DE LA RECHERCHE À L'INDUSTRIE

HIGH INTENSITY BEAM PRODUCTION AT CEA/SACLAY FOR THE IFMIF PROJECT

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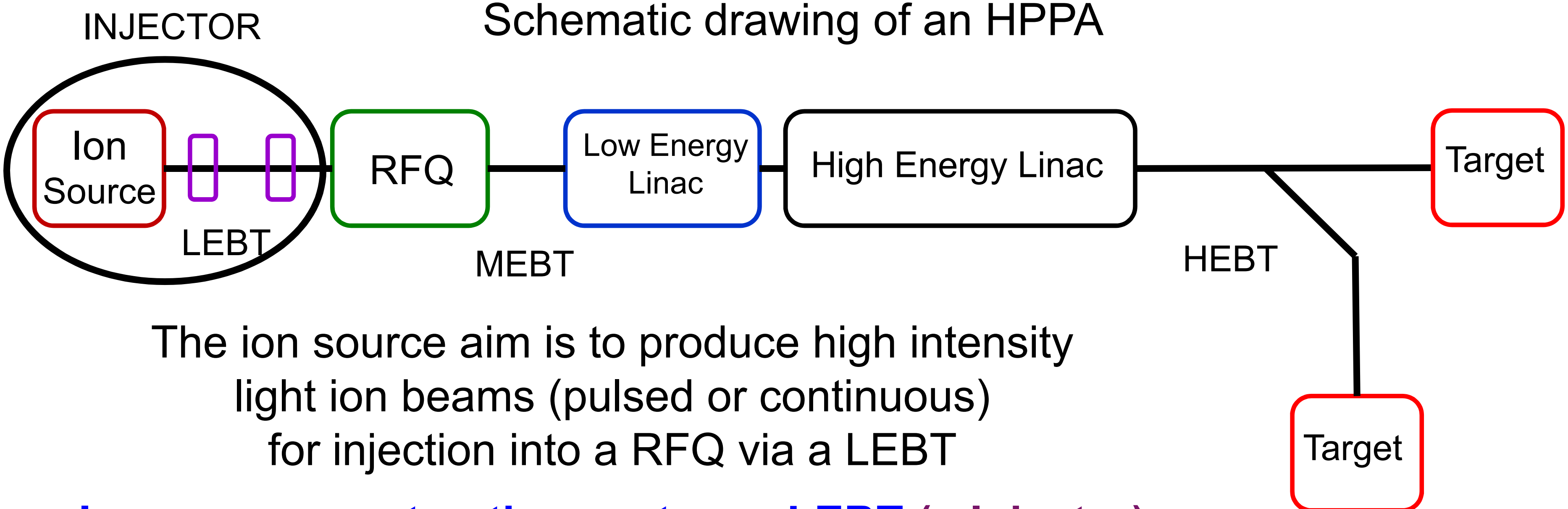
www.cea.fr

OUTLINE

- Brief presentation of the IFMIF project
- Ion source design
- LEBT design
- First beam results
- On going actions

HIGH POWER PROTON ACCELERATOR

Schematic drawing of an HPPA



The ion source aim is to produce high intensity light ion beams (pulsed or continuous) for injection into a RFQ via a LEBT

Ion source + extraction system + LEBT (= Injector) have to be considered as a whole.

(S. Gammino at ICIS 2009)

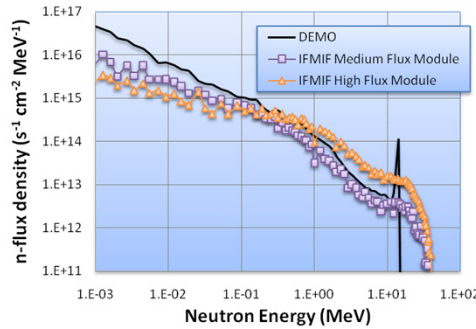
In the 90's, CEA started the IPHI project with the SILHI source.

Goal : > 100 mA H+

and is now involved in several projects: IFMIF, SPIRAL2, FAIR

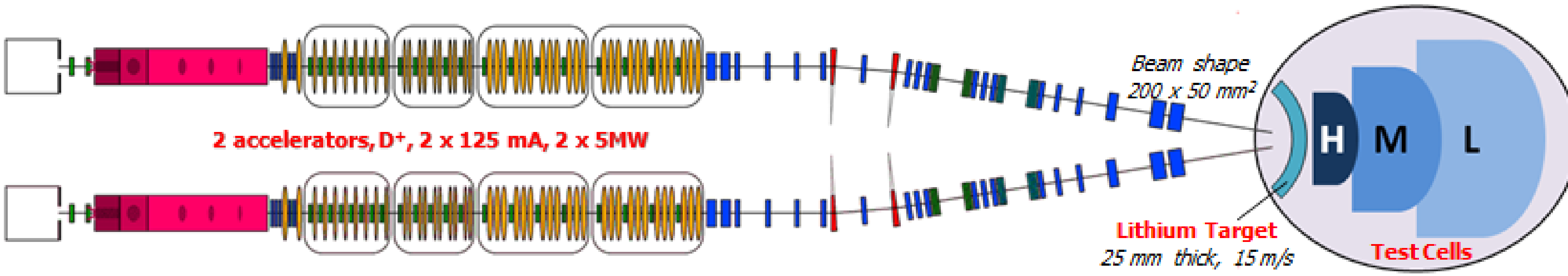
IFMIF PROJECT

Aim:
production of high neutron flux with same spectrum than futur fusion nuclear plants



The accelerator of all records

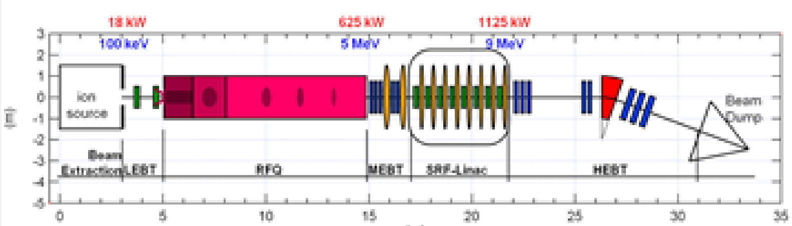
- The highest intensity
- The highest power
- The highest space charge
- The longest RFQ



IFMIF : International Fusion Materials Irradiation Facility
EVEDA: Evaluation Engineering and Design Activities

High >20 dpa/an, 0.5 L
Medium > 1 dpa/an, 6 L
Low < 1 dpa/an, > 8 L

Typical reactions
$^7Li(d,2n)^7Be$
$^6Li(d,n)^7Be$
$^6Li(n,T)^4He$



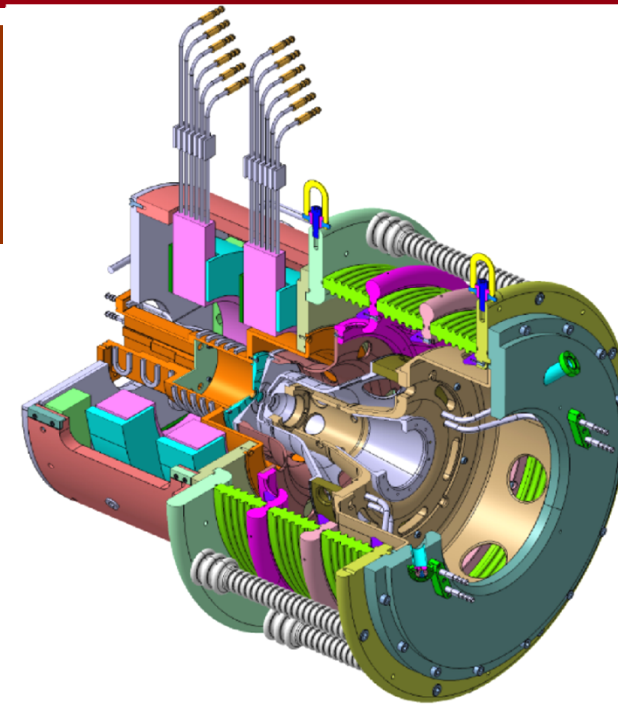
Full scale prototype 1.1 MW, Under construction

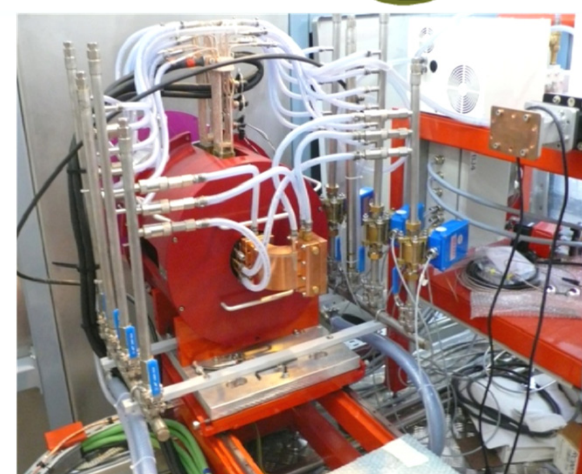
Rokkasho (JAPAN)

Request for IFMIF Injector

As previously shown , IFMIF is the machine
of all the challenges…
as soon as the exit of the source.

Requirements	Acceptance criteria	Comment
Particle type	**D^+**	H^+ for injector conditioning
Output energy **Energy stability**	**100 keV** **100 eV**	Fixed by the RFQ acceptance
Output D^+ current	**140 mA**	RFQ transmission $\geq$ 90%
Species fraction D^+	**$\geq$ 95 %**	At the output of the LEBT
Beam current noise	**$\leq$ 2 % rms**	At frequencies below ~1 MHz
rms norm. emittance	**$\leq$ 0.30 π mm mrad**	At the output of the LEBT
Duty factor	**CW**	Possibility of pulsed operation.
Modulation capability	**1 ms – CW @ 1-20 Hz**	Typically





IFMIF Injector has been designed, built and under test
at Saclay before shipment to Rokkasho site in Japan

2.45 GHZ ION SOURCE

Classical design
for high intensity
light ion beam
based on SILHI source

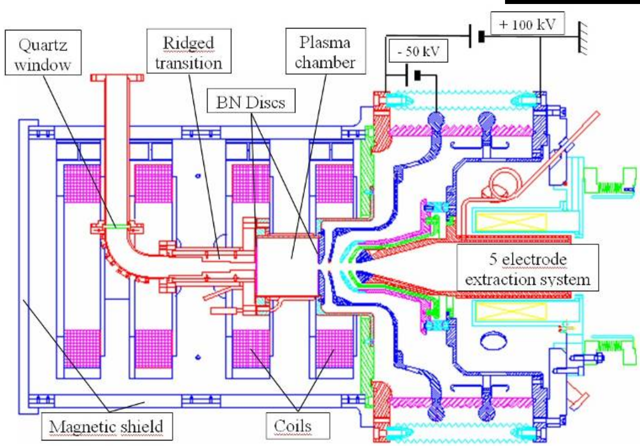
ECR Source → Resonance zone if $\omega = e\,B / m$

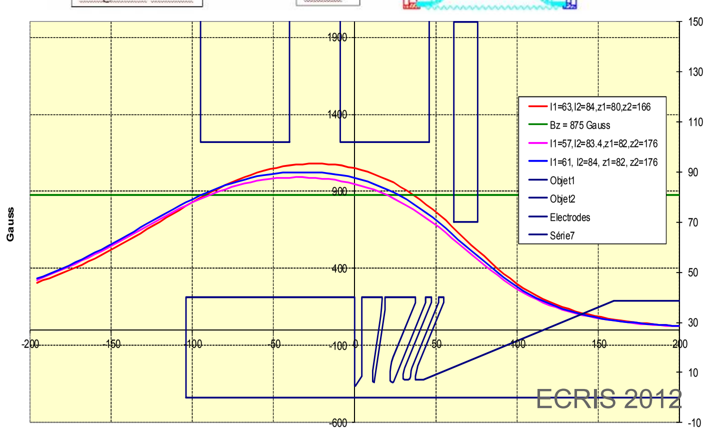
ω, pulsation
e, electron charge
B, magnetic field
m, electron mass

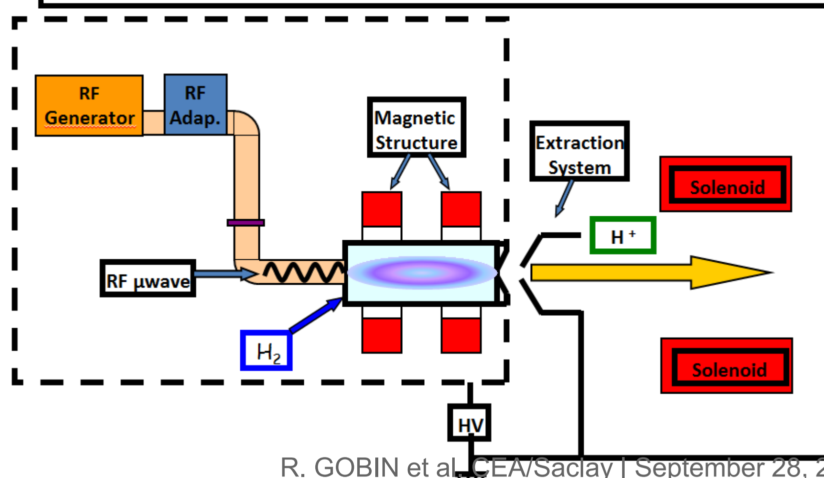
2.45 GHz → 875 Gauss

Magnetic field provided by coils
Multi-electrode extraction system

- Protection of the window
- Electron repeller
- Ridged or tapered transition on RF chain
- Ceramic disks to improve electron density
- Resonance value at plasma chamber entrance
- Negative Triple junction shielding







IFMIF Extraction System

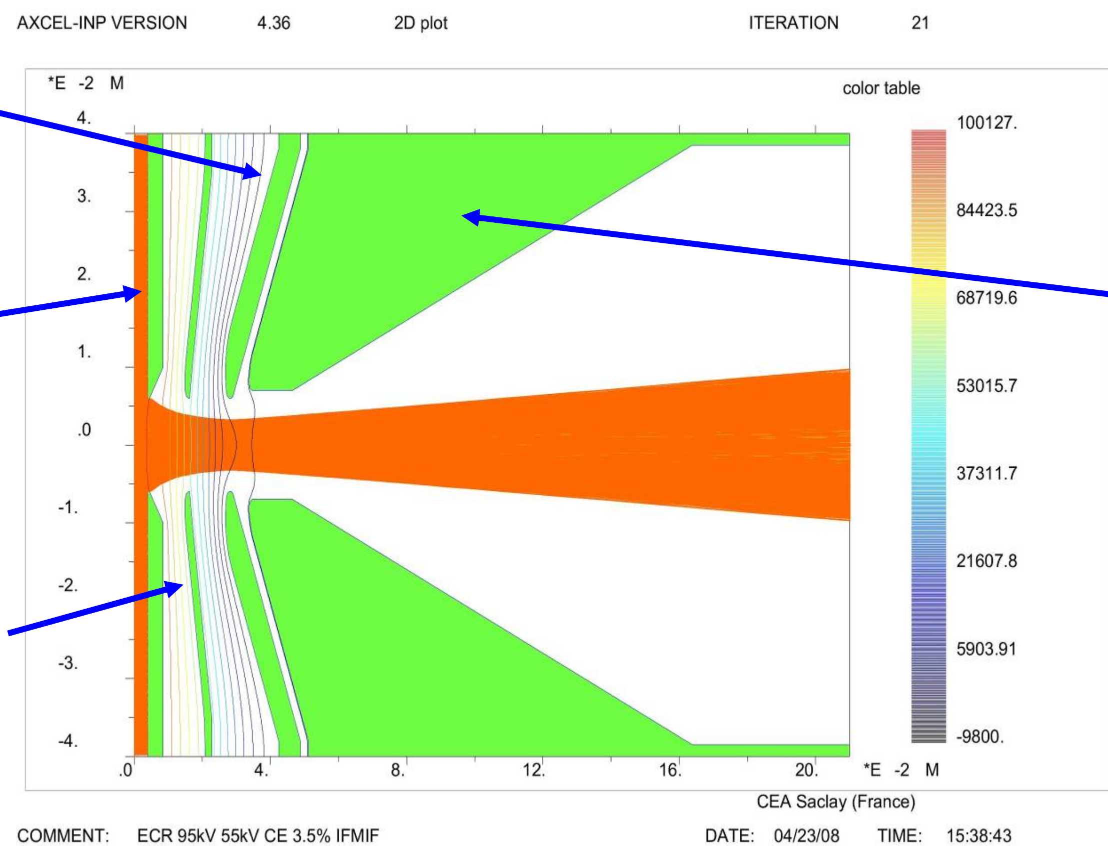
100 KeV, 175 mA total beam current, 1560 A/m² (Φ 12mm)

(80% D^+, 15% D_2^+, 5% D_3^+) ⇔ (140mA D^+, 26 mA D_2^+, 9 mA D_3^+)

e- screening electrode
Φ12mm
-9.8 kV

Plasma electrode
Φ12mm
45° angle
100 kV

Intermediate electrode
Φ12mm
Adjustable
57 kV



Grounded electrode
Φ14mm
0 kV

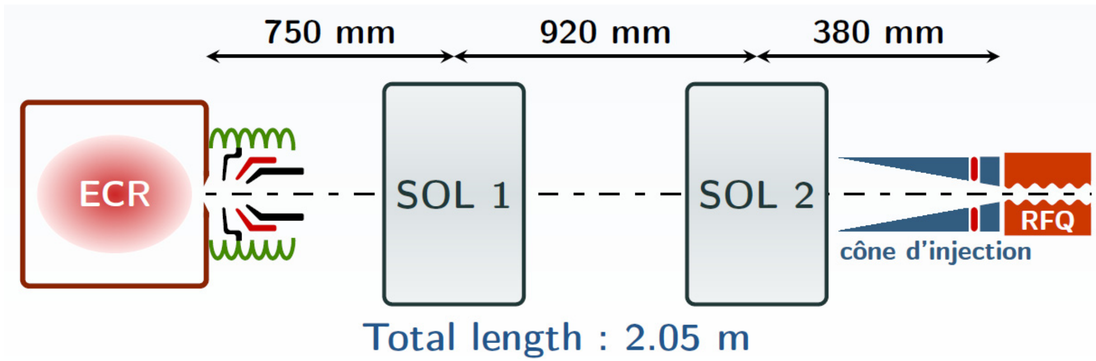
From *Child-Langmuir law*, we can calculate the *space charge limited beam current* :

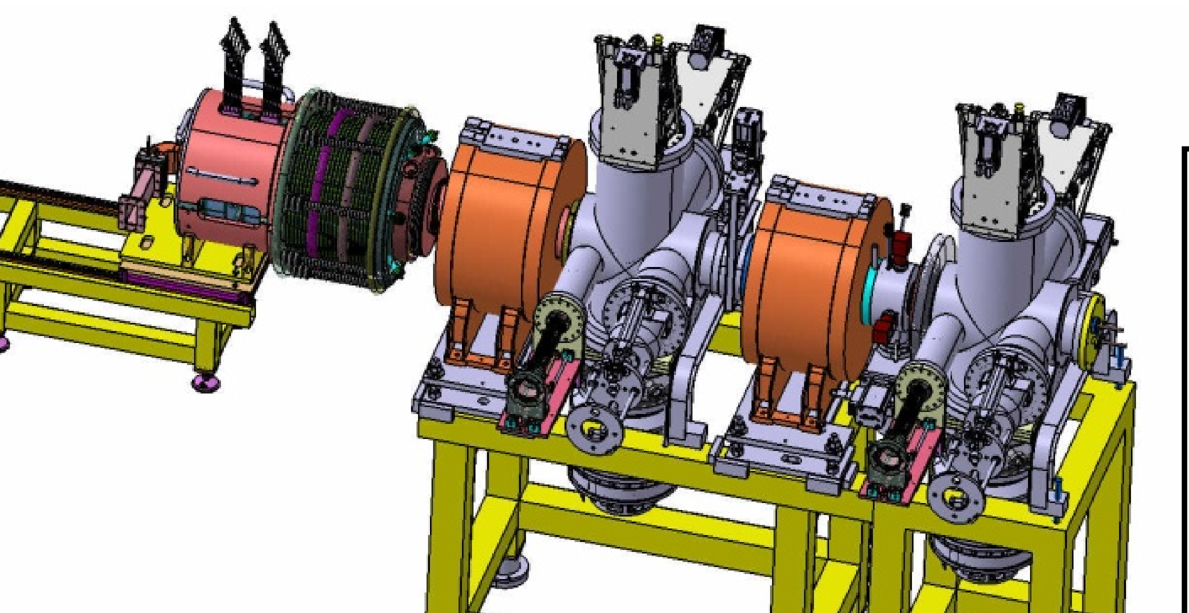
$$I = \frac{4\pi}{9}\epsilon_0 \left(\frac{2q}{m}\right)^{1/2} \frac{V_0^{3/2} r_s^2}{d^2} \quad [A]$$

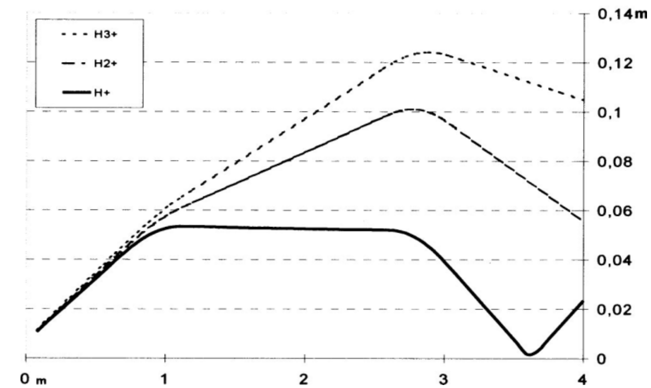
IFMIF: rs=6 10-3m, d=25mm, V0=100000 V,
q/m(D+)=4.79 107, 4pe0/9=1/81*10-9

I=3.8212*(rs/d)²=0.220 A

LEBT DESIGN







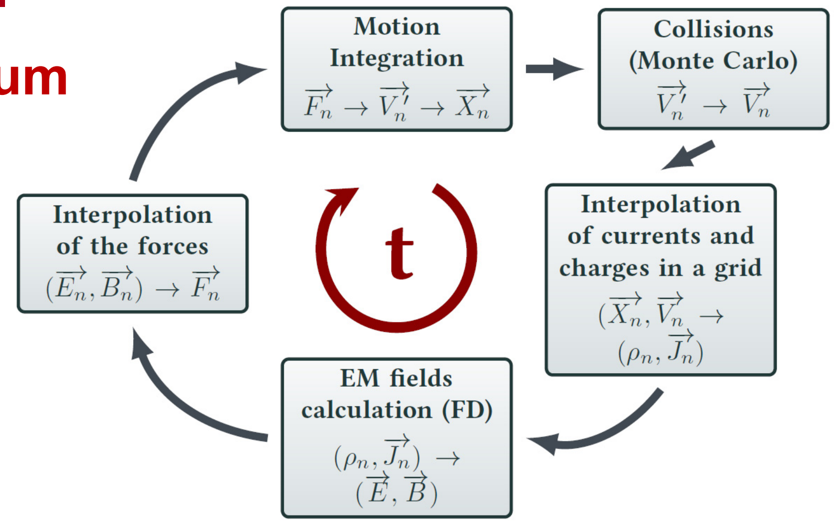
SILHI hydrogen beam envelops

- 2 solenoids design LEBT
- RFQ entrance cone
- Short LEBT to minimize emittance growth
- 2 TM pumping system
- Added Kr injection
- Limited space for diagnostics

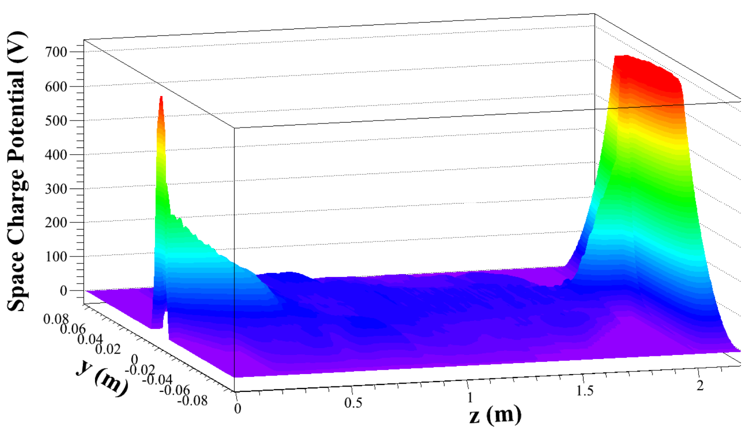
Space Charge Compensation

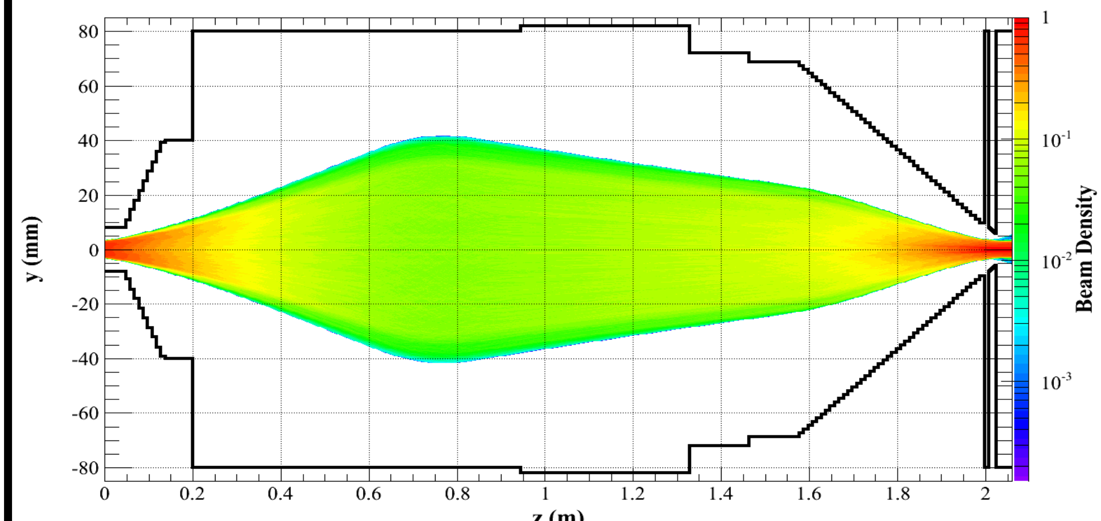
Time is needed to reach SCC equilibrium

Dedicated code **SOLMAXP**
(R. Duperrier et al.)
has been developed at Saclay
to take into account
the space charge compensation evolution



SOLMAXP gives the SC potential map
allowing calculation
of SC electric field map

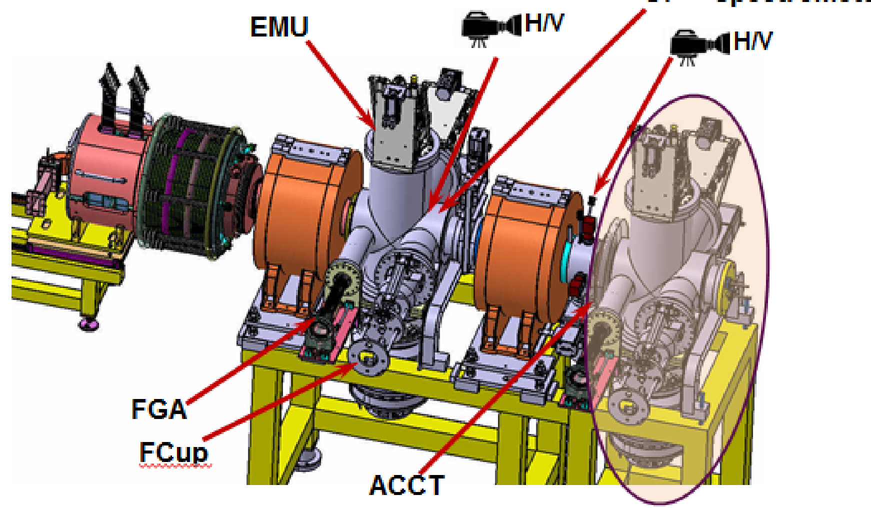


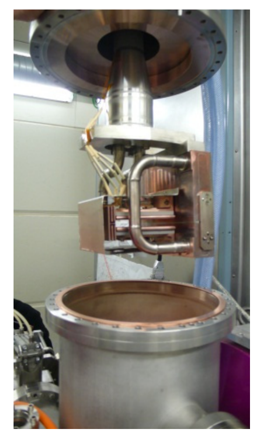


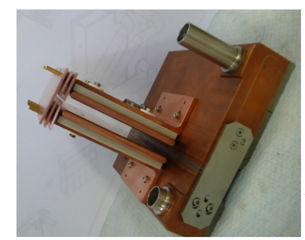
t = 20 μs

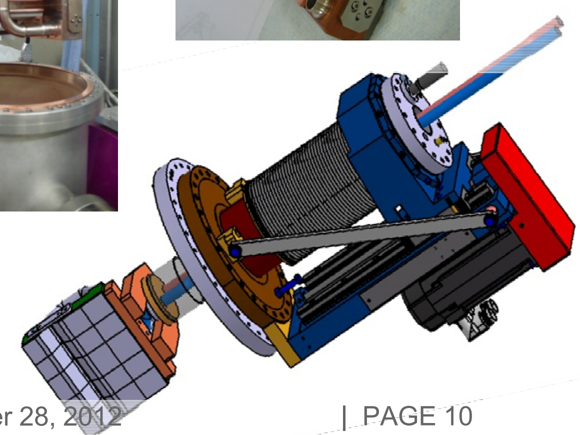
INJECTOR DIAGNOSTICS

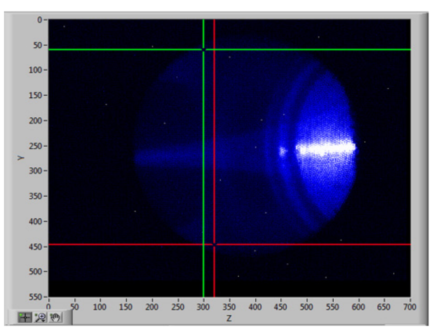
- Thermocouples
- EMU – Allison scanner designed for 15 kW continuous beam
- 4 Grid Analyzer
- CID (hardened) cameras
- Spectrometer associated with optic fiber for Doppler shift analysis
- A large ACCT installed at the RFQ entrance with specific magnetic shielding





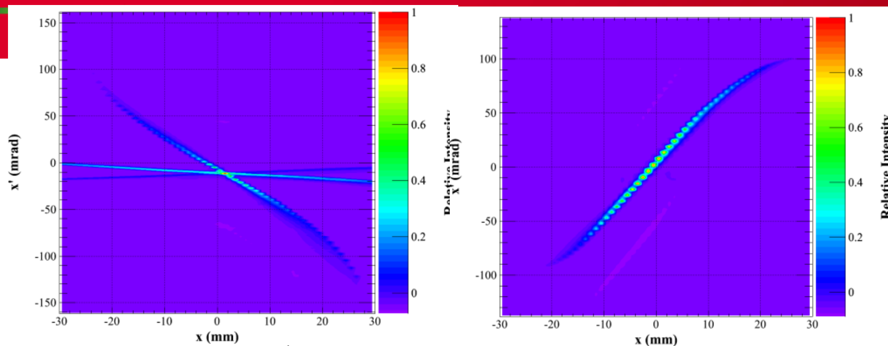






72 mA IFMIF Beam observed at 30° with a 20 m long FUJIKURA fiberscope

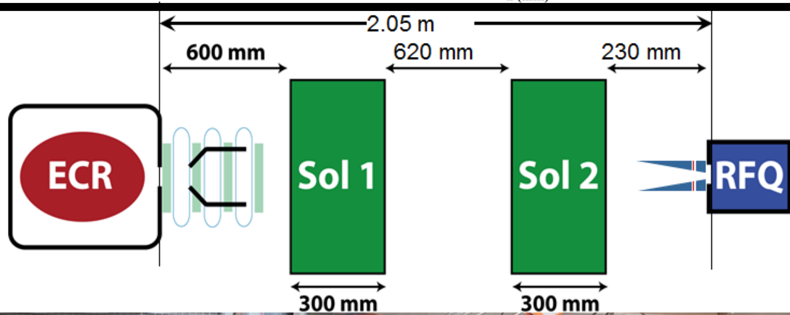
PROTON BEAM CHARACTERIZATION

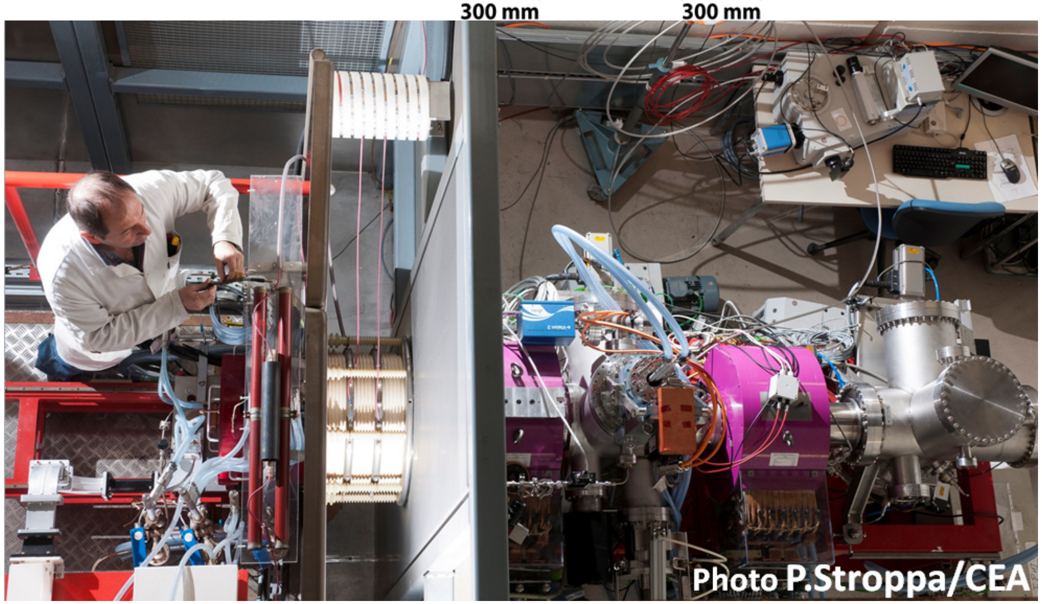


CW 50 keV H+ beam - **PE Φ 8**

Emittance:

- After Sol1, 81 mA, 0. 46 π.mm.mrad
- After cone, 42 mA, 0.29 π.mm.mrad



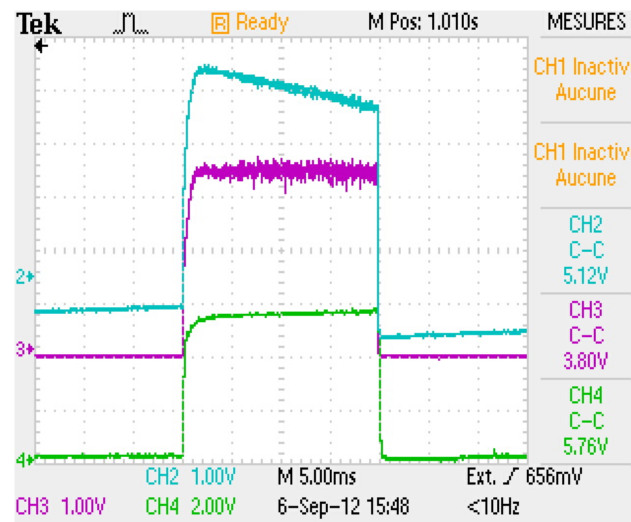


Plasma Electrode Φ 10

$I_{ext.}$ = 140 mA

I_{BS} = 75 mA (with cone)

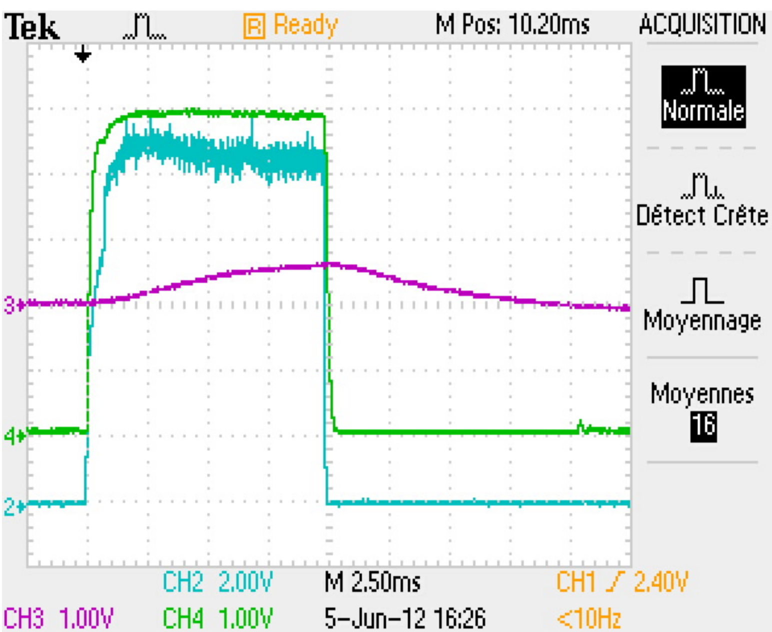
50 keV DC = 20 %



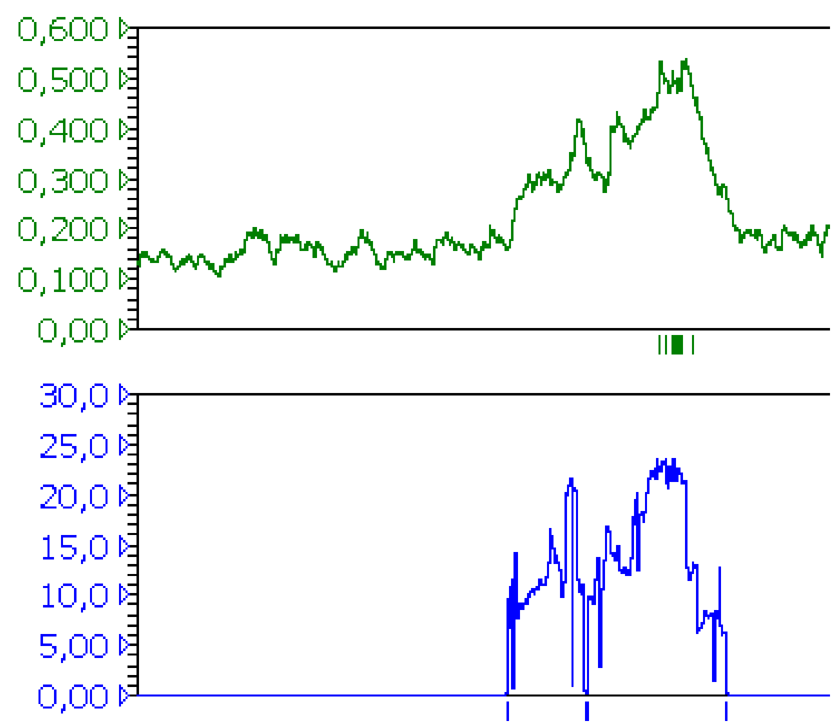
1ST DEUTERON BEAM

Due to neutron production (d,D reaction) preliminary measurements are done with 1 % duty cycle (10 ms / 1 Hz).

125 mA extracted from the source with100 keV energy



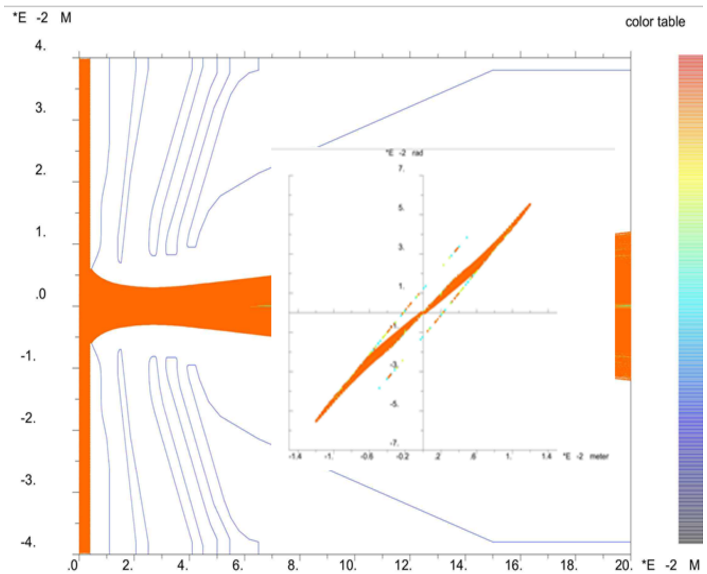
Green: current from HVPS
Blue: current on Beam Stop (w/o cone)

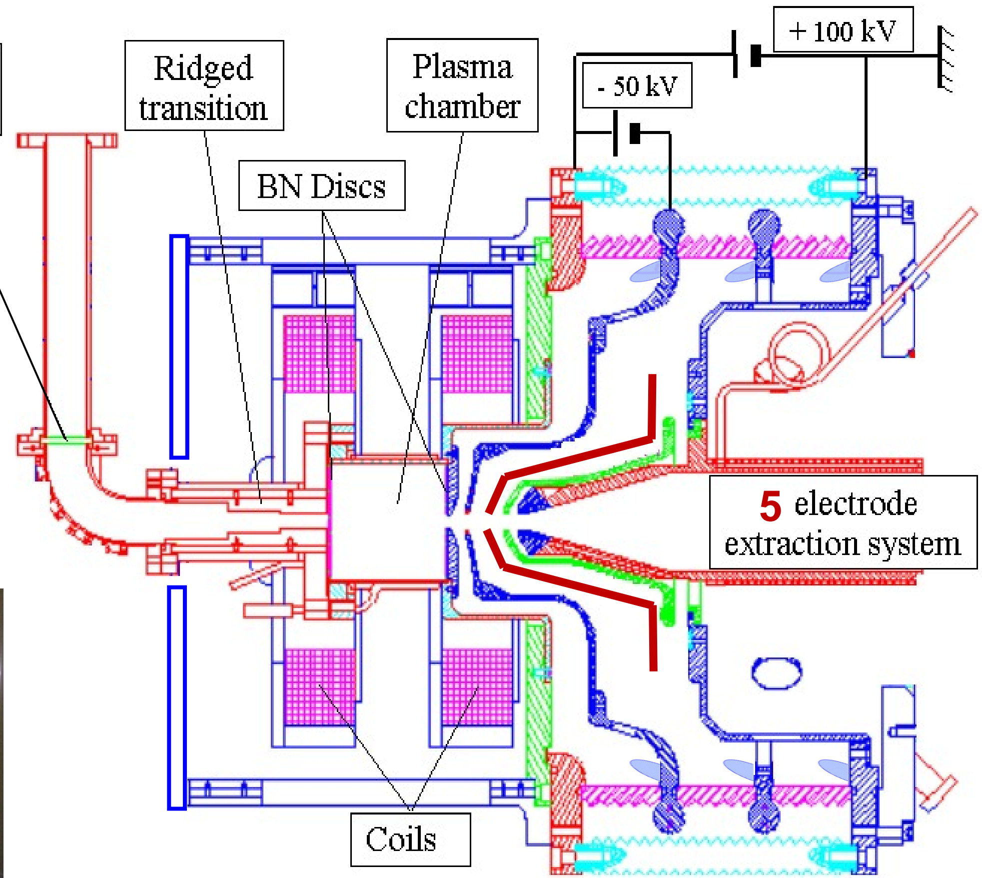


Green: X-ray probe
Blue: Neutron probe

ONGOING ACTIONS (1)

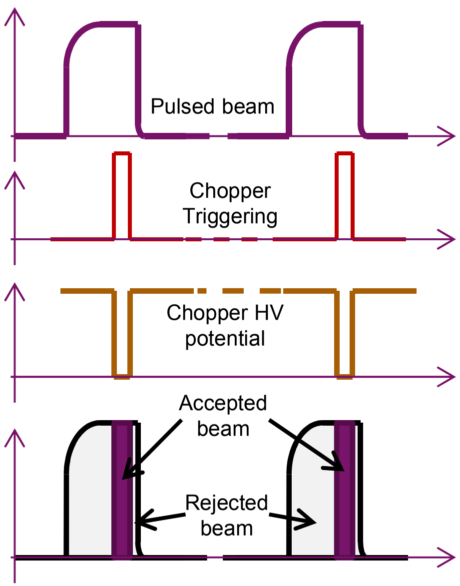
Tests at high energy (100 kV) showed high spark rate.
The installation of a 2nd grounded electrode
(between puller and repeller) has been made last week.

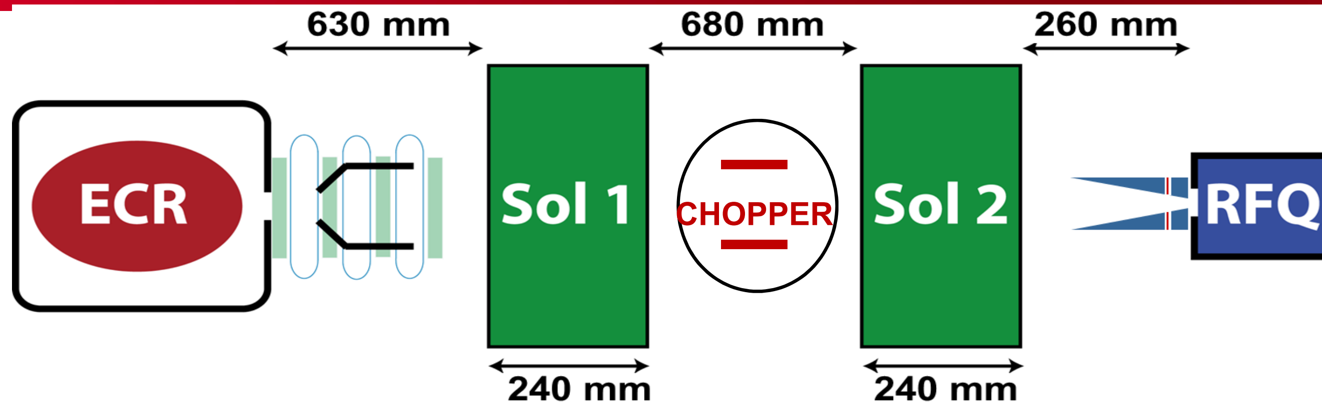


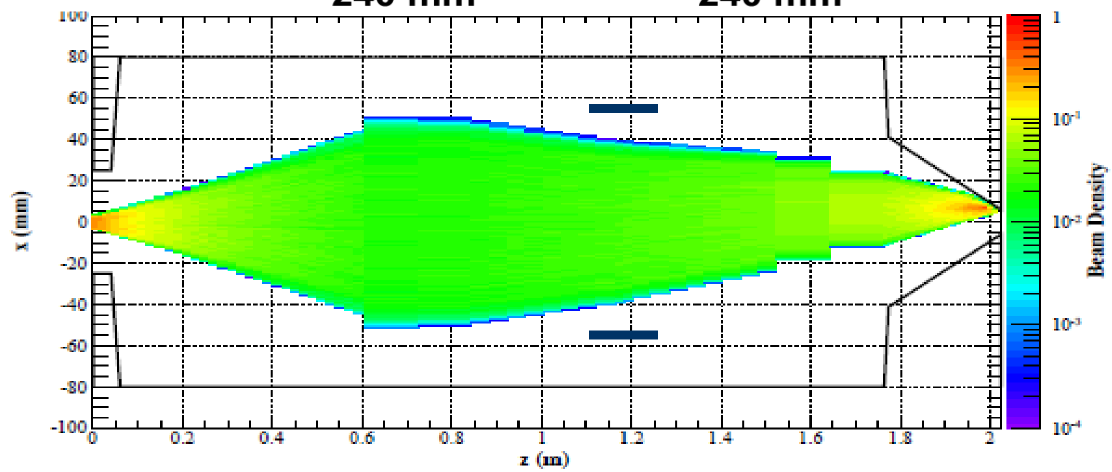


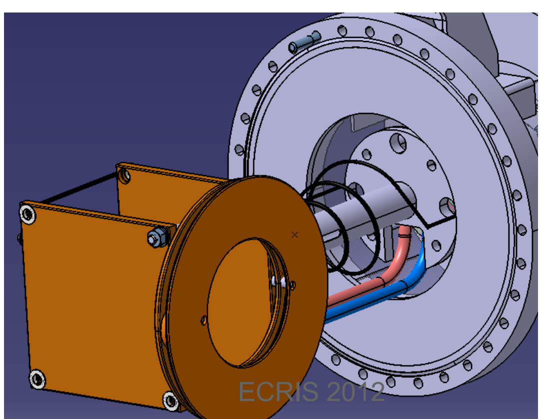
ONGOING ACTIONS (2)

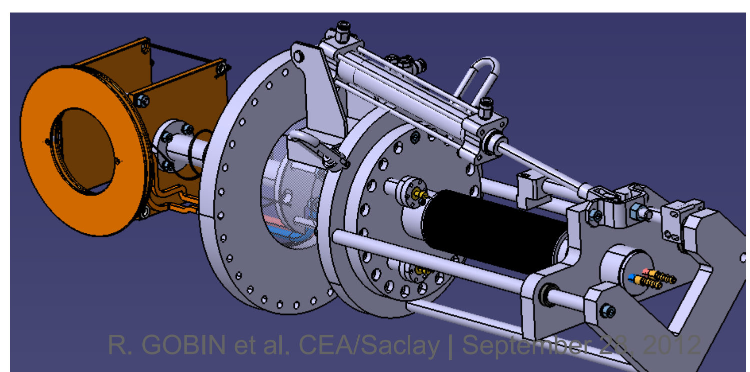
Slow Chopper
for high energy beam
characterization









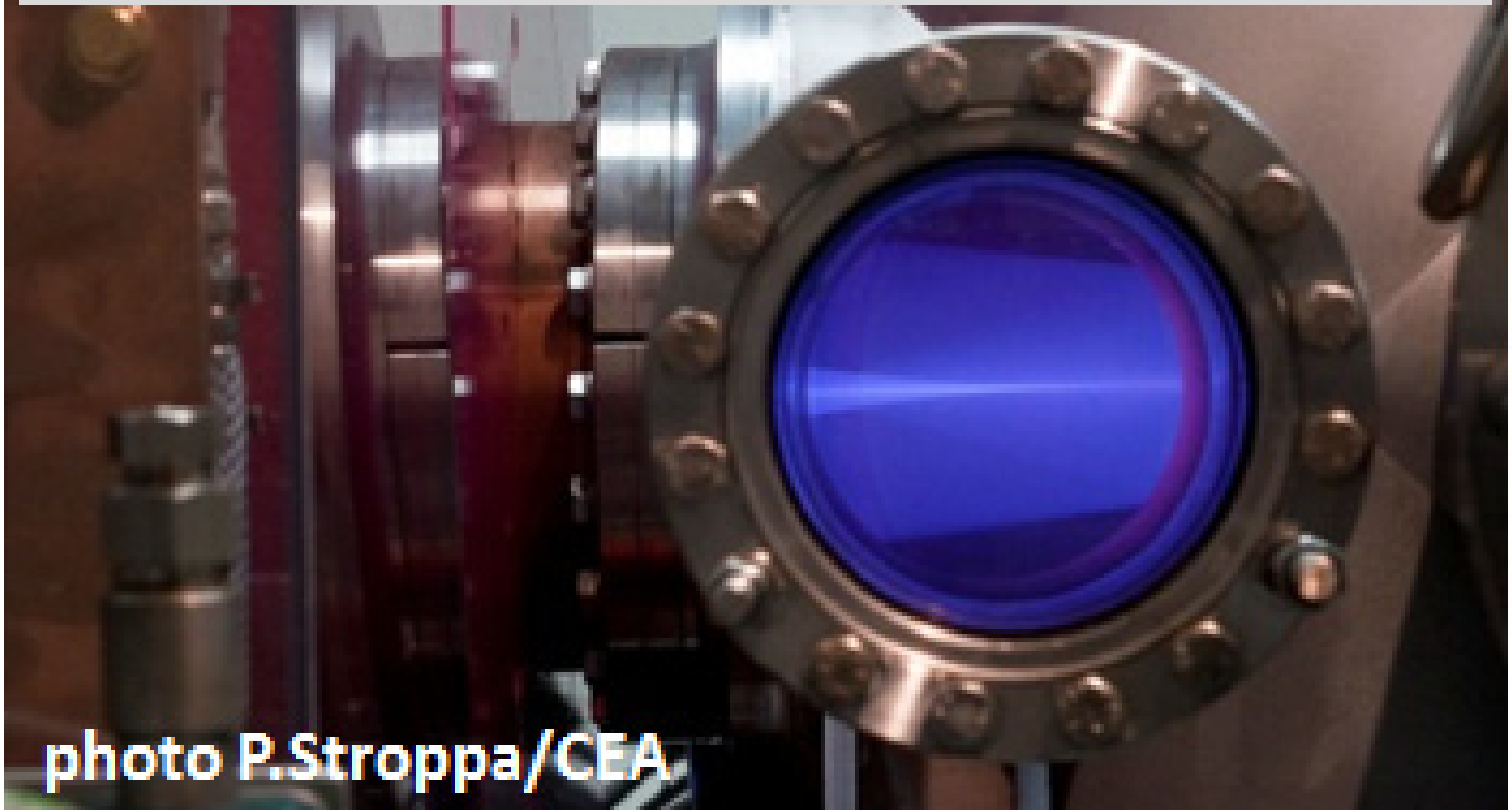


CONCLUSION

- Preliminary measurements performed with the IFMIF injector proton beams proved the expected challenges start immediately at source extraction and beam transport at low energy
- Beam optimization and characterization with the 5 electrode extraction system is expected in the next weeks
- Deuteron beam characterization before the end of 2012
- IFMIF injector transfer to Japan before summer 2013

= very challenging program

Thank you for your attention



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