WP5 - X-Ray Polarimetry Explorers

H2020-MSCA-RISE-2016 – Grant Agreement N° 734303

NEWS - General Meeting - 14/3/2018

European Commission

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EGO - Virgo

CLEVER OPERATION

POLITECNICO MILANO 1863

Prisma Electronics SA

IZDF

impex high tech

SAPIENZA UNIVERSITÀ DI ROMA

UNIVERSITÀ DEGLI STUDI DI GENOVA

Stockholm University

KTH VETENSKAP OCH KONST

UNIVERSITÀ DI PISA

FARADAY TECHNOLOGY

NASA

Fermilab 50 Years of Discovery

NINS National Institutes of Natural Sciences

CALIFORNIA INSTITUTE OF TECHNOLOGY 1891

cnrs

INFN

OVERVIEW

- **NEWS WP5 Status**
- **IXPE Mission Status**
- **Development of polarization sensitive detectors (GPD)**
- **GPD readout Electronics systems**
- **Software Developments**

WP5 OBJECTIVES

- **A 10+ years development on Micro Pattern Gas Detectors with custom CMOS readout for X-ray polarimetry**
- **NEWS intended to support development of detector, electronics and science software as mission elements**
- **Approval of IXPE mission proposal in NASA SMEX call in Jan 2017 is pushing the program to a specific mission design**

Objectives
O5.1: Build a fully functional lab prototype of a Gas Pixel Detector (GPD) for the focal plane of an X-ray polarimetric mission.
O5.2: Study and design the basic components of a space-grade data acquisition system for the GPD.
O5.3: Optimize event reconstruction and classification.
O5.4: Implement an observation-simulation framework for the X-ray polarimetry explorers.
O5.5: Define and implement science analysis tools for the X-ray polarimetry explorers.

WP5 DELIVERABLES

- **Deliverables are part of the IXPE project**

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D5.1	Design Report of a Space Grade GPD and Associated Data Acquisition System	1 - INFN	Report	Public	36
D5.2	Simulation and Science Analysis Framework for X-Ray Polarimetry	7 - UNIPI	Report	Public	48

Description of deliverables

Description

D5.1 : Design Report of a Space Grade GPD and Associated Data Acquisition System [36]

The GPD prototype will be thoroughly tested and characterized and will serve as a base for the design and definition of a space-grade assembly procedure for future flight models. A space-grade data acquisition system will also be designed.

D5.2 : Simulation and Science Analysis Framework for X-Ray Polarimetry [48]

A fully-fledged observation-simulation framework will produce a simulated event-list equivalent to real observations. This will allow to perform optimization and sensitivity studies of a polarimetric mission, and the related science analysis algorithms and tools.

WP5 Milestones

- Mission schedule really drives deliveries
  - as well as team commitments
    - with impact on secondments
  - IXPE started before NEWS KO
  - likely to deliver ahead of NEWS calendar

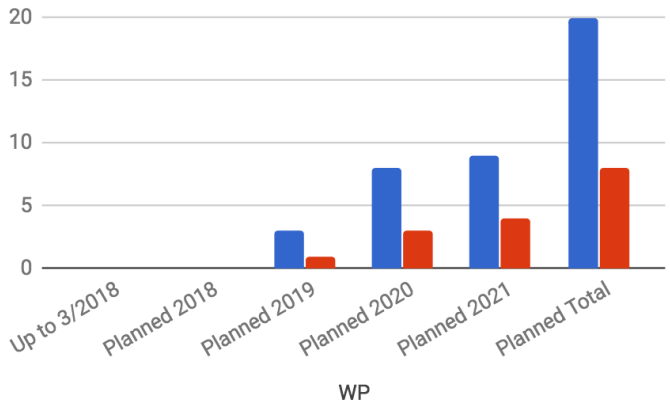
Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS6	Gas Pixel Detector Prototype	1 - INFN	24	The Gas Pixel Detector prototype will be built, thoroughly tested and characterized and will serve as a base for the design and definition of the assembly procedure of the future flight models.

WP5 Secondment Status

- **Not started yet due to strong pressure on team to complete IXPE mission phase B (design completion and qualification)**
- **Future plans reflect mission activities**

5. X-ray Polarimetry	20	8	28	Rationale
Up to 3/2018	0	0	0	Mission phase B activities
Planned 2018	0	0	0	Mission phase B activities
Planned 2019	3	1	4	Calibrations at x-ray facilities
Planned 2020	8	3	11	Calibrations and Integration support
Planned 2021	9	4	13	Support to launch and science prep
Planned Total	*20*	*8*	*28*	



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IXPE Mission Status

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IXPE ACCOMPLISHES NEW SCIENCE WITH NEW CAPABILITIES

- **Opens a new window on the universe — imaging (30“) X-ray polarimetry**
  - Is the science driver that advances and impacts high-energy astrophysics
  - Increases information space and lifts modeling degeneracies
- **Addresses key questions, providing new scientific results and constraints**
  - What is the spin of a black hole?
  - What are the geometry and magnetic-field strength in magnetars?
  - Was our Galactic Center an Active Galactic Nucleus in the recent past?
  - What is the magnetic field structure in synchrotron X-ray sources?
  - What are the geometries and origins of X-rays from pulsars (isolated and accreting)?
- **Provides powerful and unique capabilities**
  - Reduces integration time by a factor of 100 compared to the OSO-8 experiment
  - Simultaneously provides imaging, spectral, timing, and polarization data
  - Is free of false-polarization systematic effects at less than a fraction of a percent
  - Enables meaningful polarization measurements for many sources of different classes

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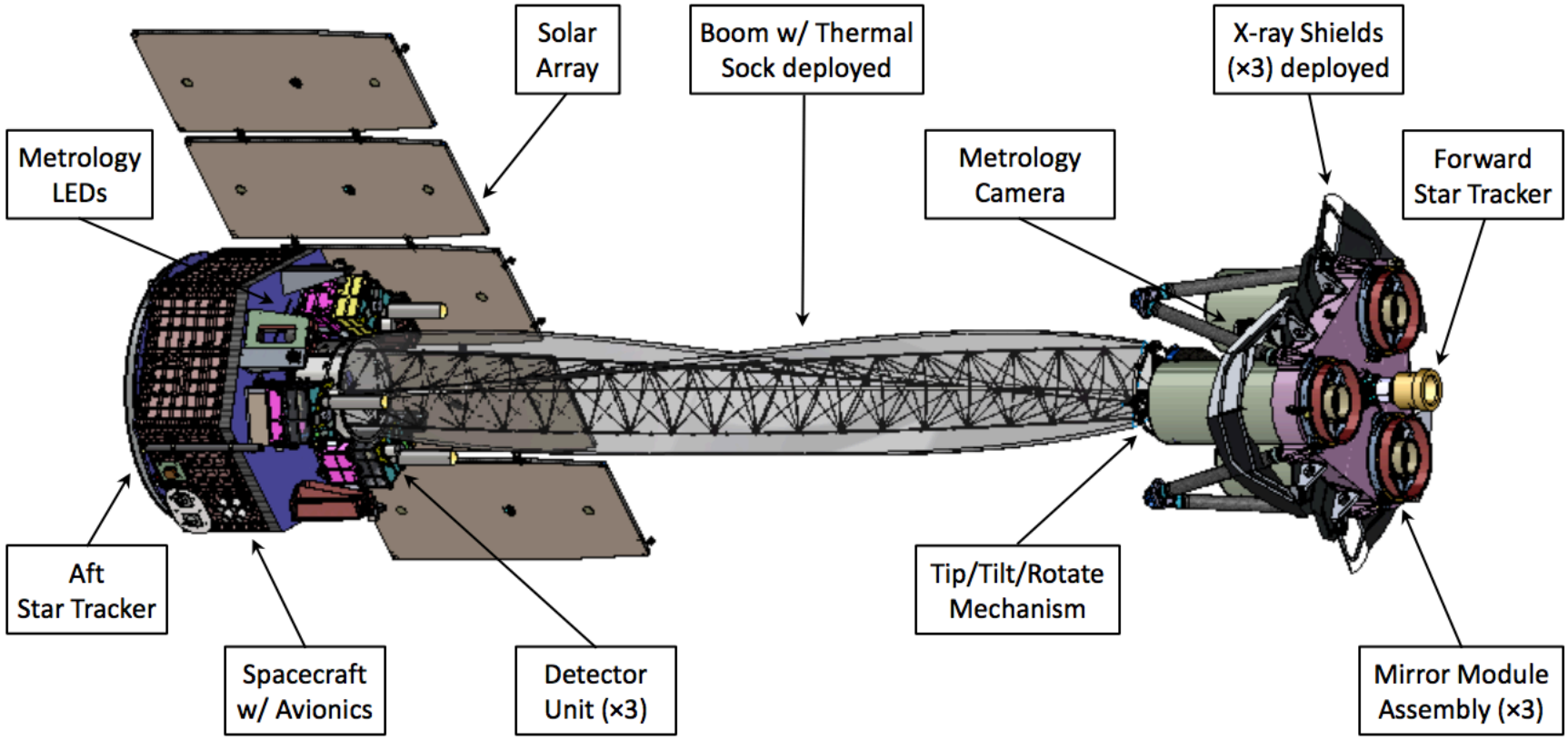
MAJOR COMPONENTS OF THE OBSERVATORY



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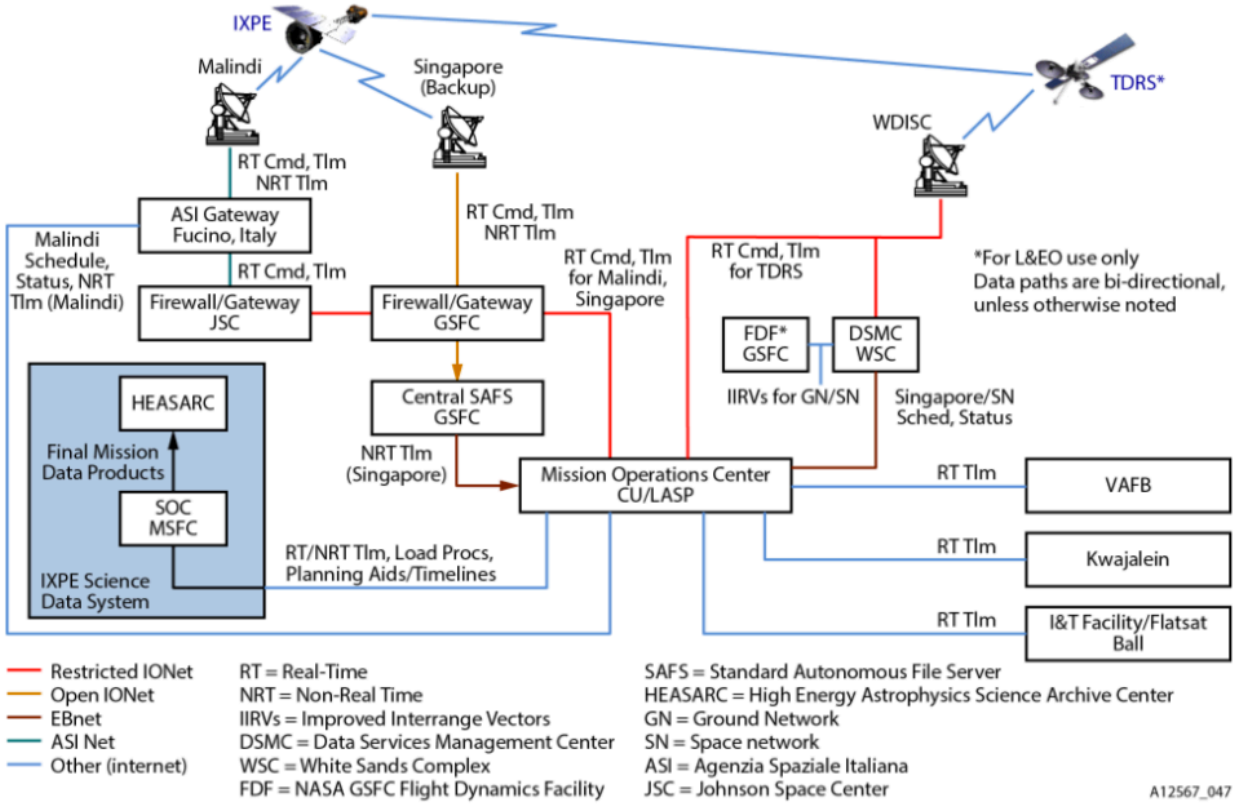
Mission Overview

- Pegasus XL launch from Kwajalein
- 540-km circular orbit at 0° inclination
- 2 year baseline mission, 1 year SEO
- Point-and-stare at known targets (~48 /year)
- Science Operations Center at MSFC
- Mission Operations Center at CU/LASP
- Malindi ground station (Singapore Backup)
- Launch ready by early 2021



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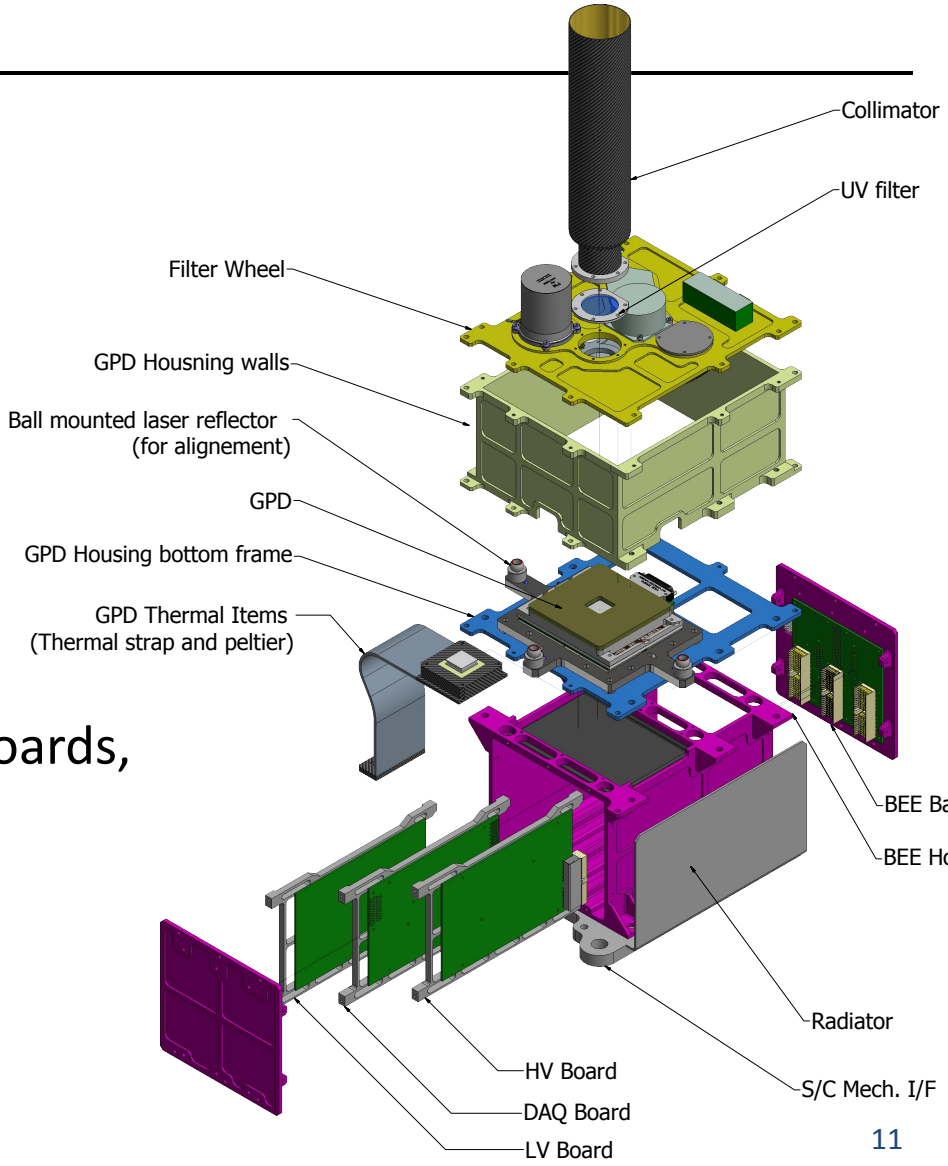
INFN RESPONSIBILITY

- **Gas Pixel Detector (GPD)**
  - Bread-Board (BB)
  - Engineering Model (EM)
- **Detector Units (DU)**
  - 3x Proto Flight Model (PFM)
  - 1x PFM spare
- **DU Electronics Boards**
  - Low Voltage, DAQ, GPD ASIC boards, backplane, harness
- **DU Mechanical Housing**
- **DU Thermal Control System**
- **Straylight collimator**



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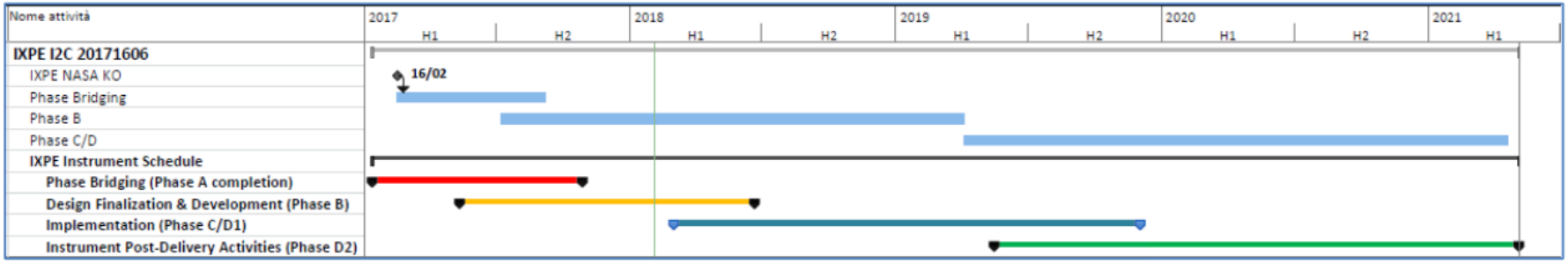
IXPE AND NEWS SCHEDULE

- **IXPE mission phases overlap**
  - **high degree of parallel activities (but higher risk)**
- **NEWS perfectly aligned**

- Phase A Completion - Preparation of phase B/C/D KO
- Phase B - Design Finalization & Development Phase
- Phase C/D1 - Implementation Phase
- Phase D2 - Instrument post-delivery Phase



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IXPE Reviews

- Instrument level (on IT team at IT agencies)
  - System Requirement, completed 12/2017
  - Preliminary Design, 3/2018
  - Critical Design, 5/2018
- Other level (IT support at US partners and agencies)
  - spacecraft PDR, 3/2018
  - Payload PDR, 4/2018
  - Mission PDR, 6/2018

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IXPE Upcoming Milestones

- **Qualification Models**
  - **Detector Unit Thermal Model, 3/2018**
    - verifies thermal simulations with a representative (ie not flight) DU model
  - **Detector Unit Structural Model, 6/2018**
    - calibrates structural loads at DU level, most notably for Filter & Calibratin Wheel
  - **Gas Pixel Detector Qualification Model, 6/2018**
    - validates new GPD assembly flow through TVAC and vibrational tests
- **Flight unit production**
  - **Proto Flight Model1, delivery 9/2018**

IXPE Imaging X-Ray Polarimetry Explorer

THE NEW MODEL PHYLOSPHY

IXPE Instrument HW Matrix	MM	SM set	TM	BB(2)	GPD-EM (3)	EM(5)	QM	PFM	FM	Spare(4)
Detector Unit						1		1	3	1
Gas Pixel Detector	1	1	1	2	1	1	1	1	3	1
GPD Mechanical Interface		1	1	2	1	1	1	1	3	1
GPD Board		1	1	2	1	1	1	1	3	1
Gas Cell		1	1	2	1	1	1	1	3	1
ASIC		1	1	2	1	1	1	1	3	1
Gas Electron Multiplier		1	1	2	1	1	1	1	3	1
Peltier & Thermal Item		1	1	2	1	1	1	1	3	1
Filter & Cal. Wheel	1		1	1		1	1	1	3	1
Holder Wheel & Driver (*)				1		1	1	1	3	1
Lid				1		1	1	1	3	1
Filters & Calibrations set				1		1	1	1	3	1
Stry-Light Collimator	1	1						1	3	1
Collimator Structure		1						1	3	1
Flanges		1						1	3	1
UV Filter		1						1	3	1
Back End Electronic	1	1	1	1		1		1	3	1
DAQ & preprocessing board		1	1	1		1		1	3	1
Backplate & Mother Board		1	1	1		1		1	3	1
LV Power Supply Board		1	1	1		1		1	3	1
HV Power Supply Board		1	1	1		1	1	1	3	1
DU Wiring			1			1		1	3	1
Wiring BEE-GPD			1			1		1	3	1
Wiring GPD Surv Heater								1	3	1
DU Housing	1	1	1			1		1	3	1
GPD Housing		1	1			1		1	3	1
DU Housing		1	1			1		1	3	1
Detectors Service Unit						1		1		
DSU Boards Set	1					1		1		1
Single Board Computer (nom.)	1					1		1		1
Single Board Computer (red.)	1					1		1		
Power & Service Board (nom.)	1					1		1		1
Power & Service Board (red.)	1					1		1		
Mother Board						1		1		
DSU Case	1					1		1		
Harness DSU to DU						1		1		

(1) For B/B Electrical Motor is flight representative while the wheel (as well sources and filters) is a dummy representative of mass and CoG only
(2) 1 B/B is the minimun expected
(3) The GPD EM will be delivered to INAF and MSFC for dry run of calibration at Instrument (INAF) and Telescope (INFN) level with Test Equipment
(4) The Flight Spare will be one of the 4 DU PFMs so it will be qualified at acceptance level as a minimum
(5) The DU-EM will be intragated using BB, EM and QM models
(6) The BEE SM and GPD EM are utilised for the development of Structural test bench for the qualification of FCW reproducing flight configuration

Additional models after I-SRR (green cells)

- GPD QM
- SM set (BEE, GPD, Collimator)
- DU EM

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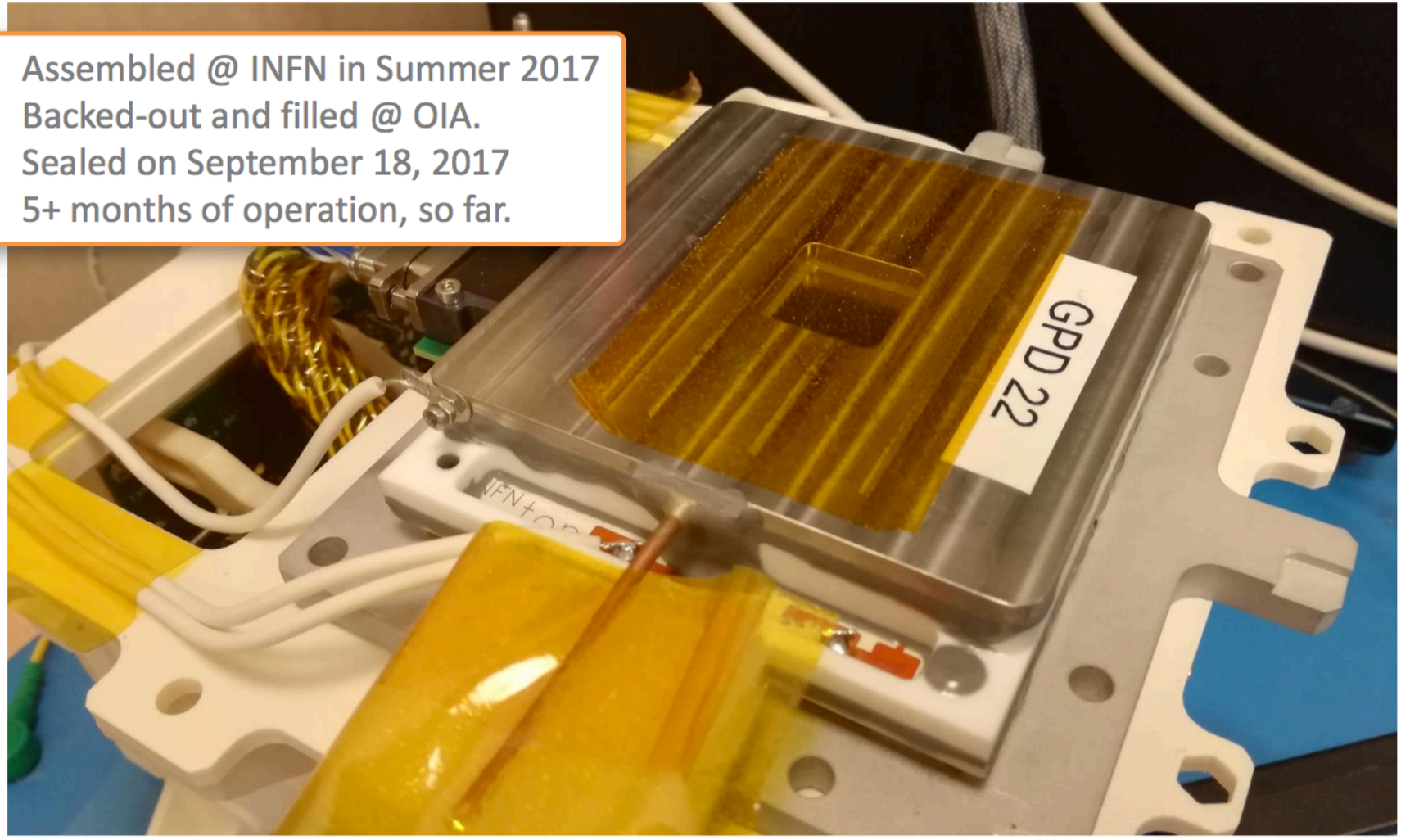
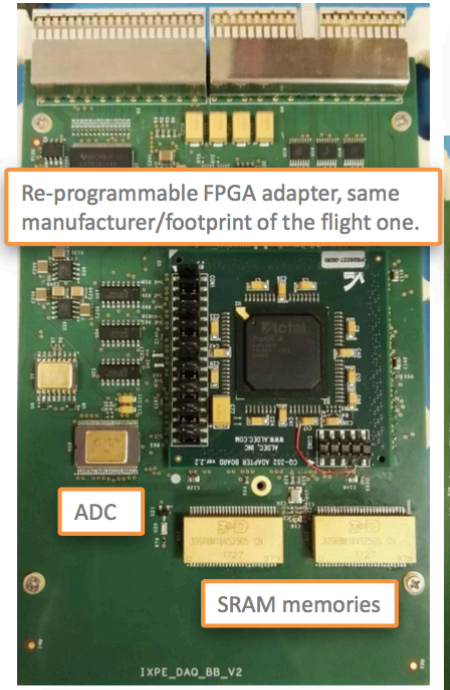
GPD Detector Prototype (NEWS O5.1)

- Assembled @ INFN in Summer 2017
- Backed-out and filled @ OIA.
- Sealed on September 18, 2017
- 5+ months of operation, so far.

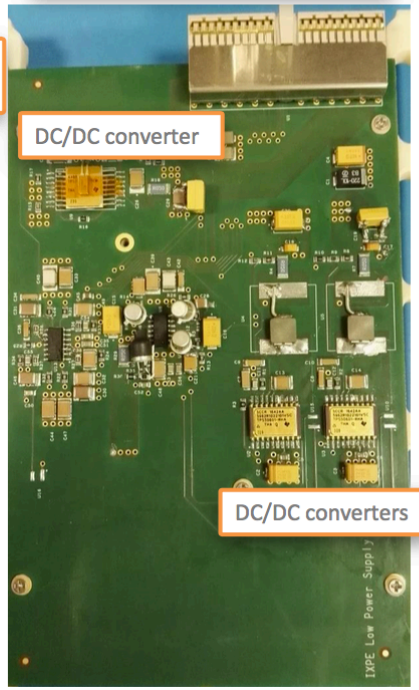


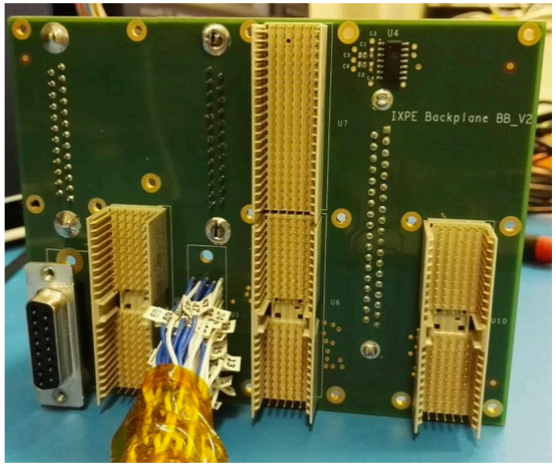
GPD READOUT ELECTRONICS SYSTEM (NEWS O5.2)

- **Two generations of readout breadboards with flight design developed for onboard DAQ**



DAQ board





Backplane

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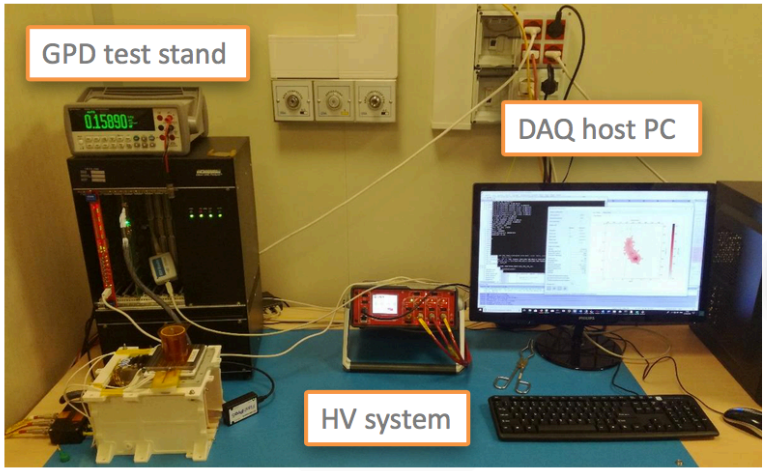
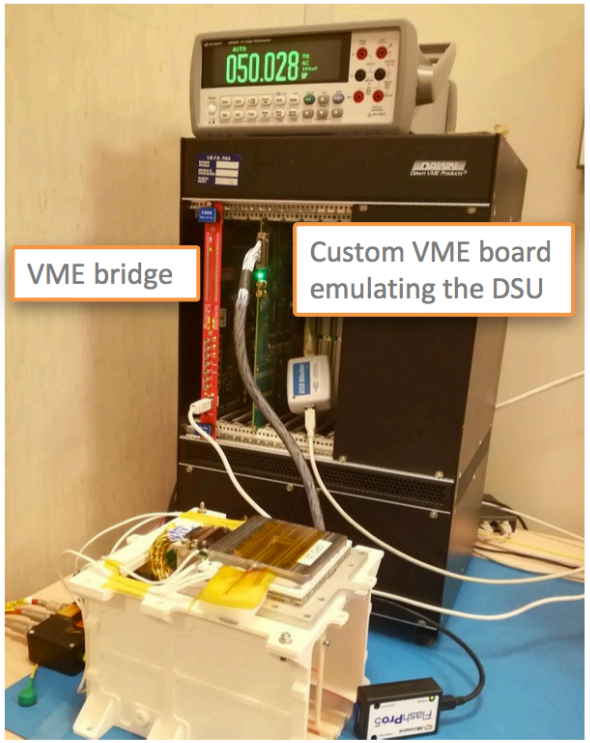
GPD READOUT ELECTRONICS SYSTEM (NEWS O5.2)

- **Laboratory test equipment to interface to onboard DAQ boards to support GPD and associated electronics development**





- Command-Control Interface (CCI)
- Science Data Interface (SDI)
- Power distribution (5 and 25 V, regulated)
- Timing (1-PPS, 1 MHz clock)

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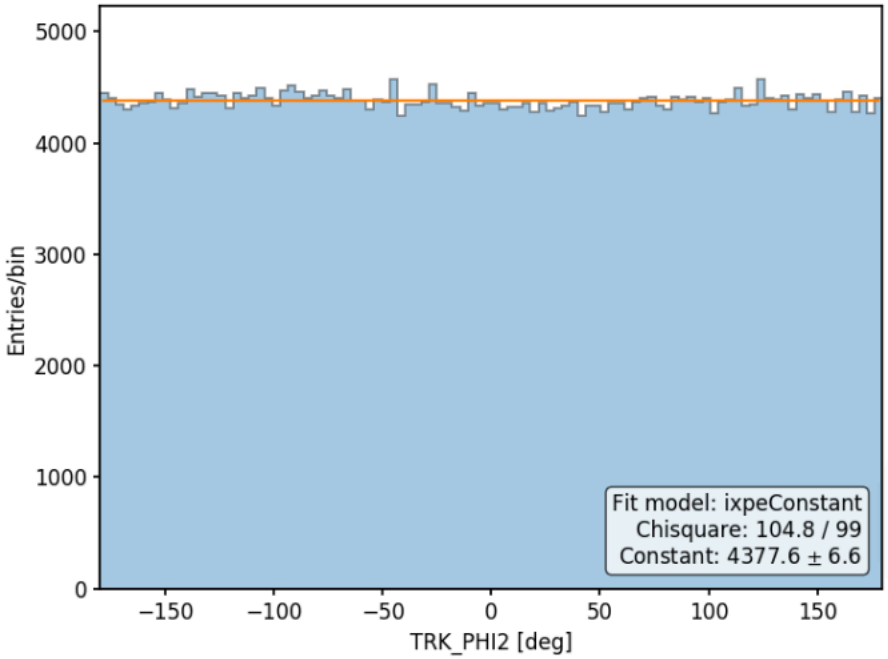
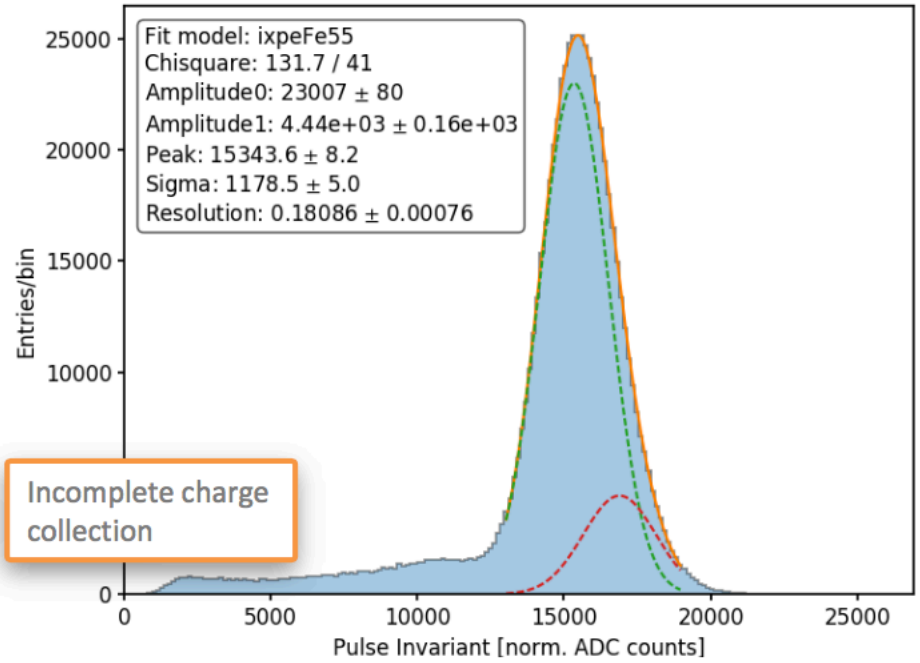
PUTTING EVERYTHING TOGETHER





- Basic performance tests with a ^{55}Fe source
  - Flat azimuthal response
  - 18 % energy resolution over the entire detector (after gain equalization)
- Caveat: this is not a thorough GPD characterization nor calibration
- Yet no evidence of performance degradation in 6 months of operation

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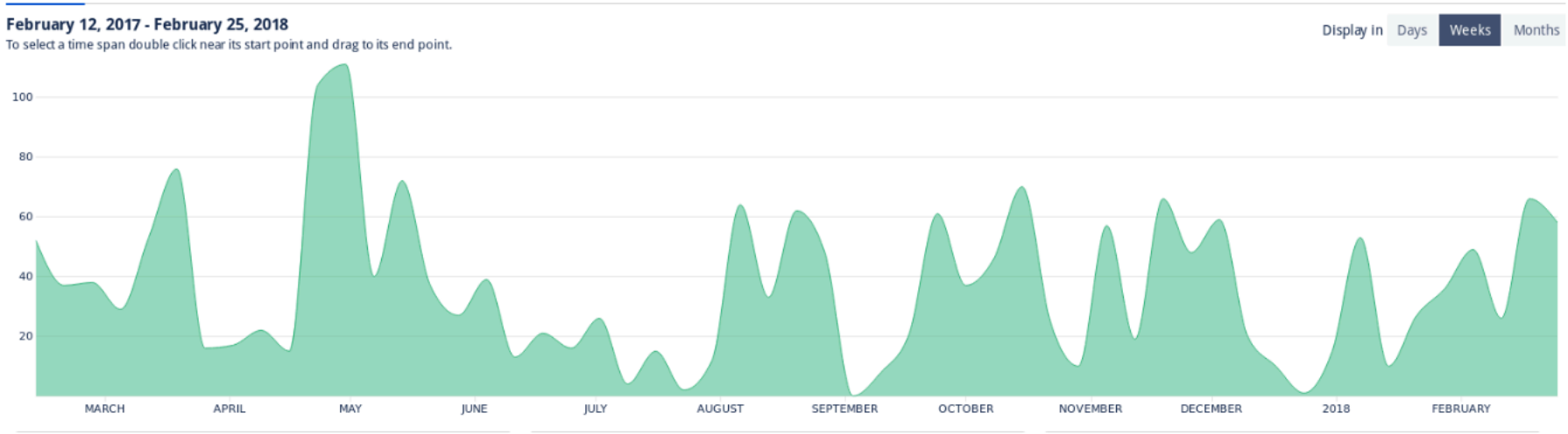
SOFTWARE ACTIVITIES



- **Substantial re-write of all the basic software components:**
  - Data acquisition
  - Detector Monte Carlo simulation
  - Track reconstruction, analysis and monitoring tools
  - Observation simulation framework
- **Tentative definition of all the relevant data formats**
  - FITS LV1 event files, CALDB
  - Active involvement of all the I2T components (including SSDC) and the SOC at MSFC
- **Processing tests and calibration data in the same fashion as flight data**

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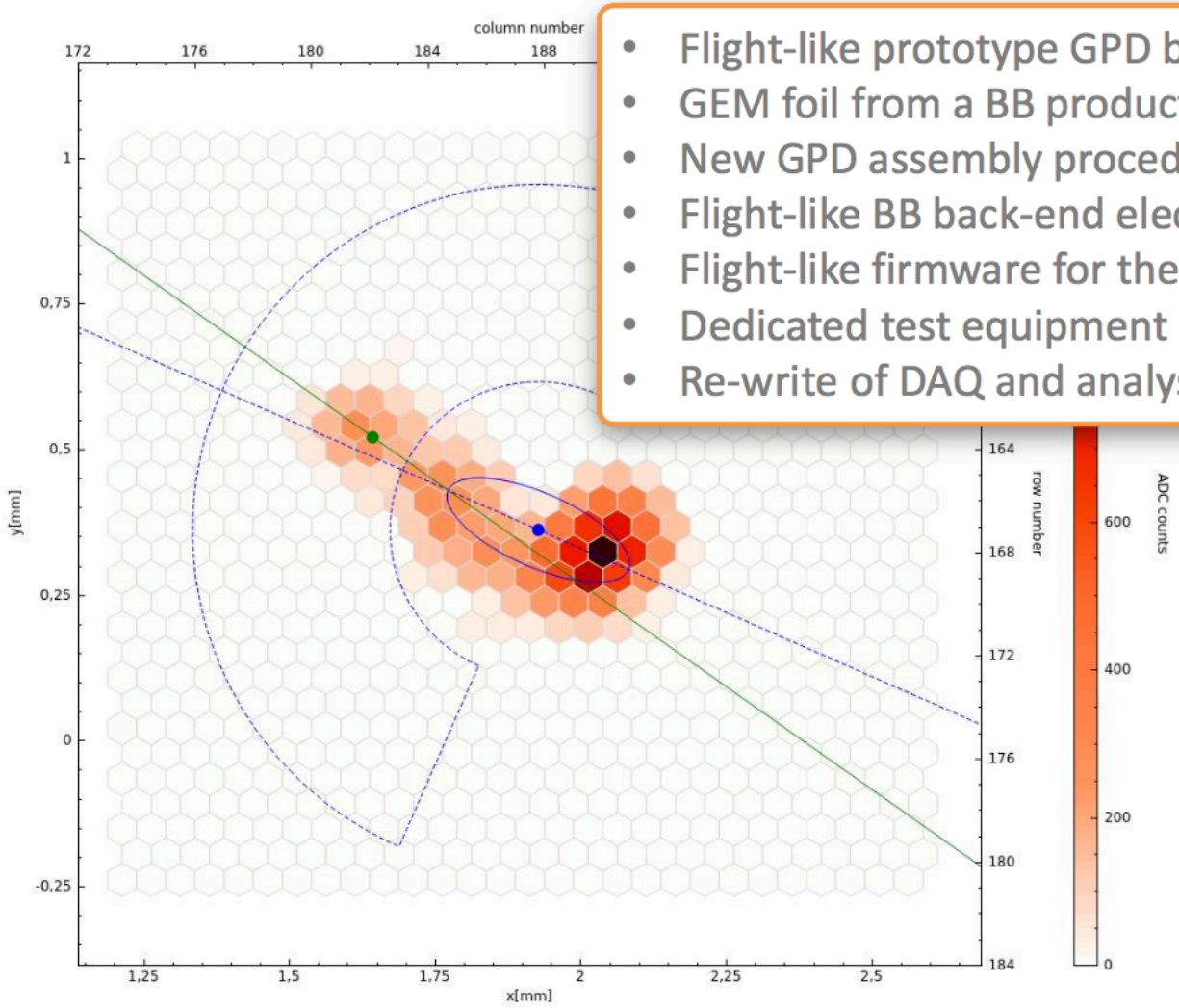
GPD Reconstruction software (NEWS O5.3)



- Flight-like prototype GPD board
- GEM foil from a BB production run
- New GPD assembly procedure
- Flight-like BB back-end electronics
- Flight-like firmware for the DAQ board
- Dedicated test equipment
- Re-write of DAQ and analysis software

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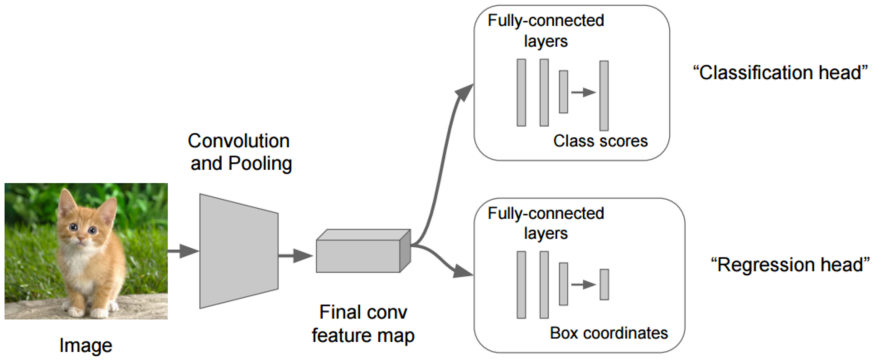
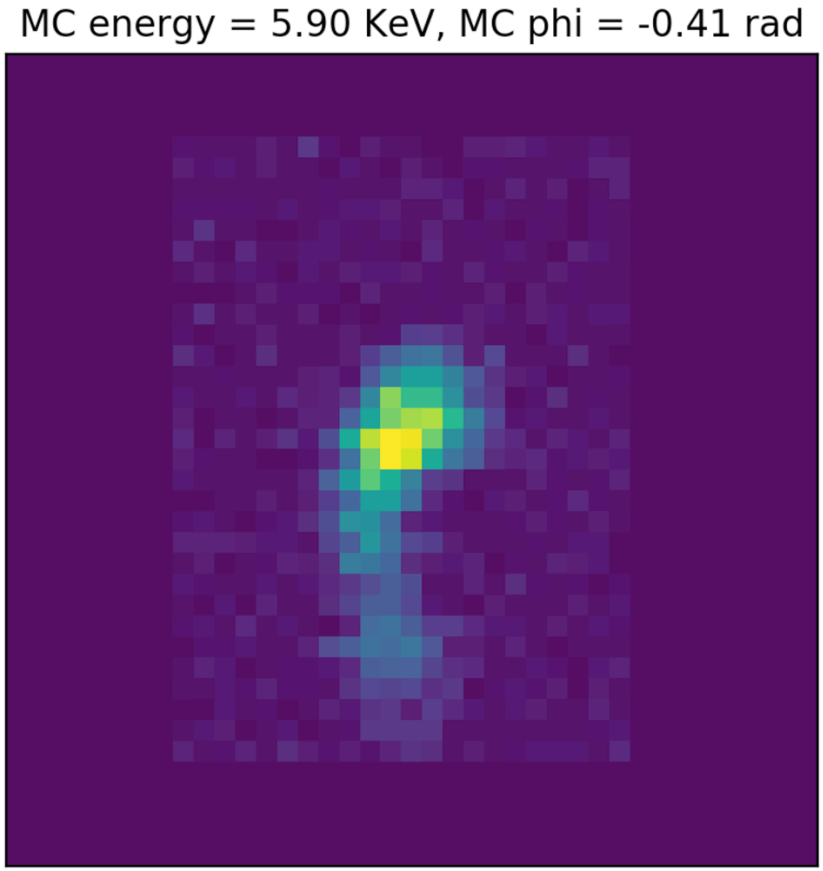
GPD Reconstruction software (NEWS O5.3)

- **Testing AI methods (Convolutional Neural Network) to improve recon**
- **Training on MC events**
- **CNN regression to extract track parameters**





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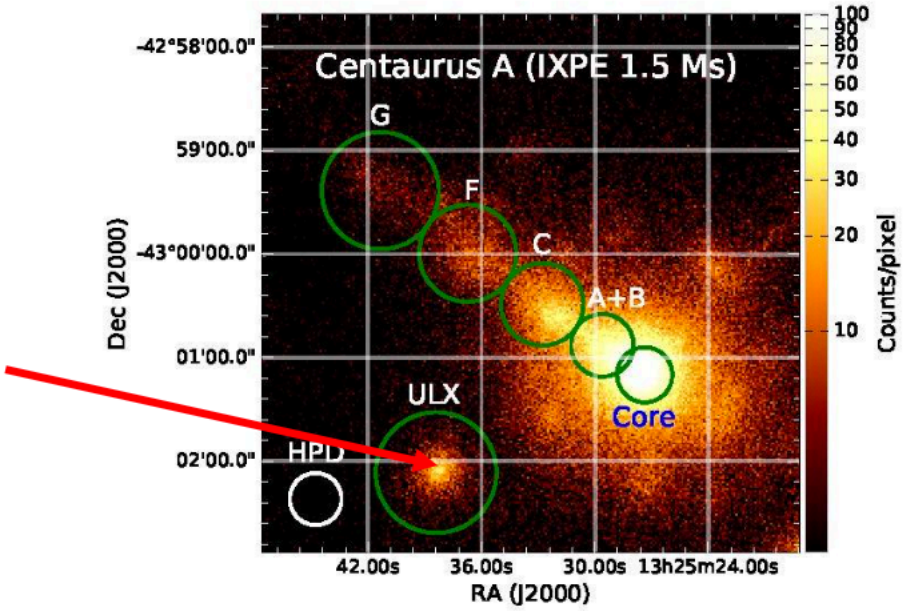
OBS. SIMULATOR FOR SCIENCE PREP (NEWS O5.4/5)

- **Active galaxies are powered by supermassive BHs with jets**
  - Radio polarization implies the magnetic field is aligned with jet
  - Different models for electron acceleration predict different dependence in X-rays
- **Imaging Cen A allows isolating other sources in the field (2 Ultra Luminous X-ray sources)**



Region	MDP_{99}
Core	**<7.0%**
Jet	**10.9%**
Knot A+B	17.6%
Knot C	16.5%
Knot F	23.5%
Knot G	30.9%
ULX	**14.8%**

Includes effects of dilution by unpolarized diffuse emission

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CONCLUSIONS

- **Significant progress in all areas pushed by tight IXPE mission schedule**
- **Use of secondments planned to start in 2019 to allow team to complete design and prototyping phase in Italy and support IXPE mission level activities**