MUSE General Meeting

Mu2e Calorimeter Crystals

Raffaella Donghia
on behalf of the Mu2e Calorimeter group

Crystal - Requirements

To match the calorimeter energy and timing resolution requirements a homogeneous calorimeter is the solution with a crystal that should have the following characteristics:

- High LY > 100 p.e./ MeV (with PMT readout)
- Good LRU: < 5%. (uniformity of response along crystal axis)
- Fast signal with small slow component: $\tau < 40$ ns, F/T > 75%

- Radiation hardness with LY loss < 40% for:
  - Ionization dose: 100 krad @ 10 krad/year;
  - Neutrons: 10^{12} n/cm^2 @ 2 x 10^{11} n/cm2/year.
  - Small RIN: < 0.6 MeV

Undoped CsI is the Mu2e choice!

Basic Property of pure CsI

	LSO/LYSO	GSO	YSO	CsI	BaF_2	CeF_3	$CeBr_3$	$LaCl_3$	$LaBr_3$	Plastic scintillator (BC 404) ①
Density (g/cm^3)	7.4	6.71	4.44	4.51	4.89	6.16	5.23	3.86	5.29	1.03
Melting point (°C)	2050	1950	1980	621	1280	1460	722	858	783	70#
Radiation Length (cm)	1.14	1.38	3.11	1.86	2.03	1.7	1.96	2.81	1.88	42.54
Molière Radius (cm)	2.07	2.23	2.93	3.57	3.1	2.41	2.97	3.71	2.85	9.59
Interaction Length (cm)	20.9	22.2	27.9	39.3	30.7	23.2	31.5	37.6	30.4	78.8
Z value	64.8	57.9	33.3	54	51.6	50.8	45.6	47.3	45.6	5.82
dE/dX (MeV/cm)	9.55	8.88	6.56	5.56	6.52	8.42	6.65	5.27	6.9	2.02
Emission Peak[a] (nm)	420	430	420	310	300 220	340 300	371	335	356	408
Refractive Index[b]	1.82	1.85	1.8	1.95	1.5	1.62	1.9	1.9	1.9	1.58
Relative Light Yield[a,c]	100	45	76	4.2 1.3	42 4.8	8.6	99	15 49	153	35
Decay Time[a] (ns)	40	73	60	30 6	650 0.9	30	17	570 24	20	1.8
d(LY)/dT[d] (%/°C)	-0.2	-0.4	-0.1	-1.4	-1.9 0.1	~0	-0.1	0.1	0.2	~0

a. Top line: slow component, bottom line: fast component.

b. At the wavelength of the emission maximum.

c. Relative light yield normalized to the light yield of LSO

d. At room temperature (20°C)

#. Softening point

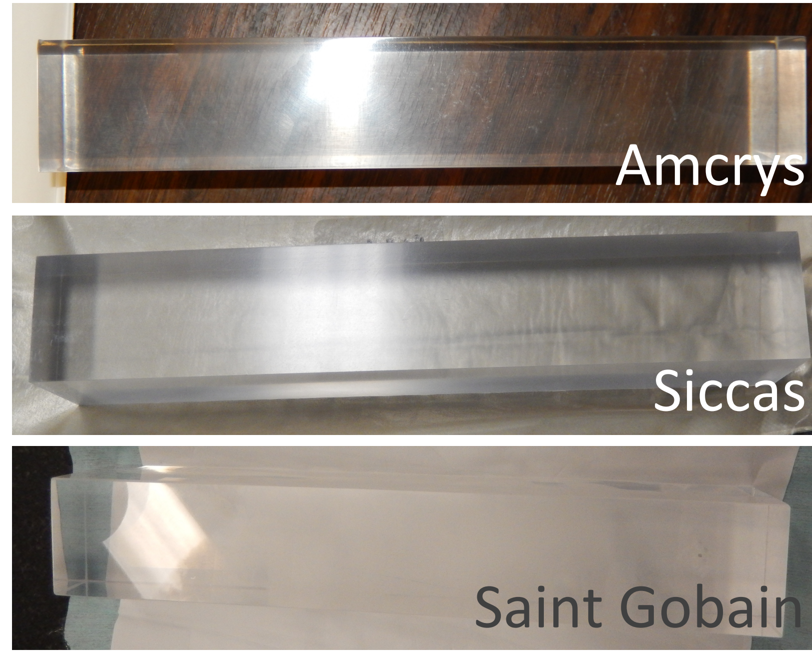
1. http://www.detectors.saint-gobain.com/Plastic-Scintillator.aspx

http://pdg.lbl.gov/2008/AtomicNuclearProperties/HTML_PAGES/216.html

Commercial available CsI crystals have slow scintillation components

Preproduction

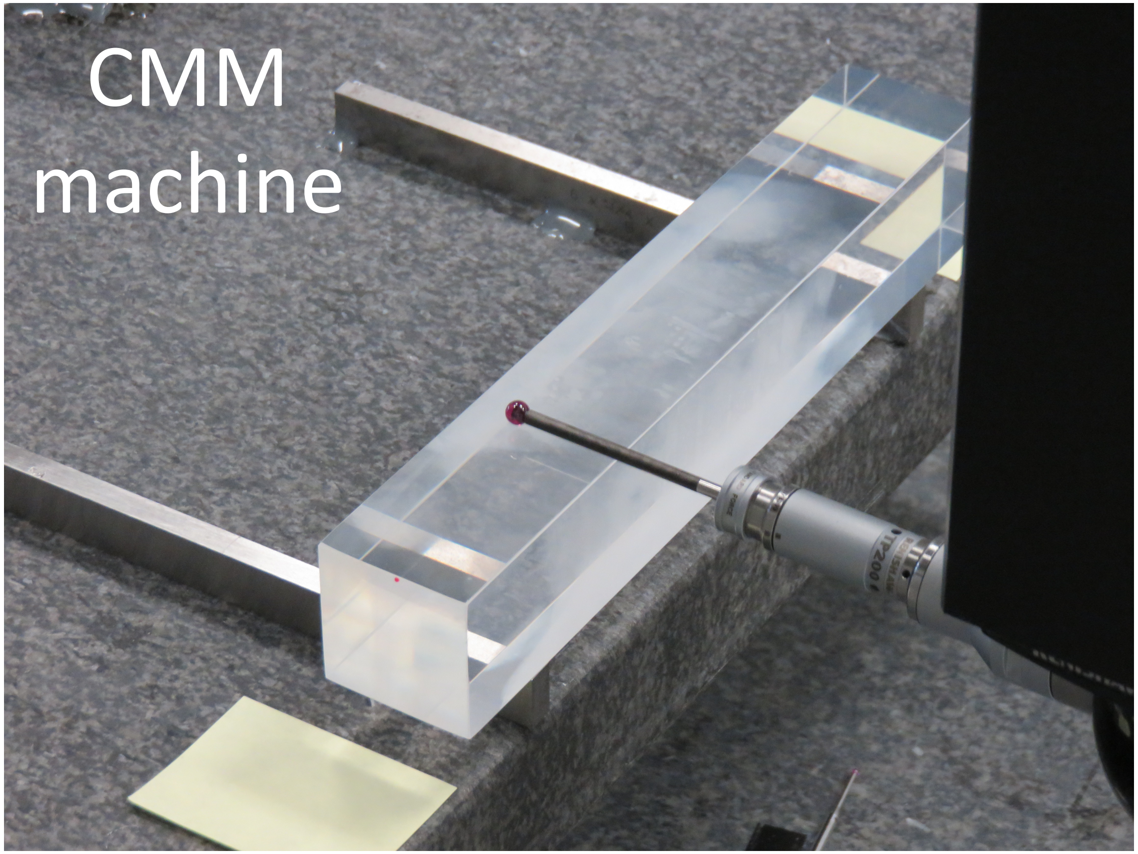
- 24 crystal from 3 different vendors (tot 72):
  - Amcrys
  - Siccas
  - Saint Gobain

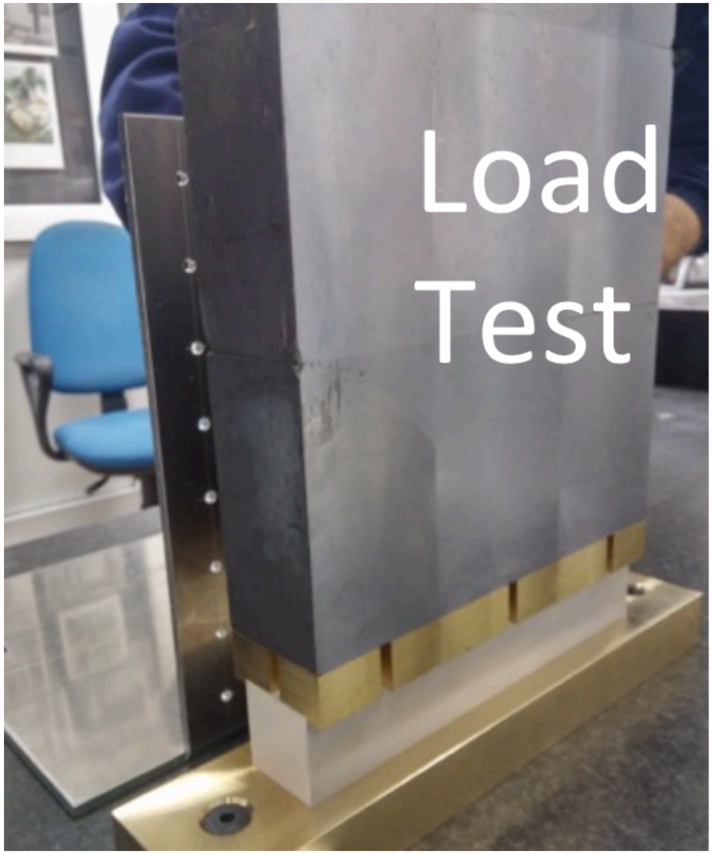


- Dimension: (34 x 34 x 200) mm^3

- Measurements:
  - LY ⟶ $N_{p.e.}/MeV = \frac{Q}{Q_{e^-}G_{PMT}E_\gamma} = \frac{\mu_Q[pC]}{1.6\times 10^{-7}\cdot 3.8\cdot 0.511MeV}$
  - LRU ⟶ *Uniformity along the crystal axis (R.M.S/peak)*
  - Radiation hardness to ionization dose and neutron flux

Mechanical measurements

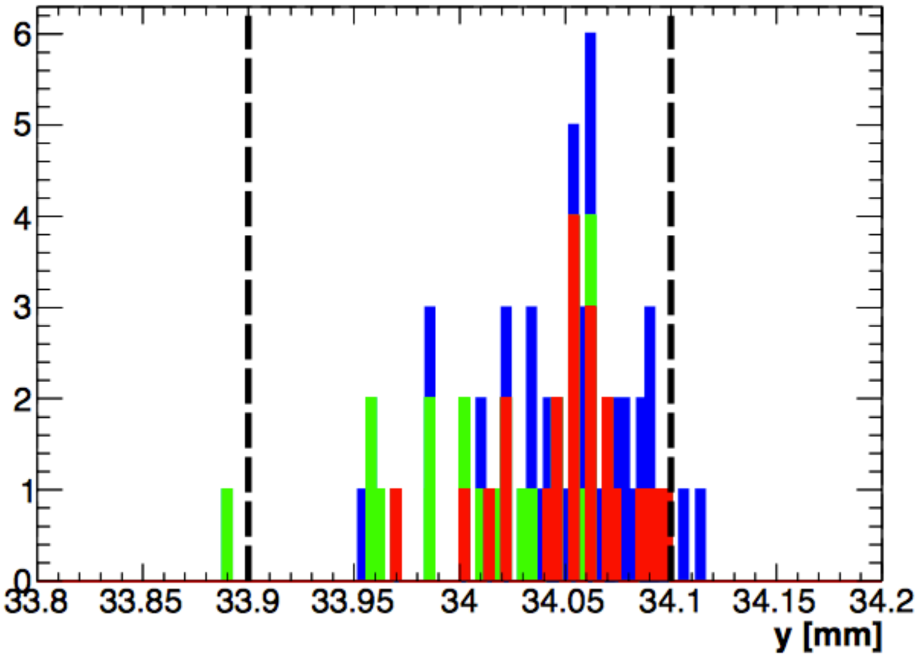


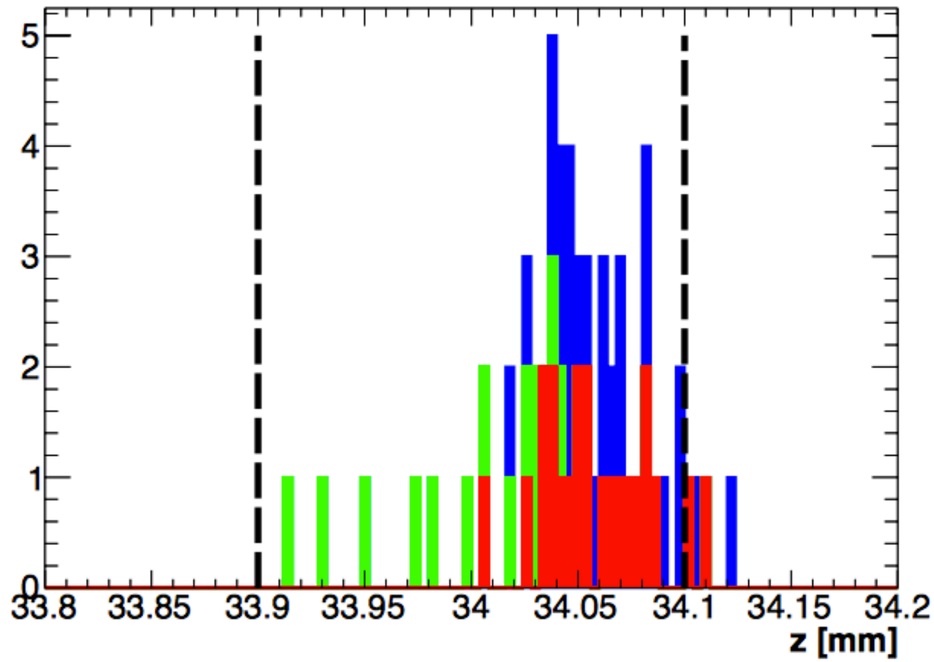


Geometrical Tollerances

Crystal dimension specification:

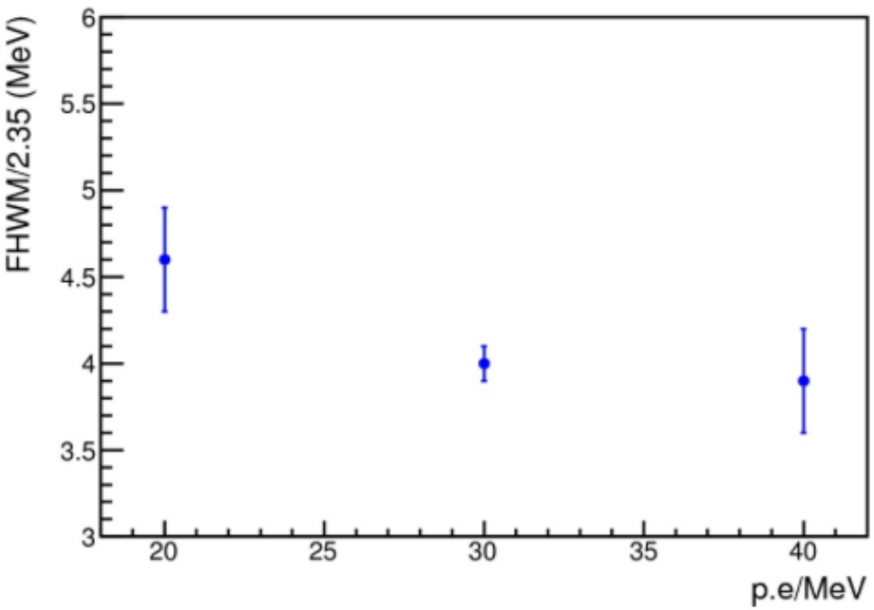
- Lateral dimension within ±100 μ
- Length within ±100 μ

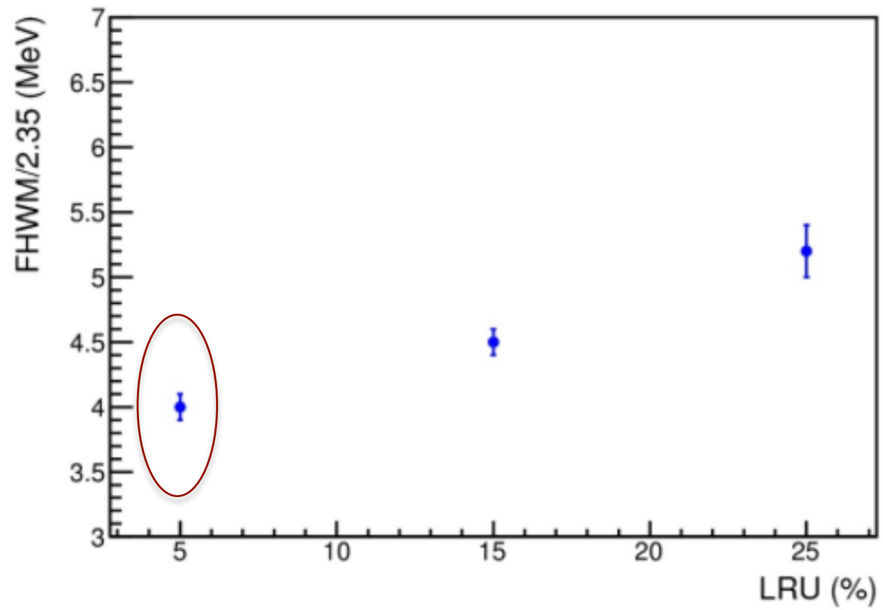




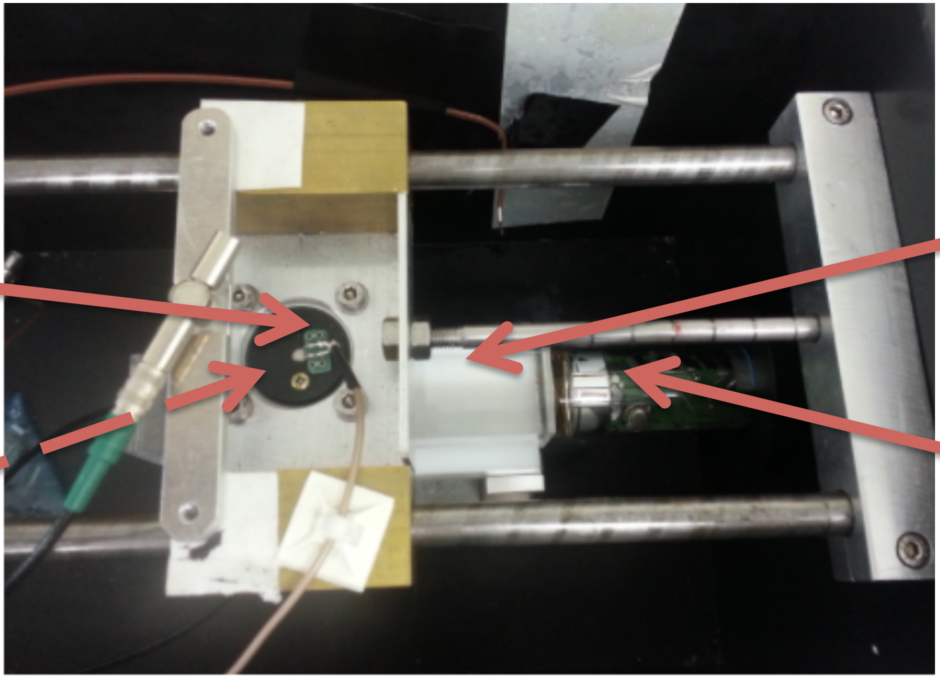
Crystal – simulation

Dependence on the photo-statistics and LRU





LY and LRU measurements - setup



Monitor system

Crystal

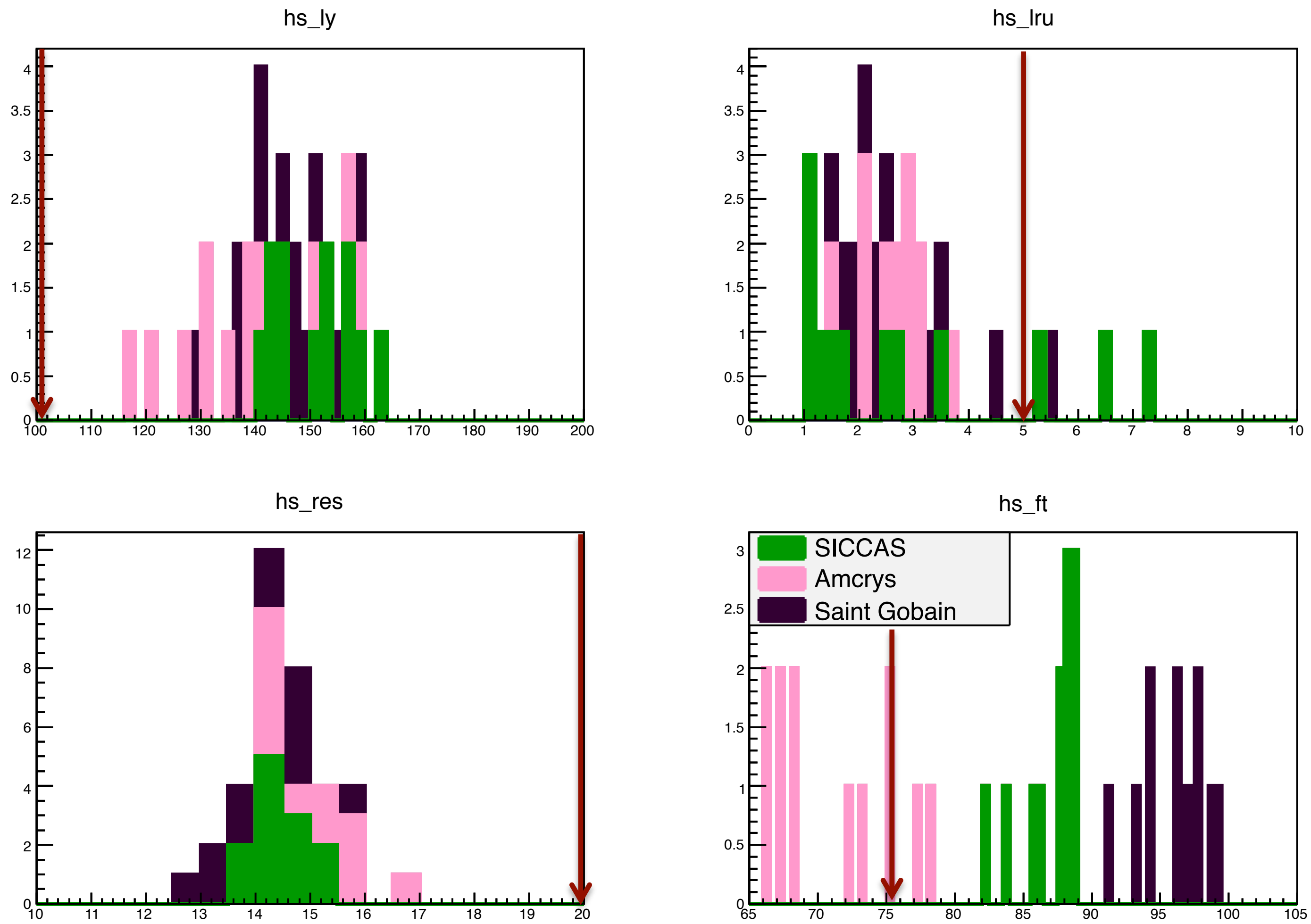
^{22}Na Source

PMT

- Automatized station in progress: source movement by remote control

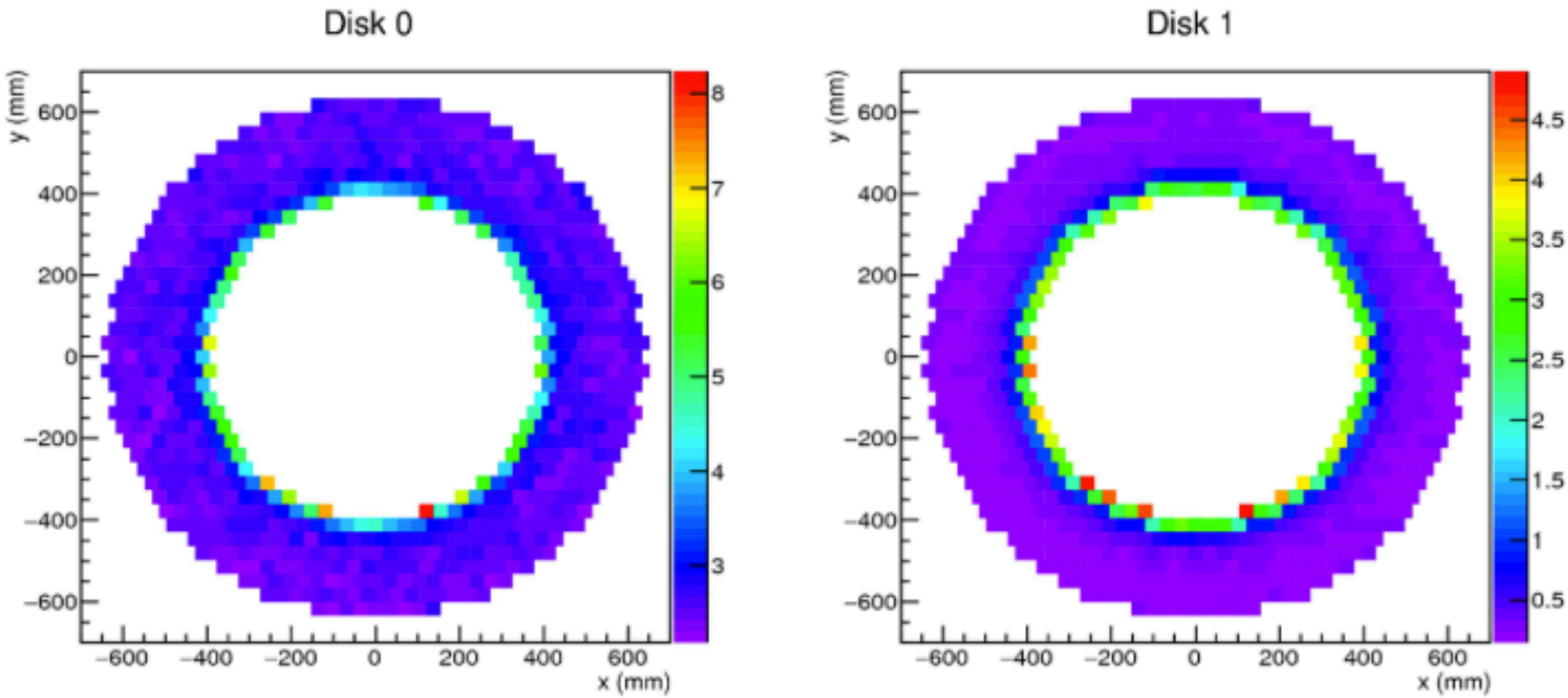
Results

- Measurement repeated at 8 points along the crystal



Radiation Hardness - simulation

Radiation dose krad / year

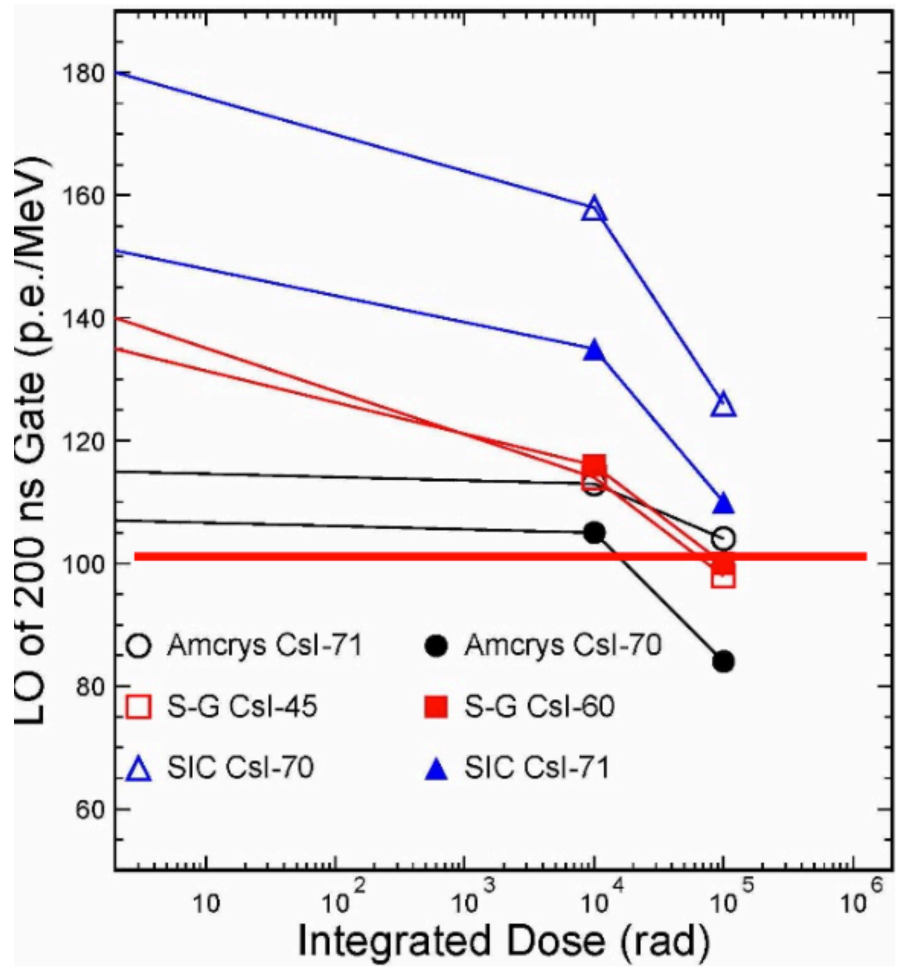


The average dose is around 3 (0.5) kRad / year for the front (back) disk, with a peak up to 8 (4) kRad / year for the innermost crystals in the front (back) disks

Radiation Hardness damage

MUSE

- No significant degradation in LY and LRU up to 100 krad, **but not beyond**
- LO Loss < 15/40% after 10/100 krad
- Similar test performed @ CALLIOPE (Casaccia facility, ENEA) by LNF group on 1 single SICCAS crystals with similar results



RIN - Radiation Induced Readout Noise

MUSE

Assuming 230 days' run (2×10^7 s) each year, the hottest crystals would see in average the following radiation environment:

- Ionization dose: 1.8 rad/h
- Neutron flux: 10^4 n/cm^2/s

The energy equivalent noise (RIN) is derived as the standard deviation of photoelectron number (N_{pe}) in the readout gate:

Radiation induced N_{pe} →

$$F = \frac{\frac{I}{e \times G_{PMT}}}{\mathrm{Rate}_{\gamma-\mathrm{ray}}}$$

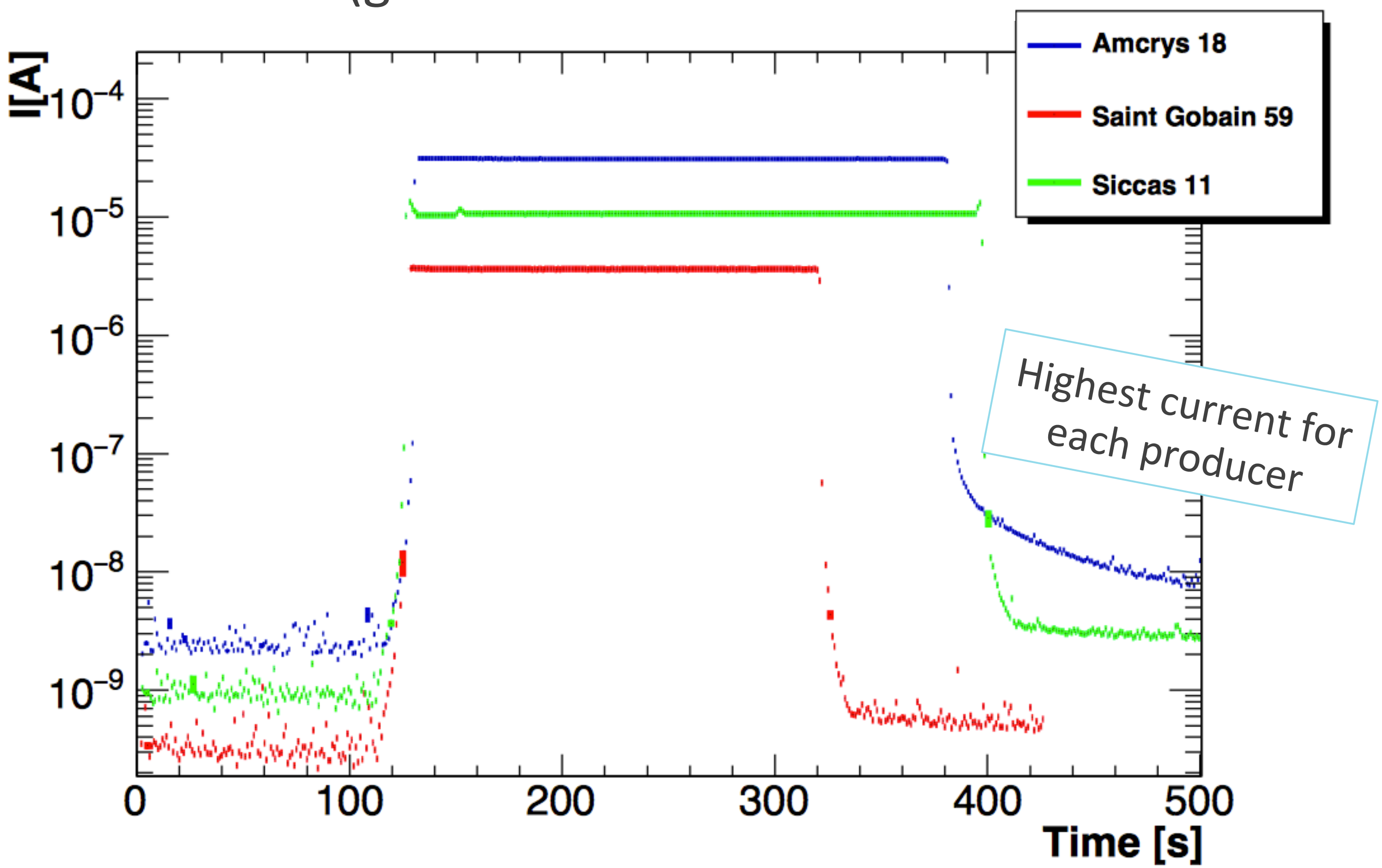
Radiation induced noise →

$$RIN = \frac{\sqrt{N_{pe}}}{LY}$$

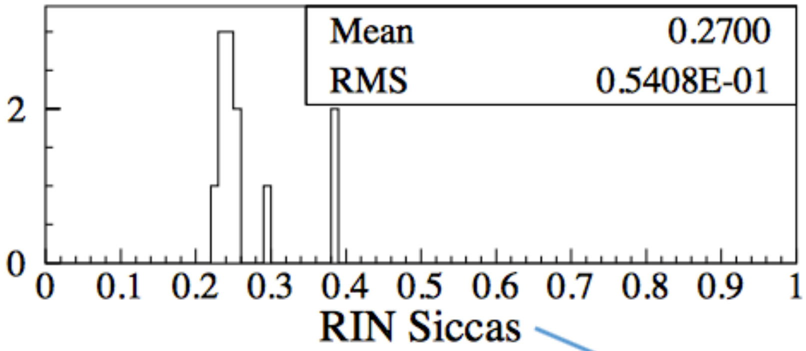
RIN – γ ray

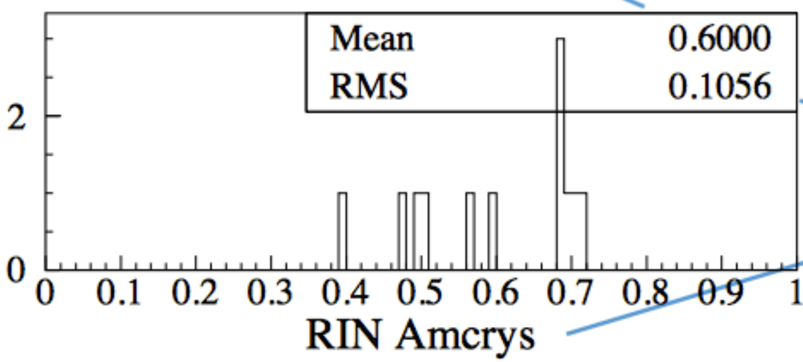
MUSE

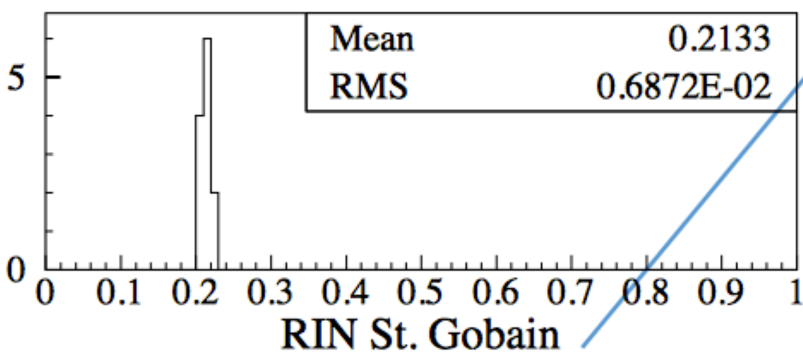
- Measured with a ^{137}Cs source (0.2 rad/h)
- PMT readout (gain ~ 2.1×10^{6})



γ ray RIN - summary







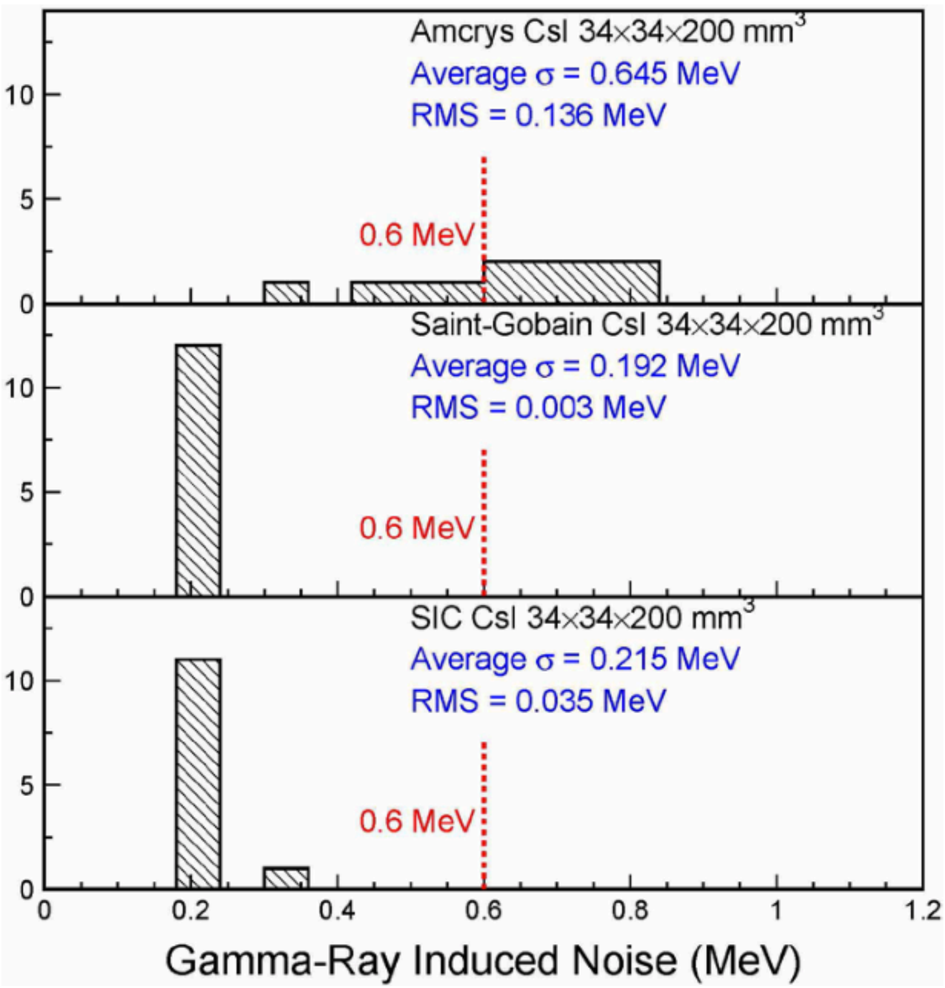
Mean LNF (best side)	RMS/Mean LNF	Mean CALTECH (both sides)	RMS/Mean CALTECH
0.270	20.0%	0.215	16.3%
0.600	17.6%	0.645	21.1%
0.213	3.2%	0.192	1.6%

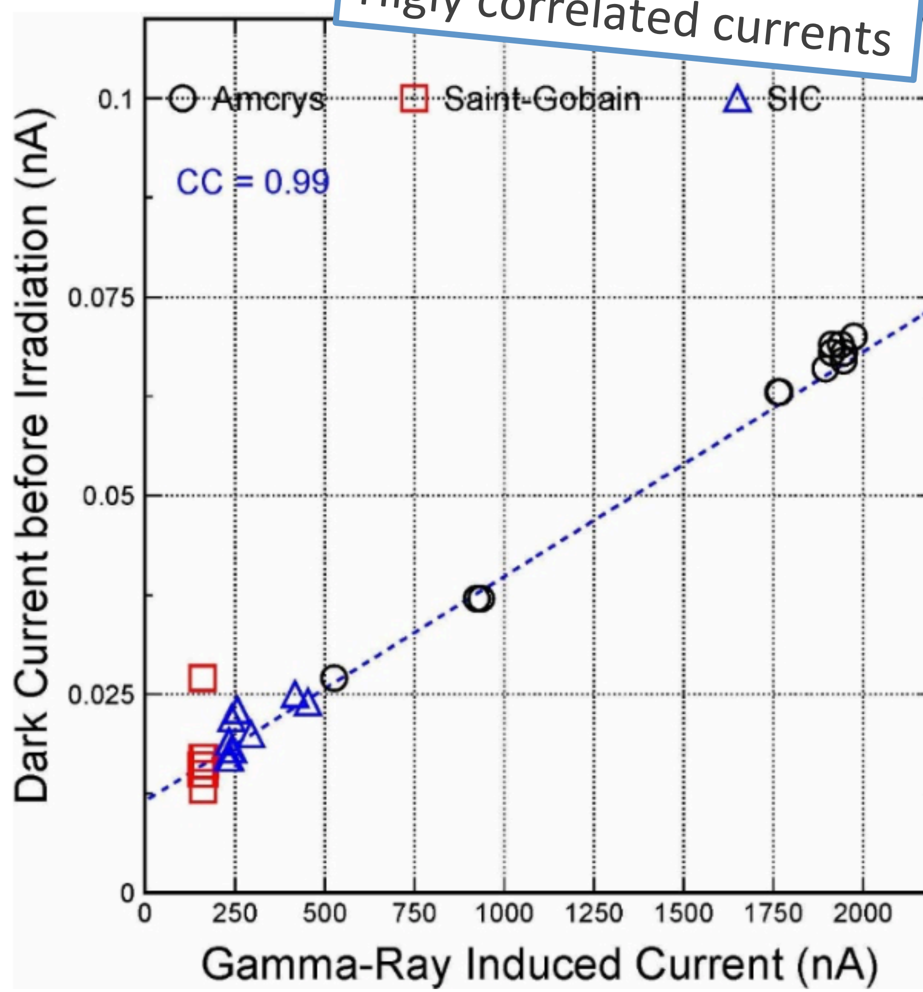
Reasonable agreement with Caltech measurements

γ ray RIN – summary - Caltech

MUSE

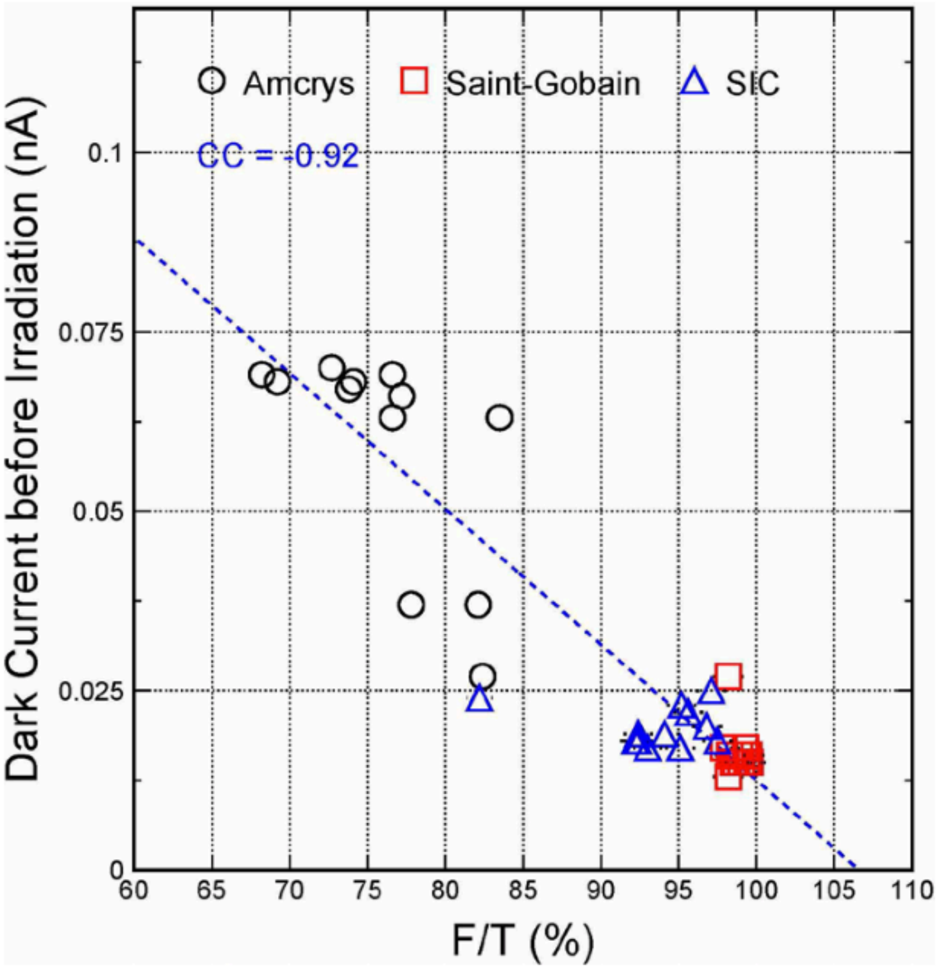
RIN ranking: Amcrys, SG, Siccas

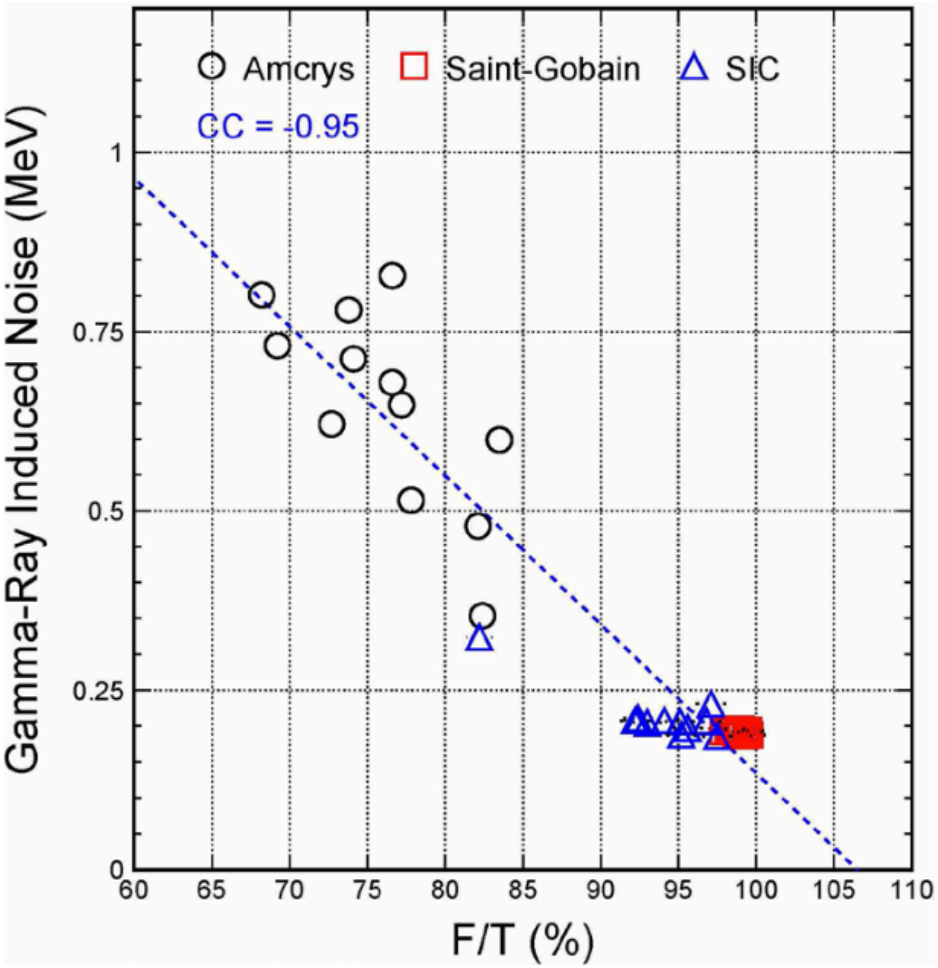




Correlation with F/T ratio

- Dark current and RIN are highly corretated with F/T ratio



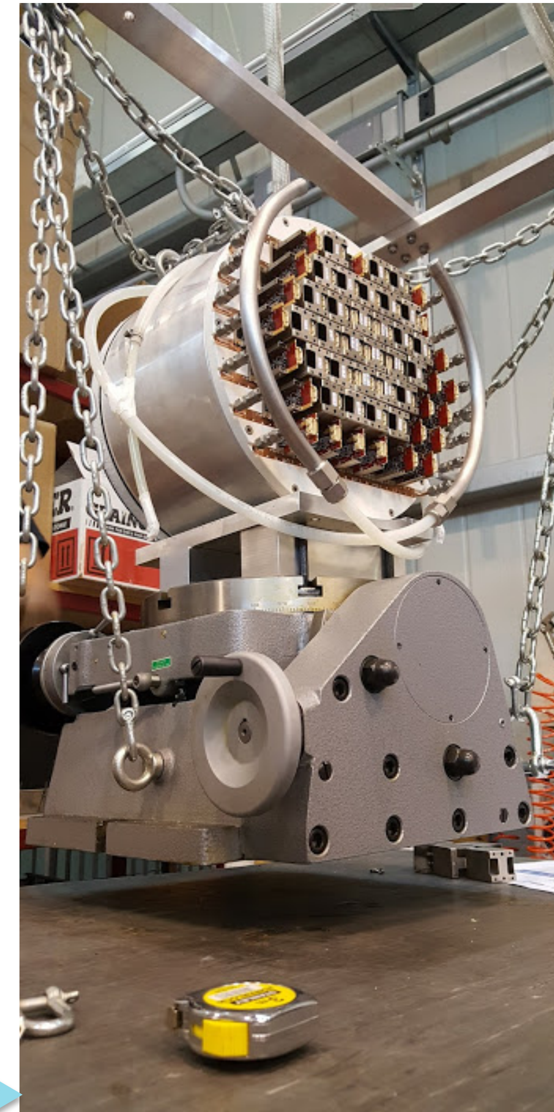


Conclusions

MUSE

Current design meets calorimeter detector requirements

- Mechanical quality are reasonable but not excellent: SG shows the best quality for eye-survey
- Optical Quality and RH tests are in general pretty good and satisfy our requirements: SG and Siccas crystals are better than Amcrys ones
- All crystals from Saint-Gobain and SICCAS meet the RIN spec. Some crystals from AMCRYS do not
- Measurement of Optical Quality between LNF and Caltech are in good agreement. Average values are consistent
- The best 51 crystals have been used for Module-0 assembly

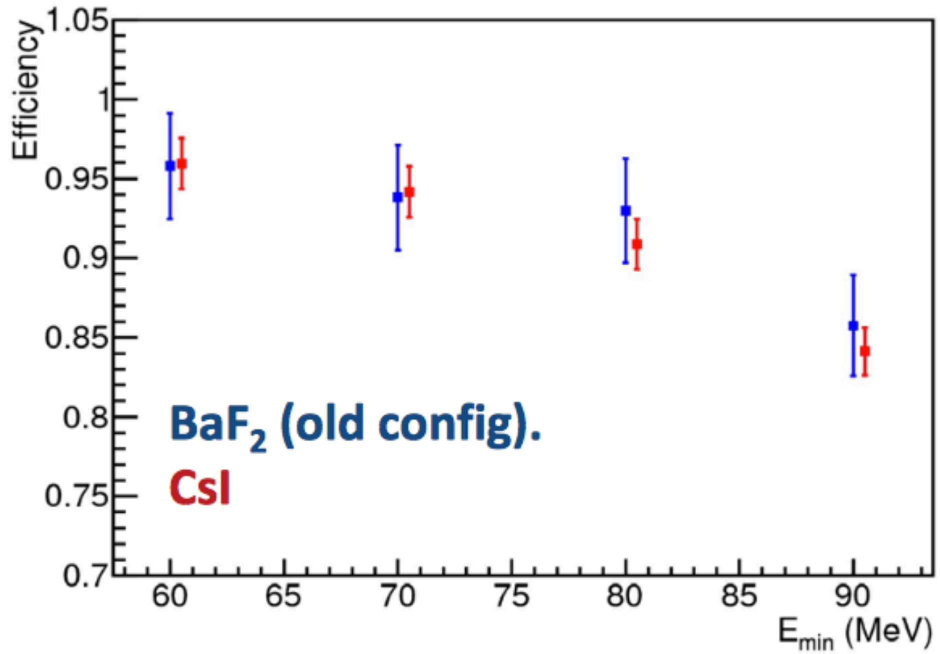


Thanks!

Spare

Signal acceptance

Efficiency = # cluster E> E_{min} with a good track / # good tracks

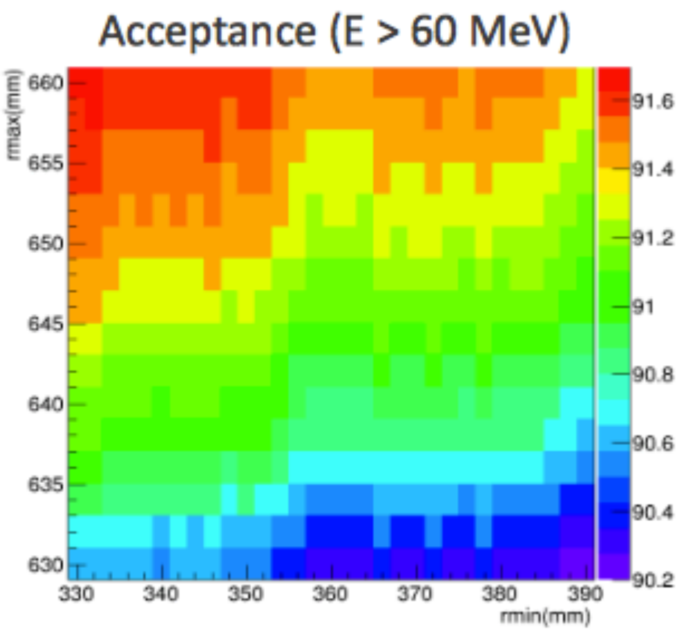


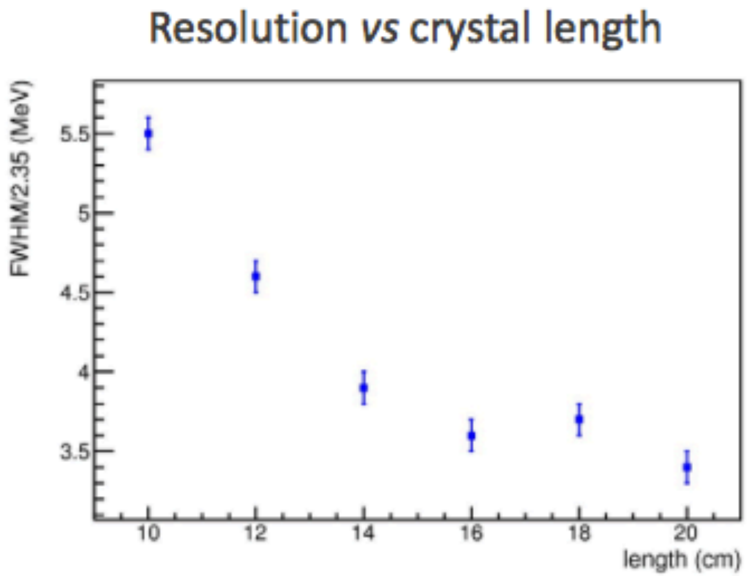
Efficiency above 95% for E_{min} > 60 MeV, inefficiency mainly due to tracks hitting the inner side of disks or missing both disks.

Calorimeter helps finding tracks by providing seed for tracking algorithm

Dimensions optimization

Simplified algorithm to estimate the efficiency *vs.* disk dimensions within constraints on calorimeter envelope, crystal and readout sizes, radiation dose and efficiency





Select promising configurations and run full signal simulation to confirm results

Final configuration robust against small perturbations:

Rin=374 mm, Rout = 660 mm, crystal size = 34 mm, crystal length = 200 mm