Nuclear Physics Mid Term Plan in Italy

LNF – Session

Frascati, December 1st - 2nd 2022

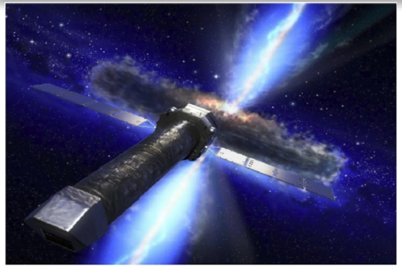
Summary of the "Detectors for X radiation" WG

Alessandro Scordo

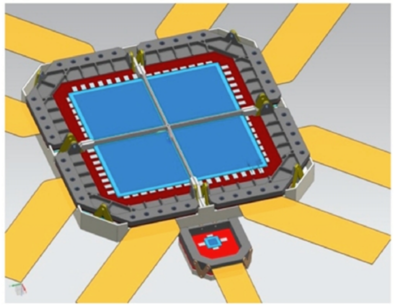
Laboratori Nazionali di Frascati INFN

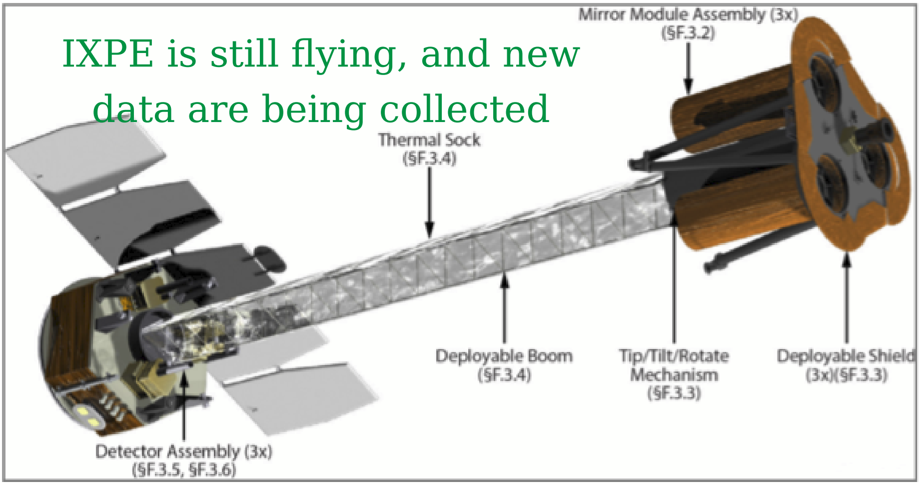
C. Fiorini – INFN, PoliMI
M. Porro - XFEL

MIXS The Mercury Imaging X-ray Spectrometer (MIXS) is NOW FLYING TOWARD Mercury where it will perform X-ray fluorescence (XRF) analysis of the surface of Mercury (2024-2025).



In the far future DePFETs are proposed for the Wide Field Imager aboard the ATHENA satellite and developed for use as real-time imager for transmission electron microscopes. Launch foreseen in 2035…stay tuned!





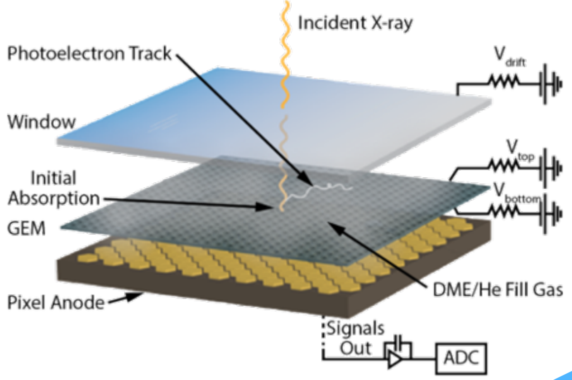
Future Perspectives

New ASIC to reduce the dead time of a factor 10 (almost reached) and increase sensitivity by matching larger optics

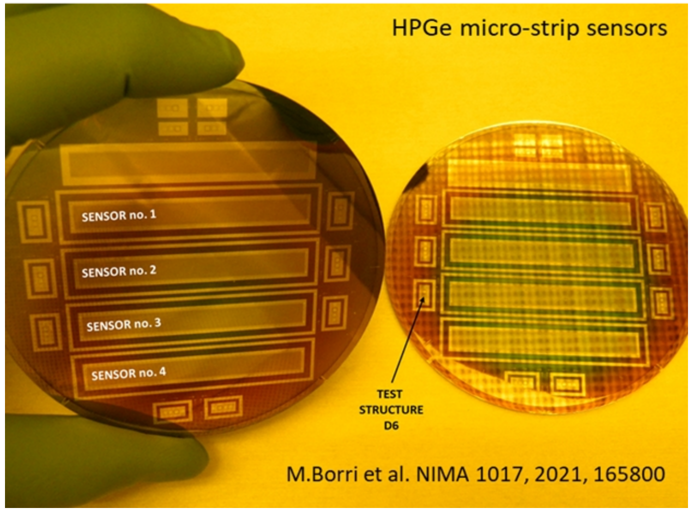
New amplification strategies to overcome the systematic effects due to non-uniformity of GEM holes

Target: eXTP Mission (2027?)

A. Manfreda, Pisa (INFN)



M. Borri, STFC-Daresbury Laboratory - UKRI

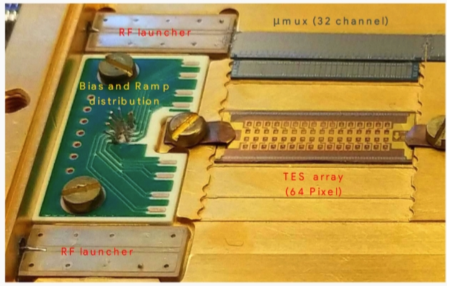


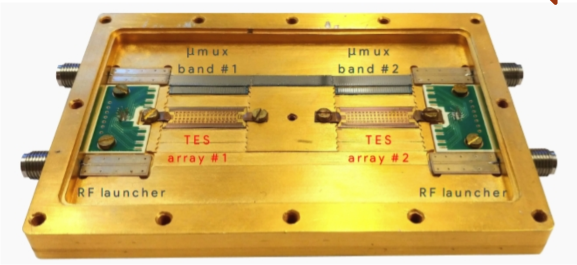
The existing system is taking data at the ESRF-EBS, a 4th generation synchrotron.

This is generating a track record of scientific output in high-pressure/high-temperature chemistry and physics.

The system is in the process of being commercialized via tech transfer grants (2023).

A. Giachero, Milano - Bicocca



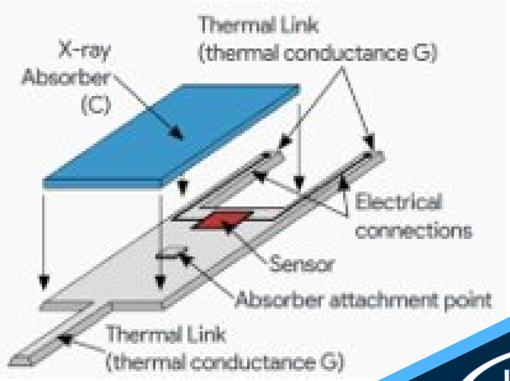


The goal of the next future experiments is the sub-eV neutrino mass sensitivity

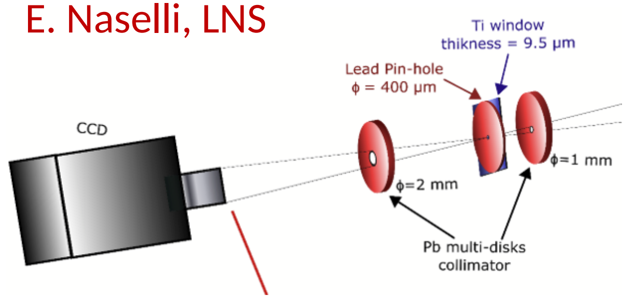
The HOLMES experiment will perform a direct measurement of the neutrino mass by using TES-based microcalorimeters with ^{163}Ho-implanted absorber

The first phase of the HOLMES experiment is expected between the end of 2022 and the beginning of 2023

Final 1024-pixel configuration, or intermediate steps, will follow;
Next step after HOLMES: 106 pixel to reach a sub-eV sensitivity



D. Mascali, LNS
E. Naselli, LNS

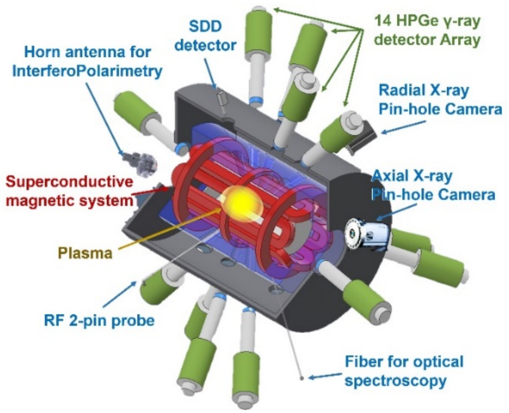


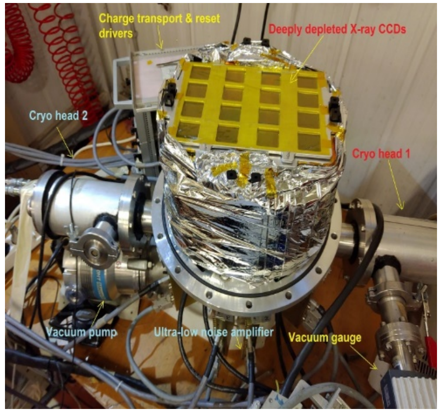
Update including fast X-ray shutters and trigger systems to allow simultaneously space and time-resolved plasma spectroscopy during transients, stable and turbulent regimes, with ms timescale.

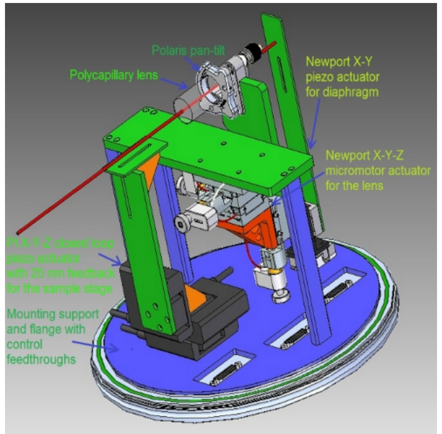
Diffractometric X-ray spectroscopy based on the use of "gratings", will allow to reach resolutions of the order of $\Delta\lambda / \lambda = 10^{-3}$ at 565 eV

XRF peak broadening measurements, giving access to the indirect measurement of the ion temperature in the plasma.

PANDORA is expected to start its operation in 2024.



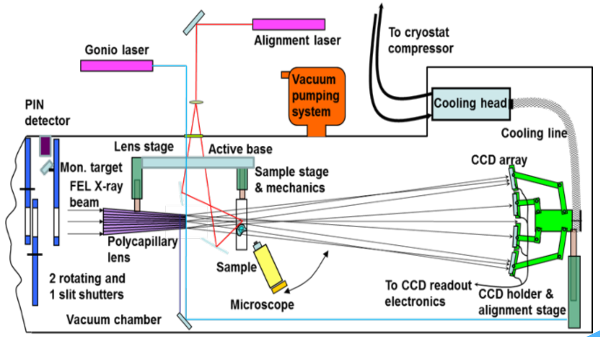




M. Iliescu, LNF

SPHINX

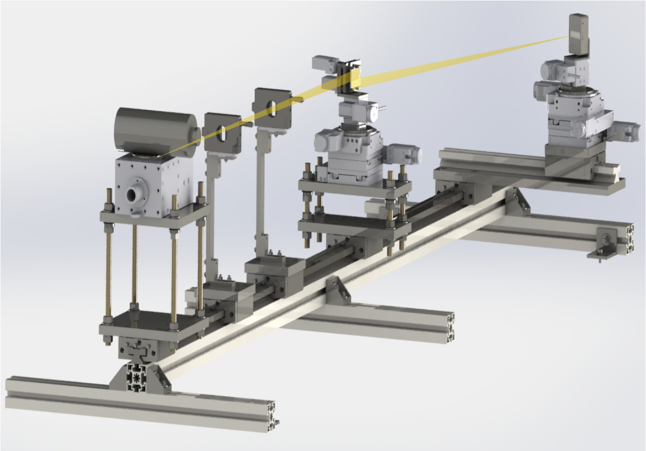
Full detector assembly completed.
Vacuum and cryogenic testing completed.
Optics bench design completed, and all components realized.
Installation in advanced phase.



Measurement plan agreed with DIAMOND synchrotron.
Contact with European X-FEL established, more specific plans to follow the optics investigation.

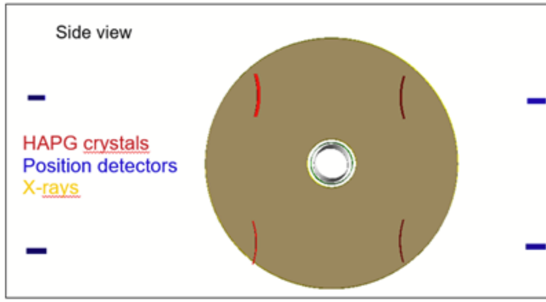
New PRIN submitted in 2022

A. Scordo, LNF

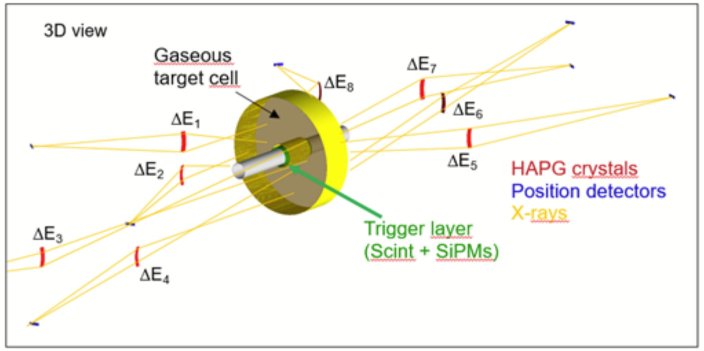


The VOXES spectrometer is presently used to develop a monitoring system for wine oxidation and metal concentration

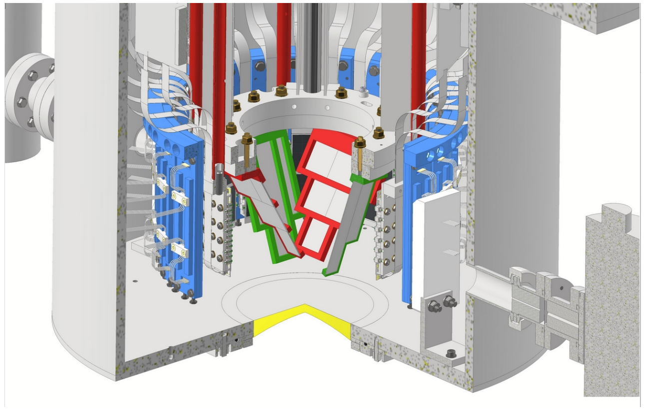
MITIQO



In the (far) future, the LNF strangeness nuclear physics group is considering the possibility to propose an advanced version of VOXES to measure kaonic atoms transitions with sub-eV precision

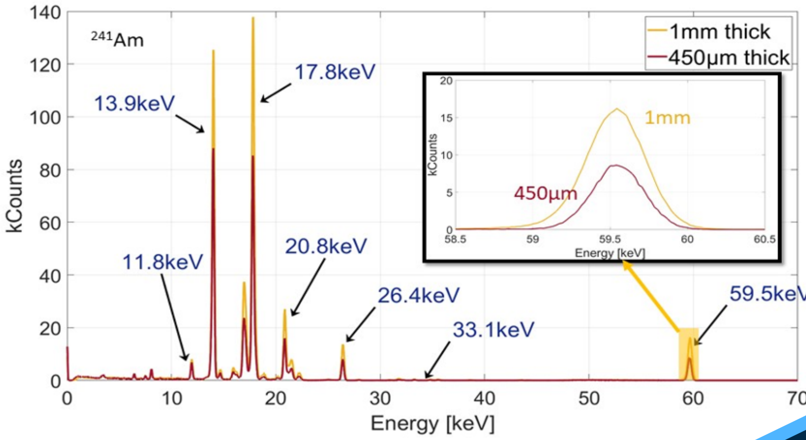


C. Fiorini, INFN, PoliMI



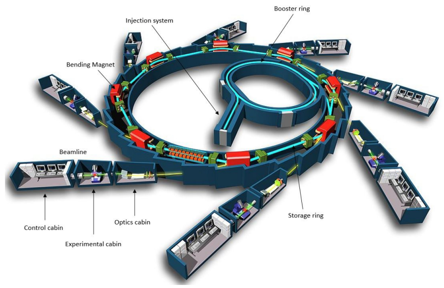
Light kaonic atoms can also be measured with 1-2 mm thick SDDs, extending the efficiency range above 30 keV

The strongly demanded $K^{3,4}He(2p \rightarrow 1s)$ transition measurement could be pinned down!



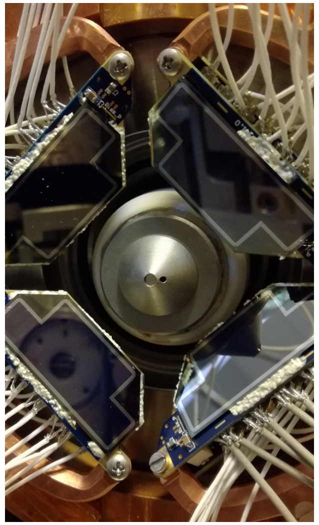
A. Vacchi, Trieste,
G. Pepponi, FBK

SDDs for synchrotron radiation-based material analyses and space applications / astrophysics from large area monolithic SDDs => to true SDD pixel detectors

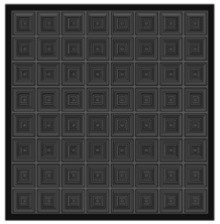


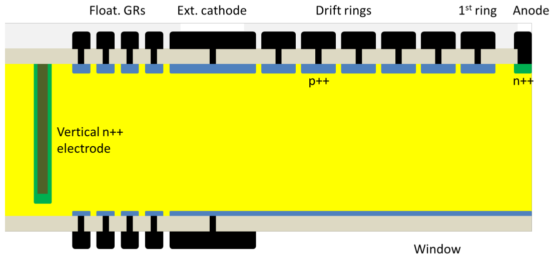
Low energy X-ray microscopy:
The ELETTRA TwinMic station needs 4 SDD arrays to cover a large solid angle and ultimate energy resolution and noise level to be able to see soft X-rays

Extreme fluences and high dynamic range -> segmentation
Beyond monolithic SDD arrays research is ongoing at FBK for a slim-edge concept with trenches to isolate the devices
And allow the composition of tiles

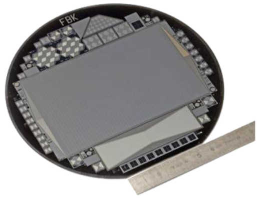


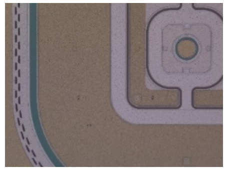
Longstanding collaborations between INFN and FBK triggered and favoured development of new, custom and groundbreaking technologies, thanks to the cleanrooms available at FBK



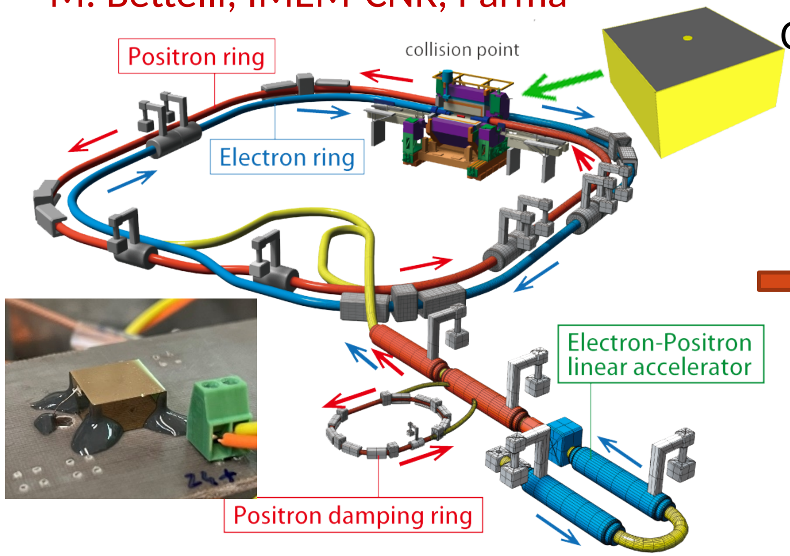


INFN and FBK have now a formal collaboration agreement which will lead to further improvement in X-ray detection technologies





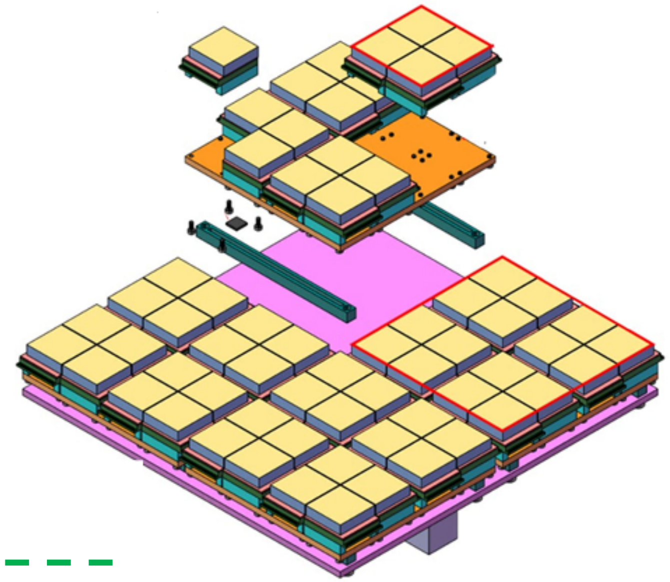
M. Bettelli, IMEM-CNR, Parma

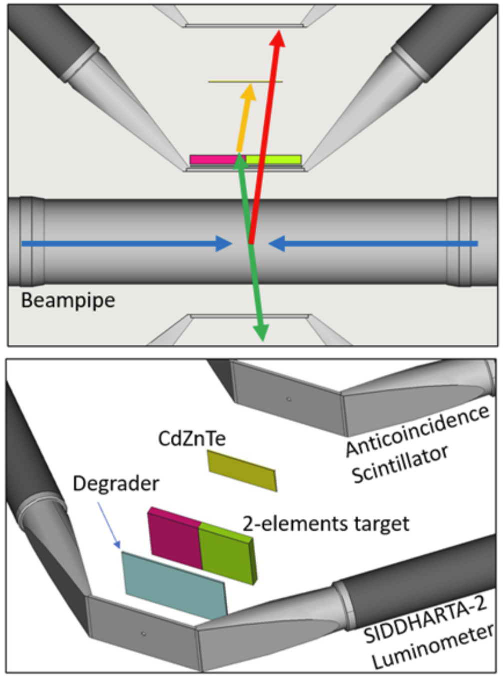


Single CZT installed successfully in DAΦNE, encouraging preliminary results achieved

High energy resolution

Modular detector under designing





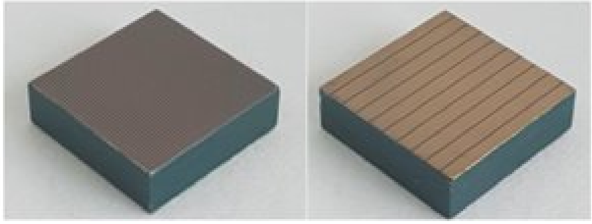
Kaonic atoms X-rays

e^+e^-

K^+K^-

MIP

A. Scordo, LNF



Crucial measurements on intermediate-mass kaonic atoms transitions can be easily performed with CZT

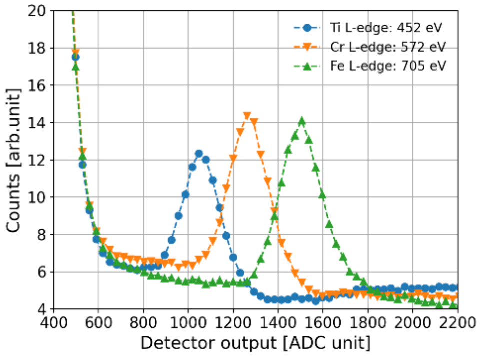
In 2023, a new campaign to measure kaonic aluminum and carbon (and others) is foreseen at DAFNE

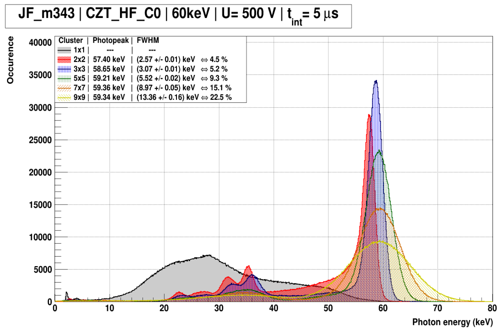
A PRIN project has been submitted for a wide measurement campaign to renew the kaonic atoms database

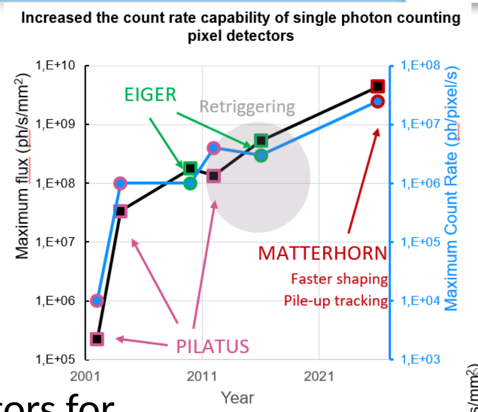
A. Bergamaschi, PSI / G. Tinti, LNF

PAUL SCHERRER INSTITUT

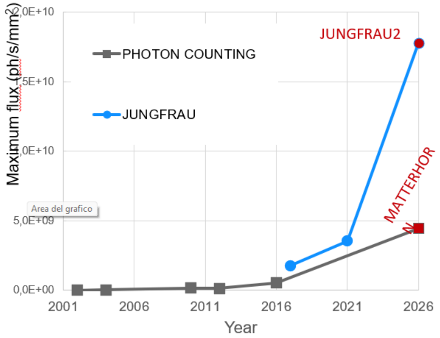
Improved sensors for < 2keV and > 20keV







Faster detectors for 4th generation synchrotrons and CW XFELs



M. Testa, LNF

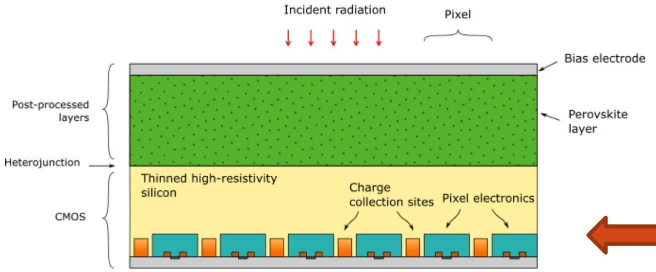
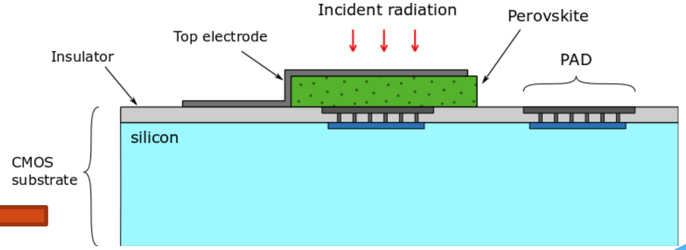


Figure 1. Simplified cross section of the proposed hybrid detector

On going activity:
Test on deposition of perovskite microchannels through microfluidics technique on CMOS substrates with aluminum pads, used as passive substrates



Next Goal:

hybrid X-ray detector structure combining a perovskite absorption layer and a CMOS silicon active layer

PRIN 2022 project proposal
L.Pancheri, M. Testa,
I.Viola

Nice people for nice technologies…

M. Testa
OMHP

M. Bettelli, CZT

A. Bergamaschi,
Hybrid detectors

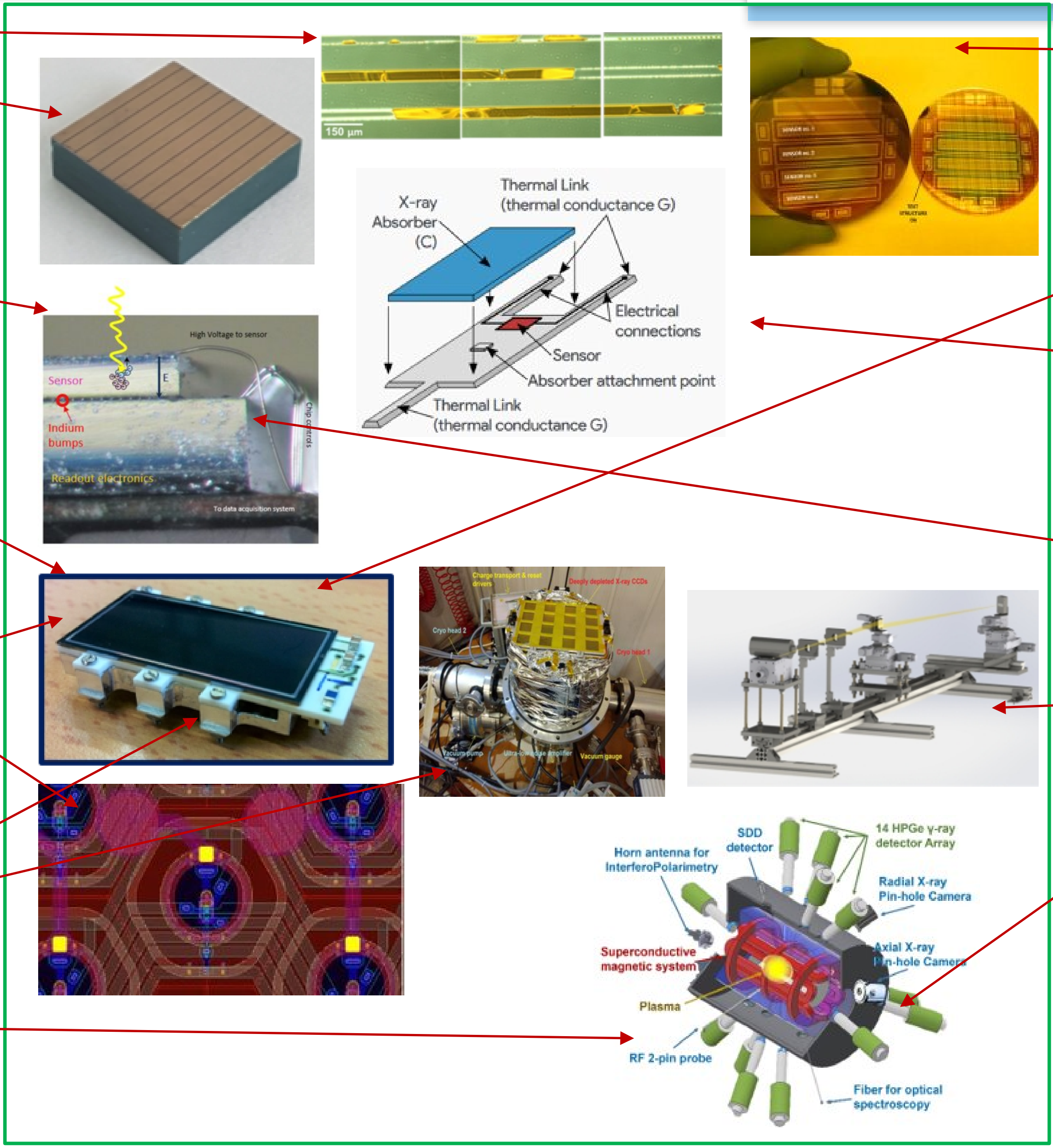
G. Pepponi,
SDD, LGAD

C. Fiorini,
DEPFET & SDD

A. Manfreda, GPD

M. Iliescu,
CCD & SDD

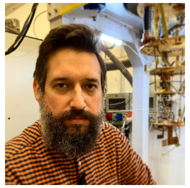
D. Mascali, LNS,
CCD & SDD & HPGe



M. Borri
STFC-Daresbury Lab.
HPGe microstrip

A. Vacchi, Trieste, SDD

A. Giachero
Milano-Bicocca, TES

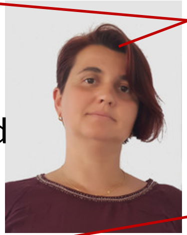


G. Tinti, LNF,
Hybrid detectors

A. Scordo, LNF,
HAPG crystals

E. Naselli, LNS,
CCD & SDD
& HPGe

G. Pepponi, FBK, SDD



A. Bergamaschi, PSI, Hybrid detectors

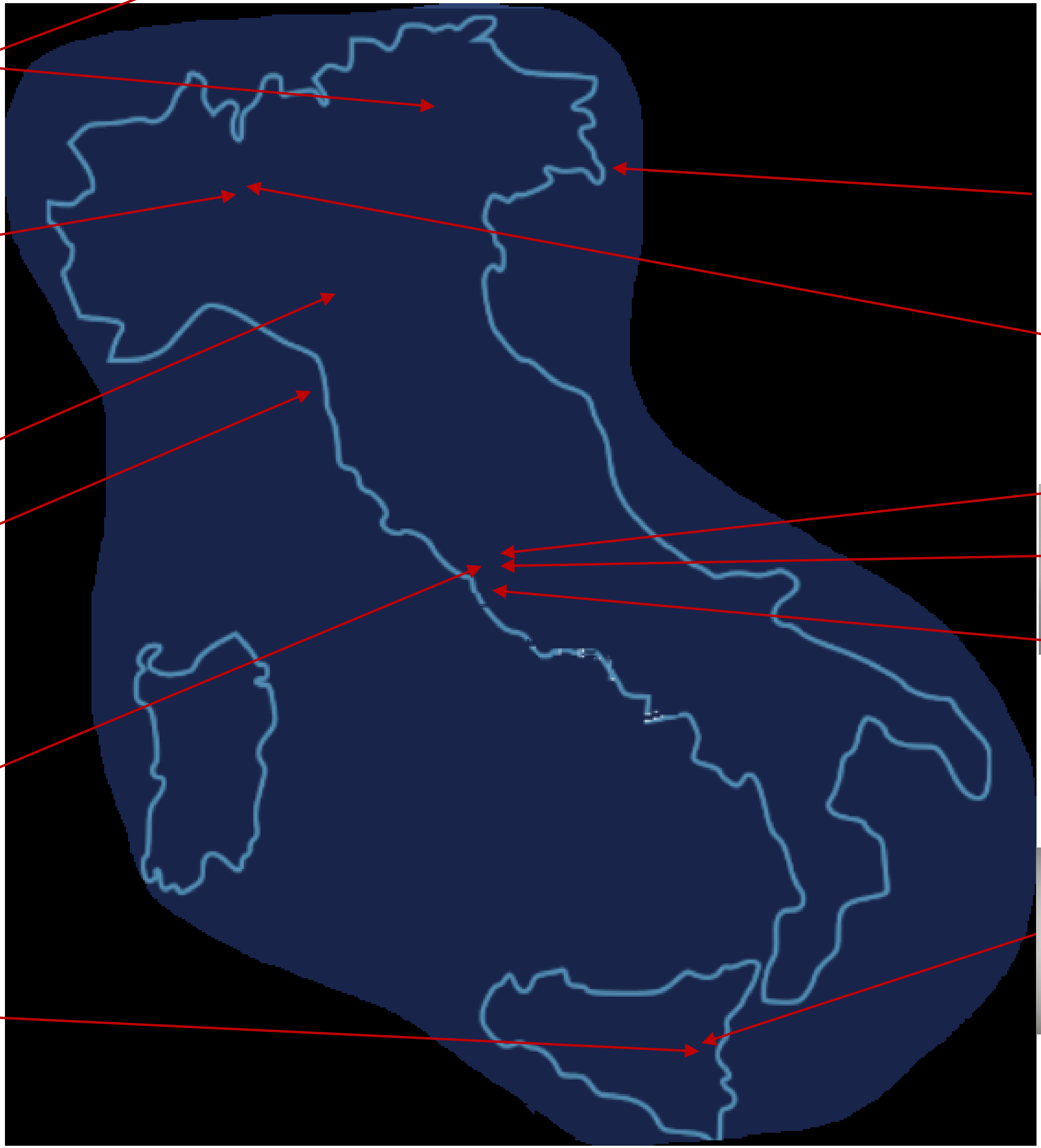
C. Fiorini, PoliMi, DEPFET & SDD

M. Bettelli, IMEM-CNR, Parma, CZT

A. Manfreda, Pisa, GPD

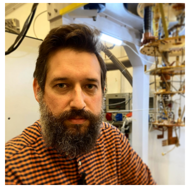
M. Iliescu, LNF CCD & SDD

D. Mascali, LNS, CCD & SDD & HPGe



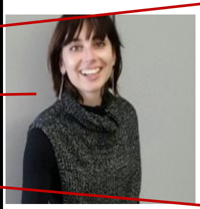
M. Borri STFC-Daresbury Lab. HPGe microstrip

A. Vacchi, Trieste, SDD



A. Giachero Milano-Bicocca, TES

M. Testa, LNF, OMHP



G. Tinti, LNF, Hybrid detectors

A. Scordo, LNF, HAPG crystals

E. Naselli, LNS, CCD & SDD & HPGe

Numbers of the Working Group:

25 subscription to the WG
14 active participants
>10 technologies
9 locations

- Very stimulating work of summary and condensation of technologies
- New insights on possible applications in nuclear physics
- Several applications and fields covered (astrophysics, medical, art, space, etc…)
- INFN is reach of smart physicists and extremely exciting new ideas and perspectives

Thanks to all the contributors for their involvement and active participation

Special thanks to

Marco Miliucci for his precious and unique work as Convener 2.

Detector	Project	Comment / Description	Critical Items for R&D	Expected time
GPDs	eXTP	Space misson for X-ray timing, polarimetry and spectroscopy	New ASIC to reduce dead time by a factor 10, new amplficaton stage to reduce systematics	2025-2027
HPGe microstrip	X-ray energy dispersive spectroscopy	Now in operation at ESRF-EBS ID24. To be commercilaised in first quarter of 2023.	High flux: spacial resultion Vs extemely high instantaneous flux; rate capabilties; effects of integrated flux.	2023-2026
TES	HOLMES	High resolution x-ray detectors to directly measure the neutrino mass	High implantation density, readout of > 1000 chanel with multiplexing	now-2026
HAPG Crystal spectrometer	VOXES/MITIQO	Bragg spectrometer with HAPG crystals for millimetric sources	Moving from 1D to 2D position spectra	2023
DEPFET	ATHENA/DSSC	Wide Field Imager for X-ray space observatory/High dynamic range (10^4) X-ray imager for XFEL	Production yield, calibration of non-linear DEPFET	2023-2030
SDD	THESEUS	Space mission - transient astronomy, with focus on Gamma Ray Bursts, aiming at the exploration of the high-redshift Universe	integration of 8x8 SDD matrix with FE (pre-amp) and Back end signal processing	2033
SDD	KAONNIS	SDD for Kaonic Atoms' spectroscopy	Increasing thickness for higher energy efficiency	2023
CCD	SPHINX	CCDs with polycapillary optics for X-ray holography	Prototype testing campaign on synchrotron	2023
CZT	Synchrotron detectors	high-Z fine pixelatated synchrotron detectors	improve maxium operative flux, improve homogeneity	2024
CZT	avatarX	CZT for Non Destructive Tests applications	improve readout under high fluxes, improve detector contacts quality	2023
CZT	gamma-Drone	development of fast and efficient radioisotope identification system	Evaluation in operative system and commercialization	2023
CZT	EMA and 3DCaTM	CZT for gamma ray telescope	evaluation of radiation damage, flight planning	2024
CZT	KAONNIS	CZT for Kaonic Atoms' spectroscopy	Moving to large area with fast timing	2023

Detector	Project	Comment / Description	Critical Items for R&D	Expected time
Hybrid Detectors	MATTERHORN	single photon counting for 4th generation synchrotrons	High rate capability obtained with multithresholds	2026
Hybrid Detectors	JUNGFRAU2	faster charge integrating detector for synchrotrons and XFELs	High rate capability and faster readout: high data throughput	2026
Hybrid Detectors	MÖNCH	25um pitch detector for energy resolved imaging with superresolution	Larger chips to increase the detector area	now
Hybrid Detectors	soft X ray LGADs	optimized pixel Low Gain Avalanche detectors for soft X-ray	optimization of performance	now- 2023
Hybrid Detectors	high Z sensors	New sensor materials for hard X -rays	material quality: uniformity of the electric field	2024
OMHP	PEROV	CMOS+perovskite for soft X-raysa	interface perovksite-CMOS;	2024
SDD	ADAM	ASI development for PixDD (pixel SDD) and slim edge sensors / tiling	bump-bonded multichannel, slim edge under verification for SDDs	2024?
SDD	HERMES	nanosat constellation for GRB localization	integration undergoing	2023
Strip Detector	PairedX	spectroscopic strip detector for portable angle-energy resolved XRD	optimization of packaging and read-out towards market	2023
SDD	Scarlet	monolithic multipixel SDD for high-rate applications (synchrotron, XFEL)	multi channel ASIC delopment and integration, charge sharing mitigation	2023
CCD	PANDORA	Pin-hole CCD system for single photon counted spectrally-resolved imaging in high dynamical range	Simultaneous time- and space-resolved spectroscopy by shutter/trigger systems & 3D tomography by multi-CCDs system	2023-2024
SDD	PANDORA	SDD for soft X-ray volumetric spectroscopy	Adaptive collimators for high flux operation mode & model improvement to link experimental information to plasma parameters	2023-2024
HPGe detector	PANDORA (& GAMMA Coll.)	Array of 14 HPGe for hard X-ray volumetric spectroscopy & in-plasma β-decaying isotope tagging	High rate capability (> 50 kHz) by new and advanced electronics and acquisition systems	2024-2025
CCD	PANDORA	Diffractometric X-ray spectroscopy with high energy resolution (Δλ/λ = 10-3 at 565 eV) by the use of curved crystals and gratings	XRF peak broadening measurements and fluorescence shift to indirectly measure the plasma ion temperature and charge state	2024-2025

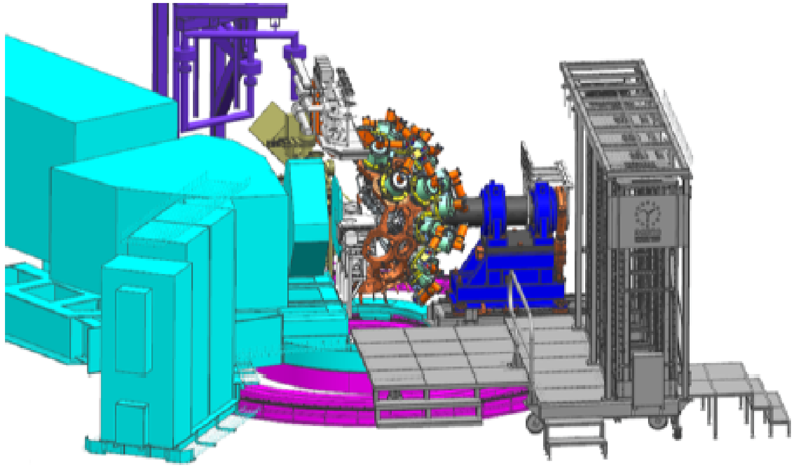
Gamma ray detectors

Walter Raniero

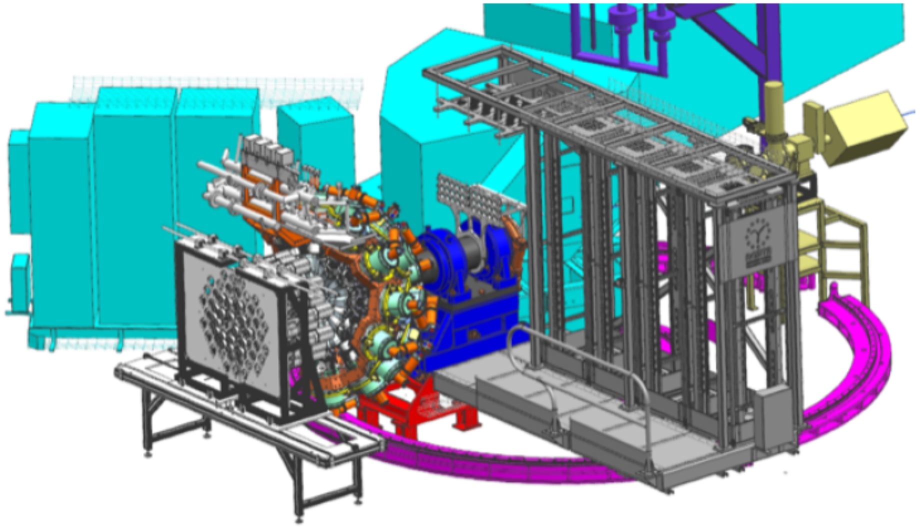
INFN-LNL

AGATA (Advanced GAmma Tracking Array) at LNL-INFN

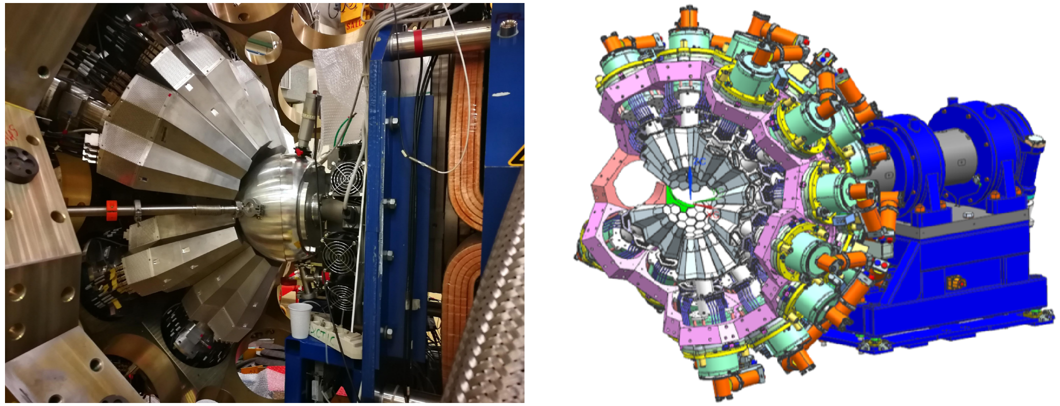
Actual configuration AGATA couple with PRISMA



R&D of new configuration AGATA at 0° is just started and we can have in the second half of 2024

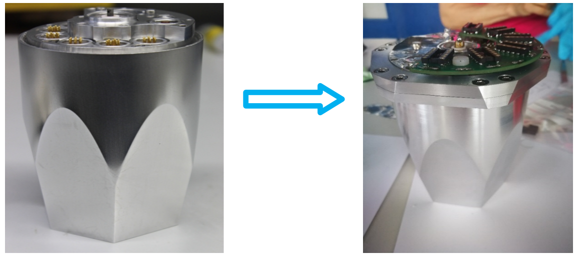


13 / 27 ATCs installed (27 ATCs end of 2025 Mirion and CTT)



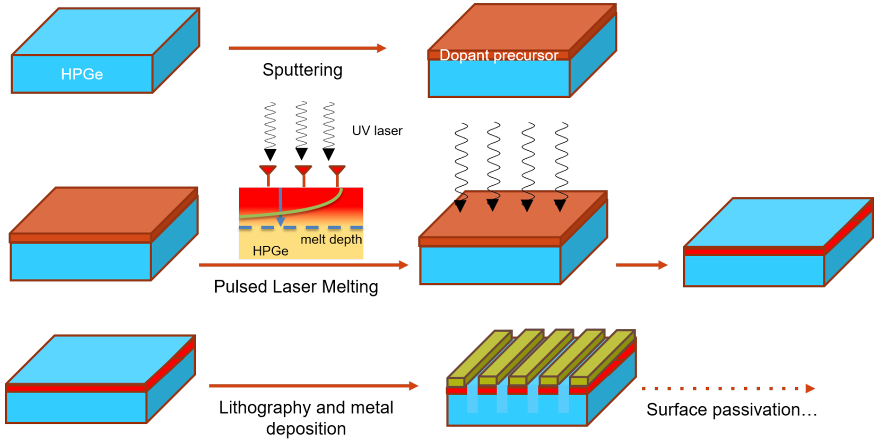
n-HPGe encapsulated detector

OLD NEW



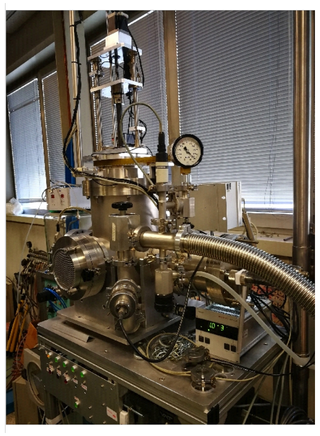
N3G (Next Generation Germanium Gamma Detectors)

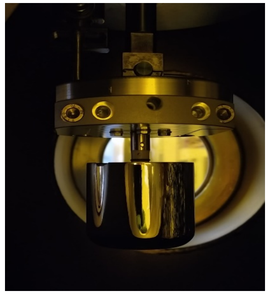
New HPGe detector using a new doping technique: **pulsed laser melting** 200-300 nm junction for n+ and p+ side without bulk contamination

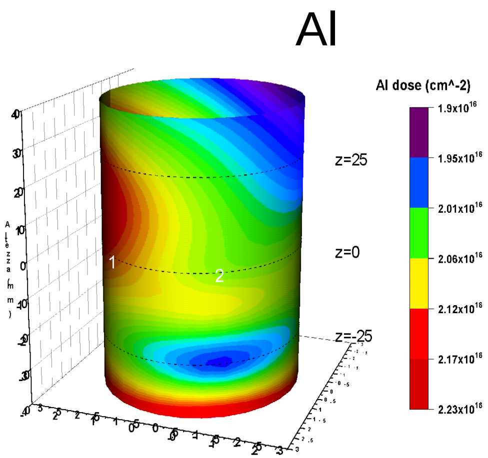


1. Planar detector prototype
2. Coaxial geometry upgrade

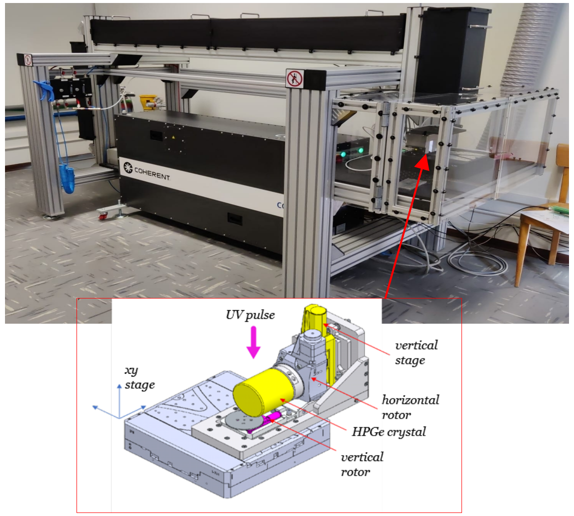
Magnetron Sputtering on coaxial HPGe crystal at LNL

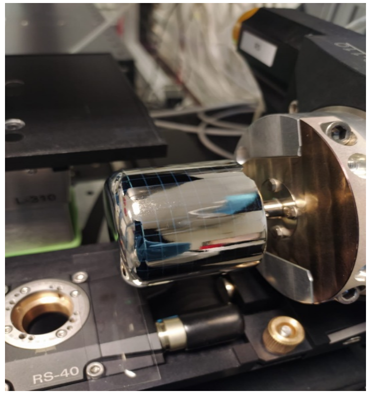






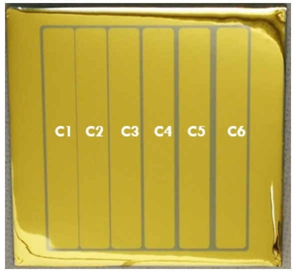
PLM technology (UNIPD - LNL)





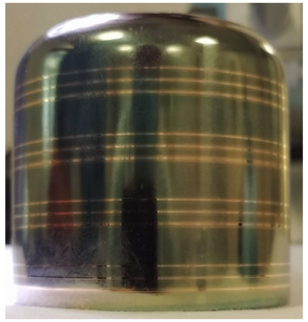
N3G (Next Generation Germanium Gamma Detectors)

Lithography for segmentation



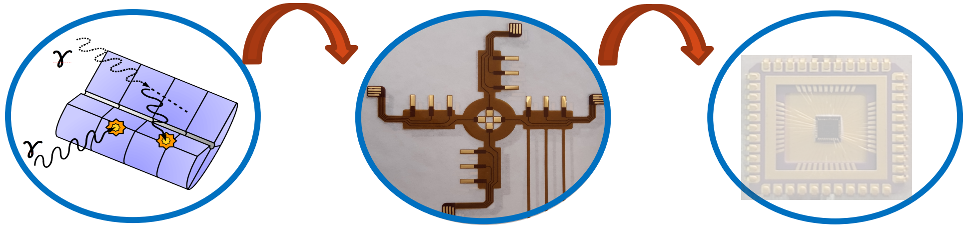
Planar geometry

3D lithography system



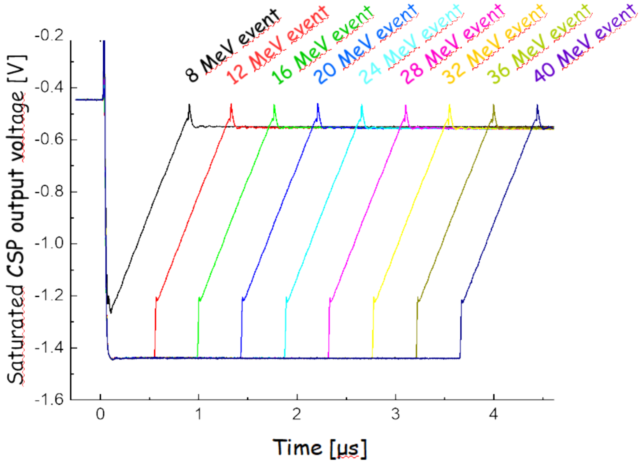
Coaxial geometry (2023)

ont End Electronics for HPGe coaxial & segmented detectors



flexible PCB

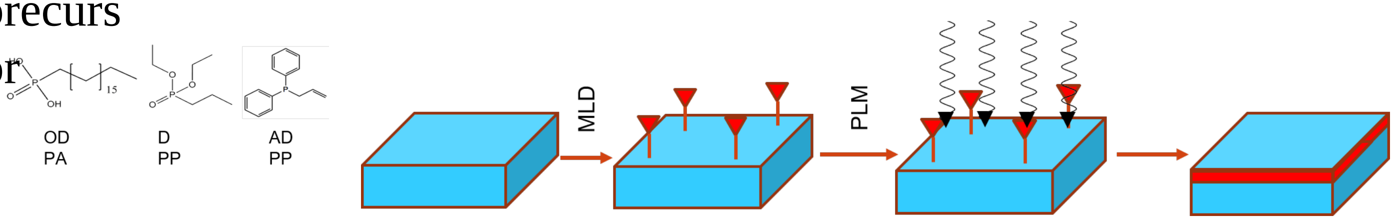
ASIC (Applied Specific Integrated Circuits)



6 mW power consumption
8 MeV dynamic range up to 40 MeV thanks to an innovative fast reset circuits (2024)

Monolayer doping: future for detector junction

precurs or

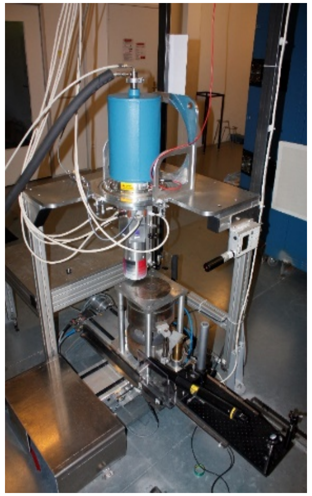


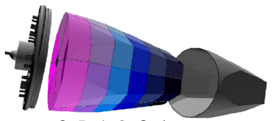
This doping method has a conformal deposition and can be wiil apply to 3D shape (coaxial detector)

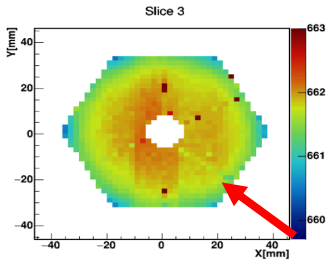
R&D to scale up to large area, and the surface chemical stability (2027)

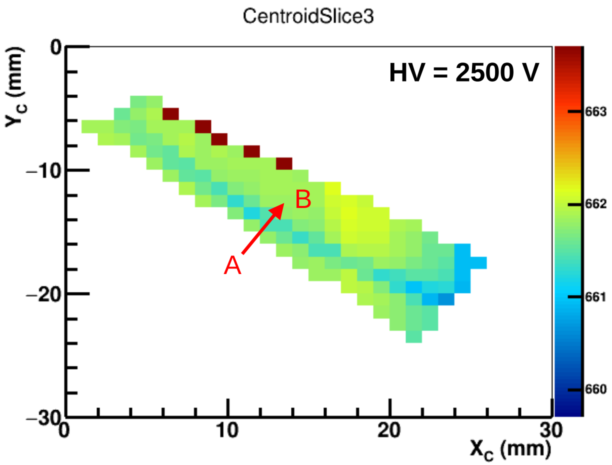
AGATA crystal characterization

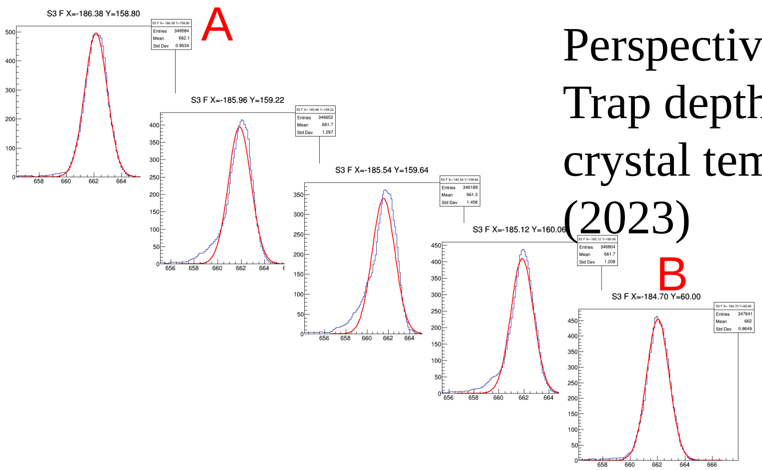
Study the electron trapping related to the energy peak shift









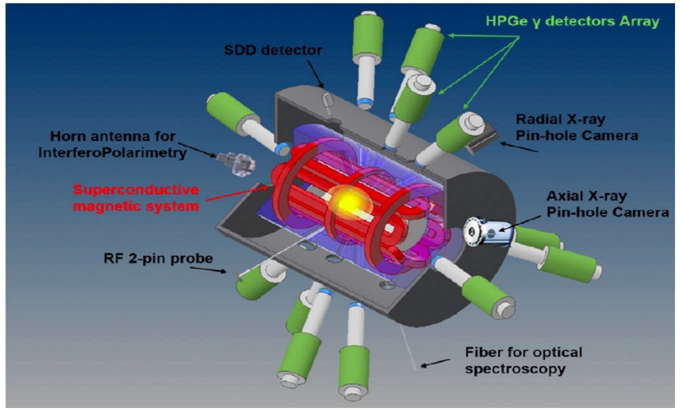


Perspectives:
Trap depth - scans vs crystal temperature (2023)

IPHC Scanning table
^{137}Cs source (662 keV)

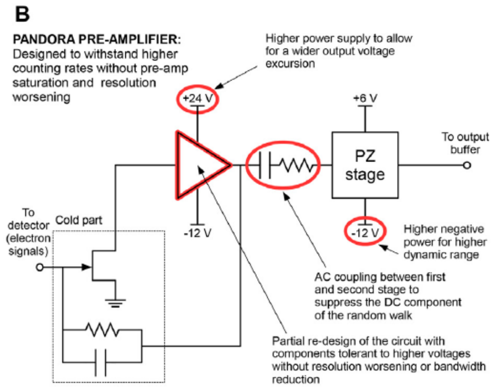
100 μm pitch
1 mm diam collimator
R ~ 15.6 mm

PANDORA (Plasmas for Astrophysics, Nuclear Decay Observation and Radiation for Archaeometry)

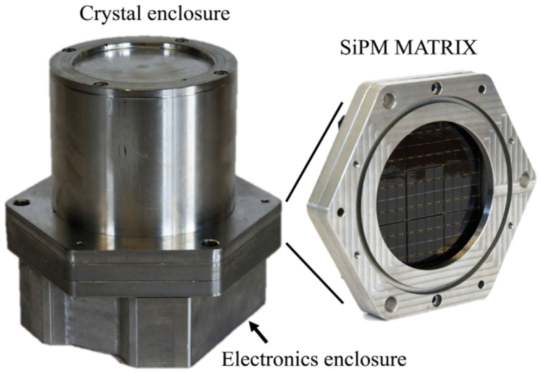


Measure, for the first time in plasma, nuclear beta-decay rates of radionuclides involved in nuclear-astrophysics processes.

- An array of 14 HPGe detect the emitted γ-rays (high counting rate up to 50 kHz on each detector).
- A new lab to store, repair and perform the maintenance of detectors in collaboration with LNL (2024).

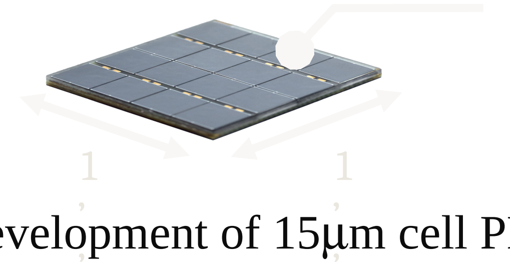


LaBr3:Ce:Sr + SiPMs scintillator



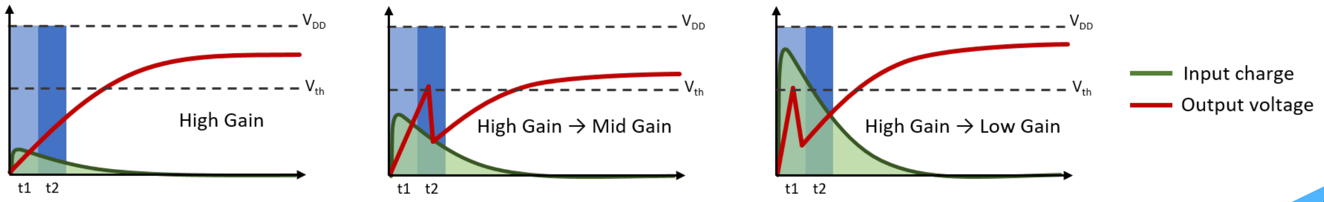
FBK NUV-HD SiPMs

16 SiPM per tile



New development of 15μm cell PDE (2024)

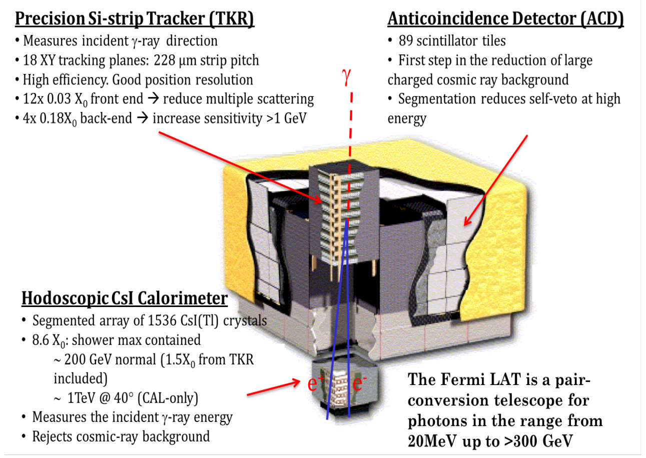
GAMMA ASIC: Adaptive Gain Control (AGC)



30keV – 30MeV energy dynamic range

Improve the time resolution ≈ 2.5 ns

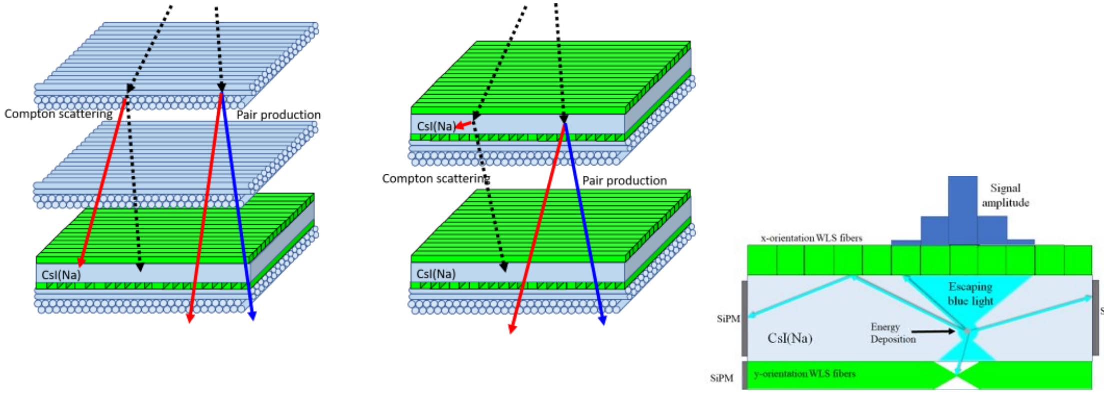
FERMI-GLAST
(Gamma-ray Large Area Space Telescope)



From 2008 FERMI GLAST is used for gamma detector in space

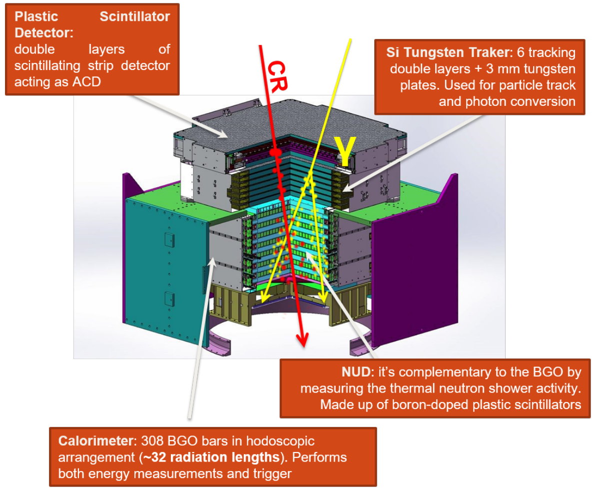
APT start test from 2025 (balloon flight south pole)

APT (Advance Particle Telescope)



Compton scattering , γ < GeV

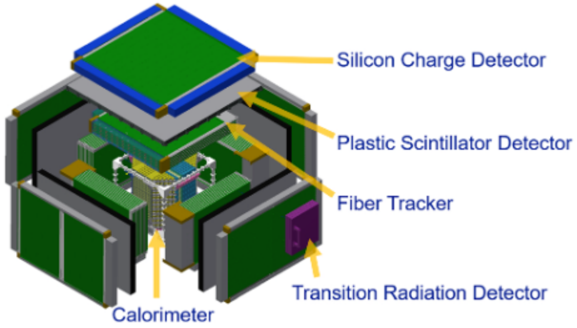
DAMPE (DArk Matter Particle Explorer)



From 2015 DAMPE is dedicated to the detection of dark matter (DM) in space and astrophysical studies

HERD 2027

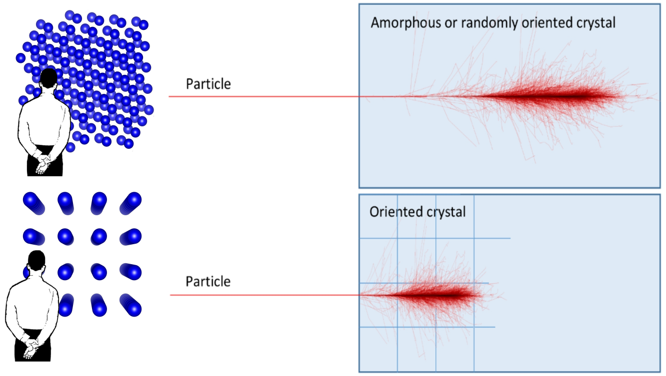
HERD (High Energy Cosmic Radiation Detection)



LYSO (Cerium doped Lutetium) 55 radiation lenghs

γ (10GeV ÷ TeV)

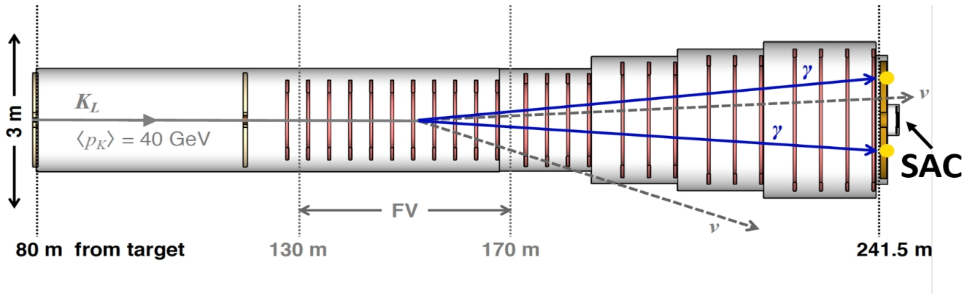
OREO (ORiEnted calOrimeter)

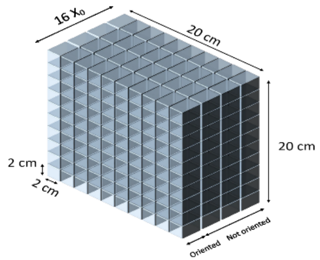


γ (some GeV to TeV)

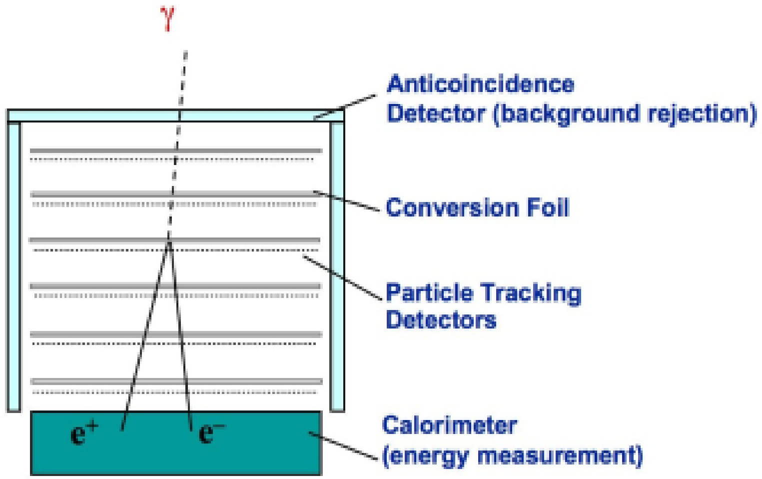
Reduction of the radiation length X_0 in comparison with amorphous media.
The volume/weight is reduced, space application

KLEVER is a proposed experiment at CERN SPS to measure $K_L \rightarrow \pi_0 \nu\nu$





FERMI - LAT



Challenge:
- Scaling to a large calorimeter
- **The KLEVER SAC ready for 2027**

- tracker length from W amorphous foils with crystalline W, improvement of the spatial/angular resolution
- oriented scintillator higher energy sensitivity above few GeV with a reduced volume/weight

Detector	Sigla	Description	Critical items for R&D	Expected Time
HPGe	AGATA	AGATA campain at LNL	- New detector and cryostat production (MIRION and CTT) to rich 27 ATCs with AGATA at 0°	2025
HPGe	N3G	R&D on PLM junction on future HPGe detector	- PLM and lithography on coaxial detector - ASIC electronic test on going - Monolayer doping: R&D to scale up, surface chemical stabilty	2023 2024 2027
HPGe	AGATA crystal	Agata crystal characterization	- to be going, the scannig require long time - Trap depht – scan vs crystal temperature (cryostat upgrade)	2023
$LaBr_3$:Ce:Sr	GAMMA	Gamma ray time resolution	- SiMPs 15mm cells upgrade from FBK to improve PDE - new ASIC (AGC) to improve time resolution $<$ 2.5ns (funds)	2024
HPGe	PANDORA	measure β-decays of nuclear astrophysical interest	- infrastructure (cooling LN2 system, new lab to maintenance and repair 14 HPGe detector) - modified electronic at high counting rate for 14 HPGe detector	2024 2023
CsI(TI) LYSO / CsI(Na)	FERMI_GLAST APT	telescope for gamma detection	- SiMPs array APT development with FBK	2025
BGO	DAMPE	dark matter particle and cosmic ray explorer	- R&D HERD telescope	2027
PWO - UF	OREO	gamma oriented crystal calorimeter	- orientated crystal matrix, scale up to large calorimeter - KLEVER SAC experiment	2025 2027

Numbers of the sub_WG Gamma Detector:
28 subscription to the WG
12 active participants
9 technologies
7 locations

Thanks to all the contributors for their involvement and active participation

- Davide De Salvador UNIPD & LNL-INFN
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- Chiara Carraro LNL-INFN
- Stefano Capra MI-INFN
- Gilbert Duchene IPHC – Uni. STRASBOURG
- Francesco Sgarbossa UNIPD & LNL-INFN
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- Laura Bandiera FE-INFN
- Walter Raniero LNL-INFN

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