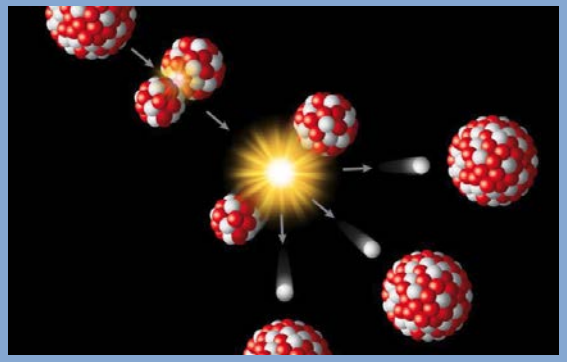
Nuclear Physics with R^3B: Research and Technical challenges

Lola Cortina



1st Joint Workshop IGFAE/LIP, May the 4th 2018

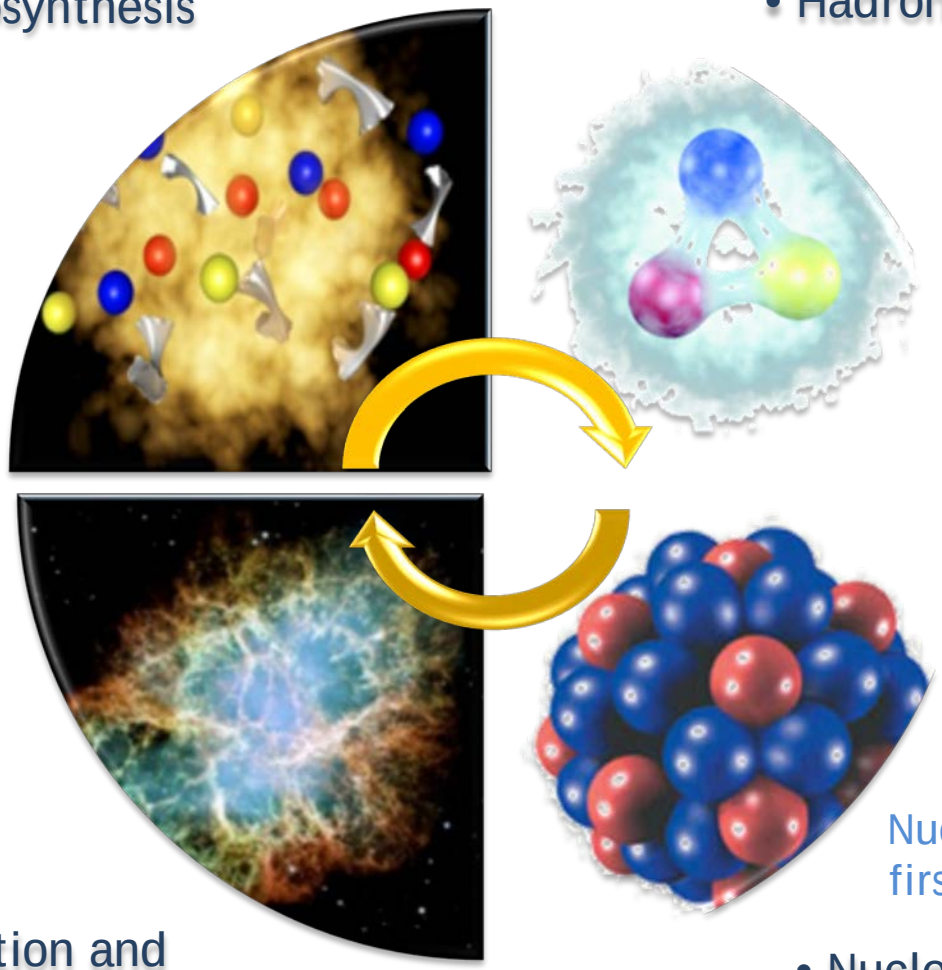
Strongly interacting matter

- Big-bang nucleosynthesis

Equation of state of nuclear matter

- Hadron composition

Hadron structure and non-perturbative QDC



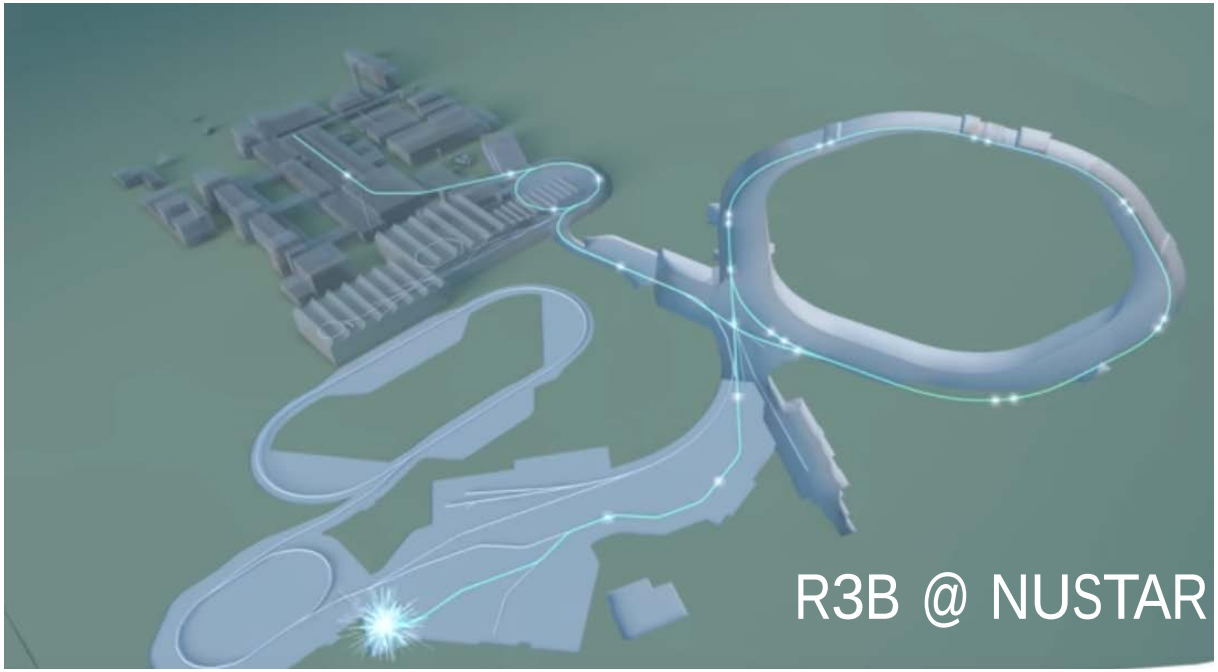
The origin of elements in Universe

- Stellar evolution and nucleosynthesis

Nuclear force from first principles

- Nucleons in Nuclei

Physics with relativistic rare beams



Relativistic beams

→ in-flight production and detection of secondary beams
→ nuclear fragments are forward focussed
→ simplified description of the reaction mechanism

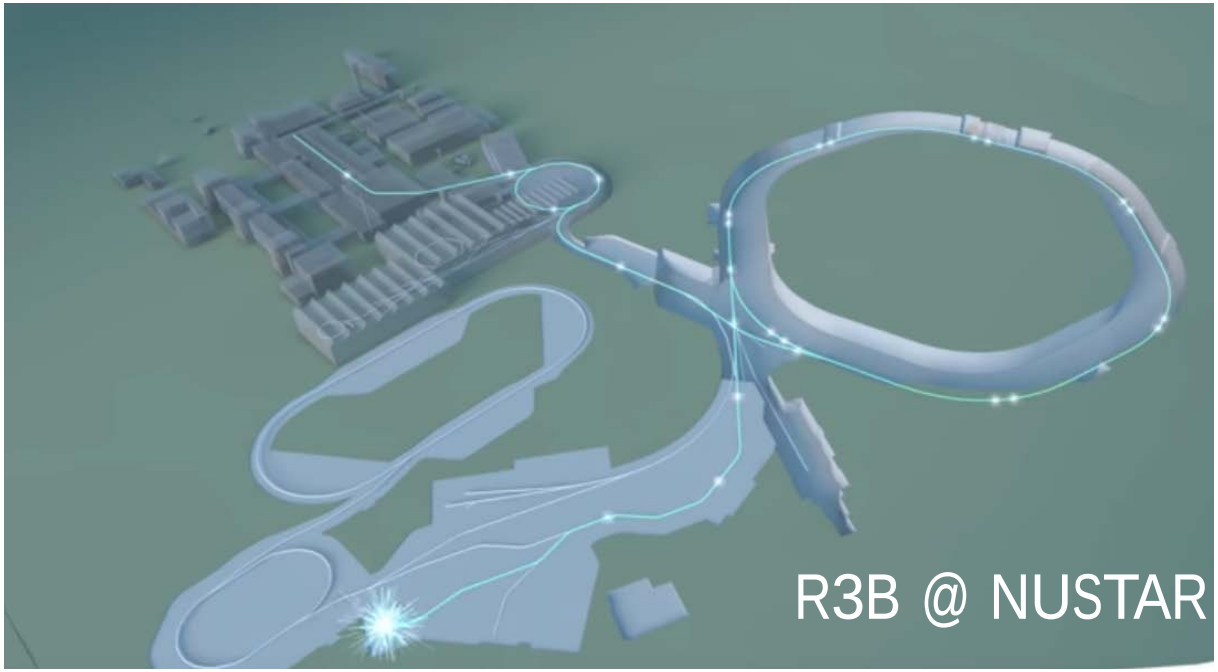
Reactions with Relativistic Radioactive Beams

→Secondary beams at 700 A.MeV
→Fixed target reactions
→Large Acceptance Dipole Magnet
→Powerful detector system: beam, fragment, gamma, Light charge particles and neutrons

Versatile program

→ NN correlations and the nuclear force
→ nuclear structure far from stability
→ nuclear dynamics: fission
→ EoS for high-density neutron-rich matter
→ in-medium excitation of baryon resonances
→ origin of the heavy elements in Universe

Physics with relativistic rare beams



FAIR Gain Factors

Primary beam intensity:
100-1000

Secondary beam intensities
Radioactive nuclei:
up to factor **10,000**

Beam energy: Factor 15

Reactions with Relativistic Radioactive Beams

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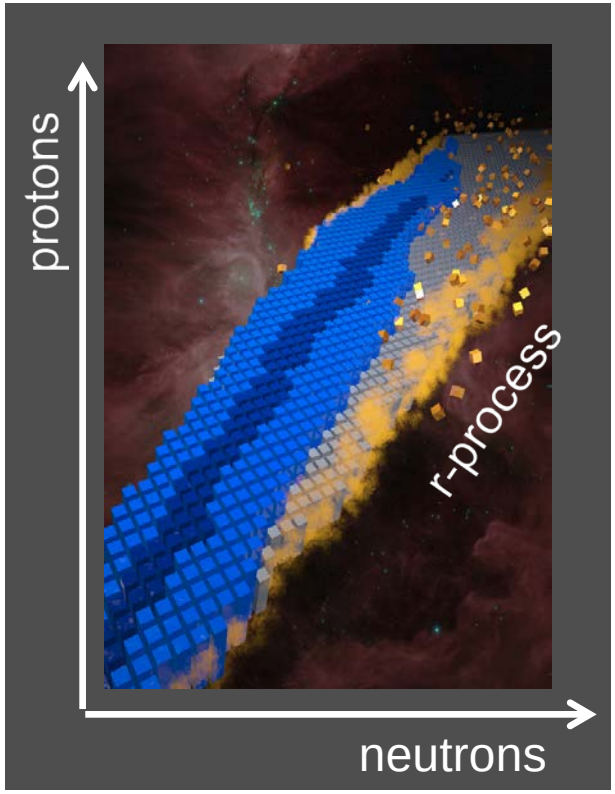
Physics case

Kilonova : Thermal glow from the radiactive decay of heavy sotopes

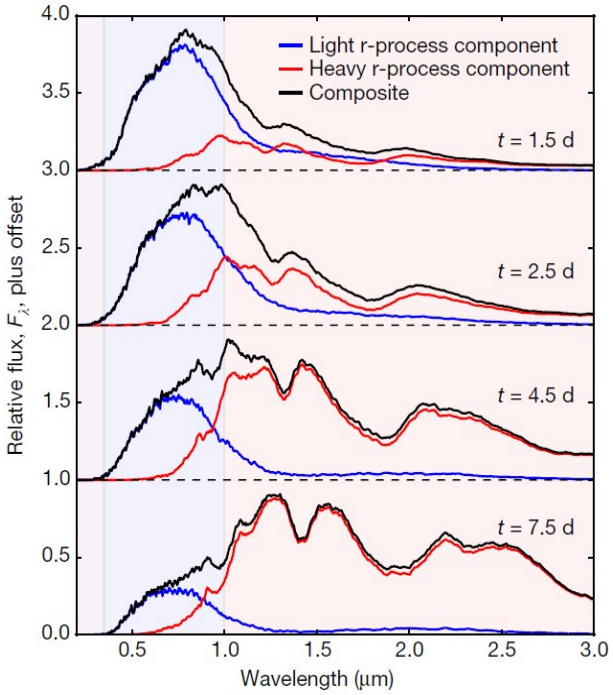


LETTER

doi:10.1038/nature24453

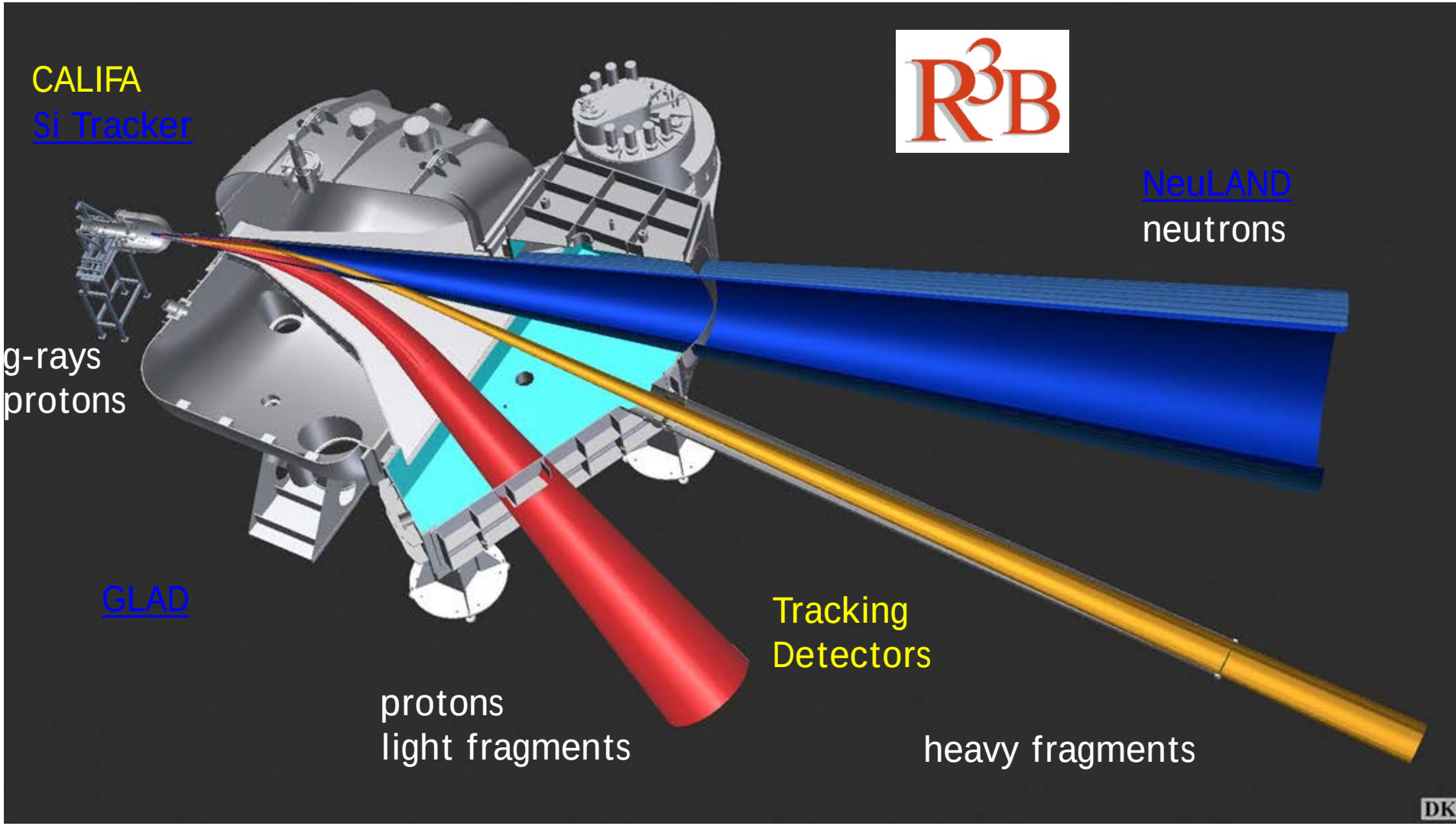
Origin of the heavy elements in binary neutron-star mergers from a gravitational-wave event

Daniel Kasen[1,2], Brian Metzger[3], Jennifer Barnes[3], Eliot Quataert[1] & Enrico Ramirez-Ruiz[4,5]



Discovery of the electromagnetic counterpart to the GW170817
→ Provides the first evidence for r-process nucleosynthesis.

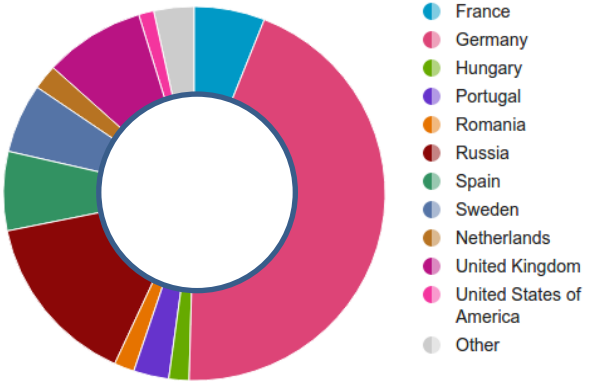
R³B Layout

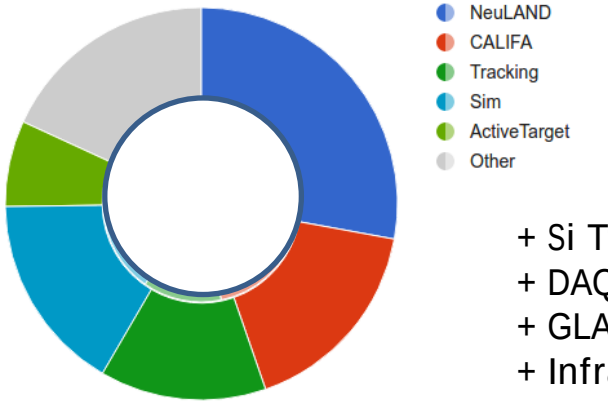

CALIFA
Si Tracker
NeuLAND
neutrons
g-rays
protons
GLAD
Tracking
Detectors
protons
light fragments
heavy fragments
DK

R³B in numbers

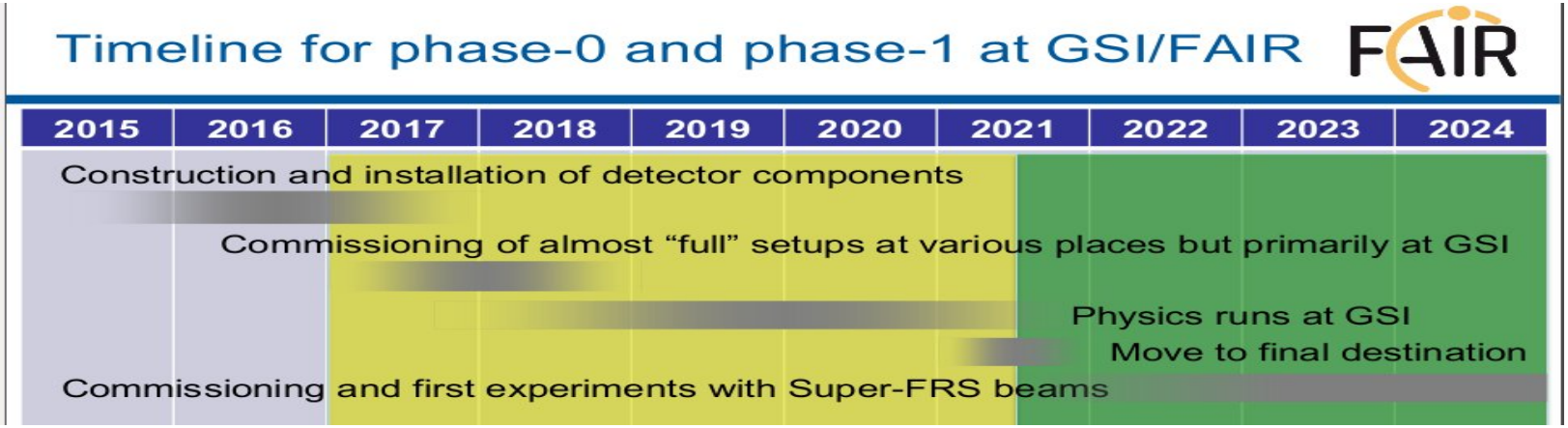
- Largest nuclear physics collaboration
- Working groups are the collaboration motor

•~ 250 collaborators
•~ 15 countries
•~ 50 Institutes





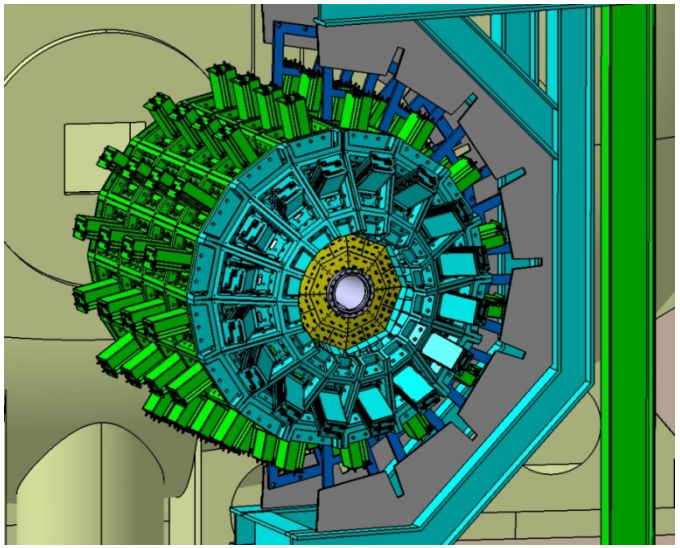
+ Si Tracker
+ DAQ
+ GLAD
+ Infrastrucure



CALIFA

Calo. Spect.

Photo Peak Eff.	40% (up to Eγ=15 MeV projectile frame)
Calorimeter for HE LCP	200-700 MeV in lab system
ΔE/E	~5-6% (FWHM at Eg=1 MeV) , ~ 3% forward
LCP resolution	~2% (stopped particles), ~ 5% (punch through)

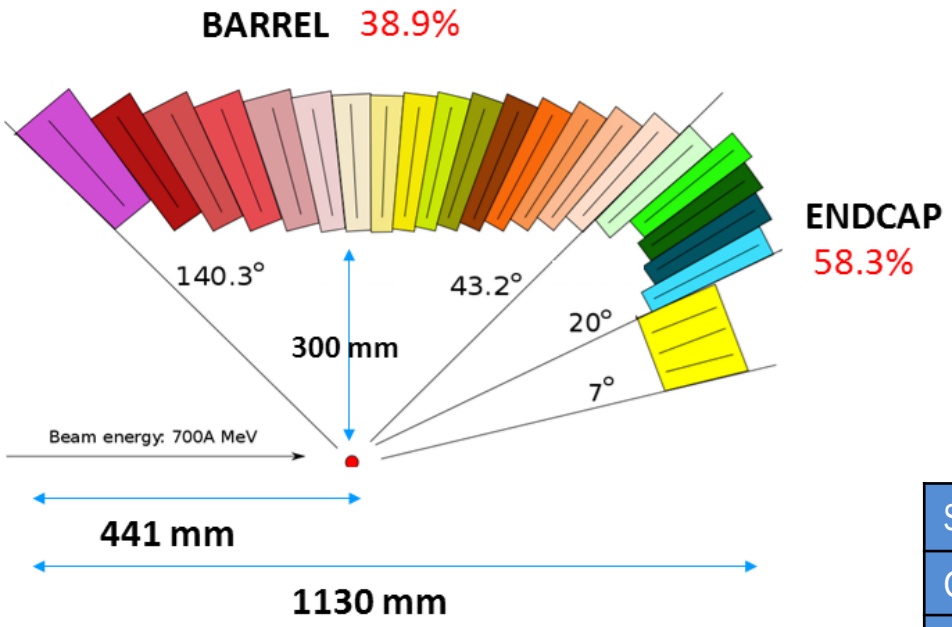


Under construction

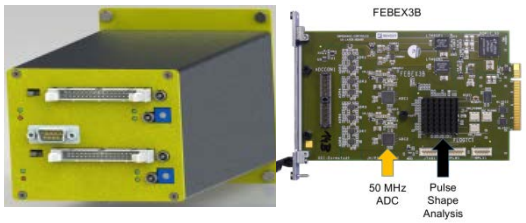
Working Group

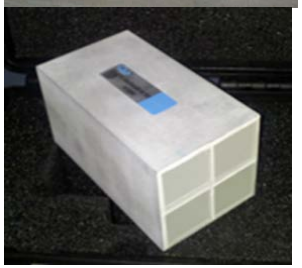
-USC IEM, Uvigo Spain
-U Lisboa LIP, Portugal
-ULund, Chalmers Sweden
-TUM, TUD Germany
-Dubna Russia

CALIFA



- External structure 3.5 x 4 m
- Detector volume ~ 1.3 m^3
- Detector weight ~ 2.5 Tm
- 2528 detection units





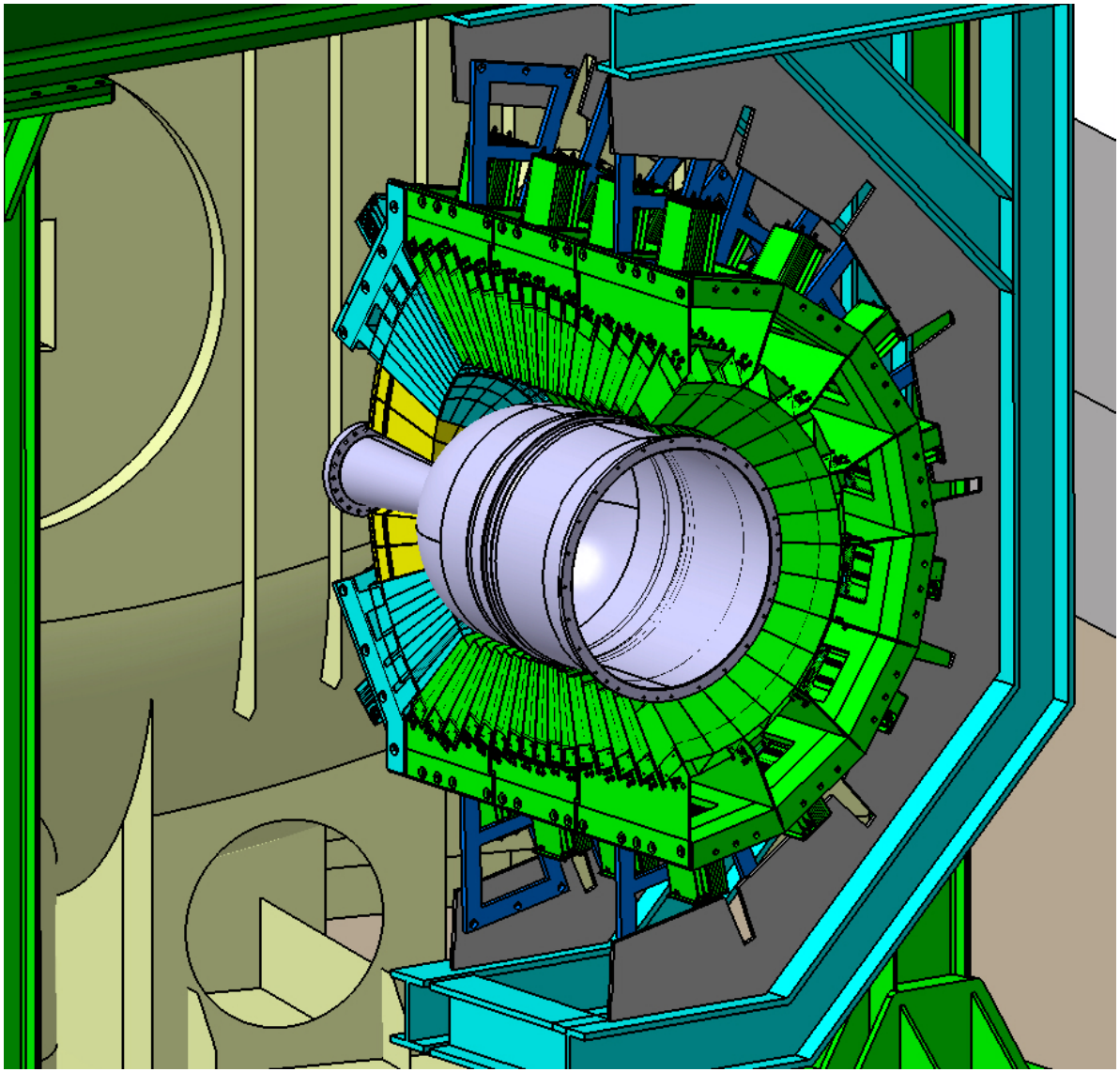
Febex4 → ADC @ 100 MHz

DRS4 → 1 GHz ADC

	Barrel	Endcap	
		iPhos	CEPA
Scintillator	CsI(Tl)	CsI(Tl)	LaBr/LaCl
Geom.	11	16	6
Crys. Len (cm)	15-22	22	4/7
Polar cov.	7-20º	20-43º	43-140º
Read-out	LAAPD	LAAPD	PM/SiPM
Dete.chan.	1952	480	96
Elec. chan.	1952	960	96
Weight (Kg)	~ 1500	~ 550	~ 50
Volume (cm^3)	285.000	90.000	11.000

CALIFA

CALIFA



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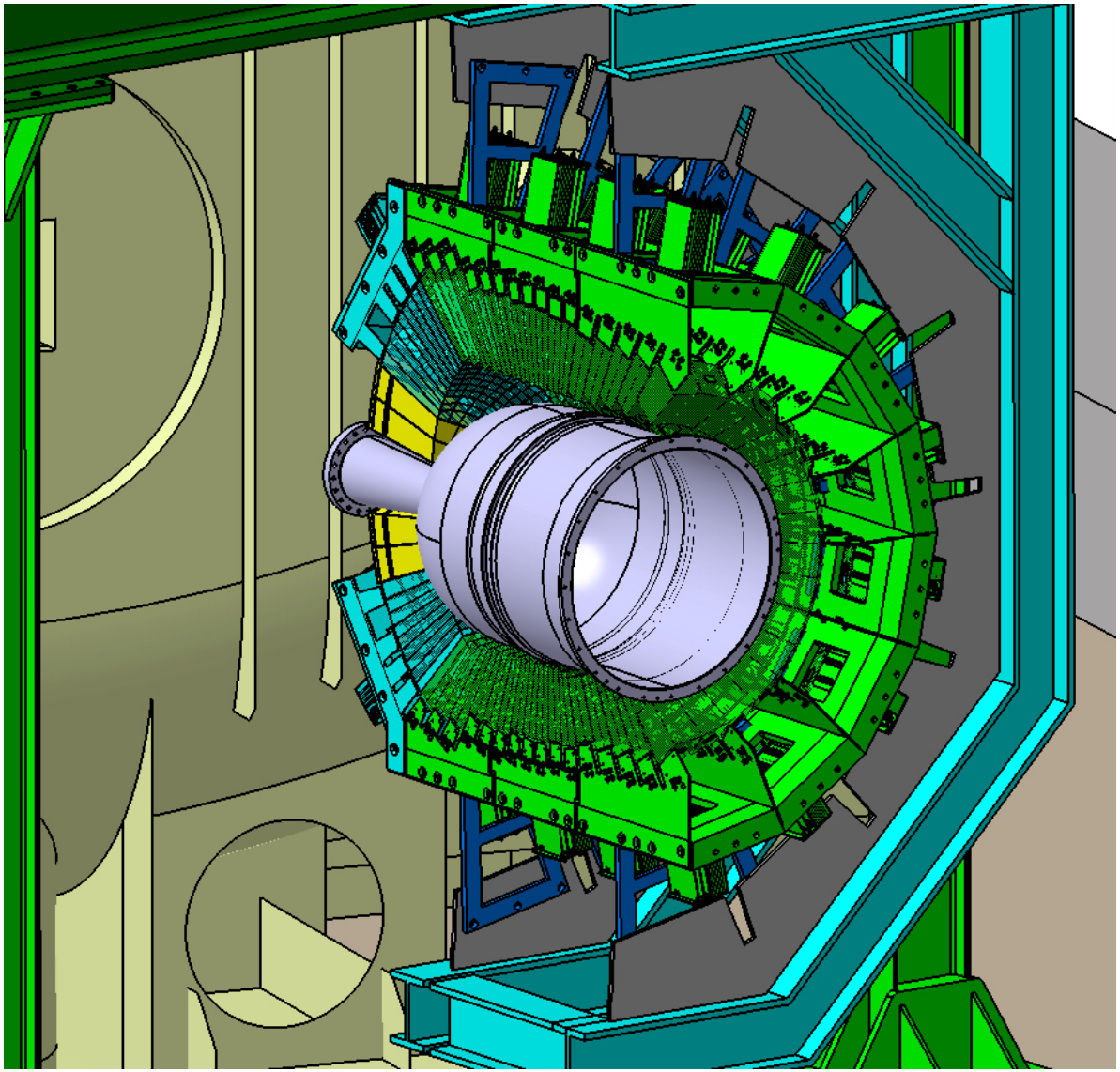

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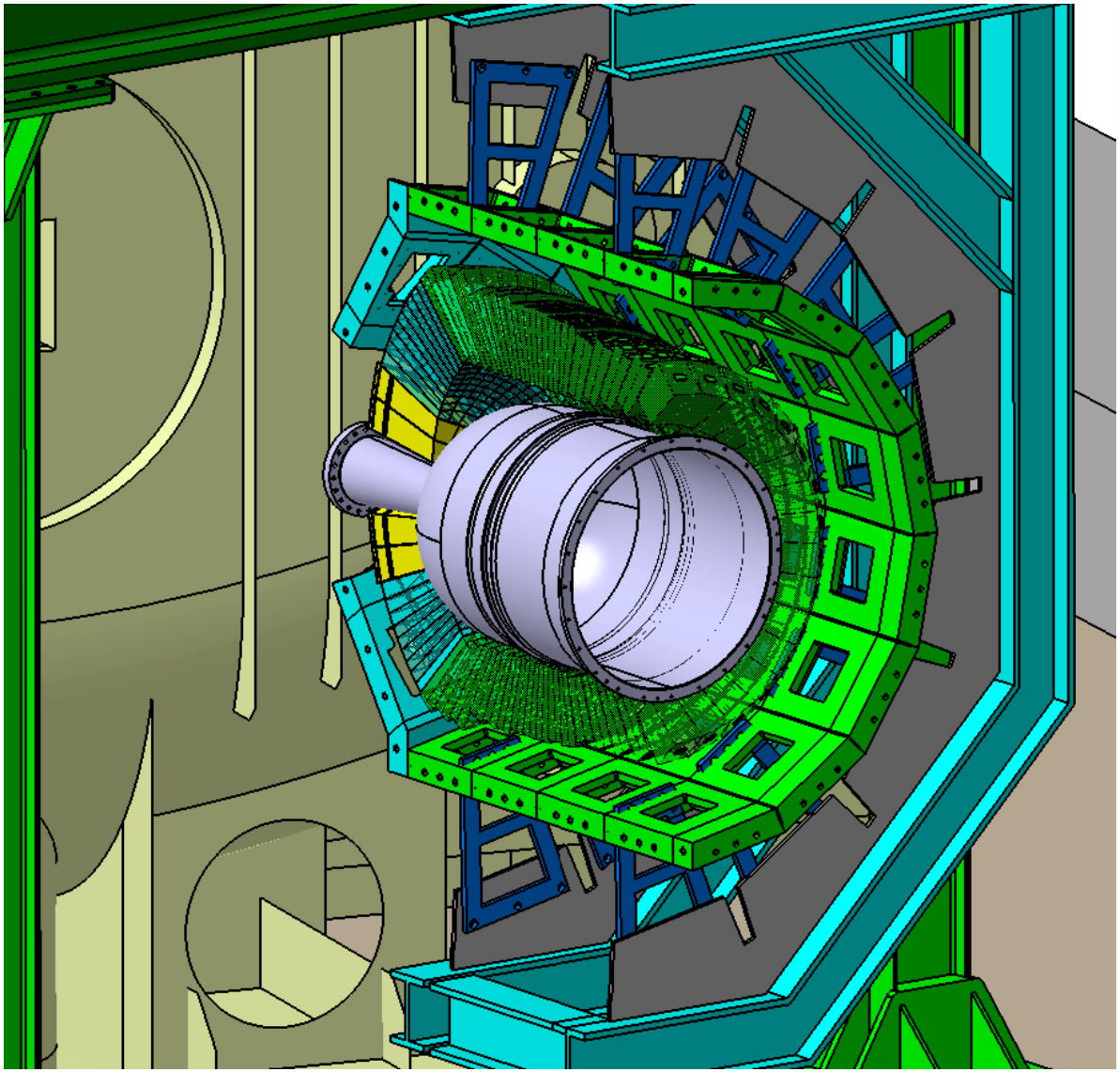
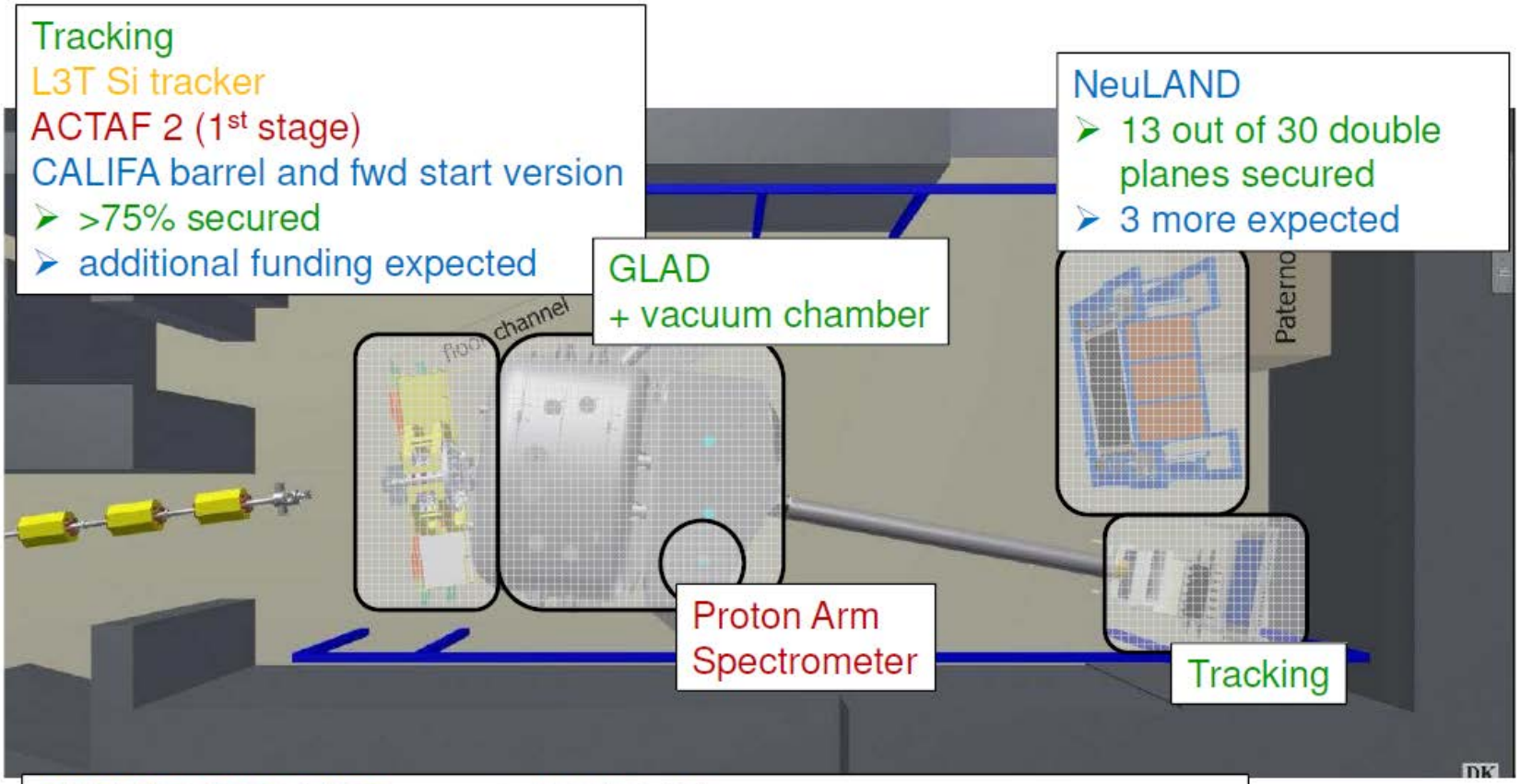


FAIR Phase-0

To R3B CAVE Phase 0 (2018)



NUSTAR-DAQ (TDR accepted 02/2018)
-Time stamps (first implementation)/local trigger logics/readout libraries
-Online analysis R³B-Root ← FAIR-Root

R3B Cave Infrastructure

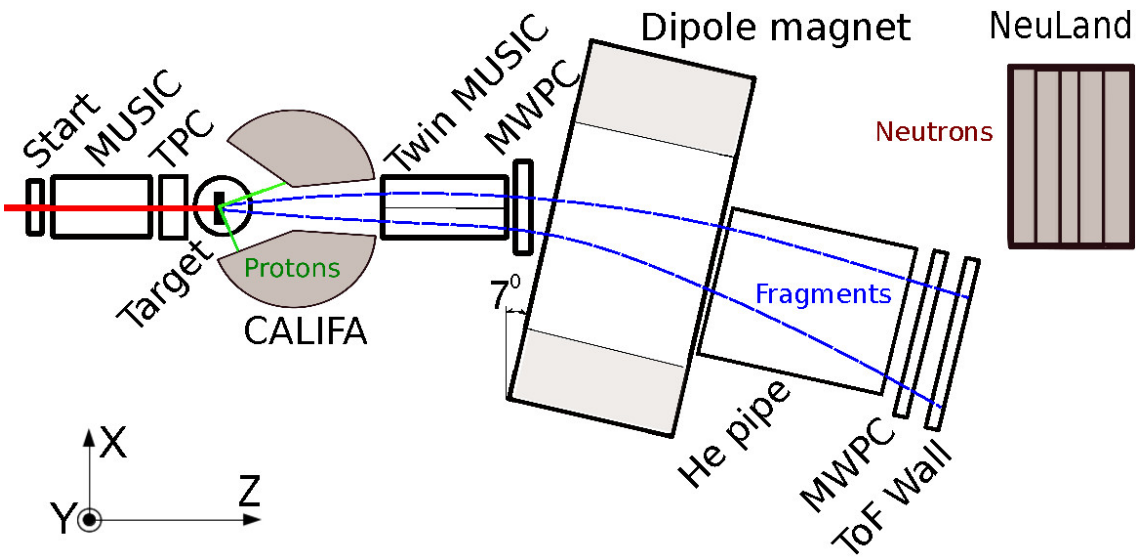
R3B Experiments approved

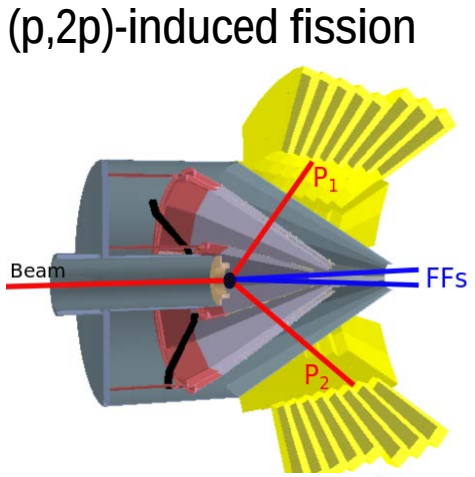
PAC call June 2017
R3B had a very good succesful rate

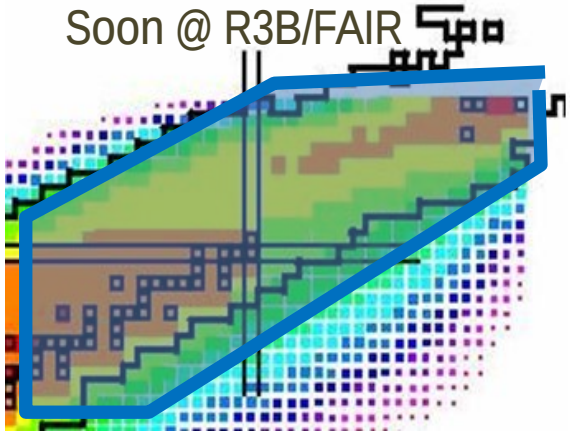
Scheduled	Experiment
October 2018	**S444:** Commissioning of main R^3B detectors
November 2018	**S473:** Constraining the energy-density functionals and the density- dependence of the symmetry energy by measurements of accurate cross-sections
November 2018	**S454:** Studying the astrophysical rate of 12C(a,g)16O via Coulomb dissociation
2019	**S455:** Fission investigated with relativistic radioactive beams and the SOFIA/R3B setup
2019	**S442:** Study of multi-nucleon configurations in nuclei towards the dripline
2019	**S467:** Single particle structure of n-rich Ca isotopes: shell evolution along Z=20

S454: GENP research programme

Most complete fission experiments coupling R3B + SOFIA





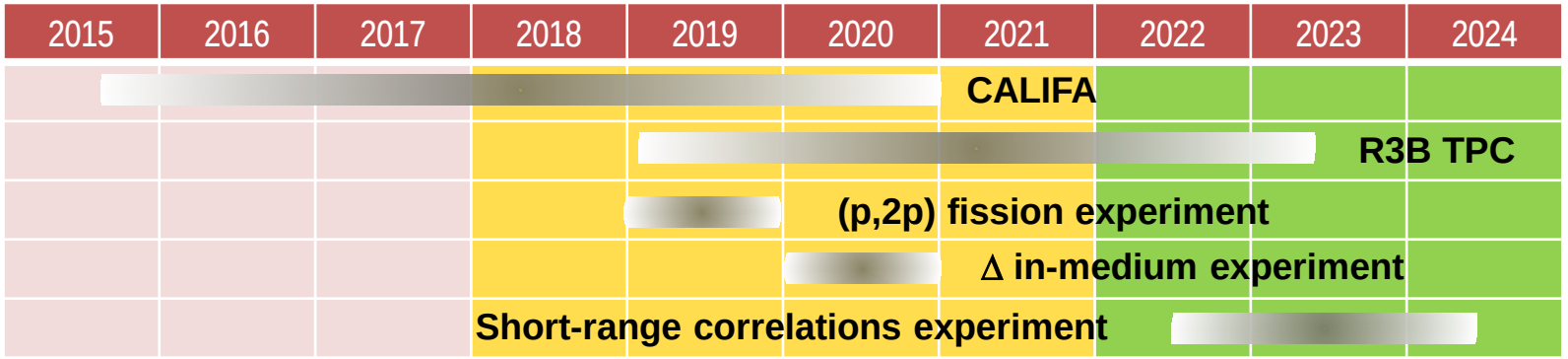


- ✓ Characterization of the fissioning nucleus (A, Z, E*)
  - → (p,2p) with CALIFA+tracker
- ✓ Characterization of the fission fragments (A, Z, TKE, n)
  - → SOFIA + NeuLAND

J. Benlliure and J.L. Rodríguez, proposal approved by the GSI/FAIR PAC

Conclusions

- R3B@FAIR offers unique opportunities to investigate neutron star matter as expected to participate in binary neutron star mergers nucleosynthesis.
- GENP/IGFAE has a large impact in the experiment: spokesperson (D. Cortina), simulation and data analysis WG convener (H. Alvarez), leading physics runs (J. Benlliure)
  - Physics interests: structure of nuclei far from stability, fission, Eos of asymmetric nuclear matter….
  - Instrumentation: CALIFA (25%), future TPC under consideration
  - Software development: R3BRoot (discussed in detail by H. Alvarez)



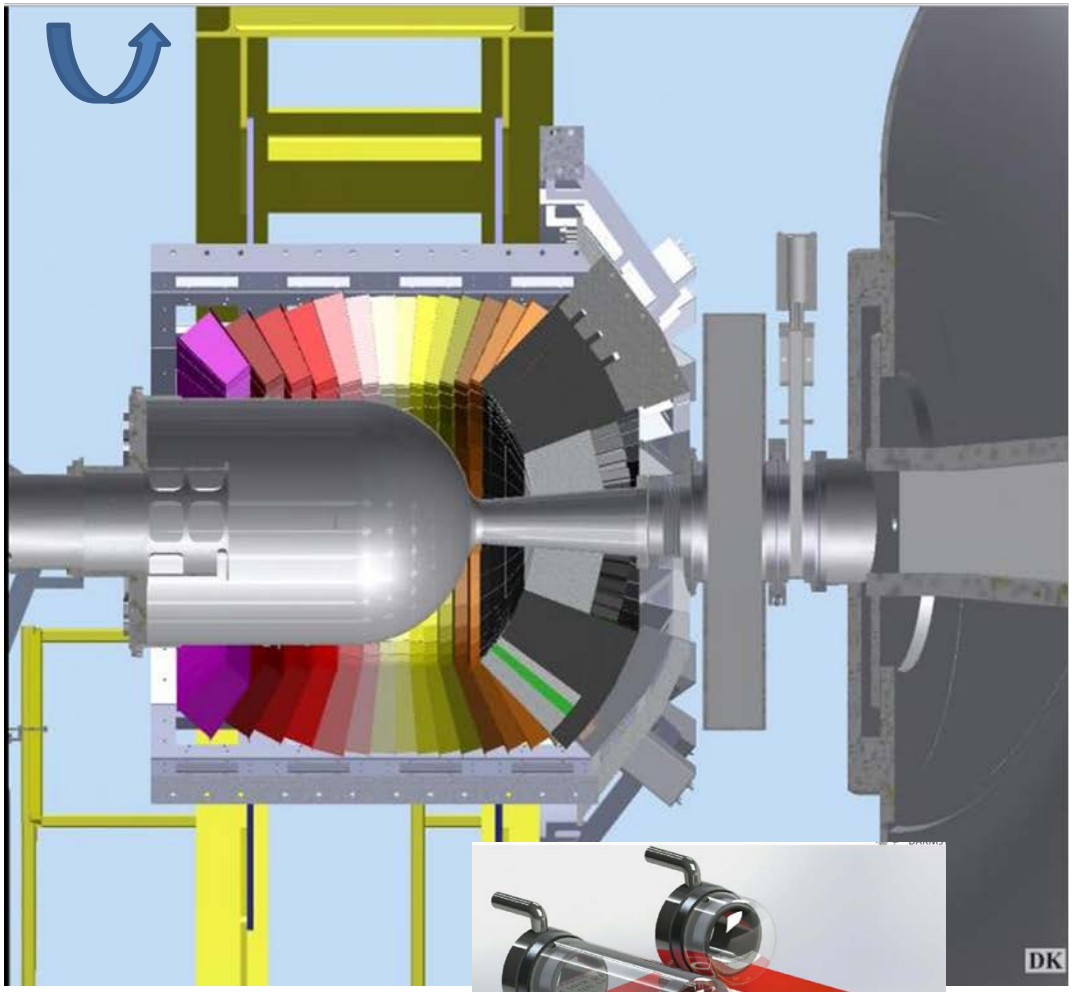
GLAD

Large aperture: horizontal (entrance: 80 cm, exit: 1,2 m), vertical (entr. 1 m, exit 4 m)

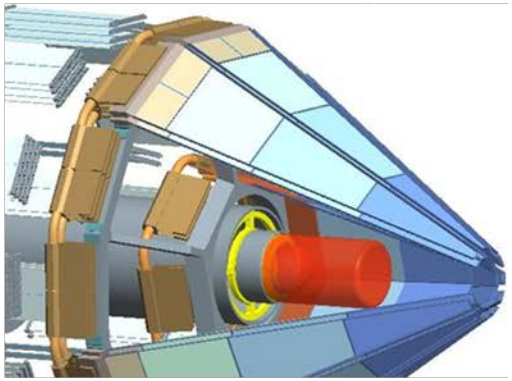
Superconducting magnet: 5 Tm (fringe field at 30 cm 20 mT)

Dimensions: length 3,5 m; width 7 m; heigth 4 m; weight 50 Tons

Target Area



Si - Tracker



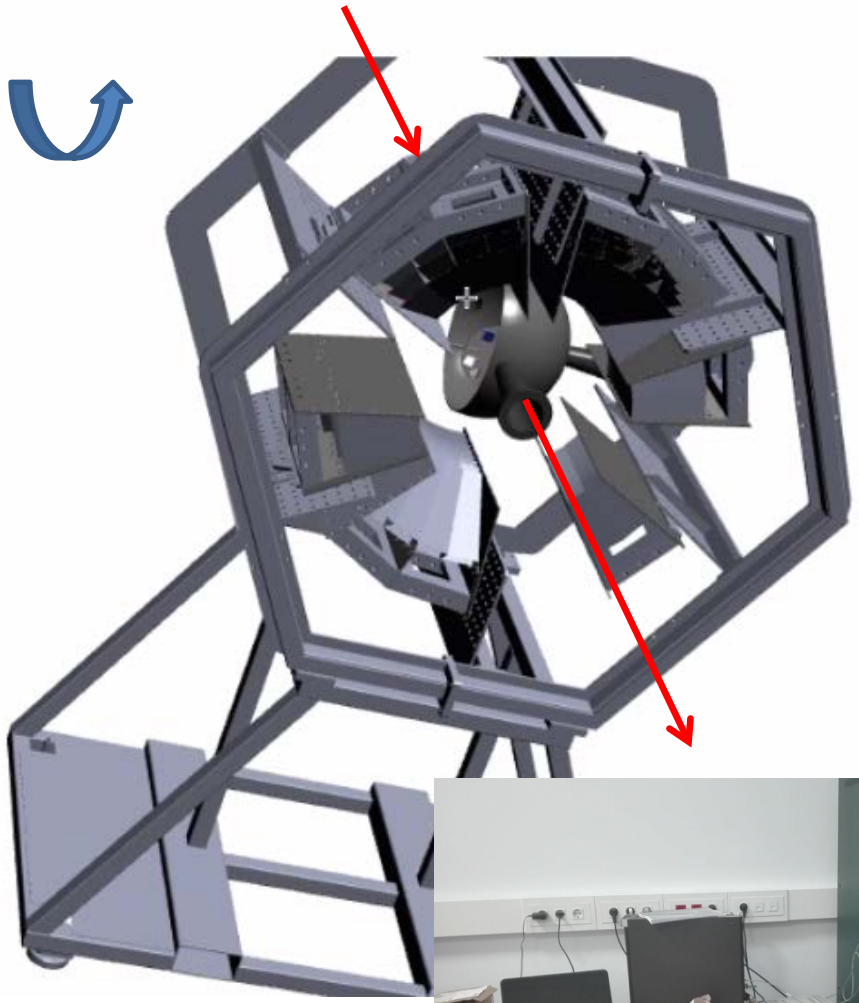
- 18 detector ladders in two conical layers 6+12.
- Strip pitch 50 mm, strip width 38 mm.
- Sensitive area 5600 cm^2.
- 912 ASICs equi. 116736 channels.
- Operated in UHV

NeuLAND Double Plane

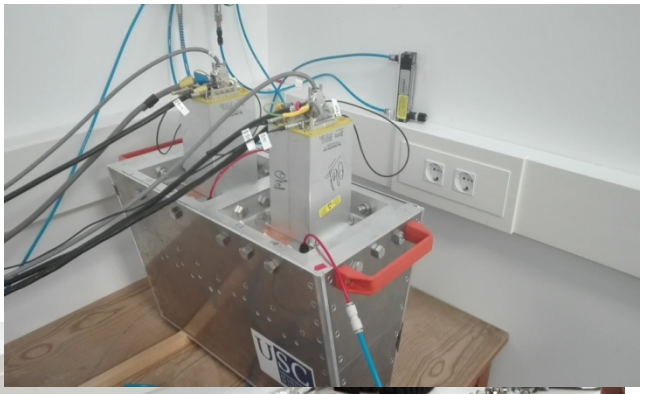
Efficiency 0.2-1.0 GeV n	**> 90%**
Multi-hit	Up to 5 n
Invariant mass resolution	ΔE < 20 keV at 100 keV above threshold

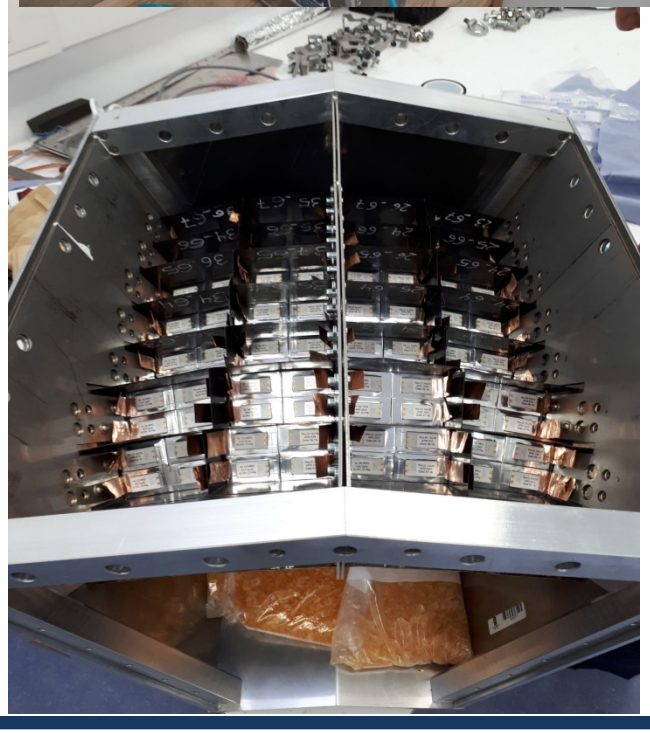
-full active detector using RP/BC408
-face size 250x250 cm^2
-active depth 300 cm
-3000 scintillator bars + 6000 PMTs
-32 tons
-$\sigma_{x,y,z} \approx$ 3cm and $\sigma_t <$ 150 ps

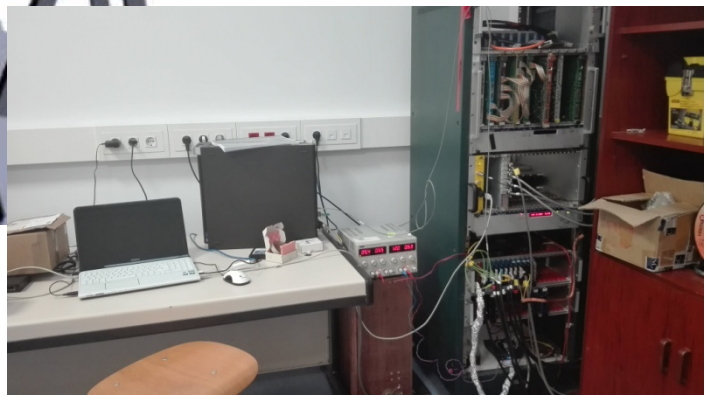
CALIFA Phase 0 construction status



GENP construction lab







Demonstrator 2018:
576 Barrel Channels