DEGAS – a novel HPGe spectrometer for NUSTAR

I. Kojouharov, GSI, Darmstadt

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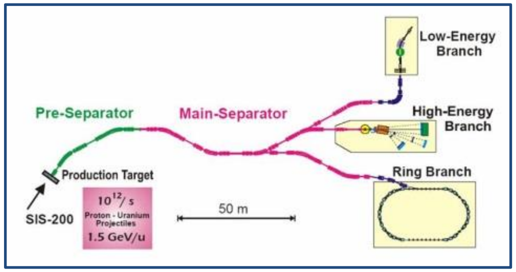
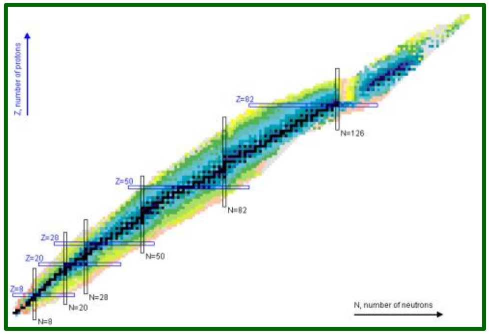
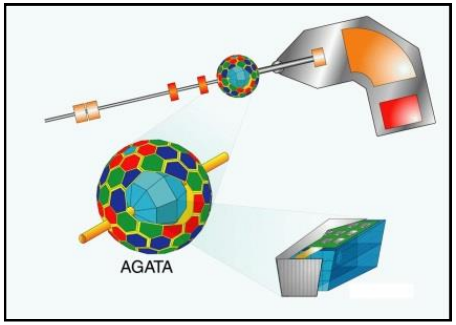
1. HISPEC/DESPEC at NuSTAR

Super FRS

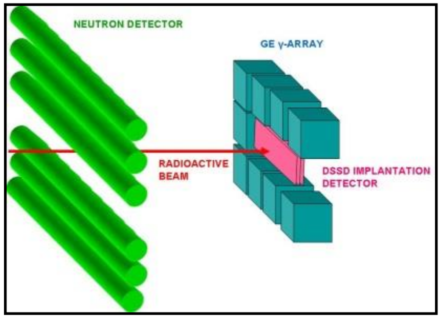




HISPEC (High-resolution In-flight SPECtroscopy)
Runs AGATA as the basic spectrometer



DESPEC (DEcay SPECtroscopy)
Runs DEGAS as the basic spectrometger



Collaboration of:

- Germany
- India
- Turkey
- Romania
- Spain
- Sweden
- UK
- Finland

DEGAS – a novel HPGe spectrometer for NUSTAR

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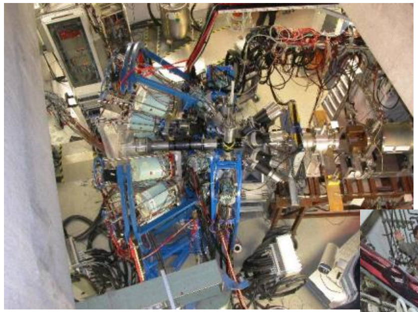
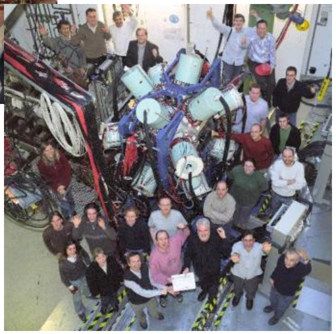
1. HISPEC/DESPEC at NuSTAR

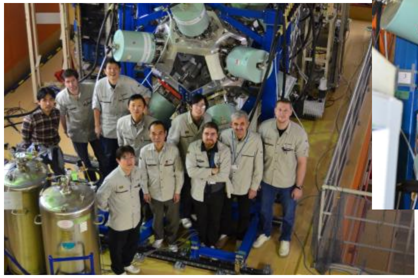
Predecessors: RISING 2003 - 2009





Cluster Detectors => DEGAS
CATE => LYCCA
Active stopper => AIDA
HECTOR => FATIMA

EURICA 2003 - 2009



DEGAS – a novel HPGe spectrometer for NUSTAR

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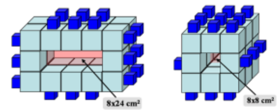
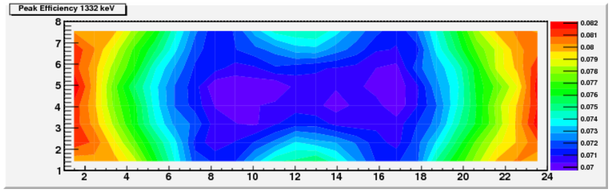
2. DESPEC setup

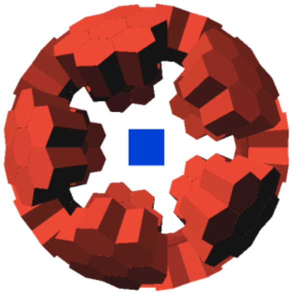
Extensive simulations have been done over the years in order to evaluate the efficiency and the overall performance of the HPGe detector array. Starting from a planar detector array…



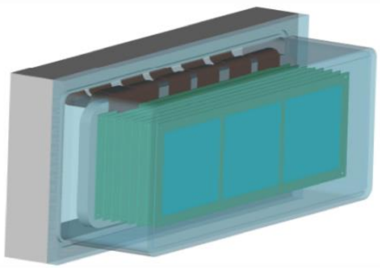


The planar array (2004) and the peak efficiency (2008)

Property	RISING	Phase I	Phase II	Phase III
Array type	Composite Ge detector array	Composite Ge detector array	Phase I complem. by γ-tracking dets.	γ-imaging array
Energy range (keV)	50-5000	50-5000	50-5000	50-5000
Noise threshold (keV)	24	15	15	10
Energy resolution (at 1.3 MeV)	2.3 keV	2.3 keV	2.3 keV	2.0 keV
Full energy γ-detection efficiency (at 1 MeV)	16%	16%	18%	>20%
Effective full energy efficiency after prompt flash blinding	13.9%	14%	16%	20%
P/T-value	34%	34%	40%	>50%
Time resolution (at 1.3 MeV)	13 ns	10 ns	10 ns	< 10 ns
Overload recovery time	≤ 1ms	100 ns/MeV	100 ns/MeV	100 ns/MeV
Relative background suppression	1	5	10	100
Coverable implantation area	16 x 8 cm^2	24 x 8 cm^2	24 x 8 cm^2	24 x 8 cm^2
Max. acceptable event rate (kHz)	3.5	10	10	10



RISING "stopped beam" configuration coupled with the short AIDA implantation detector.



The model of the AIDA implantation detector with its Al housing as considered in the simulations

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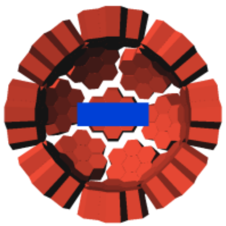
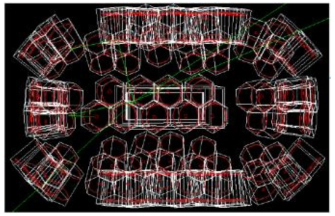
2. DESPEC setup

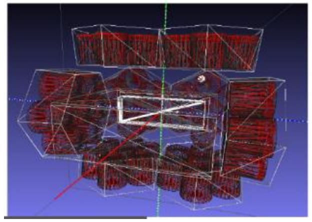
DESPEC setup definition. Based on EB encapsulated HPGe crystals detectors.



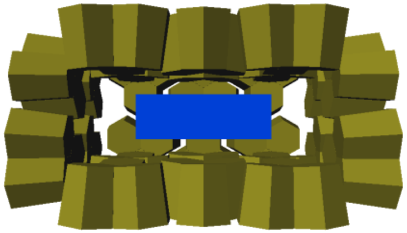
Half sphere
EB Clusters based

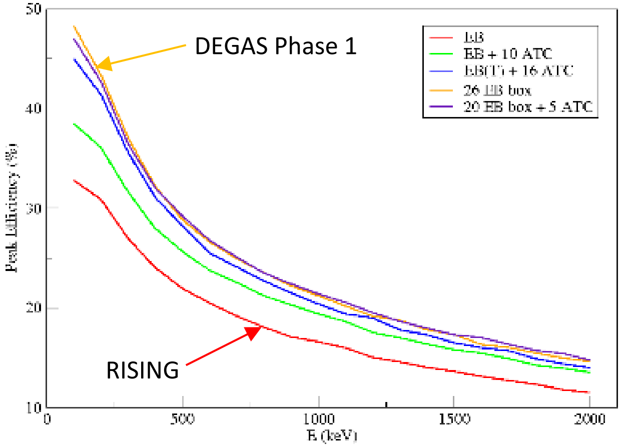


shell
Triples base



box
Triples based





The GEANT4 simulations have shown a substantial improvement of the efficiency when a box geometry adopted.

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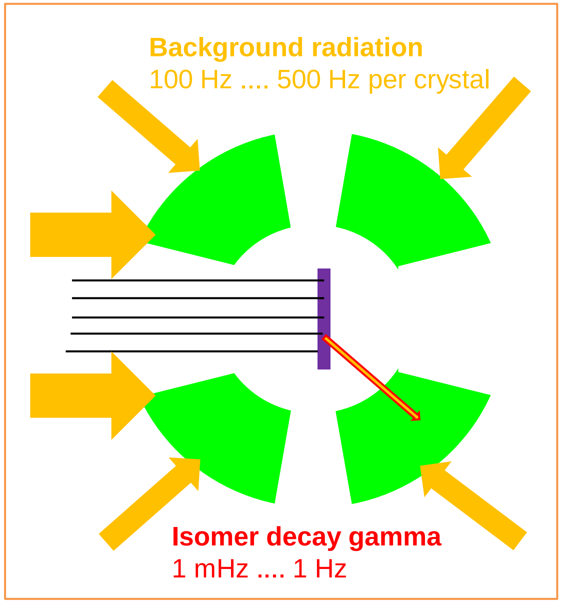
2. DESPEC setup

The background problem



The solution – use of active/passive shielding

EUROBALL Back-catcher element.

The refurbishing of the EB backcatchers – not realistic, a new design is proposed and is under realization.

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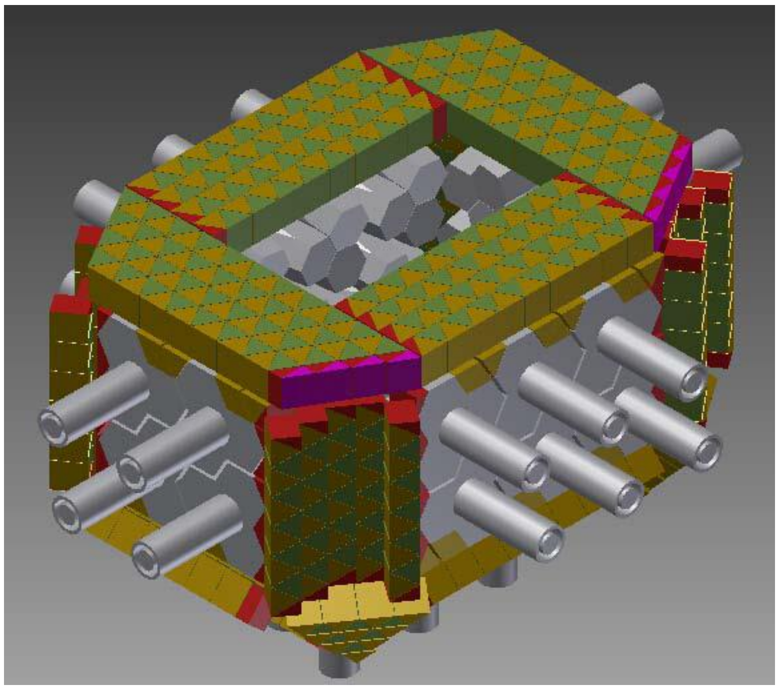
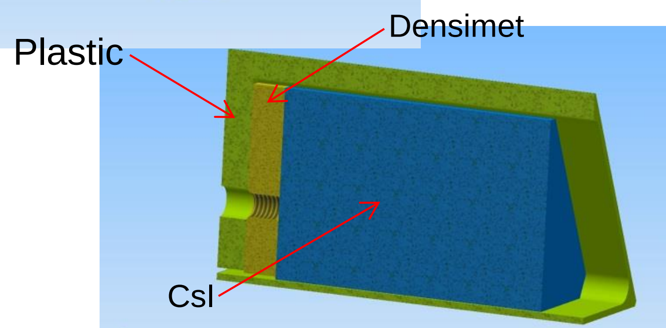
2. DESPEC setup

Side shielding



G.Li, GSI, 2016

Side shielding fills up the gaps outside the DEGAS detectors and is based on passive-active elements. The element is comprised by 50 mm long CsI scintillator read out by SiPM and is protected for the outward radiation by 6 mm Densimet plate. Two basic shapes are foreseen.



Side Shield Detector element Shape1

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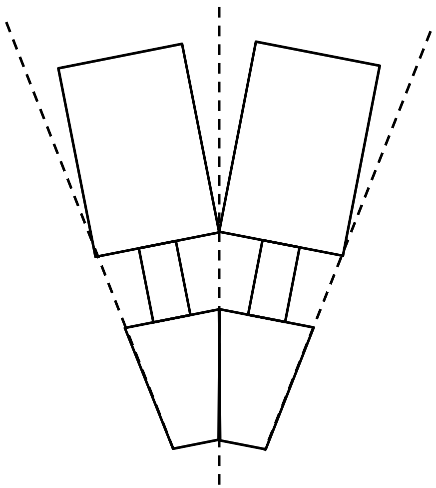
3. DEGAS detector

DEGAS Constraints

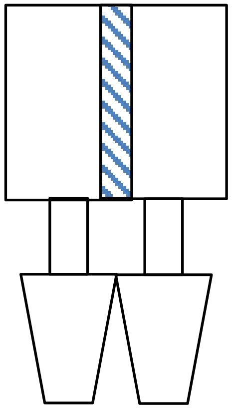
- Physical - The geometry

- Functional - Too small dewar would require too frequent filling – LN2 boiling interference, reliability, too little time for reaction by alert etc.

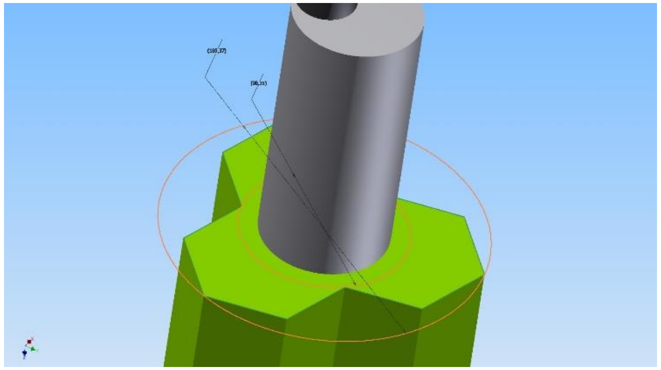
- Reliability – LN2 systems for refilling are not sufficiently reliable and too frequent filling increases the risk of failure unacceptably. Not only the filling system…

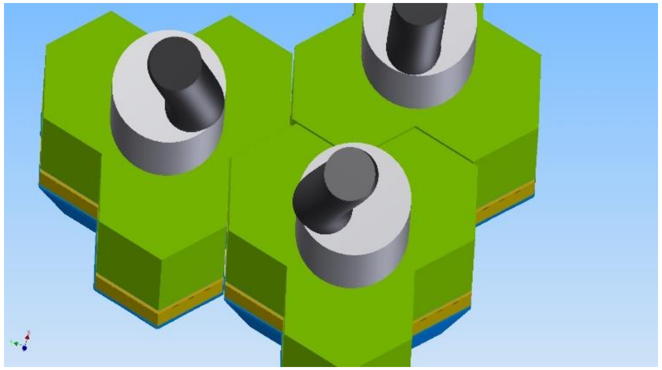


The spherical geometry tolerates any size of the dewar



The “box” geometry does not, the dewar diameter must be no larger of the detector head size.





I. Kojouharov, *GSI, Darmstadt*

3. DEGAS detector

DEGAS detector definition

Main features:

- Three electrically cooled 60% efficiency HPGe encapsulated crystals. ★
- An autonomous detector module. ★
- Interface module enabling the use of alternative cooling engines. ★
- Three Backcatcher BGO scintillators installed behind the HPGe capsules in order to absorb the forward scattered Compton, photons thus improving the P/T ratio. Also acting as active shield rejecting the background gammas events. Essentially this is the ***first low background performing*** array. (Applications?...★)
- SiPM read out of the scintillators with an onboard DAQ. ★
- Cold FET preamplifiers with a variable gain HPGe preamplifiers ★ and an active reset of the saturations.
- On board supporting electronics – HV, BSD, power supplies, monitoring and slow control based on µPC and EPICS platform. ★
- At some later stage – full on board DAQ, including digitizing of the germanium pulses, time stamping and folding. ★
- A possibility for hybridization of the detector ★ – allows to recognize the first interaction position and enables Doppler correction – In Beam Spectroscopy.

★ New development, new feature, uniqueness

DEGAS – a novel HPGe spectrometer for NUSTAR

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3. DEGAS detector

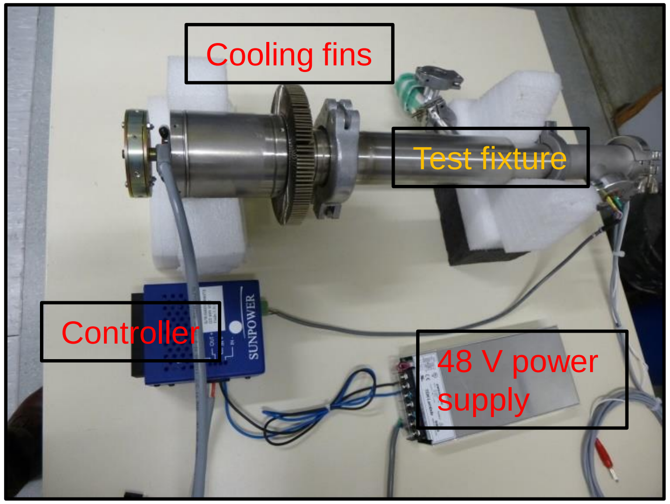
X-Cooler II, MMR/ORTEC

But only for PopTop Capsules...

Congratulations to the RHESSI satellite which has just passed its 14th year on Orbit! Originally planned for a 2 year mission, the Sunpower cryocooler has exceeded NASA expectations and continues to provide cooling power to the germanium detector, which allows valuable scientific data on solar flares to be collected and analyzed.
Fourteen years is a long time for anything to continue working, especially something that oscillates at 60 Hz. This means the piston inside the Sunpower cryocooler has cycled over 26 billion times. As periodic oil changes can't happen in space, it does this without oil to provide lubrication between the piston and piston wall. Instead, we rely on gas bearings which provide a thin protective layer of gas to prevent collisions, which have been working very well.

SunPower press release, 09.02.2016

X-Cooler II or III, MMR/ORTEC approx. 11 W cooling power, 240 VAC/500 VA Power. Connecting pipeline, 3 m, no twisting, limited radius bending.



Sunpower cooling engine Type GT:
- 16 W cooling power
- 240 W electrical

Under test:
- strong cooling power
- heavy energy dissipation – need air cooling with a defined flow. An option – cooling jacket.
- strong vibrations. There is a vibration reductor and this option is to be investigated. The detector construction has to consider vibration strong reduction if not an elimination. Engine cooling – fins are not an option, water jacket?...

3. DEGAS detector

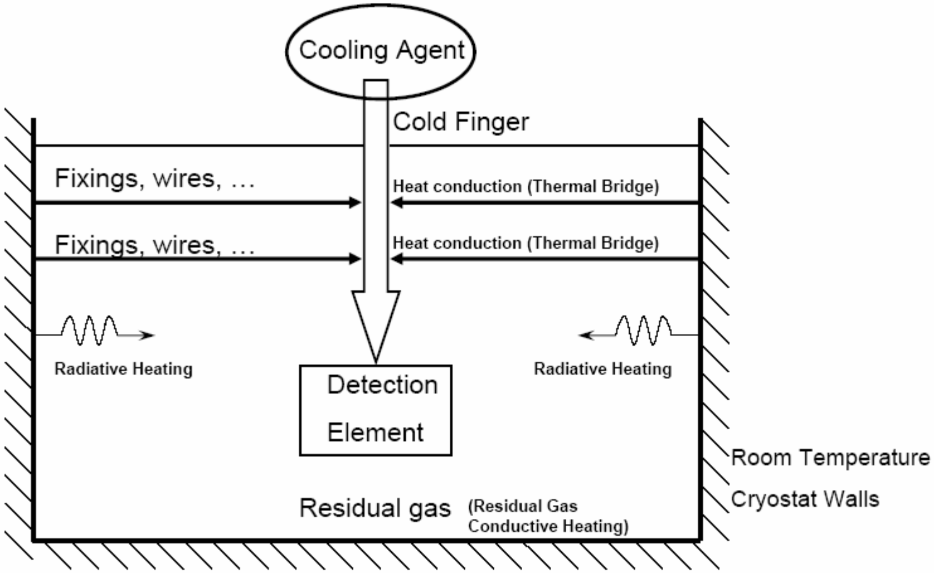
	MMR XC	SP CT
Cooling (total) power	11 W (240V/500W)	11W (24V/120W)
End temperature	-187 °C	-220 °C
Vibrations	very low	high
Life	unknown, 3-7 Years	unknown, >200 000 h
Compactness	low	high
Functionality	medium	medium

Conclusion: the use of SP GT or CT cooling engines needs further R&D, therefore initially the MMR X-Cooler has to be considered and an interface for easy transition to SP CT-cooler to be provided.

I. Kojouharov, *GSI, Darmstadt*

3. DEGAS detector

Can we cool 3 Encapsulated HPGe Crystals with these engines?



Thermodynamic model of the detector

The ***radiative transfer*** in the detector assembly is determined by the heat exchange between the outer parts of the cryostat which are at room temperature and the inner cold structure which is at near liquid nitrogen temperature by infrared rays. The path of the transfer leads through the cold finger to the heat reflector and further to the detectors housing which holds the Ge crystals.

Thermal bridges are the mechanical components used for fixing the cold structure to the warm section of the cryostat and the internal cabling between the crystal housing and the vacuum feedthroughs. The heat exchange is realized by thermoconductivity.

The ***residual gas heating*** takes place typically at low vacuum, however the specifics of the process must be taken into account.

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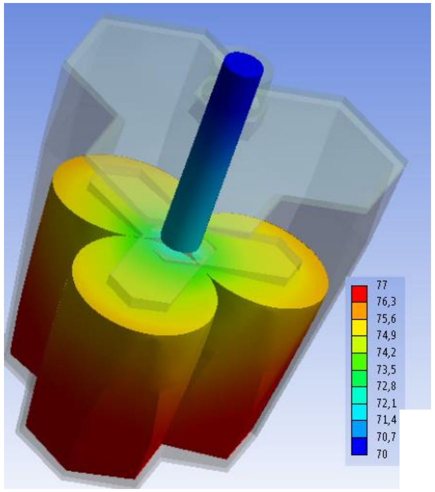
3. DEGAS detector

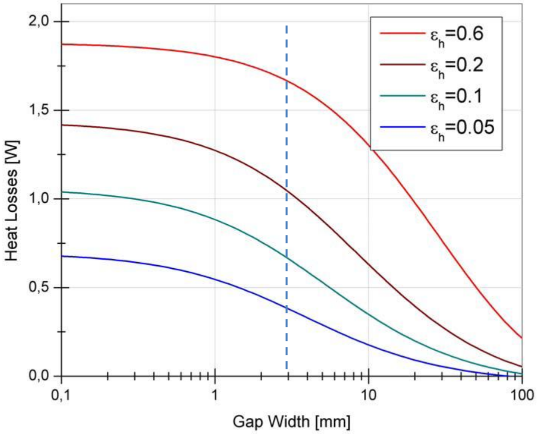
Radiative transfer effects

Temperature distribution along the Ge-capsules and the cold finger when the temperature of the cooling part is 70 K and the ambient temperature is 295.15 K. The emissivity of the Ge-capsules is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1. The total heat transfer (including the cold frame) is about 3 W.

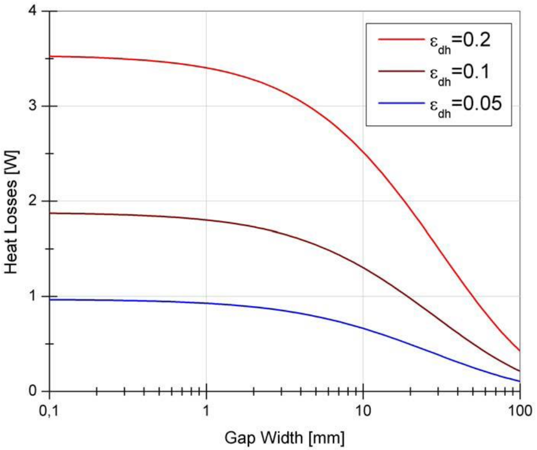


Courtesy of J.Kojouharova

Only increase of the ambient temperature in three degree causes increase of the total heat losses with 3.3 %. If the ambient temperature increases once again with five degree more, the heat losses increase with 10.2 %.



The radiative absorbed heat by the detector head vs. the gap width between the housing and the cold structure. The data plotted on left a are calculated for ε_h=0.6 and three different ε_{dh}, while on right the heat absorbed at detector head emissivity taken to be 0.1 and various housings emissivity is presented.



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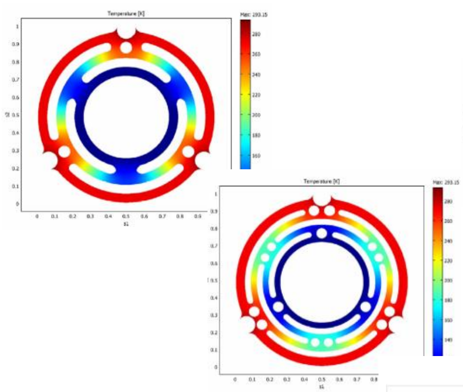
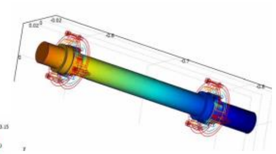
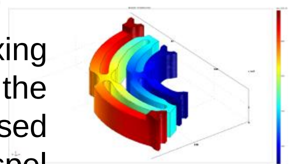
3. DEGAS detector

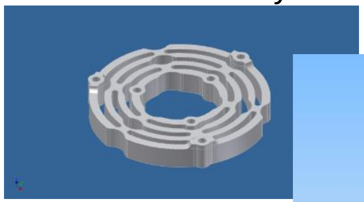
Thermal bridges effects

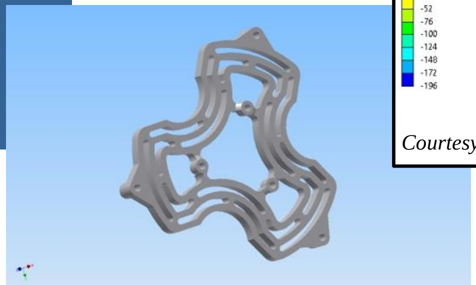




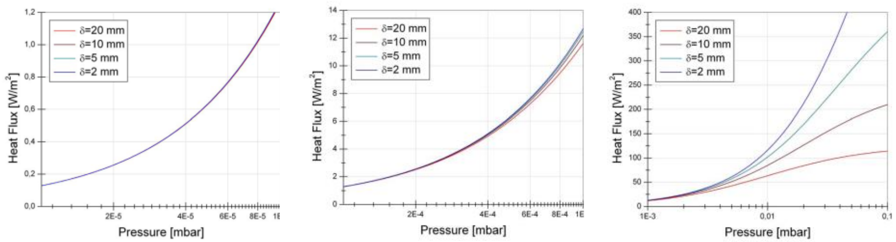


Temperature profile at the fixing component surface vs. the topology. The topology proposed results in only 50 mW (Vespel SP21) heat losses and good mechanical stability.

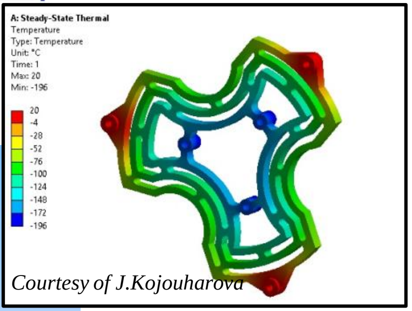




Vacuum effects



Heat flux behavior vs. residual gas pressures. Three different residual gas pressure intervals are important: lower than 1E-4 mbar, where the heat flux is “insensitive” to the gap width, between 1E-3 mbar and 1E-4 mbar being week function on gap width and above 1E-3 mbar, where strong impact of the gap width can be seen.



Courtesy of J.Kojouharova

Main supporting labyrinth of DEGAS, Vespel SP21, 110 mW

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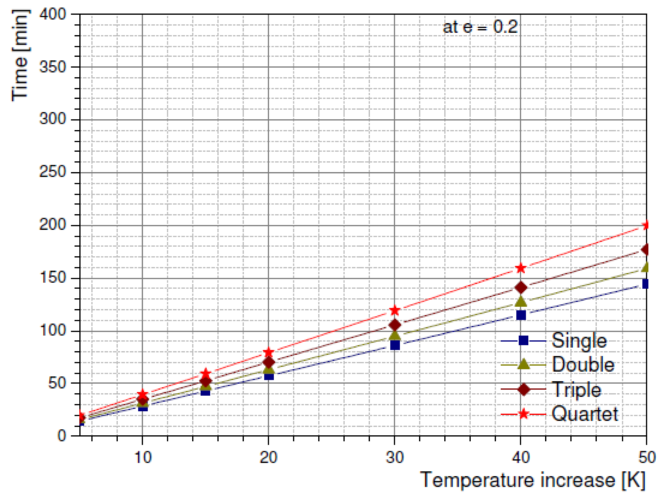
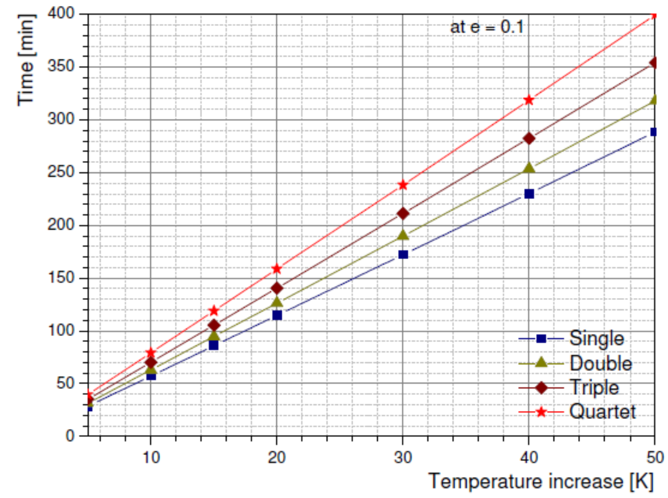
3. DEGAS detector

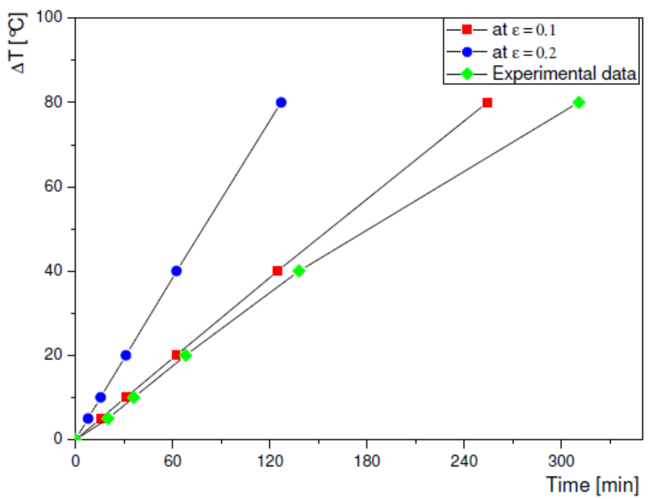
Thermal timeout

Temperature development in dependence on detector configuration and ε=0.2 (left) and ε=0.1 (right). Here the temperature of the cold part is considered to be 77 K, while the temperature of the warm part 300 K.





Courtesy of J.Kojouharova



Warming up of a single HPGe detector with 15 % efficiency (commercially available PopTop), which corresponds of 344 g Ge. The warm up time is evaluated based on typical crystal housing. The surface quality of the crystal housing suggests that by regular mechanical manufacturing technology an emissivity of <0.1 can be achieved.

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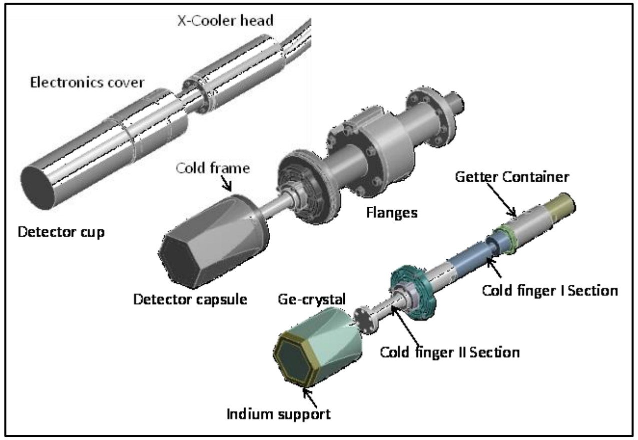
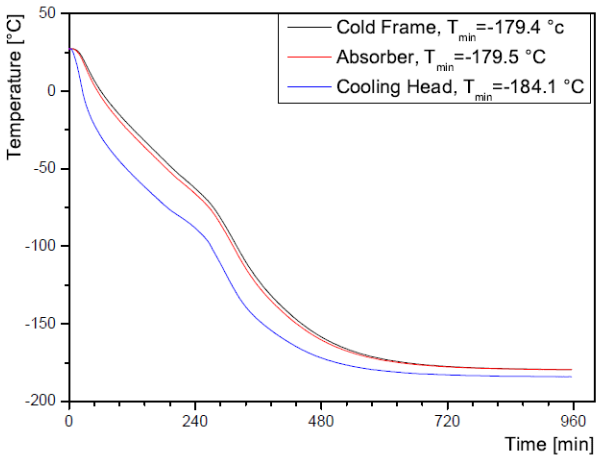
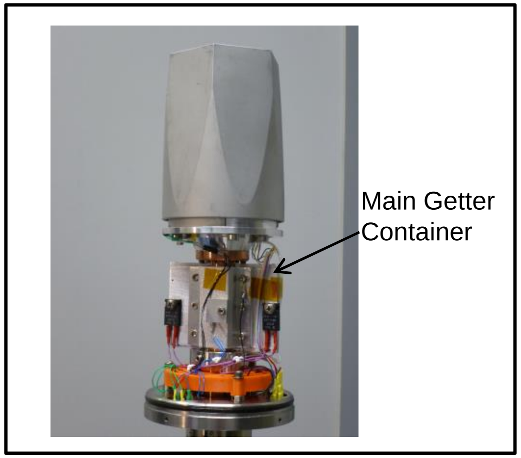
3. DEGAS detector

Single capsule detector



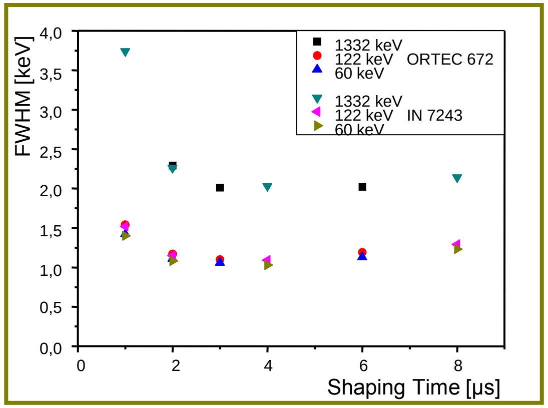


Cooling of the single capsule detector



Based on X-Cooler II

Energy resolution of HEX 146 vs. shaping time. Energy resolution at 1332 kev and LN2 cooling in Lab – 1.96 keV (GSI cold board !)



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3. DEGAS detector

<u>Can we cool 3 Encapsulated HPGe Crystals with these engines?</u>

<u>Single encapsulated HPGe Crystal – YES !</u>

It is time for 3 Encapsulated HPGe Crystals !

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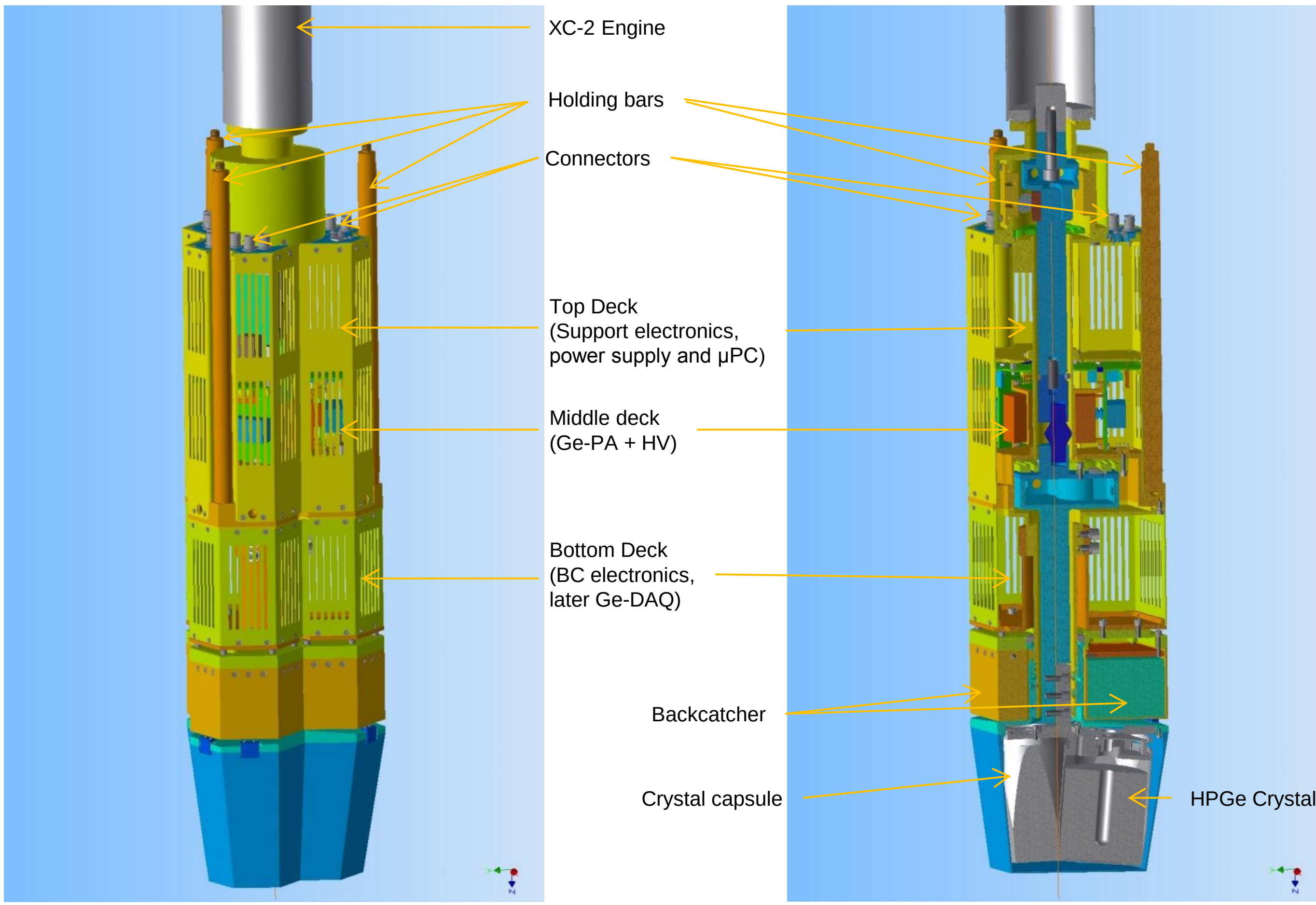
3. DEGAS detector



Developed at GSI in collaboration with Ferchau GmbH, Germany, components production in India (TIFR Mumbai), Germany (Darmstadt) and possible in Romania (Bucarest).

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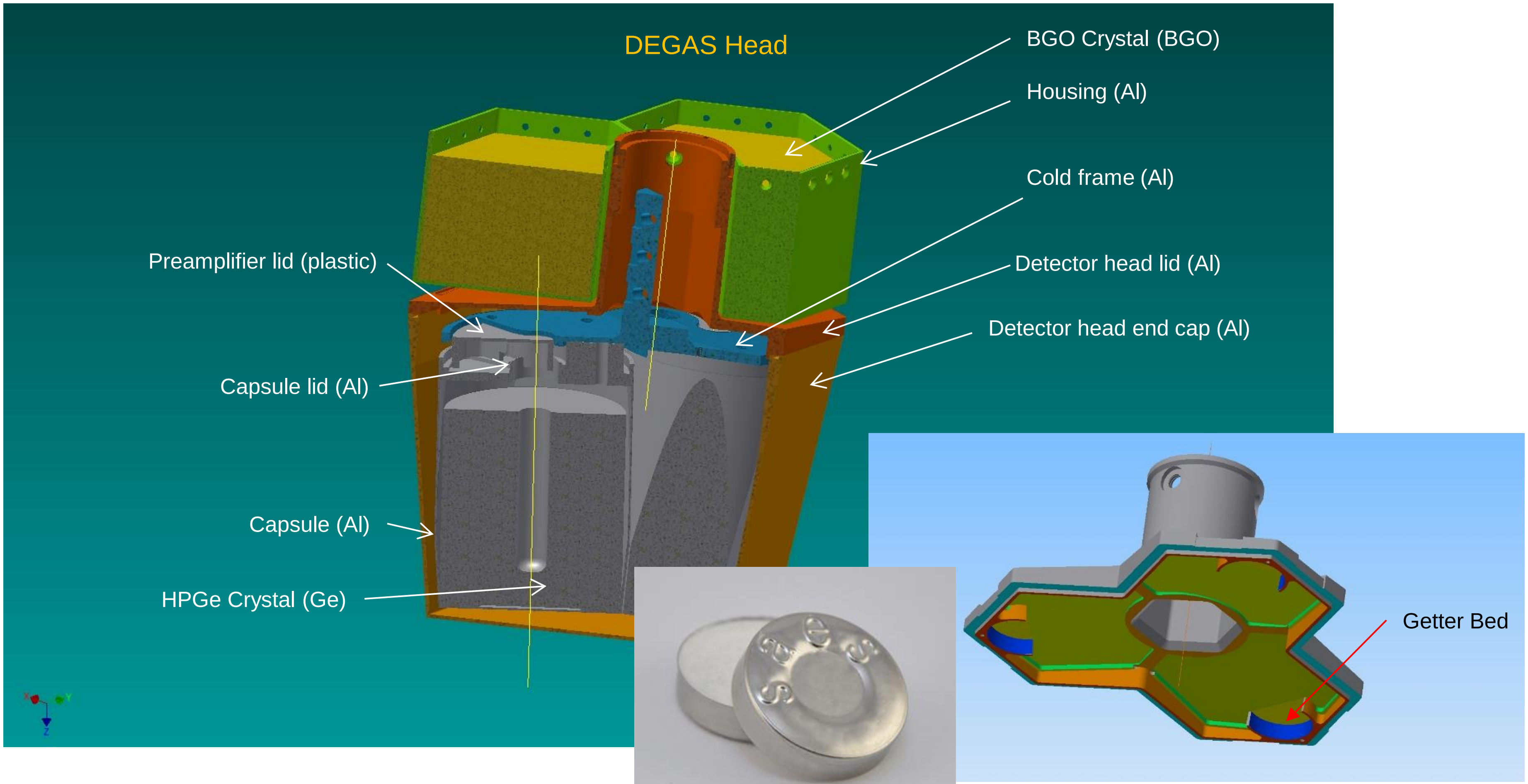
3. DEGAS detector



Combo Getter, SAES

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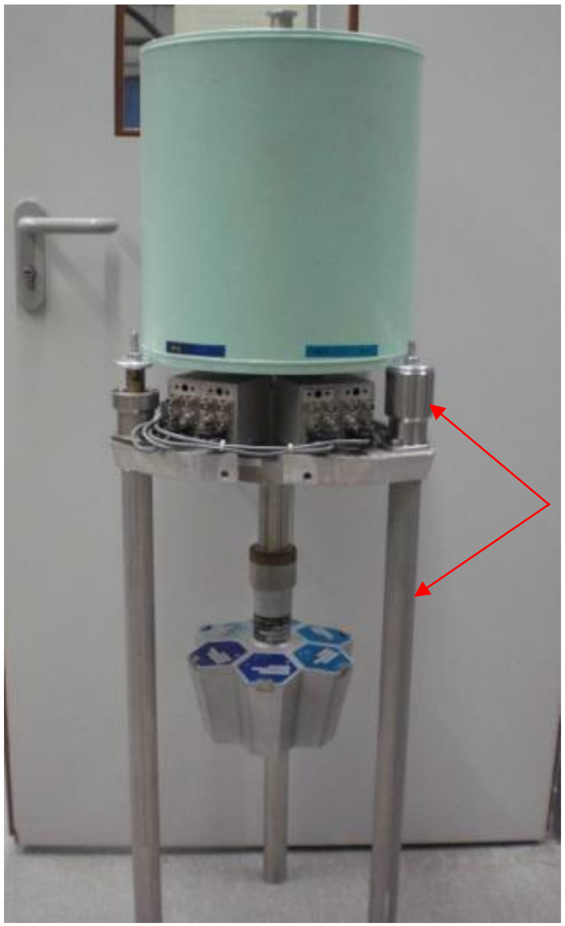
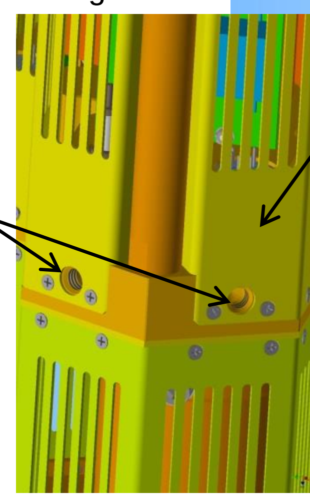
3. DEGAS detector

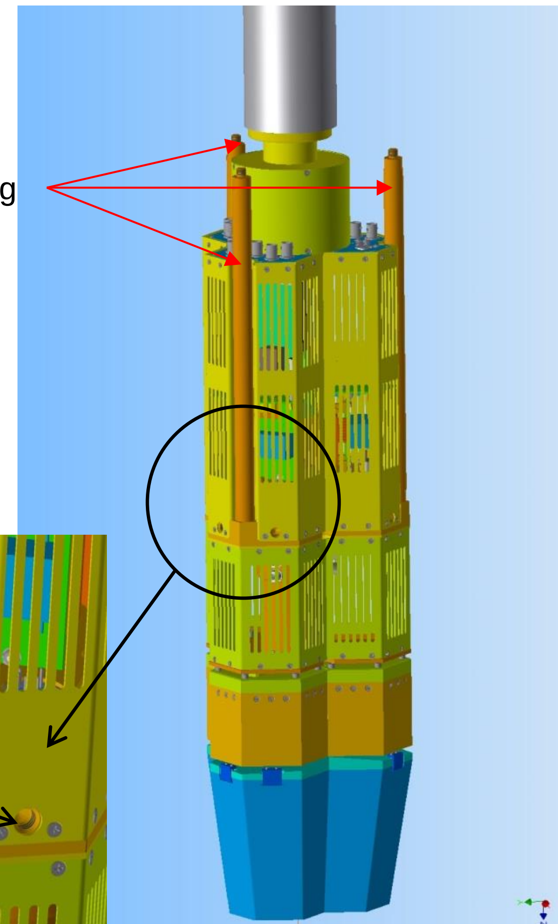


DEGAS fixing

Cluster Detector fixing

2 x M8





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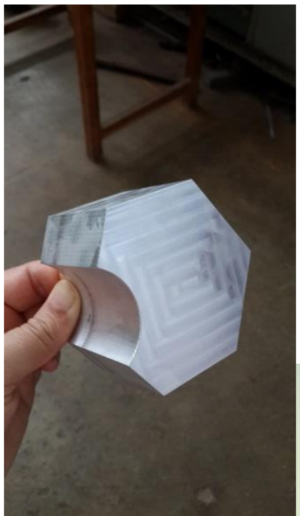
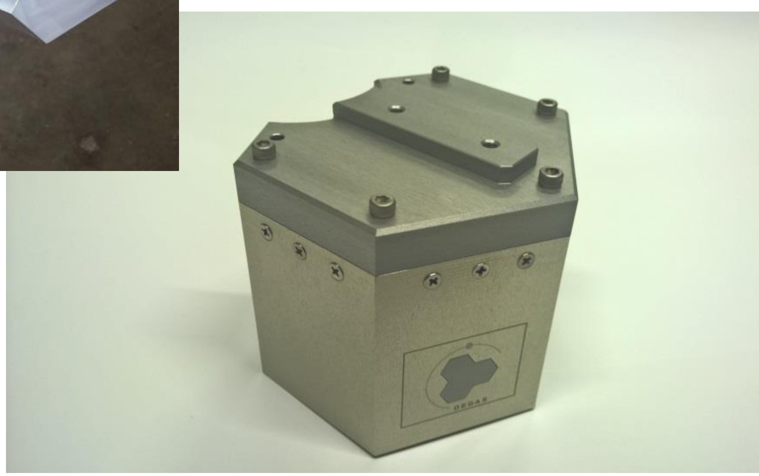
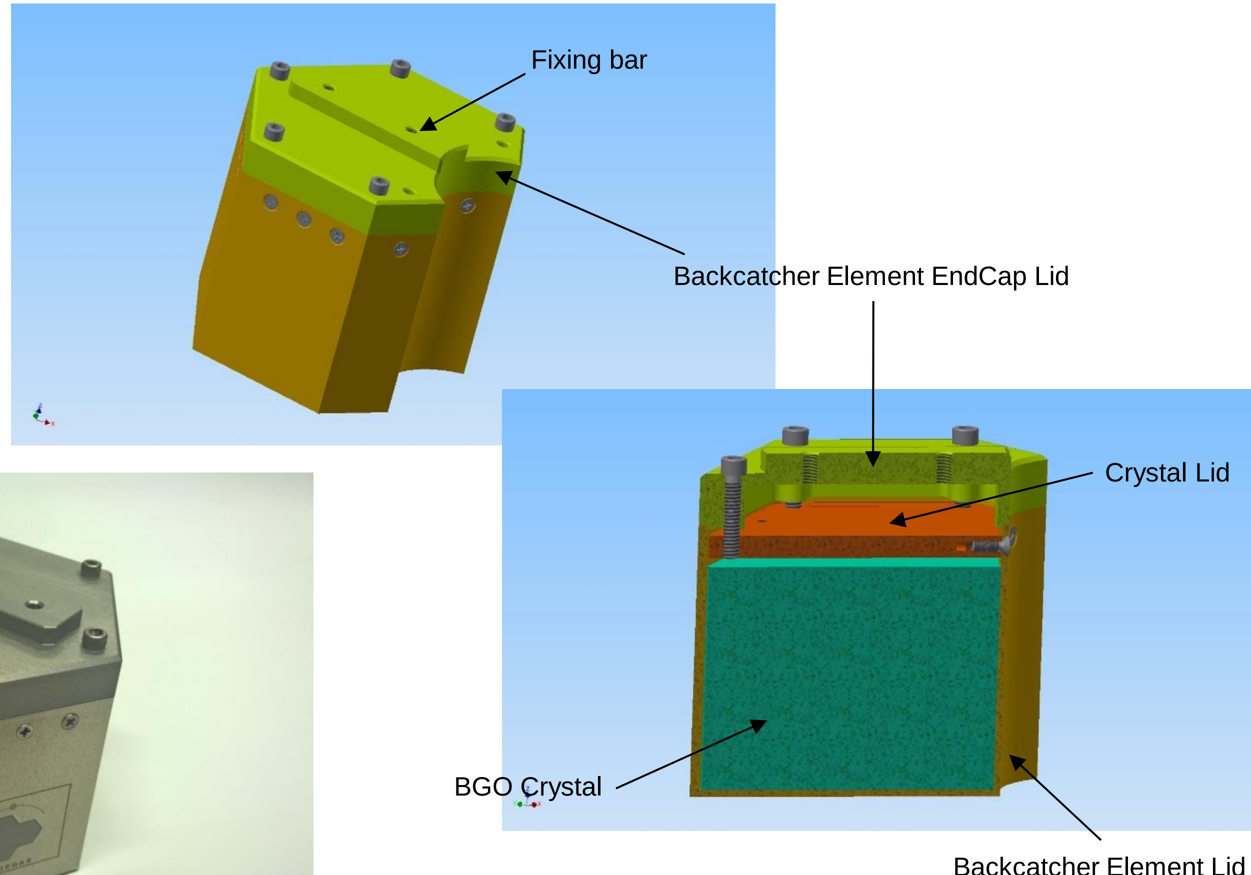
3. DEGAS detector



Backcatcher element





Backcatcher element. Developed at GSI in collaboration with Yildiz University, Istanbul, Turkey. Supposed production of the mechanics at TIFR, Mumbai, India.

The DEGAS concept foresee 3 separate and autonomous backcatcher elements hanging on the Bottom Deck of the cryostat.

DEGAS – a novel HPGe spectrometer for NUSTAR

I. Kojouharov, *GSI, Darmstadt*

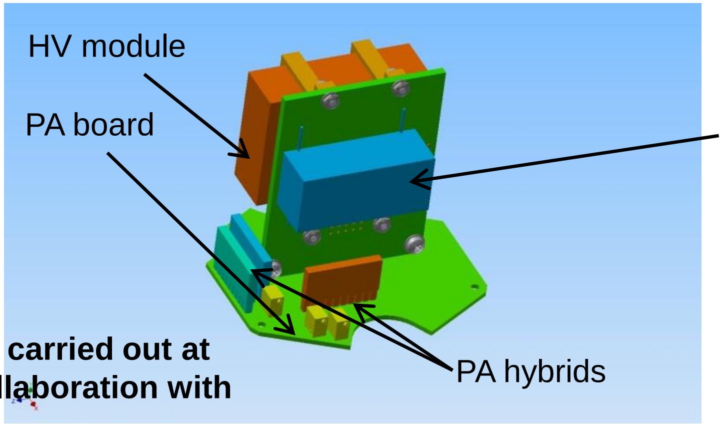
3. DEGAS detector – the Front-End Electronics

Specifications of the AGATA preamplifiers available for DEGAS and the intended improvements.

Property	AGATA	DEGAS I
Conversion gain	100 mV/MeV	Variable 50-50 mV/MeV
Noise	800 eV (0 pF)	same
Rise time	15 ns	10 ns
Decay time	30 µs	50 µs
Integral non-linearity	< 0.025%	same
Output polarity	Differential, Z = 100 Ohm	same
Fast reset speed	≈10 MeV/µs	same
Integrated pulser	yes	no
Power supply	±6.5 V, ±12.5 V	±6 V, ±12 V , ±24 V
Power consumption	< 980 mW	< 500 mW
Dimensions	62 x 45 x 7= 19530mm3	< 50000 mm3

Based on Technical Report for the Design, Construction and Commissioning of the DESPEC Germanium Array Spectrometer – DEGAS, *v12.3*

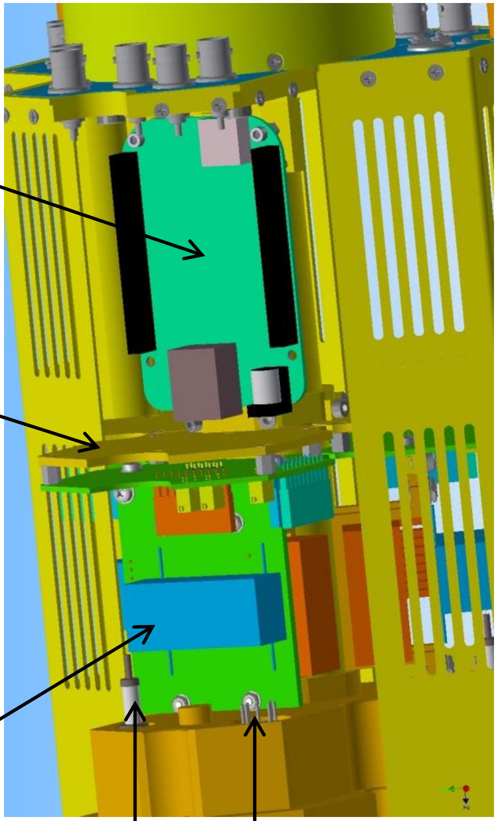
The preamplifier is based on ORTEC 0706LPA integrator chip followed by PZ with fast reset and differential output stage based on ADA4895-2 OpAmp ! The PCB development is ongoing. <u>Transistor Reset </u>??!



HV filter

μC “BeagleBone”

PA-support plate



HV Signal
Feedthroughs

Preamplifier development carried out at TIFR, Mumbai, India in collaboration with GSI, Darmstadt

DEGAS – a novel HPGe spectrometer for NUSTAR

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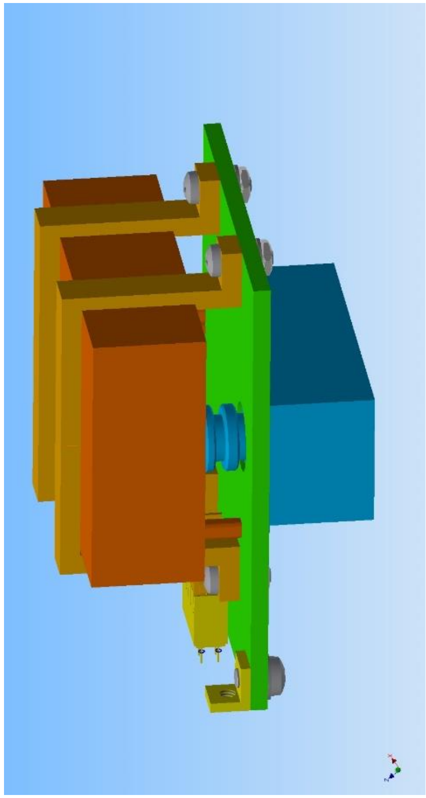
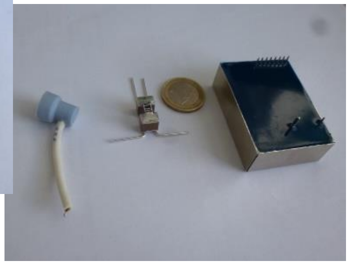
3. DEGAS detector – the Front-End Electronics

HV module

Technical Data	**BPx**[1]	**60 504 12**
Nominal output voltage	[1]x = **p**:	+ 6000
V_{NOM} [V] [2]	[1]x = **n**:	- 6000
Nominal output current I_{NOM} [mA] [2]		0,5
Ripple & noise [mV_{p-p}]		typ < 5 max 10
Protection		Overload and short circuit
Supply voltage V_{IN}		+ 12 V-DC ± 5% (PW+12 / PWGND)
Supply current I_{IN}		V_{OUT} = 0; I_{IN} < 10 mA V_{OUT} = V_{NOM}; no load; I_{IN} < 50 mA V_{OUT} = $V_{NOM\,n}$; load; I_{IN} < 500 mA
Stability V_{OUT}		ΔV_{IN}: $< 2 * 10^{-4} * V_{NOM}$
		no load to load: $< 5 * 10^{-4} * V_{NOM}$
		< 0,05% / 8 hours at constant operating conditions after 1 hour warm up
Temp. coefficient		$< 1 * 10^{-4}/K$
Reference voltage REF		5 V, ±1%, R_i = 50Ω, $I_{OUT} \le$ 0,5mA
Control on VSET		1st: Remote control with an ext. potentiometer (10 - 100kΩ) between REF and GND, sliding contact on VSET
		2nd: with analogue control voltage V_{SET} $0 \le V_{SET} \le 5\ V \Rightarrow 0 \le V_{OUT} \le \mid V_{NOM} \mid \pm 1\%$
/ON signal		TTL-level, HIGH = active ⇒ HV = 0, LOW or open ⇒ HV according V_{SET}
Monitor voltage VMON (R_i = 10k)		$0 \le V_{OUT} \le \mid V_{NOM} \mid \pm 1\%$ $\Rightarrow 0 \le V_{MON} \le 5\ V$
Monitor voltage IMON (R_i = 10k)		$0 \le I_{OUT} \le \mid I_{NOM} \mid \pm 2\%$ $\Rightarrow 0 \le V_{MON} \le 5\ V$
Operating temperature		0 ... +40 °C
Storage temperature		-20 ... +60 °C





The HV module and the HV filter are to be integrated with the PA board which will provide the best possible grounding and low noise. The control is to be made by µPC (directly) or via HadCon 2 board. Remote monitoring – 1V voltage sensitivity, 1-10 nA current sensitivity (ADC dependent).

3. DEGAS detector – the Slow Control and Monitoring

- Based on BeagleBone μComputer

- 20 Analogue Inputs (8 Temperatures), 5 ADC
- 15 Digital Inputs (1 Bit)
- 21 Digital Outs (1 Bit)
- 6 I^2C Outs (Digital Poti's)

- EPICS Software Platform
- …..

- Development carried out at HIM – Mainz, Germany

(Collaboration with PANDA and Hypernuclei Spectroscopy Group)

3. DEGAS detector – some facts

- contains
  - ❖ 49 non standard components (to be manufactured)
  - ❖ 279 fasteners
- weight of 24,85 kg (if X-Cooler used)
- length of 83 cm (with the cooling engine, if X-Cooler used)
- high technological requirements for processing
- high evolution potential
- extreme compact
- flexible, could serve as a platform for the future projects

DEGAS – a novel HPGe spectrometer for NUSTAR

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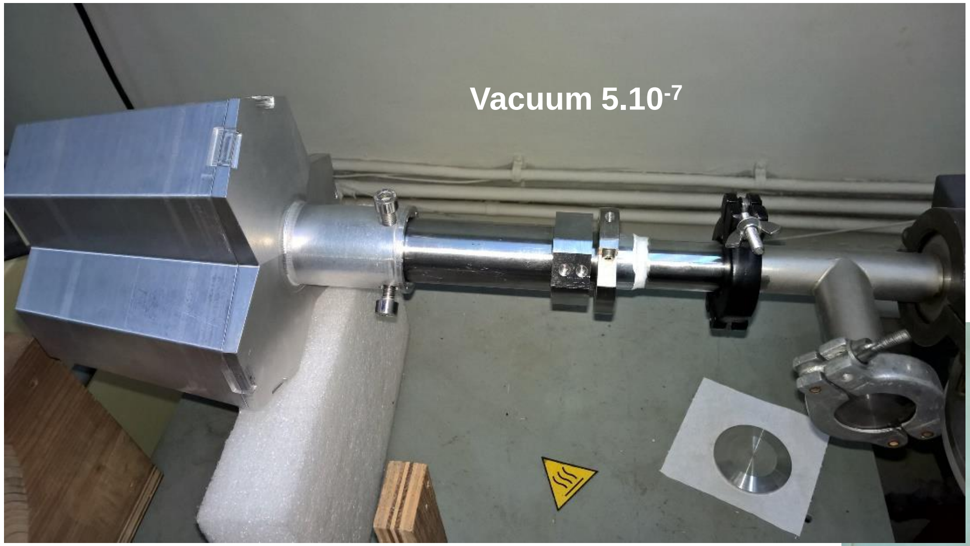
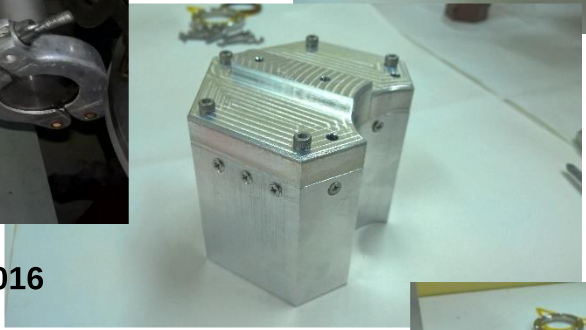
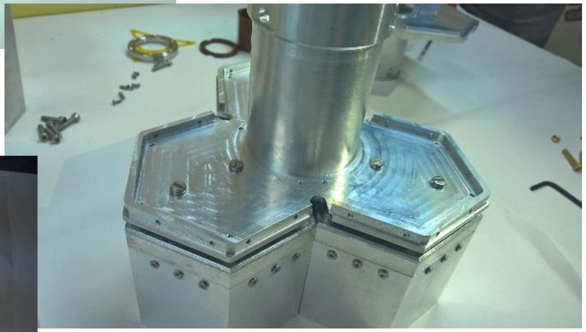
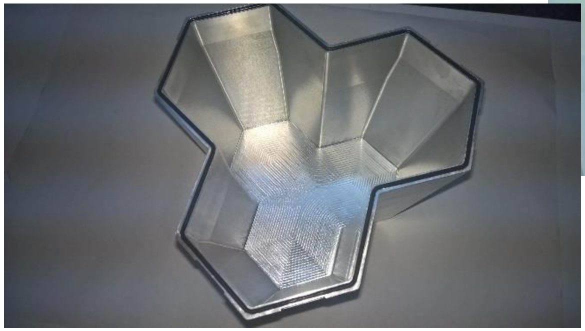




First mechanics test, TIFR, Mumbai, India, February 2016





First test and characterization – 2016
In operation - Fall 2017- Spring 2018

DEGAS – a novel HPGe spectrometer for NUSTAR

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Thank you