ECR Ion Sources R&D at LPSC* - Grenoble

** Laboratoire de Physique Subatomique et de Cosmologie*

T. Lamy

J. Angot, M. Marie-Jeanne, T. Thuillier, P. Sortais

Where, who, which ?

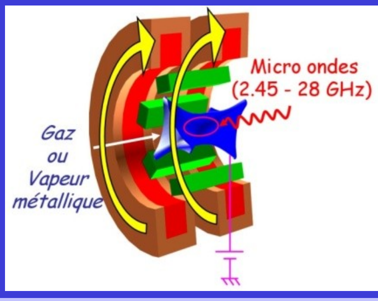
- LPSC (CNRS-IN2P3, UJF, INPG)

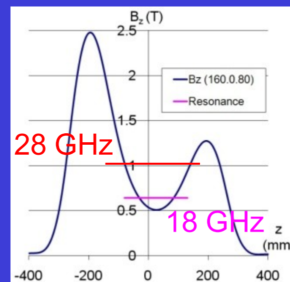
Laboratoire de Physique Subatomique et de Cosmologie Grenoble
  - 225 persons, 105 technical staff
  - Particle Physics, Cosmology, Nuclear Physics, Accelerators, Applications (energy production, medicine), industrial collaborations

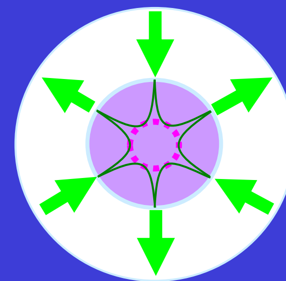
- Accelerator and Ion Sources Pole, 20 persons (6 fixed term contract)
  - Resources
    - Technical
      - 7 beam lines
      - Radio frequency laboratory and clean room
      - surface treatment laboratory
    - Financial
      - CNRS/IN2P3, European programmes, Research National Agency (ANR), projects
    - 10 persons for ECR Ion Source R&D activities

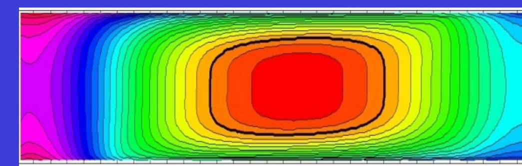
ECR Ion sources

- Present high performance ECR ion sources





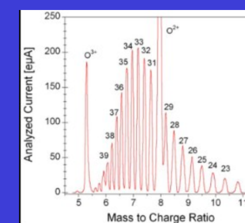




$\omega_{ce} = q_e B / M_e = \omega_{HF}$

B axial + B radial = Minimum B

- Expected for Physics
  - Higher and higher intensities... (1 mA Ar^{12+})
  - Higher and higher charge states... (500 mA U^{35+})
  - Increase of the ECR frequency in order to increase the plasma density



$I \propto \omega_{HF}^2 M_i^{-1}$

- Beyond the state of the art
  - Presently no real **experimental** R&D programme in the world
  - Superconducting prototypes (18 + 28 GHz) US – China - Japan
  - Higher frequencies prototype simulations (56 GHz)

- No novel concept

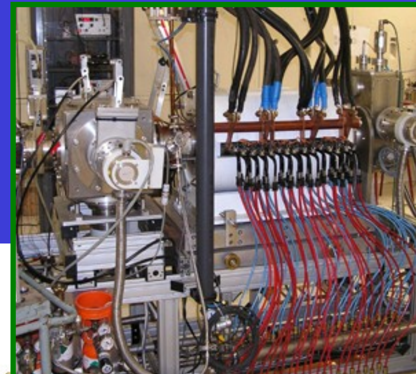
ECR Ion sources for Accelerators (I)

- SPIRAL2

High intensity stable ion beams

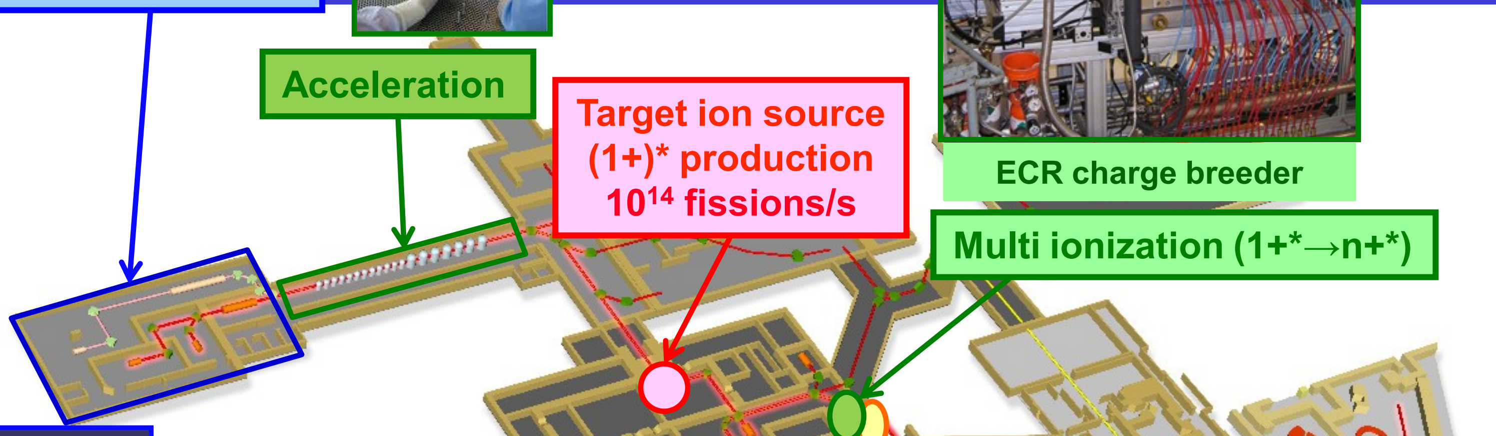
Acceleration

Target ion source (1+)* production 10^{14} fissions/s

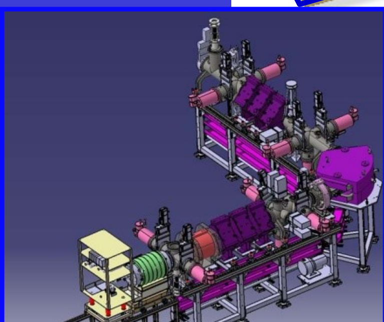


ECR charge breeder

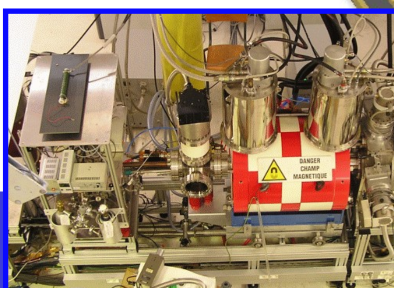
Multi ionization (1+*→n+*)



(n+)* acceleration



LEBT construction and tests

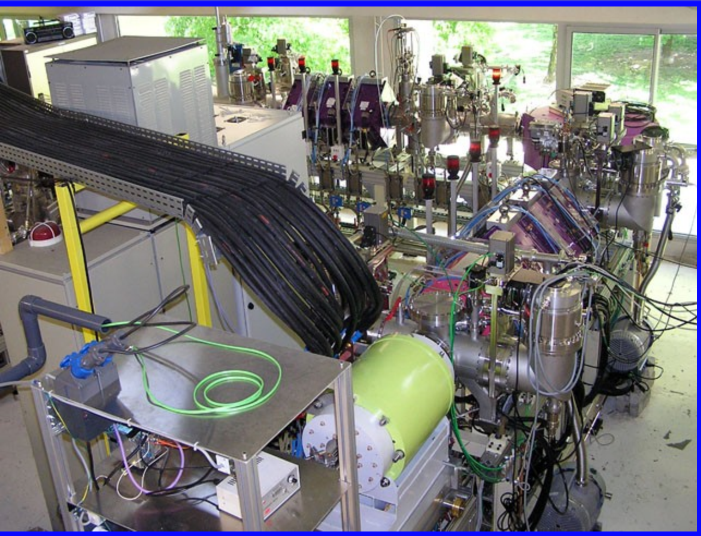


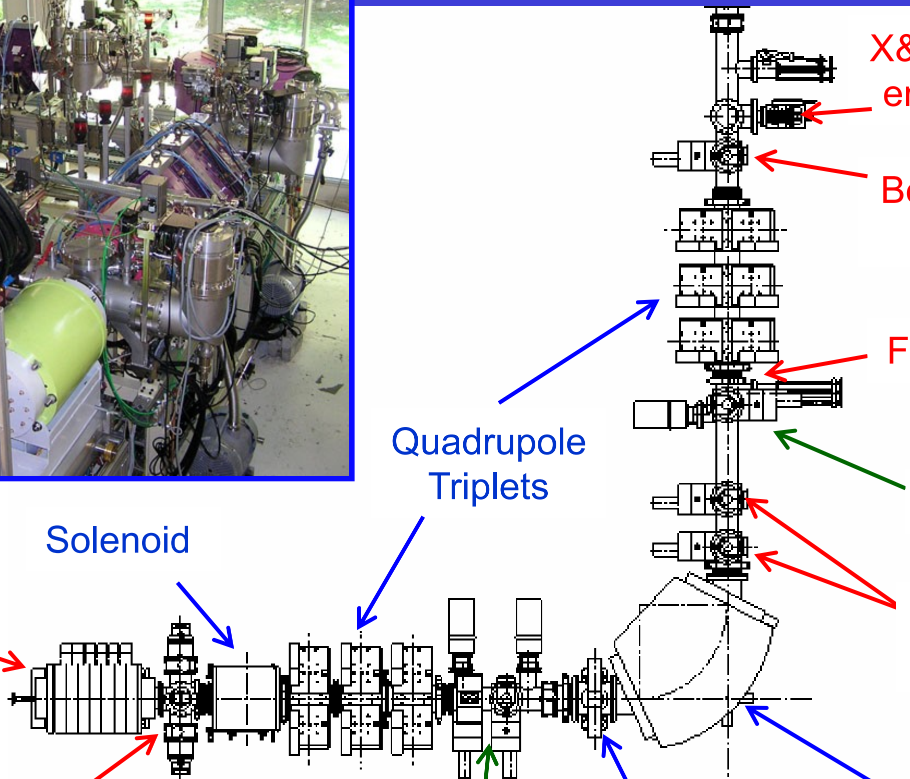
Ion source Q/A=1/3 development

Vertical N+ line design

ECR ion sources and beam lines

- ECR ion sources developments require efficient beam lines
  - Ex.: SPIRAL2 Low Energy Beam Line and the PHOENIX V2 ECR ion source





Design CEA Saclay, GANIL, IPNO

Ø 150 mm pipe, UHV
T=100 %
0.4 π.mm.mrad
(norm RMS)

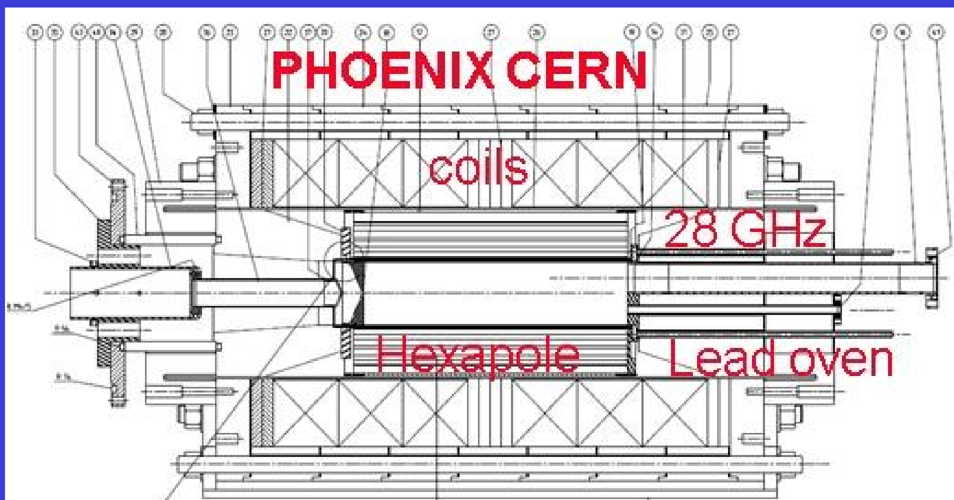
Assembled at LPSC
June 2008 – End 2009
First beam May 2009

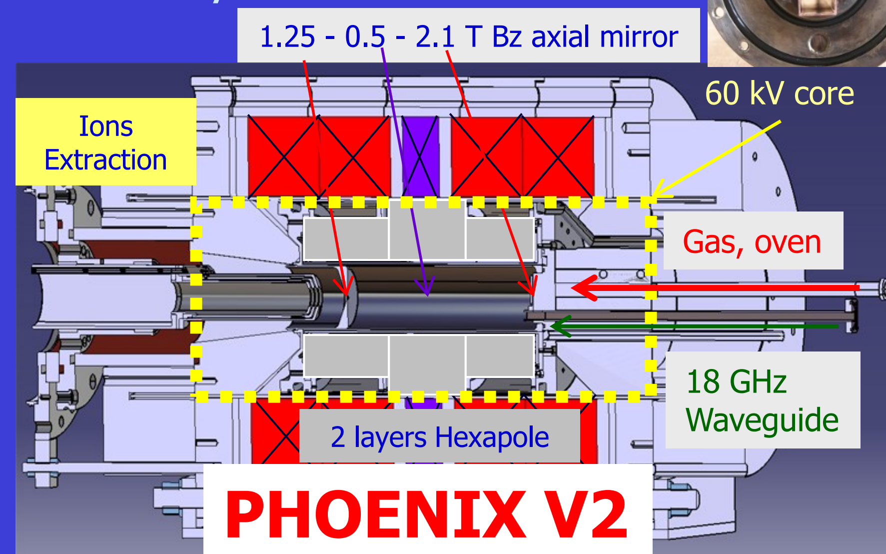
Commissioning
Ar, O, Xe

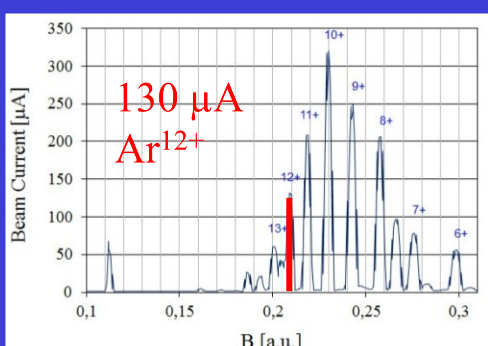
EPICS control command

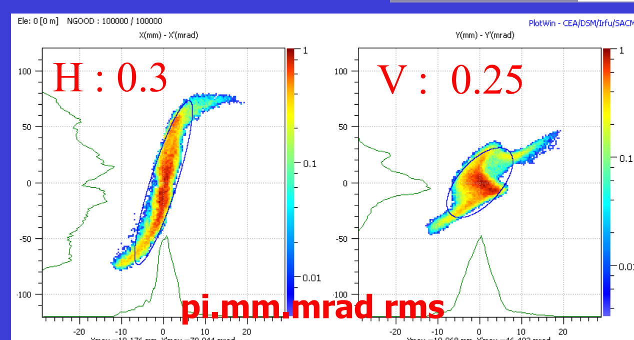
ECRIS PHOENIX V2 (18 GHz) and LEBT

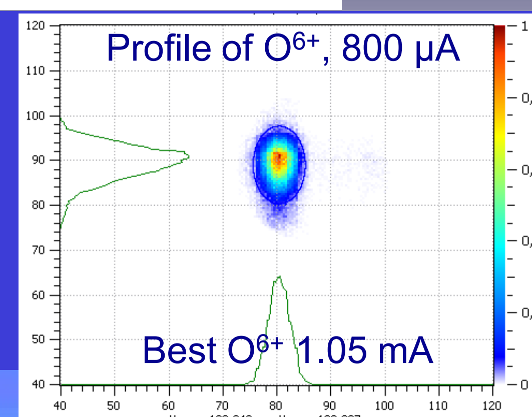
- PHOENIX source (developed for pulsed LHC beams)
  - Improved magnetic field (axial 1.7 2.1 T, radial 1.2 1.35 T)
  - Bias disk, Al plasma chamber, 60 kV extraction system …



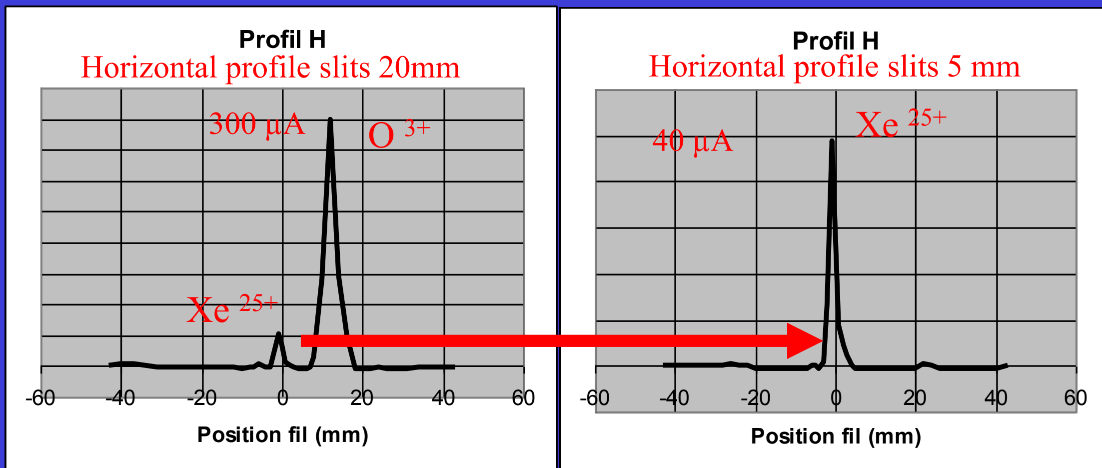


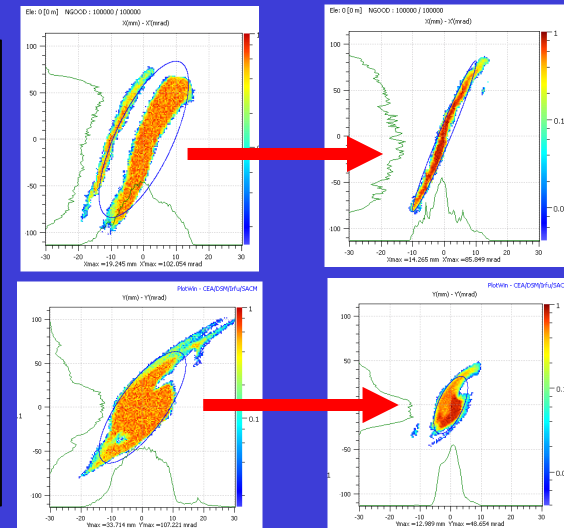






Beam line transmission and resolution



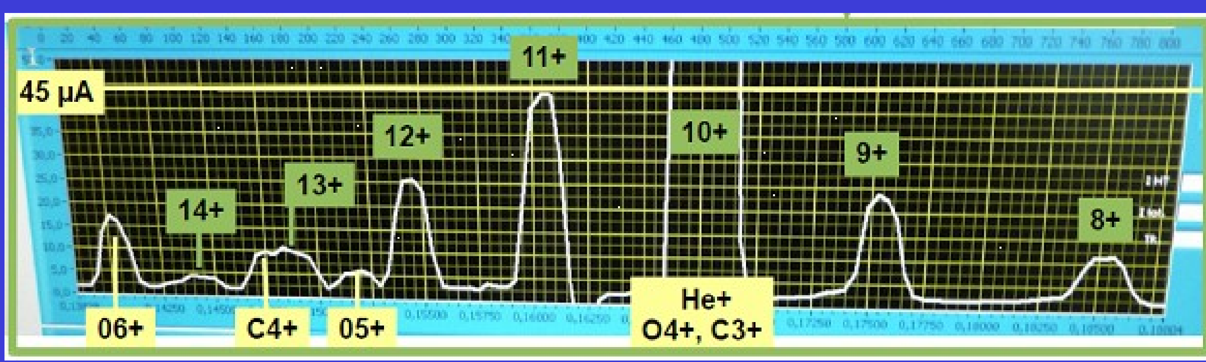


T= 95%

R= 1%

Calcium beams

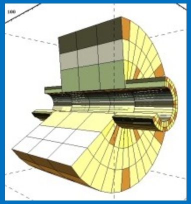
- GANIL high capacity ovens

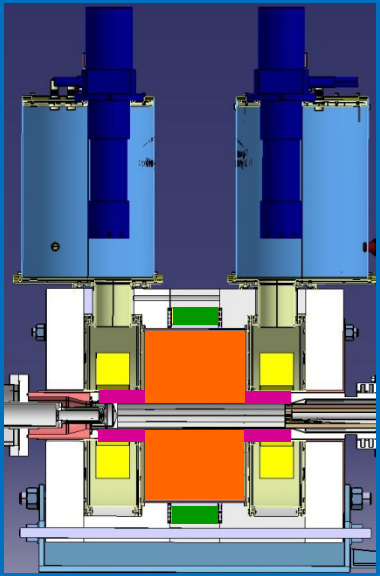


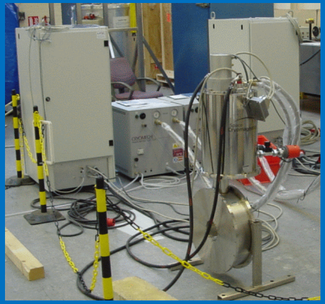
25 µA $^{40}Ca^{12+}$
Without optimization

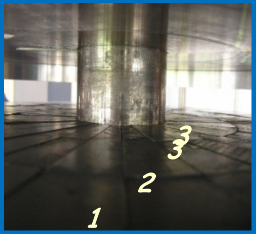
A-PHOENIX Hybrid 28 GHz ECRIS

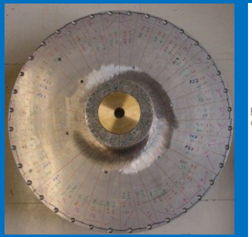
- A hybrid ECRIS :
  - 2 HTS He free coils
  - Largest permament magnet hexapole, 2 small ones under HTS coils
  - 1 room temperature Coil

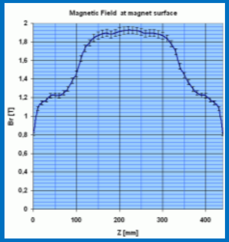




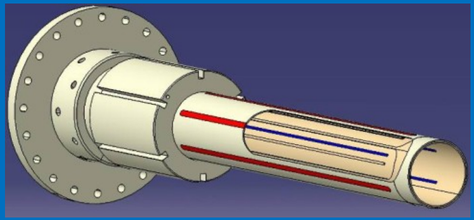


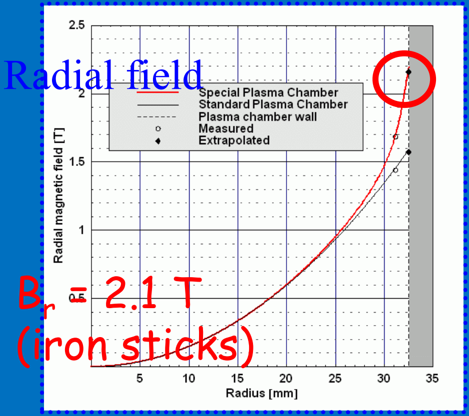


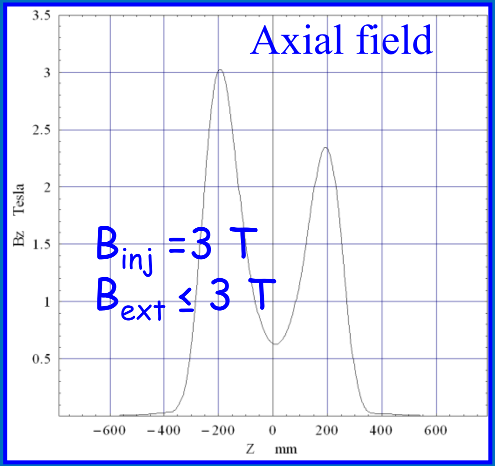




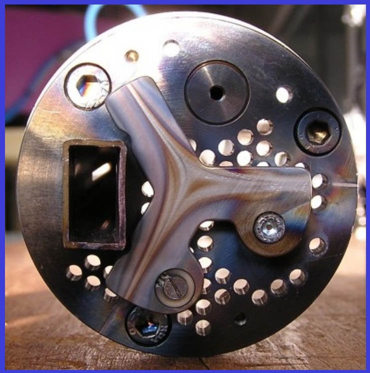
- B_{radial} > 1.9 T at magnets, 1.55 T at plasma chamber walls



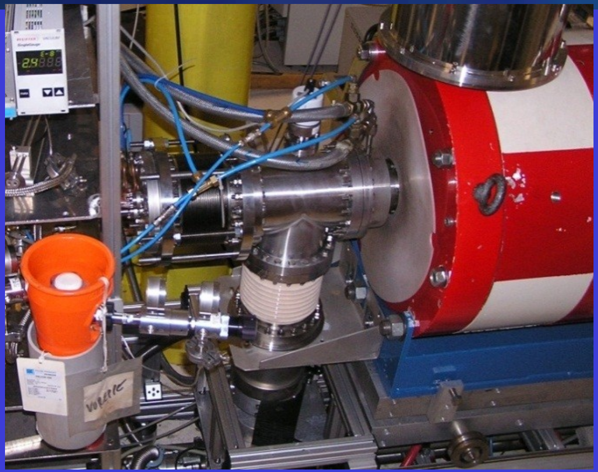




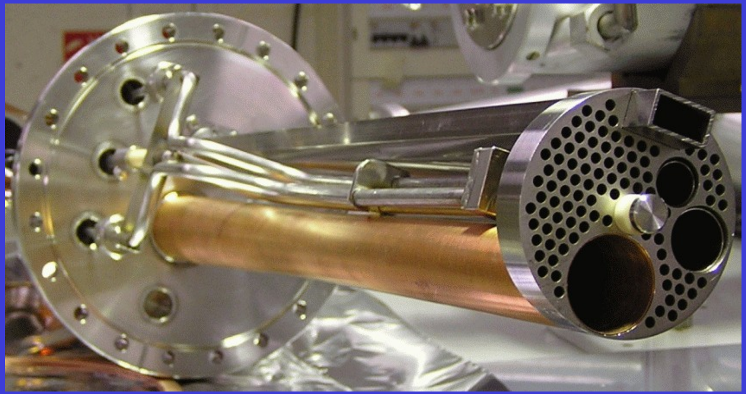
A-PHOENIX details



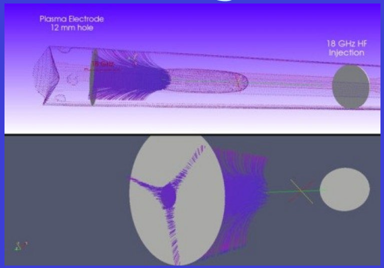
18 GHz injection flange

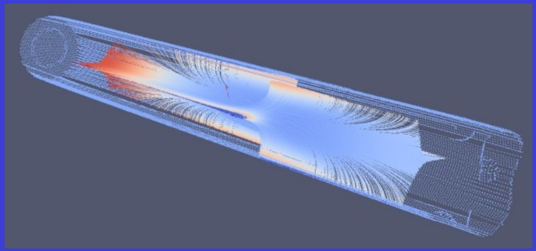


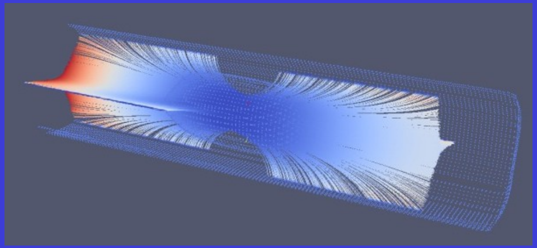
Moveable injection flange



18 GHz + 28 GHz Injection flange





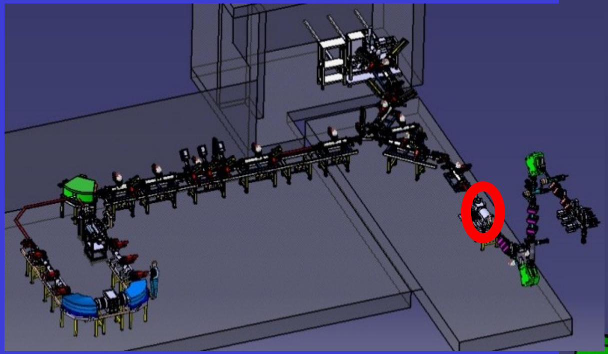


- Soon tested at 28 GHz
- SPIRAL2 commissioning with PHOENIX V2 or A-PHOENIX prototype
- New project for a fully superconducting 28 + 18 GHz ECR ion source
  - Within FP7 **C**luster of **R**esearch **I**nfrastructures for **S**ynergies in **P**hysics

PHOENIX ECR charge breeder

- Initially developed at LPSC
- SPIRAL2 and SPES – INFN/LNL charge breeders to be built at LPSC
- On going R&D with SPES – INFN/LNL, collaboration projects (ANR, NuPNET)

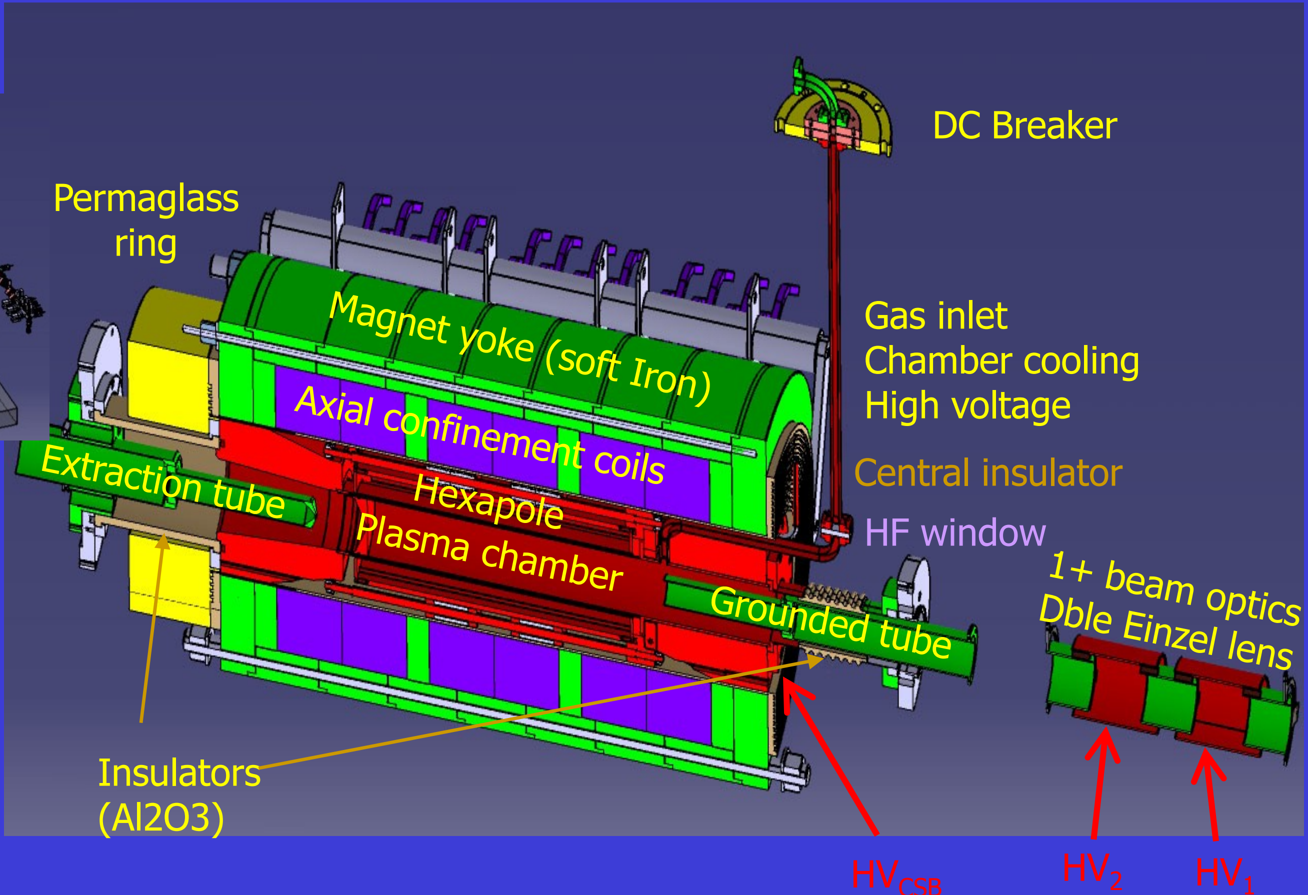
➢ Initial configuration



➢ Efficiency

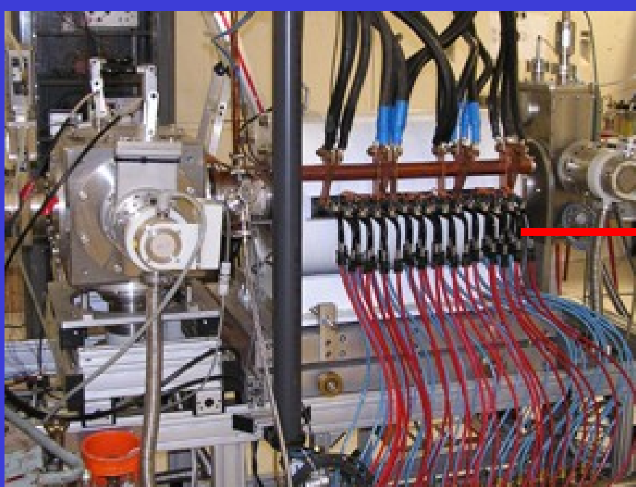
$$\eta_q = \frac{I(q+)}{q \times I(1+)}$$

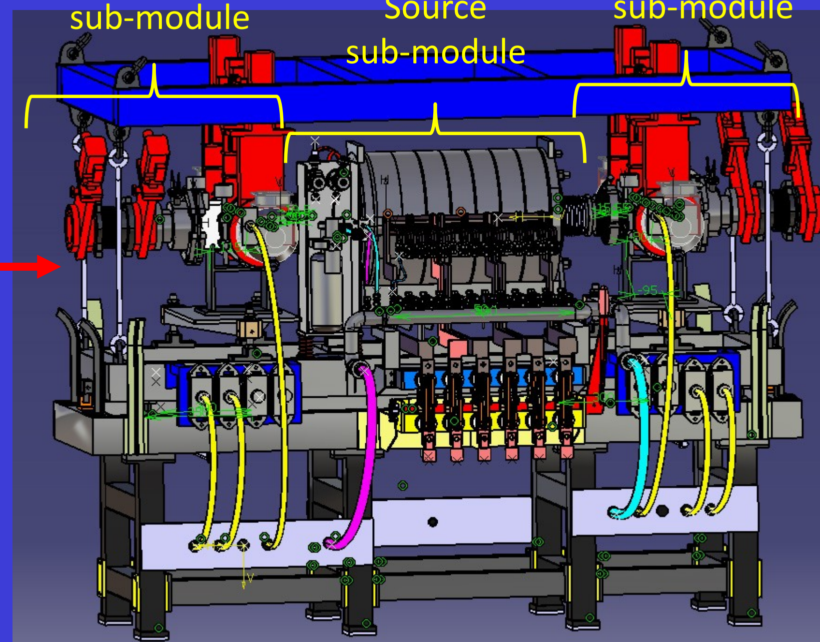
➢ Charge breeding time



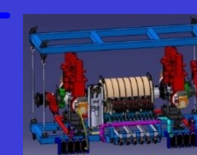
SPIRAL2 charge breeder nuclearization

- Due to potential high radioactivity: 'nuclearization' of the charge breeder
  - Increase reliability of critical components, strengthen weak parts
  - Decrease the time necessary for maintenance operations (yellow zone)
  - Study all maintenance operations

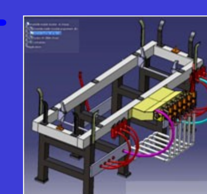




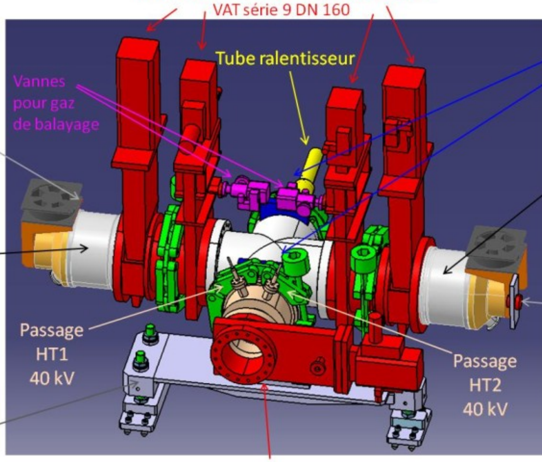
Module (mobile)



Frame (fixed)

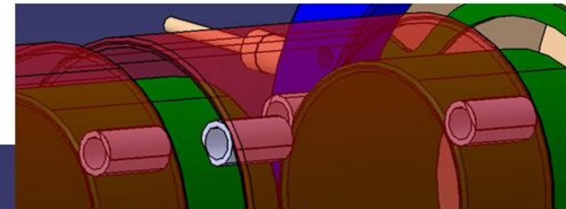


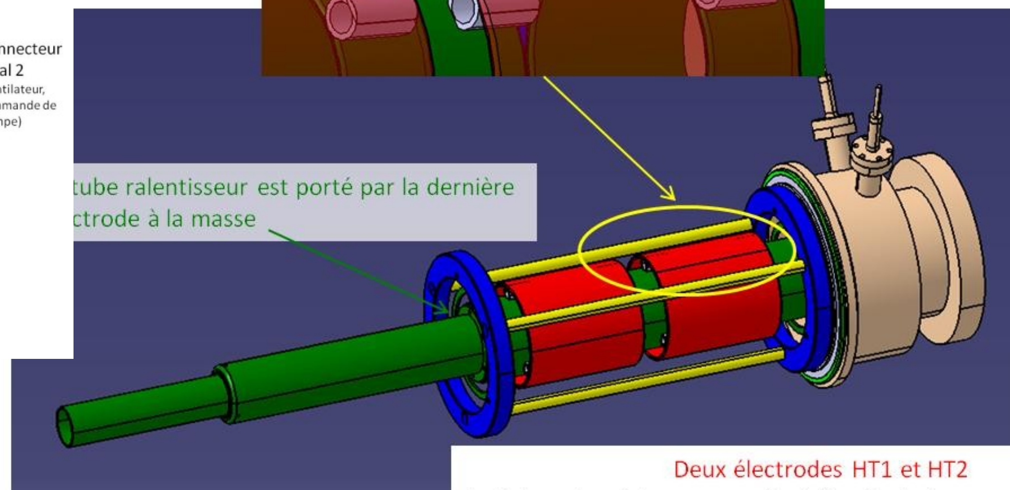
CSBreeder injection submodule details

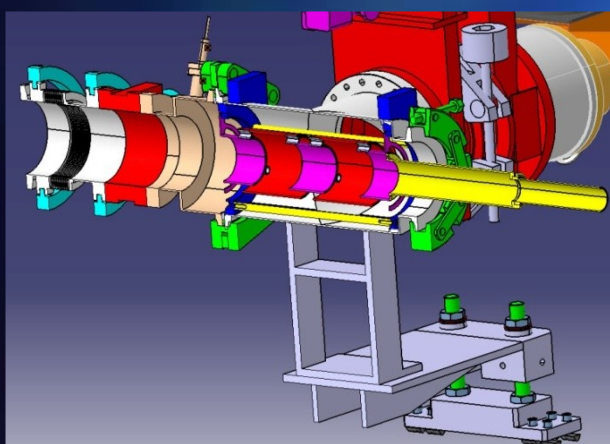


Il manque une (ou deux, redondance ?) jauges secondaires sur le caisson

Electrodes auto alignées mécaniquement



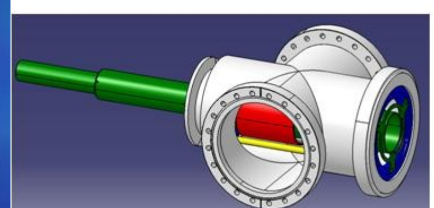




Deux électrodes HT1 et HT2

les tubes de guidages pourraient être isolants,
une âme centrale amenant la HT sur chaque électrode

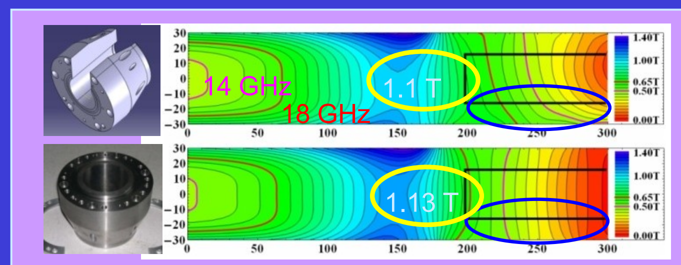
Il faudra ramener la masse physiquement sur les électrodes vertes
(un passage de masse pourrait être utile en plus des passages HT)



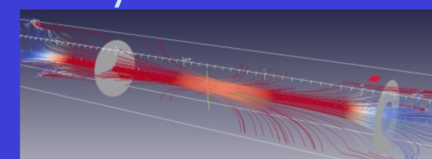
L'ensemble est glissé dans le caisson et vient se caler au fond sur la bride d'extrémité gauche
(question de la faisabilité de ce centrage...?)

Charge breeder R&D

- 'Laboratoire Européen Associé' COLLIGA agreement
  - INFN-LNL **neutron convertor** to SPIRAL2 ↔ IN2P3-LPSC **charge breeder** to SPES
    - Scientific collaboration – Conceptual design of the SPES charge breeder
    - Design and construction by LPSC – joint tests and commissioning

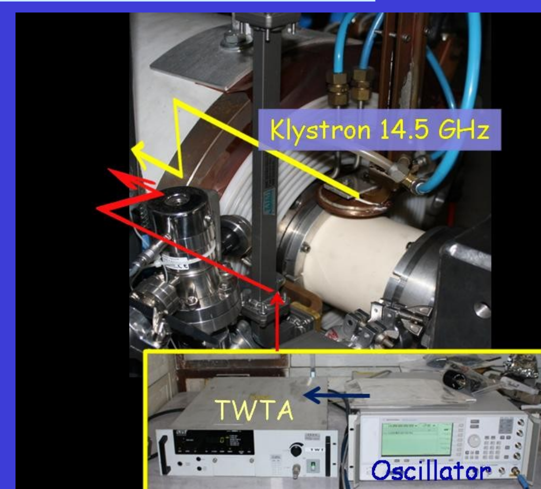


Magnetic field symetrization



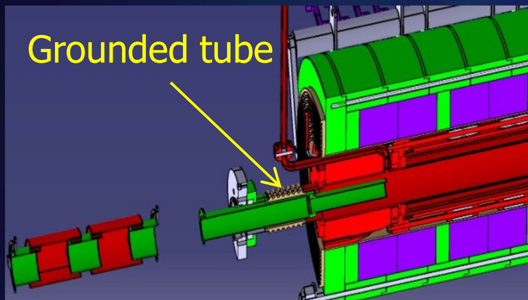
Fine frequency tuning, known in ECRIS
To improve efficiency

Traveling **W**ave **T**ube **A**mplifier
13.75 -14.5 GHz
input -17 dB (20µW)
Max Power 400 W

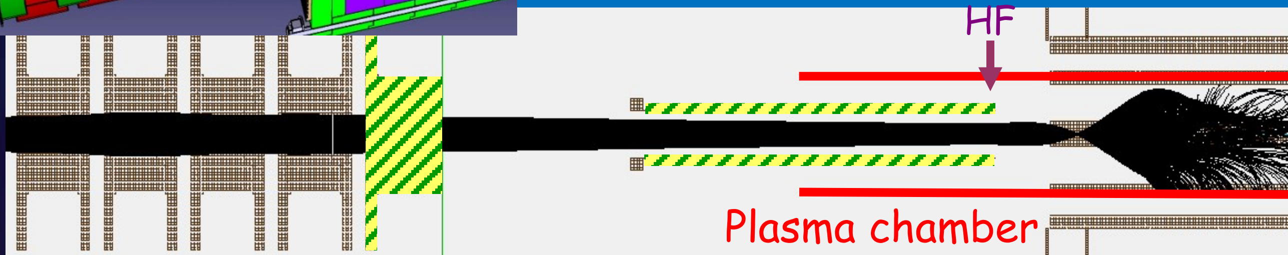


No
clear improvement
In present
Charge breeder
(due to grounded
Tube ?)

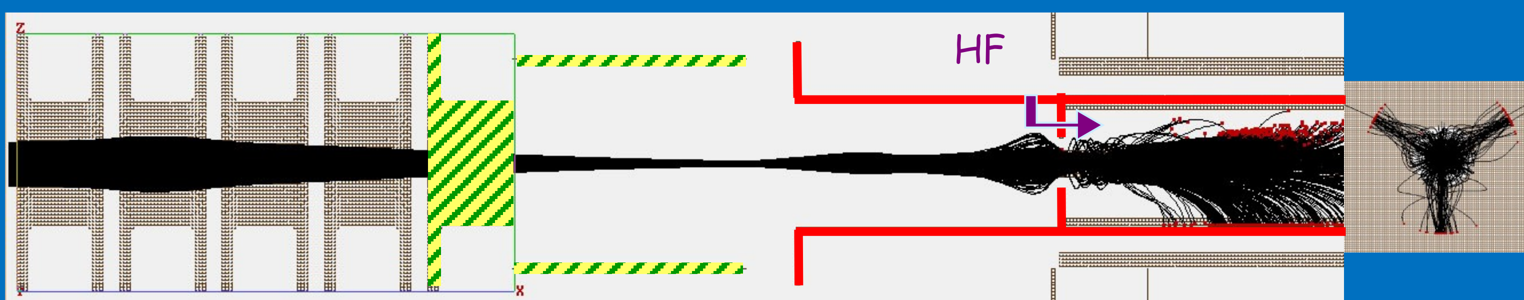
1+ injection simplification in CSB



- SIMION calculations including 3D magnetic field
  - Grounded tube to slow down 1+ ions
    - Degasing source, mechanical complexity



- Simulation of a new simplified configuration



- Much better HF coupling (2 times less power), better stability, reproducibility, tunings easier, better efficiencies ($^{85}Rb^{17+}$ from 3 to 6 %)

ECR Ion sources for Accelerators (II)

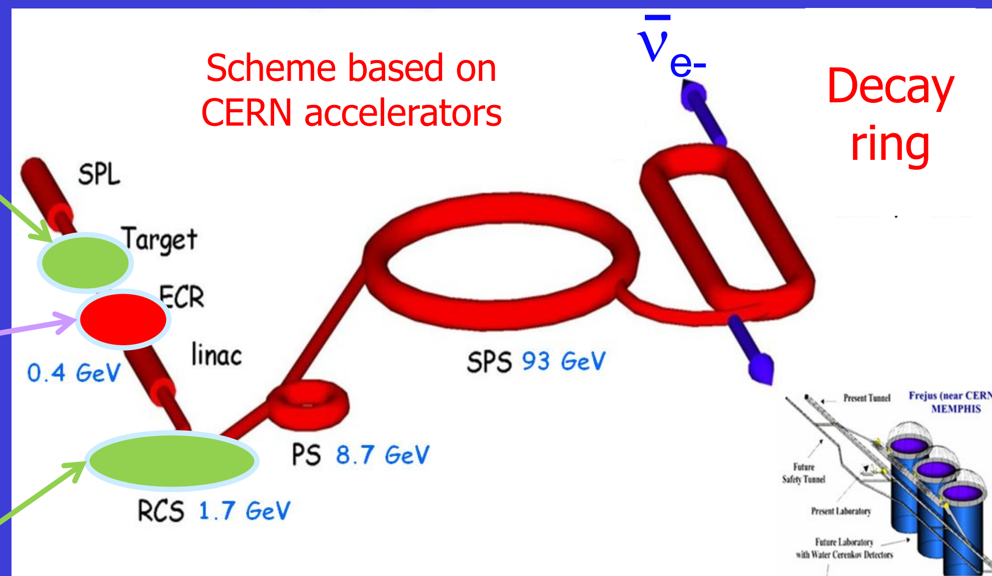
- Beta beams
  - Euro-nu (neutrino beams facility)

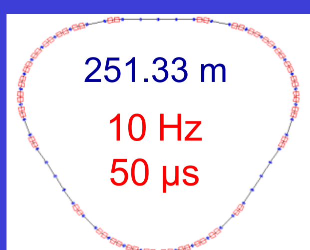
Beta Beams, EUROnu WP4

$^{6}He \rightarrow {}^{6}Li + e^{-} + \bar{\nu}_{e-}$

^{6}He ($t_{1/2}$ = **807 ms**), ^{18}Ne, ^{8}B , ^{8}Li
Continuous production
5 . 10^{13} pps

For a 100 % ionization efficiency
$I(He^{2+})$ = 32 mA + all other species
I extracted ~100 mA

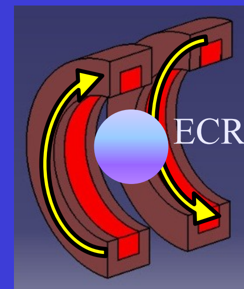


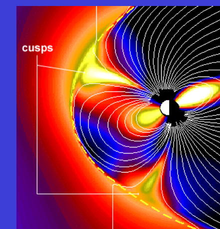


High intensity, High ionization efficiency
10 Hz operation
Radiation hard, low cost…. ECR ion source
low volume, high plasma density (high ECR frequency)

ECR ion source for Beta beams

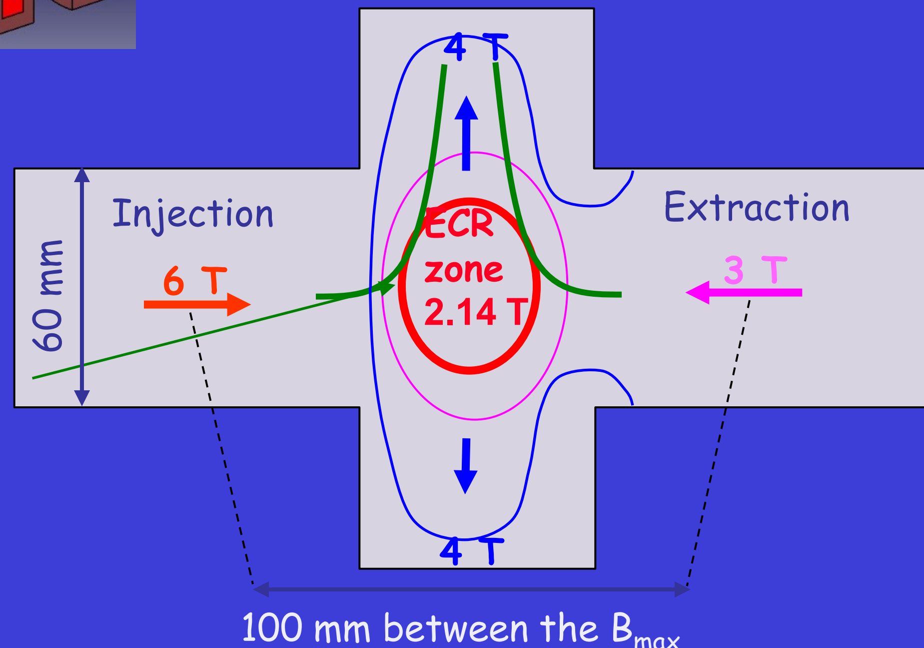
- CUSP magnetic structure
  - Compact source (l = 100 mm)
  - Spherical ECR zone at center





- Specifications
  - **60 GHz ECR, 10 Hz duty factor**
  - Cw magnetic field (future cw source)
  - Radially 4T
  - Injection 6 T
  - Extraction 3 T
  - 2.14 T Spherical zone

Magnetic field lines crossing the ECR zone don't touch the walls



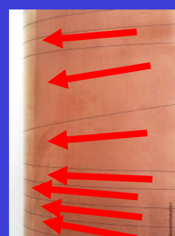
Presently no ECRIS with such a (high) magnetic field

highest ECR frequency :28 GHz

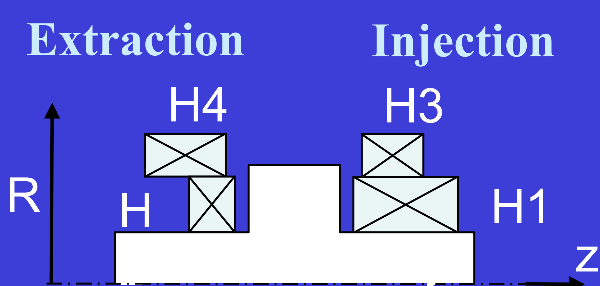
Conceptual design undergoing for superconducting 56 GHz minimum B ECRIS in US

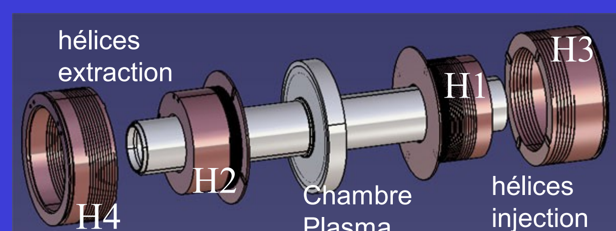
Technological choices

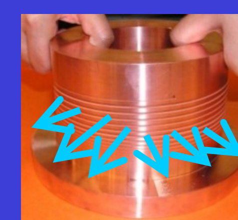
- Purpose: R&D towards high ECR frequency for future ECRIS
  - Low cost and fast development
  - No superconductors, high field techniques (copper and water)
  - Collaboration with CNRS intense magnetic fields (LNCMI)
    - Choice : Polyhelix technique (high currents in copper helices)



- It allows a continuous current density variation along the helix, so fine B optimization





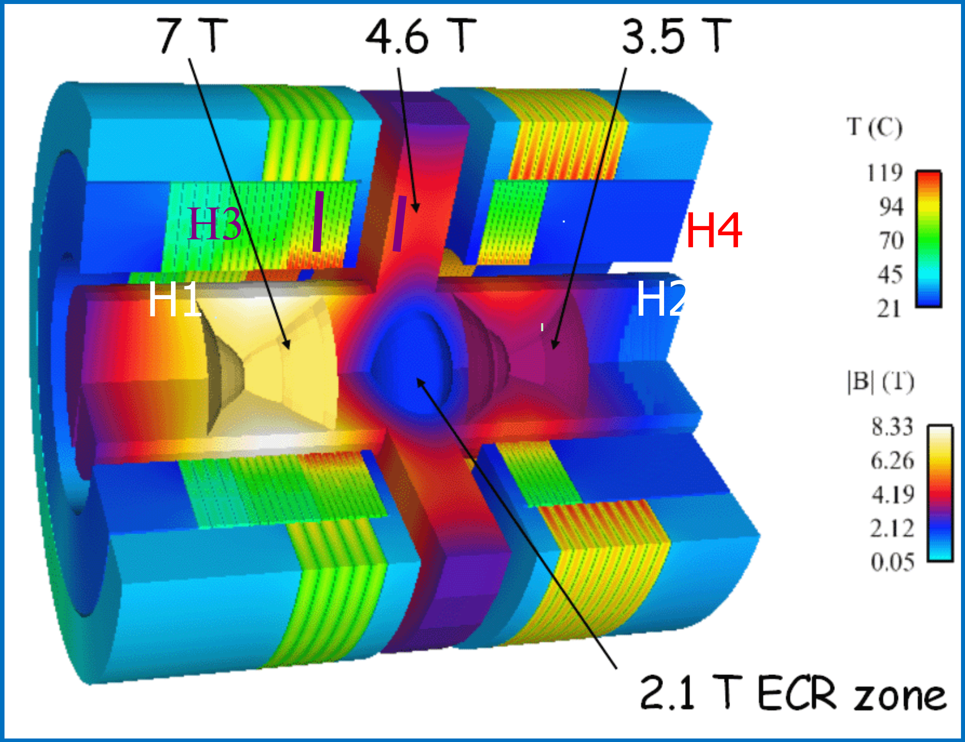


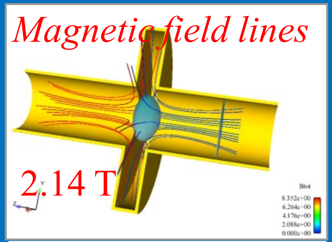
- Simulation of 4 radially cooled helices

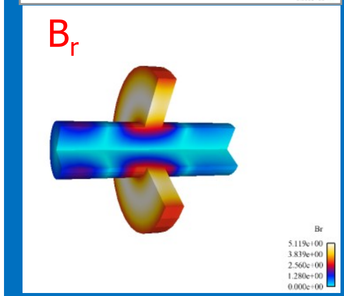
- 3D Simulation with Getdp
  - Exact geometry from CAD + mesher
  - Thermal study

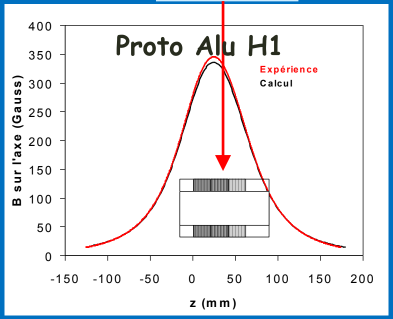
Injection

Extraction



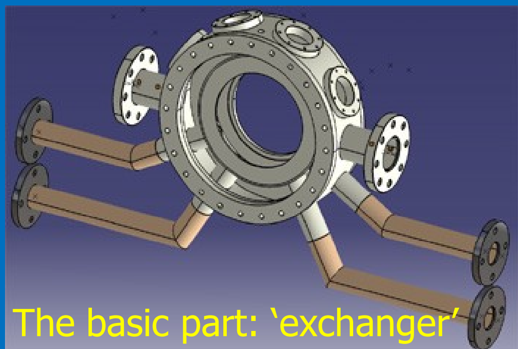


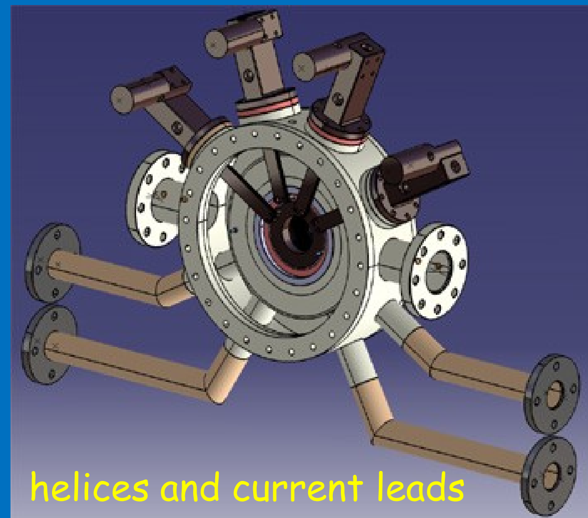


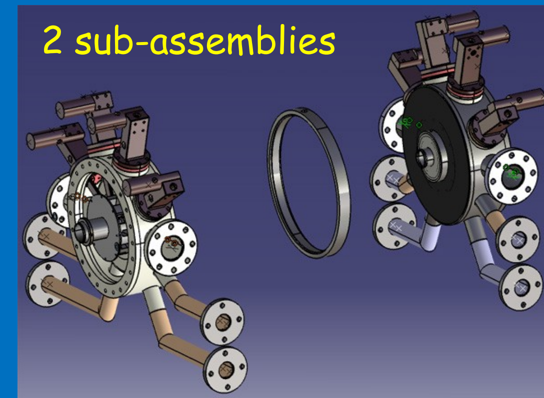


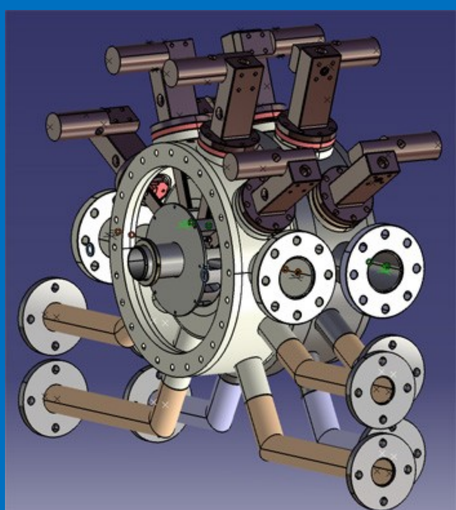
- 7 T injection (spec. 6T)
- 3.5 T ion extraction (spec. 3T)
- 4.9 T radial mirror (spec. 4T)

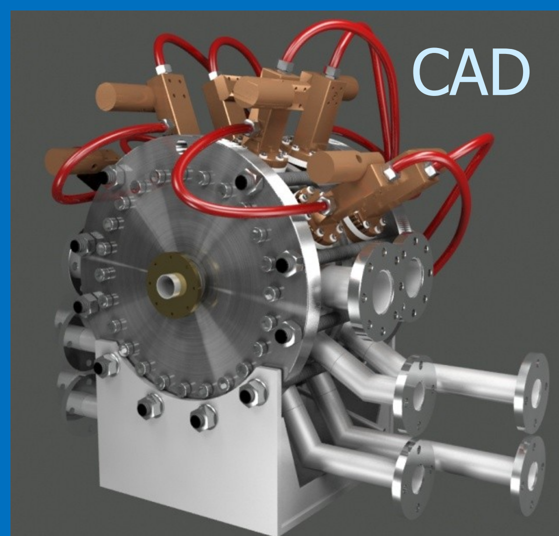
Prototype design and construction

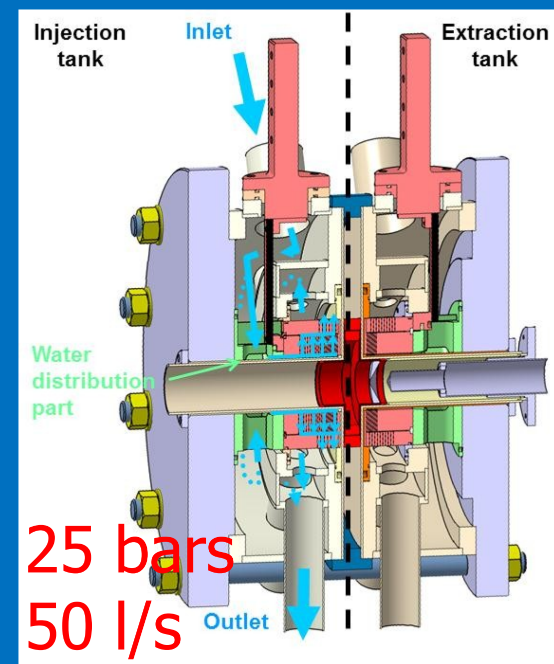




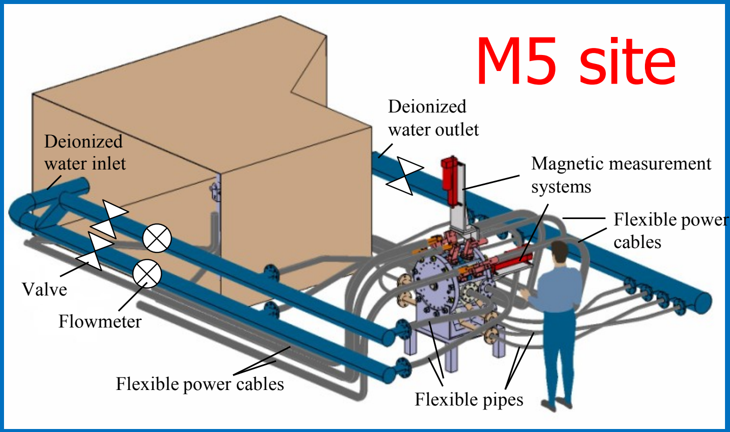








60 GHz ECRIS prototype setup



Magnetic field measurements

Up to 15000 A

Spherical 28 GHz ECR zone

Next steps 2011-2012

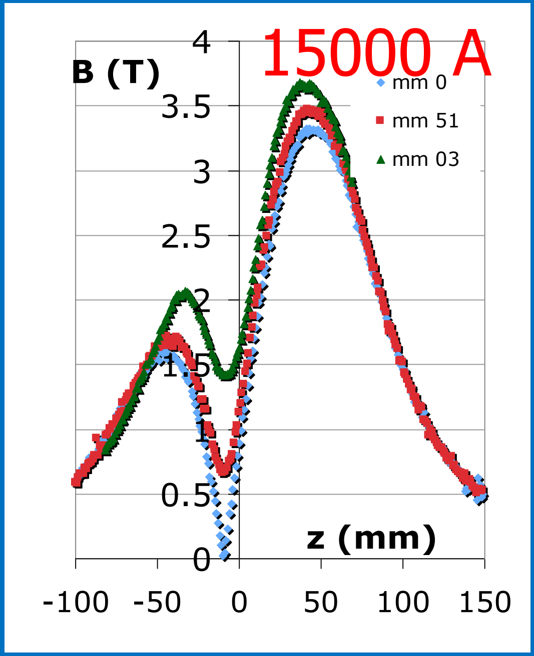
Ion beams (ECR 28 GHz)

Magnetic field measurements

Up to 30000 A

2012-2013

Ion beams at 60 GHz



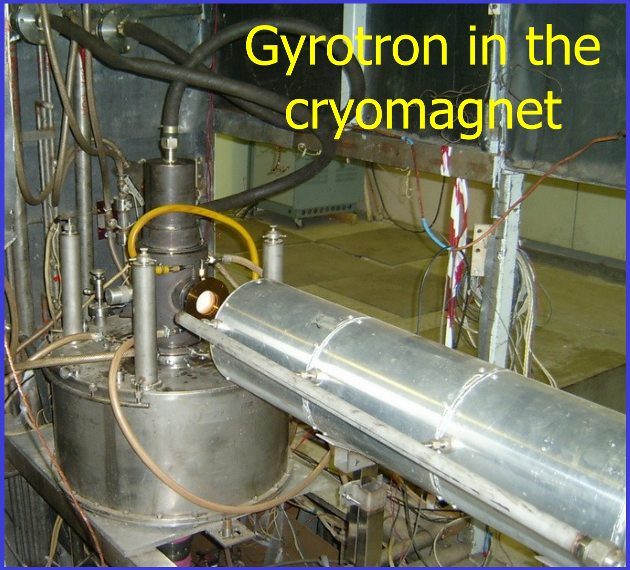
60 GHz gyrotron

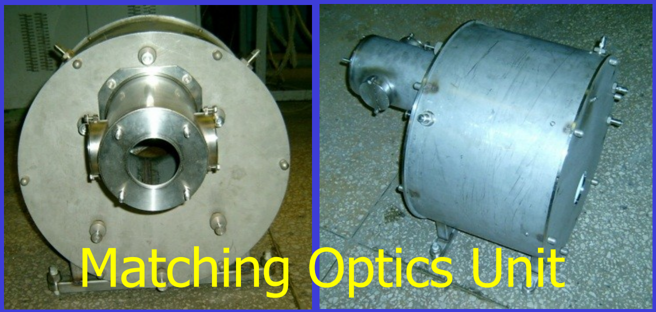
- 60 GHz 300 kW gyrotron manufacturing at

Institute of Applied Physics - RAS (Nizhny Novgorod – Russia)

ISTC Project No. 3965

  - Radiation frequency 60 GHz, MW power 10 - 300 kW
  - Pulse duration from 50 ms to 1 ms, pulse repetition rate up to 5 Hz

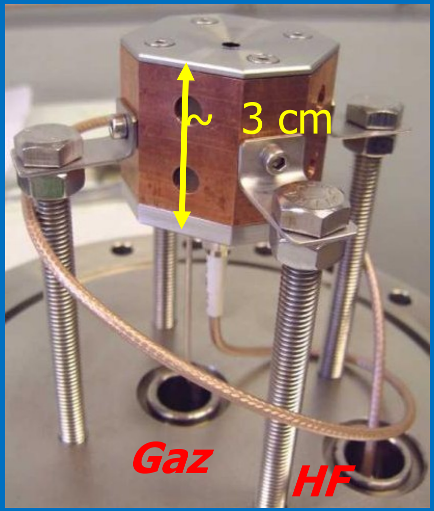




Delivery at Grenoble fall 2012

Ultra compact 2.45 GHZ ion source

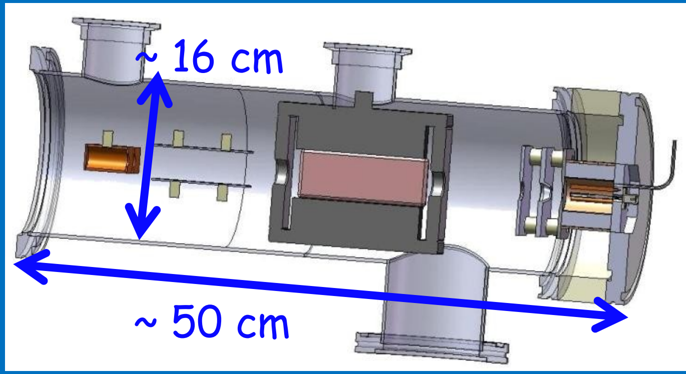
- Mono-beam : **COMIC source** Patent request : N° 0857068



Compact, low power (< 10 W)

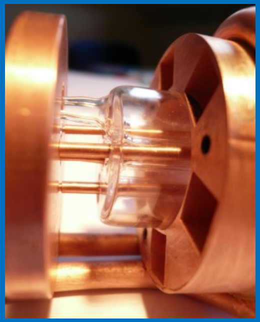
Delivers very stable currents ~ 1 mA

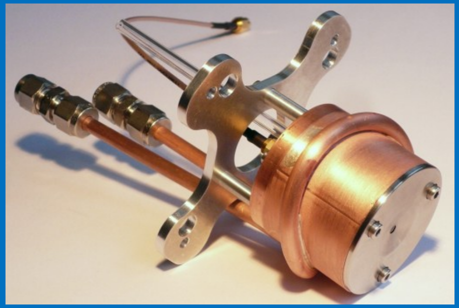
- Miniaturization allows many applications



CO-MIMAC : A moveable beam line for neutron detector calibration

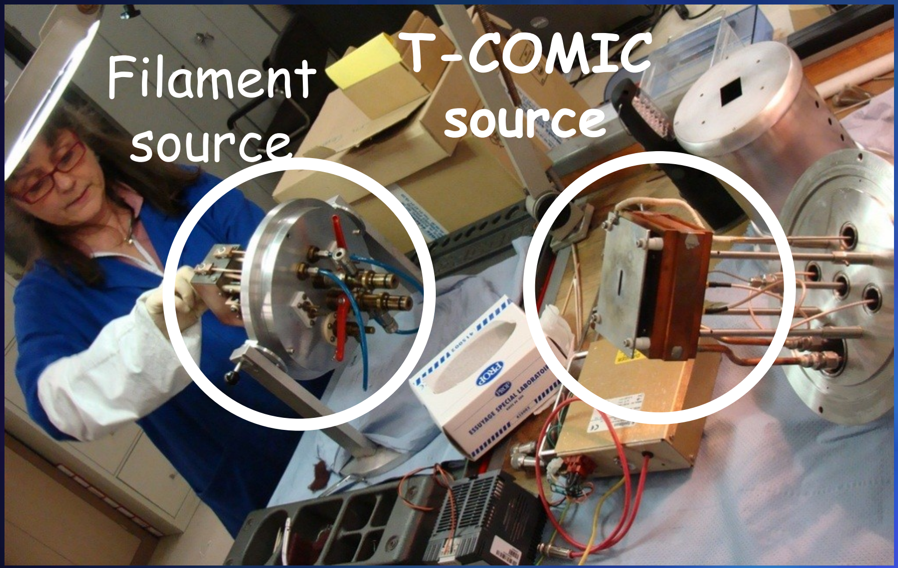
Q-COMIC : The Quartzed COMIC for on-line applications (ENSAR)

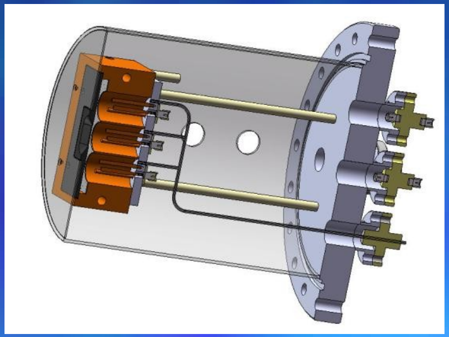




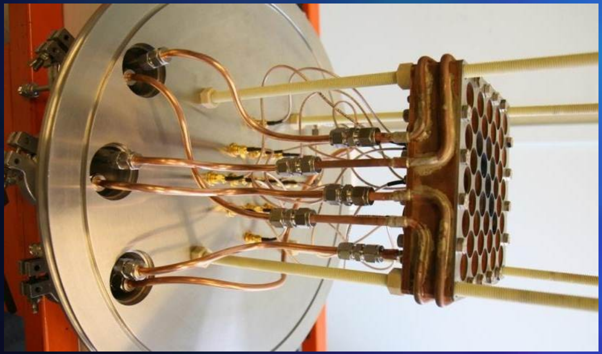
2.45 GHz COMIC source applications

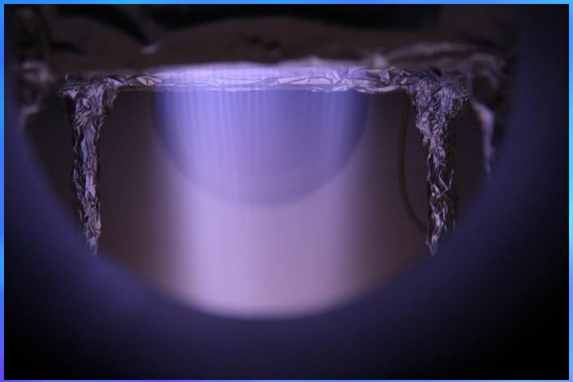
T-COMIC : a plug & play device for implanter





COMIC-Net : low energy broad beams for surface treatments





8 among
41 available
discharges

Thank you !