A LYSO calorimeter for the SuperB factory

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13th Vienna Conference on Instrumentation
11-15 February 2013

Outline

- Motivations for a LYSO calorimeter development
- LYSO crystal main characteristic
- Matrix prototype
- Beam test at CERN
- Beam Test at Frascati
- Conclusions

Motivations

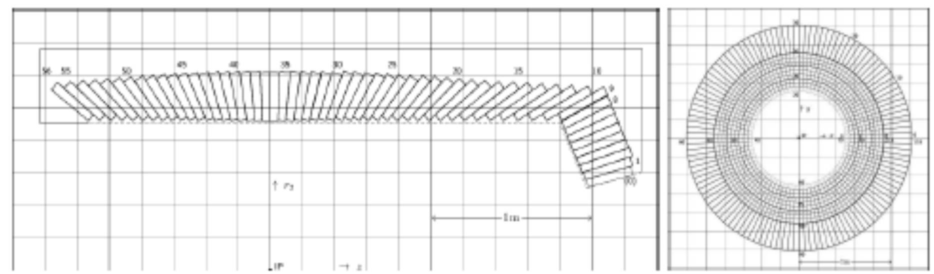
- R&D project devoted to the development of an electromagnetic calorimeter for a high intensity flavor factory
- Optimizations and studies are sometimes explicitly based on SuperB
  - high luminosity asymmetric e+e- collider
  - Center of mass energy 10.58 MeV, ϒ (4S) resonance
- Despite this aspect, the developed detector may still have an application in several other environments

Calorimetry at b-factories

- Both b-factory experiments of the last decade (BABAR and Belle) use the same kind of electromagnetic calorimeter
  - CsI(Tl) crystals calorimeter
- Main CsI(Tl) characteristic is the very high light yield which means very good performances even at low energy (few GeV)
  - BABAR resolution $$\frac{\sigma(E)}{E} = \frac{2.30}{\sqrt[4]{E(GeV)}} \oplus 1.35\%$$
- How are CsI(Tl) performances in an environment with a luminosity a factor 100 higher?

Example: BABAR calorimeter

- Asymmetric machine → asymmetric detector
- After 10 years with a Luminosity ~ $10^{34}cm^{-2}s^{-1}$:
  - "Barrel" EMC:
    - Small radiation damage
  - "Forward" EMC:
    - High radiation damage



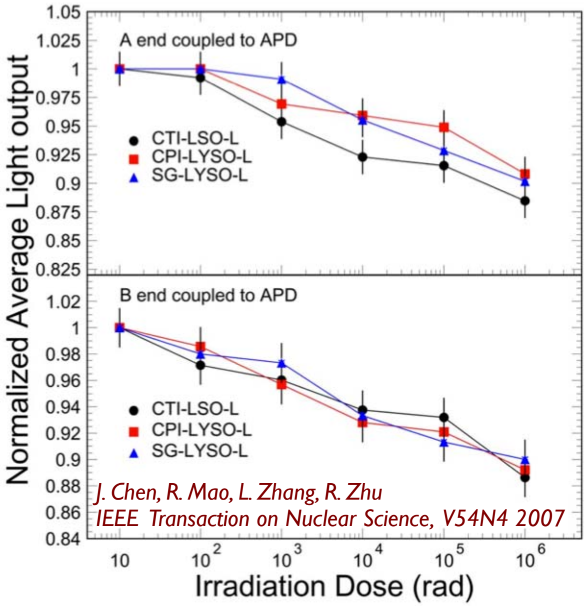
- In the hypothesis to have a machine running for 10 years at $10^{36}cm^{-2}s^{-1}$:
  - "Barrel" could sustain this rates and radiation damage is not an issue
  - "Forward" need a detector faster, with finer granularity and with an higher radiation hardness

Crystal	NaI(Tl)	CsI(Tl)	CsI	PWO	LYSO (Ce)
Density (g/cm^3)	3.67	4.51	4.51	8.3	7.1
Melting Point (°C)	651	621	621	1123	2050
Radiation Legth (cm)	2.59	1.85	1.85	0.9	1.14
Moliére Radius (cm)	4.8	3.57	3.57	2.0	2.2
Hygroscopicity	yes	slight	slight	no	no
Luminescence (nm)	410	560	420/310	560/420	420
Decay Time (ns)	230	1250	35/6	30/10	45
Light Output (%)	100	165	3.6/1.1	0.3/0.08	80
d(LO)/dT (%/°C)	~0	0.3	-0.6	-1.9	-0.3
Radiation Damage	Yes	10%/krad	2%/krad	Small	Small

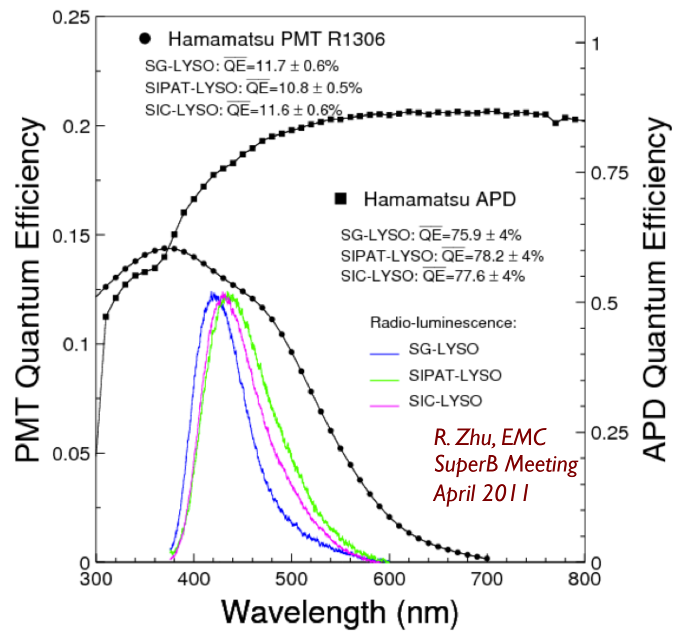
- **LYSO Crystals meets all the requirements**
- **R&D campaign started in 2010 with laboratory and beam tests**

$$Lu_{2(1-x)}Y_{2x}SiO_5$$

LYSO Characterization



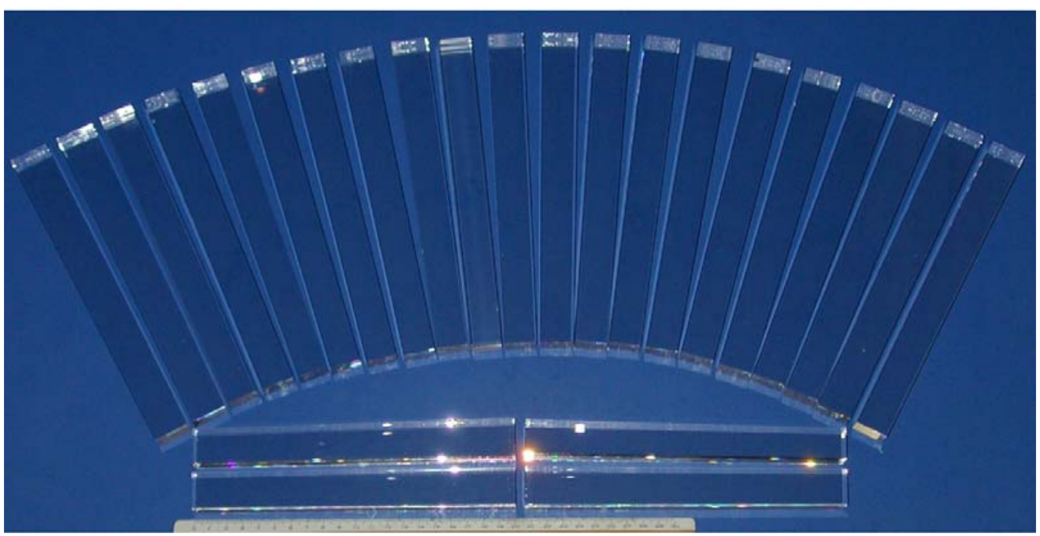
- Radiation damage on this type crystals has been measured in 2007
  - LY loss ~12% after 1Mrad

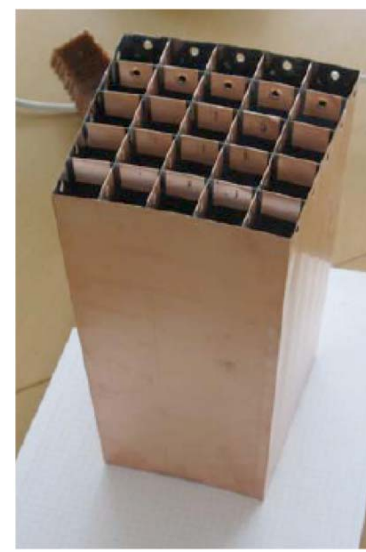


- Luminescence peak between 420 and 440 nm (depends on producer)
- Small differences in sensors QE (<2%)

LYSO Crystal Matrix Prototype

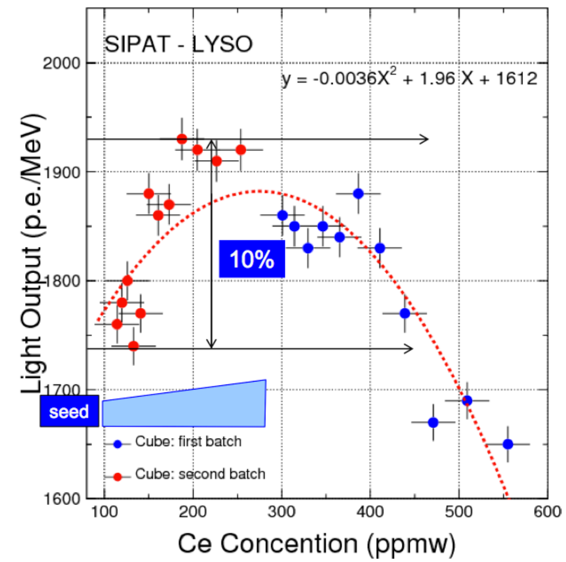
- A 5x5 matrix of LYSO crystal was built in order to perform beam tests
  - 3 different LYSO producer
    - Saint-Gobain (SG) 12 crystals
    - SIPAT 10 crystals
    - SICCAS 3 crystals
  - Crystal are 20cm long (~17.4X_0)
  - Glass fiber alveolar structure
- Before beam tests all crystals have been studied in laboratory



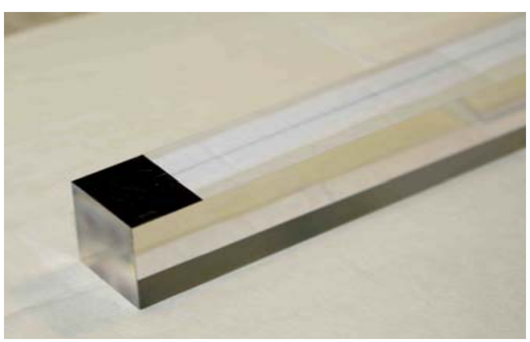


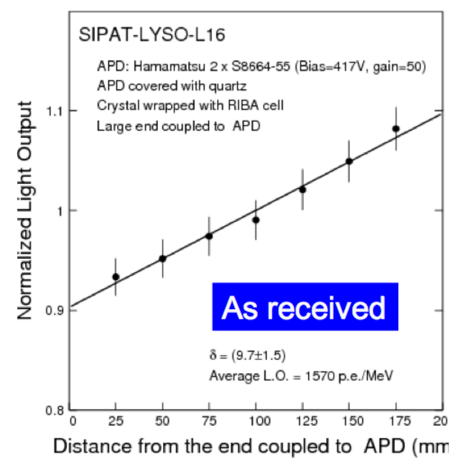
Light Output uniformity

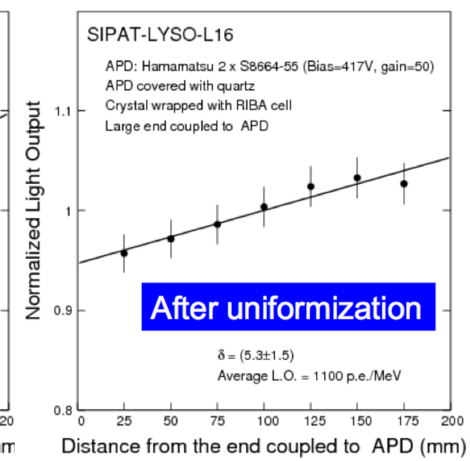
- Light output non-uniformity related to Ce concentration along crystal
- Significant non-uniformity impacts on energy resolution
- Uniformization with 15mm black band painted on the opposite side of readout
  - Pro: Fast and reversible
  - Con: ~30% of light loss



R. Zhu, EMC SuperB Meeting February 2011

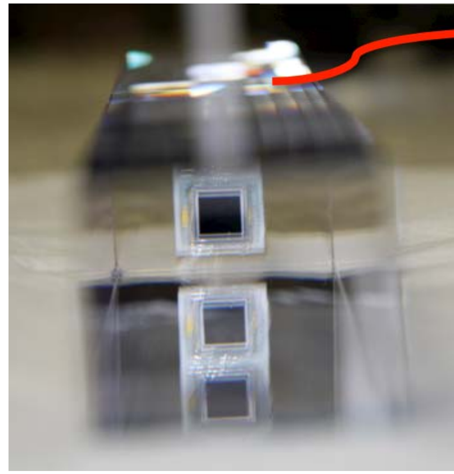


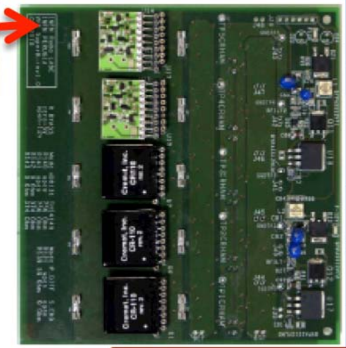


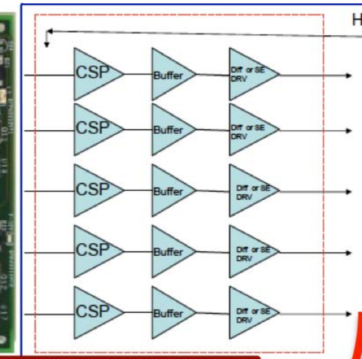


Readout Electronics

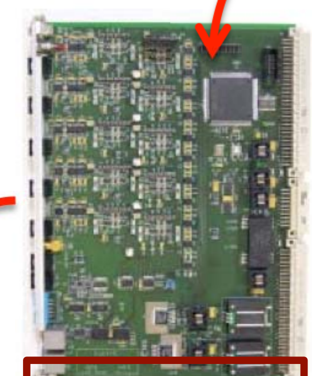
- Sensor:
  - 5x5 mm^2 Hamamatsu S8664 APD
- Very Front-End:
  - Custom made board with commercial Cremat CSP (1.4V/pC)
- Shaping Amplifier:
  - Custom VME board with commercial Cremat Shaper (100ns)
- DAQ:
  - Caen V1720 250MHz differential digitalizer



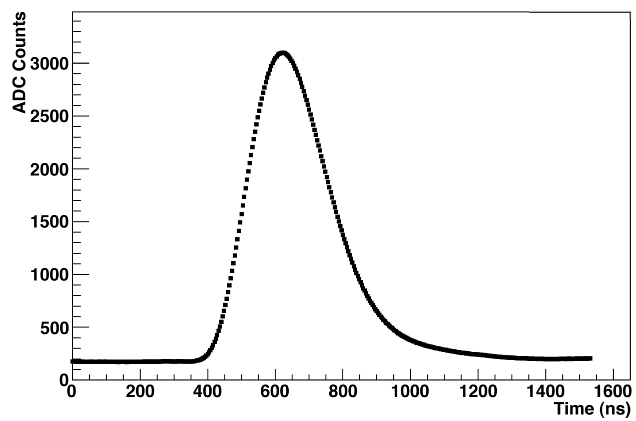




Very Front-End Board



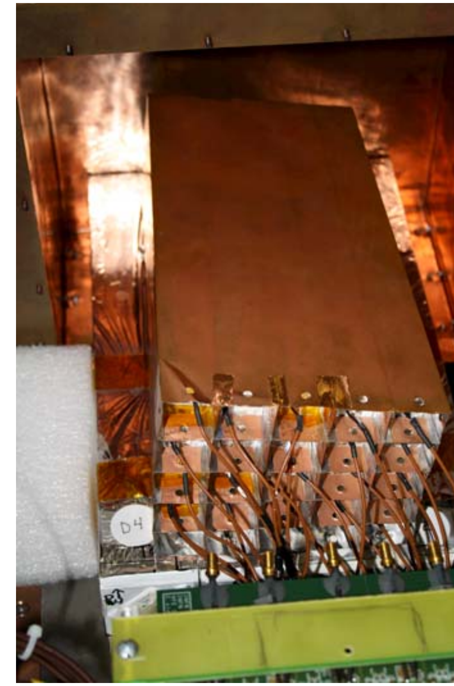
VME Shaper Board



VME Digitalizer

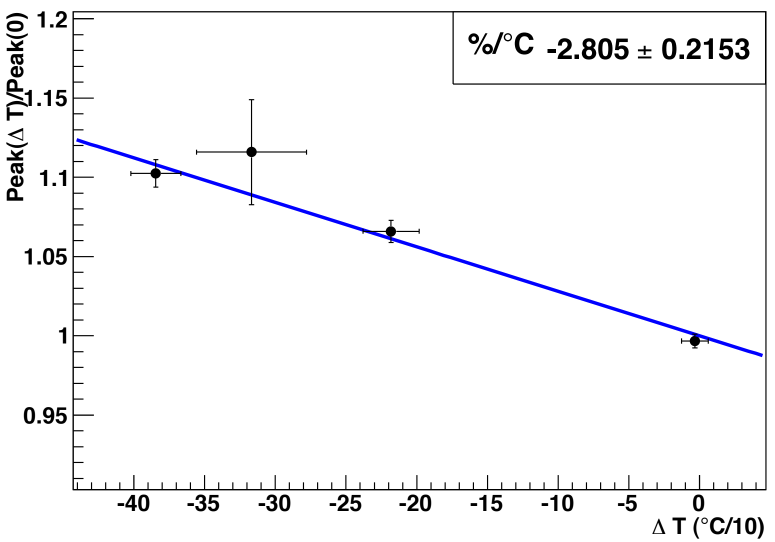
Beam Test @ CERN

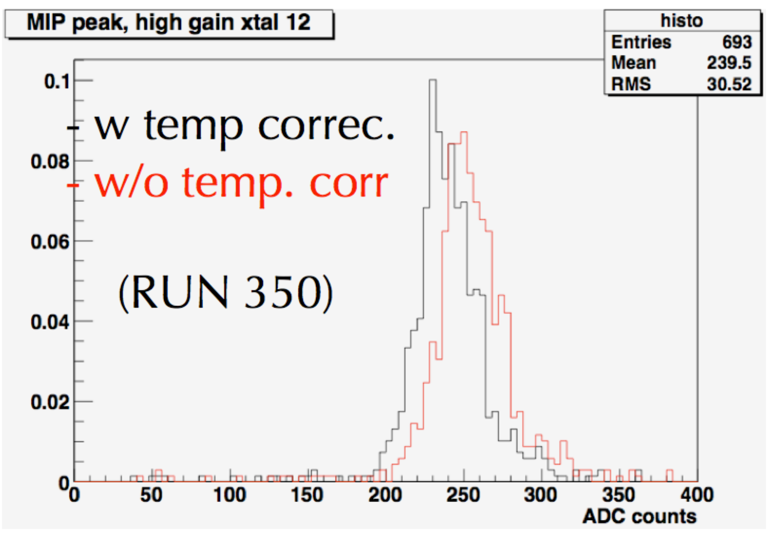
- October 2010
- Beam Test at CERN PS : 1-4GeV
  - T10 line, about 12m far from beam pipe
- Trigger with two scintillator fingers
- Cherenkov threshold detector (e/π separation)
- 5 Temperature sensors



Beam Test @ CERN

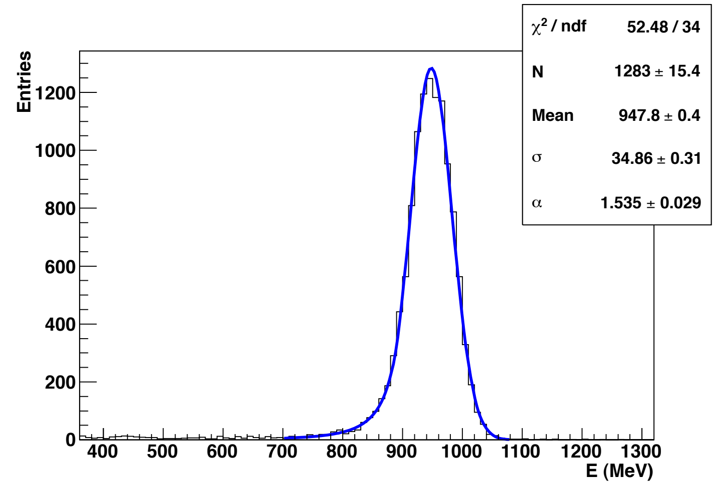
- High number of muon and π in the beam
  - MIP deposit at 1GeV along crystal ~198MeV
- Used to extract temperature correction factor for APDs: -2. 8%/C°
- Also intercalibration coefficients evaluated with MIP

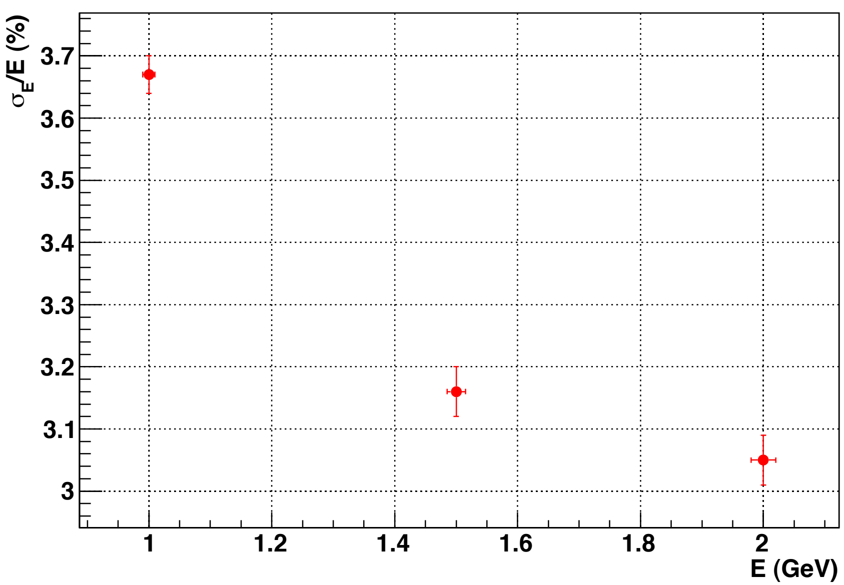




Beam Test @ CERN

- Sum over all crystals over threshold
  - Threshold: $3*\sigma_{ch}$
  - σ_{ch} ~ 800KeV
- Energy distribution fitted with crystal-ball function

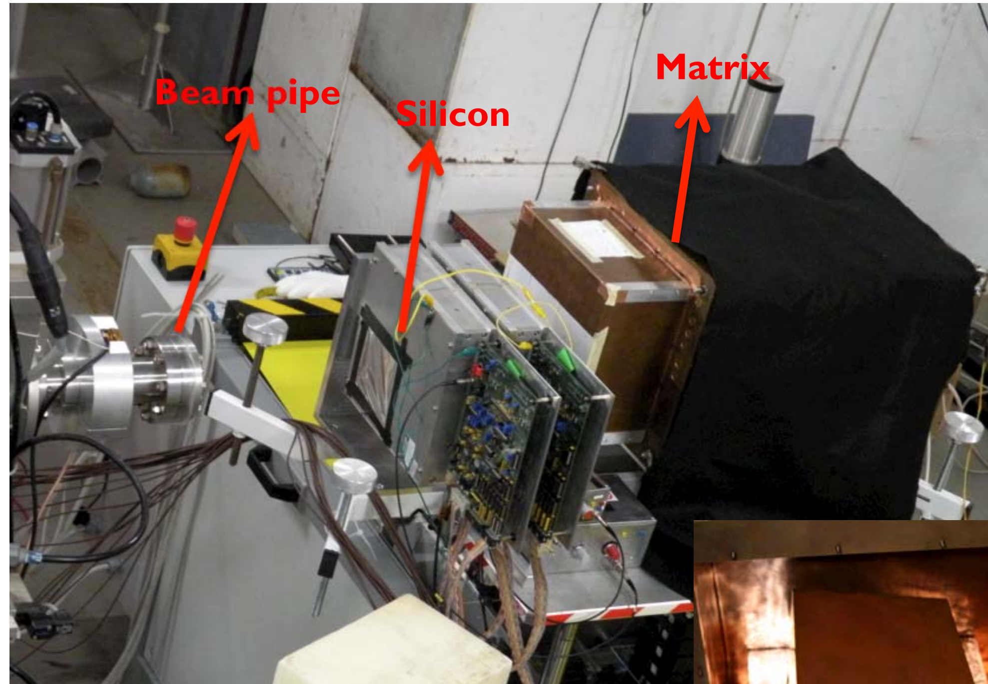


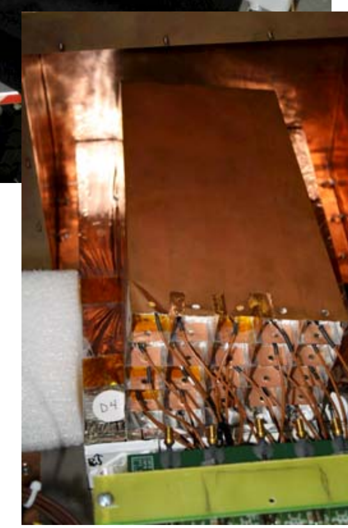


- We were able to collect data only at 3 energy (1, 1.5 and 2 GeV)
- Electron statistics inside beam too low at higher energy

Test @ Frascati Laboratory

- Beam Test Facility @ LNF.
  - 50-500 MeV
  - 50Hz with 1-10^9 e^-/spill
- Higher gain in read out chain wrt CERN test beam (~3)
- Silicon beam telescope:
  - Single-side 228μm strip pitch
  - 2 planes x-y
  - Active area 8.75x8.75 cm^2

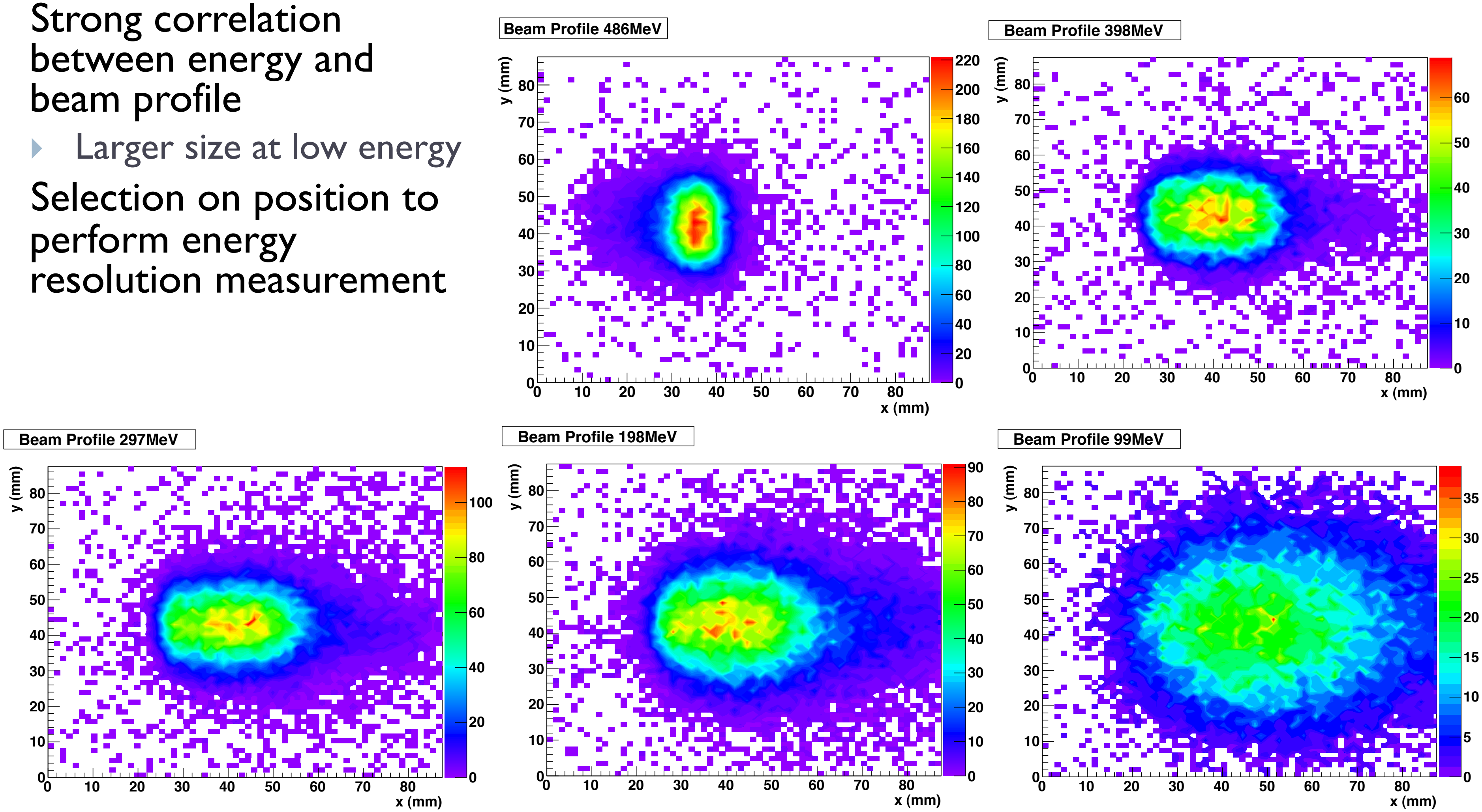




- Data:
  - 5 energies: from 487MeV to 99 MeV
  - 3 different positions

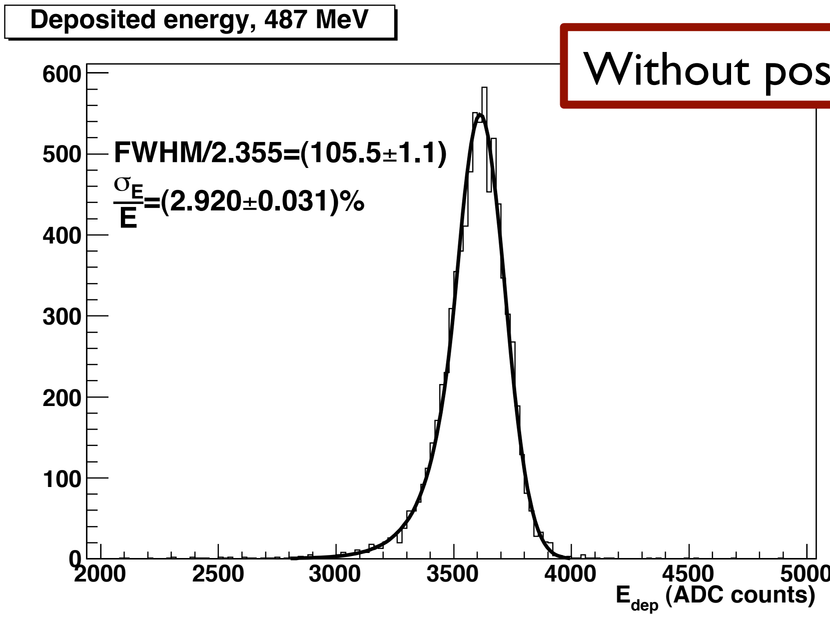
Beam profile

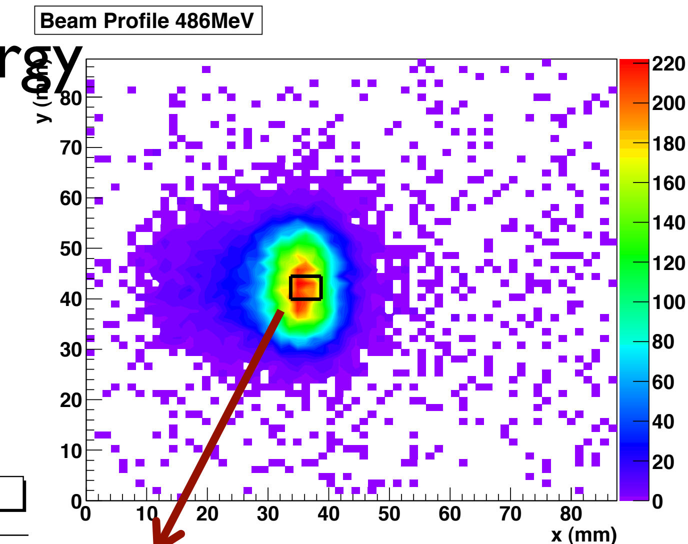
- Strong correlation between energy and beam profile
  - Larger size at low energy
- Selection on position to perform energy resolution measurement

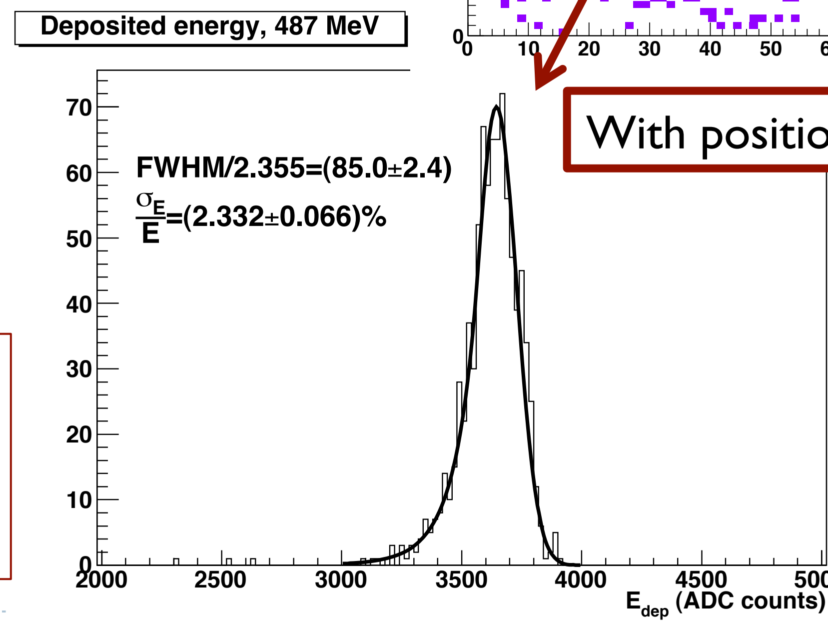


Energy reconstruction

- Ex : 487 MeV total reconstructed energy



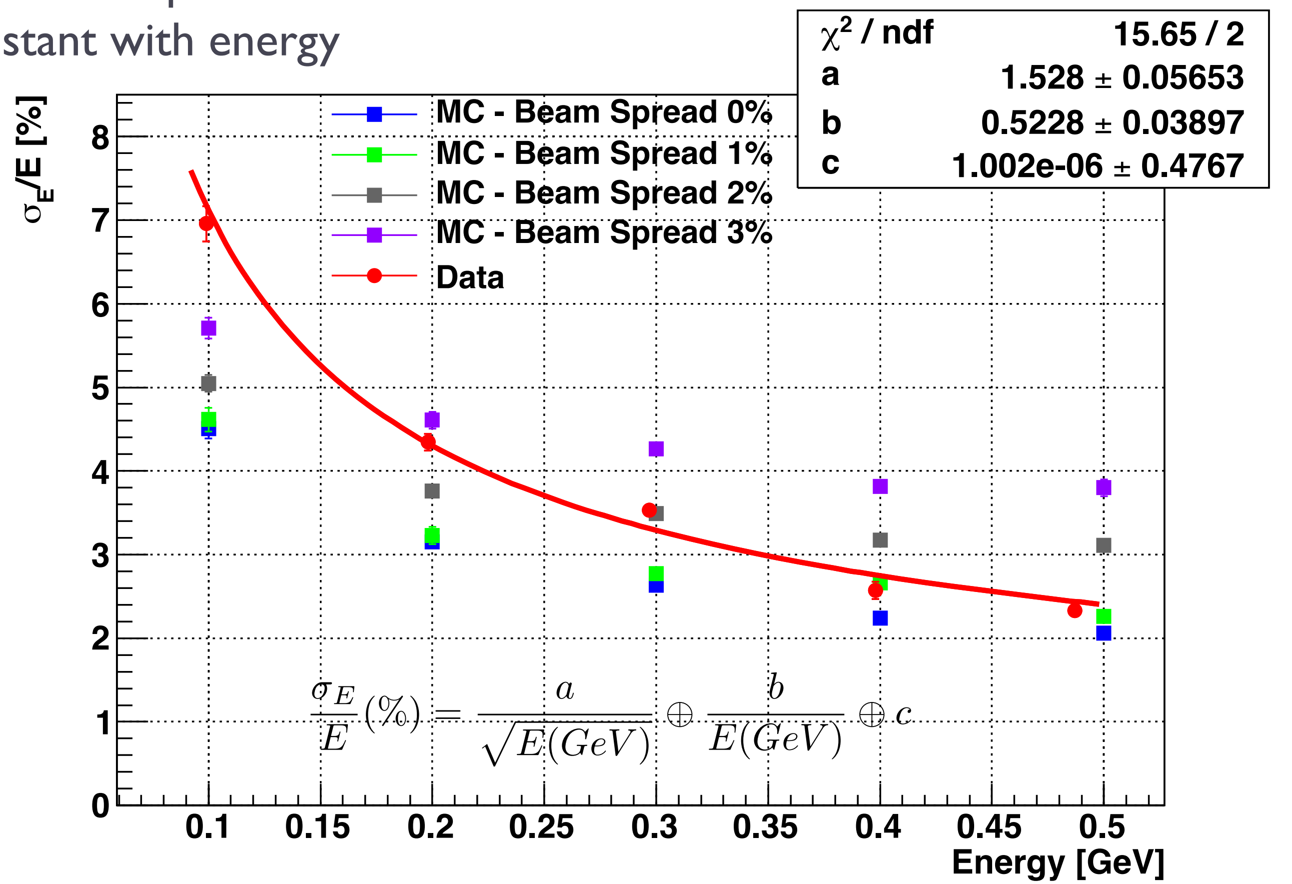




- Channel intercalibration
  - RMS minimization (e^- events)
  - Cosmic muons

Results (I)

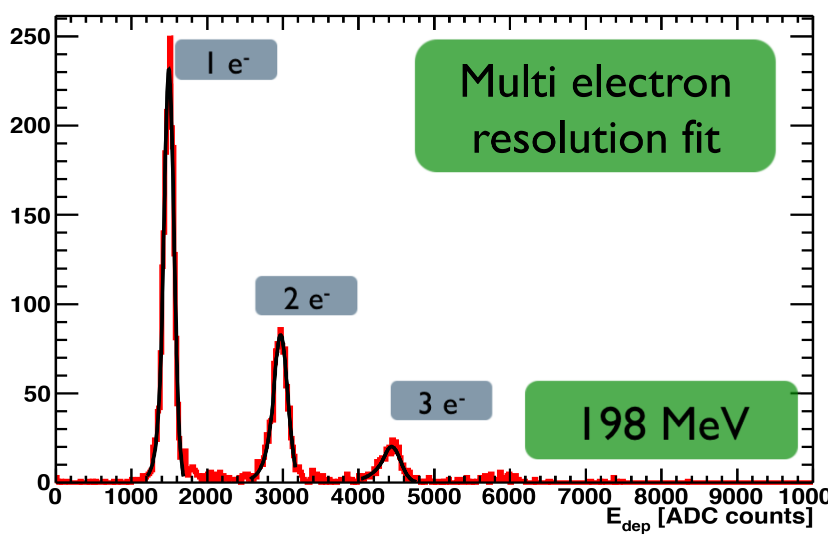
- Beam energy spread is not precisely know (estimation ~1%@500MeV)
  - MC test by changing the beam spread
  - Beam spread is not constant with energy

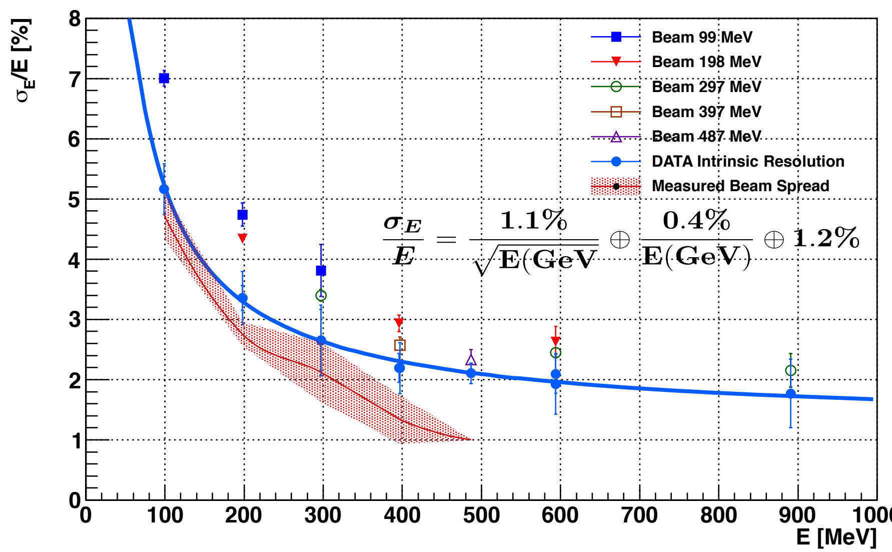


- Null constant term c
  - Due to the fact that beam spread is not constant with energy

Beam spread extraction

- Extract BS directly from data using multi particle events
  - Assume difference in resolution between N e- with energy E and 1 e- with energy NxE is due to different beam energy spread
  - Obtain beam spread and matrix resolution from minimization



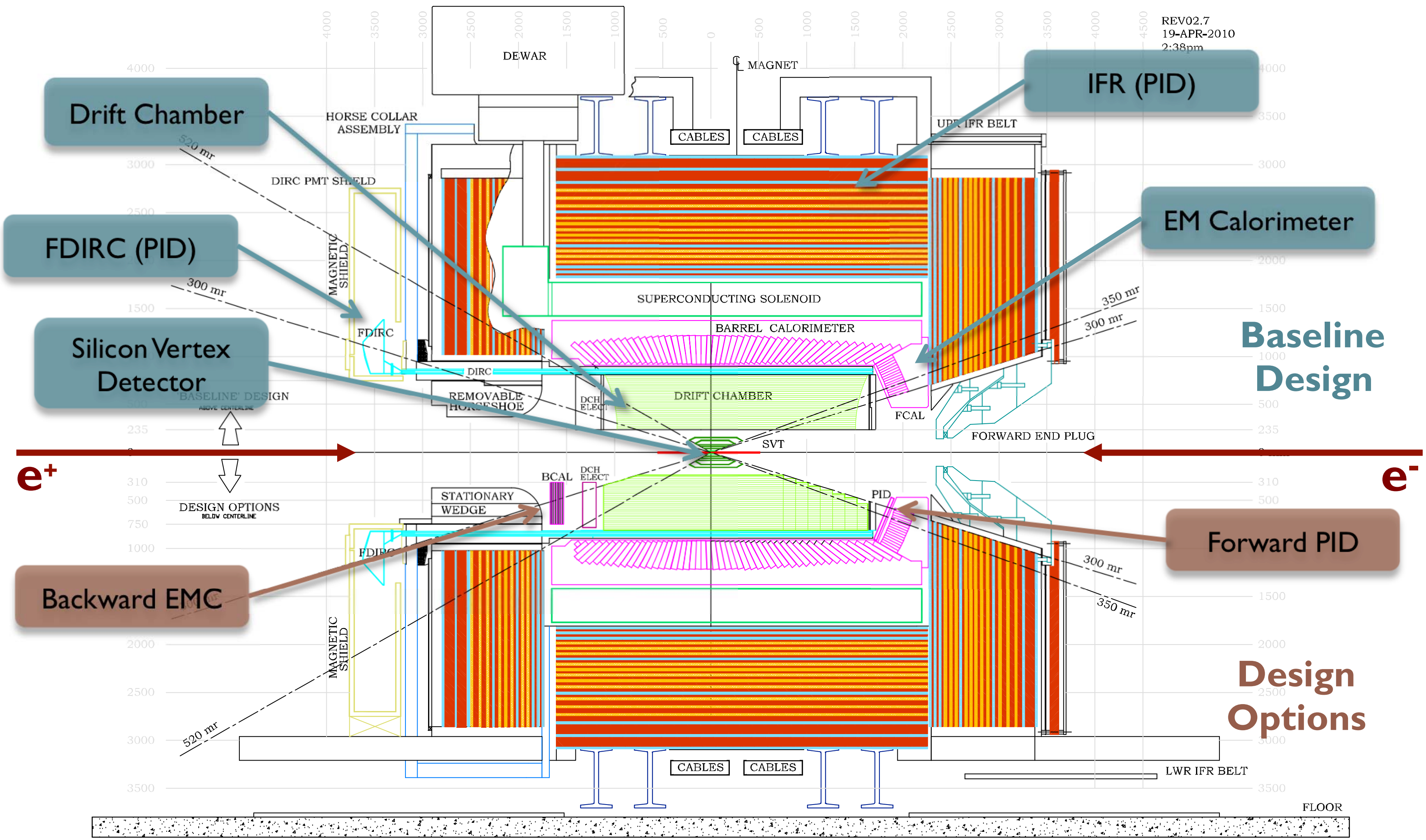


Conclusions

- R&D started with the main purpose of developing a new calorimeter for a high intensity flavor factory
  - Fast response
  - High granularity
  - Radiation hardness
- First calorimetric measurement with LYSO crystal
- Two beam tests
  - CERN: tested the response of the matrix at energy between 1 and 2 GeV
  - Frascati: measured the energy resolution at energy below 500MeV

$$\frac{\sigma_E}{E} = \frac{1.1\%}{\sqrt{E(GeV}} \oplus \frac{0.4\%}{E(GeV)} \oplus 1.2\%$$

SuperB detector

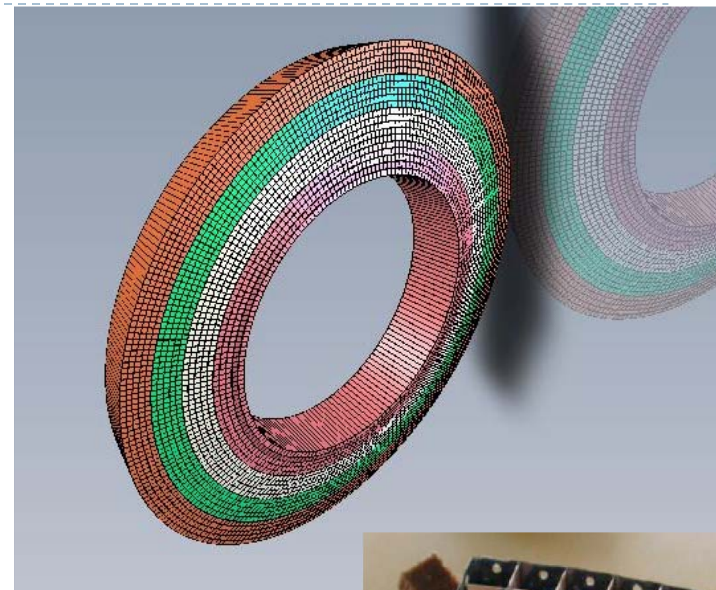


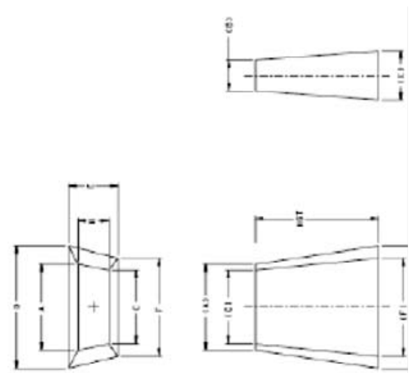
SuperB Story

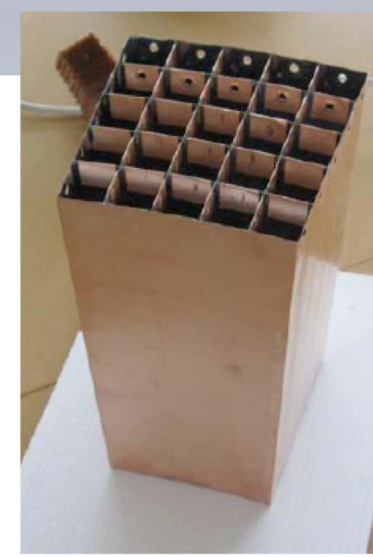
- R&D project started on 2005
- Italian Government approval in December 2010
  - First founding ~250M€
- Site selection in May 2011
  - Tor Vergata University campus (near Rome)
- Cabibbo Lab start-up signed in October 2011
- Detailed costing by Accelerator management during 2012
- November 2012 : Costing review by Italian Ministry of education university and research commission
- December 2012 : Project was closed
  - The Minister pointed out that the importance and quality of the program were out of discussion, but that the economic conditions of the country and the limits foreseen by the National Research Plan were incompatible with the estimated cost of the project.

Geometry and Mechanics

- General Layout
  - 20 rings of crystal arranged in 4 groups of 5 layers each
  - Each group of 5 layers arranged in modules 5x5
- Crystal dimensions
  - Approx 2x2 front face and 2.5x2.5 back face
  - 20cm long (~$17.5X_0$)
- Two mechanical structure prototypes (5x5 matrix) made by RIBA (Faenza, Italy)
  - Beam Test
  - Mechanical test

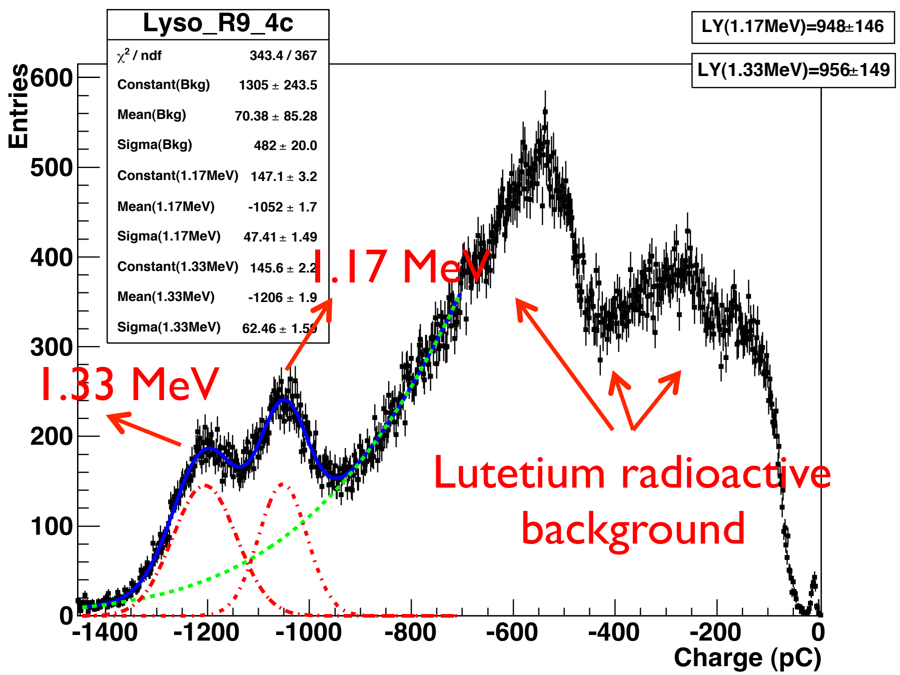


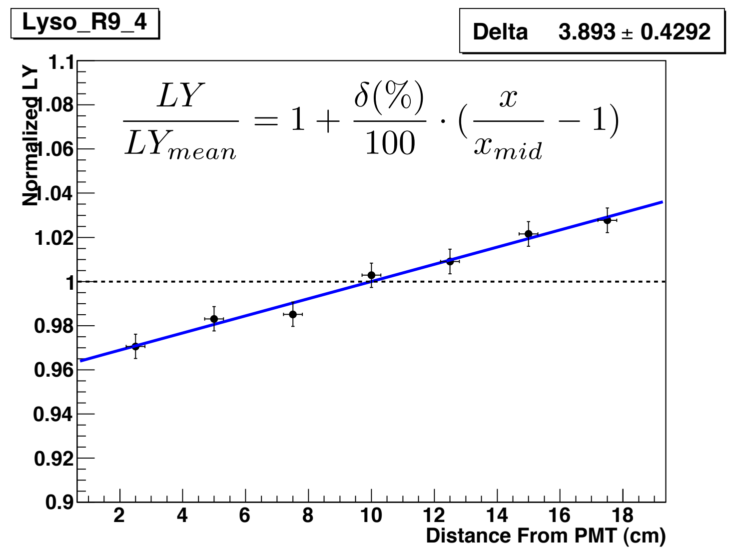




LYSO Characterization with PMT

- 12 LYSO crystals (Saint Gobain)
- Light Output e uniformity studies with a ^{60}Co source (2γ: 1.17 e 1.33 MeV)





- Delta value smaller than with APD
- Difference due to the different active surface
  - PMT cover 100% of crystal face
  - APD cover ~6% of crystal face