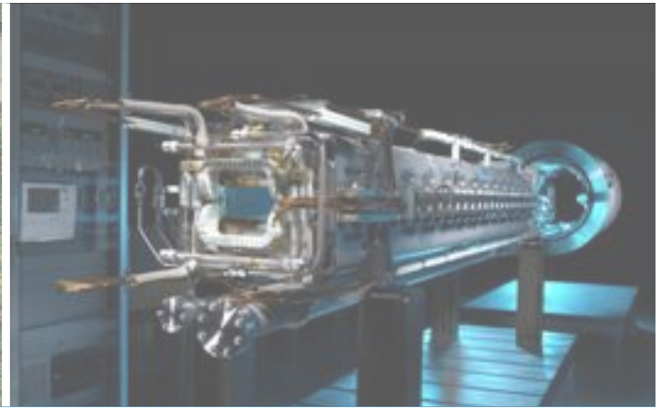


NUSTAR activities at FAIR

Nasser Kalantar-Nayestanaki

KVI-CART/University of Groningen

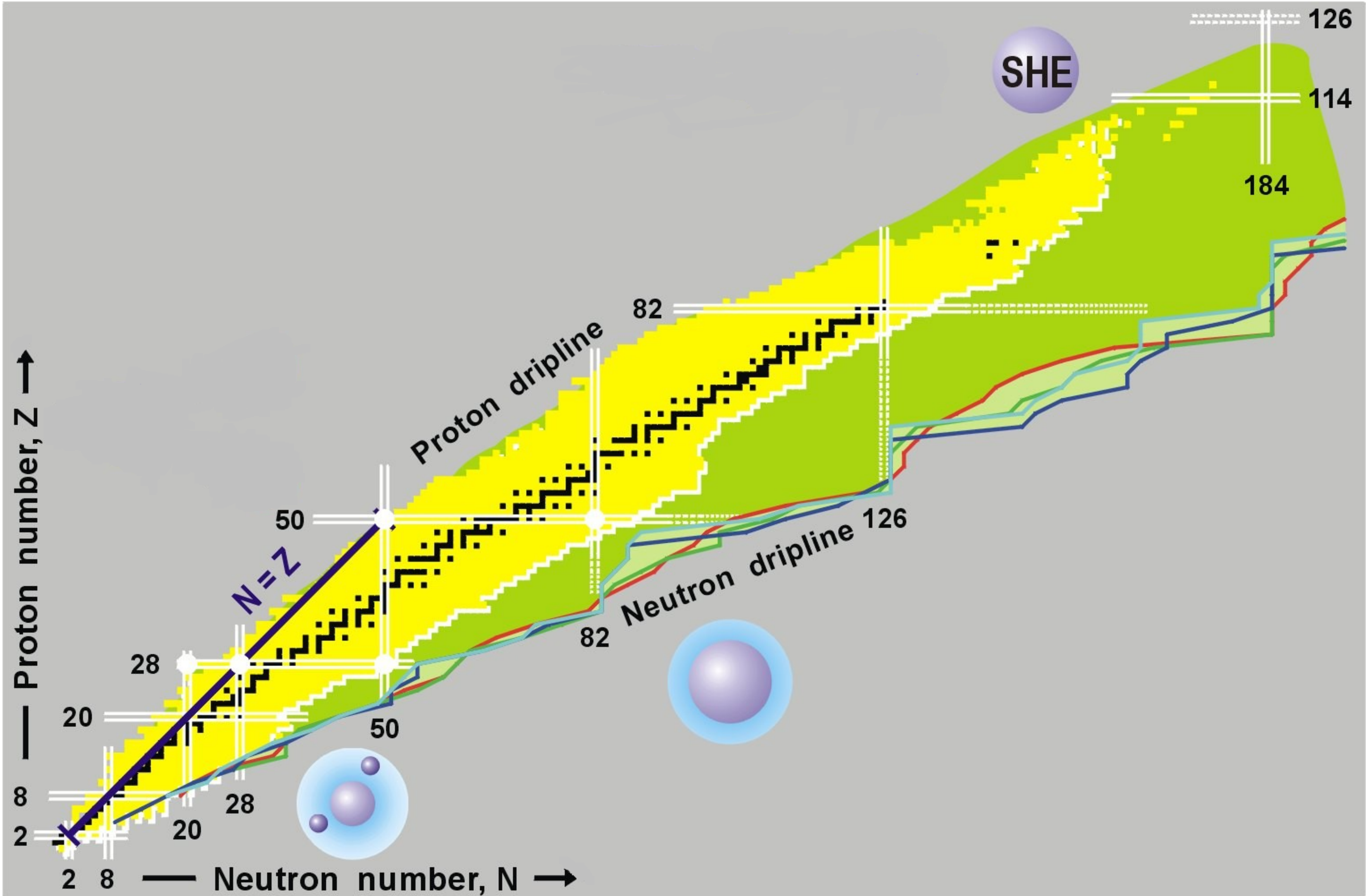
on behalf of NUSTAR collaboration

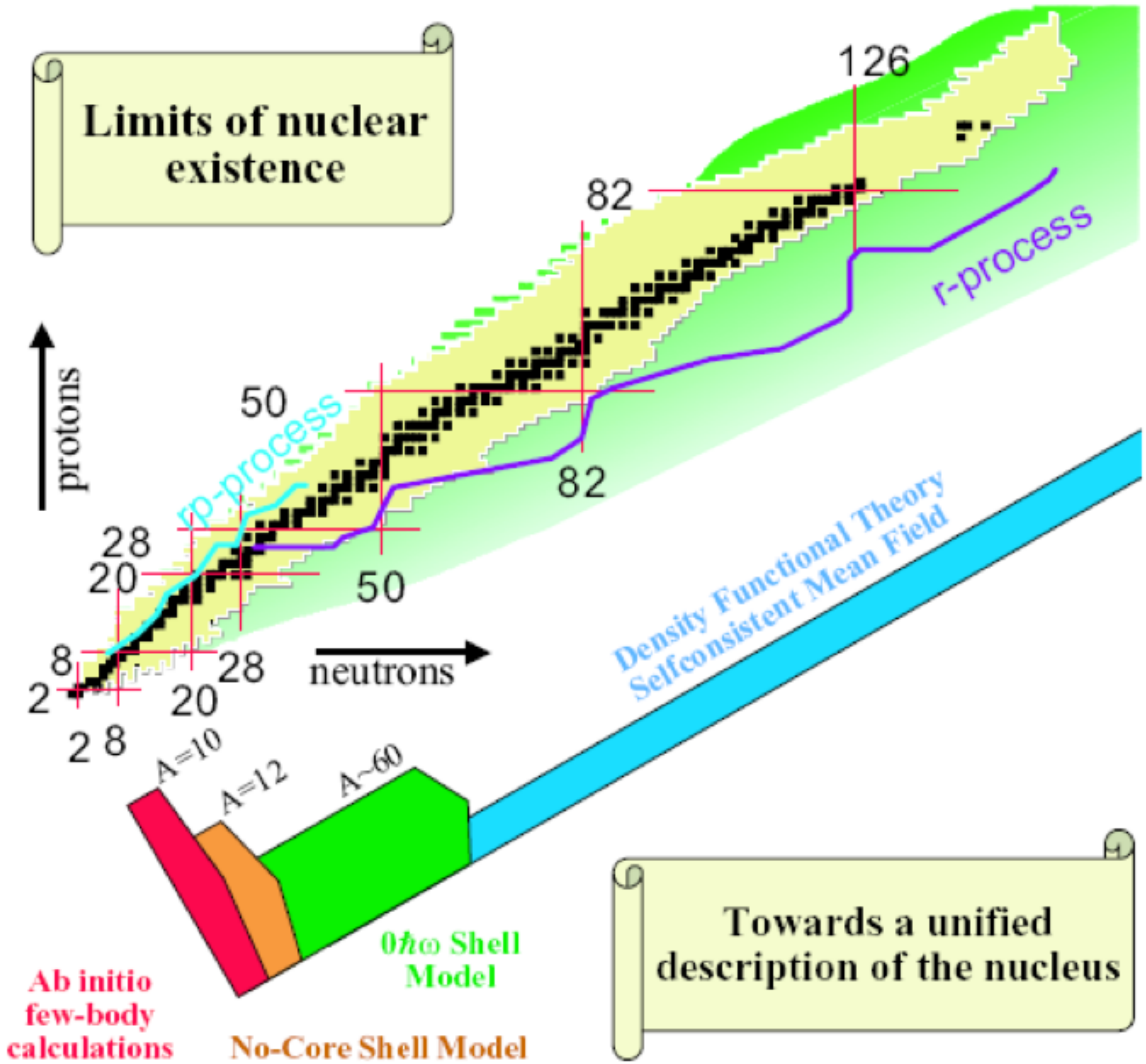
International Conference on Science and Technology for FAIR in Europe 2014

Worms, Germany, October 13, 2014

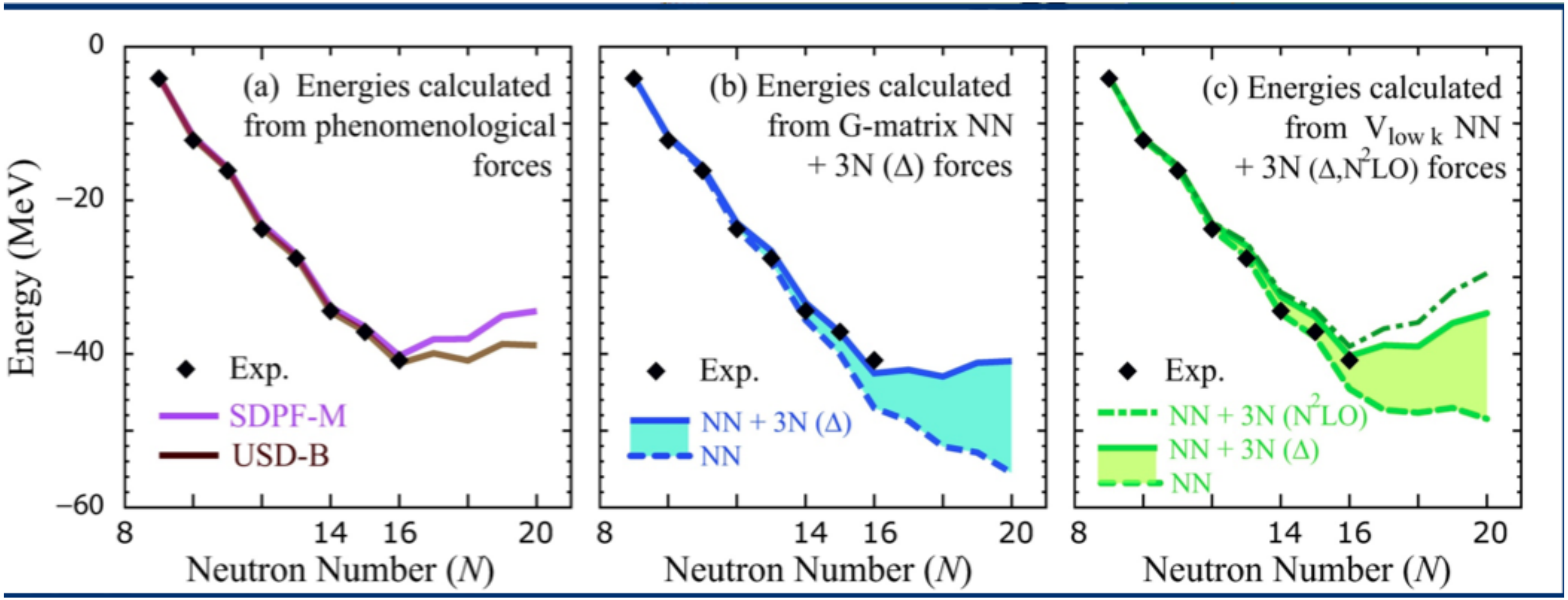
Finland France Germany India Poland Romania Russia Slovenia Sweden UK

Snapshot of the nuclear landscape




Limits of nuclear existence
protons
neutrons
126
82
50
28
20
8
2
rp-process
r-process
Density Functional Theory
Selfconsistent Mean Field
A=10
A=12
A~60
Ab initio few-body calculations
No-Core Shell Model
0ħω Shell Model
Towards a unified description of the nucleus

Binding Energies of Oxygen Isotopes



Otsuka, Suzuki, Holt, Schwenk, Akaishi, PRL 105, 032501 (2010)

Ground-st nergies

See the talk by Petr Navratil on Thursday

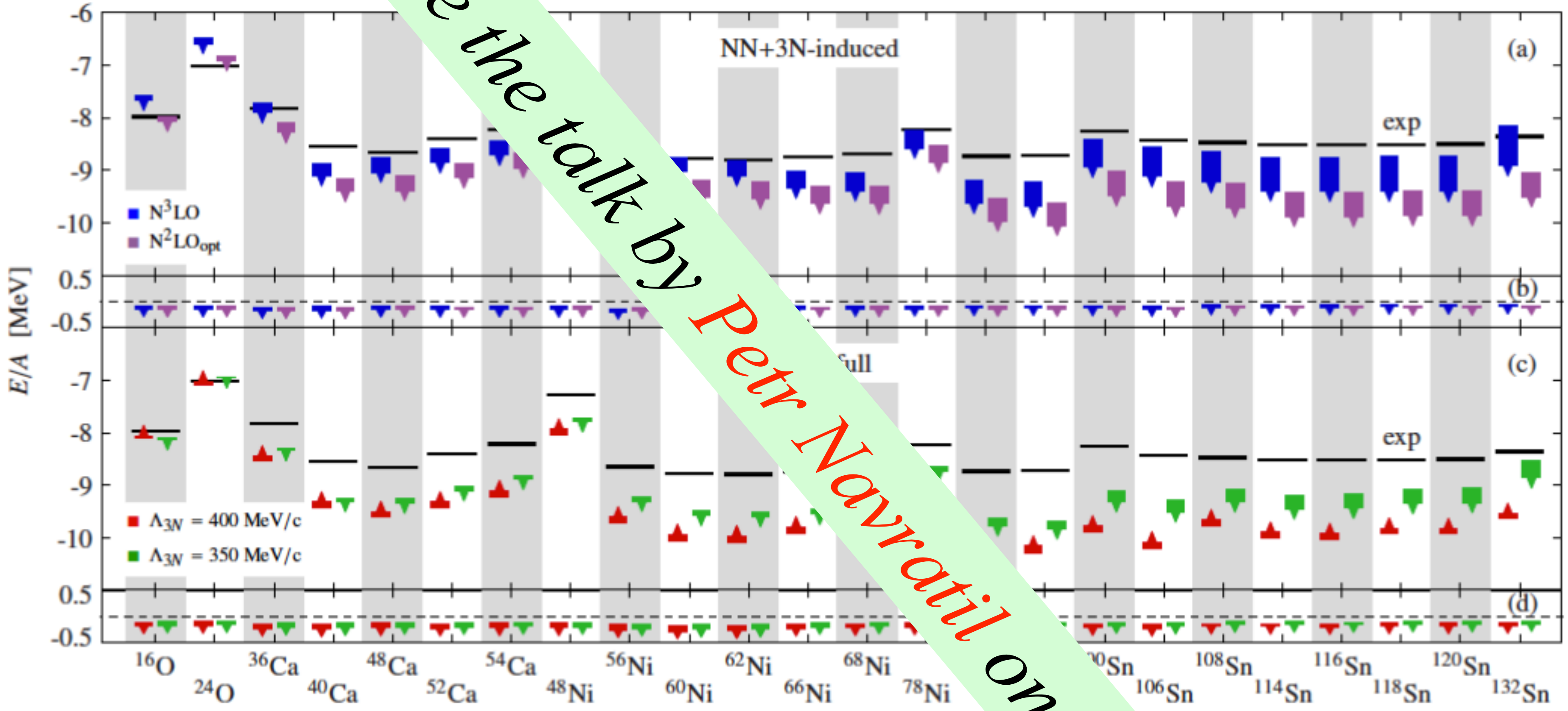


FIG. 5: (Color online) Ground-state energies from CR-CC(2,3) for (a) the *NN*+3*N*-induced starting from the N^{3}LO and N^{2}LO-optimized *NN* interaction and (c) the *NN*+3*N*-full Hamiltonian with Λ_{3N} = 400 MeV/c and eV/c. The boxes represent the spread of the results from $\alpha = 0.04$ fm^4 to $\alpha = 0.08$ fm^4, and the tip points into the direction o es of α. Also shown are the contributions of the CR-CC(2,3) triples correction to the (b) *NN*+3*N*-induced and (d) *NN*+3*N*-full sults employ $\hbar\Omega$ = 24 MeV and 3*N* interactions with $E_{3\max}$ = 18 in NO2B approximation and full inclusion of the 3*N* interaction in $E_{3\max}$ = 12. Experimental binding energies [32] are shown as black bars.

S. Binder et al., Phys. Lett. B 736, 119 (2014), http://arxiv.org/pdf/131 pdf

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?

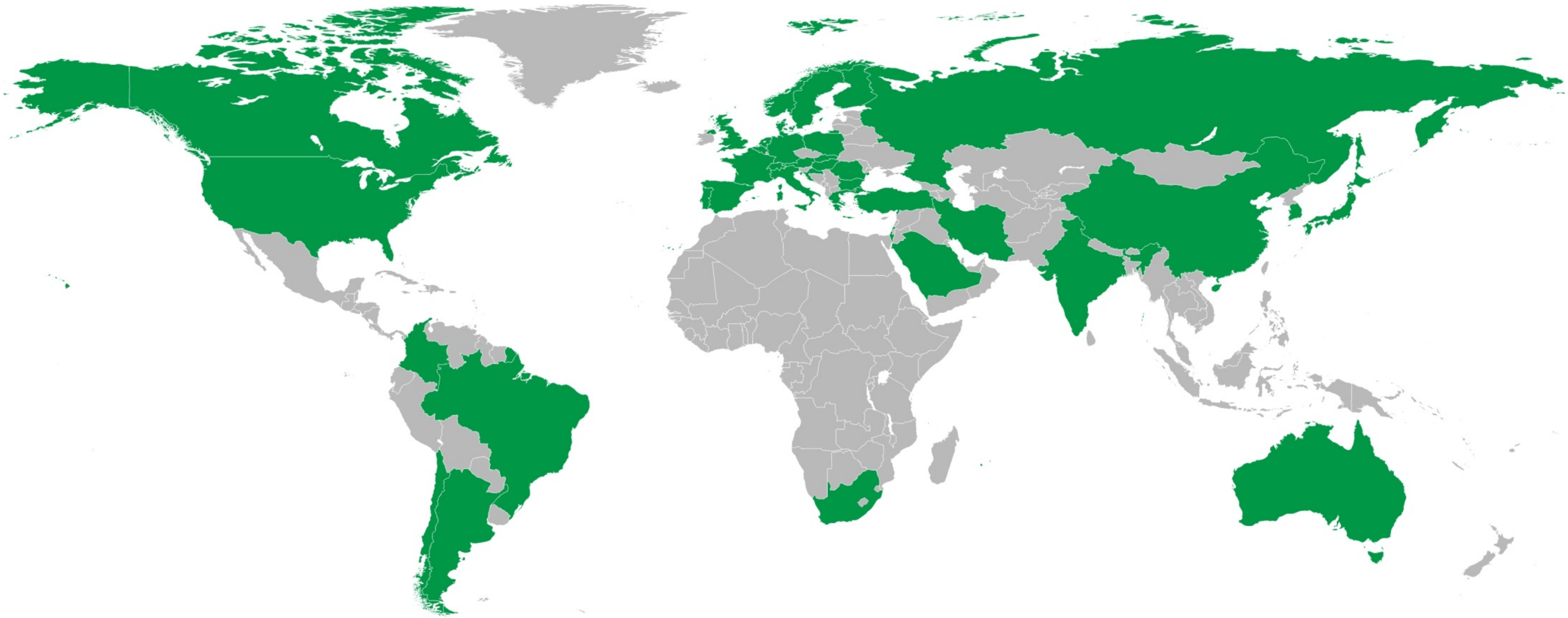
What is the effective nucleon-nucleon interaction?

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 Collaboration



>800 registered NUSTAR members
38 countries
>180 institutes

NUSTAR Week GSI March 2014

NUSTAR - The Project

Super-FRS	RIB production, identification and high-resolution spectroscopy
HISPEC/ DESPEC	in-beam γ spectroscopy at low and intermediate energy, γ-, β-, α-, p-, n-decay spectroscopy
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

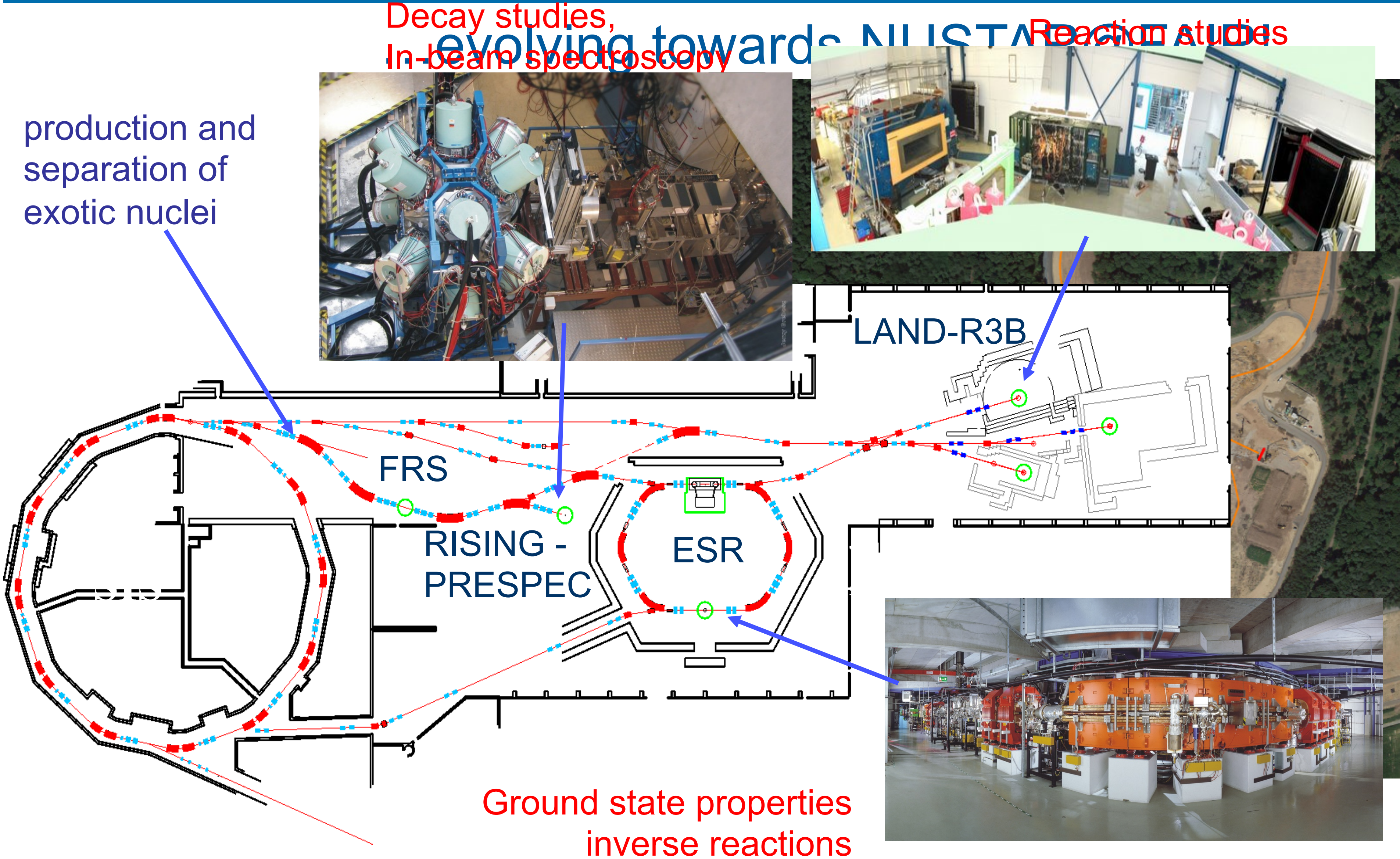
38 countries

The Investment

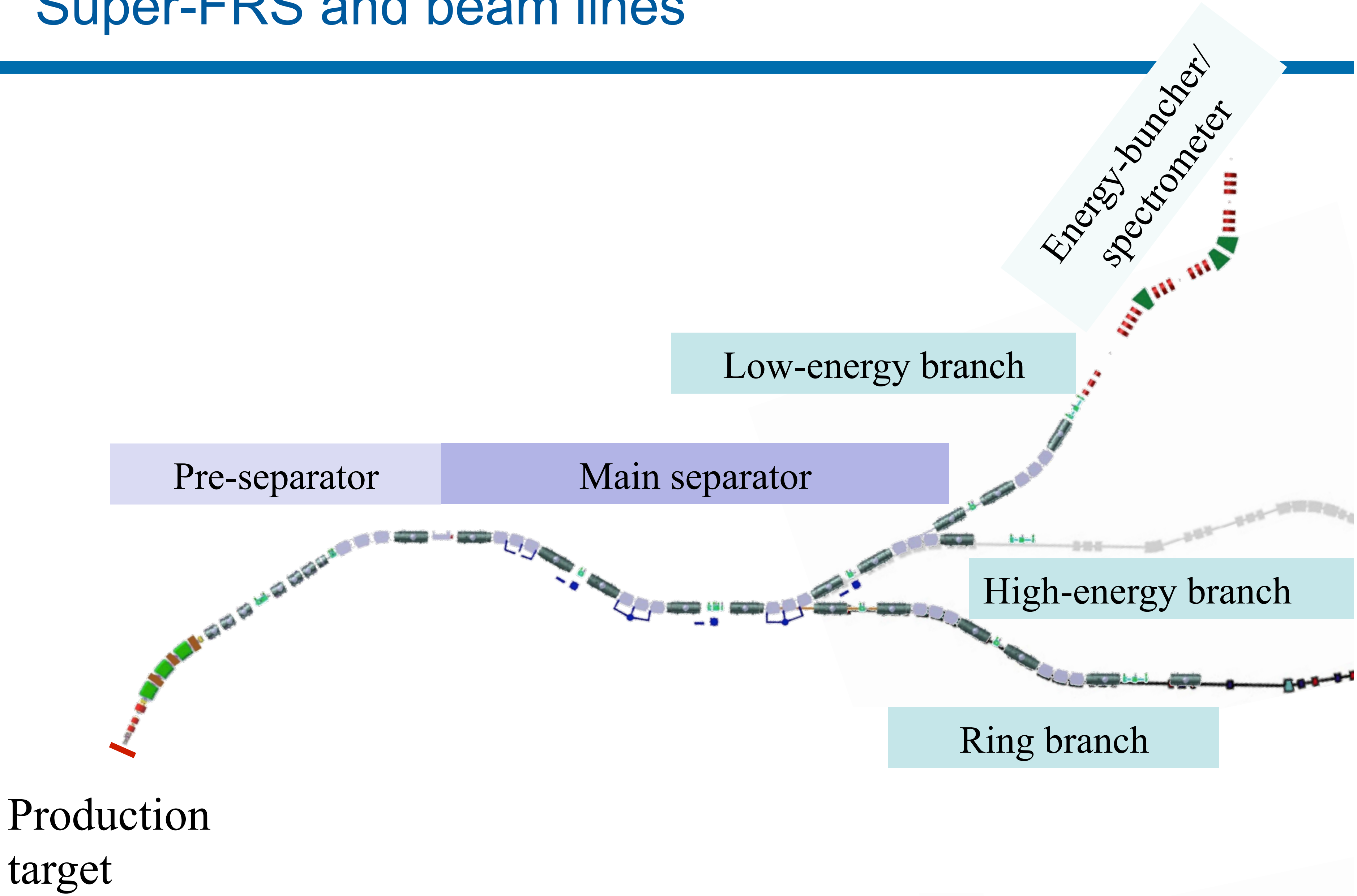
82 M€ Super-FRS

73 M€ Experiments

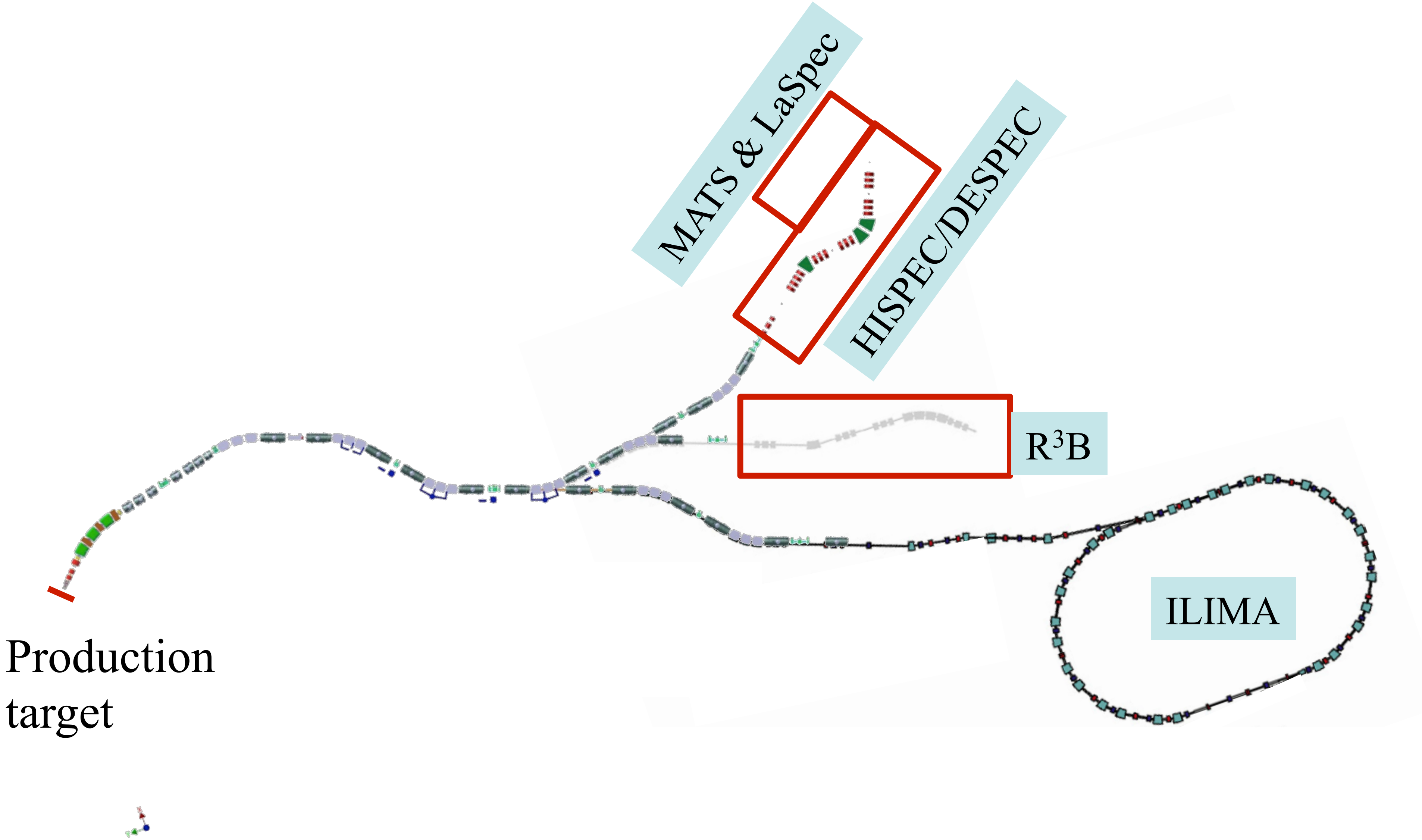
Existing research opportunities at GSI



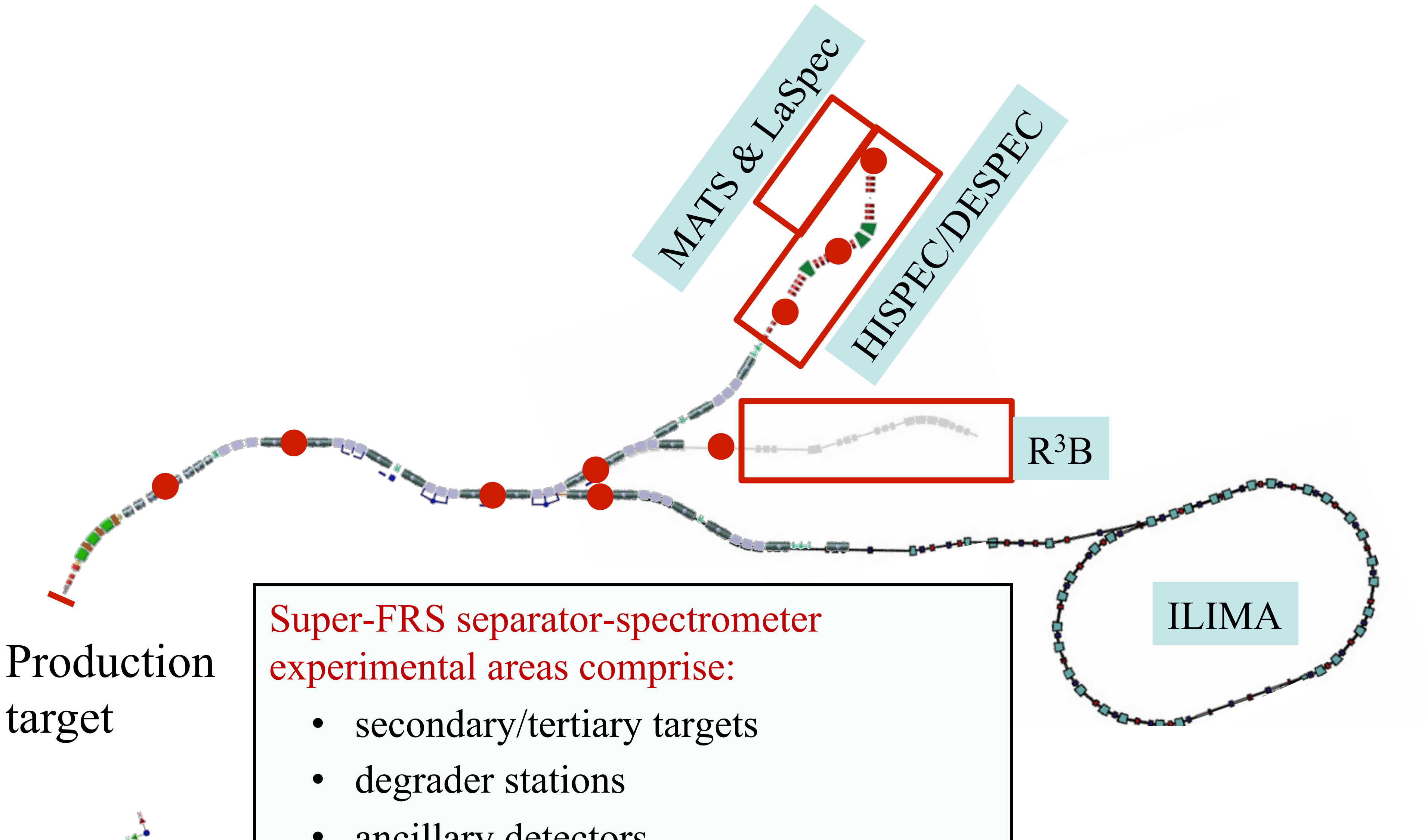
Super-FRS and beam lines



NUSTAR experimental areas



NUSTAR experimental areas

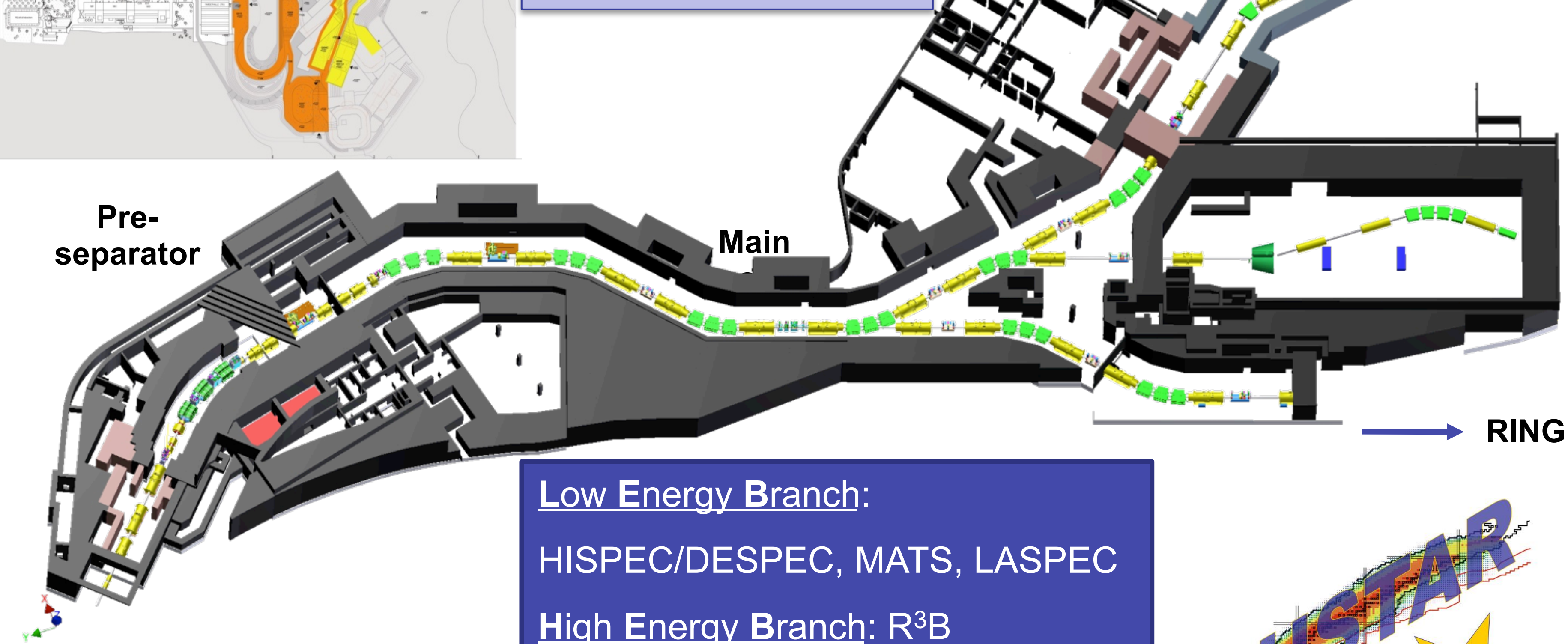


Super-FRS separator-spectrometer experimental areas comprise:

- secondary/tertiary targets
- degrader stations
- ancillary detectors

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

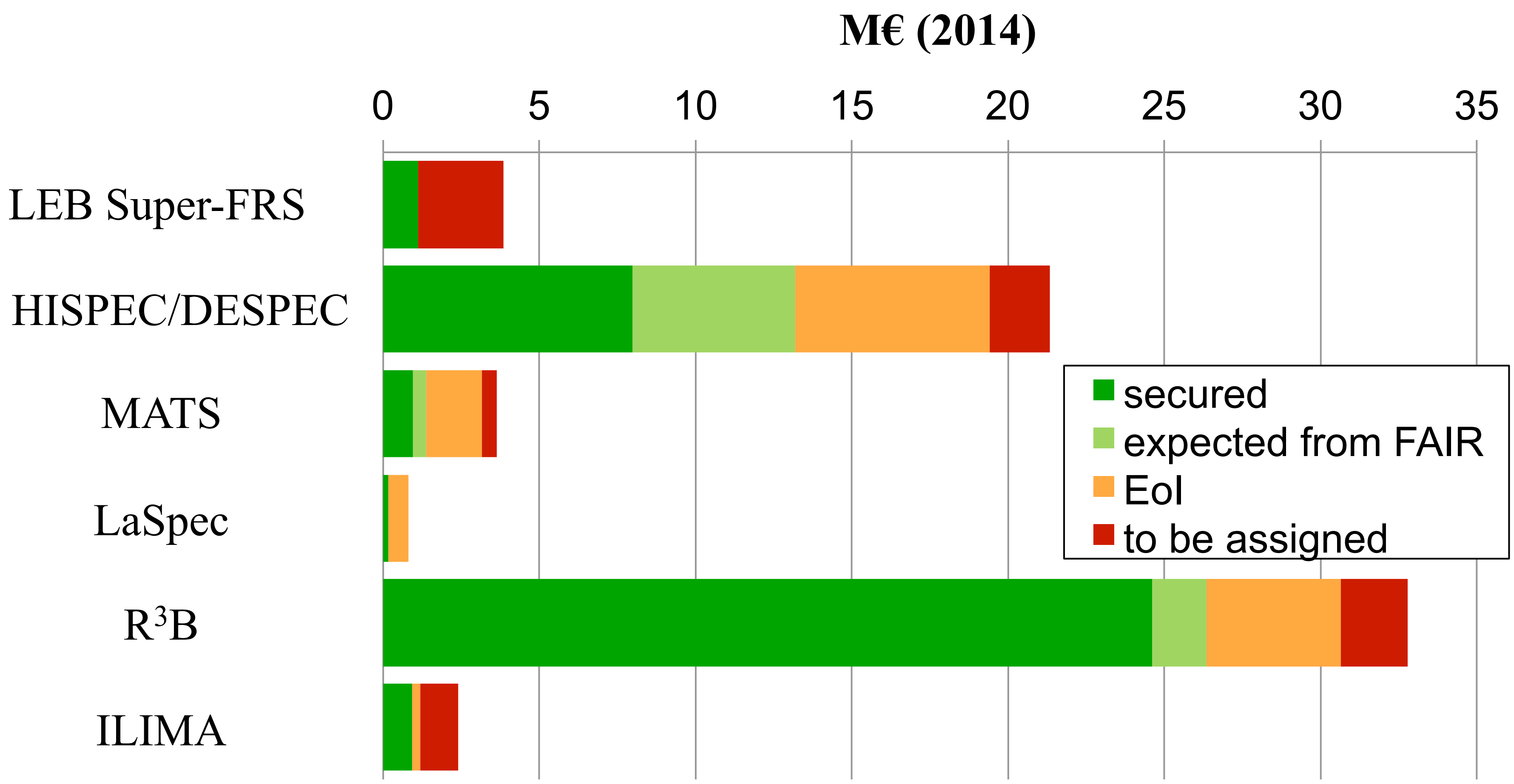
Status Technical Design Reports (35 TDRs)

- *Approved TDRs (10):*
  - *HISPEC/DESPEC (6) (LYCCA, Plunger, AIDA, BELEN, MONSTER,DTAS)*
  - *MATS + LaSpec (1) (all subsystems – except LD-RIS: no action)*
  - *R^3B (3) (Multiplet, NeuLAND, CALIFA-barrel)*

- *Submitted (4):*
  - *HISPEC/DESPEC (AGATA, DEGAS, NEDA)*
  - *R^3B (GLAD)*

TDRs expected (21) (submission profile – October 2014)				
2014	2015	2016	2017	2018
6	12	3	0	0

Status of NUSTAR experiment funding



HISPEC/DESPEC - foreseen instrumentation

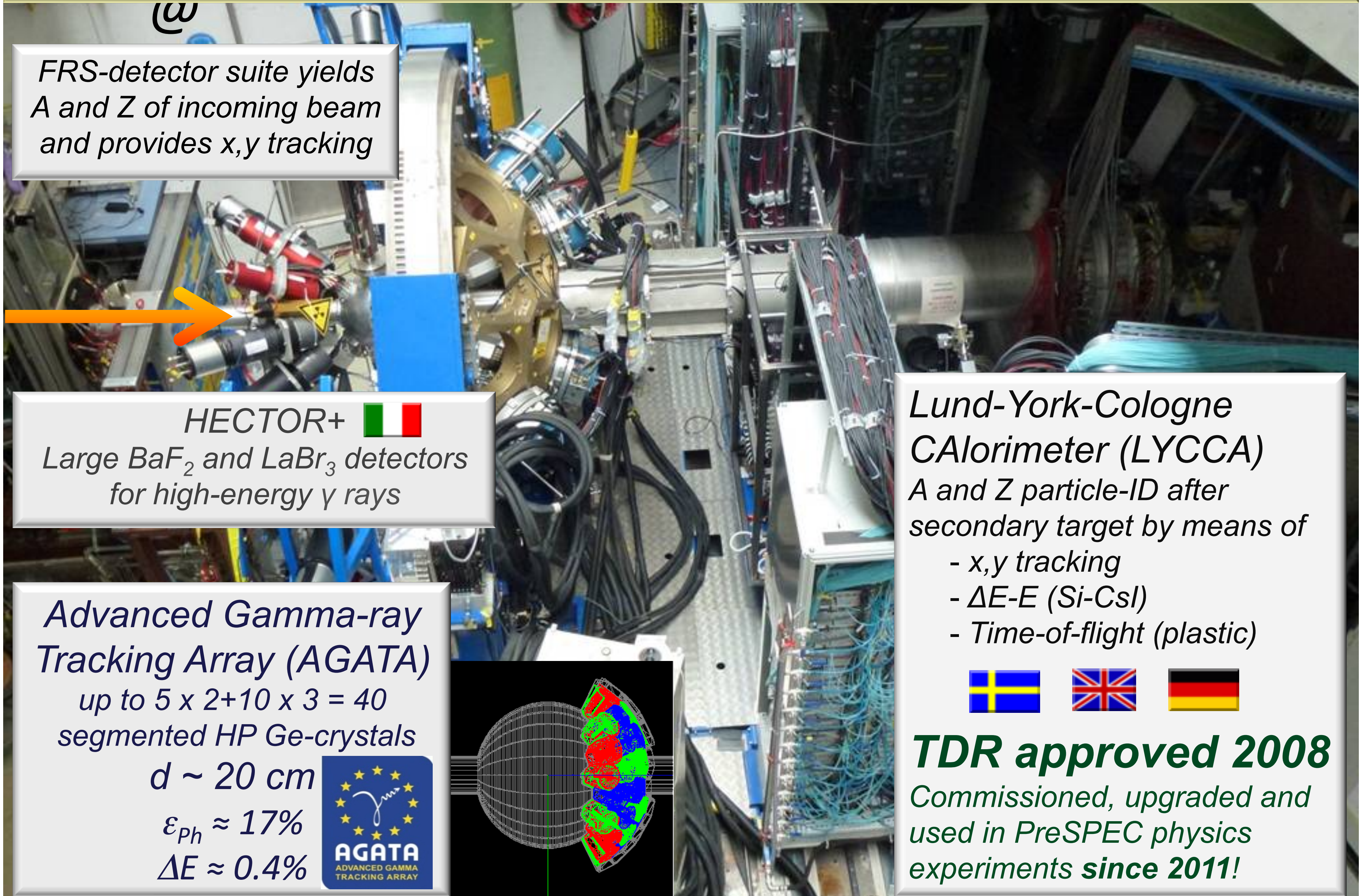
HISPEC

- AGATA gamma-tracking spectrometer
- LYCCA heavy-ion calorimeter with ToF capability
- Plunger nuclear level lifetime measurements
- MINOS Proton target
- NEDA Neutron detector array
- HYDE light charged-particle array

DESPEC

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

PreSPEC-AGATA 2012-2014: Early Implementation of HISPEC



@

FRS-detector suite yields
A and Z of incoming beam
and provides x,y tracking

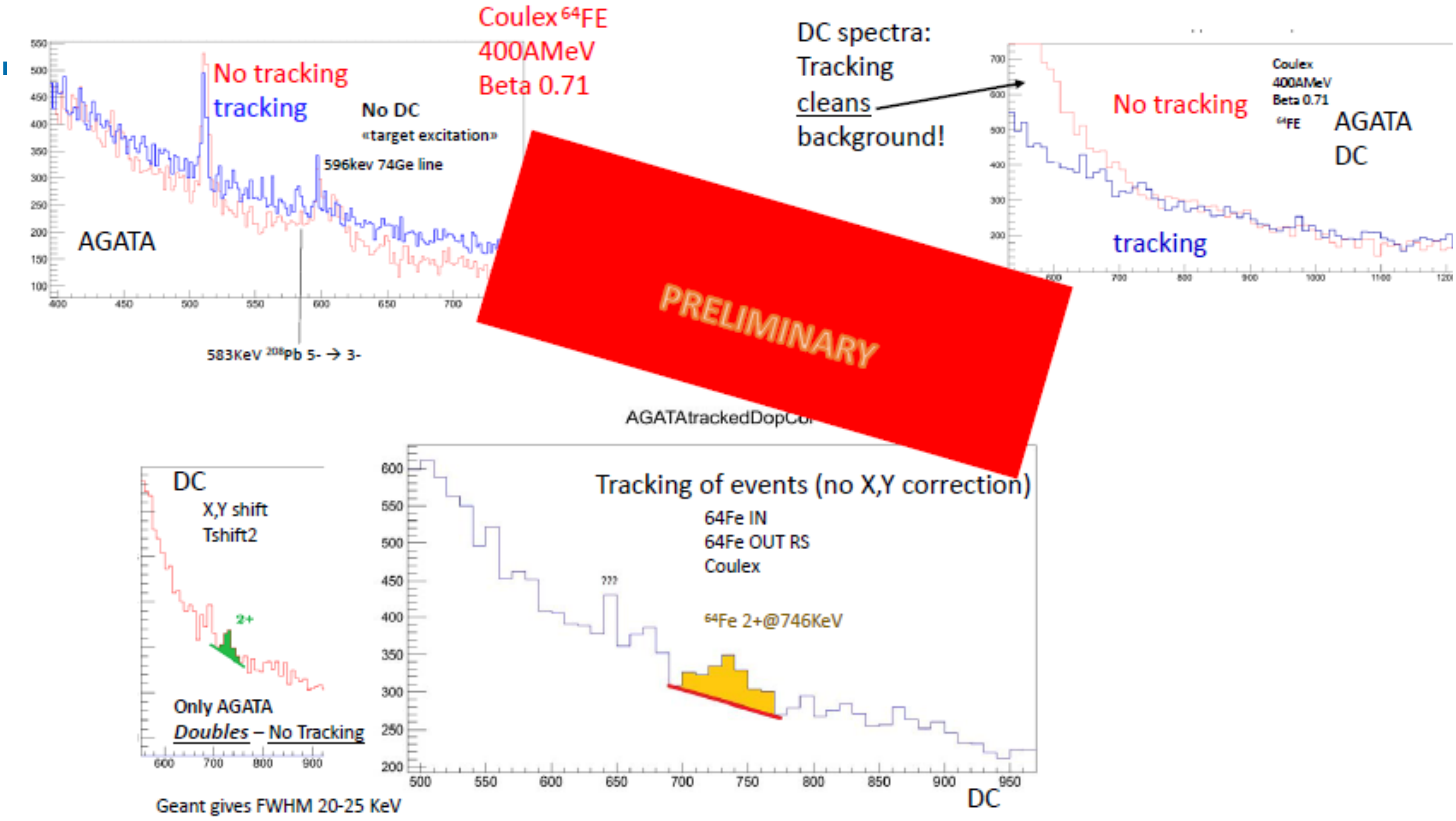
HECTOR+
Large BaF_2 and $LaBr_3$ detectors
for high-energy γ rays

Advanced Gamma-ray
Tracking Array (AGATA)
up to 5 x 2+10 x 3 = 40
segmented HP Ge-crystals
d ~ 20 cm
$\varepsilon_{Ph} \approx 17\%$
$\Delta E \approx 0.4\%$

Lund-York-Cologne
CAlorimeter (LYCCA)
A and Z particle-ID after
secondary target by means of
- x,y tracking
- ΔE-E (Si-CsI)
- Time-of-flight (plastic)

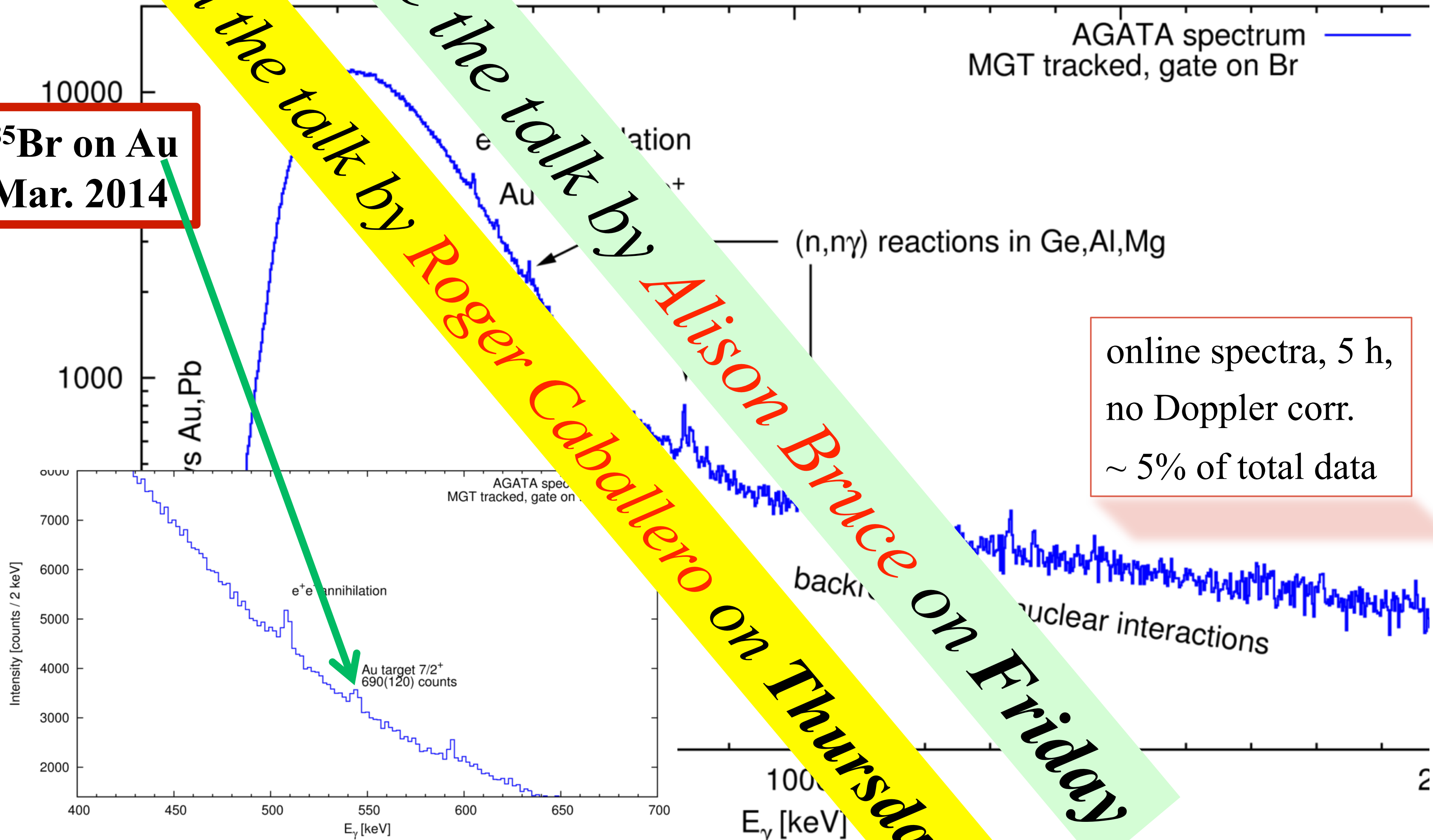
TDR approved 2008

Commissioned, upgraded and
used in PreSPEC physics
experiments **since 2011**!



O. Wieland et al.

First ... ta on ... lativistic M1-Projectile COULEX



^{85}Br on Au
Mar. 2014

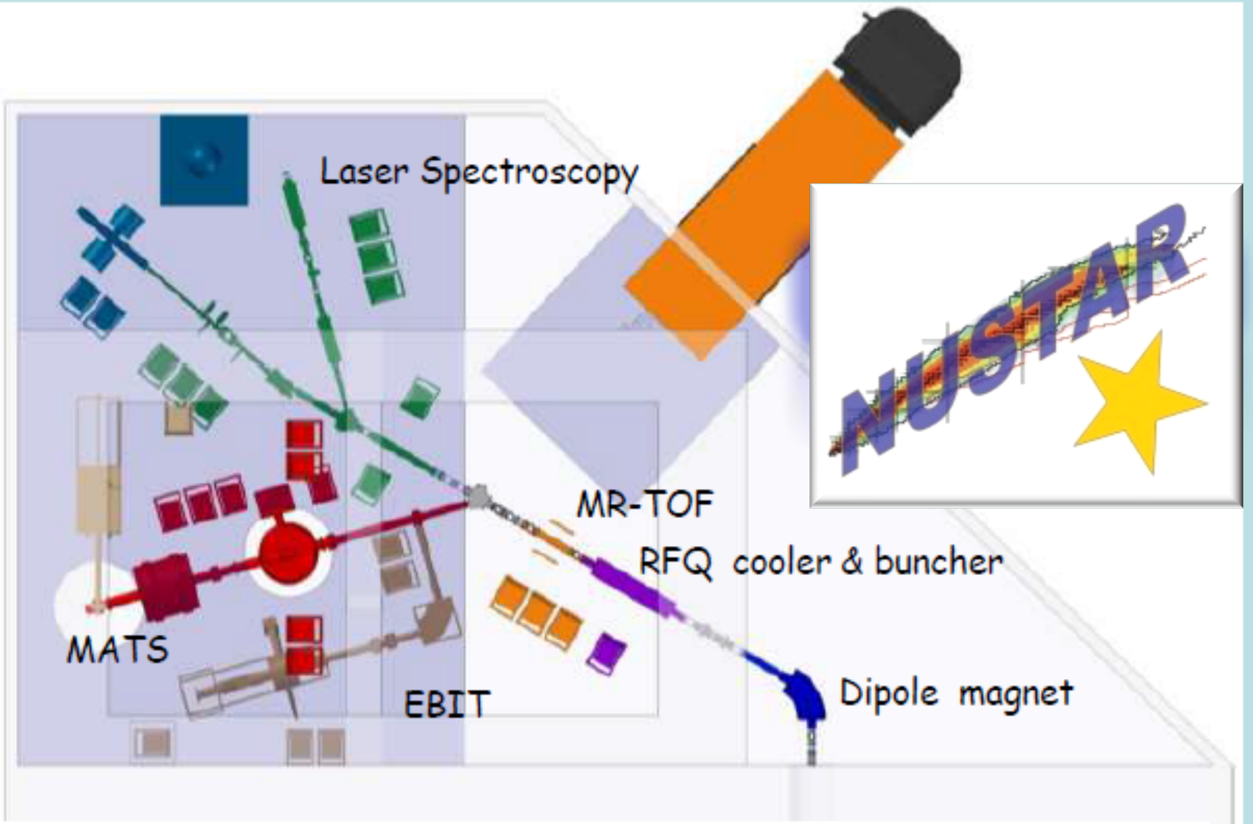
and the talk by Roger Caballero on Thursday

See the talk by Alison Bruce on Friday

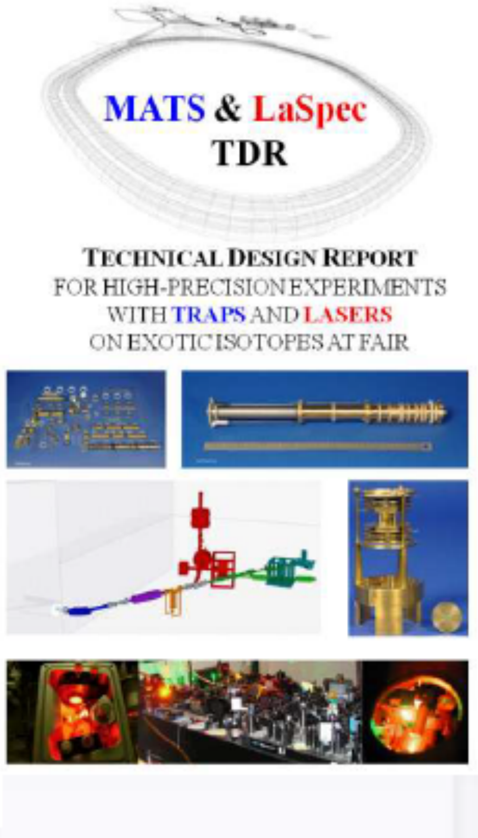
online spectra, 5 h,
no Doppler corr.
~ 5% of total data

data: M. Rees... ...il, M. Lettmann (TU Darmstadt)

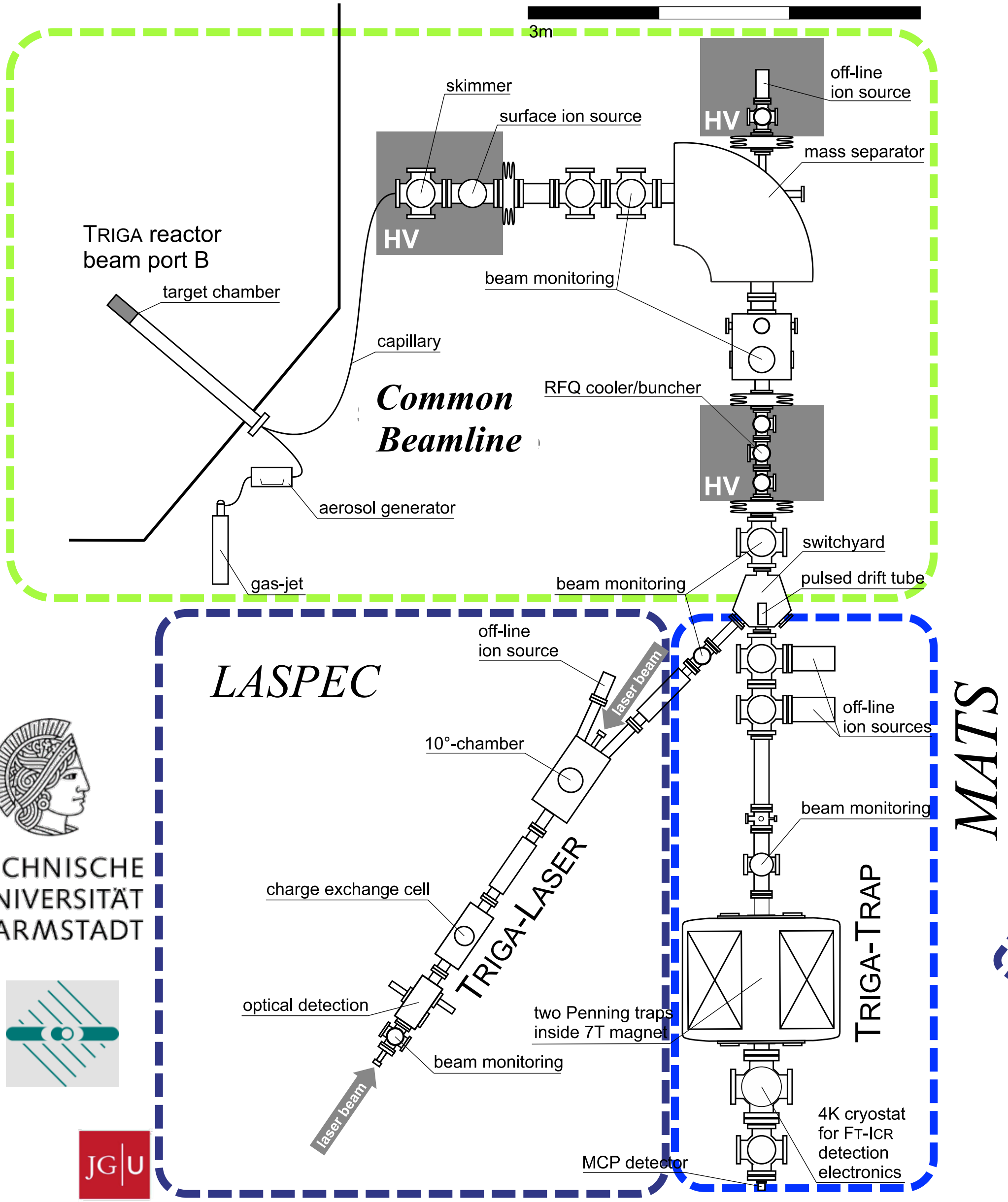
MATS/LASPEC at the Low Energy Branch (LEB)

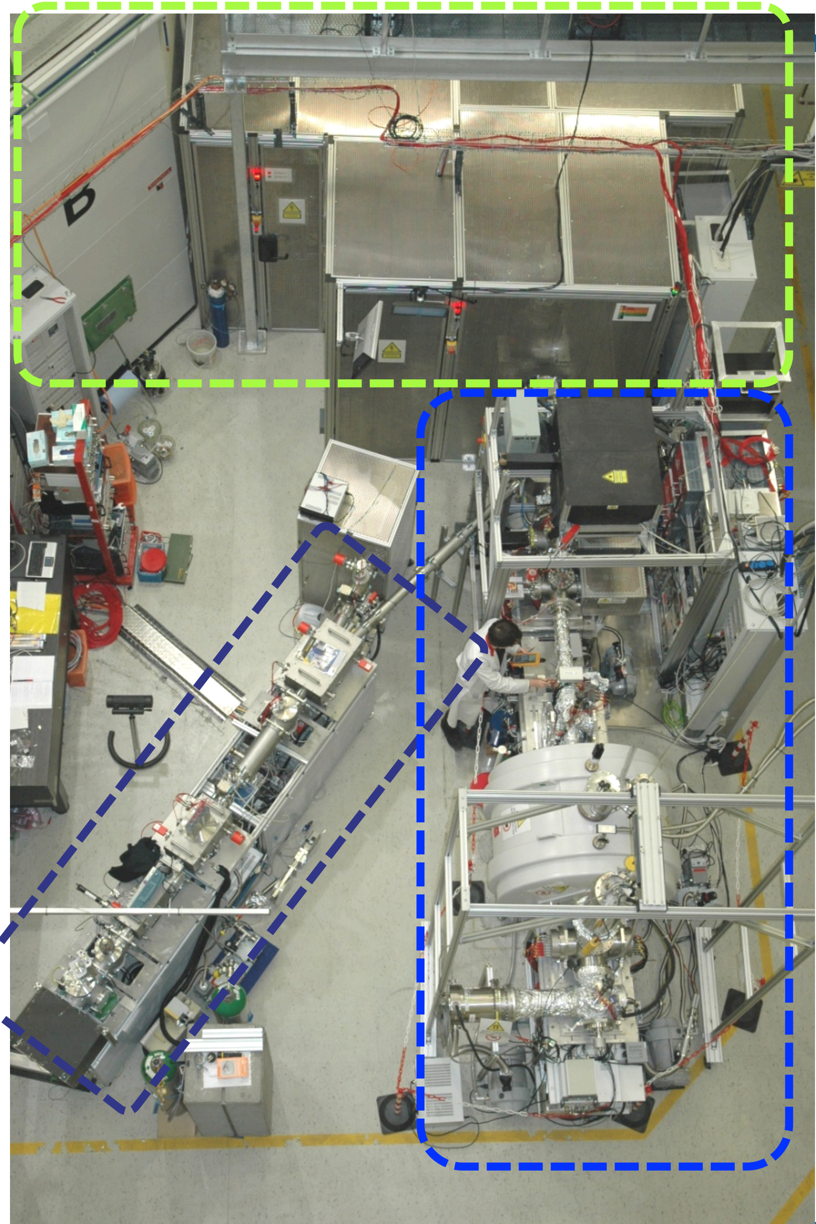


for more information see:
Technical Design Report of MATS & LaSpec:
D. Rodriguez, EPJ Special Topics 183 (2010) 1-123



TRIGA-SPEC @ Mainz: Prototype of MATS and LASPEC



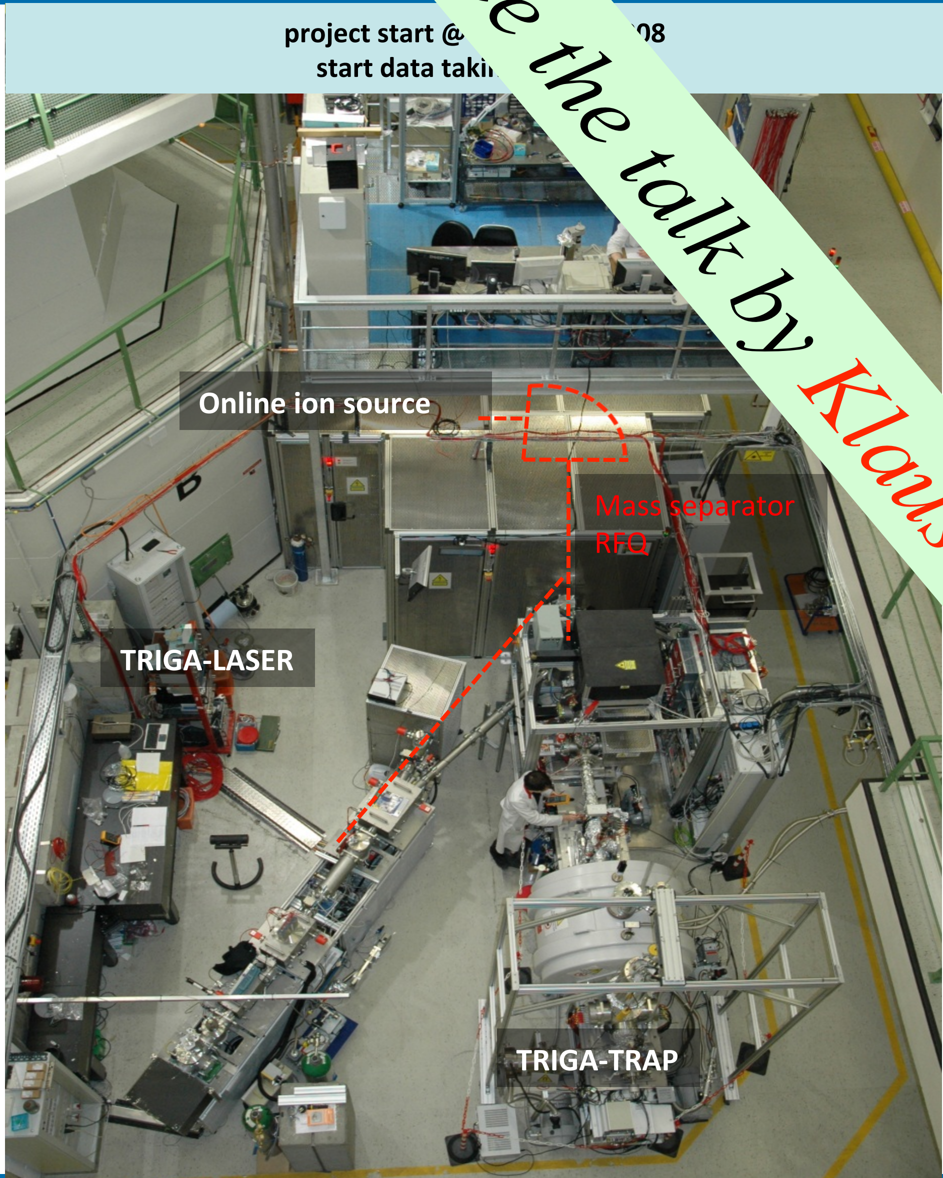


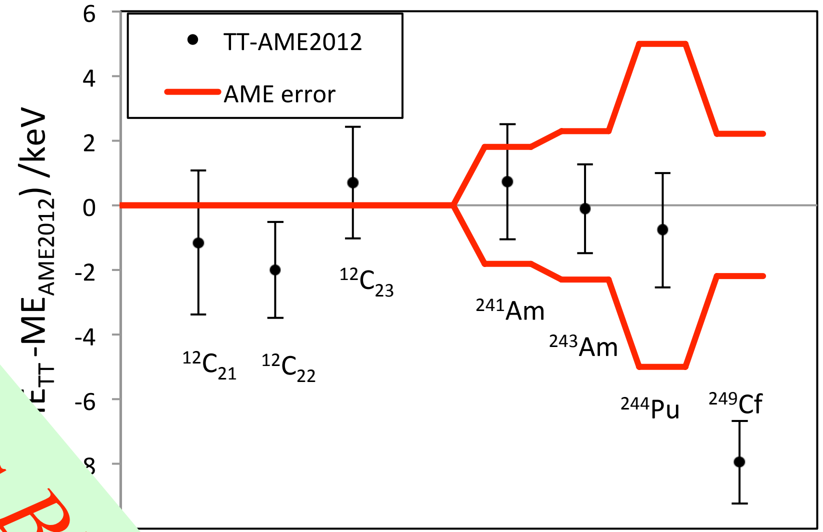
TECHNISCHE
UNIVERSITÄT
DARMSTADT

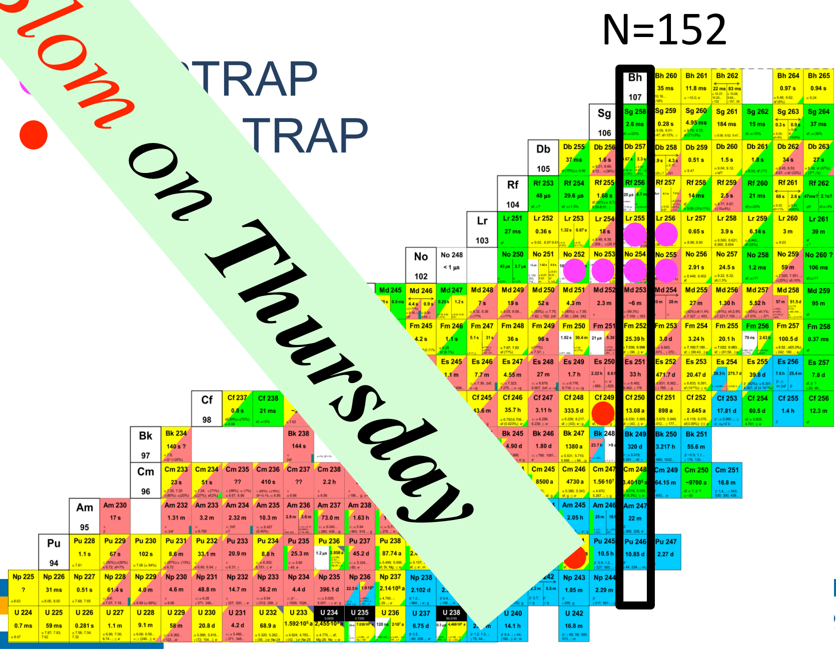
Mass Measurements at TRIGA-TRAP in 2013

First stage of ... TS (View with GSI data)

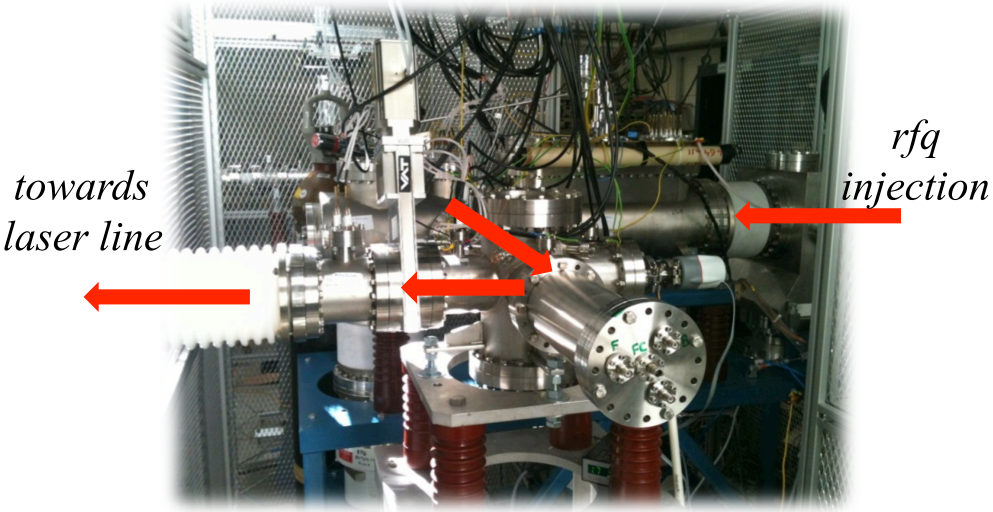
See the talk by Klaus Blom on Thursday

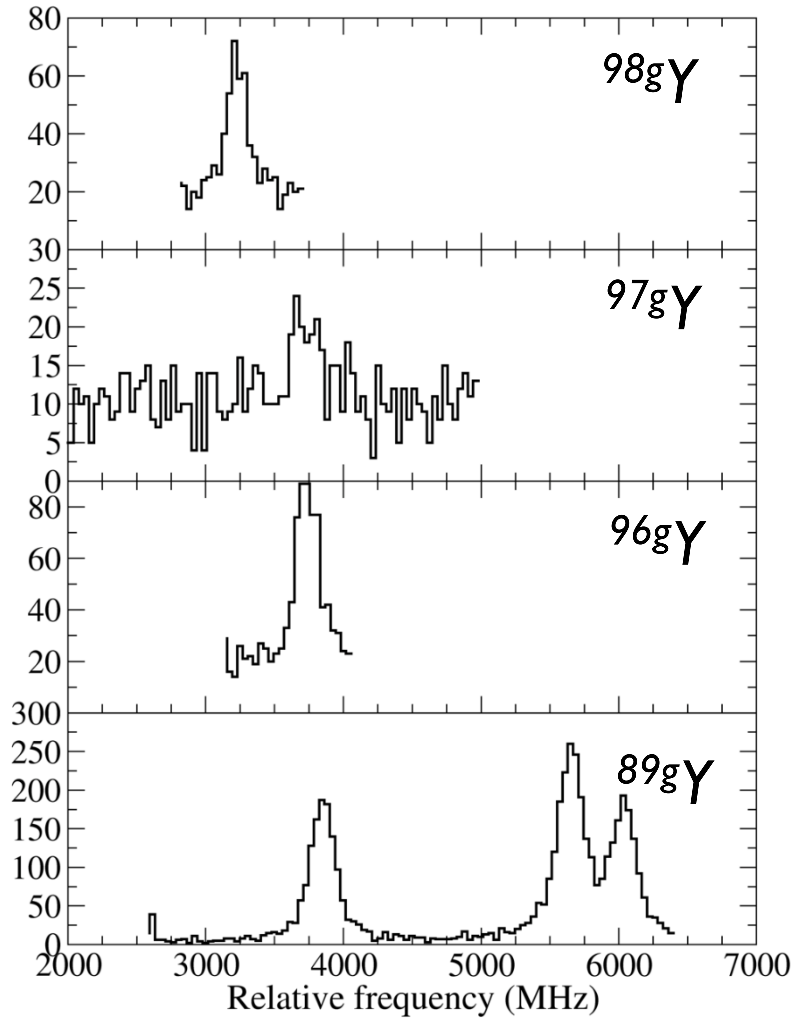






Collinear laser spectroscopy of doubly-charged fission fragments at IGISOL-4





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

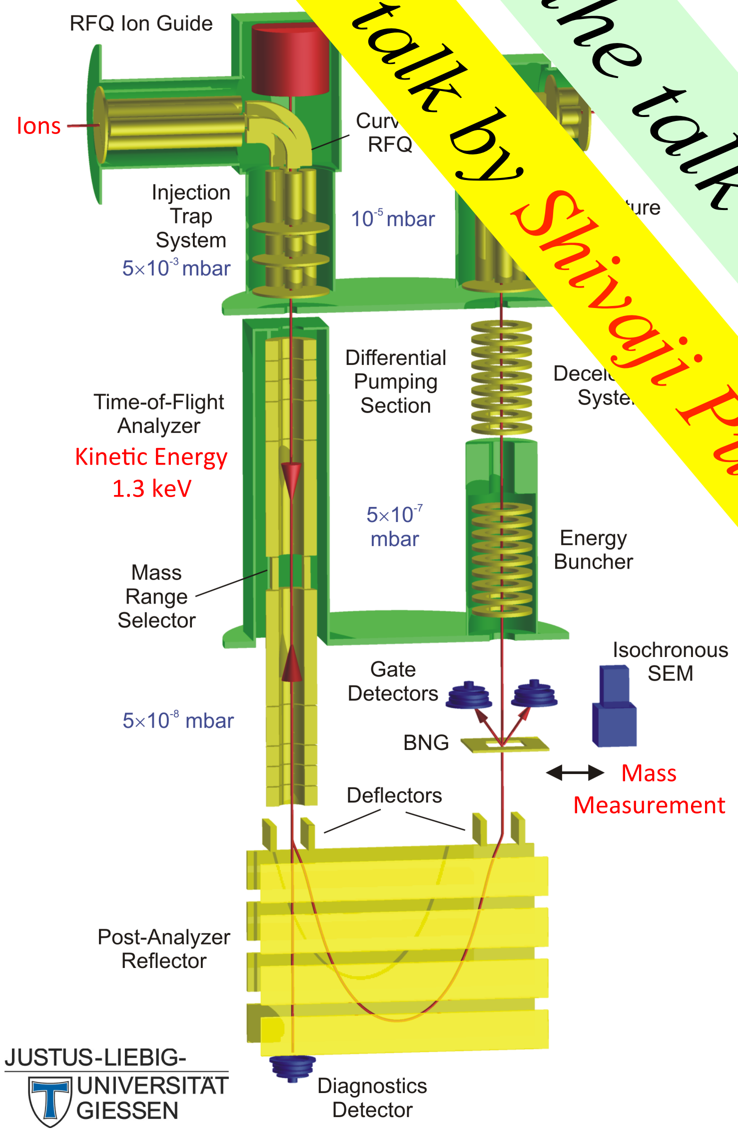
UNIVERSITY OF LIVERPOOL

MANCHESTER 1824 The University of Manchester

Multi… Time-Of Flight Mass Spectrometer

See the talk by Daniel Rodriguez on Friday

and the talk by Shivaji Purushothaman on Wednesday

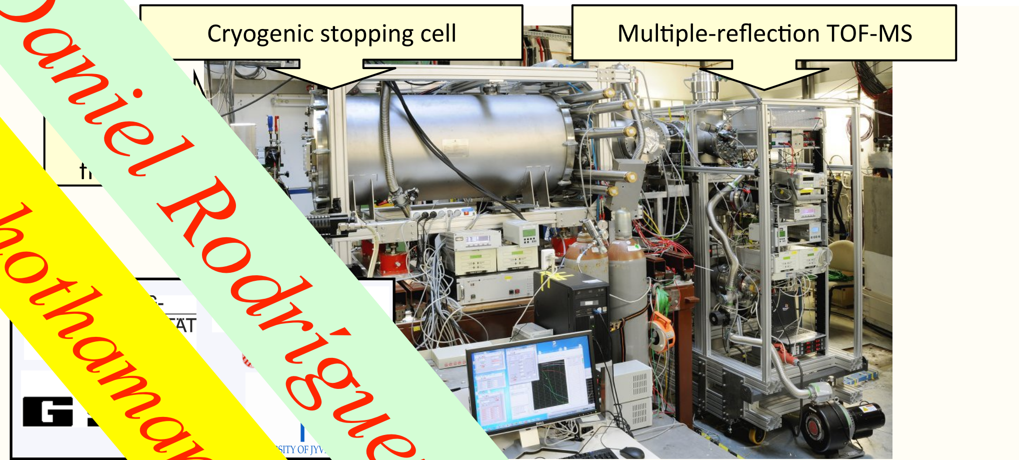


JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

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
- …epetition frequency: up to 400 Hz
- …nsmission efficiency: > 50%
- …pacity: up to 10^6 ions/s



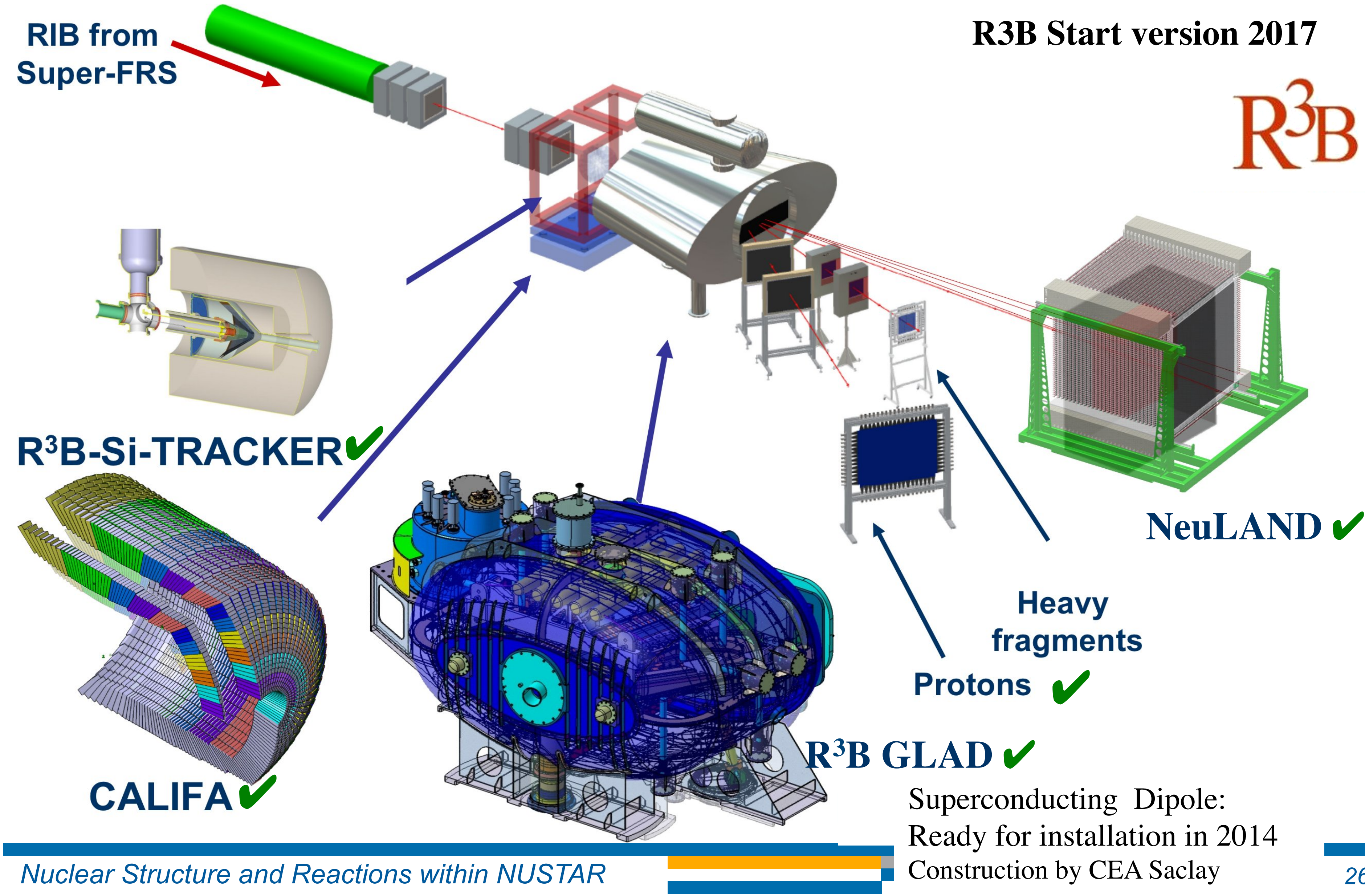
Commis…oni… FRS Ion Catcher in 2012

- First direc… eas… of ^{211}Po and ^{21}… (… ms!)
- Characterizatio… ping… rmance: MR-TOF-MS idea… tics… opping cells

Future work: Implem… ap… em / operation as (ultra-)… olu… ass 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



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)

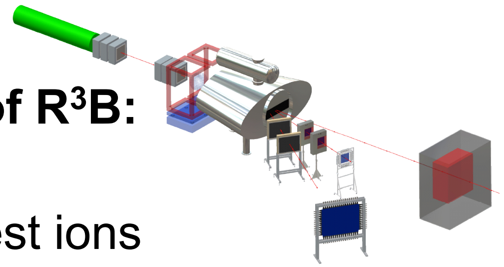
2014 Installation of 20% detectors NeuLAND and CALIFA
Commissioning run in Q3/2014 (This actually happened two weeks ago)

2015/16 Construction and installation of detector components

2017/18 Commissioning of full R3B setup and first physics run at GSI

2019 Installation of experimental setup at FAIR site including superconducting triplet

2020/21 Commissioning and first experiments at Super-FRS



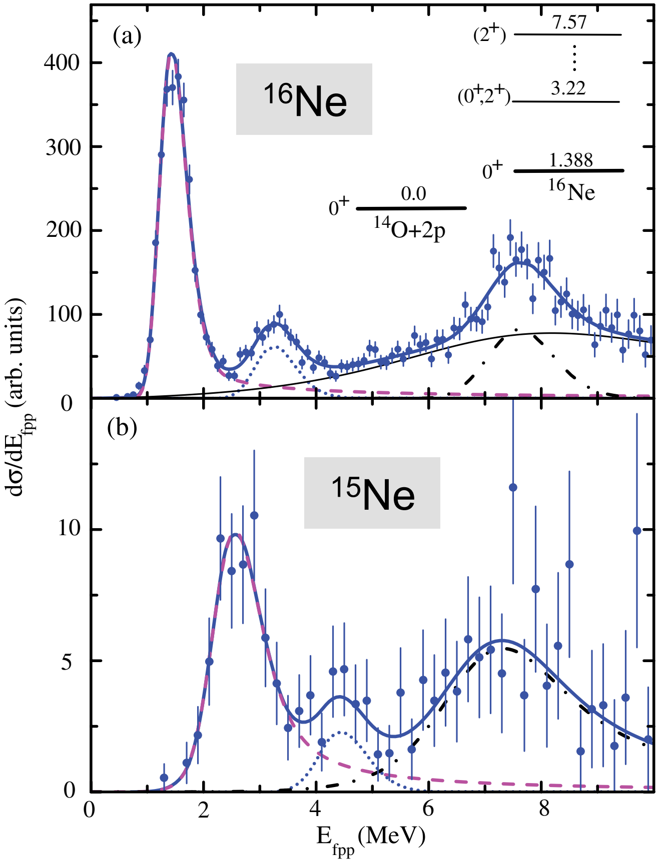
Experiments in 2020/21 will make use of uniqueness of R^{3}B:

- 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

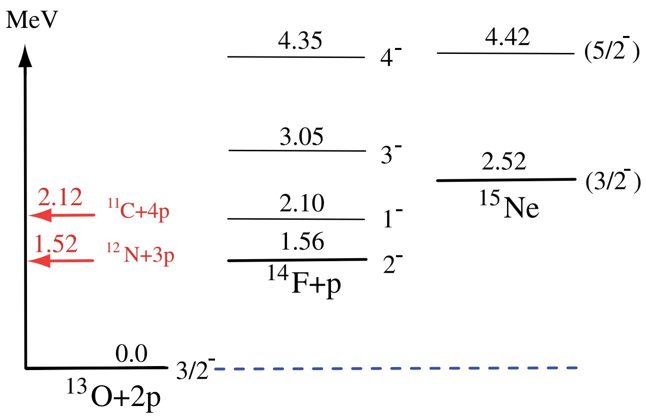
→ **Experiments possible for the first time:**

- 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

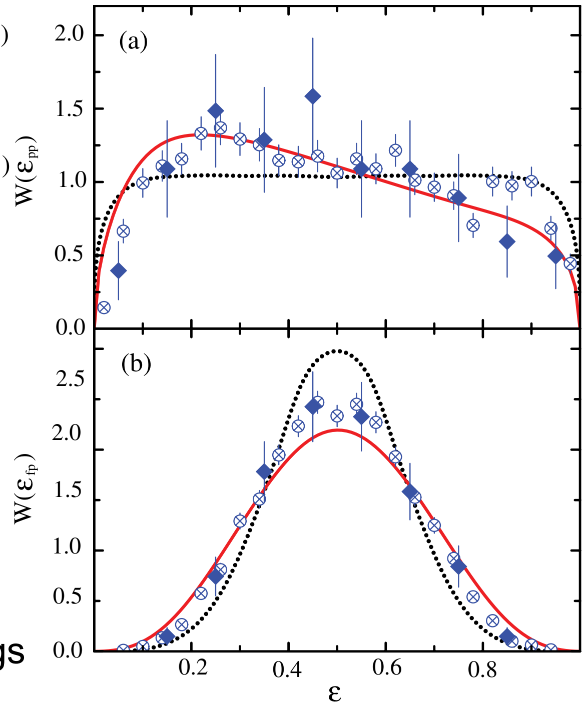
Beyond the drip line
First observation of ^{15}Ne ground and excited states



^{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

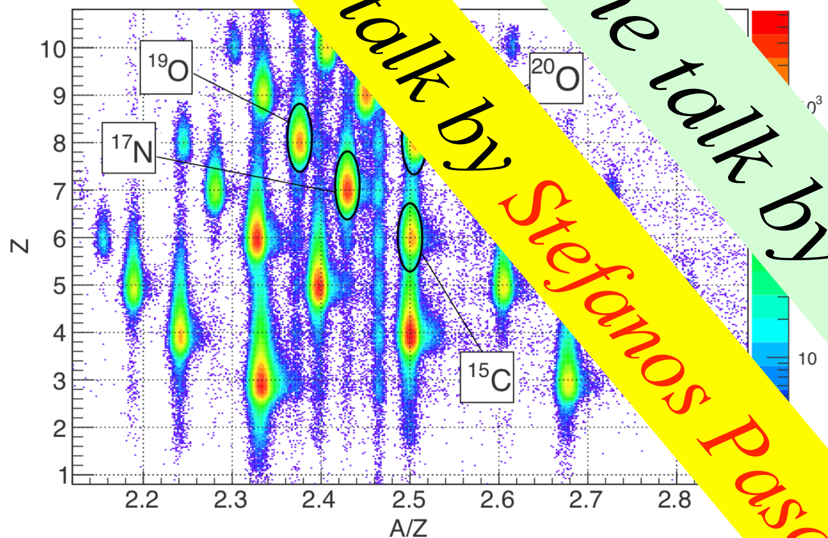
^{15}Ne ground state unbound by
S_{2p} = 2.522(66) MeV

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

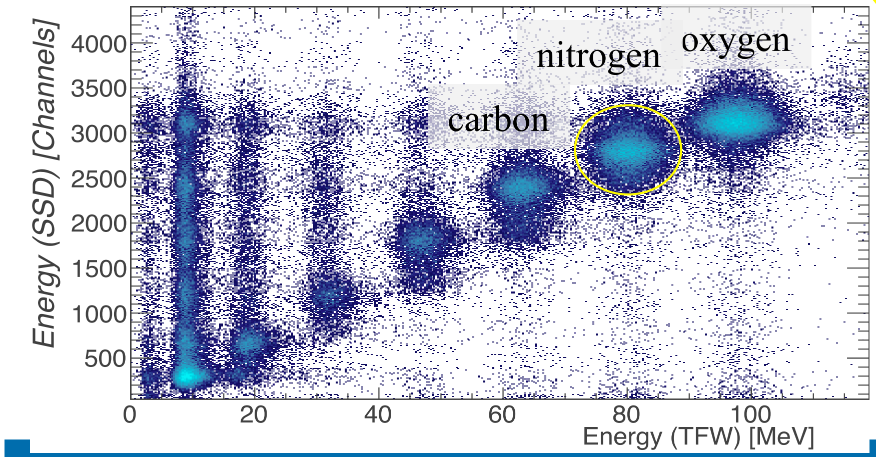
F. Wamers et al., Phys. Rev. Lett. 112 (2014) 132502

Quasi-free scattering

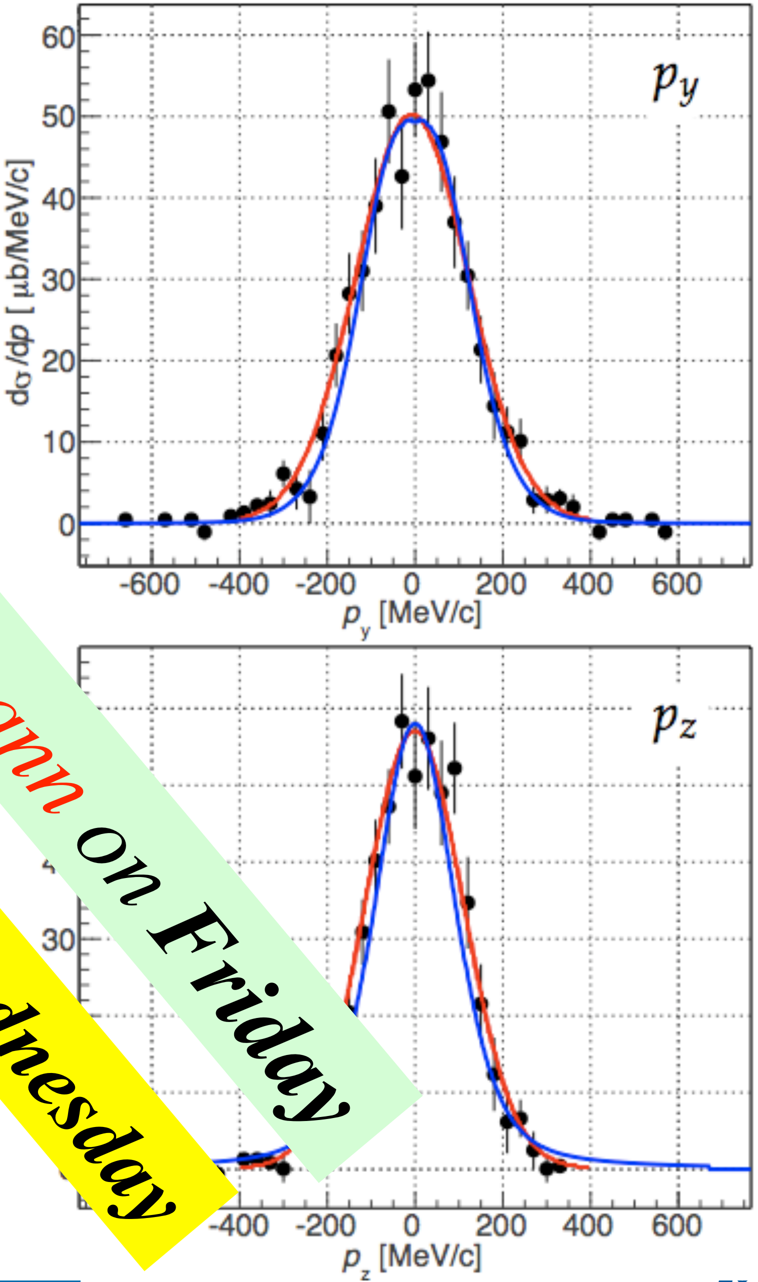
Incoming Particles



Outgoing Particles



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

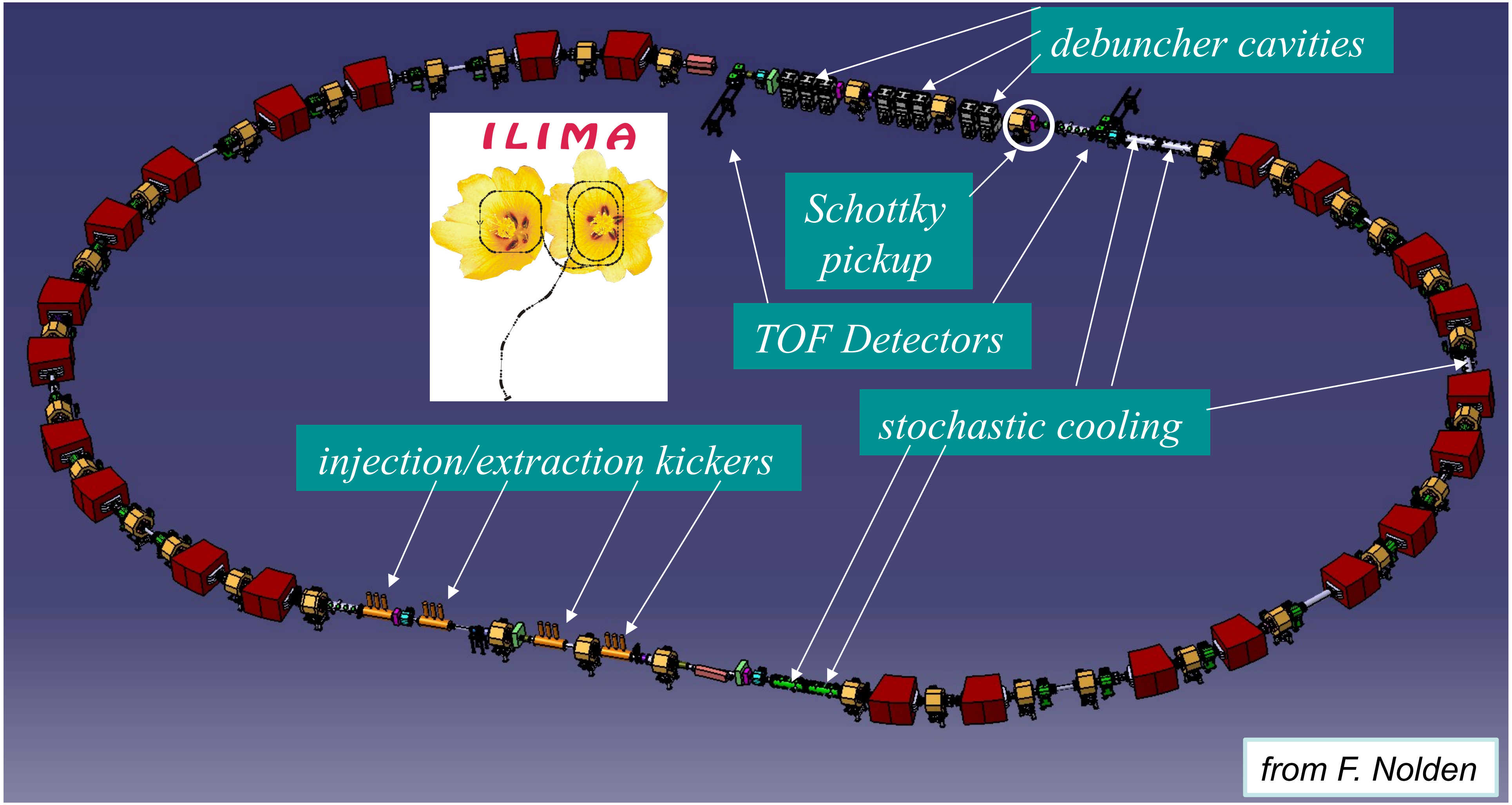


See the talk by Tom Aumann on Friday

and the talk by Stefanos Paschalis on Wednesday

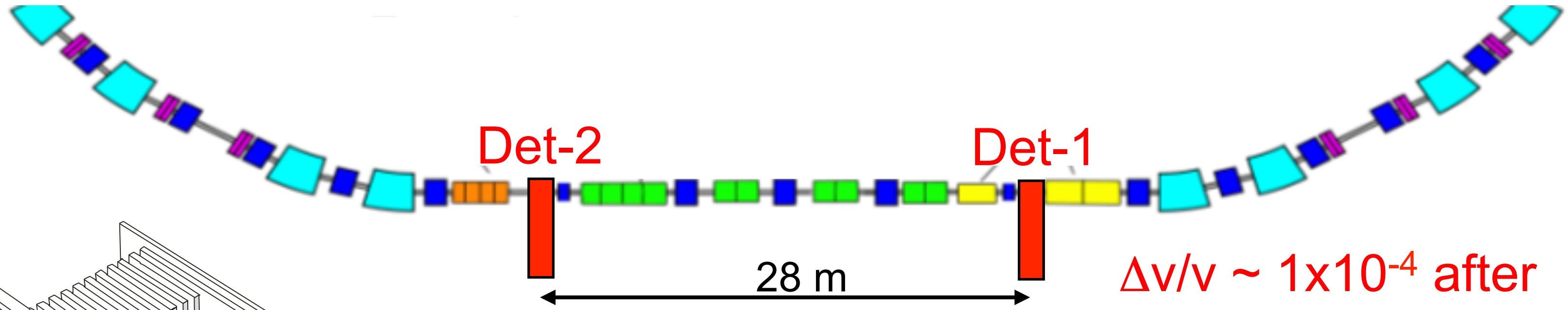
ILIMA – partial program in CR (NESR not in MSV)

CR perspective view

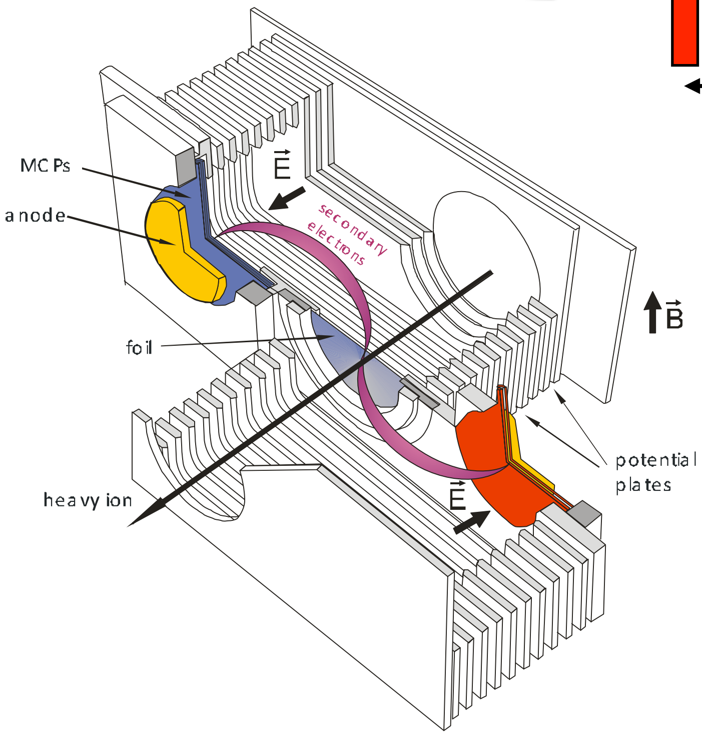


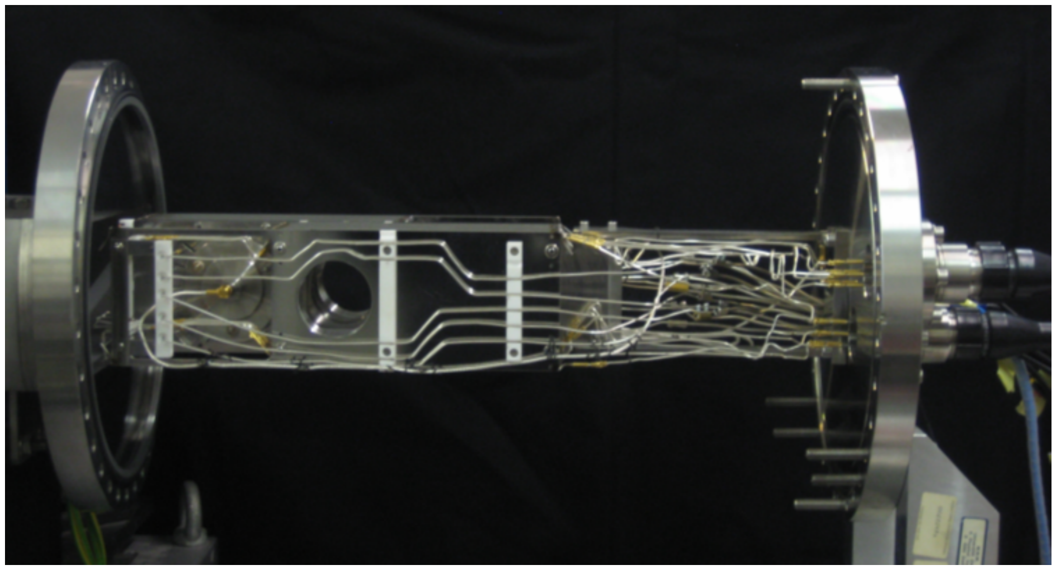
ToF Detection

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

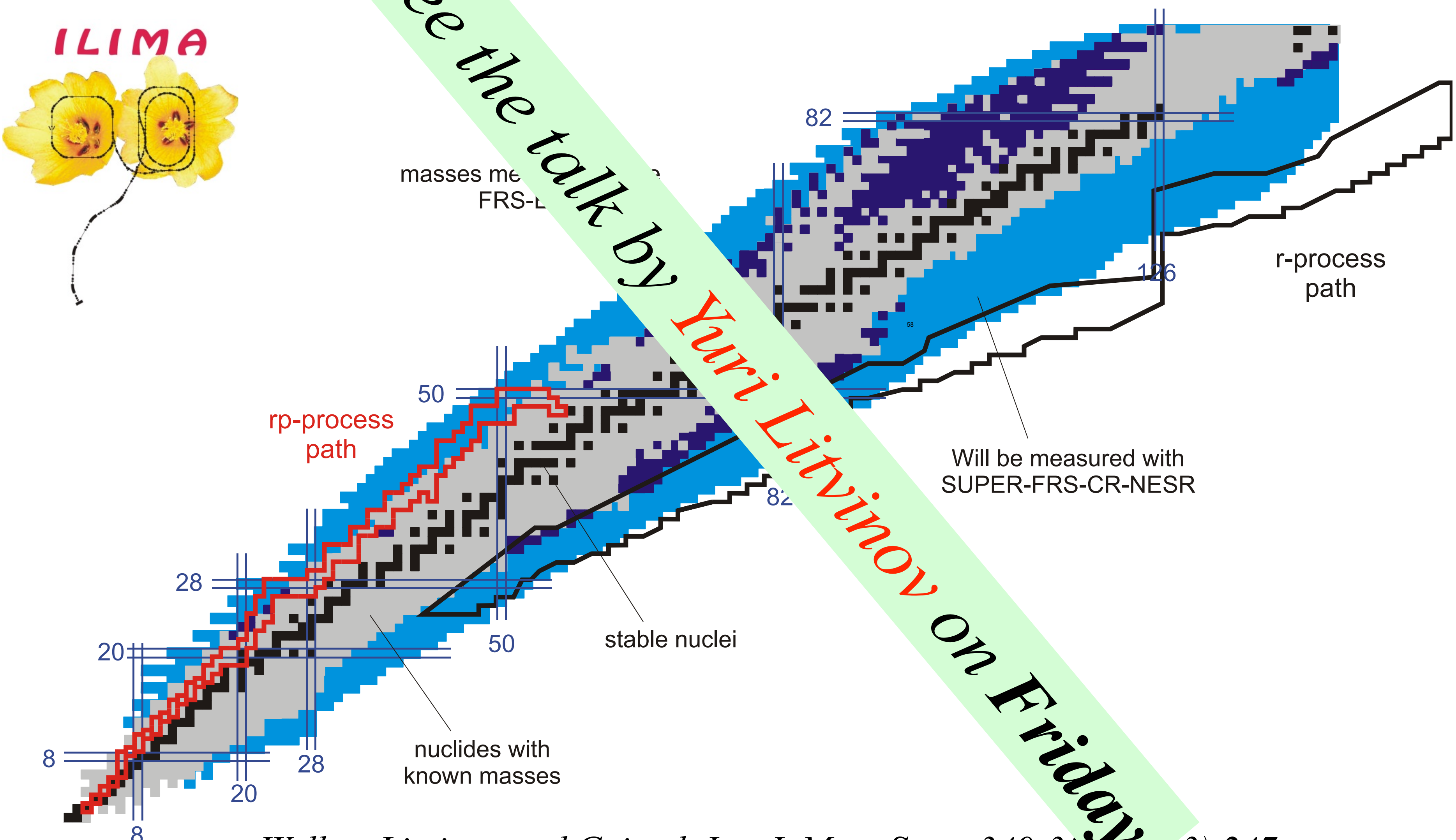


Δv/v ~ 1x10^{-4} after averaging many turns





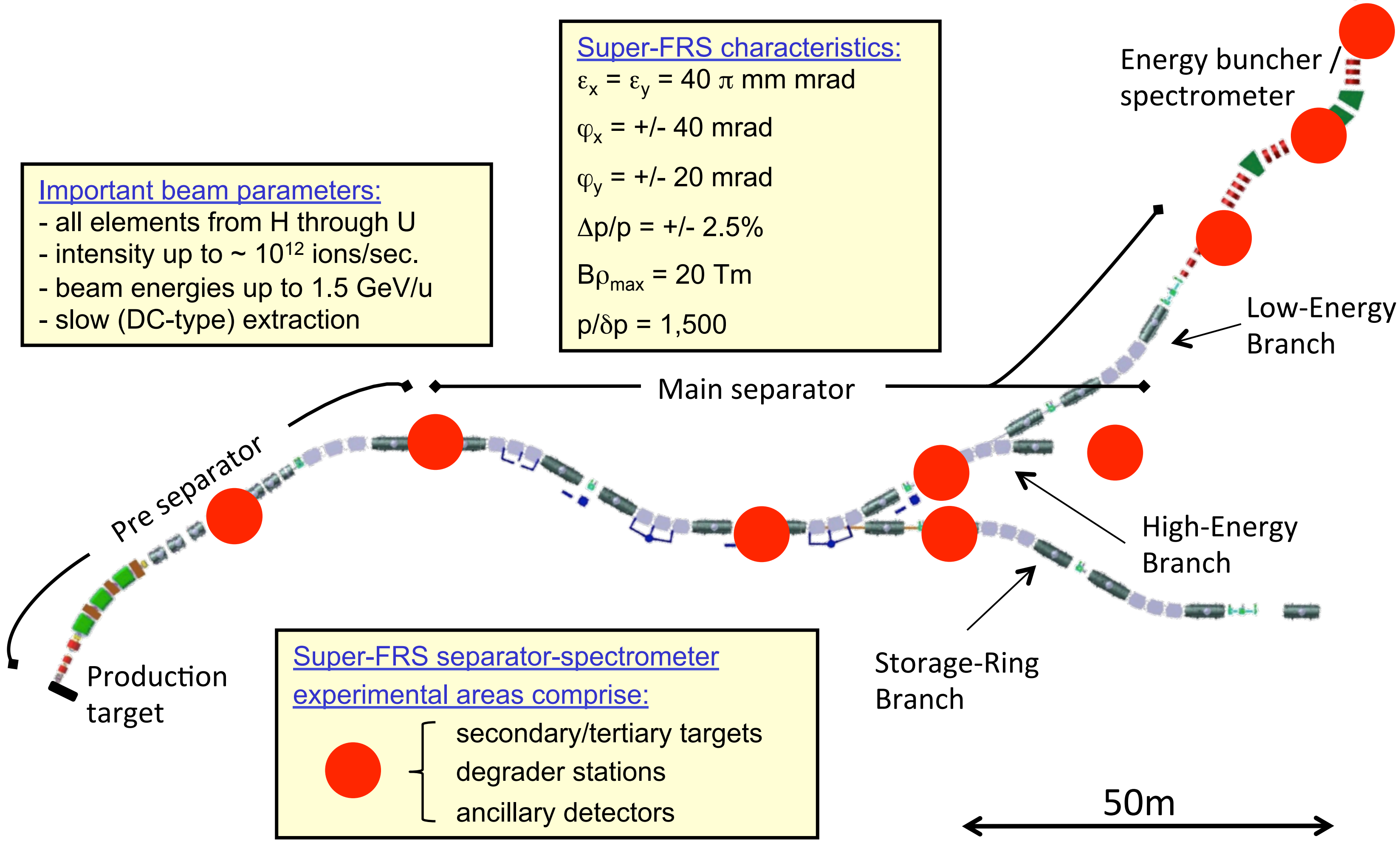
Potential for new masses with ILIMA



Walker, Litvinov and Geissel, Int. J. Mass Spec. 349-35 13) 247

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

φ_x = +/- 40 mrad

φ_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 phy[illegible]laboration within NUSTAR formally established

See the talk by Isao Tanihata on Friday

Worldwide unique featur[illegible]
- energy > 500 MeV/u
- momentum resolution p/Δp ~ 1500 ... 20000
- customized ion-optical modes

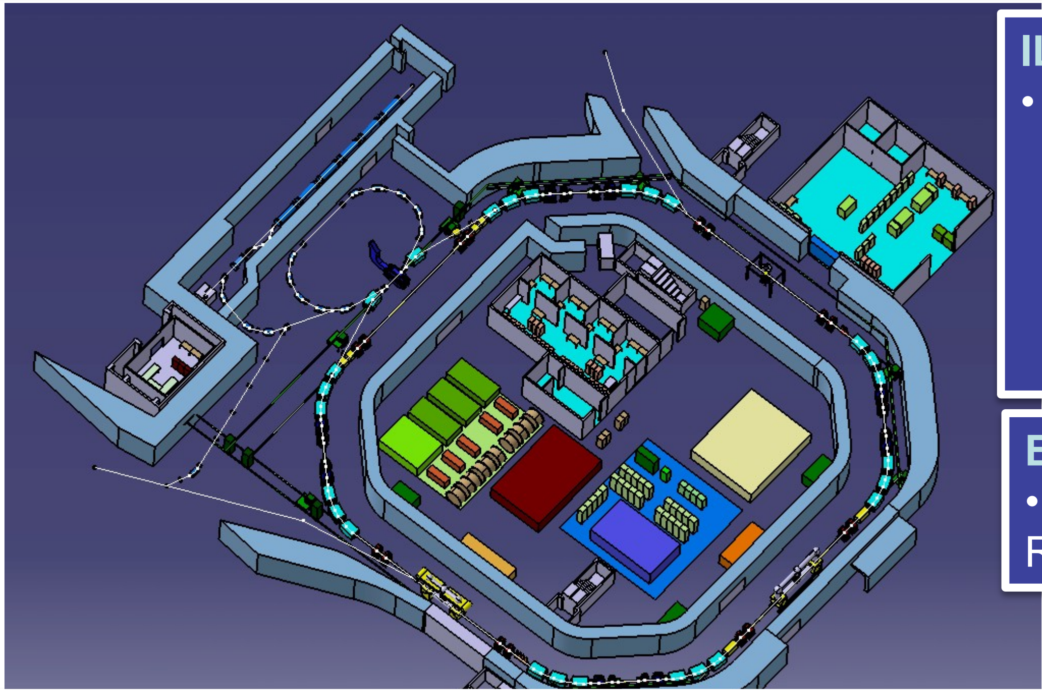
Planned experiments will use
- separator stages for high momentum resolution
- intermediate degrader and target stations
- standard equipment + (new) ancillary detectors

Super-FRS as:
- high-performance separator for mono-isotopic or cocktail beams
- high resolution spectrometer
- [illegible]I beam separator plus reaction [illegible]ctrometer

S[illegible] programme compiled, syn[illegible] 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

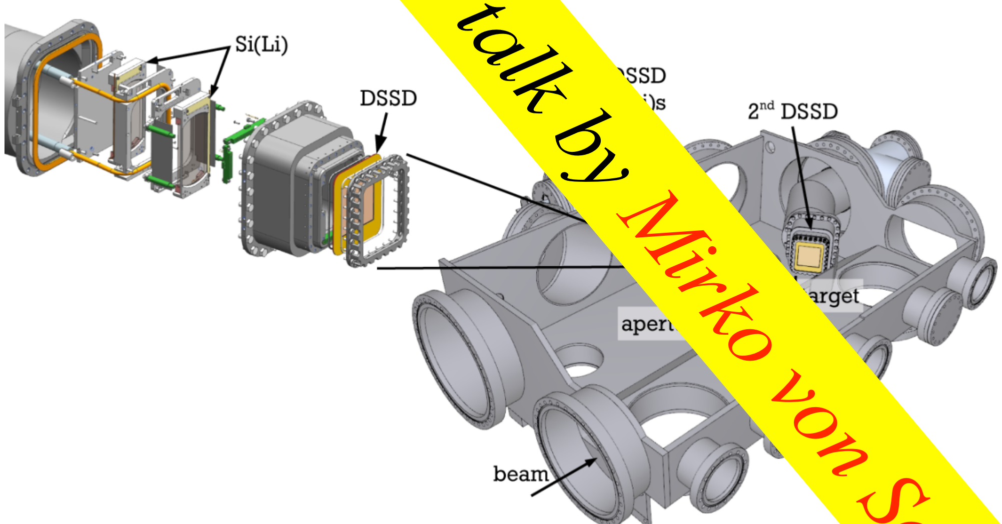
ELISe
• Elastic and inelastic electron scattering on RIBs

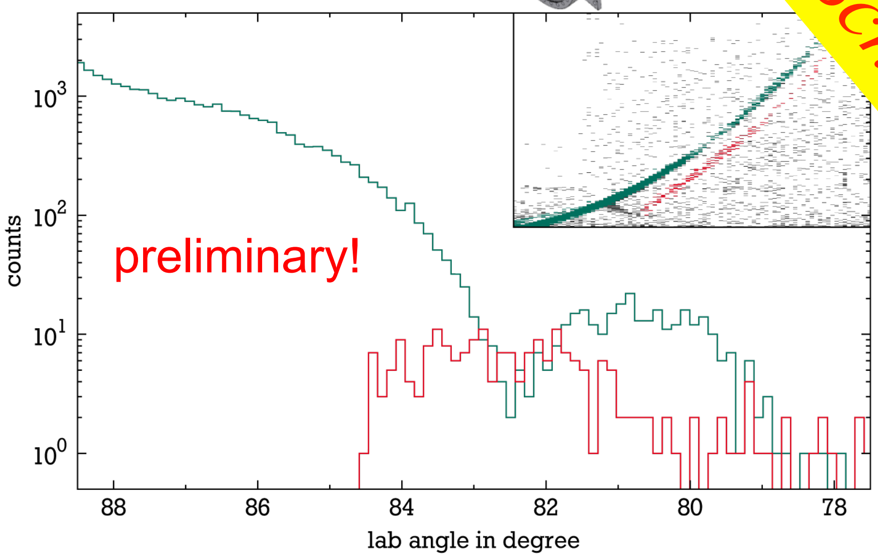
EXL: Elastic and inelastic scattering, reaction with low-momentum transfer
• matter distributions, monopole resonances, capture reactions, charge exchange reactions, transfer, knock-out
(n-skins, compressibility, GT-strength, shell evolution, nucl. astrophysics reactions)

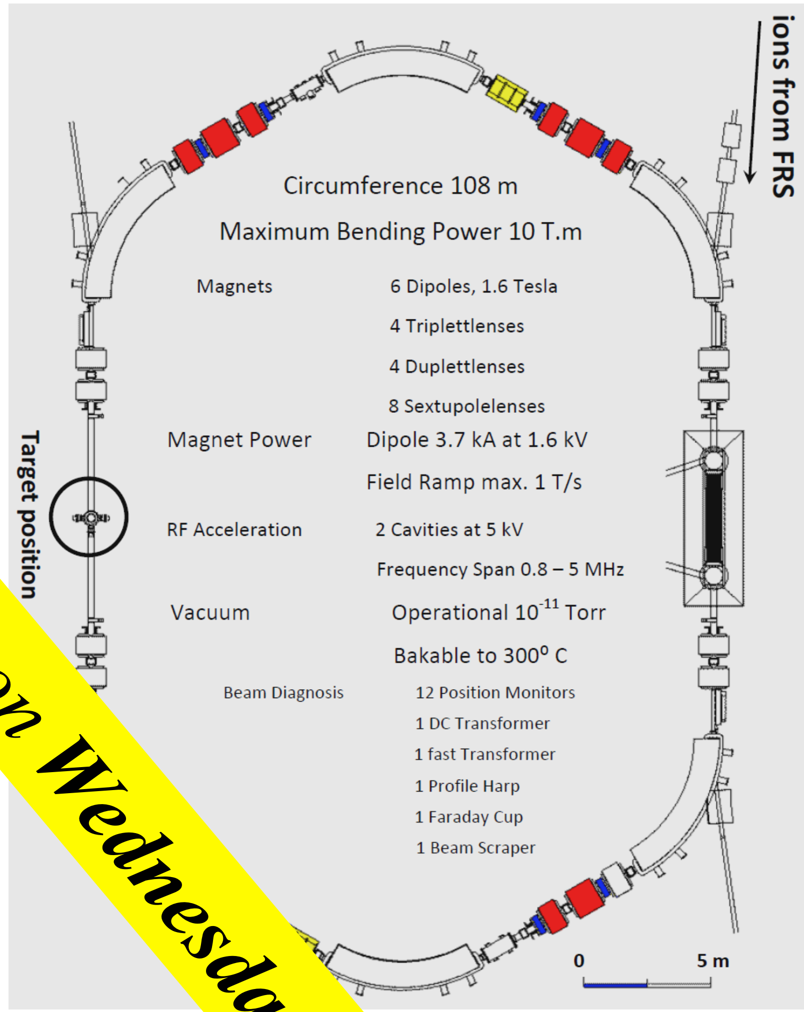
Intermediate storage ring activities @ ESR

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

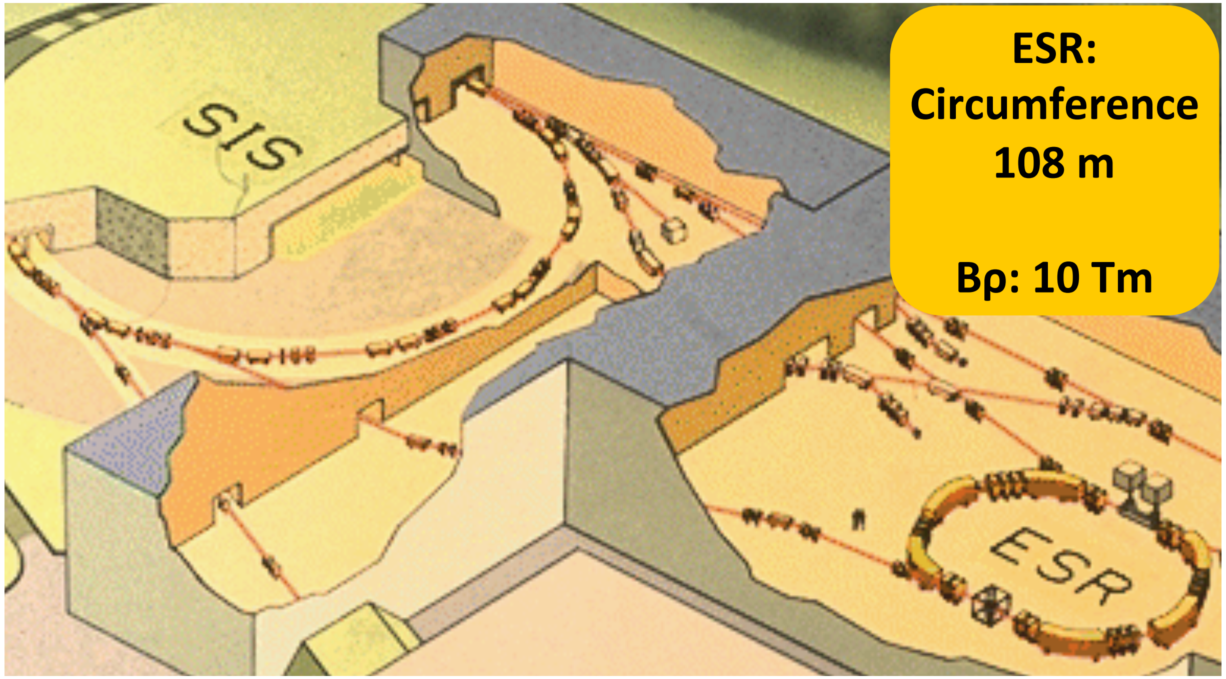
See the talk by Mirko von Schmid on Wednesday





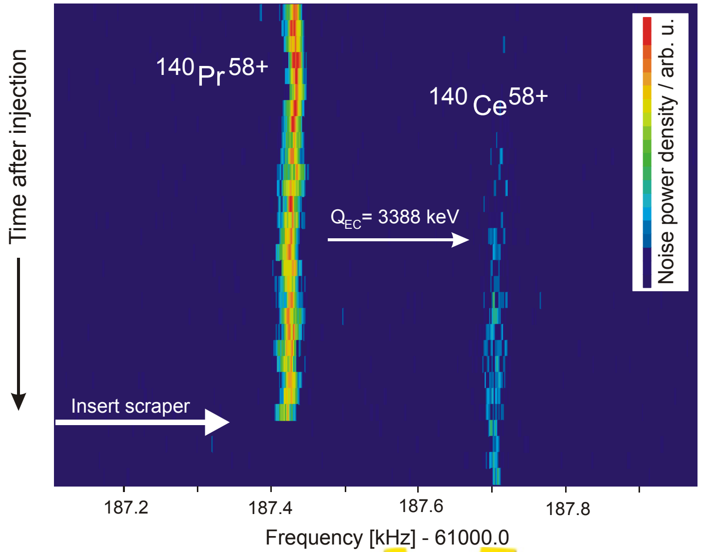


CRYRING at ESR



ESR:
Circumference
108 m

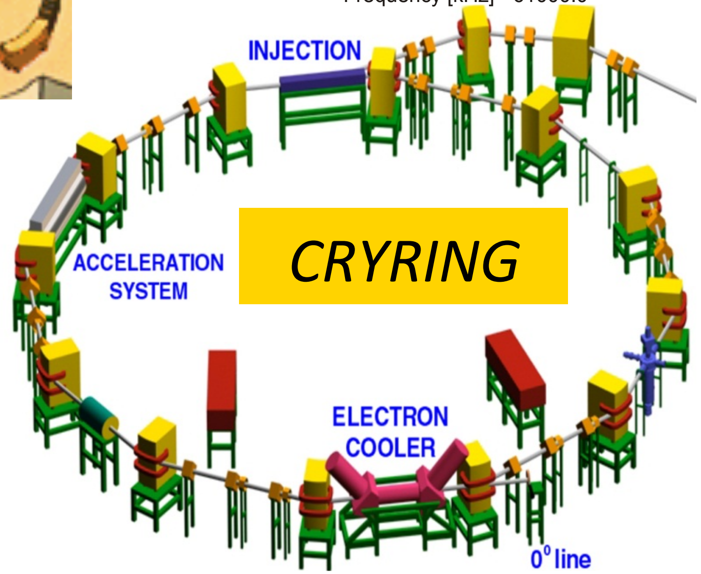
Bρ: 10 Tm



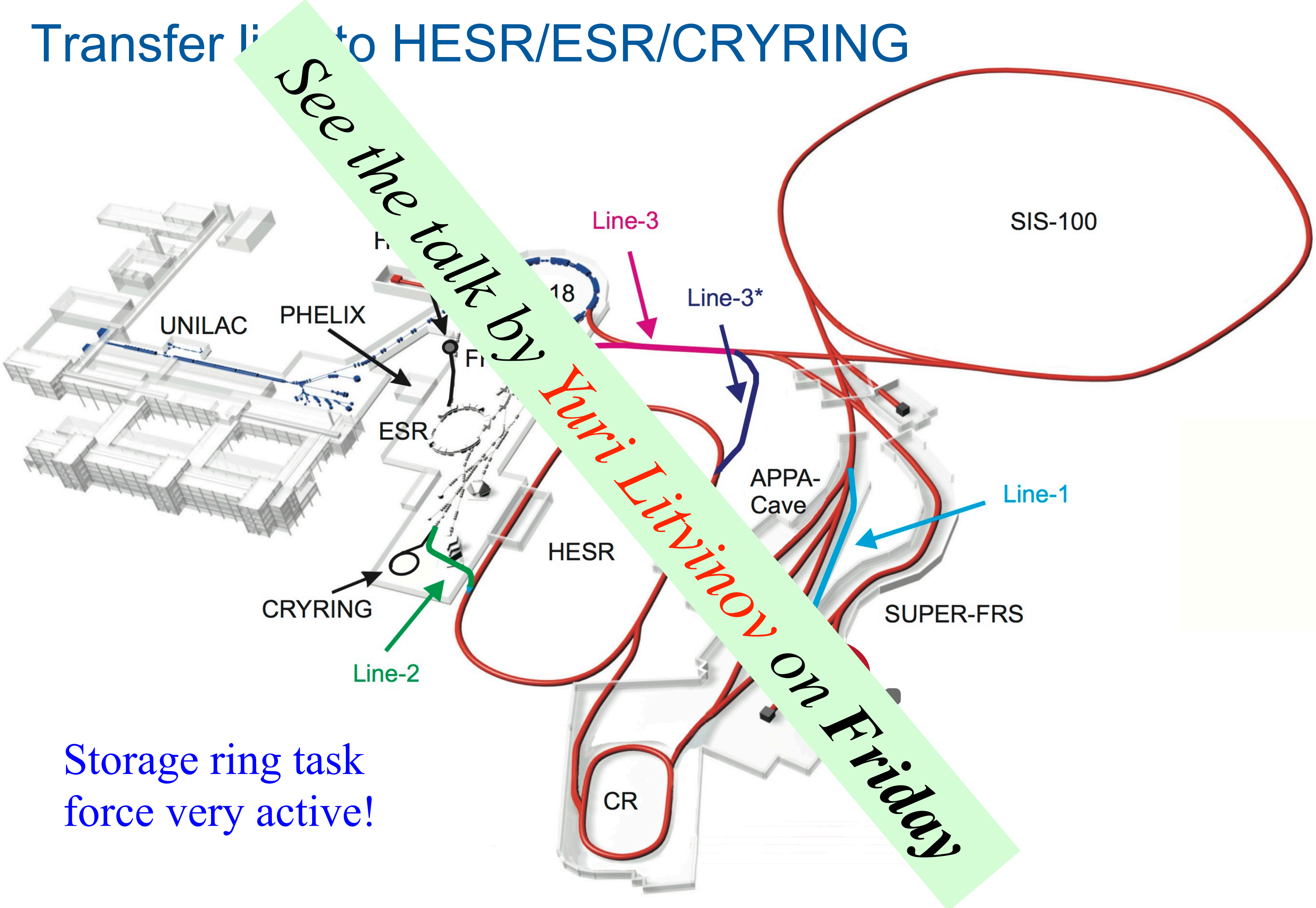
Cryring+ESR: beam energies 0.1-1.0 MeV/u - reaction rates measurements in the Gamow window of the **rp-process**

Cryring
Circumference
54 m

Bρ: 1.44 Tm

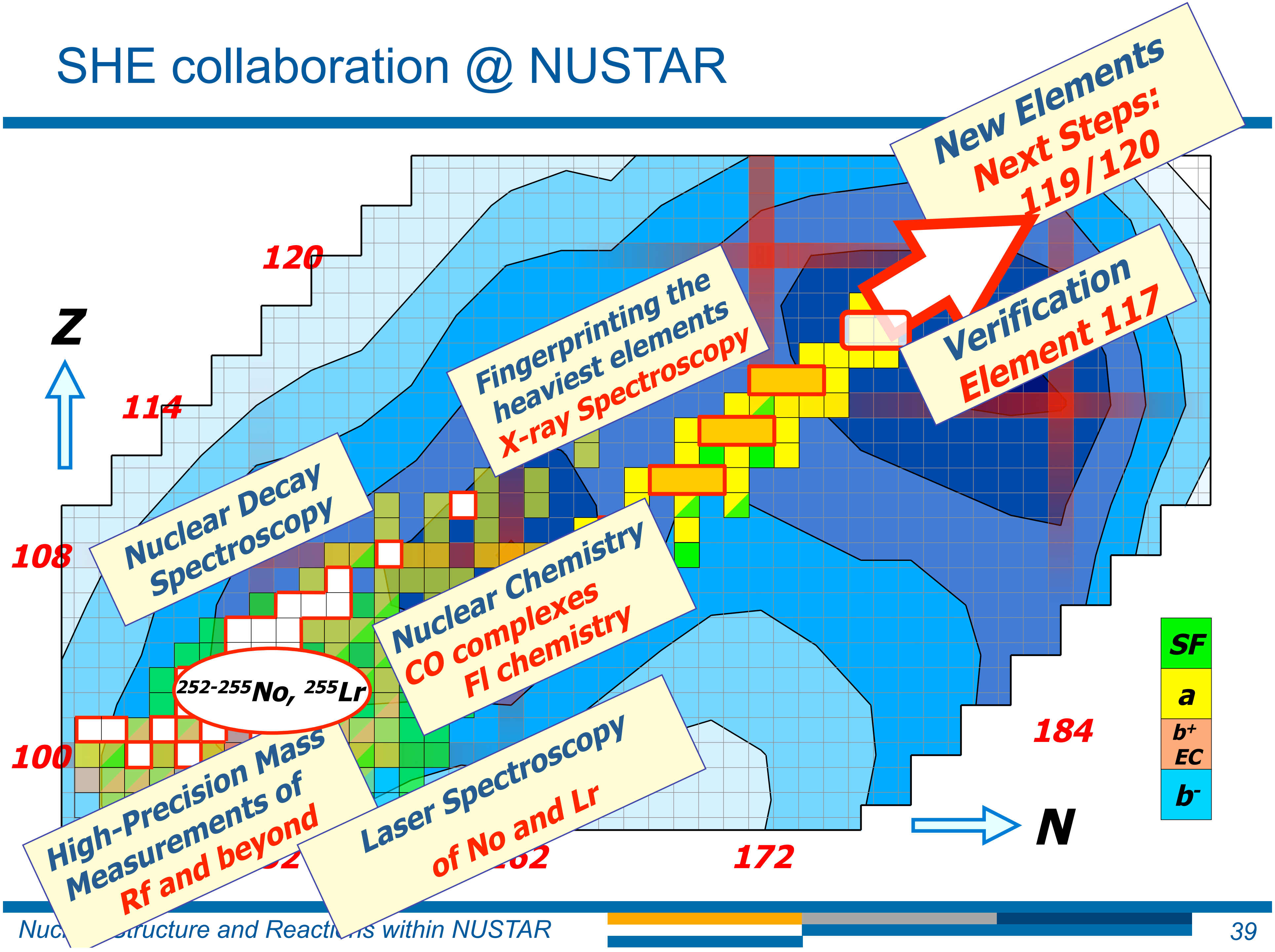


Transfer li... to HESR/ESR/CRYRING



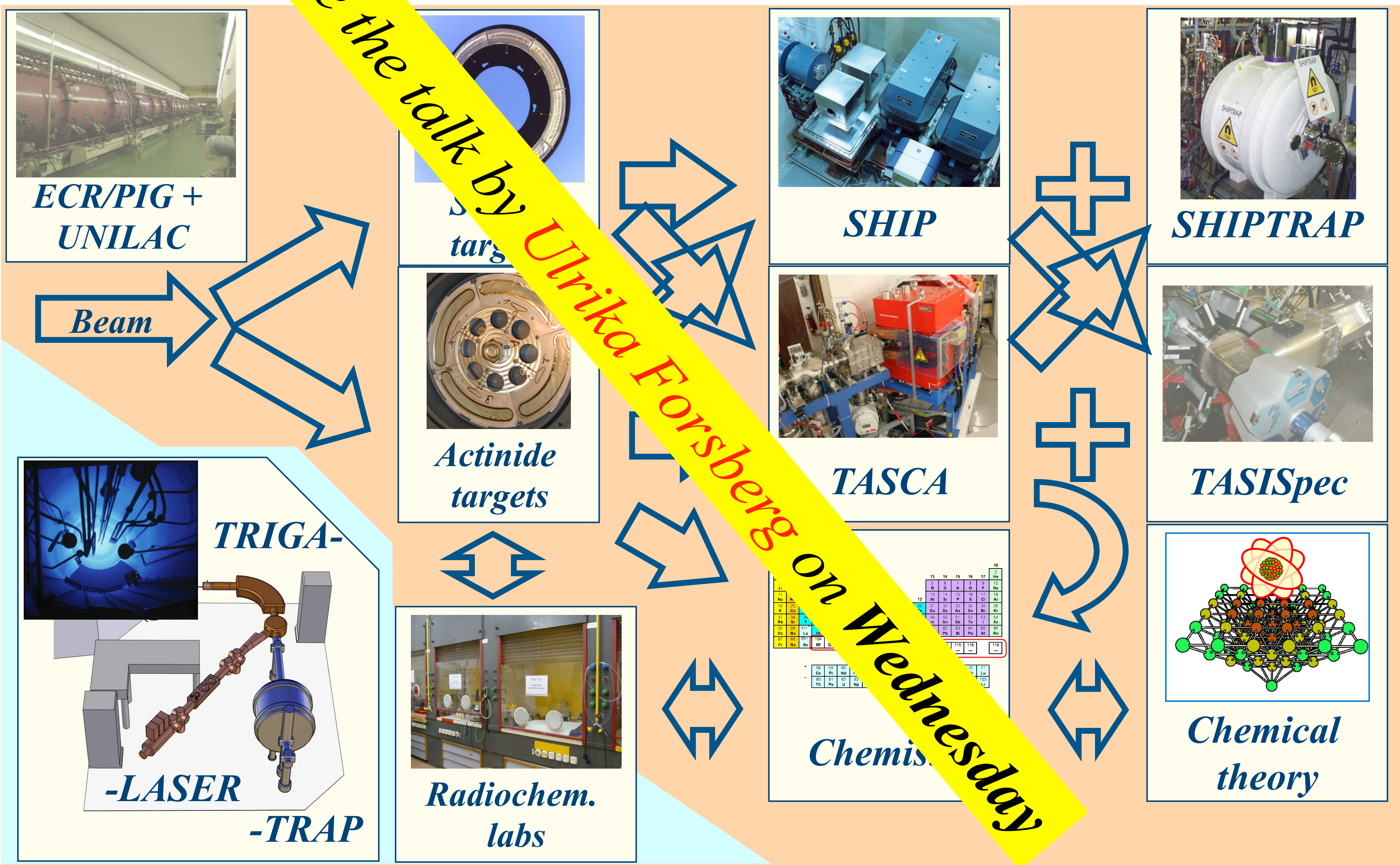
Storage ring task force very active!

SHE collaboration @ NUSTAR



Unique instrumentation for SH[illegible]search at FAIR

JOHANNES GUTENBERG UNIVERSITÄT MAINZ



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 formed following endorsement by the NUSTAR collaboration, science case recently submitted.

Spokesperson:	Rolf-Dietmar Herzberg
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)

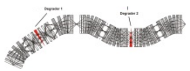
Combined with:

- 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

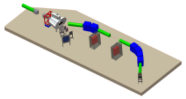
→ ***Comprehensive map of nuclear landscape***

Complementarity of NUSTAR experiments

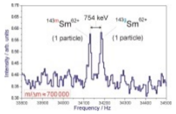
Super-FRS



R3B

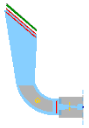


ILIMA

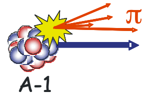


EXL

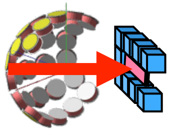
ELISE



AIC

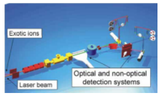


HISPEC/ DESPEC



MATS

LASPEC



	Super-FRS	R3B	ILIMA	EXL	ELISE	AIC	HISPEC/DESPEC	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			
Charge radii					charge density distribution				mean square radii
Single-particle structure	high resolution, angular momentum	complete kinematics, neutron detection	Stored isomers	low momentum transfers			high-resolution spectroscopy		Magnetic moments
Collective behavior		dipole resonance		Monopole resonance	Elelctromag. Transitioins				Quadrupole moments

Thank you!