

Second Year Presentation

Presented By: Saba Imtiaz

Research Group Head: Dr Paolo Soffitta

Supervisor: Dr Fabio Muleri

Co-Supervisor: Dr Alessandro Di Marco

Topic:

Redefining X-ray Polarimetry: Insights from Imaging X-ray Polarimetry Explorer (IXPE) and Future Directions

Introduction:

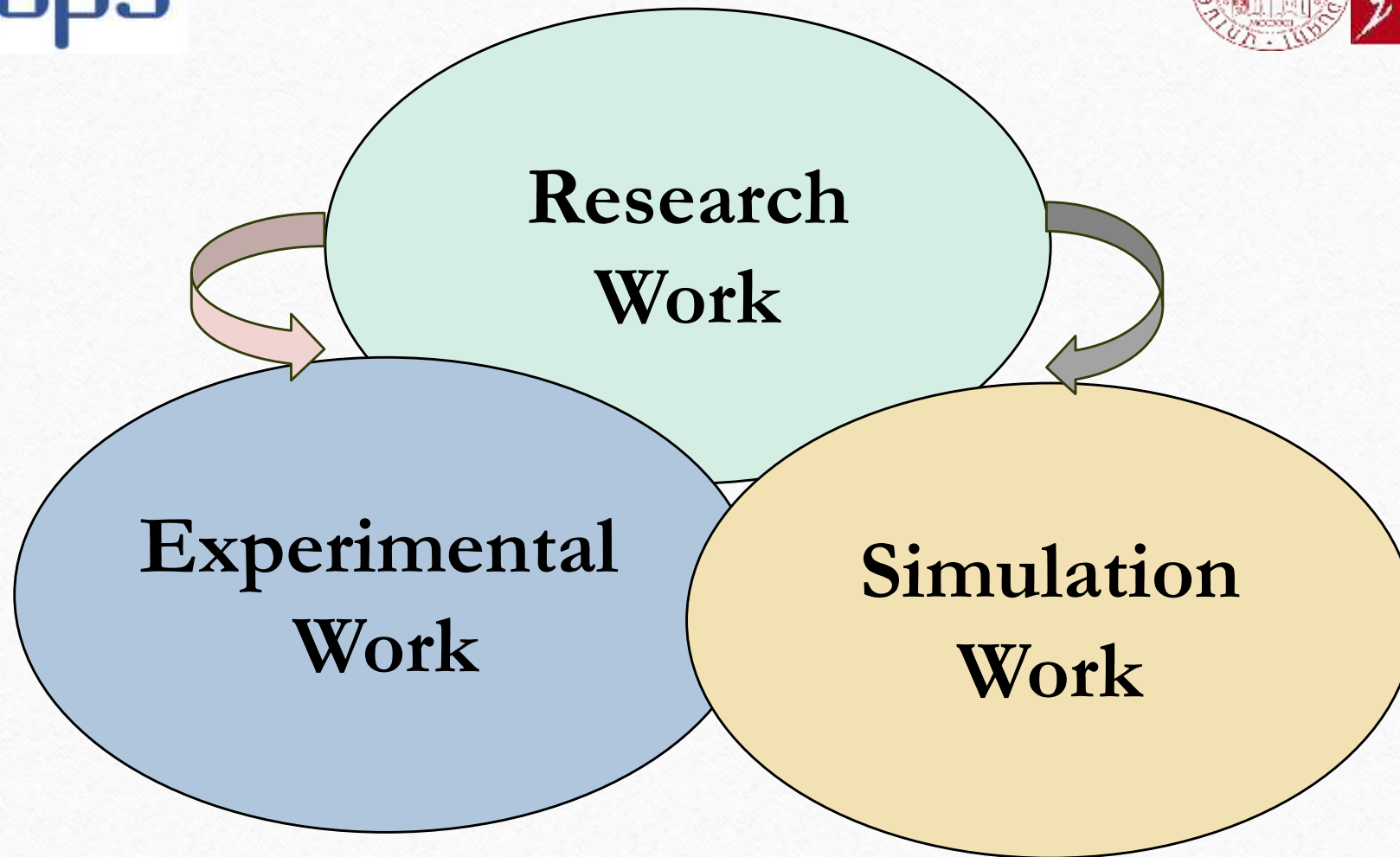
The **Imaging X-ray Polarimetry Explorer (IXPE)** has demonstrated the potential of X-ray polarimetry using Gas Pixel Detectors in the 2–8 keV energy range. To advance further, next-generation ASICs like **Timepix3** enable fast **3D track imaging**, a possibility which we are exploring with GridPix detectors.

Why We Do Polarimetry ?

By Polarimetry we understand the emission mechanisms and geometry of high-energy astrophysical sources like **neutron stars, black holes** and **supernova remnants**. By measuring the polarization of X-rays, IXPE provides insights into the magnetic field structures and particle acceleration processes in these extreme environments.



The Imaging X-ray Polarimetry Explorer (IXPE)



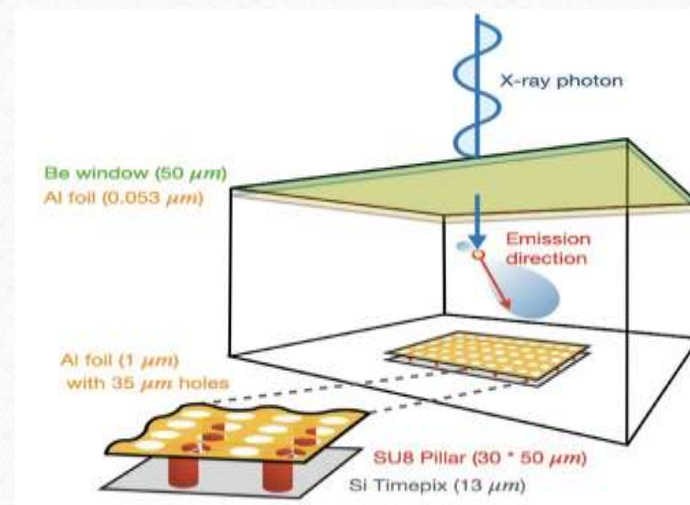
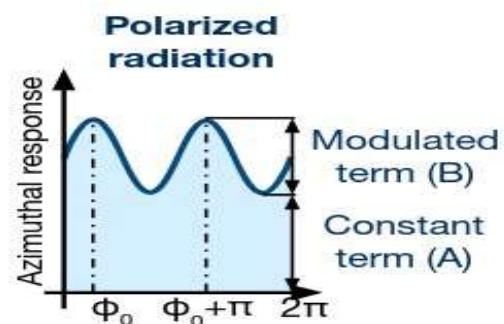
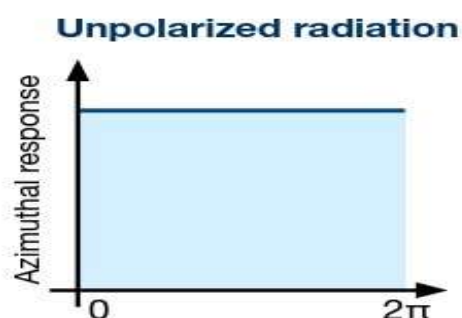
High Yield Polarimetry Experiment in X-rays (HYPE_X)

HYPE_X: The *High Yield Polarimetry Experiment in X-rays* enhances X-ray polarimeter sensitivity by using Timepix3 for 3D tracking with minimal dead time. This enables coupling to larger-area mirrors than IXPE, boosting polarimetric performance.

How we measure X ray Polarization:

X-ray polarization can be determined by the angular distribution of the photoelectron emission directions. Determining this emission direction, we can obtain a histogram following distribution.

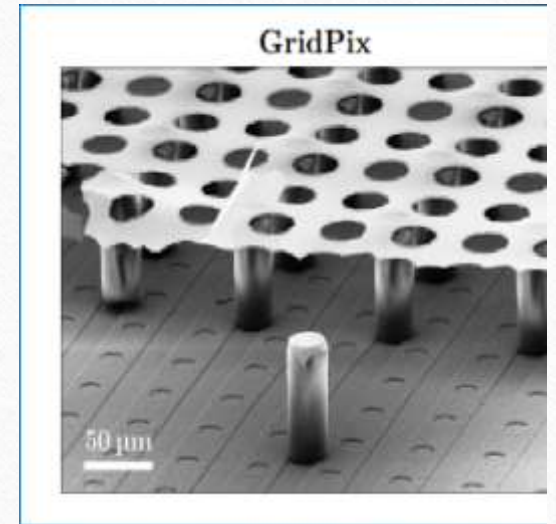
$$PD = \frac{1}{\mu} \frac{B}{2A + B}$$



Working of Detector :

Gridpix Detector and Timepix3

- It has been shown that 3D imaging of photoelectric track could improve the polarization sensitivity (modulation factor). GridPix detectors using Timepix3 ASIC could be used for this purpose as they offer fast readout
- 256×256 pixels (65,536 total) with **55 μm pixel pitch**.
- Timepix3 has negligible dead time.
- Record both Time of arrival (TOA) and time of threshold (TOT)



Experimental Work:

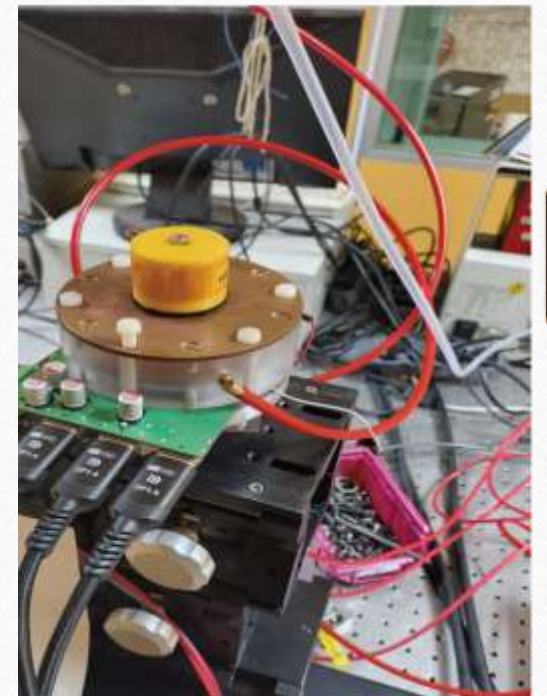
GridPix Detector and TimePix3

Initial testing at INAF/IAPS

A proto-type of the GridPix detectors was tested at the X-ray polarization calibration facility at IAPS using gas mixtures with Ar-DME(80%-20%) at various energy ranges.

Measurements at specific Energy Level

X ray source	Energy Value	Detector Position
Mo (polarized)	8.7 keV	$\epsilon = 0, \epsilon=90$
Mo (polarized)	17.4 keV	$\epsilon = 0, \epsilon=90$
Mo (unpolarized)	8.05 keV	$\epsilon = 0, \epsilon=90$



Prototype of GridPix detector at the Calibration facility at IAPS. Polarized X-ray source (X-ray tube and crystal scatterer) can be seen on the top to measure the response to fully polarized X-rays,

Analysis With Measurement Data .

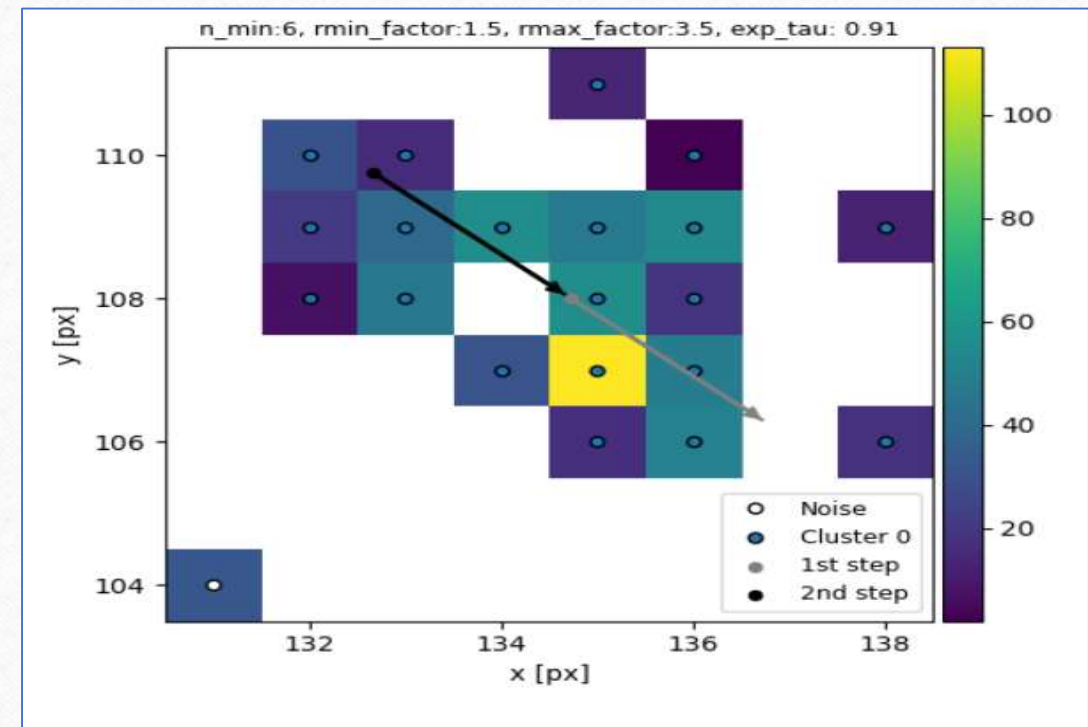
- The purpose of the data analysis is to **extract scientific information** from the instrumental raw data (i.e., the photoelectron tracks, emission angles, energies, polarization).
- **Exercise** to use and improve the current analysis software

Lv0 files: contain raw pixel hits

Lv1 files: store reconstructed tracks/events

Analysis strategy : cluster Lv0 hits into Lv1 tracks for further study

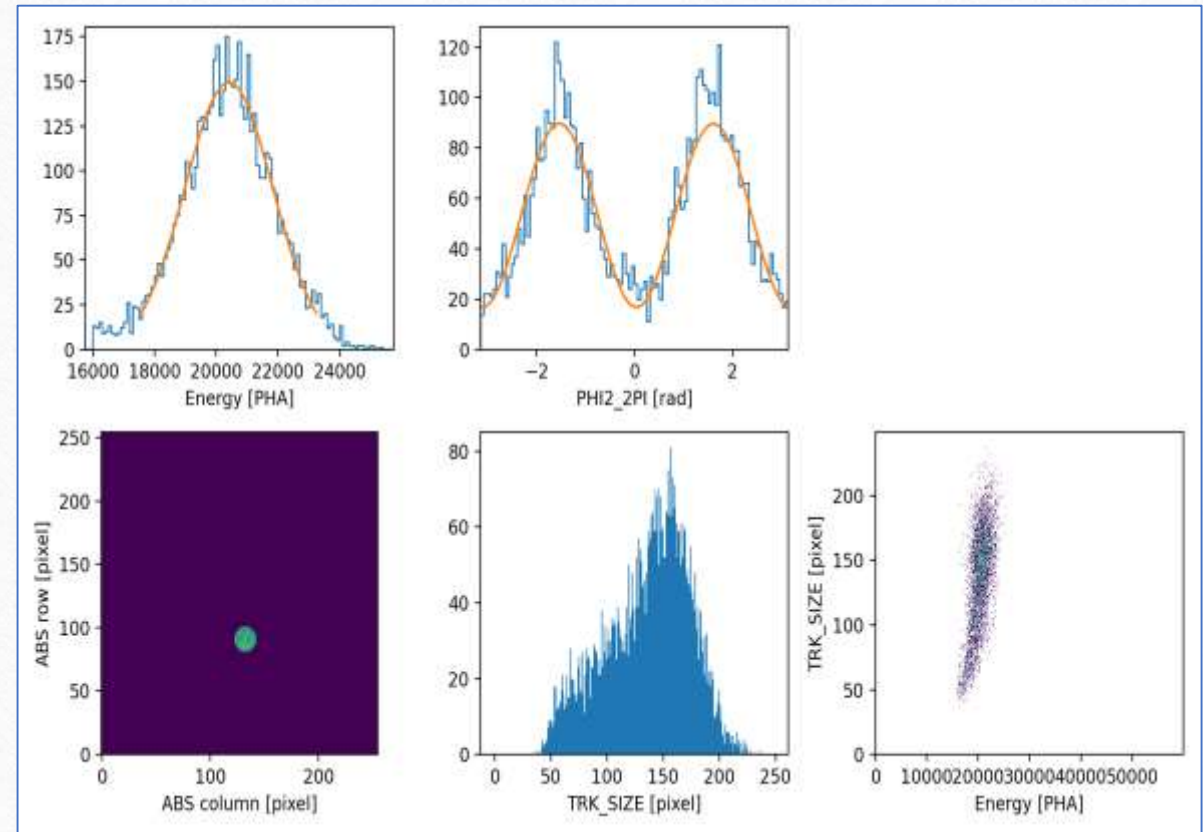
From Photoelectron image: reconstruct emission angle, energy, polarization information, and track properties.



Reconstructed Track Direction of Photoelectron

Analysis With Measurement Data .

- **Top left:** Energy spectrum (PHA) with a Gaussian fit (orange).
- **Top middle:** Azimuthal angle distribution with a cos square fit.
- **Bottom left:** 2D hit map of detector pixels.
- **Bottom middle:** Track size (TRK_SIZE) histogram (e.g, the number of hit pixel for track).
- **Bottom right:** Correlation scatter plot of Energy vs. Track size



Simulation Work

(Improvement and Debugging Phase)

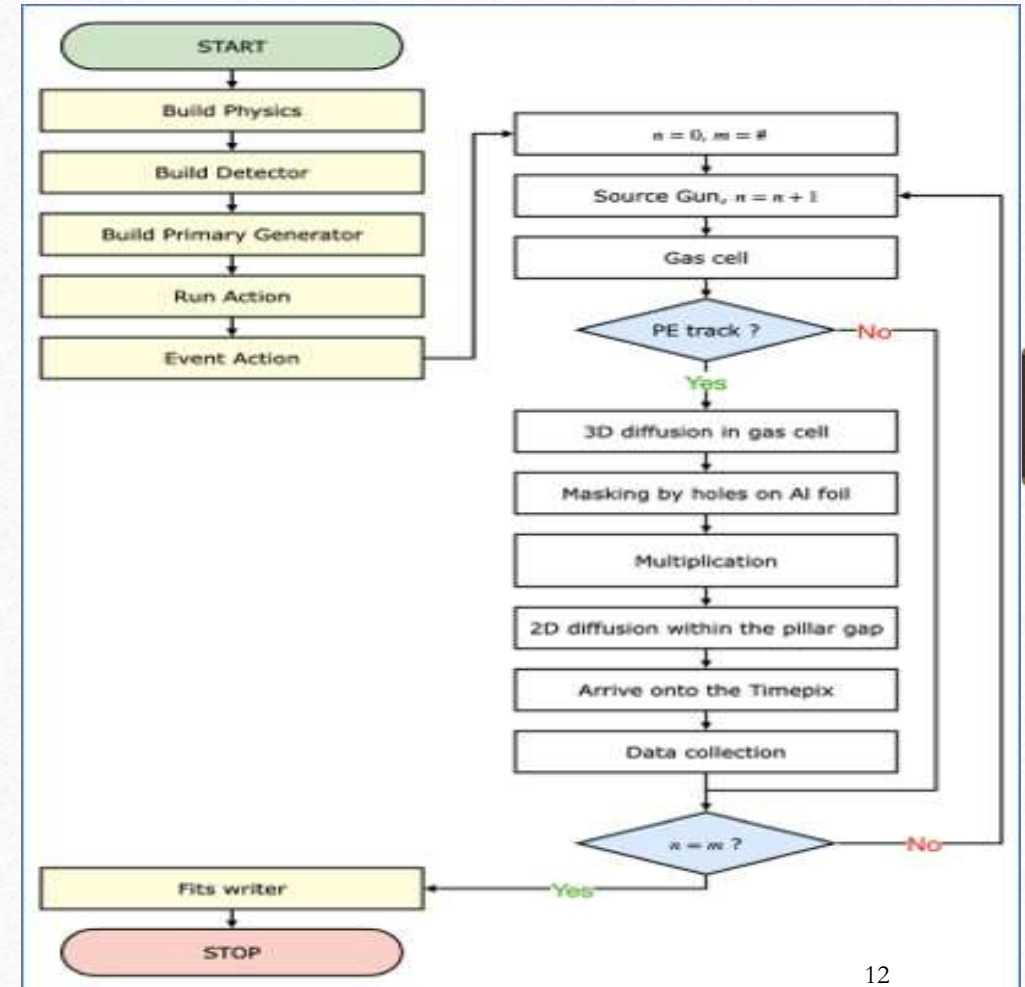
Monte Carlo study of GridPix X-ray polarimetric response to varying pressure, Energy and thickness with gas Mixtures

High Yield Polarimetry Experiment in X-rays(HYPE_X)

Simulation Workflow of Gridpix Detector

Initialization Phase

- **START** – Begin simulation.
- **Build Physics** – Define physics processes
- **Build Detector** – Construct detector geometry (gas cell, foils, pillars, Timepix chip, etc.).
- **Build Primary Generator** – Define the source (X-ray photon beam with given energy).
- **Run Action** – Initialize run-level actions (data logging, statistics).
- **Event Action** – Set up what happens for each event.

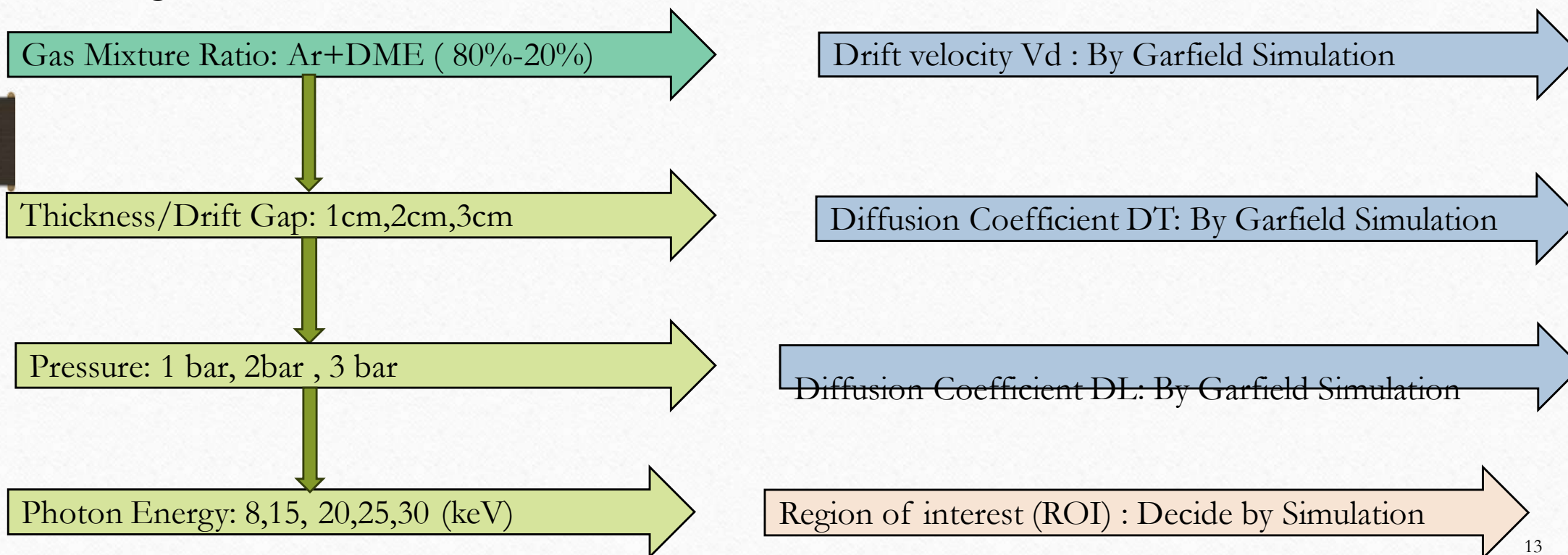


Parameters for GEANT4 Simulation:

On board In gas pixel detector (GPD) of IXPE , gas is **Dimethyl ether (DME)**.

For the new mixture : We are testing detector with **Dimethyl ether and Argon(DME+Ar)**.

Following are simulation Parameters:



Debugging Phase of Monte Carlo Simulation:

When we test new gas mixture (Ar+DME) (80:20).

Basically we found **three** main problem.

1. **Asymmetric Behavior** of modulation curve with all energies (8,15,20,25,30 KeV) (solve now)
2. found **NAN and zeros values** in Z direction at PHA =1after reconstruction data .
3. **No interaction** with Argon
4. Decide the region of interest ROI by simulation

Photoelectron Emission Direction

To determine the direction of emission of a photoelectron from the simulated tracks an algorithm for 3Dreconstruction has been applied.

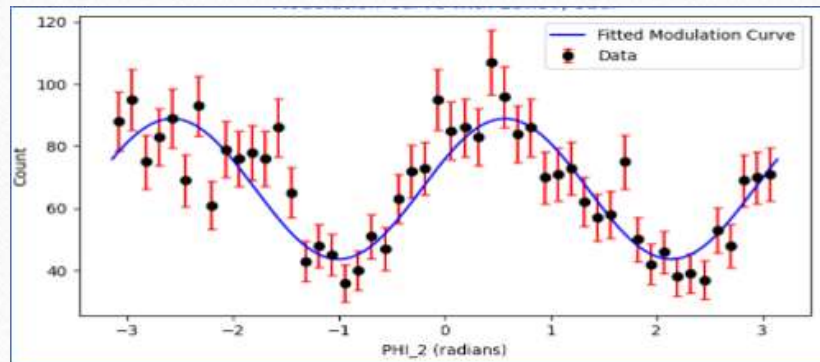
I developed new software for 3D photoelectron tracks.

Problem 1:

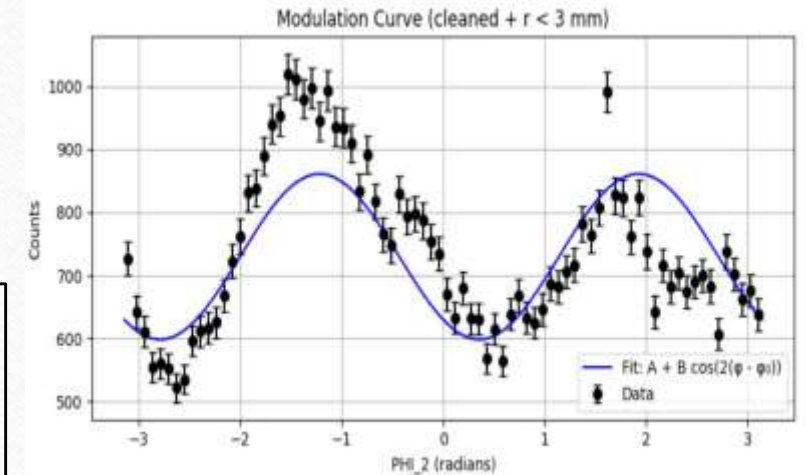
1. **Asymmetric Behavior** of modulation curve with all energies (8,15,20,25,30 KeV) (**solve now**)

Why Asymmetric Behavior?

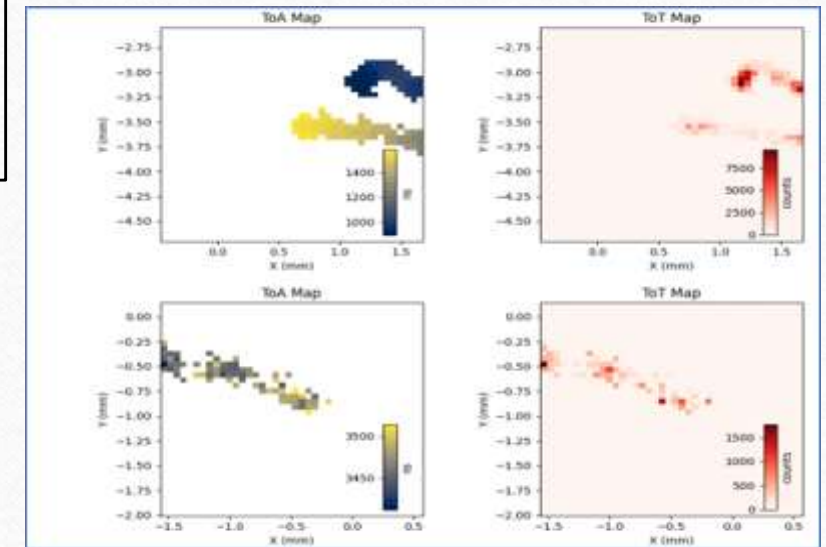
- Azimuthal distribution of photoelectron emission deviates from ideal symmetric cosine form.
- At Detector boundaries , Photoelectron track spilt charge across neighboring pixel , shifting the reconstructed angle and distorting modulation curve .



Symmetric Effect of modulation curve at 20keV



Asymmetric Effect of modulation curve at 20keV



TOA and TOT map at 20KeV₁₅

Debugging Phase of Monte Carlo Simulation:

When we test new gas mixture (Ar+DME) (80:20).
Basically we found **three** main problem.

2. found **NAN** and zeros values in Z direction at PHA =1 after reconstruction data .

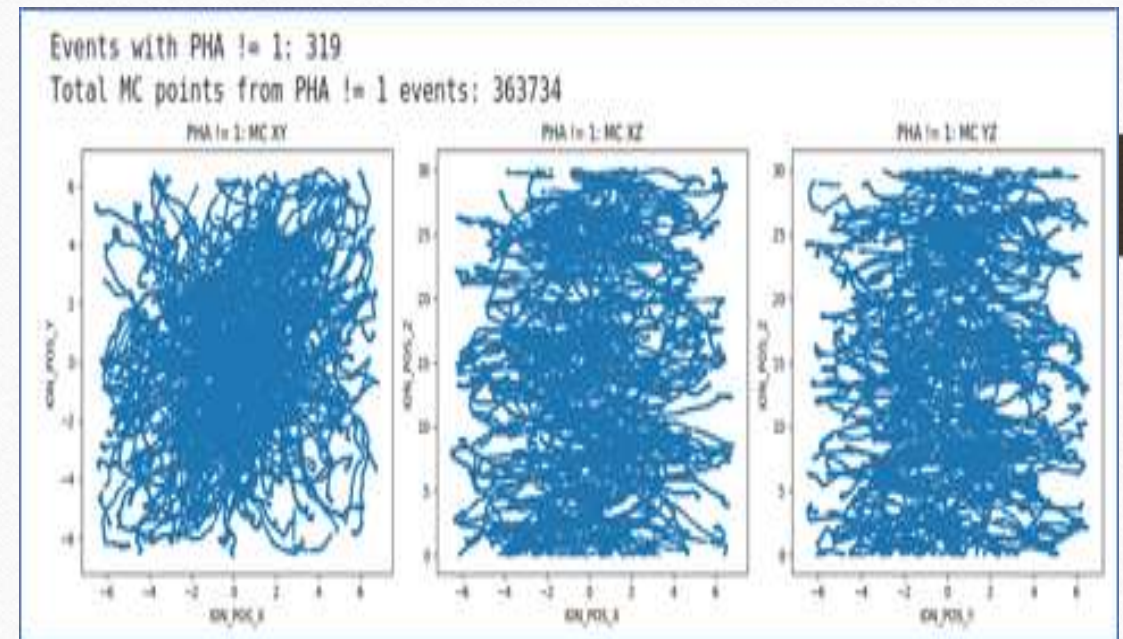
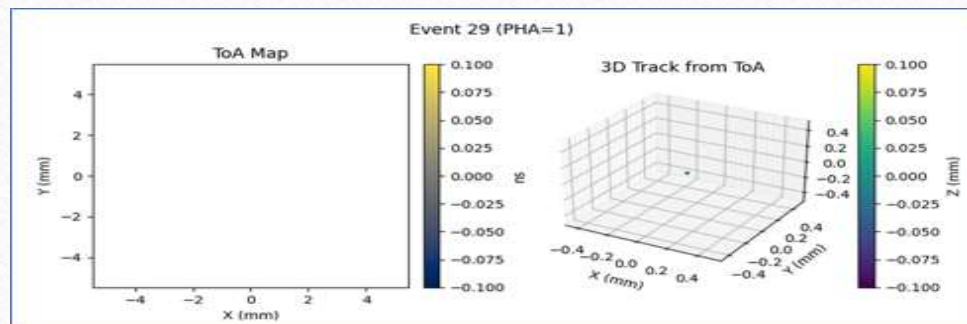
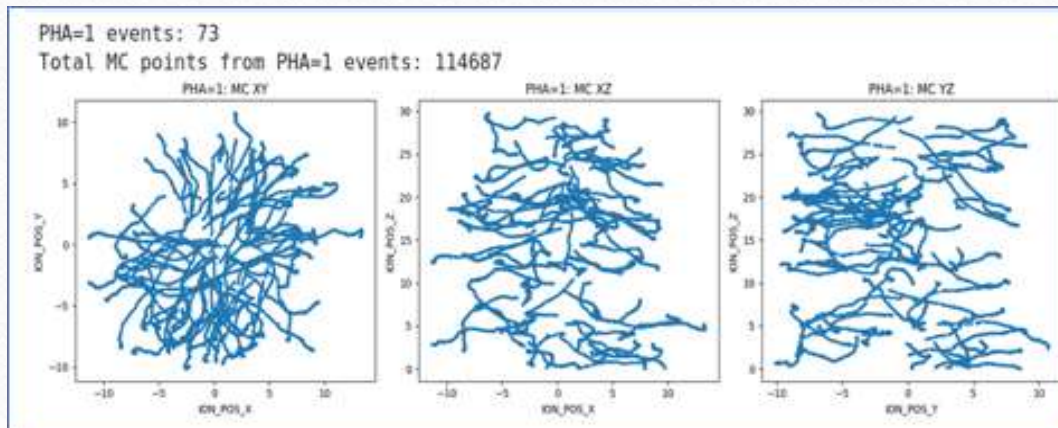
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	PE ENE	PHA	NUM_PIX	PHI_ORIGI	THETA_ORB	BARY_X	BARY_Y	BARY_Z	PHI_1	IMPACT_X	IMPACT_Y	IMPACT_Z	PHI_2	THETA
2	29.709	117937	300	-0.7484	102.869	2.45494	-1.4041	15.4798	-0.102	-0.1782	-1.0027	15.8081	-1.4153	2.75545
3	29.4627	232006	691	97.3709	124.702									
4	29.709	243507	41	-134.32	112.615	-1.3853	-1.5115	20.6555	-3.0518	-0.6771	-1.5125	21.4962	-3.1416	0.67595
5	29.709	210212	730	8.25504	72.3698	3.6174	-1.3473	18.6045	-0.0917	0.5521	-1.2272	22.1256	-2.9208	1.52783
6	29.4627	5662	16	-85.275	62.9441									
7	29.4627	234308	121	-155.51	89.1796	-1.2262	-1.4136	1.73891	1.82872	-1.0781	-1.5124	3.98598	3.12927	0.14781
8	29.4627	1	1	-116.9	108.03	0.0275	0.0275	0	1.5708	0.0275	0.0275	0	1.5708	1.5708
9	29.4627	232302	188	142.303	58.0962	-1.4829	1.09489	25.1894	-1.605	-1.4716	2.45765	24.4889	-2.9134	2.28141
10	29.709	1	1	-166.31	130.202	0.0275	0.0275	0	1.5708	0.0275	0.0275	0	1.5708	1.5708
11	29.709	185743	745	75.4563	77.8694									
12	29.709	233723	588	174.883	56.2486	-0.5345	-0.6695	14.6464	-1.3327	-1.0206	0.69005	12.9905	-2.7164	2.54594
13	29.4627	235927	304	-158.52	90.429	-1.3136	0.11774	15.6376	-2.4264	0.21274	1.05605	17.3095	-2.0445	0.78045
14	29.4627	220554	196	-153.76	118.376	-0.0278	-1.4599	14.4246	-0.0901	-1.4224	-1.4025	11.996	-2.2904	1.7336
15	29.4627	223572	30	-171.62	122.327									
16	29.709	234575	712	70.3132	130.298									
17	29.709	251329	850	43.1617	95.4121	1.98557	4.87714	13.9614	0.71101	-0.1728	3.00314	15.7988	2.56393	2.05176
18	29.4627	1	1	-142.13	136.752	0.0275	0.0275	0	1.5708	0.0275	0.0275	0	1.5708	1.5708
19	29.4627	1	1	-0.7392	105.286	0.0275	0.0275	0	1.5708	0.0275	0.0275	0	1.5708	1.5708
20	29.4627	1	1	-165.49	98.5971	0.0275	0.0275	0	1.5708	0.0275	0.0275	0	1.5708	1.5708
21	29.4627	110045	621	42.8886	91.9209	2.64294	1.47671	7.38801	0.55429	-0.3552	-0.7063	7.29893	1.54884	2.05445
22	29.709	232383	884	46.3227	91.8742									

Data after Reconstruction at 30keV with Ar+DME (80:20)

Debugging Phase of Monte Carlo Simulation:

When we test new gas mixture (Ar+DME) (80:20).
Basically we found **three** main problem.

2. found NAN and zeros values in Z direction at PHA =1 after reconstruction data .



Problem 3:

3. No Interaction with Argon

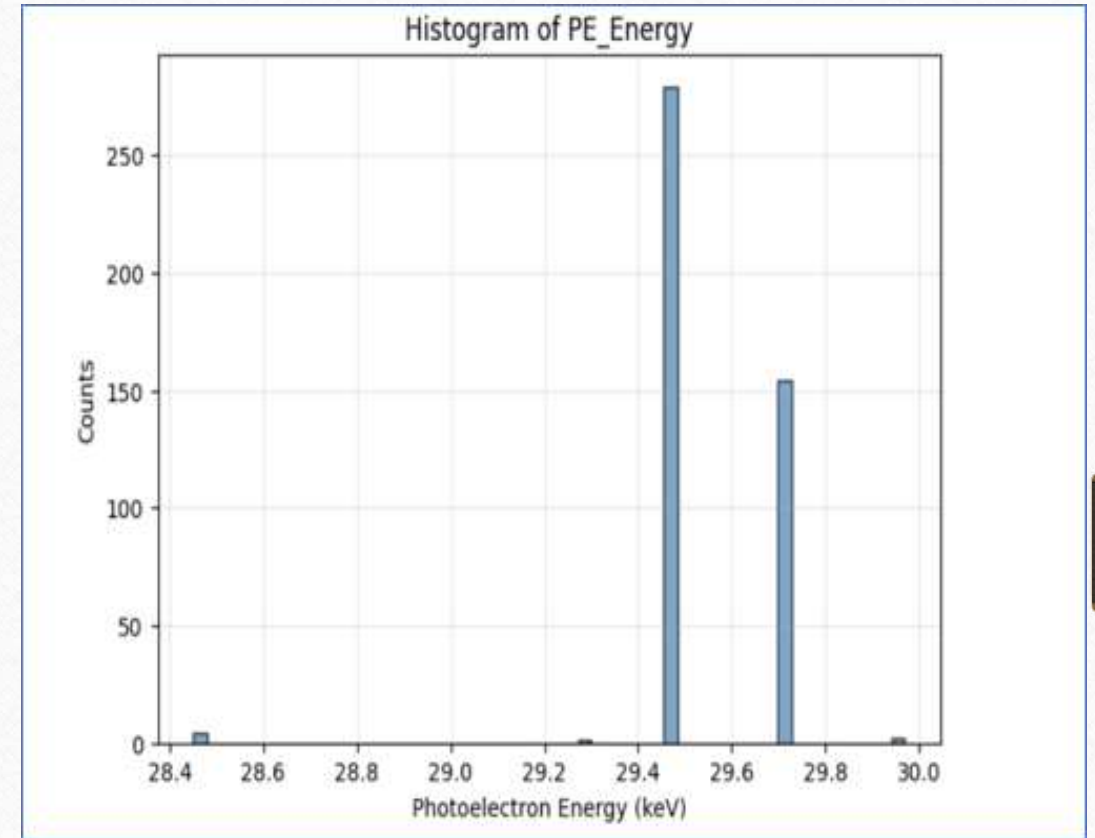
Problem 4:

4. Decide the region interest ROI :

Region of interest (ROI):

In the simulation, the **Region of Interest (ROI)** refers to the portion of the detector selected for polarization measurements.

- For the **GridPix detector**, the full sensitive area is **256×256 pixels**.
- For **pure DME gas**, an ROI of **40×40 pixels** was chosen.
- For the **DME + Ar mixture**, the ROI was finalized with **100×100 pixels** after running multiple simulations and comparing the results



Histogram of PE energy at 30KeV

Course Work

Course 1:

Credit Hours: 2

Course Title:
Advanced Electronics Sensing Devices

Course Status:
Complete and Exam Passed

To whom this may concern,

I hereby certify that Ms. Saba Imtiaz successfully attended the course “Advanced Electronic Sensing Devices” for a total of 15 hours. The course has been delivered in the context of the National PhD Program on “Technologies for fundamental research in Physics and Astrophysics”.

Dr. Andrea De Iacovo

ANDREA
DE
IACOVO
08.07.2024
07:44:54
GMT+01:00



Course 2:

Credit Hours: 2.5

Course Title:

**Machine Learning Programming
in Physics**

Course Status:

Complete and Exam Passed



Course 3:

Credit Hours: 2.5

Course Title:

Design of Readout Integrated Circuits for
Particle Detector

Course Status:

Complete and Exam Passed

Istituto Nazionale di Fisica Nucleare
SEZIONE DI BARI

Bari, 23/04/2025

This is to certify that Saba Imtiaz has successfully passed the final exam of the PhD course "DESIGN OF READOUT INTEGRATED CIRCUITS FOR PARTICLE DETECTORS" held on 24 April, 2025.

Bari, 23/04/2025

Dr. Flavio Loddo



Course 4:

Credit Hours: 2

Course Title:

New technologies for Cherenkov
telescopes

Course Status:

Complete and Exam Passed



Serena Loporchio

a Phd, me ▼

Dear Laura,

I am writing this email to inform that you that the PhD student Saba Imtiaz has attended the lectures and successfully passed the oral exam of the PhD course "New technologies for Cherenkov telescopes"

Please let me know if this email is is or if enough you need anything else.

Best regards,

Serena

International PHD School

- NOV 23-2024 to Nov 30-2024 :
_The XII Geant4 International School-Romania
- April 06-2025 to April 11-2025:
Frontiers in X-ray Polarimetry (FiXP) Academy, L'Aquila,
Italy



International PHD School:

- June 28,2025 to July 4,2025 :

VILNIUS TECH Doctoral Summer School 2025, Lithuania

- Sep 17, 2025 to Sep 25, 2025

DRD1 Gaseous Detectors School 2025, Germany

- Feb 18, 2025 to Feb 22, 2025

PHD Retreat Meeting , L'Aquila , Italy

Conferences and Seminars

2nd International Conference on Physics Horizons and Multidisciplinary Science -Pakistan

Oral talk: Entitled as:
Advancing X-ray Polarimetry: Insights
from IXPE and Future Prospects

Seminars

- INAF-OAPD Seminar
- Bologna Joint Astrophysical Colloquium
- IFPU Colloquium
- Osservatorio Astronomico di Roma
- INAF-IAPS seminars



Publications

Considerations on Possible Directions for a Wide Band Polarimetry X-ray Mission

by Paolo Soffitta ^{1,*}, Enrico Costa ^{1,*}, Nicolas De Angelis ¹, Ettore Del Monte ¹, Klaus Desch ², Alessandro Di Marco ¹, Giuseppe Di Persio ¹, Sergio Fabiani ¹, Riccardo Ferrazzoli ¹, Markus Gruber ², Takahashi Hiromitsu ³, Saba Imtiaz ^{1,4}, Philip Kaaret ⁵, Jochen Kaminski ², Dawoon E. Kim ^{1,6,7}, Fabian Kislat ⁸, Henric Krawczynski ⁹, Fabio La Monaca ^{1,6,7}, Carlo Lefevre ¹, Hemanth Manikantan ¹.

Article

Instruments for focal plane X-ray polarimetry in the next decade

Fabio Muleri ¹, Enrico Costa ¹, Klaus Desch ², Alessandro Di Marco ¹, Sergio Fabiani ¹, Riccardo Ferrazzoli ¹, Markus Gruber ², Daniel Heuchel ³, Saba Imtiaz ¹, Jochen Kaminski ², Dawoon Kim ¹, Alessandro Lacerenza ¹, Carlo Lefevre ¹, Hemanth Manikantan ¹, Vladislavs Plesanovs ², John Rankin ¹, Ajay Ratheesh ¹, Alda Rubini ¹ and Paolo Soffitta ¹.

The legacy of the IXPE instrument and prospects for the next generation of polarimetric photoelectric X-ray detectors

Hemanth Manikantan^{a,*}, Vladislavs Plesanovs^{b,*}, Paolo Soffitta^{a,*}, Dennis Sauerland^c, Reinhard Beck^c, Enrico Costa^{a,*}, Ettore Del Monte^{a,*}, Klaus Desch^{b,*}, Alessandro Di Marco^{a,*}, Sergio Fabiani^{a,*}, Riccardo Ferrazzoli^{a,*}, Markus Gruber^{b,*}, Saba Imtiaz^{a,d,*}, Jochen Kaminski^{b,*}, Alessandro Lacerenza^a, Fabio Muleri^{a,*}, Ajay Ratheesh^{a,e,*}, and Alda Rubini^a

Plan for Final Year

What I have done:

- Literature Study
- Course Work
- Experimental Work
- Command on Geant4
- Python Course
- Developed new software for 3D photoelectron tracks
- Monte Carlo Simulation (80 percent done)

What I will do in the final year

- After optimizing Monte Carlo simulation we will compare results with real data
- Thesis Writing
- Article writing
- Three months period abroad in University of Bonn Germany



thanks!