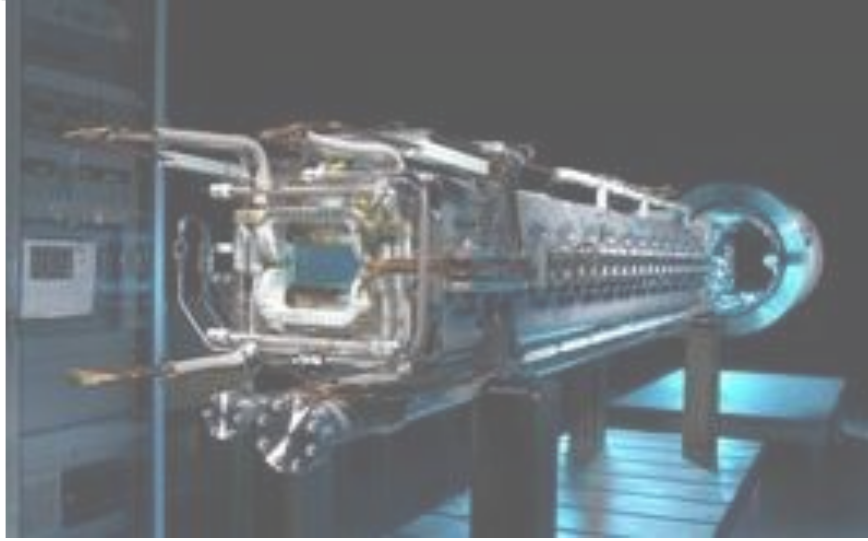


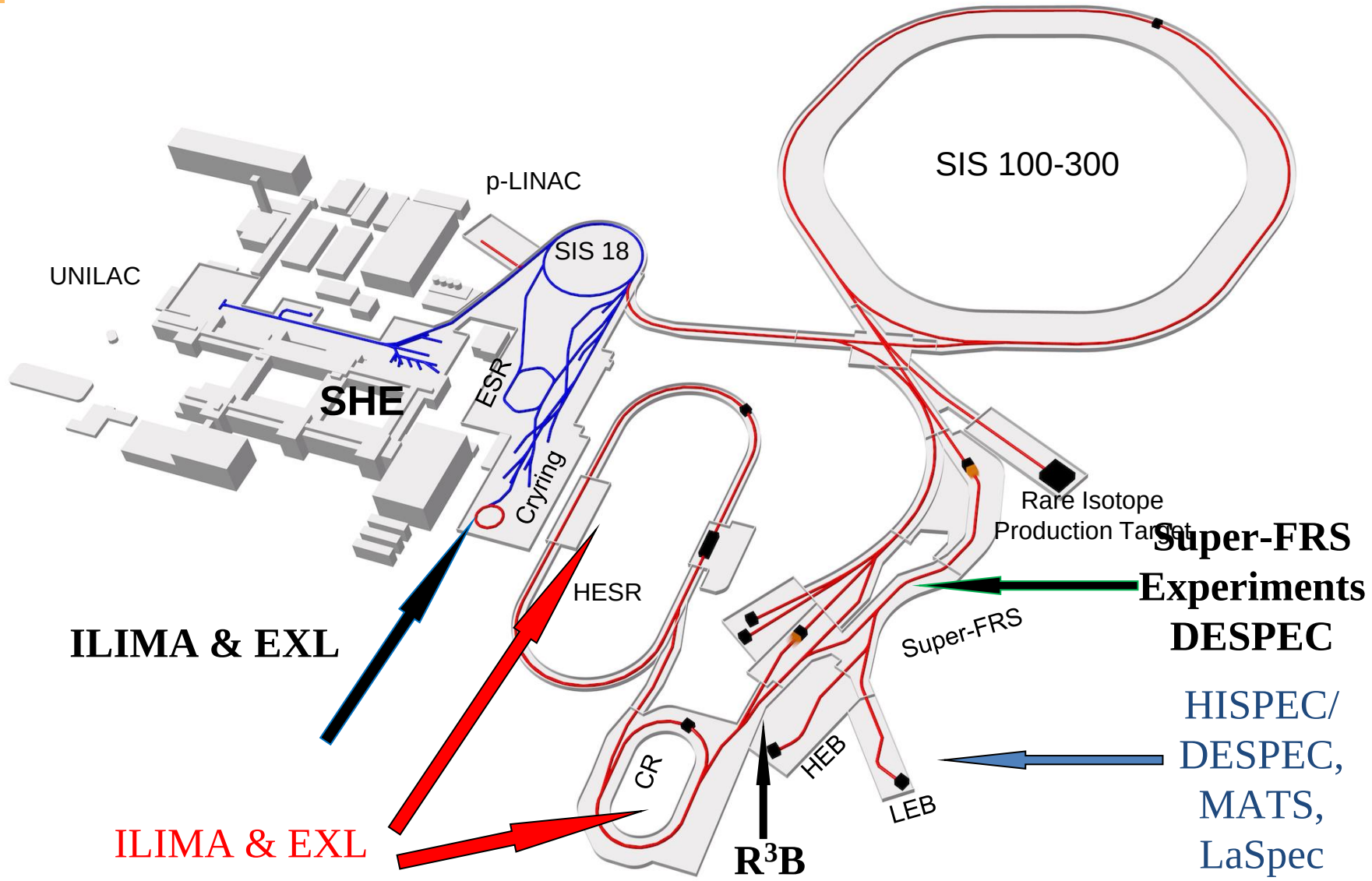
FAIR-UK ten-years plan

Zsolt Podolyák

NPF, 8th of May 2024

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

Status



SIS 100, SuperFRS, HEB,
LEB etc buildings ready (not HESR, CR)

Magnet installation just started

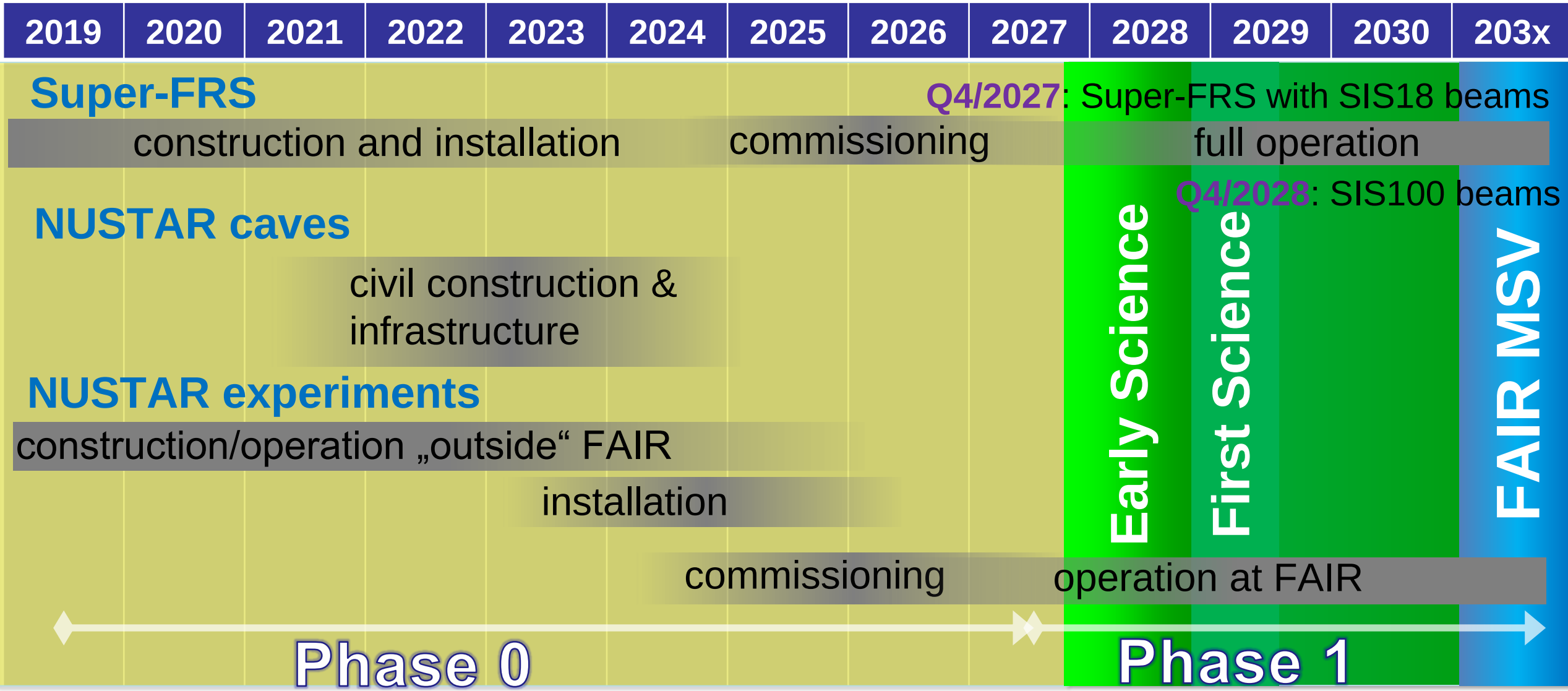
LEB building has no infrastructure (~20M needed) ~2028?

HESR, CR ~203x

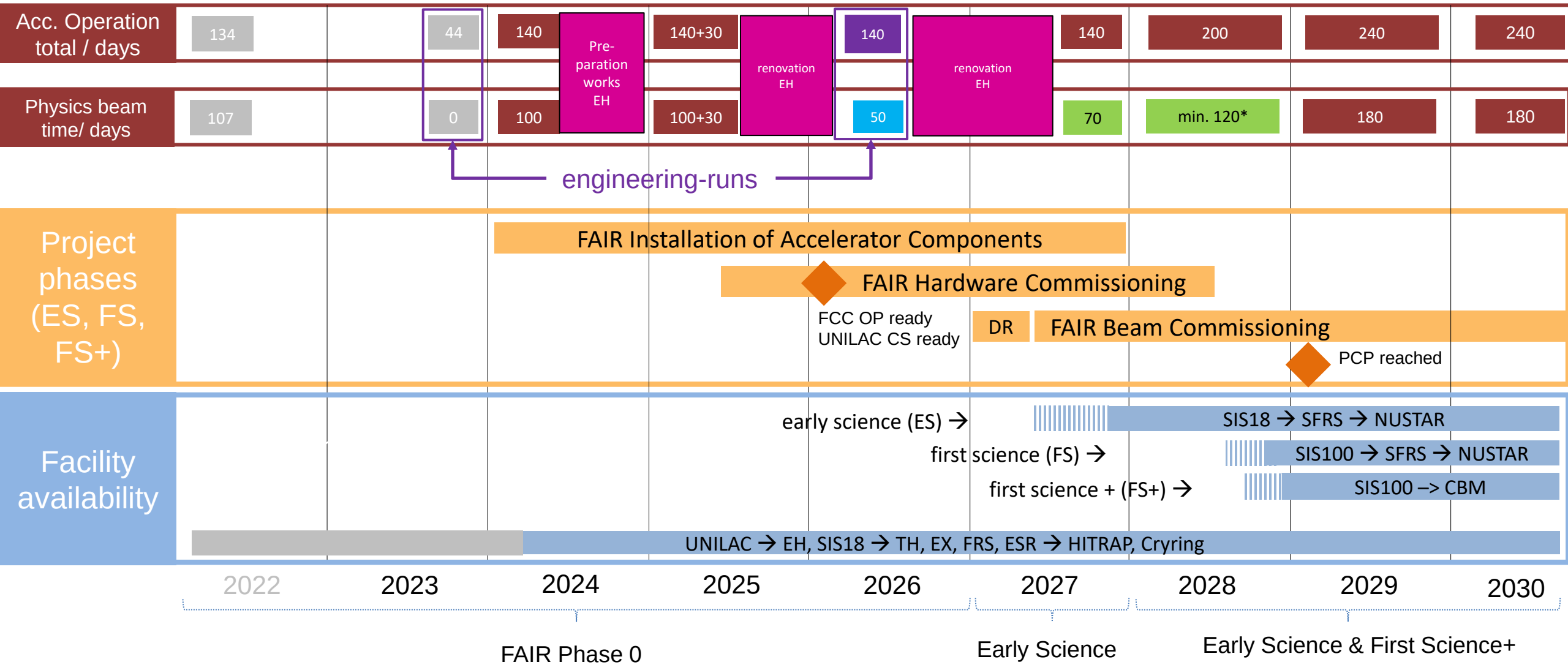
assumes funding decision in 2025

FAIR buildings finished end of 2023 (besides CR & HESR)

NUSTAR Overall schedule (optimistic scenario): From Phase-0 to FAIR MSV

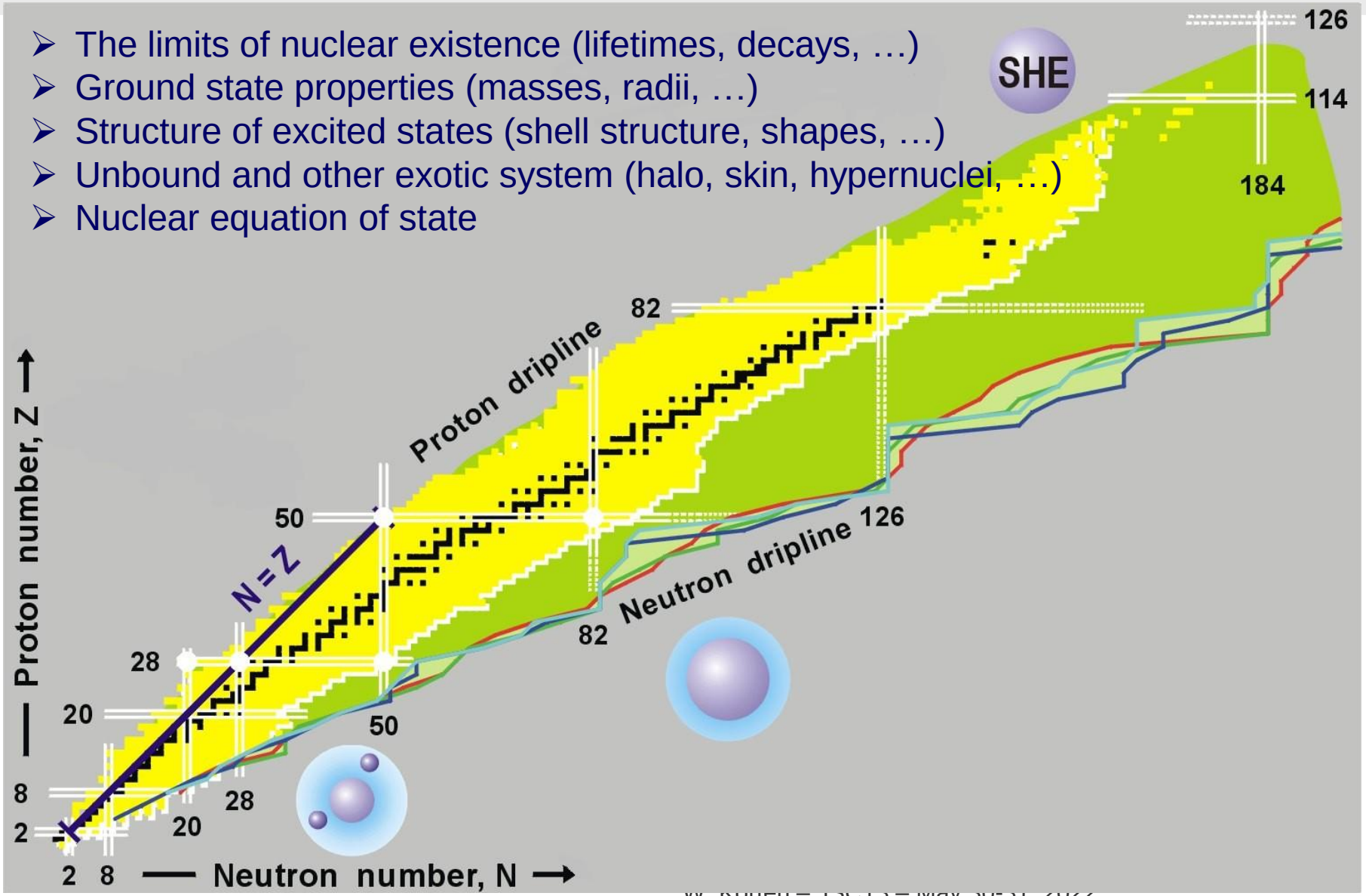


FAIR/GSI strategic operation scenario: ES, FS, towards FS+



NUclear STructure Astrophysics and Reactions

- The limits of nuclear existence (lifetimes, decays, …)
- Ground state properties (masses, radii, …)
- Structure of excited states (shell structure, shapes, …)
- Unbound and other exotic system (halo, skin, hypernuclei, …)
- Nuclear equation of state



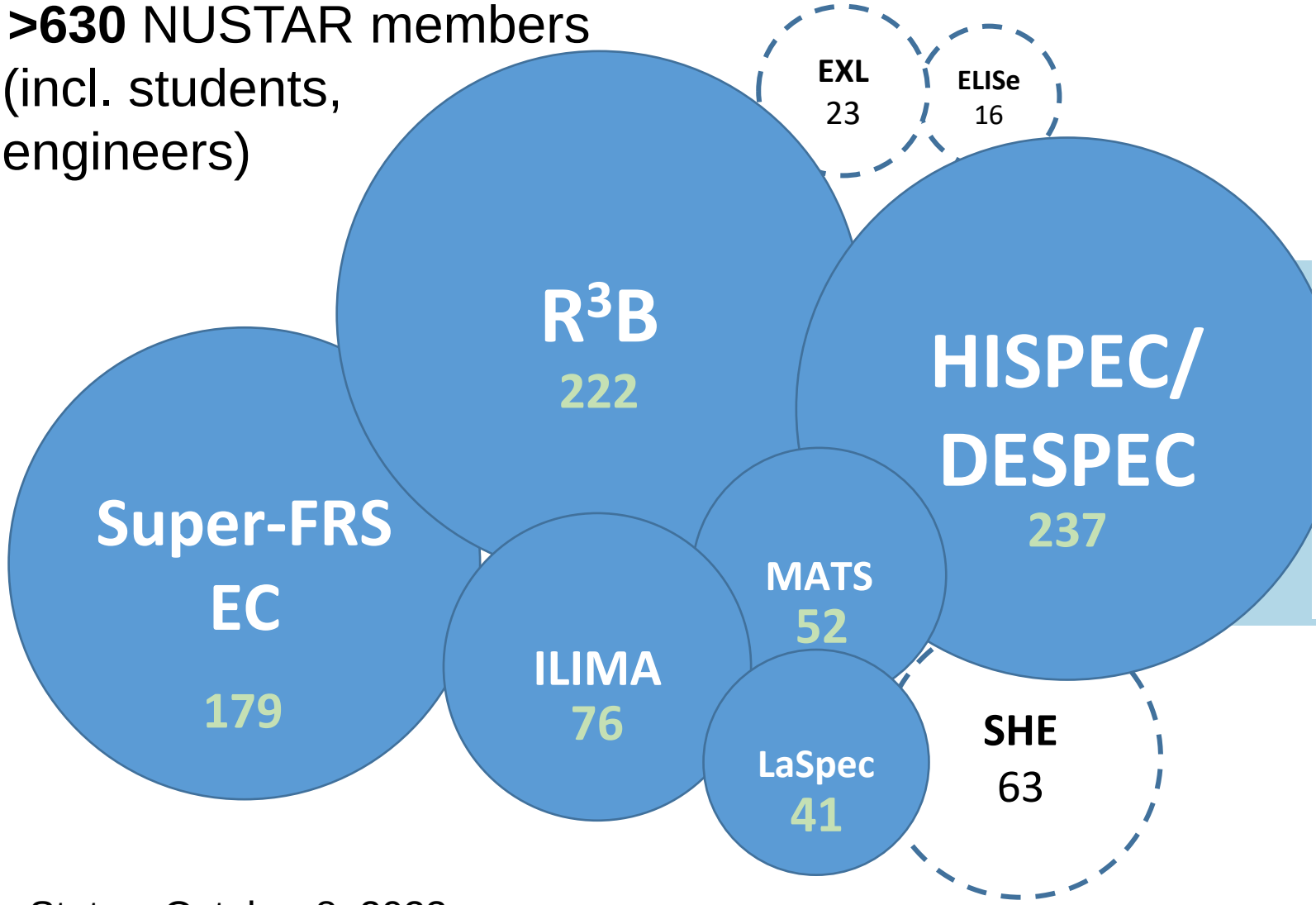
Overarching physics case: the creation of the chemical elements

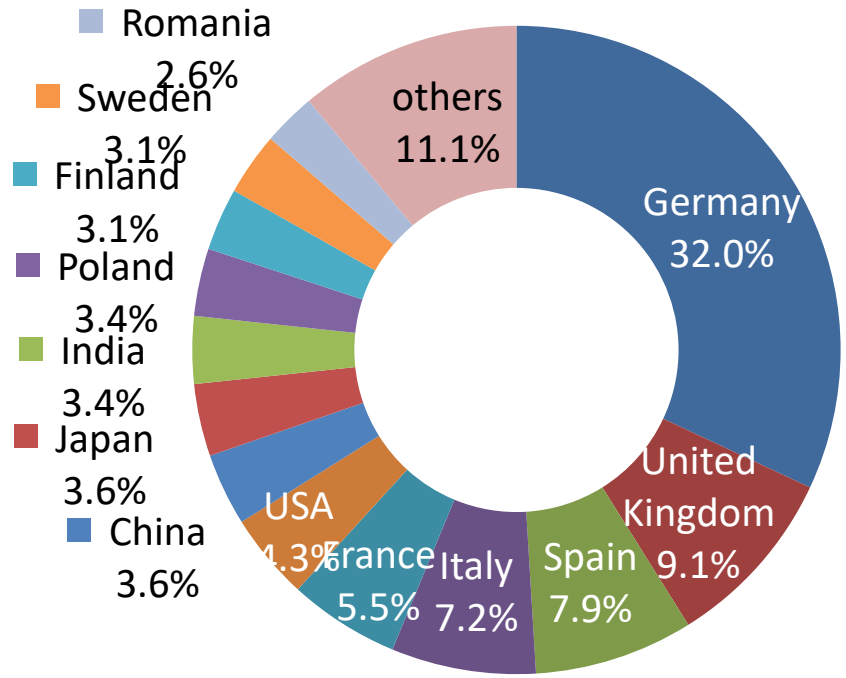
Big physics question needing information on:

- Equation of State
- Limits of existence
- Lifetimes,
- Masses
- P_{xn} values
- Fission
- Reactions in star environments

NUSTAR – a collaboration of collaborations
Sub-collaborations and members (without Russia)

>630 NUSTAR members (incl. students, engineers)





> 1000 listed "interested" scientists

> 630 registered members (incl. students, etc.)

~ 420 senior members (PhD holder w/o Russia)

> 150 institutes from 36 countries

Status: October 8, 2023

Why UK at FAIR?

High energy fragmentation beams (unique)

Storage rings (unique)

International facility (UK associate member)

UK investment so far (~20M?)

UK leadership

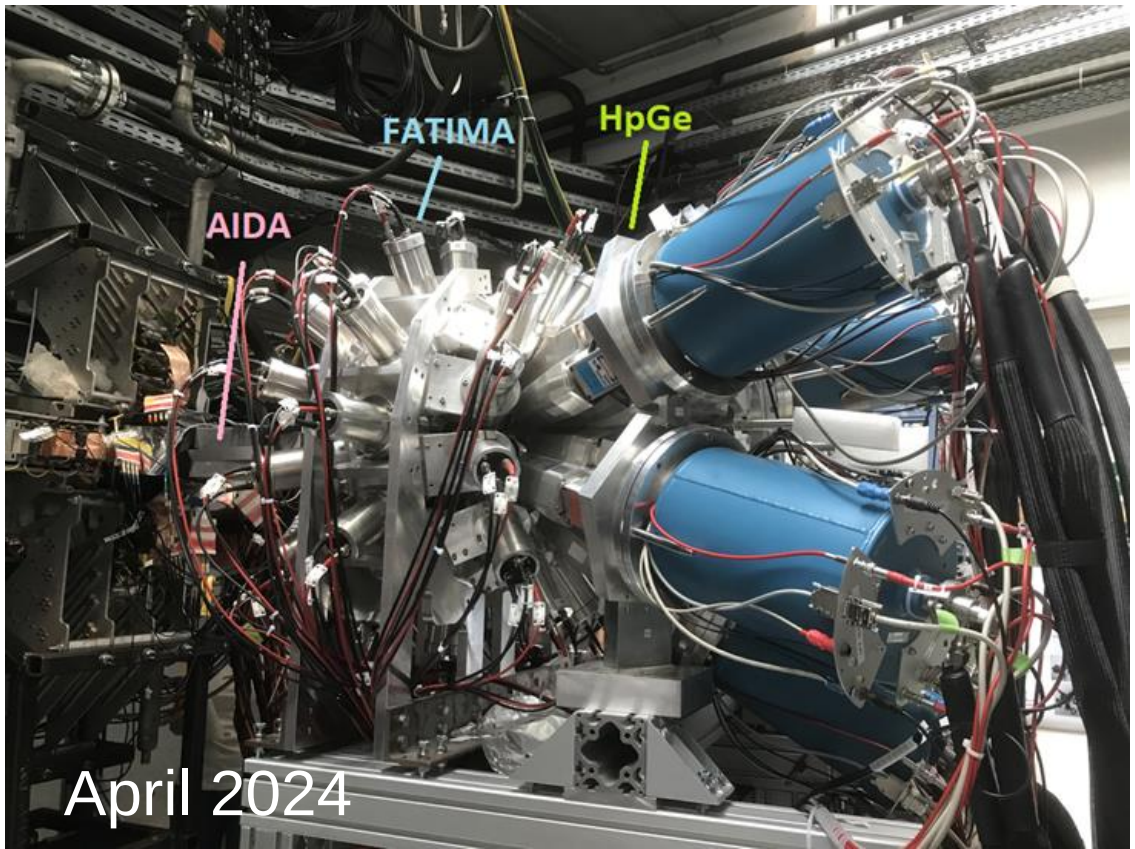
New opportunities (evolving facility)

Main investment in instrumentation so far

AIDA: implantation and decay Si array (Edinburgh, Liverpool, Daresbury, RAL).
FATIMA: LaBr3 array for fast-timing: (Surrey, Brighton, UWS, Manchester, Daresbury, Liverpool).
LYCCA: dE-E array for identification of reaction products (York, Daresbury).
CARME: Si array in storage ring (Edinburgh, Liverpool, Daresbury, RAL).
Target-recoil detector: Si for light ion detection (York, Daresbury, Liverpool)

AGATA as travelling detector

(AIDA and FATIMA also at RIKEN etc)



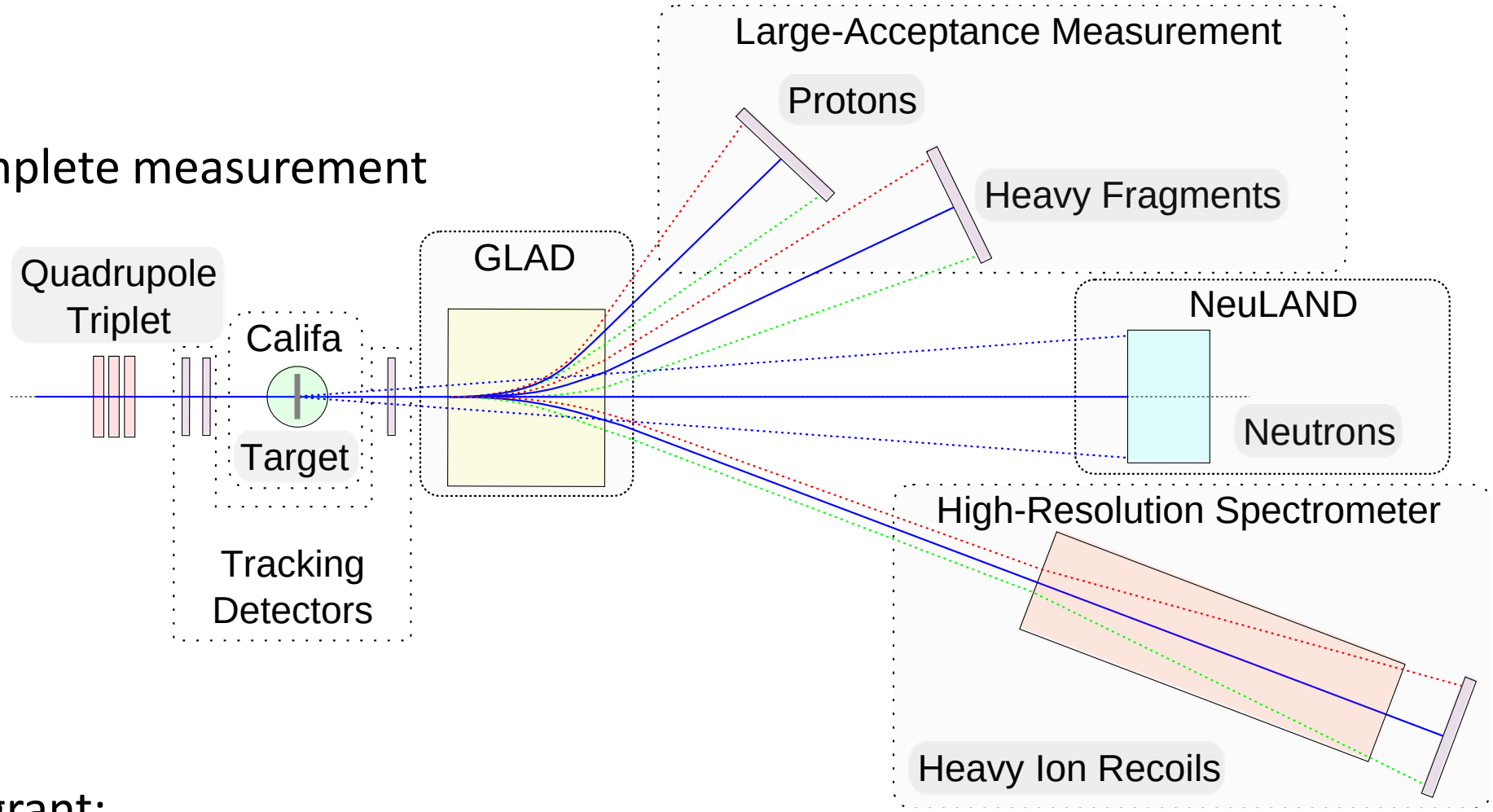
UK leadership roles

NuSTAR:
NuSTAR spokesperson (from 1 March 2024): Zsolt Podolyák (Surrey)
R3B Management Board, Scientific Director: Marina Petri (York)
LaSpec spokesperson: Bradley Cheal (Liverpool)
SHE (superheavy elements) spokesperson: Rolf-Dietmar Herzberg (Liverpool)
EXL deputy spokesperson: Marina Petri (York)

FAIR committees:
Council: Helen Beadman (STFC)
RRB (resource Review Board): Georgina Freeman (STFC), Jenny Hiscock (STFC), Zsolt Podolyak
AFC (Administrative and Finance Committee): Georgina Freeman (STFC)
AOCWG (AFC Operation Cost Working Group) : Christos Touramanis (Liverpool)
Chair of ECSG (Experiments Costs Scrutiny Group): Christos Touramanis (Liverpool)
Chair of BFC (Board of FAIR Collaborations) (in 2024): Zsolt Podolyák (Surrey)
GSI/FAIR Joint Scientific Council: Marialuisa Aliotta (Edinburgh)

Enhancing the R3B capabilities: High-Resolution Spectrometer

Kinematically complete measurement



Infrastructure grant:

£24M (capital and staff) over 7 years (it was part of a previous infrastructure request) in 2020

M. Petri

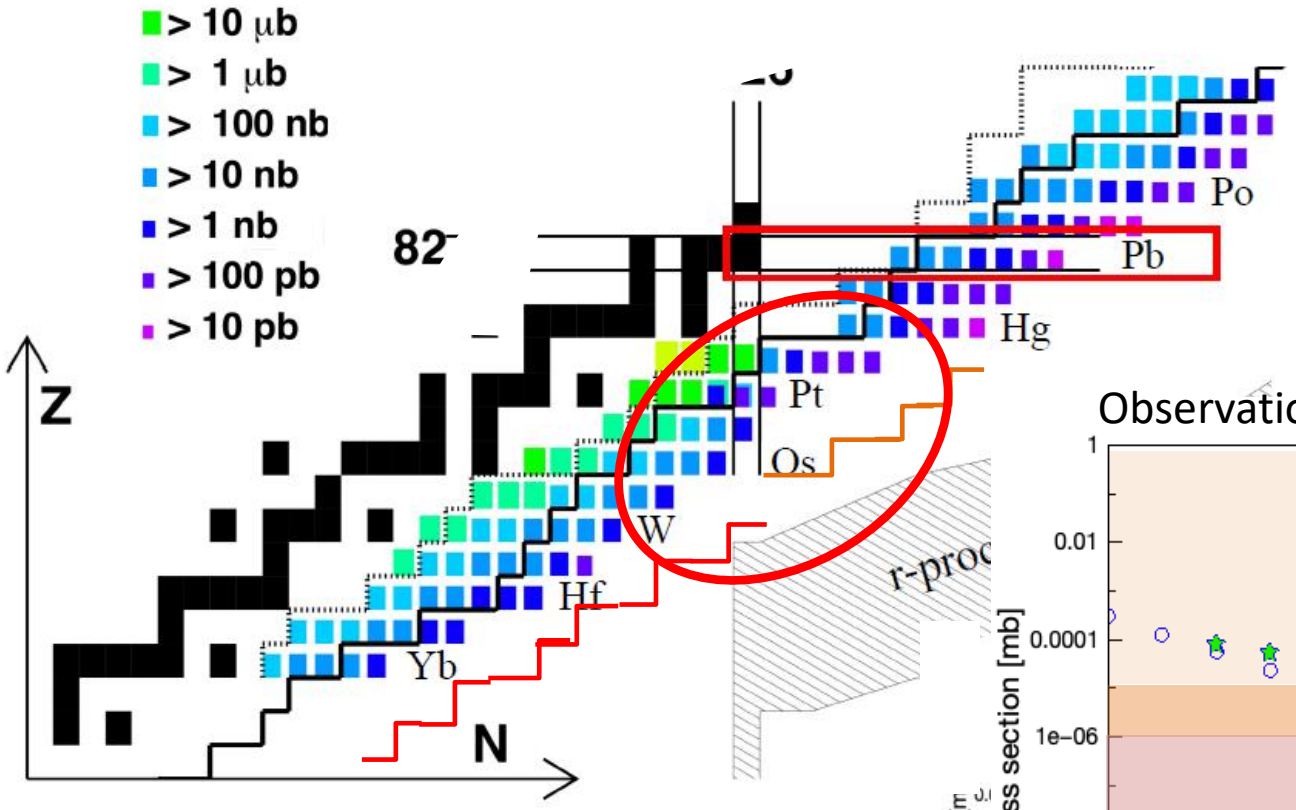
R^3B physics program with HRS

Reaction type	Physics goals
Knockout	Shell structure, valence-nucleon wave function, many-particle decay channels, unbound states, nuclear resonances beyond the drip lines
Quasi-free	Single-particle spectral functions, shell-occupation probabilities, nucleon-nucleon correlations, cluster structures
Total-absorption measurements	Nuclear matter radii, halo and skin structures
Elastic p scattering	Nuclear matter densities, halo and skin structures
Heavy-ion induced electromagnetic excitation	Low-lying transition strength, single-particle structure, astrophysical S factor, soft coherent modes, low-lying resonances in the continuum, giant dipole (quadrupole) strength
Charge-exchange reactions	Gamow-Teller strength, soft excitation modes, spin-dipole resonance, neutron skin thickness
Fission	Shell structure, dynamical properties
Spallation	Reaction mechanism, astrophysics, applications: nuclear-waste transmutation, neutron spallation sources
Projectile fragmentation and multifragmentation	Equation-of-state, thermal instabilities, structural phenomena in excited nuclei, γ-spectroscopy of exotic nuclei

Superior mass resolution necessary for heavy beams

M. Petri

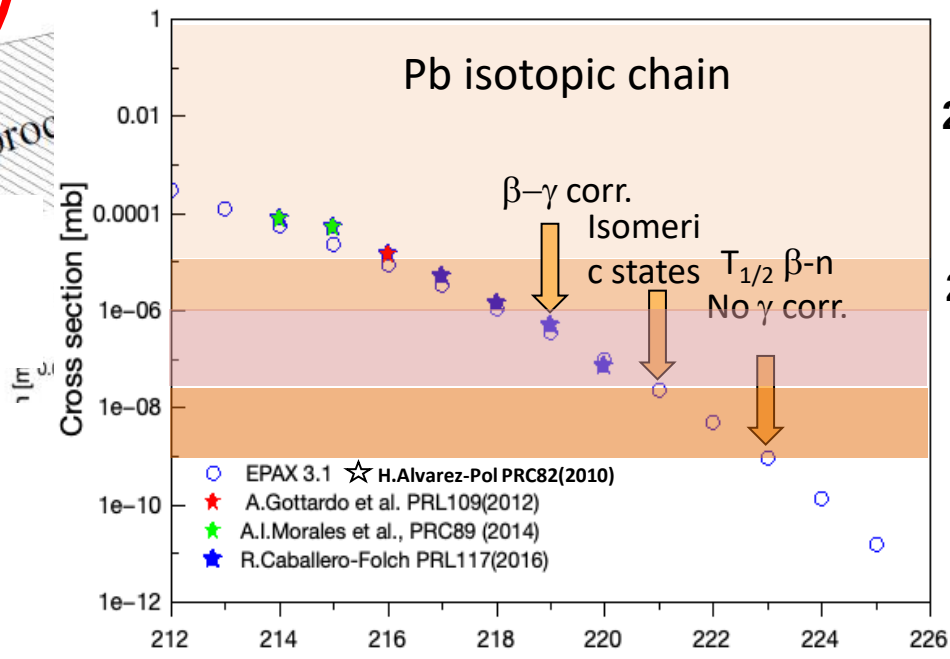
Structure of N~126 nuclei to elucidate the r-process path



Evolution of single-particle orbitals
First-forbidden beta decay

=> improved mass and $T_{1/2}$ predictions for the r-process

Observation limit before and with DESPEC



2009 RISING campaign ε_γ = 16.2%

2022 DESPEC@Phase-0 ε_γ = 21.2%
Early Science
First Science

Improved transmission and separation from Super-FRS
Improved γ efficiency
Faster DAQ

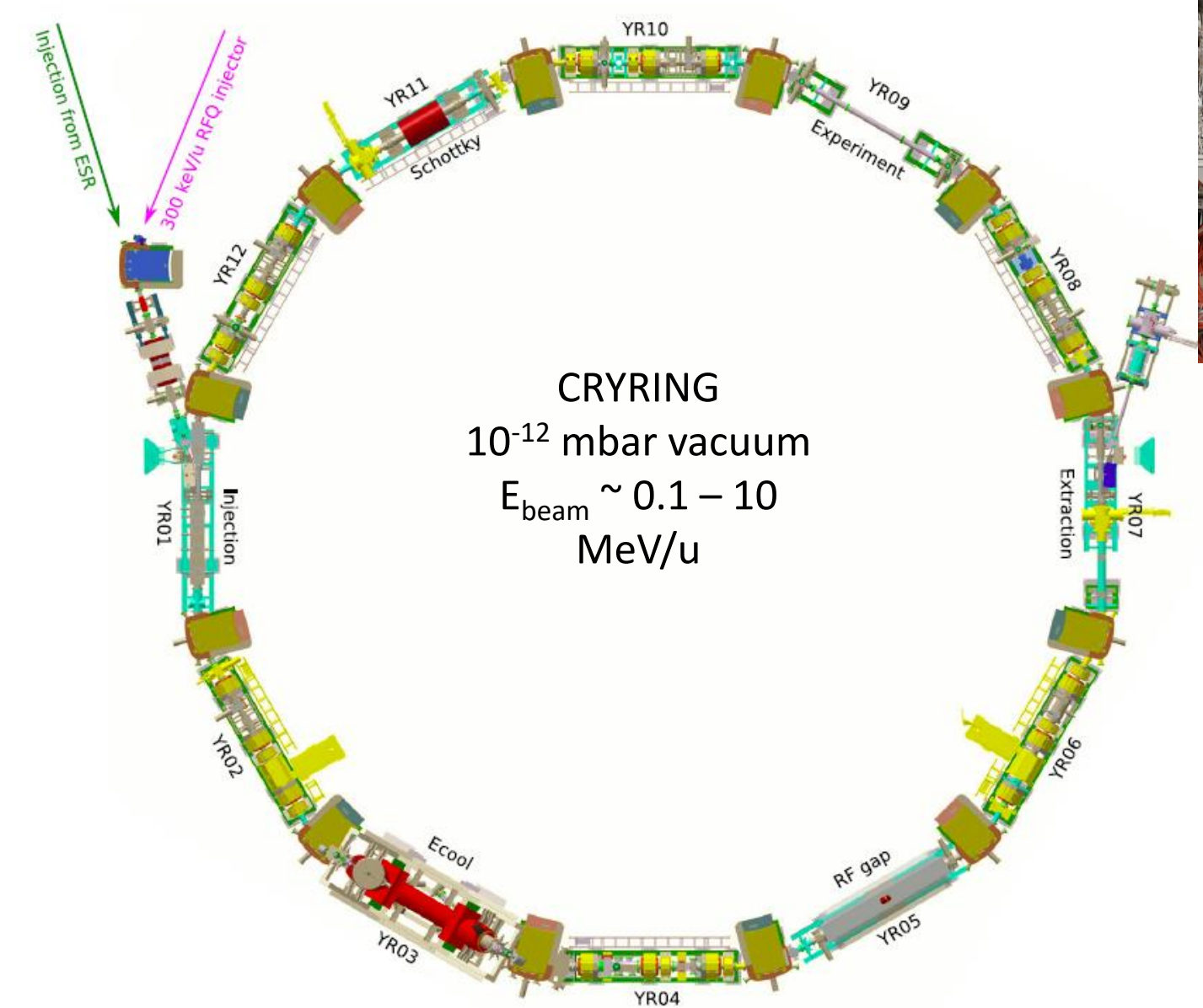
10^{-10} mb limit

10^{-9} mb limit

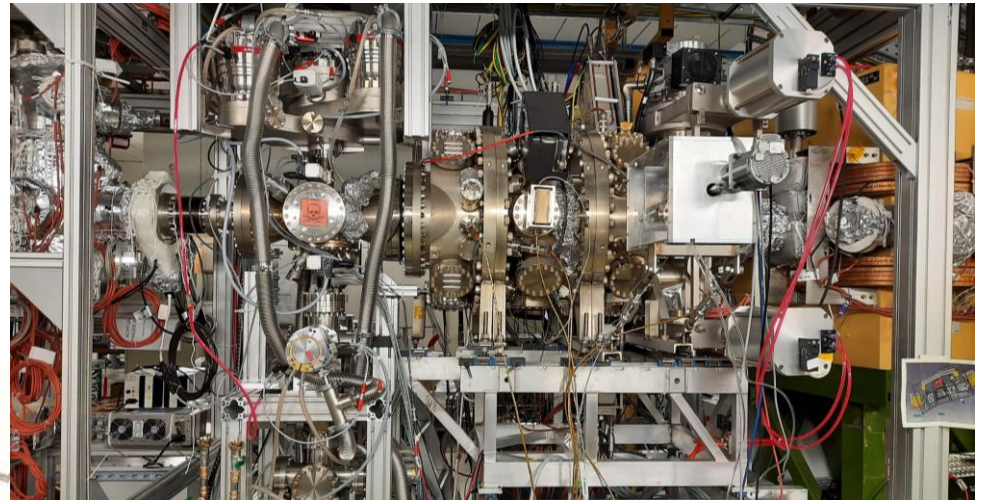
Low-energy branch (LEB):DESPEC, LASPEC, MATS

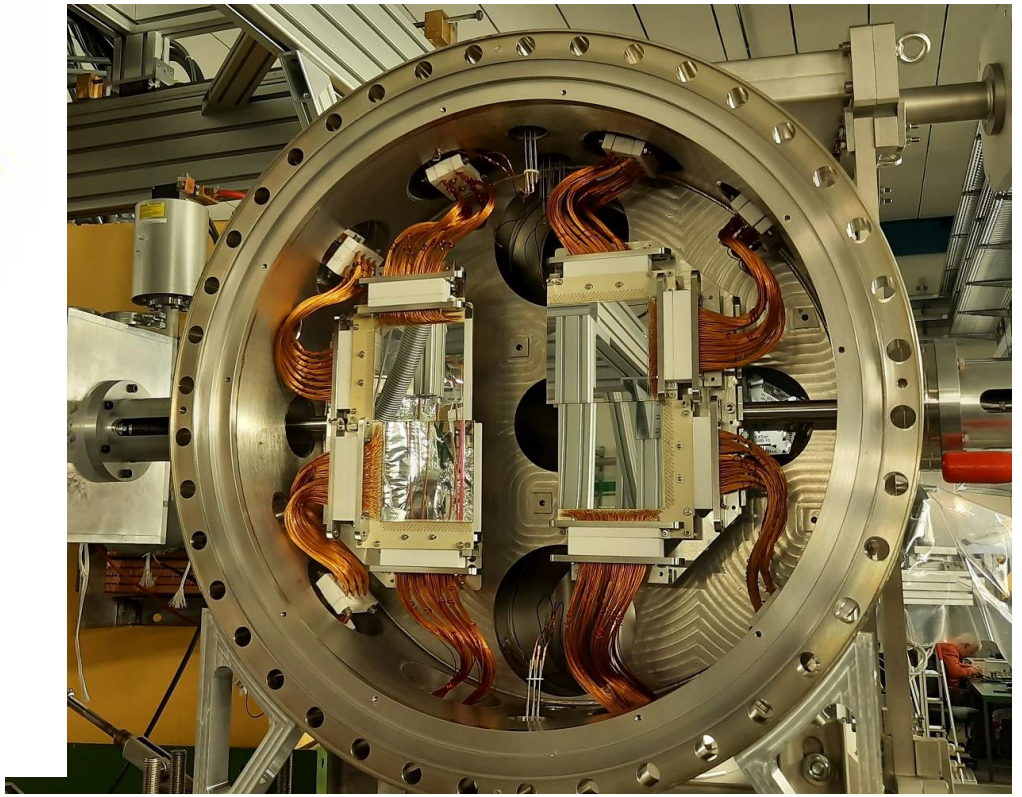
CARME @ CRYRING

From ESR or
300 keV/u injector



CRYRING
10^{-12} mbar vacuum
E_{beam} ~ 0.1 – 10 MeV/u





From C. Bruno

CARME SCIENCE PROGRAMME

World-unique opportunity to use cooled, recirculating beams produced in-flight to impinge on ultra-pure gas targets at energies relevant for astrophysical scenarios. No other rings like this in the world.

- **Designed & constructed via the ISOL-SRS Project** (PI PJ Woods, Edinburgh)
- Programme supported primarily via the ELDAR ERC StG (PI CG Bruno, Edinburgh) until 2028
- Vacuum commissioning completed in 2021 (CG Bruno *et al.*, NIM A 1048 (2023) 168007)
- Commissioning with beam completed in 2022 – first beam on conventional target for FAIR! (JJ Marsh *et al.*, EPJ A 60 (2024) 95)
- **Four** weeks of beam (local source) awarded in 2024 – extremely successful
  - ✓ $^{16}O(\alpha,\alpha)^{16}O$: classical novae (PI CG Bruno)
  - ➢ $^{6}Li(p,\alpha)$: electron screening (PI JJ Marsh, Edinburgh)
  - ➢ $^{15}N(p,\alpha\gamma)$: electron screening (PI JJ Marsh, Edinburgh)
  - ➢ $^{2}H+^{2}H$: Big Bang Nucleosynthesis (PI CG Bruno + J Glorius (GSI) + E Masha (Dresden))

(Some) future plans

- First experiments with radioactive beams at CRYRING
- Expand programme on ultra-low energy nuclear astrophysical reactions
- Expand electron screening measurements

From C. Bruno

UK opportunities, science case

exploiting the uniqueness of FAIR, such as high energy fragmentation beams and storage rings, capitalising on existing UK leadership to

-perform high energy kinematically complete measurements to address short-range correlations, quasi-free scattering, knockout, breakup etc. reactions,

-to study the properties of the most exotic (neutron and proton rich nuclei) via decay experiments, nuclear reactions (with AGATA), laser spectroscopy etc,

-perform low energy nuclear reaction measurements at existing and future storage rings for nuclear astrophysics, also addressing electron screening,

-to study the properties of superheavy elements, involving chemical, reaction, structure studies (also laser spectroscopy).

Goals, budget

Goals:

-Exploit the new science opportunities offered by the multidisciplinary environment (nuclear, atomic, biology, lasers) offered by FAIR in a coordinated way.

-Establish a sustained funding model for the exploitation of the existing capabilities.

- Drive the physics focusing on the future capabilities via development of experimental equipment.

Budget: investment to update present detection systems and establish **new capabilities connected to new infrastructure (e.g. laser spectroscopy in the low-energy cave, superheavy elements at the HELIAC accelerator, new storage ring (CR) related instrumentation**; all areas where the UK has leadership).

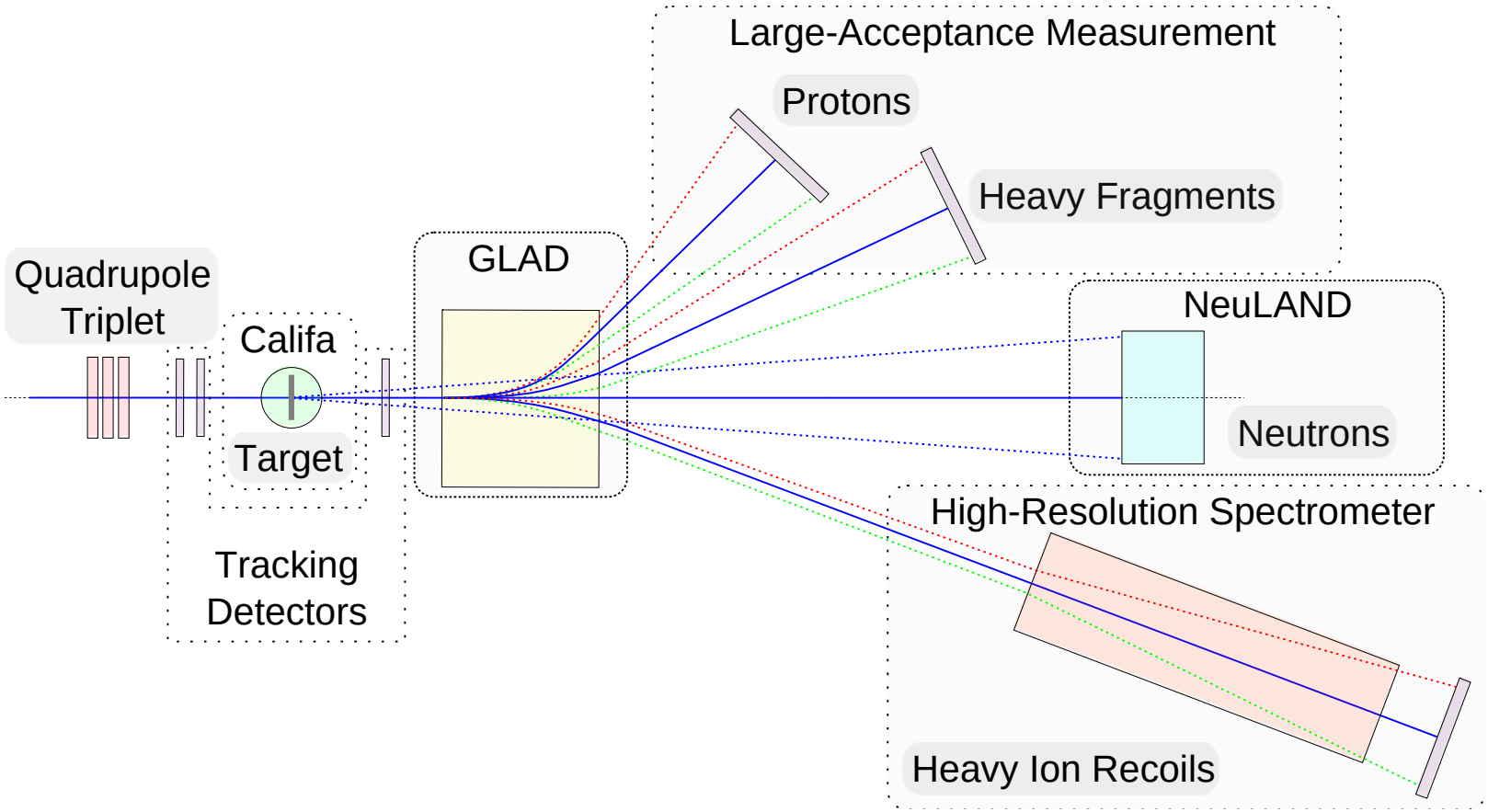
Based on past **investments (PPRP)** the estimated cost is **~£10M**

In addition, funds are needed to **exploit** the facility via long term visiting researchers, PhD studentships (£5M).

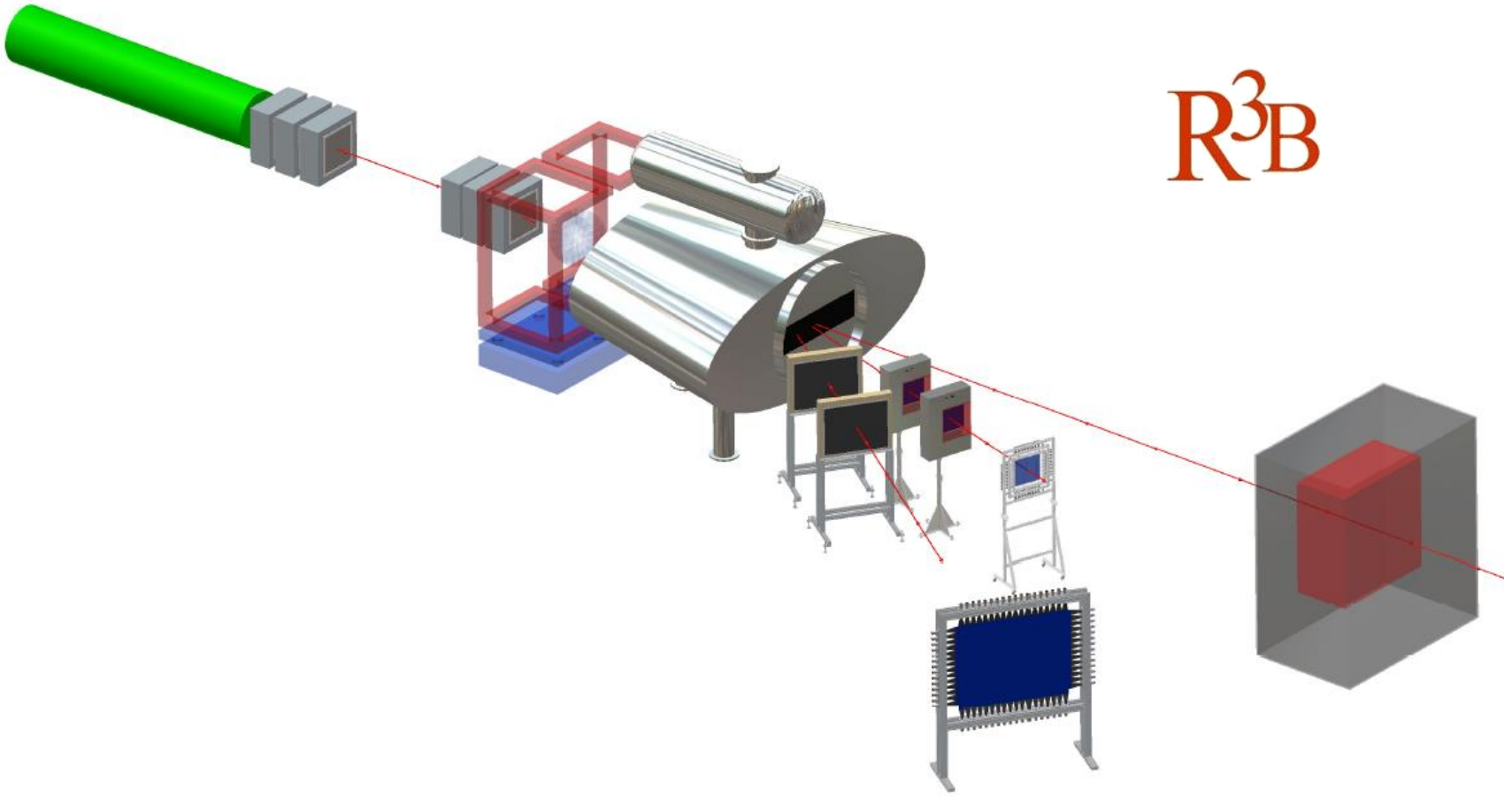
Infrastructure funds for the R3B High Resolution Spectrometer (Marina Petri). ~24M

THANKS

Enhancing the R3B capabilities at FAIR with a High-Resolution Spectrometer



- R^3B versatile setup, kinematically complete measurements of reactions with high-energy RIB
- GLAD allows bending of 15Tm beams at 18^o and enables large acceptance neutron detection



R^3B physics program

Reaction type	Physics goals
Knockout	Shell structure, valence-nucleon wave function, many-particle decay channels, unbound states, nuclear resonances beyond the drip lines
Quasi-free	Single-particle spectral functions, shell-occupation probabilities, nucleon-nucleon correlations, cluster structures
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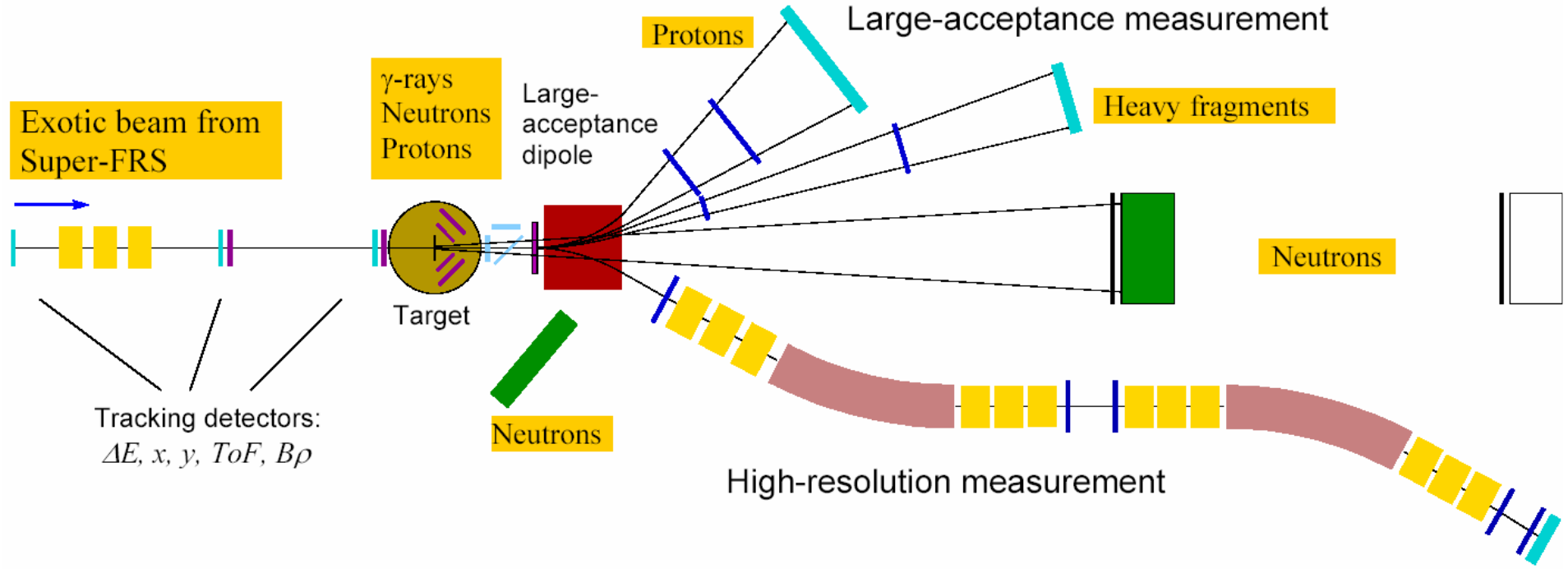
Fission	Shell structure, dynamical properties
Spallation	Reaction mechanism, astrophysics, applications: nuclear-waste transmutation, neutron spallation sources
Projectile fragmentation and multifragmentation	Equation-of-state, thermal instabilities, structural phenomena in excited nuclei, γ-spectroscopy of exotic nuclei

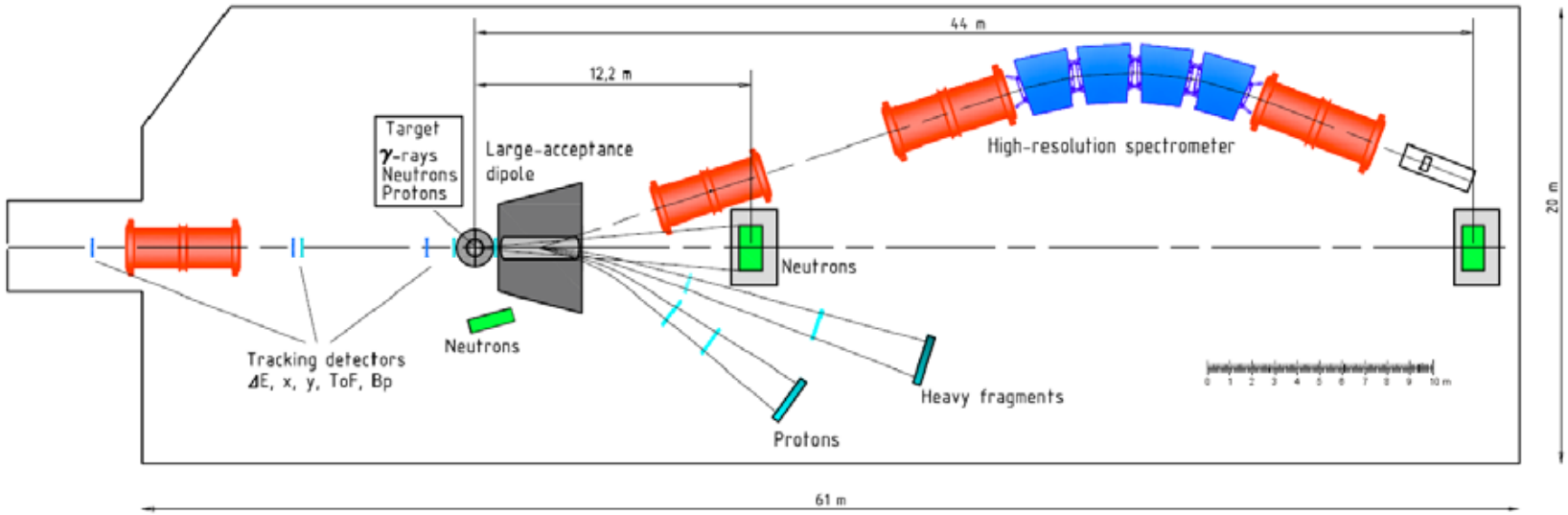
The R^{3}B experimental concept

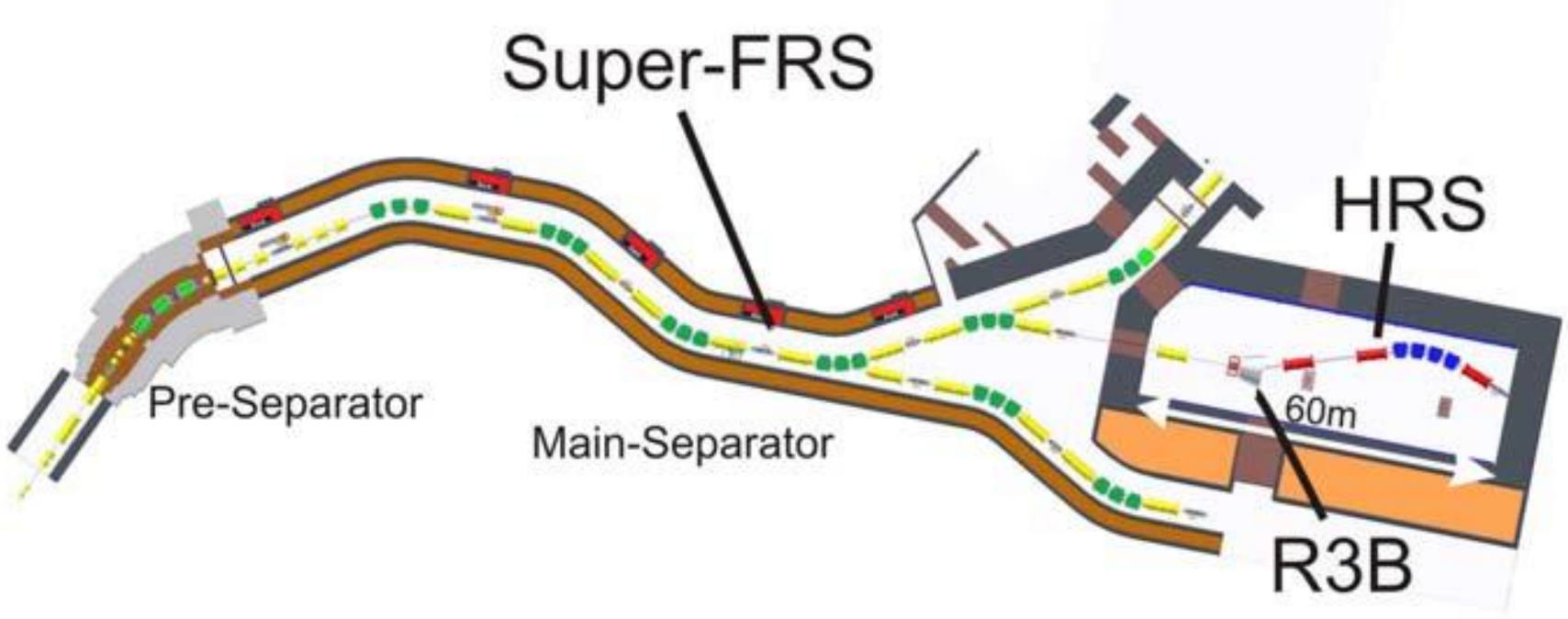


- Large-acceptance mode: $\Delta B\rho/B\rho \sim 10^{-3}$, -5 to 41 degree, ±80 mrad vert. acceptance
- High-resolution mode: $\Delta B\rho/B\rho \sim 10^{-4}$, ±2.5% mom. acc., ±80 mrad vert. at 0 degree

R^{3}B Letter of Intent (April 2004)
R^{3}B Technical Proposal (Dec 2005)

Possible layout of R3B with high-resolution





R^3B physics program with HRS

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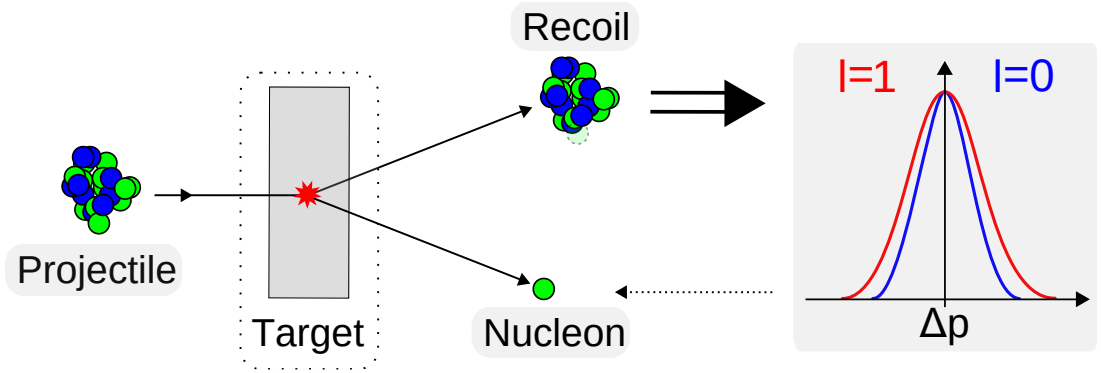
Knockout/QFS reactions

- Information on single particle structure of valence and deeply bound nucleons in exotic nuclei
- For medium and heavy beams → high-energy beams for fully stripped ions → momentum resolution 10^{-4}

Momentum resolution 10^{-4}

- For a 1 GeV/u ^{220}Pb (i.e. momentum 370 GeV/c) we can only distinguish different angular momenta if we measure momentum distribution with high resolution

  (i.e. 10^{-4} resolution translates to ~40 MeV/c (sigma))



E.g. Recoil momentum widths:
75 MeV/c for l=0 and
100 MeV/c for l=1

R^3B physics program with HRS

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Superior mass resolution necessary for heavy beams

Profiling

This project will be divided into two phases:

- 1) (First Phase) Finalising the design of the R3B HRS, utilising postdoctoral research effort and ion-optics engineering support to explore and simulate the resolution response arising from combinations of elements within the spectrometer system.

- 2) (Construction Phase) Constructing the R3B HRS following the Technical Design Report developed in the first phase.

The UK has the opportunity to invest in both phases and take the lead in the construction of the R3B HRS

Budget

£24M (capital and staff resources) over 7 years (2 years for first phase and 5 years construction phase)

This project will catalyse the UK's position in FAIR science programme and gives a unique opportunity to take the lead in the construction of the High-Resolution Spectrometer at R3B with significant investment. A strategic objective would be to elevate the membership status of the UK from present associate to full member status because of this investment.