ICTR-PHE 2014

Usage of long axially oriented crystals for PET applications: AX-PET Demonstrator and beyond

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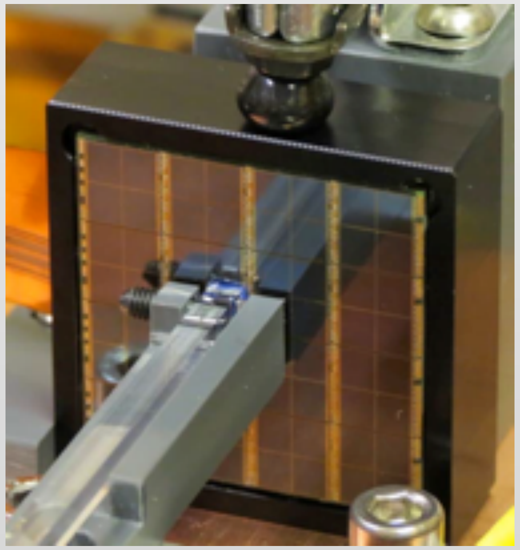
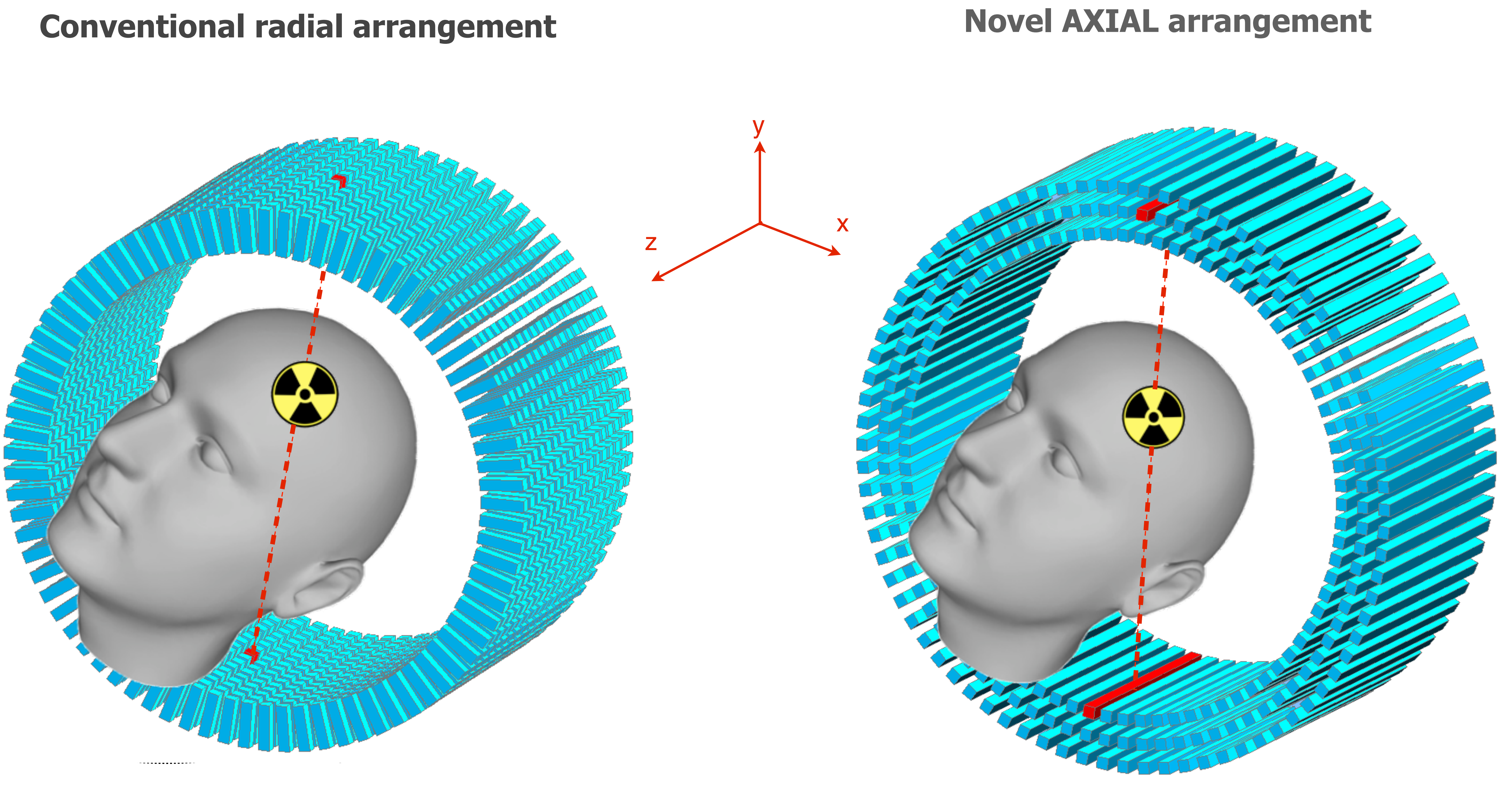
AX-PET : fully operational demonstrator for a PET scanner (up to small animals image reconstruction)

Usage of long axial crystals **with digital SiPM**: timing and axial resolutions



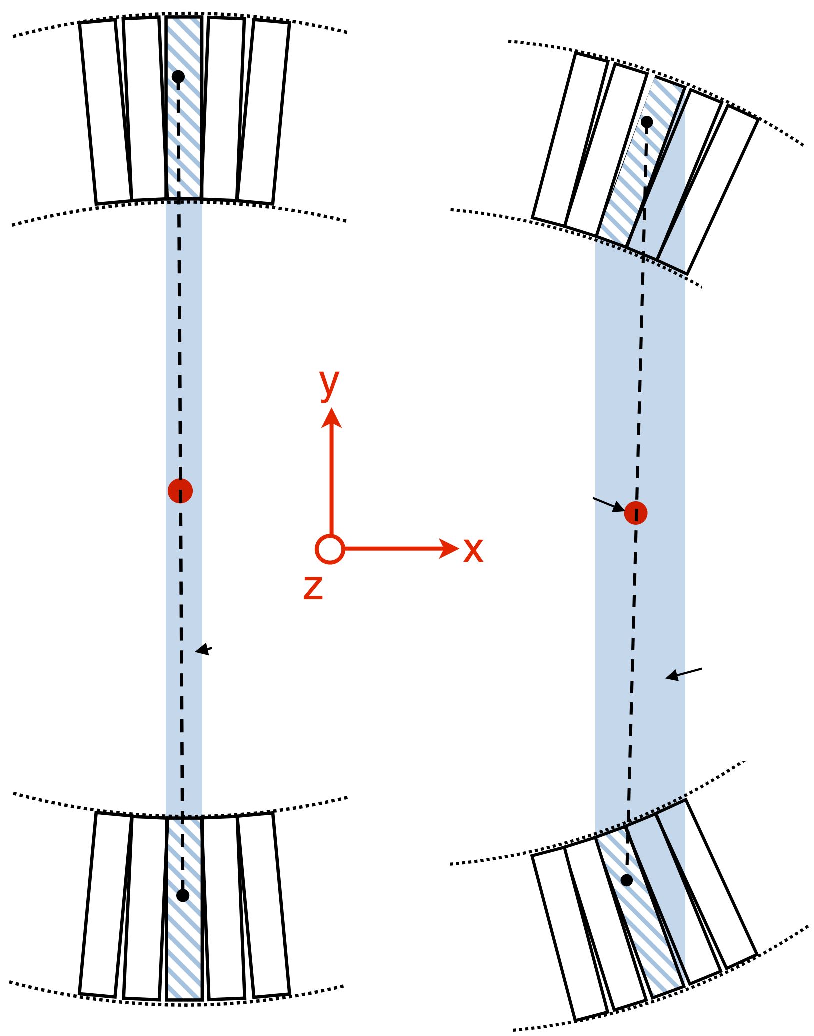
Axial arrangement of crystals in a PET



Which is the advantage of axially oriented crystals?

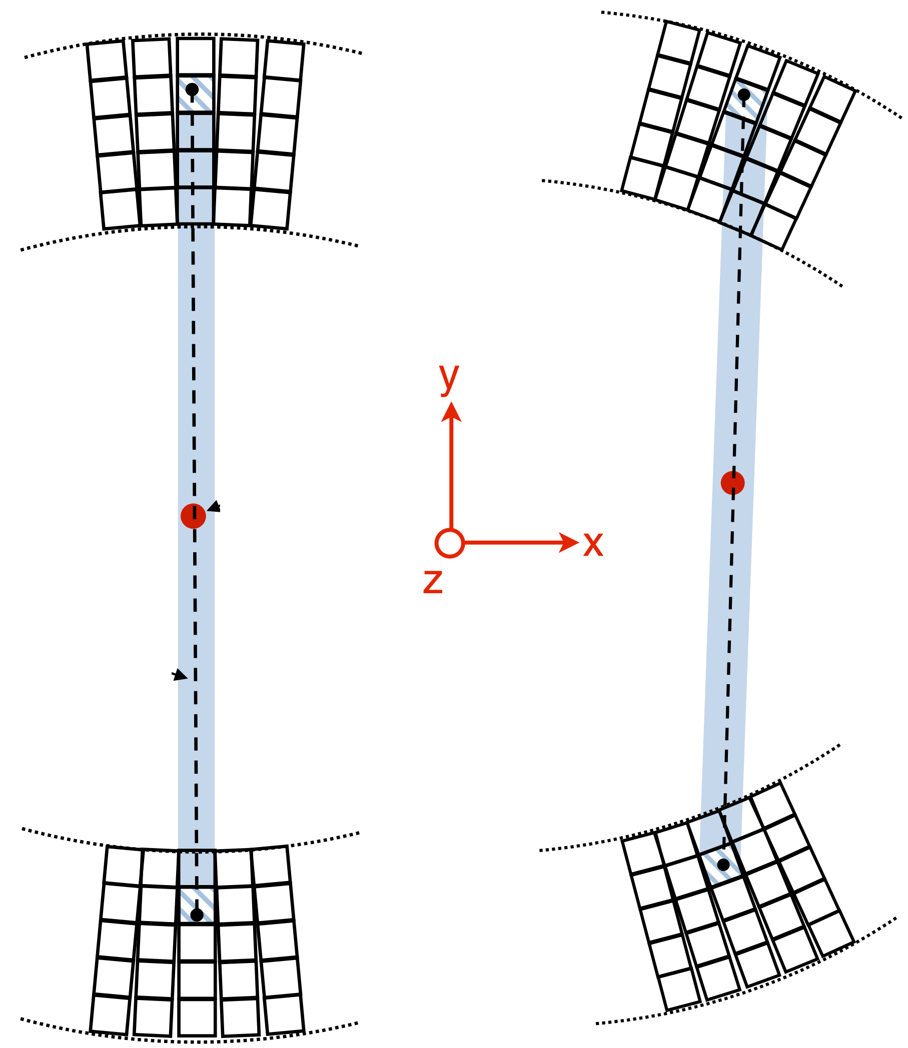
Axial arrangement of crystals in a PET

Conventional radial arrangement



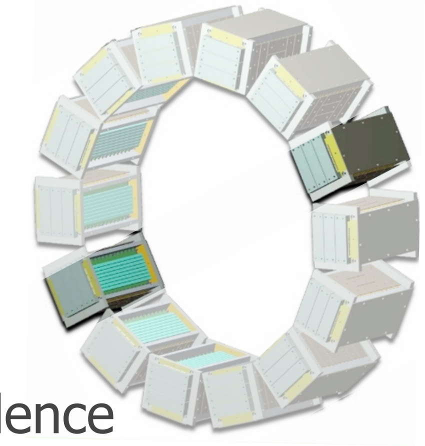
- parallax error
- compromise between spatial resolution and sensitivity (length of the crystal)
- <u>DOI techniques required</u>

Novel AXIAL arrangement



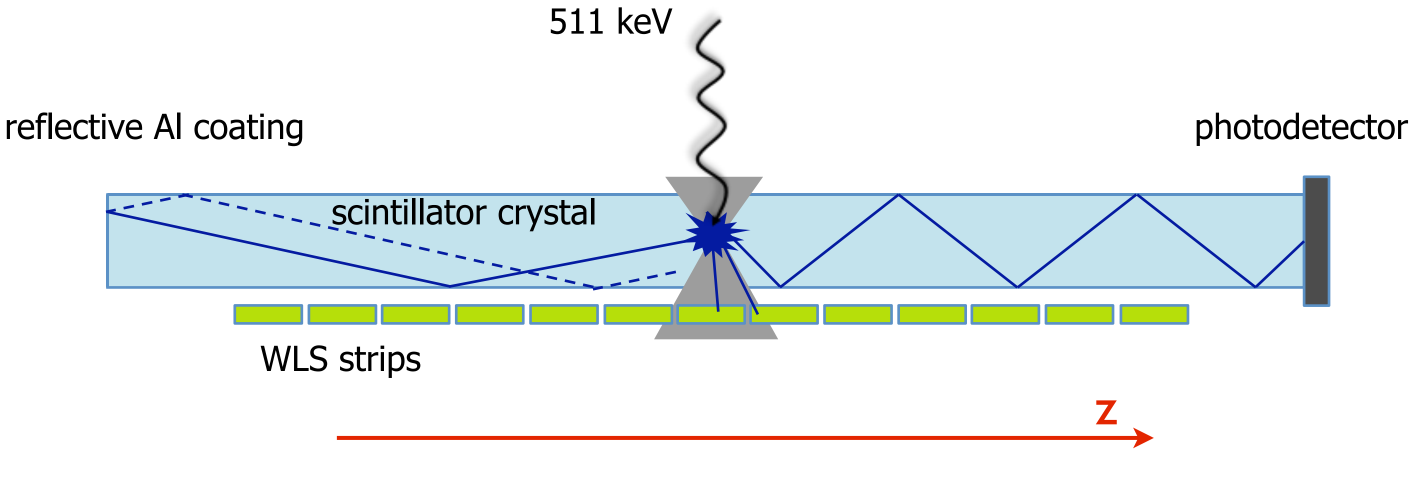
- sensitivity <=> nr of layers
- spatial resolution <=> crystal cross-sectional(x,y) size
- decoupled sensitivity and resolution
- <u>need to define the axial(z) coordinate</u>

The AX-PET Demonstrator

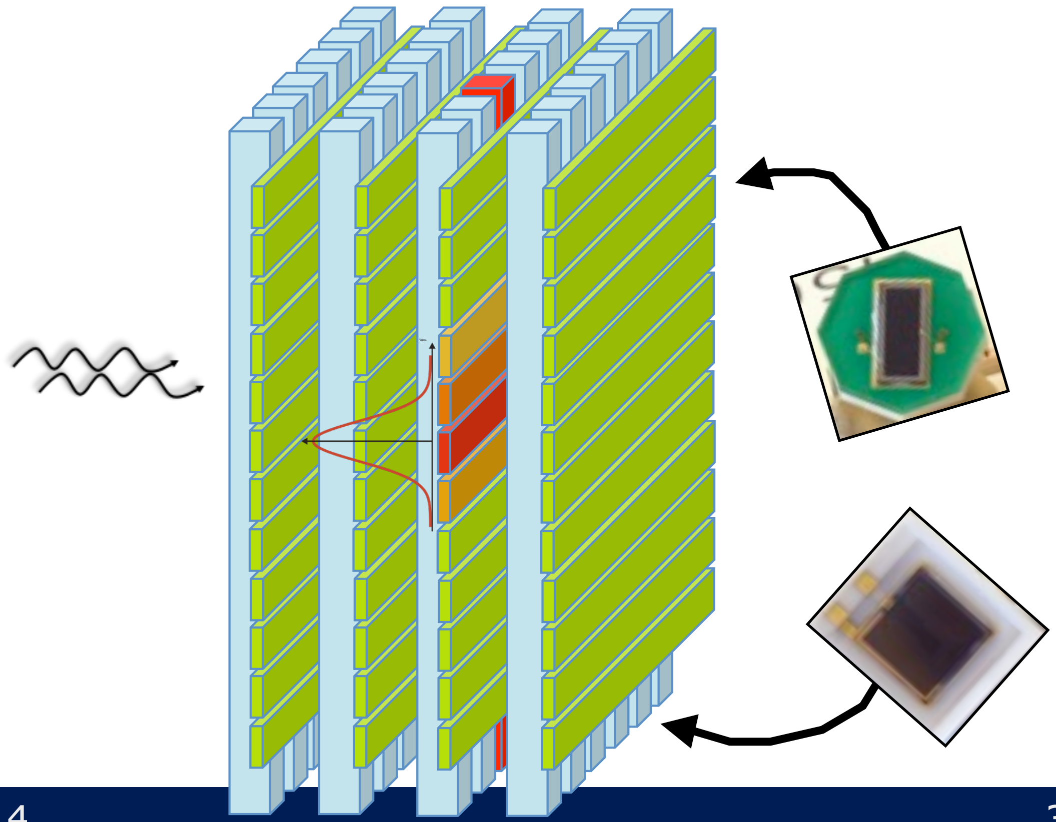


- **AX**ial - **P**ositron **E**mission **T**omography **=> AX-PET**
- existing example of the usage of **axial crystals**
- fully operational **demonstrator** for a PET scanner
- **two modules** of axially oriented crystals (**LYSO**, **3x3x100 mm^3** each), operated in coincidence
- developed, constructed and characterized **at CERN**
- collaboration merging expertise of medical imaging with high energy physics (HEP)

axial coordinate definition using **arrays of Wave-Length Shifting** (**WLS**) **Strips**

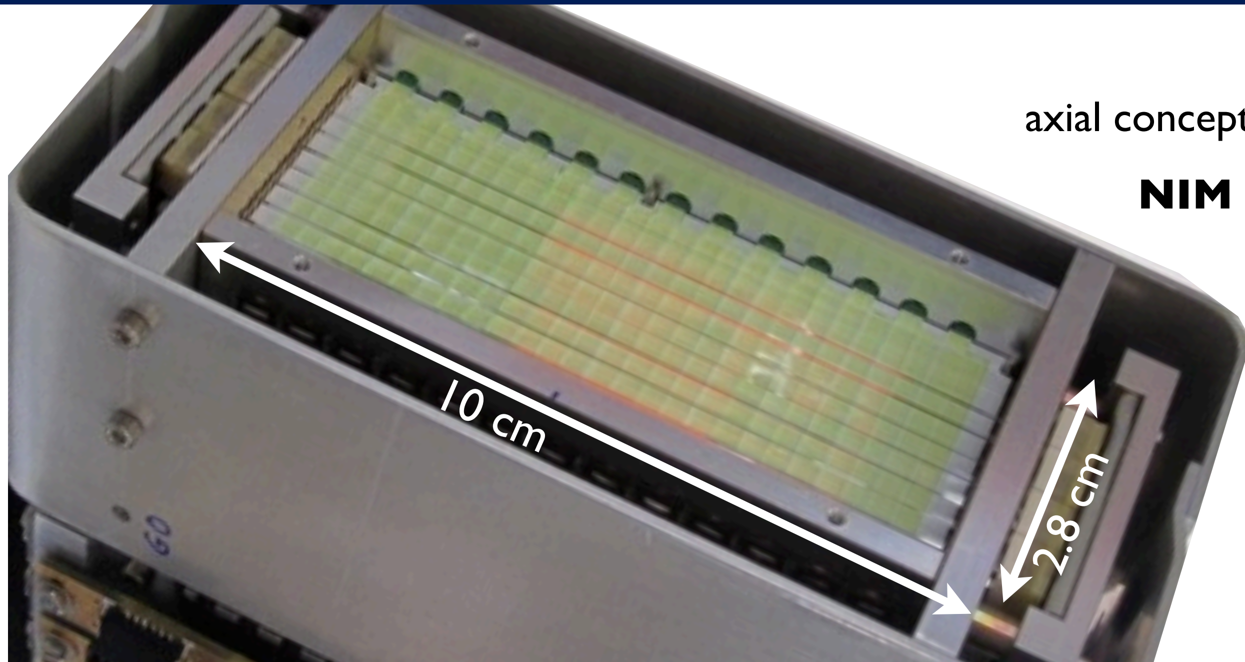


AX-PET module : **matrix of layers of scintillator crystals and WLS strips arrays,** all individually **readout by SiPM**



AXPET collaboration
CERN, ETH Zurich, IFIC and University of Valencia,
INFN Italy (Bari, Cagliari), Ohio State University,
University of Michigan, University Oslo, Tampere University

Milestones of the experiment

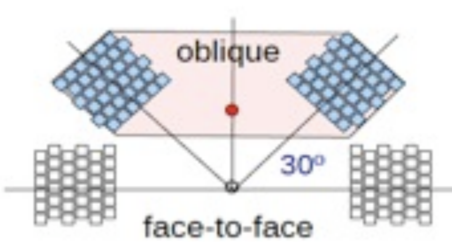


- two modules built
- module performance assessed
- measurements campaigns (phantoms and animals)
- tomographic image reconstruction (our own software)
- all stages fully supported by simulations

2008
axial concept, light sharing technique, hybrid photodiodes on both sides of the crystals
NIM A 586 (2008) 300-308 => wavelength shifter strips and SiPM readout
small scale setups
Jul 2009
Module 1 ready
Sept 2009
Module 2 ready
Modules characterization measurements (both individually and in coincidence, 22-Na source)
Apr 2010
Phantom measurements, ETH
Jul 2010
Phantom measurements, AAA
NIM A 654 (2011) 546-559 => detector performance
Jul 2011
Phantom measurements, AAA
Jun 2012
Animal measurements, ETH

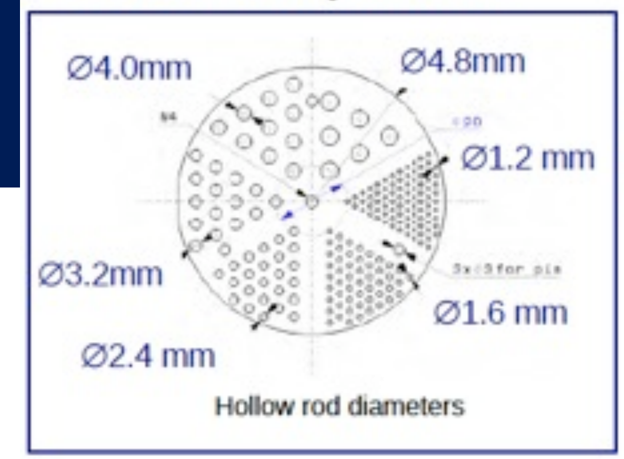
Peculiarities of AX-PET detector (wrt conventional PET detectors)

- novel axial geometry
- usage of WLS strips for the axial coordinate definition => 3D info on photon interaction point
- scalability of the design (nr layers, crystals dimensions...)
- high spatial resolution
  R_axial ~ 1.35 mm FWHM in coincidence
  unaffected by the positioning of the modules i.e. parallax free system



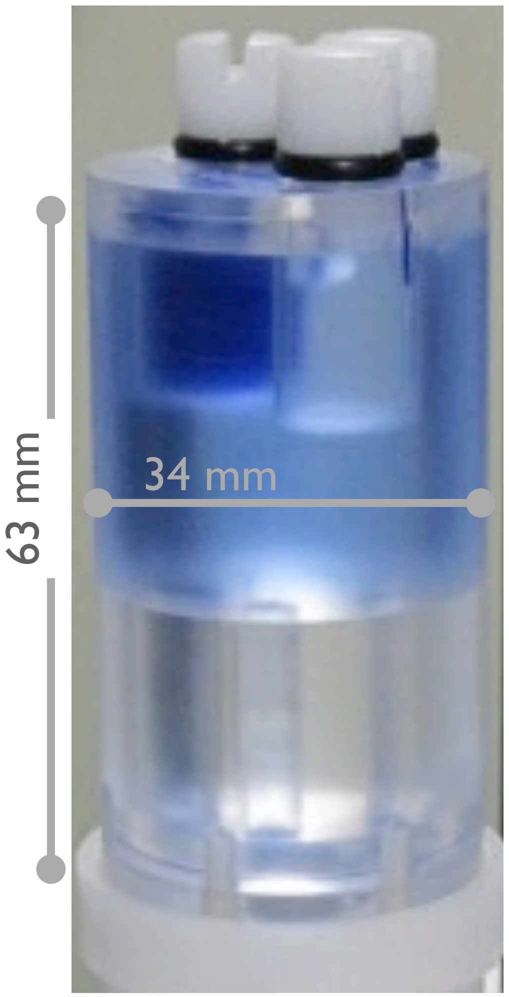
- high granularity & good energy resolution (**ΔE/E ~ 12% FWHM**, @511 keV)
  => Compton scattering events can be included in the reconstruction (enhanced sensitivity)

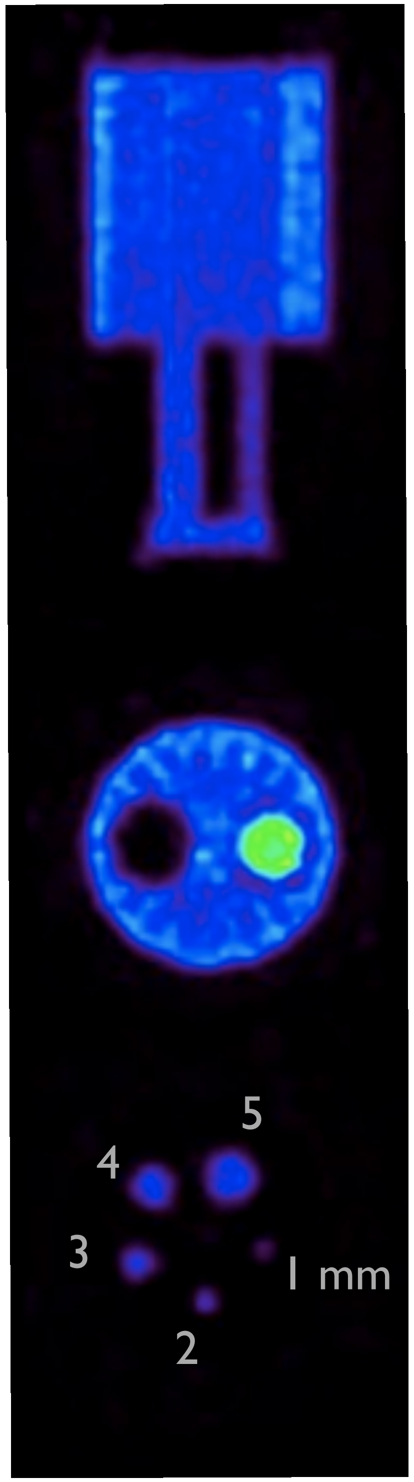
Phantoms reconstructed images



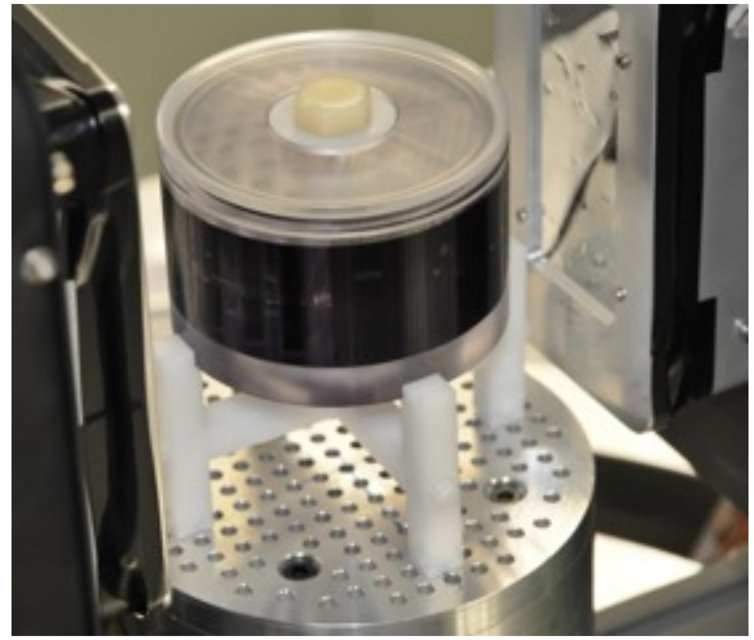
- **F-18** in water solution
- at AAA (Advanced Accelerator Applications), St Genis, France

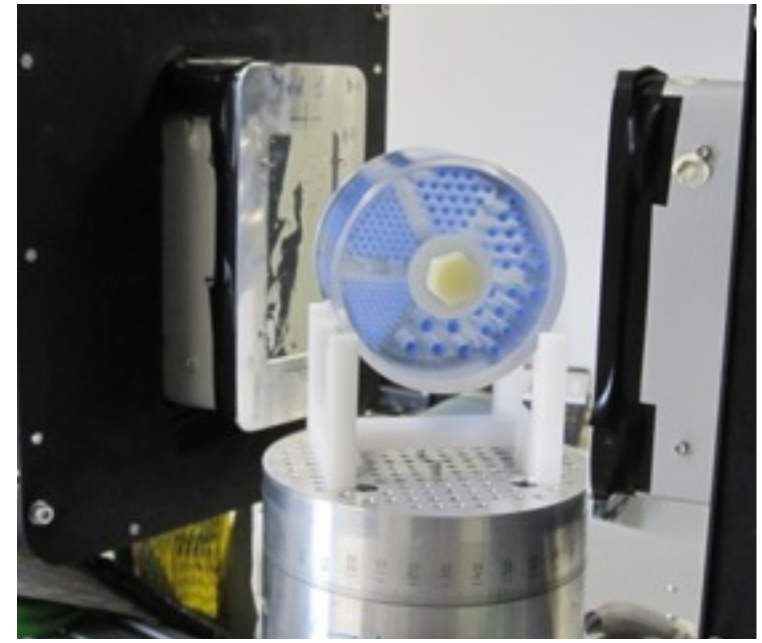
NEMA phantom

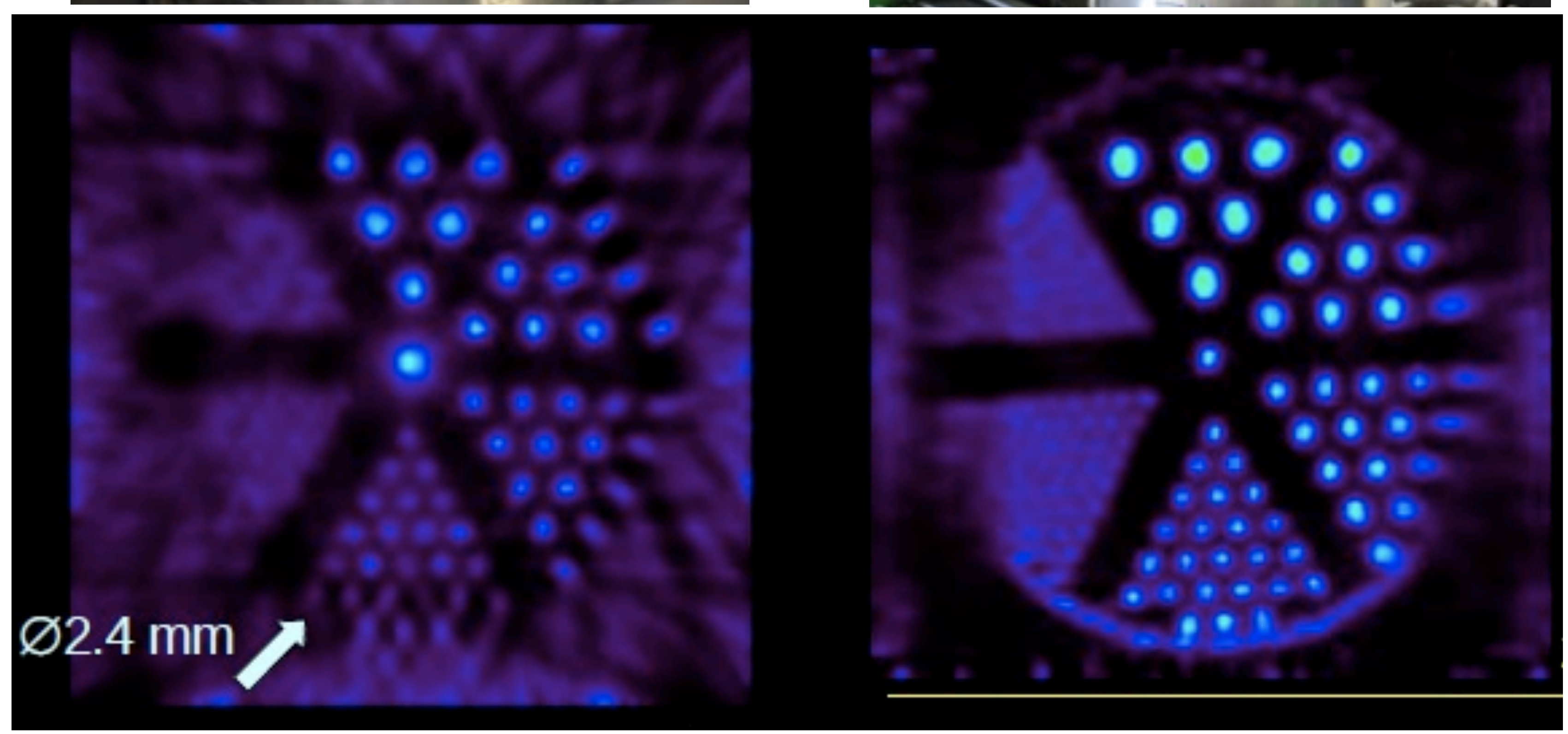




Mini Deluxe phantom







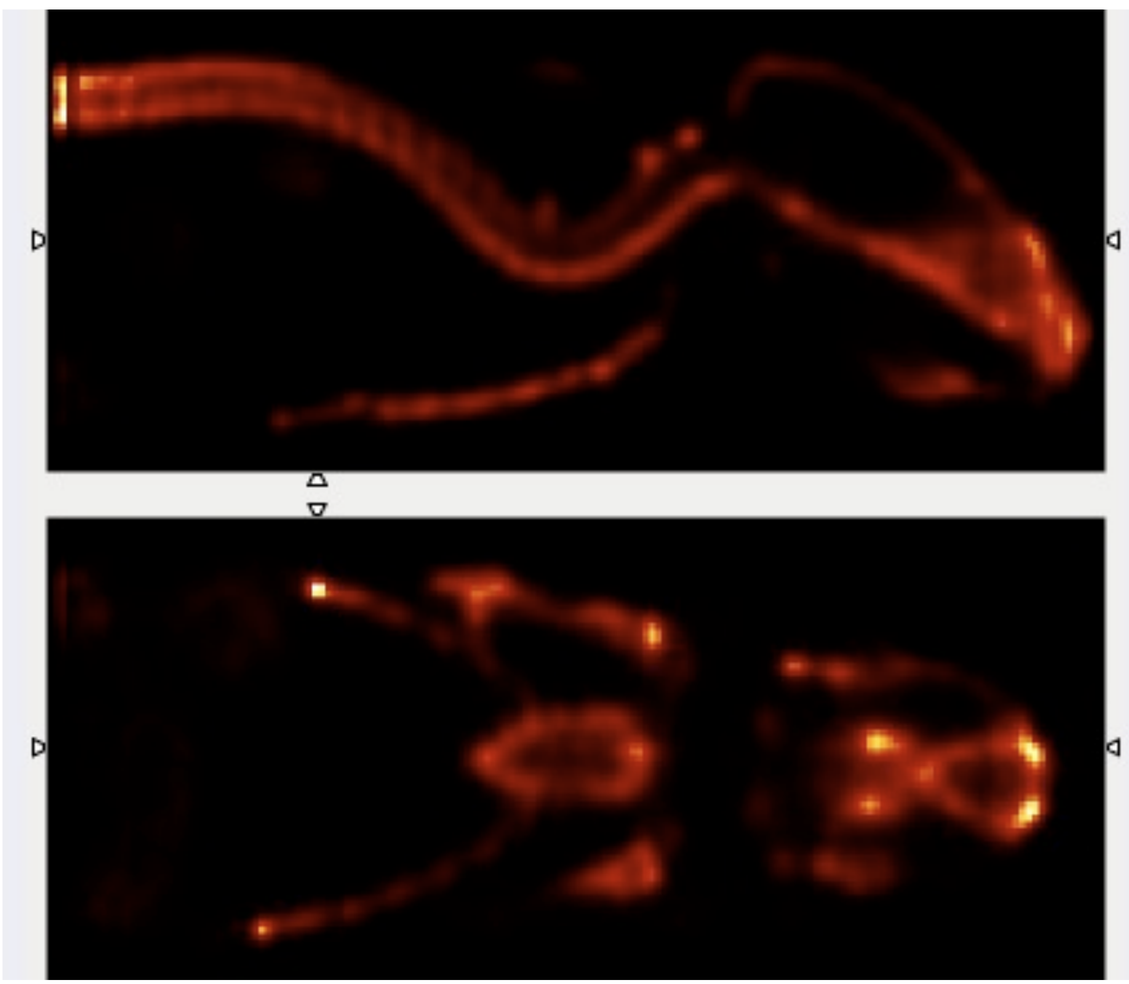
P. Beltrame et al, 2011 IEEE NSS Conference Record MIC 22-5

Small animal reconstructed images

- **SMALL ANIMAL IMAGING CAMPAIGN**

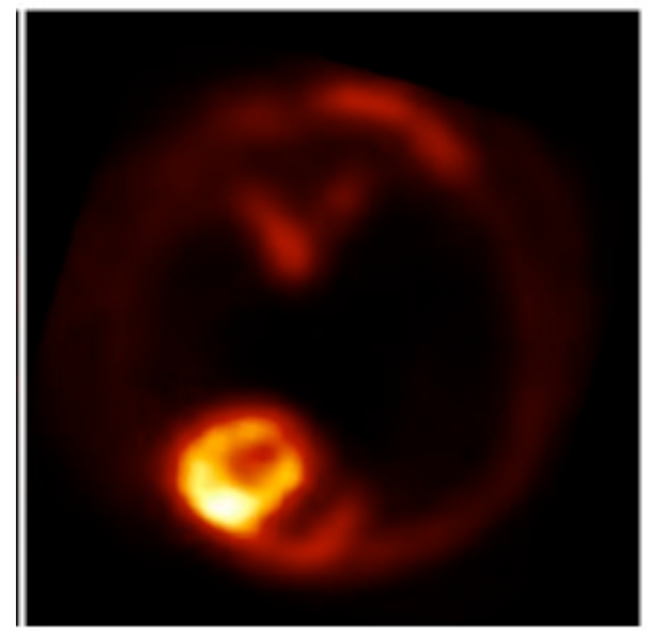
- **F-18 bone scan** of one young rat (post-mortem)
- two **FDG studies**, one young rat, one mouse (post-mortem)
- at Animal Imaging Center - PET @ ETH Zurich, June 2012

Rat F-18 => Bone scan



- **fine structure visible (high spatial resolution)**
- **large axial coverage (single step acquisition)**

Rat FDG => zoomed coronal image of the rat hearth



low contrast regions (ventricular myocardium) visible

first rodent images from a PET with axial geometry !

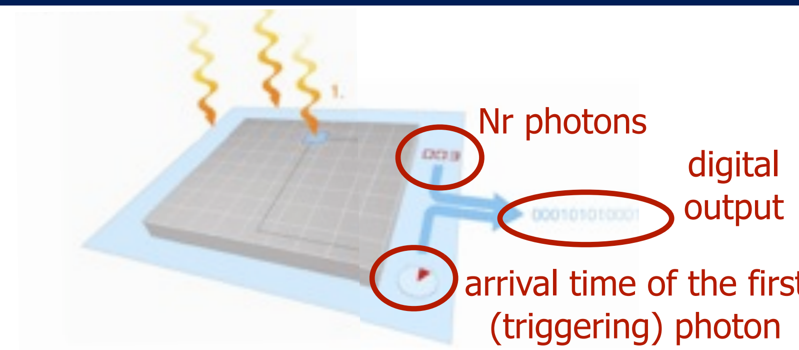
satisfactory quality of the reconstructed images – despite the limitations of the experimental setup (i.e. two modules only, large crystals cross section)

paper in preparation!

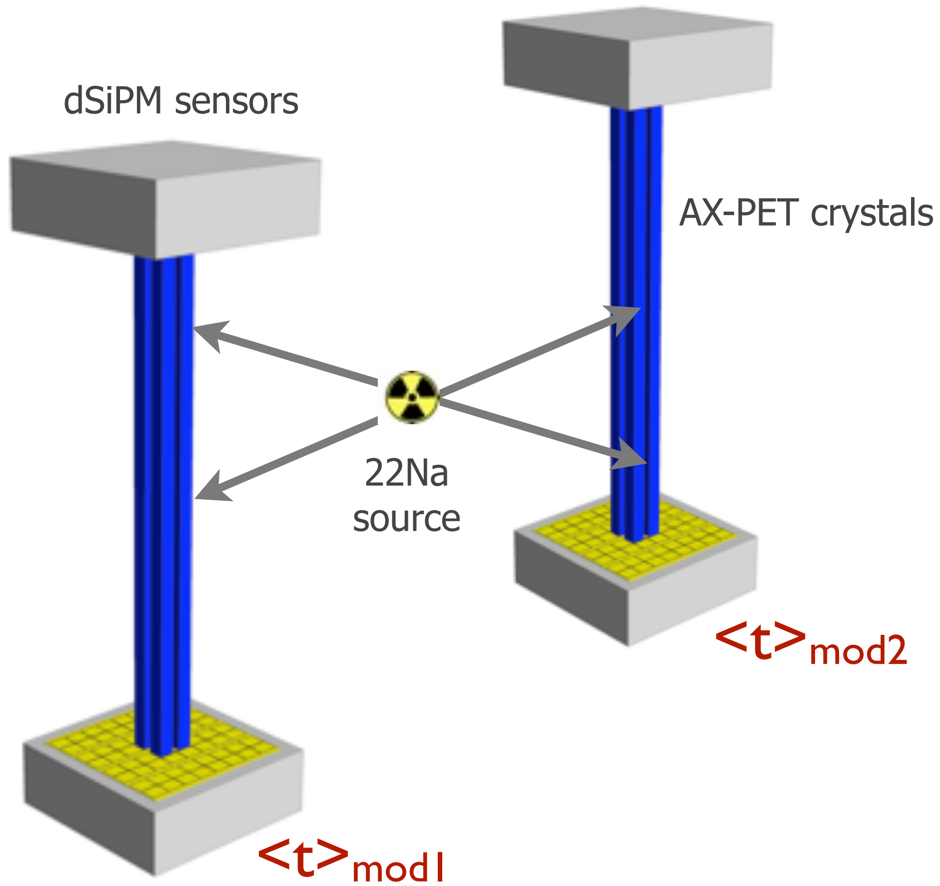
AX-PET follow-up: towards TOF capabilities?

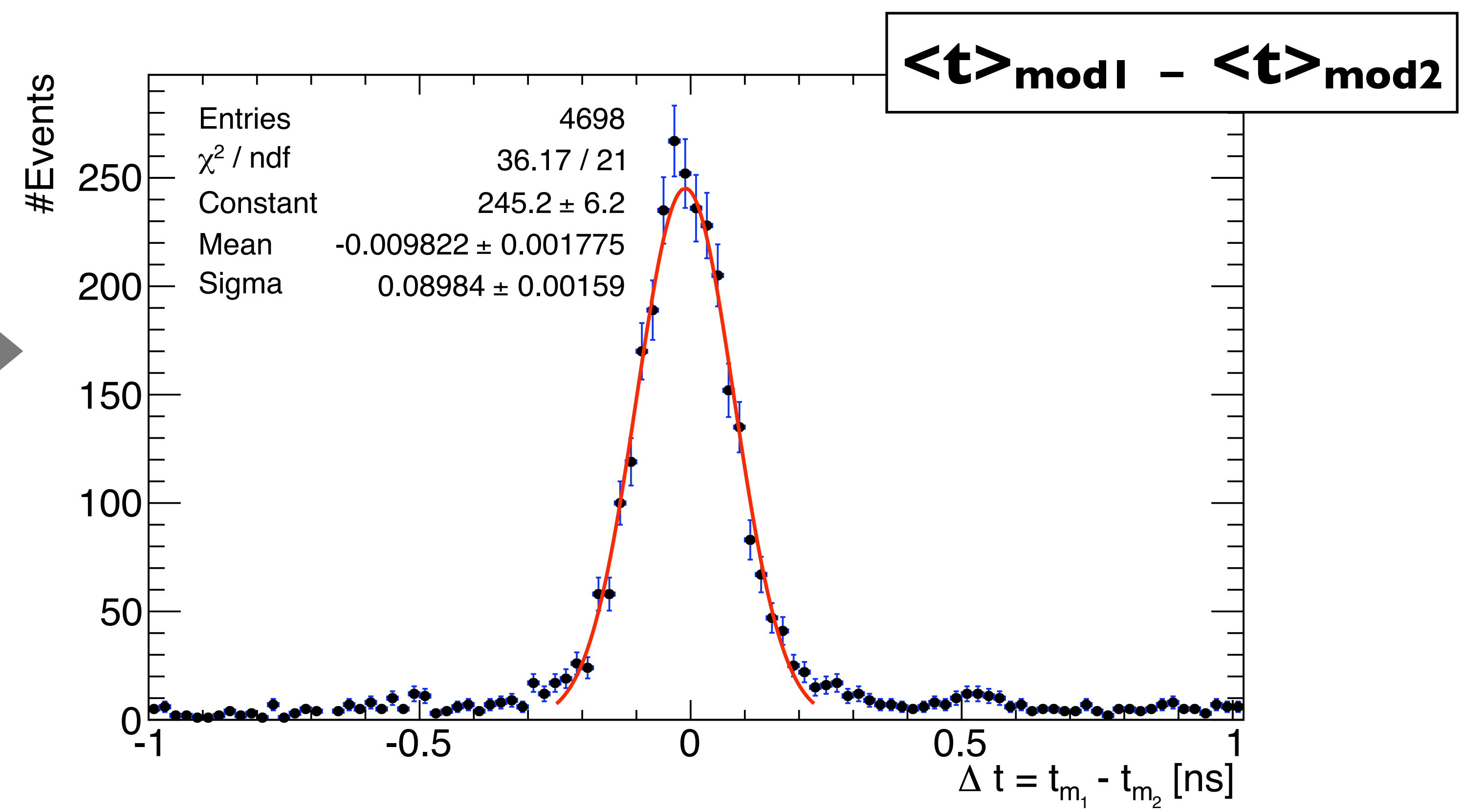
- good performance of AX-PET
- availability of **digital SiPM** (high performance photodetectors, with excellent timing performance)

=> **"AX-PET like" detector with Time Of Flight capabilities ?**



- fully digital implementation of SiPM
- high resolution TDC (19.5 ps resolution)
=> time information ; ~ 50 ps intrinsic time res.
- high compactness, high level of integration





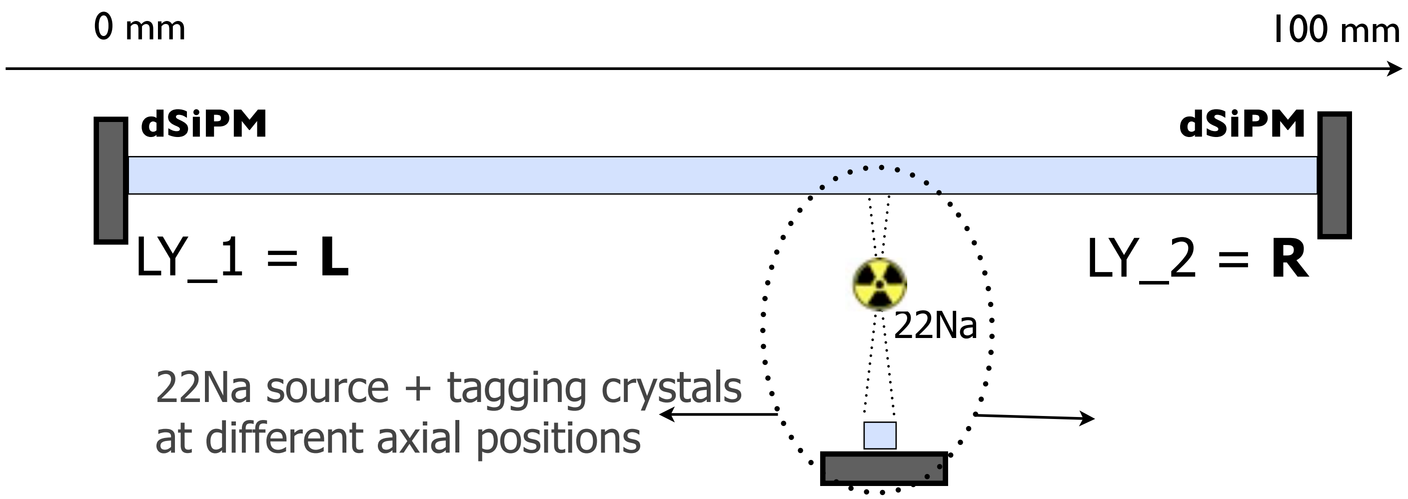
- small scale "digital axial modules"
- 4 crystals (LYSO, 3x3x100 mm3) / module, coupled to dSiPM
- dual sided readout => <t>
  by definition correcting for the path length dependence

CRT ~ 211 ps, FWHM

There is a TOF potential !

NIM A 736 (2014) 161-168

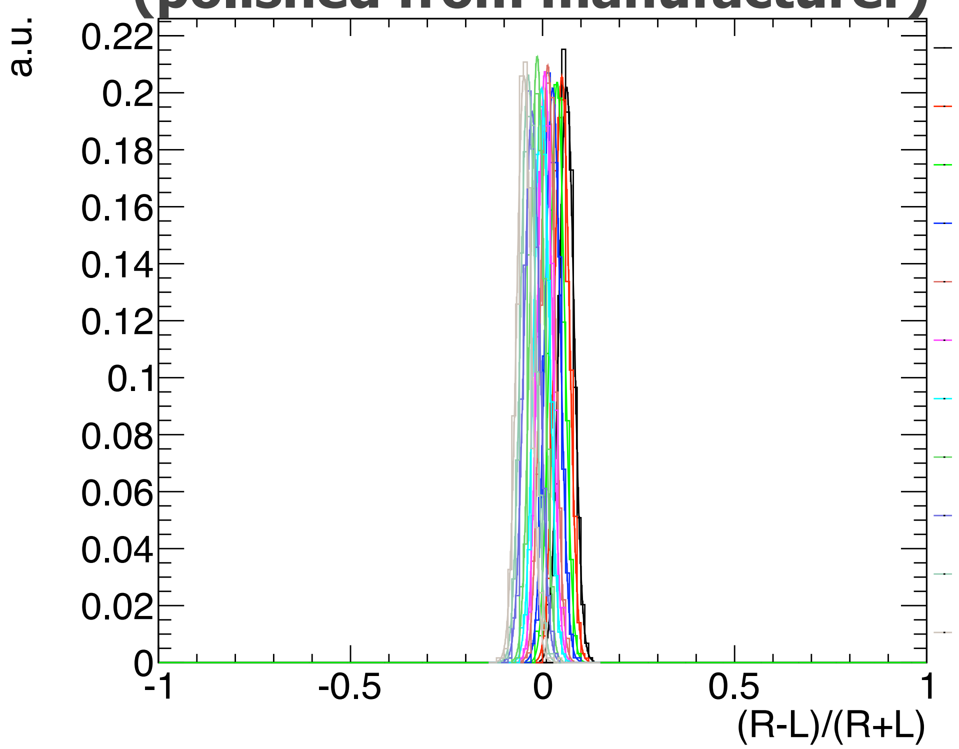
Long crystals, dual sided readout: axial resolution ?



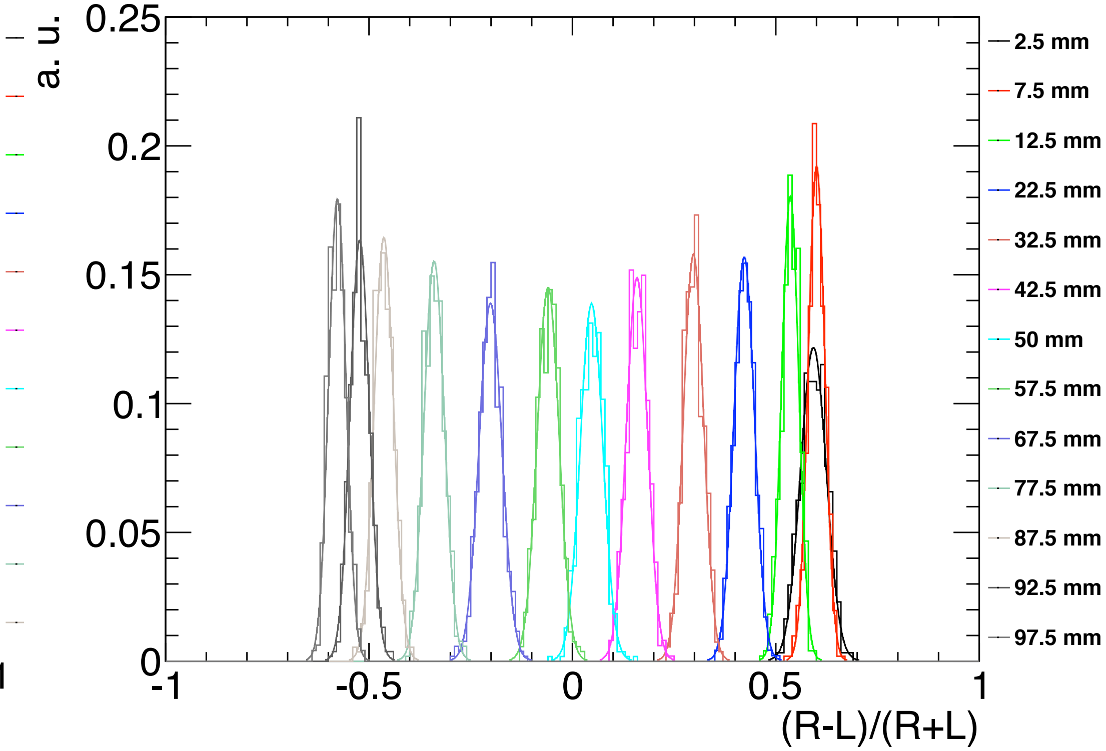
Which is the spatial resolution achievable by light sharing techniques on dual sided readout long crystals ?

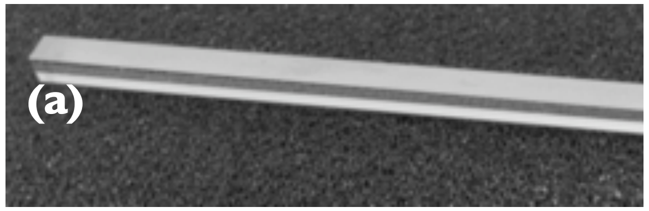
dSiPM still used for this study, but not strictly needed

untreated crystal (polished from manufacturer)

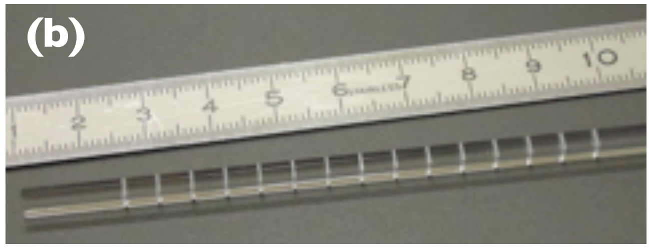


crystal with treated surface

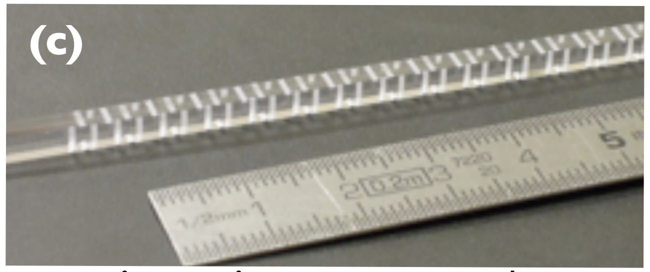




continuous, two depolished surfaces



discrete pattern



semi-continuous, staggered pattern

crystal treatment: mechanical CNC etching (diamond tool) @ CERN

it is **mandatory to "destroy" the crystal** to increase its optical attenuation length and be able to appreciate differences in the LY for different axial coordinates !

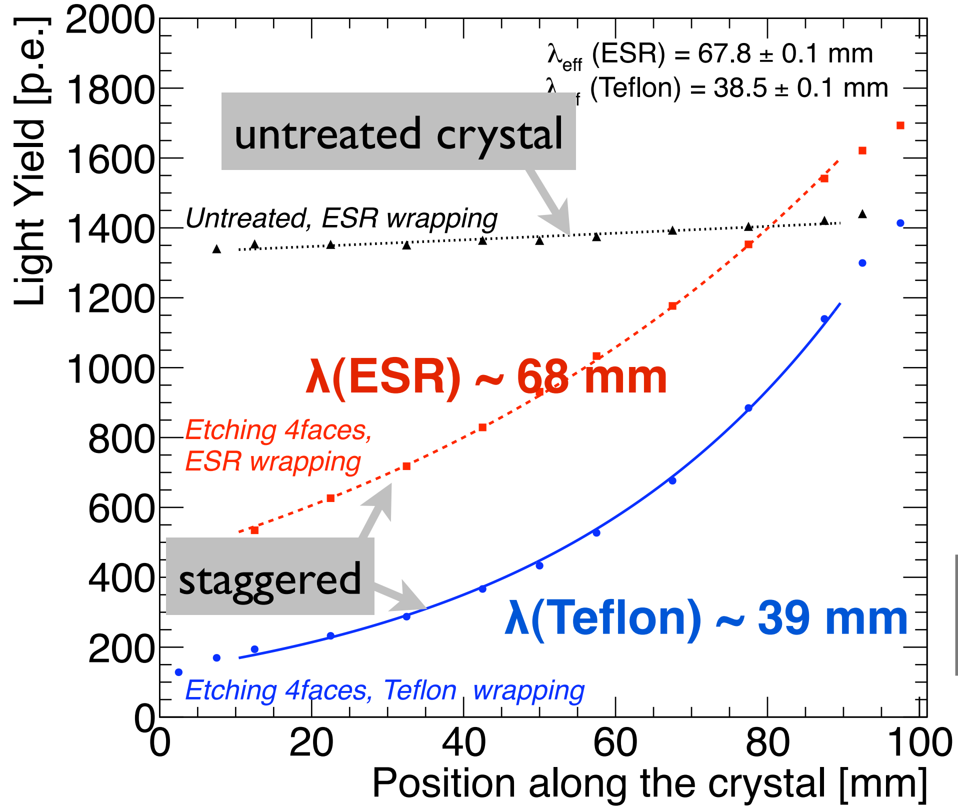
Axial resolution without WLS readout

(staggered pattern)

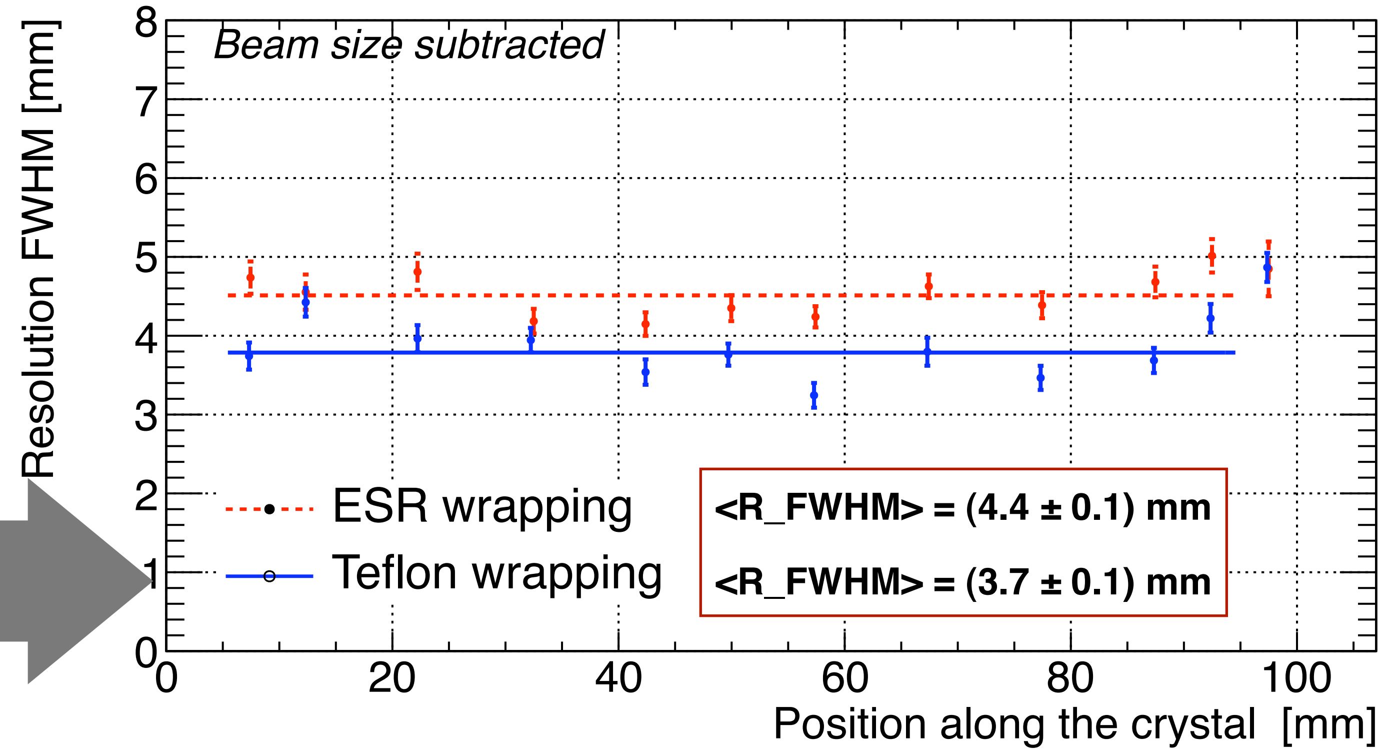
representative of the general results

100 mm long

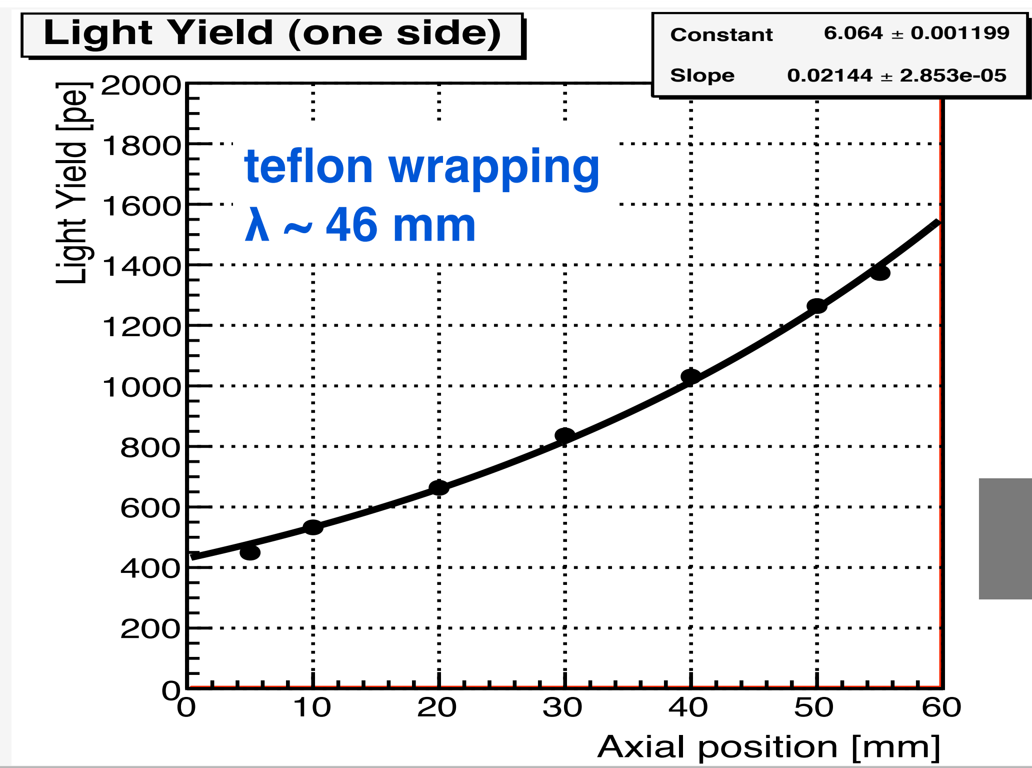
Detected **light yield** (one side)

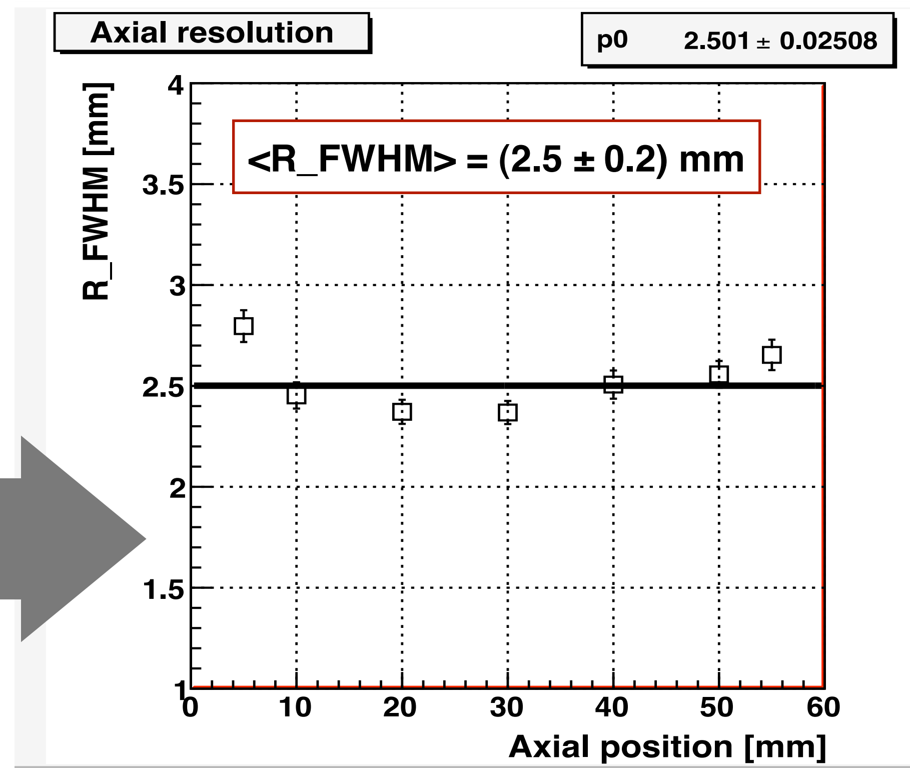


Achieved axial resolution



60 mm long





Dual Sided readout / No-WLS solution :

- still good spatial res
- not competitive with WLS solution (at the achieved λ and LY)
- advantages: compactness, simplicity, nr channels...

Usage of long axially oriented crystals for PET applications: AX-PET Demonstrator and beyond

AX-PET Demonstrator :
excellent example of
1.small scale calorimeter (crystals, WLS, SiPM) used for medical applications
2.capabilities of axial geometry PET as a solution towards high sensitivity and high resolution PET scanner

If the axial crystals are coupled to fast photodetectors & readout,
Time Of Flight capabilities can be added to the detector
(our measurements : dSiPM dual sided readout, average timing => CRT ~ 211 ps)

Compromising on the axial resolution (and/or on the axial length)
satisfactory axial resolutions with dual sided readout (light sharing technique) is achieved, **without the WLS strips solution**
(our measurements : Resolution ~ 4 mm / 2.5 mm FWHM (100 / 60 mm long xtals))
Advantage of a compact, simple, no electronics in the FOV, few channels detector)
interesting e.g. for **PET/MRI development ?**

Usage of long axially oriented crystals for PET applications: AX-PET Demonstrator and beyond