Beam commissioning of the high intensity proton source developed at INFN-LNS for ESS

Lorenzo Neri

On behalf of INFN-LNS Accelerator R&D team:

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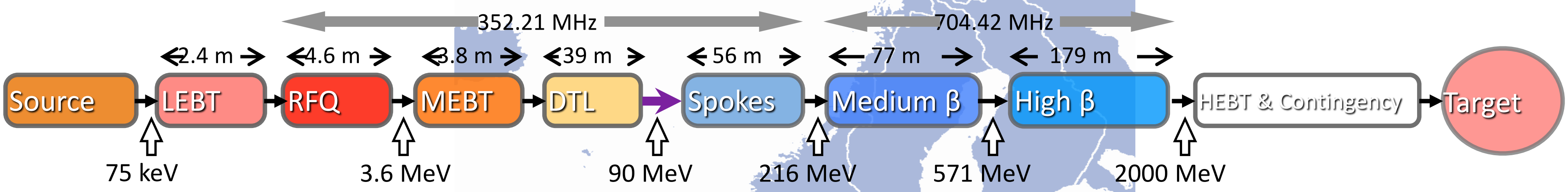
Summary

- Italian In-Kind Contribution to European Spallation Source
- Status of the construction of proton source and LEBT
- Improvements with respect to TRIPS and VIS sources
- Commissioning strategy
- Achievement of ESS requirements
- Conclusions

Italian IK-Contribution:

Proton Source, LEBT	INFN-LNS
DTL	INFN-LNL
T-REX, VESPA	CNR
RF systems, Magnets&PS, diagnostics	Elettra



Partners for proton source and LEBT:

INFN-LNS	WP leader, Overall design, Construction, Commissioning, Installation
ESS	Vacuum, Controls, Beam diagnostics
CEA	Controls, Beam diagnostics

Status of the construction

Source fully assembled

Source commissioning setup

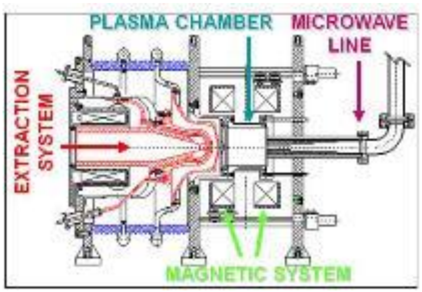
LEBT

Under construction

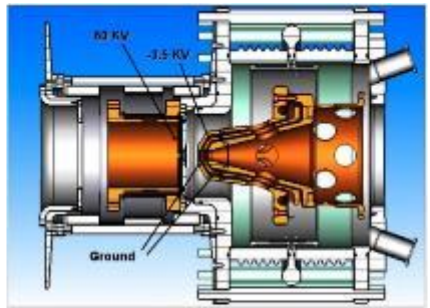
Activity	Start	End
Phase 1: IS with FC and DSM	03/10/16	31/10/16
Phase 2: + EMU	02/11/16	30/04/17
Phase 3: Full LEBT	01/05/17	29/09/17
Packaging and shipping	02/10/17	31/10/17
Ready for Installation	03/11/17	

Background for IKC of INFN-LNS

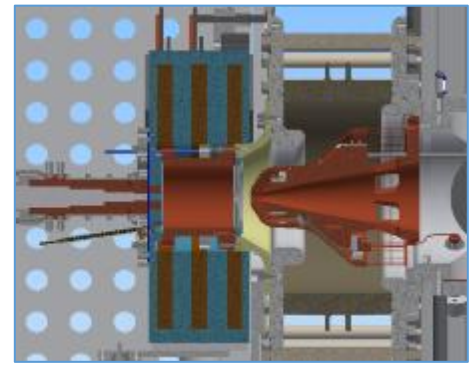
TRIPS (2001)



VIS (2008)



PS-ESS (2016)



Performance	Value
Beam energy	80 Kev
Proton beam current	55 mA
Proton fraction	≈80%
RF frequency	2.45 GHz
RF power	Up to 1 kW
Axial magnetic field	875-1000 G
Duty factor	100 % (DC)
Extraction aperture	6 mm
Reliability	99.8% @ 35 mA
Transverse emittance (σ)	0.07 pi.mm.mrad @ 35 mA
Start-up after maintenance	32 hours

+ 25%

from dc to pulsed

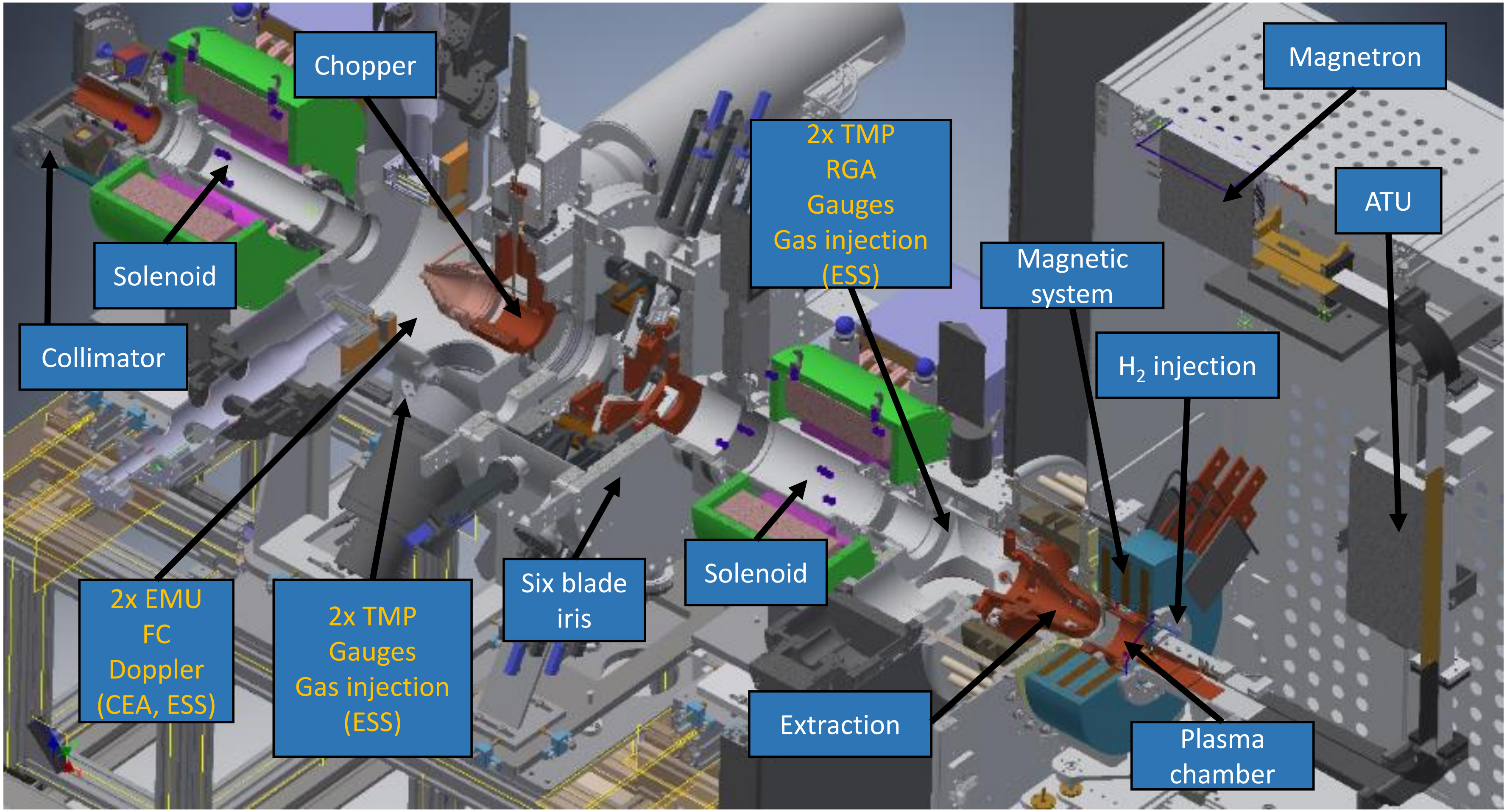
High stability

Low emittance

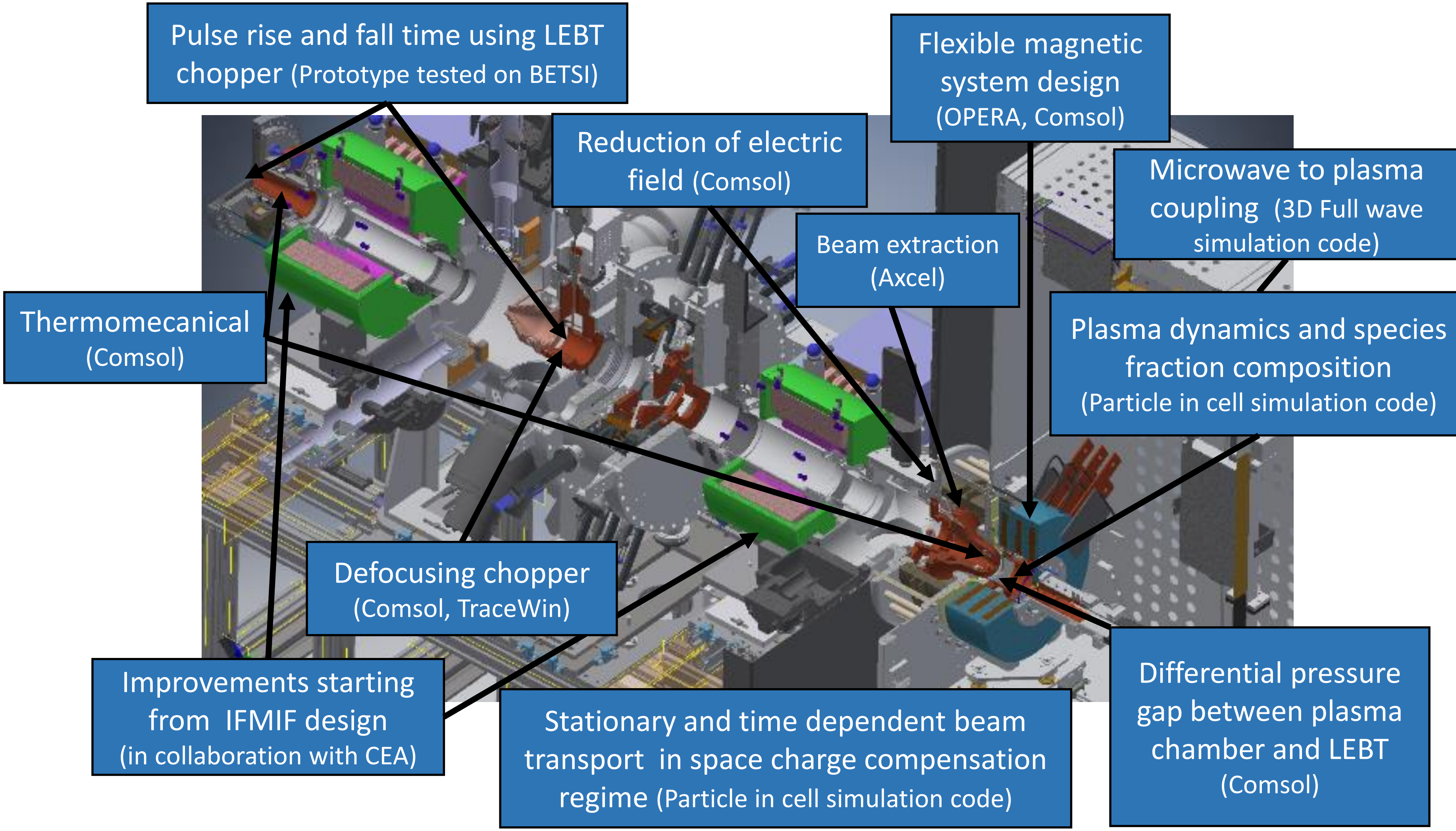
Easy maintenance

Requirement	Value
Beam energy	75±5 keV
Energy adjustment	±0.01 keV
Total beam current	>90 mA
Proton beam current	74 mA
Proton beam current range	67-74 mA
Proton fraction	>75%
Pulse length	6 ms
Pulse flat top	3 ms
Repetition rate	14 Hz
Pulse to pulse stability	±3.5 %
Flat top stability	±2 %
Transverse emittance (99%)	1.8 pi.mm.mrad
Beam divergence (99%)	<80 mrad
Start-up after maintenance	32 hours

Proton Source and LEBT at INFN-LNS



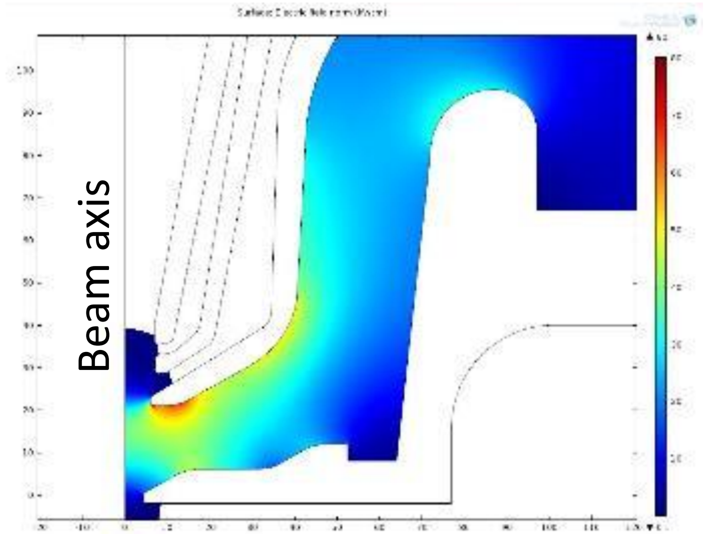
Improvements with respect to TRIPS and VIS



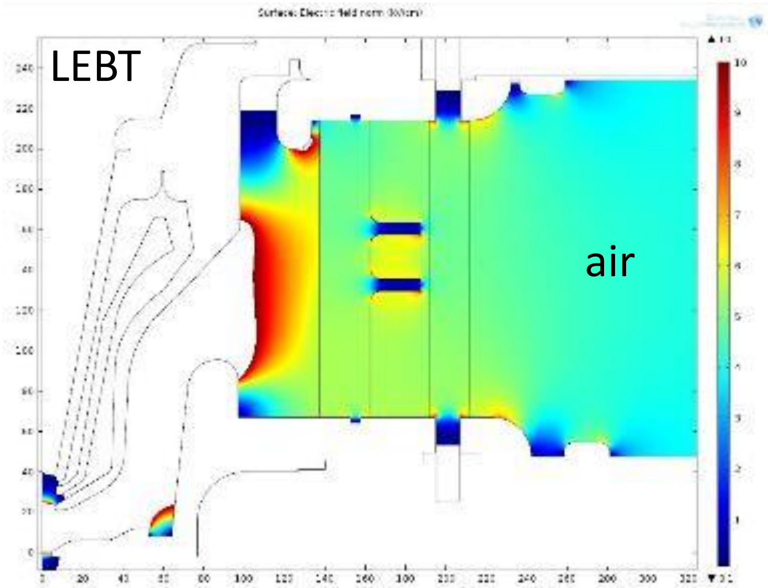
Improvements in the extraction system

- **Lower the useless electric field** close to the extraction
- **X Ray protection**
- **Beam dynamics** through electrodes

- **Single alumina** to minimize the electric field on the external surface (< 6.6 kV/cm)
- **New triple point design** (< 6.4 kV/cm)



Plasma chamber

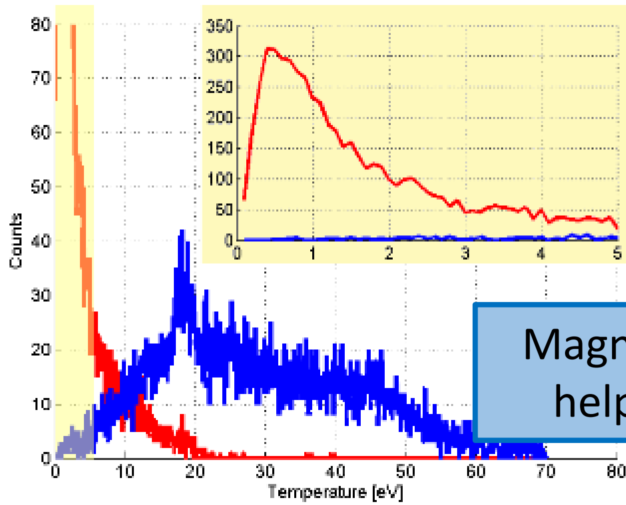


Plasma chamber

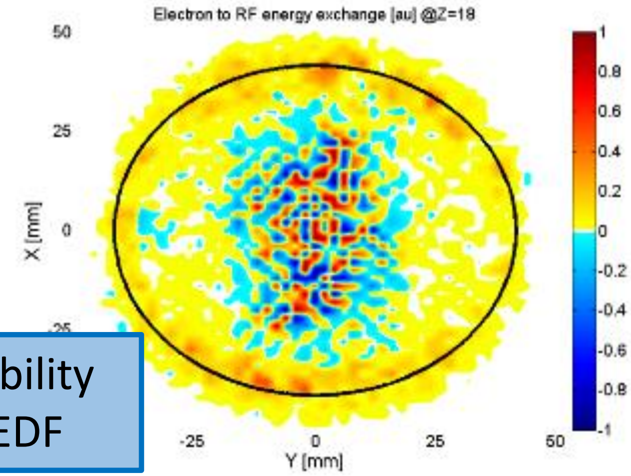
We had not serious problems of discharge during beam extraction at 75 kV. Extraction column was tested up to 90 kV.

Plasma modeling

Electron Energy Distribution Function



RF energy adsorption

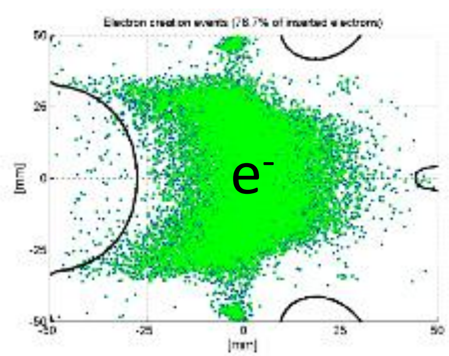


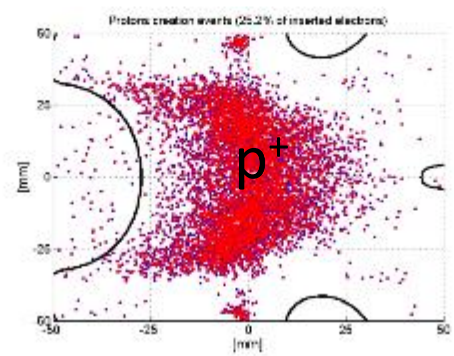
Magnetic system flexibility helps to tailor the EEDF

Ion formation

$H_2 + e \to H + H + e$, $E_{th} = 9.2$ eV,
$H_2 + e \to H_2^+ + e + e$, $E_{th} = 15.42$ eV,
$H_2 + e \to H^+ + H + e + e$, $E_{th} = 18.15$ eV,
$H_2^+ + e \to H^+ + H + e$, $E_{th} = 12$ eV,
$H_2^+ + e \to H^+ + H^+ + e$, $E_{th} = 15.2$ eV,
$H + e \to H^+ + e + e$, $E_{th} = 13.6$ eV,
$H + e \to H^{*2p} + e$, $E_{th} = 10.2$ eV,
$H + e \to H^{*2s} + e$, $E_{th} = 10.2$ eV,
$H^{*2s} + e \to H^+ + e$, $E_{th} = 3.4$ eV,
$H_2^+ + e \to H + H$, $E_{th} = 0$ eV.

Generation maps



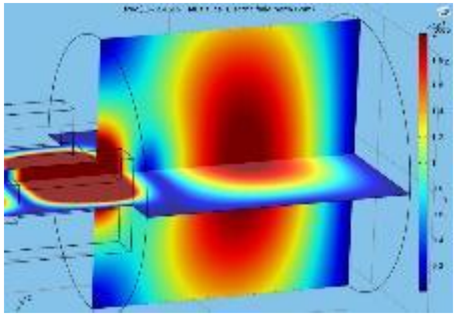


L. Neri et al. "Recent progress in plasma modelling at INFN-LNS", Rev. Sci. Instrum. 2016 Feb, 87(2):02(A)505

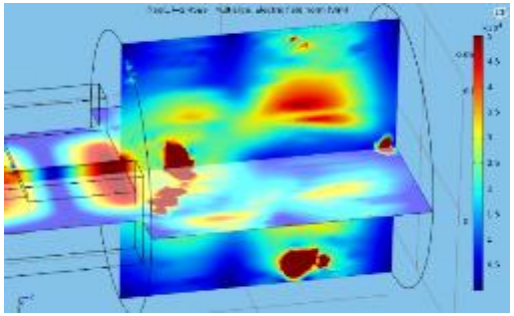
Microwave to plasma coupling

3D full wave e-m simulation in presence of the electron plasma density and strong magnetic field has driven the design of **the matching transformer**

Empty cavity

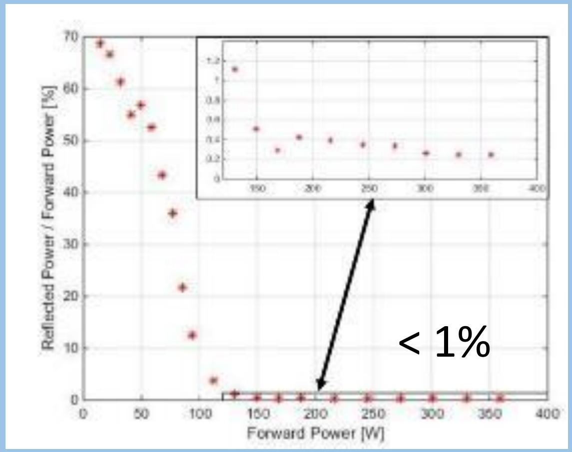


Cold tensor plasma approximation

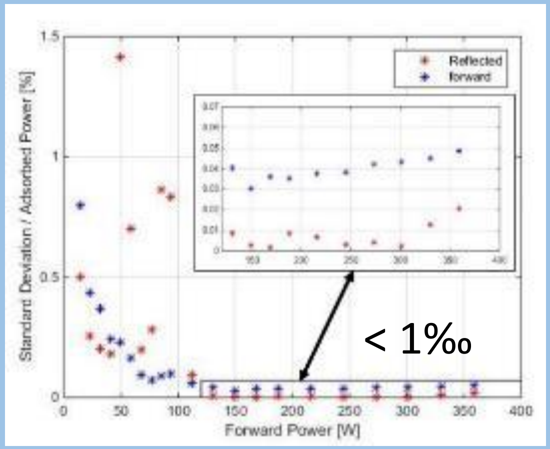


G. Torrisi et al. "Full-wave FEM simulations of electromagnetic waves in strongly magnetized non-homogeneous plasma", JEWA 2014 vol. 20, no. 9, 1085-1099

Low measured reflected power



High measured stability of forward and reflected power

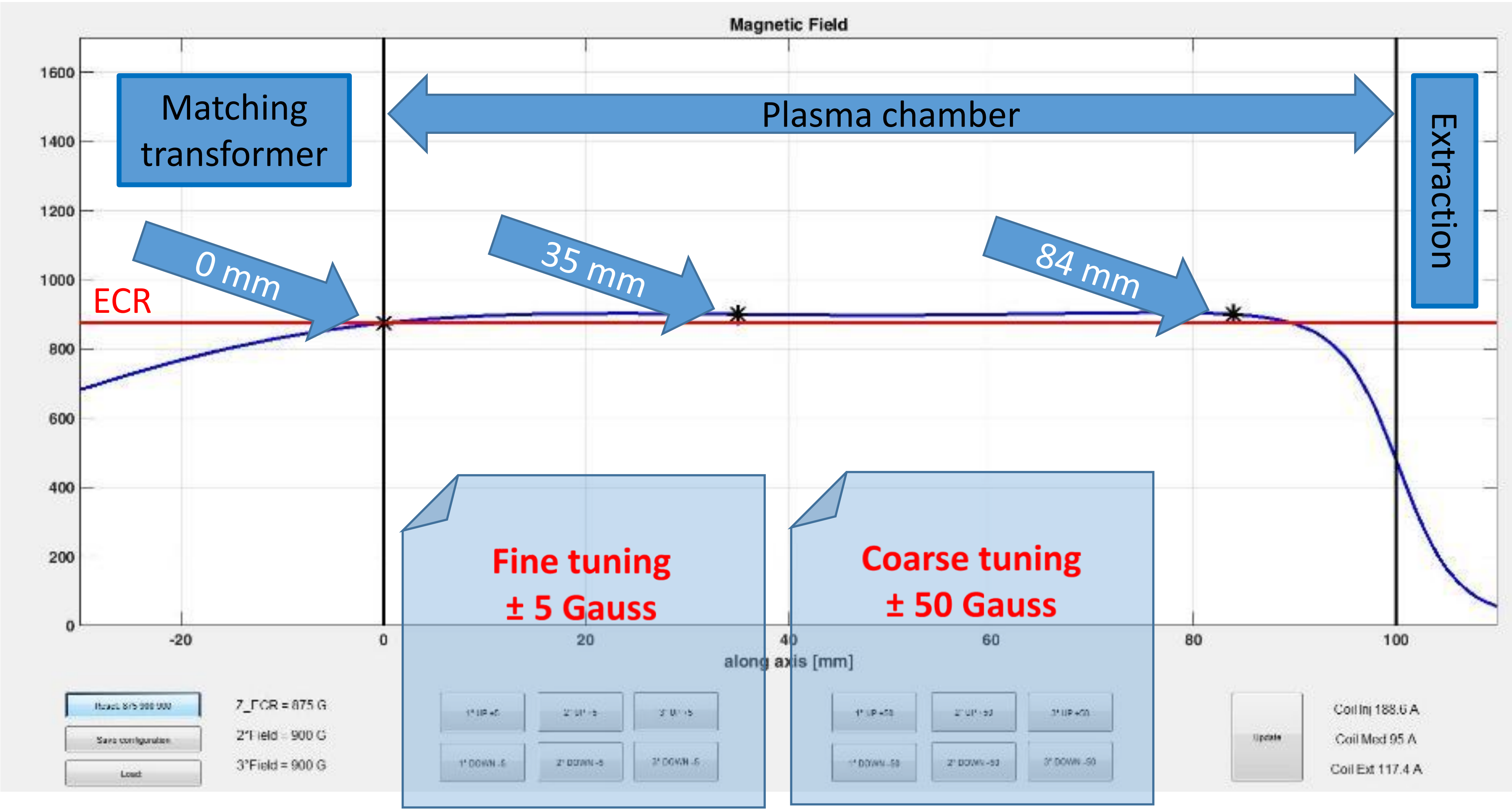


Measured forward and reflected pulsed power

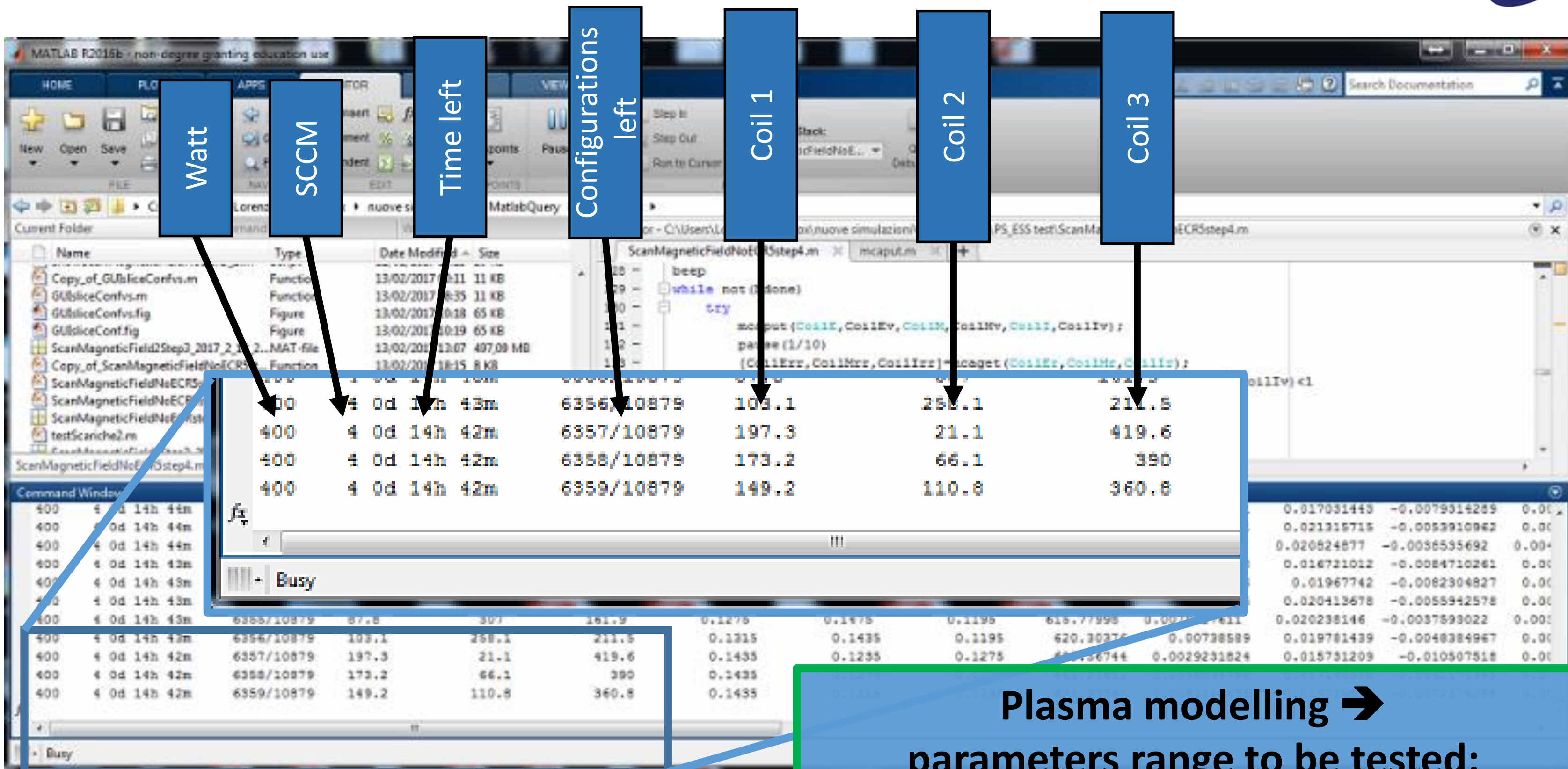
G. Torrisi et al. "Microwave injection and coupling optimization in ECR and MDIS ion sources", this conference

Magnetic system control interface

Very high magnetic flexibility required a dedicated interface developed at INFN that enable direct control and high reproducibility



Semi-automatic characterization tool



From the 23/01/2017 the source is extracting beam seamless, more than 300˙000 tested configurations, no stops due to sparks.

Plasma modelling ➔ parameters range to be tested:

Field @ 0 mm ==> 835:20:975 Gauss

Field @ 35 mm ==> 795:40:1395 Gauss

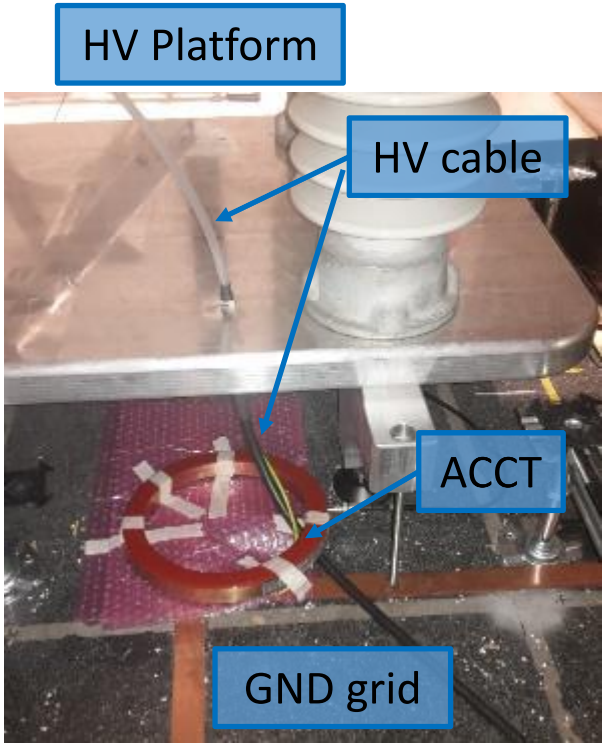
Field @ 84 mm ==> 675:40:1995 Gauss

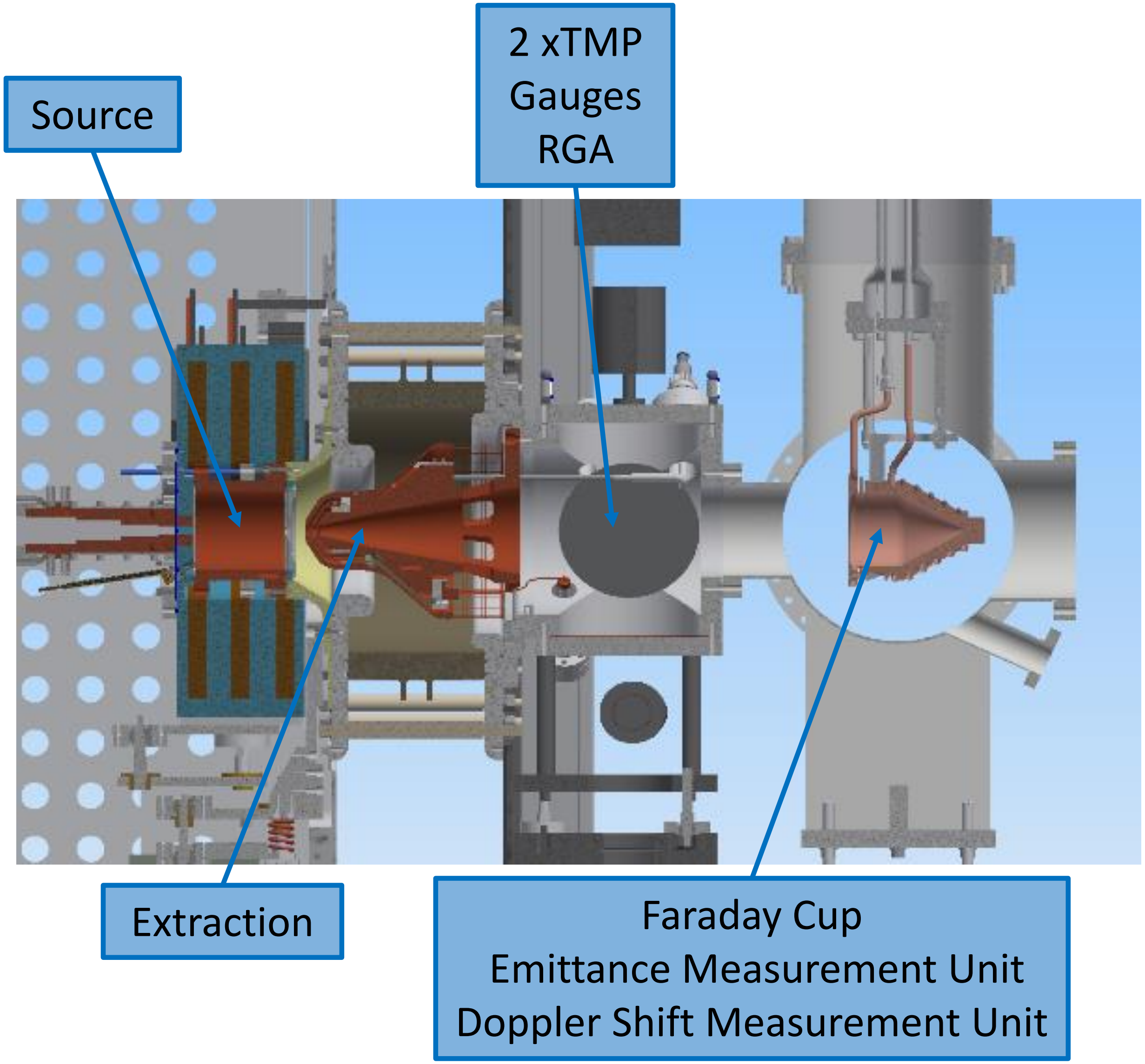
H_2 flow ==> 2:1:5 SCCM

RF power ==> 600:200:1200 Watt

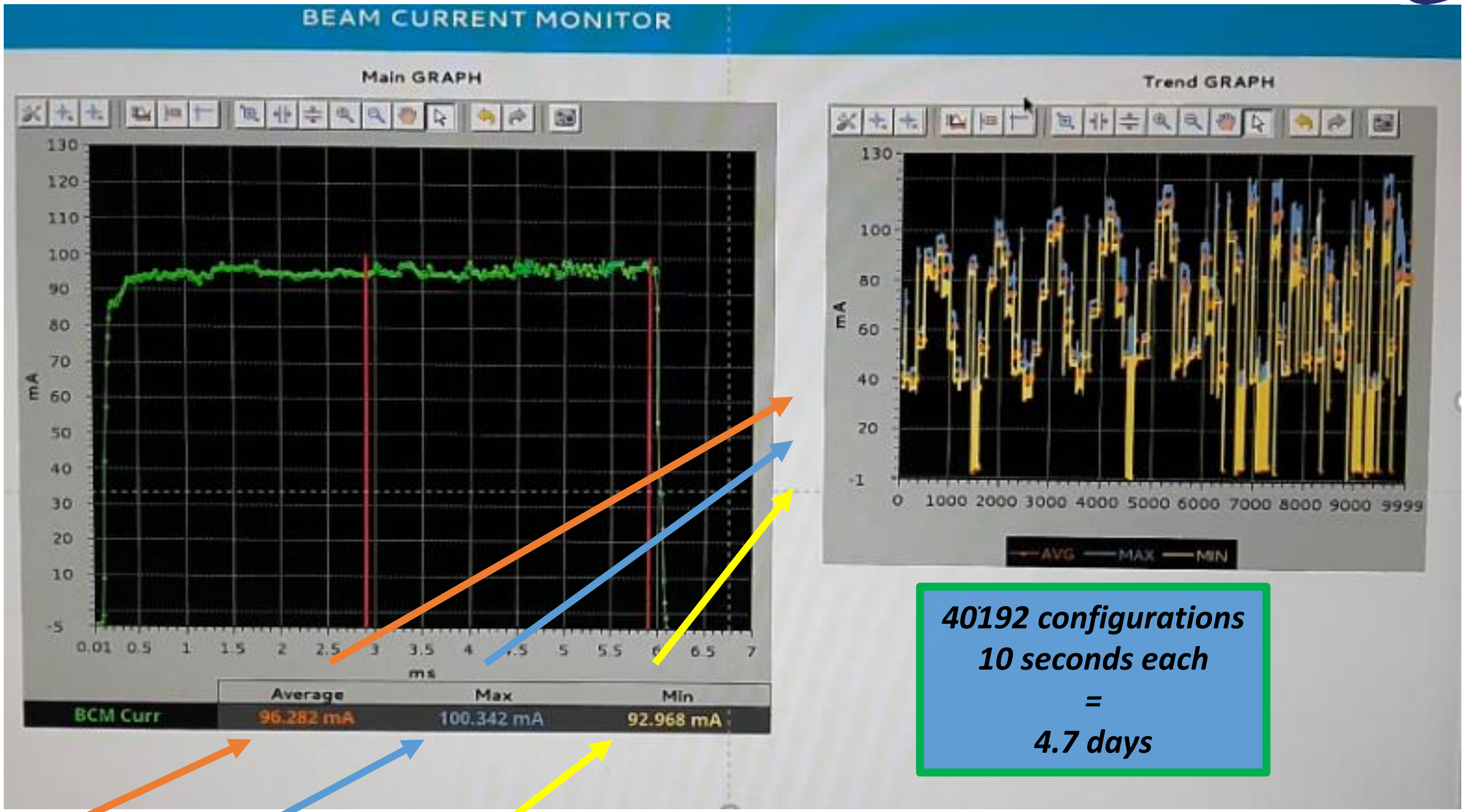
40192 configurations

Experimental setup for source commissioning





Semi-automatic characterization

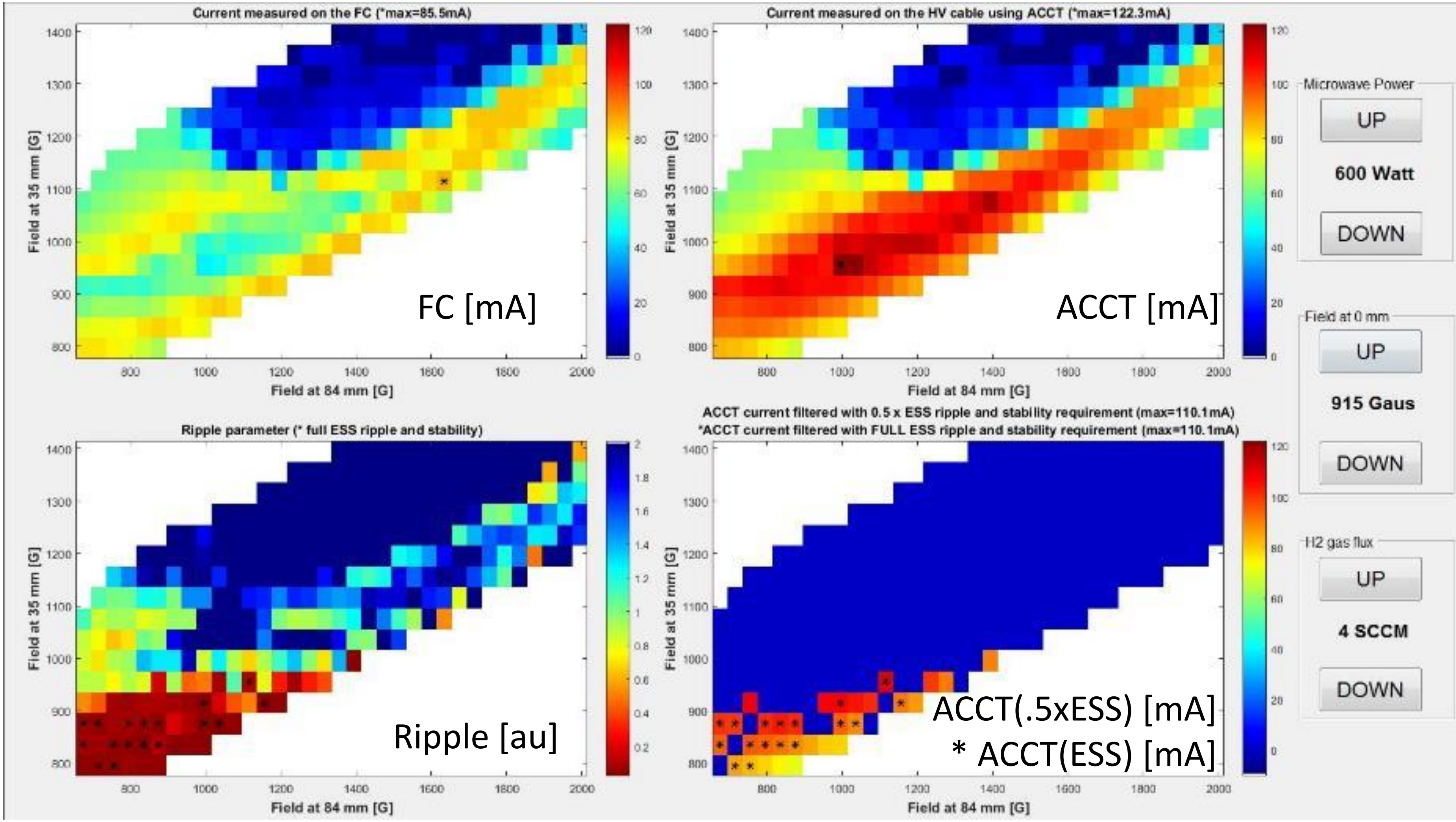


40192 configurations
10 seconds each
_=_
4.7 days

In the graphical interface: average, maximum and minimum are evaluated and the trend showed for the beam pulse between 2.9 ms and 5.9 ms .

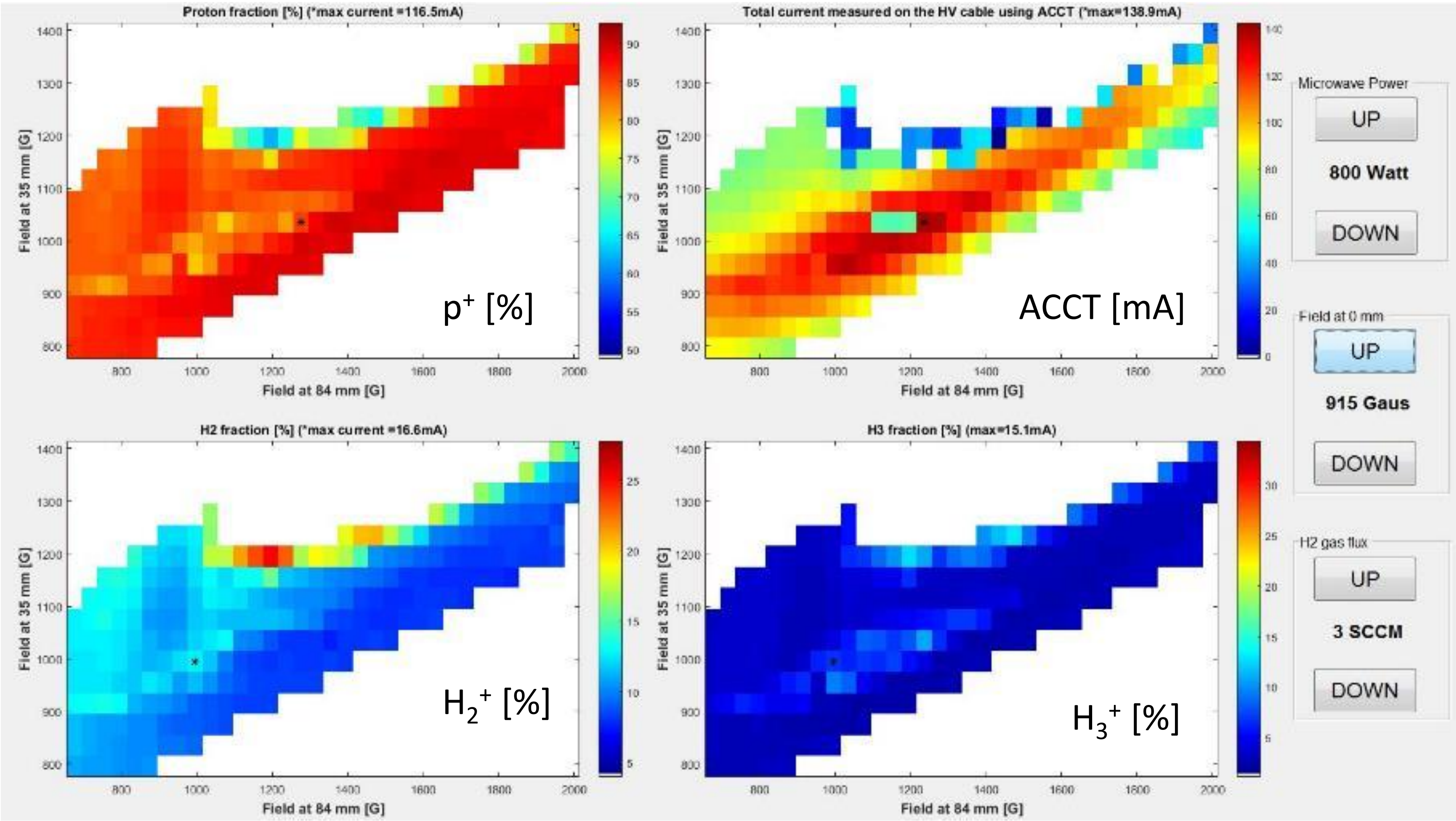
In the semi-automatic characterization code 26 parameters and two wave forms (@1Ms/s) are saved for each pulse produced at nominal repletion rate of 14Hz.

Data analysis of thousands of different configurations



Doppler shift measurement beam characterization

Proton fraction > 75% SATISFIED



ESS stable configurations versus injected H_2 gas flux and microwave power

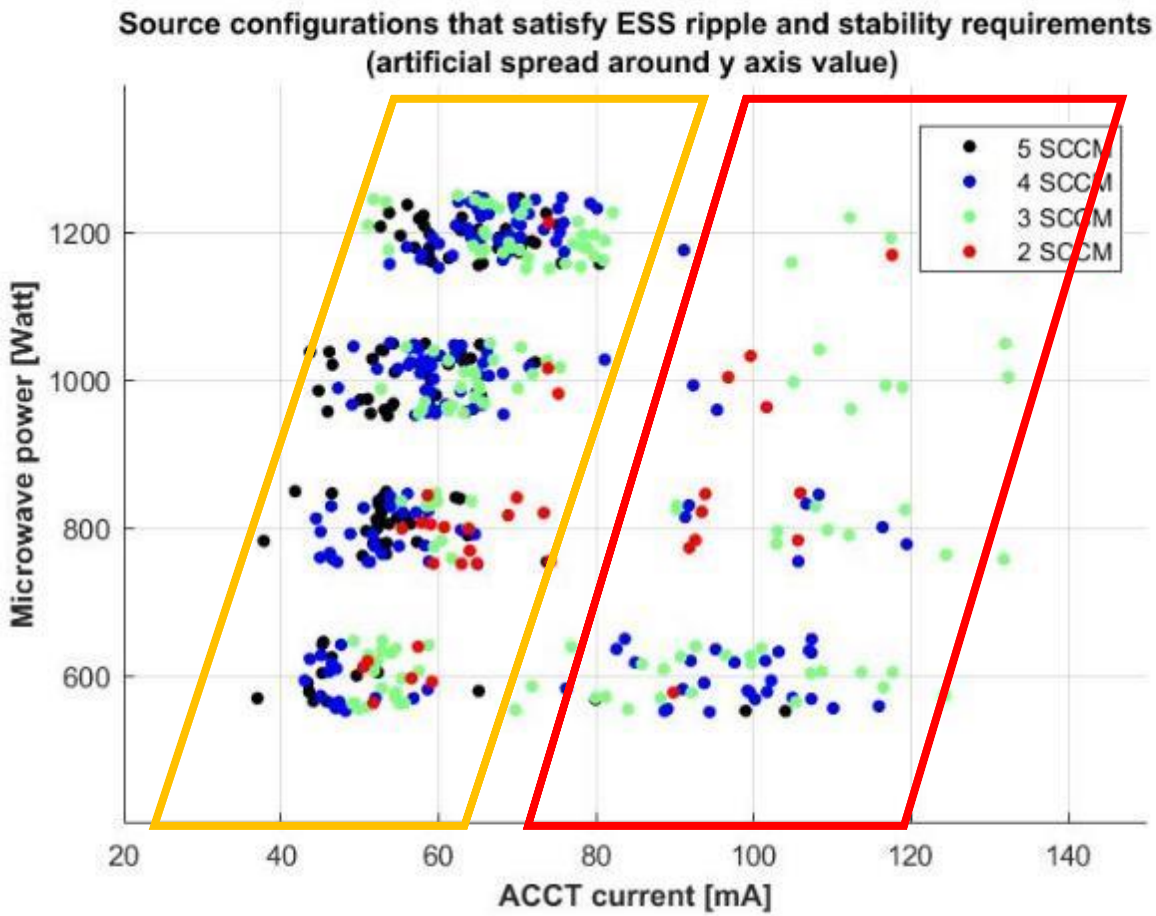
Total current = 100 mA SATISFIED

Increasing the injected microwave power increase the energy transfer and consequently the plasma density

Each point is a large operative range (20 Gauss x 40 Gauss x 40 Gauss x 1 SCCM x 200 Watt)

Lower current (2-5 sccm)

High current (2-4 sccm)

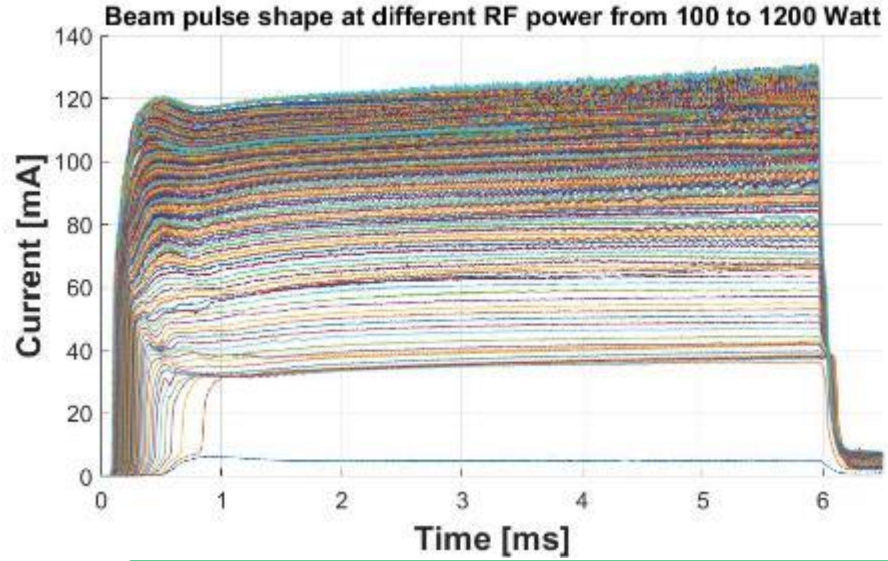


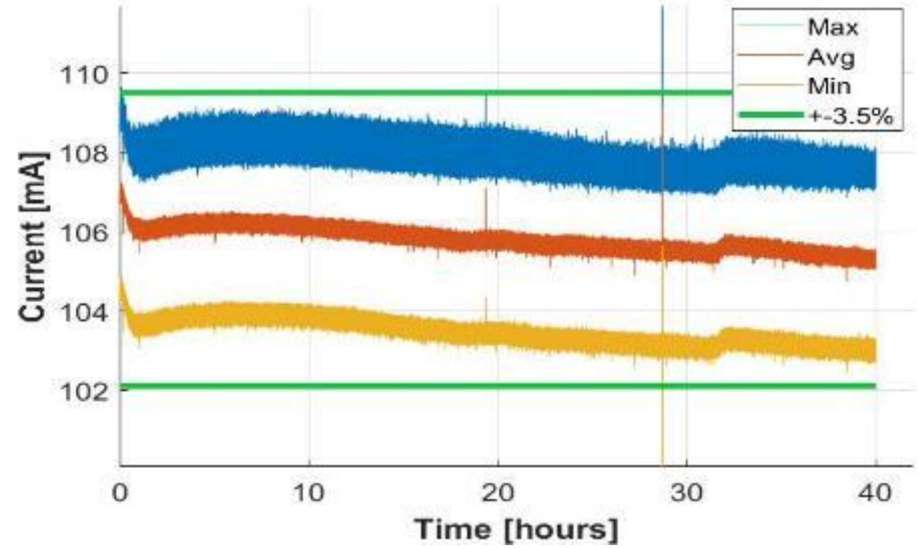
Candidate nominal configuration

109 A coil1; 67 A coil2; 228 A coil3; 3 SCCM H_2

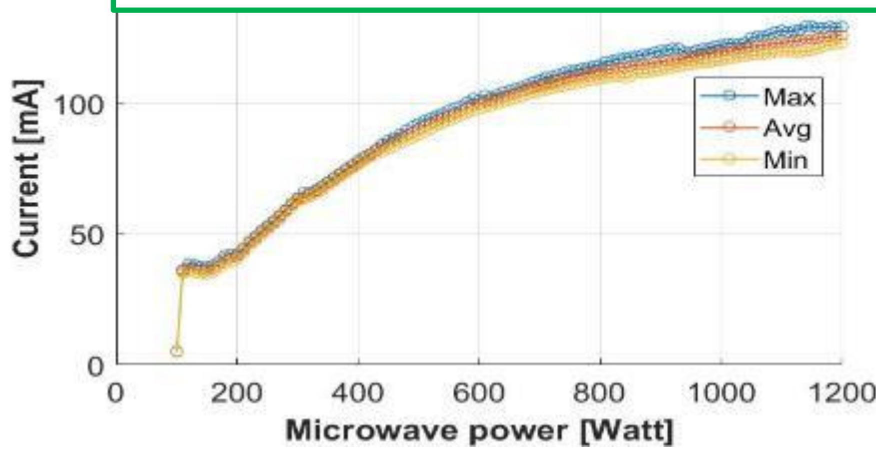
Intra-pulse stability < ±2% SATISFIED

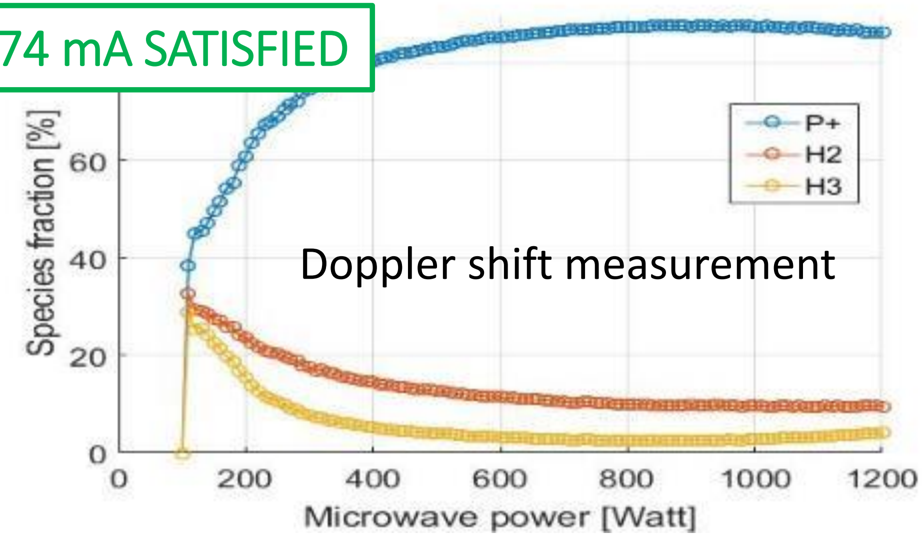
Pulse to pulse stability < ± 3.5% SATISFIED





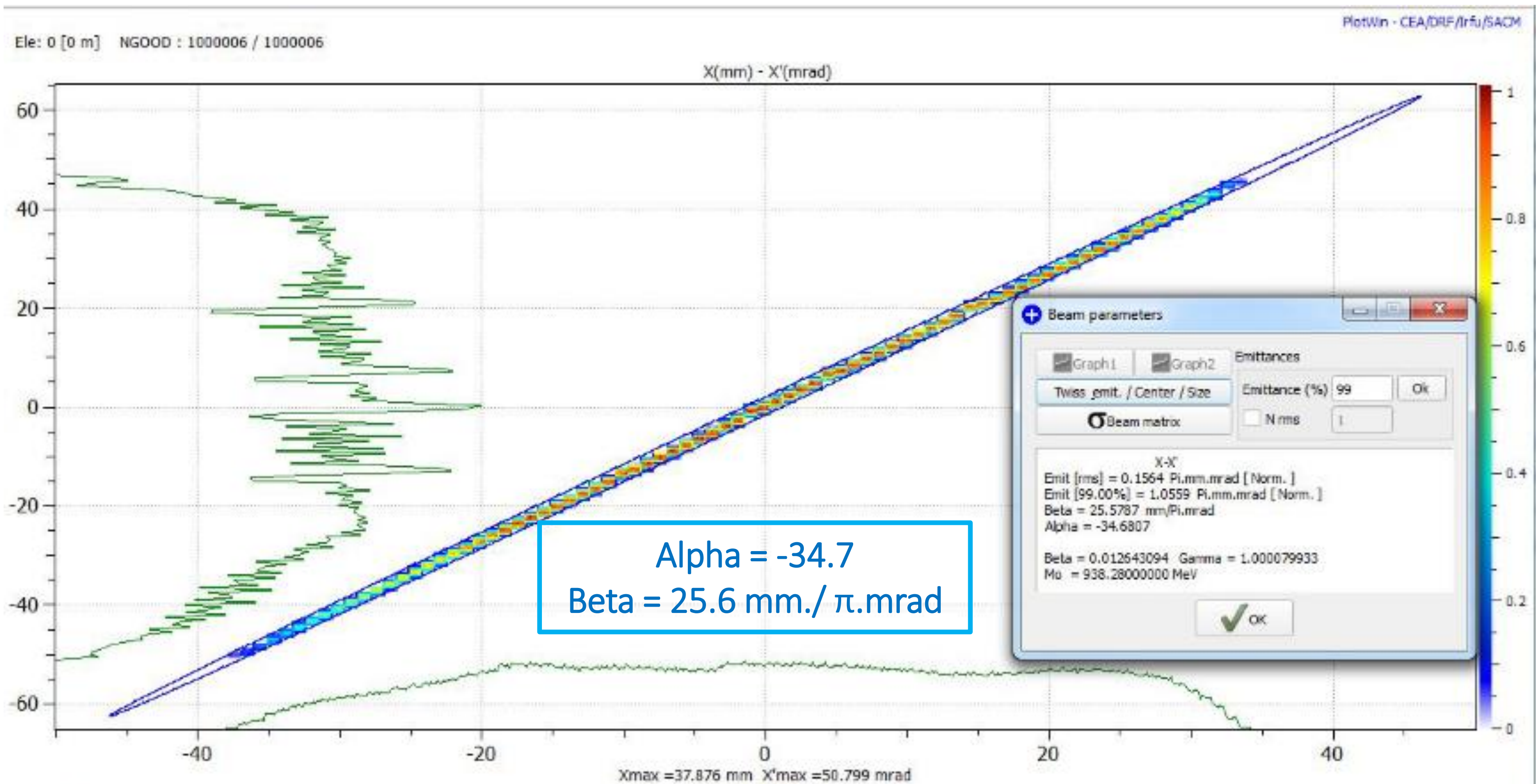
Minimum proton current range 67-74 mA SATISFIED





Preliminary beam emittance measurements

Measurement done at 82 mA (74 mA @ 85% ➔ 87 mA) (+ 6%)
Source Emittance: 1.06 π.mm.mrad (< 1.8 π.mm.mrad t.b.c.) (- 41%)
Max divergence: 55 mrad (< 80 mrad t.b.c.) (- 45%)



Check of requirements

Requirement	Value	**Measurement done for configurations that satisfy the ESS stability requirements**	**Comments**
Total beam current	>90 mA	40 - 140 mA	✓
Nominal proton beam current	74 mA	40 - 105 mA	✓
Proton beam current range	67-74 mA	40 - 105 mA	✓
Proton fraction	>75%	Up to 85%	✓
Pulse length	6 ms	6 ms	✓
Pulse flat top	3 ms	3 ms	✓
Flat top stability	±2 %	< ±2 % up to 1.5%	✓
Pulse to pulse stability	±3.5 %	< ±3.5 % up to 3%	✓
Repetition rate	14 Hz	14 Hz	✓
Beam energy	75±5 keV	75 keV	✓
Energy adjustment	±0.01 keV	±0.01 keV	✓
Transverse emittance (99%)	1.8 pi.mm.mrad	1.06 pi.mm.mrad @ 82 mA	Characterization ongoing
Beam divergence (99%)	<80 mrad	50 mrad @ 82 mA	Characterization ongoing
Start-up after source maintenance	32 hours	32 hours	✓

Conclusion

- The flexibility inserted in the design enabled the satisfaction of ESS requirements
- NO sparks relevant problems remain unsolved
- Construction of the LEBT is in time
- Training of ESS staff started

Perspectives

- Fast characterization procedure and data analysis will be used also in our the future sources
- The characterization provided know how for the developing of different type of source, different current range and/or different species
- Second source procurement ongoing
- The installation in Lund is planned without delay

Thanks for your attention

Comments are welcome

Thanks to all INFN-LNS staff to valuable support provided during all the phases of the project.

The collaboration with ESS and CEA was intense, profitable, always solution oriented.