



cherenkov  
telescope  
array



# Procedure di Test e caratterizzazione di fotomoltiplicatori al silicio per applicazioni in ambito astrofisico

Luca Tosti, Università e INFN Perugia

Gruppo INFN-SCT:

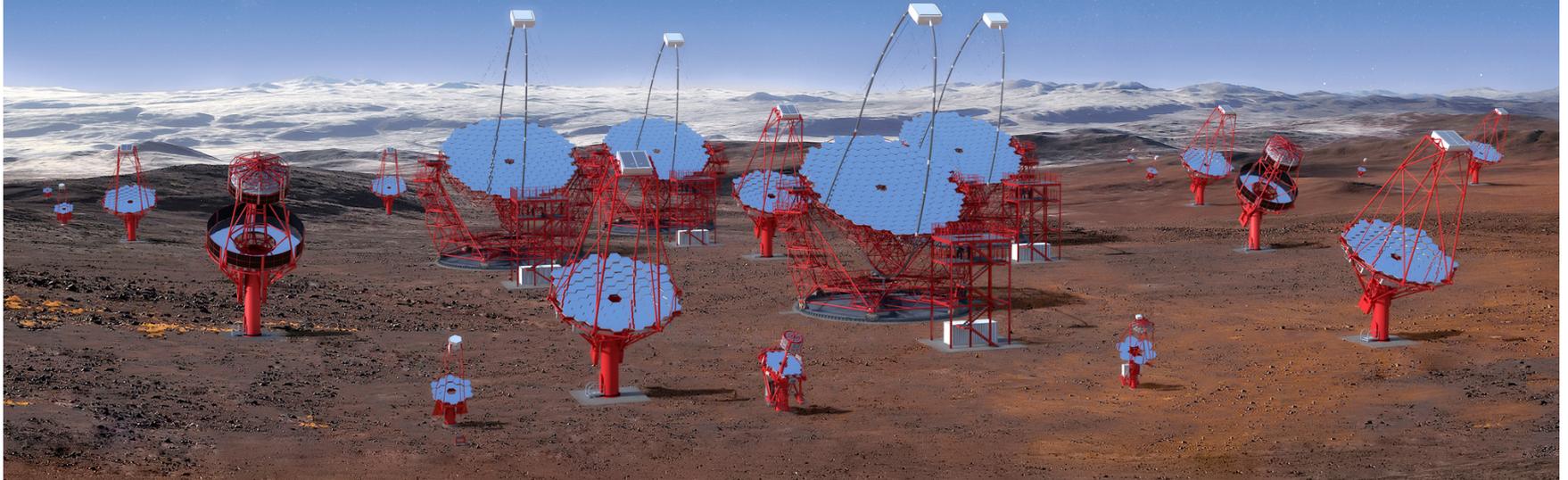
G. Ambrosi, M. Ambrosio, C. Aramo, B. Bertucci, E. Bissaldi, M. Bitossi, A. Boiano, C. Bonavolontà, M. Caprai, L. Consiglio, L. Di Venere, E. Fiandrini, N. Giglietto, F. Giordano, M. Ionica, F. Licciulli, S. Loporchio, F.R. Pantaleo, R. Paoletti, A. Rugliancich, L. Tosti, V. Vagelli

Per il progetto CTA SCT

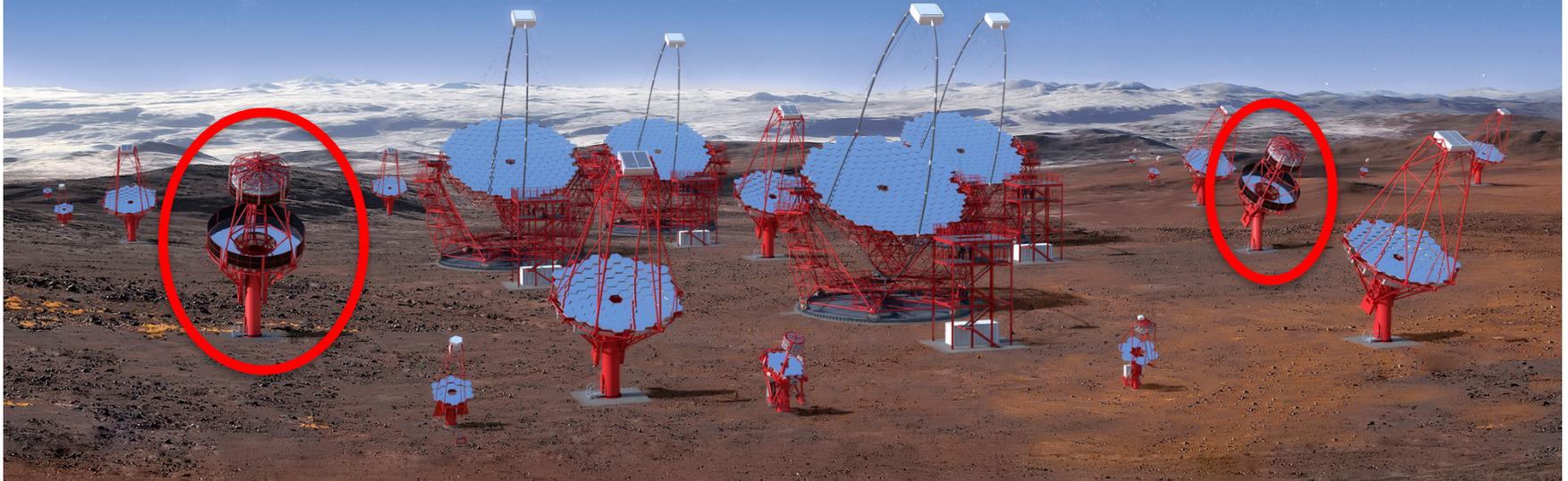


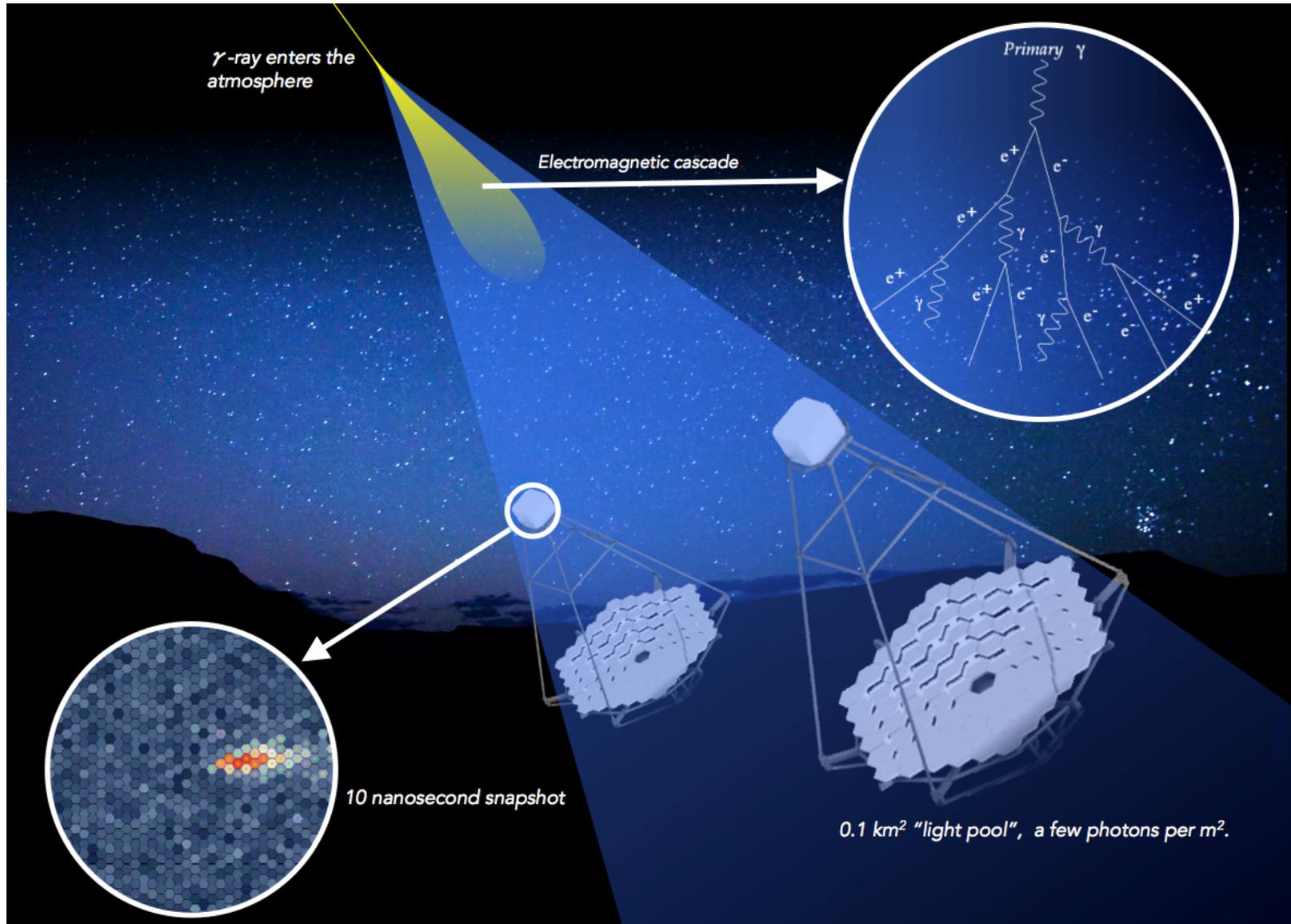
[www.cta-observatory.org](http://www.cta-observatory.org)

- Rivelazione gamma indiretta attraverso la misura della luce Cherenkov degli sciami atmosferici [30 GeV - 300 TeV]
  - Emisfero Nord: La Palma (ES)
  - Emisfero Sud: Paranal (Chile)
- Copertura totale del cielo
- +100 telescopi connessi
  - 3 scale di telescopi: Large (LST), Medium (MST) e Small (SST)
  - Completa operatività dell'osservatorio stimata per il 2025

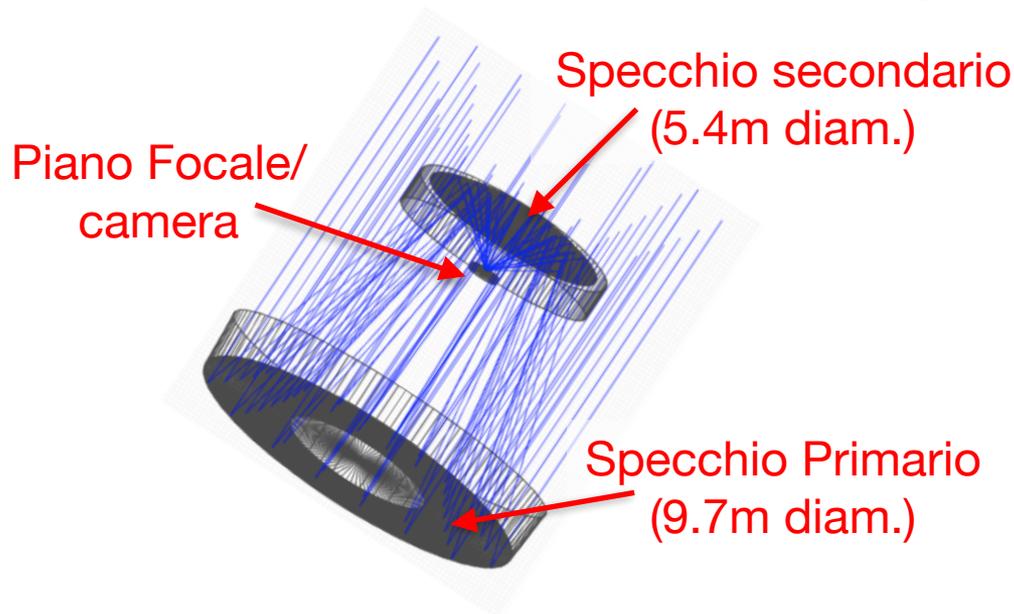


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## Schwarzschild-Couder doppio specchio Medium Size Telescope



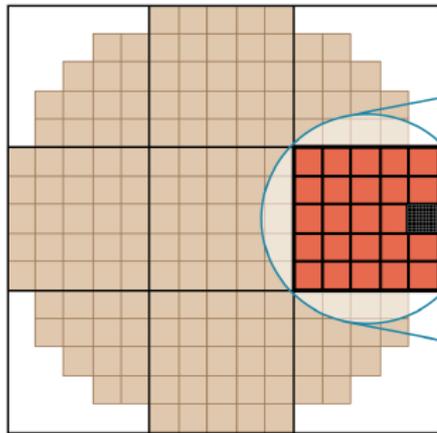
**Ottica a doppio specchio:** sostanziale riduzione delle aberrazioni nelle immagini.

- Contenuta **Point Spread Function (PSF)**
- **Alta risoluzione angolare**
- Compatibile con una **camera ultra compatta e ad alta risoluzione (equipaggiata con SiPM)**

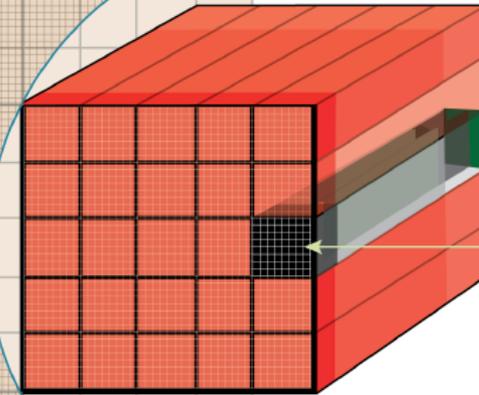
**Problematiche principali -> stabilità meccanica e allineamento specchi**

# La Camera di SCT

Full camera = 9 sub-fields  
11,328 image pixels

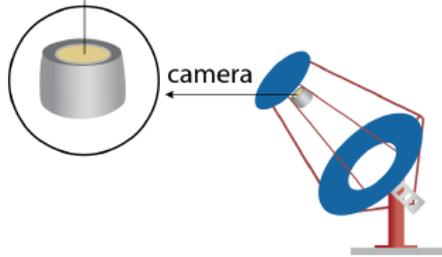


1 sub-field = 25 modules



Module of  
64 image  
pixels

4 image pixels =  
1 trigger pixel



- 177 moduli (64 pixel)
- Moduli Hamamatsu MPPC (prima stesura del progetto)
- **FBK NUV-HD3/4 SiPM (conosciuti come Low-CT)**

# Confronto tra MST

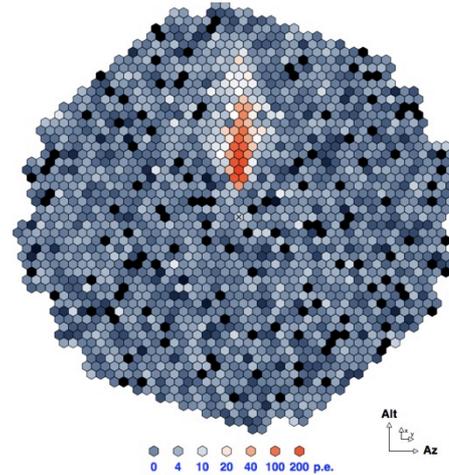
## MST

Singolo specchio  
Davies-Cotton

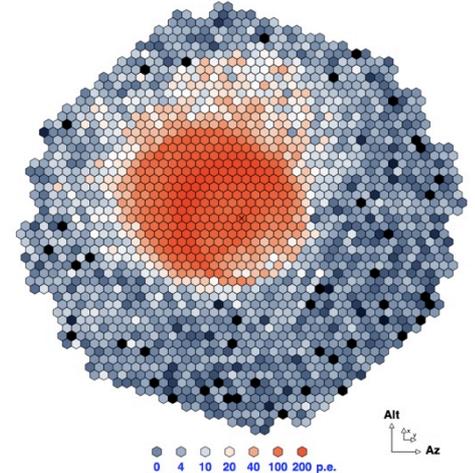
~ 2k PMTs



1 TeV sciame EM( $\gamma$ )  
distanza impatto: 100m



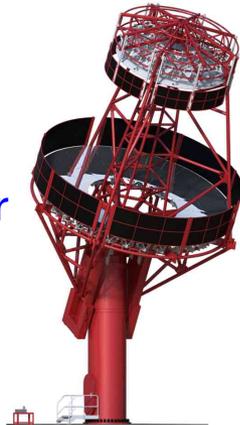
3.16 TeV sciame adronico  
(protone)  
distanza impatto: 0m



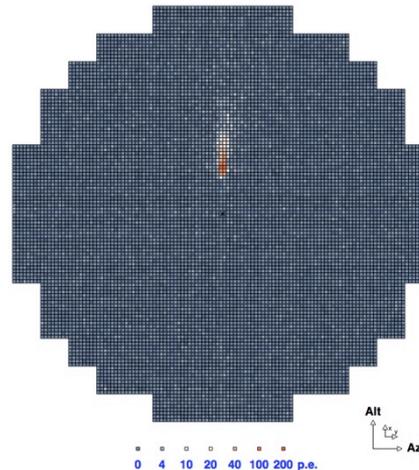
## SCT

Doppio specchio  
Schwarzschild-Couder

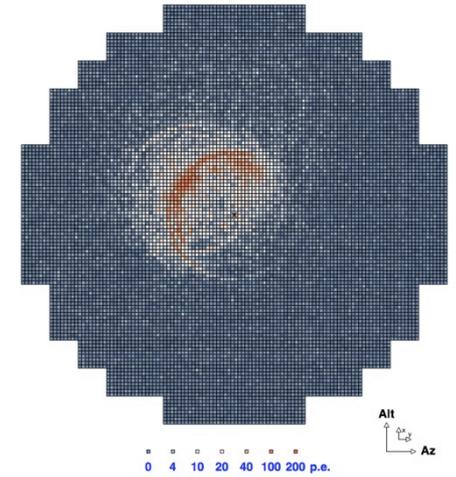
~ 11k SiPMs



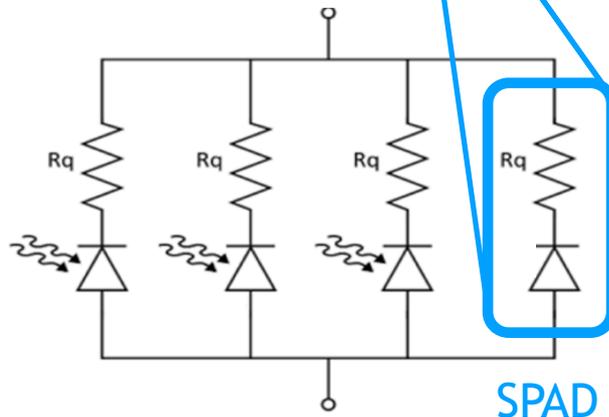
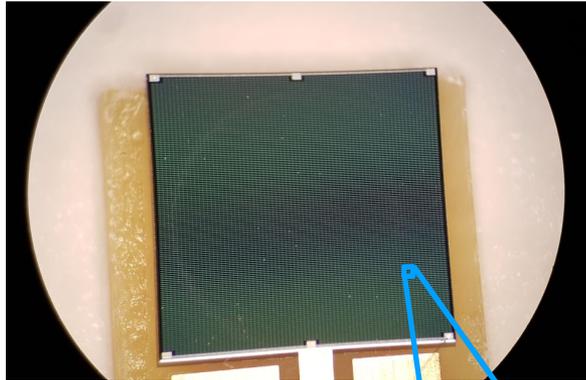
1 TeV sciame EM( $\gamma$ )  
distanza impatto: 100m



3.16 TeV sciame adronico  
(protone)  
distanza impatto: 0m



# Fotomoltiplicatori al silicio (SiPM)



- Near UV High Density (Low-CT)
- Dimensioni :  $6 \times 6 \text{ mm}^2$
- $40 \times 40 \text{ } \mu\text{m}^2$  per microcella
- Area attiva (Fill factor) = 76%

- Utilizzo come singoli Pixel della camera -> ricostruzione dell'energia e direzione dello sciame
- Ottimizzati per massimizzare la probabilità di rivelazione
- Conteggio dei SINGOLI fotoni
- Veloce risposta temporale

I SiPM NUV-HD Low-CT sono prodotti dalla  
Fondazione Bruno Kessler (FBK-IT) in collaborazione con INFN

# Caratteristiche da ottimizzare

**Efficienza di Rivelazione (PDE) :**  
probabilità di rivelazione di una fotone



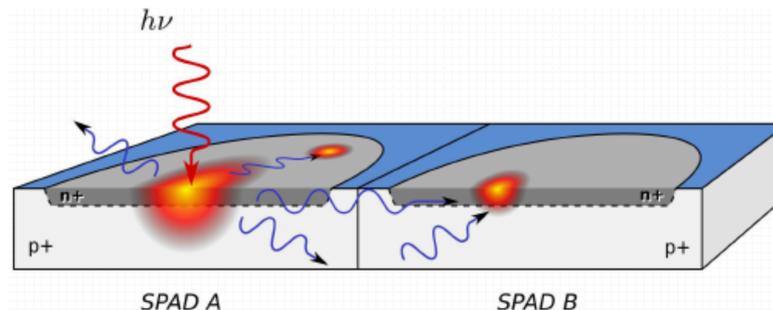
Ottenere la più alta PDE  
nell'intervallo di frequenze  
da misurare

**Frequenza di conteggi al buio (DCR) :**  
conteggi (coppie  $h^+e^-$ ) nel silicio

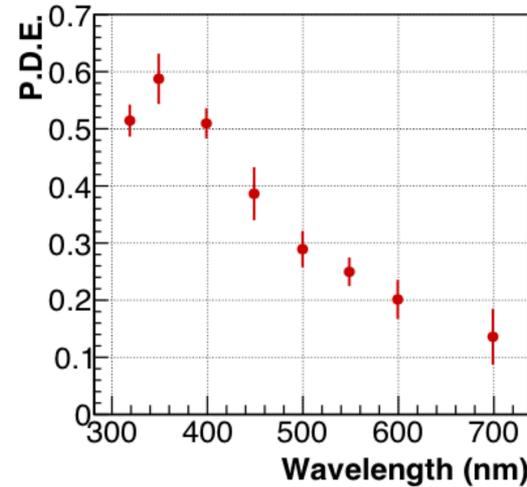
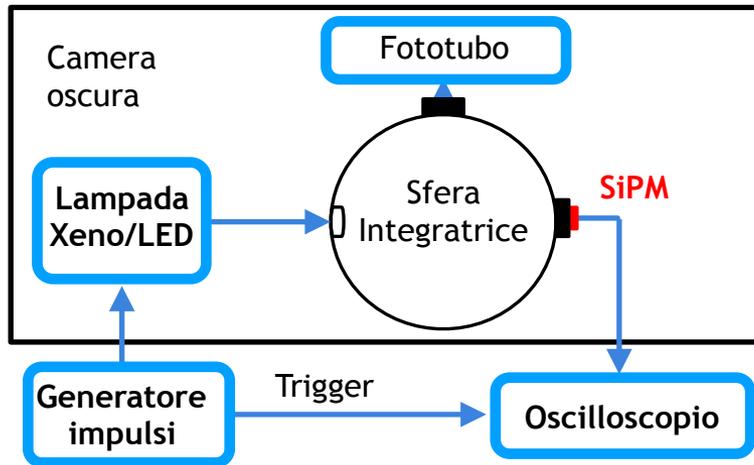


Da minimizzare per  
diminuire le rivelazioni  
spurie

**Probabilità di Crosstalk (CT) :**  
induzione di valanghe nelle SPAD adiacenti

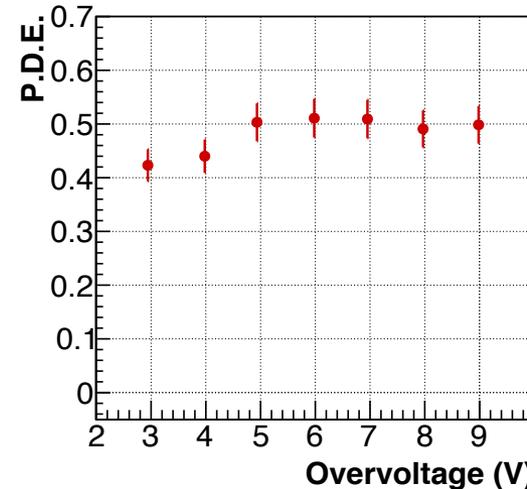


# Misura della PDE



@ +6 OV

Lampada  
a Xeno  
(no impulsato)



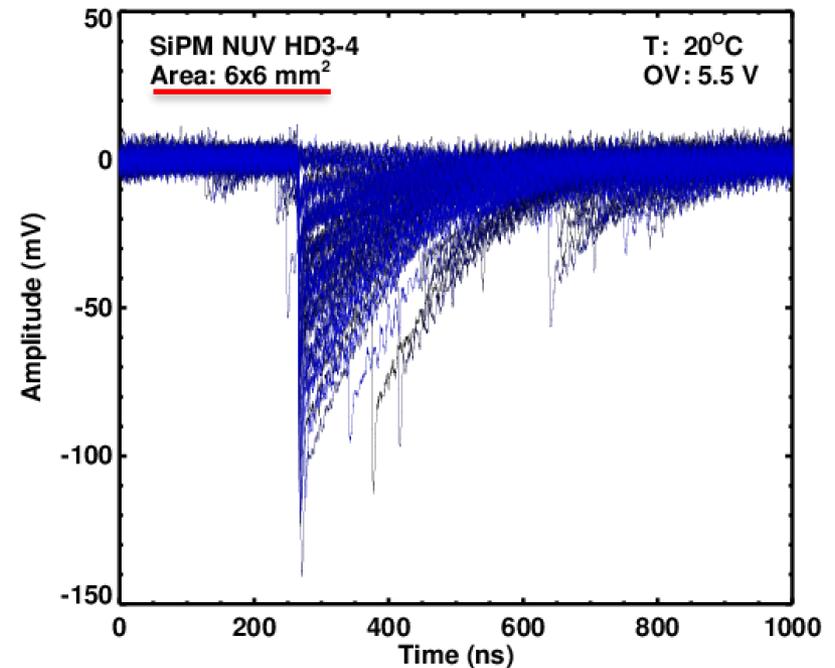
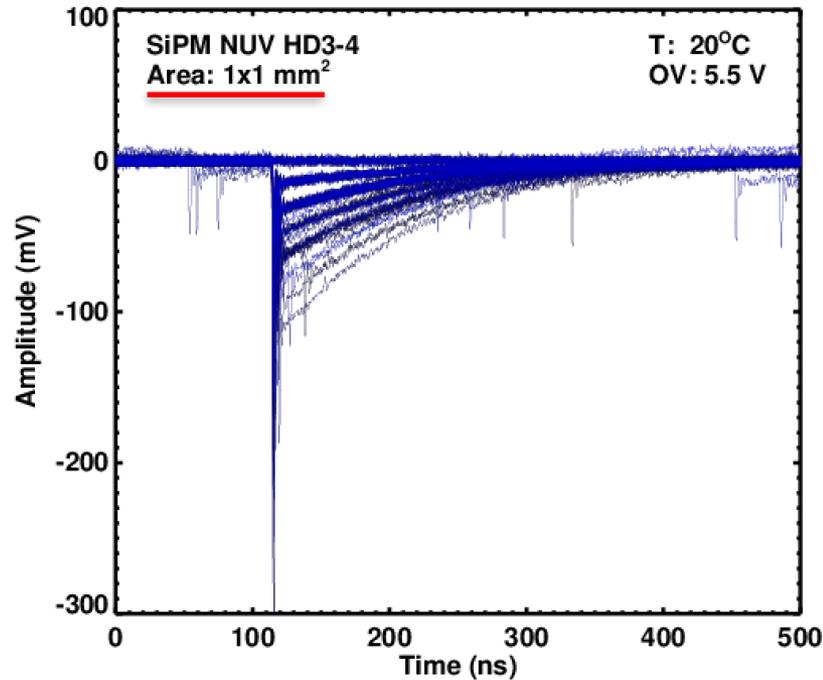
@ 400 nm

LED  
impulsato  
(40ns)

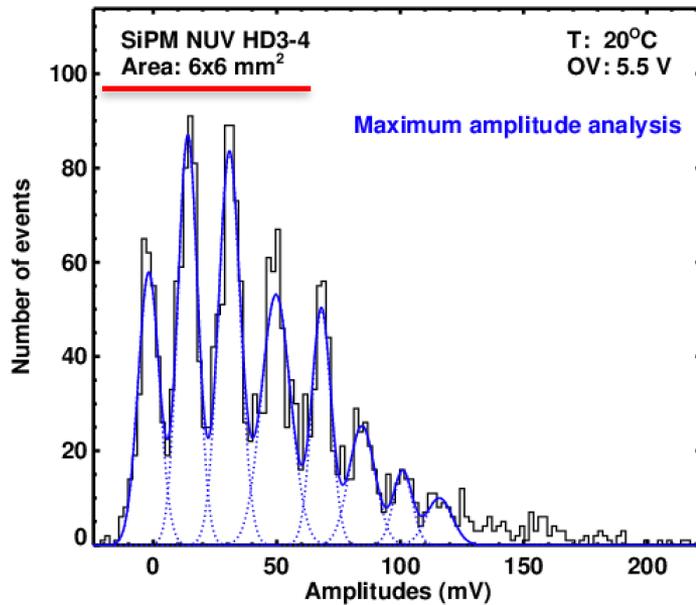
- PDE massima a ~ 350 nm (picco di emissione Cherenkov)
- Valore massimo della PDE ~60% (+6 OV)

# Caratterizzazione con buio/laser

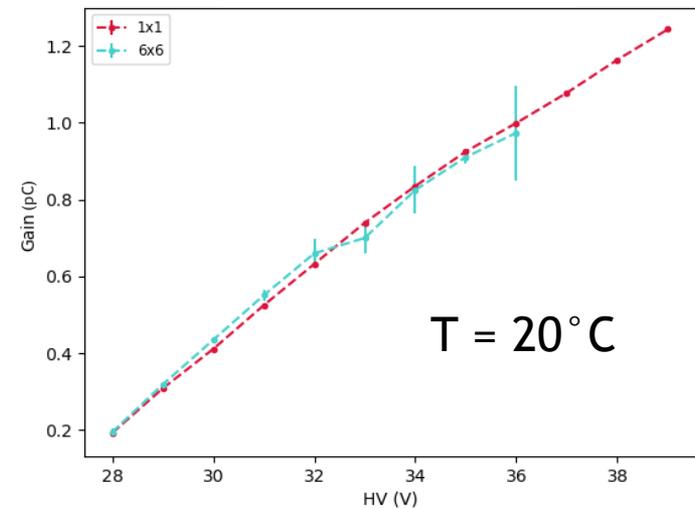
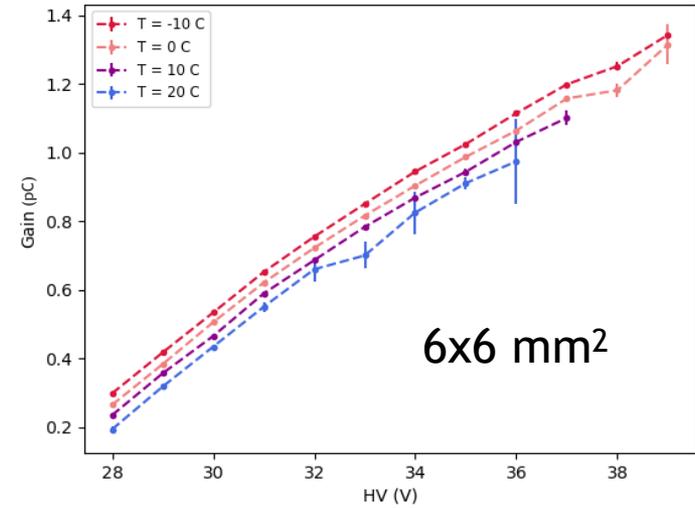
- Scelta sensori  $1 \times 1 \text{ mm}^2$  (test) e  $6 \times 6 \text{ mm}^2$  (standard) -> ottimizzazione misure
- Acquisizione della forma d'onda -> misura del tempo di ricarica della cella



# Caratterizzazione con buio/laser

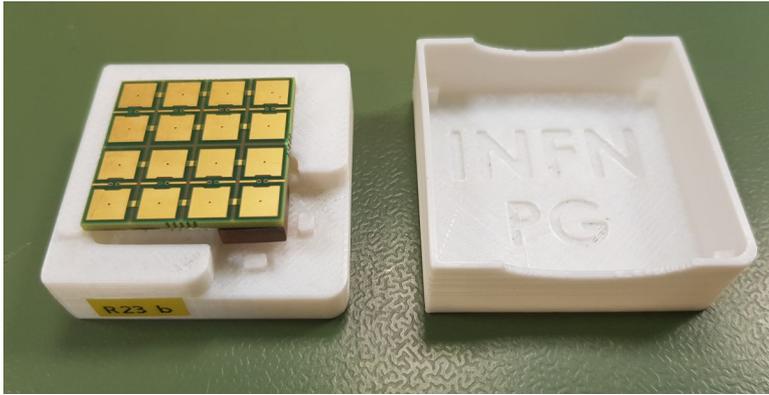


“Manina” in ampiezza

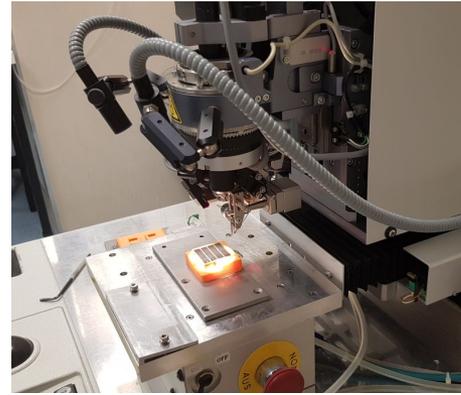


# Assemblaggi

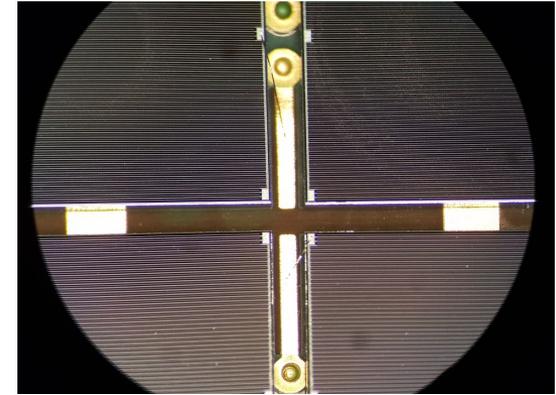
Posizionamento  
e incoraggio su scheda



Saldatura ad ultrasuoni dei  
contatti elettrici (bonding)



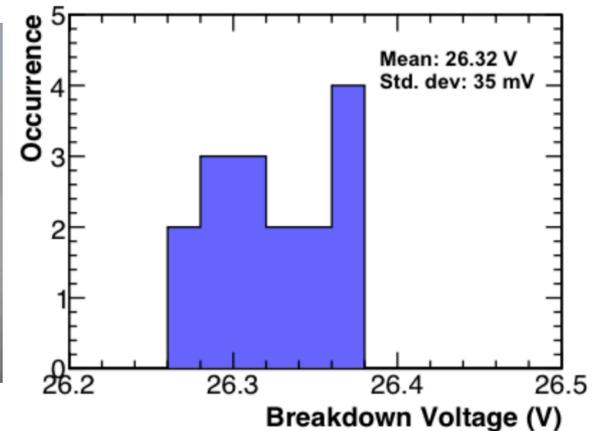
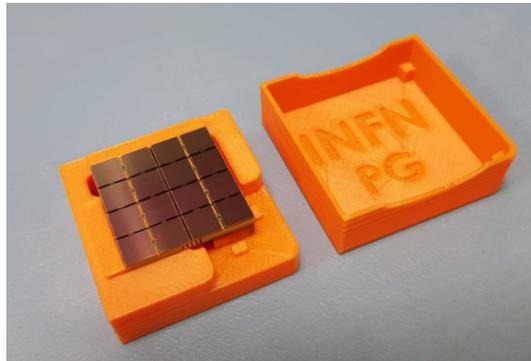
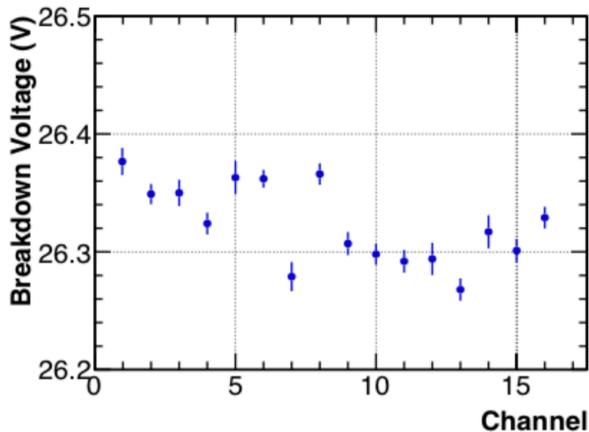
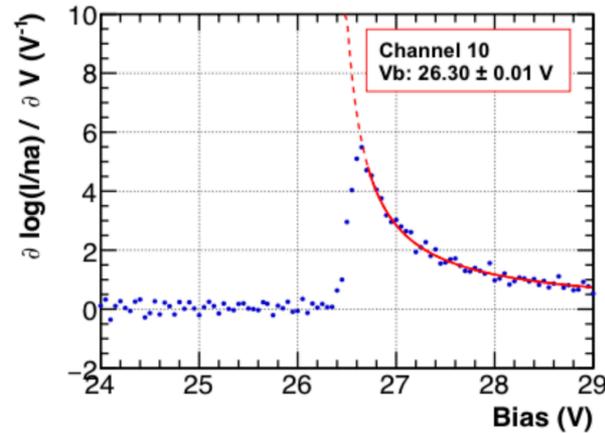
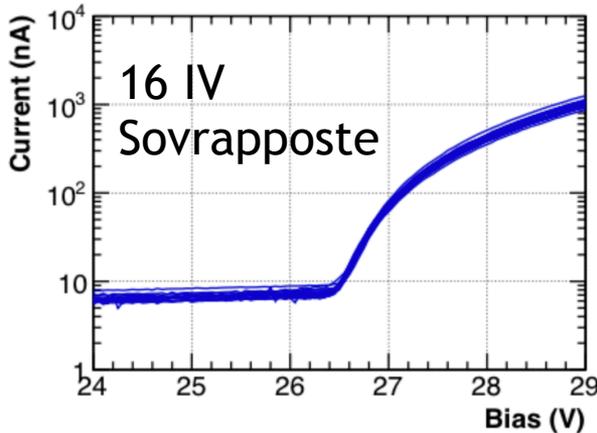
Bonding  
with 25  $\mu\text{m}$  diameter 1%AlSi wire



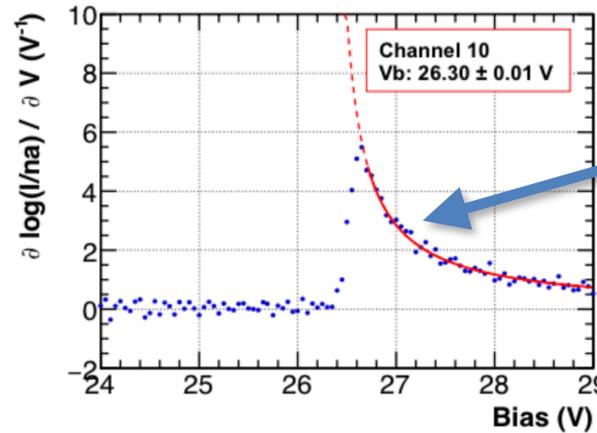
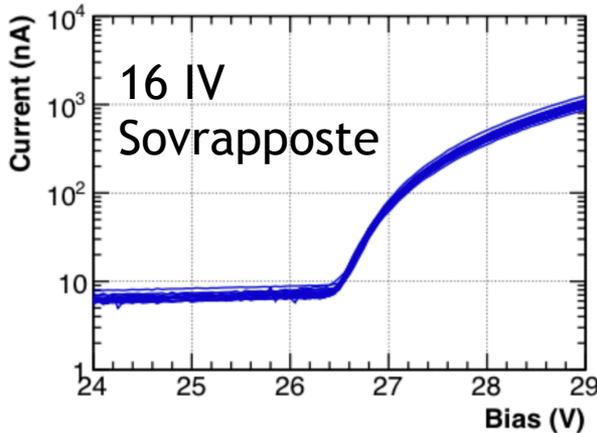
**Moduli pronti per la caratterizzazione**

- 150 matrici assemblate (inclusi i prototipi), 50 con NUV-HD Low-CT
- Tutte 50 idonee per la camera
- **36 delle migliori selezionate per equipaggiare la camera**

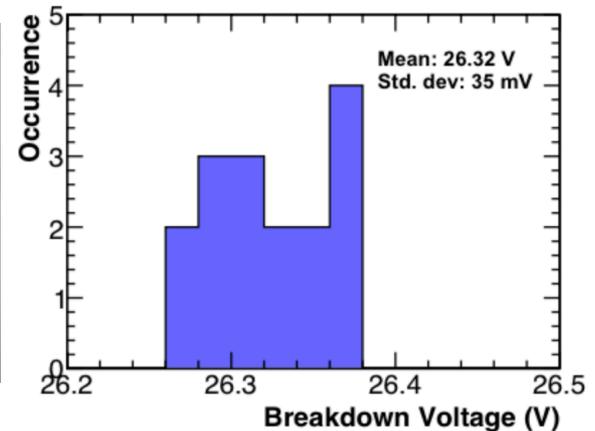
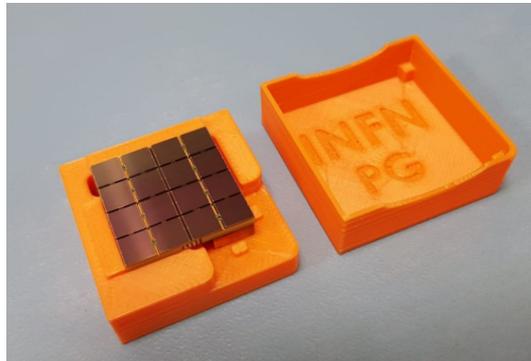
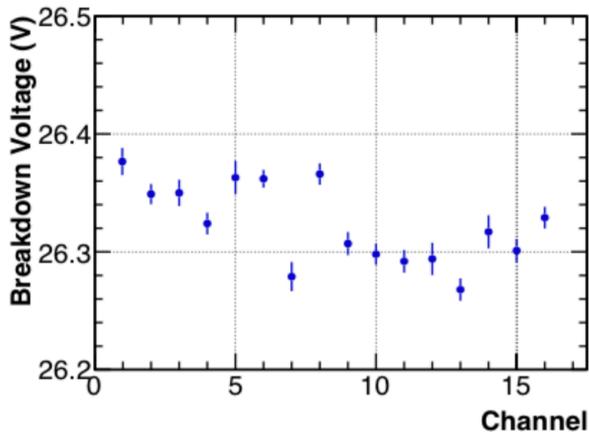
Per maggiori dettagli consultare il poster di Serena Loporchio  
(INFN Bari, sezione “nuove tecnologie”)



Misura della curva caratteristica (IV) -> controllo integrità e uniformità dei sensori

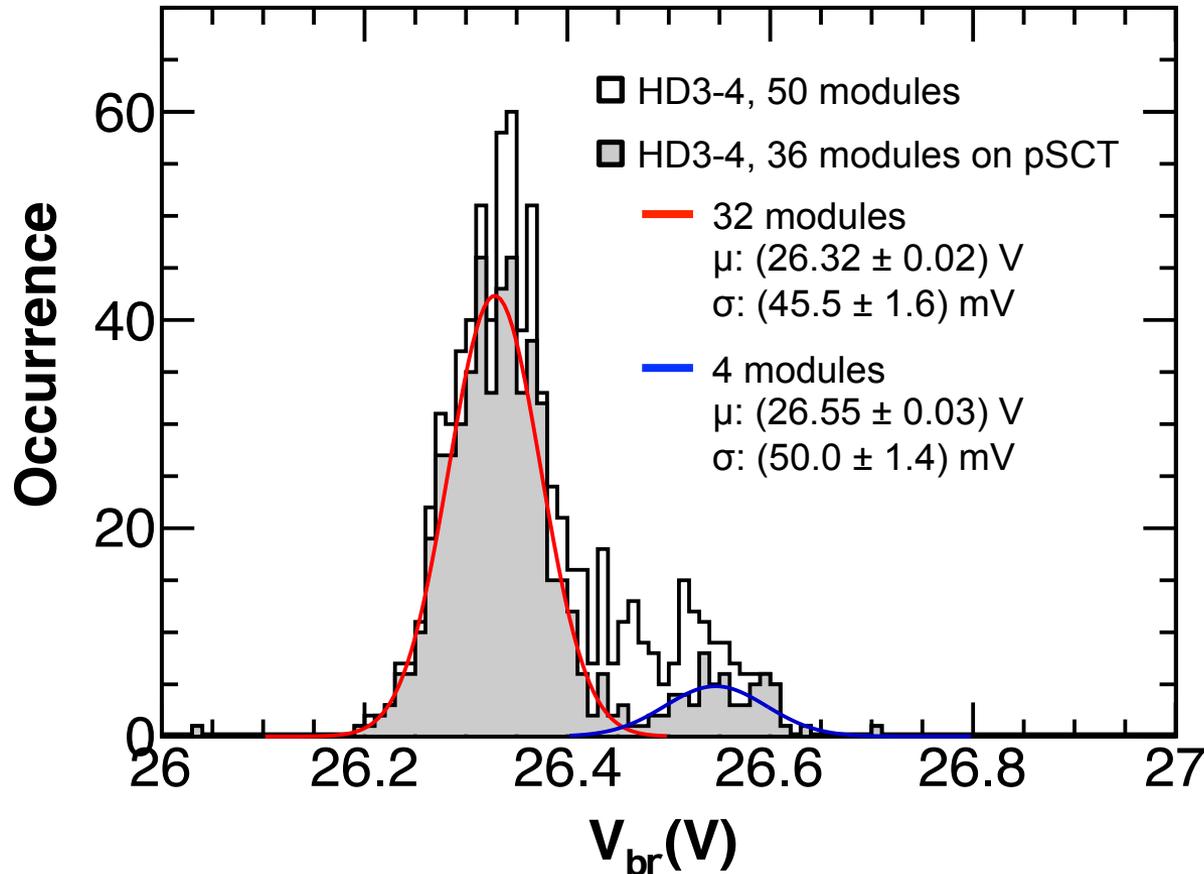


$$\approx \frac{2}{V - V_{br}}$$



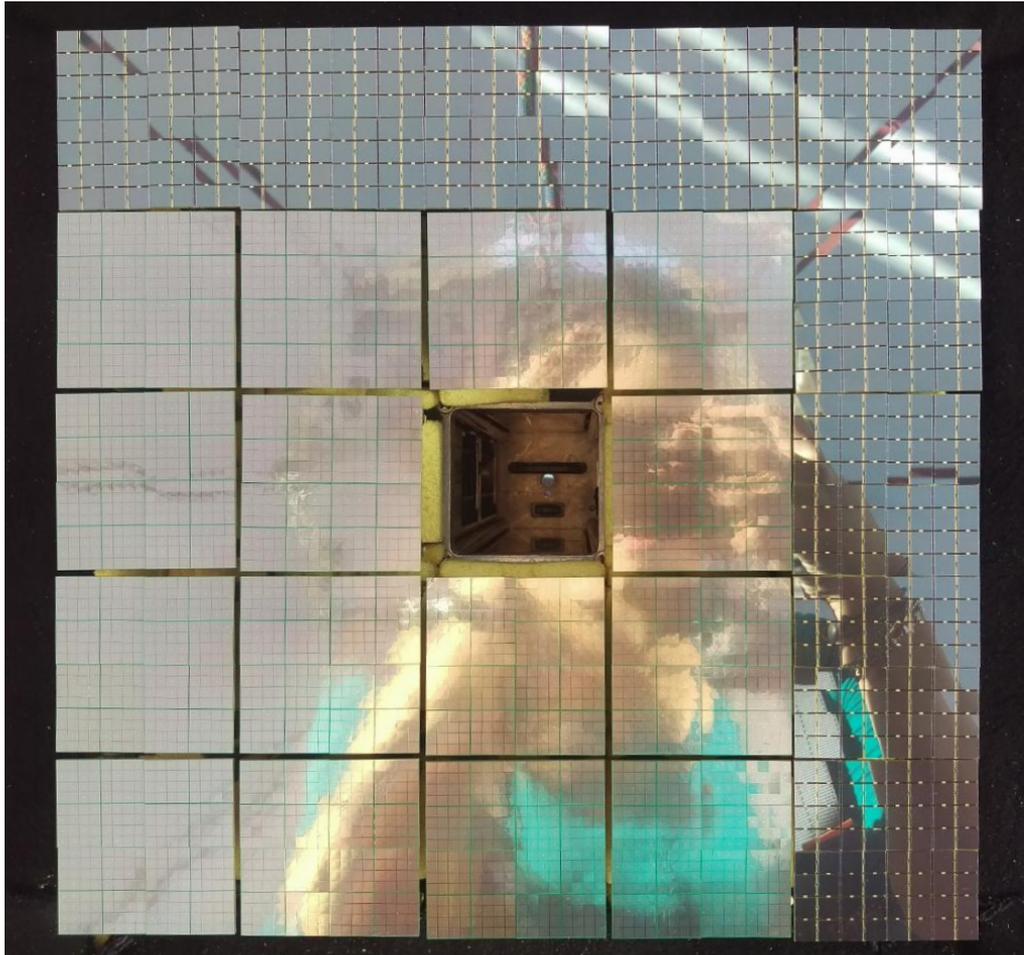
Misura della curva caratteristica (IV) -> controllo integrità e uniformità dei sensori

# Uniformità $V_{br}$



**Alta uniformità del breakdown in tutta la popolazione di SiPM testati provenienti da uno stesso wafer (curve rosse e blu in figura)**

# Utilizzo dei sensori (camera SCT)



- Procedura di allineamento e test di interfaccia con l'elettronica della camera
- 9 moduli INFN-FBK (bordo superiore e laterale destro)
- Modulo centrale rimosso -> inserimento modulo per la procedura di puntamento del telescopio

**Pronti per vedere le  
prime luci**

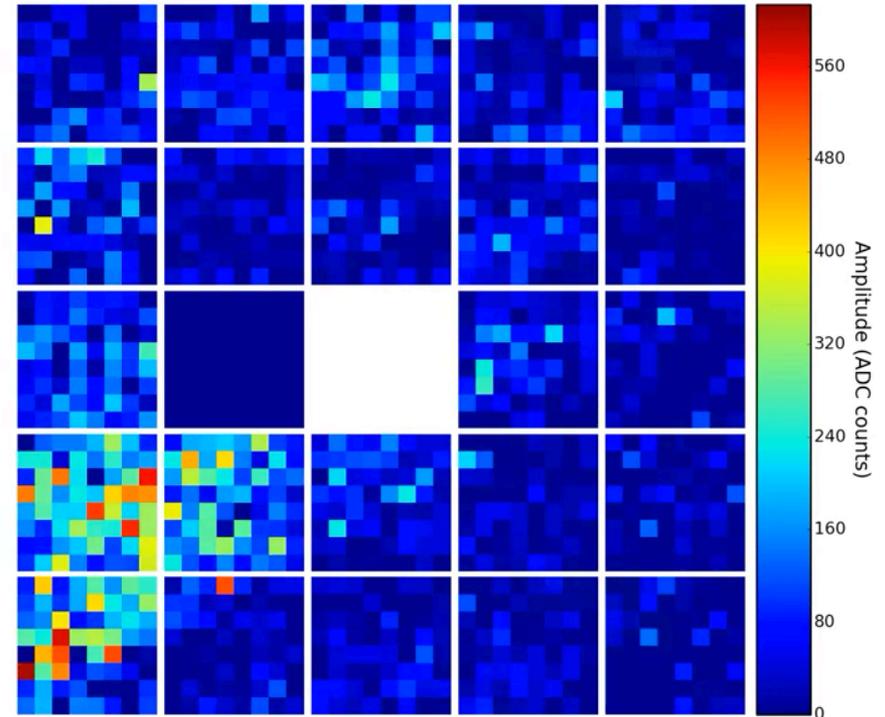
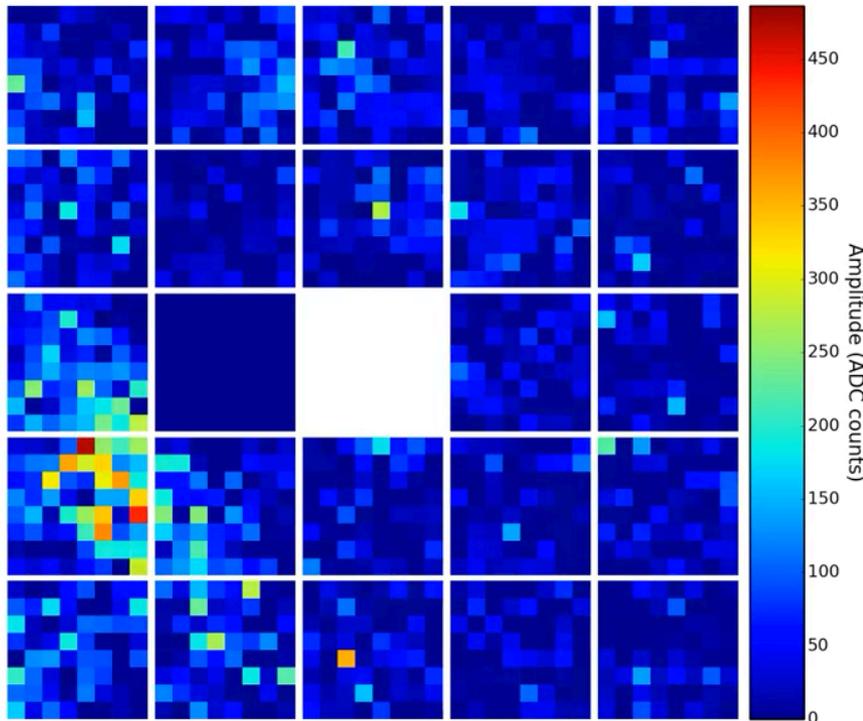
# Inaugurazione



Fred Lawrence  
Whipple Obs.  
Amado, AZ(USA)

Gennaio 17-18 2019

# Obiettivo raggiunto: Prime luci



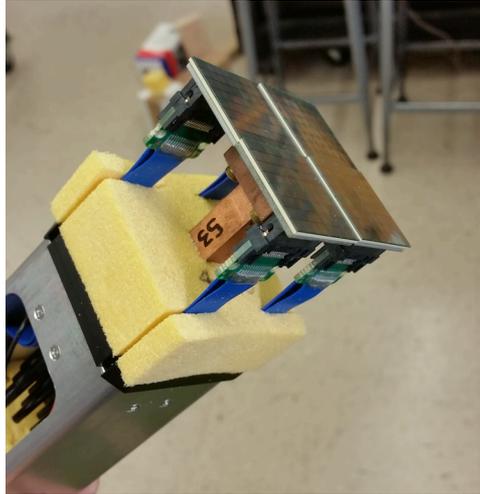
Scatti dagli eventi del 23 Gennaio 2019  
<https://www.cta-observatory.org/sct-first-light/>

- Rivelazione prime luci -> inizio collaudo della camera
- Produzione 25 moduli FBK (1600 pixels) con elettronica ottimizzata (fine 2019)
- Piano focale completo con sensori FBK (177 moduli, fine 2021)

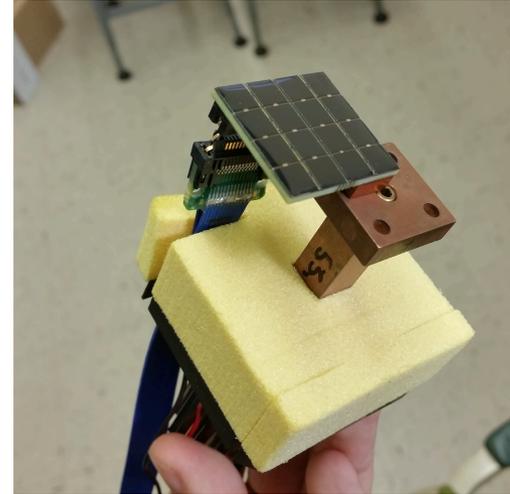


BACKUP

# pSCT Camera (optical modules)



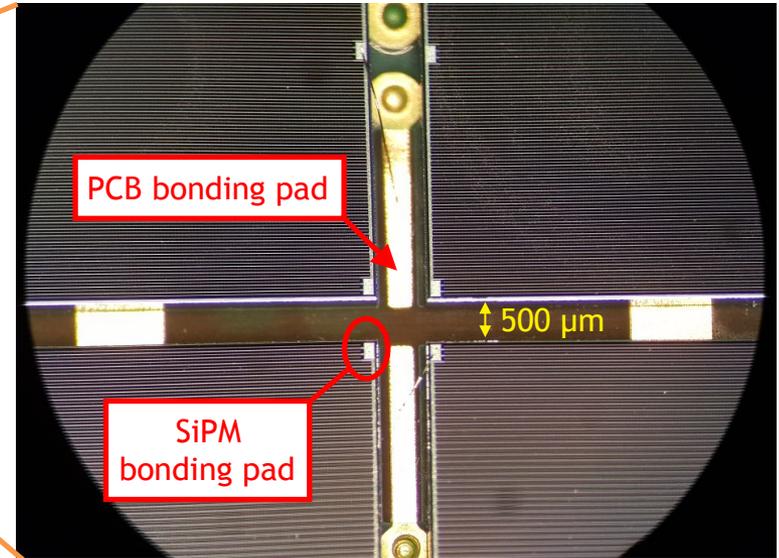
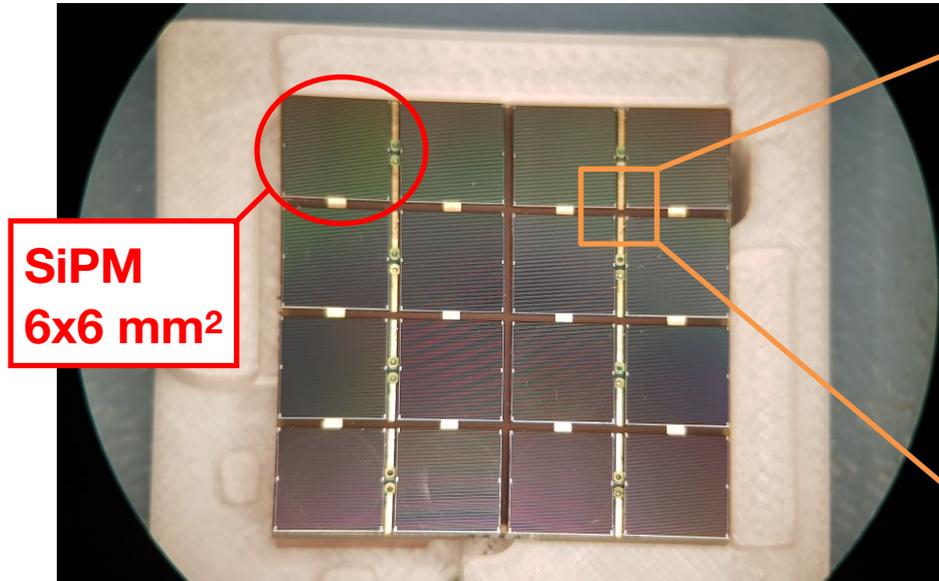
**Hamamatsu US module**



**INFN FBK prototype (2016)**



# INFN optical modules



Custom PCB designed by INFN

27x27mm<sup>2</sup> PCB equipped with 16  
SiPMs

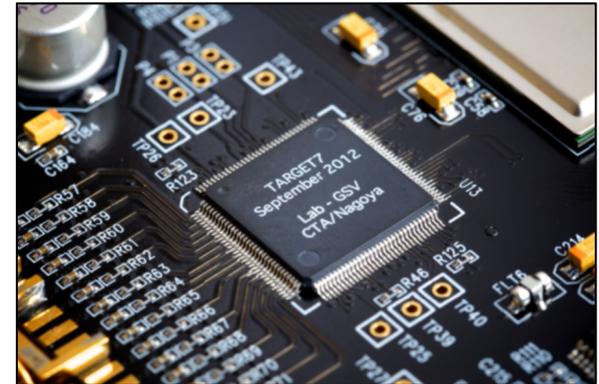


maximum uniformity of the camera  
covering



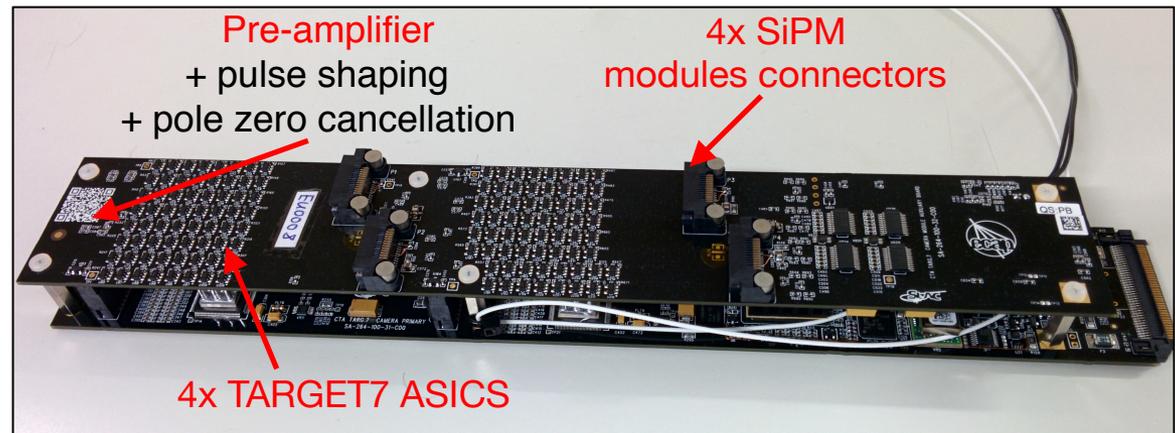
Signal read with “**TeV Array Readout with GS/s sampling and Event Trigger**” board (TARGET7)

- **Compact chip for high density channel camera**
- 16 input channels
- Analogical Buffer (16384 capacitors)
- Switched Capacitors Array
- **Sampling and waveform digitation (  $16\mu s$  ) at 1GS/s**



Quality tests made in INFN section of Pisa and Bari:

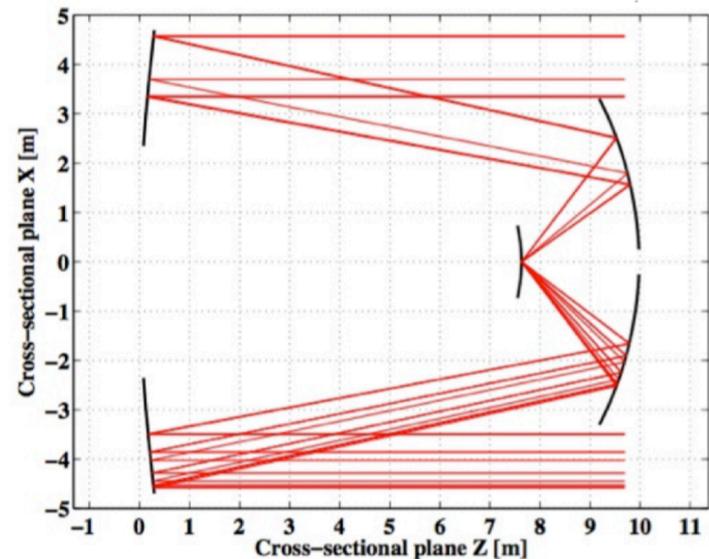
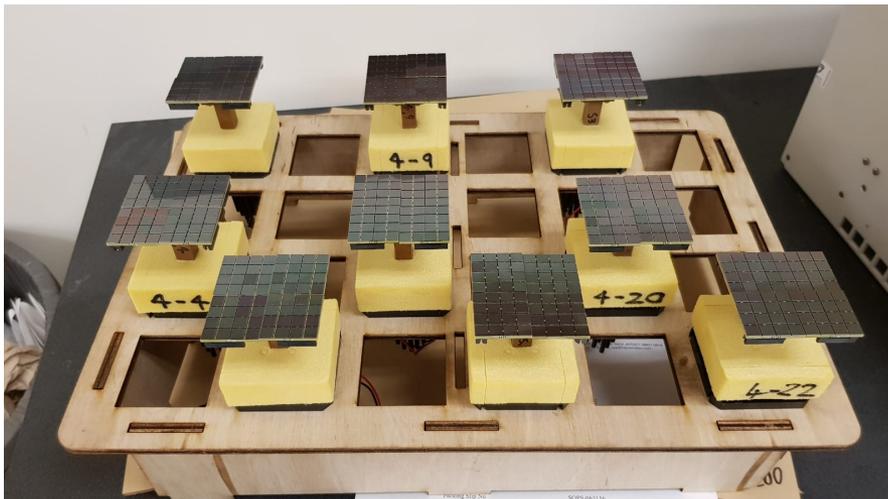
- Pedestal calibration
- Waveform acquisition (with laser)
- Trigger efficiency tests



**9 modules TARGET7 for SiPM FBK signal readout (99% of 576 channels are working properly)**

# Optical Modules alignment

Every module was aligned in requirement of focal plane curved surface with 0.02mm of tolerance (Georgia Institute of Technology, Atlanta US).



**Modules layout completely defined and tested (central sub-field)**  
(In study the upgrade to TSV SiPM sensors with borosilicate protecting covering)

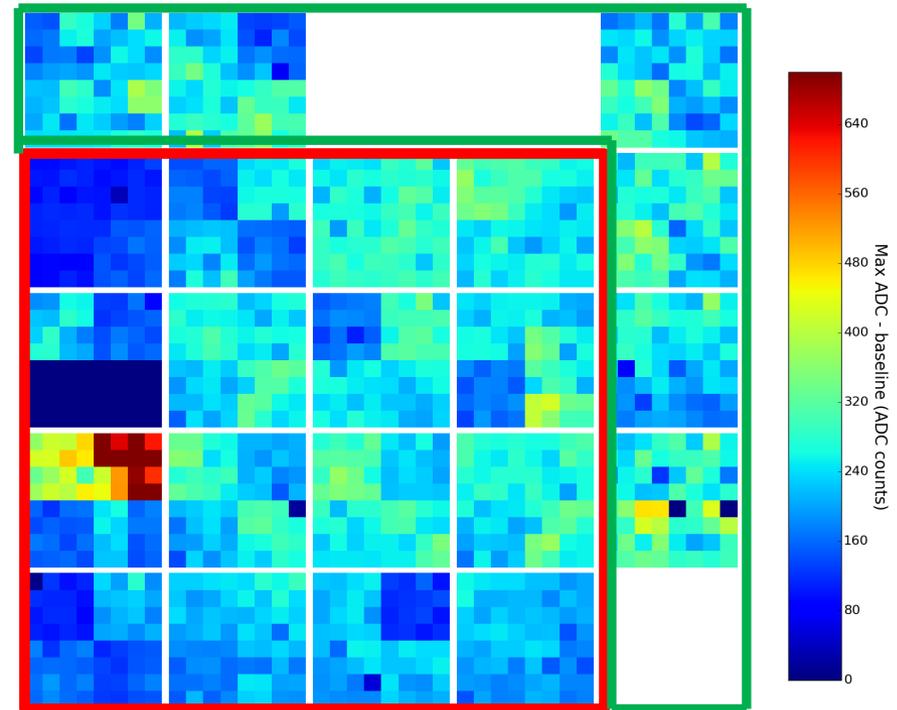
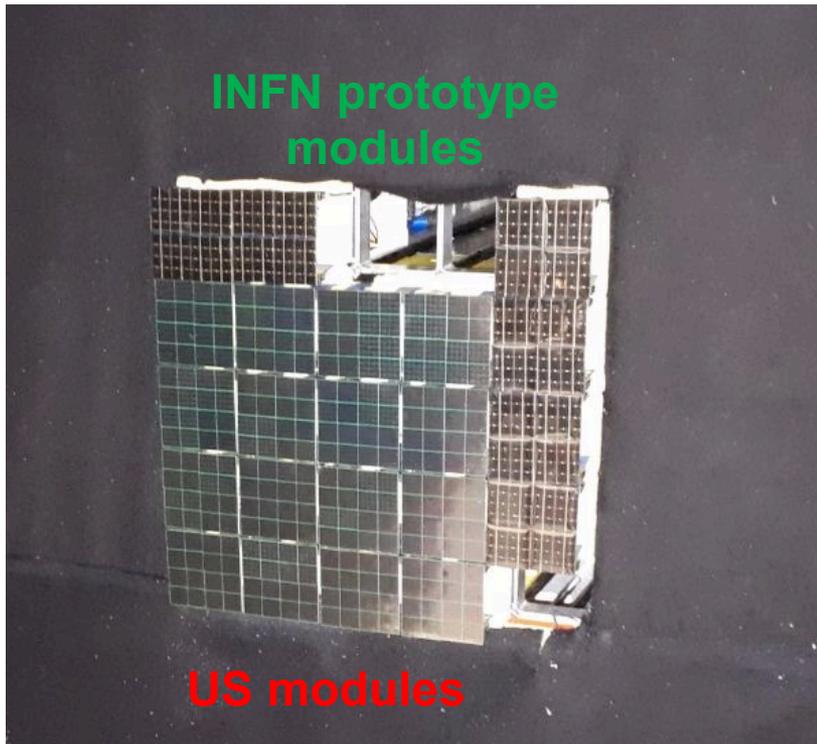
# Camera test (6 modules)

University Of Wisconsin, Madison (2017)

15 US + 6 INFN modules (1408 pixels)

- Tests under LED flasher at 100 Hz and TARGET 7 internal trigger
- Trigger applied on 4 pixel clusters
- The other 3 INFN modules were tested alone after a second shipping in USA

INFN prototype modules



US modules