Mu2e-II calo general requirements

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Calorimeter requirements and generic

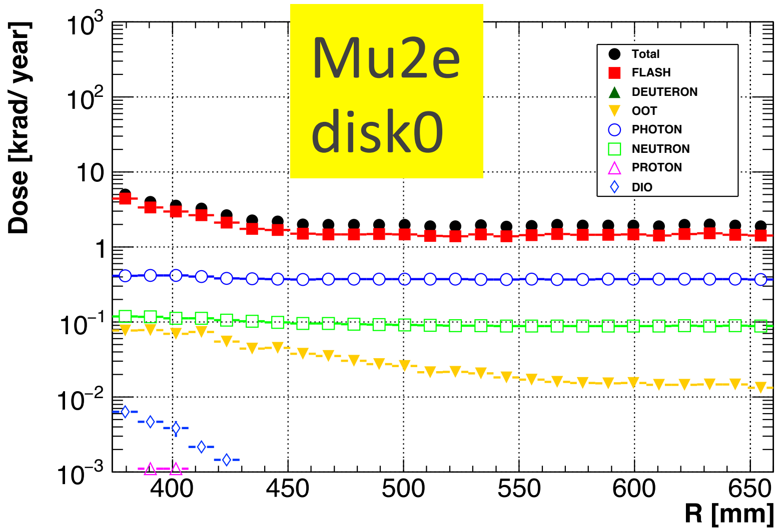
- We aim to same energy (< 10%) and time (< 500 ps) resolutions as in Mu2e.
- Aiming to provide standalone trigger, track seeding and PID as before.
- Work in vacuum @ 10^{-4} Torr, keep a low level of outgassing.
- To be resistant to the strong radiation environment and cope with intensity → (x 10 dose, x 3 occupancy/microbunch) :

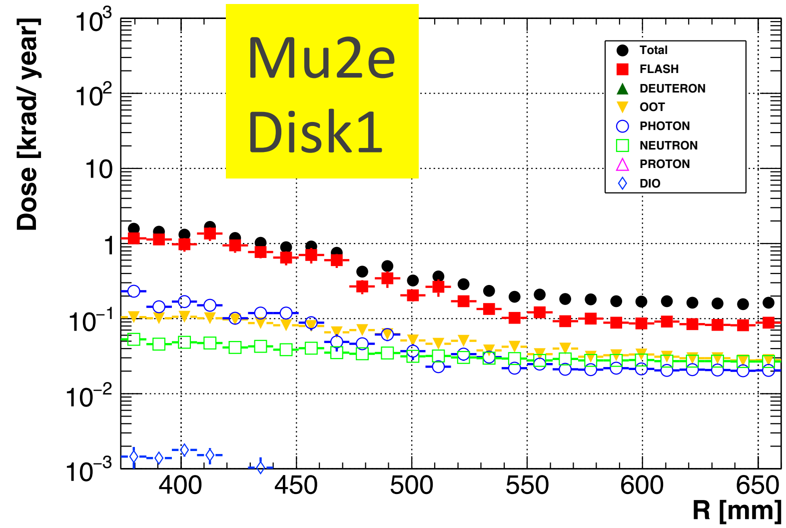
→ I still believe that in the outermost region and in the second disk a revised CsI+fast SiPMs can still be used → no hope for this in the innermost regions

→ For each technical choice/combination of crystals, sensors, electronics … we have still to take into consideration the effort on the calorimeter infrastructure: as for instance .. **Cooling and electronics**

→ **It will be great if we could save most of the mechanical structure**

Example of Dose distribution in crystals





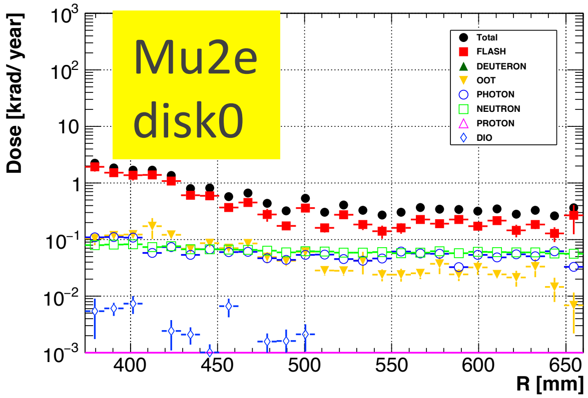
X 10 Factor →

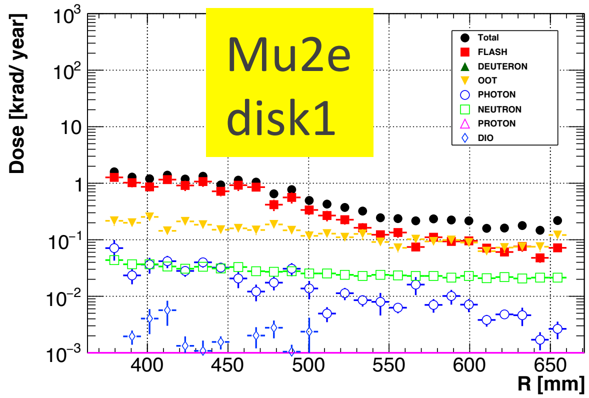
Disk1:
Inner:(60x 5 x 3 → 900 krad
Outer:((15x5x3) → 180 krad

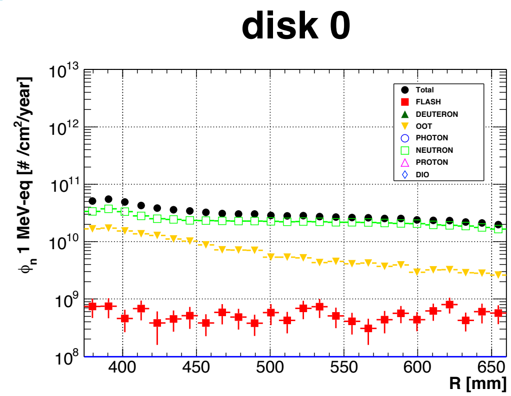
Disk2:
Inner: (10x 5 x 3) → 150krad
Outer:(5x5x3) → 75 krad

→ With respect to dose, disk 2 could be almost left as it is with CsI + SiPM readout Speeding up the amplification stage.
→The innermost area of first disk will need a drastic change

Example of Dose/n distribution in SiPM







X 10 Factor →

Disk1: Inner:
(10x2x 5 x 3) → 300 krad
Outer: (10x0.5x5x3) → 75 krad

Disk2:
Inner: (10x1x 5 x 3) → 150 krad
Outer = (10x0.5x5x3) → 75 krad

Latest SiPM Dose test indicated no hints of deterioration up to 80 krad

X 10 Factor

Disk 1 = 10 x 6 x 10^{10} x 5 x 3 = 900 x 10^{10} = 9 x 10^{12}

Neutron fluence up to 10^{13} n_1MeV/cm^2 → -40 C

Comparison between crystals

Specs/Crystal	$PbW0_4$	PbF_2	BaF_2	CsI	LYSO
Light Yield (pe/MeV)	**10**	**2**	100 (400)	100	2000
Wavelength (nm)	420	UV-Blue	220 (350)	315	420
Emission time (ns)	10	prompt	0.9 **(600)**	**30**	**40**
Rad-hardness LY loss @ 1 Mrad	**80%**	**Not well known**	50%	**80%**	50%
Density (g/cm^3)	7.0	7.0	4.6	4.6	7.0
Radiation Length (cm)	0.9	0.9	1.8	2.0	0.9

- **BaF_2 is the best crystals for the hottest places.**
- It matches all requirements .. .. apart the existence of a slow component.
- **It has also the same density of CsI → good for mechanical replacement!!**

R&D considerations ··· and infrastructures ..

List of R&D tests for whatever proposed solution

→ Measure resistance to doses

→ Measure resistance to neutrons up to 10^{13} n_1MeV/cm^2

→ Control behavior at low temperatures

→ Measure resistance for large integrated charge

List of engineering details:

- Qualify MTTF
- Work on improving Cooling system and cooling distribution
- Improve/change the electronics:
    (1) FEE → Move to ASIC?
    (2) FEE → Move it to Mezzanine boards
    (3) DIRAC → new proposals ..of picoTDC

Additional material

SiPMs @ Mu2e-II: Radiation Induced Current

- ❑ In Mu2e, there is a current drawn by the sensors that is due to the direct illumination by low gamma irradiation or by induced phosphorescence.

- ❑ **For CsI and BaF_2 this has been measured during Mu2e R&D path**

→ The highest RIC source is the dose, a smaller contribution from neutrons.
→ In Mu2e, we expect to have a RIC of 200-300 uA dominated by beam-flash dose.

→ In Mu2e-II, this situation could be reversed, neutron fluence coming from capture on the target could be the highest source.

- ❑ **This RIC is independent from the photosensor cooling** and depends only on the crystal "induced" light

→ **In Mu2e-II, the average current induced by neutrons could reach 2 mA/channel**

SiPMs @ Mu2e-II: Radiation Induced Noise

- From the RIC we estimate the radiation induced noise (RIN) in MeV looking at the fluctuation of the photoelectrons in a given gate.

- In Mu2e we evaluated the RIN (with SiPM) in a 200 ns gate
  - → We estimate around 300-500 keV / channel
  - →The noise factor is proportional to SQRT(Npe−rin) i.e. to SQRT(RIC)
  - → In Mu2e-II, we expect a factor SQRT(10) = 3 of increase in RIC
  - → This means a factor of 3 on RIN → **1-1.5 MeV noise per channel.**

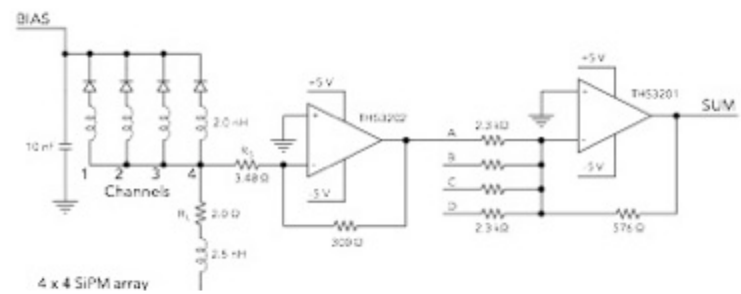
- **Fortunately the technical requirement of requiring for Mu2e-II narrow signals helps to reduce the noise contribution:**
  - → In MU2E we evaluate the noise in 200 ns.
  - → In MU2E-II we can do that in 20-30 ns
  - → The noise scales down with SQRT(DT-Gate) → it will be reduced to 1/3

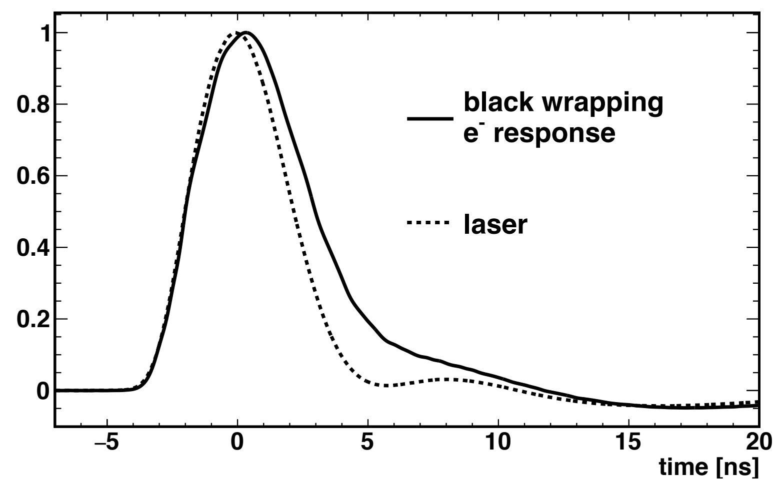
The RIN noise in Mu2e-II will be comparable to Mu2e

SiPM preamplification

Corradi/Miscetti

- 4 6x6 mm^2 SiPM in series + Preamp + Shaper (ala Mu2e) ..
- 16 3x3 mm^2 SiPM in Parallel configuration +
  2 stages of operational sum (4 x 4) + single pole shaper (ala g-2)





For Mu2e-II → BaF_2 + SiPMs matched with the g-2-like solution is favored

Possible digitization scheme (1)

- In Mu2e we are digitizing signals with Waveform sampling at 200 Msps
- This is working nicely in Mu2e but has to be abandoned for Mu2e-II

- The sampling will be too slow for pileup separation and timing resolution for the "much narrower" envisaged signals of 20 ns → **at least 1 Gsps needed!**
- Increasing the sampling will drastically increase power consumption
- X 10 radiation hard

Possible scheme solution: fan-out signals at MB level

→ First copy discriminated and digitized with multi-hits TDC (picoTDC of CERN)

https://indico.cern.ch/event/548960/contributions/2225641/attachments/1303647/1947295/DT_elec_up_DR.pdf

→ Second copy readout with a lower rate FADC

→ Find RadHard components

POLARFIRE FPGA and DCDC converters (FEAST of CERN)

Spinella/Pezzullo

http://project-dcdc.web.cern.ch/project-dcdc/public/Documents/FEAST%20datasheet.pdf

Possible digitization scheme (2)

- Instead of sampling the waveform we want to use TDCs for:
  - Precise time reconstruction
  - Charge evaluation using time over threshold
- Rad hard ADC @ 50-100 MHz for charge reconstruction? **(simulation needed)**
- The **PolarFire** FPGA should be sufficiently rad hard
- **VTRx** optical transceivers
- **The board could also include the PreAmp + shaper section**
  (thanks to the SiPM or MCP-LAPPD high gain)
  - TID reduction & neutron flux by a factor of ~ 10
  - simplified cooling system

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