R³B

a setup for kinematical complete measurements @ FAIR- Facility for Antiproton & Ion Research

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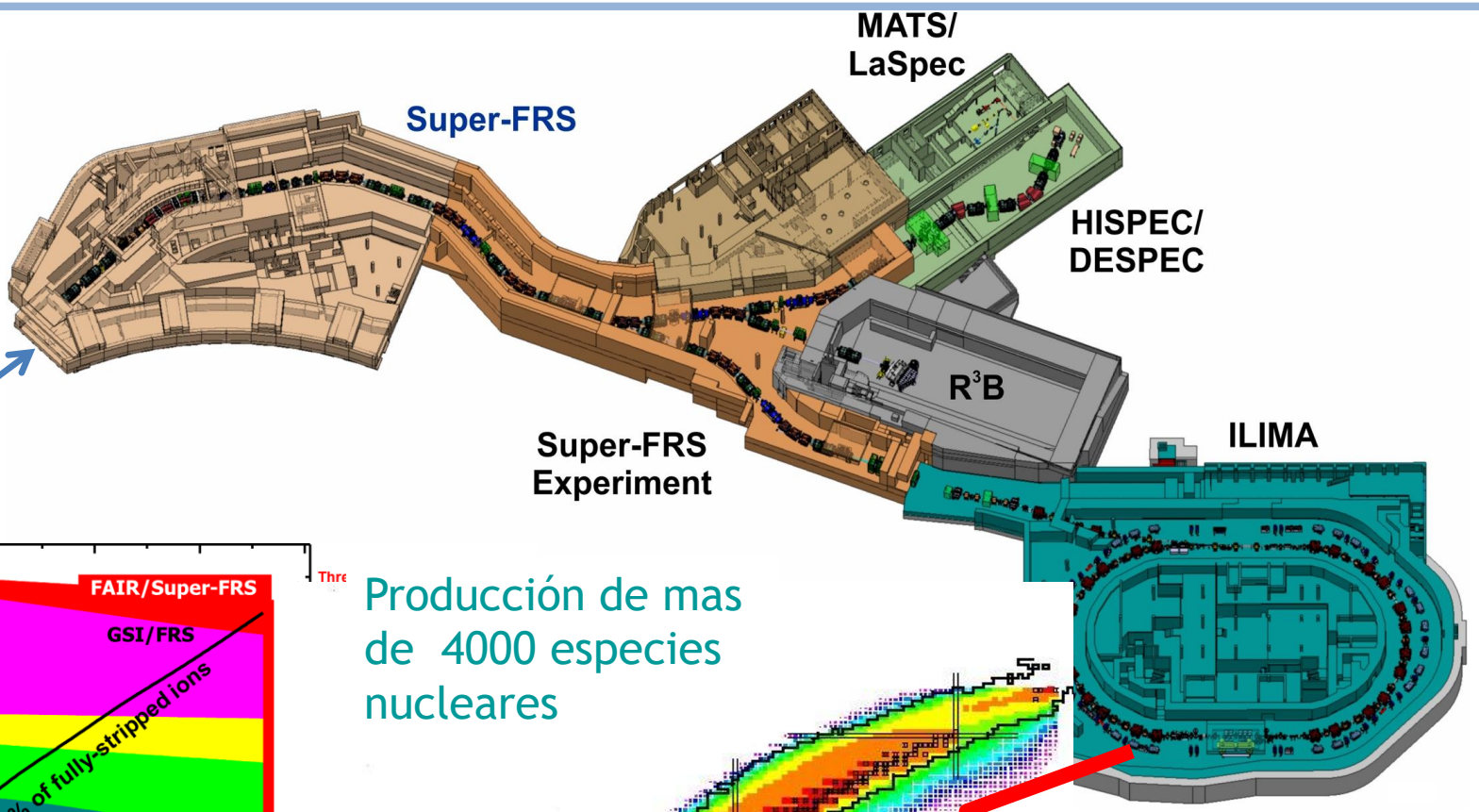
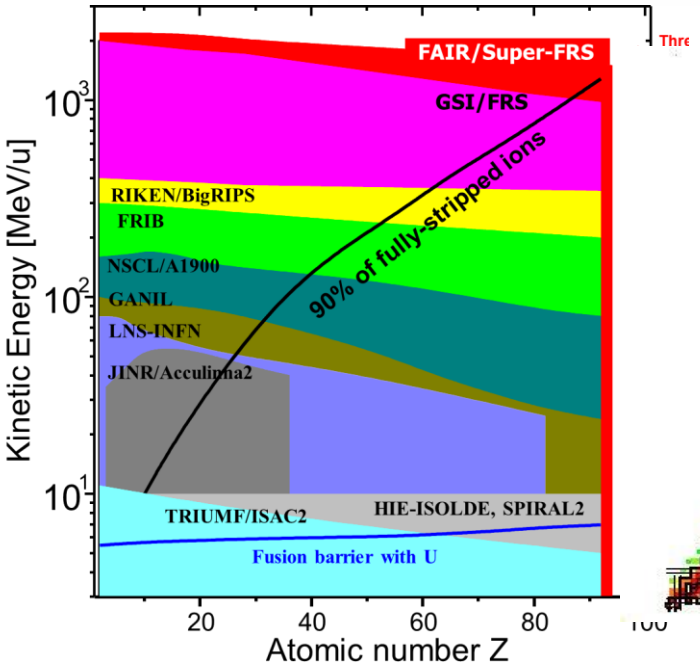
Design parameters U^{28+}		
	SIS18	SIS100
Energy	200 MeV/u	1.5 GeV/u
Ions per cycle	1.5×10^{11}	5×10^{11}
Repetition rate	2.7 Hz	0.3 Hz

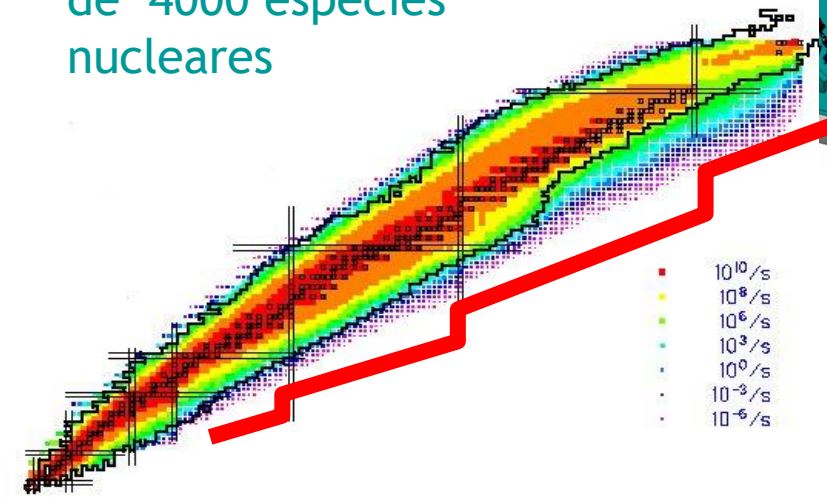
FAIR en un futuro no muy lejano

NUSTAR NUclear STructure & Astrophysis Research

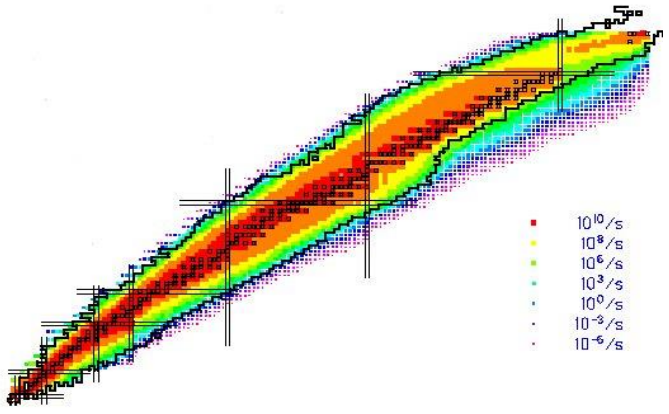




Producción de mas de 4000 especies nucleares



NUSTAR:
NUclear Structure, Astrophysics and Reactions



What are the limits for existence of nuclei?

- Where are the proton and neutron drip lines situated?
- Where does the nuclear chart end?

How does the nuclear force depend on varying proton-to-neutron ratios?

- What is the isospin dependence of the spin-orbit force?
- How does shell structure change far away from stability?

How to explain collective phenomena from individual motion?

- What are the phases, relevant degrees of freedom, and symmetries of the nuclear many-body system?

How are complex nuclei built from their basic constituents?

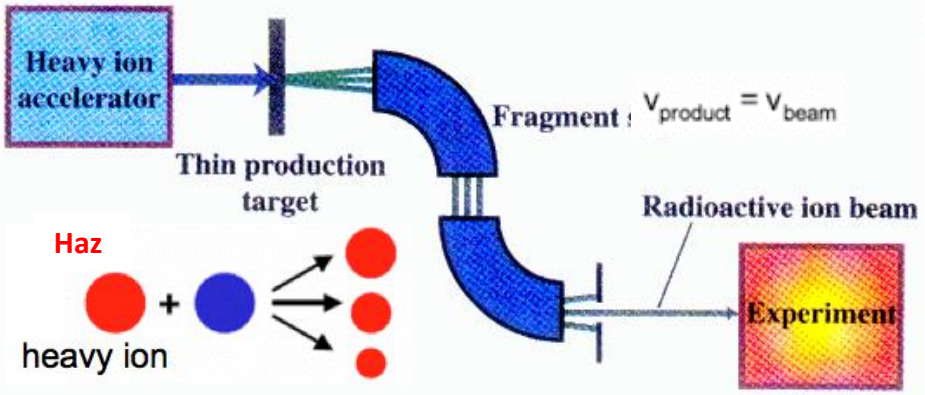
- What is the effective nucleon-nucleon interaction?
- How does QCD constrain its parameters?

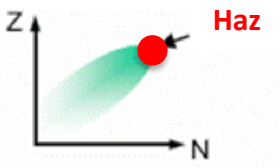
Which are the nuclei relevant for astrophysical processes and what are their properties?

- What is the origin of the heavy elements?

Producción de Haces Radioactivas

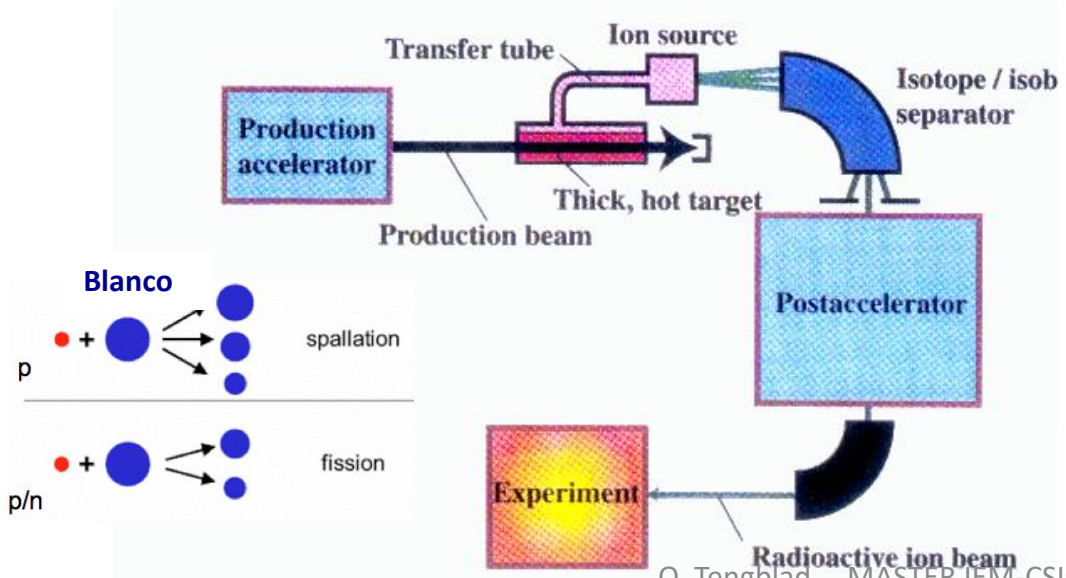
Fragmentación del Haz

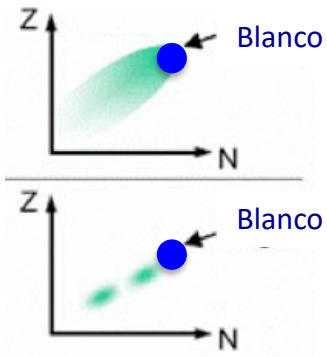




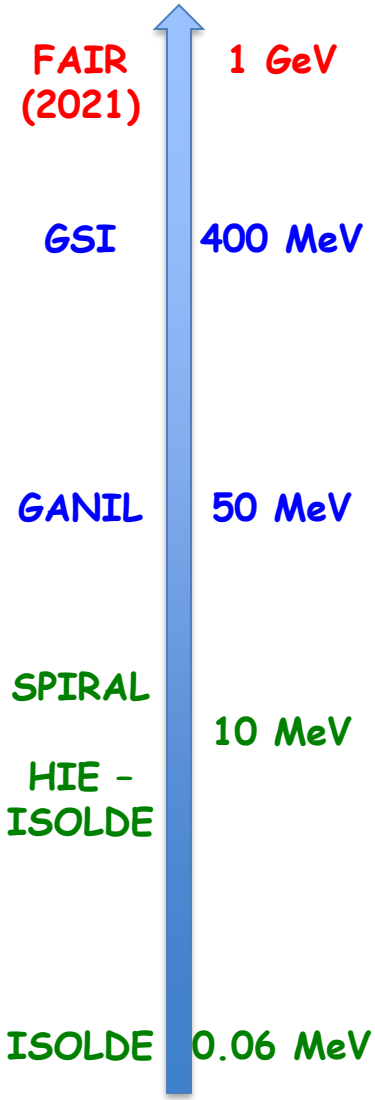
High energy, large variety of species,
Short half-lives (μs), cocktail beam

ISOL – Isotope Separation On Line

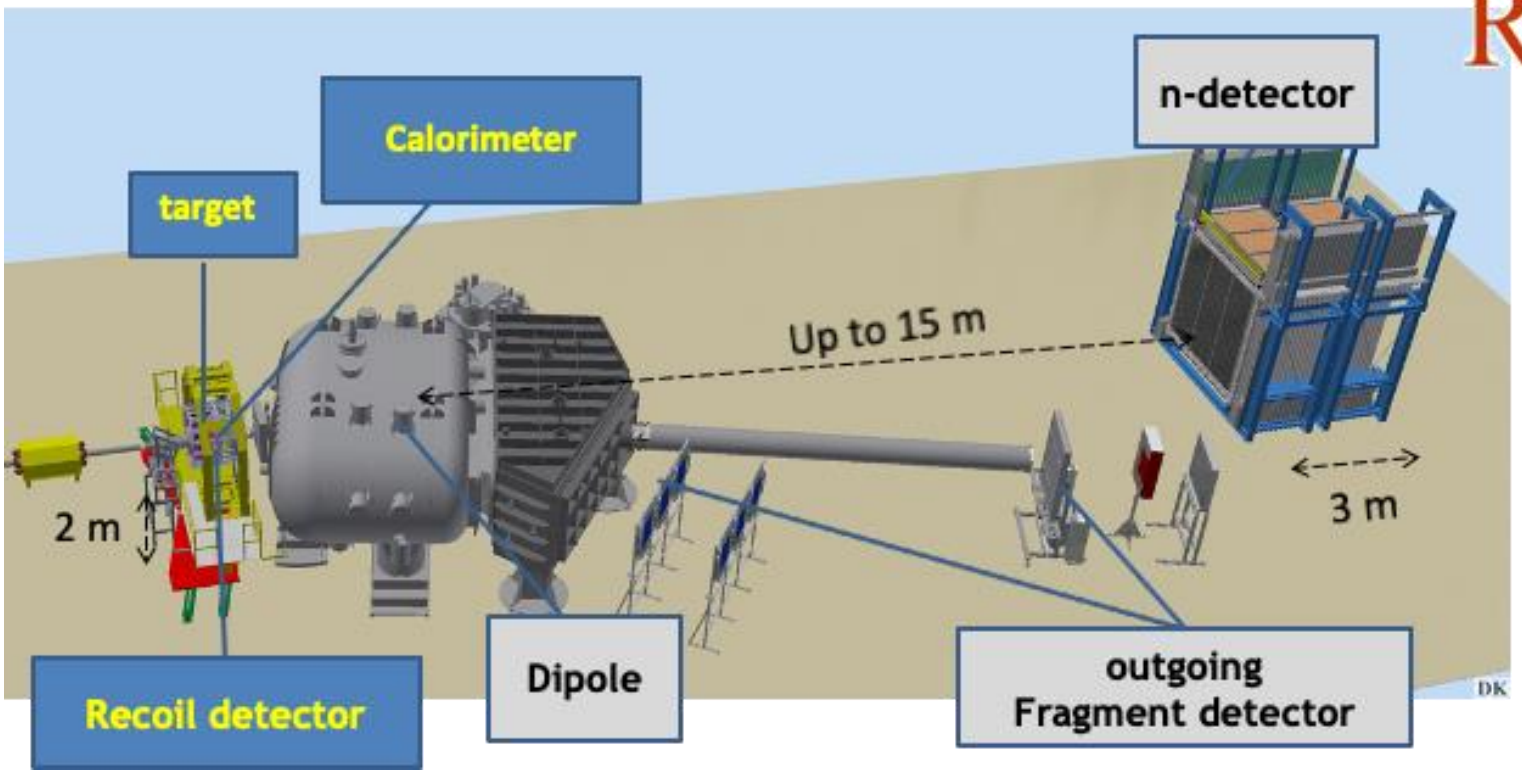




Variable energy, high intensity, good beam qualities



R³B: Reactions with Relativistic Radioactive Beams



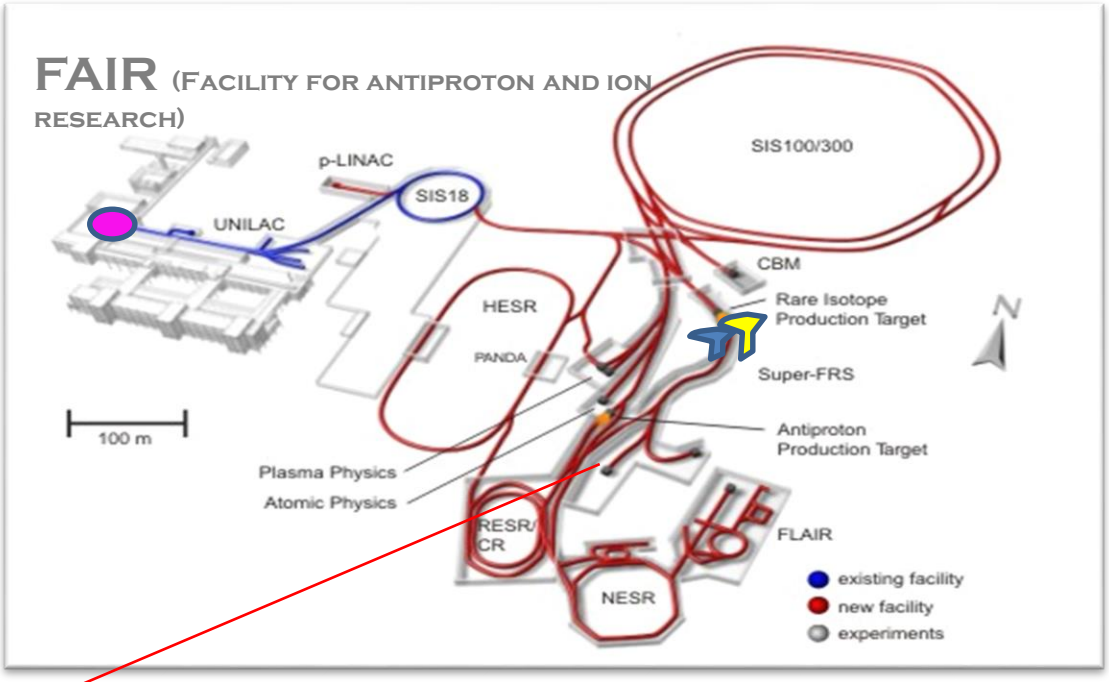
Kinematically complete measurement of reactions with high-energy secondary beams

- **Nuclear Astrophysics**
- **Structure of exotic nuclei**
- **Neutron-rich matter**

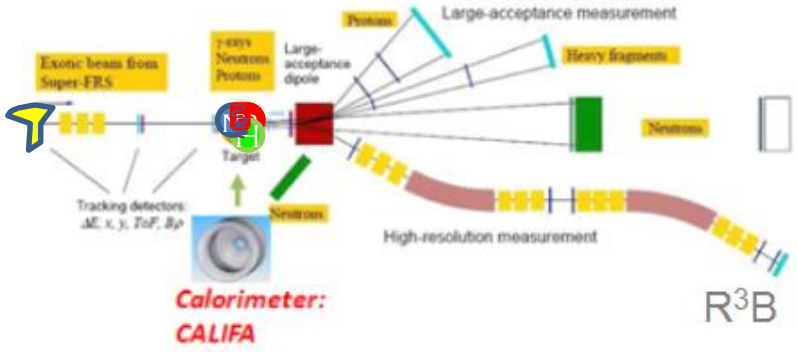
•fixed-target experiment for complete inverse-kinematics reactions with relativistic RIBs ~100 MeV/u – 1.5 GeV/u

•Experiments with the most exotic (<1 ion/s) and short-lived nuclei - exploring the isospin frontier at and beyond the drip-lines

How does it work



R³B



1. Accelerated beam impact on Production Target

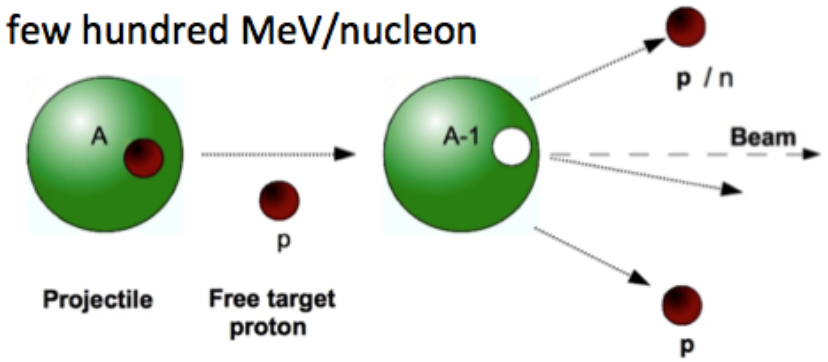
2. Products are separated in FRS

3. Separated isotopes directed to experiment

4. Isotope of interest impact on Reaction Target

5. Reaction fragments and gammas are detected

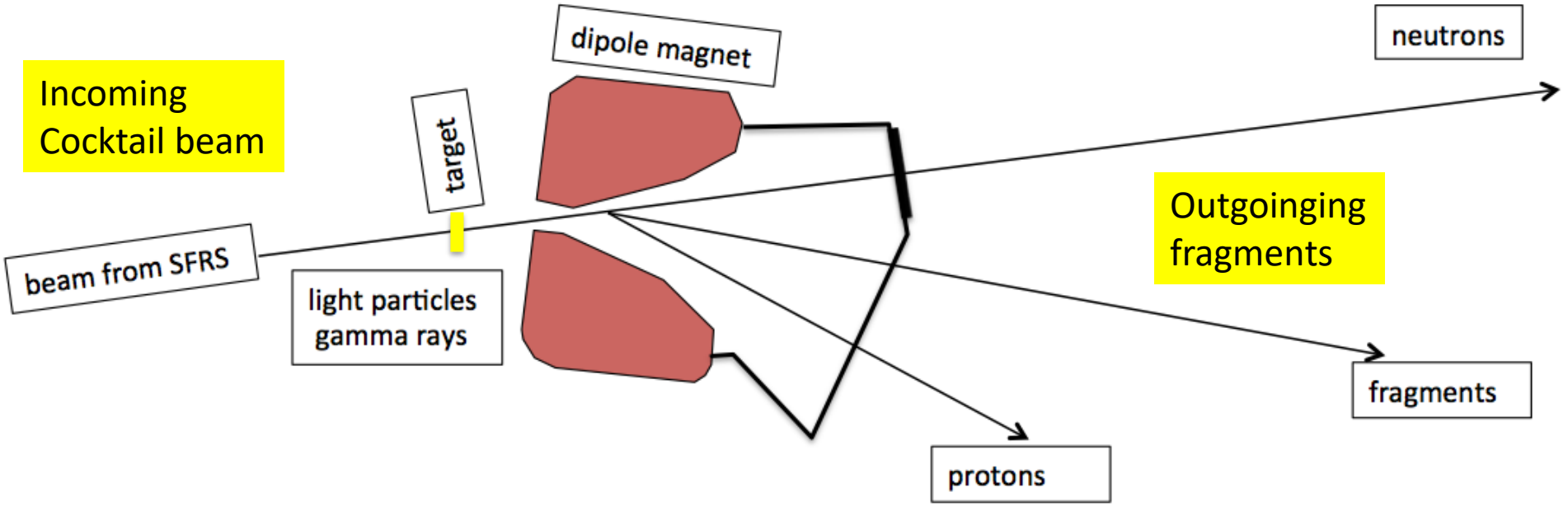
R3B Concept



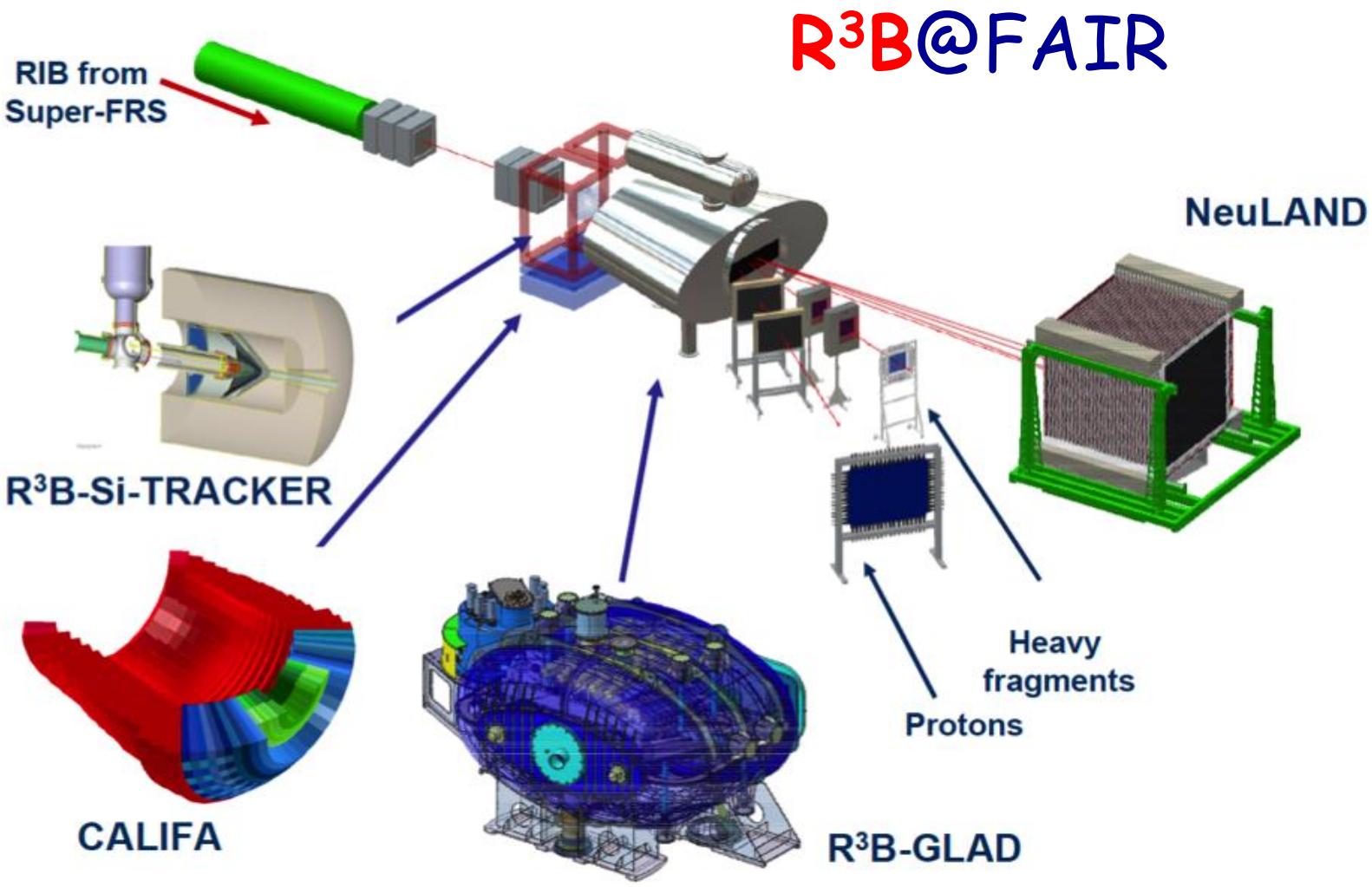
After the reaction: heavy fragment, neutrons, protons, gammas

Aim: measure all reaction products

Cinemática completa!!

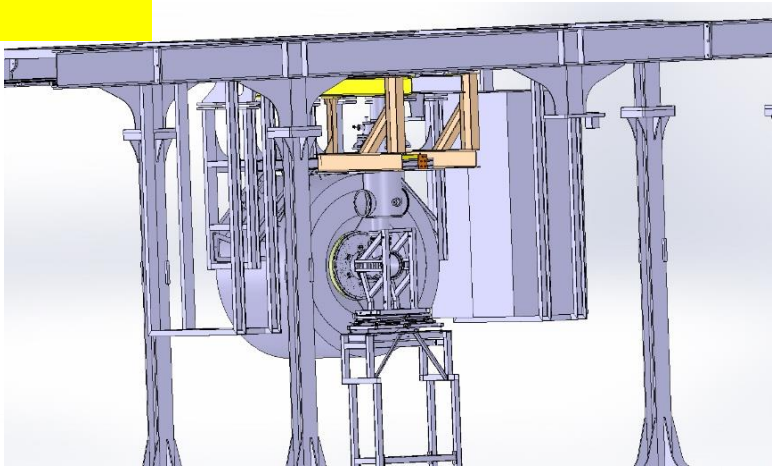


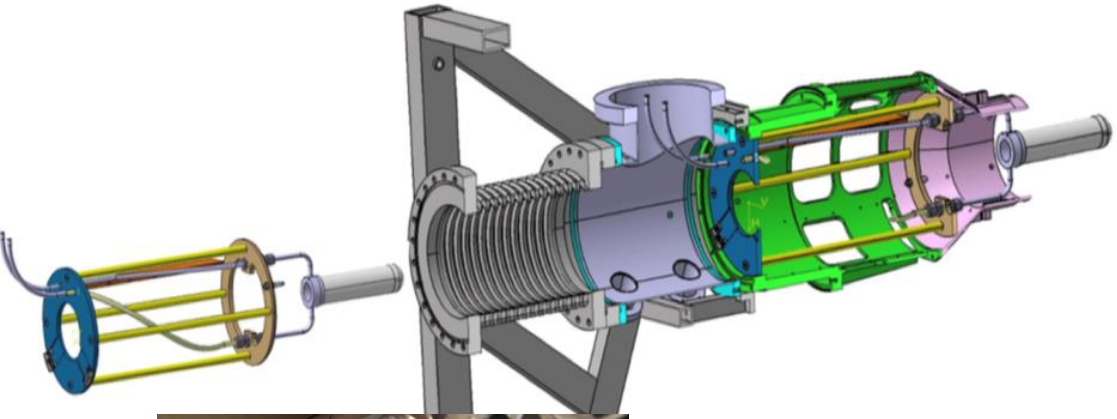
R3B: (Key) Components



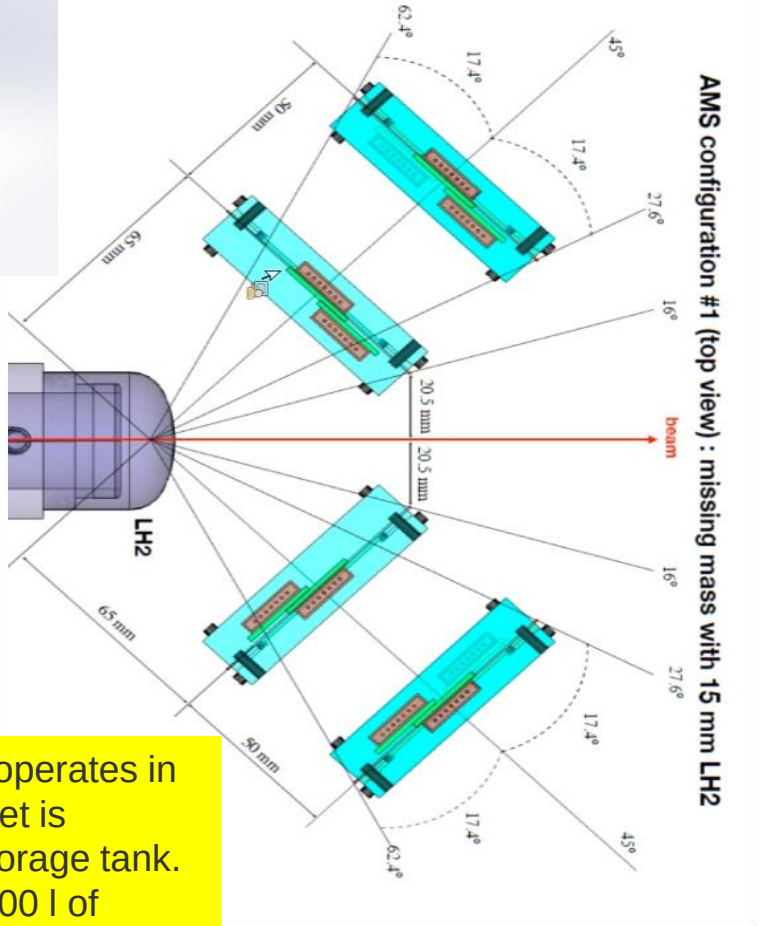
LH_2 target with Si-detector

The target cell diameter is 42 mm,. Three target length of 15, 50 and 150 mm.



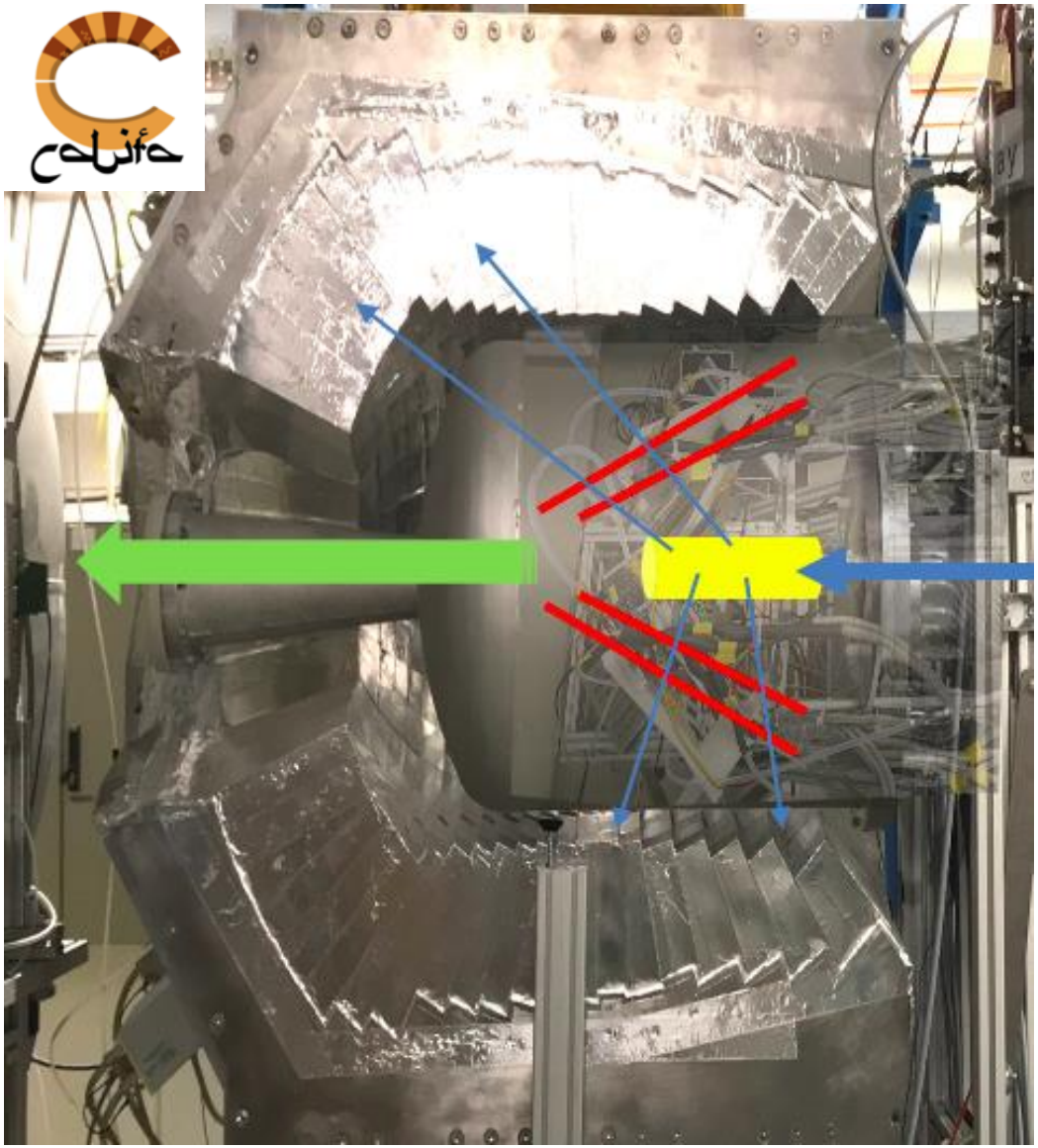


The target cell is made of Mylar



The cryogenic system operates in a closed loop. The target is connected to a 852 l storage tank. The tank is filled with 800 l of hydrogen at room temperature. After liquefaction the hydrogen is at 20.3 K and 1041 mbar.

Reaction chamber: LH_2-target, p-tracker, γ-spec-calori-meter



Identify and track recoils emmitted at large angles

- **High angular resolution (better than 1 mrad) → very high segmentation**
- **Low noise level → detection of MIP**
- **Multi-layer sensors 50-100 μm for 1st layer → minimize multiple scattering or shadow γ rays**
- **Low threshold 25 KeV**
- **Multi-hit capability**

Further:

- **Closed geometry around the extended target→ 4p vertex reconstruction**
- **Spark protection against ionising particles hit**
- **Operate in the proximity of strong magnetic fields and vacuum**

Dedicated electronics

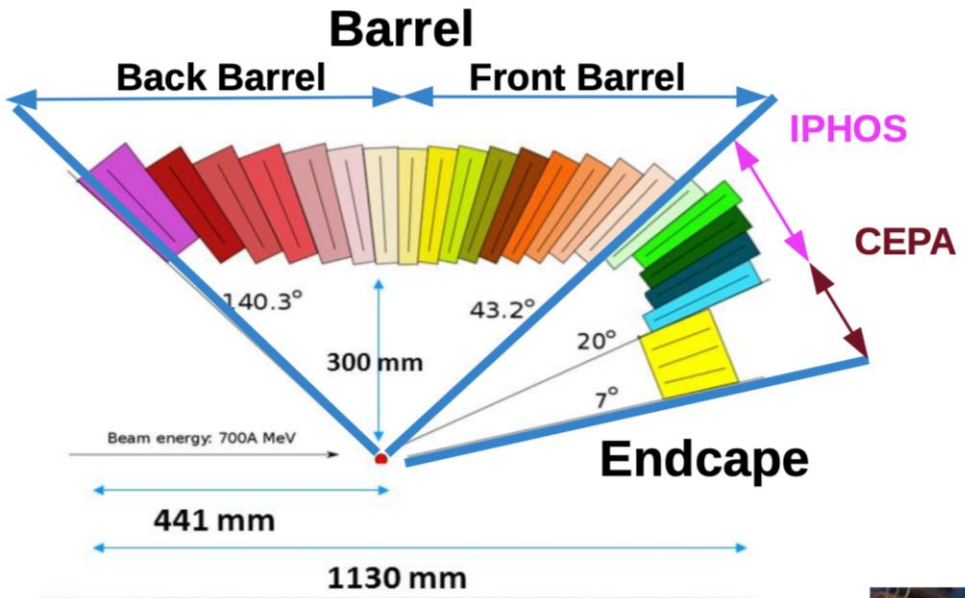
https://igfae.usc.es/igfae/es/califa-instalado-fair/

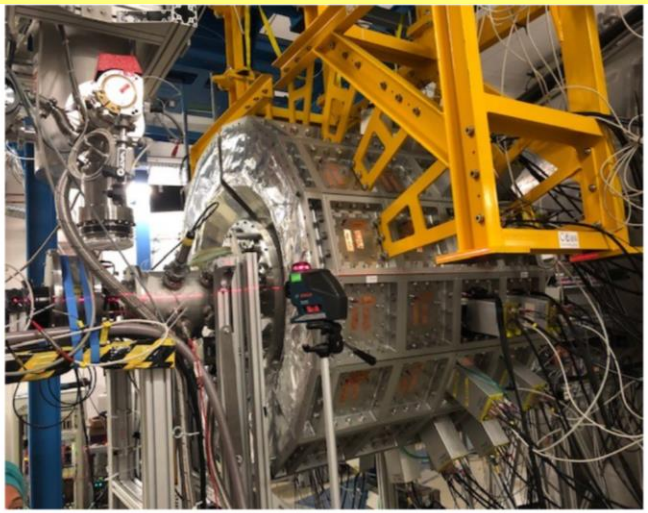
CALIFA: Highly segmented
Thick detection volume
Inner radius 50cm

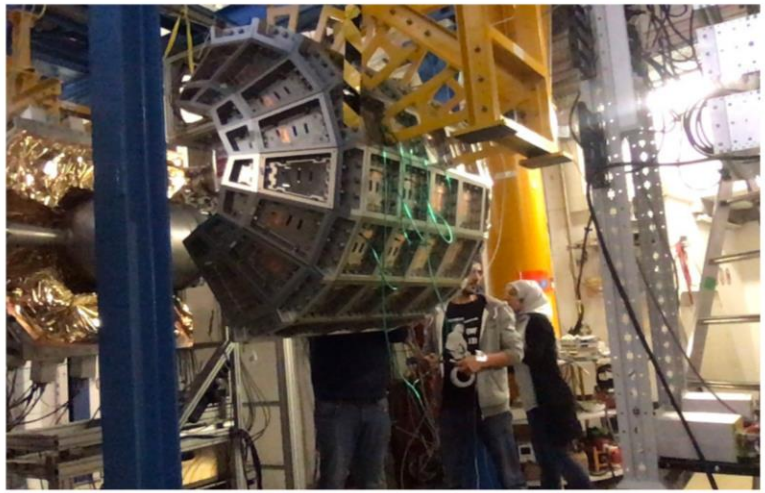
Barrel: Crystal length 15-20 cm
1952 crystals = 2 Ton

EndCap: 680 crystals = 1 Ton

CALIFA barrel and forward endcap (gamma/particle calorimeter)





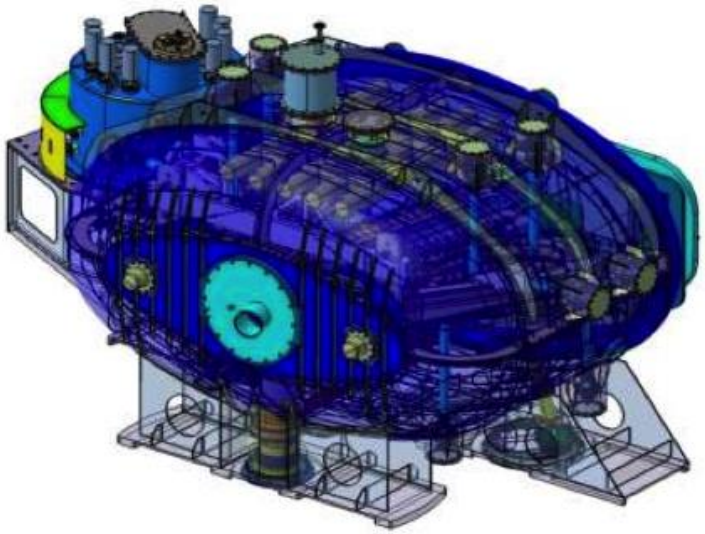


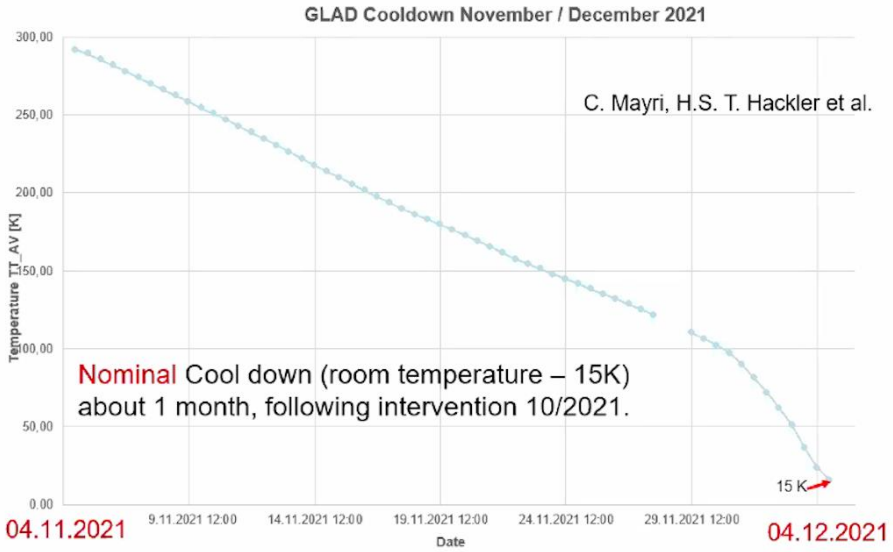
GLAD - Large-acceptance superconductingdipole magnet

http://fpsalmon.usc.es/r3b/reports/R3B-Glad_MT20_Preprint_IEEEref-PID488807.pdf

Magnet parameters: Weight: 50 t

- Large vertical gap ± 80 mrad
- High integrated field of 4.8 Tm
- Fringe field at the target position less than 20 mT
- Operational temperature 4.6 K
- The overall size of the conical cryostat: 3.5 m long, 3.8 m high and 7 m wide.





NeuLAND - High-resolution neutron ToF spectrometer

https://www.gsi.de/work/forschung/nustarenna/nustarenna_divisions/kernreaktionen/r3b_project_group/neuland

NeuLAND detector parameters:

- full active detector using RP/BC408
- face size 2.50x2.50 m^2
- active depth 3m (30 double-planes)
- 3000 scintillator bars
- 6000 PM / readout channels (both ends)
- 32 tons

2022: 15 DP installed

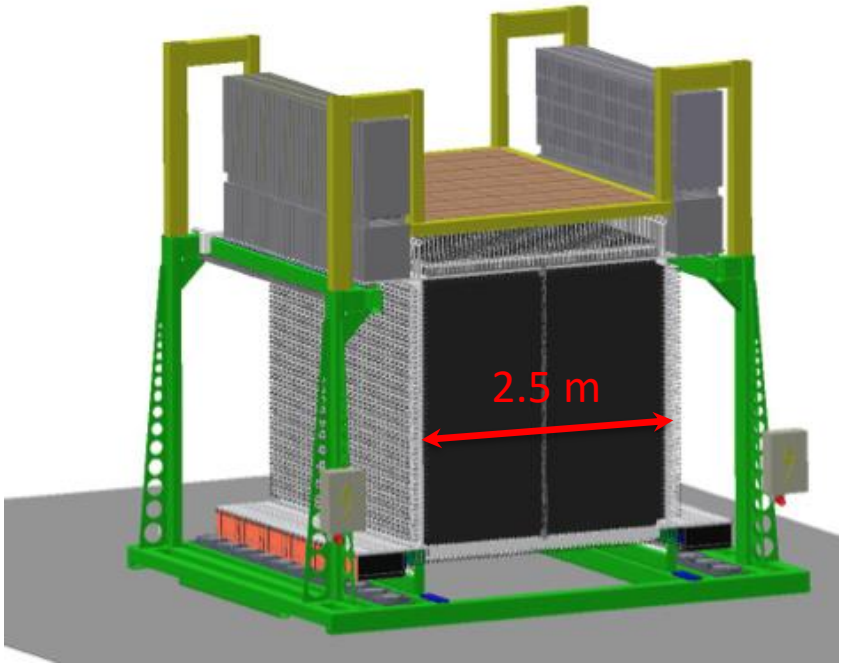
NeuLAND design goals:

- >90% efficiency for 0.2-1.0 GeV neutrons
- Multi-hit capability for up to 5n
- invariant-mass resolution:

  NeuLAND to target distance 35 m

  ΔE < 20 keV at 300 keV

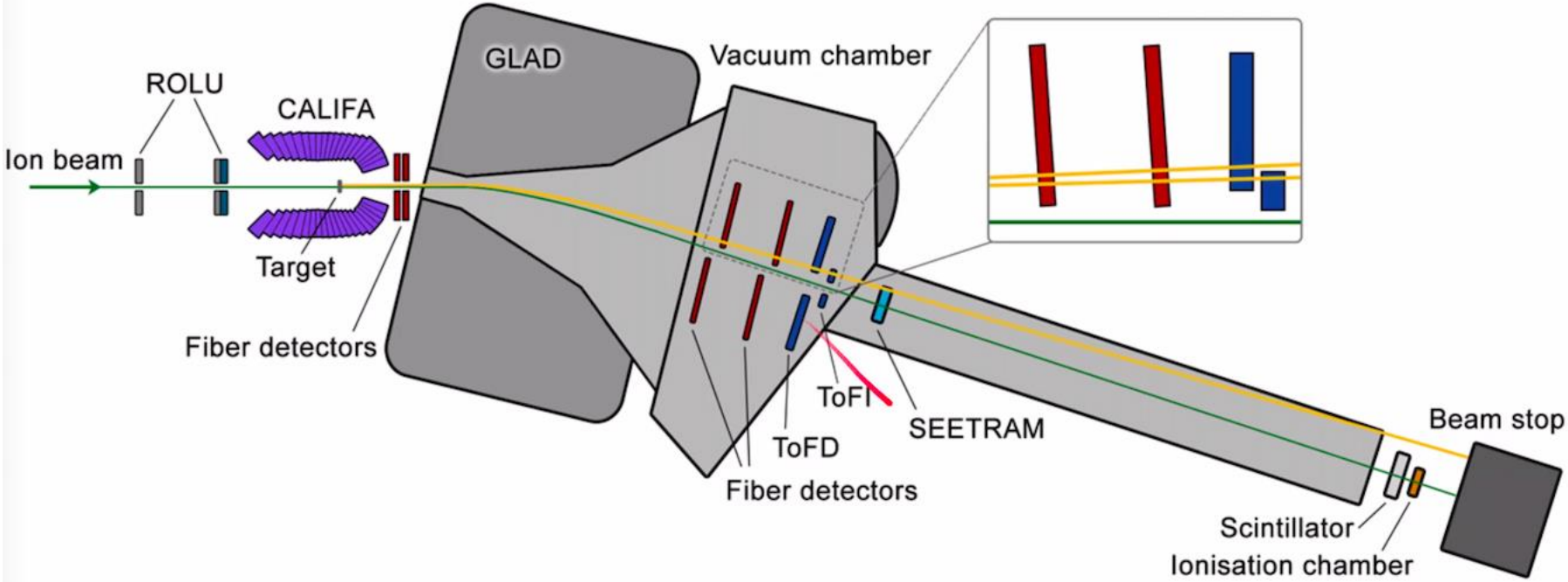
x100 = one double-plane



For full kinematic reconstruction & reaction channel ID we need to know

- Energy loss → Nuclear charge Z
- Time of Flight → Mass identification
- Trajectory → Momentum

for incoming and outgoing fragments, beam, gammas



R3B tracking system

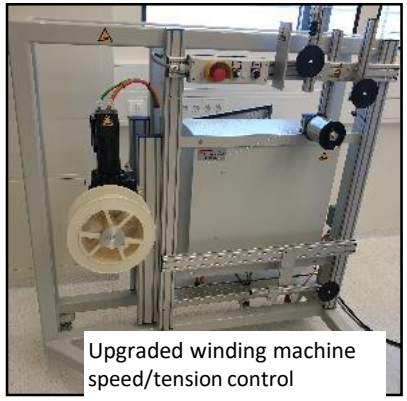
Square fibers 0.2x0.2 mm^2
Number of fibers ~ 10^4 fibers
→ 60 μm resolution

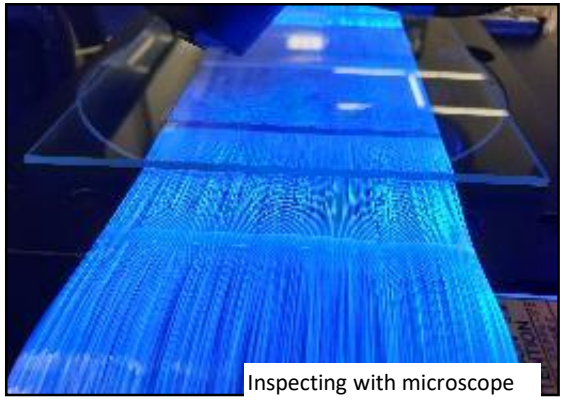
Scintillating Fiber Tracker

4d Tracking at High Rate with High Dynamic Range

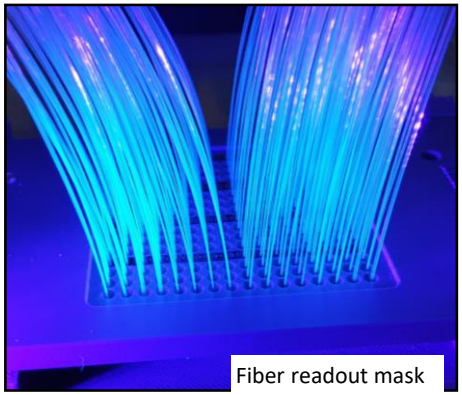
C. Caesar and D. Savran

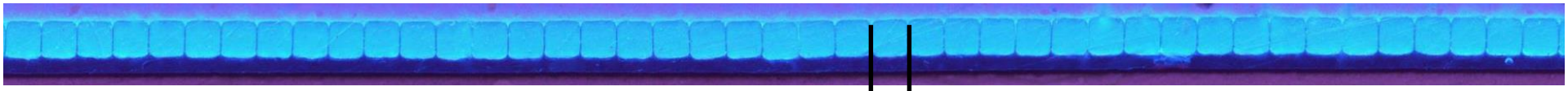
Infrastructure upgrades

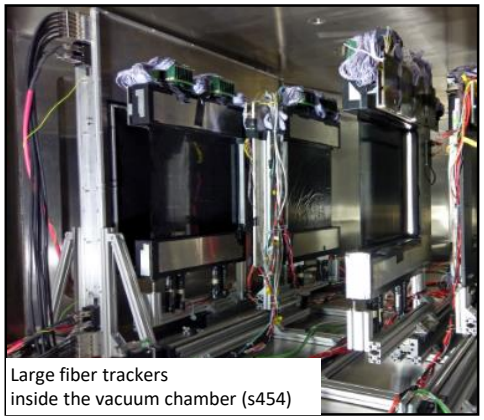

Upgraded winding machine
speed/tension control


Inspecting with microscope

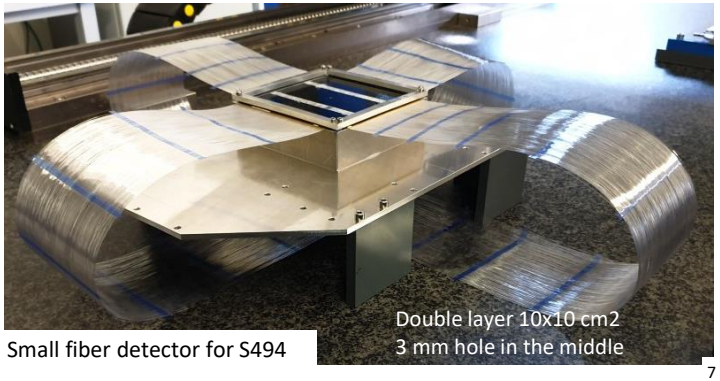

New infrastructure for sorting fibres into a mask


Fiber readout mask




Large fiber trackers
inside the vacuum chamber (s454)


Manufacturing process



Small fiber detector for S494

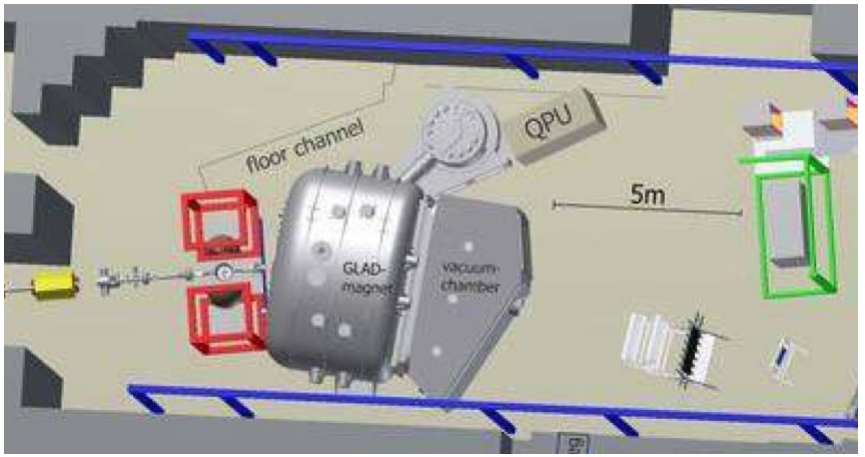
7

R3B Summary:
Schedule and first experiments @ GSI in Cave C

2020 **50% NeuLAND and 50% CALIFA & Si-Tracker + tracking detector prototypes**
Liquid Hydrogen target (LH_2)

2019-23 **Physics runs at GSI (Cave C) (phase 0)**

2024 - 2025? Move to HEC- cave @FAIR



Experiments will make use of uniqueness of R3B:
- Reactions at high beam energies up to 1 GeV/u
- Tracking and identification capability for the heaviest ions
- Multi-neutron tracking capability, high-efficiency calorimeter

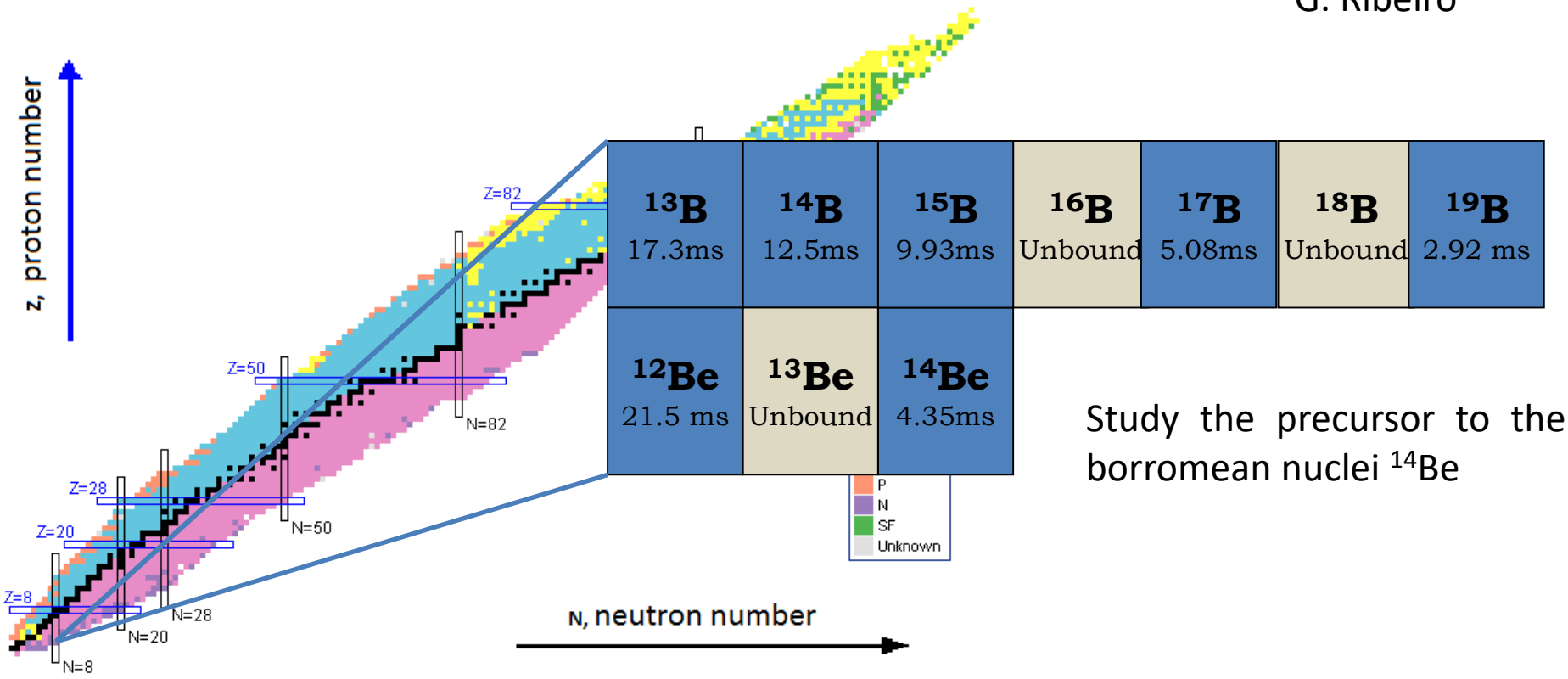
Experiments possible for the first time:
- 4 neutron decays beyond the drip-line and for heavier n-rich isotopes
- Kinematically complete measurements of quasi-free nucleon knockout reactions
- Electric dipole and quadrupole response of Sn nuclei beyond N=82, and of neutron-rich Pb isotopes (polarizability, symmetry energy)
- Fission barriers from (p,2p) reactions (→ r-process)

S393 experiment

Study of light neutro-rich nuclei using kinematically complete measurements in inverse kinematics @ GSI

quasi-free scattering: $^{14}B(p,2p)^{13}Be$

G. Ribeiro



^{13}B 17.3ms	**^{14}B** 12.5ms	**^{15}B** 9.93ms	**^{16}B** Unbound	**^{17}B** 5.08ms	**^{18}B** Unbound	**^{19}B** 2.92 ms
^{12}Be 21.5 ms	**^{13}Be** Unbound	**^{14}Be** 4.35ms				

Study the precursor to the borromean nuclei ^{14}Be

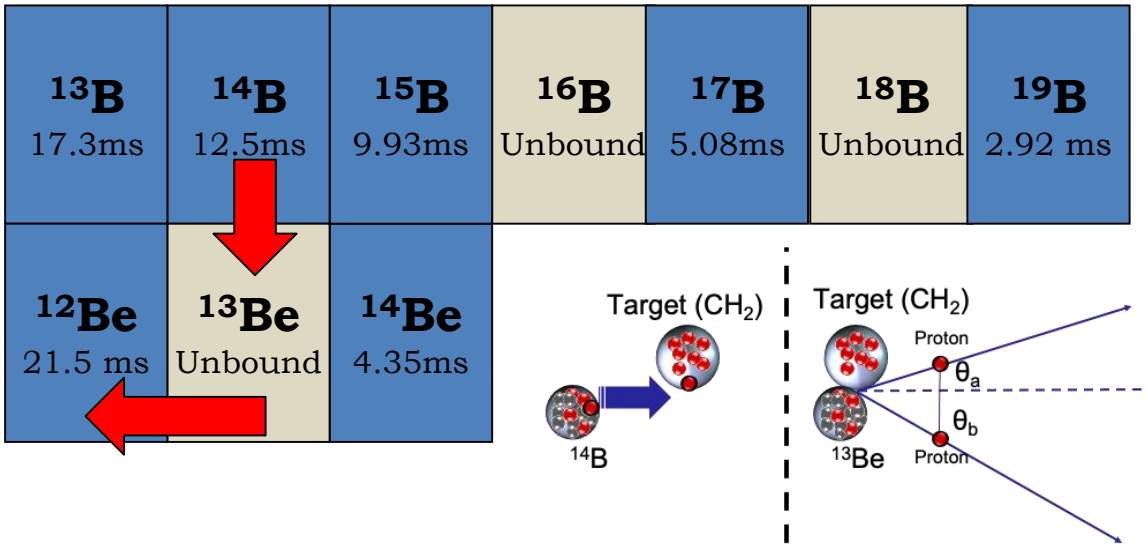
Quasi-Free Scattering: Knockout reaction

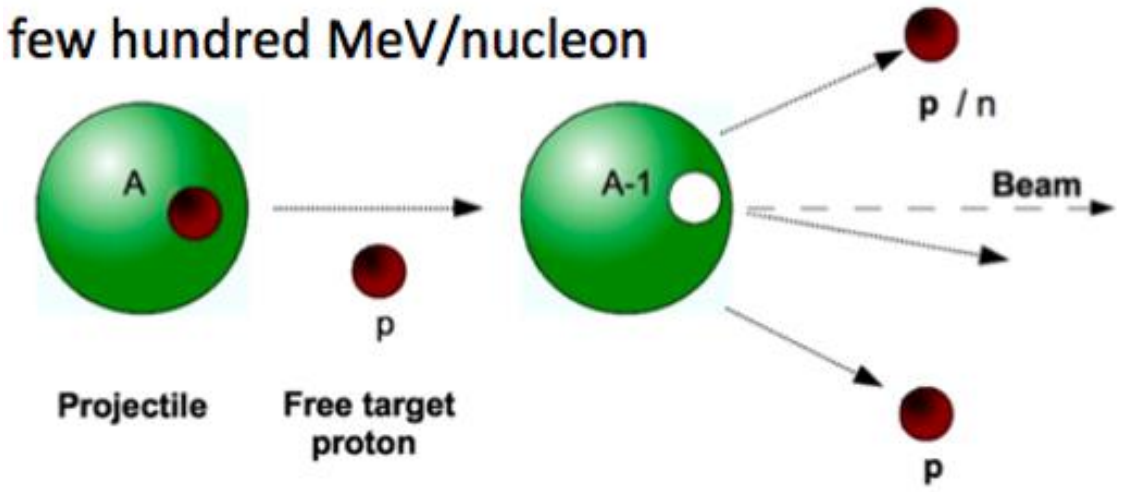
^{14}B(p,2p)^{13}Be

- Direct Reaction: quick and direct **from initial to final states without intermediate compound state**.
- If both outgoing particles have the same masses, in the lab system:

$$\theta_A + \theta_B \simeq 81^\circ$$

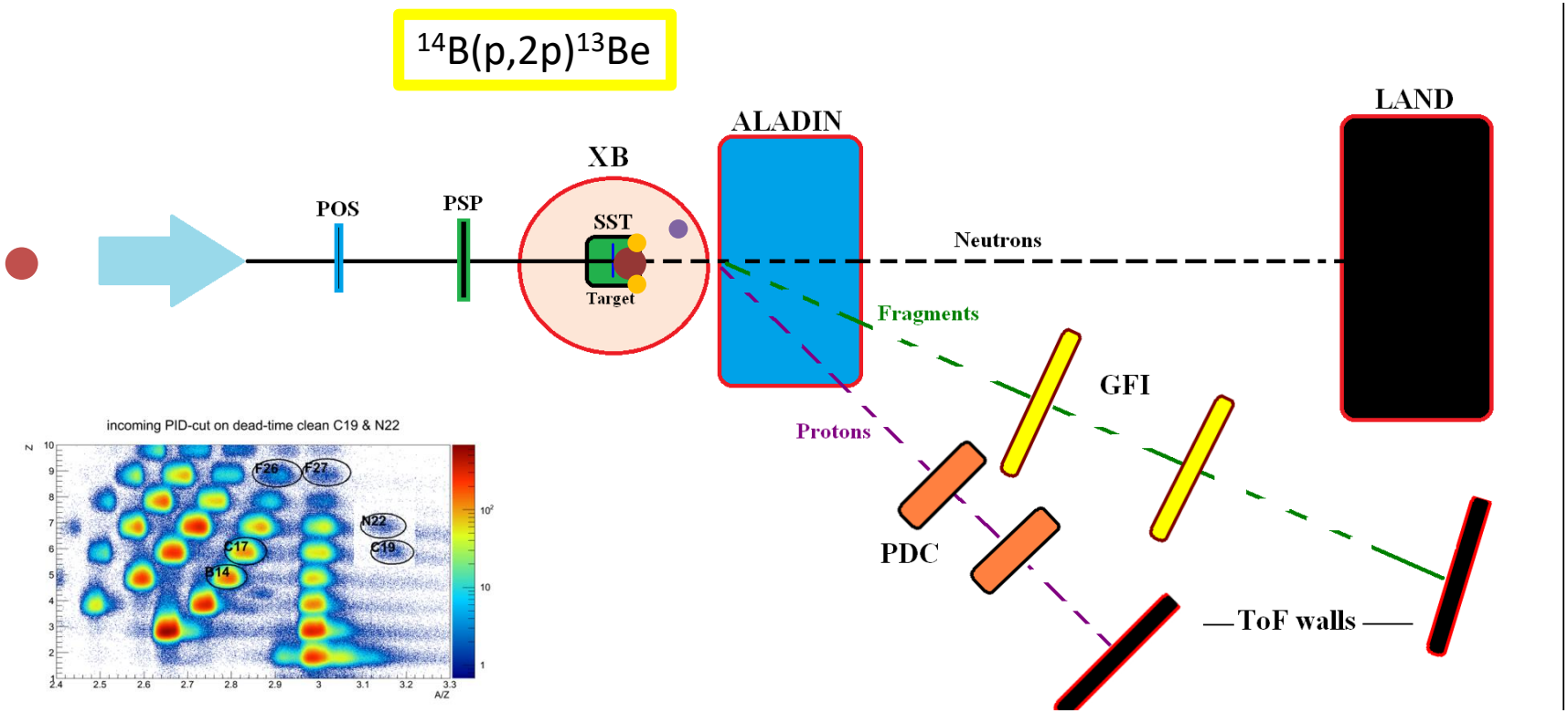
(p,2p), (p,np)





Experiment:Cave C

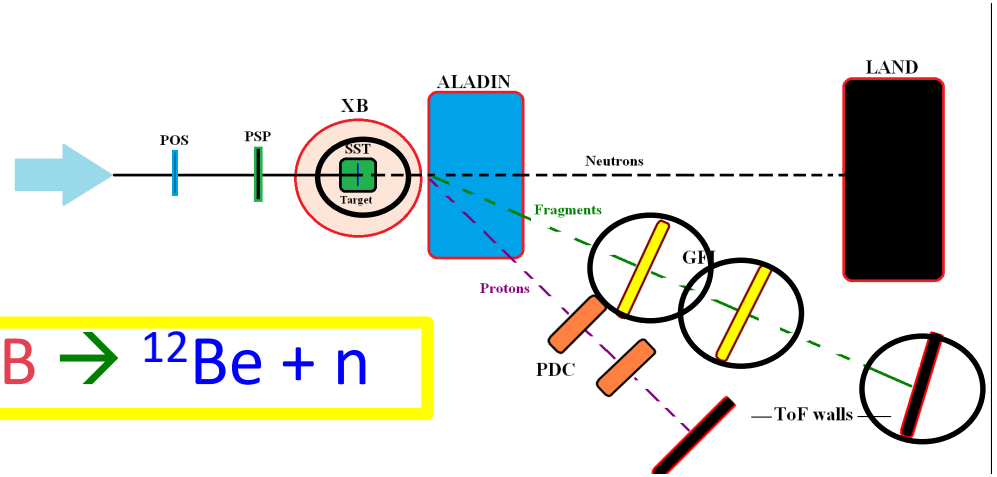
$^{14}B(p,2p)^{13}Be$



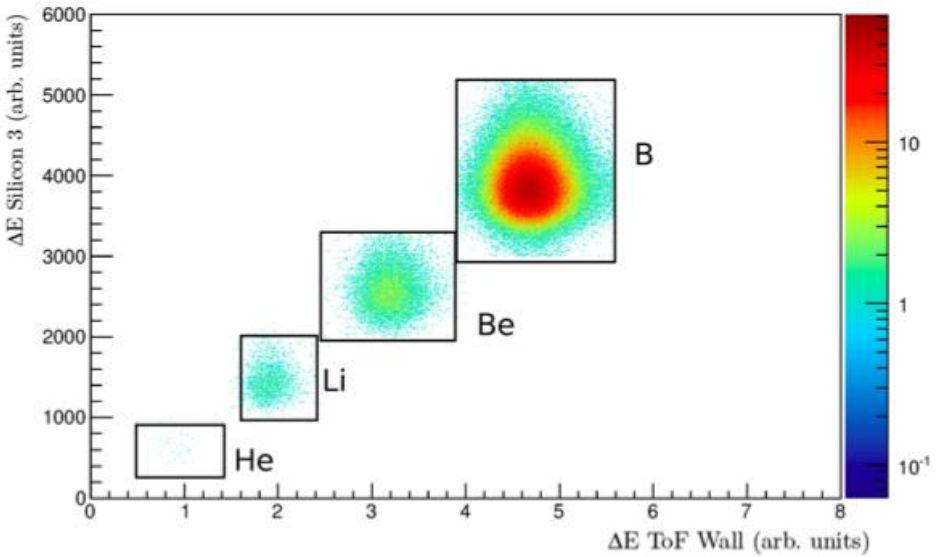
Primary beam	$^{40}Ar^{11+}$ @ 490 MeV/u
Intensity	$6 \cdot 10^{10}$ ions/spill.
Production target	Be 4 mg/cm^2
Reaction target	**H, C, empty**

Reaction channel Idenitifcation

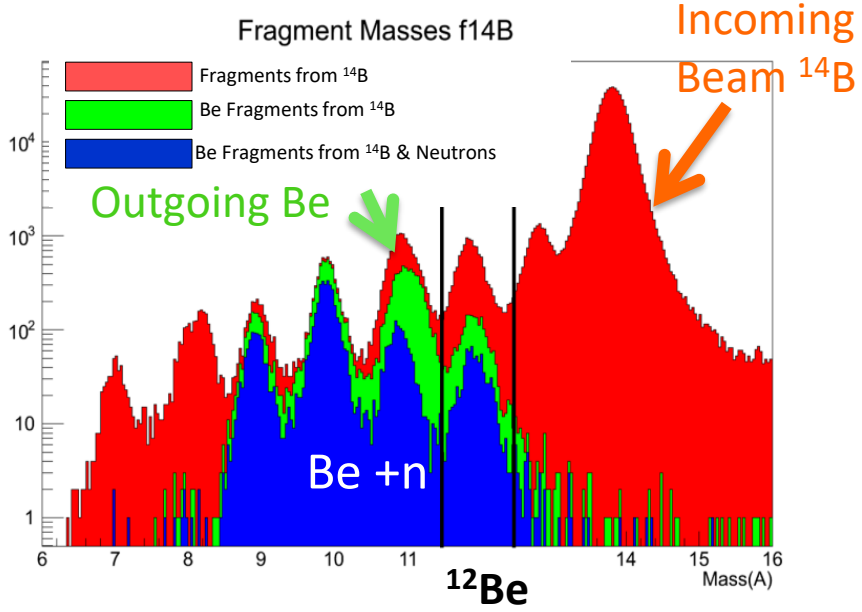
- Energy loss in the ToFW after the target → Identify the element after the reaction.
- Identify the isotope from the ALADIN position deviation and beta of the fragment.



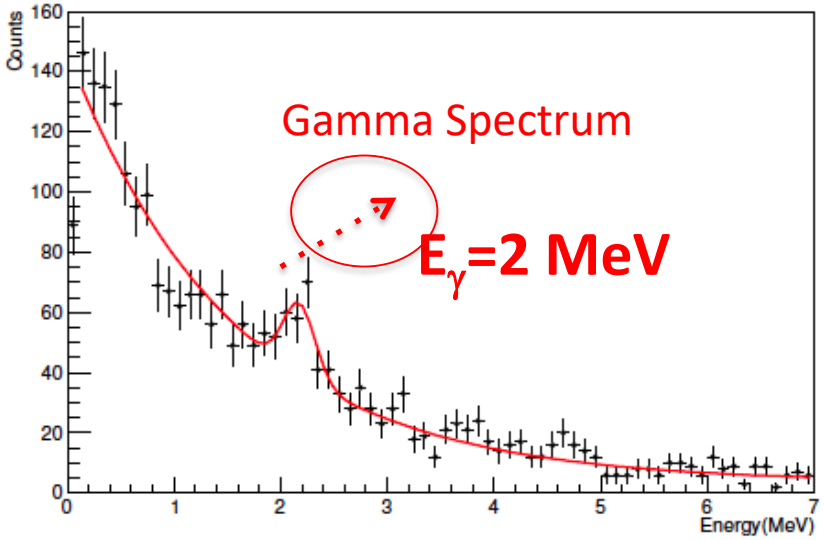
$^{14}B \rightarrow {}^{12}Be + n$



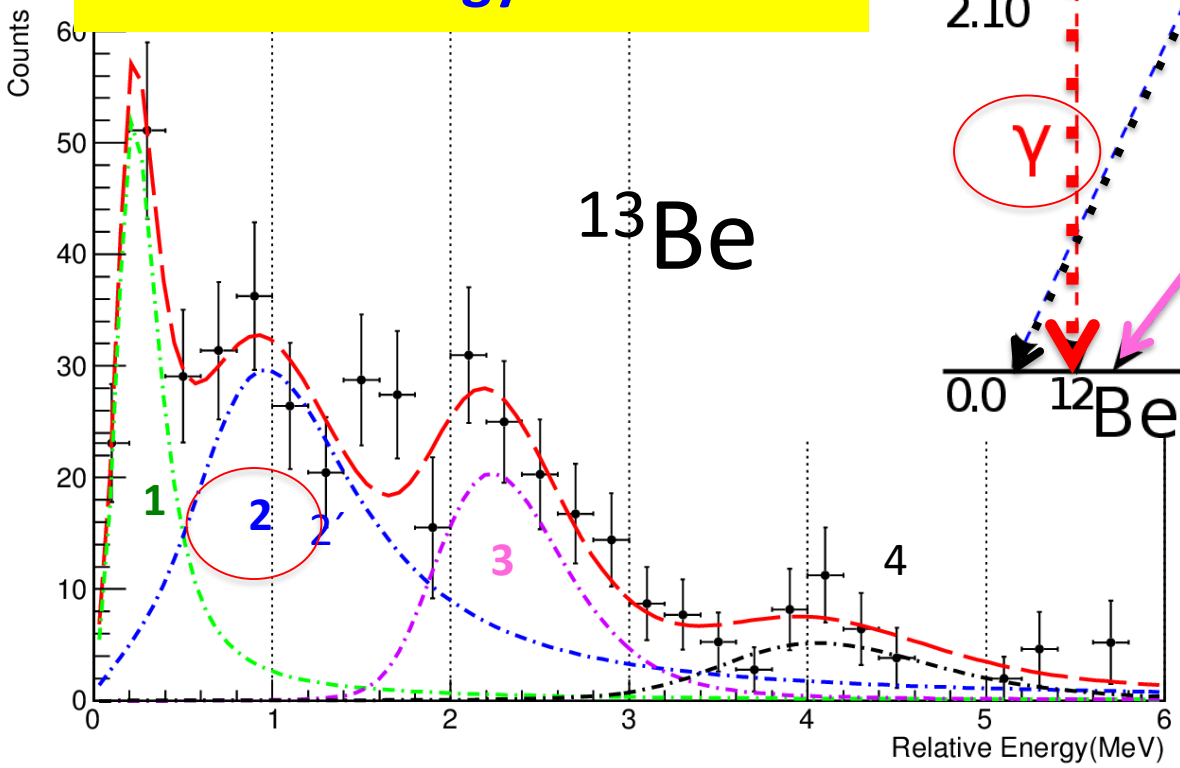
Charge identification from energy loss

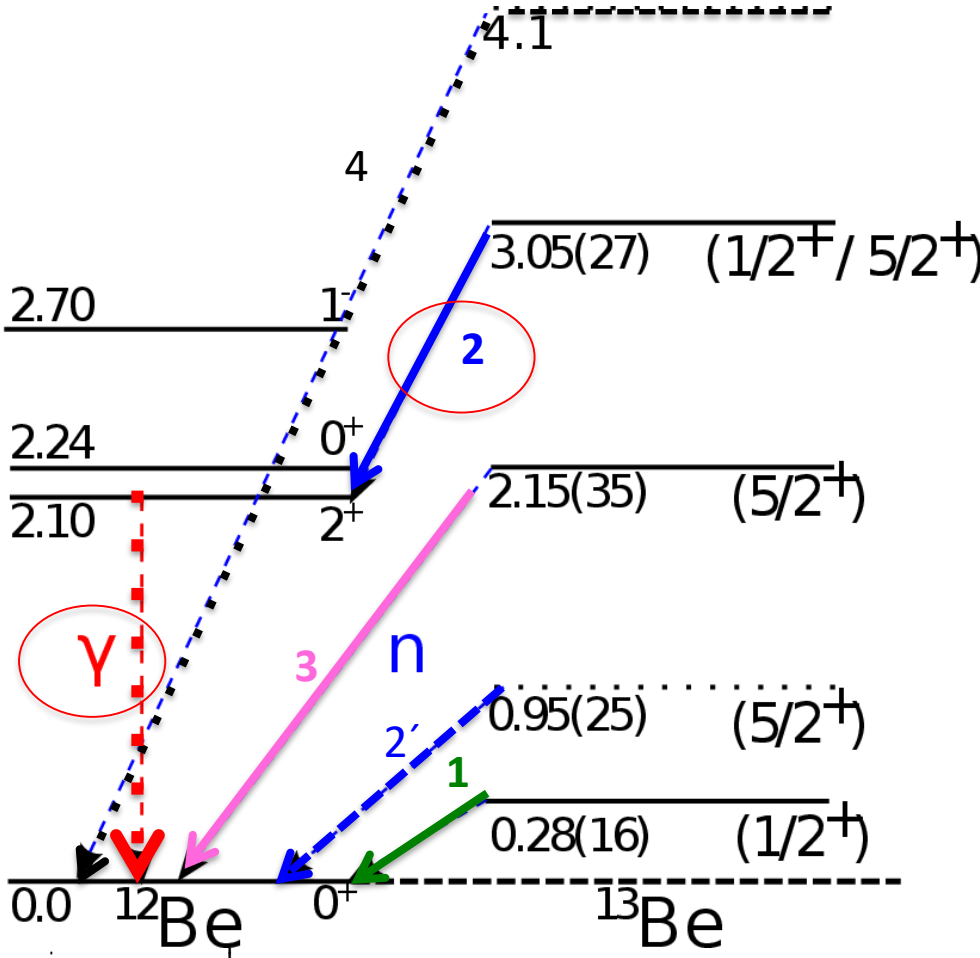


Mass identification from ToF tracking



Relative Energy of ^{12}Be + n:

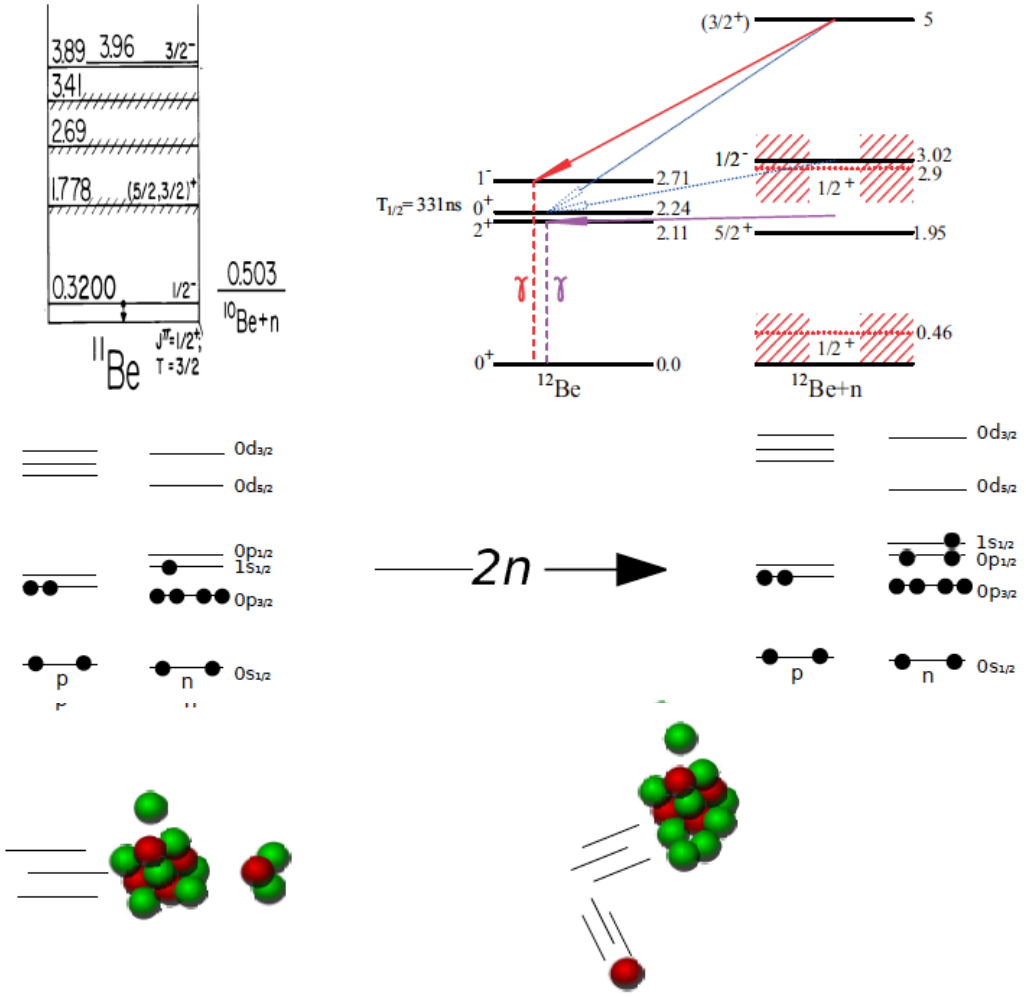




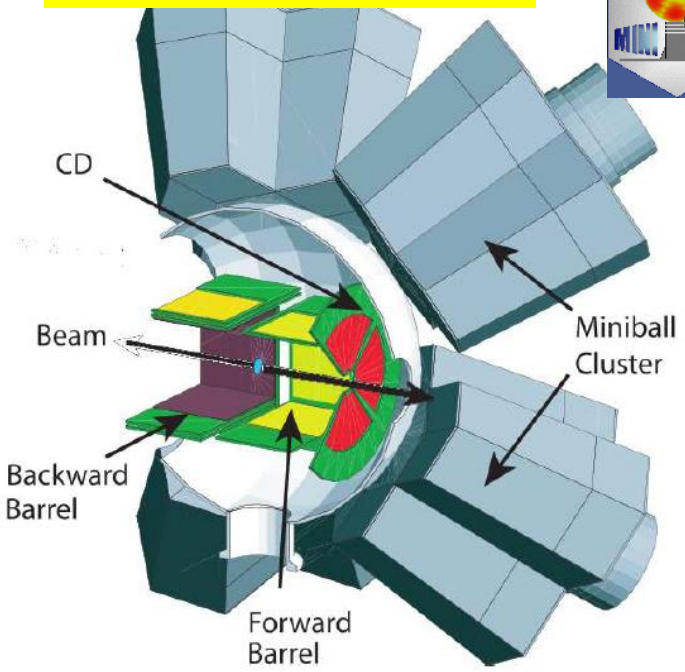
Complementary Experiment

Can we settle this problem via the two-neutron transfer reaction, ^{11}Be(t,p)^{13}Be @ HIE-ISOLDE

^{11}Be ^{11}Be(t, p) ^{13}Be ^{13}Be



Miniball + T-REX



- Standard setup
  - 8 HpGe clusters
  - 12 silicon detectors (telescopes)
- Additionally
  - 1 HpGe detector at beamdump
  - Stopper foil after the CD

Experimentos de NUSTAR: pensar y recordar!

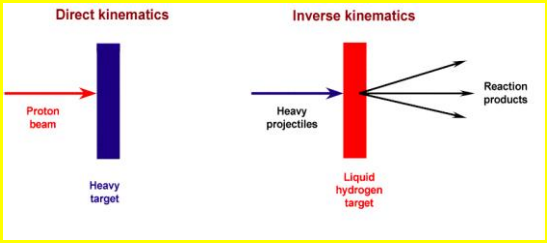
Acrónimos: **FAIR** **NUSTAR** **SFRS** **R3B**

Que método de producción se usa en experimentos de NUSTAR?

Cual es el **haz primario**, y de que origen normalmente?
Cual es el blanco de **Producción?**

Cual es el **haz secundario**? Cual es el blanco de **Reacción?**
Por que usamos **varios blancos** de reacción en el mismo experimento?

Por que cinemática inversa?



Que significa cinemática completa?

Como se selecciona el canal de reacción de interés del experimento?

Como se determina la carga, masa, la energía, el momento,
Y no olvides la importancia de medir las: γ y neutróns!

R3B MEMBER DATABASE REPORT (REP-06)
Member List

	Affiliation	Name
CAN	Saint Mary University	**Kanungo, Rituparna**
	Members: 1	
DEU	Extreme Matter Institute	**Savran, Deniz**
	Members: 3	Isaak, Johann
		Silva, Joel
DEU	GSI Darmstadt	*Aumann, Thomas*
	Members: 15	*Langer, Christoph*
		Löher, Bastian
		Movsesyan, Alina
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		Simon, Haik
		Boretzky, Konstanze
		Caesar, Christoph
		Heil, Michael
		Kelic-Heil, Aleksandra
		Kiselev, Oleg
		Kurz, Nikolaus
		Körper, Daniel
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		Plag, Ralf
		Rossi, Dominic
		Wamers, Felix
		Egelhof, Peter
		Geissel, Hans
		Gerl, Jürgen
DEU	Goethe University Frankfu	**Reifarth, Rene**
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		Göbel, Kathrin
		Heftrich, Tanja
		Langer, Christoph
		Pohl, Moritz
		Sonnabend, Kerstin
		Endres, Anne
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		Reinicke, Stefan
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		Cowan, Thomas
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		Holl, Matthias
		Horvat, Andrea
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		Kahlbow, Julian
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		Löher, Bastian
		Miki, Kenjiro
		Movsesyan, Alina
		Pain, Valerii
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		Schindler, Fabia
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		Törnqvist, Hans

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		Rhee, Han-Bum
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		Zuber, Kai
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		Klenze, Philipp
		Le Bleis, Tudi
		Mücher, Dennis
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	Members: 1	
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		Laurent, Benoit
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	Members: 0	
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	Members: 2	**Krasznahorkay, Attila**
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		Heinz, Andreas
		Lindberg, Simon
SWE	Lund University	**Cederkall, Joakim**
	Members: 4	Avdeichikov, Vladimir
		Fahlander, Claes
		Golubev, Pavel
USA	Texas A&M University-Comm	**Bertulani, Carlos**
	Members: 1	

Explanation
Name in italic indicates member with different main affiliation

250 Members
40 Institutes
15 Countries

Spokesperson: Lola Cortina USC
Technical Director: Olof Tengblad CSIC

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Univ. Santiago de Compostela

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