

NuSTAR

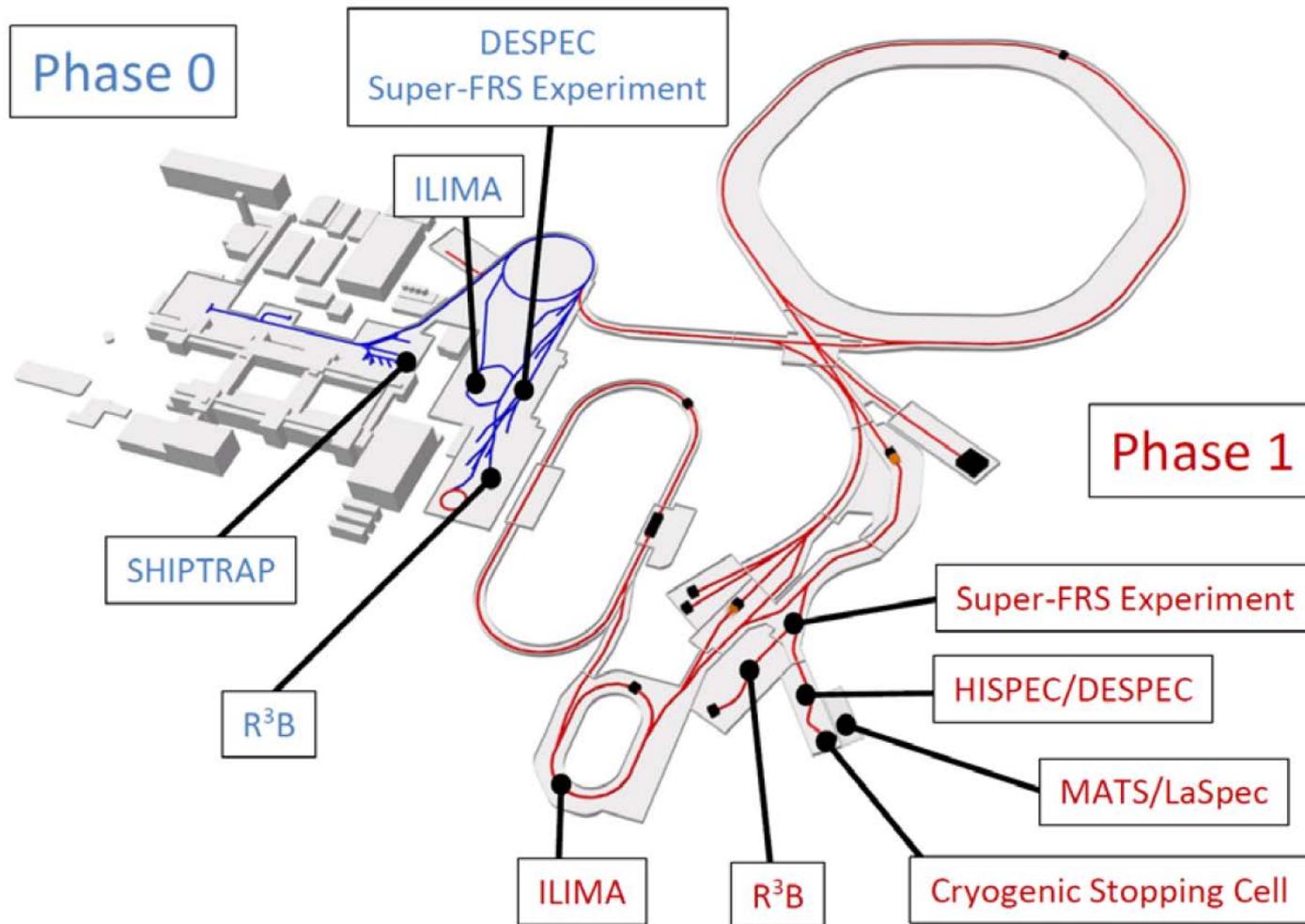
NUclear **ST**ructure, **A**strophysics and **R**eactions

KHuK Jahrestagung 2020
Bad Honnef, Germany
Dec-10, 2020

René Reifarth
Goethe Universität Frankfurt



NUSTAR – now and future



NUSTAR – on paper

PSP code	Super-FRS	RIB production, separation, and identification
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	R³B	Kinematical 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

NUSTAR – very active

DESPEC	R3B	ILIMA	(S-)FRS	SHE
22 proposals	10 proposals	3 proposals	14 proposals	6 proposals
A: 5 (+3 dev.)	A: 4	A: 1	A: 4 (+3 dev.)	A: 5
A-: 1	A-: 1		A-: 1	
SIS shifts: 108 (main) 30 (second.)	SIS shifts: 108 (main) 18 (second.)	SIS shifts: 6 (main)	SIS shifts: 73 (main) 46 (second.) UNILAC shifts: 27 (second.)	UNILAC shifts: 232 (main) 149 (second.)

NUSTAR:

19 A ratings

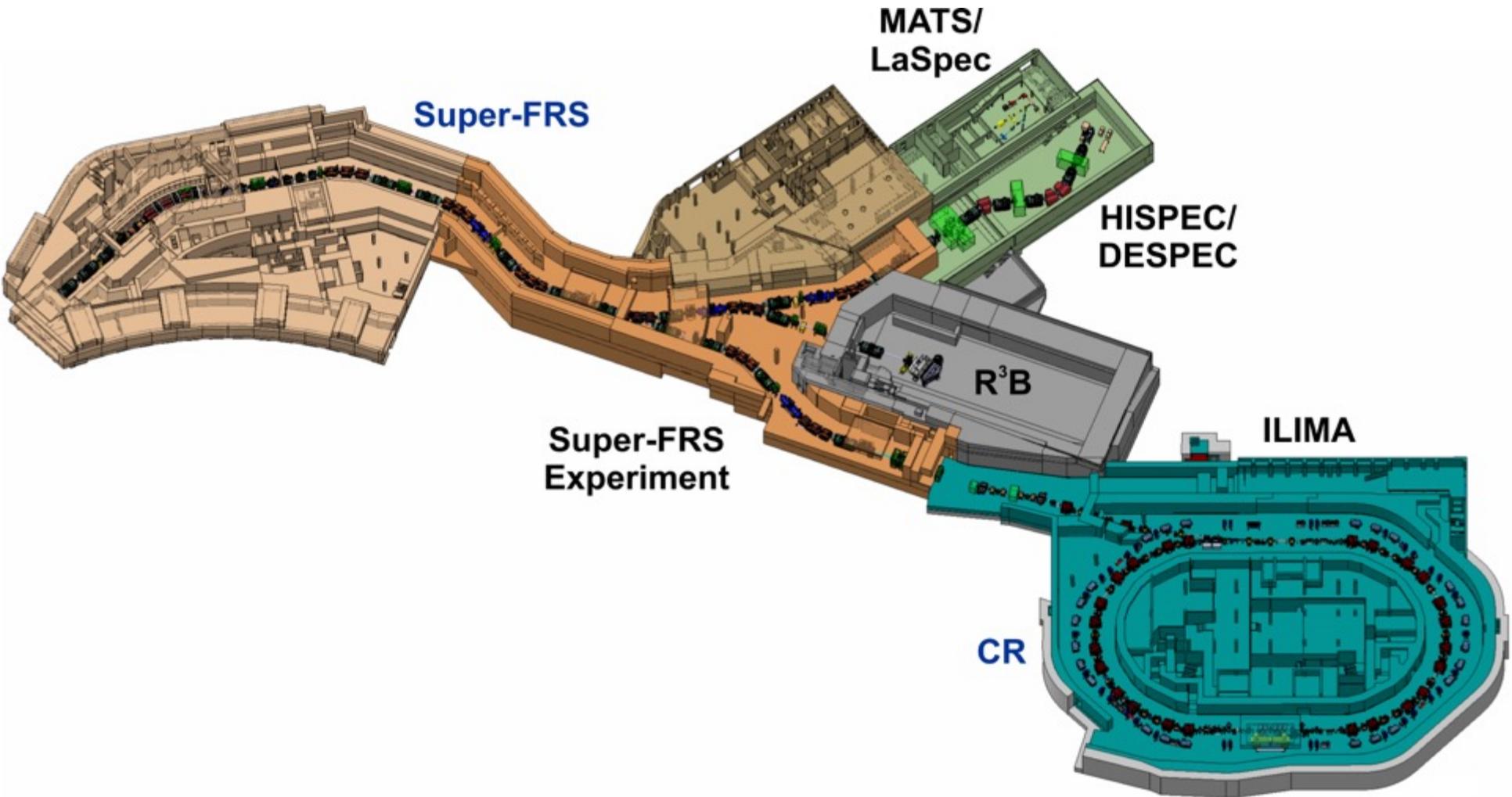
SIS beamtime shifts:

295 (main) + 94 (second.)

UNILAC beamtime shifts:

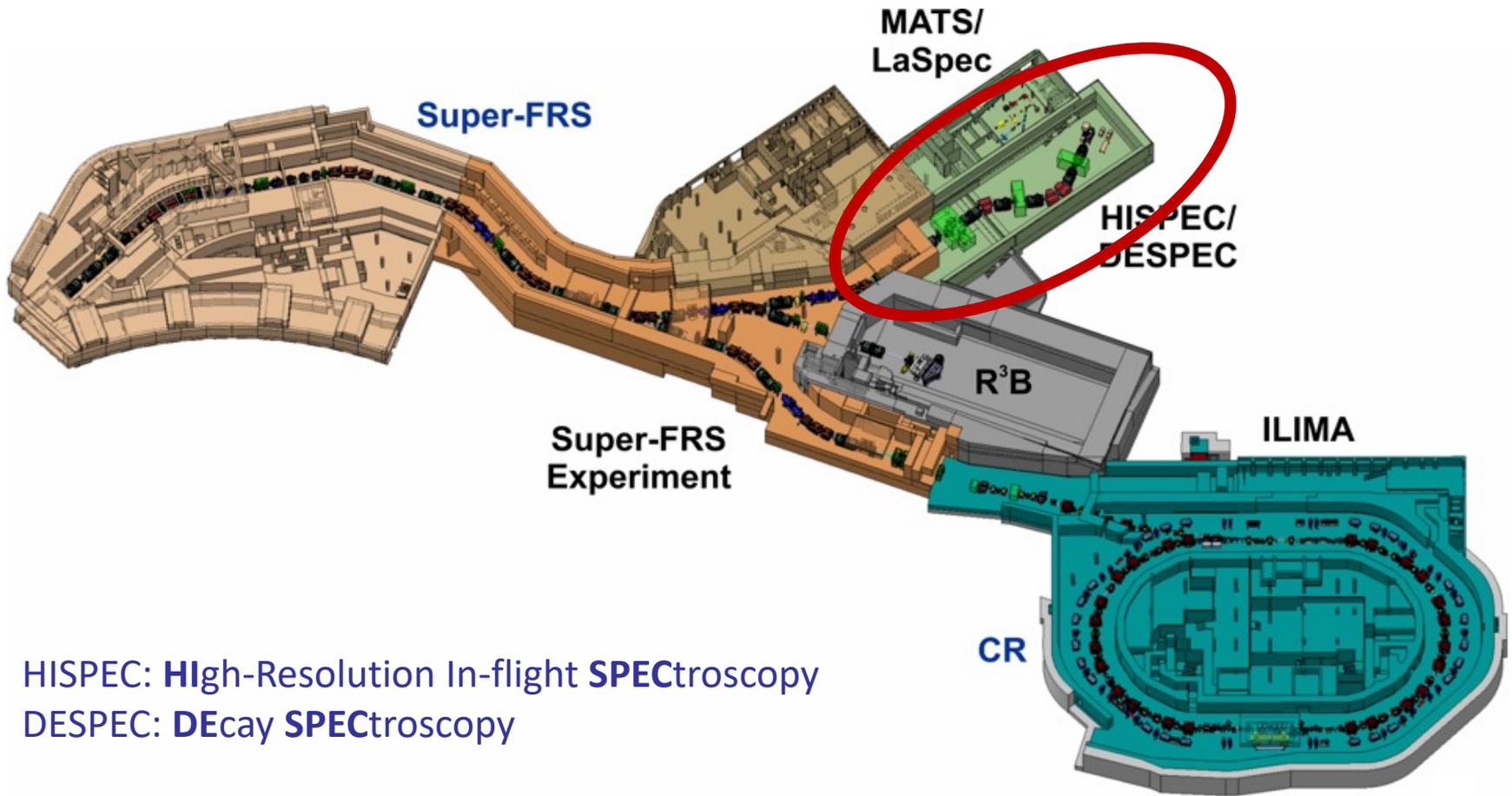
232 (main) + 176 (second.)

NUSTAR – in „real live“





NUSTAR – HISPEC/DESPEC



HISPEC: **H**igh-Resolution In-flight **SPEC**troscopy
DESPEC: **DE**cay **SPEC**troscopy

NUSTAR – HISPEC/DESPEC

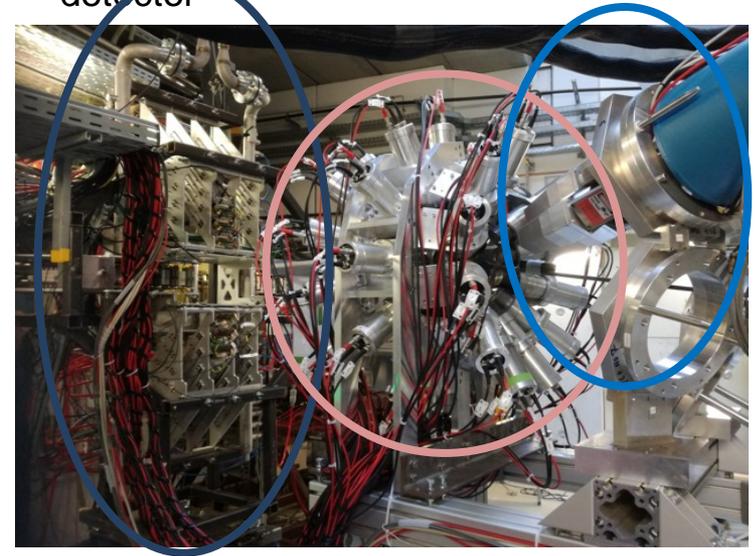
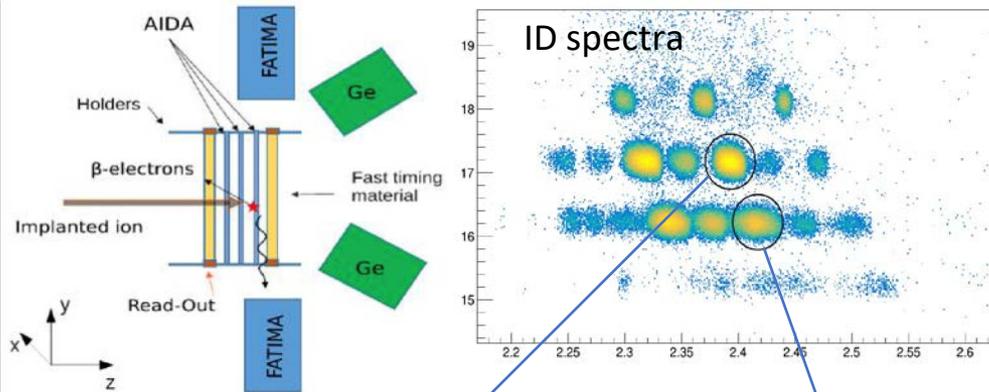
Engineering run Nov/Dec 2019

Implant ↔ decay ↔ γ -ray
Correlations tested and working

AIDA
implantation
and decay
detector

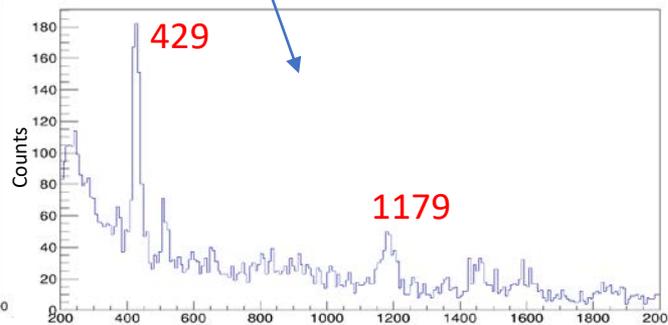
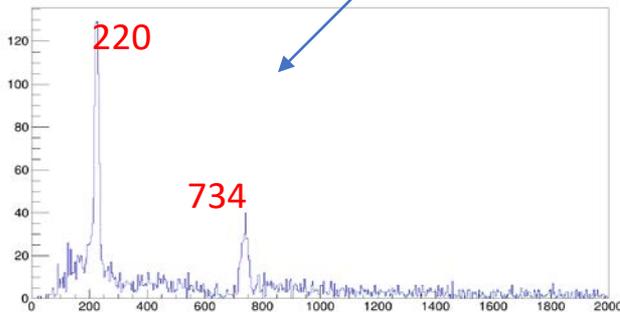
FATIMA
Fast Timing
LaBr₃ Array

DEGAS/GTC
HPGe Array



FATIMA isomer spectrum in ³²Al

Fatima spectrum of ³⁴Al beta decay



- Detectors fully performing
- Tested electronics from each branch
- Fully integrated DAQ
- On-line and off-line sorting programs

Energy [keV]

NUSTAR – HISPEC/DESPEC

First “real” DeSpec experiment

Level schemes of $^{92,94,96}\text{Pd}$

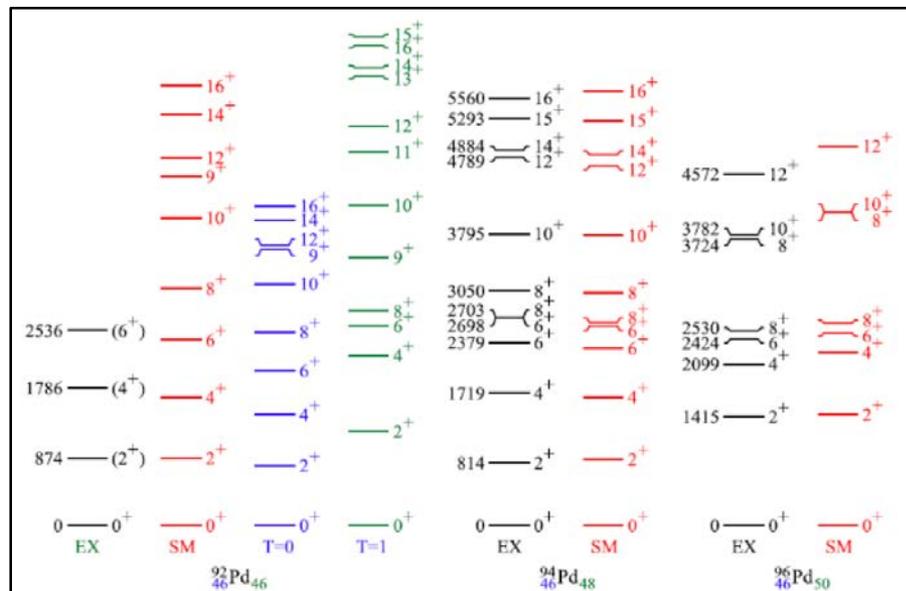
S480 ^{124}Xe beam 9 – 15 March 2020:

Structure of the heaviest N=Z nuclei:

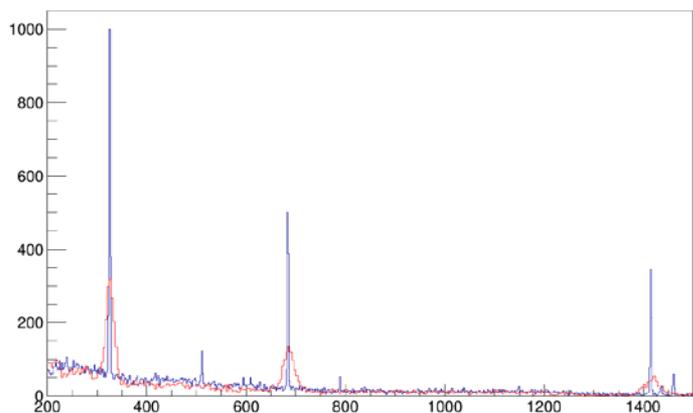
Seniority Transitions in ^{94}Pd

Spokespersons: Regan, Gorska, Cederwall

→ New lifetimes in the ps-to-ns regime



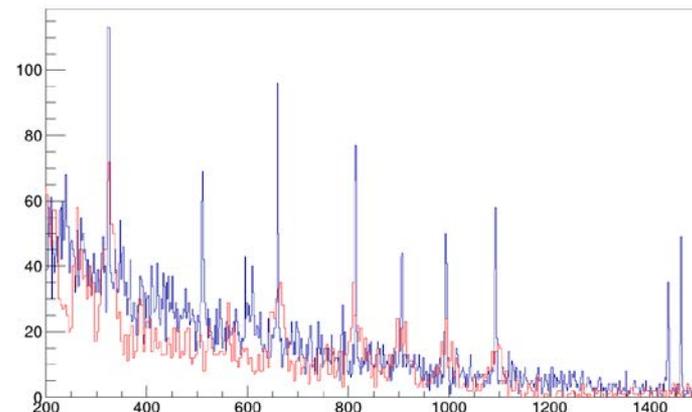
Reference nucleus ^{96}Pd



PRELIMINARY!
from 16h of data

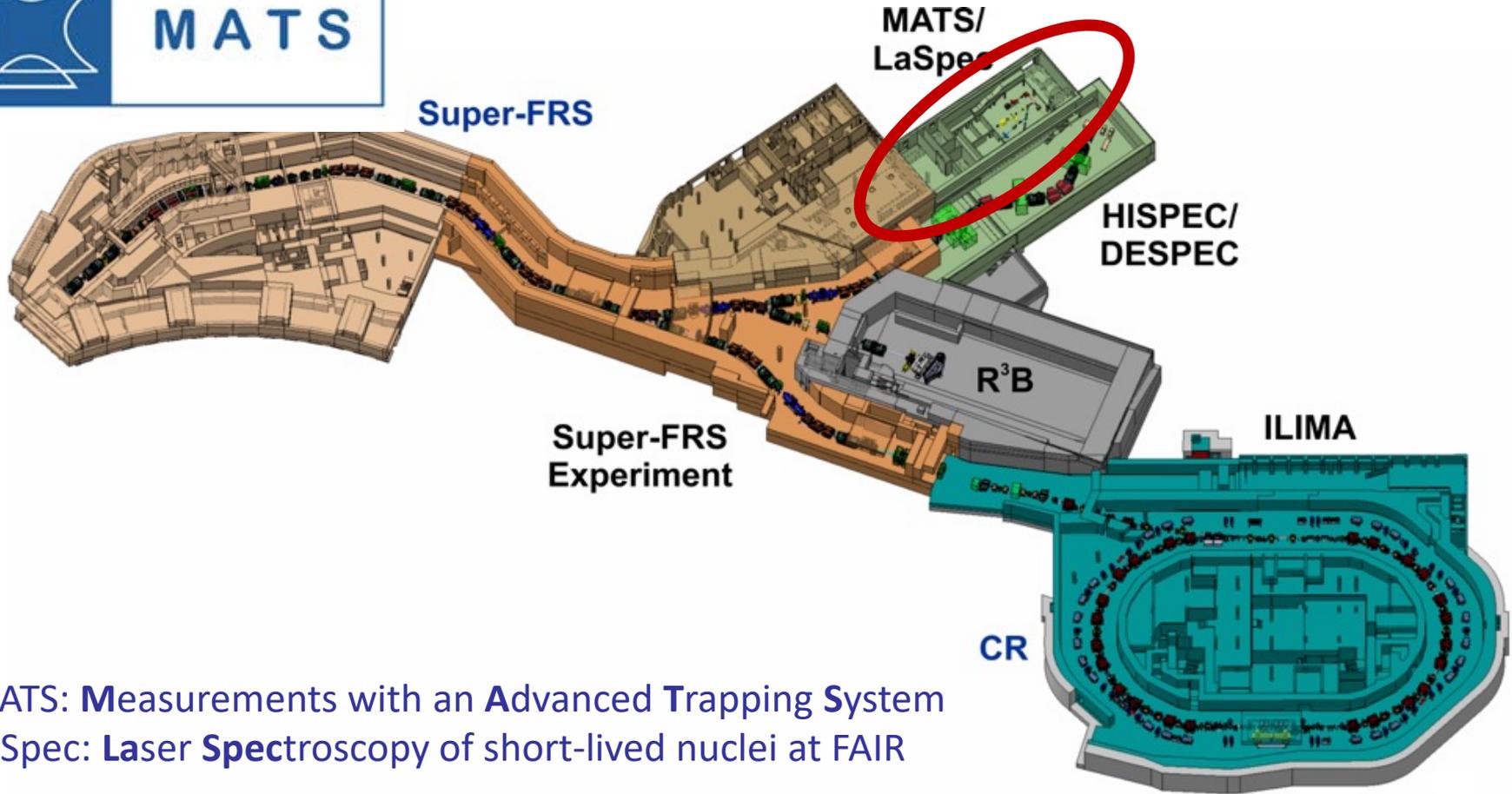
Galileo and FATIMA
isomer spectra

^{94}Pd





NUSTAR – MATS+LaSpec

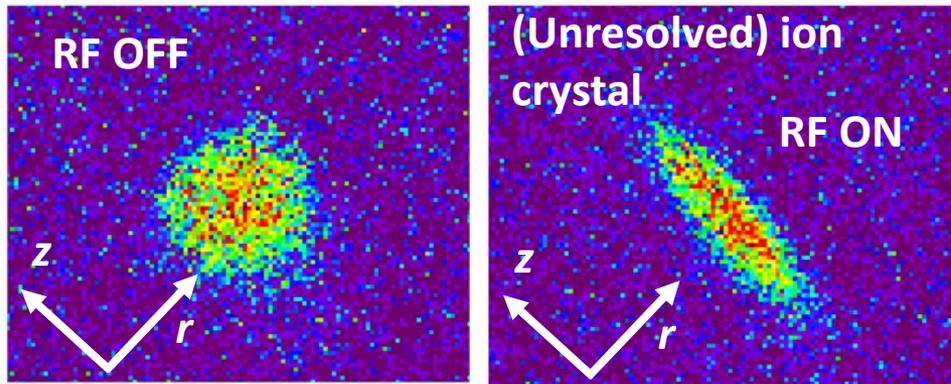


MATS: **M**easurements with an **A**dvanced **T**rapping **S**ystem
LaSpec: **L**aser **S**pectroscopy of short-lived nuclei at FAIR

Aiming at single-ion super sensitivity

- Idea: measure mass of unknown ion via quantum logic techniques with $^{40}\text{Ca}^+$ sensor ion
- optical detection using a laser-cooled $^{40}\text{Ca}^+$ ion
- motional and internal frequency measurements through 397-nm photons.
- status: axialization (squeezing the radial motion) accomplished in a 7-tesla Penning trap

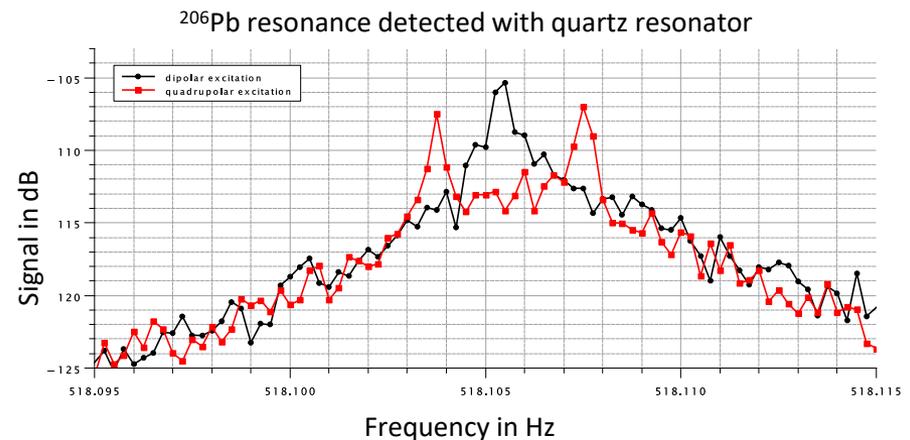
$$\nu_{\text{RF}} = \nu_c (^{40}\text{Ca}^+) = 2.689 \text{ MHz.}$$



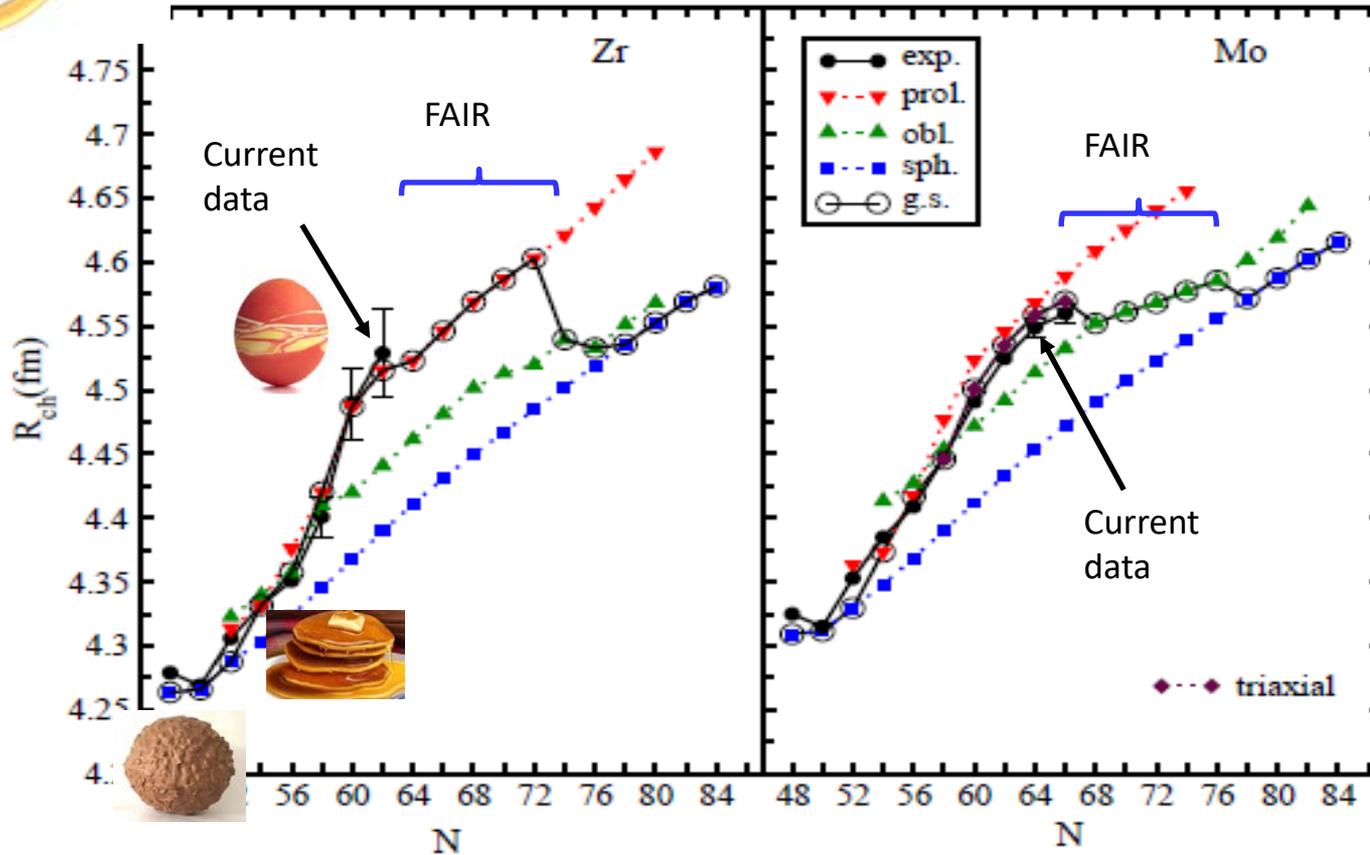
M. Gutiérrez et al., New J. Phys. 21 (2019)
D. Rodriguez and the TRAPSENSOR collaboration

Towards single-ion mass measurements

- electronic detection circuit with **quartz resonator**
- proof-of-principle mass measurement of $^{206-207}\text{Pb}$ with TRIGA-TRAP
- sensitivity: tens of ions with prototype at room temperature



S. Lohse et al. Rev. Sci. Instrum. 90, 063202 (2019)
S. Lohse, D. Rodriguez and the TRIGA-TRAP collaboration



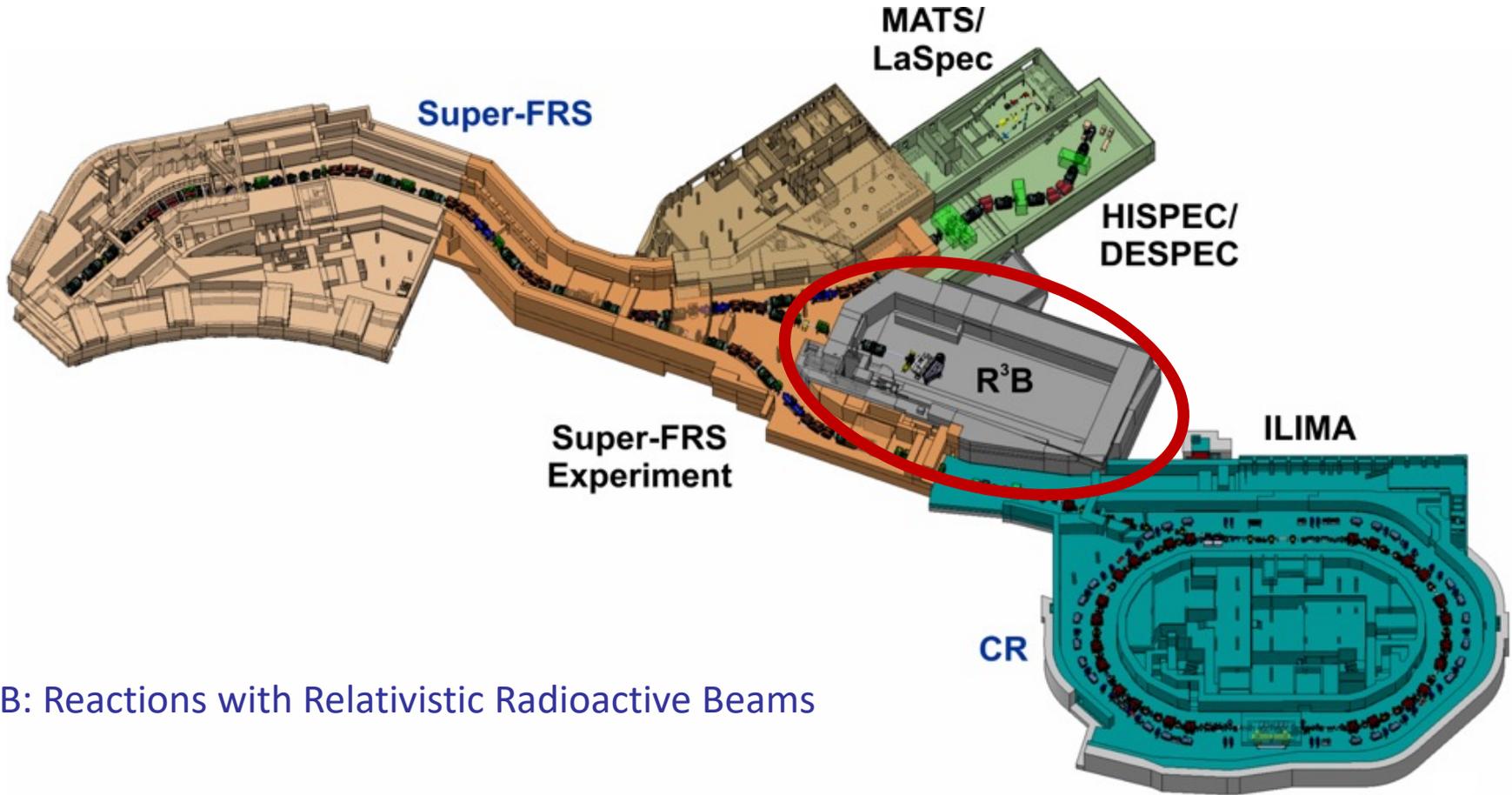
Nuclear shape evolution and shape coexistence in Zr and Mo isotopes

Pankaj Kumar^{a,1}, Virender Thakur¹, Smriti Thakur¹, Vikesh Kumar¹,
Shashi K. Dhiman¹

arXiv:2007.07491v2 (July 2020)

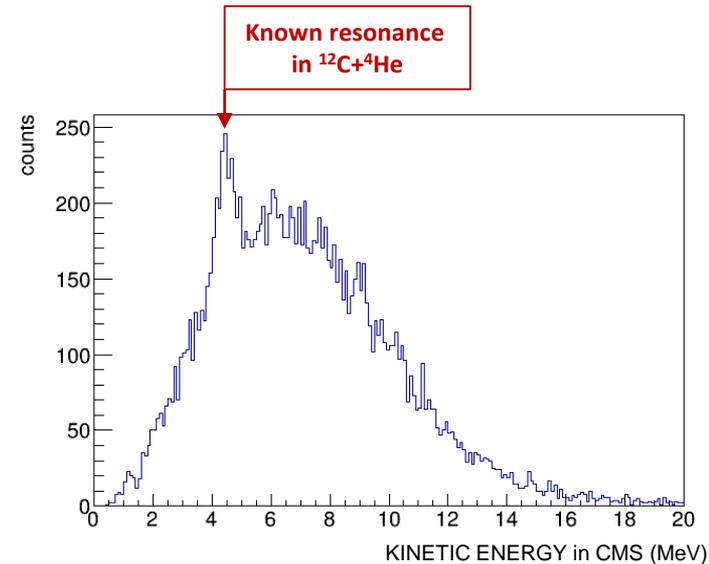
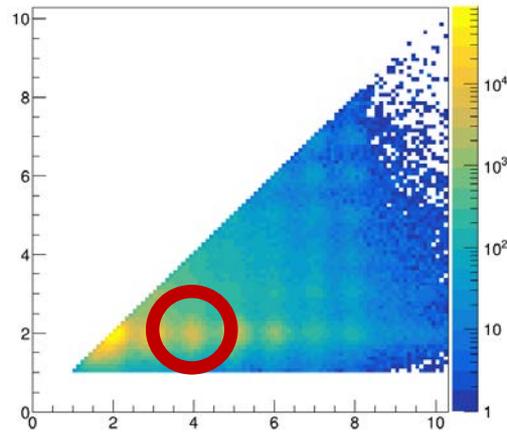
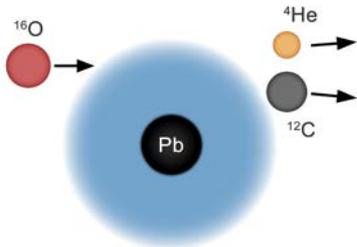
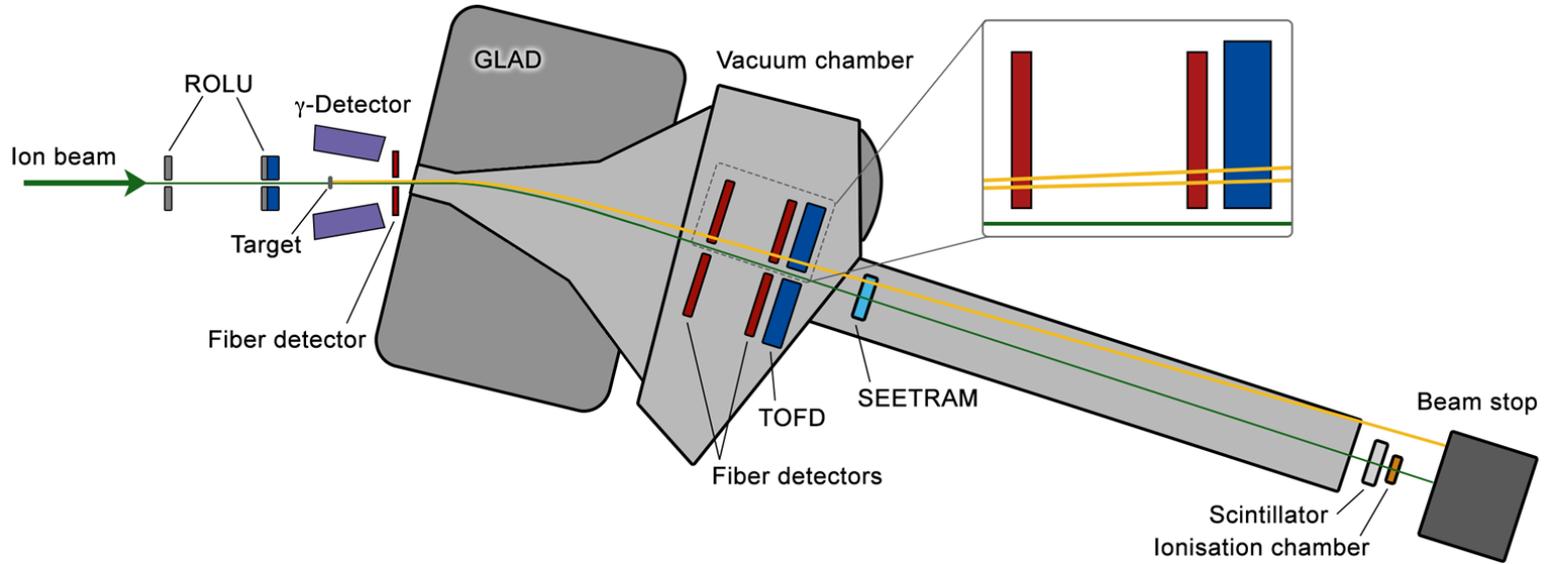
¹Department of Physics, Himachal Pradesh University, Summerhill, Shimla 171005, India

NUSTAR – R³B



R³B: Reactions with Relativistic Radioactive Beams

NUSTAR – R³B



- **S467 Single-particle structure of n-rich Ca: shell evolution along Z=20**
- **Goal:** probe the quenching of spectroscopic factors as a function of isospin asymmetry, and establish the evolution of the shell structure at Z=20 and around N=28,30 and towards N=32

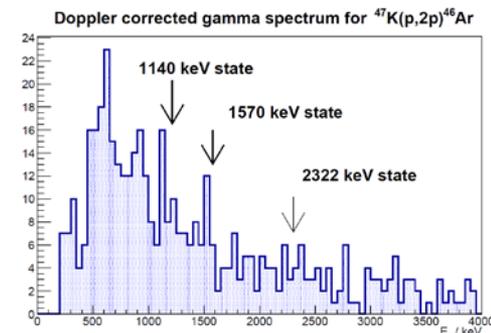
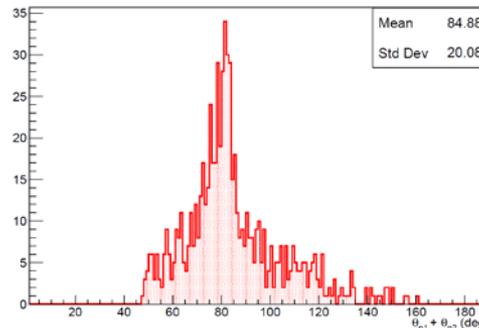
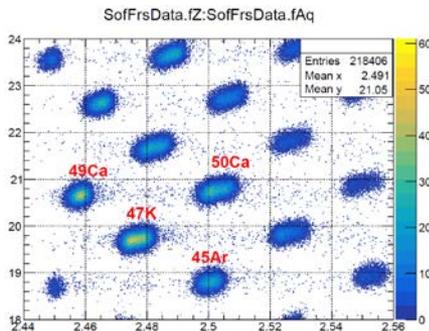
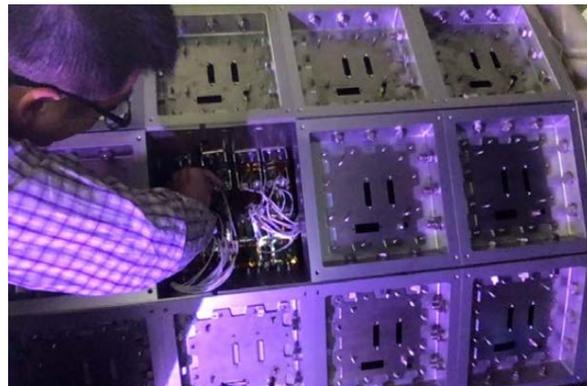
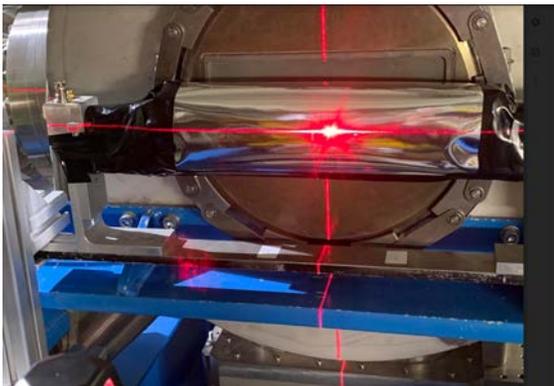
⁸⁶Kr @ 580 MeV/u

Excellent performance of gas-tracking detectors (PID)

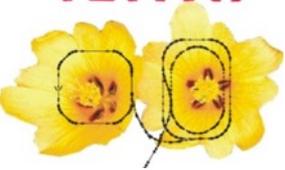
Preliminary (online) results

Excellent CALIFA performance in a huge dynamic range

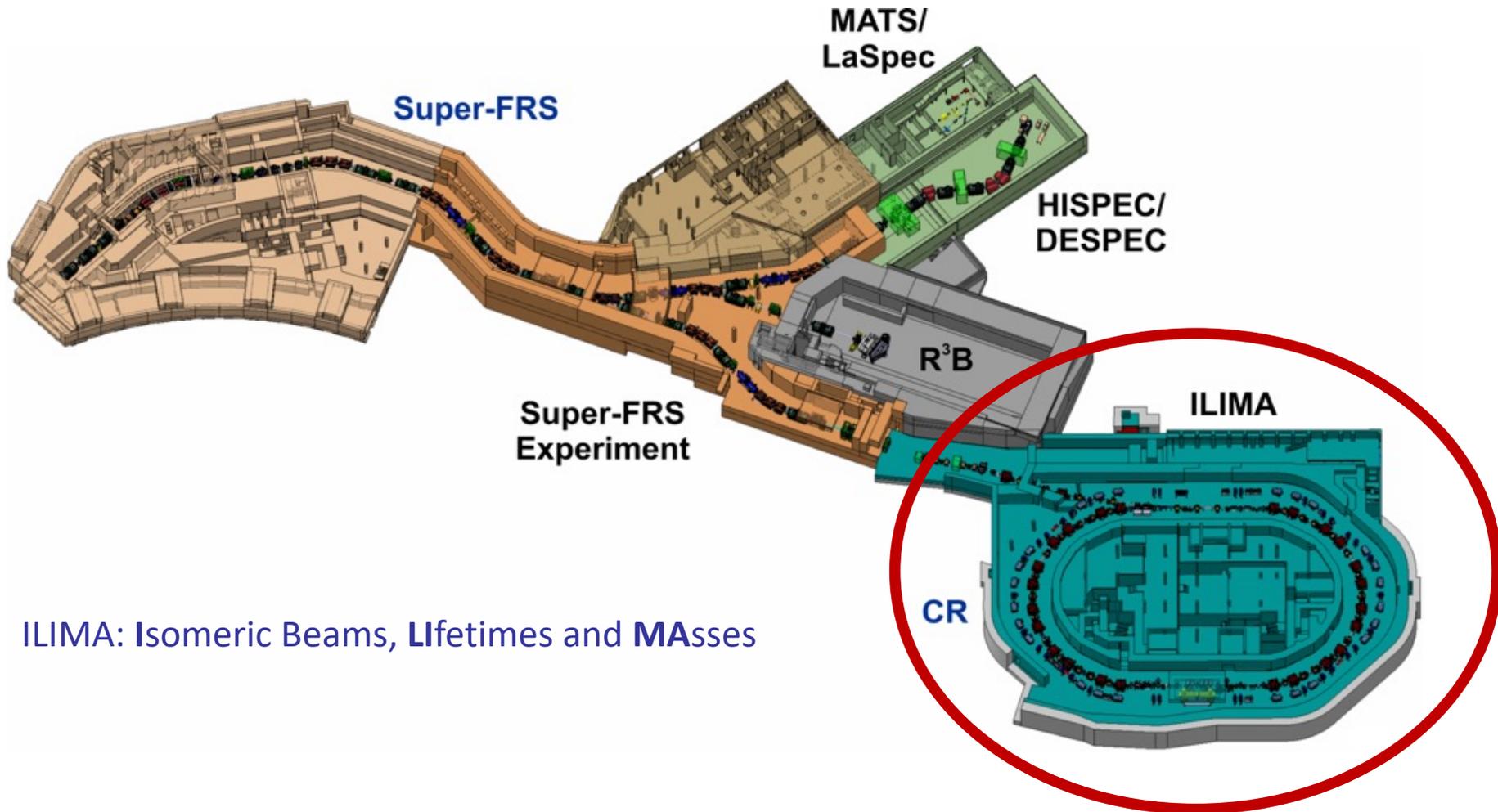
⁴⁷K(p,2p)⁴⁶Ar p-p correlation



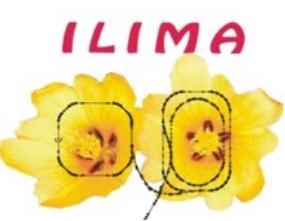
ILIMA



NUSTAR – ILIMA



ILIMA: Isomeric Beams, Lifetimes and **MA**sses

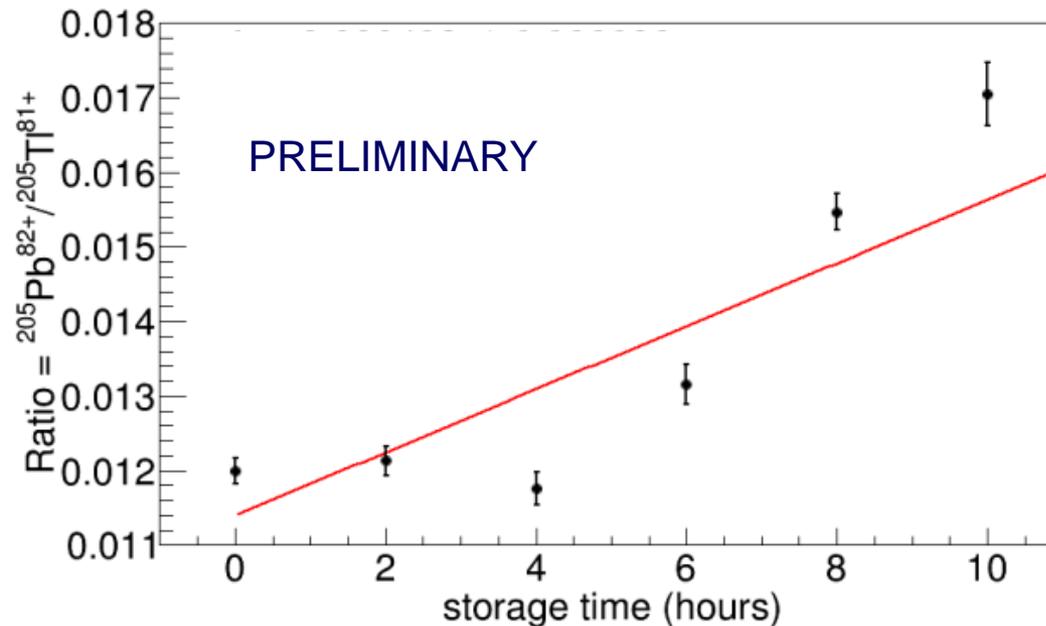


NUSTAR – ILIMA

E121: Bound-state beta decay of $^{205}\text{Tl}^{81+}$ ions

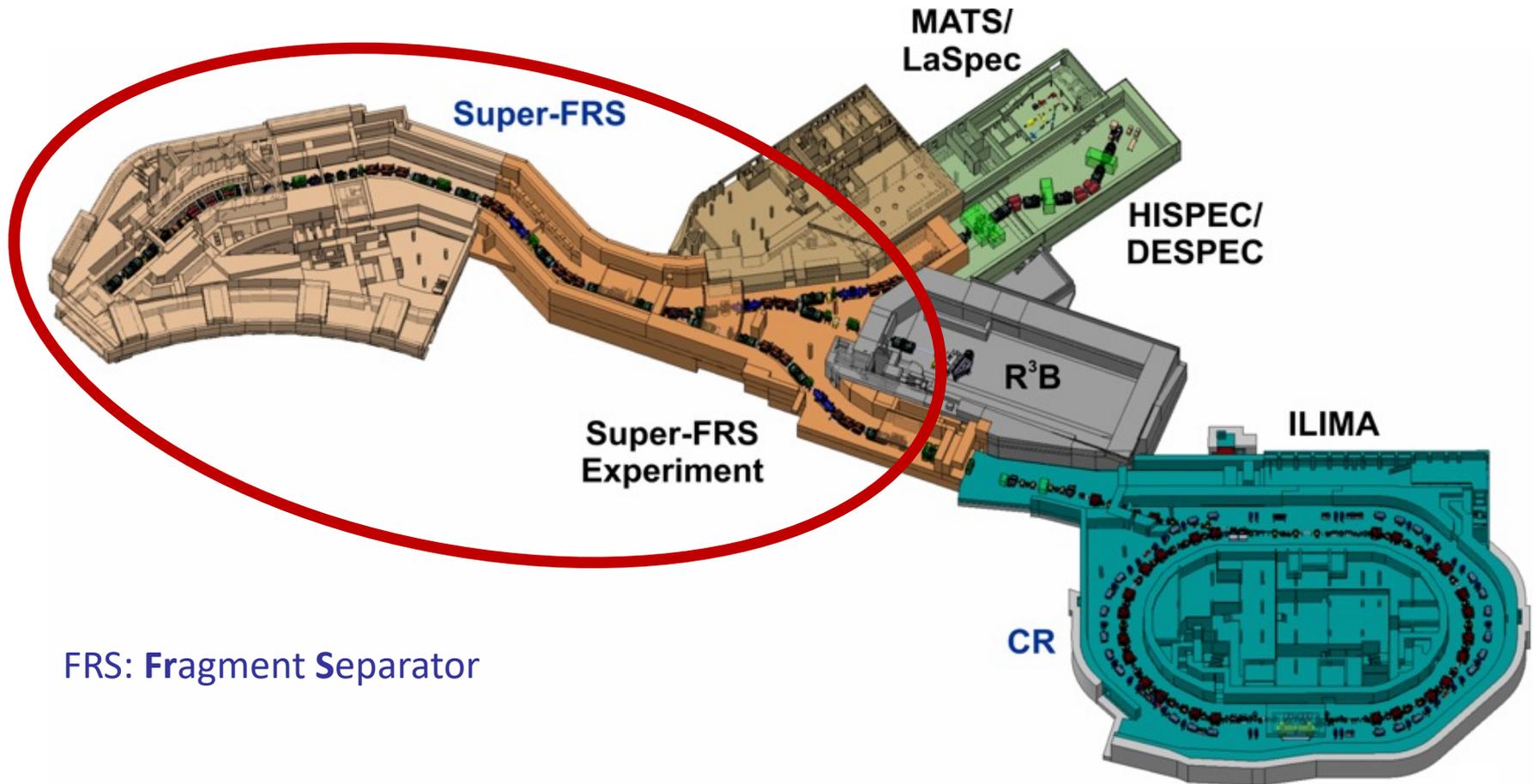
The half-life of secondary ions of about 100 d is addressed

- Successful production and separation in the FRS
- Successful cooling and accumulation in the ESR
- Breeding times of up to 10 hours

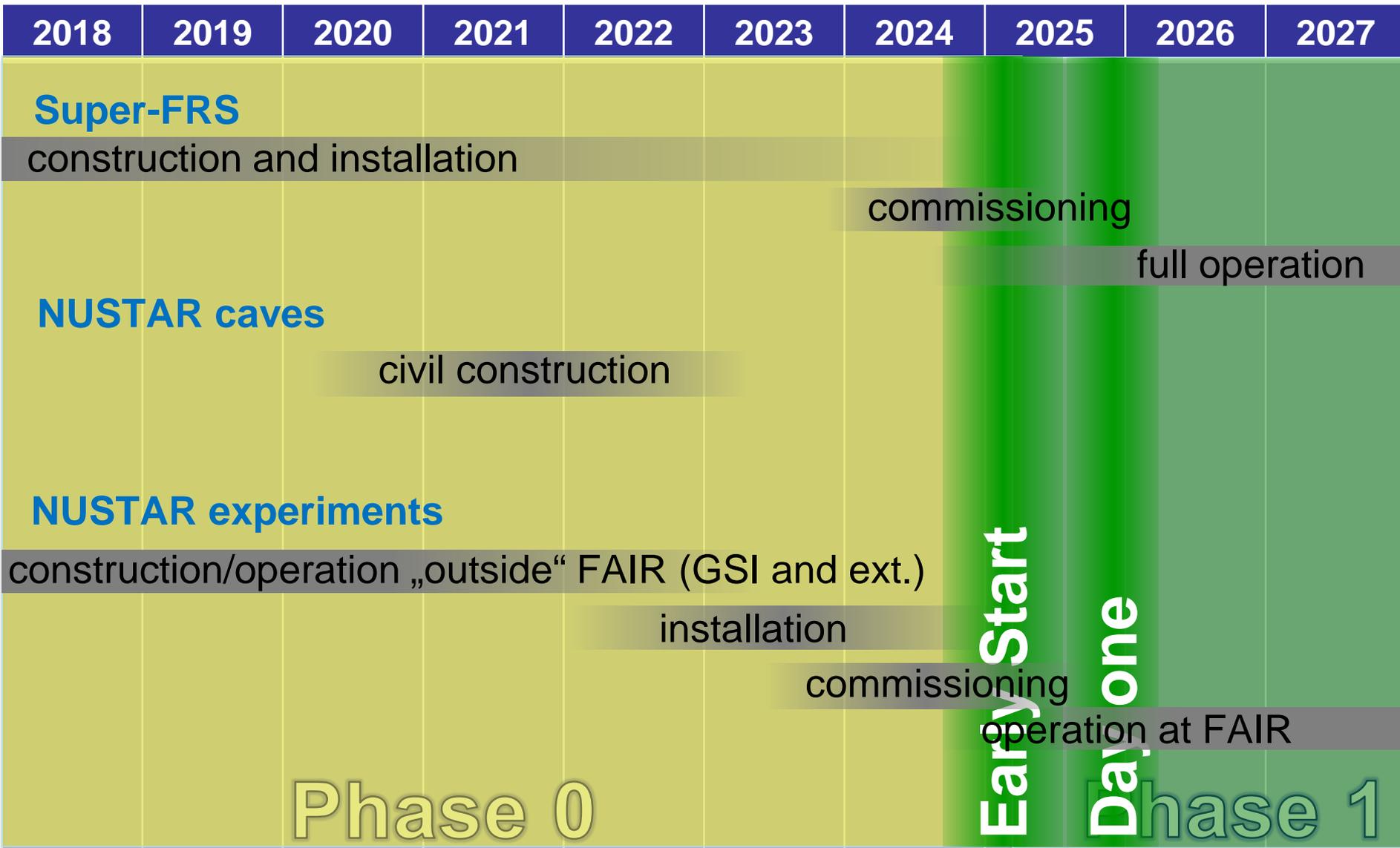


Number of $^{205}\text{Pb}^{82+}$ ions as a function of breeding time

NUSTAR – Super-FRS



NUSTAR – Super-FRS



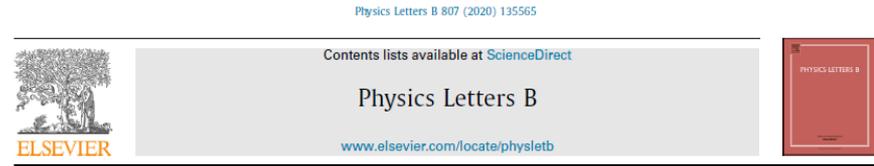
NUSTAR – Super-FRS

High-resolution spectrometer experiments at the border line of nuclear, atomic and hadron physics

FRS Ion Catcher (2020)



Cryogenic Stopping Cell

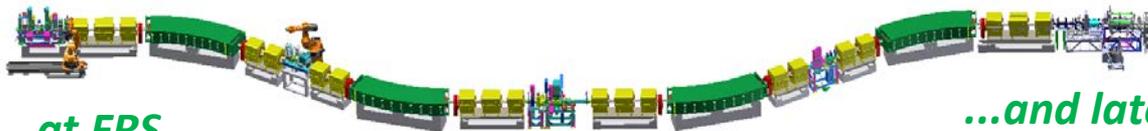


Study of Δ excitations in medium-mass nuclei with peripheral heavy ion charge-exchange reactions



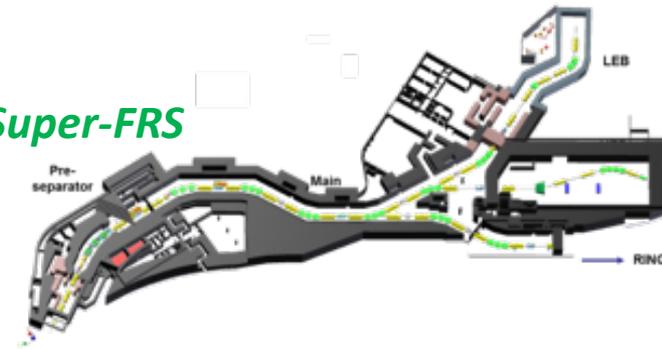
J.L. Rodríguez-Sánchez^{a,b,c,*}, J. Benlliure^{a,b}, I. Vidaña^d, H. Lenske^e, C. Scheidenberger^f, J. Vargas^{a,1}, H. Alvarez-Pol^{a,b}, J. Atkinson^c, T. Aumann^{c,f}, Y. Ayyad^{a,2}, S. Beceiro-Novo^{a,3}, K. Boretzky^c, M. Caamaño^{a,b}, E. Casarejos^g, D. Cortina-Gil^{a,b}, P. Díaz Fernández^a, A. Estrade^{c,h,4}, H. Geissel^c, E. Haettner^c, A. Kelić-Heil^c, Yu.A. Litvinov^c, C. Parodela^{a,5}, D. Pérez-Loureiro^a, S. Pietri^c, A. Prochazka^c, M. Takechi^{c,6}, Y.K. Tanaka^{c,1}, H. Weick^c, J.S. Winfield^c

Prime example for High-level publications in conjunction with theory

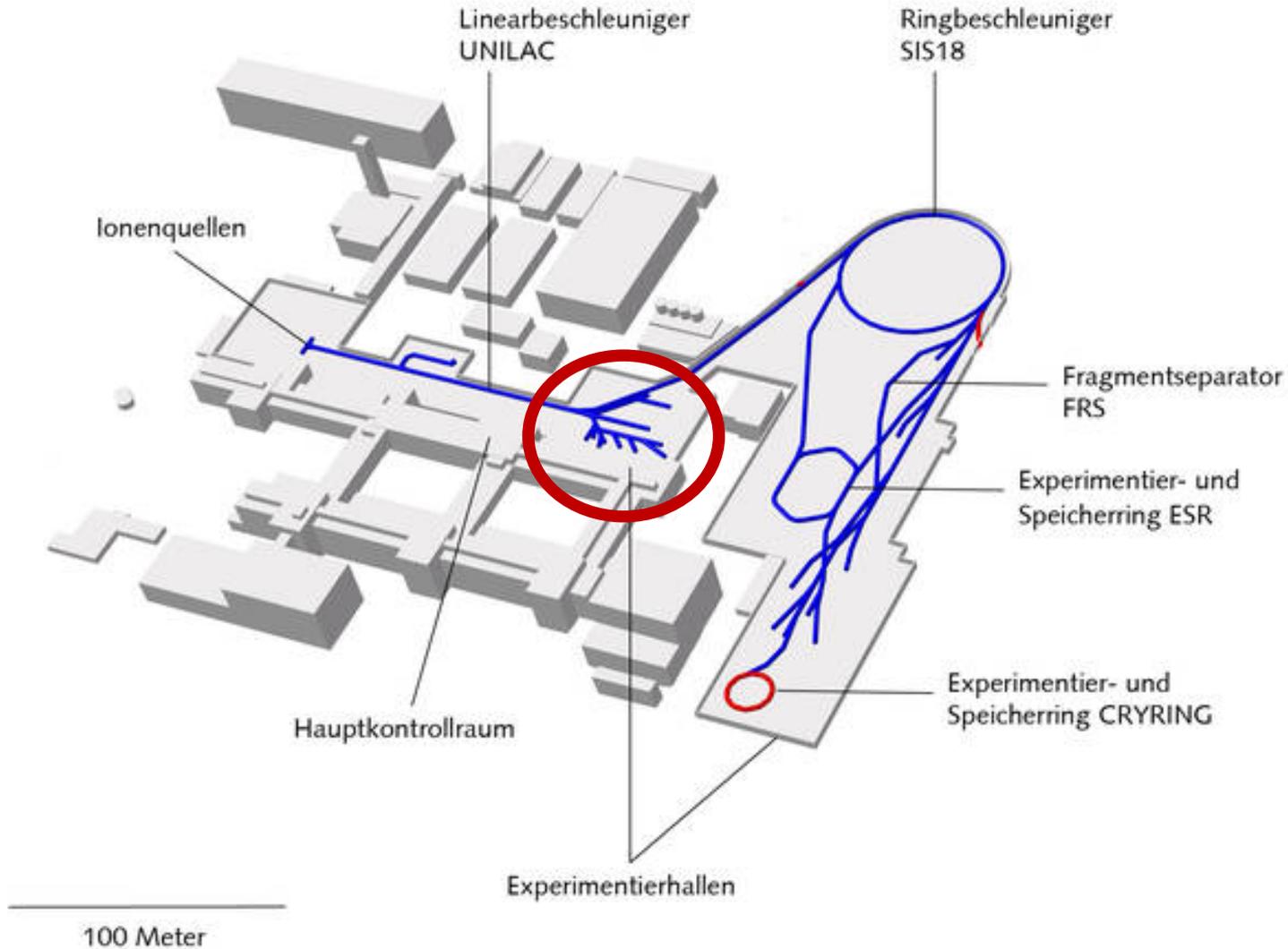


at FRS...

...and later Super-FRS



NUSTAR – SHE



SHE: Super Heavy Elements

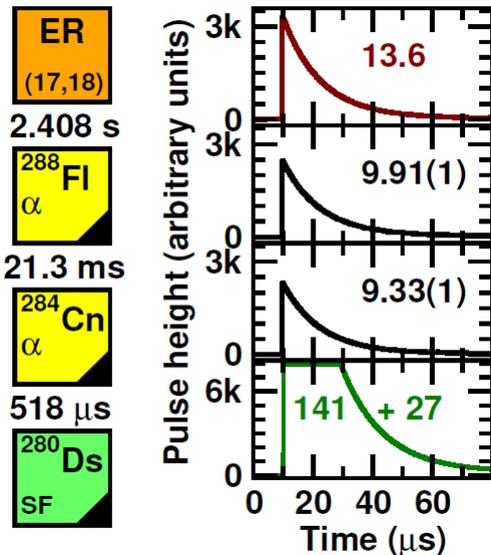
NUSTAR – SHE

Element 114 (flerovium)

U310

First nuclear structure studies of even-Z element near the island of stability

March 2, 2020, 08:55



- 32 candidate decay chains observed at TASCA with upgraded TASIpec detector setup
- new isotope ^{280}Ds observed via ^{284}Cn α branch, providing first Q_α -sequence *across* $Z=114$ [1,3]
- excited 0^+ state in ^{282}Cn : shape coexistence [1,3]
- nuclear structure information via α -decay fine structure along ^{289}Fl chains [2,3]

Experiment U310

D. Rudolph *et al.*
(Lund University)

[1] A. Sămark-Roth *et al.*, PRL, in press.

[2] D.M. Cox *et al.*, PRL, in preparation.

[3] A. Sămark-Roth *et al.*, PRC, in preparation.

NUSTAR – nutshell

- Very broad physics program
- Large variety of methods and approaches
- Very active with forefront physics in FAIR-Phase 0
- On track for phase 1!

