Euratom MAX project

The MYRRHA Accelerator eXperiment R&D programme

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EURATOM FP7 MAX project coordinator

1. Introduction

2. The MYRRHA accelerator concept
3. Some MAX recent achievments
4. Perspectives

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

❶ ADS demonstrator

❷ Fast neutron irradiation facility

❸ Pilot plant for LFR technology

The MYRRHA accelerator: background

- **End 90's**: several collaborative R&D activities worldwide on ADS accelerators *(APT/AAA, TRASCO, etc. w/ especially a CEA/CNRS/INFN collaboration)*
- **2001:** "The European roadmap for developing ADS for Nuclear Waste Incineration", European Technical Working Group on ADS *(chaired by C. Rubbia, ENEA)*
- **2002**: pre-design "**Myrrha Draft 1**" *(cyclotron 350 MeV)*
- **2002-2004:** MYRRHA is studied as one of the 3 reactor designs within the **PDS-XADS FP5 project** (coord. Framatome/AREVA) *(cyclotron turns into linac, first reliability analyses show a need for fault-tolerance capability)*

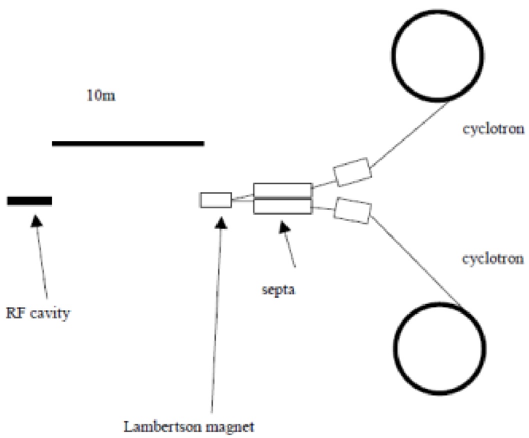


Figure 40 – Overall Layout for the Cyclotron XADS option.

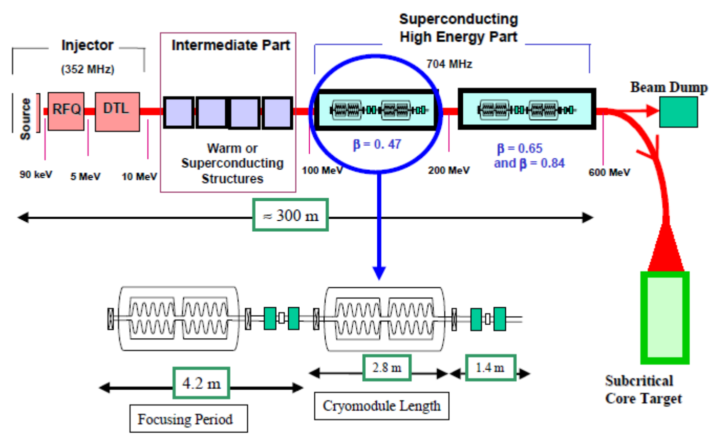
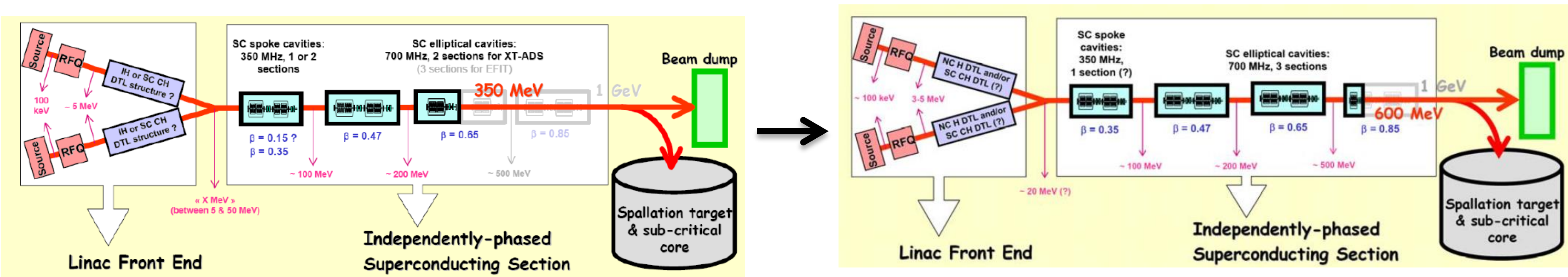


Figure 1 – Schematic layout of the XADS accelerator in the linac option.

The MYRRHA accelerator: background

- **2005**: updated pre-design "**Myrrha Draft 2**" *(linac 350 MeV)*
- **2005-2010:** MYRRHA is studied as the XT-ADS demo within the **EUROTRANS FP6 project** (coord. FZK)
  (600 MeV linac conceptual design, R&D activities w/ focus on reliability)



- **2010:** MYRRHA is on the ESFRI list, and officially supported by the Belgium government at a 40% level *(384M€, w/ 60M€ already engaged)*
- **2010-2014:** MYRRHA accelerator advanced design phase w/ support from the **EURATOM FP7 projects** *(MAX especially)*
- **2015-2019:** possible construction phase
- **2020-2023:** possible commissioning phase & progressive start-up

MYRRHA within EURATOM FP7: 2010-2014

CDT

Reactor design

SCK•CEN

MARISA

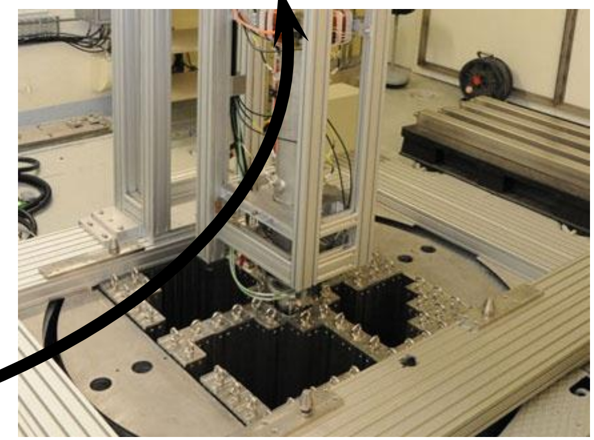
Support action

SCK•CEN

FREYA

GUINEVERE experiment

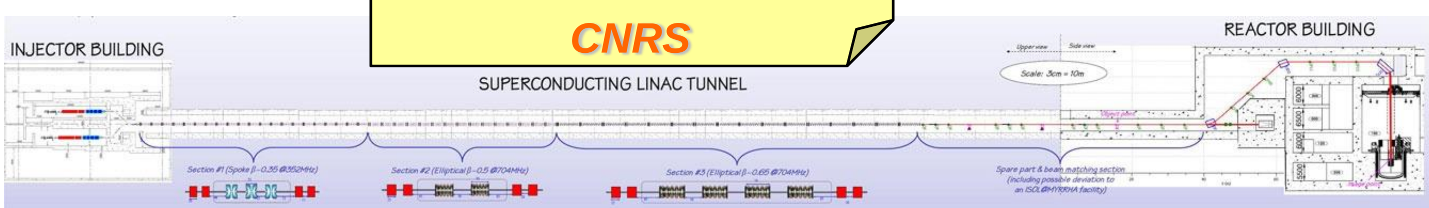
SCK•CEN



MAX

Accelerator design

CNRS

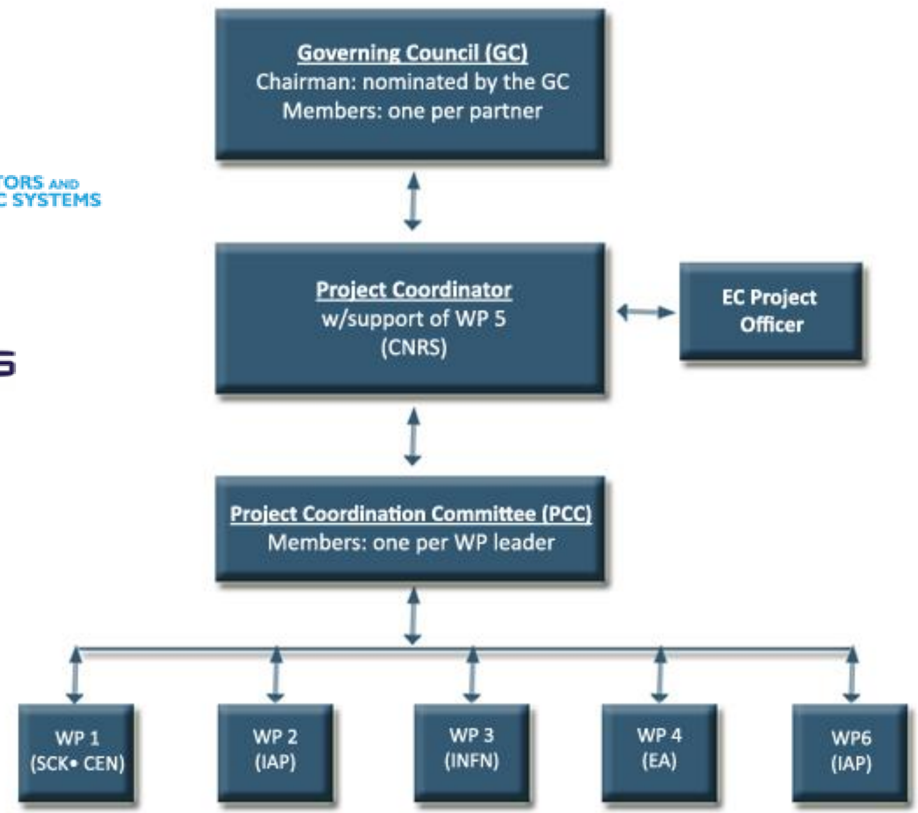


The MAX project

Goal: deliver a consolidated reference layout of the MYRRHA linac with sufficient detail and adequate level of confidence in order to initiate in 2015 its engineering design and subsequent construction phase

COORDINATOR

http://ipnweb.in2p3.fr/MAX/



WP1: Global accelerator design

WP2: Injector developments

WP3: Main linac developments

WP4: System optimisation

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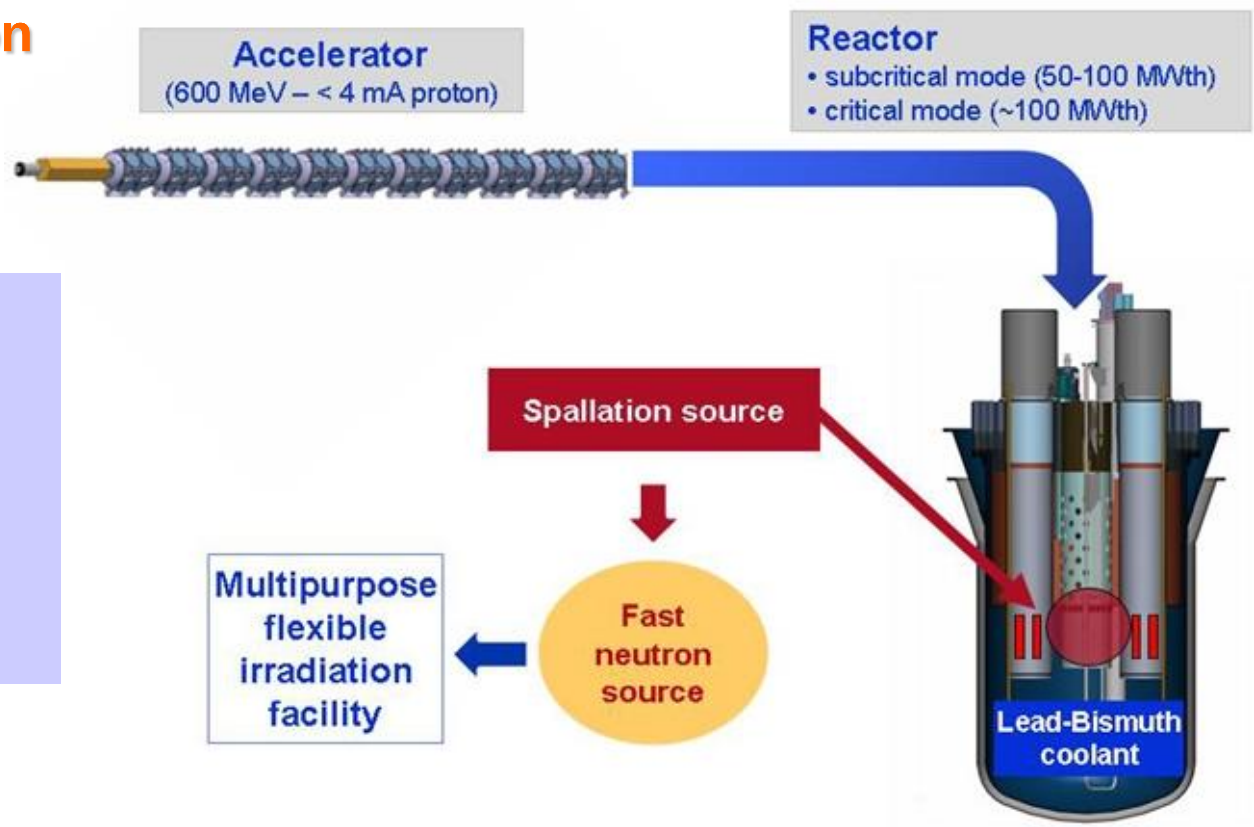
MYRRHA as an ADS demonstrator

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

- Demonstrate the **ADS concept** (coupling accelerator + spallation source + power reactor)
- Demonstrate the **transmutation** (experimental assemblies)



Main features of the ADS demo

50-100 MWth power

Highly-enriched MOX fuel

Pb-Bi Eutectic coolant & target

k_{eff} around 0.95 in subcritical mode

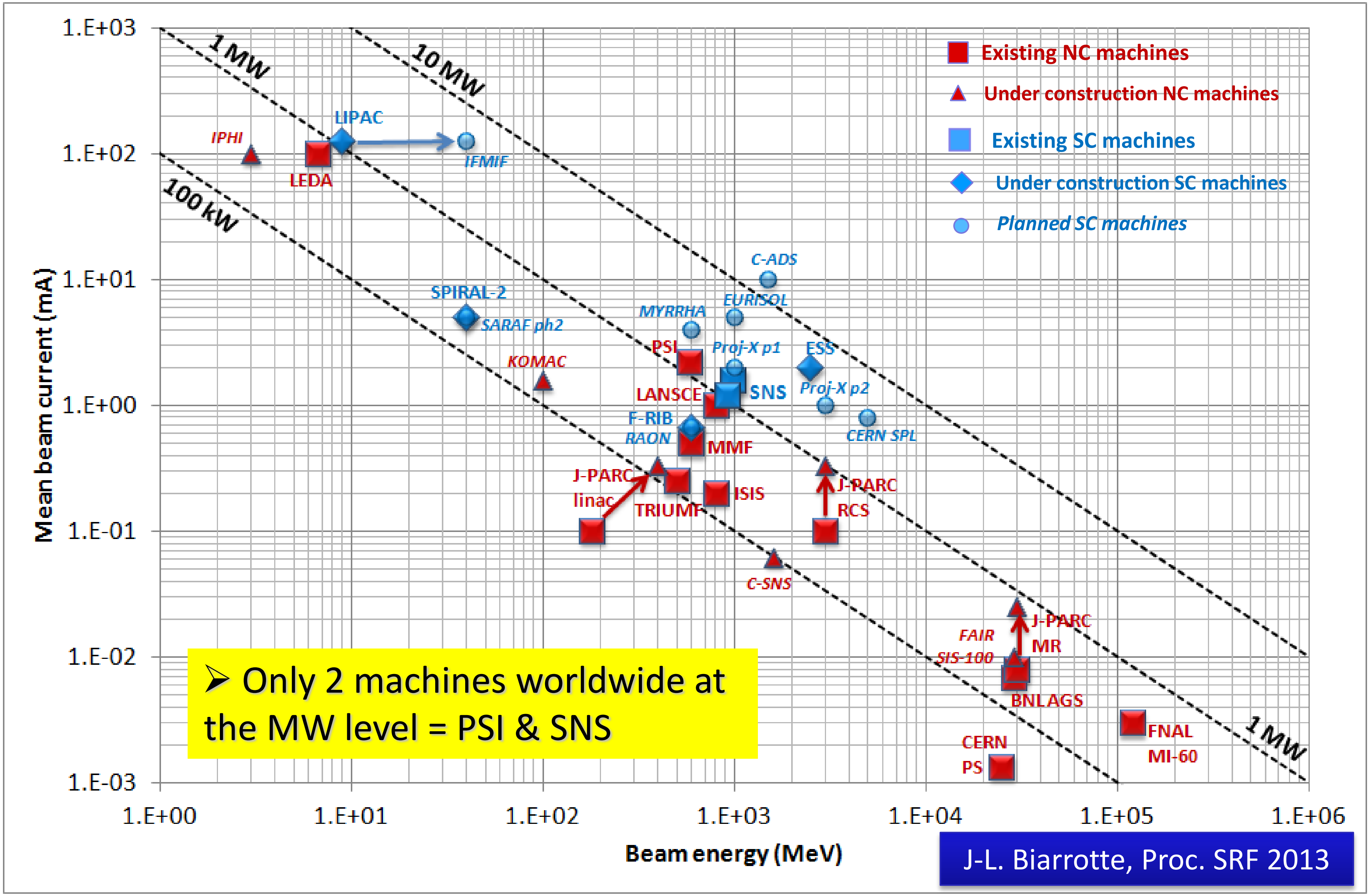
600 MeV, 2.5 - 4 mA proton beam

MYRRHA proton beam requirements

→ High power proton beam (up to 2.4 MW)

Proton energy	600 MeV
Peak beam current	0.1 to 4.0 mA
Repetition rate	1 to 250 Hz
Beam duty cycle	10^{-4} to 1
Beam power stability	< ± 2% on a time scale of 100ms
Beam footprint on reactor window	Circular ∅85mm
Beam footprint stability	< ± 10% on a time scale of 1s
# of allowed beam trips on reactor longer than 3 sec	10 maximum per 3-month operation period
# of allowed beam trips on reactor longer than 0.1 sec	100 maximum per day
# of allowed beam trips on reactor shorter than 0.1 sec	unlimited

Panorama of high-power proton accelerators



➢ Only 2 machines worldwide at the MW level = PSI & SNS

J-L. Biarrotte, Proc. SRF 2013

MYRRHA proton beam requirements

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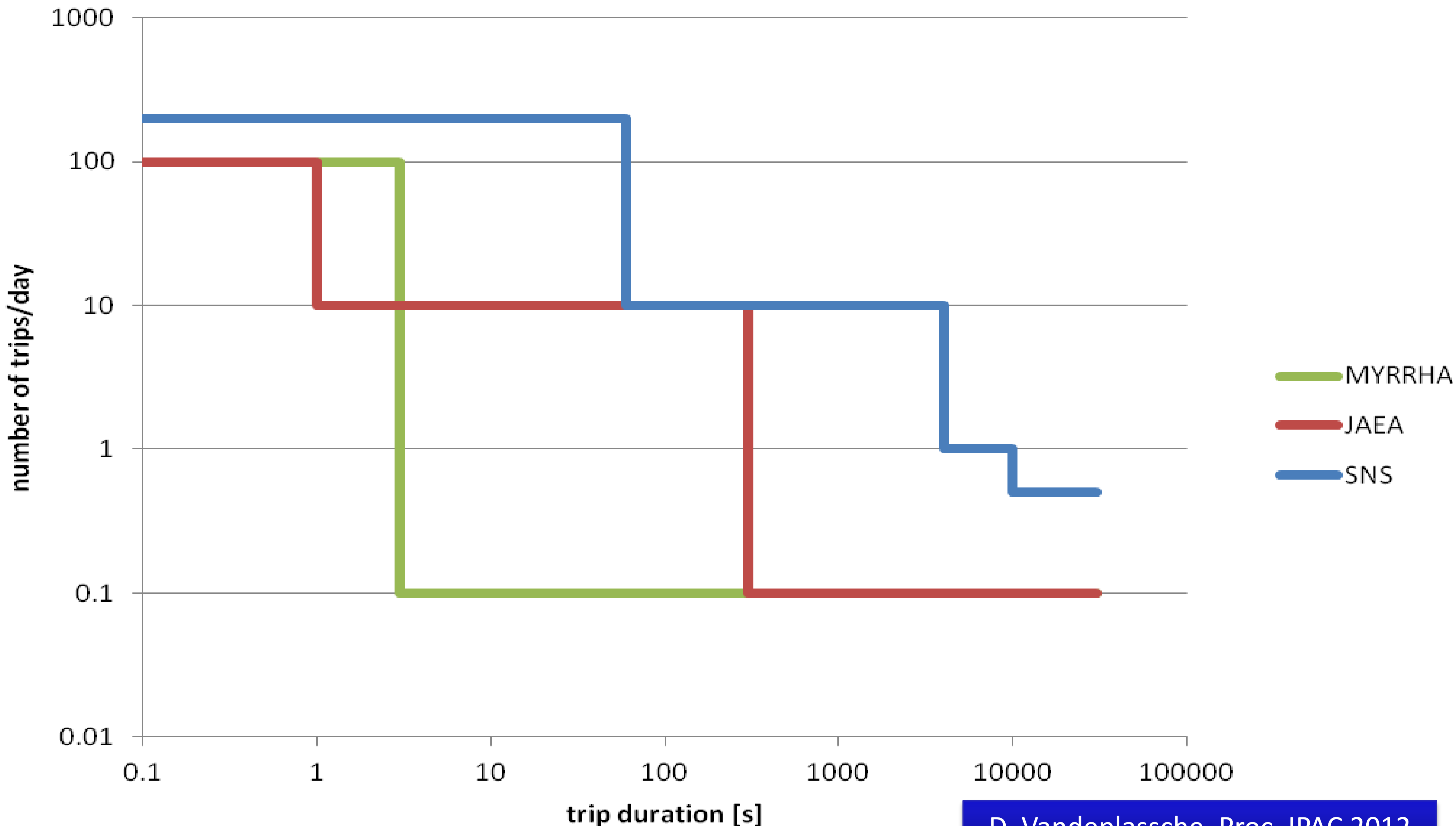
→ **Extreme reliability level**

The ADS reliability requirement



D. Vandeplassche, Proc. IPAC 2012

The ADS reliability requirement

- **Beam trips longer than 3 sec** must be very rare:
  - To limit thermal stress & fatigue on the target window, reactor structures & fuel assemblies
  - To ensure a 80% availability – given the foreseen reactor start-up procedures

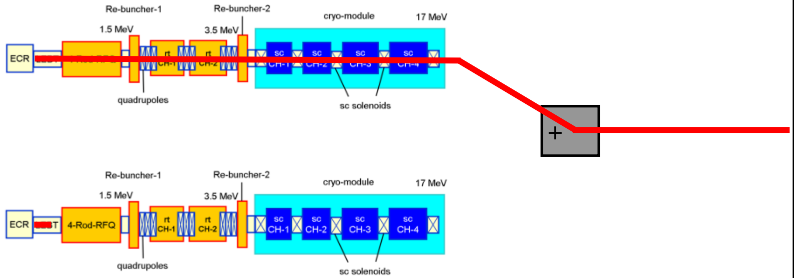
- **Present MYRRHA spécifications:** <10 beam trips per 3-month operation period (i.e. MTBF > 250h) – derived from the PHENIX reactor operation analysis
  - Far above present HPPA accelerator performance – MTBF is a few hours at PSI or SNS
  - Far above present ADS specifications in US or Japan – based on simulations

- **In any case, reliability guidelines are needed for the ADS accelerator design:**
  - **Strong design** i.e. robust optics, simplicity, low thermal stress, operation margins…
  - **Repairability** (on-line where possible) and efficient maintenance schemes
  - **Redundancy** (serial where possible, or parallel) to be able to tolerate failures

Strategy for a fault in the injector = parallel redundancy

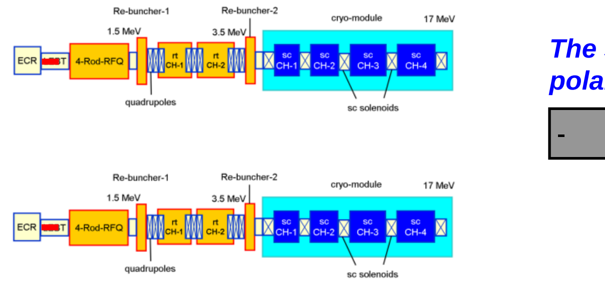
❶ Initial configuration

Operational injector 1: RF + PS + beam ON



Warm stand-by injector 2: RF+ PS ON, beam OFF (on FC)

❸ The failure is localized in injector

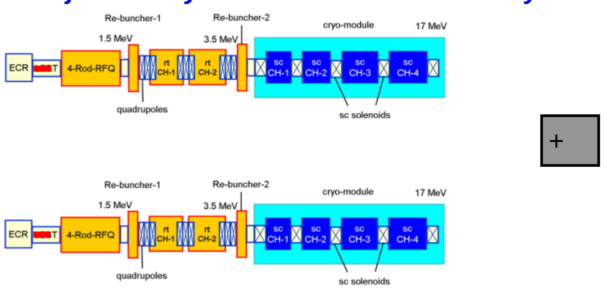


The switching magnet polarity is changed (~1s)

Need for an efficient fault diagnostic system !

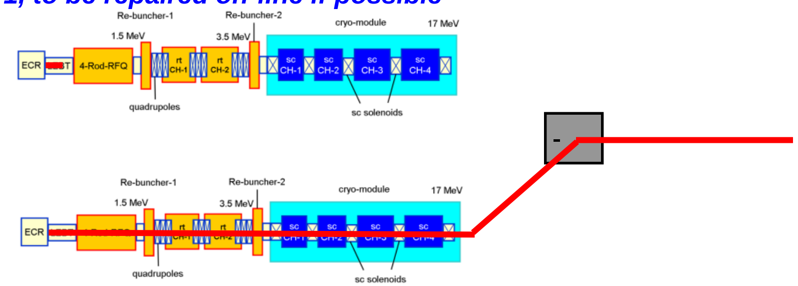
❷ A failure is detected anywhere

Beam is stopped in injector 1 by the Machine Protection System @t_0



❹ Beam is resumed

Failed injector 1, to be repaired on-line if possible



Injector 2 operational (@$t_1 < t_0$ +3sec)

Strategy for a fault in the main linac = serial redundancy

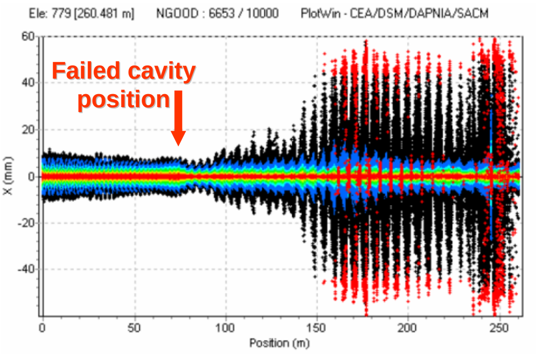


Figure 12 : Transverse beam distribution at 220 µs, in red are plotted the losses

❶ A failure is detected anywhere

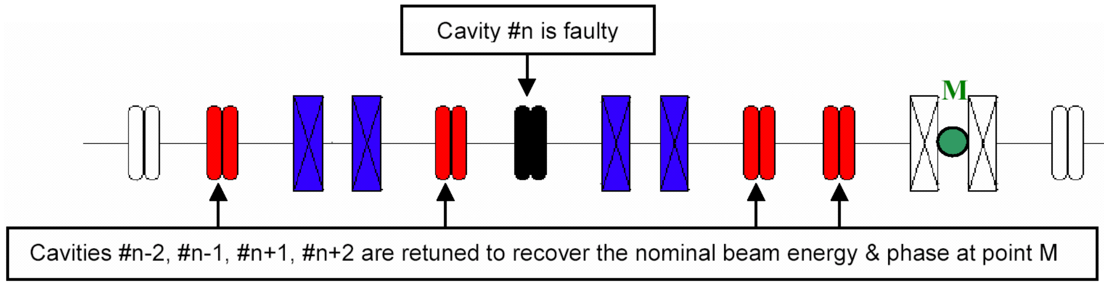
→ Beam is stopped by the MPS in injector at t_0

❷ The fault is localized in a SC cavity RF loop

→ Need for an efficient fault diagnostic system

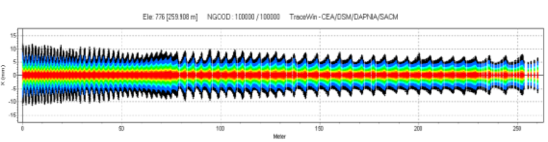
❸ New V/φ set-points are updated in cavities adjacent to the failed one

→ Set-points determined via virtual accelerator application and/or at the commissioning phase



❹ The failed cavity is detuned (to avoid the beam loading effect)

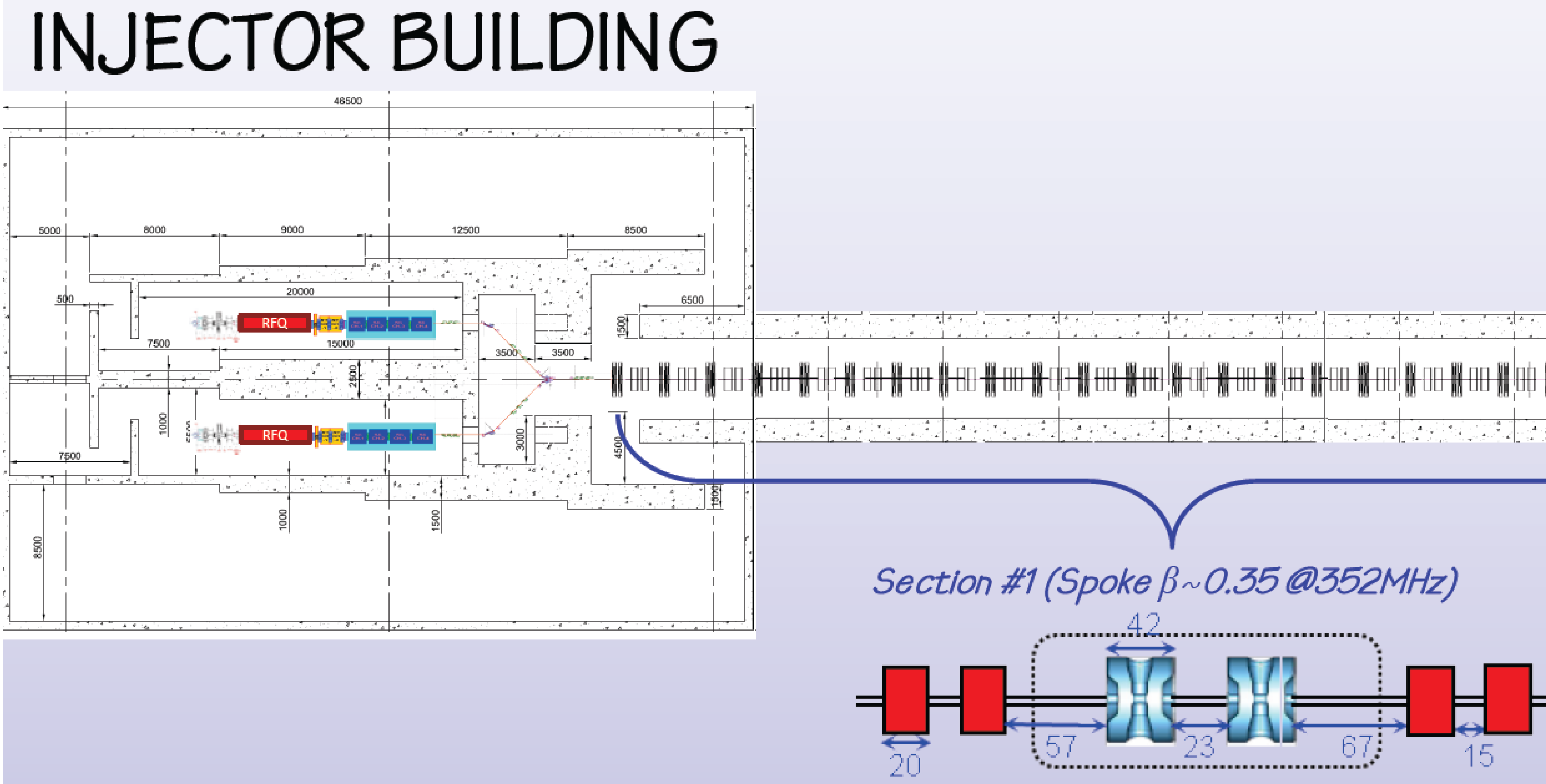
→ Using the Cold Tuning System



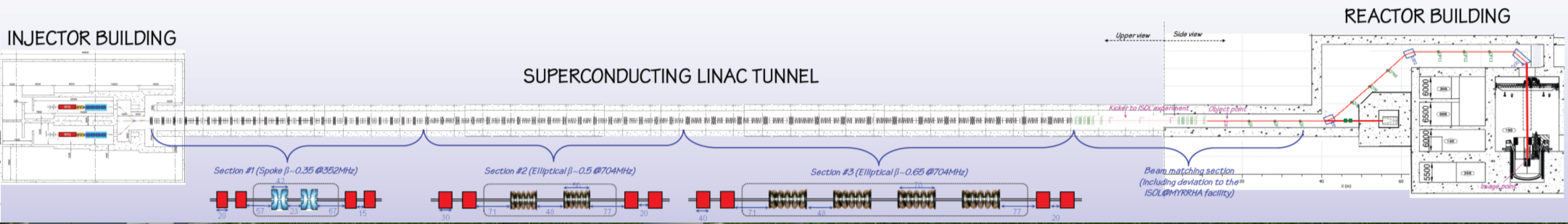
❺ Once steady state is reached, beam is resumed at $t_1 < t_0 + 3sec$

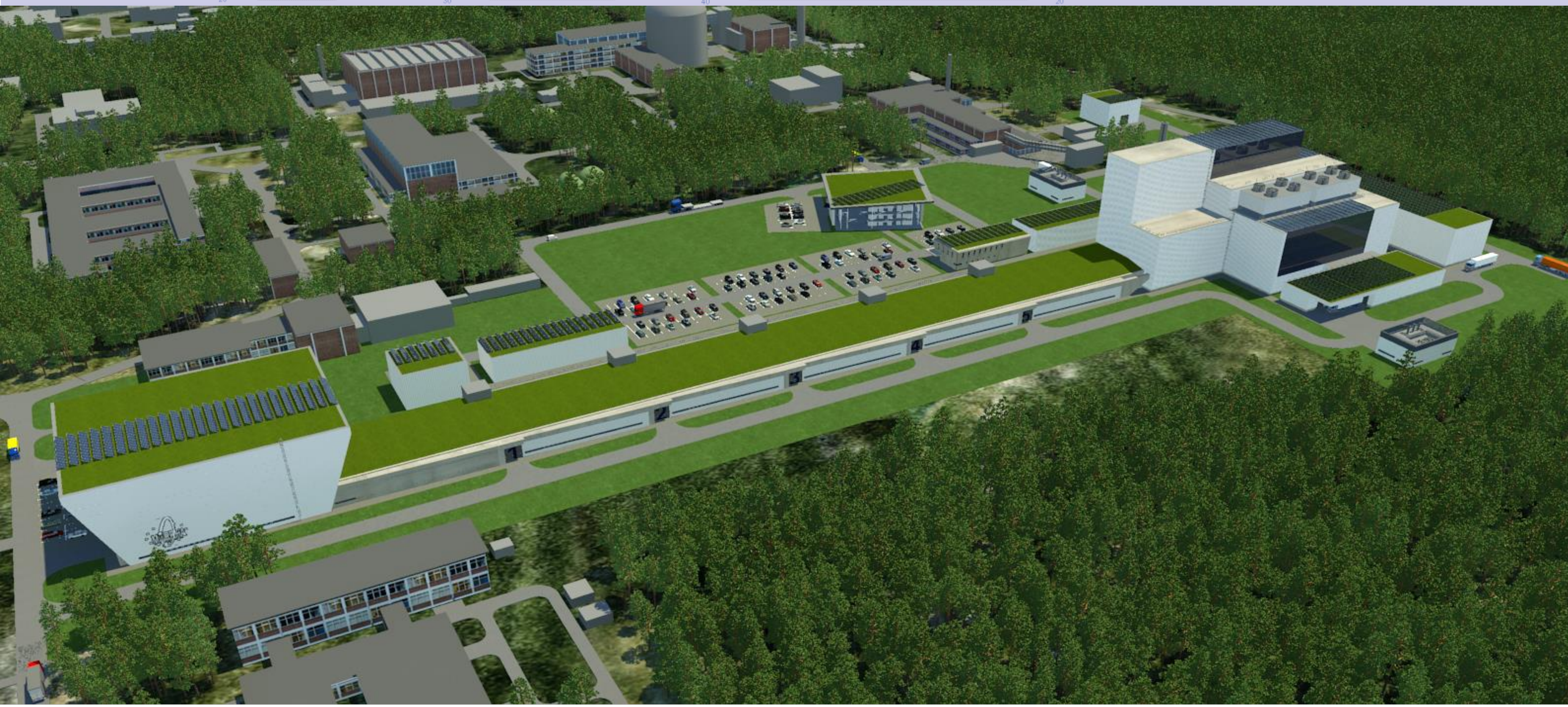
→ Failed RF cavity system to be repaired on-line if possible

Layout of the MYRRHA linac



Layout of the MYRRHA linac





1. Background
2. The MYRRHA accelerator concept

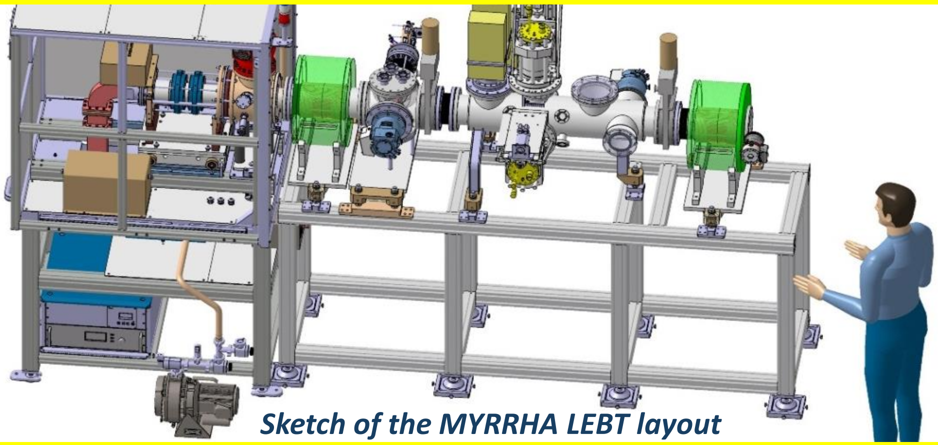
3. Some MAX recent achievements

4. Perspectives

Low Energy Beam Transport (30 keV)

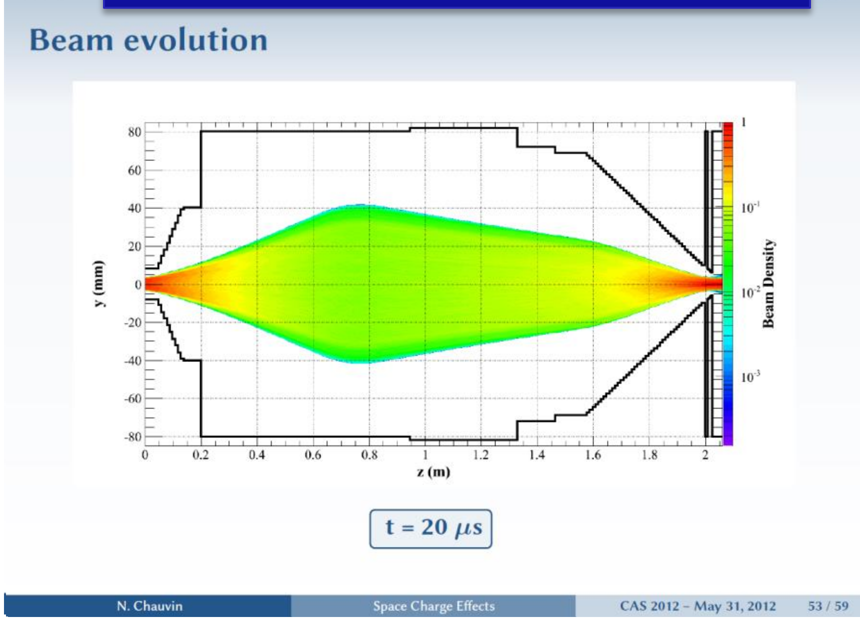
- ➢ LEBT conceptual design achieved - Detailed technical design & construction phase has started (SCK*CEN + LPSC Grenoble)
- ➢ Source from Pantechnik: commissioning at SCK

LPSC Grenoble — SCK•CEN STUDIECENTRUM VOOR KERNENERGIE CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE — IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY



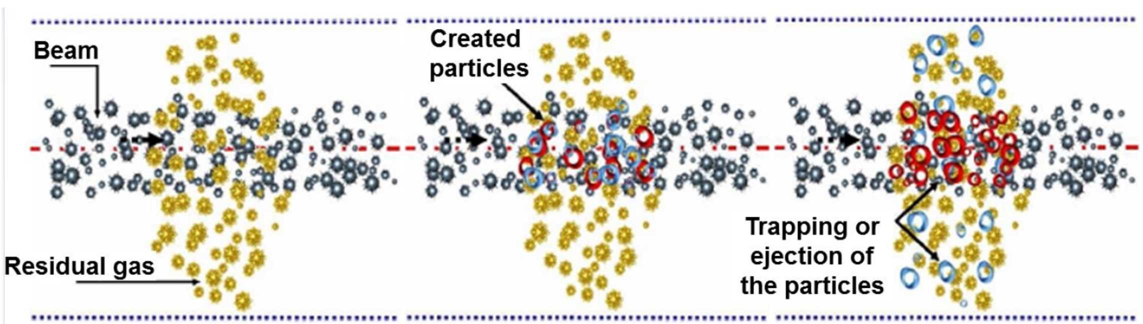
Sketch of the MYRRHA LEBT layout

R. Salemme et al., Proc. TC-ADS 2013



Impact of SSC rising time, courtesy of N. Chauvin CEA Saclay

- ➢ Beam Physics research topic : Space-charge compensation regime

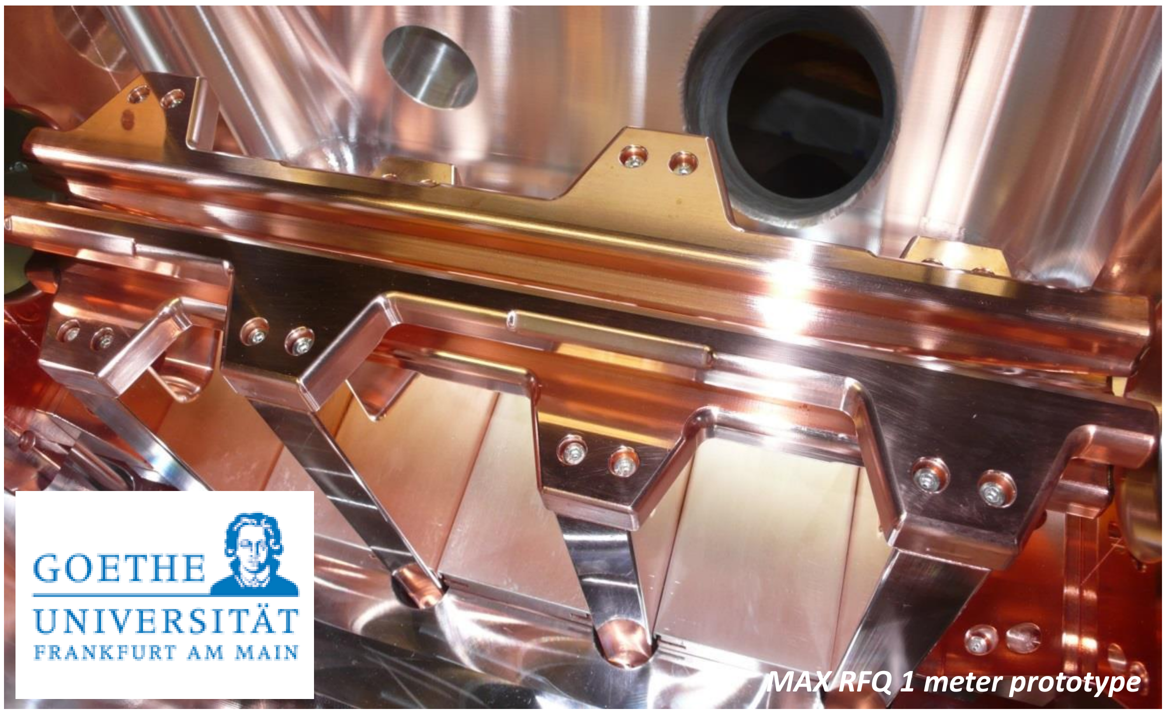


Space-charge compensation process

RFQ (30 keV – 1.5 MeV)

- Present reference = 4-rod structure at 176.1 MHz
- R&D at IAP Frankfurt on thermal effects

- Construction of RFQ 1-m prototype achieved (ready for high-power RF test)
- Next SCK*CEN step will be to build the full RFQ

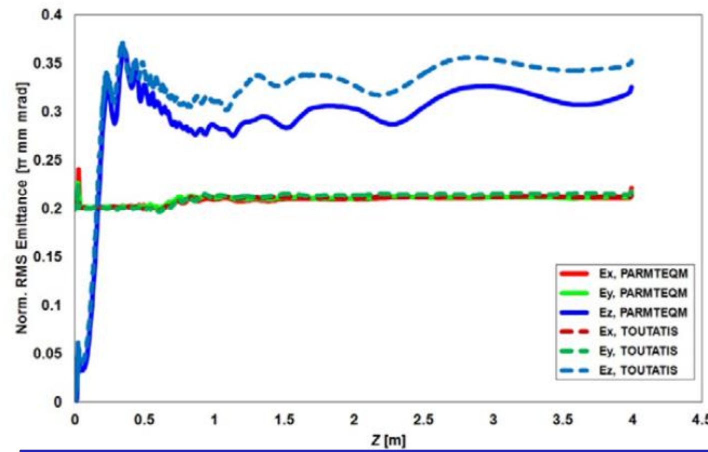


MAX RFQ 1 meter prototype

Parameter	EUROTRANS	MYRRHA	SARAF
f [MHz]	352	**176**	176
W_{in} [MeV] / W_{out} [MeV]	0.05 / 3	**0.03 / 1.5**	0.02 / 1.5
U [kV]	65	**40**	32.5
$E_{s,max}$ / E_k	1.7	**1**	0.8
a_{min} [mm]	2.3	**2.9**	2.7
m_{max}	1.8	**2.3**	2.7
g_{min} [mm]	2.6	**3.6**	3.7
$\varepsilon_{in}^{t., n., rms}$ [π mm-mrad]	0.2	**0.2**	0.175
$\varepsilon_{out}^{t., n., rms}$ [π mm-mrad]	0.21 / 0.20	**0.22 / 0.22**	0.19* / 0.19*
$\varepsilon_{out}^{l., rms}$ [π keV-deg]	109	**64.6**	36*
L [m]	4.3	**4.0**	3.8
T [%] / T_{10mA} [%]	~100 / ~100	**~100 / ~100**	95.5* / 92.3*
R_p [kΩm]	61 (MWS)	**67 (after SARAF)**	67 (meas.)
P_c [kW/m]	69.8 (MWS, +20%)	**23.5**	15.8

* *Simulated by A. Bechtold using the RFQSim code without image effects or multipole effects.*

MYRRHA RFQ parameters & emittance evolution

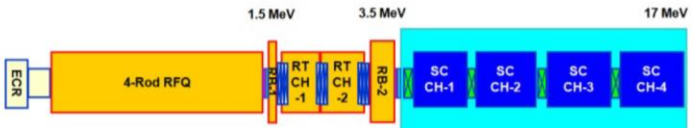


M. Zhang et al., Proc. LINAC 2012

M. Vossberg et al., Proc. LINAC 2012

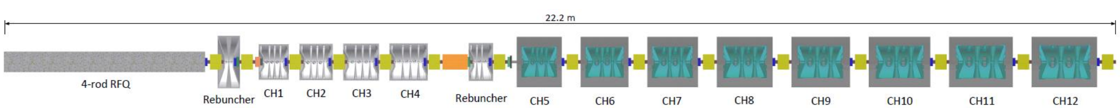
CH booster (1.5 – 17 MeV)

- As compact as reasonably possible
- Presently based on the KONUS beam dynamics concept, but a safer alternative design is in-work



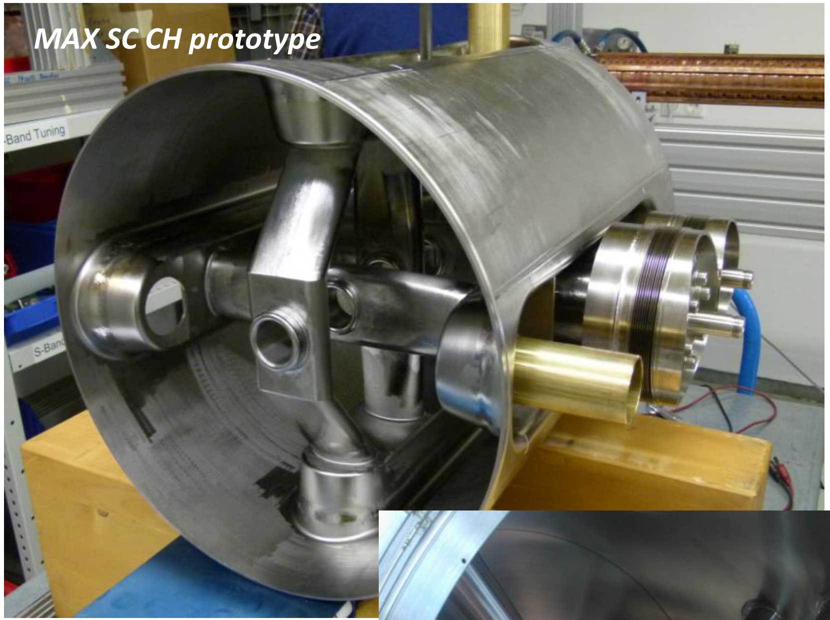
	N_{gaps}	V_{eff} [MV]	L_{cell} [m]	β_{avg}	E_a [MV/m]	*Upstream transv. focusing* [T/m or T]
RB 1	2	0.15	0.10	0.06	1.56	-
RT-CH 1	10	1.03	0.54	0.06	1.91	(triplet) 44.5/43.5/44.5
RT-CH 2	10	1.14	0.66	0.08	1.72	(triplet) 47.0/48.0/47.0
RB 2	5	0.525	0.36	0.09	1.45	(triplet) 51.0/53.5/51.0
SC-CH 1	10	3.50	0.87	0.10	4.02	(solenoid) 2.50
SC-CH 2	9	3.98	1.01	0.13	3.94	(solenoid) 3.05
SC-CH 3	8	4.18	1.07	0.16	3.89	(solenoid) 3.50
SC-CH 4	7	4.09	1.07	0.18	3.82	(solenoid) 4.30

MYRRHA reference injector layout



MYRRHA alternative injector layout

- Construction of 176 MHZ CH prototypes achieved (ready for tests)



M. Bush et al., Proc. SRF 2013

D. Mäder et al., Proc. SRF 2013

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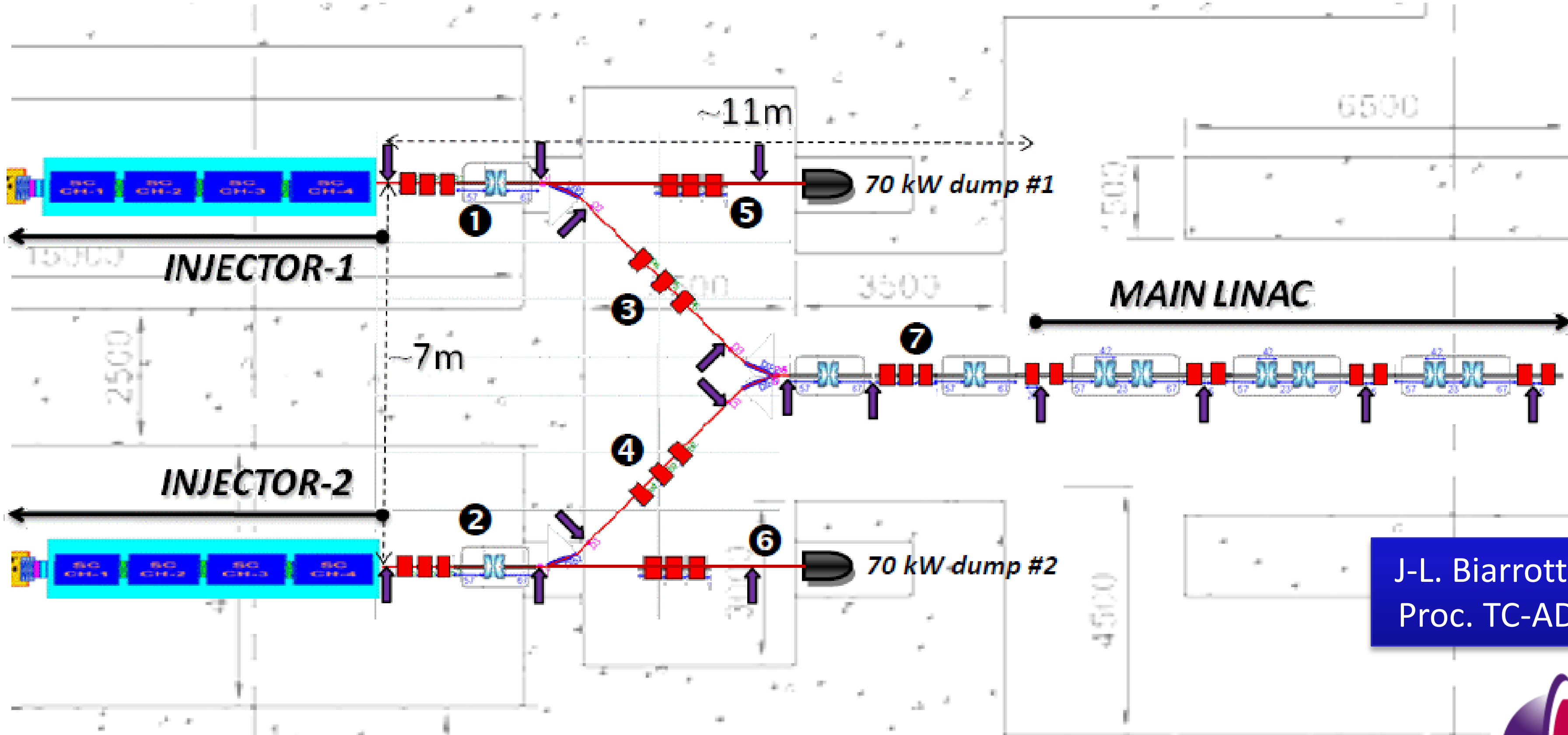
Medium Energy Beam Transport (17 MeV)

- Conceptual design of the doubled injector connection
- Preliminary definition of associated fast switching procedures



General layout of the MYRRHA MEBT, superimposed on a preliminary building layout

J-L. Biarrotte et al., Proc. TC-ADS 2013

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Main superconducting linac (17 – 600 MeV)

- Design of the 230 metres SC linac incl. fault-tolerance capabilities
- Main concern = physics of beam halo during fault-recovery scenarios

- Generic R&D for spoke-type cavities
- Design of MYRRHA spoke cryomodule
- Prototyping of 2 MYRRHA spoke cavities is launched

M. El Yakoubi et al., Proc. TC-ADS 2013

J-L. Biarrotte et al., Proc. SRF 2013

Main parameters of the MYRRHA linac

Section #	#1	#2	#3
E_{input} (MeV)	17.0	80.8	184.2
E_{output} (MeV)	80.8	184.2	600.0
Cav. Technology	Spoke	Elliptical	
Cav. freq. (MHz)	352.2	704.4	
Cavity optimal β	0.375	0.510	0.705
Nb of cells / cav.	2	5	5
Focusing type	NC quadrupole doublets		
Nb cav / cryom.	2	2	4
Total nb of cav.	48	34	60
Nominal E_{acc}* (MV/m)	6.4	8.2	11.0
Synch. phase (deg)	-40 to -18	-36 to -15	
4 mA beam load / cav. (kW)	1.5 to 8	2 to 17	14 to 32
Nominal Qpole gradients (T/m)	5.1 to 7.7	4.8 to 7.0	5.1 to 6.6
Section length (m)	73.0	63.9	100.8

**E_{acc} is given at optimal beta and normalized to $L_{acc} = N_{gap}.\beta.\lambda/2$*

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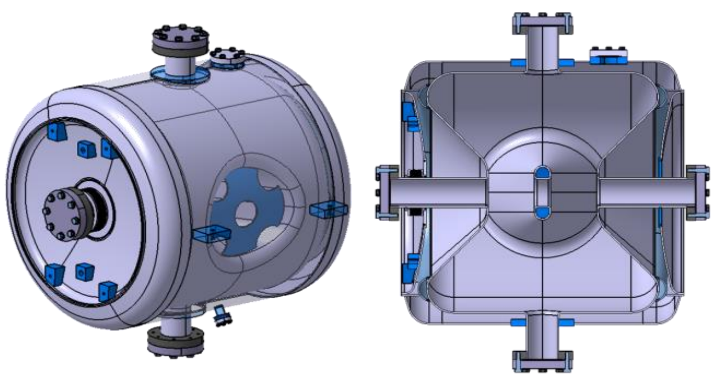
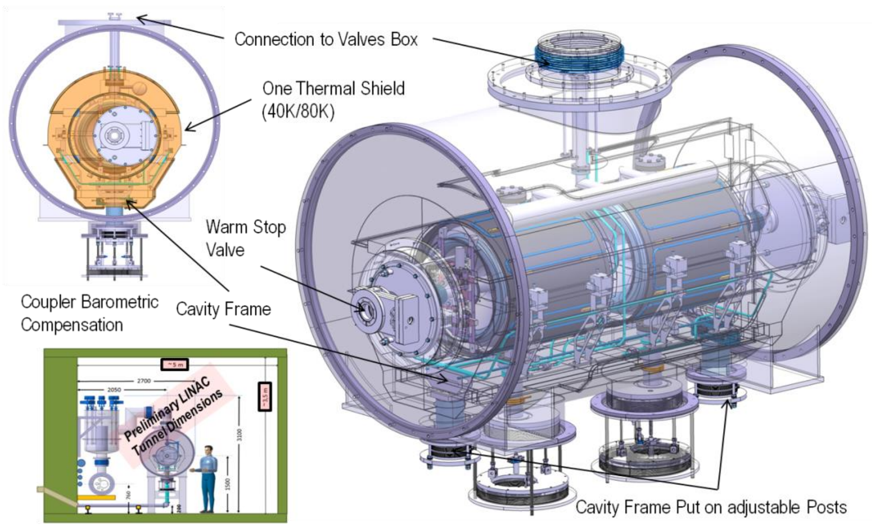
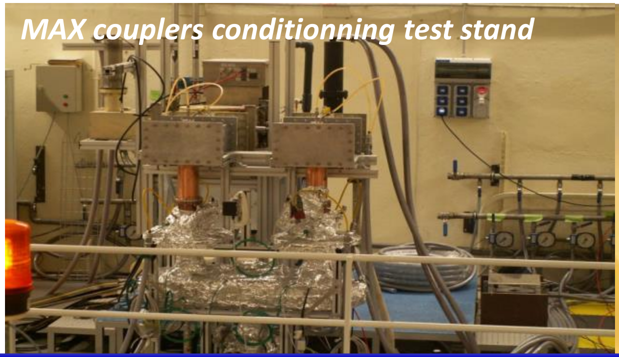




MYRRHA spoke module & cavity overview

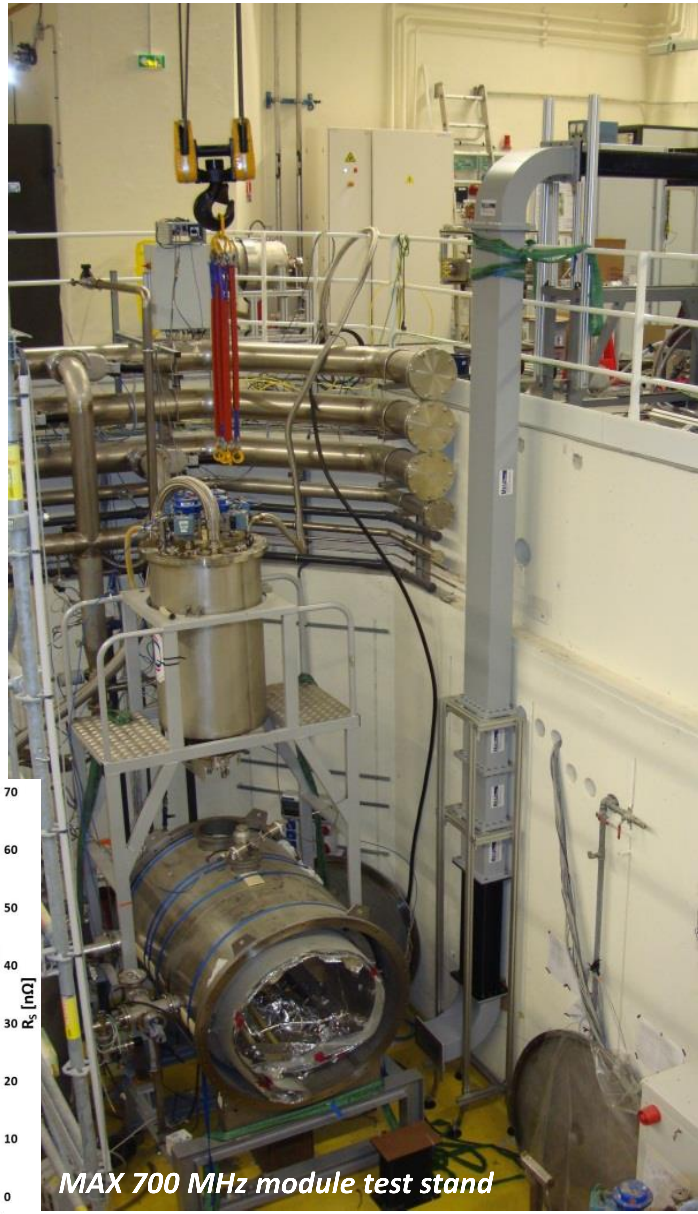
Main superconducting linac (17 – 600 MeV)

- Demonstration of 700 MHz cavity CW RF operation in accelerator-like environment
- Present status = couplers conditioned, first 80kW 2K operation should come very soon

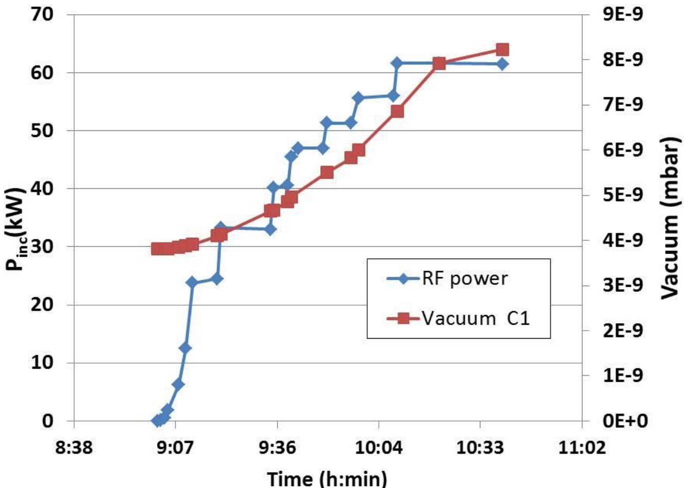


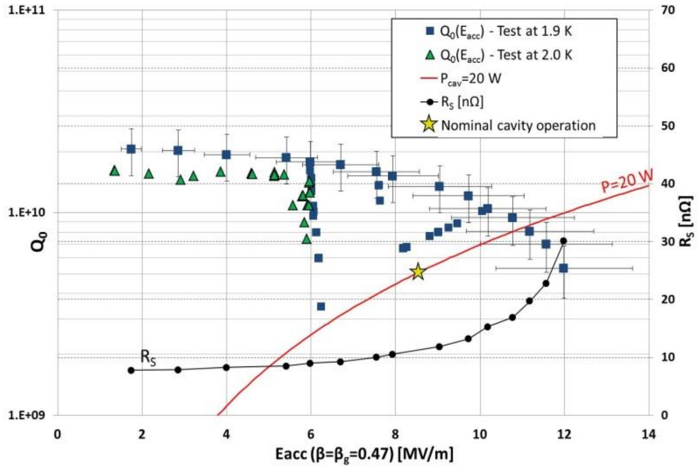
MAX couplers conditionning test stand

F. Bouly, M. El Yakoubi, et al., Proc. SRF 2013



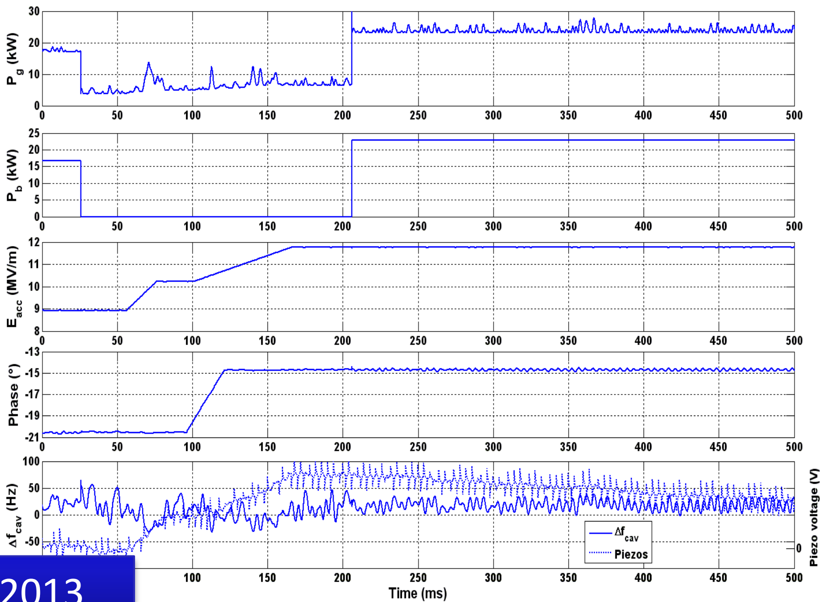
MAX 700 MHz module test stand





Main superconducting linac (17 – 600 MeV)

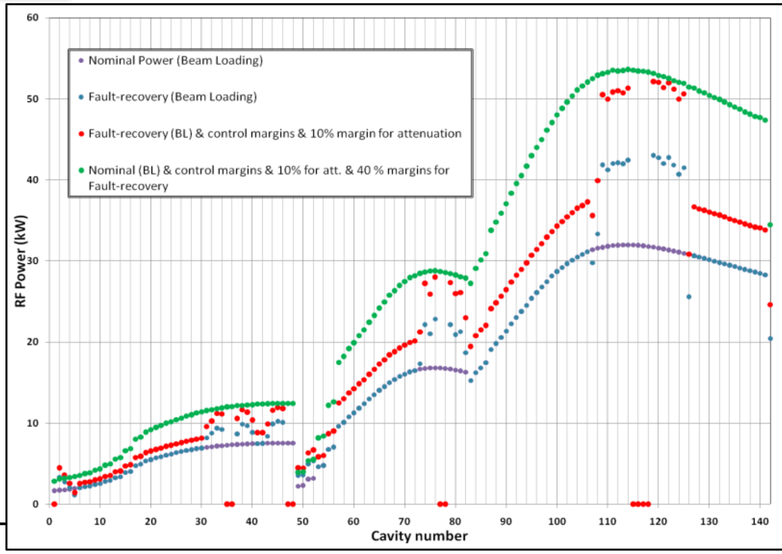
- ➢Planned experiments on fast fault recovery schemes (w/ suited management of tuner, DLLRF)
- ➢ Model of superconducting cavity developed to study the fast fault-recovery feasibility
- ➢ Main concern = Physics of beam halo during fault-recovery scenarios
- ➢ Impact on RF power requirements (~70 % margins)

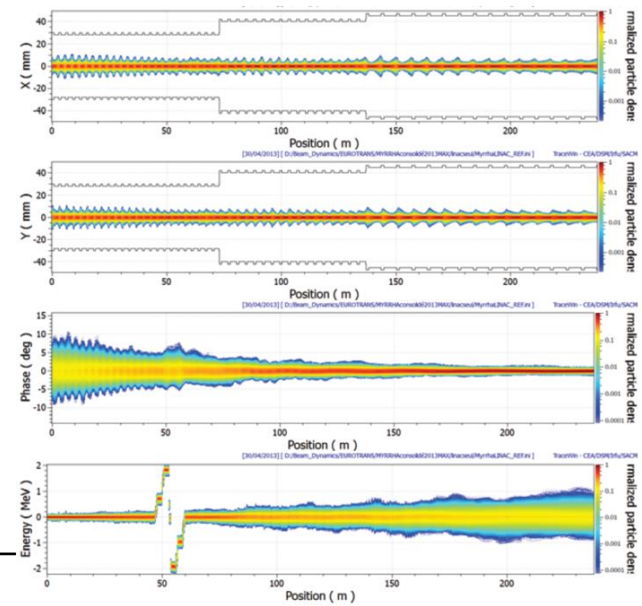


J-L. Biarrotte et al., Proc. SRF 2013

F. Bouly, thèse de doctorat, 2011

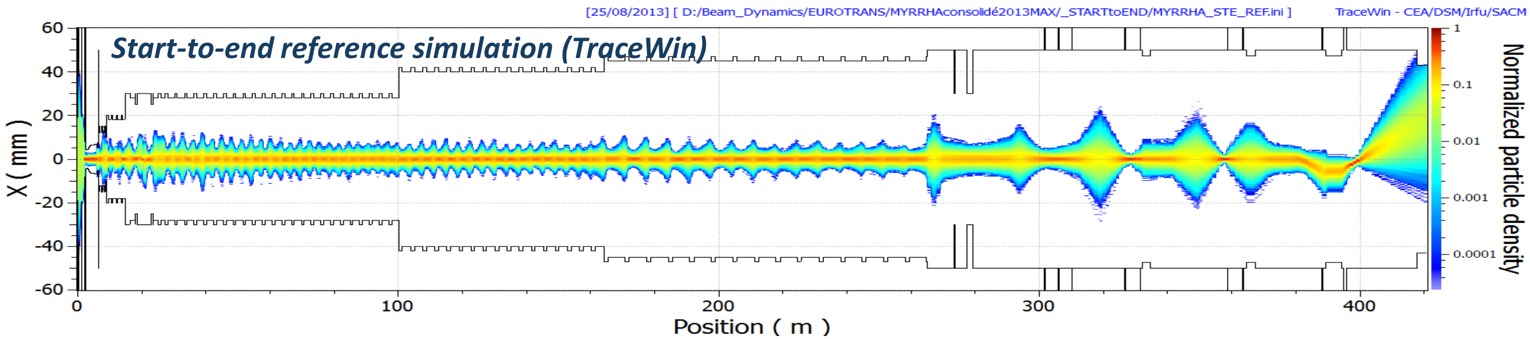
Fast set-point update strategy



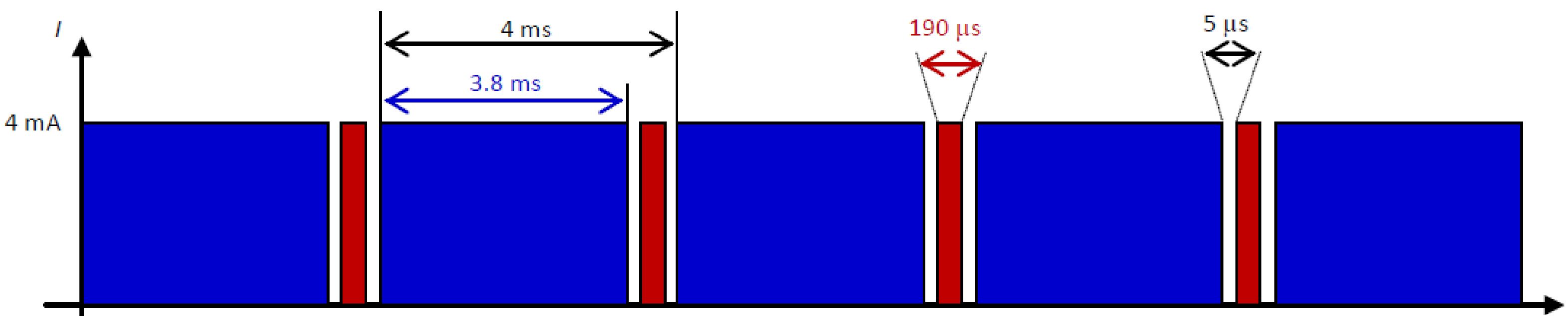


Beam simulations

- Reference source-to-target beam simulation
- Benchmarking activities (TraceWin, LORASR, Track)
- Monte Carlo error studies will start soon



- Definition of beam time structure & power control strategy



Reference MYRRHA beam time structure for 2.4 MW operation:
-> long 4mA blue pulses are sent to the reactor (mean power is adjusting with pulse length)
-> short red ones are sent to ISOL (creating 200us beam holes for reactor subcriticity monitoring)

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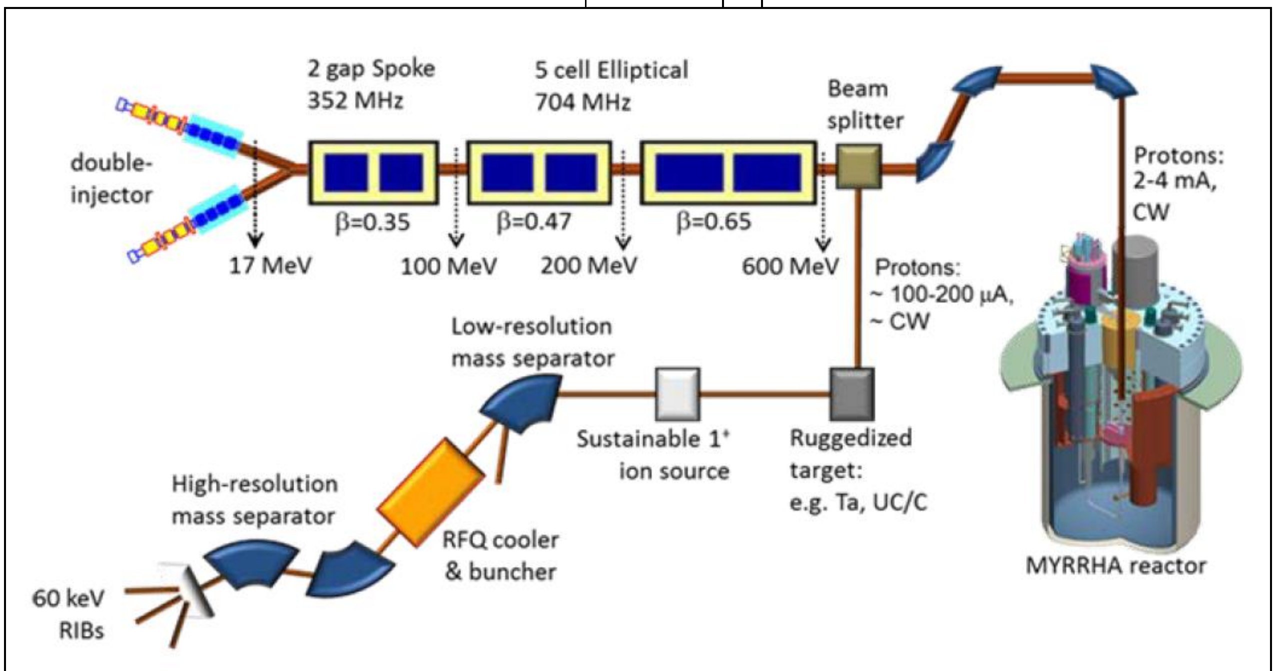
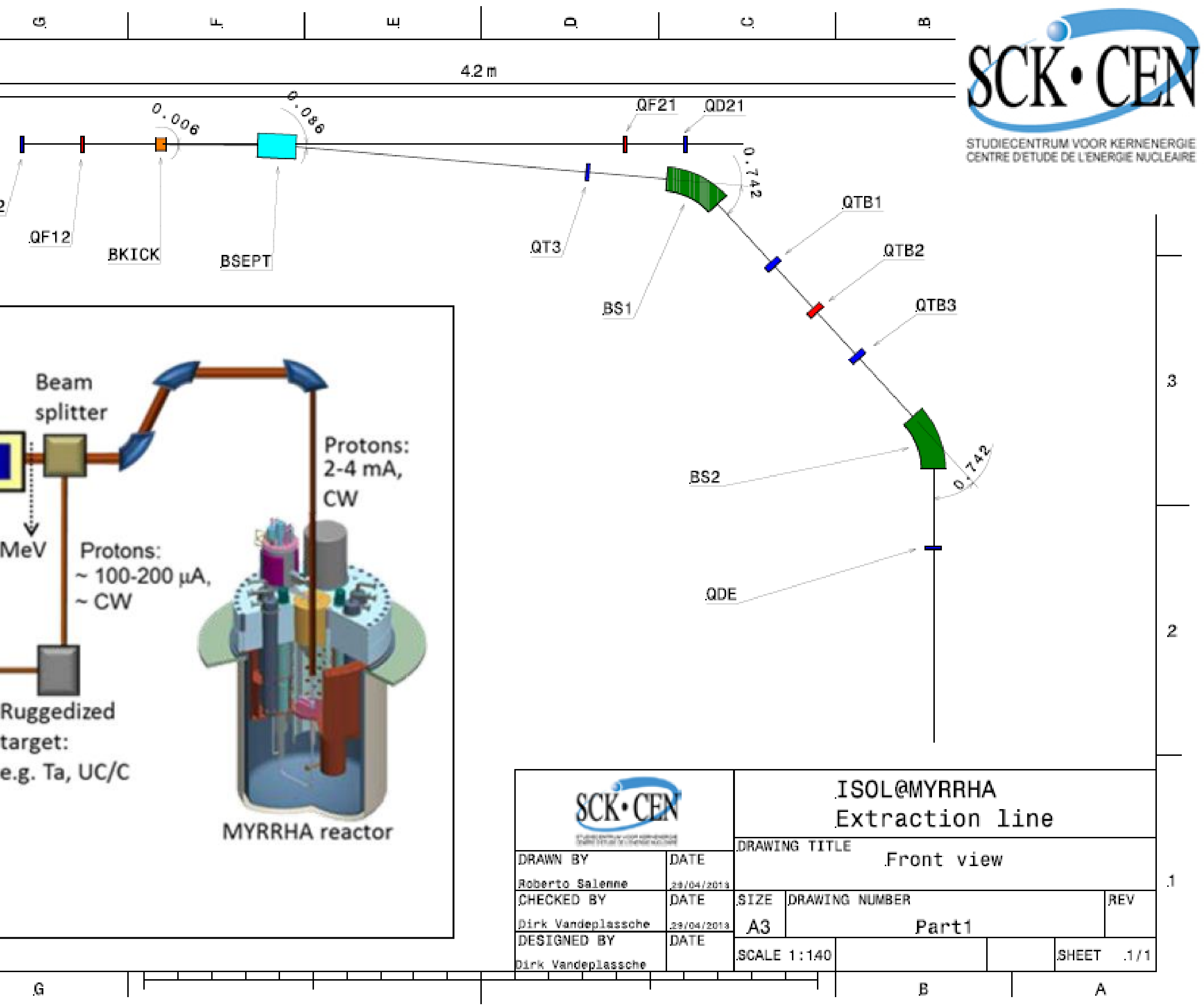
J-L. Biarrotte et al., Proc. TC-ADS 2013

ISOL@MYRRHA extraction (600 MeV)

- Conceptual design based on fast kicker
- 200us 4mA beam pulses at 250 Hz

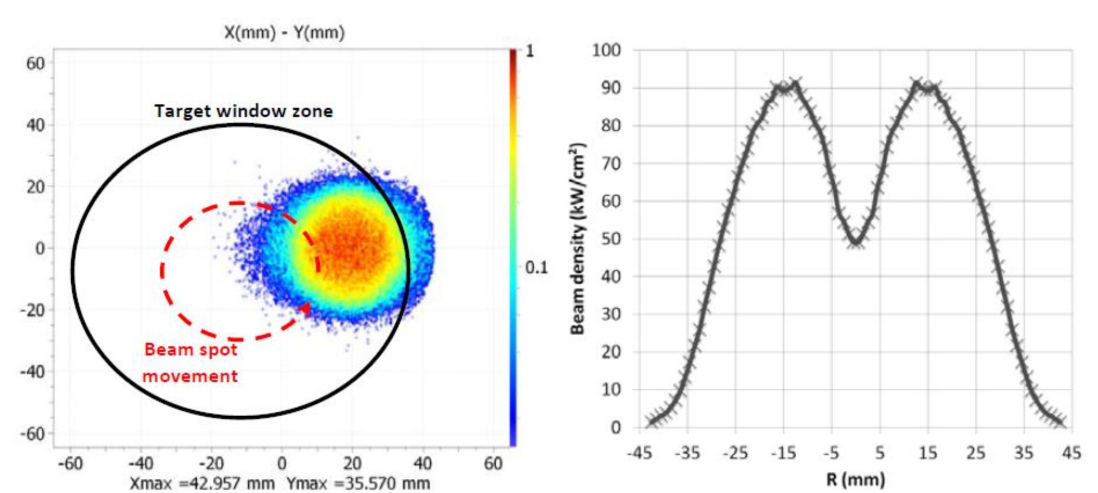




Preliminary layout of the ISOL@MYRRHA extraction zone

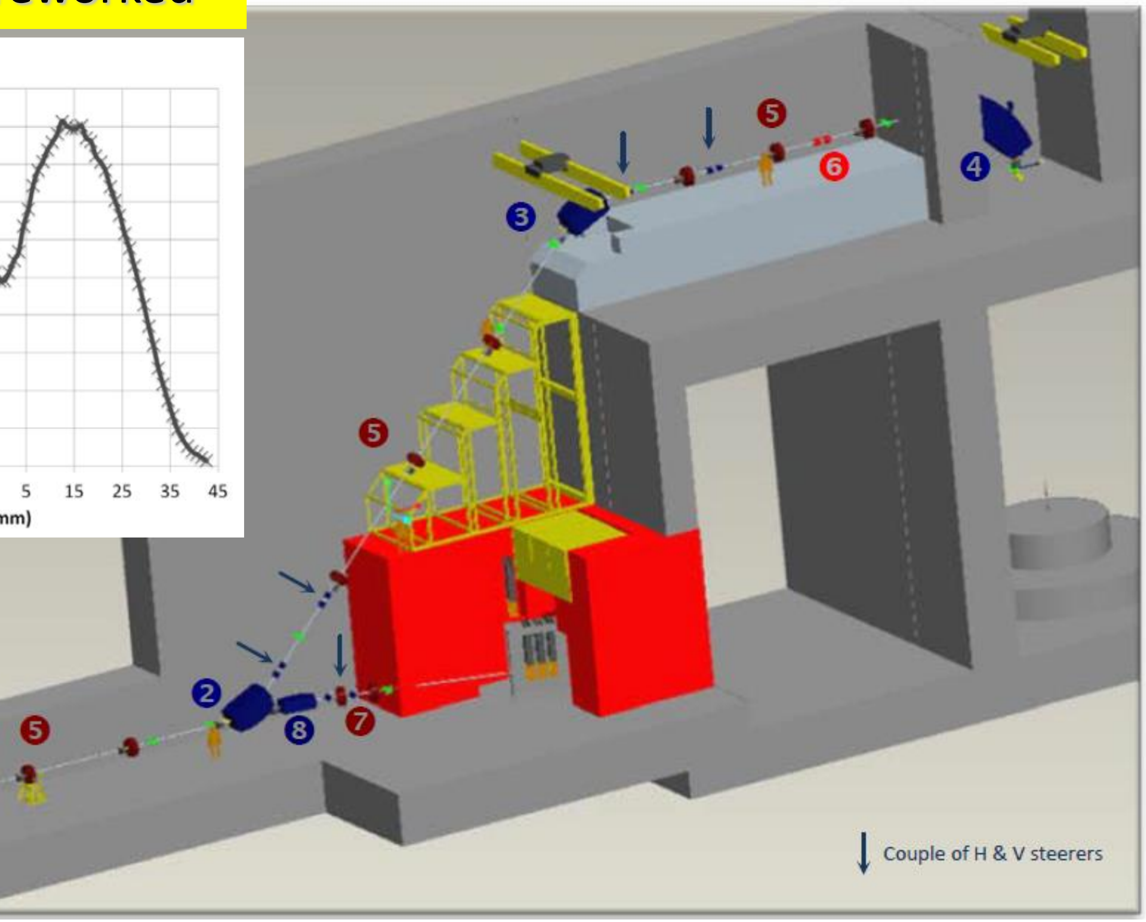
High Energy Beam Transport (600 MeV)

- Preliminary design exists, incl. PSI-like 2.4 MW beam dump & raster scanning on target
- Interface with reactor to be further reworked



Beam distribution on spallation window

H. Saugnac et al., Proc. IPAC 2011

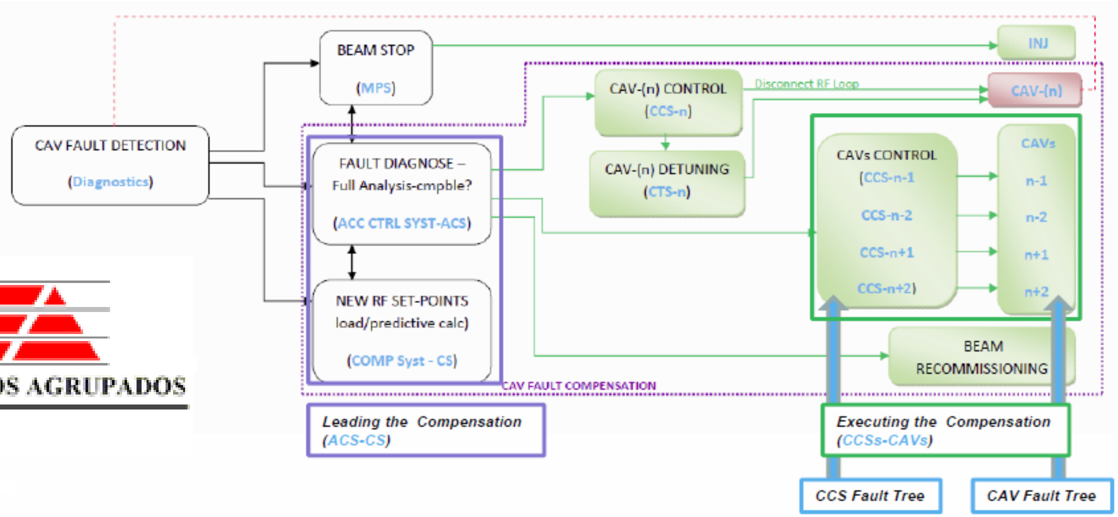


Layout of the MYRRHA beam lines to reactor & dump

Systems, reliability

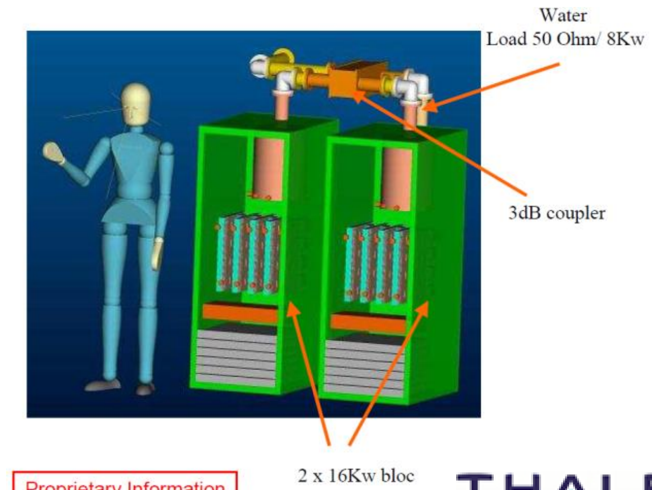
- SNS linac reliability model has been developed & successfully benchmarked with operation data
- MYRRHA linac reliability model is in-work

A. Pitigoï, Proc. TC-ADS 2013



Local compensation sequence: basis for « COMP » fault tree

- R&D on 700 MHz solid-state amplifiers



- Preliminary design of MYRRHA cryogenic plant

T. Junquera et al., Proc. SRF 2013

1. Background
2. The MYRRHA accelerator concept
3. Some MAX recent achievments

4. Perspectives

Conclusions & perspectives

- **The successful & reliable production of the MYRRHA high power & stable beam is a very interesting challenge**
  - Huge R&D investment is still needed to fully demonstrate the feasibility & prepare for construction
- **Present R&D is mainly dedicated to general design and developments on a few main primary components. It will need to be push further towards an engineering design phase**
  - Construction of a full injector demonstrator – started with the LEBT (SCK/LPSC)
  - Prototyping: CH-DTL & RFQ at IAP - 700 MHz experiment & spoke design at IPNO
- **MAX is going on until October 2014 (tbc)**
  - A possible follow up (2015-2018) is under study
- **Further implication from the SCK*CEN side will be required if MYRRHA construction is to be launched in the 2/3 next years**
  - Nowadays, present SCK accelerator group is 3 people…

Thank You
for your attention!

http://ipnweb.in2p3.fr/MAX/

http://myrrha.sckcen.be/

Coordinator