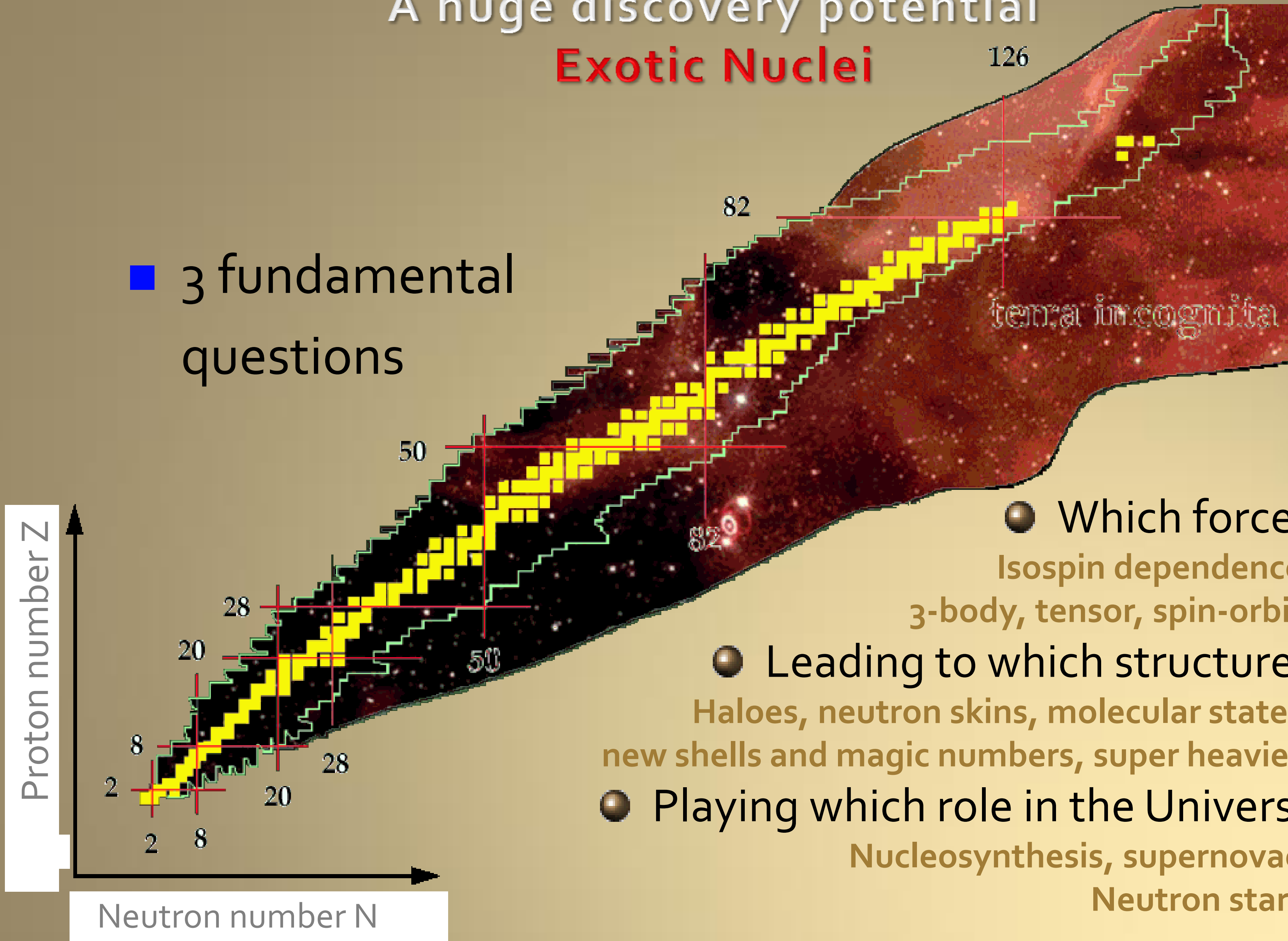
CHALLENGES OF RADIOACTIVE BEAM FACILITIES

COMPARING SOLUTIONS AT SPIRAL2 AND FAIR

R. Ferdinand – SPIRAL2

A huge discovery potential
Exotic Nuclei



- 3 fundamental questions

- Which force?
  Isospin dependence, 3-body, tensor, spin-orbit.
- Leading to which structure?
  Haloes, neutron skins, molecular states, new shells and magic numbers, super heavies.
- Playing which role in the Univers?
  Nucleosynthesis, supernovae, Neutron stars.

New facilities

- Production and study of Radioactive Ion Beams (RIB) arrived at various mature techniques
- New facilities have objectives to provide better tools
- Drivers are cyclotrons, synchrotrons, LINACs
  - ARIEL, CARIF, EURISOL, FAIR, FRIB, HiE-ISOLDE, KoRIA, SPES, SPIRAL2
- Energies of drivers range from few MeV/u to few GeV/u
- In Europe, two were recognized of prime importance by NuPECC (Nuclear Physics European Collaboration Committee)
  - FAIR
  - SPIRAL2
- recommended for construction by ESFRI (European Strategy Forum on Research Infrastructures).

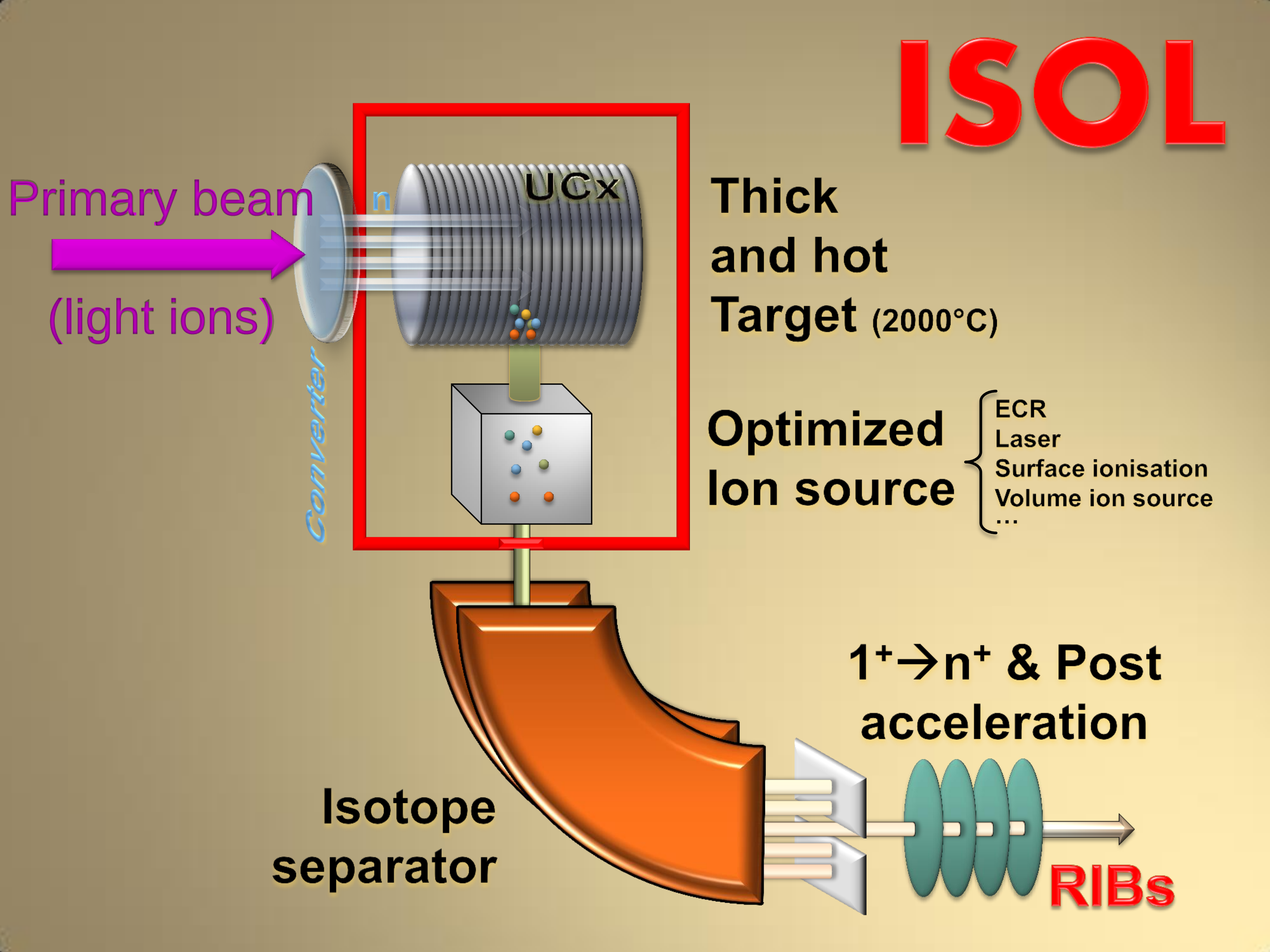
Challenges for RIB production

- Low production cross section
  - higher production rate associated to higher intensity of the primary beam (increase the number of reaction products)
- Short life time
  - An Efficient extraction
- Huge amount of unwanted particles
  - An efficient separation is required
  - Management of the high level of radioactivity produced

- The probability of production of a fragment is related to its production cross section
  - Depends of the target materials (mass, thickness), the types of primary particles and kinetic energy

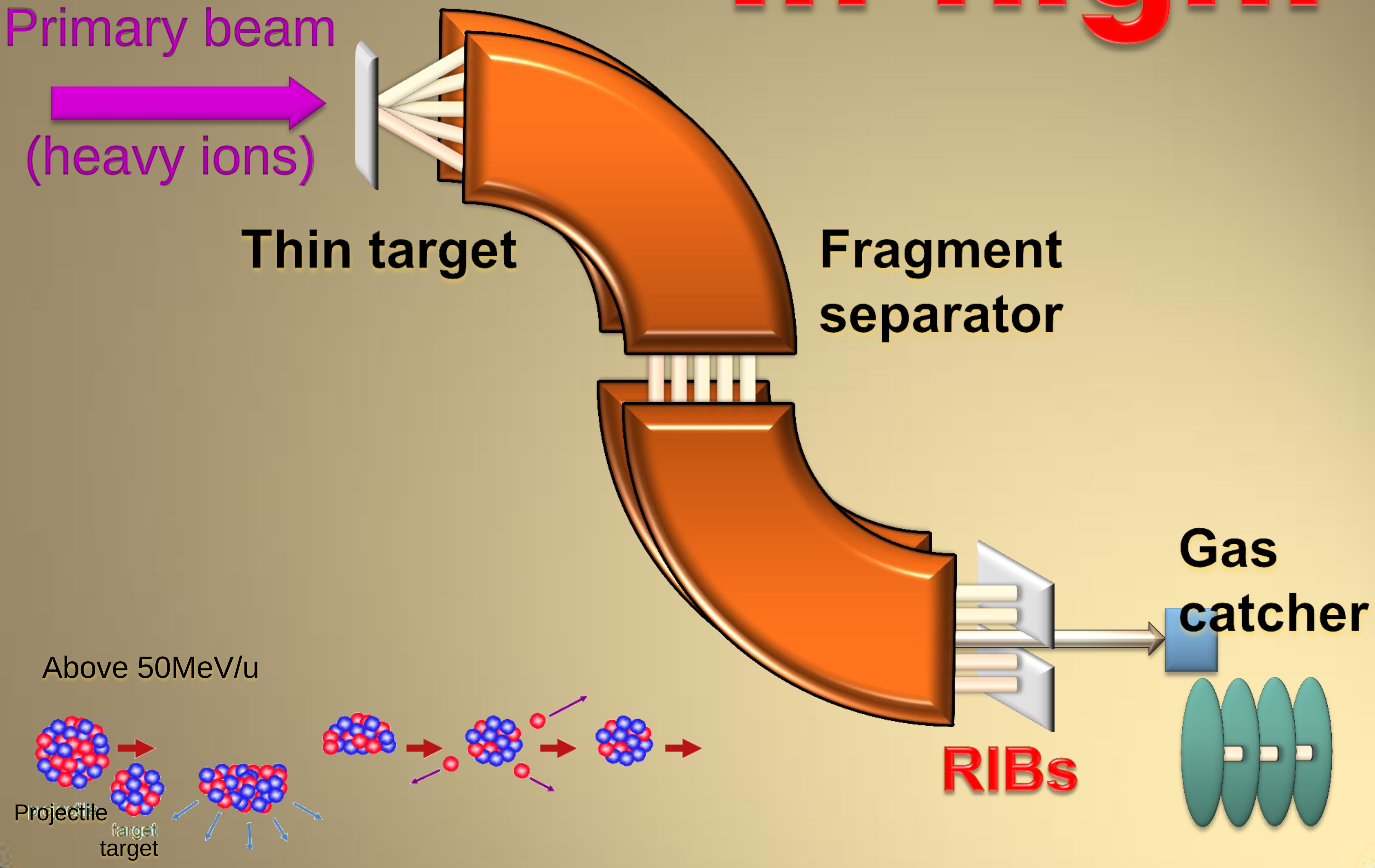
$$P = \frac{N(\tau)}{N_0} = \left(1 - e^{-\frac{\tau N_a \sigma}{A_t}}\right)$$

τ target thickness (g/cm²)
N_a Avagodro's number
A_t target mass number
σ production cross section



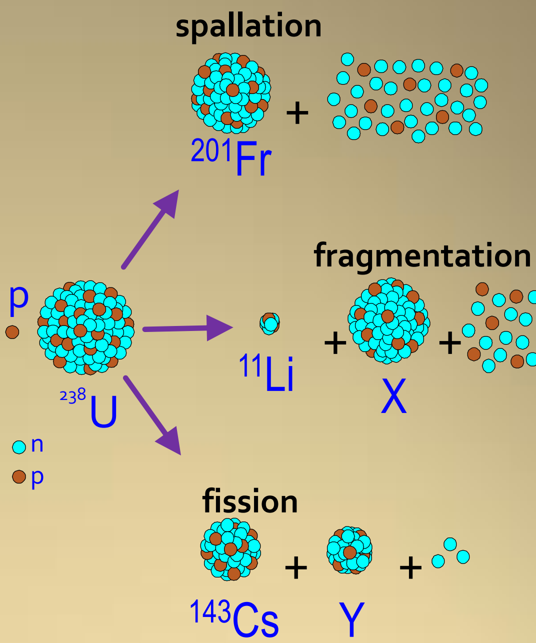
ISOL
Primary beam
(light ions)
Converter
n
UCx
Thick
and hot
Target (2000°C)
Optimized
Ion source
ECR
Laser
Surface ionisation
Volume ion source
...
1+→n+ & Post
acceleration
Isotope
separator
RIBs

In-flight


Primary beam
(heavy ions)
Thin target
Fragment separator
Gas catcher
RIBs
Above 50MeV/u
Projectile
target

Advantages/drawbacks

- ISOL
  - \+
    - Good beam quality (ΔE/E small)
    - Pure beam (better selectivity with chemistry)
    - Higher production rate for the "extractable" species
    - Low energy, light ions => smaller facility
  - \-
    - Life time has to be ≥ 10ms
    - Beam energy varies within the thick target (and so does the efficiency of the production)
    - Safety issues with the inerted hot cells
- In-flight
  - \+
    - Access to very short lived fragments (≥ 600ns)
    - Direct relation between cross sections and observed production rates → knowledge for the ISOL methods
    - Provides beams with energy near that of the primary beam
  - \-
    - Important energy dispersion
    - Simplest production target but sophisticated fragment separation
    - High energy, heavy particles lead to big facility
- Reaction mechanism are mostly different
  - Different fission fragments



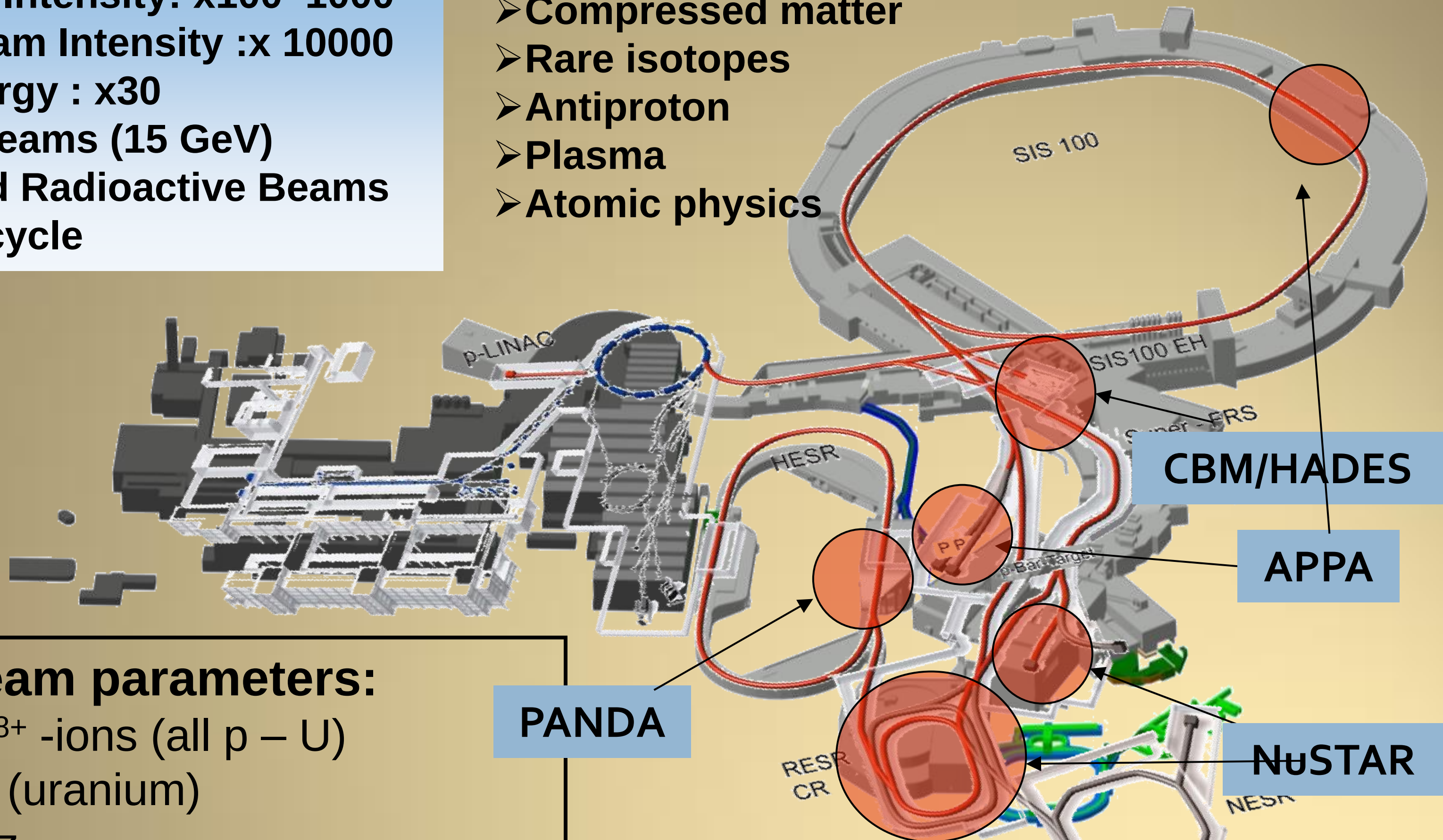
FAIR

Thanks to O. K. Kester for providing the elements

FAIR – Beam Parameters

- Primary Beam Intensity: x100–1000
- Secondary Beam Intensity :x 10000
- Heavy Ion Energy : x30
- Cooled pbar Beams (15 GeV)
- Intense Cooled Radioactive Beams
- Variable duty cycle

Research
- ➢Compressed matter
- ➢Rare isotopes
- ➢Antiproton
- ➢Plasma
- ➢Atomic physics



SIS100 ion beam parameters:

Ion species : U^{28+} -ions (all p – U)

N: $5x10^{11}$ /cycle (uranium)

Rep. rate: 0.5 Hz

Energy : 400 – 2715 MeV/u for heav

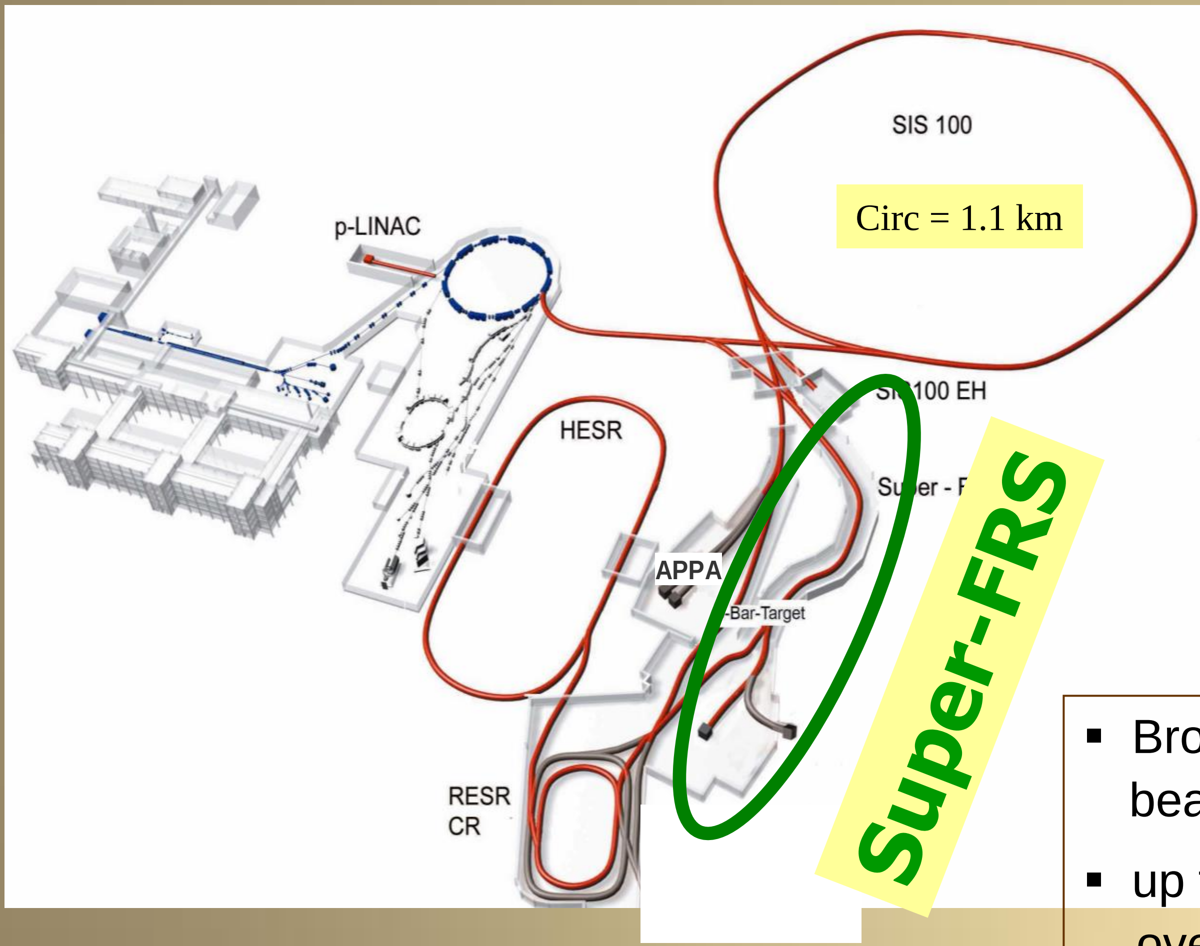
Pulse length : 30 – 90 ns

WEOBA01 - Peter SPILLER

Status of the FAIR Synchrotron Projects SIS18 Upgrade and SIS100

Courtesy of O. K. Kester

Super-Fragment Separator at FAIR



Primary Beams

- **$3 \cdot 10^{11}$ $^{238}U^{28+}$/s (Slow extr.)** @ 1.5 GeV/u
- **$4 \cdot 10^{11}$ $^{238}U^{28+}$ (pulsed)** @ 1 GeV/u
- factor of **10** in intensity over present SIS18 performance

Secondary Beams

- Broad range of radioactive beams up to **1.5 GeV/u**
- up to **factor 10 000 in intensity** over present

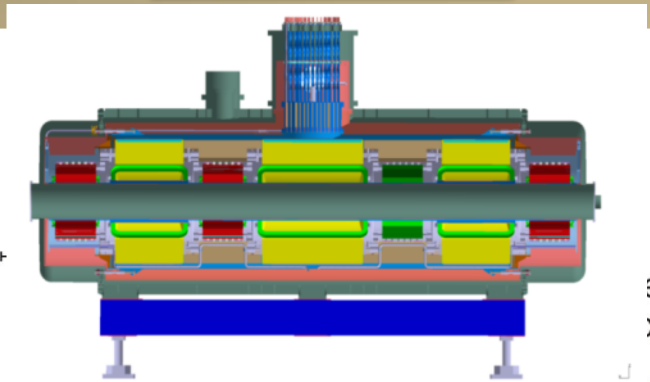
Courtesy of O. K. Kester

Work on the Super-FRS

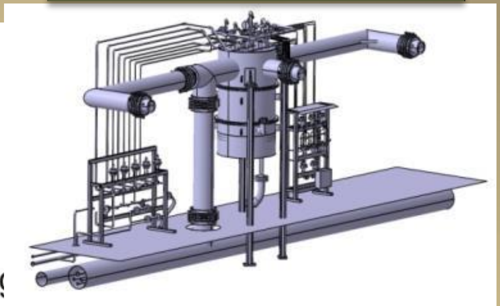
Remote Handling

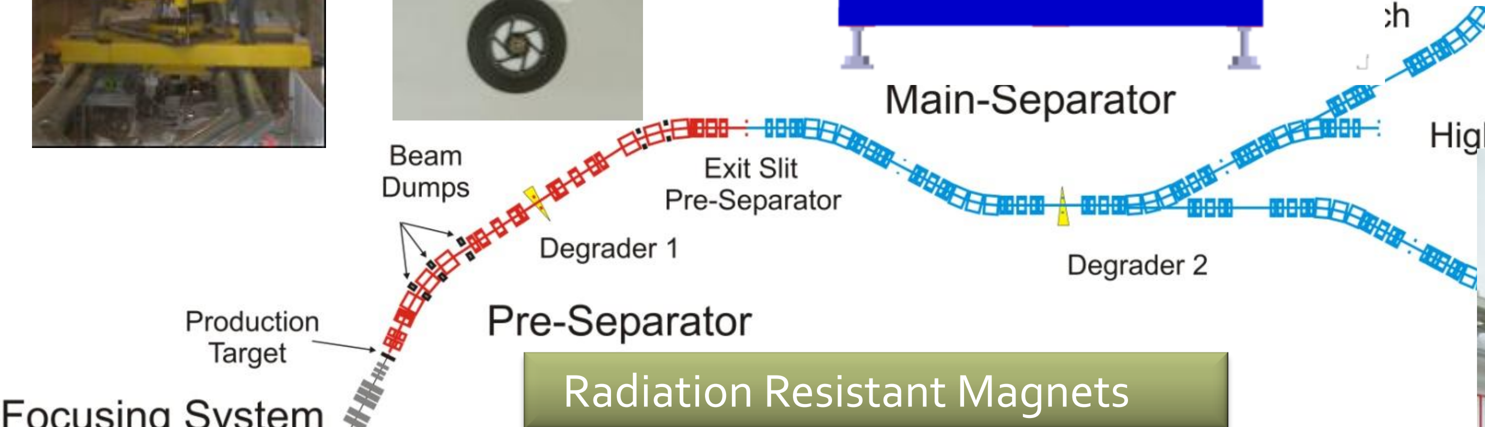
Target

SC Multiplets



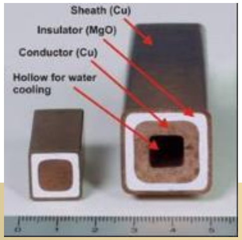
Local Cryogenics





SC Dipoles

Radiation Resistant Magnets



Courtesy of O. K. Kester

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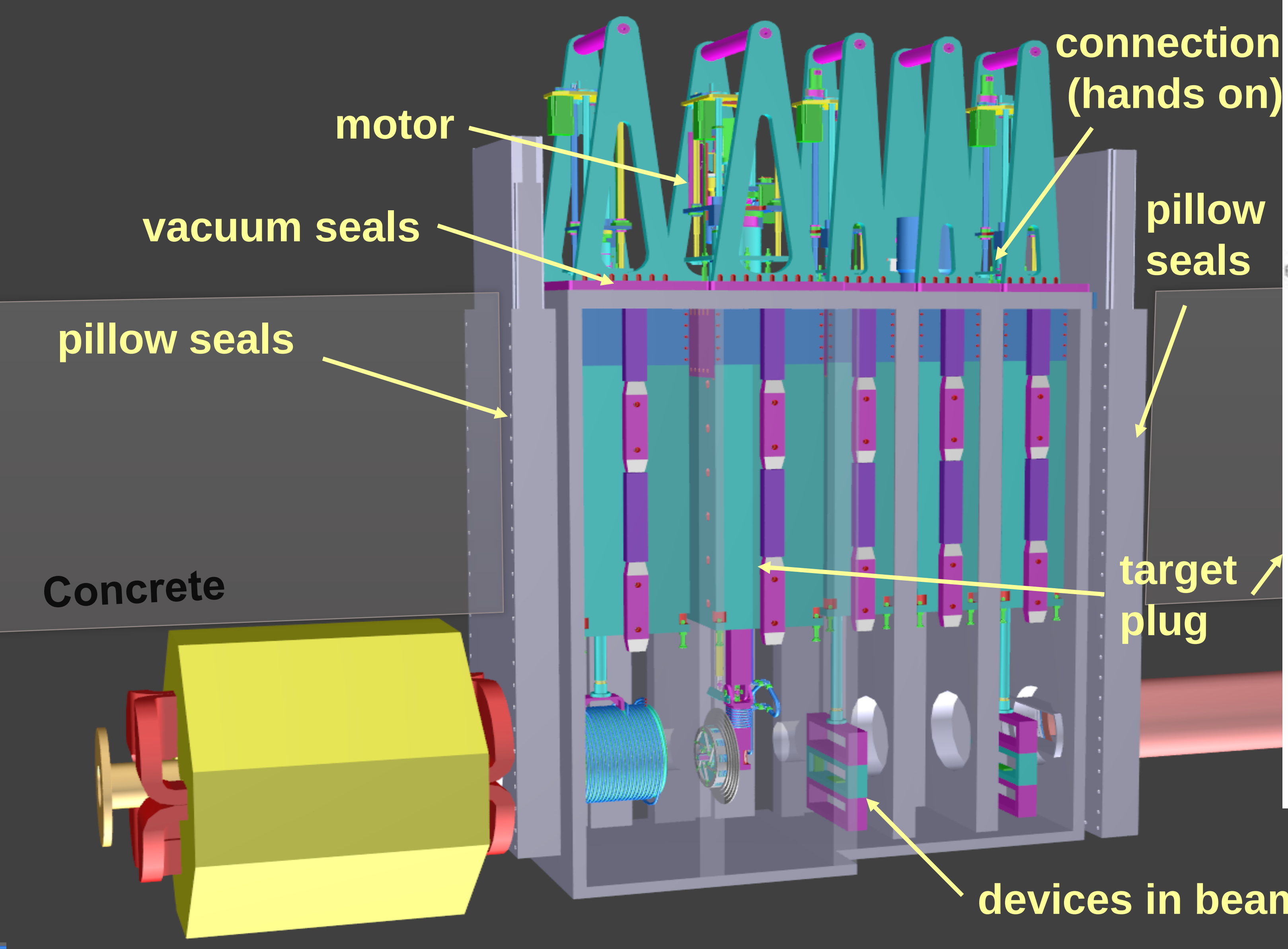
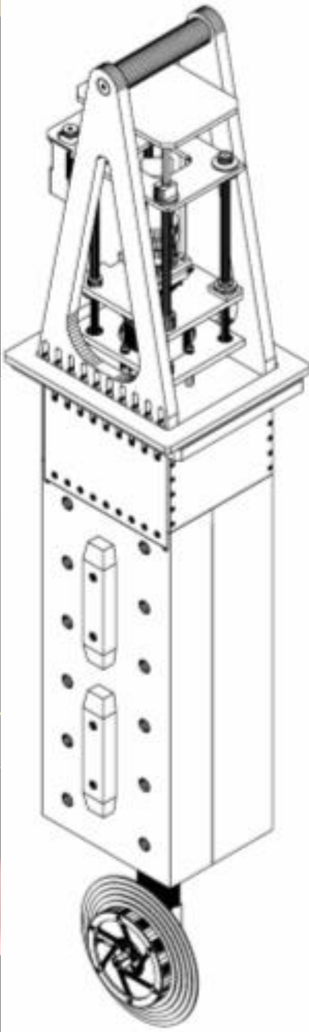
Target Chamber



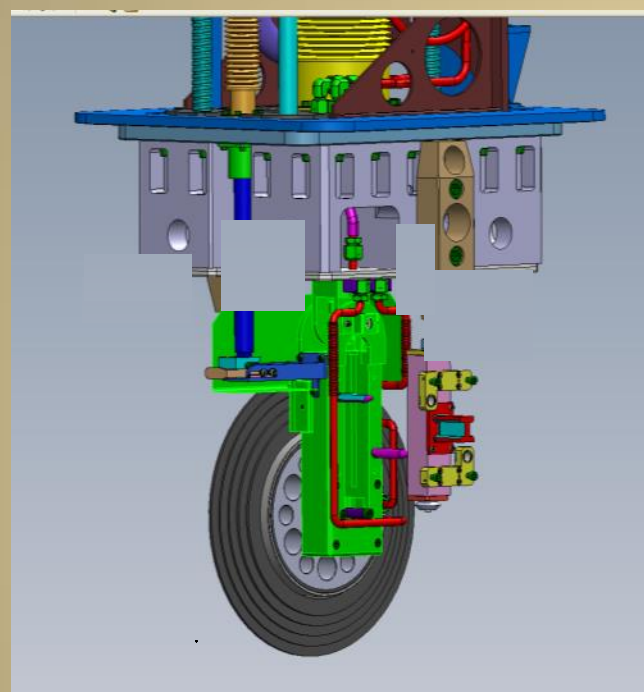


Courtesy of O. K. Kester

Target Wheel

d = 450mm (prototyp)

- ➢ Revision ongoing
  - larger wheel size
  - omit transverse motion (moving mechanism)
  - design for remote handling
- ➢ WP will be done in collaboration with KVI-CART



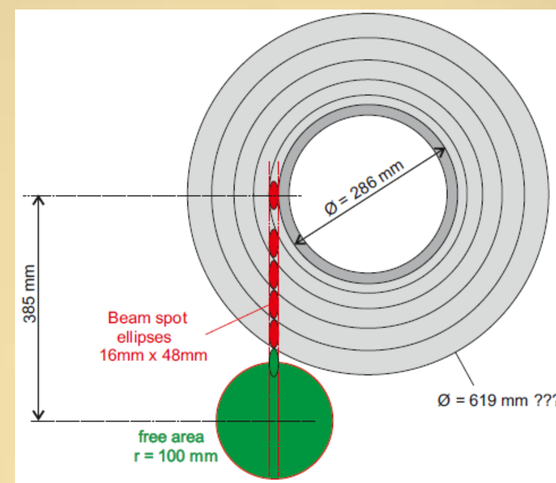
increase beam spot size

usually (σ): 1x2 mm²

to (σ): 4x6 mm²

to have target survive

$P_{max\ tensile}$ ~ 26 MPa



biggest issue, bearings in vacuum

Courtesy of O. K. Kester

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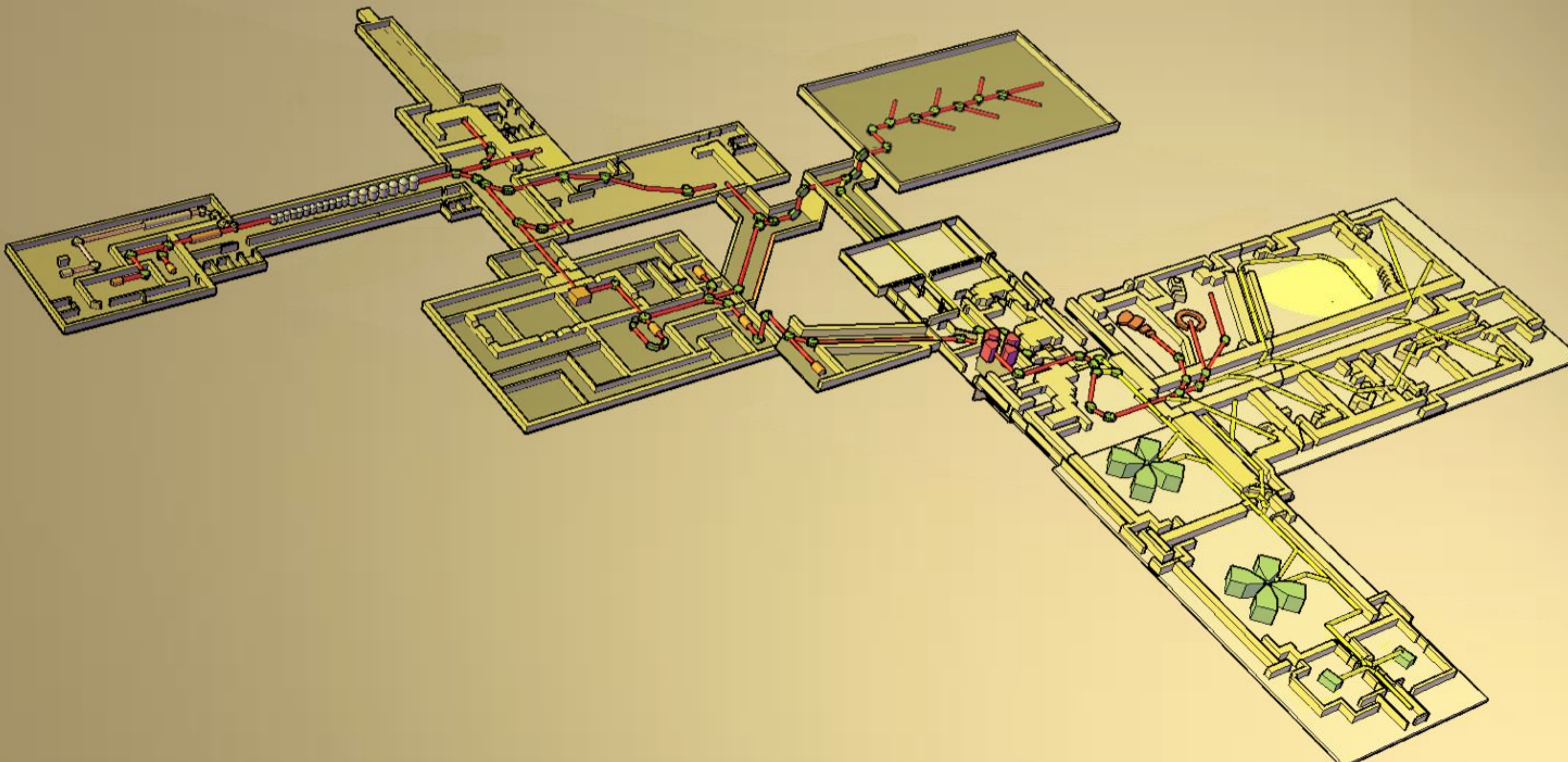
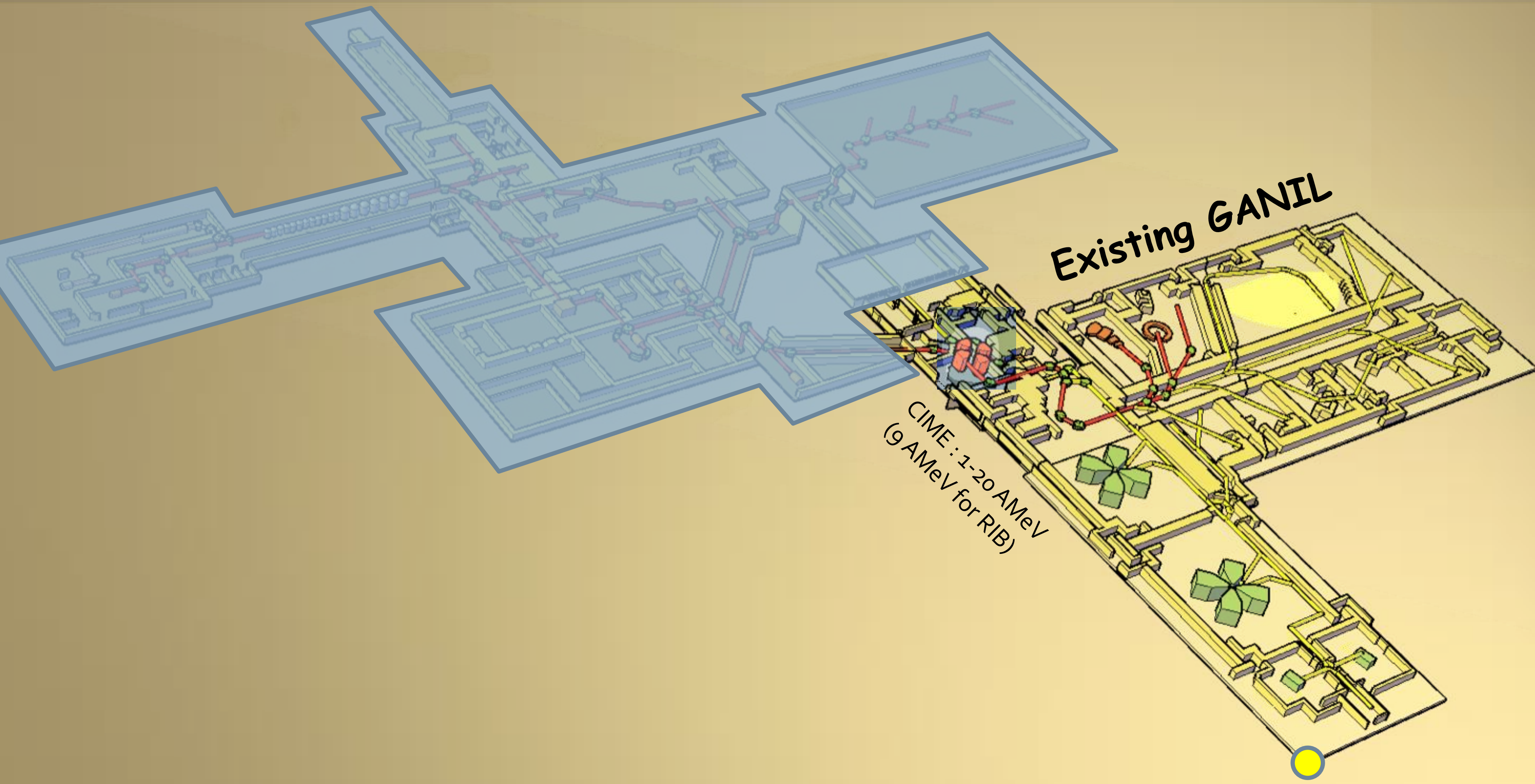
SPIRAL2

Thanks to the team !

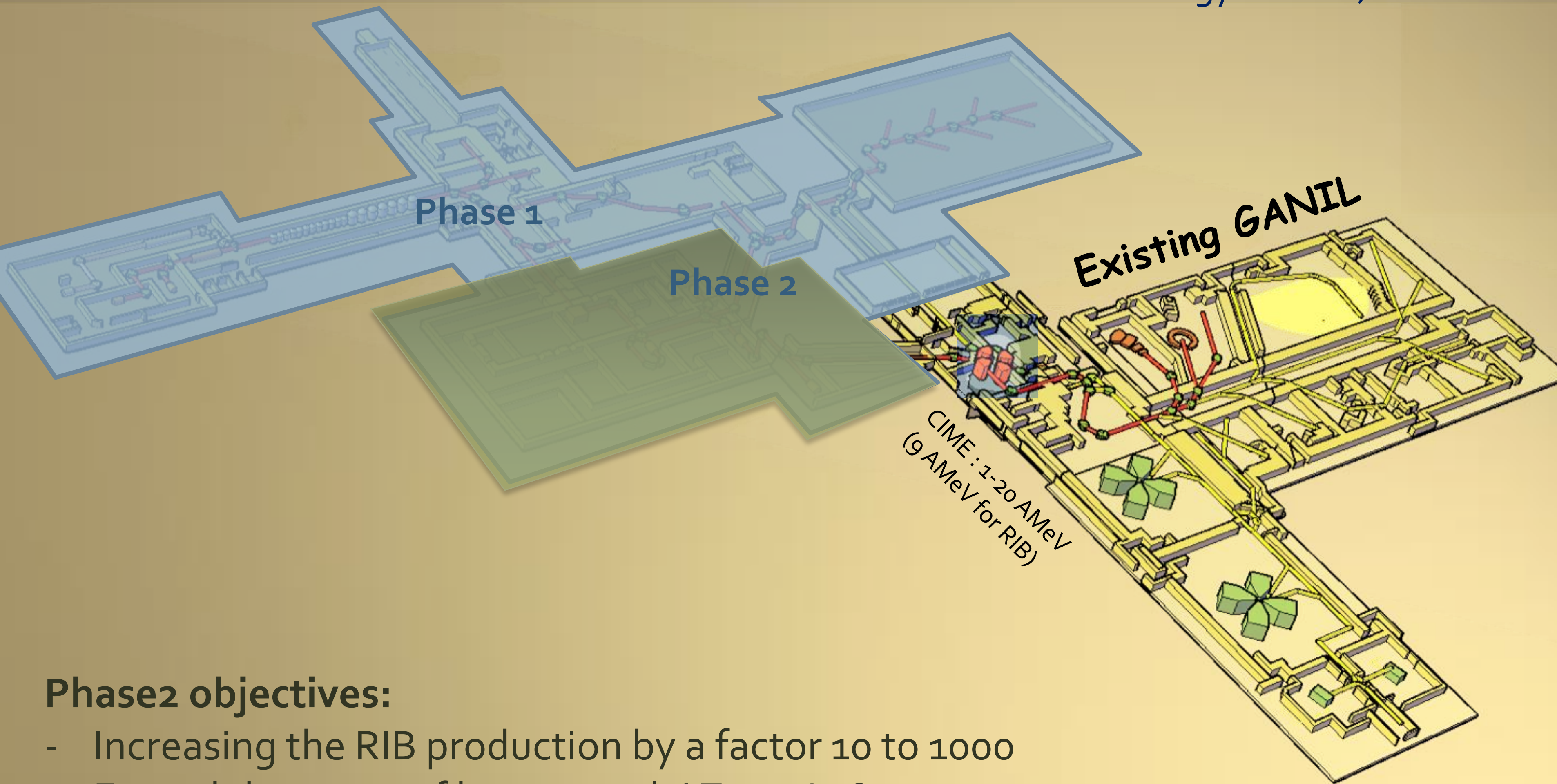




Existing GANIL
CIME : 1-20 AMeV
(9 AMeV for RIB)

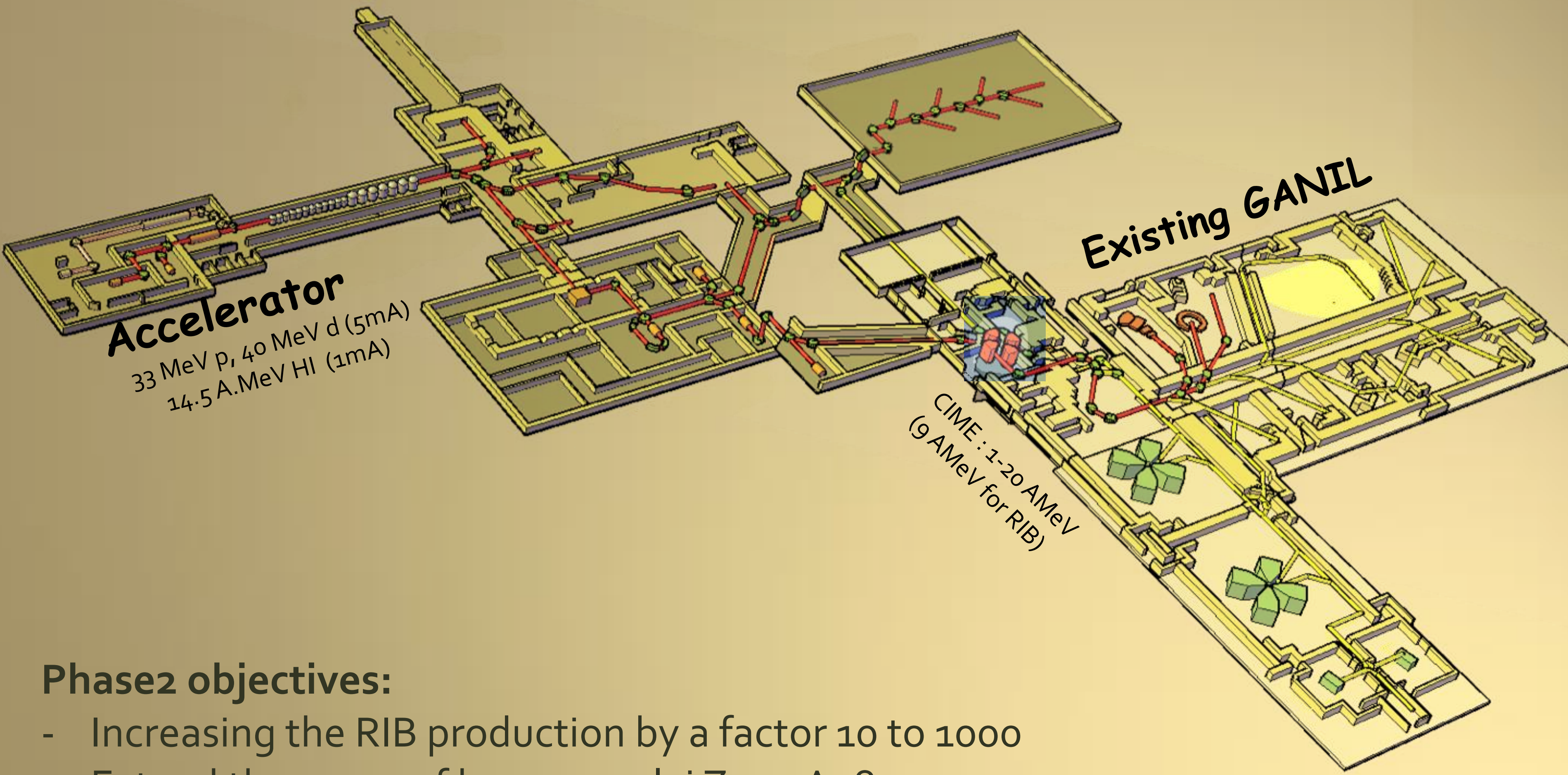
Phase1 objective:
Increasing the stable beam power by a factor 10 to 100

DESIR (very low energy studies)



Phase2 objectives:
- Increasing the RIB production by a factor 10 to 1000
- Extend the range of beams nuclei Z>40 A>80

Phase1 objective:
Increasing the stable beam power by a factor 10 to 100



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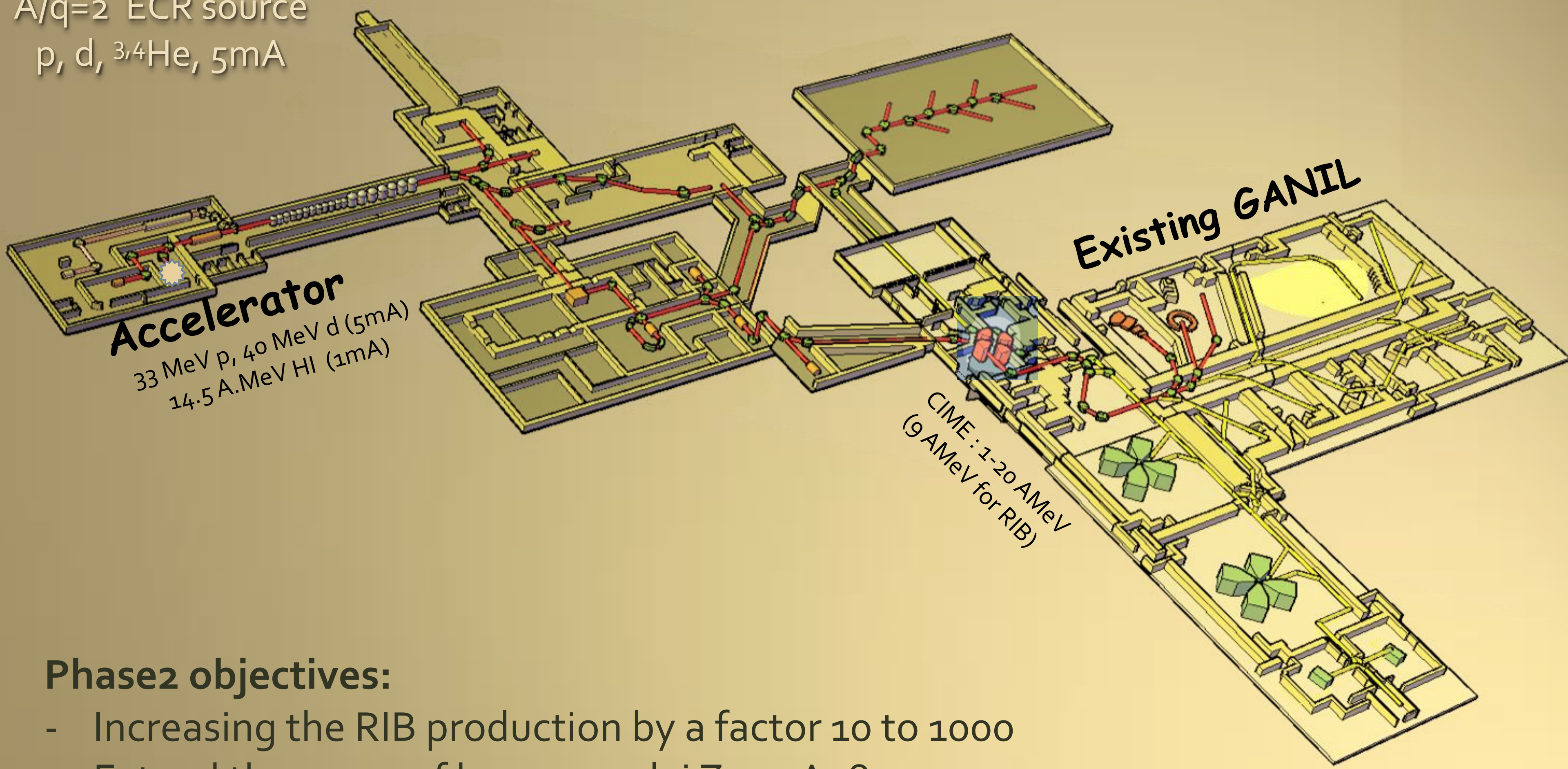
DESIR (very low energy studies)

A/q=2 ECR source
p, d, ^{3,4}He, 5mA



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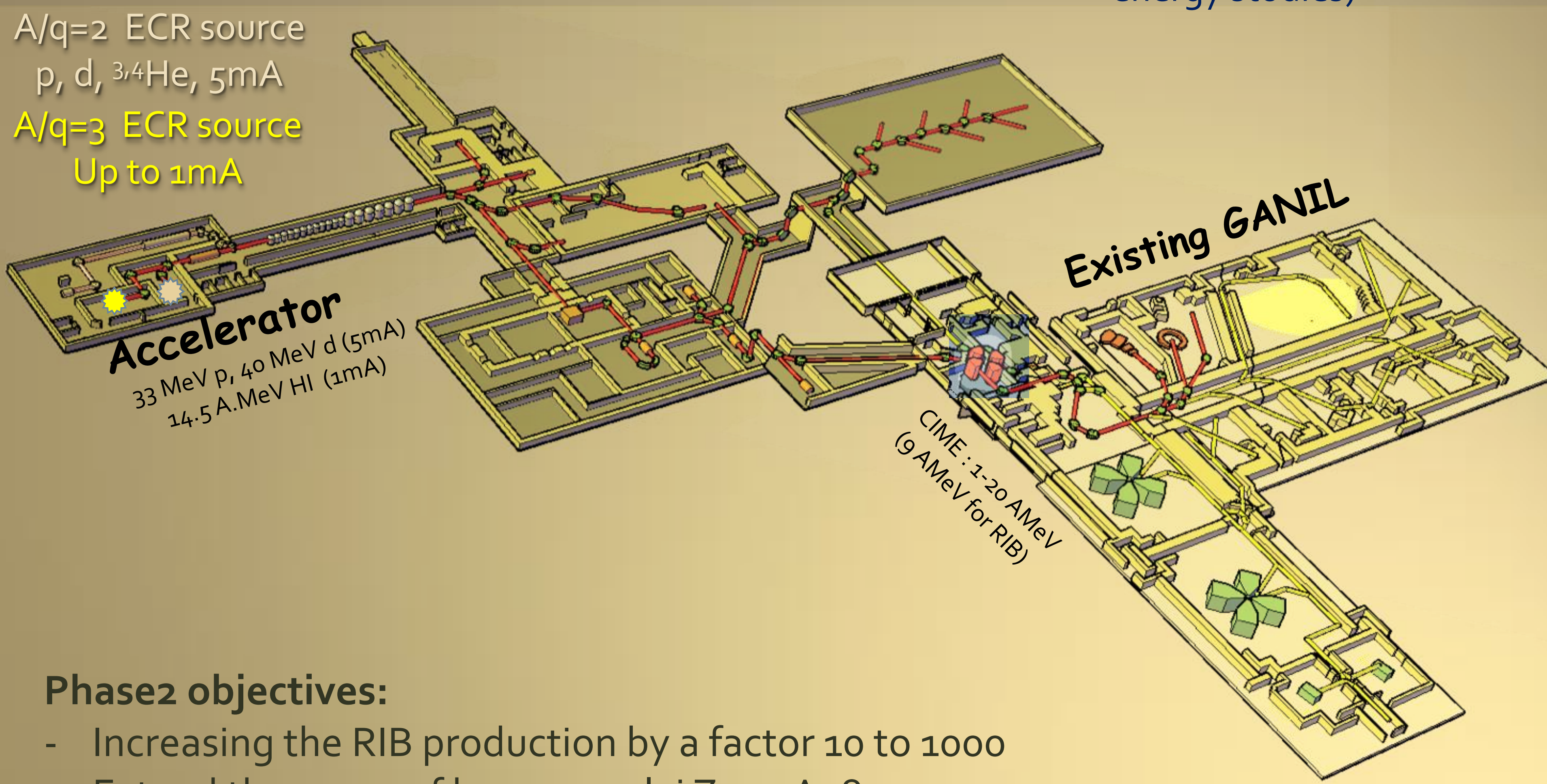

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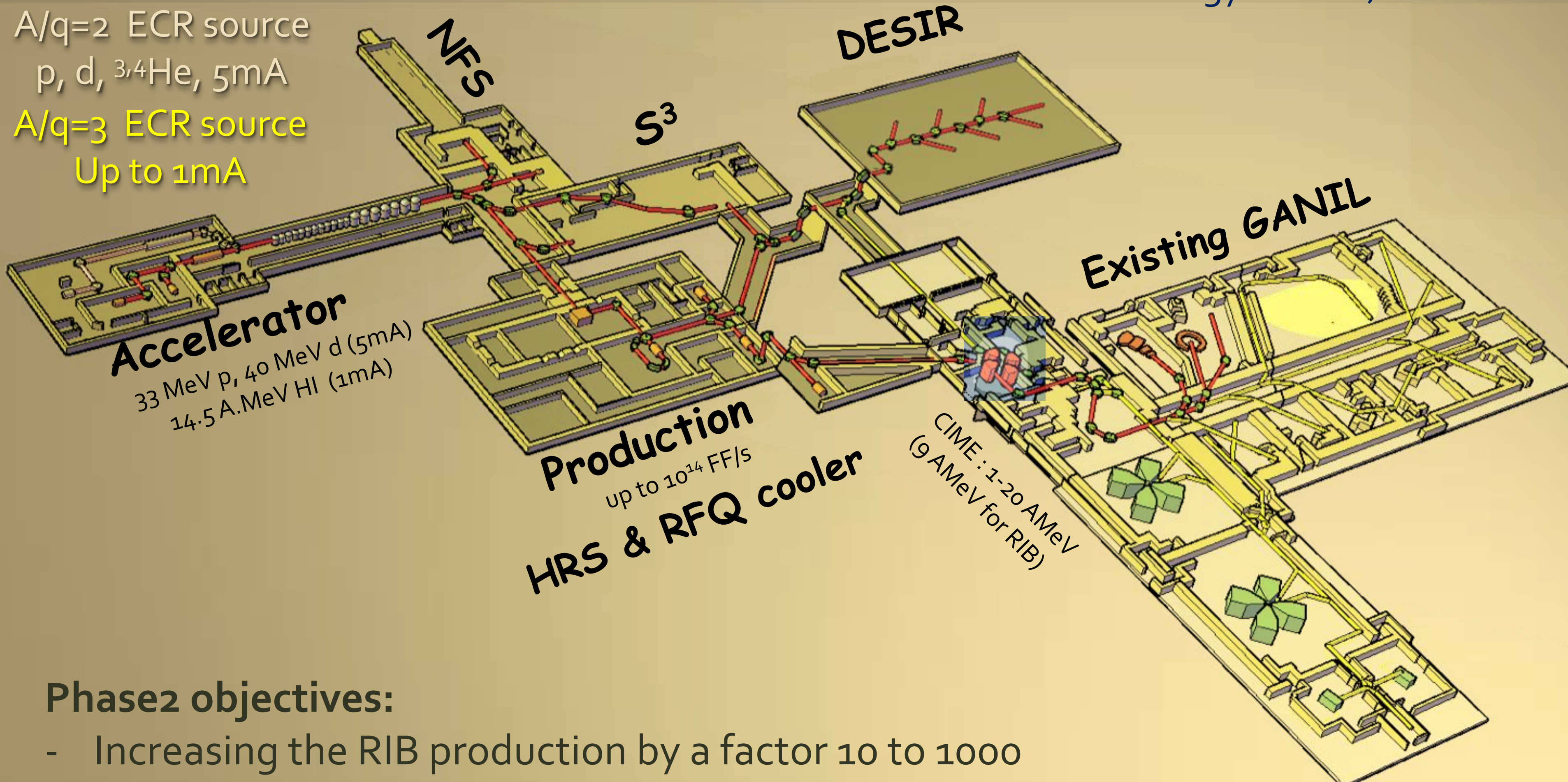


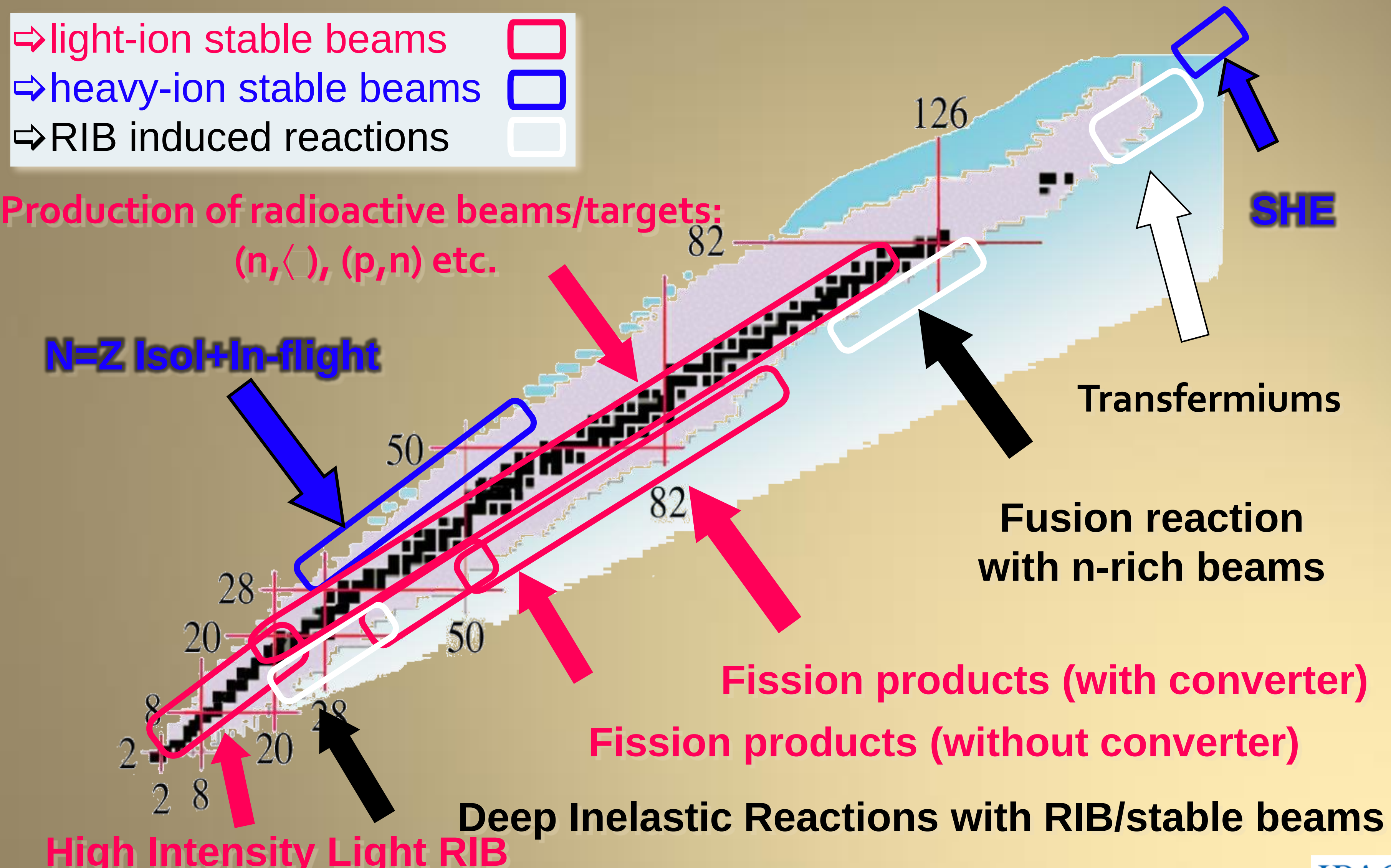
Phase2 objectives:

- Increasing the RIB production by a factor 10 to 1000
- Extend the range of beams nuclei Z>40 A>80

SPIRAL2 Scientific objectives

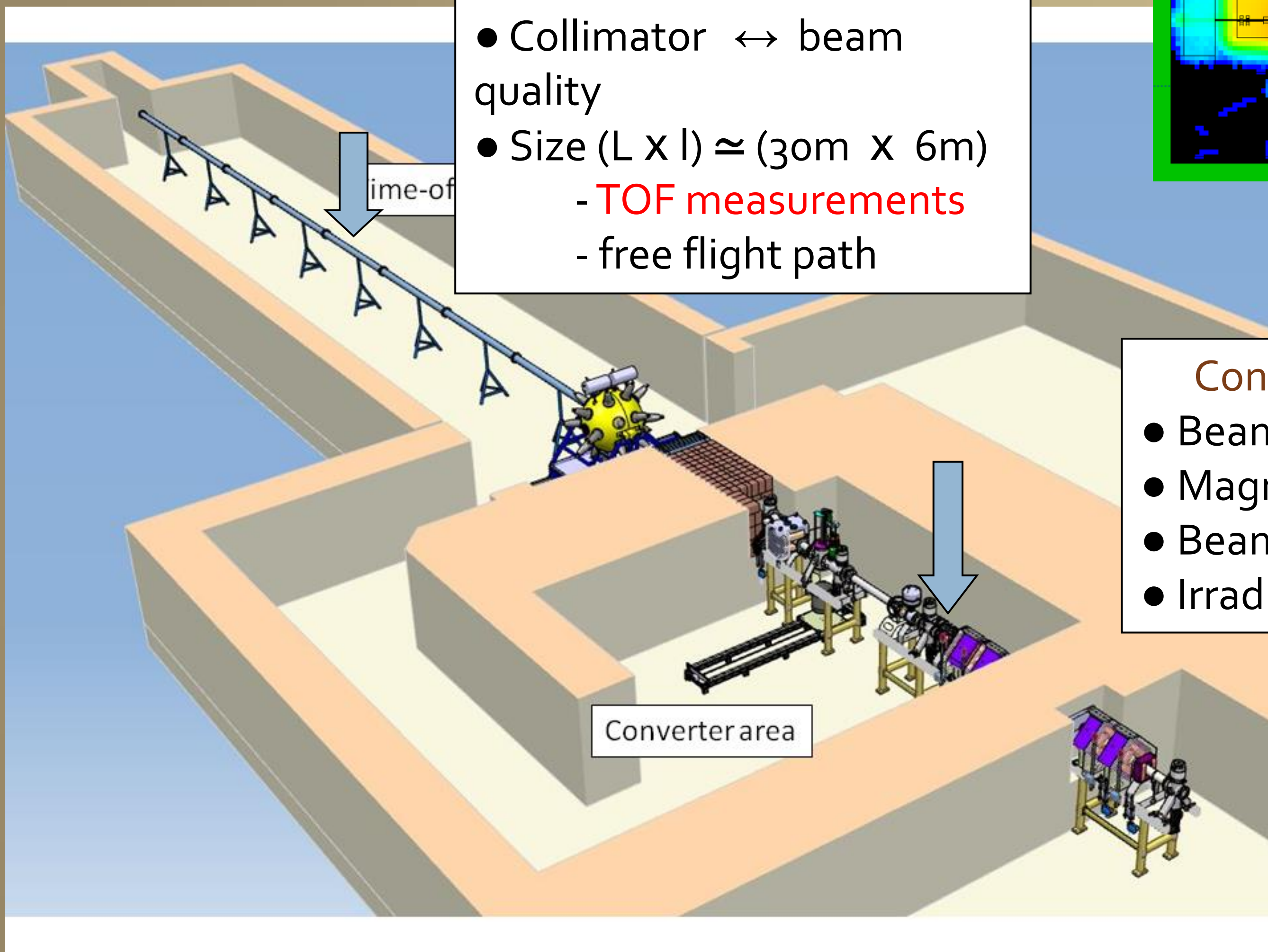
- Strong demand of radioactive beams by the nuclear and astrophysics communities (Prod)
  - Establish a bridge between nuclei-nuclei interaction and underlying quarks and gluons
  - Produce RIB using the ISOL technique
  - 10^9 pps for ^{132}Sn, 10^{10} pps for ^{92}Kr
- Research with high intensity stable beams (S3)
  - low-energy in-flight techniques using stable beam
  - N=Z, nuclear structure study through collisions, chemical and physical studies of heavy and super heavy elements,
  - Ions-ions collisions
- Neutron for science (NFS) and interdisciplinary studies :
  - Production of an intense neutron flux
  - Material irradiation, cross section measurements (for ADS, generation IV, fusion etc...)

Regions of the Chart of Nuclei Accessible



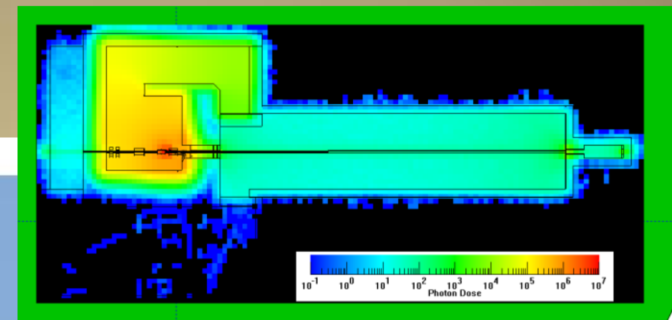
Energy range of SPIRAL 2 RIB : ≤ 60keV and 1-20 MeV/nucl.

Neutron For Science



Time-of-flight area

- Beam at 0°
- Collimator ↔ beam quality
- Size (L x l) ≃ (30m x 6m)
  - TOF measurements
  - free flight path



Converter cave

- Beam line extension
- Magnet
- Beam stop
- Irradiation station (n, p, d)

Use of radioactive samples

A< 1 GBq for thin layers

A< 10 GBq for thick samples

I < 50 µA P < 2 kW

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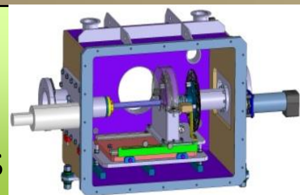
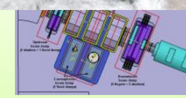
Super Separator Spectrometer

Angular acceptance +/-60 mrad in X and Y
Bρ acceptance +/- 10%

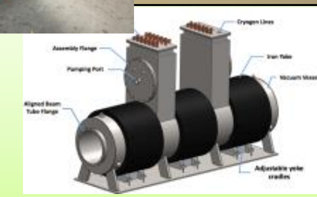
High power
Rotating targets
Stable + actinides

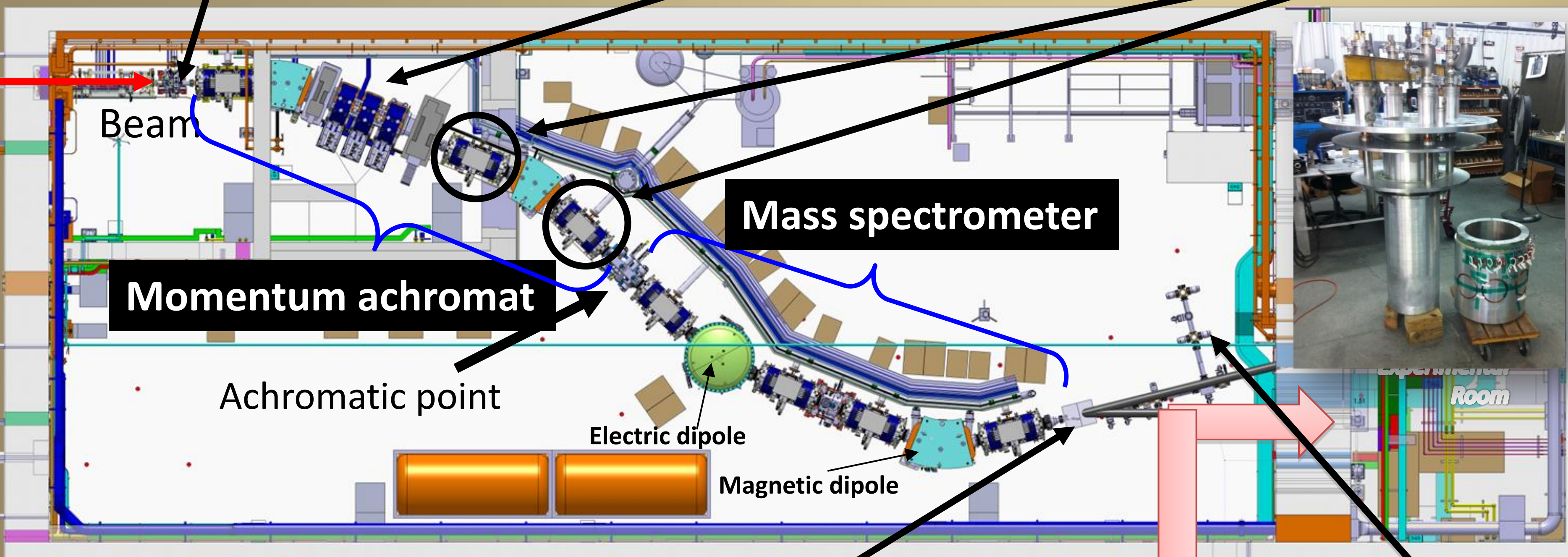


External Beam dump
& Movable fingers
Get rid of >99,9% of the beam

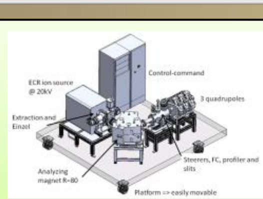


Large
acceptance
Multipoles

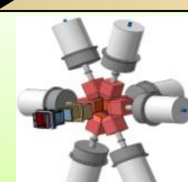




FISIC setup
Fast Ion Slow
Ion Collisions

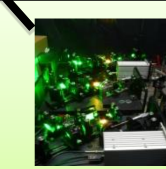


Implantation-decay
station @ the mass
dispersive plane

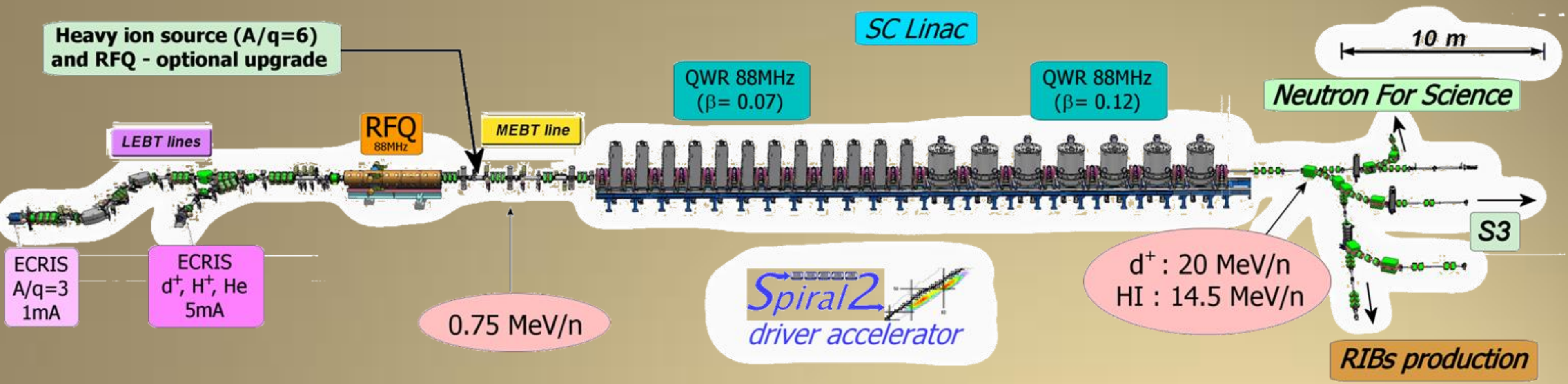


DESIR

Low
Energy
Branch



Accelerator Baseline Configuration



Particles	H^+	$^3He^{2+}$	D^+	Ions	
Q/A	1	2/3	1/2	1/3	1/6
I (mA) max.	5	5	5	1	1
W_O max. (MeV/A)	33	24	20	15	9
CW max. beam power (KW)	165	180	200	44	48

Total length: 65 m (without HE lines)

Slow (LEBT) and Fast Chopper (MEBT)
RFQ (1/1, 1/2, 1/3) & 3 re-bunchers

12 QWR beta 0.07 (12 cryomodules)
14 (+2) QWR beta 0.12 (7+1 cryomodules)
1.1 kW Helium Liquifier (4.5 K)
Room Temperature Quadrupoles
Solid State RF amplifiers (10 & 20 KW)
6.5 MV/m max $E_{acc} = V_{acc}/(\beta_{opt}\lambda)$ with $V_{acc}=\int E_z(z)e^{i\omega z/c}dz$.

SPIRAL2 Challenges

- Huge number of different beams
  - Intensities (diagnostics), energies (cavities and RF), particles (facility operation, safety)
- Accelerator components
  - Heavy Ion source (1mA Ar^{12+})
  - RFQ transmission + frequency (88MHz) → tolerances
  - Cryomodules
    - 6.5 MV/m in operation
    - Separate vacuum, compactness (transition and helium buffer)
  - Safety issues
    - Losses < 1W/m
    - Tunnel accessibility, Nuclear ventilation
    - earthquake
- RIB Production module (primary beam : D^+, 200kW)
  - Reliability, maintenance
  - Connections
  - UCx oven
  - D→n Converter and delay window

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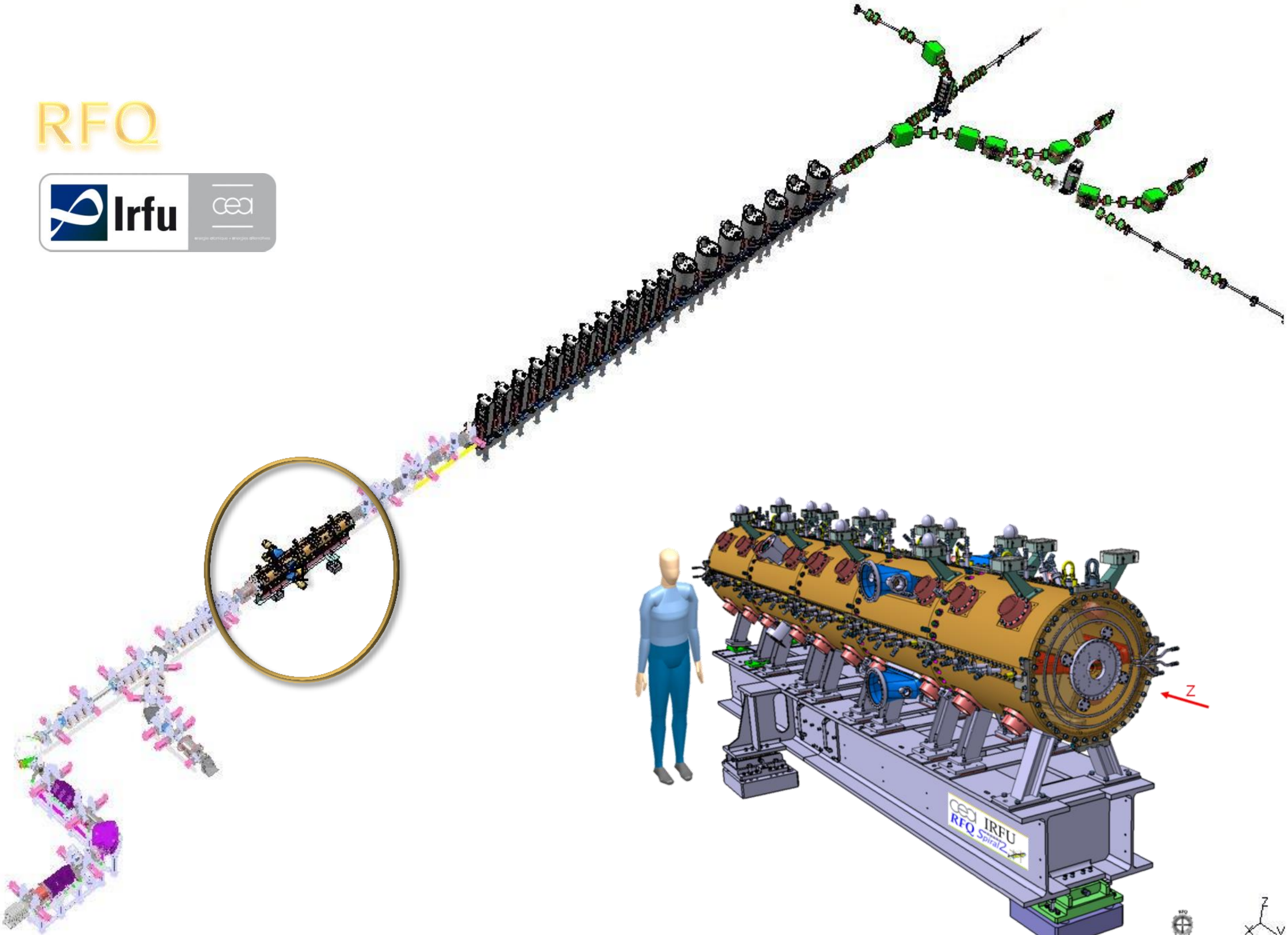
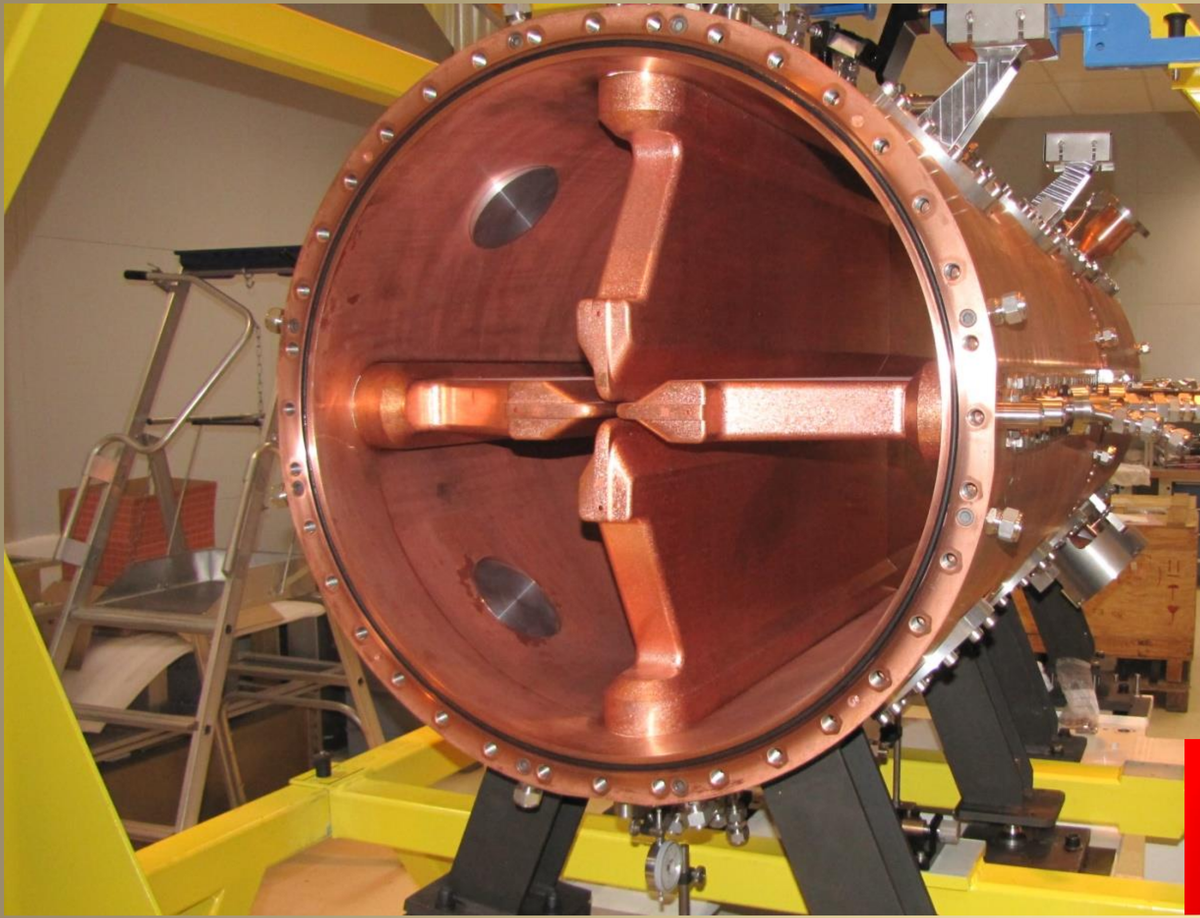
RFQ



RFQ description

- 5-m long, 88.05 MHz, 4-vanes, >99% transmission



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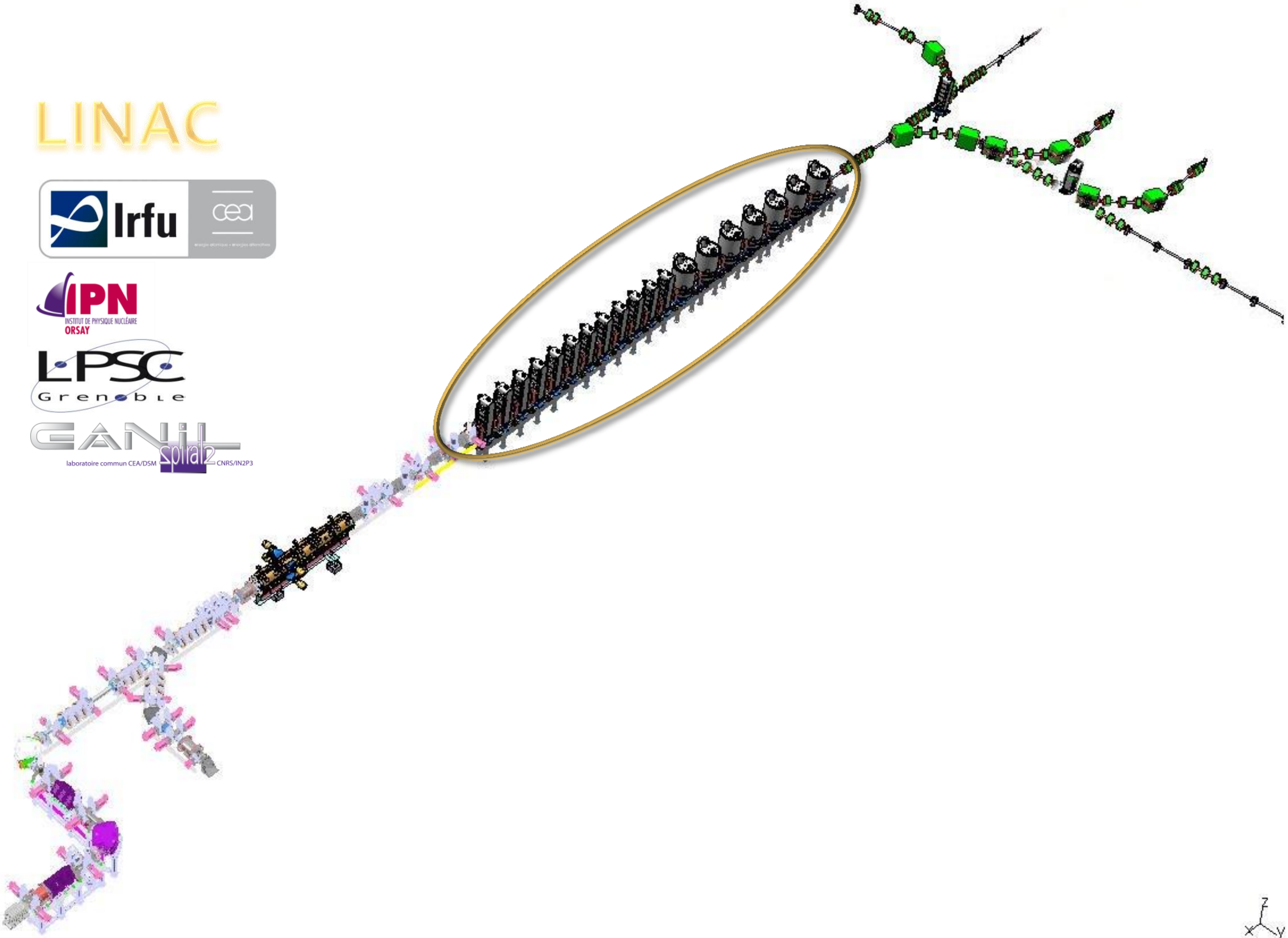
LINAC

Irfu cea

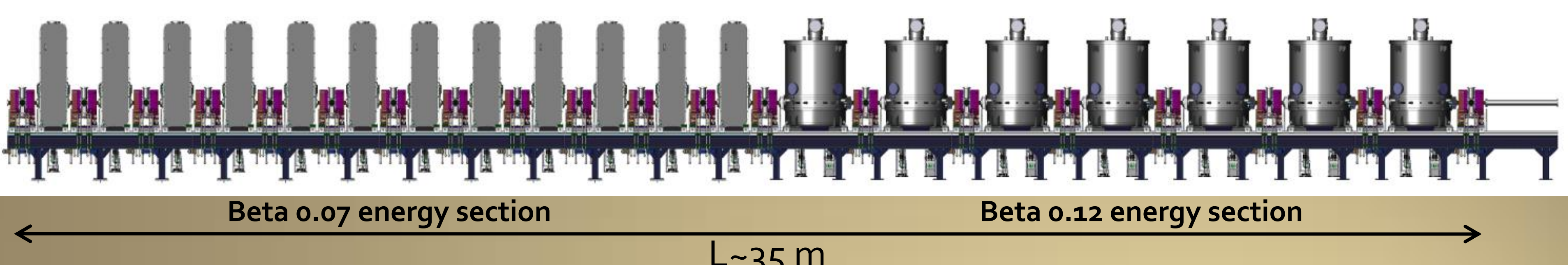
IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

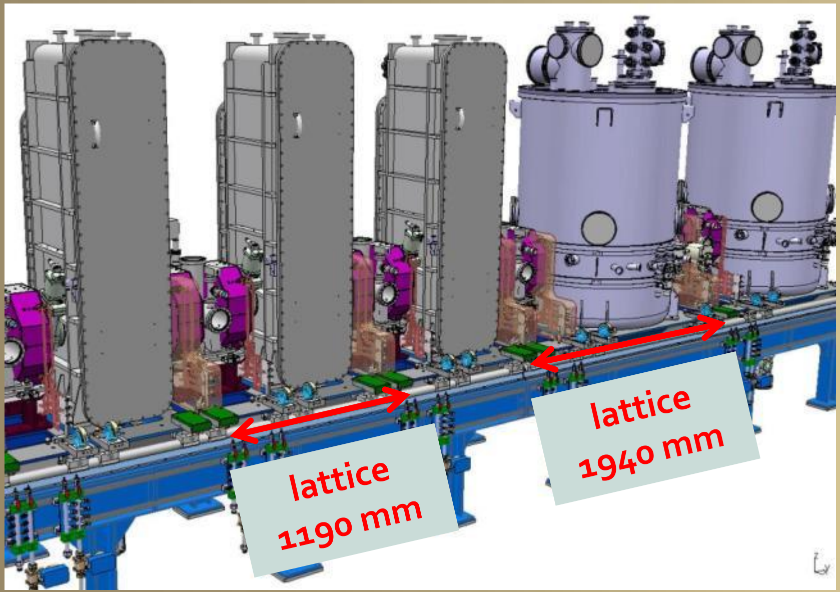
LPSC Grenoble

GANIL spiral2 laboratoire commun CEA/DSM CNRS/IN2P3



SC LINAC





Cryomodule A	Cryomodule B	Power coupler
CEA Saclay	IPN Orsay	LPSC Grenoble

Cryomodule	A	B
Valve-to-valve length [mm]	610	1360
# cavities	12	14
f [MHz]	88.05	88.05
β_{opt}	0.07	0.12
Epk/Ea	5.36	4.76
Bpk/Ea [mT/MV/m]	8.70	9.35
r/Q [Ω]	599	515
Vacc @ 6.5 MV/m & β_{opt}	1.55	2.66
Lacc [m]	0.24	0.41
Beam tube $\varnothing$ [mm]	38	44

Cryomodule status

- Cavities :
  - All QWR cavities qualified

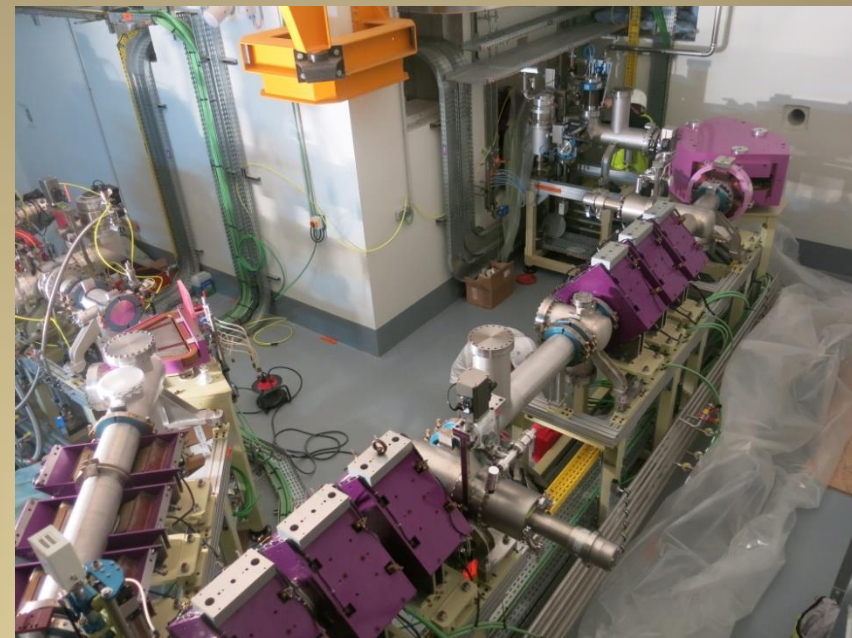
- Cryostats :
  - Eight A-type cryomodules conditioned and qualified with FPC
  - Four B-type cryomodules conditioned, qualified delivered to GANIL
  - Installation in the tunnel starts

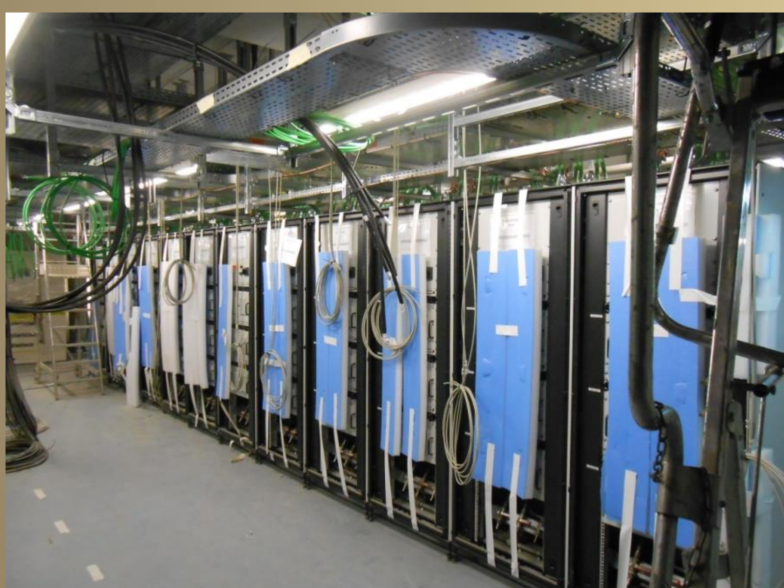
Cryomodule status

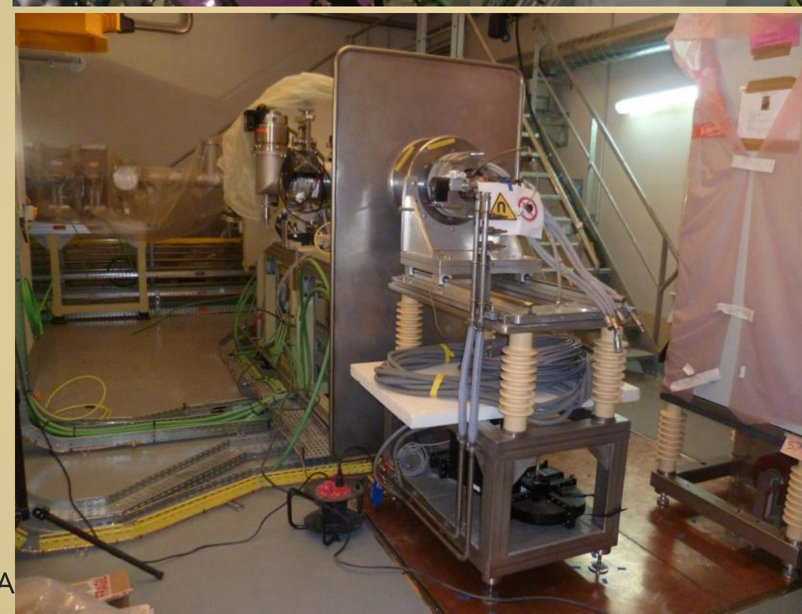
- Cavities :

	Unit	Specs	CMA4	CMA6	CMA7	CMA2	CMA3	CMA5	CMA9	CMA8
Max. acc. Gradient	MV/m	>6.5	8.85	8.34	9	8.6	7.95	9.1	8.44	9
Rx activity @6.5MV/m	µSv/h		560	91	14.3	730	494	1.5	677	32
Total losses @4K, 6.5MV/m	W	<20.5	20.8	11.4	11.8	15.56	17.9	11.3	12.6	10.38
Static losses @4K	W	<8.5W	6.5	3.98	4.1	3.11	4.34	3.6	4.47	3.12
Pressure sensitivity	Hz/mbar	<5	-1.58	-1.32	-1.45	-1.31	-1.08	-1.22	-1.24	-1.66
Cavity alignment	mm	◎ 1.3	0.52	0.4	0.48	1.46	0.4	0.24		0.76
	Unit	**Specs**	**CMB1**		**CMB2**		**CMB3**		**CMB4**	
Max. acc. Gradient	MV/m	> 6.5	>8.0	>8.0	>8.0	>8.0	>8.0	>8.0	>8.0	>8.0
Rx activity @6.5MV/m	µSv/h		22000	0	160	0	0	0	70	0
Total losses @4K, 6.5MV/m	W	< 36.0	29		29		27		31.5	
Static losses @4k	W	<12.5	17		19		19		19	
Pressure sensitivity	Hz/mbar	< 8.0	-5.3	-4.95	-5.4	-5.8	-5.2	-4.5	-4.9	-5.2
Beam vacuum	mbar	< 5.0e-7	5E-08		3E-08		4E-08		6E-08	
Cavity alignment	mm	◎ 1.2	0.16	0.34	0.62	0.42	0.24	0.38	0.14	0.36

Process installation



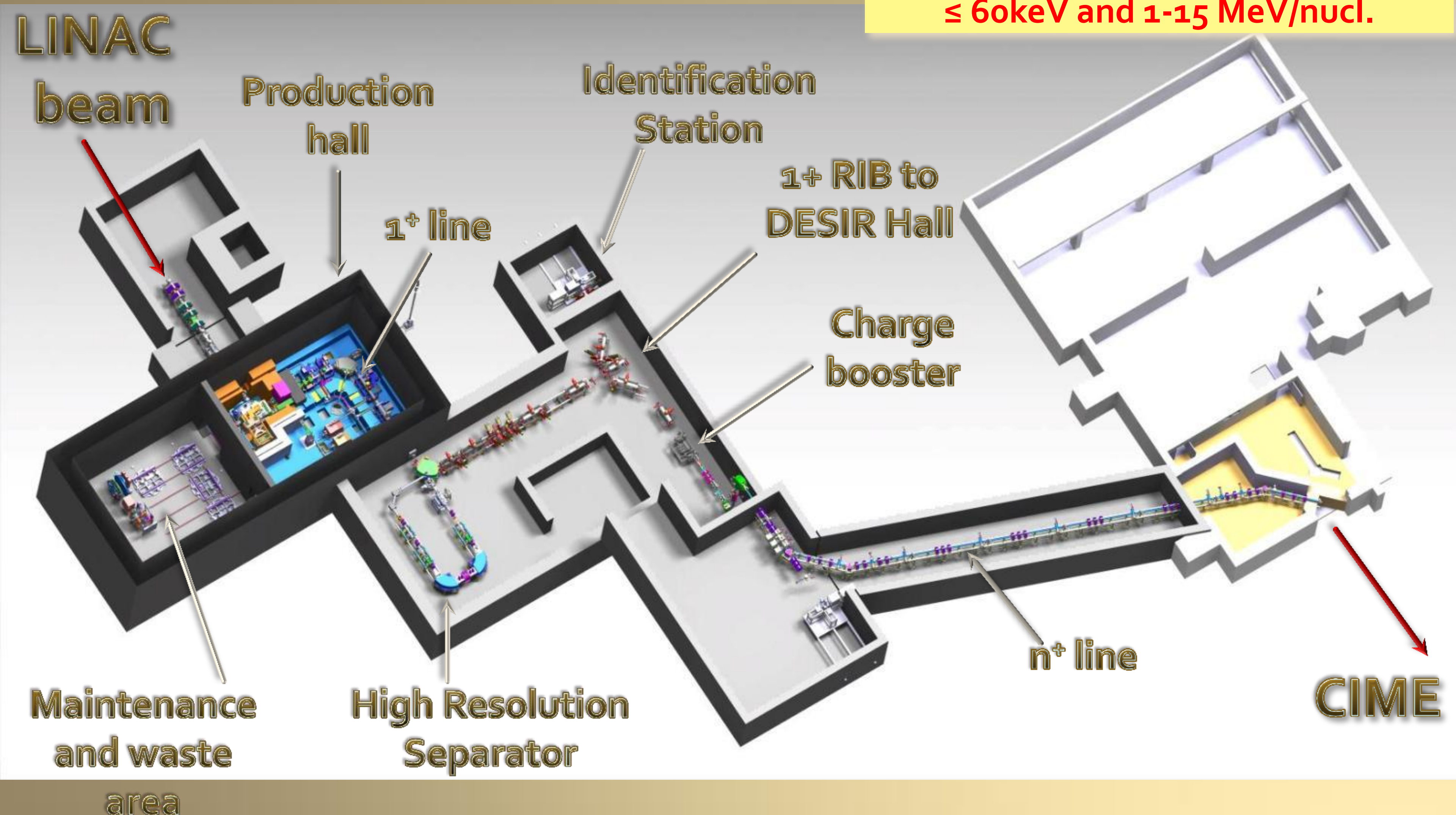




Process installation

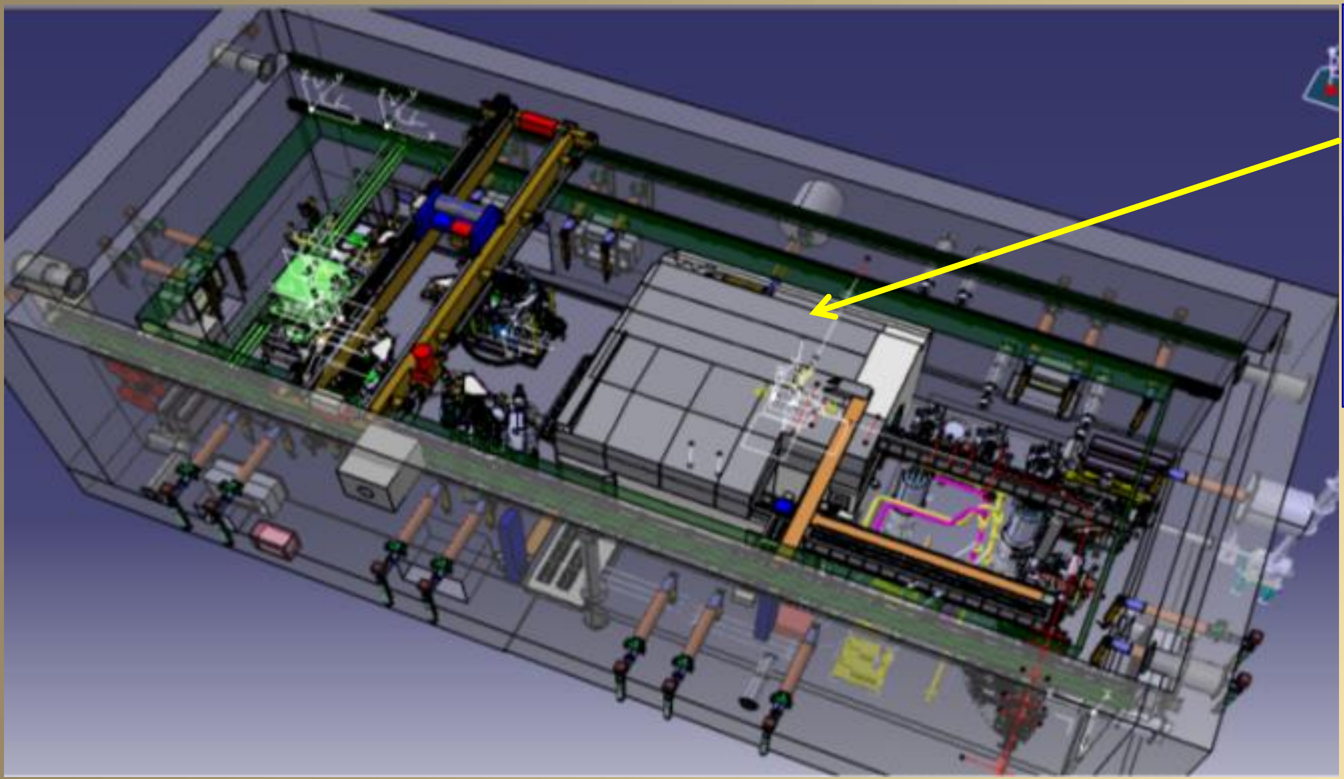
RIB production

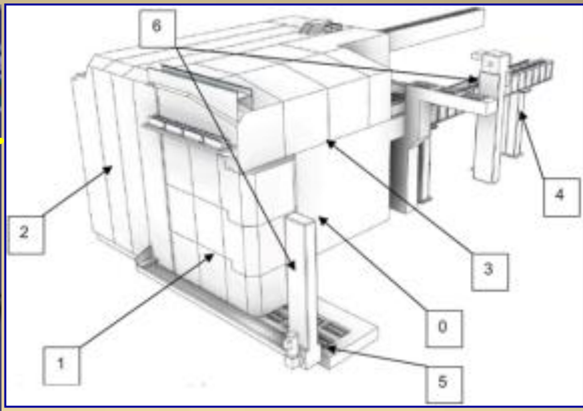
Energy range of SPIRAL2 ISOL RIB :
≤ 60keV and 1-15 MeV/nucl.



Production Cell

- Totally remote-operated system

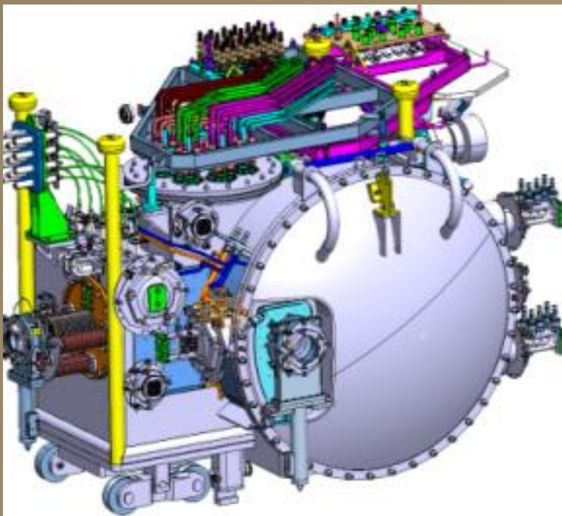




cocoon

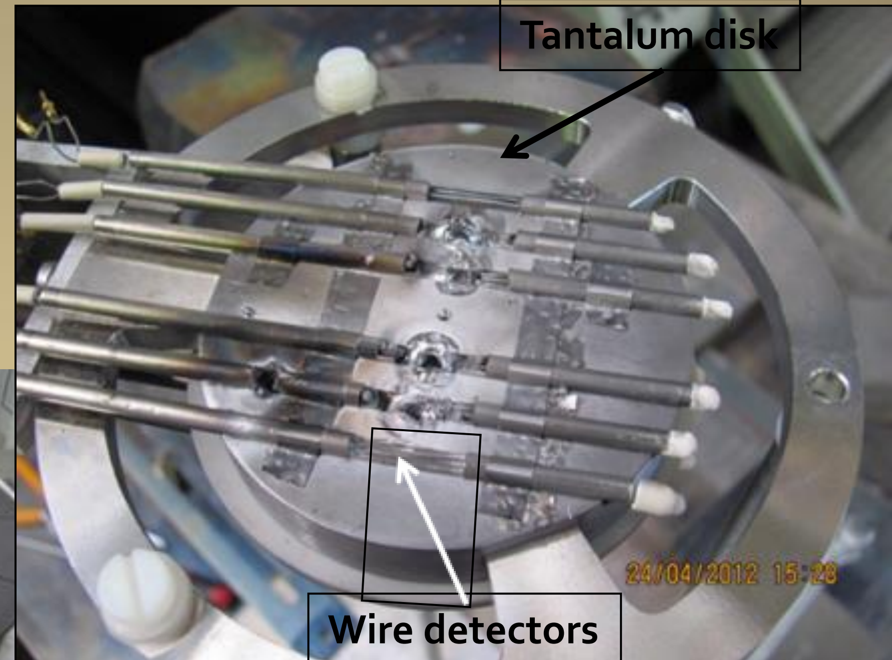
- Takes into account radiological environment, safety and contamination handling rules

Production module



Delay window

- 200kW D^+ : 580ms
- Electrons tests : 800ms



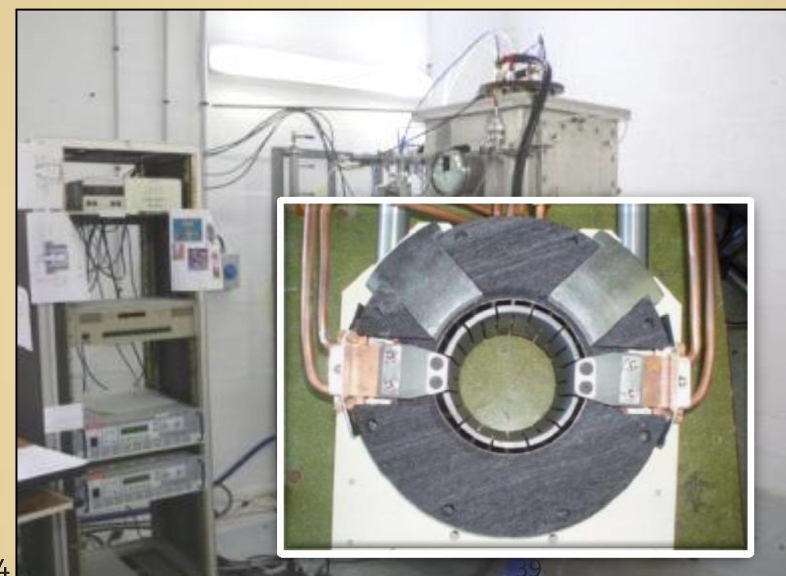
50 kW converter

Converter test bench

- 50/200kW test chamber assembled and tested @ INFN/LNL and GANIL

Ucx Oven

- 1.2 l
- Tested above 2000°C



Conclusion

- FAIR and SPIRAL2 : major nuclear facility
  - Complementary since they are using different production methods
  - broad range of research
- FAIR – In flight
  - highlights
    - High energy, parallel users
    - Size of the project
    - First equipments are coming
  - First beam is expected 2019 for SIS100 and 2020 for Super-FRS.
- SPIRAL2 - ISOL and In flight
  - Highlights
    - No short lived nuclei apart from S3
    - safety issues mastered for the hot cell
    - Major Phase-1 parts are now constructed and under installation
  - First beam tests expected by end of 2014, LINAC beam by 2015
- Lots of possible researches to come in Europe

Scaled FAIR and SPIRAL2 facilities

Thank you for your attention

IPAC14