Proton source and ESS front-end (ESS-WP6 report)

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ESS-SPL meeting- Lund – 2010/07/01

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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**
WU 2	**Source and LEBT**
WU 3	**RFQ**
WG 4	**MEBT**
WG 5	**NC Linac**

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Scientific Challenges

I. Starting point: actual state of the art

II. Critical design requirements

III. Scientific and technological step breakthroughs

Scientific Collaboration

ESS-Lund, CEA-IRFU, INFN-LNS, INFN-LNL, ESS-Bilbao….

ATOMKI and Uni-Frankfurt will be contacted soon

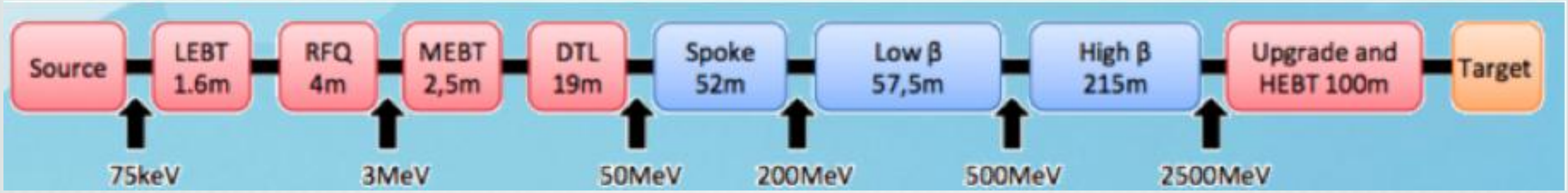
CERN expertise is particularly relevant for the NC Linac

Clear and obscure issues

Clear elements: the main requirements, the items that deserve additional R&D.

“Obscure” elements: partnership definition is quite complicated because of the workloads of involved research teams.

Strength points: for all the components of the Front-End until the warm-cold transition there is a sufficient/remarkable experience within the Institutions involved in ESS.



Ion Source & LEBT

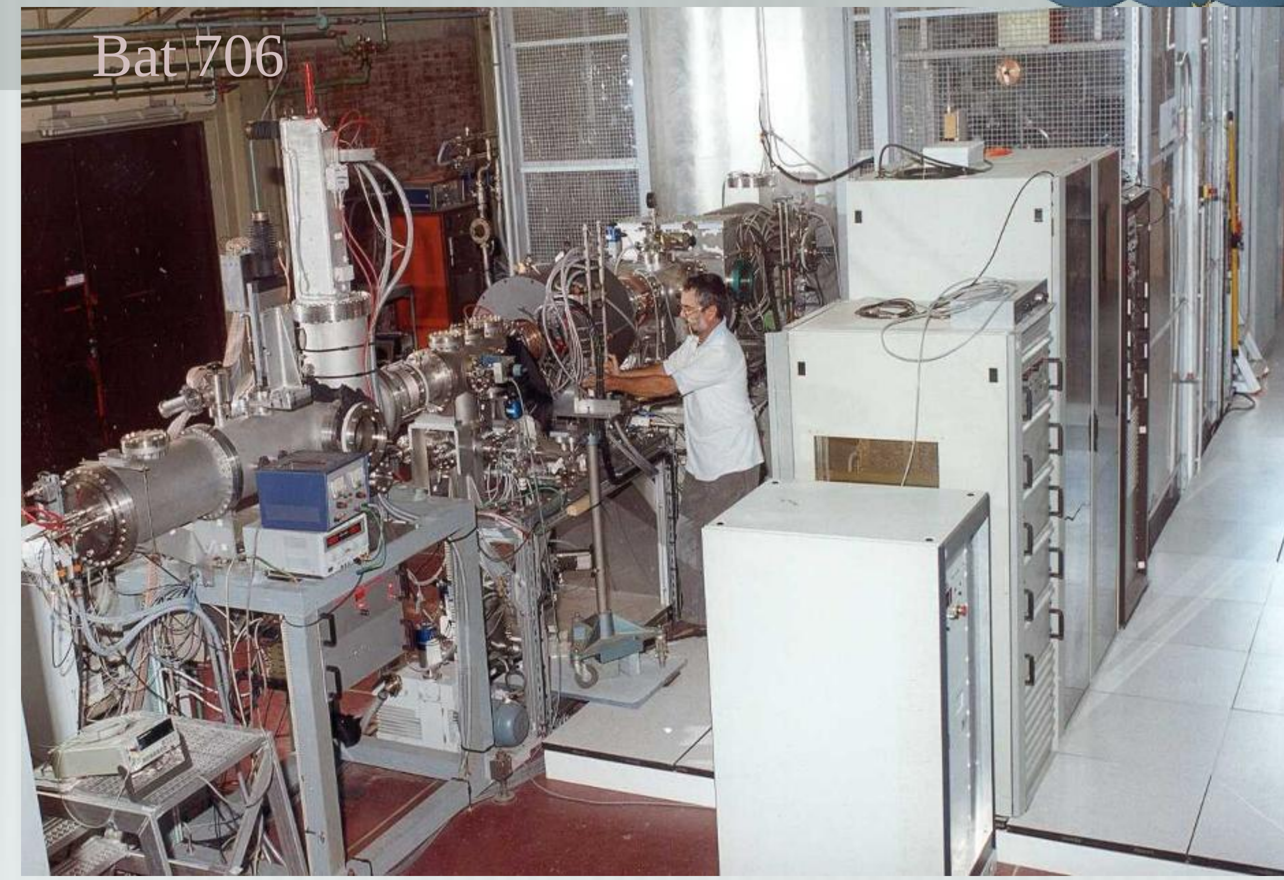
- INFN-LNS (Catania) and CEA-Saclay will contribute to the design of the injector part (the proton source and the LEBT) in close collaboration.
- The high current proton source will be based on the know-how acquired during the design phase and the construction phase and commissioning of the sources named 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 60/90 mA with a quite low emittance as required by the following RFQ.

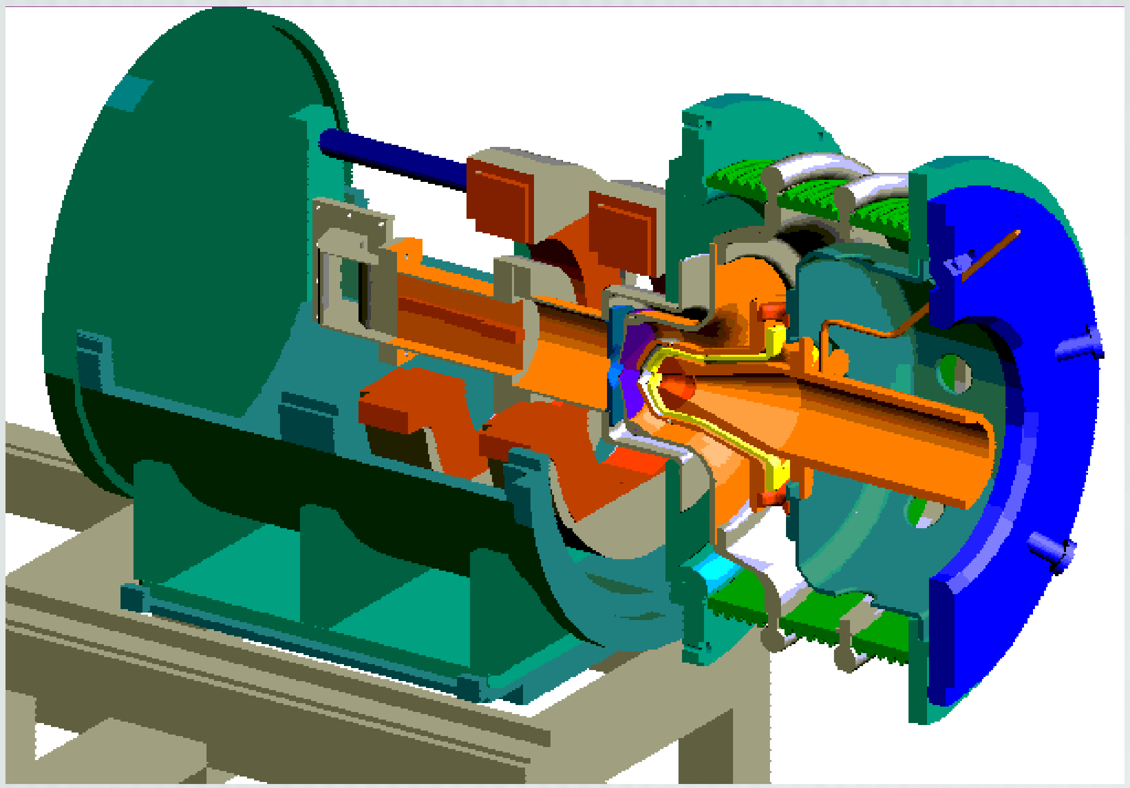
Scientific Challenges

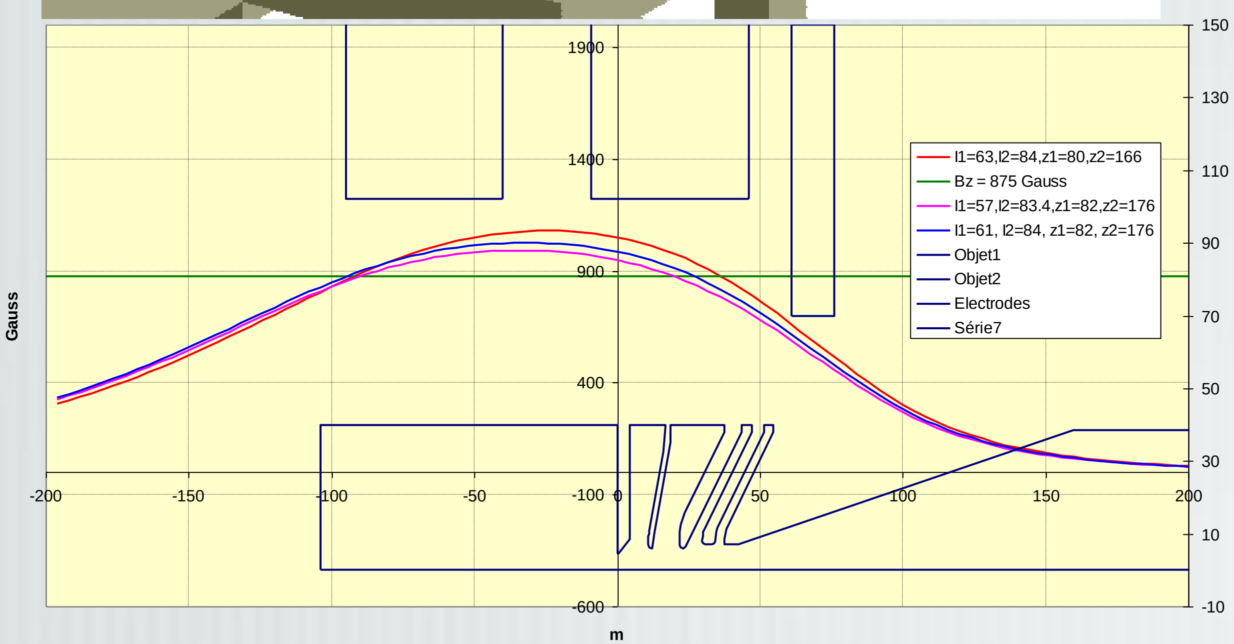
- Large currents (60-**90** mA)
- Low emittance (**0.2** to 0,3 π mm mrad)
- Long lifetime (>> 1 mo.)
- High reliability (> 99%)
- Pulsed operation (**2 ms- 20 Hz**)
- Short pulse rise time (100 ns)
- Robust extraction system
- LEBT optimization (know-how available)

SILHI source and LEBT

SILHI operates at 2.45 or 3 GHz







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

H+ $_{\text{Intensity}}$ > 100 mA at 95 keV

H+ fraction > 80 %

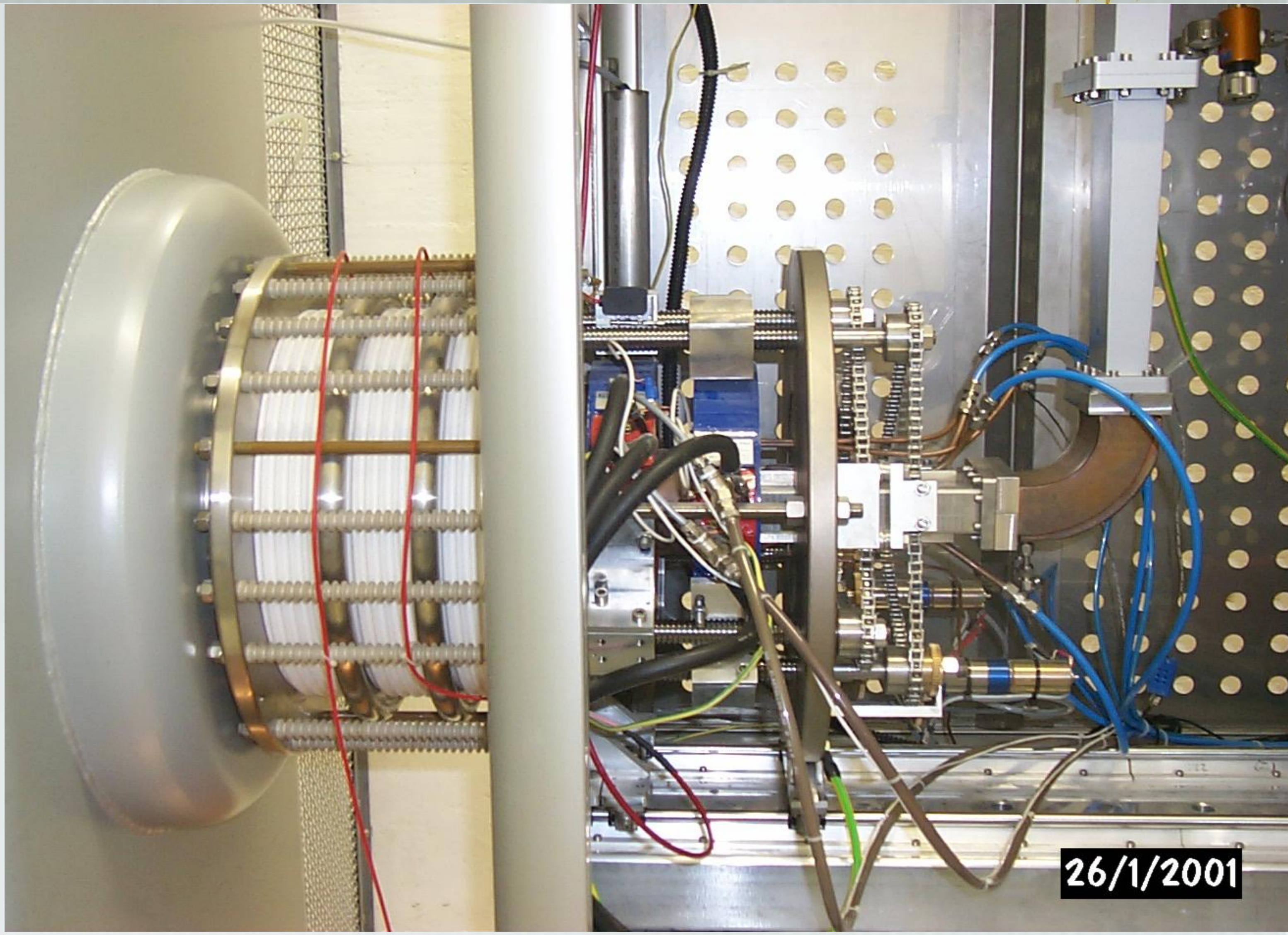
Beam noise < 2%

95 % < Reliability < 99.9 %

Emittance < 0.2 π mm.mrad

CW or pulsed mode

TRASCO INTENSE PROTON SOURCE (TRIPS)



Beam energy 80 keV

Current up to 60 mA

Proton fraction > 80%

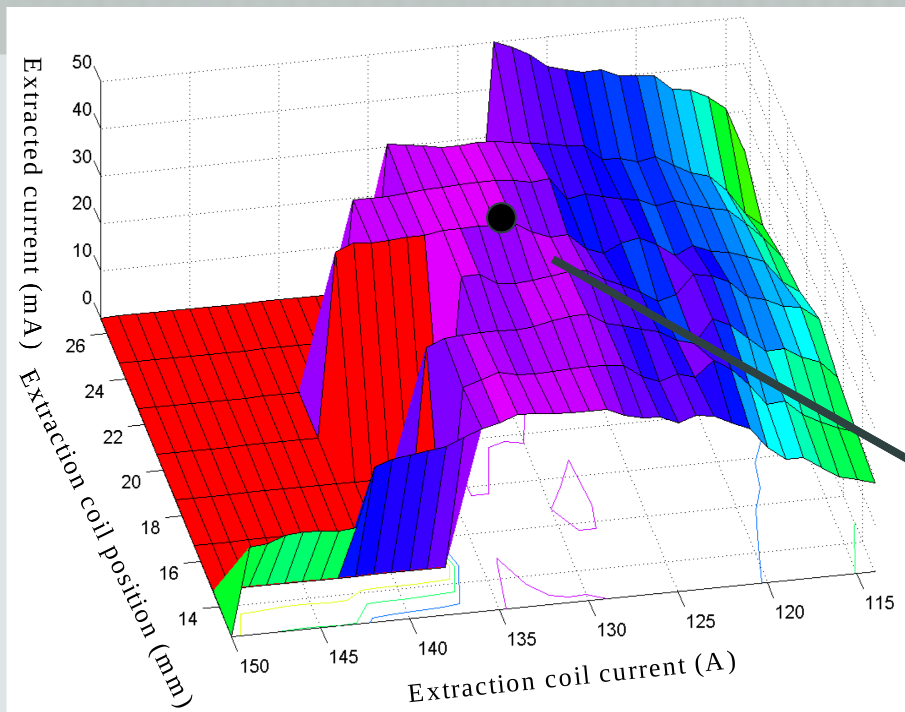
RF power < 1 kW @ 2.45 GHz

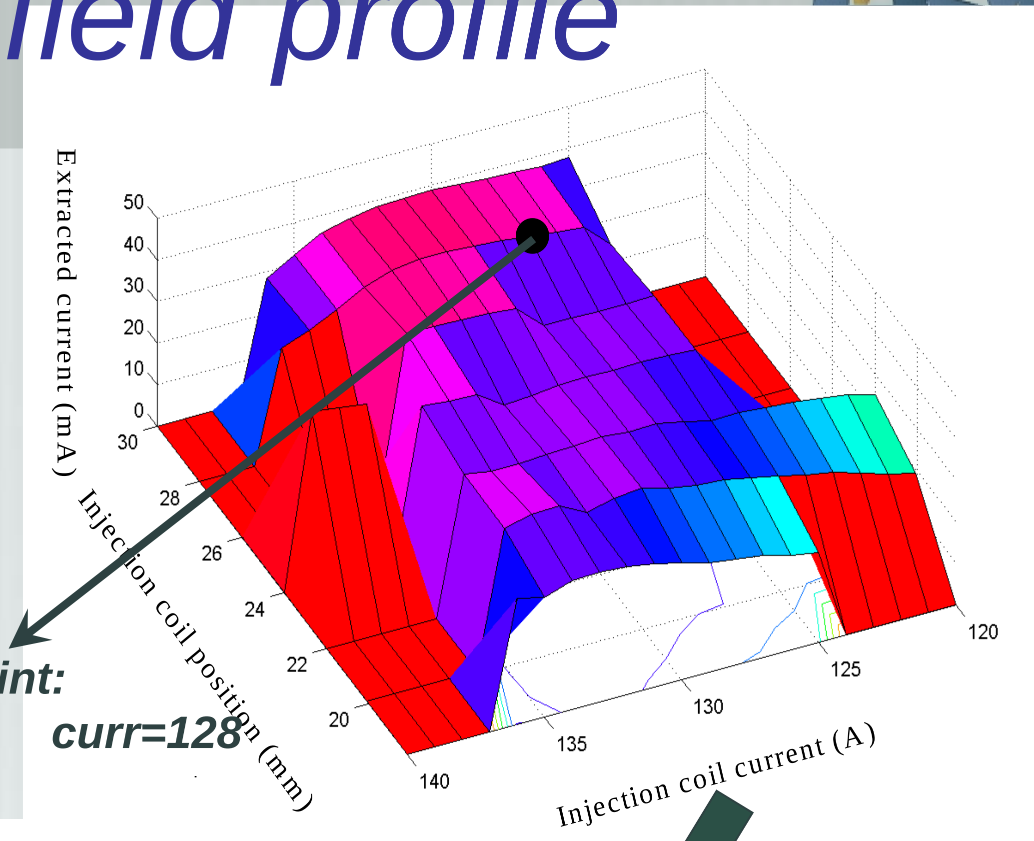
CW mode

Reliability 99.8% over 142 h (35 mA)

Emittance 0.07 π mm mrad (32 mA), 0.15 to 0.25 at max current

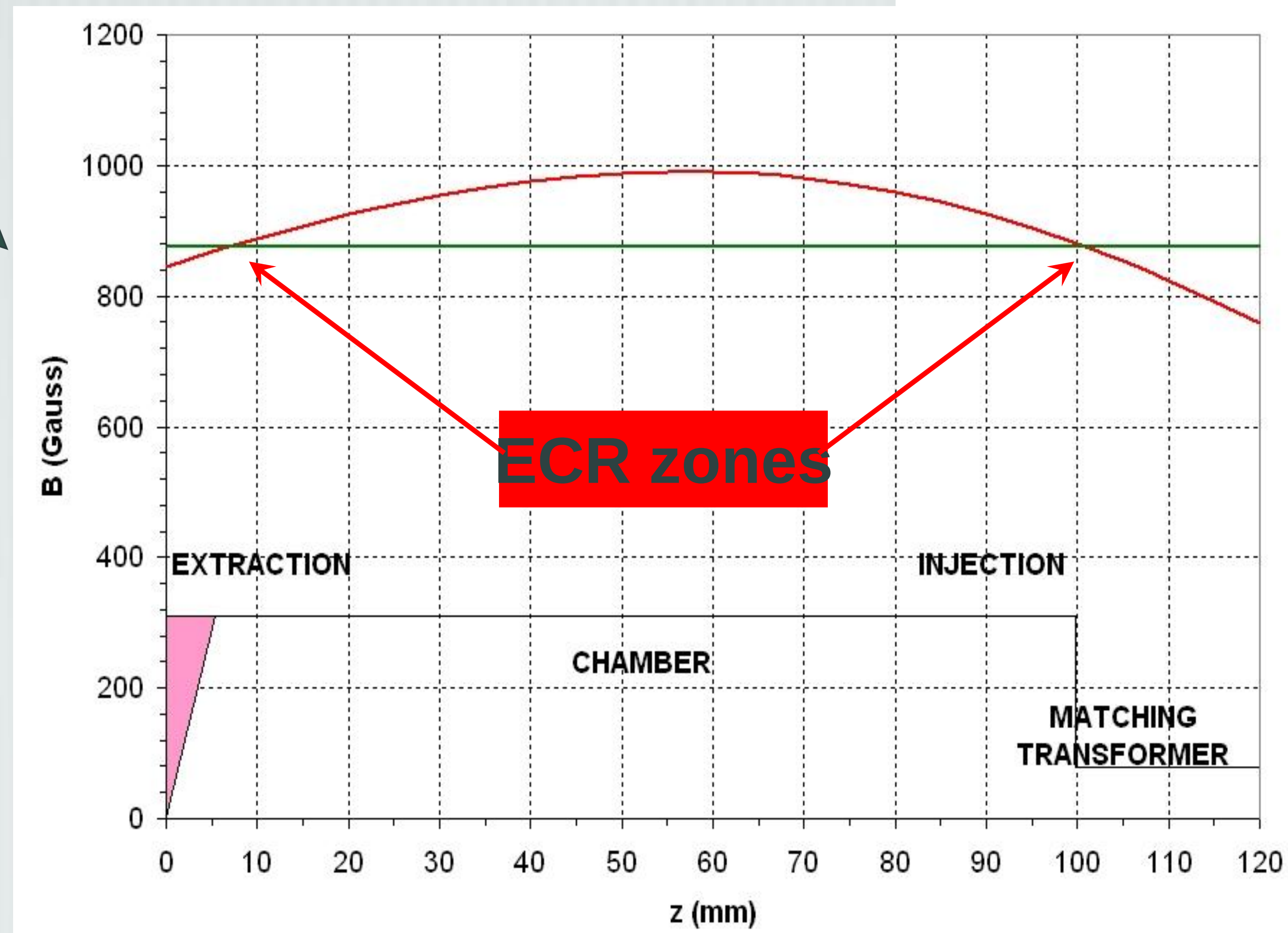
Optimum magnetic field profile



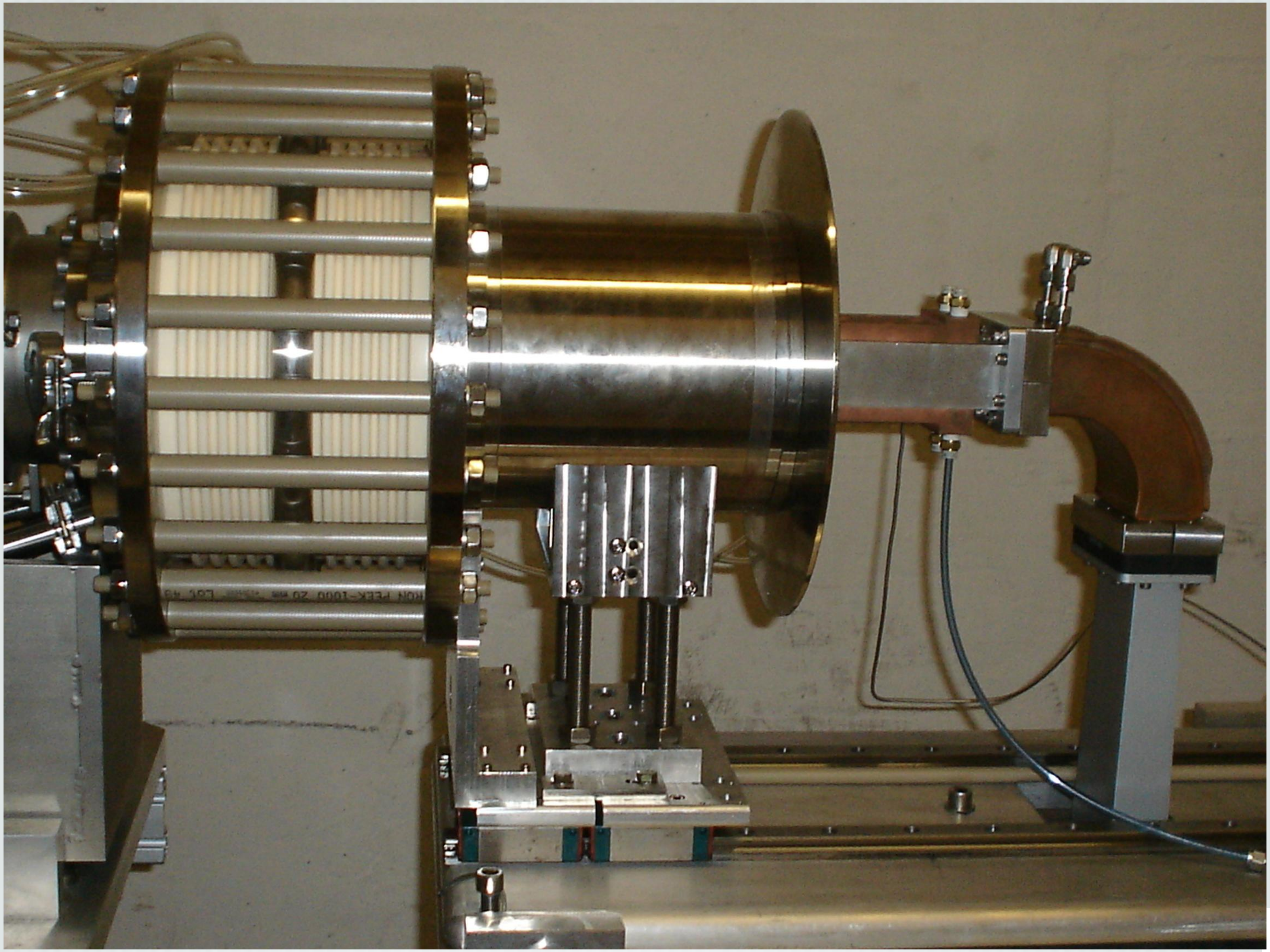


Best operational point:

Extraction coil: pos= 22 mm curr=128 A



Versatile Ion Source (2008)



Proton source and LEBT

- A new design of the magnetic field profile is considered as a possible option (in order to get a denser plasma → HELIOS programme at INFN) and the microwave injection system will be deeply revised according to the recent experience gained with the VIS source. New ideas to enhance the electric field in the plasma chamber will be tested in order to get highest ionization rates.

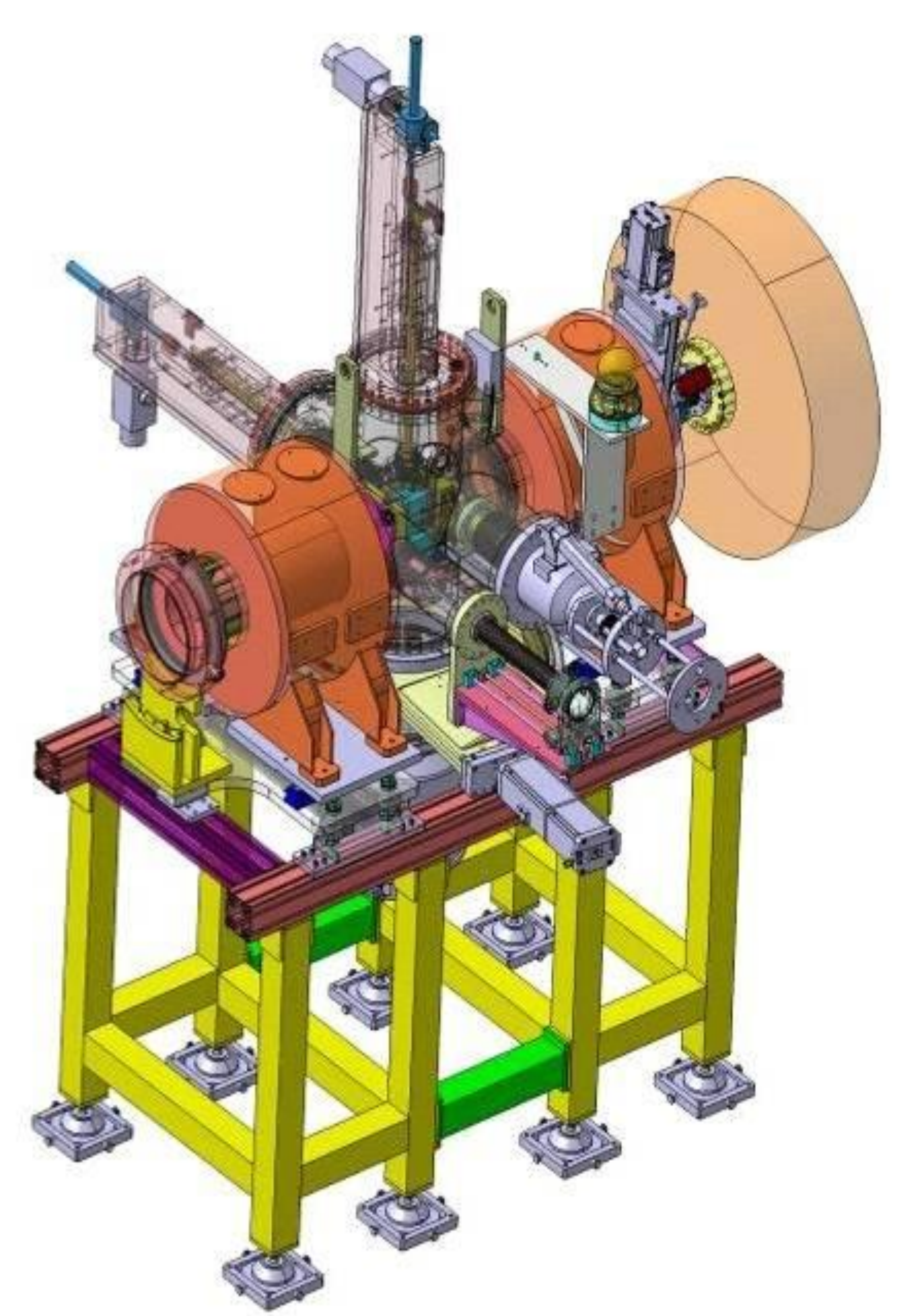
- Further studies about brightness optimization are mandatory, which can be carried out either at CEA and at INFN-LNS.

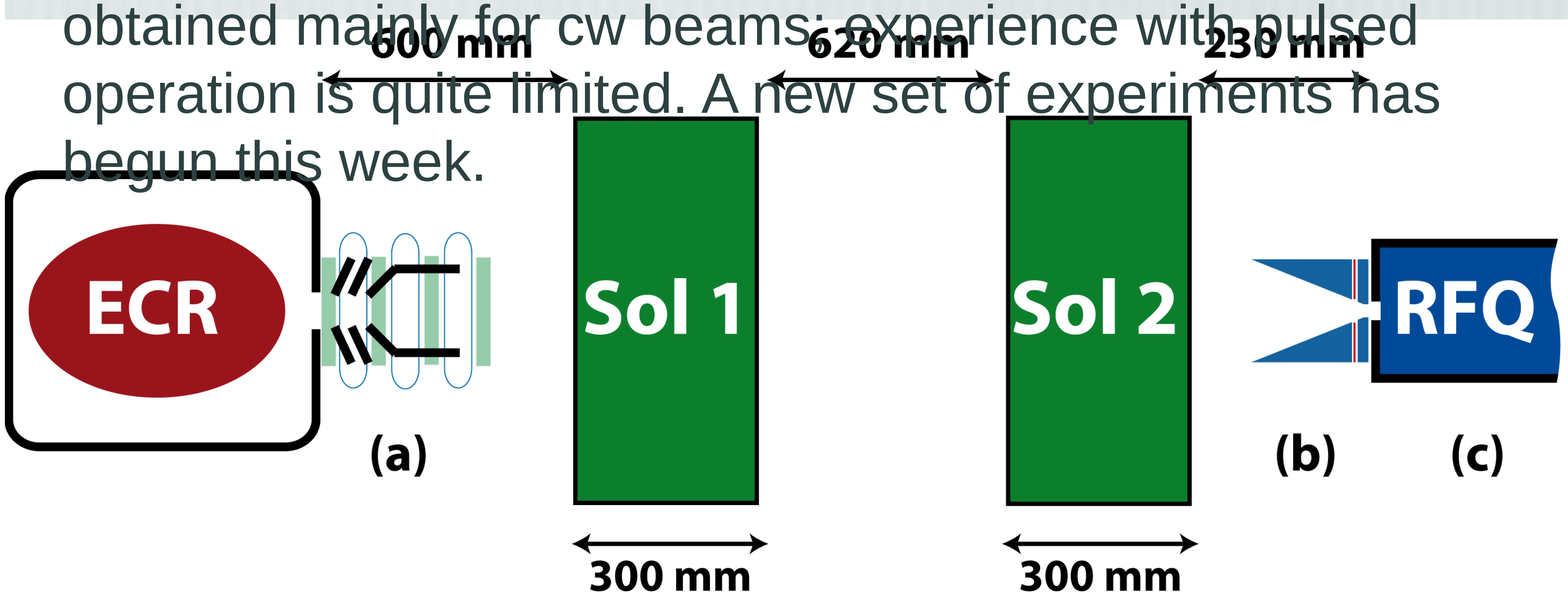
- The LEBT from the source extractor to the RFQ entrance must take into account different and competitive requests as it should be the shortest as possible and it should permit to allocate the necessary diagnostics and the low energy chopper.

Proton source and LEBT

We have to manage a low energy beam with a power of about 5 kW and to guarantee an optimum matching with the RFQ. A remarkable R&D is available from the studies carried out at Saclay, in particular some of the considerations which are valid for the IFMIF project may be exported for ESS Linac LEBT.

Weakness: reliability and brightness optimization have been obtained mainly for cw beams; experience with pulsed operation is quite limited. A new set of experiments has begun this week.





Total Beam Line Length : 2.050 m

IFMIF Beamline

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

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), **DTLs** (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

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

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

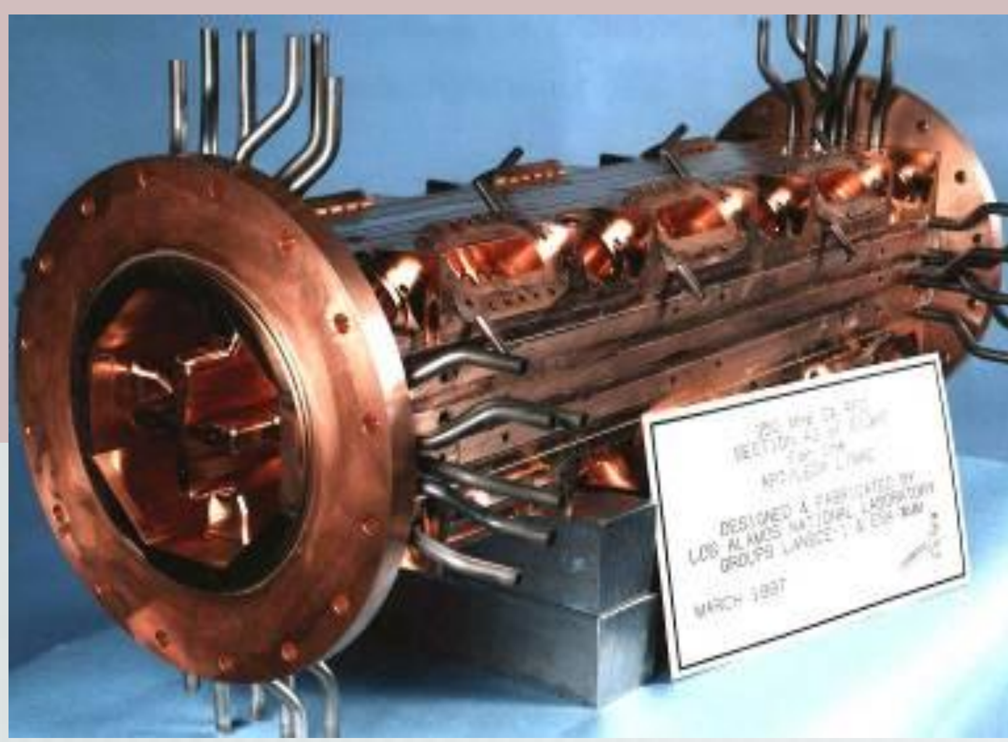
RFQ Nightmares…

- 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.

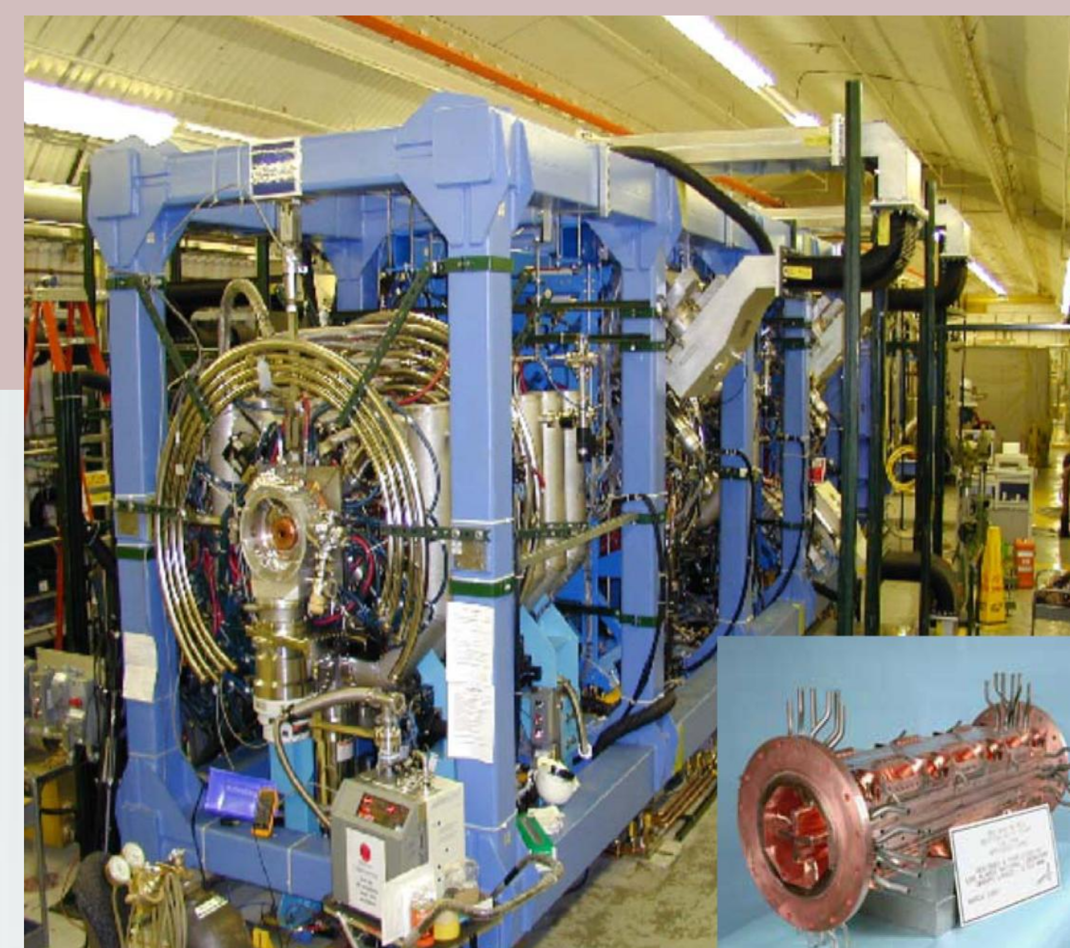
RFQs general parameters

	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	operate
	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*

LEDA



Technology established.
Beam performances reached
About 110 hrs of operating above 90 mA
cw



Research Programs in Europe related to ADS studies

	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	operate
	IFMIF EVEDA	**LNL**	**d**	**2.5**	**79-132**	**130**	**650**	**585**	**175**	**9.8**	**5.7**	**1.8**	**3.5**	**30**	**NO**
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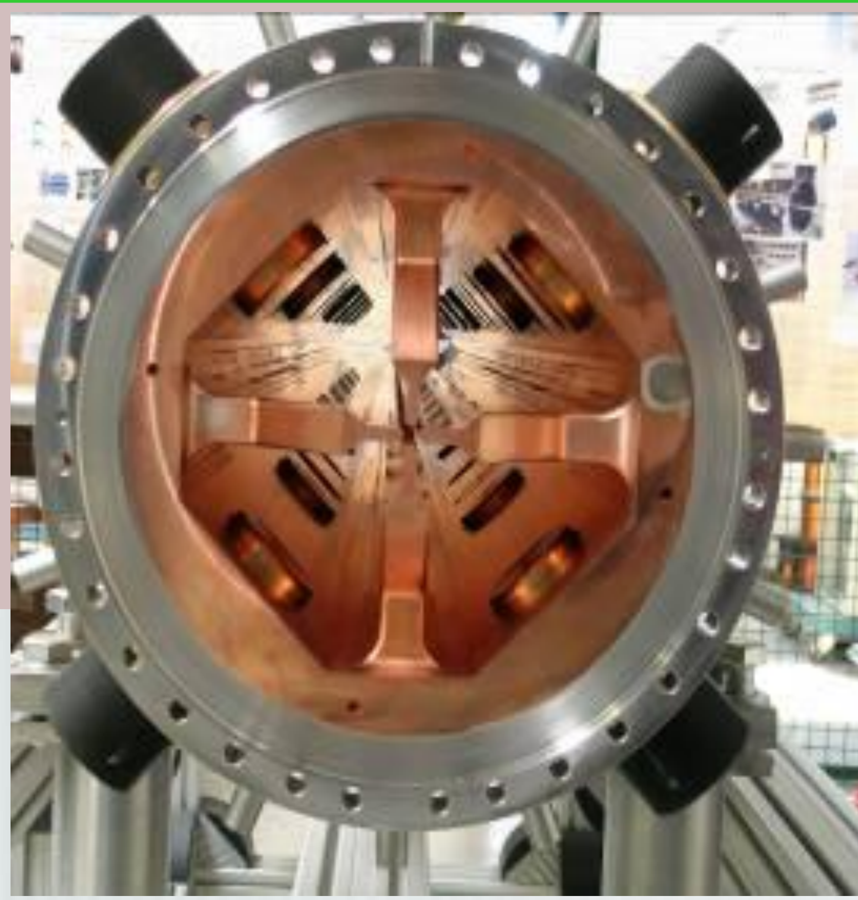
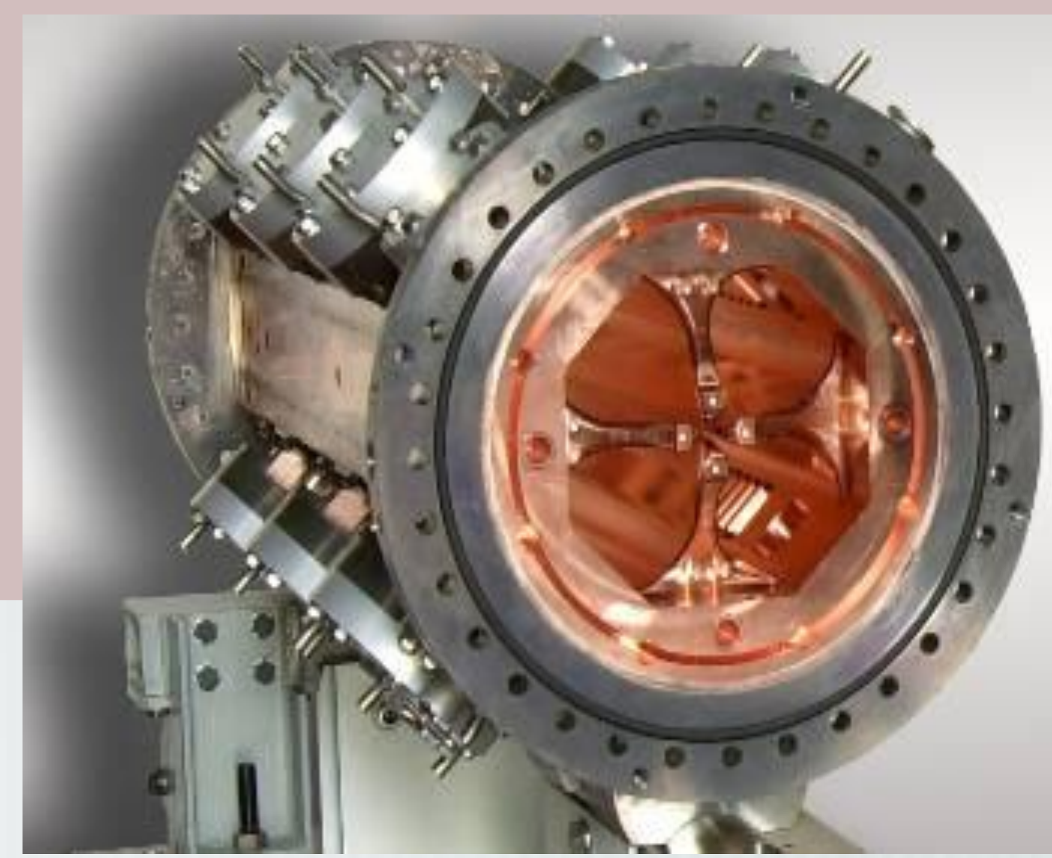
	CERN linac 3	LNL	A/q=8.3	0.25	70	0.08	0.04	300	101	2.5	0.8	1.9			*YES*
CW	LEDA	LANL	p	6.7	67-117	100	670	1450	350	8	9.3	1.8	11.4	65	*YES*
	FMIT	LANL	d	2	185	100	193	407	80	4	1.0	1	0.4		*YES*
high p	IPHI	CEA	p	3	87-123	100	300	750	352	6	7.0	1.7	15	120	*NO*
	TRASCO	LNL	p	5	68	30	150	847	352	7.3	8.6	1.8	6.6	90	*NO*



TRASCO@LegnaroINFN



IPHI@Saclay.CEA

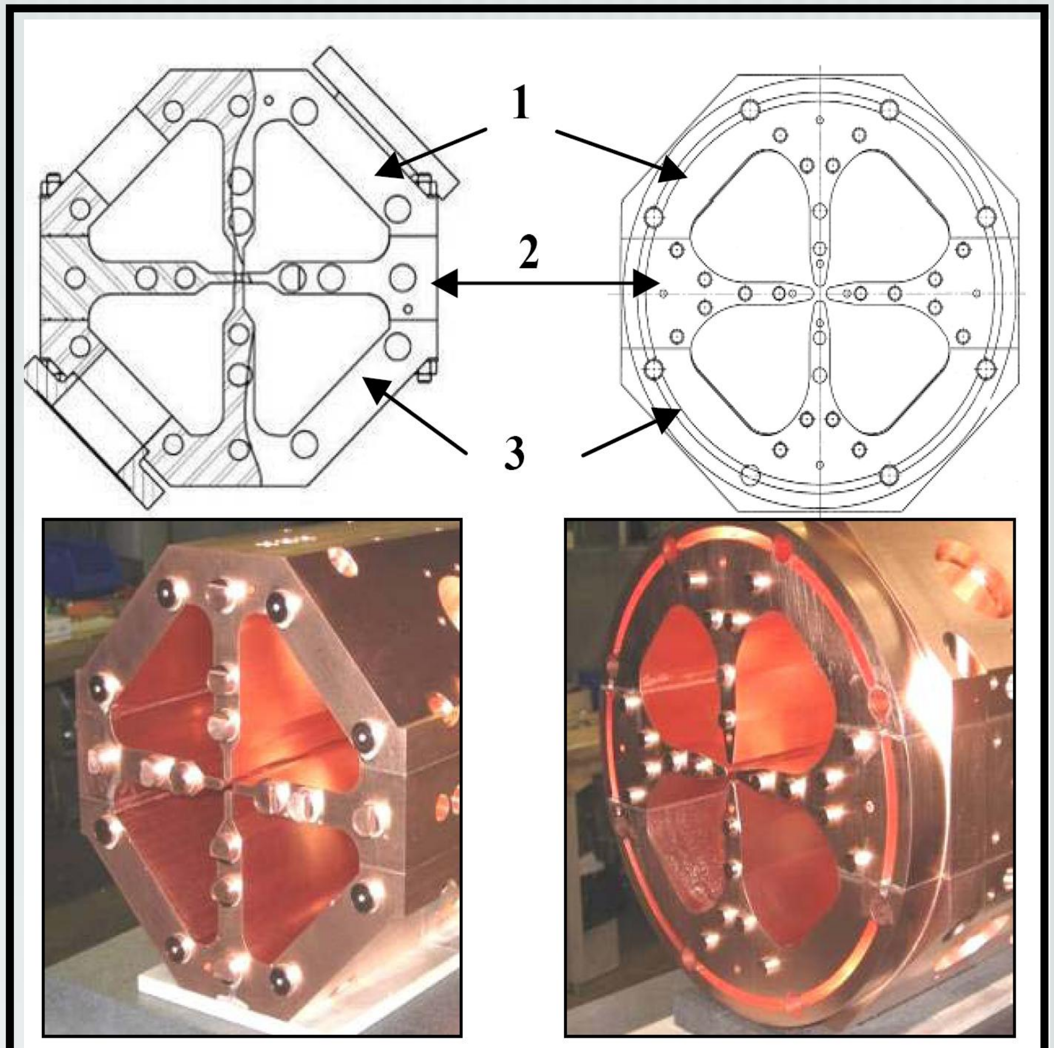
IPHI and TRASCO RFQ

- 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



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

arm tuning).

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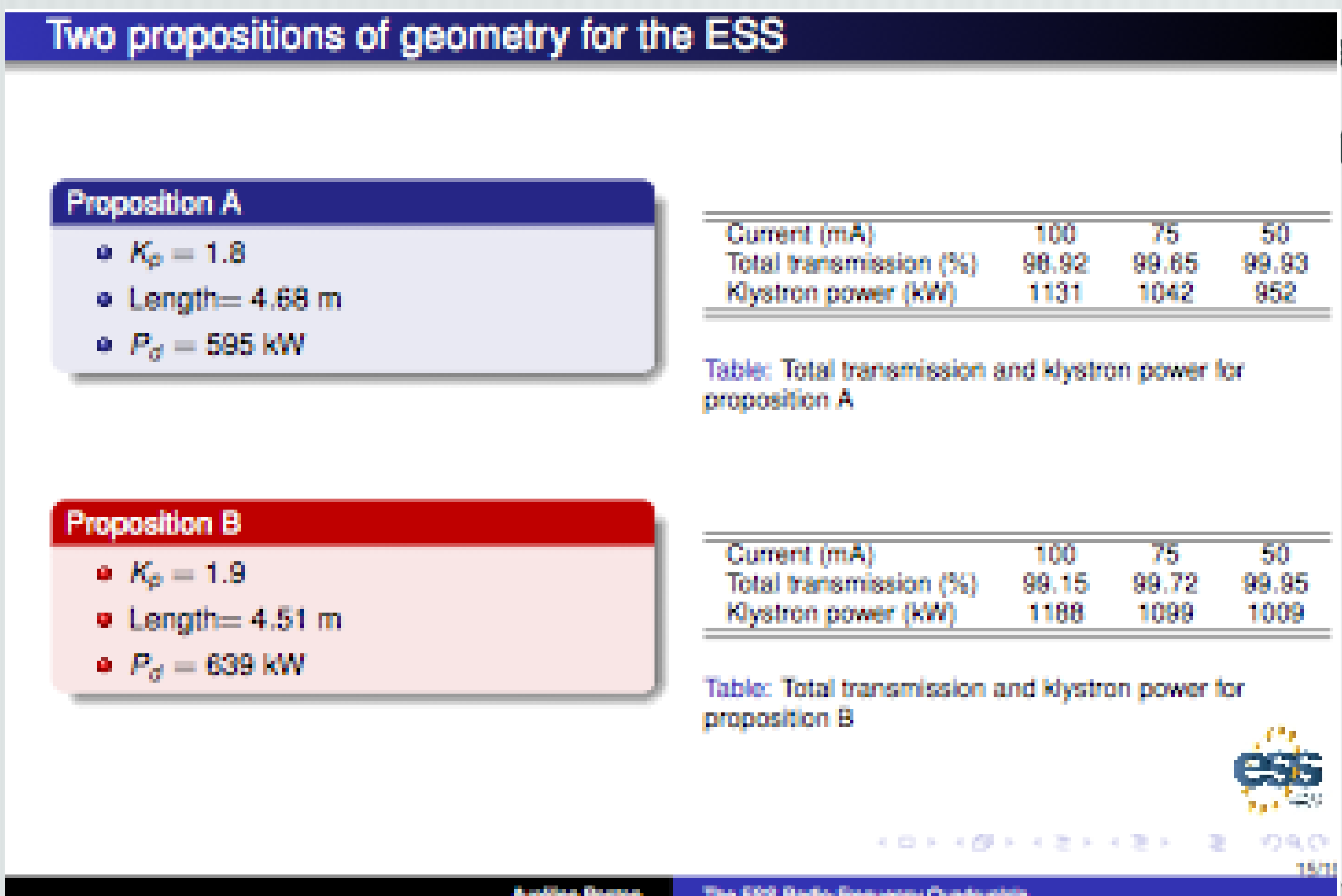


Two propositions of geometry for the ESS

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

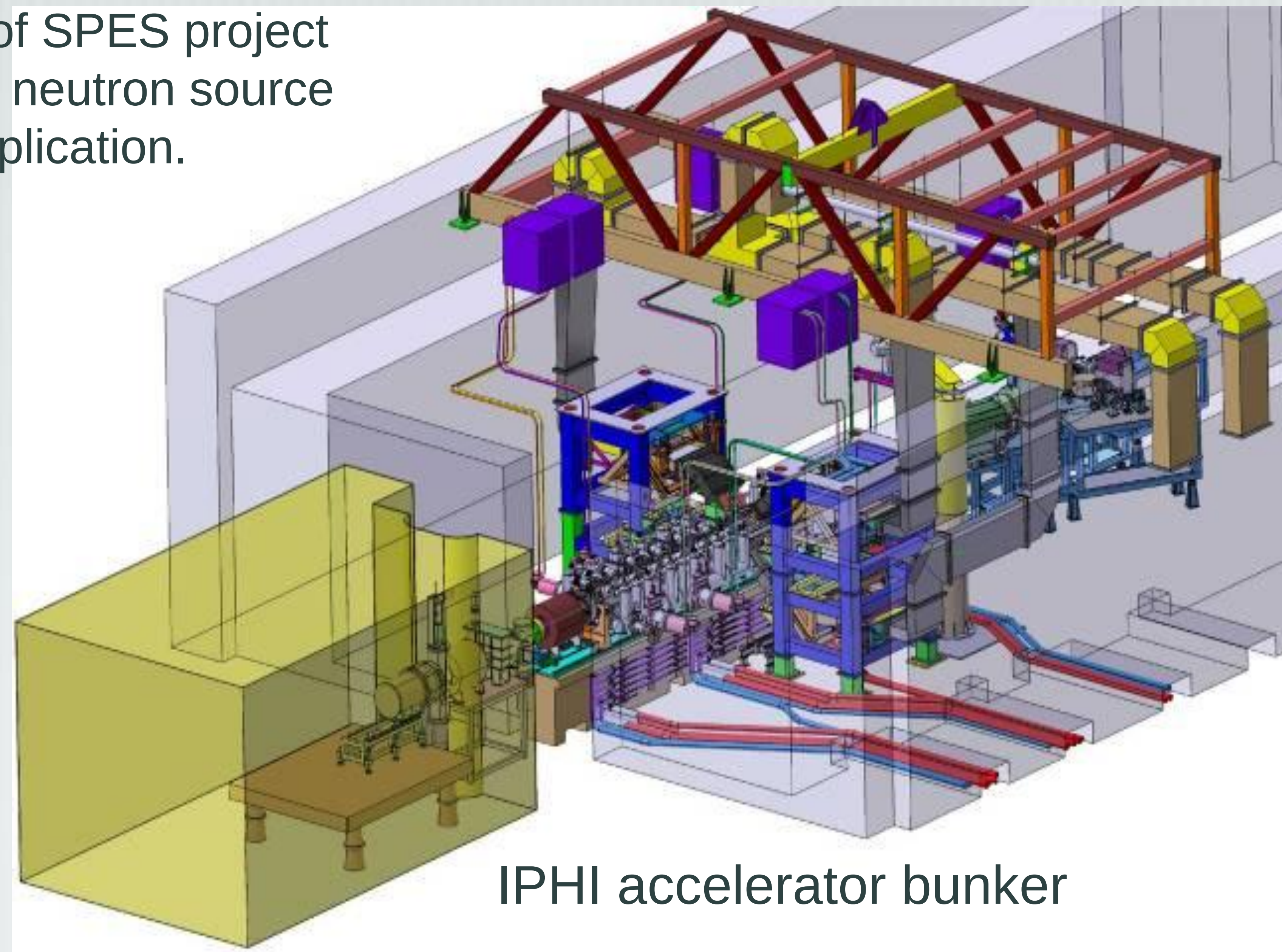
Table: Total transmission and klystron power for proposition B

Aurélien Ponton | The ESS Radio-Frequency Quadrupole | 15/11

Status of infrastructures

IPHI site at Saclay is ready (with the ion source tested, two LEP klystrons installed, the cooling system ready

The building for TRASCO RFQ has been recently designed as part of SPES project and should be funded as a neutron source mainly for BNCT application.



IPHI accelerator bunker

IPHI RF system

IPHI's RFQ contribution to ESS'RFQ design

- To validate the theory of RF adjustement with operation

  Adjustement of position's slugs according to fabrication's errors

  Relation between frequency and temperature

- To study the stability of the tension law according to the temperature
- To analyse the behavior of automatic control during the conditioning
- To study the effect of RF window, tuners, ….
- To study the thermic reaction with many pick up

  Effect on the tension law → Effect on particles' dynamics

- To do a long run to see:

  Stability of beam energy :

  Stability of resonance spectrum

  Stability of the tension law

  Stability of vacuum pressure :

  To verify the appropriate surface treatment

  To verify the pumping design

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

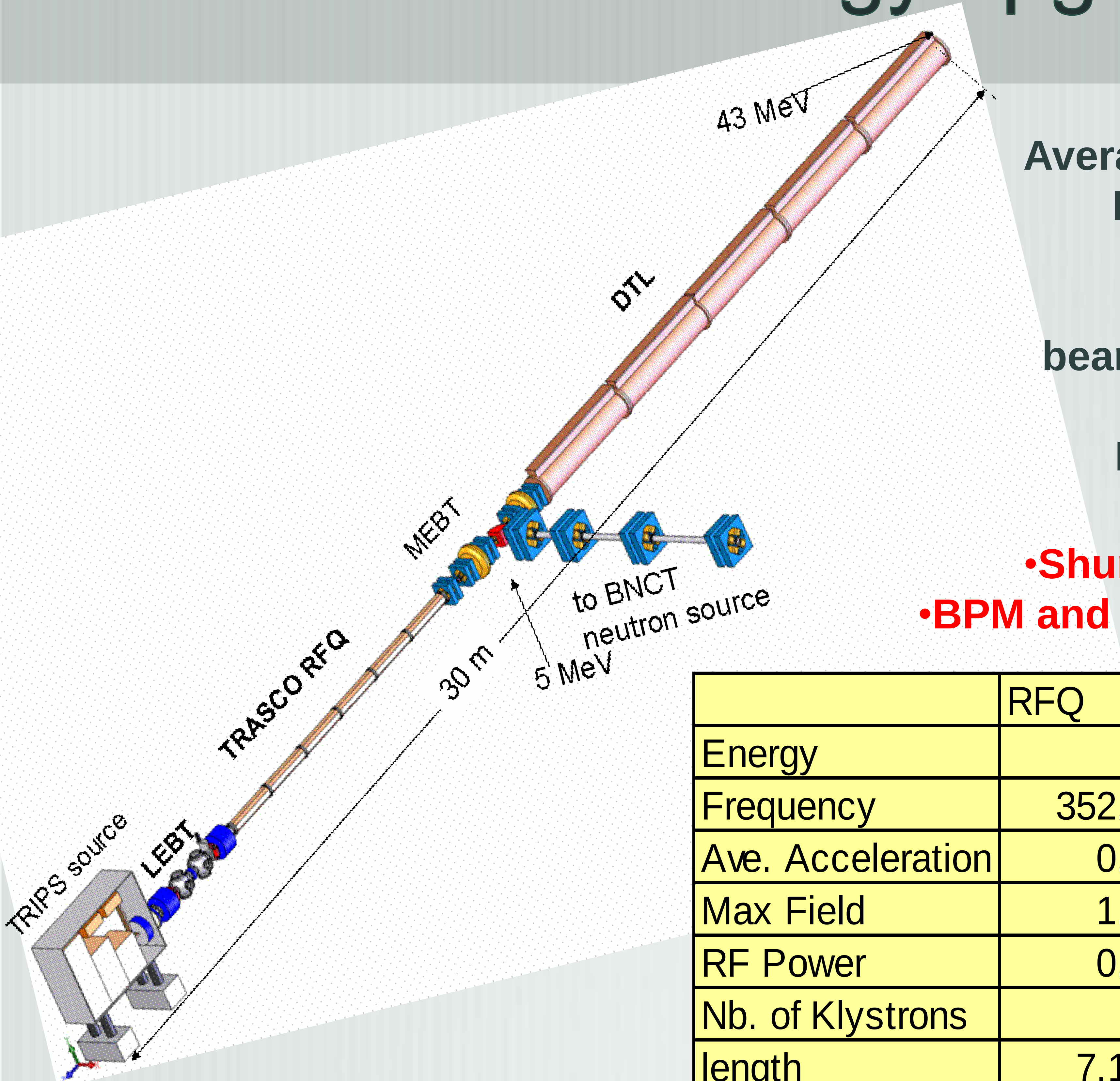
As for this part, INFN-LNL team has already designed an accelerator with similar performances and has prototyped with Italian industry, together with CERN Linac4 team, a common prototype tank approximately 1 m long (prototype for Linac4 and SPES driver).

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

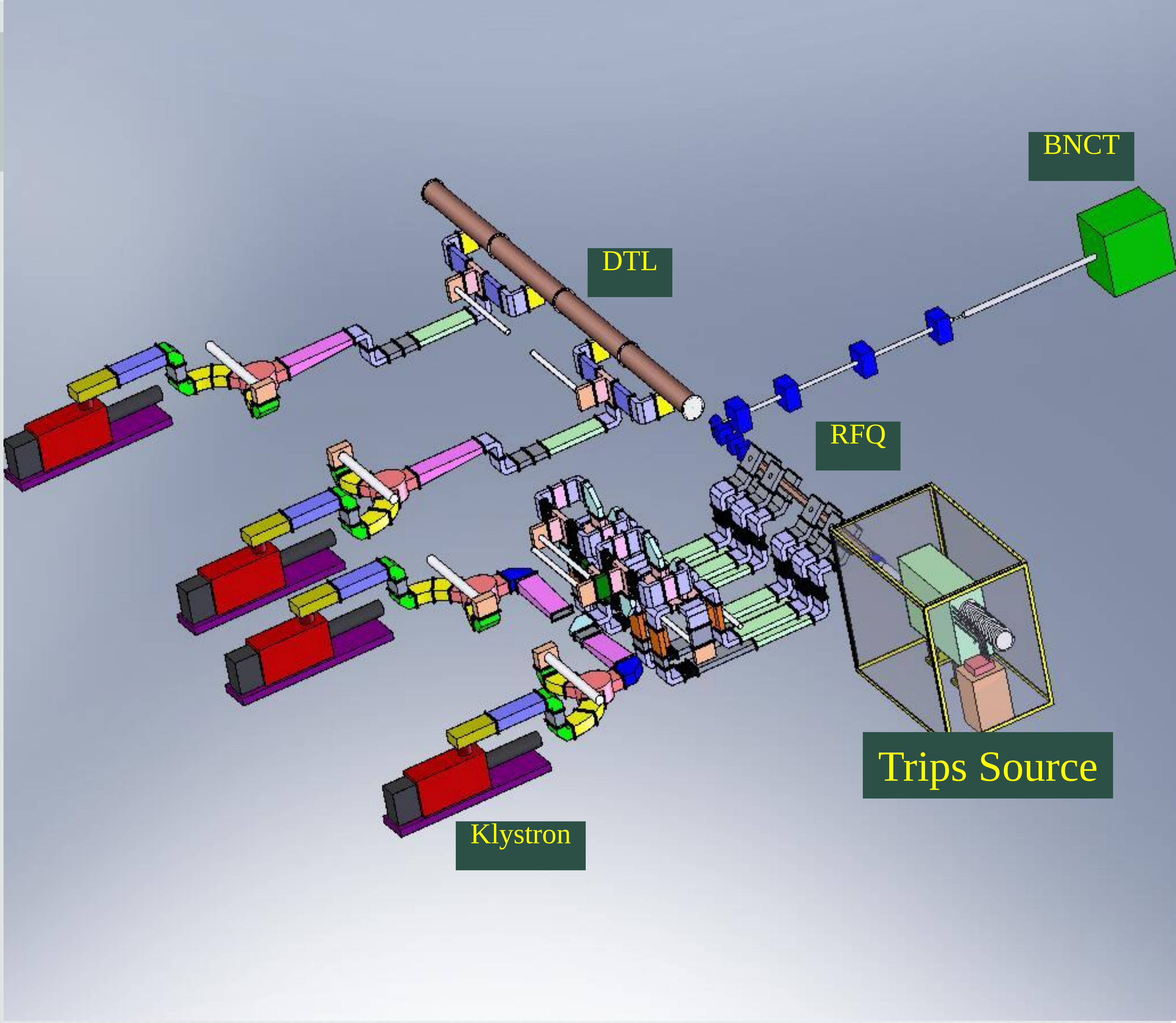
Driver linac-energy upgrades



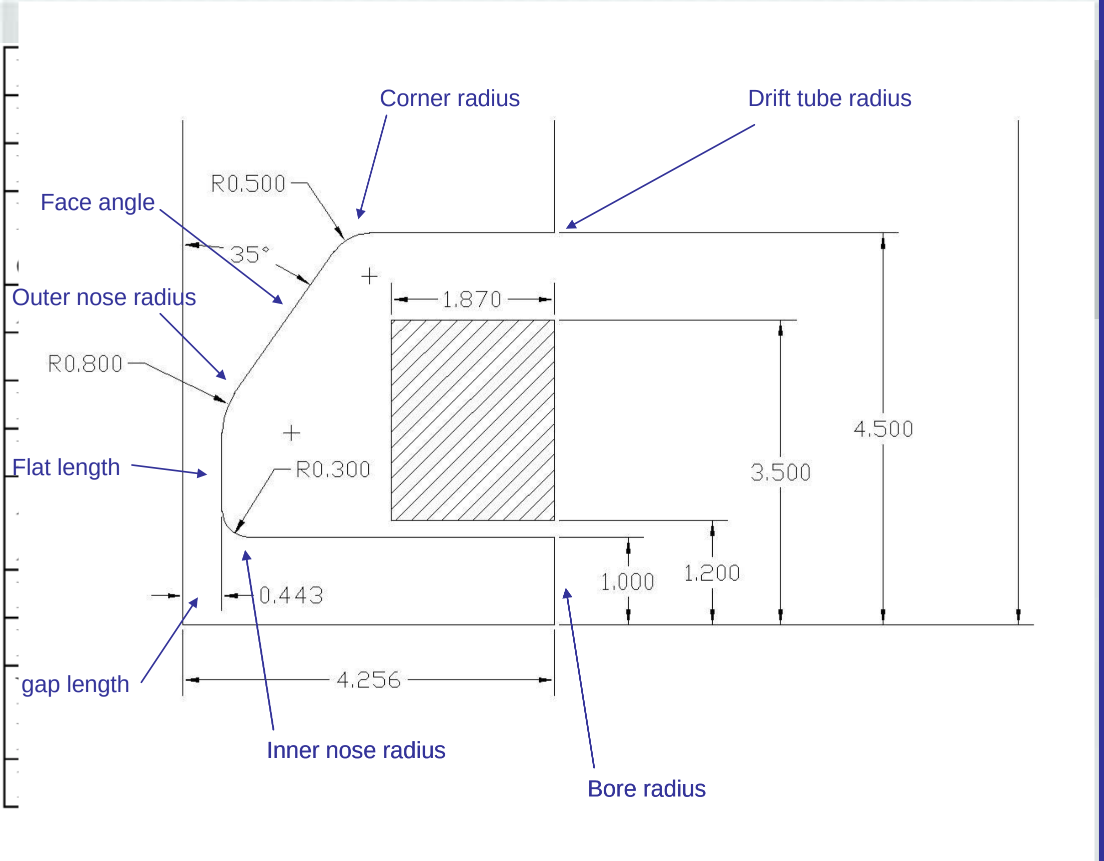
Beam energy: ~43 MeV
Average beam current : up to 1.5 mA
Beam pulse length 0.600 ms
Repetition rate 50 Hz
RF frequency: 352.2 MHz
beam emittance (transv. Norm RMS <0.4 mmmrad)
Possible upgrade to 95 MeV

- **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)



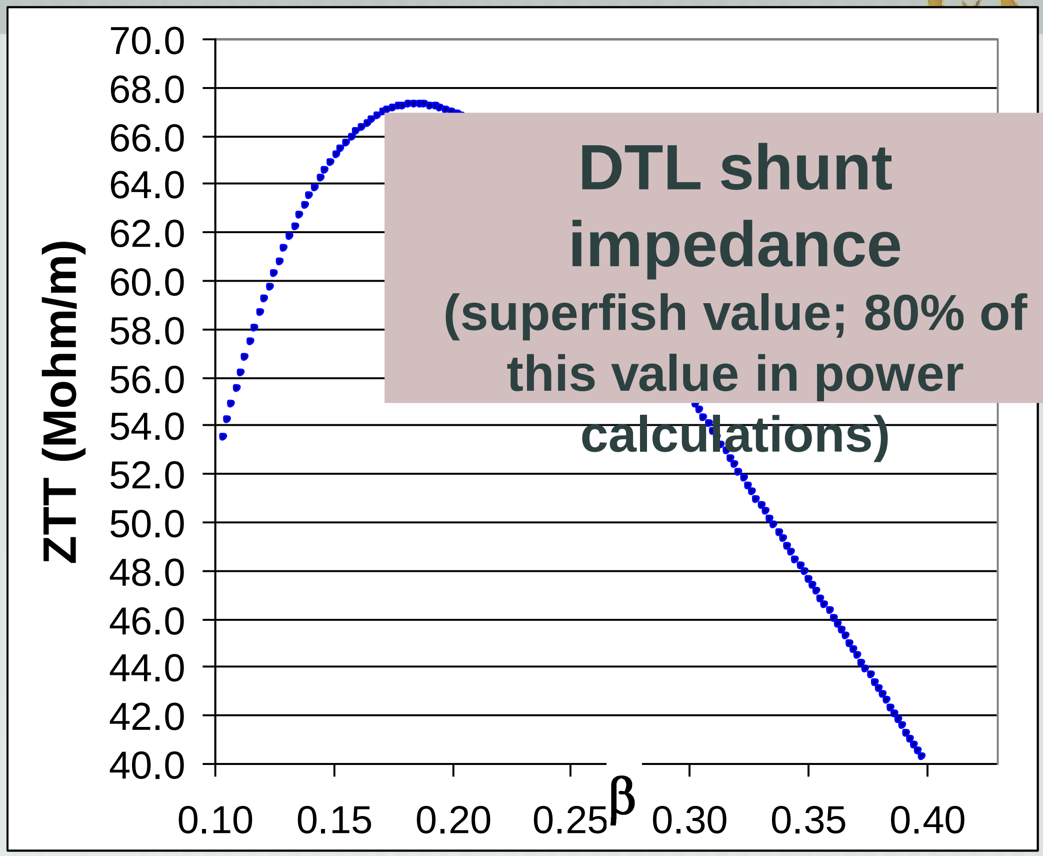
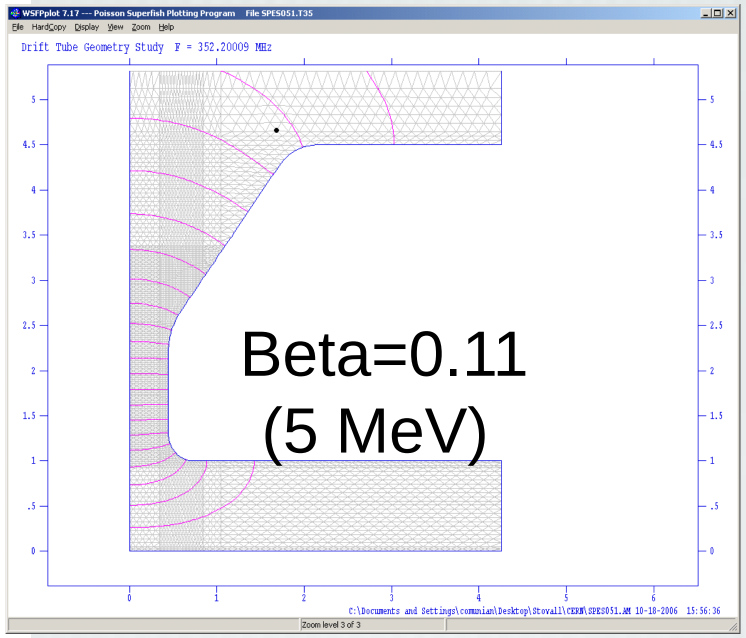
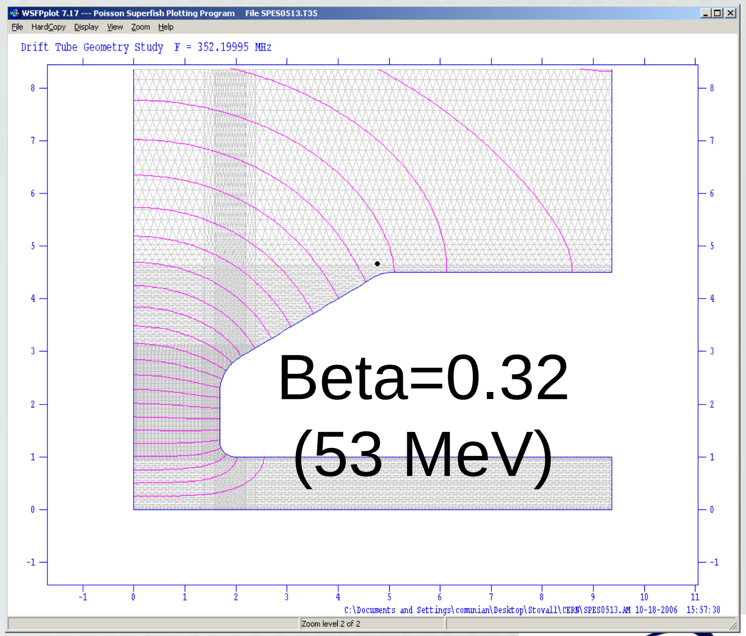
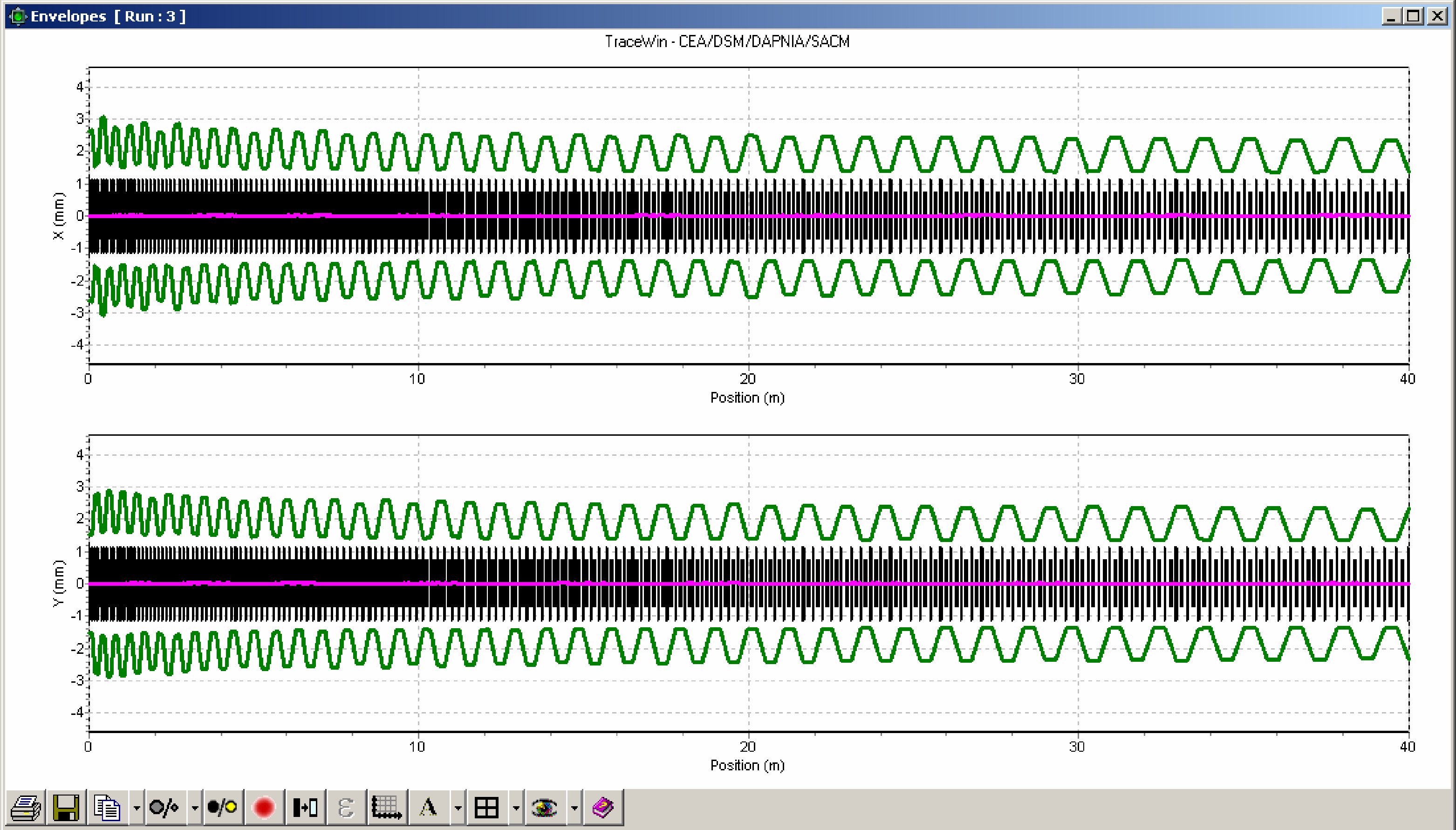


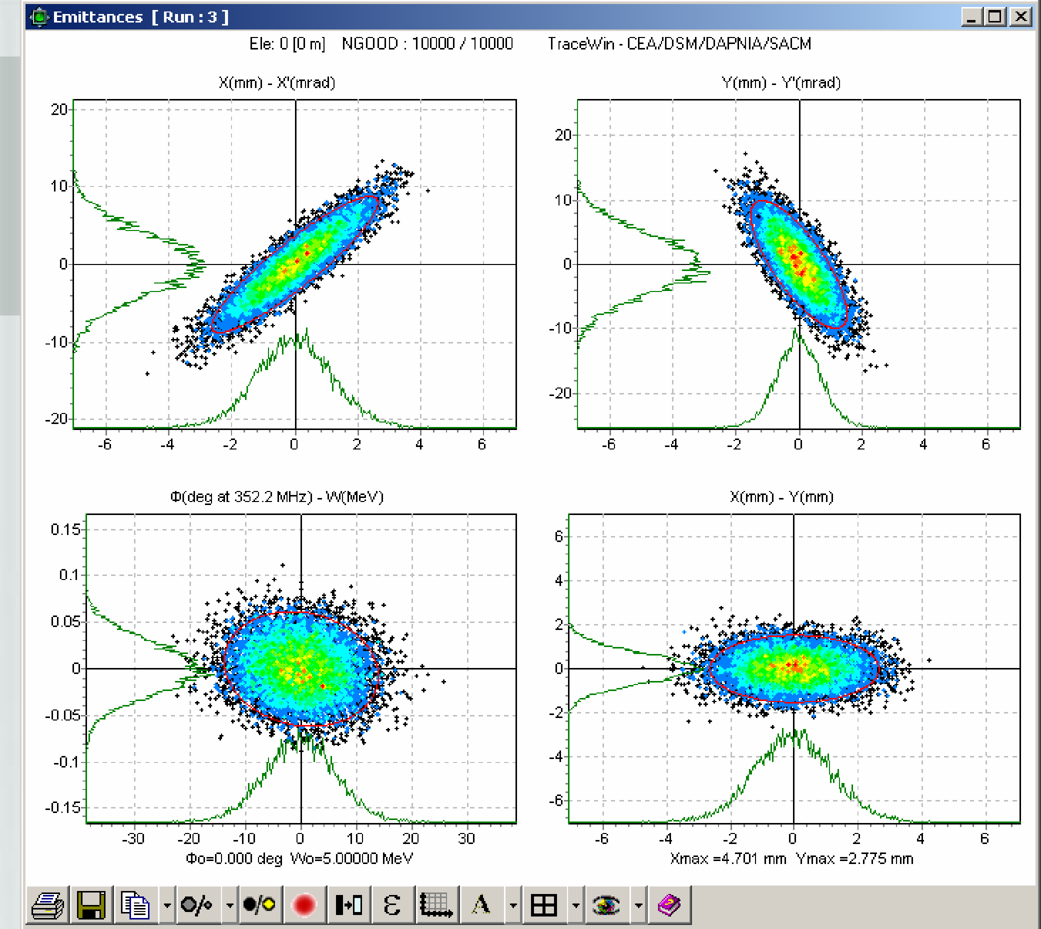
Table 4.6: Parameters of the first five DTL Tanks up to 61 MeV.

	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

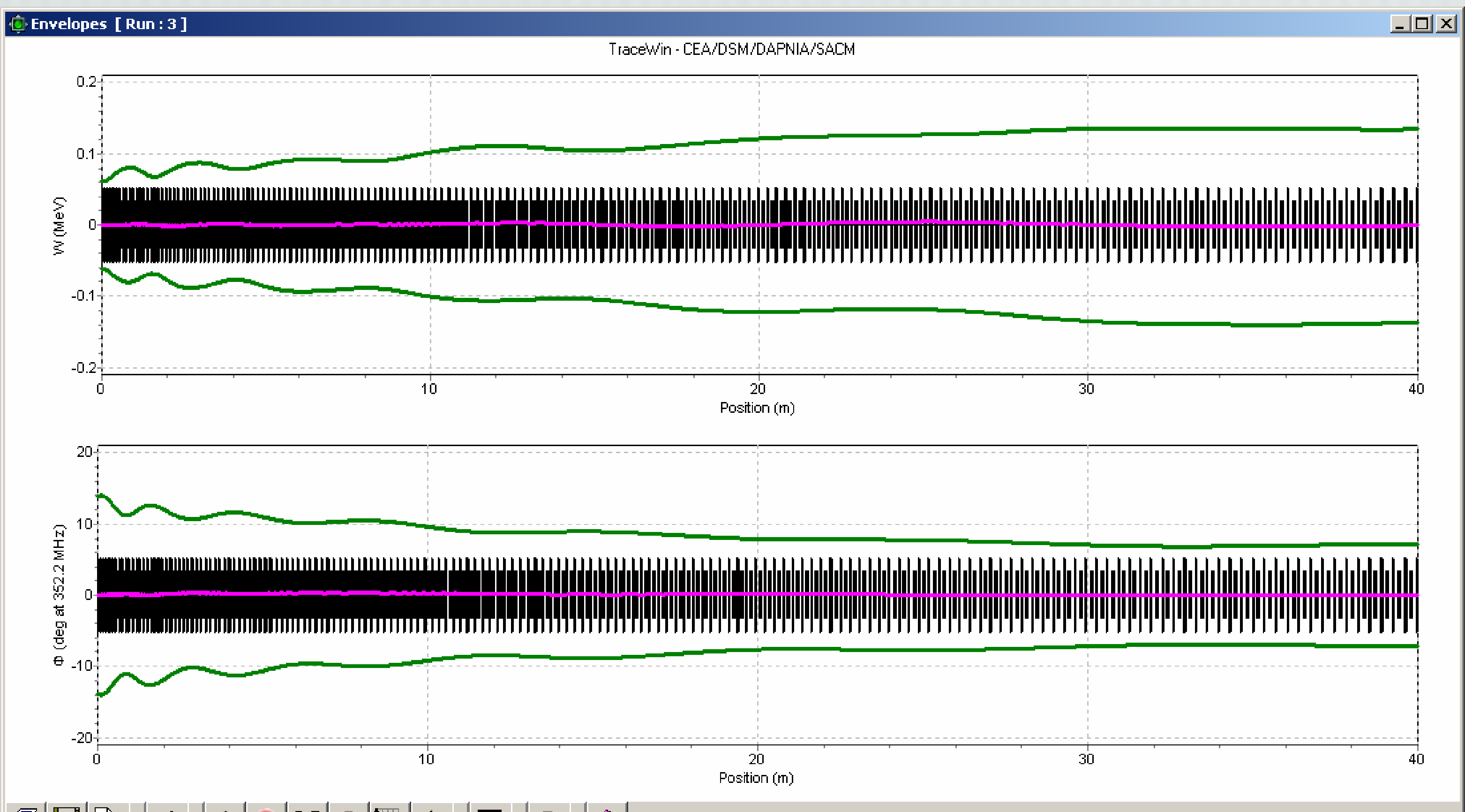


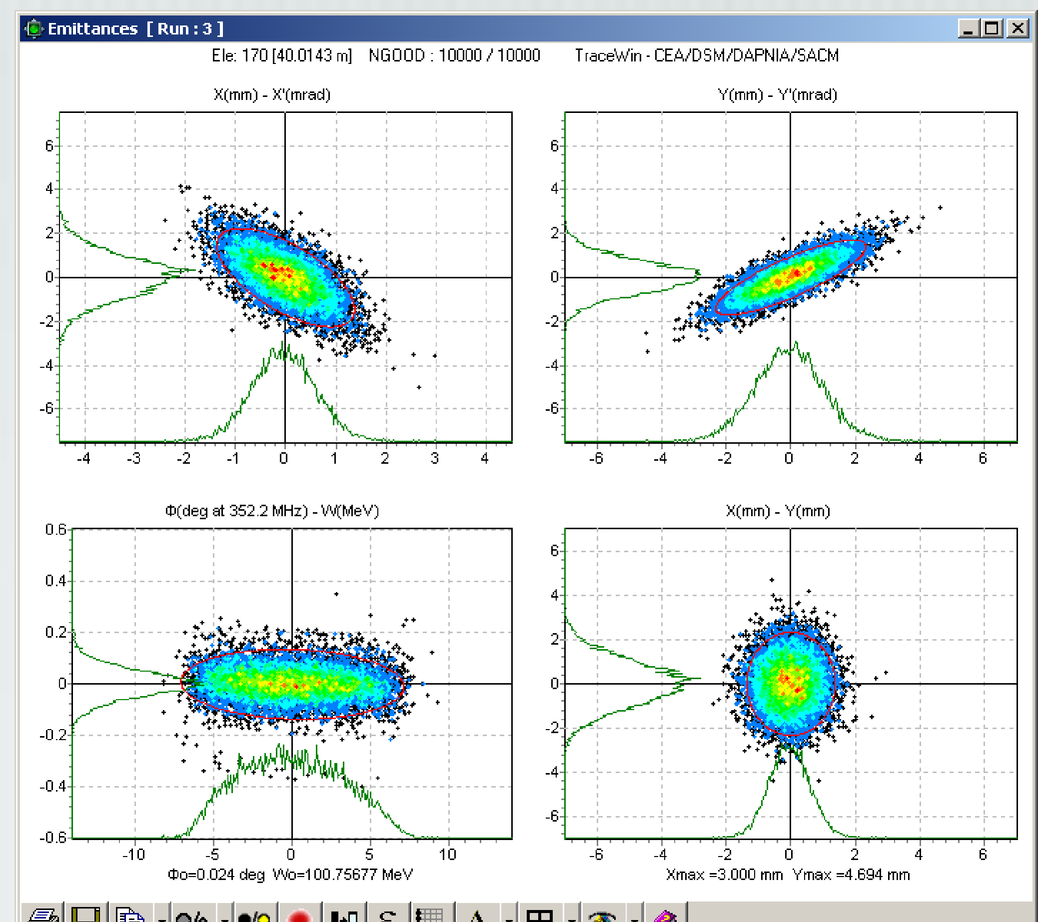






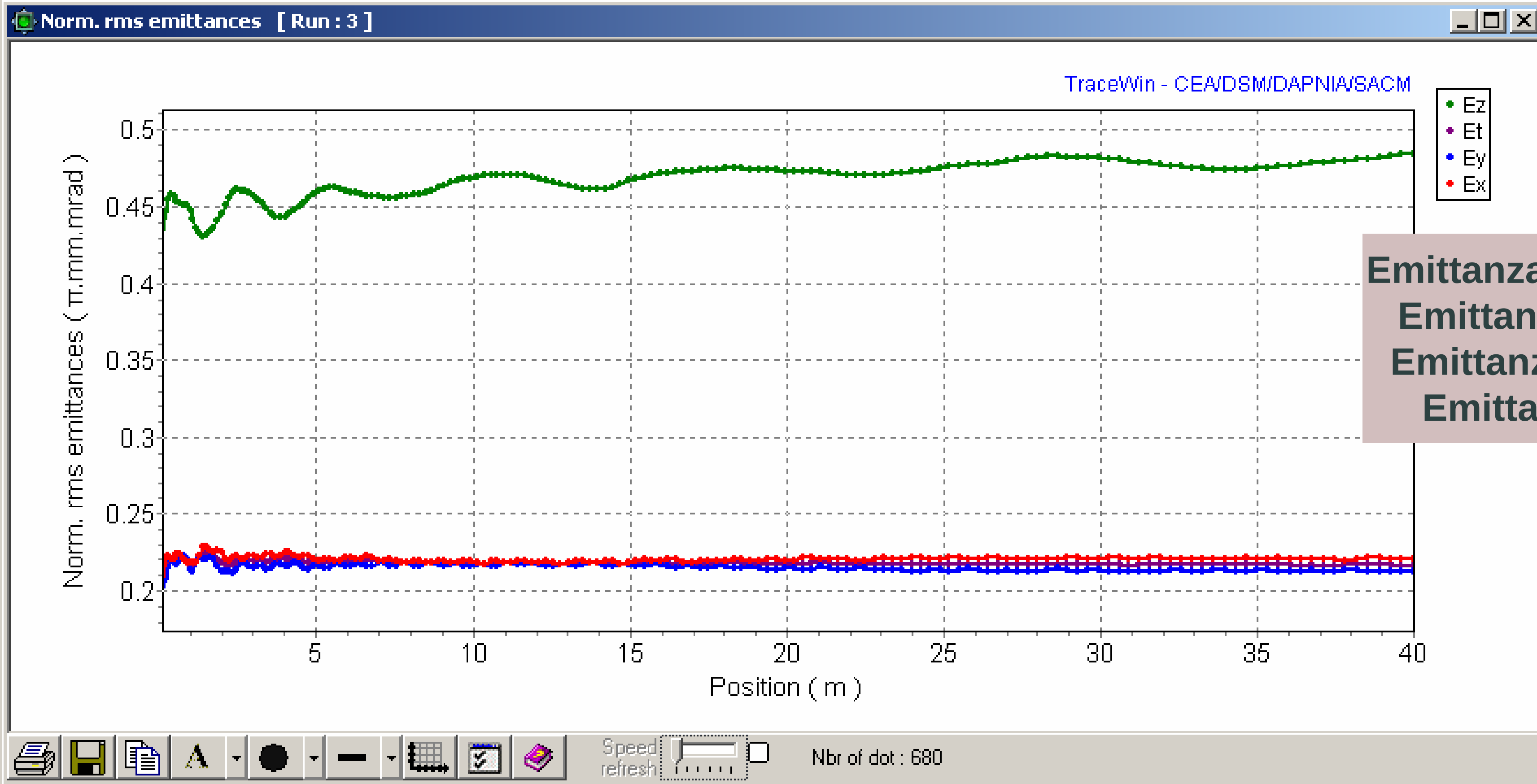
Fascio in ingresso a 5 MeV



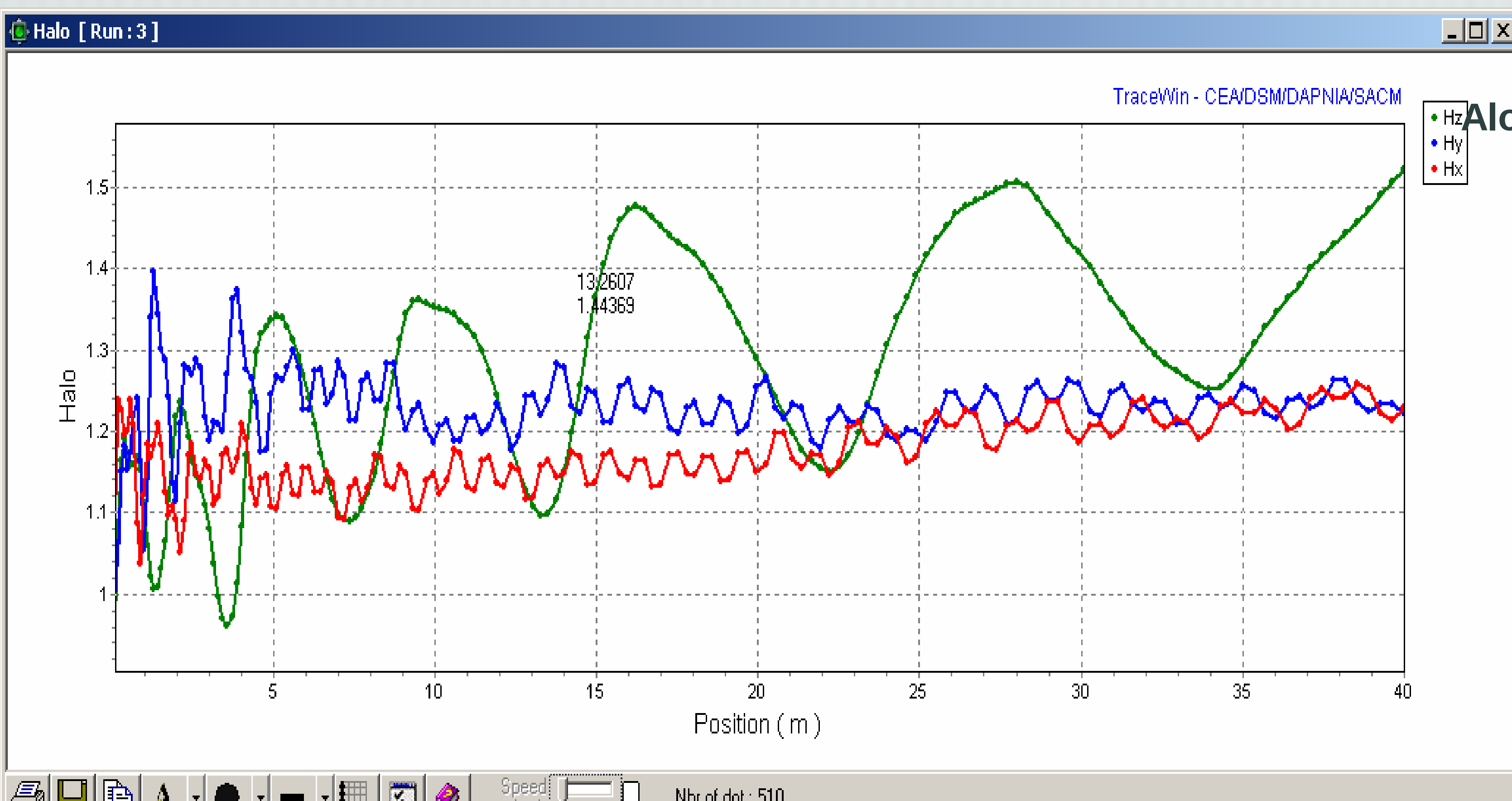


Trasporto di 50 mA nel DTL, assumendo un fascio iniziale gaussiano (4 sigma).
I plot sono 5 volte la dimensione RMS del fascio.
Il fascio e' trasportato senza perdite da 5 a 100 MeV.

Fascio in uscita a 100 MeV



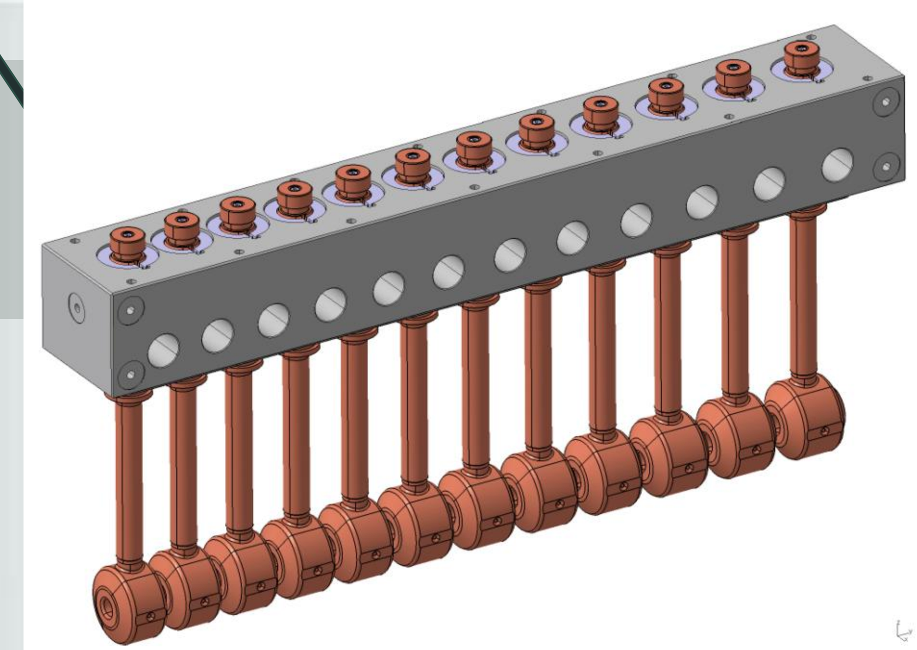
Emittanza trasversa RMS norm. in ingresso: 0.20 mmmrad
Emittanza longitudinale RMS in ingresso: 0.17 MeVdeg
Emittanza trasversa RMS norm. in uscita: 0.22 mmmrad
Emittanza longitudinale RMS in uscita: 0.19 MeVdeg



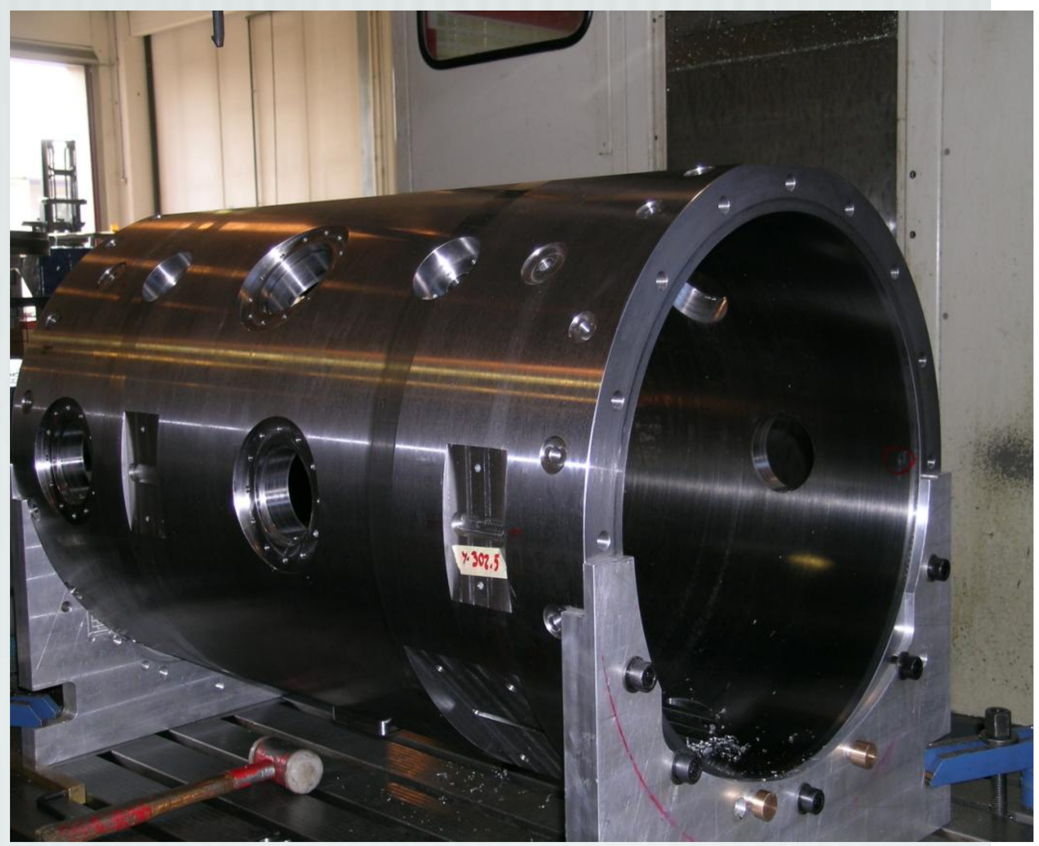
Alone gaussiano del fascio in ingresso
su tutti I piani (4 sigma): 1
Alone trasverso in uscita: 1.21
Alone Longitudinale in uscita: 1.5

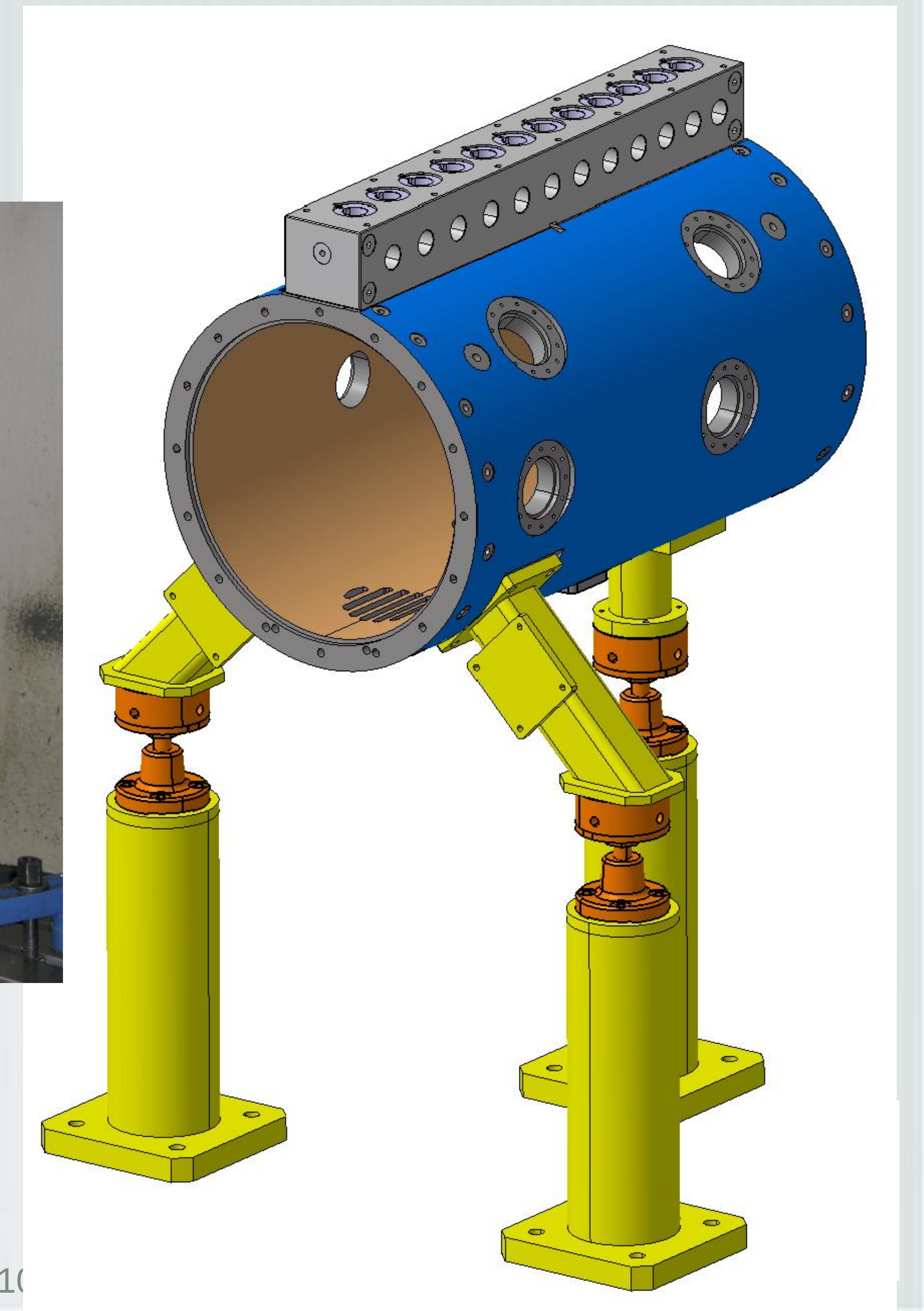
Trasporto di 50 mA nel DTL, assumendo un fascio iniziale
Gaussiano (4 sigma), I plot sono le emittanze e l'alone lungo il DTL (fino a 100 MeV)

ERN-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)

Prototipo del DTL

DRIFT TUBE LINAC DESIGN AND PROTOTYPING FOR THE CERN LINAC4

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CONCLUSIONS

The DTL design for the Linac4 at CERN incorporates new features in a basic design: Peak fields are ramped in the first cavity in order to reduce probability for breakdown

Figure 4: DTL prototype in the assembly stage.

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Elements to be evaluated in the choice

- Beam dynamics

  Losses in the accelerator

  Possibility of Hands-on maintenance

  Possible low losses, thick wall

  Beam quality preparation for the following accelerators

  Emittance conservation

  Beam Halo formation

  Short longitudinal period and smooth focusing

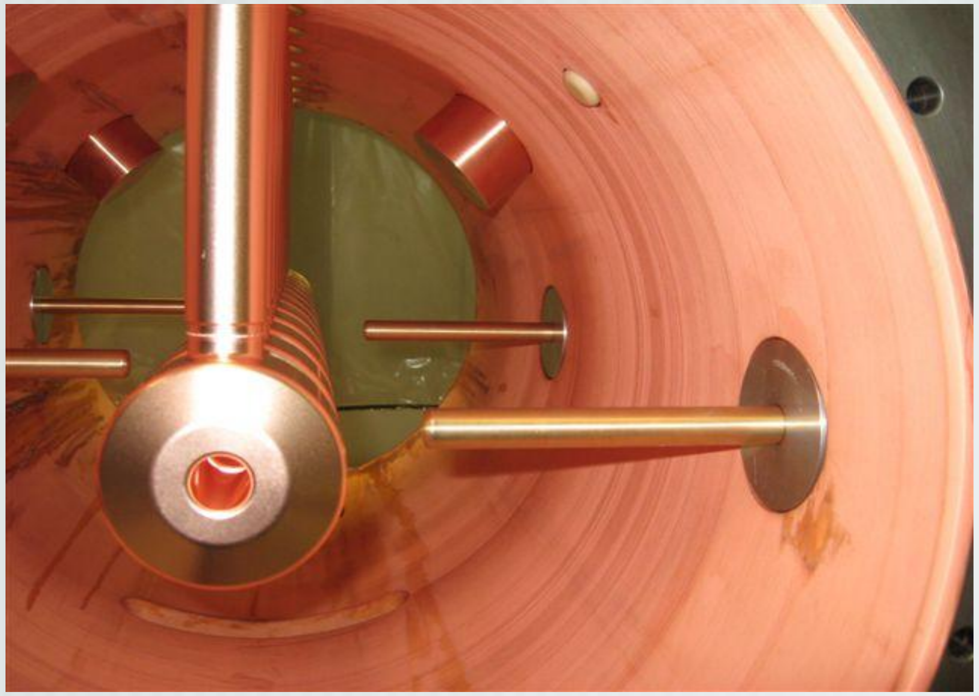
- Realization

  Technological challenges

  Possible improvement but ESS-Linac4 indicates the evolution of modern Alvarez

  Constructions costs

  Mechanics can be well estimated, Two companies are now offering 2.5 MW klystrons at 352 MHz



A specific drift tube prototype for the DTL, post couplers field stabilizing system, geometrical error tolerance, beam steering and space charge insensitive MEBT matching are issues to be considered.

Conclusion

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.

Conclusion

Normanni → Vikings

<u>A Sicilian byword says “The freshness of the fish is declared by its head”</u>

→ i.e. by its Front-End

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