The HISPEC/DESPEC project at FAIR

HISPEC – High-resolution in-flight spectroscopy
DESPEC – Decay spectroscopy

Zsolt Podolyák
PAC (March 2005) results : HISPEC DESPEC

The PAC feels that the value of the science is indisputable and an important component of research at the future FAIR facility. The need for the measurements in this proposal is high.

For intermediate energies, HISPEC uses methods that are technically feasible and will benefit from the implementation of the forward fraction of AGATA. The experiments are well conceived and should produce excellent physics.

DESPEC is a natural exploitation of the rare exotic nuclei beams that emanate from FAIR. Decay spectroscopy of new nuclei is one of the key elements of exotic nucleus research. The experiments will employ highly segmented detectors to overcome the problem of gamma-flash from the degrading foil that slows the beams to 10 MeV/u, which will affect the performance in the sub-ms half life regime. It is noted that the distance to the final slowing down foil can be of the order of 10 meters which should lessen the effect of the photon shower and possibly allow standard clover detectors to be used in place of the complex highly segmented system. The design of the segmented gamma- and the high-resolution neutron-detector arrays should be pursued with high priority.
However, for low energies, there are several perceived problems in the experimental configuration as proposed. In particular, beam identification at 5 MeV/u is an area that requires considerable R&D. The beam characteristics will impact the design of any subsequent detector array and beam tracking/identification system. Despite initial simulations, there is evidently significantly more work that has to be done in this area. Further simulations and design studies depend crucially on the progress of the LEB design. Another possibility to improve the low energy beam quality is to use cooled and slowed down beams from the NESR. Studies of this possibility must take into account the fairly long slowing down times to Coulomb Barrier energies (ca. 60 s, which, though would still enable 68Ni and 132Sn beams). The collaboration has made the case for a large solid angle magnetic spectrometer; however, this case is too general and does not specify which physics problems it will address. The spectrometer also has to adapt to the large momentum spread of any recoil products. This proposal should have laid out a better structure for the development of the technically challenging instrumentation for slowed down beams. It is important that this R&D be pursued, but a better framework has to be found, and the collaboration should work more cohesively towards this direction. It should be noted, though, that the collaboration is very large and diverse and represents a large number of areas of particular expertise.
Overall, the HISPEC/DESPEC proposal is unique to FAIR for exotic nuclei that cannot be produced in reasonable quantities at other fragmentation facilities or for refractory elements that cannot be produced at ISOL facilities. Additionally, the high energy part of HISPEC is unique to FAIR for exotic nuclei that cannot be produced in reasonable quantities at other fragmentation facilities and for the study of double fragmentation. The present RISING program at the FRS provides an excellent R&D study ground for the key design problems of the entire proposal.

This proposal is on track for 2010 except for the low-energy part of HISPEC that needs considerable R&D, and design work. This part of the proposal would benefit from an early and clear definition of the beam quality and parameters following degrading to Coulomb barrier energies. There is a close connection between the beam specifications, the design of the beam identification and tracking system, the civil engineering for the experimental area, and the space requirements. These issues must be addressed promptly and in a coordinated way.
<table>
<thead>
<tr>
<th>Part of the basic research program as defined by the CDR</th>
<th>✓</th>
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<tbody>
<tr>
<td>Part of the core experimental facility of FAIR</td>
<td>yes</td>
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</table>

The experiment is approved, on the basis of the LOI and the TP, to work towards the TDR. The approval of the low energy part depends on the resolution of the open issues.
HISPEC (Technical proposal 2005)
DESPEC (Technical proposal 2005)

NEUTRON DETECTOR

GE $\gamma$-ARRAY

RADIOACTIVE BEAM

DSSD IMPLANTATION DETECTOR
## NUSTAR – The project

<table>
<thead>
<tr>
<th>PSP</th>
<th>Experiment</th>
<th>Description</th>
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<tbody>
<tr>
<td>1.2.2</td>
<td>HISPEC/DESPEC</td>
<td>In-beam $\gamma$-spectroscopy at low and intermediate energy, n-decay, high-resolution $\gamma$, $\beta$, $\alpha$, p-, spectroscopy</td>
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<tr>
<td>1.2.3</td>
<td>MATS</td>
<td>In-trap mass measurements and decay studies</td>
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<td>1.2.4</td>
<td>LaSpec</td>
<td>Laser spectroscopy</td>
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<td>1.2.5</td>
<td>R$^3$B</td>
<td>Kinematical complete reactions with relativistic radioactive beams</td>
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<td>1.2.6</td>
<td>ILIMA</td>
<td>Large-scale scans of mass and lifetimes of nuclei in ground and isomeric states</td>
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<td>1.2.10</td>
<td>Super-FRS</td>
<td>High-resolution spectrometer experiments</td>
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<tr>
<td>1.2.11</td>
<td>SHE</td>
<td>Synthesis and study of super-heavy elements</td>
</tr>
<tr>
<td>1.2.8</td>
<td>ELISe(*)</td>
<td>Elastic, inelastic, and quasi-free e$^-\cdot$A scattering</td>
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<tr>
<td>1.2.9</td>
<td>EXL(*)</td>
<td>Light-ion scattering reactions in inverse kinematics</td>
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</table>

(*) NESR required – alternative/intermediate “operation” within MSV under discussion. SHE physics case to be evaluated.
## Complementarity of NUSTAR experiments

<table>
<thead>
<tr>
<th>Super-FRS</th>
<th>HISPEC/DESPEC</th>
<th>LASPEC</th>
<th>MATS</th>
<th>R3B</th>
<th>ILIMA</th>
<th>SHE</th>
<th>ELISe</th>
<th>EXL</th>
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<tbody>
<tr>
<td><strong>Masses</strong></td>
<td>Q-values, isomers</td>
<td>dressed ions, highest precision</td>
<td>unbound nuclei</td>
<td>resonance width, decay up to 100ns</td>
<td>bare ions, mapping study</td>
<td>precision mass of SHEs</td>
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<tr>
<td><strong>Half-lives</strong></td>
<td>ps...ns-range</td>
<td>dressed ions, s...s</td>
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<tr>
<td><strong>Matter radii</strong></td>
<td>interaction x-section</td>
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<td><strong>Charge radii</strong></td>
<td>charge-changing cross sections</td>
<td>mean square radii</td>
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<tr>
<td><strong>Single-particle structure</strong></td>
<td>high resolution, angular momentum</td>
<td>high-resolution particle and γ-ray spectroscopy</td>
<td>magnetic moments, nucl. spins</td>
<td>evolution of shell str., pairing int., valence nucl.</td>
<td>quasi-free knockout, short-range and tensor</td>
<td>evolution of shell closures, pairing corr.</td>
<td>shell structure of SHEs</td>
<td>low momentum transfers</td>
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<tr>
<td><strong>Collective behavior</strong></td>
<td>electromag. transitions</td>
<td>quadrupole moments</td>
<td>halo structure</td>
<td>dipole response</td>
<td>changes in deformation</td>
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<td>electromag. transitions</td>
<td>monopole resonance</td>
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<td><strong>EoS</strong></td>
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<td>polarizability, neutron skin</td>
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<td>neutron skin, Compressibility</td>
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<td><strong>Exotic Systems</strong></td>
<td>bound mesons, hypernuclei, nucleon res.</td>
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Exploring the extremes with NUSTAR@FAIR
Scenario for phase 0 and phase 1 operation

<table>
<thead>
<tr>
<th>Year</th>
<th>Super-FRS construction and installation</th>
<th>NUSTAR caves civil construction</th>
<th>NUSTAR experiments construction and operation “outside” FAIR</th>
<th>Phase 0 installation</th>
<th>Phase 0 commissioning</th>
<th>Phase 1 operation</th>
<th>Phase 1 operation at FAIR</th>
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<tbody>
<tr>
<td>2015</td>
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Exploring the extremes with NUSTAR@FAIR
Low-energy branch building added to MSV following a FAIR re-evaluation
**Detectors (funding for Phase 1):**

<table>
<thead>
<tr>
<th>Detector</th>
<th>Funding Percentage</th>
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<tbody>
<tr>
<td>LYCCA</td>
<td>100%</td>
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<tr>
<td>Plunger</td>
<td>100%</td>
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<tr>
<td>AIDA</td>
<td>100%</td>
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<tr>
<td>DEGAS</td>
<td>87% (740 kEUR not secured)</td>
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<tr>
<td>FATIMA</td>
<td>97% (25 kEUR not secured)</td>
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<tr>
<td>BELEN</td>
<td>100%</td>
</tr>
<tr>
<td>MONSTER</td>
<td>79% (261 kEUR not secured)</td>
</tr>
<tr>
<td>DTAS</td>
<td>88% (50 kEUR not secured)</td>
</tr>
</tbody>
</table>
Missing funds for:

Infrastructure,
DEGAS phase 2,
MONSTER
γ-ray spectroscopy at GSI (and FRS)

PreSPEC phase

LYCCA-D

commissioning of new HISPEC/DESPEC equipment via inclusion in experiments

AGATA 2012-2014
RISING $\gamma$-array for fast beams

Typically: 100MeV/u, $\varepsilon_{\gamma}=0.06$, $\Delta E_{\gamma}/E_{\gamma}=0.02$
4 clusters with BGO anticompton shields and short collimators
4 clusters with the former RISING shields
Total efficiency (Eu source) = 1.9 – 2.3 %
Stopped Rising Array @ GSI: 15 x 7 element CLUSTERs

$\varepsilon_v = 11\%$ at 1.3 MeV, 20\% at 550 keV, 35\% at 100 keV

flight time $\sim 300\text{ns}$
Passive stopper:
For isomeric decays, $T_{1/2} < 1$ ms
Active stopper: correlation between implantation and charged particle decay

5 cm x 5 cm DSSSD (16 strips by 16 strips = 256 pixels)
3 positions across focal plane, room for 3 detectors deep.
AGATA + HECTOR + LYCCA

LYCCA

AGATA

Hector

**AGATA**

Tracking array

3x2 + 6x3 crystals

R = 12 – 22 cm

$\varepsilon_{ph} = 5 - 9\%$

$\Delta E = 0.4 - 1.2\%$
AGATA demonstrator at GSI (Germany) ~20 crystals
HISPEC: high-resolution in-flight spectroscopy

Time of flight measurement: diamond, Si or plastic?
LYCCA TOF solutions:

Plastic-plastic:
\[ \Delta t \text{ (FWHM)} = 61 \text{ ps} \Rightarrow 43 \text{ ps for one detector} \hspace{1cm} \text{(requirement=}100\text{ps}) \]
\[ \Delta A \text{ (FWHM)} = 0.5 \]

This is within specifications and this solution is used in the AGATA campaign.

Diamond-plastic:
Home made diamond:
\[ \Delta t \text{ (FWHM)} < 100 \text{ ps for high } Z \]
F. Schirru et al., J. of Instr. 7, P05005(2012)
Mass abundances depend on the detailed structure of N=126 nuclei around the 3rd r-process waiting point.

DESPEC will measure:
- β-lifetimes
- neutron-branchings
- strength distributions
- level structure

Physics workshop held in September 2016
Focus on heavy neutron-rich nuclei
\(^{208}\text{Pb}\) and \(^{238}\text{U}\) beams
Several detector systems ready:
DTAS, FATIMA, AIDA, DEGAS, BELEN

DESPEC in 2018-2020 (phase 0)

\[ \text{old } T_{1/2} \text{ predictions} \quad \text{new } T_{1/2} \text{ predictions} \]

Abundance

\[ 10^6 \quad 10^7 \quad 10^8 \]

130 140 150 160 170 180 190 200 A

3rd. waiting point
Secondary beam intensities at NuSTAR

- ♠ isotopes of all elements (0 MeV/u < E < 2 GeV/u)
- ♥ ions with short lifetimes (>100 ns)
- ♣ isomeric beams
- ♦ storage rings
RARE-ISOTOPE BEAM FACILITIES

Element number

Energy, MeV/u

90% of fully-stripped ions

Fusion barrier with U

TRIUMF/ISAC2

HIE-ISOLDE, SPIRAL2

JINR/Acculinna2

LNS-INFN

NSCL/A1900

GANIL

FRIB

RIKEN/BigRIPS

GSI/FRS

FAIR/Super-FRS

RARE-ISOTOPE BEAM FACILITIES
Experimental considerations

- fragmentation/spallation of $^{238}$U, $^{208}$Pb ($^{209}$Bi)
  fragmentation: GSI/FAIR, (RIKEN)
  spallation: ISOLDE

- multinucleon transfer on $^{208}$Pb ($^{198}$Pt)
  with particle identification (thin target)
  without particle identification (thick target)
  RIKEN, GANIL, ANL
Neutron-rich nuclei from $^{136}$Xe+$^{198}$Pt

![Graph showing cross sections for Hg and Os isotopes.](image)

**FIG. 2** (color online). Experimentally deduced (open circles) and calculated by GRAZING (histograms) cross sections for Hg (left) and Os (right) isotopes. Isotopic distributions for different windows of total kinetic energy loss from $-25$ to $25$ MeV and from $175$ to $225$ MeV are indicated by different filled symbols of circles and squares, respectively.

Isomeric states (from fragmentation)

- 208Hg, 209Tl

N. Aldahan et al., PRC80, 061302(R) (2009).


- Isomeric state

RISING: isomeric decays
Beta decay

A.I. Morales et al., PRC 88 (2013) 014319
N. Alkhomashi et al., PRC 80 (2009) 064308

T1/2: G. Benzoni et al., PLB 715 (2012) 293
A.I. Morales et al., PRC 89 (2014) 014324

N. Al-Dahan et al., PRC 85 (2012) 034301
N. Alkhomashi et al., PRC 80 (2009) 064308

implanted decay into
The most neutron-rich $N=126$ for which lifetime was measured is $^{204}$Pt.
At the beginning (2018) lower beam intensity
⇒ start with equipment never used at GSI:
DTAS+AIDA
Active Si stopper used at RIKEN, where 2-mm thick 65 x 45 mm² plastic detectors were sandwiching 5 Si DSSSDs, with an estimated efficiency of 30%. On the right hand side a sketch of the implantation segmented fast plastic is shown.
And later (with higher beam intensities):
DEGAS +AIDA + (FATIMA)

Detector capsule, cooling engine and high-voltage control board
DESPEC in 2018-2020 (phase 0)

Physics workshop held in September 2016
Focus on heavy neutron-rich nuclei
$^{208}\text{Pb}$ and $^{238}\text{U}$ beams
Several detector systems ready:
DTAS, FATIMA, AIDA,
DEGAS, BELEN

- old $T_{1/2}$ predictions
- new $T_{1/2}$ predictions

9 (+1) proposals
241 shifts requested

parasitic beam during beam development (months before exps.)
GPAC on 19-21 Sept. 2017