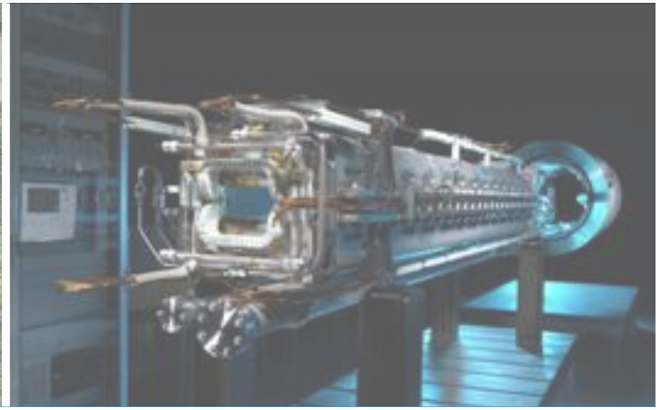


Exploring the extremes with NUSTAR @ FAIR

Nasser Kalantar-Nayestanaki
KVI-CART/University of Groningen

NUSTAR Annual Meeting

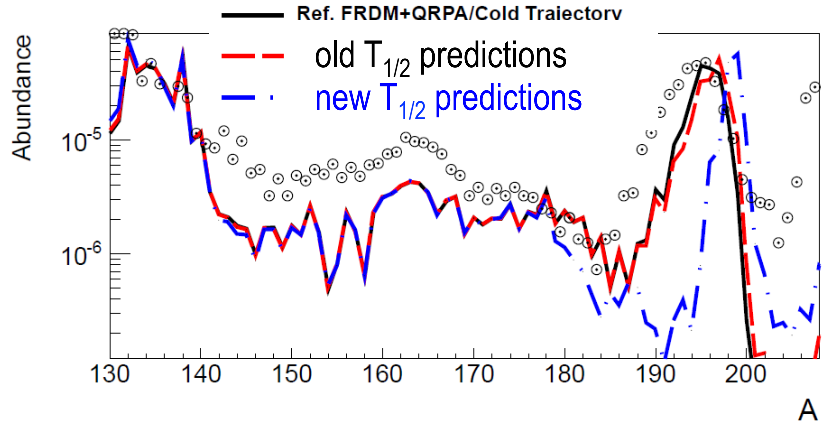
Darmstadt, Germany, February 28, 2018

Finland France Germany India Poland Romania Russia Slovenia Sweden UK

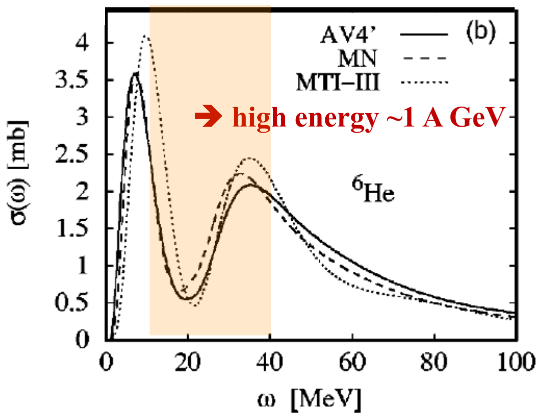
The Physics Program

Spear points of NUSTAR Phase 1

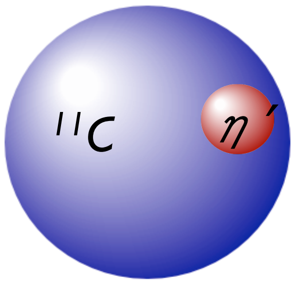
- Heavy nuclei, 3rd r-process peak



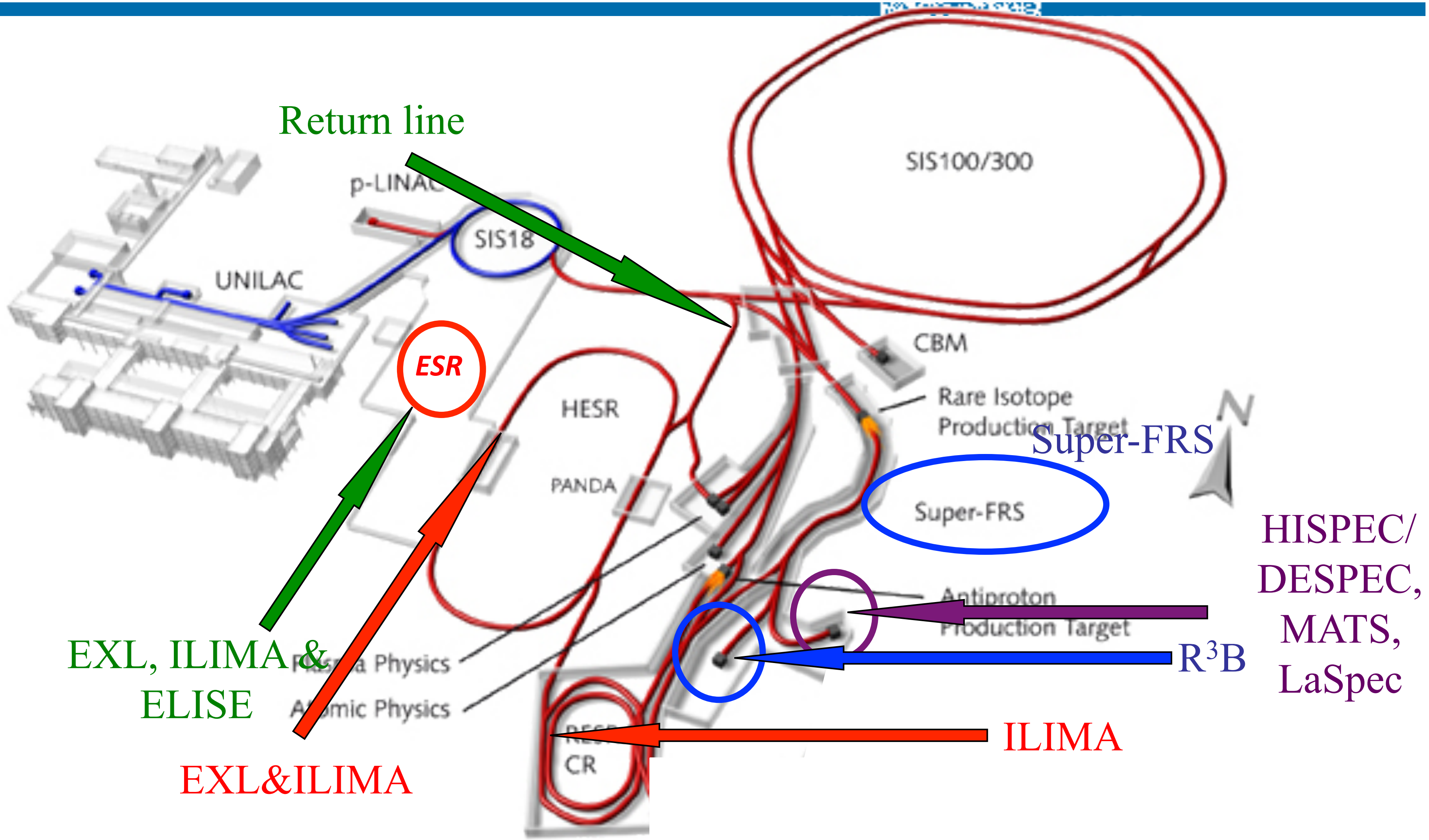
- High excitation energies



- Study of exotics



MSV and consequences for NUSTAR



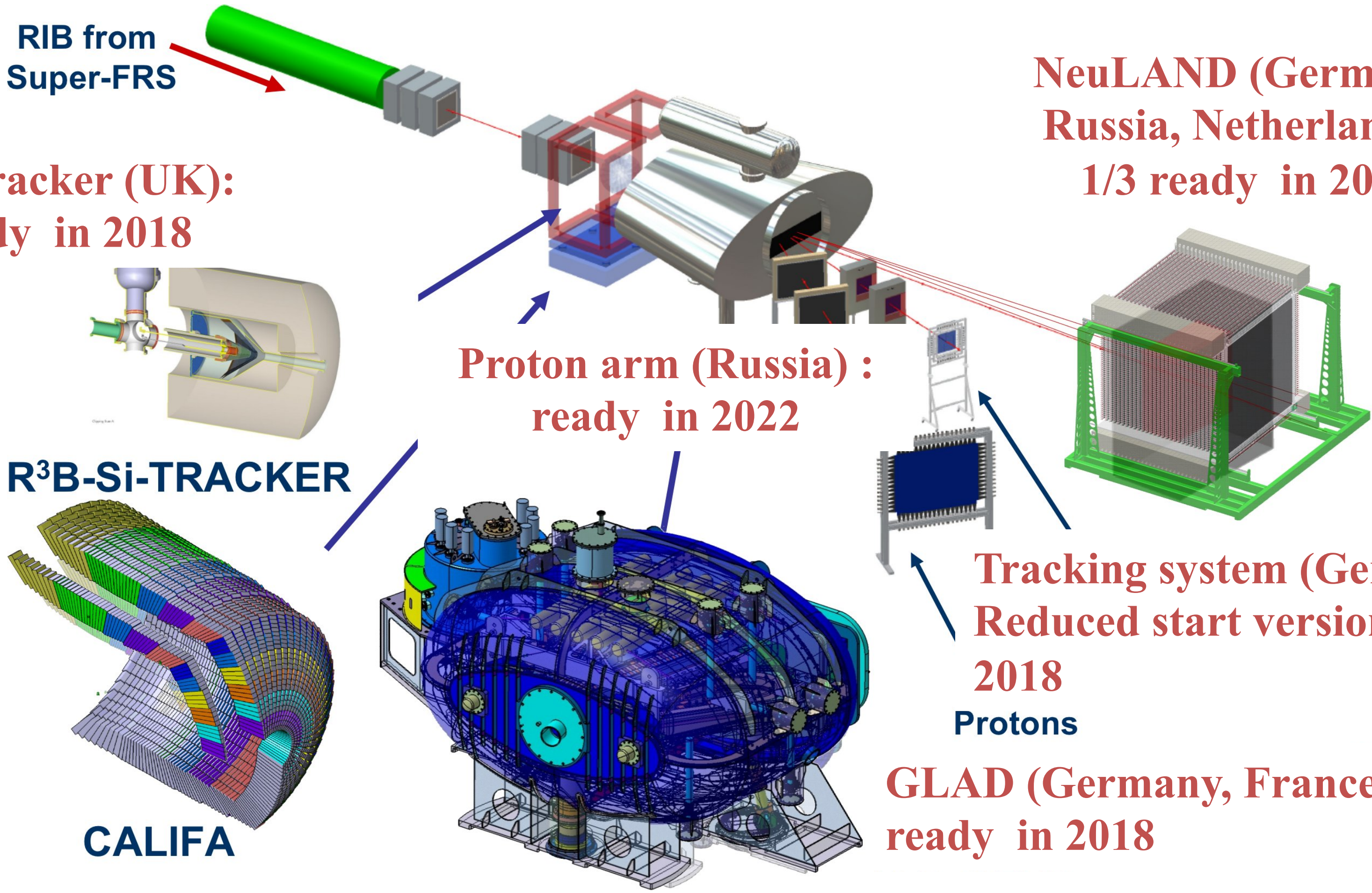
Strategy

Definition of NUSTAR experiment phases

- **Phase 0**
  - R&D and experiments to be carried out with present facilities and FAIR/ NUSTAR equipment
- **Phase 1**
  - Core detectors and subsystems completed
  - First measurements with FAIR/Super-FRS beams
  - ➢ **Carry out experiments with highest visibility as part of the core program and within the FAIR MSV**
- **Phase 2**
  - FAIR evolving towards full power
  - Completion of experiments within MSV
  - ➢ **Essentially the full program of MSV can be performed**
- **Phase 3**
  - Moderate projects, which have been initiated on the way (outside MSV) can be included (e.g. experiments related to return line for rings)
- **Phase 4**
  - Major new investments and upgrades for all experiments

R^3B

Start version for Phase 0 (Status 2018)



NeuLAND (Germany, Russia, Netherlands): 1/3 ready in 2018

Si tracker (UK): ready in 2018

Proton arm (Russia) : ready in 2022

Tracking system (Germany): Reduced start version ready in 2018

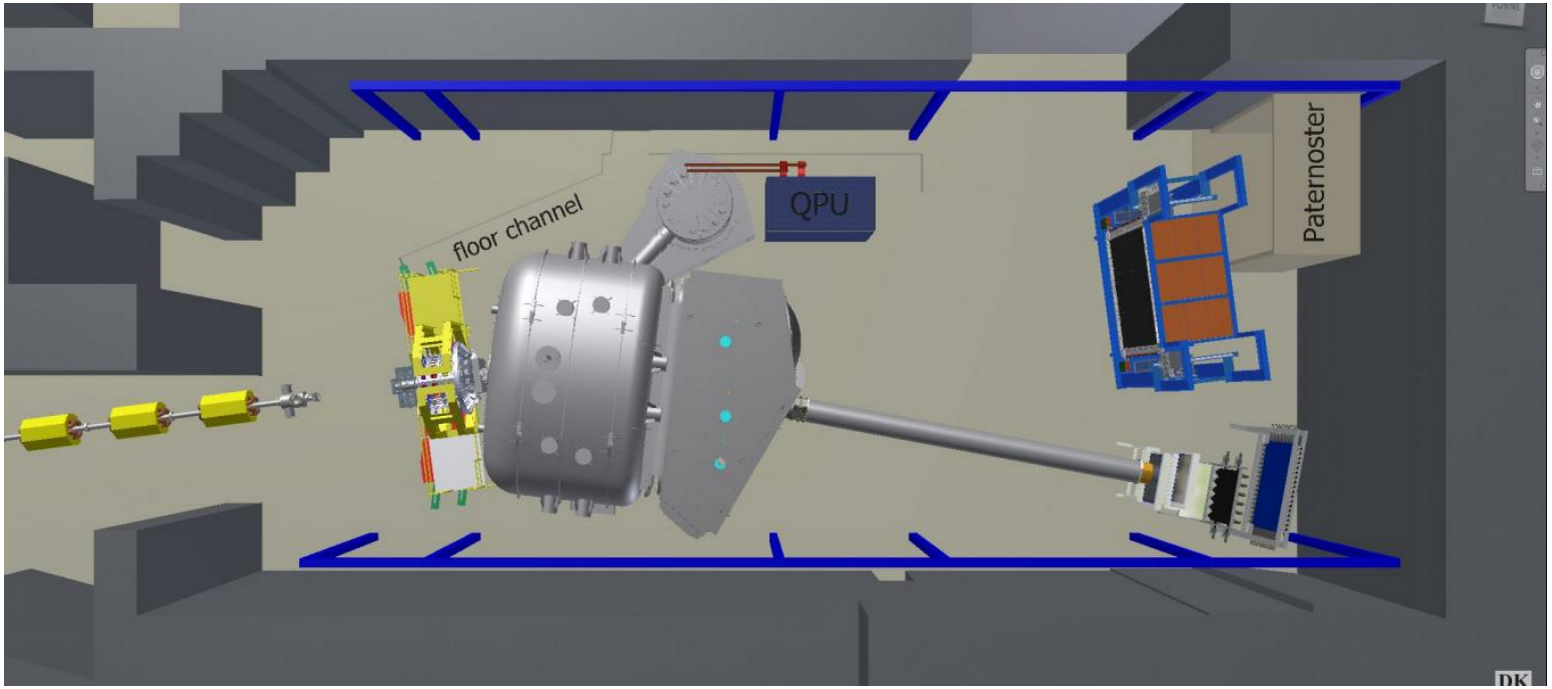
GLAD (Germany, France): ready in 2018

CALIFA (Sweden, Spain, Germany, Russia):
Barrel without backward part ready in 2018
Frontcap missing! -> part of the program delayed

Recent Achievements

Modifications in Cave C to accomodate R³B equipment for FAIR Phase-0

- Target area (CALIFA+ LT3)
- GLAD (including Vaccuum chamber)
- NeuLAND
- Tracking detectors (beampipe)



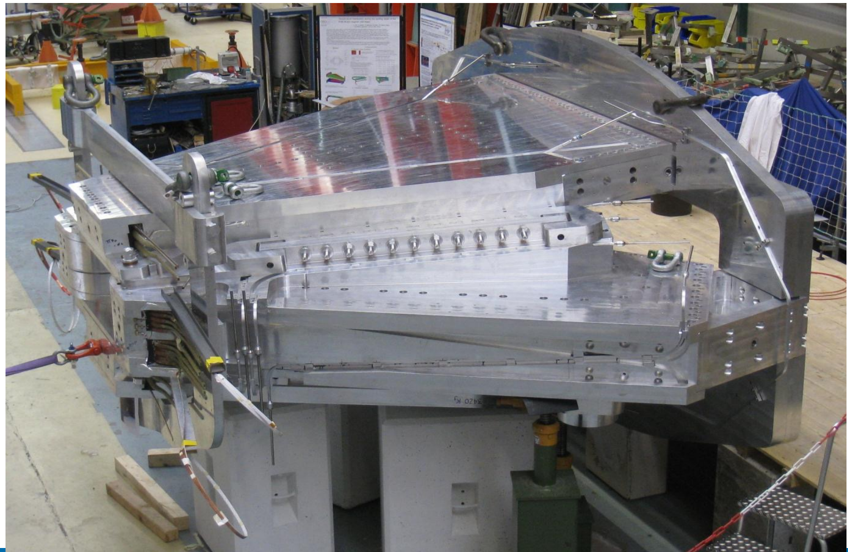
5 experiments approved by GSI-PAC (October 2017) for realization during the 2018/2019 period (85 shifts main beam + 34 shifts parasitic beam).

Recent Achievements

- Detection set-up implementation

Magnet parameters:
- Large vertical gap ± 80 mrad
- High integrated field of 4.8 Tm. Fringe field at the target position less than 20 mT
- Operational temperature 4.6 K

GLAD
- Installation in Cave C 2016/2017
- First cooling down started in Spring 2017
- Present status:
  - ✓ verification of the cryogenic plant parameters completed
  - ✓ identification and correction of different problems (small flow)
  - ✓ Some open issues are still under investigation : limit in busbar cooling flow

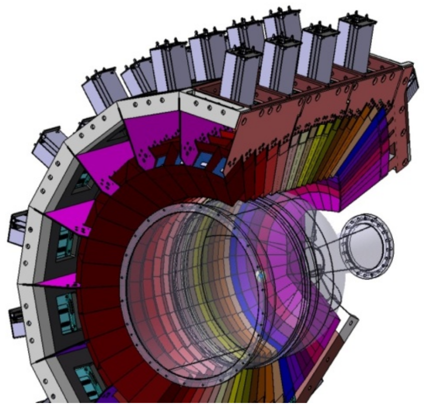


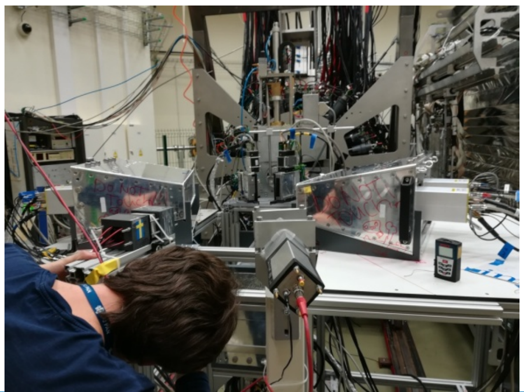
Recent Achievements

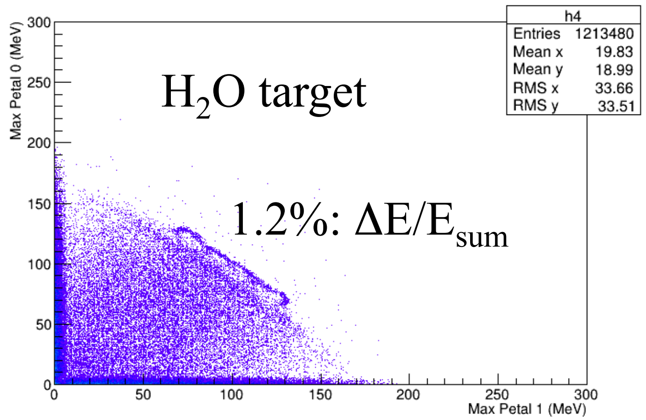
CALIFA

- Construction phase 2017
  - Demonstrator (20% detector) available for Phase 0 experiments
  - Barrel stage 1&2 and Endcap expected for 2020
    (Nustar-R3B JINR Contract, BMBF 2017 funds, Mineco 2017 funds)
- Nov. 2017 Successful test of Barrel prototypes: Efficiency and detector response using $^{16}O(p,2p)$ in direct knematics @ Cracow proton cyclotron

Photo Peak Eff.	40% (up to Eγ=15 MeV projectile frame)
Calorimeter for HE LCP	200-700 MeV in lab system
ΔE/E	~5-6% (FWHM at Eg=1 MeV), ~ 3% forward
LCP resolution	~2% (stopped particles), ~ 5% (punch through)





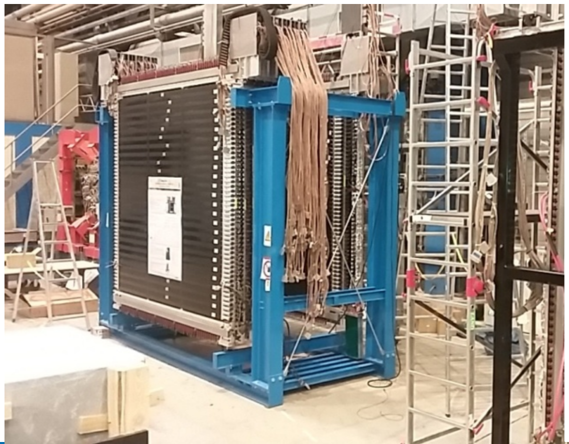


Recent Achievements

NeuLAND

- NeuLAND demonstrator back from RIKEN after participation in 9 experiments, incl. studies of light exotic systems (4n) up to EOS of heavy tin systems
- Production ongoing → version for phase 0 (130 cm active depth, 2600 channels, >40% detector)
- Series production of GSI developed NeuLAND electronics underway: multichannel FEE card TAMEX for high-resolution time and charge measurements

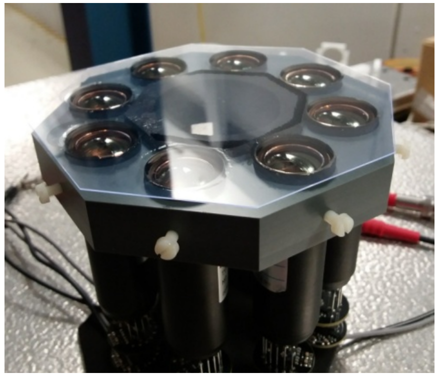
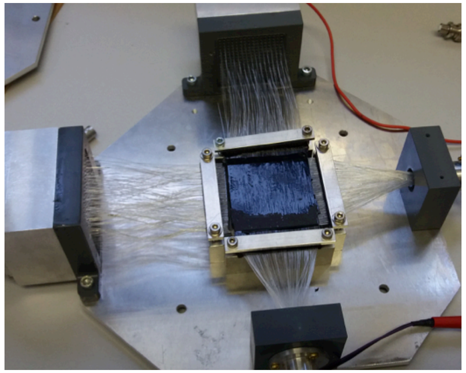
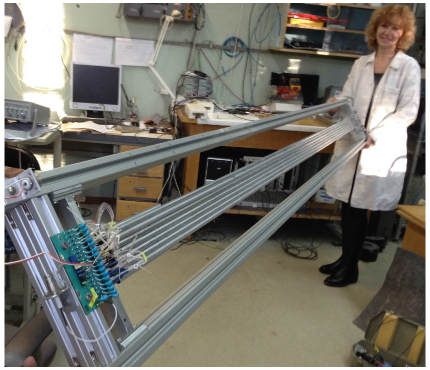
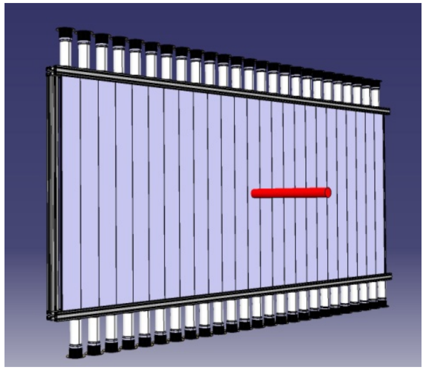
Efficiency 0.2-1.0 GeV n	**> 90%**
Multi-hit	Up to 5 neutrons
Invariant mass resolution	ΔE < 20 keV at 100 keV above threshold



Recent Achievements

Tracking detectors

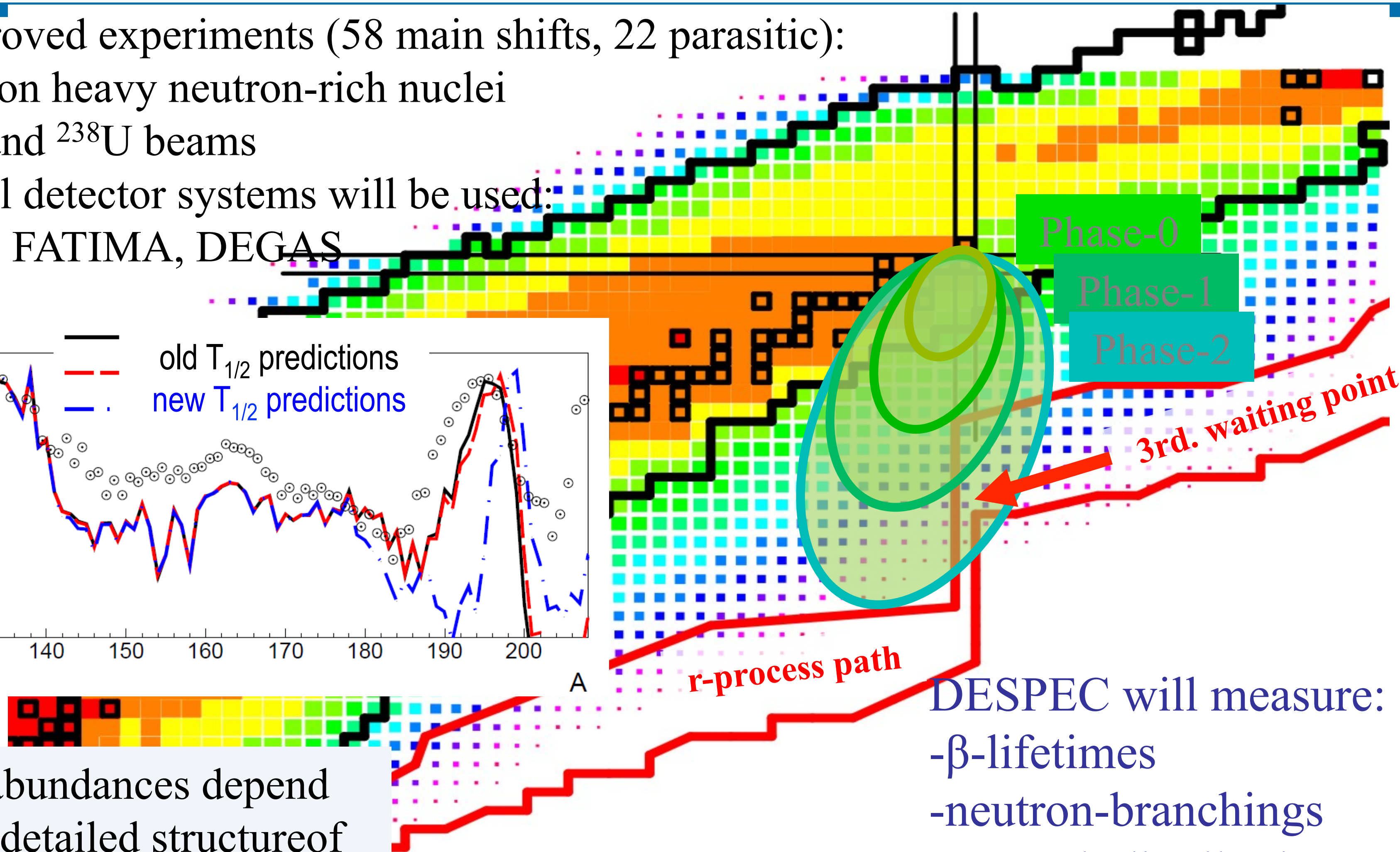
- Good progress on beam and fragment tracking detectors
  - Beam tracking: Improved design of LOSS detector, good performances of SSD detectors.
  - Fragment Arm: Construction of a MUSIC detector for heavy fragment tracking before GLAD. Feasibility tests of Scintillation Fiber detectors construction. Construction of Plastic Scintillation ToF Wall in progress.
  - Proton Arm → Promising preliminary results of a Proton Arm spectrometer (Straw tubes) PAS prototype. Complete design of scintillator-based proton-trigger PTOF (2 layer Plastic scintillators)

HISPEC/DESPEC

DESPEC in 2018-2020 (phase-0)

5 Approved experiments (58 main shifts, 22 parasitic):
Focus on heavy neutron-rich nuclei
^{208}Pb and ^{238}U beams
Several detector systems will be used:
AIDA, FATIMA, DEGAS

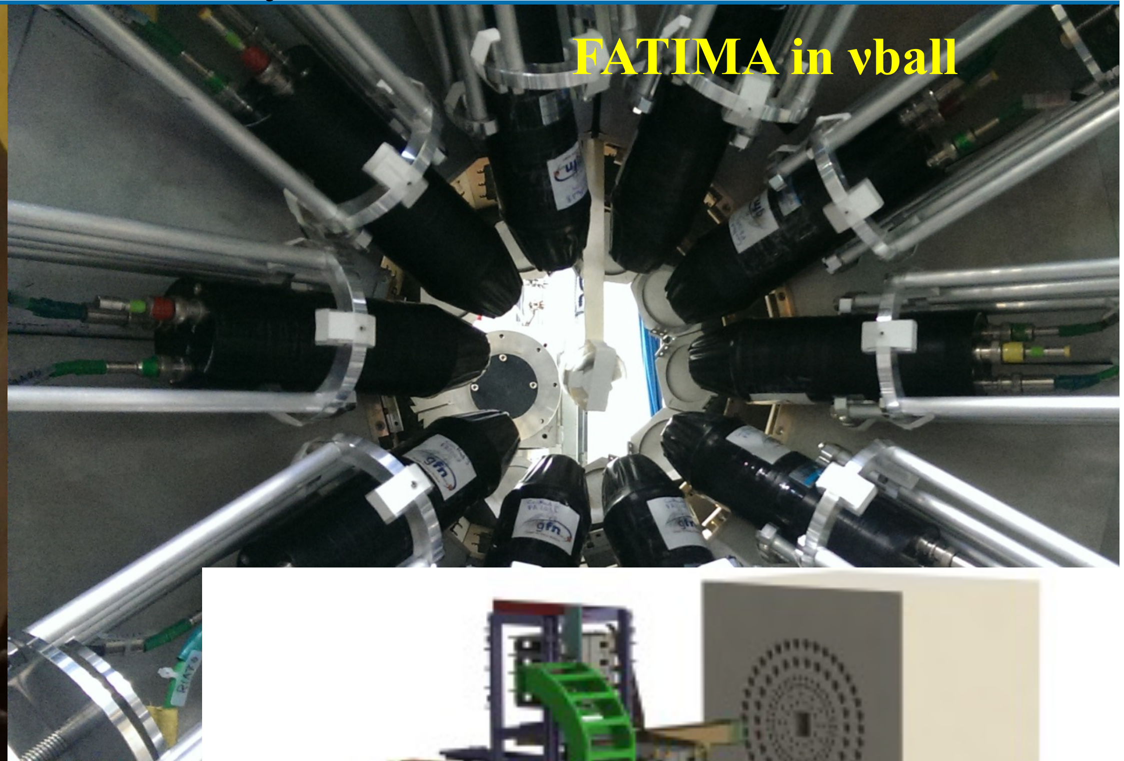


Mass abundances depend on the detailed structureof N=126 nuclei around the 3rd r-process waiting point

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

DESPEC (FAIR Phase-0) campaign at other labs

FATIMA fast-timing array in GANIL and Orsay, France

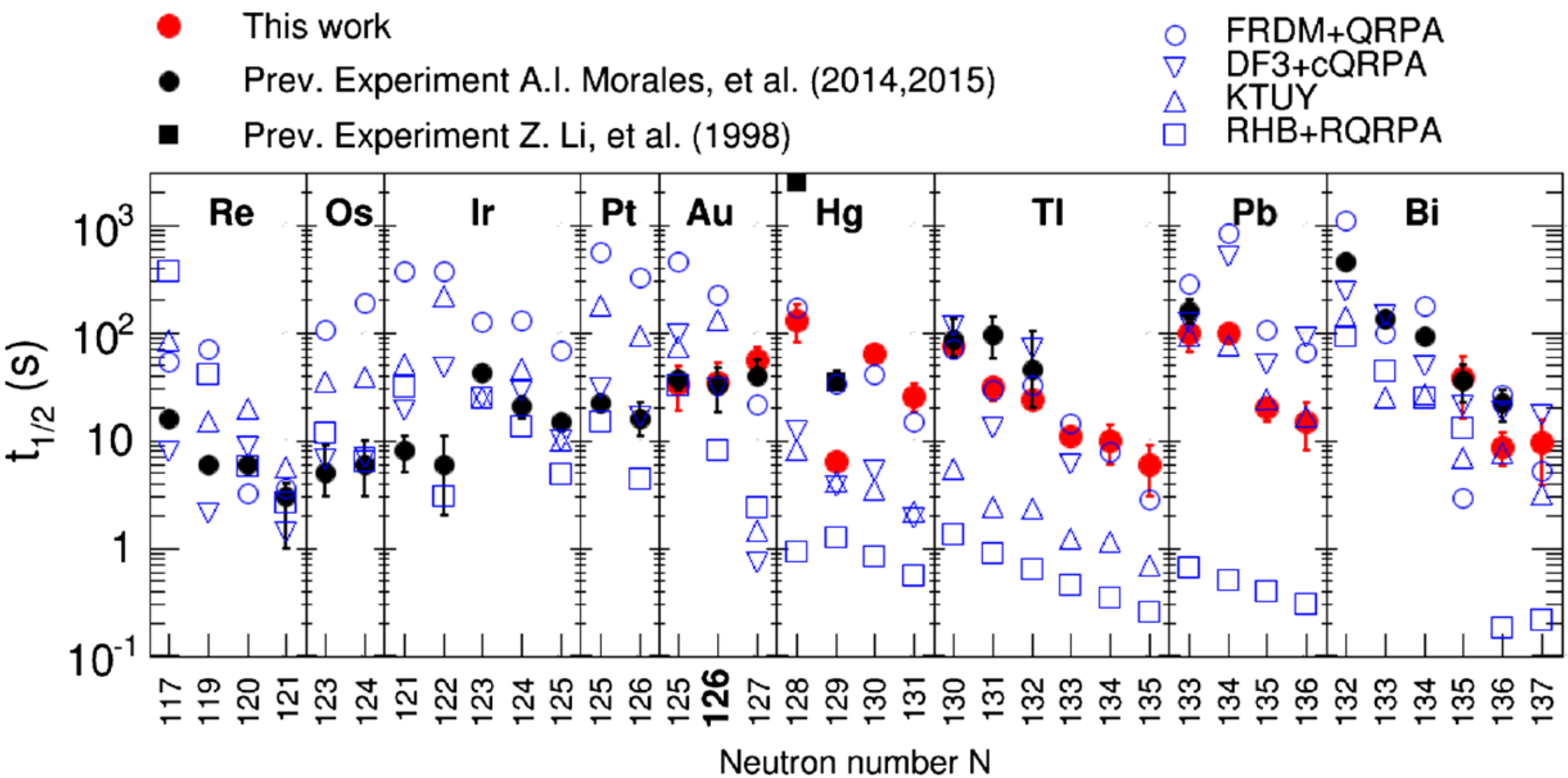


AIDA implantation and decay detector
and
BELEN neutron counter
in RIKEN, Japan

First Measurement of Several β-Delayed Neutron Emitting Isotopes Beyond $N = 126$

R. Caballero-Folch,[1,2] C. Domingo-Pardo,[3,*] J. Agramunt,[3] A. Algora,[3,4] F. Ameil,[5] A. Arcones,[5] Y. Ayyad,[6] J. Benlliure,[6] et al.

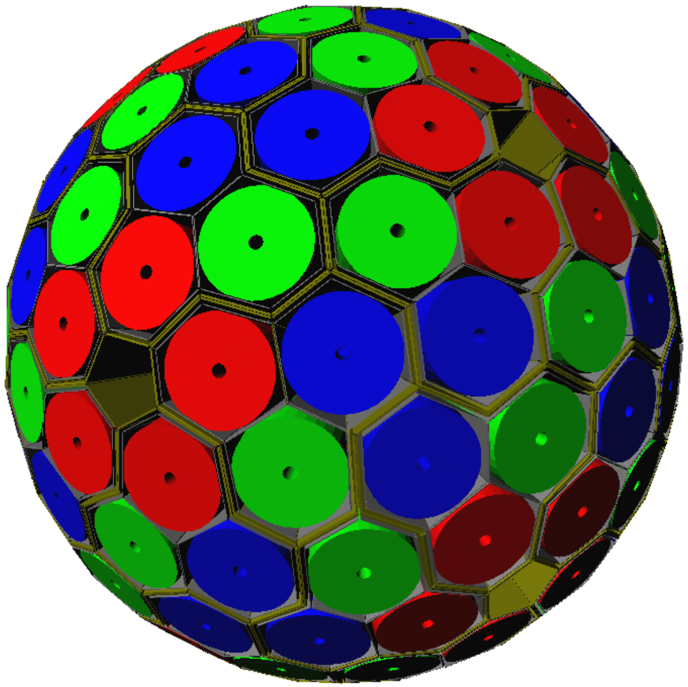
Relevant for the nucleosynthesis of heavy elements



BELEN neutron counter used; DESPEC experiment at GSI

AGATA@FAIR in 2025

(Advanced GAmma Tracking Array)
4π γ-array for Nuclear Physics Experiments at European accelerators providing radioactive and high-intensity stable beams



Main features of AGATA

Efficiency: 40% (M_γ=1) 25% (M_γ=30)
today's arrays ~10% (gain ~4) 5% (gain ~1000)

Peak/Total: 55% (M_γ=1) 45% (M_γ=30)
today ~55% 40%

Angular Resolution: ~1° →
FWHM (1 MeV, v/c=50%) ~ 6 keV !!!
today ~40 keV

Rates: 3 MHz (M_γ=1) 300 kHz (M_γ=30)
today 1 MHz 20 kHz

- 180 large volume 36-fold segmented Ge crystals in 60 triple-clusters
- Digital electronics and sophisticated Pulse Shape Analysis algorithms allow
- Operation of Ge detectors in position sensitive mode → γ-ray tracking

MATS

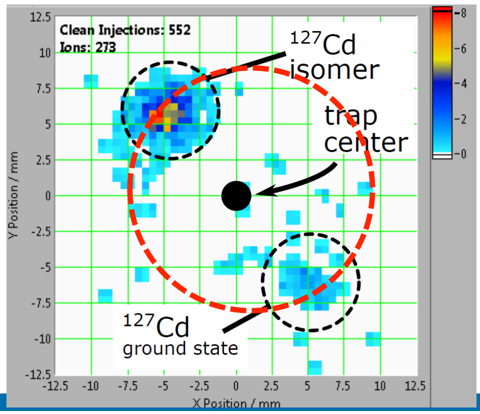
Resolving isomers with ion motional phases in a Penning trap

Demonstration of isomeric cleaning with the novel phase-sensitive PI-ICR technique at JYFLTRAP. Isomerically clean beam of ^{127}Cd provided to post-trap TASISPEC decay setup.

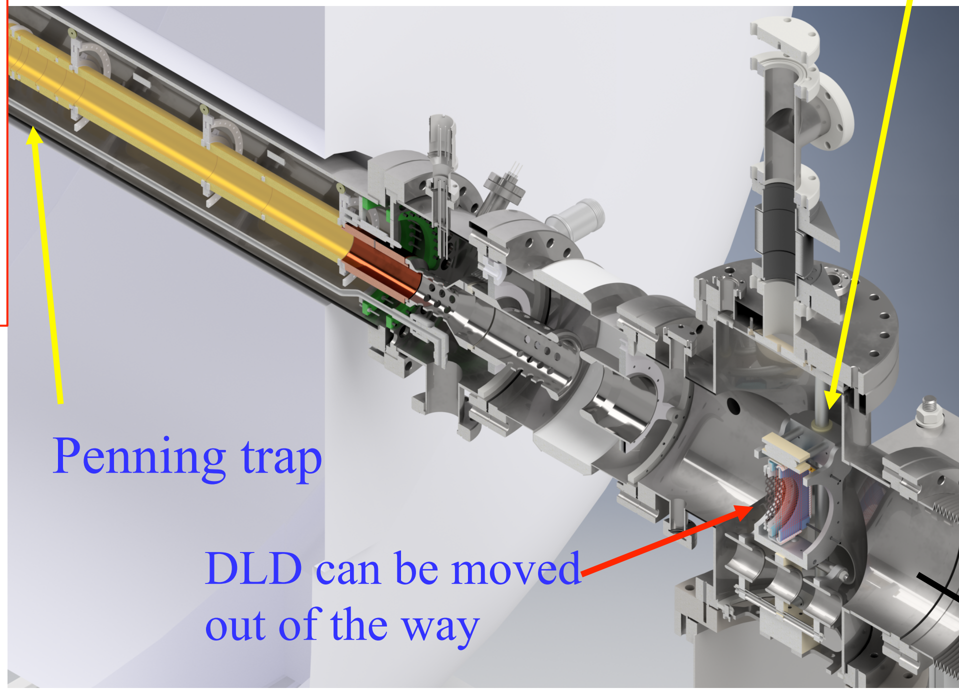
^{127}Cd and ^{127m}Cd: ~280 keV mass difference ($T_{1/2}$ ~300 ms). With 250 ms excitation pattern, a maximal 180° separation achieved.
With subsequent excitation, the state of interest is centered while unwanted ones are pushed further out.

LUND UNIVERSITY

UNIVERSITY OF JYVÄSKYLÄ

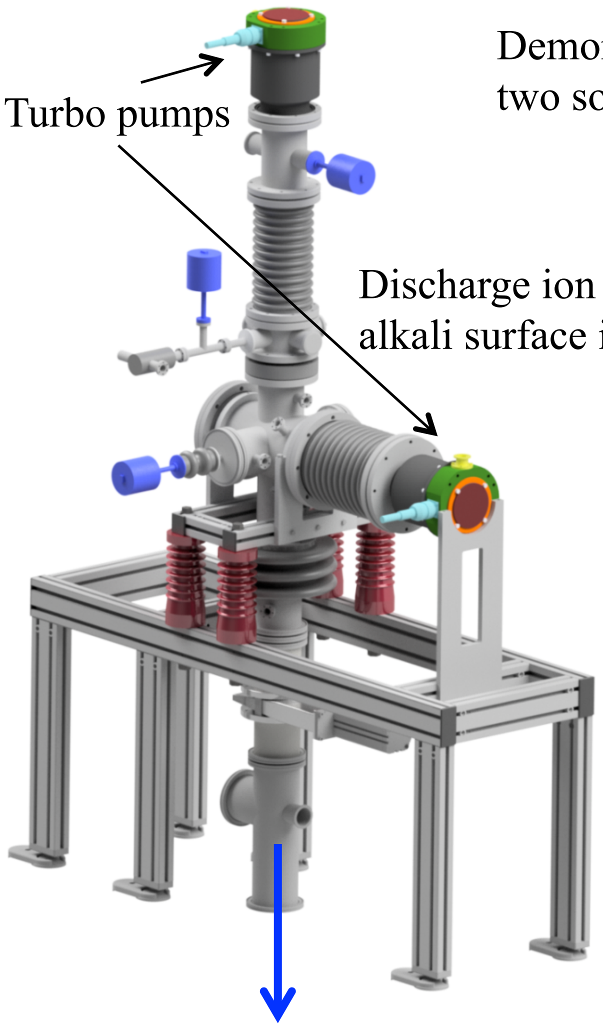


Roentdek DLD40 MCP with delay line anode

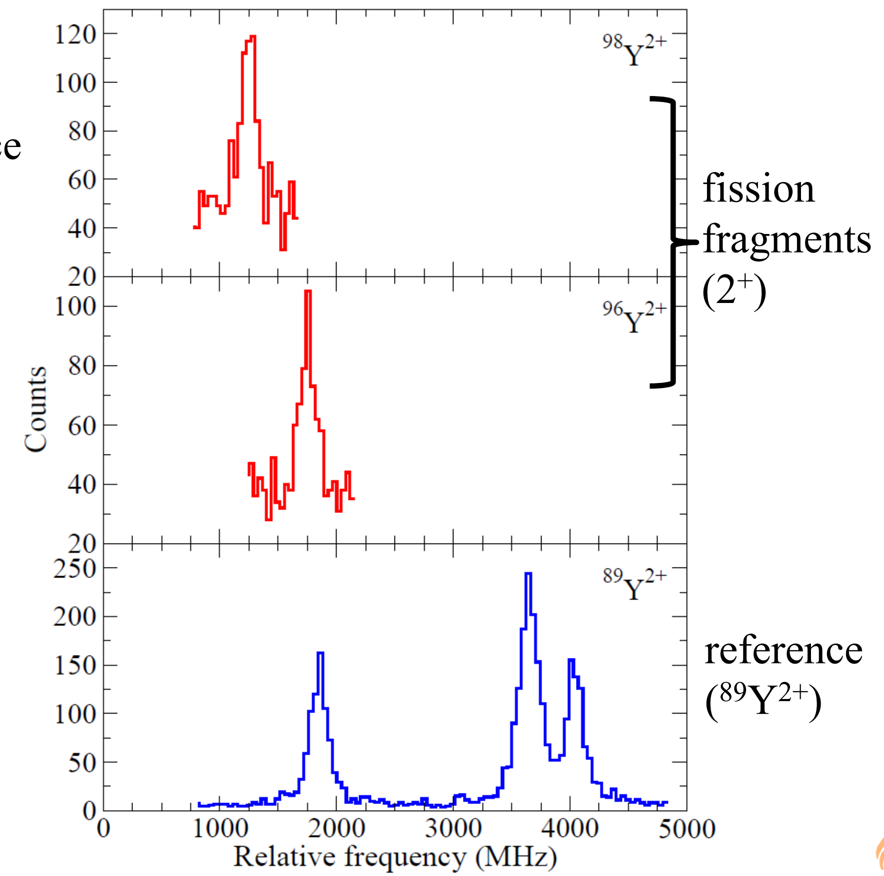


LaSpec

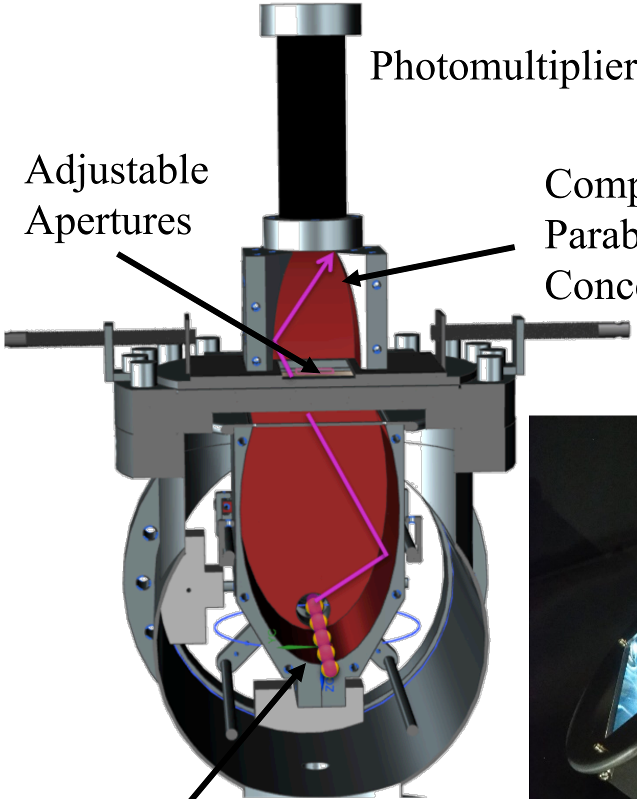
Merging of ion beams for collinear laser spectroscopy

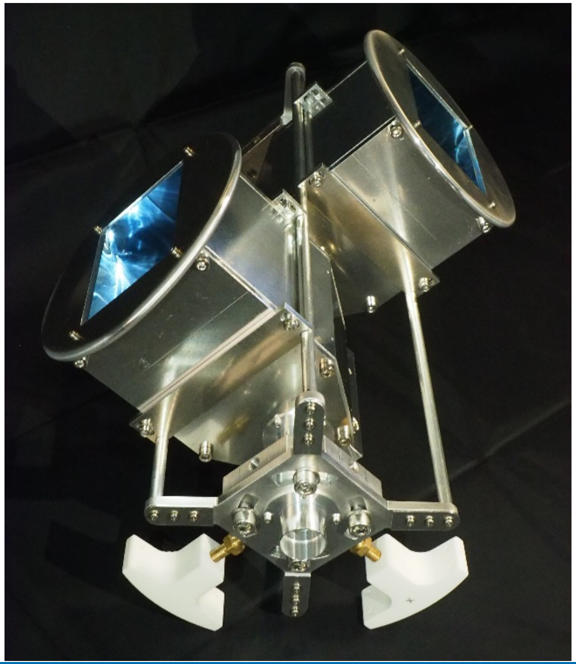


Demonstration of simultaneously-available ion beams from two sources (off line - stable reference; on-line fission fragments)

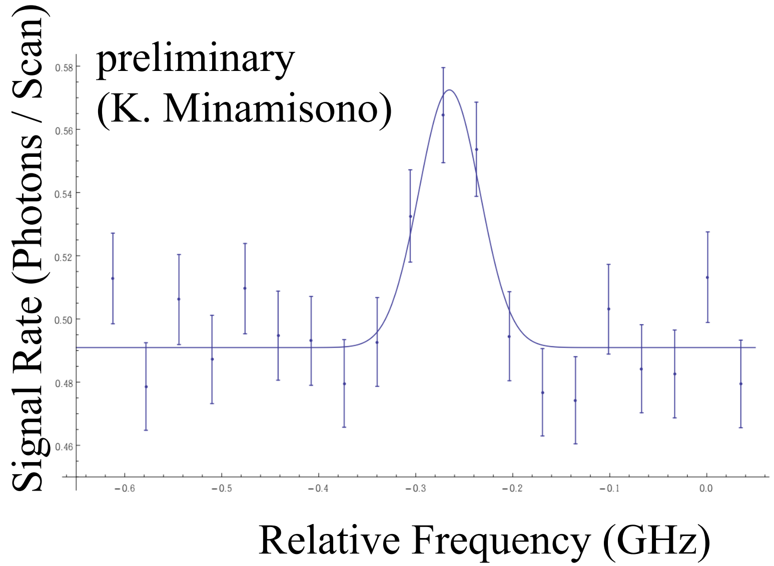


First online application of LaSpec's new detection region





Resonance Signal of ^{36}Ca, taken at NSCL

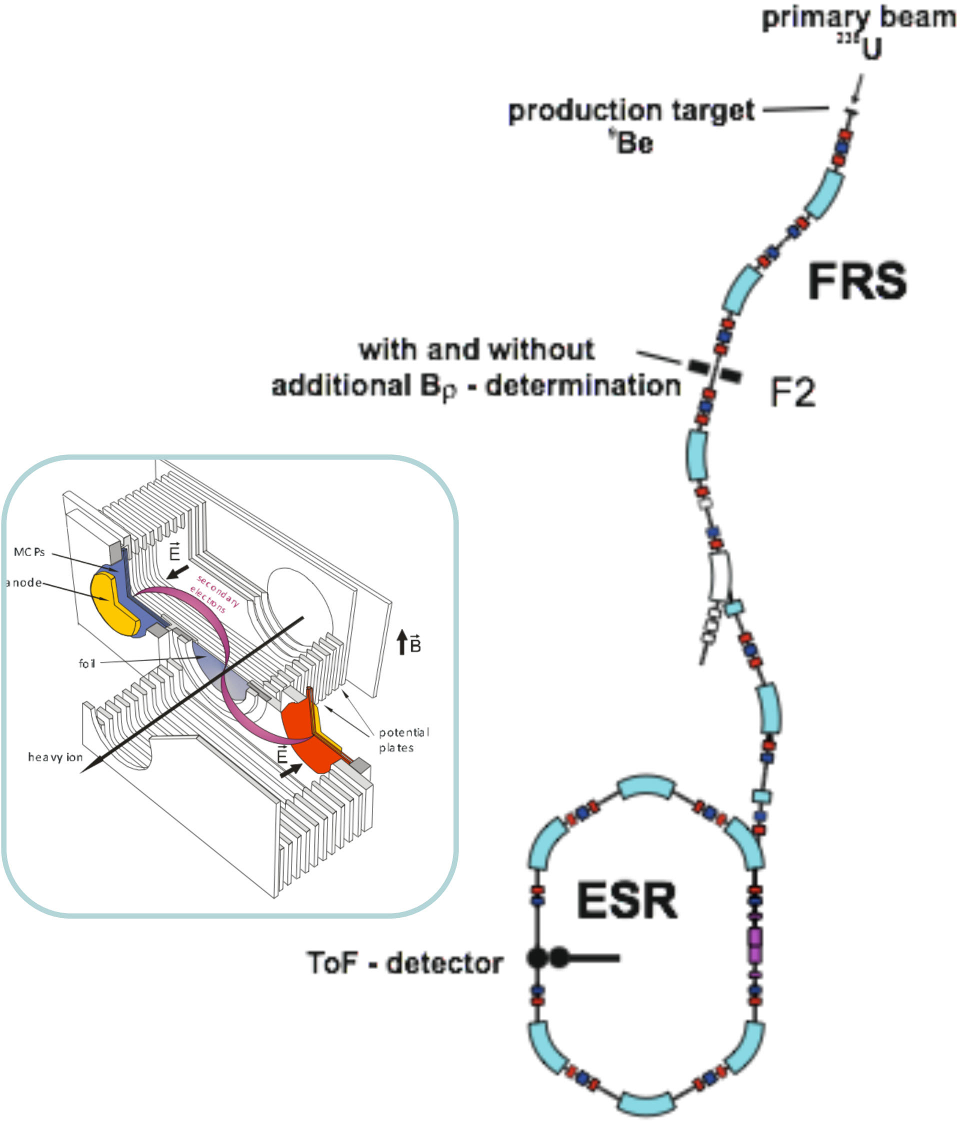


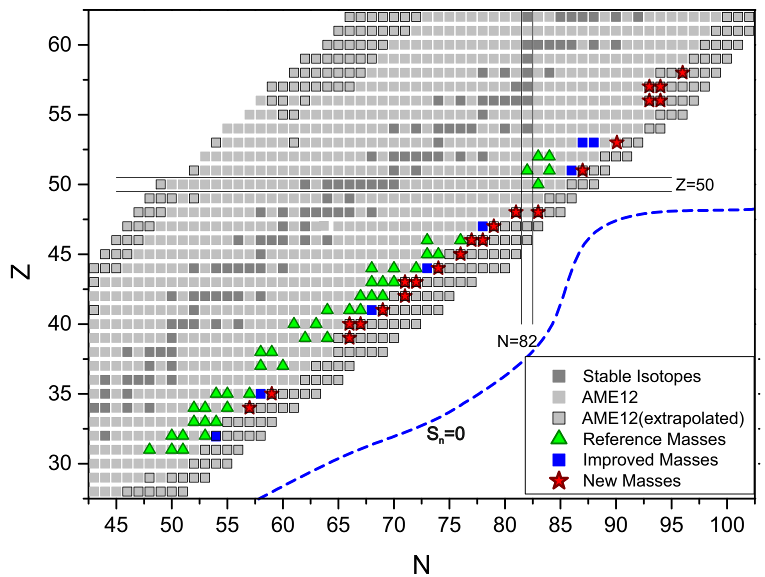
Signal recorded with ≈ 25 ions/sec

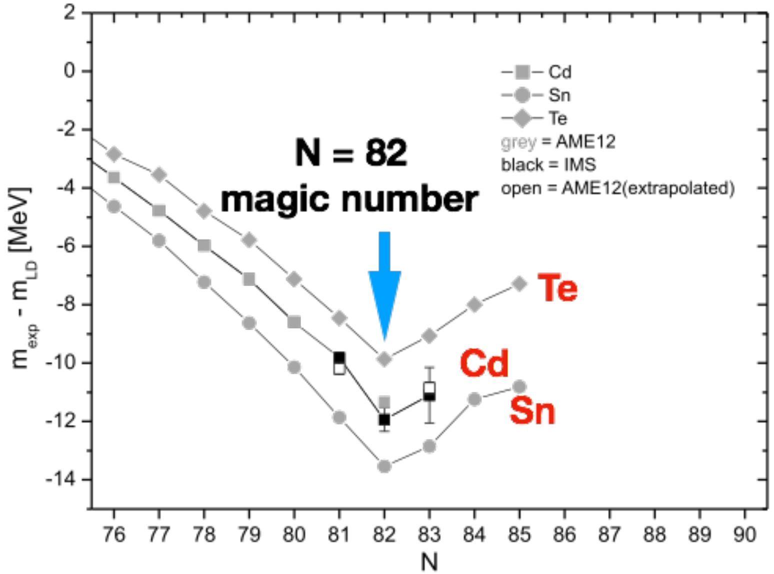
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung
HIC for FAIR Helmholtz International Center
SFB 1245
DFG Deutsche Forschungsgemeinschaft

ILIMA

New masses around N=82

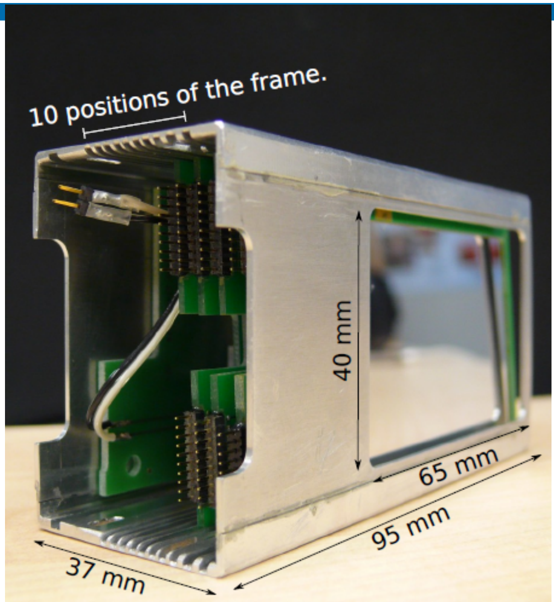


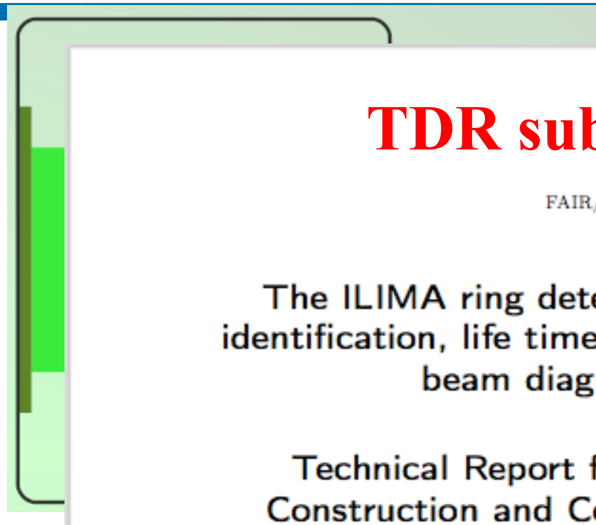




Knöbel et al. EPJ A52 (2016) 138; PLB 754 (2016) 288

ILIMA: CsISiPHOS (heavy-ion) detector for in-ring decay





TDR submitted

FAIR/NUSTAR/ILIMA/TDR/DETECTOR

The ILIMA ring detector for particle identification, life time measurement and beam diagnostics

Technical Report for the Design, Construction and Commissioning of The Heavy Ion Detector

November 2, 2017

ILIMA

ILIMA	Name	E-Mail
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Contact Person at the FAIR site	Helmut Weick	H.Weick@gsi.de
Detector Convener	Roman Gernhäuser	Roman.Gernhaeuser@tum.de
Deputy	Thomas Faestermann	Thomas.Faestermann@ph.tum.de

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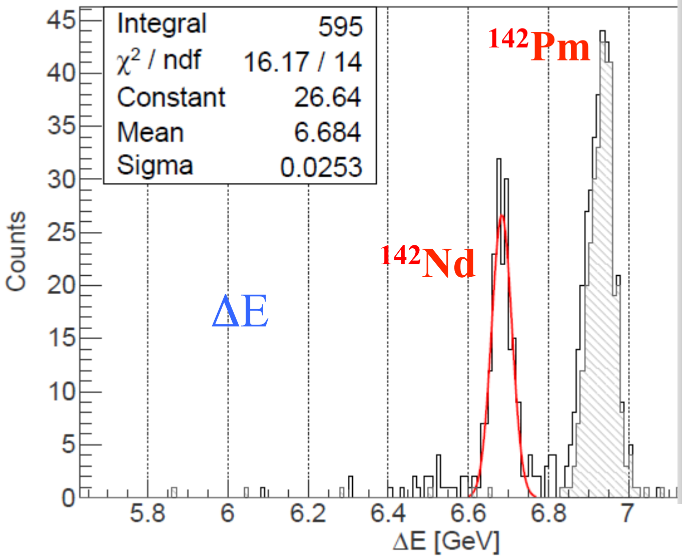
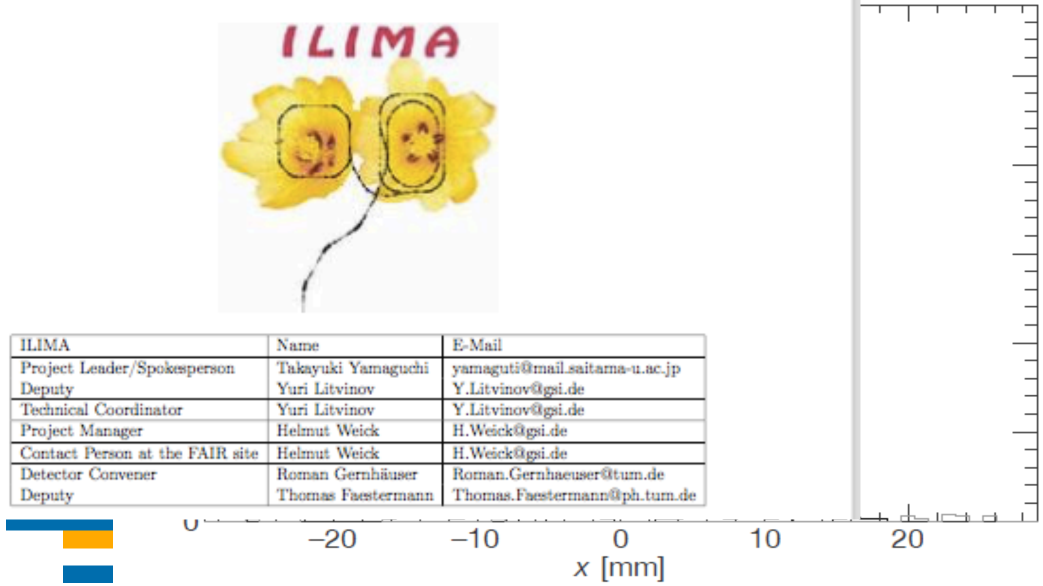
…6 (2016) 1

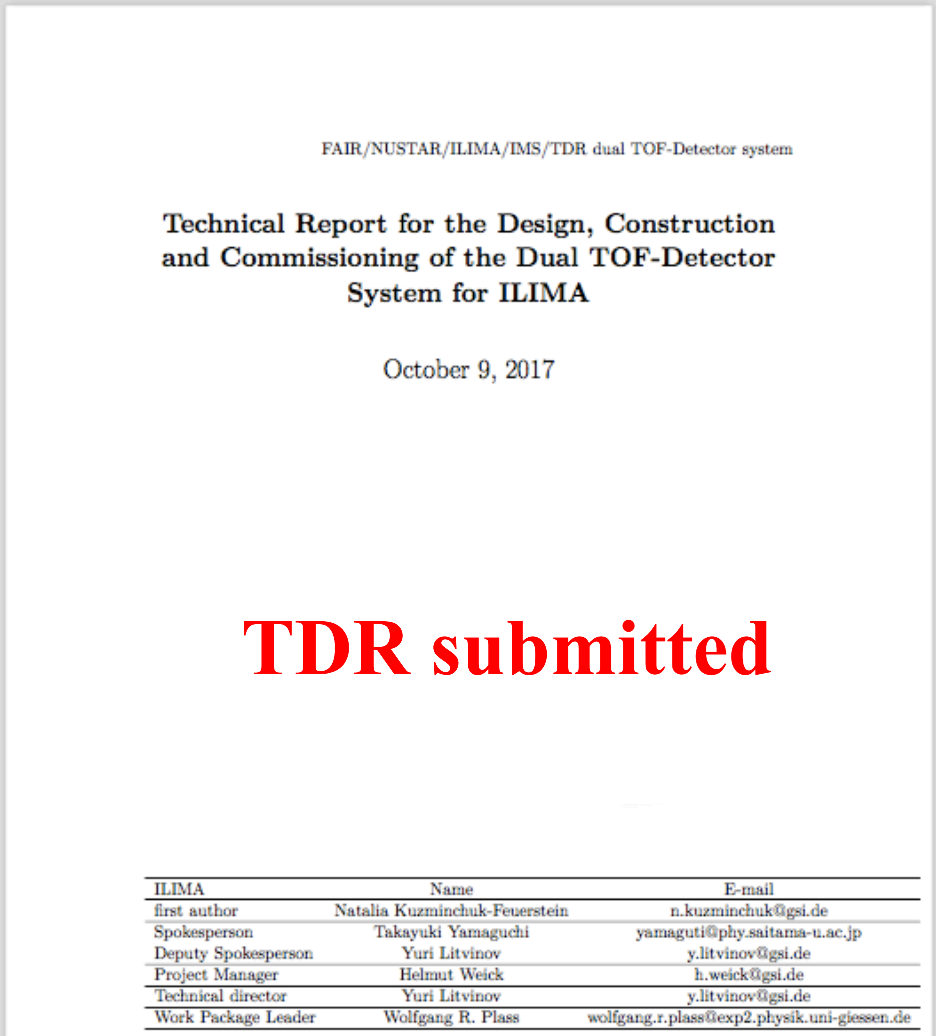
β^+ decay: $^{142}Pm^{60+} \rightarrow {}^{142}Nd^{59+}$, a…





Tome-of-Flight detectors

N. Kuzminchuk-Feuerstein et al. NIM A 821 (2016) 160



FAIR/NUSTAR/ILIMA/IMS/TDR dual TOF-Detector system

Technical Report for the Design, Construction and Commissioning of the Dual TOF-Detector System for ILIMA

October 9, 2017

ILIMA	Name	E-mail
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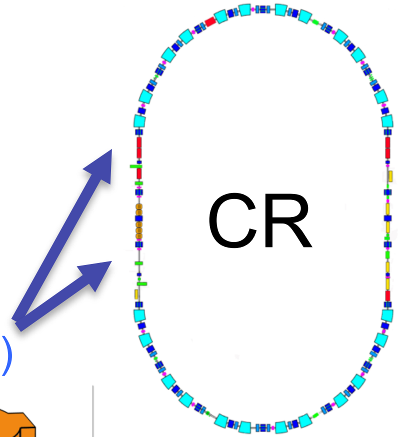
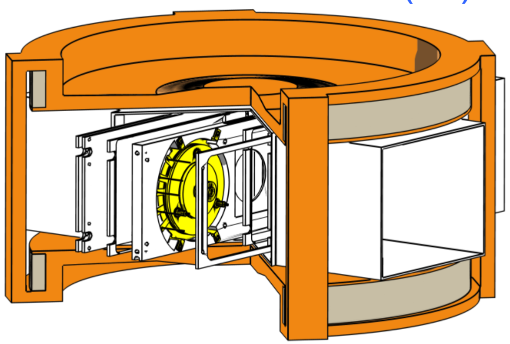
Deputy Spokesperson	Yuri Litvinov	y.litvinov@gsi.de
Project Manager	Helmut Weick	h.weick@gsi.de
Technical director	Yuri Litvinov	y.litvinov@gsi.de
Work Package Leader	Wolfgang R. Plass	wolfgang.r.plass@exp2.physik.uni-giessen.de

TDR submitted

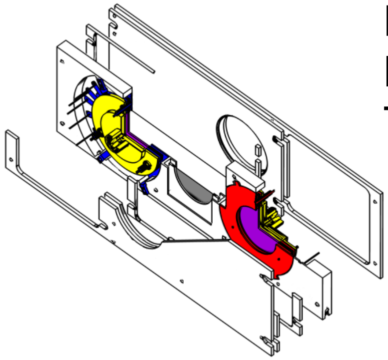
$L = 221.45$ m
$B\rho = 13$ Tm
$\gamma_t = 1.67$
$\Delta p/p = 0.5$ %
$\varepsilon_x = 100$ mm mrad



TOF detector (2x)



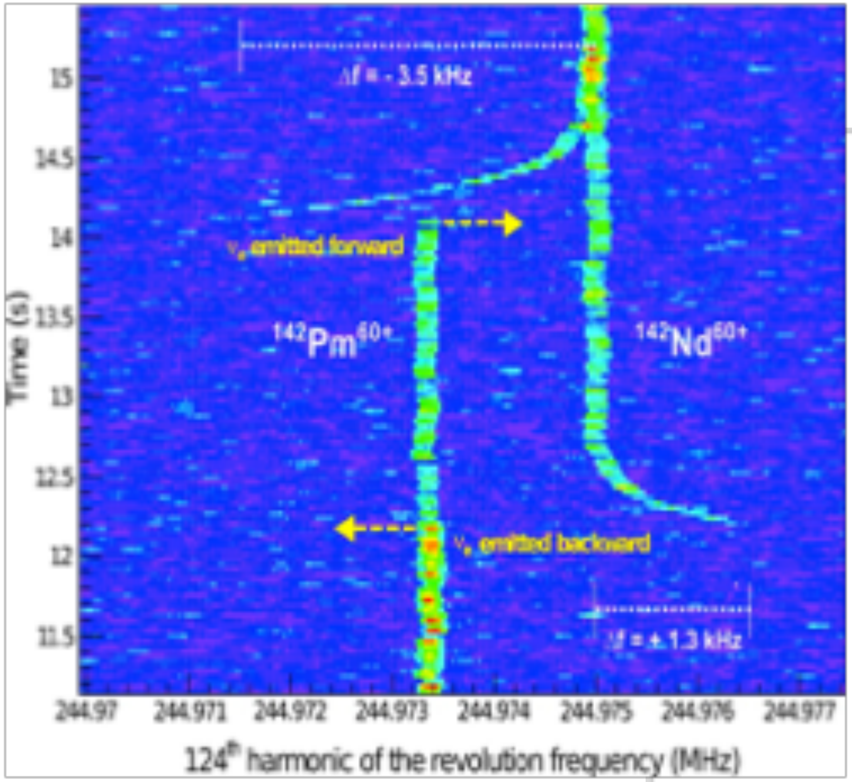
B-field homogeneity radius 200 mm



Foil diameter 80 mm
Efficiency ≈ 98%
Timing accuracy ≈ 35 ps

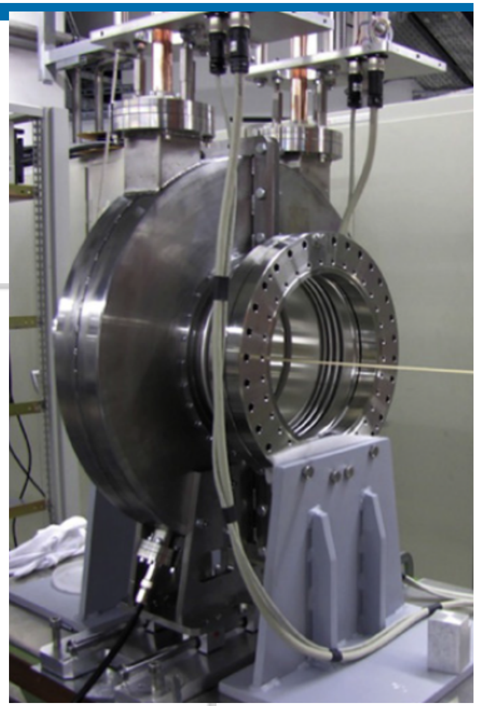
Schottky pickups

$$^{142}\mathrm{Pm}^{60+} \rightarrow {}^{142}\,\mathrm{Nd}^{60+} + \nu_e$$



F. Nolden et al., NIM A 659 (2011) 69
M.S. Sanjari et al., Phys. Scr. T156 (2013) 014088
M.S. Sanjari et al., Phys. Scr. T166 (2015) 014060
X. Chen et al., NIM A 826 (2016) 39

TDR submitted



Technical Report for the Design, Construction and Commissioning of the Schottky Detector System for ILIMA

Created: August 24, 2016
Last modified: November 12, 2017

Author:	S. Sanjari	s.sanjari@gsi.de
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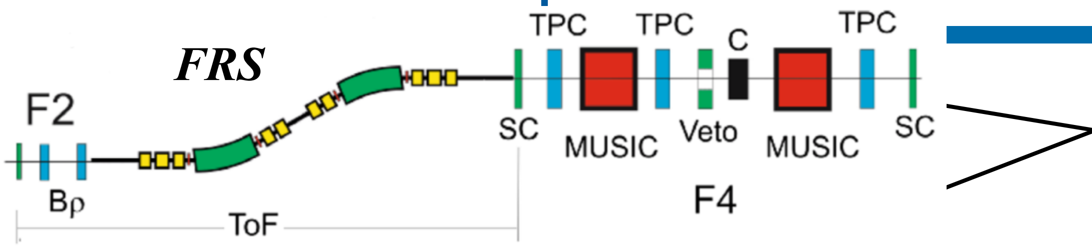
Project manager:	H. Weick	h.weick@gsi.de
Technical director:	Yu. A. Litvinov	y.litvinov@gsi.de
Work Package Leader:	Ch. Kozhuharov	c.kozhuharov@gsi.de

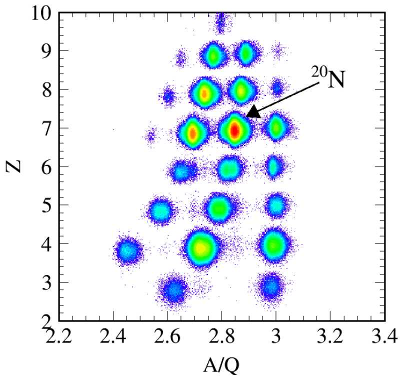
2 experiments (36 shifts) approved with CRYRING

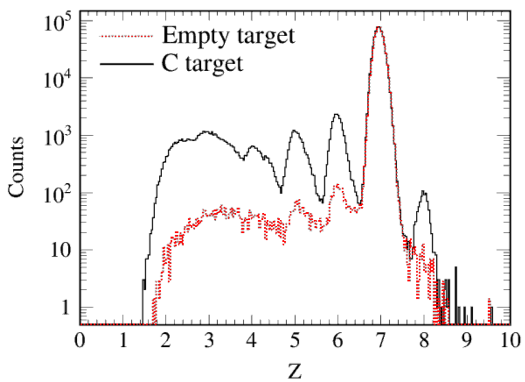
Super-FRS

N=14 shell gap found from measured proton radii of neutron-rich N-isotopes

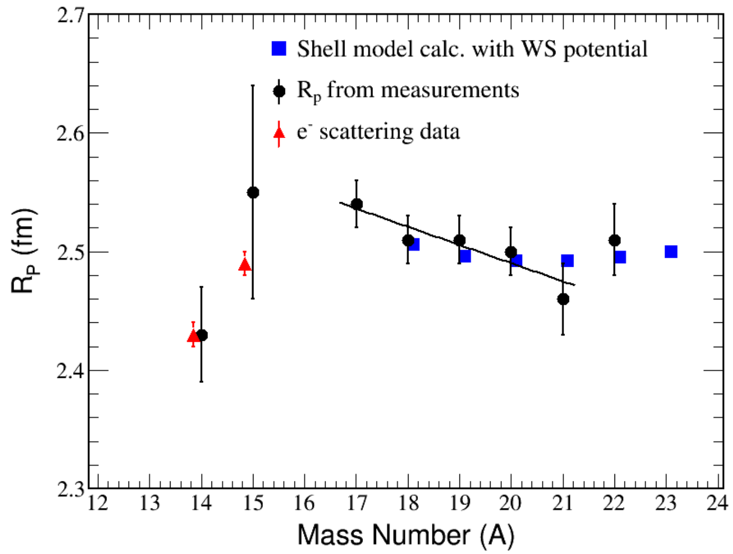


Z identification in MUSIC behind target with selection of nucleus of interest in front of target





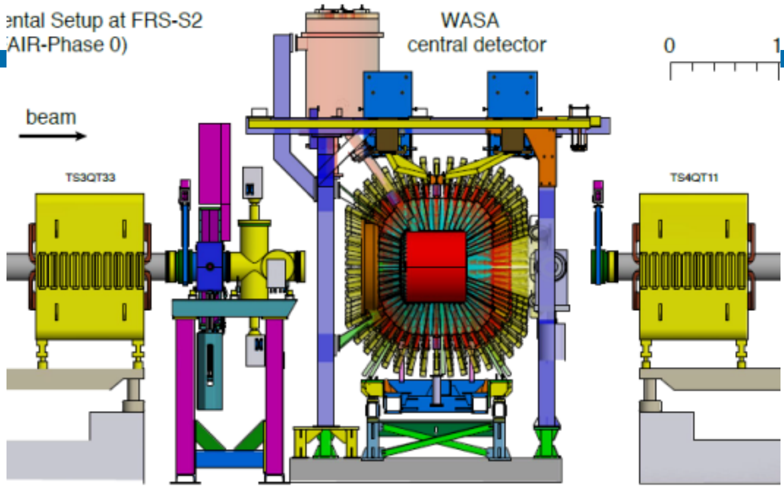
Empty target run needed to eliminate the effects of interaction of the beam from non-target material (detectors, windows,...).



- R_p of $^{17-20}$N gradually decreases.
- $1d_{5/2}$ orbital is filled up, which is related to the decrease in deformation approaching the N = 14 shell closure.
- Increase in R_p within the uncertainty for ^{22}N results from its extended neutron density for valence neutron in the $2s_{1/2}$ orbital with a closed-shell core of ^{21}N.

S. Bagchi et al., submoitted for publication

WASA@FAIR (to be installed first at FRS-S2)

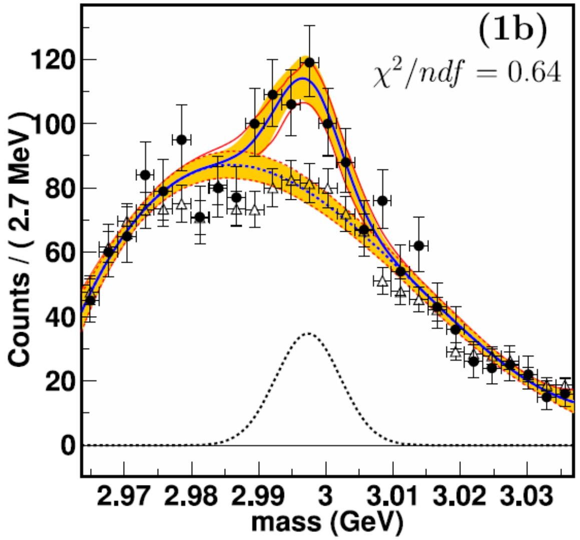


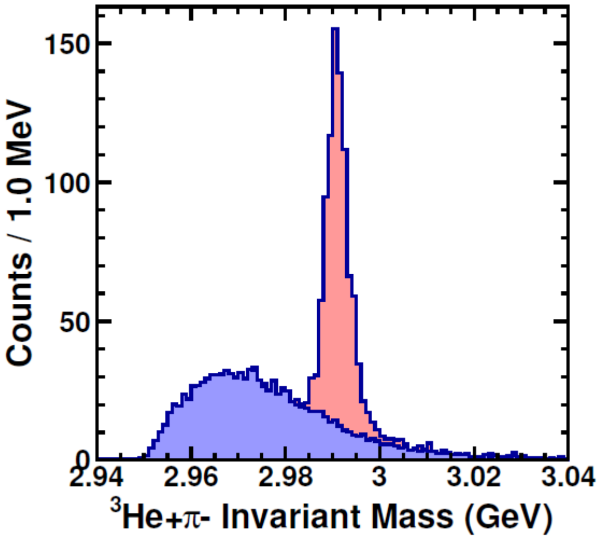
Combination of WASA with FRS provides unique setup for exclusive measurements:

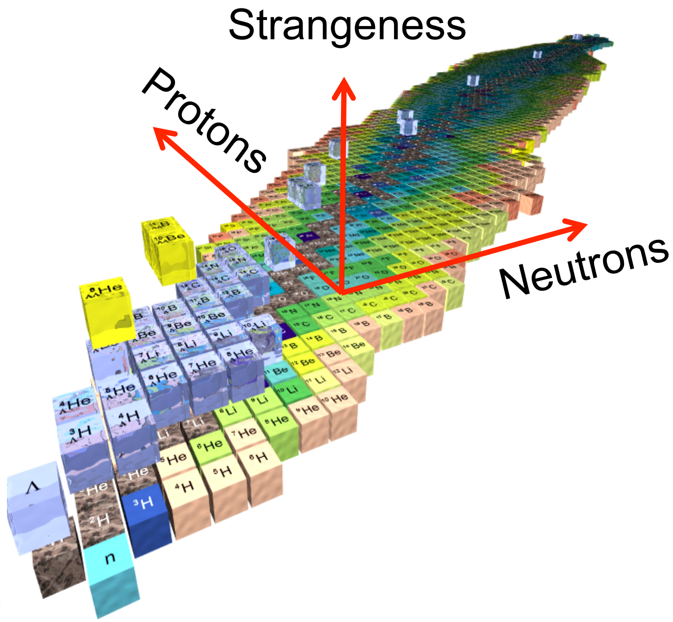
- FRS for high resolution spectroscopy of forward particles
- WASA for decay particles

Hypernuclei:

Goals: Short lifetime of ${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$
Solve puzzle of nnΛ state

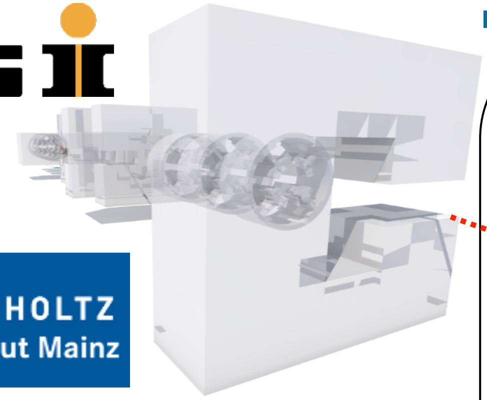


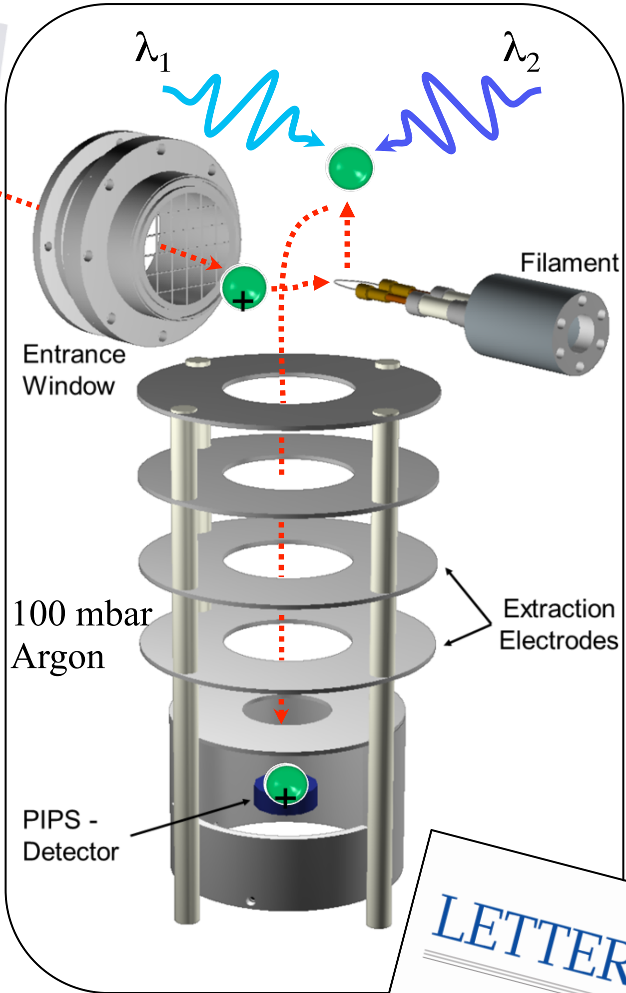


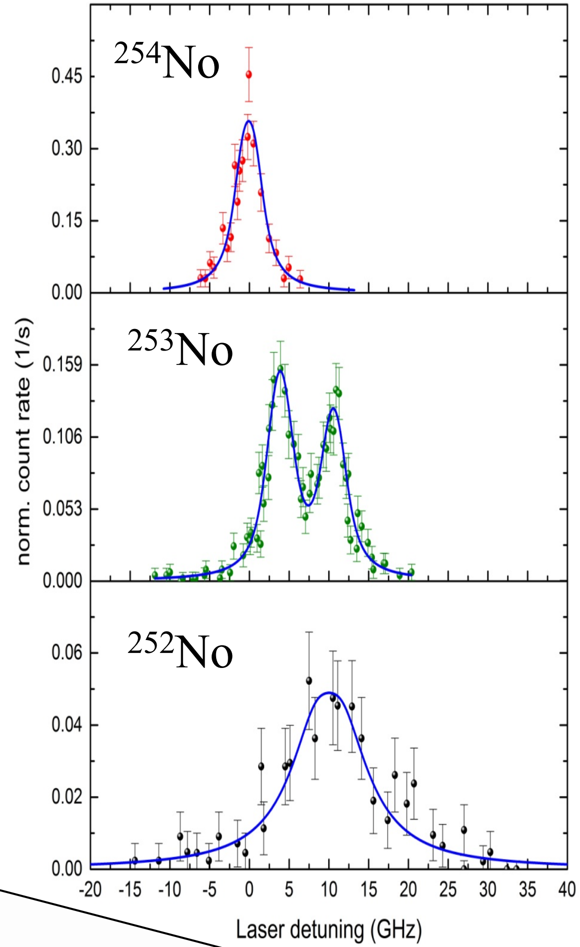


SHE

Super Heavy Elements (SHE):
First Spectroscopic Investigation of Nobelium (Z=102)







Achievements:

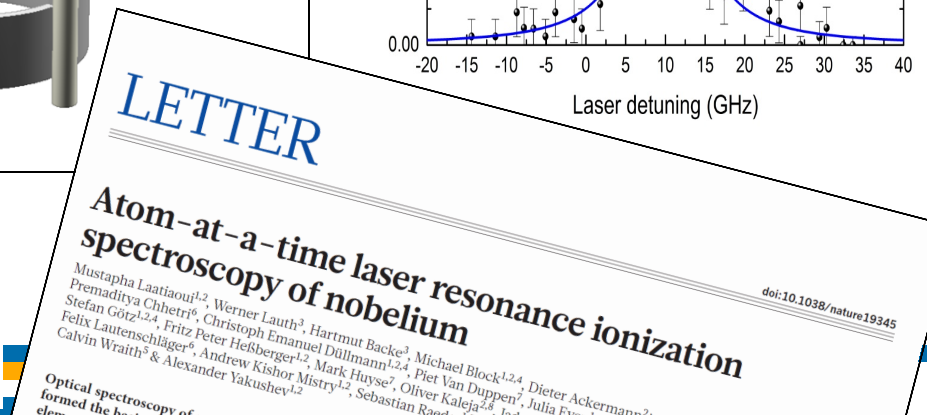
➔ First ever successful laser spectroscopy beyond fermium

➔ Production rates: ~ 1 atom/s

➔ Overall efficiency up to 10%

➔ First ionization potential of nobelium precisely measured

➔ Nuclear spin and moments extracted for the isotope ^{253}No


LETTER

doi:10.1038/nature19345

Atom-at-a-time laser resonance ionization spectroscopy of nobelium

Mustapha Laatiaoui[1,2], Werner Lauth[3], Hartmut Backe[3], Michael Block[1,2,4], Dieter Ackermann[2,...], Premaditya Chhetri[6], Christoph Emanuel Düllmann[1,2,4], Piet Van Duppen[7], Julia Ev..., Stefan Götz[1,2,4], Fritz Peter Heßberger[1,2], Mark Huyse[7], Oliver Kaleja[2,8], ..., Felix Lautenschläger[6], Andrew Kishor Mistry[1,2], Sebastian Raed..., Calvin Wraith[5] & Alexander Yakushev[1,2]

Optical spectroscopy of ... formed the ba...

Bundesministerium für Bildung und Forschung

TECHNISCHE UNIVERSITÄT DARMSTADT

KU LEUVEN

UNIVERSITY OF LIVERPOOL

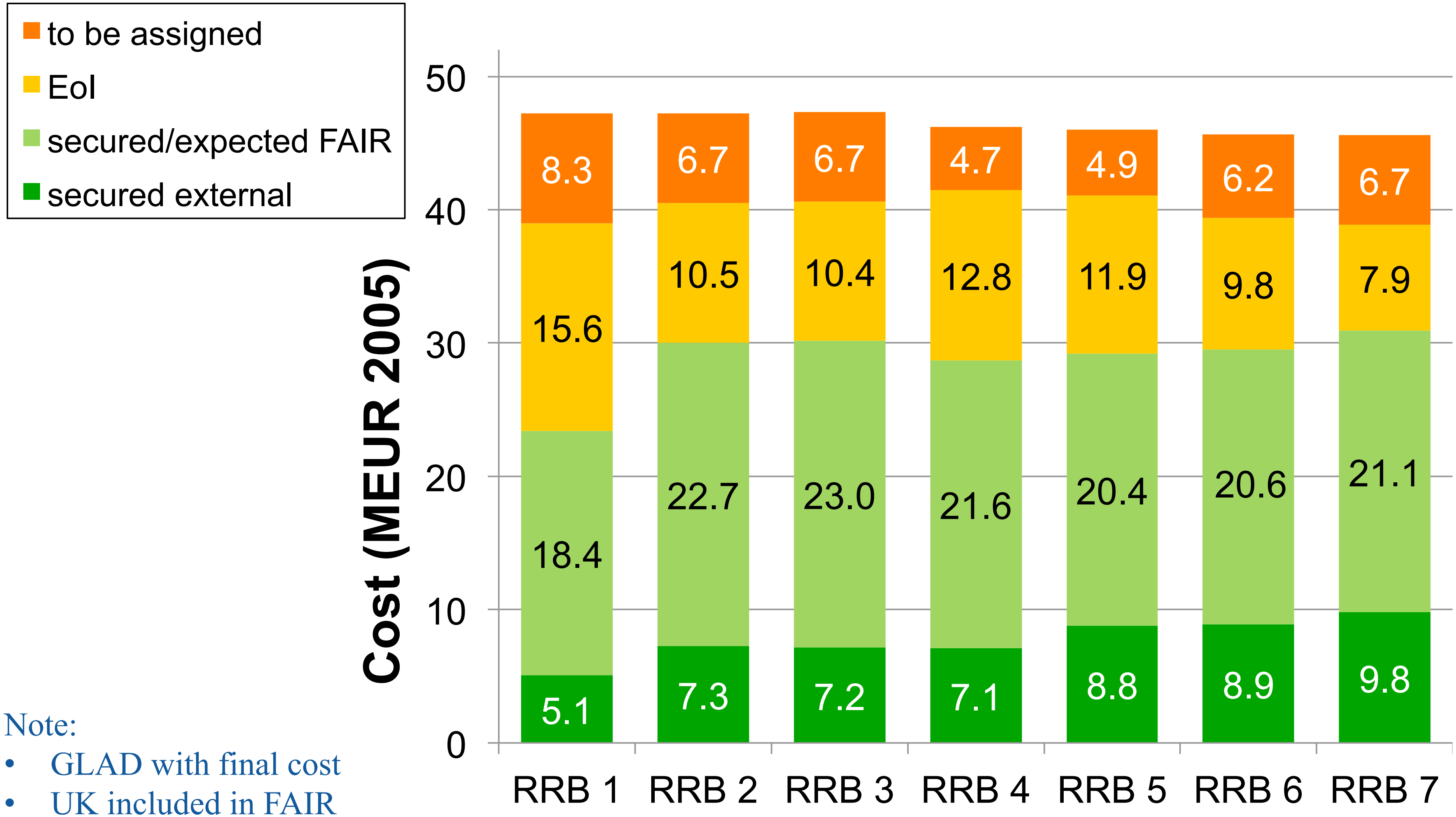
Funding and TDRs

NUSTAR – The project 1.2

	Super-FRS	RIB production, separation, and identification
PSP	**Experiment**	**Description**
1.2.2	**HISPEC/ DESPEC**	In-beam γ-spectroscopy at low and intermediate energy, n-decay, high-resolution γ-, β-, α-, p-, spectroscopy
1.2.3	**MATS**	In-trap mass measurements and decay studies
1.2.4	**LaSpec**	Laser spectroscopy
1.2.5	**R^{3}B**	Kinematically complete reactions with relativistic radioactive beams
1.2.6	**ILIMA**	Large-scale scans of mass and lifetimes of nuclei in ground and isomeric states
1.2.10	**Super-FRS**	High-resolution spectrometer experiments
1.2.11	**SHE**	Synthesis and study of super-heavy elements
1.2.8	**ELISe(*)**	Elastic, inelastic, and quasi-free e$^-$-A scattering
1.2.9	**EXL(*)**	Light-ion scattering reactions in inverse kinematics

(*) NESR required – alternative/intermediate "operation" within MSV under discussion.
SHE physics case to be evaluated.

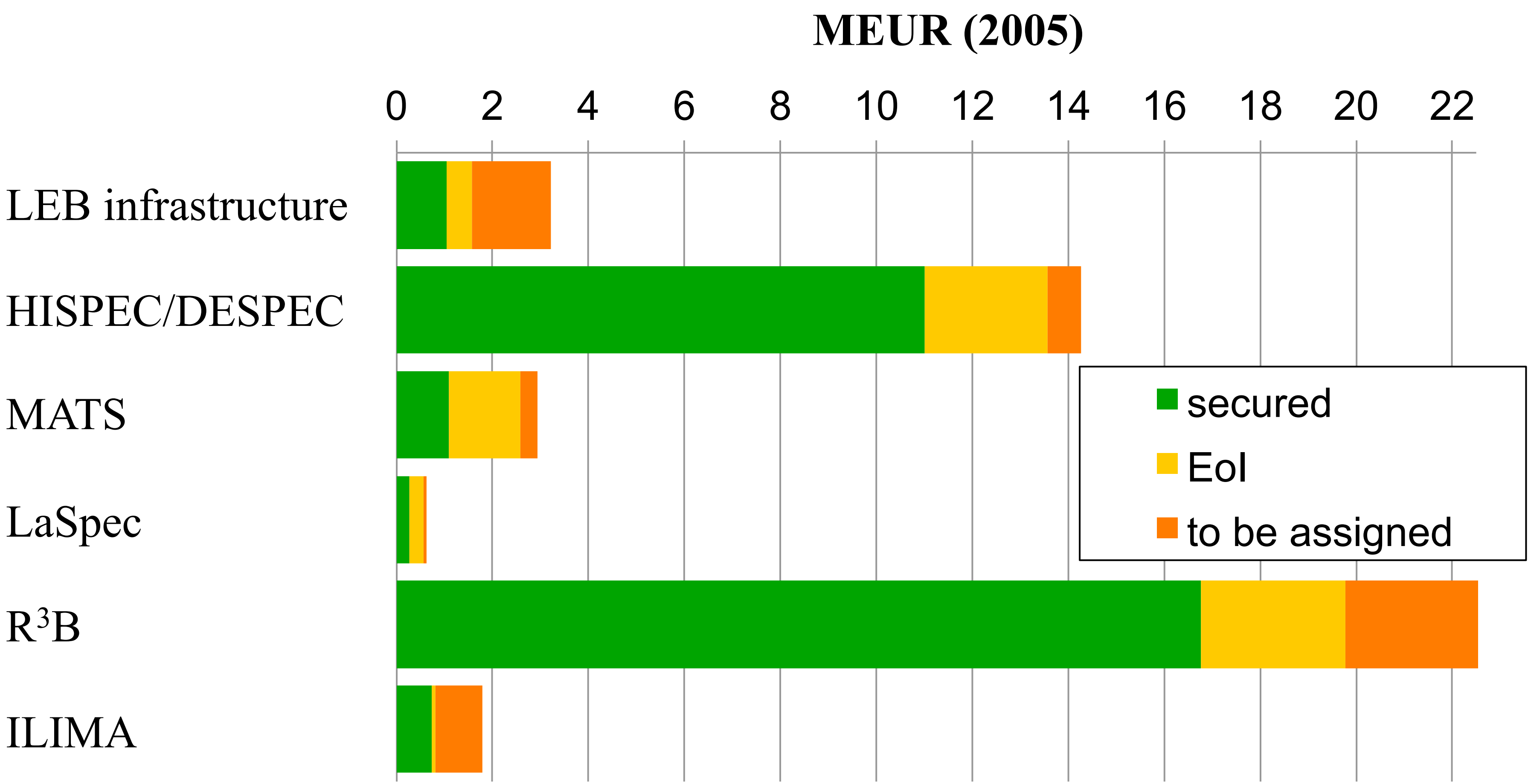
Evolution of NUSTAR project funding (MSV)



Note:

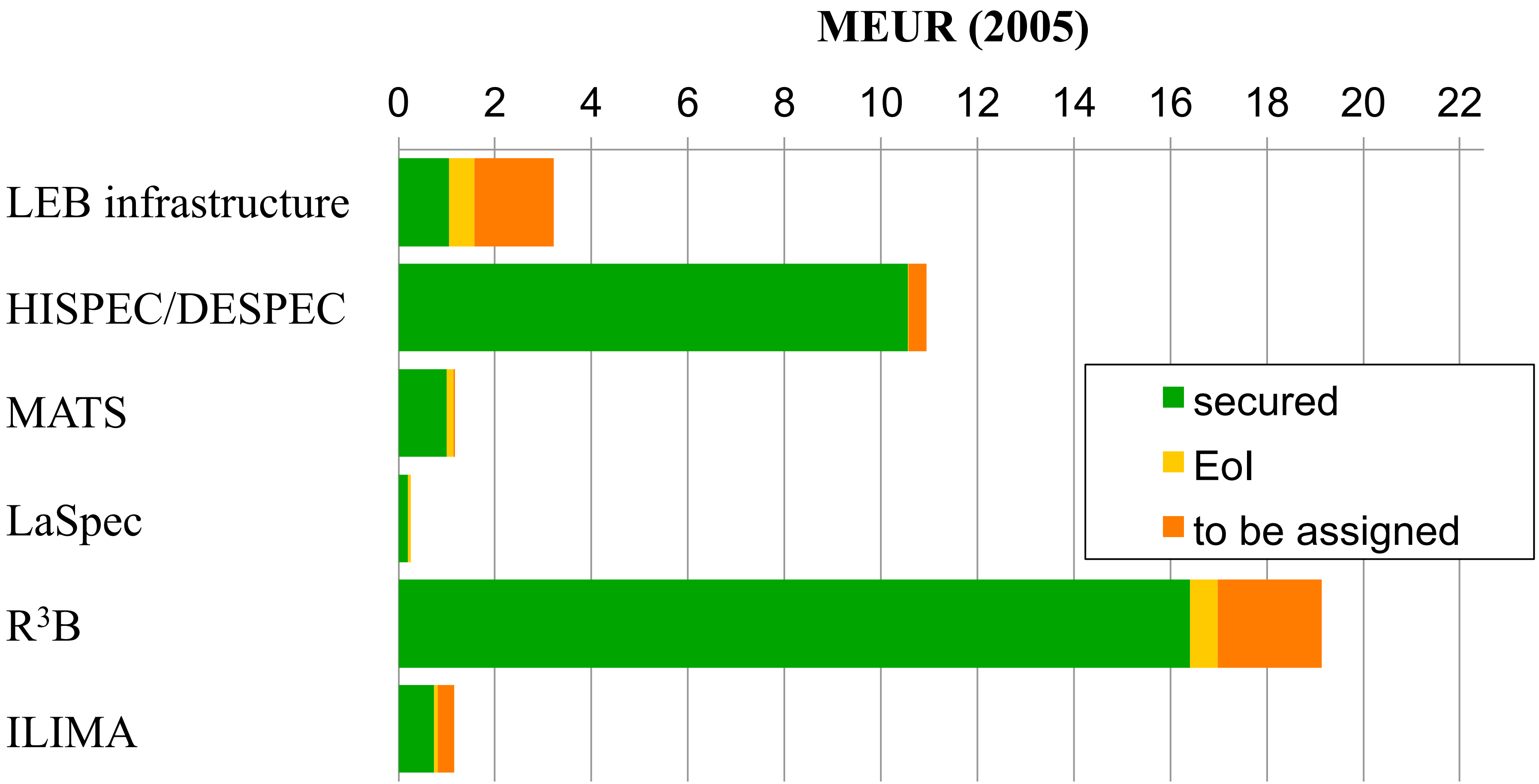
- GLAD with final cost
- UK included in FAIR

Status of NUSTAR experiment funding (MSV)

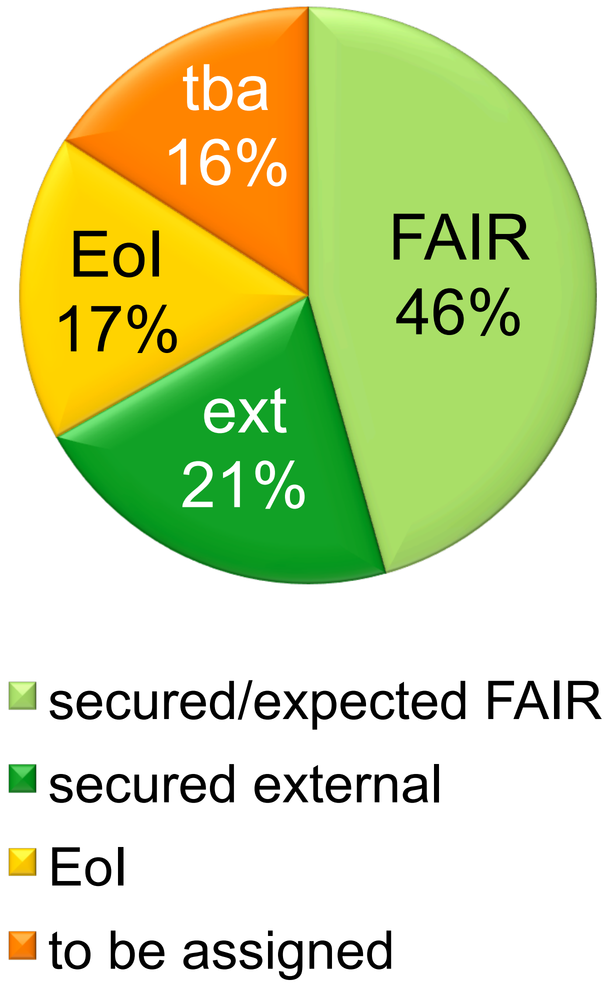


Status: February, 2018

NUSTAR experiment funding (MSV, **Day one**)



NUSTAR MSV – funding status



Status: February, 2018

- funding (secured and expected) from:
  (**FAIR members/associates** in bold face)
  - Australia
  - Belgium
  - Bulgaria
  - Canada
  - **Finland**
  - **France**
  - **Germany**
  - Hungary
  - **India**
  - Netherlands
  - **Poland**
  - **Romania**
  - **Russia**
  - Spain
  - **Sweden**
  - Turkey
  - **United Kingdom**

Status Technical Design Reports (33 TDRs)

- Approved TDRs (18):
  - HISPEC/DESPEC (9):
    AIDA, BELEN, DEGAS, DTAS, FATIMA, LYCCA, MONSTER, NEDA, Plunger
  - MATS + LaSpec (1): all subsystems
  - R^3B (7):
    ACTAF, CALIFA barrel, CALIFA endcap, GLAD, R^3B multiplet, NeuLAND, Tracking detectors
  - *Super-FRS Experiment (1):*
    EXPERT

- Submitted (4):
  - NUSTAR DAQ (just approved!)
  - ILIMA – Heavy Ion Detector
  - ILIMA – Schottky detector
  - ILIMA – TOF detector

Phase 0 program (2018/19)

Approved (highest priority: A) physics experiments

No commissioning, equipment development, parastic beam, SHE experiments shown.

E121	Measurement of the bound-state beta decay of bare ^{205}Tl ions
E127	Measurements of proton-induced reaction rates on radioactive isotopes for the astrophysical p process
S465	Dipole response of the drip-line nuclei ^{6}He and ^{22,24}O
S442	Study of multi-neutron configurations in atomic nuclei towards the drip line
S467	Single-particle structure of neutron-rich Ca isotopes: shell evolution along Z=20
S455	Fission investigated with relativistic-radioactive beams and the advanced SOFIA@R3B setup
S447	Studies of the d+p signal and lifetime of the ${}^{3}_{\Lambda}$H and ${}^{4}_{\Lambda}$H hypernuclei by new spectroscopy techniques with FRS
S474	Detector tests with the prototype of the CSC for the Super-FRS and direct mass measurements of neutron-deficient nuclides below ^{100}Sn
S468	Search for new neutron-rich isotopes and exploratory studies in the element range from terbium to rhenium
S452	The Oblate-Prolate Shape Transition around A~190
S460	Investigation of 220-A-230 Po-Fr nuclei lying in the south-east frontier of the A~225 island of octupole deformation
S450	Study of N=126 nuclei: isomeric and beta decays in ^{202}Os and ^{203}Ir

EXL ILIMA

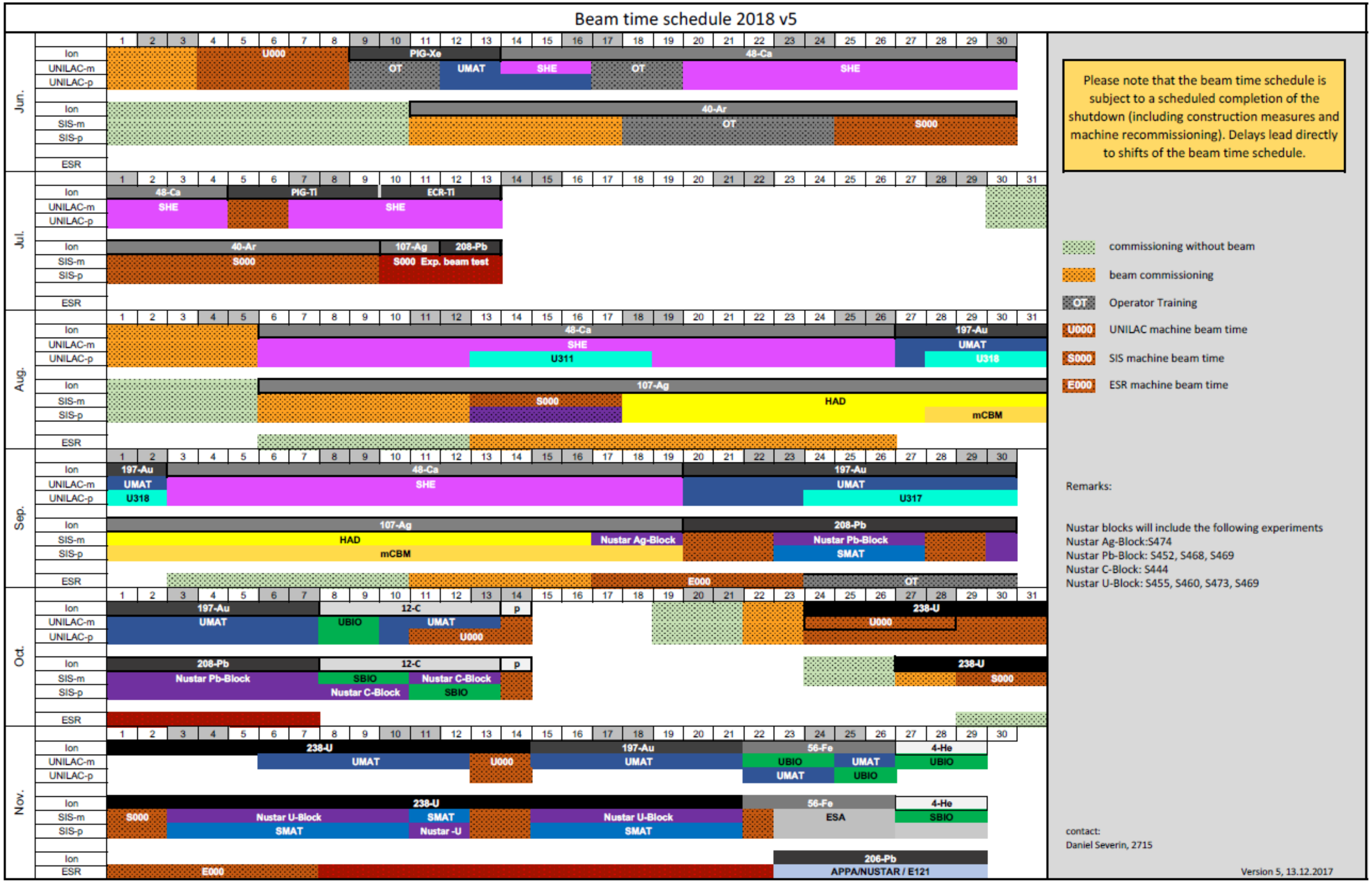
R3B

SuperFRS

DESPEC

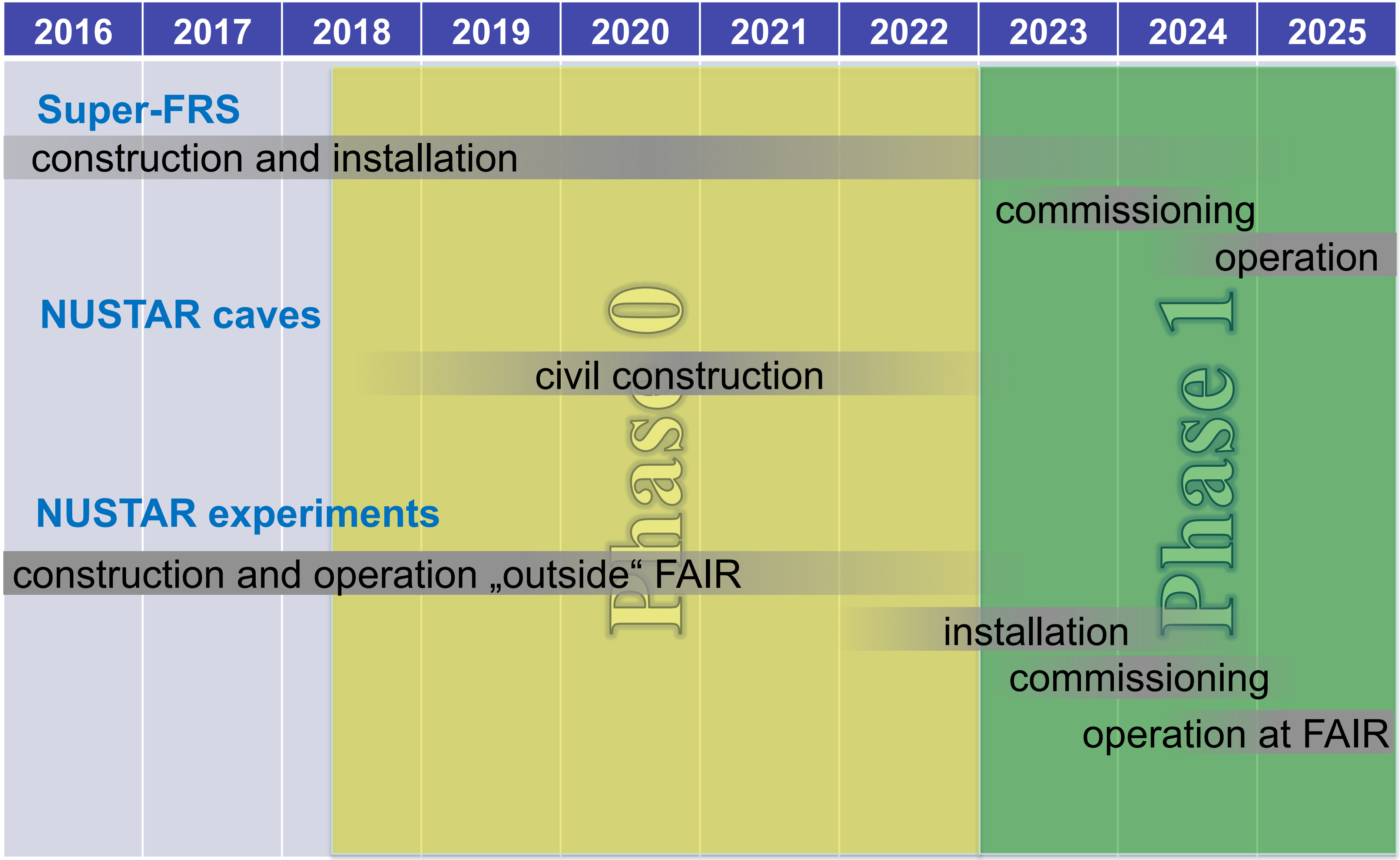
Beam-time schedule for 2018

NUSTAR



Timeline

Scenario for NUSTAR Phase 0 and 1



Conclusions

NUSTAR is ready to GO!

Phase 0 at GSI experiments approved for 2018-19

R^{3}B, DESPEC, ILIMA, SuperFRS, EXL, SHE experiments at GSI

Phase 0 MATS, LaSpec experiments at Argonne, Jyväskylä etc.

Day 1:

higher beam intensities (more exotic nuclei)

higher energies: high-energy reactions, ‘exotics’

Phase 1: Starts with day one and completes the proposed program.

Physics case based on uniqueness/strengths of FAIR

Thank you!