Prospects for open quantum system studies at GSI and the way to FAIR

Halo Week `24 - June 9 - 14, Chalmers University of Technology, Gothenburg, Sweden

Haik Simon – GSI Darmstadt

FAIR Construction Site

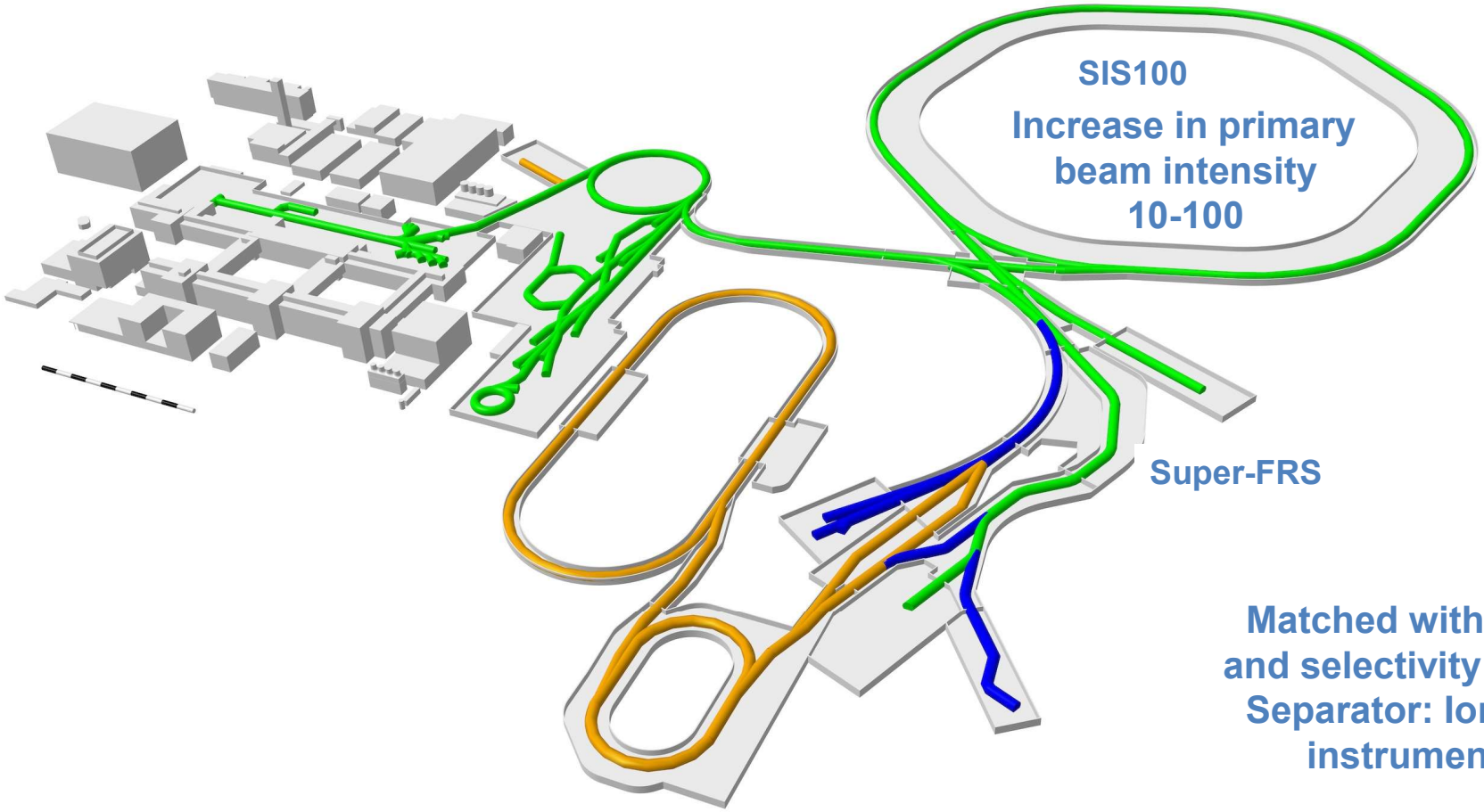
April 2024

April 2024 – Shell construction Finished – Groundbreaking July 2017

FAIR Project Progress – Civil Construction

Construction Area South – Only TBI and landscaping missing

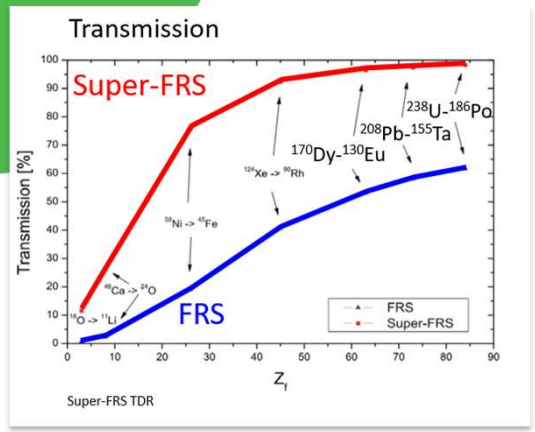
Fair-28: Main Objectives - NUSTAR



Matched with acceptance and selectivity of a versatile Separator: Ion optics and instrumentation …

➔ Experiments

Super-FRS (@SIS18/SIS100) workhorse for NUSTAR

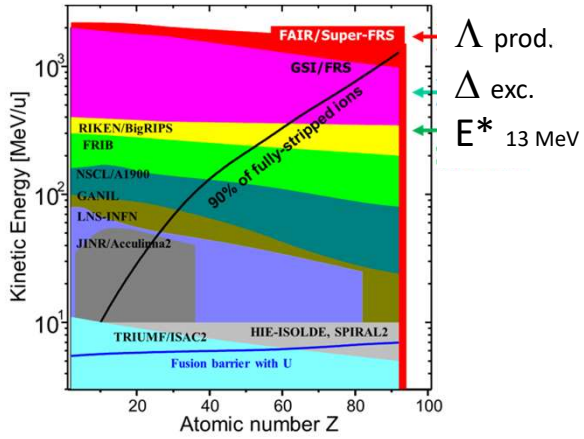


One of worlds most powerful separators for exotic nuclei

Low energy Branch with Energy buncher

High energy Branch

Ring Branch



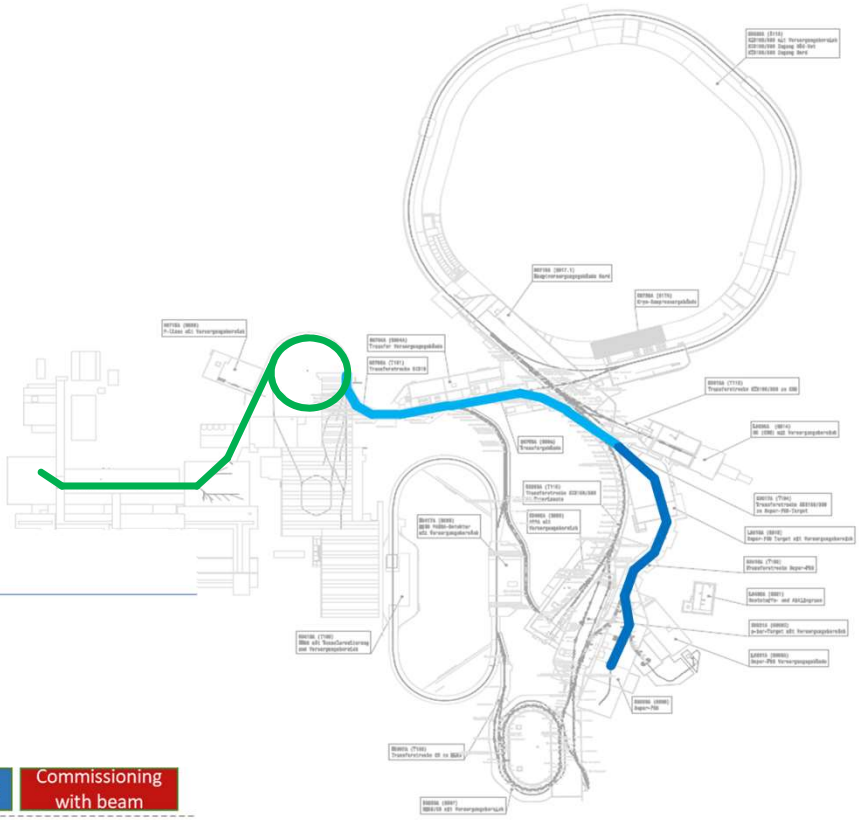
Λ prod.
Δ exc.
E* 13 MeV

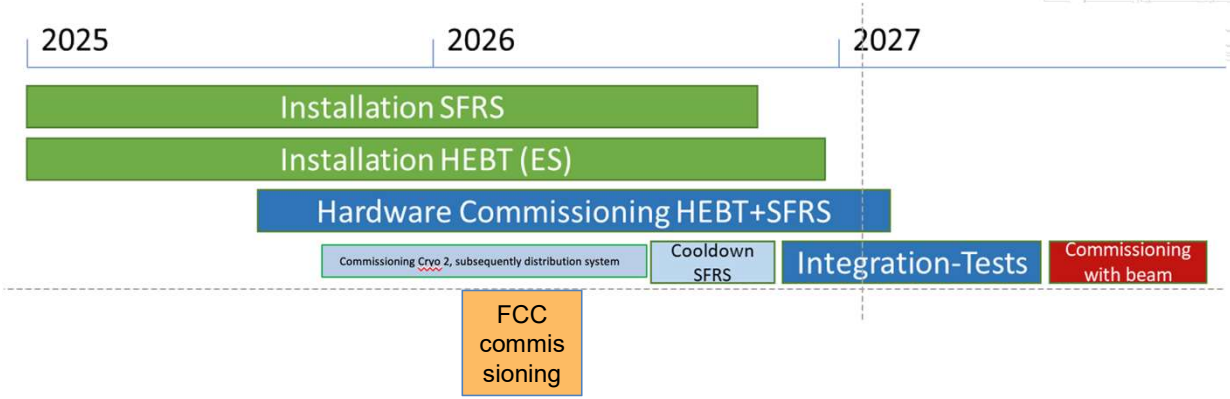
Large acceptance
High rigidity, minimized losses
→ Thick production targets
→ Most effective use of primary beam for experiments

Technical Design Report:
H. Geissel, M. Winkler, H. Weick, et al. (2009)

Early Science Objective

- Start version taking beam from SIS18 via Super-FRS to the High Energy Branch
- Beam intensity increase through optimized beam transport and transmission from SIS18





HE Beam Transport Early Science (SIS18 – Super-FRS)

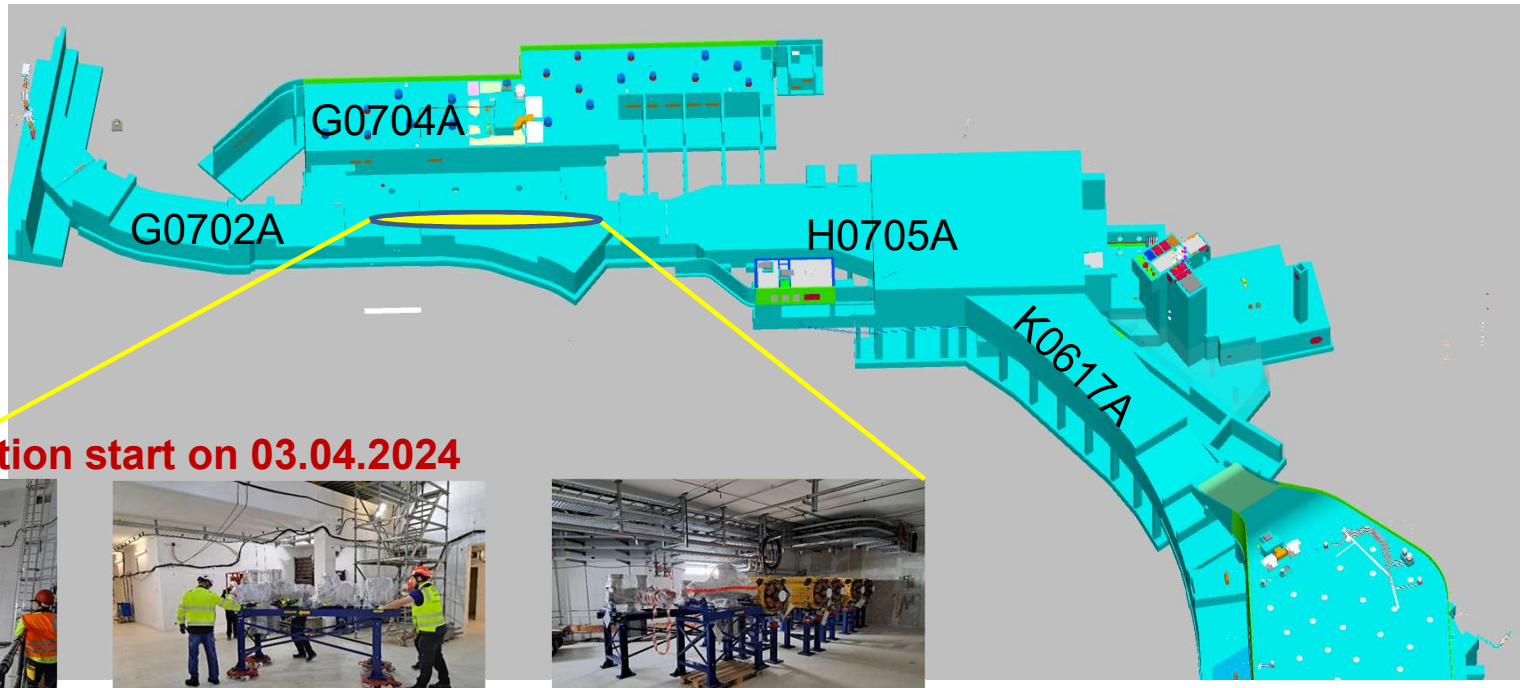
2024				2025				2026				2027			
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4

Installation HEBT Early Science

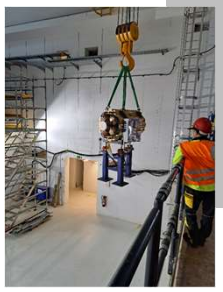
Commissioning HEBT Early Science

Installation HEBT First Science

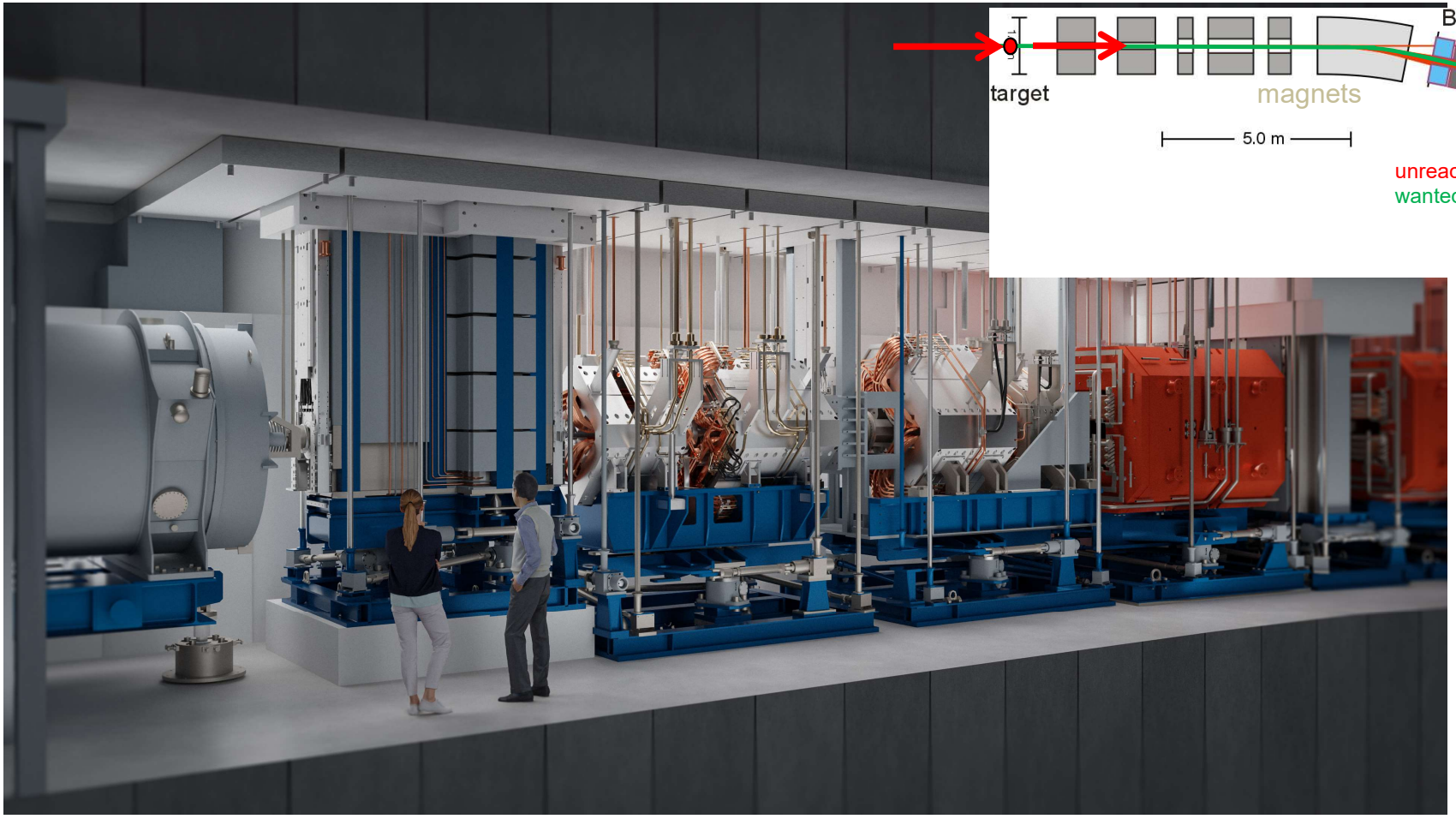
Commissioning HEBT First Science



Installation start on 03.04.2024



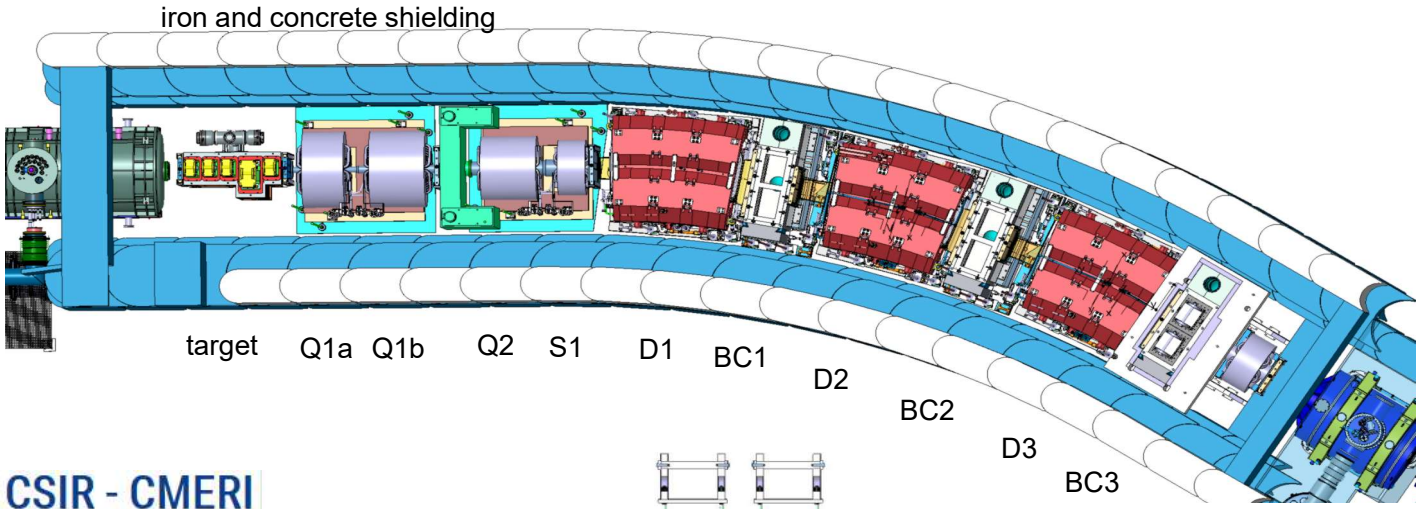
Super-FRS Target area (artists‘ view)



Preselection in
The pre-separator
allows to cope with
100-fold intensity from
SIS-100.

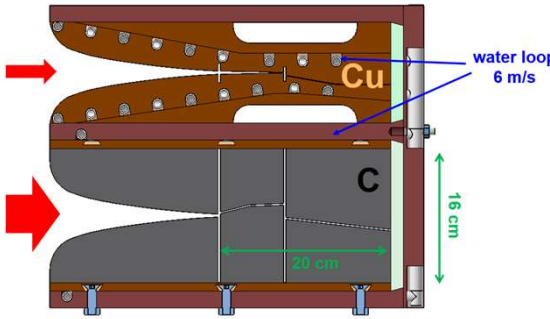
Technically challenging
Radiation area.

Target area components

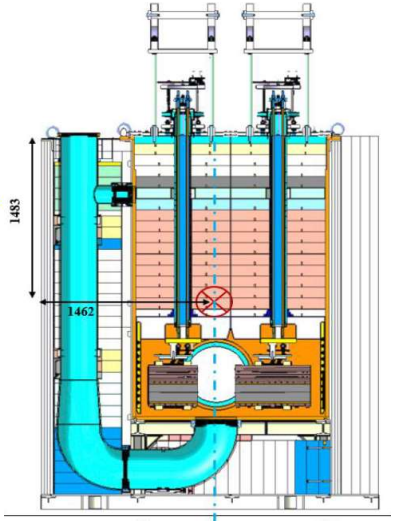


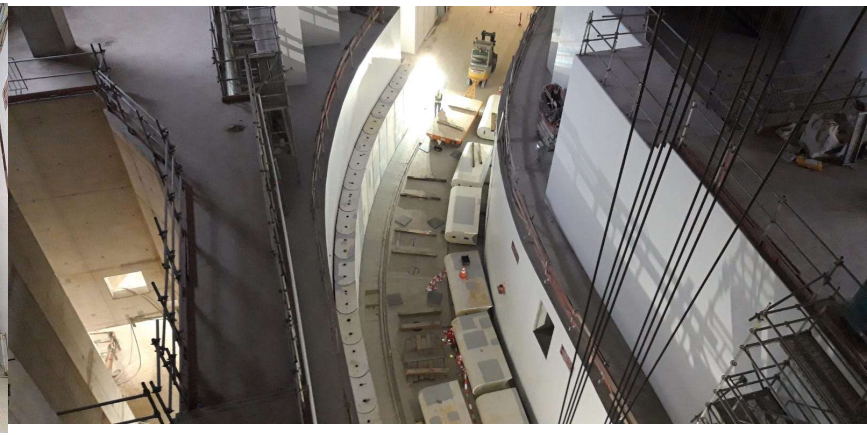
Russian In-kind contributions from BINP (Novosibirsk) IOFFE Institue (St Peterburg) needed replacement !

CSIR - CMERI
सी एस आई आर - केन्द्रीय यांत्रिक अभियांत्रिकी अनुसंधान संस्थान
CSIR - Central Mechanical Engineering Research Institute

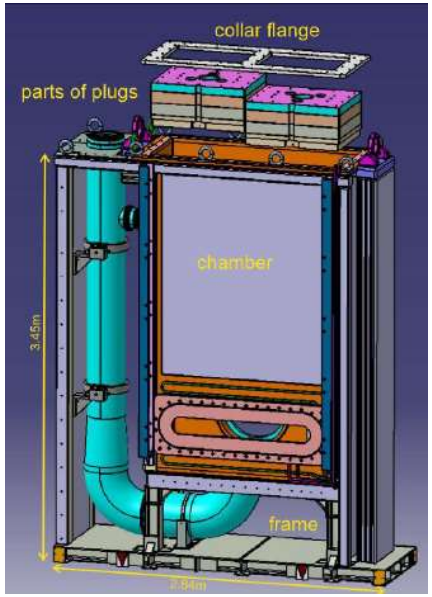


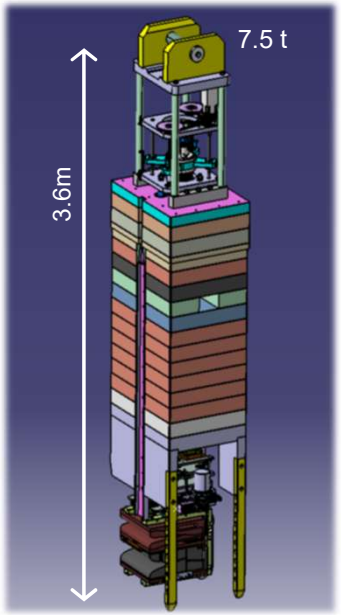
Graphite (SGL R6650) or copper (OFHC) absorber, with water cooled heat sink.





Area of success:
All target component entering production or running





Ex Russian In-kind:
rad-hard Dipoles (2) and Multipoles (2) again in production (Buckley NZ, SigmaPhi F)

Welding test chamber 1:1 at Trident, Kanpur

plug parts

Ex Russian
- vacuum system
- Local cryogenics components
- detectors

Again in production !

Sc Magnets are key components: Testing at CERN of sc magnets


CERN Bulletin

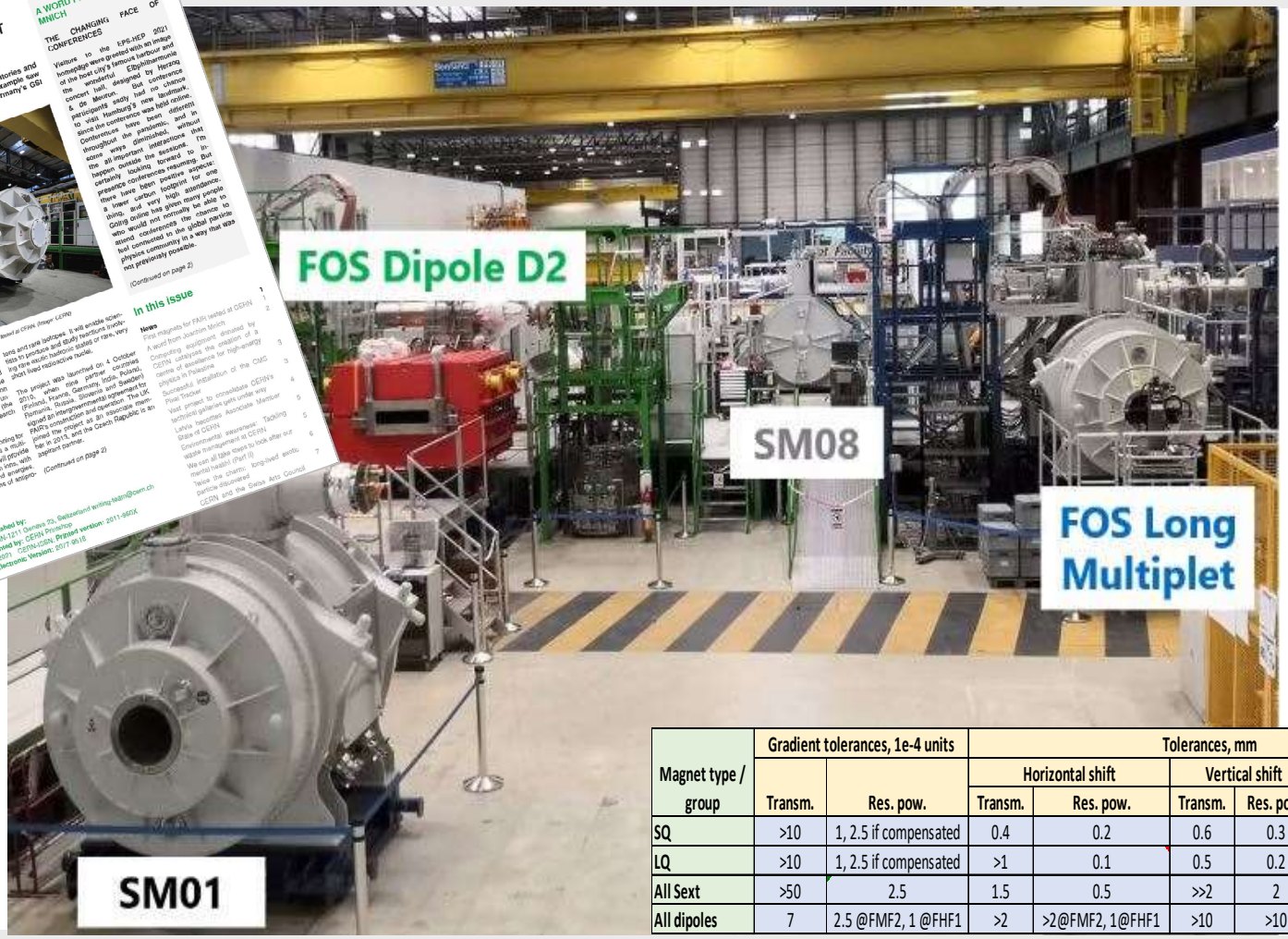
FIRST MAGNETS FOR FAIR TESTED AT CERN

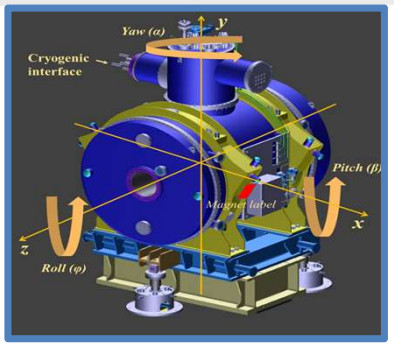
CERN has strong partnerships and collaborations with laboratories and research infrastructures in the Member States. One recent example saw superconducting magnets for the future FAIR facility at Germany's GSI laboratory being tested at CERN

A WORD FROM JOACHIM MNICH

THE CHANGING FACE OF CONFERENCES

In this issue





Very successful tests @ CERN
Ion optical performance well achieved ! (99% done ,,,)

But:
magnet leaks at cold observed

Magnet type / group	Gradient tolerances, 1e-4 units		Tolerances, mm						Tolerances, mrad					
			Horizontal shift		Vertical shift		Longitudinal shift		Pitch		Jaw		Roll	
	Transm.	Res. pow.	Transm.	Res. pow.	Transm.	Res. pow.	Transm.	Res. pow.	Transm.	Res. pow.	Transm.	Res. pow.	Transm.	Res. pow.
SQ	>10	1, 2.5 if compensated	0.4	0.2	0.6	0.3	5	1	>2	>2	>2	>2	≥4	≥0.5
LQ	>10	1, 2.5 if compensated	>1	0.1	0.5	0.2	5	1	>2	>2	>2	>2	≥4	≥0.5
All Sext	>50	2.5	1.5	0.5	>>2	2	5	0.5	>2	>2	>2	>2	≥4	7
All dipoles	7	2.5 @FMF2, 1 @FHF1	>2	>2@FMF2, 1@FHF1	>10	>10	>10	>10	1.7453	0.87266	>20	>10	>2	>2

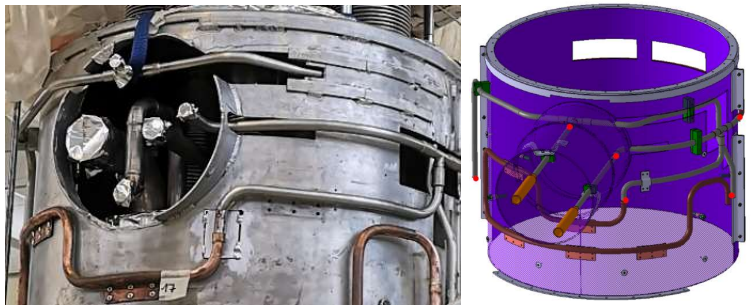
Superconducting Magnets
Re-Entering Series Production after Prototype testing and repair

Technical issues with thermal shield brazing connections

➔

Reworks and Design change was neccessary

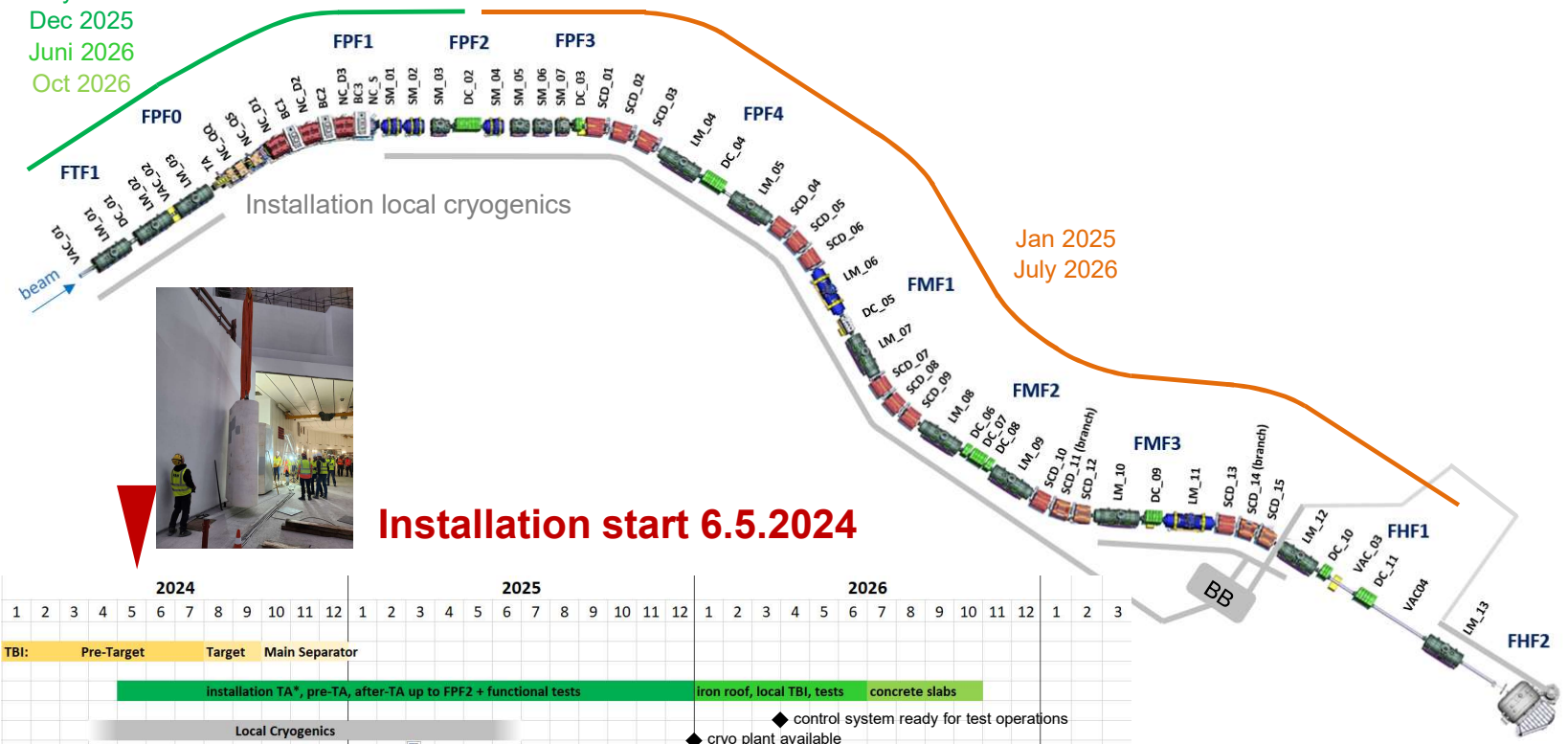
Intense ollaboration with CERN to resolve the issue with manufacturers.



Similar activity with Elytt (Dipoles)
➔ entering series testing if running tests are successful

Overall installation schedule – entering 3 dense years after a lot of stride

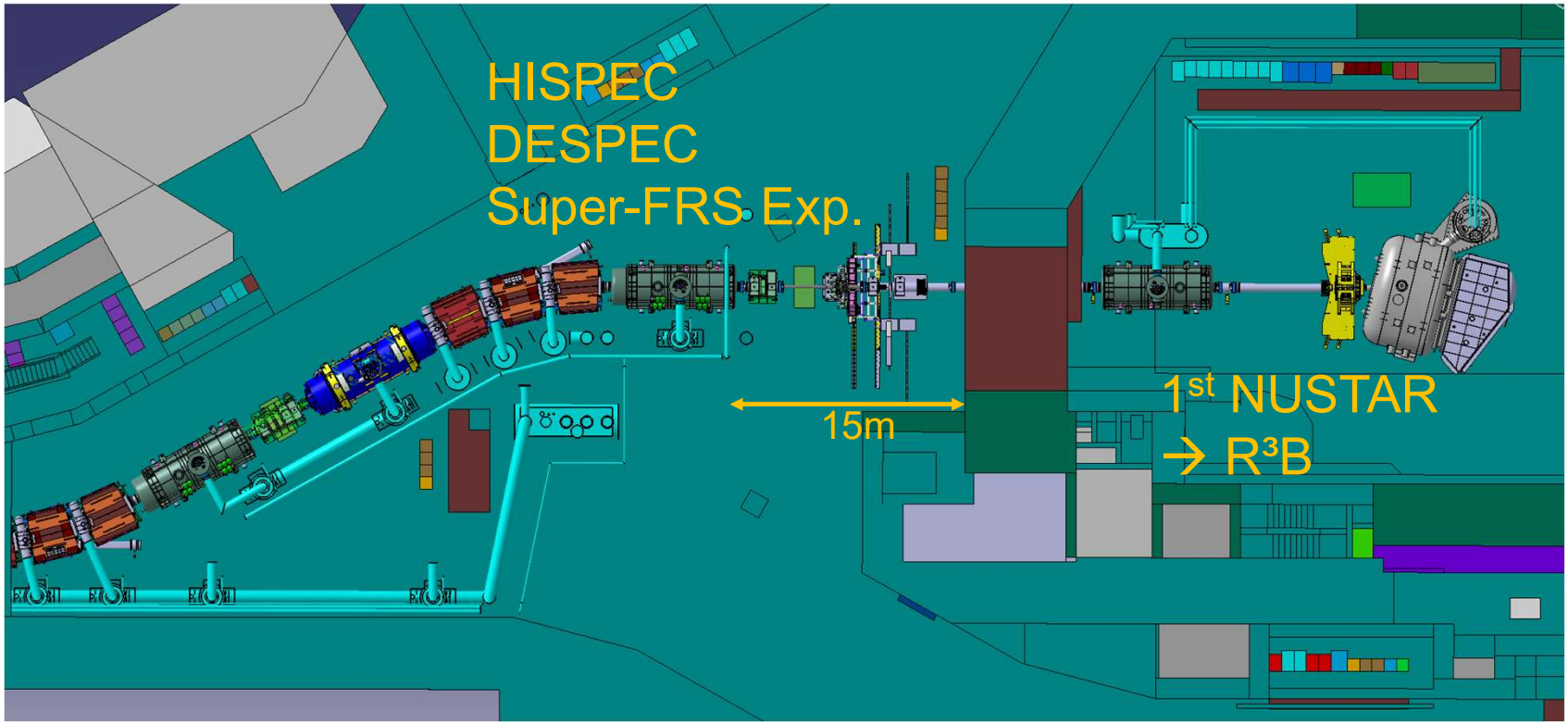
May 2024
Dec 2025
Juni 2026
Oct 2026



Installation start 6.5.2024

Many issues solved
But still some on the way !

Prospects: First stage:
High energy branch R3B/GLAD (and setup @ FHF1)

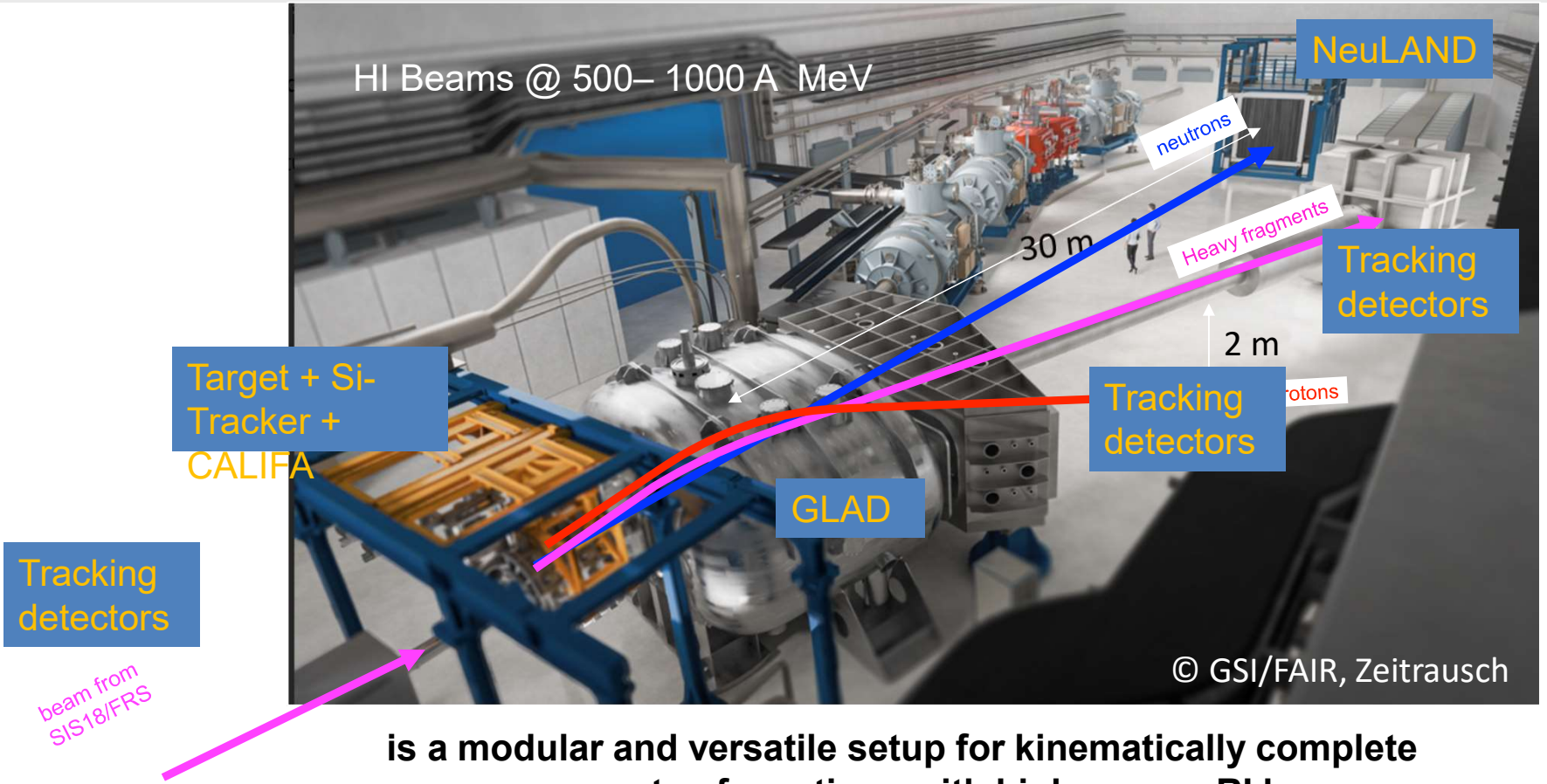


All NUSTAR Experiments possible
(some in start versions @ FHF1)

Exception: ring experiments &
MATS LASPEC @ Super-FRS

R3B experiment

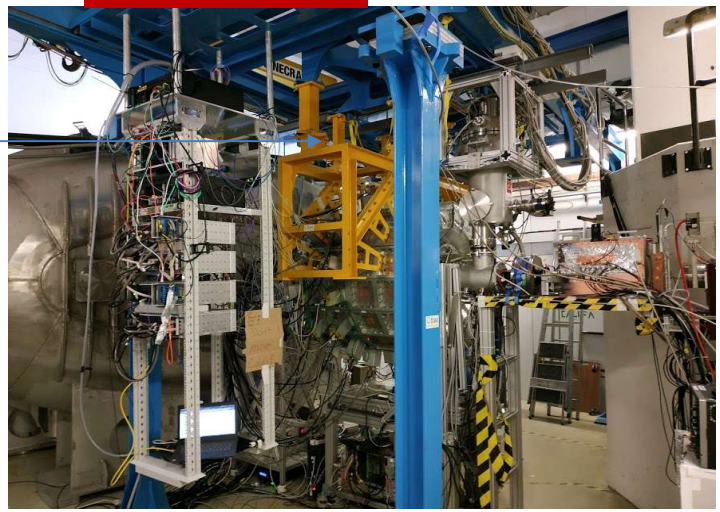
Reactions with **R**elativistic **R**adioactive **B**eams



is a modular and versatile setup for kinematically complete measurements of reactions with high-energy RI beams

R³B in Cave C @ GSI ➔ preparing for FAIR

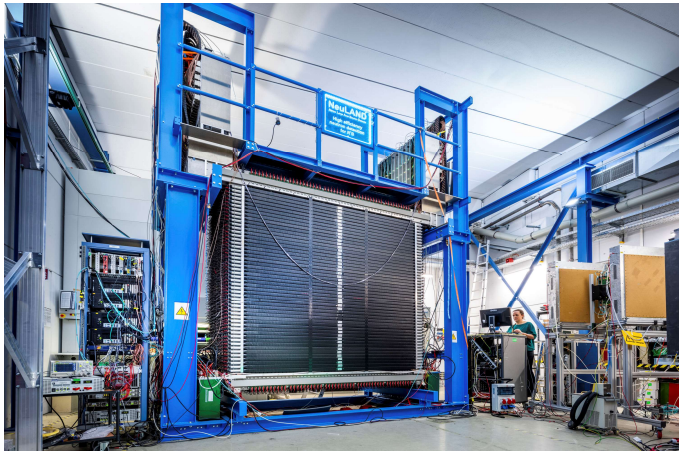
2015 - 2020

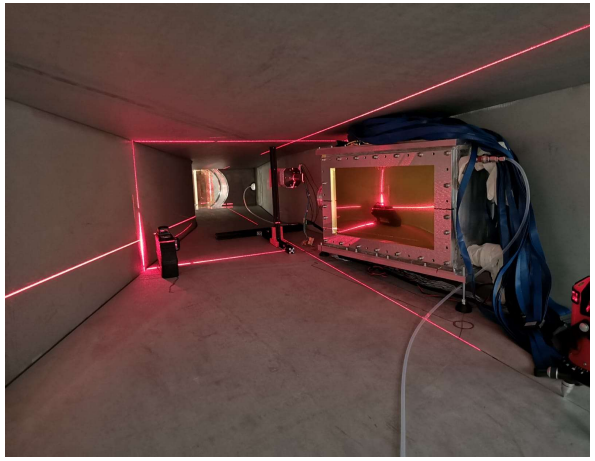


Lola Cortina

R³B in Cave C @ GSI ➔ preparing for FAIR

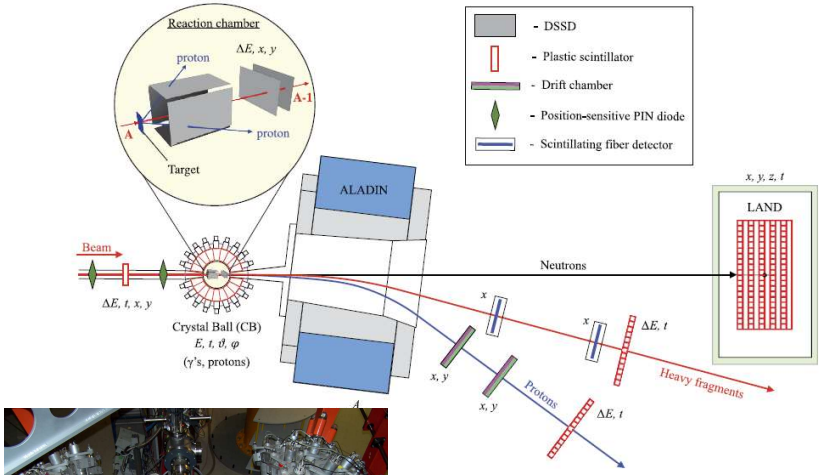
2020 -

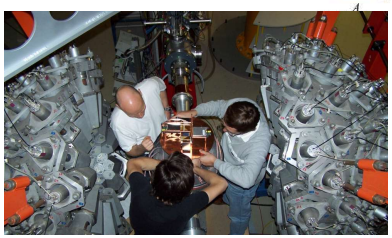


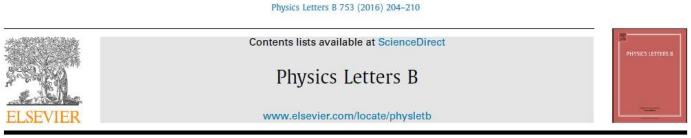


Lola Cortina

First ^{12}C(p,2p) experiment @ 400AMeV
- „R^{3}B prototype setup“

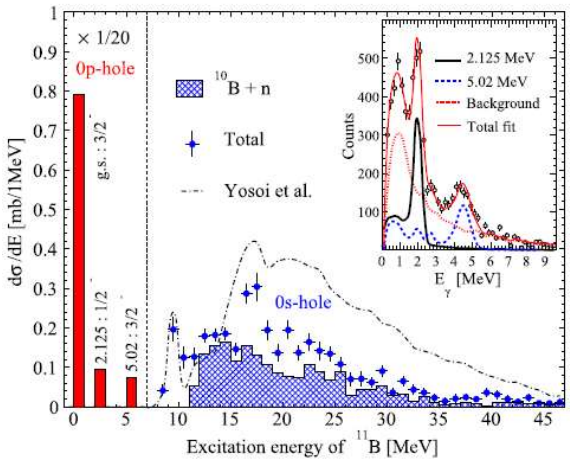




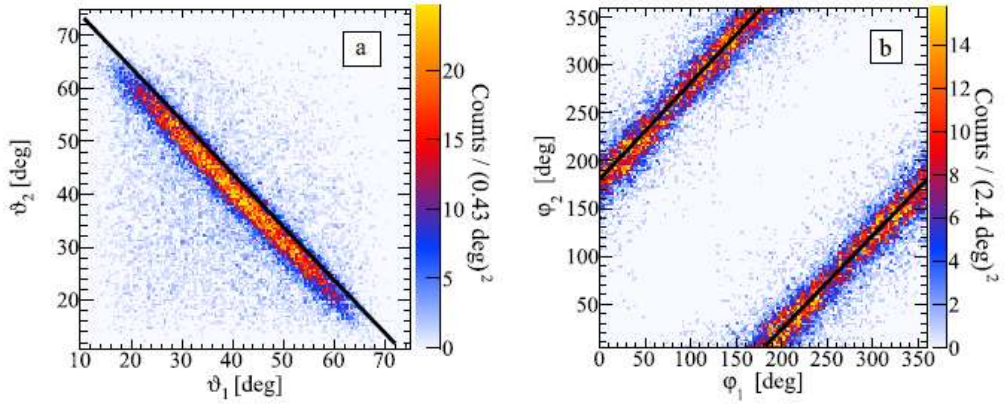


Exclusive measurements of quasi-free proton scattering reactions in inverse and complete kinematics

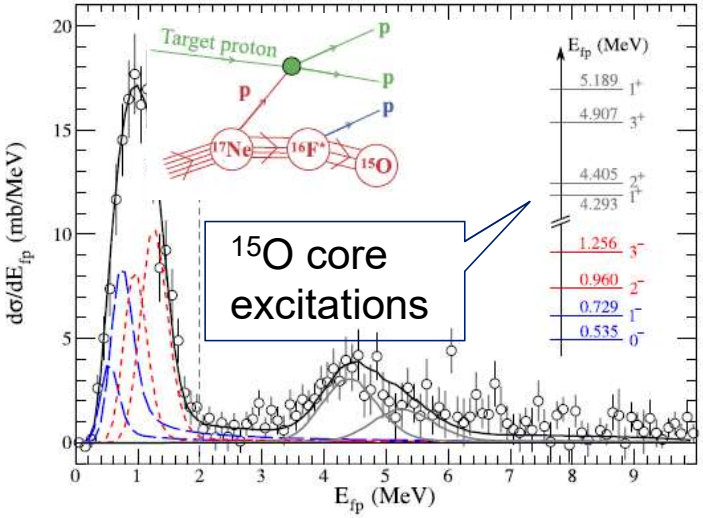
V. Panin[a,*], J.T. Taylor[b], S. Paschalis[a], F. Wamers[a,c], Y. Aksyutina[c], H. Alvarez-Pol[d], T. Aumann[a], C.A. Bertulani[e], K. Boretzky[c], C. Caesar[a], M. Chartier[b], L.V. Chulkov[f], D. Cortina-Gil[d], J. Enders[a], O. Ershova[g], H. Geissel[c], R. Gernhäuser[h], M. Heil[c], H.T. Johansson[i], B. Jonson[i], A. Kelić-Heil[c], C. Langer[g], T. Le Bleis[h], R. Lemmon[j], T. Nilsson[i], M. Petri[a], R. Plag[c], R. Reifarth[g], D. Rossi[c], H. Scheit[a], H. Simon[c], H. Weick[c], C. Wimmer[g]



V. Panin et al. / Physics Letters B 753 (2016) 204–210



The ^{17}Ne 2p halo quest (@500 AMeV)



Rather small
2s² - contribution 35(3) %

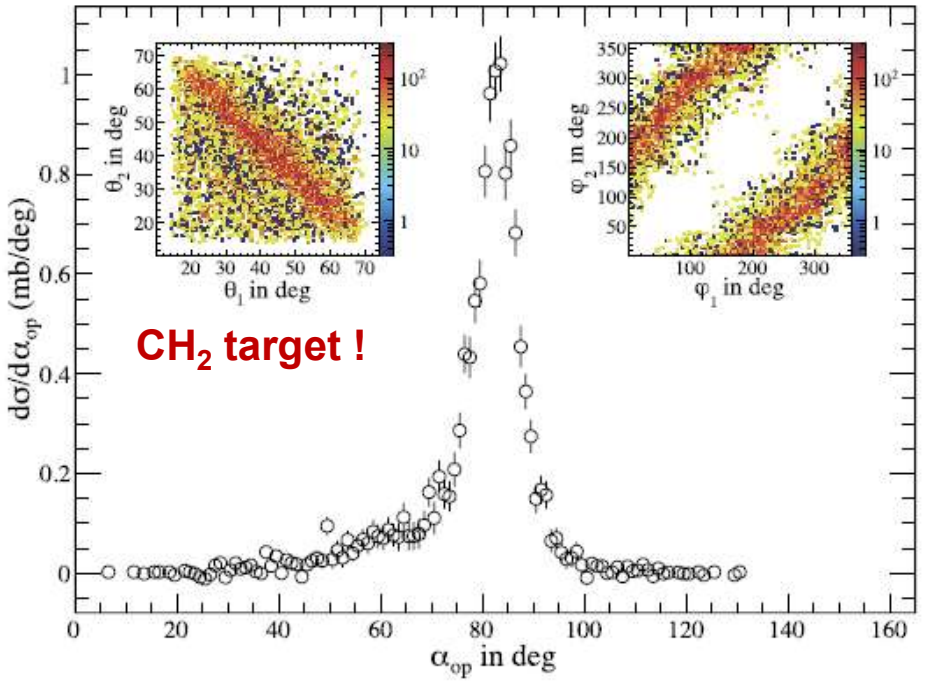
➔ Suppressed halo

ELSEVIER www.elsevier.com/locate/physletb

Unveiling the two-proton halo character of ^{17}Ne: Exclusive measurement of quasi-free proton-knockout reactions

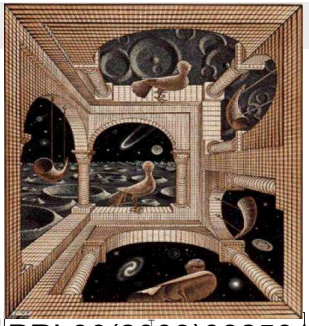
C. Lehr[a], F. Wamers[a,b], F. Aksouh[a,b,1], Yu. Aksyutina[b], H. Álvarez-Pol[c], L. Atar[a,b], T. Aumann[a,b,d,*], S. Beceiro-Novo[c,2], C.A. Bertulani[e], K. Boretzky[b], M.J.G. Borge[f], C. Caesar[a,b], M. Chartier[g], A. Chatillon[b], L.V. Chulkov[b,h], D. Cortina-Gil[c],

Physics Letters B 827 (2022) 136957

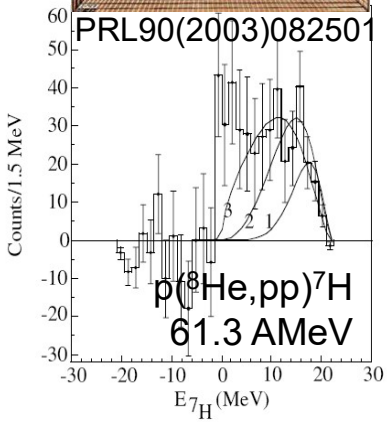


^{7}H ↓ and 4n →

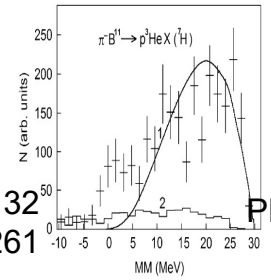
- Missing mass analysis

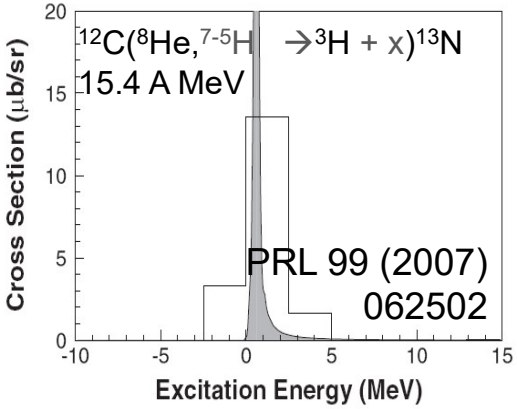


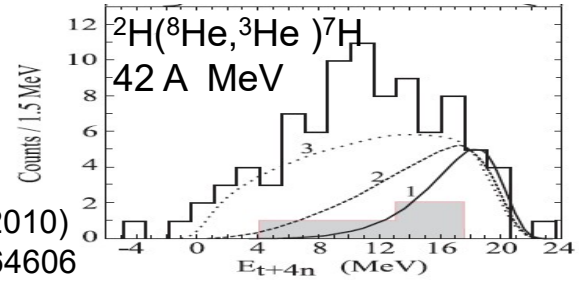
PRL90(2003)082501



EPJA 32 (2007) 261

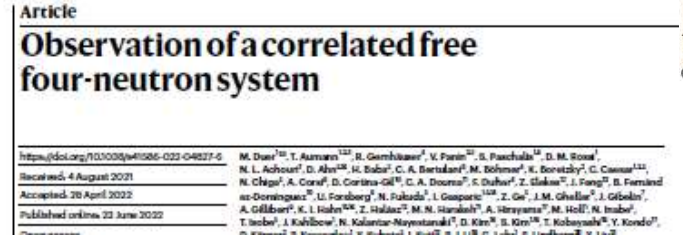






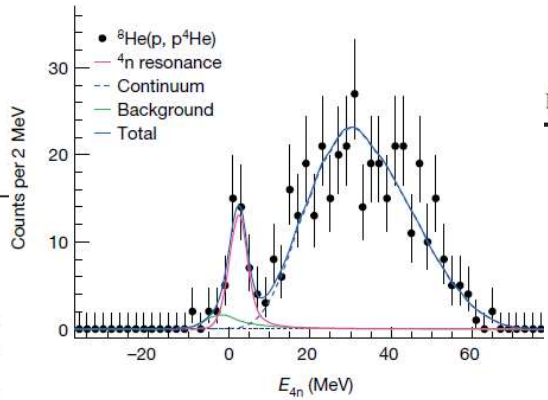
PRC81 (2010) 064606

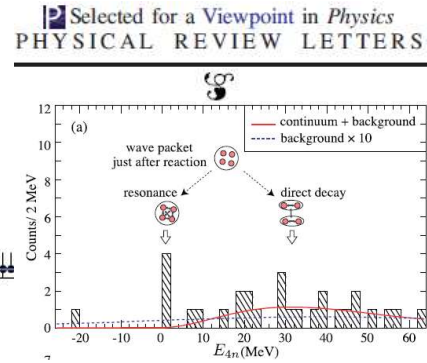
M. Duerr et al.
^{8}He(p,pa)
@ 156 A MeV



Article

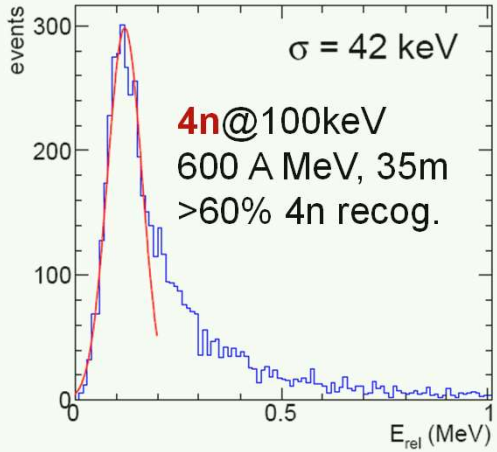
Observation of a correlated free four-neutron system





K. Kisamori et al.
^{4}He(^{8}He; ^{8}B)
@ 186 A MeV

- Direct study is enabled by exclusive measurements

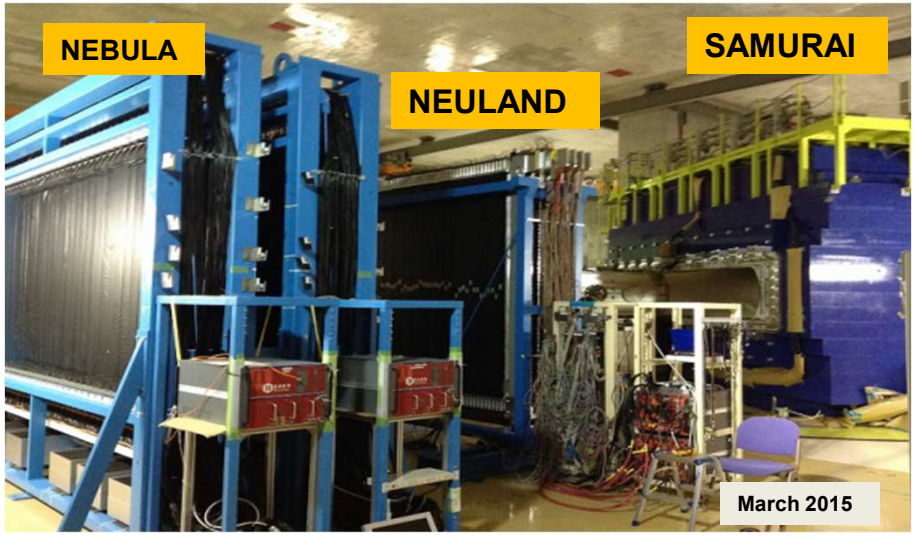


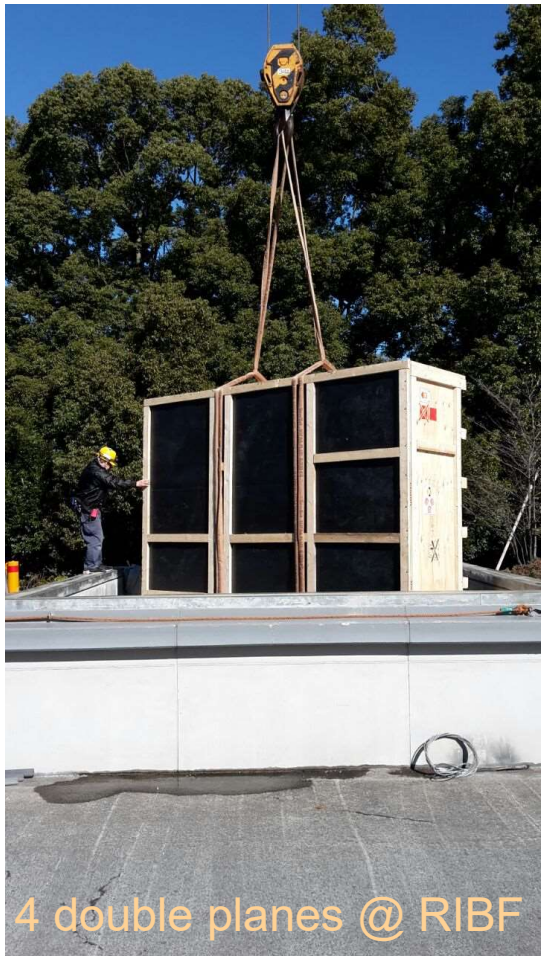
➔ NeuLAND.

Neuland demonstrator @ RIKEN

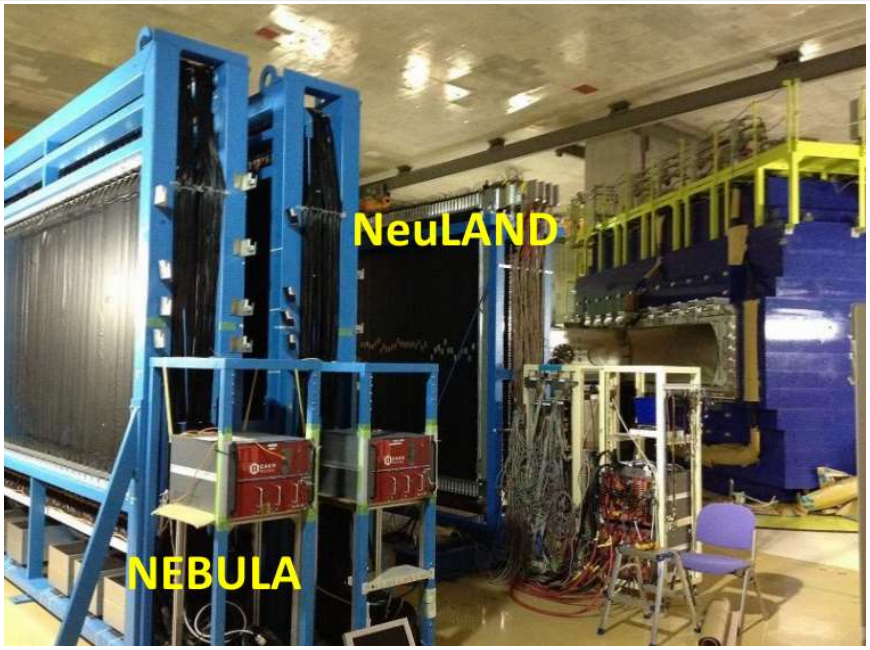
- NeuLAND demonstrator (40 cm depth with 4/30 double planes and 800 readout channels) at RIKEN 2014-2017, participation in various beam times

- Several experiments performed and published (e.g. M. Duerr et al., Nature 606 (2022) 678)





O-28 a first Landmark for fragment + 4n detection



Article

First observation of ^{28}O

https://doi.org/10.1038/s41586-023-06352-6
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Accepted: 21 June 2023
Published online: 30 August 2023
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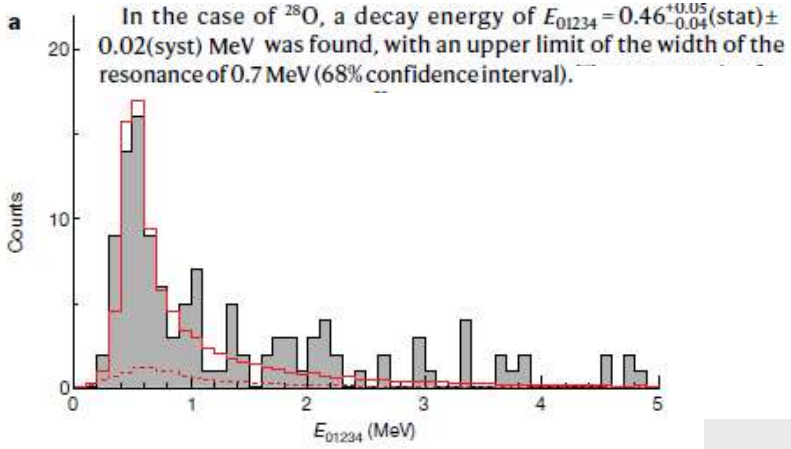
Y. Kondo[1,2✉], N. L. Achouri[3], H. Al Falou[4,5], L. Atar[6], T. Aumann[6,7,8], H. Baba[2], K. Boretzky[7], C. Caesar[6,7], D. Calvet[9], H. Chae[10], N. Chiga[2], A. Corsi[9], F. Delaunay[3], A. Delbart[9], Q. Deshayes[3], Zs. Dombrádi[11], C. A. Douma[12], A. Ekström[13], Z. Elekes[11], C. Forssén[13], I. Gašparić[2,6,14], J.-M. Gheller[9], J. Gibelin[3], A. Gillibert[9], G. Hagen[15,16], M. N. Harakeh[7,12], A. Hirayama[1], C. R. Hoffman[17], M. Holl[6,7], A. Horvat[7], Á. Horváth[18], J. W. Hwang[19,20], T. Isobe[2], W. G. Jiang[13], J. Kahlbow[2,6], N. Kalantar-Nayestanaki[12], S. Kawase[21], S. Kim[19,20], K. Kisamori[2], T. Kobayashi[22], D. Körper[7], S. Koyama[23], I. Kuti[11], V. Lapoux[9], S. Lindberg[13], F. M. Marqués[3], S. Masuoka[24], J. Mayer[25], K. Miki[22], T. Murakami[26], M. Najafi[12], T. Nakamura[1,2], K. Nakano[21], N. Nakatsuka[26], T. Nilsson[13], A. Obertelli[9], K. Ogata[27,28,29], F. de Oliveira Santos[30], N. A. Orr[3], H. Otsu[2], T. Otsuka[2,23], T. Ozaki[1], V. Panin[2], T. Papenbrock[15,16], S. Paschalis[6], A. Revel[3,30], D. Rossi[6], A. T. Saito[1], T. Y. Saito[23], M. Sasano[2], H. Sato[2], Y. Satou[20], H. Scheit[6], F. Schindler[6], P. Schrock[24], M. Shikata[1], N. Shimizu[31], Y. Shimizu[2], H. Simon[7], D. Sohler[11], O. Sorlin[30], L. Stuhl[2,19], Z. H. Sun[15,16], S. Takeuchi[1], M. Tanaka[32], M. Thoennessen[33], H. Törnqvist[6,7], Y. Togano[1,34], T. Tomai[1], J. Tscheuschner[6], J. Tsubota[1], N. Tsunoda[24], T. Uesaka[2], Y. Utsuno[35], I. Vernon[36], H. Wang[2], Z. Yang[2], M. Yasuda[1], K. Yoneda[2] & S. Yoshida[37]

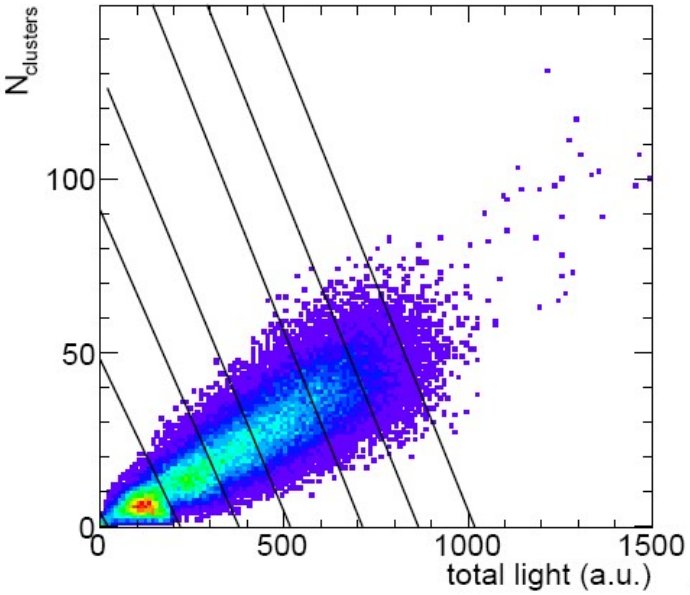


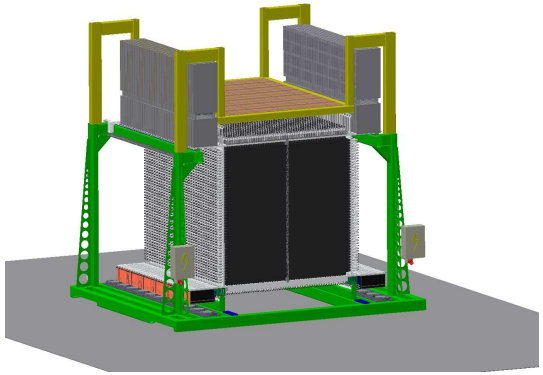
Causallity cuts only 16% remaining background
ε(3n)=2% ε(4n)=0.4%

Very intense RIBF beams ➔ detection efficiency is key !

Novel Neutron Detector: NeuLAND

Fully active neutron detector based on scintillators (calorimetry & tracking)





Previously < 50%

Previously <5% !

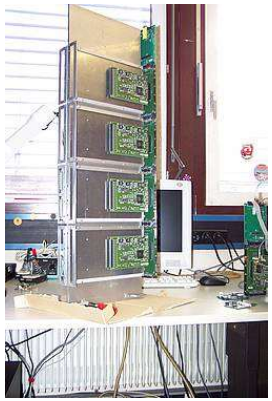
		1000 MeV generated				
	%	1n	2n	3n	4n	5n
detected	1n	**89**	12	1	0	0
	2n	7	**78**	23	3	0
	3n	0	8	**63**	26	5
	4n	0	0	12	**63**	40
	5n	0	0	0	7	**46**
	6n	0	0	0	0	8

ELSEVIER journal homepage: www.elsevier.com/locate/nima

NeuLAND: The high-resolution neutron time-of-flight spectrometer for R^3B at FAIR

K. Boretzky [a,*], I. Gašparić [b,c,a], M. Heil [a], J. Mayer [d], A. Heinz [e], C. Caesar [a,c], D. Kresan [a,c], H. Simon [a], H.T. Törnqvist [c], D. Körper [a], G. Alkhazov [f], L. Atar [a], T. Aumann [c,a,g], D. Bemmerer [h],

NIMA **1014** (2021) 165701

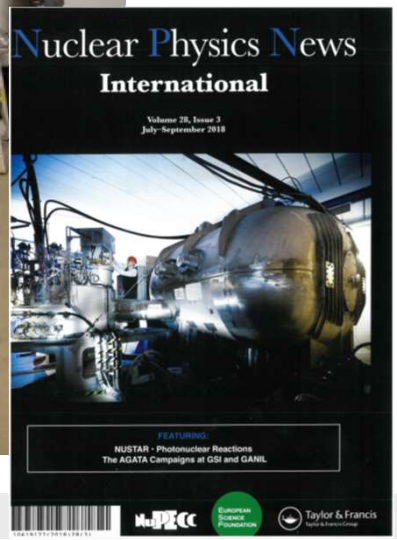


30 double planes
2 x 50 paddles each
5 x 5 x 250 cm³
RP408 / R8619ASSY
FPGA TDC readout

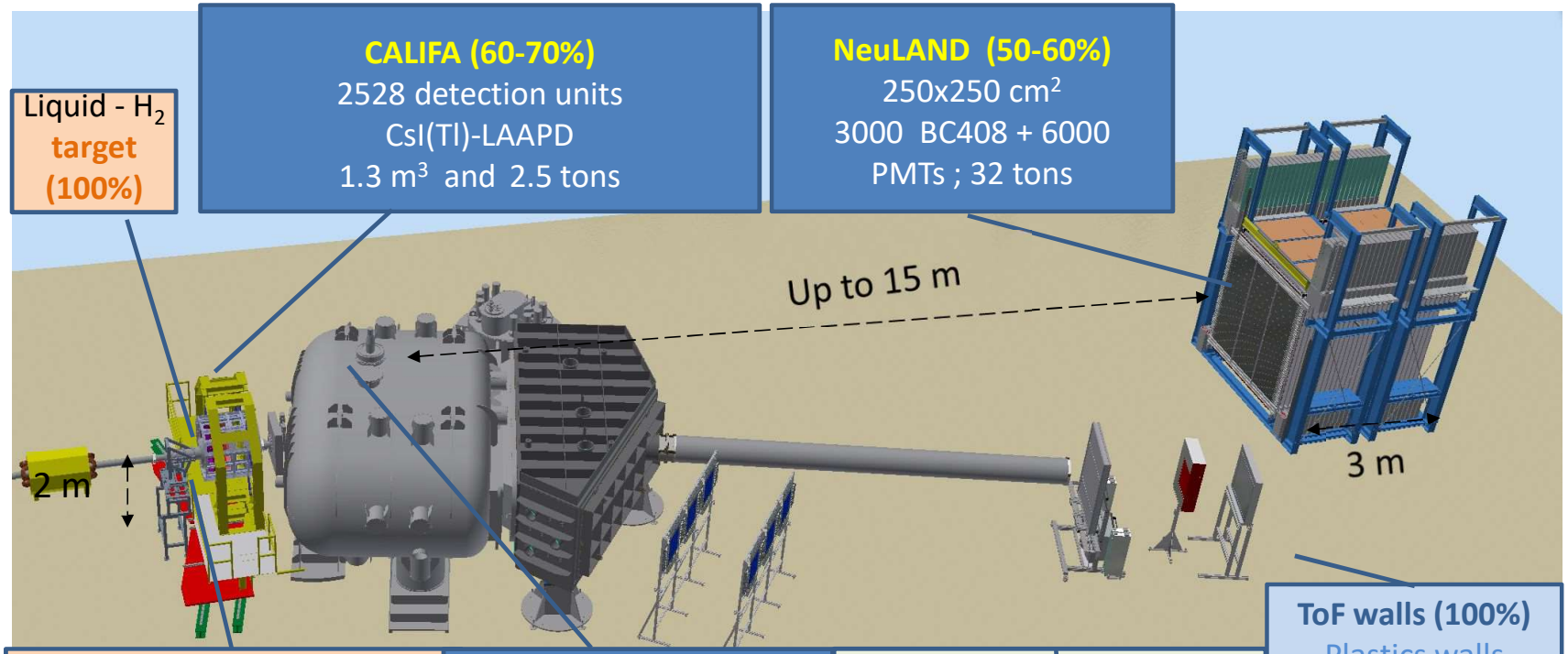
➔ 4n coincident four-momentum detection

Split detector + causality cuts could be added.

From R³B prototype to R³B precursor



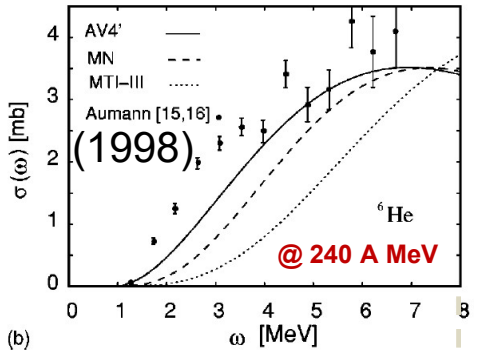
R³B setup ready to move to FAIR in 2025/6



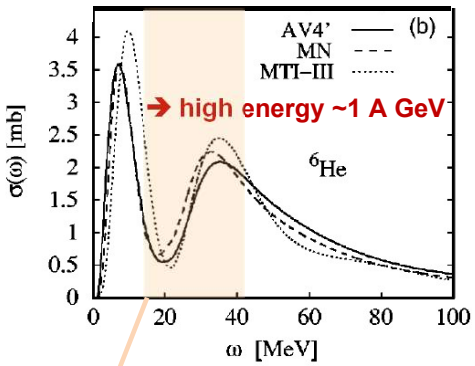
FAIR beams (with suitable intensities)

- Up to 20Tm beam rigdity ➔ high energy coulomb excitation

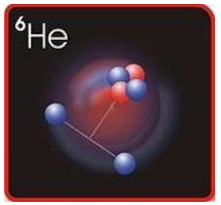
GSI



FAIR



S. Bacca et al.
PRL **89** (2002) 052502
PRC **69** (2004) 057001



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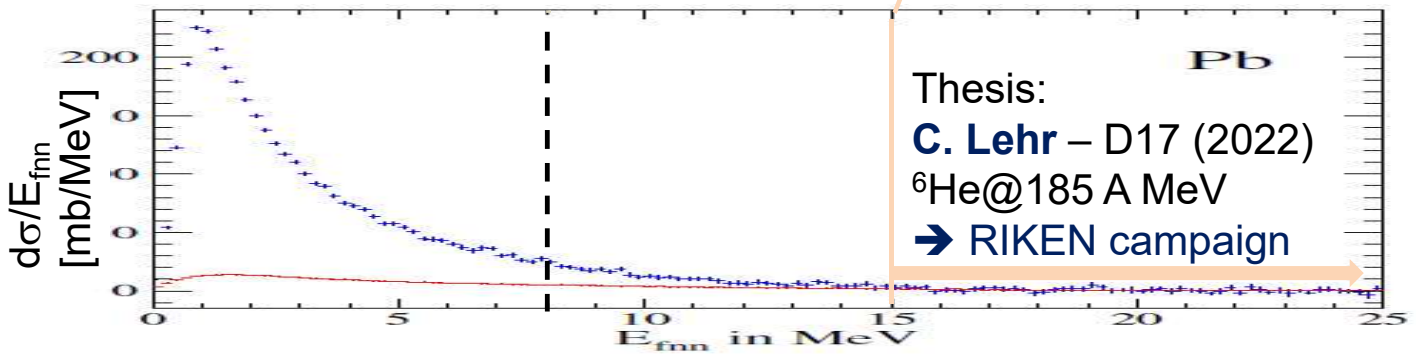
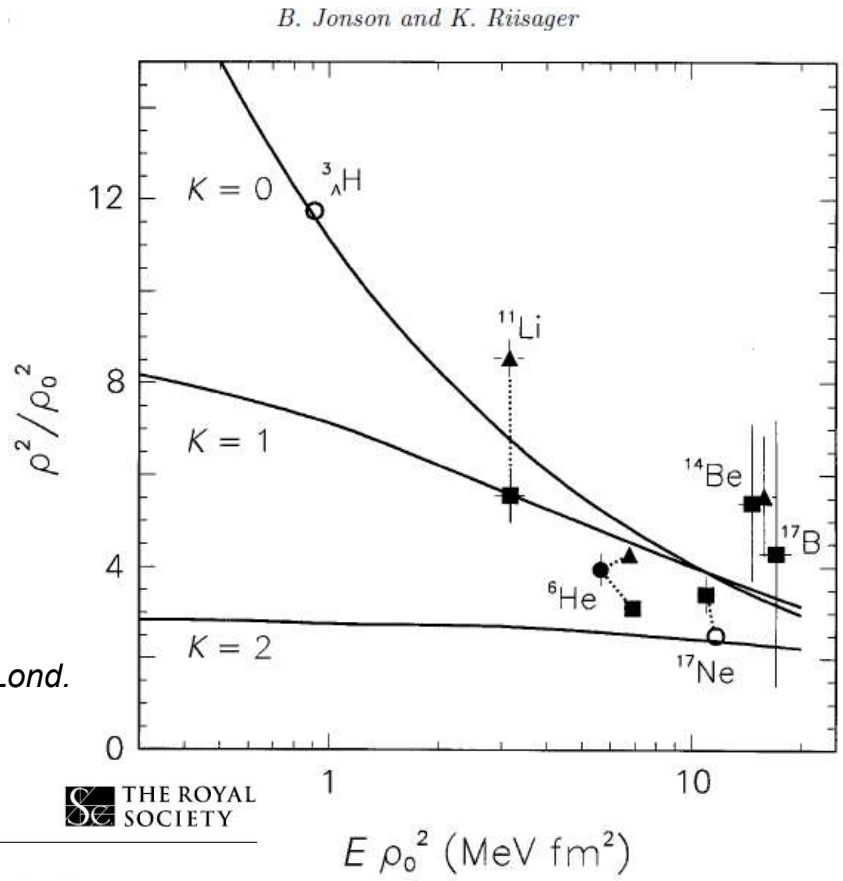


Thesis:
C. Lehr – D17 (2022)
^{6}He@185 A MeV
➔ RIKEN campaign

Heavier systems !
- clean separation
- no charge states

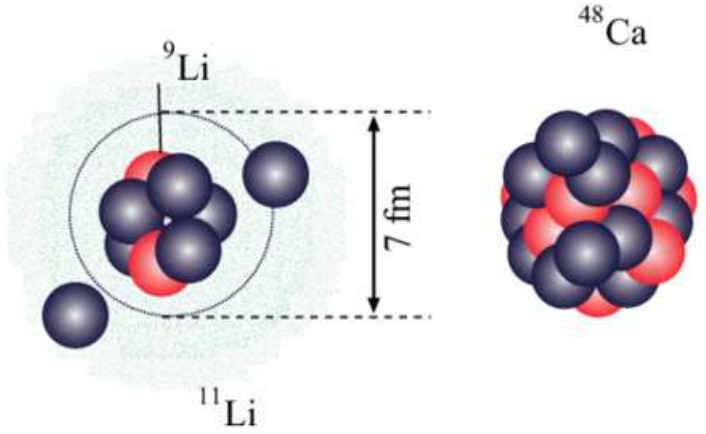
FAIR beams (with suitable intensities)

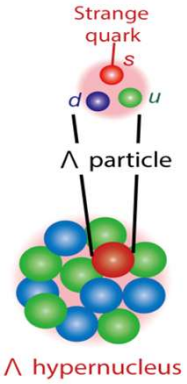


Phil. Trans. R. Soc. Lond.
A**356** **(1998)** 2063

Halos and halo excitations

By B. Jonson[1] and K. Riisager[2]





Not only ^{11}Li but also
$^{3}_{\Lambda}$H forms presumably a halo system !

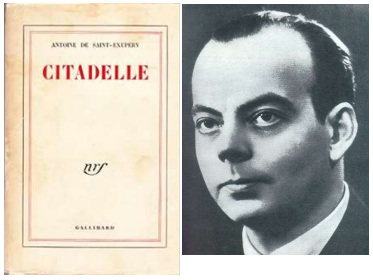
➔ **1.57 A GeV threshold**

A. Obertelli

Summary

- Instrumentation suitable for halo and dripline physics constructed and commissioned within Phase-0 experiments of the R³B experiments, examples presented (Nikhil, Stefanos, …)
- FAIR facility enables exclusively dedicated program especially suited for energetic intense secondary beams
  in particular also for heavy nuclei (N=126)
- Installation/(commissioning) schedule and scenario for NUSTAR experiments@FAIR presented
  → dedicated program during ramp up

- "If you want to build a ship, don't drum up people to collect wood and don't assign them tasks and work, but rather teach them to long for the endless immensity of the sea."
  - Antoine de Saint Exupéry



Thanks

- Super-FRS project group and

www.gsi.de/superfrs

www.gsi.de/r3b
www.r3b-nustar.de

collaboration