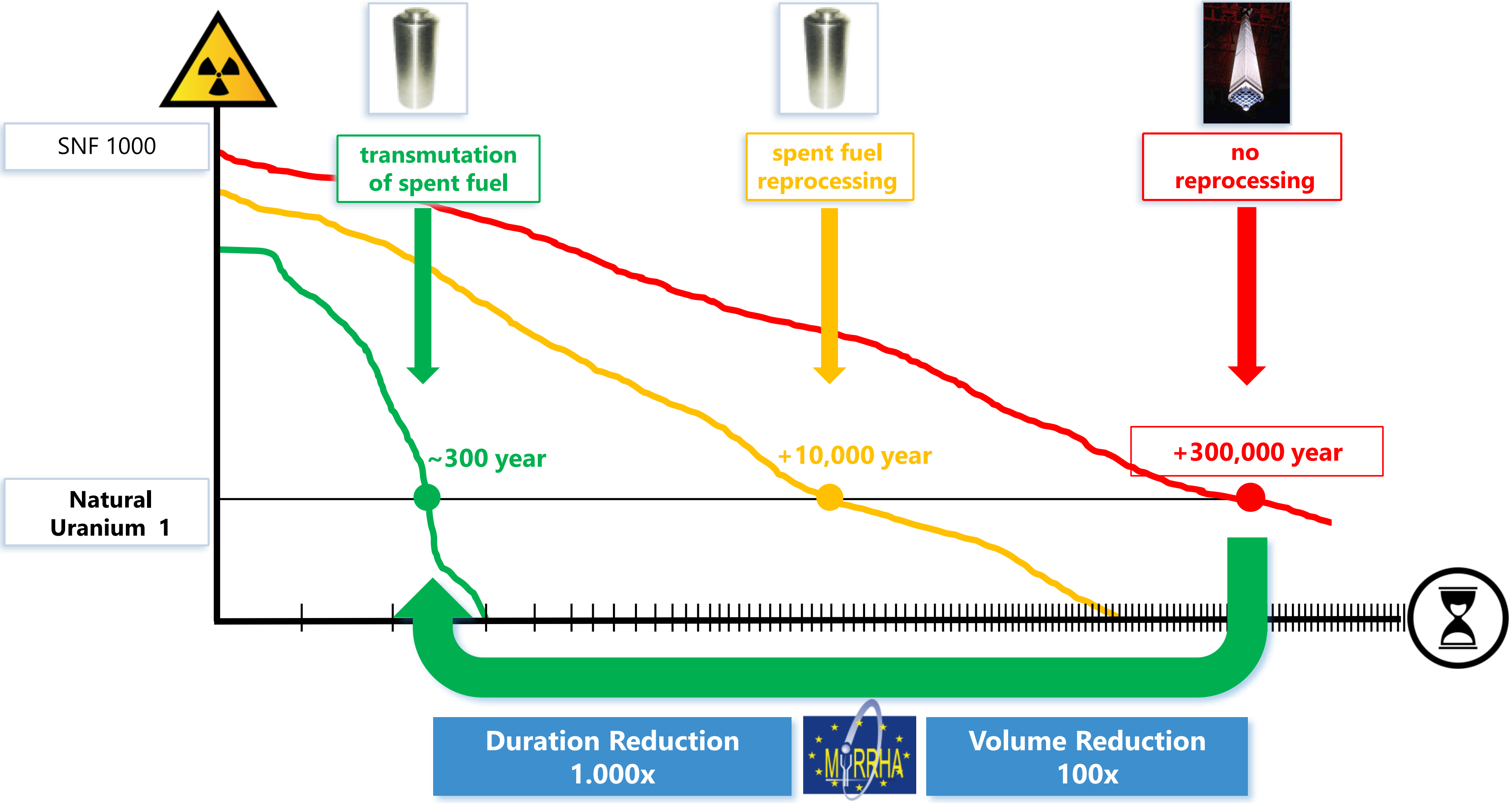
The MYRRHA project and the challenges of its linear accelerator

Dirk Vandeplassche

Future Circular Collider week Brussels, June 26th, 2019

Transmutation: better solution for Spent Nuclear Fuel

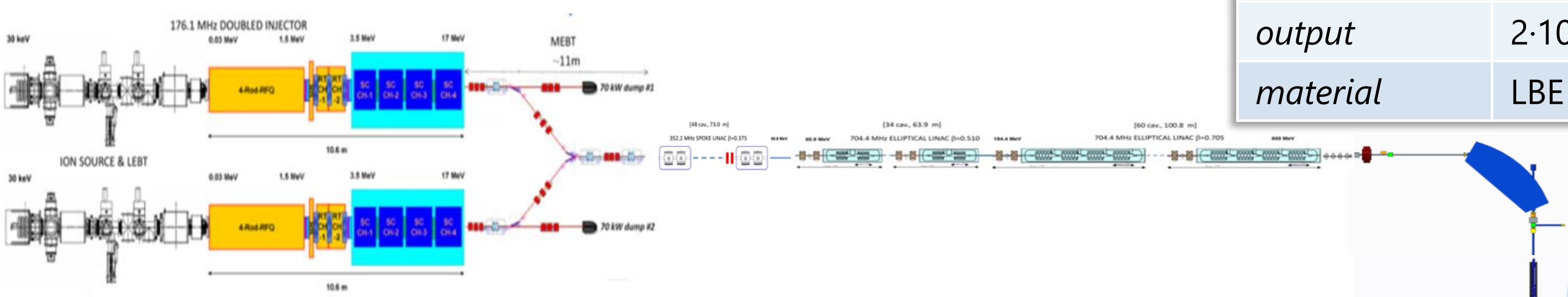


Source: European Commission Strategy Paper on Partitioning & Transmutation (2005), SCK•CEN MYRRHA Project Team

MYRRHA = Accelerator Driven System
Key Objectives

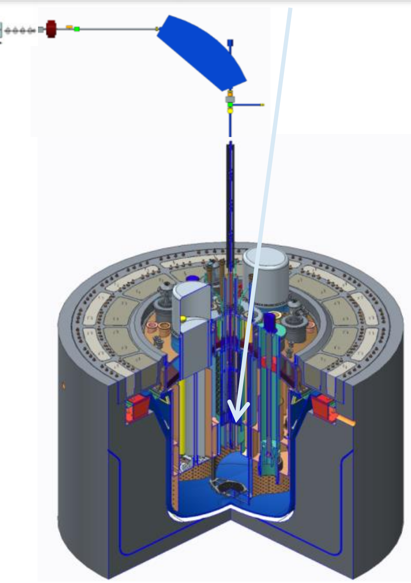
1. **Demonstrate the ADS concept at pre-industrial scale**
2. **Demonstrate transmutation**
3. **Multipurpose and flexible irradiation facility** (with fast neutron source)

Target	
main reaction	spallation
output	$2{\cdot}10^{17}$ n/s
material	LBE (coolant)



Accelerator	
particles	protons
beam energy	600 MeV
beam current	2.4 to 4 mA

Reactor	
power	65 to 100 MW_{th}
k_{eff}	**0,95**
spectrum	fast
coolant	LBE



Belgian Government decision on September 7, 2018

- **Decision to build** in Mol a new large research infrastructure MYRRHA
- Belgium **allocated budget** of 558 M€ for the period 2019 - 2038:
  - 287 MEUR investment (CapEx) for building MINERVA (Accelerator up 100 MeV + PTF) for 2019 - 2026
  - 115 MEUR for further design, R&D and Licensing for phases 2 (accelerator up to 600 MeV) & 3 (reactor) for 2019-2026.
  - 156 MEUR for OpEx of MINERVA for the period 2027-2038
- Establishment of an **International Non-Profit Organization**
  - in charge of the MYRRHA facility for welcoming international partners
- **Political support** for establishing MYRRHA international partnerships
  - Belgium mandates Vice Prime Minister Kris Peeters for promoting and negotiating international partnerships

MYRRHA application portfolio

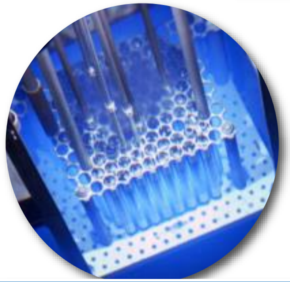
SNF*/ Waste

Fusion

Medical Radioisotopes

Multipurpose
h**Y**brid
Research
Reactor for
High-tech
Applications

Fundamental research



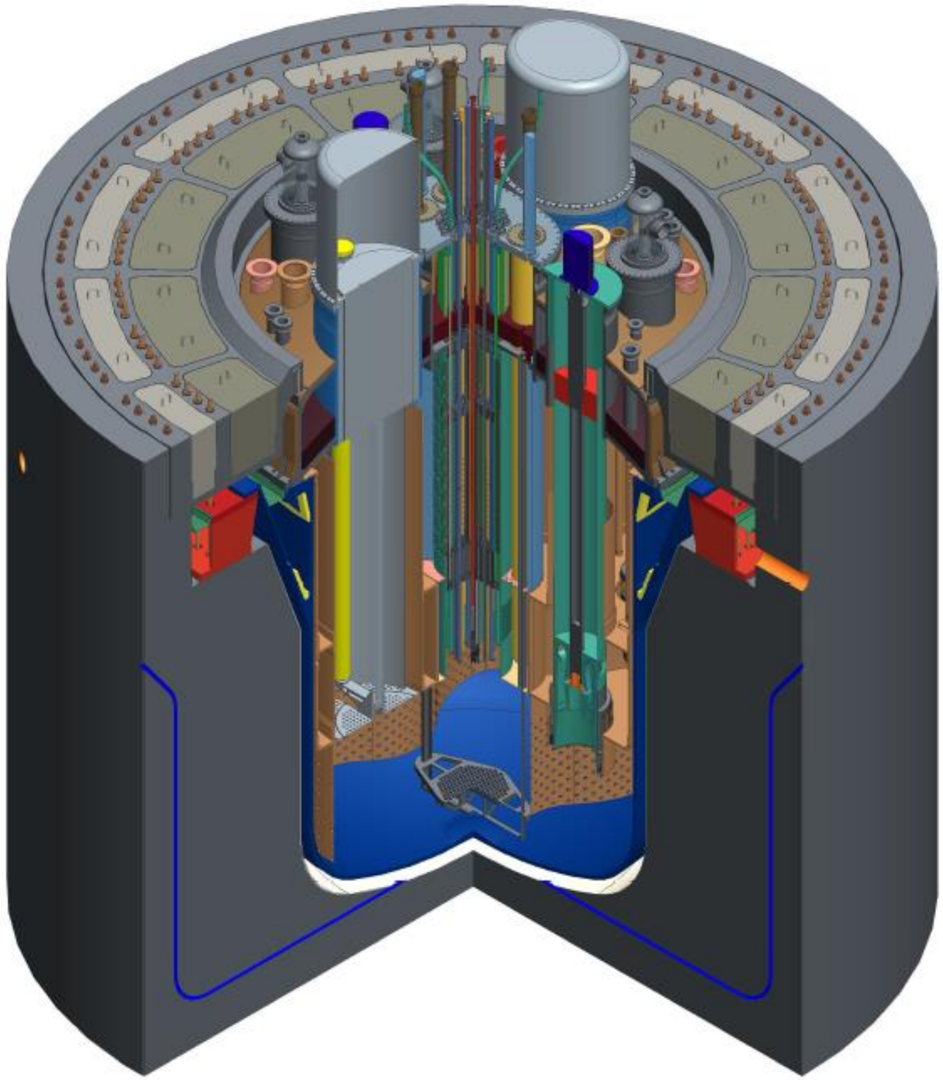
Support Fission GEN IV

Support to SMR LFR

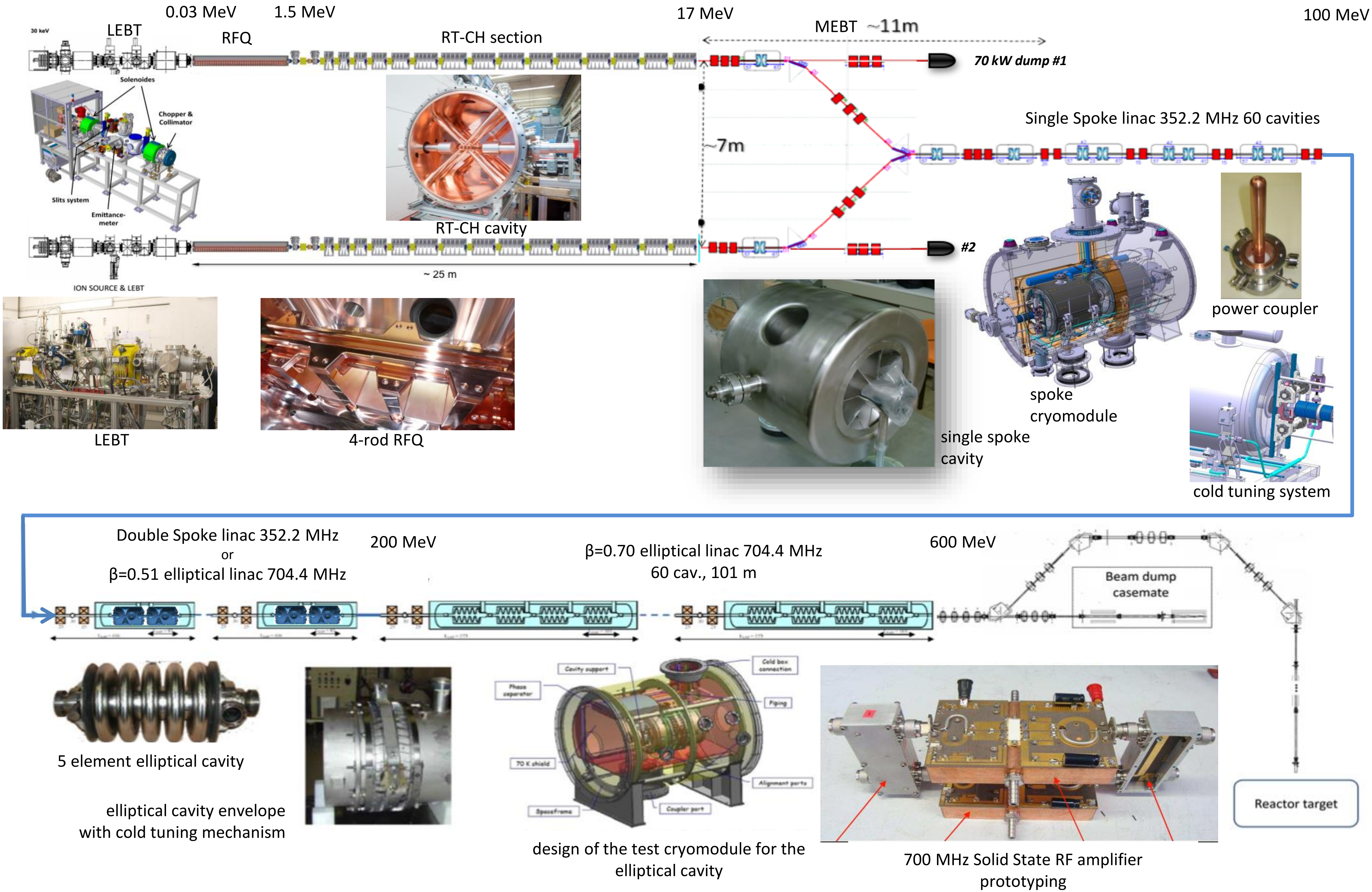
*SNF = Spent Nuclear Fuel

Source: SCK•CEN MYRRHA Project Team, MYRRHA Business Plan

MYRRHA: reactor pool type



Source: SCK•CEN MYRRHA Project Team



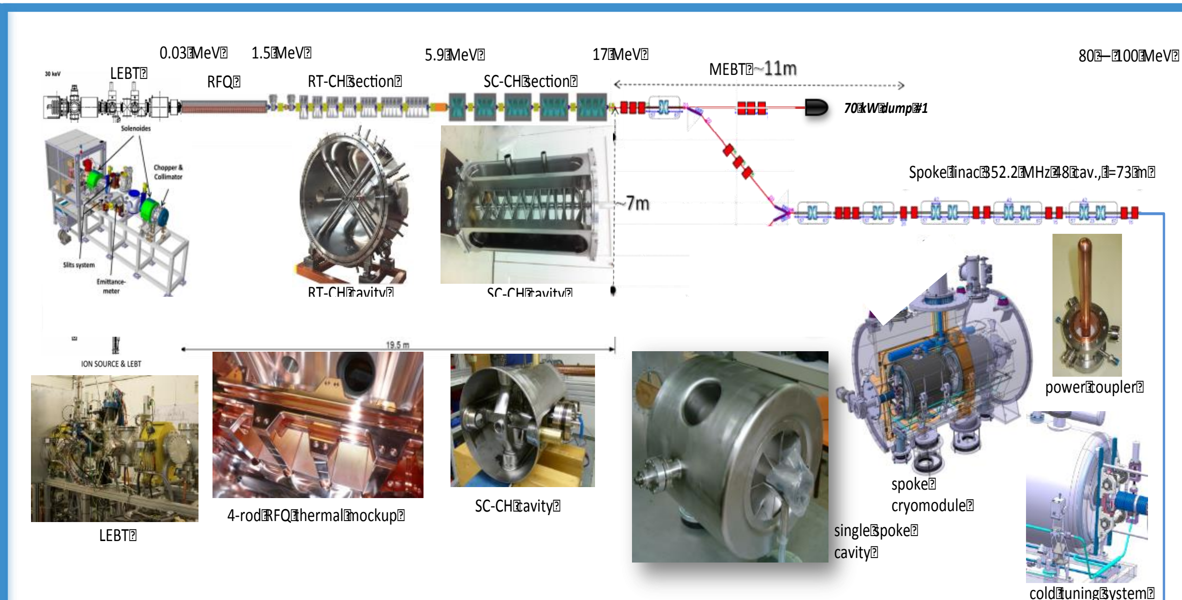
0.03 MeV
1.5 MeV
17 MeV
100 MeV
30 keV
LEBT
RFQ
RT-CH section
MEBT ~11m
70 kW dump #1
Solenoides
Chopper & Collimator
Slits system
Emittance-meter
Single Spoke linac 352.2 MHz 60 cavities
~7m
RT-CH cavity
#2
~ 25 m
ION SOURCE & LEBT
power coupler
LEBT
4-rod RFQ
spoke cryomodule
single spoke cavity
cold tuning system
Double Spoke linac 352.2 MHz
or
β=0.51 elliptical linac 704.4 MHz
200 MeV
β=0.70 elliptical linac 704.4 MHz
60 cav., 101 m
600 MeV
Beam dump casemate
5 element elliptical cavity
elliptical cavity envelope with cold tuning mechanism
Cavity support
Cold box connection
Phase separator
Piping
70 K shield
Alignment ports
Spaceframe
Coupler port
design of the test cryomodule for the elliptical cavity
700 MHz Solid State RF amplifier prototyping
Reactor target

MYRRHA's phased implementation strategy

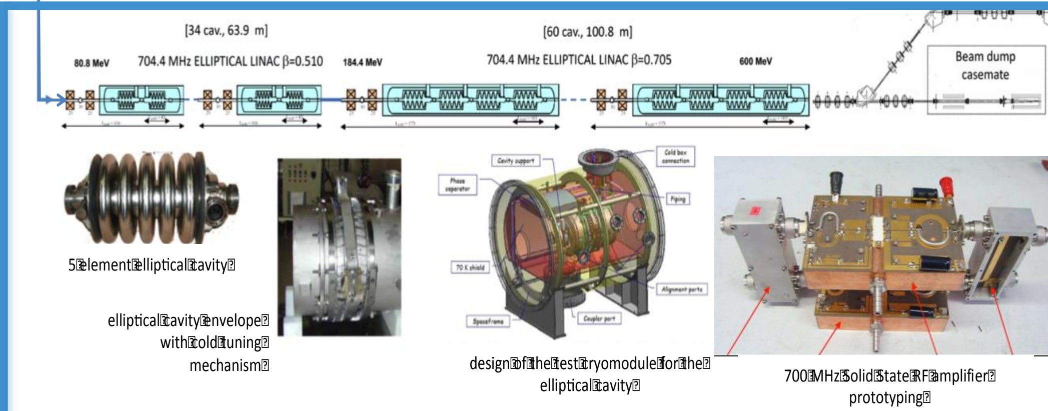
Benefits of phased approach:

- Reducing technical risk
- Spreading investment cost
- First R&D facility available in Mol end of 2026

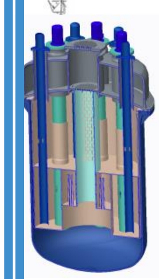
Phase 1 – 100 MeV



Phase 2 – 600 MeV

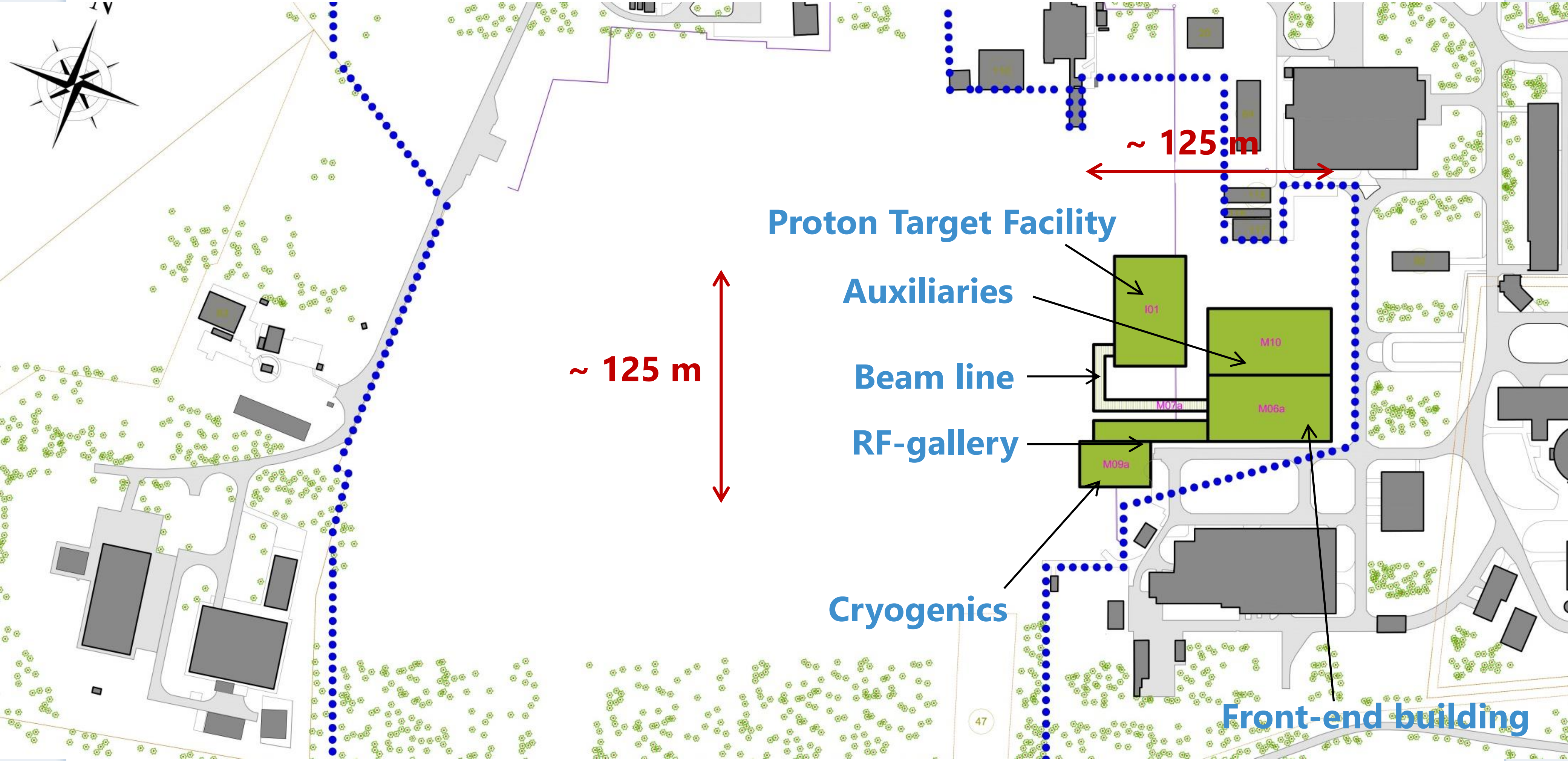


Phase 3 – Reactor



Source:SCK•CEN MYRRHA Project Team

MYRRHA masterplan: Linac 100 MeV + Proton Target Facility



High level requirements 600 MeV

- beam particle : protons
- beam energy : 600 MeV
- beam intensity : 4 mA
- beam delivery : CW with regular holes
- proton beam extraction → PTF
- beam MTBF : 250 hours, a failure = a beam trip > 3 s

Source: [TBD]

High level requirements 100 MeV

- beam particle : protons
- beam energy : 100 MeV
- beam intensity : 4 mA
- beam delivery : CW with regular holes
- proton beam extraction → PTF 100 MeV
- full power proton beam → fusion target

- beam MTBF : tbd, a failure = a beam trip > 3 s
- feed reliability model

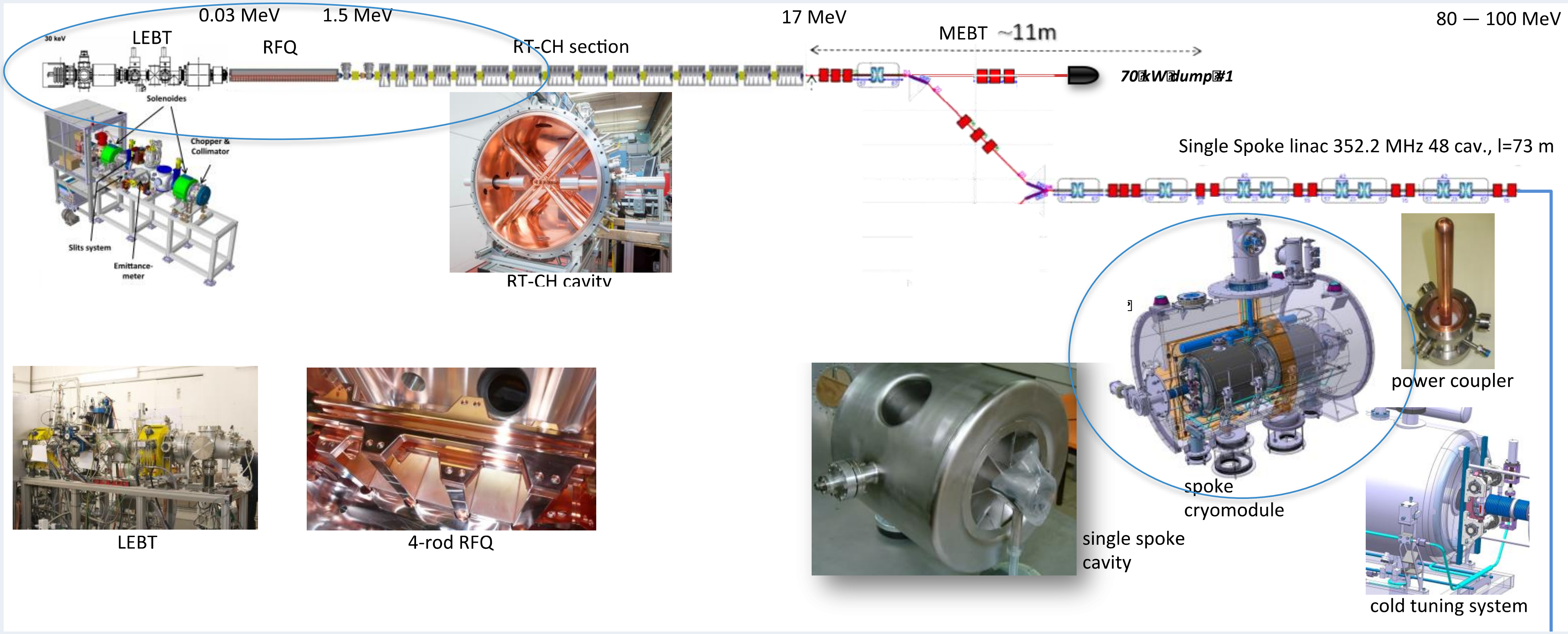
Source: [TBD]

Goals of the Phase 1 accelerator

- evaluation of the reliability of the 600 MeV MYRRHA driver
  - test platform for the fault recovery procedure
  - test platform for redundancy schemes
  - test platform for individual components
- test of industrial approach
  - series of cryomodules
  - control system
- feed of a PTF as a secondary target *in parallel* with the primary target

Source: [TBD]

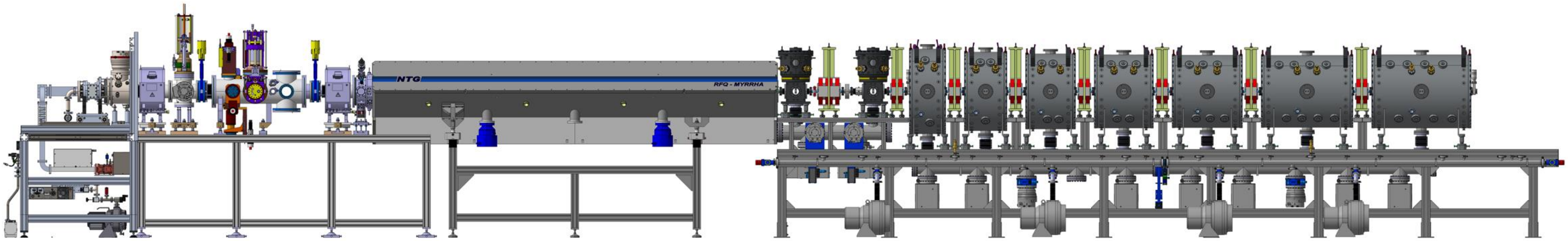
100 MeV / integrated R&D topics



- + R&D on distributed items:
  - Solid State RF amplifiers, LLRF, diagnostics, controls, …

Source: [TBD]

Integrated prototyping : inj @ LLN



1. Injector, at LLN up to 5.9 MeV

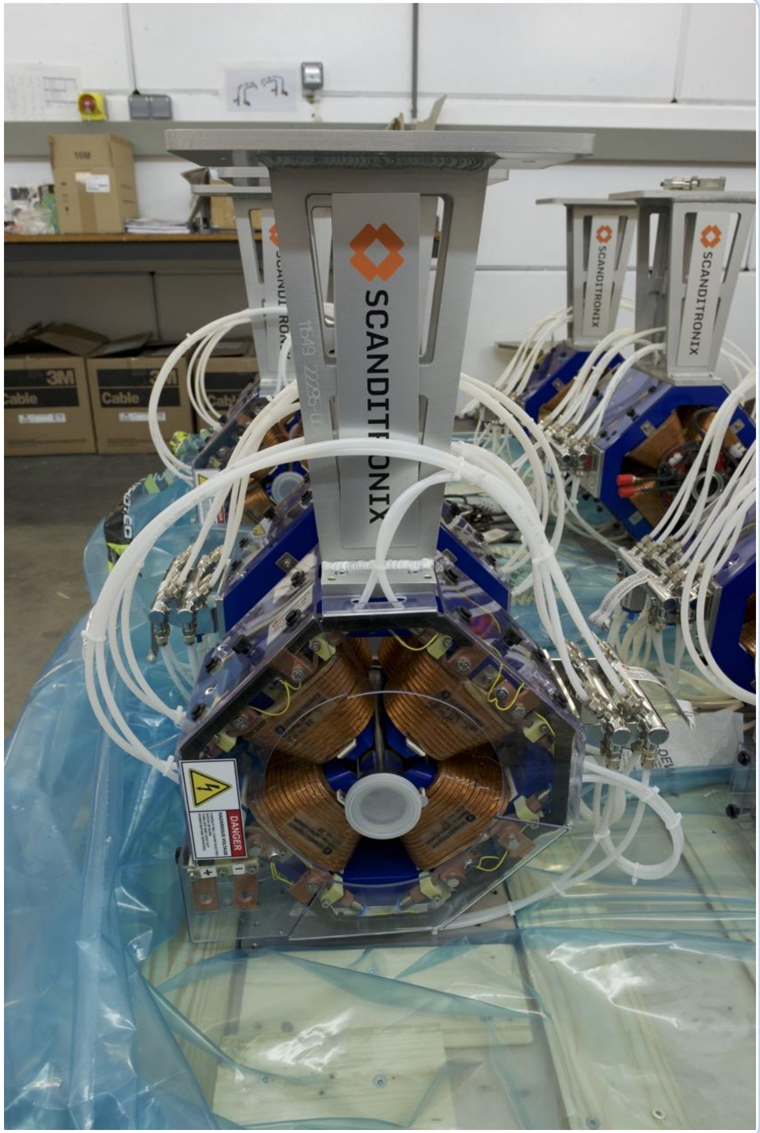
- Overview
  - full injector = 17 MeV : 15 copper CH cavities, separated function design
  - 5 mA max → 4-rod RFQ

Source: [TBD]

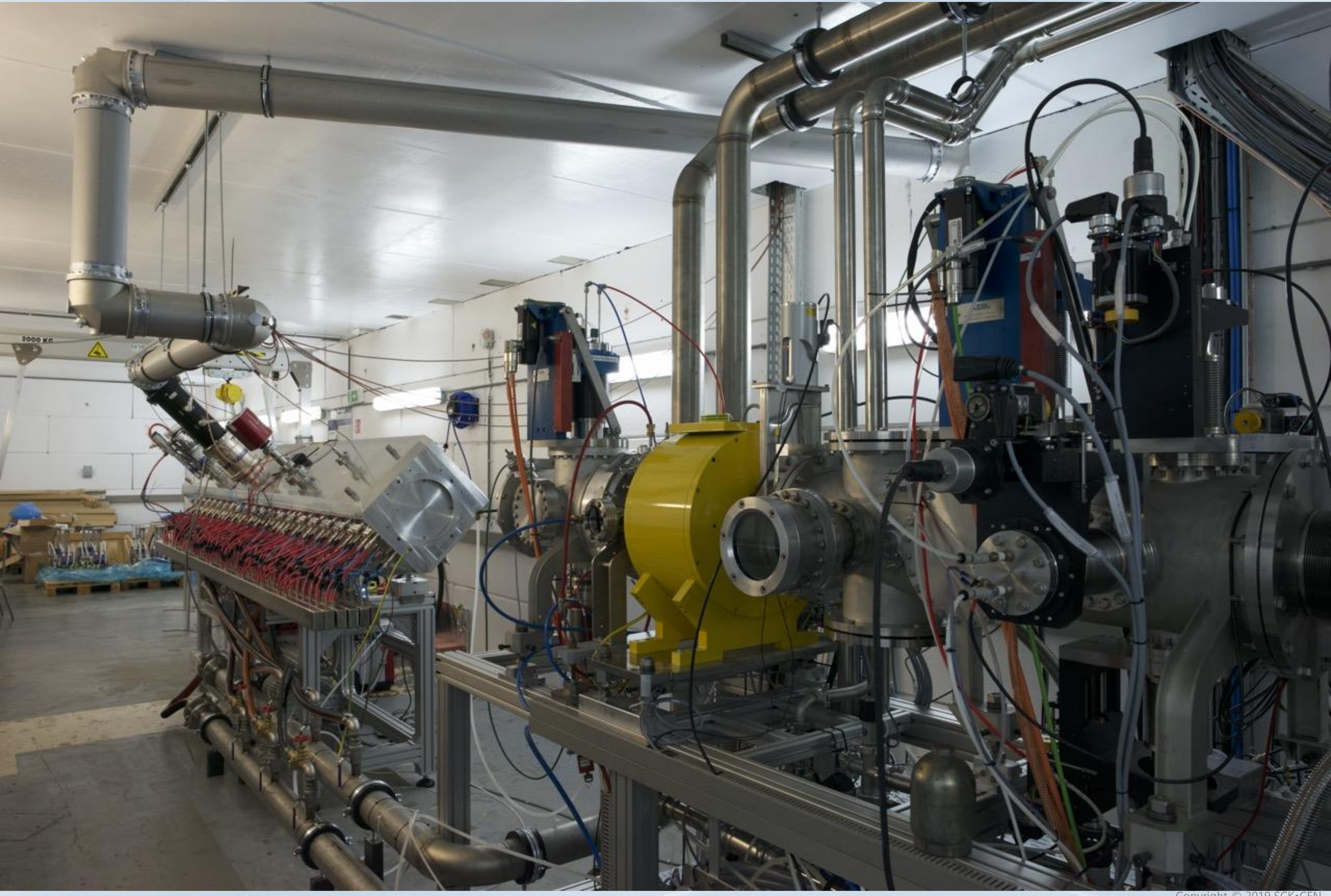
Integrated prototyping : inj @ LLN

1. Injector, at LLN up to 5.9 MeV

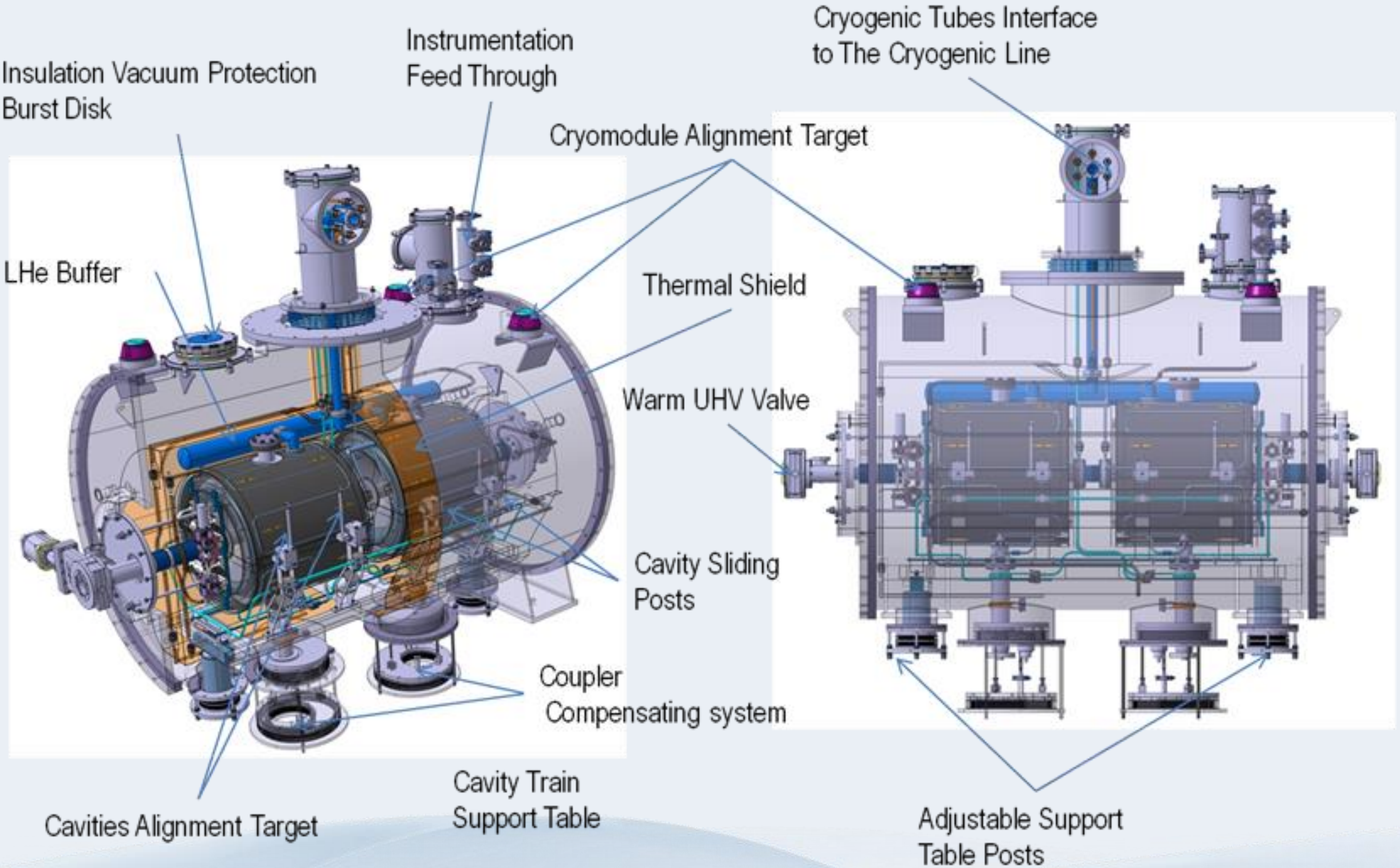
- RFQ : 4-rod, 176.1 MHz, 44 kV for 108 kW
  - now connected to SSA
  - present status : conditioning
  - LLRF : being finalized
- MEBT1 : matching section
  - longitudinal : 2 rebuncher cavities (1/4 wave)
  - transverse : quadrupole triplet
  - steerers, diagnostics (ACCT, BPM)
- CH-string : 1 – 7



Source: [TBD]


2000 KG

Integrated prototyping : spoke cryomodule



Source: [TBD]

Integrated prototyping : spoke cryomodule

2. Single Spoke cryomodule, by IPN Orsay

- Cavities
  - 2 new single spoke cavities under fabrication
  - treatment procedures finalized (excellent test results)
- Cryostat : manufacturing launched
- Power couplers : new development by LPSC
  - dedicated coupler test stand to be set up at LAL Orsay
  - cold test cavity+coupler to be foreseen "asap"
  - 4 couplers under call for tender (2 versions)
- Valve box : for prototype cryomodule
- Cold Tuning System : special development, compatible with fault recovery
  - final design stage

Source: [TBD]

Integrated prototyping : controls

3. Control system : industrial scenario
   - fundamental role in
     - overall reliability → need for "redundancy-compatible" architectures
     - fault recovery procedure and MPS
   - present status
     - covering very basic needs for now
     - fundamental EPICS central services : soon
     - towards a coherent global framework : following ESS
     - first steps into µTCA

Source: [TBD]

The approach to Fault Tolerance

- Initial approach : intuitive, experience based
- reliability of individual components
  - ranking & selection
  - increase the MTBF by operation point
- global linac design
  - → margins for reliability
  - → margins for *fault tolerance*
  - given the prerequisite of *modularity*

Source: [TBD]

The approach to Fault Tolerance

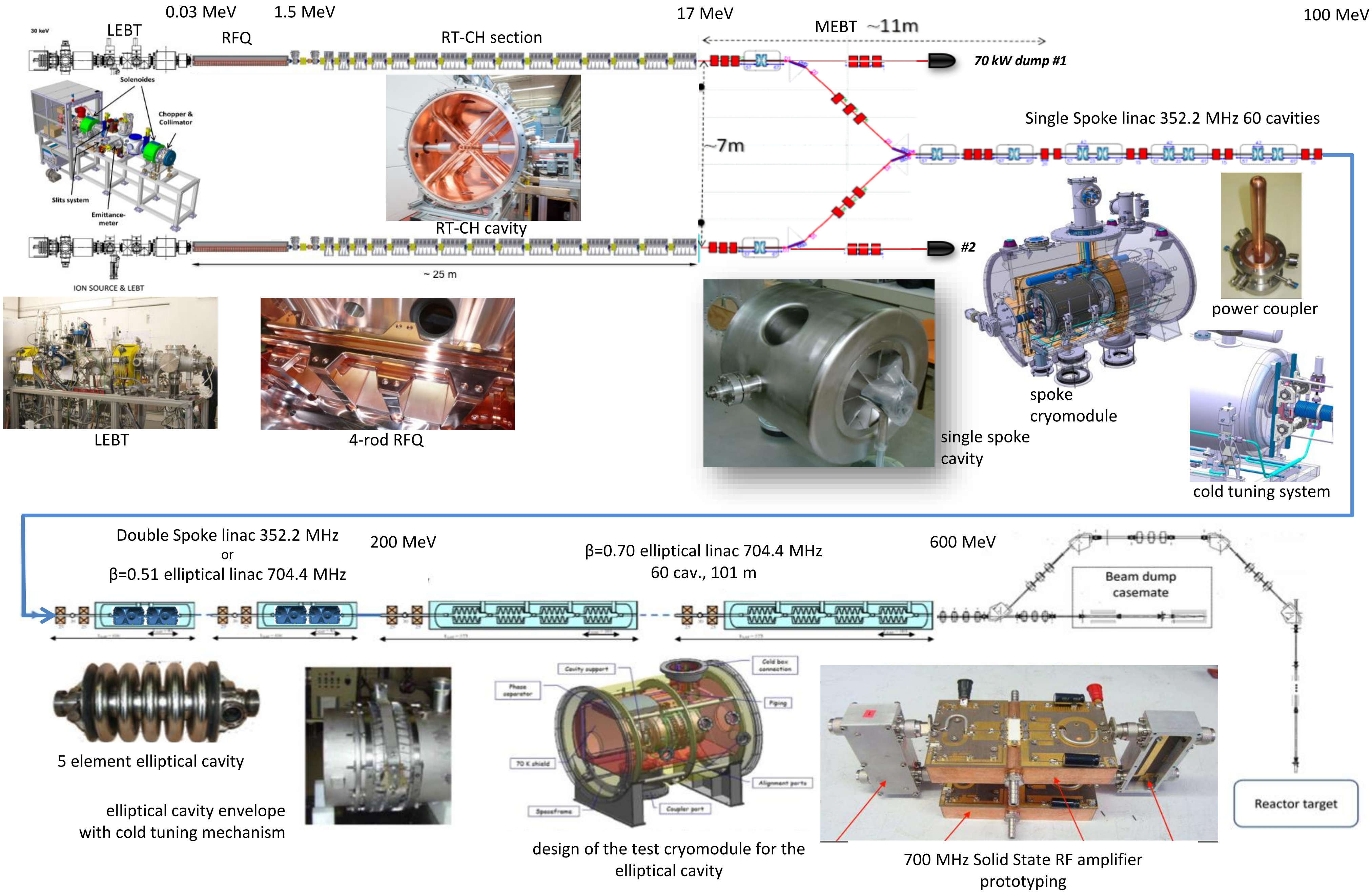
- The mechanism(s) of fault tolerance : some form of redundancy
  - at the level of the modular linac : serial redundancy
    - the adjacent cavity scenario
    - requirement 1 : individually powered cavities
    - requirement 2 : 3 seconds recovery time

fault recovery procedure

  - at the level of the individual cavity linac : parallel redundancy
    - requirement : 3 seconds recovery time

fast switching

Source: [TBD]



0.03 MeV
1.5 MeV
17 MeV
100 MeV
LEBT
RFQ
RT-CH section
MEBT ~11m
70 kW dump #1
Solenoides
Chopper & Collimator
Slits system
Emittance-meter
RT-CH cavity
~7m
Single Spoke linac 352.2 MHz 60 cavities
#2
~ 25 m
ION SOURCE & LEBT
LEBT
4-rod RFQ
single spoke cavity
spoke cryomodule
power coupler
cold tuning system
Double Spoke linac 352.2 MHz
or
β=0.51 elliptical linac 704.4 MHz
200 MeV
β=0.70 elliptical linac 704.4 MHz
60 cav., 101 m
600 MeV
Beam dump casemate
Reactor target
5 element elliptical cavity
elliptical cavity envelope with cold tuning mechanism
design of the test cryomodule for the elliptical cavity
700 MHz Solid State RF amplifier prototyping

The approach to Fault Tolerance

- other applications of *serial* redundancy :
  - Solid State RF power amplifiers
- other applications of *parallel* redundancy :
  - power converters
  - hardware components of the control system

effective needs to be obtained from modeling

- beam diagnostics : redundancy from overdetermined systems
  - statistical methods
  - model fitting
  - decision taking, fault identification or (better) fault prediction

Source: [TBD]

The approach to Fault Tolerance

- Basic requirements for effective redundancy :
  - reproducible modules
    - control of the process of industrialisation / serialisation
    - QC
  - control of MTTR

Source: [TBD]

The challenges for MINERVA 100 MeV

- Beam dynamics supporting the fault tolerance
  - start-to-end simulations
  - error studies
  - optimisation of the longitudinal acceptance
- Fault recovery procedure
  - 3 seconds : the rationale is operational
  - 3 seconds : 3 main tasks
    1. fault detection / identification of the cause
    2. reconfiguration
       - obtain new configuration
       - install new configuration
       - i.c., fast cavity detuning

Source: [TBD]

The challenges for MINERVA 100 MeV

3. beam recovery

- fast tools (esp. for 2.)
  - data base applications (storage of alternate configurations)
  - simulations (calculation of alternate configurations)
  - decision taking
- Reliability modeling
  - compulsory for making the step phase 1 (100 MeV) → phase 2 (600 MeV)
    - predictive model
  - collaboration with CERN being set up
    - modeling
    - fault tracking tools : feeding the models with data

Source: [TBD]

The challenges for MINERVA 100 MeV

- Machine Protection System
  - main fault indication system
  - HPPA → MPS with 10's of μs response is vital
  - false interlocks must be identified immediately
- *compatible* Control System
  - procured from industry
  - compatible in performance
    - demands from reliability
    - Fault Recovery Procedure
  - compatible in its own reliability (and redundancy)
  - capabilities of "virtual operator" → AI tools

Source: [TBD]

Solid State RF Amplifiers

- Linac fault statistics : RF share of 40 – 50%
  - redundancy ? (CW for MYRRHA)
- search for serial redundancy → modularity
  - transistor-based approach offers this
  - cfr. Soleil = pioneer
- search for a compact realisation
  - IBA's interest
  - partnership through MYRTE (H2020)
  - → RFQ amplifier 192 kW CW, 176 MHz
  - connected to RFQ cavity, no circulator

Source: [TBD]

Solid State RF Amplifiers

- RFQ amplifier by IBA
- 176 MHz, 192 kW CW
- very positive initial testing (1 retrofit campaign)
- connected to RFQ cavity without circulator
- ready for long duration tests
- other amplifiers (176 and 352 MHz) through a bilateral collaboration agreement

Source: [TBD]

Conclusion

- MYRRHA : medium term ADS demonstrator in view of
  - transmutation of minor actinides
  - production of innovative medical radioisotopes
- reactor R&D (Pb-Bi cooled, pool type) is ongoing
- accelerator reliability (availability ?) is of *vital* importance
- need for scenarios, tools, methods, … and a new way of thinking
- Cfr. many future accelerator projects : need for reliability becomes a common concern
- Common problems should be tackled in common : collaborations
- 100 MeV prototype will be built for learning, hopefully to the benefit of the community

Source: [TBD]

In Belgium, for Europe and beyond: sustainable & innovative applications from nuclear research

SCK•CEN
Studiecentrum voor Kernenergie
Centre d'Etude de l'Energie Nucléaire
Belgian Nuclear Research Centre

Stichting van Openbaar Nut
Fondation d'Utilité Publique
Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSELS
Operational Office: Boeretang 200 – BE-2400 MOL