



Reacciones con Iones

B)

R³B

*a setup for kinematical complete measurements;
Quasifree scattering reaction $^{14}\text{B}(p,2p)^{13}\text{Be}$.*

O. Tengblad

*Instituto de Estructura de la Materia,
IEM – CSIC, Serrano 113 bis, ES-28006 Madrid*

	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



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?

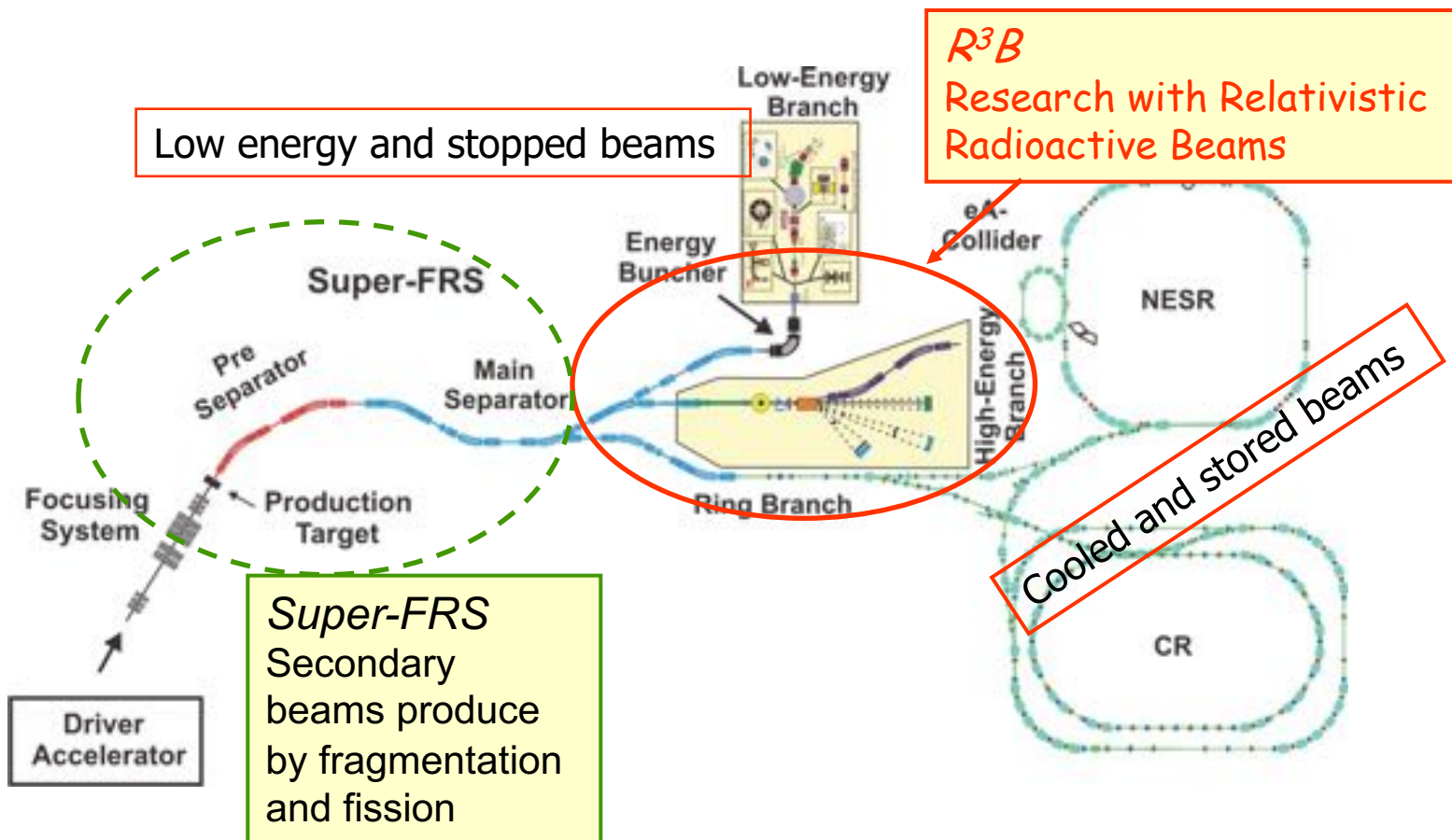
How are complex nuclei built from their basic constituents?

What is the effective nucleon-nucleon interaction?

How does QCD constrain its parameters?

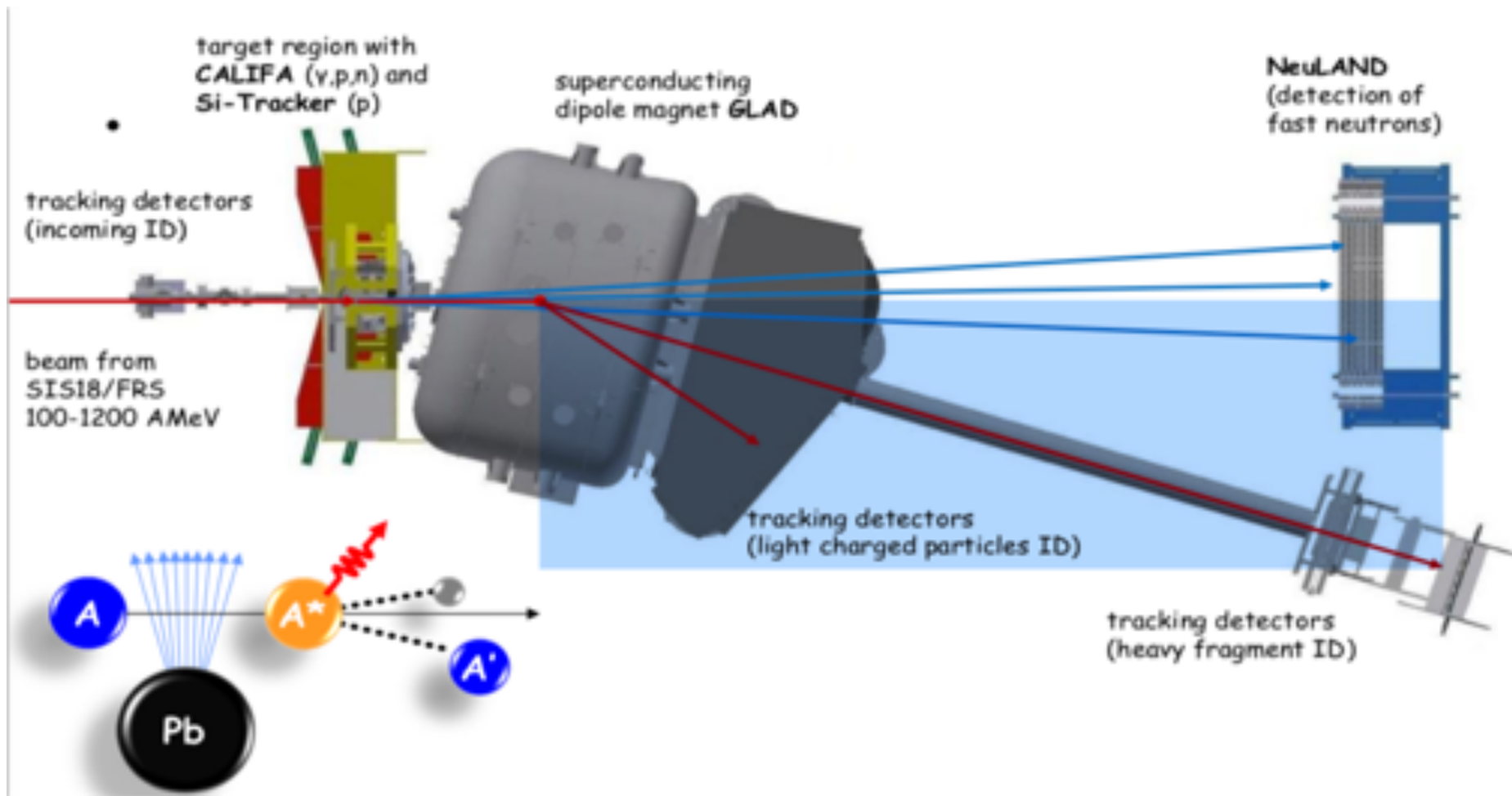
Which are the nuclei relevant for astrophysical processes and what are their properties?

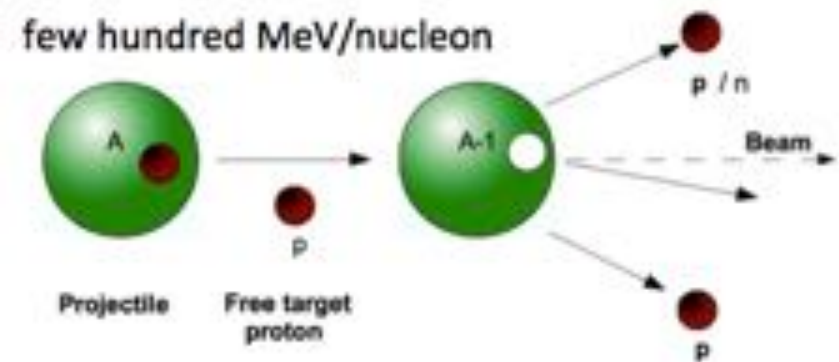
What is the origin of the heavy elements?



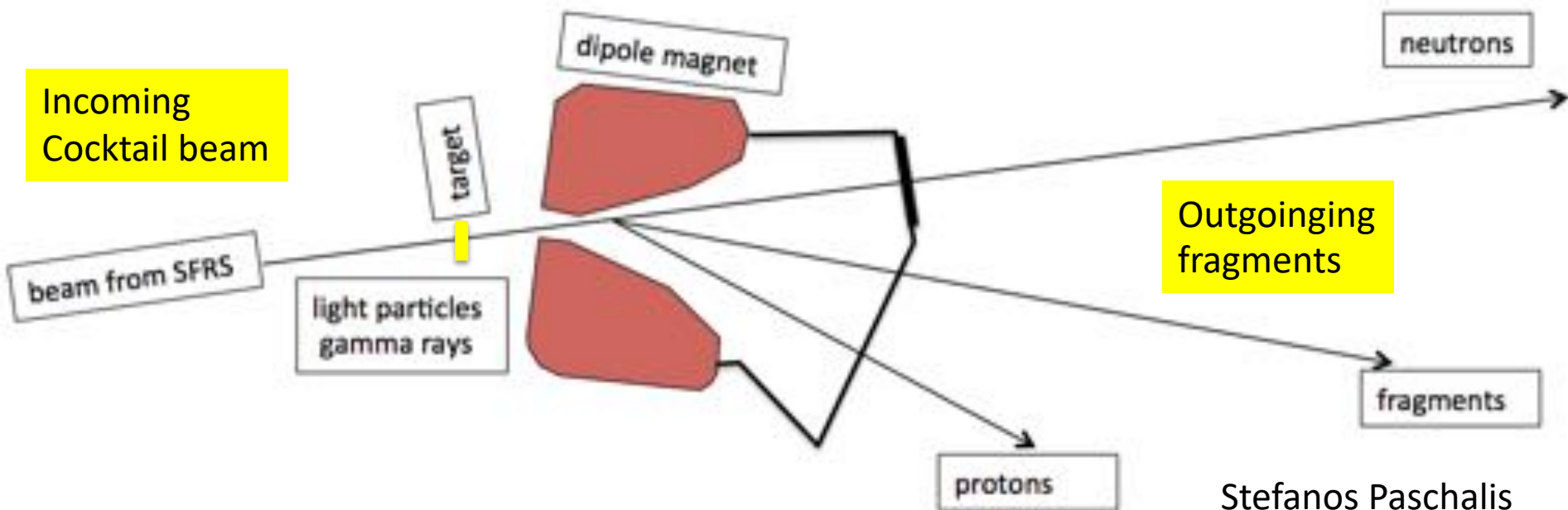
Kinematically complete measurement of reactions with high-energy secondary beams

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



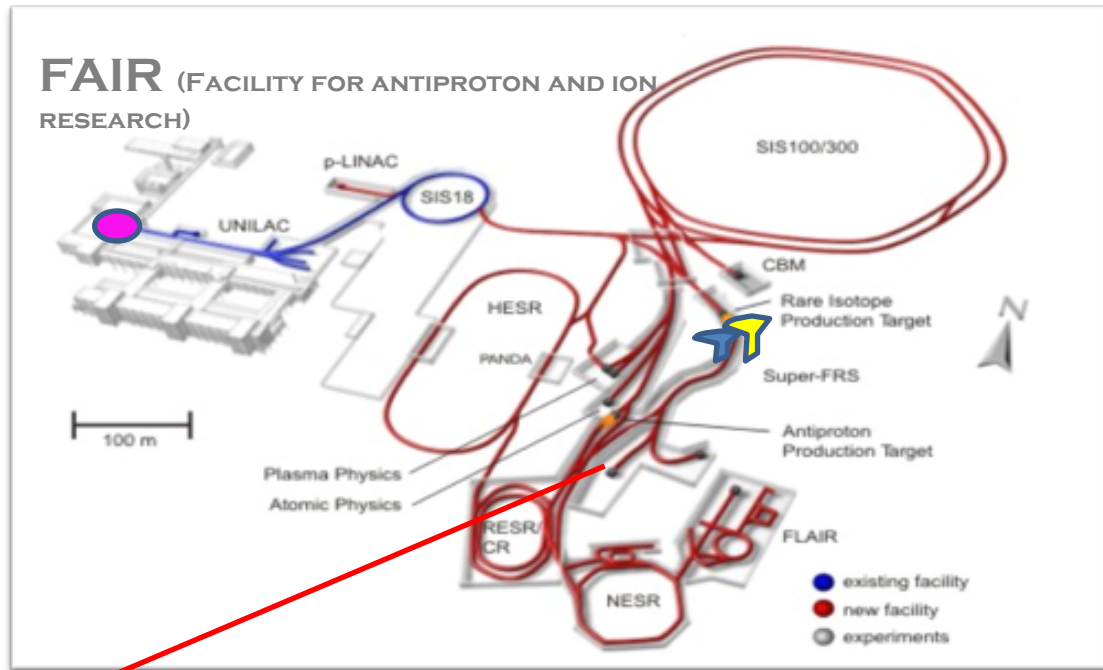


After the reaction: heavy fragment, neutrons, protons, gammas
Aim: measure all reaction products



Stefanos Paschalis

How does it work



1. Accelerated beam impact on Production Target

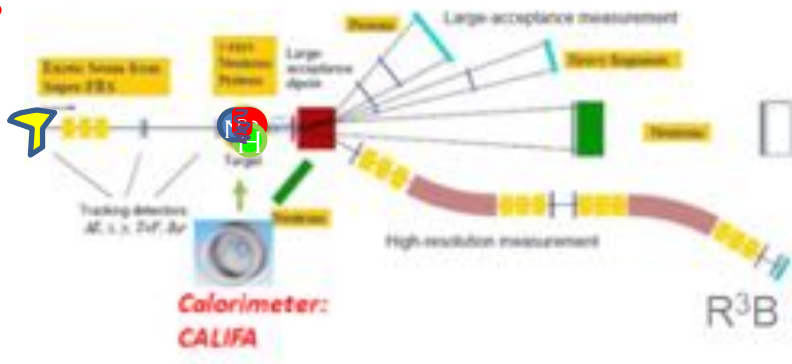
2. Products are separated in FRS

3. Separated isotopes directed to experiment

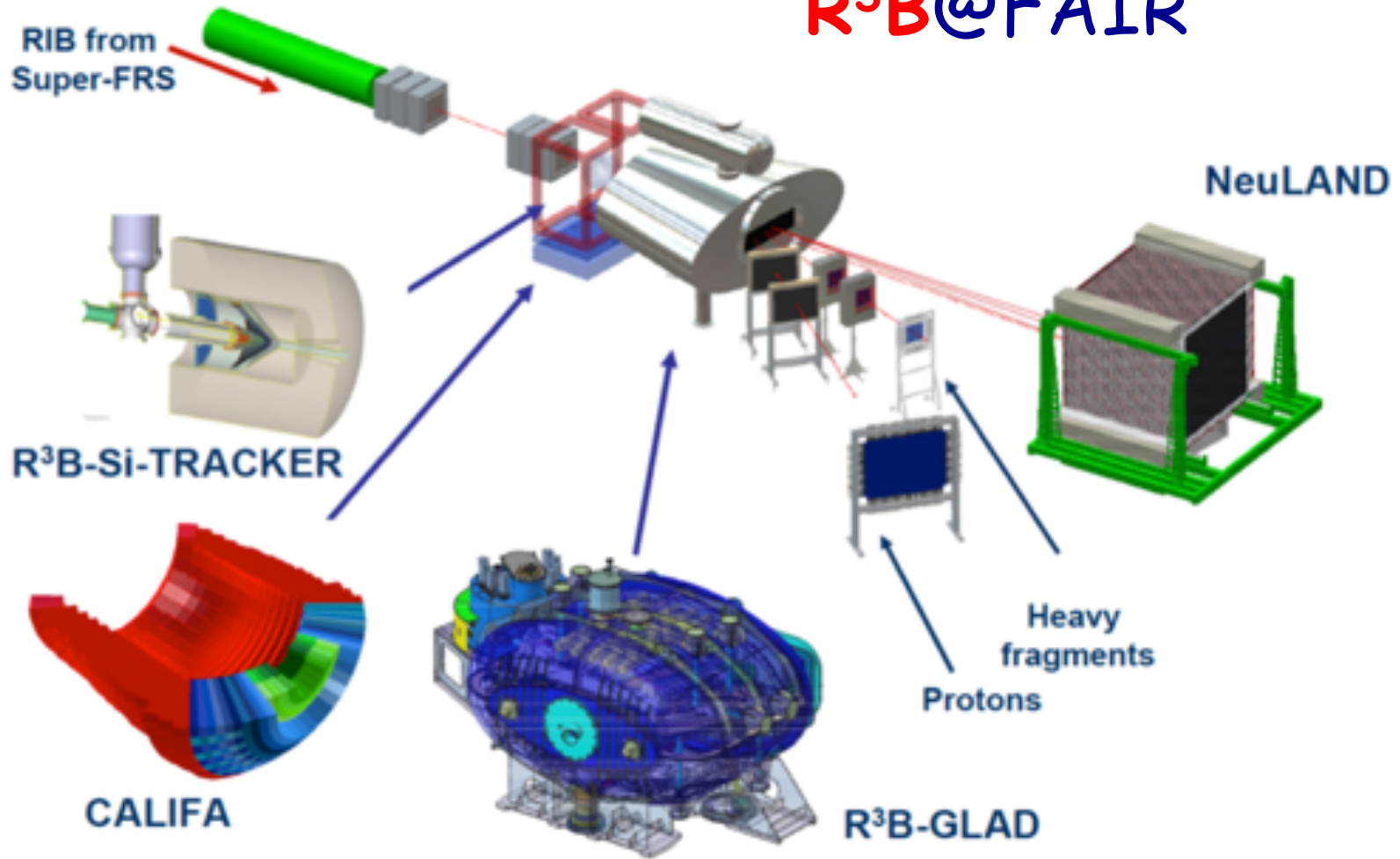
4. Isotope of interest impact on Reaction Target

5. Reaction fragments and gammas are detected

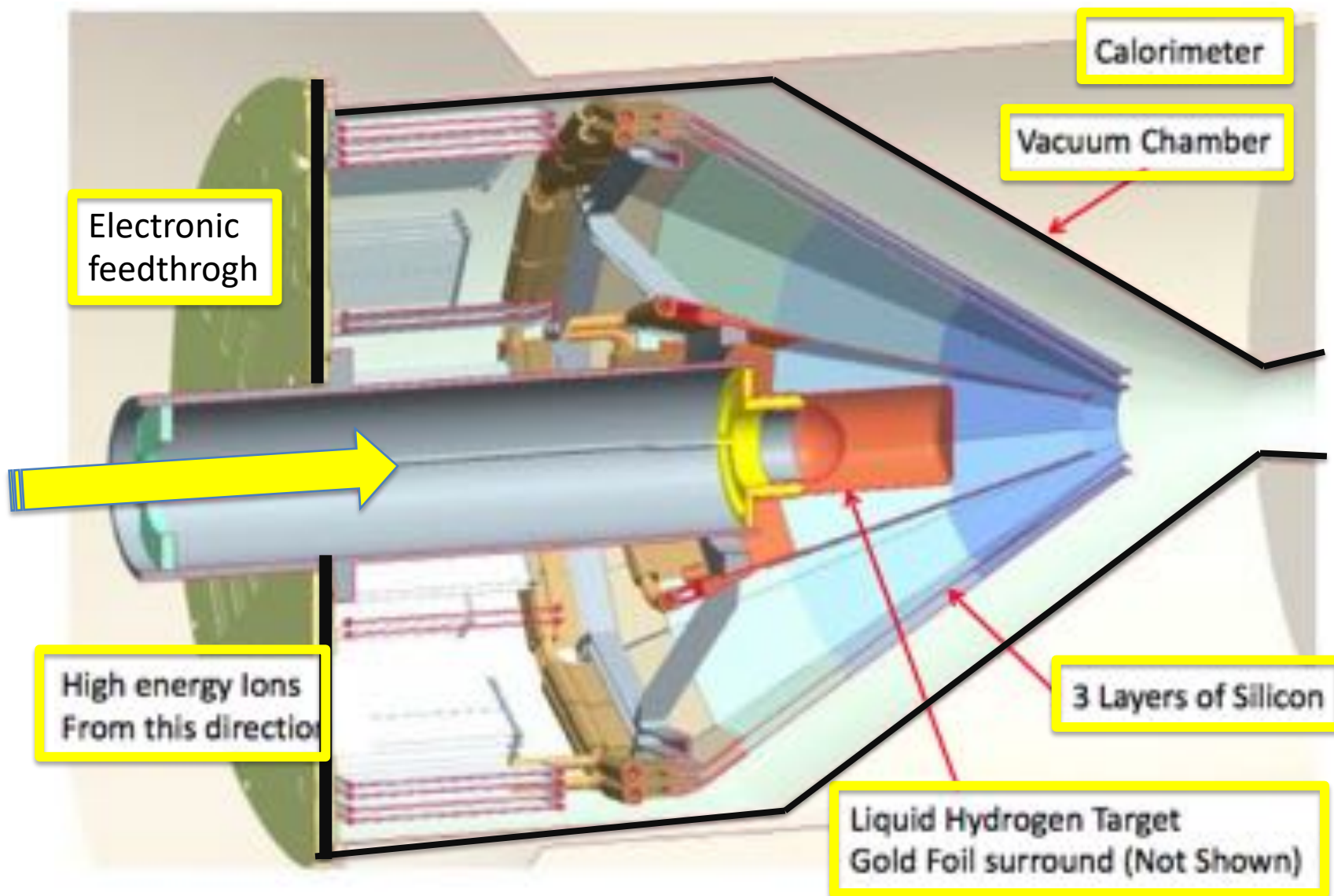
R³B

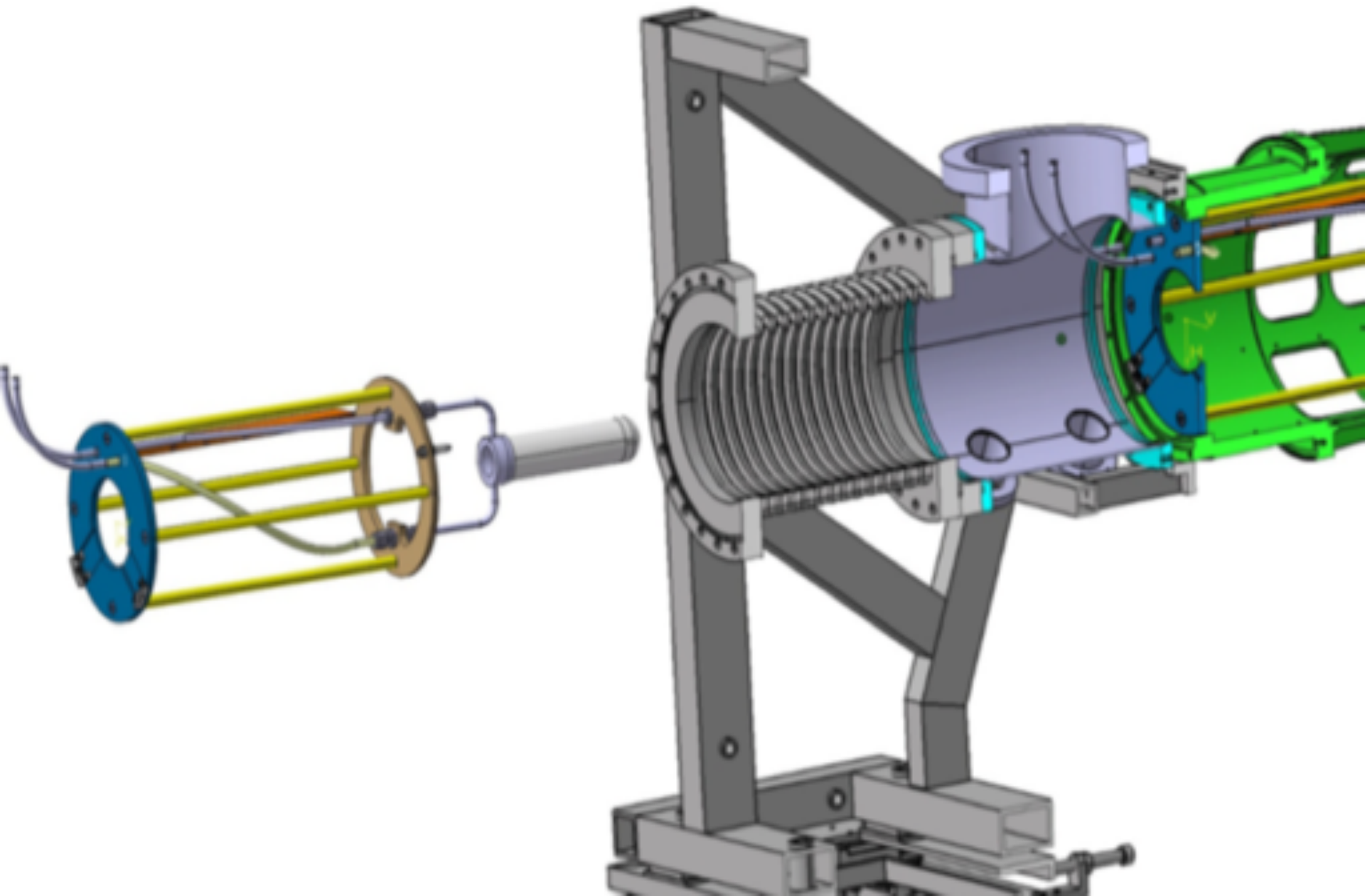


R³B@FAIR



An idea of a Si – tracker for R3B!!

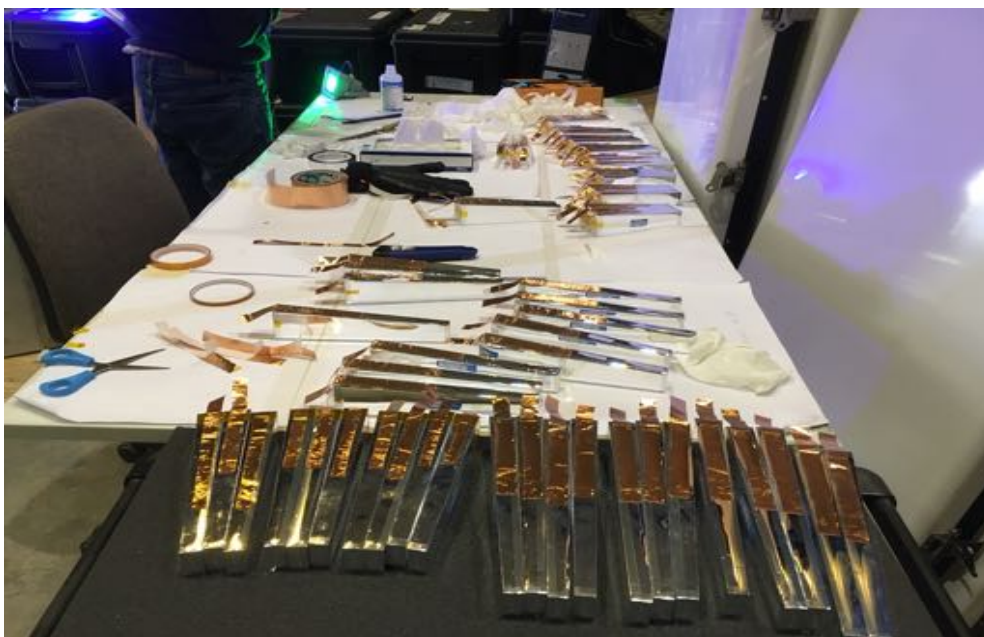




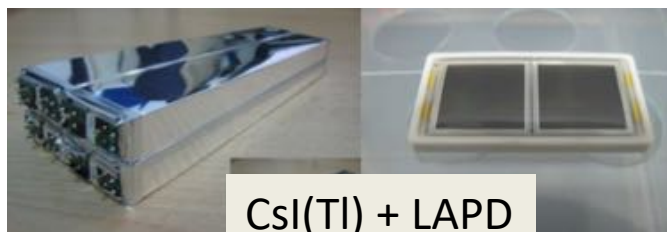
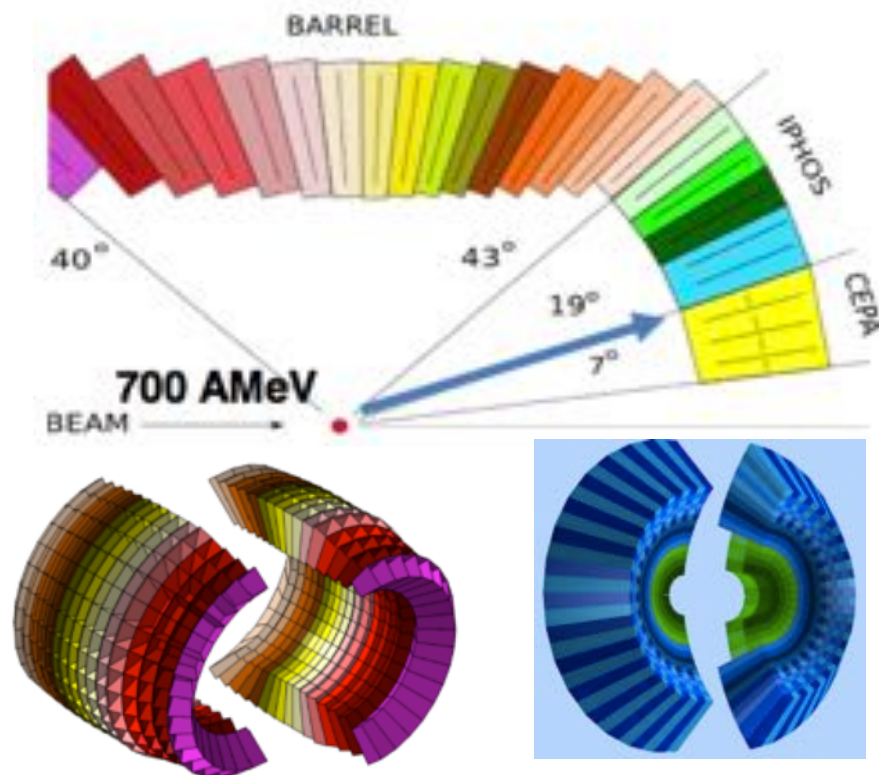


CALIFA

J. Cederkäll
T. Kröll



CALorimeter for In Flight detection of γ -rays and charged pArticles.

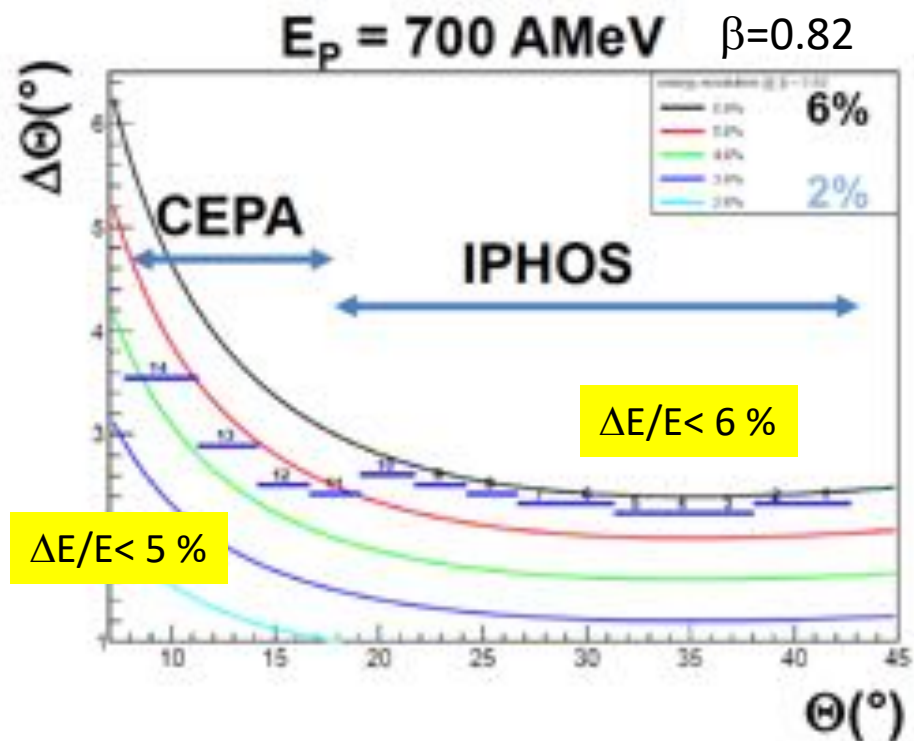
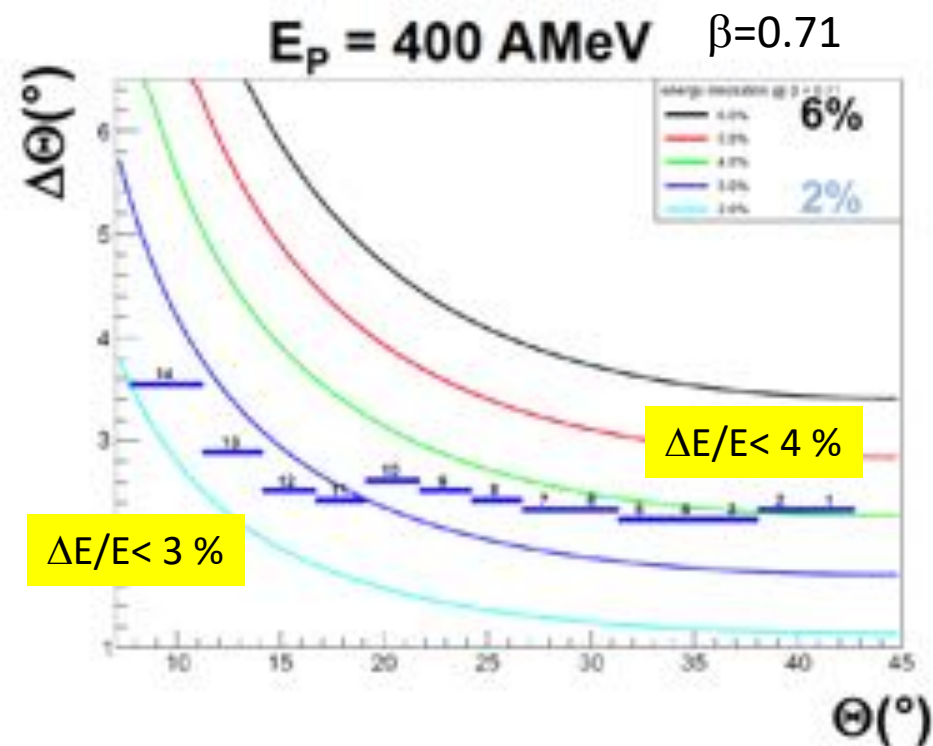
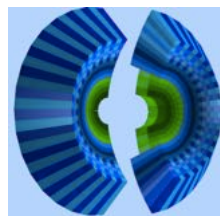


CsI(Tl) + LAPD

CALIFA Working Group



CALIFA: HIGHLY SEGMENTED
THICK DETECTION VOLUME
INNER RADIUS 50CM
BARREL: CRYSTAL LENGTH 15-20 CM
1952 CRYSTALS = 2 TON
ENDCAP: 608 CRYSTALS = 1 TON



IPHOS - Intrinsic Phoswich Detectors

CEPA - Califa Endcap Phoswich Array

length limit 22cm:

- geometrical space,
- light collection
- crystal properties
- efficiency and cost

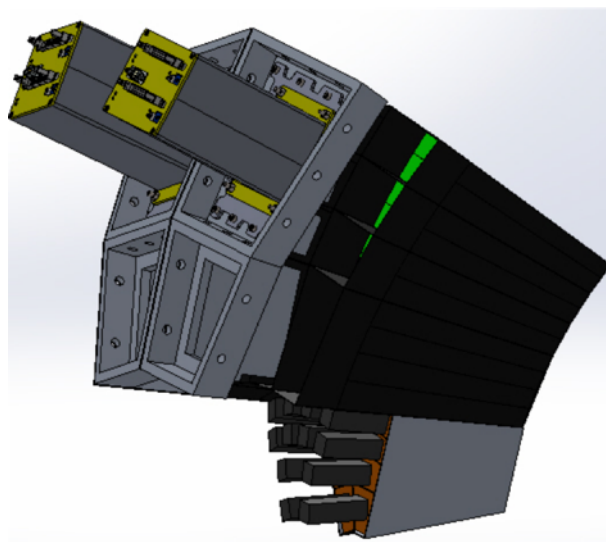
- high rate capability
- best resolution
- high light yield
- depth information
- redundant DE for particles

Phoswich

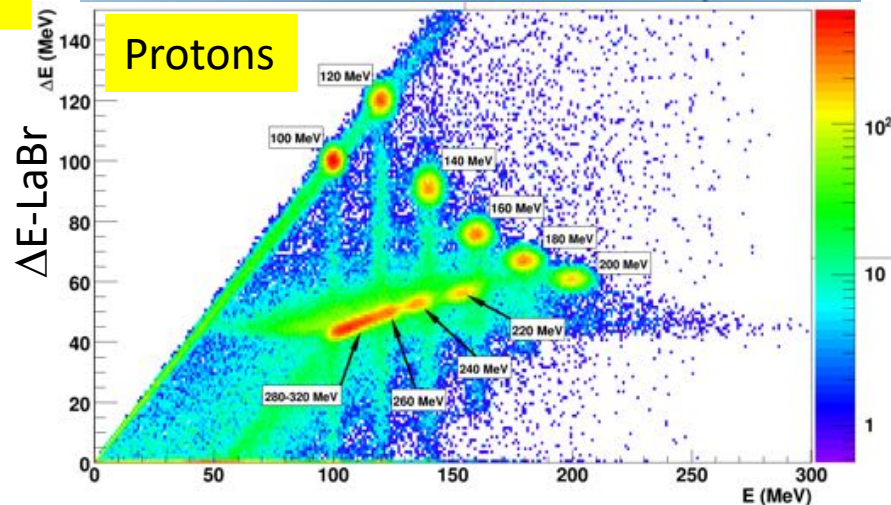
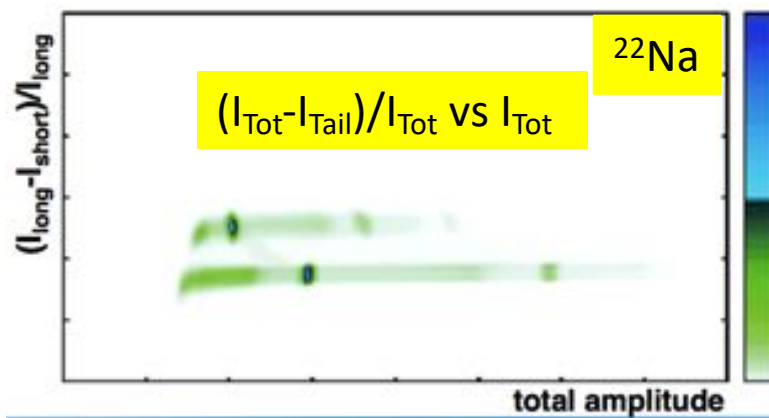
LaBr₃(Ce)+LaCl₃(Ce)

2 scintillators

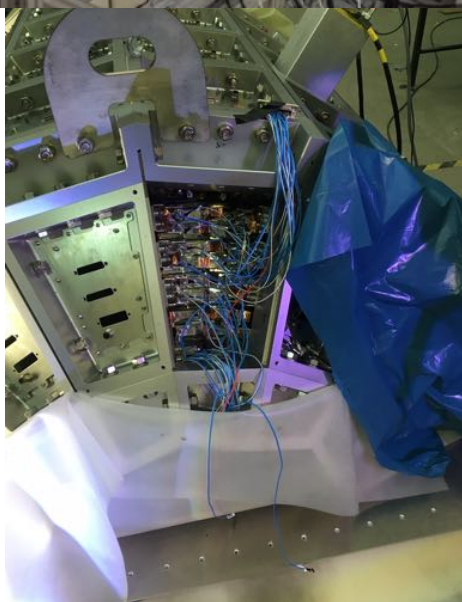
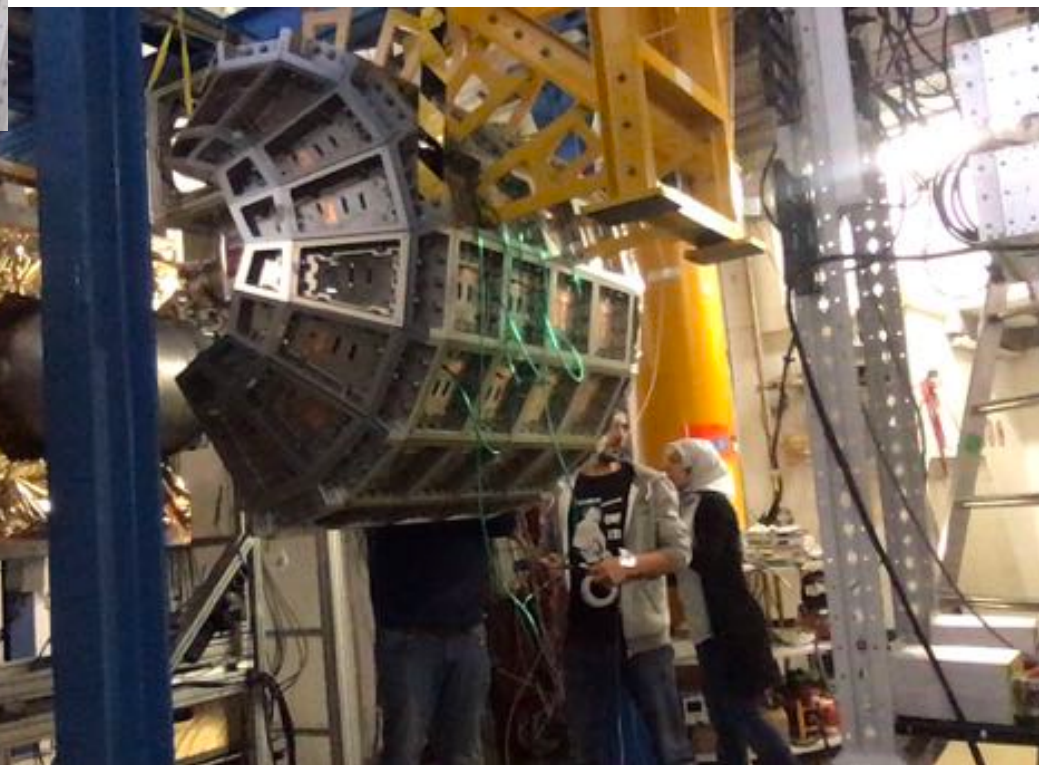
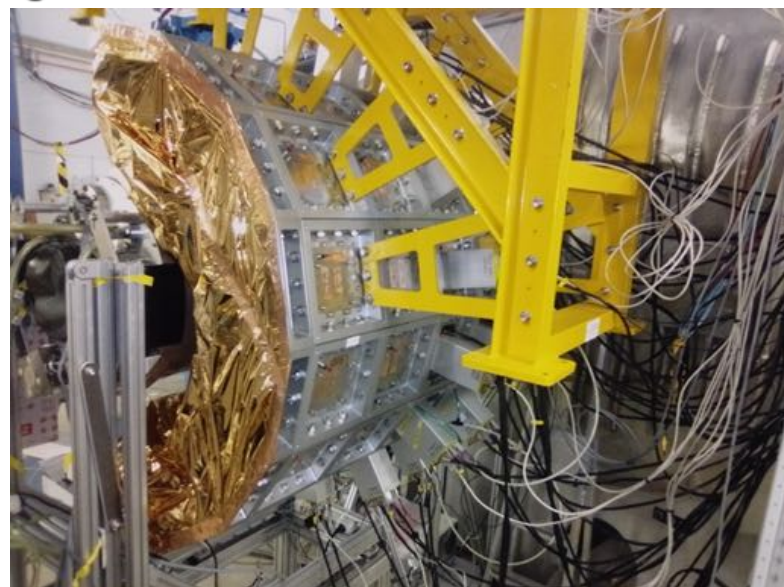
1 optical readout



8 x 5Kg units of
12 Phoswich
crystals



Materials	$\Delta E/E$ (% at 662 keV)	Light yield (photons/keV)	Decay time (ns)	$\lambda_{\text{emission}}$
LaBr ₃	2.9	63	16	380 nm
LaCl ₃	3.8	49	28	350 nm



Magnet parameters:

- 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.

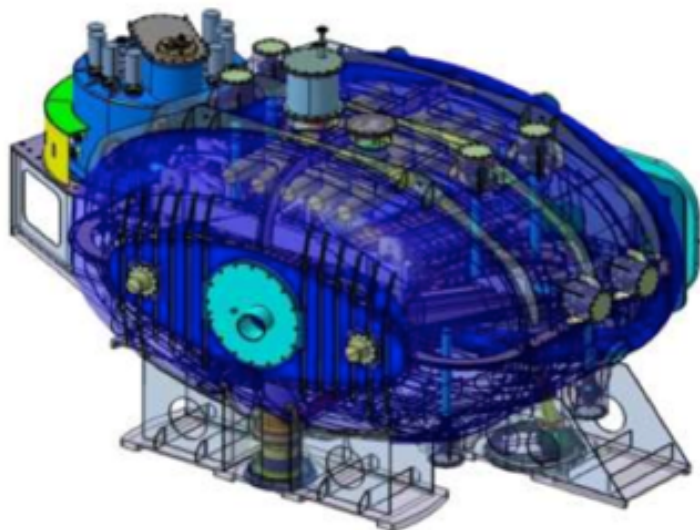
@CEA SACLAY

- + MAGNET COLD MASS READY AND TESTED, DEC 2013.
- + INTEGRATION INTO CRYOSTAT MOSTLY DONE.
- + WAS DELIVERED TO GSI 3RD OF NOV 2015.

@ GSI Cryoplant has been installed

Cryolines (33m) on site Compressor (+ Controls) test

2019 fully tested and operational in Cave C



NeuLAND - High-resolution neutron ToF spectrometer

I. Gasparic
K. Boretzky

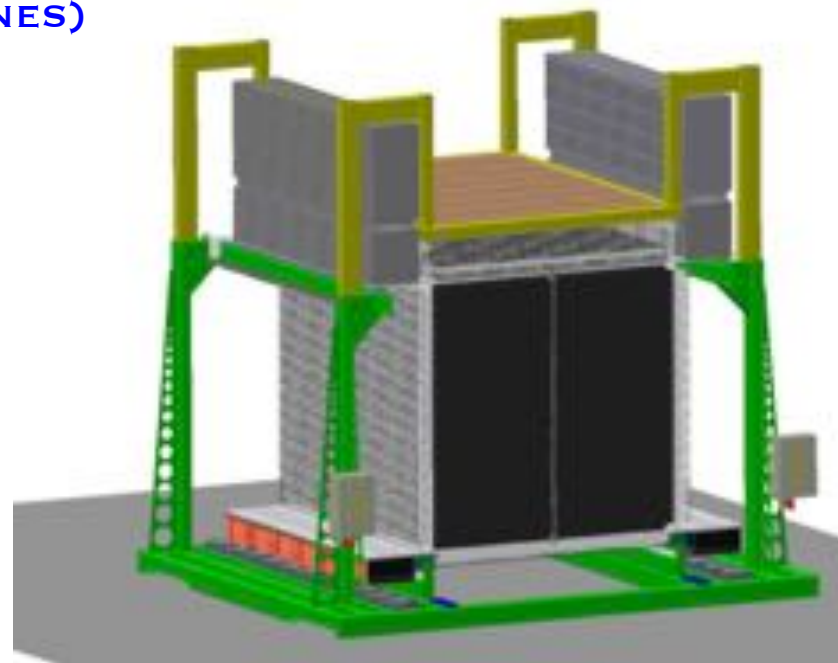
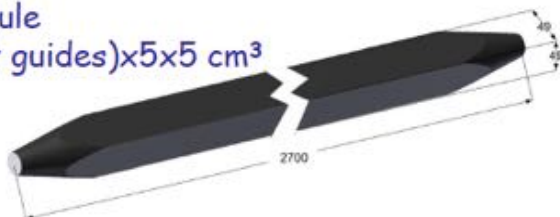
NEULAND DETECTOR PARAMETERS:

- FACE SIZE 250X250 CM²
- ACTIVE DEPTH 300 CM (30 DOUBLE-PLANES)
- 3000 SCINTILLATOR BARS
- 6000 PM / READOUT CHANNELS
- 32 TONS

2020: 12 DP installed

NeuLAND submodule
250(270 incl. light guides)x5x5 cm³

1 DP = 50 + 50
scintillator bars



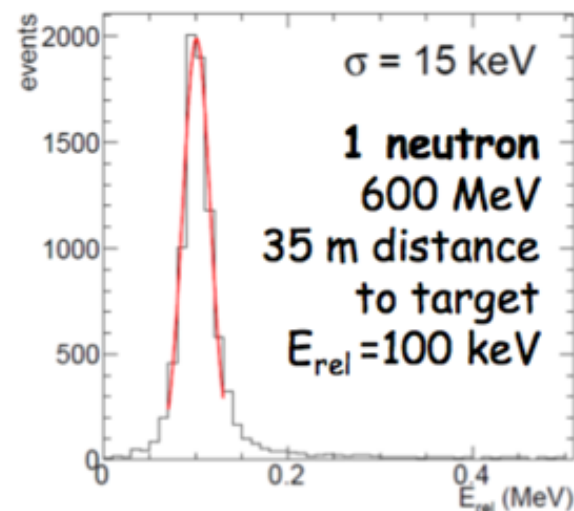
NEULAND DESIGN GOALS:

- >90% EFFICIENCY FOR 0.2-1.0 GEV NEUTRONS
- MULTI-HIT CAPABILITY FOR UP TO 5 NEUTRONS
- INVARIANT-MASS RESOLUTION: NEULAND-TARGET DISTANCE 35 M
 $\Delta E < 20 \text{ KEV}$ AT 100 KEV ABOVE THE NEUTRON THRESHOLD

HIGH MULTI-NEUTRON DETECTION

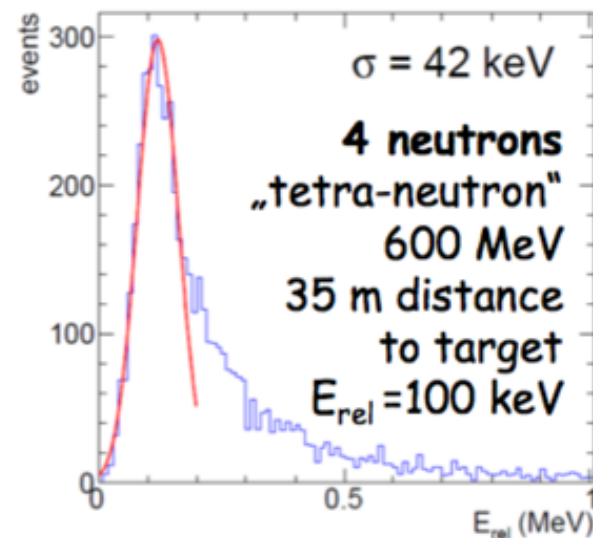
		600 MeV generated				
	%	1n	2n	3n	4n	5n
detected	1n	92	22	2	0	0
	2n	2	71	32	7	1
	3n	0	6	55	32	9
	4n	0	0	10	57	50
	5n	0	1	1	4	35
	6n	0	0	0	0	5

HIGH RESOLUTION @ PARTICLE THRESHOLD



HIGH EFFICIENCY FOR LOW NEUTRON ENERGIES

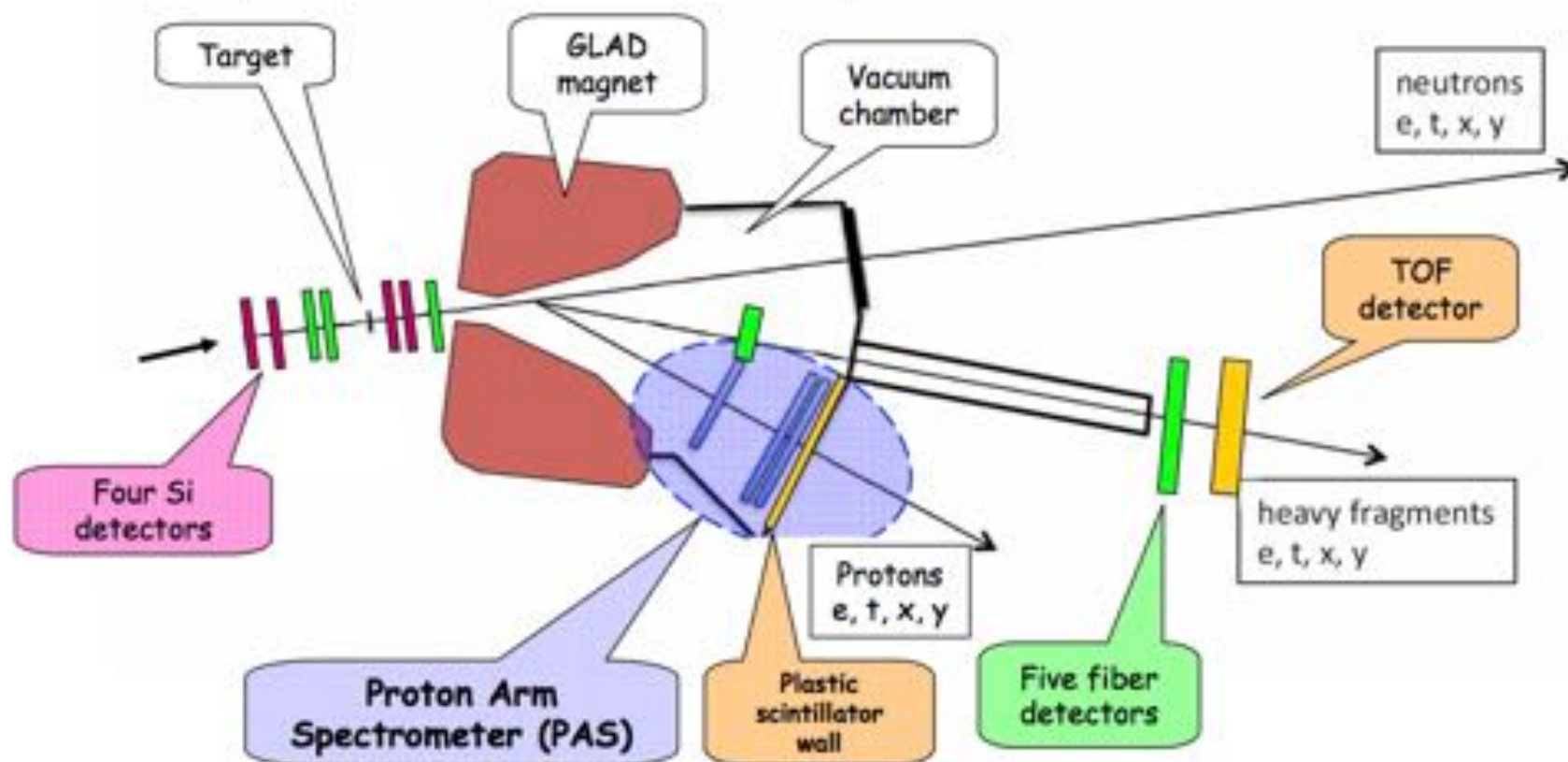
$E_n [\text{MeV}]$	Eff. [%]
50	79
100	94
150	95
200	91



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

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

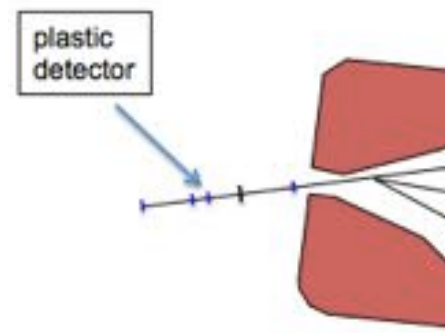
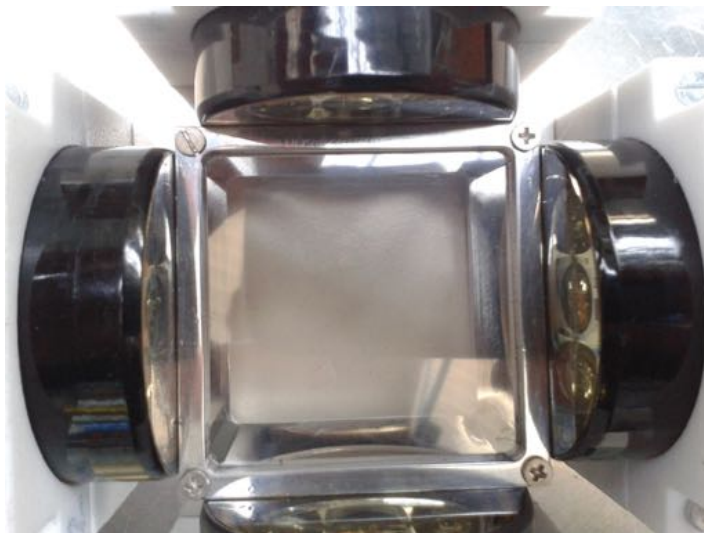
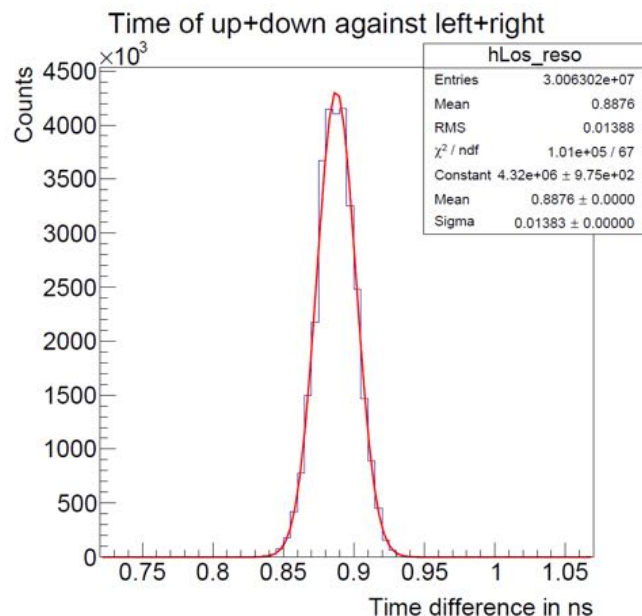
for incoming and outgoing fragments, beam, gammas



Start-timing detector: **PLASTIC SCINTILLATOR FOIL** in-beam time resolution

M. Heil

^{58}Ni @ 500MeV/u



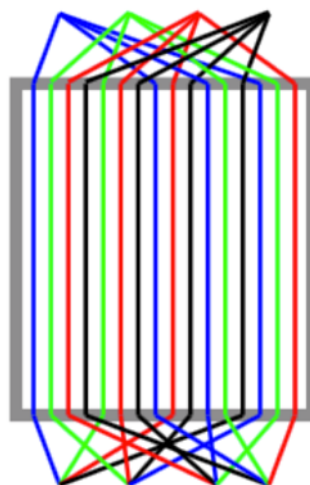
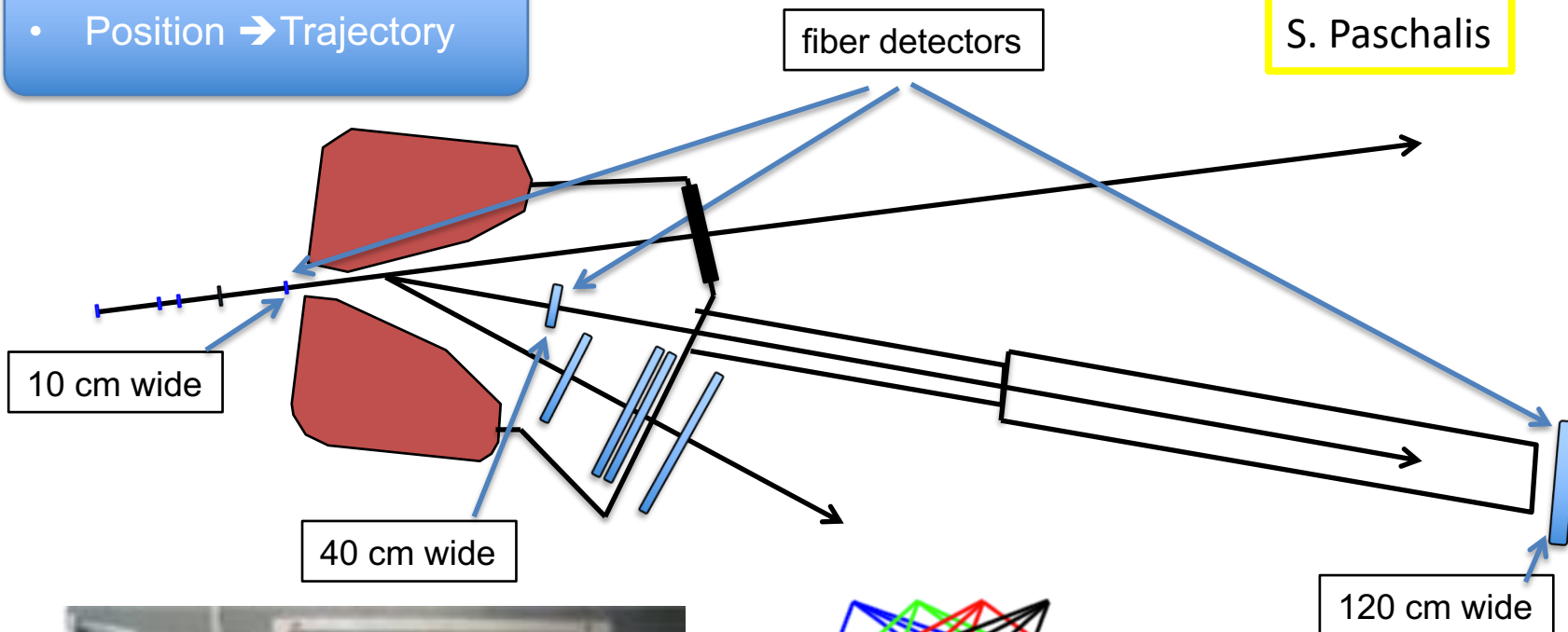
5x5 cm² Ham. R9779-20 PM tube
0.5 mm thick
EJ230 plastic scintillator foil

Measured Δt between PM pairs: $\sigma_t = 14$ ps
→ time resolution for the full detector: $\sigma_t = 7$ ps

Tested with Mesytec MCFD16-PMT CFD
and PADI + VFTX readout

- Position → Trajectory

D. Rossi
S. Paschalis



Square fibers $0.2 \times 0.2 \text{ mm}^2$
Number of fibers $\sim 10^4$ fibers
→ 60 μm resolution

**Bundling to reduce
the number of
channels (32 → 1)**

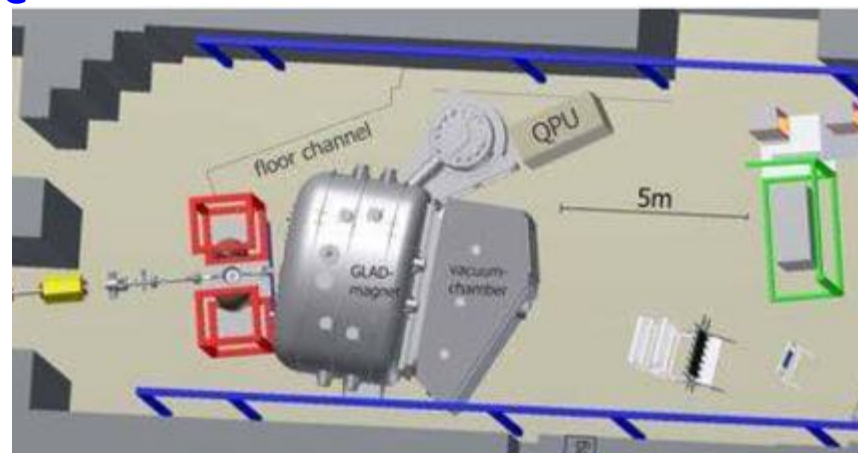
SCHEDULE AND FIRST EXPERIMENTS @ GSI IN CAVE C

2014 20% NeuLAND and 10% CALIFA & Si-Tracker + tracking detector prototypes
→ 2021 Construction and installation of detector components

2019 S444 -Commissioning of 50%R3B in Cave C

2019-20 Physics runs in Cave C (phase 0)

2025 Move to HIE-cave @FAIR



Experiments will make use of uniqueness of R3B:

- Reactions at high beam energies up to 1 GeV/u
- Tracking and identification capability even for the heaviest ions
- Multi-neutron tracking capability, high-efficiency calorimeter

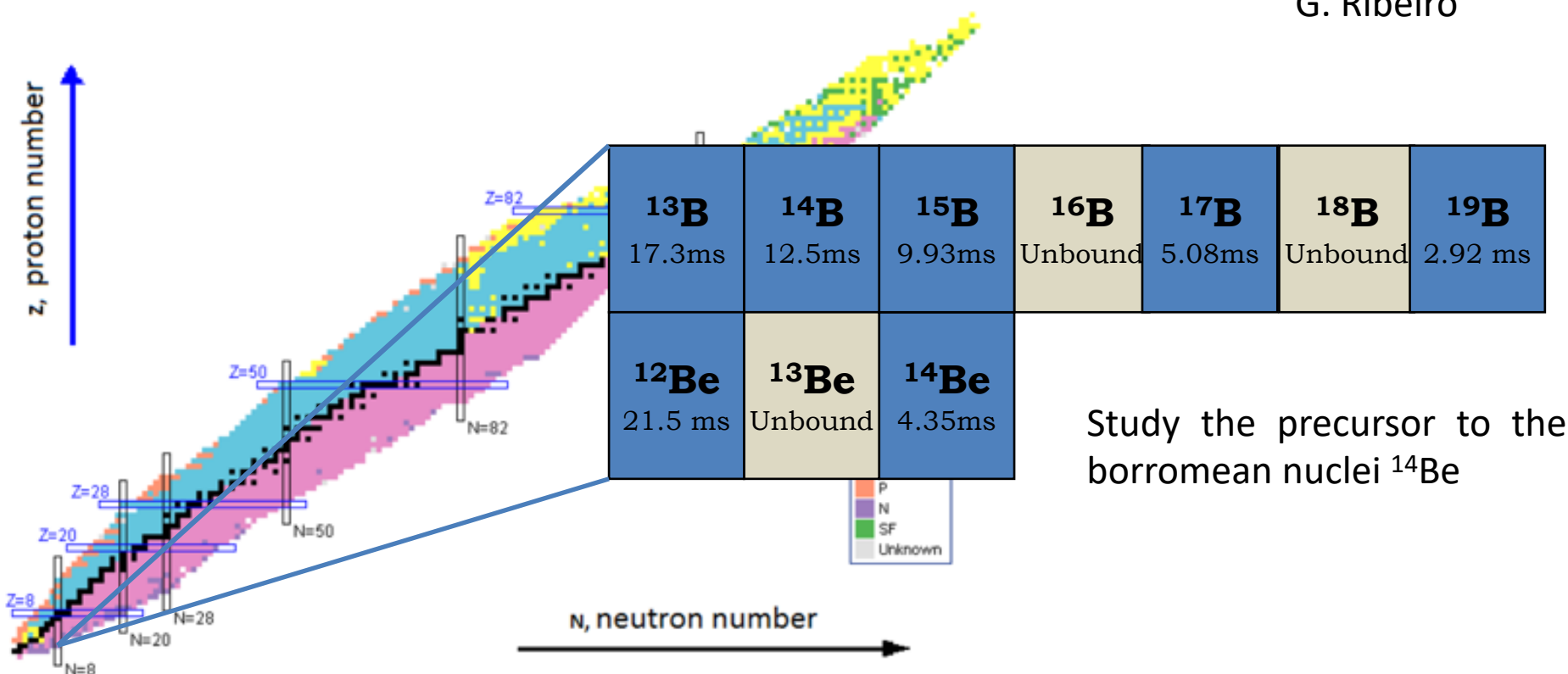
Experiments possible for the first time:

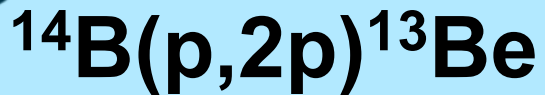
- 4 neutron decays beyond the drip-line and for heavier n-rich isotopes
- Kinematically complete measurements of quasi-free nucleon knockout reactions
- Electric dipole and quadrupole response of Sn nuclei beyond N=82, and of neutron-rich Pb isotopes (polarizability, symmetry energy)
- Fission barriers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

Study of light neutro-rich nuclei (Be-Ne), using kinematically complete measurements in inverse kinematics @ GSI

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

G. Ribeiro

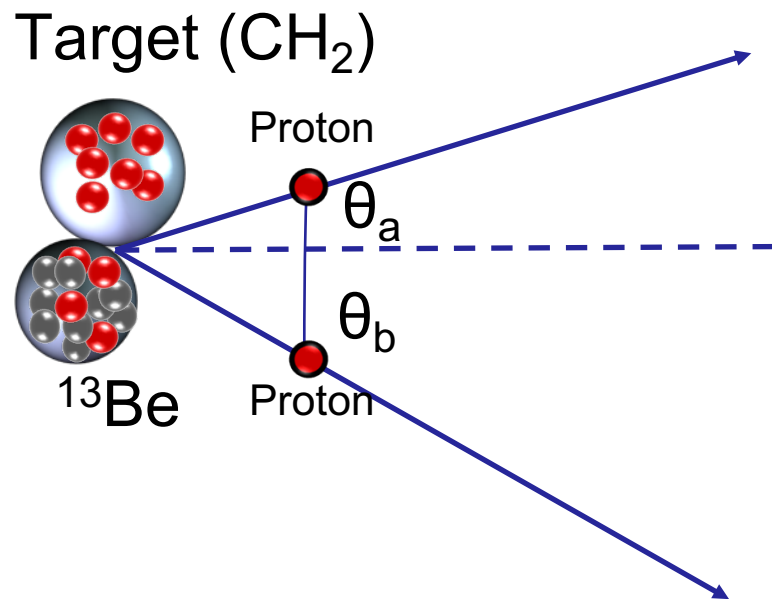
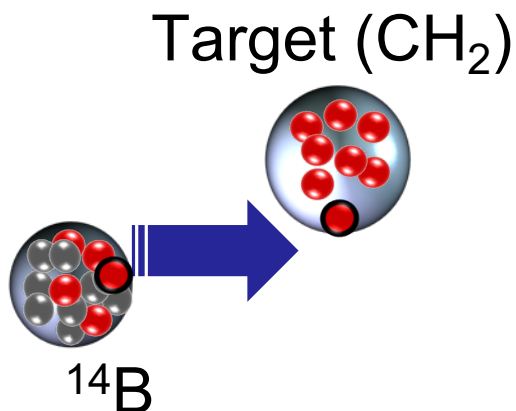




- Direct Reaction: quick and direct from initial to final states without intermediate compound state.
- If both outgoing particles have the same masses, in the lab system:

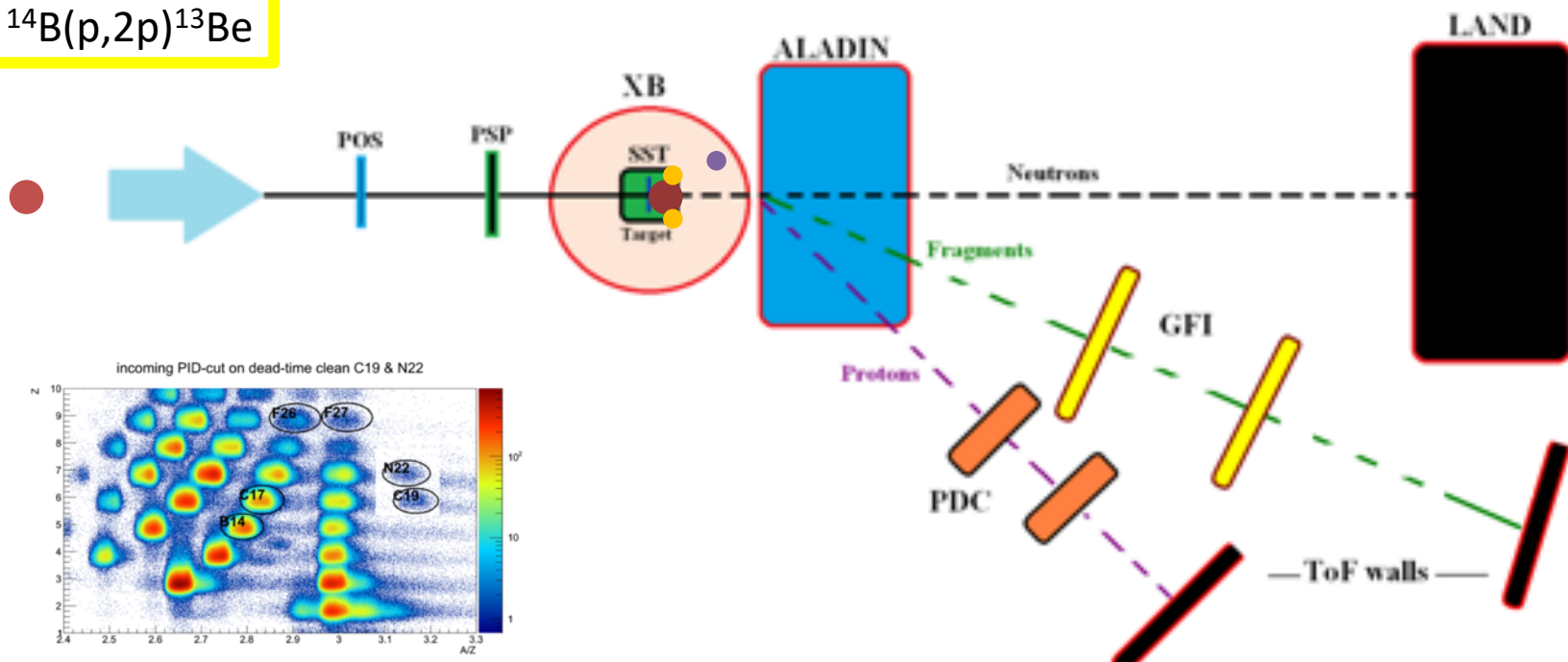
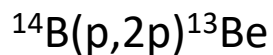
$$\theta_A + \theta_B \simeq 81^\circ$$

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



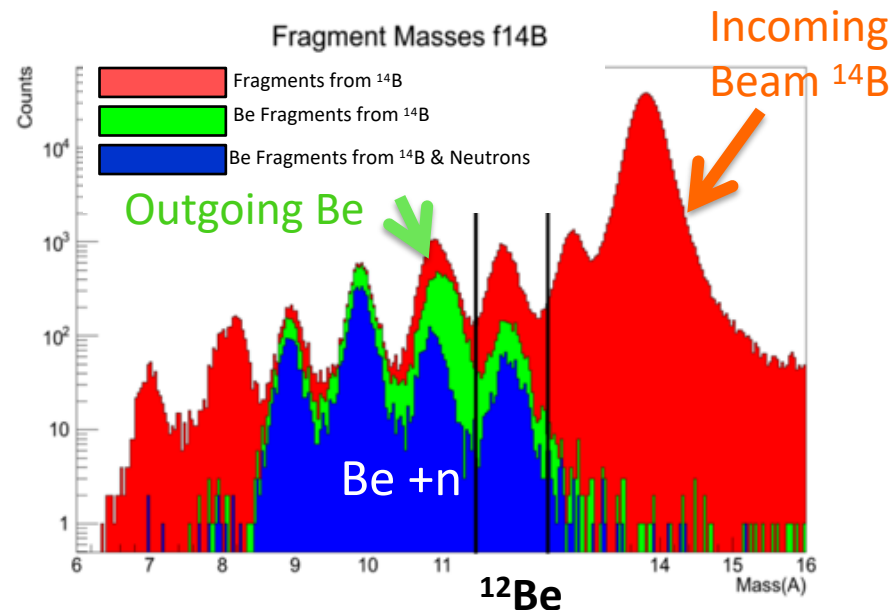
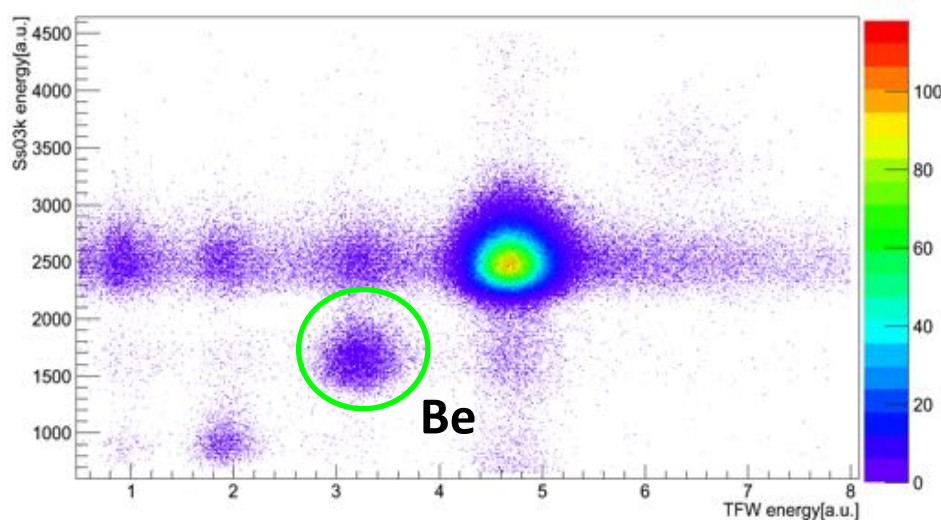
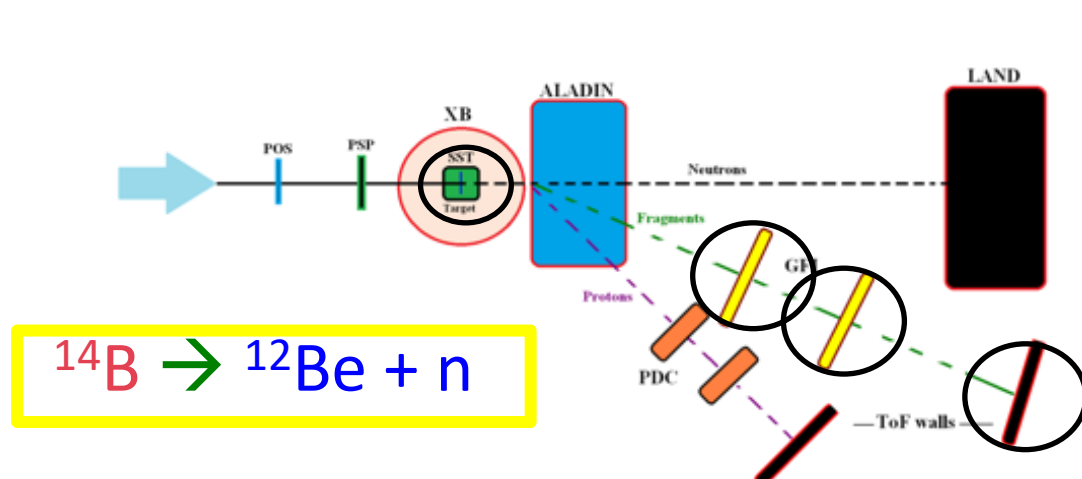
¹³B 17.3ms	¹⁴B 12.5ms	¹⁵B 9.93ms	¹⁶B Unbound	¹⁷B 5.08ms	¹⁸B Unbound	¹⁹B 2.92 ms
¹²Be 21.5 ms	¹³Be Unbound	¹⁴Be 4.35ms				

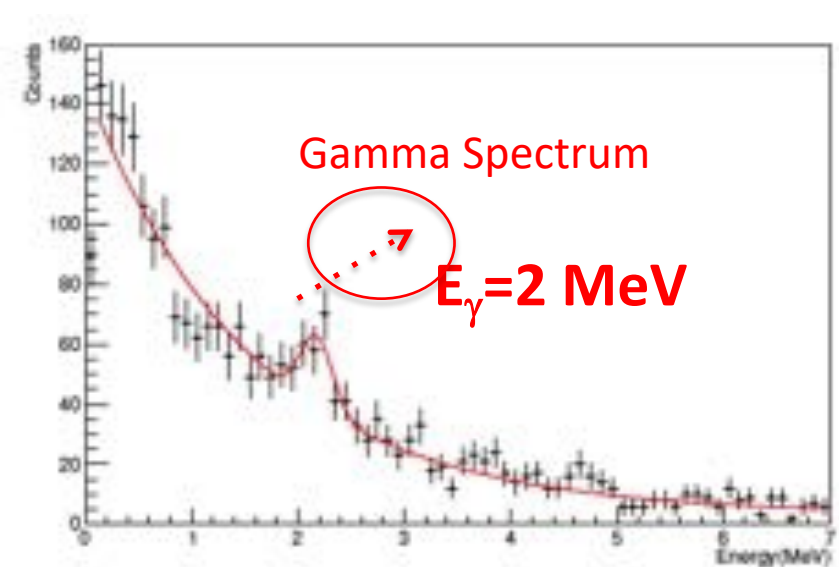
Studies beyond the neutron dripline using quasifree (p,2p) reactions: the case of ^{13}Be .



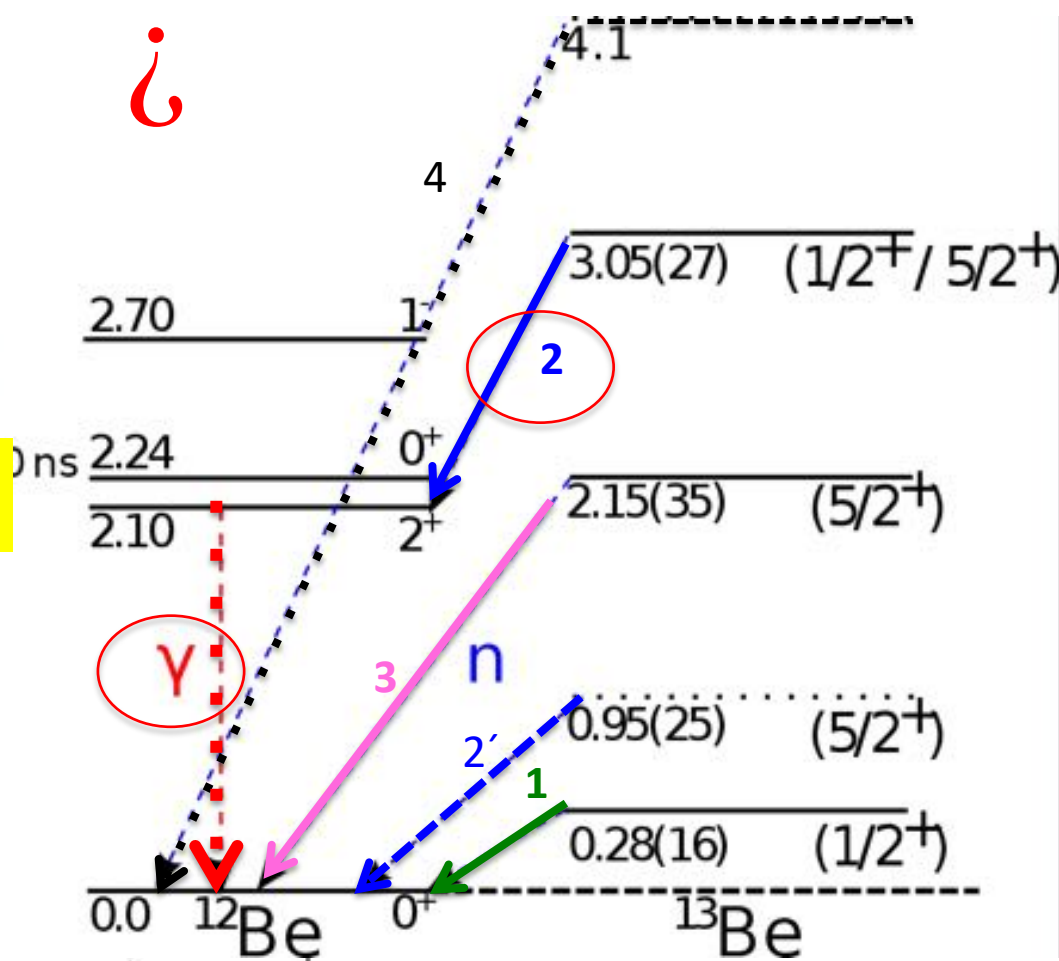
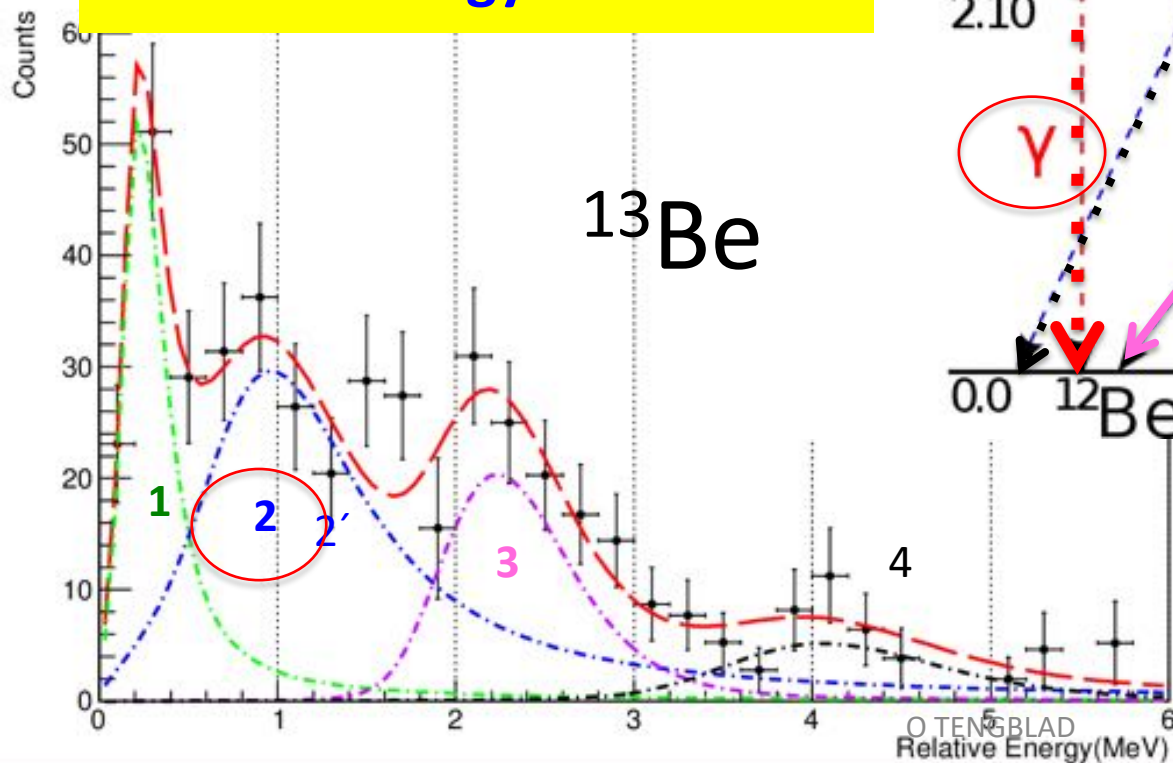
Primary beam	$^{40}\text{Ar}^{11+}$ @ 490 MeV/u
Intensity	$6 \cdot 10^{10}$ ions/spill.
Production target	Be 4 mg/cm ²
Reaction target	H, C, empty

- Energy loss in the TFW & SST after the target:
Identify the element after the reaction.
- Identify the isotope from the ALADIN position deviation and beta of the fragment.



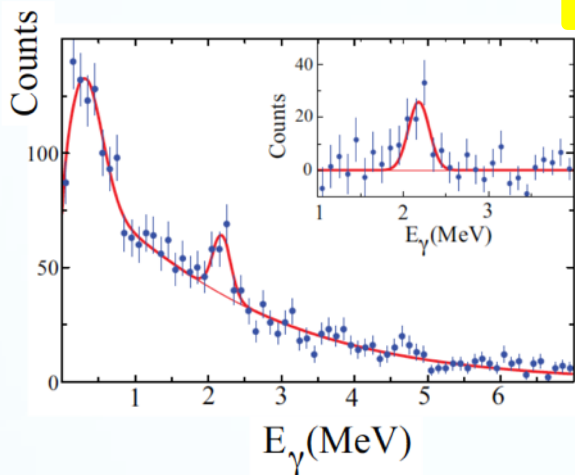


Relative Energy of $^{12}\text{Be} + n$:



?

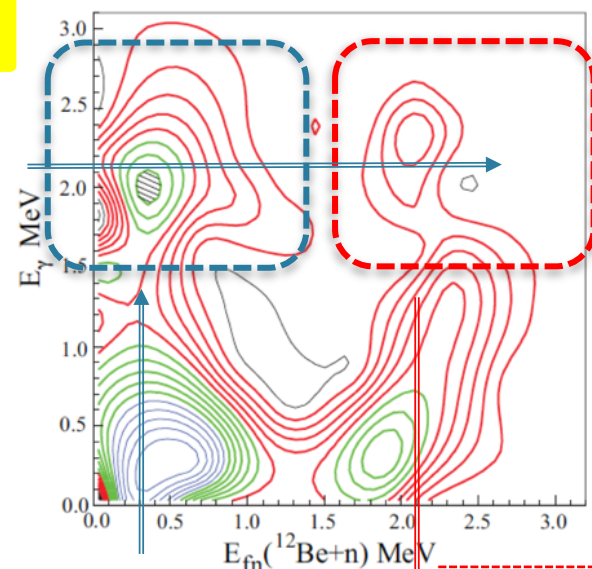
$^{14}\text{B}(p,2p)^{13}\text{Be}$ @ 490 MeV/u



γ , $^{12}\text{Be} + n$ coincidences

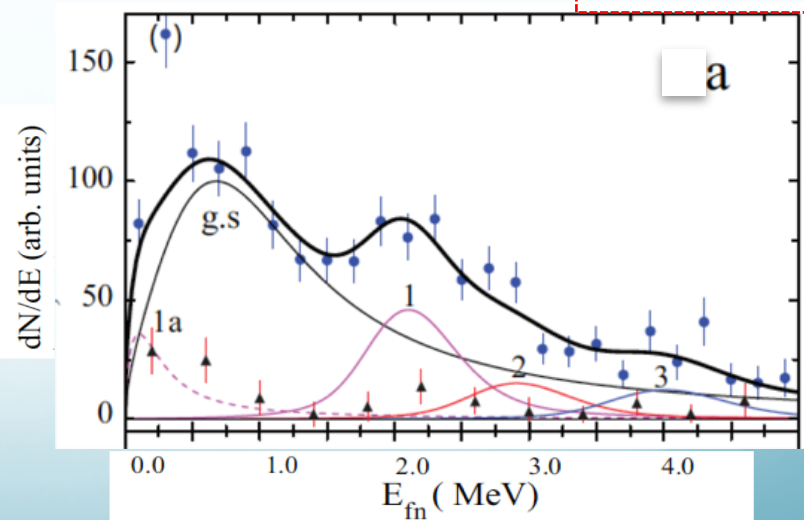
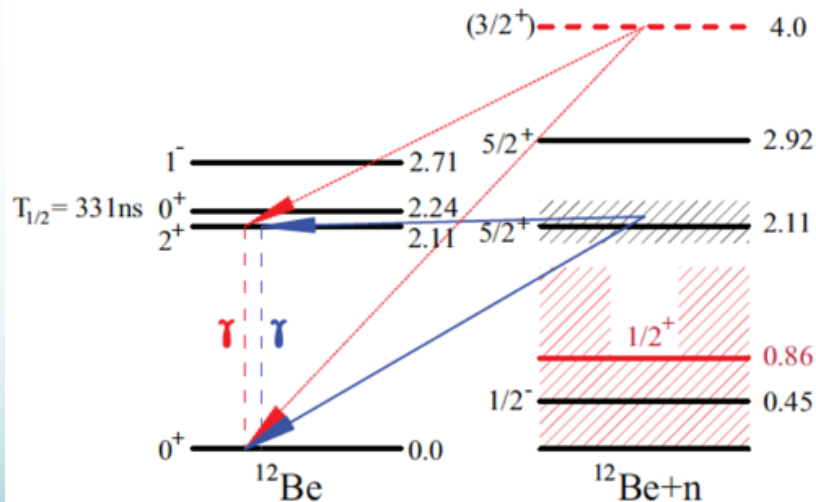


$E_\gamma = 2.1$ MeV



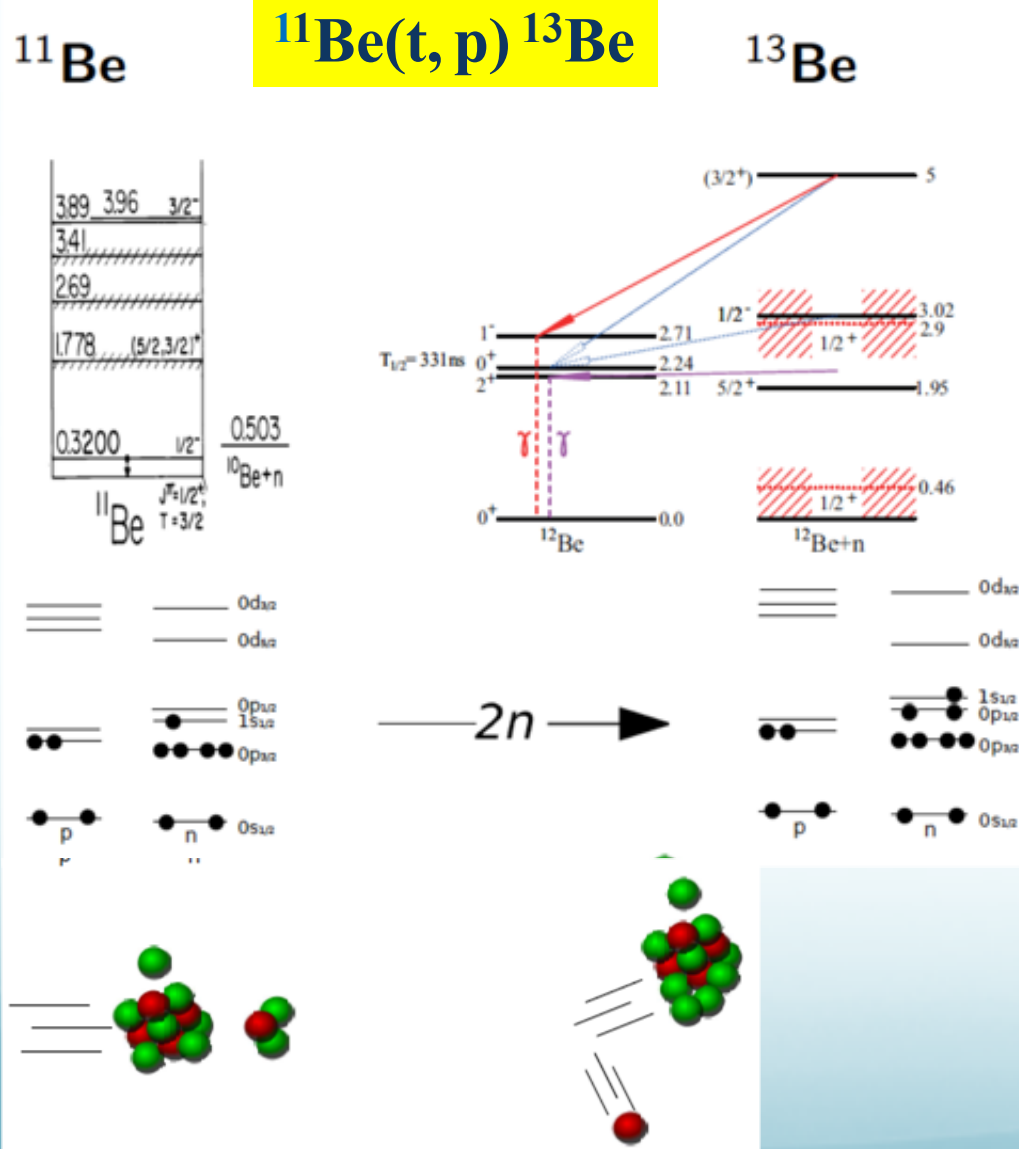
1a

3: 4 MeV level

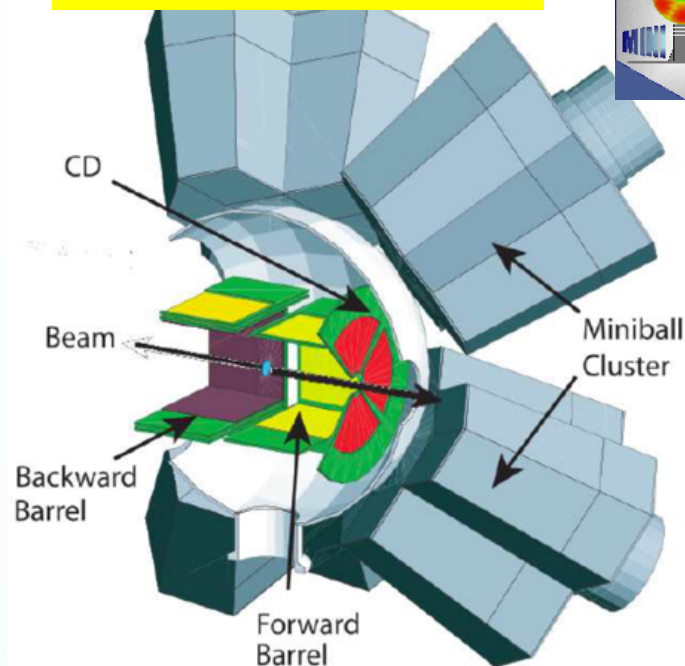
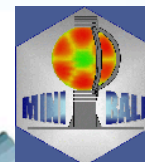


G. Ribeiro *et al.* (R3B Collaboration)

Phys. Rev. C 98, 024603



Miniball + T-REX



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

R3B MEMBER DATABASE REPORT (REP-04)		
Member List		
Affiliation	Name	
CAN Saint Mary University Members: 1	Kanango, Rituparna	
DEU Extreme Matter Institute Members: 3	Savran, Denis Isaak, Johann Silva, Joel	
DEU GSI Darmstadt Members: 15	Aumann, Thomas Langner, Christoph Löber, Sebastian Movsesyan, Alina Schrock, Philipp Simon, Naik Boretzky, Konstanze Caesar, Christoph Heil, Michael Kalic-Nell, Aleksandra Kiselev, Oleg Kurz, Nikolaus Körper, Daniel Pietri, Stéphane Pieg, Ralf Rossi, Dominic Wamers, Felix Egelhof, Peter Geissel, Hans Gerl, Jürgen	
DEU Goethe University Frankfurt Members: 9	Reifarth, Hans Heinrucker, Clemens Glorius, Jan Göbel, Kathrin Hefrich, Tanja Langner, Christoph Pohl, Noritz Sosabehnd, Kerstin Endres, Anne	
DEU Helmholtz-Zentrum Dresden Members: 5	Wagner, Andreas Bommerer, Daniel Reinhardt, Tobias Reinicke, Stefan Röder, Marko Cowan, Thomas	
DEU TU Darmstadt Members: 31	Aumann, Thomas Atar, Leyla Dentinger, Gregor Duchêne, Marc Heine, Marcel Holl, Matthias Horvat, Andrea Johansen, Jacob Kahlbow, Julian Kiesel, Robert Löber, Bastian Miki, Kenjiro Movsesyan, Alina Paulin, Valeril Paschalis, Stefana Scheit, Heiko Schindler, Fabia Schrock, Philipp Tscheuschner, Joachim Törnqvist, Hans	

ROB Member Database Report - Official Document - 10 Mar 2015 / 08:38 UTC (automatic REP-04)

R3B MEMBER DATABASE REPORT (REP-04)		
Member List		
Affiliation	Name	
DEU TU Dresden Members: 2	Kroll, Thorsten Fernández Martínez, Guillermo Hartig, Anna-Lena Komm, Tilja Ignatov, Alexander Ilieva, Stoyanka Rhee, Han-Bum von Schmid, Mirko Petri, Marina Reil, Sebastian Syndikus, Ina Cowan, Thomas Röder, Marko Reinhardt, Tobias Zuber, Kai	
DEU TU München Members: 9	Gernhäuser, Roman Bendel, Michael Reise, Benjamin Klenze, Philipp Le Biele, Tudi Michler, Dennis Reichert, Sebastian Kemmla, Patrick Winkel, Max Riliges, Andreas Reinig, Andreas Mayer, Jan Netterdon, Lars Pickstone, Simon	
ESP CSIC Madrid Members: 8	Tengblad, Olof Borge, Maria José Garrido, Eduardo Garzon Camacho, Alejandro Marroquin Alonso, Irene Nacher, Enrique Pereira, Angel Ribeiro, Guillermo	
ESP Universidad Complutense d Members: 1	Fraile, Luis	
ESP Universidad de Vigo Members: 1	Casarejos, Enrique	
ESP University of Santiago de Members: 5	Cortina-Gil, Dolores Alvarez-Pol, Hector Benlliure, Jose Cabanelas Eiras, Pablo Pietras, Benjamin	
FRA CEA Bruyeres le Chatel Members: 3	Taleb, Julies Chatillon, Audrey Laurent, Benoit	
FRA CEA Saclay Members: 5	Obertelli, Alexandre Corei, Anna Pollacco, Emanuel Santamaría, Clementine Kortens, Wolfram	
FRA GANIL Members: 2	Sorlis, Olivier Vandebrouck, Marine	

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R3B MEMBER DATABASE REPORT (REP-04)		
Member List		
Affiliation	Name	
FRA IPN Orsay Members: 4	Andouin, Laurent Gorbinet, Thomas Tassan-Got, Laurent Yan, Yinan	
FRA Université Paris Sud Members: 0	Andouin, Laurent	
GBR STFC Daresbury Laboratory Members: 7	Leemon, Roy Borri, Marcello Grant, Alan Kogitais, Moschos Labiche, Marc Lazarus, Ian Pucknell, Victor	
GBR University of Birmingham Members: 1	Freer, Martin	
GBR University of Edinburgh Members: 4	Wood, Phil Devinson, Thomas Estrade, Alfredo Lederer, Claudia	
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HUN ATOMKI Debrecen Members: 2	Elekcs, Soltan Krasznahorkay, Attila	
HUN Eötvös Loránd Univers Members: 1	Norvath, Ákos	
LTU University of Vilnius Members: 1	Deltuva, Arnoldas	
NLD KVI-CANT Members: 3	Kaizer-Sayestanski, Nasser Karakah, Nuhia Rigollet, Catherine Crespo, Raquel	
PRT Instituto Superior Tecnico Members: 1		
PRT Nuclear Physics Center, U Members: 3	Gaiaviz Redondo, Daniel Henriques, Ana Tebis, Pamela	
ROU Institute of Space Scienc Members: 2	Haiduc, Maria Potlog, Petru-Mihai	
RUS JINR Dubna Members: 5	Fomichev, Andrey Seabach, Andrey Golovkov, Mikhail Gorshkov, Alexander Krupok, Sergey	
RUS SSC Kurchatov Institute M Members: 5	Chelkov, Leonid Korsheninnikov, Alexey Kuzmin, Evgeny Nikolskii, Evgenii Volkov, Vasily	
RUS VNIIT Gatchina Members: 20	Alkhasov, Georgij Balin, Dmitri Battist, Leonid Dobrovolsky, Alexander Fetisov, Andrey Gennady, Petrov	

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R3B MEMBER DATABASE REPORT (REP-04)		
Member List		
Affiliation	Name	
SVN Josef Stefan Institut Lju Members: 1	Vencelj, Matjaz	
SWE Chalmers University of Te Members: 6	Nilsson, Thomas Johansson, Råkan Jonsson, Björn Thies, Ronja Heine, Andreas Lindberg, Simon	
SWE Lund University Members: 4	Cederkall, Joakim Avdeichikov, Vladimir Fahlender, Claus Golubev, Pavel	
USA Texas A&M University-Comm Members: 1	Bertulani, Carlos	

Explanation
Name in *italic* indicates member with different main affiliation



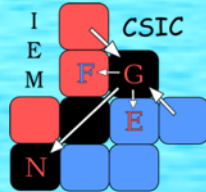
O TENGBLAD

250 Members
40 Institutes
15 Countries

Spokesperson: Lola Cortina USC
Technical Director: Olof Tengblad CSIC



-- Collaboration



Grupo de Física
Nuclear Experimental



Univ. Santiago de Compostela



TECHNISCHE
UNIVERSITÄT
DARMSTADT



Technische Universität München



CHALMERS



JOINT INSTITUTE
FOR NUCLEAR RESEARCH



LUND
UNIVERSITY

In summary: I have discussed the
 R^3B - Reactions with Relativistic Radioactive Beams
its experimental set-up being built for the
High Energy Branch of NUSTAR @FAIR

I also discussed one example of experiments to be done at this
facility some time in 2020 and onwards

Quasifree scattering reactions like $^{14}\text{B}(p,2p)^{13}\text{Be}$

Thanks for your attention!