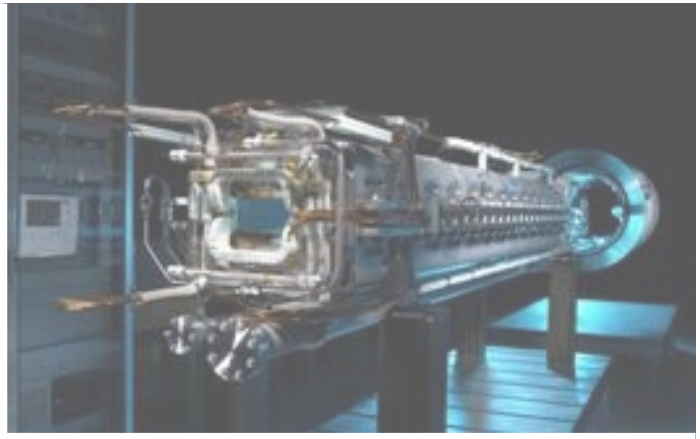




NUSTAR Collaboration Report

Wolfram Korten
IRFU - CEA Paris-Saclay

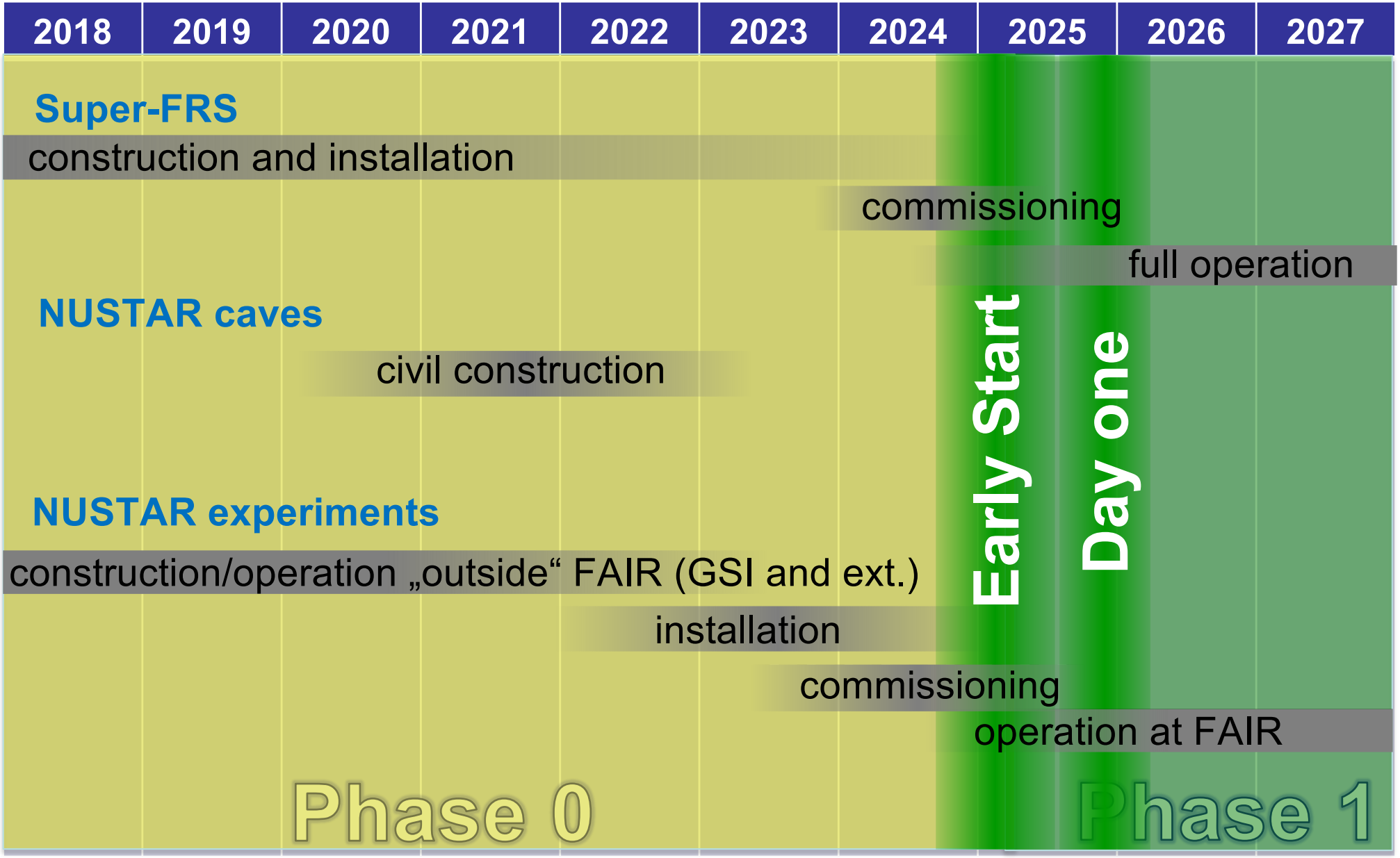
NUSTAR Week 2020

Darmstadt, Germany, September 30th, 2020

Finland France Germany India Poland Romania Russia Slovenia Sweden UK Czech Republic

FAIR

NUSTAR Day-1 and Phase 1

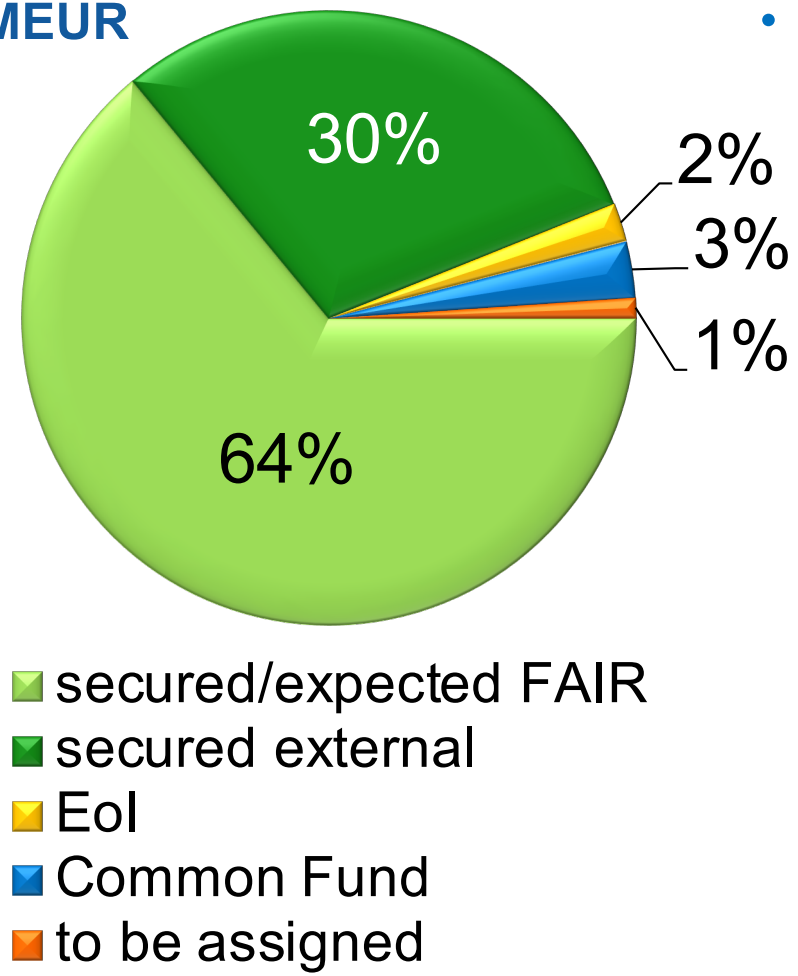


NUSTAR status for FAIR committees

	NUSTAR sub-system	TDR	Cost [k€ 2005]	Funding	Construction	Date completion	Test/ Commissioning
Day 1	LEB infrastr.		1,806			06/2023	
	HISPEC/DESPEC		10,886			03/2024	
	MATS		1,173			08/2024	
	LaSpec		253			05/2021	
	R3B		17,788			03/2023	
	ILIMA		1,099			12/2023	
		92% *value weighted*	33,004	94% *secured*	59% *value weighted*		40% *value weighted*
Change since report 2020-I		+4%	--	--	--		+1%

Funding status (Day one)

33.0 MEUR



- funding (secured and expected) from:
  (**FAIR members/associates** in bold face)

Bulgaria	Netherlands
Canada	**Poland**
Finland	**Romania**
France	**Russia**
Germany	**Slovenia**
Hungary	Spain
India	**Sweden**
Israel	**United Kingdom**

Common Fund

➢ to be defined

Status: November, 2019

Infrastructure items for Common Fund

- Several components required for the Day-one configurations have been identified by the NUSTAR Collaboration as common infrastructure items.
- These items cannot be taken over by partner institutes.
- Update is **in progress, should be finalized for the next RRB**

PSP	Name	cost (2005) [k€]
1.2.1.2.4	Detectors and slit system in front CSC	135.7
1.2.1.2.5	Beam line to MATS-LaSpec hall	154.0
1.2.1.7	Beam line to MATS RFQ	200.0
1.2.2.3.5	HISPEC/DESPEC Mechanics	10.4
1.2.2.5.1	Safety measures	96.4
1.2.5.1.1.3.3	Valve box GLAD	128.1
1.2.5.1.1.3.4	Infrastructure magnets	200.0
NUSTAR Common Fund		**924.6**

NUSTAR Phase-0 experiments (as reported to JSC in May 2020)

Beamtime in 2020 strongly influenced by Covid-19 epidemy

- Safe working conditions possible (limited number of persons onsite etc.) ?
- Experimental set-up complete and team sufficient (locally and remote) ?
- Beamtime schedule relaxed (increased set-up time, extensions possible)

→ Spokespersons and local teams had to decide whether the experiment could be performed

- **~50/70%** of the NUSTAR experiments at **SIS18/UNILAC** could be performed
- **Remote** near-line **analysis** pursued and **controlling** of certain set-ups
- Extended commissioning of **all NUSTAR equipment** incl. **FRS/ESR**
- Additional beam time may still be needed (→ G-PAC requests)
- Expected "backlog" for 2021+: **52 days** at **SIS18**, **23 days** at **UNILAC**

→ Severe constraints for new NUSTAR proposals

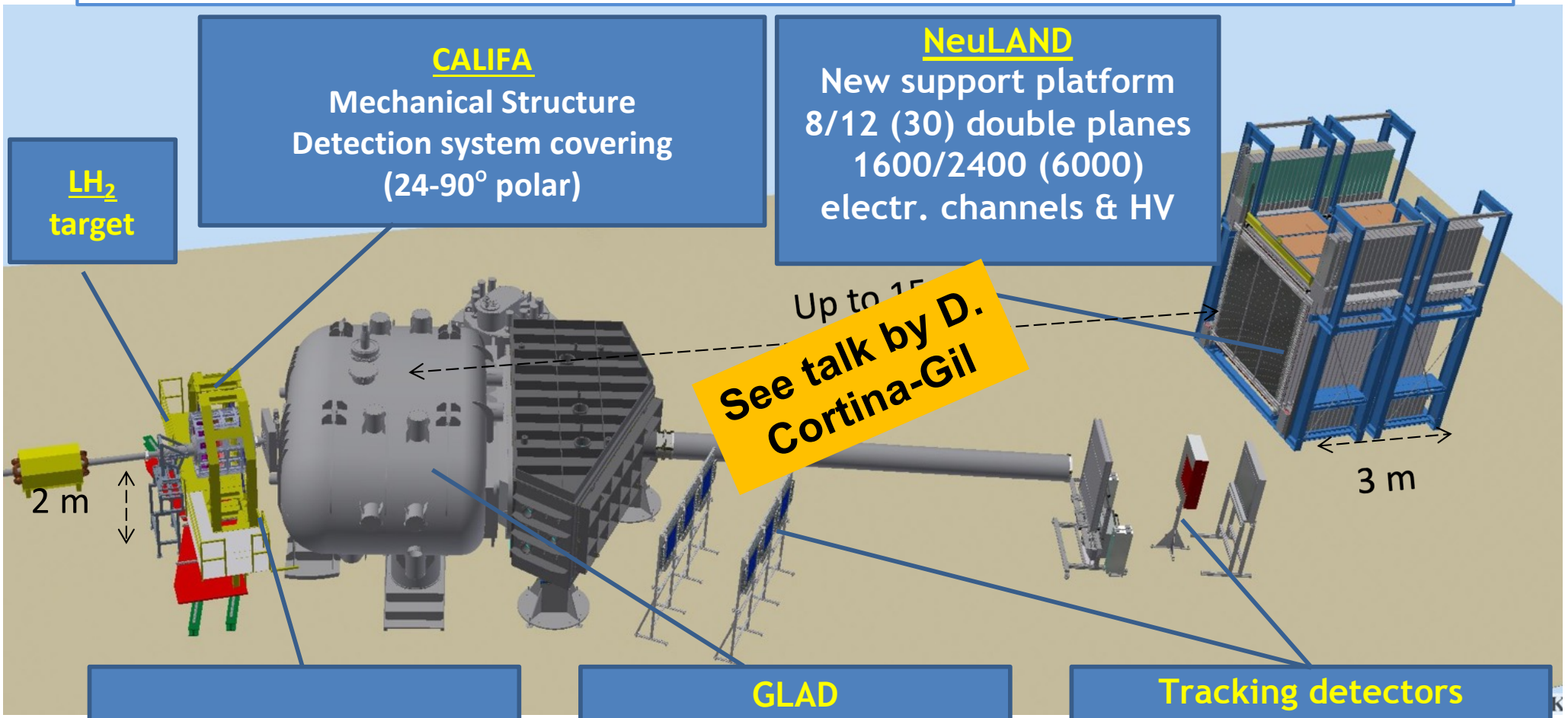
NUSTAR-FRS experiments 2020

Experiment	Title	Beam	Begin	End	RoI	Destination
S467 (Paschalis) NUSTAR-R3B	Single-particle structure of neutron-rich Ca isotopes: shell evolution along Z=20	650 MeV/u ^{86}Kr	21.2.	25.2.	Ca isotopes	Cave C
S474 (Plass) NUSTAR-SEC	Detector tests with the prototype of the CSC for the Super-FRS and direct mass measurements of neutron-deficient nuclides below 100Sn	600…1155 MeV/u ^{124}Xe	27.2.	4.3.	^{89}Ru…^{98}Cd	HFS
S459+ (Chudoba, Mukha, Mardor) NUSTAR-SEC	Proton radioactivity studies with EXPERT, and online-test of a novel method for measuring β-delayed neutron emission probabilities	972 MeV/u ^{124}Xe	4.3.	9.3.	^{70}Br	HFS
S480 (Regan) NUSTAR-DESPEC	Structure of the heaviest N=Z nuclei: seniority transitions and EM transition rates in ^{94}Pd	980 MeV/u ^{124}Xe	9.3.	16.3.	^{94}Pd	HFS
E127 (Reifarth) NUSTAR, APPA	Measurements of proton-induced reaction rates on radioactive isotopes for the astrophysical p process	561 MeV/u ^{124}Xe	18.3.	23.3.	^{118}Te	ESR
E121 (Litvinov) NUSTAR-ILIMA, APPA-SPARC	Measurement of the bound-state beta decay of bare 205Tl ions	590 MeV/u ^{206}Pb	25.3.	6.4.	^{205}Tl	ESR
S468 (Pietri) NUSTAR-SEC	Search for new neutron-rich isotopes and exploratory studies in the element range from terbium to rhenium	1050 MeV/u ^{208}Pb	8.4.	21.4.	^{193}W, ^{190}Lu	HFS
S482 (Hornung) NUSTAR-SEC	Mean range bunching for experiments with stopped beams	1050 MeV/u ^{208}Pb	21.4.	24.4.	^{140}Tb, ^{126}Pm	HFS
S452 (Witt) NUSTAR-DESPEC	The Oblate-Prolate Shape Transition around A~190	1050 MeV/u ^{208}Pb	25.4.	27.4.	^{193}W	HFS
S469 (Purushothaman) NUSTAR-SEC	Accurate slowing-down measurements of heavy ions in gases and solids in the kinetic energy range of (30 to 300) MeV/u with the high-resolution magnetic spectrometer FRS	35…280 MeV/u ^{208}Pb	29.4.	2.5.	^{208}Pb	HFS

43 days of PAC-approved beamtime for NUSTAR-FRS experiments in 2020 (resulting in ~55 days of FRS running)

R3B in FAIR phase-0

Complete kinematics, fixed target experiment to study **R**eactions with **R**elativistic **R**adioactive **B**eams with high acceptance, resolution and efficiency



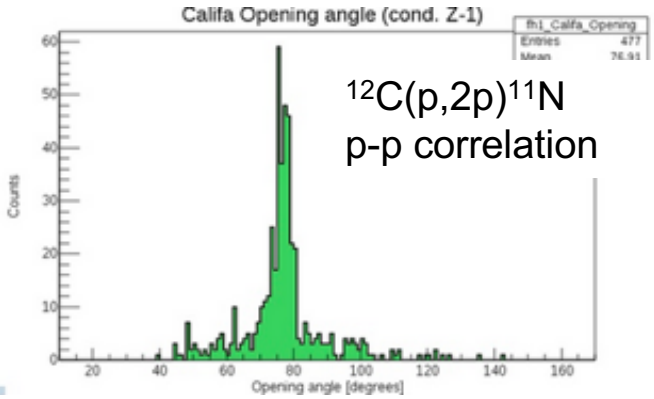
Commissioning for Phase-0 experiments

- **S444 R3B Detector Commissioning**
  - AMS & LH2 target test:
    - original vacuum chamber failed;
    - new chamber available in April
    - LH2 target test postponed due to COVID-19
  - CALIFA Barrel + Full frame installed
  - New R3B gas tracking detectors

New chamber @GSI
10 AMS operational

^{12}C @ 500 A. MeV

Successful commissioning of R3BMUSIC, SOF MW´s, TwinMusic and ToF (PID) and CALIFA



Experiments in 2020 (pre COVID-19)

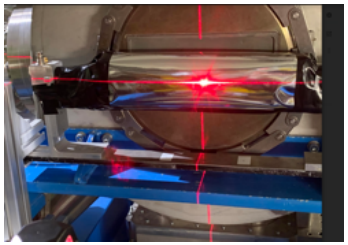
- **S467 Single-particle structure of n-rich Ca: shell evolution along Z=20**

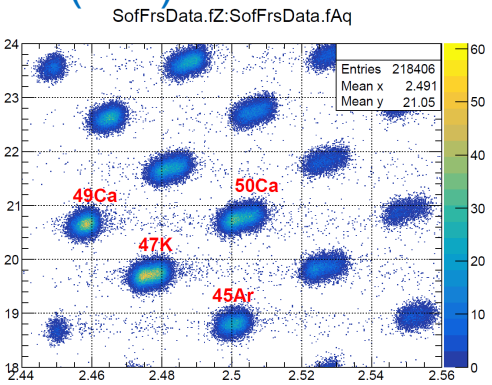
- **Goal**: probe the quenching of spectroscopic factors as a function of isospin asymmetry, and establish the evolution of the shell structure at Z=20 and around N=28,30 and towards N=32

^{86}Kr @ 580 A. MeV

Excellent performance of gas-tracking detectors (PID)

MAR´20

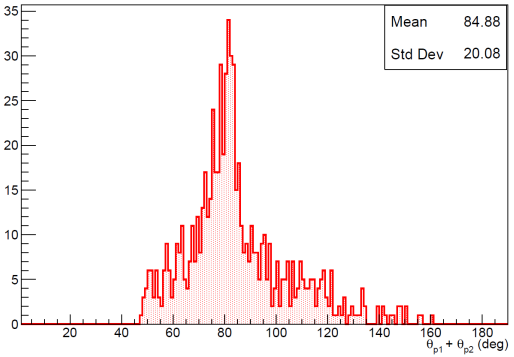


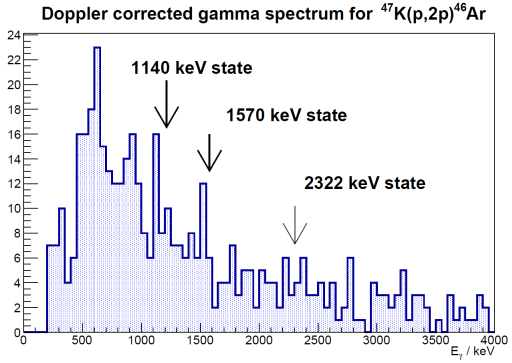


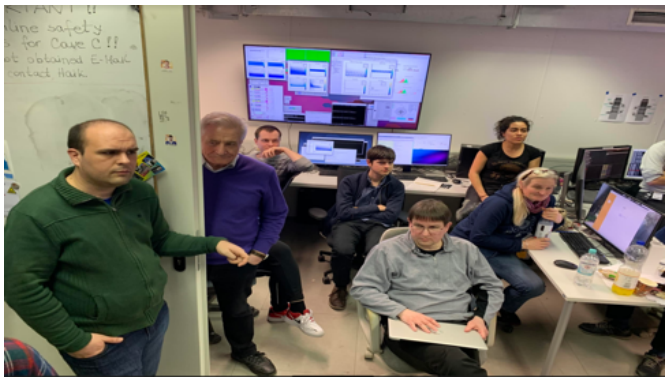
Preliminary (online) results

Excellent CALIFA performance in a huge dynamic range

^{47}K(p,2p)^{46}Ar p-p correlation



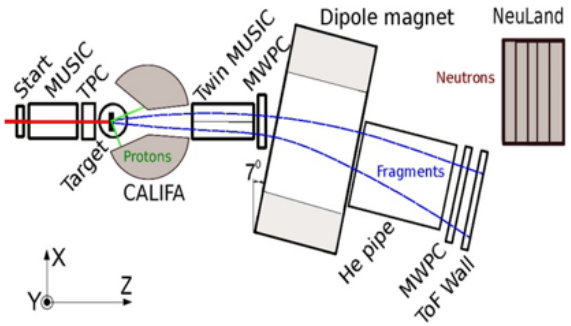




Further planned experiments in 2020

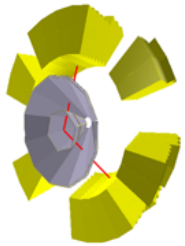
- **S455 Fission studies (originally scheduled April-May)**
- **Postponed due to COVID´19, ready to run some weeks after end of lockdown**

Goal: investigate the potential-energy surface and the dynamics of fission over a broad range in fissility and excitation energy, taking advantage of relativistic radioactive beams and the advanced SOFIA@R3B setup, using (p,2pf) and Coulomb excitation to investigate fission of unstable nuclei in inverse kinematics.



Coulex(active U target)

(p,2pf) (LH_2 target)



Study of the impact of δ–electrons on PID in the target tracker

^{208}Pb @ 500 and 250 A. MeV

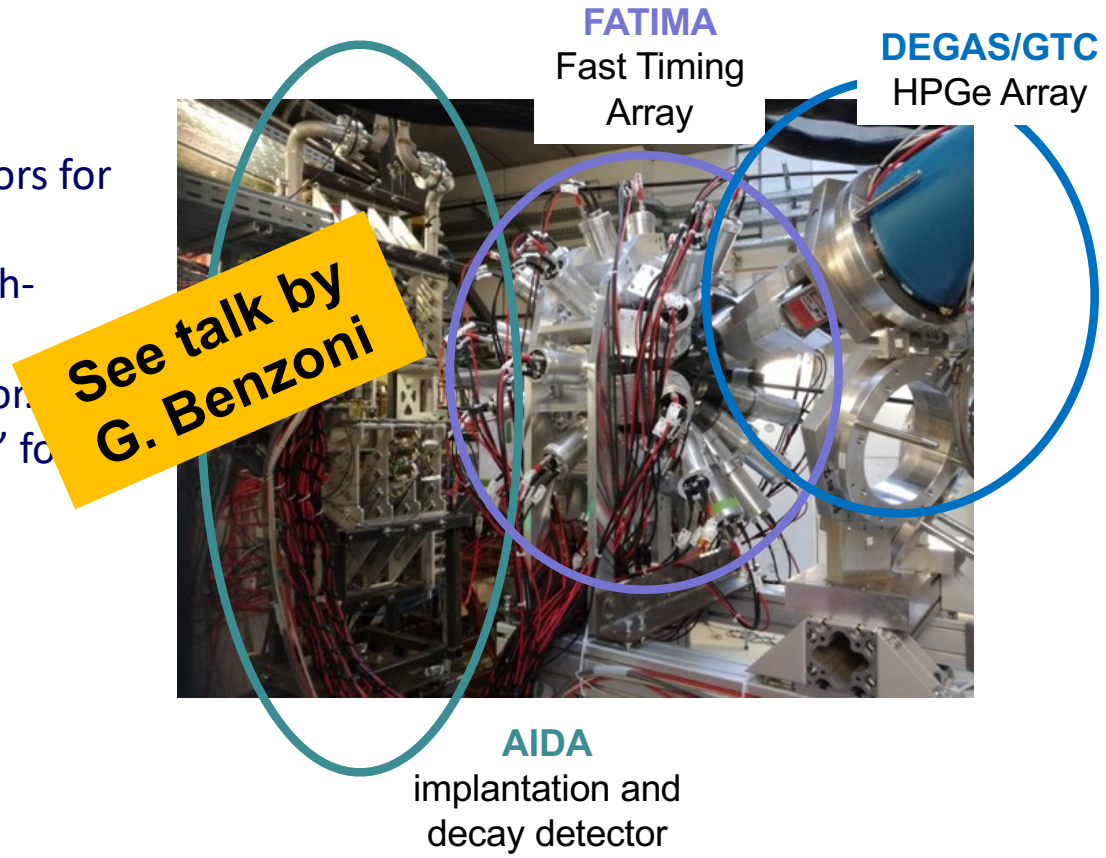
HISPEC-DESPEC Setup for 2020

Spectroscopy & lifetimes of neutron-rich nuclei close to N=126

Ready for experiments (S452, S460 & S468): *AIDA & DEGAS/GTC & FATIMA*

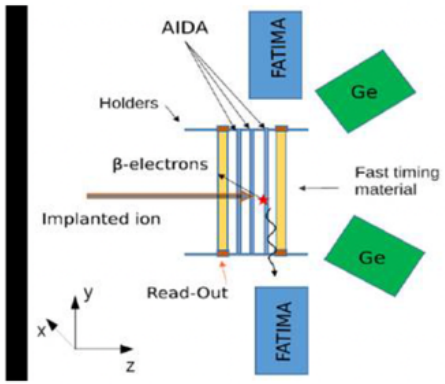
DESPEC PHASE-0 INSTALLED AND UNDERGOING COMMISSIONING (in-house and outside GSI)

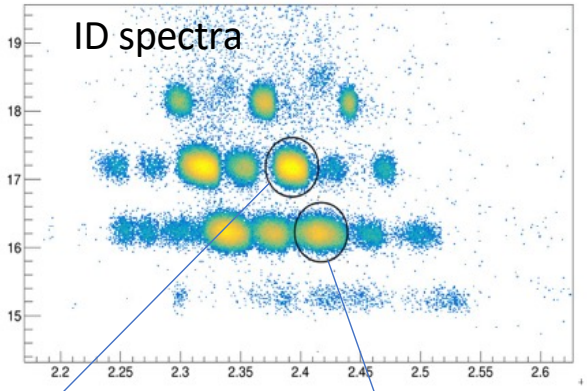
- DESPEC 2020: up to 36 FATIMA LaBr3 detectors for fast-timing / isomer gamma spectroscopy.
- Gallileo triple Ge clusters in front ring for high-resolution tagging.
- AIDA active stopper; pixelated silicon detector.
- Front and back of AIDA fast-plastic 'windows' fo coincident fast-timing beta-signal.



Engineering run Nov/Dec 2019

Implant↔decay ↔ γ-ray
Correlations tested and working

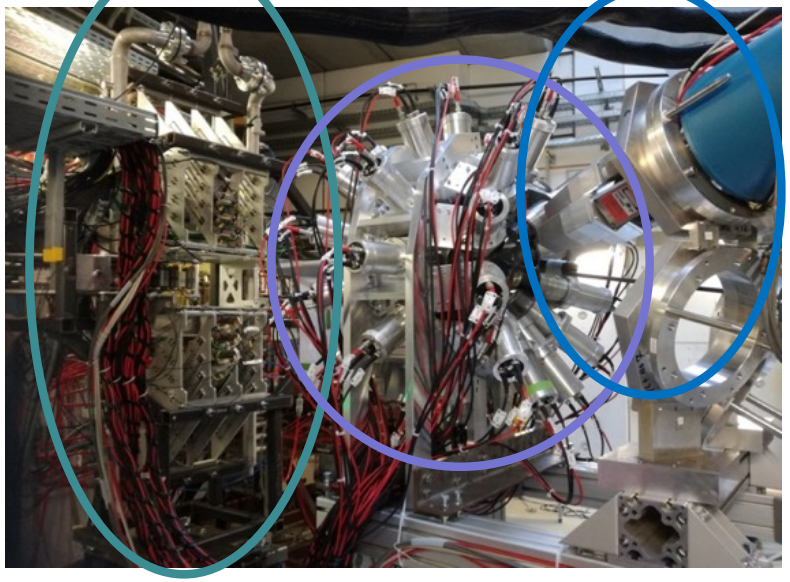




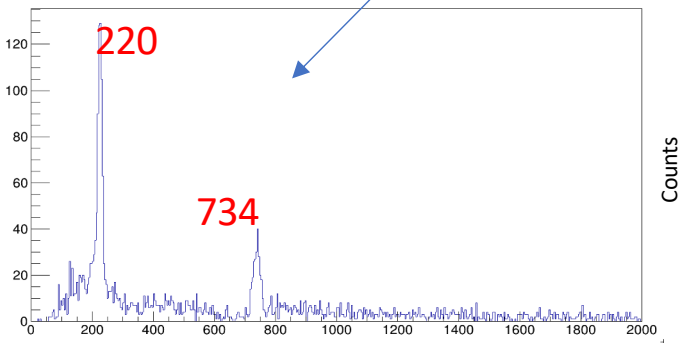
AIDA
implantation and decay detector

FATIMA
Fast Timing $LaBr_3$ Array

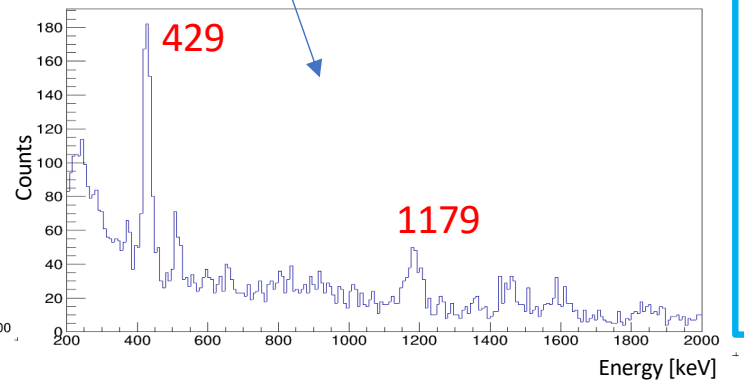
DEGAS/GTC
HPGe Array



FATIMA isomer spectrum in ^{32}Al

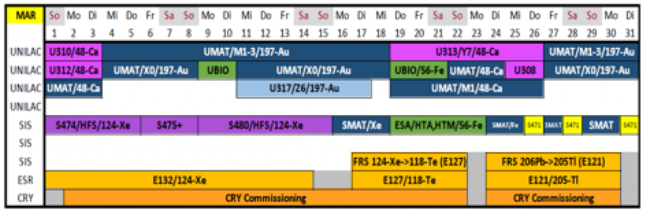


Fatima spectrum of ^{34}Al beta decay



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

DeSpec experiments in 2020



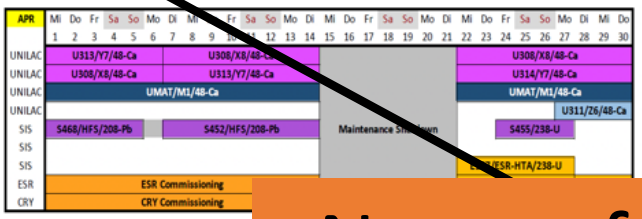
S480 ^{124}Xe beam 9 – 15 March 2020:

Structure of the heaviest N=Z nuclei: Seniority Transitions in 94Pd

Regan, Gorska, Cederwall

Isomer search + p-radioactivity

Ion-γ and Ion-β/p-γ



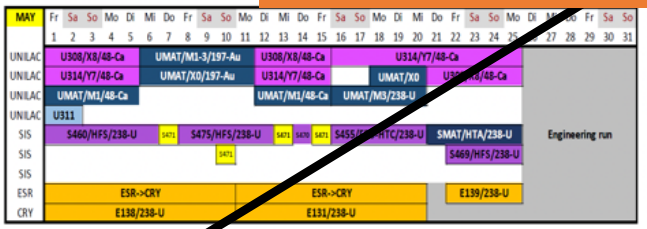
S452 ^{208}Pb beam 7 – 14 April2020

Prolate-Oblate Shape Transition around A~190

Isomer search+ Fast-timing following β decay

Ion-γ and Ion-β-γ–γ

Not performed owing to COVID-19 pandemie



S460 ^{238}U beam 1 - 6 May 2020

Investigation of 220<A<230 Po-Fr nuclei lying in the south-east frontier of the A~225 island of octupole deformation

Morales, Benzoni, Valiente-Dobòn

Isomer search+ Fast-timing following β decay

Ion-γ and Ion-β-γ–γ

First “real” DeSpec experiment

S480 ^{124}Xe beam 9 – 15 March 2020:

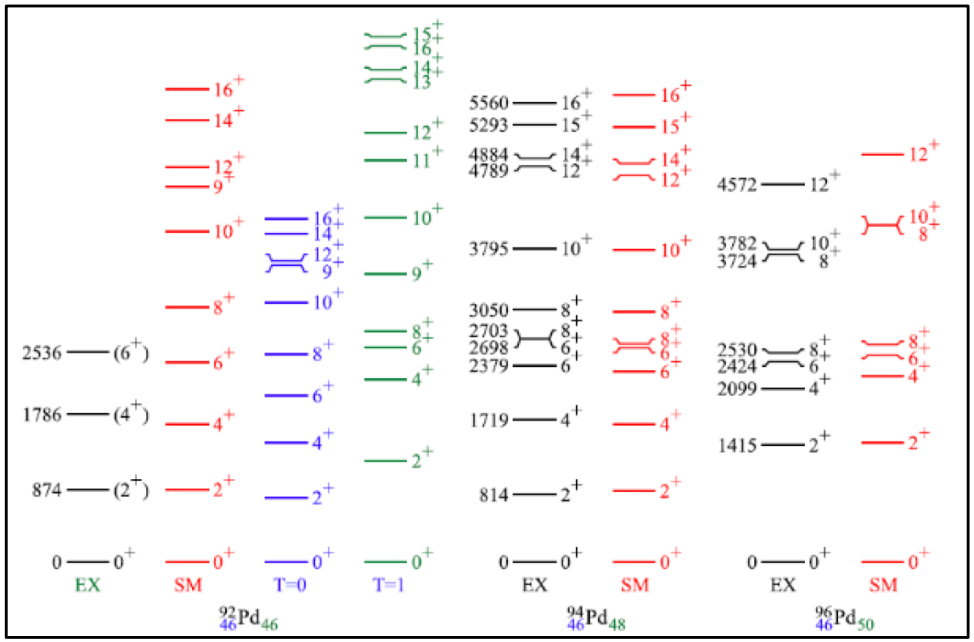
Structure of the heaviest N=Z nuclei:

Seniority Transitions in ^{94}Pd

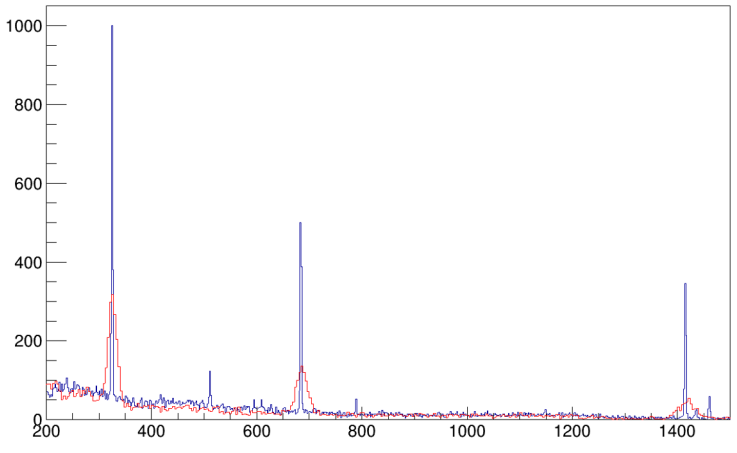
Spokespersons: Regan, Gorska, Cederwall

→ New lifetimes in the ps-to-ns regime

Level schemes of ^{92,94,96}Pd



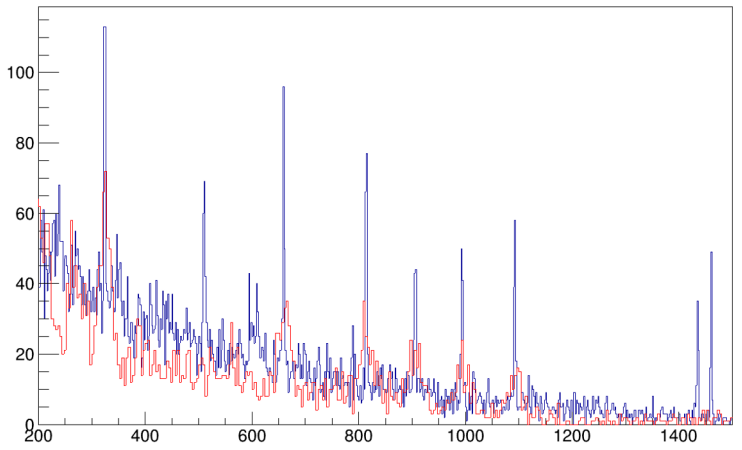
Reference nucleus ^{96}Pd



PRELIMINARY! from 16h of data

Galileo and FATIMA isomer spectra

^{94}Pd

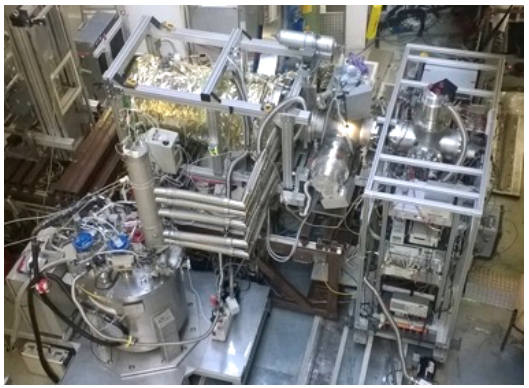


Super-FRS Experiment Collaboration

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

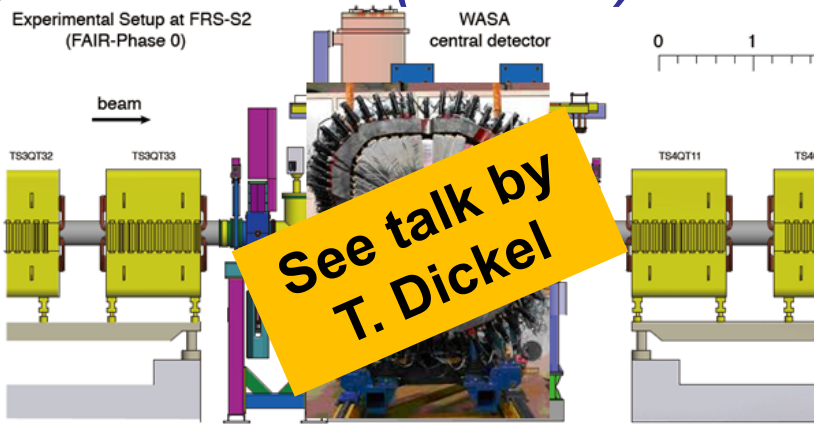
(Super-)FRS as multiple-stage magnetic system (separator, analyser, spectrometer, energy buncher) combined with ancillary detectors, e.g. with:

FRS Ion Catcher (2020)

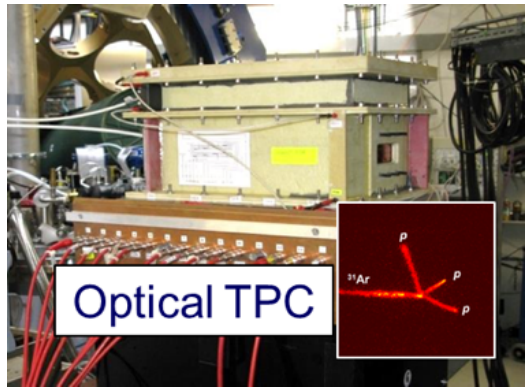


→ ***Cryogenic Stopping Cell***

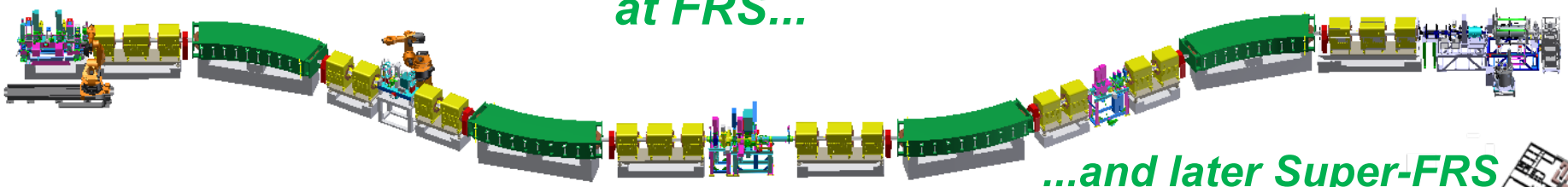
WASA (2021/22)



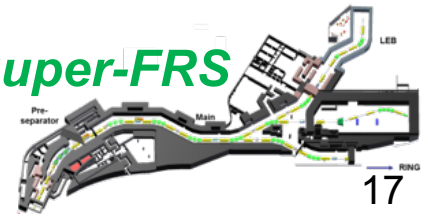
EXPERT (2022)



at FRS...



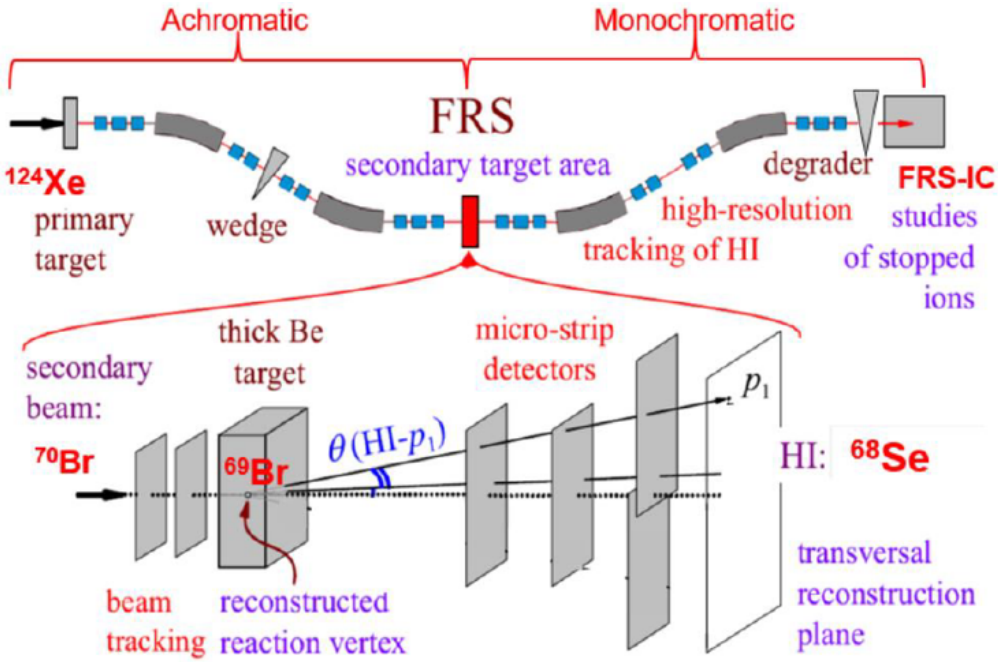
...and later Super-FRS



Super-FRS Experiment Collaboration

Joint experiment S459+ (EXPERT@S2 & FRS Ion Catcher@S4)

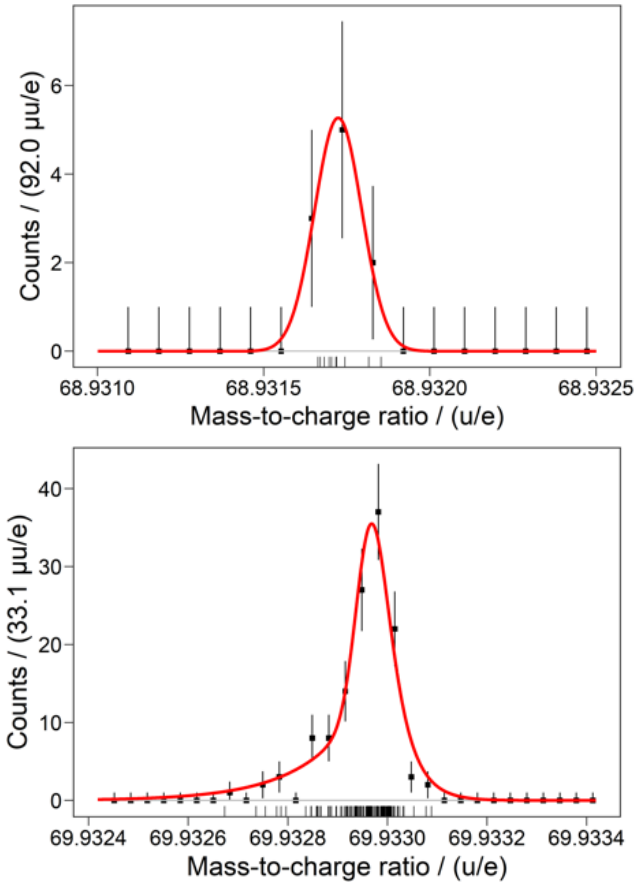
- Experiment **S472** of the FRS Ion Catcher Group ran in March 2020 **jointly** with **S459** and **S443** of the EXPERT group (coined **S459+**)
- The two groups used **simultaneously the same primary beam** (^{124}Xe) to measure properties of exotic isotopes at and beyond the proton dripline
- The **FRS Ion Catcher** setup is at the final focus plane of the FRS (**S4**) whereas the **EXPERT** detectors are at its mid-focus (**S2**)



Joint experiment S459+

Preliminary physics results from FRS ion catcher and MR-TOF-MS

- First **direct** mass measurement of ^{69}**As**, with better accuracy than the literature value.
- Mass measurement of ^{70}**Se** with an expected uncertainty of **~2-3 keV**, probably the **best** achieved with a **MR-TOF-MS** in this mass range.
- Additional A=71 mass peaks are under analysis

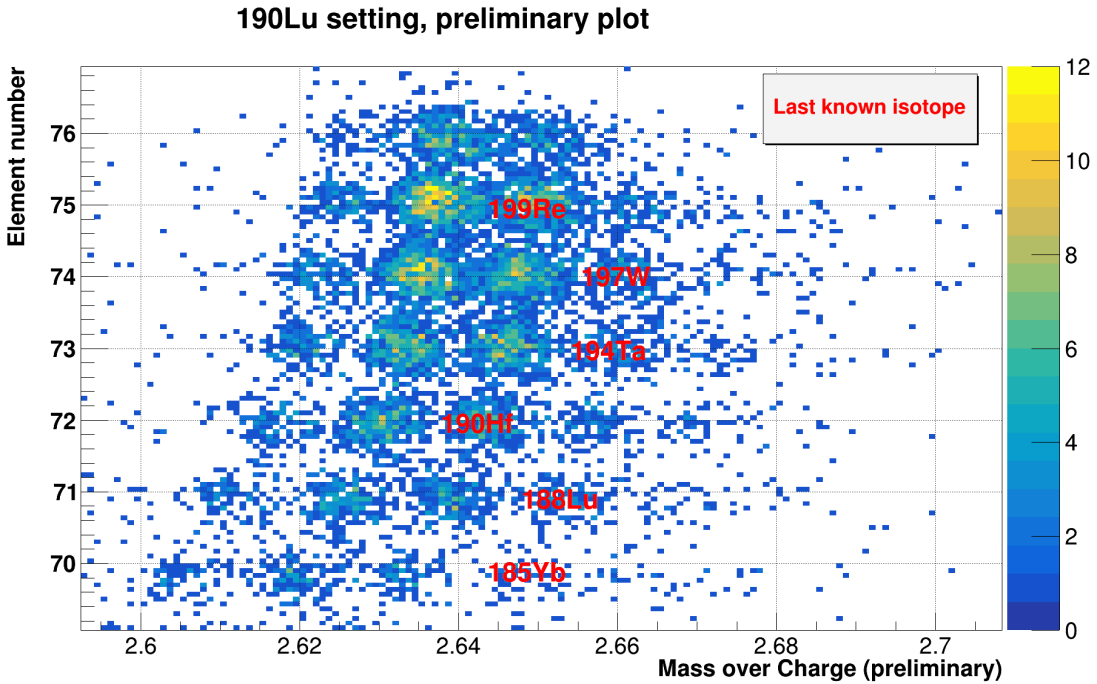


Partial statistics of the 190Lu setting

➔ in red the last known isotope of this element

To claim discovery 3 counts are needed

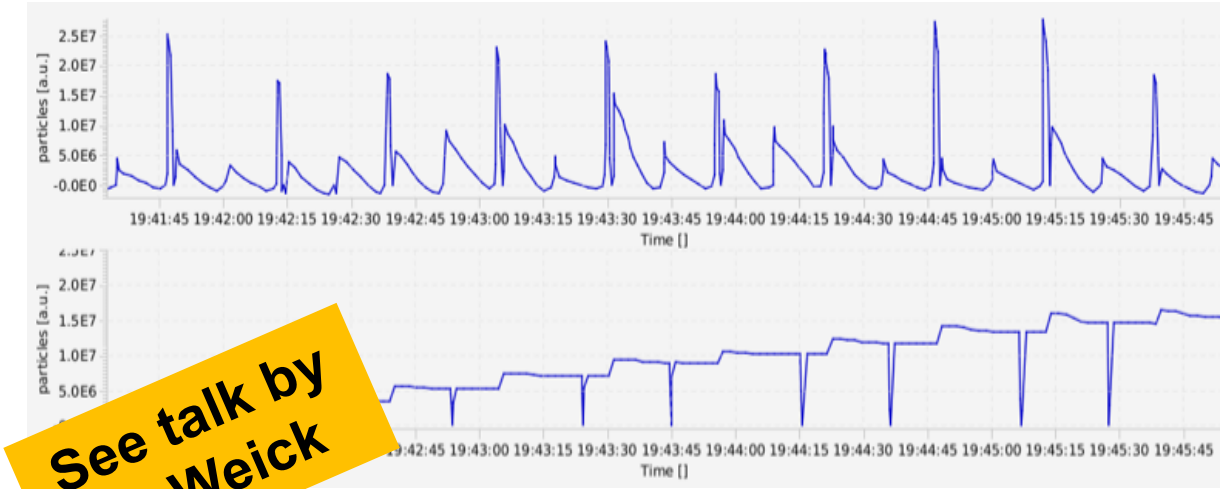
Work ongoing on estimating background



ESR experiments in 2020

APPA and NUSTAR experiments

- Experiments at the ESR
- E135: $^{84}Kr^{32+}$ (laser)
- E132: ^{124}Xe (deceleration, Xe gas-jet, e- spectrometer)
- E127: ^{124}Xe, ^{118}Te (FRS, stochastic cooling, deceleration, H_2 gas-jet, DSSSD detector setup)
- E121: ^{205}Tl (FRS, stochastic cooling, accumlation, Ar gas-jet, CsISiPHOS detector, long storage times)



See talk by H. Weick

- ✓ **All major manipulation capabilities and instrumentations of the ESR were taken into operation during setting up of the experiments.**
- ✓ **Stable operation during experiments.**

ILIMA Phase-0 program in 2020

ILIMA Phase-0 program: ^{205}Tl bound-state beta decay

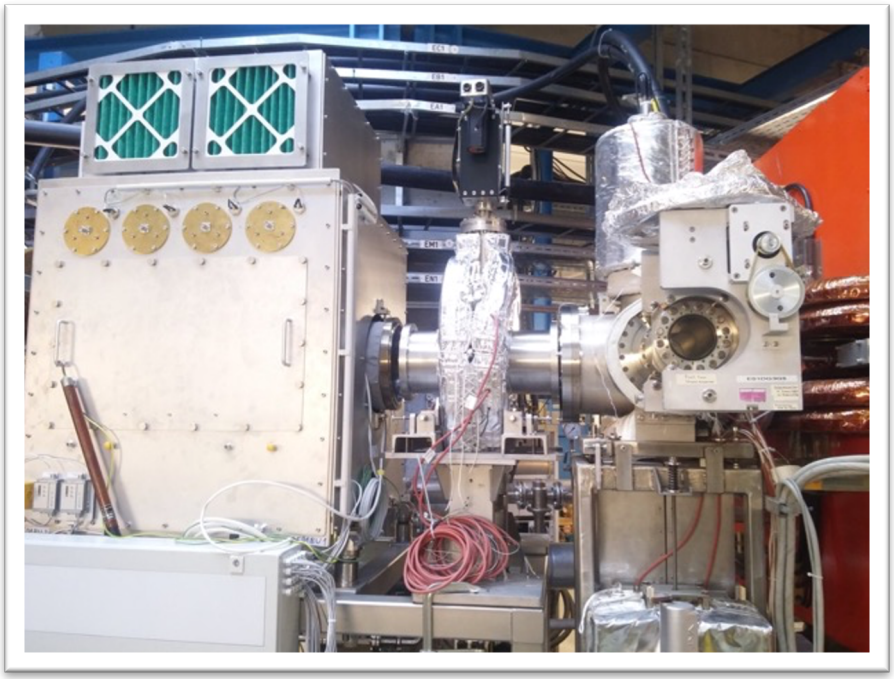
- New prototype Schottky detector installed in ESR
  - Variable resonance frequency: 408-416 MHz
  - Variable Q value: approx. 500-3000
  - High sensitivity

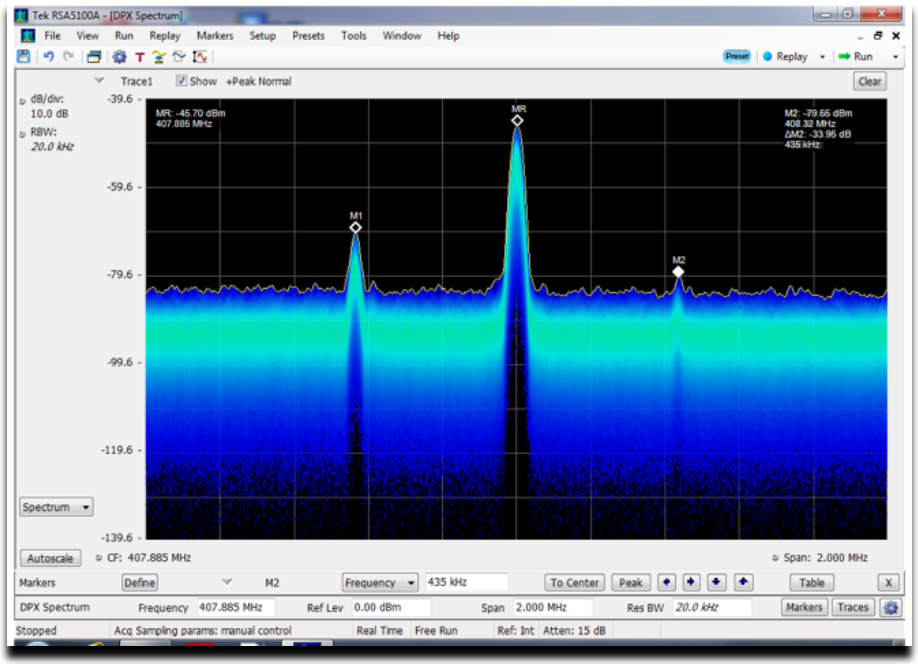
Engineering run in 2019

250 MeV/u $^{40}Ar^{18+}$ beam with 185uA

Resonance at 407.855 MHz

Betatron sidebands visible (machine tune)



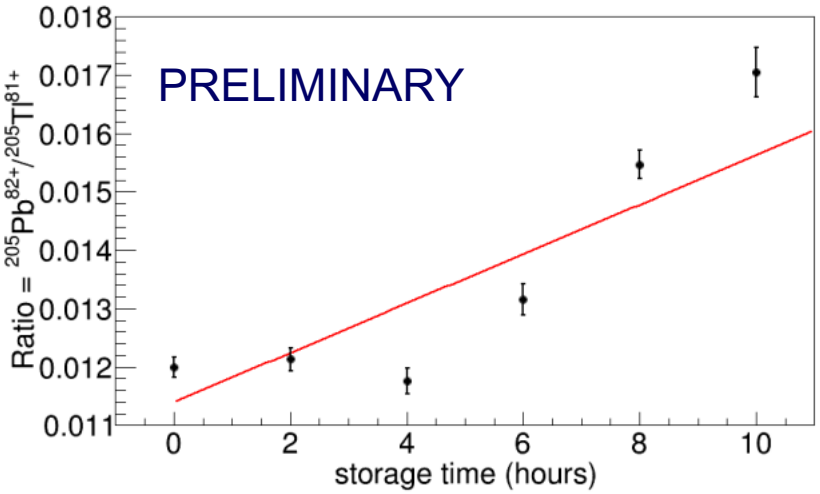


S. Sanjari

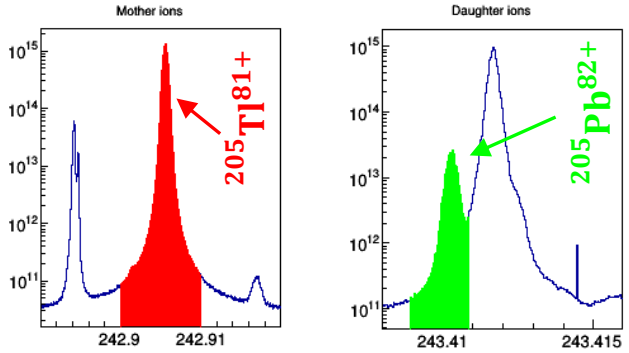
E121: Bound-state beta decay of $^{205}Tl^{81+}$ ions

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

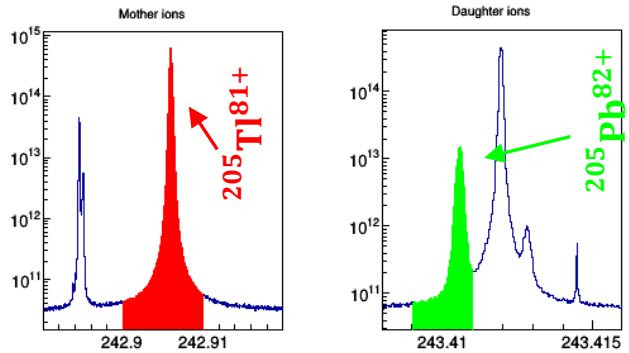
- Successful production and separation in the FRS
- Successful cooling and accumulation in the ESR
- Breeding times of up to 10 hours



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



Waiting time 0 hours

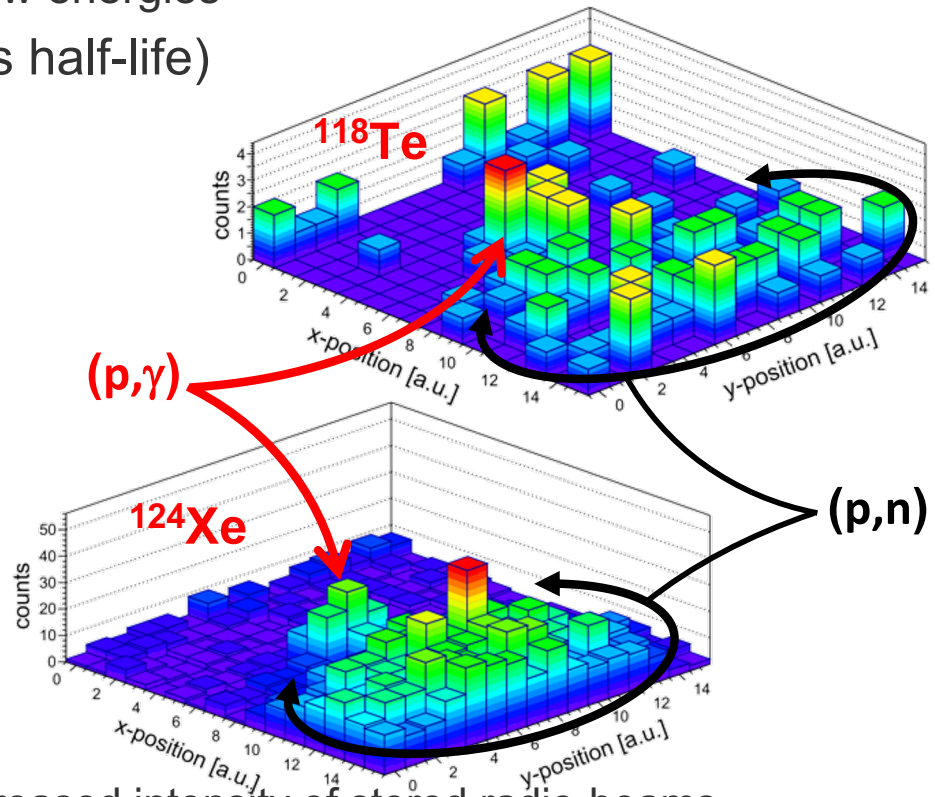


Waiting time 10 hours

E127: Proton-capture rates for nuclear astrophysics

The first reaction study on a stored radio-beam at low energies

- successful study of radioactive ^{118}Te (6 days half-life)
  - production, storage, cooling and deceleration of ^{118}Te in the FRS-ESR complex
  - about 10^5 $^{118}Te^{52+}$ ions available at 10 MeV/u
  - very low statistics for (p,γ), but clear signature

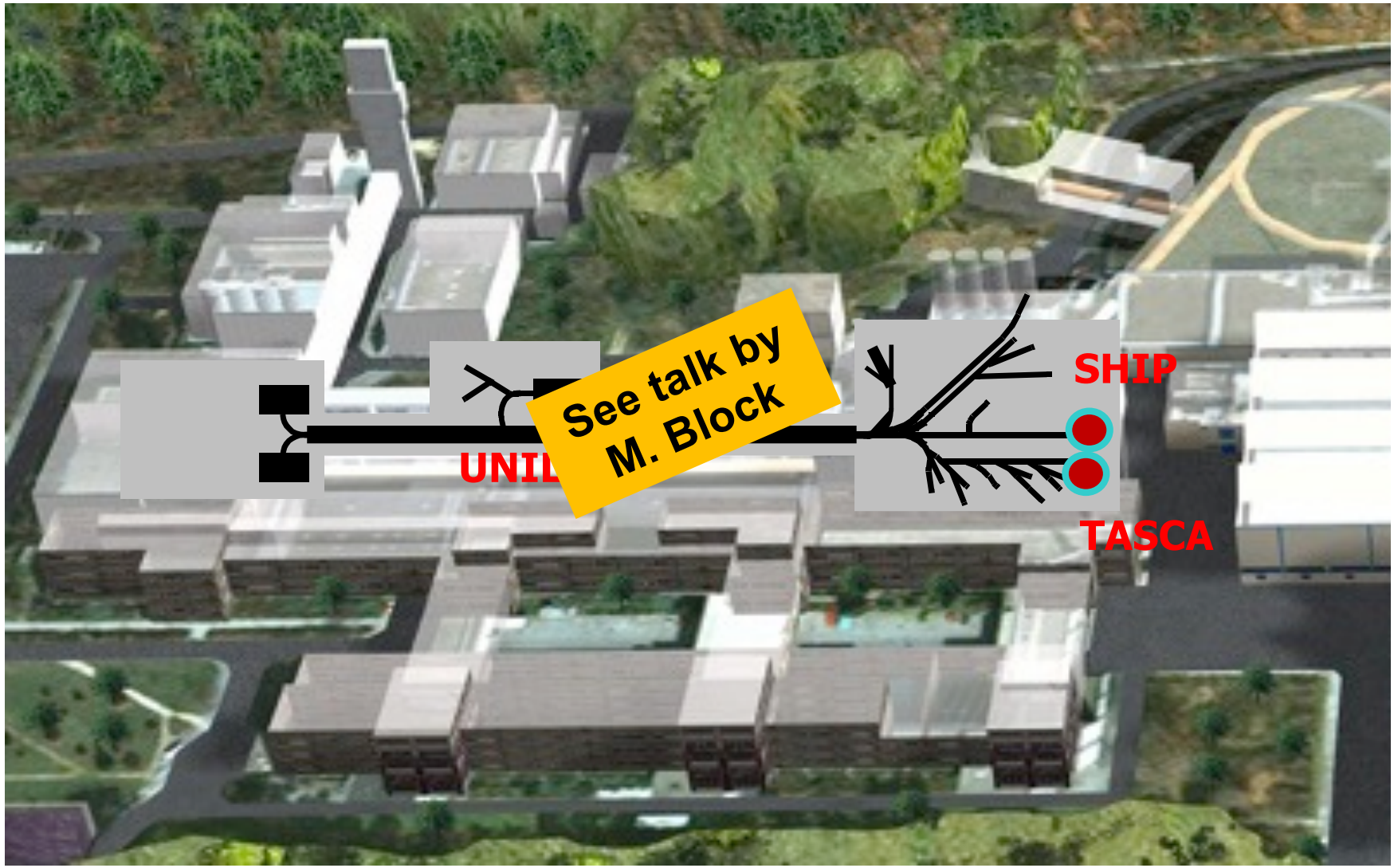


- new background-free detection method demonstrated with ^{124}Xe primary beam
  - maximized sensitivity for detection of various nuclear reaction channels

- future improvements:
  - accumulation of beam in ESR (stacking) ► increased intensity of stored radio-beams
  - proton-capture experiments in CRYRING ► access to lowest beam energies (Gamow window)

Superheavy element research at GSI/FAIR

SHE experiments use GSI Facility – research is integral part of NUSTAR



NUSTAR UNILAC beam time in 2020

U308	50-Ti	Yakushev	2020-02-13	2020-02-20	NUSTAR-SHE-C	First chemical study of element 113 behind TASCA	7
U310	48-Ca	Rodolph	2020-02-20	2020-03-04	NUSTAR-SHE-C	Spectroscopy of Flerovium	13
U308	48-Ca	Yakushev	2020-03-25	2020-03-27	NUSTAR-SHE-C	First chemical study of element 113 behind TASCA	2
U308	48-Ca	Yakushev	2020-04-01	2020-04-07	NUSTAR-SHE-C	First chemical study of element 113 behind TASCA	6
U308	48-Ca	Yakushev	2020-04-07	2020-04-15	NUSTAR-SHE-C	First chemical study of element 113 behind TASCA	8
U308	48-Ca	Yakushev	2020-04-22	2020-05-06	NUSTAR-SHE-C	First chemical study of element 113 behind TASCA	14
U308	48-Ca	Yakushev	2020-05-12	2020-05-16	NUSTAR-SHE-C	First chemical study of element 113 behind TASCA	4
U308	48-Ca	Yakushev	2020-05-21	2020-05-26	NUSTAR-SHE-C	First chemical study of element 113 behind TASCA	5
U313	48-Ca	Laatiaoui	2020-03-19	2020-03-27	NUSTAR-SHE-P	Laser spectroscopy of nobelium and lawrencium / High-resolution laser spectroscopy of nobelium	8
U313	48-Ca	Laatiaoui	2020-04-01	2020-04-07	NUSTAR-SHE-P	Laser spectroscopy of nobelium and lawrencium / High-resolution laser spectroscopy of nobelium	6
U313	48-Ca	Laatiaoui	2020-04-07	2020-04-15	NUSTAR-SHE-P	Laser spectroscopy of nobelium and lawrencium / High-resolution laser spectroscopy of nobelium	8
U314	48-Ca	Räder	2020-04-22	2020-05-06	NUSTAR-SHE-P	Laser spectroscopy of nobelium and lawrencium / High-resolution laser spectroscopy of nobelium	14
U314	48-Ca	Räder	2020-05-12	2020-05-16	NUSTAR-SHE-P	Laser spectroscopy of nobelium and lawrencium / High-resolution laser spectroscopy of nobelium	4
U314	48-Ca	Räder	2020-05-16	2020-05-26	NUSTAR-SHE-P	Laser spectroscopy of nobelium and lawrencium / High-resolution laser spectroscopy of nobelium	10
U312	50-Ti	Block	2020-02-13	2020-02-20	NUSTAR-SHE-P	Direct mass measurements with SHIPTRAP	7
U312	48-Ca	Block	2020-02-20	2020-03-04	NUSTAR-SHE-P	Direct mass measurements with SHIPTRAP	13

U310 - α-photon Spectroscopy of Flerovium Decay Chains

- **Spokesperson:** D. Rudolph
  Contact: A. Yakushev, Ch.E. Düllmann

- Magic number at proton number Z = 114 (Fl)?
- Search for even-Z odd-N experimental anchor points for nuclear structure theory in the superheavy regime.
- ^{48}Ca+^{244}Pu to conduct first α-photon coincidence spectroscopy along decay chains of ^{289}Fl.
- **Preliminary summary**:

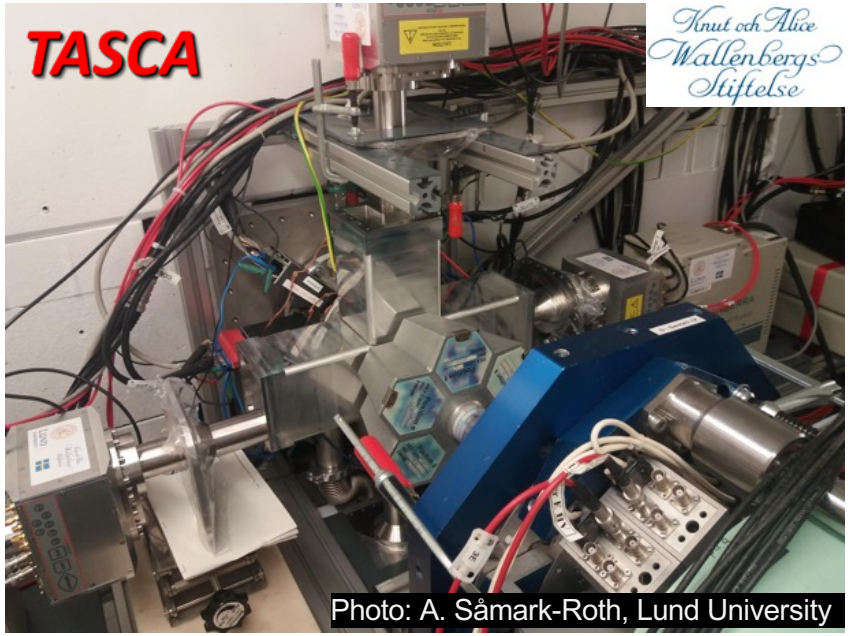
  Beam integral on target: ~ 6 · 10^{18}

  Decay chains expected at σ_{prod} = 10 pb: ~30

  Decay chains observed: ≥ 25

World data on directly produced ^{289}Fl more than doubled!

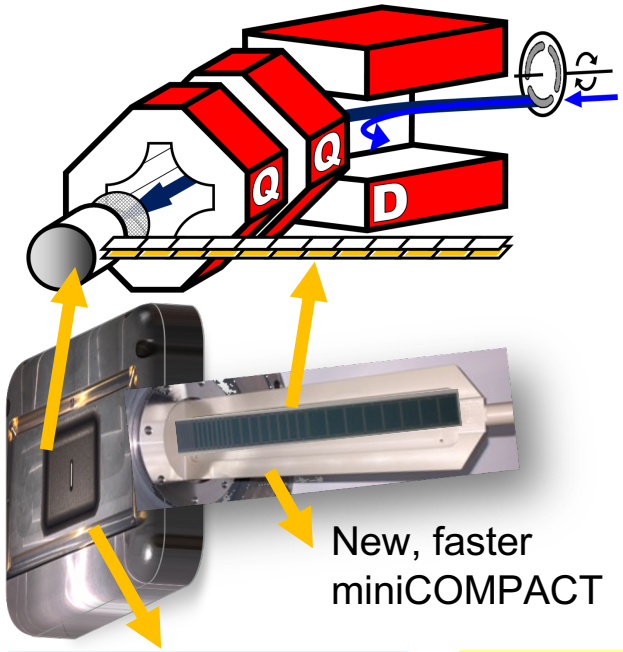
TASISpec



Upgraded decay station in the focal plane of the TASCA gas-filled separator, comprising four new COMPEX Germanium detectors, financed by the Knut and Alice Wallenberg foundation, as well as a former EUROBALL Cluster detector. The idea is to detect *X* rays and γ rays stemming from flerovium α-decay chains.

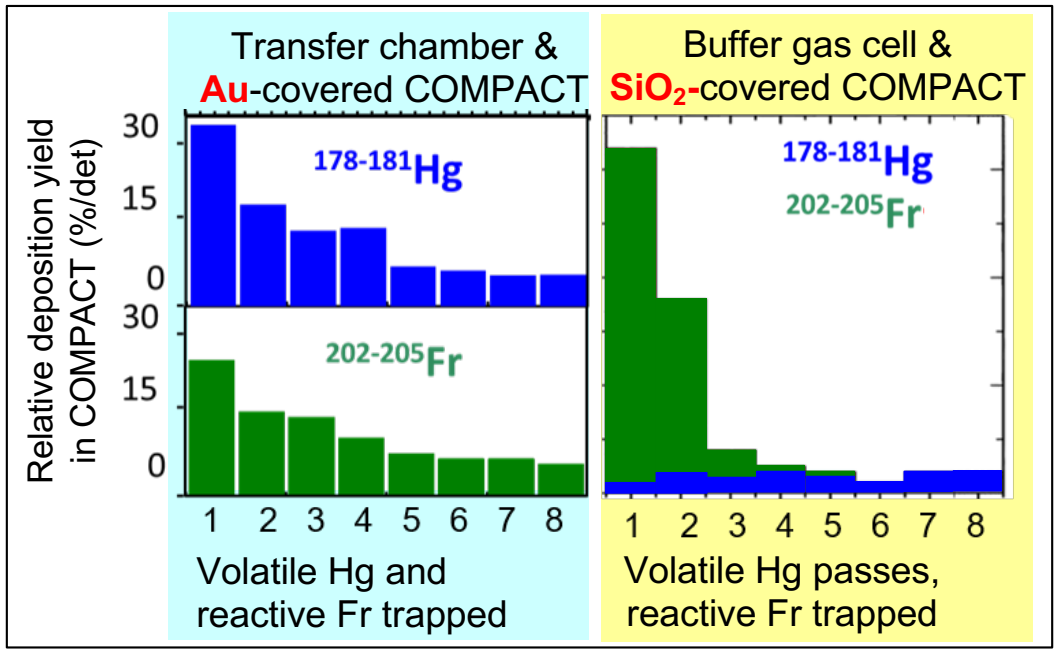
SHE Chemistry (U308) : Ready for element 113

- Full **readiness for chemical studies of short-lived reactive SHE** demonstrated by measuring volatile $_{80}$Hg and non-volatile $_{90}$Th (including 26-ms ^{216}Th!), $_{102}$No, $_{103}$Lr with high efficiency
  - Combination of a new detection setup with a gas buffer cell opens **perspective for chemical studies with elements above Fl**



New, faster miniCOMPACT

New transfer chamber vs. existing buffer gas cell from TASCA to COMPACT



A. Yakushev et al. (***TASCA*** Collaboration)

NUSTAR proposals for G-PAC 44 (2020)

DESPEC	(S-)FRS	ILIMA	R3B	SHE
22 proposals **12 new** **3 A resubm,** 3 other resub. 4 detector dev.	**14 proposals** **6 new** **1 A resubm.** 6 other resub. 1 detector dev.	**3 proposals** **2 new** 1 other resub.	**10 proposals** **6 new** **2 A resubm.** 2 other resub.	**6 proposals** **6 new**
SIS: **362+62 shifts**	**SIS:** **190+27 shifts** **UNILAC** **30 shifts**	**SIS:** **42 shifts**	**SIS:** **238+43 shifts**	**UNILAC** **384 shifts**

NUSTAR: 55 proposals, incl. 6 A-rated resubmissions

SIS request: **832** + **132** shifts (for **~400 available**)

UNILAC request: 414 shifts

Backlog of NUSTAR-FRS experiments

S460	238-U	Valiente Dobon	2020-05-01	2020-05-07	NUSTAR-DESPEC	Investigation of 220-A-230 Po-Fr nuclei lying in the south-east frontier of the A~225 island of octupole deformation	6
S470	238-U	Pietri	2020-05-14	2020-05-15	NUSTAR-DESPEC	Test of an HISPEC TEGIC detector for Low Energy Branch experiments	1
S455	238-U	Taieb	2020-04-23	2020-04-28	NUSTAR-R3B	Fission investigated with relativistic-radioactive beams and the advanced SOFIA@R3B setup	5
S455	238-U	Taieb	2020-05-16	2020-05-21	NUSTAR-R3B	Fission investigated with relativistic-radioactive beams and the advanced SOFIA@R3B setup	5
S452	208-Pb	Witt	2020-04-07	2020-04-15	NUSTAR-SFRS	The Oblate-Prolate Shape Transition around A~190	8
S475	238-U	Dickel	2020-05-08	2020-05-13	NUSTAR-SFRS	Reaction studies with the FRS Ion Catcher: A novel approach and universal method for the production, identification of and experiments with unstable isotopes produced in multi-nucleon transfer reactions with stable and unstable beams	5
S442	40Ar	Sorlin	2021/22		NUSTAR-R3B	Study of multi-neutron configurations in atomic nuclei towards the neutron drip line	7
S450	208Pb	Podolyak	2021/22		NUSTAR-DESPEC	Study of N=126 nuclei: isomeric and beta decays in 202Os and 203Ir	6
S447	6Li	Saito	2021/22		NUSTAR-SFRS (WASA)	Studies of the d + π− signal and lifetime of the 3 H and 4 H hypernuclei by new spectroscopy techniques with FRS	9

Open NUSTAR experiments of 52 days for 2021+

G-PAC 44 results for NUSTAR

DESPEC	(S-)FRS	ILIMA	R3B	SHE
22 proposals 12 "new" A: 5 (+3 dev.) (w. 3 resubm.) A-: 1	14 proposals 6 "new" A: 4 (+3 dev.) (w. 1 resubm) A-: ?	3 proposals 2 "new" A: 1 (no resub.)	10 proposals 6 "new" A: 4 (w. 2 resubm.) A-: 1	6 proposals 6 "new" A: 5
SIS shifts: 108 (main) 30 (second.)	SIS shifts: 72 (main) 46 (second.) UNILAC shifts: 27 (second.)	SIS shifts 6 (main)	SIS shifts 108 (main) 18 (second.)	UNILAC shifts: 232 (main) 149 (second.)

NUSTAR: 19 A ratings, incl. 6 A-rated resubmissions

SIS beamtime shifts: 294 (main) + 94 (second.)

UNILAC beamtime shifts: 232 (main) + 176 (second.)

Optimisation of NUSTAR experiments

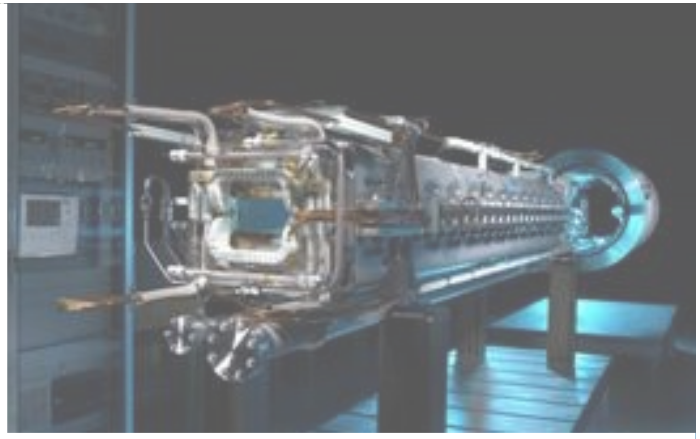
- Optimal beam parameters	*Discussion with accelerator and FRS* *FRS well in advance of the experiments* *provide diagnostic help for machine side* *on-line control beam parameters*
- Maximal set-up efficiency	*Maximize detector efficiencies* *Minimize DAQ dead time*
- Minimal set-up time with beam	*Need for engineering runs* *beam sharing during set-up time* *pre-adjust EDAQ with sources and pulsers*
- Maximal production time	*Minimize maintenance downtimes* *Maximize detector/EDAQ reliability*

adapted from J. Ger (NUSTAR TB)

Conclusions

- **NUSTAR Phase-0 experiments are well underway**
  - Successful (but still limited) experimental campaign in spring 2020
  - Important remaining backlog for 2021/22
- **NUSTAR at the G-PAC meeting 2020**
  - Community is eager and preparing a large number of proposals
  - Satisfactory outcome in view of the limited amount of available time
  - Difficult planning due to the large variety of different set-ups
- **NUSTAR planning for 2021/22**
  - Ongoing discussion to fit as many experiments as possible
  - Several limiting factors (readiness, WASA set up at FRS S2, etc.)
- **Preparation of NUSTAR MoU**
  - Common MoU with Collaboration Agreements as Annexes
  - Need to finalise common fund requests from TDRs





Thank you for your attention

and to the NUSTAR collaboration committee

for providing the material

NUSTAR Annual Meeting

Darmstadt, Germany, September 30th, 2020

Finland France Germany India Poland Romania Russia Slovenia Sweden UK Czech Republic

FAIR