HPGe X-ray detector performance at MIRION

M.Ginsz, V.Marian, D.Ralet, J.Masseron, G.Ilie

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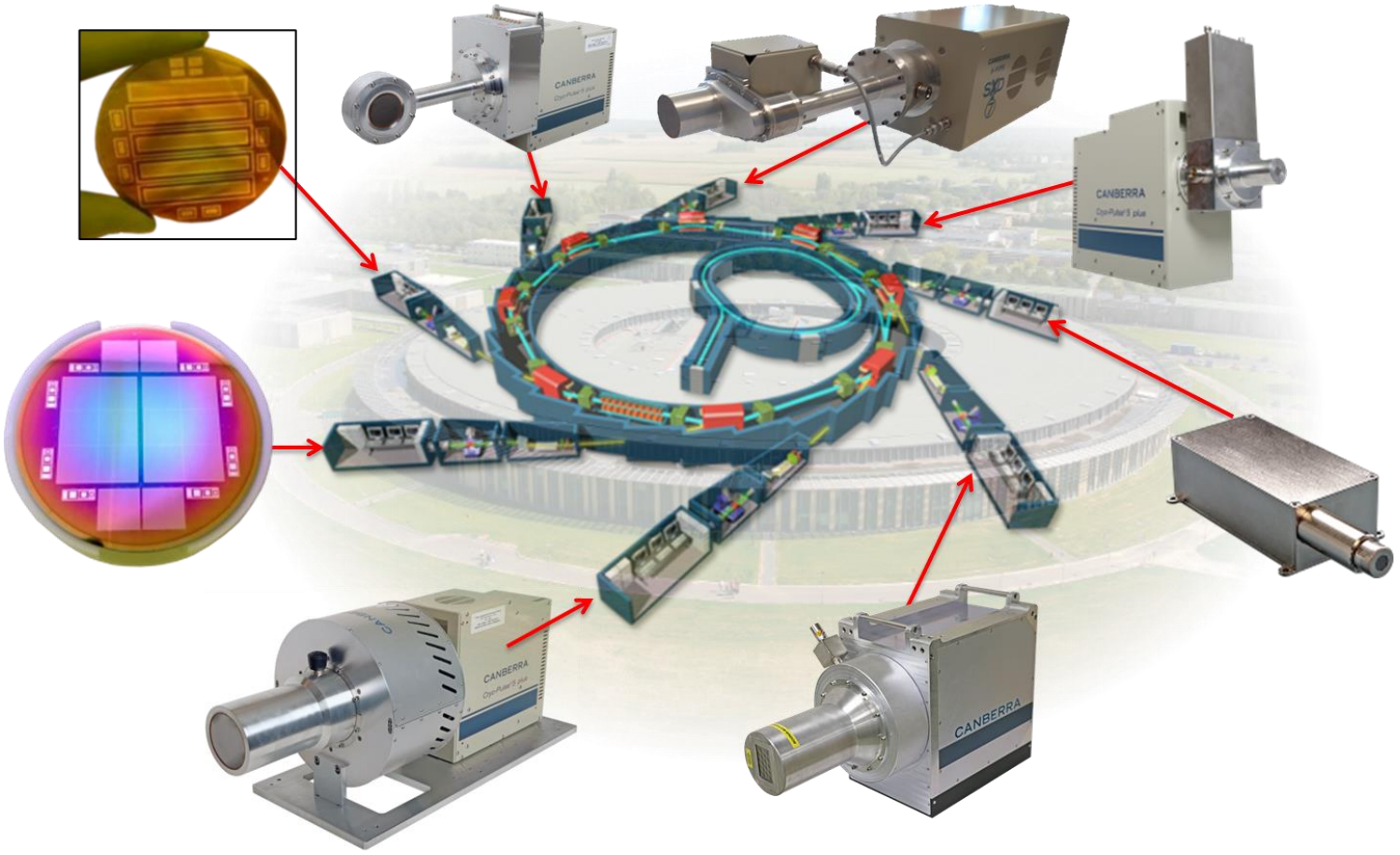
MIRION TECHNOLOGIES

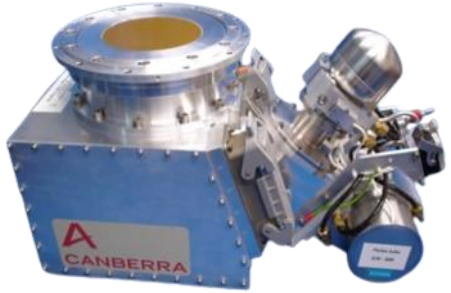
MIRION complete offer for Synchrotrons

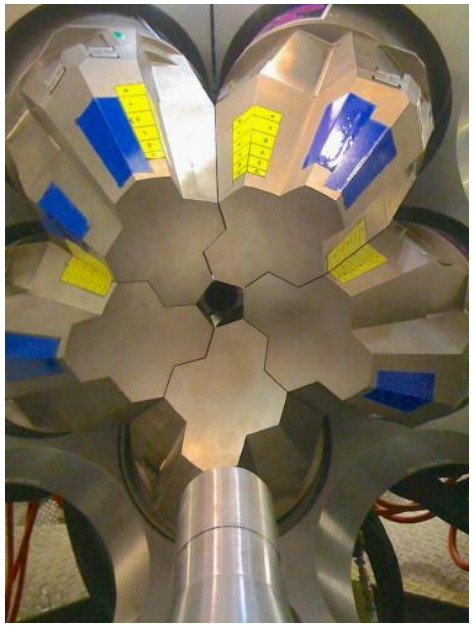
- **Spectroscopy**
  - Silicon: X-PIPS, SDD (Si drift diodes) – single or multichannel
  - HPGe: single or multichannel
- **Imaging**
  - Strip detectors: single side segmented detectors or double side segmented detectors (DSSD)
  - Finely pixelated detectors, down to a micrometric pitch

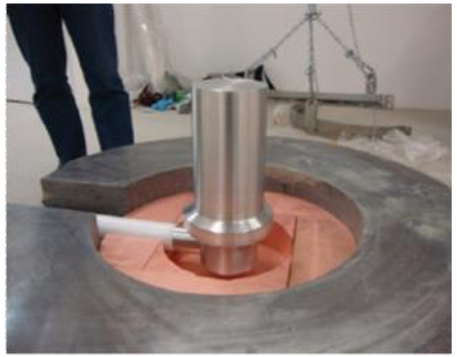


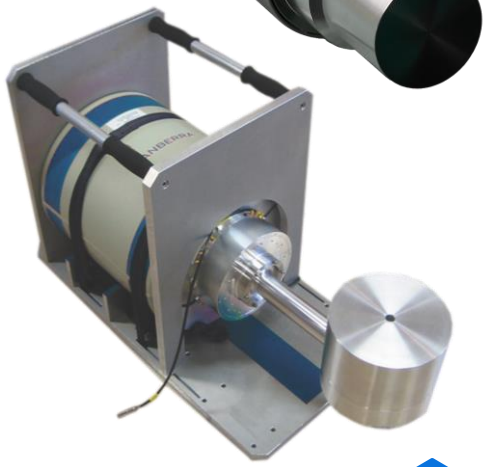
MIRION Specialty HPGe detectors

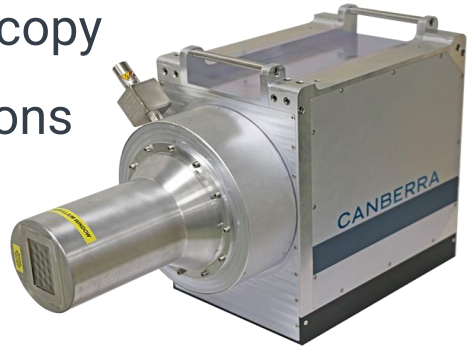
- More than 50 years in expertise manufacturing HPGe detectors from standards to specialty solution
- Covering several fields of application
  - Fundamental nuclear research
  - Ultra-low contamination counting labs
  - **X-Ray Fluorescence**
  - OEM solutions
  - In-situ spectroscopy
  - Space applications











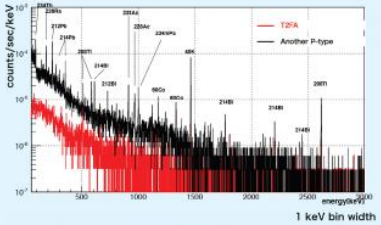
Ultra Low Background detectors

10^{-5} ct.s^{-1}.cm^{-1}
40-2700 keV range

DETECTOR PERFORMANCE

- Typical energy resolution
- Efficiency and well size configuration
- Background achieved with various detector in different underground lab around the world

BG spectrum



Background spectra obtained for S-ULB coaxial detector [4]

EGMP 80-30 with double preamplifier (AC and DC) with ISOCS characterization

400CC P21 SAGeWell detector made with copper [4]

Material selection and screening of components to reduce mass and intrinsic background of critical components:
- Electronics components
- Soldering material
- Cable
- Screws

Metal selection: aluminum and/or copper with 0.1 ppb U+Th

Isocs characterization available

Electrically cooled detector

Specific configuration : double preamplifier

SPECIALTY ULTRA-LOW-BACKGROUND DETECTOR

Cryostat design with various possibility:
- Arm length
- Detector head configuration
- Crystal size and diameter
- Multi germanium detector configuration
- Electrically segmented crystal

HPGe crystal selection to reduce cosmogenic activation with underground storage 700 mwe and no plane transportation

Underground cave near Lingolsheim

EGMP 100-35: large diameter crystal in S-ULB cryostat with Carbon entrance windows

Detector array[1] operated by CUP, IBS. Image copyright CUP, IBS, 2017.

SAGeWell detector installed inside a lead castle

MIRION TECHNOLOGIES

Mirion Technologies (Canberra) SAS.
1 Chemin de la Roseraie Parc des Tanneries
Lingolsheim Alsace 67380 France
www.mirion.com

SELECTION OF S-ULB DETECTOR PERFORMANCES

Detector	Crystal size (mm)	Weight (kg)	Location Lab	122 keV FMHM (keV)	1332 keV FWHM (keV)	Background 40 to 2700 keV (counts per kg per day)
EGMP 90- 30 BeGe detector	90 x 30	1,03	Boulby	0,63	1,73	150 [2]
EGMP 90-33 BeGe detector	90 x 33	1,13	SURF	0,61	1,75	X
EGMP 100-35	100 x 35	1,48	CANADA	0,66	1,72	X
P21 400CC Well detector	80 x 85	2,13	Canfranc	0,69	1,91	640 [5]
P21 400CC Well detector	80 x 85	2,13	Modane	0,74	1,87	505 [3]
P21 250 CC Well detector	80 x 63	1,33	HADES	0,68	1,88	795 [6]
EGPC 80-185 P-type Coaxial detector	75 x 73	1,68	KAMIOKA	0,85	1,9	115 [4]
EGPC 120-215 P-Type coaxial detector	84 x 84	2,44	CHINA	0,93	1,98	X

REFERENCES

[1] D.S. Leonard et al. NIM A 989 (2021) 164954
[2] Courtesy P.R. Scovell, STFC Boulby underground Laboratory
[3] Courtesy P. Sabatier, University Savoie Mont Blanc
[4] Courtesy K. Ichimura, Tohoku University
[5] Courtesy G. Zuzel, Jagiellonian University
[6] Courtesy M. HULT, JRC-Geel

HPGe detectors for X-ray applications

TYPICAL VALUES

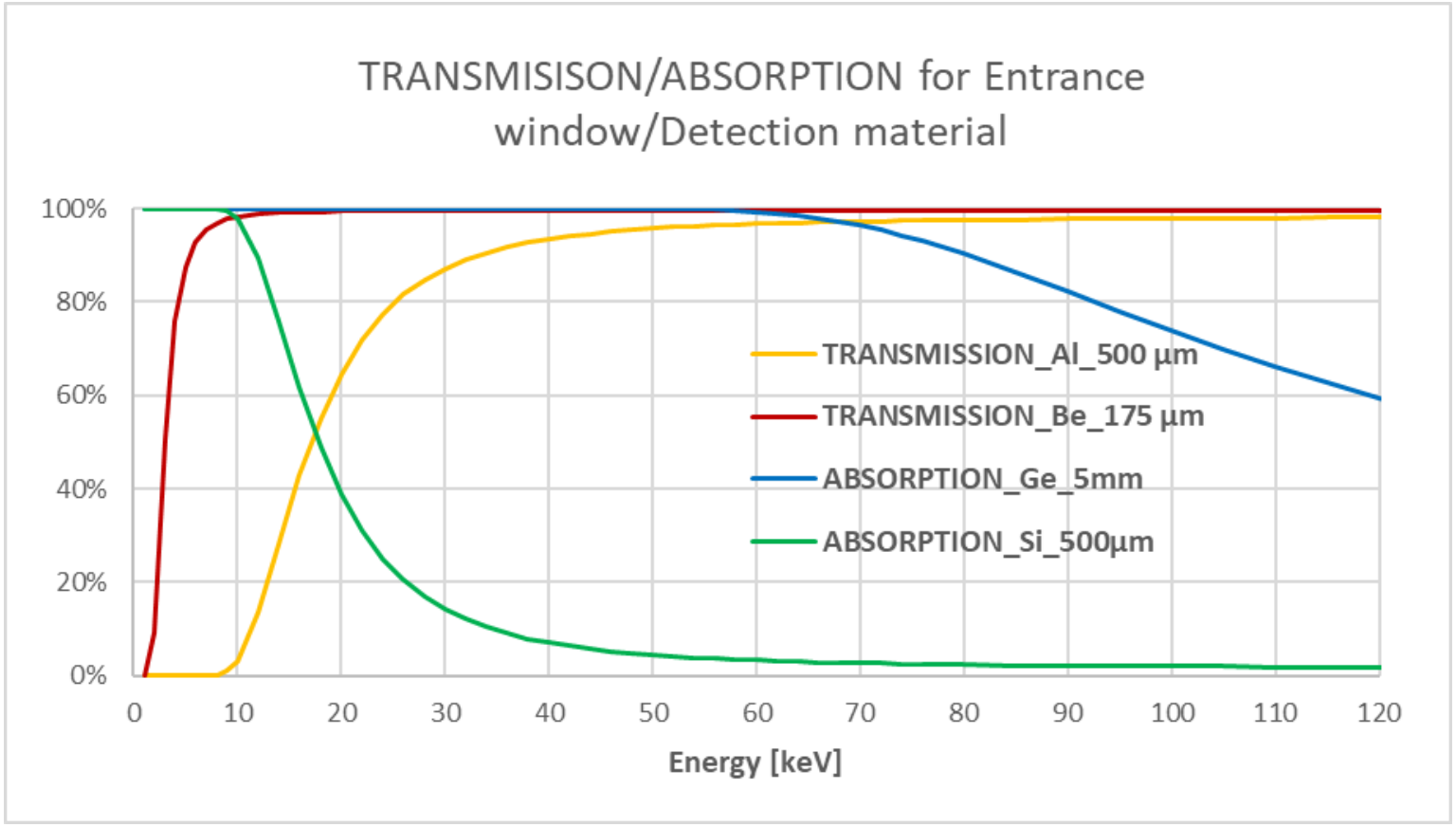
- HPGe detection material
  - Thickness: typical 5 to 15 mm
  - Energy range: from 2 up to 200 keV
  - High Voltage bias: up to 2 kV
  - ELEMENTS: Typical **50mm²** – **450mm²** up to 1200 mm²
  - MONOLITHIC SEGMENTED: typical 64 mm²
- Cryogenic cooling required -185°C: CP5-Plus cryocooler
- Entrance window: Beryllium OR Aluminum for energies higher than ~20 keV
- CMOS Electronics
  - Up to several million count per seconds
  - Dedicated readout electronics to sustain such high count-rates

Basic decision criteria HPGe vs. SDD

EFFICIENCY

- What is the energy range of the physics to be done ?

Energy range	Best efficiency
< 10 keV	SDD
10 - 20 keV	SDD HPGe with Beryllium entrance window
> 20 keV	HPGe with Aluminum entrance window HPGe with Beryllium entrance window ++



MITIGATION

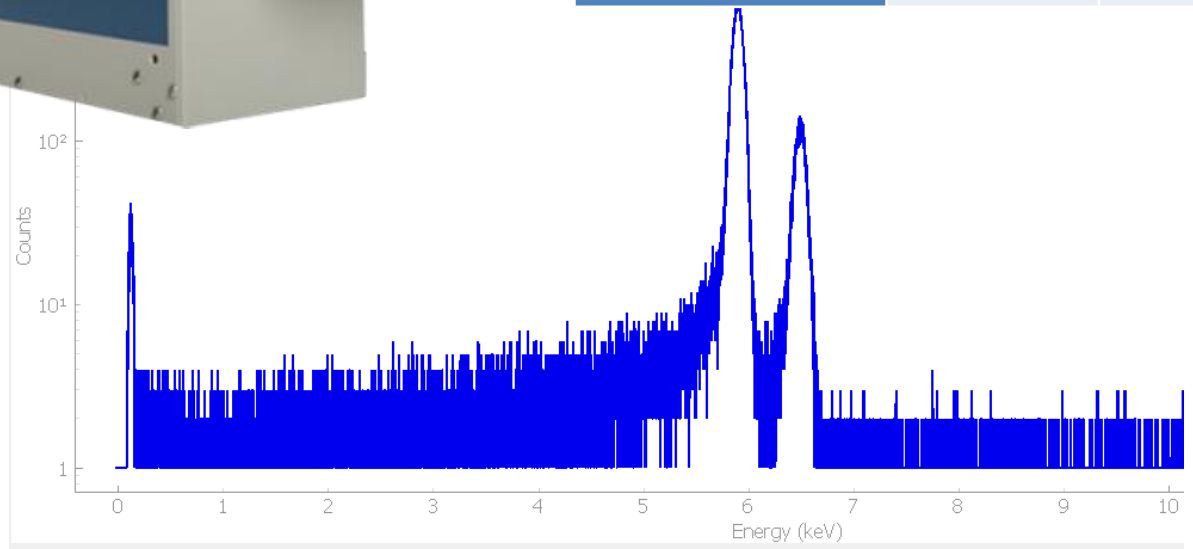
- 11 keV X-ray emission line of Ge
- SDDs have superior Peak-to-Valley ratio for Fe55

Single Element

- Single cristal / single channel detector
  - 50mm² (Ø 8mm) – 5mm thick
  - 200mm² (Ø 16mm) – 10 mm thick
  - 500mm² (Ø 25mm) – ≥ 10 mm thick
  - Larger version possible
- Low fluorescence Aluminum cryostat
- Optional
  - Be / Al / Windowless
  - CP5-plus electrical cooler
  - Water chiller
- Electronics fast CMOS preamplifiers

Demo Detector available

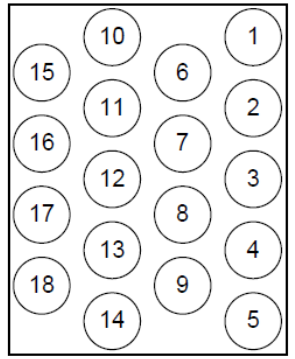
Energy resolution	Typical	Guaranteed
1000 cps 6µs shaping time	< 120 eV	< 130 eV
100 000 cps 0.5 µs shaping time	< 120 eV	< 145 eV
100 000 cps 0.1 µs shaping time	< 150 eV	< 170 eV
1 000 000 cps FalconX or xspress3 mini	< 175 eV	< 190 eV



Multi-Element

- 18 element detector
- Active area for each element: 50mm² (8mm diam)
- Active thickness: 5mm
- Low fluorescence Aluminum cryostat
- Be window thickness 50µm
- CP5-plus electrical cooler
- Water chiller
- Ion pump
- Electronics fast CMOS preamplifiers

Element	FWHM at 5.9 keV in eV			
	3-6 µs / 1kcps (≤ 140 eV)	0.5 µs / 100kcps (≤ 160 eV)	0.1 µs / 100kcps (≤ 200 eV)	1Mcps (≤ 250 eV)
1	124	142	165	190
2	113	135	166	193
3	125	145	160	181
4	122	150	188	215
5	125	141	163	186
6	122	147	172	190
7	121	144	159	184
8	126	147	176	201
9	132	134	168	205
10	121	141	167	194
11	122	136	168	193
12	120	134	158	178
13	130	137	166	185
14	123	144	165	193
15	131	156	200	231
16	128	138	152	171
17	118	130	152	182
18	117	130	159	188



Monolithic Pixelated

- Total active area : 48mm x 48mm
- Active thickness: 7mm
- Segmentation: 36 pixels / 25 / 16

31	25	19	13	7	1
32	26	20	14	8	2
33	27	21	15	9	3
34	28	22	16	10	4
35	29	23	17	11	5
36	30	24	18	12	6

Detector front view

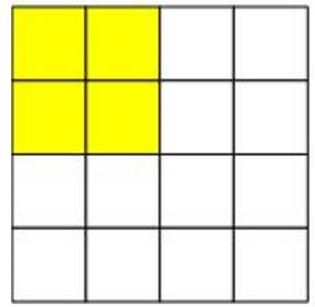
- Low fluorescence aluminum cryostat
- CP5-plus electrical cooler
- Be window thickness 175µm
- Collimator: Titanium alloy with 100µm Al coating
- Electronics fast CMOS preamplifiers

FWHM AT 5.9 KEV

PIXEL	1 KCPS < 160 EV	100 KCPS < 230 EV	PIXEL	1 KCPS < 160 EV	100 KCPS < 230 EV	PIXEL	1 KCPS < 160 EV	100 KCPS < 230 EV
1	154	189	13	146	175	25	151	184
2	147	192	14	142	176	26	143	188
3	146	178	15	145	185	27	147	188
4	150	176	16	150	188	28	154	209
5	153	187	17	157	202	29	157	198
6	155	187	18	154	204	30	150	206
7	148	186	19	150	186	31	145	182
8	158	195	20	153	186	32	157	173
9	147	187	21	158	185	33	150	185
10	150	187	22	148	185	34	52	189
11	158	212	23	160	204	35	145	192
12	148	195	24	152	207	36	151	206

Pixel Next Generation

- Total active area : 36mm x 36mm
- Active thickness: 5 mm
- Segmentation:
  - Linear or squared arrangement
  - Pixels: 4x4 / 8x2 / 8x1 / 2x2



- Low fluorescence aluminum cryostat
- CP5-plus electrical cooler
- Electronics fast CMOS preamplifiers

Channel	Energy resolution Vs (energy / count rate / Gaussian shaping time)			
	6keV 1kcps 4µs [eV]	6keV 100kcps 0.5µs [eV]	60keV 1kcps 4µs [eV]	122keV 1kcps 4µs [eV]
1	124	125	329	483
2	119	128	341	487
3	117	126	328	472
4	126	134	340	483

Demo Detector available

Pixel Next Generation

- Copper Ka **– 8.1 keV**
- Measurement and tests performed at DLS
  - XPRESS4 readout

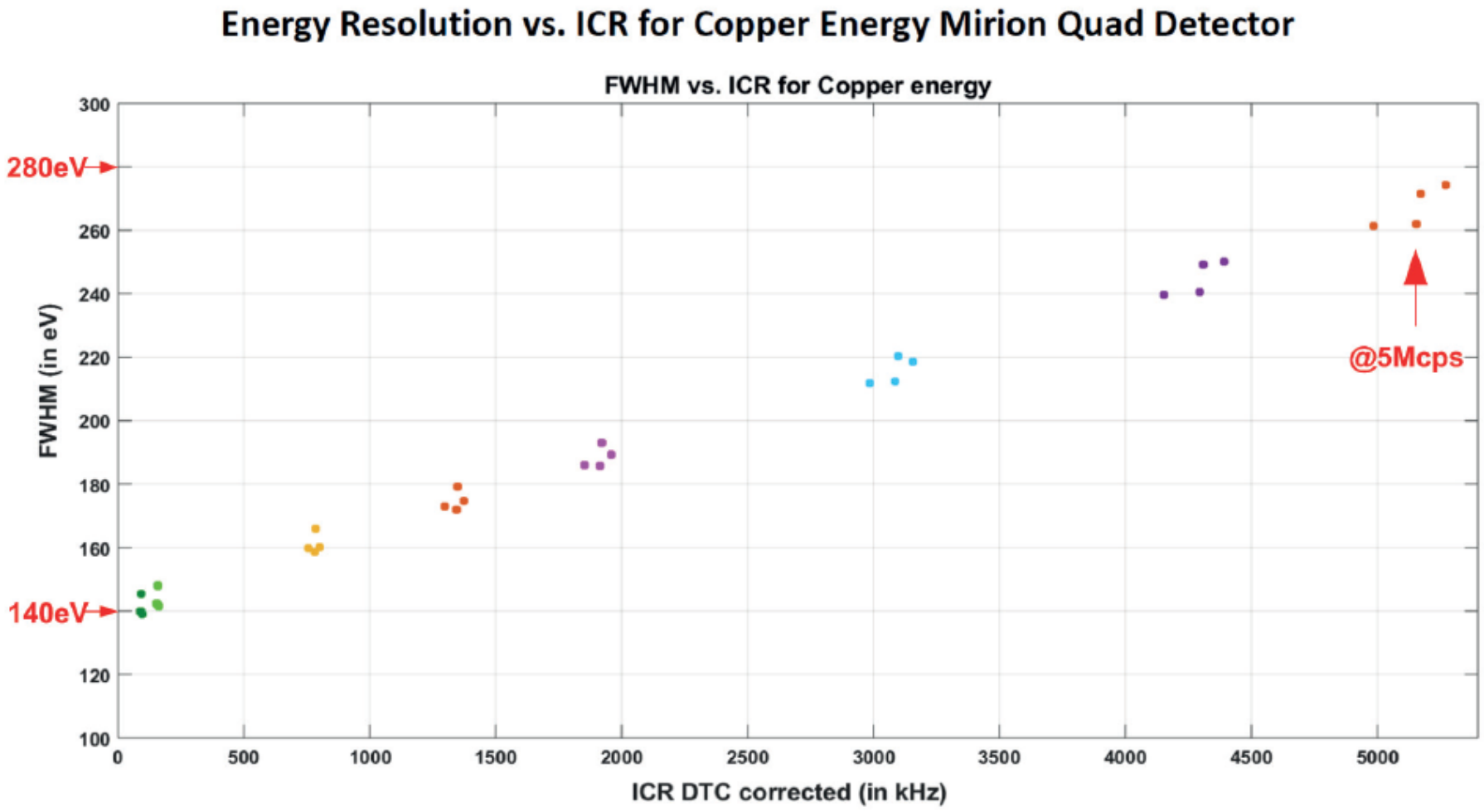


Figure by courtesy of Sudeep Chatterji & Nicola Tartoni, Diamond Light Source

Pixel Next Generation

- Zirconium Ka – **15.8 keV**
- Measurement and tests performed at DLS
  - XPRESS4 readout

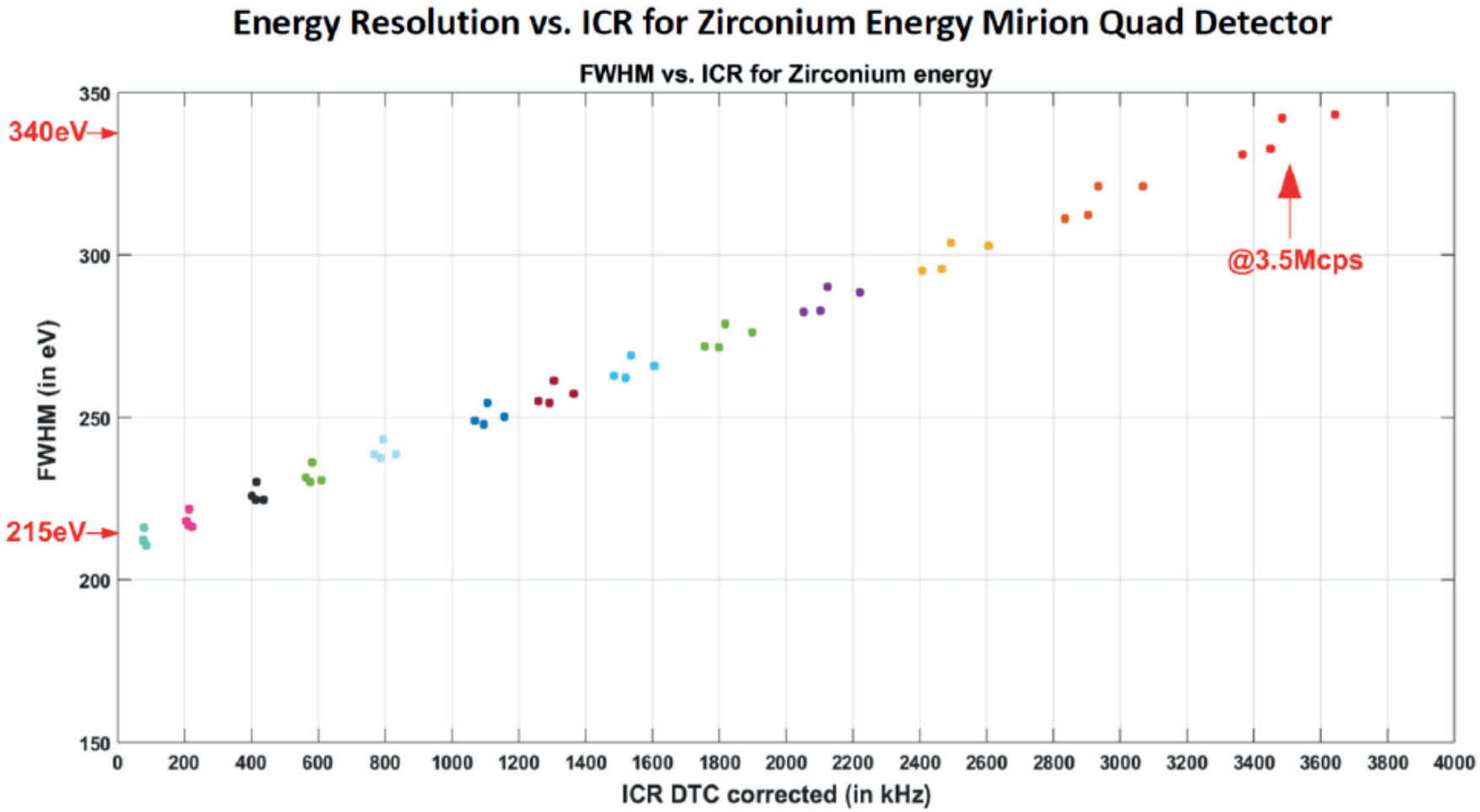


Figure by courtesy of Sudeep Chatterji & Nicola Tartoni, Diamond Light Source

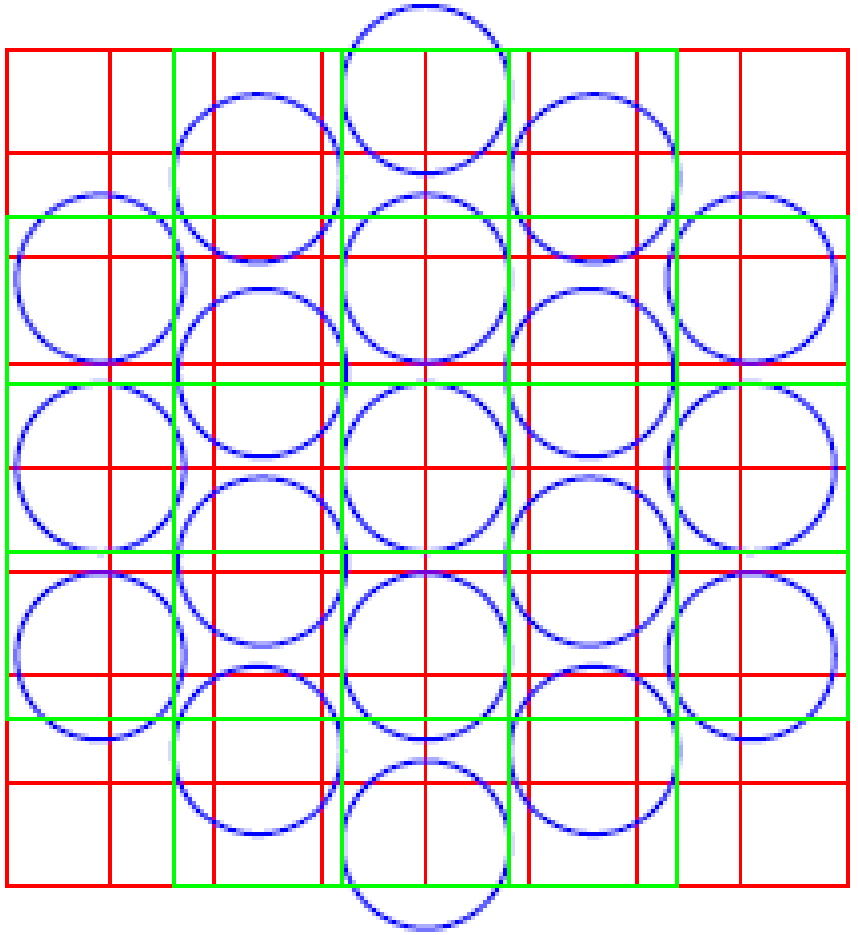
Monolithic Pixel vs. Multi-Elements detectors

Detector parameter	Monolithic pixels detectors	New generation pixels detectors	Discrete arrays
Energy resolution	Good	Best	Best
Peak to background	Good	Best	Best
Count rate capability	Good	Best	Best
Number of channels	Up to 100	Up to 16	Up to 24
Solid angle	Largest	Very good	Large surface Lower active coverage
Energy range	2 : 200 keV	2 : 200 keV (down to 0.3 keV)	2 : 200 keV (down to 0.3 keV)
Charge sharing	Mitigated (collimator grid)	None	None

Monolithic Pixel vs. Multi-Elements detectors

Solid angle Coverage

- 19 elements array
- 64 pixel – monolithic
- New generation pixel detector



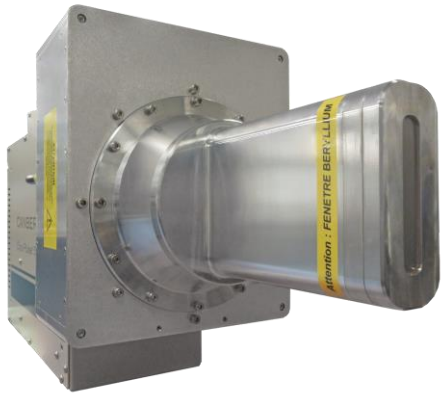
Custom configurations

Idea ?
Hybrid 8-element
4x SDD
4x HPGe

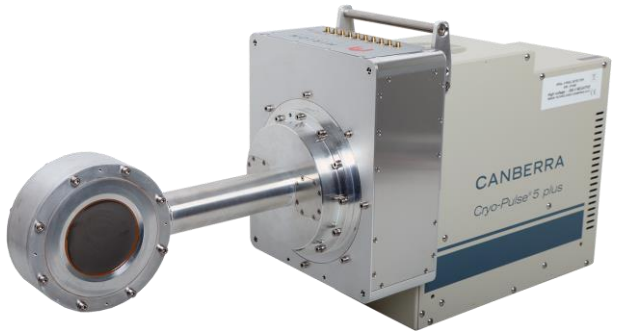
Windowless cryostats

- Gate Valve to open the cryostat to vacuum chamber
- Linear stage and bellow to move the HPGe inside the chamber

Elements arrangement



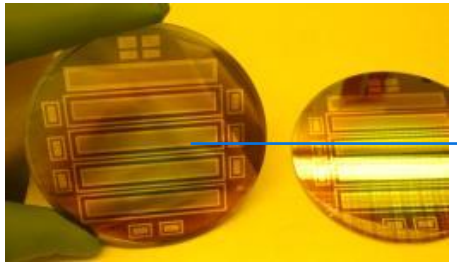
7-element linear

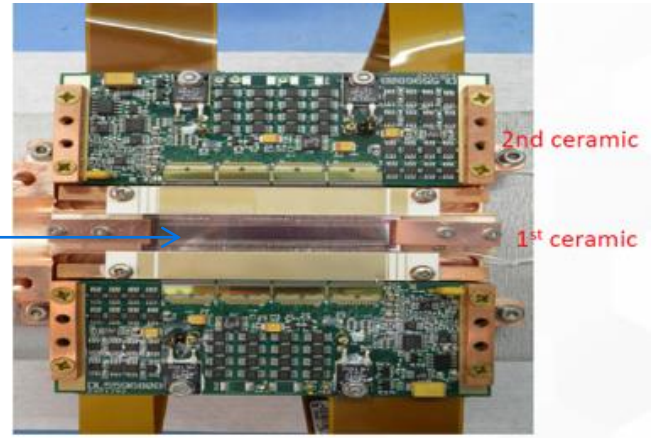


4-pix NG transmission cryostat

Wafers

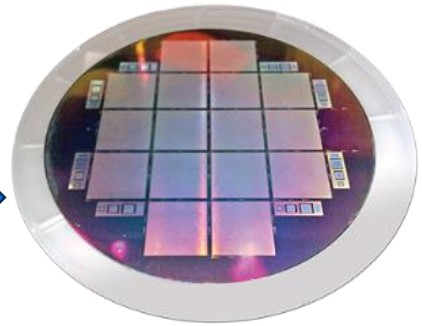
Segmented HPGe wafers

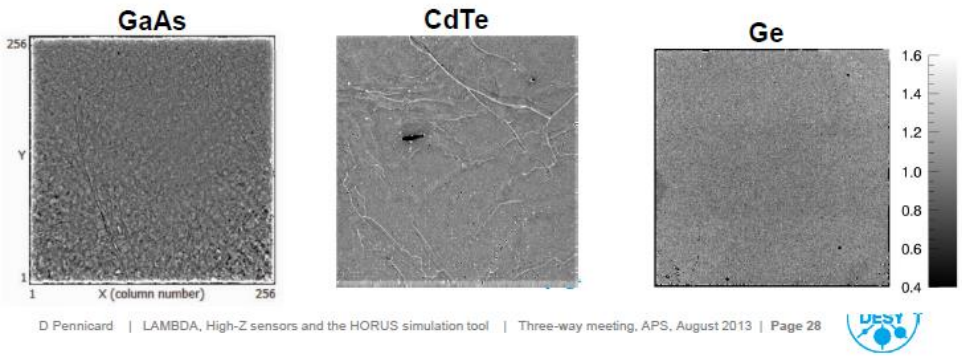




Some realisations

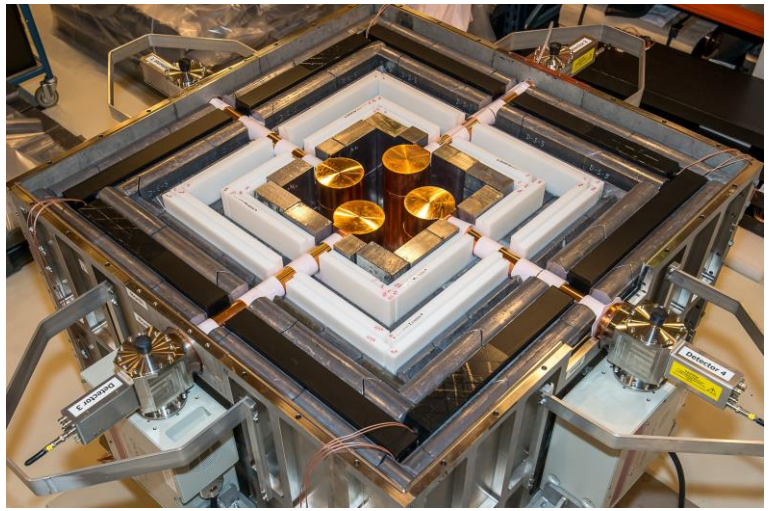
- Linear diffractor – 1024 strip – 50 µm pitch – 1mm-thick
- Medipix chip – 256x256 pix, 50 µm pitch – 1 mm-thick
- LEAPS – 10 segments pattern – 4mm-thick





Exotic detectors

https://en.wikipedia.org/wiki/CONUS-Experiment#/



Neutrino / Dark matter applications

High efficiency Point Contact detectors with best pulser resolution for Rare Events detection

- CMOS electronics for best low-energy threshold
- Large (2.4 kg) PPC detectors
- Radiopure: Ultra-Low background materials
- <80 eV FWHM test pulser with 2.4 kg crystal

Cnclusion & outlook

CONCLUSION

- Specialty HPGe detector solutions
- Large panel of existing solutions
  - Single channel
  - Arrays
  - Wafers – fine pitch
- Configuration customization

OUTLOOK – improve performances

- Mid-term : new HPGe consolidation
  - Better performances FWHM & high count-rates
  - Check for reproducibility & robustness
- Long-term R&D:
  - Crystals for Holes charge collection with faster risetime and improved high-energy performances

