The European Spallation Source Linac and the prospective contribution of INFN to its Design Update

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The ESS project

- A world leading European science lab
- Scientific breakthroughs expected
- Many challenges:
  - Challenging and complex technology (accelerator, target, moderator)
  - Large investments and significant annual budget
  - Political decision making, competition and negotiations
  - Committment to minimize the environmental impact.
  - AVERAGE NEUTRON FLUX: 3.1×10^{14} n/cm^{2}s
  - PEAK NEUTRON FLUX: 1×10^{16} n/cm^{2}s

The ESS project

ACCELERATORS

- High power, highly **reliable Front Ends**
- High intensity light ions **Linacs** : systems design, beam dynamics, performance and current projects, reliability issues,
- **Synergies** with ongoing and planned projects on accelerator driven systems, transmutation, neutrino factories, HEP injectors, materials science

INPUT		Nominal	Upgrade
Average beam power	[MW]	5.0	7.5
Macro-pulse length	[ms]	2.0	2.0
Pulse repetition rate	[Hz]	20	20
Proton kinetic energy	[GeV]	2.5	2.5
Peak coupler power	[MW]	1.0	1.0
Beam loss rate	[W/m]	< 1.0	< 1.0
OUTPUT			
Duty factor		0.04	0.04
Ave. pulse current	[mA]	50	75
Ion source current	[mA]	60	90
Total linac length	[m]	418	418

- **Beam loss handling** and **diagnostics systems** for high brightness hadron accelerators ($\ll$1 W/m with localized exceptions)
- Current state of **theory** and **simulation tools**, confronting predictions with experiment,
- **Low-energy superconducting structures,** to be checked: how competitive they are for energies below 100 MeV…

The ESS project

ACCELERATORS

- **Radio frequency** issues: where are we on high-gradient cavities and high power couplers, and current expectancies; current problems with the operation of high power, high duty cycle klystron/modulator systems,
- Compatibility of the proposed ESS design with **future upgrades**
- **Energy usage**, how to minimize electricity consumption without seriously compromising the performance

TARGET

- Spallation targets from **liquid-metal and liquid metallic-alloys** : Experiments and simulations on liquid metal loops
- **Solid metallic targets** : known limits
- The **Target/Reflector/Moderator** complex, simulation tools and current problems.

The ESS project

Tentative parameters for the ESS linac

In comparison to the originally proposed design (5 MW, 1 GeV, 150 mA, 16.7 Hz) the parameters have been modified in 2009 in order to ***simplify the linac design*** *and to* ***increase its reliability****. In essence, the current has been decreased and the final energy increased, keeping the footprint of the accelerator the same.*

- ✓ ***Decrease in current*** *– With increased energy the average pulse current can be reduced by the same factor to 60/90 mA*
- ✓ ***Increase of the cavity gradient*** *– By decreasing the current, the gradient can be raised to 15 MV/m, keeping the coupler power constant at 1.0 MW/m for 5-cell 704 MHz cavities.*
- ✓ ***Increase of beam energy*** *- the final energy was increased from 1 to 2.5 GeV.*
- ✓ ***Repetition rate*** *- The originally proposed repetition rate of 16.67 Hz has been increased to 20 Hz.*
- ✓ ***Pulse length*** *–2 ms*

The ESS project

*The tentative linac parameters that were used are consistent with the **SRF technology** available today or that is expected to be in a 2 to 3 year period.* ***No fundamental issue was identified.*** *However there is still a large amount of work that remains to be done towards the engineering various components, or in order to provide the information necessary to choose between various options.*

Cavities and Cryomodules

- ✓ ***Power Couplers***
- ✓ ***Transition Energy from Warm to Cold Sections***
- ✓ ***Higher Order Modes***
- ✓ ***Cryomodules***
- ✓ ***Cryogenics***

High-power RF architecture

- ✓ ***1 klystron per cavity***
- ✓ ***1 klystron to power several cavities***

The ESS project

Main topics addressed: modelling codes, radiation issues, longitudinal and transverse measuring techniques

Main message: more diagnostic equipment than envisaged

- ✓ ***Beam Diagnostics***
- ✓ ***Linac Front-Ends***
- ✓ ***Beam Dynamics***

Beam Diagnostics

- ✓ *The primary linac diagnostic needs include **beam position**, **beam arrival time** (or phase), **beam bunch length**, **beam transverse profiles**, and **beam loss**.*
- ✓ *Especially important for high power operation are **sensitive beam loss measurement** and **profile resolution** over a wide dynamic range.*
- ✓ *Techniques for **halo measurement** in a superconducting environment need to be developed.*

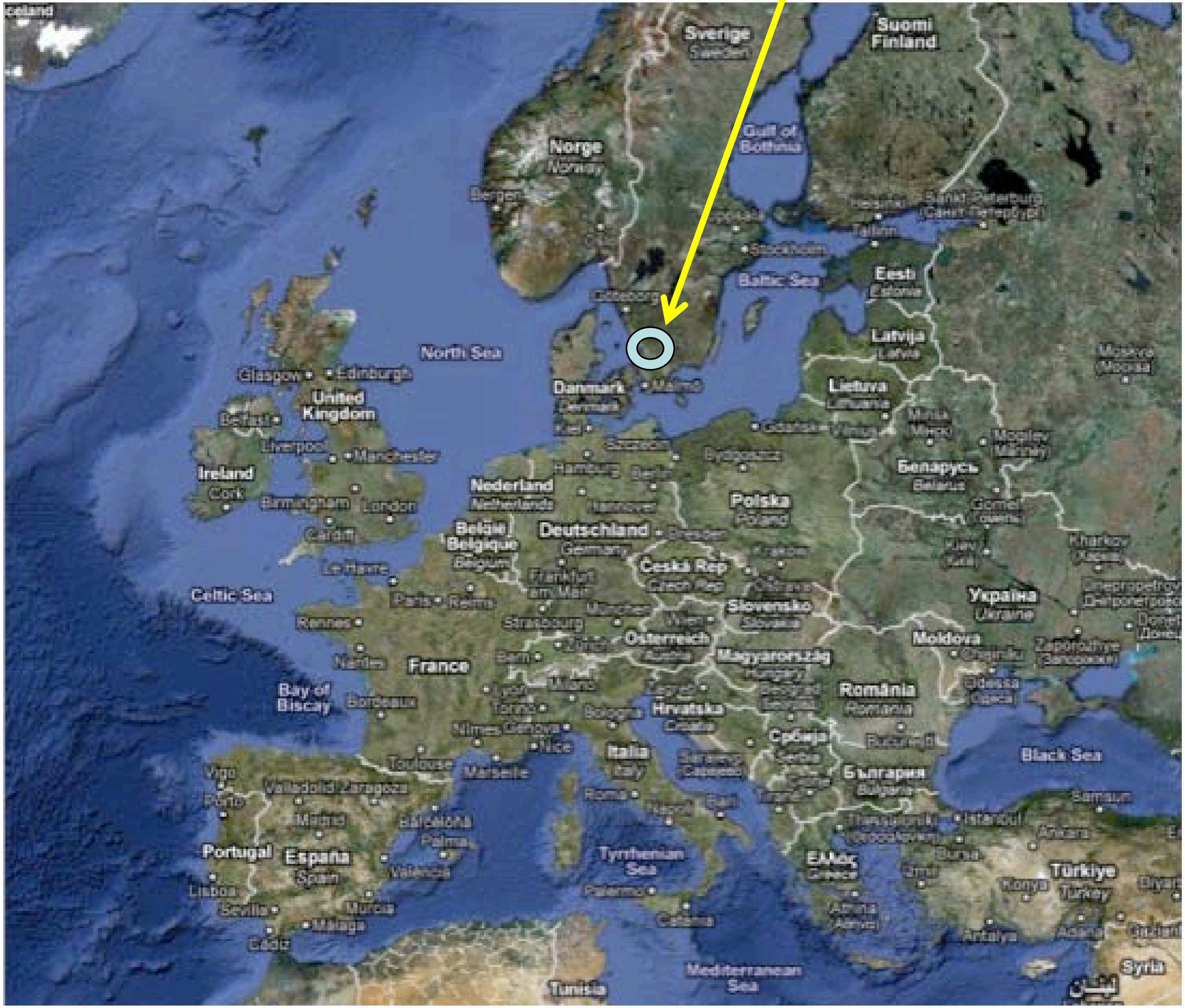
The ESS project

ESS-Bilbao WORKSHOP TARGET

Eleven R&D *and conceptual design activities needed to support development of the ESS target.*

1. *Cavitation damage of mercury target vessel*
2. *Avoidance of boiling mercury*
3. *Structural performance of target*
4. *Maintenance concept and overall configuration for a rotating solid target*
5. *Irradiated tungsten database development*
6. *Instrumentation for rotating solid targets*
7. *Rotating target seals, bearings and drives*
8. *Tungsten cladding*
9. *Beam profile diagnostic*
10. *Elimination of high energy shutters*
11. *Moderator development*

ESS in Lund



Sverige
Sweden
Suomi
Finland
Norge
Norway
Gulf of Bothnia
Bergen
Stockholm
Baltic Sea
Eesti
Estonia
Latvija
Latvia
North Sea
Glasgow
Edinburgh
United Kingdom
Danmark
Denmark
Malmö
Lietuva
Lithuania
Belfast
Liverpool
Manchester
Ireland
Cork
Birmingham
London
Cardiff
Nederland
Netherlands
Hamburg
Berlin
Polska
Poland
België
Belgique
Belgium
Deutschland
Germany
Celtic Sea
Česká Rep
Czech Rep
Slovensko
Slovakia
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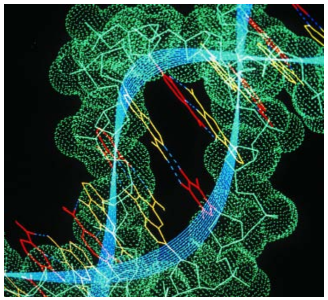
Ukraine
Moldova
Österreich
Austria
Magyarország
Hungary
France
Bay of Biscay
Bordeaux
România
Romania
Hrvatska
Croatia
Србија
Serbia
Black Sea
Italia
Italy
България
Bulgaria
Portugal
España
Spain
Lisboa
Madrid
Barcelona
Valencia
Marseille
Toulouse
Roma
Tyrrhenian Sea
Ελλάς
Greece
Türkiye
Turkey
Istanbul
Ankara
Mediterranean Sea
Tunisia
Syria

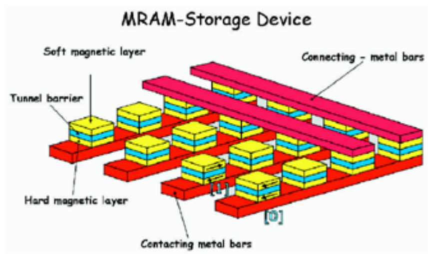
ESS in Lund

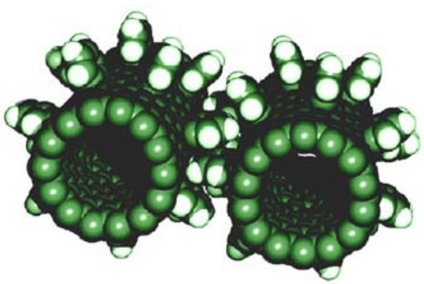

The ESS Scandinavia site
The Öresund
Lund
Copenhagen Airport
Skåne
Malmö
The Öresund Bridge

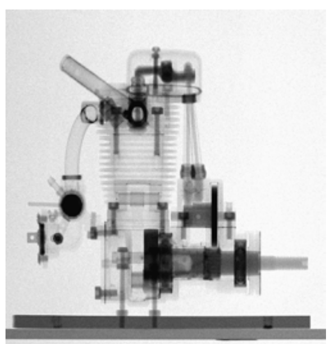
ESS – multi-science with neutrons

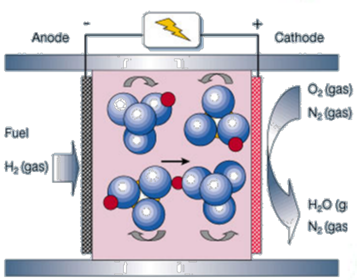
Materials science	Bio-technology	Nano science
Energy Technology	Hardware for IT	Engineering science











- Neutrons can provide unique and information on almost all materials.

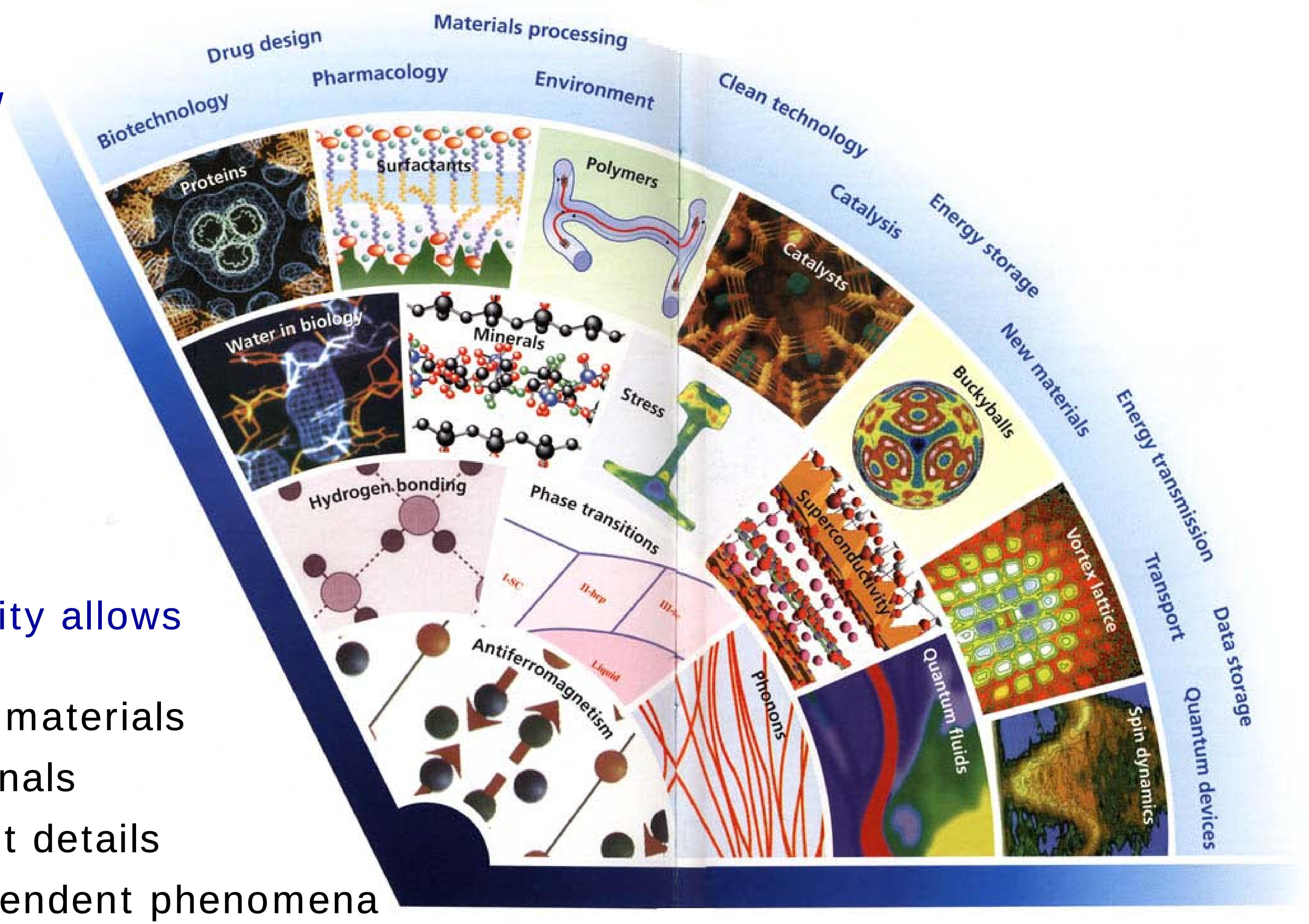
- Information on both structure and dynamics simulaneously. ”Where are the atoms and what are they doing?”

- 5000 users in Europe today Access based on peer review.

- Science with neutrons is limited by the intensity of today’s sources

Intensity opens new possibilities

Complexity/
Count-rate



ESS intensity allows studies of

– complex materials
– weak signals
– important details
– time dependent phenomena

Details/Resolution

ESS and NP

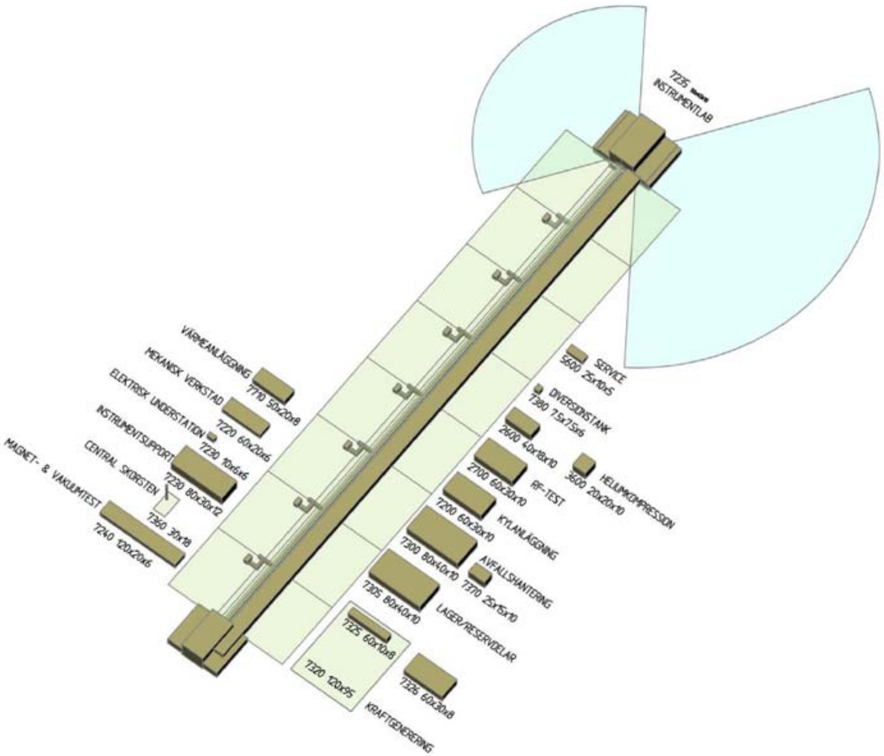
Interesting for Nuclear Physics?

High intensities of 2.5 GeV protons they are….

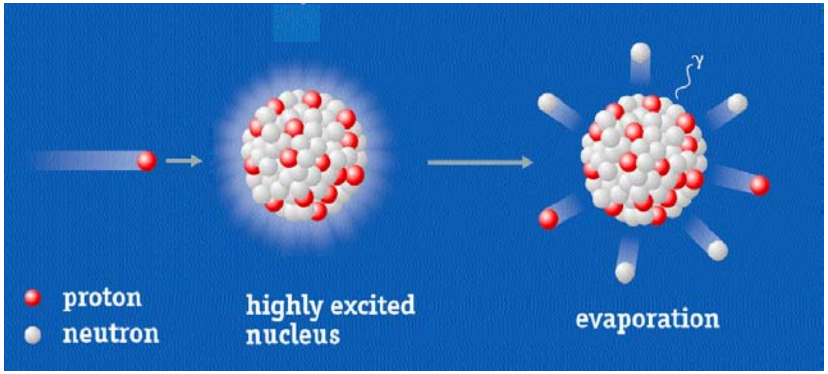
"The production of high intensity beams at ESS will be devoted to material science and life science, but undoubtedly the availability of such beams will open new frontiers in the research, being a typical case for cross-fertilization of different fields." (NUPECC Long Range Plan 2010)

"The field of high-intensity accelerators and targets largely benefits from the synergies between studies for radioactive beam production, ADS (MYRRHA project), IFMIF, radiopharmaceutical isotope production, and ESS." (NUPECC Long Range Plan 2010)

How does ESS work?



- An ion source creates positive hydrogen ions (protons).
- Pulses of protons are accelerated into a target with neutron rich atoms.
- In the target neutrons are liberated by a a spallation reaction.
- The neutrons are then guided to instruments where they are used for materials studies.



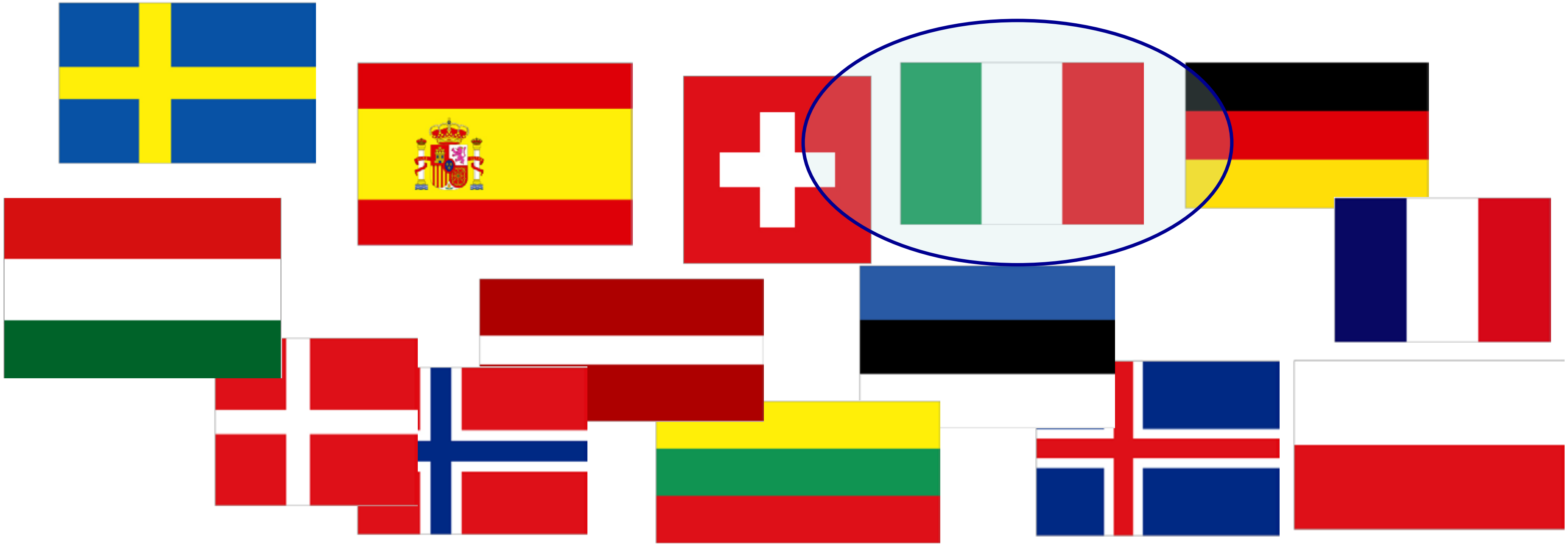
Preconstruction phase

1st ESS Steering Committee

22nd & 23rd October 2009 Copenhagen

strong support from 13 countries to:

- to engage in the ESS Design Update
- to prepare organisation aimed for construction



Time lines

first design

2002-2003

ESFRI Report
2003

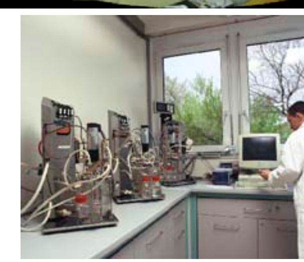
site
decision
2009

ESS Pre-construction phase 2010-2012

ESS Construction phase 2013-2018

Completion phase 2019-2025

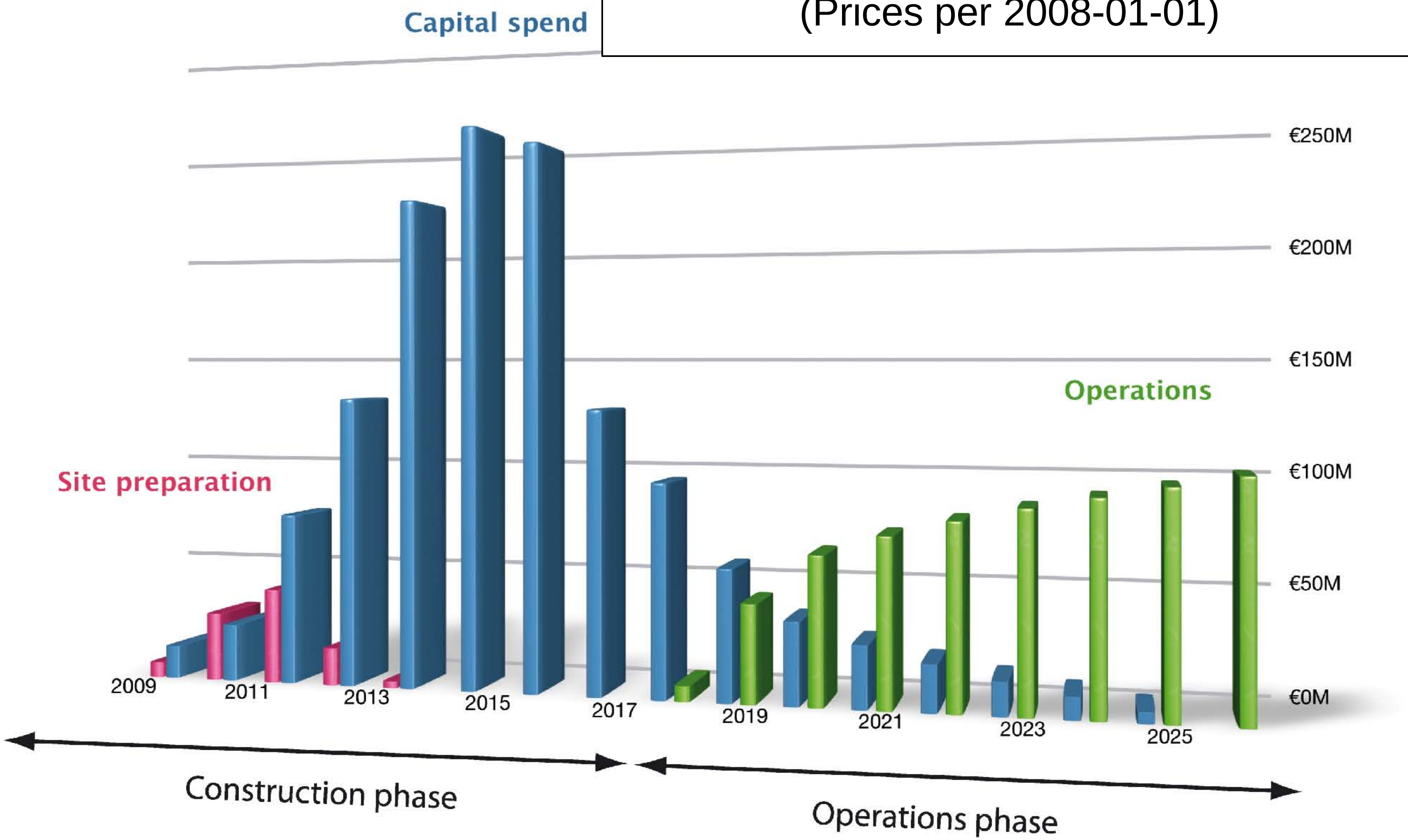
Operations phase 2026-2066



Decommissioning phase !!! 2067-2071

ESS cost estimates

Investment: 1478 M€ / ~10y
Operations: 89 M€ / y
Decomm. : 346 M€
(Prices per 2008-01-01)



The Sustainable Research Centre

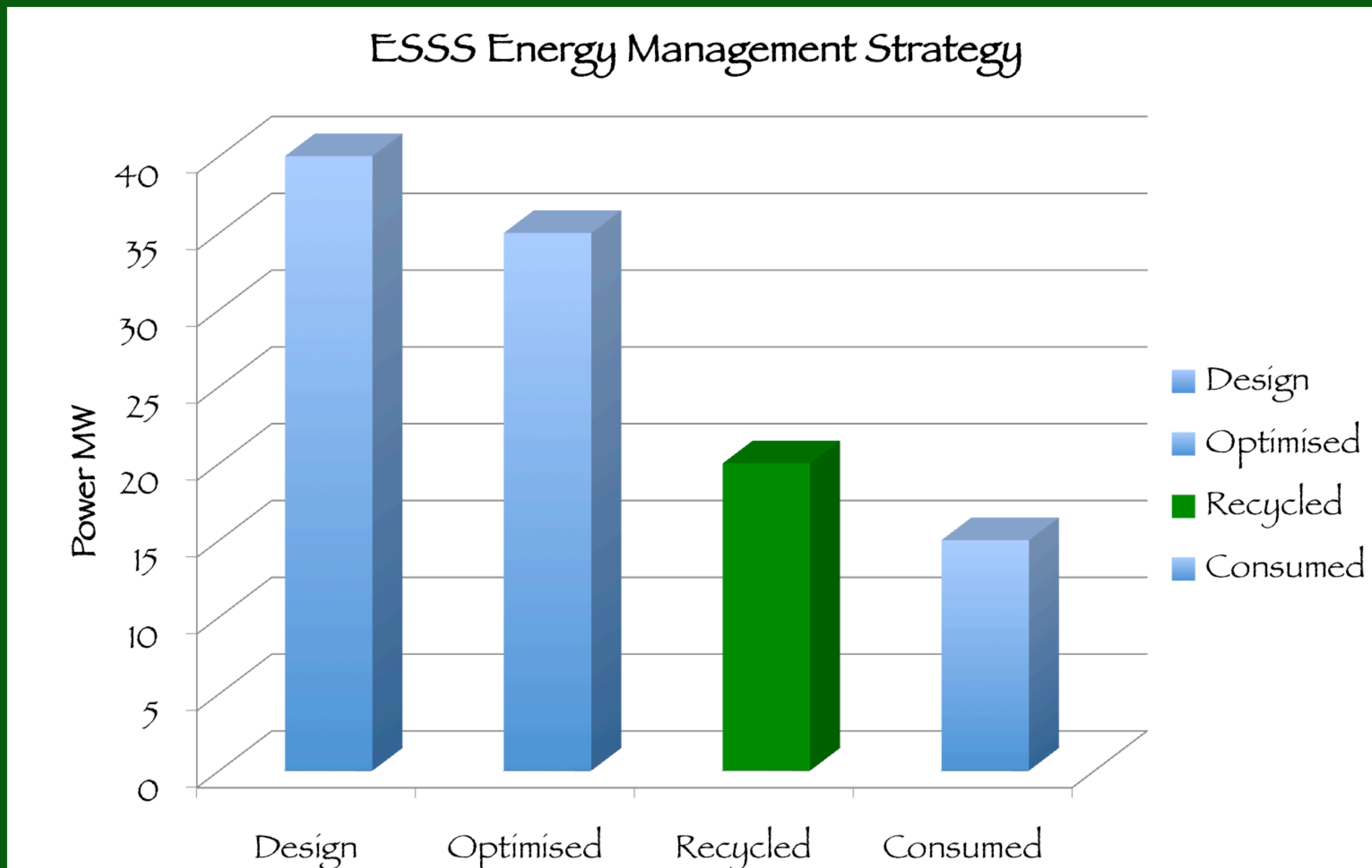
Responsible – Recyclable – Renewable

↓

To be carbon dioxide neutral over the lifetime of the facility, including transportation to and from the site.

Innovative Energy Policy

ESS Energy Management Strategy



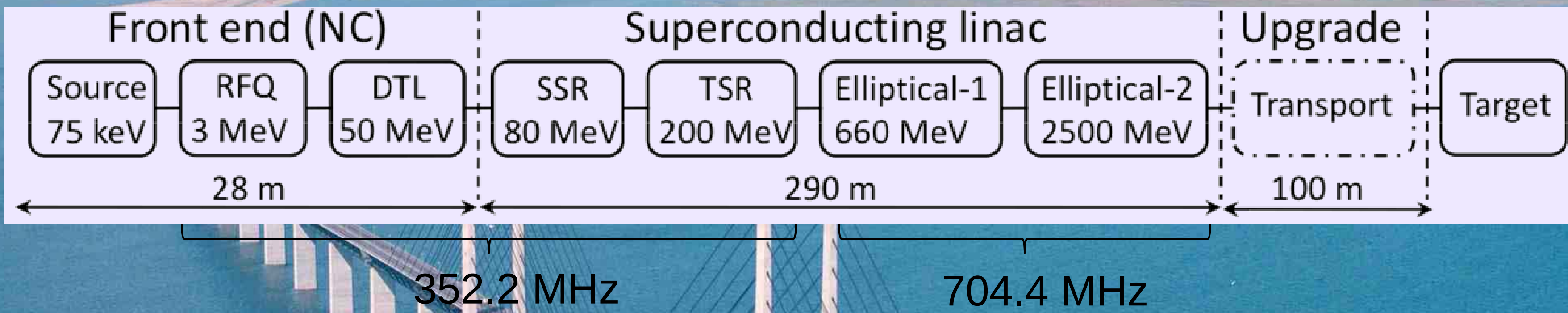
CO_2 neutral !

ESS facility technical objectives:

5 MW (upgrade 7.5 MW) long pulse source

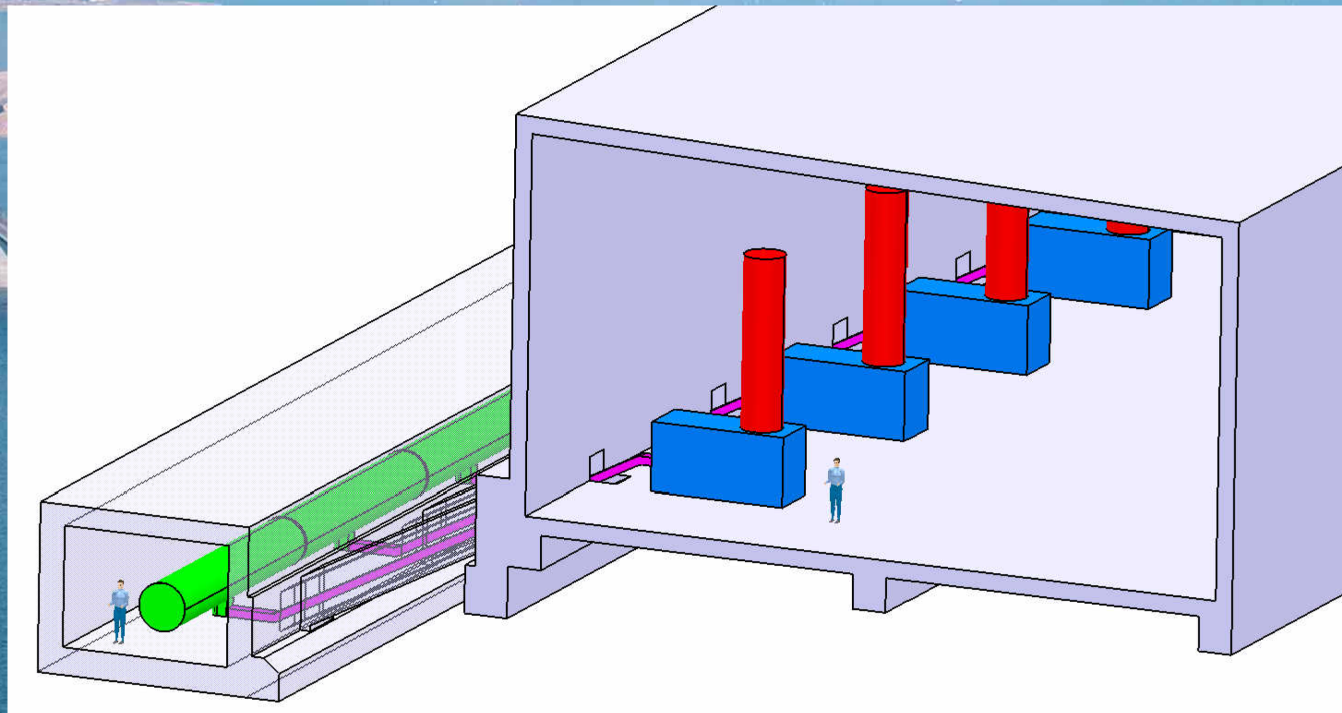
- ≤2 ms pulses
- ≤20 Hz
- Protons (H+)
- Low losses
- High reliability, >95%

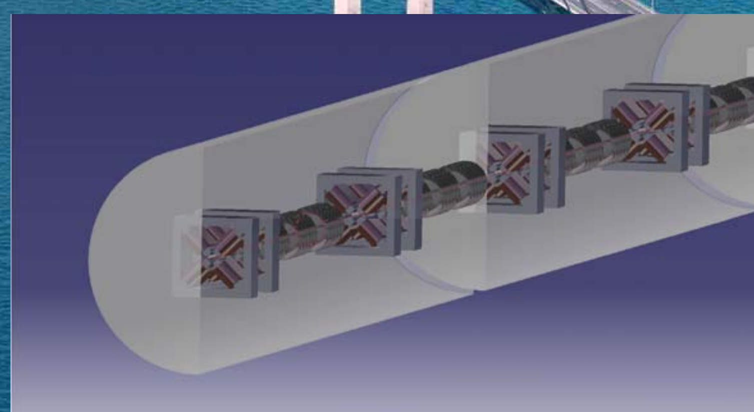
Design update: ESS (S and B) Preparatory work



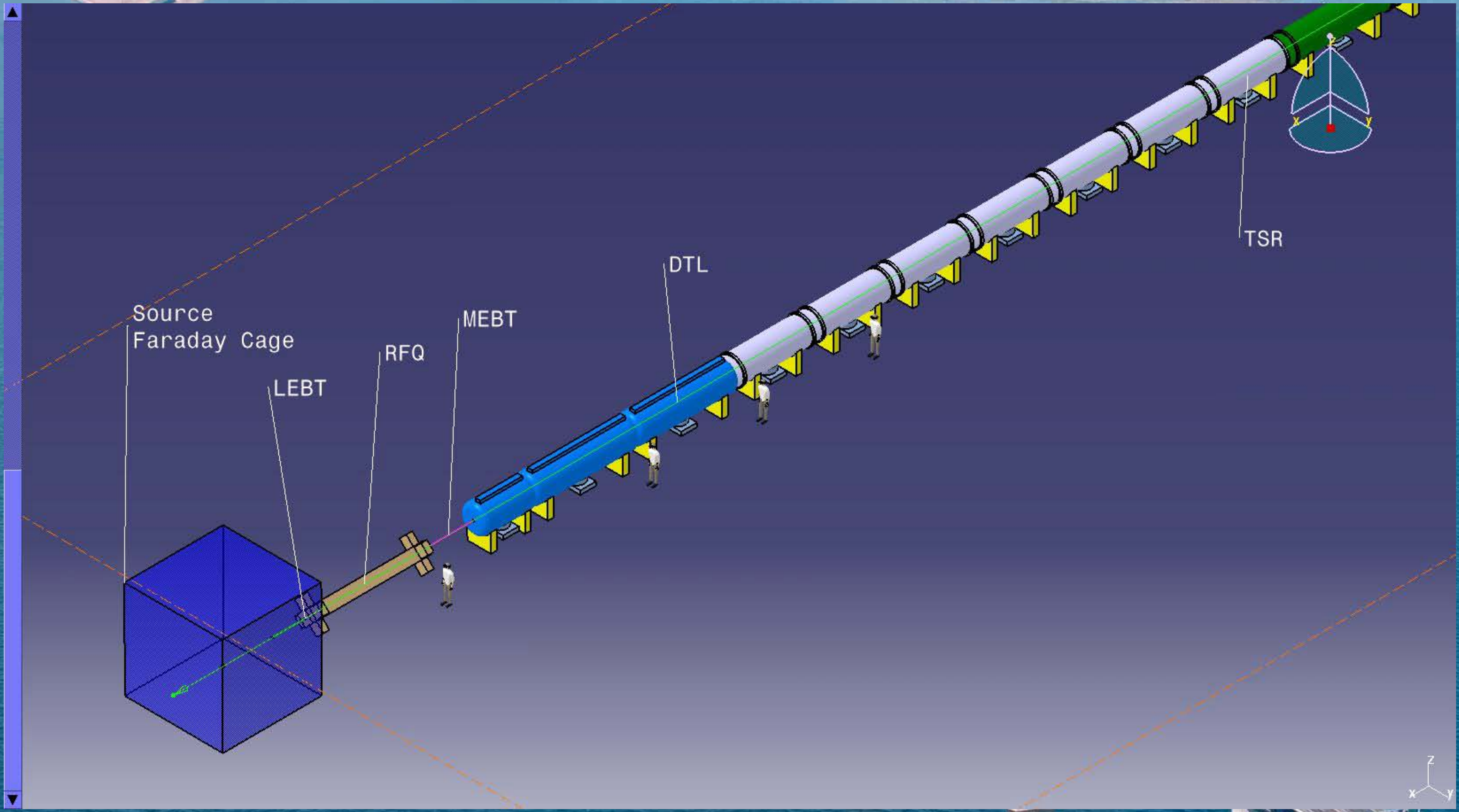
INPUT		B		S
Average beam power	[MW]		5.0	
No. of instruments			22	
Macro-pulse length	[ms]	1.5		2.0
Pulse repetition rate	[Hz]		20	
Proton kinetic energy	[GeV]	2.2		2.5
Peak coupler power	[MW]	1.2		1.0
Beam loss rate	[W/m]		<1.0	
OUTPUT				
Duty factor		0.03		0.04
Ave. current on target	[mA]	2.3		2.0
Ave. pulse current	[mA]	75		50
Ion source current	[mA]	$\sim$90		60
Total linac length	[m]		$\sim$420	

Ideas for linac lay-out





Ideas for lay-out

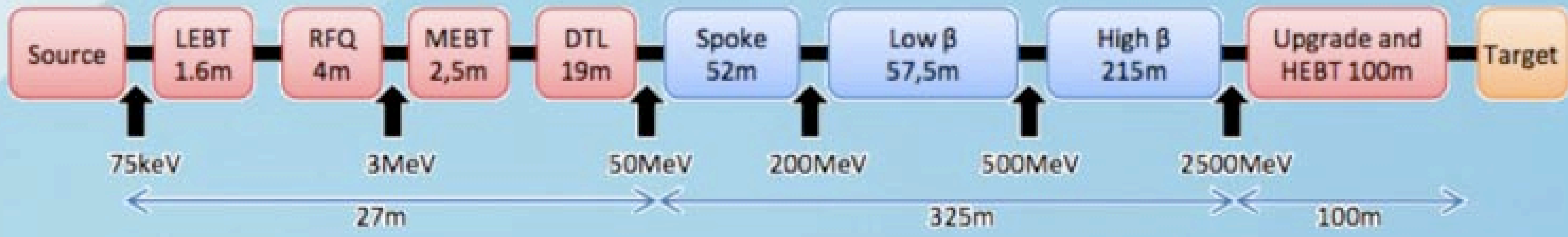


The 74.7 ha plot for ESS, Thanks to Region Skåne

Introduction

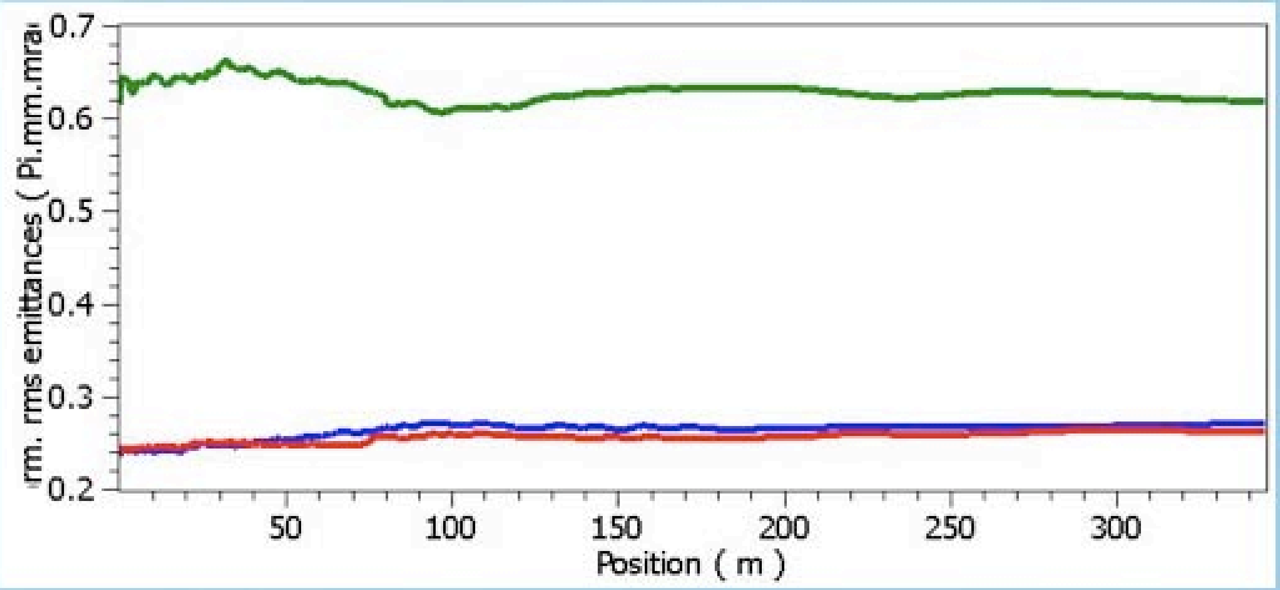
* The European Spallation Source, ESS, uses a high current proton LINAC to provide 5 MW of power to the target at 2500 MeV with a 50 mA beam of protons.
* The LINAC may include the ability to upgrade to the higher power of 7.5 MW at a fixed energy of 2500 MeV, e.g. by increasing the current from 50 to 75 mA and adding extra cryo-modules in an area reserved for this purpose.
* All the components are evaluated for their ability to need no significant changes in case of this potential power upgrade.

LINAC layout

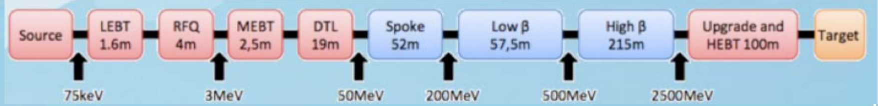


	Length (m)	Input Energy (MeV)	Frequency (MHz)	Geometric β	# of Sections	Temp (K)
RFQ	4	75×10^{-3}	352.2	--	1	≈ 300
DTL	19	3	352.2	--	3	≈ 300
Spoke	52	50	352.2	0.45	14	≈ 2
Low Beta	57.5	200	704.4	0.63	10	≈ 2
High Beta	215	500	704.4	0.75	19	≈ 2
HEBT	100	2500	--	--	--	--

Emittances



	ε_x (π.mm.mrad)	ε_y (π.mm.mrad)	ε_z (π.mm.mrad)
RFQ	0.2	0.2	--
DTL	0.239	0.234	0.617
Spoke	0.245	0.242	0.645
Low β	0.248	0.260	0.623
High β	0.257	0.267	0.623
HEBT	0.262	0.270	0.620



European Spallation Source

Ion Source

* The ESS LINAC will use an ECR proton source to deliver macro-pulses of up to 2 ms in length & currents of up to 90 mA. The nominal pulse repetition rate is 20 Hz, but the source frequencies as high as 33 Hz are viable.

* ECR sources have the advantage that they can work in low vacuums of order 10^{-4} Torr, enabling very high currents. The absence of hot filaments significantly increases the mean time between maintenance.

* ECR sources are very reliable in terms of current stability and availability.

Source and LEBT

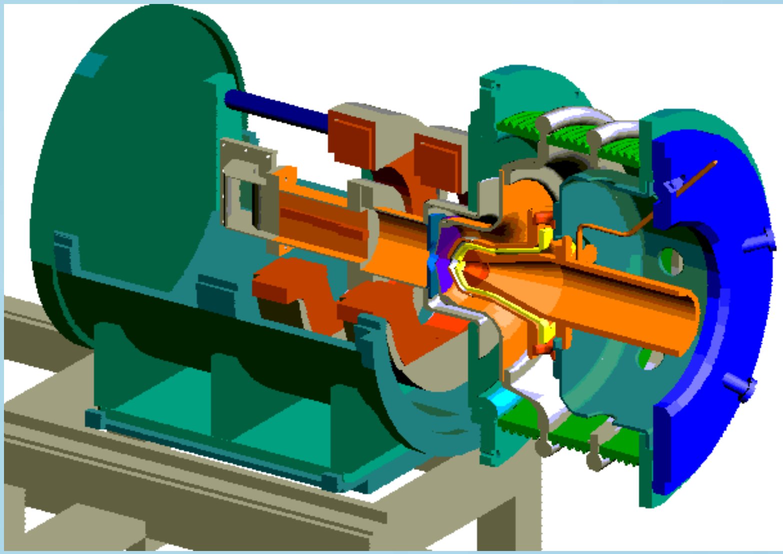
INFN-LNS (Catania) and CEA-Saclay will contribute to the design of the injector part (the proton source and the LEBT) in close collaboration.

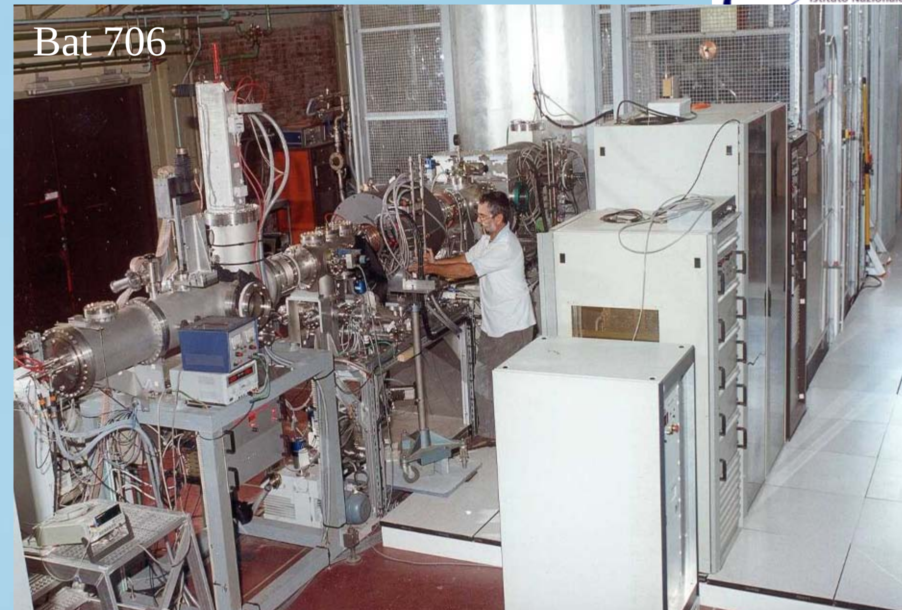
The high current proton source will be based on the know-how acquired during the design phase and the construction phase and commissioning of the sources named TRIPS and VIS at INFN-LNS and of the SILHI source at CEA-Saclay, but surely some remarkable improvements are to be developed because of the high current at a relatively low extraction voltage.

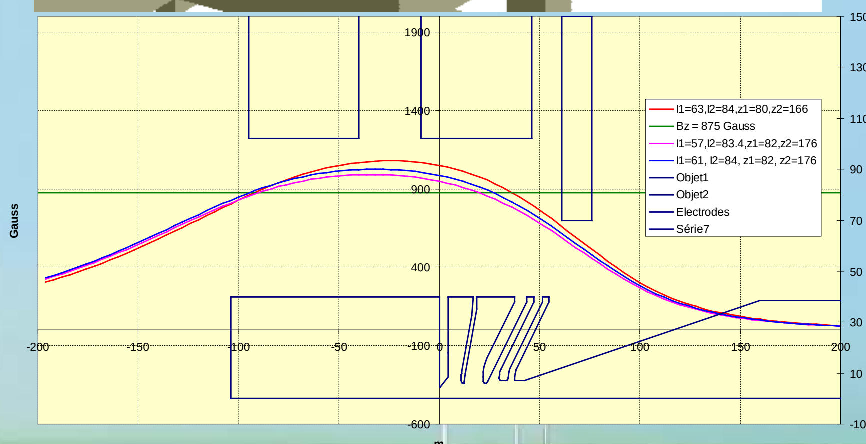
A new extraction system has to be developed for a pulsed beam of about 60 mA with a quite low emittance as required by the following RFQ. An option for larger current will be considered.

SILHI source and LEBT

SILHI operates at 2.45 or 3 GHz
1 ECR zone at RF entrance







Since 1996, SILHI produces H+ beams with good characteristics:

H+ Intensity > 100 mA at 95 keV
H+ fraction > 80 %

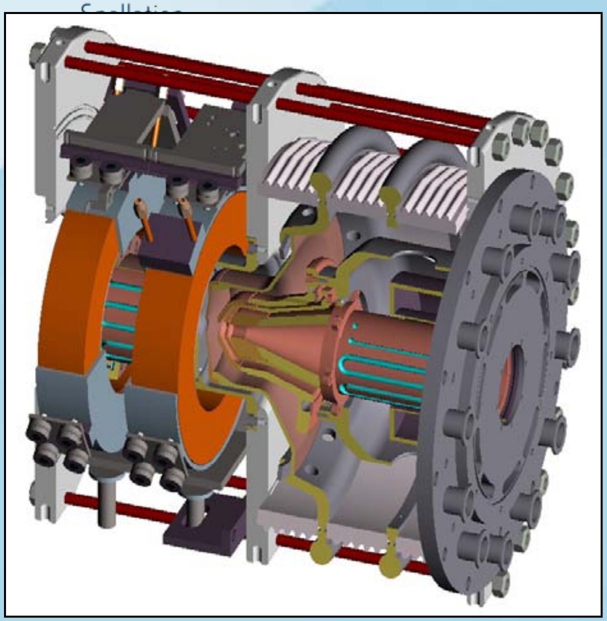
Beam noise < 2%

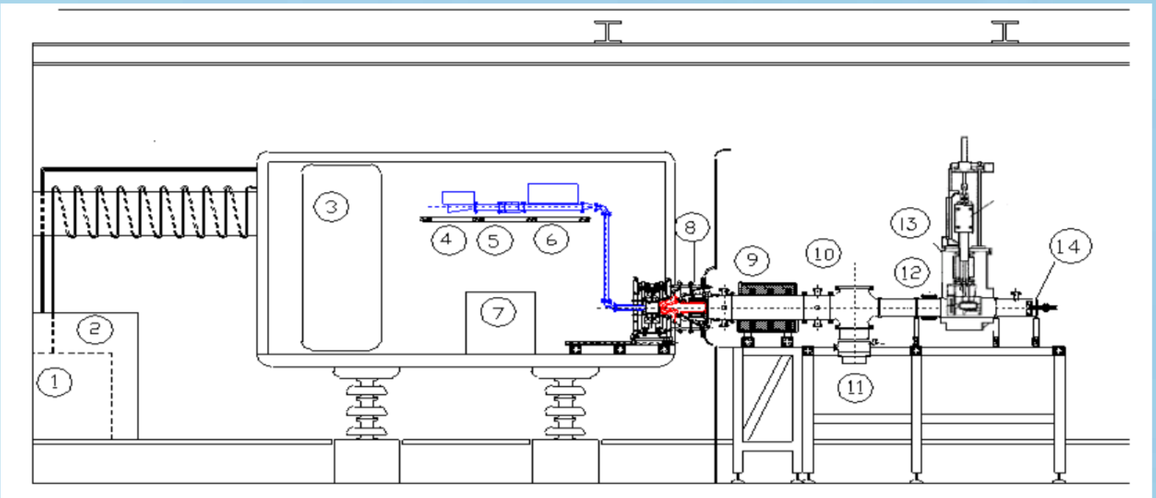
95 % < Reliability < 99.9 %

Emittance < 0.2 π mm.mrad

CW or pulsed mode

TRIPS (TRasco Intense Proton Source)



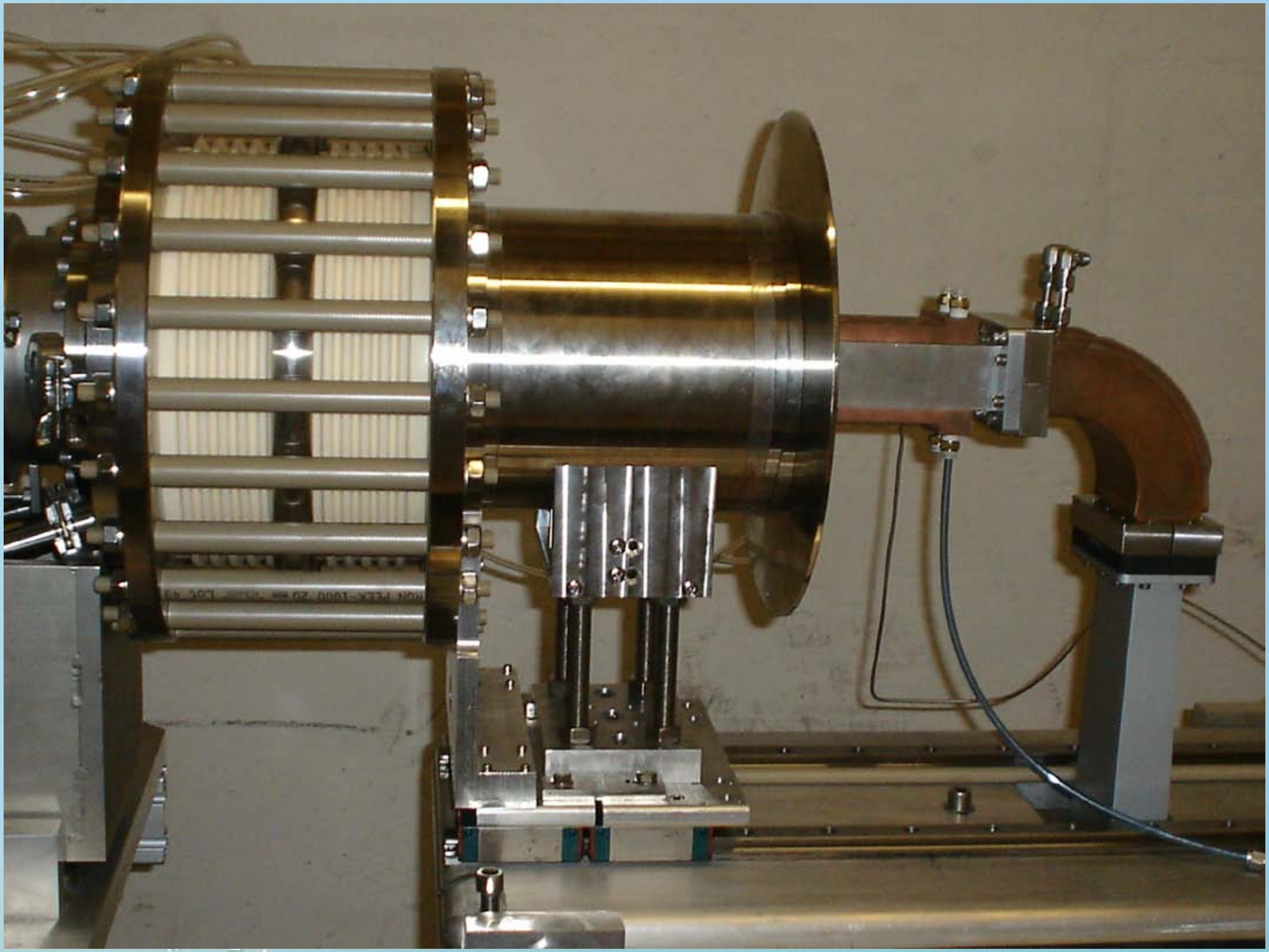


A layout of the whole set-up at INFN-LNS:
1- Demineralizer; 2- 120 kV insulating transformer; 3- 19" Rack for the power supplies and for the remote control system; 4- Magnetron and circulator; 5- Directional coupler; 6 – Automatic Tuning Unit; 7- Gas Box; 8- DCCT 1; 9- Solenoid; 10 – Four sector ring; 11- Turbomolecular pump; 12- DCCT 2; 13- EMU ; 14- Beam stop.

Proton beam current:
35 mA dc
Beam Energy:
80 keV
Beam emittance:
$\varepsilon_{RMS} \leq 0.2\,\pi$ ***mm mrad***
Reliability:
close to 100%

Based on CRNL design
MANY INNOVATIONS

Versatile Ion Source (2008)



Source and LEBT

A new design of the magnetic field profile is to be considered (in order to get a denser plasma) and the microwave injection system will be deeply revised according to the recent experience gained with the VIS source. A new idea to enhance the electric field in the plasma chamber will be tested in order to get highest ionization rates. Further studies about brightness optimization are mandatory, which can be carried out either at CEA and at INFN-LNS.

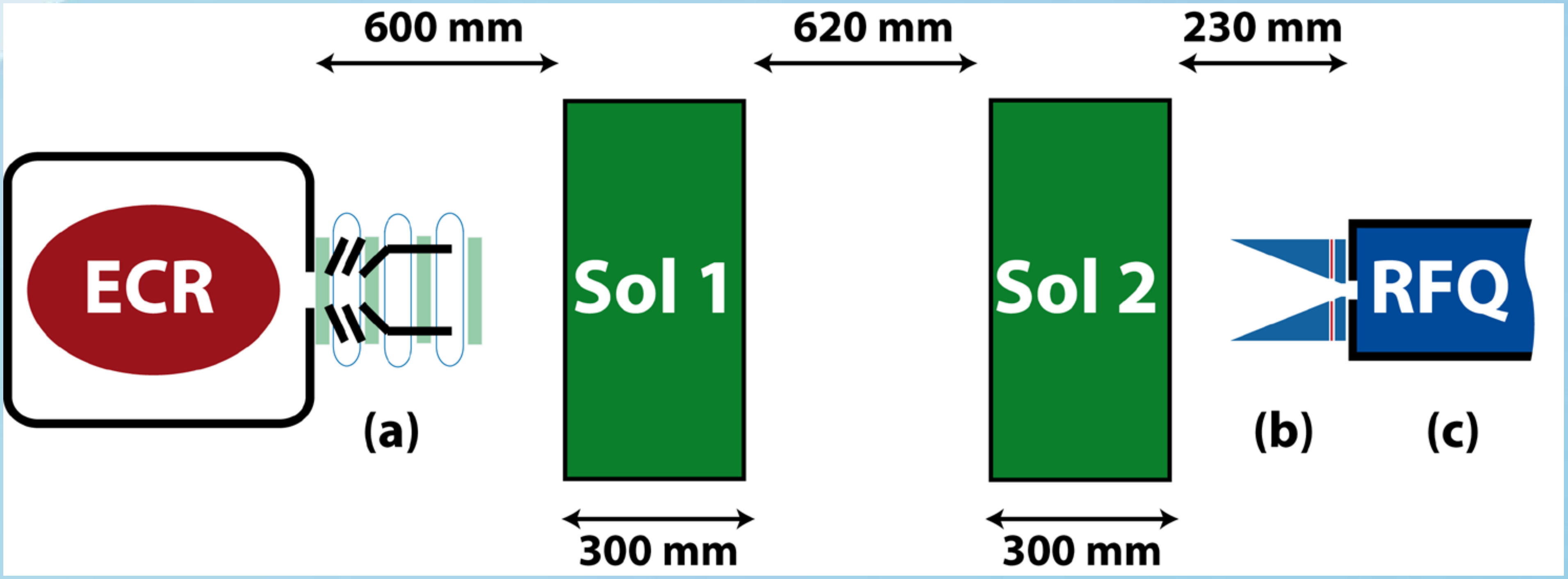
The LEBT from the source extractor to the RFQ entrance must take into account different and competitive requests as it should be the shortest as possible and it should permit to allocate the necessary diagnostics and the low energy chopper.

Weakness: reliability and brightness optimization have been obtained mainly for cw beams; experience with pulsed operation is quite limited in the involved laboratories.

Scientific Challenges

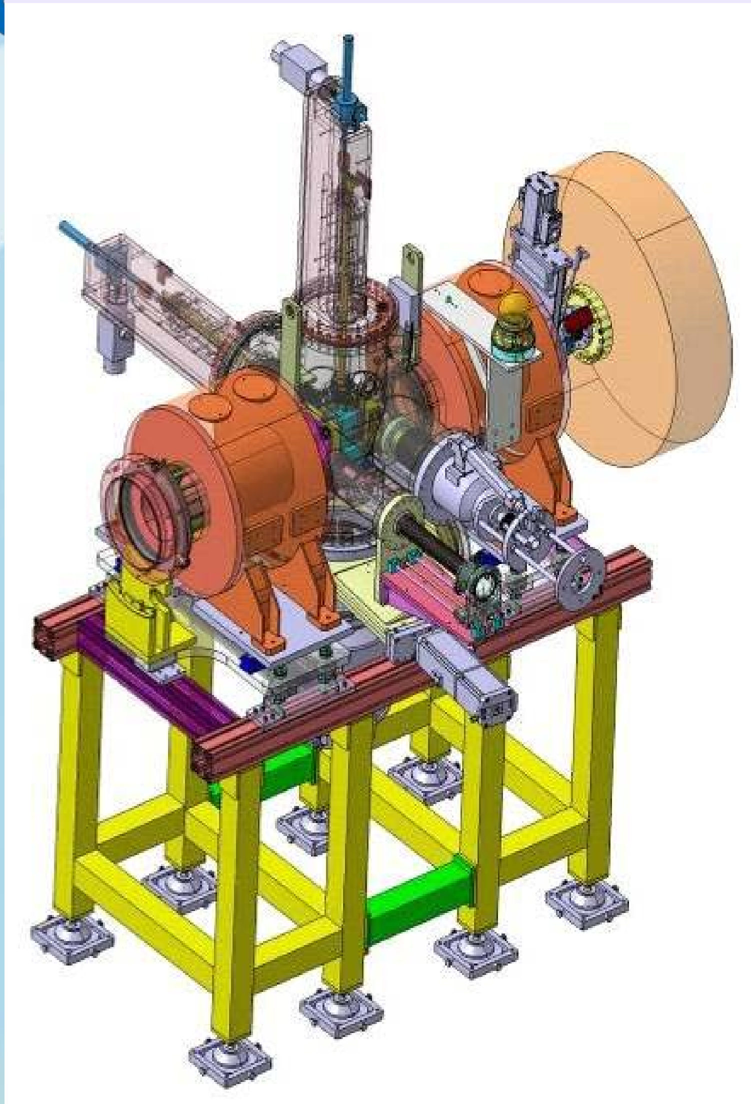
- Large currents (60-**90** mA)
- Low emittance (**0.2** to 0,3 π mm mrad)
- Long lifetime (>> 1 mo.)
- High reliability (> 99%)
- Pulsed operation (**2 ms- 20 Hz**)
- Short pulse rise time (100 ns)
- Robust extraction system
- LEBT optimization (know-how available)

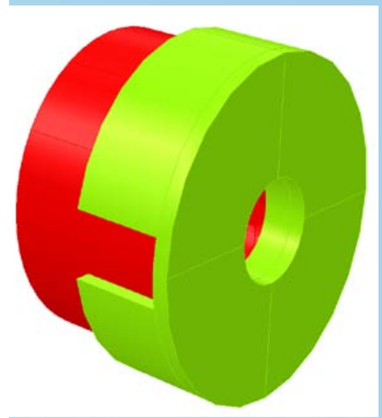
IFMIF Beam Line Layout

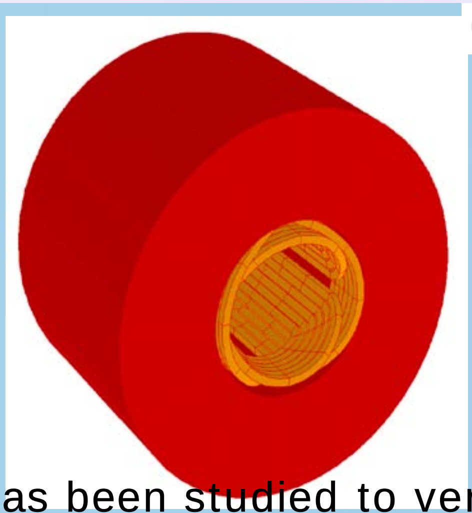


Total Beam Line Length : 2.050 m

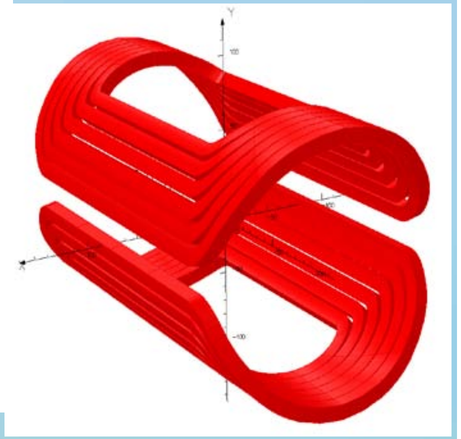
Shorter LEBT: solenoids with H+V steerers inside

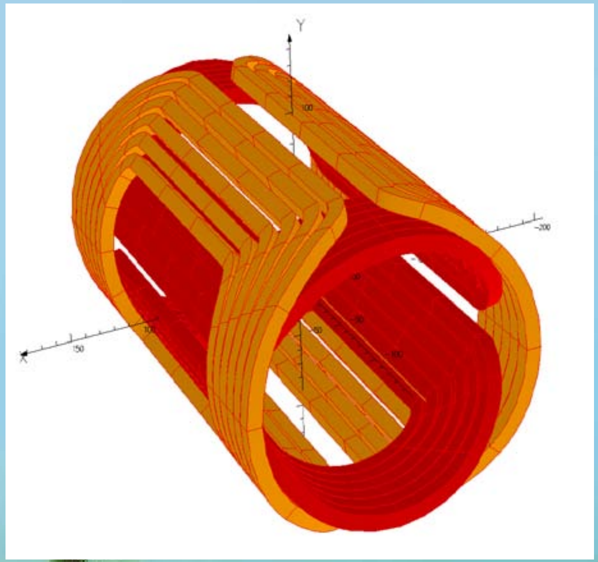






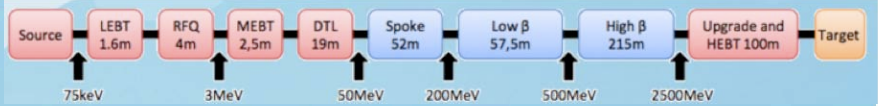
A 3D simulation has been studied to verify the possible field integral achievable and the compatibility with the beam dynamics requirements.





FORTHCOMING ACTIVITY

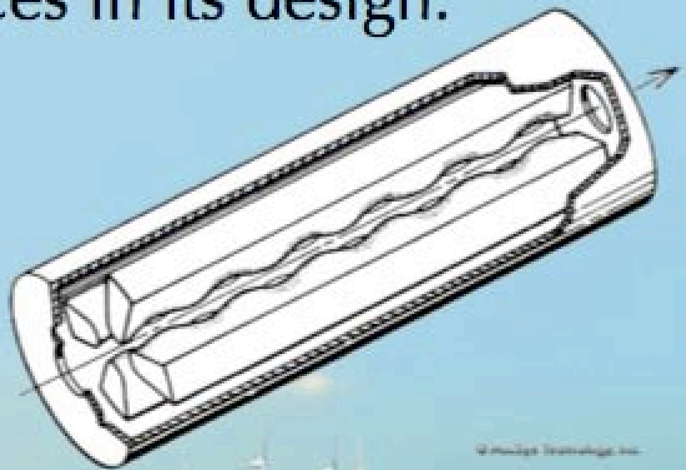
- Study of pulsed operation (2 ms-20 Hz) with VIS or SILHI
- Plasma chamber shape? INTRIGUING….
- Beam dynamics vs plasma simulations
- Study of FTE (frequency tuning effect) and emittance
- Plasma chamber dimensions? (larger dimensions may improve the uniformity of plasma?)
- LEBT optimization
- Electron donors (Al_2O_3, CNT)
- Microwave coupling:
  - Larger rf frequency (emittance? Energy spread?)
  - Multiple frequencies
  - Different plasma heating scheme

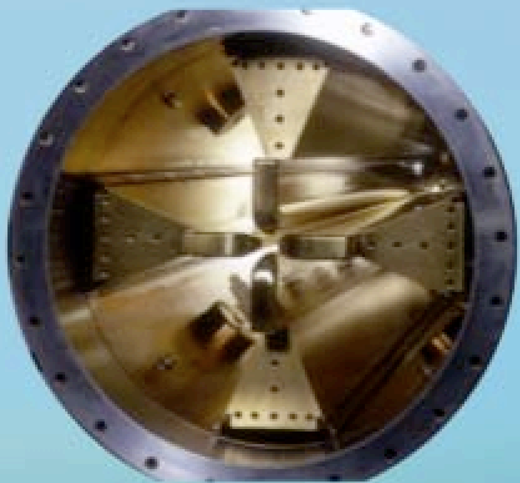


RFQ

* The Radio Frequency Quadrupole is the first accelerating structure used in LINACs. It bunches and accelerates the beam of charged particles.

* The RFQ has a significant role in determining the quality of the beam in the rest of the accelerator, so high beam intensity and low emittance growth are driving forces in its design.





RFQ

High beam intensity and low emittance growth are driving forces in the RFQ design, playing a significant role in determining the quality of the beam in the rest of the linac. The length of the bunching section exceeds 1 m in order to bunch the beam as adiabatically as possible. The conservative Kilpatrick value of 1.7-1.8 allows significant margins for a 4% duty cycle. The four vane structure has a variable voltage increasing from 66 kV to 100 kV, providing a high current limit.

No resonant coupling gap is needed, thanks to the 4 m length. The resonator is mechanically divided into four segments, each with four tuners per quad- rant.

RFQ

The design, construction and commissioning of the RFQ may be under the responsibility of CEA, Saclay, in close collaboration with INFN-LNL (the terms of the partnerships has to be defined in the next months).
In spite of the fact that a remarkable know-how is available in terms of RFQs designed for high intensity beams (IPHI, TRASCO, EVEDA), it seems envisageable to review these designs after a period of tests of pulsed mode operation at the IPHI RFQ, tailored to ESS parameters, with particular attention to the long term reliability (e.g. 3 months) with a duty factor of 20 Hz and 2 ms pulse length.
The experience of INFN-LNL researchers and of Italian companies seems to be available for the following phases (in terms to be analyzed too).

MEBT

This part may be under the responsibility of ESS Bilbao, in cooperation with CIEMAT, CEA and INFN-LNL.
The design of the MEBT could be simplified in a first phase, by considering a system, as suggested by INFN-LNL and CEA people.

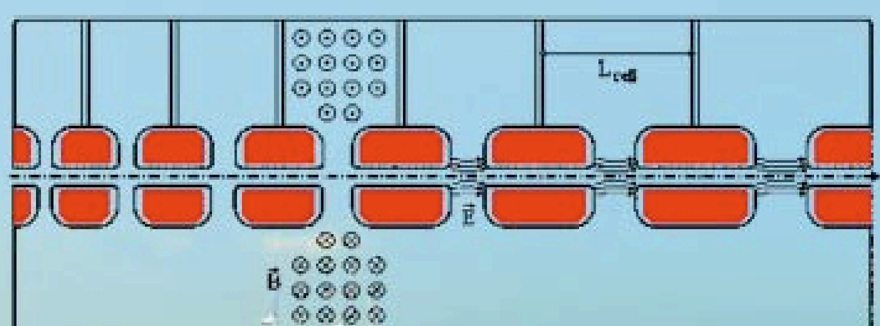
The matching between RFQ and DTL is probably a crucial point for beam halo formation. The ramping of the RFQ and DTL voltage (increasing in the last RFQ part and first DTL part) should make possible to match the longitudinal and transverse Phase advance per meter, and to get a space charge independent matching.

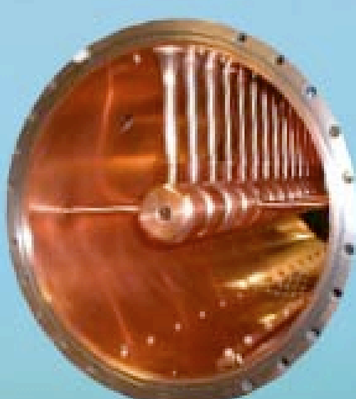
A short MEBT line could be possible, with diagnostics and electromagnetic quads. For the future upgrading, fast chopper may be taken in consideration.

European Spallation Source

DTL

- The Drift Tube LINAC accelerates the proton beam from 3 to 50 MeV in three tanks. Each tank is fed by a single klystron.
- RF field perturbations caused by static manufacturing errors are compensated by fixed post couplers.
- Transverse focusing is achieved by permanent magnet quadrupoles arranged in an FFDD lattice.





NC Linac

The DTL accelerates beam to 50 MeV, using a Linac4 based scheme in which three tanks are each fed by a single klystron (1.3 and 2.5 MW), for an accelerating gradient of more than 3 MV/m.

Post-couplers installed at every third drift tube stabilize the field profile against structural perturbations.

The DTL has a very high shunt impedance thanks to the compact size of the drift tubes, which contain PMQs in an FFDD lattice.

NC Linac

As for this part, INFN-LNL team has already designed an accelerator with very similar performances and has prototyped in Italian industry, together with CERN Linac4 team, a common prototype tank approximately 1 m long (prototype for Linac4 and SPES driver).

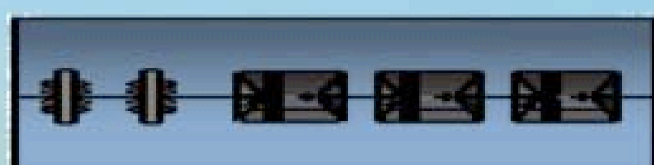
The collaboration with CERN team could continue and the DTL may be built on the basis of this R&D.

If we look in details to the different parameters of the Linac4 and ESS DTL, there is an evident similarity concerning pulse current, gradient, injection energy, and some difference exists for output energy and duty cycle only.

For this reason, there is no need of prototyping for NC Linac, but a careful analysis of the optimum design, adapted to the ESS parameters, is quite necessary.

Spokes

- Superconducting Spoke resonators are used for the range of 50 to 200 MeV using 14 cryo-modules.
- SC spoke resonators at low frequencies have the advantage of providing a large longitudinal acceptance, in addition to their large transverse acceptance thanks to their relatively large apertures.
- Another advantage is the flexibility to phase and tune spoke resonators independently.

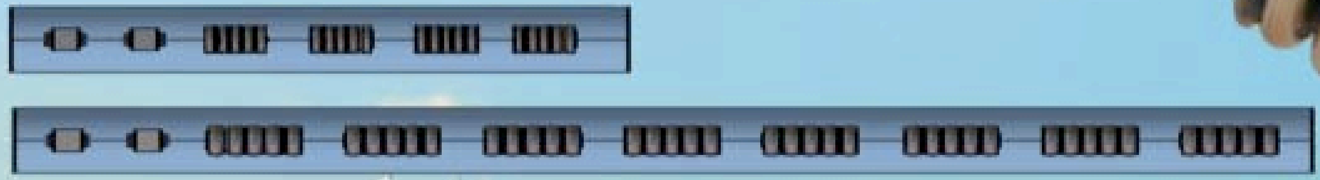


Single and Triple Spoke Resonator cavities are chosen to accelerate beam to 200 MeV because they are much less sensitive to mechanical perturbations than elliptical cavities, and because they provide large transit time factors in the β range from 0.3 to 0.5. Installing SSRs with a FODO lattice just after the DTL enables cavities to be independently phased at relatively low energies, responding to the SNS experience that this is very useful for longitudinal acceptance tuning.

Ellipticals

* The superconducting elliptical cavities operate at 704.4 MHz. Two families of elliptical cavities are found to optimize the acceleration in the range of 200 to 2500 MeV.

* Each cavity is fed by a power coupler delivering 1 MW of power, 90% of which is available for acceleration.



The design reduces the surface fields and relaxes tuning criteria. The power couplers will deliver 1 MW of peak power with a 4% duty factor, causing the accelerating gradient to decrease in inverse proportion to the beam current. There is one coupler per cavity, with a single disk-type ceramic window to isolate the cavity vacuum.

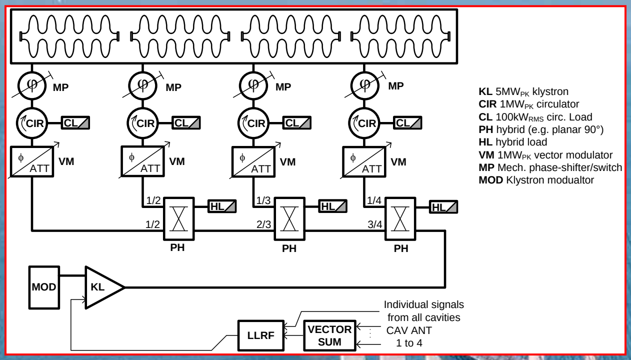
Lorentz detuning is dynamically compensated in order to constrain the resonant frequency of each cavity within the available bandwidth, maximizing the efficiency of energy transfer to the beam.

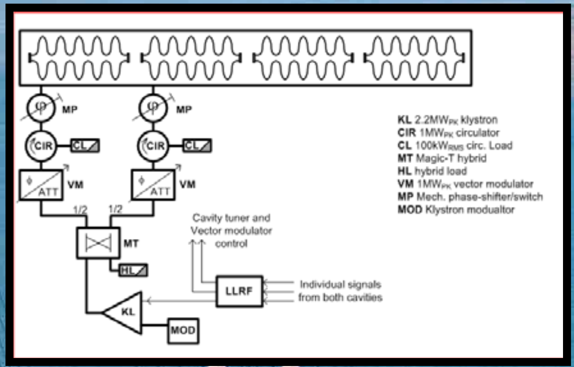
Microphonics due to ambient accoustical noise also need to be considered. Stiffeners may be needed, to compensate for the inherent structural weakness of elliptical cavities. Detailed finite element analysis is under way to evaluate and optimize the closed loop system, including RF fill factor, cavity response, and dynamic tuning.

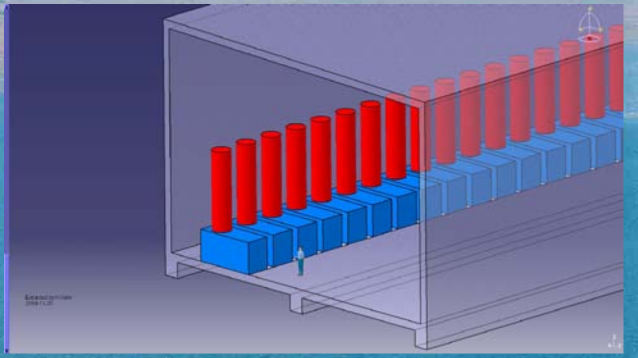
HEBT

- The High Energy Beam Transport structure delivers the beam from the LINAC to the Target using normal conducting magnets.
- This area will house the extra cryo-modules for the enhanced reliability and the potential power upgrade.
- A chicane in the end of the HEBT guarantees that none of the back scattered neutrons from the target reaches the LINAC.

RF distribution





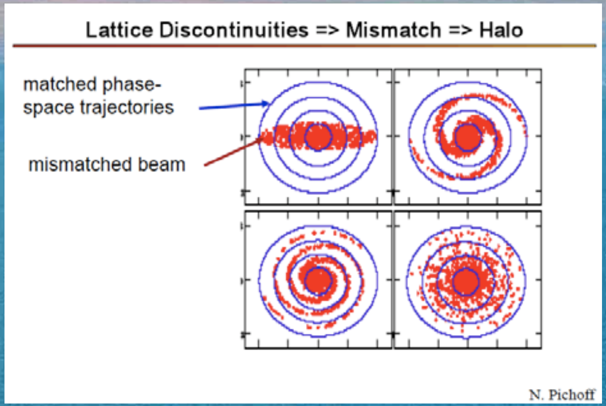


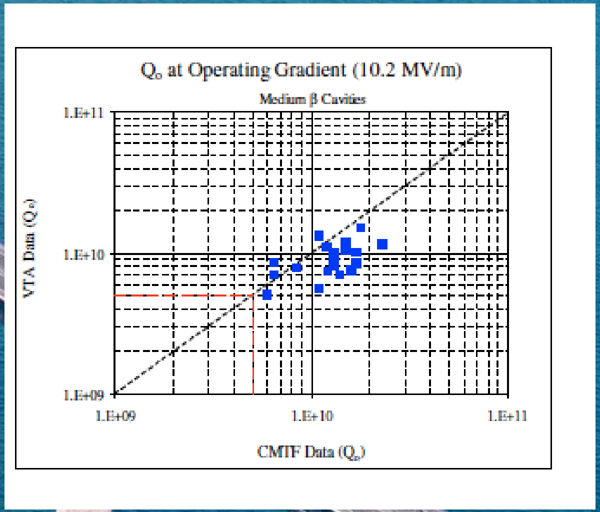
Option	Configuration	Cost of 4 cavity (K-Euro)	For	Against
1	Four cavities per Klystron	2420	Fewest power sources	Complexity, bulk, power overhead, fault tolerence
2	One Cavity per Klystron	2880	Reduced hardware inventory, minimum R&D, fully independent control, minimum RF power overhead, best fault tolerance, easy upgrade to HPSPL	Number of power sources
2a	One cavity per IOT	2520	As above, perhaps cheaper & more compact	HPSPL would need doubling of IOTs, or larger rating IOTs
3	Two cavities per Klystron	2520	Half the number of klystrons	Need full hardware set, associated R&D, Power overhead, Reduced flexibility wrt option 2
3-VM	Two cavities per Klystron Without VMs	2370	Half the number of klystrons, more economical than Option 3	Risk for higher intensity?

RF test stand in Uppsala – Energy efficiency

Examples of risks to be addressed

- High losses in the linac
  - Action: Comprehensive studies of beam dynamics (simulations and theory)
- Poor reproducibility in cavity performance
  - Action: Quality control during manufacturing and prototyping of a sufficient large number of cavities
- Limits in cavity performance due to field emission
  - Action: Prototyping and comprehensive tests of complete cryomodule
- Lower power limit than expected of power couplers
  - Action: Prototyping, sufficient conditioning facilities and contingency in linac design





Writing Group for linac project plan

- Project plan for the linac design update and prototyping
  - Design Report for the end of 2012, 20% precision in costing
  - Readiness to construct by the end of 2012 -- the design will be a safe baseline design with technical choices made for which the writing of specifications, detailed drawings and completion of late prototypes could be launched without any further delay after 2012
  - Energy budget and sustainability should be taken into account in each work package

- Responsibilities within WG
  - S.Peggs – Accelerar Physics and configuration control
  - R. Duperrier – System engineering
  - C.Oyon – Project planning
  - M. Lindroos – Coordination and planning

Collaboration model: Required

- A collaboration to share interesting R&D, assure an all European effort and kick start the ESS work
- A strong Coordination Team in Lund to take the intellectual ownership of the design, to follow the work, to assure good project cost control, and to be responsible for project integration
- A collaboration board to assure good coordination and to address poor performance
- Use of common standards, web based documentation, regular reporting and appropriate costing tools
- Regular reviews of critical path deliverables and even milestones of large work packages (if at a single institute)

Collaboration model for linac design

Work Package (work areas)

1. Management Coordination – ESS (Mats Lindroos)

2. Accelerator Science – ESS (Steve Peggs)

3. Infrastructure Services – Tekniker, Bilbao (Luis Uriarte)

4. SCRF Spoke cavities – IPN, Orsay (Sebastien Bousson)

5. SCRF Elliptical cavities – CEA, IRFU-Saclay (Guillaume Devanz)

with contribution by INFN-Milano (P. Pierini)

6. Front End and NC linac – INFN, LNS-Catania (Santo Gammino)

7. Beam transport, NC magnets and Power Supplies – Århus University (Søren Pape-Møller)

8. RF Systems – Uppsala university (Roger Ruber)

Work Package description

I.Objectives: "Design and prototype the proton source, RFQ, NC linac, and the MEBT section."

II.Leader: S. Gammino (INFN-LNS, Catania)

III.Work break down structure

WU 1	**Planning of the activities (resp. INFN-LNS)**
WU 2	**Source and LEBT (resp. INFN-LNS)**
WU 3	**RFQ (resp. CEA-IRFU)**
WG 4	**MEBT (resp. ESS-Bilbao)**
WG 5	**NC Drift-Tube Linac (resp. INFN-LNL, contribution by CERN)**

From RFQ to DTL

For the accelerating part of the normal conducting linac, even if JPARC and SNS are a reference point for many aspects, the frequency choice and the experience of the European teams indicate a clear direction, related to existing accelerating structures.

RFQ (TRASCO, IPHI and LINAC4,), **MEBT** (design LINAC4 or Rutherford lab with choppers, developed in HIPPI, or a simpler design without choppers but with phase advance matching between RFQ and DTL), **DTL** (LINAC4 design with advantage of SNS experience).

So the existing efforts for prototyping and realizing structures for these projects can be directly reused for the TDR and none major specific prototype is identified for ESS.

Beam dynamics study is necessary for the RFQ, MEBT and DTL design in such a way to have the best possible matching.

WP6-WU3: RFQ

The WU 3 is dedicated to the design of the ESS RFQ and the test of the IPHI RFQ with relevant parameters for ESS (duty cycle, peak current, pulse length) for reliability studies.

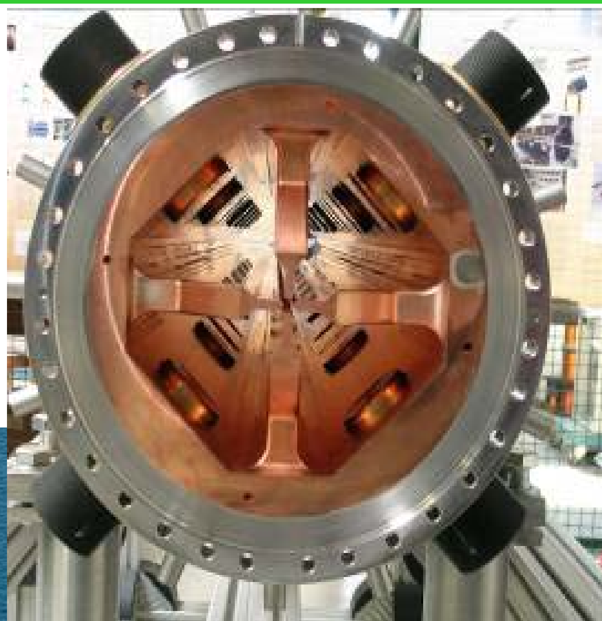
A design review will be done after a period (3 months) of tests of pulsed mode operation with a duty factor of 20 Hz and 2 ms pulse length.

Deliverable number	Deliverable name
D0	**Kick off**
D1	**RFQ design**
D1.1	Design report on the pole tips parameters
D1.2	Design report on the RF 2D section
D1.3	Design report on the 3D RF section
D1.4	Design report on the tuner design
D1.5	Design report on the pumping port design
D1.6	Design report on the RF pick-up
D1.7	Design report on the power coupler
D1.8	Design report on the cooling system
D1.9	ICD for the RFQ system
D2	**IPHI RFQ reliability tests**
D2.1	Test plan report
D2.2	Reliability test report
D3	**Concept Design Review**
D3.1	Intermediate design report
D3.2	Final design report

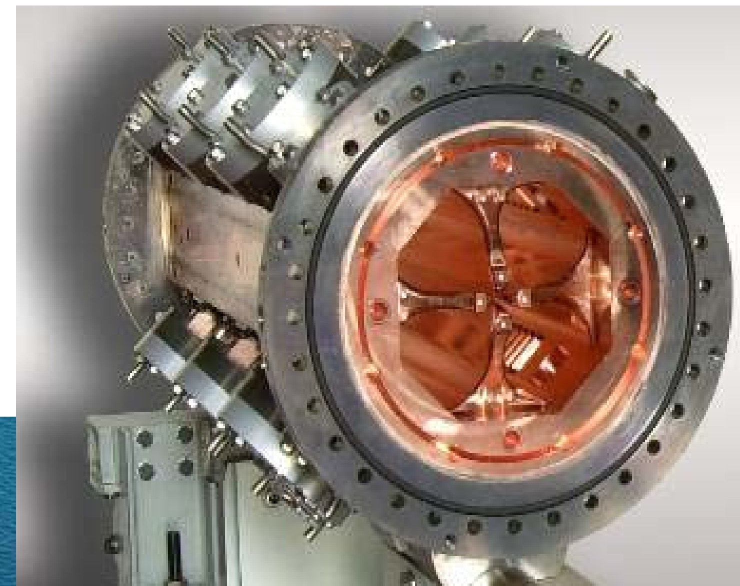
RFQ Nightmares…

- SNS: problem with the tuning during operation, decision to build a new RFQ with a 4 vanes structures.
- J-PARC: high sparking rate, they are replacing it and are switching to a 4 vanes structures.
- SARAF: impossible to reach the power for deuteron acceleration.
- IPHI, LINAC4 and IFMIF-EVEDA : 4 vanes structures in construction
- LEDA: never worked in CW at the nominal current (110 mA) and the cavity behaviour has not been fully understood.

	Name	Lab	ion	energy MeV/u	vane voltage kV	beam current mA	power kW	RF Cu power kW	Freq. MHz	length m	lambda	Emax kilpat	Power density ave W/cm^2	max W/cm^2	operated
	IFMIF EVEDA	**LNL**	**d**	**2.5**	**79-132**	**130**	**650**	**585**	**175**	**9.8**	**5.7**	**1.8**	**3.5**	**30**	**NO**
pulsed	CERN linac 2	CERN	p	0.75	178	200	150	440	202	1.8	1.2	2.5			YES
	SNS	LBNL	H-	2.5	83	70	175	664	402.5	3.7	5.0	1.85	1.1	10	*YES*
	CERN linac 3	LNL	A/q=8.3	0.25	70	0.08	0.04	300	101	2.5	0.8	1.9			*YES*
CW	LEDA	LANL	p	6.7	67-117	100	670	1450	350	8	9.3	1.8	11.4	65	*YES*
	FMIT	LANL	d	2	185	100	193	407	80	4	1.0	1	0.4		*YES*
high p	IPHI	CEA	p	3	87-123	100	300	750	352	6	7.0	1.7	15	120	*NO*
	TRASCO	LNL	p	5	68	30	150	847	352	7.3	8.6	1.8	6.6	90	*NO*
CW	SARAF	NTG	d	1.5	65	4	12	250	176	3.8	2.2	1.4	24	54	*NO*
mid p	SPIRAL2	CEA	A/q=3	0.75	100-113	5	7.5	170	88	5	1.5	1.65	0.6	19	*NO*
CW	ISAC	TRIUMF	A/q=30	0.15	74	0	0	150	35	8	0.9	1.15	-	-	*YES*
lp	PIAVE	LNL	A/q=7.3	0.58	280	0	0	8e-3 (SC)	80	2.1	0.5	2.1	-	-	*YES*



TRASCO@LegnaroINFN



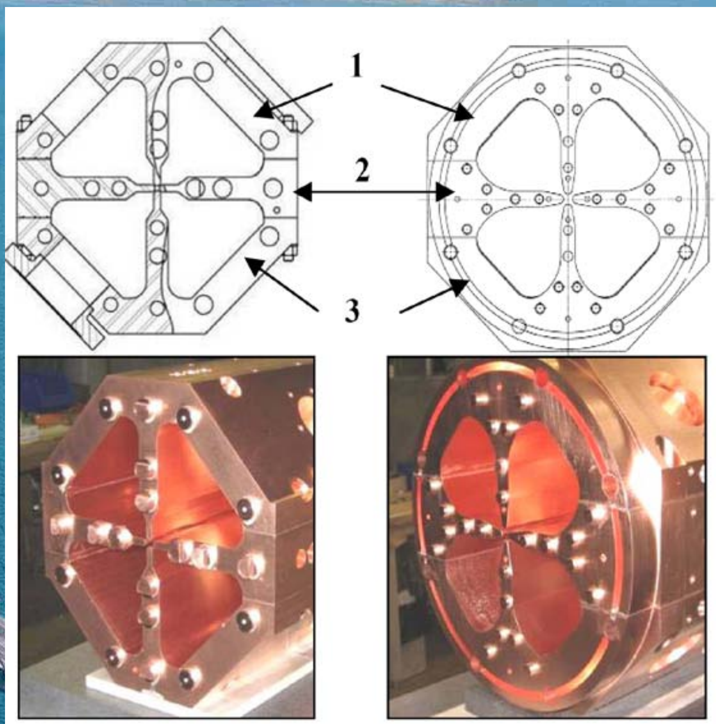
IPHI@Saclay.CEA

Research Programs in Europe related to ADS studies

RFQ

- The design is quite different (also respect to LEDA);
  - **IPHI** (3 MeV 100mA) is built in six modules (1 m each), has a ramped voltage, a cross section with a specific geometry and has been optimized for a very high transmission (above 98%);
  - **TRASCO** (5 MeV 30 mA) has constant voltage, 2d vane machining and a cross section simpler to machine; it is built in six modules (1.2 m long, for cost optimization).

- The two RFQs (machined respectively in Italian and French industry) brazing at CERN follows the same work sequence and few differences are due to the details of the mechanical design and realization.



TRASCO IPHI

RFQ

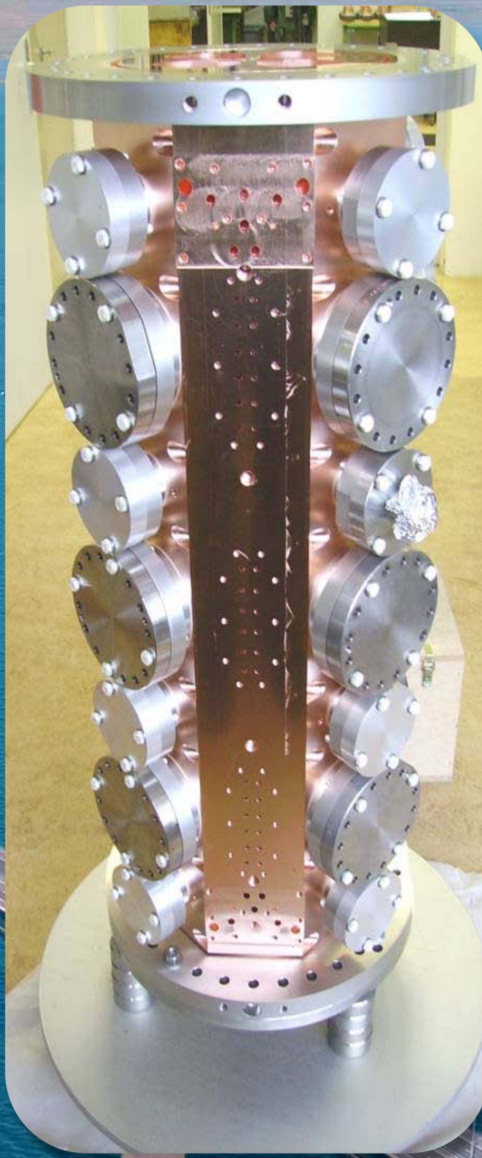
At this frequency and for this duty cycle, four vanes structures are mandatory.

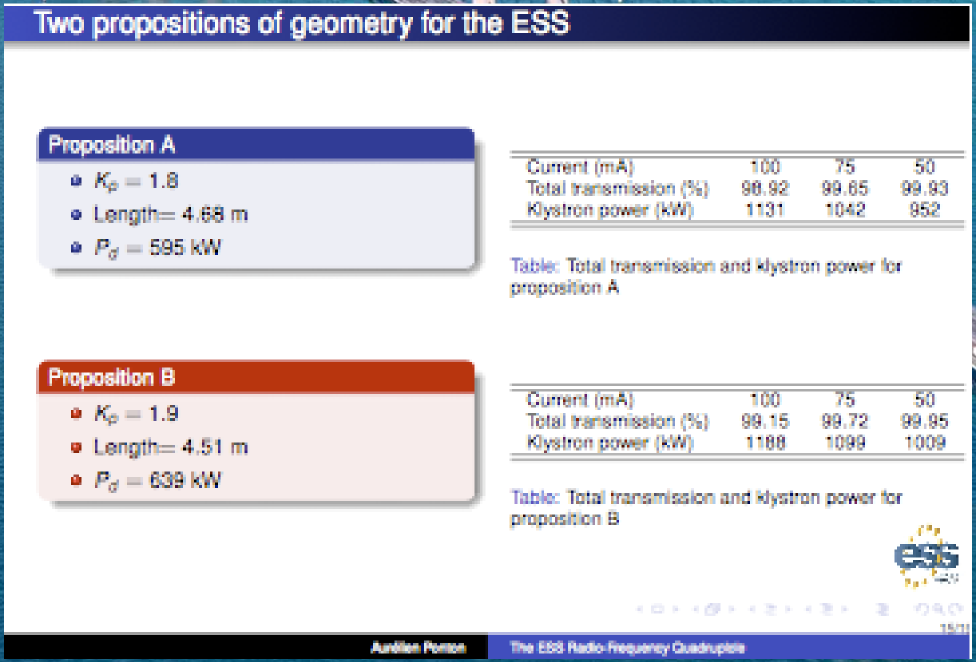
Milling with tolerances within +/- 25 microns (1% capacitance error) is now mastered.

Keep such tolerances after the brazing is still a problem, but it has been performed for LEDA, IPHI and TRASCO.

Thermo-mechanical design is still to be investigated to well control the cavity in operation (cold tuning = warm tuning).

Choice of Kilpatrick is always a source of debate.




Two propositions of geometry for the ESS

Proposition A

- $K_p = 1.8$
- Length= 4.68 m
- $P_d = 595$ kW

Current (mA)	100	75	50
Total transmission (%)	98.92	99.65	99.93
Klystron power (kW)	1131	1042	952

Table: Total transmission and klystron power for proposition A

Proposition B

- $K_p = 1.9$
- Length= 4.51 m
- $P_d = 639$ kW

Current (mA)	100	75	50
Total transmission (%)	99.15	99.72	99.95
Klystron power (kW)	1188	1099	1009

Table: Total transmission and klystron power for proposition B

MEBT

The design of the MEBT is to be simplified in a first phase, as suggested by INFN-LNL and CEA people.

The matching between RFQ and DTL is one of the crucial points for beam halo formation.
The ramping of the RFQ and DTL voltage (increasing in the last RFQ part and first DTL part) should make possible to match the longitudinal and transverse phase advance per meter, and to get a space charge independent matching.

A short MEBT line could be possible, with diagnostics and electromagnetic quads.

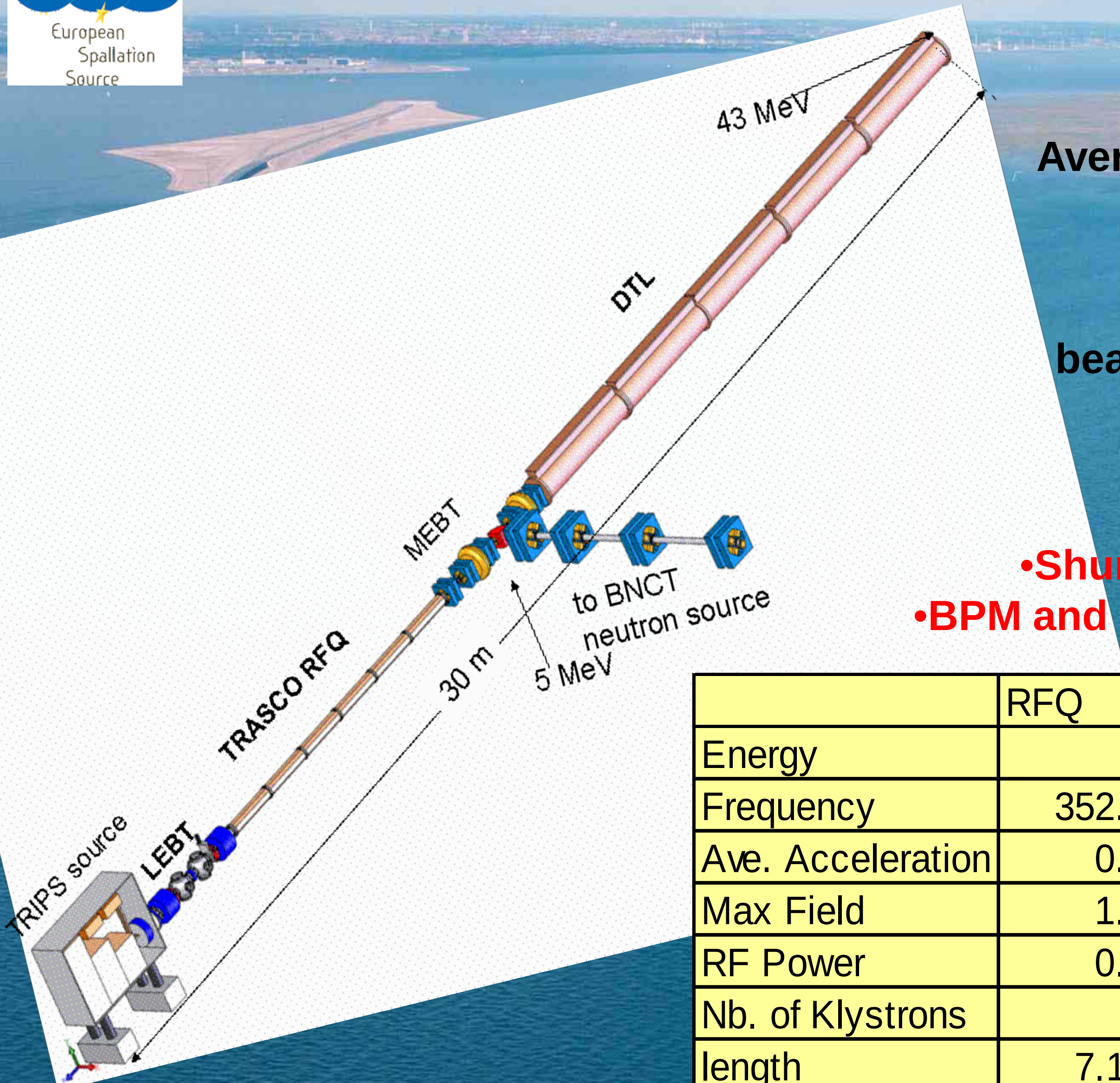
NC Linac

As for this part, INFN-LNL team has already designed an accelerator with similar performances and has prototyped with Italian industry, together with CERN Linac4 team, a common prototype tank approximately 1 m long (prototype for Linac4 and SPES driver).

The collaboration with CERN team could continue and the DTL may be built on the basis of this R&D.

If we look in details to the different parameters of the Linac4 and ESS DTL, there is an evident similarity concerning pulse current, gradient, injection energy, and some difference exists for output energy and duty cycle only.

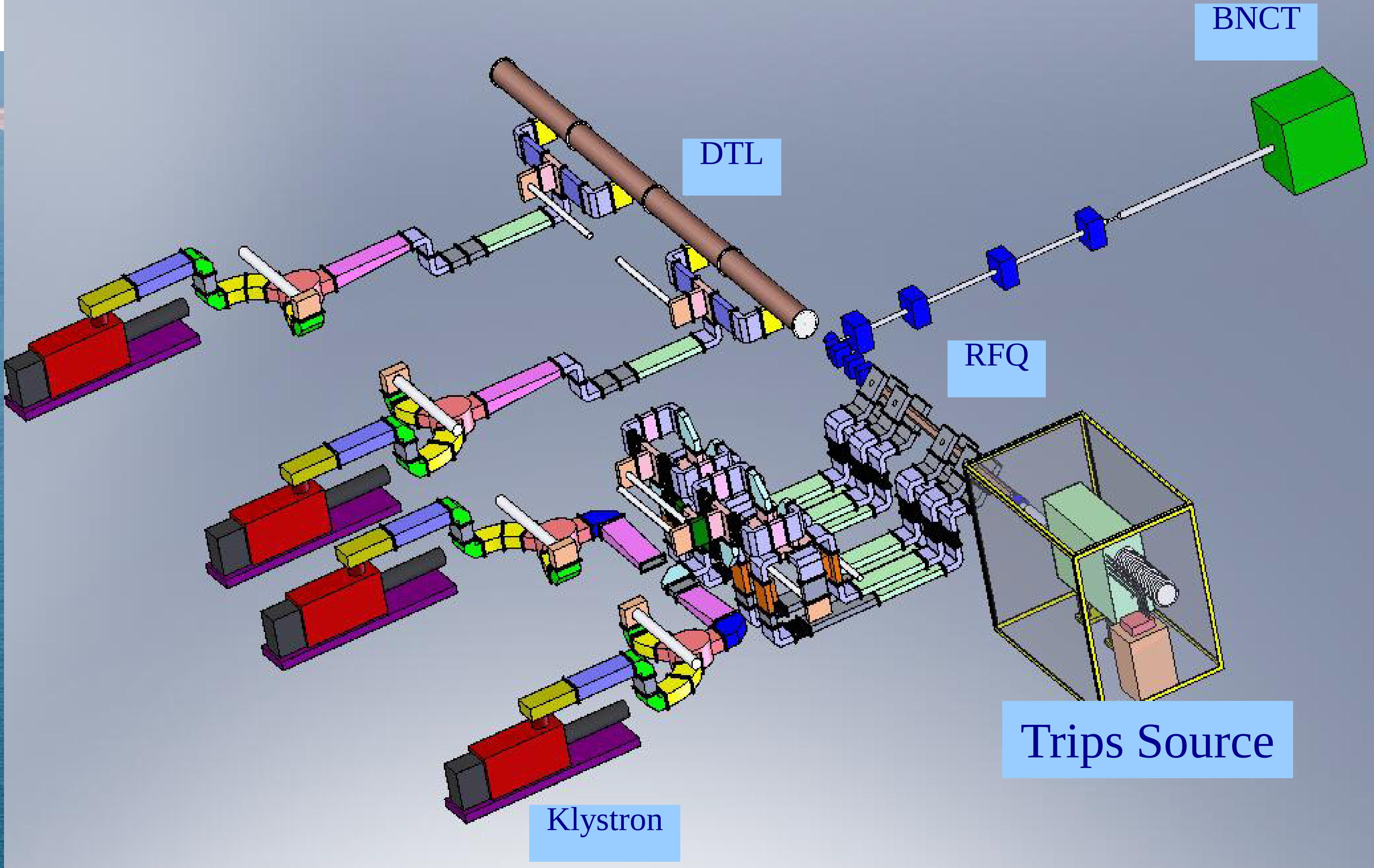
For this reason, there is no need of prototyping for NC Linac, but a careful analysis of the optimum design, adapted to the ESS parameters, is quite necessary, to put in evidence possible criticalities.



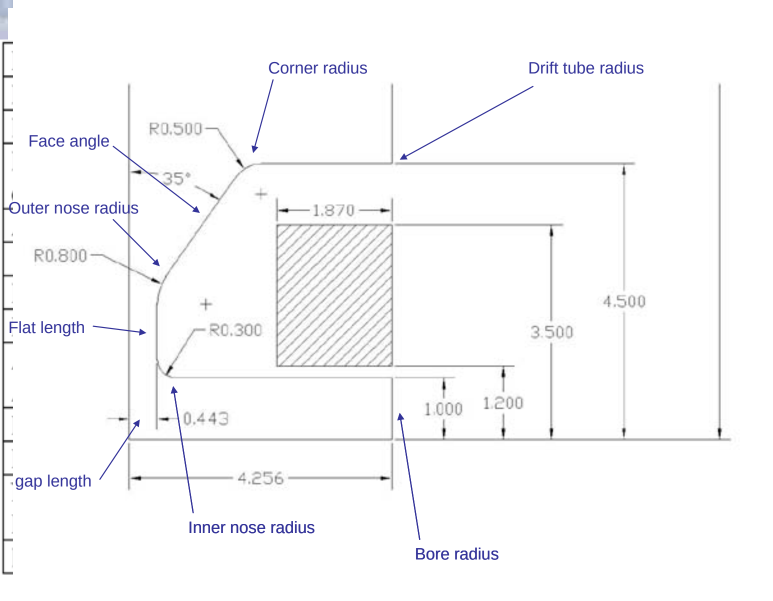
Beam energy: ~43 MeV
Average beam current : up to 1.5 mA
Beam pulse length 0.600 ms
Repetition rate 50 Hz
RF frequency: 352.2 MHz
beam emittance (transv. Norm RMS <0.4 mmmrad)
Possible upgrade to 95 MeV

- **Shunt impedance still very good**
- **BPM and active steering can be introduced**

	RFQ	DTL	DTL upgrades		
Energy	5	43	60.8	95.5	MeV
Frequency	352.2	352.2	352.2	352.2	MHz
Ave. Acceleration	0.7	2.5	2.3	2.1	MeV/m
Max Field	1.8	1.6	1.3	1.3	Ekp
RF Power	0.8	4.03	2	4.1	MW
Nb. of Klystrons	1	2	1	2	
length	7.13	15.2	7.6	16.3	m


BNCT
DTL
RFQ
Trips Source
Klystron

DTL; Physical design up to 96 MeV
(FFDD permanent quads all along)



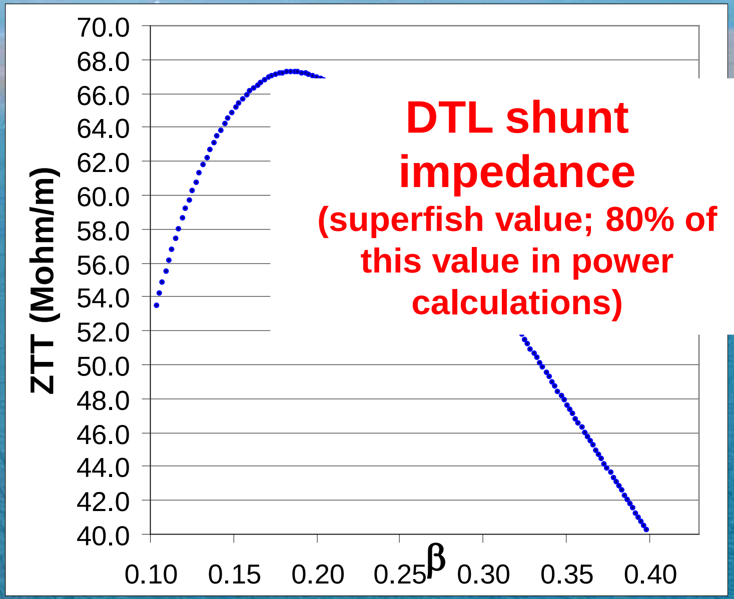
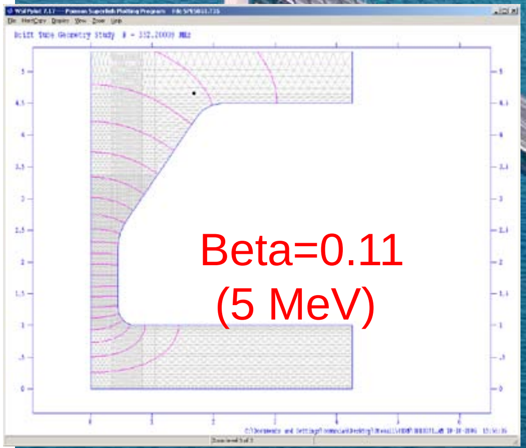
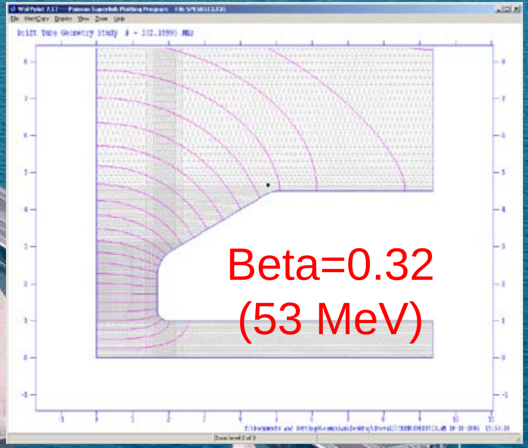
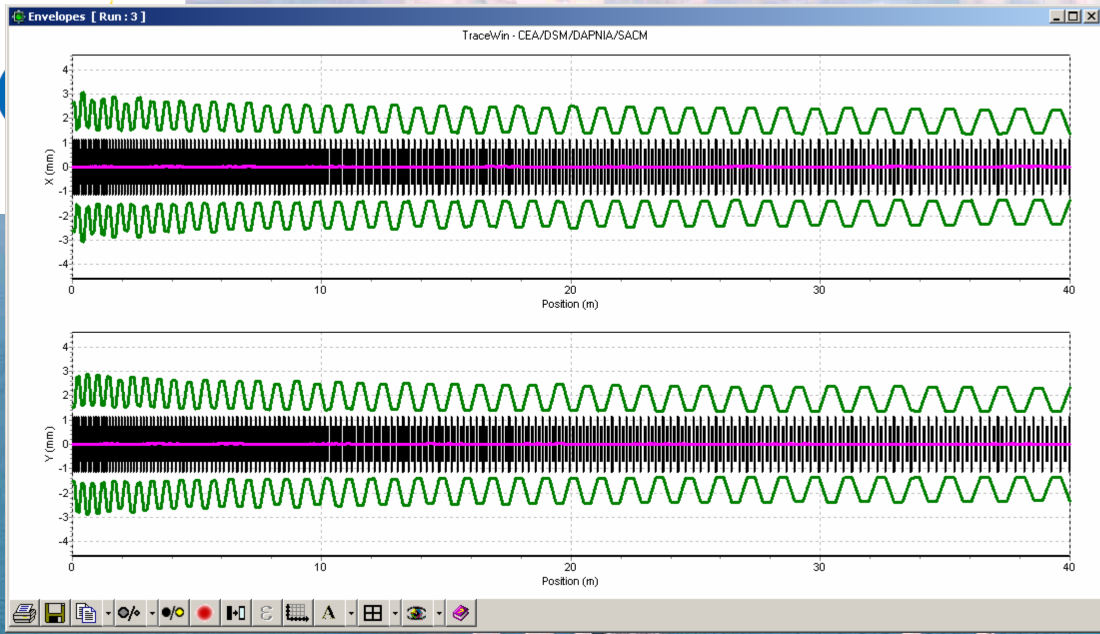


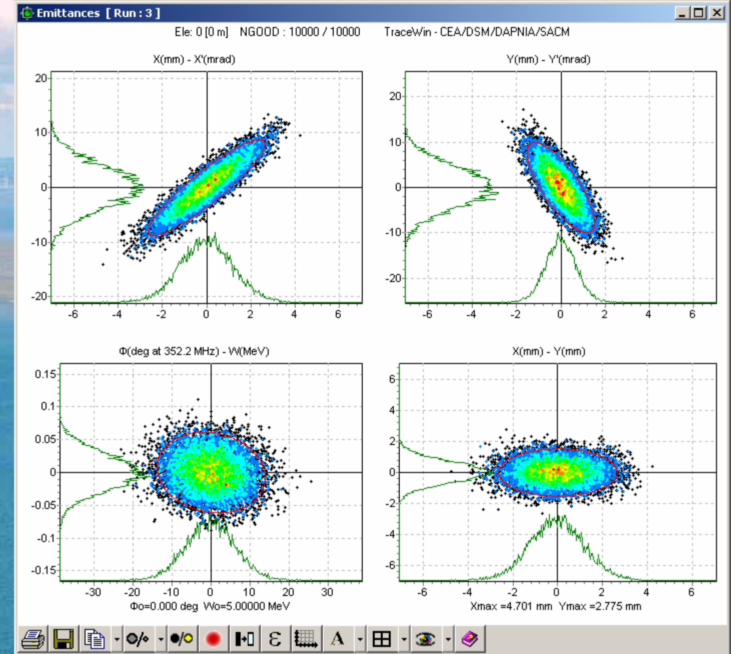
Table 4.6: Parameters of the first five DTL Tanks up to 61 MeV

	Tank 1	Tank 2	Tank 3
Output energy [MeV]	23.82	43	60.76
Frequency [MHz]	352.2		
Gradient E_0 [MV/m]	3.10	3.10	3.10
Synchronous phase [deg]	-35/-20	-20	-20
Lattice	FFDD		
Aperture radius [mm]	10		
Diameter [m]	0.52		
Drift tube diameter [mm]	90		
Length [m]	7.53	7.68	7.59
Max surface field [kilp.]	1.6	1.23	1.15
Peak RF power [MW]	2	2	2
N. of klystrons	1	1	1
Quadrupole length [mm]	45		
N. of gaps	55	35	28
Stem diameter [mm]	28		
N. of post-couplers	27	17	14
Post coupler diameter [mm]	20		
Frequency tuning	Water temperature		
Fixed tuner diameter [mm]	90		
N. of fixed tuners	10	10	10

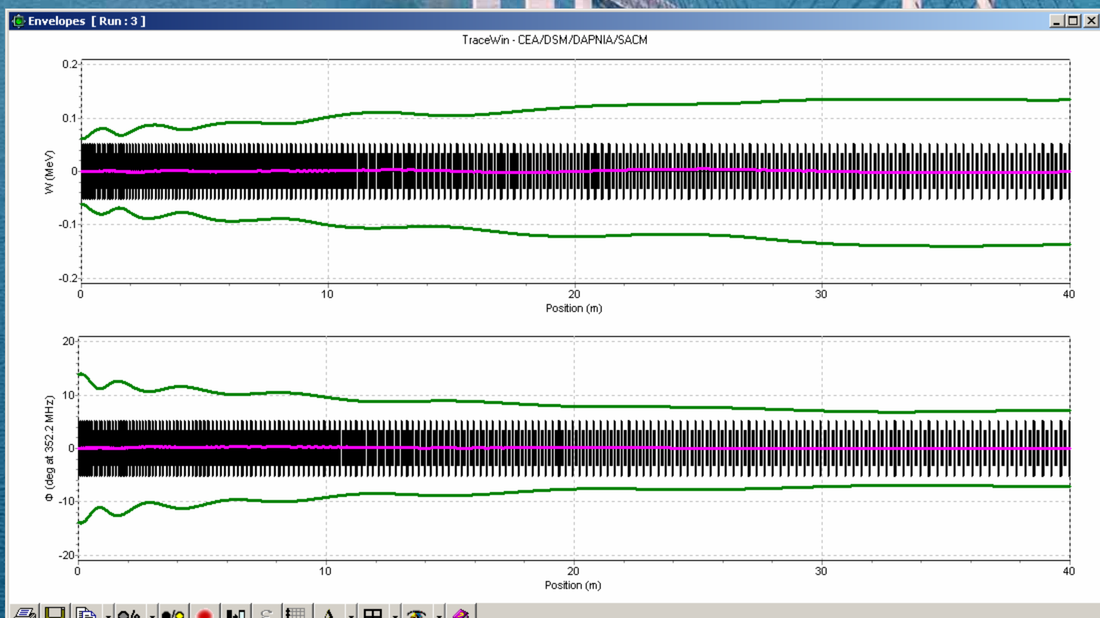


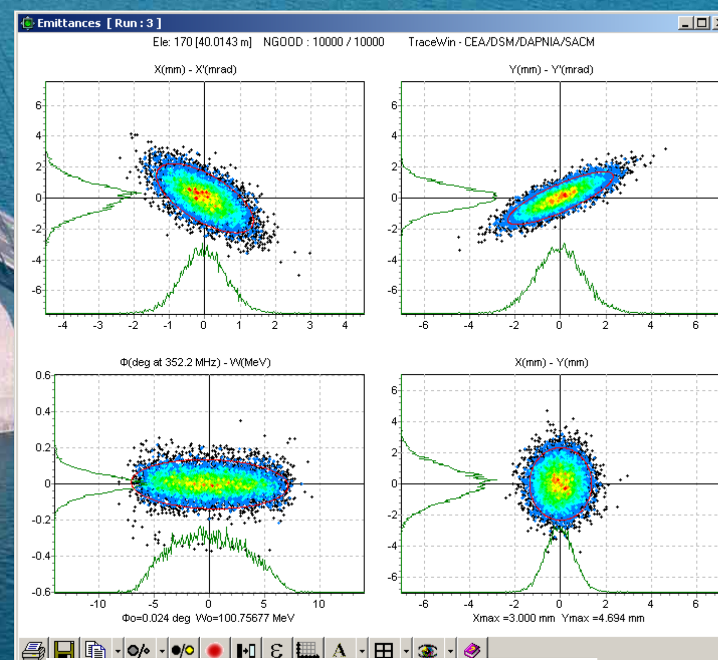






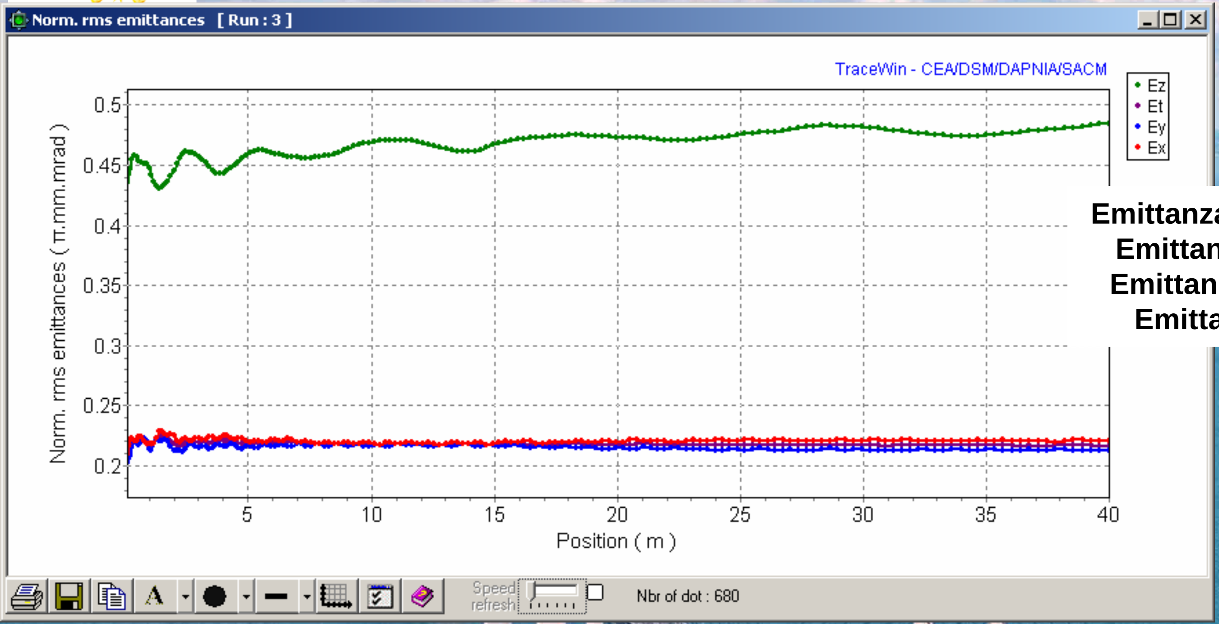
Fascio in ingresso a 5 MeV



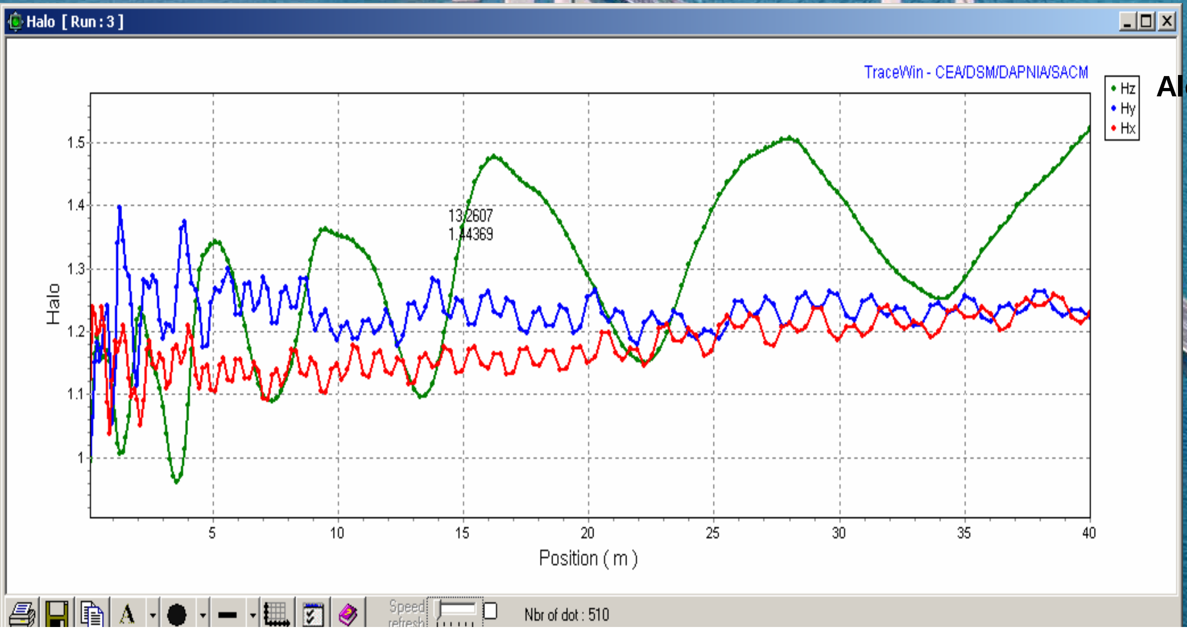


Trasporto di 50 mA nel DTL, assumendo un fascio iniziale gaussiano (4 sigma).
I plot sono 5 volte la dimensione RMS del fascio.
Il fascio e' trasportato senza perdite da 5 a 100 MeV.

Fascio in uscita a 100 MeV



Emittanza trasversa RMS norm. in ingresso: 0.20 mmmrad
Emittanza longitudinale RMS in ingresso: 0.17 MeVdeg
Emittanza trasversa RMS norm. in uscita: 0.22 mmmrad
Emittanza longitudinale RMS in uscita: 0.19 MeVdeg



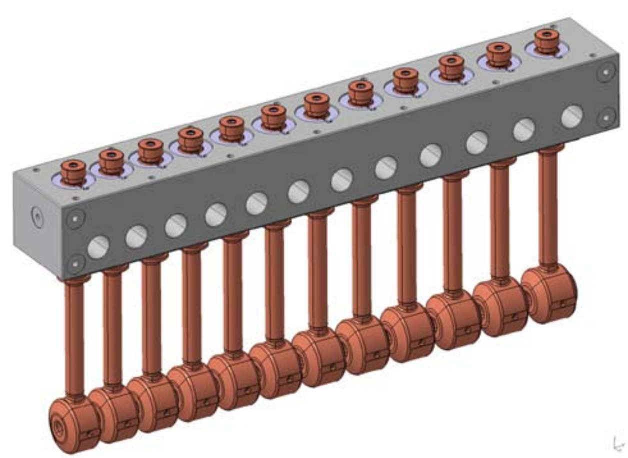
Alone gaussiano del fascio in ingresso su tutti I piani (4 sigma): 1
Alone trasverso in uscita: 1.21
Alone Longitudinale in uscita: 1.5

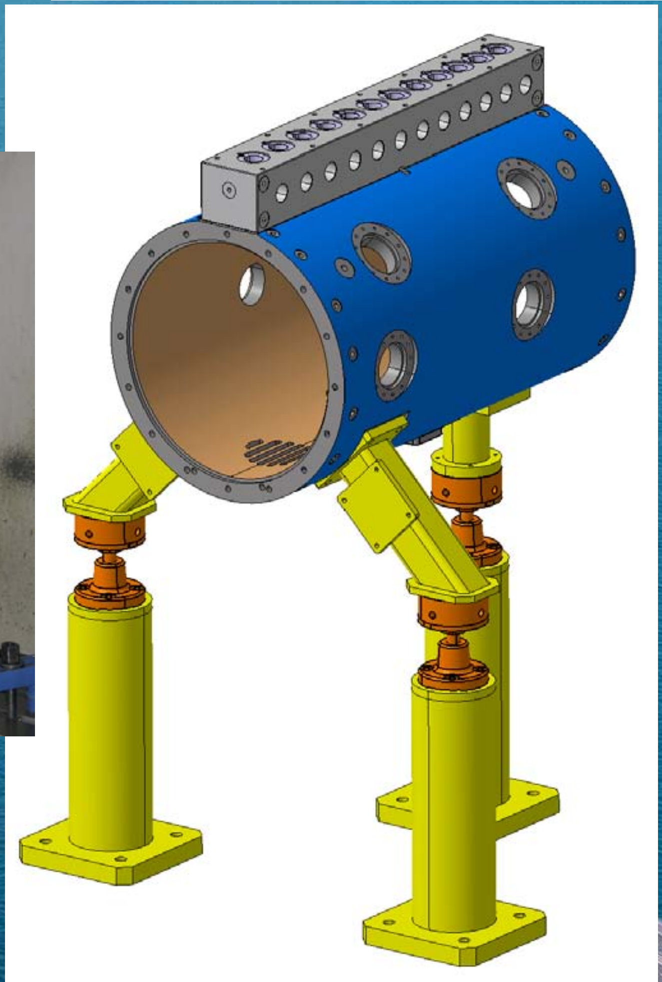
Trasporto di 50 mA nel DTL, assumendo un fascio iniziale Gaussiano (4 sigma), I plot sono le emittanze e l'alone lungo il DTL (fino a 100 MeV)

CERN-LNL DTL prototype, based on CERN design

LNL part : machining of the tank and all components.

CERN for e-beam welding of the tubes, Cu plating of the tank, final assembly and RF high power tests.





Tank machining at Cinel (Vigonza-Italy)

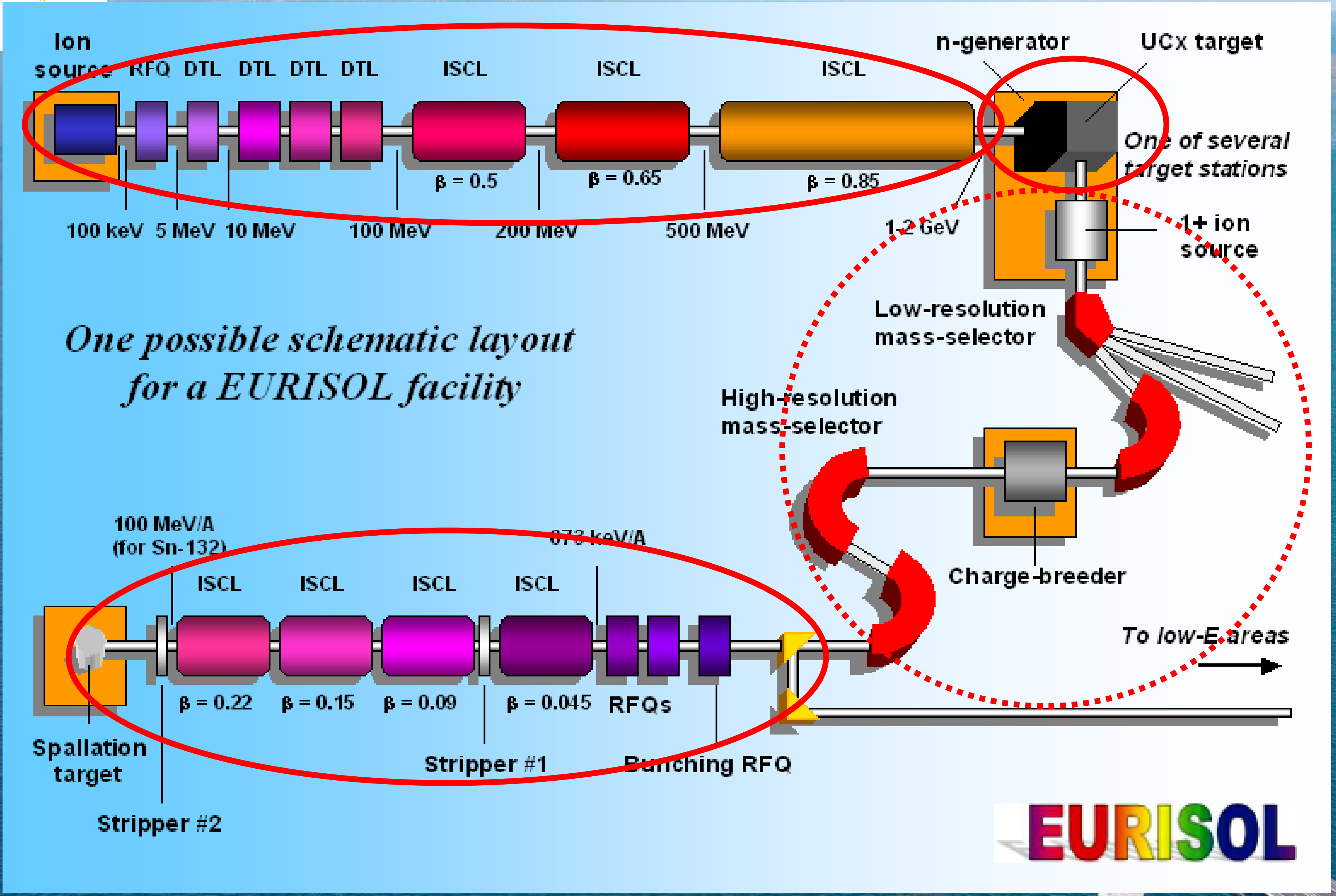
The IPHI and TRASCO projects, the Linac4 experience, the studies for SPES, the components prototyped for all these projects are a good starting point for the design of the Front-End of ESS.

R&D: Major improvement are related to the optimization of construction details and they are aimed to improve reliability and safety margins.

No major criticalities seem to endanger the ESS project in this part of the LINAC but the ability to run the machine with sufficient margins is strongly dependent on further improvements of the available know-how.

Front-End performances will define the LINAC performances.

Synergies for linac



Synergies for linac

Half-wave resonators

- Two prototypes @ 352 MHz (β 0.17 and β 0.31) fabricated and tested

Spoke resonators

- Two prototypes @ 352 MHz (β 0.15 and β 0.35) fabricated and tested.

ALL SUCCESFULLY TESTED !

Target

The Target is being studied in details to choose the safest, and most neutron optimized concept.

The concept choice is foreseen for end 2010

Several Institutes participate to the monthly meetings to prepare the target concept selection, including CRS4 in Sardegna (particularly involved in windowless target, due to their participation in ADS projects).

Target

- Design optimization of the ESS Long Pulse Target Station is driven by the following constraints:

1: Optimize neutron fluxes for all the instruments

2: Ambitious and realistic safety objectives during operation, maintenance and dismantling of the facility

3: Use of robust and qualified nuclear standards for the design and construction of the Target system

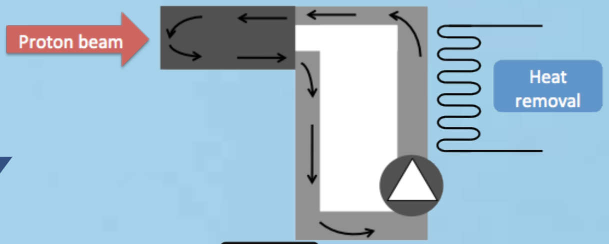
	Beam Power (MW)	Energy / pulse (kJ)	H. Beam size (m)	V. Beam size (m)	Local Collimator Power (MW)
Nominal	5	250	0.05	0.12	0.2
Upgrade	7.5	375	0.06	0.15	0.3

European Spallation Source

Target

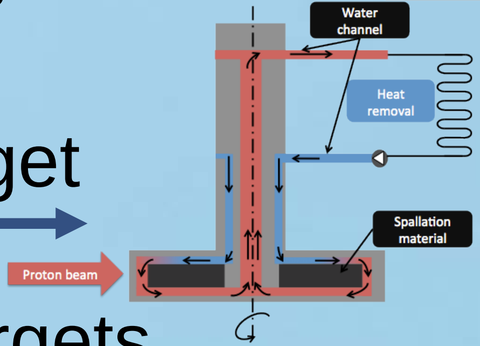
- There are several target concepts under study:

1: Mercury loops

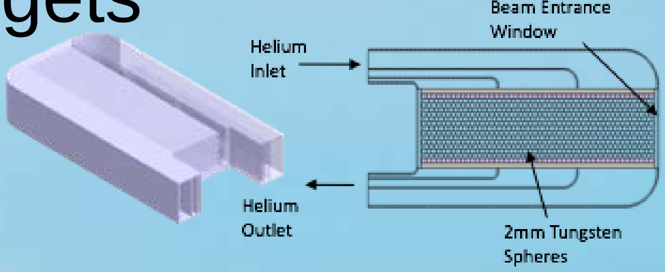


2: Lead and Lead alloys loops

3: Water cooled Tungsten target

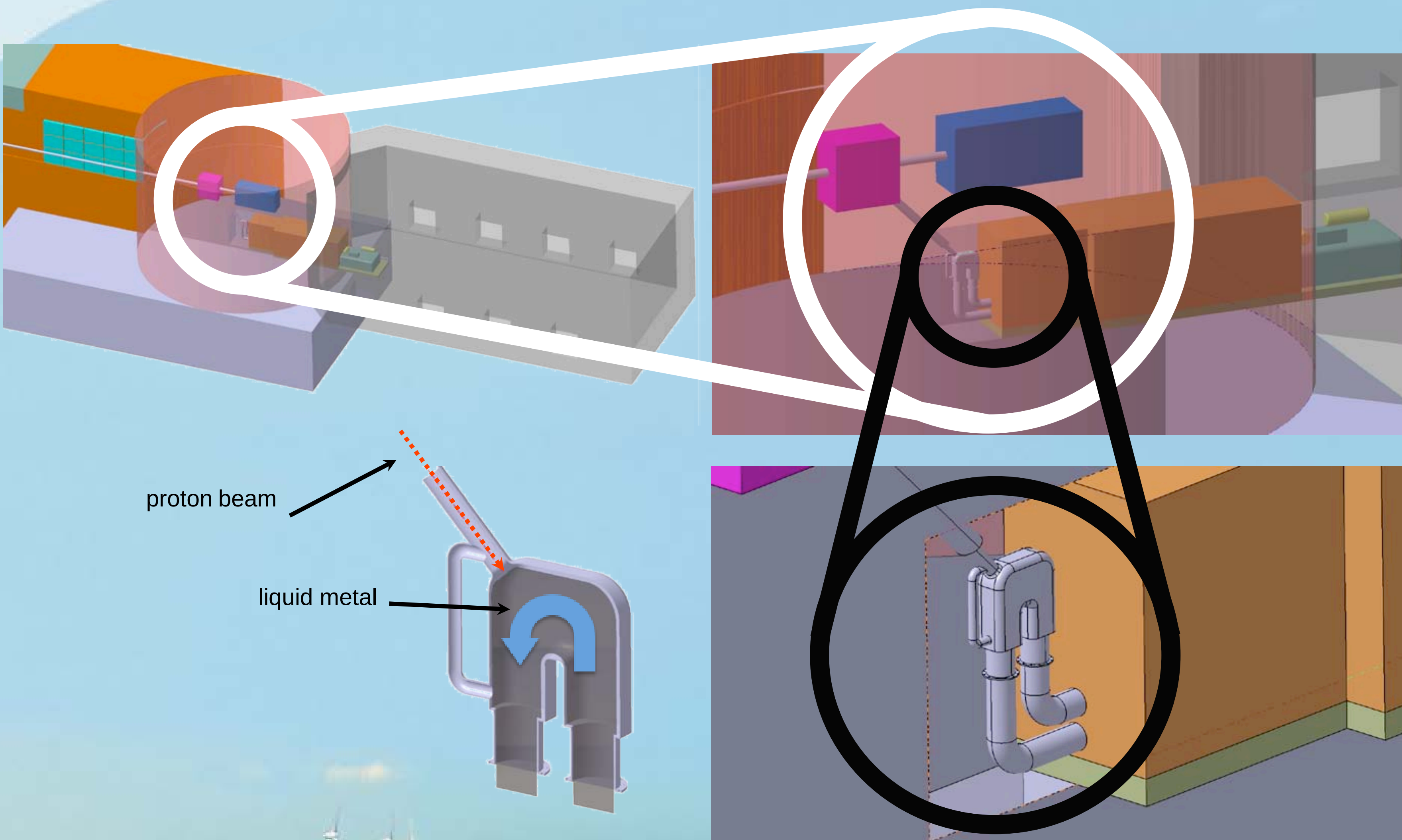


4: Helium cooled Tungsten targets

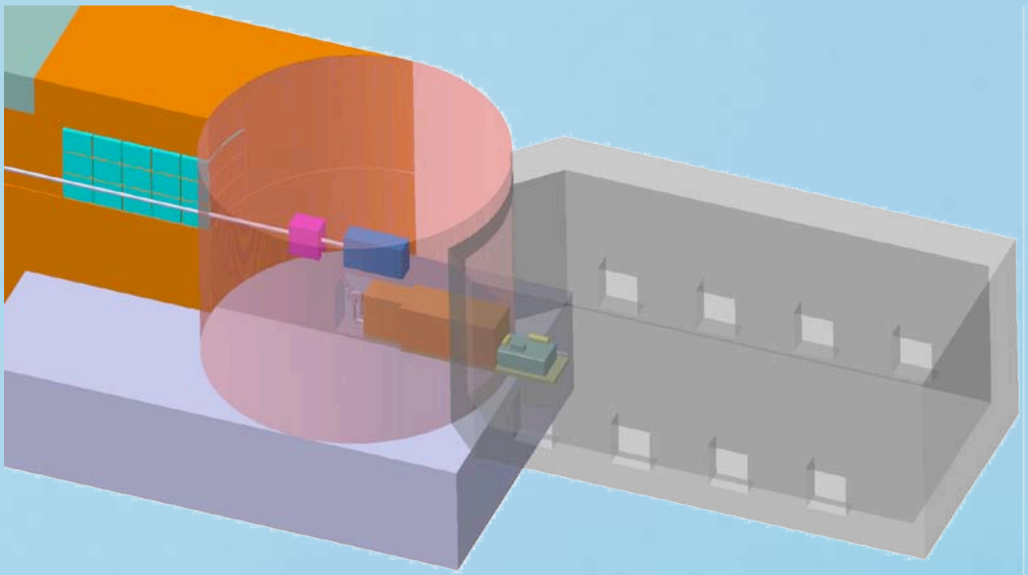


5: *Windowless* targets

Windowless Target



Alternative layout are also explored



Don’t ask me about: the contacts between ADU WG and target WG are rare.

Conclusions

The road towards the preparation of a detailed TDR is going to be completed.

The possibility to take into account future upgradings of the project at this early stage is to be evaluated, especially for what concerns the civil engineering design. Some areas should be overdimensioned and in this sense the area that will host the Front-End should take in consideration the possibility to modify the injector in future, e.g. with a more complex MEBT.

Warning: a fast definition of the partnership will make more effective the possibility to start the preparation of the TDR in due time.

Action: ESS management could finalize the definition of partnership, by catalyzing the different bilateral/multilateral contacts.

COMMENT: my impression is that it will be not so challenging to prepare a valuable TDR for the Accelerator in due time, unless there is an underestimation of the existing criticality (e.g. availability of budget/manpower in the right time, not too early, not too late, reliability issues, long-term operations).

Conclusions

The possible contribution of INFN groups will be defined according to government inputs, but it is clear that without additional resources, INFN engagement in the construction may not be significant.

The government declared to agree about a contribution, probably around 5% of the whole facility cost, but no official documents have been signed up to now.

In the course of the next weeks the contribution to the ADU will be defined (much smaller, evidently…), but it highly probable that no definition of in-kind contribution after 2013 will come out in the next future.

INFN contribution to ADU will regard at least 4 units: LNS (source&LEBT) as group leader, LNL (DTL Linac), Milano (elliptical cavities), Napoli (RFQ and DTL Linac). Other contributions may be considered, e.g. for targets studies.

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