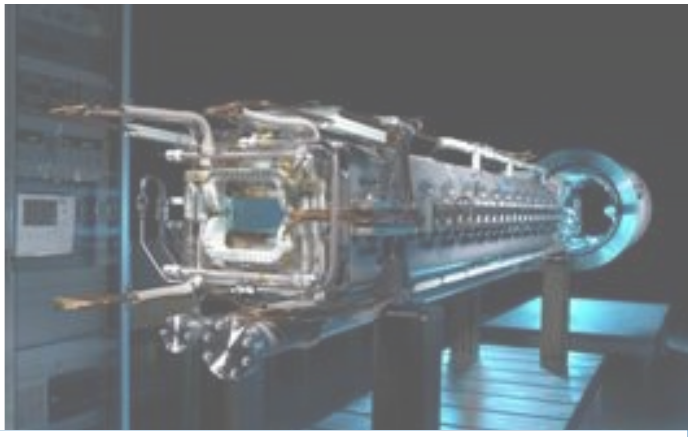




NUSTAR Collaboration Report

NUSTAR Annual Meeting 2021

February 23-26, 2021

FAIR/GSI, Darmstadt, Germany

Wolfram Korten

NUSTAR Spokesperson

IRFU, CEA Paris-Saclay

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

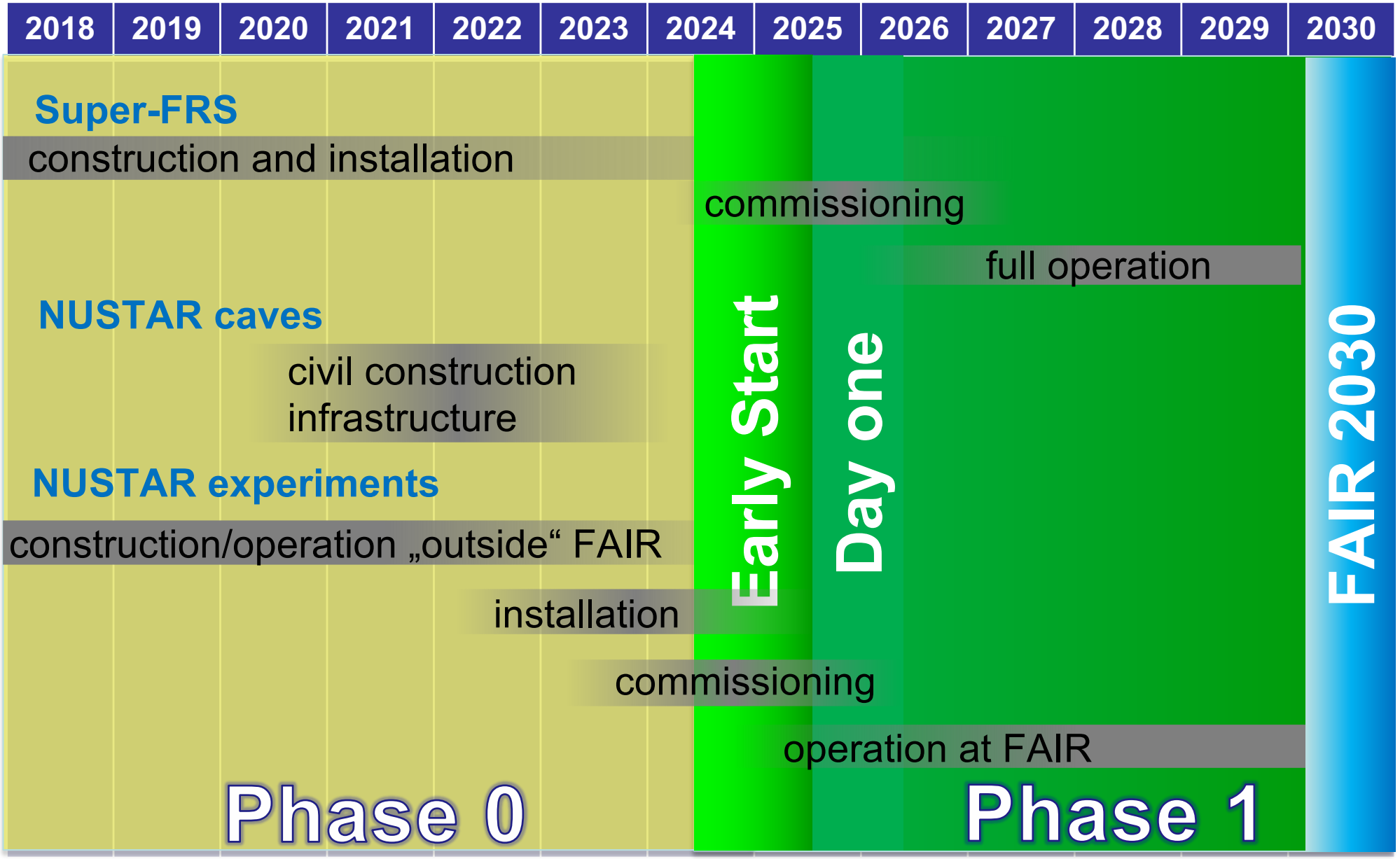
FAIR

NUSTAR - The Project

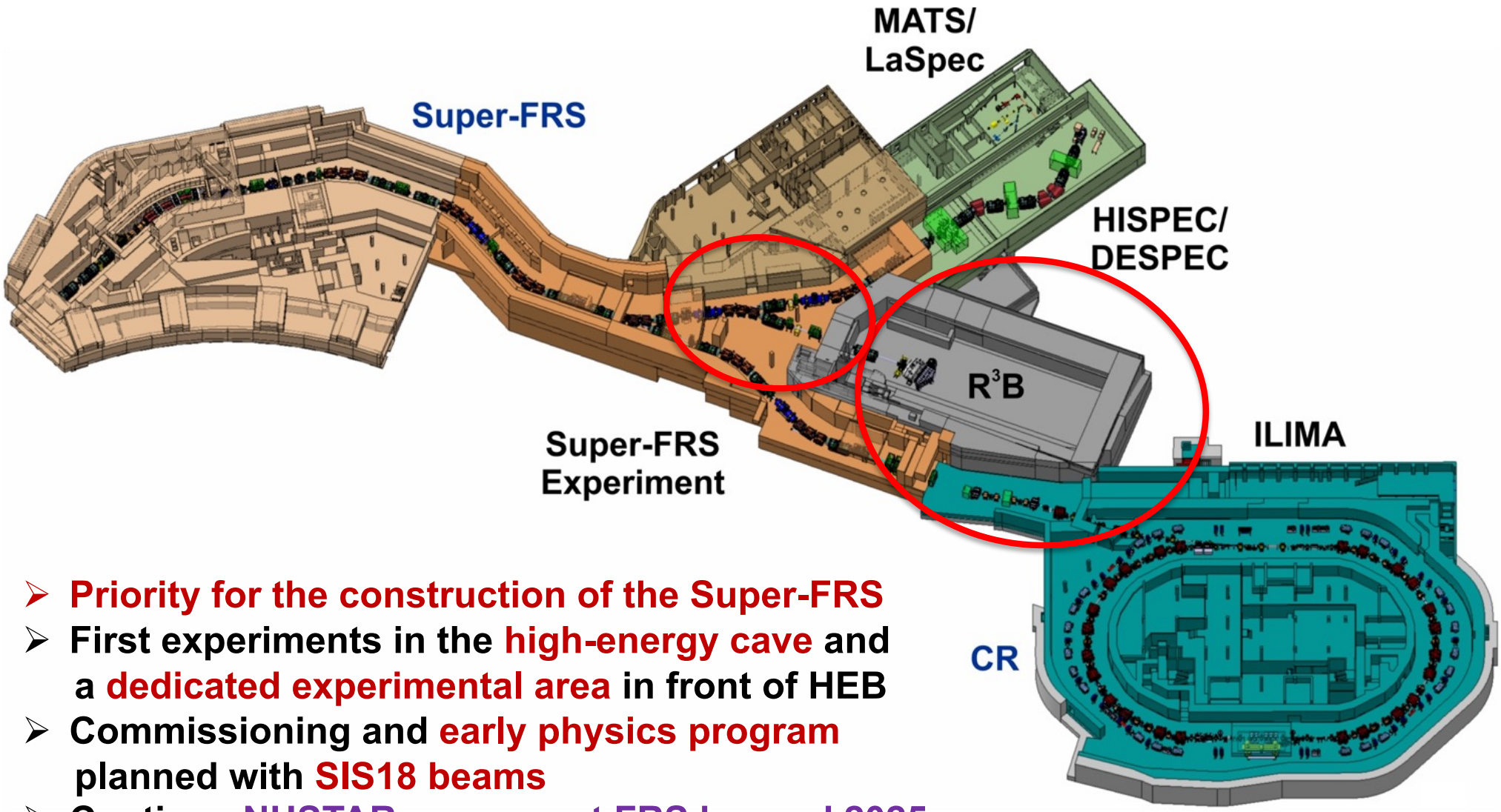
PSP code	Super-FRS	RIB production, separation, and identification
1.2.2	**HISPEC/ DESPEC**	In-beam γ-spectroscopy at low and intermediate energy, n-decay, high-resolution γ-, β-, α-, p-, spectroscopy
1.2.3	**MATS**	In-trap mass measurements and decay studies
1.2.4	**LaSpec**	Laser spectroscopy
1.2.5	**R^3B**	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
1.2.8	**ELISe(*)**	Elastic, inelastic, and quasi-free e^--A scattering
1.2.9	**EXL(*)**	Light-ion scattering reactions in inverse kinematics

(#) NUSTAR experiments using FAIR MSV accelerators – preparing formal approval by council
(*) Experiments requiring NESR – alternative solutions within FAIR MSV under consideration

NUSTAR from Phase-0 to FAIR 2030

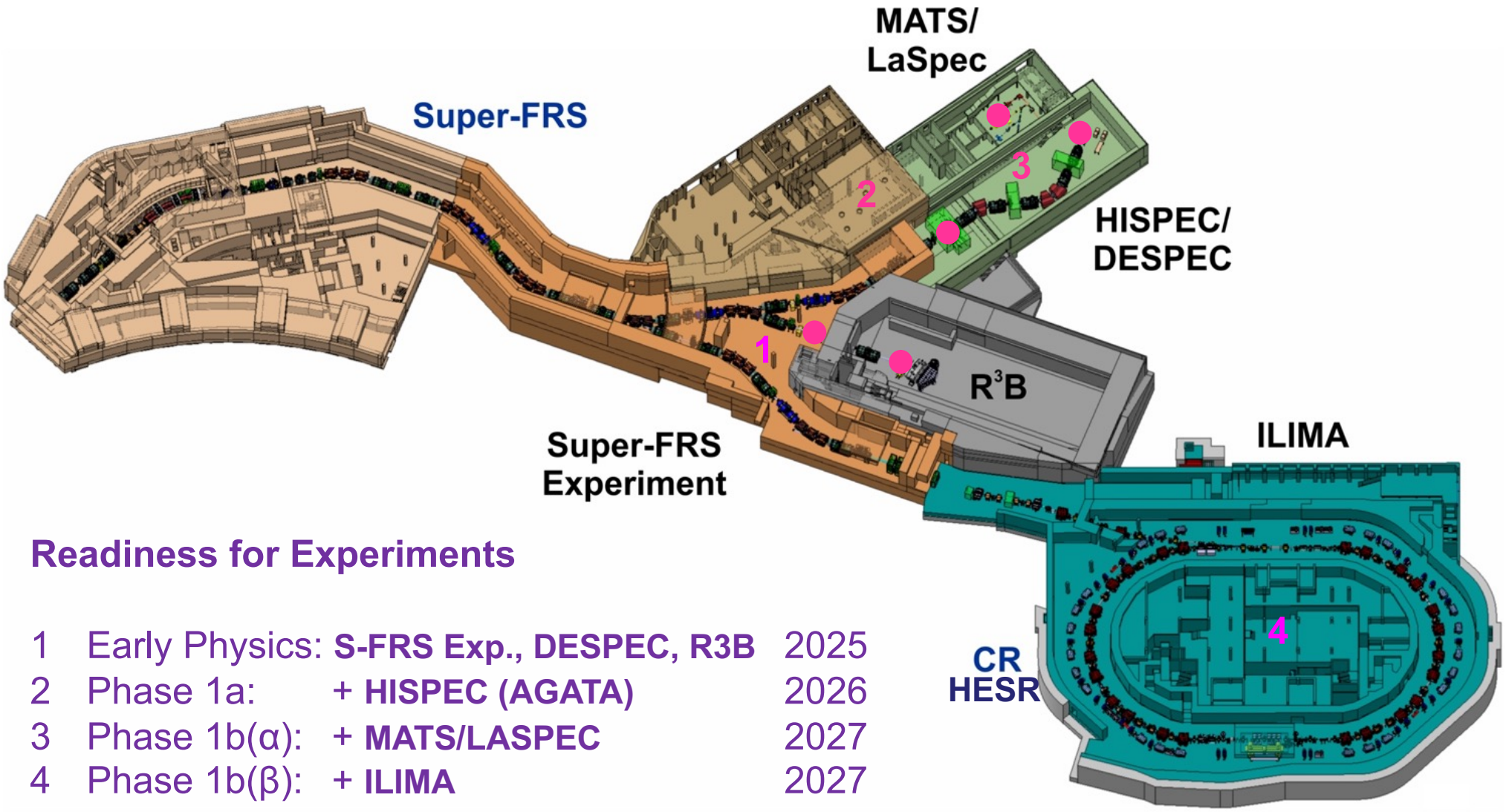


NUSTAR Early Start Version



- **Priority for the construction of the Super-FRS**
- **First experiments in the high-energy cave and a dedicated experimental area in front of HEB**
- **Commissioning and early physics program planned with SIS18 beams**
- **Continue NUSTAR program at FRS beyond 2025, in particular using ESR and Cryring**

NUSTAR Physics Startup at the FAIR facility



Readiness for Experiments

1	Early Physics:	**S-FRS Exp., DESPEC, R3B**	2025
2	Phase 1a:	+ **HISPEC (AGATA)**	2026
3	Phase 1b(α):	+ **MATS/LASPEC**	2027
4	Phase 1b(β):	+ **ILIMA**	2027

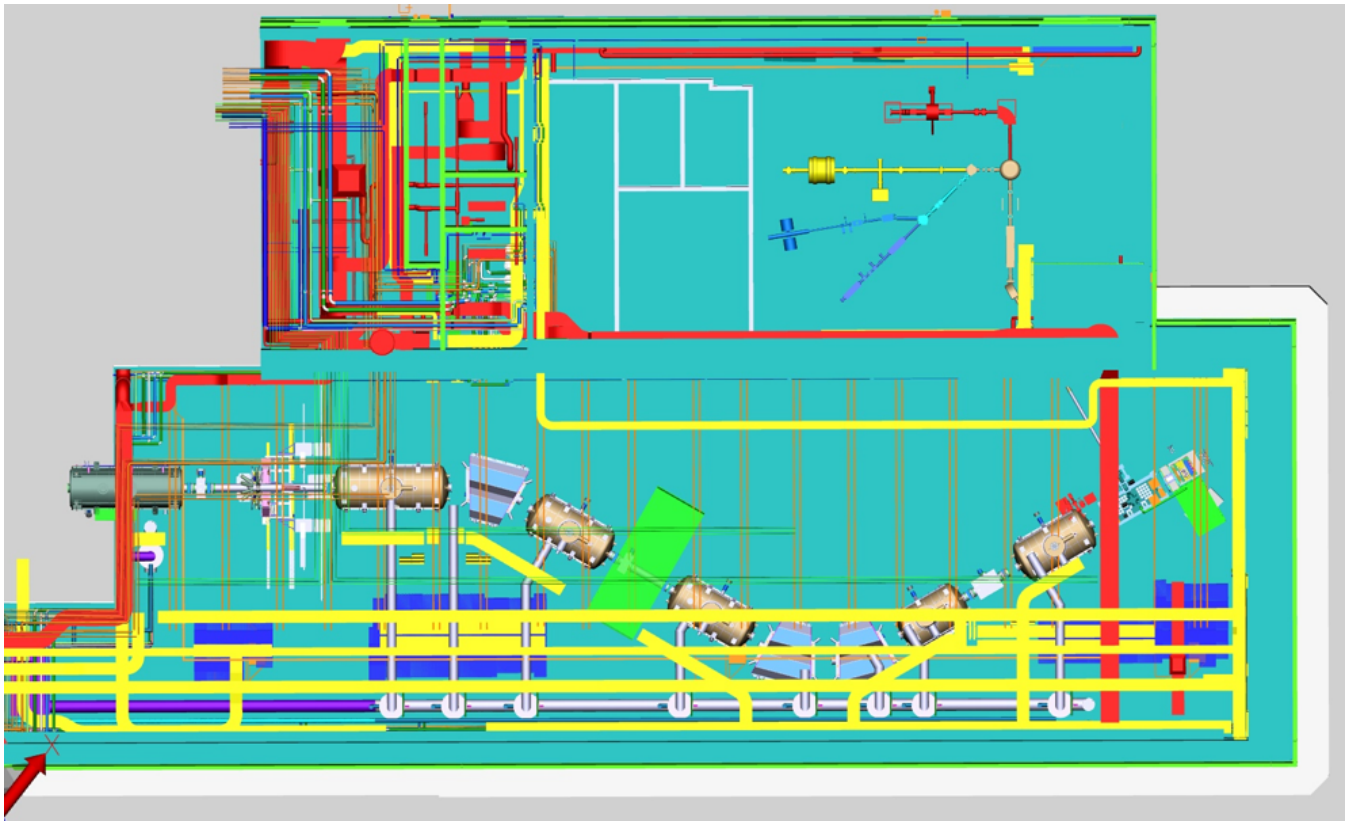
1 SIS18 beams possible, 2 preferably SIS100 operation, 3/4 SIS100 operation needed

Infrastructure preparations

Many activities are going on

- cable lists
- door lists
- emergency switches
- cryo-line optimization
- collision checks
- LEB Cabin
- installation planning
- ….

Example: Low-energy Cave



Courtesy J. Gerl

News from the NUSTAR experiments

NUSTAR Phase 0 program (2021/22)

- **G-PAC 44 results for NUSTAR**
  - **19 A ratings**, incl. 6 A-rated resubmissions
  - 295 (main) SIS18 and 232 (main) UNILAC beamtime shifts
  - Very dense program in 2021/22 (see supplements for details)

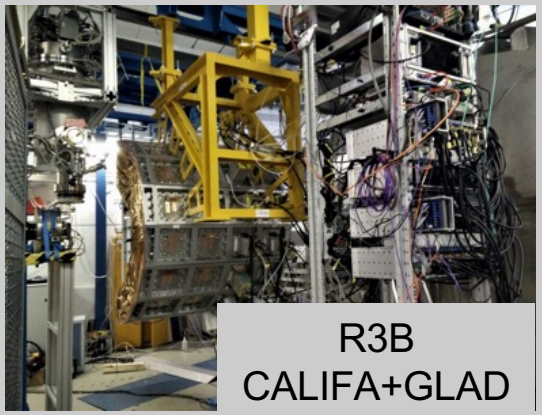
- **All PAC approved experiments should be carried out by 2022**
  - Preparation for campaign in 2021 is well advanced
  - **"Remote" operation** and/or participation largely developed
  - Relatively **few external participants** expected (some long-term visitors)

- **Prolongation of Phase-0 program until the start of FAIR**
  - Optimise experiments for Day-1 at Super-FRS
  - Keep collaborations active at FAIR

Preparation for the Campaign in 2021

Basic set-ups for FAIR Phase-1 have already been constructed and commissioned

Ready for Physics Experiments in FAIR Phase-0 at



Remote Operation and Cooperative Working

The Virtual Messhütte has been established

- Remote monitoring and control of detectors/DAQs
- 24/h Zoom sessions with breakout rooms
- E-LOG
- Instant messaging platforms

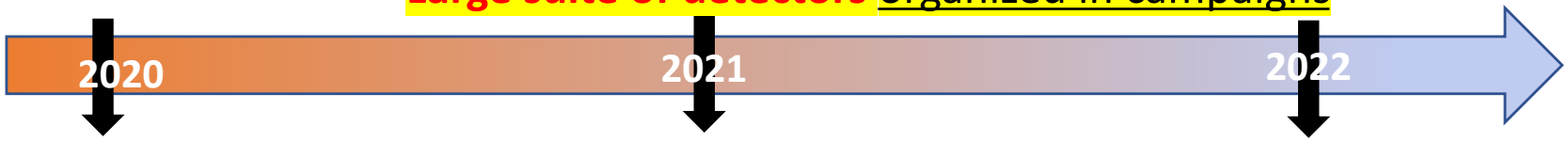
DeSPEC experiments in 2020-22

Complete picture of the β-decay process requires both **high-resolution** and **high-efficiency studies**

- **high-resolution:** aiming at a **detailed reconstruction of decay scheme**. Exploits combination of AIDA+HPGe detectors, coupled to ancillaries such as FATIMA and BELEN to enhance the sensitivity to specific observables (levels lifetimes or delayed neutron spectroscopy).

- **high-efficiency:** Total Absorption Spectrometry technique measuring the **full decay strength**, requires the use of highly efficient scintillator detectors.

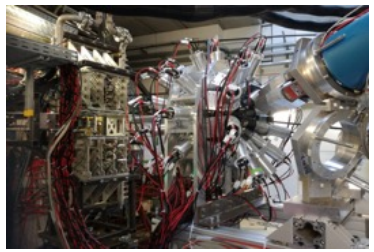
Large suite of detectors organized in campaigns

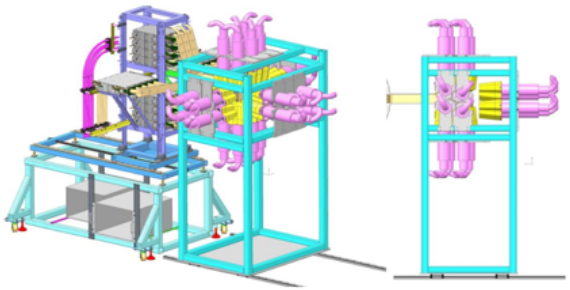


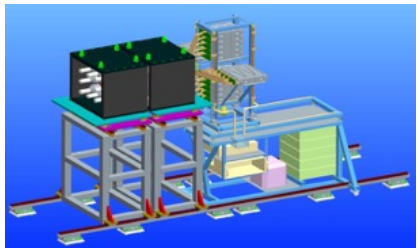
FATIMA-bPLAST
+AIDA
+DEGAS/GTC

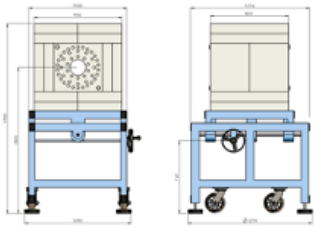
Wide AIDA
+DEGAS/GTC
+FATIMA-bPlast

AIDA
+DEGAS
+DTAS



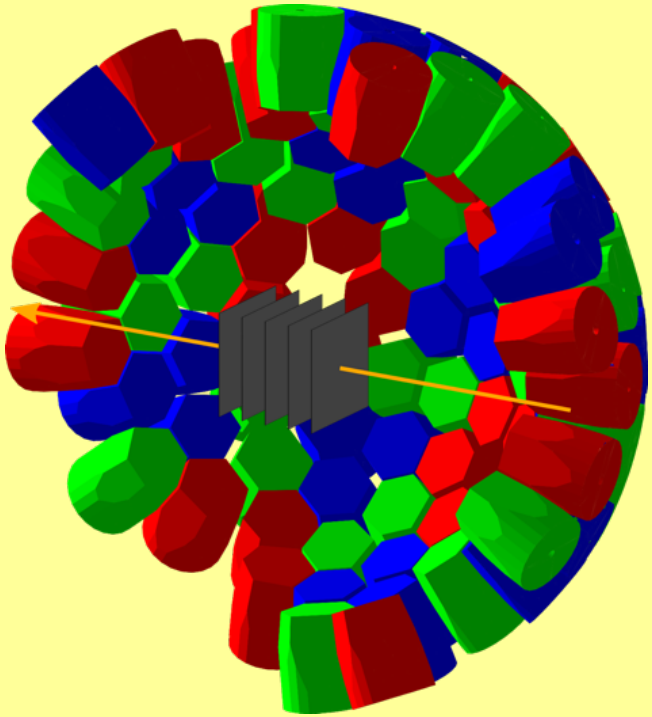


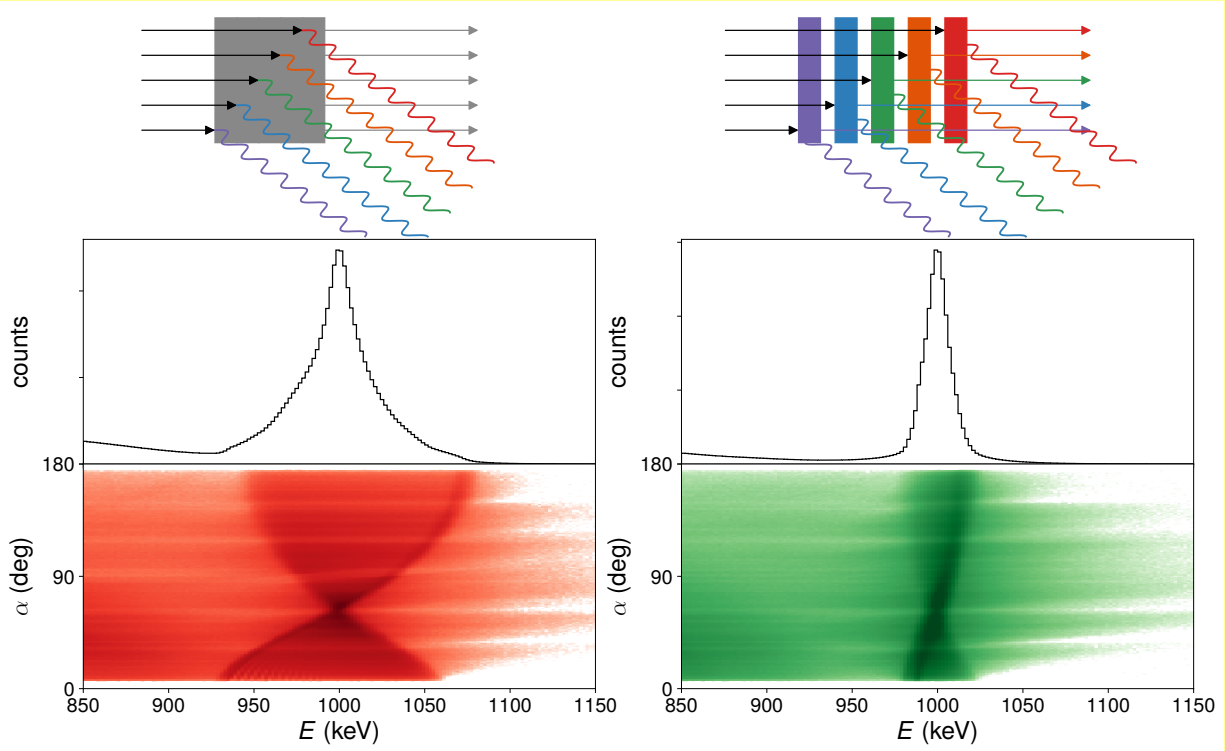




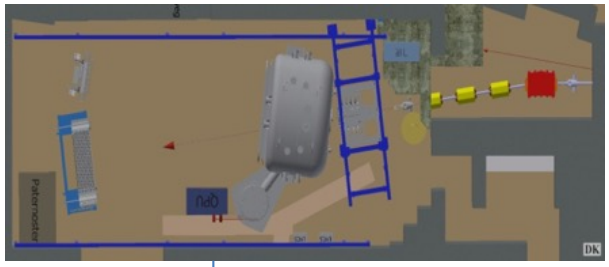
ERC consolidator grant for HISPEC

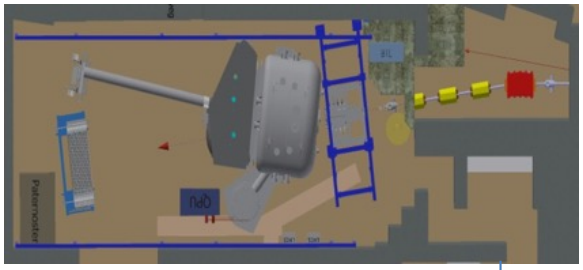
- Grant Holder : Kathrin Wimmer (CSIC Madrid)
- High resolution γ-ray spectroscopy with **AGATA** using **active diamond targets** enhancing the sensitivity for **lifetime measurements** of exotic nuclei.

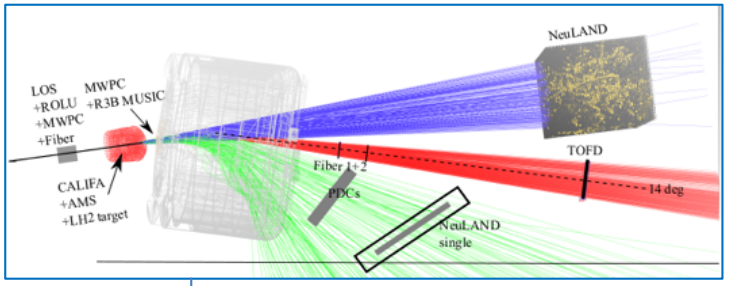




experiments in 2020-22





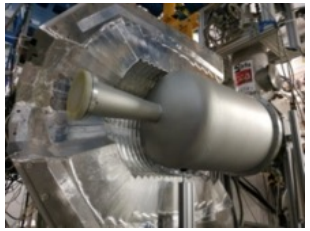


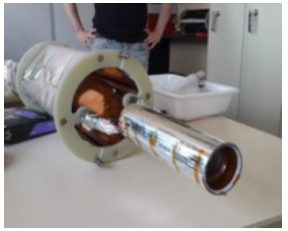
2020
CALIFA Barrel
NeuLAND (8 DP)
SOFIA tracking detectors
R3BMusic

2021
CALIFA iPHOS
NeuLAND 12 DP
+ LH2 +

New Fiber Detectors

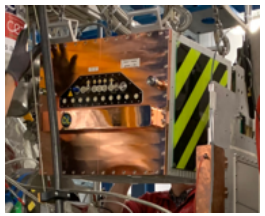
2022
+ Proton arm behind GLAD





S509 Study of multi-neutron correlations in drip-line nuclei
S522 First characterization of Short-Range Correlations in exotic nuclei @R3B

S444 Detection system comm.
S467 Single-particle structure of neutron-rich Ca isotopes



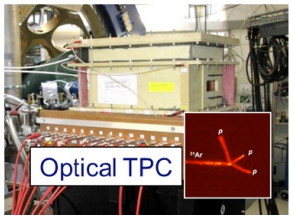
S455 Fission studies @R3B
S515 Constraining energy-density functionals and the density-dependence of the symmetry energy
S494 Coulomb dissociation of ^{16}O into ^{12}C and ^{4}He.

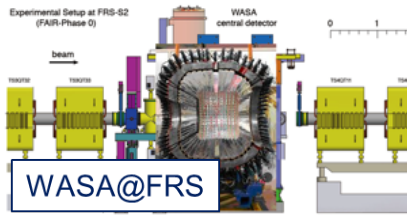
S-FRS collaboration experiments in 2020-22

High-resolution spectrometer experiments with FRS and ancillary detectors

→ **broad science spectrum**

- **New isotopes**, new reaction studies (MNT etc.)
- **Exotic nuclei** (proton radioactivity, fission isomers)
- **Atomic-collision** studies
- **Hyper nuclei**: nnΛ, $^{3}_{\Lambda}$H, $^{4}_{\Lambda}$H
- **Hadron physics**: eta-prime mesic nuclei
- **Applications**: nuclear astrophysics, biology, nuclear imaging





2020

S468 New isotope search „south“ of Pb (N~126), masses and half-lives
S469 Gas-solid difference in heavy ion stopping
S474 Direct mass measurements around ^{100}Sn
S459+ In-flight decay spectroscopy of proton-unbound nuclei and mass meas.
S482 Mean range bunching

2021

S526 Direct mass measurements of heavy N=Z nuclei
S530 Fission isomer studies at FRS
S533 Atomic and nuclear interaction studies for ion-beam therapy with β^{+}-emitting nuclei

2022

S447 Studies of hypernuclei by new spectroscopy techniques with WASA@FRS
S490 Search for eta‘-mesic nuclei in ^{12}C(p,dp) reaction
U323 Study of MNT processes in different reactions
S523 In-cell MNT reactions at the FRS Ion Catcher

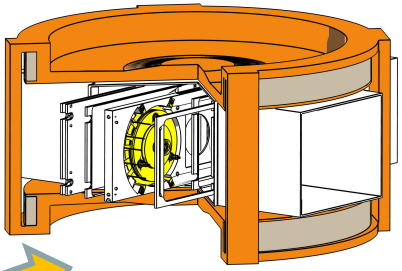
2023

ILIMA in Phase-0 and towards Day-1

Phase-0 experiments aim both at exciting physics goals and at the development of detection systems and methods which are indispensable for ILIMA@FAIR

Detectors

ILIMA



In-kind contract signed
-- in production --

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

Time-of-Flight

Telescopes

One detector was commissioned in **E121** (2020)
New detector and DAQ upgrade as in-kind from Canada
-- to be tested in **E156** (not approved)

A. Najafi, et al., NIM A (2016)

Schottky

A prototype for CR/HESR was tested in the ESR in **E121**
Major characteristics (sensitivity) will be determined in **E143**

M.S. Sanjari et al., Rev. Sci. Instrum. 91, 083303 (2020)

MATS – Programme for Phase-0 and Day-1

FAIR phase 0:

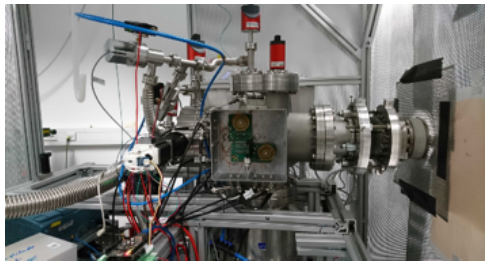
- operation of MATS prototype TRIGA-TRAP at TRIGA Mainz for technical and methodical developments:
  - single–ion mass spectrometry with cryogenic trapping systems
  - optimization of novel phase-imaging technique (PI-ICR) for short-lived nuclides and low-lying isomers
- construction of RFQ system at JYFL
- on-line experiments at different laboratories within the collaboration: ISOLTRAP, JYFLTRAP, SHIPTRAP ...

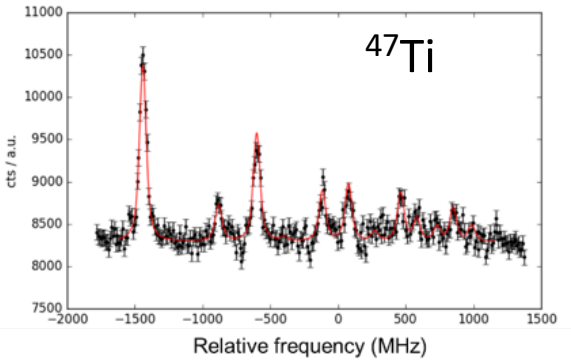
FAIR phase 1:

- Experiments on neutron-rich nuclides relevant for 3rd r-process peak
- Experiments on selected neutron-rich isotopes, e.g. Zr isotopes

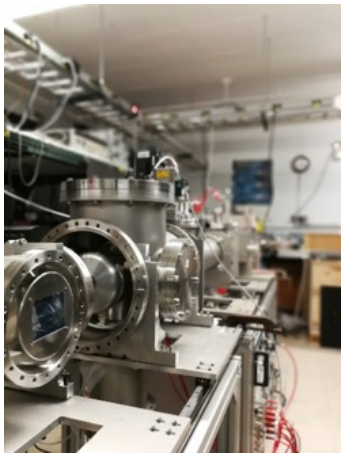
LaSpec Phase-0 and Day 1 program on refractory elements

2020 → 2021 → 2022 → Towards FAIR operations



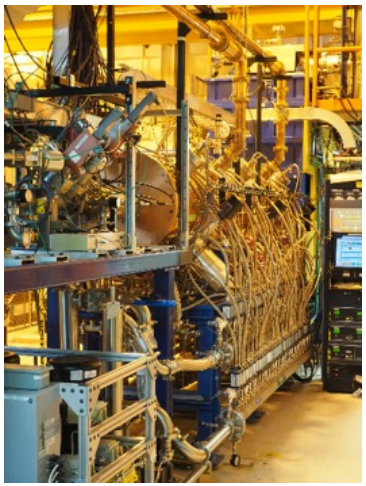


Versatile LASPEC off-line ion source in operation
(Developed & tested @ COALA / TU Darmstadt)



Operation of LASPEC @ CARIBU (Pd, Ru)

Enhancing UV capabilities of detection region



^{8}B Measurements at ATLAS/ANL

Design of transport beamline from gas cell to MATS/LASPEC hall

Preparing pulsed acceleration for beam transport from stopping cell to MATS/LASPEC hall.

SHE experiments in 2021/22 towards Day-1

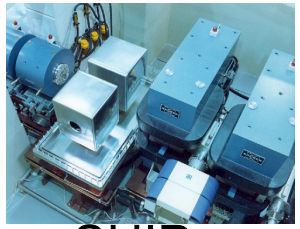
Comprehensive study of superheavy elements: production, nuclear, atomic, and chemical properties at SHIP and TASCA:

2020 → 2021 → 2022 → Day-1

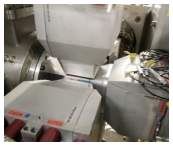
				Day-1 Setups
Nuclear structure:				
Focal plane det. (FPD)	✓ new ^{244}Md			FPD, COMPASS
TASISpec ⟶ LUNDIUM	✓ α-γ $_{114}$Fl chains	Construct. LUNDIUM	👍 Commiss. ($_{94}$Pu)	LUNDIUM
ANSWERS Setup	Construction	👍 Commiss. ($_{104}$Rf)		ANSWERS
Atomic properties:				
Masses (SHIPTRAP)	✓ $_{102}$No-$_{104}$Rf	👍 $_{104}$Rf/$_{105}$Db	👍 $_{104}$Rf/$_{105}$Db	SHIPTRAP
Laser spec in gas-cell	✓ $_{100}$Fm	👍 $_{102}$No/$_{103}$Lr	👍 $_{103}$Lr	RADRIS
in gas-jet	Construction	👍 Commiss.	👍 $_{102}$No	In-Gas-Jet
Chemical properties:				
RTC-based ($T_{1/2}$ >500 ms)	✓ $_{113}$Nh (RTC)	👍 $_{115}$Mc (RTC / miniCOMPACT)		miniCOMPACT
UniCell ($T_{1/2}$ >2 ms)	Design UniCell	Construction	Commiss. UniCell	UniCell

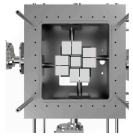
✓ Successful beamtime
👍 Beamtime in schedule


TASCA

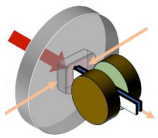

SHIP

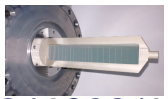

SHIPTRAP


COMPASS

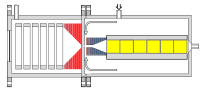

LUNDIUM

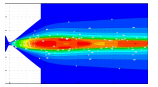

RADRIS


ANSWERS


miniCOMPACT


TASCA FPD

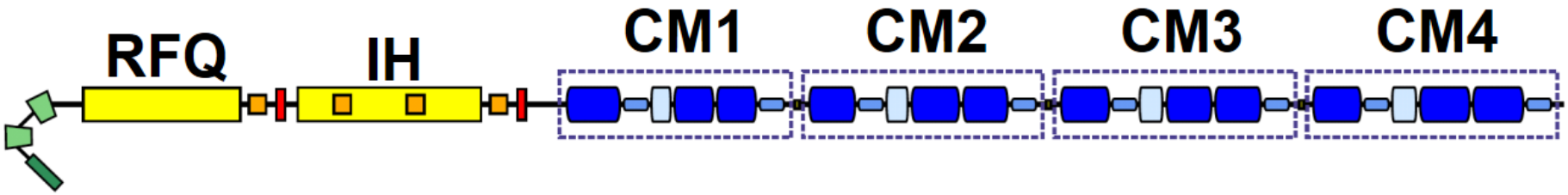

UniCell


Laser Gas-Jet

Future of SHE program at FAIR

HIM

After **UNILAC upgrade for FAIR operation** no high-duty cycle mode
Possible solution through a dedicated CW LINAC (HI Mainz & GSI)

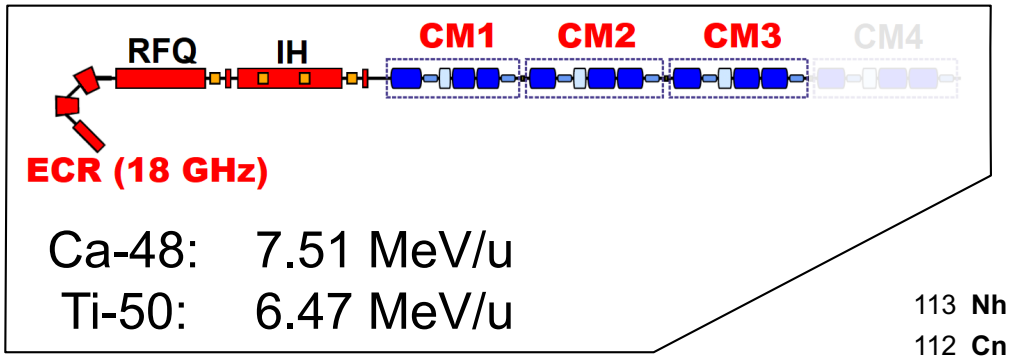


Old 14 GHz ECR & existing injector → 25% duty factor
New 18 GHz ECR & new injector → 100% duty factor (c.w.)

Conclusions from the retreat of the FAIR research division:
Three cryo-modules with the existing pre-accelerator and the 18GHz ECR source would allow a compelling science programme, while having only two modules would be inadequate.
A fourth module and/or a pre-accelerator would further enhance the capability significantly.

Future of SHE program at FAIR

HIM



Ca-48: 7.51 MeV/u

Ti-50: 6.47 MeV/u

New 18 GHz ECR and new CW injector
allows full current physics program including
search for new SHE with Z > 118

SHE chemistry studies of elements up to Z = 118 and beyond

1																	18
1 H	2											13	14	15	16	17	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg	3	4	5	6	7	8	9	10	11	12	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71 La-Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103 Ac-Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
119 ---	120 ---																

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

News from the NUSTAR collaboration

Changes to the NUSTAR Board of Representatives

- Many thanks to the outgoing members

Zsolt Podolyak (U. Surrey)

Haik Simon (GSI and FAIR)

- Welcome to the newly elected members

Mike Bentley (U. York)

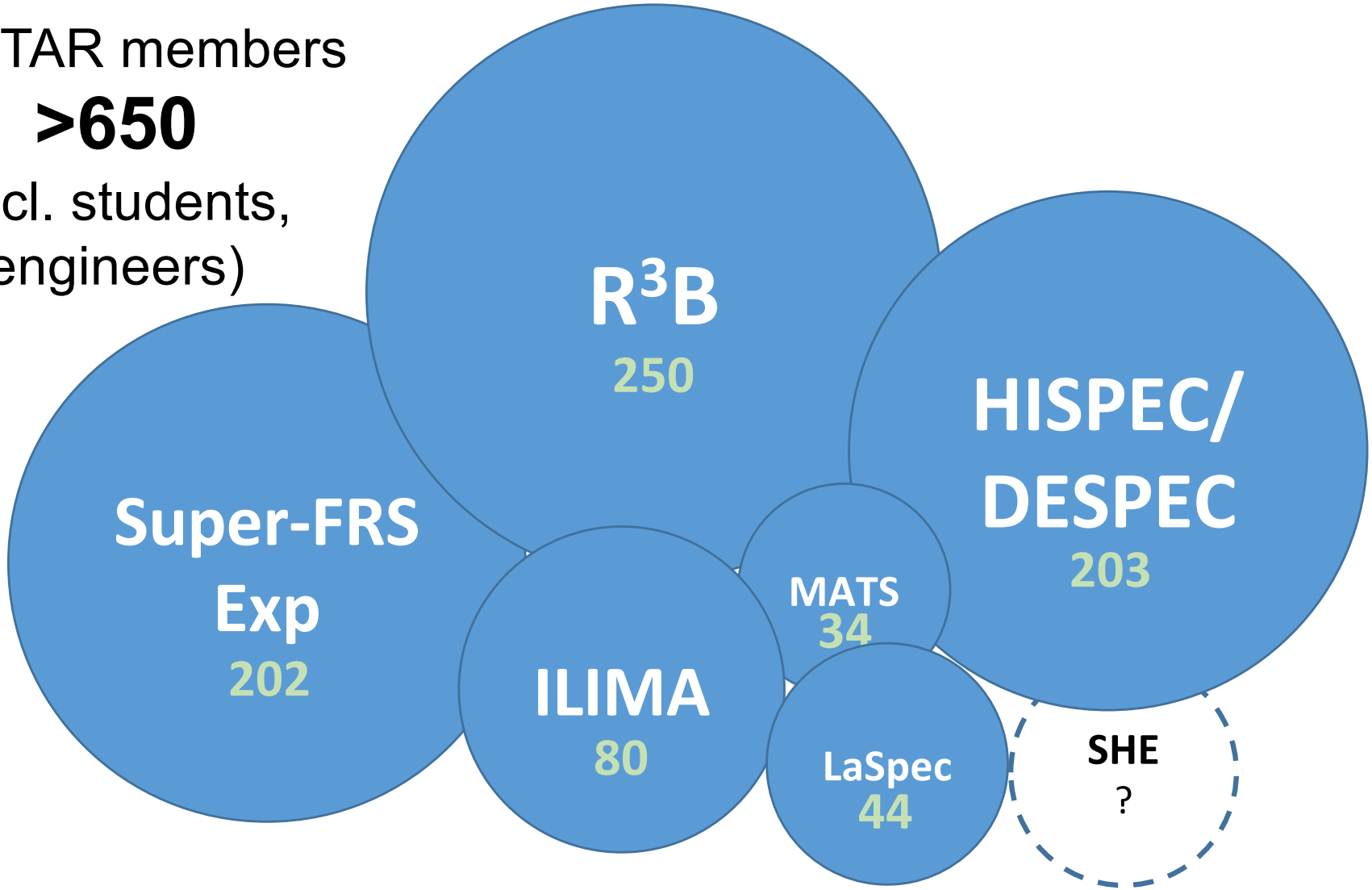
Peter Thirolf (LMU München)

NUSTAR members – survey in progress …

NUSTAR members

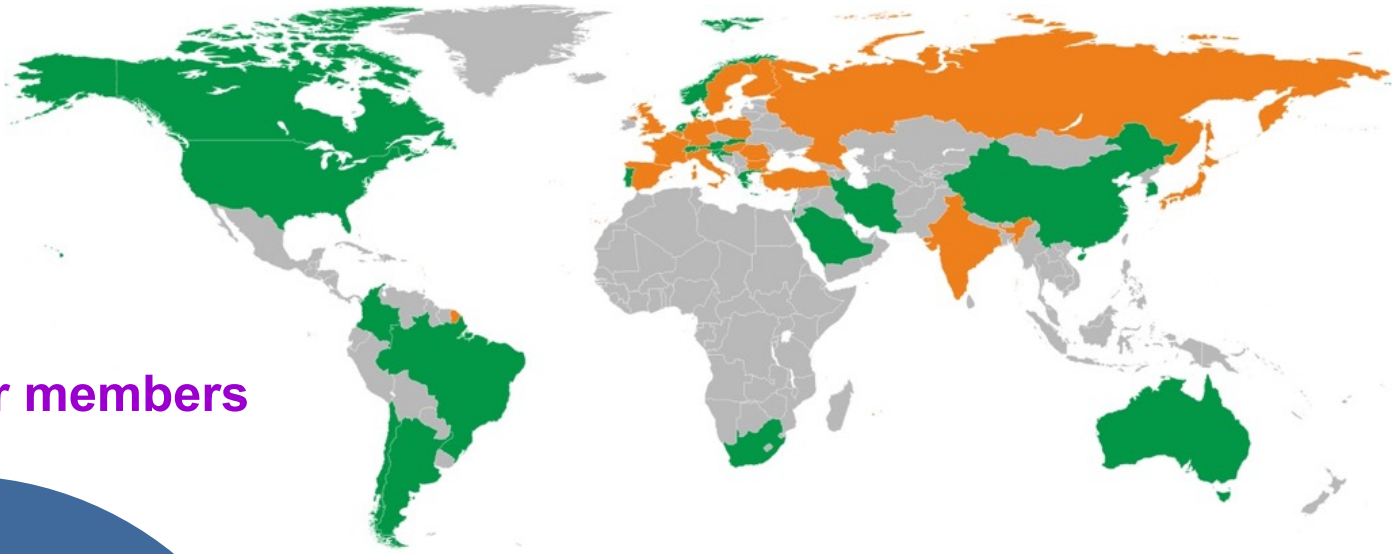
>650

(incl. students, engineers)

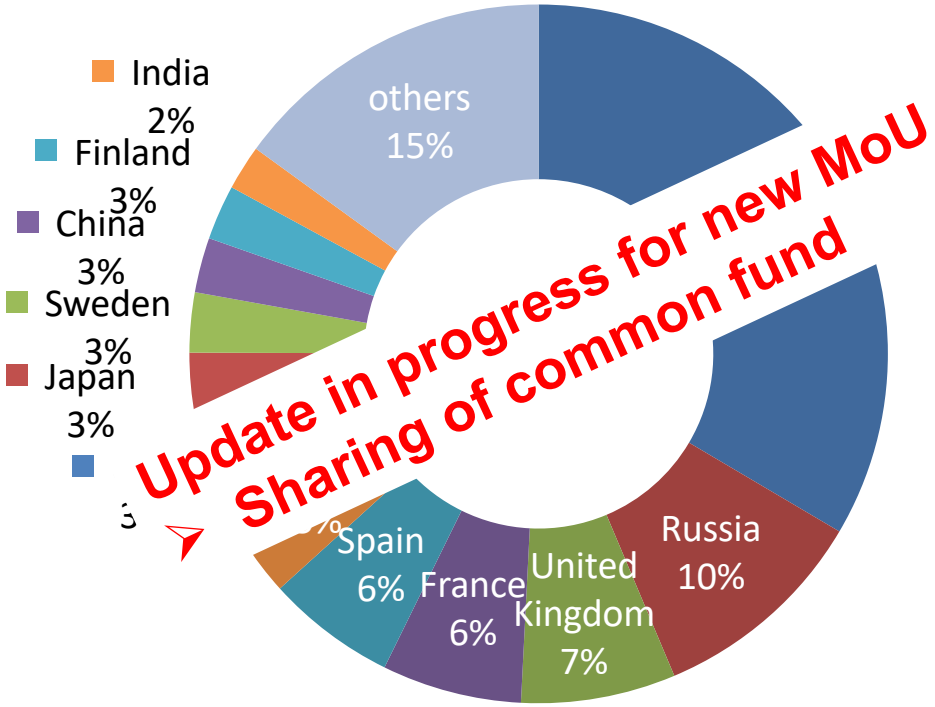


status: February 5, 2021

The NUSTAR collaboration



NUSTAR senior members



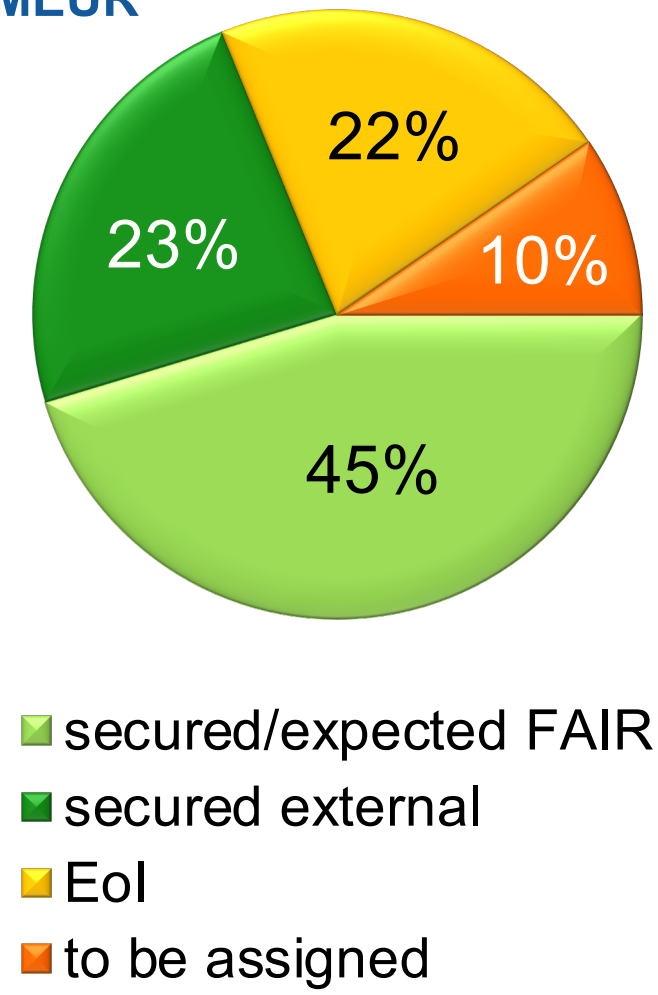
Update in progress for new MoU
Sharing of common fund

> 1000 "interested" scientists
> 650 registered members
> 450 senior members (PhD etc.)
> 180 institutes from 39 countries

Secured funding and expression of interest in funding **from 19 countries** (incl. 9 FAIR partner countries)

NUSTAR MSV – funding status

46.5 MEUR



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

- Australia
- Belgium
- Bulgaria
- Canada
- China
- Czech Republic
- **Finland**
- **France**
- **Germany**
- Hungary
- **India**
- Israel
- Japan
- Netherlands
- **Poland**
- **Romania**
- **Russia**
- Slovenia
- Spain
- **Sweden**
- Turkey
- **United Kingdom**

Status: February, 2021

FAIR 2030: Completing the NUSTAR experiments

Complete instrumentation for MSV (approved TDRs):

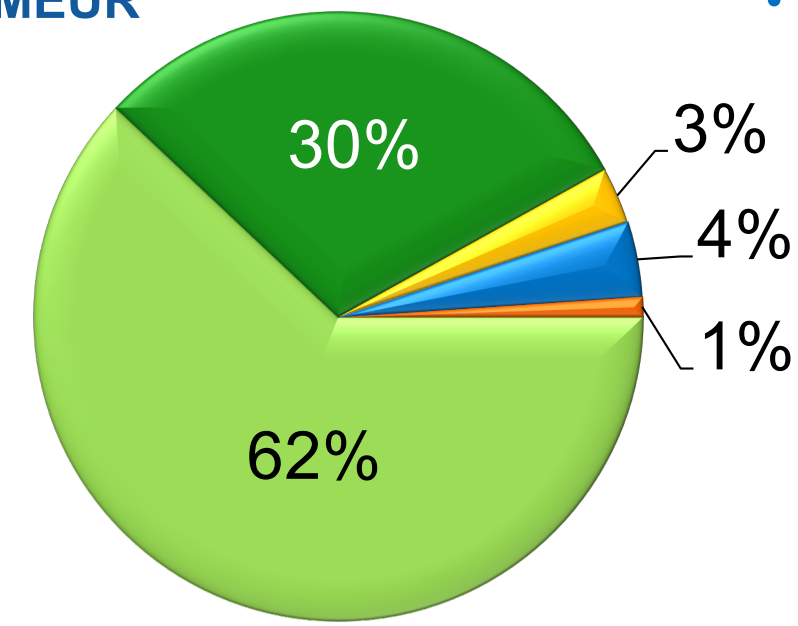
- **DESPEC**: Full DEGAS Ge and MONSTER neutron detector array
- **HISPEC**: Complete AGATA (externally funded)
- **ILIMA**: Complete detectors (ToF, HI, Schottky) for CR
- **R3B**: Full CALIFA CsI/LaBr3 calorimeter and NEULAND neutron wall
- **S-FRS EC**: Complete EXPERT set-up

Add new capabilities (EoIs):

- **LEB:** Instrumentation for experiments with slowed-down beams
- **DESPEC:** g-SPEC for g-factor measurements
- **HISPEC:** HYDE charged-particle array
- **LASPEC:** CRIS capabilities for collinear beamline
- **R3B:** High-resolution spectrometer
- **EXL:** Detection system(s) for ESR and HESR
- (**S-FRS EC**: SuperWASA)

NUSTAR Day-one – funding status

34.0 MEUR



Status: February, 2021

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

- Bulgaria
- Canada
- China
- Czech Republic
- **Finland**
- **France**
- **Germany**
- Hungary
- **India**
- Israel
- Japan
- Netherlands
- **Poland**
- **Romania**
- **Russia**
- Slovenia
- Spain
- **Sweden**
- **United Kingdom**

Common Fund : ~1900 kEUR (2021)
(under preparation for ECE/ECSG)
(~1k EUR per senior member and year)

Funding status of **Day-one** configuration

	NUSTAR sub-system	TDR	Cost [k€ 2005]	Funding	Construction	Date completion	Test/ Commissioning
Day 1	LEB infrastr.		2,109			06/2023	
	HISPEC/DESPEC		10,881			03/2024	
	MATS		1,219			08/2024	
	LaSpec		253			12/2021	
	R3B		18,054			03/2023	
	ILIMA		1,101			12/2023	
	Super-FRS Exp		398			12/2023	
		91% *value weighted*	34,015	92% *secured*	58% *value weighted*		40% *value weighted*

- Score card from September 2020:
  - **updated** with respect to TDR status and funding
  - **Added Super-FRS Experiment**
  - Next official update for April 2021

NUSTAR MoU for Construction

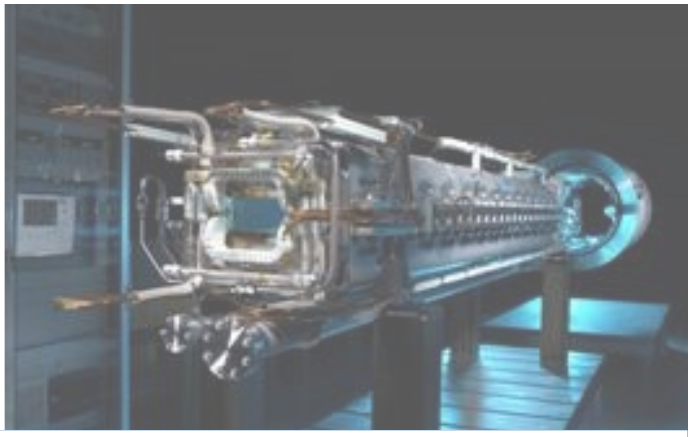
- NUSTAR MoU for Construction
  - Similar structure of the MoU for all FAIR experiments
  - MoU for CBM as blueprint, but NUSTAR specific items, e.g. concise annexes for individual experiments (“collaboration agreements”)
  - Updating NUSTAR organizational structures and procedures
    - Election of 4 members of NUSTAR board (2 year term, renewable)
    - Direct election of spokesperson (chair of the NUSTAR board)
- Steps towards new MoU (endorsed by NUSTAR council)
  - NUSTAR Common Fund (submission to ECE/ECSG by 04/2021)
  - List of NUSTAR members (t.b.c. by collaborations/institutes)
  - Definition of the installation procedure and required resources
  - Presentation to NUSTAR CC and Council (Q2/2021)
  - Feedback from first funding agencies (Q3/2021)
  - Validation by NUSTAR Resource board (Q4/2021)

Summary and Conclusions

- **NUSTAR experiments are progressing constantly towards Day-1**
  - Day-1 equipment is to a **large extend already constructed** and **ready in 2025**
  - **Common funds** needed for the completing the infrastructure of the experiments
  - Construction MoU in preparation and to be submitted towards the end 2021
  - Future emphasis to **complete the full MSV configurations**

- **Phase-0 experiments are an integral part of our preparation for Day-1**
  - Extended commissioning of **all NUSTAR equipment** incl. **FRS/ESR**
  - Several **successful experiments** despite limitations due to Covid-19
  - Secondments for **experiments** and **beam team** are difficult
  - NUSTAR campaign in 2021/22 will heavily rely on external participation
  - Need **sufficient phase-0 beam time** to keep collaborations **competitive**





Thank you for your attention

Acknowledgements:
J. Gerl, A. Herlert and
the NUSTAR collaboration committee

NUSTAR Annual Meeting 2021

Darmstadt, February 23-26, 2021

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

FAIR