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Y UNIVERSIDADES

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

R³B

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

O. Tengblad

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

Grupo de Física Nuclear Experimental

R3B -- España

USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

GENP Grupo Experimental de Núcleos y Partículas

Univ. Santiago de Compostela

Universidade Vigo

CIMA UNIVERSIDAD DE VIGO

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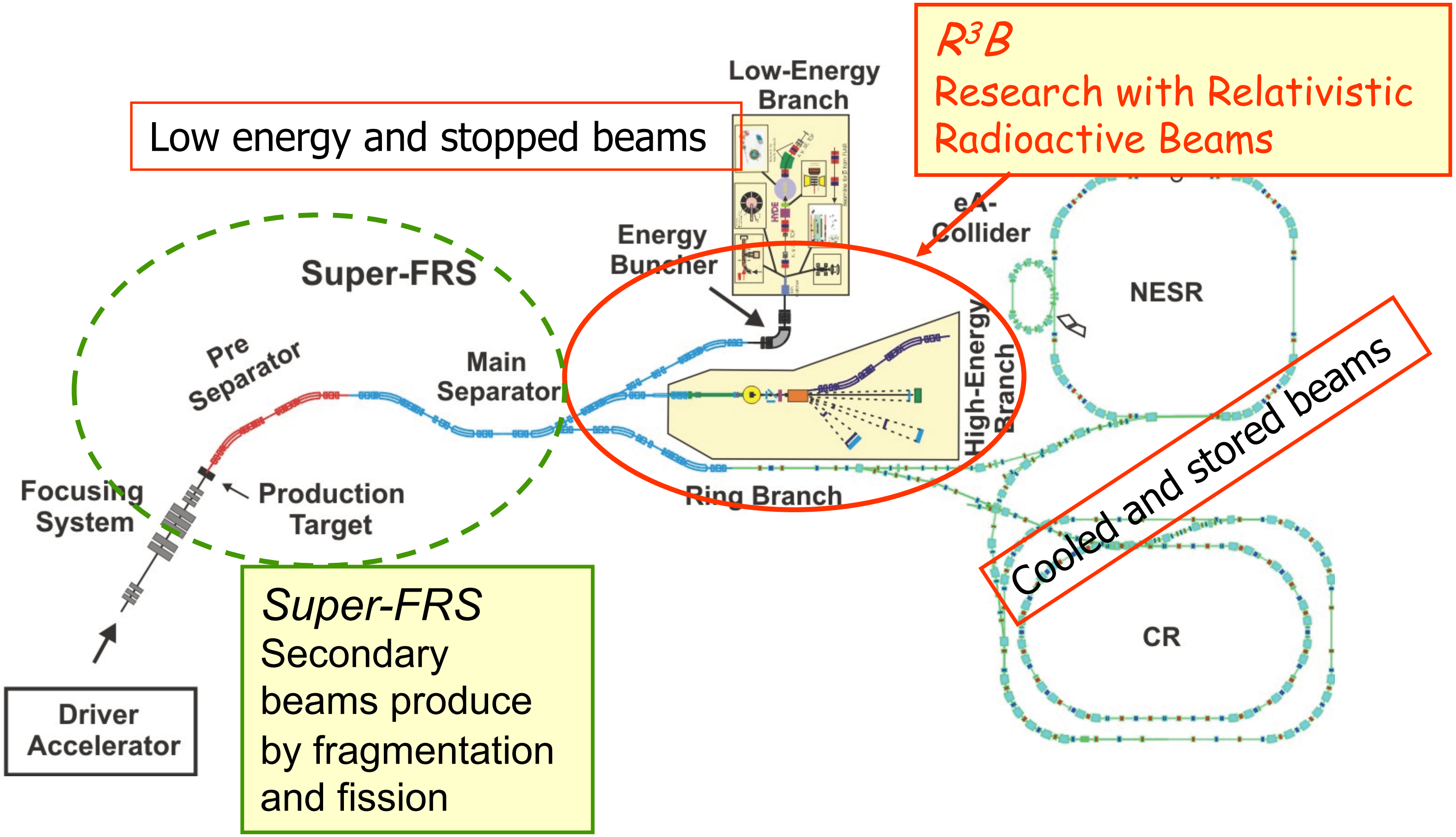
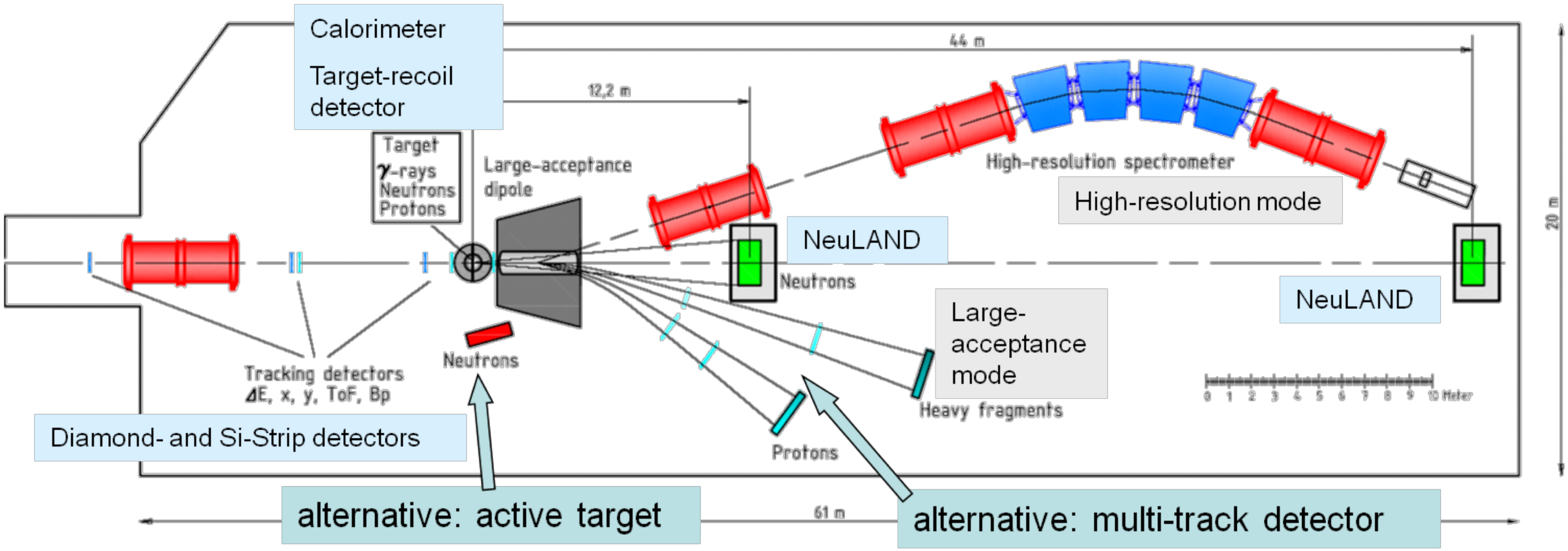
IEM CSIC

Grupo de Física Nuclear Experimental

NUSTAR – a facility for NUclear STructure & Astrophysis Research



R^3B: Reactions with Relativistic Radioactive Beams



Kinematically complete measurement of reactions with high-energy secondary beams

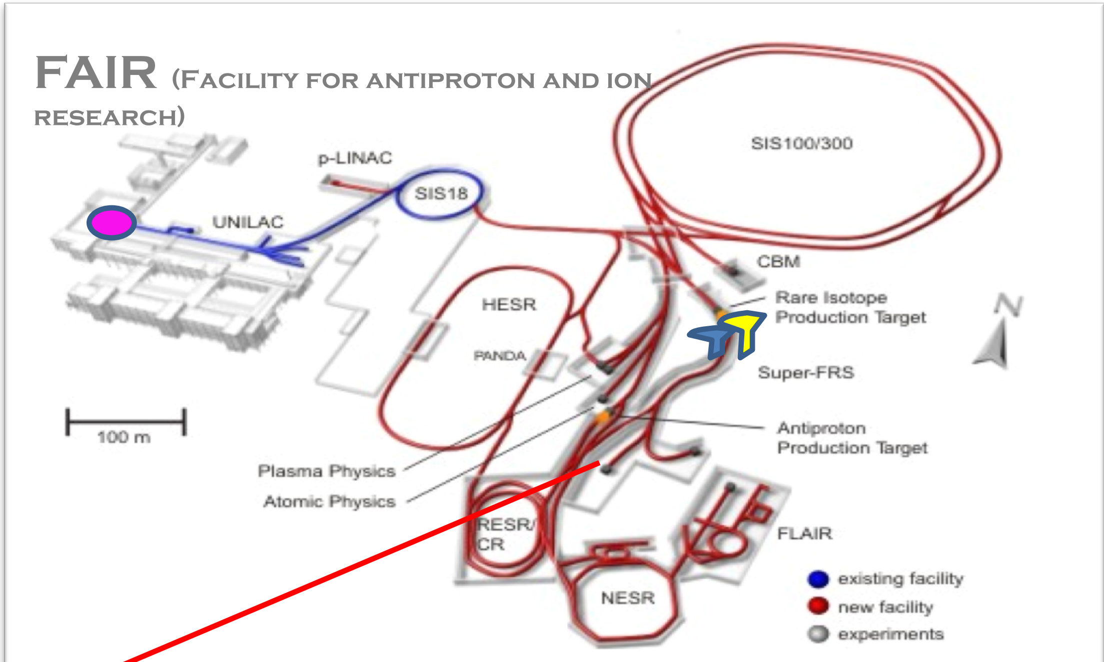
- **Nuclear Astrophysics**
- **Structure of exotic nuclei**
- **Neutron-rich matter**

•A universal fixed-target experiment for complete inverse-kinematics reactions with relativistic RIBs ~100 MeV/u – 1 GeV/u

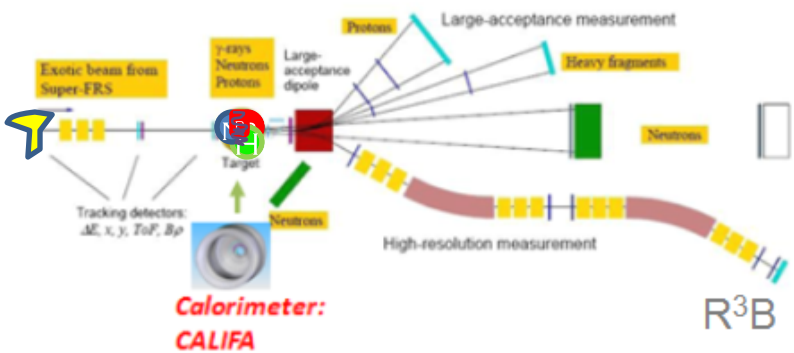
•Experiments with the most exotic (<1 ion/s) and short-lived nuclei – exploring the isospin frontier at and beyond the drip-lines –

•Concept built on existing ALADIN-LAND experiment at GSI

How does it work



R^{3}B



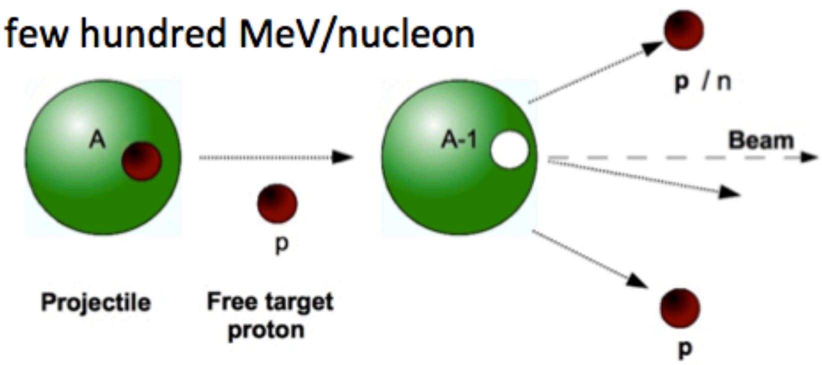
1. Accelerated beam impact on Production Target

2. Products are separated in FRS

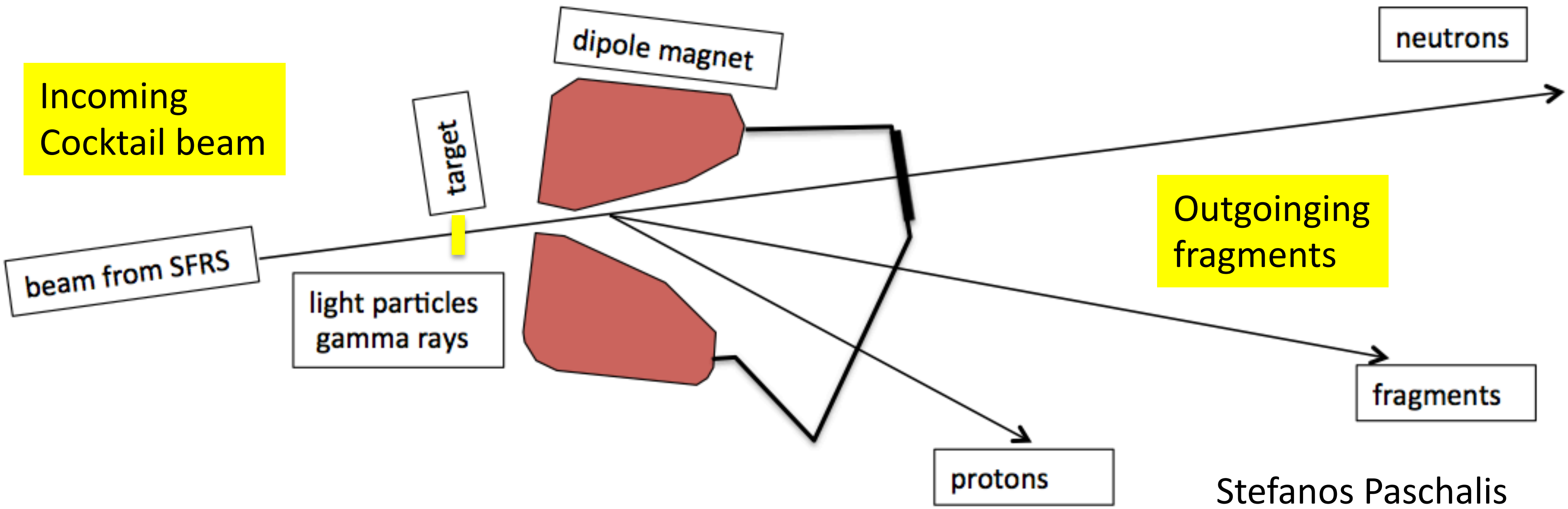
3. Separated isotopes directed to experiment

4. Isotope of interest impact on Reaction Target

5. Reaction fragments and gammas are detected

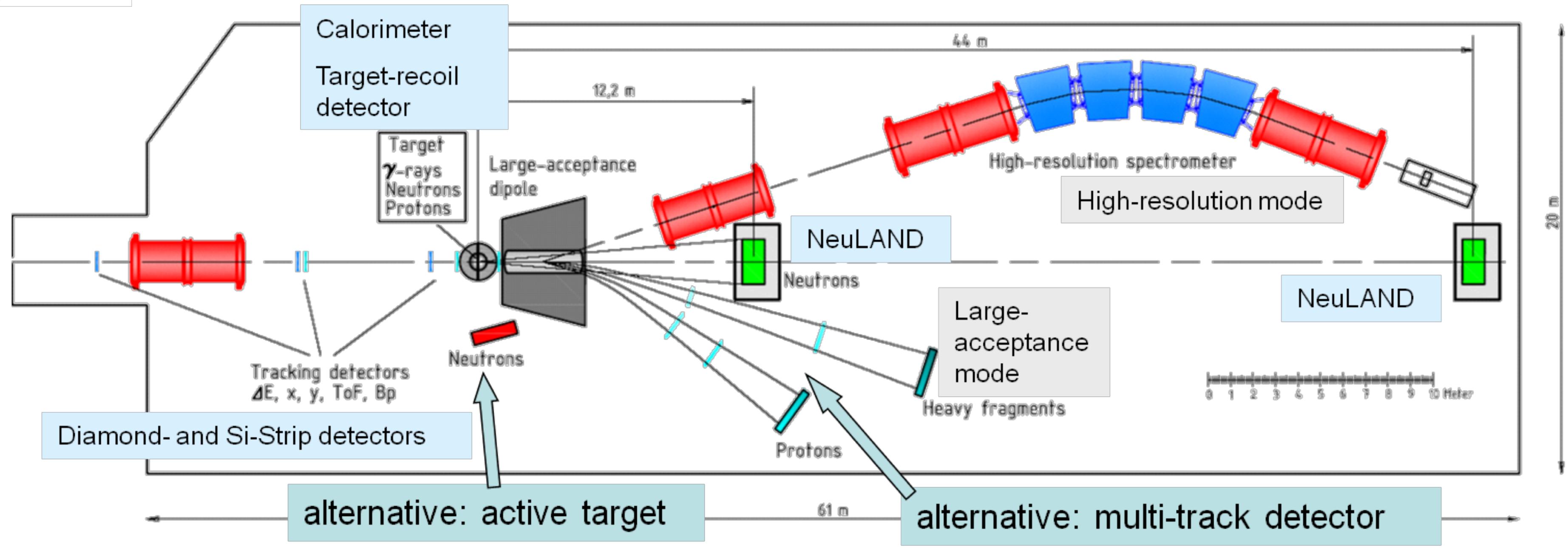


After the reaction: heavy fragment, neutrons, protons, gammas
Aim: measure all reaction products



Stefanos Paschalis

R3B: (Key) Components



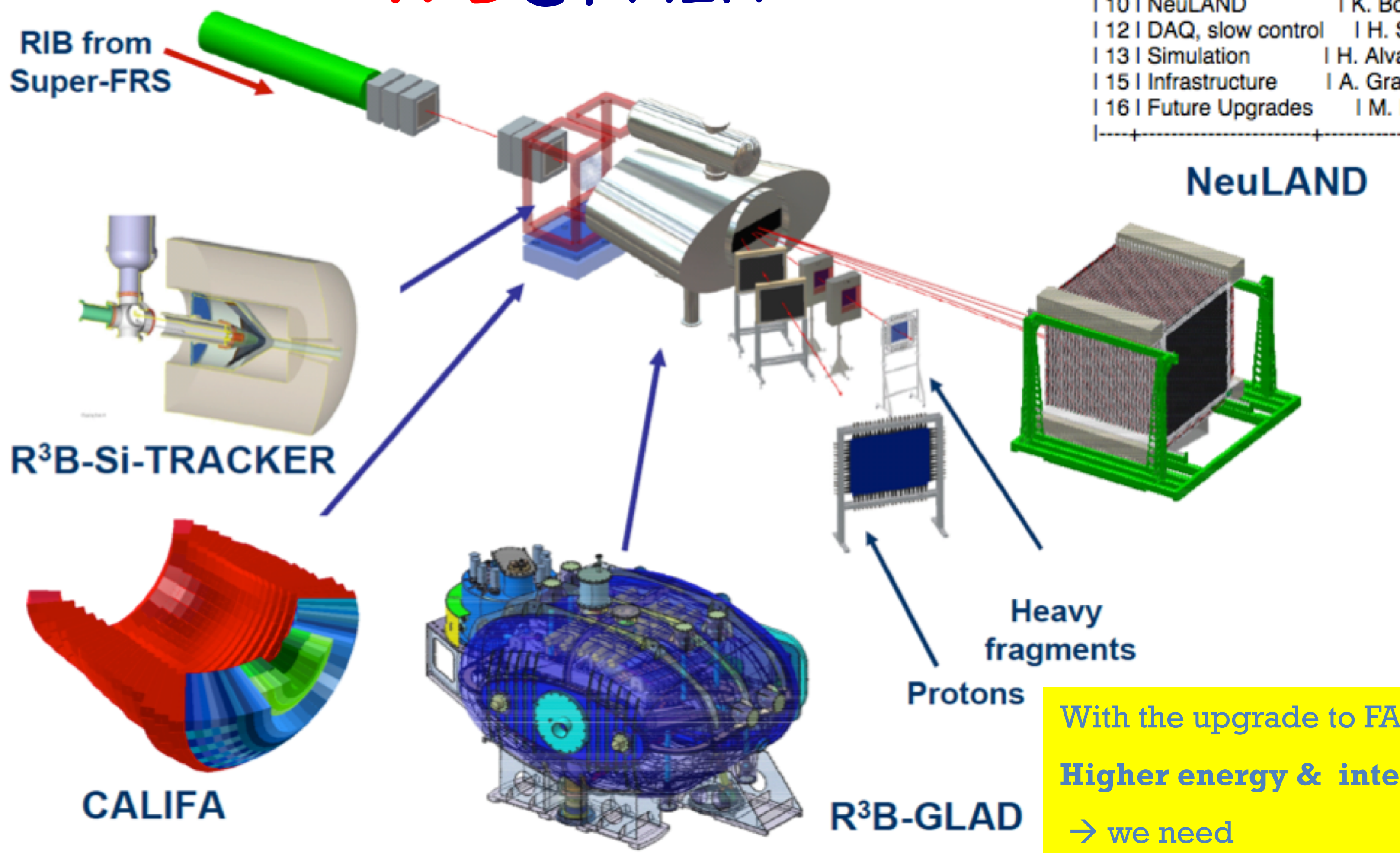
- active target
- Low energy neutron detector
-
- CALIFA:
  γ/p calorimeter-spectrometer
- Si-tracker:
  target recoil detector
- GLAD: large acceptance dipole magnet

- tracking, DAQ, simulation, infrastructure
- NeuLAND: neutron time-of-flight spectrometer
- High-resolution spectrometer

R3B: (Key) Components

WG	Name	chair	deputy
1	R3B-GLAD	H. Simon	Ch. Mayri
2	High-res spectrometer	H. Geissel	---
3	Tracking detectors	S. Paschalis	(PNPI)
6	CALIFA	D. Cortina	J. Cederkall
7	Si-tracker	R. Lemmon	M. Chartier
8	Active Target	P. Egelhof	E. Maev
10	NeuLAND	K. Boretzky	A. Heinz
12	DAQ, slow control	H. Simon	N. Kurz
13	Simulation	H. Alvarez-Pol	M. Labiche
15	Infrastructure	A. Grant	D. Körper
16	Future Upgrades	M. Petri	---

R^3B@FAIR



With the upgrade to FAIR we get:

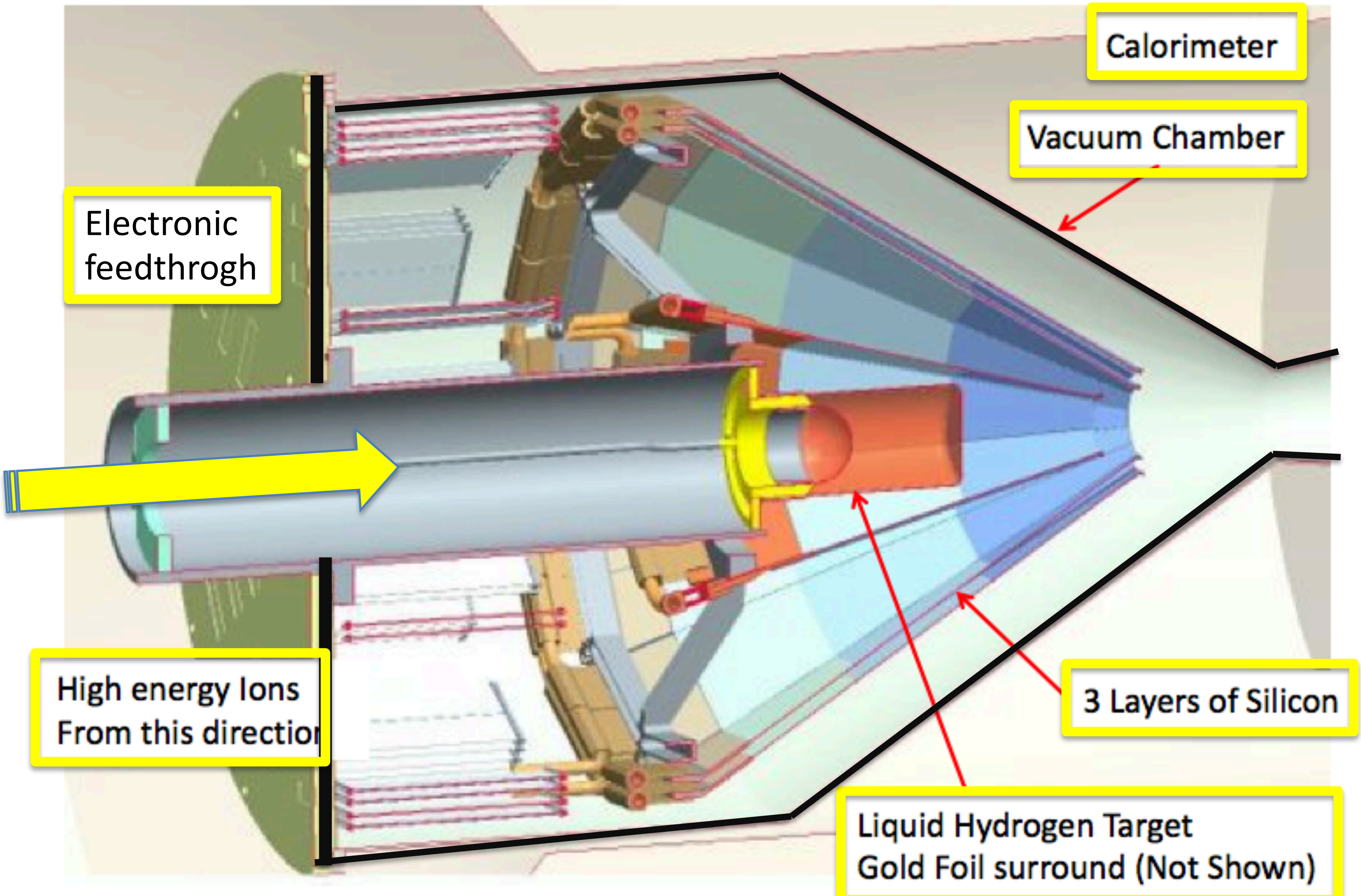
Higher energy & intensity

→ we need

1) New Magnet GLAD

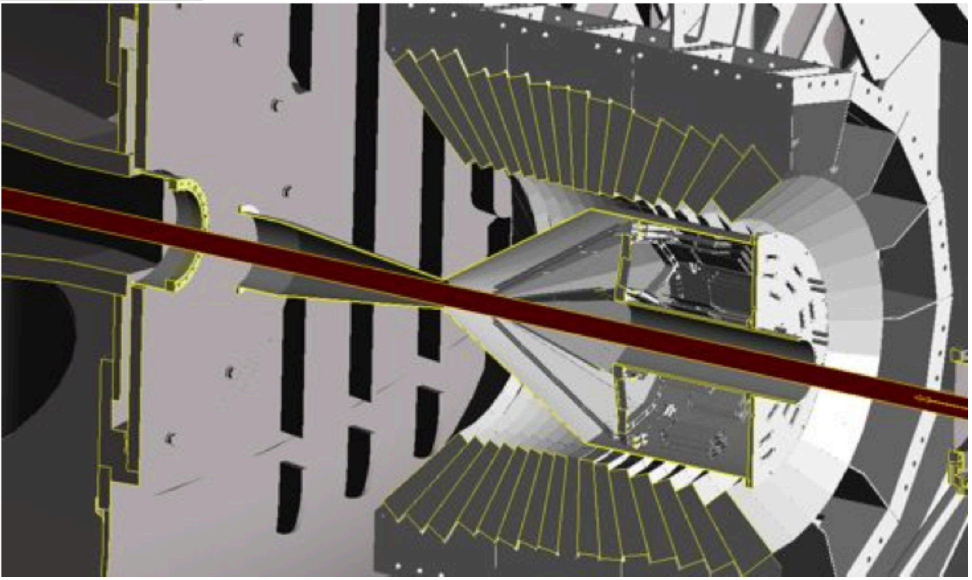
2) **New detectors**

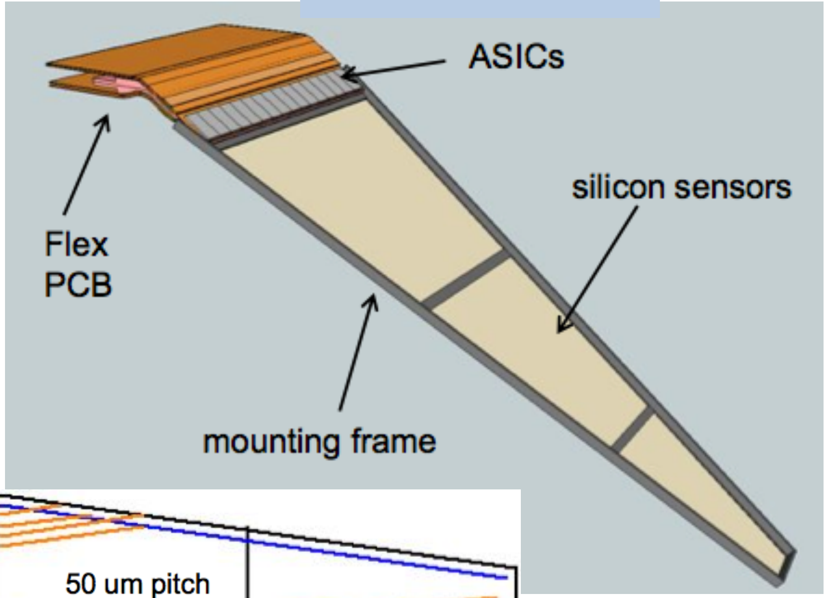
R3B: Si - tracker

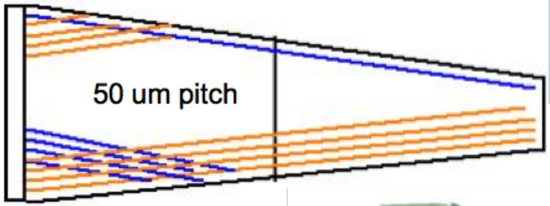


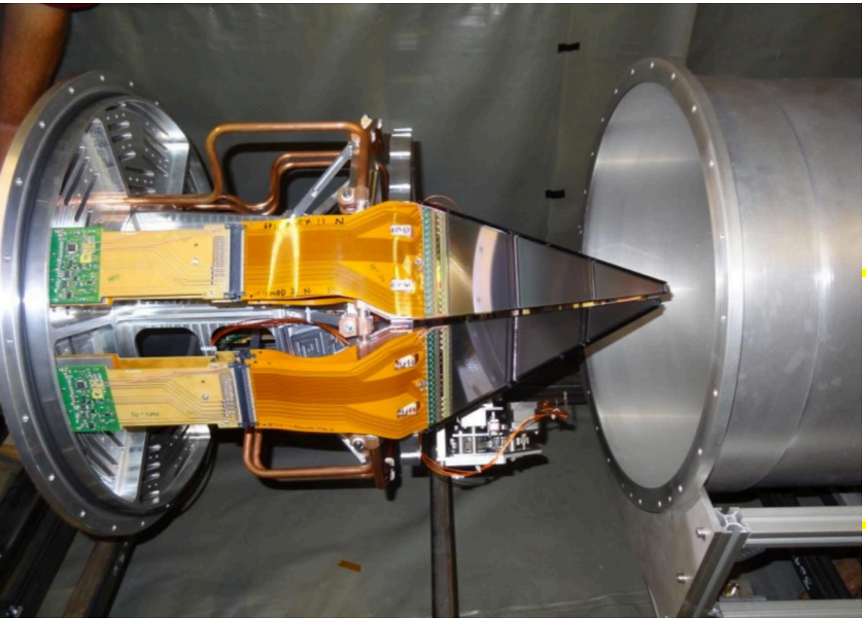
R3B: Si – tracker (UK)

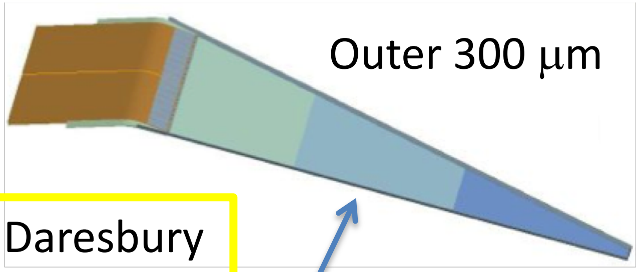
120k Si strips
C fibre structure

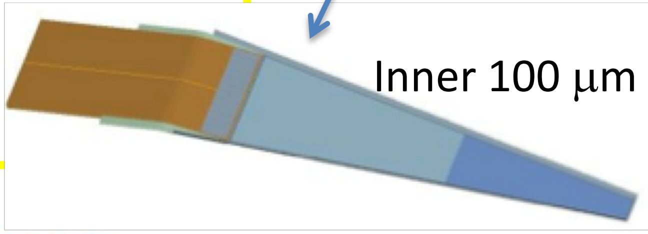








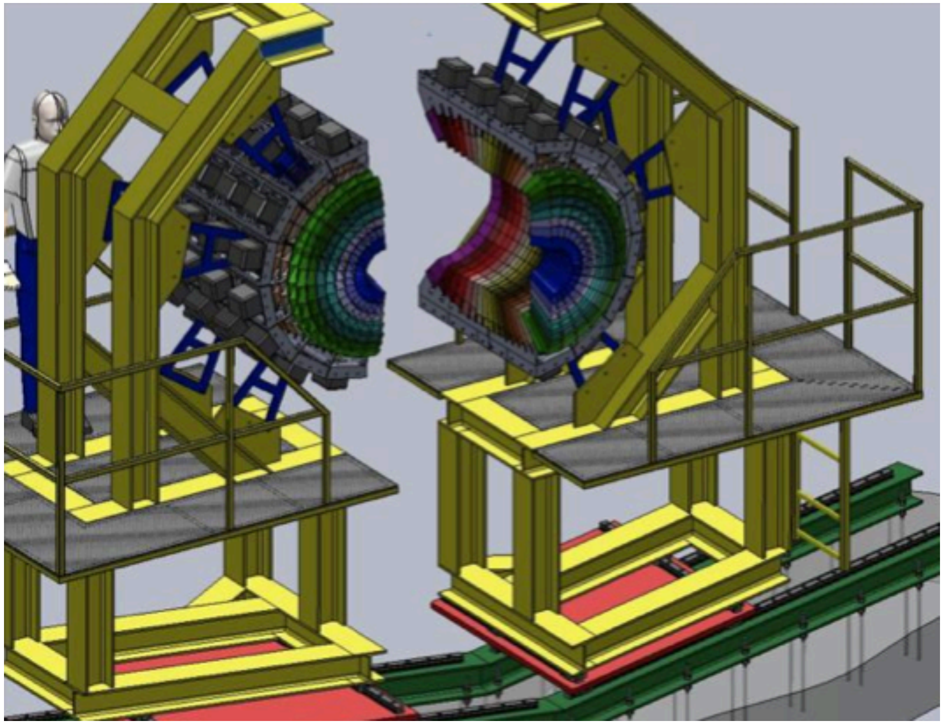


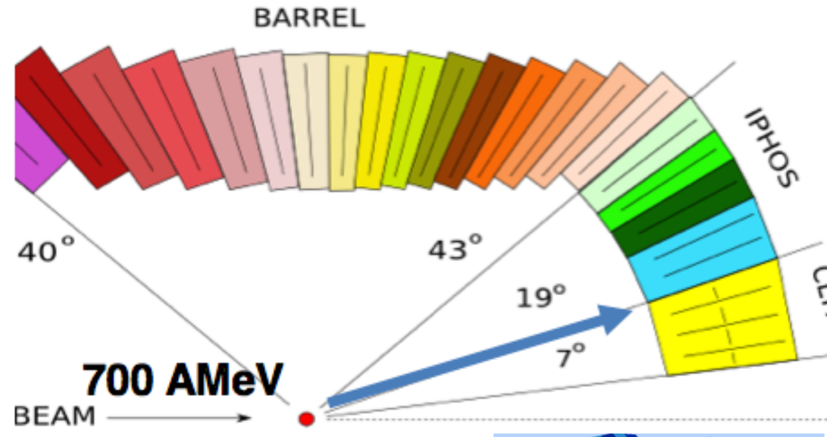


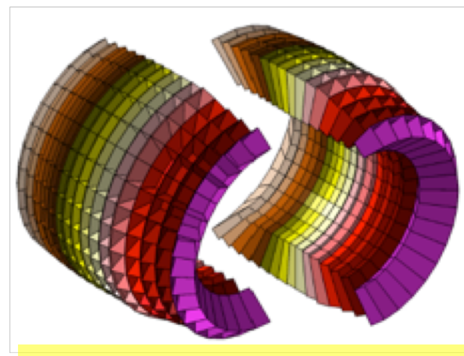
Univ. of Liverpool & Daresbury
M. Chartier,
R. Lemon,
Alan Grant,

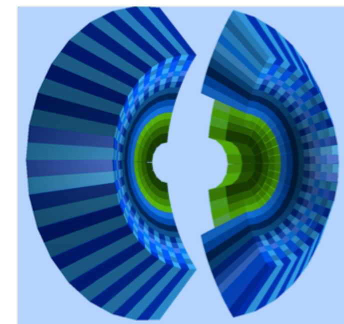
CALIFA

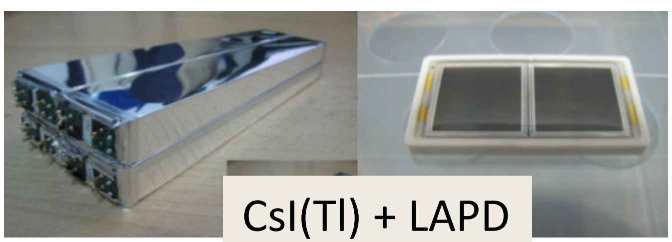
CALorimeter for In Flight detection of γ-rays and charged pArticles.







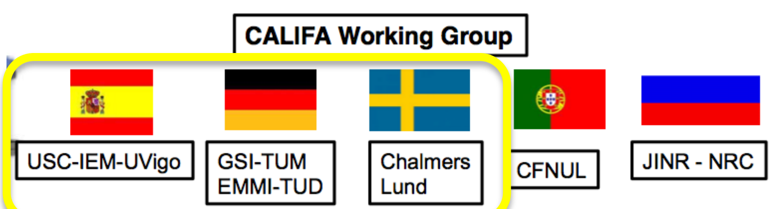




CALIFA: Highly segmented
Thick detection volume
Inner radius 50cm

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

EndCap: 680 crystals = 1 Ton



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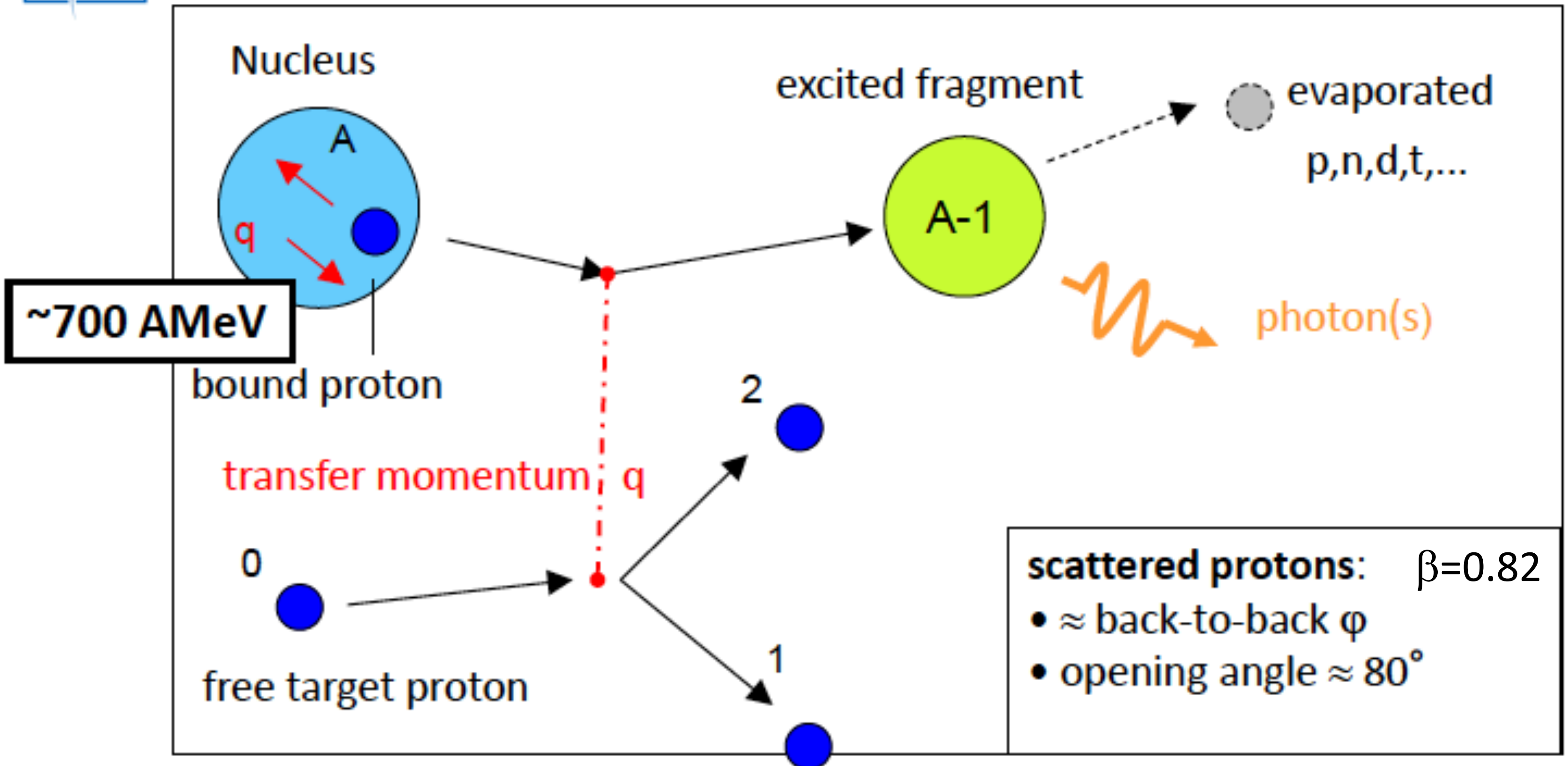
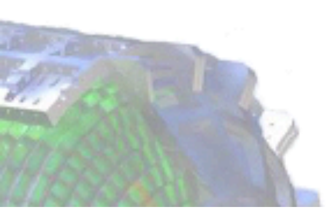
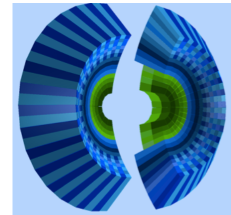


Requirements for CALIFA:

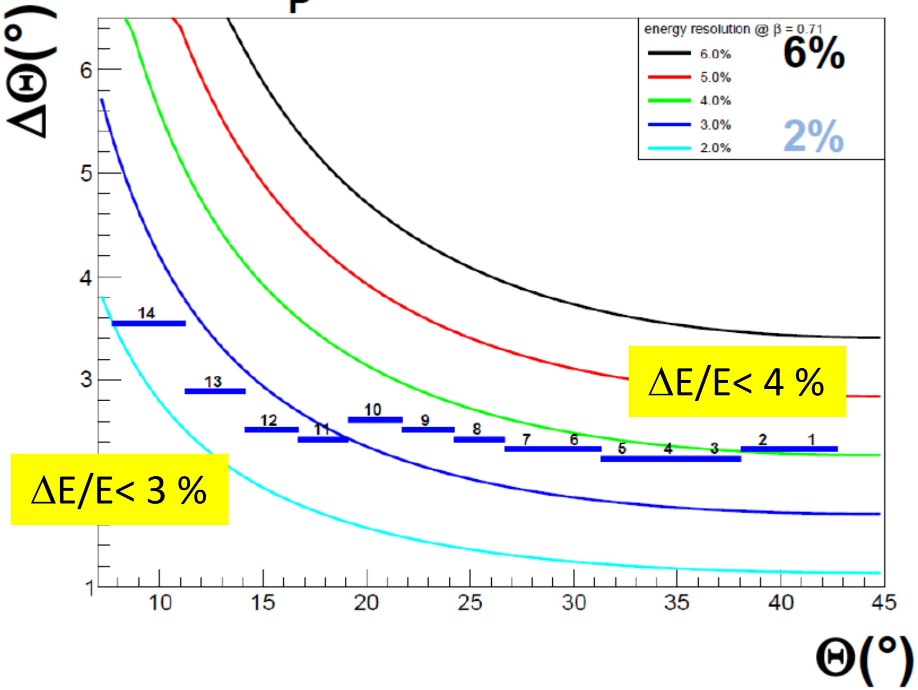
- high dynamic range
  100keV γ-rays – 700 AMeV charged particles
- high efficiency
- high granularity -> Doppler correction
- particle identification



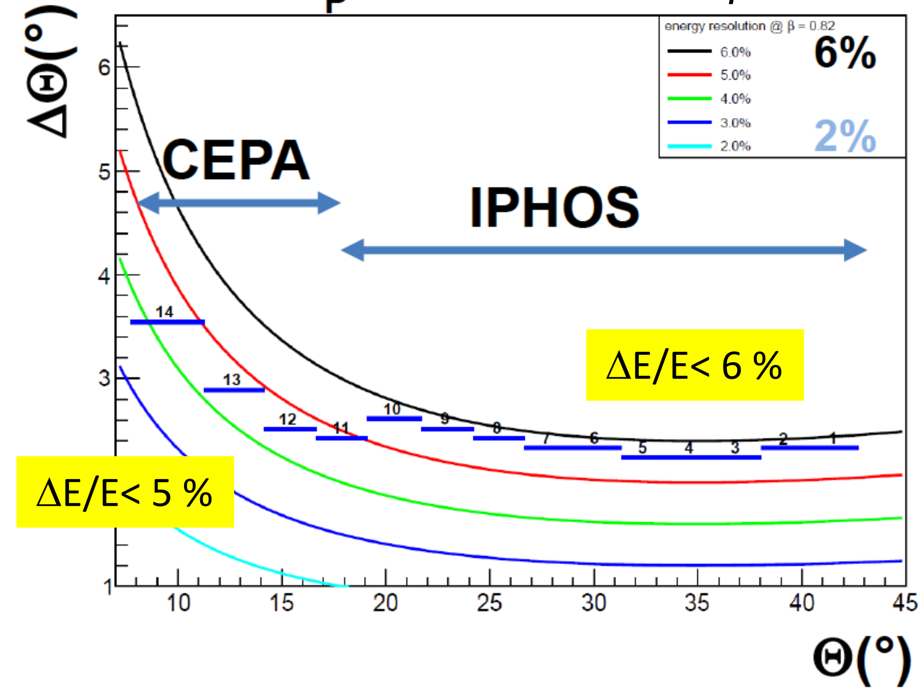
CALIFA ENDCAP



E_P = 400 AMeV   β=0.71



E_P = 700 AMeV   β=0.82



IPHOS - Intrinsic Phoswich Detectors
CEPA - Califa Endcap Phoswich Array

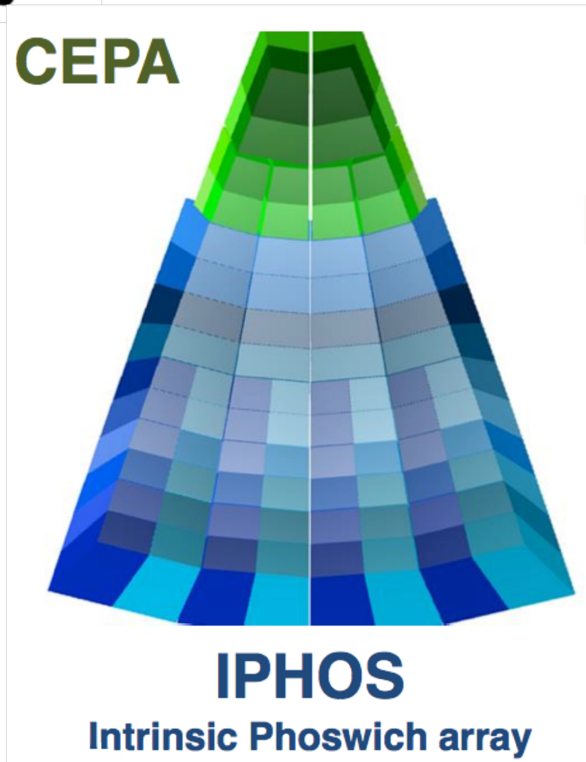
DE -> E consept to separate reactions
QFS @ 700AMeV

length limit 22cm:

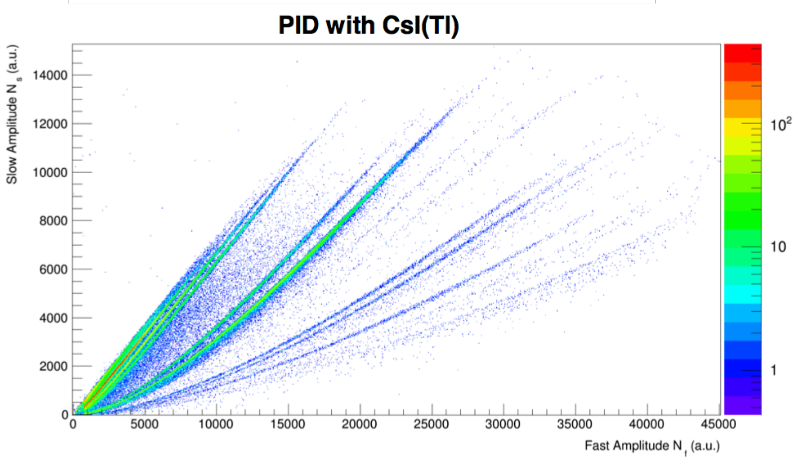
- geometrical space,
- light collection
- crystal properties
- efficiency and cost

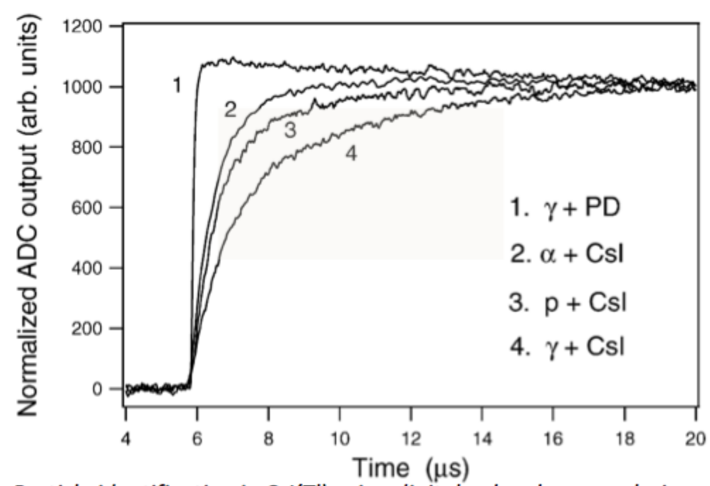
θ (°)	E_p (MeV)	Proton range(mm) in CsI(Tl)	eff.
7	686	718	15% ..
15	637	645	
20	592	597	
30	480	421	
40	356	264	50%

IPHOS Outer-ring EndCap



Distance to target	41 cm	
Numb. of crystals	608	
Diff. crystal geometries	18	
Crystal volume (CsI(Tl))	$\approx$ 90.020 cm^3	512
Crystal weight (CsI(Tl))	$\approx$ 408 kg	
Crystal volume ($LaBr_3/LaCl_3$)	$\approx$ 10.700 cm^3	96
Crystal weight ($LaBr_3/LaCl_3$)	$\approx$ 47 kg	
Full operation system weight	$\approx$ 1100 kg	

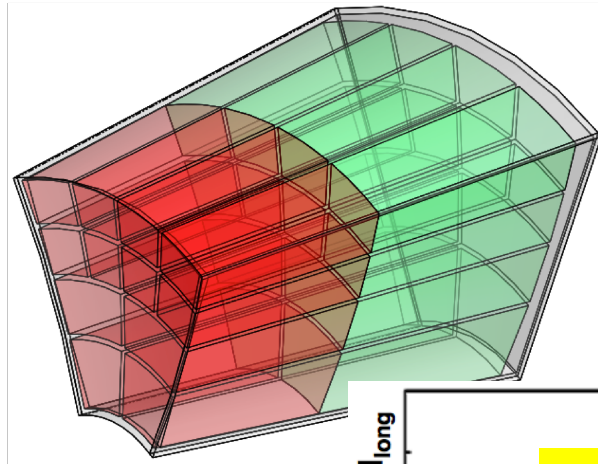




Particle identification in CsI(Tl) using digital pulse shape analysis – W. Skulski, M. Momayezi, NIM A 458, (2001) 759-771

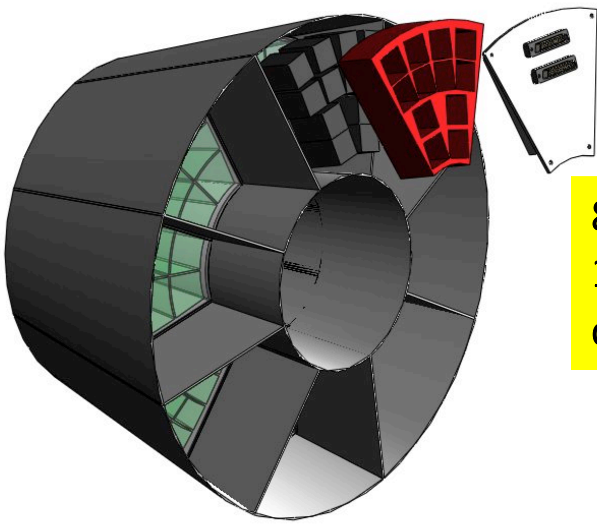
CEPA Inner-ring EndCap of CALIFA

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

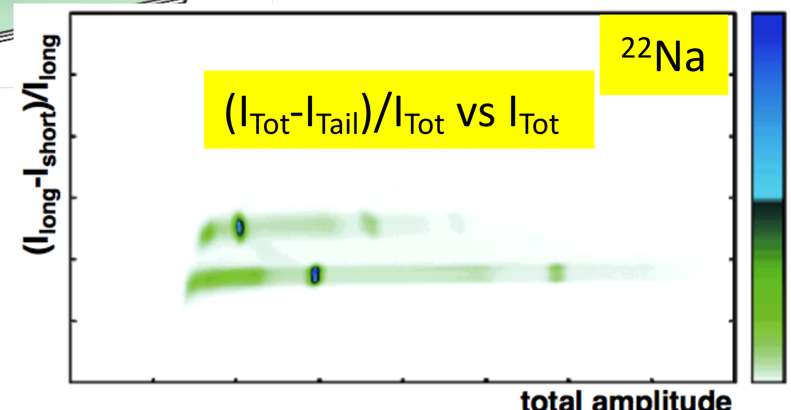


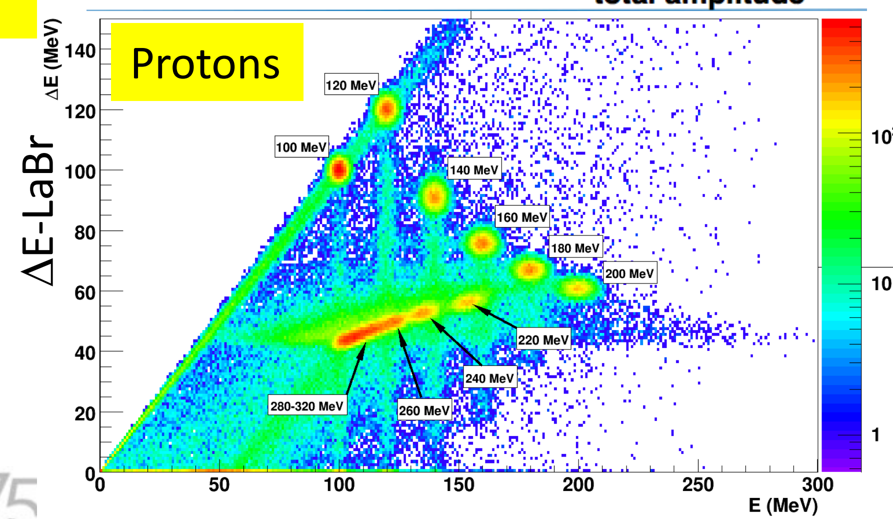
Phoswich
$LaBr_3(Ce)+LaCl_3(Ce)$

2 scintillators
1 optical readout



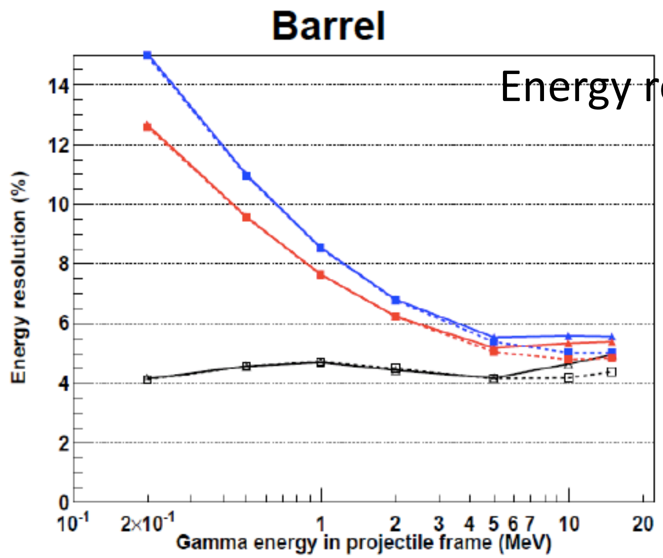
8 x 5Kg units of 12 Phoswich crystals

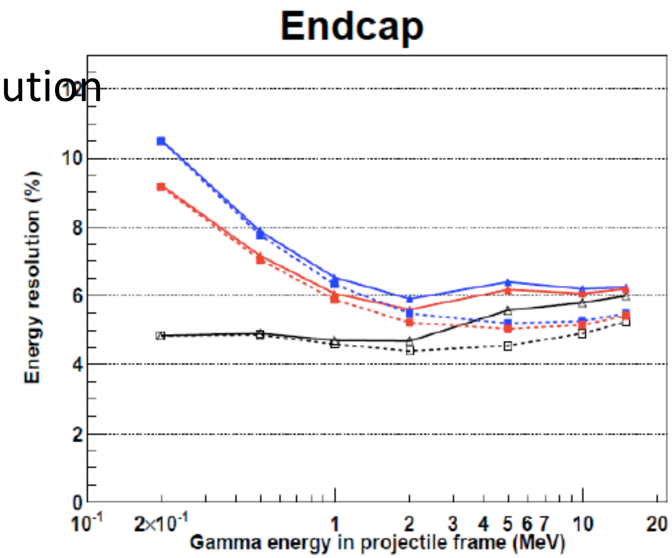




Materials	ΔE/E (% at 662 keV)	Light yield (photons/ keV)	Decay time (ns)	$\lambda_{emision}$
$LaBr_3$	2.9	63	16	380 nm
$LaCl_3$	3.8	49	28	350 nm

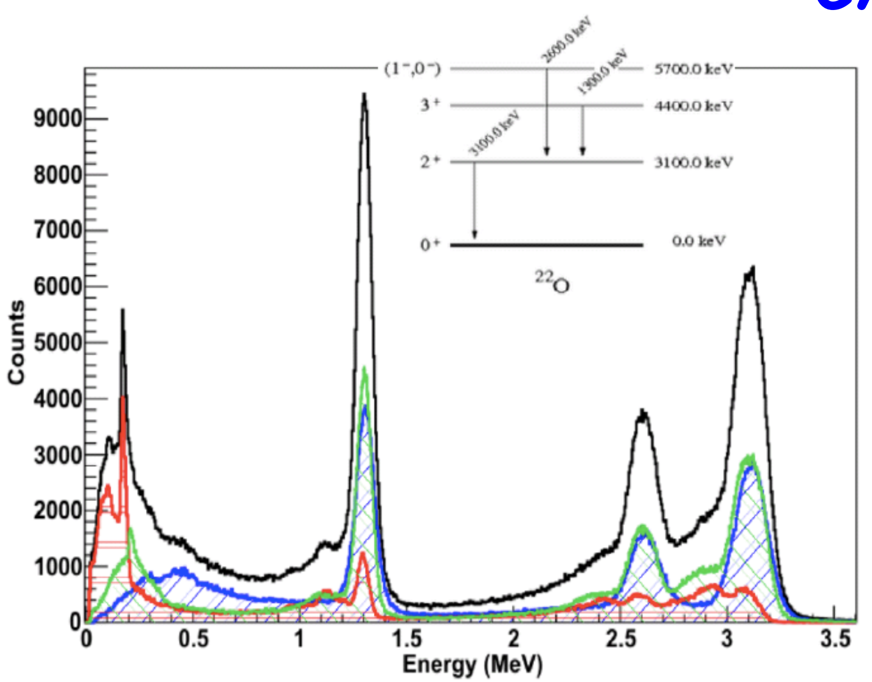
Energy resolution



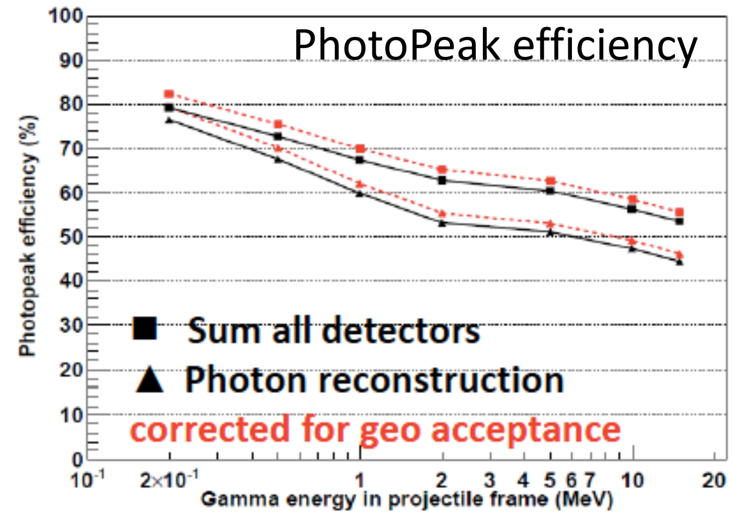


CALIFA

One Neutron Knockout from ^{23}O



Califa Barrel + Endcap

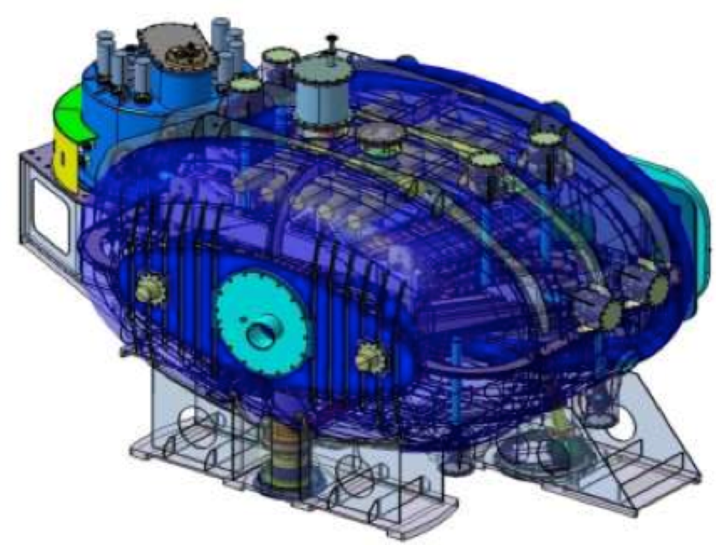


GLAD - Large-acceptance superconducting dipole magnet

H. Simon

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.



Inkind contribution: France - Germany

@ GSI Cryoplant has been installed

Cryolines (33m) on site Compressor (+ Controls) test Q4/2014. Cryoplant operation Q4/2014 Infastructure installation

@CEA Saclay

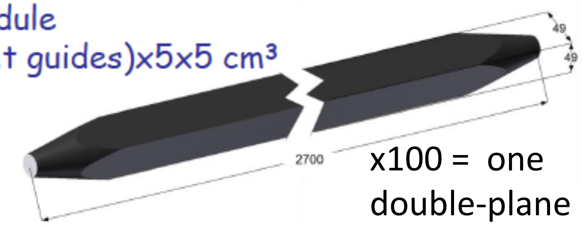
- Magnet cold mass ready and tested, Dec 2013.
- Integration into cryostat mostly done.

- Was Delivered to GSI 3rd of Nov 2015.

NeuLAND - High-resolution neutron ToF spectrometer

K. Boretzky

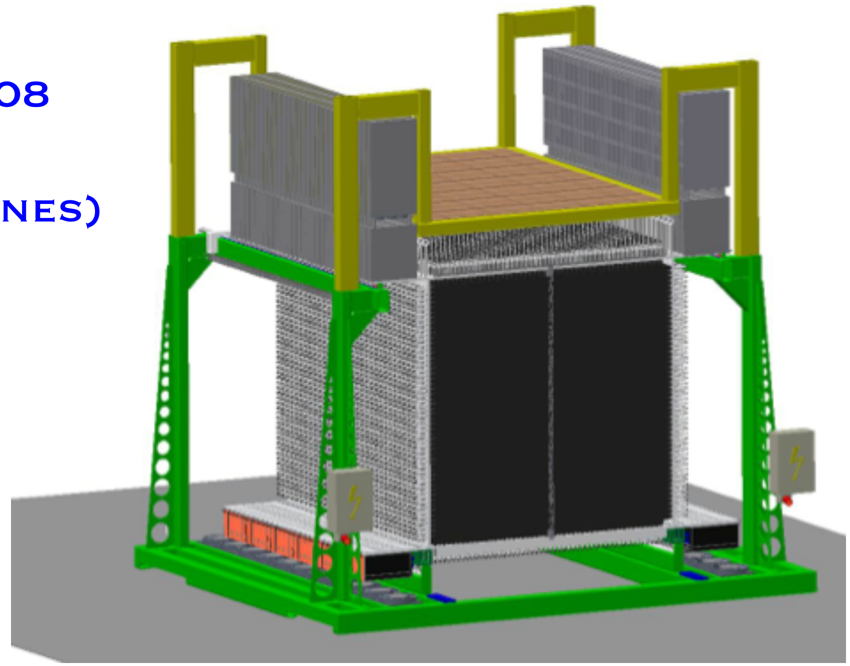
4 double-planes are installed at Riken for experimental campaign 2015-2016



x100 = one double-plane

NeuLAND detector parameters:

- full active detector using RP/BC408
- face sice 250x250 cm2
- active depth 300 cm (30 double-planes)
- 3000 scintillator bars
- 6000 PM / readout channels
- 32 tons



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

  ΔE < 20 keV at 100 keV above the neutron threshold

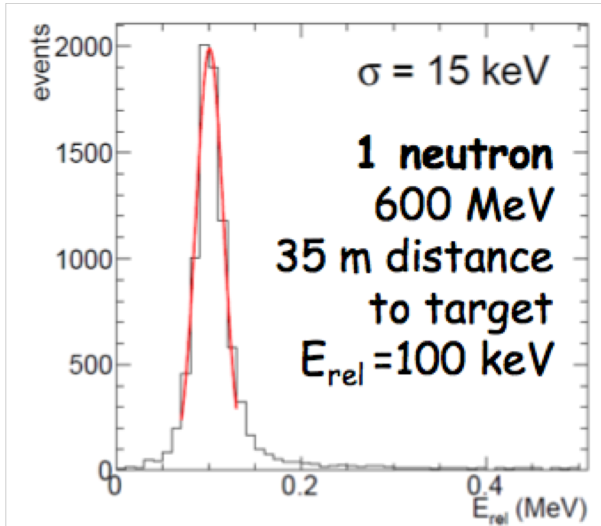
NeuLand

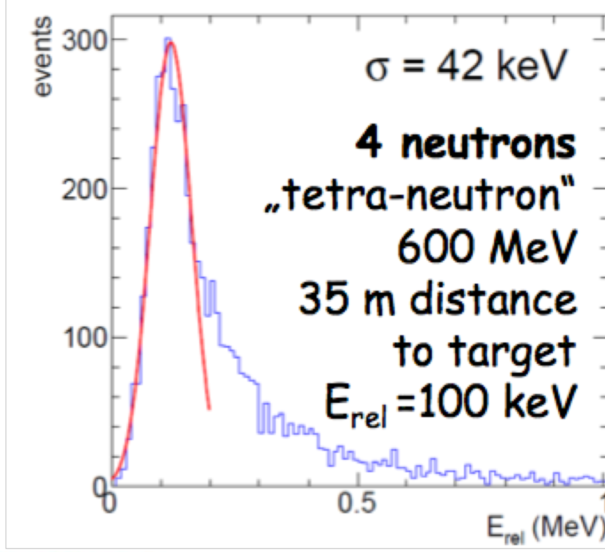
K. Boretzky

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 [MeV]	Eff. [%]
50	79
100	94
150	95
200	91

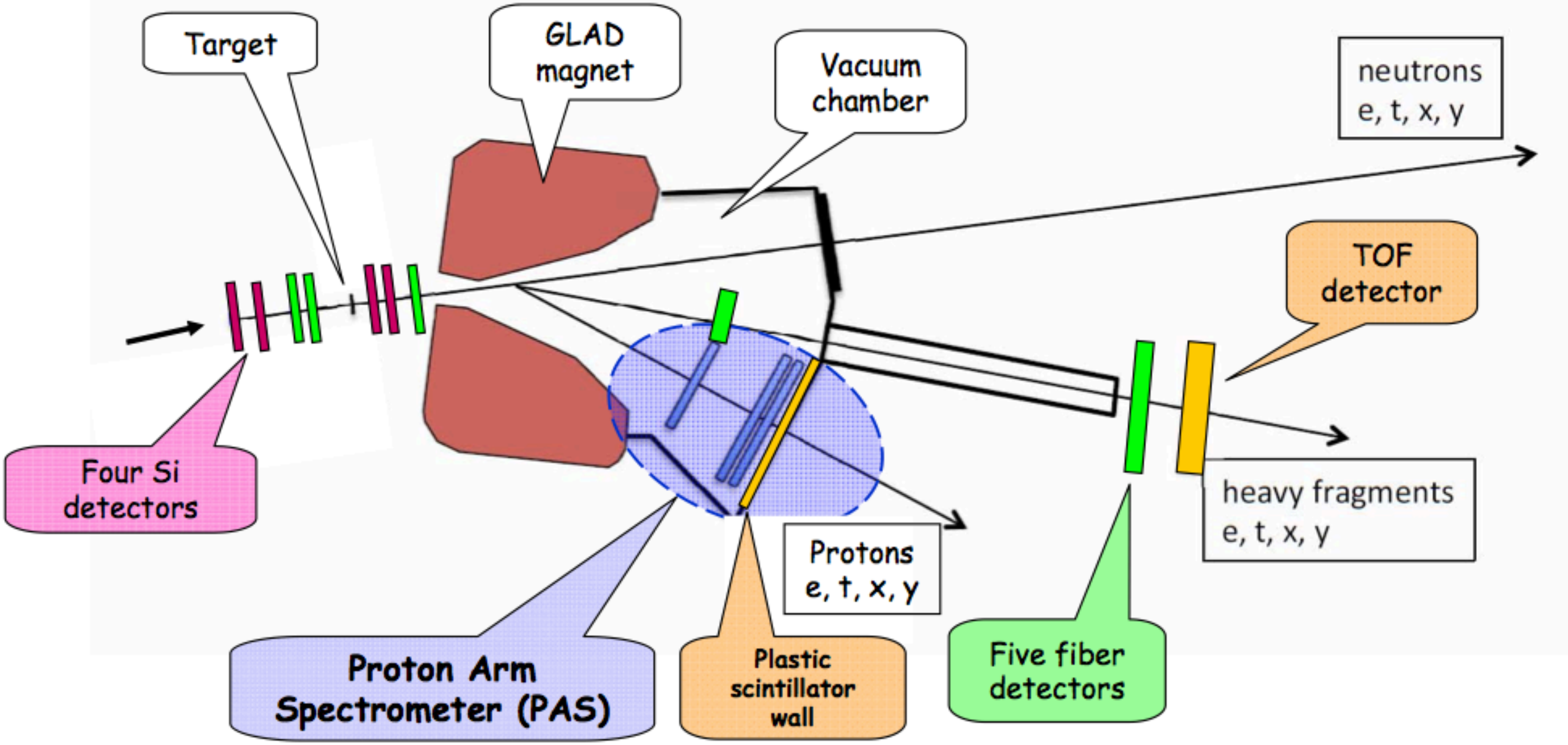
R3B TRACKING SYSTEM

Stefanos Paschalis

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

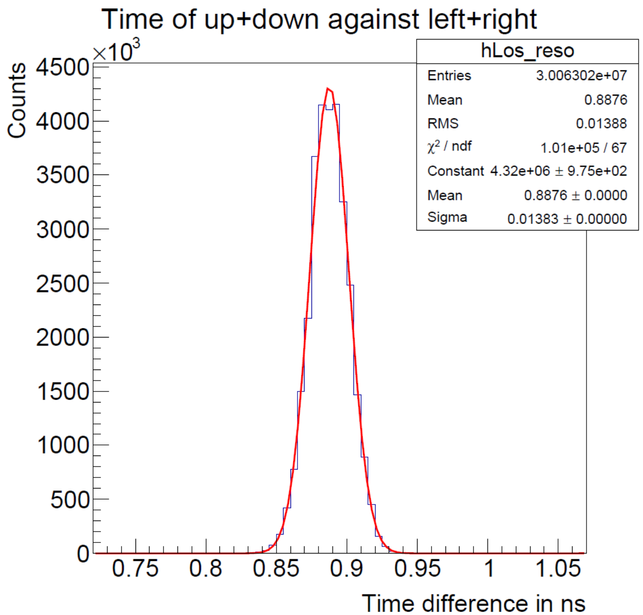
- Energy loss → Nuclear charge Z
- Time of Flight → Mass identification
- Trajectory → Momentum

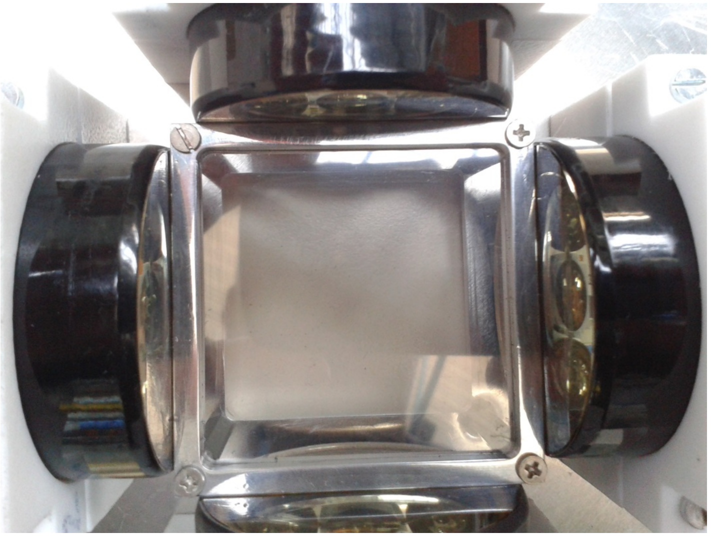
for incoming and outgoing fragments, beam, gammas

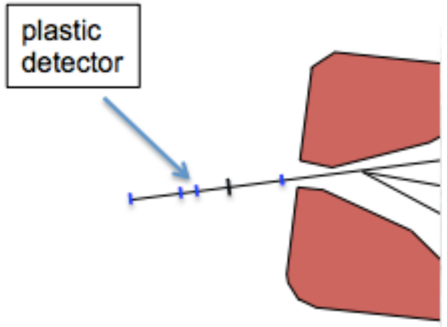


Start-timing detector: PLASTIC SCINTILLATOR FOIL
in-beam time resolution

^{58}Ni @ 500MeV/u







$5x5\ cm^2$

Ham. R9779-20 PM tube

0.5 mm thick

EJ230 plastic scintillator foil

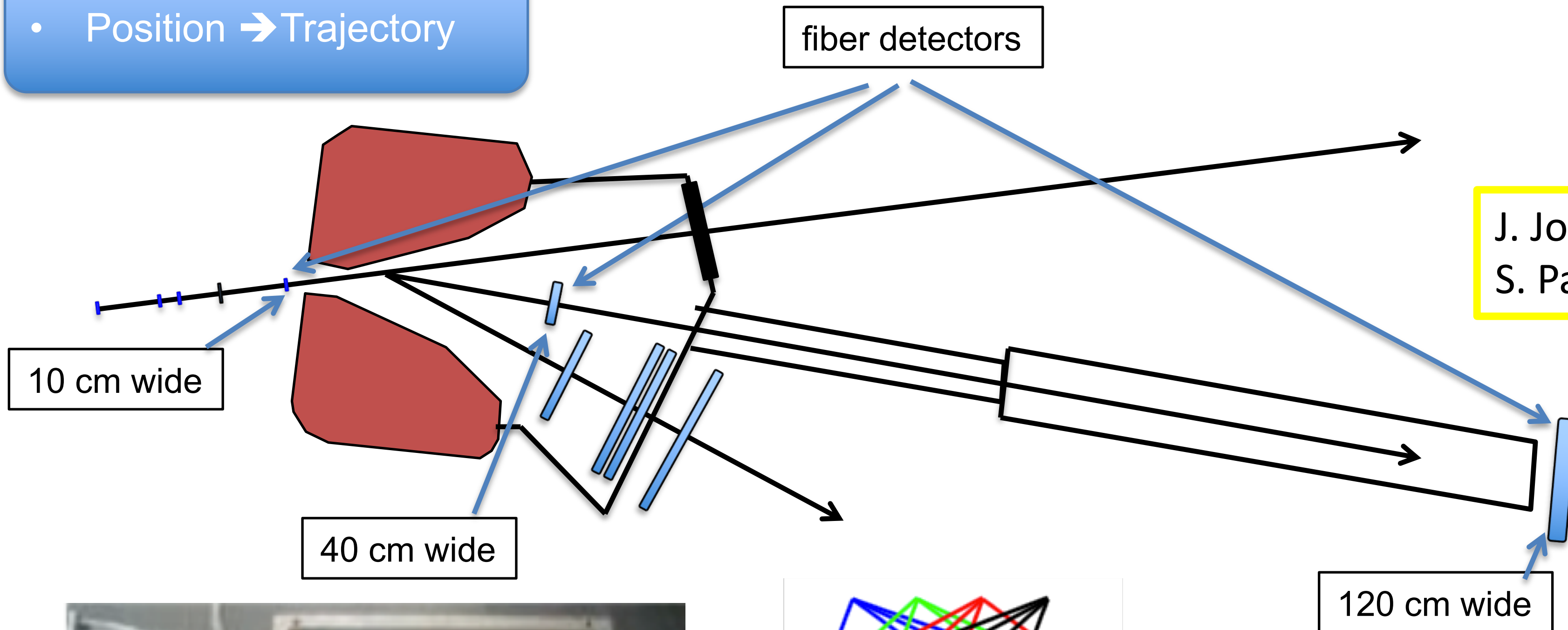
Measured Δt between PM pairs: $\sigma_t = 14$ ps
➔ time resolution for the full detector: $\sigma_t = 7$ ps

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

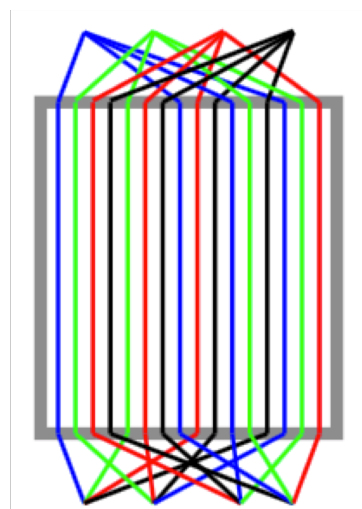
M. Heil

PLASTIC SCINTILLATING FIBERS

- Position → Trajectory



J. Johanssen
S. Paschalis



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

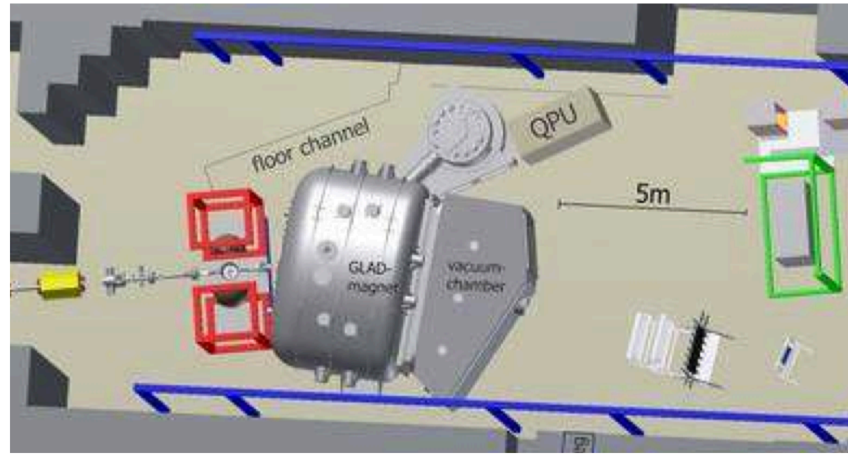
Bundling to reduce the number of channels (32 → 1)

Summary:

Schedule and first experiments @ GSI in Cave C

2014 **20% NeuLAND and 10% CALIFA & Si-Tracker + tracking detector prototypes**
Commissioning run was performed in Q3/2014

2015-16 Construction and installation of detector components



~~2017-18~~ Commissioning of full R3B setup (Cave C)

2019-20

2018-20 Physics runs at GSI (Cave C) (phase 0)

2024 - 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:

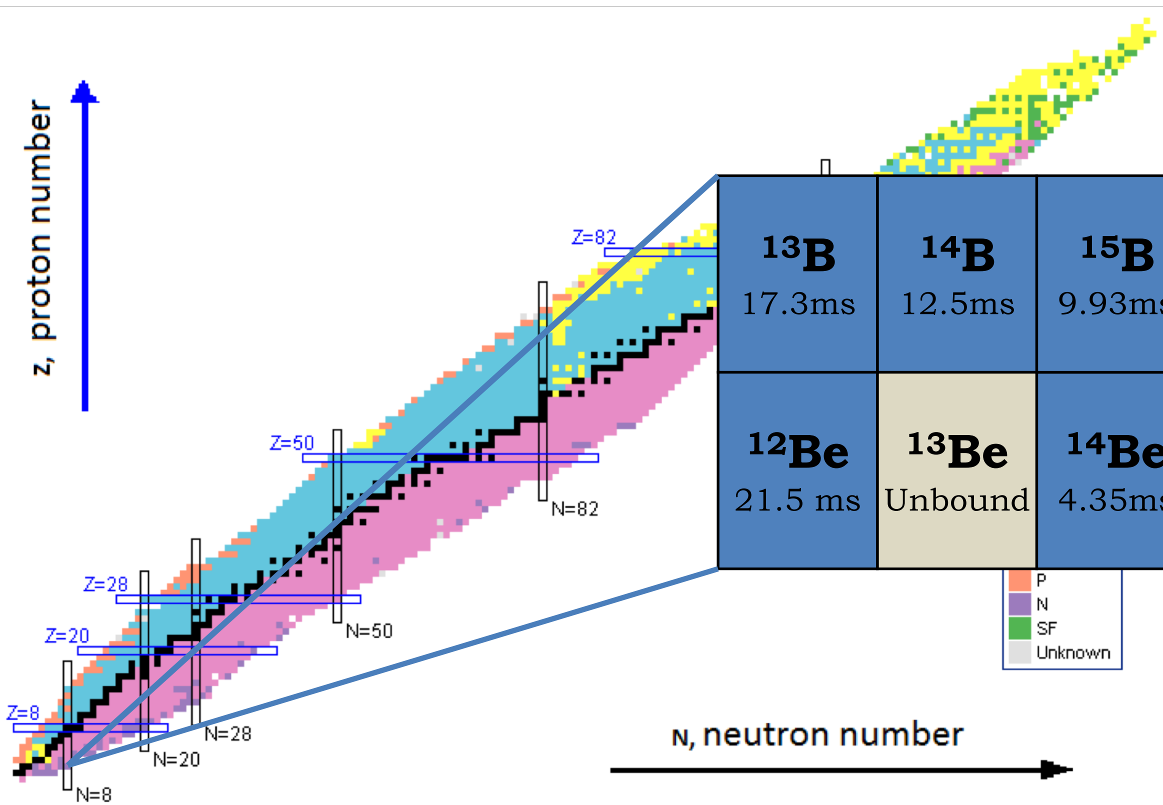
- 4 neutron decays beyond the drip-line and for heavier n-rich isotopes
- Kinematically complete measurements of quasi-free nucleon knockout reactions
- Electric dipole and quadrupole response of Sn nuclei beyond N=82, and of neutron-rich Pb isotopes (polarizability, symmetry energy)
- Fission barriers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

S393 EXPERIMENT

Study of light neutro-rich nuclei (Be-Ne), 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

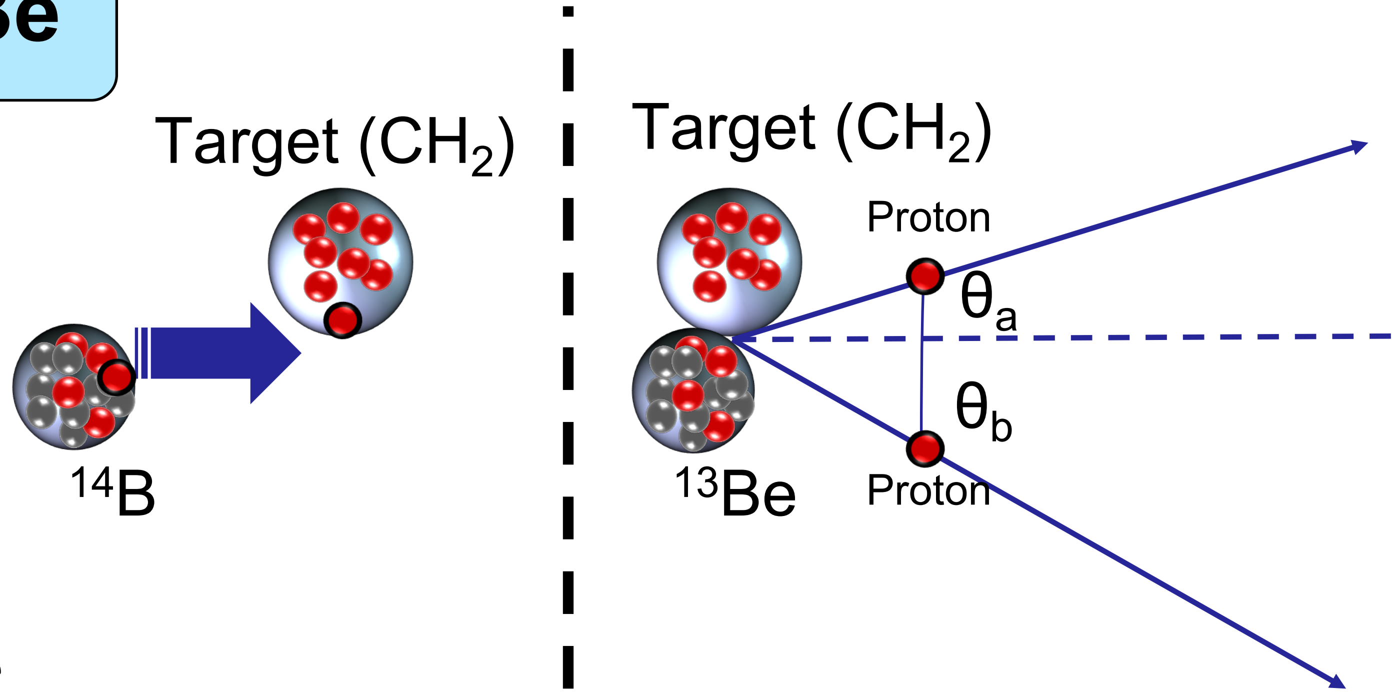
$^{14}B(p,2p)^{13}Be$

- 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:

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

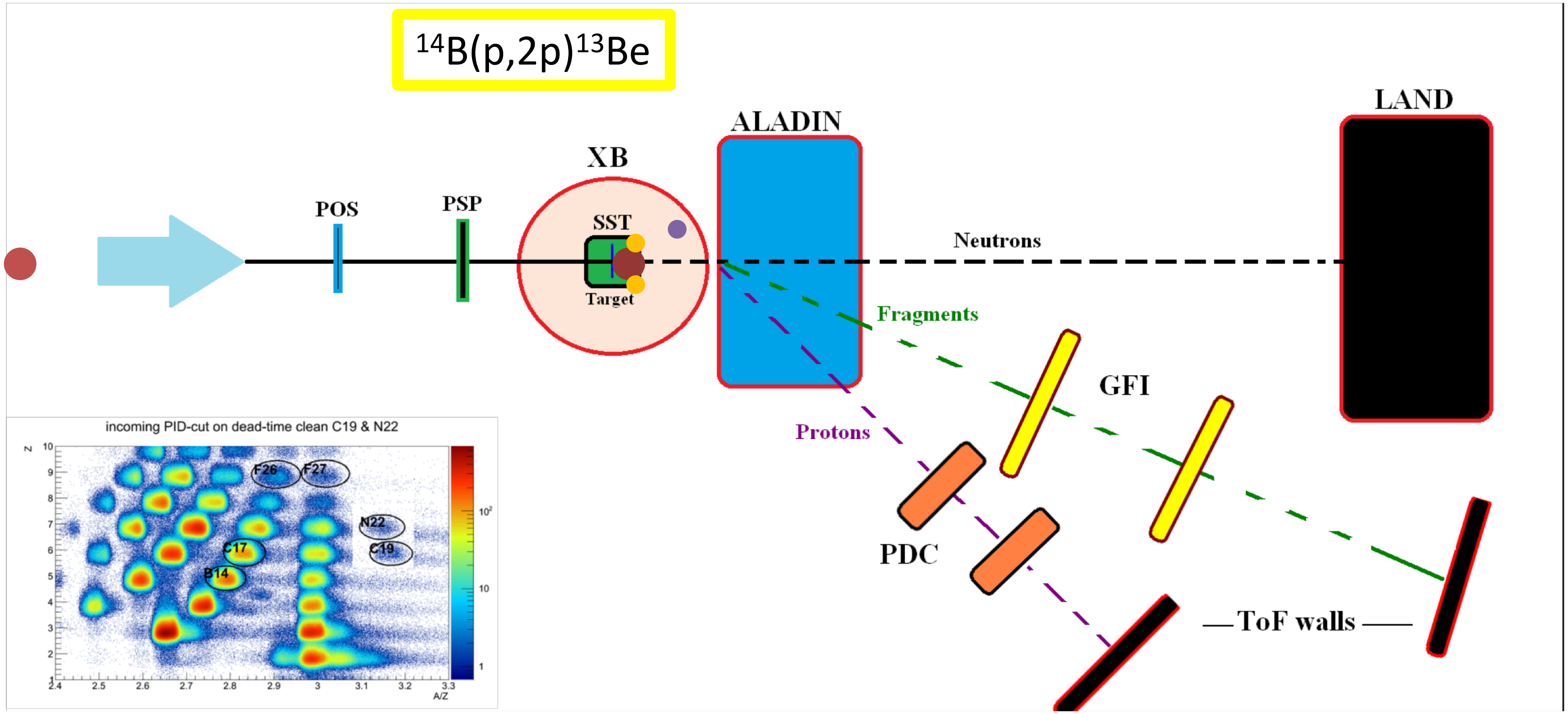
(p,2p), (p,np)



^{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				

Experiment:Cave C

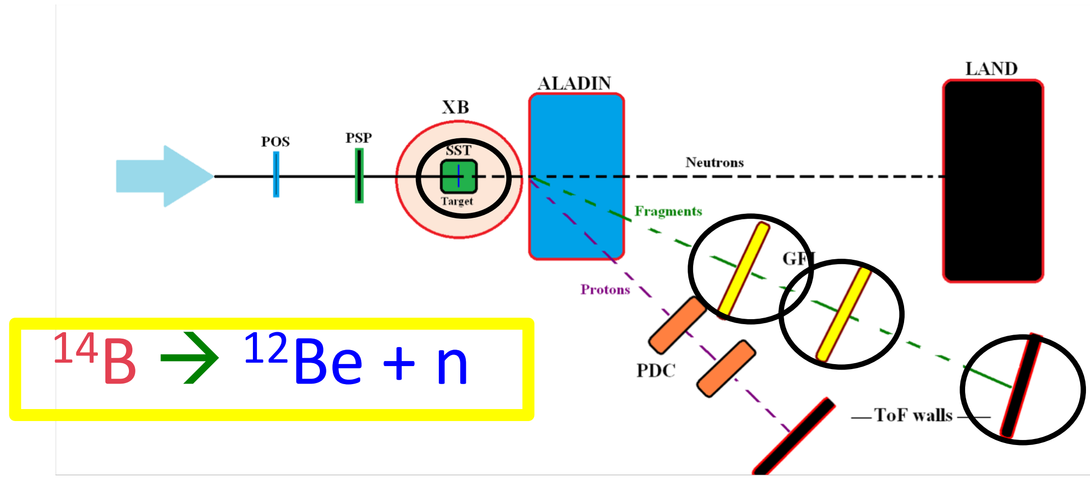
$^{14}B(p,2p)^{13}Be$

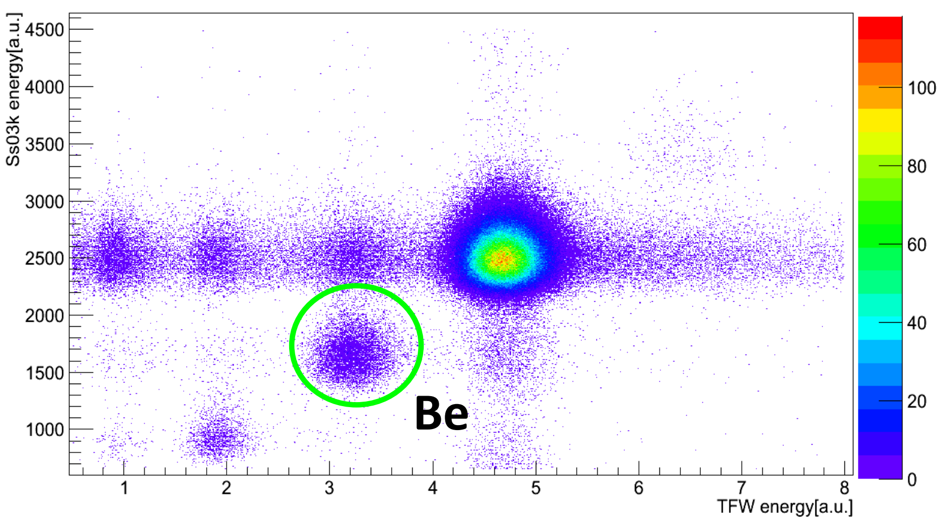


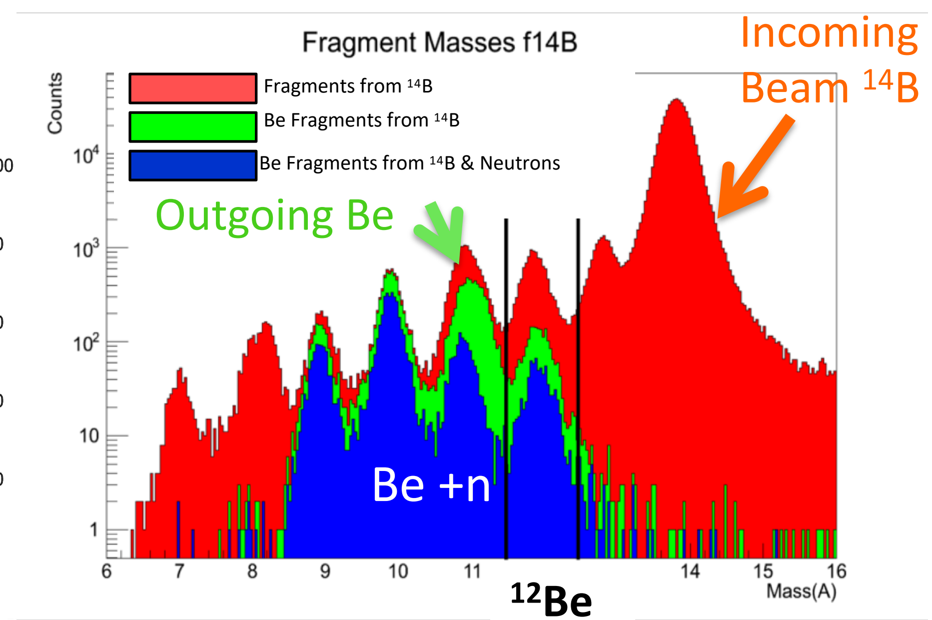
Primary beam	$^{40}Ar^{11+}$ @ 490 MeV/u
Intensity	$6 \cdot 10^{10}$ ions/spill.
Production target	Be 4 mg/cm^2
Reaction target	H, C, empty

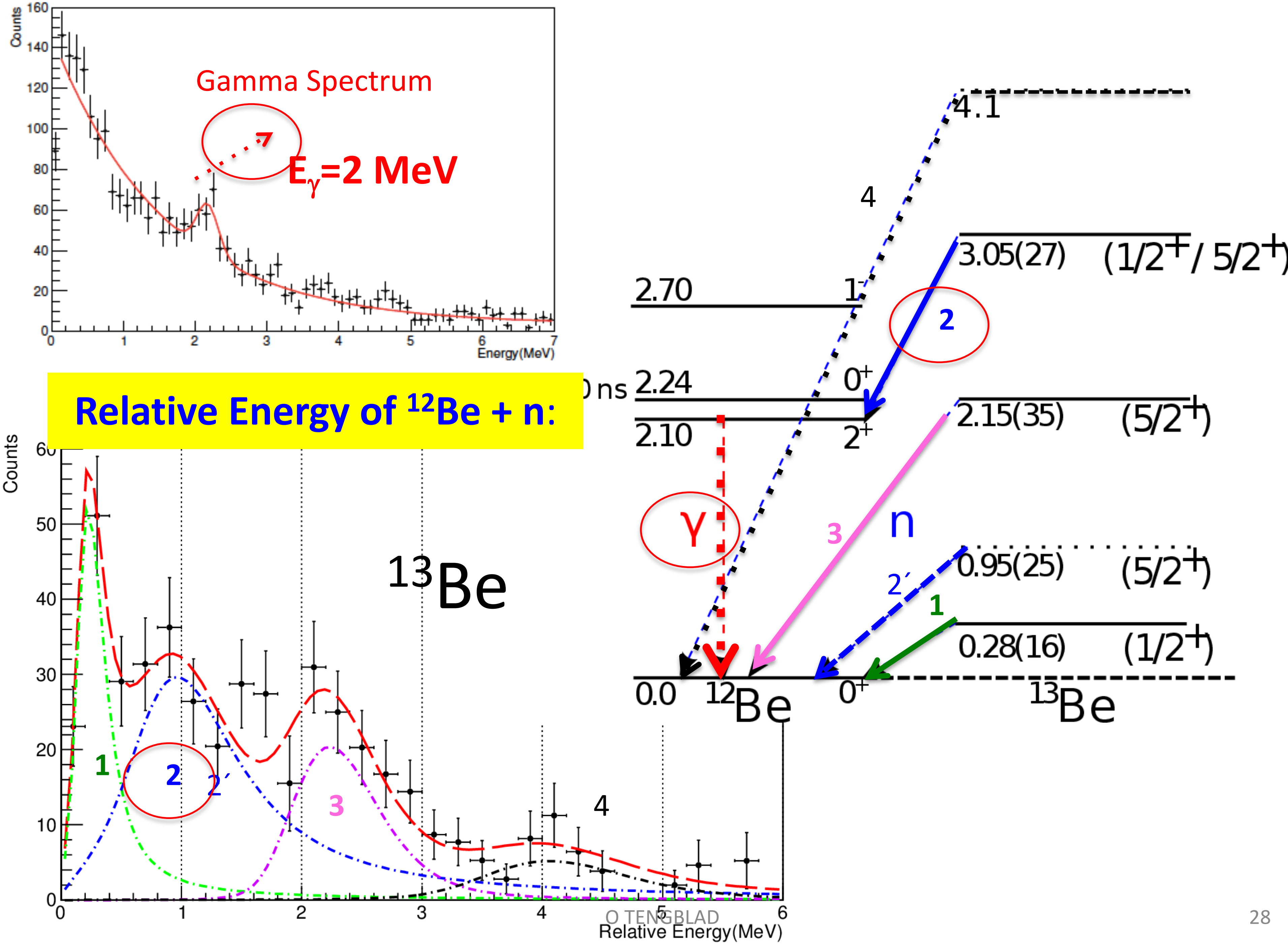
Reaction channel Idenitifcation

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



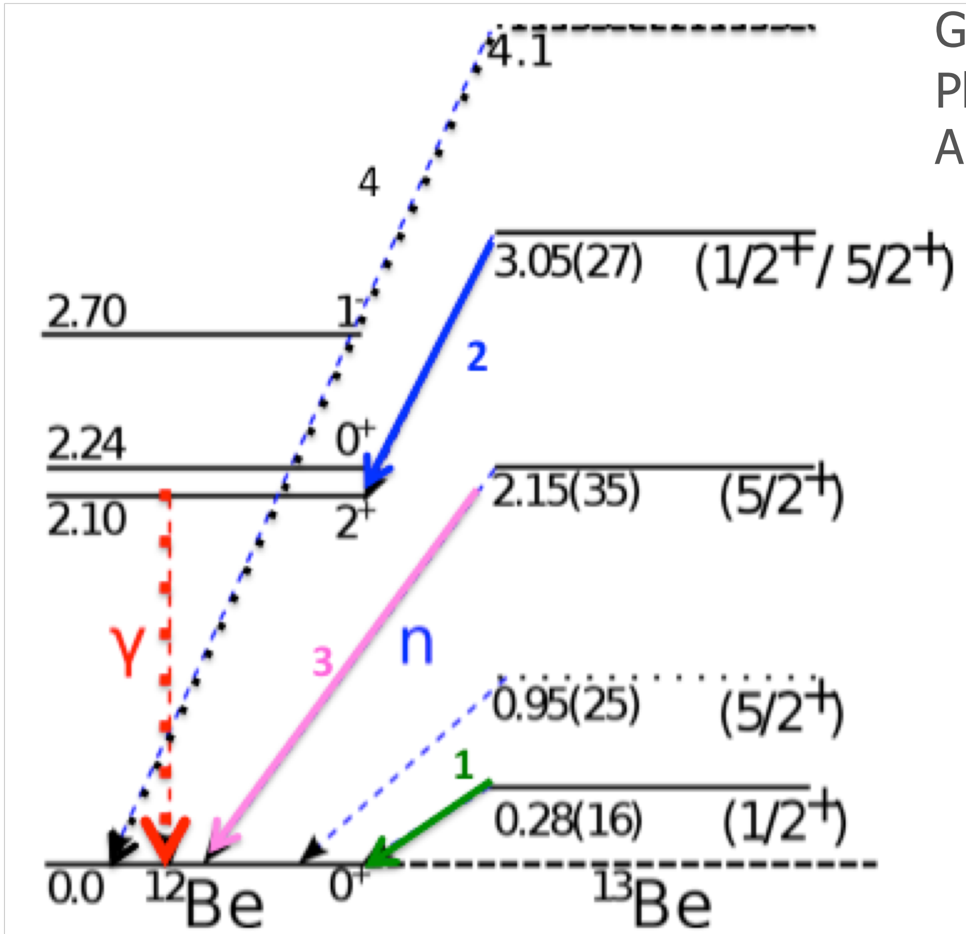





Counts
Gamma Spectrum
Eγ=2 MeV
Energy(MeV)
Relative Energy of 12Be + n:
Counts
13Be
1
2
2´
3
4
Relative Energy(MeV)
4.1
4
3.05(27) (1/2+/ 5/2+)
2.70
1-
2
0+
2.24
2.10
2+
2.15(35) (5/2+)
γ
3
n
0.95(25) (5/2+)
2´
1
0.28(16) (1/2+)
0.0
12Be
0+
13Be

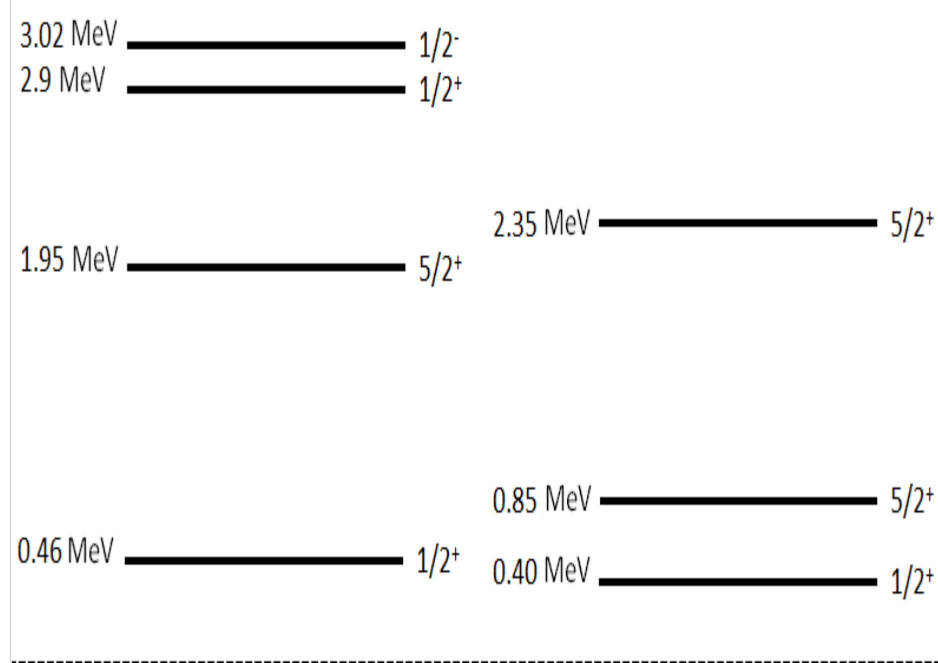
Thesis: 03.07.2015 UCM: Guillermo Ribeiro;
Studies beyond the neutron dripline using quasifree (p,2p) reactions: the case of 13Be.

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



This work

G. Ribeiro *et al.* (R3B Collaboration)
Phys. Rev. C **98**, 024603 – Published 3 August 2018



Y. Aksyutina (GSI)
PHYS REV C 87, 064316 (2013)

G. Randisi et.al. (GANIL)
PHYS REV C 89, 034320 (2014)

$^{14}Be(p,pn)^{13}Be$

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

No γ detection

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		Rhee, Han-Bum
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R3B

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		Gruzinsky, Nikolay
		Inglessi, Alexander
		Khanzadeev, Alexey
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		Krivshich, Anatoly
		Kuznetsov, Viacheslav
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		Maisuzenko, Dmitrii
		Orishchin, Evgeny
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		Vikhrov, Vladimir
		Zhdanov, Andrey
SVN	Josef Stefan Institut Lju	**Vencelj, Matjaz**
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SWE	Chalmers University of Te	**Nilsson, Thomas**
	Members: 6	Johansson, Håkan
		Jonson, Björn
		Thies, Ronja
		Heinz, Andreas
		Lindberg, Simon
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		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

R3B Sponsors of the activity

Programa Nacional de Física de Partículas

GANAS

JAE predoc contracts

Horizon 2020

califa -- Collaboration

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Olof Tengblad
María Borge
Enrique Nacher (IFIC)
Angel Perea
Guillermo Ribeiro

In summary: I have discussed the

R^3B- Reactions with Relativistc 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 2022

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

Thanks for your attention!