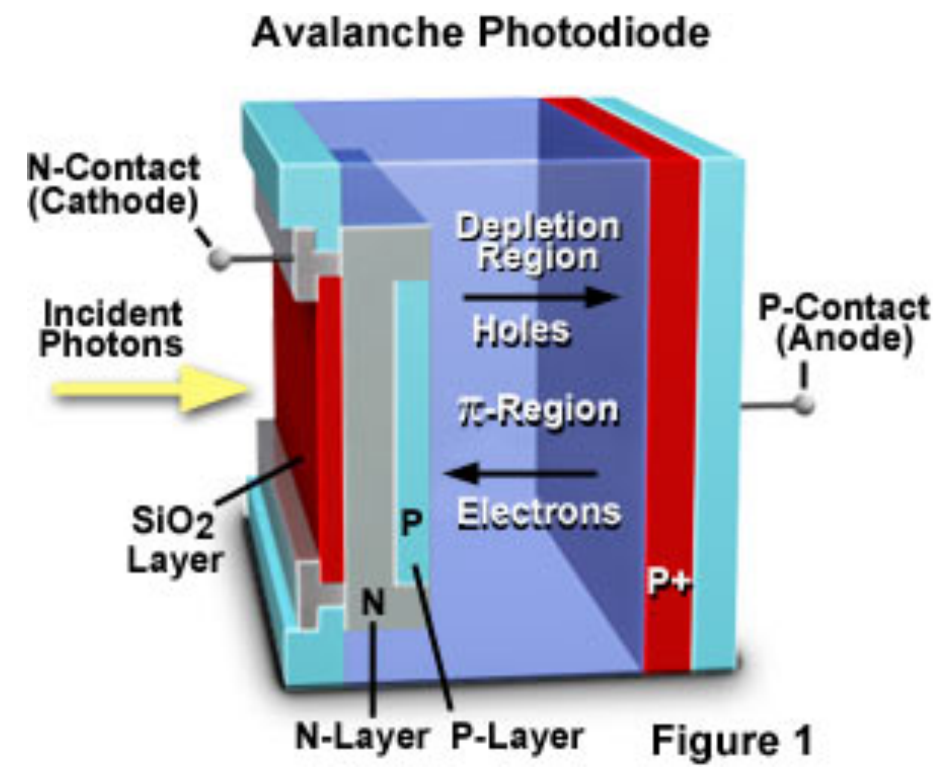
OUTLOOK ON PARTICLE DETECTORS

SENSORS

SIPM



Array of Single Photon Avalanche Diodes (SPAD) operating in GM mode —> proportional response (photon counting);

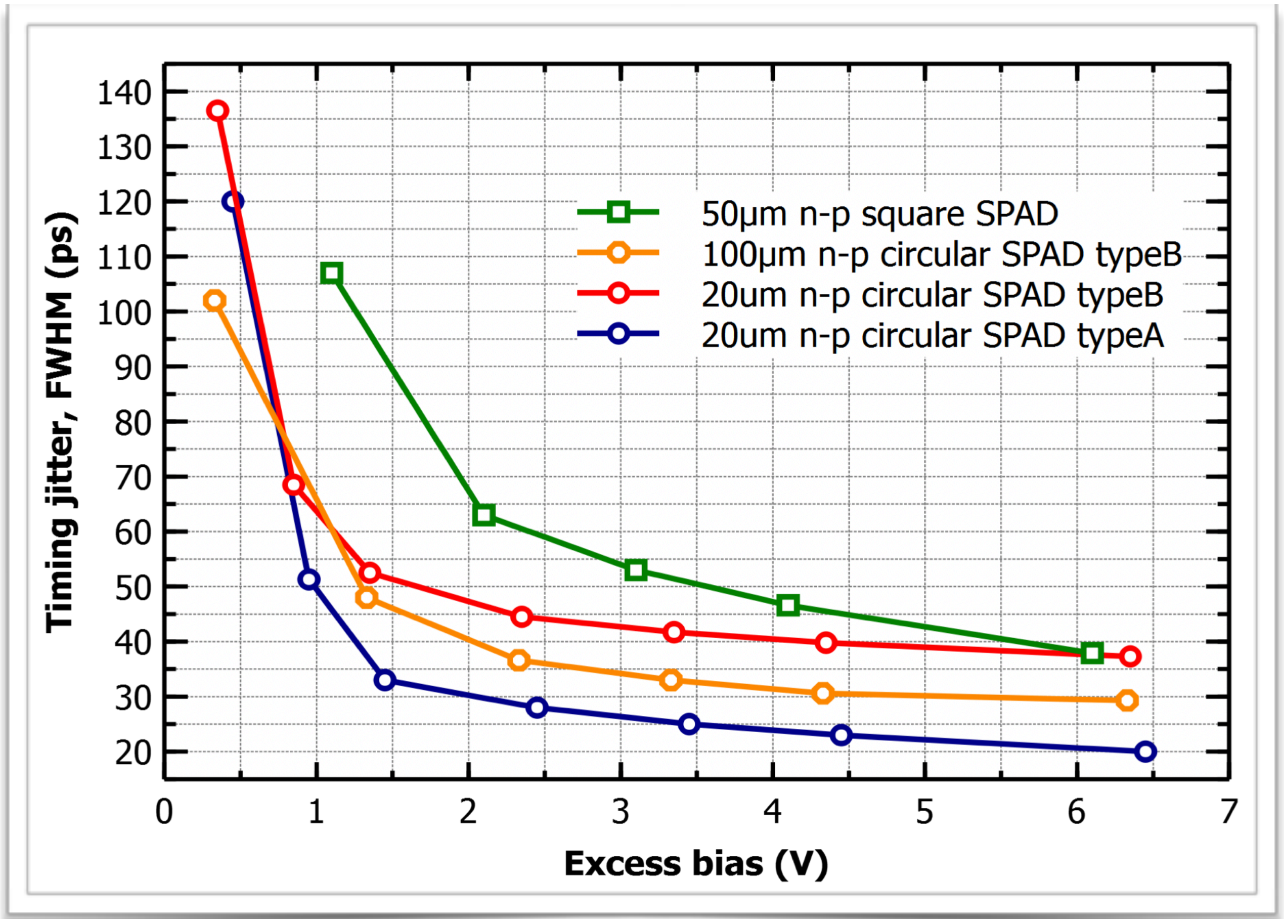
New issues:

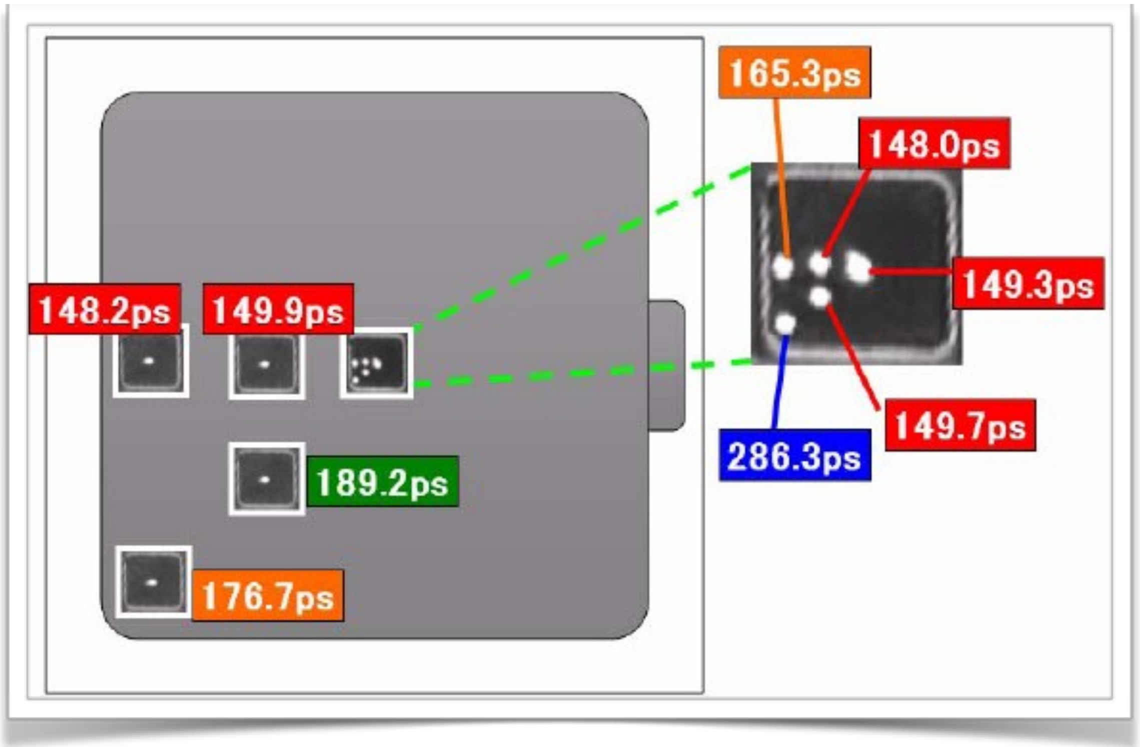
- Single photon **time resolution** (SPTR), **uniformity** performances;
- the photo-detection efficiency (PDE), the **fill factor** (FF) that for small cell size can be quite low;
- **dark count rate** (DCR) because of high probability to include noisy cells in a device;
- the **optical cross-talk** (CT) among cells;

SIPM: TIME RESOLUTION

SiPM are intrinsically very fast, SPTR dependence on position;

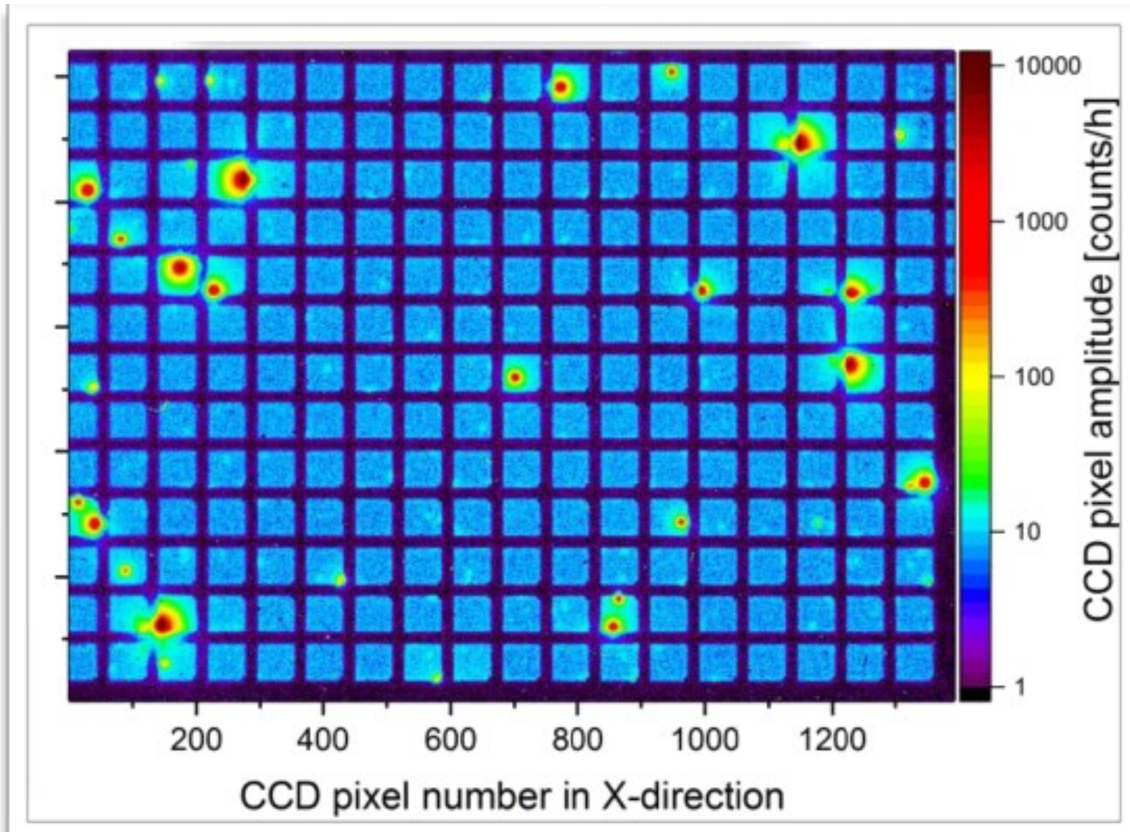
- **lower field** at edges → slower avalanche transverse propagation there;
- **time delay** across the SiPM can differ significantly and need to be equalized



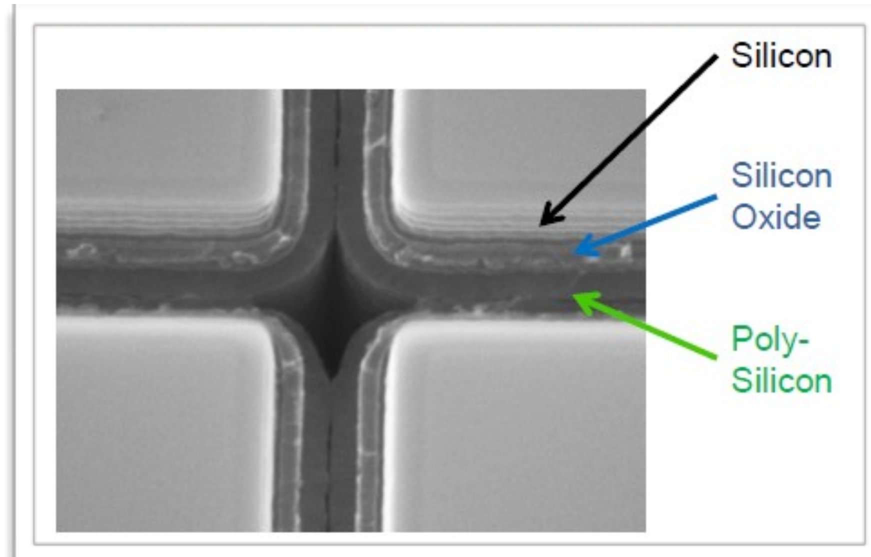


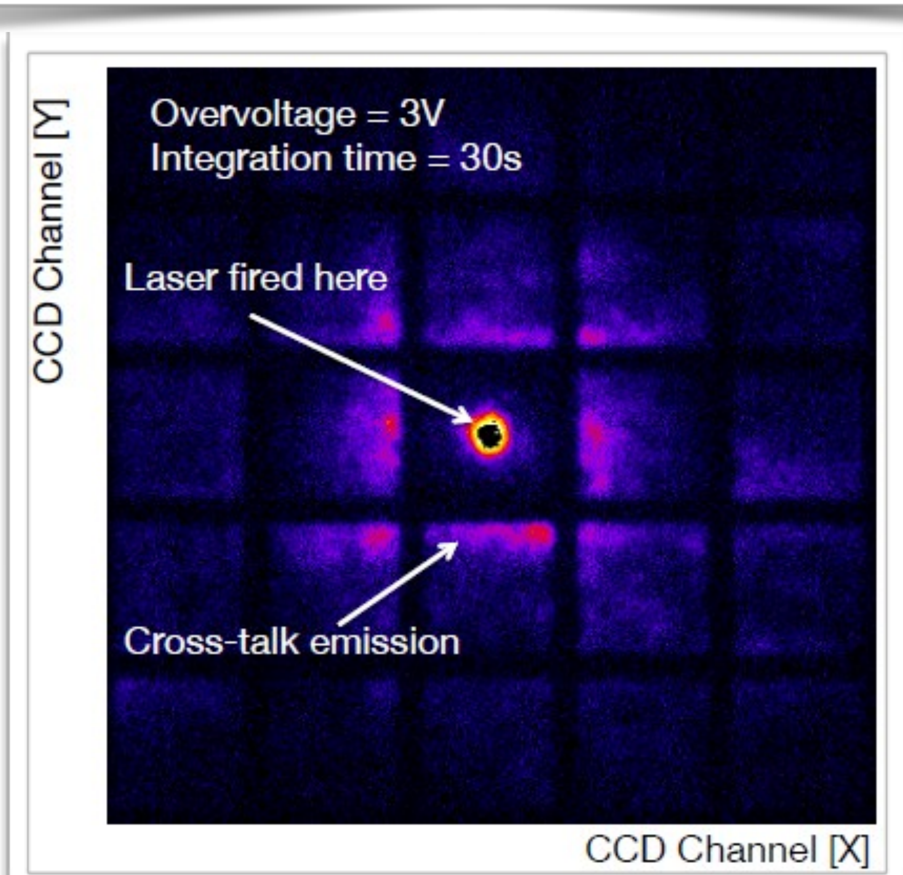
Tiny cells perform very fast timing

SIPM: DARK COUNT RATE

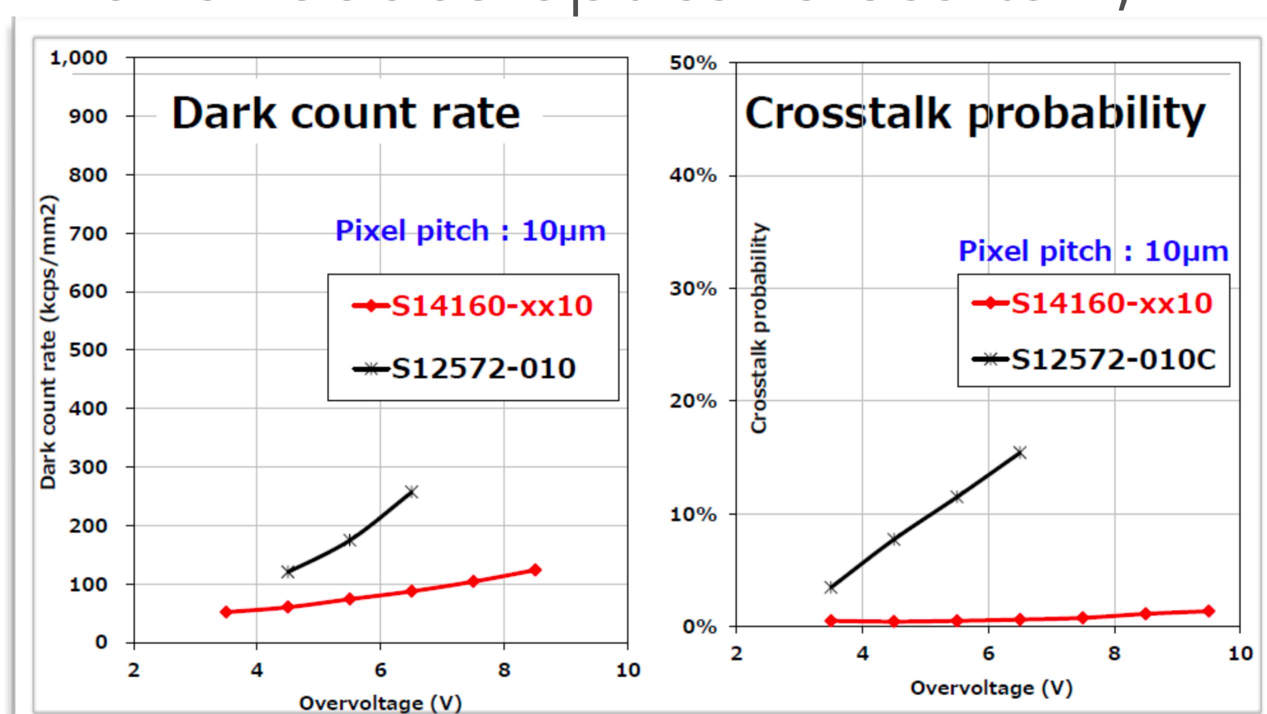


Most of the DCR noise generated by few high noise cells (avalanches emit light);





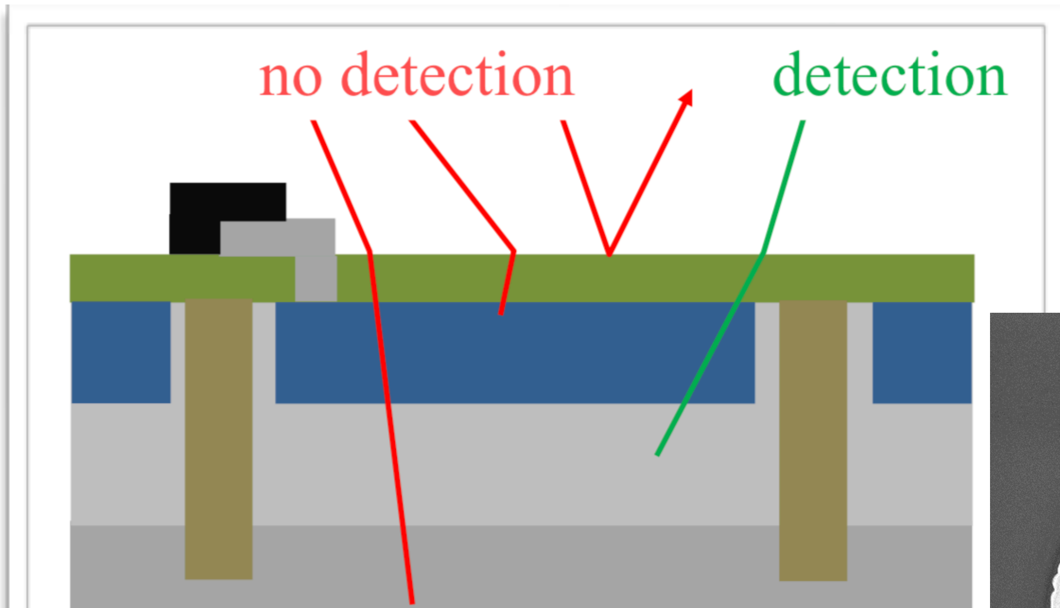
Poly-Silicon trenches to absorb light and reduce optical cross-talk;

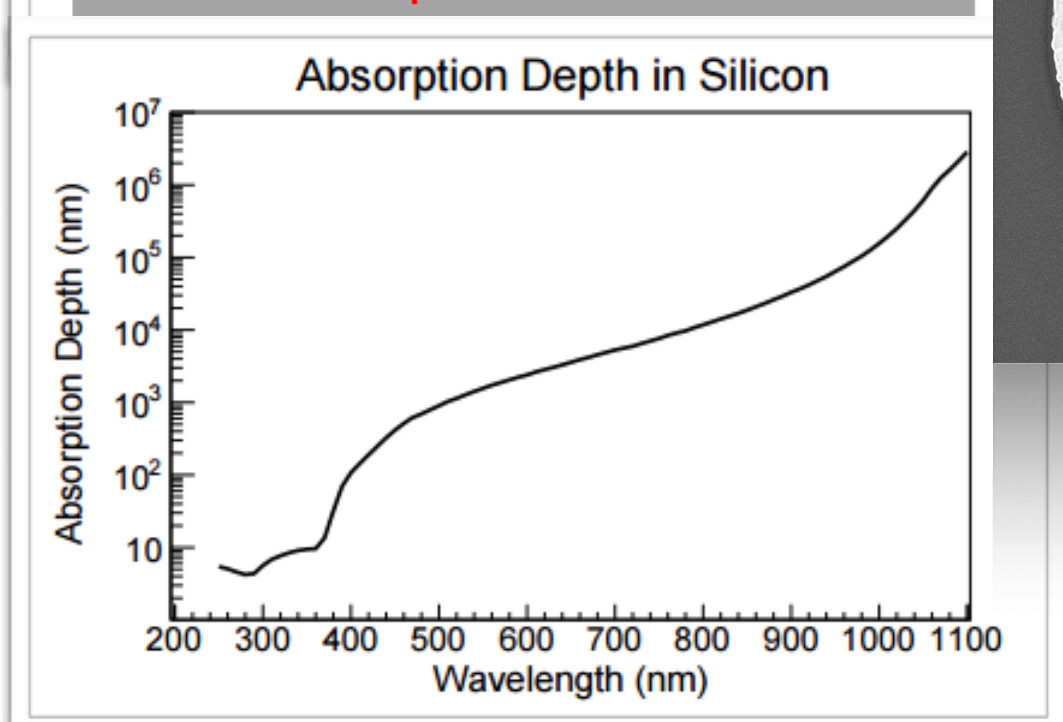


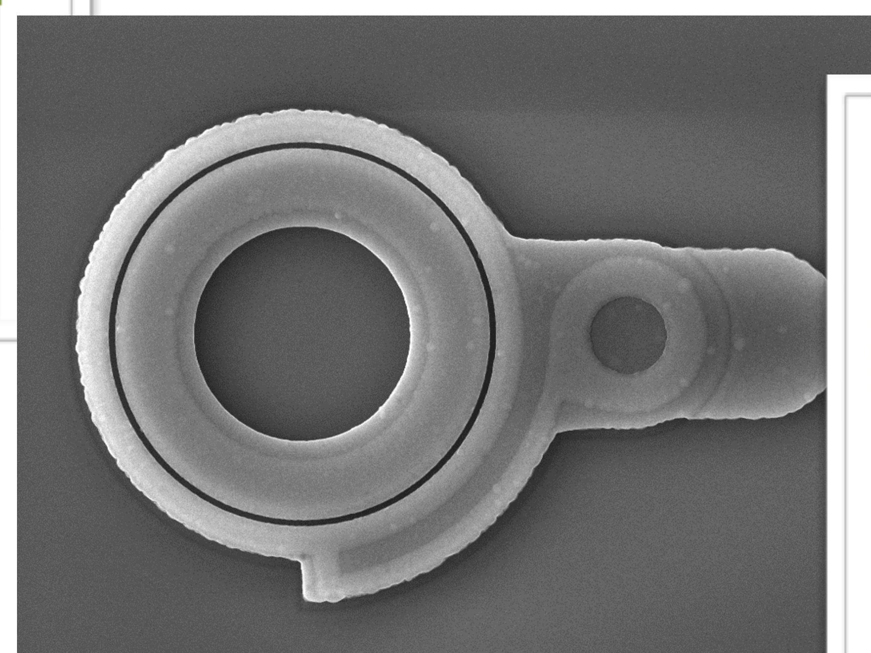
SIPM: PHOTON DETECTION EFFICIENCY

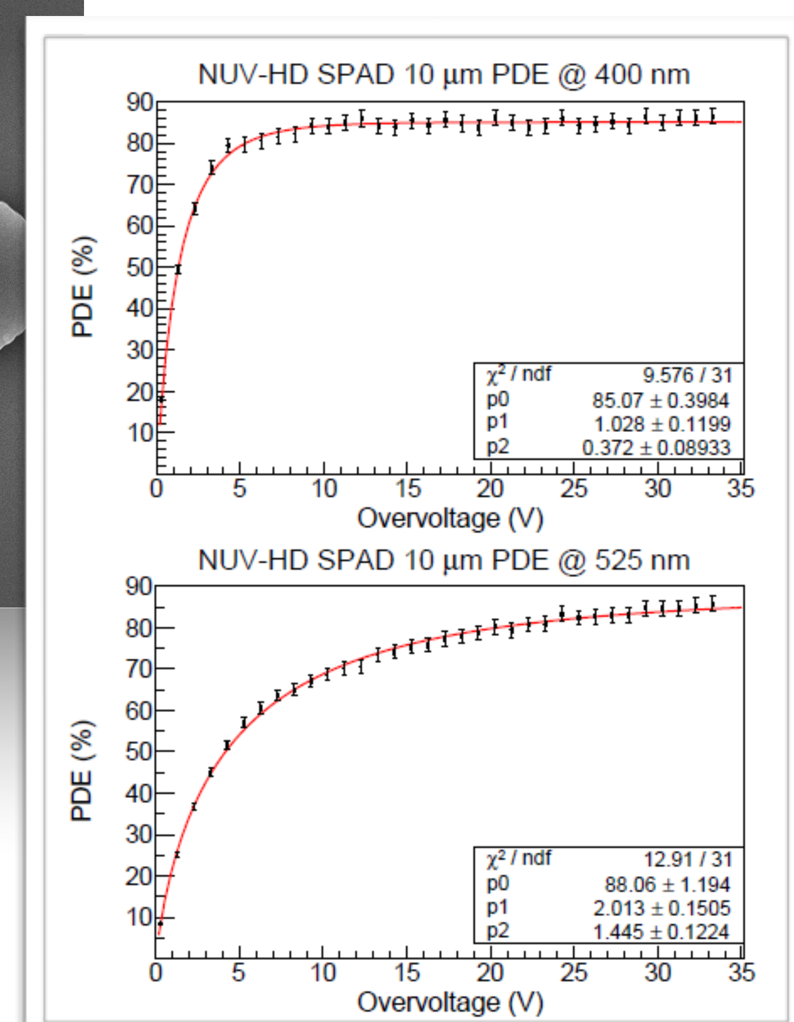
SiPM PDE is controlled by the silicon absorption probability and the active area ratio (Fill Factor);

SPAD size is defined by metal opening which is within the high-field region (FF reached almost 100%);





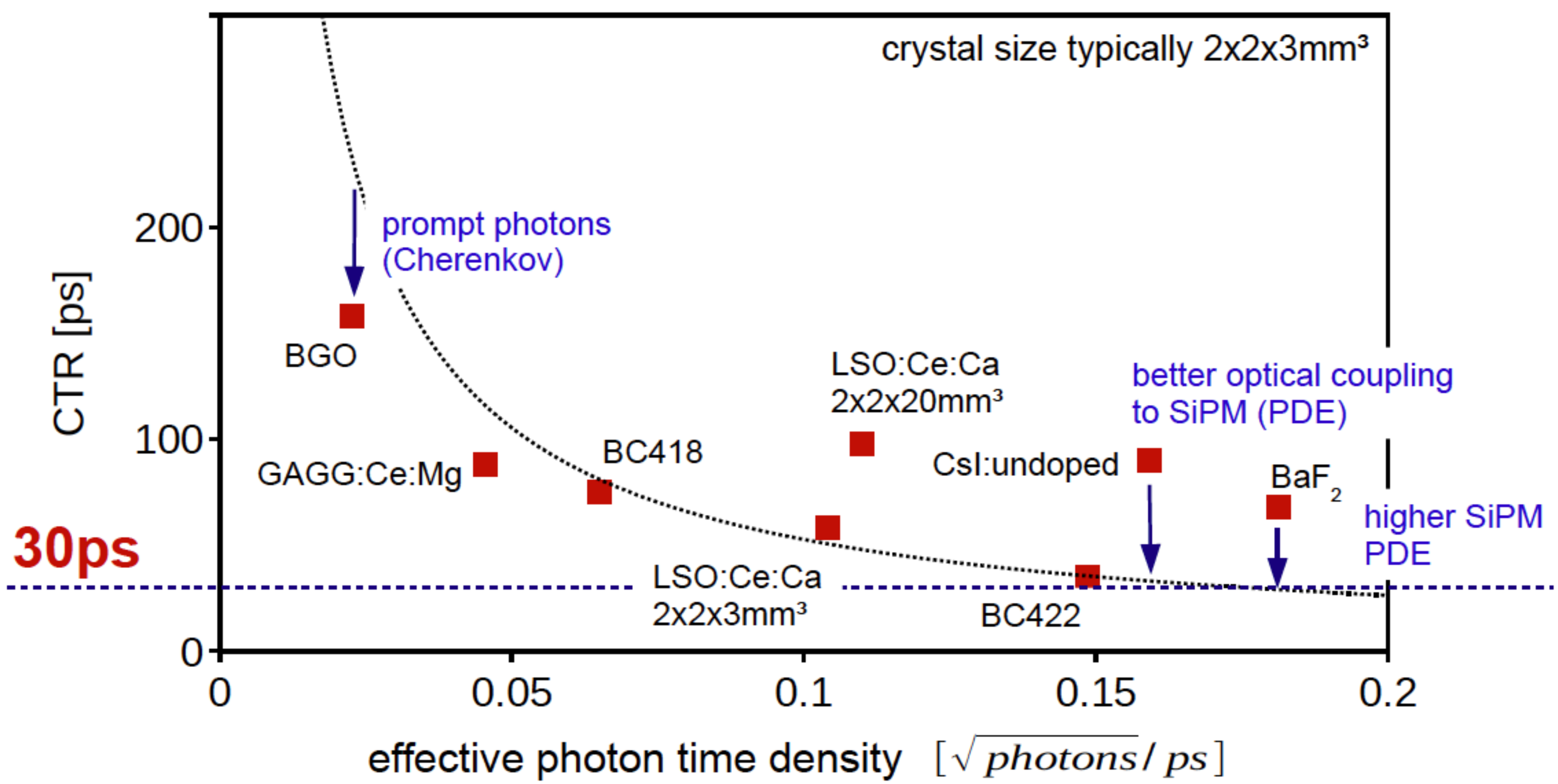




TIME RESOLUTION+CRYSTALS

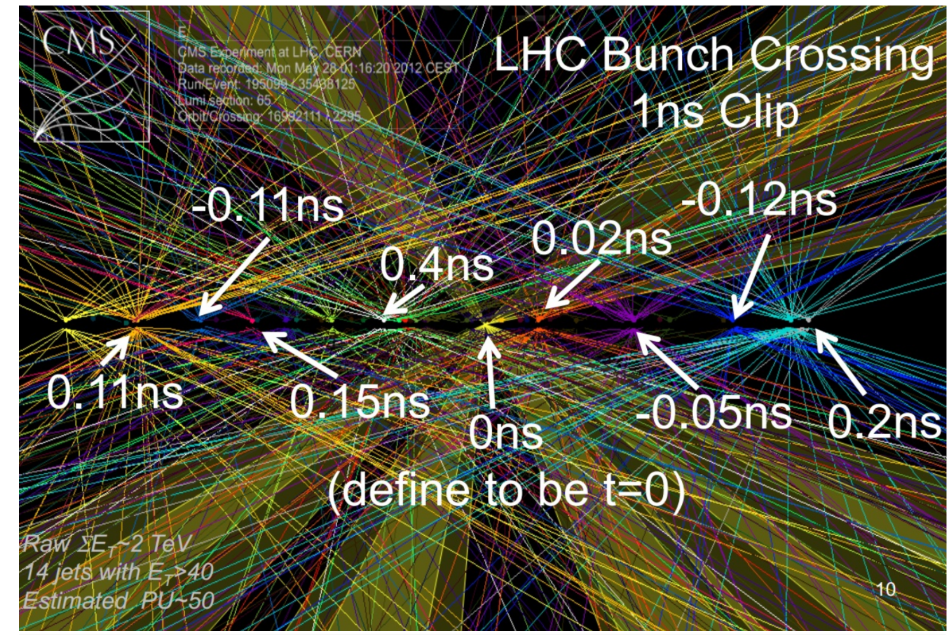
When coupled with a scintillating crystal, overall time resolution depends also on the amount of simultaneous photo-electrons:

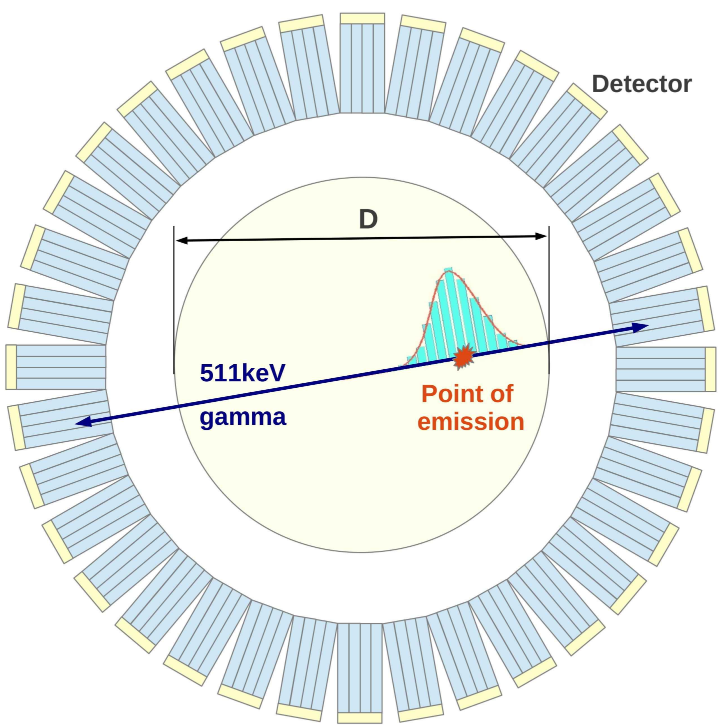
- crystal light yield;
- scintillation emission time;



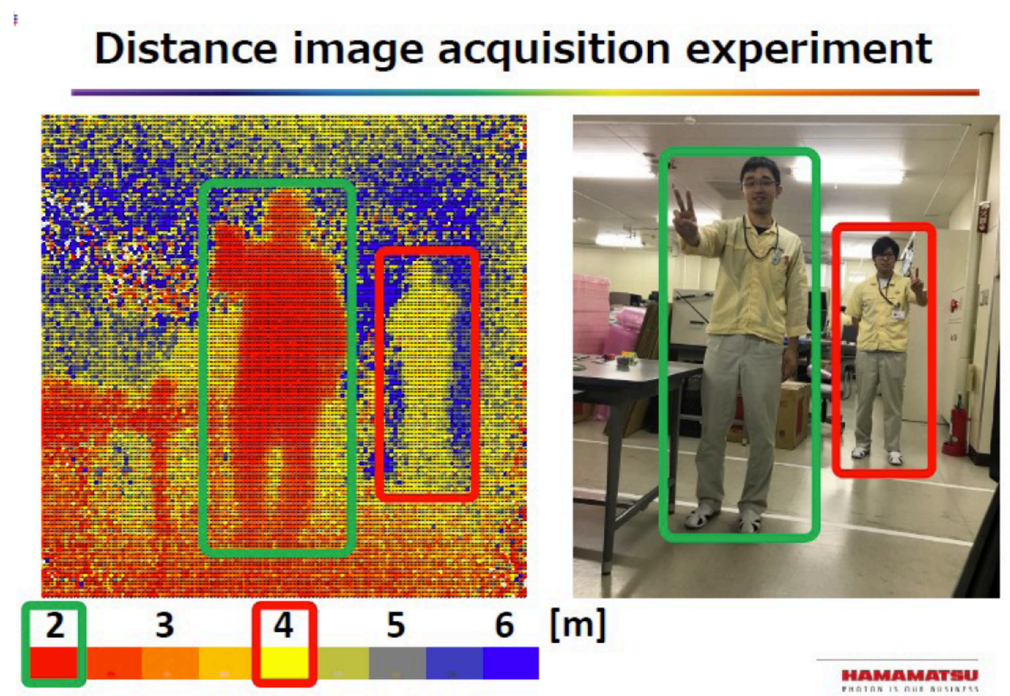
SIPM APPLICATIONS

High luminosity colliders: precision timing of ~ 25 ps can reduce pile up effects (such as vertex merging);





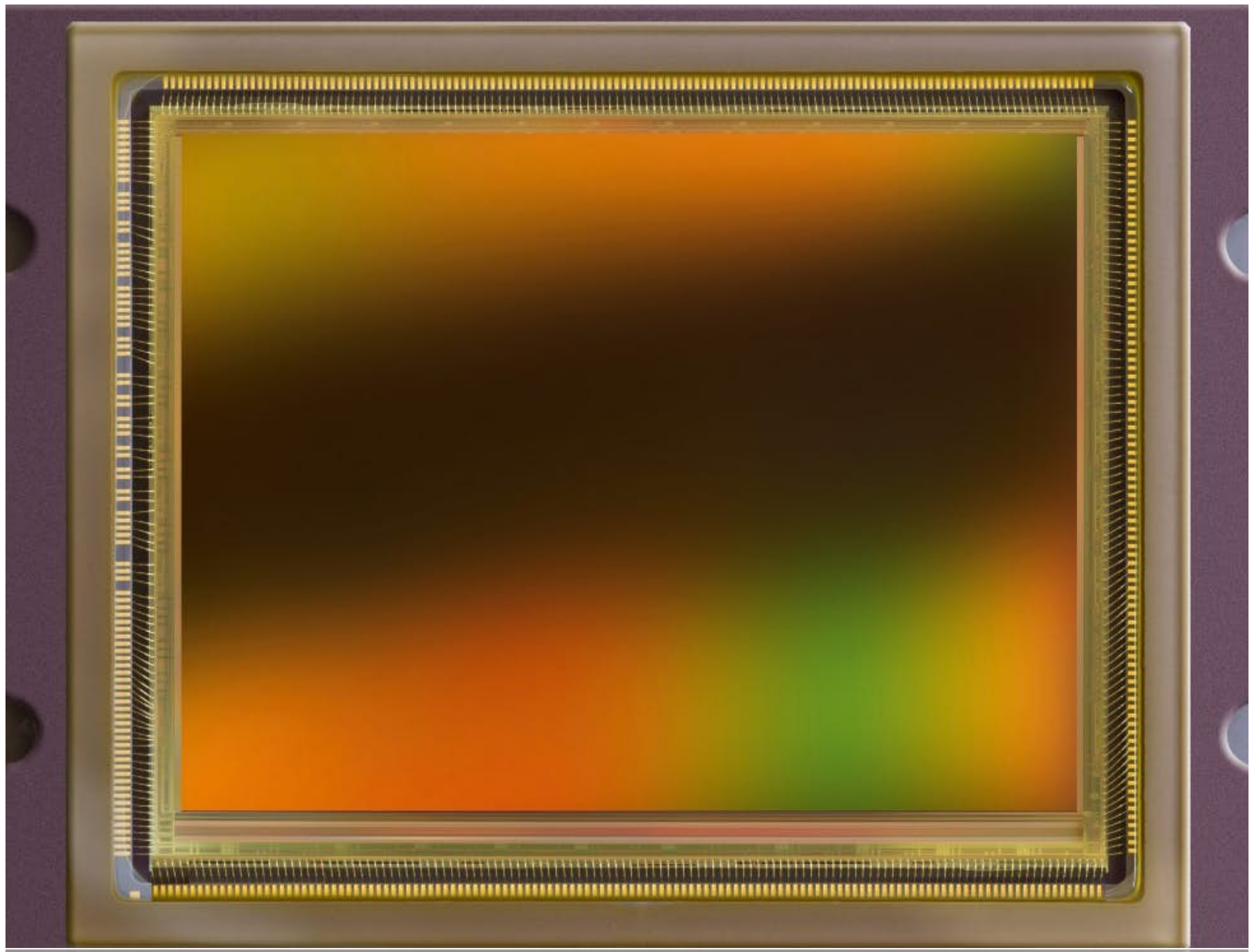
Time of flight in PET: whole body PET has 3-5mm spatial resolution and, hence, 25-35ps FWHM are sufficient to benefit fully from TOF;

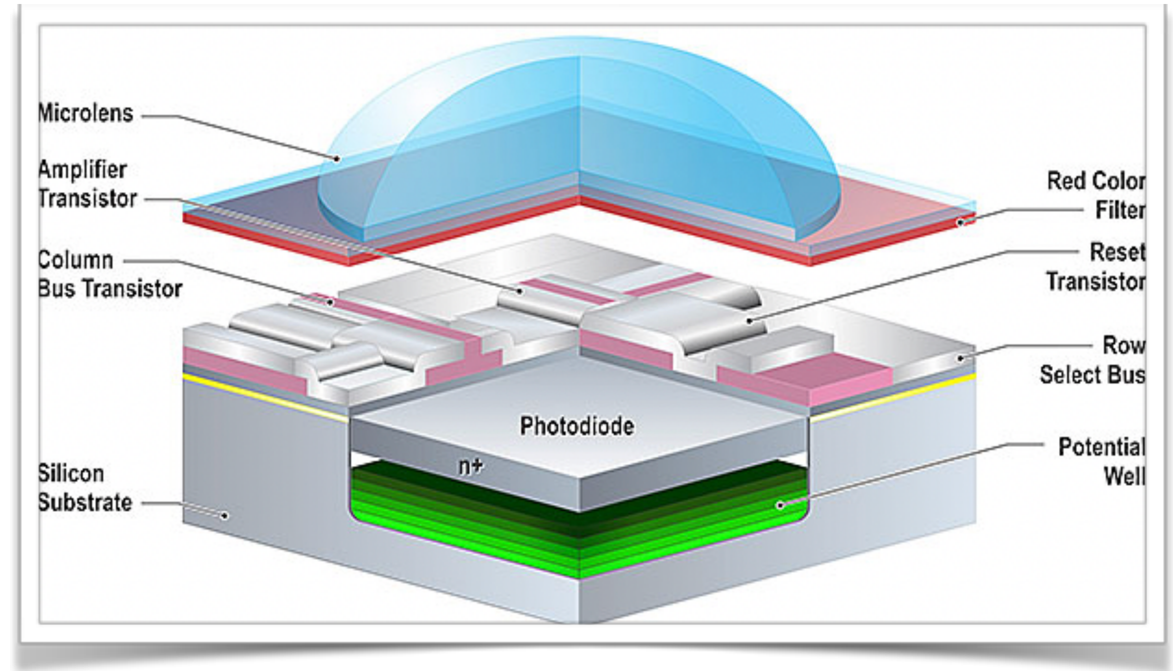


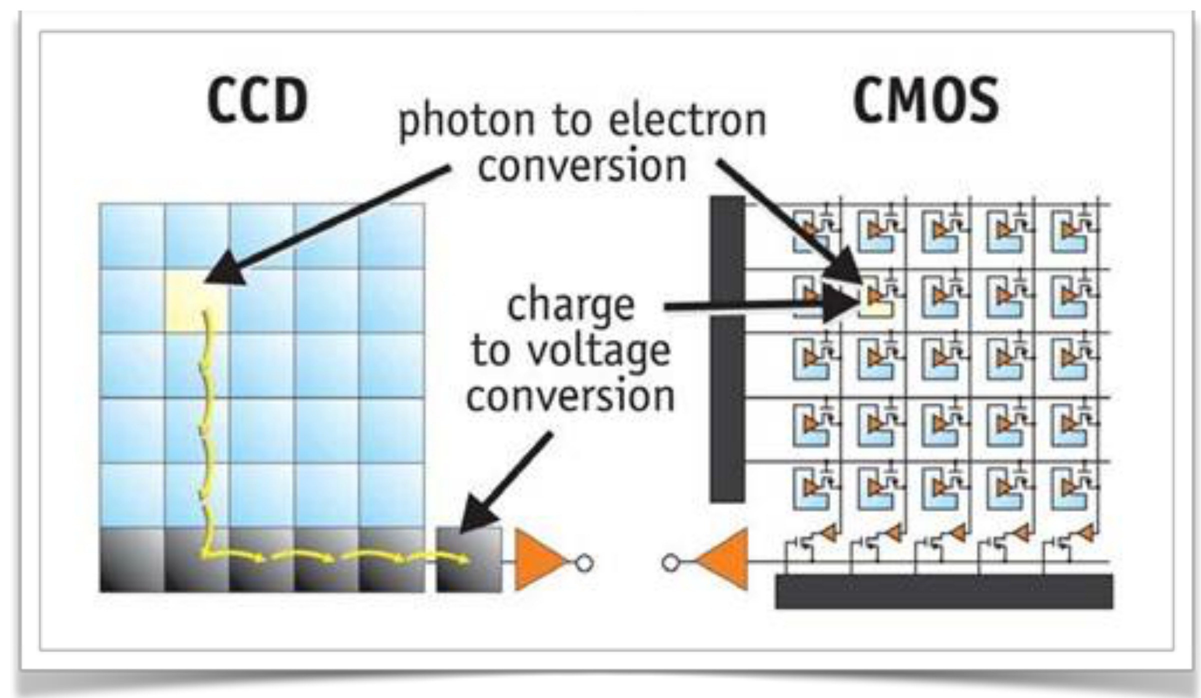
Single shot light detection and ranging (**Lidar**).

SENSORS: CMOS

48 Megapixel sensor



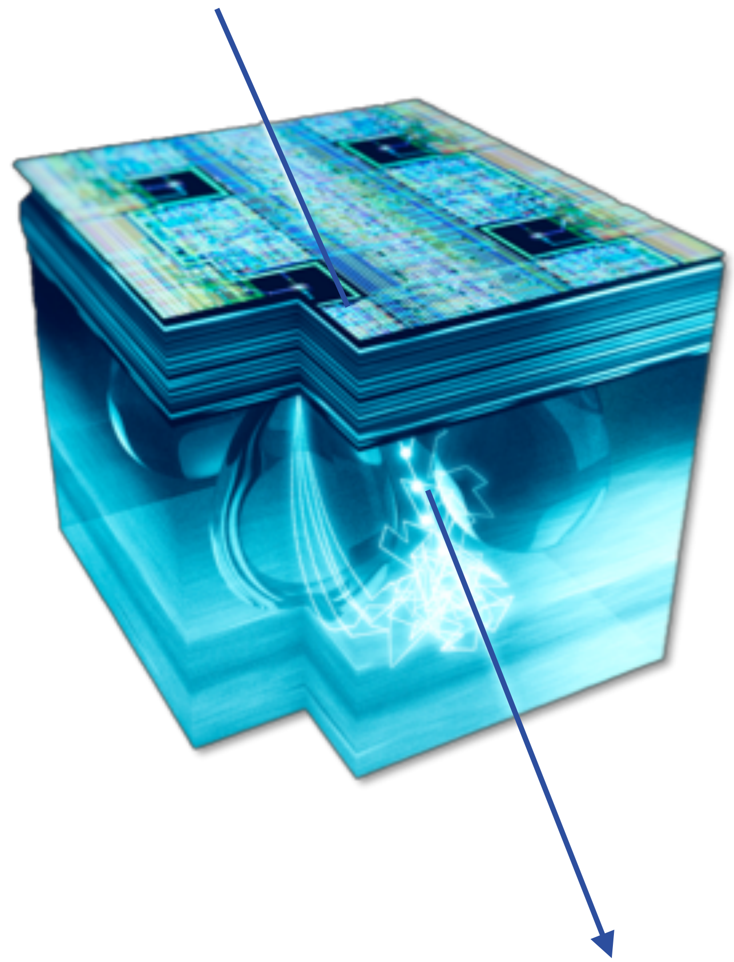


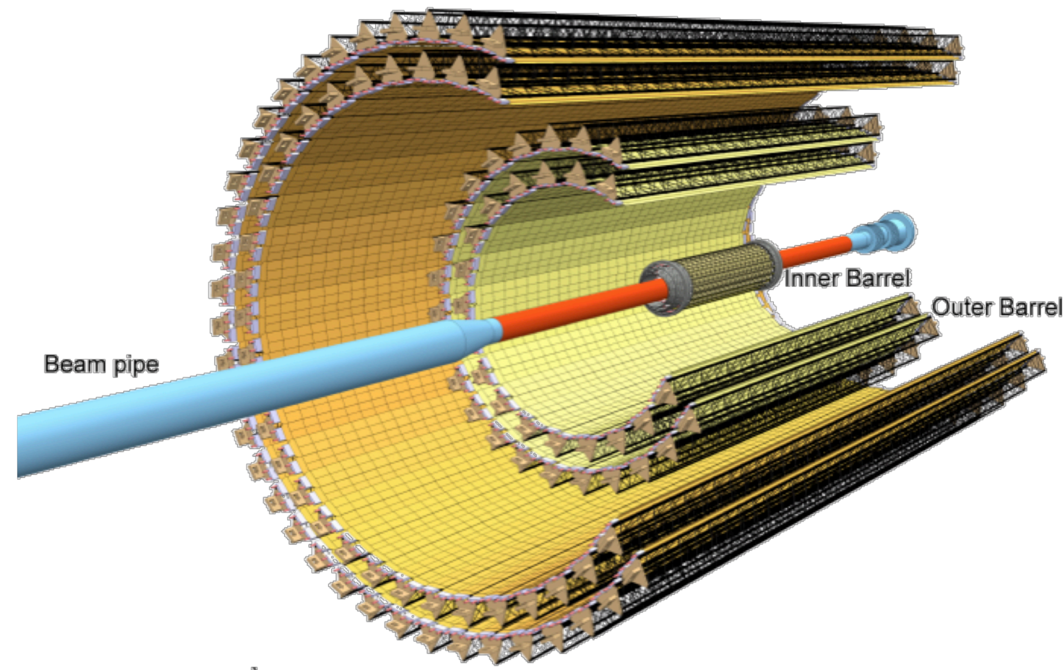


CMOS Image Sensors provide:

- in-pixel q to V conversion;
- column-parallel readout voltage conversion; **very low noise level**

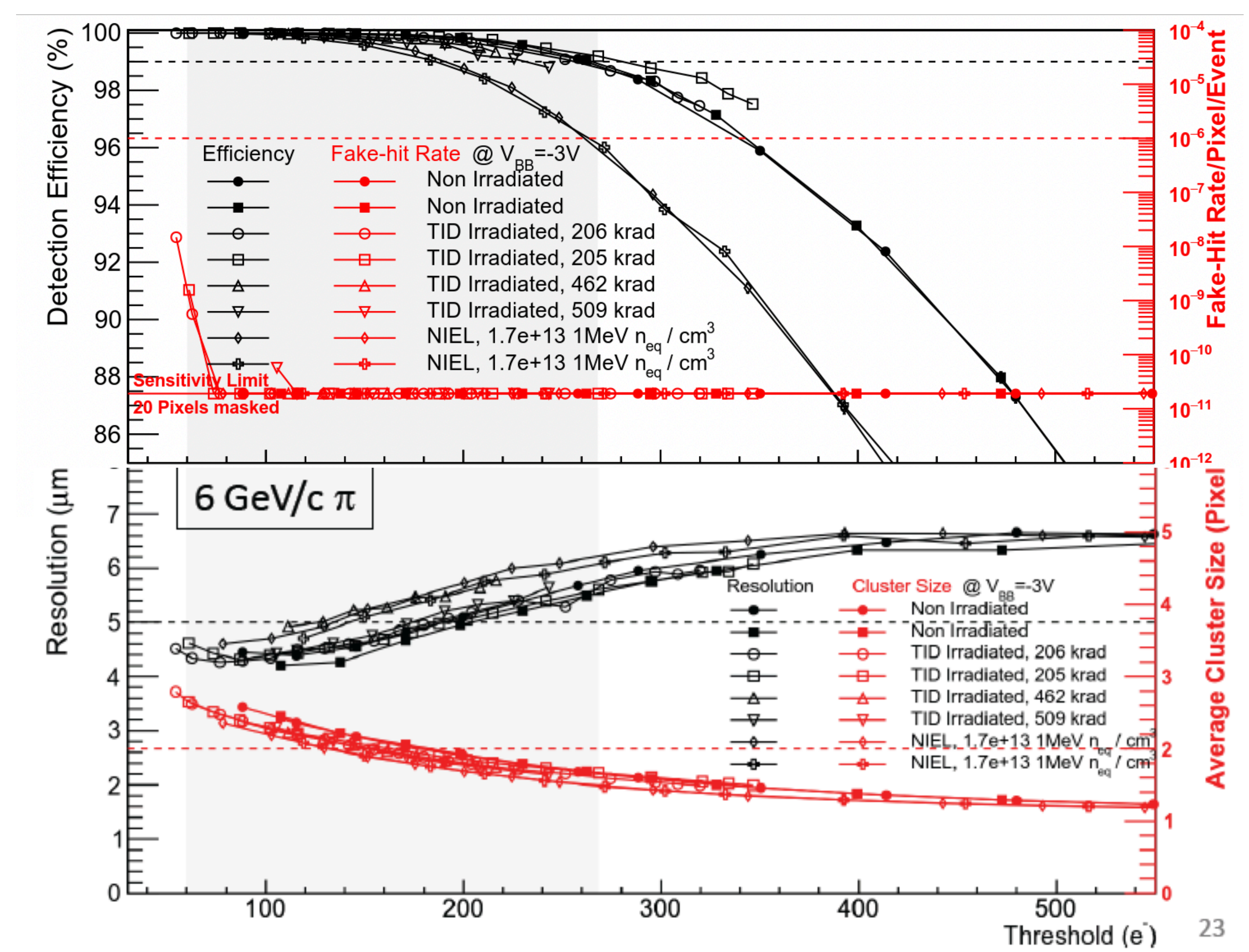
CMOS: CHARGED PARTICLE DETECTION





Low noise allows low threshold operation:

- **full detection** efficiency;
- very **high space** resolution;

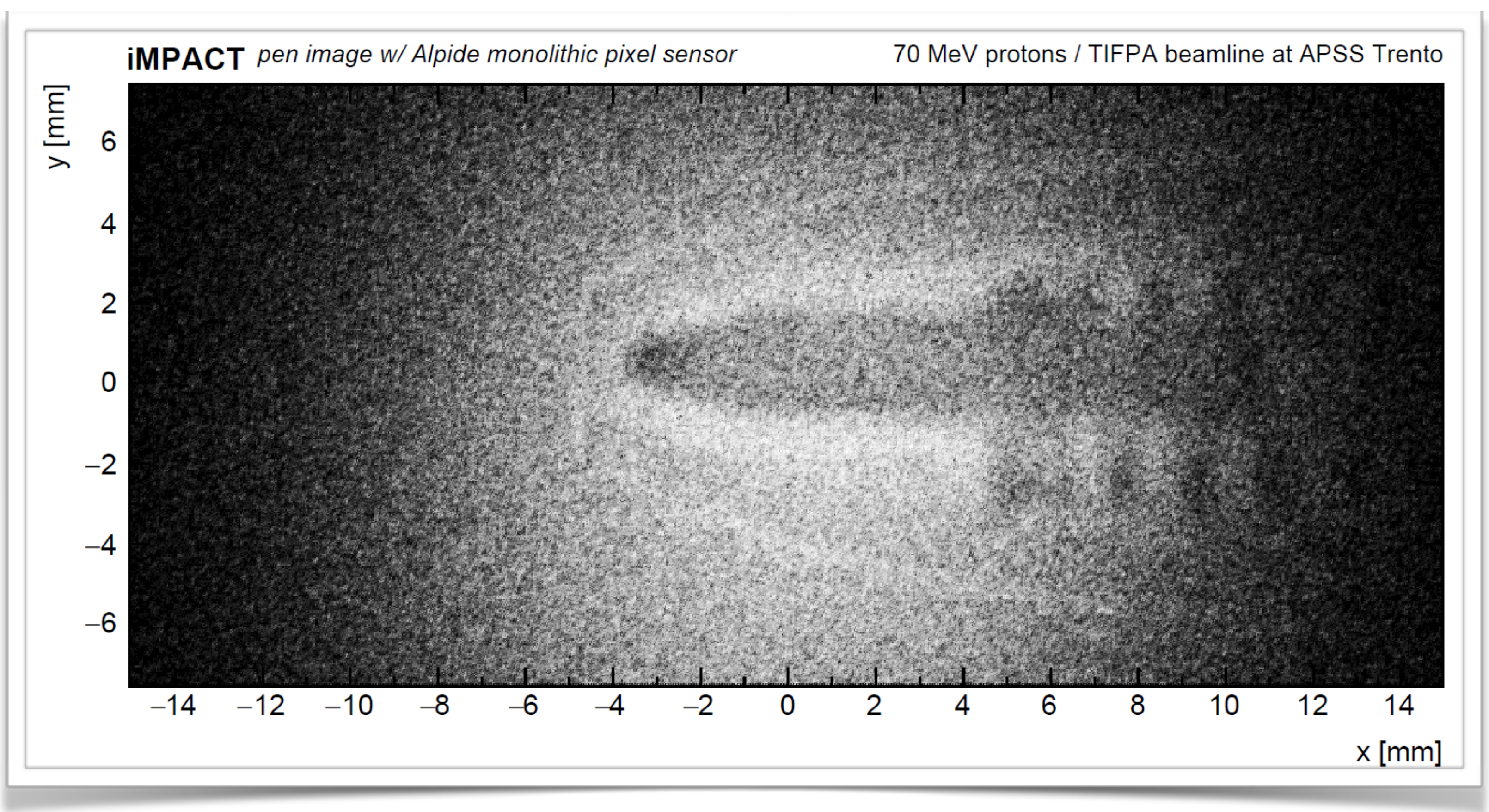


CMOS: PROTON TOMOGRAPHY

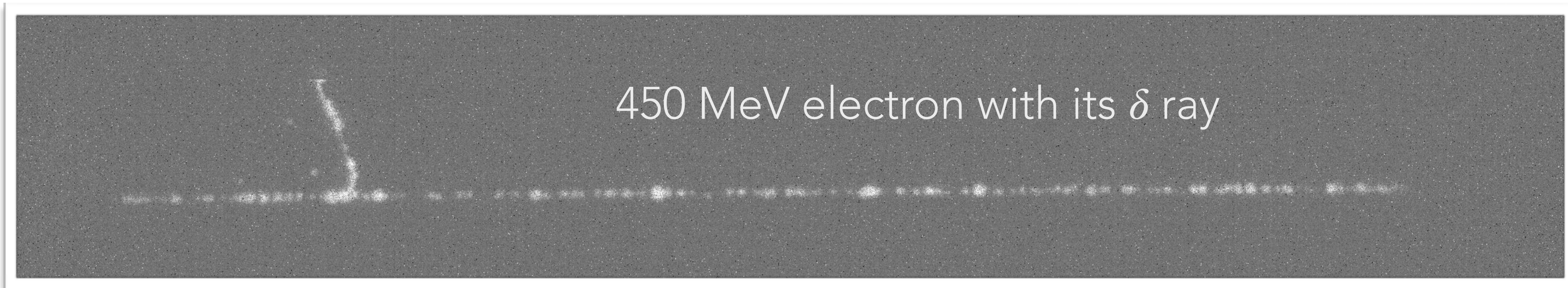
pCT principle: recording particles passing through the target to reconstruct a 3D image (as a X-rays CT).

While photons are absorbed, protons also scatter;

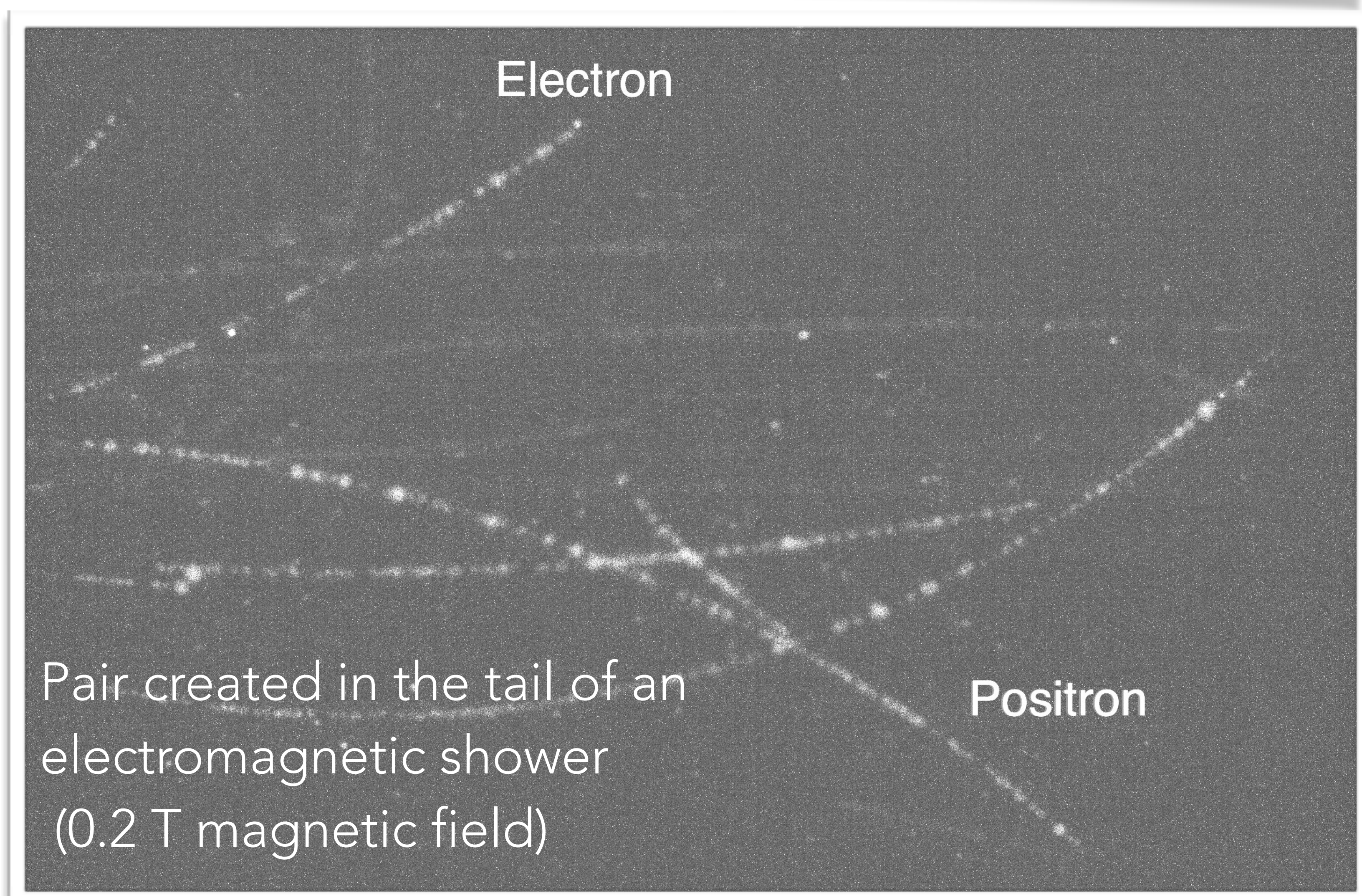
X-ray 3D CT **cannot distinguish tissue** densities but **protons actually can** (and with much less dose)



CMOS: IMAGE DETECTION



Low noise level allows to clearly reconstruct minimum ionizing tracks by collecting even **few (5-10) photons per pixels**

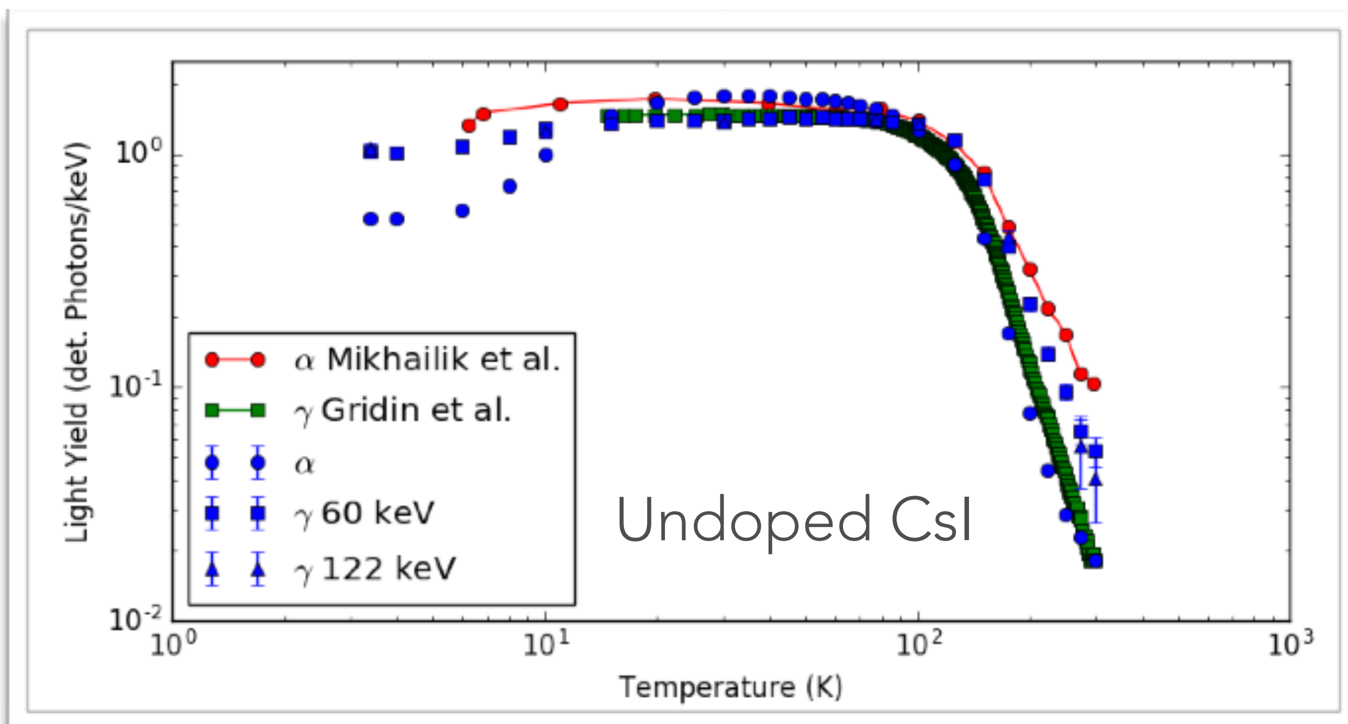


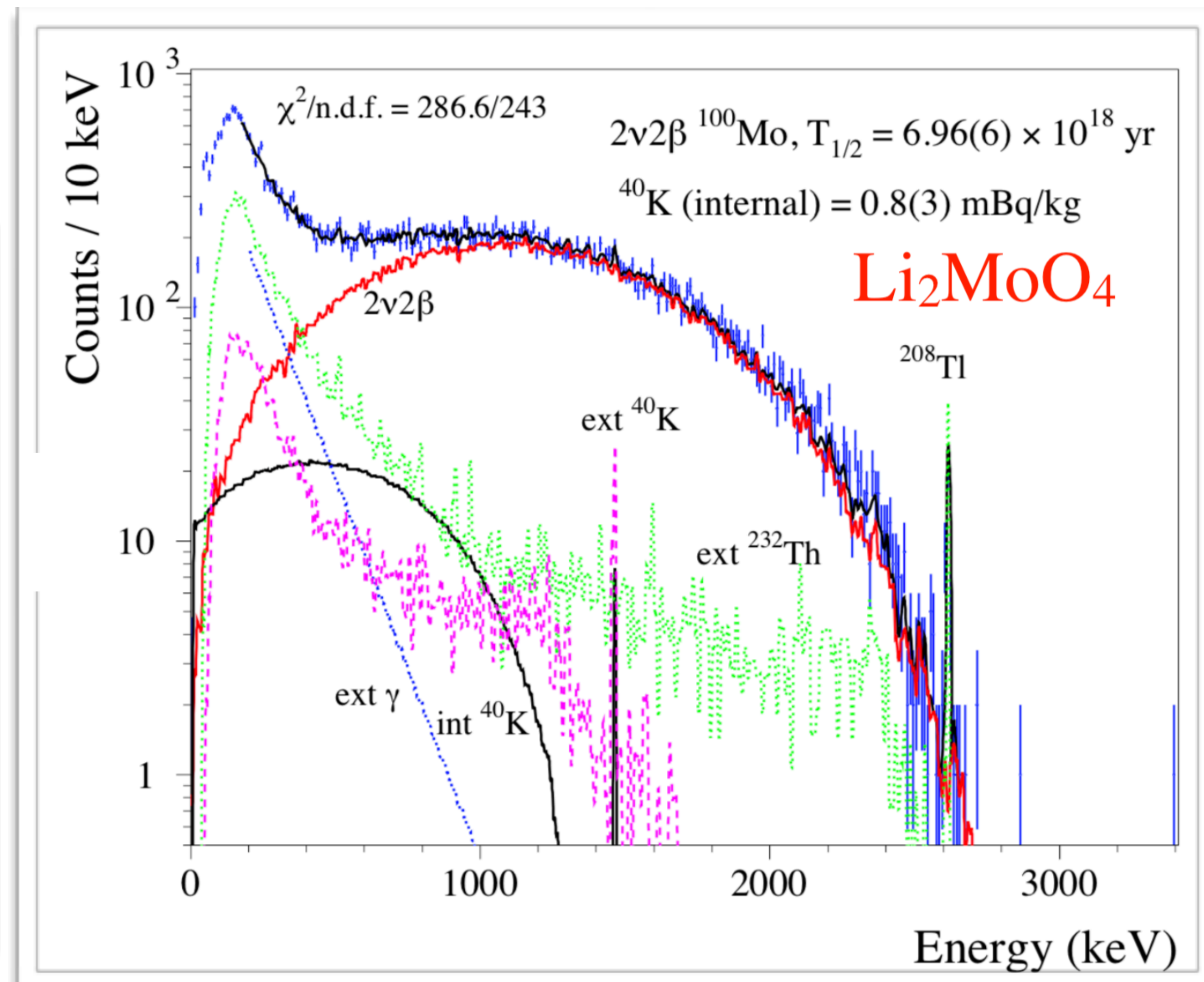
CRYSTALS

BOLOMETRIC SCINTILLATORS

Properties of a lot of different scintillator crystals are being studied in very low temperature conditions for bolometric applications

Factor 100 light yield increase





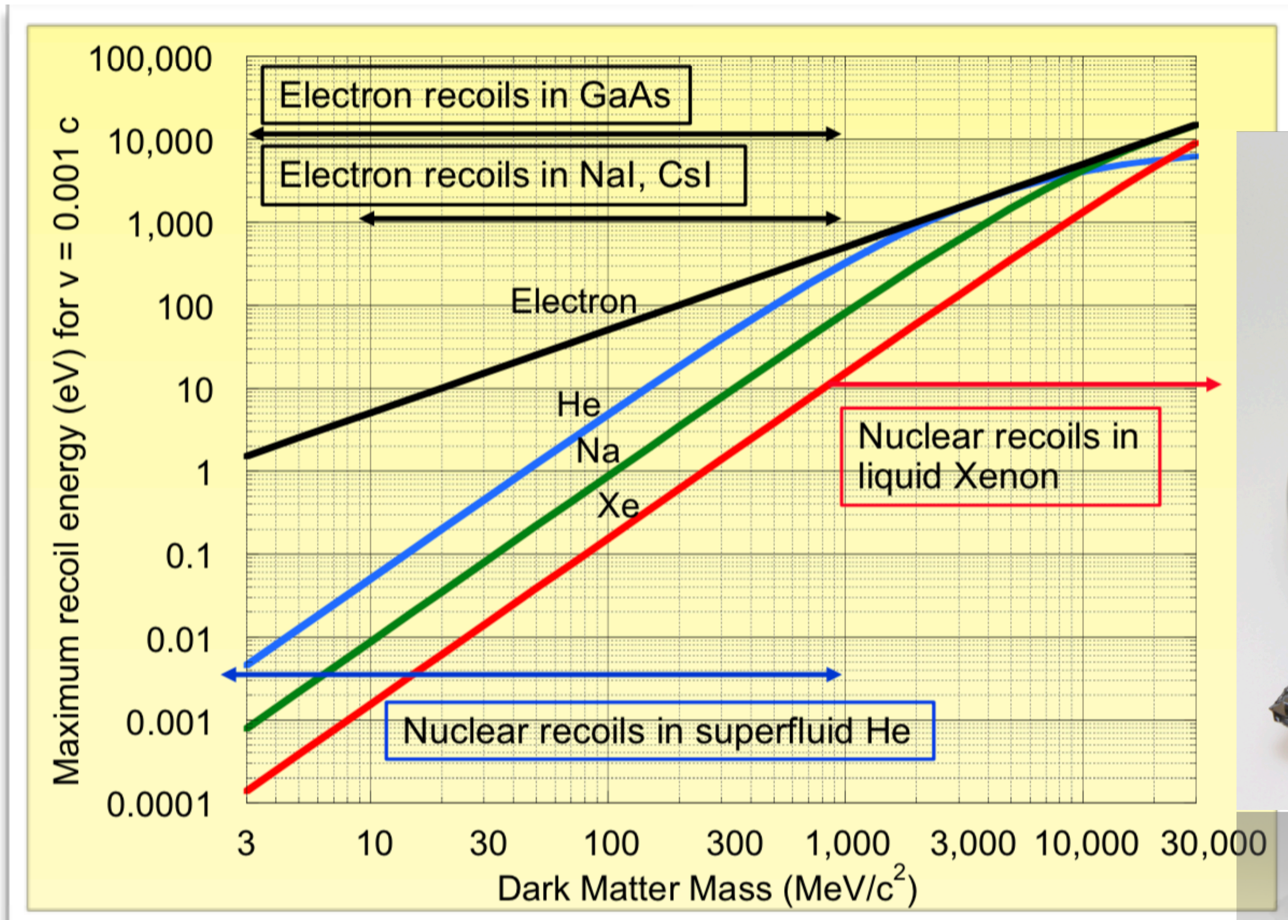
High radiopurity is obtained with contaminations of the order of 1-100 μBq/kg are obtained

^{228}Th $< 3\ \mu$Bq/kg

^{226}Ra $< 3\ \mu$Bq/kg

^{210}Po : [20 - 450] μBq/kg

SEMICONDUCTOR SCINTILLATORS

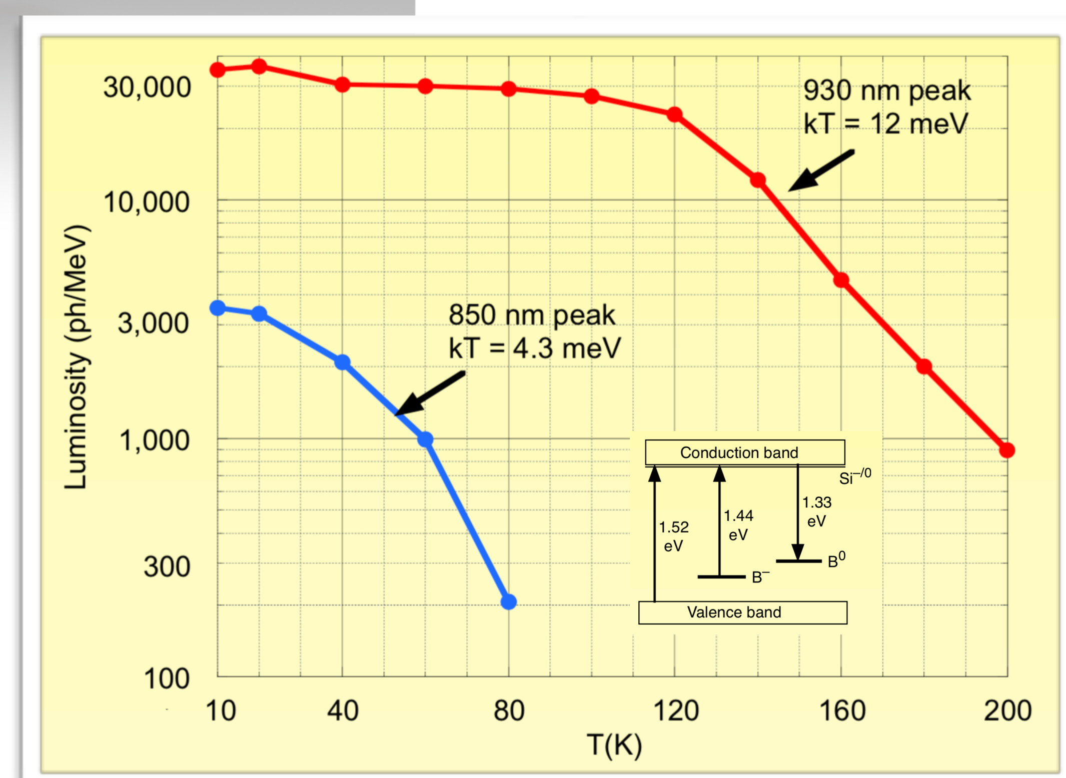


10 cm GaAs crystal grown at IKZ, Berlin;

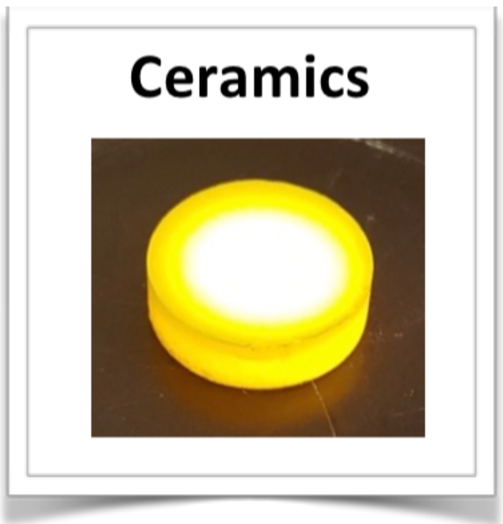
Large crystals available in high purity: K, Rb, La, Lu < 0.5 ppb;

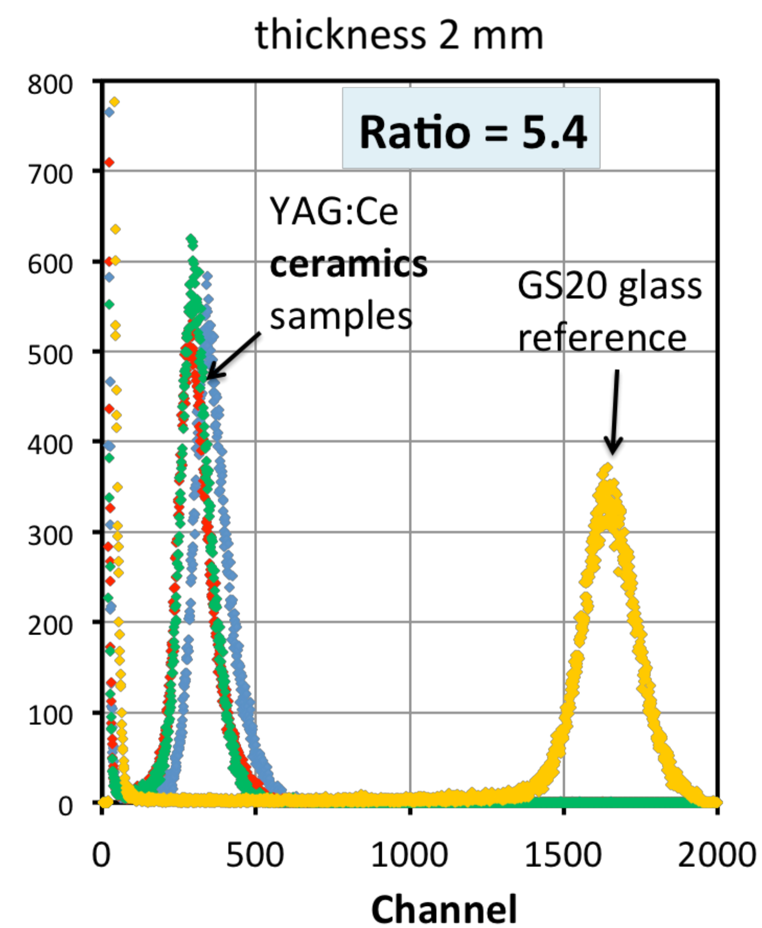
DM lighter than 1 GeV, better momentum transfer to electrons

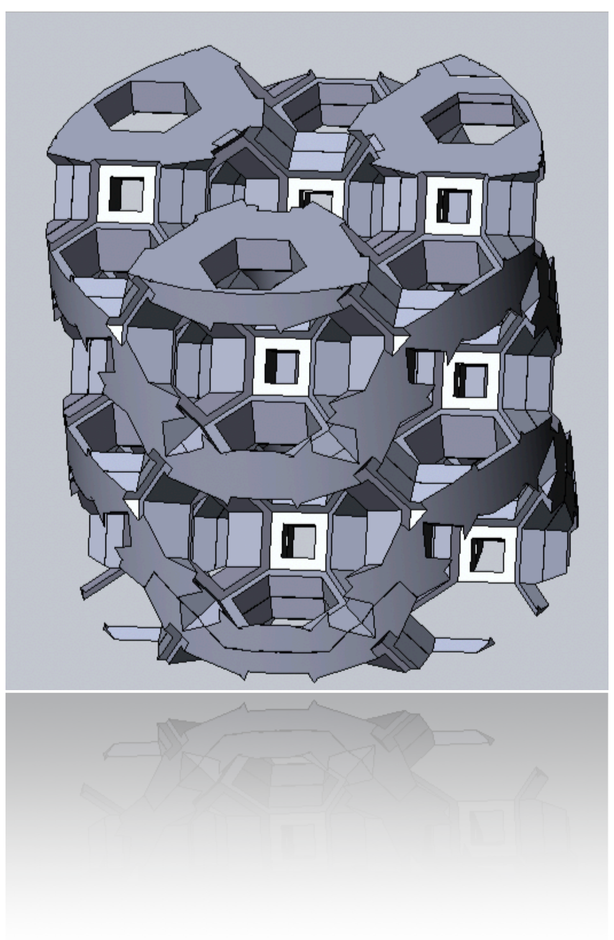
Light yield of 40 photons/keV allows to detect single electron recoils down to few tens of eV;

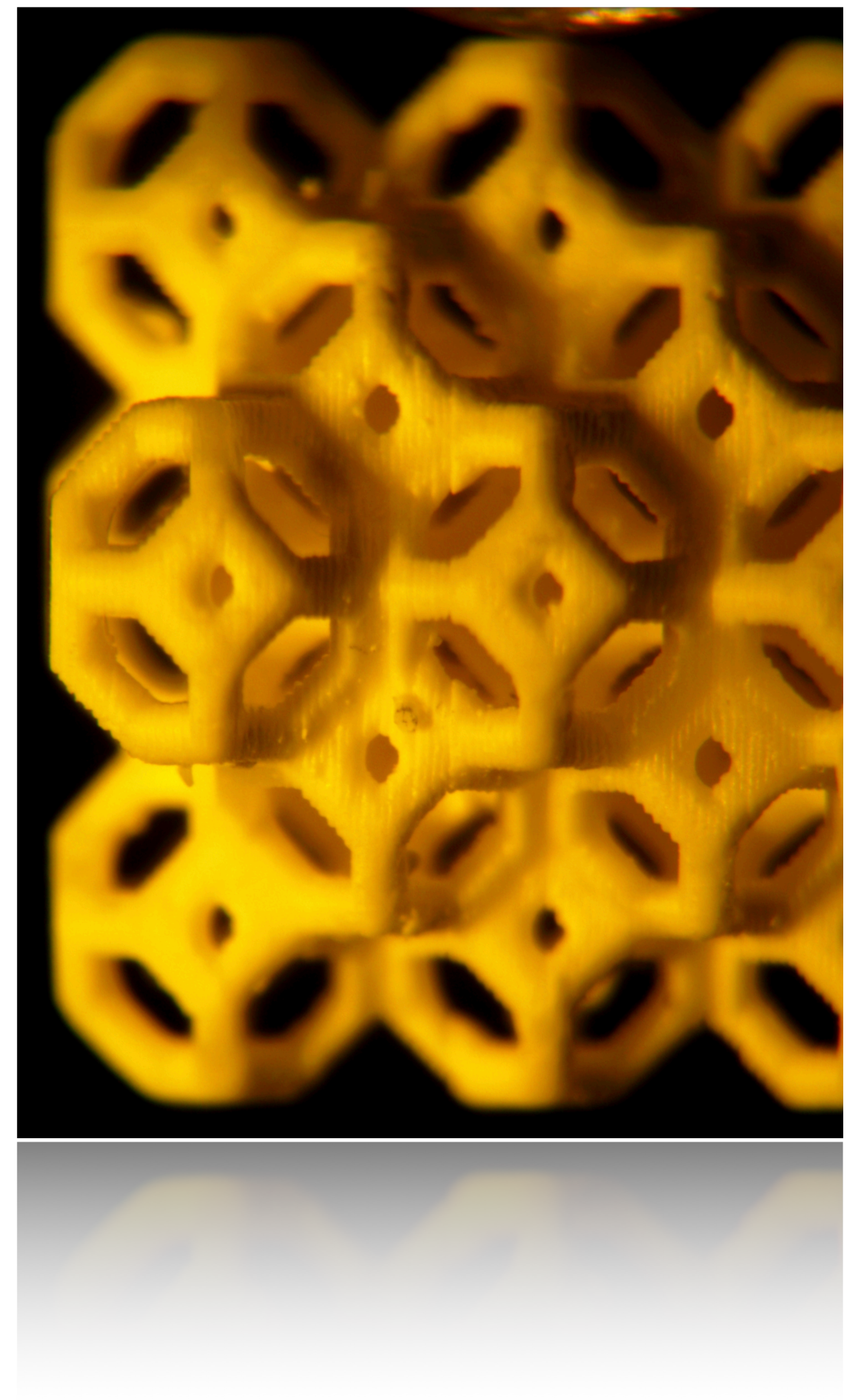


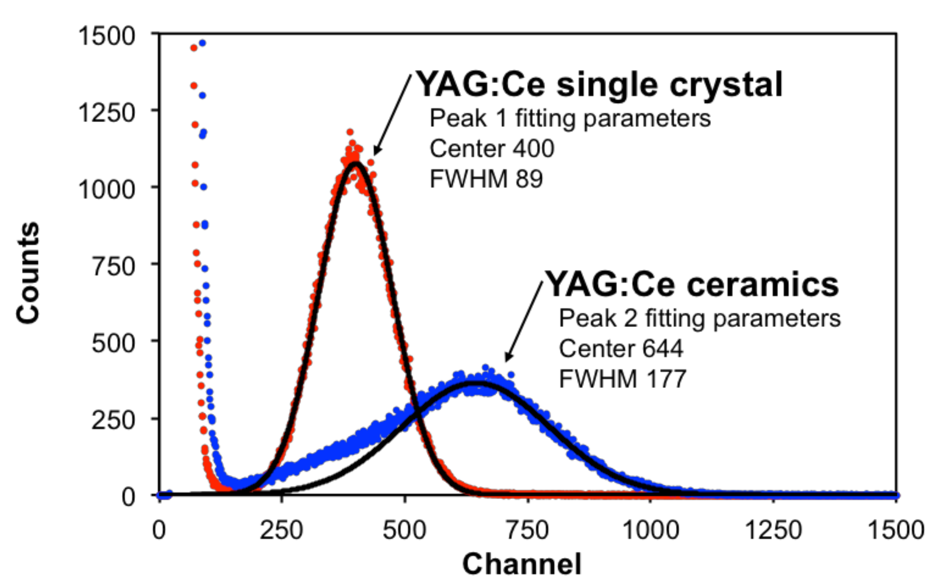
CERAMICS SCINTILLATORS







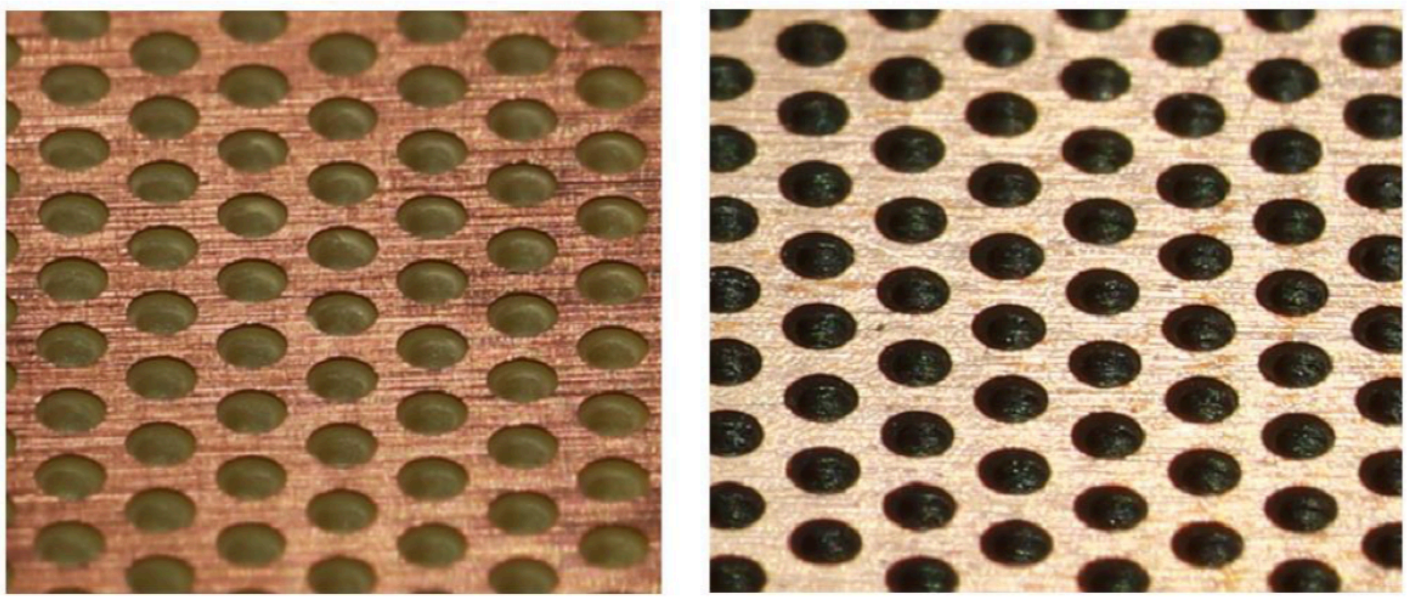




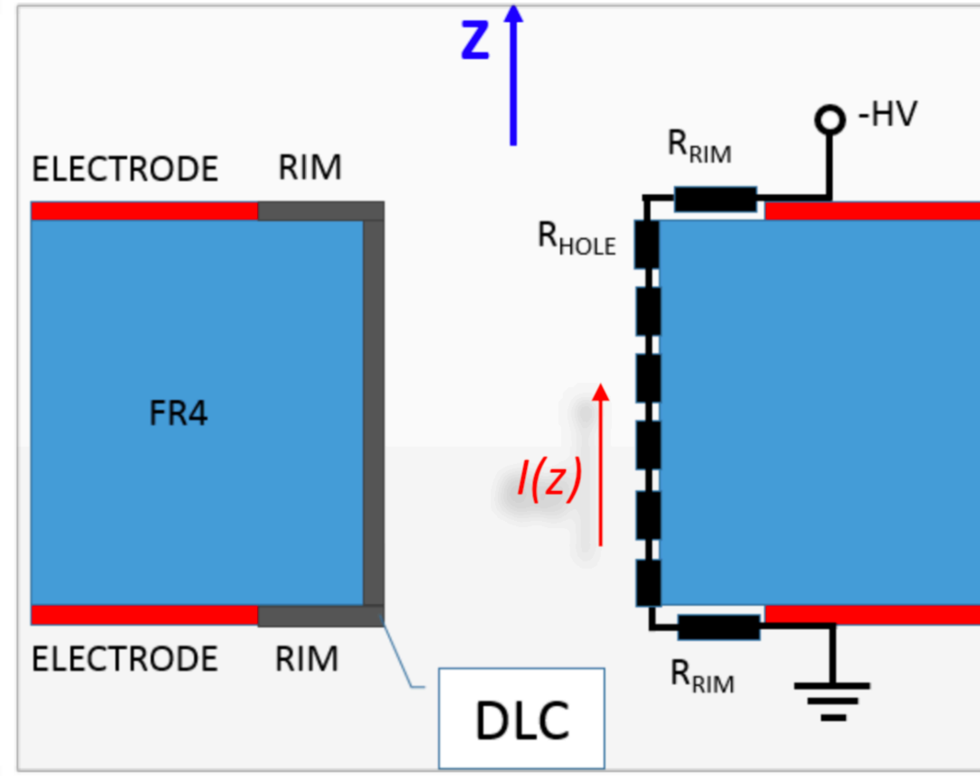
MPGD

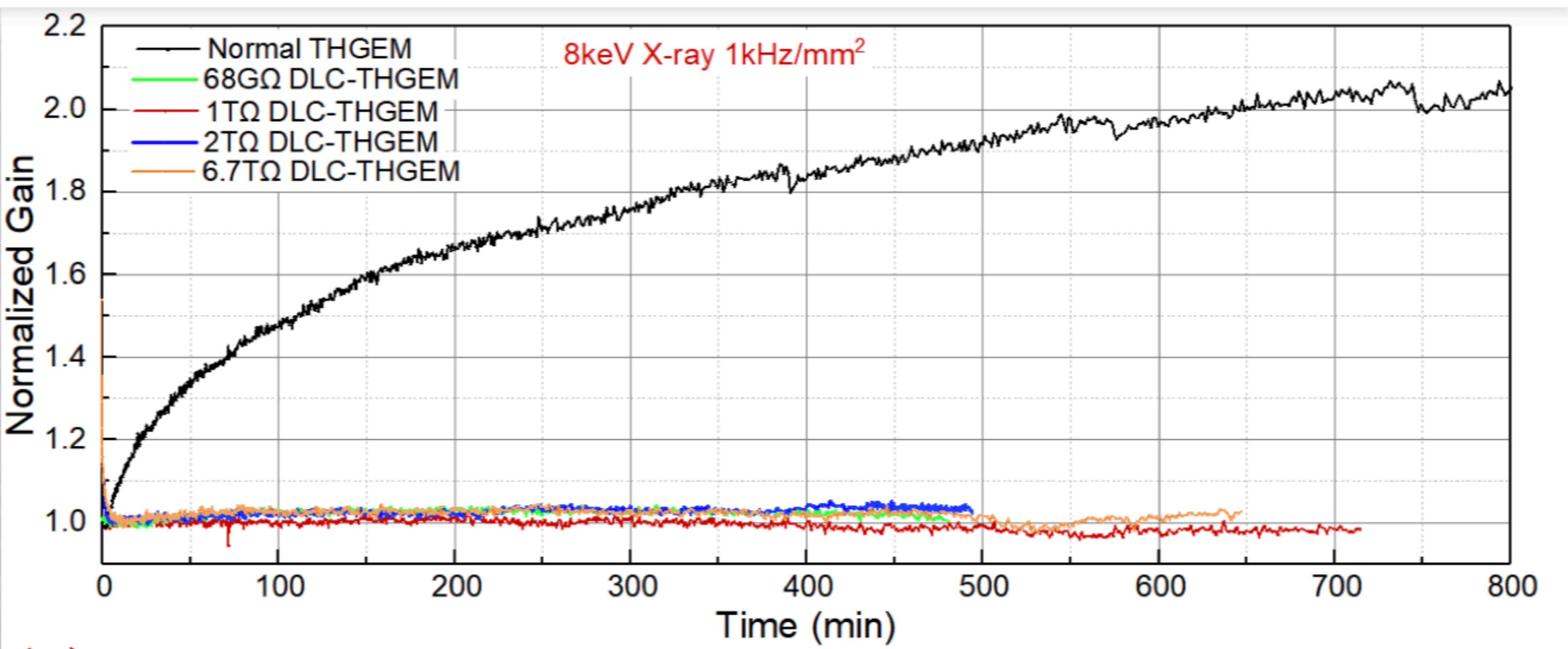
RESISTIVE WAY

Low conductive conductors

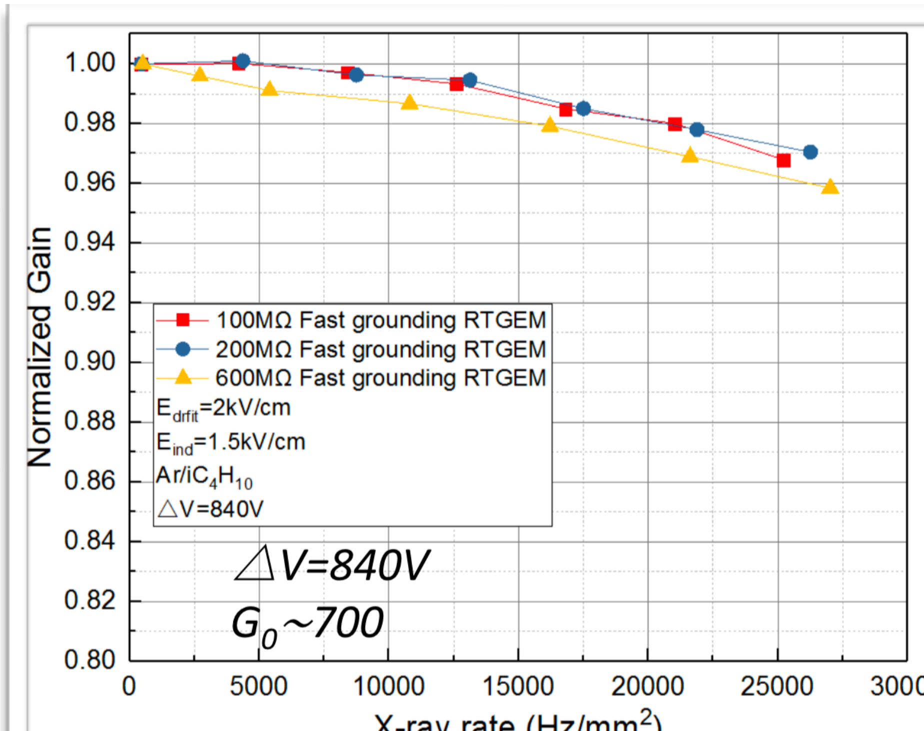


Photography of the bare THGEM DLC-THGEM



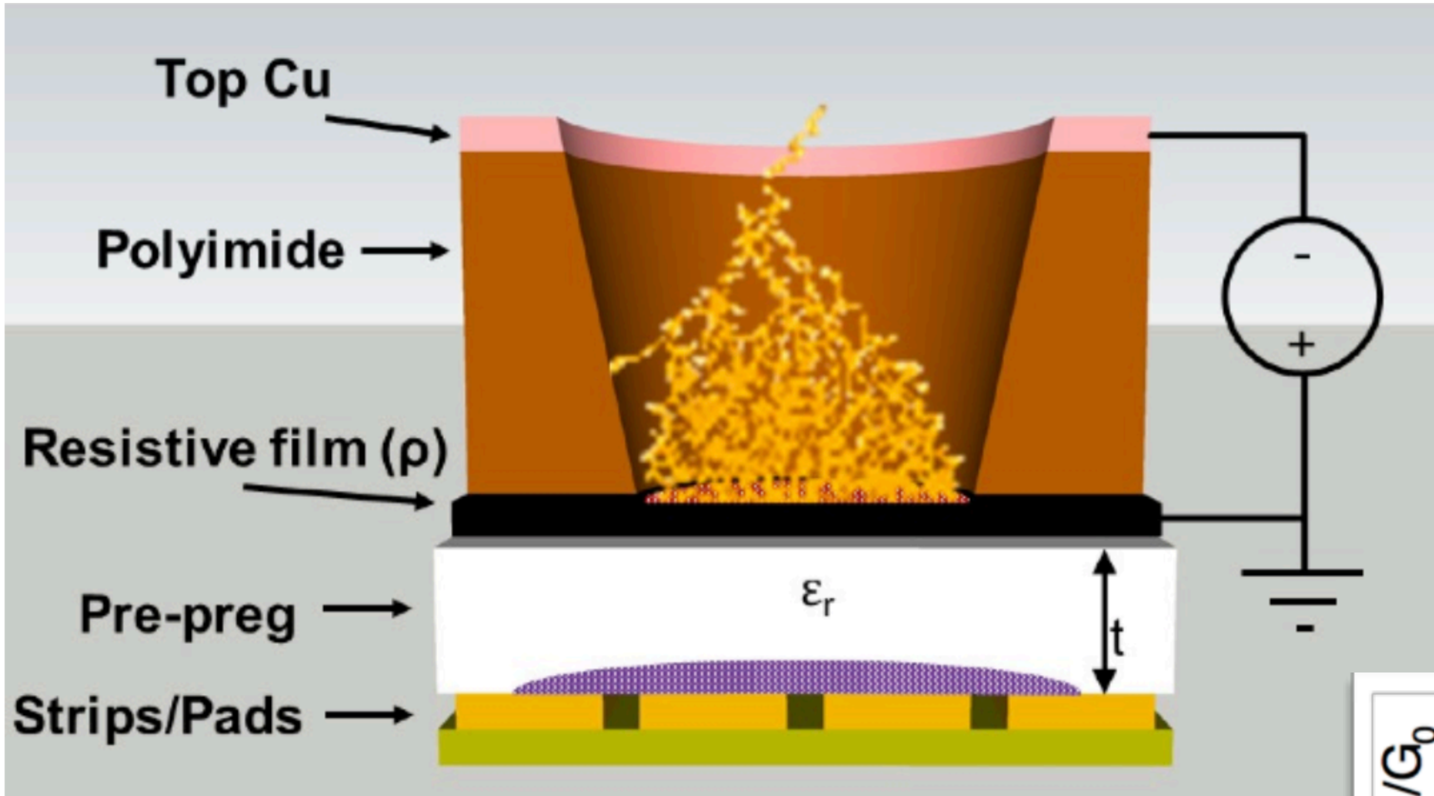


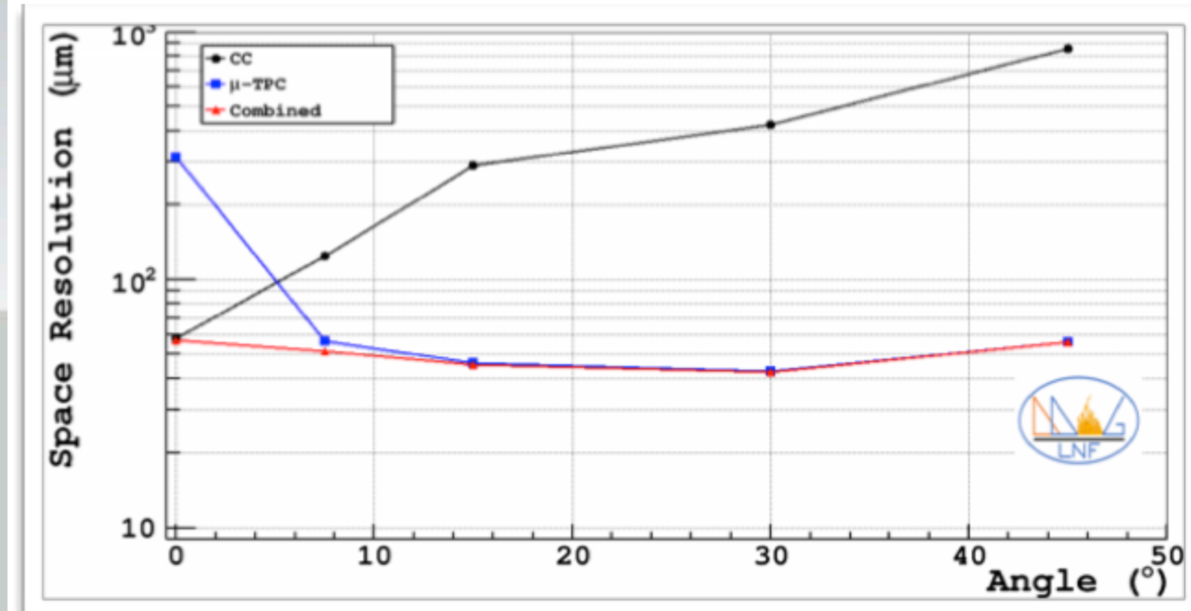
(c) Time evolution of gain of DLC-THGEMs with different resistance

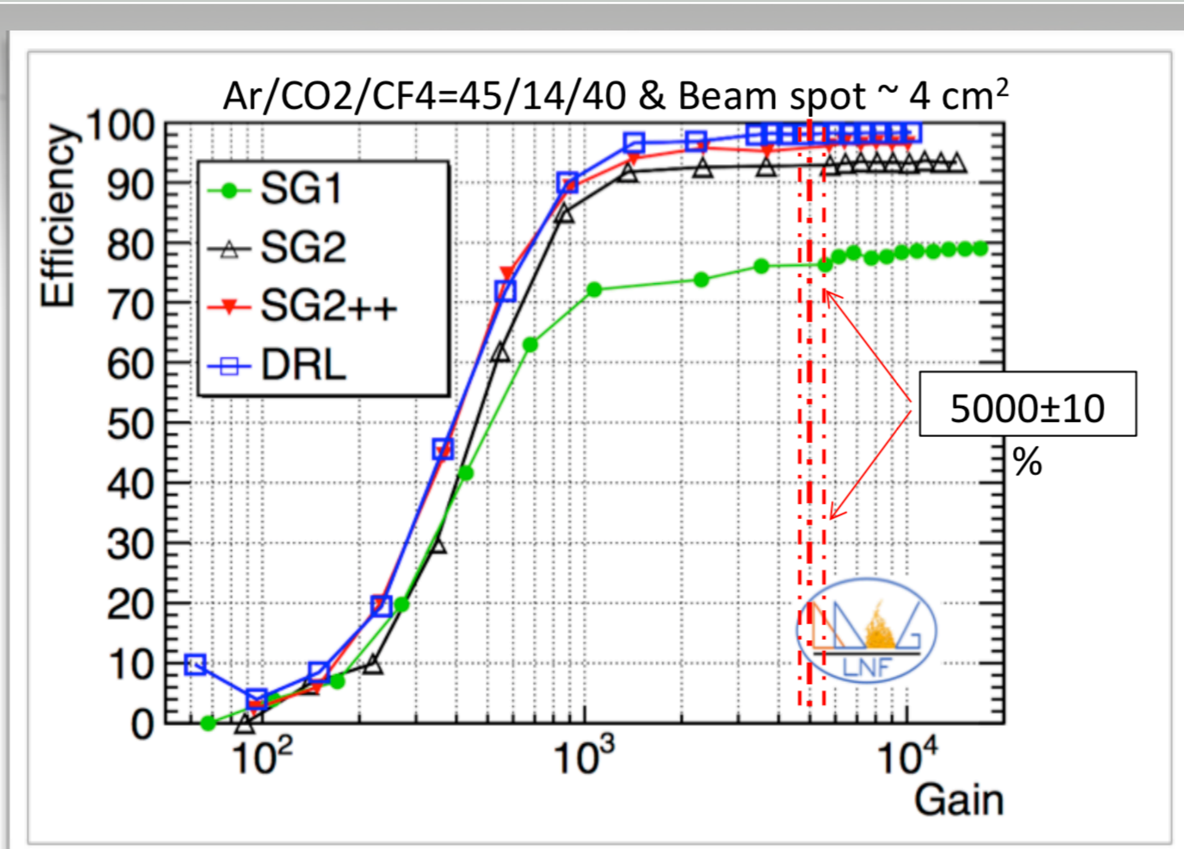


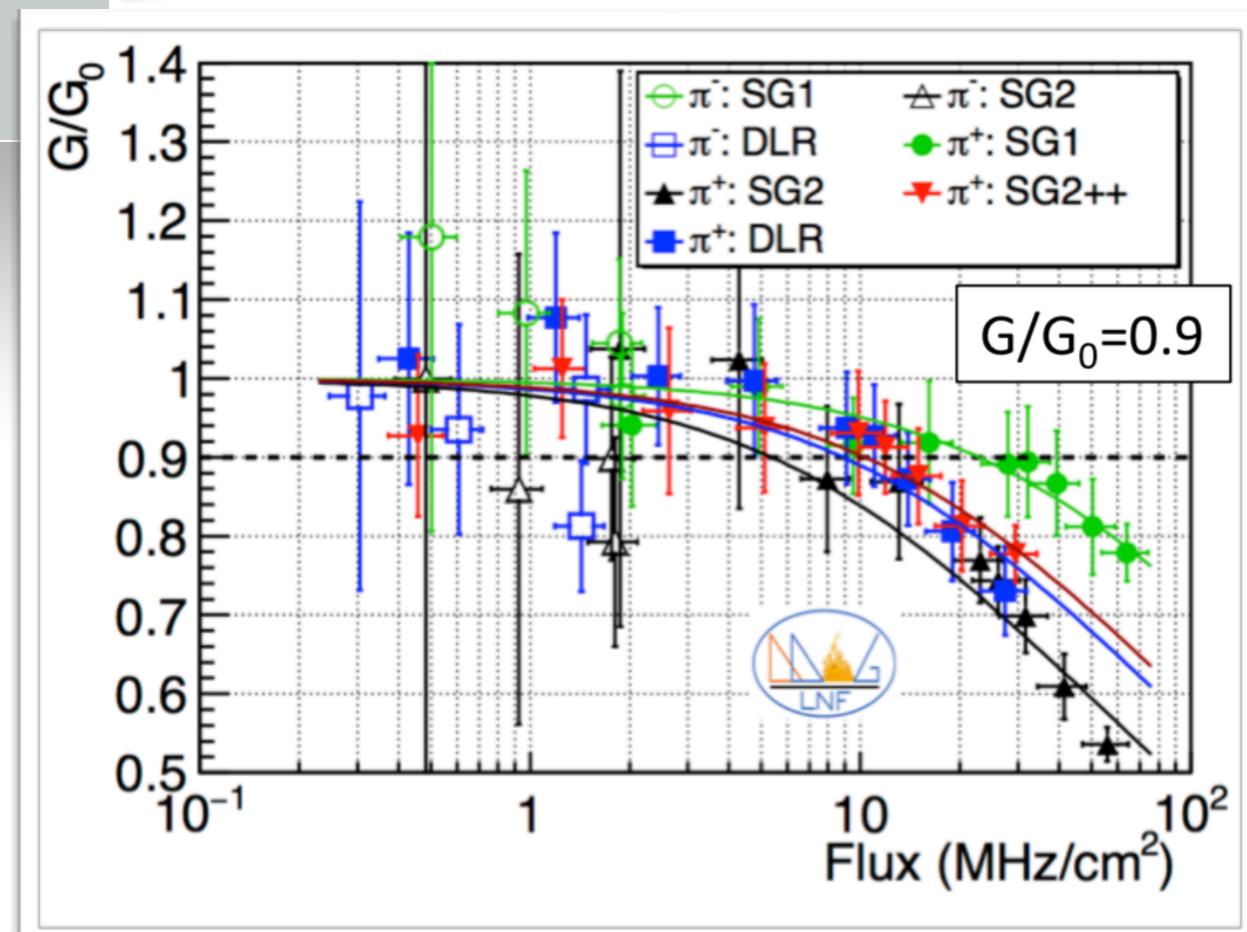
RESISTIVE WAY

Low insulating insulators



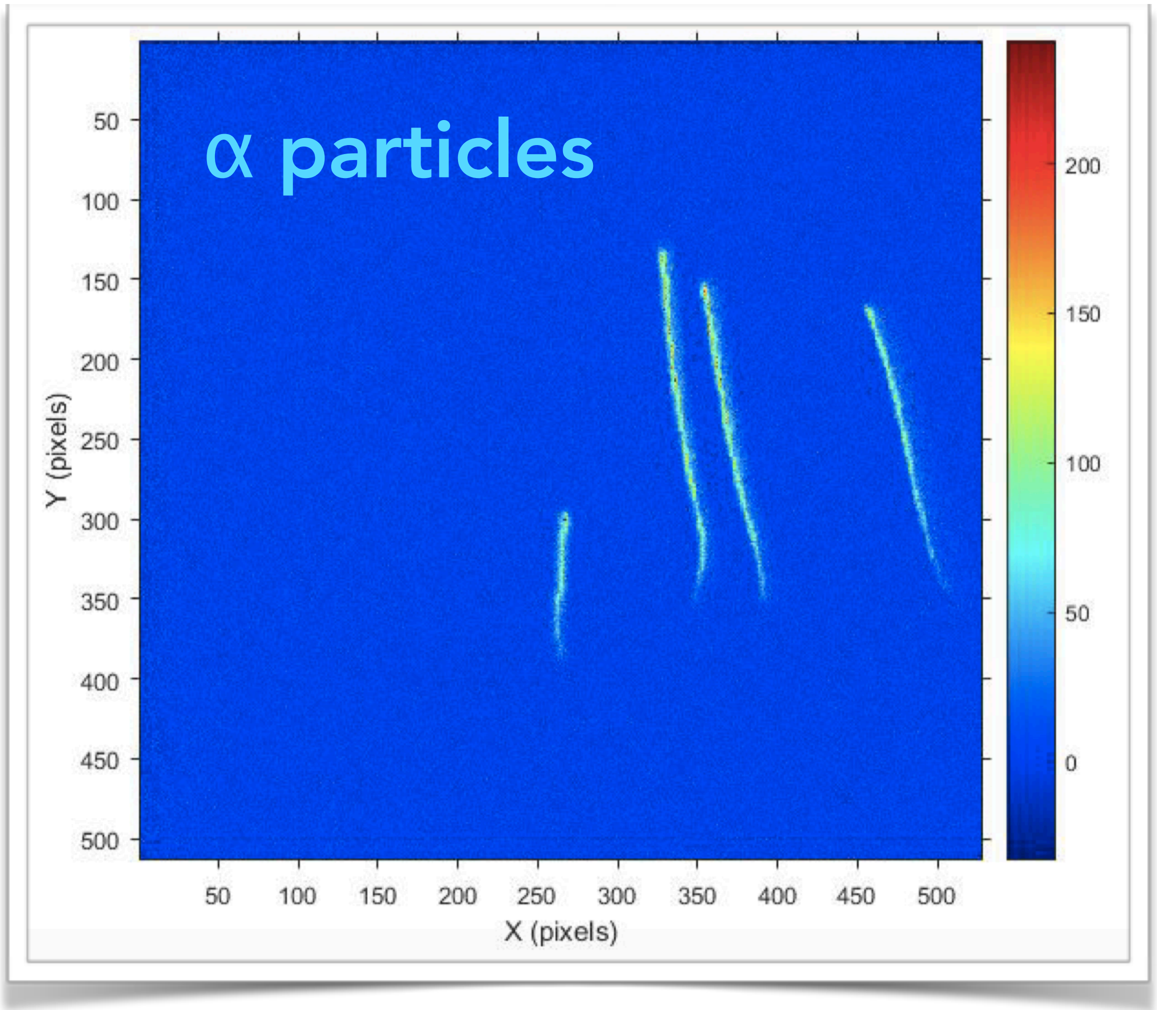


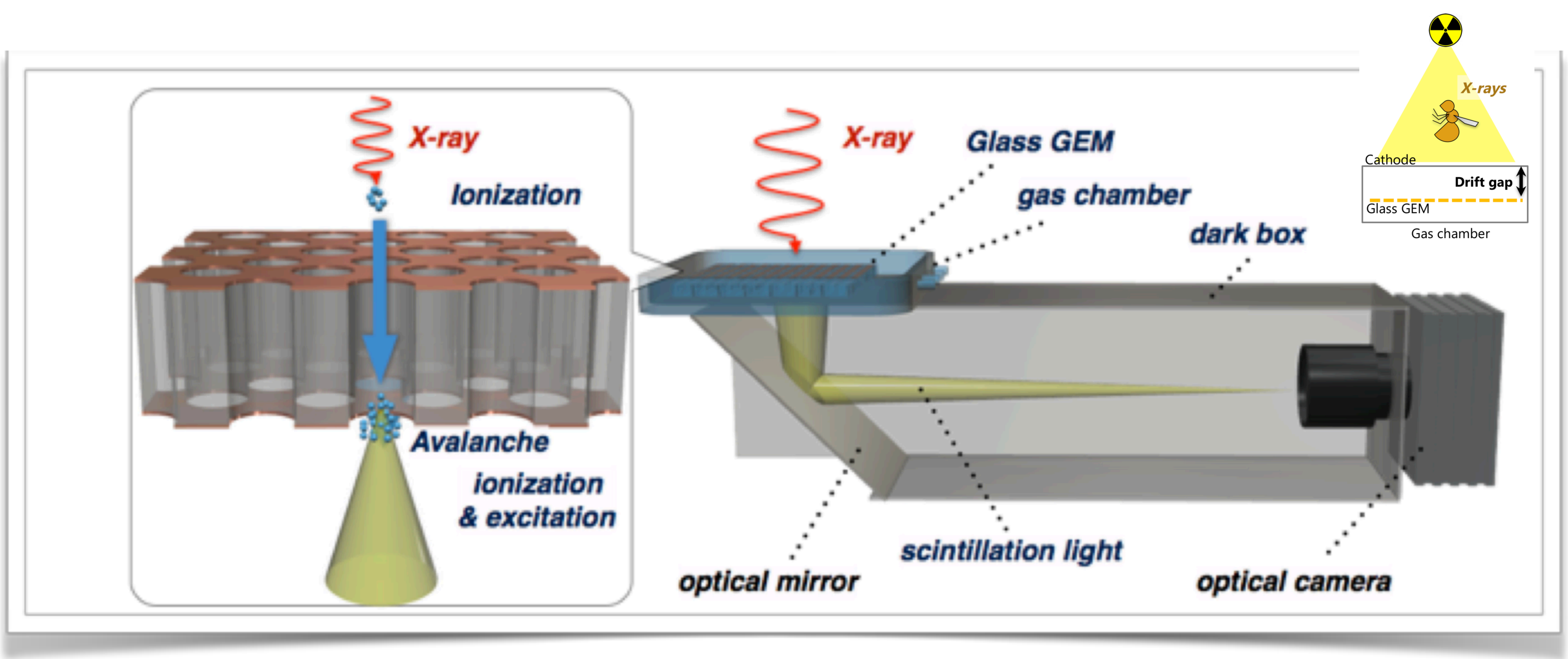


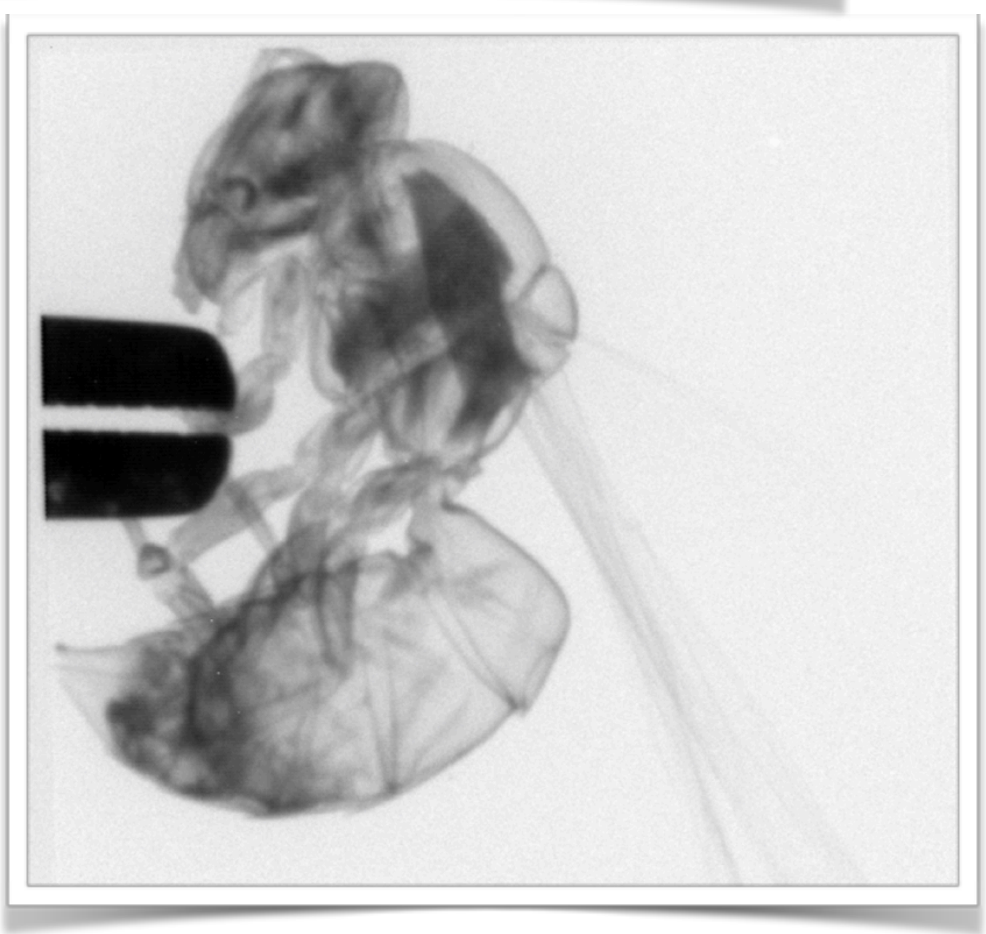


LUMINOUS WAY

Fluorescence light emitted during the avalanche processes in the Micropattern Gaseous Detectors can be acquired by high granularity optical sensors allowing very resolved image reconstruction

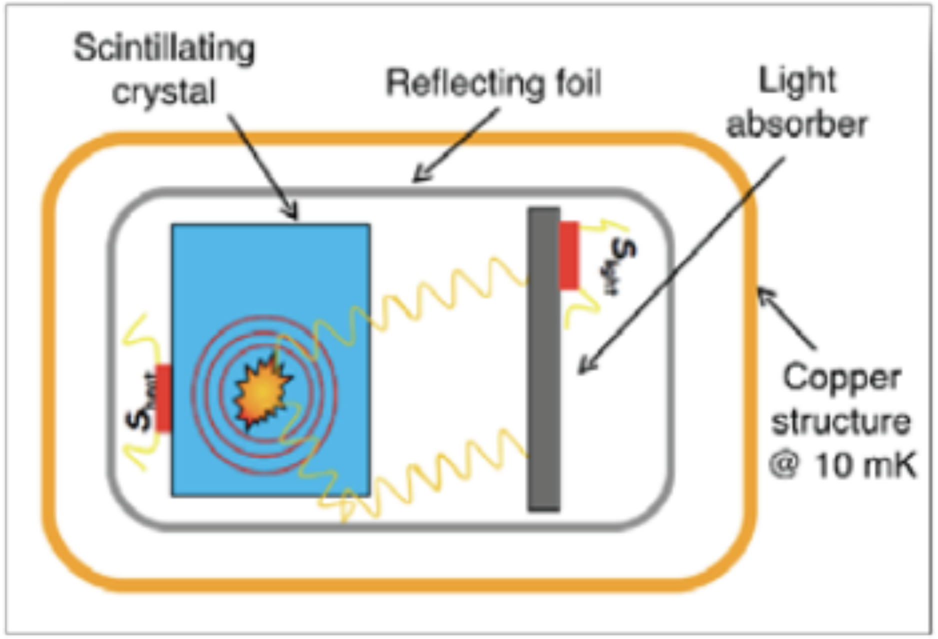


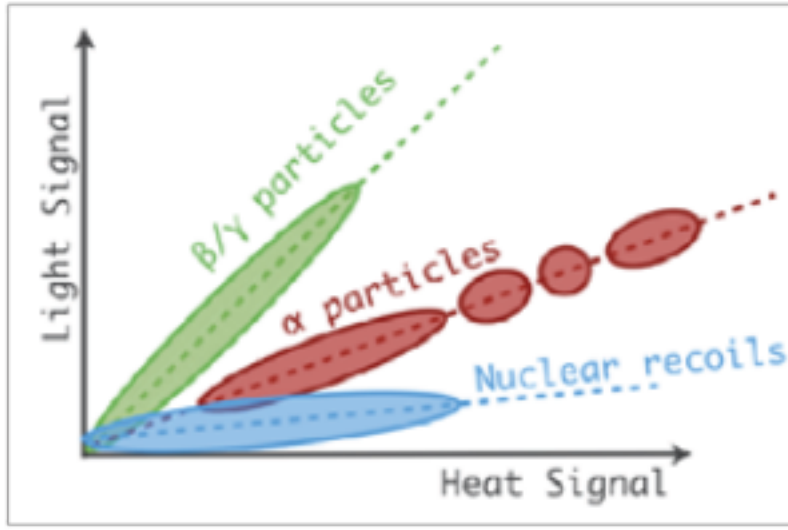




DOUBLE READOUT

CUPID: LIGHT AND ENERGY





The simultaneous read-out of **HEAT** and **LIGHT** allows particle identification

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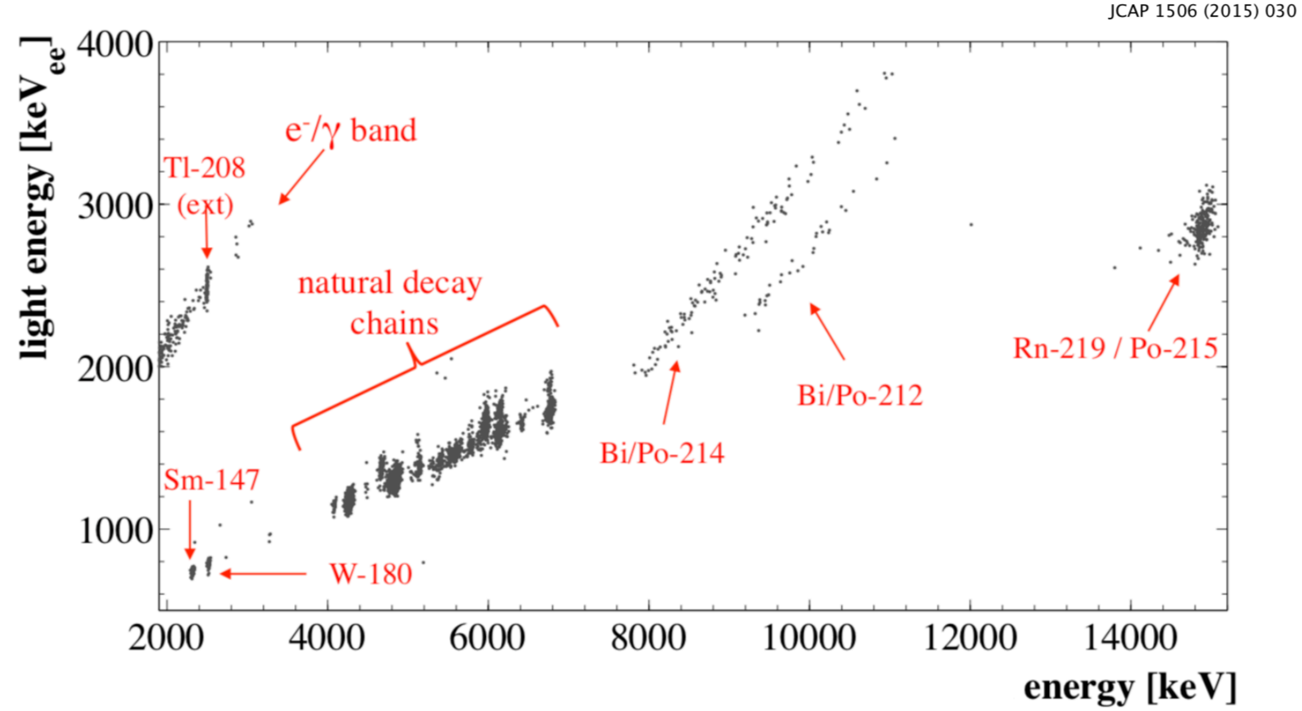
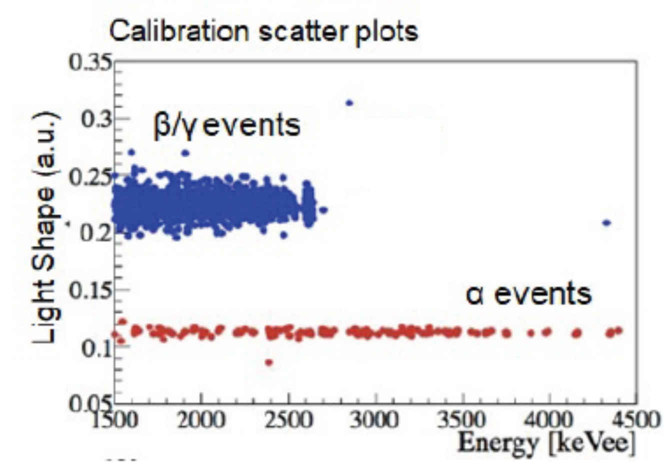
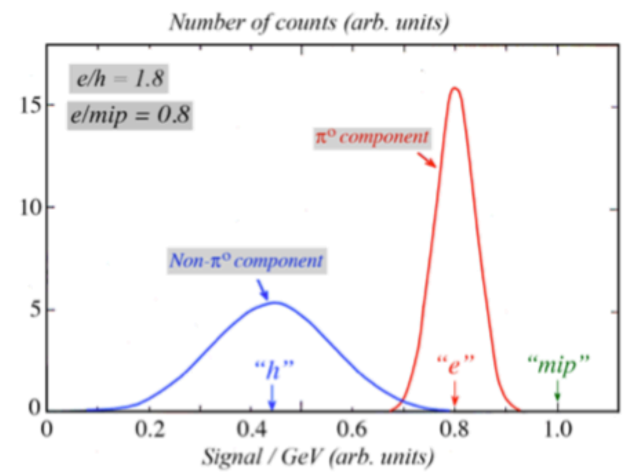


Excellent discrimination can be obtained based on the shape of the light pulse



DREAM: DUAL READOUT CALORIMETRY



The calorimeter response is different for the two components:

$$\frac{h}{e} \neq 1$$

$$E = \frac{S - \chi C}{1 - \chi} \qquad \chi = \frac{1 - (h/e)_s}{1 - (h/e)_c}$$

Scintillation signal from scintillating fibers: every ionizing particle passing through them releases a light signal.

$$S = E[fem + \left(\frac{h}{e}\right)_s (1 - fem)]$$

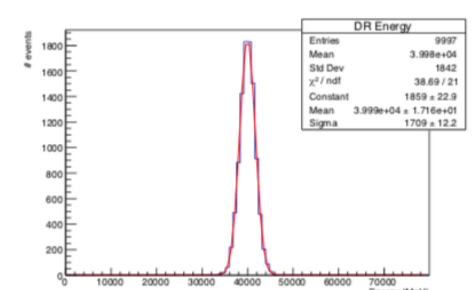
Cherenkov signal from clear-plastic fibers: every relativistic charged particle (almost exclusively electrons) passing through them releases a light signal.

$$C = E[fem + \left(\frac{h}{e}\right)_c (1 - fem)]$$

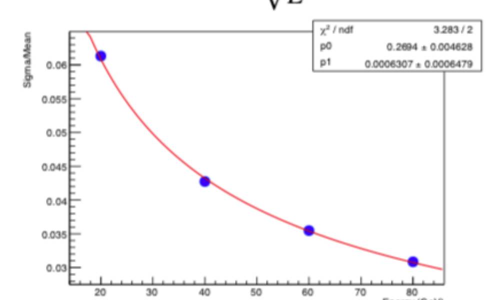
$$\frac{S}{C} = \frac{fem + \left(\frac{h}{e}\right)_s (1 - fem)}{fem + \left(\frac{h}{e}\right)_c (1 - fem)}$$

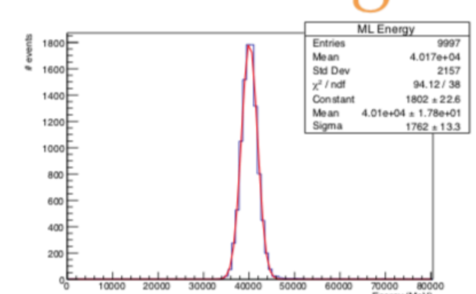
It is possible to estimate *fem* by measuring the ratio of the two signals event-by-event

Dual Readout method vs. Machine Learning

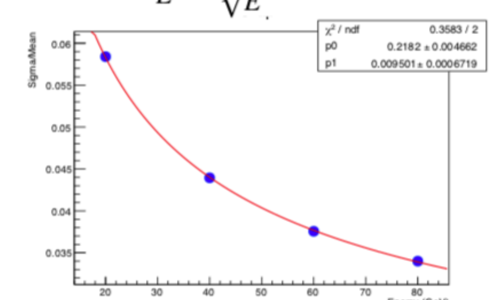


$$\frac{\sigma}{E} = \frac{27\,\%}{\sqrt{E}}$$



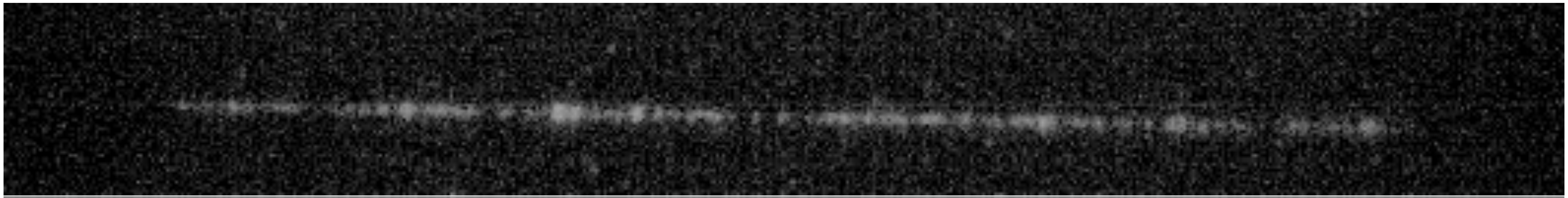


$$\frac{\sigma}{E} = \frac{22\,\%}{\sqrt{E}} \pm 0.9\,\%$$

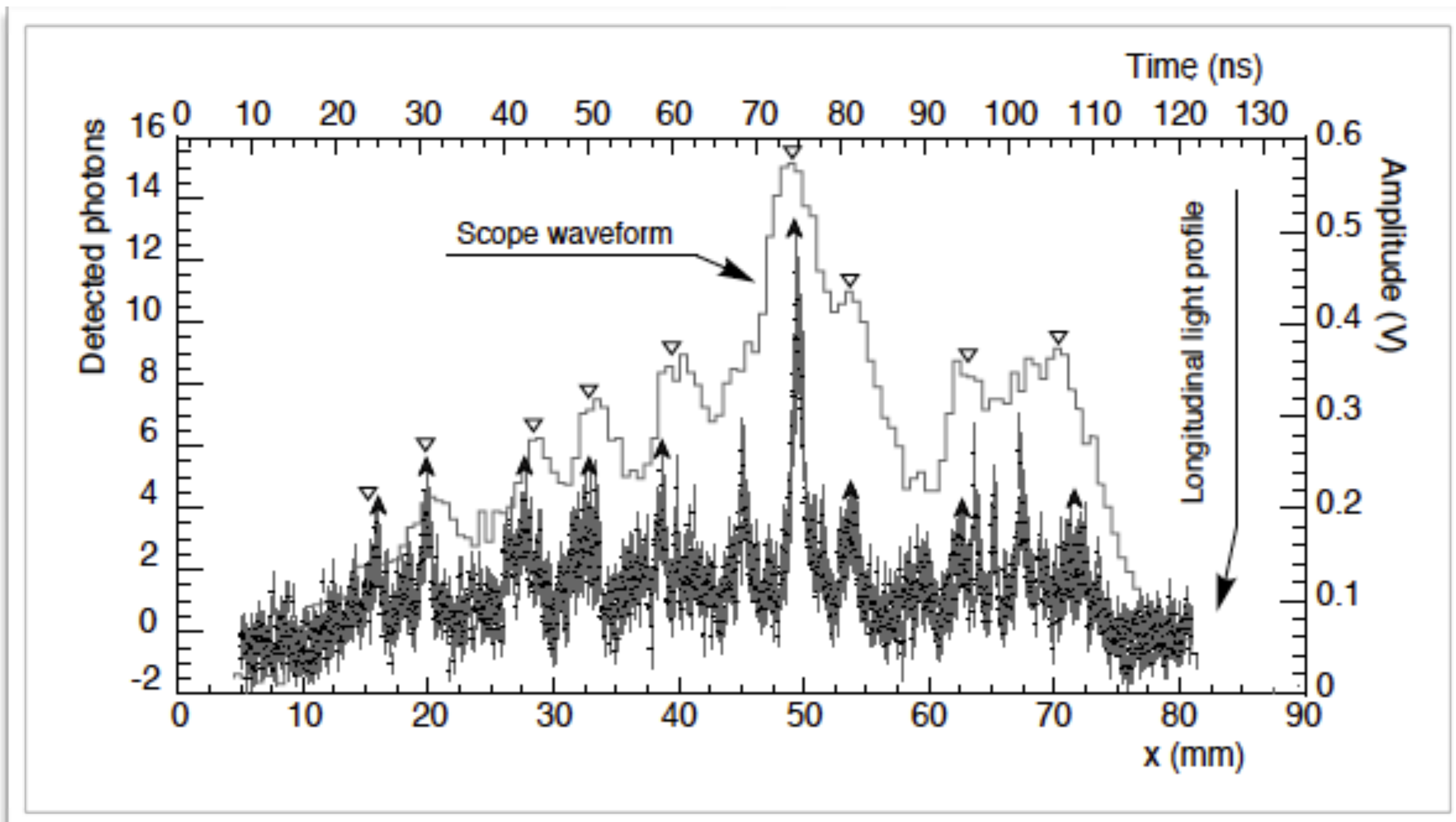


Lead based calorimeter - 40 GeV π^-

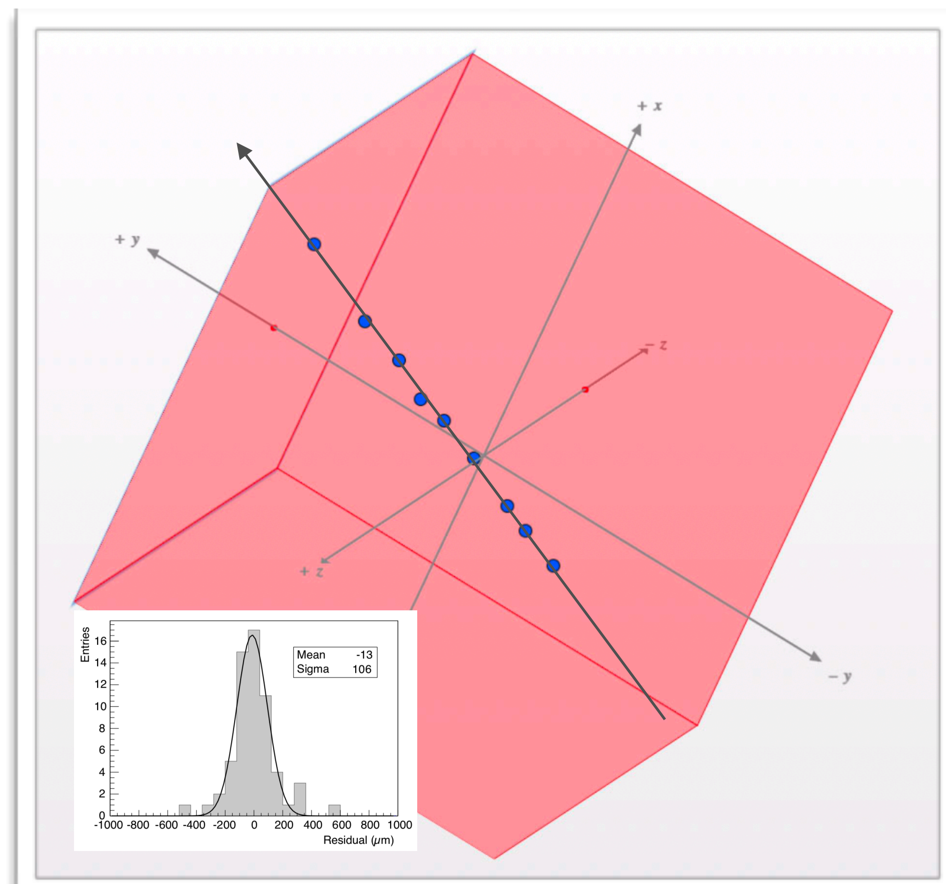
CYGNO: COMBINED LIGHT READOUT



High granularity CMOS sensors allow a very detailed track reconstruction



BUT they are slow!



The combined use of a fast light sensor provide time structure of the signal —> 3D

WHAT ABOUT ROMA1

There are a lot of people working in building and developing particle detectors;

These activities require competences, expertises and tools in different fields:

- gaseous detectors;
- highly radiopure materials;
- crystal developing;
- sensor study and applications;

Coordination and synergy in this effort can give a precious boost;

WHAT ABOUT ROMA1

To share competences and knowledges, we should find:

Time

Last year Roma1 Dark Matter Workshop was an important opportunity. We should foresee other thematic workshops;

Space

Some of these activities take place at Segre Laboratories;

We should transform it in a functional lab (not a storage place), with services (gas, grounding, network, air conditioning…) with room assigned on demand to active groups.