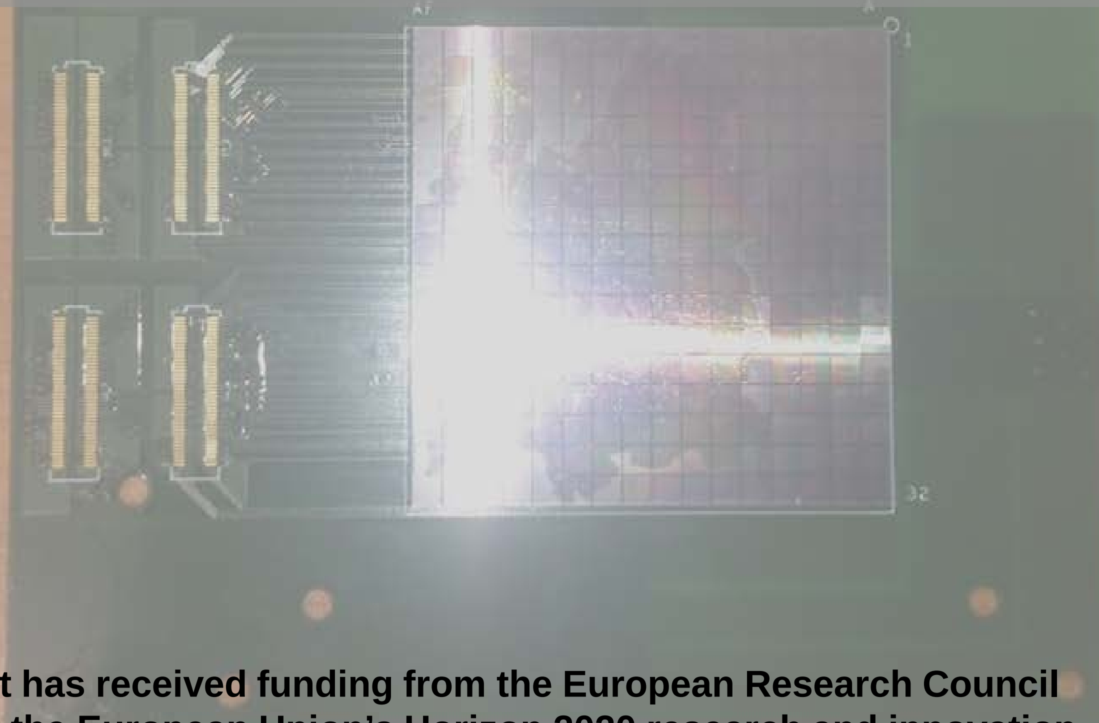
i-TED

Total Energy Detector with γ-imaging capability

L. Caballero Ontanaya, C. Domingo-Pardo, P. Gramage, I. Ladarescu, JL Tain (IFIC)

C. Guerrero (US)

and the n_TOF Collaboration



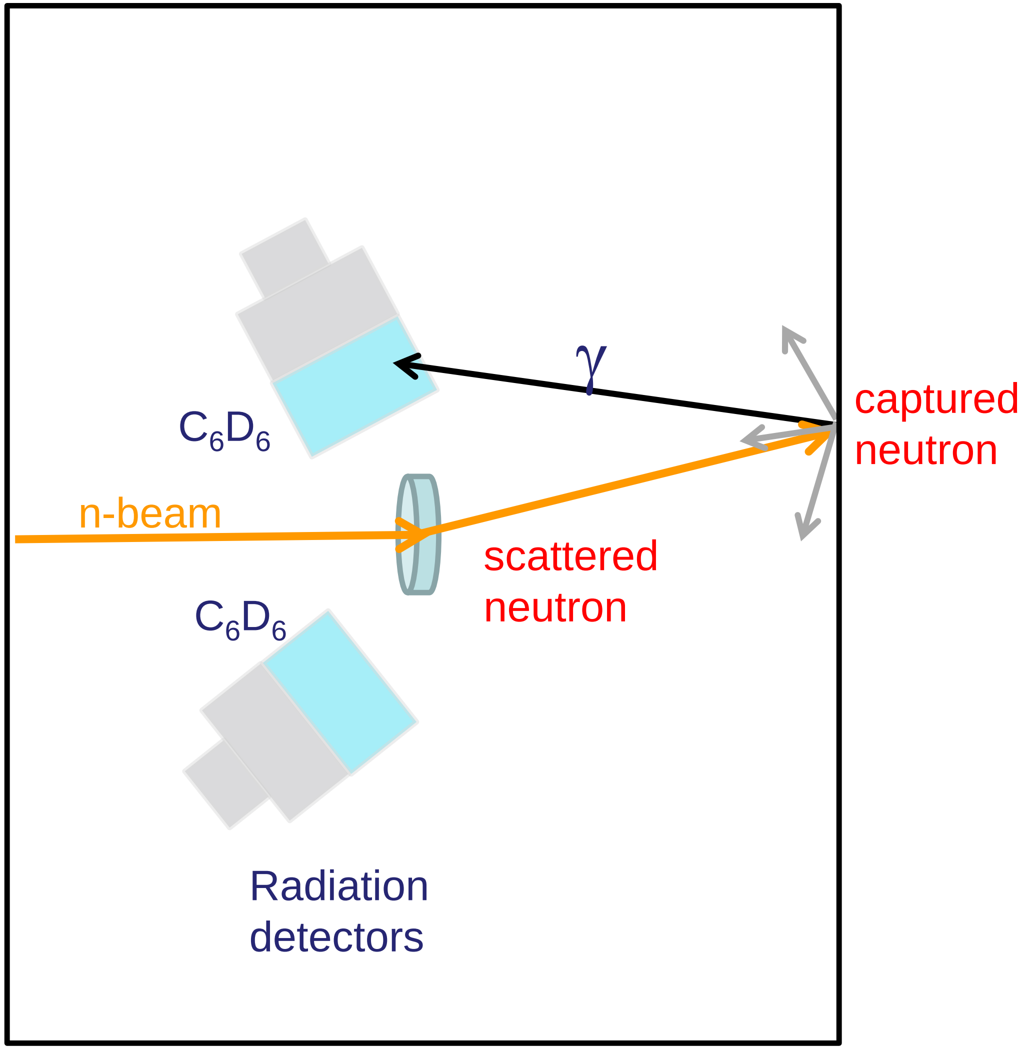
This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 681740).

Outline

- The concept of i-TED
- i-TED planning
- Ongoing developments on i-TED instrumentation
- Outlook & Conclusions

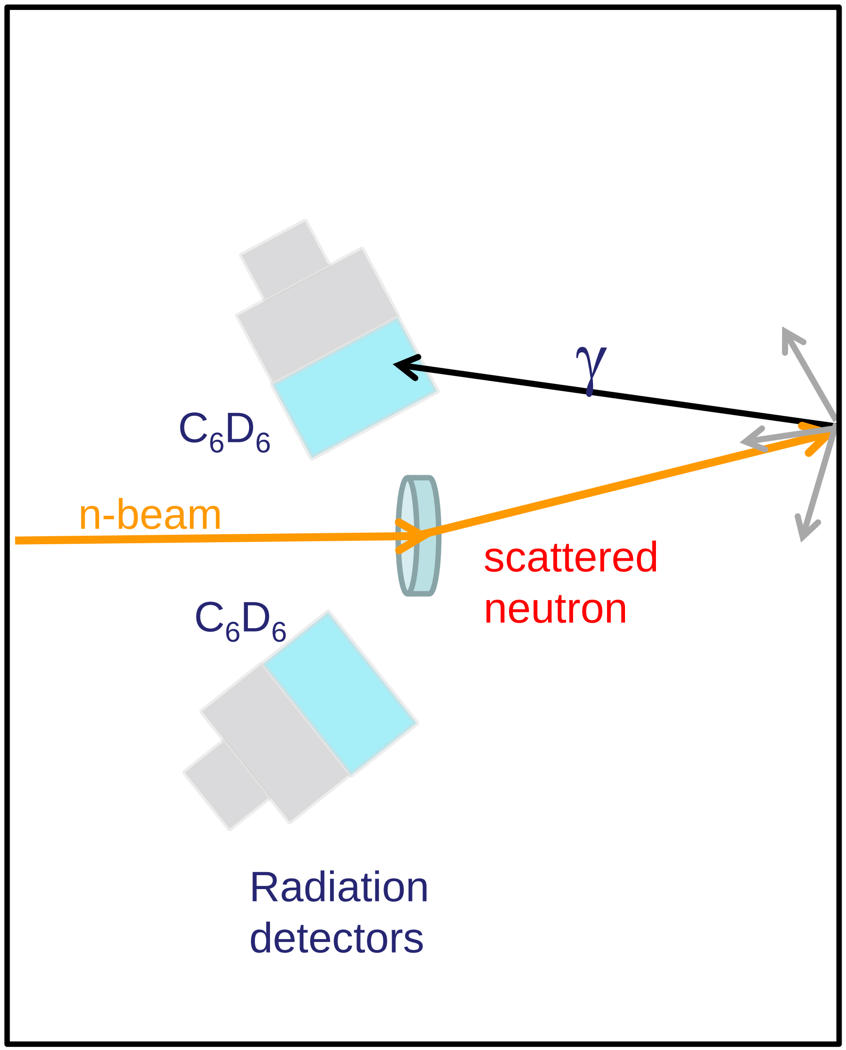
The i-TED concept

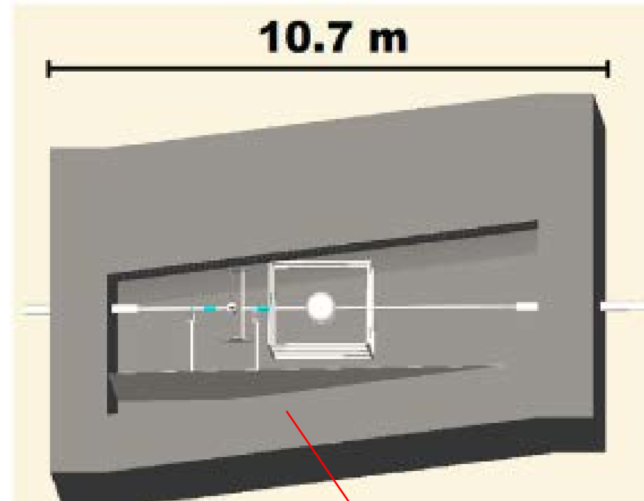
→ Reduce "extrinsic" neutron sensitivity background

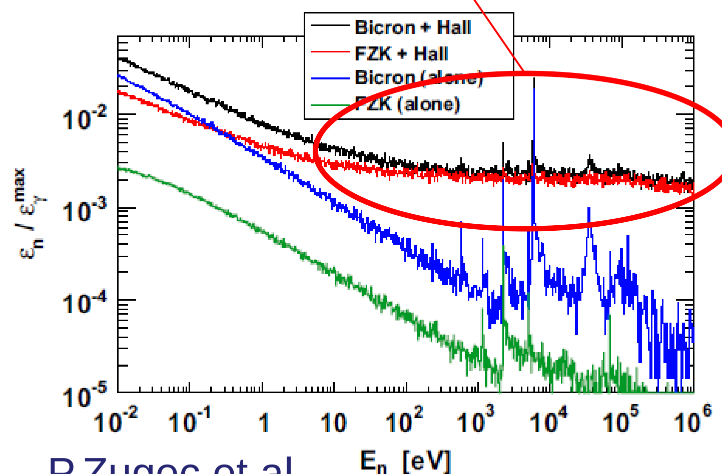


The i-TED concept

→ Reduce “extrinsic” neutron sensitivity background







P.Zugec et al.

Nuclear Instruments and Methods in Physics Research A 760 (2014) 57–67

Contents lists available at ScienceDirect

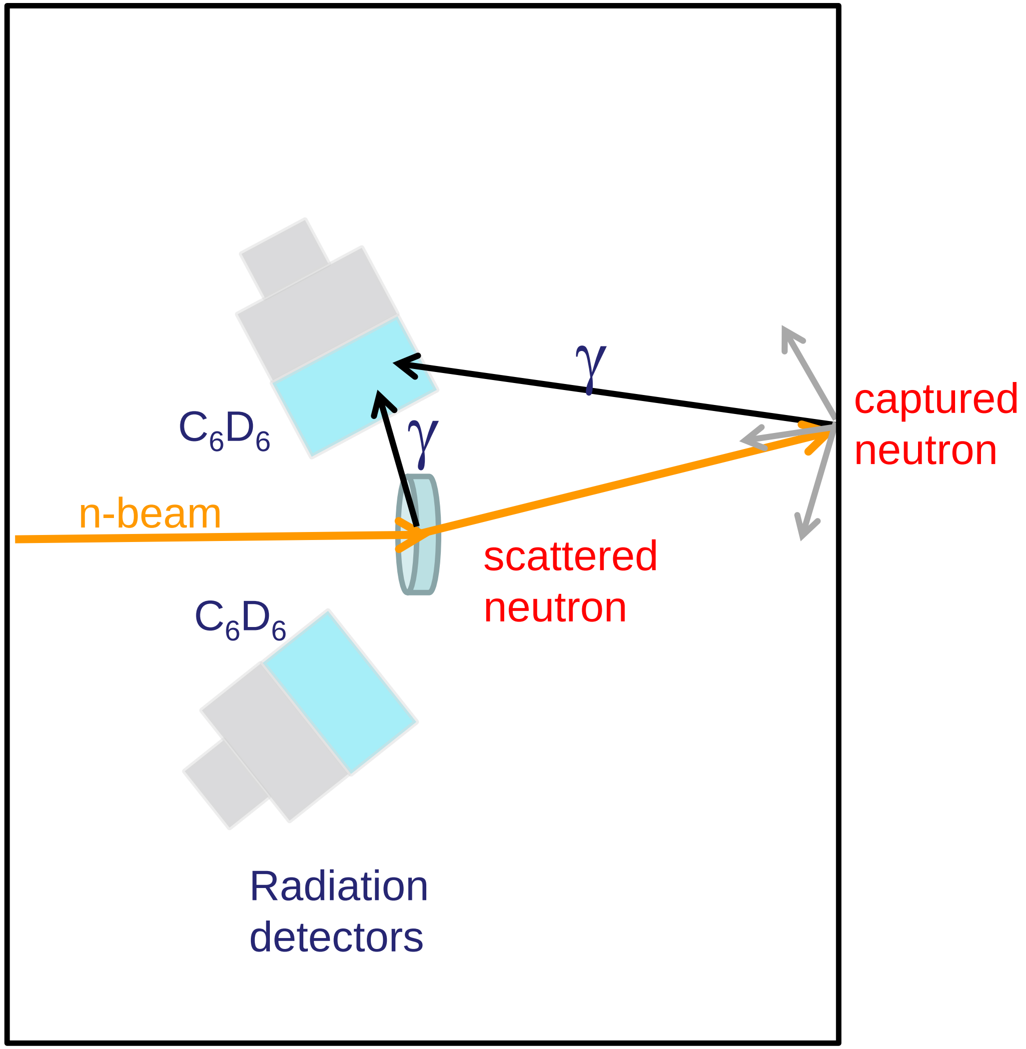
Nuclear Instruments and Methods in Physics Research A

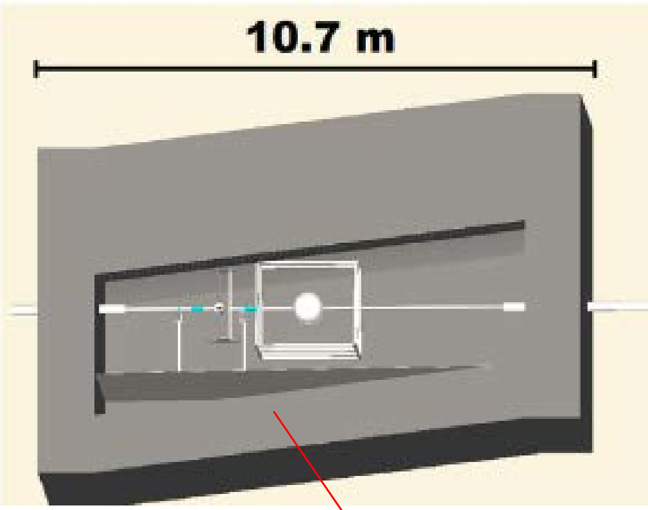
journal homepage: www.elsevier.com/locate/nima

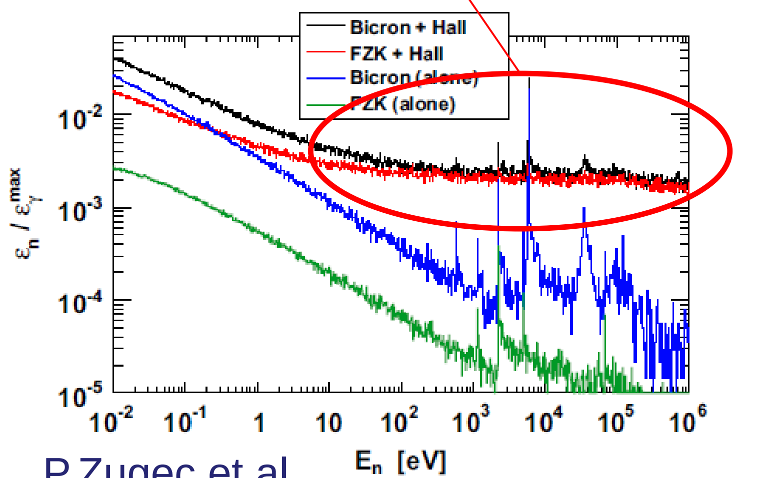
GEANT4 simulation of the neutron background of the C_6D_6 set-up for capture studies at n_TOF

The i-TED concept

→ Reduce “extrinsic” neutron sensitivity background







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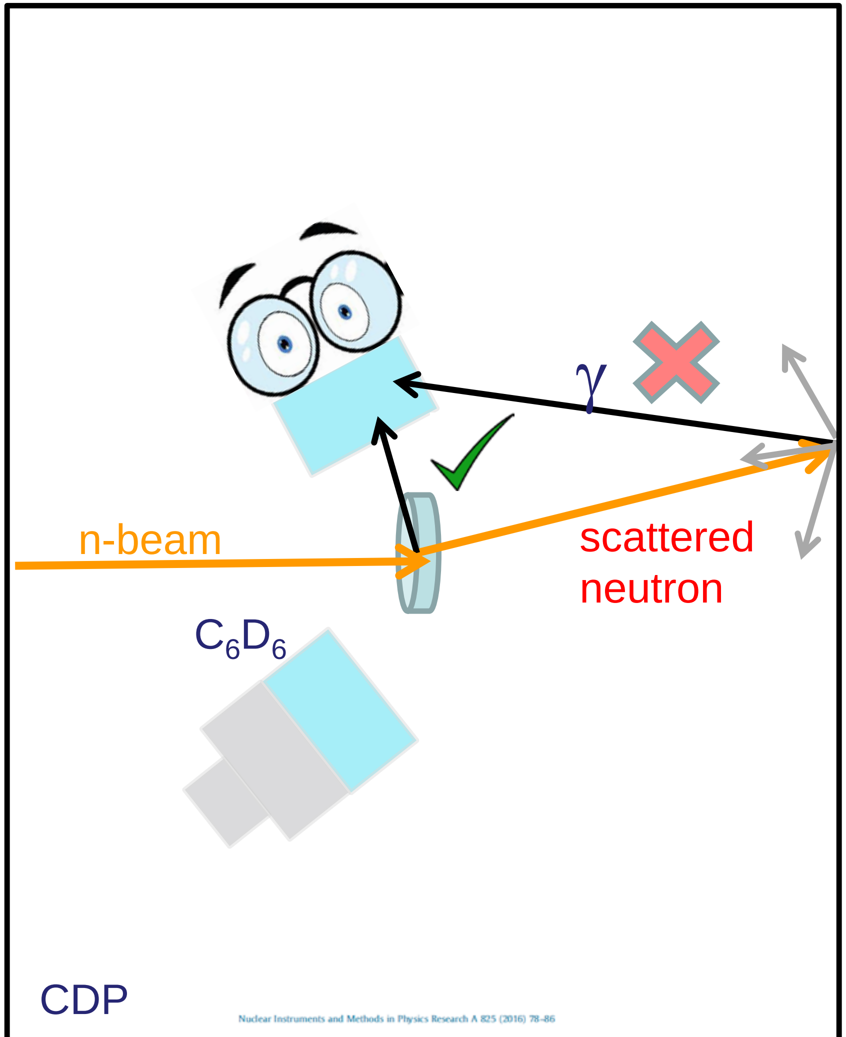

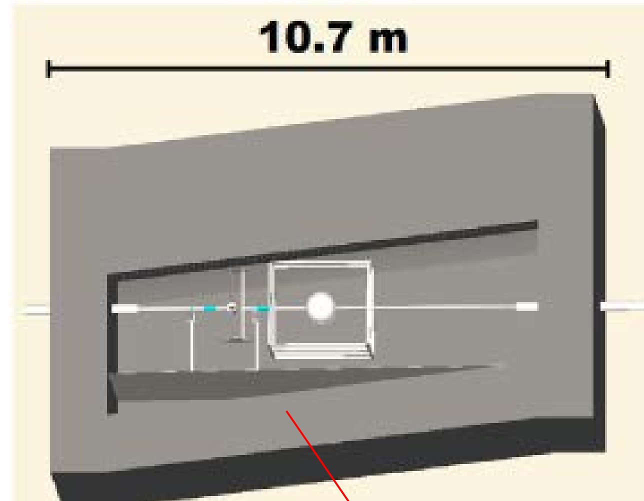

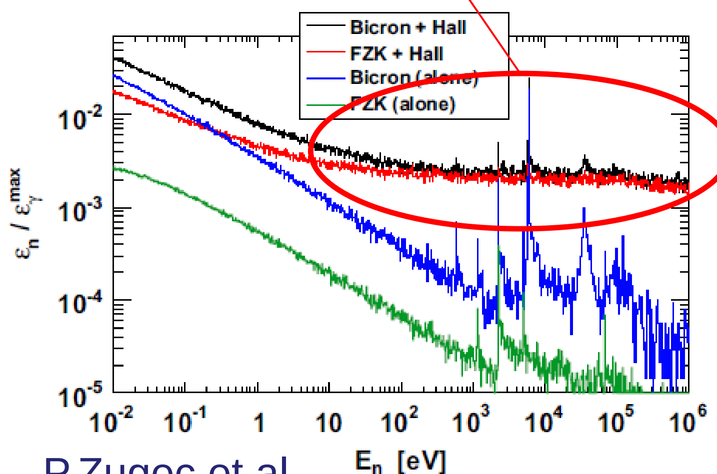

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Nuclear Instruments and Methods in Physics Research A 825 (2016) 78–86

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

i-TED: A novel concept for high-sensitivity (n,γ) cross-section measurements

Nuclear Instruments and Methods in Physics Research A 760 (2014) 57–67

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Nuclear Instruments and Methods in Physics Research A

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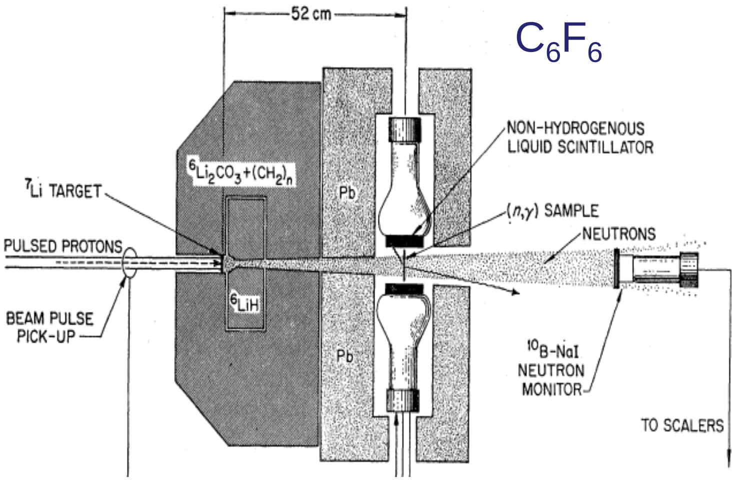
GEANT4 simulation of the neutron background of the C_6D_6 set-up for capture studies at n_TOF

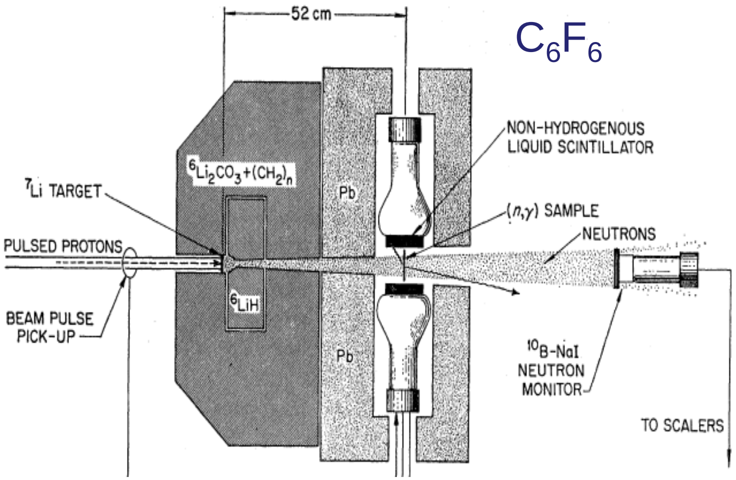
How to get it?



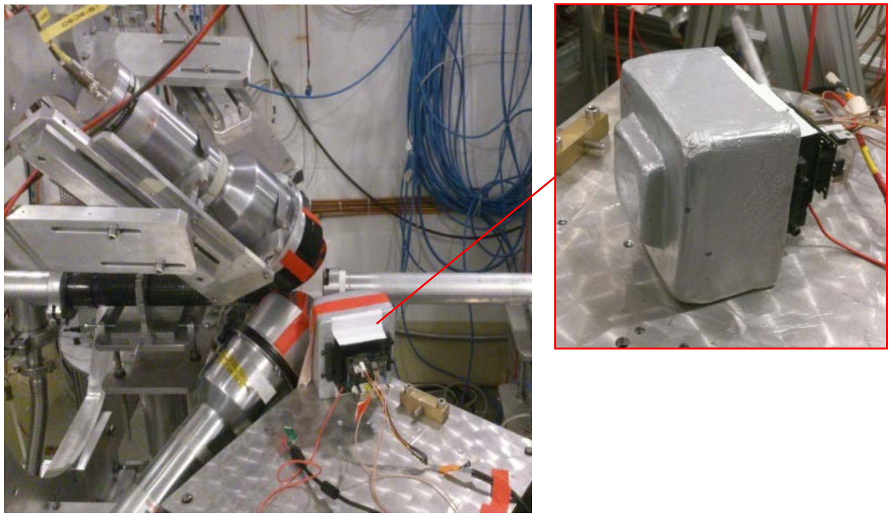
C_6F_6

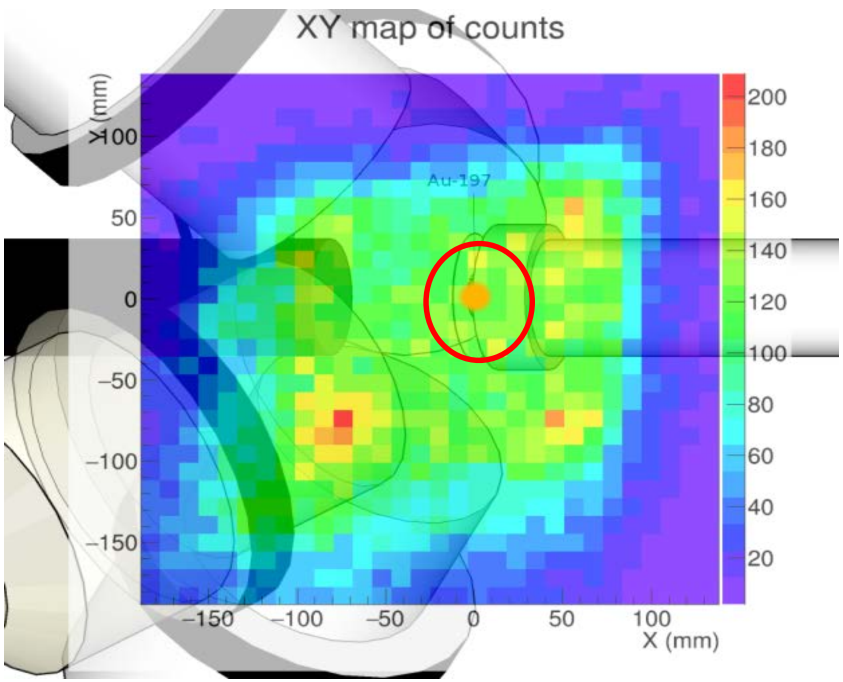
Macklin & Gibbons, ORNL, **1967**

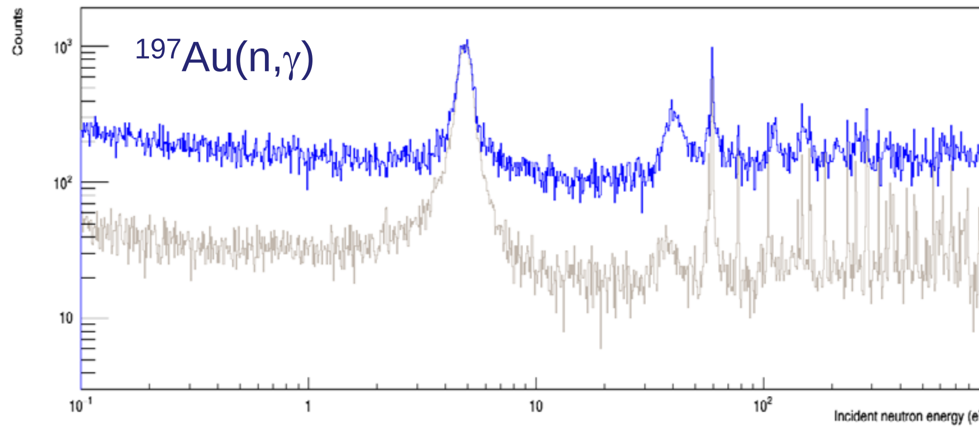
How to get it?



Macklin & Gibbons, ORNL, **1967**







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Nuclear Instruments and Methods in Physics Research A

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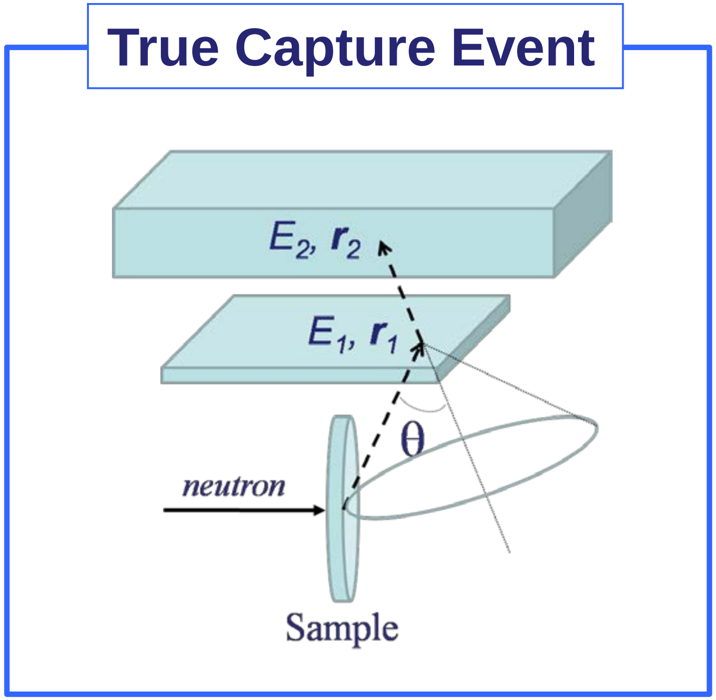
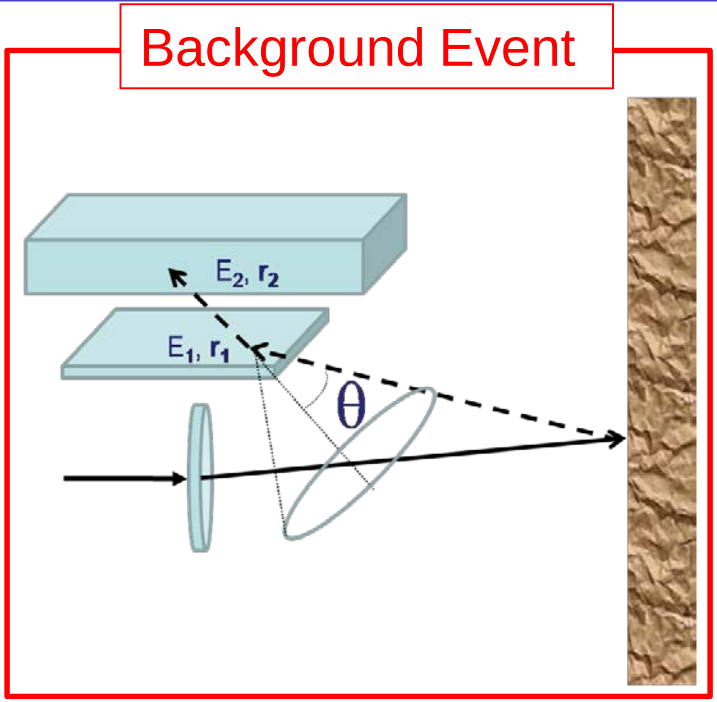
First tests of the applicability of γ-ray imaging for background discrimination in time-of-flight neutron capture measurements

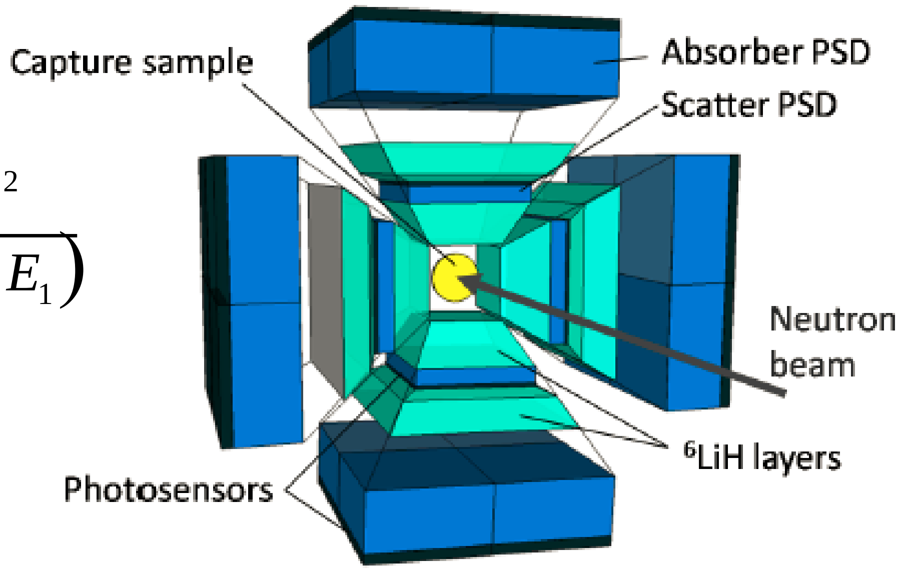
D.L. Pérez Magán [a], L. Caballero [a], C. Domingo-Pardo [a,*], J. Agramunt-Ros [a], F. Albiol [a], A. Casanovas [b], A. González [c], C. Guerrero [d], J. Lerendegui-Marco [d], A. Tarifeño-Saldivia [a,b]

i-TED: imaging-Total Energy Detector



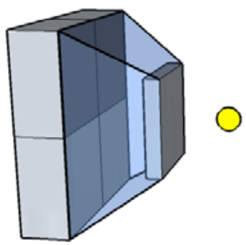


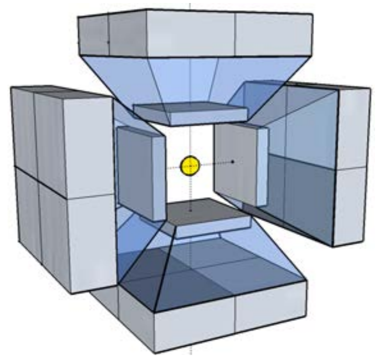
$$\cos\theta = 1 - \frac{E_1 m_0 c^2}{E_\gamma (E_\gamma - E_1)}$$



HYMNS: High sensitivitY Measurements of key stellar Nucleo-Synthesis reactions

i-TED time plan:



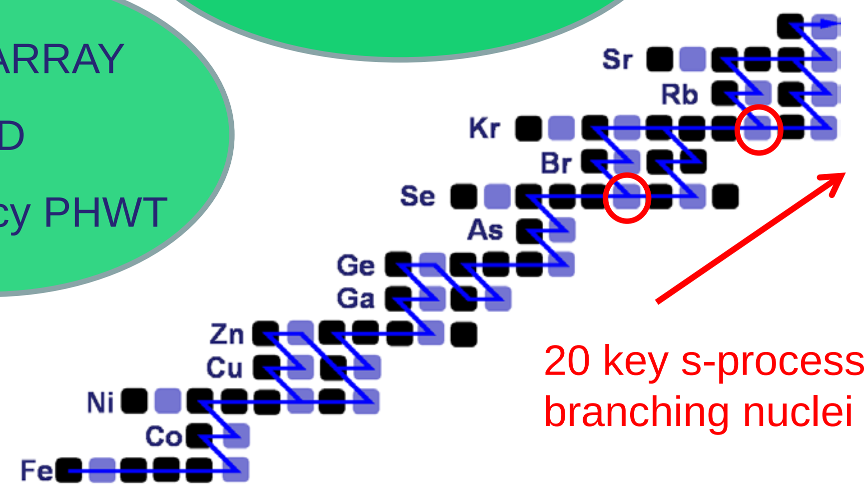


- MC Design
- Neutron ints.

- DEMONSTRATOR
- Focusable module
- Proof-of-principle

- FULL ARRAY
- 4π i-TED
- Accuracy PHWT

- First $^{79}Se(n,\gamma)$
- Nuclear Thermometer
- Massive stars



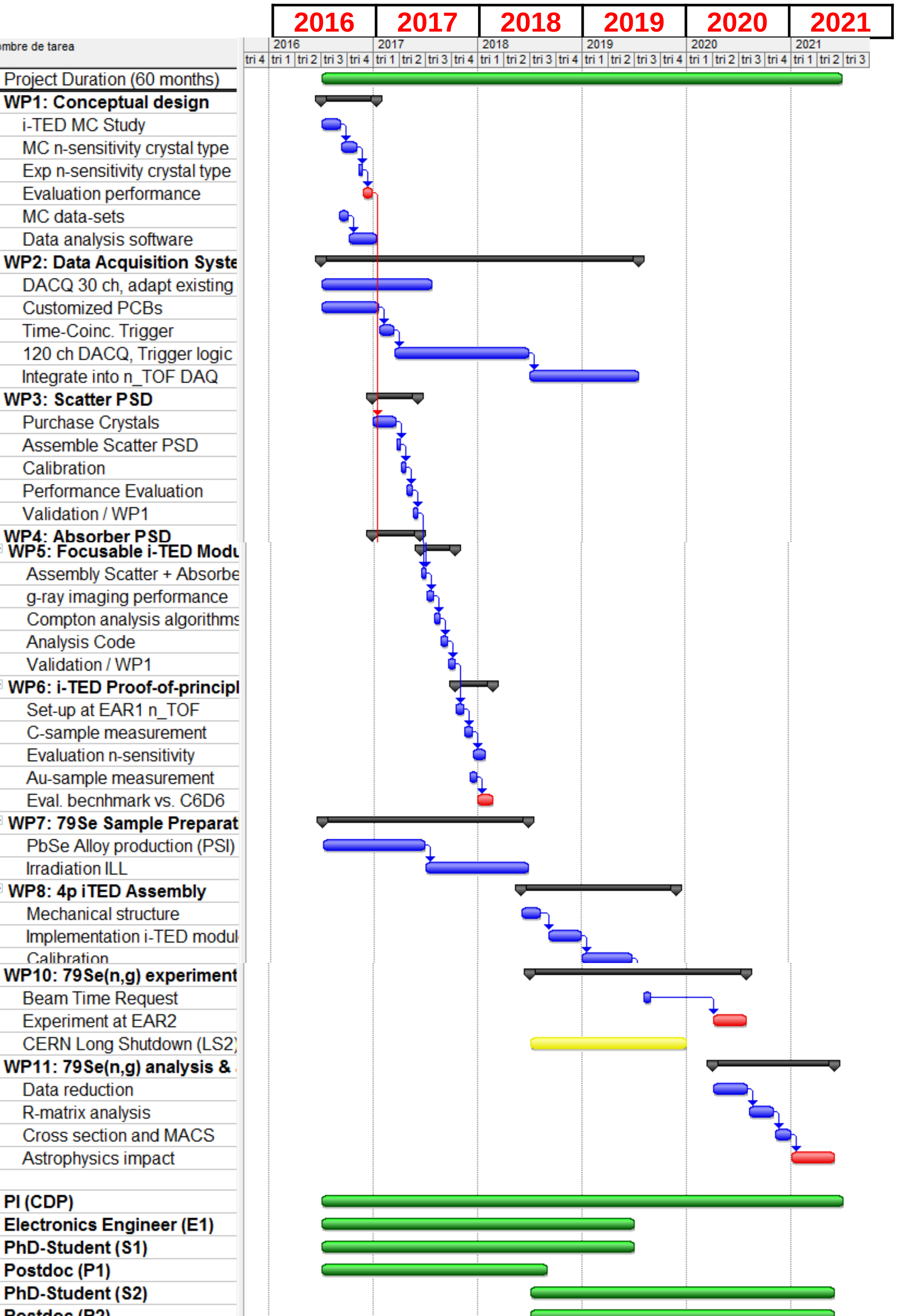
20 key s-process branching nuclei

ERC-Consolidator Grant

2016 2017 2018 2019 2020 2021 -

LS2

HYMNS Work Plan, Resources and WP-Distribution



WP	Task distribution
1 Design	**P1**: MC **S1**:Analysis Software + CDP
2 DAQ	**E1** + P1 + P2+ CDP
3 S-PSD	**P1** + (S1) + CDP
4 A-PSD	**P1** + (S1) + CDP
5 Foc. i-TED	**S1** + **P1**+ CDP
6 Proof of Prin.	**S1** + P1 + P2+ CDP
7 ^{79}Se Sample	**P1**+ CDP
8 4p i-TED	**P1** + S1+ CDP
9 Exp.Val.	**P2** + S2+ CDP
10 ^{79}Se(n,g)	**S2** + P2+ CDP
11 Analysis	S2: Data+ P2: Astro. + CDP

Resources (time/human)

Tasks & Sub-tasks

Milestones

Constraints

i-TED: ongoing developments

Neutron capture measurements require:

→ Low intrinsic neutron sensitivity

→ Fast timing

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Electronic collimation requires (γ-Imaging):

→ Good energy resolution (4-6%) → High photon yield inorganic crystals

→ Good position resolution (1-2 mm) → Pixellated PMT or SiPMs

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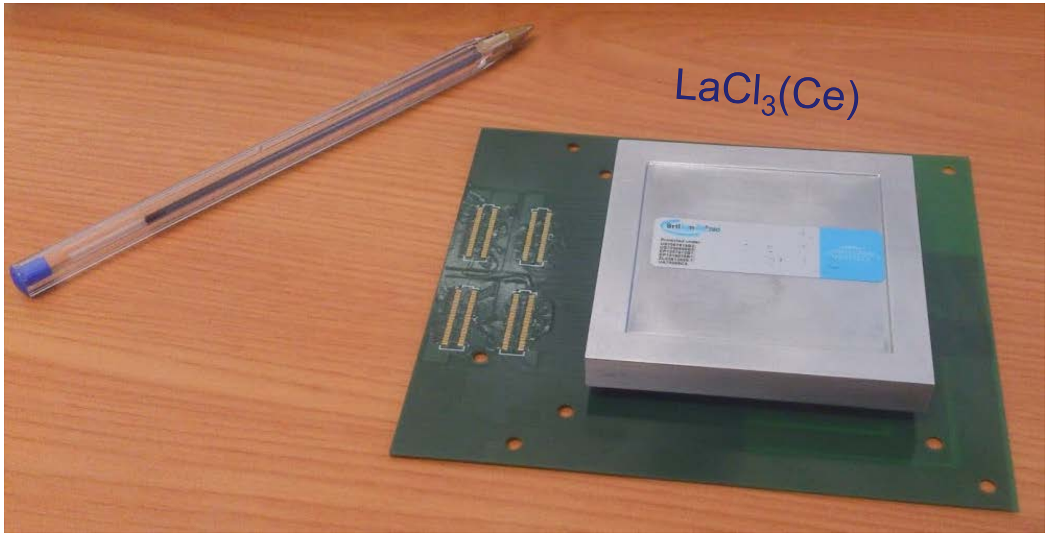
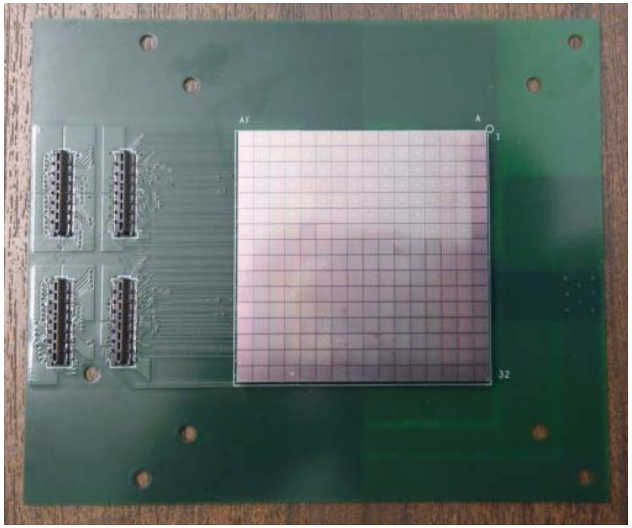
$LaCl_3(Ce)$
+ SiPMs





i-TED: ongoing developments

Neutron capture measurements require:

→ Low intrinsic neutron sensitivity

→ Fast timing

$LaCl_3$(Ce)
+ SiPMs

Electronic collimation requires (γ-Imaging):

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Energy resolution / **$LaCl_3$(Ce)** tests at IFIC:

→Tested large (5x5cm2) monolithic crystals of several **thicknesses: 10 mm / 20 mm / 30 mm**

→To test neutron sensitivity at CERN n_TOF (2017) / parasitic with any other commissioning

i-TED: energy resolution

Neutron capture measurements require:

→ Low intrinsic neutron sensitivity

→ Fast timing

$LaCl_3(Ce)$
+ SiPMs

Electronic collimation requires (γ-Imaging):

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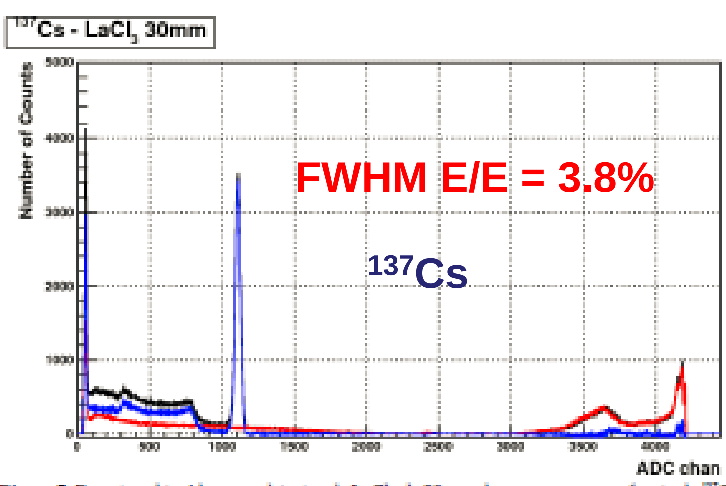
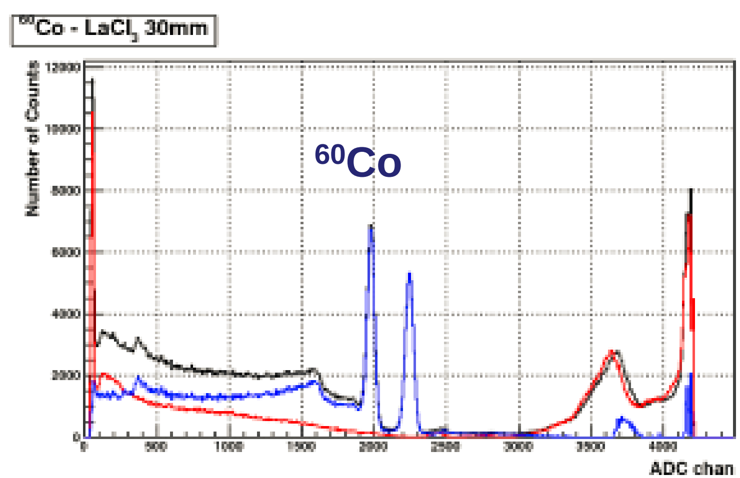




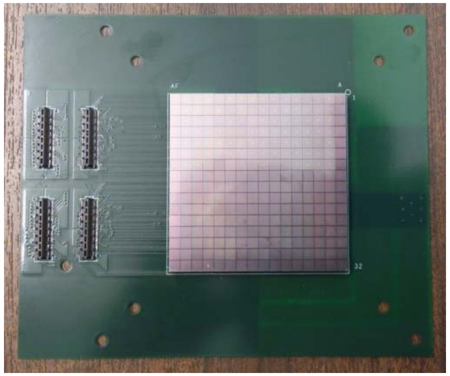
with PMT!

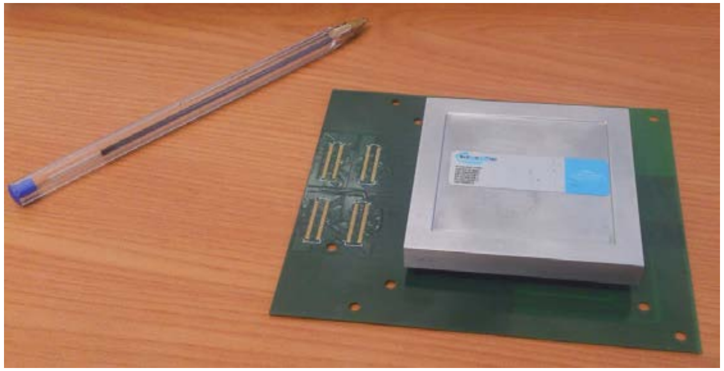
i-TED: photosensors validation

Electronic collimation requires:

→ Good energy resolution (4-6%) → High photon yield inorganic crystals

→ Good **position resolution** (1-2 mm) → **Pixellated PMT or SiPMs**



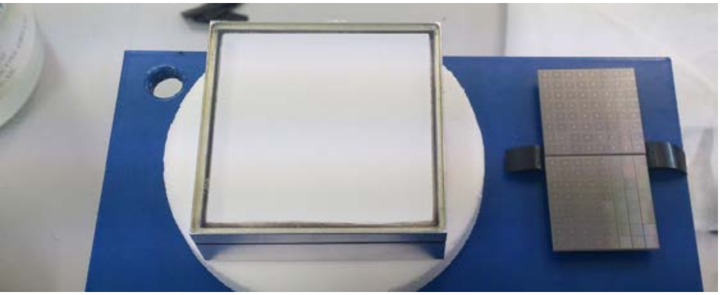


→ 1 SiPM (Hamamatsu)

→ # pixels= 16x16y = 256 ch

→ pixel size = **3x3 mm²**

→ area = 5x5 cm² = 25 cm²

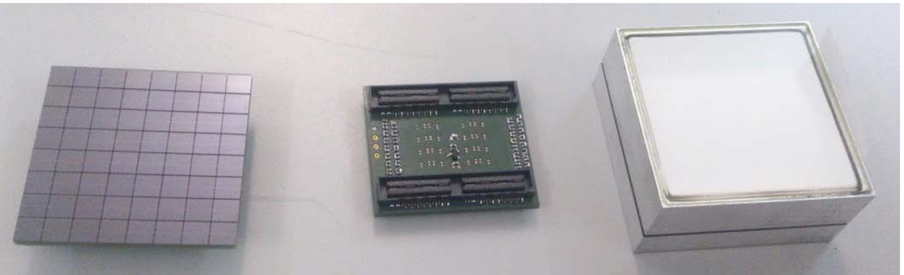


→ 4 x SiPMs (Hamamatsu)

→ # pixels/SiPM= 8x8y = 64 ch

→ pixel size = **3x3 mm²**

→ area = 2.5x2.5 cm² = 6.2 cm²



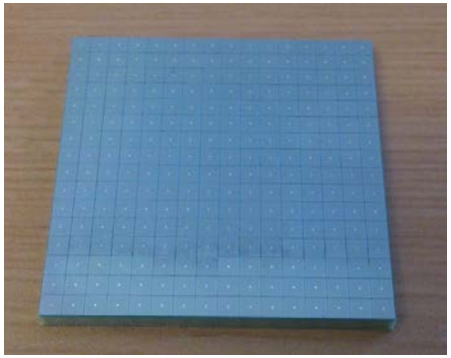
→ 1 SiPM (senseL)

→ # pixels= 8x8y = 64 ch

→ pixel size **= 6x6 mm²**

→ area = 5x5 cm² = 25 cm²

i-TED: pixellation and complexity/scalability

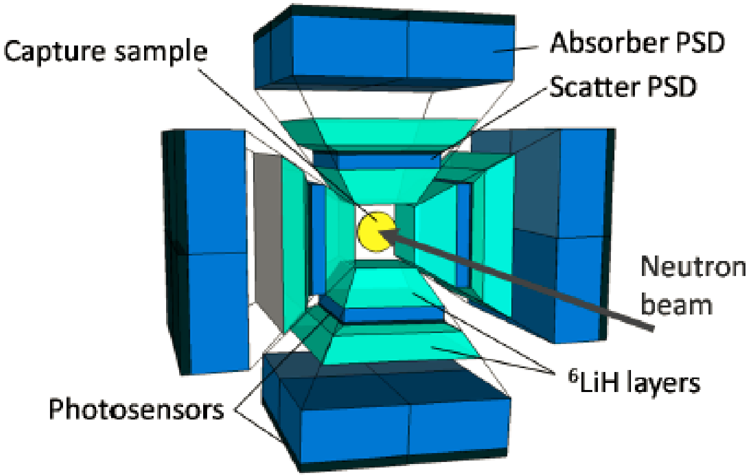


→ # pixels= 16x16y = 256 ch

→ pixel size = **3x3 mm²**

→ area = 5x5 cm² = 25 cm²

→ **5120 channels!**

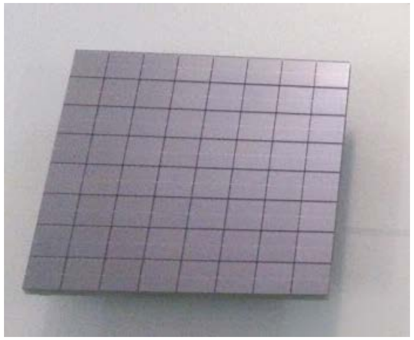


→1xScatter = 5x5 cm²

→ 1xAbsorber = 10x10 cm²

} 1 x i-TED module

→Full i-TED = 4S+4A= 500 cm²



→ # pixels= 8x8y = 64 ch

→ pixel size **= 6x6 mm²**

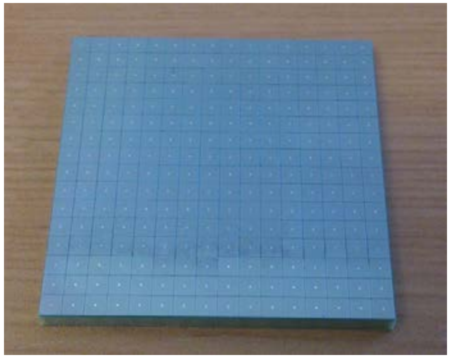
→ area = 5x5 cm² = 25 cm²

→ **1280 channels!**

i-TED: pixellation and complexity/scalability

Pixel size makes a difference … in complexity!

But probably low impact in position resolution



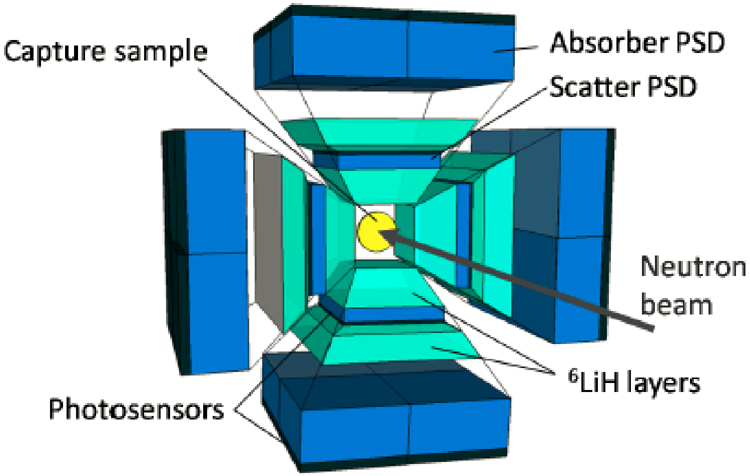
→ # pixels= 16x16y = 256 ch

→ pixel size = **3x3 mm²**

→ area = 5x5 cm² = 25 cm²

→ **5120 channels!**

(128 TACs)



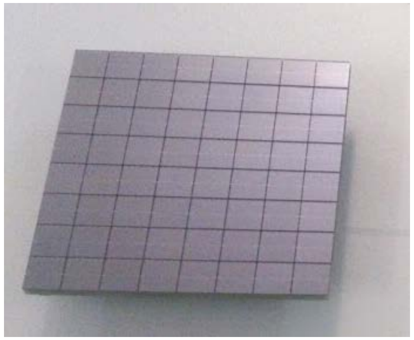
Largest ratio channels/efficiency ever ;-)

→1xScatter = 5x5 cm²

→ 1xAbsorber = 10x10 cm²

} 1 x i-TED module

→Full i-TED = 4S+4A= 500 cm²



→ # pixels= 8x8y = 64 ch

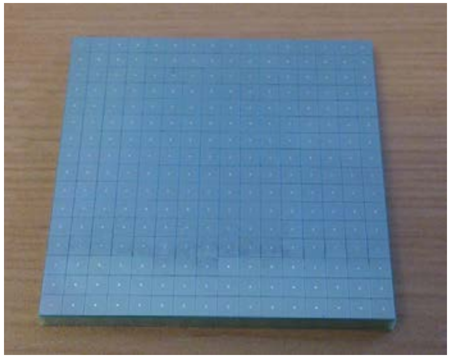
→ pixel size = **6x6 mm²**

→ area = 5x5 cm² = 25 cm²

→ **1280 channels!**

(32 TACs)

i-TED: pixellation & spatial resolution



→ # pixels= 16x16y = 256 ch

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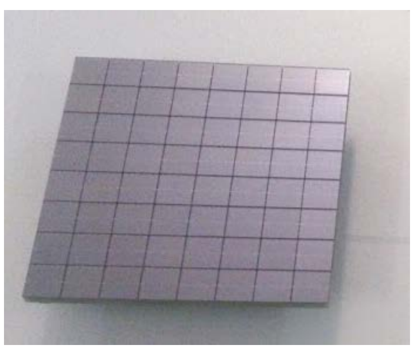


→ # pixels= 8x8y = 64 ch

→ pixel size = **6x6 mm²**

→ area = 5x5 cm² = 25 cm²

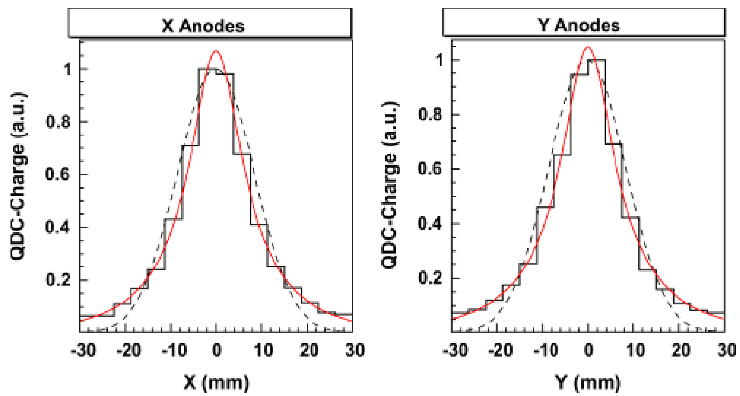
Pixel size makes a difference … in complexity!

But probably low impact in position resolution

ΔX_{FWHM} = 0.91 (8) mm

pixelation = 6 mm

with PMT!

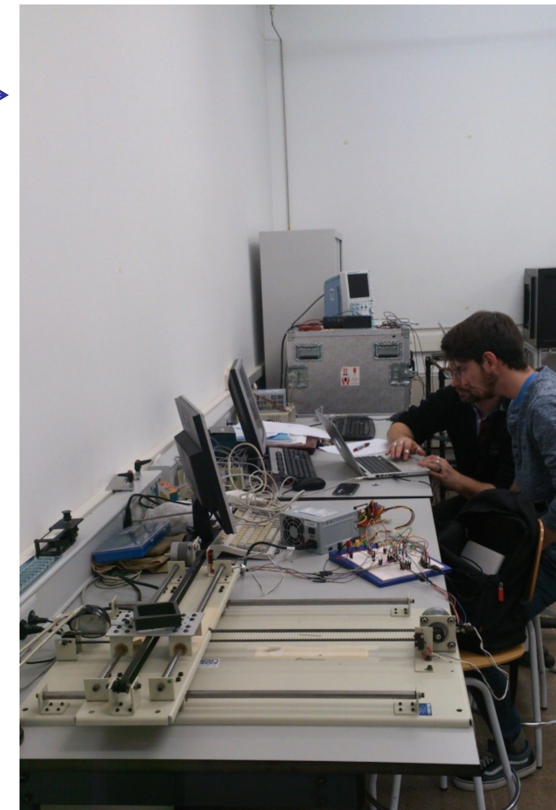


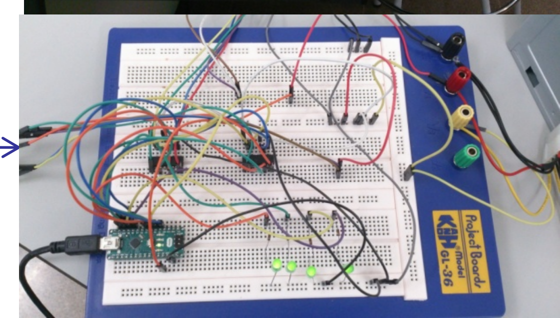
IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 28, NO. 12, DECEMBER 2009 2007

A Position Sensitive γ-Ray Scintillator Detector With Enhanced Spatial Resolution, Linearity, and Field of View

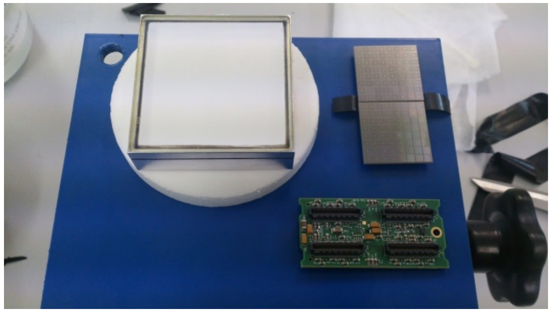
César Domingo-Pardo*, Namita Goel, Tobias Engert, Juergen Gerl, Masahiro Isaka, Ivan Kojouharov, *Member, IEEE*, and Henning Schaffner

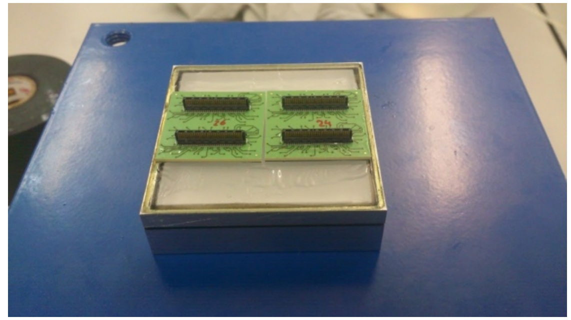
Most proably 6mm pixels are OK !

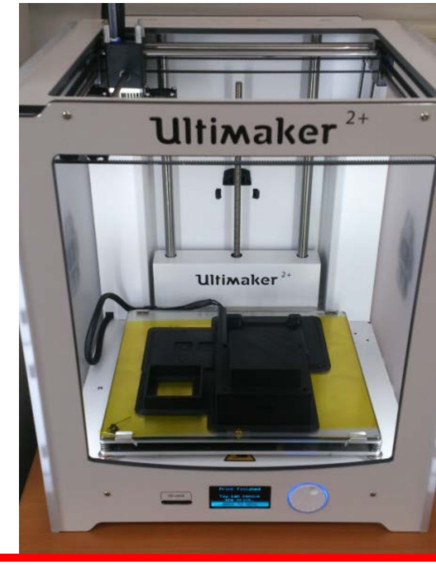




i-TED: detector finishing

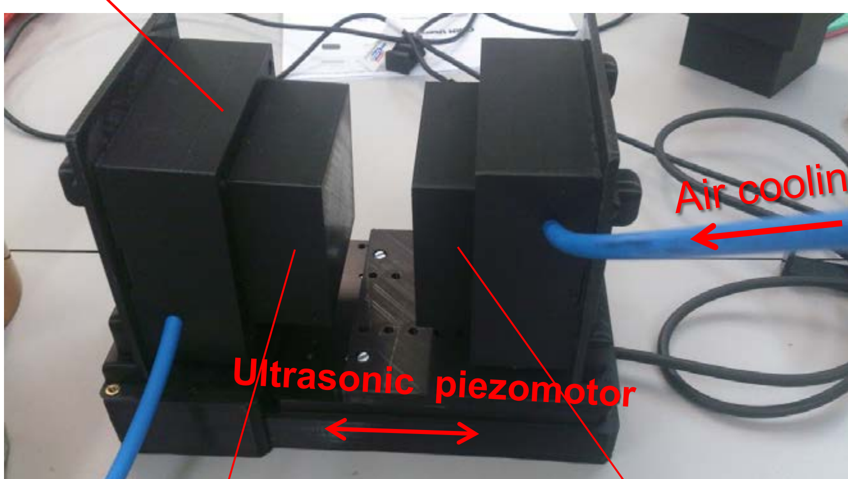




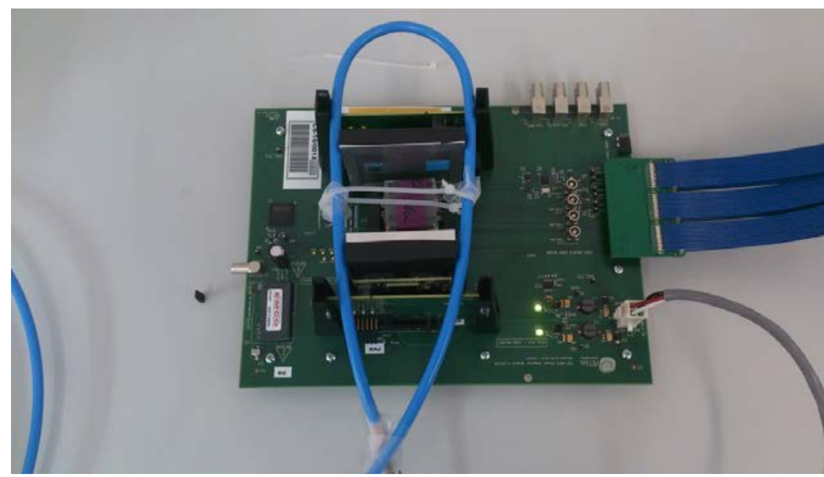


→First i-TED prototype (ready!)

PLA ($C_3H_3O_2$) ρ_{PLA}=1.2 < ρ_{Cfiber} = 1.5-1.6 g/cm^3



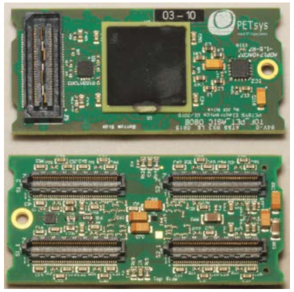
Absorber PSD **Scatter PSD**

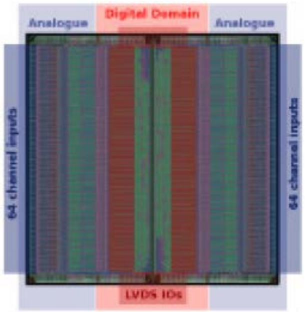


PETsys Electronics

Presently testing frontend readout and processing electronics from PETsys Electronics

i-TED: readout electronics (PETsys)





→128 channels (or pixels from SiPM)

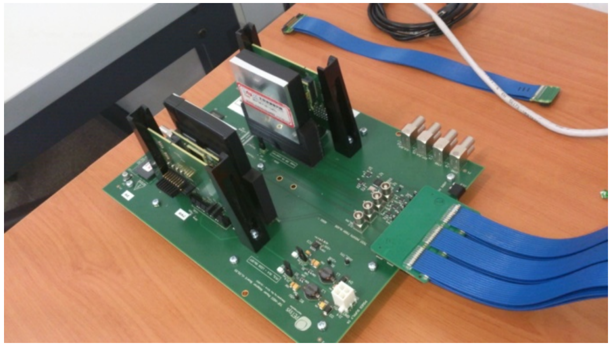
→ 25 ps intrinsic t-resolution / 32 ps SiPM+ASIC/ 100 ps Crystal + SiPM + ASIC

→ low threhold for timing /high threshold event def.

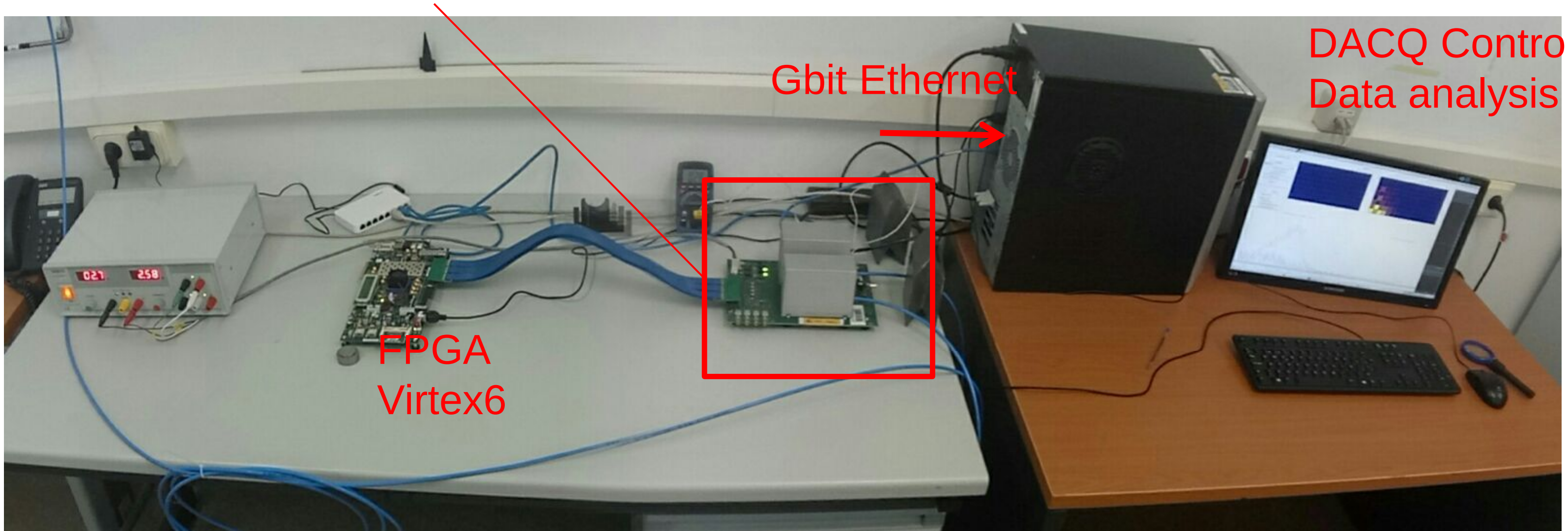
→ max. rate 160 kEvents/ch or 12 Mevents/board

→ energy via tot-technique… not accurate enough (to be improved in a forthcoming version of this ASIC)

PETsys
Electronics

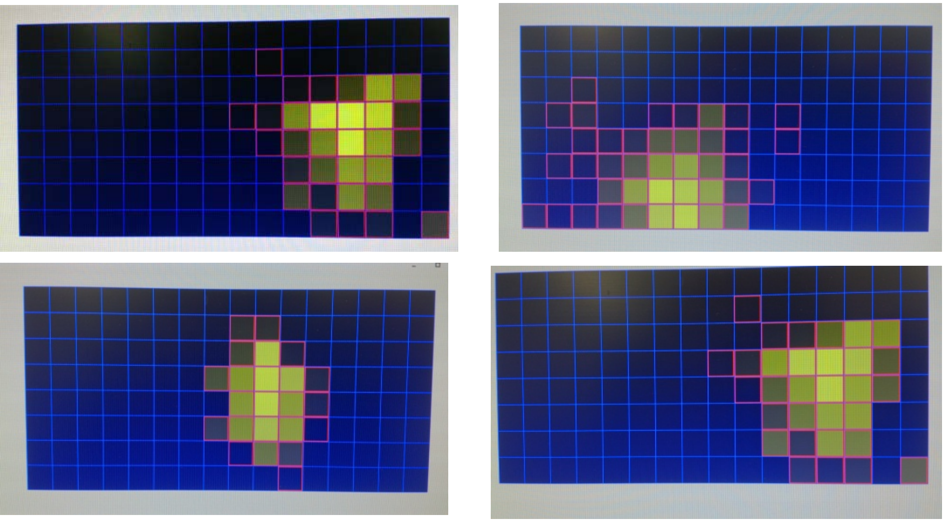


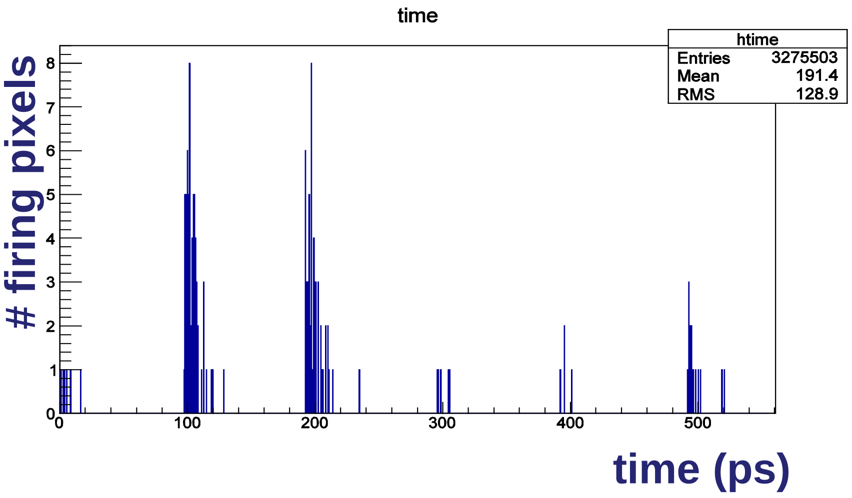
FPGA



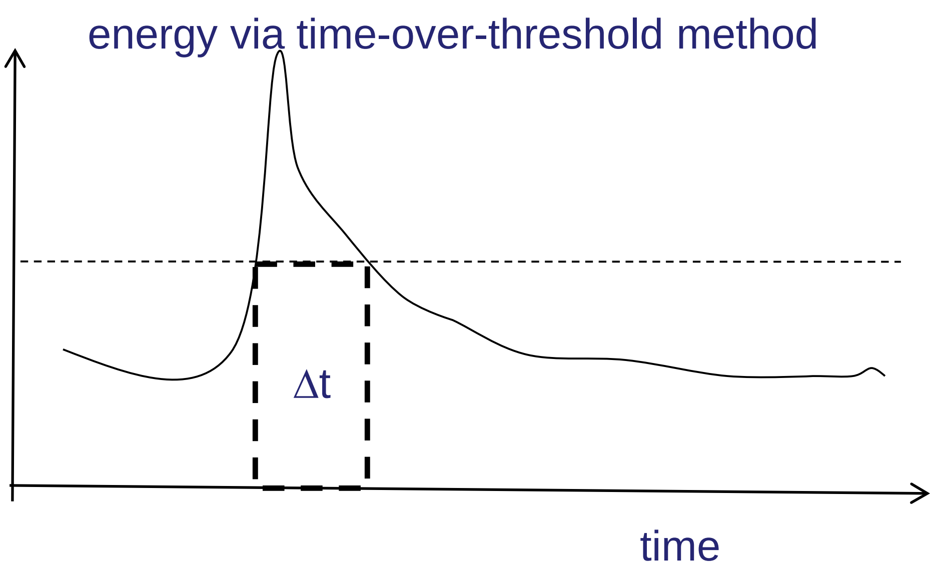
i-TED: readout electronics (PETsys)

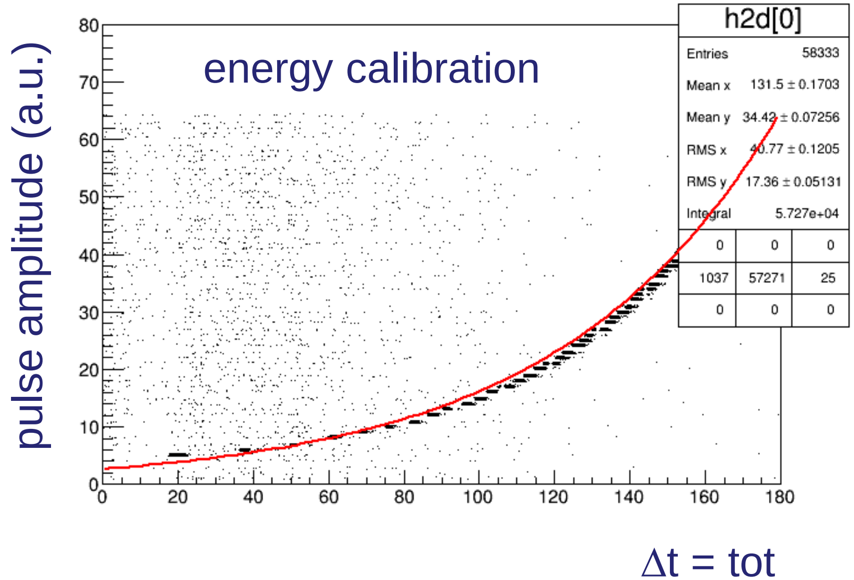
• Spatial and time response seem ok, reasonable (still being tested in detail)





• Drawback: Still poor spectroscopic performance, to be improved with the new version of the ASIC





i-TED: readout electronics (PETsys)

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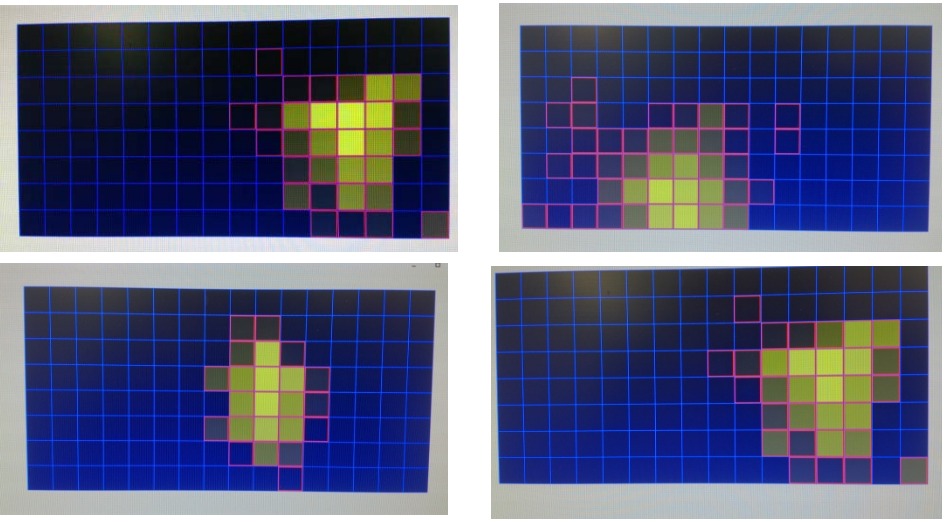
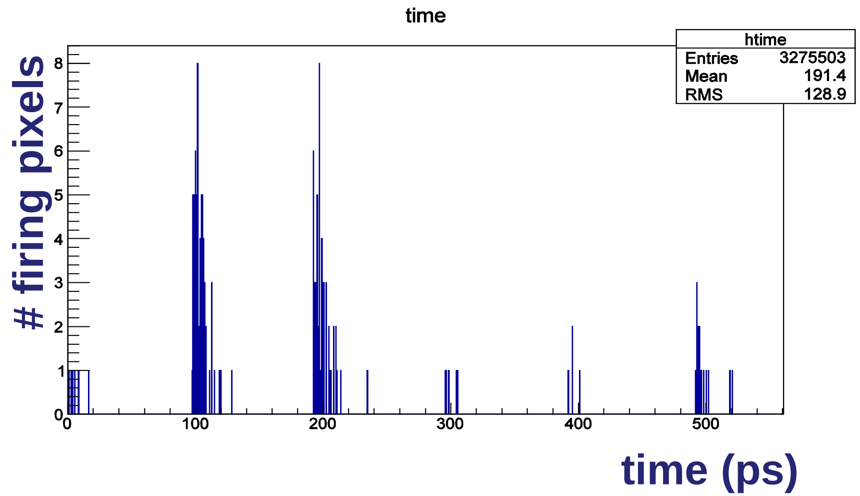
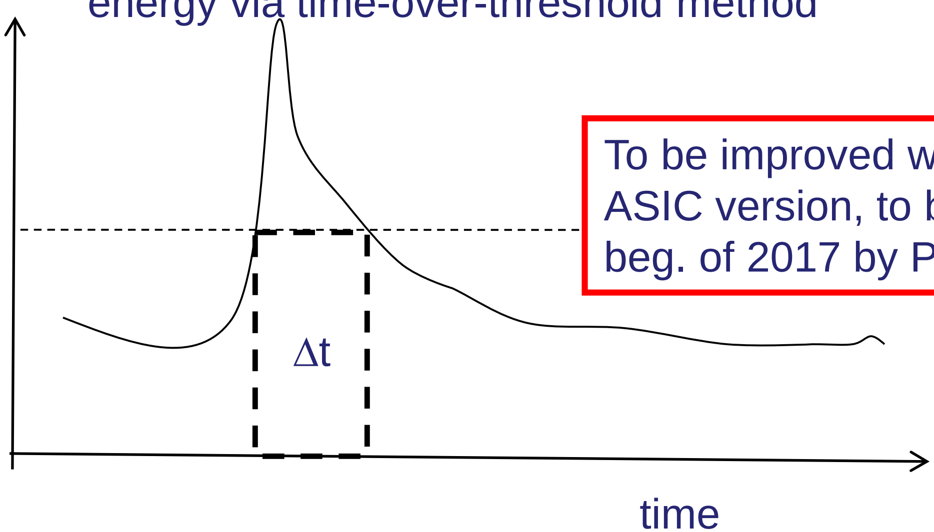


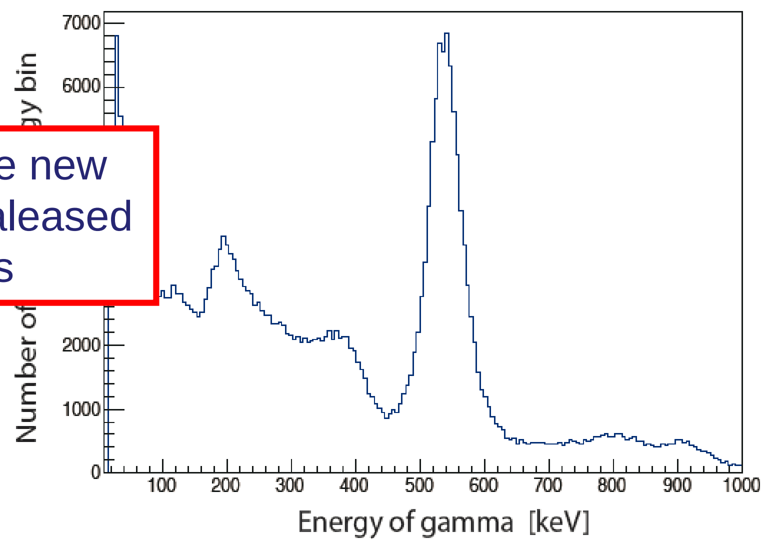


- Drawback: Still poor spectroscopic performance, to be improved with the new version of the ASIC

energy via time-over-threshold method



To be improved with the new ASIC version, to be realeased beg. of 2017 by PETsys



^{22}Na source with LYSO, from PETSYS flyer

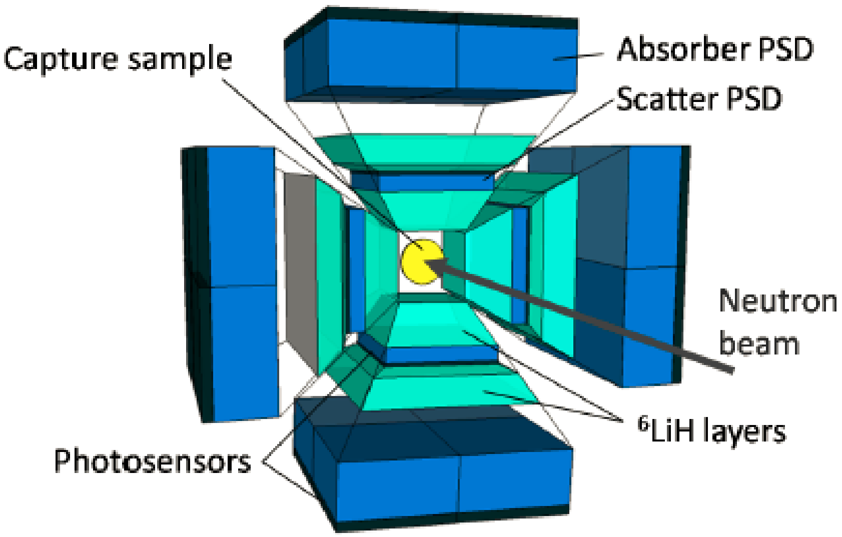
i-TED: Summary & Outlook

- Presently developing i-TED demonstrator based on one 2-PSD module
- $LaCl_3$(Ce) crystals validated regarding energy resolution
- Tests ongoing for E-resolution using SiPM arrays
- Tests ongoing to determine spatial resolution using SiPM arrays of different pixelation and different manufacturers (sensL, Hamamatsu)
- Main front open: readout- control- and pre-processing electronics (PETsys)
- In parallel (not presented):
    - MC Simulations of the full array including neutron propagation (Geant4)
    - Working together with PSI and ILL on the production of ^{79}Se sample for the ^{79}Se(n,g) measurement at n_TOF.

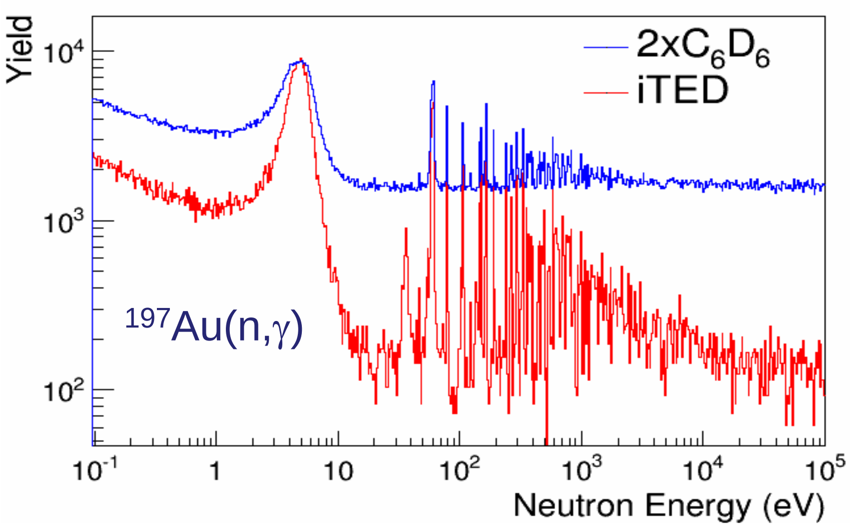
THANKS FOR YOUR ATTENTION

Backup slides

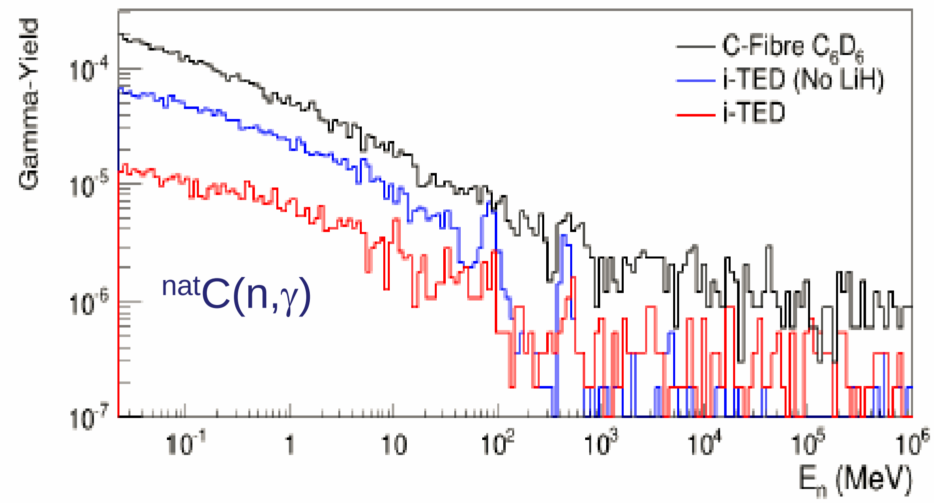
Intrinsic neutron sensitivity: i-TED with ^{6}LiH absorber pads



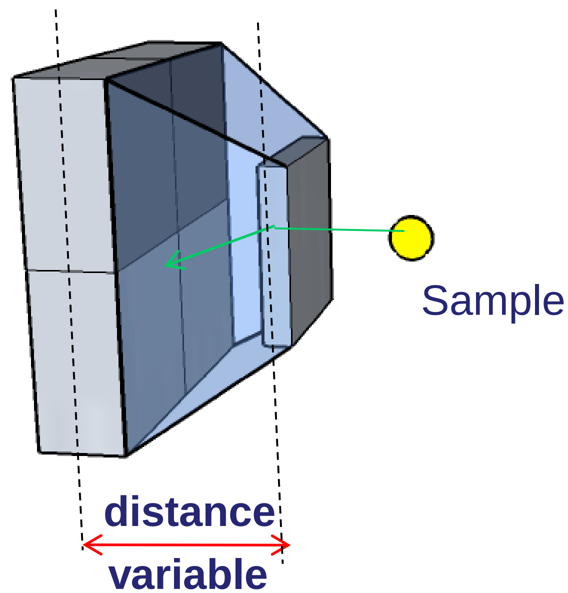
→extrinsic neutron sensitivity:



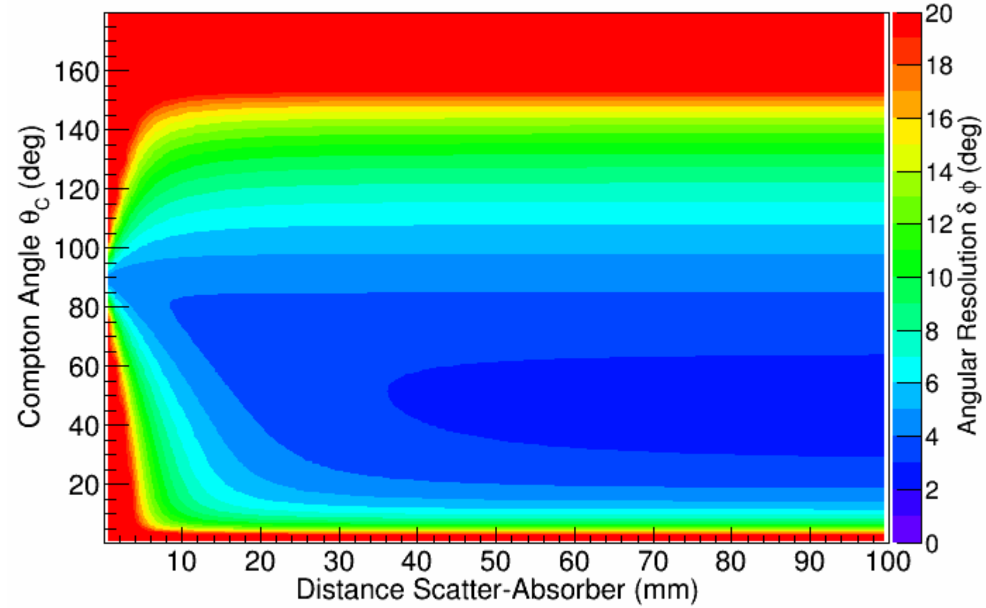
→intrinsic neutron sensitivity:

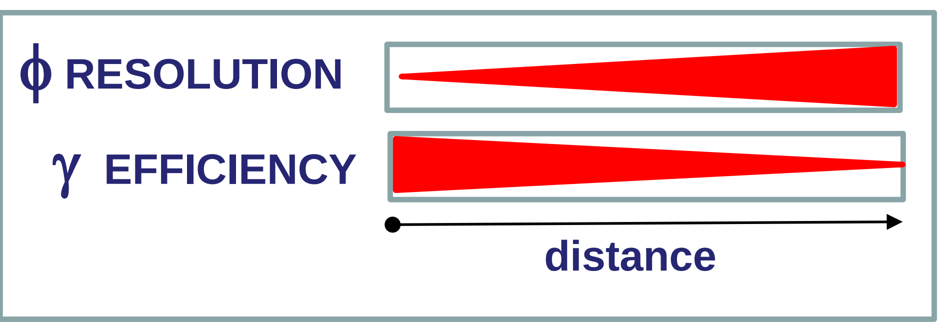


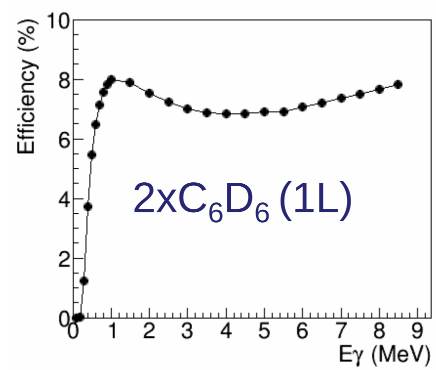
Focusable i-TED module

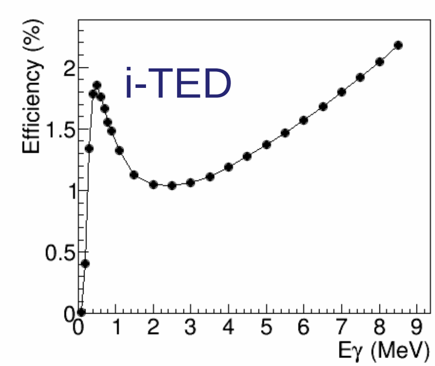


Angular resolution vs. distance between detectors

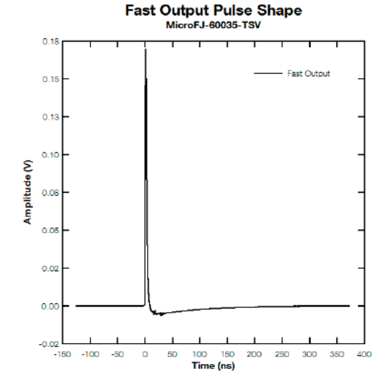


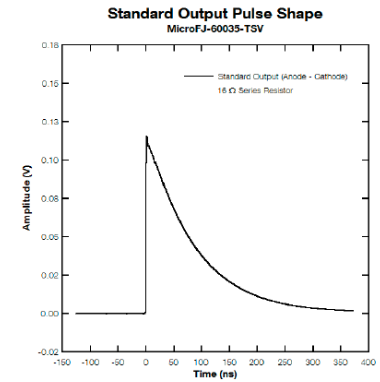






Sensor Size	Microcell Size	Parameter	Overvoltage	Min.	Typical	Max.	Units
3mm	20µm	Gain (anode-cathode)	Vbr + 2.5V		9.1×10^6		
3mm	35µm	Gain (anode-cathode)	Vbr + 2.5V		2.8×10^6		
3mm	20µm	Gain (anode-cathode)	Vbr + 5.0V		1.7×10^6		
3mm	35µm	Gain (anode-cathode)	Vbr + 5.0V		5.3×10^6		
6mm	35µm	Gain (anode-cathode)	Vbr + 2.5V		2.8×10^6		
6mm	35µm	Gain (anode-cathode)	Vbr + 5.0V		5.3×10^6		
3mm	20µm, 35µm	Dark Current	Vbr + 2.5V		0.2	0.3	µA
3mm	20µm, 35µm	Dark Current	Vbr + 5.0V		1.1	1.6	µA
6mm	35µm	Dark Current	Vbr + 2.5V		0.9	1.3	µA
6mm	35µm	Dark Current	Vbr + 5.0V		4.1	5.8	µA
3mm	20µm, 35µm	Rise time [6] - anode-cathode output			100		ps
6mm	35µm	Rise time [6] - anode-cathode output			300		ps
3mm	20µm	Microcell recharge time constant [7]			12		ns
3mm	35µm	Microcell recharge time constant [7]			37		ns
6mm	35µm	Microcell recharge time constant [7]			48		ns
3mm	20µm	Capacitance [8] (anode output)	Vbr + 2.5V		TBD		pF
3mm	35µm	Capacitance [8] (anode output)	Vbr + 2.5V		1000		pF
6mm	35µm	Capacitance [8] (anode output)	Vbr + 2.5V		4000		pF
3mm	20µm	Capacitance [8] (fast terminal)	Vbr + 2.5V		TBD		pF
3mm	35µm	Capacitance [8] (fast terminal)	Vbr + 2.5V		60		pF
6mm	35µm	Capacitance [8] (fast terminal)	Vbr + 2.5V		200		pF
3mm	20µm	Fast output pulse width (FWHM)			1.4		ns
3mm	35µm	Fast output pulse width (FWHM)			1.4		ns
6mm	35µm	Fast output pulse width (FWHM)			3.0		ns
3mm	20µm	Crosstalk	Vbr + 2.5V		5		%
3mm	35µm	Crosstalk	Vbr + 2.5V		7		%
3mm	20µm	Crosstalk	Vbr + 5.0V		10		%
3mm	35µm	Crosstalk	Vbr + 5.0V		22		%
6mm	35µm	Crosstalk	Vbr + 2.5V		7		%
6mm	35µm	Crosstalk	Vbr + 5.0V		22		%
3mm	20µm, 35µm	Afterpulsing	Vbr + 2.5V		0.1		%
3mm	20µm, 35µm	Afterpulsing	Vbr + 5.0V		1.0		%
6mm	35µm	Afterpulsing	Vbr + 2.5V		0.1		%
6mm	35µm	Afterpulsing	Vbr + 5.0V		1.0		%
3mm	20µm, 35µm	Temperature dependence of Vbr [9]			<21.5		mV/°C
6mm	35µm	Temperature dependence of Vbr [9]			<21.5		mV/°C





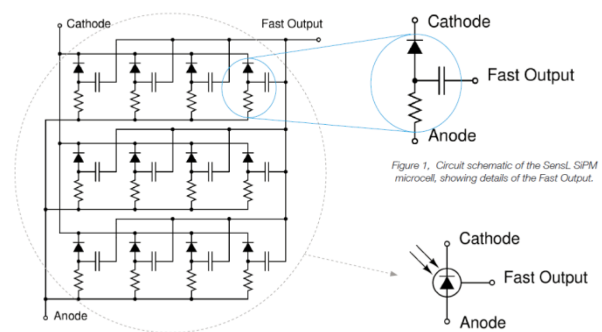


Figure 1, Circuit schematic of the SensL SiPM microcell, showing details of the Fast Output.

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Electronics

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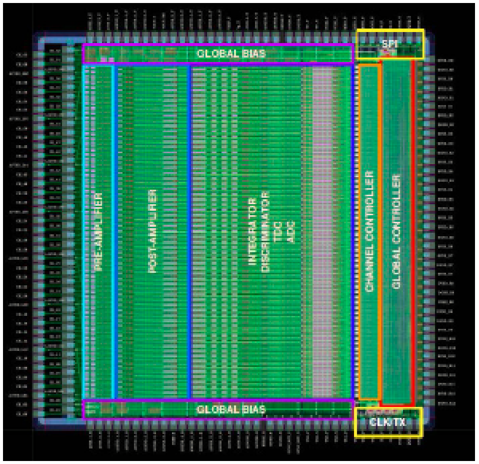
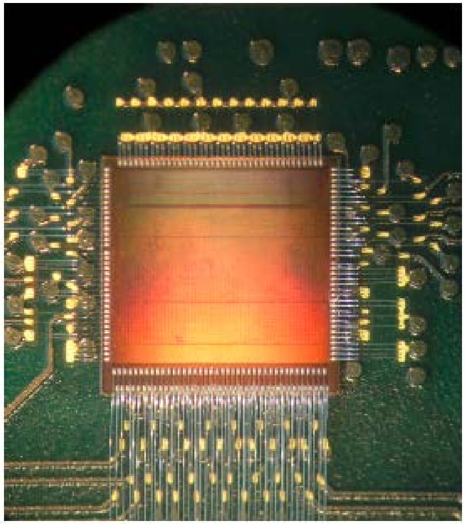
High performance TOFPET2 ASIC



Layout of the TOFPET2 ASIC.



Detail of test board showing the TOF-PET2 ASIC bonded on the board.

- Designed in standard CMOS 110 nm technology
- Signal amplification and discrimination for each of 64 independent channels.
- Dual branch quad-buffered analogue interpolation TDCs for each channel. The first branch is used for timing measurement. The second branch can either be used for time-over-threshold (ToT) or charge measurement (ADC).
- Quad-buffered charge integration for each TDC or ADC in each channel.
- Dynamic range: 1500 pC.
- SNR 25 dB for Q_{in}=200 fC (≈1 p. e.) and input capacitance of 320 pF.
- TDC time binning: 40 ps (option 20 ps).
- Gain adjustment per channel: 1, 1/2, 1/4, 1/8.
- Supports positive or negative signal polarity
- On-chip calibration pulse generator with 6-bit programmable amplitude.
- Max channel hit rate: 600 kHz.
- Rejects dark counts without triggering, allowing to handle over 1 MHz of dark counts.
- Separately configurable timing and trigger thresholds for each channel.
- Configurable charge integration time up to one microsecond.
- Fully digital output, 4 LVDS data links double data rate (DDR) compatible.
- Max output data rate: 3.2 Gb/s.
- Operation frequency: 200 MHz.
- Power consumption per channel: 5-8 mW, depending on certain settings.