Departamento
de Física

UNIANDES HEP LABORATORY

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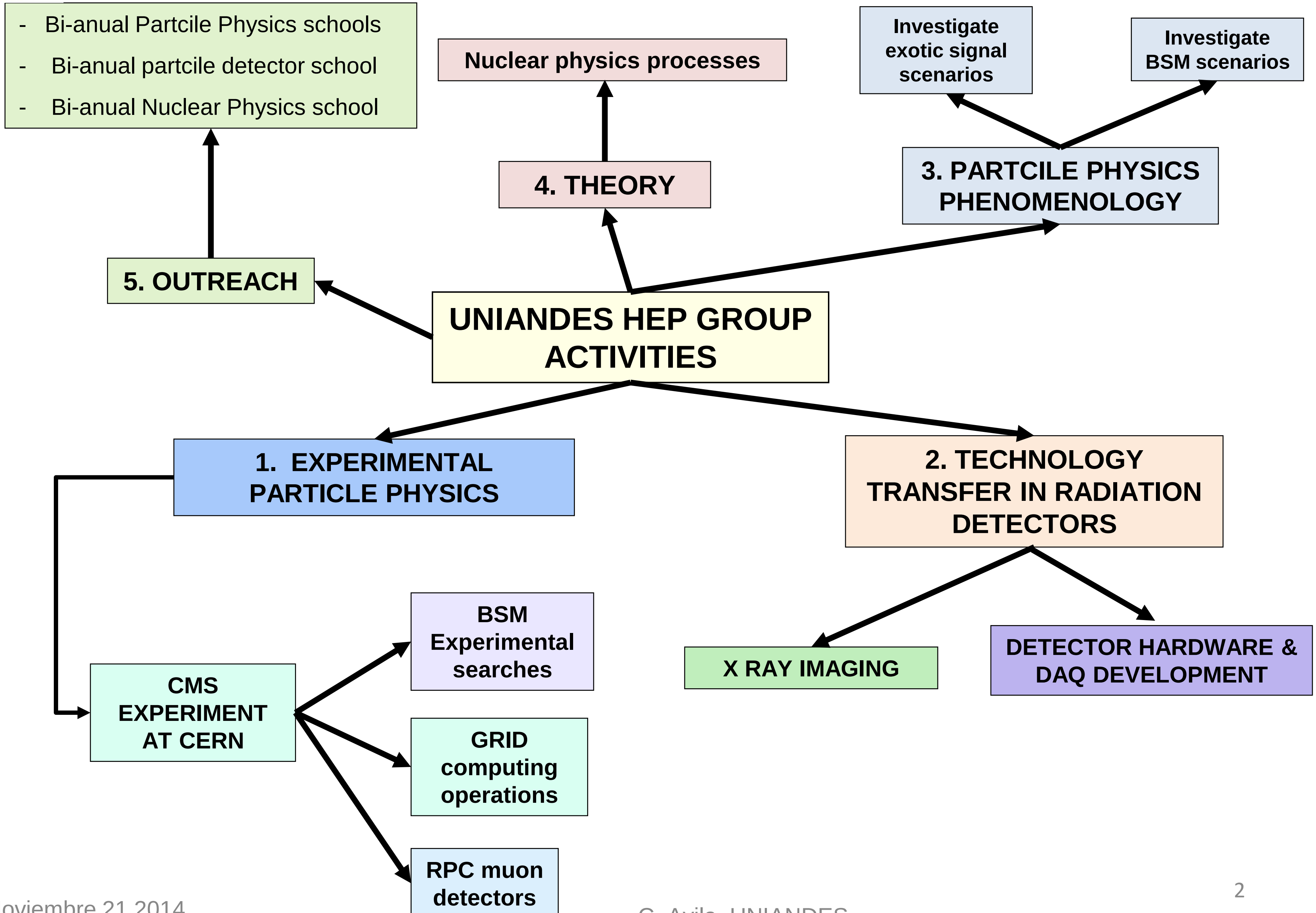
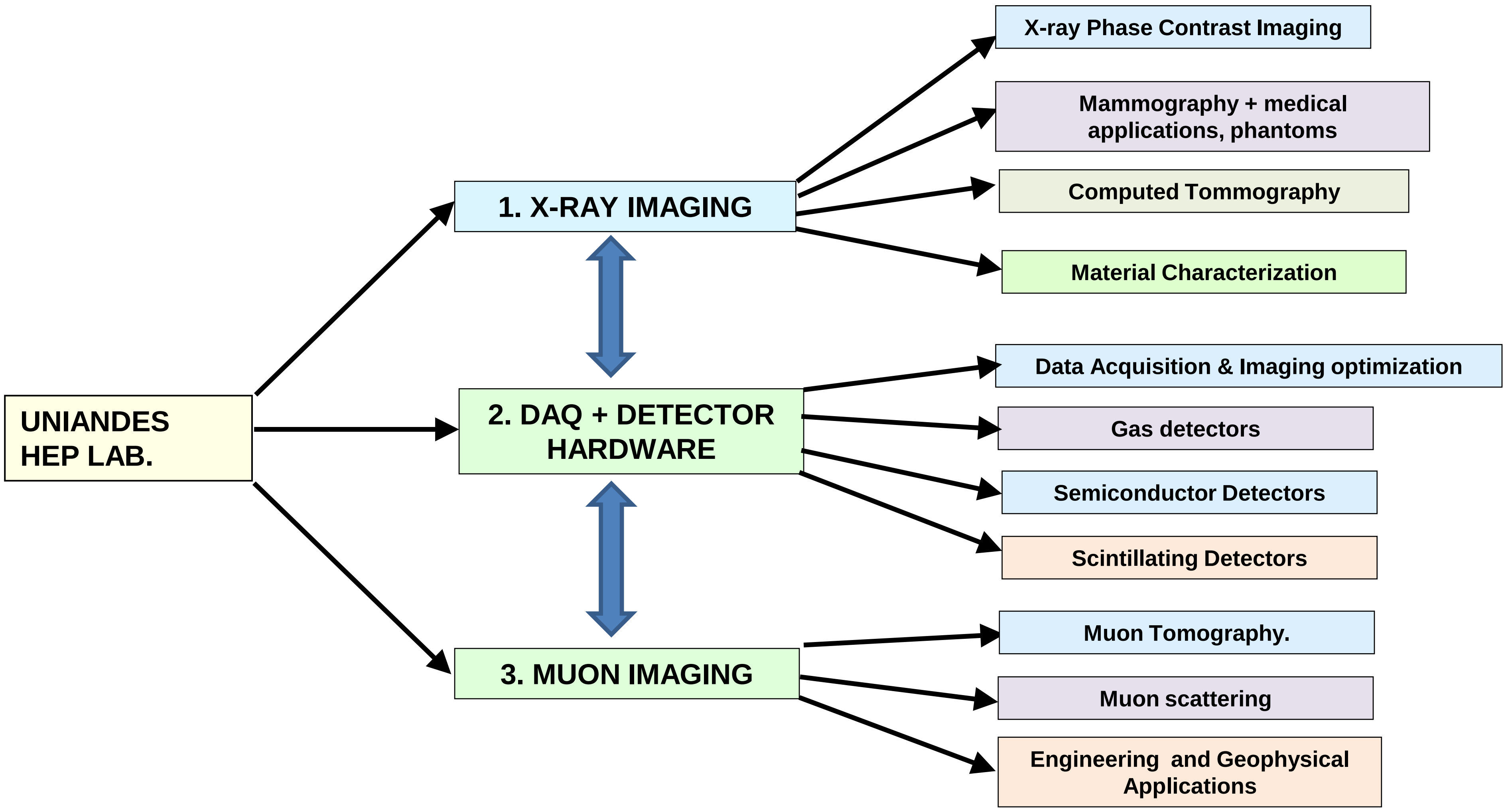

- Bi-anual Partcile Physics schools
- Bi-anual partcile detector school
- Bi-anual Nuclear Physics school
Nuclear physics processes
Investigate exotic signal scenarios
Investigate BSM scenarios
4. THEORY
3. PARTCILE PHYSICS PHENOMENOLOGY
5. OUTREACH
UNIANDES HEP GROUP ACTIVITIES
1. EXPERIMENTAL PARTICLE PHYSICS
2. TECHNOLOGY TRANSFER IN RADIATION DETECTORS
BSM Experimental searches
X RAY IMAGING
DETECTOR HARDWARE & DAQ DEVELOPMENT
CMS EXPERIMENT AT CERN
GRID computing operations
RPC muon detectors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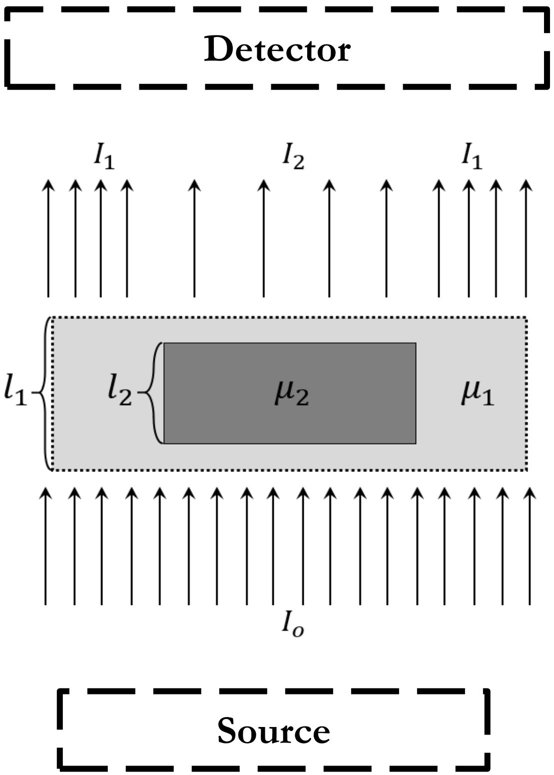
HEP LAB.
1. X-RAY IMAGING
2. DAQ + DETECTOR HARDWARE
3. MUON IMAGING
X-ray Phase Contrast Imaging
Mammography + medical applications, phantoms
Computed Tommography
Material Characterization
Data Acquisition & Imaging optimization
Gas detectors
Semiconductor Detectors
Scintillating Detectors
Muon Tomography.
Muon scattering
Engineering and Geophysical Applications

X-RAY ATTENUATION IMAGING BASIC PRINCIPLE



Starting from Beer-Lambert law:

$$I(E,z) = I_o Exp[-\mu(E,z)z]$$

For an object embedded in a medium:

$$I_2 = I_1 Exp[-\mu_1(l_1 - l_2)] \cdot Exp[-\mu_2 l_2]$$

Contrast can be defined as:

$$C = \frac{I_1 - I_2}{I_1} = 1 - Exp(-l_2(|\Delta\mu|))$$

For polychromatic sources:

$$I(x,y) = \int I_0(x,y) e^{-(\mu_1^\lambda - \mu_2^\lambda)T_0(x,y)} D(\lambda) d\lambda$$

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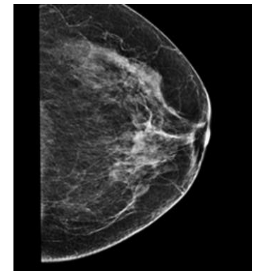
X ray phase contrast imaging

Many biological and human tissues are soft: they have low X- ray absorption → they are difficult to visualize with conventional X ray techniques:

2 specific cases:

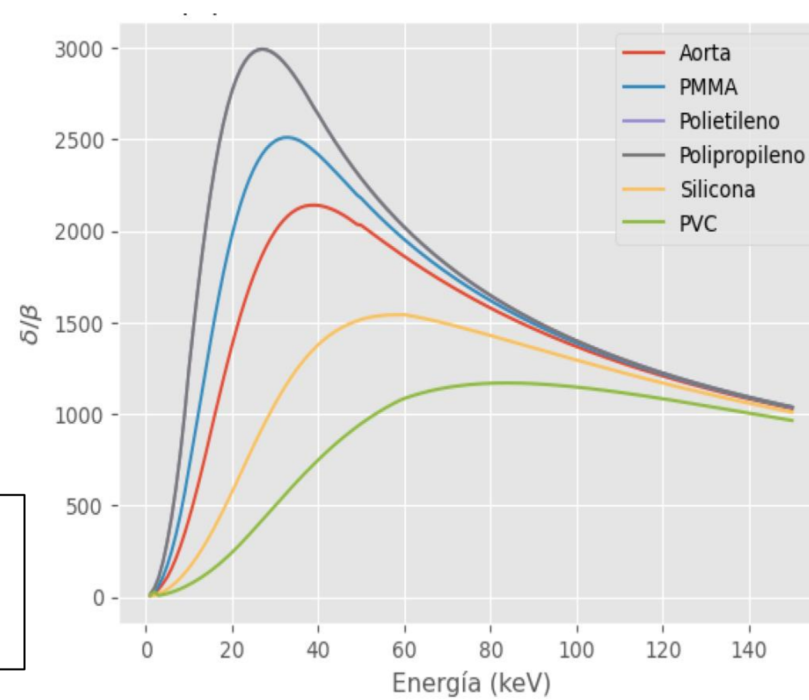
- Breast Tissue
- Blood Vessels (withouth a contrast agent)



The EM wave propagating through tthe sample is $\psi = \psi_0 exp\left(i\frac{n\omega}{c}z\right)$

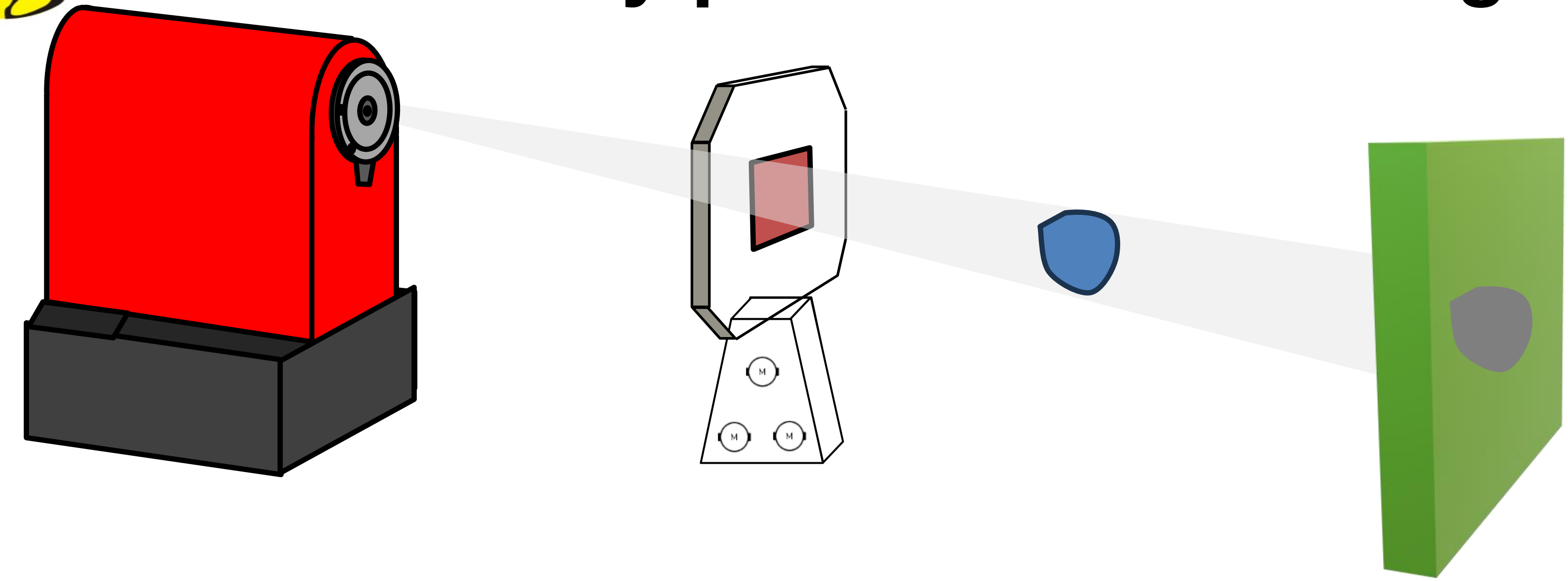
In the x ray energy range the index of refraction can be written as : $n = 1 - \delta + i\beta$

- Phase effects are produced by δ
- Attenuation effects are caused by β



For many soft tissues δ is ~ 3 orders of magnitude greater than β → phase effects could enhance Image constrast

X ray phase contrast imaging



- A microfocus X –ray source is required (focal spot of ~ μm) to have a high spatial coherent beam
- A high resolution detector is needed to observe small changes in intentsity due to phase variations
- Photon energy measurements by the detector will allow to perform spectral image análisis.
- A grating (a mask or sand paper) diffracts the X-ray beam producing a known phase shift, allowing tomeasure the phase shift induced by the sample.
- Specialized phase-retrieval algorithms need to be applied to the final image.

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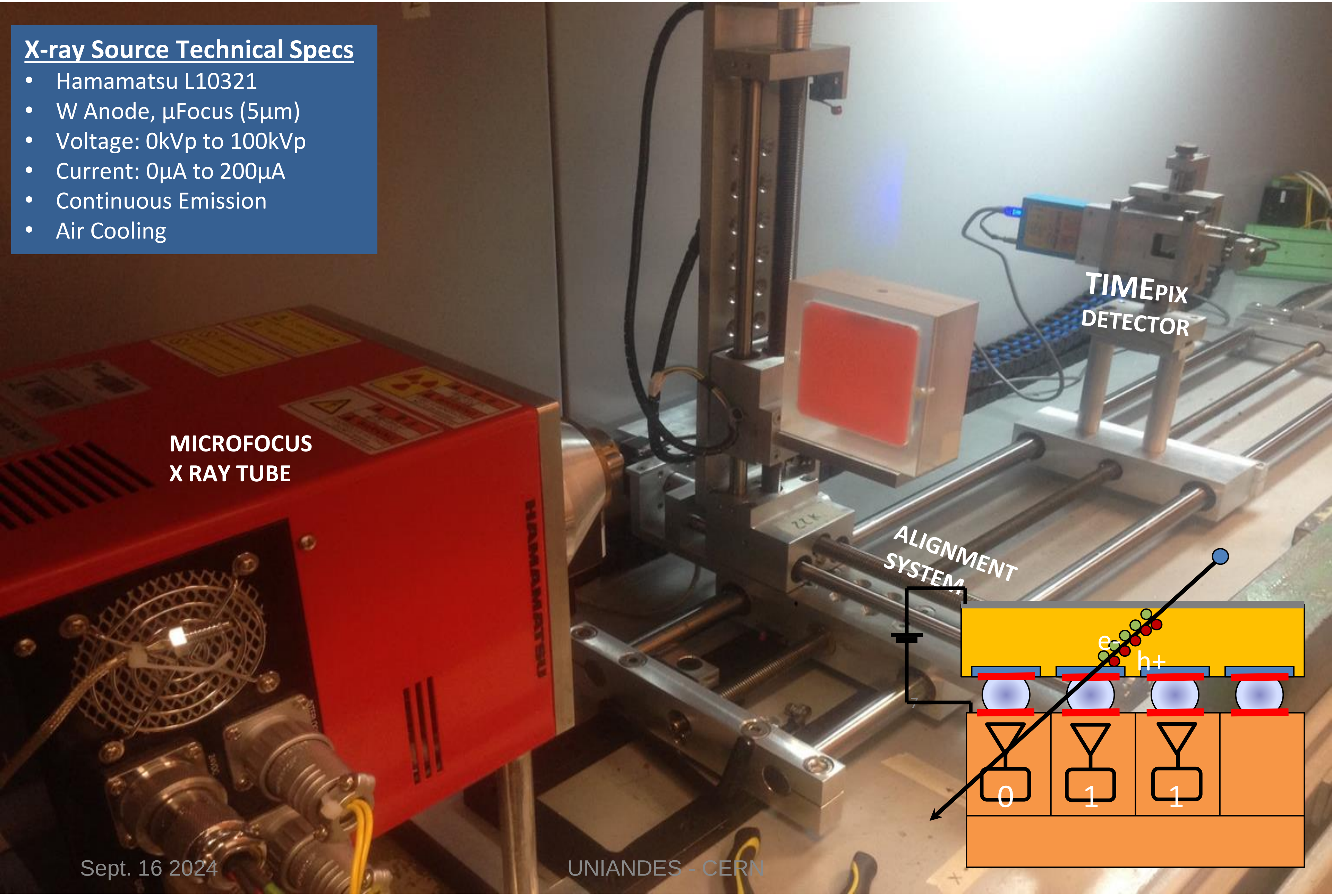
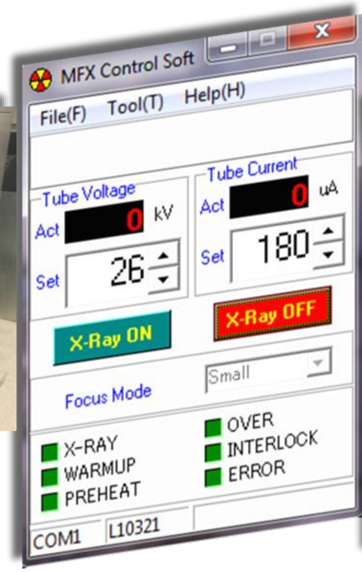
UNIANDES X RAY TEST SETUP

X-ray Source Technical Specs

- Hamamatsu L10321
- W Anode, µFocus (5µm)
- Voltage: 0kVp to 100kVp
- Current: 0µA to 200µA
- Continuous Emission
- Air Cooling



UNIANDES X RAY TESTING SETUP

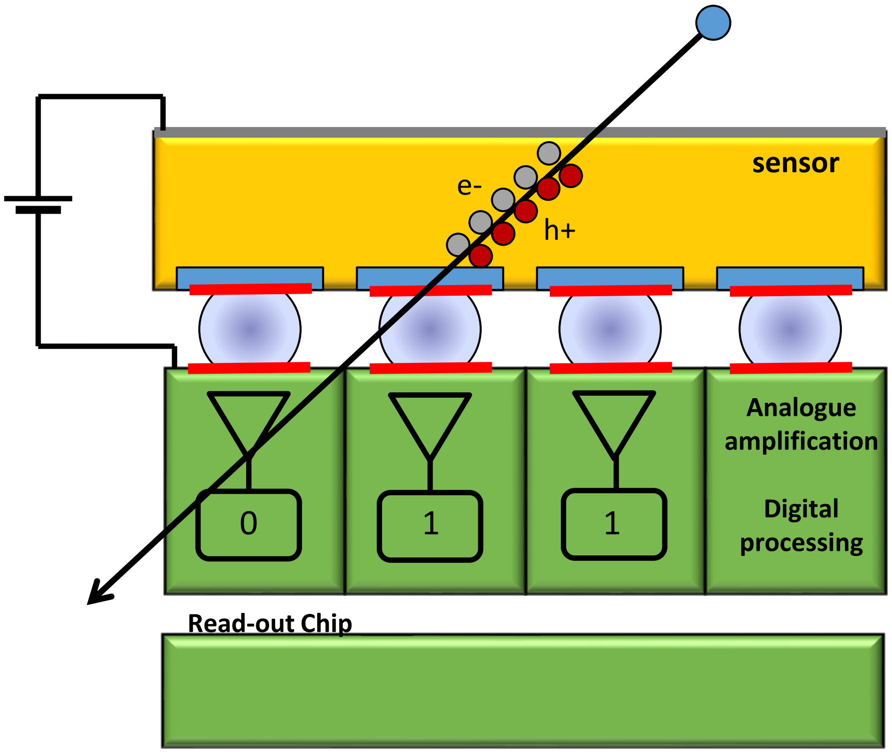


<u>X-ray Shielding Cabinet</u>
Steel casing over Pb shielding
Pb glass
Heat Exhaust port
Dimensions: 2m x 1m x 0.8m

<u>Safety Interlocks</u>
→ Temperature (24°C max)
→ Door
→ Software Comm (3s poll time)
→ External Timer

<u>Positioning System w/ 4 axis</u>
X: 10µm/step
Y: 1.25µm/step, with position sensor
Z: 10 µm/step
θ: 0.03°/step

MEDIPIX Detector



An incident photon generates e-hole pairs

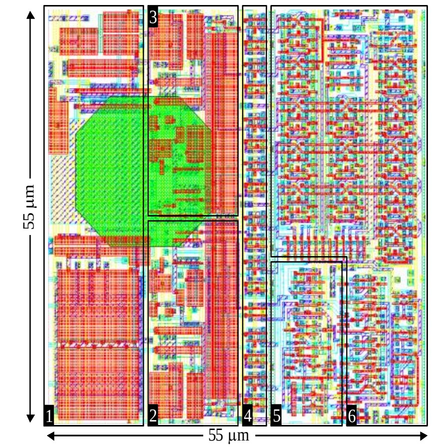
The reverse biasing of the sensor diode structure drives the charge to the readout chip

The charge is shaped and a threshold applied

Digital processing and readout occurs

The data is read out off the chip

Electronics for 1 pixel:



- **Analog side:**

Preamplifier, High Level Discriminator, Low Level Discriminator, 8-bit Pixel memory

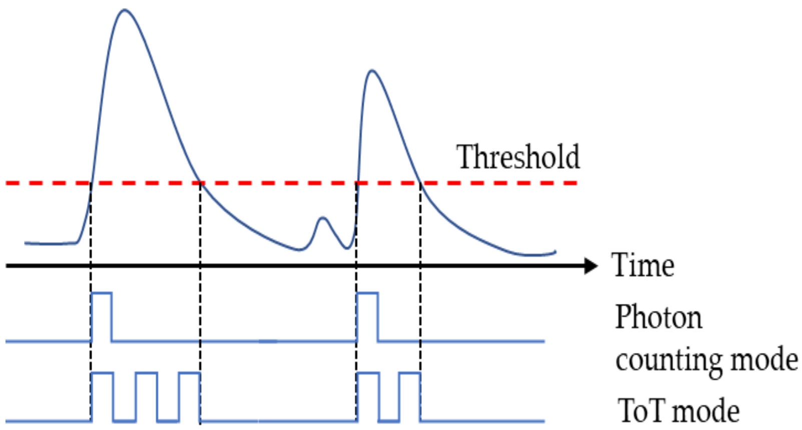
- **Digital side:**

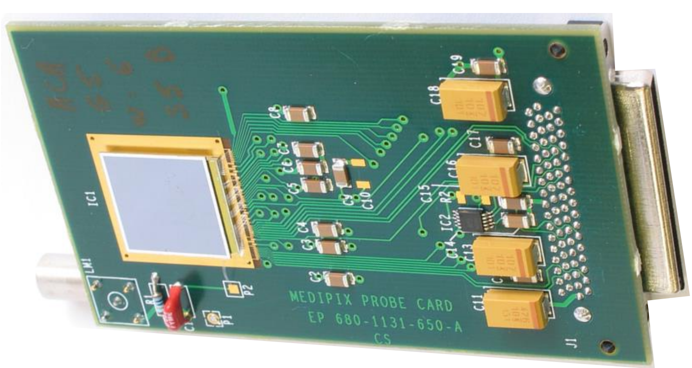
Window discrimination logic, 13-bit Counter

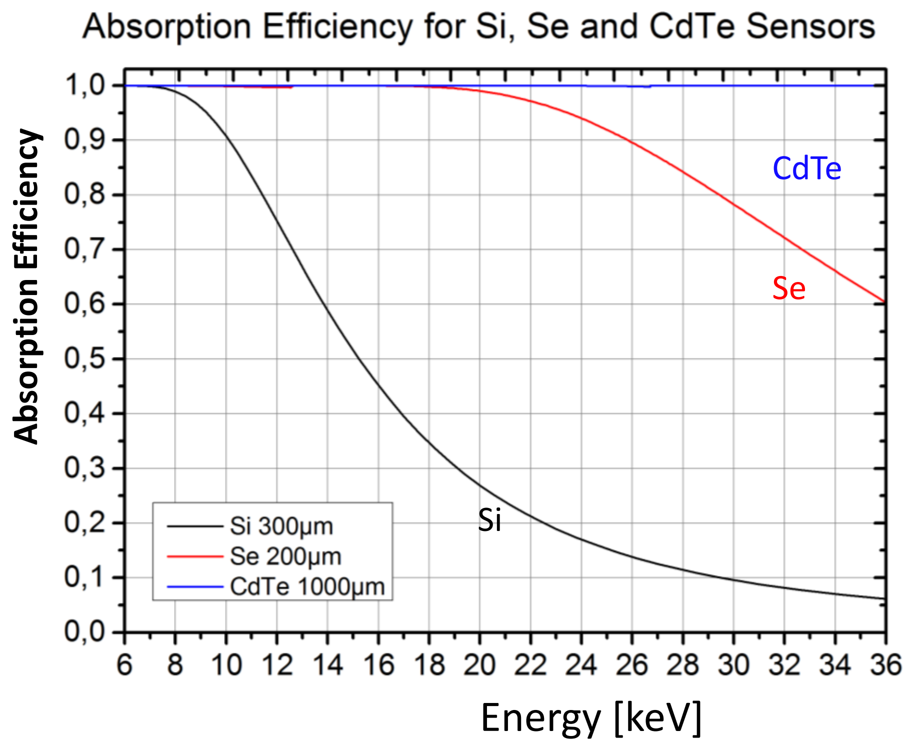
>500 transistors/pixel

SPECIAL FEATURES OF THE TIMEPIX3 DETECTOR

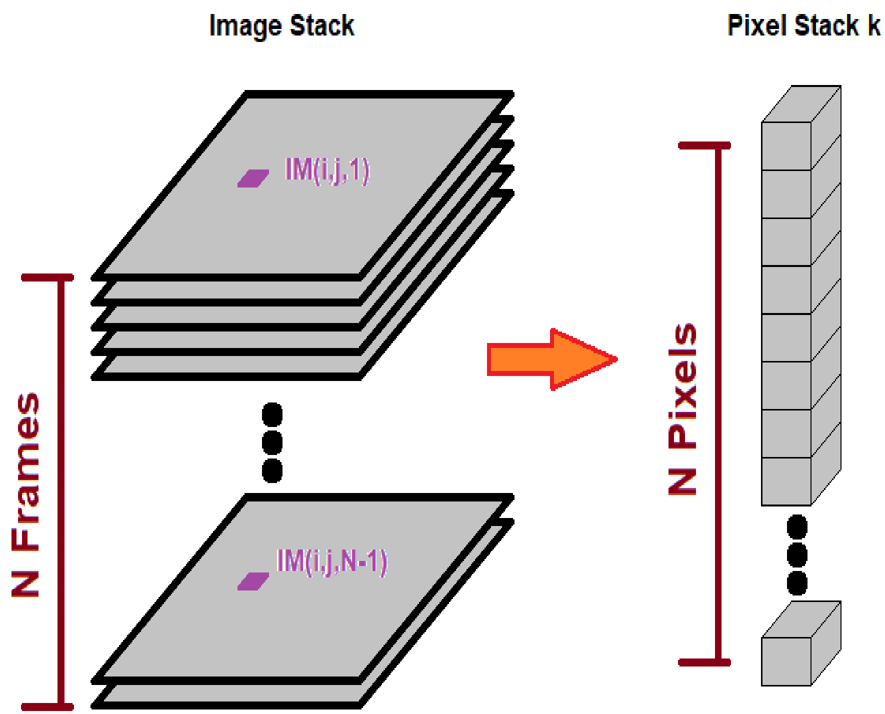
Timepix3 detector working principle.







DAQ METHODOLOGY



Dataset:

- Frame stack with at least 6x Full dose
- 5s frames

Dose Reconstruction:

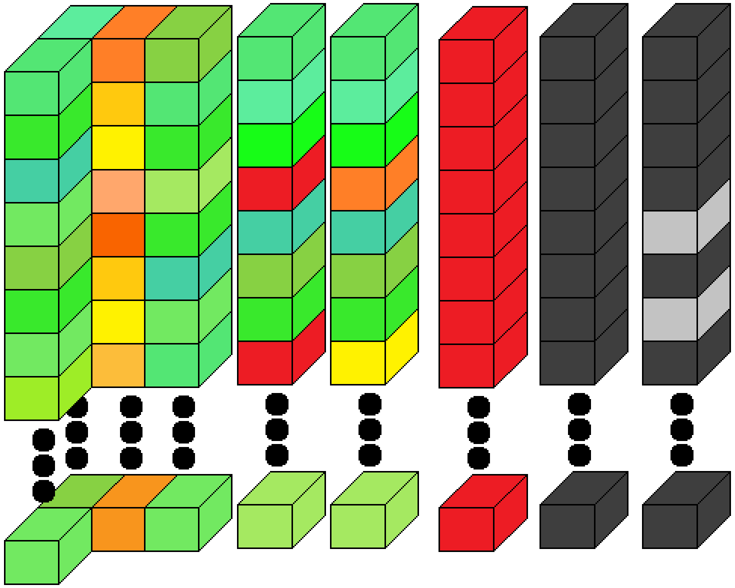
- Sum frames equal to desired dose

Flat Field Mask:

- As much dose as possible, considering detector stability in time

NOISY PIXEL CORRECTIONS

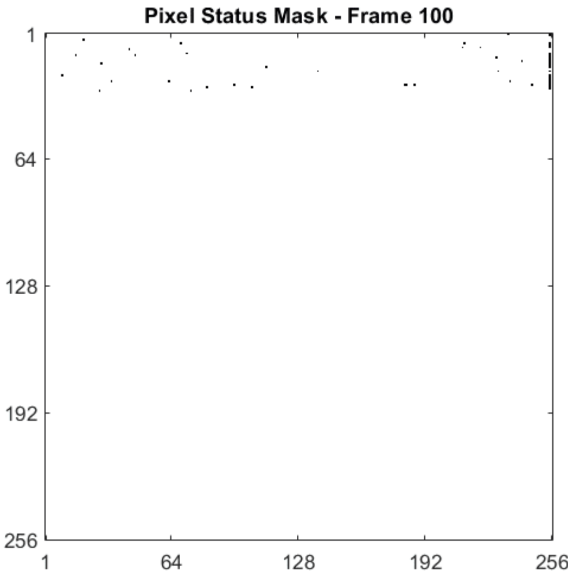
Malfunctioning Pixel Analysis



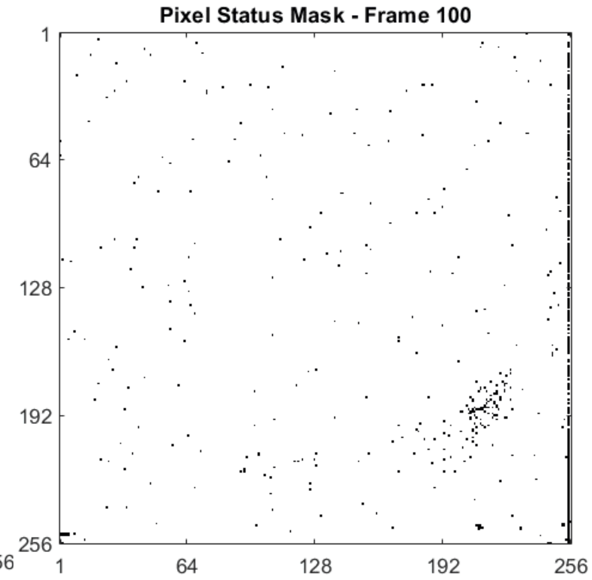
Correction Masks

8-Neighbor Interpolation

Noisy Pixels – 1 frame



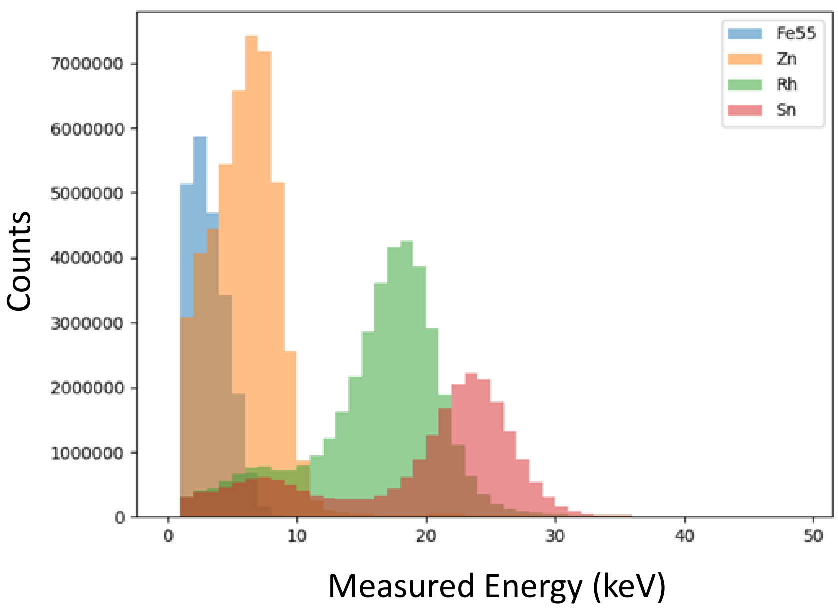
Noisy Pixels – Various frames



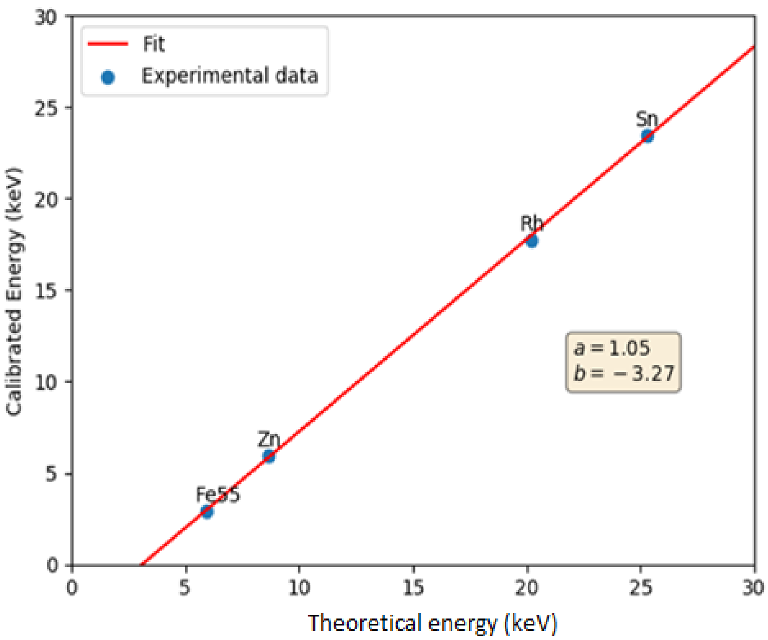
ENERGY CALIBRATION

- Linearity of the calibration with X-ray fluorescence and Radioactive Fe-55

Histograms of the X-ray fluorescence and Radioactive (Fe-55) spectrums



Energy calibration linearity of the Timepix3 detector



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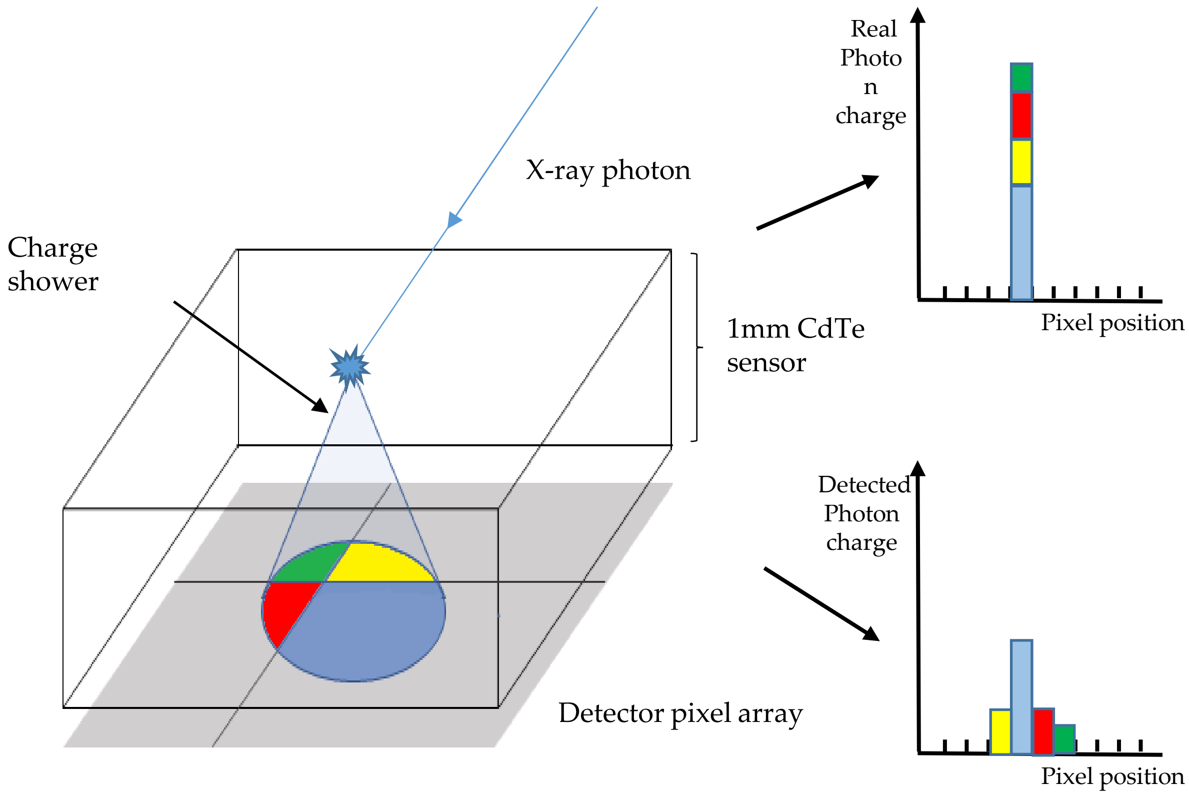
CHARGE SHARING + CLUSTERING

- Charge-sharing in Photon-counting detectors



Charge-sharing increases with:
- Sensor thickness.
- Smaller pixel pitch.
- Lower bias voltaje.

Three methods:
- **Unclustered** Image.
- **One-pixel clusters:** Only events that took place in a single pixel.
- **'Full clusters':** All pixel size clusters. Energy volume is allocated to the pixel closer to the cluster centroid.

Requires individual photon energy information.

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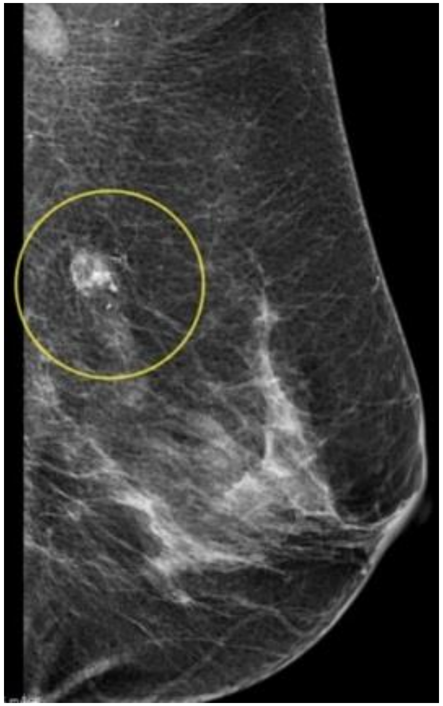
MAMMOGRAPHY APPLICATIONS



- Microcalcifications present in malignant breast tumors are composed mainly of Calcium Hydroxiapatyte.[1]

- Benefit of mammography screening could be reduced due to the risk of radiation-induced tumors.[2]

Early diagnosis of breast cancer is vital for increased survival, with the lowest possible radiation exposure!

1 M. C. Jansen-van der Weide, M. J. Greuter, L. Jansen, J. C. Oosterwijk, R. M. Pijnappel, and G. H. de Bock, Eur Radiol, vol. 20, no. 11, pp. 2547-2556, Nov. 2010 .

IMAGING SETUP - COMMERCIAL DEVICE

Hologic Selenia Dimensions w/ AWS5000

5

X-ray Source Technical Aspects

- W anode
- 50µm Rh filter
- Operated at 28kVp
- High power: 7kW
- Focal Spot size > 100µm

X-ray Detector Technical Aspects

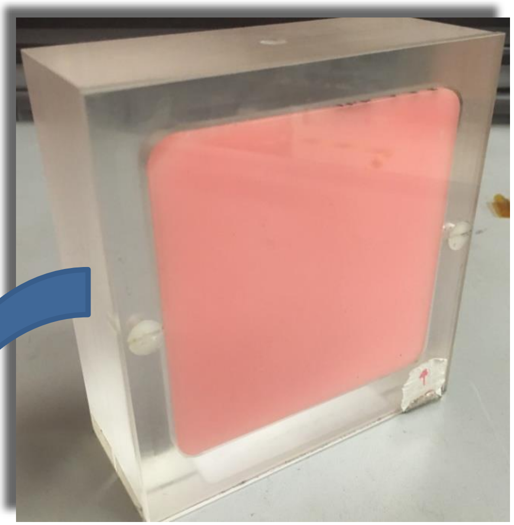
- a-Se Direct Conversion FPD
- 200µm thickness
- 70µm pixel pitch
- Charge-Integration

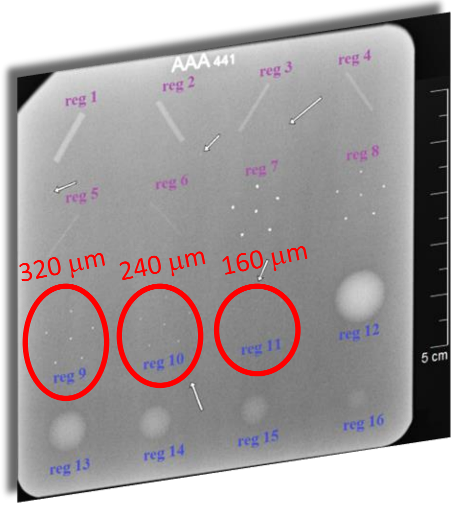
X-ray Imaging Geometry

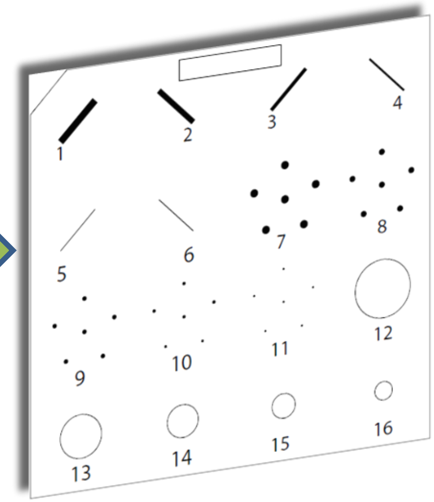
- Source-Detector Distance: 70cm
- Source-Object Distance: 63cm

5 *Selenia Dimensions with AWS 5000 – A flexible platform for the next dimension in breast imaging,* Hologic Inc., Marlborough, MA, 2011

APPLICATIONS IN MAMMOGRAPHY





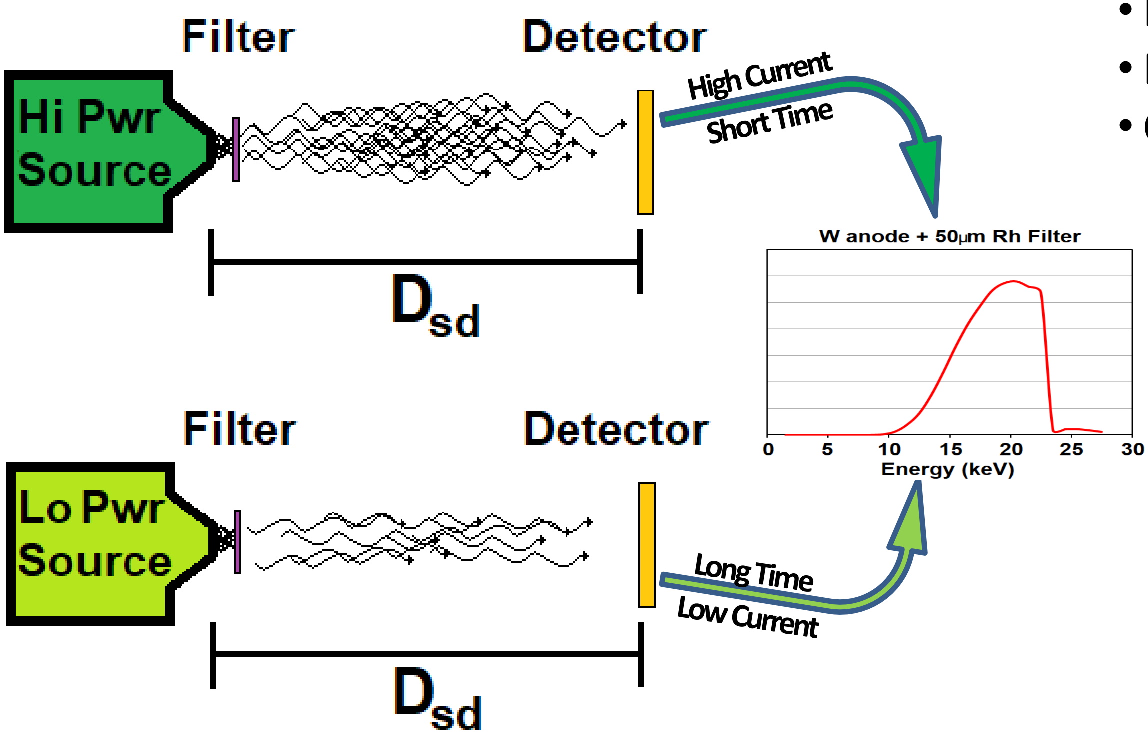


WAX INSERT					
FIBERS (Nylon Fiber)		**SPECKS** (Al_2O_3 speck)		**MASSES** (Thickness)	
1.	1.56 mm	7.	0.54 mm	12.	2.00 mm mass
2.	1.12 mm	8.	0.40 mm	13.	1.00 mm mass
3.	0.89 mm	9.	0.32 mm	14.	0.75 mm mass
4.	0.75 mm	10.	0.24 mm	15.	0.50 mm mass
5.	0.54 mm	11.	0.16 mm	16.	0.25 mm mass
6.	0.40 mm	-		-	

Mammography Accreditation Phantom CIRS, model 015

DOSE CALIBRATION

Both setups generate the same spectrum, with different intensities



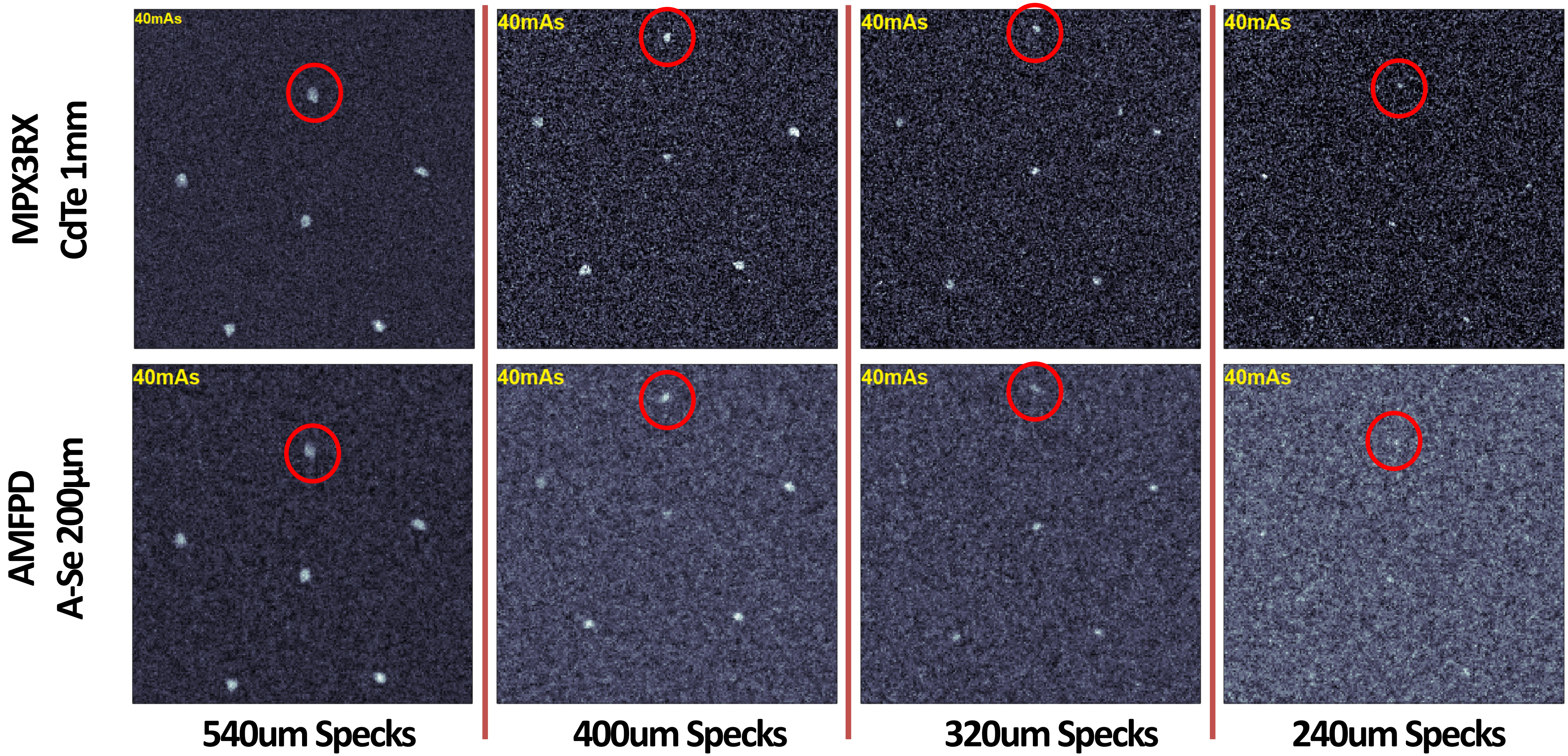
Timepix Si Detector as Dose Calibrator:

- Highly stable detector
- Fast Acquisition Times: 1μs – 10μs
- ESD [mGy] ➔ total photon counts
- Cts/s and source pulse characterization

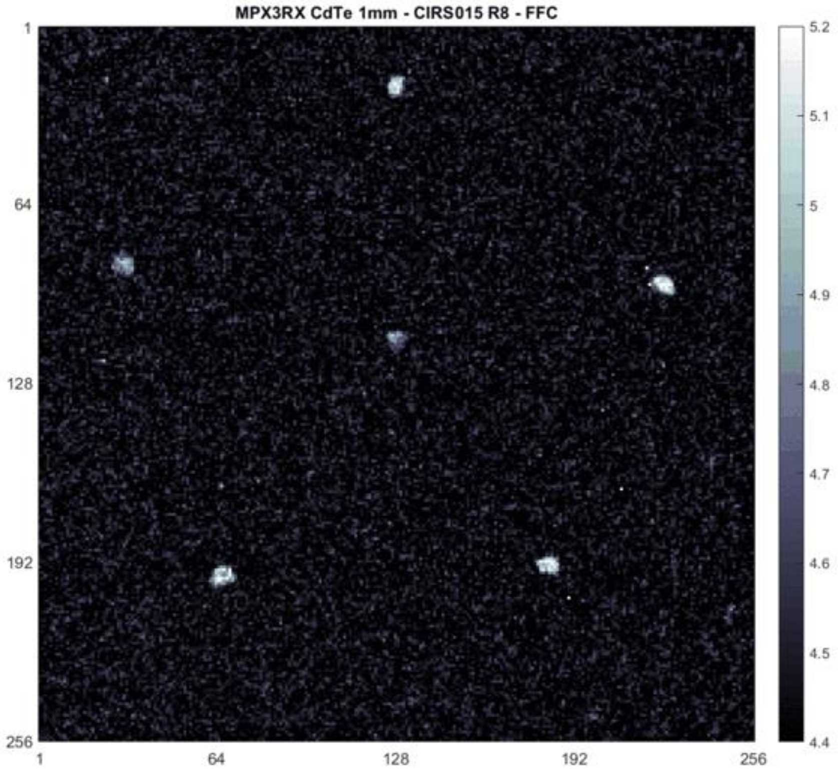
6 Dose Measurements:

- 40mAs ➔ 1.79 mGy
- 50mAs ➔ 2.09 mGy
- 60mAs ➔ 2.52 mGy
- 70mAs ➔ 2.95 mGy
- 80mAs ➔ 3.36 mGy
- 90mAs ➔ 3.79 mGy

PHANTOM X-RAY IMAGES



CNR - SPECK SEGMENTATION

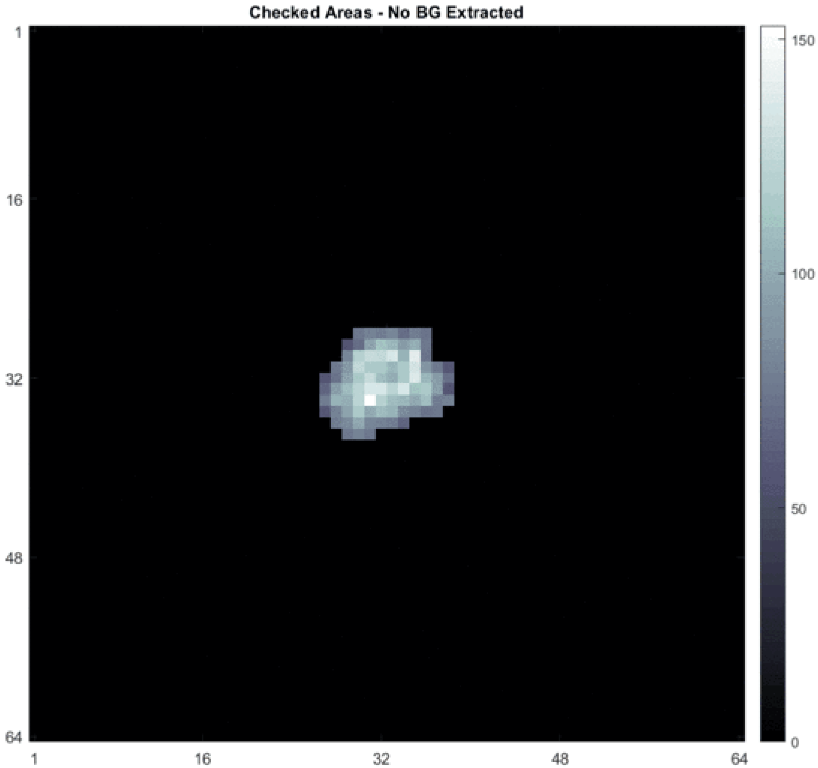


$$CNR = \frac{S - \bar{B}}{\sigma_B}$$

Signal Calculation

$$S = \sum_k s_k$$

CNR - BACKGROUND SAMPLING



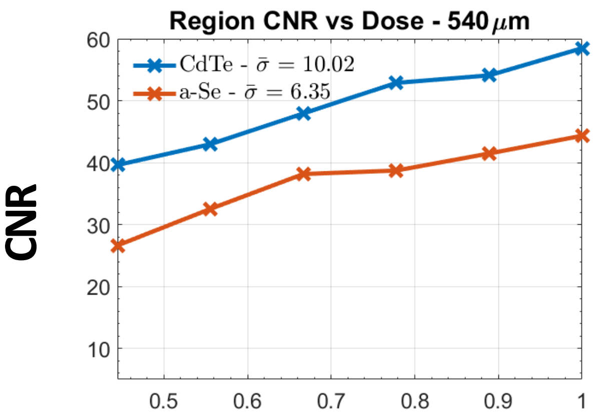
Background Calculation

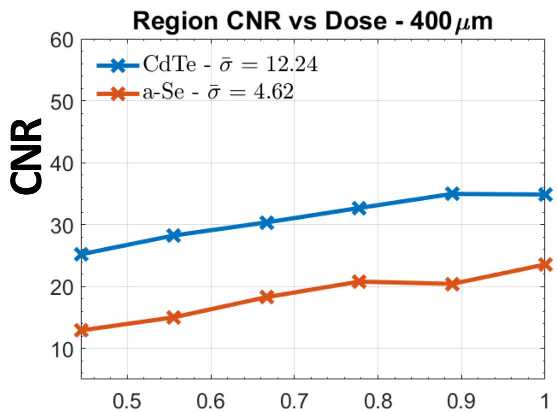
$$\bar{B} = \frac{1}{N}\sum_{i=1}^{N}\sum_{k}(b_k)_i = \frac{1}{N}\sum_{i=1}^{N} B_i$$

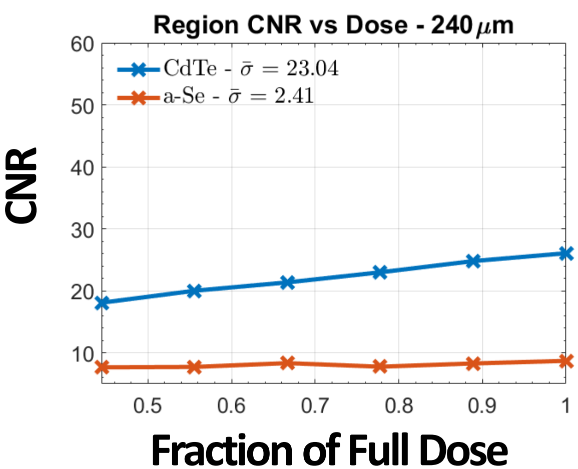
Noise Calculation

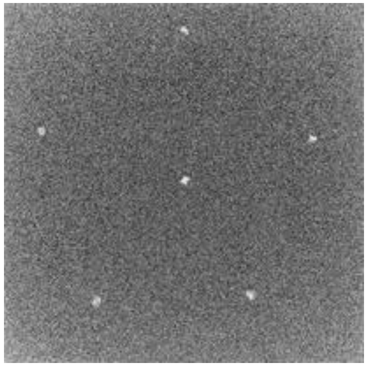
$$\sigma_B = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\bar{B} - B_i)^2}$$

RESULTS – CNR PER REGION









1.1X to 38X

- Average CNR for photon counting CdTe detector is greater at all doses and all speck sizes.
- Standard image quality could be achieved with lower radiation doses.
- MDPX + CdTe has better resolution for smaller crystal sizes which could be critical for early diagnosis.

Study of Contrast-to-Noise Ratio performance of a Medipix3RX CdTe detector for low dose mammography imaging

Gerardo Roque [a,*], Carlos Avila [a], Maria L. Pérez-Lara [a], Luis Mendoza [b], Simon Procz [c]

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[b] Departamento de Física - Universidad Militar Nueva Granada, 110221, Cra. 11 No. 101-80, Bogotá D.C., Colombia
[c] Freiburger Materialforschungszentrum - Albert-Ludwigs-Universität Freiburg, Stefan-Meier-Straße 21, 79104 Freiburg i. Br., Germany

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TECHNICAL REPORT

CNR performance of semiconductor materials for X-ray imaging of breast calcifications

L. Mendoza,[a,*] C. Avila,[b] R. Rodriguez,[b] L. Loaiza[c] and G. Roque[b]

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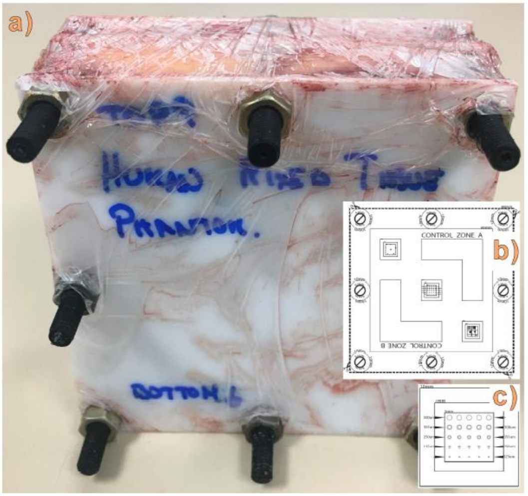
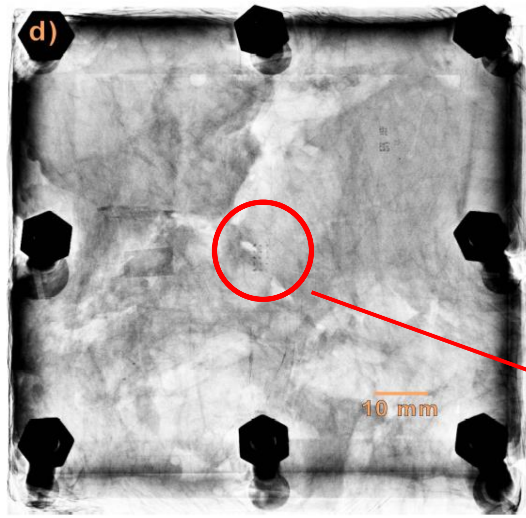
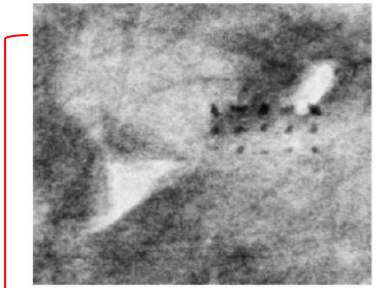
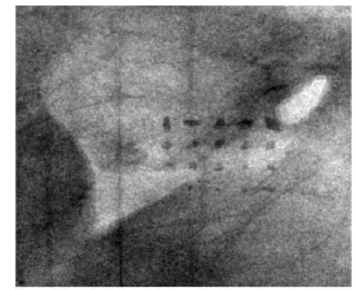
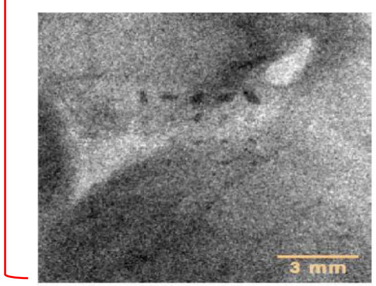
TESTS WITH A HUMAN BREAST TISSUE PHANTOM






Hologic Selenia, Se-detector


1 mm CdTe-Medipix3RX



0.5 mm Si-Medipix3RX

Phantom constructed with breast Human tissue and with hidroxiapatite crystasl embeded atifically by us. Tissue donated by a patient with breast reduction.

X-RAY image taken with a Selenia mammographic system of the Brest human phantom.

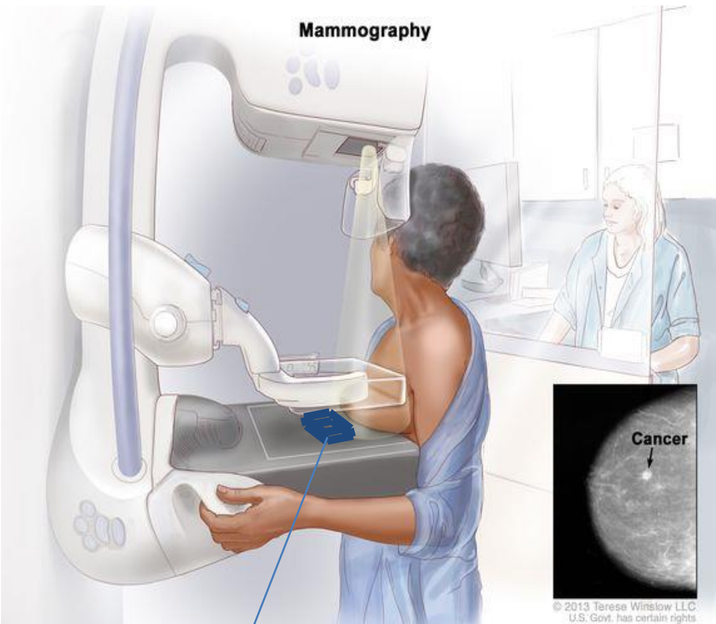
All ethical protocols and permissions were followed.

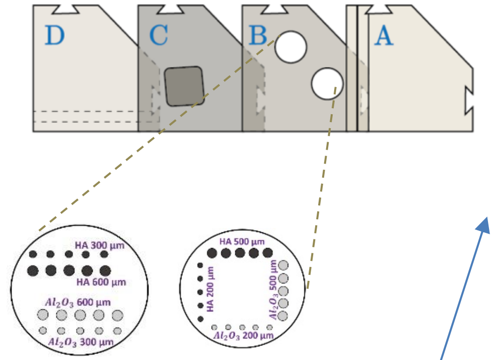
Investigation of CdTe, GaAs, Se and Si as Sensor Materials for Mammography

Simon Procz, Gerardo Roque, Carlos Avila, Jorge Racedo, *Student Member, IEEE*, Roberto Rueda, Ivan Santos, and Michael Fiederle

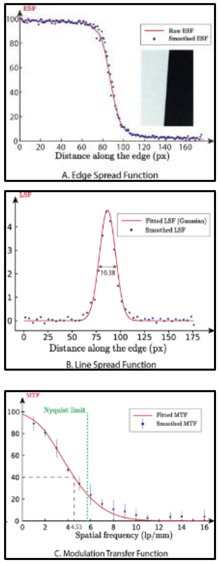
IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 39, NO. 12, DECEMBER 2020

IMPROVING PHANTOM REQUIREMENTS FOR MAMMOGRAPHY STUDIES

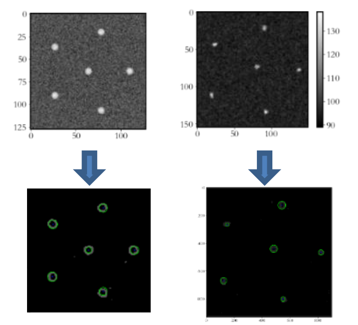




Microcalcifications

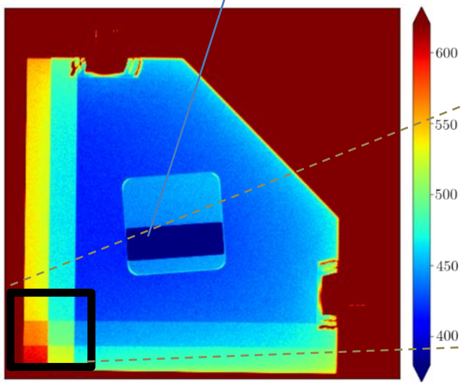


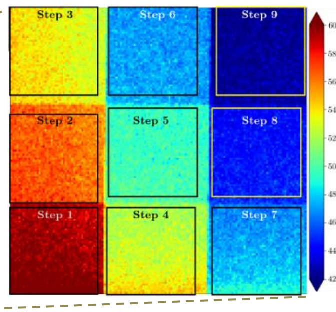
Interpolation of known lessions to diagnose real lessions:



Diagnostic + calibration phantom for simultaneous Xray imageswith patients, allow:

1) MTF, CNR in-vivo calibration equipment measurements.
2) Diagnostic guide of microcalcificatio imaging vs breast composition.





Patent: C. Avila. G. Roque, J. S. Calderon, Patente, “Fantoma de Calibración y diagnóstico”, Octubre 2022, SIC 054-2019

J Bermúdez, G Roque, J Calderón, P Pardo, M Sánchez, V Ramos, C Ávila, “3D phantom for image quality assessment of mammography systems”, Phys Med Biol. 2023 Oct 13; 68(20). https://doi.org/10.1088/1361-6560/acfc10

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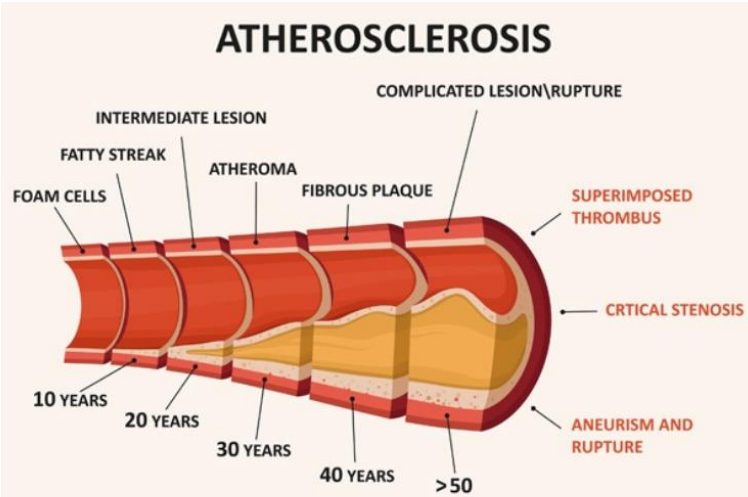
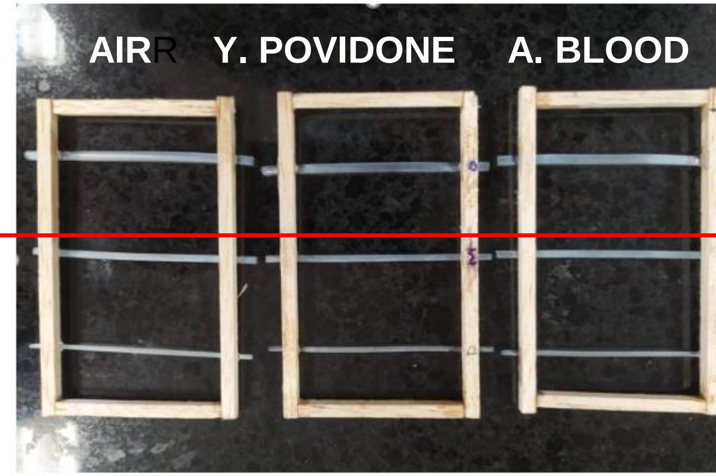
Impact of phase retrieval in Angiography



https://www.medicoverhospitals.in/diseases/atherosclerosis/



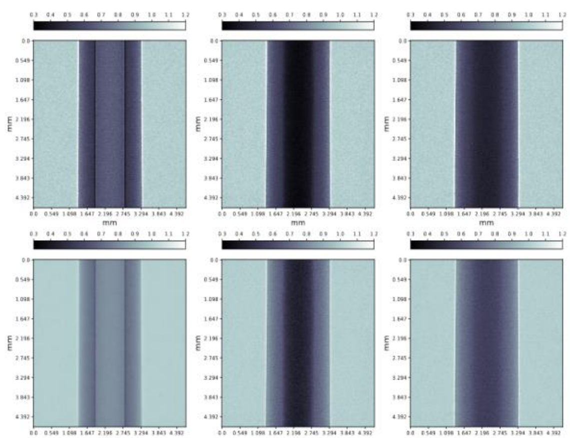
0.92 mm

1.85 mm

2.82 mm

Raw Images

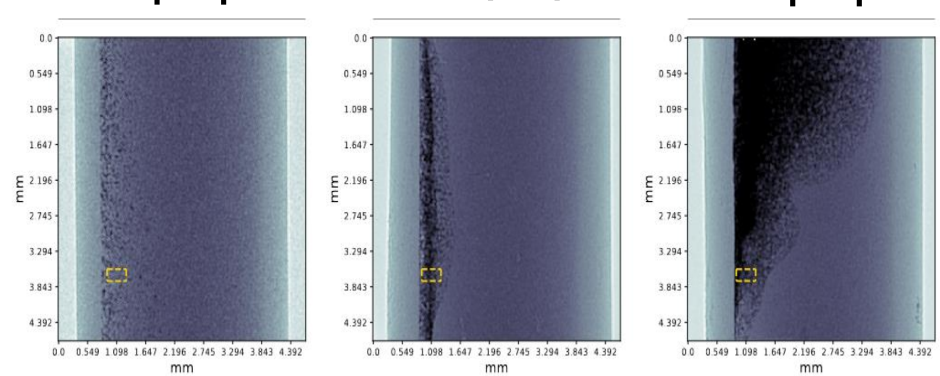
Phase Images

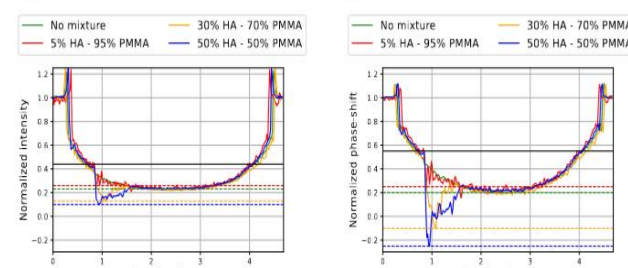


5% plaque

30% plaque

50% plaque





Raw Images

Phase Images

Plaque + A. blood No contrast agent

Phase retrieval contributes to enhance Image contrast → plaque can be observed witouth any contrast agent

Results submitted to Phys. Med. Biol.

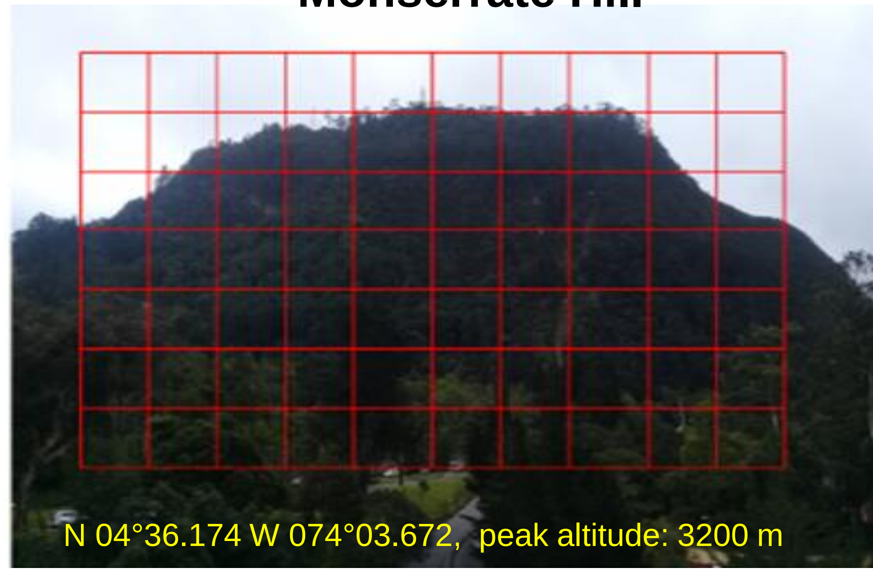
MICRO COMPUTED TOMOGRAPHY

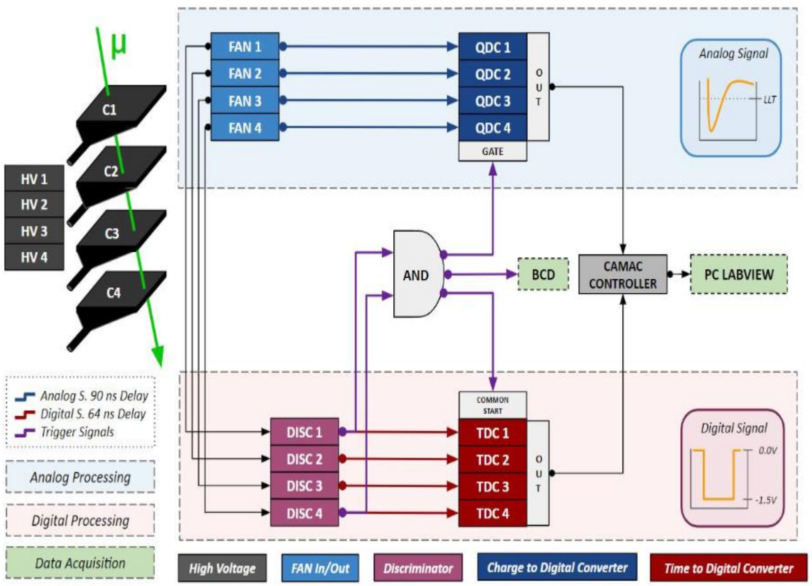
- A X20 magnification factor can be achieved to increase pixel resolution to about 3 um.
- our setup can take up to 3600 different projections for high resolution 3D images.
- We are working on configuring PCI and spectral CT´s

Leg of a carpenter bee.

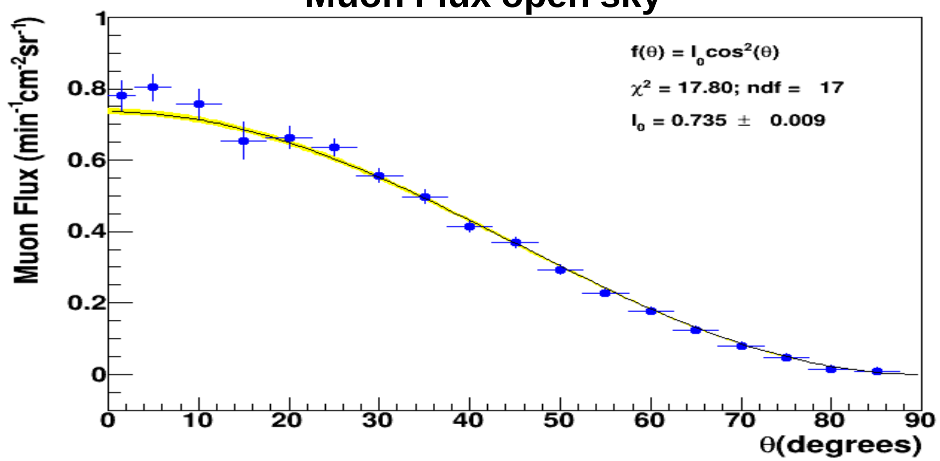
Atmospheric Muons

Monserrate Hill





Muon Flux open sky



instruments MDPI

Article

Atmospheric Muon Flux Measurement near Earth's Equatorial Line

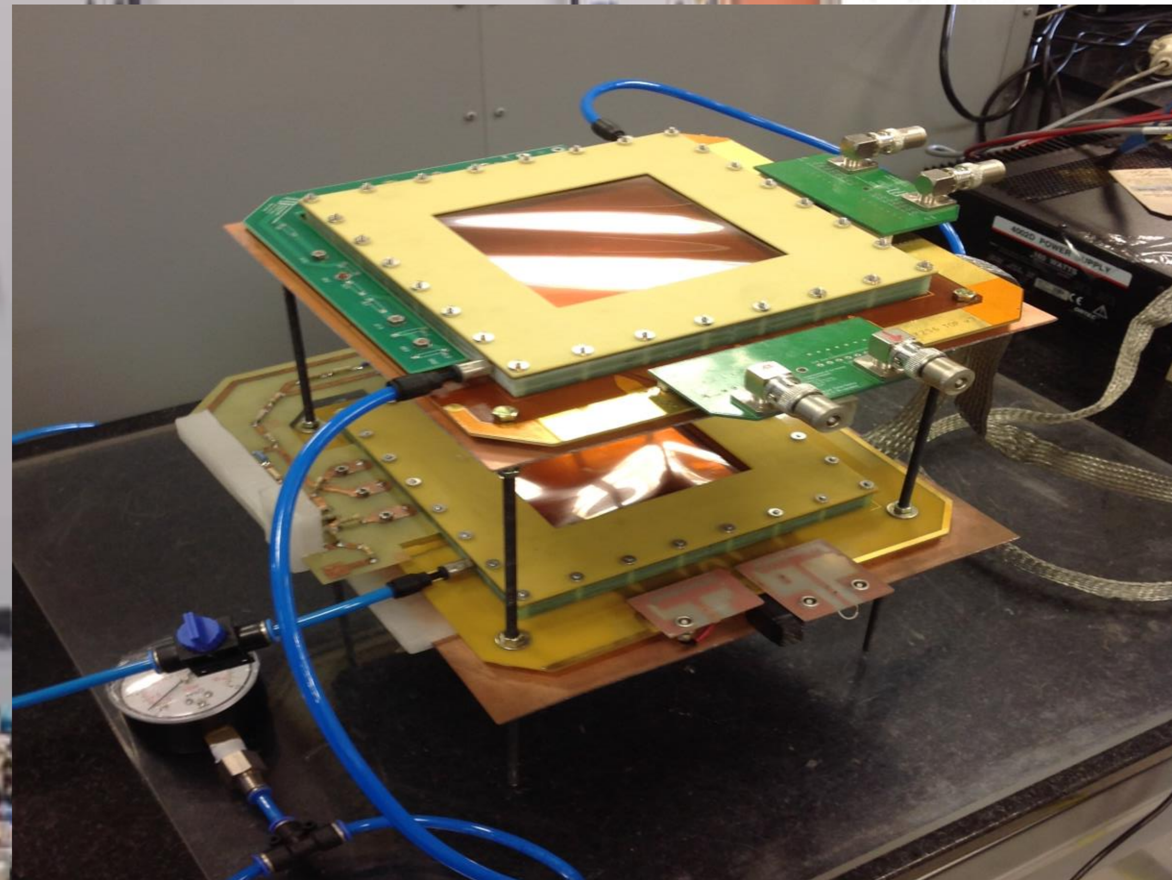
Cristian Borja *,†, Carlos Ávila †, Gerardo Roque and Manuel Sánchez *

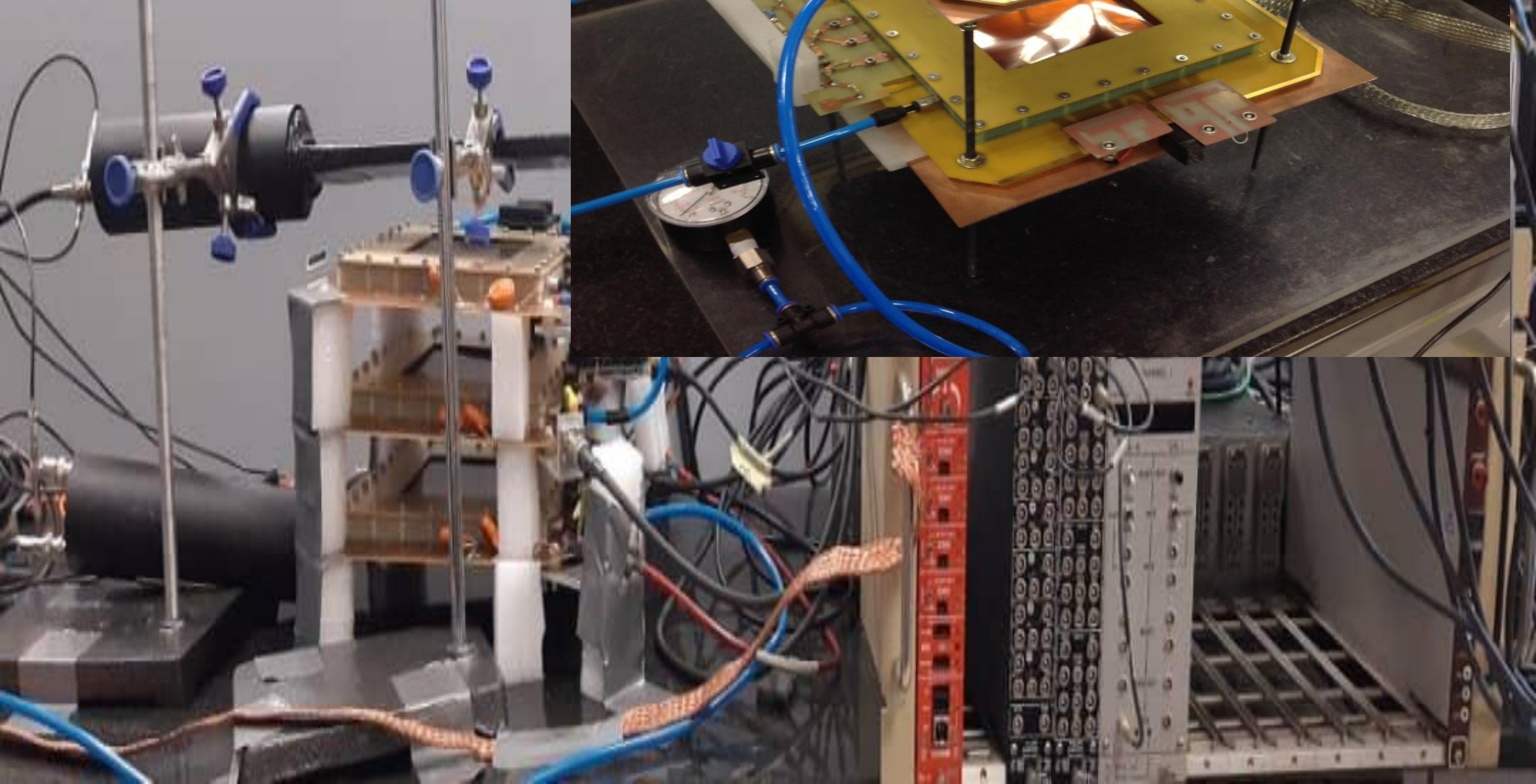
Muon flux at Bogotá = 1.53 ± 0.03 $cm^{-2}s^{-1}$

Instruments **2022**, *6*(4), 78; https://doi.org/10.3390/instruments6040078

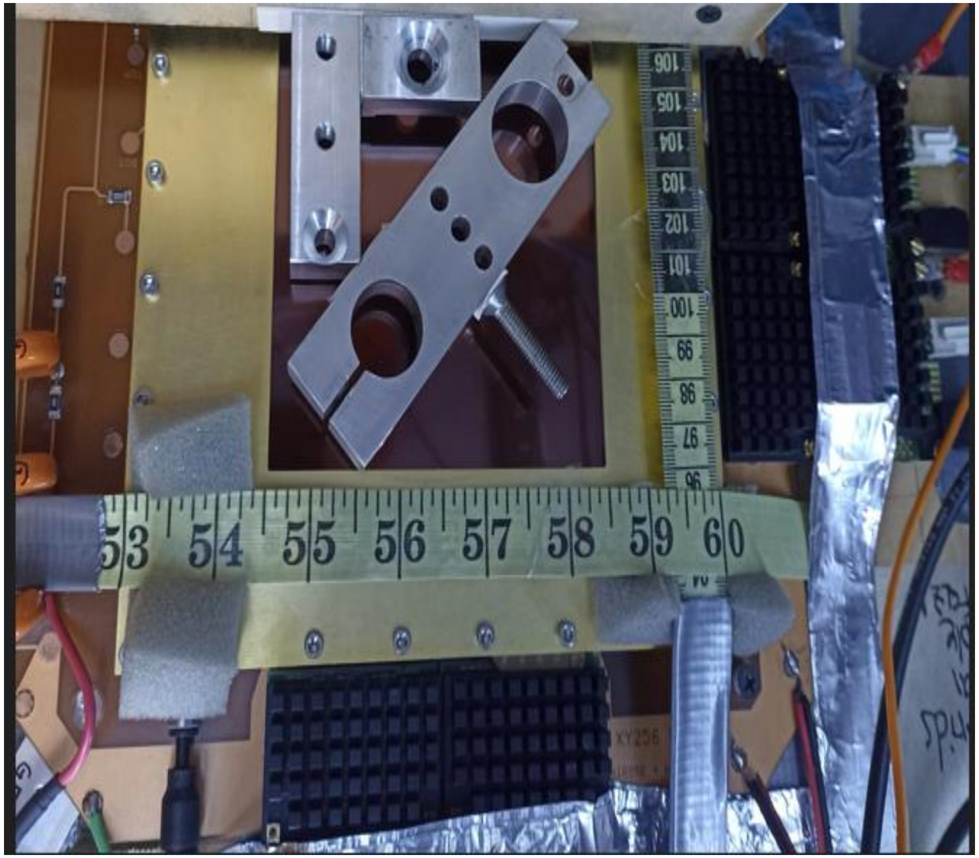
Universidad de los Andes

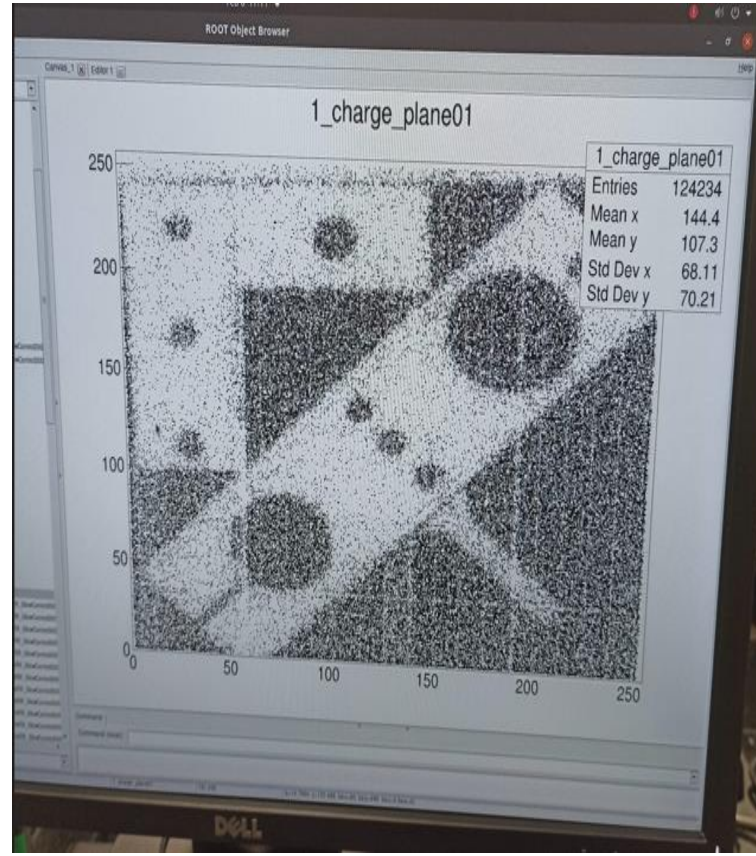
UNIANDES GEM DETECTORS



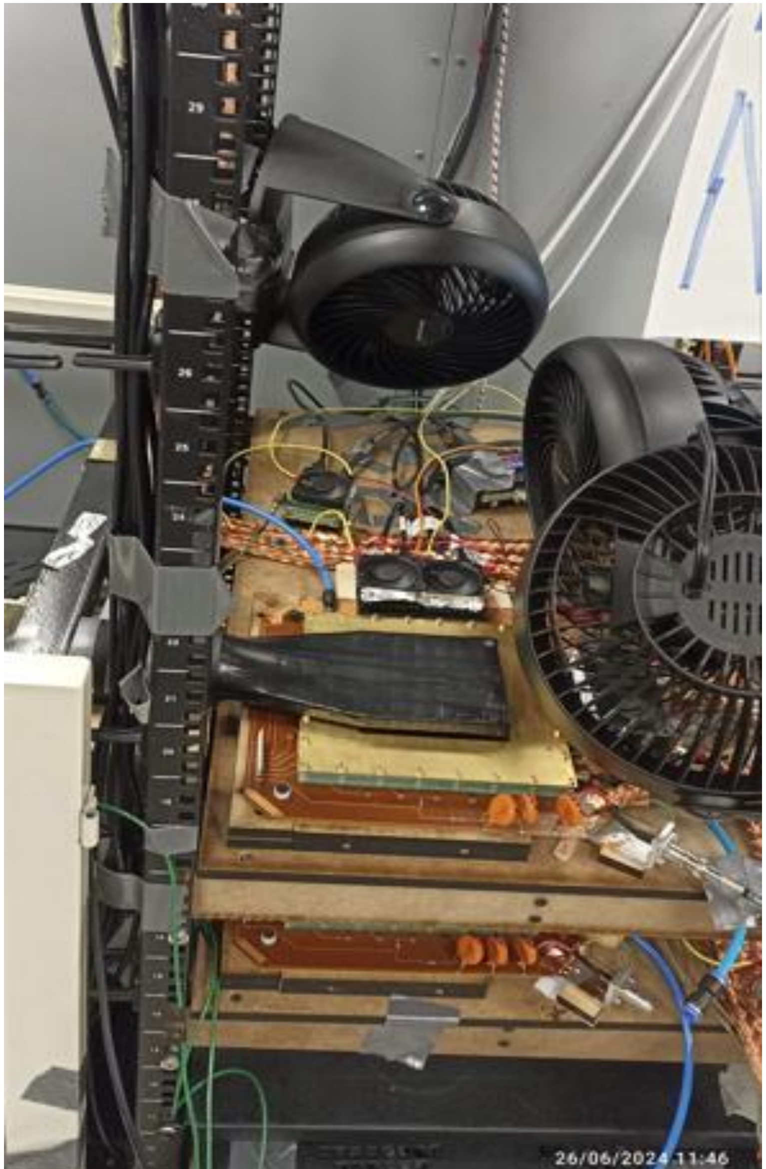


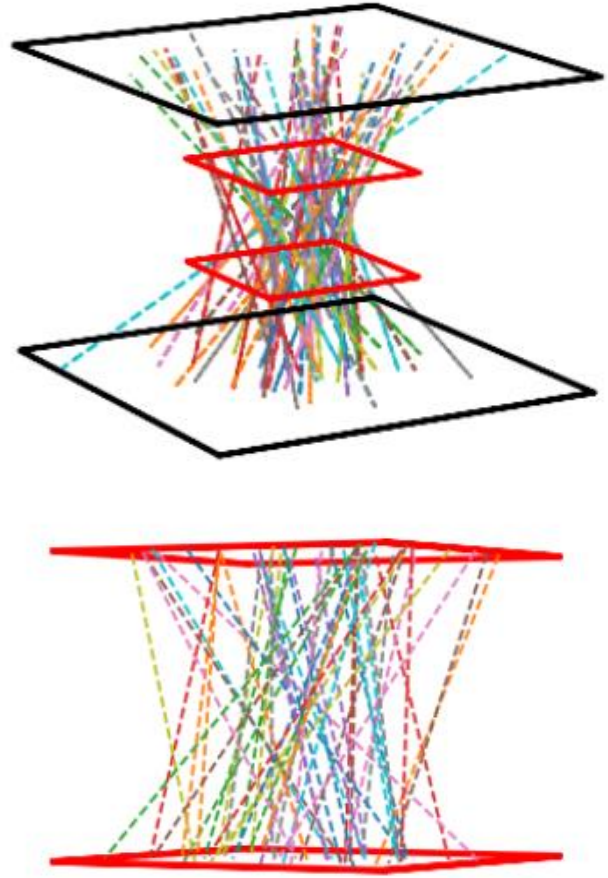
X-ray test with a full readout GEM detector





Atmospheric muon tracking with a full readout GEM detector

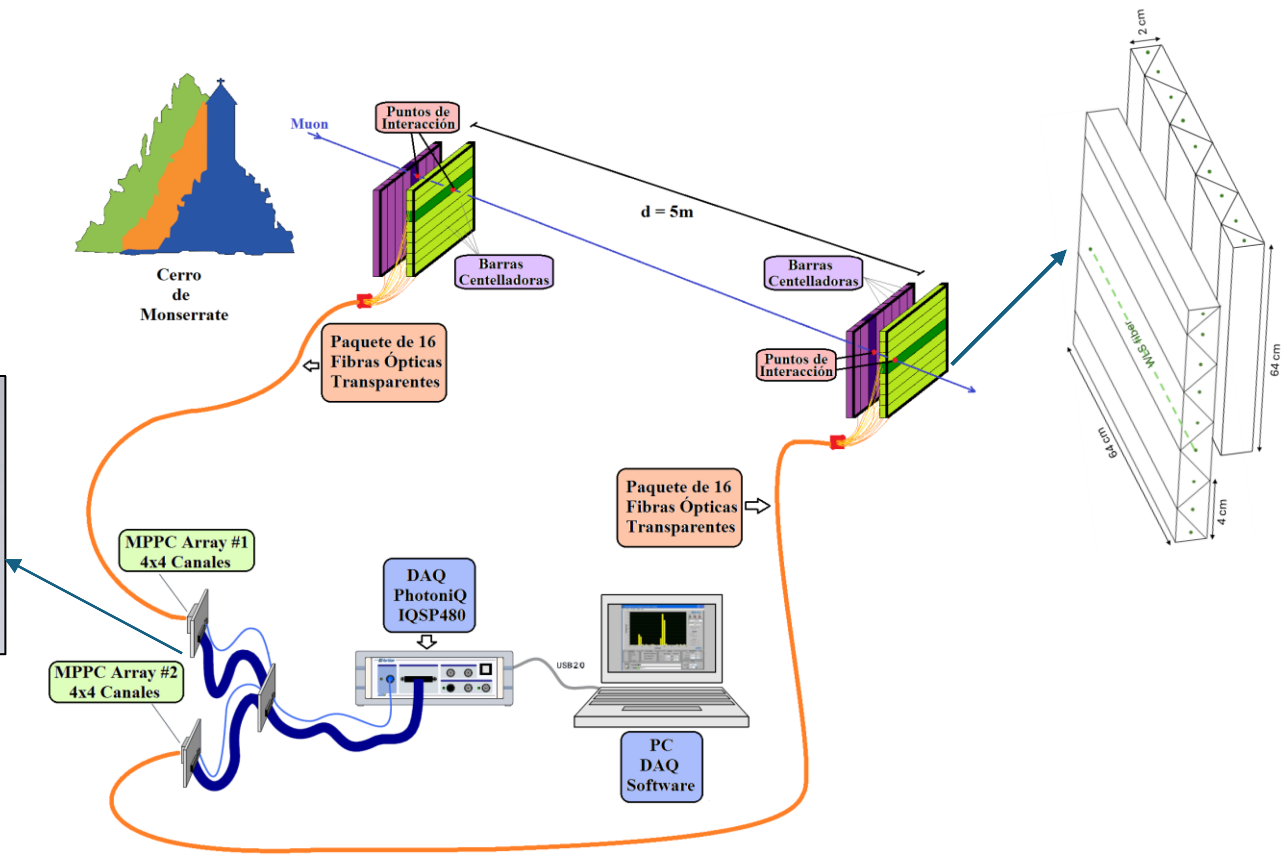




- **Still need to improve efficency: ~80% for each GEM detector**
- **24/7 operation requires further improvements in daq stability, specially temperature.**

Scintillation matrx readout by SiPMs
Hodoscope

MPPC ARRAY



UNIANDES HEP lab: some recent publications

1. Carlos A. Avila, Luis M Mendoza, Gerardo Alfonso Roque, Leonardo Loaiza, Jorge M. Racedo, Roberto J. Rueda, "Feasibility study of a TIMEPIX detector for mammography applications", Proc. of SPIE Vol. 10572 105720Z-2, https://doi.org/10.1117/12.2285910

2. Juan Sebastián Calderón García, Gerardo Roque and Carlos Avila, "Construction of mammography Phantoms with a 3D printer and tested with a TIMEPIX system", Proc. of SPIE Vol. 10572 ,105720Y (2017), https://doi.org/10.1117/12.2285897

3. J.S. Useche Parra and C. Avila, "Estimation of cosmic-muon flux attenuation by Monserrate Hill in Bogota", *Journal of Instrumentation* 14 P02015, 2019, https://doi.org/10.1088/1748-0221/14/02/P02015

4. S. Procz, C. Avila, J. Fey, G. Roque, M. Schuetz, E. Hamann, "X-ray and gamma imaging with Medipix and Timepix detectors in medical research", Radiation Measurement, Vol. 127, 2019, https://doi.org/10.1016/j.radmeas.2019.04.007

5. C. Navarrete, S. Procz, M. Schütz, G. Roque, J. Fey, C. Avila, A. Olivo, M. Fiederle, "Spectral X-ray phase contrast imaging with a CdTe photon-counting detector", Nuclear Instruments and Methods in Physics Research Section A, Volume 971, 2020, https://doi.org/10.1016/j.nima.2020.164098

6. S. Procz, G. Roque, C. Avila, J. Racedo, R. Rueda, I. Santos, M. Fiederle, "Investigation of CdTe, GaAs, Se and Si as Sensor Materials for Mammography", *IEEE Transactions on Medical Imaging*,June 2020, doi: 10.1109/TMI.2020.3004648, , https://doi.org/10.1109/TMI.2020.3004648

7. S. Procz, G. Roque, M. Perez, L. Mendoza, C. Avila, "Study of Contrast-to-Noise Ratio performance of a Medipix3RX CdTe Detector for Low Dose Mammography Imaging", Nuclear Instruments and Methods in Physics Research Section A, Volume 992, 2021, https://doi.org/10.1016/j.nima.2020.165000

8. C. Avila. G. Roque, J. S. Calderon, Patente, "Fantoma de Calibración y diagnóstico", Octubre 2022, SIC 054-2019

9. C. Borja, C. Avila, G. Roque, M. Sanchez, "Atmospheric Muon Flux Measurement near Earth's Equatorial Line ", *Instruments* **2022**, *6*(4), 78; https://doi.org/10.3390/instruments6040078

10. J. S. Useche Parra, M.K. Schütz G. Roque, J. Fey, C. Avila, M. Fiederle*a* and S. Procz, "Dose estimation in X-ray backscatter imaging with Timepix3 and TLD detectors", *JINST* **18** P05042 https://dx.doi.org/10.1088/1748-0221/18/05/P05042

11. J Bermúdez, G Roque, J Calderón, P Pardo, M Sánchez, V Ramos, C Ávila, "3D phantom for image quality assessment of mammography systems", Phys Med Biol. 2023 Oct 13; 68(20). https://doi.org/10.1088/1361-6560/acfc10 PMID:37733054 .

12. L. Mendoza, C. Avila, R. Rodríguez, L. Loaiza and G. Roque. "CNR performance of semiconductor materials for X-ray imaging of breast calcifications", JINST 18 T11001,). https://doi.org/10.1088/1748-0221/18/11/T11001

= Nombre de estudiante participando del estudio

GRACIAS!