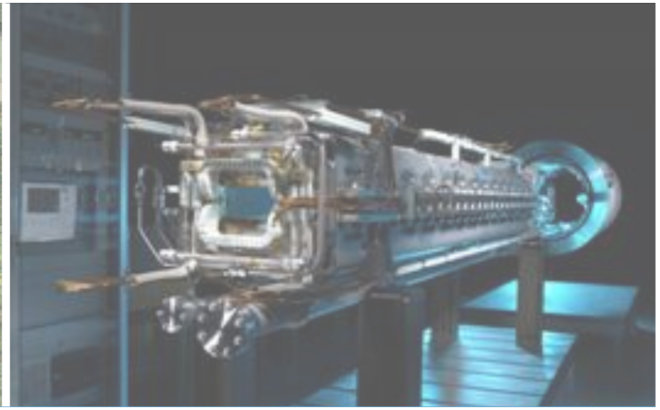


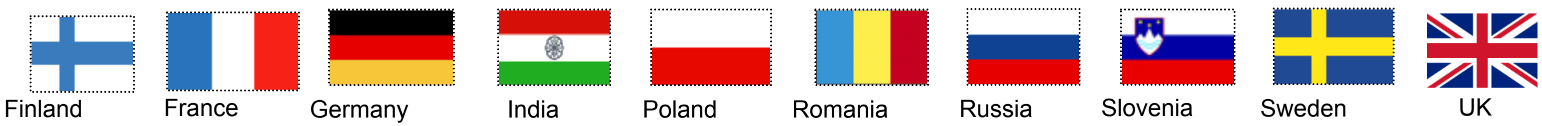


Nuclear Structure and Reactions within NUSTAR

Nasser Kalantar-Nayestanaki
KVI-CART/University of Groningen

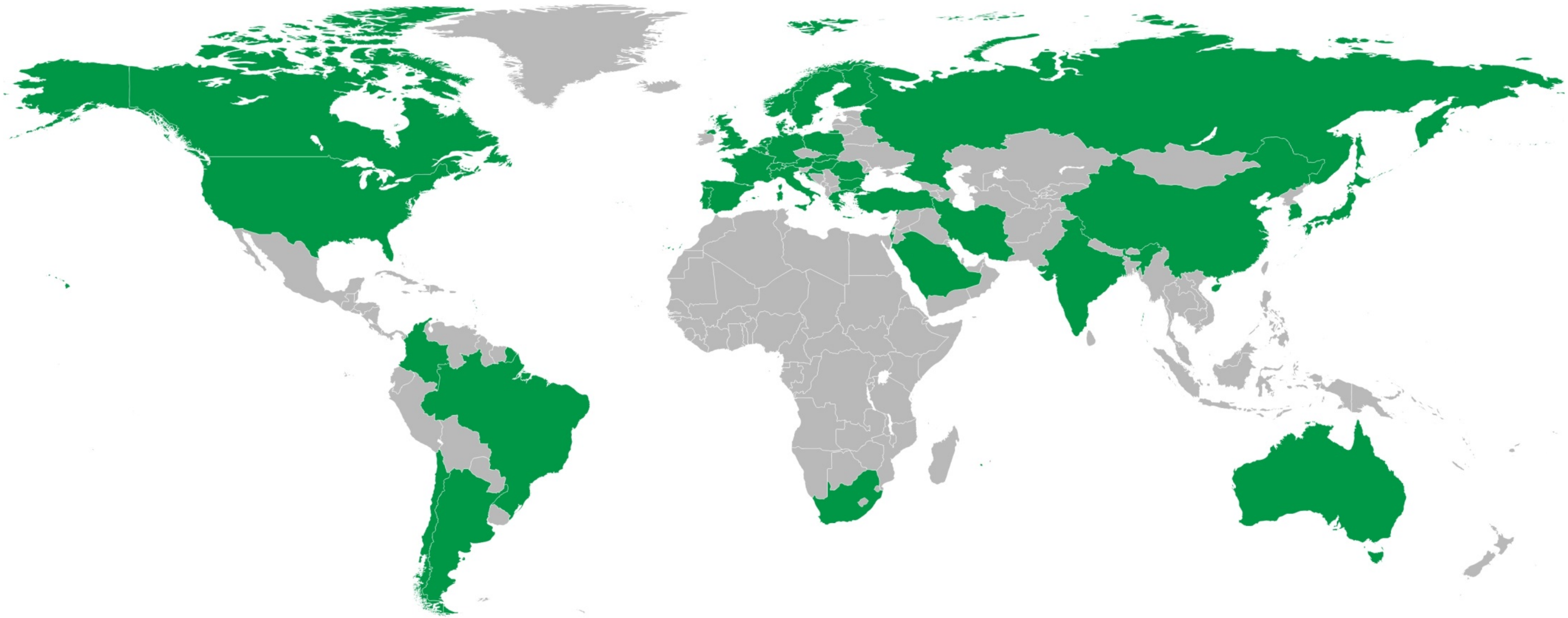
PKU-CUSTIPEN Nuclear Reaction Workshop on
"Reactions and Spectroscopy of Unstable Nuclei"

Beijing, China, August 11, 2014



FAIR

NUSTAR Collaboration



>800 registered NUSTAR members
38 countries
>180 institutes

NUclear STructure Astrophysics and Reactions

What are the limits for existence of nuclei?

- *Where are the proton and neutron drip lines situated?*
- *Where does the nuclear chart end?*

How does the nuclear force depend on varying proton-to-neutron ratios?

- *What is the isospin dependence of the spin-orbit force?*
- *How does shell structure change far away from stability?*

How to explain collective phenomena from individual motion?

- *What are the phases, relevant degrees of freedom, and symmetries of the nuclear many-body system?*

How are complex nuclei built from their basic constituents?

- *What is the effective nucleon-nucleon interaction?*
- *How does QCD constrain its parameters?*

Which are the nuclei relevant for astrophysical processes and what are their properties?

- *What is the origin of the heavy elements?*

NUSTAR - The Project

Super-FRS	RIB production, identification and high-resolution spectroscopy
DESPEC	γ-, β-, α-, p-, n-decay spectroscopy
HISPEC	in-beam γ spectroscopy at low and intermediate energy
ILIMA	masses and lifetimes of nuclei in ground and isomeric states
LASPEC	laser spectroscopy
MATS	in-trap mass measurements and decay studies
R^{3}B	kinematically complete reactions at high beam energy
Super-FRS	high-resolution studies with high-performance separator
ELISE	elastic, inelastic, and quasi-free e^-A scattering
EXL	light-ion scattering reactions in inverse kinematics

The Approach

Complementary measurements leading to consistent answers

The Collaboration

> 800 scientists

> 180 institutes

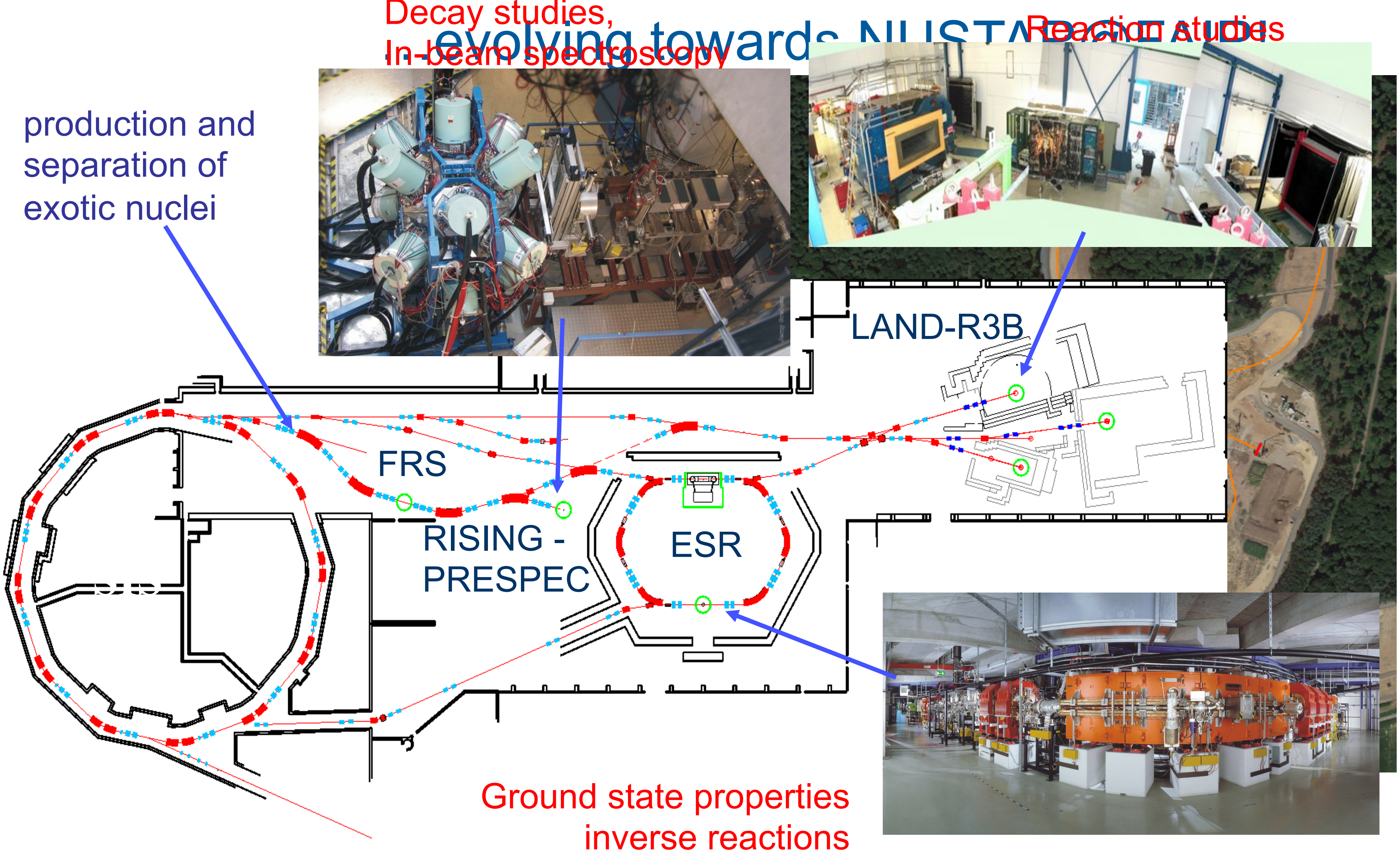
38 countries

The Investment

82 M€ Super-FRS

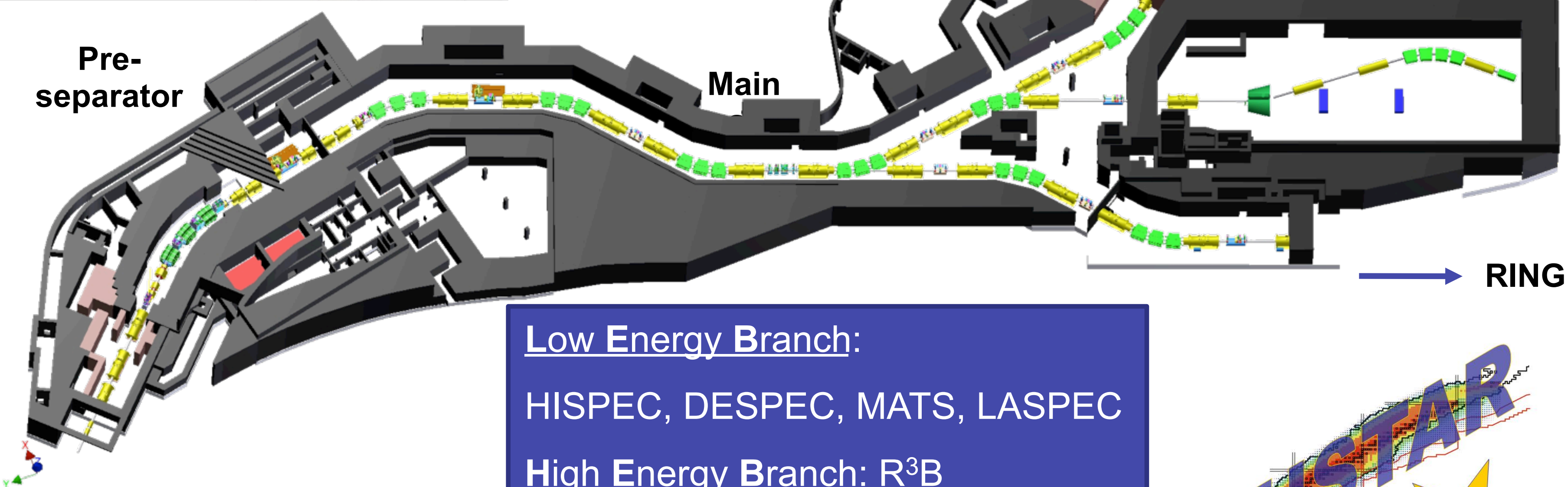
73 M€ Experiments

Existing research opportunities at GSI



NUSTAR - The Facility

Beam intensity improvement FRS –Super-FRS: 10^2 to 10^5!



Low Energy Branch:

HISPEC, DESPEC, MATS, LASPEC

High Energy Branch: R^3B

Ring Branch: EXL, ILIMA, ELISE

HISPEC/DESPEC - foreseen instrumentation

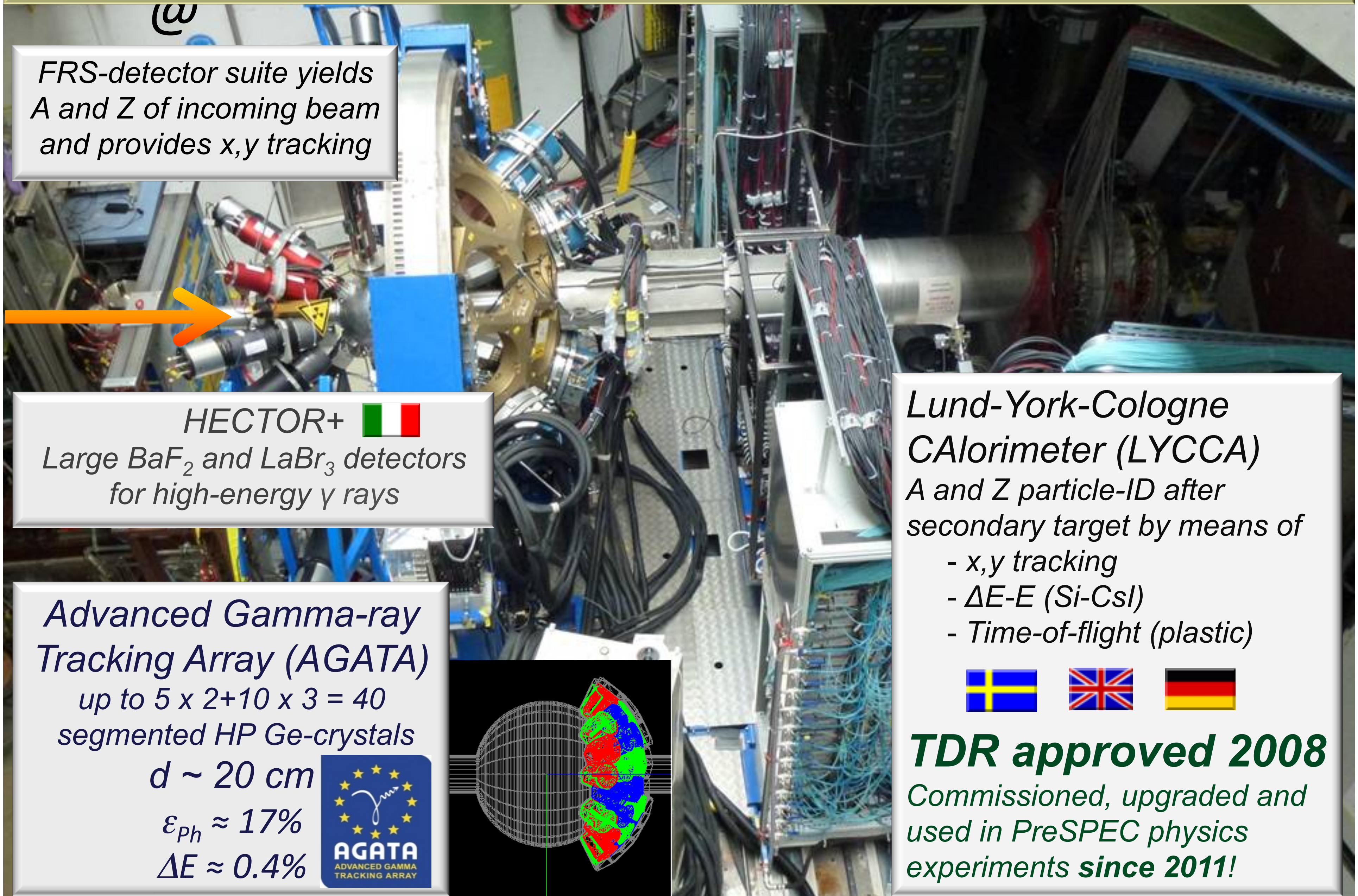
HISPEC

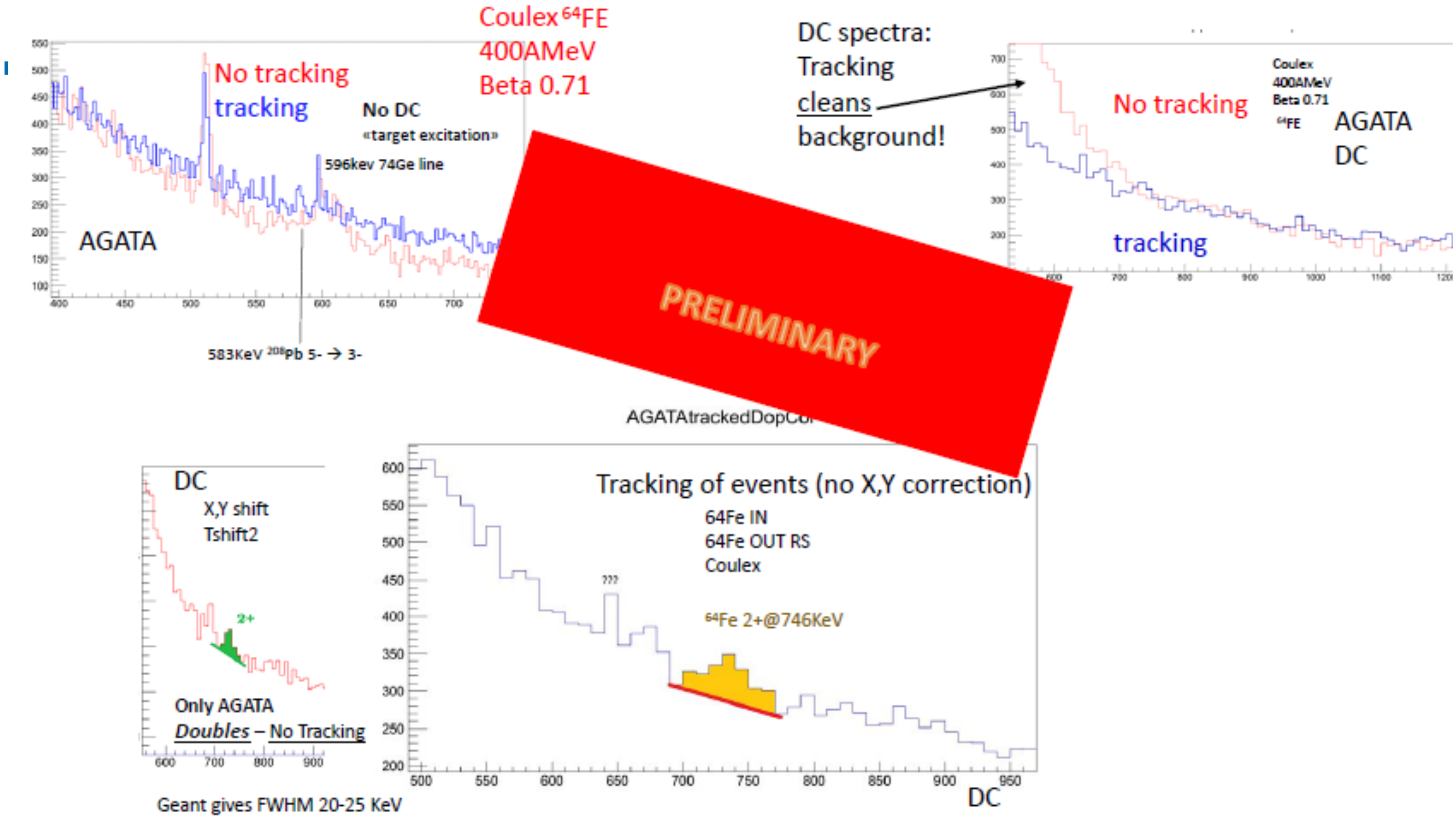
- LYCCA heavy-ion calorimeter with ToF capability
- AGATA gamma spectrometer
- HYDE light particle array
- NEDA Neutron Detector Array
- EDAQ dedicated electronics and DAQ based on several branches
- Plunger nuclear level lifetime measurements

DESPEC

- AIDA active implantation device
- MONSTER neutron ToF array
- BELEN neutron detection array
- DTAS Decay Total Absorption Spectrometer
- DESPEC Ge Array gamma spectrometer
- FATIMA Fast TIMing Array

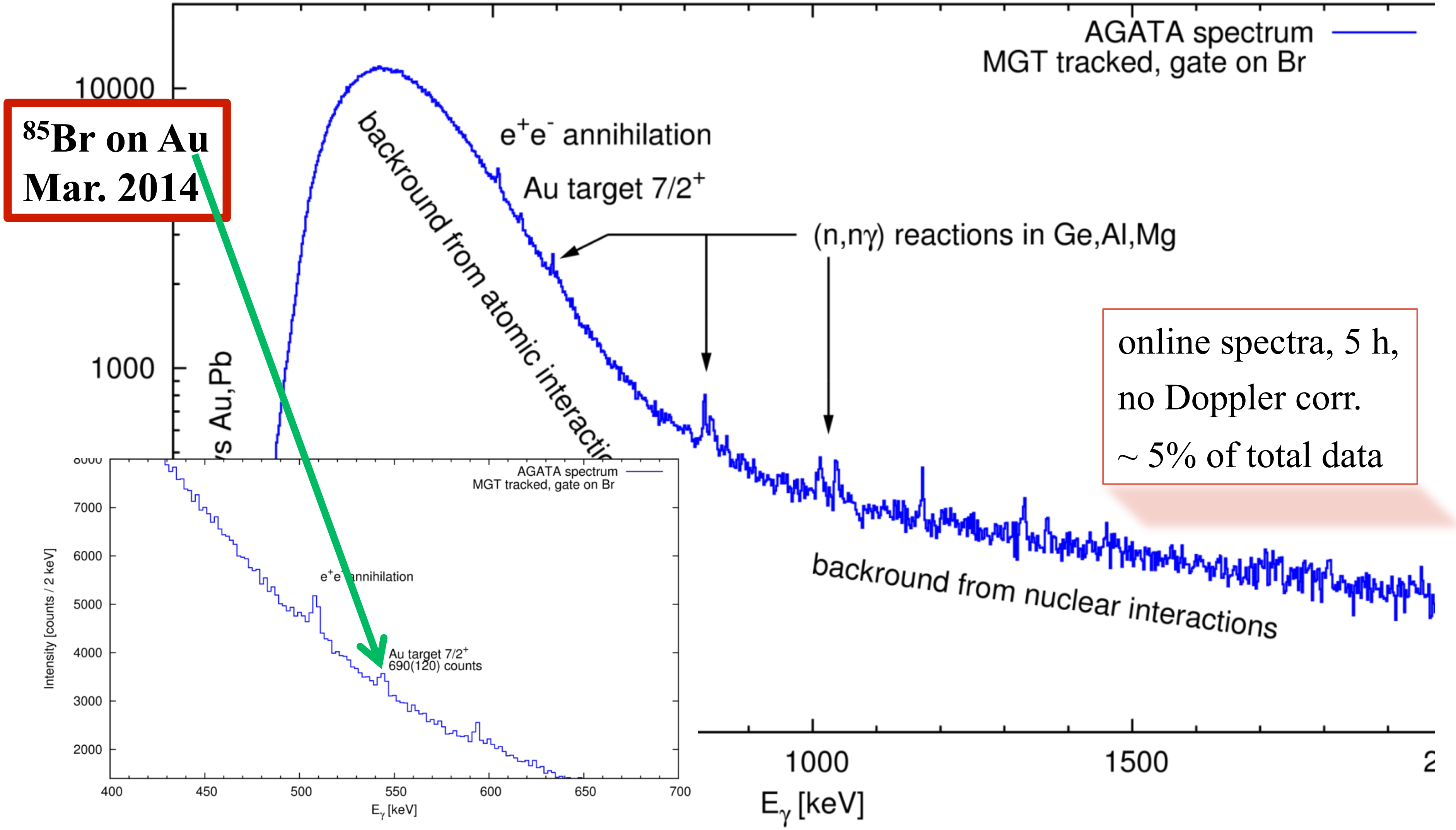
PreSPEC-AGATA 2012-2014: Early Implementation of HISPEC





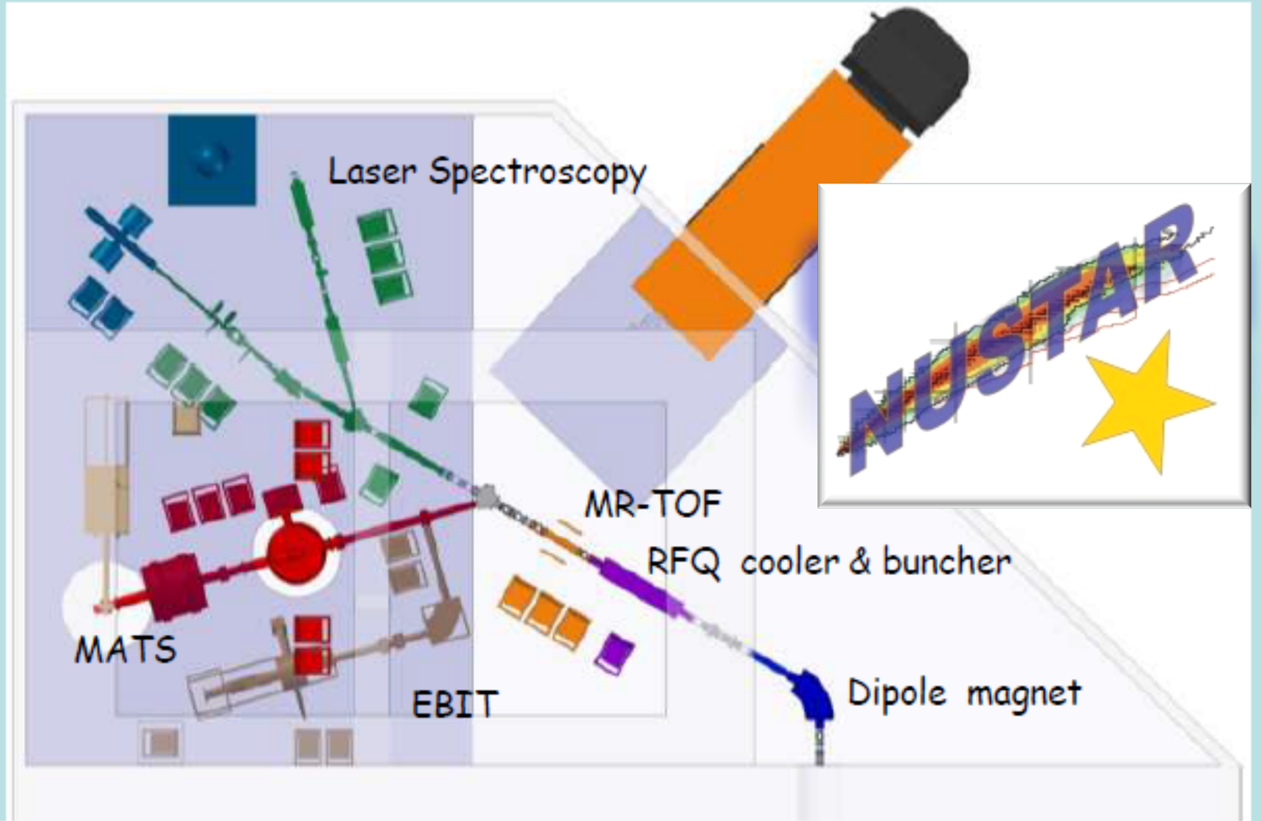
O. Wieland et al.

First data on Relativistic M1-Projectile COULEX

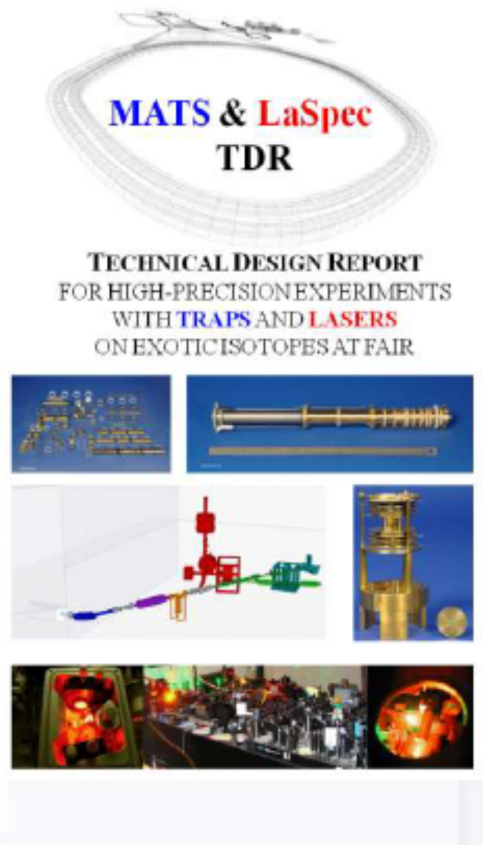


data: M. Reese, C. Stahl, M. Lettmann (TU Darmstadt)

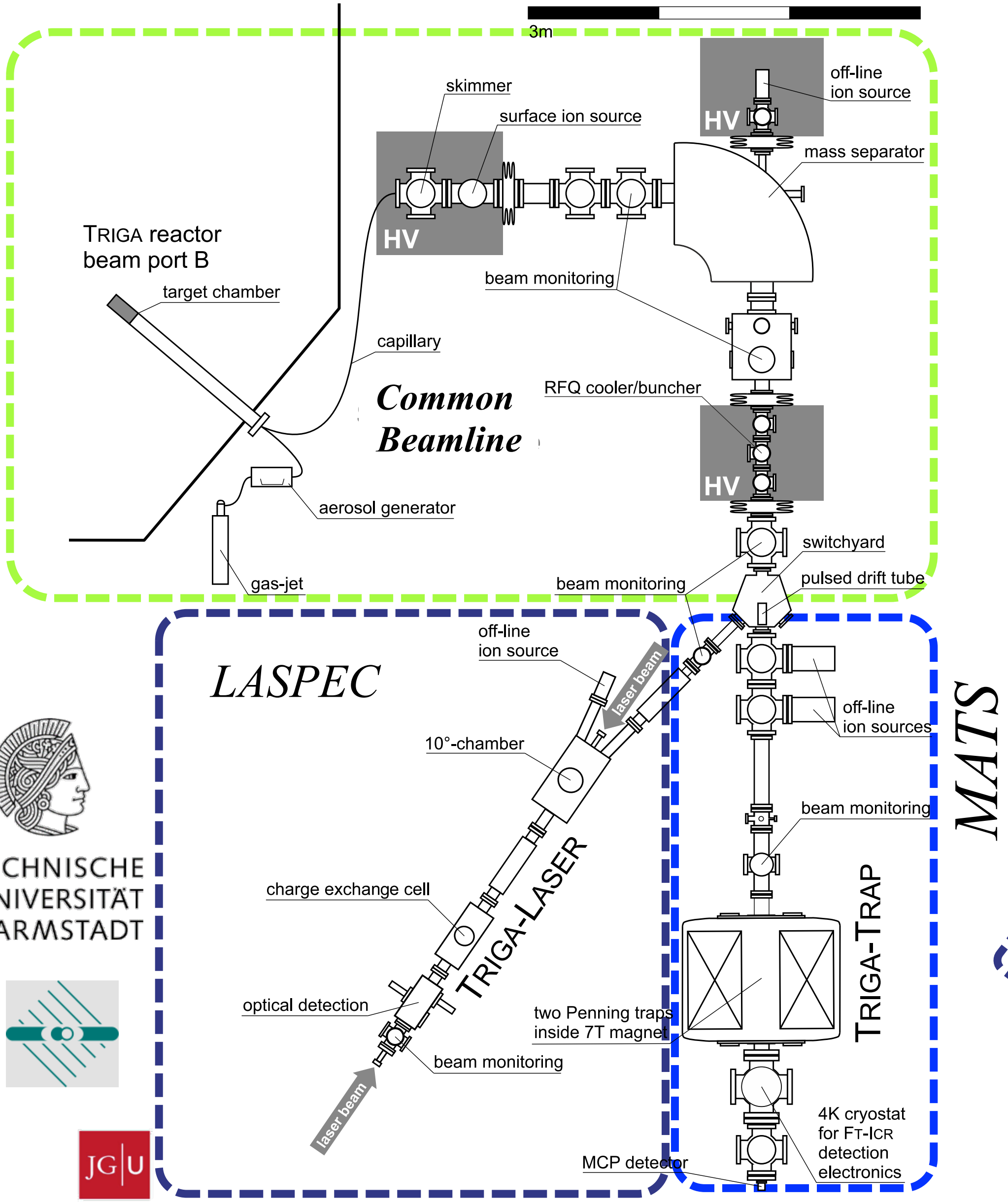
MATS/LASPEC at the Low Energy Branch (LEB)

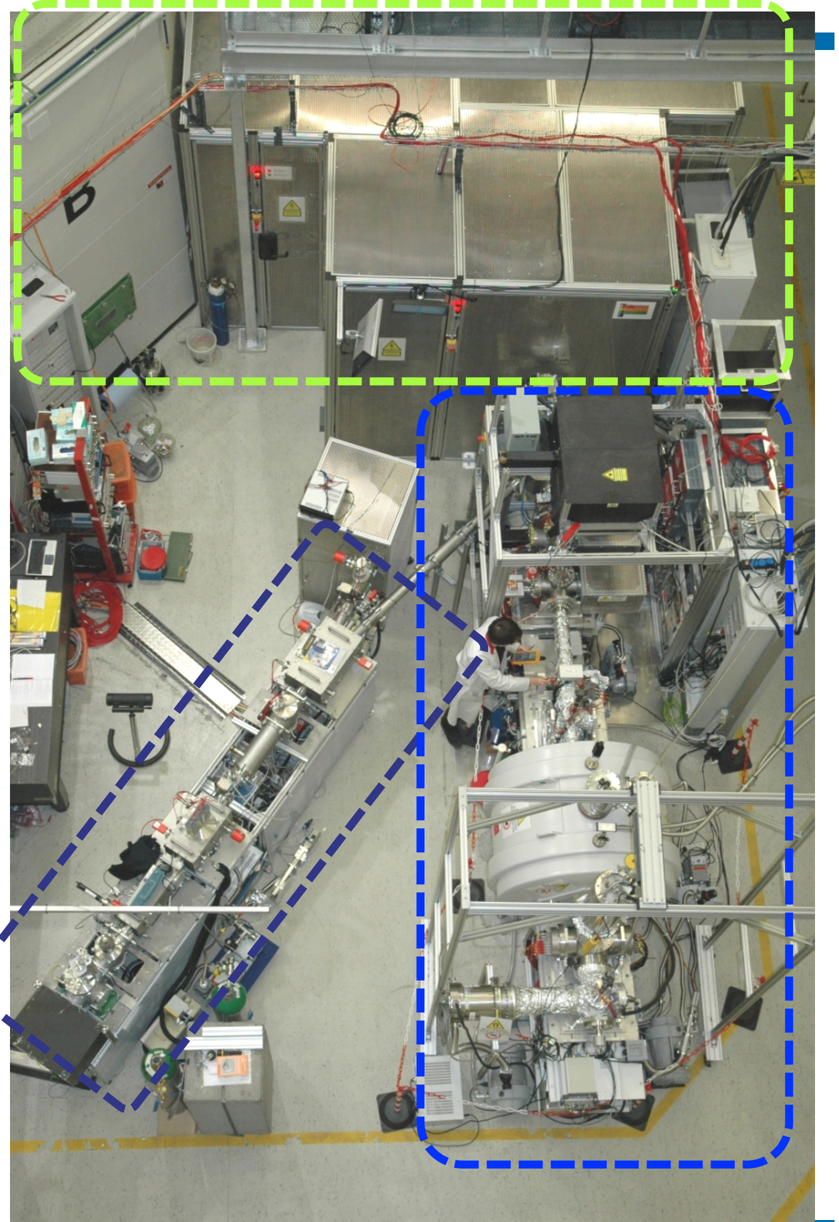


for more information see:
Technical Design Report of MATS & LaSpec:
D. Rodriguez, EPJ Special Topics 183 (2010) 1-123



TRIGA-SPEC @ Mainz: Prototype of MATS and LASPEC





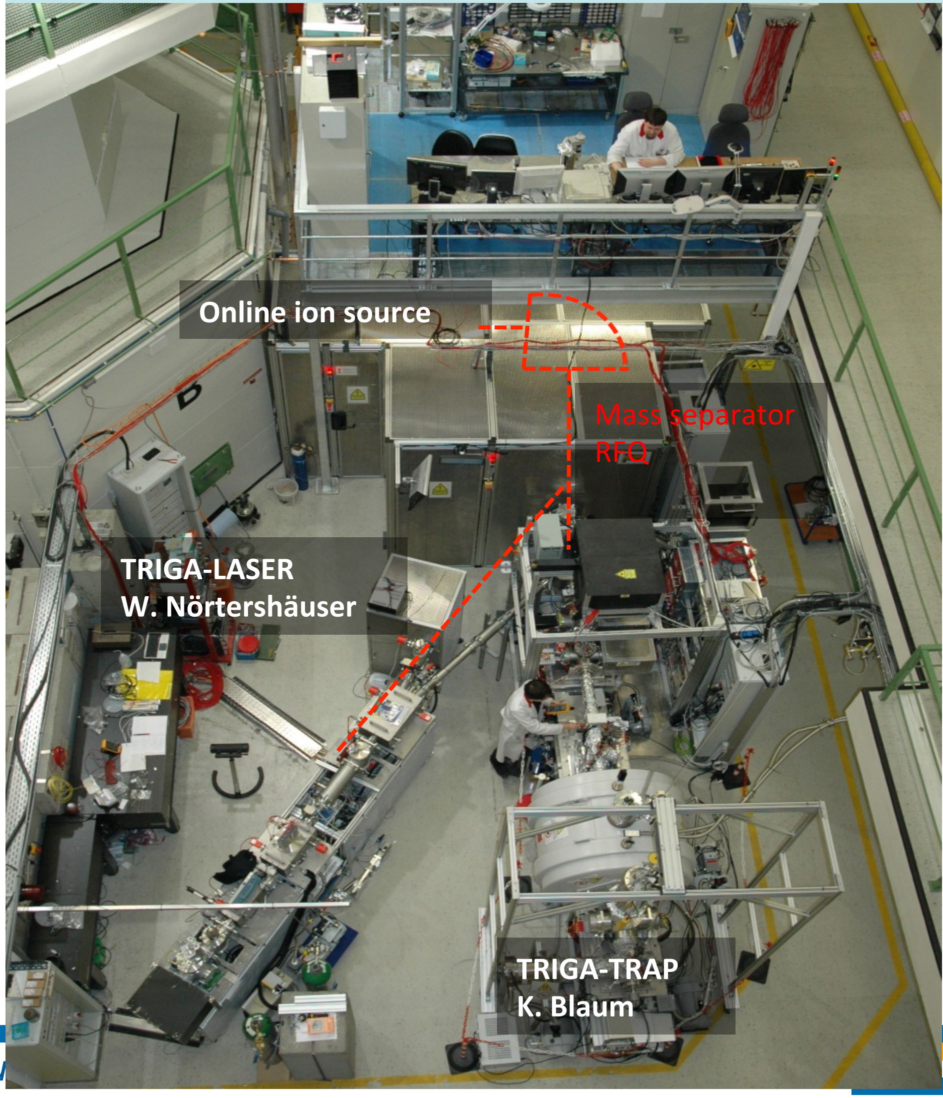
TECHNISCHE UNIVERSITÄT DARMSTADT

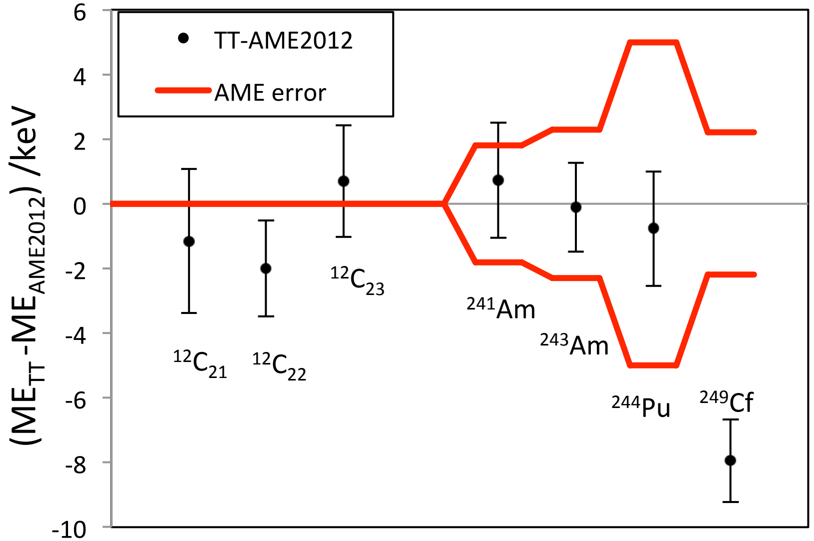
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

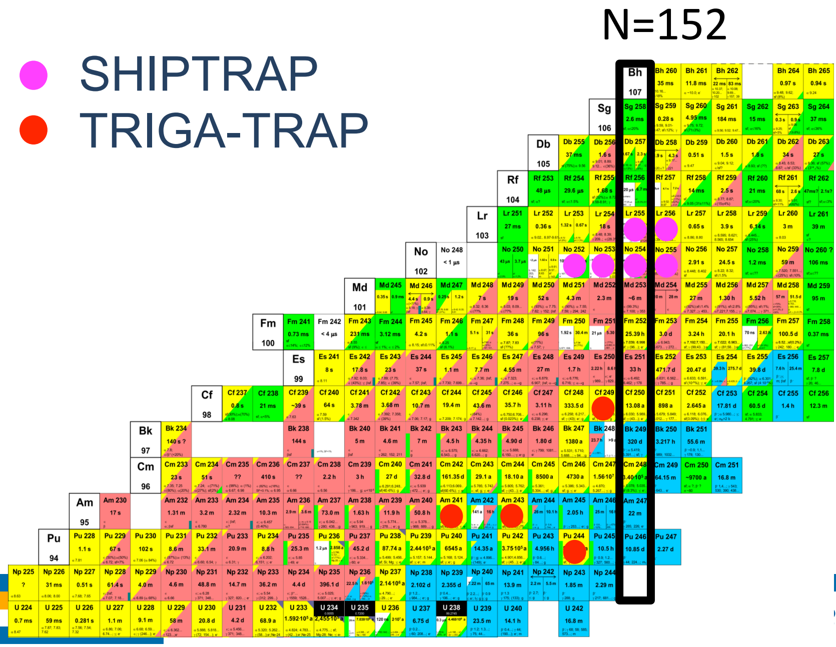
Mass Measurements at TRIGA-TRAP in 2013
First stage of MATS (View with GSI data)

MPIK, Mainz
K. Blaum,
S. Nagy et al.,

project start @ TRIGA: 01/2008
start data taking: 05/2009

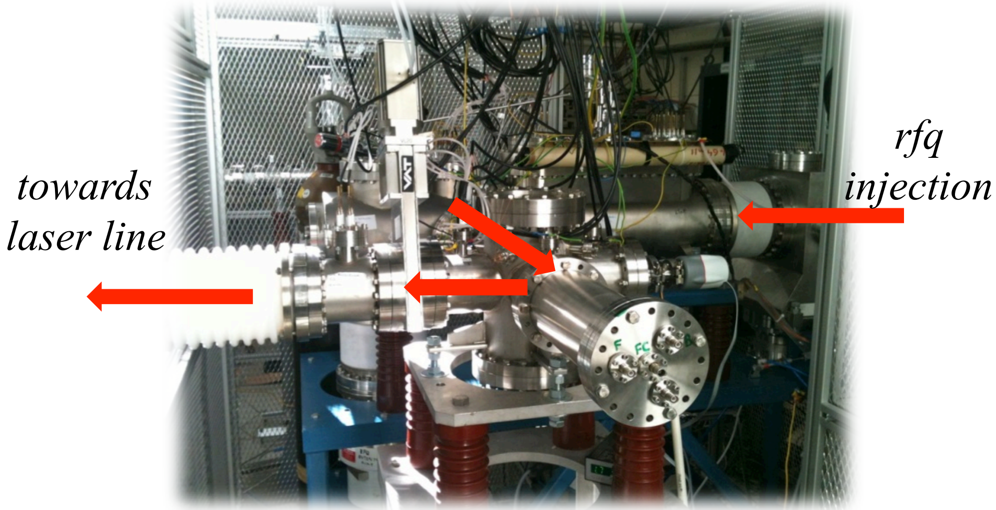


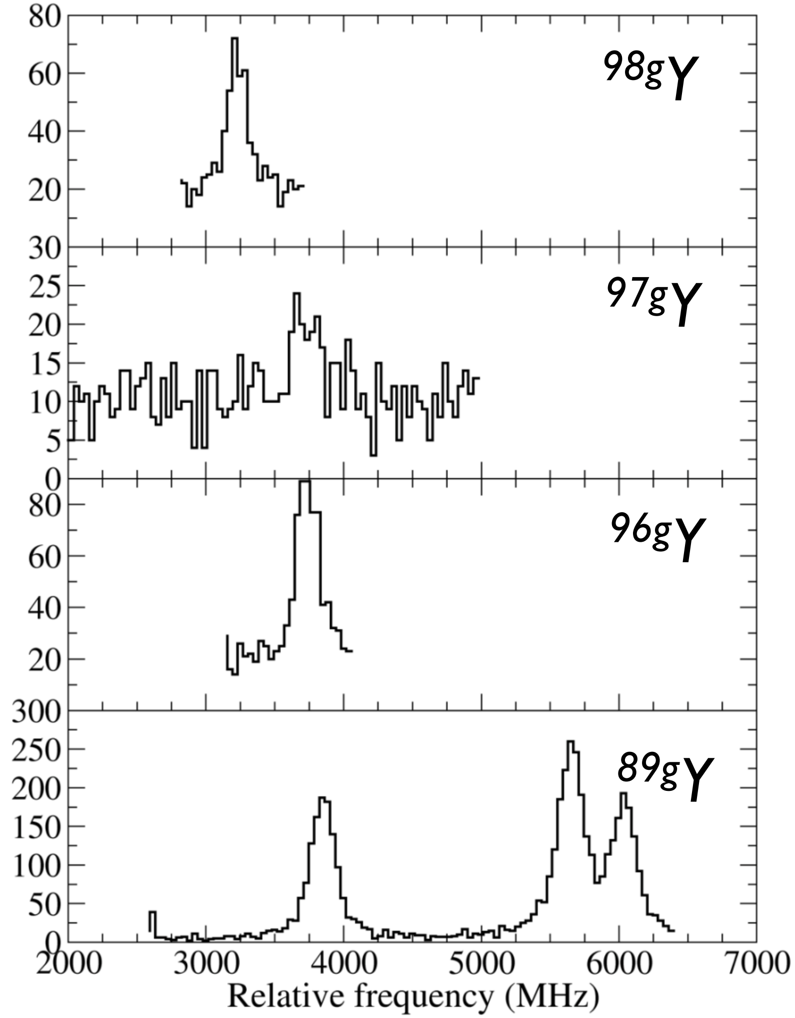




Collinear laser spectroscopy of doubly-charged fission fragments at IGISOL-4

150
AHEAD OF ITS TIME
FOR 150 YEARS





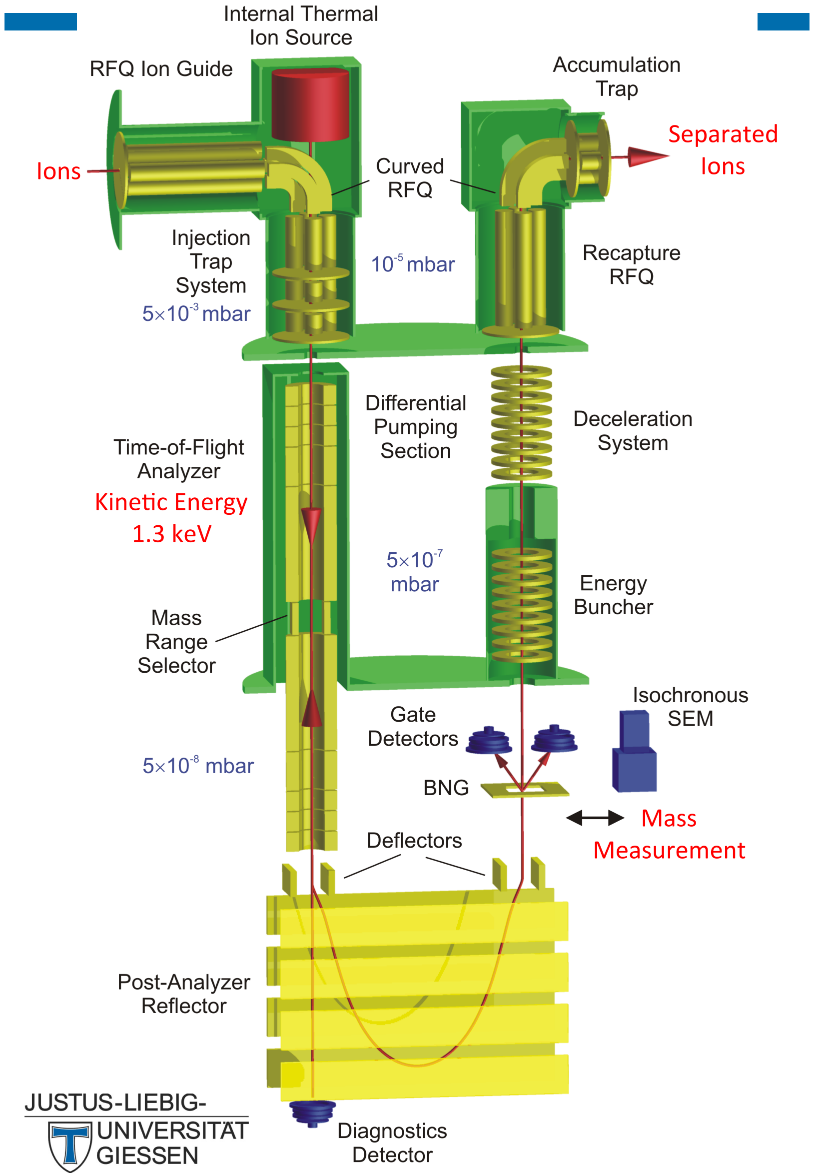
- First spectroscopy on 2^{+} charge states
- Optical manipulation in rfq
- s→p transition from metastable state
- Calibrate atomic factors in yttrium

UNIVERSITY OF LIVERPOOL

MANCHESTER 1824
The University of Manchester

Multi-Reflection Time-Of Flight Mass Spectrometer

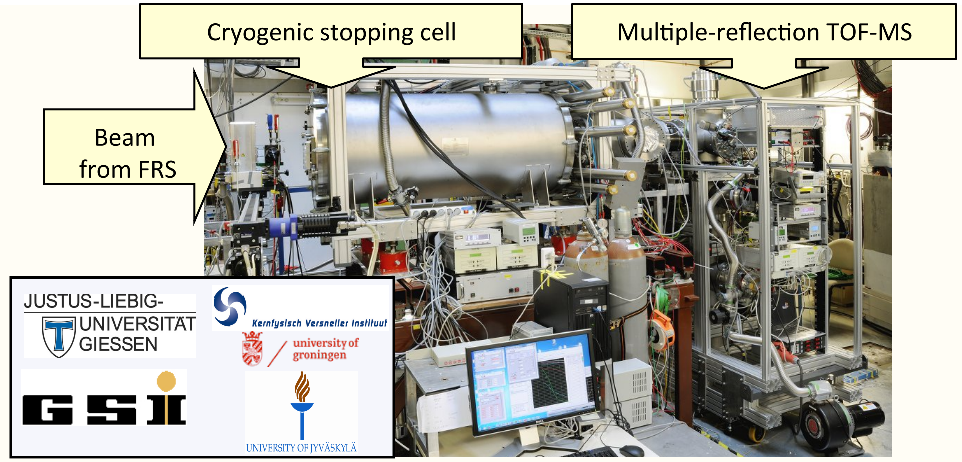
Giessen
W. Plass et al.



Mass spectrometer (direct mass measurements, broadband diagnostics) and isobar separator

Features world-wide unique performance characteristics:

- Mass resolving power: up to 600,000
- Mass measurement accuracy: down to 10^{-7}
- Measurement duration: ~ few ms
- Repetition frequency: up to 400 Hz
- Transmission efficiency: > 50%
- Ion capacity: up to 10^6 ions/s



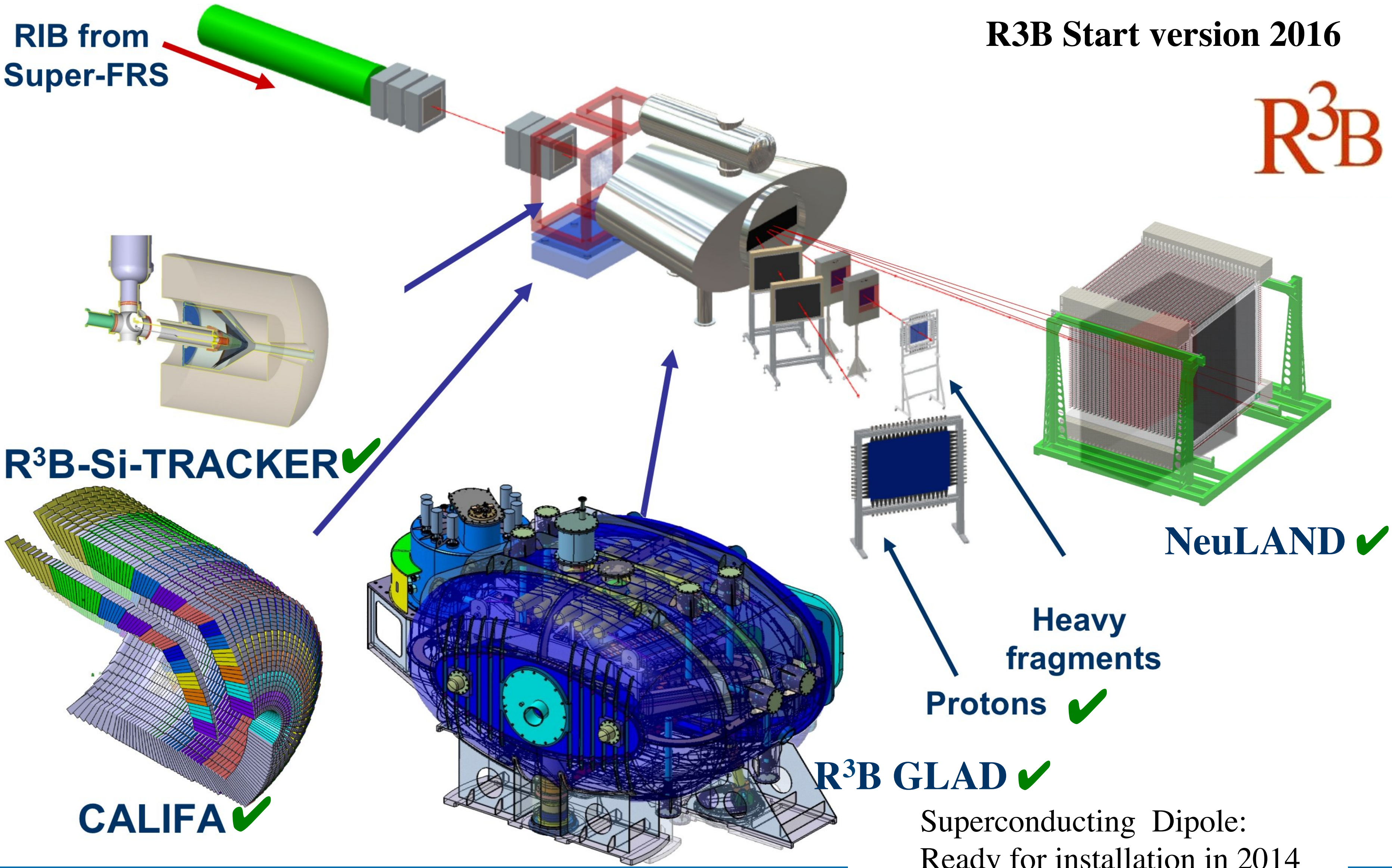
Commissioned online at the FRS Ion Catcher in 2012

- First direct mass measurements of ^{211}Po and ^{211}Rn, ^{213}Rn ($T_{1/2}$ = 19.5 ms!)
- Characterization of stopping cell performance: MR-TOF-MS ideal diagnostics tool for stopping cells

Future work: Implement recapture system / operation as (ultra-)high resolution mass separator

W.R. Plaß et al., NIM B 266 (2008) 4560
W.R. Plaß et al., Int. J. Mass Spectrom. 394 (2013) 134

Reactions with Relativistic Radioactive Beams



Superconducting Dipole:
Ready for installation in 2014
Construction by CEA Saclay

Schedule and first experiments

2013 Installation of infrastructure in Cave C for GLAD (He cryo-system, power supply)
Delivery and installation of superconducting dipole GLAD (expected Q4/2014)

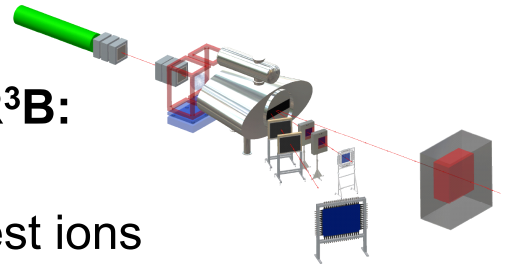
2014 Installation of 20% detectors NeuLAND and CALIFA
Commissioning run in Q3/2014

2015/16 Construction and installation of detector components

2017 Commissioning of full R3B setup and first physics run at GSI

2018 Installation of experimental setup at FAIR site including superconducting triplet

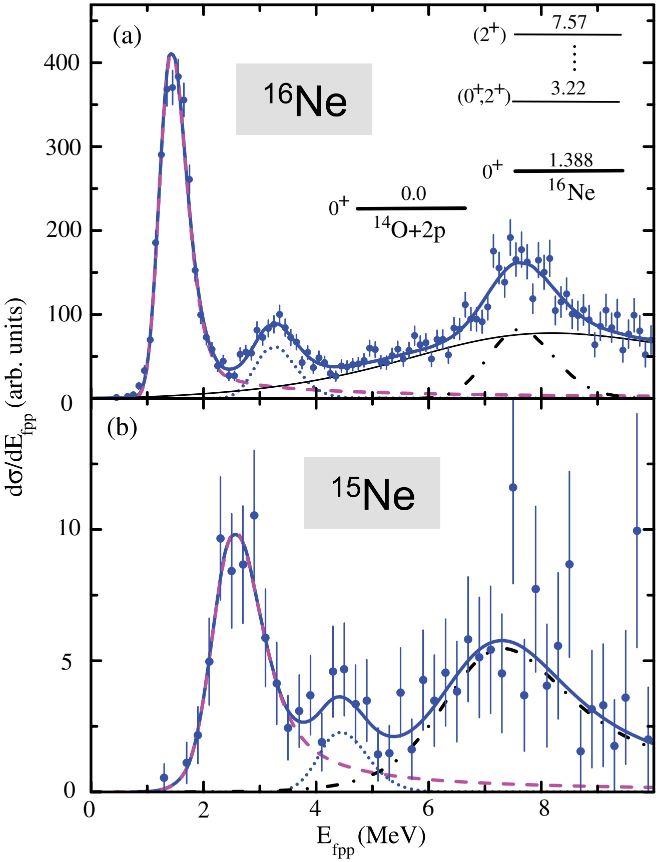
2019 Commissioning and first experiments at Super-FRS



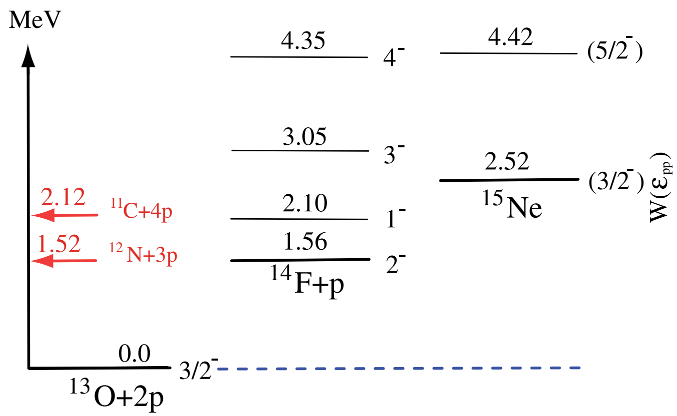
Experiments in 2019 will make use of uniqueness of R^3B:
- Reactions at high beam energies up to 1 GeV/nucleon
- Tracking and identification capability even for the heaviest ions
- Multi-neutron tracking capability, high-efficiency calorimeter

→ **Experiments possible for the first time:**
- 4 neutron decays beyond the drip-line and for heavier n-rich isotopes
- Kinematically complete measurements of quasi-free nucleon knockout reactions
- Electric dipole and quadrupole response of Sn nuclei beyond N=82, and of neutron-rich Pb isotopes

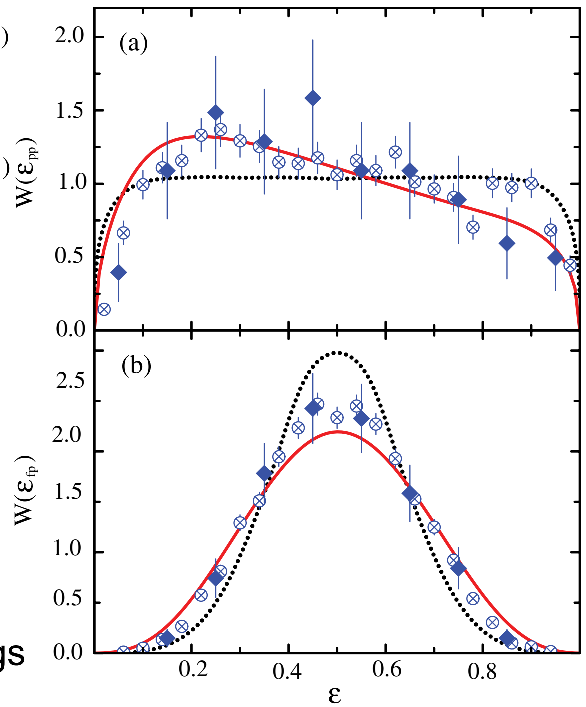
Beyond the drip line
First observation of ^{15}Ne ground and excited states



^{15}Ne and daughter nuclei



^{15}Ne 3-body decay



⊗ *^{16}Ne exp data*

◆ *^{15}Ne exp data*

^{16}Ne isotropic 3-body decay

sequential decay via the ^{14}F gs

^{15}Ne ground state unbound by S_{2p} = 2.522(66) MeV

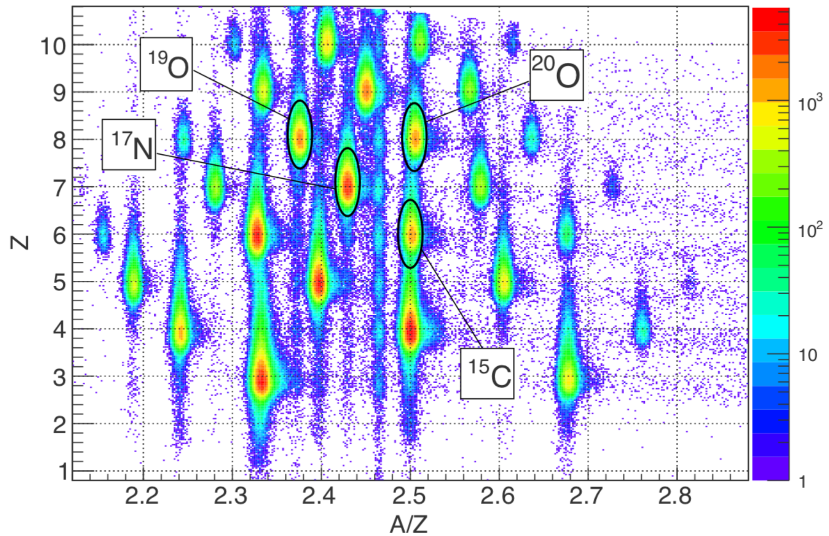
^{15}Ne is (like ^{16}Ne) a true 2p-decay nucleus, (despite available states in ^{14}F)

R3B

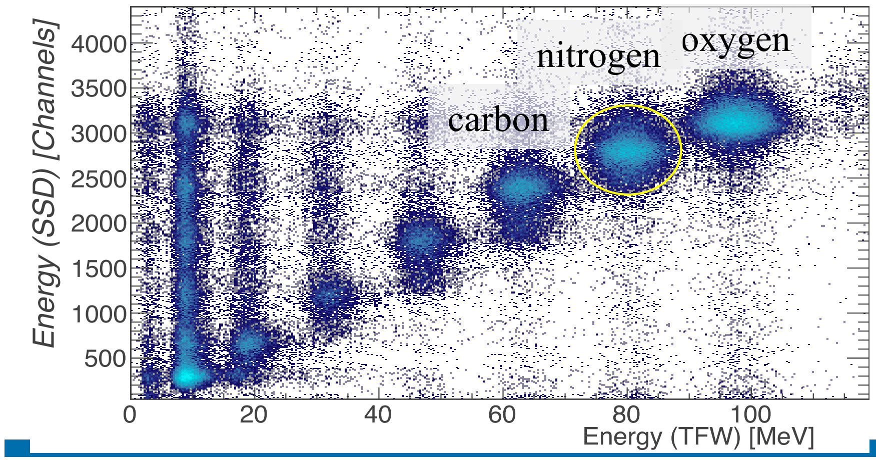
F. Wamers et al., Phys. Rev. Lett. 112 (2014) 132502

Quasi-free scattering

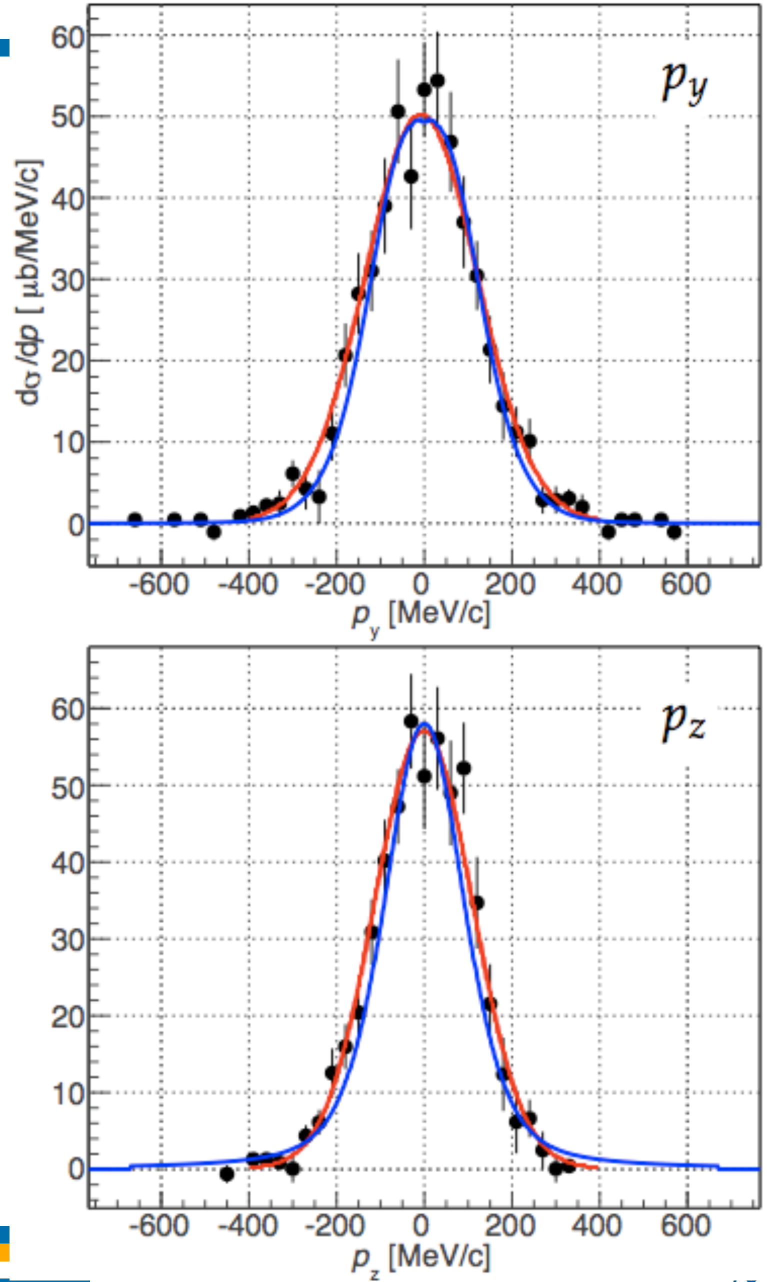
Incoming Particles



Outgoing Particles

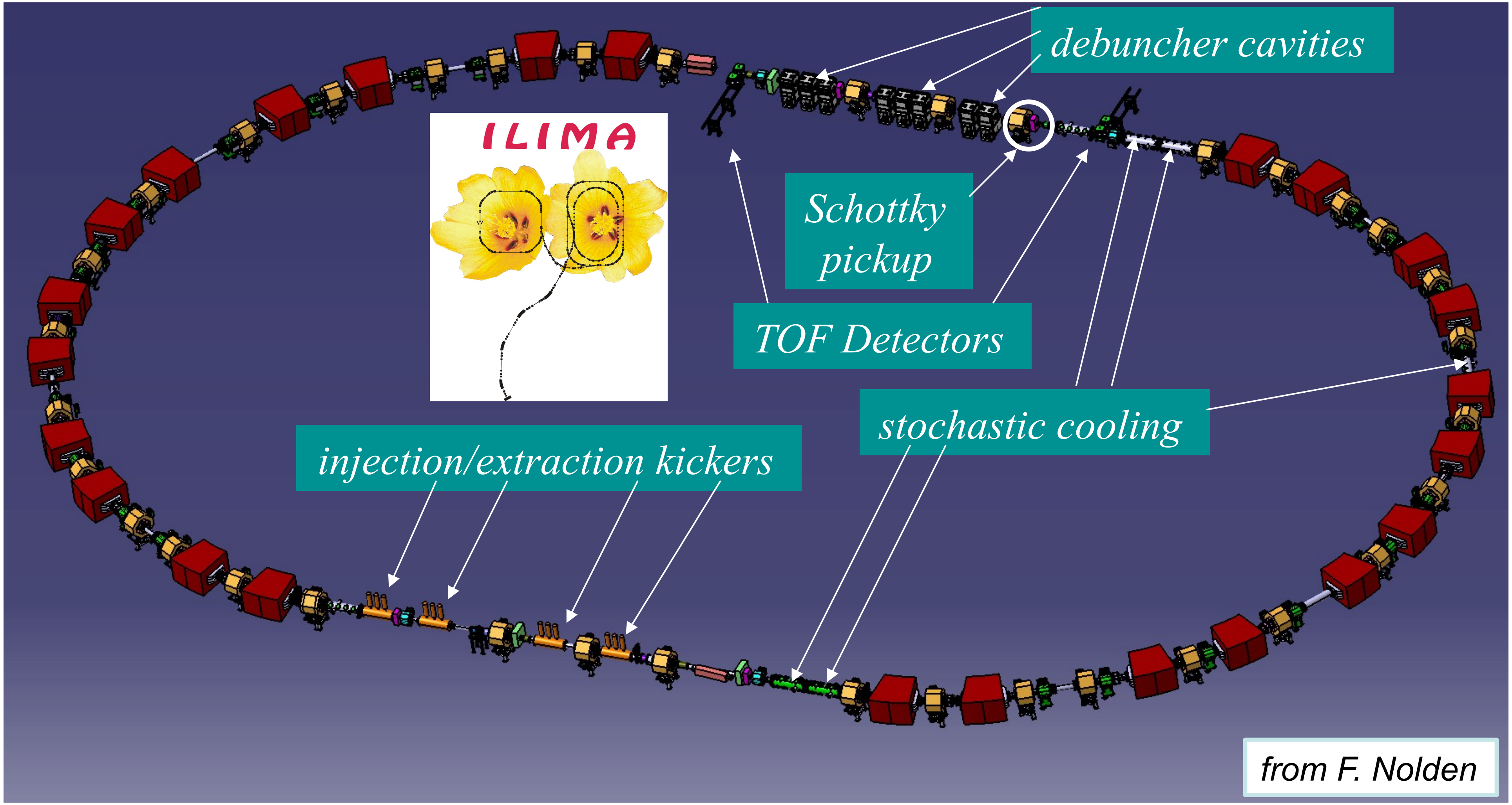


p(^{20}O , pp^{19}N)



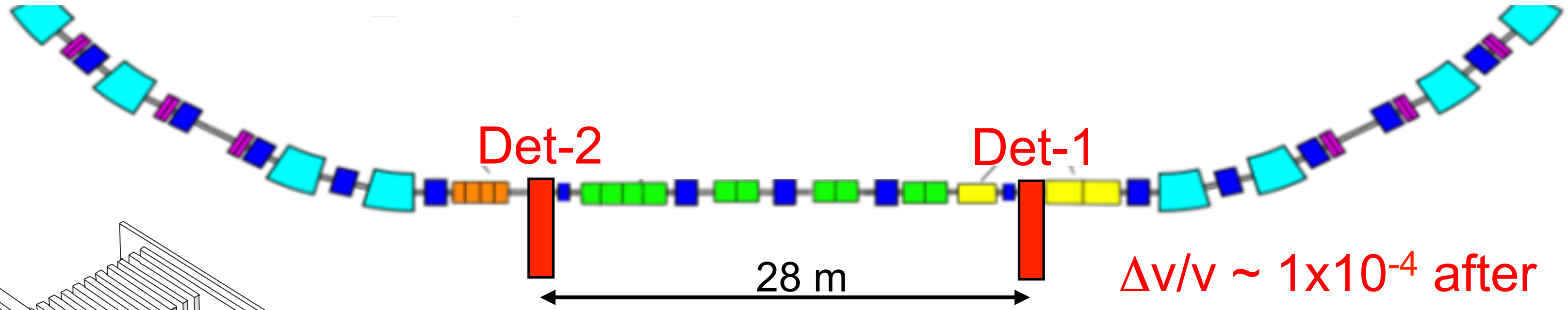
ILIMA – partial program in CR (NESR not in MSV)

CR perspective view

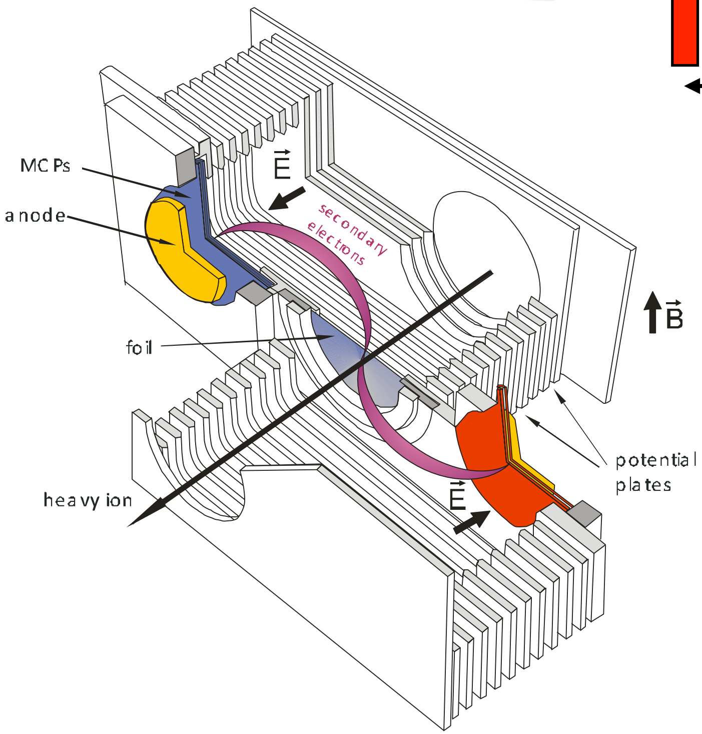


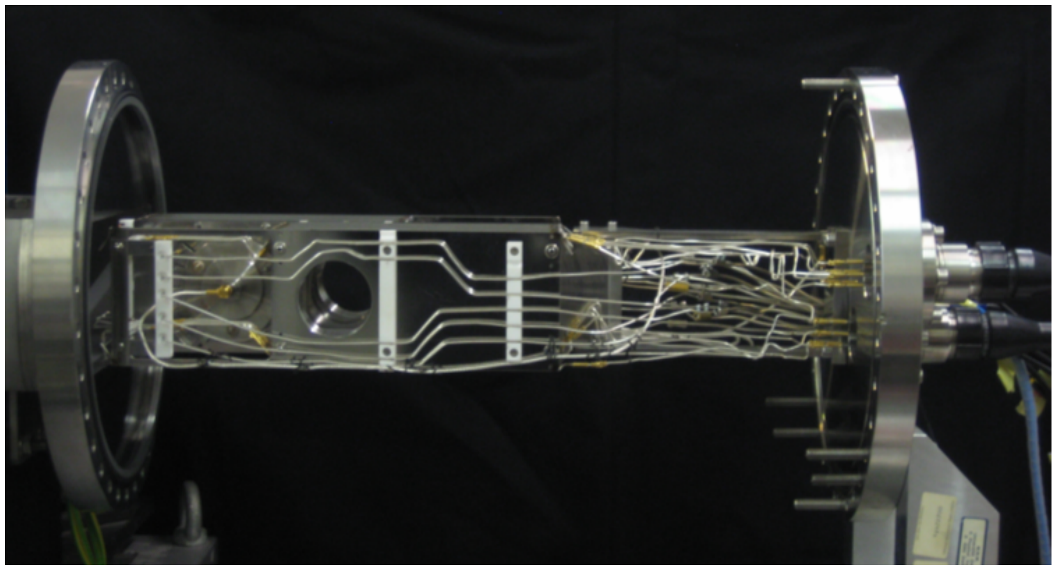
ToF Detection

How to operate in a ring without an electron cooler?
→ Measure velocity and also position simultaneously with two ToF detectors.



$\Delta v/v \sim 1x10^{-4}$ after averaging many turns





Super-FRS as an experimental setup

High-resolution spectrometer for relativistic beams

Important beam parameters:
- all elements from H through U
- intensity up to ~ 10^{12} ions/sec.
- beam energies up to 1.5 GeV/u
- slow (DC-type) extraction

Super-FRS characteristics:

$\varepsilon_x = \varepsilon_y = 40\ \pi$ mm mrad

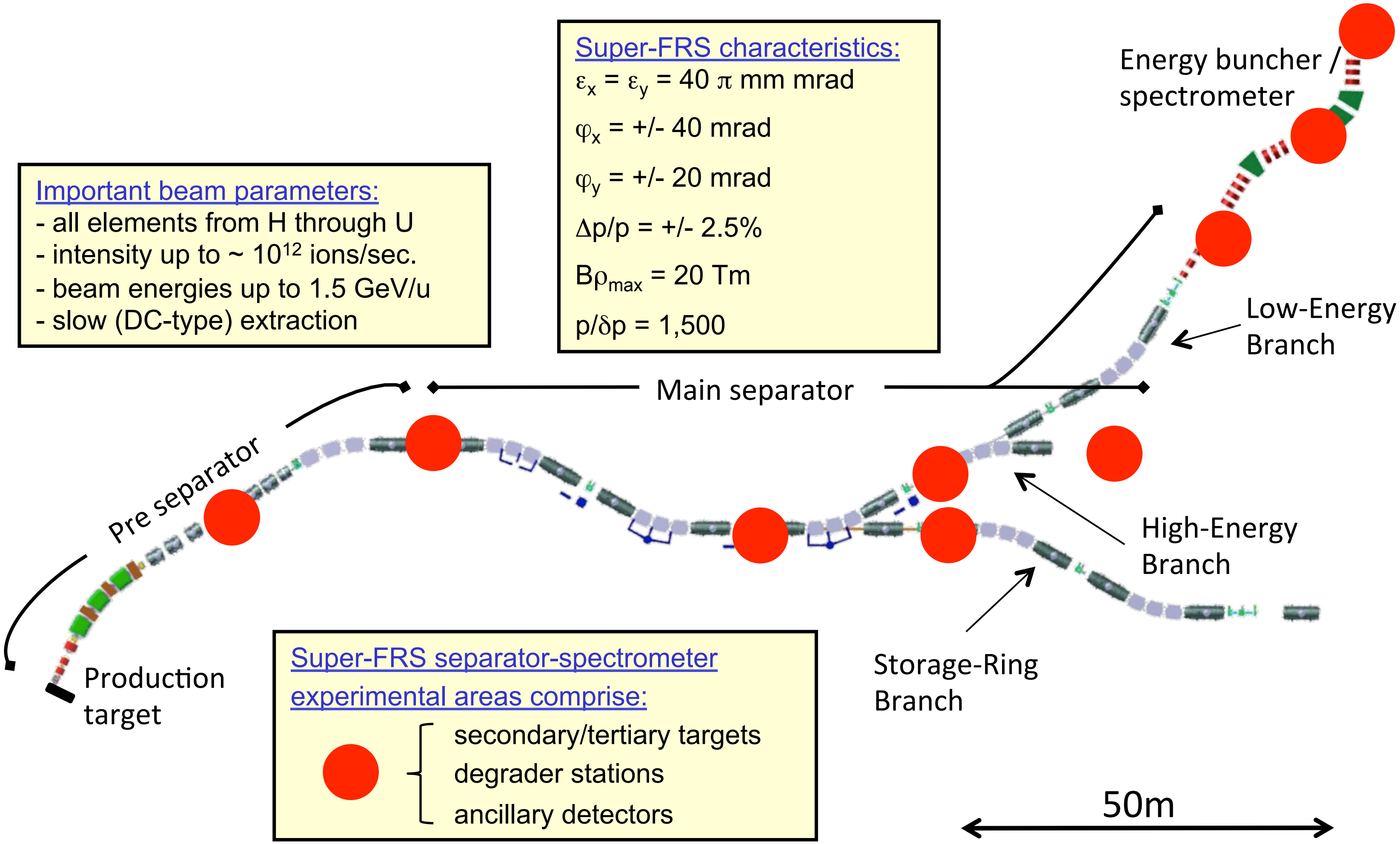
$\varphi_x = +/- 40$ mrad

$\varphi_y = +/- 20$ mrad

$\Delta p/p = +/- 2.5\%$

$B\rho_{max} = 20$ Tm

$p/\delta p = 1{,}500$



Super-FRS separator-spectrometer experimental areas comprise:
- secondary/tertiary targets
- degrader stations
- ancillary detectors

Super-FRS experiments

Super-FRS physics collaboration within NUSTAR formally established

Worldwide unique features:

- energy > 500 MeV/u
- momentum resolution $p/\Delta p \sim$ 1500 ... 20000
- customized ion-optical modes

Planned experiments will use

- separator stages for high momentum resolution
- intermediate degrader and target stations
- standard equipment + (new) ancillary detectors

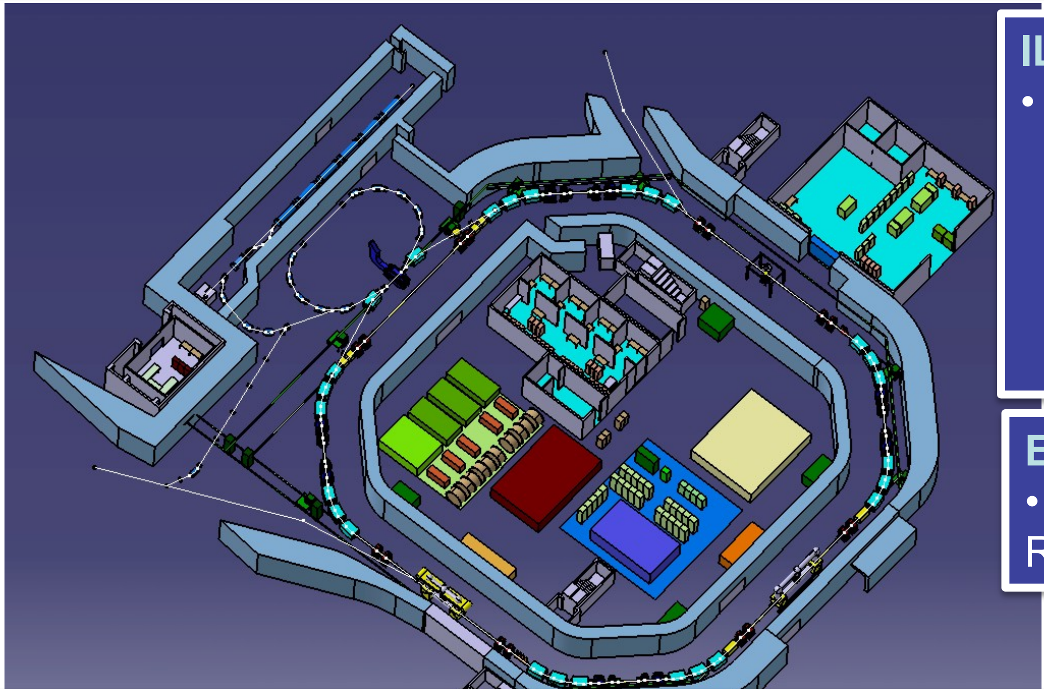
Super-FRS as:

- high-performance separator for mono-isotopic or cocktail beams
- high resolution spectrometer
- RI beam separator plus reaction spectrometer

Science programme compiled, synergies and overlaps identified

Beyond MSV: NUSTAR program at the NESR

Experiments with stored, electron cooled ion beams
• World-wide unique
• Conceptionally new experiments



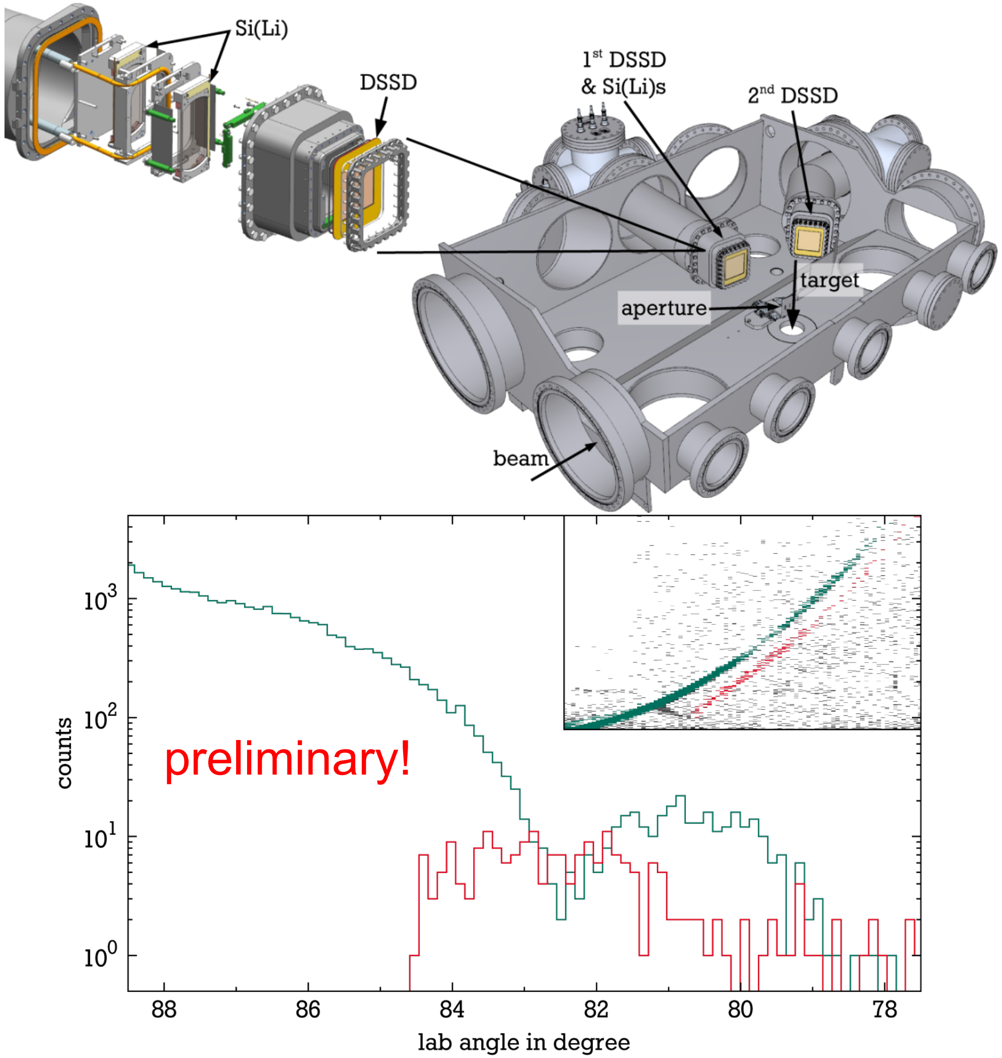
ILIMA
• electron cooled beams needed for
  • higher precision and separation (ground and isomeric states)
  • time-resolved studies (unique decay modes, e.g. bound beta decay)
  • studies with pure isomeric beams

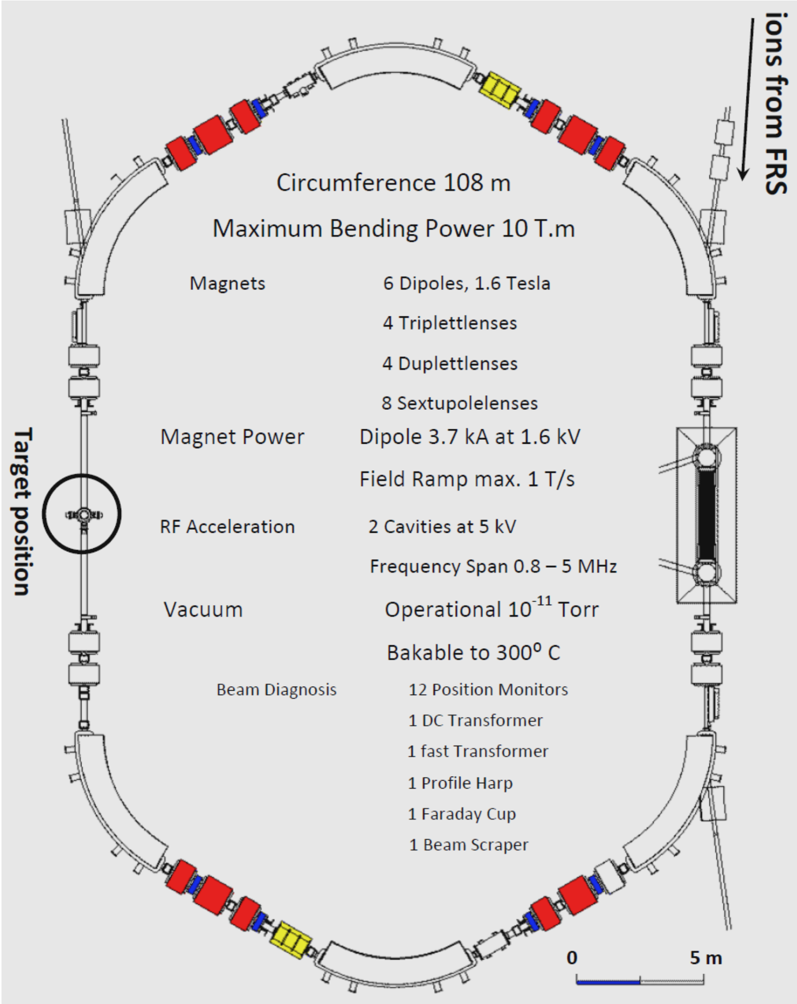
ELISe
• Elastic and inelastic electron scattering on RIBs

EXL: Elastic and inelastic scattering, reaction with low-momentum transfer
• matter distributions, monopole resonances, capture reactions, charge exchange reactions, transfer, knock-out
(n-skins, compressibility, GT-strength, shell evolution, nucl. astrophysics reactions)

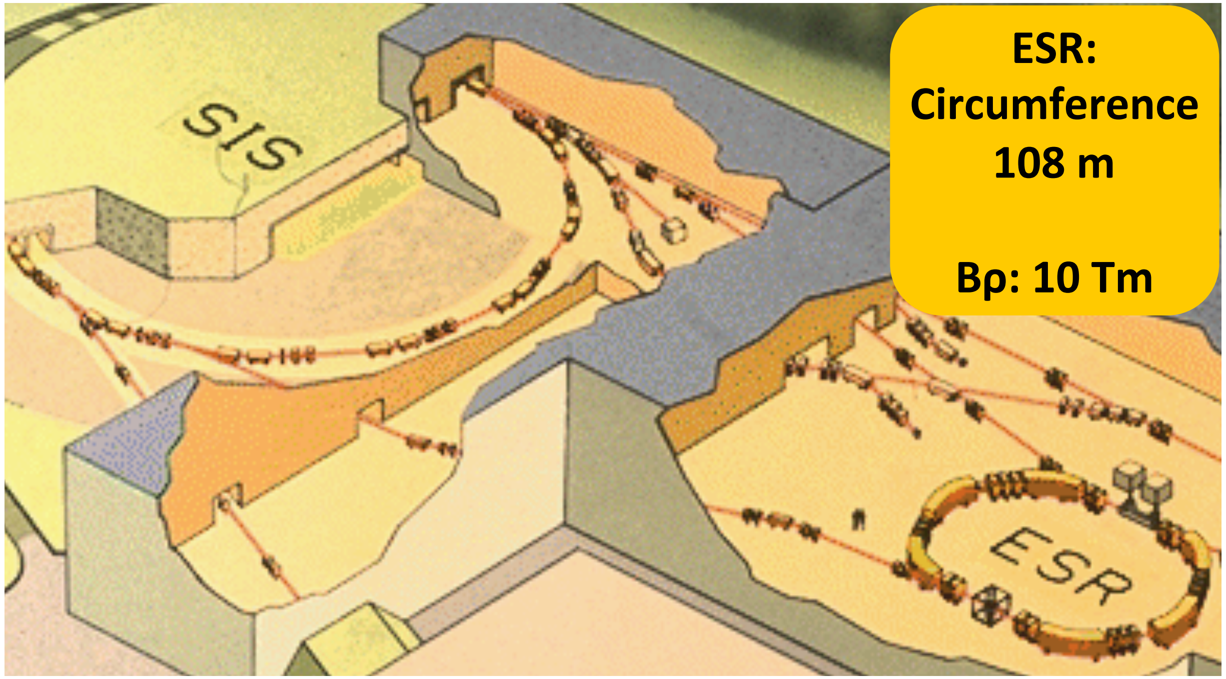
Intermediate storage ring activities@ESR/"Green Paper"

Elastic p-scattering off ^{56}Ni (E105)



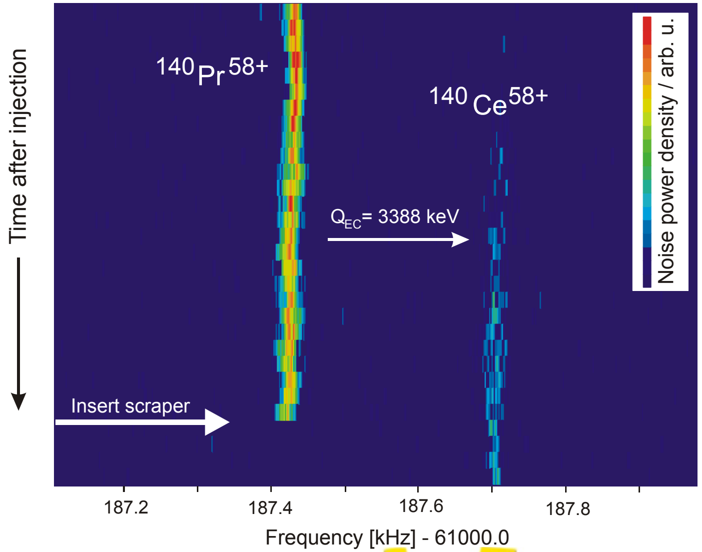


CRYRING at ESR



**ESR:
Circumference
108 m**

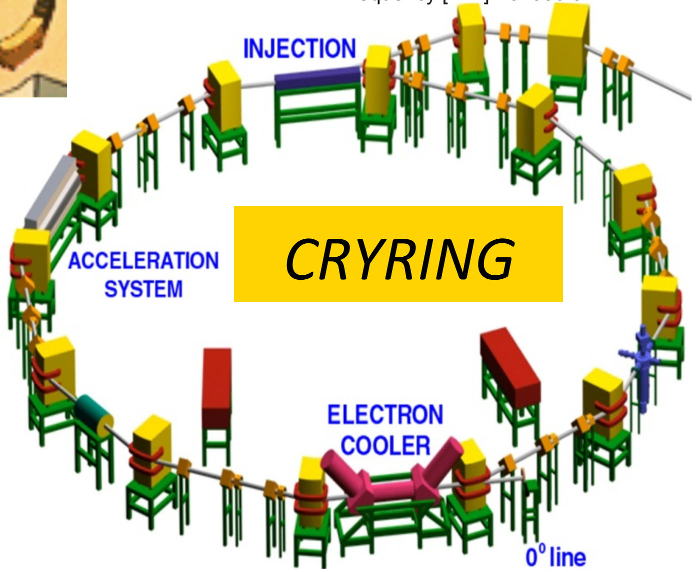
Bρ: 10 Tm



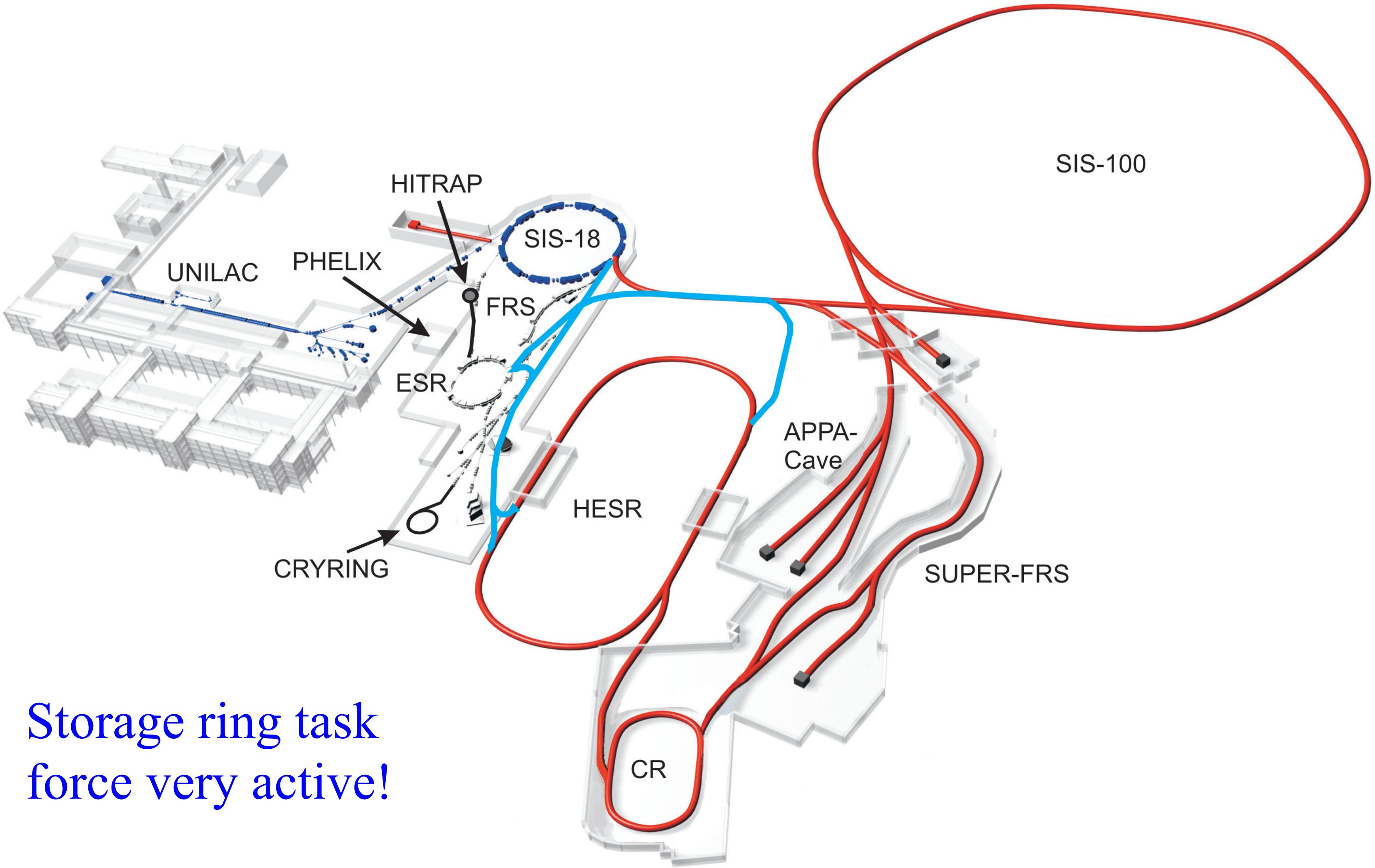
Cryring+ESR: beam energies 0.1-1.0 MeV/u - reaction rates measurements in the Gamow window of the **rp-process**

**Cryring
Circumference
54 m**

Bρ: 1.44 Tm

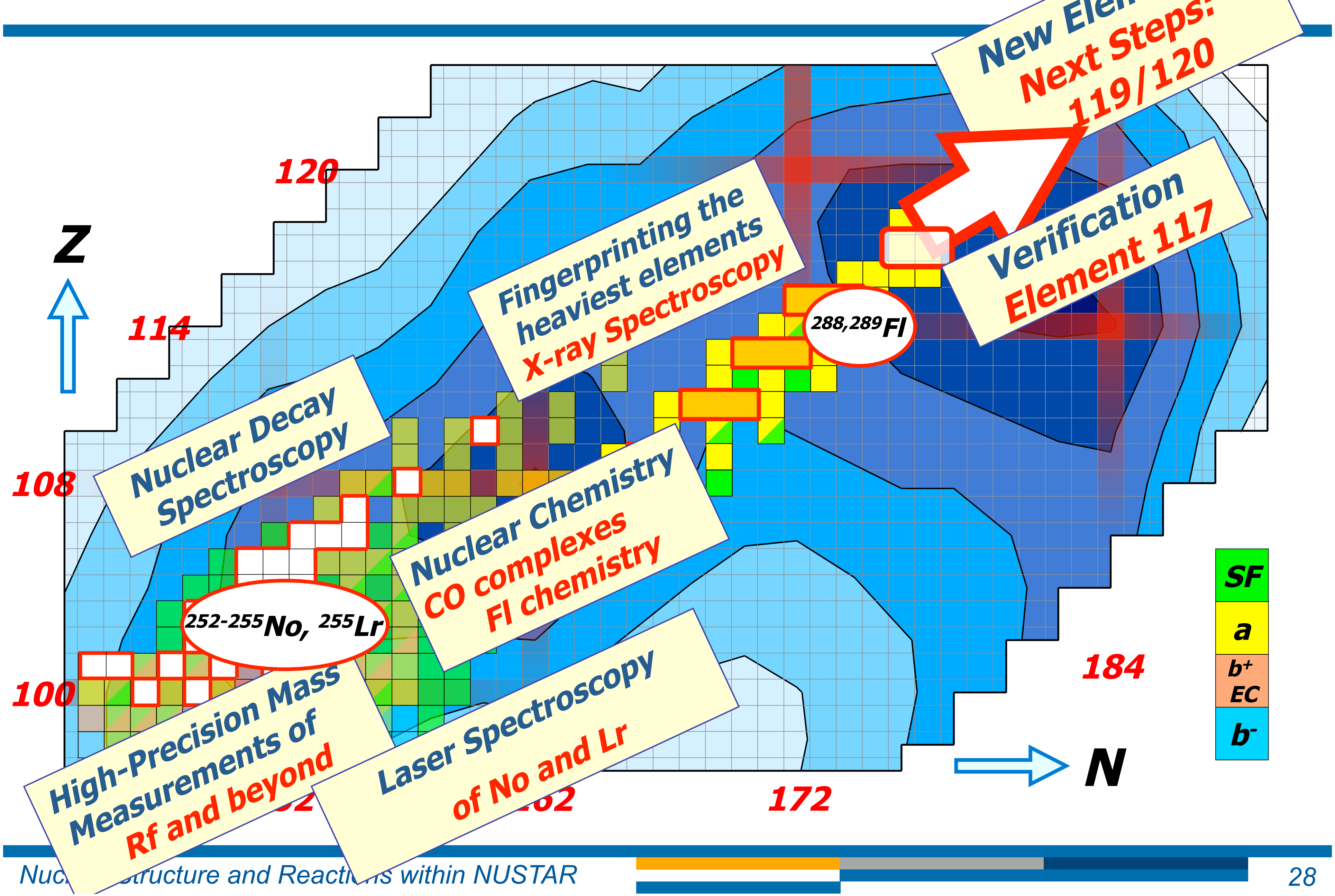


Transfer line to HESR/ESR/CRYRING



Storage ring task
force very active!

SHE collaboration @ NUSTAR



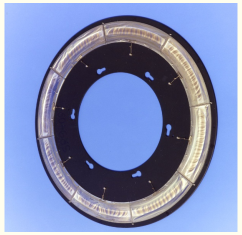
Unique instrumentation for SHE research at FAIR

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

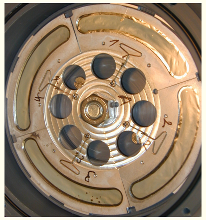
GSI

ECR/PIG + UNILAC

Beam



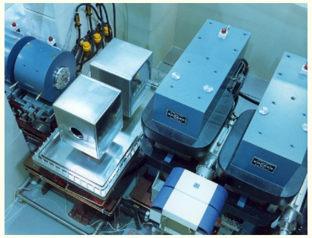
Stable targets



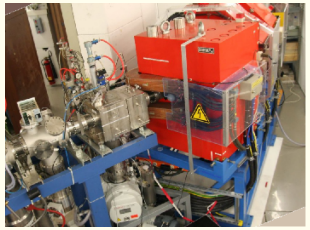
Actinide targets

TRIGA- -LASER -TRAP

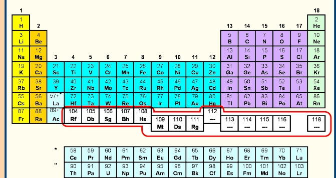
Radiochem. labs



SHIP

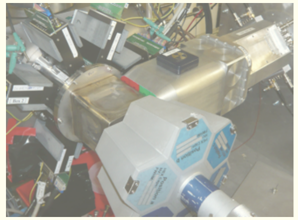


TASCA

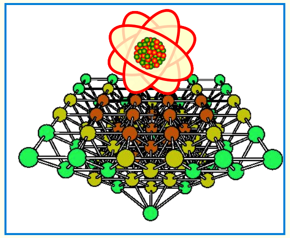


Chemistry

SHIPTRAP



TASISpec



Chemical theory

SHE collaboration @ NUSTAR

SHE research will complement NUSTAR scientific program

- Comprehensive approach to study atomic, chemical, and nuclear properties of the heaviest elements (Z > 100)
- versatile cutting-edge setups such as SHIP, SHIPTRAP, TASCA, TASISpec and more ready for experiments
- steps toward realization of high-intensity CW Linac for SHE research underway: accelerator R&D at HIM/GSI/GUF ("demonstrator" funded)

SHE sub-collaboration is being formed following endorsement by NUSTAR board, science case recently submitted.

Spokesperson:	Christoph Düllmann
Deputy Spokesperson:	Michael Block
Technical Coordinator:	Alexander Yakushev

NUSTAR@FAIR

World-wide unique synchrotron-based RIB production for:

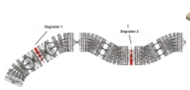
- High-energy Radioactive Beams (≤1.5 GeV/u)
  - Efficient production, separation, transmission and detection aided by Lorentz boost
  - Access to the heaviest nuclei without charge-state ambiguities
  - Large range of attainable reaction mechanisms
- Storage rings
  - Mass measurements and beam preparation/manipulation
  - Isomeric beams
  - Novel experimental tools (beyond MSV/with CRYRING, ESR and HESR)

Combined with:

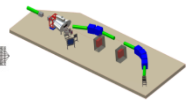
- Wide range of state-of-the-art instrumentation – *not monolithic!*
  - Strong evolution from existing programs
  - Dynamic progress in terms of TDRs/construction/operation
  - Some NUSTAR FAIR experiments could already start in 2017/2018

Complementarity of NUSTAR experiments

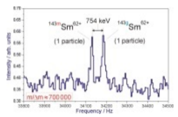
Super-FRS



R3B

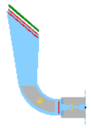


ILIMA

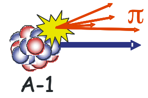


EXL

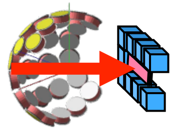
ELISE



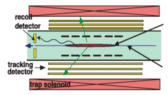
AIC



HISPEC/ DESPEC

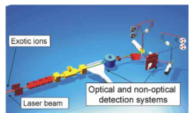


exo+ pbar



MATS

LASPEC



	Super-FRS	R3B	ILIMA	EXL	ELISE	AIC	HISPEC DESPEC	exo+pbar	MATS	LASPEC
Masses			bare ions, mapping study				Q-values, isomers		dressed ions, highest precision	
Half-lives	ps…ns-range		bare ions, s…h				dressed ions, µs…s			
Matter radii	interaction x-sect	matter radii		matter densitiy distributions		matter radii from absorption		nuclear periphery		
Charge radii					charge density distribution					mean square radii
Single-particle structure	high resolution, angular momentum	complete kinematics, neutron detection		low momentum transfers			high-resolution spectroscopy			

Thanks!