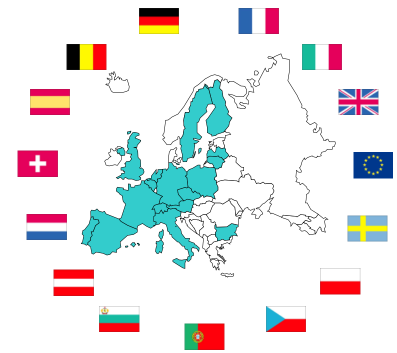
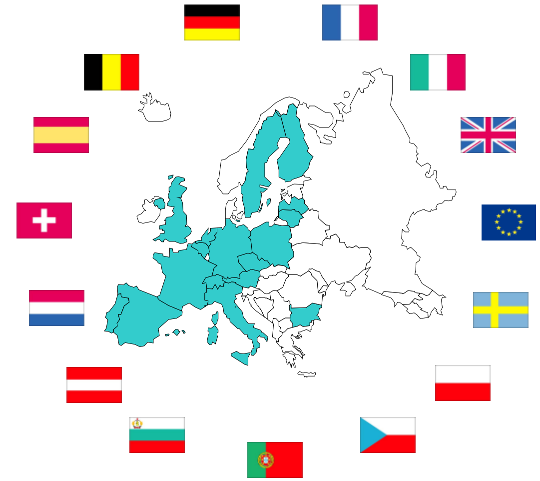


Accelerator design for MYRRHA

J-L. Biarrotte, CNRS-IN2P3 / IPN Orsay



1 . The MYRRHA project @ SCK•CEN Mol

2. The MYRRHA linac conceptual design
3. Related R&D activities
4. Conclusion

Goals of the MYRRHA project

MYRRHA Project

Multi-purpose hYbrid Research Reactor for High-tech Applications At Mol (Belgium)

Development, construction & commissioning of a new large fast neutron research infrastructure to be operational in 2023

➊ ADS demonstrator

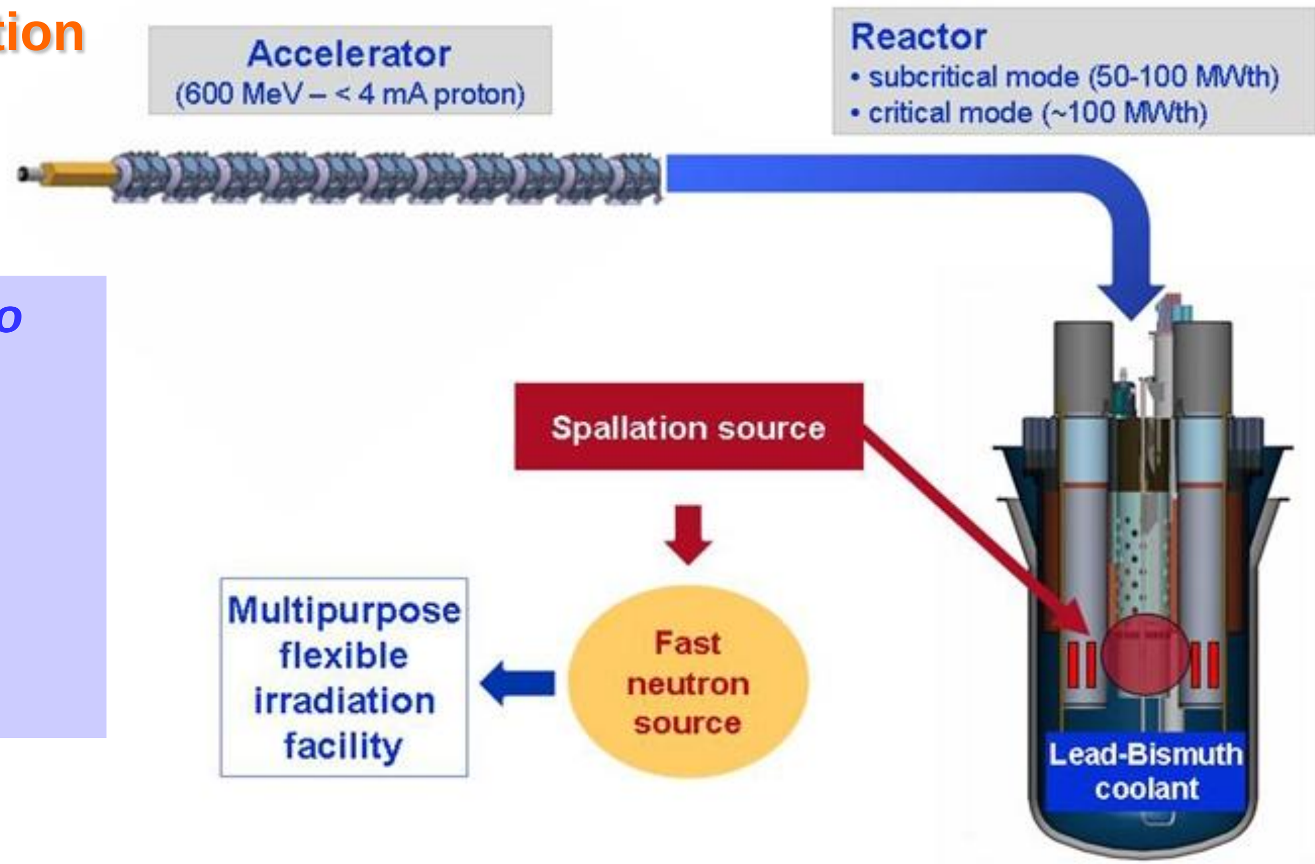
➋ Fast neutron irradiation facility

➌ Pilot plant for LFR technology

MYRRHA as an ADS demonstrator

Demonstrate the physics and technology of an Accelerator Driven System (ADS) for transmuting long-lived radioactive waste

- ➢ Demonstrate the **ADS concept**
- ➢ Demonstrate the **transmutation**



Main features of the ADS demo

50-100 MWth power

k_{eff} around 0.95

600 MeV, 2.5 - 4 mA proton beam

Highly-enriched MOX fuel

Pb-Bi Eutectic coolant & target

MYRRHA as a fast spectrum irradiation facility

- All **European irradiation Research Reactors** are about to close within 10-20 years
- The **RJH** (Réacteur Jules Horowitz) project, is presently the only planned MTR (Material Tests Reactor), and provides mainly a thermal spectrum
- MYRRHA is the **natural fast spectrum complementary facility**

Réacteurs de recherche européens

Pays	*Réacteurs de recherche*	*Age en 2015 (ans)*
Belgique	*BR2 à Mol*	*52*
Hollande	*HRF à Petten*	*54*
Norvège	*HRP à Halden*	*55*
France	*Osiris à Saclay*	*49*
Suède	*R2 à Studsvik*	*Mis à l'arrêt en 2005*
République tchèque	*LVR15 à Řež*	*58*

Main applications of the MYRRHA irradiation facility

Test & qualification of innovative fuels and materials for the future Gen. IV fast reactor concepts

Test of new materials for the development of fusion energy

Production of neutron irradiated silicon to enable technologies for renewable energies (windmills, solar panels, electric cars)

Production of radio-istopes for nuclear medecine (^{99}Mo especially)

Fundamental science in general (also using the proton linac by itself !)

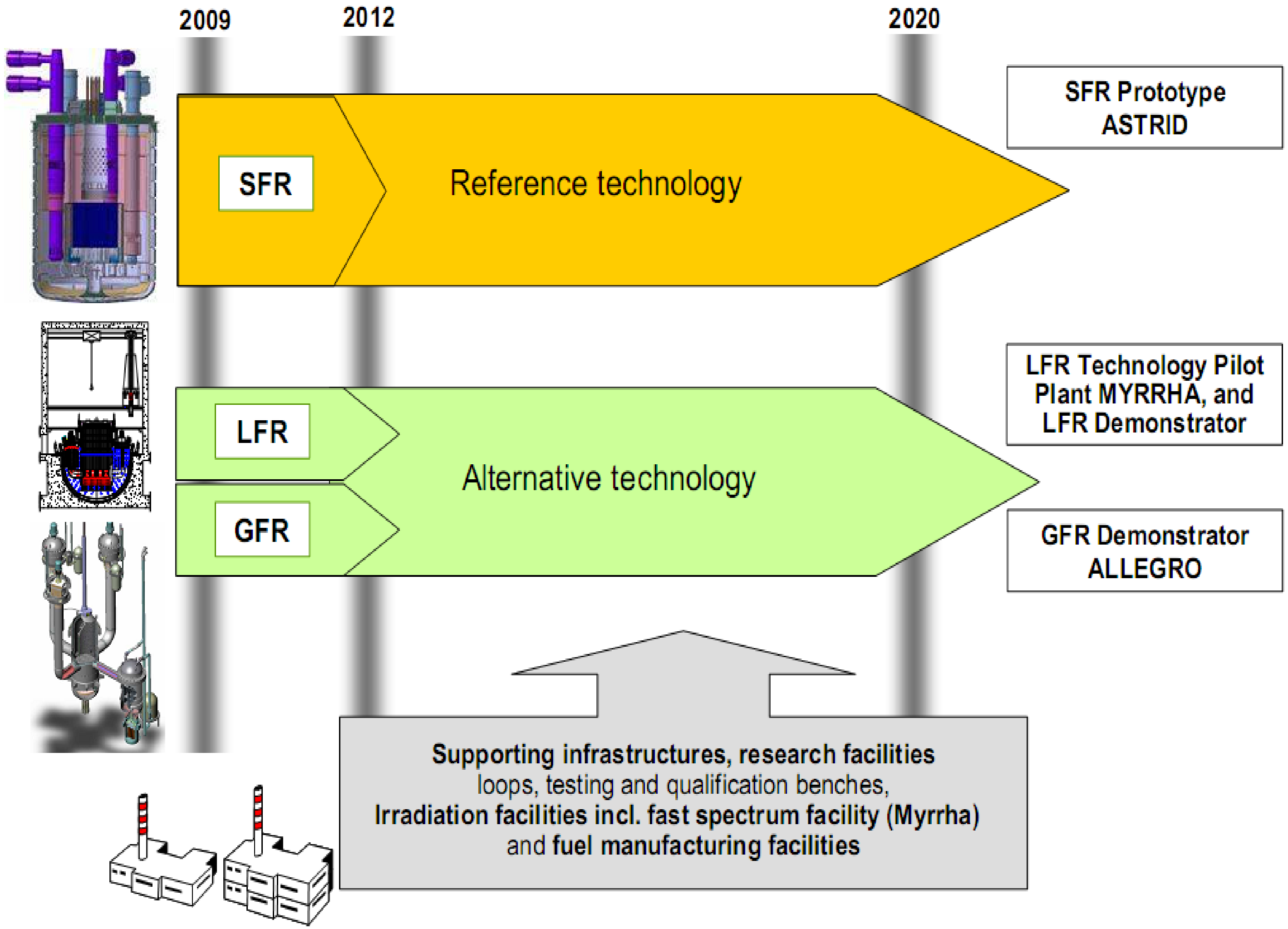
MYRRHA as a Gen.IV demonstration reactor

SEVENTH FRAMEWORK PROGRAMME

Serve as a technology Pilot Plant for **liquid-metal based reactor concepts** (e.g. Lead Fast Reactors)

European commission scope for the development of Gen.IV advanced reactor systems demos

(ESNII roadmap)

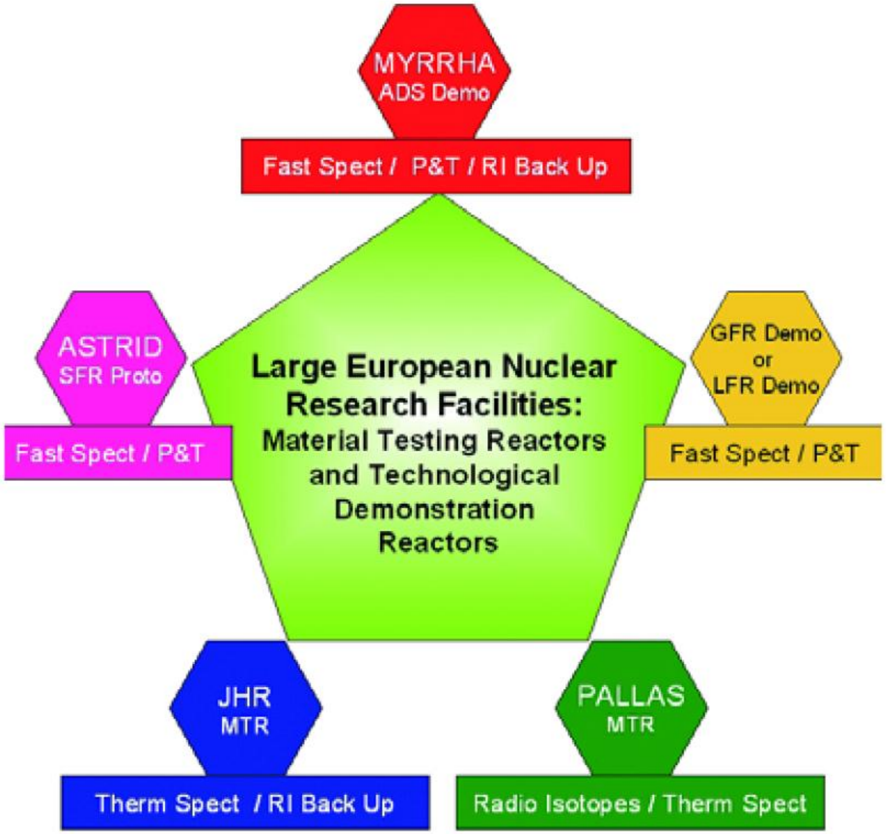


SNETP
SUSTAINABLE NUCLEAR ENERGY TECHNOLOGY PLATFORM

MYRRHA in brief

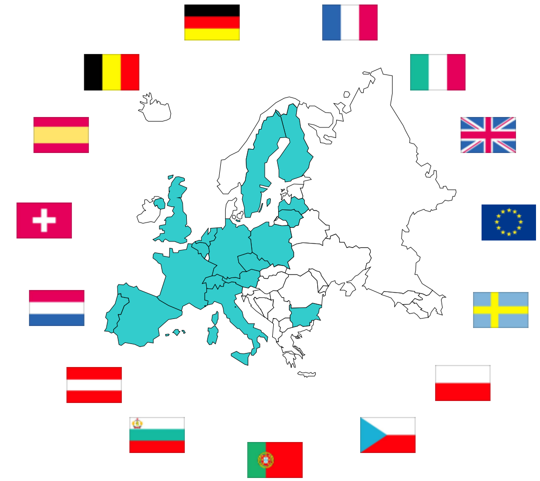
MYRRHA is considered as **a strategic stone**:

- for **SCK•CEN**, as a replacement for the BR2 reactor (shut-down in 2026)
- for the European picture of **Material Testing Reactors**, as a complement to the RJH
- For the future of **sustainable nuclear energy**, as an ADS demonstrator & a strong support to the development of Gen. IV reactors



MYRRHA key dates

- **1998**: first studies
- **2002**: pre-design "**Myrrha Draft 1**" *(350 MeV cyclotron)*
- **2002-2004:** studied as one of the 3 reactor designs within the **PDS-XADS FP5 project** *(cyclotron turns into linac, fault-tolerance concept is introduced)*
- **2005:** updated design "**Myrrha Draft 2**" *(350 MeV linac)*
- **2005-2010:** studied as the XT-ADS demo within the **FP6 IP-EUROTRANS** *(600 MeV linac conceptual design, R&D activities w/ focus on reliability)*
- **2010:** MYRRHA is on the **ESFRI list**, and is **officially supported by the Belgium government** at a 40% level (384M€, w/ 60M€ already engaged)
- **2010-2015:** Engineering design, licensing process, set-up of the international consortium, w/ support from the **FP7 projects CDT and MAX** especially
- **2016-2019:** construction phase
- **2020-2023:** commissioning and progressive start-up
- **2024**: full exploitation



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Proton beam specifications

SEVENTH FRAMEWORK PROGRAMME

Proton beam general initial specifications within EUROTRANS

	Transmuter demonstrator (XT-ADS / MYRRHA project)	Industrial transmuter (EFIT)
Proton beam current	2.5 mA (& up to 4 mA for burn-up compensation)	~ 20 mA
Proton energy	600 MeV	800 MeV
Allowed beam trips nb (>1s)	~ < 5 per 3-month operation cycle	~ < 3 per year
Beam entry into the reactor	Vertically from above	
Beam stability on target	Energy: ±1% - Current: ±2% - Position & size: ±10%	
Beam time structure	CW (w/ low frequency 200µs beam "holes" for sub-criticality monitoring)	

Extreme reliability required

High-power proton CW beams

The reliability requirement

- **Beam trips longer than 1 sec are forbidden** to avoid thermal stresses & fatigue on the ADS target, fuel & assembly & to provide good plant availability.
- **Present SPECIFICATIONS** (inspired from the PHENIX requirements for emergency stops number)

  Less than 5-10 beam trips (>1-3sec) per 3-month operation cycle (MYRRHA)

- **Reliability guidelines have been followed during the ADS accelerator design**

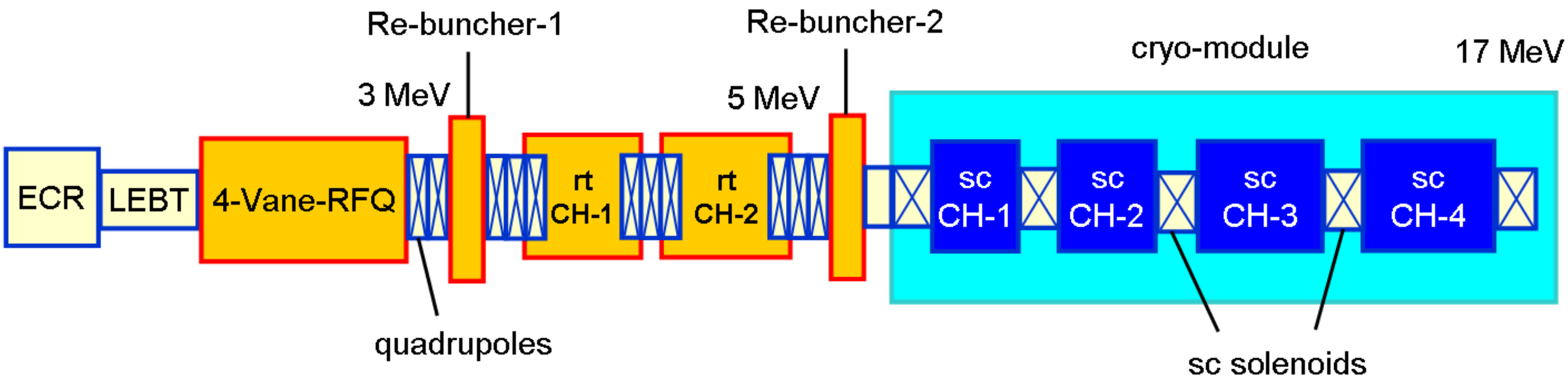
  1. Strong component design ("overdesign")
  - All components are derated with respect to technological limitations

  2. Inclusion of redundancies in critical areas
  - Possible doubled front-end (hot stand-by injector), solid-state RF power amplifiers where possible…

  3. Enhance the capability of fault-tolerant operation
  - "Fault-tolerance" = ability to pursue operation despite some major faults in the system
  - Expected in the independently-phased superconducting linac, especially for RF faults (RF systems = critical reliability area)

The 17 MeV injector

The reference ADS linac 17 MeV injector

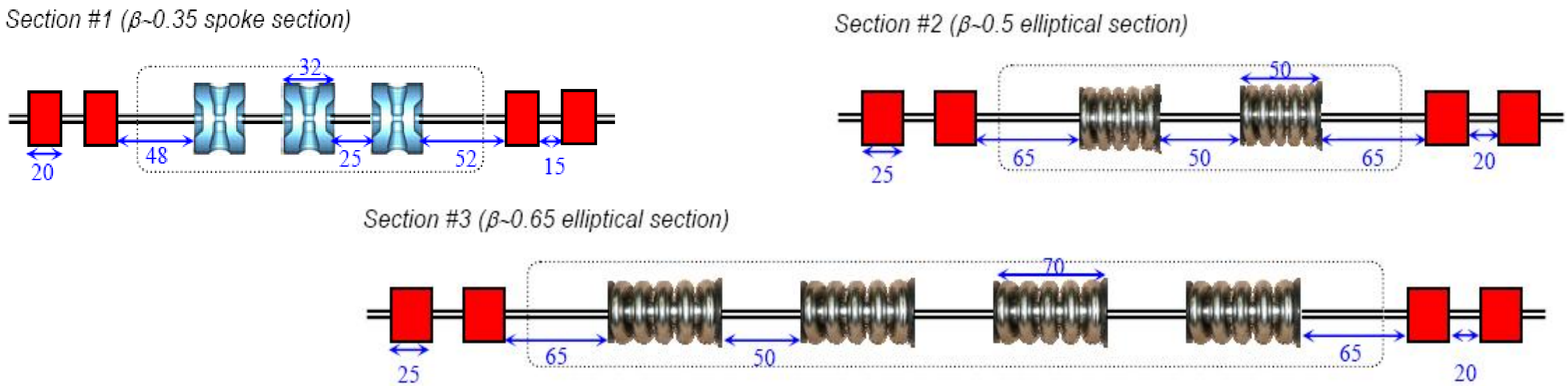


- Proton source: ECR type, 5 mA, 50 kV
- 4-vane RFQ, 352 MHz, 3 MeV
- 2 copper CH-cavities, 352 MHz, up to 5 MeV
- 4 superconducting CH-cavities, 352 MHz up to 17 MeV
- **Very good acceleration efficiency** (< 20m long)
- **A redundant injector could be added** (w/ a fast switch) to improve reliability.

This is only an OPTION for MYRRHA

The 17-600 MeV main SC linac

Lattices of the XT-ADS 2010 reference linac (distances in cm)

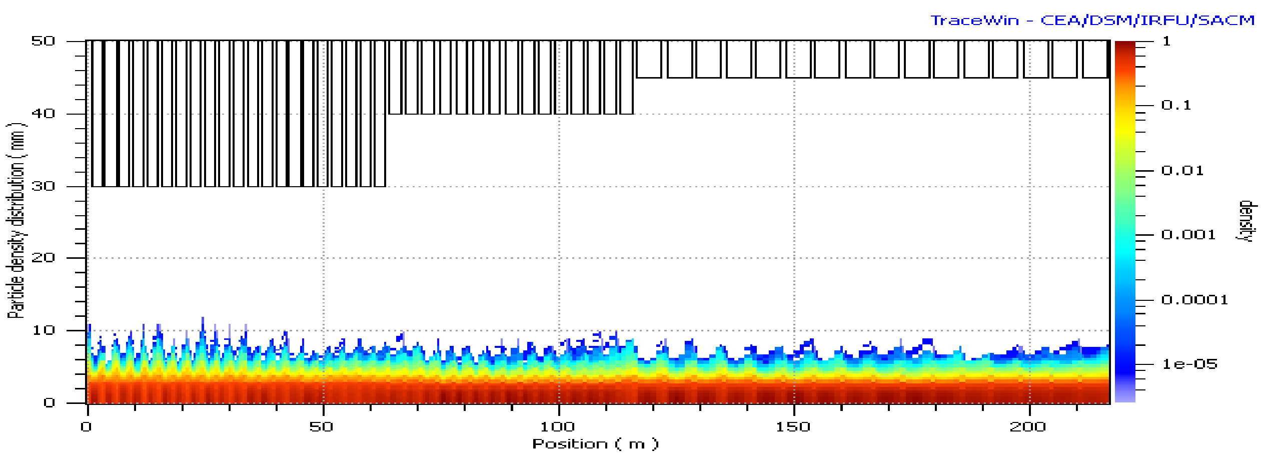


- Superconducting Spoke cavities, 352 MHz, up to 90 MeV (1 section, 63 cavities)
- Superconducting Elliptical cavities, 704 MHz, up to 600 MeV (2 sections, 94 cavities)
- 17 to 600 MeV overall length: about 215m
- **Modular and independently-phased accelerating structures**
- **Capability to implement a fault-tolerant scheme** w/ fast fault-recovery scenarii
- **Moderate accelerating gradients w/ operation margins**

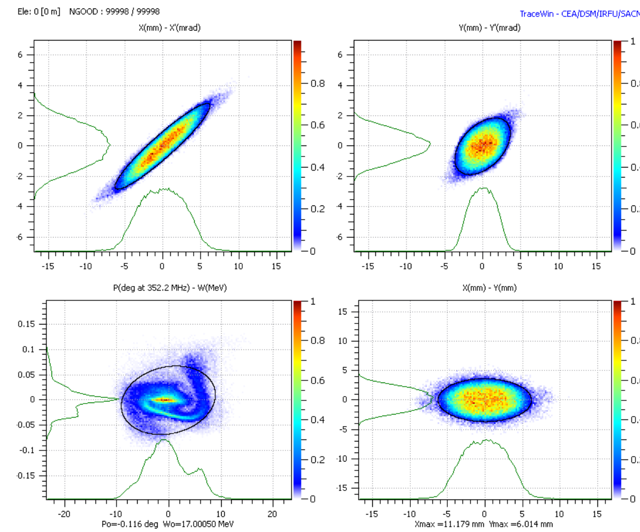
The 17-600 MeV main SC linac

The 17 – 600 MeV XT-ADS reference design

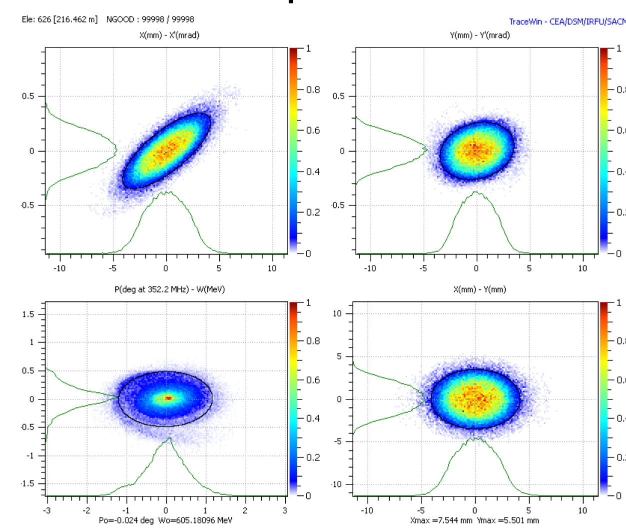
Section number	1	2	3
Input energy (MeV)	17.0	86.4	186.2
Output energy (MeV)	86.4	186.2	605.3
Cavity technology	Spoke 352.2 MHz	Elliptical 704.4 MHz	
Cavity geometrical β	0.35	0.47	0.66
Cavity optimal β	0.37	0.51	0.70
Nb of cells / cavity	2	5	5
Focusing type	NC quadrupole doublets		
Nb of cavities / cryomodule	3	2	4
Total nb of cavities	63	30	64
Acc. field (MV/m @ opt. β)	5.3	8.5	10.3
Synchronous phase (deg)	-40 to -18	-36 to -15	
5mA beam loading / cav (kW)	1 to 8	3 to 22	17 to 38
Section length (m)	63.2	52.5	100.8



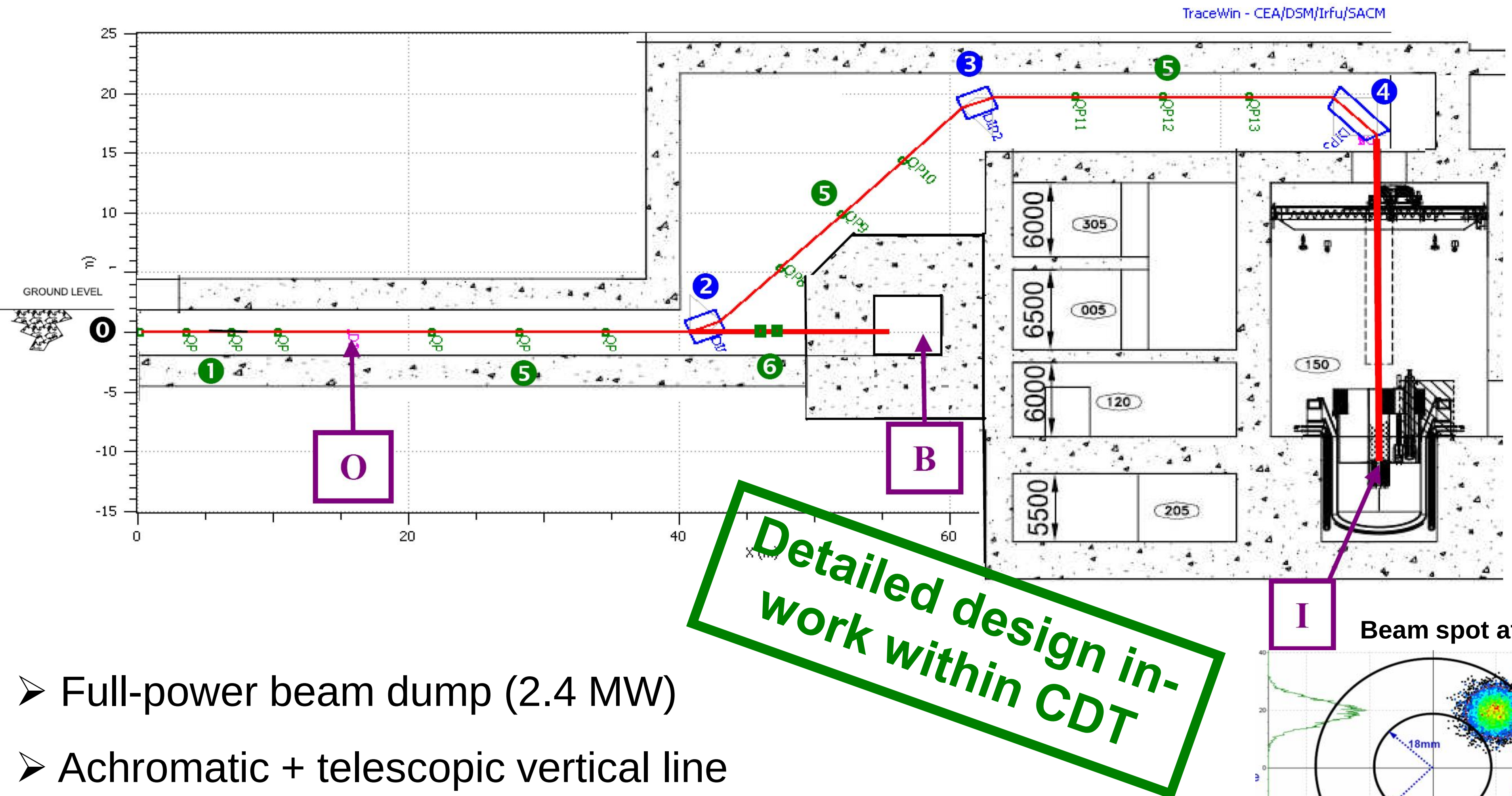
17 MeV input distribution

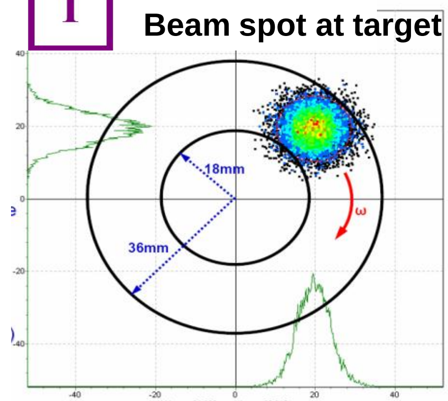


600 MeV output distribution



Final beam line to reactor





- Full-power beam dump (2.4 MW)
- Achromatic + telescopic vertical line
- Target painted using beam scanning

MYRRHA linac cost estimate

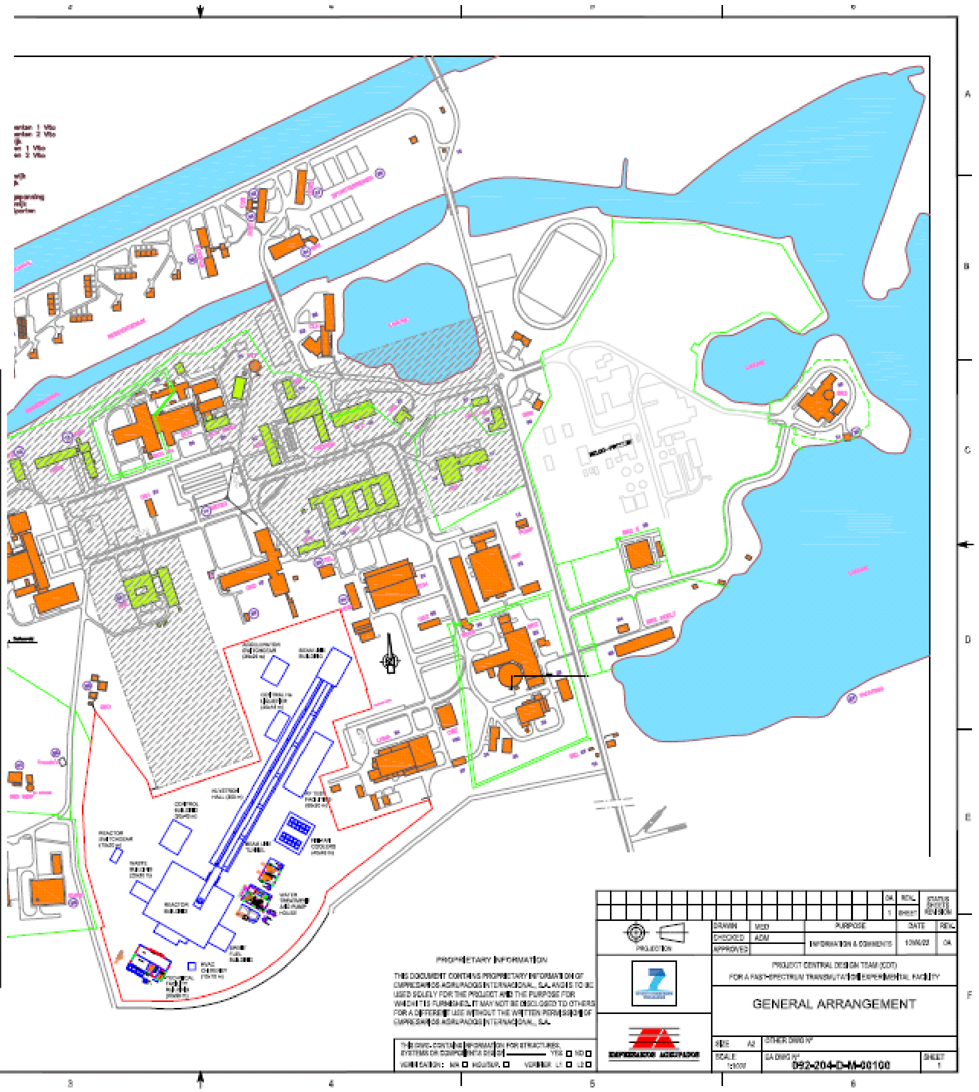
SEVENTH FRAMEWORK PROGRAMME

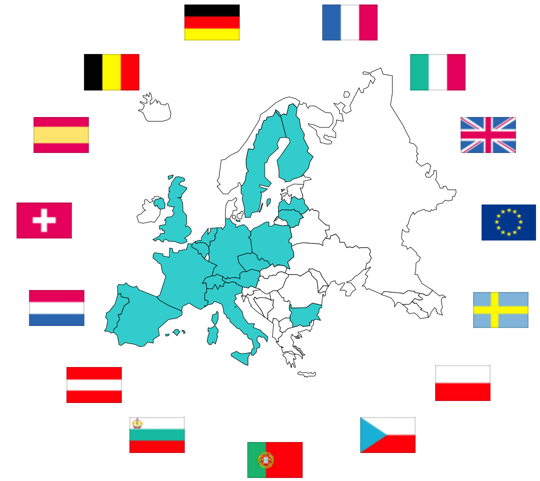
- **Total MYRRHA cost is about 1B€**

- **<u>MYRRHA linac cost estimate: about 240 M€</u>**
(includes direct & indirect costs + conting. does NOT include buildings & utilities)

Item	Direct Cost (M€)	Indirect & Suppl. Costs (M€)	Contengency. (M€)	Best Estimate (M€)
Linac front-end	8.040	5.936	4.193	**18.169**
Main SC linac	52.868	10.176	18.913	**81.957**
Final beam lines	6.900	2.120	2.706	**11.726**
Cryogenic System	24.445	4.240	8.606	**37.291**
RF systems	40.535	4.240	13.433	**58.208**
Command, Control & lab equipments	19.000	7.632	7.990	**34.622**
TOTAL	**151.788**	**34.344**	**55.840**	**241.972**

Cost estimate of the 600 MeV XT-ADS accelerator





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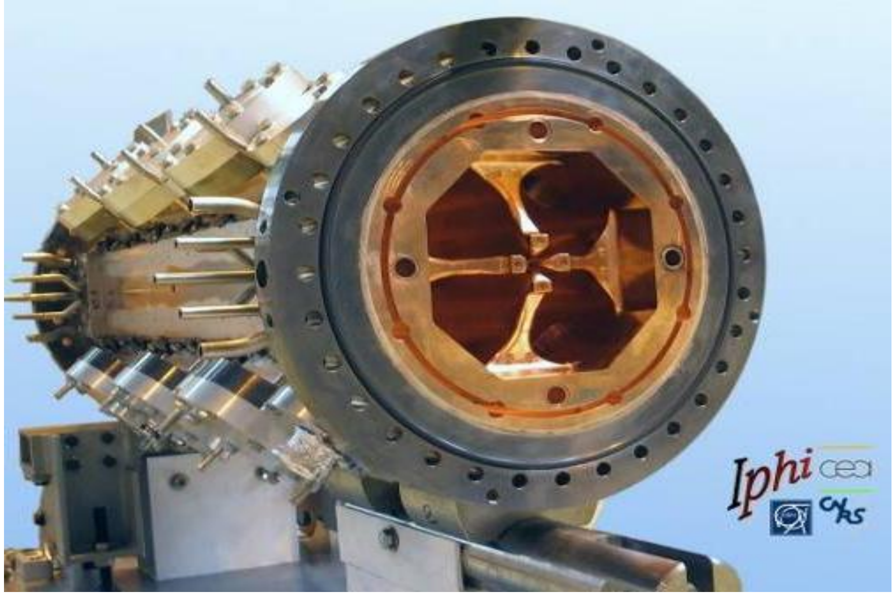
Injector long reliability test run

IP-EUROTRANS - INTEGRATED PROJECT ON EUROPEAN TRANSMUTATION -

Proton source status

- SILHI ECR p source (95kV, 100mA) operational with very promising reliability

- Sharp 200μs “beam holes” have been produced successfully



RFQ status

- IPHI 4-vane RFQ last sections still under fabrication

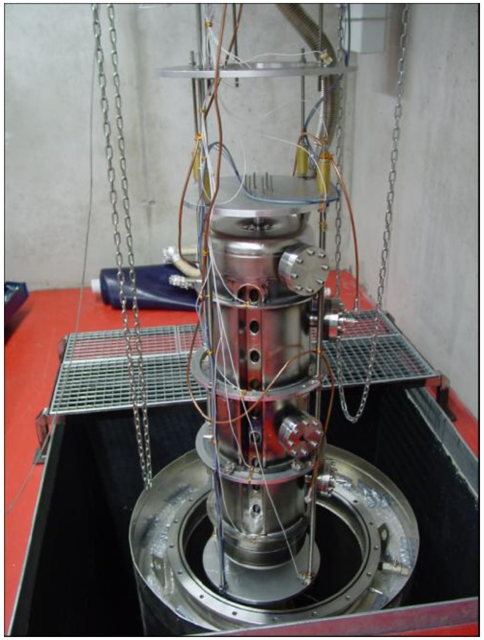
- A lot of experience gained on the brazing procedures

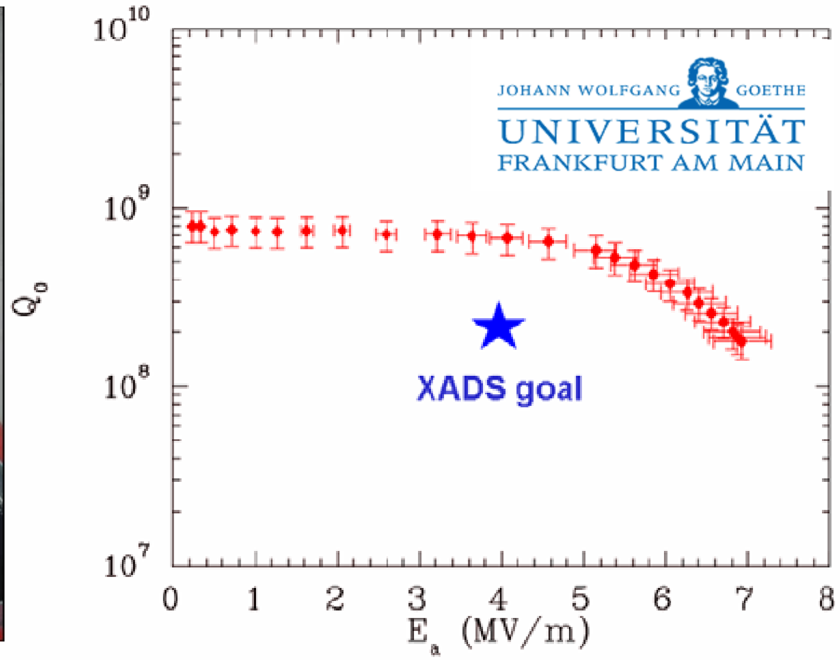
- But such a 4-vane RFQ has been identified as very (too?) challenging on the technological point of view

- Once IPHI commissioned (2011?), the 3 MeV beam will be continuously operated for a 2 months period @30mA. Results will be made available to the EUROTRANS community when available

SC CH cavities development

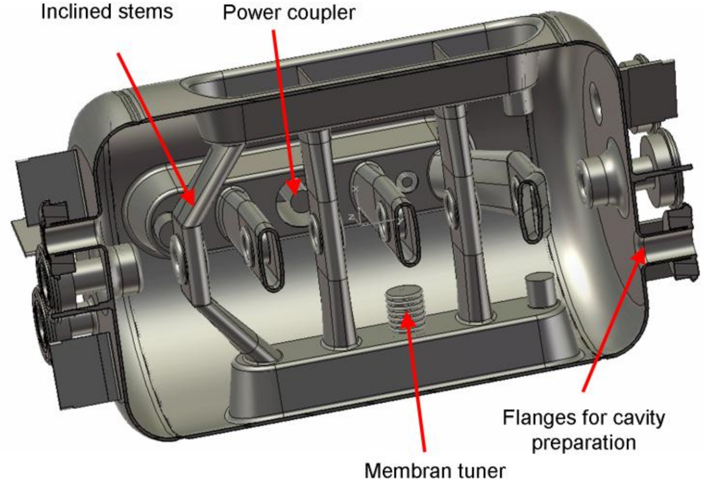
IP-EUROTRANS - INTEGRATED PROJECT ON EUROPEAN TRANSMUTATION -





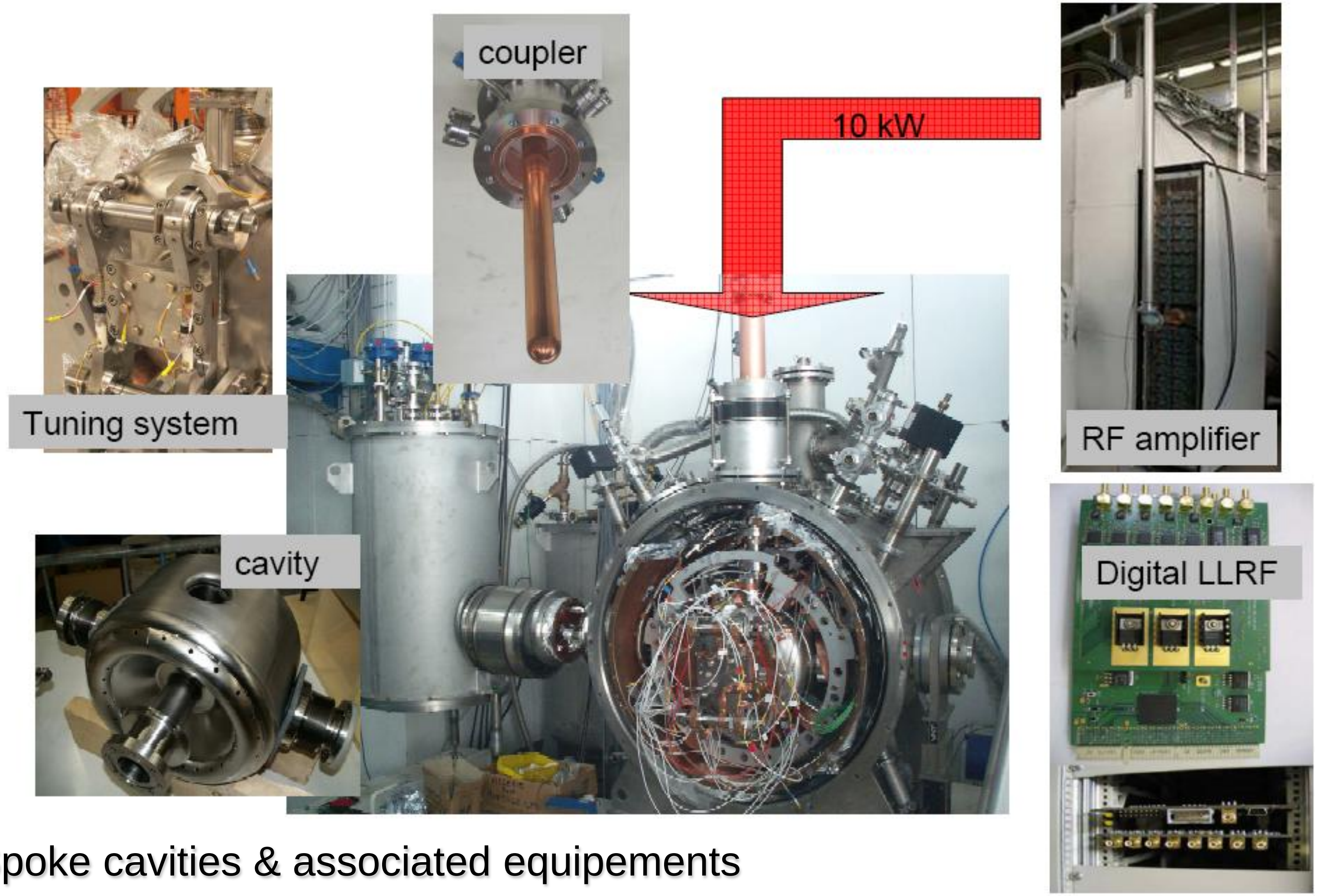
- 19-gap superconducting CH-DTL prototype, first of its kind, built & successfully tested @4K (up to 7MV/m)

- Design of a new optimized prototype cavity suited to the XT-ADS needs.



Spoke cavities development

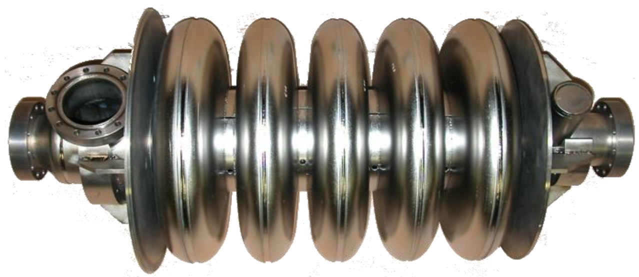
IP-EUROTRANS
- INTEGRATED PROJECT ON EUROPEAN TRANSMUTATION -

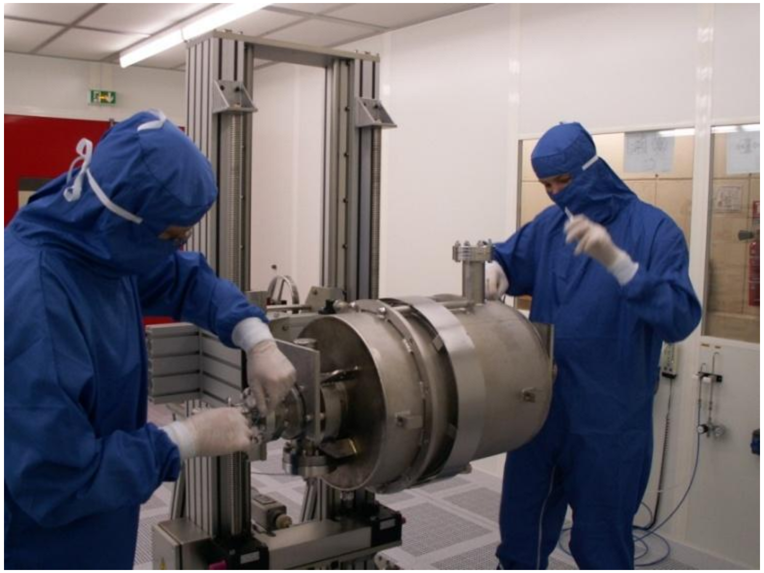


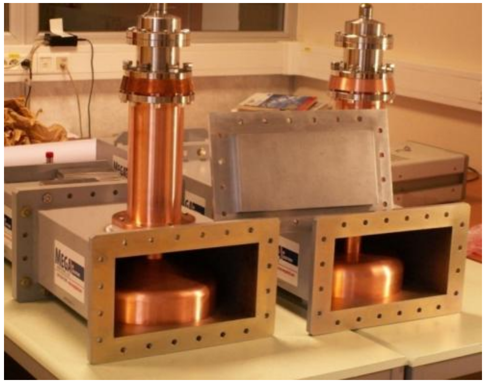
- Development of Spoke cavities & associated equipements
- Multi-spoke cavities identified as a possible alternative for high-energy
- High power integrated tests successfully performed at 4K & 2K

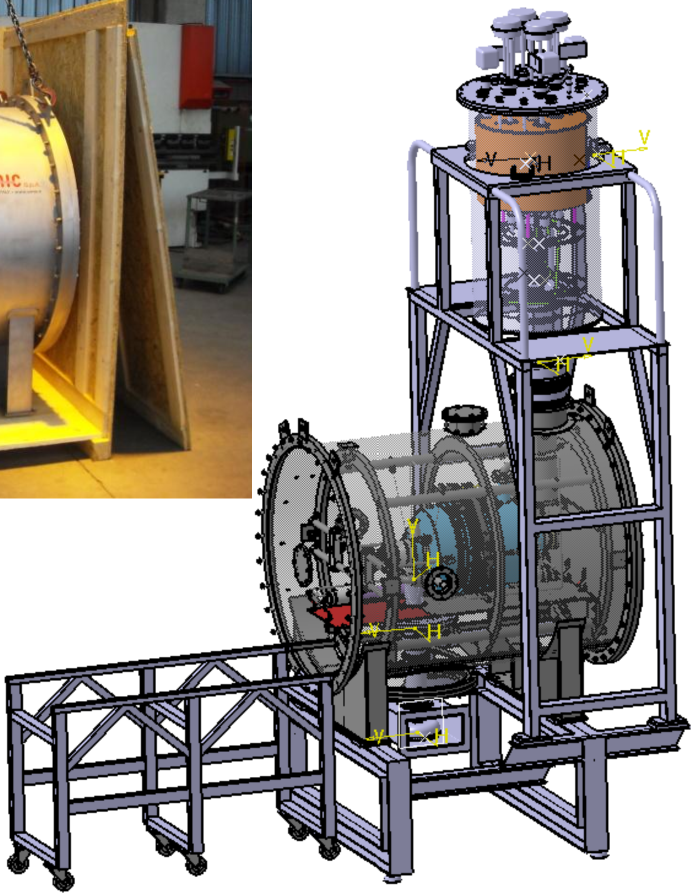
700 MHz module prototyping

IP-EUROTRANS
- INTEGRATED PROJECT ON EUROPEAN TRANSMUTATION -





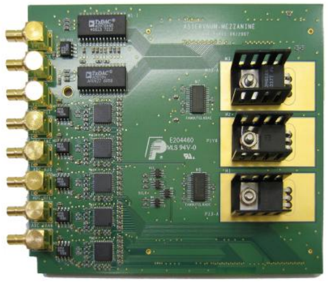


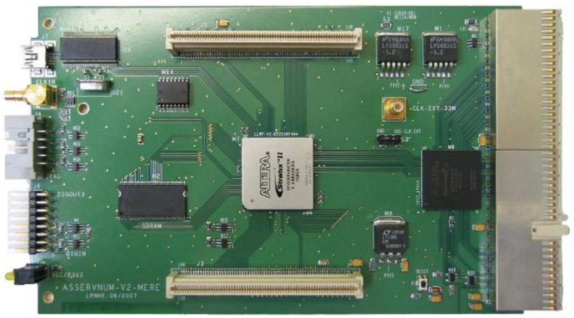


- Design & construction of a prototypical Elliptical ADS cryomodule, from scratch
- Commissioning phase presently on-going at 80 kW
- To be used as a test-bench for reliability-oriented experiments

Digital LLRF activities

IP-EUROTRANS
- INTEGRATED PROJECT ON EUROPEAN TRANSMUTATION -





➲ DLLRF reference scheme defined (suited to fault-tolerance procedures)

- a FPGA chip, able to process the feedback control algorithms,
- several ADCs and DACs, to convert the received and produced signals,
- a RAM memory, used to store set-points or save operating parameters,
- a serial bus, to communicate with the general control/command system,
- a fast serial bus, to communicate with adjacent boards.

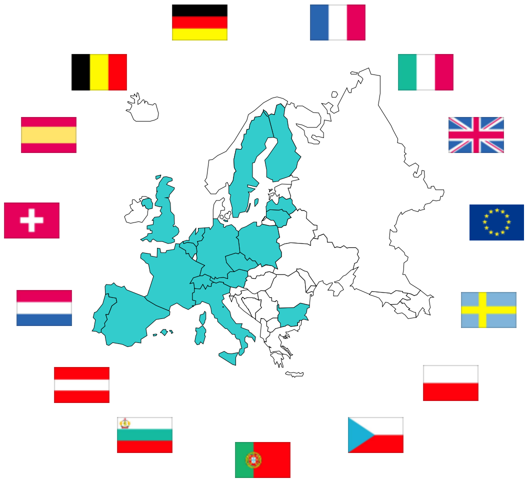
➲ Definition of a reference "fast fault-recovery scenario"

- **detect (or anticipate) the RF fault** (via dedicated diagnostics & interlocks) & **trigger beam shut-down**
- **update the new LLRF field and phase set-points** of the correcting cavities (data have been determined & stored in FPGAs during commissioning)
- **detune the failed cavity** (w/ piezo-actuators) and cut off the failed RF loop
- **trigger beam re-injection** once steady state is reached

FP7 Roadmap within MAX (2011-2013)

MAX
MYRRHA Accelerator eXperiment, research & development programme

- **On the linac global design**
  - Some elements still need to be further designed (connecting lines especially)
  - Start-to-end beam dynamics simulation w/ error study is needed
  - A much more detailed reliability analysis is strongly required, using the methodology of the current Nuclear Power Plants
  - Cryogenic & RF systems needs to be expertised & optimized
- **On the injector**
  - Explore the 176 MHz injector alternative (w/ a 4-rod RFQ) & associated R&D
  - Pursue the R&D on the very promising CH-DTL cavities, w/ focus on MYRRHA
- **On the main superconducting linac**
  - Engineering design of a MYRRHA-like spoke 350 MHz cryomodule
  - Use the 700 MHz prototypical cryomodule for reliability-oriented experiments



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Conclusions & short-term perspectives

➲ MYRRHA aims at developing & building a new large fast neutron research infrastructure to be operational in 2023

➲ A conceptual design of the MYRRHA accelerator has been settled within the EUROTRANS project

➲ Several R&D activities have been successfully performed, leading to design choices & recommendations

➲ Activities will be pursued in FP7, hopefully in the MAX project (Myrrha Accelerator eXperiment R&D programme)

➲ In parallel, special focus will be made at Mol to prepare the MYRRHA 1st phase: set up of international consortium, and injector engineering design

THANK YOU

for your attention !