

DEGAS – the HPGe array spectrometer for NUSTAR

I. Kojouharov, GSI, Darmstadt

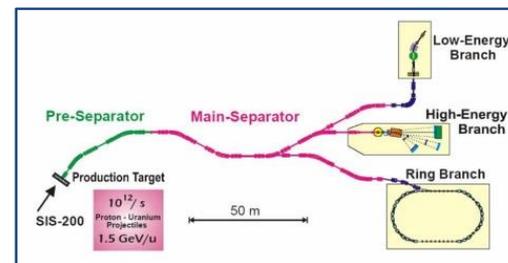
DEGAS – the HPGe array spectrometer for NUSTAR



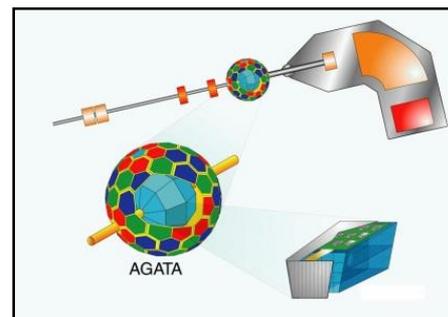
I. Kojouharov, GSI, Darmstadt

1. HISPEC/DESPEC at NuSTAR

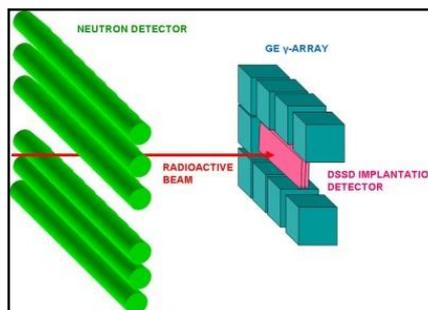
Super FRS



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



DESPEC (DEcay SPECTroscopy)
Runs DEGAS as the basic spectrometer



Collaboration of:

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

DEGAS – the HPGe array spectrometer for NUSTAR

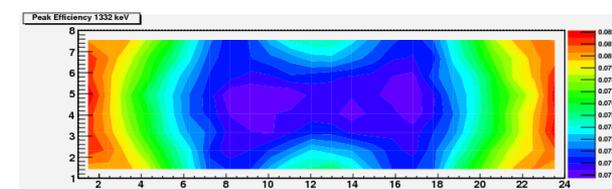
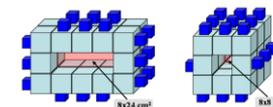


I. Kojouharov, GSI, Darmstadt

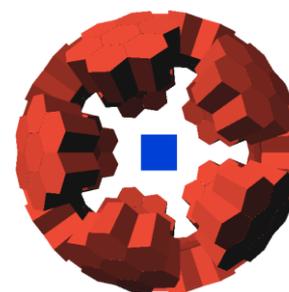
2. DESPEC setup

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...

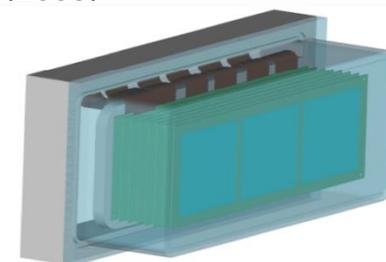
Property	RISING	Phase I	Phase II	Phase III
Array type	Composite Ge detector array	Composite Ge detector array	Phase I compl. by γ -tracking dets.	γ -imaging array
Energy range (keV)	50-5000	50-5000	50-5000	50-5000
Noise threshold (keV)	24	15	15	10
Energy resolution (at 1.3 MeV)	2.3 keV	2.3 keV	2.3 keV	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	≤ 1 ms	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



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



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

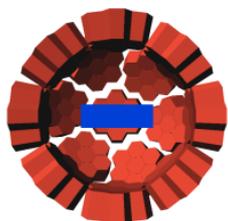
DEGAS – the HPGe array spectrometer for NUSTAR



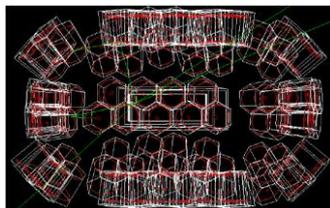
I. Kojouharov, GSI, Darmstadt

2. DESPEC setup

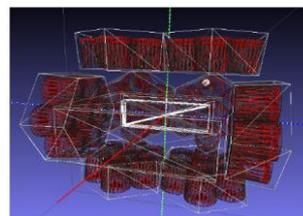
DESPEC setup definition. Based on EB encapsulated HPGe crystals detectors.



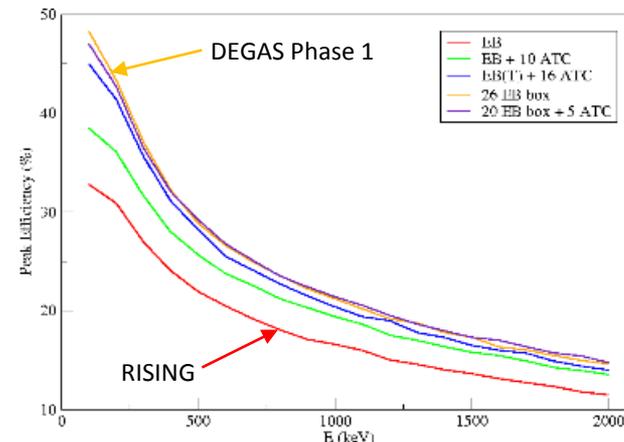
Half sphere
EB Clusters based



shell
Triples base



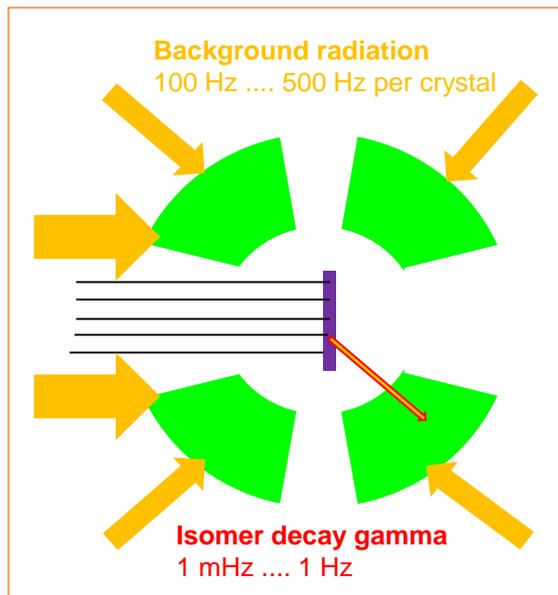
box
Triples based



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

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.

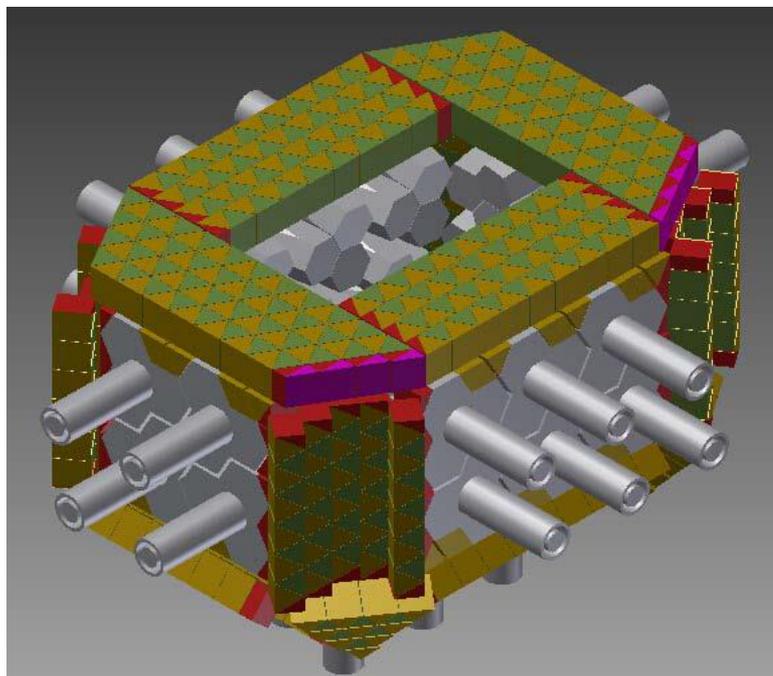
DEGAS – the HPGe array spectrometer for NUSTAR



I. Kojouharov, GSI, Darmstadt

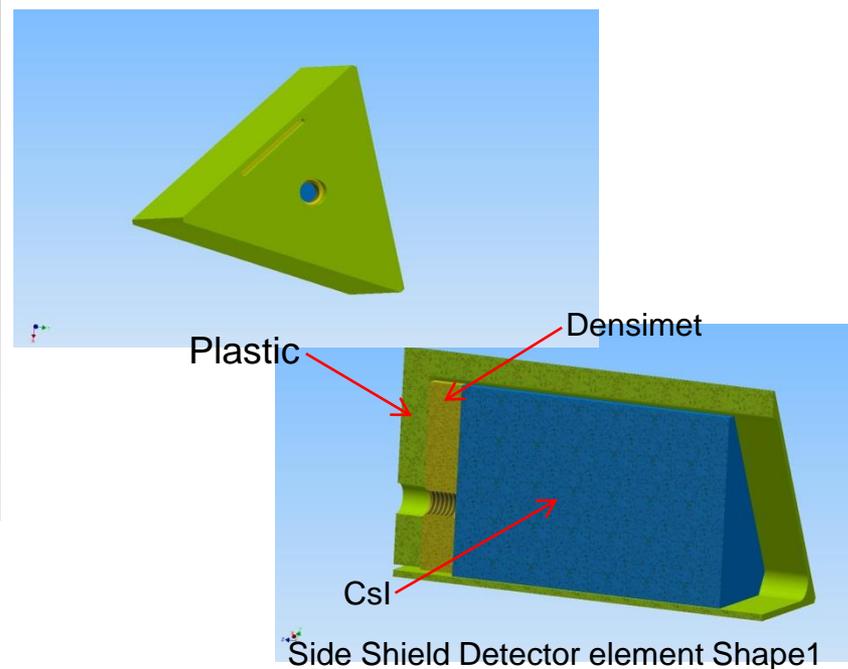
2. DESPEC setup

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.



DEGAS – the HPGe array spectrometer for NUSTAR

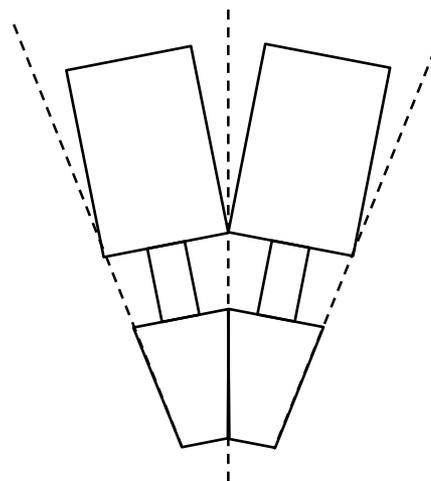


I. Kojouharov, GSI, Darmstadt

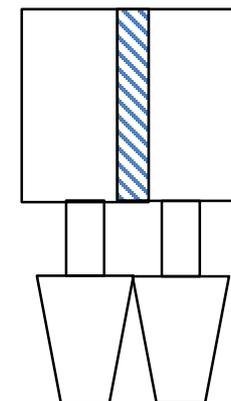
3. DEGAS detector

DEGAS Constraints

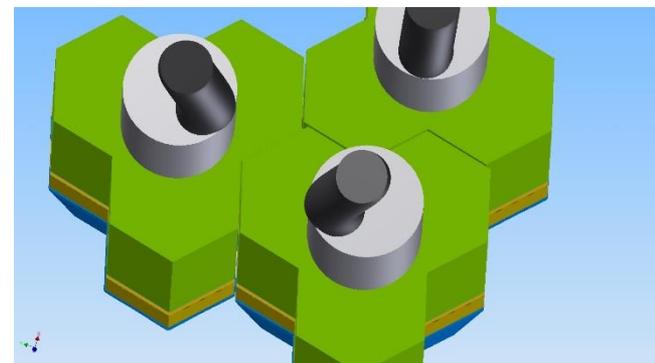
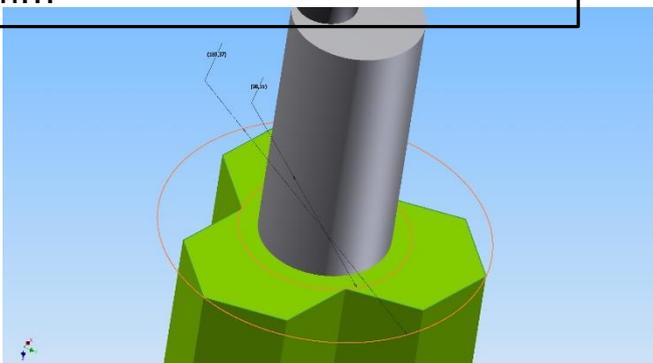
- Physical - The geometry
- Functional - Too small dewar would require too frequent filling – LN2 boiling interference, reliability, too little time for reaction by alert etc.
- Reliability – LN2 systems for refilling are not sufficiently reliable and too frequent filling increases the risk of failure 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.



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 μ PC 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.

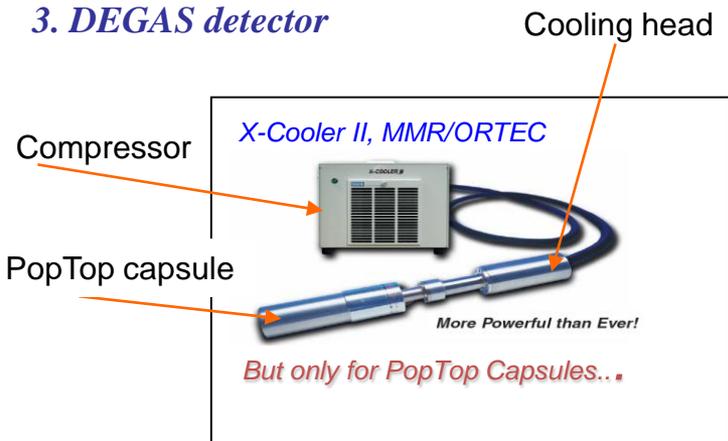
★ New development, new feature, uniqueness

DEGAS – the HPGe array spectrometer for NUSTAR



I. Kojouharov, GSI, Darmstadt

3. DEGAS detector



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.

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.

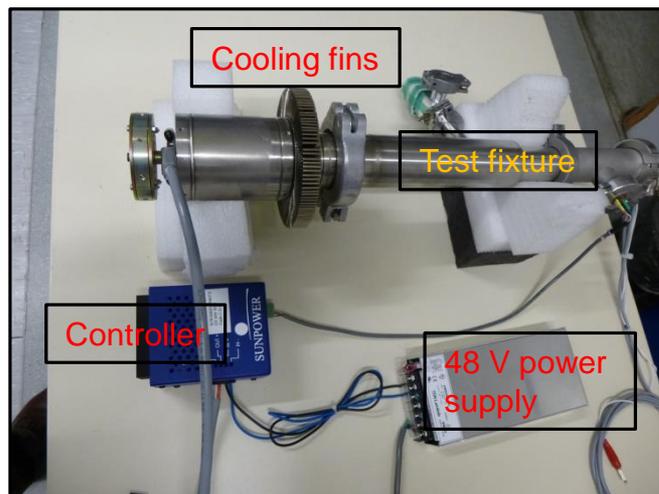
SunPower press release, 09.02.2016

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?...



DEGAS – the HPGe array spectrometer for NUSTAR



I. Kojouharov, GSI, Darmstadt

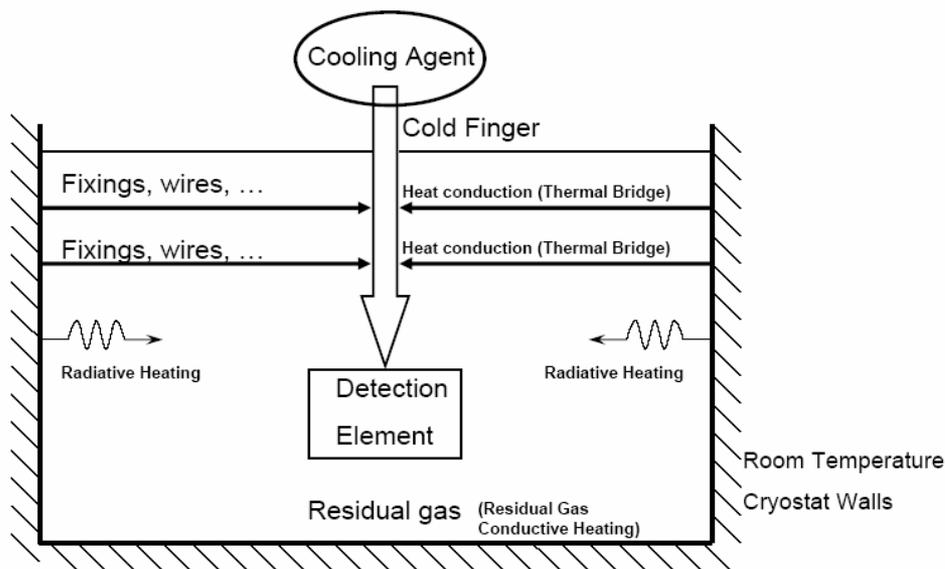
3. DEGAS detector

	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.

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.

DEGAS – the HPGe array spectrometer for NUSTAR

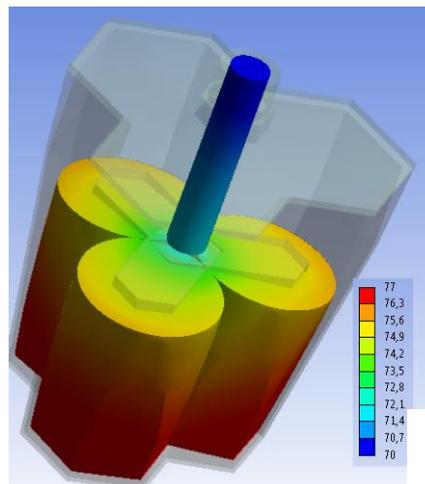


I. Kojouharov, GSI, Darmstadt

3. DEGAS detector

Radiative transfer effects

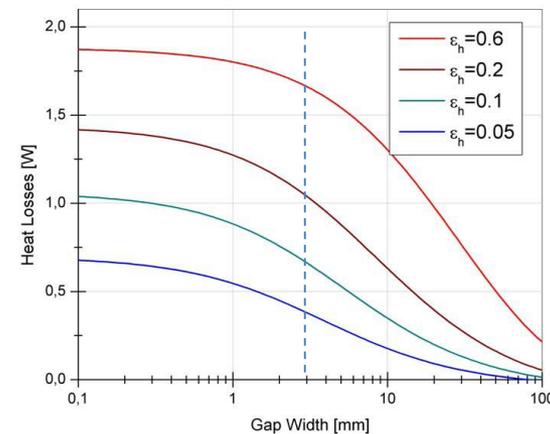
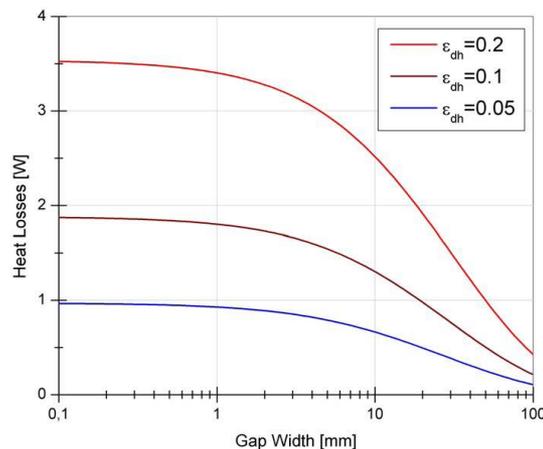
Temperature distribution along the Ge-capsules and the cold finger when the temperature of the cooling part is 70 K and the ambient temperature is 295.15 K. The emissivity of the Ge-capsules is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1. The total heat transfer (including 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 $\epsilon_h=0.6$ 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.



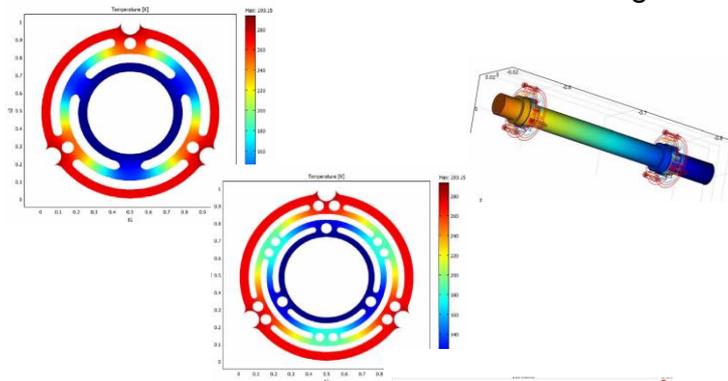
DEGAS – the HPGe array spectrometer for NUSTAR



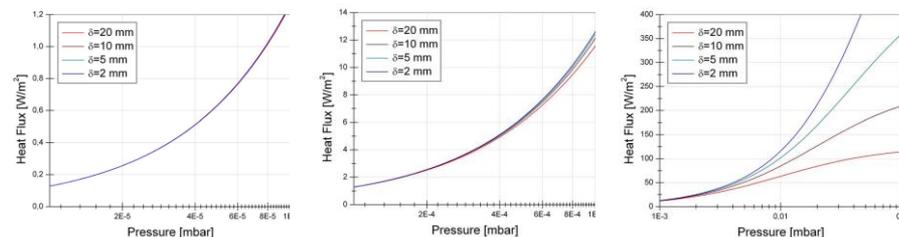
I. Kojouharov, GSI, Darmstadt

3. DEGAS detector

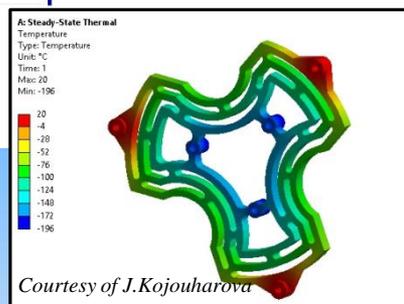
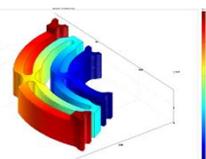
Thermal bridges effects



Vacuum 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.



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 weak function on gap width and above 1E-3 mbar, where strong impact of the gap width can be seen.

Main supporting labyrinth of DEGAS, Vespel SP21, 110 mW

DEGAS – the HPGe array spectrometer for NUSTAR

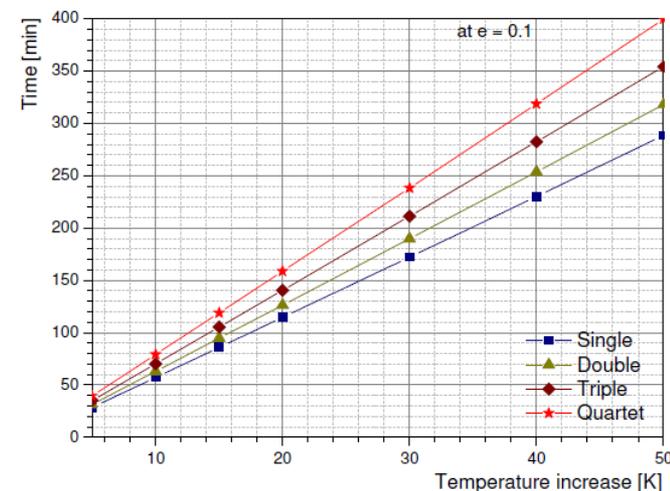
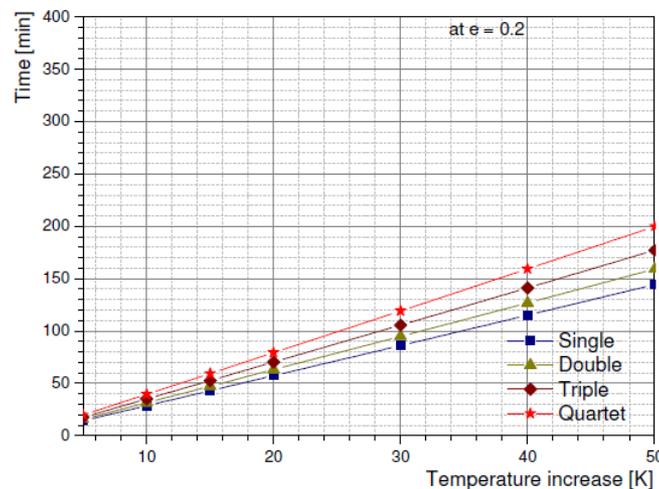


I. Kojouharov, GSI, Darmstadt

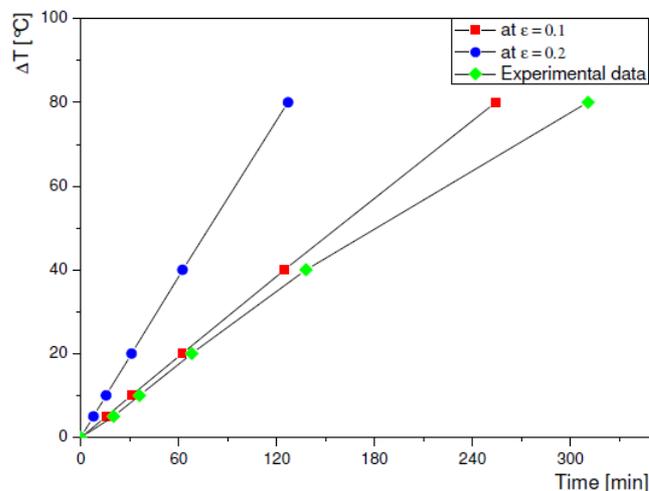
3. DEGAS detector

Thermal timeout

Temperature development in dependence on detector configuration and $\epsilon=0.2$ (left) and $\epsilon=0.1$ (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.

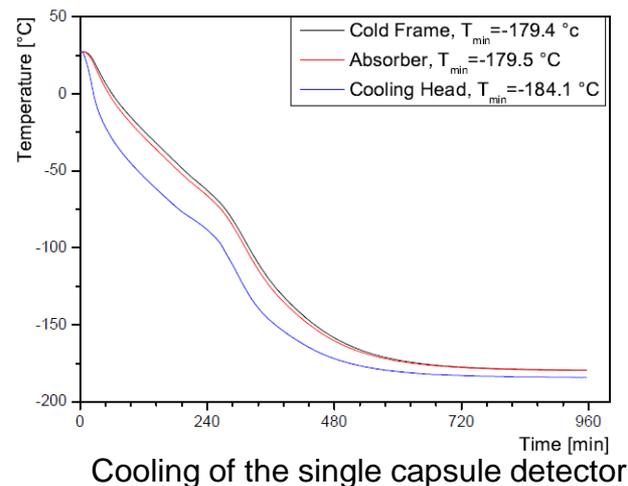
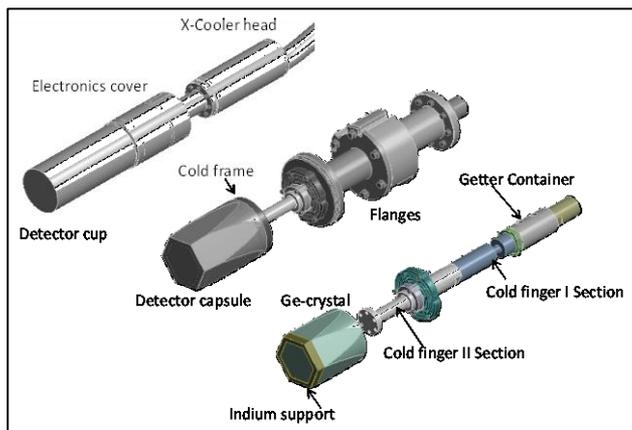
DEGAS – the HPGe array spectrometer for NUSTAR



I. Kojouharov, GSI, Darmstadt

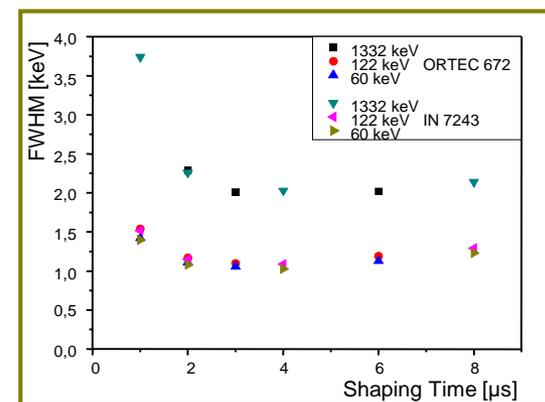
3. DEGAS detector

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 !)



DEGAS – the HPGe array spectrometer for NUSTAR



I. Kojouharov, GSI, Darmstadt

3. DEGAS detector

Can we cool 3 Encapsulated HPGe Crystals with these engines?

Single encapsulated HPGe Crystal – YES !

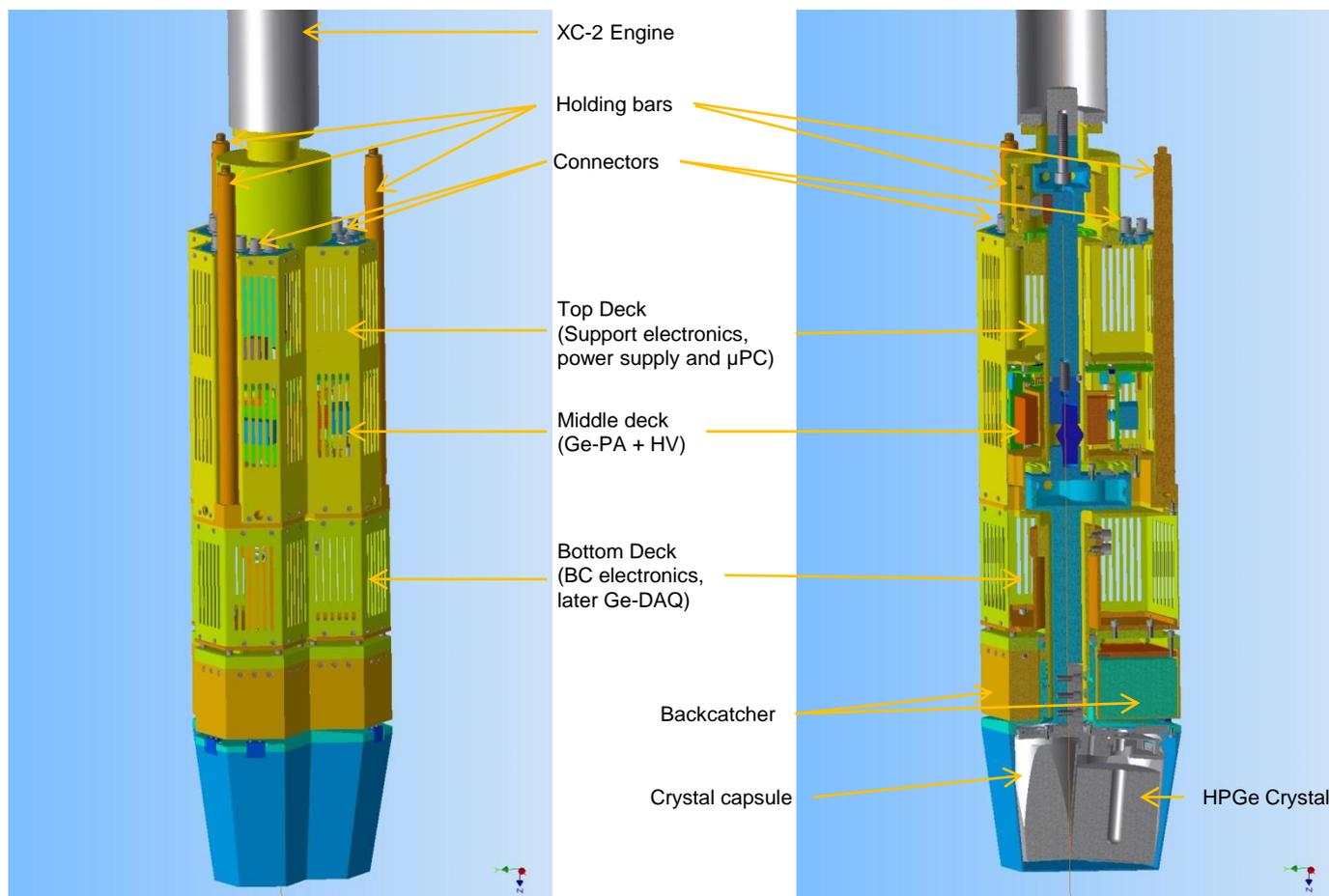
It is time for 3 Encapsulated HPGe Crystals !

DEGAS – the HPGe array spectrometer for NUSTAR



I. Kojouharov, GSI, Darmstadt

3. DEGAS detector



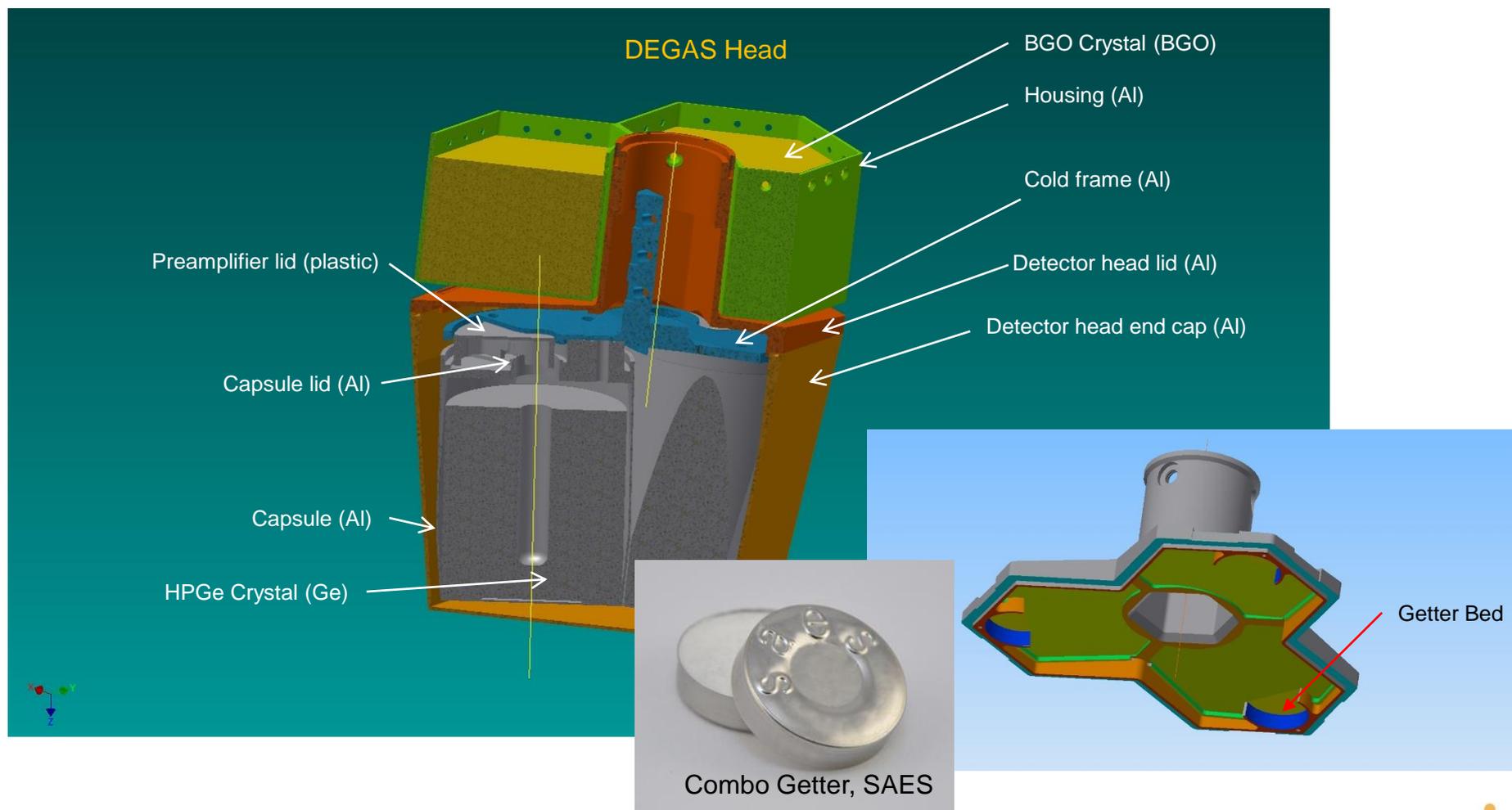
Developed at GSI in collaboration with Ferchau GmbH, Germany, Partial production at TIFR, Mumbai, India.

DEGAS – the HPGe array spectrometer for NUSTAR



I. Kojouharov, GSI, Darmstadt

3. DEGAS detector

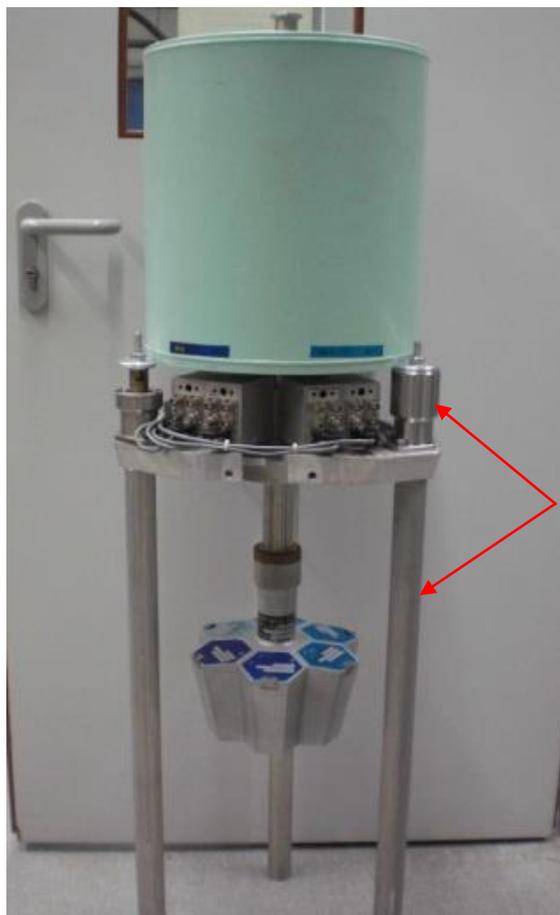


DEGAS – the HPGe array spectrometer for NUSTAR

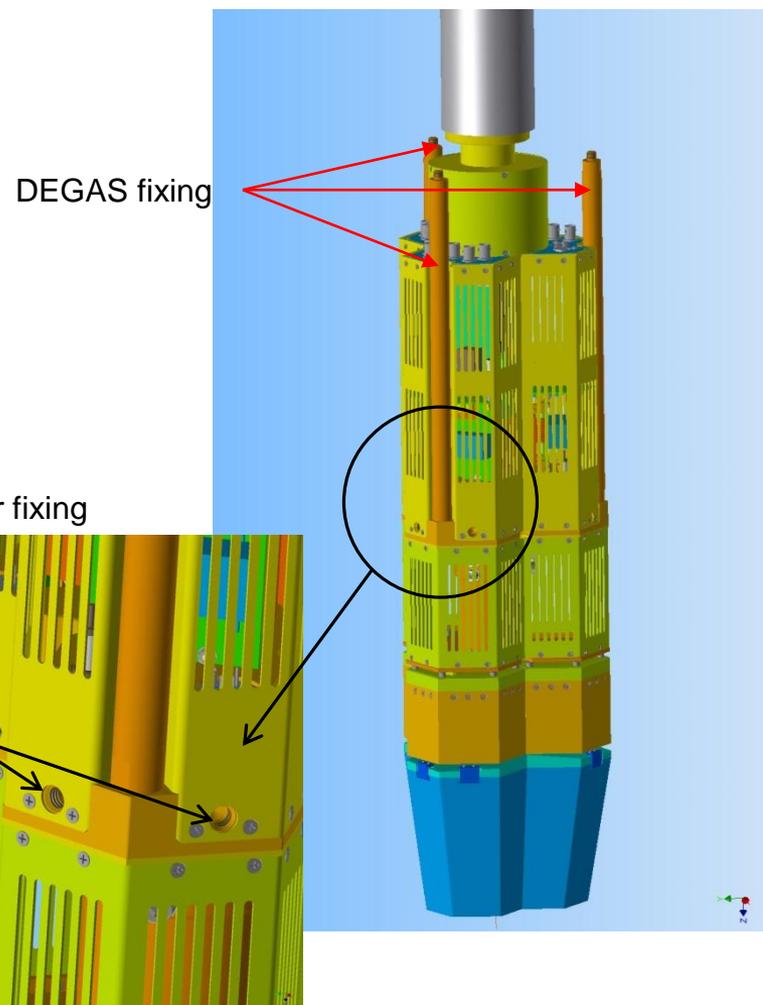


I. Kojouharov, GSI, Darmstadt

3. DEGAS detector



Cluster Detector fixing



DEGAS fixing

2 x M8

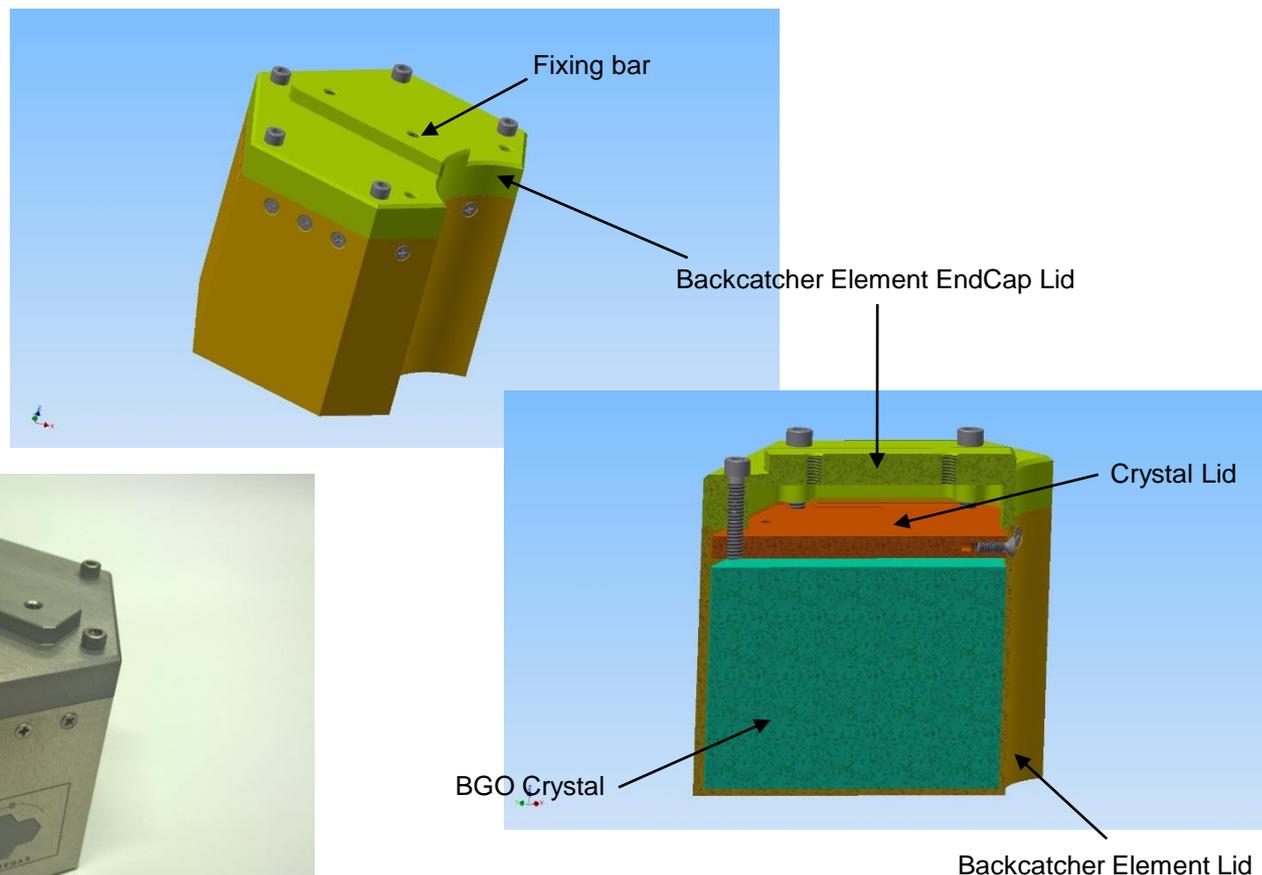
DEGAS – the HPGe array spectrometer for NUSTAR



I. Kojouharov, GSI, Darmstadt

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 foresees 3 separate and autonomous backcatcher elements hanging on the Bottom Deck of the cryostat.

DEGAS – the HPGe array spectrometer for NUSTAR

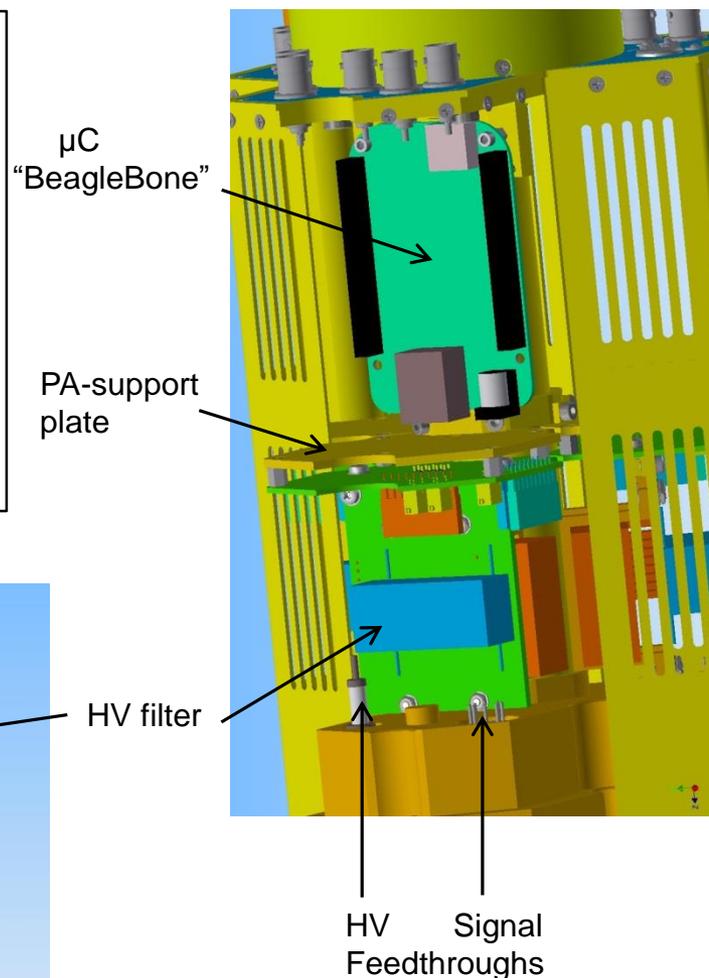


I. Kojouharov, GSI, Darmstadt

3. DEGAS detector – the Front-End Electronics

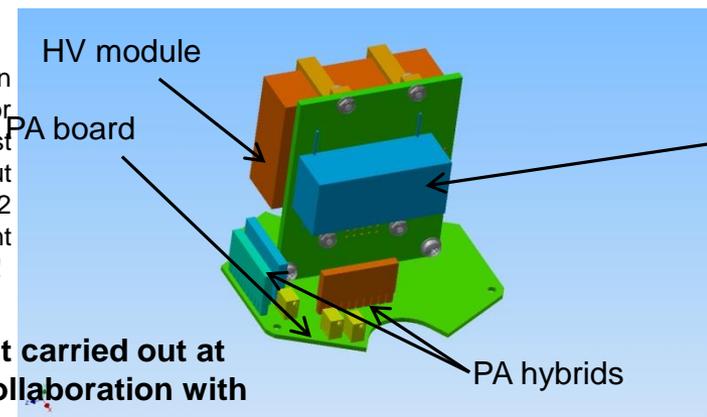
Specifications of the AGATA preamplifiers available for DEGAS and the intended improvements.

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 μ s	50 μ s
Integral non-linearity	< 0.025%	same
Output polarity	Differential, Z = 100 Ohm	same
Fast reset speed	\approx 10 MeV/ μ s	same
Integrated pulser	yes	no
Power supply	\pm 6.5 V, \pm 12.5 V	\pm 6 V, \pm 12 V, \pm 24 V
Power consumption	< 980 mW	< 500 mW
Dimensions	62 x 45 x 7= 19530mm ³	< 50000 mm ³



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. Transistor Reset ???



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

DEGAS – the HPGe array spectrometer for NUSTAR

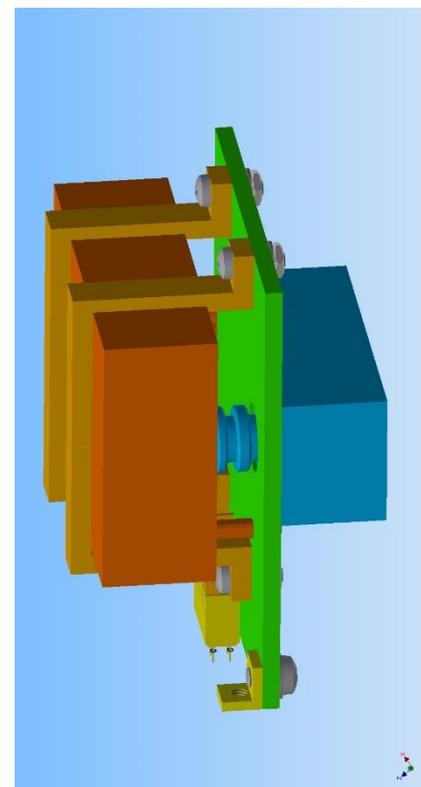


I. Kojouharov, GSI, Darmstadt

3. DEGAS detector – the Front-End Electronics

Technical Data	BPx ¹	60 504 12
Nominal output voltage	²¹ X = p:	+ 6000
V _{NOM} [V] ²	²¹ 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} ; 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} ≤ 0,5mA	
Control on VSET	1 st : Remote control with an ext. potentiometer (10 - 100kΩ) between REF and GND, sliding contact on VSET 2 nd : with analogue control voltage V _{SET} $0 \leq V_{SET} \leq 5 V \Rightarrow 0 \leq V_{OUT} \leq V_{NOM} \pm 1\%$	
/ON signal	TTL-level, HIGH = active \Rightarrow HV = 0, LOW or open \Rightarrow HV according V _{SET}	
Monitor voltage V _{MON} (R _I = 10k)	$0 \leq V_{OUT} \leq V_{NOM} \pm 1\% \Rightarrow 0 \leq V_{MON} \leq 5 V$	
Monitor voltage I _{MON} (R _I = 10k)	$0 \leq I_{OUT} \leq I_{NOM} \pm 2\% \Rightarrow 0 \leq V_{MON} \leq 5 V$	
Operating temperature	0 ... +40 °C	
Storage temperature	-20 ... +60 °C	

HV module



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 μ PC (directly) or via HadCon 2 board. Remote monitoring – 1V voltage sensitivity, 1-10 nA current sensitivity (ADC dependent).



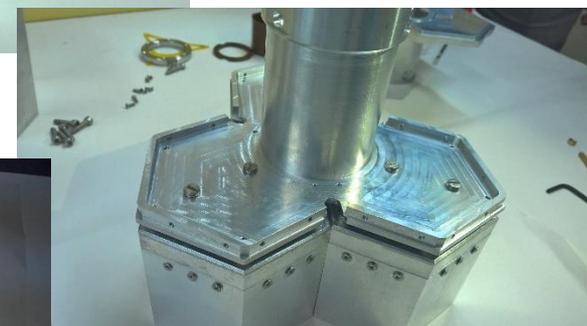
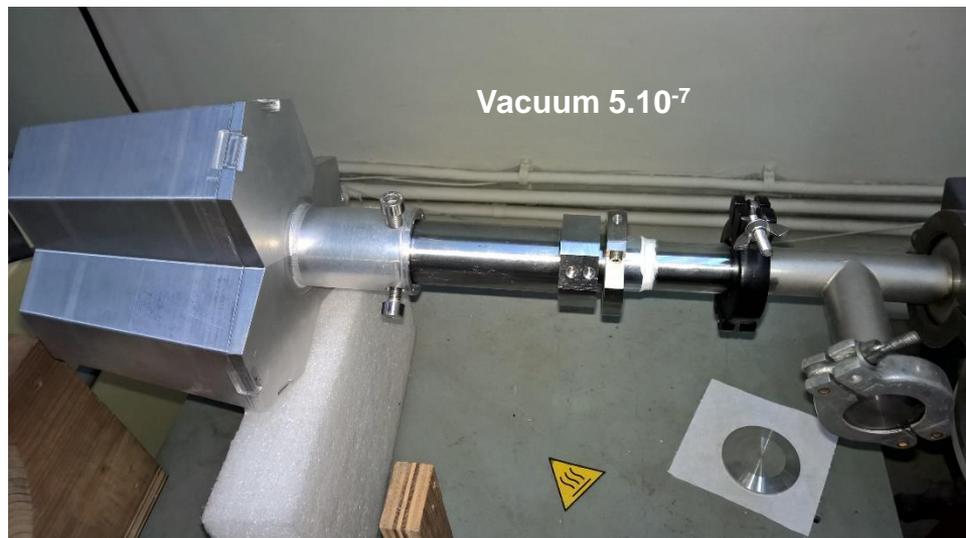
3. DEGAS detector – the Slow Control and Monitoring

- Based on BeagleBone μ Computer
- 20 Analogue Inputs (8 Temperatures), 5 ADC
- 15 Digital Inputs (1 Bit)
- 21 Digital Outs (1 Bit)
- 6 I²C Outs (Digital Poti's)
- EPICS Software Platform
-
- Development carried out at HIM – Mainz, Germany
(Collaboration with PANDA and Hypernuclei Spectroscopy Group)

DEGAS – the HPGe array spectrometer for NUSTAR

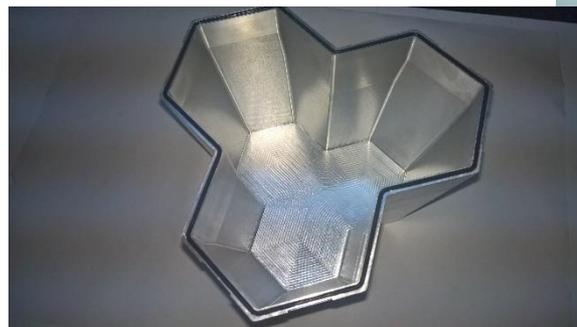


I. Kojouharov, GSI, Darmstadt



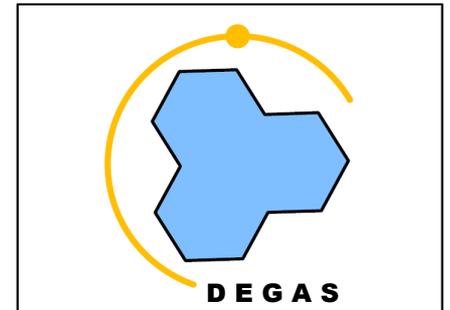
First mechanics test, TIFR, Mumbai, India, February 2016

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



DEGAS – the HPGe array spectrometer for NUSTAR

I. Kojouharov, GSI, Darmstadt



Thank you