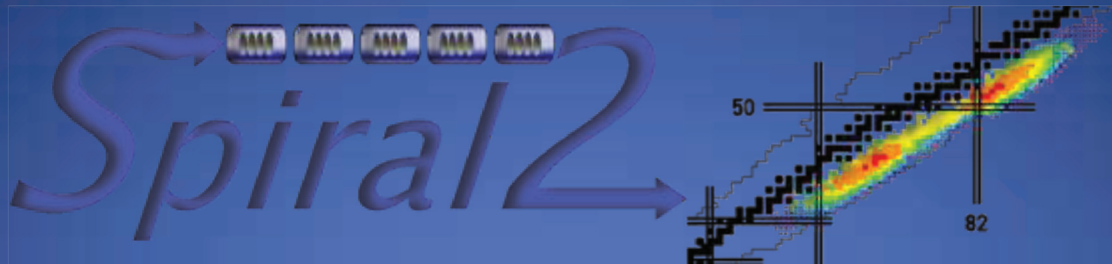


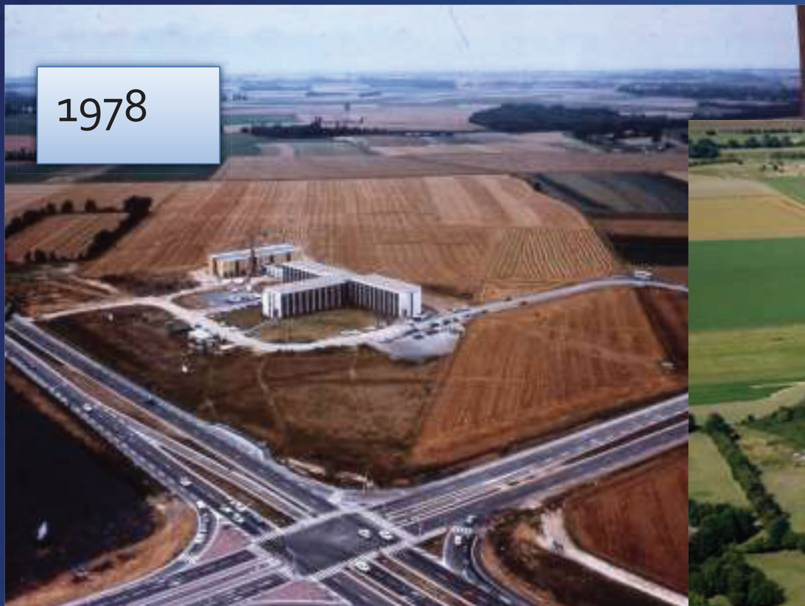
STATUS AND CHALLENGES OF SPIRAL2 SRF LINAC

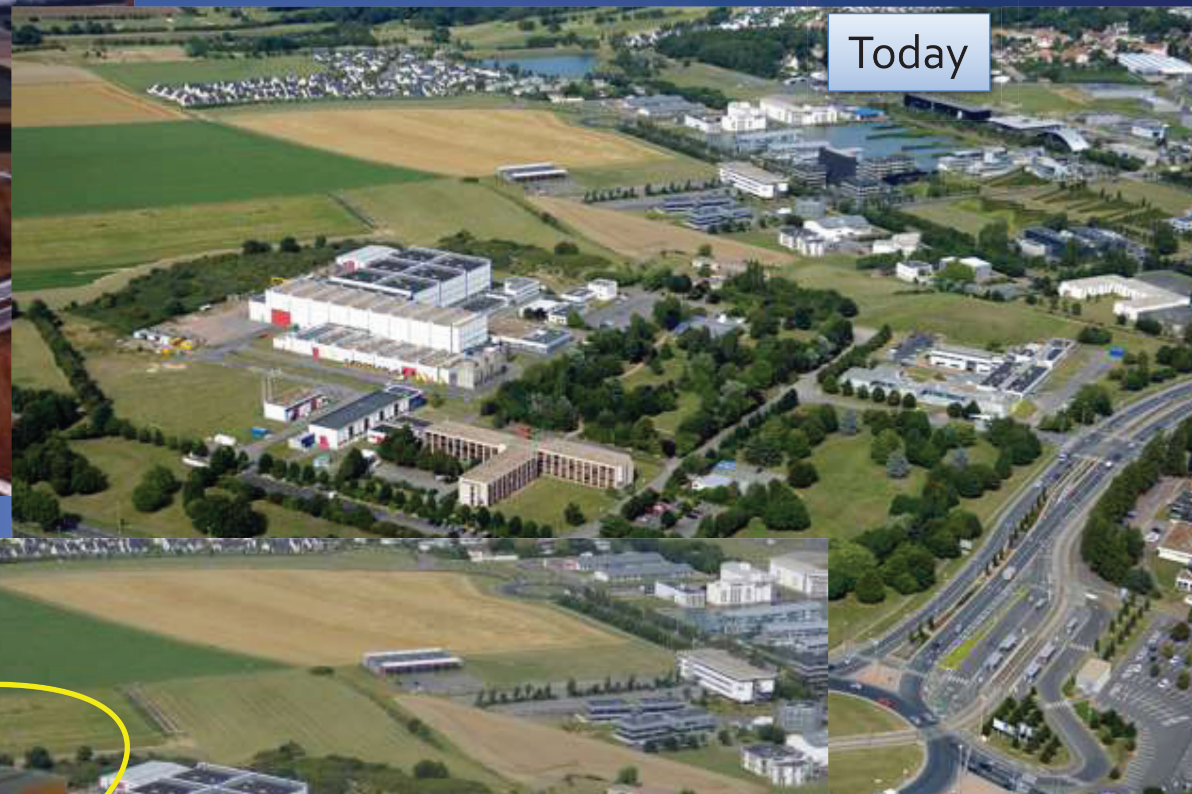
R. Ferdinand
P-E. Bernaudin, P. Bosland, M. Di Giacomo, Y. Gómez Martínez, G. Olry


1978


1978


Today
© Piel Jean-Marc





GANIL spiral2

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 132Sn, 10^{10} pps for 92Kr
- 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…)

GANIL spiral2

Regions of the Chart of Nuclei Accessible

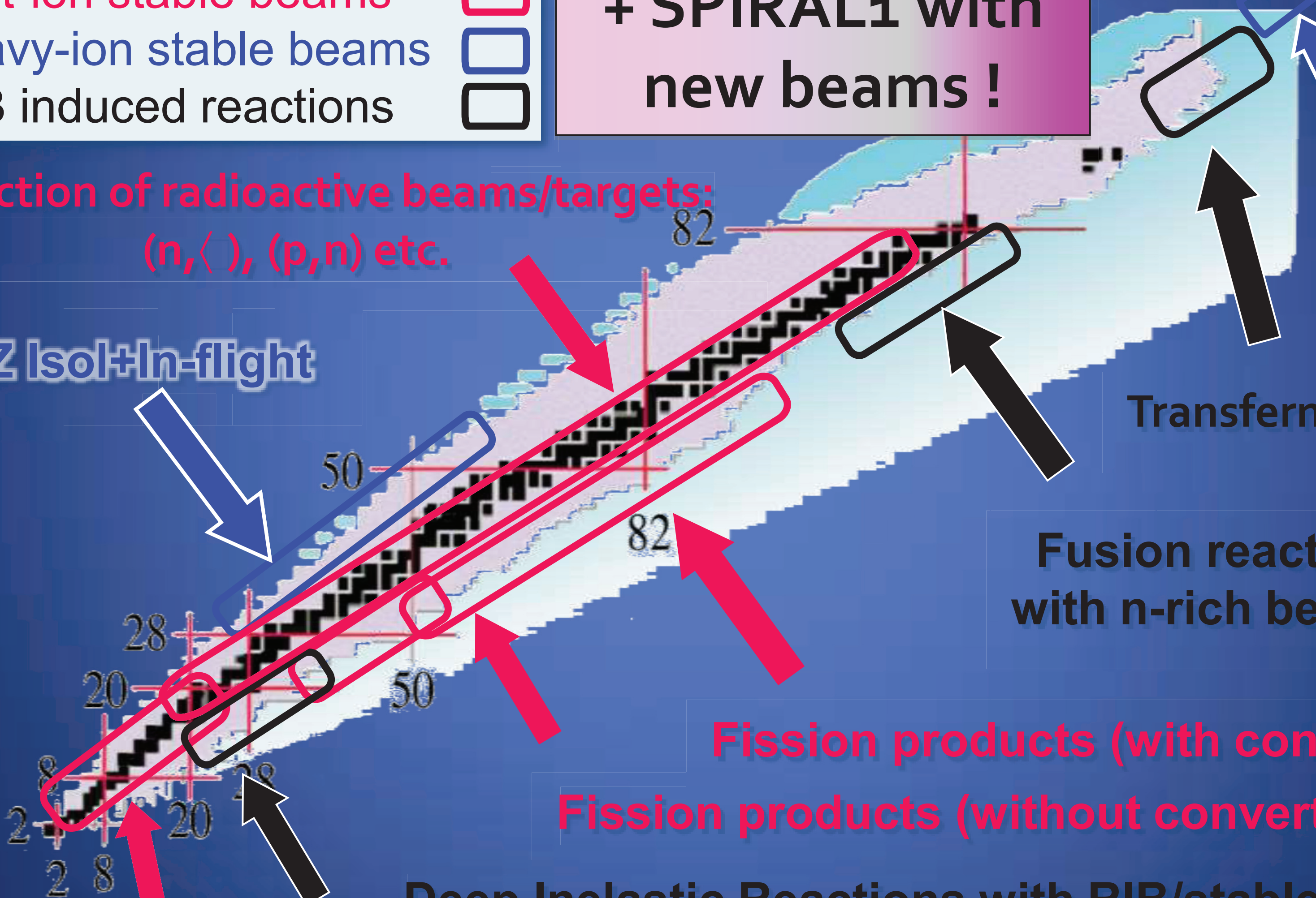
⇨light-ion stable beams
⇨heavy-ion stable beams
⇨RIB induced reactions

+ SPIRAL1 with new beams !

Production of radioactive beams/targets:
(n,〈), (p,n) etc.

N=Z Isol+In-flight

SHE



Transfermiums

Fusion reaction with n-rich beams

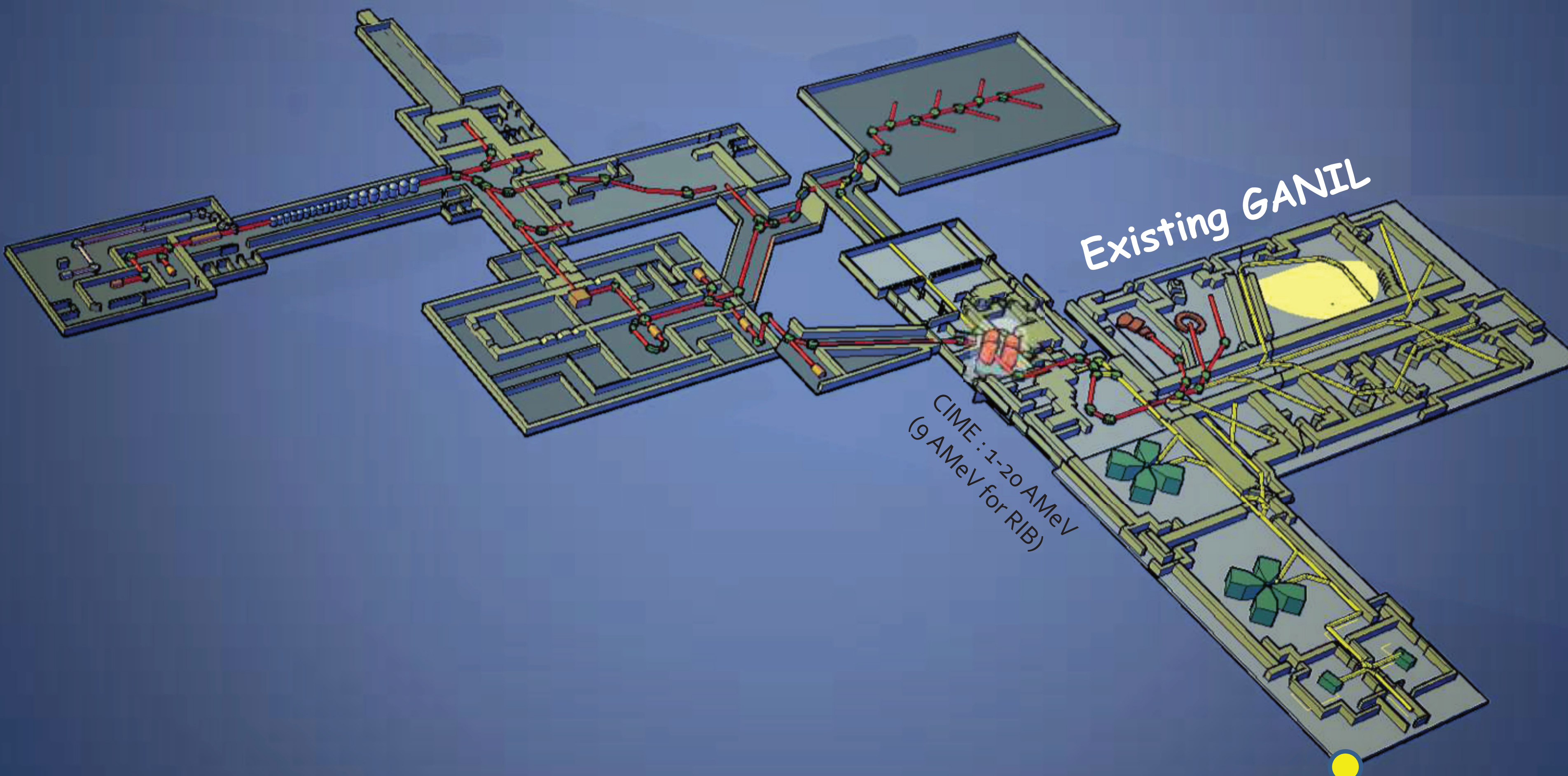
Fission products (with converter)

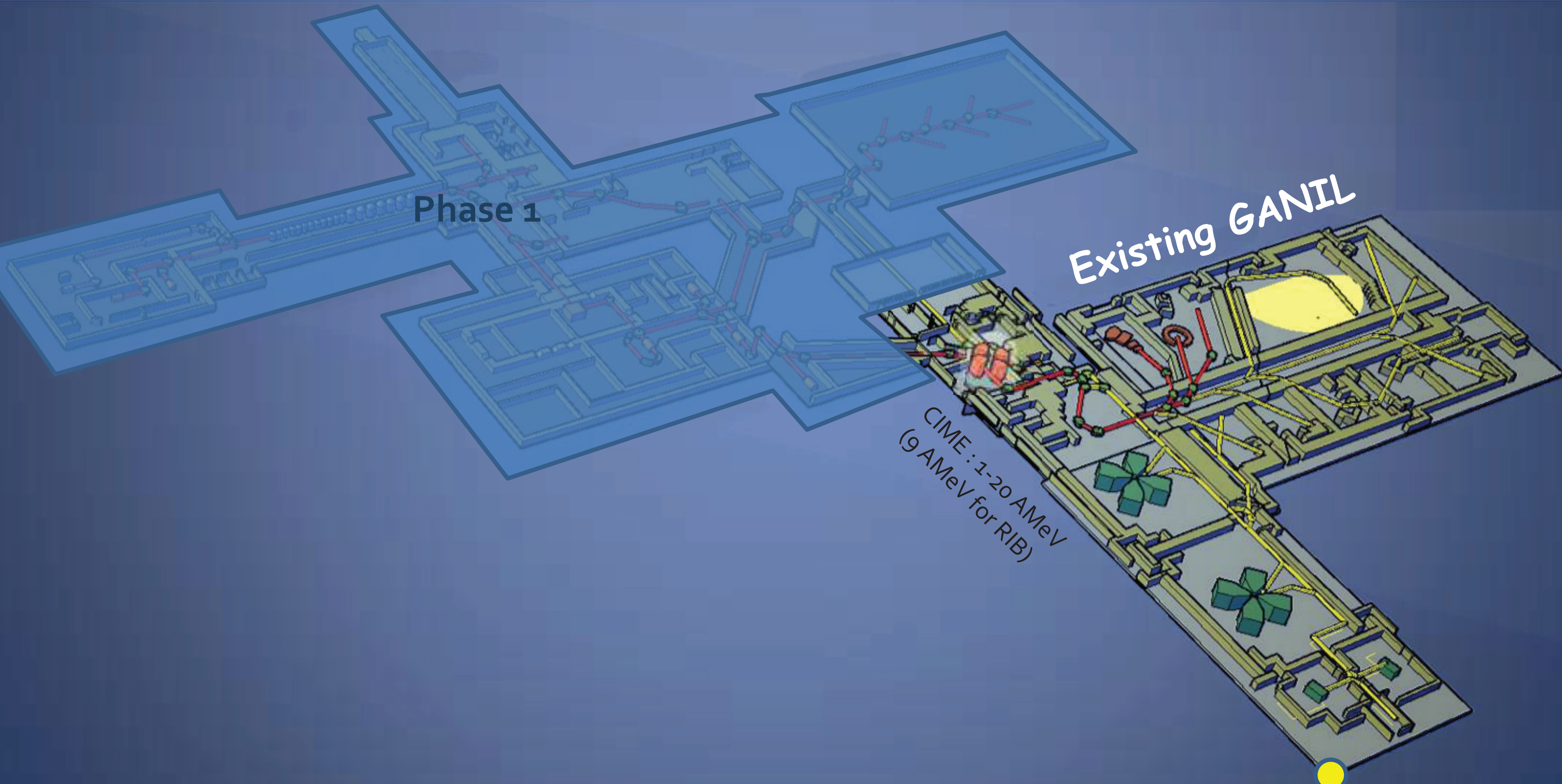
Fission products (without converter)

Deep Inelastic Reactions with RIB/stable beams

High Intensity Light RIB

Energy range of SPIRAL2 RIB : ≤ 60keV and 1-20 MeV/nucl.


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


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


Phase 1
Phase 2
Existing GANIL
CIME : 1-20 AMeV
(9 AMeV for RIB)

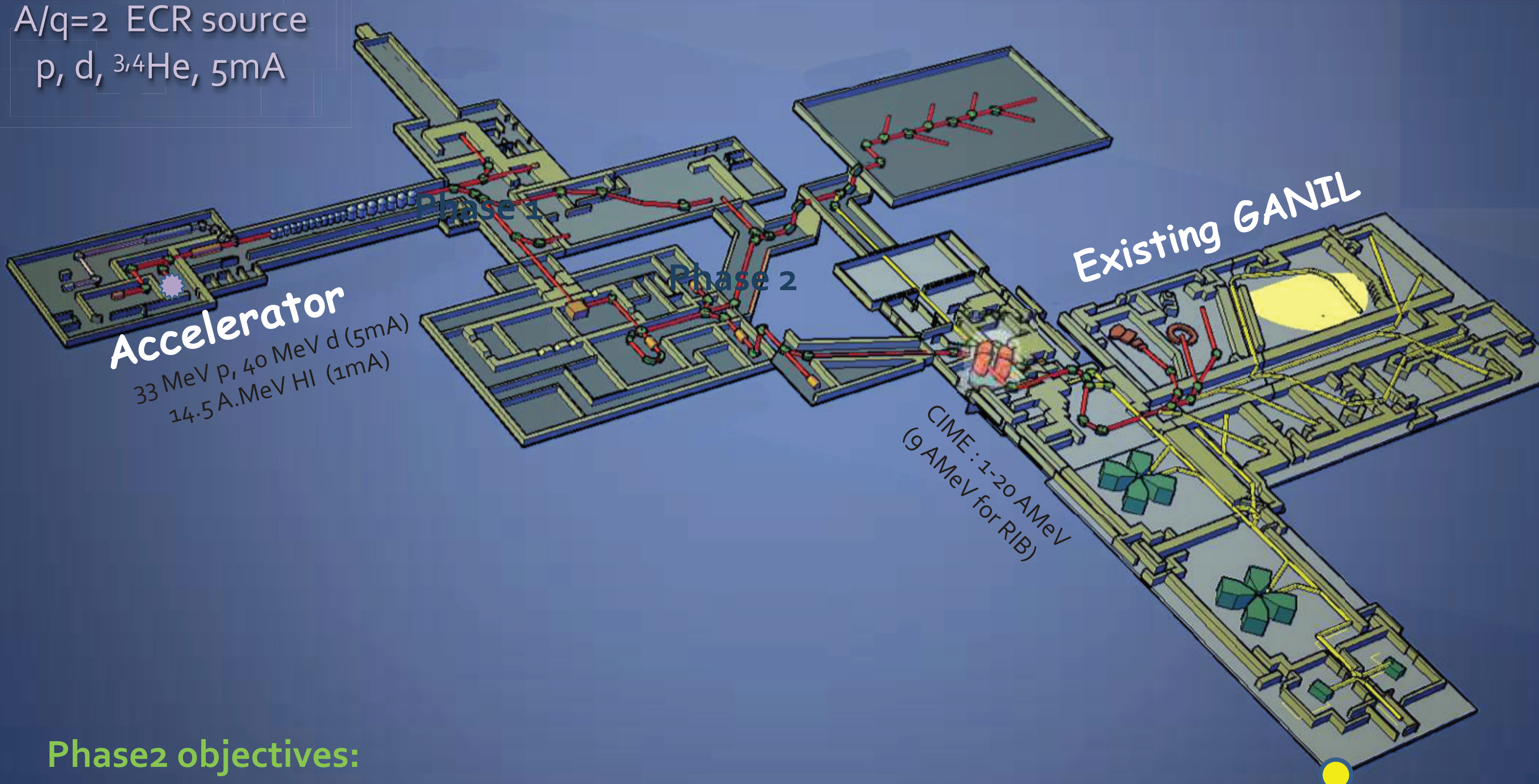
Phase1 objective:
Increasing the stable beam power by a factor 10 to 100

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

DESIR (very low energy studies)



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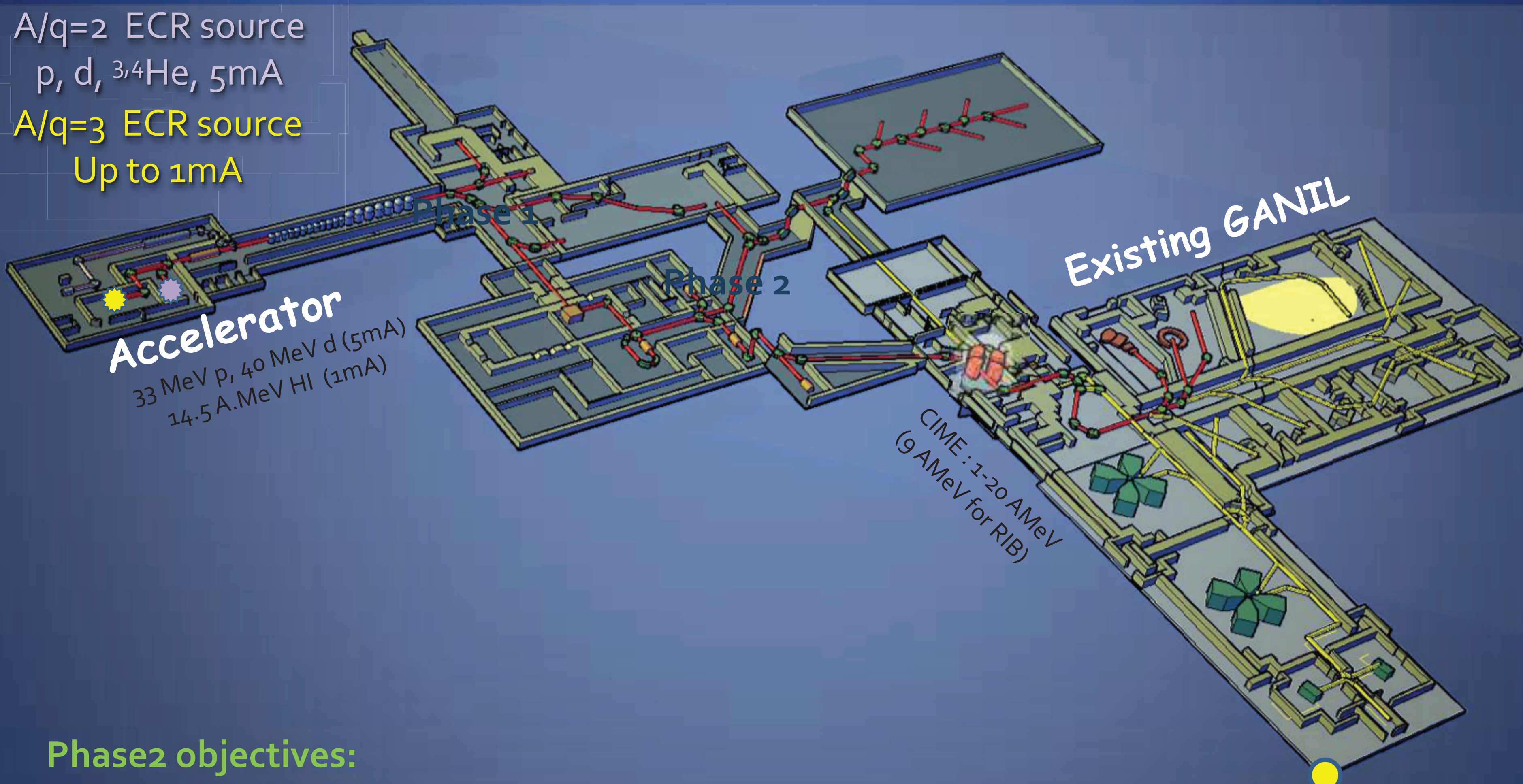

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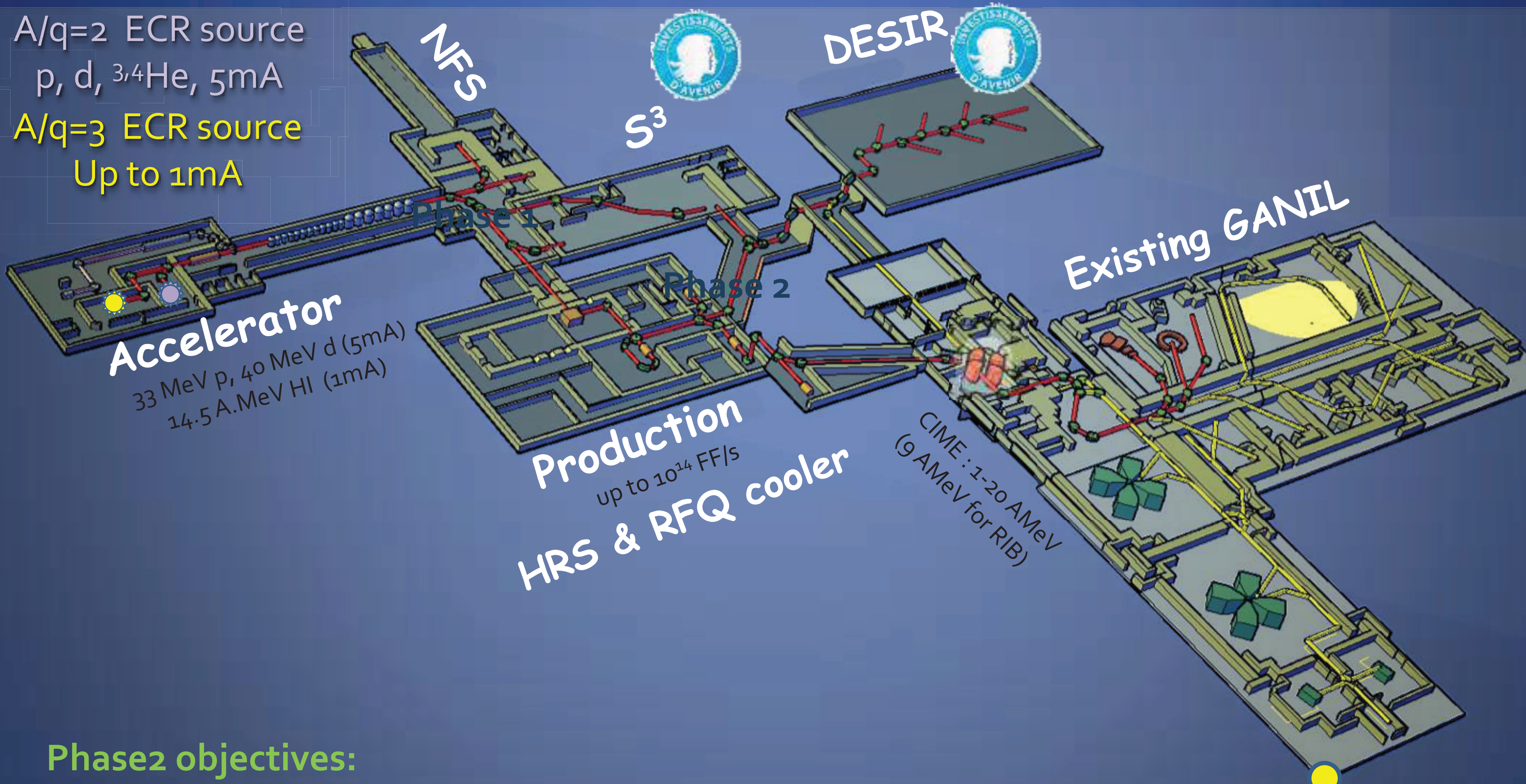
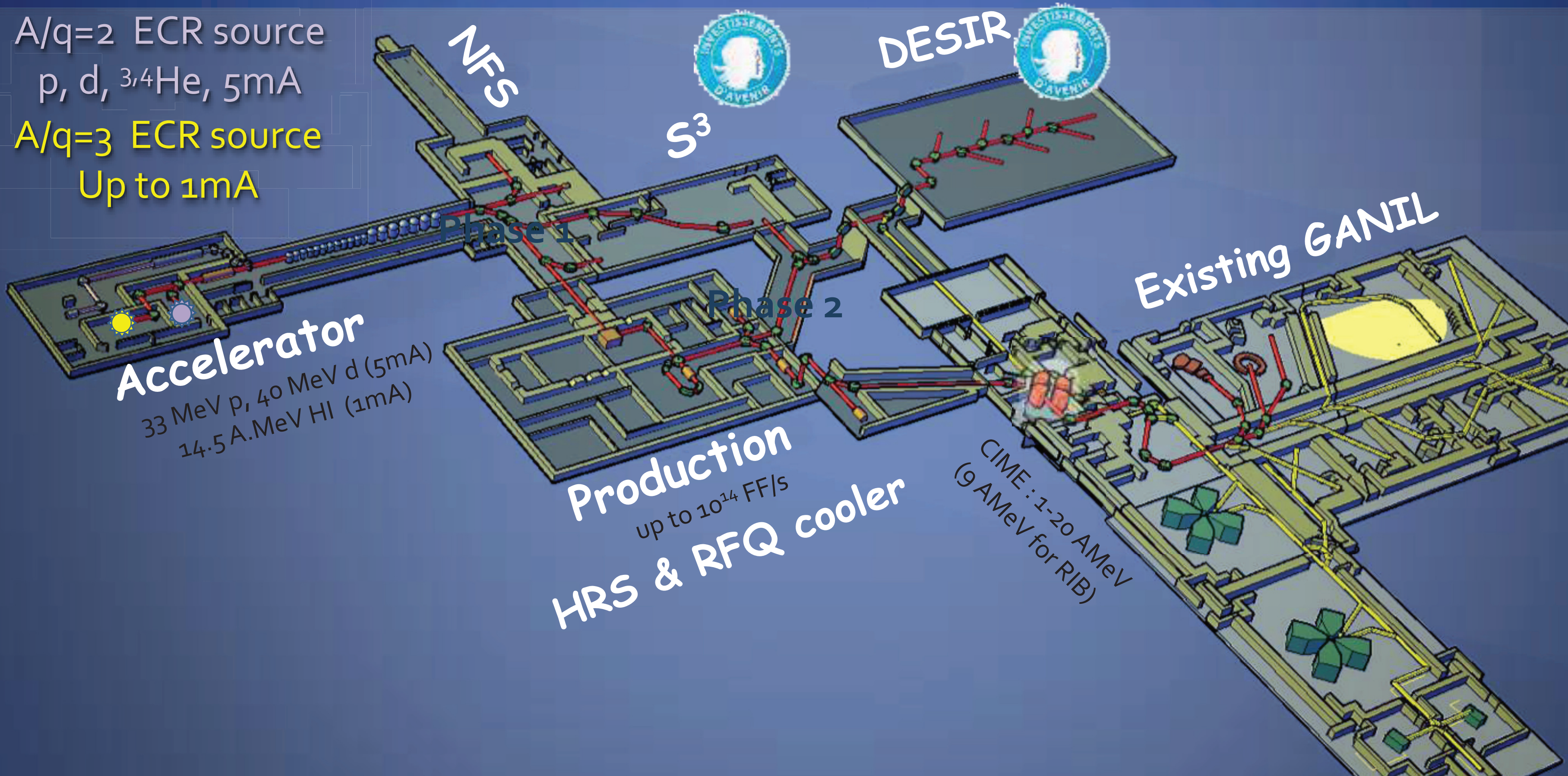


Phase2 objectives:

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

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

Nominal operation of GANIL/SPIRAL2:
- ✓ up to 79 weeks/y of stable-ion beams
- ✓ up to 53 weeks/y of RIB
- ✓ up to 5 beams (2 RIB) simultaneously
- ✓ 800-900 users



Phase2 objectives:
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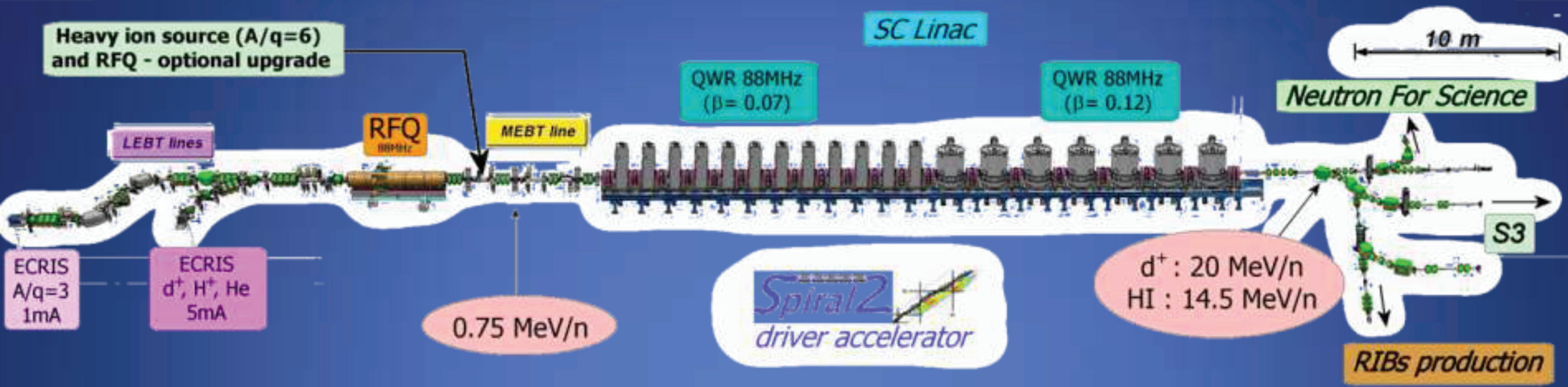
GANIL spiral2

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

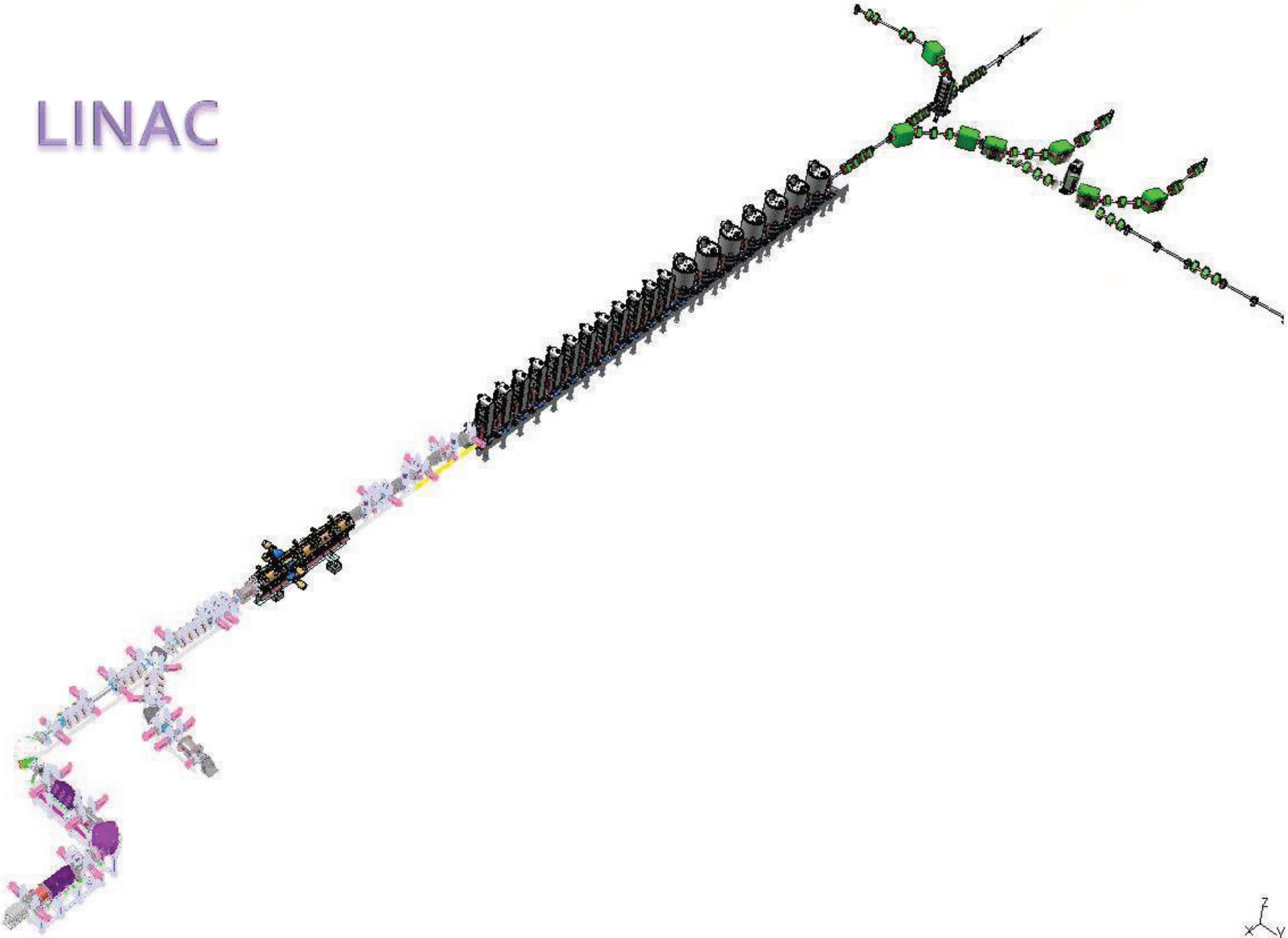
12 QWR beta 0.07 (12 cryomodules)
14 (+2) QWR beta 0.12 (7+1 cryomodules)
1.1 kW Helium Liquifier (4.5 K)
Room Temperature Quadrupoles
Solid State RF amplifiers (10 & 20 KW)
6.5 MV/m max $E_{acc} = V_{acc}/(\beta_{opt}\lambda)$ with $V_{acc}=\int E_z(z)e^{i\omega z/c}dz$.

SPIRAL2 Challenges

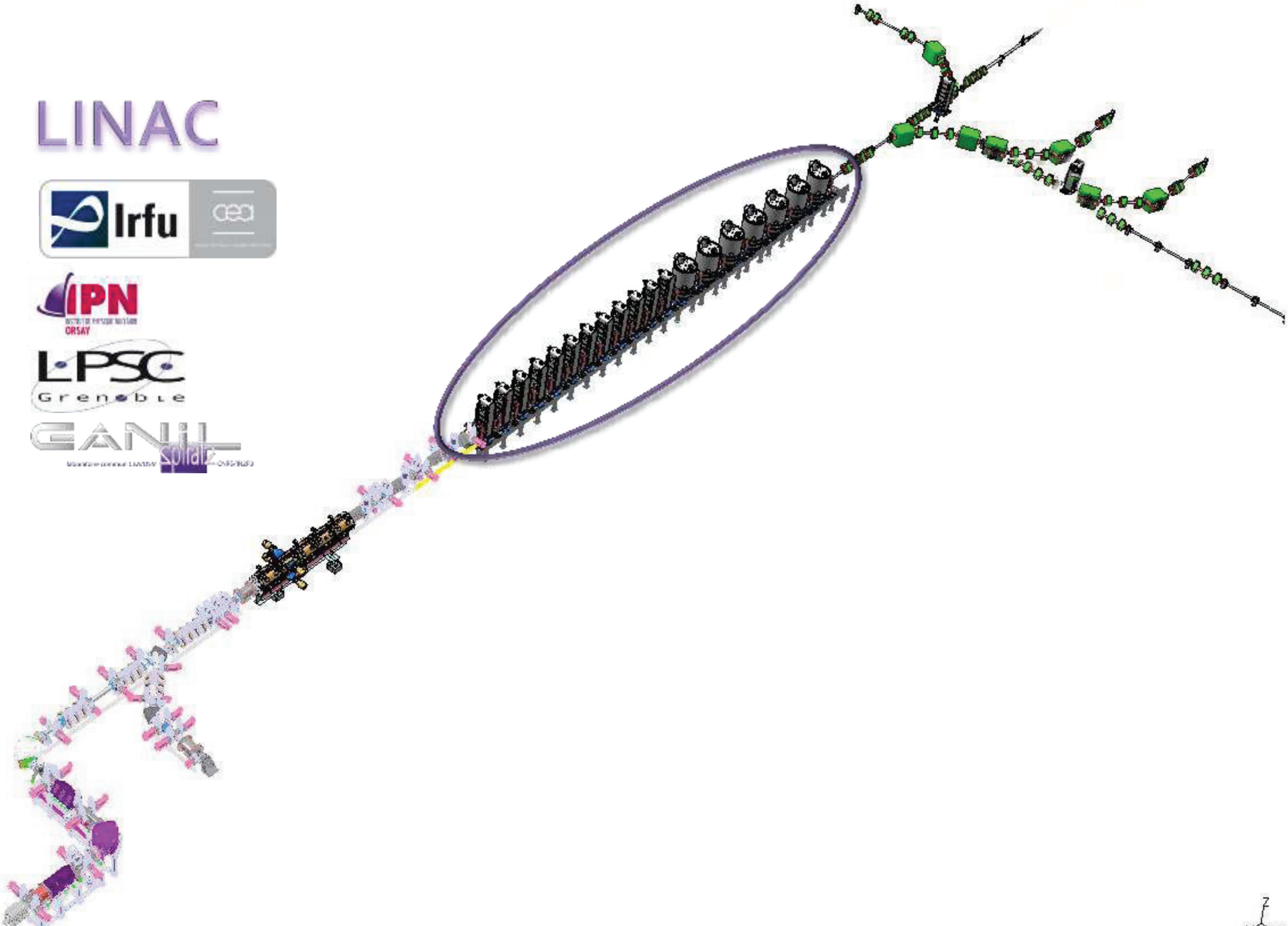
- Huge number of different beams
  - Intensities (diagnostics), energies (cavities and RF), particles (facility operation, safety)
- Accelerator components
  - Heavy Ion source (1mA Ar^{12+})
  - RFQ transmission + frequency (88MHz) → tolerances
  - Cryomodules
    - 6.5 MV/m in operation
    - Separate 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

GANIL spiral2

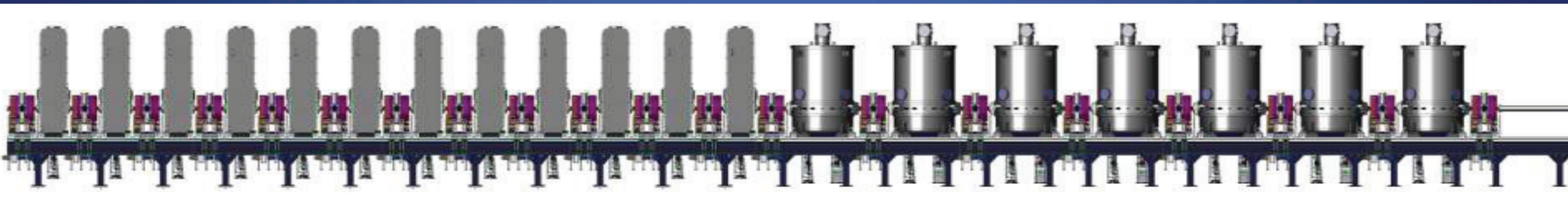
LINAC



LINAC

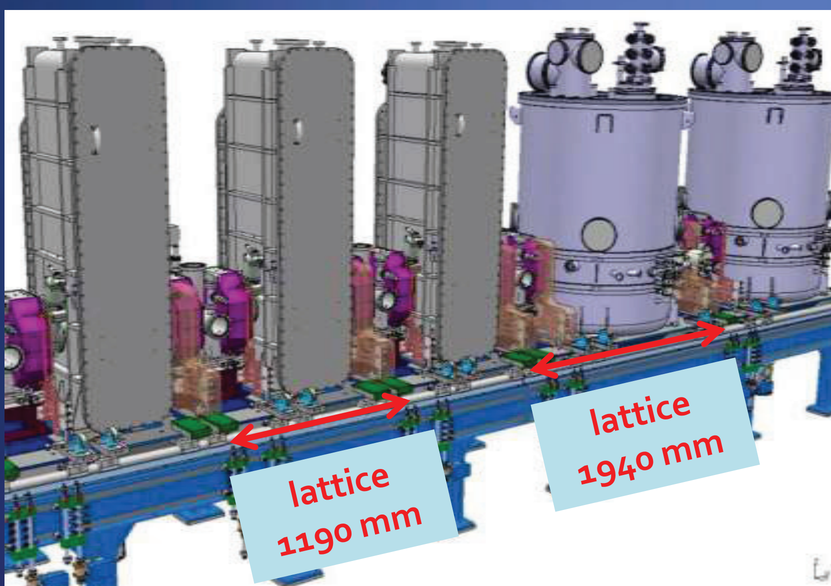


SC LINAC



Beta 0.07 energy section **Beta 0.12 energy section**

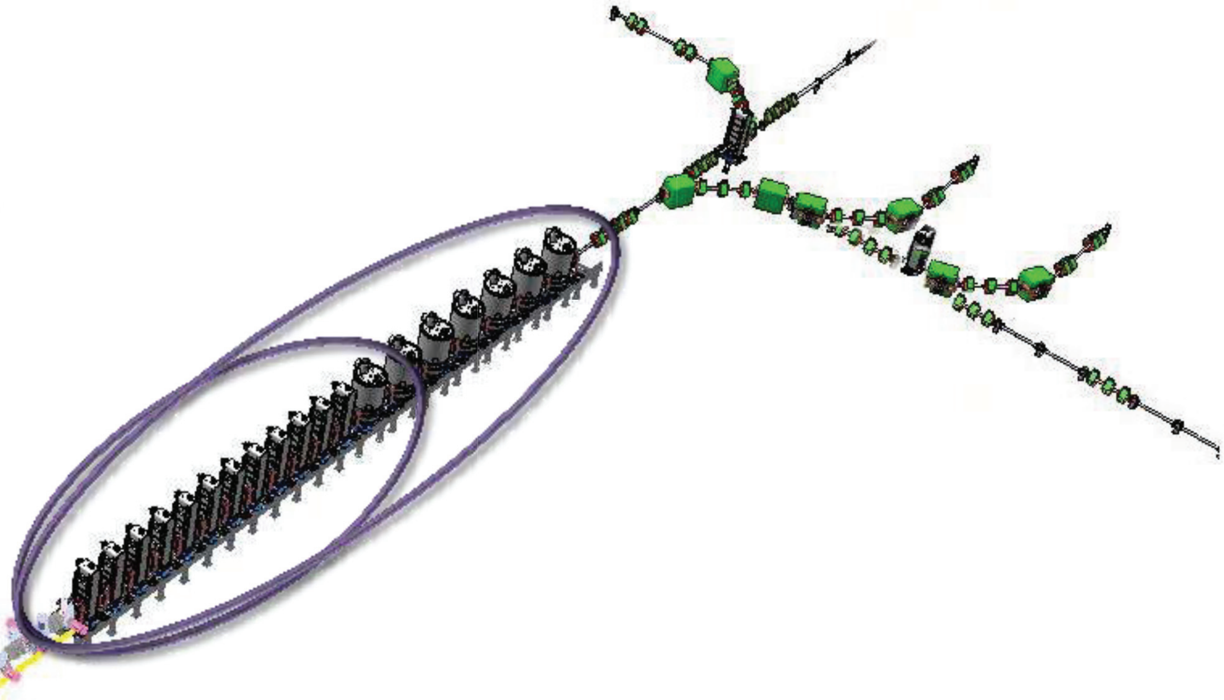
L≈32 m



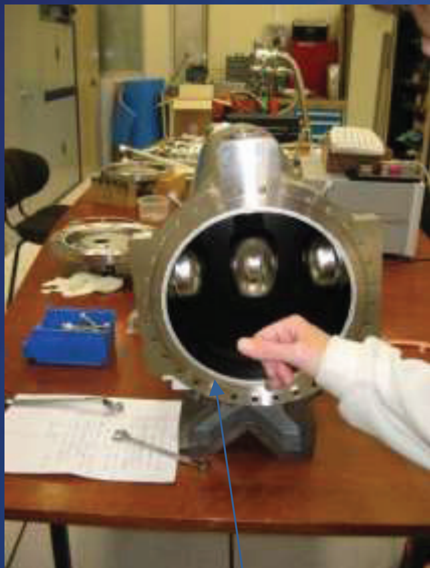
Cryomodule A	Cryomodule B	Power coupler
CEA Saclay	IPN Orsay	LPSC Grenoble

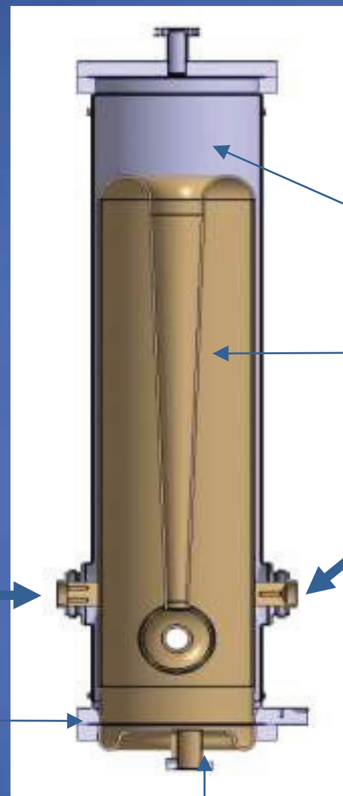
Cryomodule	A	B
Valve-to-valve length [mm]	610	1360
# cavities	12	14
f [MHz]	88.05	88.05
β_{opt}	0.07	0.12
Epk/Ea	5.36	4.76
Bpk/Ea [mT/MV/m]	8.70	9.35
r/Q [Ω]	599	515
Vacc @ 6.5 MV/m & β_{opt}	1.55	2.66
Lacc [m]	0.24	0.41
Beam tube ∅ [mm]	38	44

LINAC – CMA
β = 0.07



Low beta cavity design





P_{cav} < 10 W @ 6.5 MV/m

P_{Cu} ~ 1.5 W @ 6.5 MV/m

Stainless steel LHe tank

Bulk niobium cavity

Tuning system applicators

Indium gasket

Removable bottom plate (in copper)

f [MHz]	88.05
β_{opt}	0.07
E_{pk}/E_{acc}	5.36
B_{pk}/E_{acc} [mT/(MV/m)]	8.70
r/Q [Ω]	599
V_{acc} @ 6.5 MV/m & β_{opt}	1.55
L_{acc} [m]	0.24
Beam tube ∅ [mm]	38

- End plate sealing
  - *Motivation:* numerous leakage with helicoflex seal
  - *Advantage:* no leaks anymore, slightly better Q_0
  - *Disadvantage:* indium is difficult to remove/clean → no HPR after VC

Cryogenic changes

- Porous metallic plates ("Poral") in pyramidal shape to optimize helium phase separation + return of helium gas displaced for the thermosiphon
  - *Motivation:* cryogenic instability, helium level regulation difficult
  - *Advantage:* cryogenic system is now stable, no more "fake" losses

Cryogenic changes

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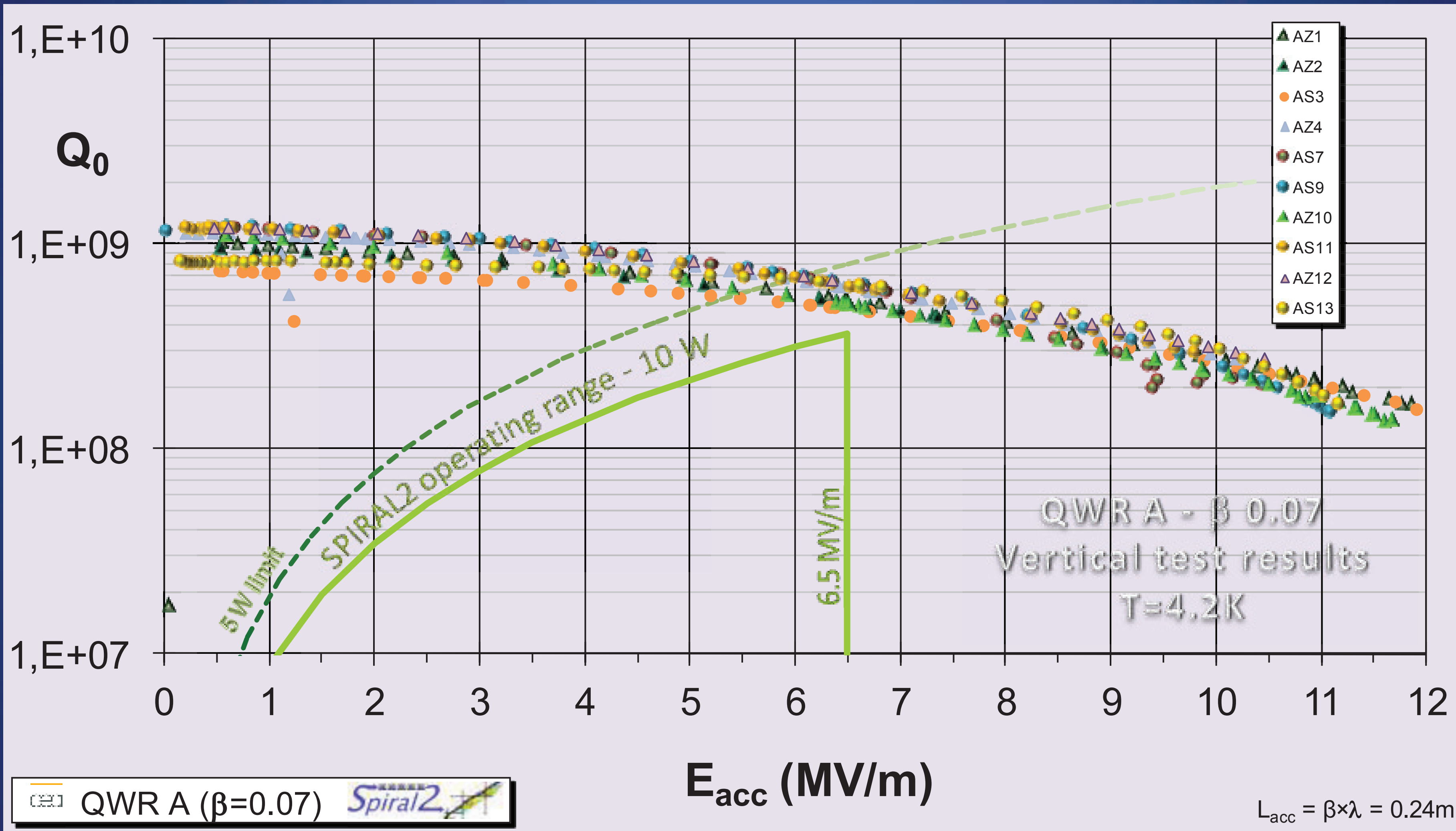
  - *Motivation:* cryogenic instability, helium level regulation difficult
  - *Advantage:* cryogenic system is now stable, no more "fake" losses

Low beta cavity status

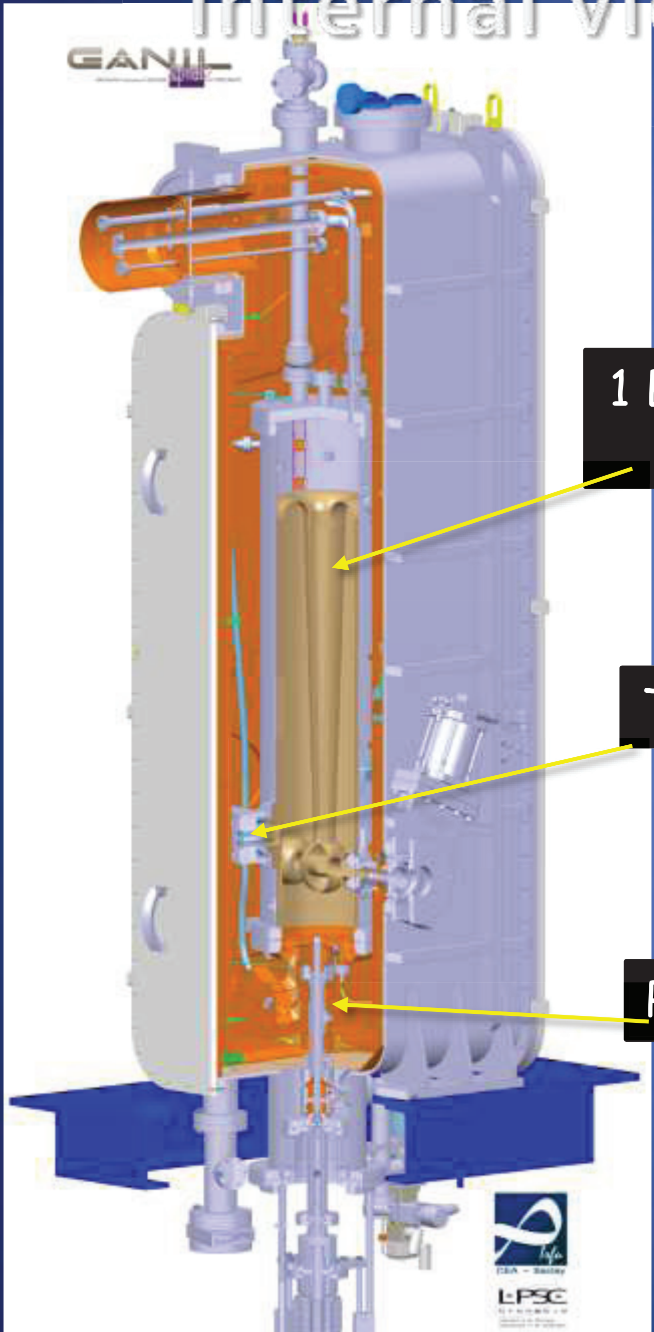
- All cavities received and tested
- The spare cavity under repair
- Copper bottom cap and Indium seal
- Qi : $5{,}8.10^{5}$ to $1.1.10^{6}$
- Qt : $2{,}4.10^{10}$ to $5.3.10^{10}$

Zanon and SDMS cavities

Low beta cavity status



Internal view of a cryomodule A



1 Beta 0.07 QWR per module

Tuning system

Power coupler

Cryomodule A general design

Vacuum vessel

Magnetic shield (against the vacuum vessel wall)

Cryogenic connections (towards valves box)

Super-insulation

Tuning system

Beam gate valves (metal)

60K thermal screen

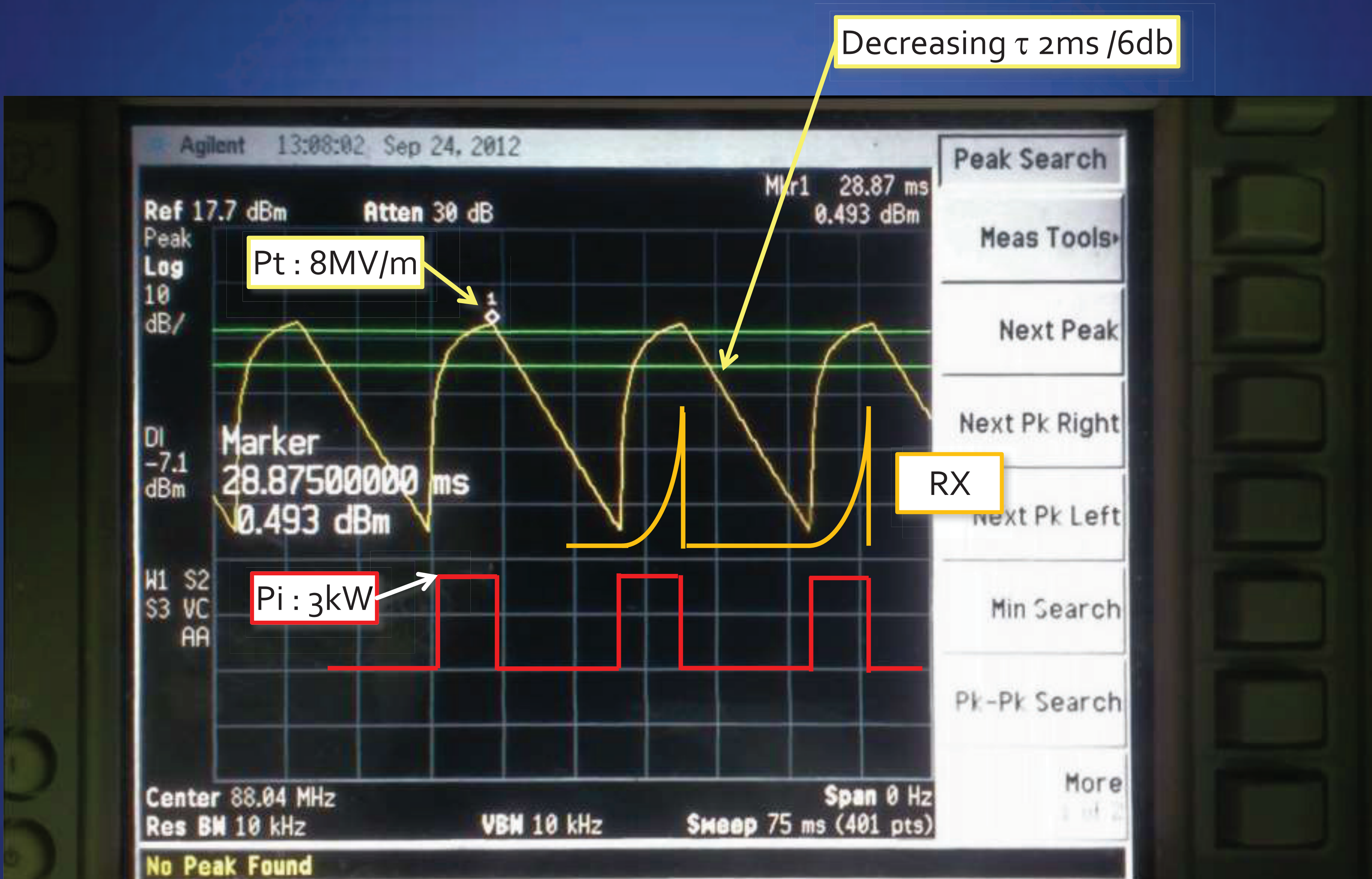
Specifications:

- Separate vacuum
- Static losses < 11 W
- Dynamic losses < 10 W per cavity for E_{acc} 6.5 MV/m

CMA conditioning method

- RF conditioning is required (coupler extremity)
- Room temperature up to 10kW, cw (≈1h)
- Again at 4.5k, cavity detuned
- Cavity tuned
  - up to 4 MV/m in CW mode, limited by RX
  - kind of High Peak Power Processing, 50Hz
  - Duty cycle is limited to level accepted by the cryogenics (≈15 to 30%)
  - RF power to ignite the electronic emission sites, at the quench limit.
  - Rise progressively Pi up to full power (8-10kW), field at the end up to 8 to 10MV/m

Thanks to Luc Maurice



For CMA3 pulse operation last 30 min from 4 to 8MV/m

Some CMA tests results

- Sequential cooling (thermal shield cooled down first during 1 day)
- Cavity cool down 250K→4K: < 1 hour (except cavity bottom)
- Mean static losses: 4.3 W (Specs <8.5W)
- Mean total CM losses @ 6.5MV/m : 15 W (Specs <20.5 W)
- Mean total CM losses @ 7.8MV/m : 30 W
- LLRF system successfully tested on cryomodule, very low µphonics
  - Stiff cavities
  - -1.3 Hz/mbar

Some CMA tests results

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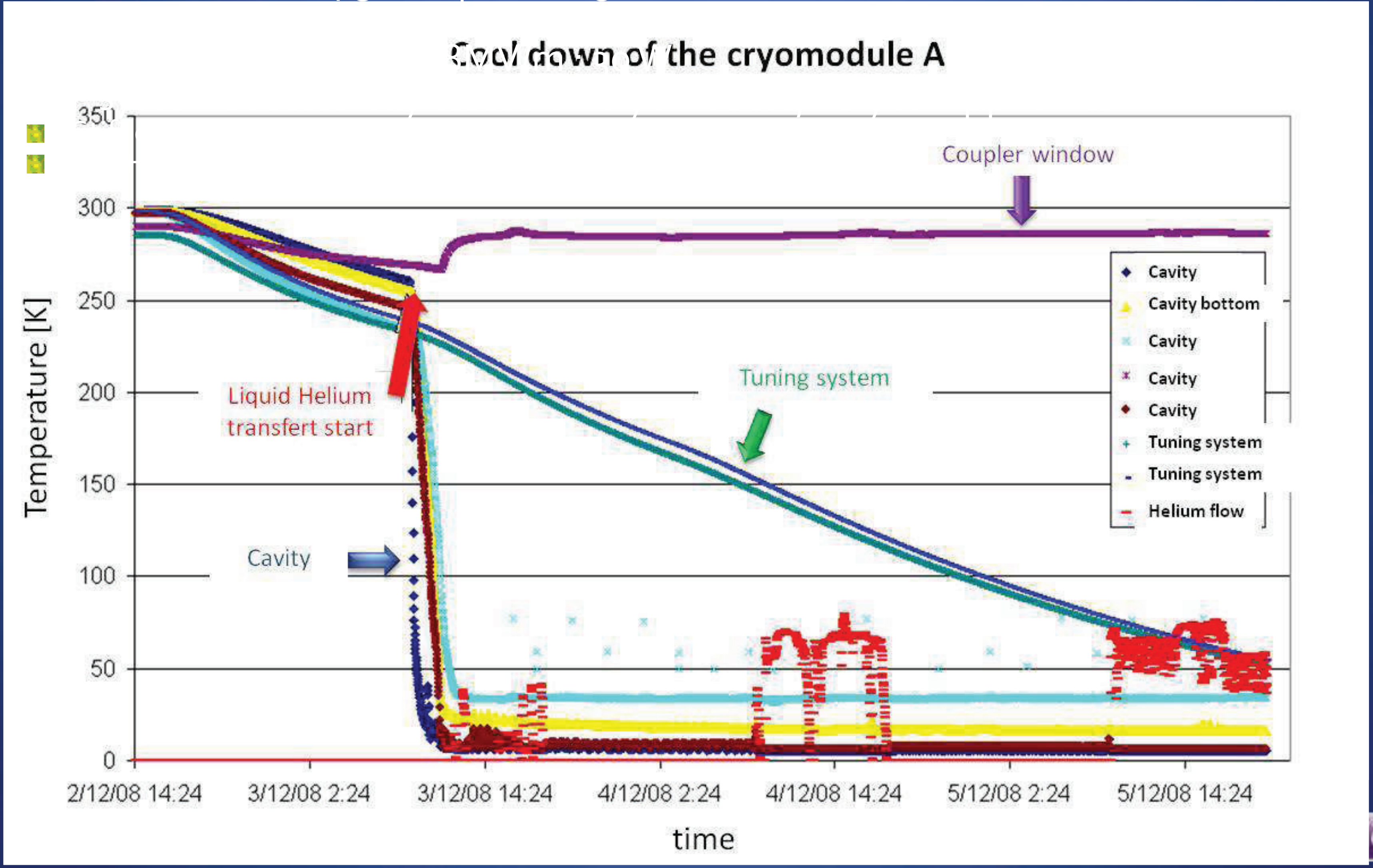
- Cavity cool down 250K→4K: < 1 hour (except cavity bottom)
- Mean static losses: 4.3 W (Specs <8.5W)



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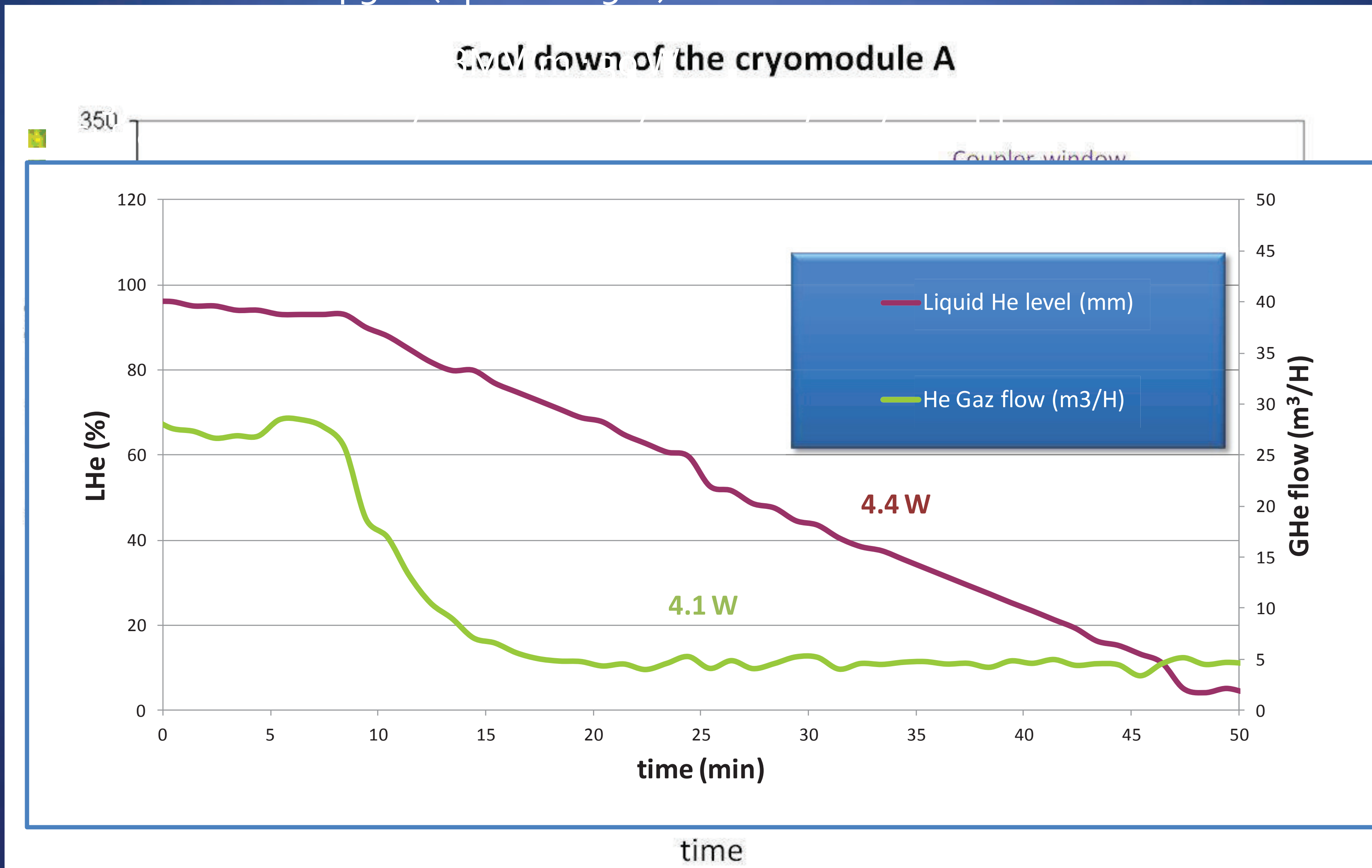
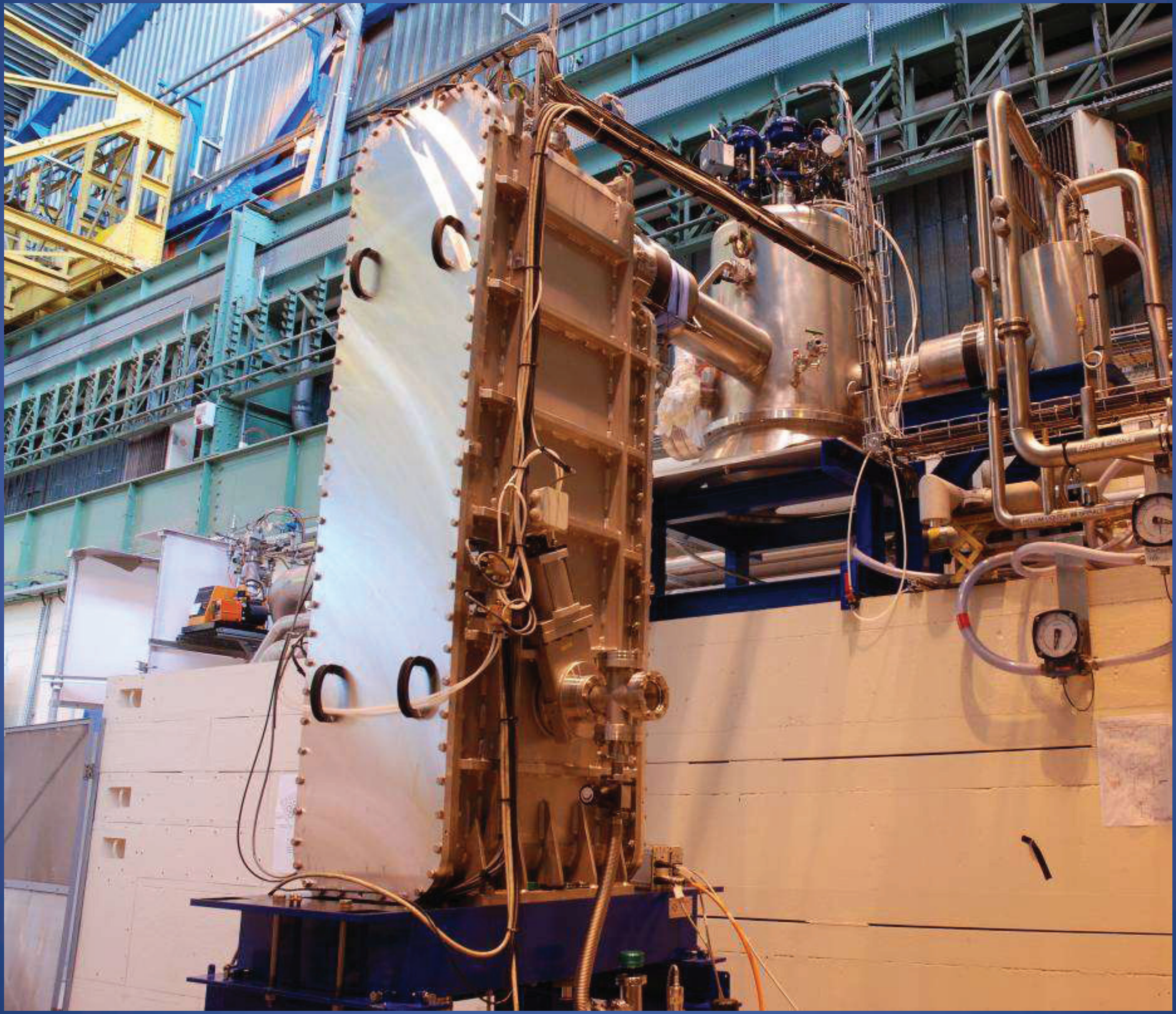


Cryomodules A - $\beta = 0.07$



CMA test stand in Saclay

CMA status

- Cavities :
  - All cavities qualified
  - spare cavity being repaired by manufacturer
- Cryostats :
  - Eight cryomodules assembled, 6 tested
  - All CMA to be delivered to GANIL before end 2013

LINAC – CMB
$\beta = 0.12$

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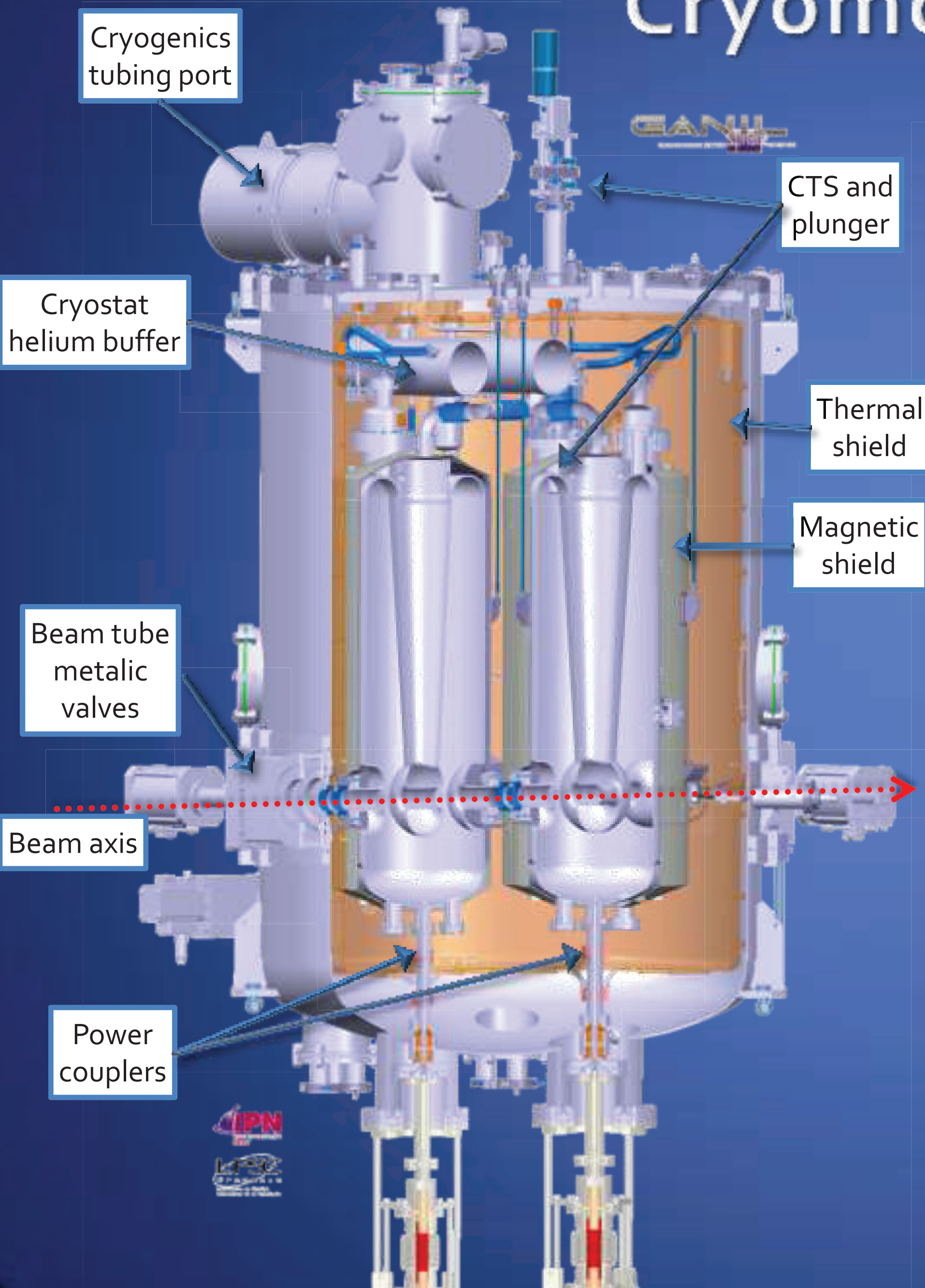
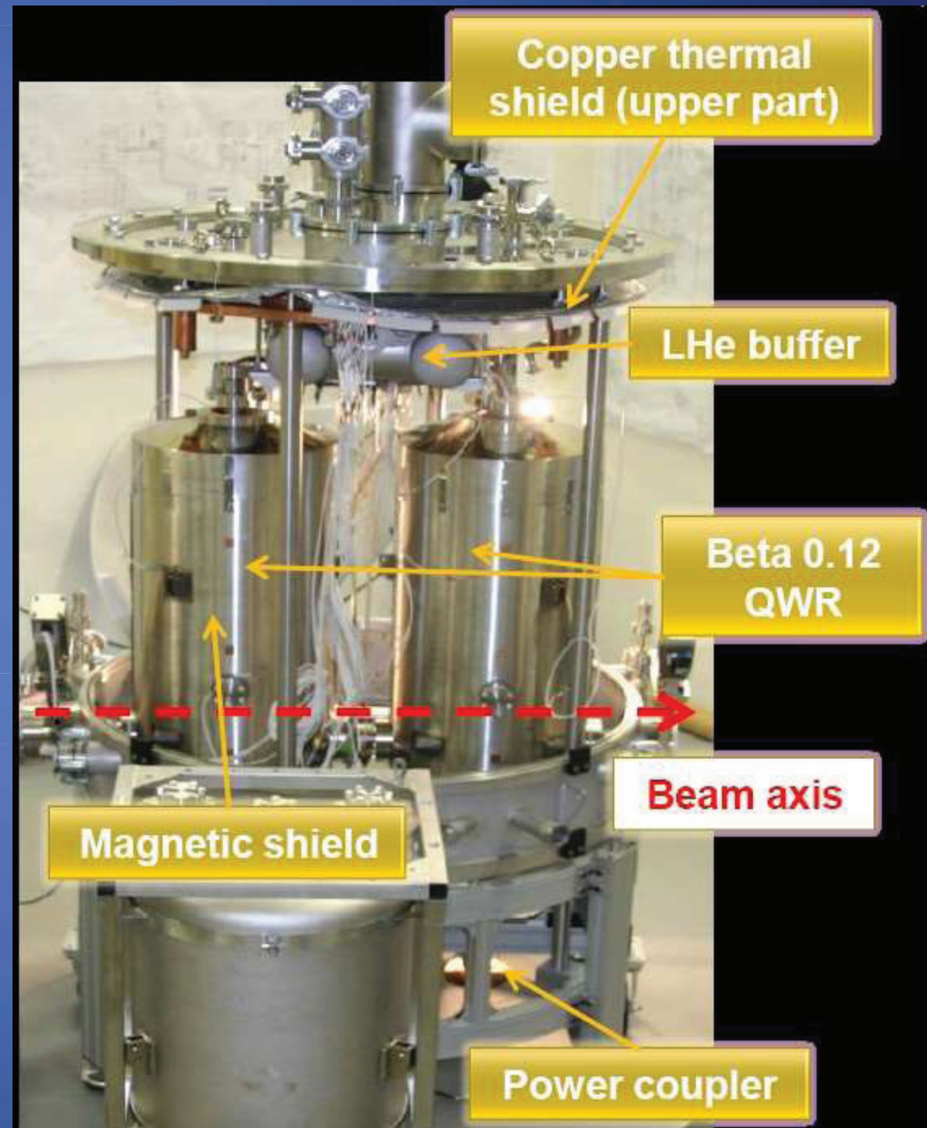
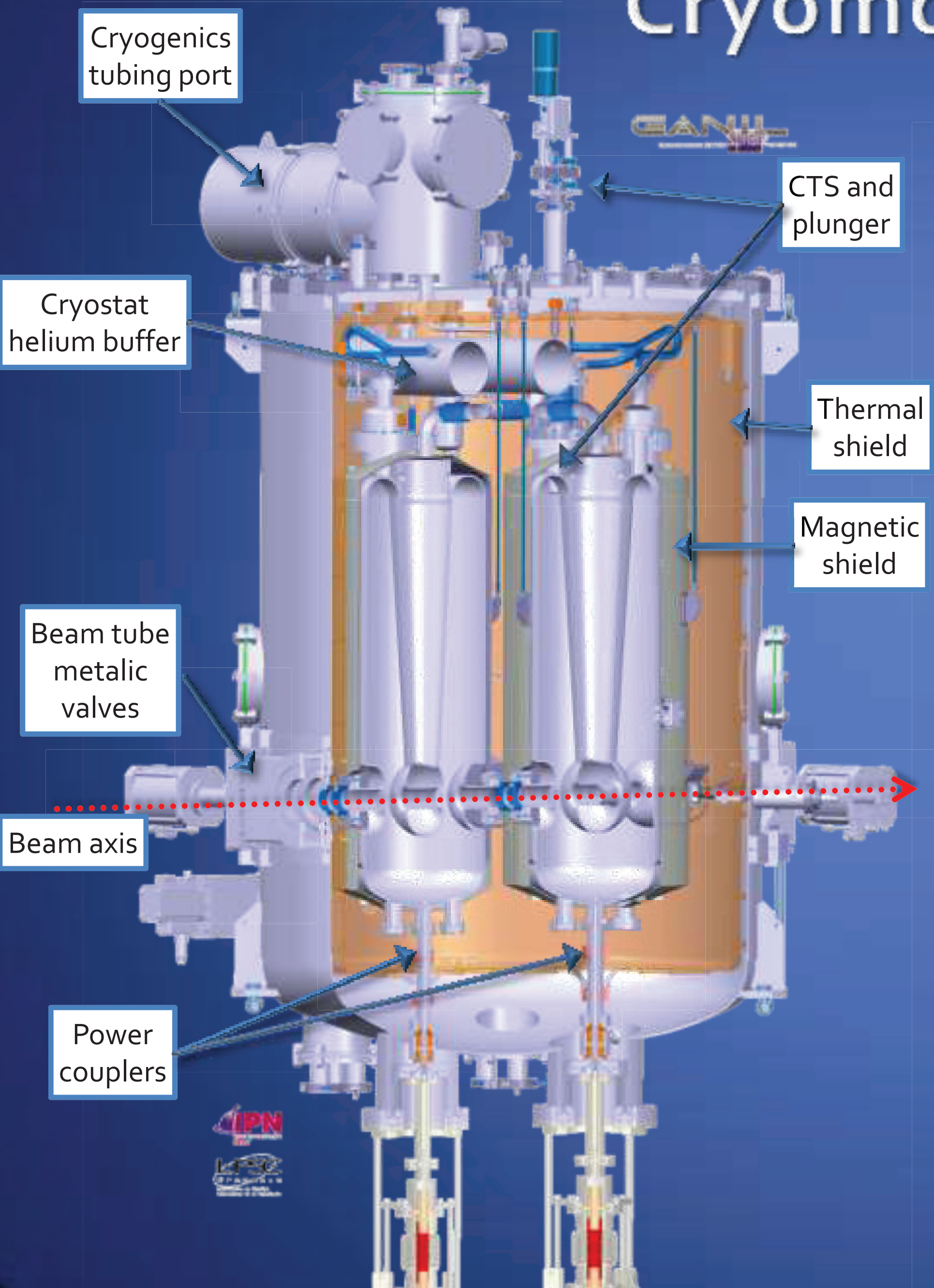
ORSAY

Cryomodule B





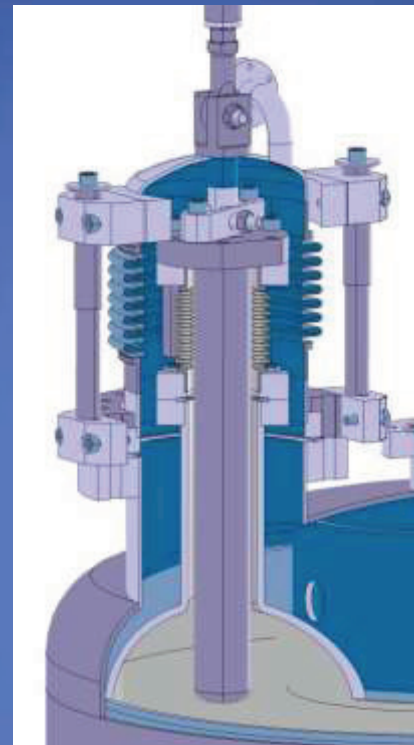
Cryomodule B



Specifications:

- Separate vacuum
- Alignment from outside
- Static losses < 11 W
- Dynamic losses < 10 W per cavity for E_{acc} 6.5 MV/m

High beta cavity design



Tuning system

- Welded bottom end
- Titanium LHe tank
- Plunger based tuning system

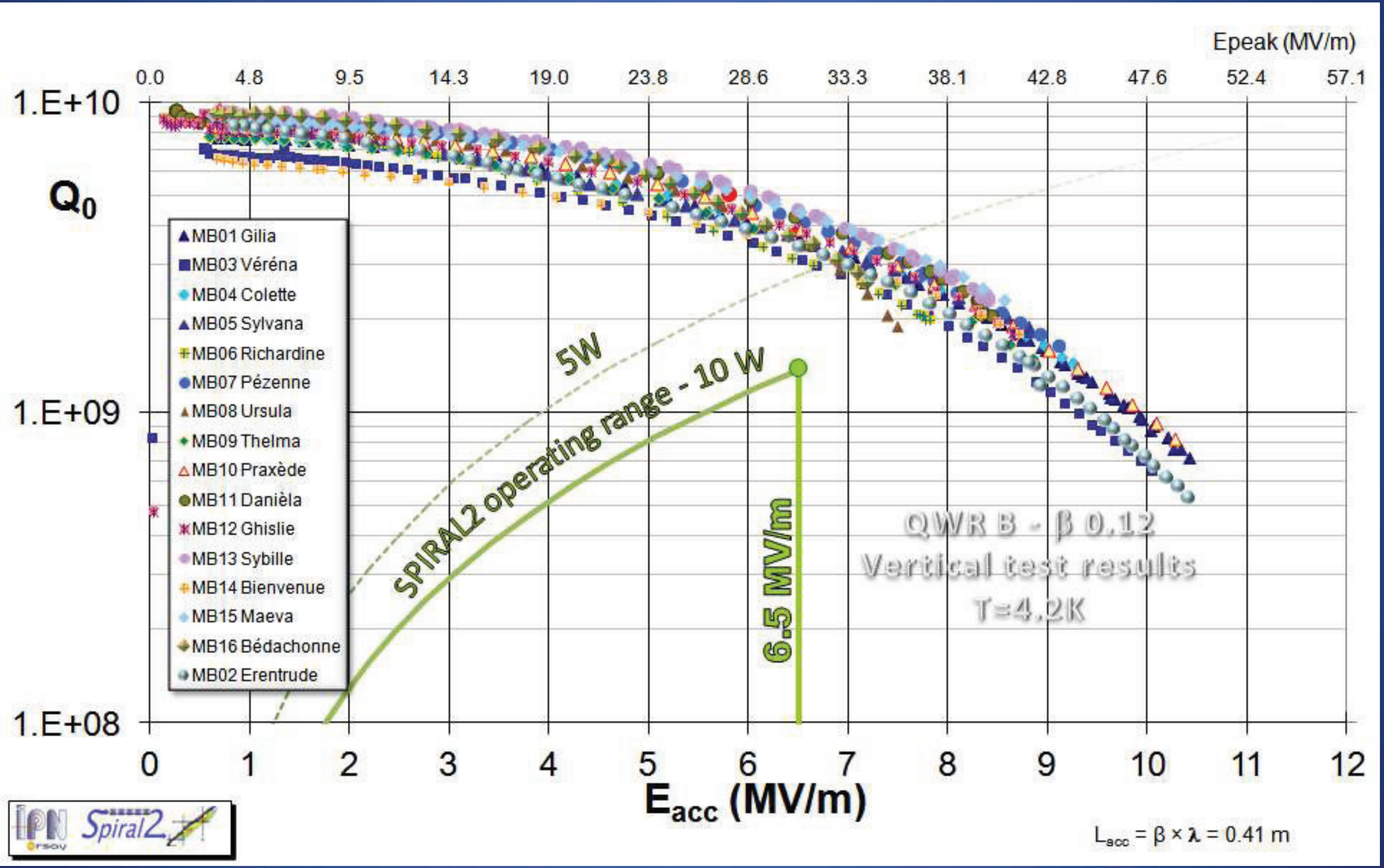
f [MHz]	88.05
β_{opt}	0.12
E_{pk}/E_{acc}	4.76
B_{pk}/E_{acc} [mT/(MV/m)]	9.35
r/Q [Ω]	515
V_{acc} @ 6.5 MV/m & β_{opt}	2.66
L_{acc} [m]	0.41
Beam tube $\varnothing$ [mm]	44

CMB status

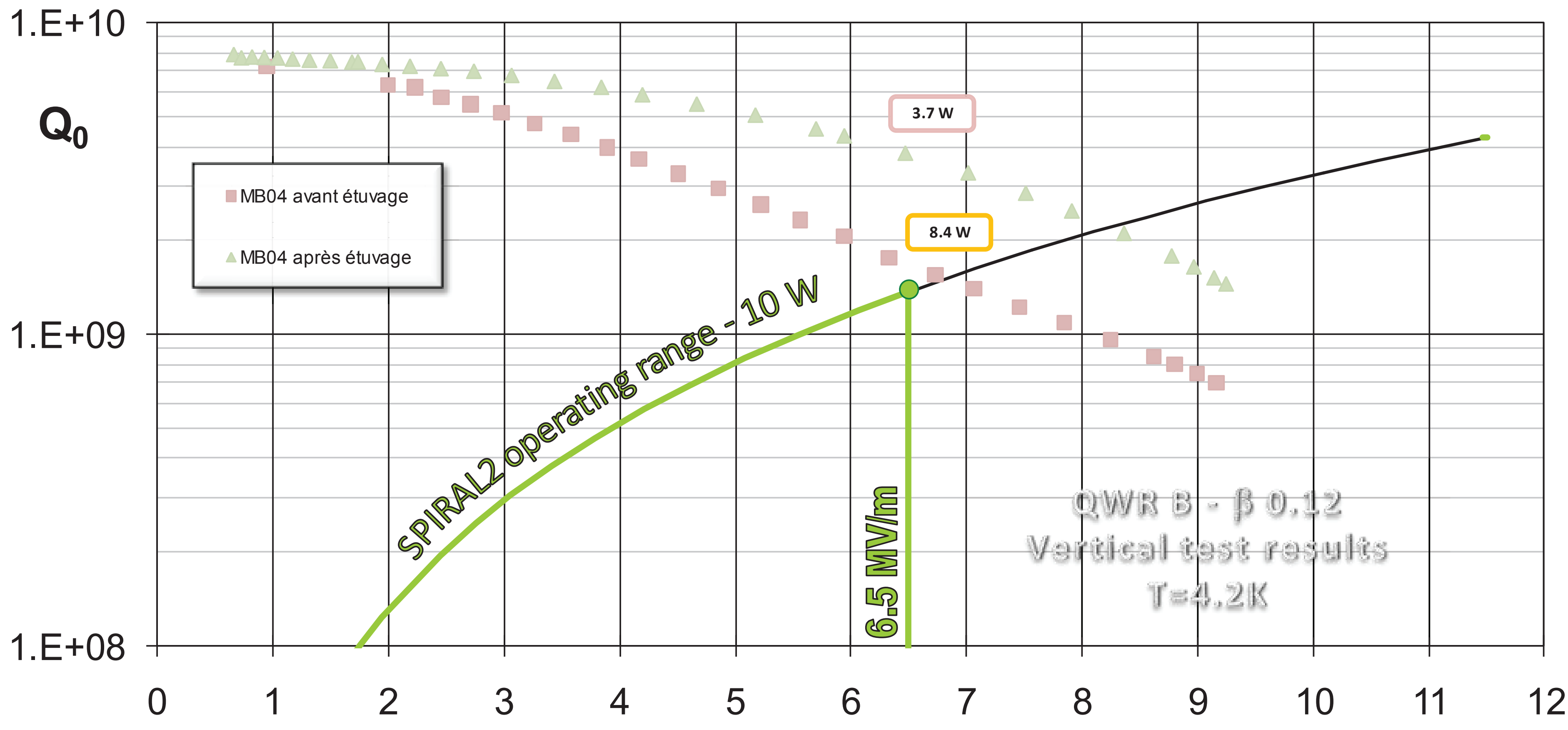
- Company RI GmbH selected for the 16 series cavities (14 needed at first)
  - **All** cavities delivered
  - **All** cavities tested, with specs OK
  - Chemistry done in Orsay
  - Only one cavity needed repair (too high in frequency at first, local chemistry in H field area)
- Cryostats all manufactured by SDMS

CMB status

CMB status


Epeak (MV/m)
0.0
4.8
9.5
14.3
19.0
23.8
28.6
33.3
38.1
42.8
47.6
52.4
57.1
1.E+10
1.E+09
1.E+08
Q_0
MB01 Gilia
MB03 Véréna
MB04 Colette
MB05 Sylvana
MB06 Richardine
MB07 Pézenne
MB08 Ursula
MB09 Thelma
MB10 Praxède
MB11 Danièla
MB12 Ghislie
MB13 Sybille
MB14 Bienvenue
MB15 Maeva
MB16 Bédachonne
MB02 Erentrude
5W
SPIRAL2 operating range - 10 W
6.5 MV/m
QWR B - β 0.12
Vertical test results
T=4.2K
0
1
2
3
4
5
6
7
8
9
10
11
12
E_{acc} (MV/m)
$L_{acc} = \beta \times \lambda = 0.41$ m
Spiral2

Baking



$L_{acc} = \beta \lambda = 0.41$ m

2 days @ 110°C

Some CMB tests results

- 2011 tests: pollution (X rays near cavity >100 mSv/h)
- Latest test showed good results (rust parts and new coupler preparations)
- Had some concern with “negative backlash” of tuning system: due to mechanics. Solved.

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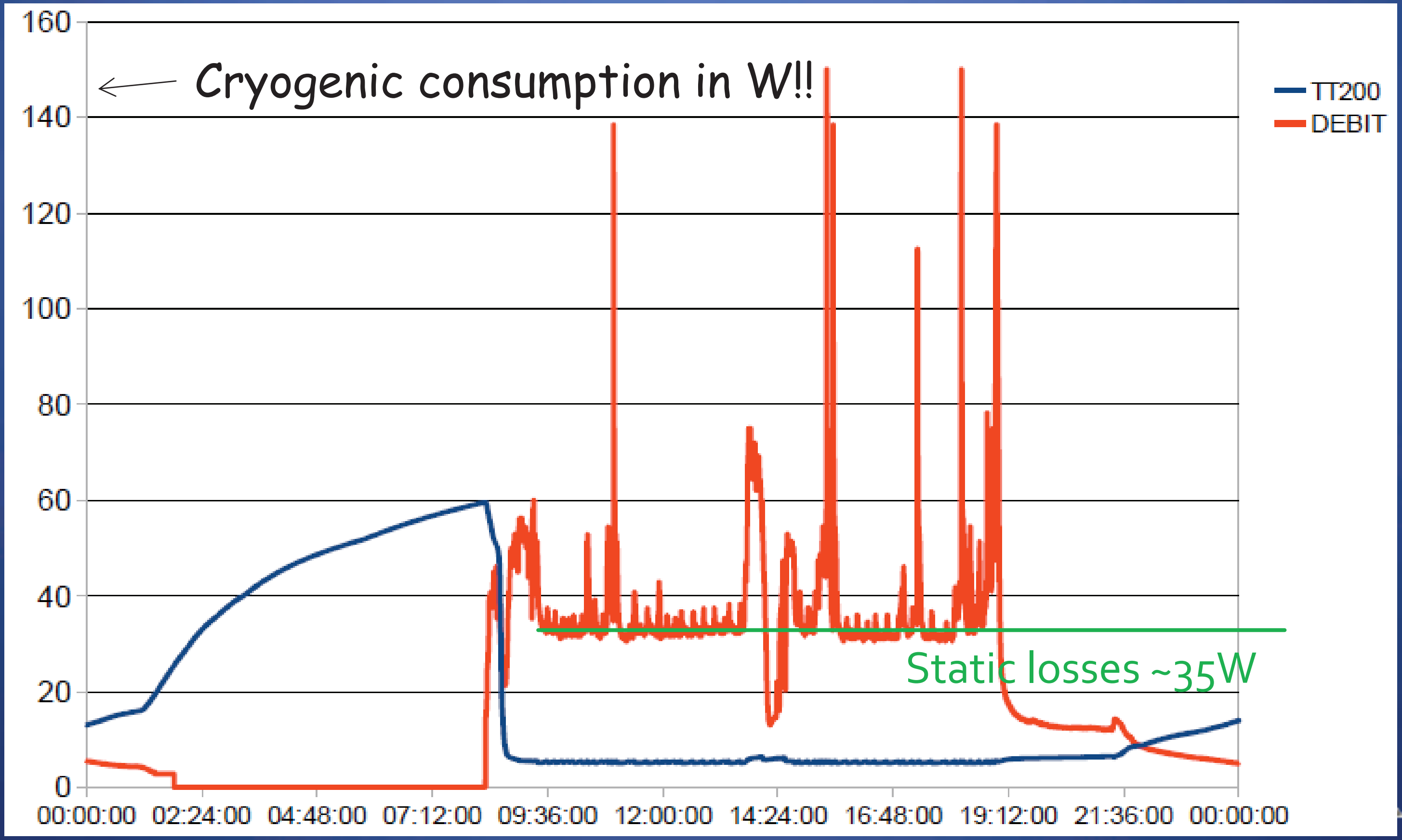

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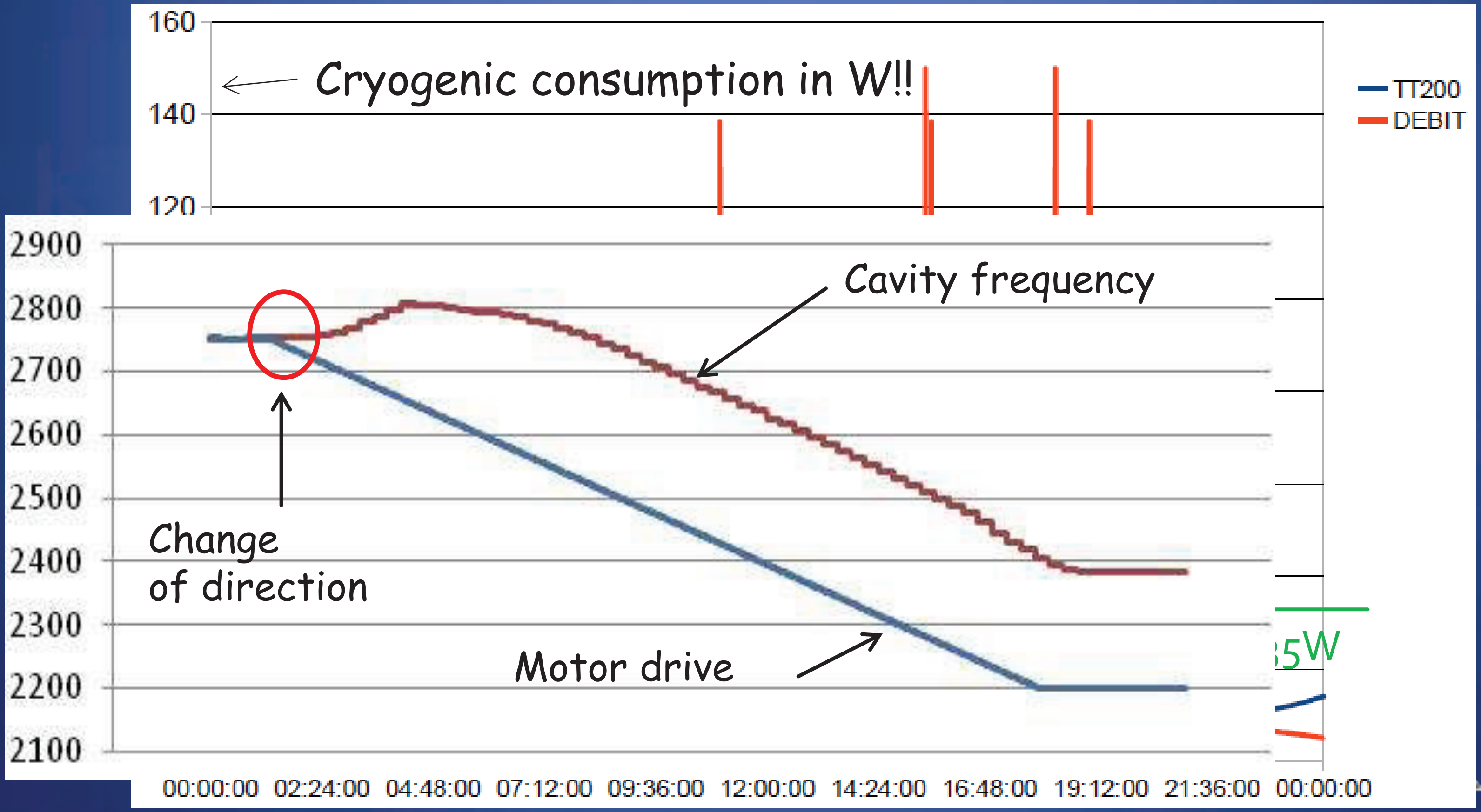

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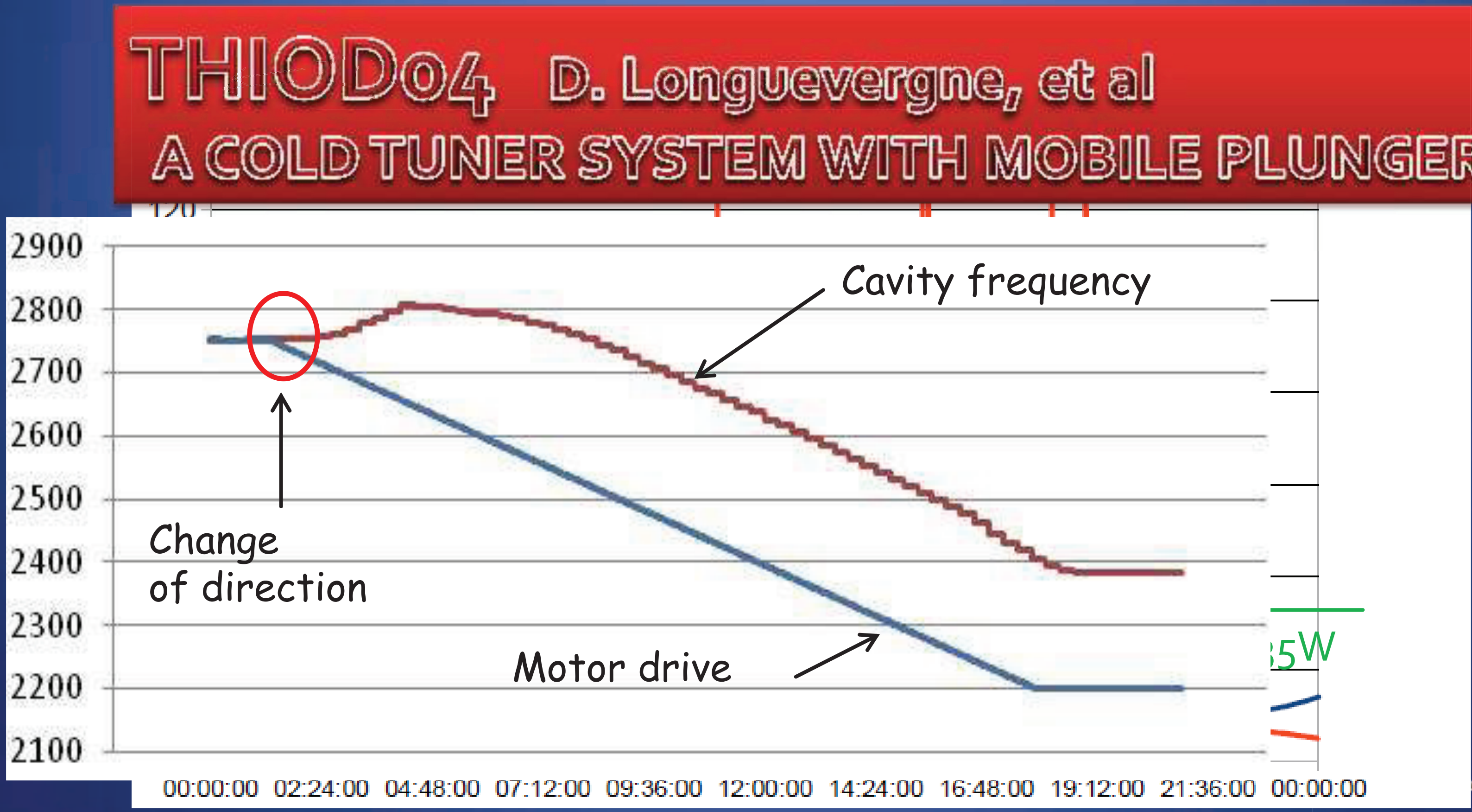


CMB status

- Cavities :
  - All cavities have been qualified without and with plunger

- Cryostats :
  - Two cryomodules validated with respect to RF, vacuum and cryogenic loss requirements (one is misaligned)
  - One cryomodule already delivered to GANIL
  - All cryomodules B to be delivered to GANIL before sept .2014
  - *All difficulties solves (hopefully!)*

CMB status

- Cavities :
  - All cavitie … r

MOP010 G. olry, et al

Spiral2 Cryomodules B Tests Results

- Cryostats :
  - Two cryomodules validated with respect to RF, vacuum and cryogenic loss requirements (one is misaligned)
  - One cryomodule already delivered to GANIL
  - All cryomodules B to be delivered to GANIL before sept .2014
  - *All difficulties solves (hopefully!)*

Transportation test

Cryomodule status

	Unit	Specs	CMA4	CMA6	CMA7	CMA2	CMA3	CMA5
Max. acc. Gradient	MV/m	>6.5	8.8	8.3	9	9.1	7.95	9.1
Total losses @4K, 6.5MV/m	W	<20.5	20.8	11.4	11.8	15.56	17.9	11.3
Static losses @4K	W	<8.5W	6.5	3.98	4.1	3.11	4.34	3.6
Pressure sensitivity	Hz/mbar	<5	-1.58	-1.32	-1.45	-1.31	-1.08	-1.22
Beam vacuum leaks	mbar.l/s	<5e-10	9.5E-10	< 1e-10	< 1e-10	< 1e-10	< 1e-10	<1e-10
Cavity alignment	mm	◎ 1.3	0.52	0.4	0.48	1.46	0.4	

	Unit	Specs	CMB1		CMB2	
Max. acc. Gradient	MV/m	> 6.5	>8.0	>8.0	>8.0	>8.0
Total losses @4K, 6.5MV/m	W	< 36.0	29.5		32	
Static losses @4k	W	<12.5	17		18	
Pressure sensitivity	Hz/mbar	< 8.0	5.7	5.1	5.3	5
Beam vacuum	mbar	< 5.0e-7	< 6.0e-8		< 6.0e-8	
Beam vacuum leaks	mbar.l/s	< 5e-10	< 1e-10		< 1e-10	
Cavity alignment	mm	◎ 1.2	0.16	0.34	0.88	2.54

Cryomodules preparation and assembling

HPR rinsing and beam vacuum sealing in ISO 4 clean rooms

(Coupler prepared in LPSC clean room)

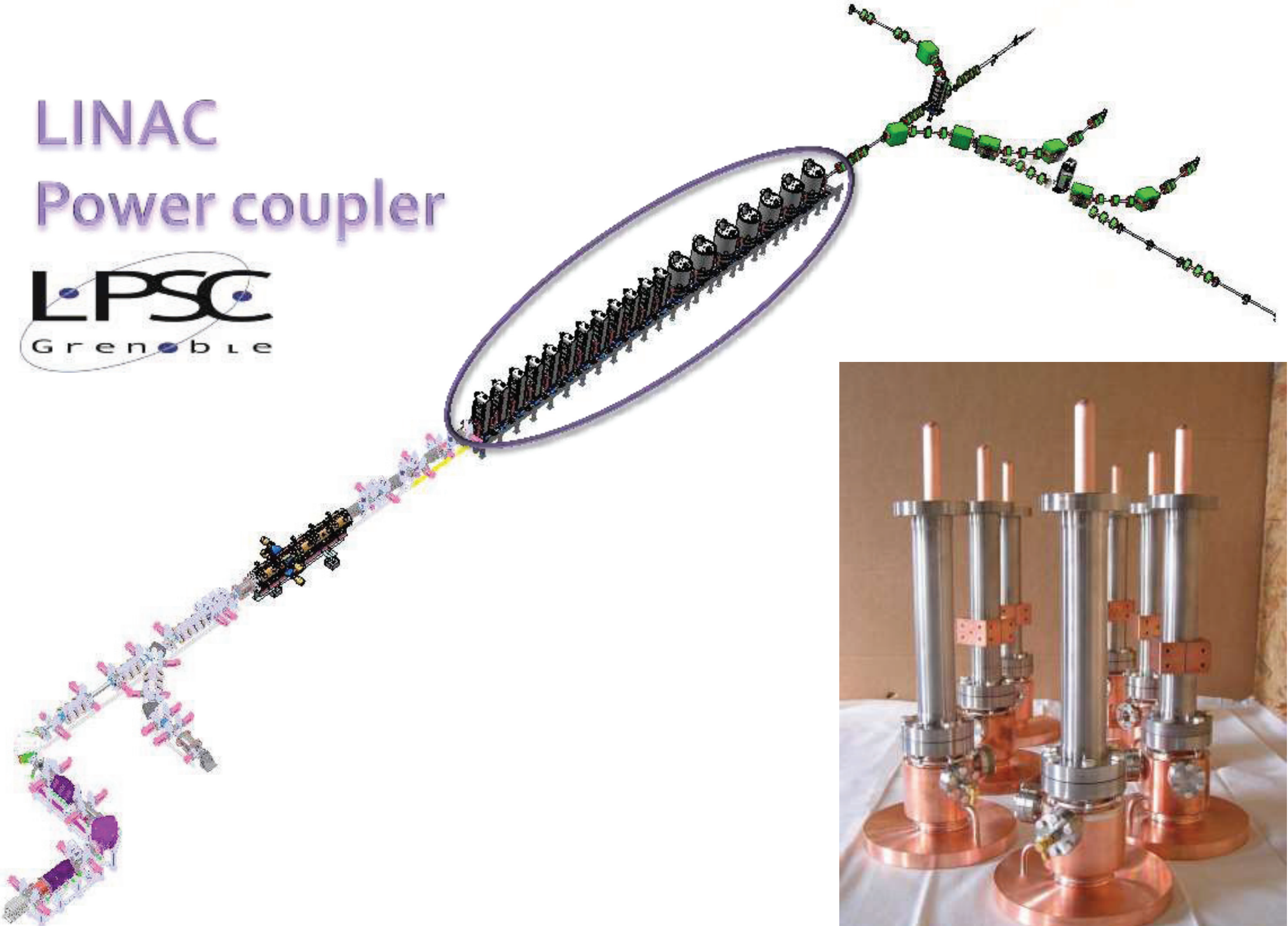
Cryomodules preparation and assembling

Check of dust particles rate for all components connected to the cavity

Cryomodules A: no more HPR rinsing between VC test and CM assembly (slow refilling with filtered N)

LINAC
Power coupler

LPSC Grenoble



RF power coupler

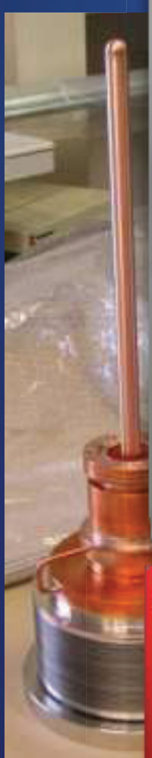
- Validated up to 40kW CW in traveling wave
- 20 were conditioned up to 20kW CW in standing wave (open circuit)
- Time is now shorter than one hour
- Plan to finish the preparation of all the couplers by Christmas 2013

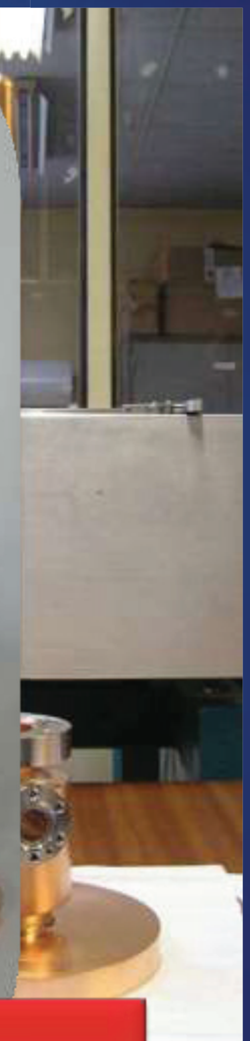
LPSC Grenoble

GANIL Spiral2

Success story

Success story



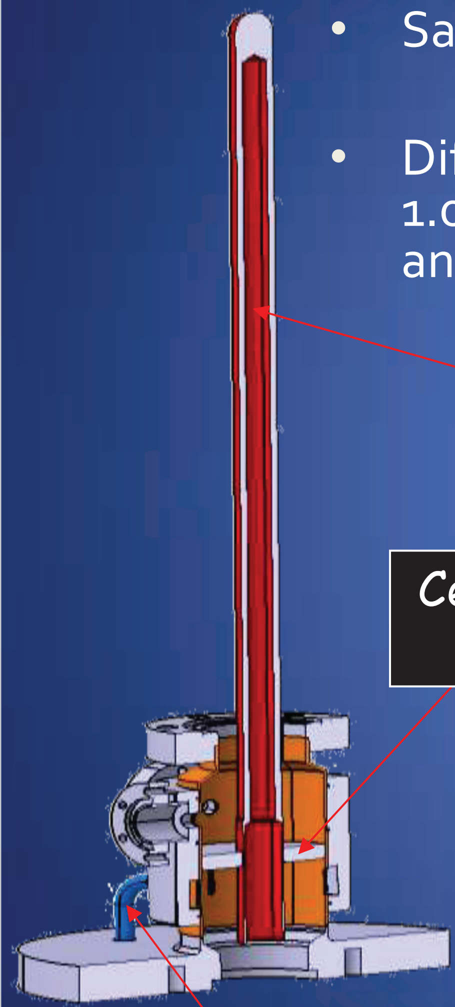


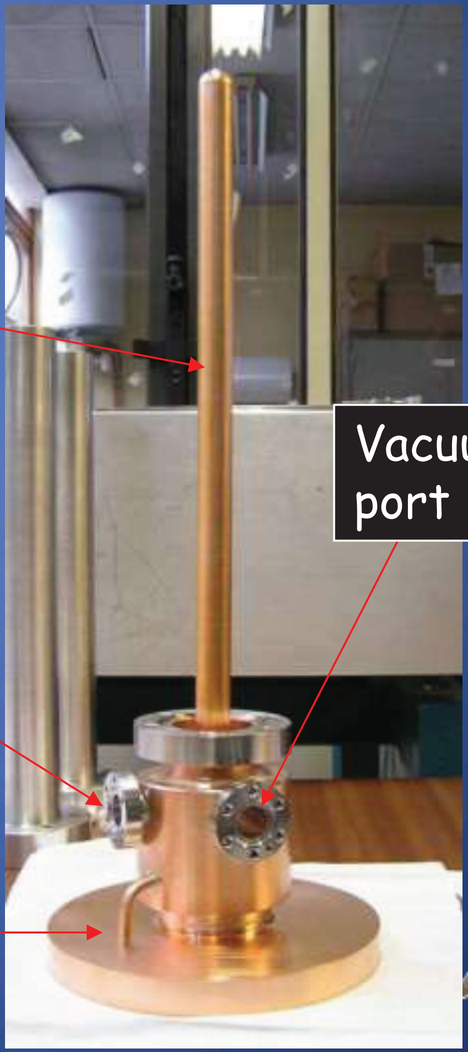
THP054 , Y. Gómez Martínez et al

Last Spiral 2 Couplers Preparation and RF Conditioning

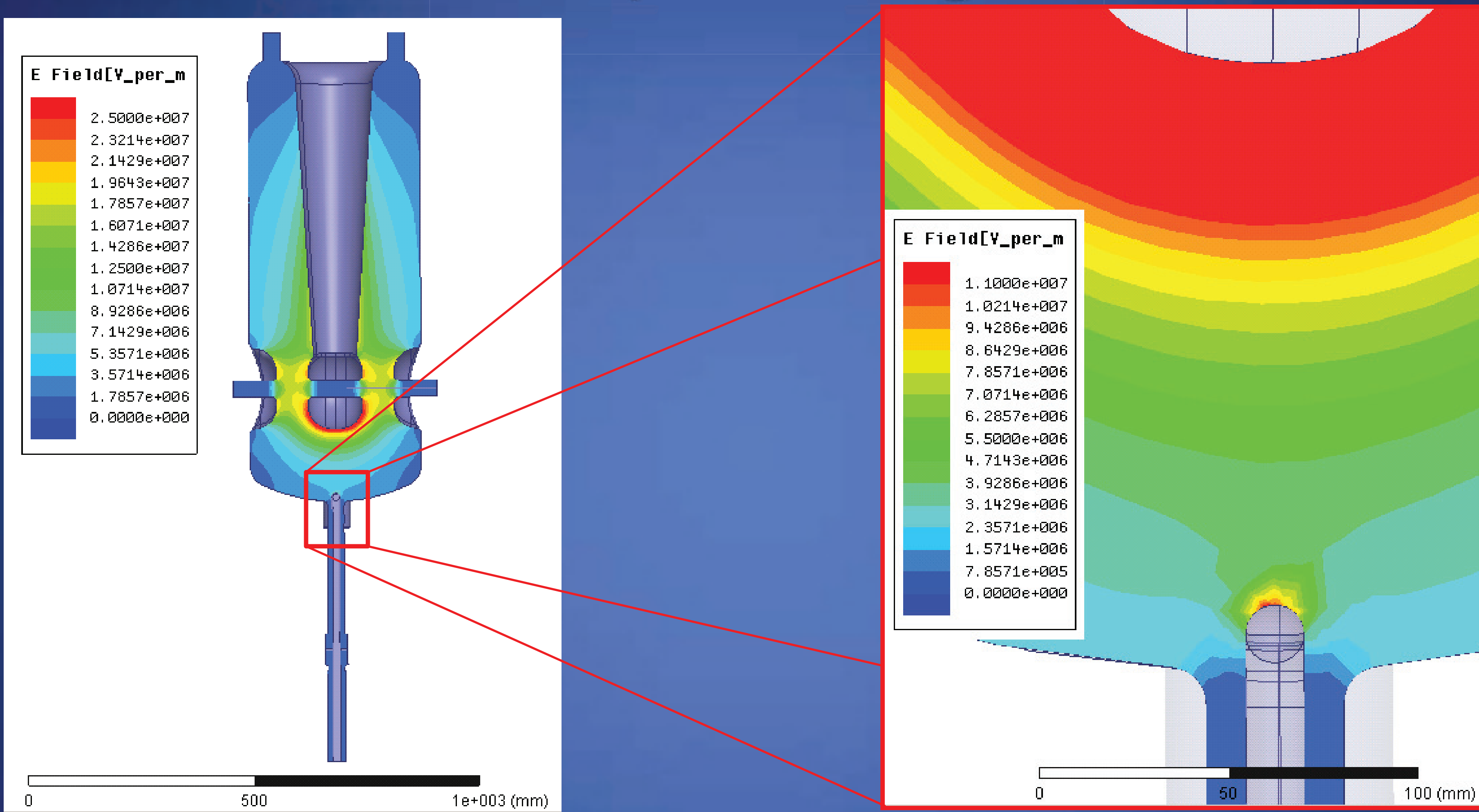
Coupler design

- Same coupler for both cavities
- Different coupling ($5.5\ 10^5$ and $1.0\ 10^6$) achieved by a different antenna penetration depth



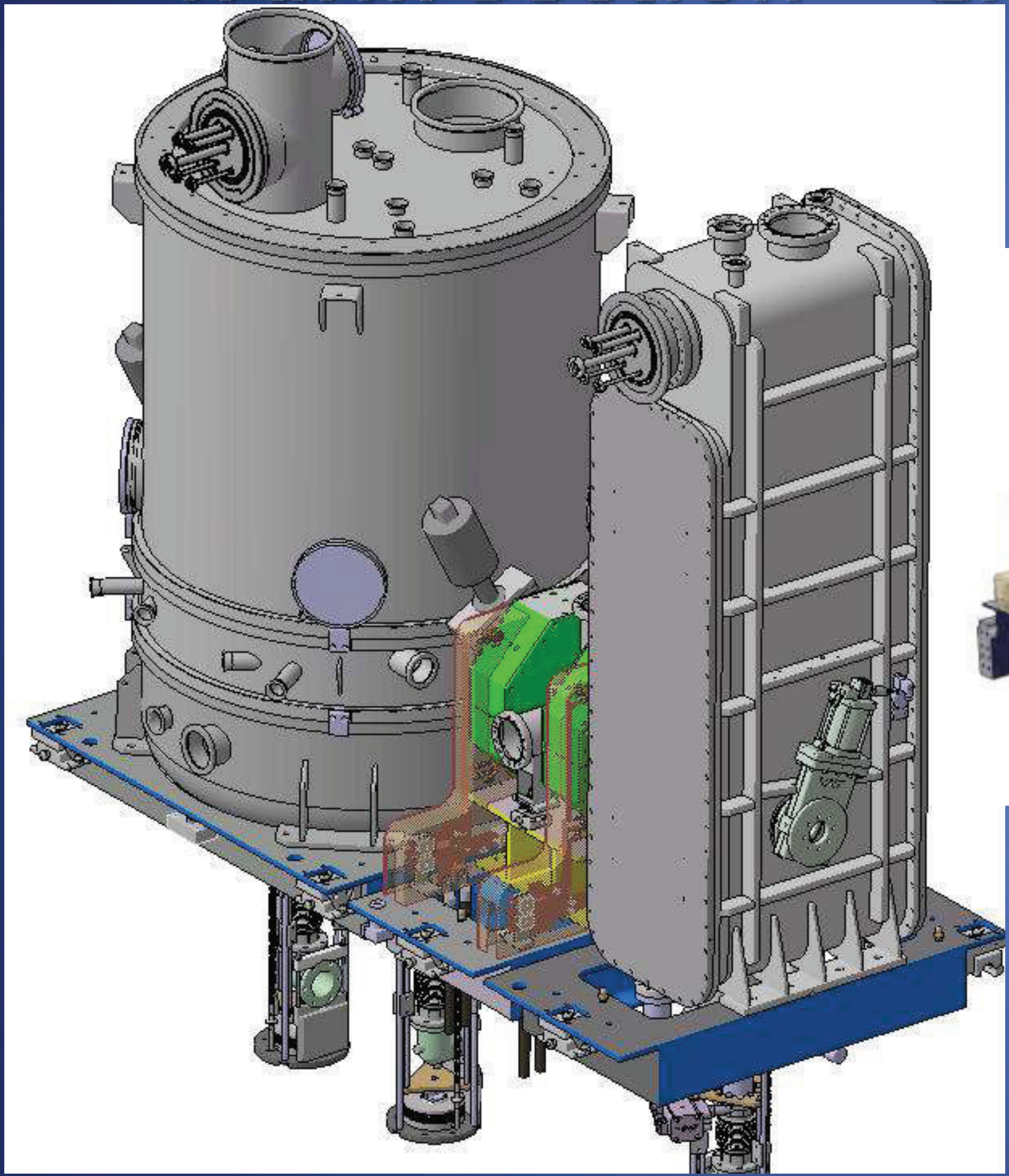


Coupler design

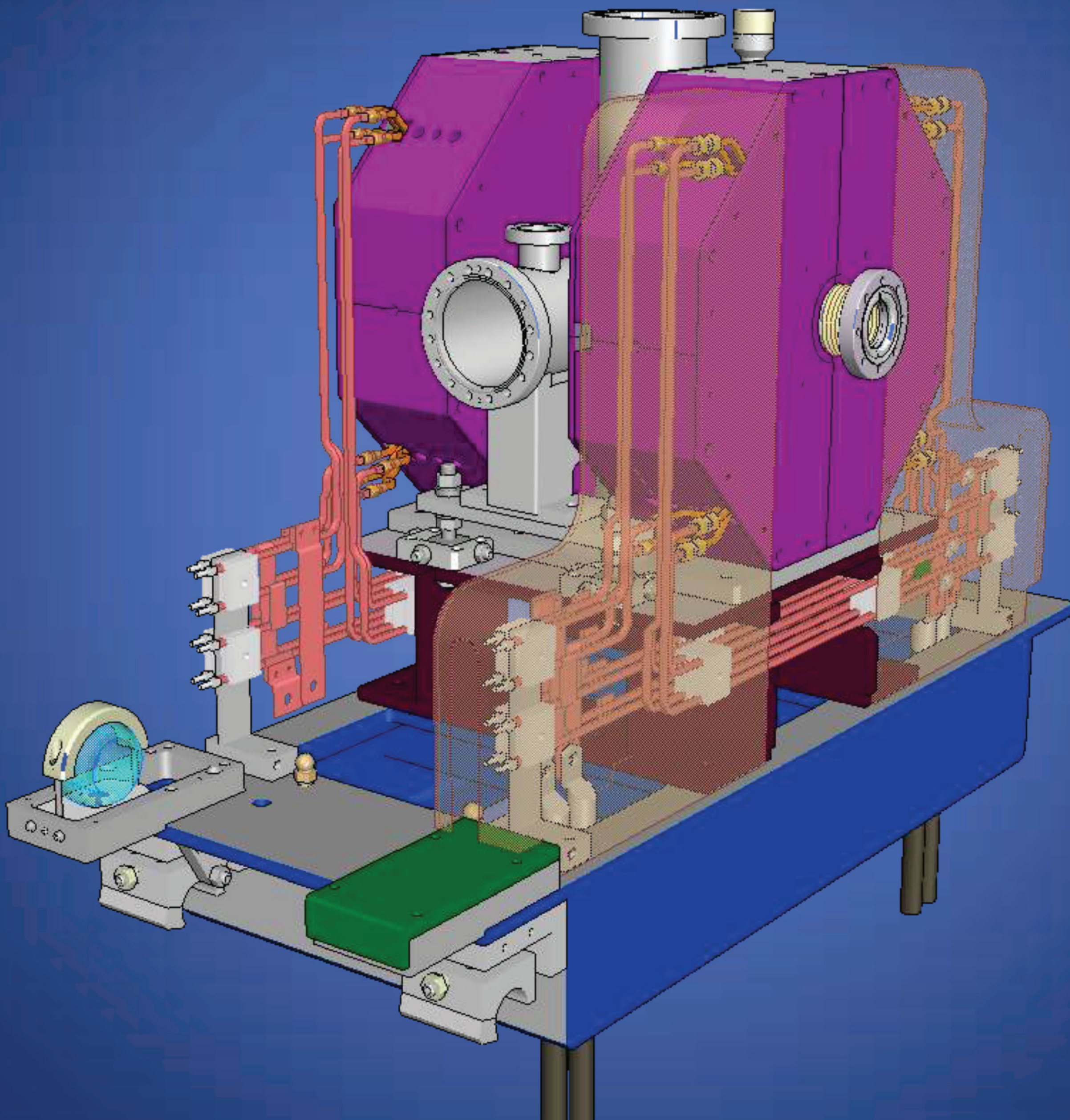


- E up to 12 MV/m (CMA) at the antenna extremity for nominal accelerating gradient (accelerating gap area around 37 MV/m)
- Static + dynamic losses 1.0 to 1.5 W (as computed and as measured)
- No MP above 150 W of forward power

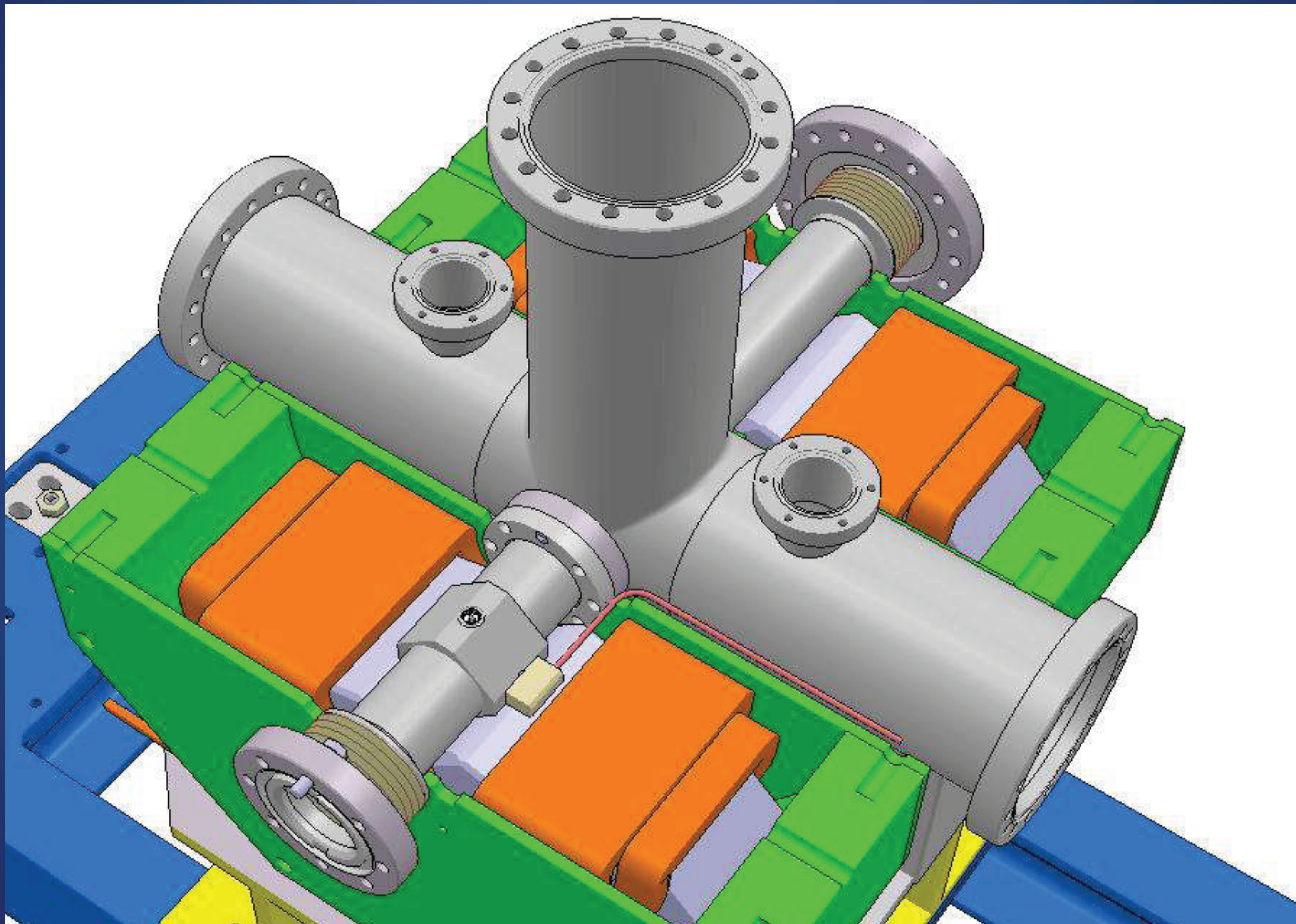
Warm section – GANIL and IPN



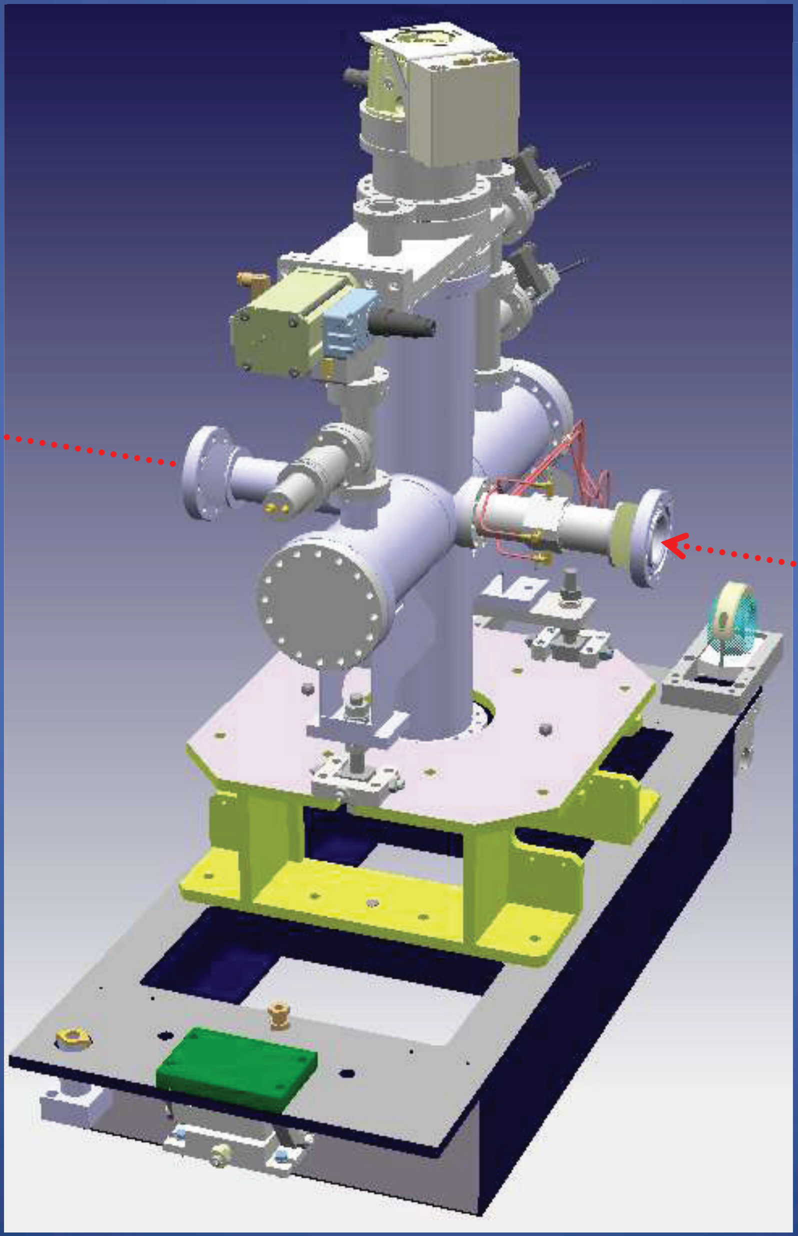
Warm section – GANIL and IPN



Warm section – GANIL and IPN

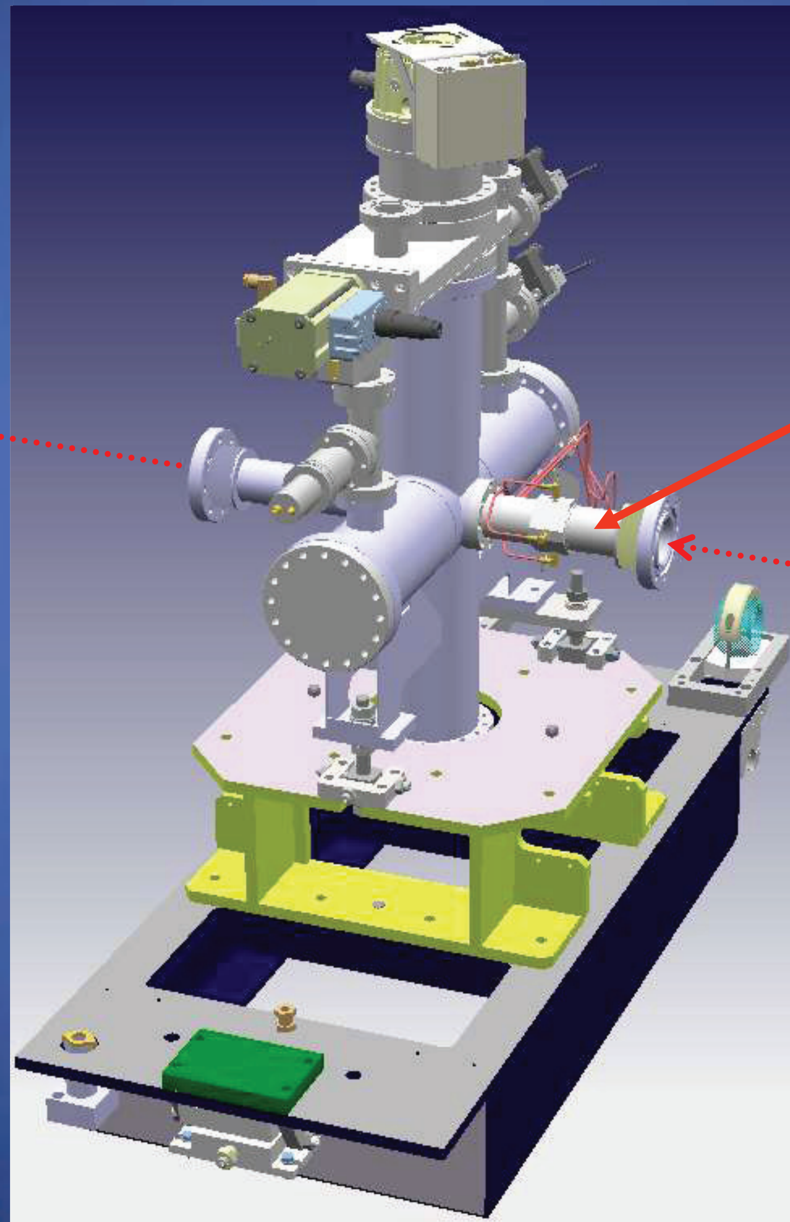


Diagnostics box



Beam axis

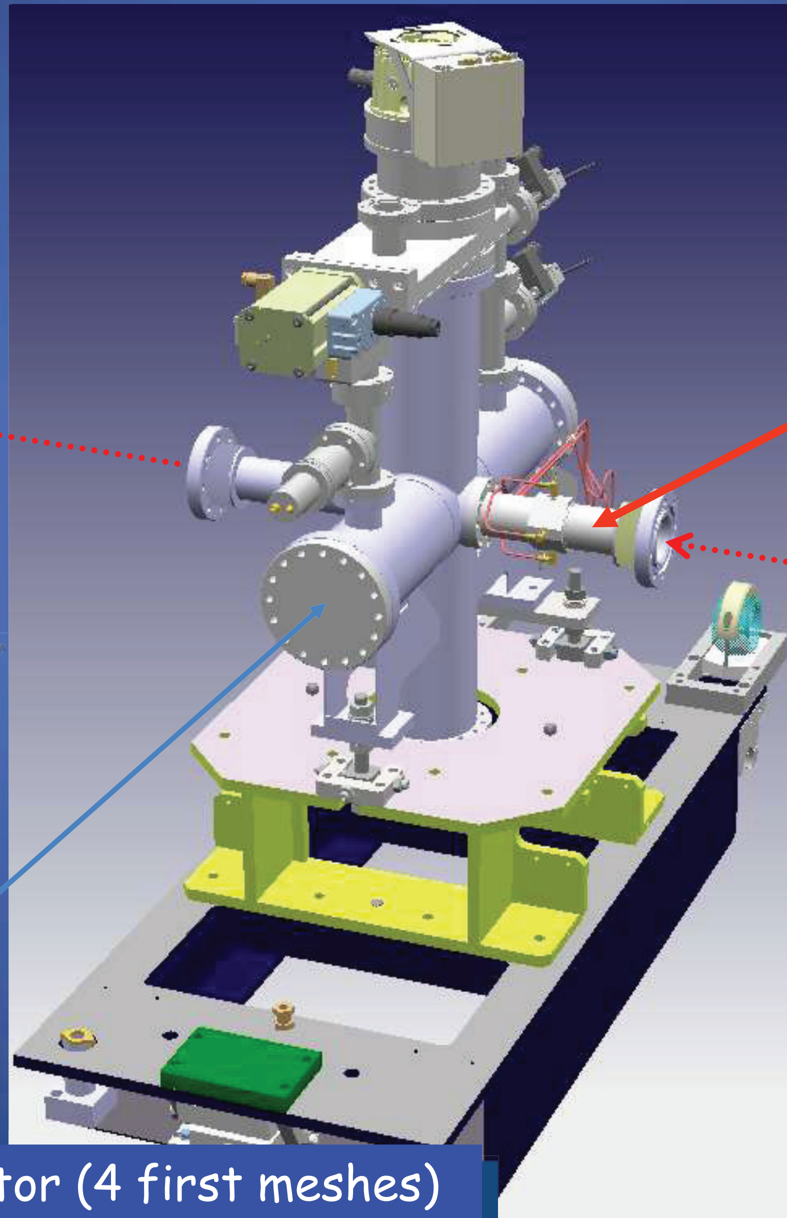
Diagnostics box



Many functions:

- correct the position (QWR, errors)
- transverse tuning of the Linac using the quadripolar moments
- Beam phase measurem.
- Time of flight measurement

Diagnostics box



BPM

Beam axis

Many functions:

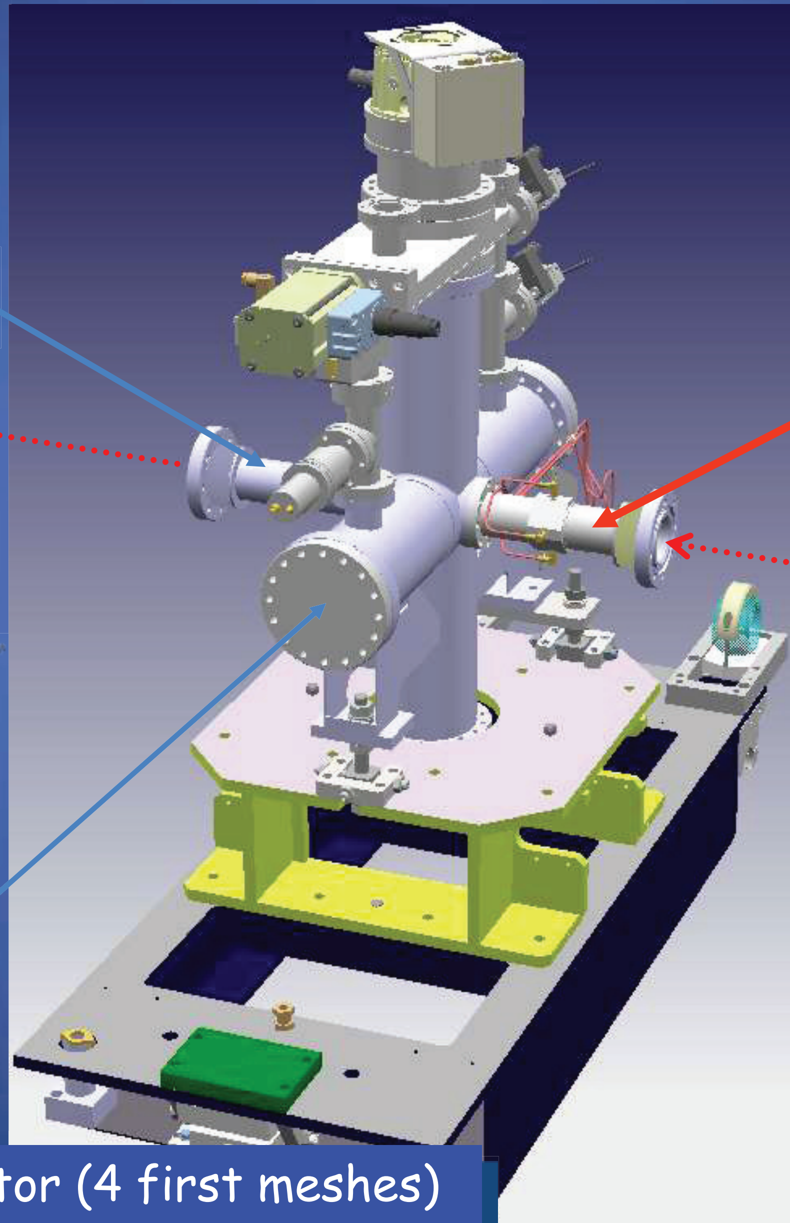
- correct the position (QWR, errors)
- transverse tuning of the Linac using the quadripolar moments
- Beam phase measurem.
- Time of flight measurement

Bunch Extension Monitor (4 first meshes)

Diagnostics box

Room for a pick up

Beam axis



BPM

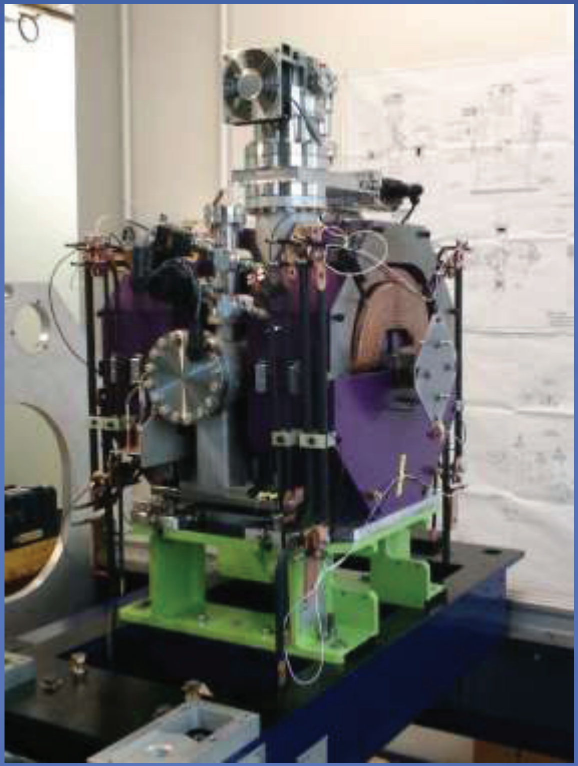
Bunch Extension Monitor (4 first meshes)

Many functions:

- correct the position (QWR, errors)
- transverse tuning of the Linac using the quadripolar moments
- Beam phase measurem.
- Time of flight measurement

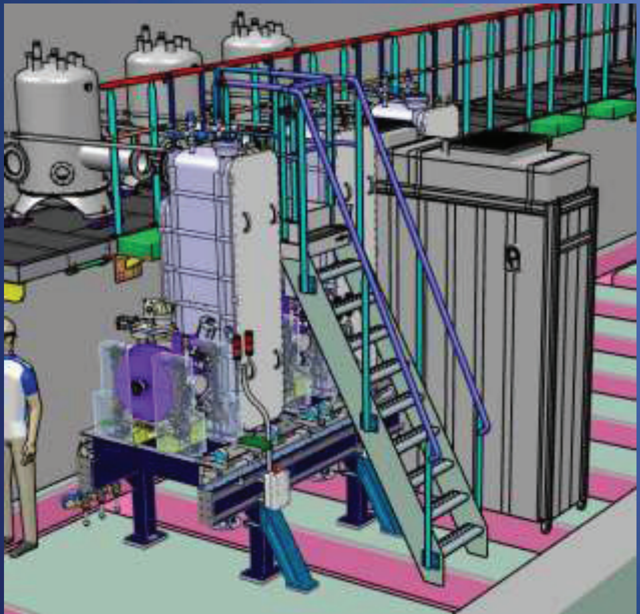
LINAC Warm Sections activities…

clean room (iso5) assembly



on alignment bench

Connexion test with a CMA



Tunnel installation under laminar flow (iso5)

GANIL Spiral2

LINAC
Liquefier

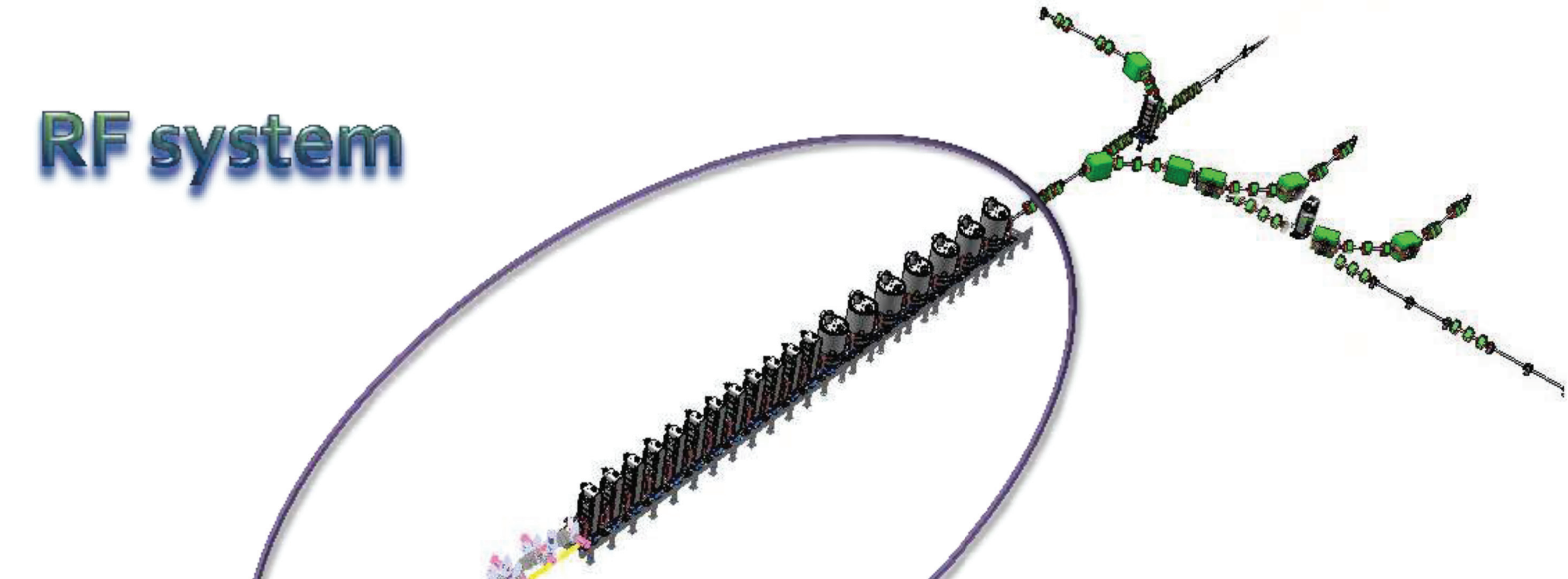
Heat loads and liquefier

Cryomodule model	A	B
β cavity	0.07	0.12
Number of cavities	1	2
Length [m]	0.65	1.4
Overall height [m]	3.25	3.15
Static heat load @ 4.4 K [W] (w coupler)	8.5	12.5
Dynamic heat load @ 4.4 K [W]	12	22
Heat load @ 60 K [W]	40	60

Valve box and associated transfer line sectors	
Type A quantity	12
Type B quantity	7
External diameter [m]	0.7
Height [m]	1.2
Regulating He cryogenic valves	5
Static heat load @ 4.4 K [W]	8
Power @ 60 K [W]	25

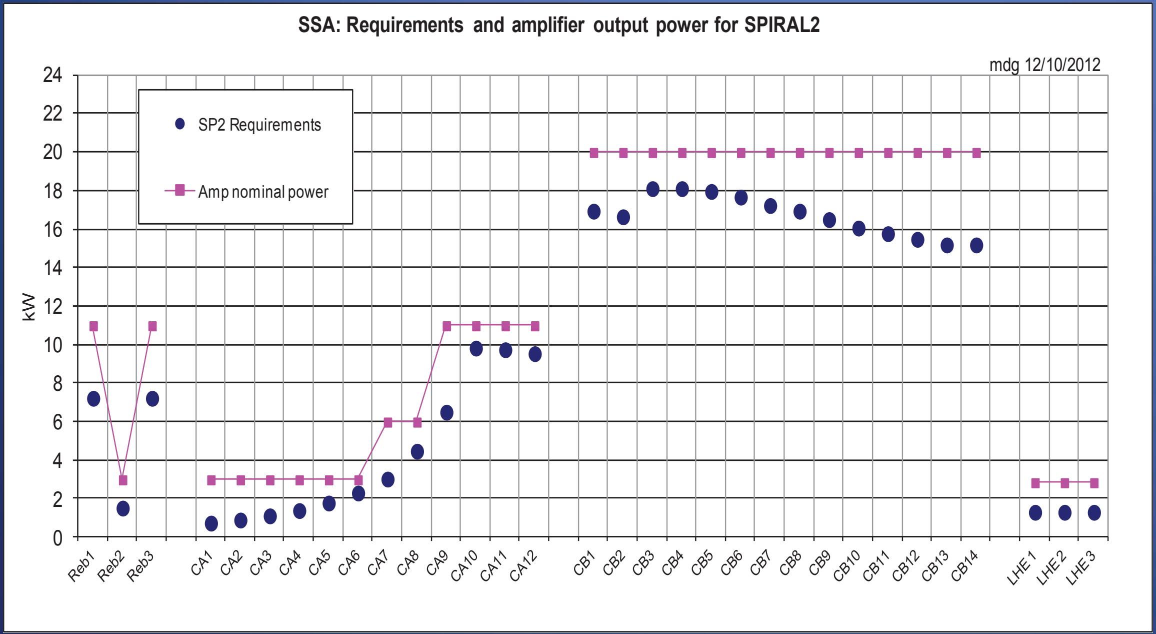
	SPIRAL2 values
Power capacity at 4.4 K	1100 W
Power capacity at 60 K	3000 W
Liquefaction at 4.4k	10l/h
Dewar pressure	1.3 bar
He in the tunel	1800l
Pressure stab. <1s	+/- 3mbar
Max slope	100 mbar/h

RF system



RF SYSTEM

- Independently phased cavities (one power chain and control feedback per cavity)
- One operating frequency : 88.05250 MHz
- Amplitude stability: 1%
- Phase stability : 1°
- Solid state technology based on 3 kW modules
- 2.5 kW, 5 kW, 10 kW and 19 kW units
- Class AB for linearity, phase stability on large dynamics range (35 dB)



Process installation

Process installation

Conclusion

- SPIRAL2 : a major nuclear facility
  - Complementary to existing and futur facilities
  - broad range of research in GANIL
- Major parts are now constructed and under installation
- Cryomodules are now in a routine assembly process and testing
  - Six A-type cryomodules ready for installation,
  - One B-type cryomodule also, delivered to GANIL
- First source beam tests expected by mid 2014, or as soon as possible
- Linac installation : January next year
- at 4 k by the end of the year.

Many thanks to

- thanks to the Saclay, IPN-Orsay, LPSC Grenoble and GANIL teams for their wonderful jobs and successes all along the project development.