^{8}He: Structure studies via Coulomb breakup -From RIKEN/Samurai to FAIR/R^{3}B

Zakopane 2026 Conference on Nuclear Physics

Haik Simon – GSI Darmstadt

Menu

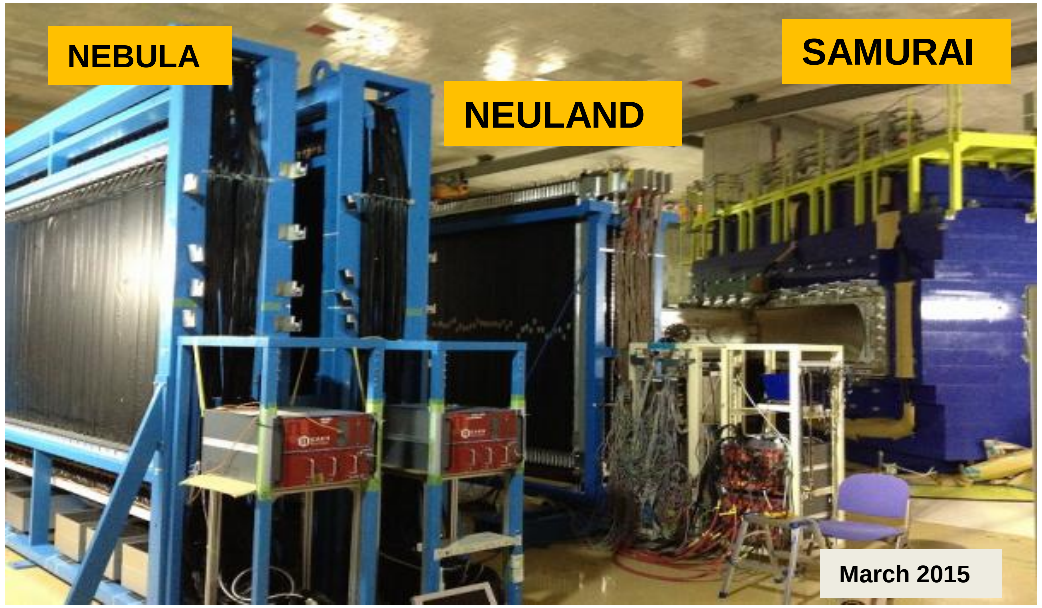
- Recent Study of ^{8}He at RIKEN facility
  ➔ 10^{5} pps @ 185 AMeV
- Neutron detection:
  Nebula Array & NeuLAND demonstrator ➔ 4n correlations
- Structure of Helium isotopes

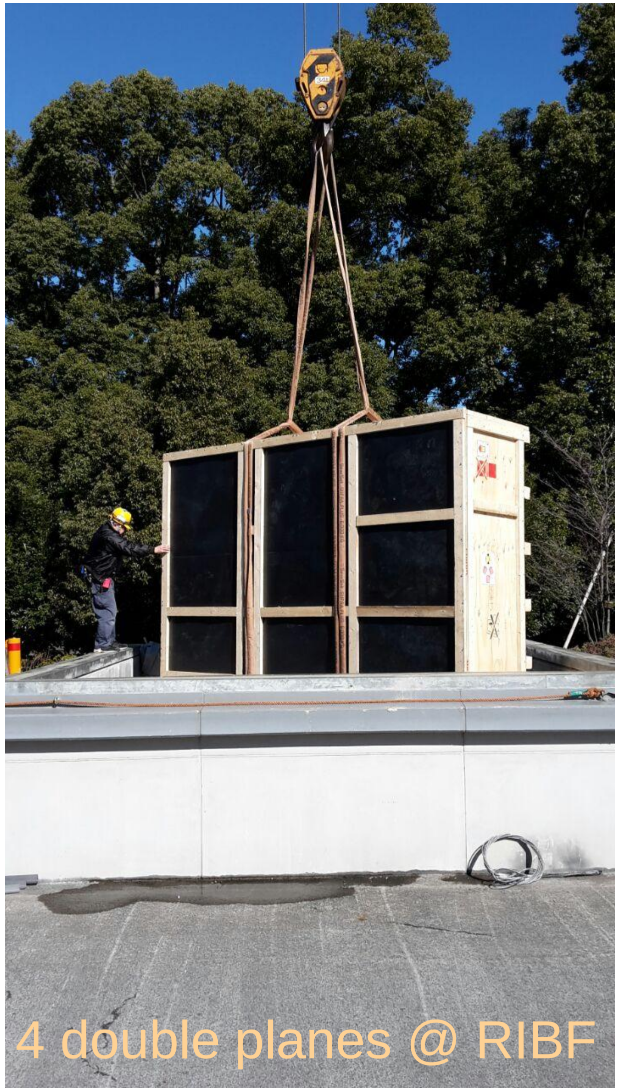
- Preparations at GSI
- Prospects at FAIR

Neuland demonstrator @ RIKEN

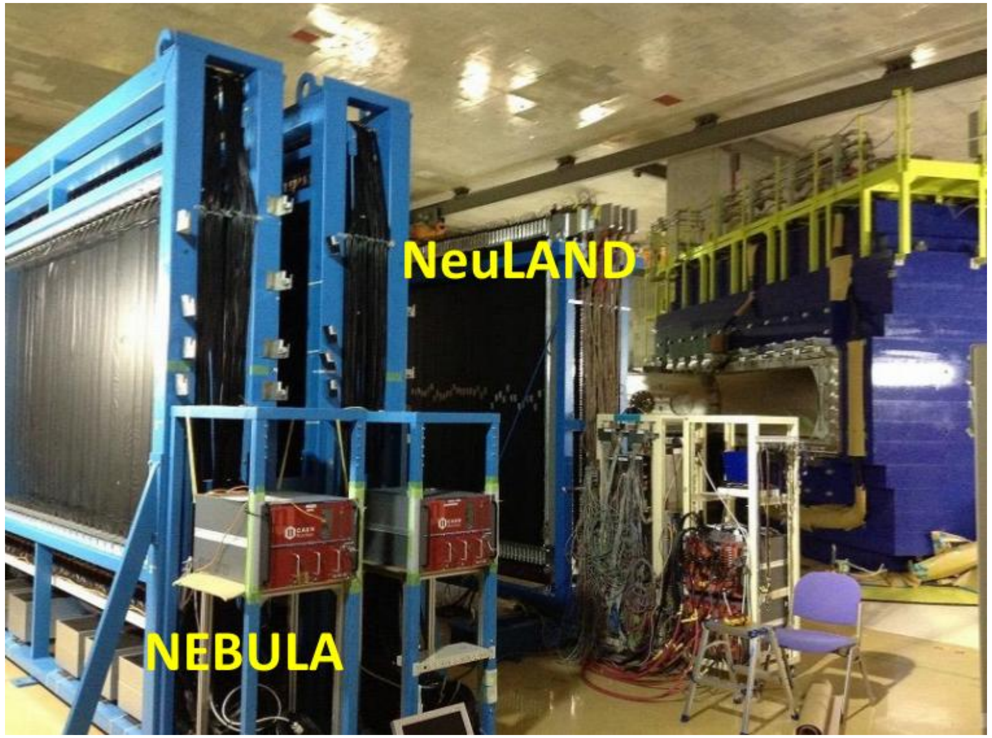
- NeuLAND demonstrator (40 cm depth with 4/30 double planes and 800 readout channels) at RIKEN 2014-2017, participation in various beam times

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





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



Article

First observation of ^{28}O

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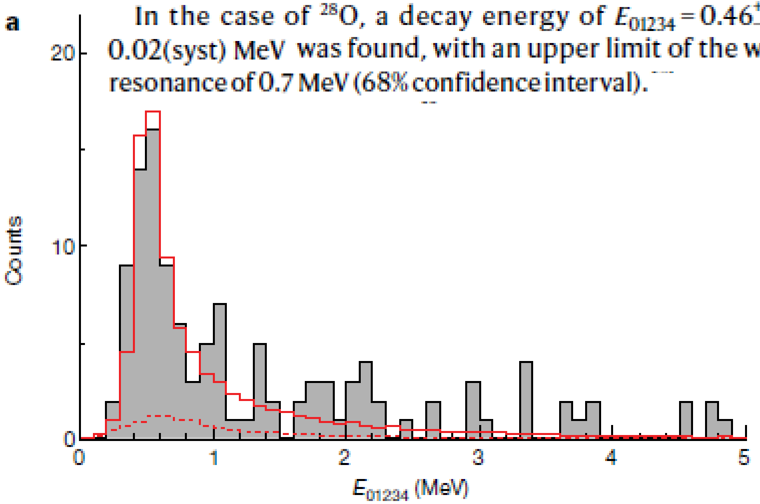
Check for updates

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]

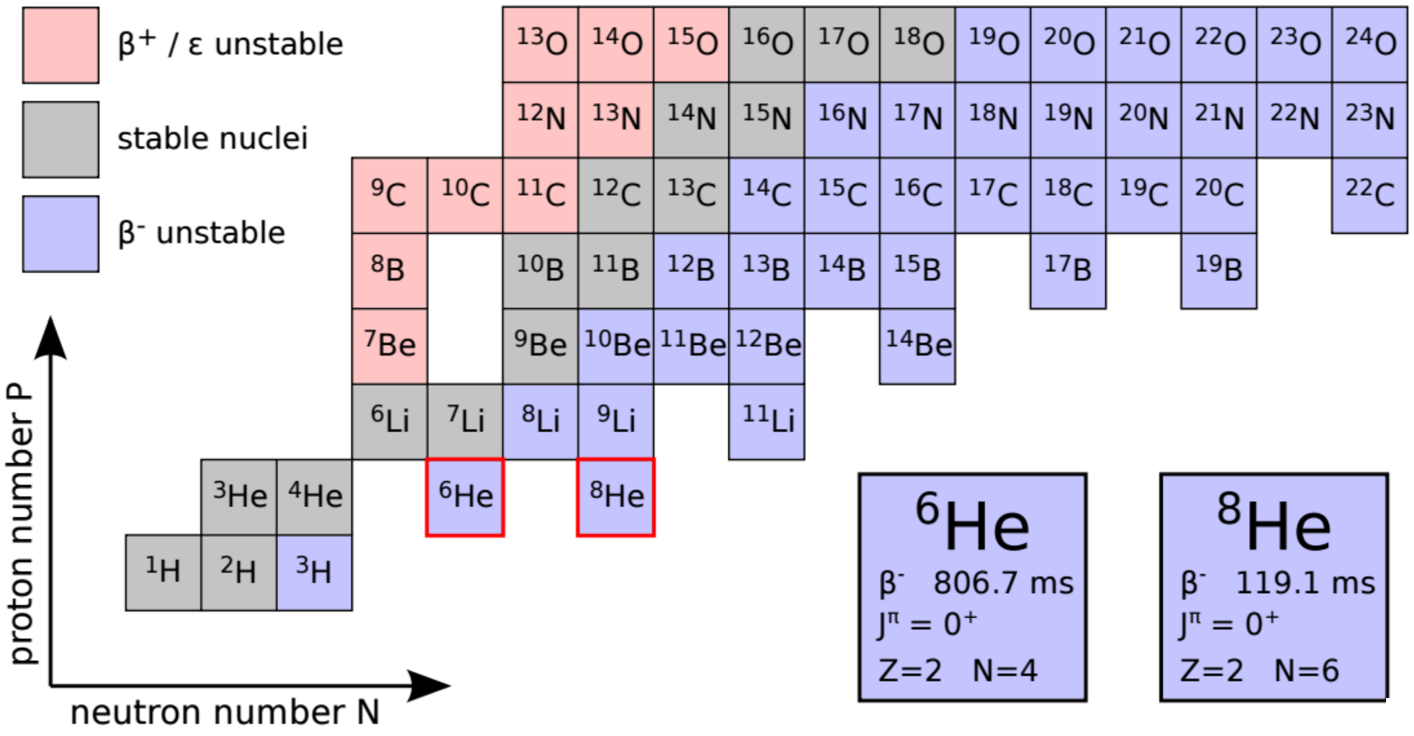
In the case of ^{28}O, a decay energy of $E_{01234} = 0.46^{+0.05}_{-0.04}$(stat) ± 0.02(syst) MeV was found, with an upper limit of the width of the resonance of 0.7 MeV (68% confidence interval).



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

Very intense RIBF beams ➔ detection efficiency is key !

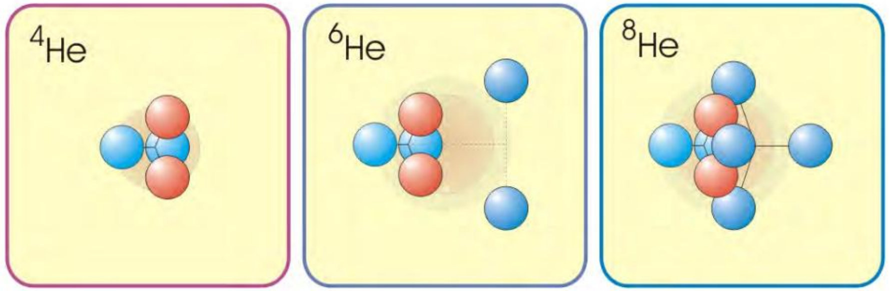
The Helium case



^{6}He is a clear Borromean α+2n
Halo nucleus

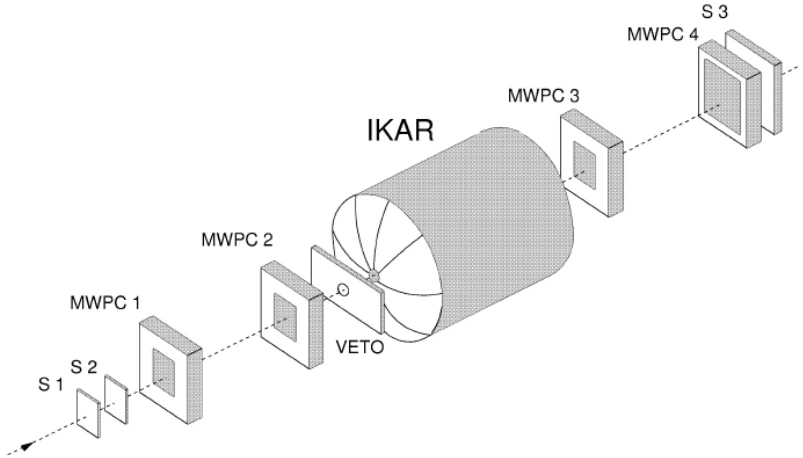
→ Structure of ^{8}He as core+4n system could be eg.
- α + 4n
- ^{6}He +2n

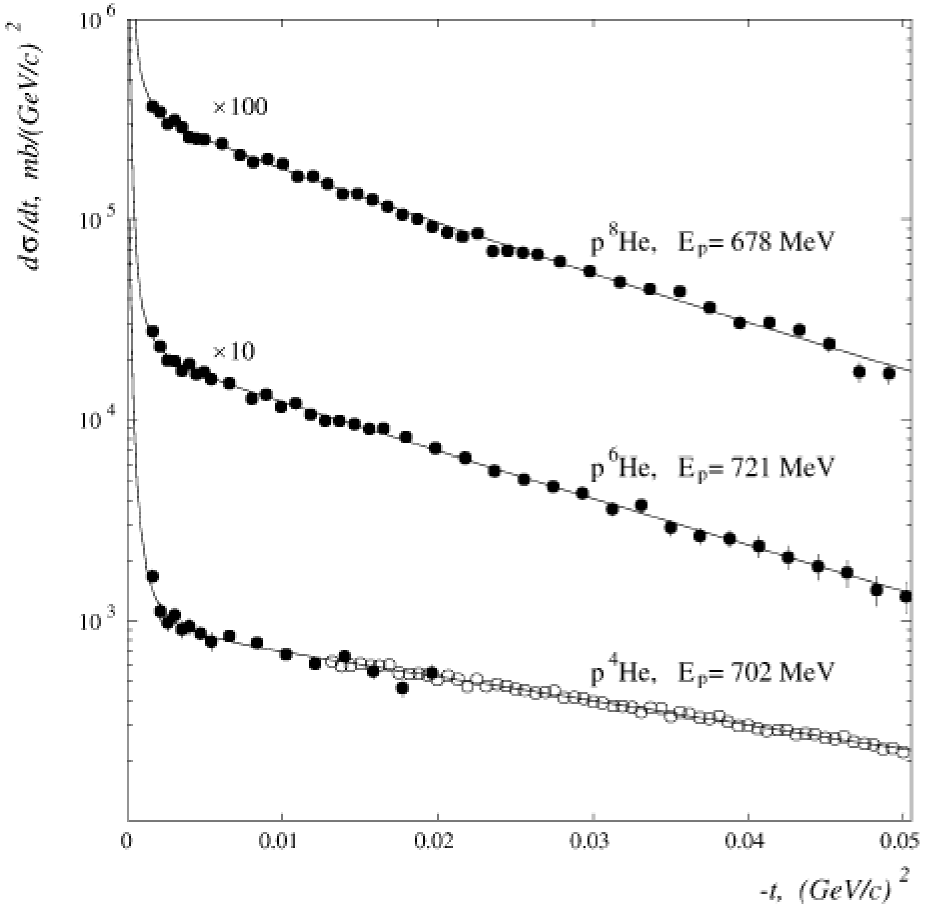
Measure:
Coulomb breakup and decay channels

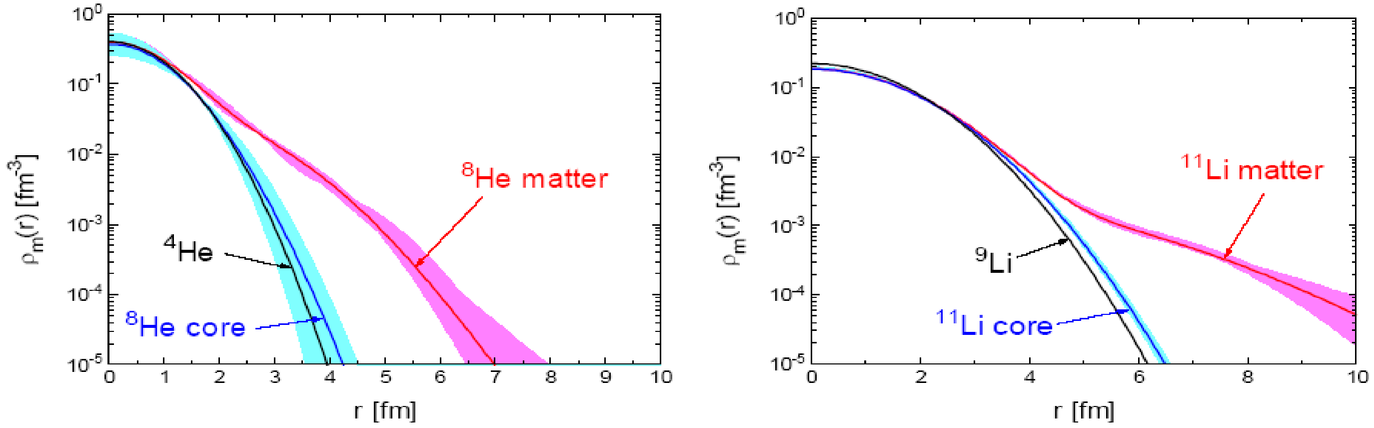


Thesis:
C. Lehr – D17 (2022)

Elastic Scattering data ^{4,6,8}He, ^{11,9}Li (@~700 AMeV)





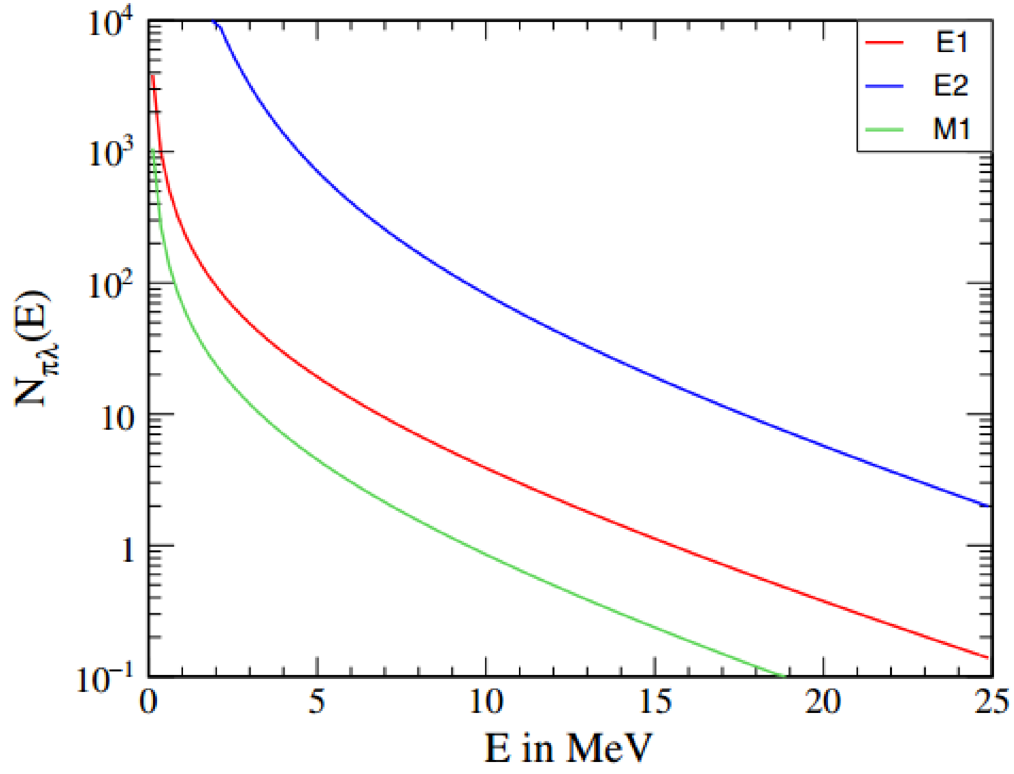


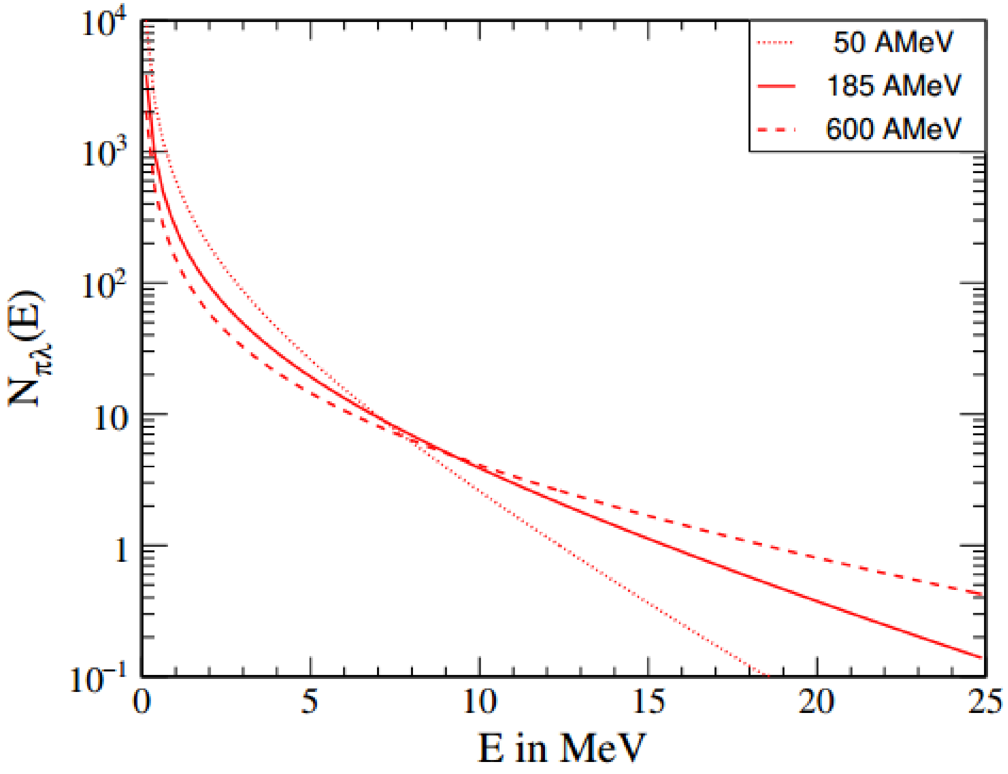
nucleus	R_{matter}, fm	R_{core}, fm	R_{halo}, fm
^{4}He	1.49 (3)	--	--
^{8}He	2.45 (7)	1.55 (15)	3.08 (10)
^{9}Li	2.43 (7)	--	--
^{11}Li	3.62 (19)	2.55 (12)	6.54 (38)

e.g. S. Neumaier et al., NPA 583 (1995) 799
IKAR collaboration (P. Egelhof et. al.),
EXL collaboration (N. Kalantar et al.)

Different shapes for extracted matter distributions

Idea: Measure coulomb induced breakup and measure up to 4n

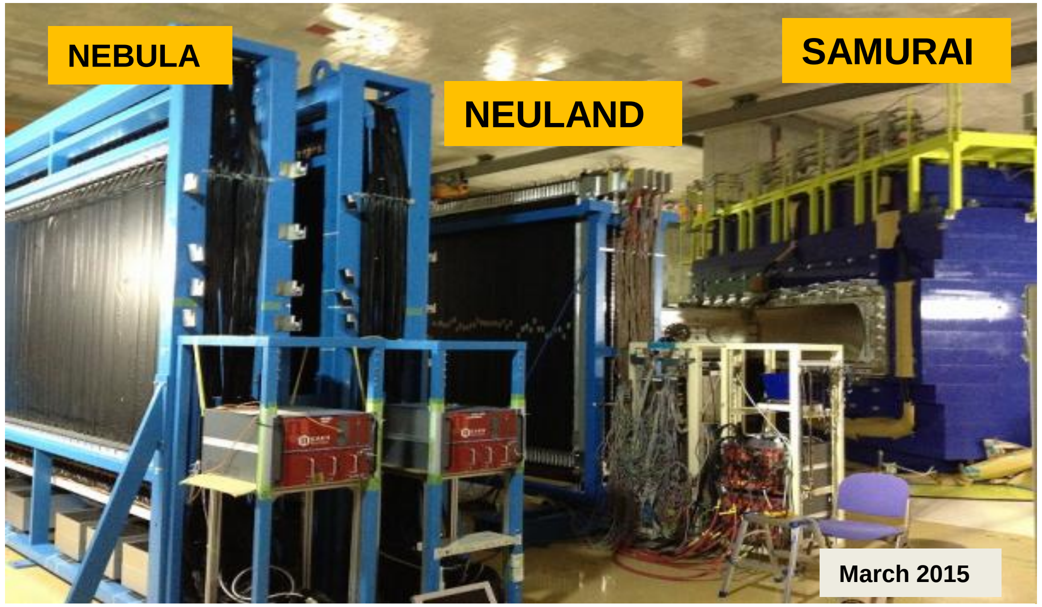




Thesis:
C. Lehr – D17 (2022)

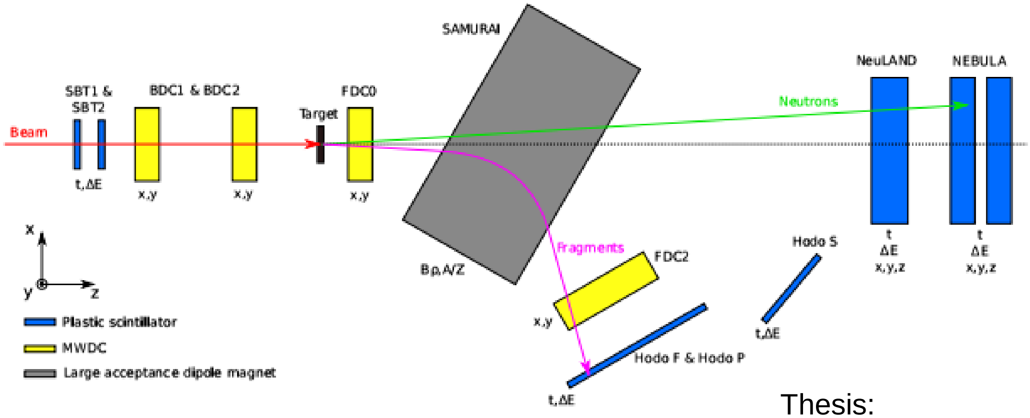
@185 AMeV Excitations up to 10-15 MeV in reach
S_{2n}=2.1MeV, S_{4n}=3.1 MeV – GSI E* ~ 4 MeV

4n detection is challenging



NeuLAND (FoS prototype) 40 cm
NEBULA 2 x 24 cm scintillator depth

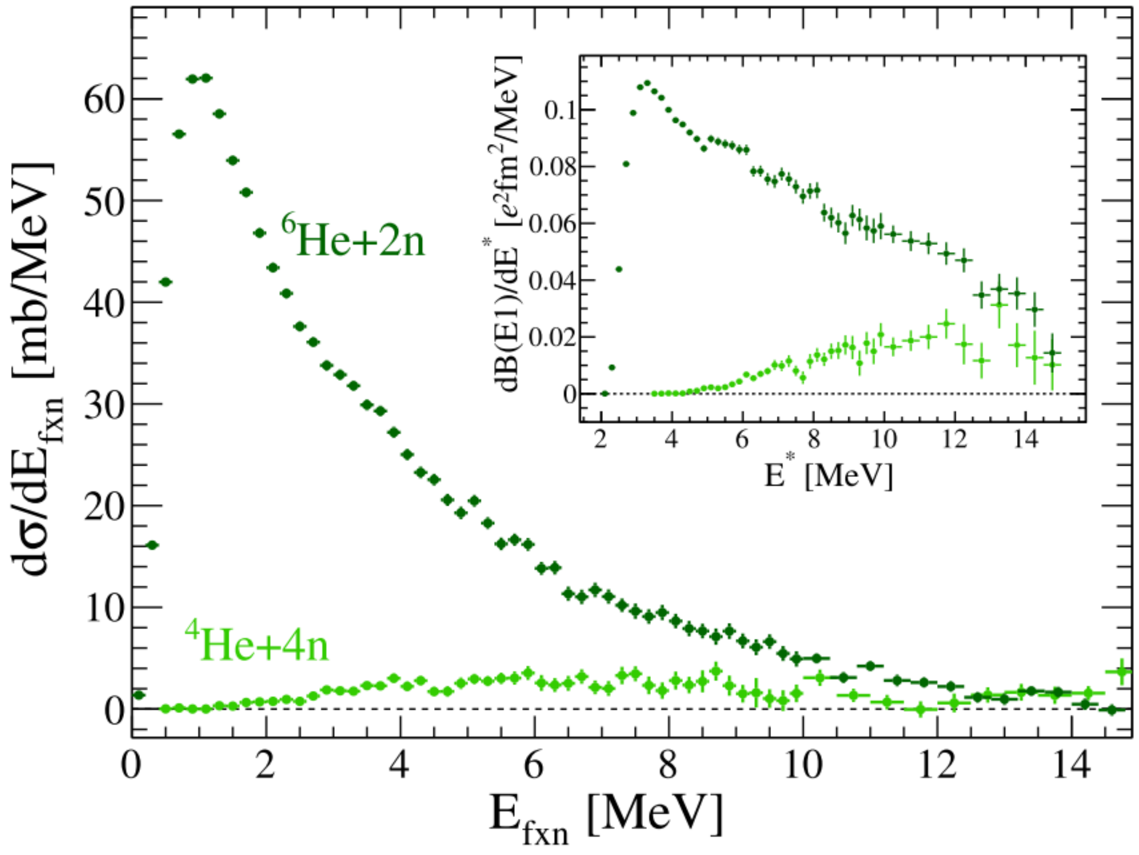
Arrays used with causality cuts
→ About 1.2 % detetion efficiency or neutrons at 1MeV E_{rel} with ca. 10% cross talk



Thesis:
C. Lehr – D17 (2022)

SAMURAI setup
- SBT scintillators
- BDC, FDC multi wire drift chambers
- TOF/ΔE Hodoscopes

Result



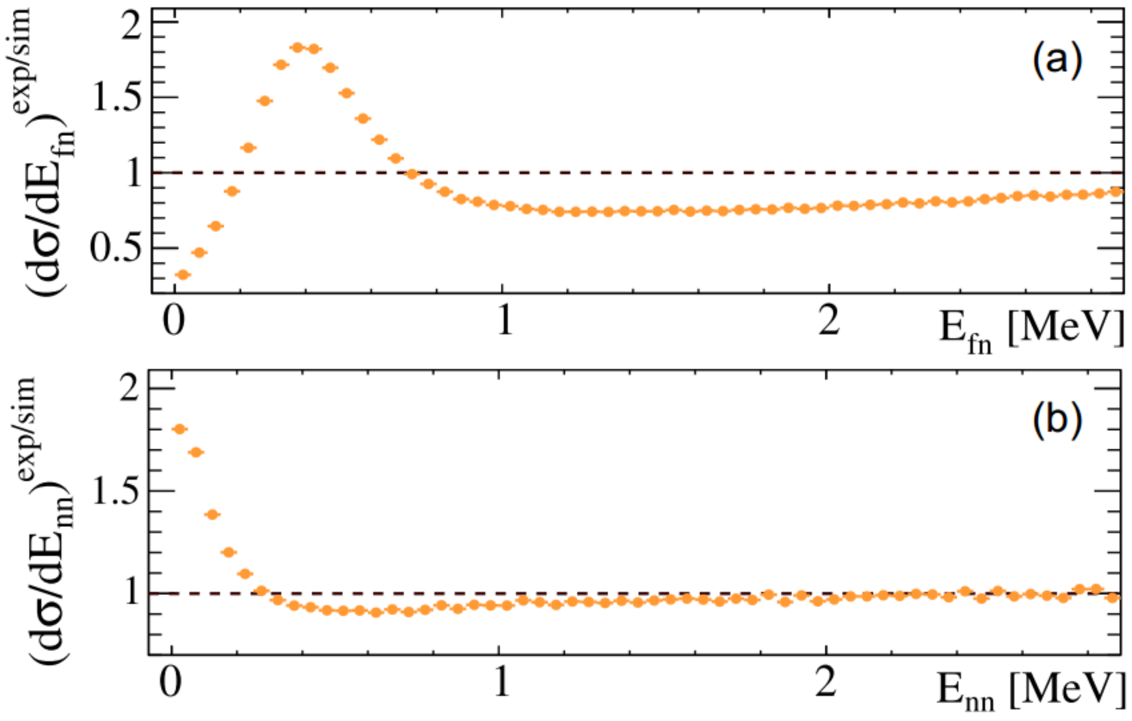
C. Lehr, T. Aumann, M. Duer, et al.
PRL 136 (2026) 172501

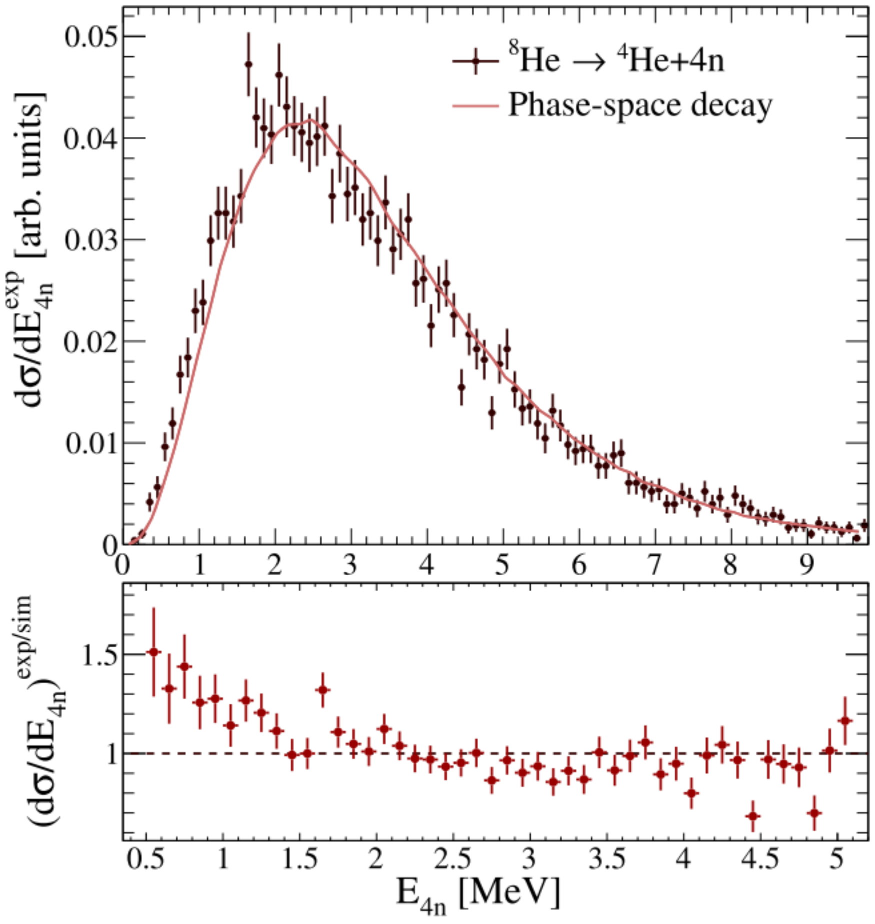
Already from the cross section and B(E1) distribution (insert)

no strong a + 4n breakup distribution is visible

Clear soft dipole enhancement at
E* ~ 3MeV (as previously measured at GSI)
with about 1/3 TRK sum rule up to
E* 15 MeV in both channels

Energy Correlations

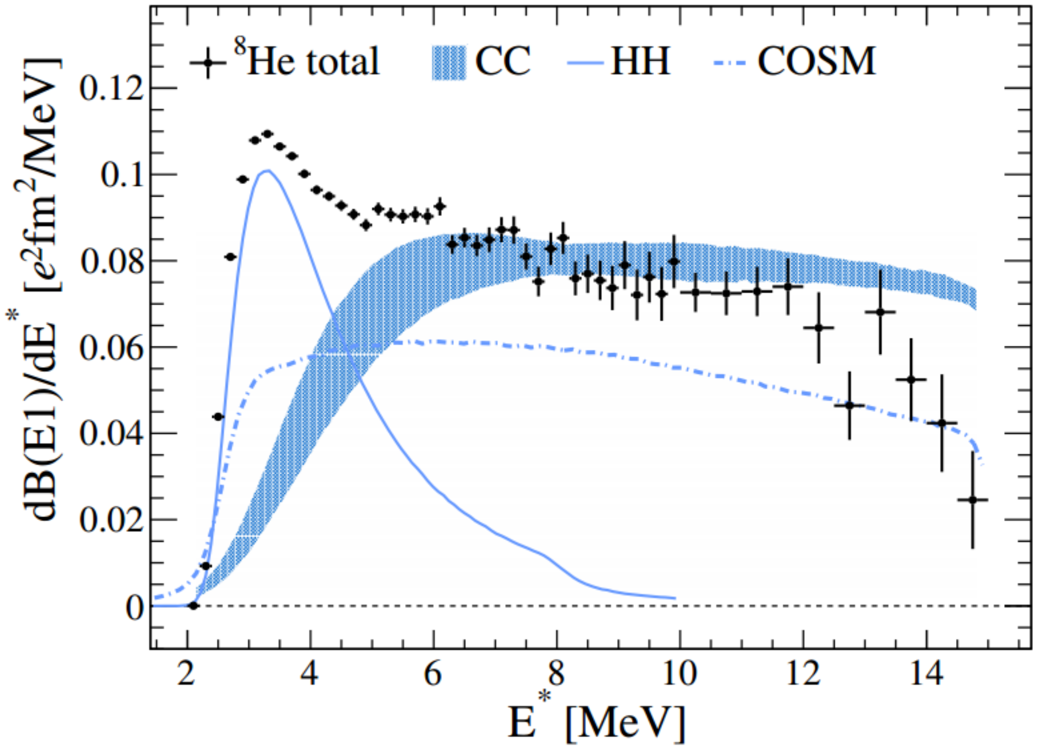




C. Lehr, T. Aumann, M. Duer, et al.
PRL 136 (2026) 172501

Mainly 2 body sequential decays

Findings



[CC] F. Bonaiti, S. Bacca, and G. Hagen, Ab initio coupled cluster calculations of ground and dipole excited states in ^{8}He, Phys. Rev. C 105, 034313 (2022).

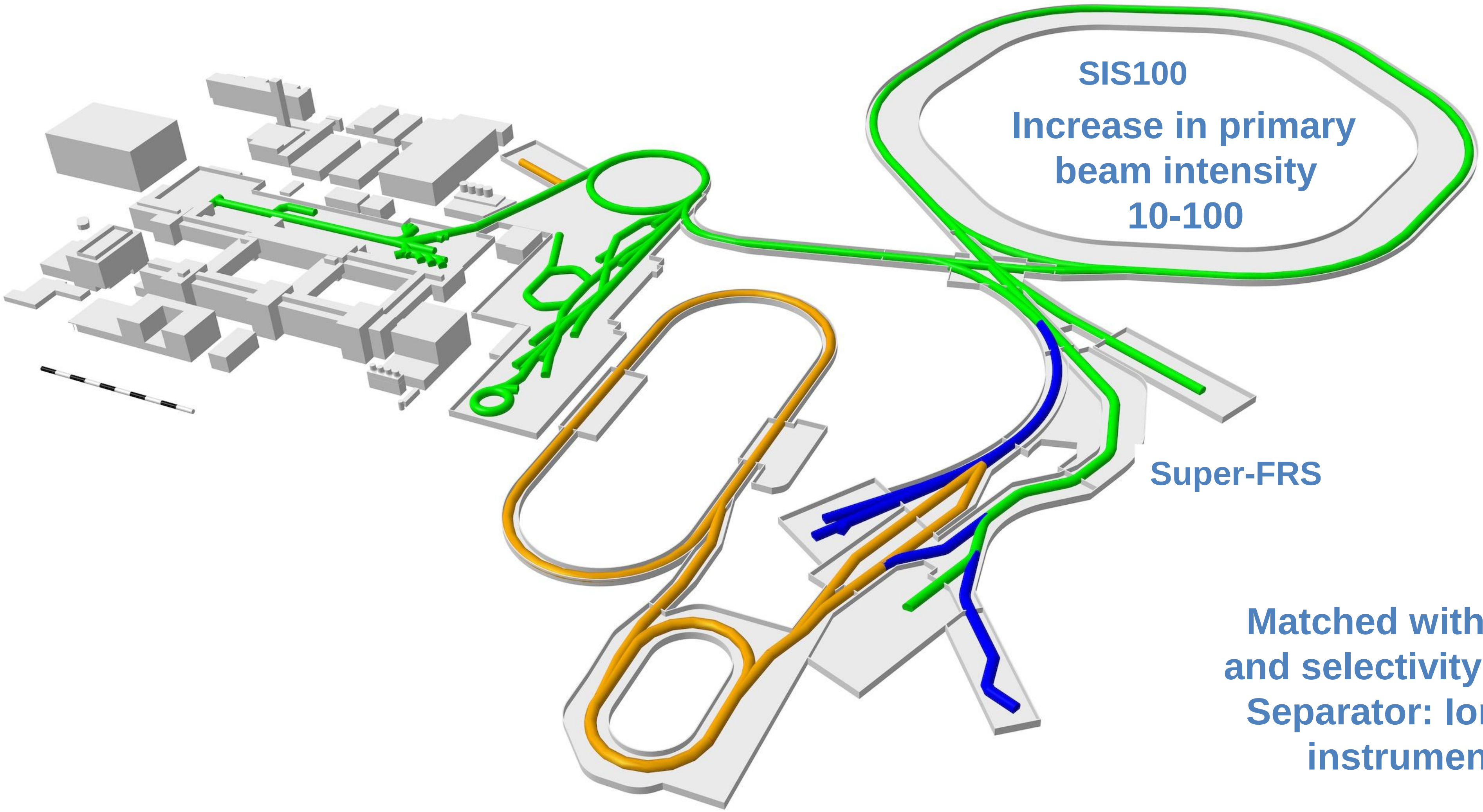
[HH] L. V. Grigorenko et al., Soft dipole mode in ^{8}He, Phys. Part. Nucl. Lett. 6, 118 (2009).

[COSM] T. Myo and K. Katō,
Modeling the electric dipole strength of neutron-rich 8He: Prediction of multineutron collective excitations,
Phys. Rev. C 106, L021302 (2022).

C. Lehr, T. Aumann, M. Duer, et al.
PRL 136 (2026) 172501

Light systems with „simple“ reaction mechanism serve as bench mark for theoretical modelling.

FAIR: Main Objectives - NUSTAR

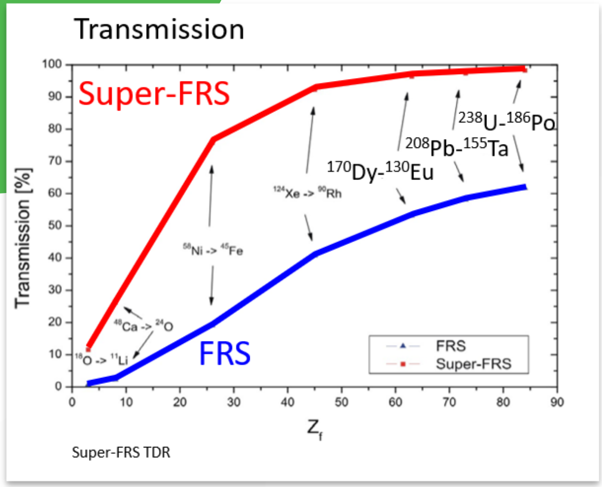


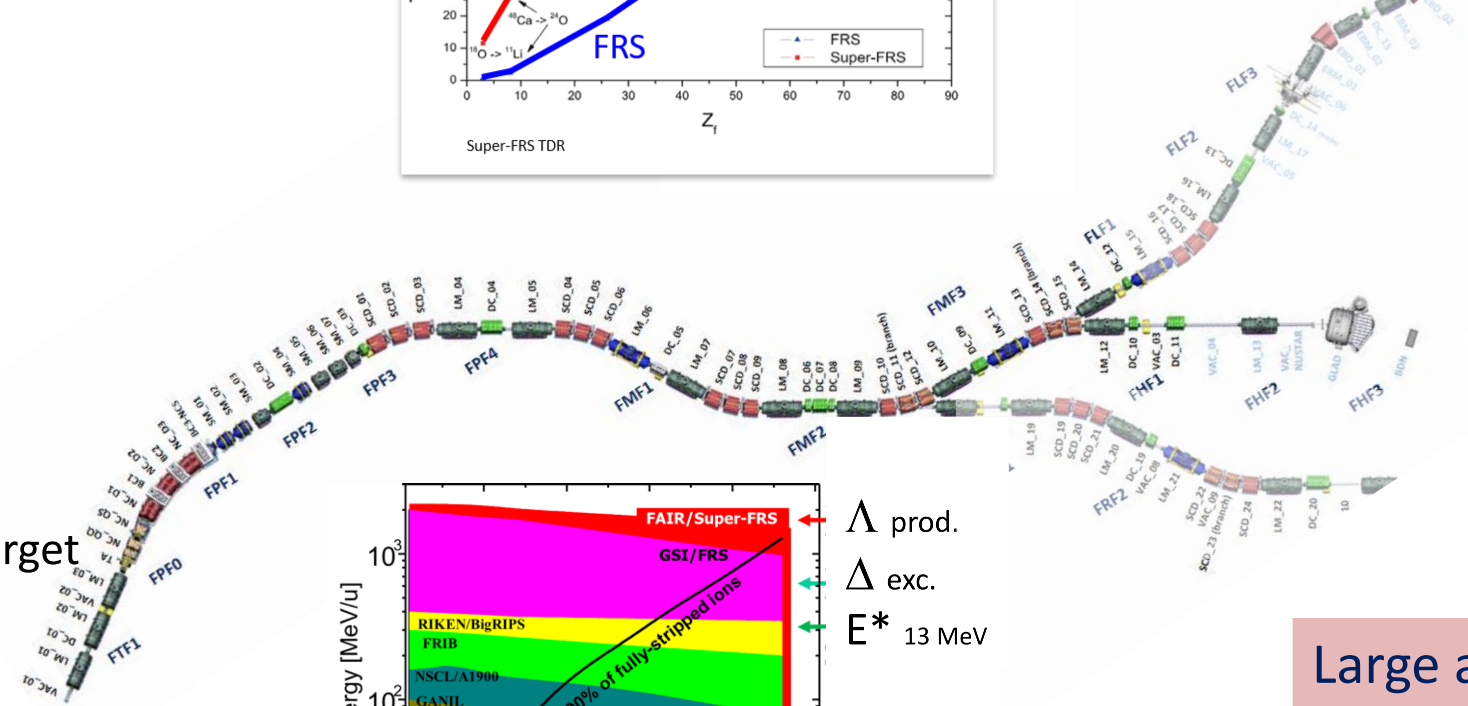
Matched with acceptance and selectivity of a versatile Separator: Ion optics and instrumentation …

➔ **Experiments**

Super-FRS (@SIS18/SIS100) workhorse for

NUSTAR





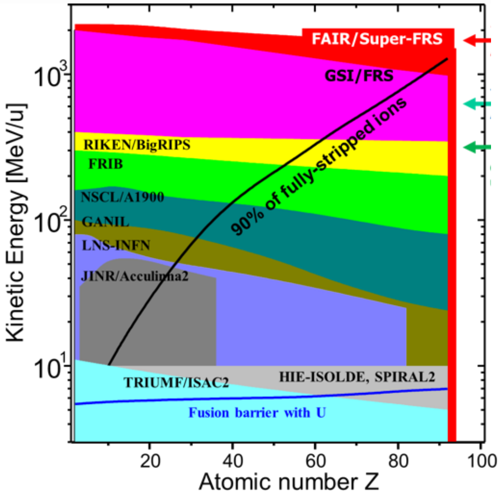
Low energy Branch with Energy buncher

High energy Branch

Ring Branch

One of worlds most powerful separators for exotic nuclei

Target



Λ prod.

Δ exc.

E* 13 MeV

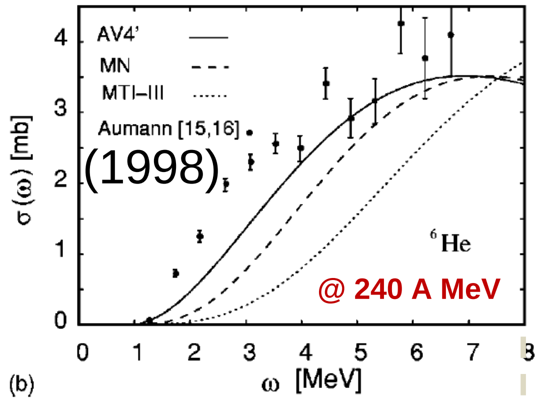
Large acceptance
High rigidity, minimized losses
→ Thick production targets
→ Most effective use of primary beam for experiments

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

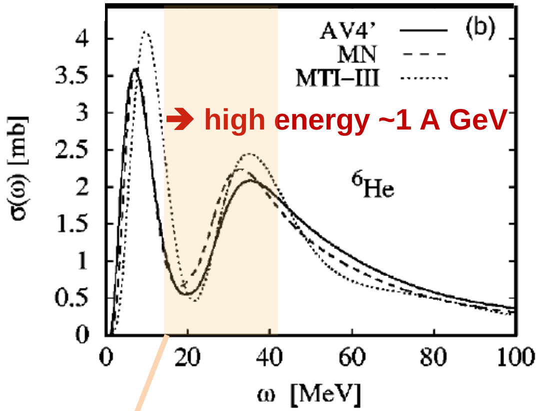
FAIR beams (with suitable intensities)

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

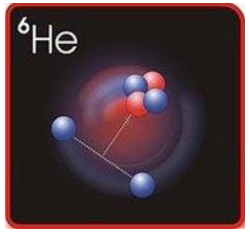
GSI



FAIR



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



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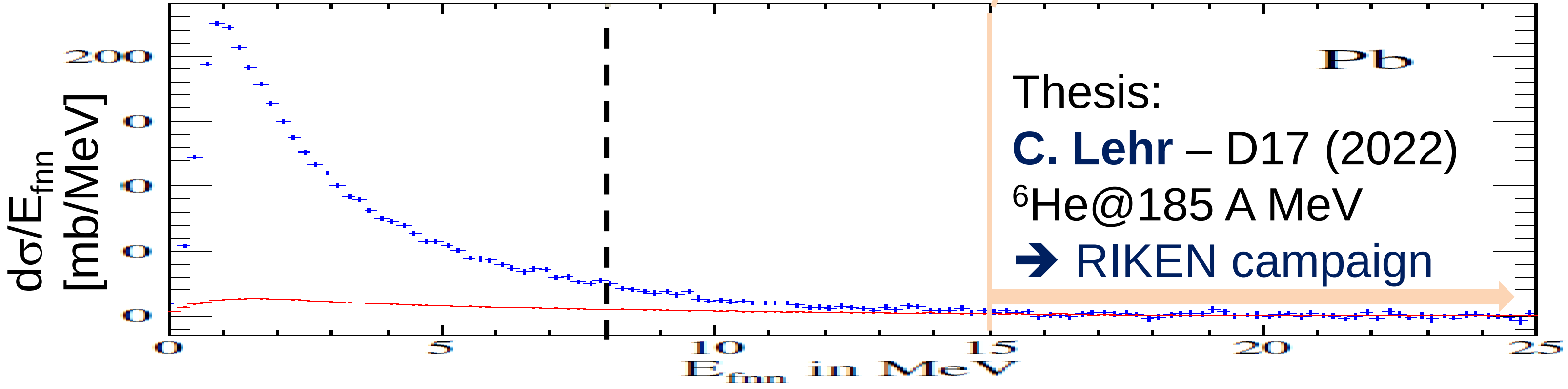
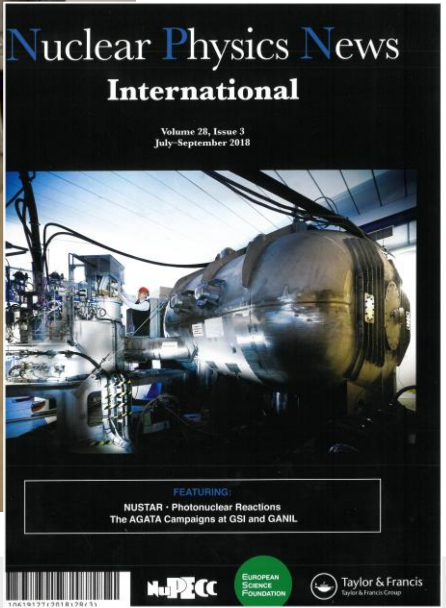


Heavier systems !
- clean separation
- no charge states

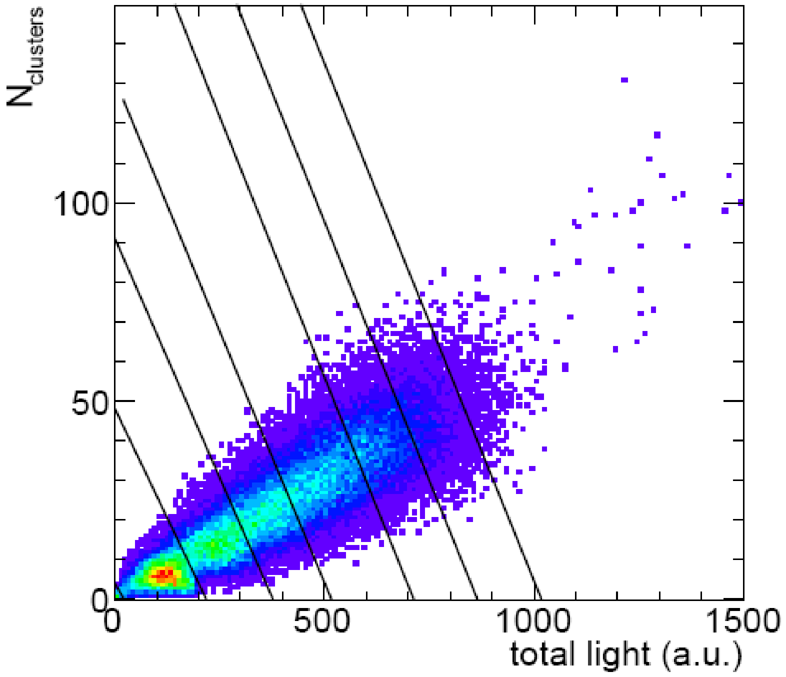
R^{3}B

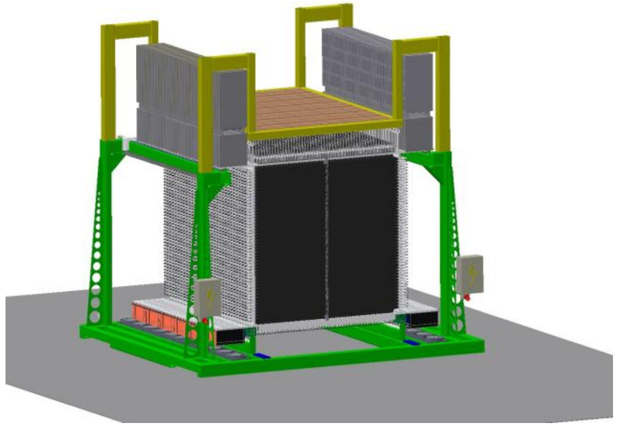
From R³B prototype to R³B precursor



Novel Neutron Detector: NeuLAND

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





	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

Previously < 50%

Previously <5% !

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

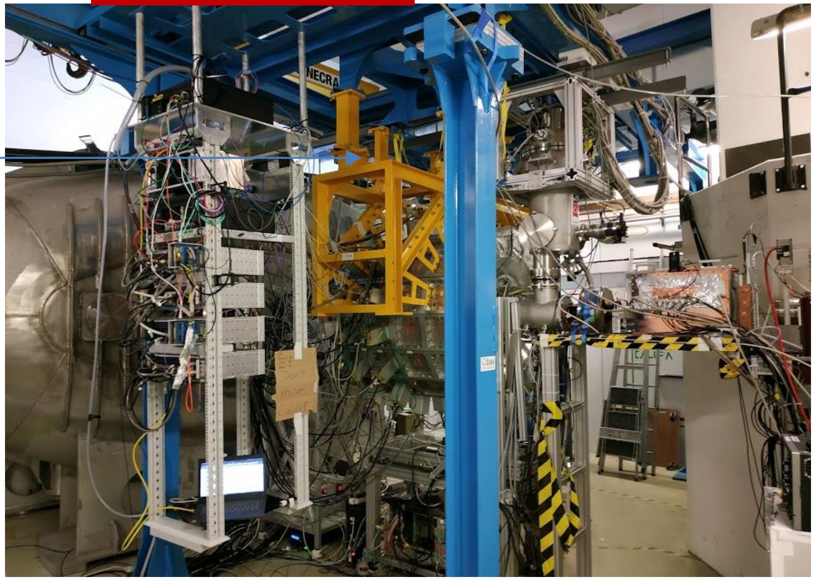
➔ 4n coincident four-momentum detection

Split detector + causality cuts could be added.

R³B in Cave C @ GSI ➔ preparing for FAIR



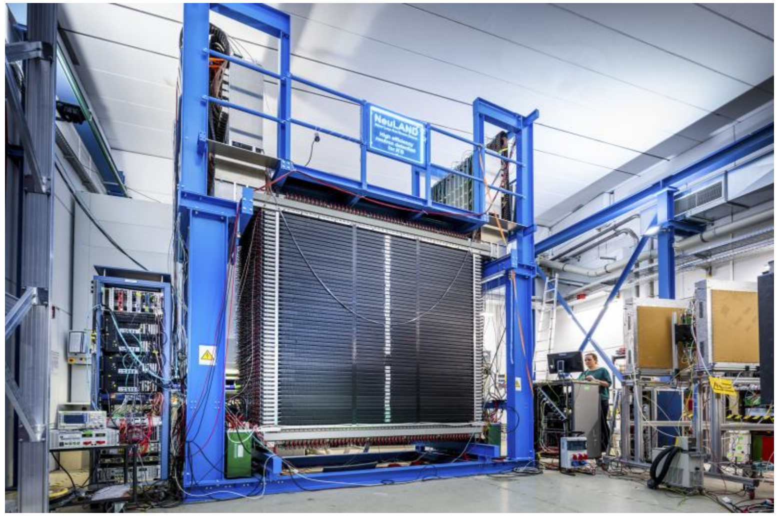
2015 - 2020


Lola Cortina

R^{3}B in Cave C @ GSI ➔ preparing for FAIR

2020 - 2026



Final warm up of GLAD just started

Lola Cortina

First R³B components enter FAIR High energy Cave

NUSTAR installs first major component at FAIR: GLAD vacuum chamber successfully placed in High-Energy Cave

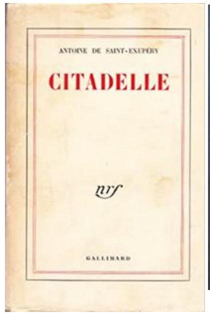
Start of the transport

28.05.2026 | At the FAIR construction site, the NUSTAR collaboration has reached an important milestone: The GLAD vacuum chamber – the first major component of the NUSTAR experimental setup – was successfully transported to the NUSTAR High-Energy Cave.

Summary

- Flexible setup comprising instrumentation also suitable for halo and dripline physics constructed and commissioned within Phase-0 experiments of the R^{3}B experiments, and a dedicated campaign an RIKEN within the SAMURAI collaboration
- High energies allow to bridge the excitation energy range from soft E1 excitations to the GDR
- Suitable beams at FAIR for the beginning could be energetic light nuclei; followed by heavier nuclei

- "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

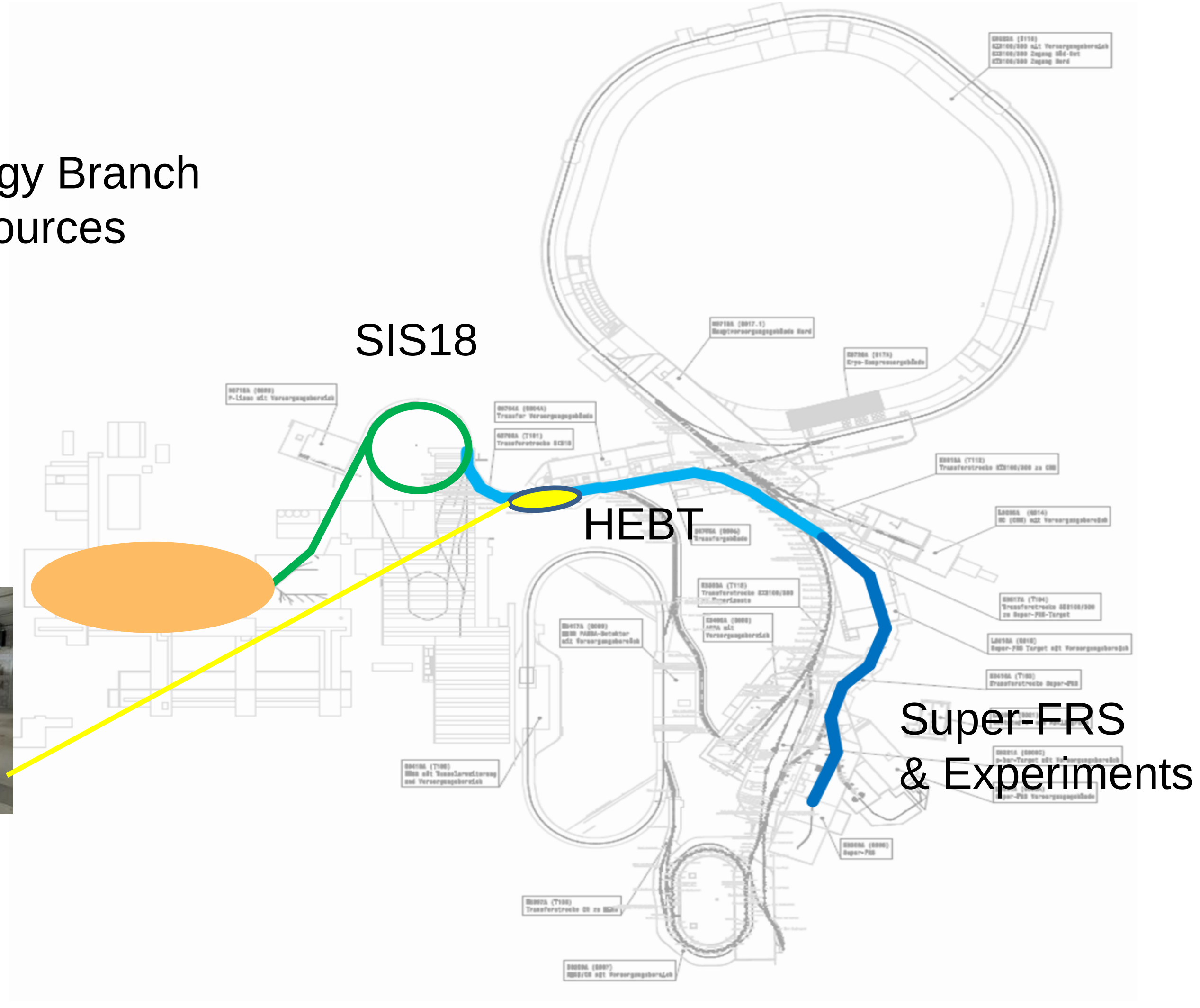


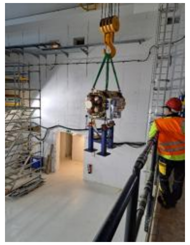
UNILAC is not operational for a while …

Two intermediate accelerator options already in preparation !
Repair work started.

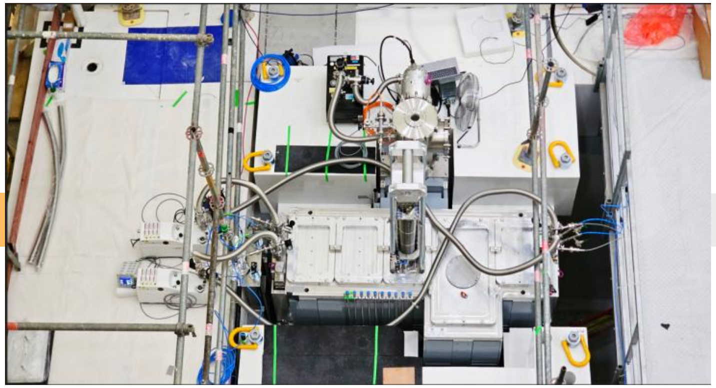
First Objective

- Start with beam directly from SIS18 via HEBT, Super-FRS to the High Energy Branch
- Start up scenario with different beam sources for SIS18 **in preparation**
- **UNILAC repair in parallel**



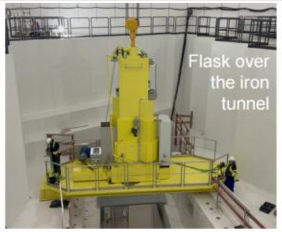


HEBT Installation start 03.04.2024



Super-FRS Installation

←27.8.2026 start of 1st Hardware Commissioning !



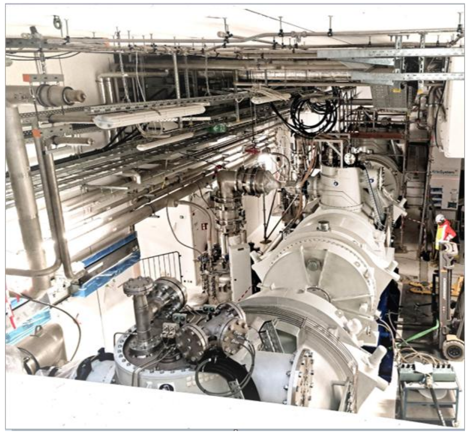
various components

Nov. 2025 –
April 2025 –
Mar 2026 –
FTF1
FPF0
FPF1
FPF2
FPF3
FPF4
FMF1
FMF2
FMF3
FHF1
FHF2
beam
Installation local cryogenics
BB

All sc multiplets produced, testing at CERN in full swing.

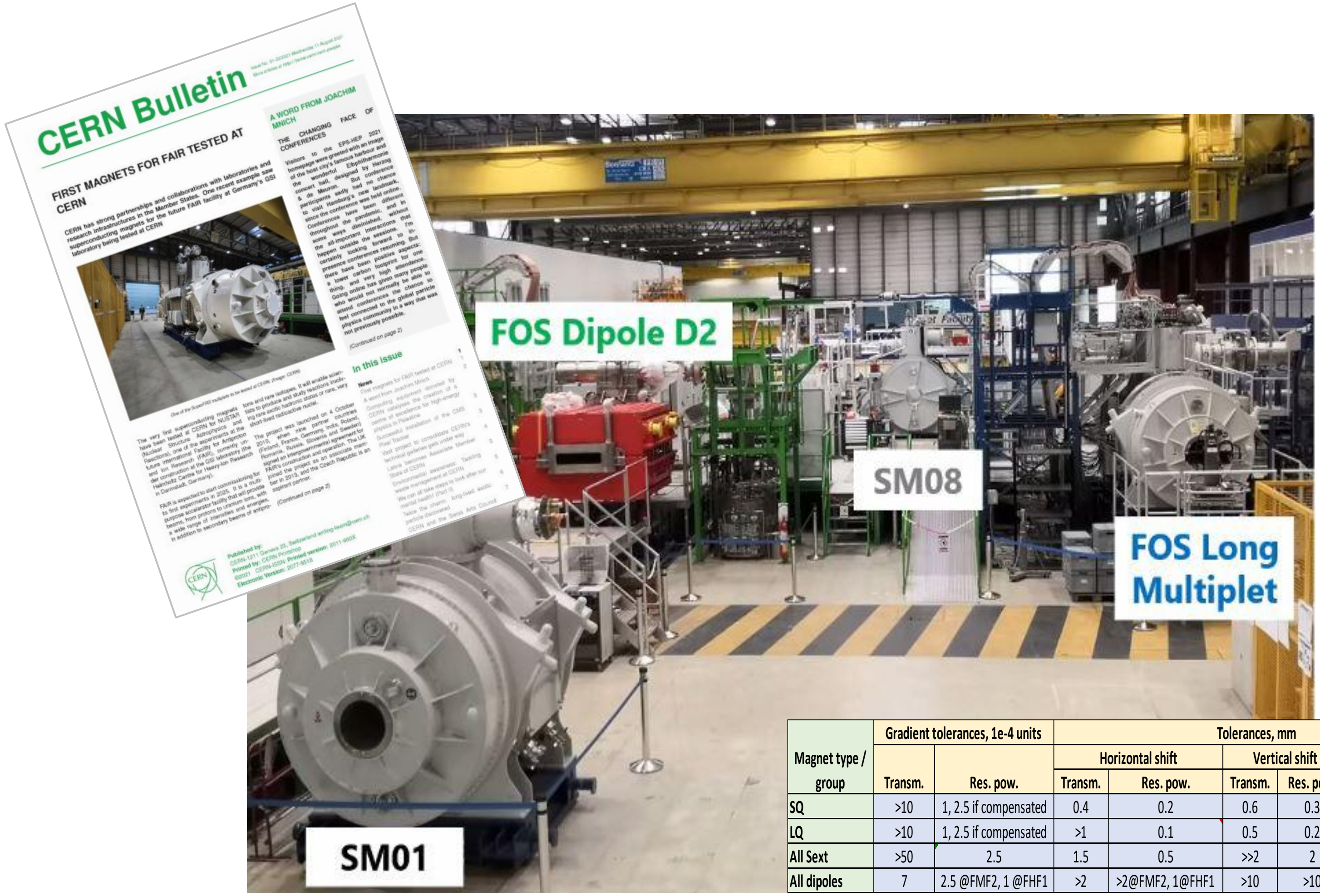
Installation Target Chamber 11.6.2026

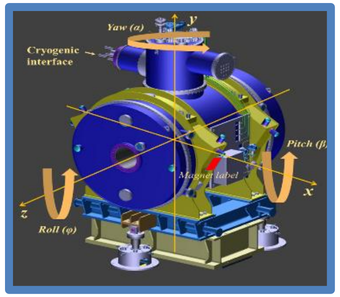
Installation start 06.05.2024



Installation Separator (Tunnel) ongoing

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





Very successful tests @ CERN
Ion optical performance well achieved !

Series Production in full swing
All magnets at CERN Q1/2027

Beam Commisioning (@FAIR) 2027

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

Thanks

- Super-FRS project group and

www.gsi.de/superfrs

R3B

www.gsi.de/r3b
www.r3b-nustar.de
collaboration - with SAMURAI