁻ beam
$\tau \to e\gamma$	Yellow	Yellow	Green	Yellow	Green	
$B_{u,d}$ Decays						
$B \to \tau\nu, \mu\nu$	Yellow	Red	Blue	Red	Blue	very precise with improved detector
$B \to K^{(*)+}\nu\overline{\nu}$	Red	Red	Green	Red	Green	Statistically limited: Angular analysis with >75ab^{-1}
S in $B \to K^0_S\pi^0\gamma$	Yellow	Red	Green	Red	Yellow	Right handed currents
S in other penguin modes	Yellow	Yellow	Green	Blue	Yellow	SuperB measures many more modes
$A_{CP}(B \to X_s\gamma)$	Blue	Yellow	Green	Yellow	Green	systematic error is main challenge
$BR(B \to X_s\gamma)$	Blue	Yellow	Green	Yellow	Yellow	control systematic error with data
$BR(B \to X_s\ell\ell)$	Yellow	Red	Green	Red	Green	
$BR(B \to K^{(*)}\ell\ell)$	Yellow	Blue	Green	Green	Yellow	SuperB measures e mode well, LHCb does μ
B_s Decays						
$B_s \to \mu\mu$	Red	Blue	Red	Green	Green	
β_s from $B_s \to J/\psi\phi$	Red	Blue	Red	Green	Green	
$B_s \to \gamma\gamma$	Red	Red	Blue	Red	Green	
a_{sl}	Red	Blue	Green	Green	Green	
D Decays						
mixing parameters	Yellow	Blue	Green	Green	Green	
CPV	Red	Blue	Green	Green	Green	Clean NP search
Precision EW						
$\sin^2\theta_W$ at $\Upsilon(4S)$	Red	Red	Green	Red	Green	Theoretically clean
$\sin^2\theta_W$ at Z-pole	Red	Blue	Red	Green	Yellow	b fragmentation limits interpretation

Golden measurements: CKM

Comparison of relative benefits of SuperB ($75ab^{-1}$) vs. existing measurements and LHCb ($5fb^{-1}$) and the LHCb upgrade ($50fb^{-1}$).

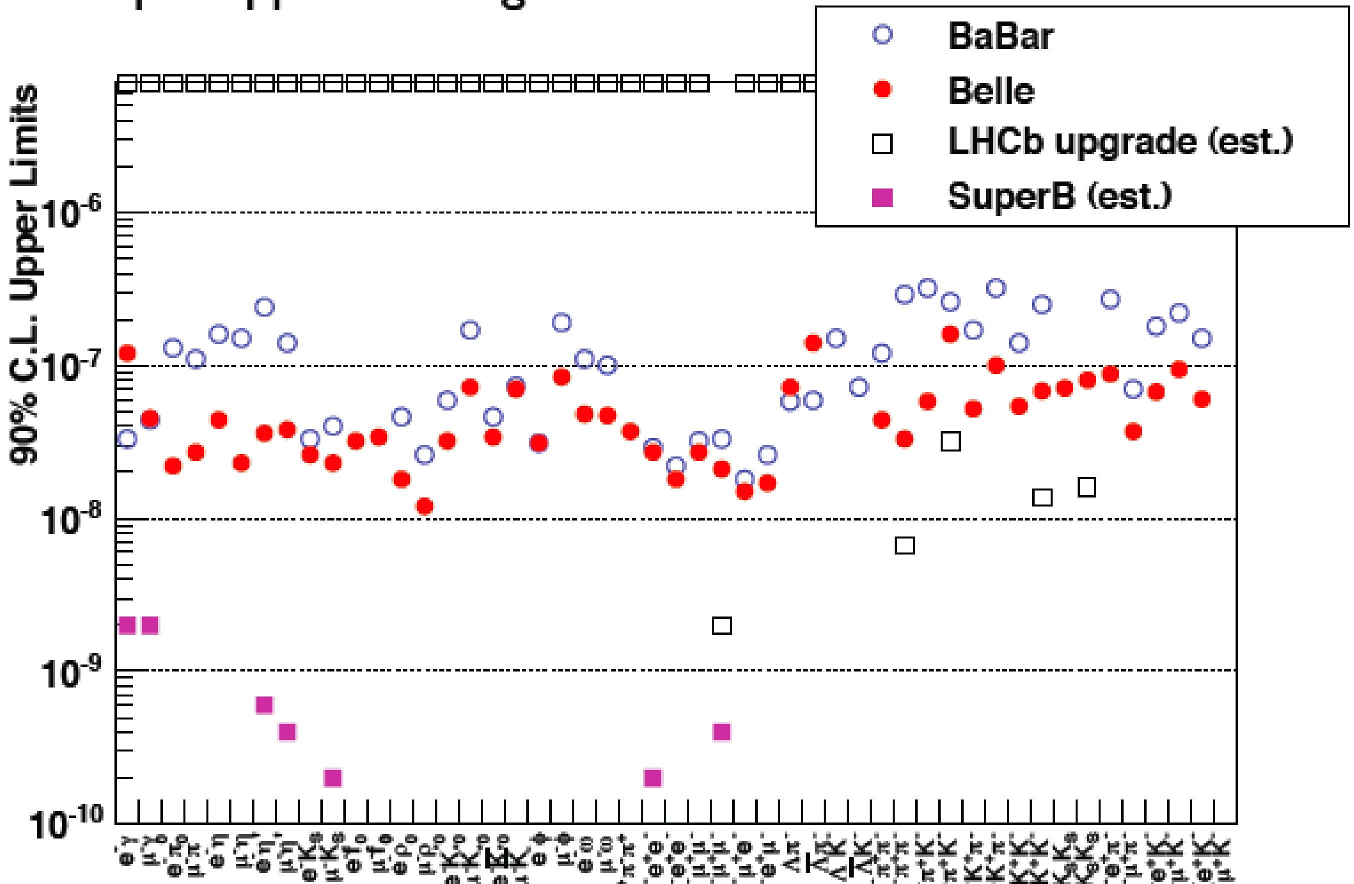


τ Lepton Flavor Violation (LFV)

- ν mixing leads to a low level of charged LFV ($B \sim 10^{-54}$).
  - Enhancements to observable levels are possible with new physics.
- e^- beam polarisation helps suppress background.

Two orders of magnitude improvement at SuperB over current limits.

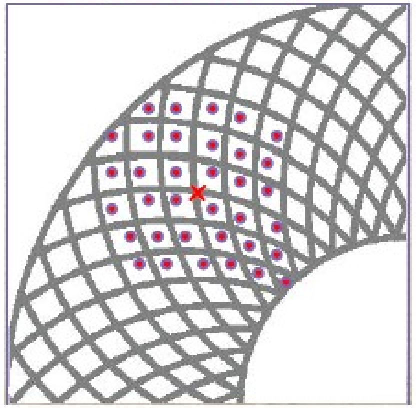
Hadron machines are not competitive with e^+e^- machines for these measurements.



Backward EMC status

Backward EMC prototype status

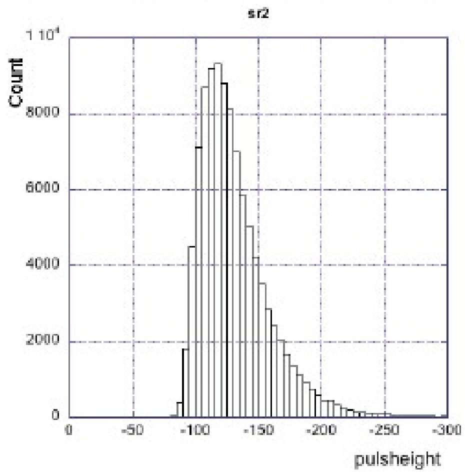
Spiral strips



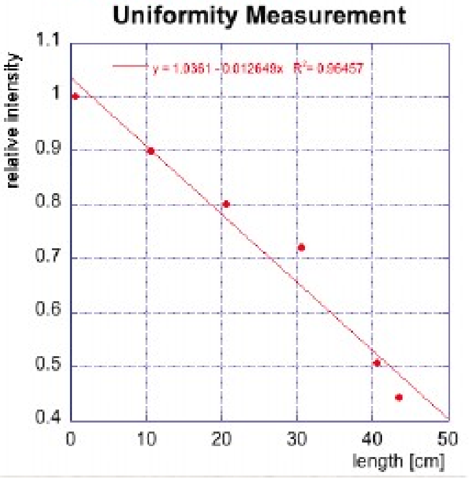
Straight wedges

Lead sheets (2.8 mm)

MIP peak = 5.9 p.e.



Uniformity



(Eigen)

Open Detector Design Issues

System	Baseline	Issues
MDI	Initial IR designed	Magnetic elements and radiation masks. Background simulations: global map, detector occupancy
SVT	6-layer silicon	Technology for Layer 0: striplets or pixels. Thin pixels R&D. Readout chip for strips.
DCH	Stereo-axial with a gas mixture He-Based	Background rates. Mechanical structure. Cluster counting option R&D.
EMC	Babar Barrel with CsI(Tl) FWD: LYSO	Electronics and trigger. Mechanical structure. Forward EMC technology:LYSO / LYSO+CsI(Tl); Pure CsI. Backward EMC: cost/benefit analysis
PID	DIRC with FBLOCK	FBLOCK design. Photon detection. Forward PID: cost/benefit analysis. Different technologies.
IFR	Scintillator+fibers	8 vs 9 layers, and optimized configuration. SiPM radiation damage and location. Extra 10cm iron. Mechanical design and yoke reuse.
ETD	Synchronous with constant latency	Fast link rad hardness. L1Trigger (jitter and rate). ROM design. Link to computing for HLT.