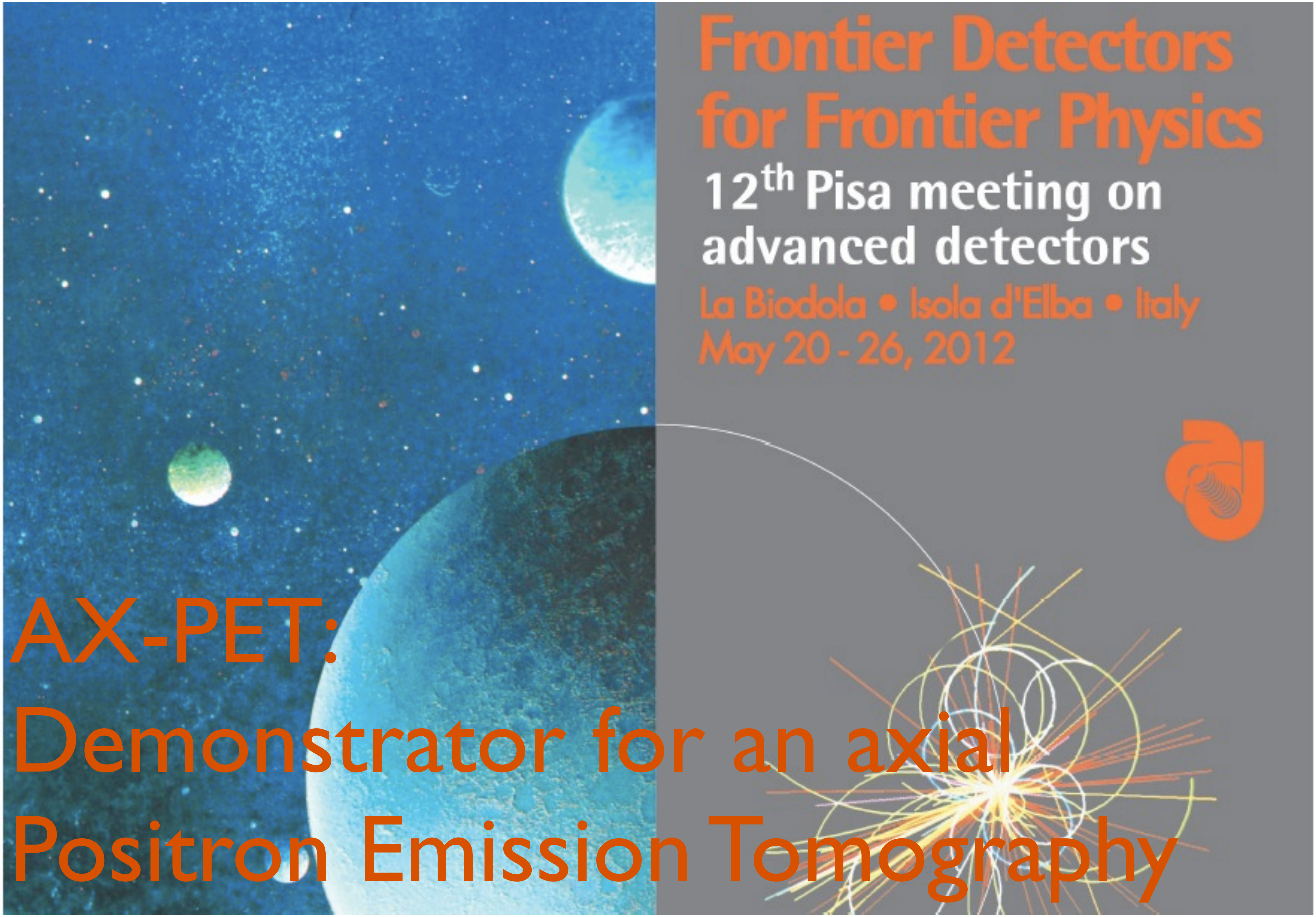
AX-PET: Demonstrator for an axial Positron Emission Tomography



Frontier Detectors for Frontier Physics

12th Pisa meeting on advanced detectors

La Biodola • Isola d'Elba • Italy

May 20 - 26, 2012

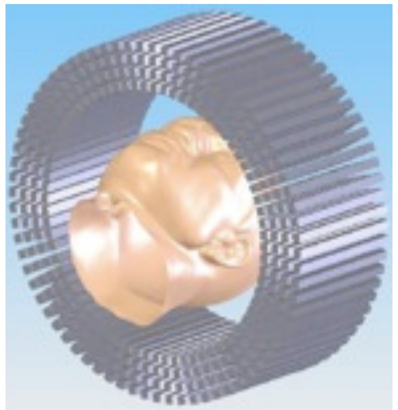
ETH Institute for Particle Physics

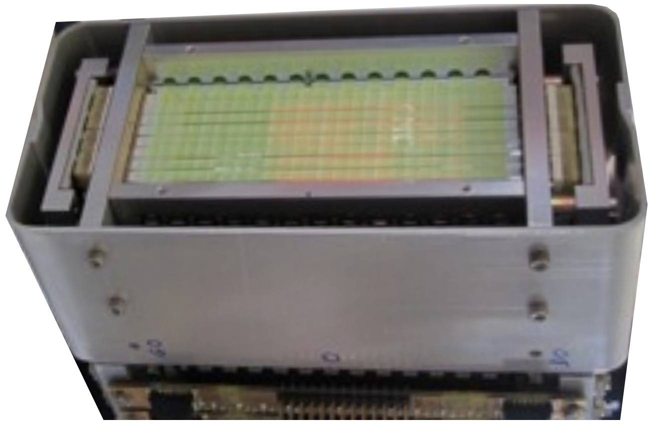
Chiara Casella, ETH Zurich

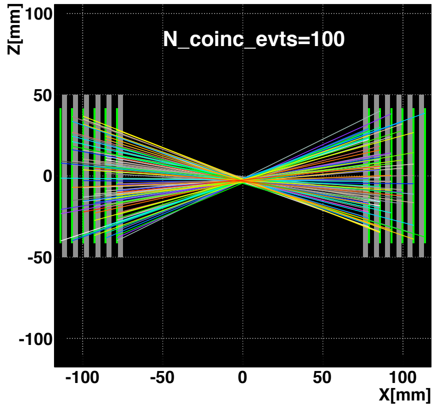
AX-PET

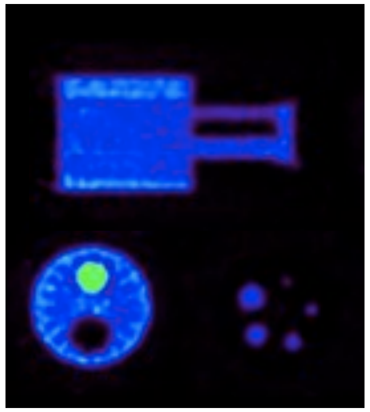
Outline

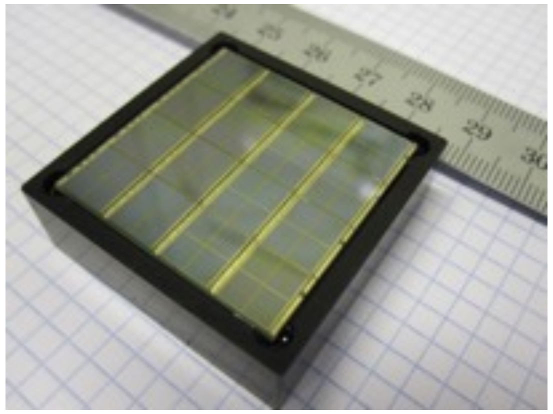
AX-PET: Demonstrator for an axial Positron Emission Tomography











- **Axial concept**
  What is it ? Why?
- **AX-PET detector**
  “Demonstrator” for a PET scanner
- **AX-PET detector performance**
  from characterization measurements with 22-Na sources
- **Tomographic image reconstruction, few examples**
- **Preliminary results with Digital Si-PM from Philips**
  as alternative photodetectors for the AX-PET

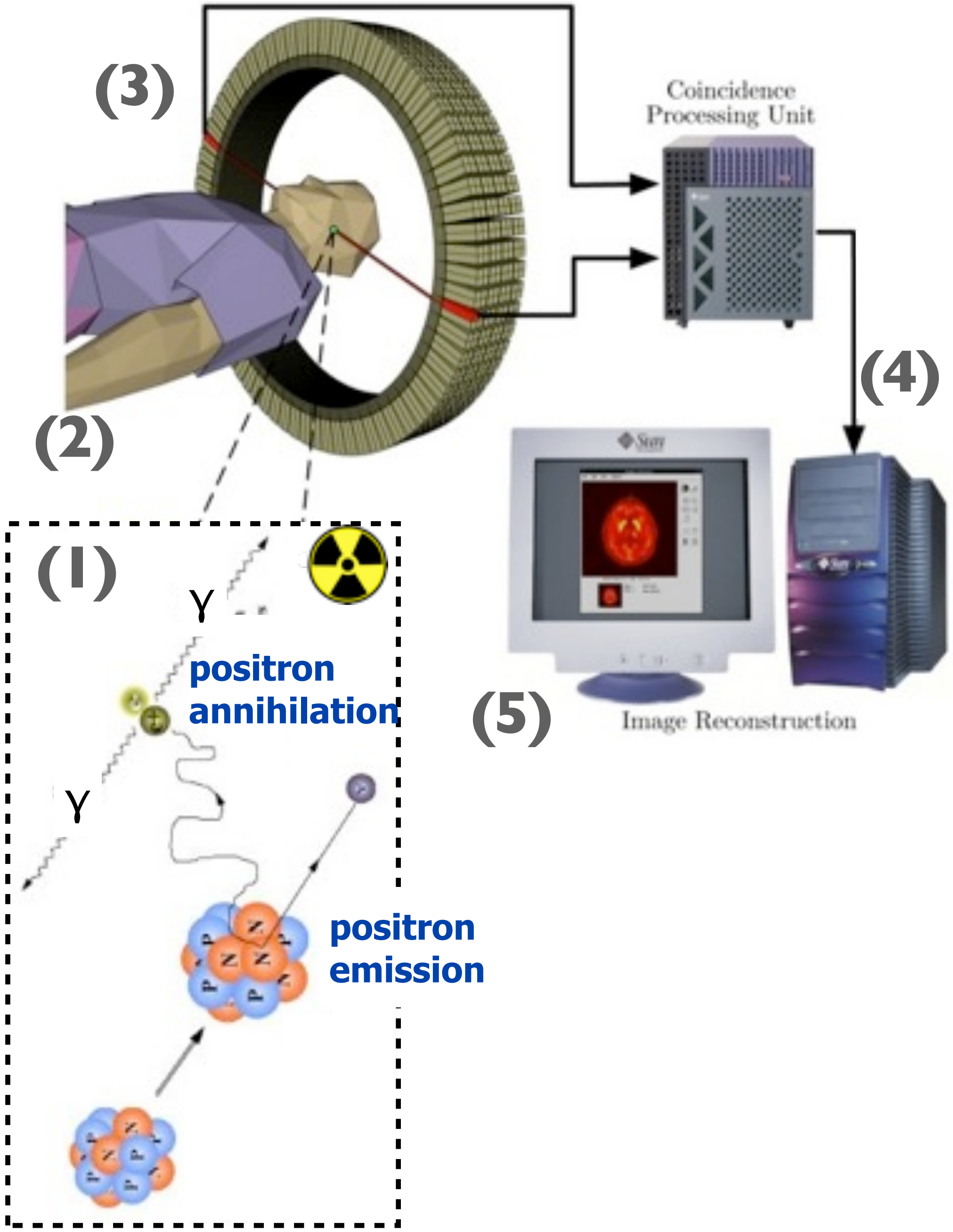
Positron Emission Tomography

PET : **"in-vivo" functional imaging** technique in nuclear medicine

Positron Emission : $p \rightarrow n + e^{+} + \nu_e$

Positron Annihilation : $e^{+}e^{-} \rightarrow \gamma\gamma$

$$(E_\gamma = 511\ keV)$$



How does a PET work ?

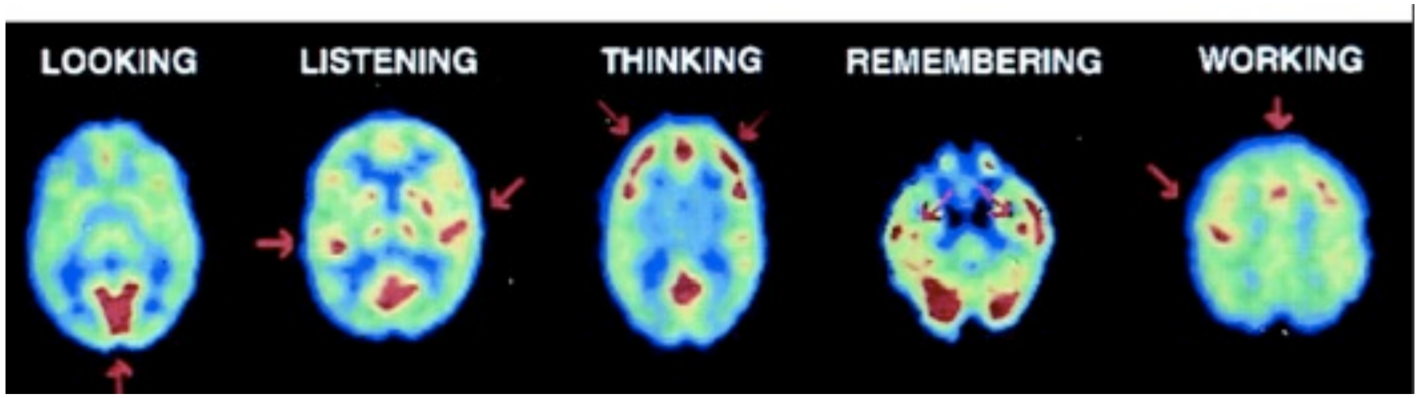
(1) Inject the **radiotracer into the body**
radiotracer : biologically active compound mixed to the positron emitter.

(2) Wait for uptaking period

(3) Start the acquisition (i.e. **detection of coinc. events**)
clear event signature : coincidence of 2 photons of known energy (511 keV) emitted co-linearly

(4) Feed the data into the reconstruction algorithms

(5) Obtain the **image** of the **activity concentration**

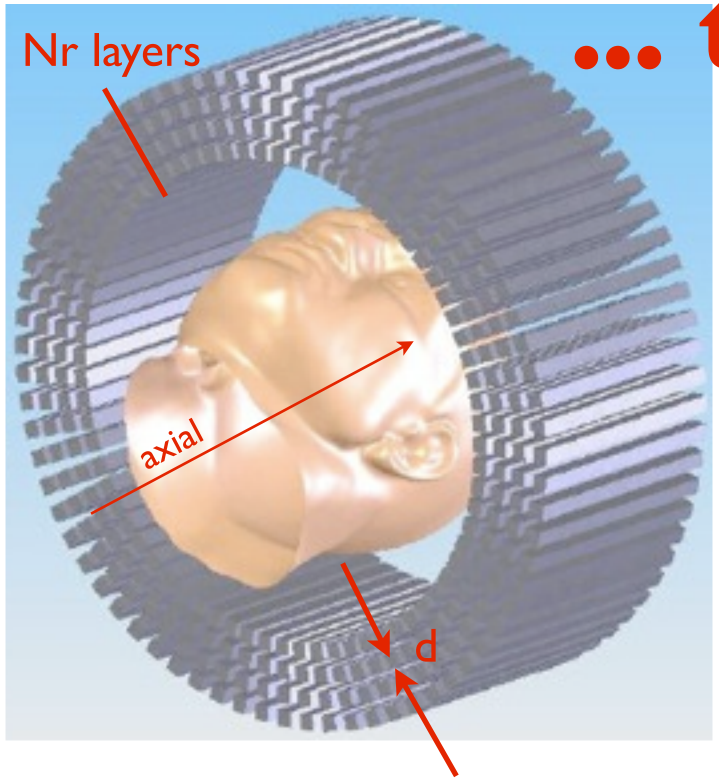


A.Del Guerra, CERN Academic Training 2009

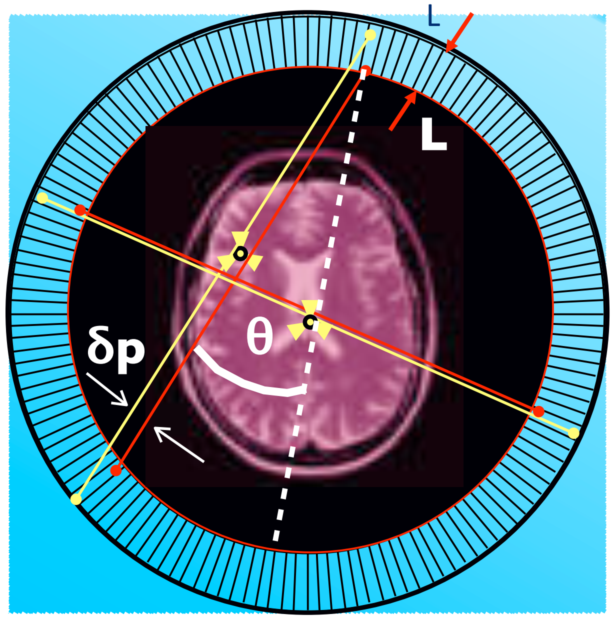
Axial concept

from radial ...

... to axial !



- long crystals
- oriented along the axial direction
- several layers arrangement



max **interaction efficiency, long L**

$$\epsilon = 1 - e^{-\mu \cdot \boxed{L}}$$

min **parallax error => short L**

- deterioration of the spat. resol.
- non uniformity in the field of view

$$\delta p = \boxed{L} \cdot sin\theta$$

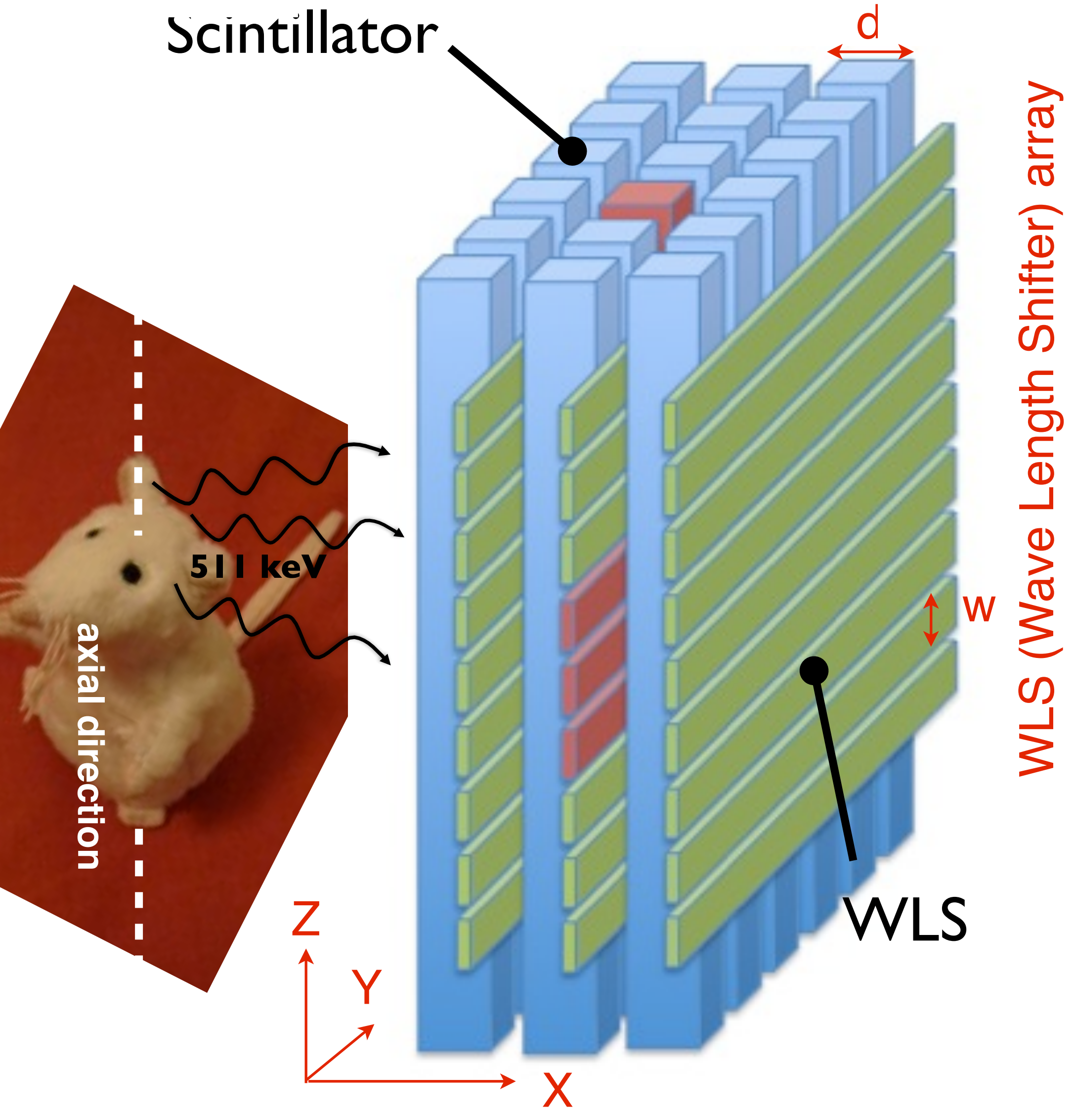
always a compromise between
good spatial resolution (small L, small δp)
or good sensititvity (long L)

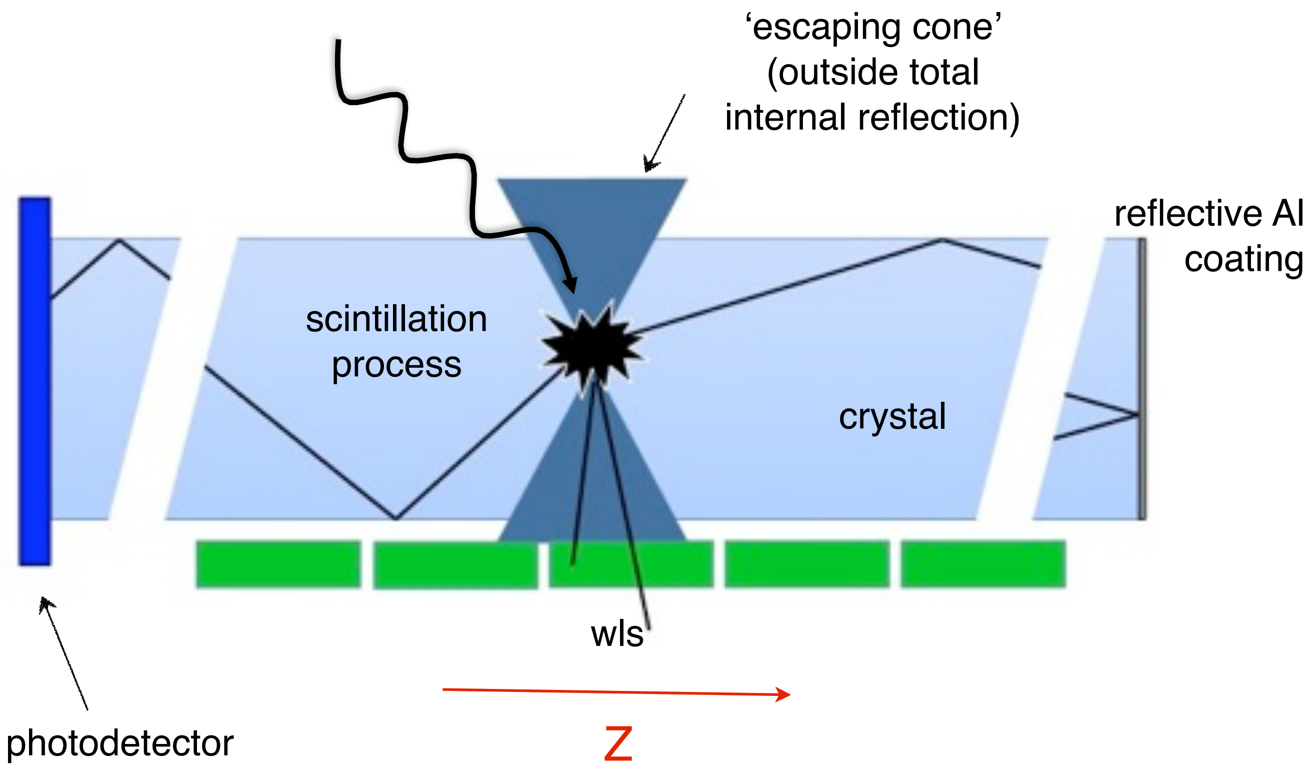
the axial geometry allows for a parallax free system, in which spatial resolution and sensitivity are completely decoupled :

- improve spatial resolution <=> reduce d

- improve sensitivity <=> increase Nr layers

AX-PET detector concept





Crystals:

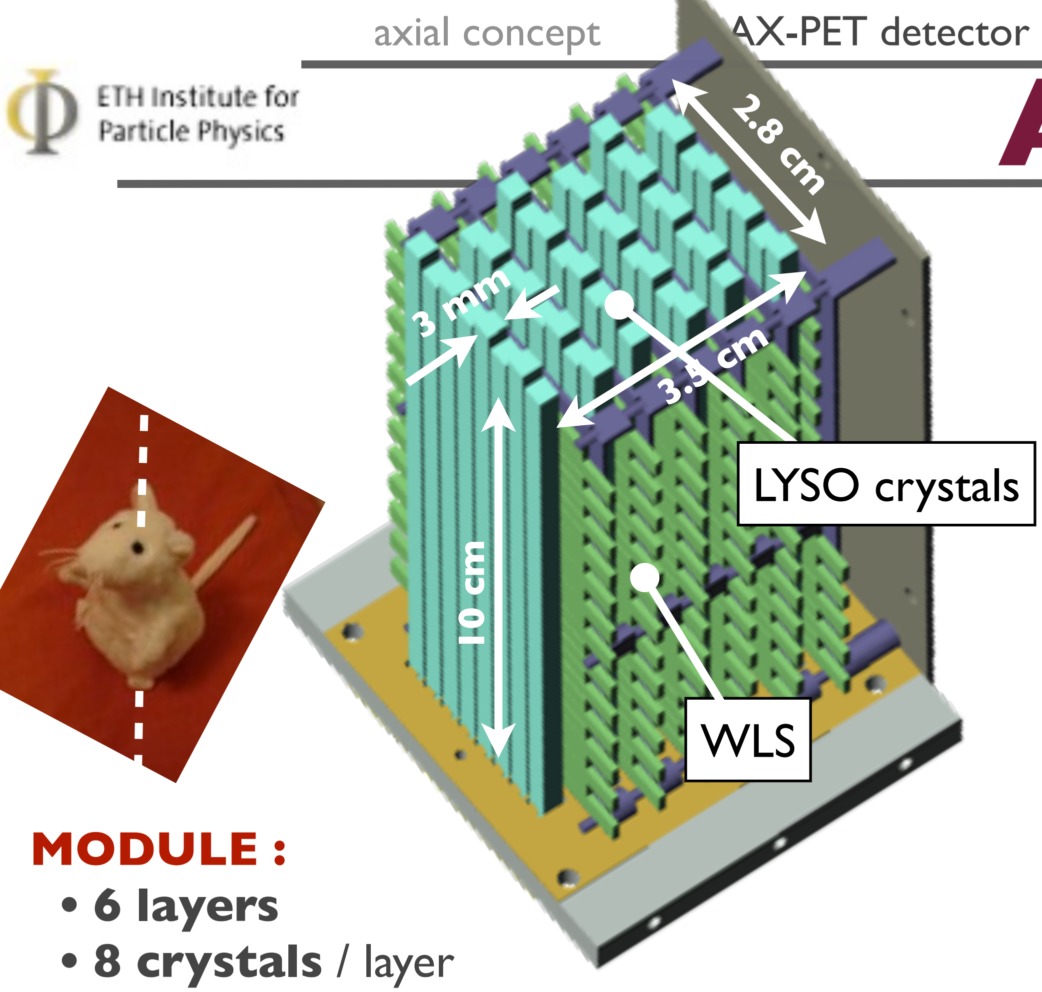
- trans-axial coordinate (x,y)
  - digital resolution from crystal size (d/√12 x 2.35 FWHM)
- energy

Wave length shifter strips :

- axial coordinate (z)
  - center of gravity => resolution better than digital (<w)

- 3D localization of the photon interaction point + energy measurement
- high granularity => possibility to identify Compton scattering events in the detector

AX-PET module



MODULE :
- **6 layers**
- **8 crystals** / layer
- **26 WLS** / layer
- 48 crystals + 156 WLS = **204 channels**
- staggering in the crystals layout

- SCINTILLATOR CRYSTALS :
- Inorganic **LYSO** ($Lu_{1.8}Y_{0.2}SiO_5$: Ce, Prelude 420 Saint Gobain) **crystals**
  - high atomic number
  - high density ($\rho = 7.1$ g/cm^3)
  - λ @511 keV ~ 1.2 cm
  - quick decay time ($\tau = 41$ ns)
  - high light yield (32000 γ / MeV)
- **3 x 3 x 100 mm^3**

- WAVE LENGTH SHIFTING STRIPS (WLS) :
- ELJEN EJ-280-10x
- highly doped (x10 compared to standard) to optimize absorption
- **0.9 x 3 x 40 mm^3**

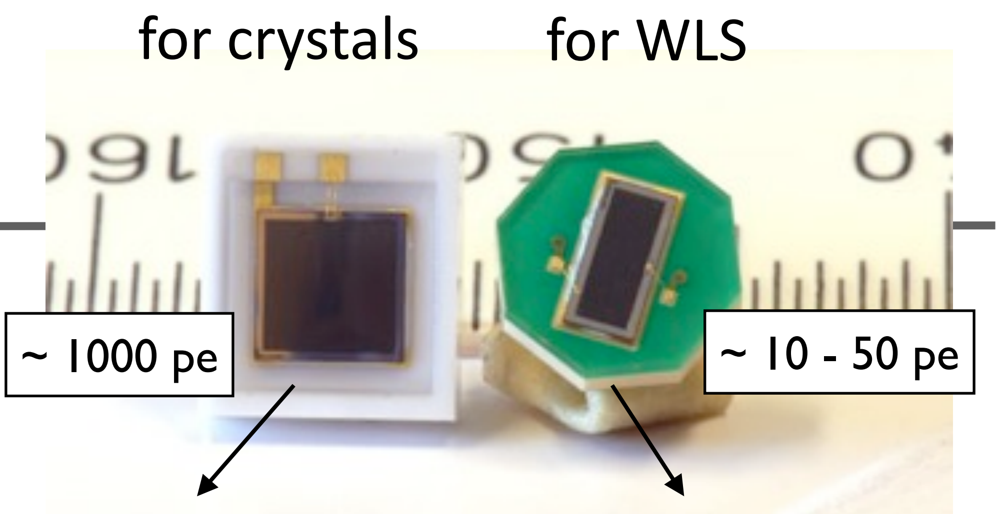
- Each crystal and WLS strip is readout individually by its own photodetector

Photodetectors

- MPPC (Multi Pixel Photon Counter) from Hamamatsu

- also known as **SiPM / G-APD**
  - high PDE (~ 50%) √
  - high gain (10^5 to 10^6) at low bias voltage √
  - **insensitive to magnetic field** √
  - **compact size** √

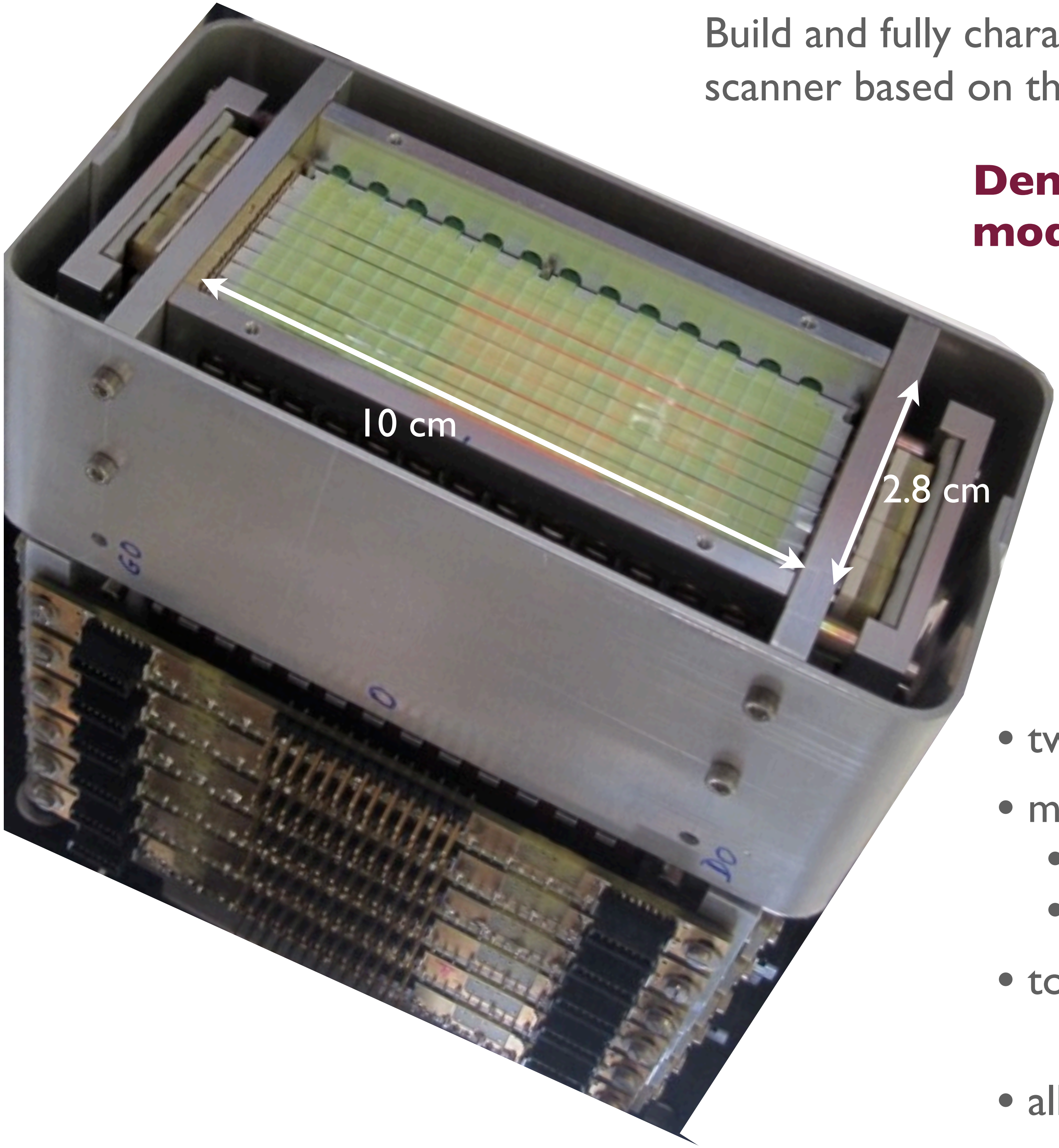
  - temperature dependent √
  - dark rate √



MPPC S10362-33-050C :
- 3x3 mm^2 active area
- 50 μm x 50 μm pixel
- **3600 pixels**
- Gain ~ 5.7 x 10^5

MPPC 3.22×1.19 Octagon-SMD :
- 1.2 x 3.2 mm^2 active area
- 70 μm x 70 μm pixel
- **1200 pixels**
- Gain ~ 4 x 10^5
- custom made units

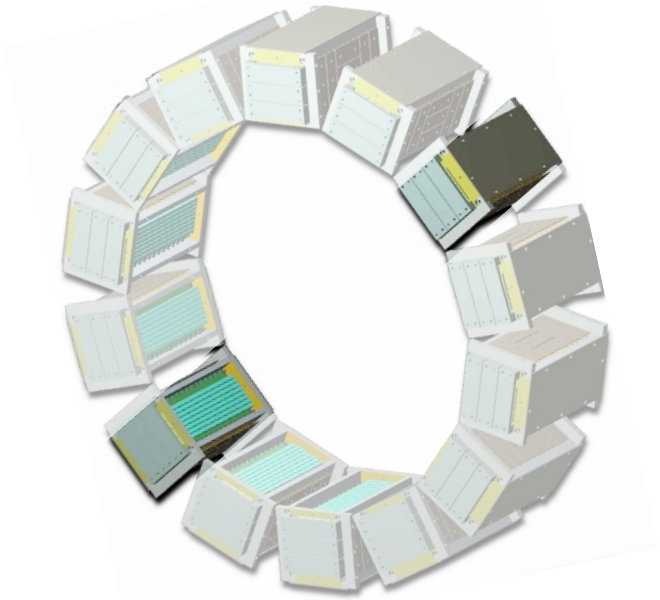
AX-PET demonstrator



Goal of the collaboration:

Build and fully characterize a **“demonstrator”** for a PET scanner based on the axial concept. Assess its performances.

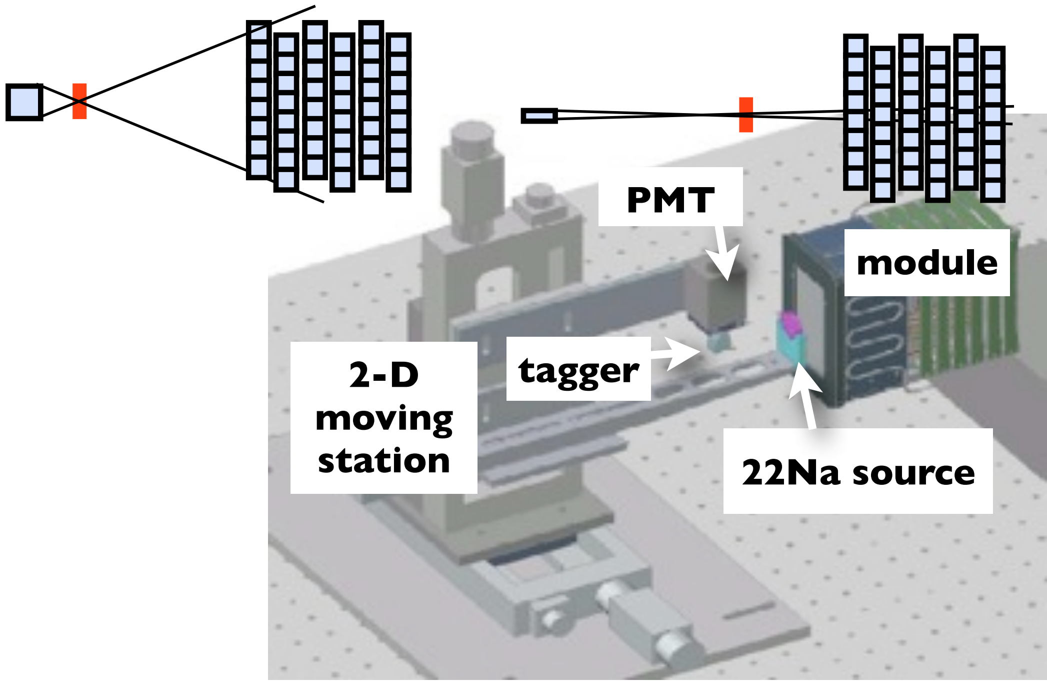
Demonstrator : Two identical AX-PET modules, used in coincidence



- two modules built - at CERN
- module performance assessed (22-Na source)
  - individually - at CERN
  - in coincidence
- tomographic image reconstruction (with a dedicated gantry setup)
- all stages fully supported by simulations

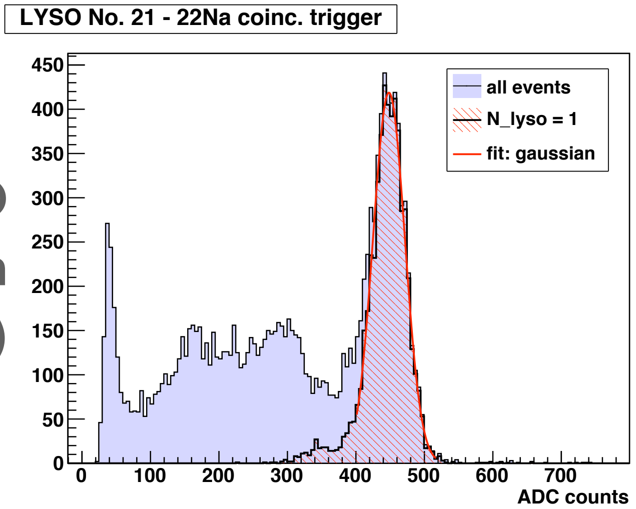
AX-PET detector performance

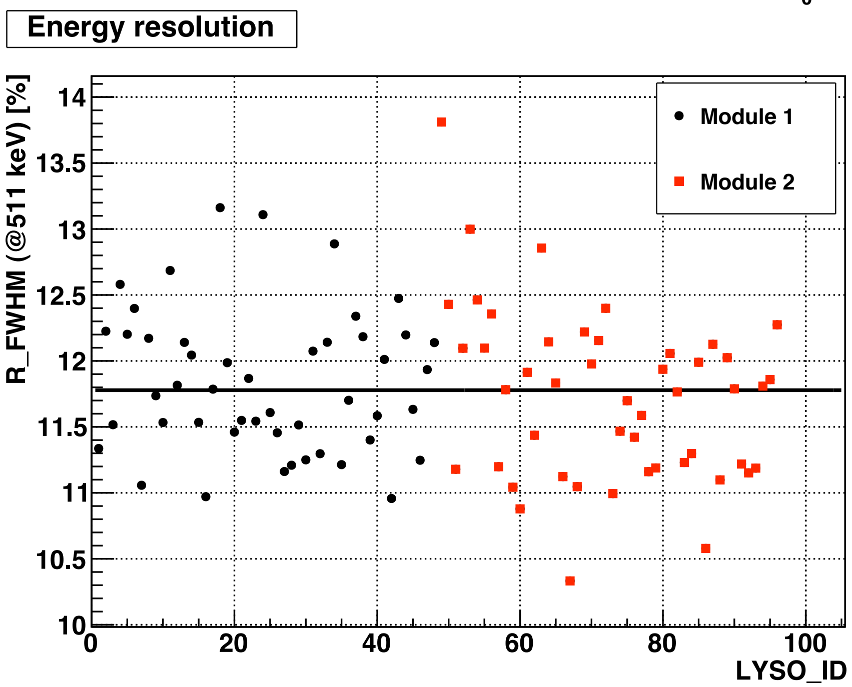
- Characterization measurements with 22-Na source + tagger
- Methods and results in: **NIM A 654 (2011) 546-559**



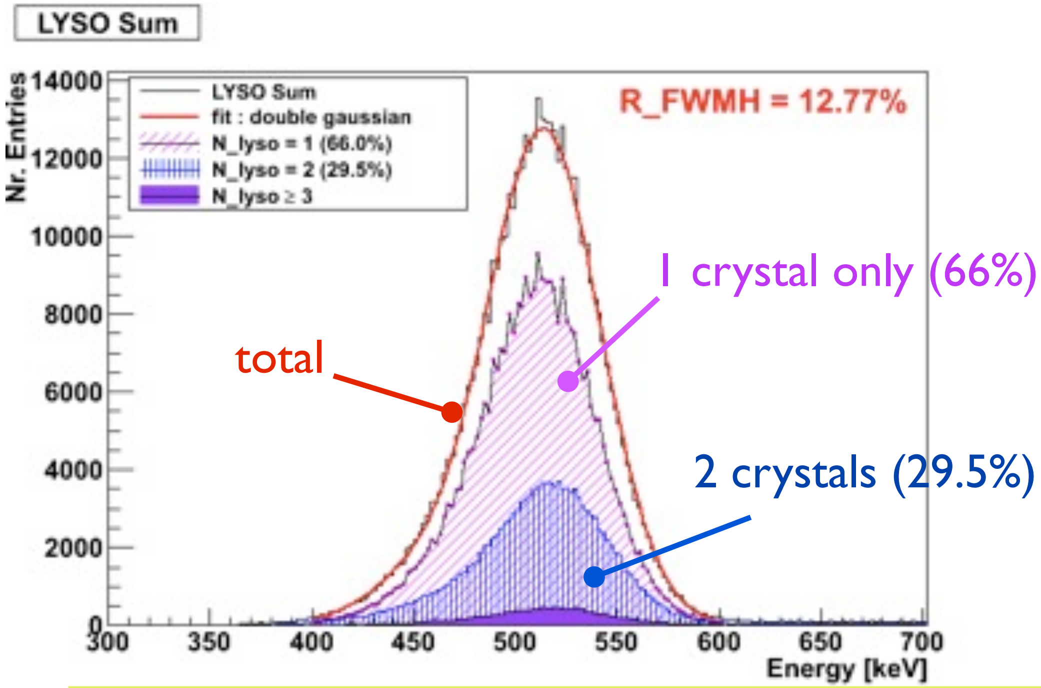
- **LYSO energy response**

typical LYSO energy spectrum (in ADC counts)





after energy calibration



<ΔE/E> ~ **11.8 % FWHM** @511 keV

(averaged over 96 crystals)

ΔE/E ~ **12.8 % FWHM** @511 keV

(on the module sum)

- **Multiplicities** : when 2 modules coincidence: $(0.66)^2$ ~ **0.43 photoelectric interactions**

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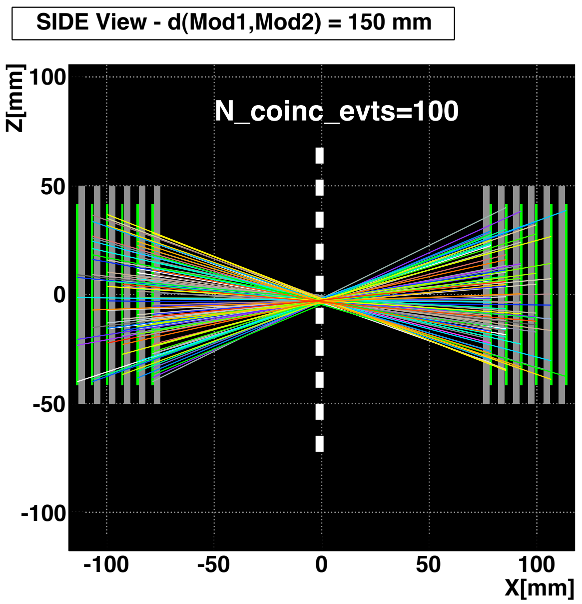
AX-PET detector performance

- **Spatial resolution** :

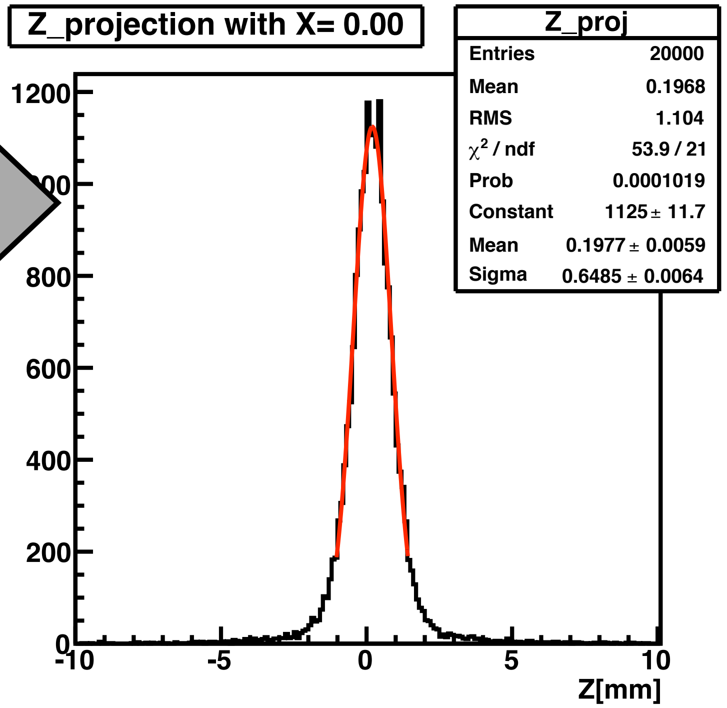
1. **axial direction** (two detector coincidences) :

axial coordinate : from center of gravity method (continuous distribution)

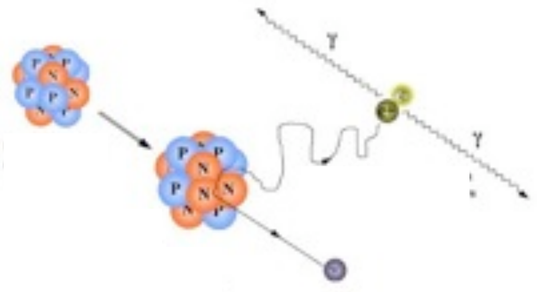


Intersection of the LOR with the central plane.

Includes contribution from :
- intrinsic resolution
- physics of positron emission



$$R_{intr} = \sqrt{R^2_{meas} - R^2_{\rho} - R^2_{180}}$$ **≈ 1.35 mm, FWHM**



limits to the achievable spatial resolution in a PET system, due to the **physics of positron emission** :

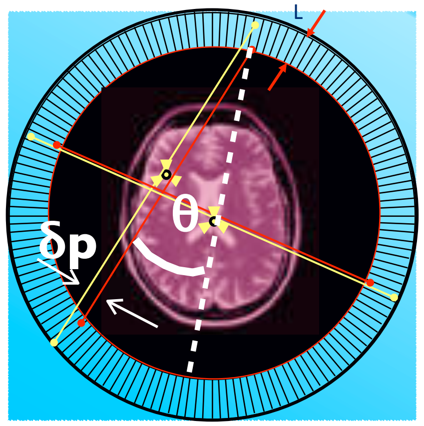
- **positron range** : $R_\rho{}^2 = [\ 0.54\ \text{mm}\ ]^2$
- **non collinearity** : $R_{180}{}^2 = [\ 0.0022 \times \text{Diameter}\ ]^2 = [\ 0.33\ \text{mm}\ ]^2$

2. **trans-axial direction** : digital, from crystal size

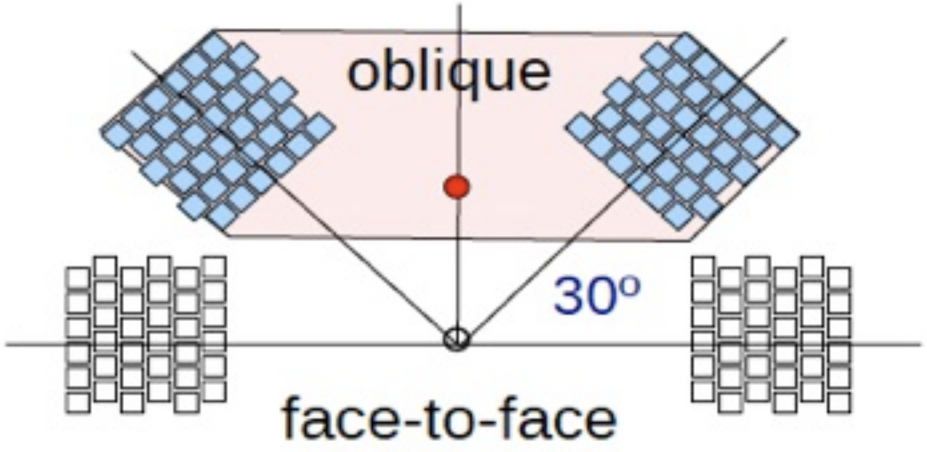
R_x,y= (3mm/√12)x2.35 ~ 2 mm FWHM

AX-PET detector performance

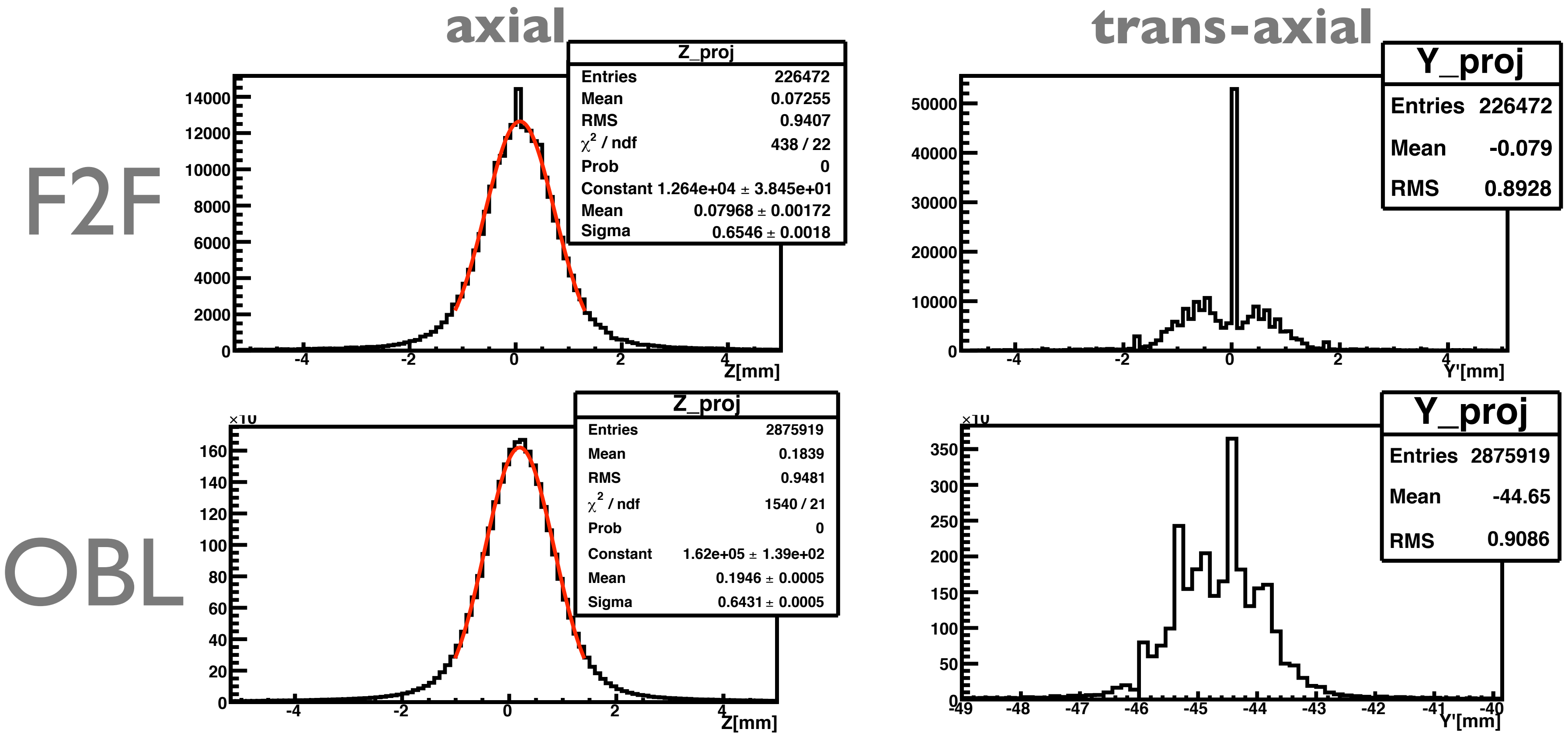
- **Parallax free demonstation**



parallax error is more and more important outside the center of the FOV



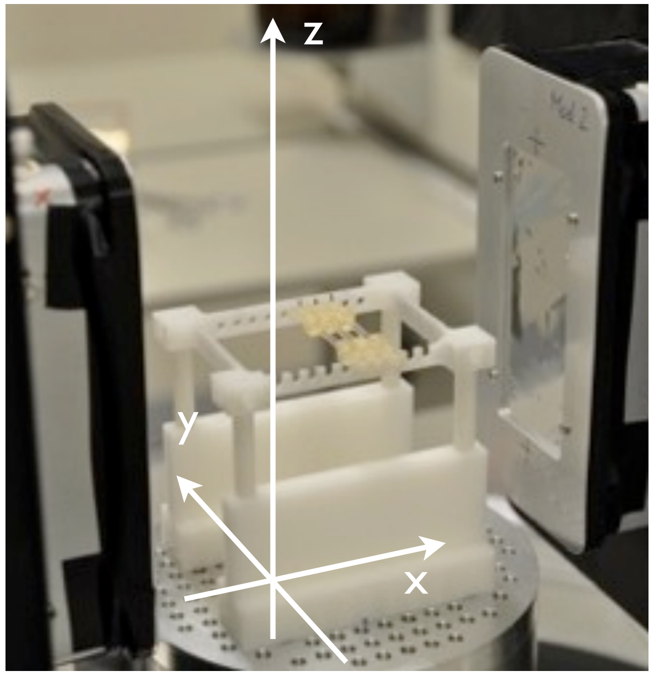
intersection of LORs with the plane containing the source

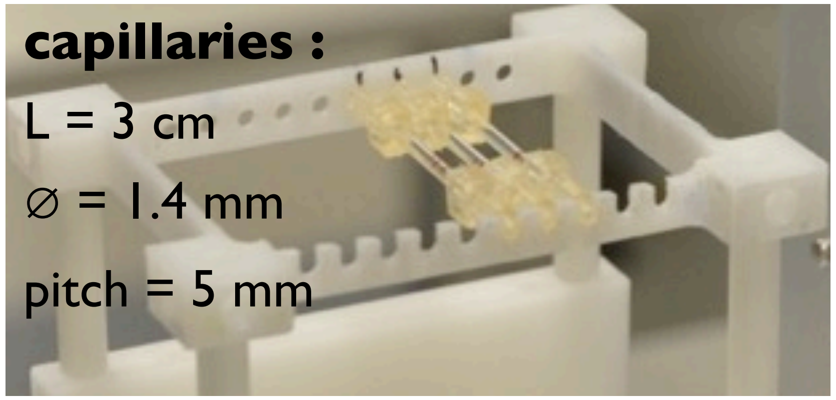


	axial	transaxial
F2F	σ=0.655	RMS=0.893
OBL	σ=0.643	RMS=0.909

Intrinsic resolution is **not degraded by parallax effects**, even in very oblique configuration !

Simple image reconstruction





capillaries :

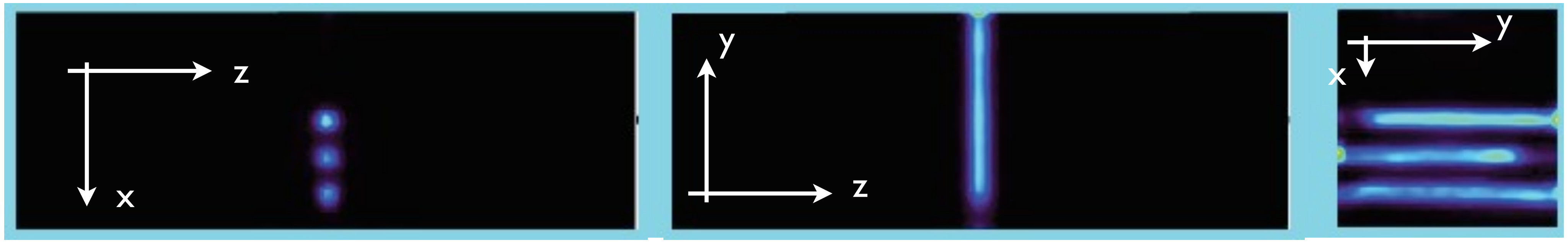
L = 3 cm

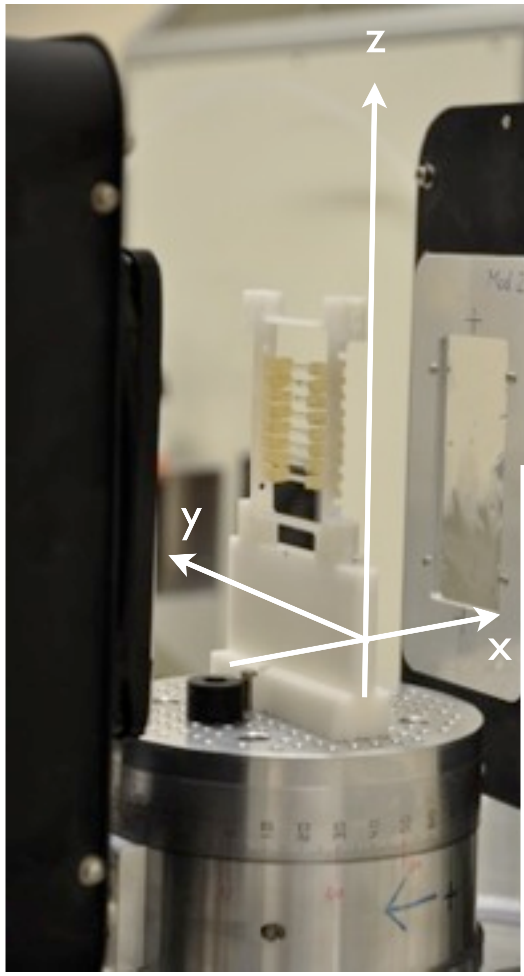
∅ = 1.4 mm

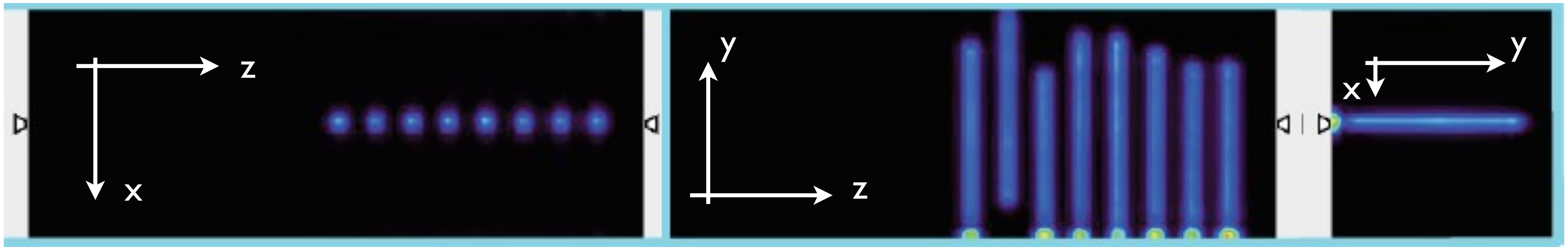
pitch = 5 mm

- central FOV
- measurements performed at ETH Zurich, Radiopharmaceutical Institute
- capillaries filled with 18-F in water solution

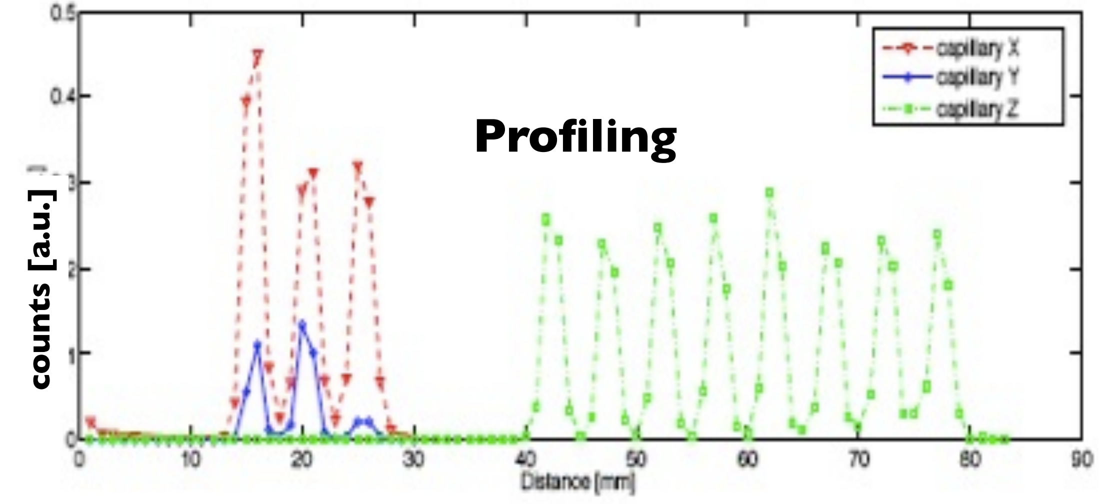
ETH, Apr 2010

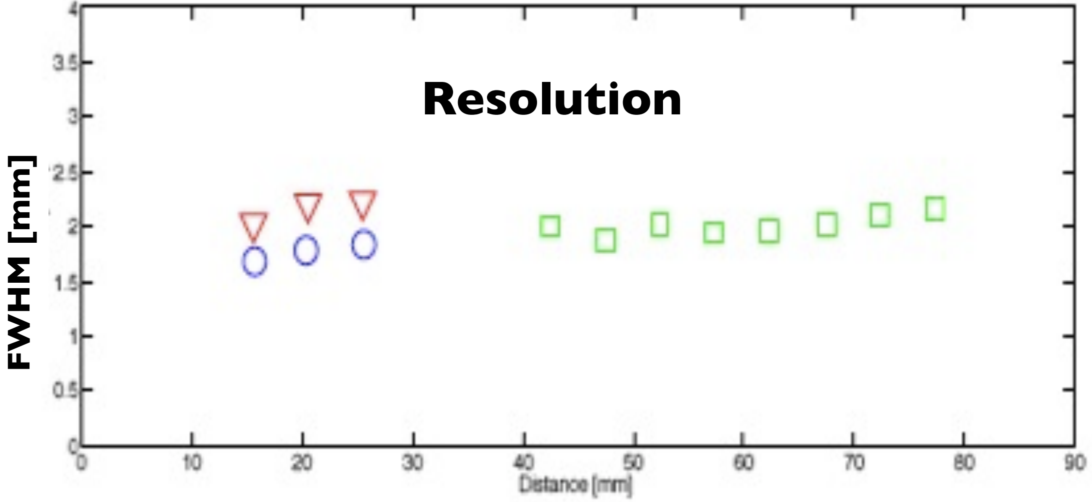






Profiling of the reconstructed capillaries (3 different measurements) and resolutions (FWHM) of reconstructed sources. The resolution still includes the capillary finite size (1.4 mm inner diameter).





NEMA phantom

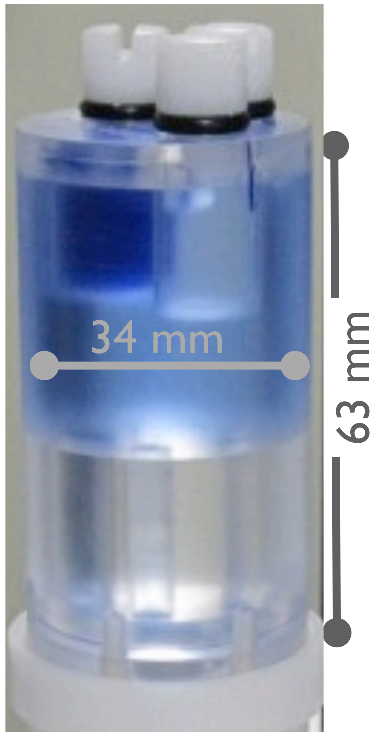
NEMA-NU4 IQ (mouse) phantom :

Three regions in the same phantom to address three different aspects

Hot & Cold rods for **contrast**

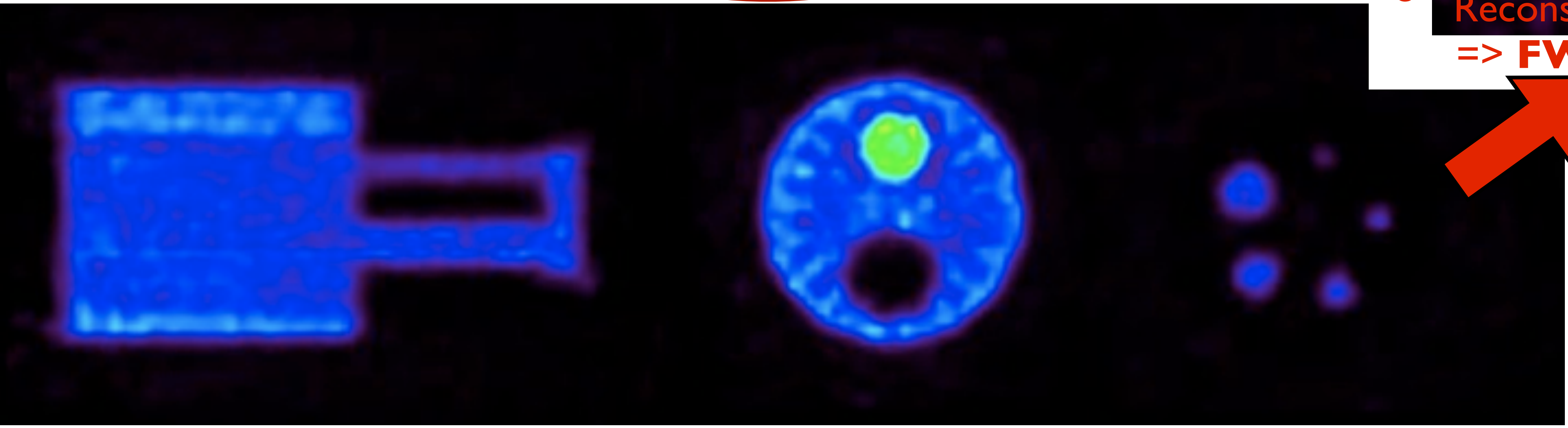
Homogeneous cylinder for assessing the **ability to reconstruct homogeneous distributions**

Series of small rods for **resolution**

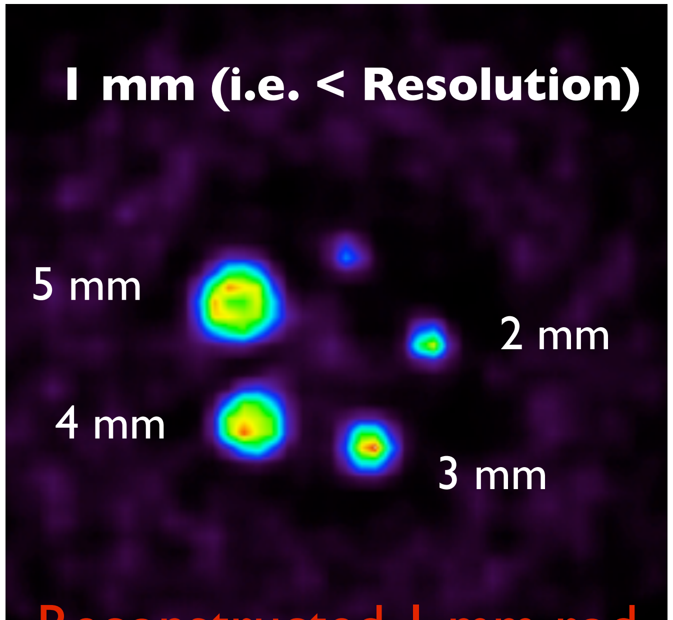


- extended FOV
- measurements performed at AAA (Advanced Accelerator Applications), St Genis, France
- July 2011
- phantom filled with 18-F in water solution

NEMA phantom hot / cold / warm - July 2011, AAA



different color scale !



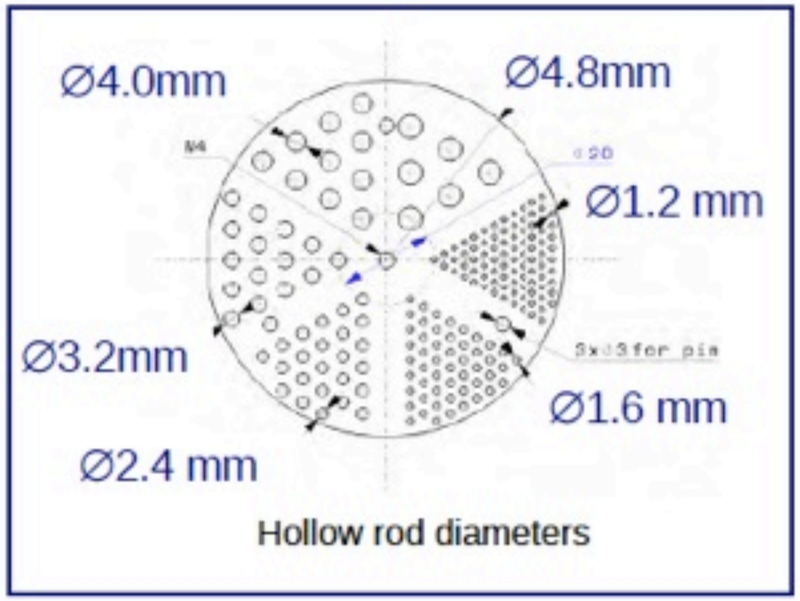
Reconstructed 1 mm rod

=> FWHM ~ 1.6 mm

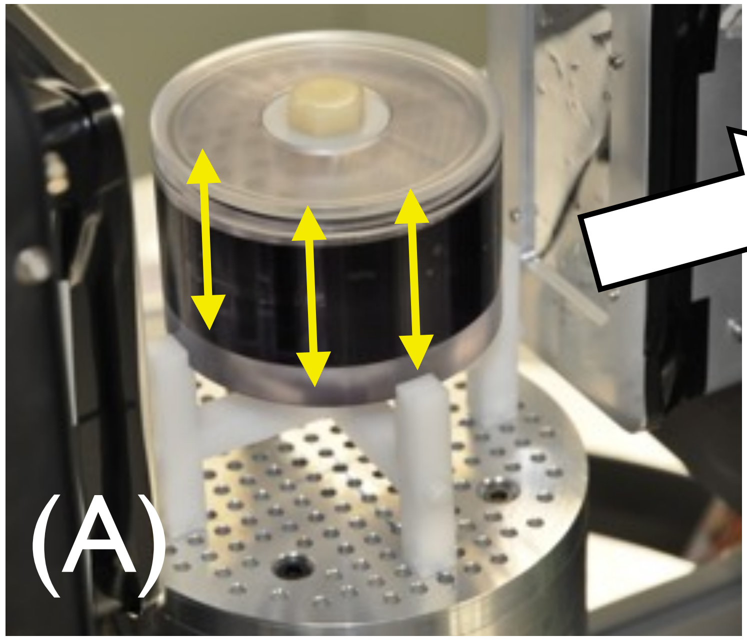
Resolution phantom

Mini Deluxe phantom

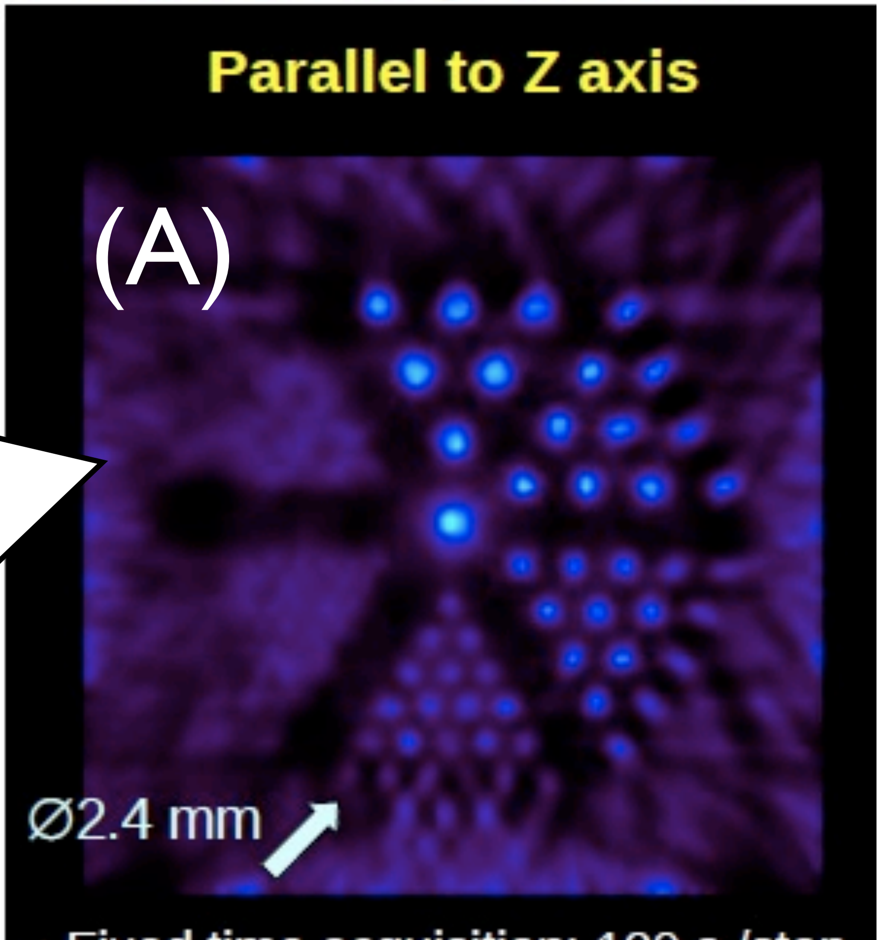
- extended FOV
- measurements performed at AAA
- phantom filled with 18-F in water solution



July 2011,AAA



Rods oriented parallel to Z axis

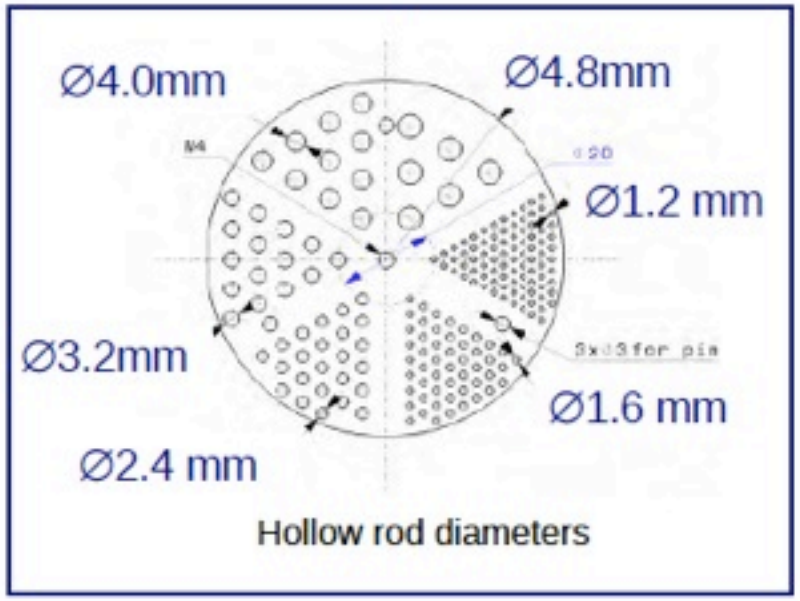


- Fixed time acquisition: 120 s /step
- 60 iterations + post-reconstruction smoothing
- No corrections
- Artefacts due to data truncation (FOV too small...)

ETH Institute for Particle Physics

Resolution pha

Mini Deluxe phantom

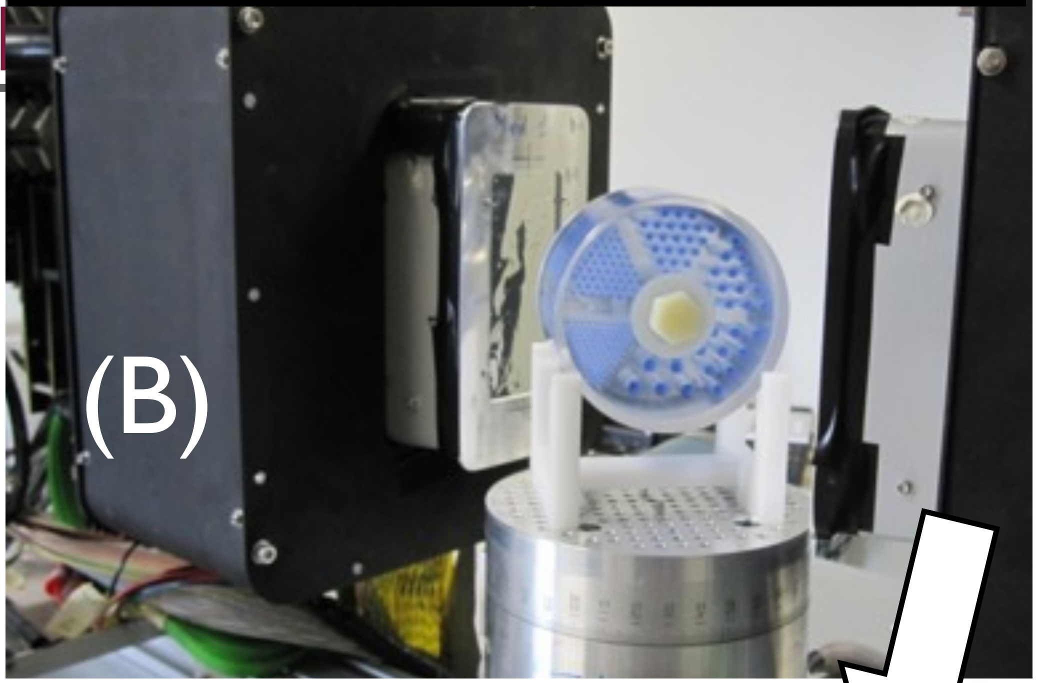


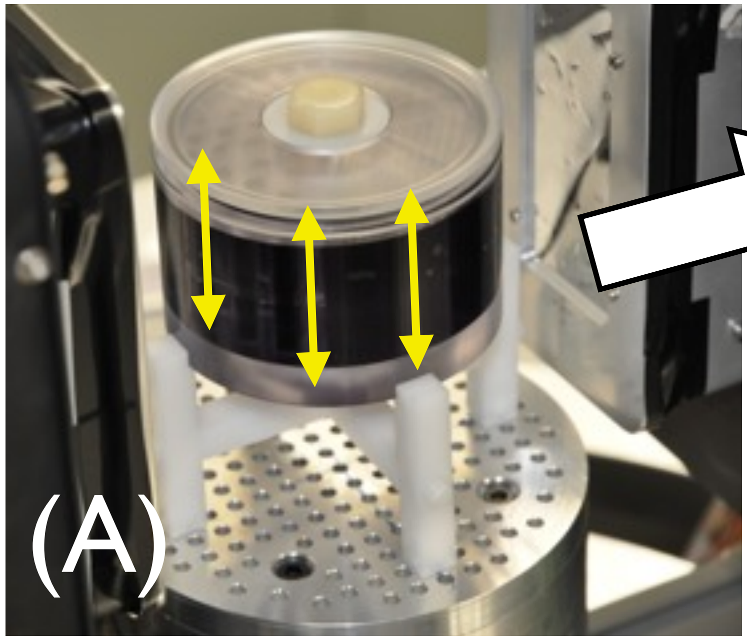
Hollow rod diameters

- extended FOV
- measurements performed at AAA
- phantom filled with 18-F in water solution

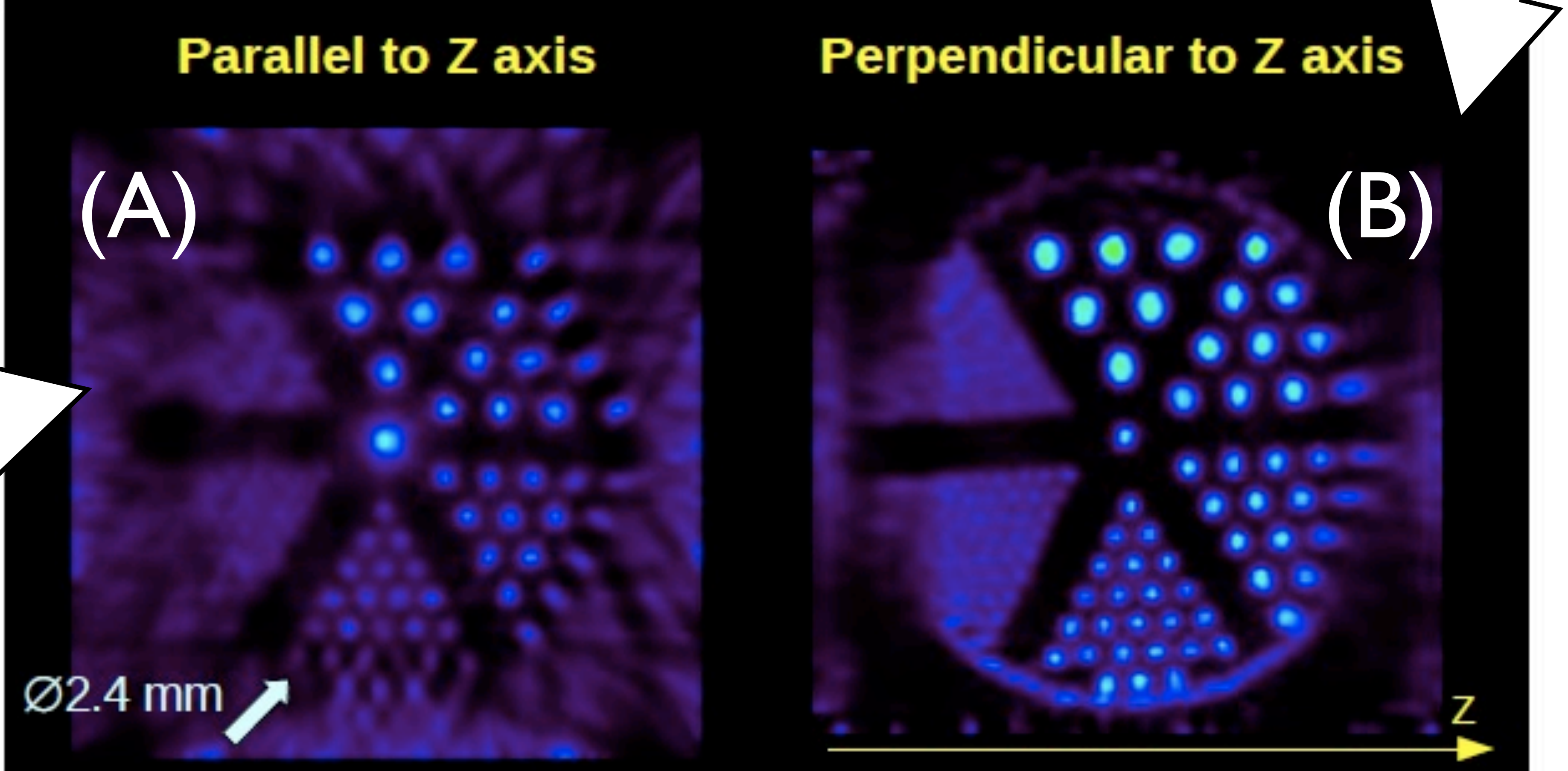
July 2011,AAA

Rods oriented perpendicular to Z axis





Rods oriented parallel to Z axis



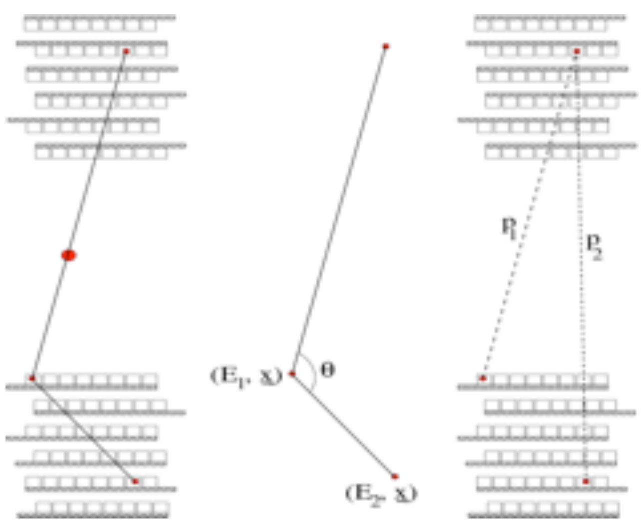
- Fixed time acquisition: 120 s /step
- 60 iterations + post-reconstruction smoothing
- No corrections
- Artefacts due to data truncation (FOV too small...)

Results presented in Valencia, IEEE 2011

Inter-Crystal Scattering (ICS)

Images shown before used only photoelectric absorption events !

But ignoring ICS events is **underutilization of the acquired data**
=> **Attempts to <u>include ICS events</u> in the reconstruction <u>i.e. improve sensitivity</u>**

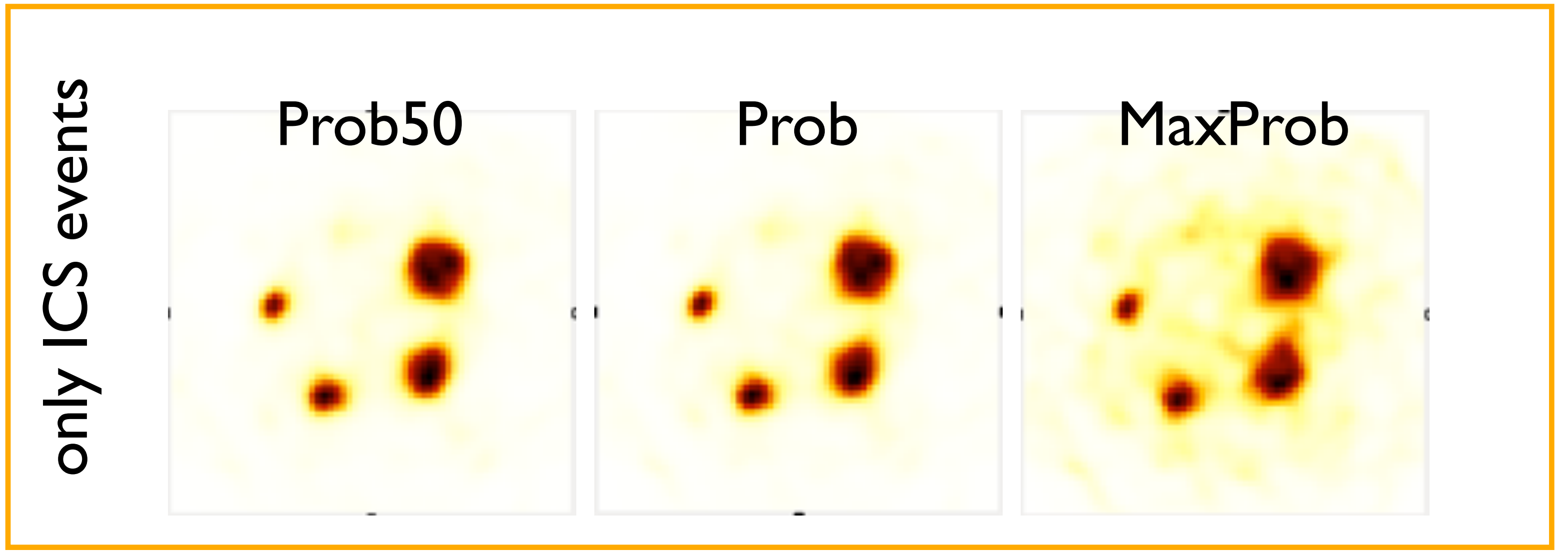


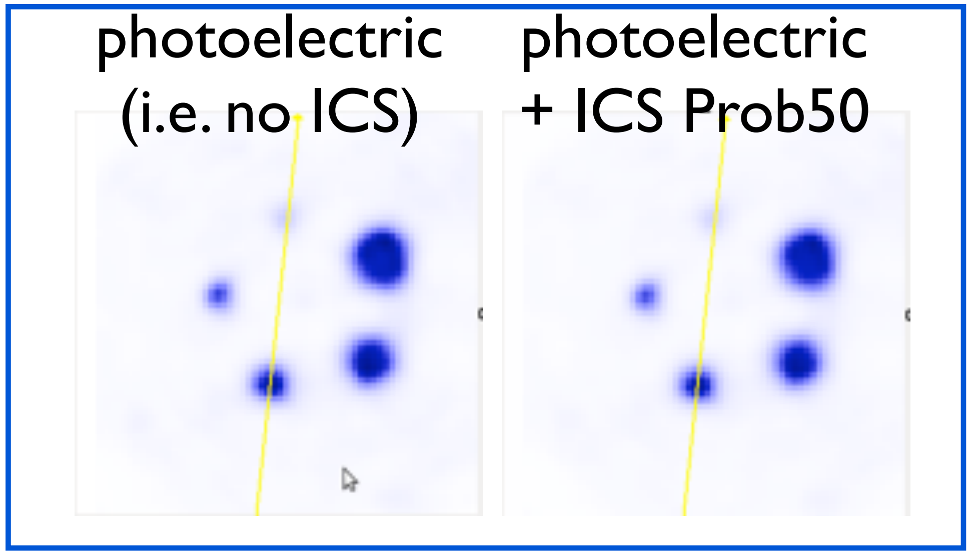
"triple" ICS events => 2 possible LOR :

- include both LOR, equal weight ("Prob50")
- include both LOR, weight from $(d\sigma/d\Omega)_{\text{Klein-Nishina}}$ ("Prob")
- include only one LOR, the one with max Prob. $(d\sigma/d\Omega)_{\text{Klein-Nishina}}$ ("MaxProb")

NEMA Phantom :

- **triple ICS (correctly reconstructed) / photoelectric ~ 20 %**
- photoelectric events largely dominate the reconstruction

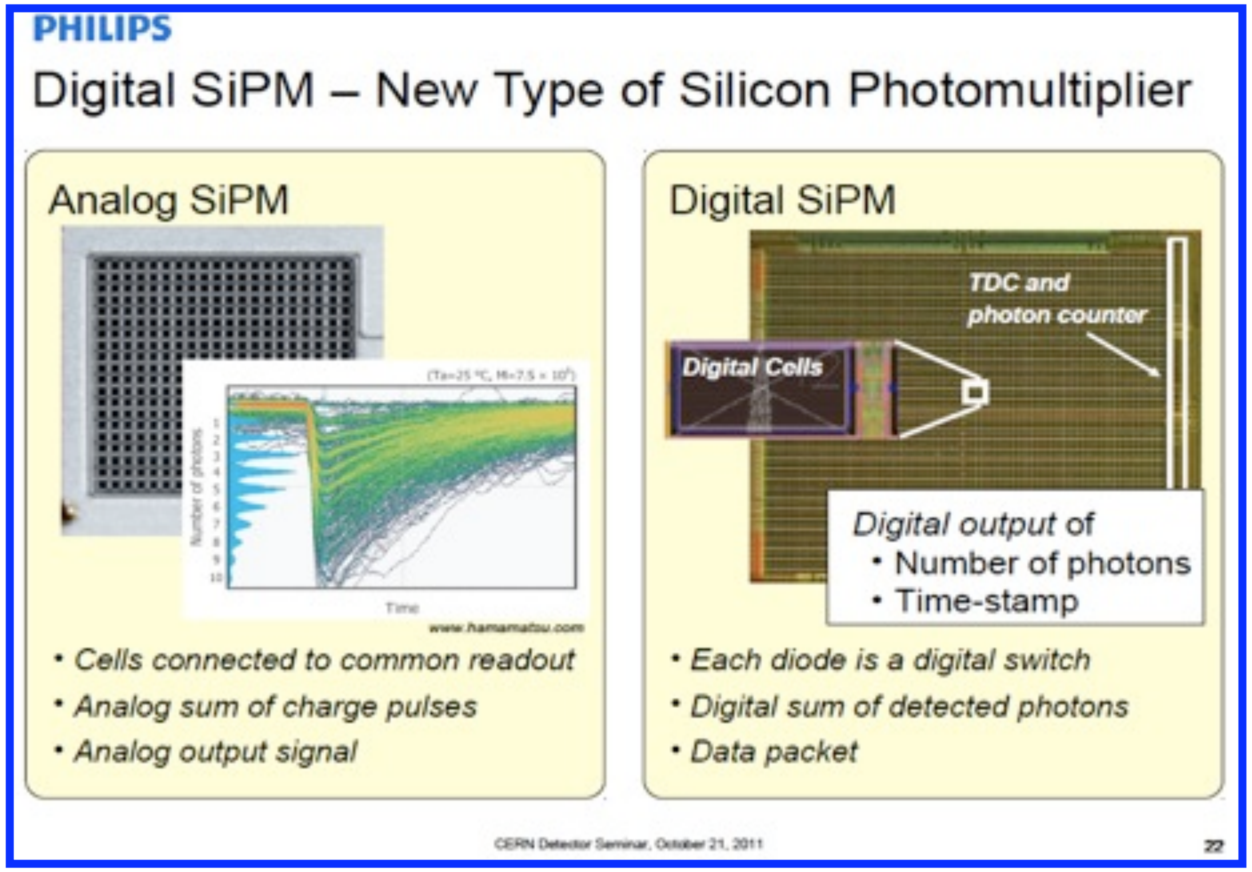




Works in progress!!! Preponderance of standard (photoelectric) coincidences => ICS inclusion provides only a small advantage. **Improvement expected to increase for smaller data sets.**

Digital SiPM from Philips

Digital SiPM: currently under test as possible alternative photodetector for AX-PET



PHILIPS

Digital SiPM – New Type of Silicon Photomultiplier

Analog SiPM

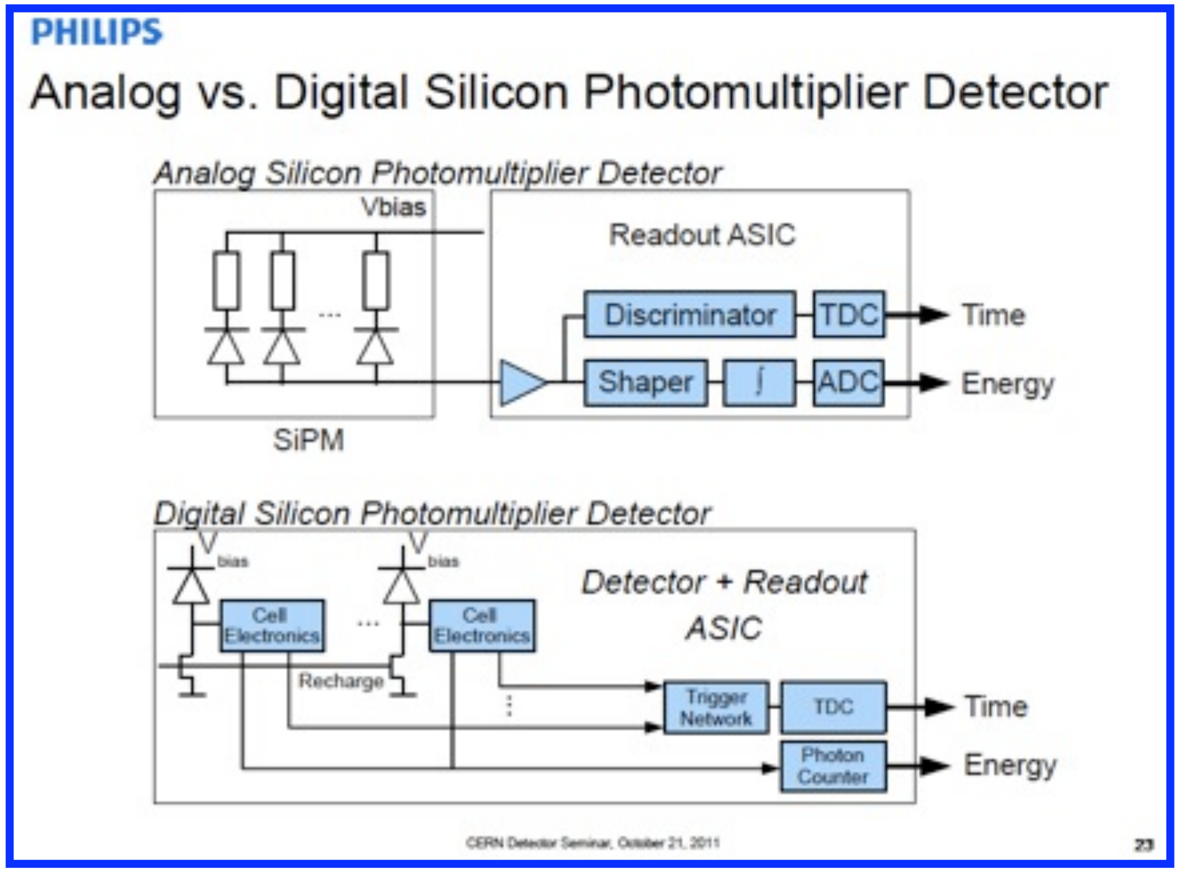
- *Cells connected to common readout*
- *Analog sum of charge pulses*
- *Analog output signal*

Digital SiPM

Digital output of
- Number of photons
- Time-stamp

- *Each diode is a digital switch*
- *Digital sum of detected photons*
- *Data packet*

CERN Detector Seminar, October 21, 2011 22



PHILIPS

Analog vs. Digital Silicon Photomultiplier Detector

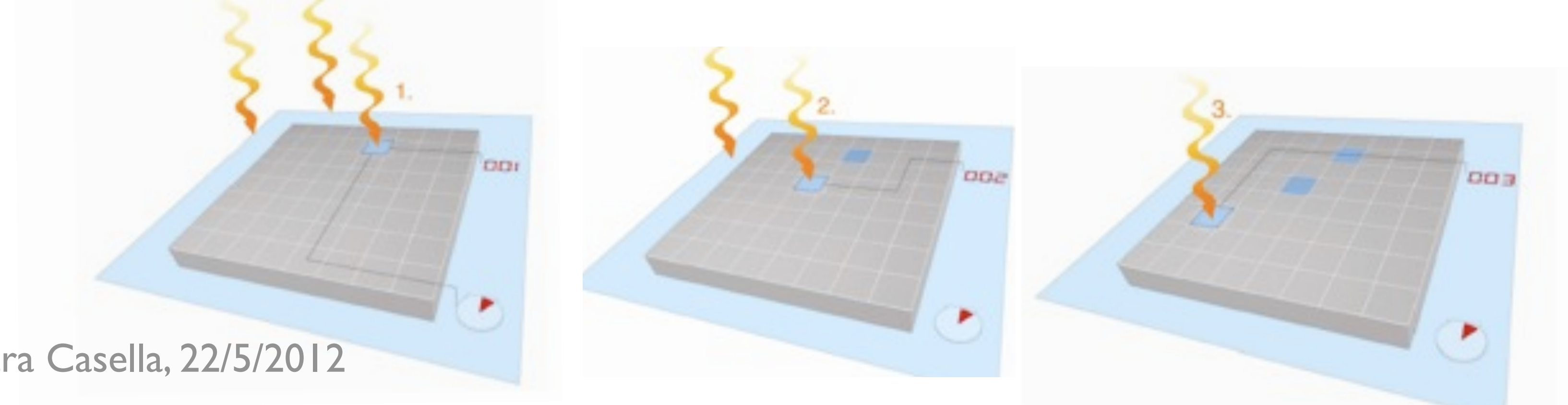
Analog Silicon Photomultiplier Detector

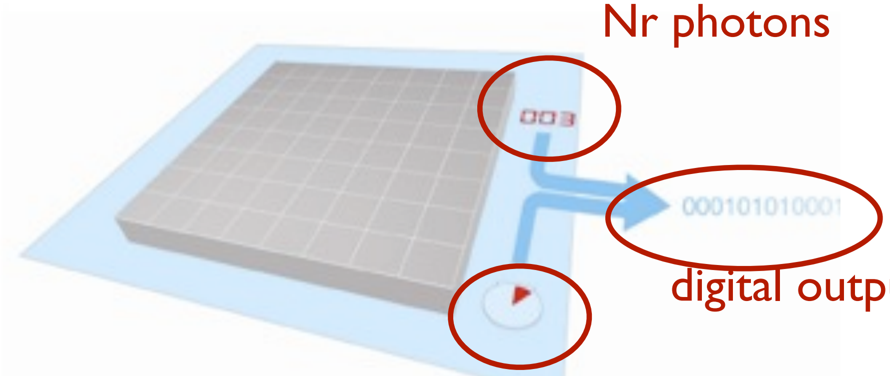
Digital Silicon Photomultiplier Detector

CERN Detector Seminar, October 21, 2011 23

Thomas Frach, CERN Detector seminar, Oct 2011

- fully digital implementation of SiPM / G-APD
- CMOS electronics integrated in the same substrate of each photodiode
- all photodiodes + their electronics connected to :
  - Photon counter
  - **TDC => time information**





Nr photons

digital output

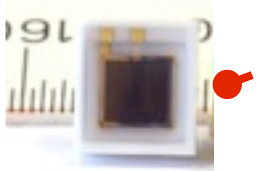
arrival time of the first
(triggering) photon

dSiPM for AX-PET

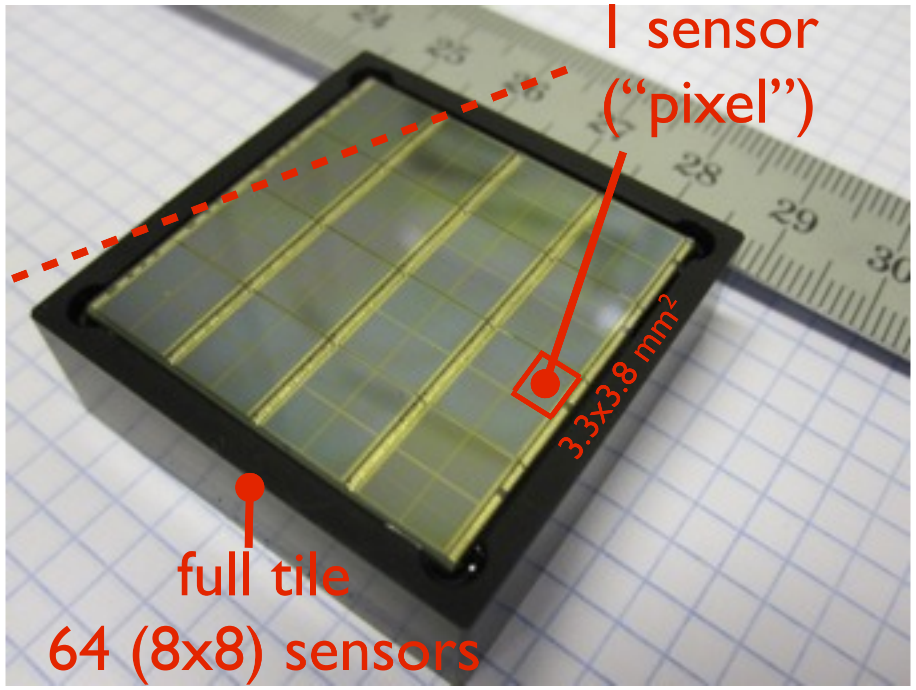
Interest of dSiPM for PET applications :

- **Timing information; intrinsically very good time resolution (~ 50 ps)**

  => Great potential for TOF-PET
- Small ; high level of integration; e.g. bias supply included => Compactness
- Digital => Low noise.
- Digital => Temperature and gain stability less crucial than in analogue devices.
- Possibility to disable individual cells => Significant reduction in the dark count rate (but lower PDE)
- MRI compatible



MPPC :
3600 cells
3x3 mm^2



DPC3200-22-44

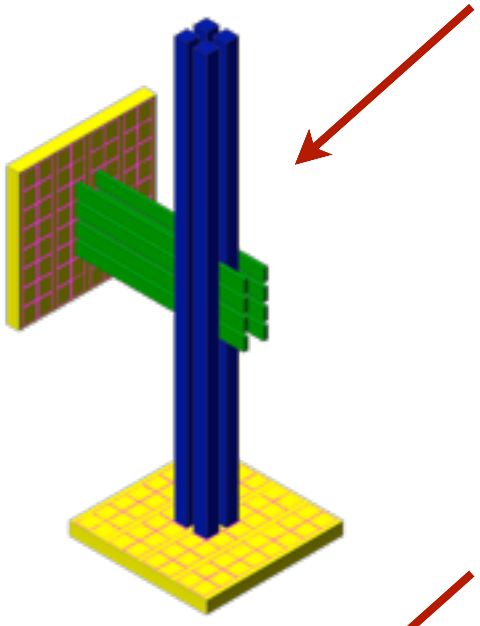
two different implementations

- DPC6400-22-44 : 6400 cells / pixel
- DPC3200-22-44 : 3200 cells / pixel

{ - better filling factor, higher PDE
- larger dark count rate
- higher saturation

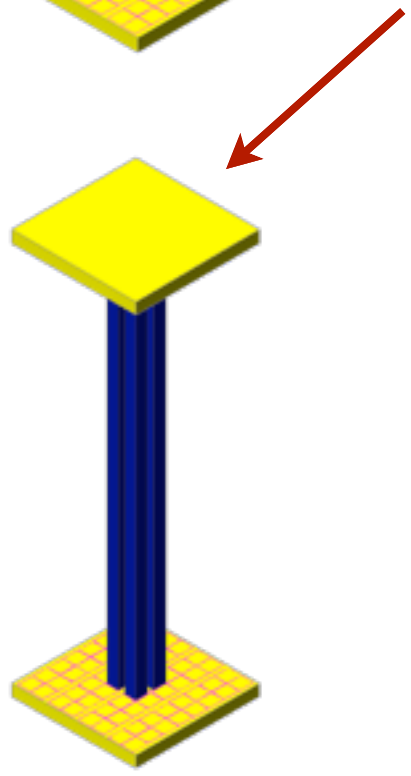
AX-PET setup with dSiPM

Goal : test the potentiality of a TOF-PET combined with the axial concept



reduced size AX-PET like module

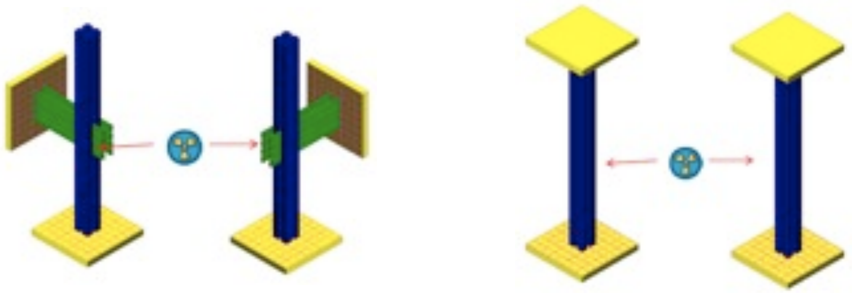
- 4 LYSO (2x2) and 16 WLS strips (2x8)
- dSiPM coupled to LYSO and WLS strips
- axial coordinate measurement, axial resolution
- timing of the photons vs axial position



dual side readout of the LYSO

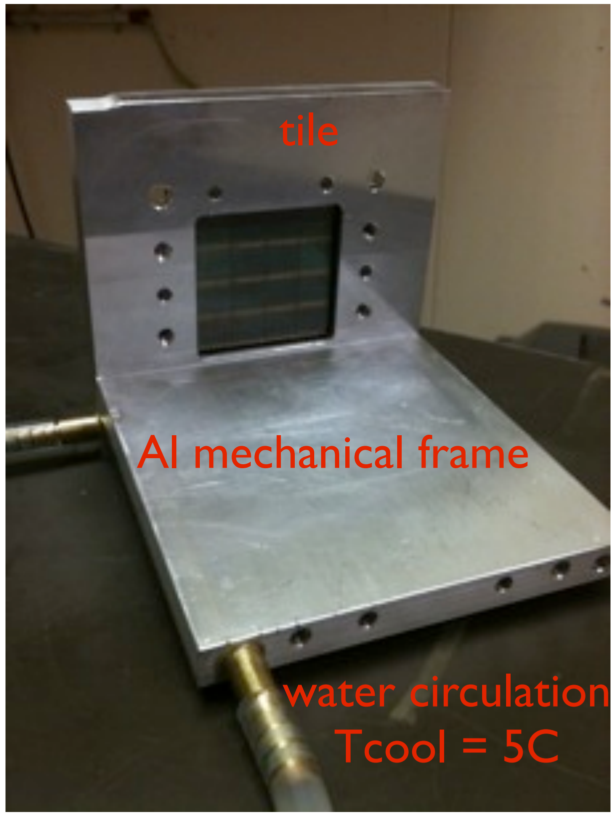
- timing (mean time measurement)
- (modest) axial coordinate measurement (both from time and from light yield sharing)

coincidences setup



Setups currently being built !

Tile need to be cooled to reduce the dark count rate !

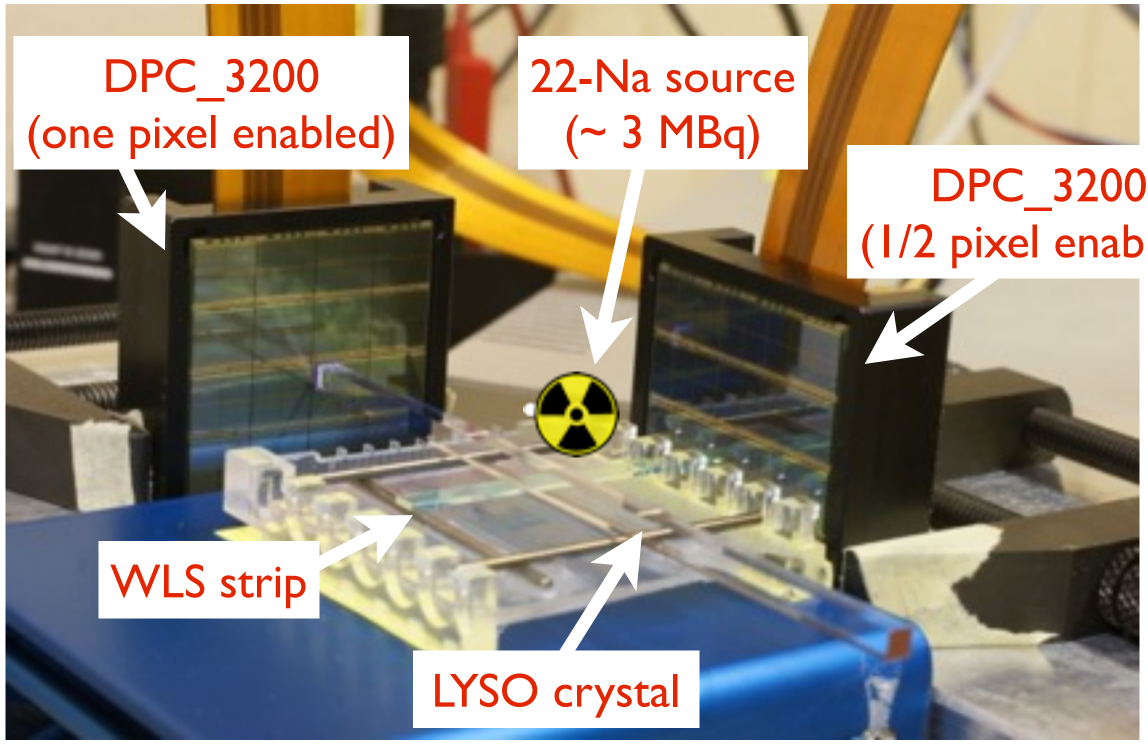


	dark count PER CELL	dark count PER PIXEL
room T	~ 2.5 kHz	8 MHz
10 ˚C	~ 1 kHz	3.2 MHz
10 ˚C 10% worst cells disabled	~ 350 Hz	~ 1 MHz

measured on DPC3200-22-44

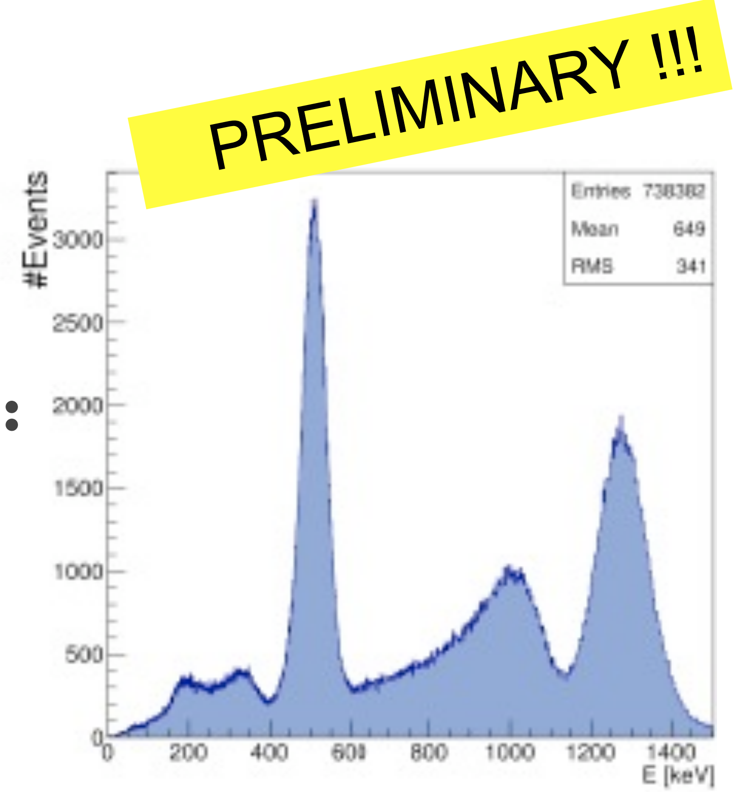
Minimal AX-PET like setup

- basic setup, poor mechanical precision and reproducibility - no cooling

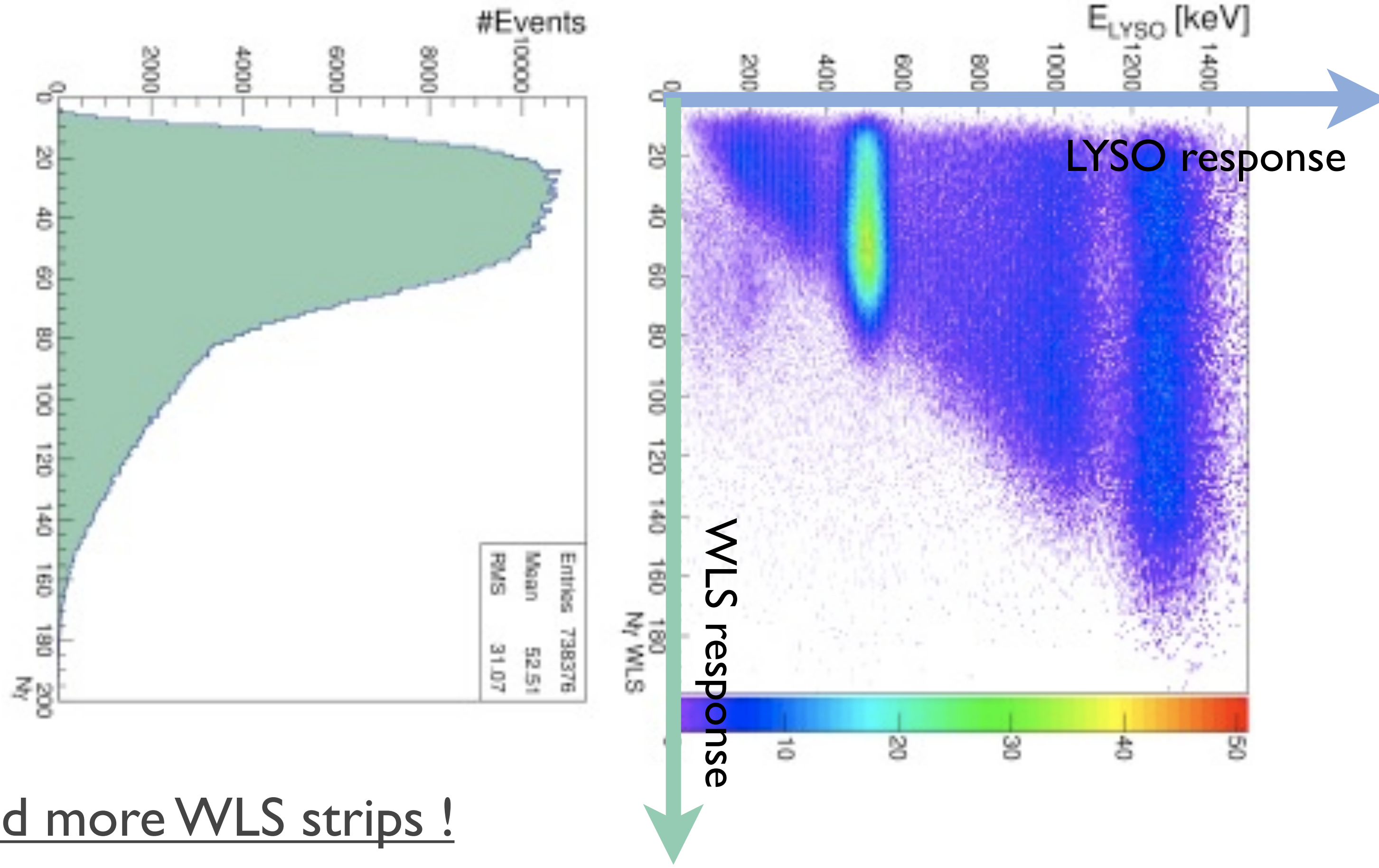


AX-PET components :

- one LYSO crystal
- one WLS strip
- 22-Na source



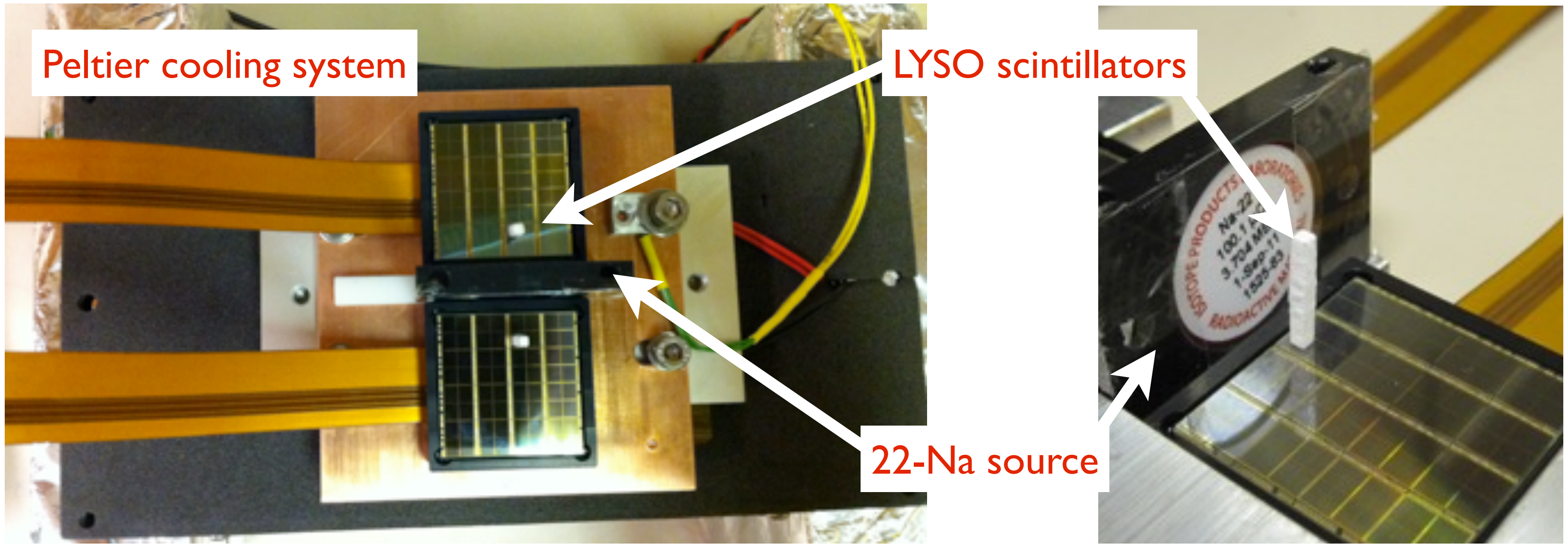
- **(LightYield)$_{\mathbf{lyso}}$ ~800-1500 pe** @511 keV
  (strongly dependent on optical coupling)
- after correcting for dSiPM saturation
  => **R_FWHM ~ 12.3%** @511 keV
- **(LightYield)$_{\mathbf{wls}}$ ~ 50 pe**
  (@511 keV energy deposition in the LYSO)
- clear correlation in the LYSO/WLS responses
- large spread in the WLS response due to non collimated beam



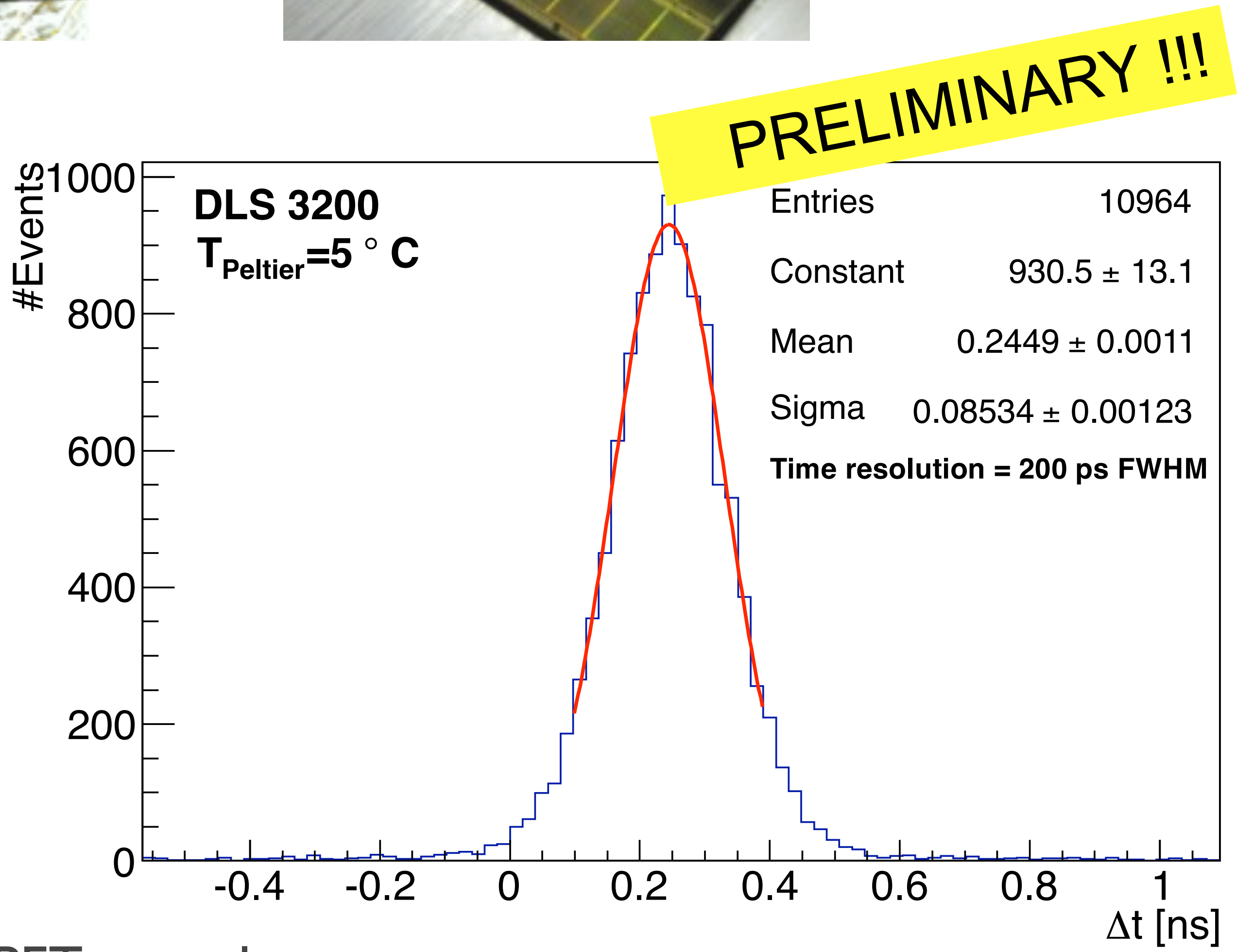
- <u>no axial coordinate measurement, this would need more WLS strips !</u>

Timing perfs, first results

- basic setup, poor mechanical precision and reproducibility



- **two small LYSO scintillator crystals**
  - **non AX-PET standard**
  - (2x2x12)mm^3 ; (2x2x15)mm^3
  - teflon wrapped, optical coupling with grease
- two DLS_3200 tiles
- 22-Na source
- measure the time difference (Δt) between the arrival of the first photons in the tiles
- **Δt = 200 ps, FWHM**
(cutting on events with 511 keV energy deposition)
- Tile cooling with a Peltier unit ($T_{Peltier}$ = 5˚C)
- Need to repeat the measurement with the long AX-PET crystals



Conclusions

Axial concept for a PET scanner :

i.e. long and axially oriented scintillation crystals, intrinsically parallax free system

Spatial resolution and sensitivity could both be optimized

AX-PET implementation :

3D spatial information of the photon interaction point with :

matrix of LYSO crystals and WLS strips

individual readout of each channel (Si-PM)

Two modules built (i.e. **AX-PET demonstrator**)

Energy resolution ~ 12% FWHM,@ 511 keV

Spatial resolution ~ 1.35 mm FWHM

(competitive with state of the art PET)

AX-PET demonstrator :

Extensively tested with sources and successfully used for phantoms image reconstruction!

Digital SiPM as promising alternative for photodetector for AX-PET

excellent time resolution => great potentiality for TOF-PET

currently being tested for the possibility of TOF-PET combined with the axial concept

final setup being built

preliminary promising results (from rudimentary setups) :

Δt ~ 200 ps FWHM (with short crystals!!!)

LY ~ 1500 pe for AX-PET LYSO scintillators

ΔE/E ~ 12% FWHM @511 keV

axial resolution ...... (results still to come....)

- **calorimeter with tracking capabilities** (granularity)
- **novelty as a PET detector :**
  - geometry
  - materials and technology “stolen” from high energy physics
  - WLS implementation
  - Compton scattering reconstruction

So... Stay tuned :-) !!!

The AX-PET Collaboration

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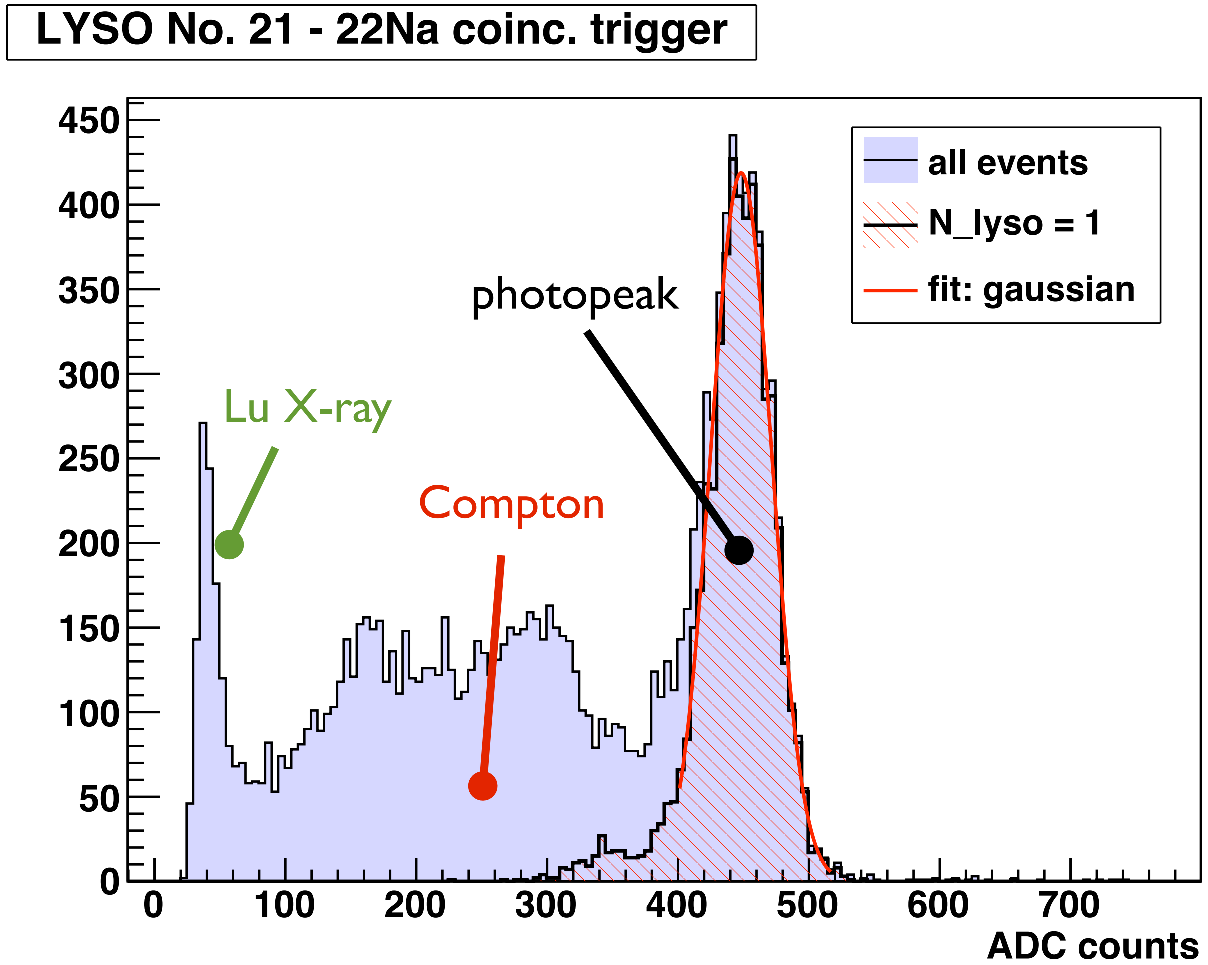
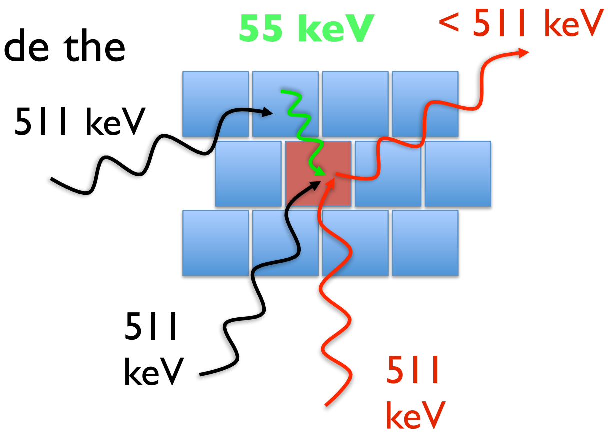
LYSO energy response



typical energy spectrum of one LYSO inside the module :

- photopeak (511 keV)
- Compton continuum (0 - 340 keV)
- Lu X-ray peak (~ 55 keV)

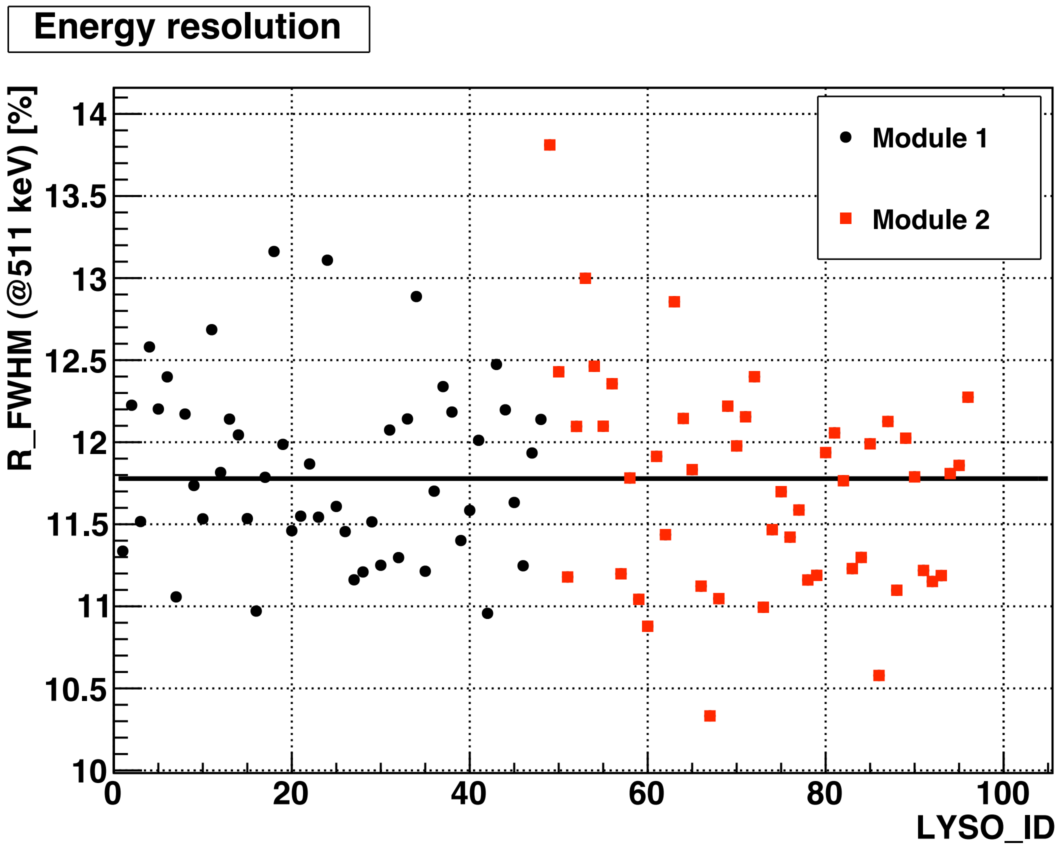


Light yield at 511 keV ~ 1000 pe

(from independent calibration measurements)

Energy resolution

- from gaussian fit of the photopeak
- AFTER ENERGY CALIBRATION

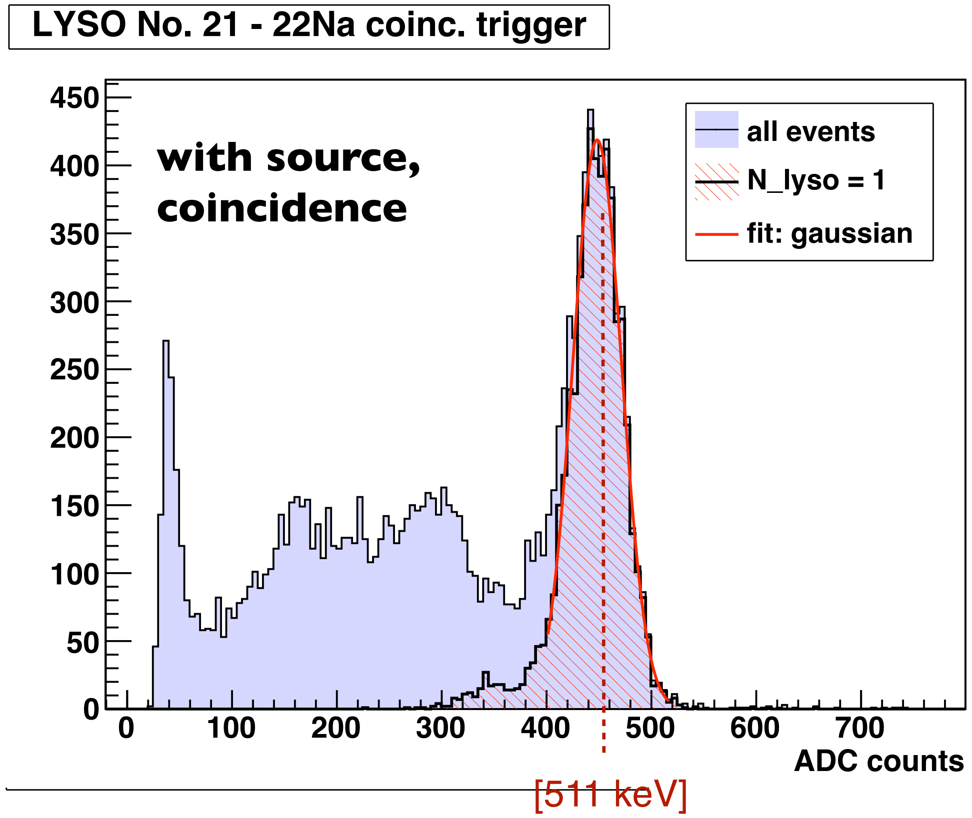


< R_FWHM > ~ 11.8% @511 keV

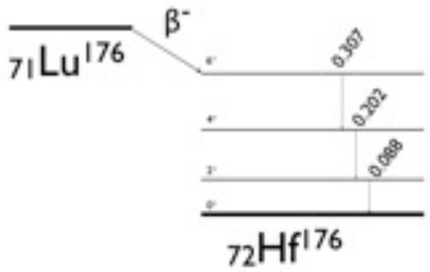
(averaged on 96 LYSO crystals)

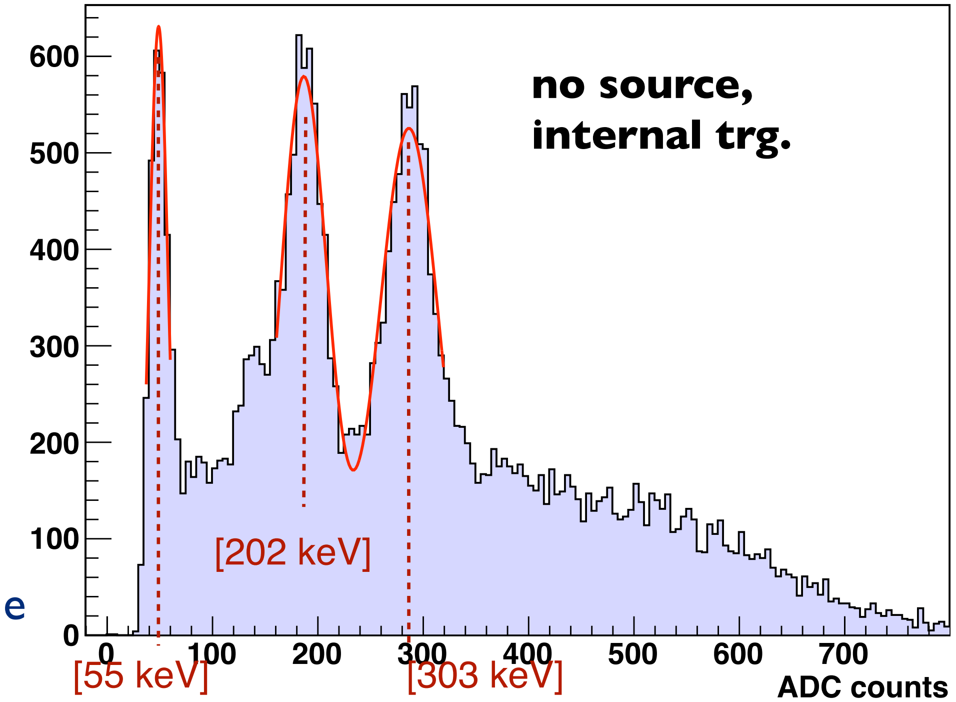
LYSO energy calibration

Photopeak + Intrinsic Lu radioactivity: very good tool for the energy calibration



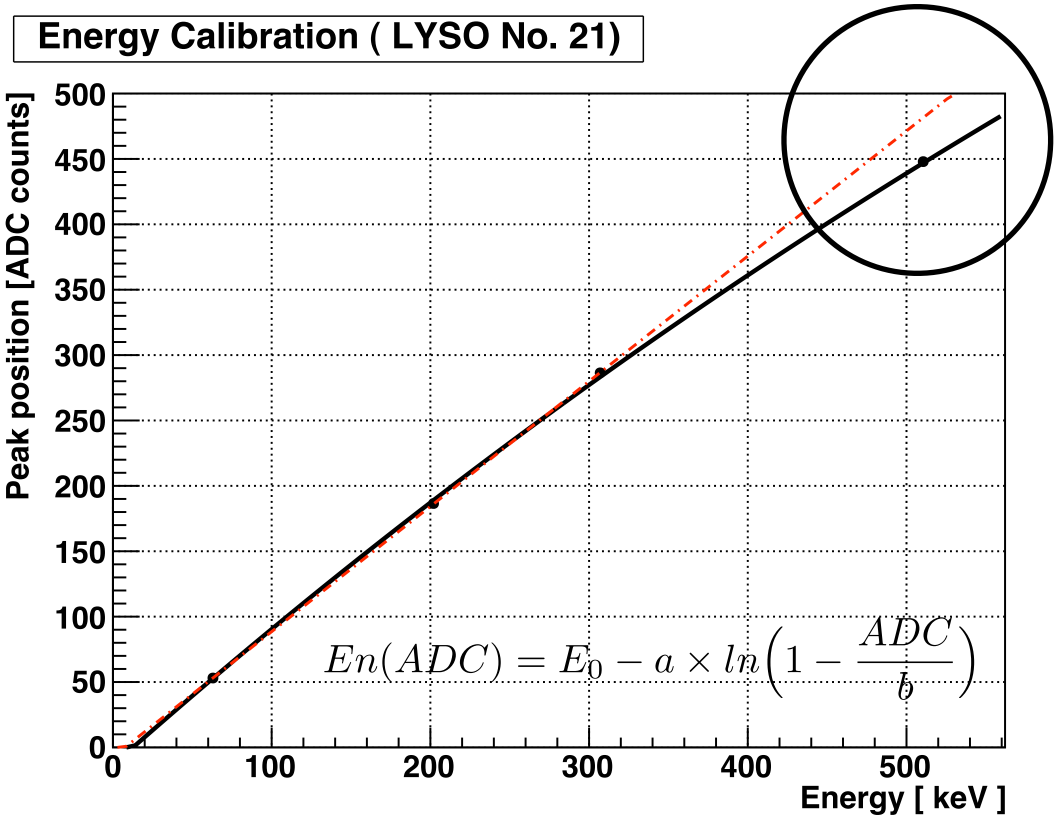
same procedure applied identically for every channel





- LYSO contains Lu-176
- A ~ 39 cps/g
  => ~ 250 Bq / bar
  => ~ 12 kHz / module

deviation from linearity (~ 5% effect)

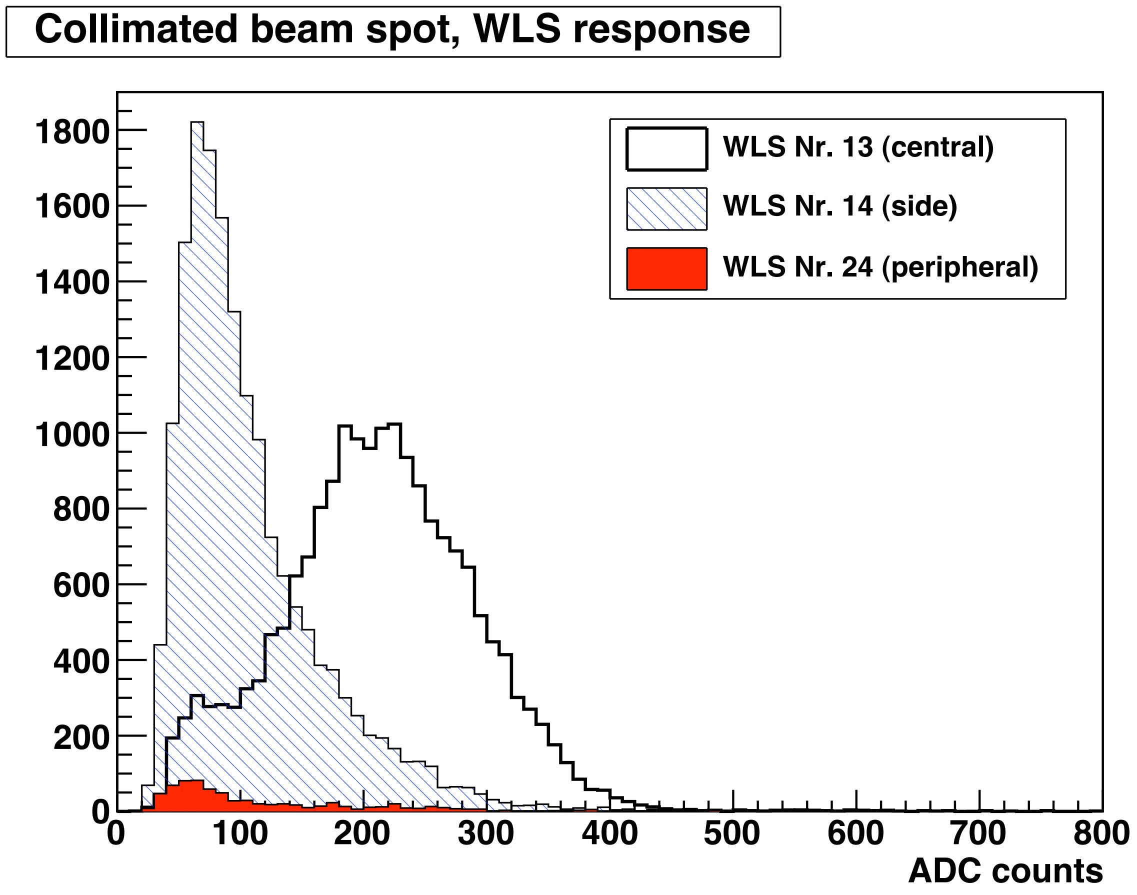


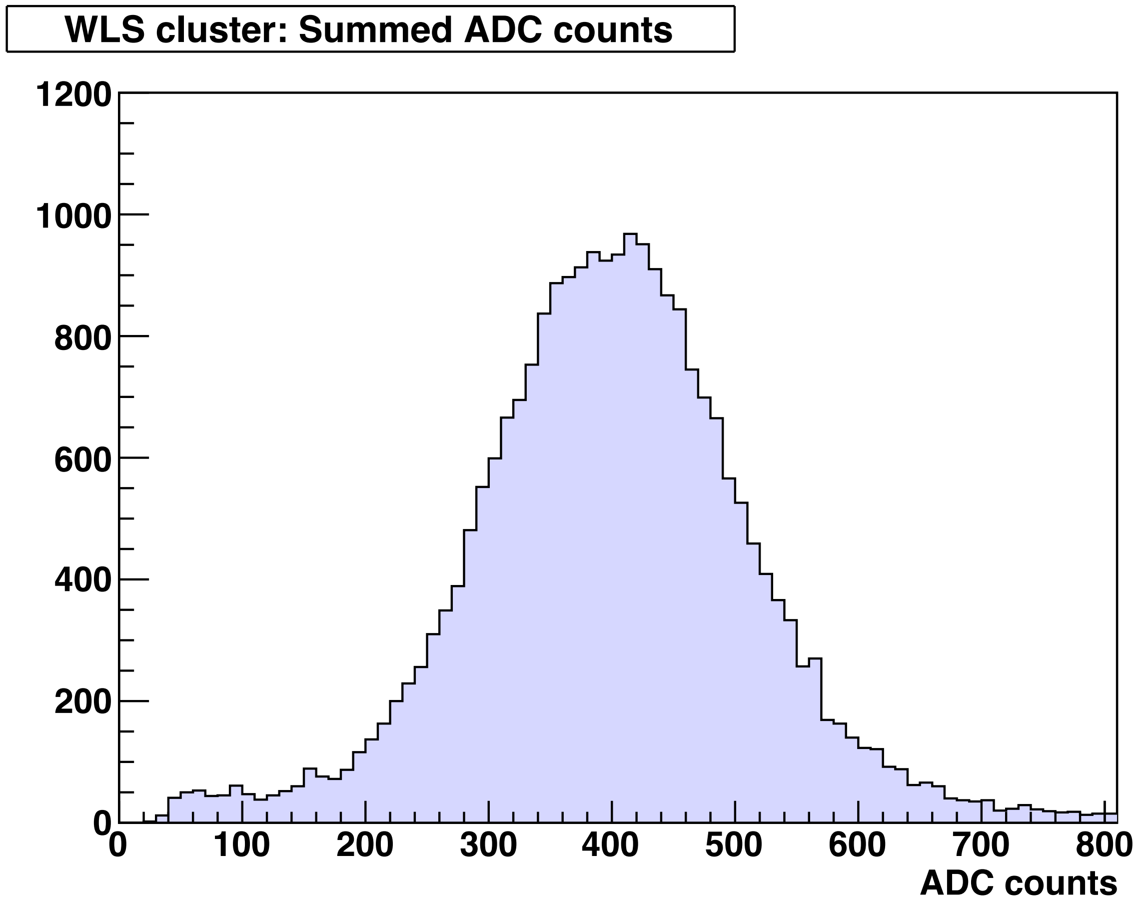
MPPC saturation. Due to:
- limited nr of cells in the MPPC (3200)
- important light yield in the scintillator (~1000).

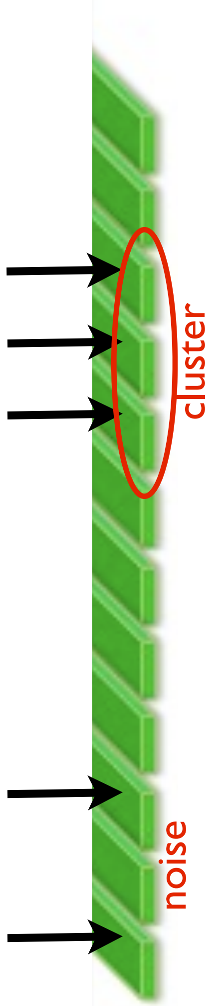
WLS response

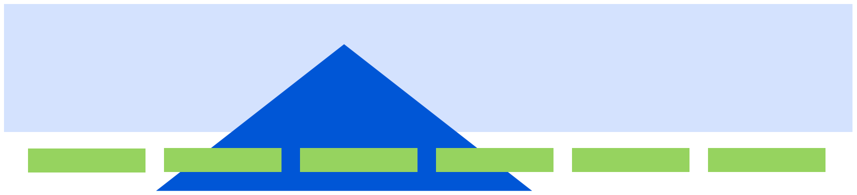
typical integrated raw spectra of few WLS strips

- beam spot collimated at the center of the module (WLS 13)
- 511 keV energy deposition in the LYSO









- more than1 WLS participate to the event (typically 2-4)
- noise should not be included

Light yield in WLS cluster ~ 100 pe
@511 keV LYSO energy deposition

(from independent calibration measurements: 1pe ~ 4 ADC)

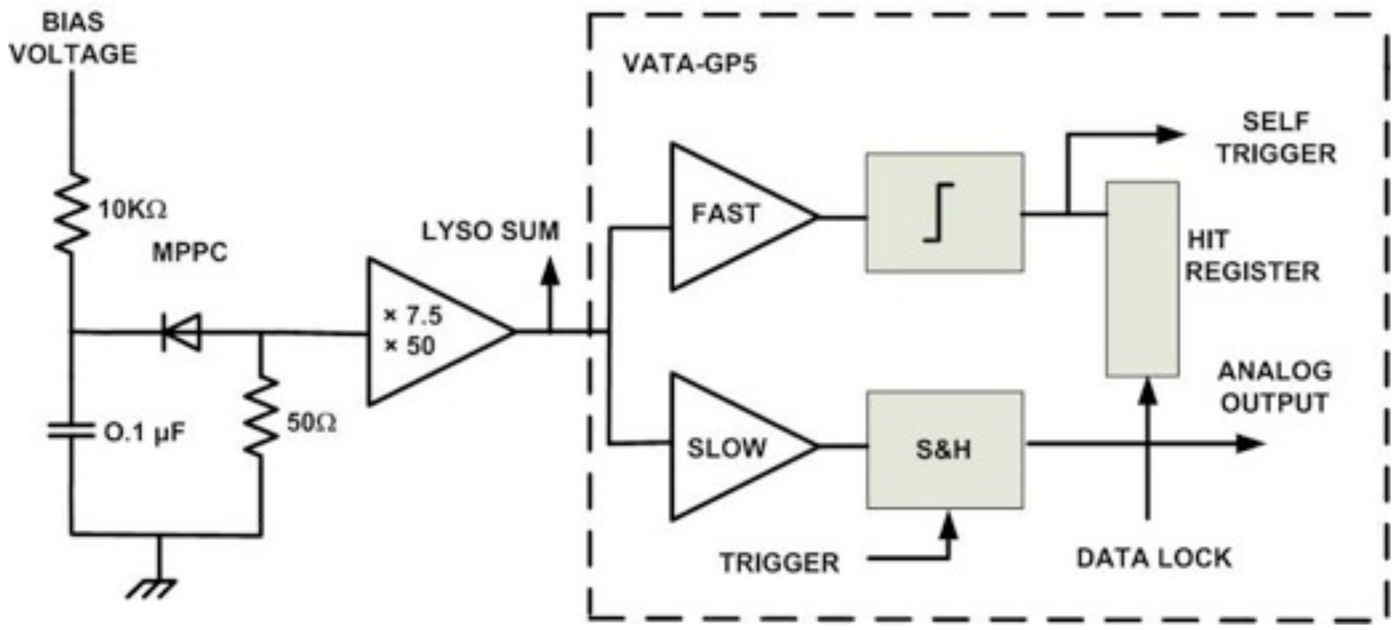
axial coordinate :
derived from center of gravity method
from all the WLS participating to the cluster

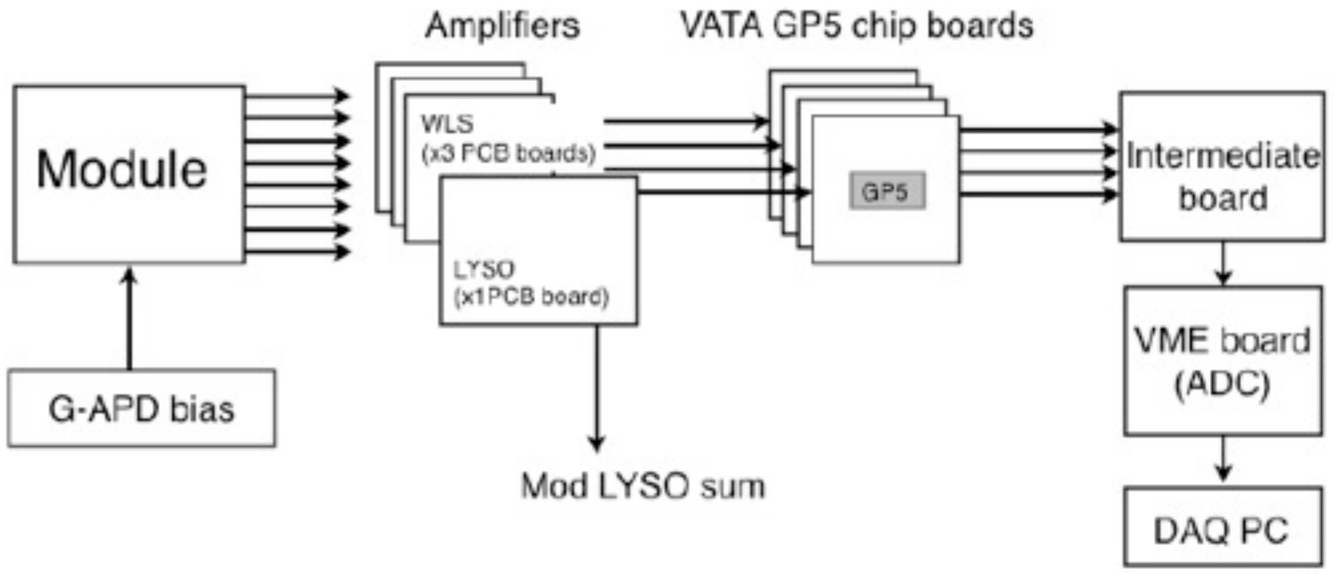
Readout & DAQ

Individual analogue readout of MPPC output
Custom designed DAQ system

- **fully analogue** readout chain
- **not optimized** at all for this specific application

- **Amplifiers:** OPA486 (Lyso) / OPA487 (WLS)
- Fast **energy sum** for all the crystals in the module
- **VATA GP5 chip**
  - 128 ch charge sensitive integrating
  - fast (~ 50ns shaper + discriminator) / slow (~ 250ns shaper) branches
  - **sparse readout** mode: only the channels above thr are multiplexed into the output
- analogue info processed by custom made VME **ADC**





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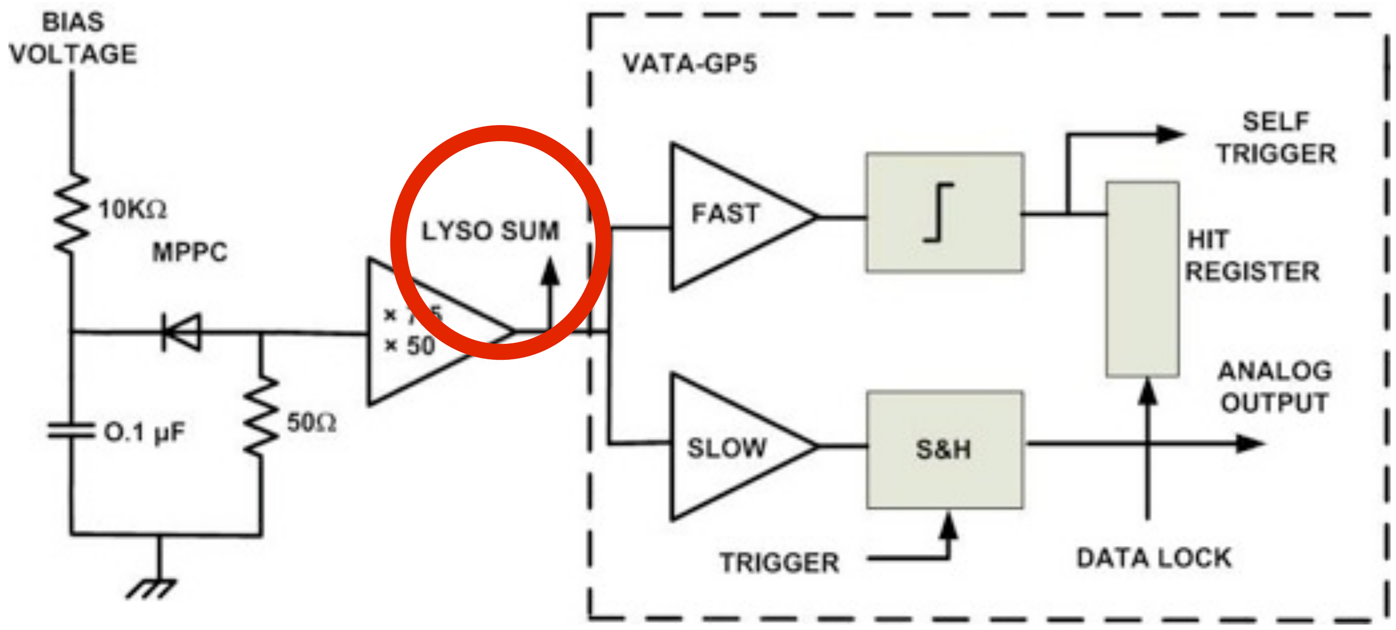
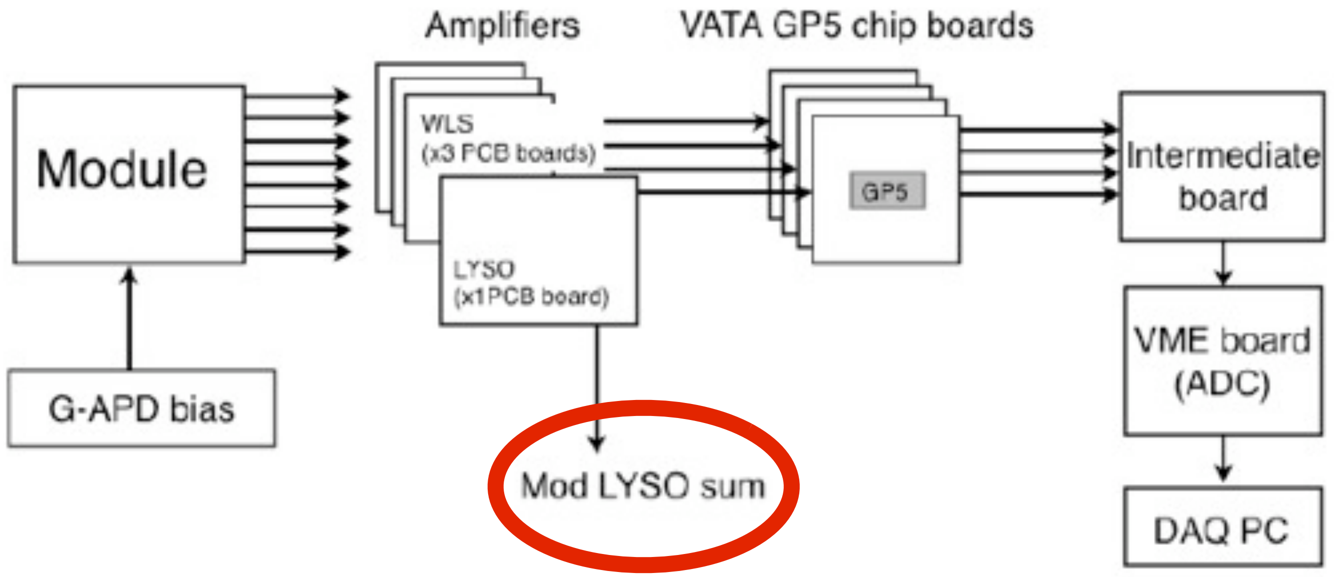
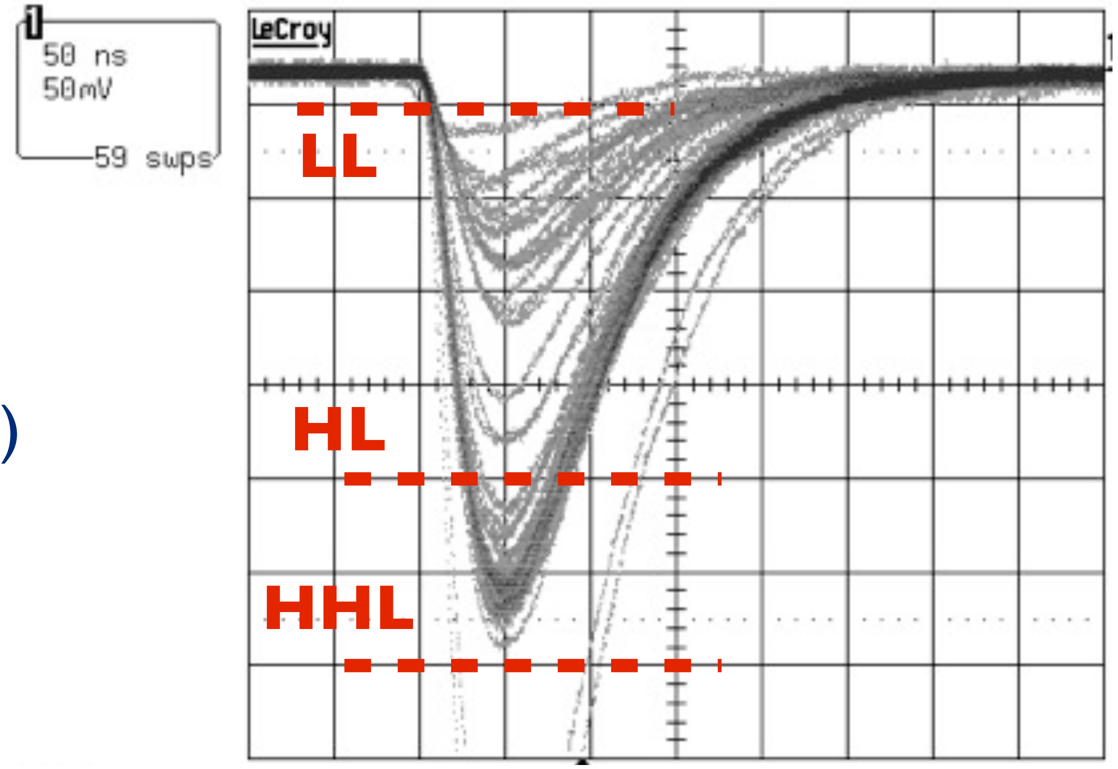




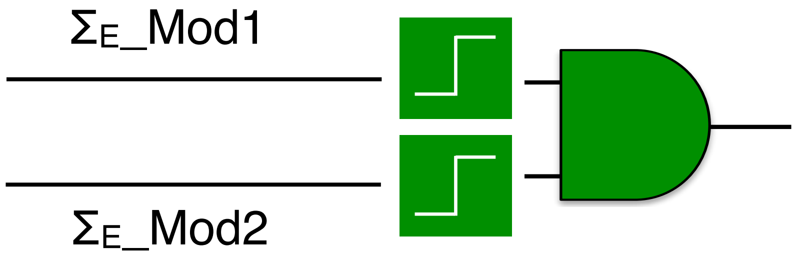
Fast energy sum & Trigger

- analogue sum of the whole module (i.e. total energy over 48 crystals)
- with a proper threshold choice (LL x HL X notHHL) => select only events with **511 keV total energy deposition**



Mod 1, energy sum (scope measurement), ^{22}Na source

TRIGGER

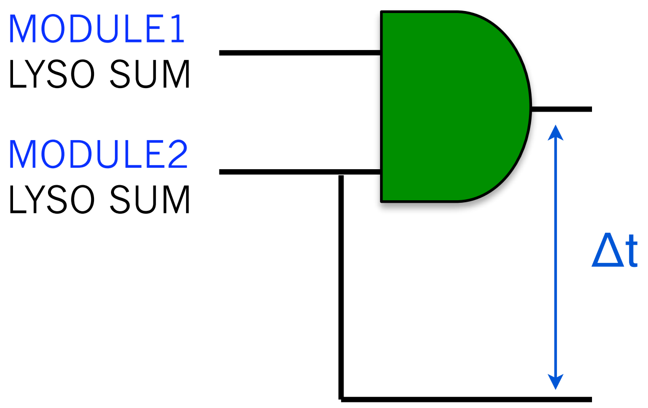


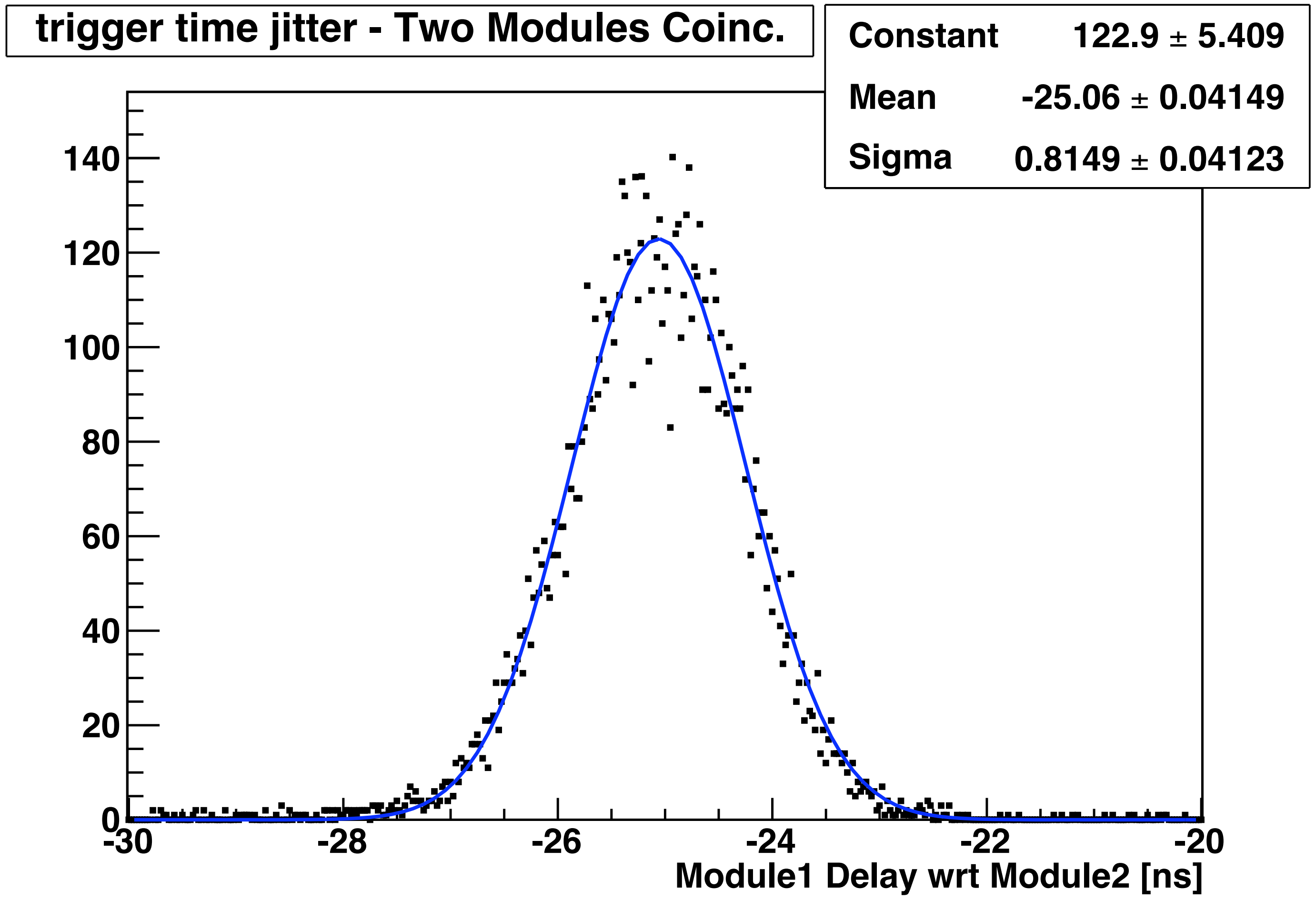
TRIGGER = 2 modules
- each one discriminated @ 511 keV energy sum
- used in coincidence

=> Selection of the good events

Time resolution

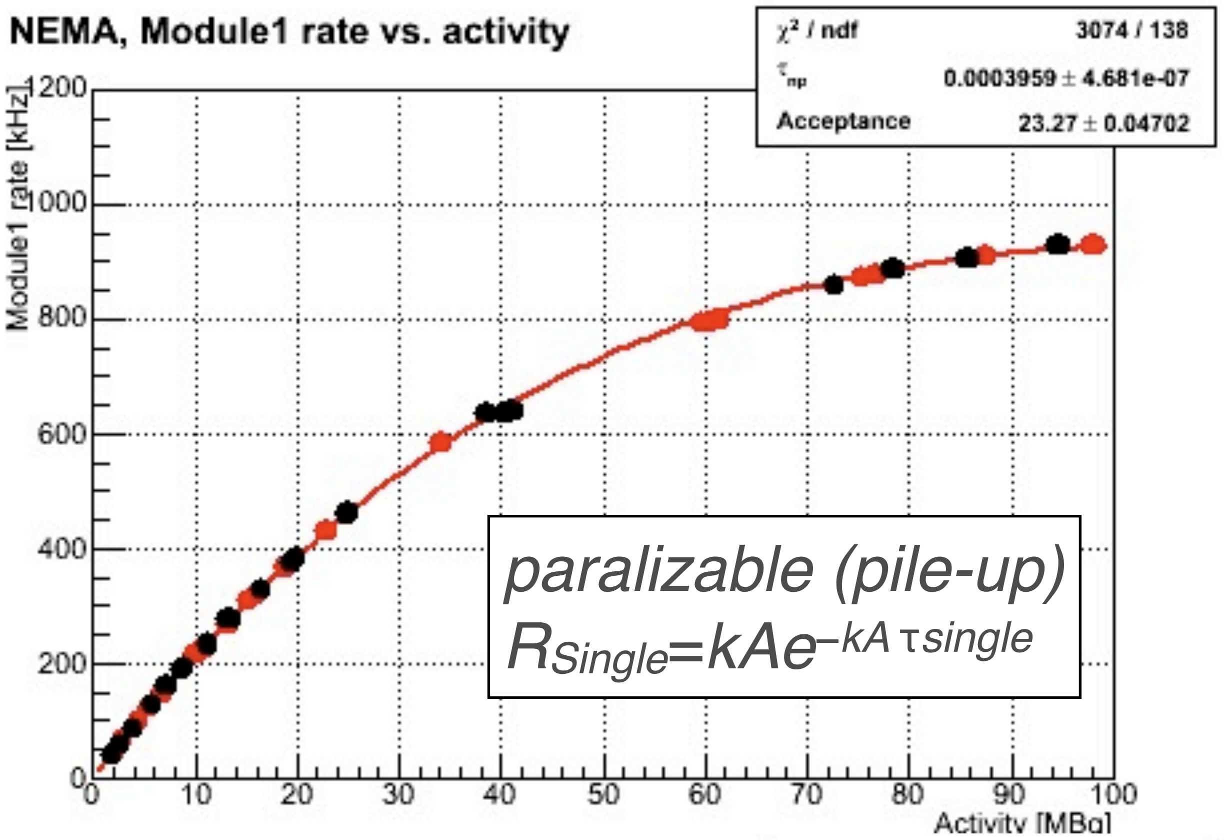
- measure delay of coincidence wrt Mod2
- measurement from the scope [Lecroy Waverunner LT584 L 1GHz]
  (no time information in the AX-PET readout)





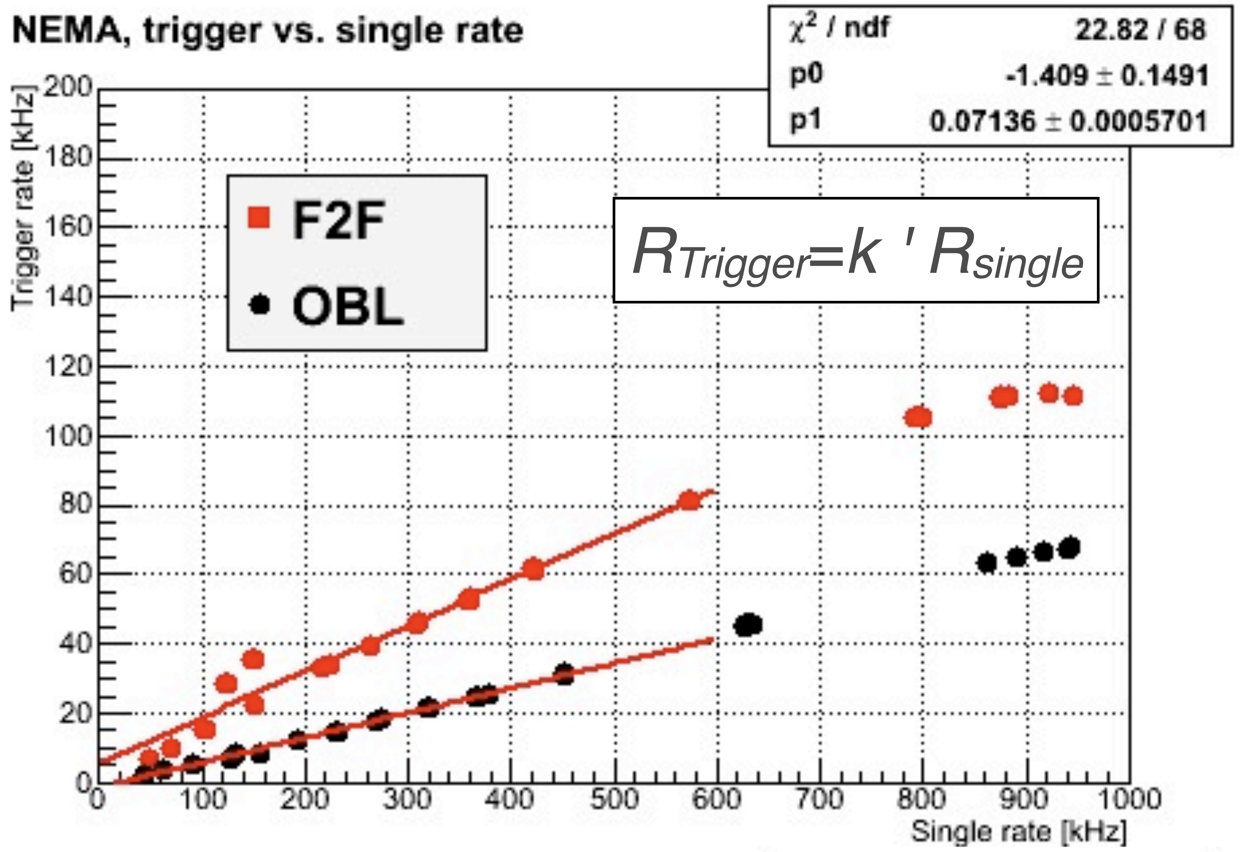
Measured time resolution : **FWHM ~ 1.9 ns**

Count rate curves (example : NEMA phantom)

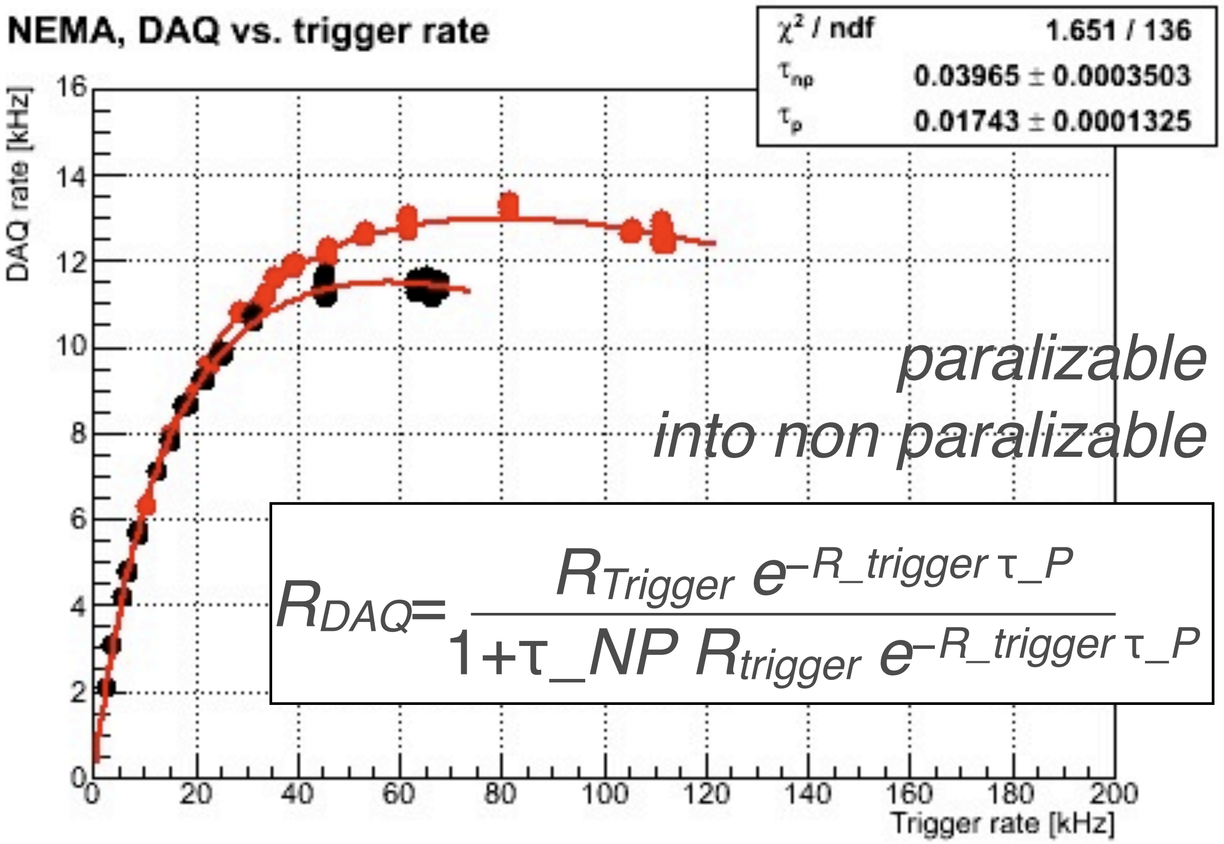


paralizable (pile-up)

$R_{Single}=kAe^{-kA\,\tau single}$

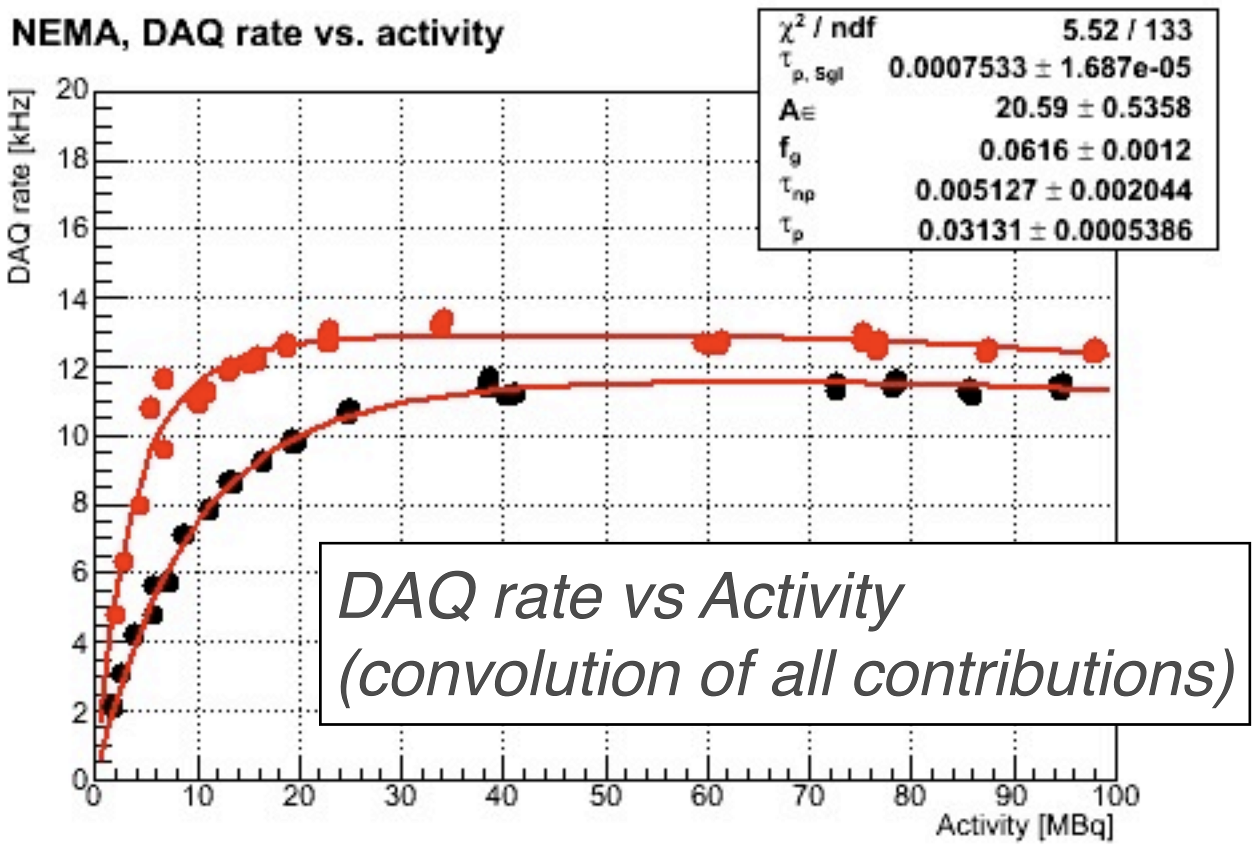


$R_{Trigger}=k\,'\,R_{single}$



paralizable
into non paralizable

$$R_{DAQ}=\frac{R_{Trigger}\ e^{-R\_trigger\,\tau\_P}}{1+\tau\_NP\ R_{trigger}\ e^{-R\_trigger\,\tau\_P}}$$



DAQ rate vs Activity
(convolution of all contributions)

Towards a tomographic reconstruction...

How to mimic a full scanner with 2 modules only available?

Central FOV :

rotating the phantom...

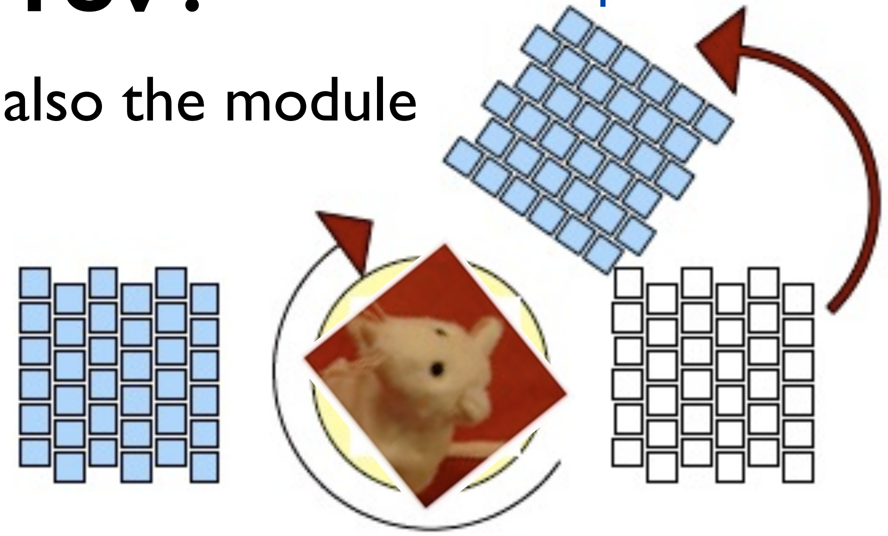
$\varphi = 0^\circ$

$\theta = 0^\circ, 20^\circ, 40^\circ \ldots 180^\circ$ **(9 steps)**

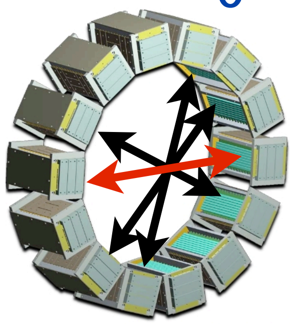
Extended FOV :

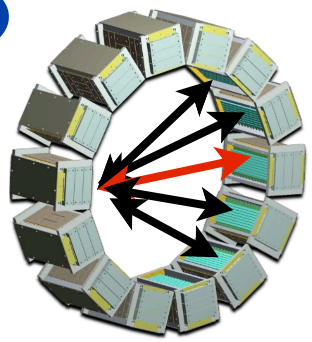
...and rotating also the module

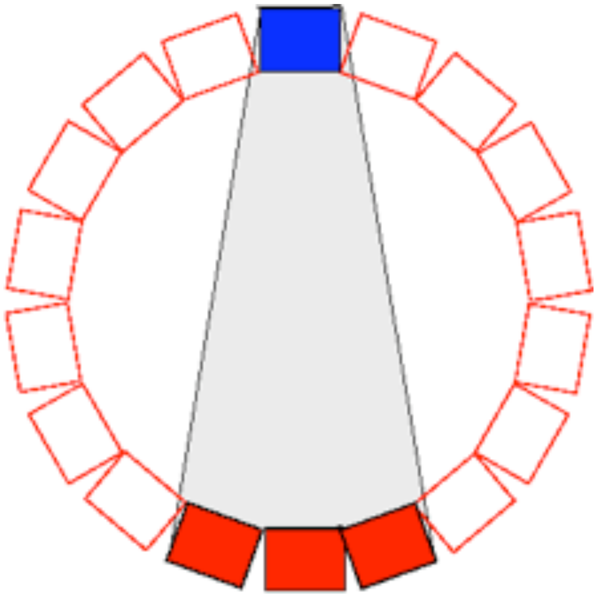
$\varphi = 20^\circ$



$\theta = 0^\circ, 20^\circ, 40^\circ \ldots 360^\circ$ **(18 steps)**



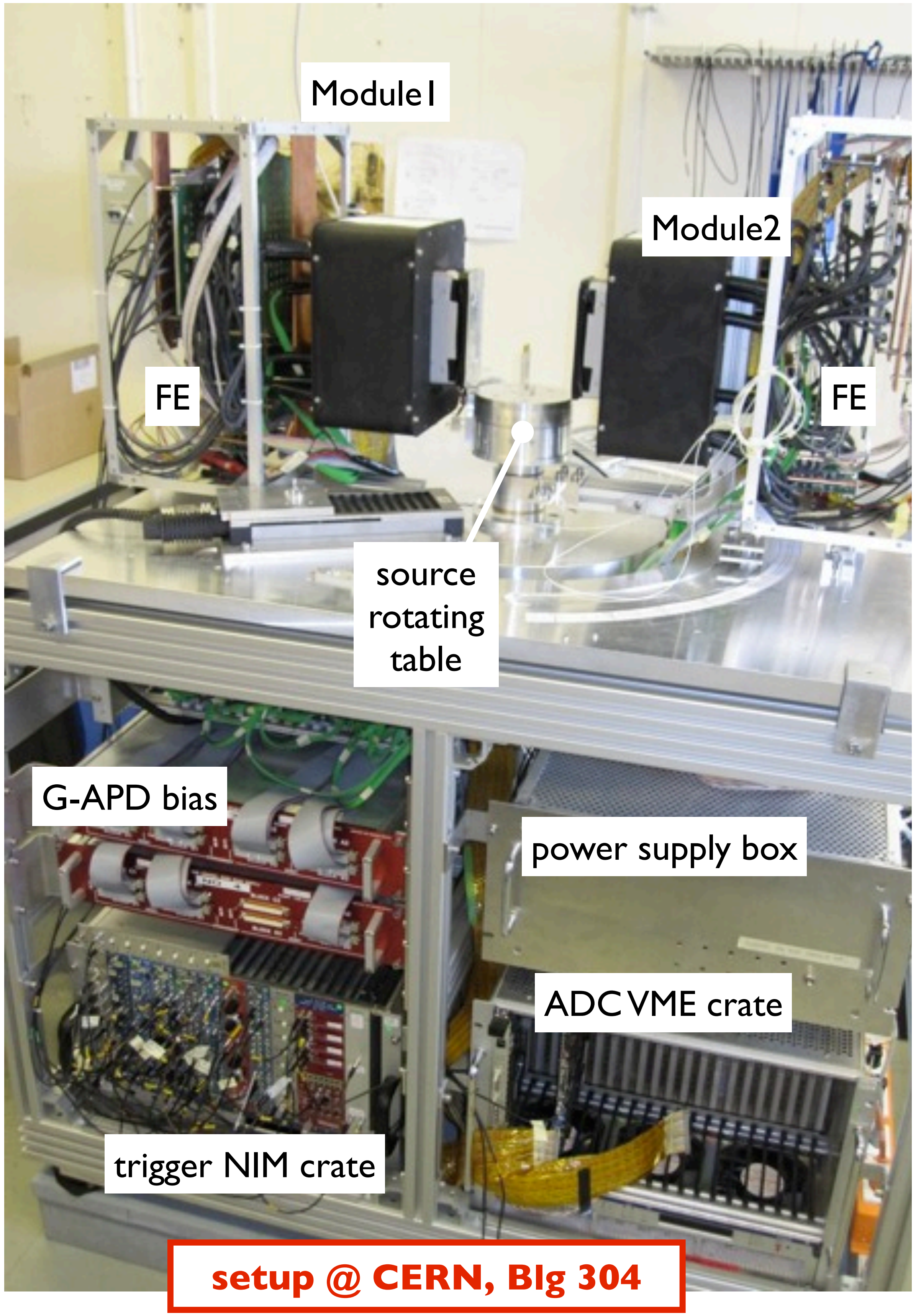




1 tomographic acquisition
= 27 steps acquisition

mimics a 18-modules ring, with coincidences between face-to-face ± one adjacent modules

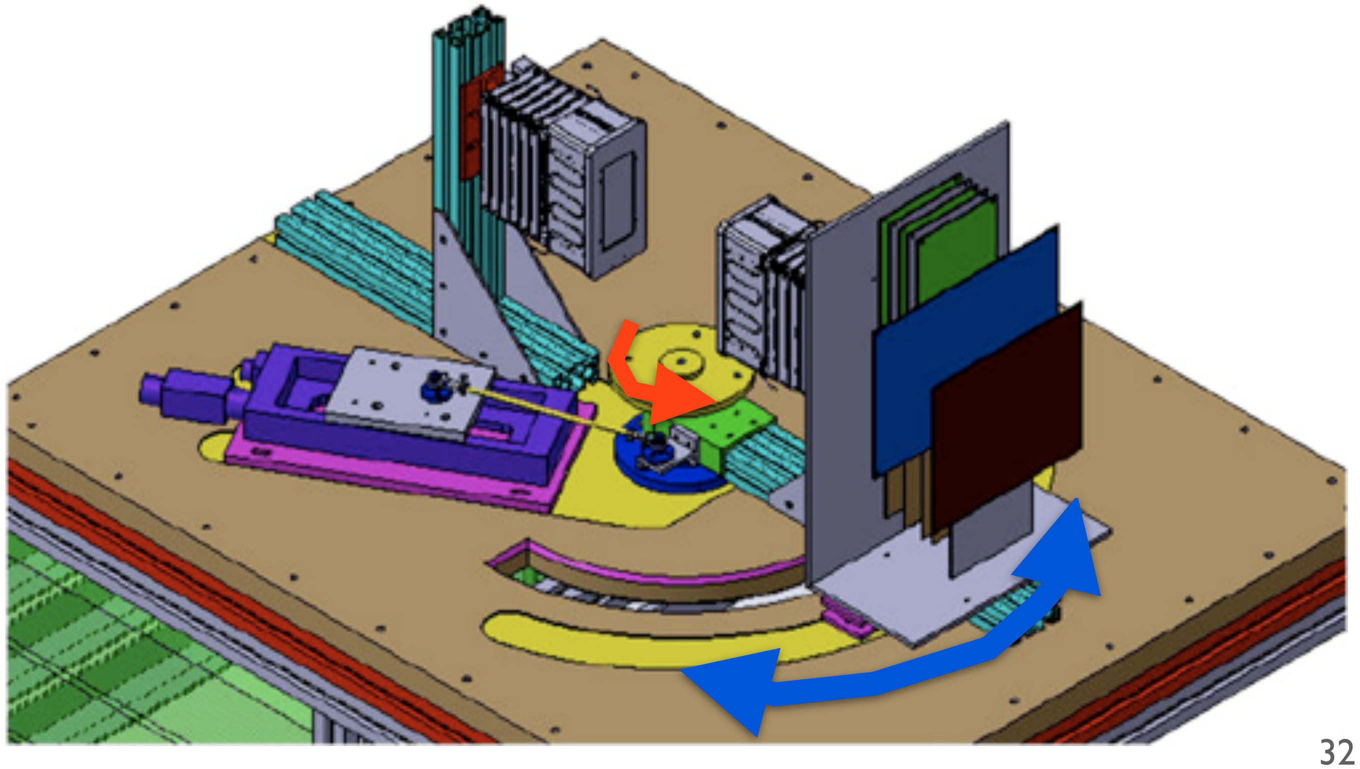
Setup for tomographic reconstruction



setup @ CERN, Blg 304

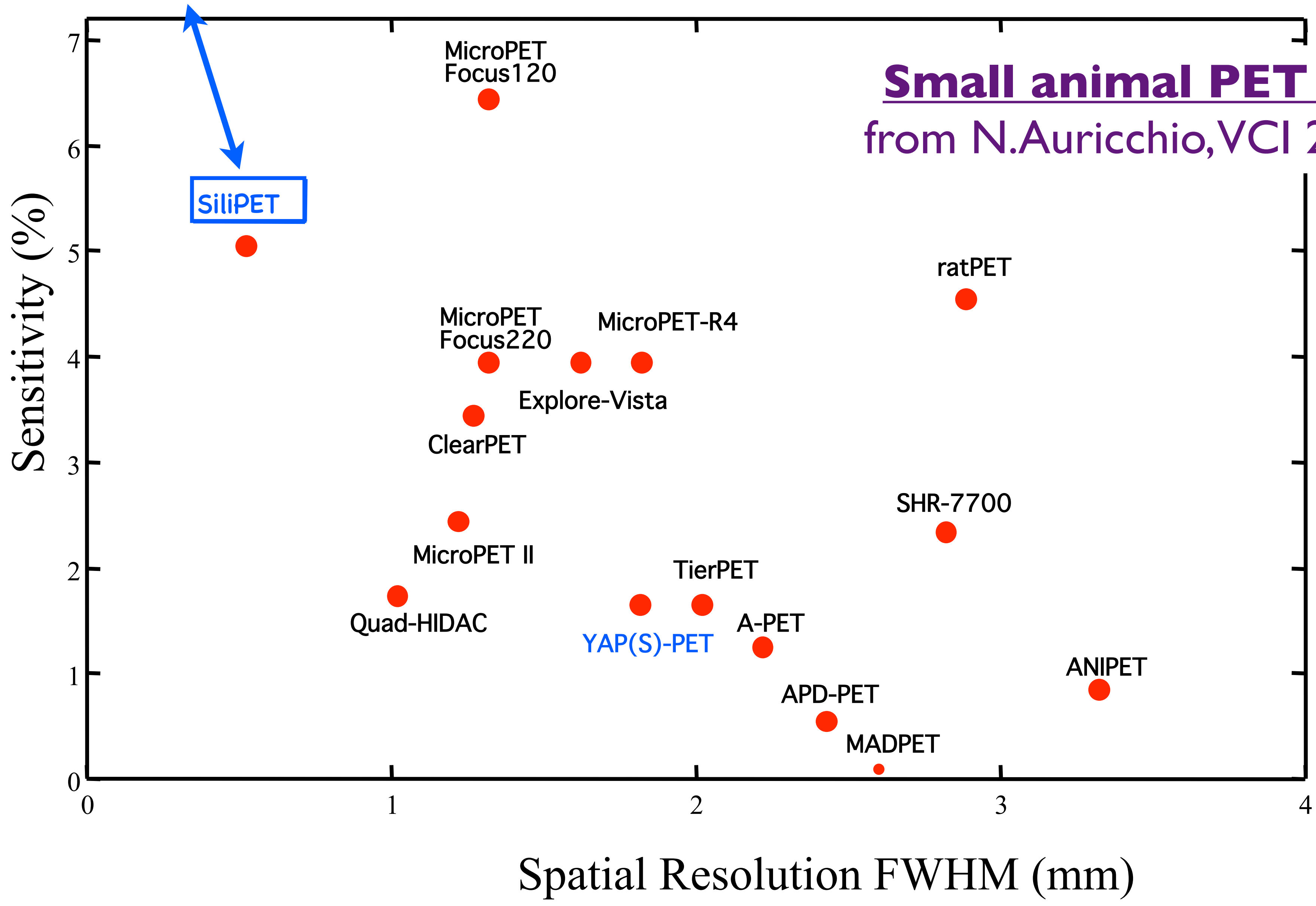
The two modules are mounted on top of a portable platform, which houses also the electronics, power supply, etc...

- One rotating motor for the source / phantom
- One module fixed (Mod1); the other rotating (Mod2)



Spatial resolution: small animal PET comparison

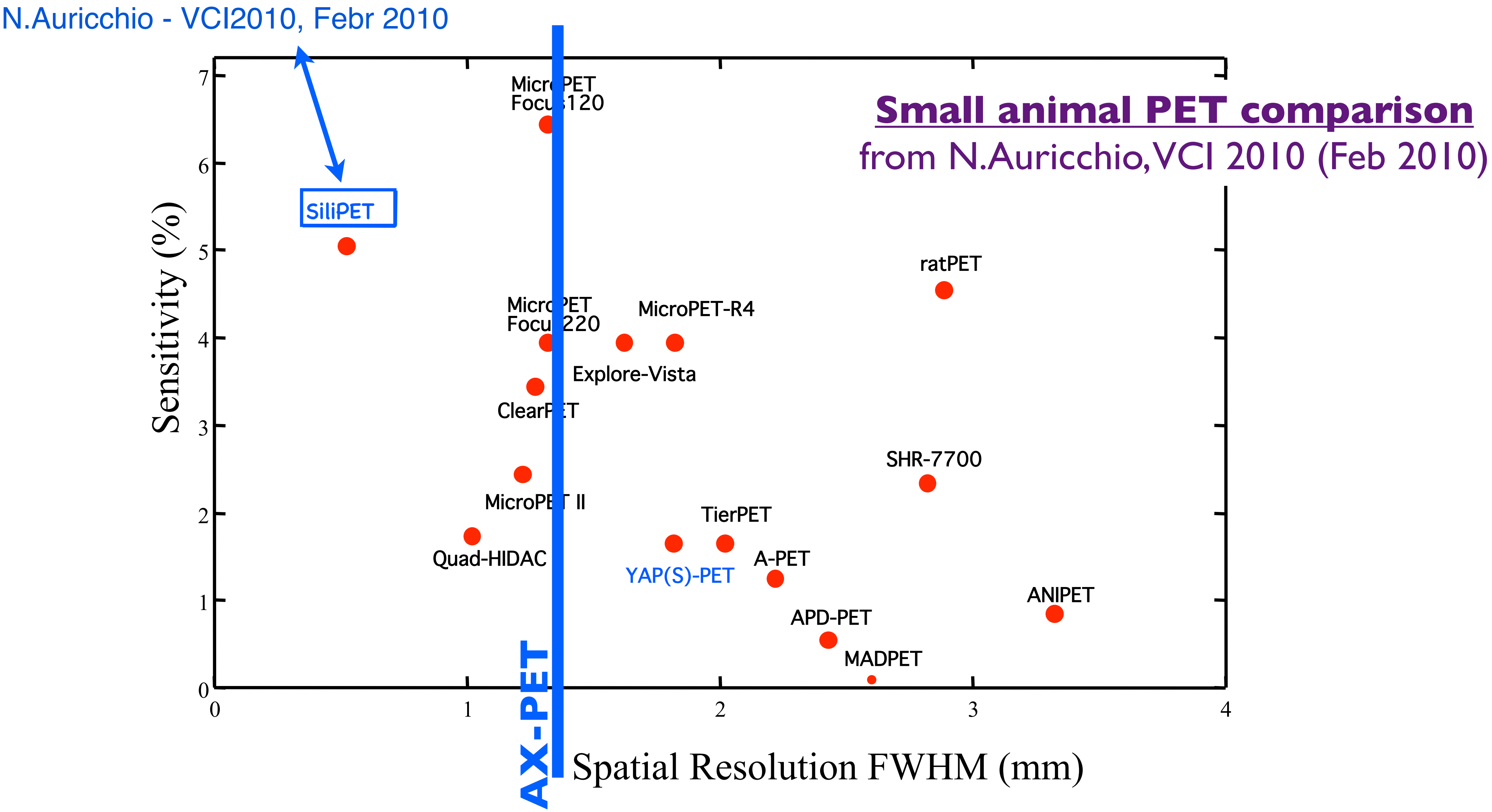
N.Auricchio - VCI2010, Febr 2010



Small animal PET comparison

from N.Auricchio, VCI 2010 (Feb 2010)

Spatial resolution: small animal PET comparison

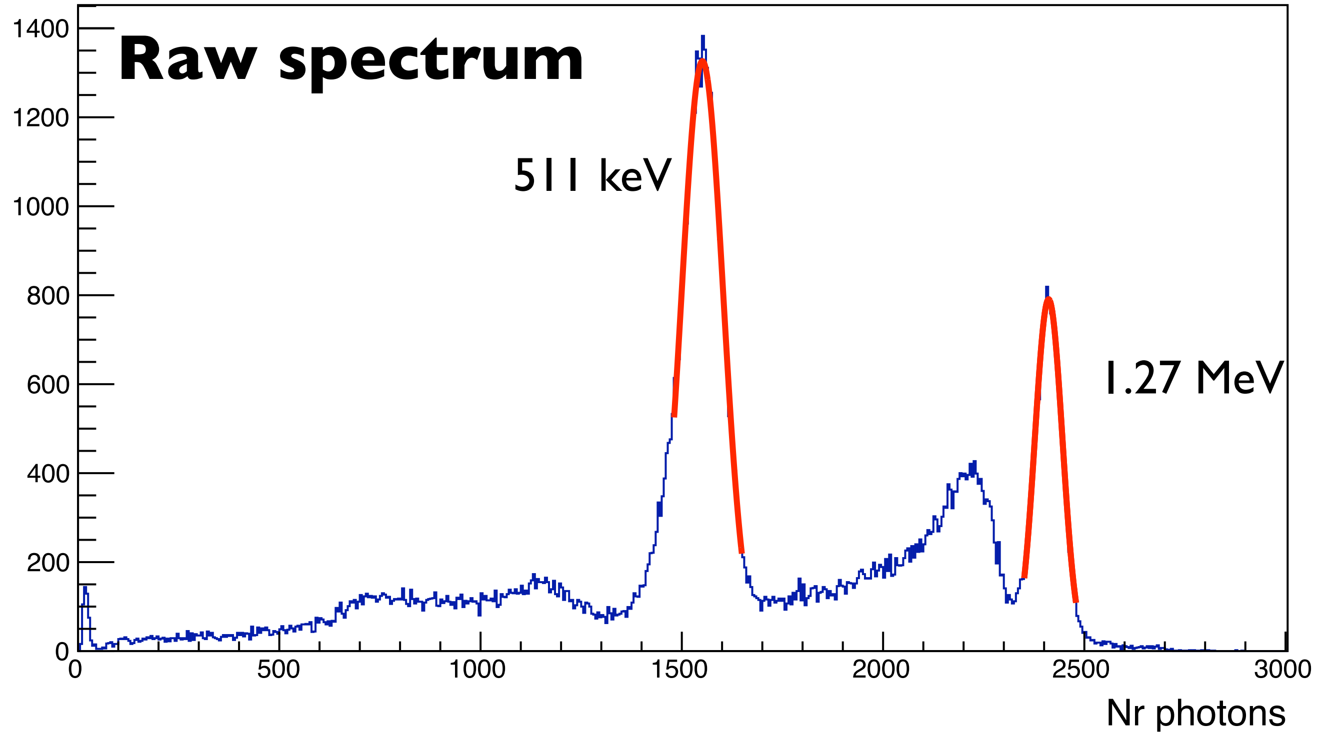


- **AXPET** result (R_FWHM ~ 1.35 mm) is **competitive with** (commercial) **state of the art PET scanner**

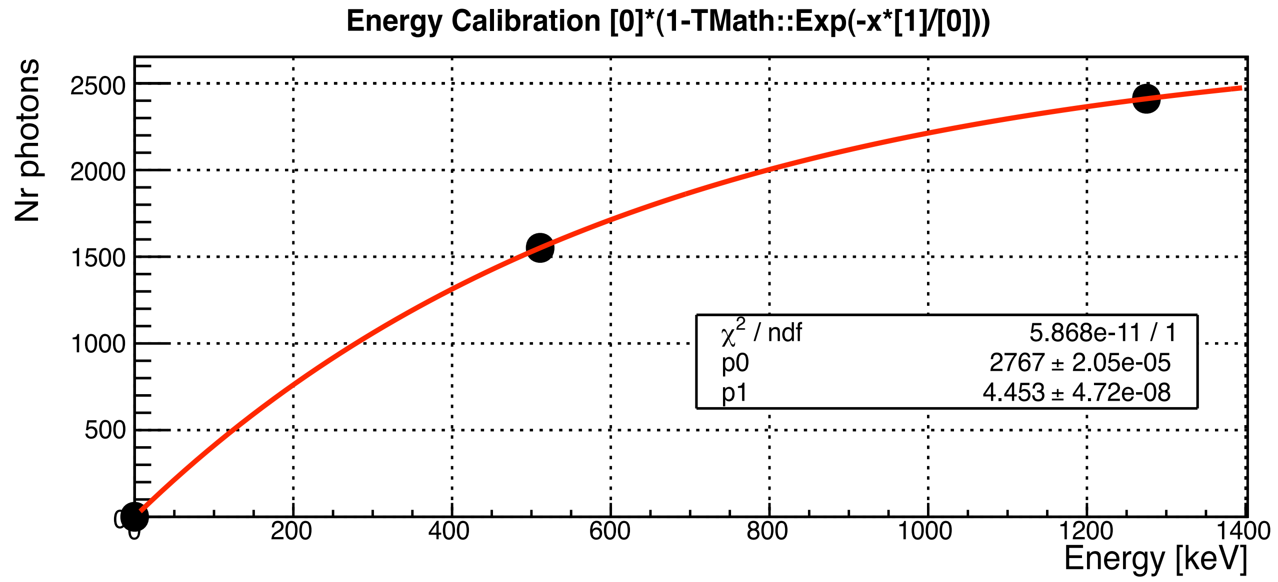
- Sensitivity parameter is not meaningful in the demonstrator setup (2 mods only, limited solid angle coverage)
- AXPET not really tuned to be a small animal PET !

D-SiPM: first preliminary results

Raw LYSO spectrum, Na-22 source

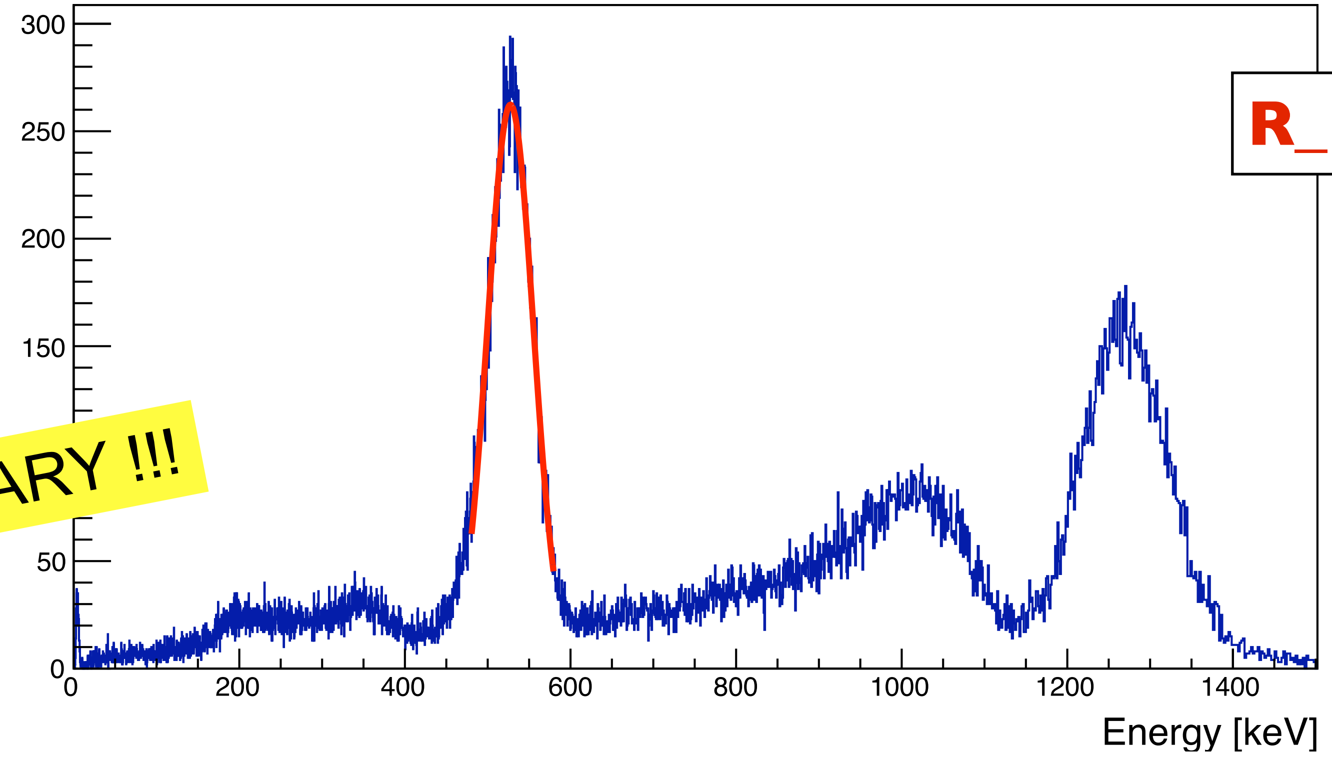


LYSO light yield



LYSO energy spectrum, Na-22 source

Energy spectrum
(calibrated, corrected
for saturation)

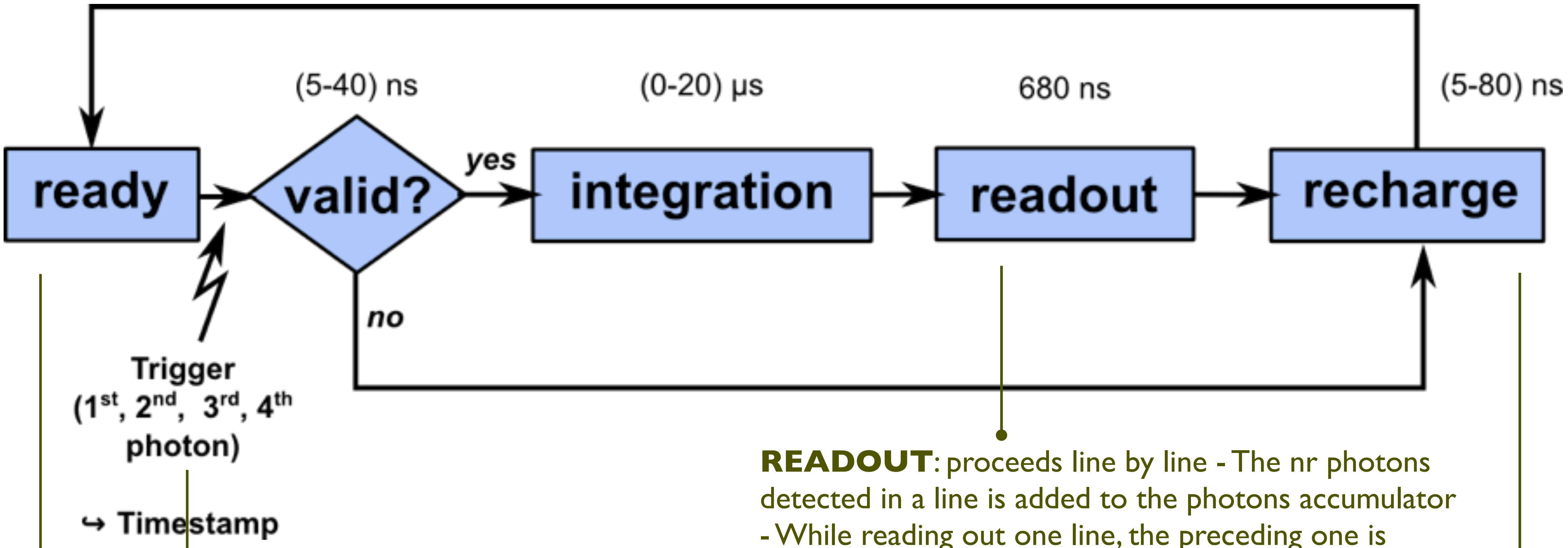


R_FWHM ~ 12.3%

PRELIMINARY !!!

Digital Silicon Photomultiplier (D-SiPM)

pixel (i.e. diode) state machine :



READOUT: proceeds line by line - The nr photons detected in a line is added to the photons accumulator - While reading out one line, the preceding one is recharged
Sensor is still sensitive during readout => ~1/2 readout time still contributes to the integration time

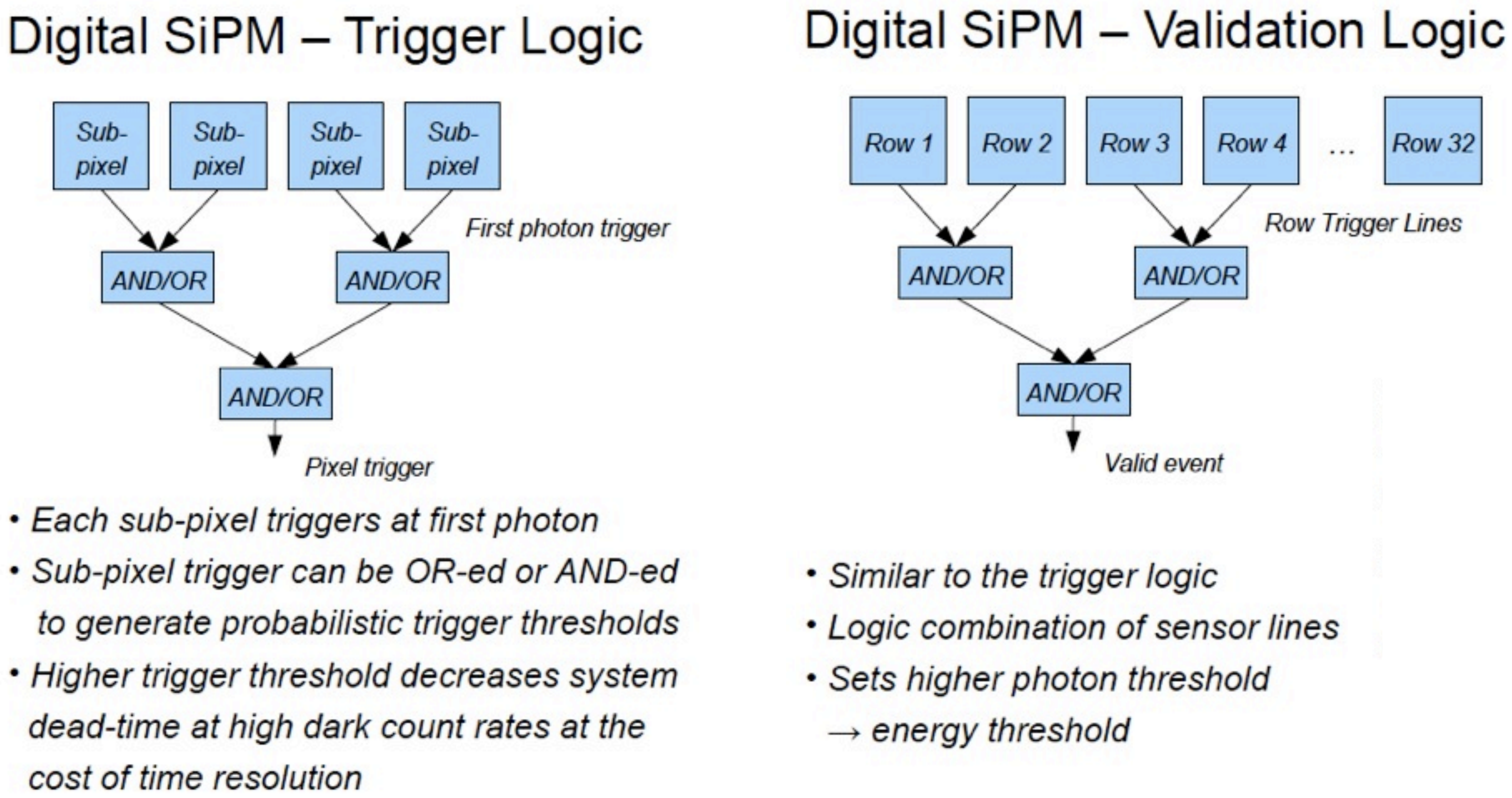
higher **trigger** level: better control of the system dead time but loss of time resolution

READY :
all diodes charged above breakdown
recharge transistors open

RECHARGE / RESET :
global pixel recharge
TDC reset

see : Thomas Frach, CERN Detector seminar, Oct 2011

Digital Silicon Photomultiplier (D-SiPM)



Digital SiPM – Trigger Logic

- *Each sub-pixel triggers at first photon*
- *Sub-pixel trigger can be OR-ed or AND-ed to generate probabilistic trigger thresholds*
- *Higher trigger threshold decreases system dead-time at high dark count rates at the cost of time resolution*

Digital SiPM – Validation Logic

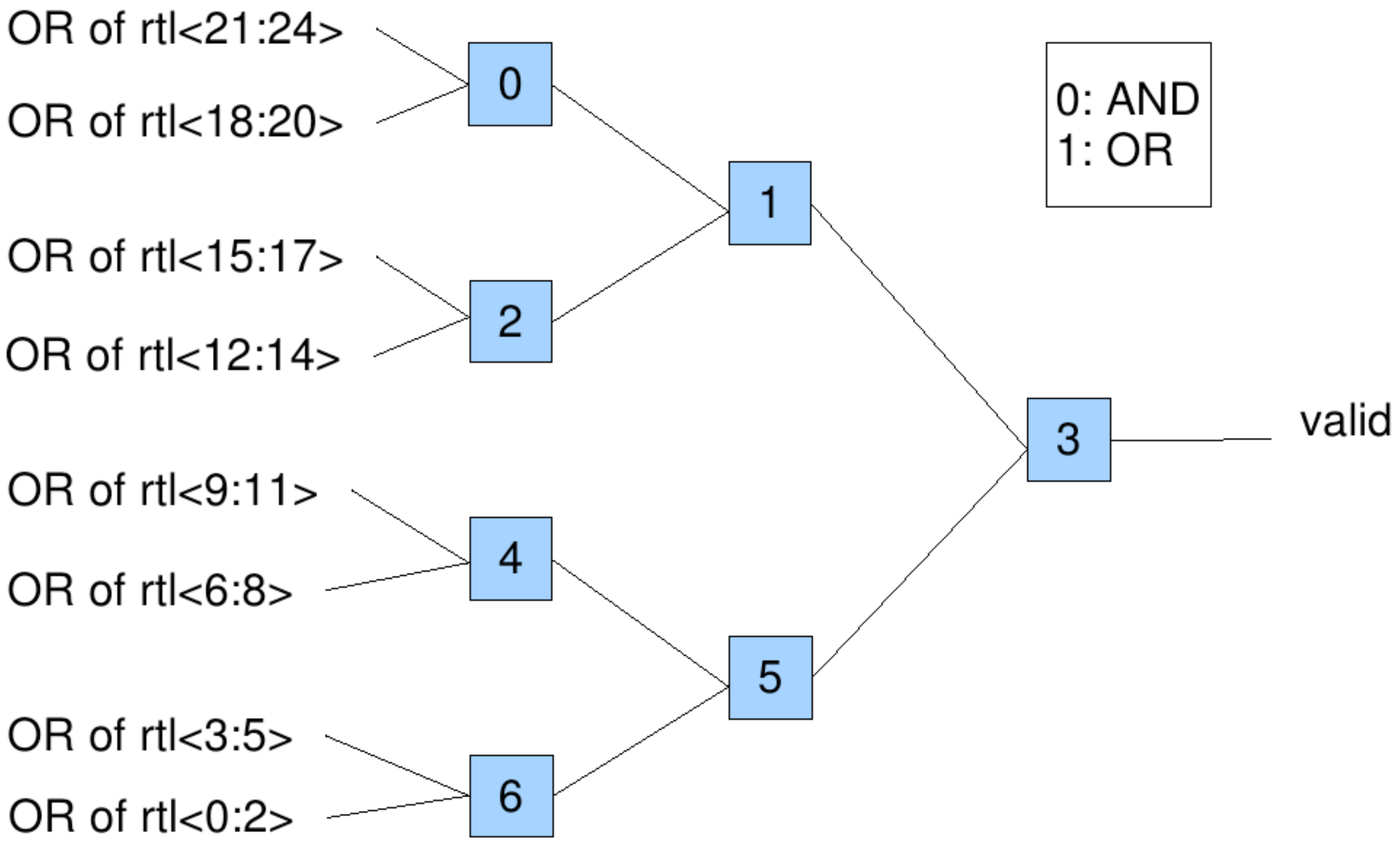
- *Similar to the trigger logic*
- *Logic combination of sensor lines*
- *Sets higher photon threshold → energy threshold*

validation check : at the subpixel level

see : Thomas Frach, CERN Detector seminar, Oct 2011

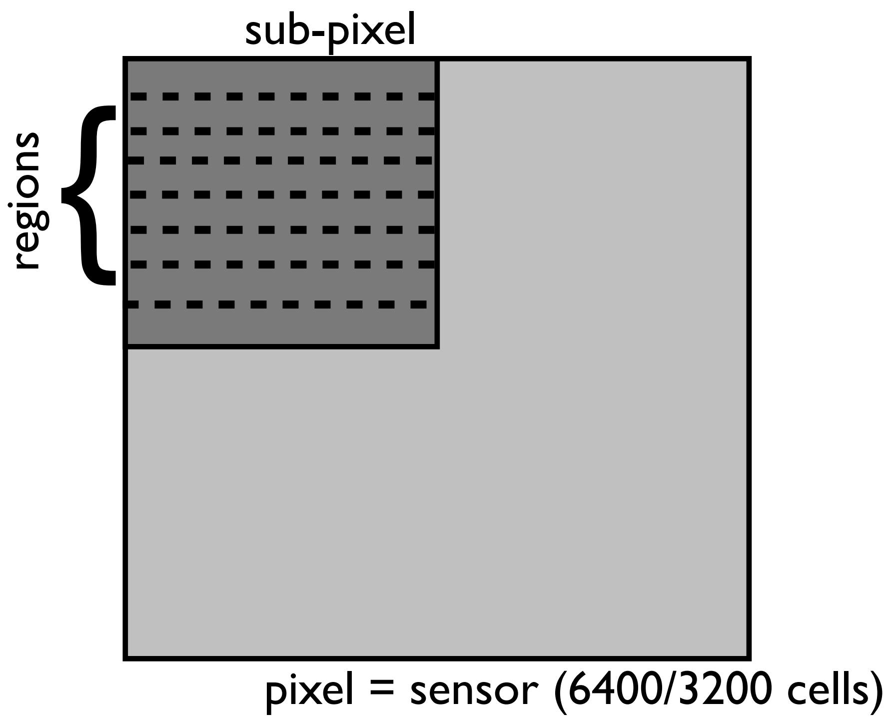
Digital Silicon Photomultiplier (D-SiPM)

Validation check : **at the subpixel level**


OR of rtl<21:24>
OR of rtl<18:20>
OR of rtl<15:17>
OR of rtl<12:14>
OR of rtl<9:11>
OR of rtl<6:8>
OR of rtl<3:5>
OR of rtl<0:2>
0
1
2
3
4
5
6
valid
0: AND
1: OR

each subpixel is divided in rows regions

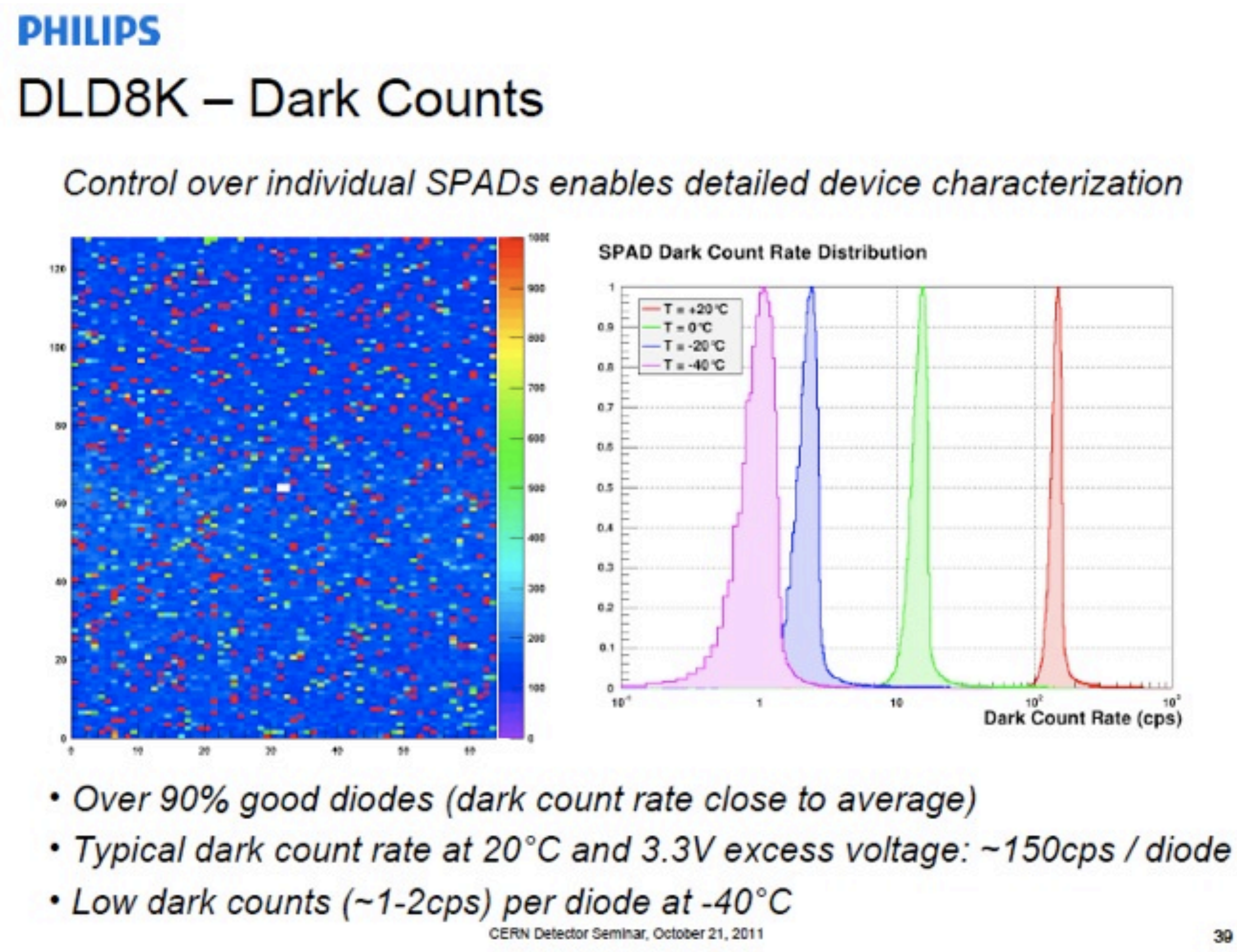
regions ORed / ANDed depending on the exact validation pattern



Management of the subpixels validation:

- DLS_6400 : All subpixels are ANDed <=> Validations patterns : [4, 8, 16, 32]
- DLS_3200 : All subpixels are ORed <=> Validations patterns : [1, 2, 4, 8]

D-SiPM: Dark counts



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DLD8K – Dark Counts

Control over individual SPADs enables detailed device characterization

- *Over 90% good diodes (dark count rate close to average)*
- *Typical dark count rate at 20°C and 3.3V excess voltage: ~150cps / diode*
- *Low dark counts (~1-2cps) per diode at -40°C*

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see : Thomas Frach, CERN Detector seminar, Oct 2011

switching off diodes is equivalent to loss of sensitive area => PDE reduction

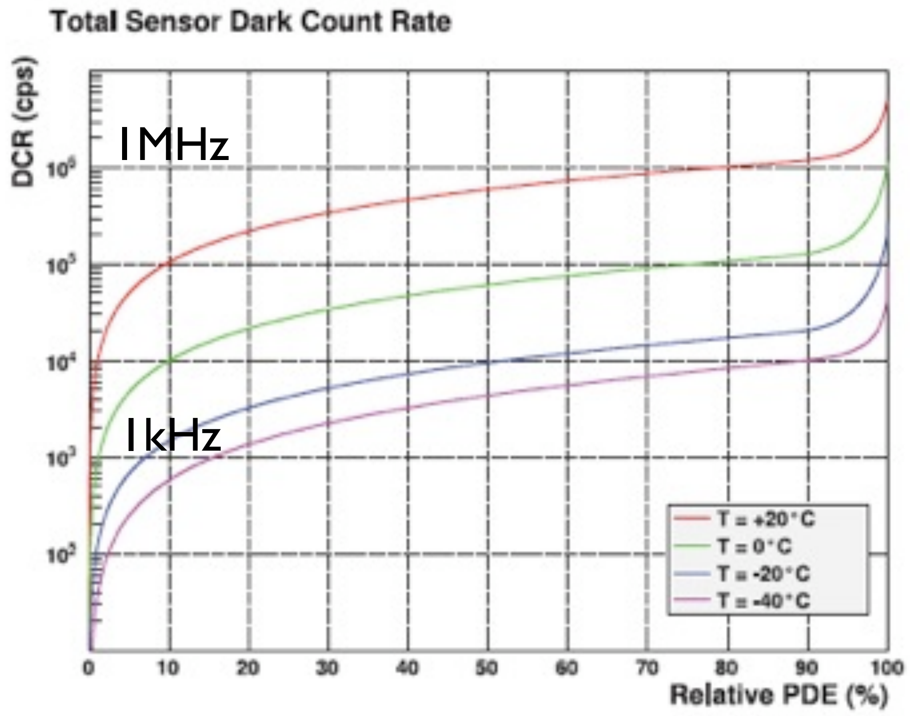
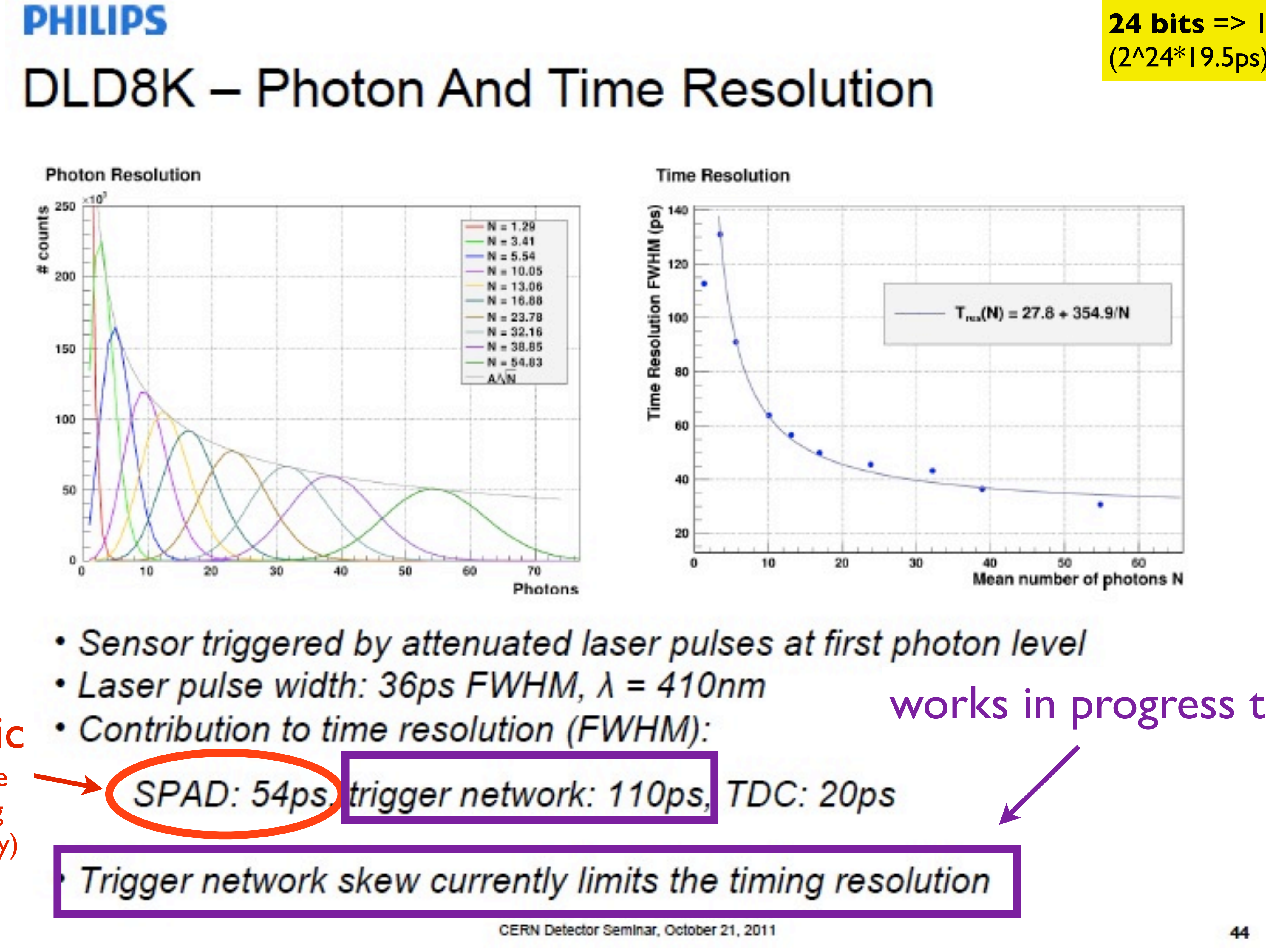


Fig. 6. Total dark count rate of the sensor at different temperatures.

Thomas Frach, NSS-MIC_Conference_Record_2009_N28-005.pdf

D-SiPM: Timing properties

TDC:
1 tick = 19.5 ps
24 bits => 1 frame ~ 330 μs
(2^24*19.5ps)



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DLD8K – Photon And Time Resolution

- *Sensor triggered by attenuated laser pulses at first photon level*
- *Laser pulse width: 36ps FWHM, λ = 410nm*
- *Contribution to time resolution (FWHM):*

SPAD: 54ps, trigger network: 110ps, TDC: 20ps

- *Trigger network skew currently limits the timing resolution*

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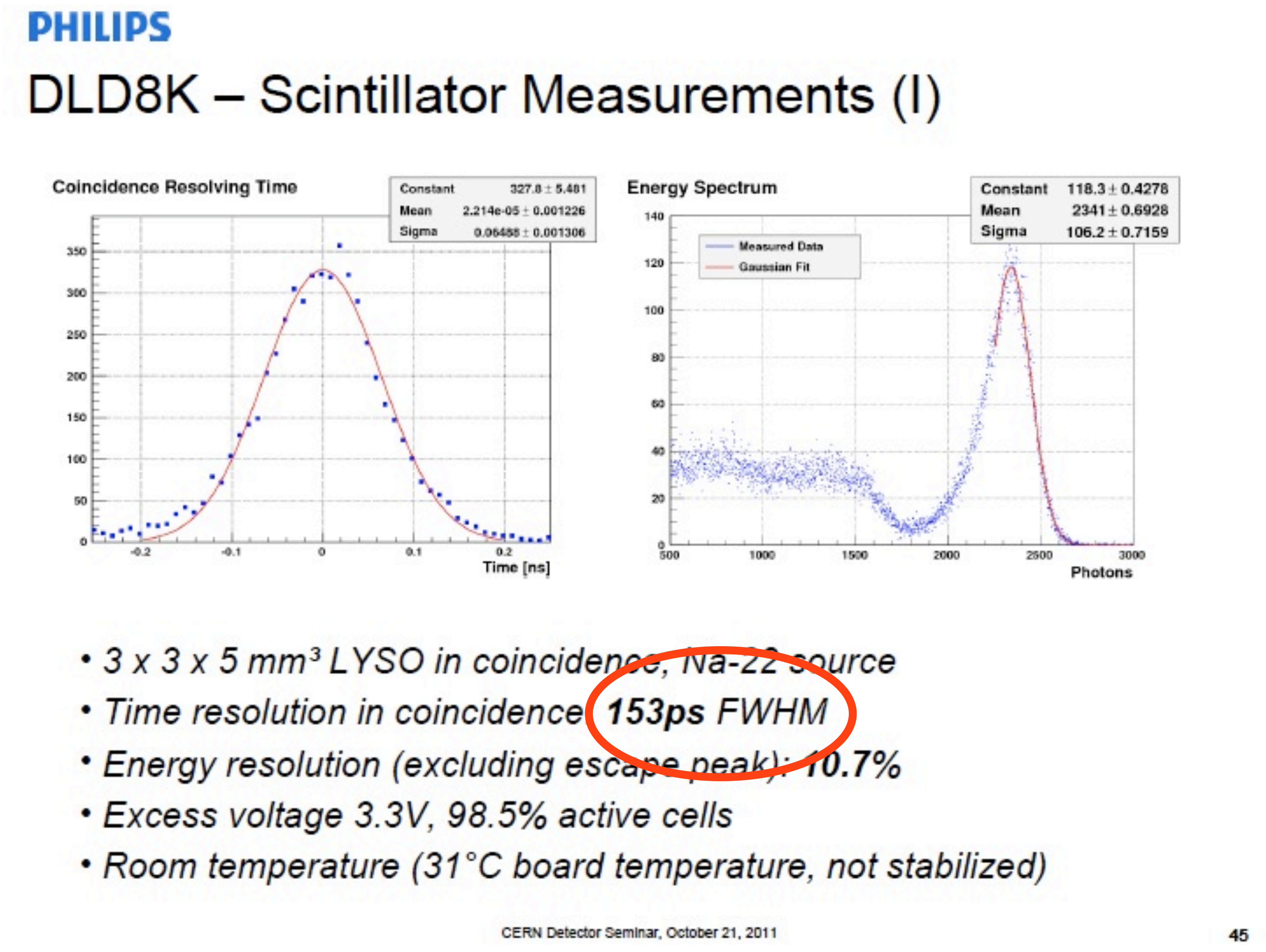
intrinsic
(avalanche spreading uncertainty)

works in progress to reduce it

see : Thomas Frach, CERN Detector seminar, Oct 2011

D-SiPM: Scintillator measurements



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DLD8K – Scintillator Measurements (I)

- *3 x 3 x 5 mm³ LYSO in coincidence, Na-22 source*
- *Time resolution in coincidence* ***153ps** FWHM*
- *Energy resolution (excluding escape peak):* ***10.7%***
- *Excess voltage 3.3V, 98.5% active cells*
- *Room temperature (31°C board temperature, not stabilized)*

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see : Thomas Frach, CERN Detector seminar, Oct 2011

Philips Digital Photon Counting

Preliminary Short Data Sheet

PHILIPS

Digital Light Sensor Array DLS 6400-22-44 V2.0

Key Features

- 8 x 8 pixel array
- Single photon counting capability
- Integrated Time-to-Digital converter
- First photon trigger
- Excellent timing resolution
- Fully digital interface
- Four side tileable

Specifications

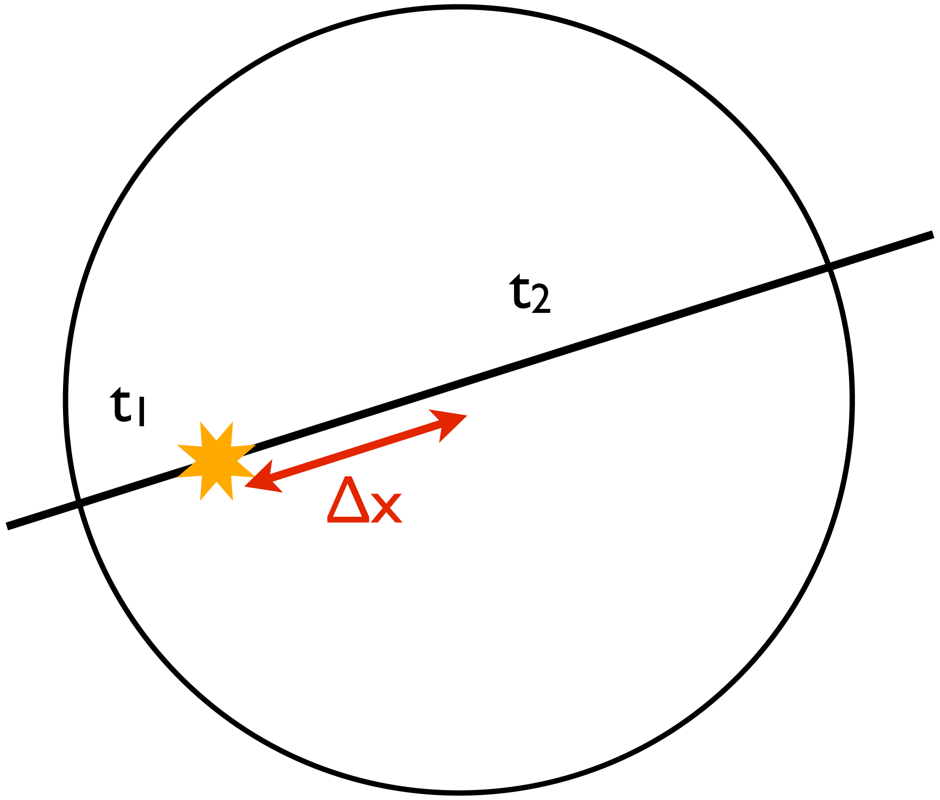
DLS 3200-22

Physical Characteristics	DLS 6400-22-44 V2.0	DLS 3200-22
Outer Dimensions	32.6 x 32.6 mm^2	
Pixel Pitch (H x V)	4.0 mm x 4.0 mm	
Pixel Active Area	3.8 x 3.3 mm^2	
Number of Cells Per Pixel	6396	3196
Cell Size	30 x 50 µm²	59.4 x 64 µm2
Spectral Response Range	380 nm – 700 nm	
Peak Sensitivity Wavelength (λ_p)	420 nm	
Quantum Efficiency (PDE) @ λ_p	30 %	43%
Fill Factor	54 %	78%
Dark Count Rate	< 5 MHz / pixel at room temperature	
Operational Bias Voltage	< 35 V	
Temperature Dependence of PDE	-0.33%/°C in the range of 15°C - 25°C	
Intrinsic Timing Resolution	approx. 40 ps	

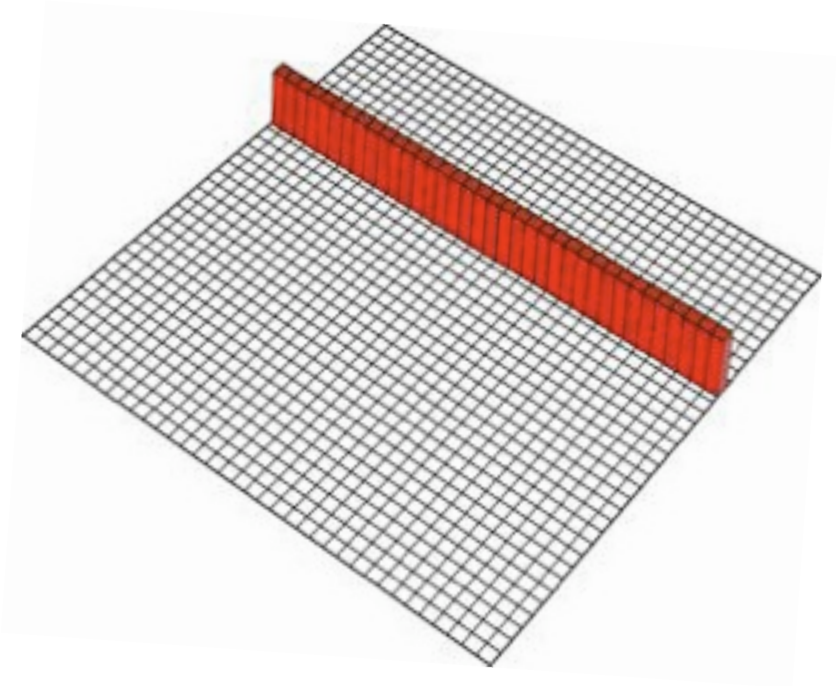
TOF - PET

Time of Flight PET :
constraint the location of the emission point in a LOR measuring the arrival time of the two 511 keV photons

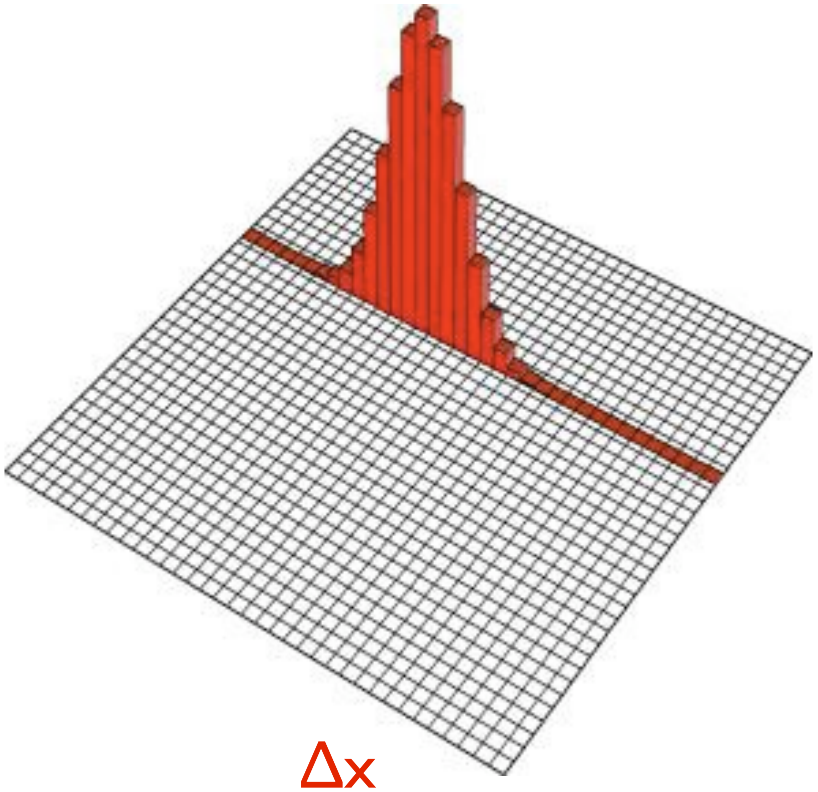
not tight enough to avoid image reconstruction
significantly improves S/N



no TOF :
The probability for the event to be located along the LOR is uniform



Time Of Flight PET :
The most likelihood position is in the center of the error distribution



$$\Delta x = \frac{c}{2}\Delta t$$

position of the annihilation wrt the center of the FOV

Δt	Δx
800 ps	12 cm
500 ps	7.5 cm
100 ps	1.5 cm

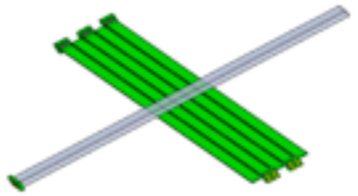
AX-PET inspired other developments

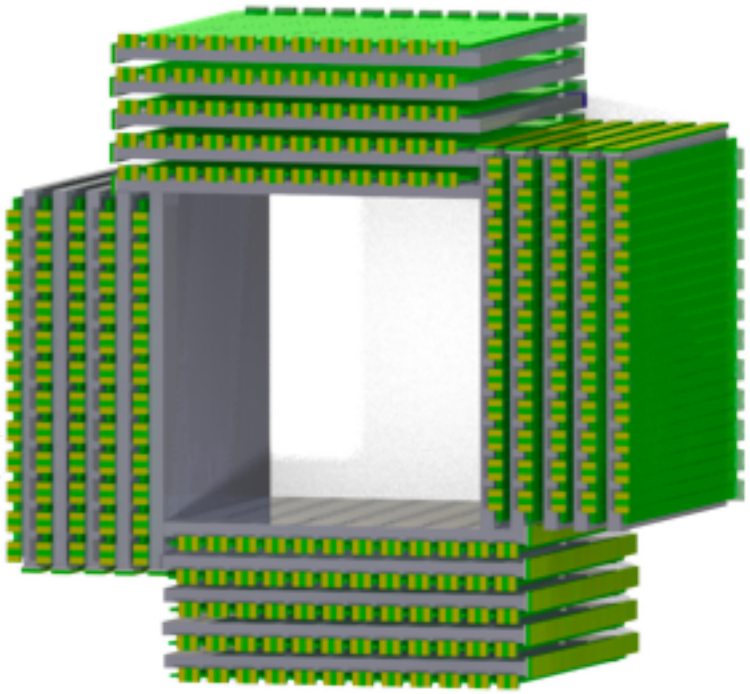
COMPET :
University of Oslo, Norway - E. Bolle et al.

research project for a pre-clinical PET scanner with high sensitivity, high resolution. MRI compatible

- no axial geometry
- 3D reco of photon interaction point with LYSO + WLS + G-APD

E. Bolle et al, NIM A 648(2011) S93-S95





Tampere University (Finland) :
build a small specific scanner based on AX-PET (toward possible commercialization...)

Low cost planar detector for PET
Triumph, Canada - F. Retiere et al.

F. Retiere, NIM A (2011) doi:10.1016/j.nima.2011.12.084