Status of C6D6+SiPM developments

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The n_TOF Collaboration

European Research Council

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Outline:

- Objectives of a new C6D6 design
  - Neutron sensitivity
  - Electrical signal response
  - B-field insensitivity

QUICK SUMMARY

- **Readout electronics for SiPM and fast signals**
- **Encapsulation optimization**
- **Schedule and possible proposals**

ONGOING WORK

C6D6/SiPM goals:

- Further **reduce the intrinsic Neutron Sensitivity** (compared to state-of-the-art C6D6)
- Better **suited for high CRs and γ-flash (EAR2)** by reducing volume (1/4 L6D6)→ Better suited for high En-range
- Clean electrical output signals (no VDs → no rebounds → To be tested in the lab during LS2) → **Reliable PSA**
- Fast response, comparable or better than PMTs→ Well suited for neutron-TOF
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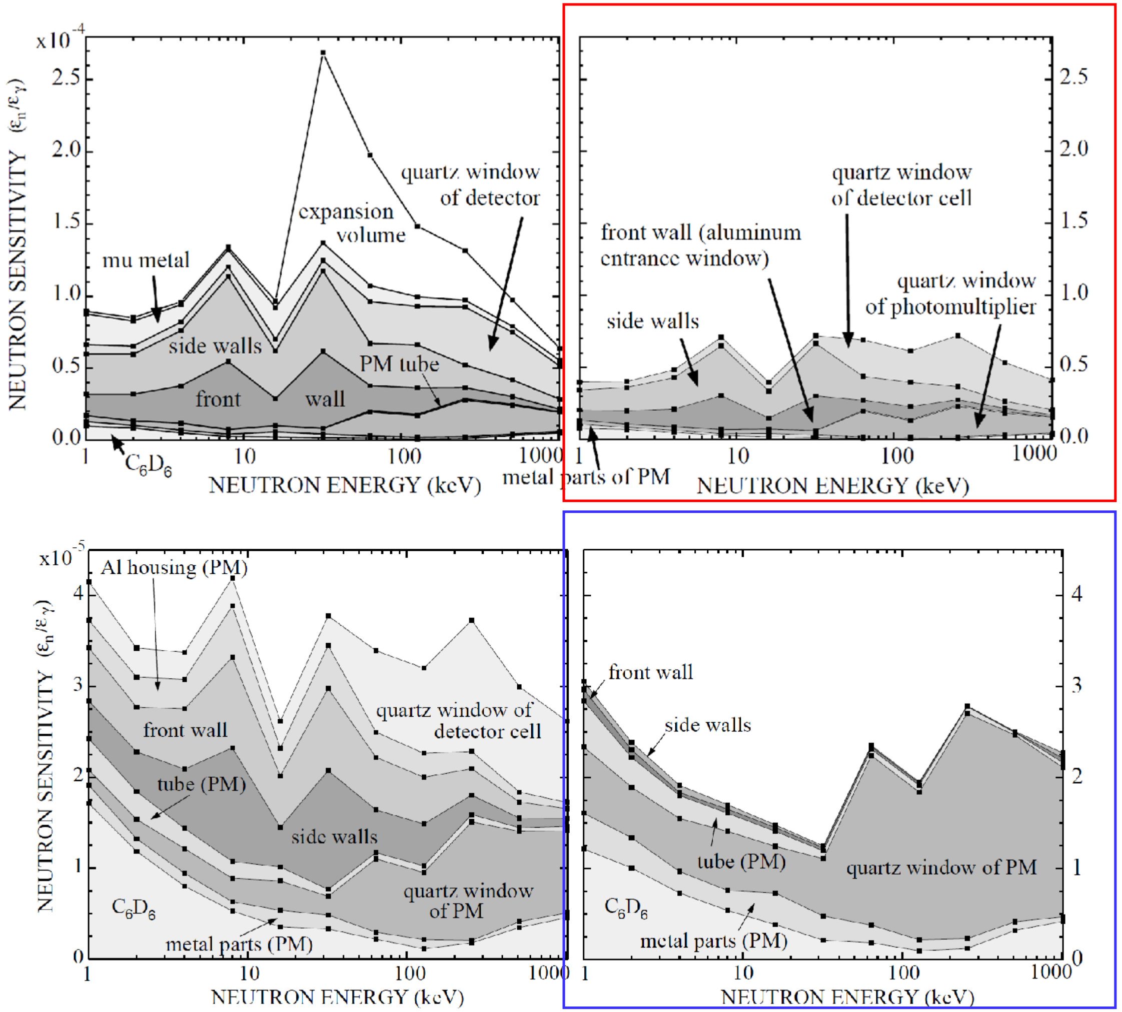
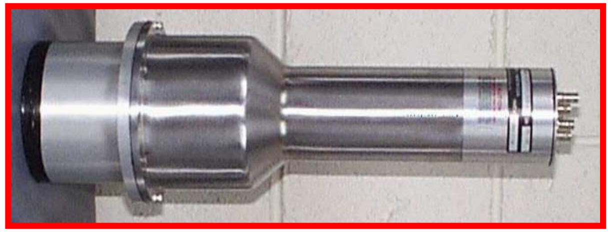
- Aspect 1: neutron sensitivity





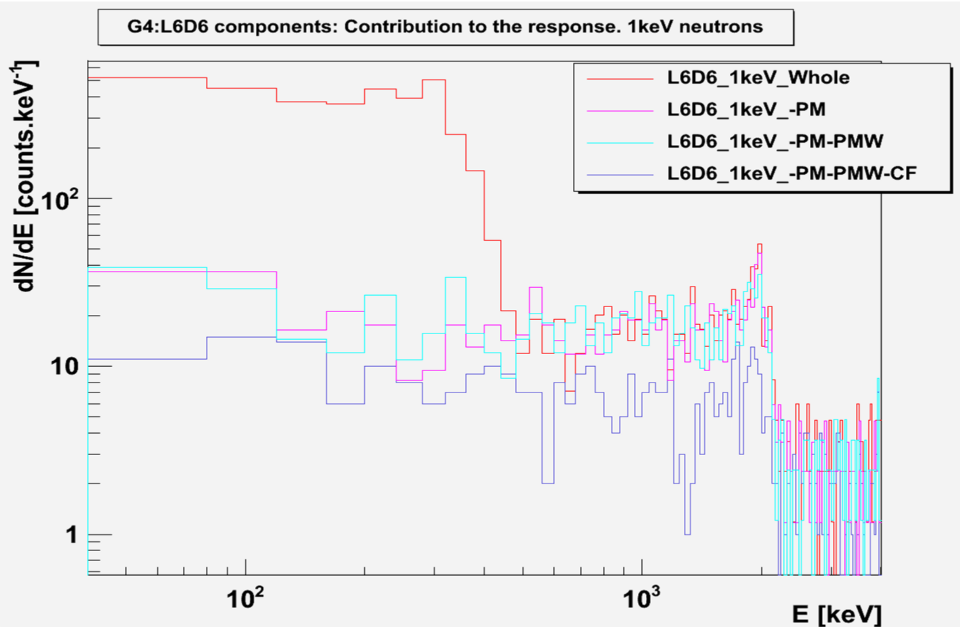
R.Plag et al. Nucl. Instr. Meth. A 496, Issue 2, p. 425-436 (2004).

C6D6/PMT Neutron sensitivity: could it be improved further?

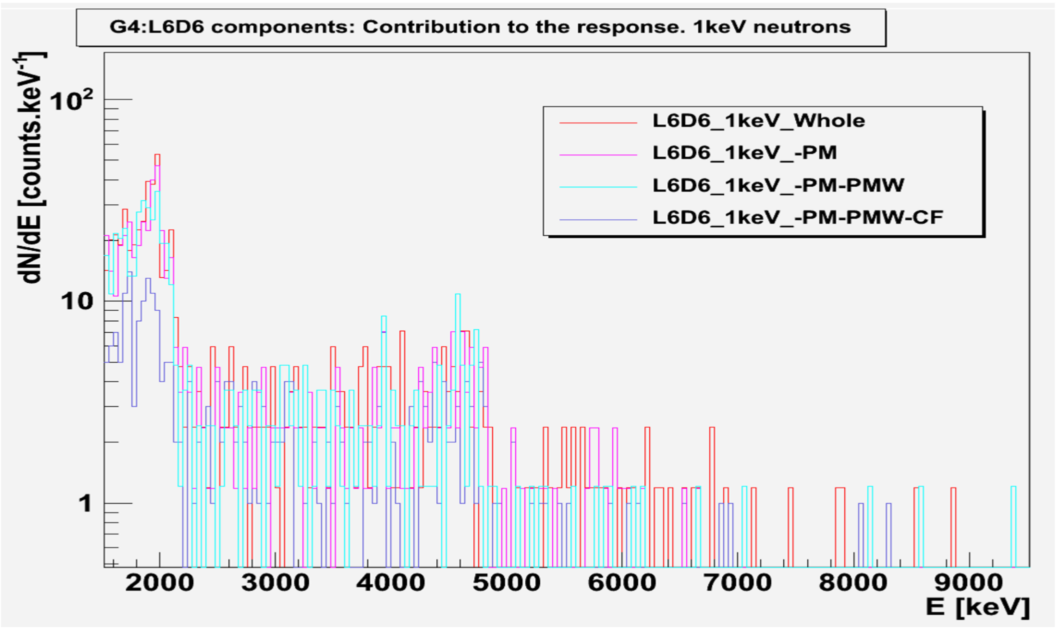
- Aspect 1: neutron sensitivity

L6D6 Response to Neutrons (C. Guerrero & J.Lerendegui-Marco, U

- Analysis of main contributions to neutron sensitivity of the L6D6 :



PMT is main contributor (E< 500keV)



CF main cotribution at ~2.2 MeV

→ Thus, avoiding PMT (thereby reducing also total amount of CF) should help to reduce NS further down(!)

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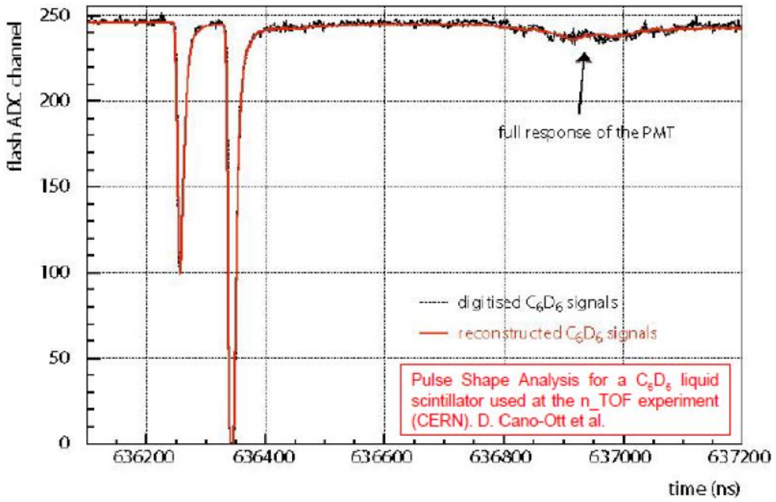
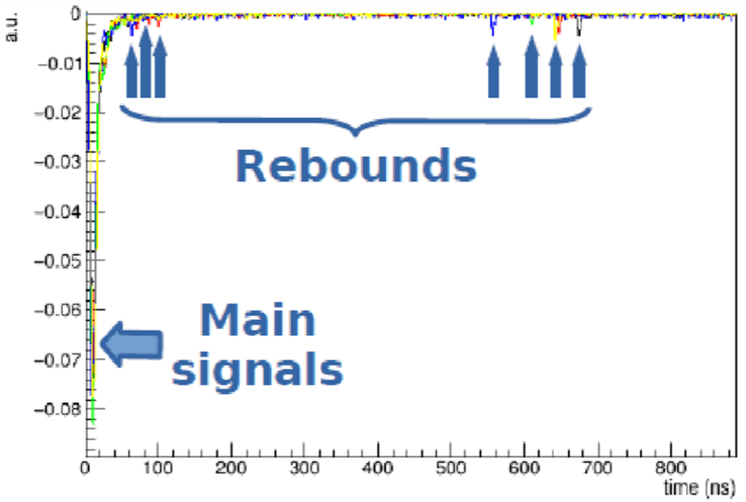
C6D6/PMT response: affected by artifacts (rebounds) probably arising from PMT's Voltage Divider:

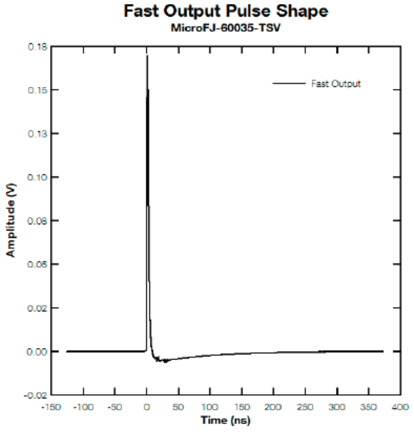
→ Aspect 2: ringing and rebounds produce a "dirty" electrical response

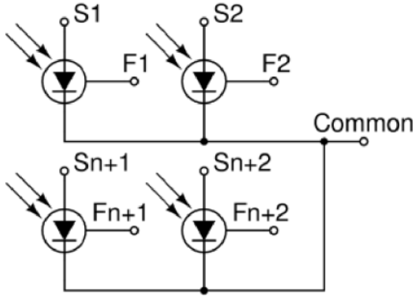
PMT + Voltage Divider:

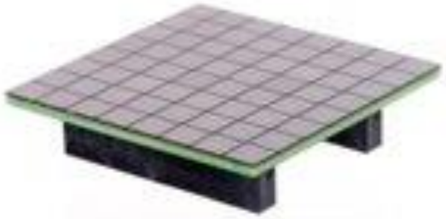




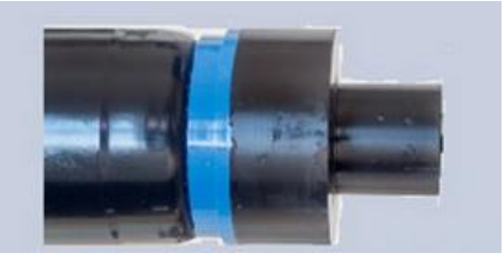
SiPM:

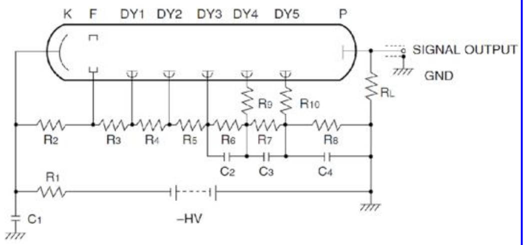






Hypothesis: Impedance mismatch issues due to voltage divider





Input from **Lucia Gallego**.
After pulse desexcitation:

Meas. Sci. Technol. 7 (1996) 121–135.

J. P. E 10 (1977) Volume 10 1044

NIM A 574 (2007) 121–126

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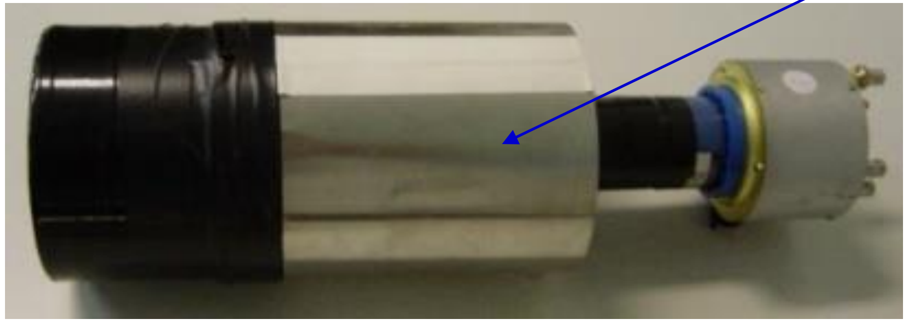
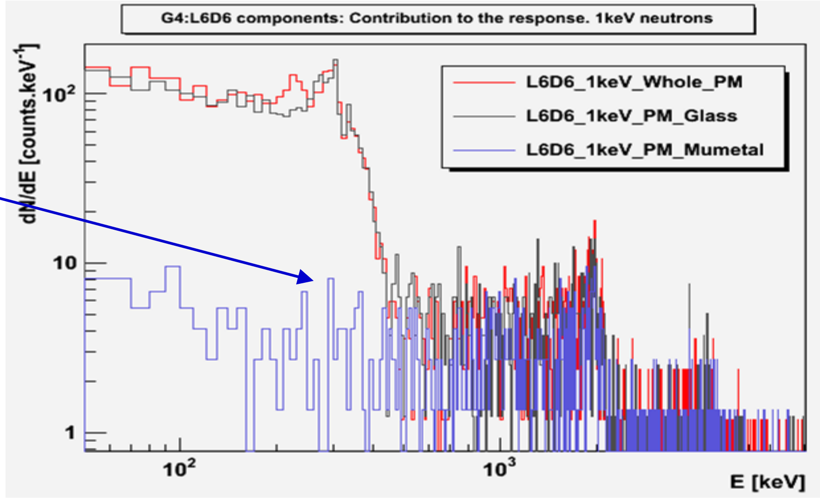
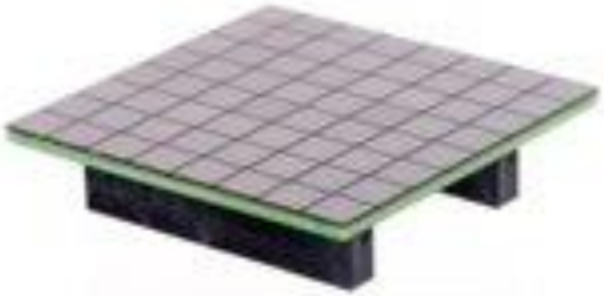
C6D6/PMT B-field sensitivity: can we avoid it?

- Aspect 3: mu-metal & magnetic fields screening

mu-metal



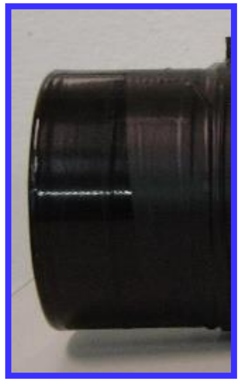


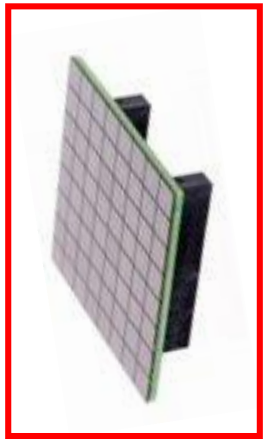


From conventional C6D6/PMT towards C6D6/SiPM: the proposal to develop a new C6D6

→ Aspect 1: "dirty" signal response
→ Aspect 2: neutron sensitivity (PMT)
→ Aspect 3: B-field sensitivity (mu-metal)

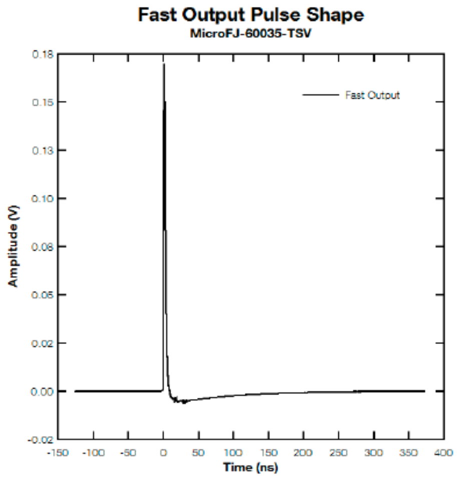
Replace PMT+VD by SiPM





"Mock" prototype of IFIC-C6D6: i6D6

- 250 ml C6D6
- SiPM Sensl 50x50mm^2
- 1/4th of L6D6 volumen (four of these make one L6D6)

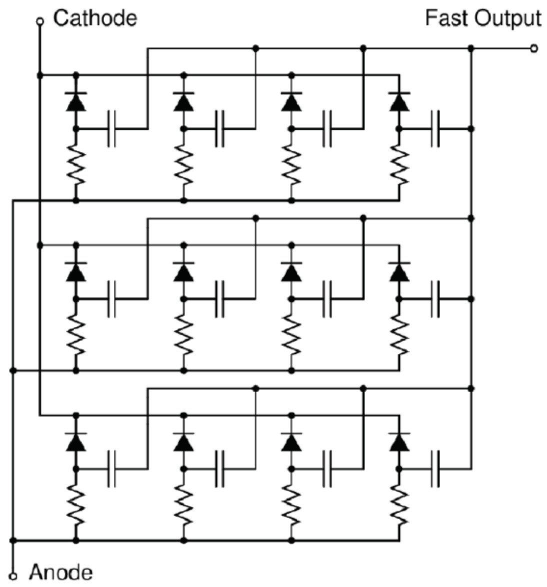


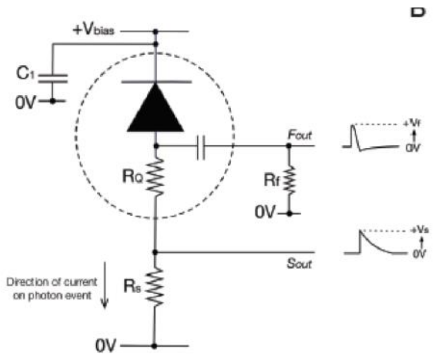
Status of C6D6+SiPM developments (Ongoing work)

→ Readout electronics design for fast SiPM summed output

C6D6/SiPM electronic RF readout design

- SiPM output capacitance is of 200 pF/channel (Fast Output) and 4nF/channel (STD Output).
- Direct sum is not reliable as it leads to a very high capacitance in the output and a very time extended output (slows down the output), additionally dark-current from non-firing pixels is added to the final signal, thus worsening the noise a lot.
- Need of a special impedance-matching network to keep initial time response of the fast SiPM output





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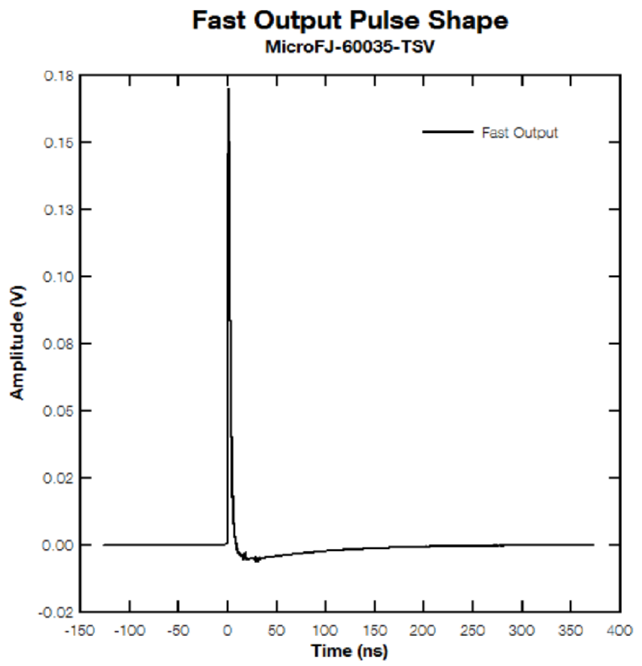
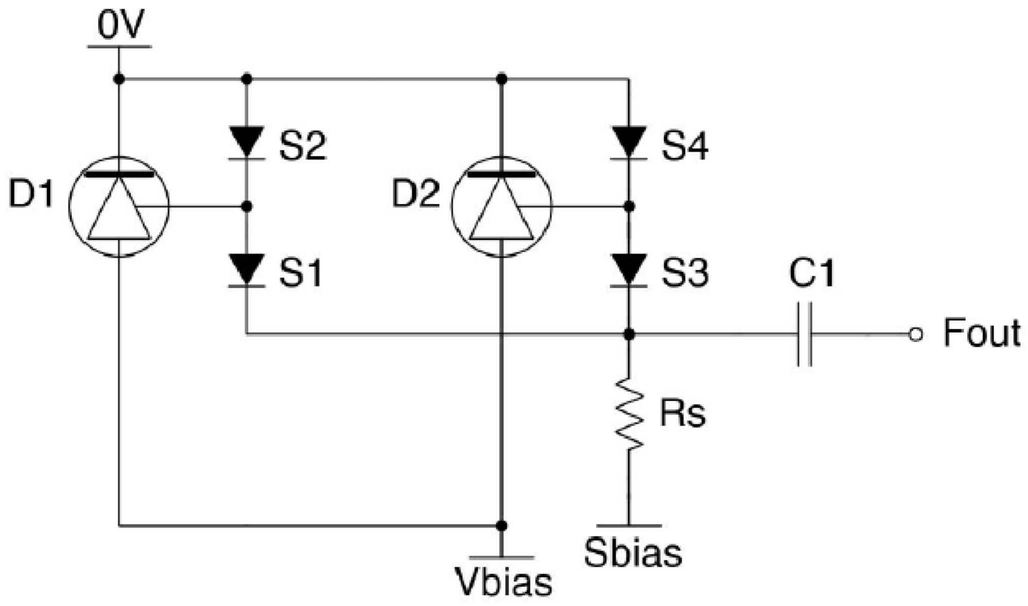
- Solution: **multiplexed Schottky-diode based readout network**





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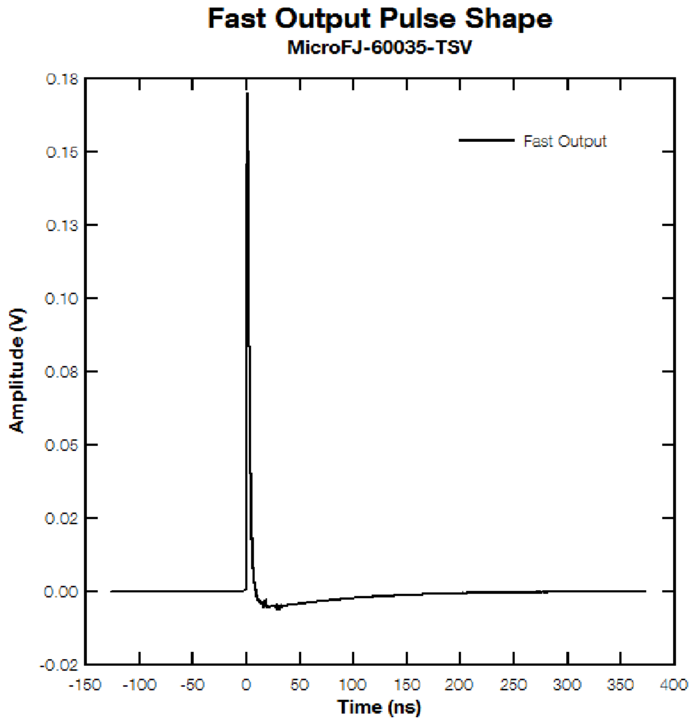
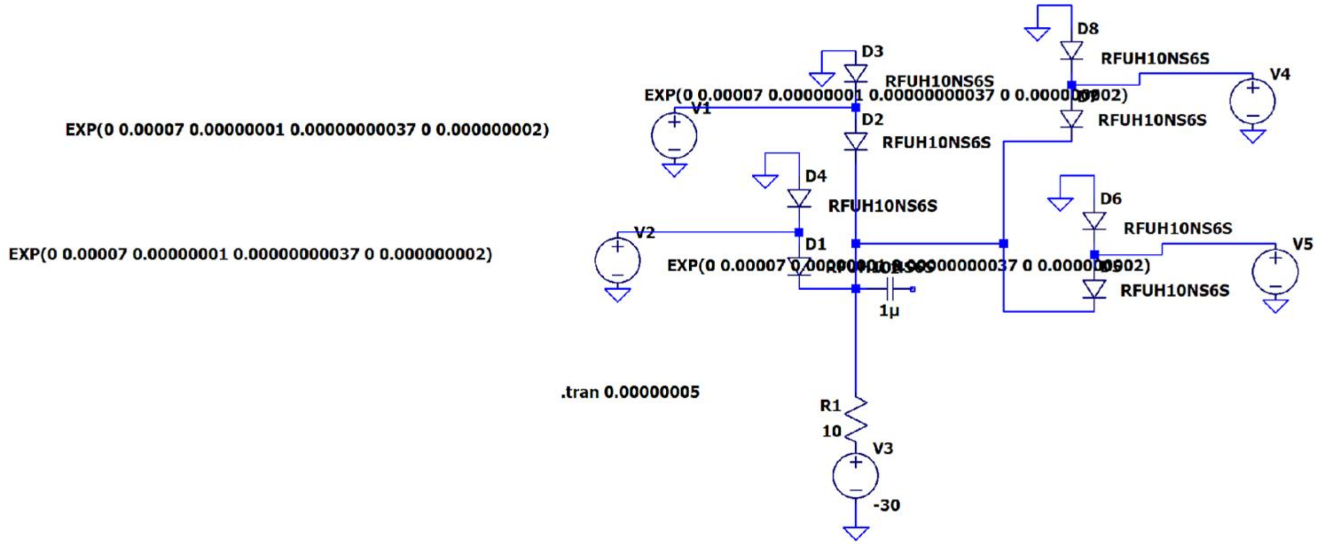


SPICE simulation for 4 pixels



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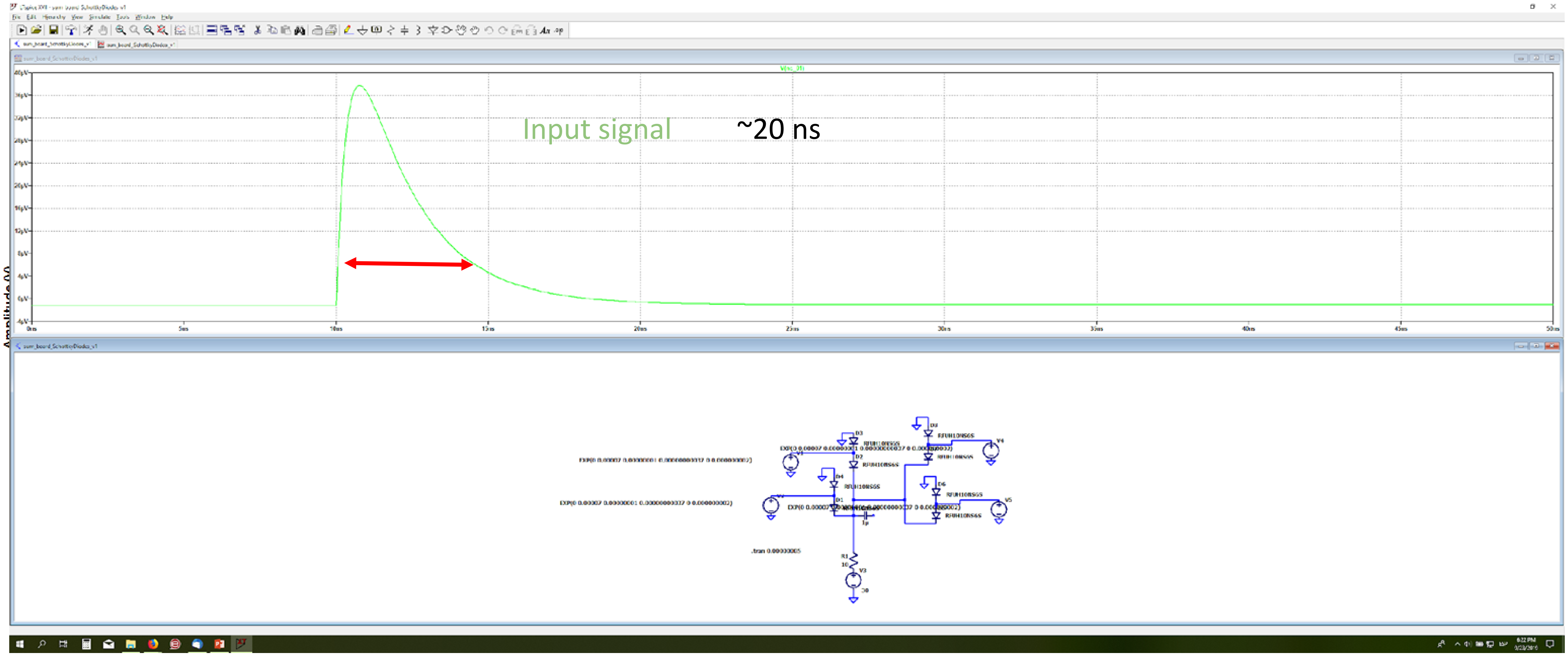

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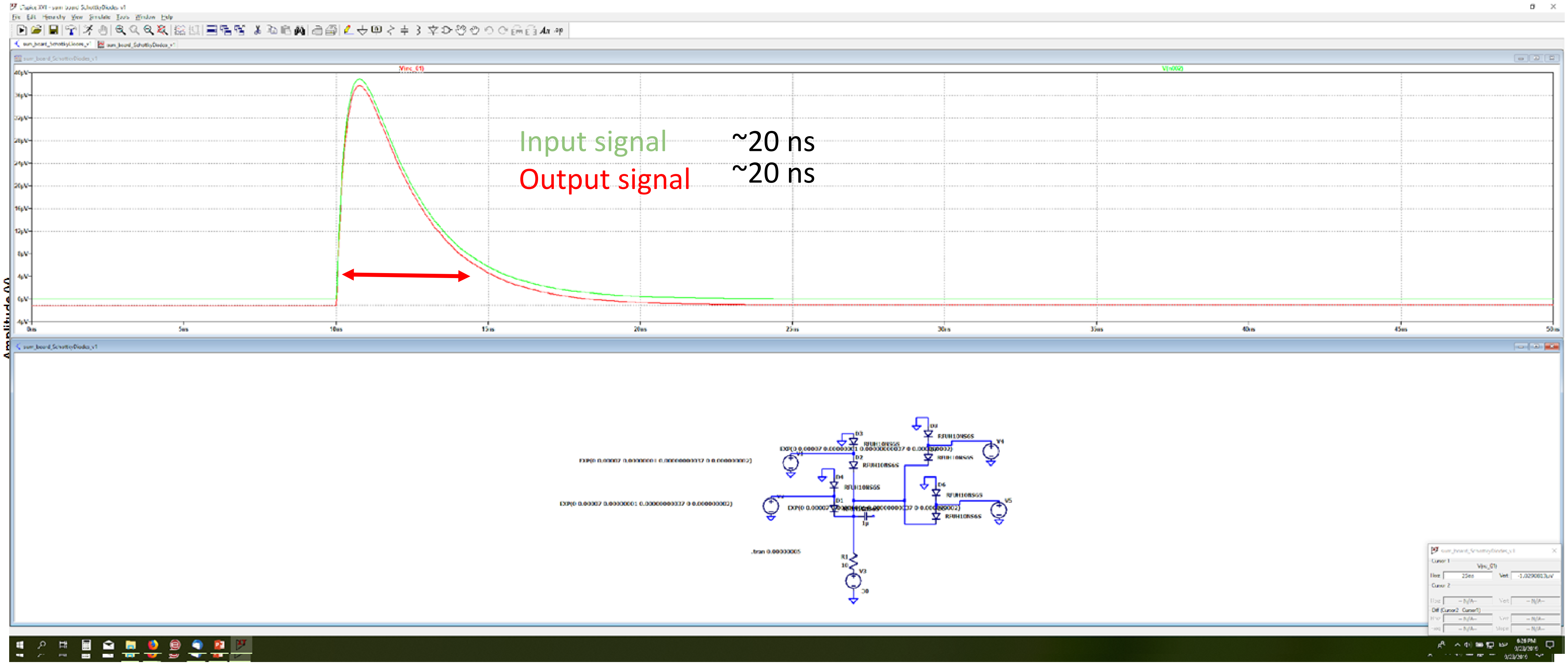

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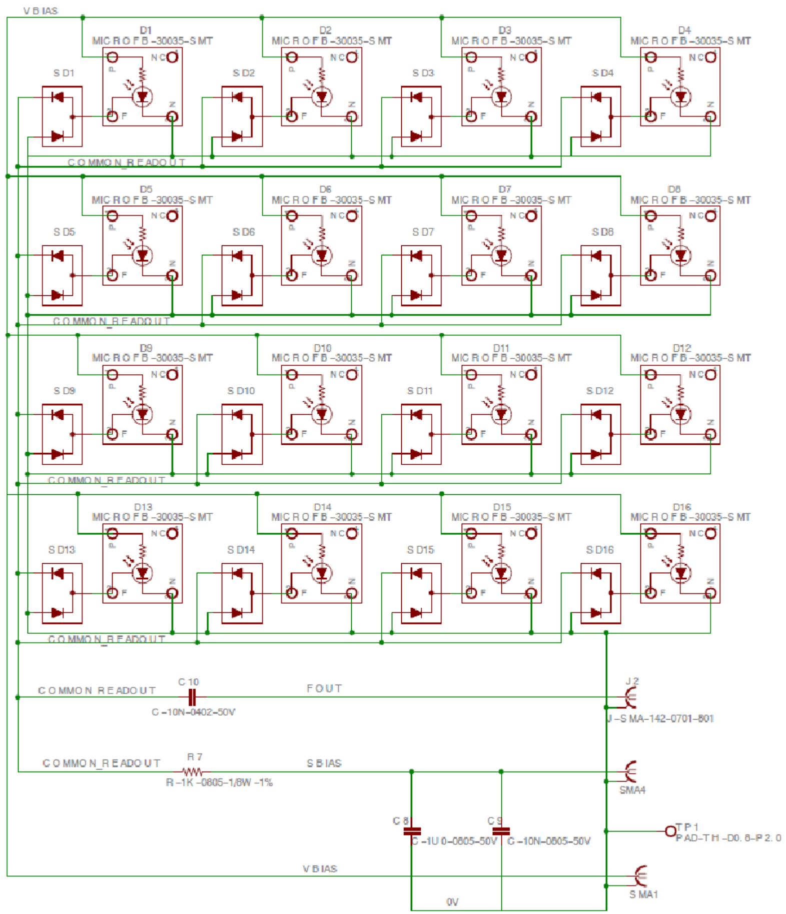
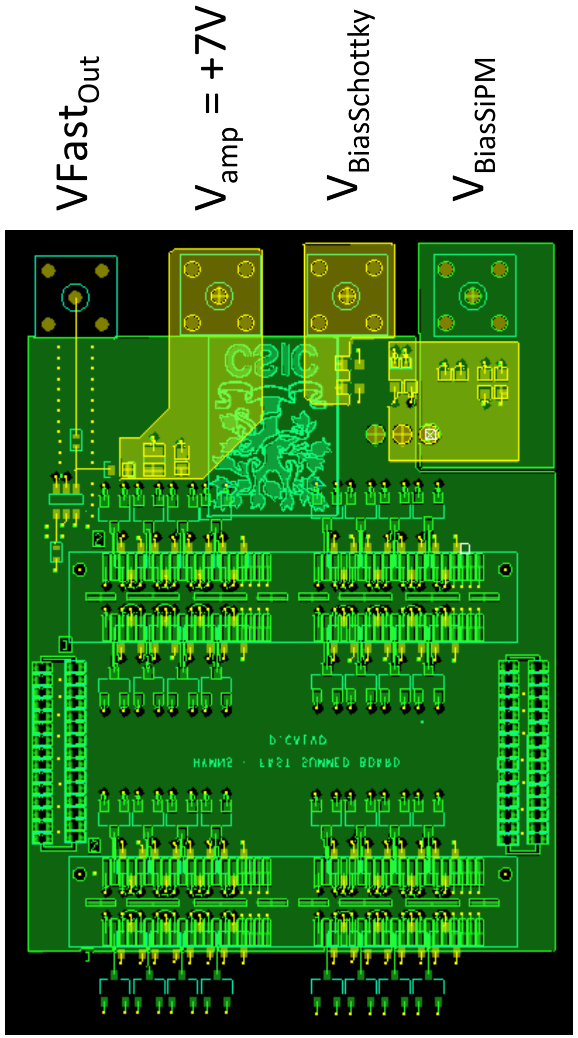
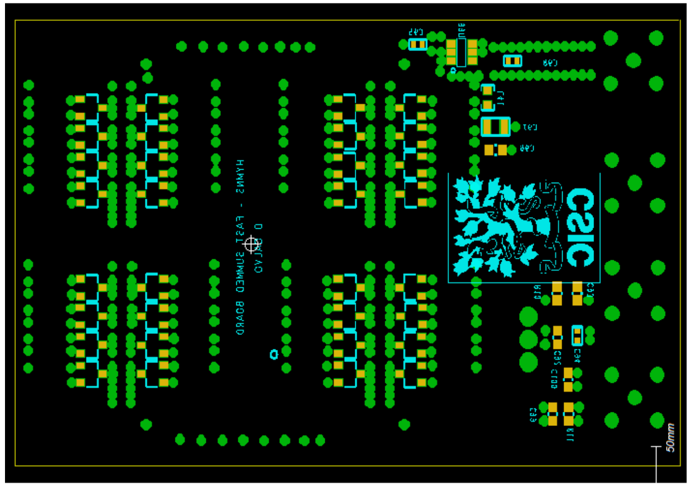
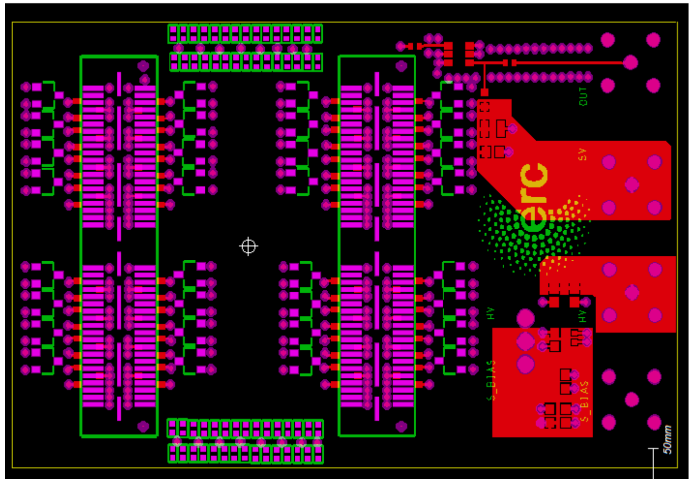








Status of C6D6+SiPM developments (Ongoing work)

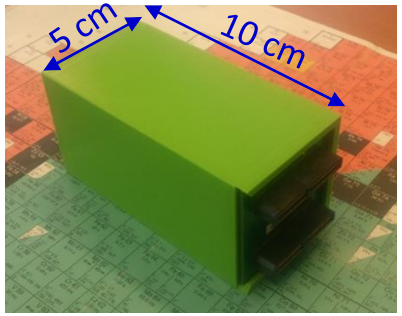
→ Encapsulation optimization for high-count rate capability

C6D6/SiPM encapsulation design and optimization for high count rates

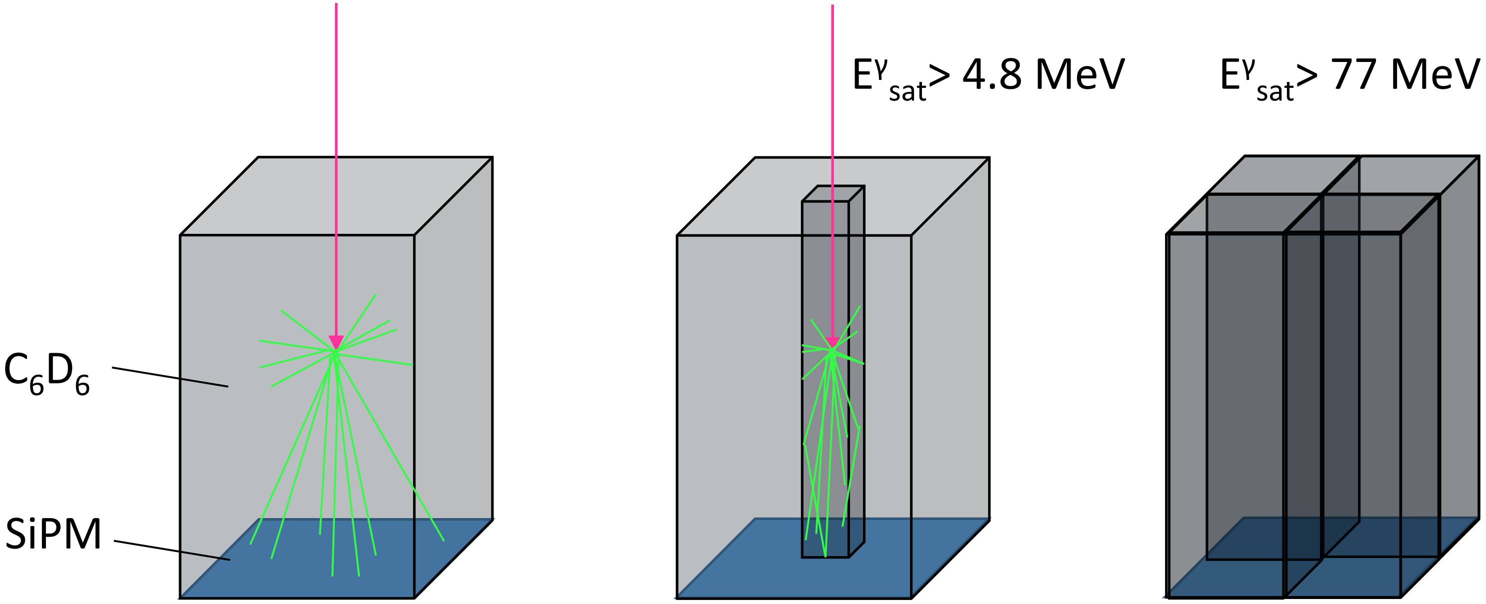
- Reduced size of the sensitive (C6D6) volumen: 250 ml represents 1/4th of C-fiber C6D6+PMT detectors

1 L Volume

250 mL Volume



- Pixelation of the sensitive (C_6D_6) volume, helps? let's test it



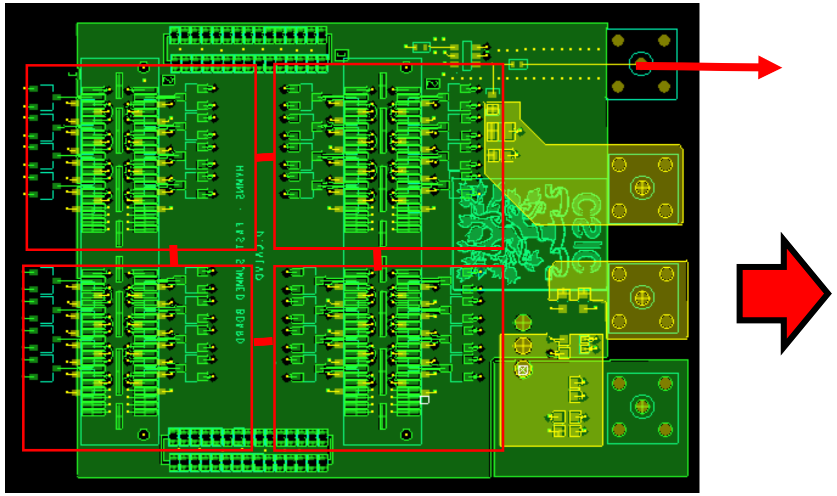
C_6D_6 (BC535 equivalent)

PROPERTIES	EJ-315
Light Output (% Anthracene)	60
Scintillation Efficiency (photons/1 MeV e⁻)	9.200
Wavelength of Maximum Emission (nm)	425
Decay Time, Short Component (ns)	3.5
Bulk Light Attenuation Length (m)	>3
Specific Gravity	0.954
Refractive Index	1.498
Flash Point (°C)	-11
Boiling Point (°C at 1 atm)	79

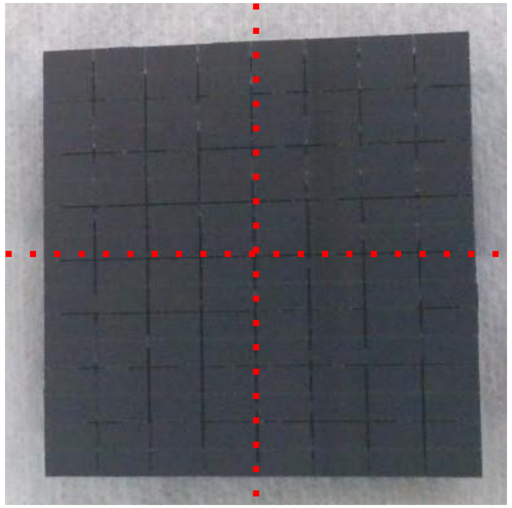
SiPM

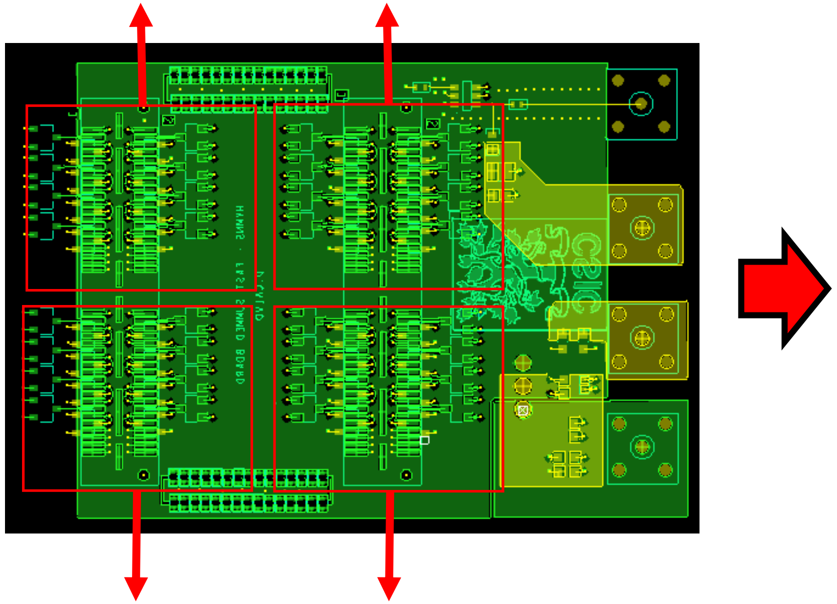
Product Code	Microcell size (Total number per pixel)
6 mm Sensor Arrays	
ArrayJ-60035-4P-BGA	35 um (22.292 microcells)
ArrayJ-60035-64P-PCB	

C6D6/SiPM encapsulation design and optimization for high count rates

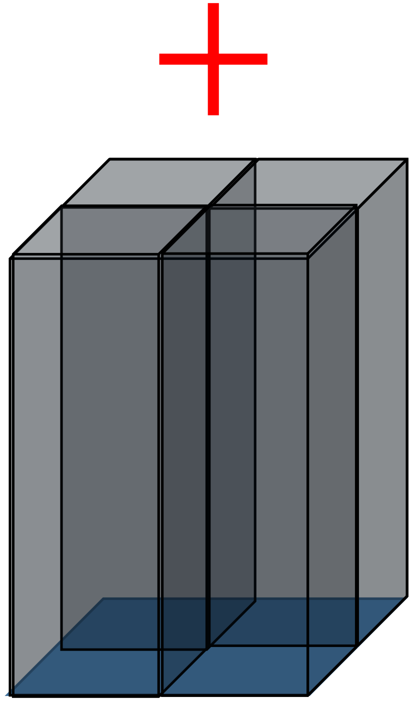


Jumper for summing up reading





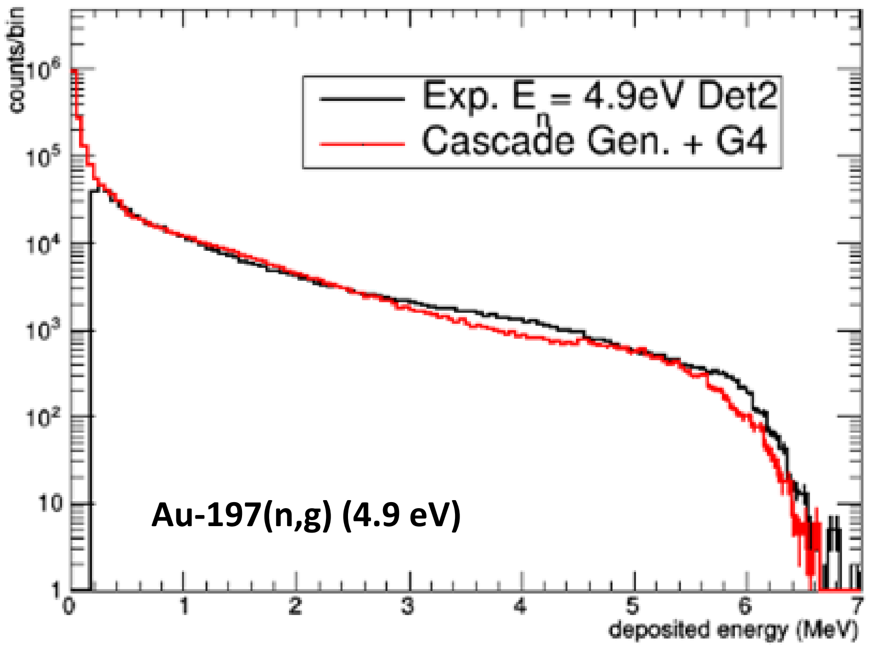
4 independent C6D6 detection cells



C6D6+SiPM / LaCl3+ SiPM proposal for TED technique

- Threshold correction depends strongly on the isotope and the detection threshold.
- Example: Pu-242(n,g): After normalization to Au→ threshold correction still 4-7% using 150-250 keV threshold

	f_{thr}		
	250 keV	200 keV	150 keV
^{242}Pu	1.150(4)	1.121(4)	1.090(3)
^{197}Au	1.078(3)	1.066(3)	1.052(3)
^{242}Pu/^{197}Au	1.067(4)	1.052(4)	1.035(4)



$$Y(E_n) = \frac{1}{N_{sample}} \frac{1}{f_{th}} \frac{C(E_n) - B(E_n)}{\varphi(E_n)\varepsilon(E_n)}$$

Large correction in some cases (!)

C6D6+SiPM / LaCl3+ SiPM proposal for TED technique

Proposal:

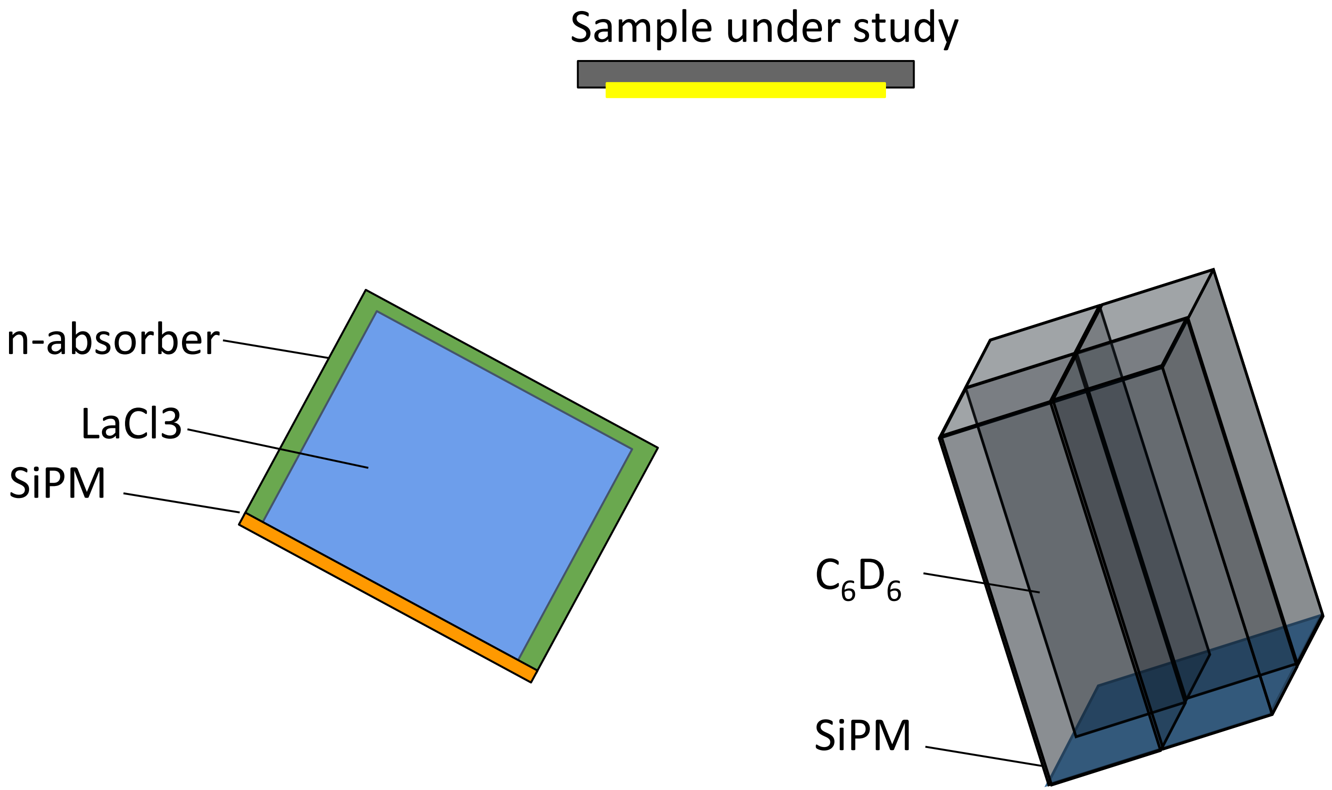
In parallel to the C6D6+SiPM commissioning.

Measurement of reference capture spectra using LaCl3+SiPM together with the C6D6/SiPM detectors.

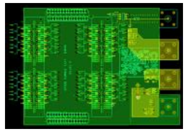
Spectroscopic information about the nuclei under study.

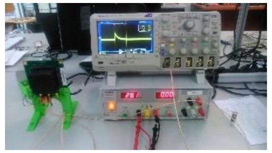
Improve the modeling of neutron capture cascades.

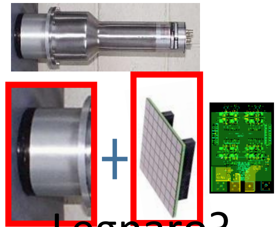
Further Improvement of threshold corrections for TED technique.



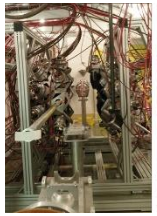
C6D6+SiPM development Workplan

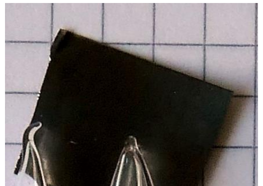






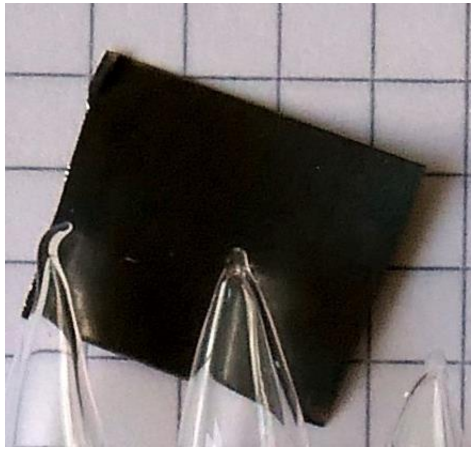
Legnaro?
Bicron?





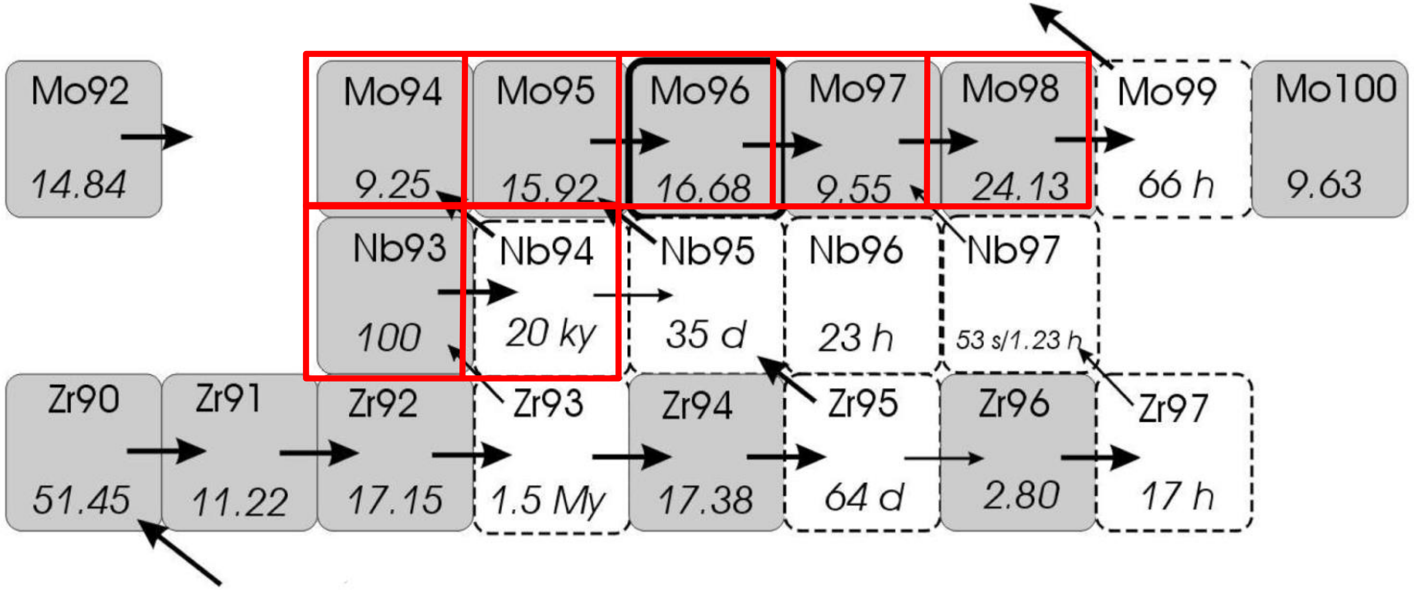
Task	Dates						
PCB Fast Sum	< 15 October IFIC						
PCB Fast Sum test in Lab		15-30 October @ IFIC					
1st test with C6D6 Bicron + SiPM			11-24 November'19@ CERN				
ENCAPSULATION 4 fold C6D6-cell (customized)				Dec.19 – June.20 (?)			
2nd test: C6D6+SiPM & n-sensitivity					July-Dec.'20@ CNA-Seville		
3rd Test: (>LS2, during target #3 commissioning)						Jan-June'21 @ n_TOF	
Nb-94 (n,g) **Mo-95-98 (n,g)** Proposals							Near future

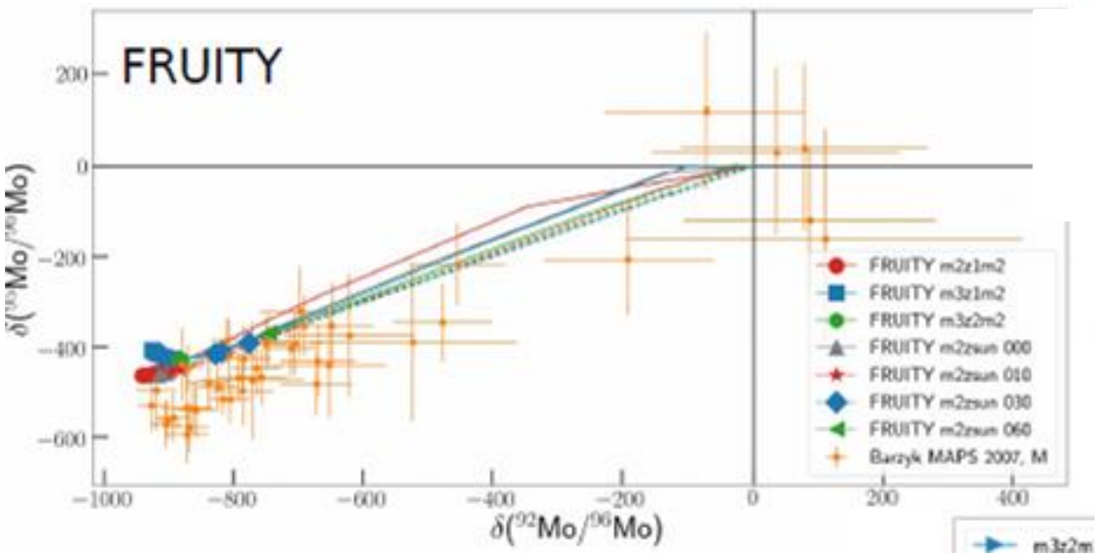
C6D6+SiPM: Future plans for proposals



- **Nb-94(n,g):**
  - Sample available: Nb-93(n,g)Nb-94 @ ILL
    - 5 ultrahigh purity Nb samples, each 5-10 MBq ^{94}Nb, ≈30 MBq ^{95}Nb, ≈100 MBq ^{93m}Nb
  - Radioactive isotope→ **First measurement ever**
  - Nugrid calculations on the XS impact to be performed

- **Mo-95-98**
  - NPA-IX (A. Tattersall): Mo-96 s-process only (powerful tool)
  - Models have problems in reproducing the 95Mo/96Mo ratio from pre-solar grains → Increase of Mo-95(n,g)∽30%
  - **Main request from sensitivity study: re-measure Mo-94(n,g), Mo-95(n,g), Mo-96(n,g), Mo-97(n,g), Mo-98(n,g)**





backup stuff

Uncertainties in s-process nucleosynthesis in low-mass stars determined from Monte Carlo variations

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Table A1. The key reaction rates for the standard model. Key rates in levels 1–3 are shown, along with their correlation factors r_{cor0}, r_{cor1}, and r_{cor2}, respectively. Not all s-process nuclides analysed are listed but only those for which key rates were found. Also shown for each rate are the ground state contributions X_0 to the stellar rate of the (n,γ) reaction and uncertainty factors of the β-decay rate at two plasma temperatures, respectively.

Nuclide	$r_{cor,0}$	$r_{cor,1}$	$r_{cor,2}$	Key rate Level 1	Key rate Level 2	Key rate Level 3	X_0 (8, 30 keV)	Weak rate uncertainty factor (8, 30 keV)
[illegible]		[illegible]		[illegible]			[illegible]	
		0.14	0.67		^{64}Ni(n, γ)^{65}Ni		1.00, 1.00	
^{95}Mo		−0.85		^{95}Mo(n, γ)^{96}Mo			1.00, 1.00	
		0.29	0.65		^{64}Ni(n, γ)^{65}Ni		1.00, 1.00	
^{96}Mo		−0.94		^{96}Mo(n, γ)^{97}Mo			1.00, 1.00	
^{97}Mo		−0.87		^{97}Mo(n, γ)^{98}Mo			1.00, 1.00	
^{98}Mo		−0.94		^{98}Mo(n, γ)^{99}Mo			1.00, 1.00	
[illegible]				[illegible]				

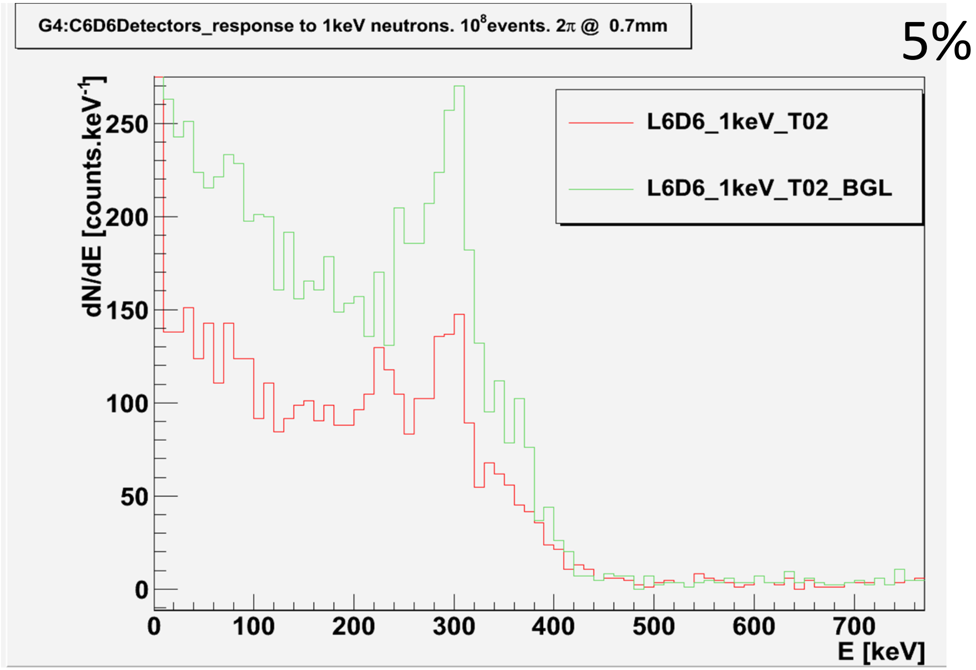
C6D6/PMT Neutron sensitivity: could it be improved further?

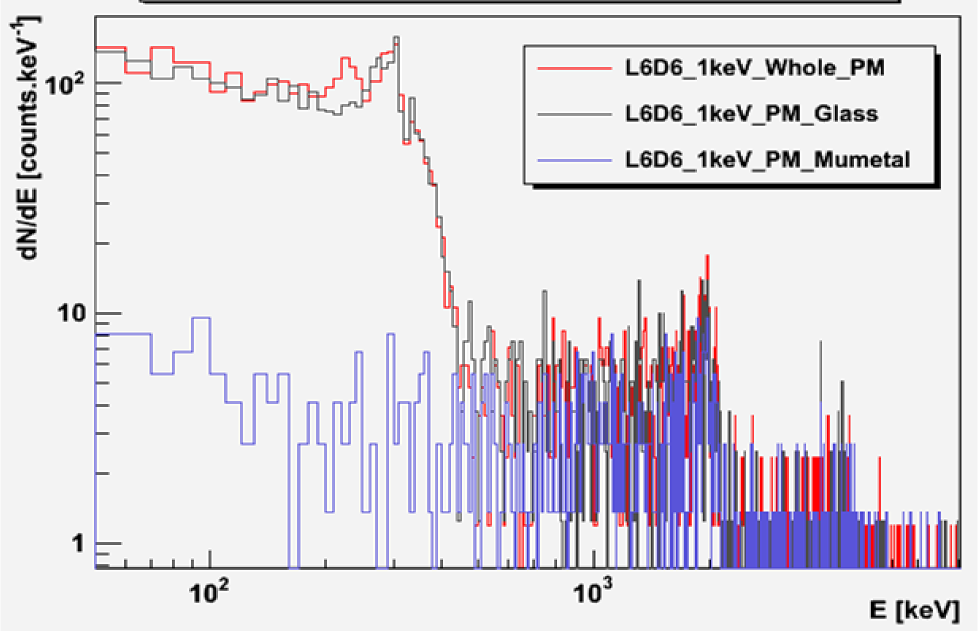
- Aspect 1: neutron sensitivity

L6D6 Response to Neutrons (C. Guerrero & J.Lerendegui-Marco, US):

- PMT : empty glass bottle surrounded by a thin Mumetal layer

Impact of Boron
5%(BGL) vs 2% B-Glass





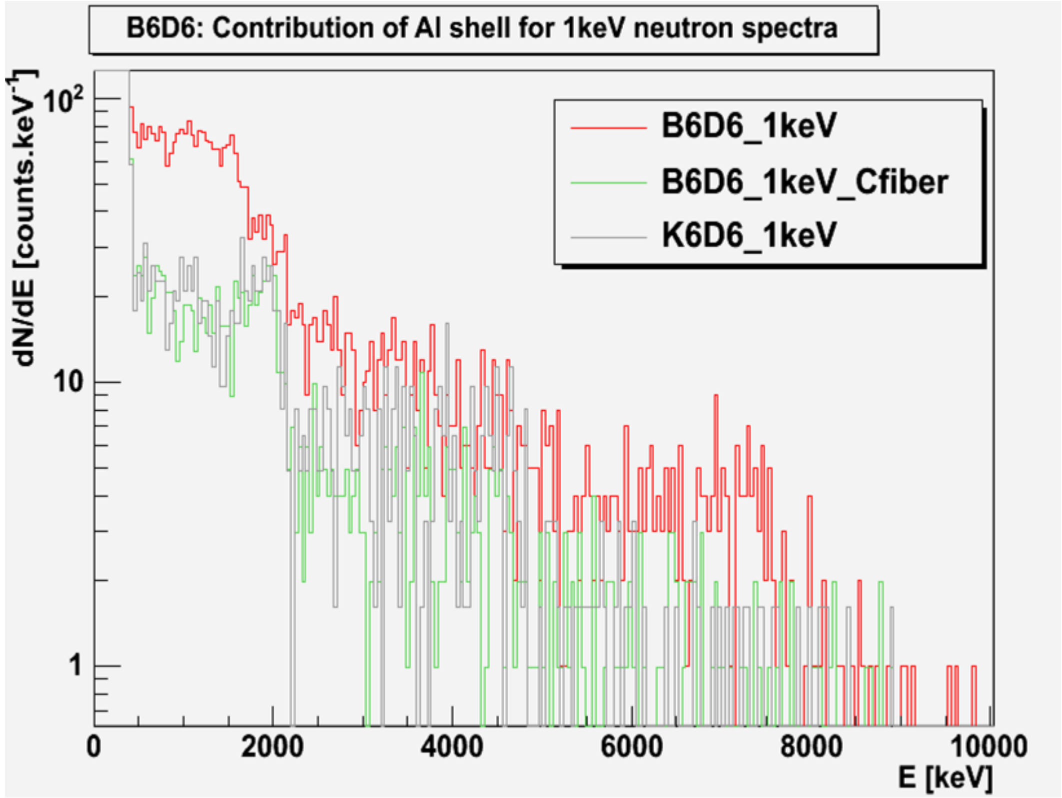
- Thus, avoiding PMT (thereby reducing also total amount of CF) should help to reduce NS further down(!)

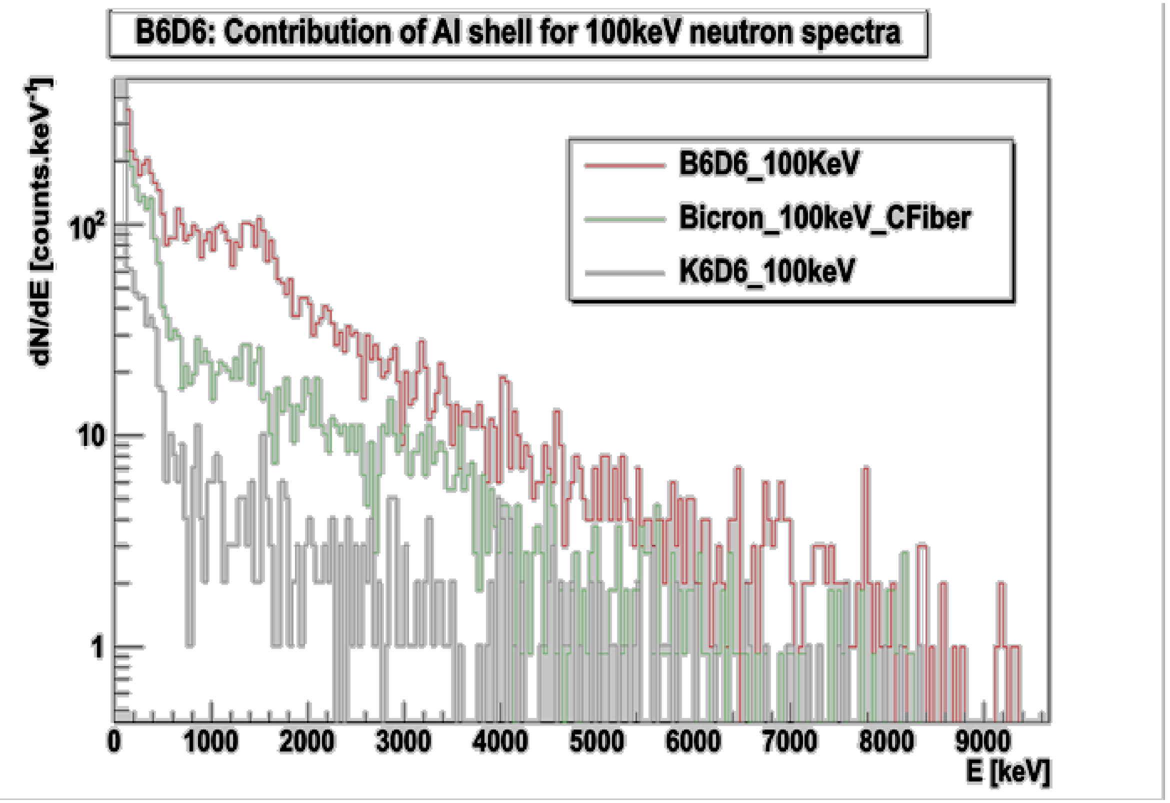
C6D6/PMT Neutron sensitivity: could it be improved further?

- Aspect 1: neutron sensitivity

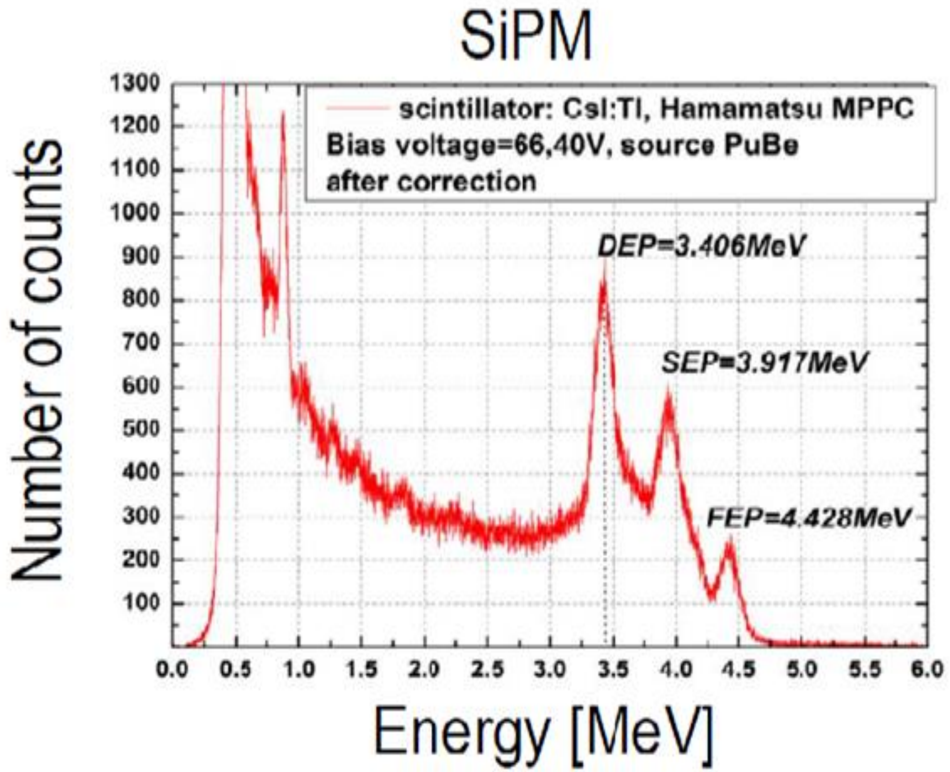
L6D6 Response to Neutrons (C. Guerrero & J.Lerendegui-Marco, US):

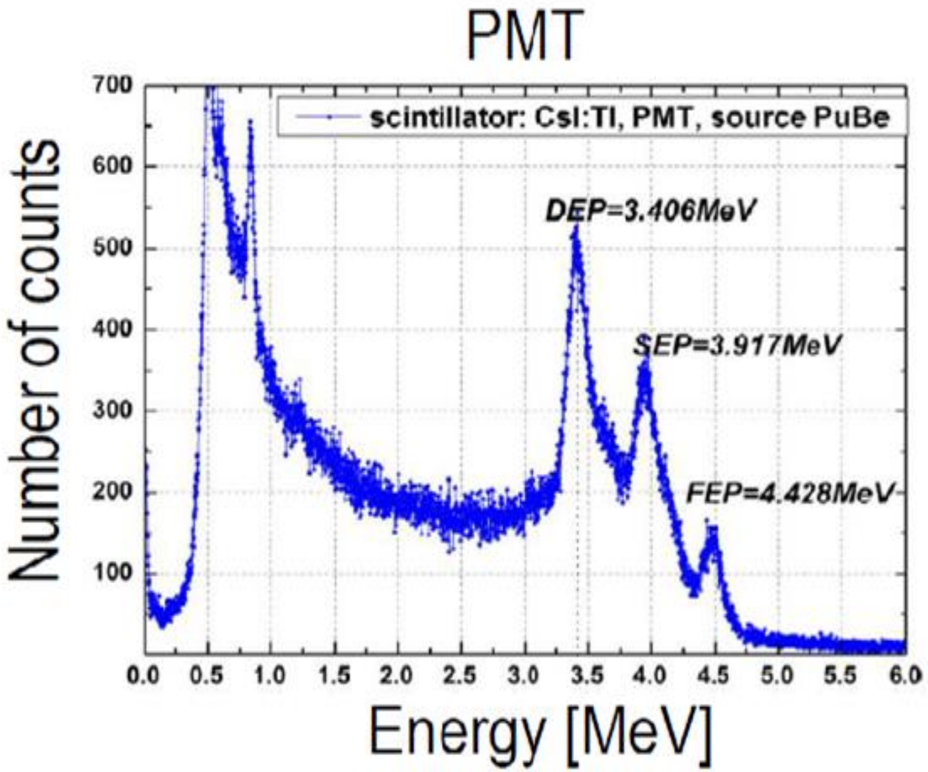
Influence of Al/Carbon Fiber





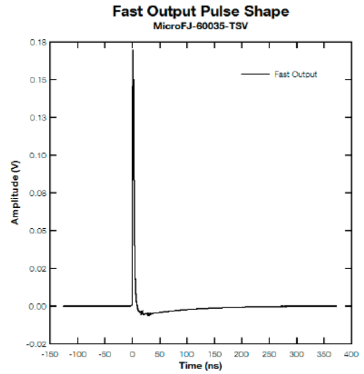
SiPM vs. PMT in γ-ray detection

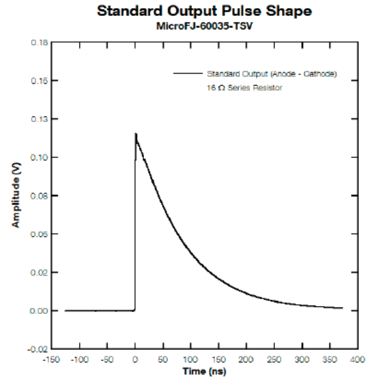




Example of energy spectra from Grodzicka et al. 2017 [Nuclear Inst. and Methods in Physics Research, A 874 (2017) 137–148]

Sensor Size	Microcell Size	Parameter	Overvoltage	Min.	Typical	Max.	Units
3mm	20µm	Gain (anode-cathode)	Vbr + 2.5V		9.1×10^5		
	35µm				2.8×10^6		
	20µm		Vbr + 6.0V		1.7×10^6		
	35µm				6.3×10^6		
6mm	35µm		Vbr + 2.5V		2.8×10^6		
			Vbr + 6.0V		6.3×10^6		
3mm	20µm	Dark Current	Vbr + 2.5V		0.2	0.3	µA
	35µm						
	20µm		Vbr + 6.0V		1.1	1.6	µA
	35µm						
6mm	35µm		Vbr + 2.5V		0.9	1.3	µA
			Vbr + 6.0V		4.1	6.8	µA
3mm	20µm, 35µm	Rise time [6] - anode-cathode output			100		ps
6mm	35µm				300		ps
3mm	20µm	Microcell recharge time constant [7]			12		ns
	35µm				37		ns
6mm	35µm				48		ns
3mm	20µm	Capacitance [8] (anode output)	Vbr + 2.5V		TBD		pF
	35µm				1000		pF
6mm	35µm				4000		pF
3mm	20µm	Capacitance [8] (fast terminal)	Vbr + 2.5V		TBD		pF
	35µm				50		pF
6mm	35µm				200		pF
3mm	20µm	Fast output pulse width (FWHM)			1.4		ns
	35µm				1.4		ns
6mm	35µm				3.0		ns
3mm	20µm	Crosstalk	Vbr + 2.5V		5		%
	35µm				7		%
	20µm		Vbr + 6.0V		10		%
	35µm				22		%
6mm	35µm		Vbr + 2.5V		7		%
			Vbr + 6.0V		22		%
3mm	20µm, 35µm	Afterpulsing	Vbr + 2.5V		0.1		%
	20µm, 35µm		Vbr + 6.0V		1.0		%
6mm	35µm		Vbr + 2.5V		0.1		%
			Vbr + 6.0V		1.0		%
3mm	20µm, 35µm	Temperature dependence of Vbr [8]			21.5		mV/°C
6mm	35µm						





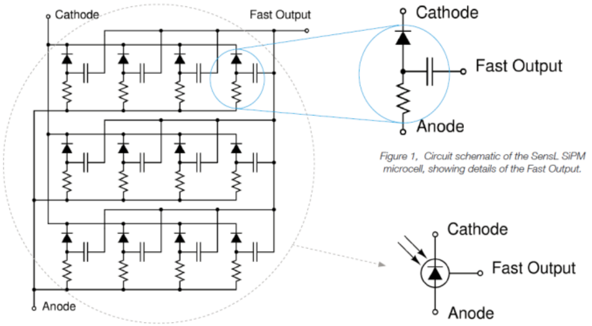


Figure 1. Circuit schematic of the SensL SiPM microcell, showing details of the Fast Output.