Mu2e-II Calo R&D: BaF2 + Deep UV Photo Trap

Riunione Preventivi Mu2e
July 17, 2023

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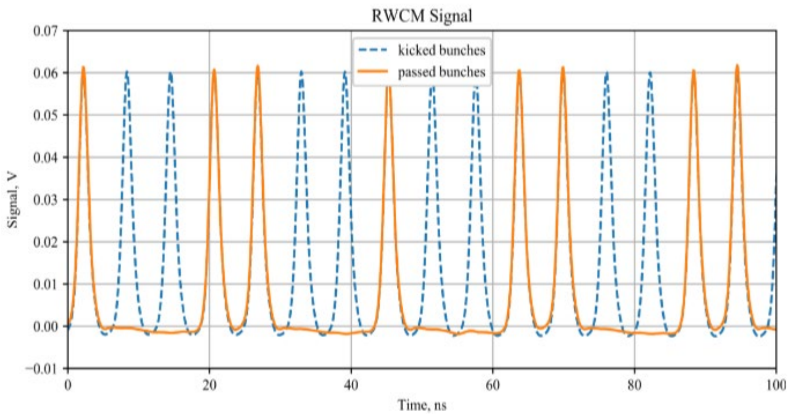
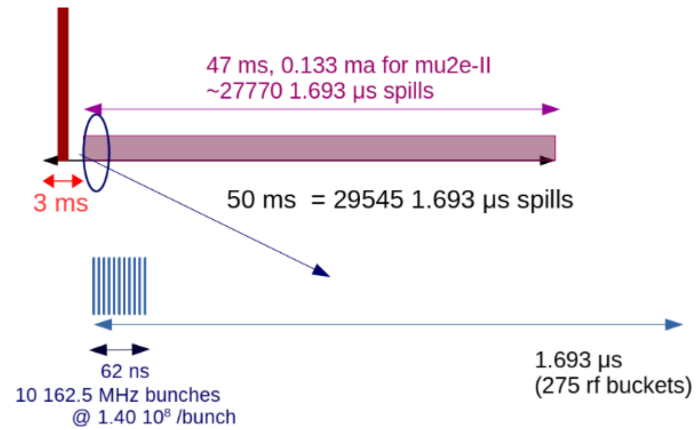
What is different in Mu2e-II?

- Mu2e-II will use the **800 MeV** proton beam from the **PIP-II** Linac:
  - Chopper system can produce an arbitrary pattern of filled or empty **162.5 MHz** (6.25 ns) buckets
  - Mu2e-II will use **10 buckets** each composed of 1.4 x 10^8 protons, total 1.4x10^9 p in 62.5 ns
  - SMuons/POT ratio for 800 MeV p of 9x10^-5 -> **SM/muBunch of 1.2 x10^5 … 2 times Mu2e**
  - Only 3 ms out of every 50 ms are required - > **Duty Factor of 94% … 3,5 times Mu2e**

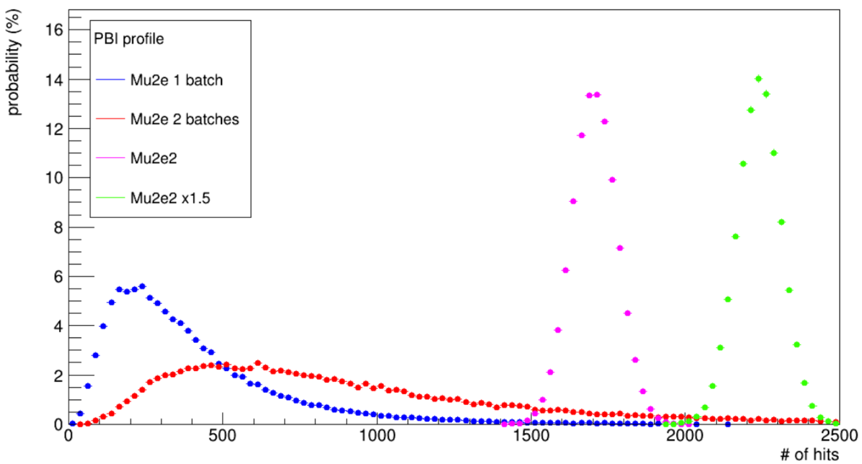


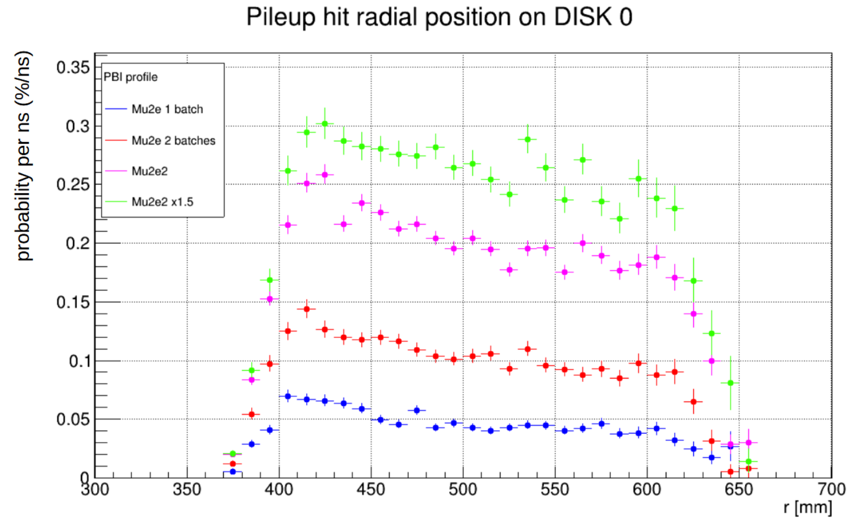


- Running **5 years** with PIP-II is possible to reach a **x10 SES** wrt Mu2e:
  - Detectors must increase **bkg rejection** to limit new total expected bkg events below 1 count
  - **Radiation hardness** requirements from x10 stopped muons and x10 beam flash
  - New instantaneous luminosity poses new requirements on **pileup handling** and **data transmission**

Occupancy and Pileup Considerations

- The instantaneous luminosity is x 2 the average luminosity in the 2batch mode of Mu2e Run II (characterized by a large variability due to the slow resonant extraction)
  - In principle it can be also more intense, because Mu2e proton pulse was 250 ns and we are using only 65 ns of PIP-II stream.. the limit is the power dissipation in the PS and the pileup level

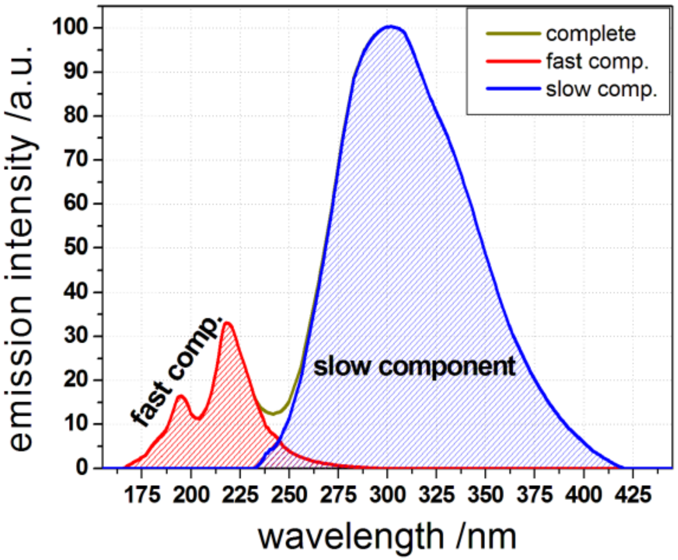


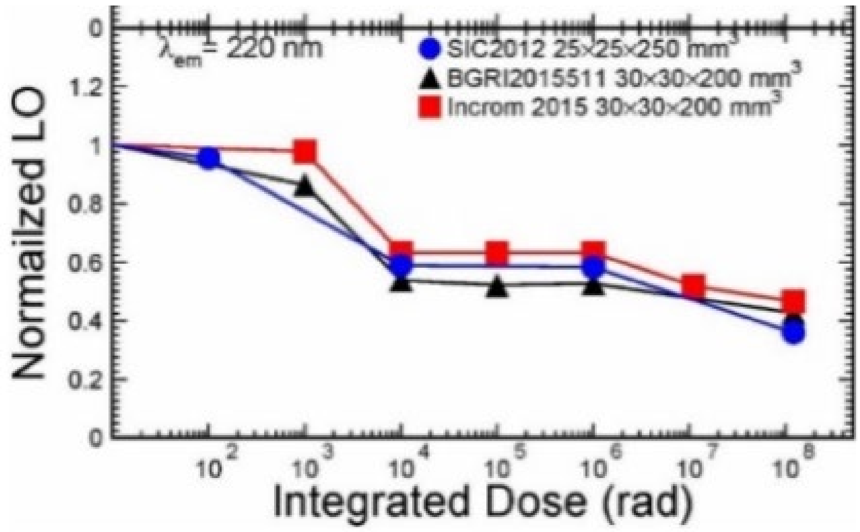


- The pileup with respect to CE seems to scale linearly with beam intensity, so to keep the same level we have in Mu2e (15%) with 150 ns we need to rescale the new signals length
  - The length for Mu2e-II should be 75 ns (50 ns for 1.5 times Mu2e-II)
  - Pileup resolution in the waveform fit **is still under study** and can loose this requirement

Fast & Rad Hard Crystals?

- BaF 2 is an excellent candidate for a fast, high rate, radiation-hard crystal for the Mu2e-II calorimeter, provided that one has a way of utilizing the 220 nm cross-luminescence fast component without undue interference from the larger 320 nm slow component
  - There are actually two fast components (**τ = 0.6 ns**) at 195 and 220 nm and two slow components (**τ = 630 ns**) at 320 and 400 nm
  - Light Yield of the Fast Component is very similar to the LY of the CsI used in Mu2e.. 5% of LYSO

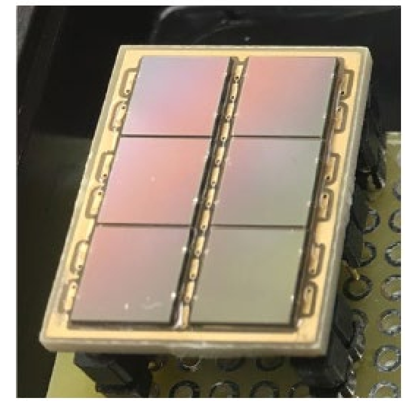




- An ideal filter would be a short pass filter with a sharp edge between 230 nm and 235 nm.

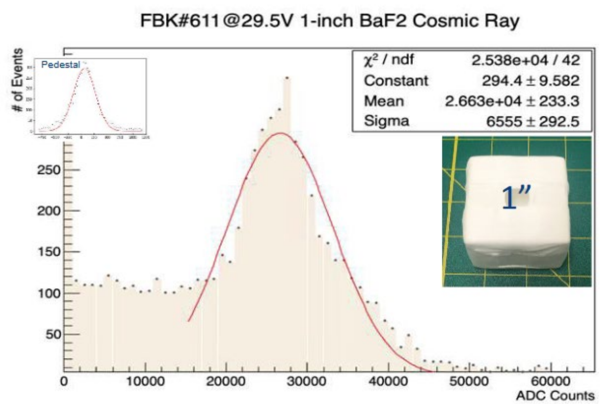
Solar Blind SiPMs - CIT/JPL/FBK R&D

- A possibility is to develop a photosensor that is sensitive only to the fast component
- A Caltech/JPL/FBK collaboration is carrying on an R&D, originally proposed as baseline for Mu2e, to integrate directly an optical filter on a VUV SiPM surface
  - Very expensive R&D that is going on since more than 10 years
- Incorporate a **three-layer ALD** filter **on a 6x6 mm NUV SiPM structure**, exploring different SiNx passivation layers, guard ring structures, …



Fast / Slow Ratio ~ 4

quenching time 150 ns



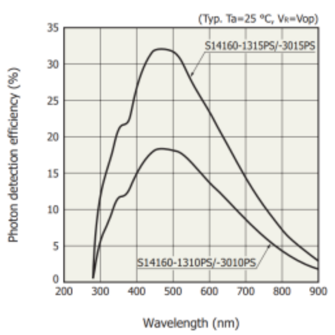
6x6 mm2, 75 μm
11 pe/MeV

- Fabricated RMD APDs worked well, but were fragile and noisy at room temperature
- Even if results are promising, **major concern is radiation hardness and reliability**

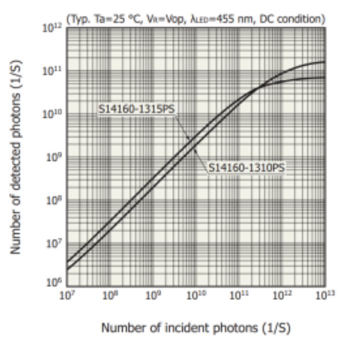
What kind of SiPM can Survive Mu2e-II?

- With the current technology the only SiPMs that can operate in the Mu2e-II radiation environment (10^{13} neutrons/cm2) without changing the cooling system (-10 C) are the ones with 10/15 μm pixels

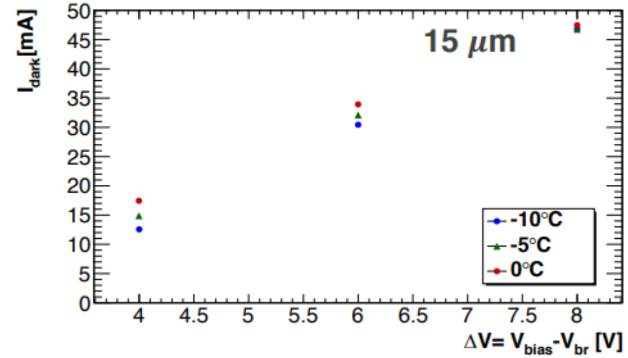
S14160 series with small pixels
- Small pixel pitch : 10µm, 15µm
- Wide dynamic range
- High fill factor & High sensitivity
- Low operating voltage (VB=38V typ.)
- Photosensitive area : 1.3x1.3mm^2, 3x3mm^2

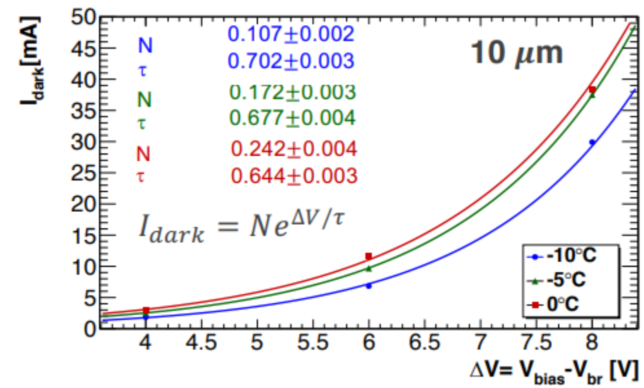


PDE vs. Wavelength



Linearity
(Photosensitive area :1.3x1.3mm^2)

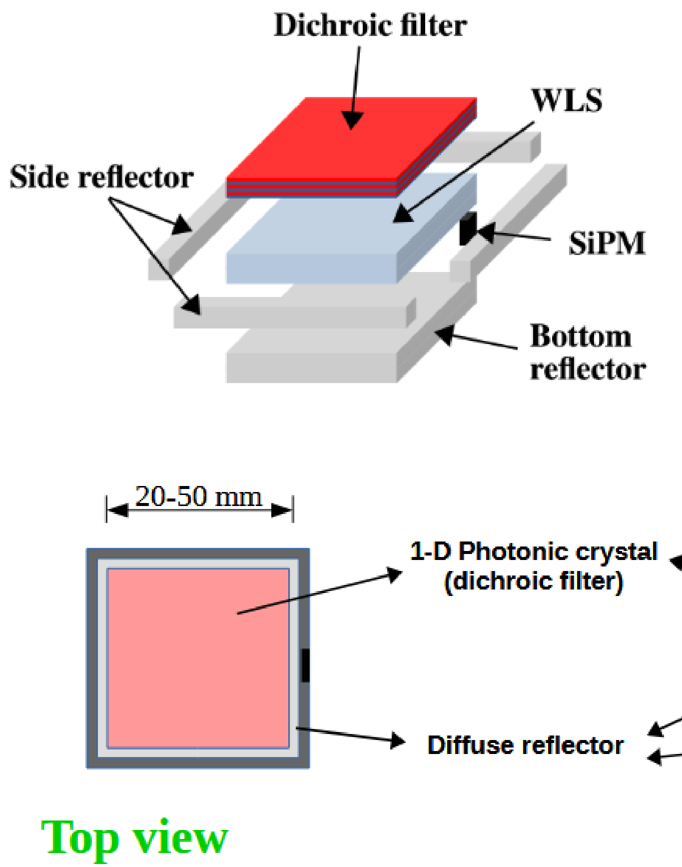




- PDE drops due to the high FF.. 30% (15%) at 450 nm, **not available the VUV version**

New BaF2 Readout proposal: Filter + WLS

- Our idea is to use a **commercial optical filter** to eliminate the slow component and then a **WLS** material to shift the 200 nm fast component to the 450 nm where there is the peak of **rad hard SiPMs** PDE and collect the shifted light with a **photon trap**



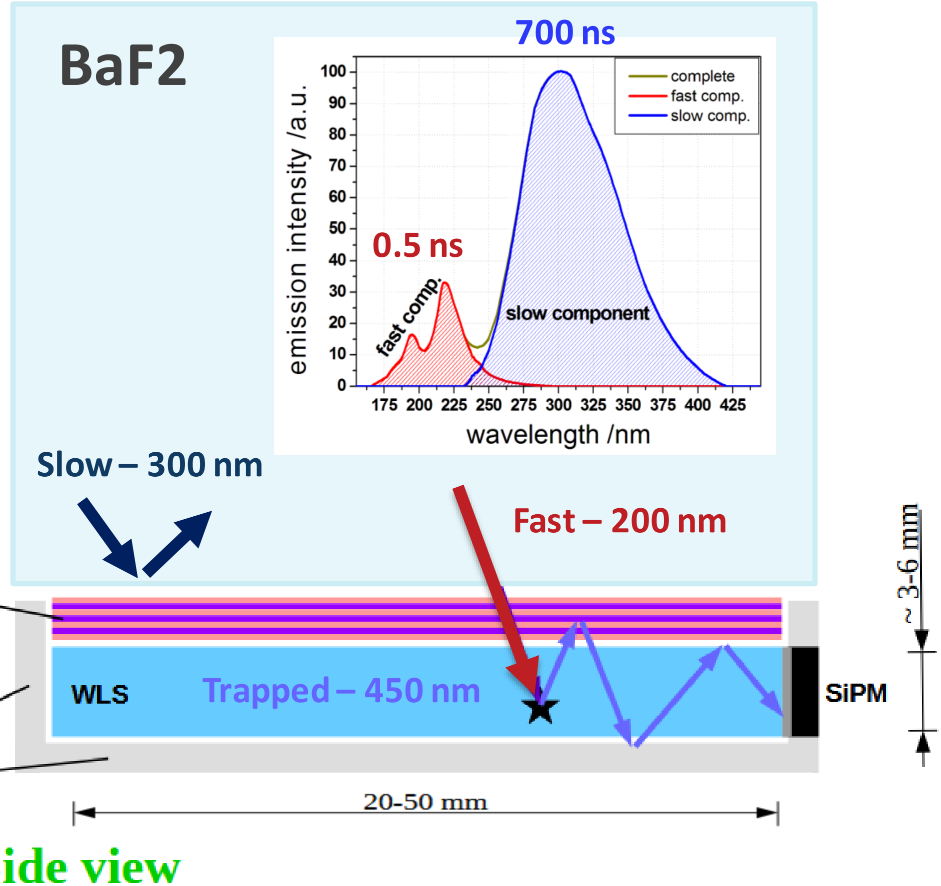
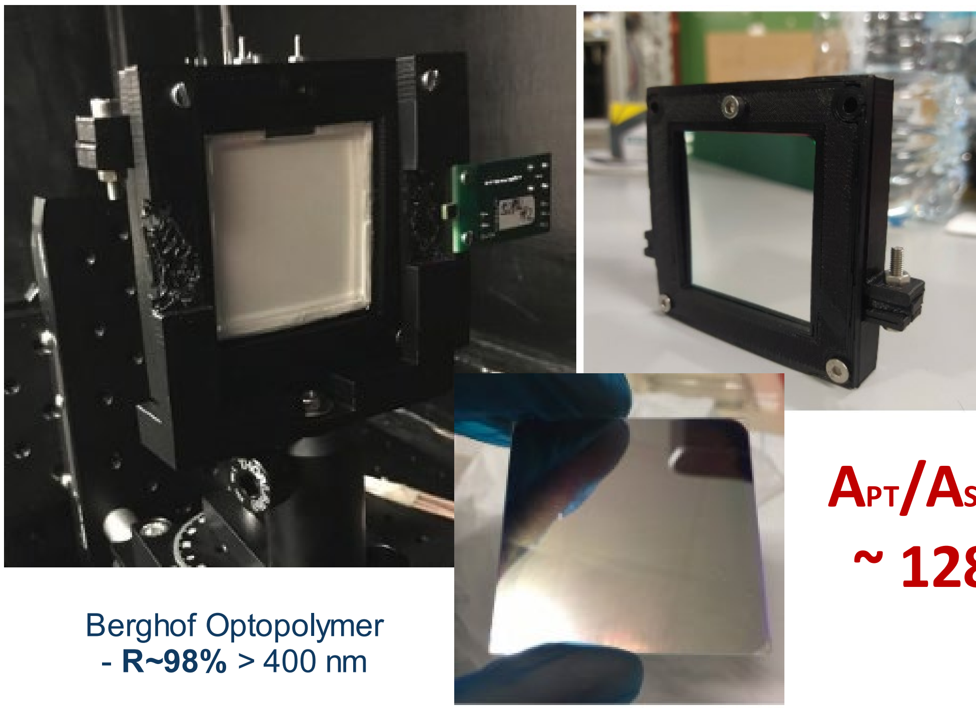


Photo Trap Prototype

- This is a prototype of Photo-Trap built @ INFN – Pisa for photons at 350 nm (thanks to Daniel Guberman)

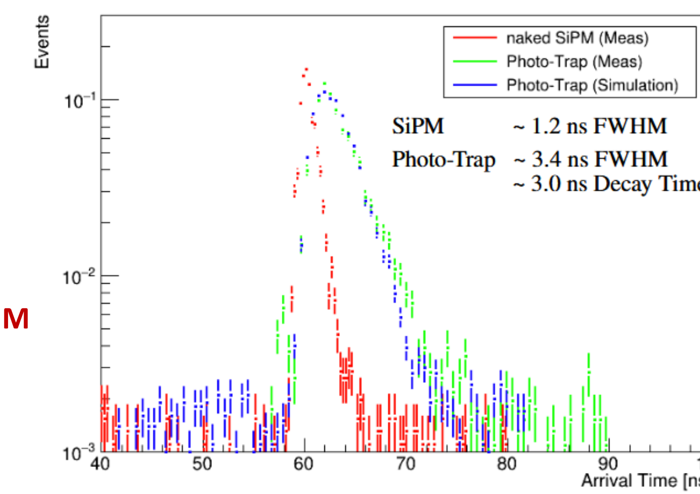
	PMT	SiPM	Photo-Trap
PDE*	~35%	~50%	~5-25 %
Time resolution [ns]	~1	~0.1	~2-3



Berghof Optopolymer
- **R~98%** > 400 nm

A_{PT}/A_{SiPM} ~ 128

Prototype III: 3x3 mm² SiPM – 4x4 cm² WLS



Arrival time distribution for 1 phe events

- Photo-Trap induces a degradation of the timing performance which is due to the re-emission time of the WLS and the difference in the optical paths
  - Distributing SiPMs on the sides improves the timing and the light collection

Wavelenght Shifter 200 nm to 450 nm

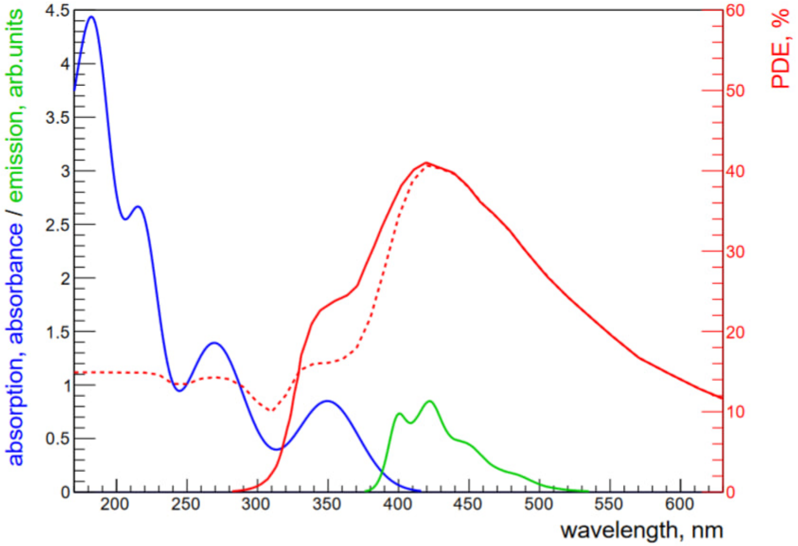
- Wavelenght shifter materials for these wavelengths have been studied for noble liquid gasses applications: **LArgon** scintillation light is peaked **at 128 nm**, while **LXenon at 178 nm**

- Most common WLS used are **TPB** (TetraPhenyl Butadiene) and **PEN** (PolyEthylene Naphthalate), but at room temperature a slow component starts to arise

- Another solution discovered in the last years are **NOL** (Nanostructured Organosilicon Luminophore), a wsl material that combine absorber and emitter in the same molecula

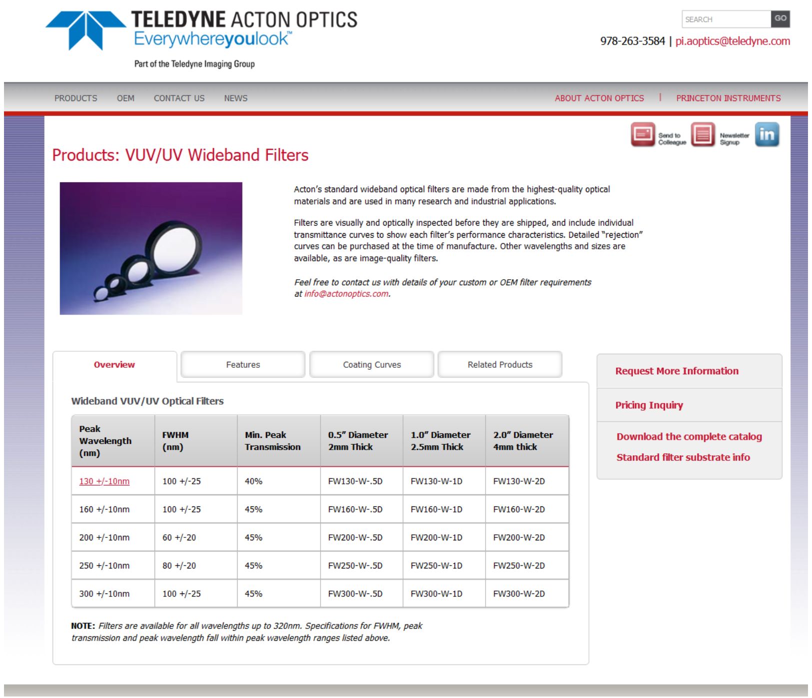
- In particular **NOL-1** seems to work well at BaF2 wavelengths: it can be deposited as a thin film layer of 200 nm directly on the reflector surface

- We are in contact with Luminotech that can provide same samples to carry on the R&D



Optical Filter to Cut Slow Component

- A commercial wideband interferential filter has been used for the TAPS BaF2 calorimeter upgrade in order to increase the maximum sustainable rate.. 20 ns with a deep uv PMT..



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Wideband VUV/UV Optical Filters

Peak Wavelength (nm)	FWHM (nm)	Min. Peak Transmission	0.5" Diameter 2mm Thick	1.0" Diameter 2.5mm Thick	2.0" Diameter 4mm thick
130 +/-10nm	100 +/-25	40%	FW130-W-.5D	FW130-W-1D	FW130-W-2D
160 +/-10nm	100 +/-25	45%	FW160-W-.5D	FW160-W-1D	FW160-W-2D
200 +/-10nm	60 +/-20	45%	FW200-W-.5D	FW200-W-1D	FW200-W-2D
250 +/-10nm	80 +/-20	45%	FW250-W-.5D	FW250-W-1D	FW250-W-2D
300 +/-10nm	100 +/-25	45%	FW300-W-.5D	FW300-W-1D	FW300-W-2D

NOTE: *Filters are available for all wavelengths up to 320nm. Specifications for FWHM, peak transmission and peak wavelength fall within peak wavelength ranges listed above.*

Request More Information
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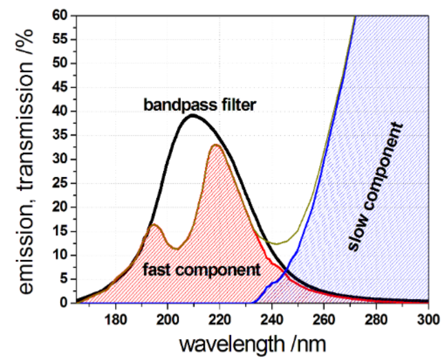
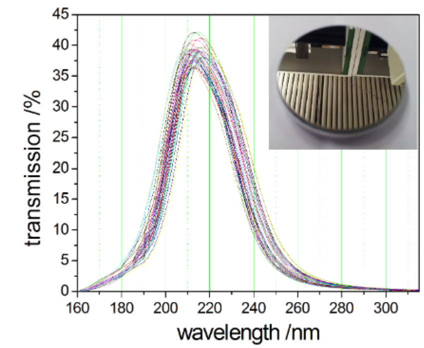
Standard filter substrate info





- Transmission efficiency is around 40% at the emission peak
- A fraction of the slow component still pass the filter, but F/S greater than 5

- An ideal filter would be a short pass filter with a sharp edge between 230 nm and 235 nm
  - We are in contact with ASAHI and AHS to understand if it's possible to improve filter performances
  - Prices go around 0.8/1.2 kE for a 3.4x3.4 cm2 sample filter

Requests

- The idea is to start building a prototype of a photo trap and try different combinations of filters and WLS to evaluate the Light Collection and timing

- We also need to develop a PCB to host the SiPMs, the shaper and the amplifieer, integrated with the cooling

		$$
BaF2 Crystal	1 crystal, 3.4 x 3.4 x 20 cc @ 10$/cc	2k
Optical Filter	1 wideband filter + 2 low pass filters (about 1k/each)	4k
WSL and coating	NOL-1 and PEN samples	4k
Mechanics and Cooling	Photo Trap and SiPM cooling + holder	1.5k
SiPMs and PCB	12 x 10 um, 12 x 15 um, PCB + Shaper/Amplifier	2.0k
Readout Electronics	Fast ADC board and FPGA	1.5k

15k