SAC: the PbF_2 calorimeter of PADME experiment

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The SAC Calorimeter

At PADME (LNF) we have developed a Small Angle Calorimeter (SAC) that meets these requirements:

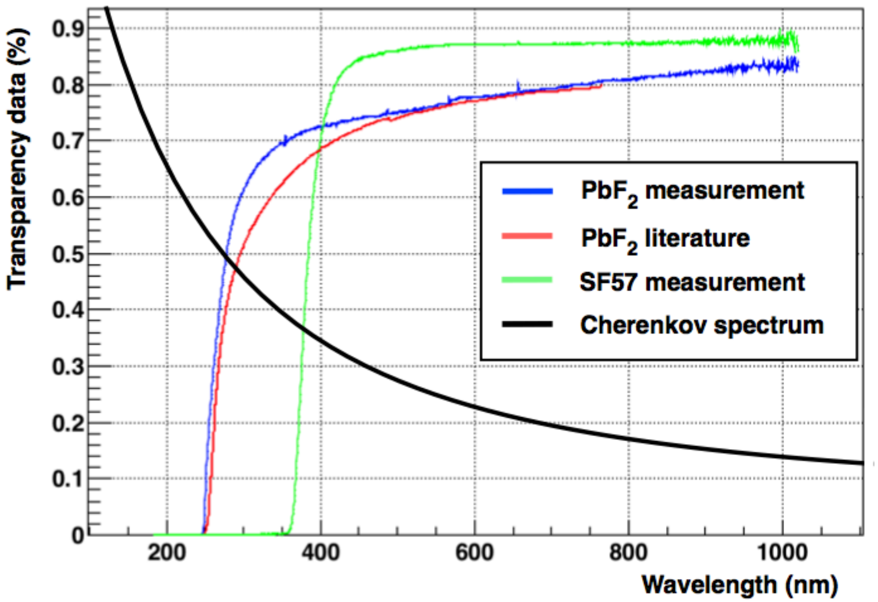
1. Need to measure photons from ~100 MeV
2. Need to cope with very high rate several ~10 e+ per 100ns
   → Avoid scintillation mechanism if possible (time too long)
3. Need a good time resolution ~200 ps
   → Need very fast photosensors with low transit time spread
4. Need to be radiation tolerant (oder 1Gy per 10^{13} e+ on target)

In this talk, we evaluate the performance of the SAC with a test beam done at LNF, using fast Lead Fluoride 87 crystals (**PbF2**) and the newly developed Hamamatsu R13478UV photomultiplier tube (**PMT**), optimized for fast response.

Crystal Choices

The SAC consists of 25 PbF_2 crystals, each with transverse dimensions 30×30 mm^2 , and length 140 mm.

- PbF2 crystals, compared with the Cherenkov spectrum, show a very good transparency down to ~250 nm.



Properties of PbF_2, BGO, BaF_2 and CeF_3 scintillators

Crystal	PbF_2	BGO	BaF_2	CeF_3
Density [g/cm^3]	7.77	7.13	4.87	6.16
Radiation length [cm]	0.93	1.1	2.1	1.7
Moliere radius [cm]	2.22	2.7	4.4	3.8
Decay constant [ns]	Ch	300	0.6, 620	5, 30

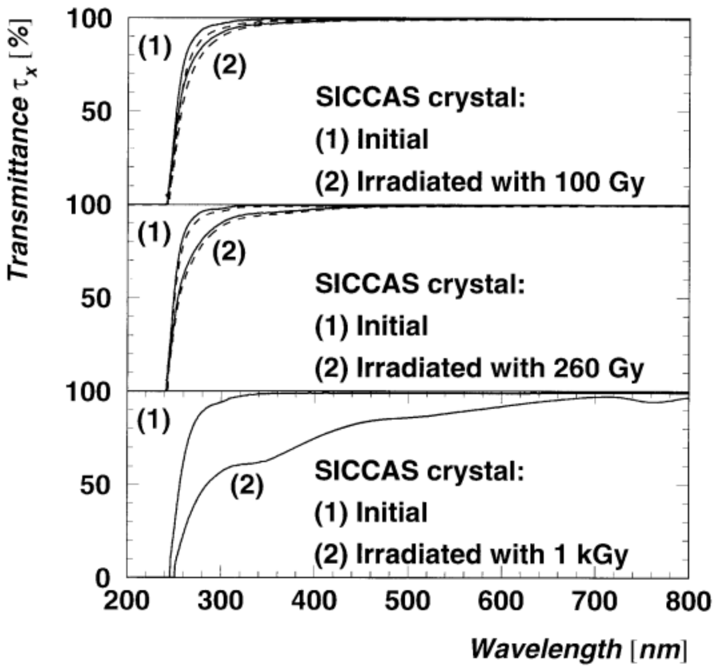
PbF2 has short radiation length and small Moliere radius:

→Smaller electromagnetic showers reduce the detector occupancy, thus enhancing the rate capabilities of such a detector.

Radiation Damage (1)

In term of Radiation Damage there are incongruous results:

NIM A 416 (1998) 357—363



NIM A A 484 (2002) 149–152

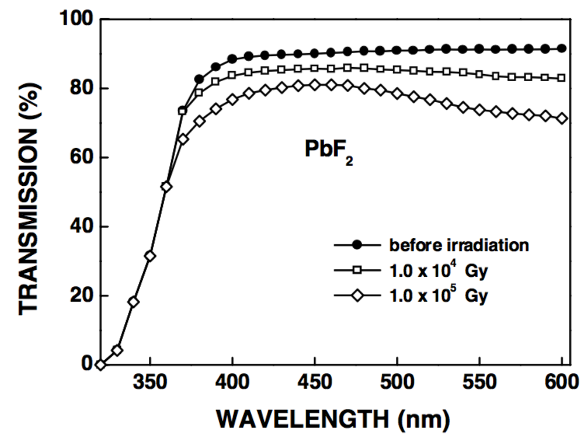


Fig. 1. Transmission spectra before and after ^{60}Co gamma-ray irradiation for PbF_2. The optical transmissior longitudinally.

we can do our measurement!

Radiation Damage (2)

NIM A 416 (1998) 357—363:

- In damaged crystals some small spontaneous recovery at room temperature was observed.

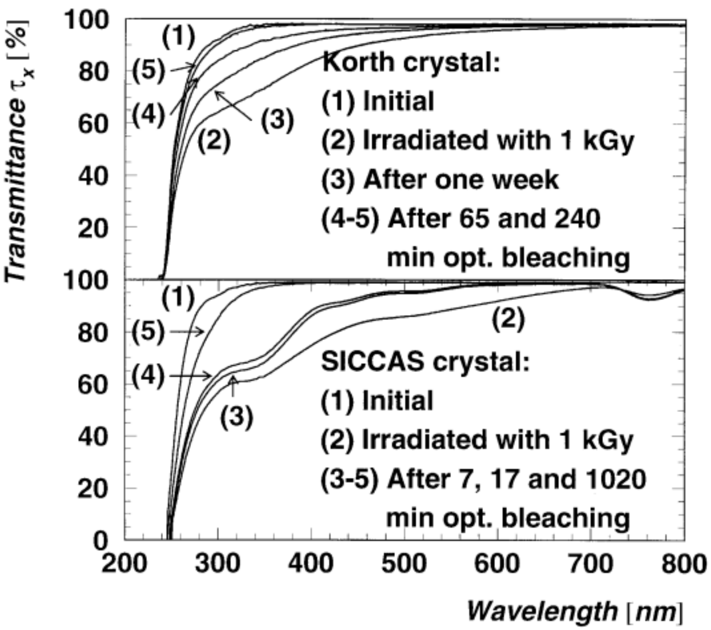


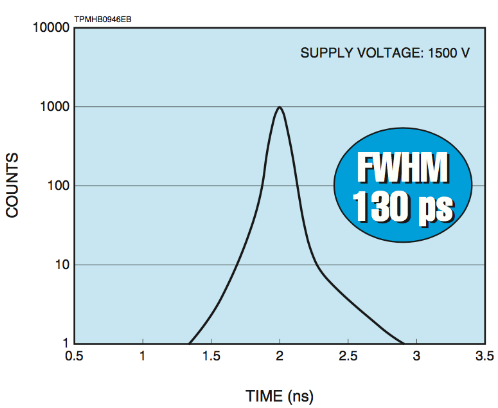
Fig. 8. Reduction of the initial (1) internal transmittance τ_X^i induced by γ-irradiation (2) and its restoration (3–5) in PbF_2 crystals. Optical bleaching was performed with two different lamp sources. Top: a filtered mercury lamp. Bottom: a quartz tungsten halogen lamp.

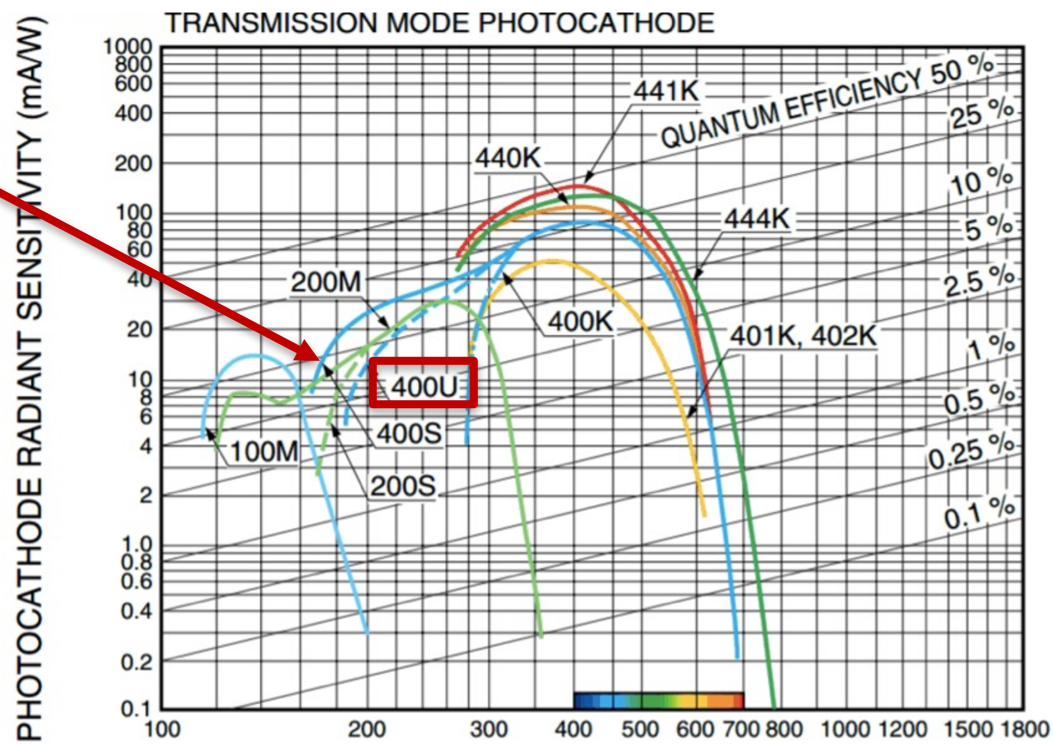
- An **almost complete recovery** could be induced by illuminating the crystals with **blue light**. Recovery even after excessive doses of 7 kGy could be achieved within a few hours of bleaching utilizing commercial mercury or QTH lamps.

PMT Choices

For the readout, the Hamamatsu R13478 UV has been chosen.

- This PMT has a diameter of 26 mm (22 mm of which is sensitive area) and thus covers a large area overall **(42%).**
- **QE ~ 15% @ 250 nm**
  ~ 20% @ 300 nm
  ~ 25% @>350 nm
- Gain ~ (5-10)x10^5
- **Extremely Fast Pulse Shape**

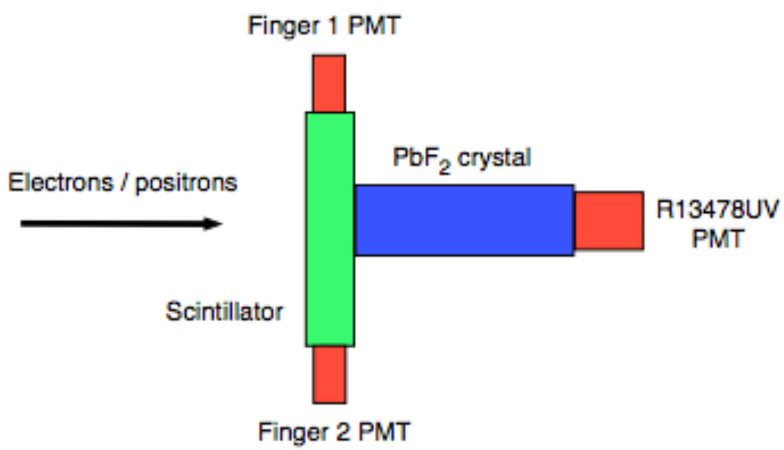




Test Beam setup

The chosen crystal and PMT options were subjected to a test beam at the LNF's Beam Test Facility (BTF), in order to characterize the SAC response and measure the energy and timing resolution, including the double-peak separation capability.

- A schematic of the detector test:

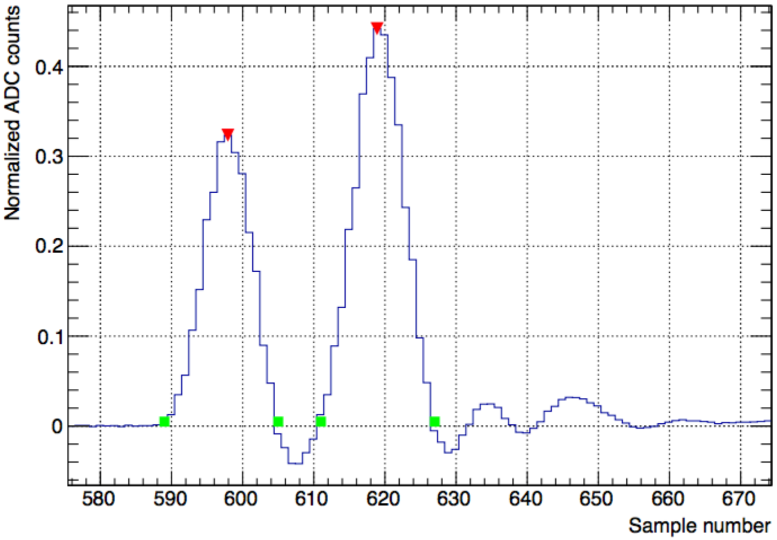


- A plastic scintillator coupled to two small 'finger' PMTs (model R9880U-110) provided a reference signal for comparison with the PbF_2 one.
- A R13478UV PMT was coupled to a PbF2 crystal, **wrapped with 50 um black Tedlar**, using optical grease and then connected to a 12-bit, 5 GSPS, 1024-sample digitizer (model CAEN V1742) for data acquisition.

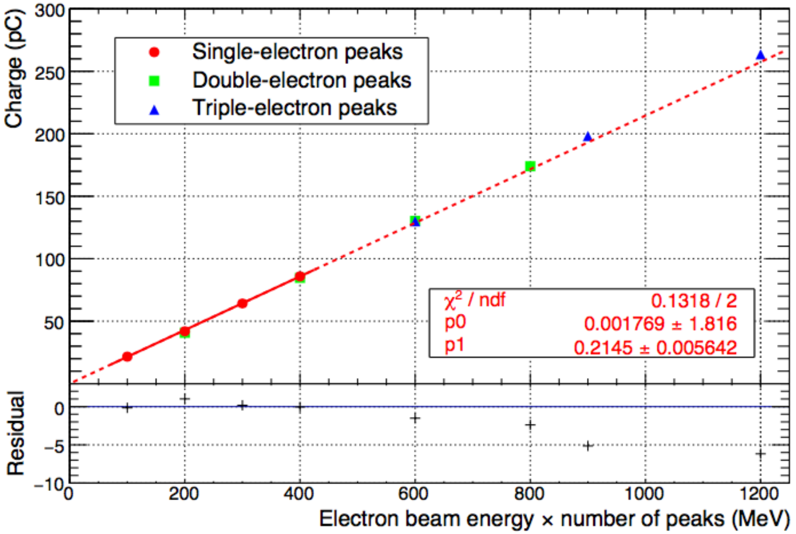
Charge Results

All the results are preliminary and still need to be corrected for deposited energy estimated by MC.

Amazing electrons separation
1 sample = 0.2 ns
~3 ns overall signal



HV = 1600 V
G = 8e5
N p.e. = 1.7 p.e./MeV

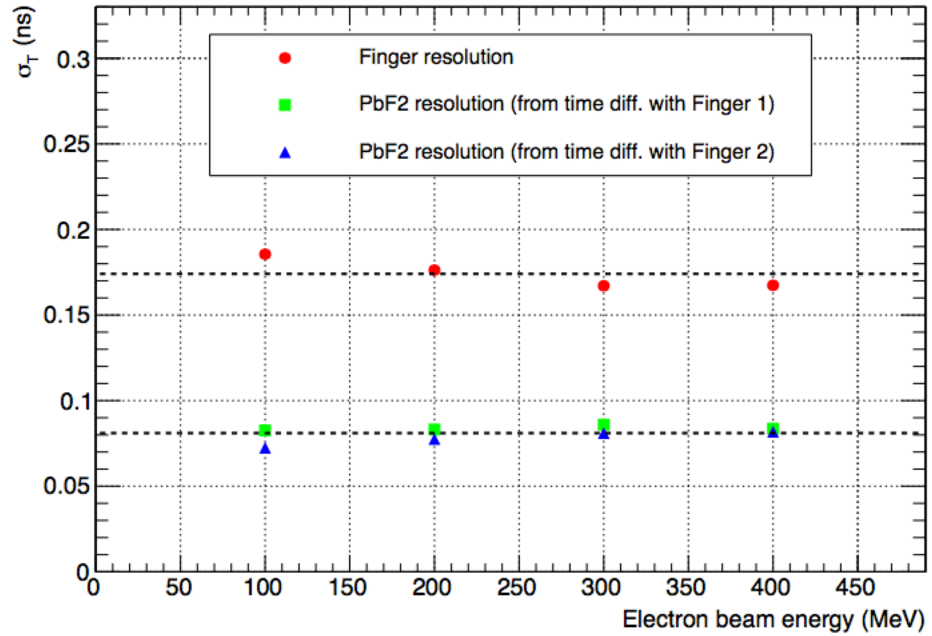


Time Results

- A cut was imposed on the integrated charge to select events with only one electron.

- The rising edge of the electron pulse was fit to a straight line, using as endpoints the 20% and 80% heights of the pulse amplitude. The location of the fit at 50% of the amplitude was then taken as the reference time.

- The PbF2 resolution was extracted by inserting the calculated finger resolution and summing in quadrature.



Conclusions

- A PbF_2 calorimeter seems to be a possible solution for Mu2e-II
  → Fast Cherenkov light emission.
  → High density, low X_0.
  → Number of photoelectron ~ 2 p.e./MeV with: ~15% QE, ~40% coverage area, optical grease, BLACK wrapping.

- We don't need a such good double-peak separation capability (1.8 ns @ PADME) → Teflon/Al/Tyvek to maximize the light yield

Photo-sensors are the real challenge:

- Extended UV SiPM → *neutrons damage* → *threshold problem* → *-20 C?*
- High gain APD (new Hamamatsu, RMD) → *high gain electronics?*
- Mesh PMT / MCP → *?*

A new R&D phase begins…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