Nufact 11
XIIIth International Workshop on Neutrino Factories, Super Beams and Beta E
CERN / UNIGE, 2011, 1st-6th August

60 GHz
ECR source status

* Sixty GHz ECR Ion Source using Megawatt Magnets

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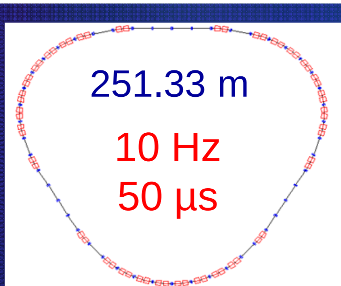
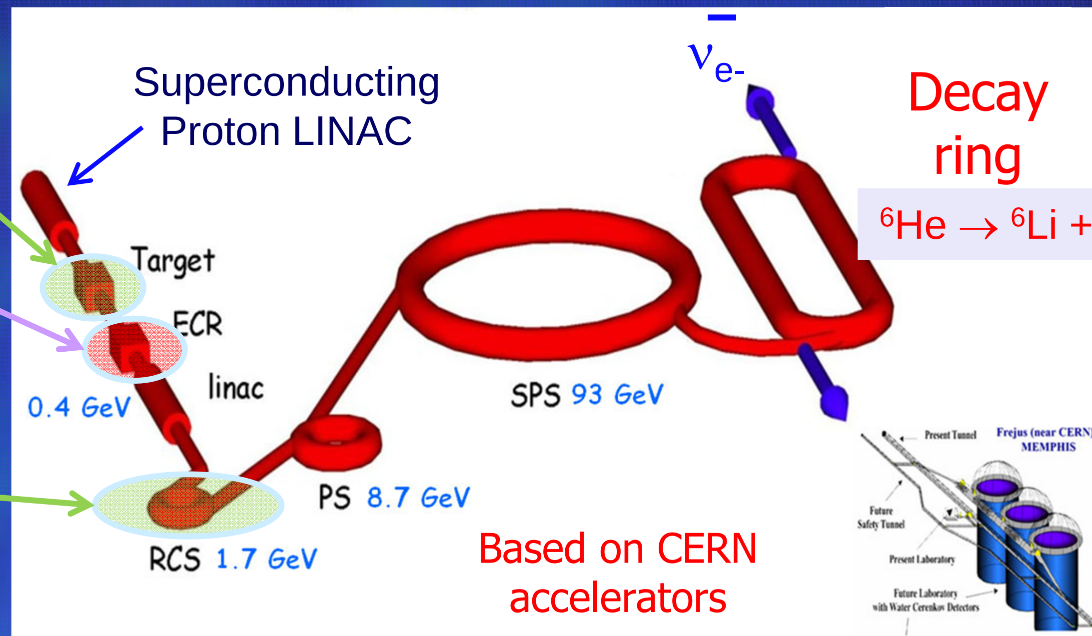
60 GHz ECR ion source for the Beta Beams

- Euro-nu **Beta Beams**

^{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 ~ several 100 mA



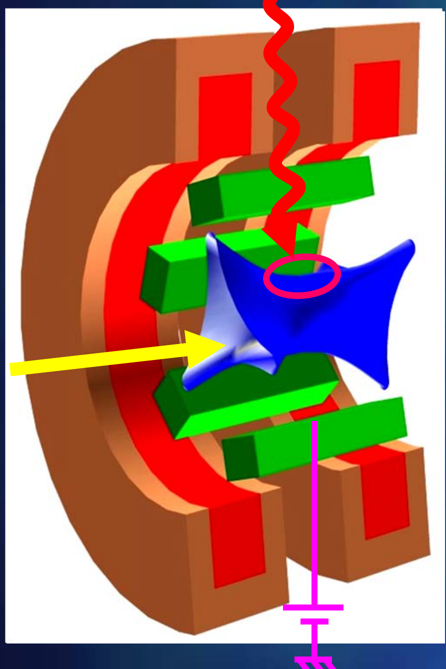


$^{6}He \rightarrow {}^{6}Li + e^{-} + \bar{\nu}_{e-}$

- High ionization efficiency ion source required, delivering high intensity
  - Radiation hard ECR ion source
  - low volume, high plasma density (high ECR frequency)
  - 10 Hz operation
- LPSC long term strategy in ECR ion sources development
  - To take advantage of this project to develop the ECR ion source operating
    - ***At the highest present ECR frequency***
    - ***For a reasonable cost (warm technology for the magnet)***

Electron Cyclotron Resonance Ion Sources (Basics)

- Classical 'Minimum B' ECRIS



Vacuum chamber

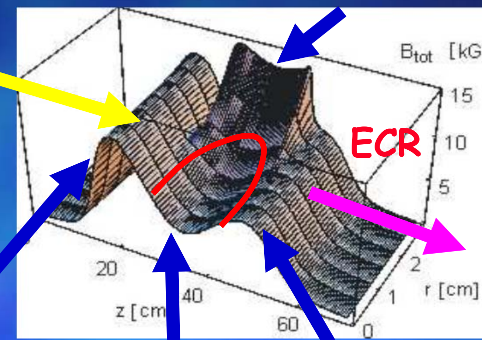
Magnetic field (axial + radial)

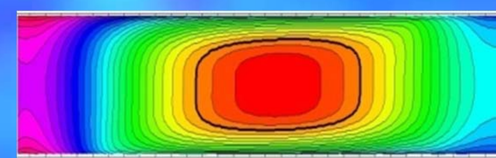
Gas injection (typically 2) or vapor + gas

Microwaves (ECR)
Electron heating
Confinement of the plasma (hot e⁻, cold ions)

Step by step ionization

Extraction (High Voltage)





$$I_{extracted} \propto n_i = \quad n_e = \frac{\varepsilon_0 \times m_e}{e^2} \times \omega_{pe}^2$$

Electronic cyclotronic Resonance
Cutoff density $\omega_{pe} = \omega_{ce}$

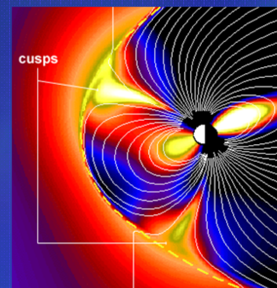
$$\mathbf{I \propto \omega_{ce}^2}$$

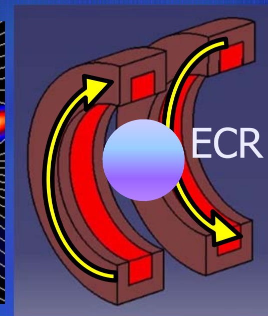
To increase I, increase n_e so ω_{ce} and consequently B

First 60 GHz ECRIS 'SEISM' prototype specifications

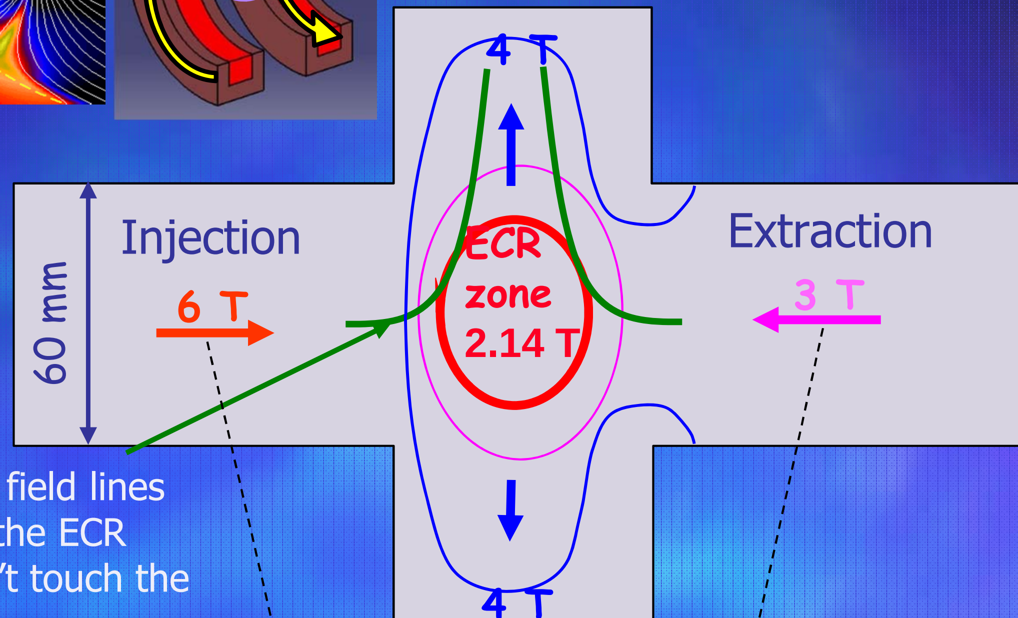
'simple' magnetic structure, pulsed Microwave

- 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)
    - Injection 6 T
    - Extraction 3 T
    - Radial 4T
    - 2.14 T Spherical ECR zone



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

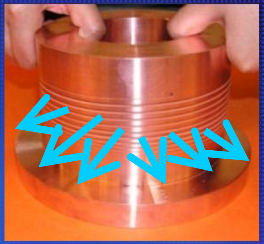
100 mm between the B_{max}

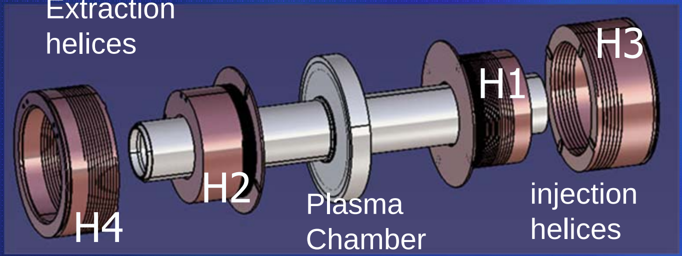
Presently no ECRIS with such a (high) magnetic field (and high gradient)

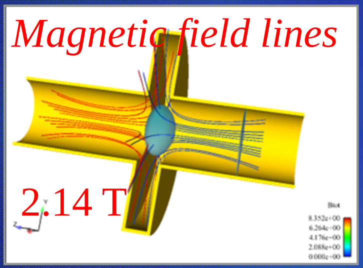
Conceptual design undergoing for superconducting 56 GHz minimum B ECRIS in US and China

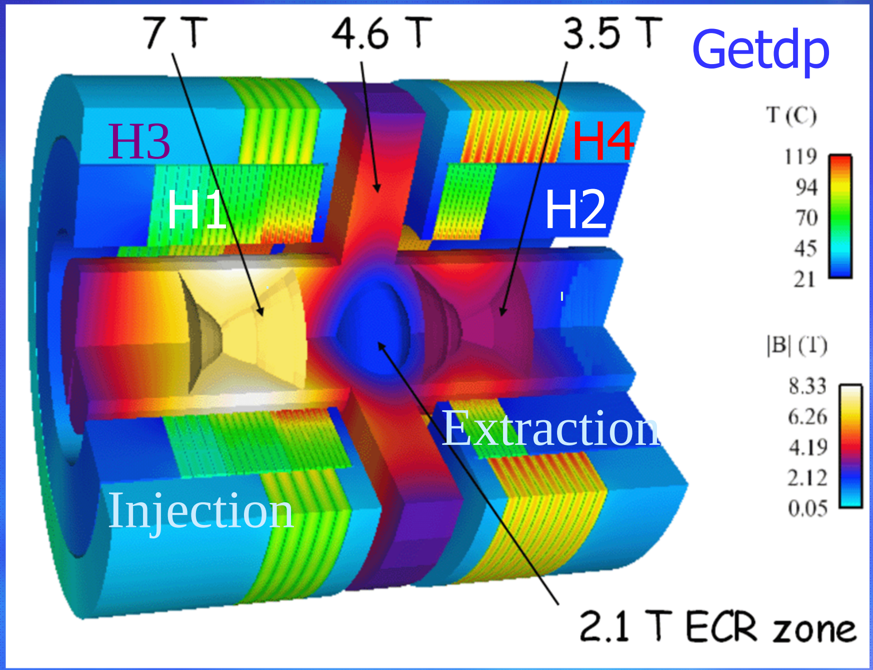
60 GHz ECRIS prototype simulation

- 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 laboratory (LNCMI)
    - Choice : Polyhelix technique (high currents in copper helices)







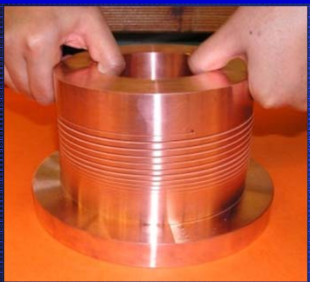


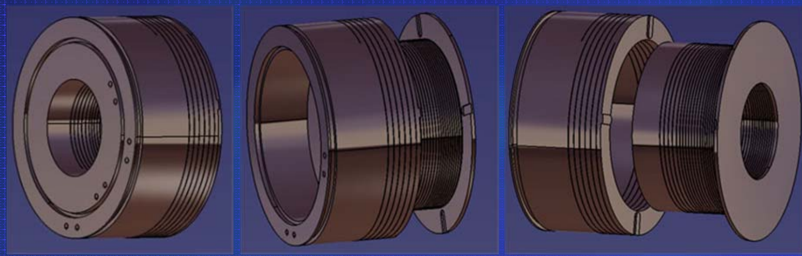
- 30000A, J~650 A/mm2
- P ~ 6 MW
- T_{Max} loc. ~ 330 °C (H1)
- T_{Mean} ~ 80°C to 180°C (H1)

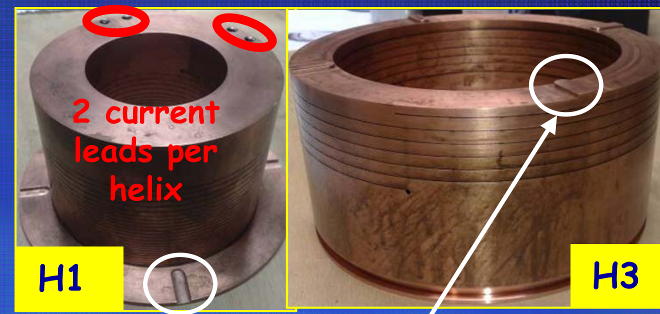
- > 7 T injection (spec. 6T)
- > 3.5 T ion extraction (spec. 3T)
- > 4.6 T radial mirror (spec. 4T)

Helices construction

Helical slit cut
by spark erosion







Ring with recess
on the internal coils

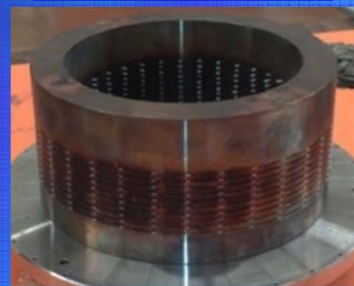
Keys on the external coils

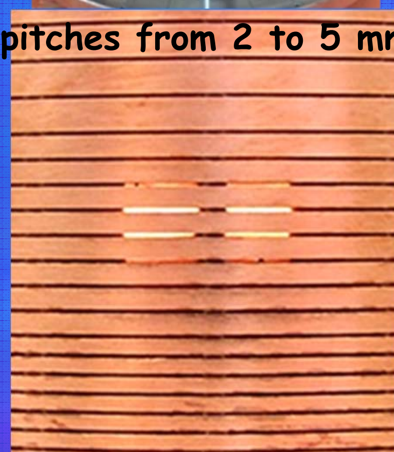
Chemical treatment

Positioning the prepreg insulators

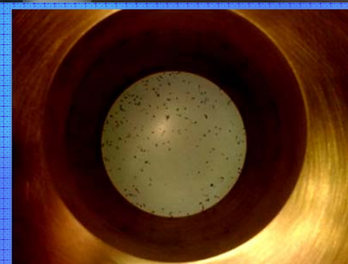
Oven

Final machining

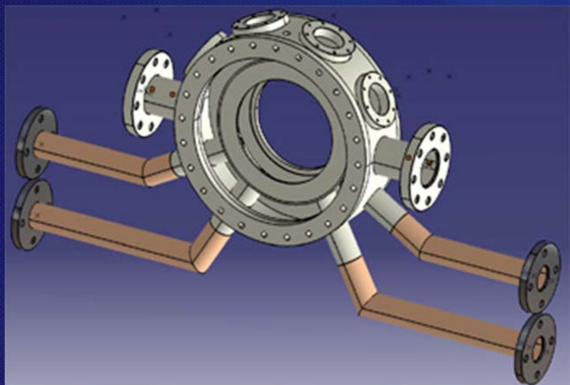




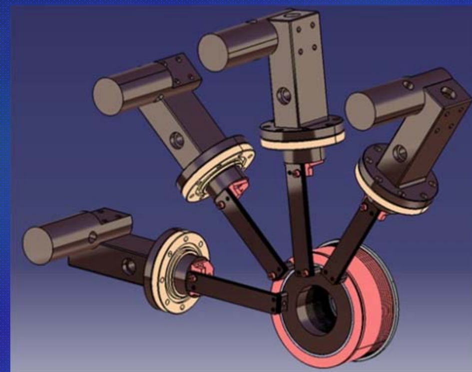
Cleaning
to prevent
shortcuts

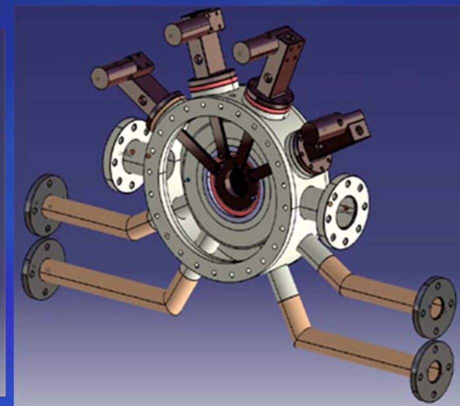


Prototype mechanical design

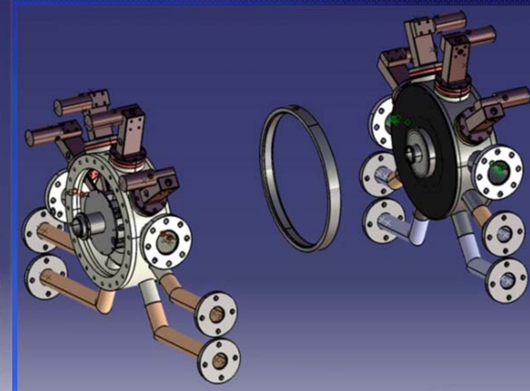


The basic part: 'exchanger'

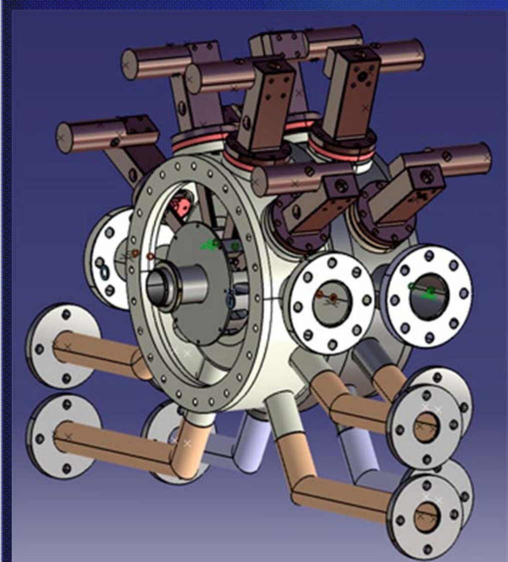


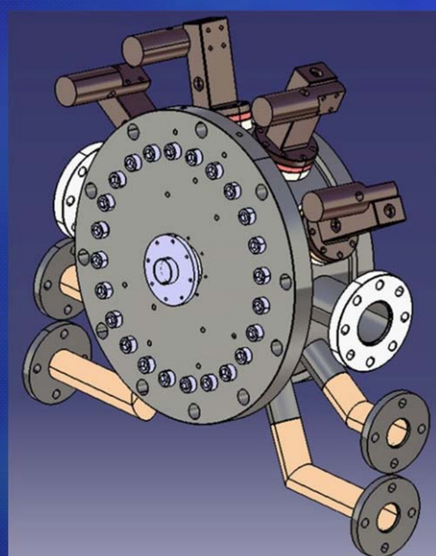


helices and current leads

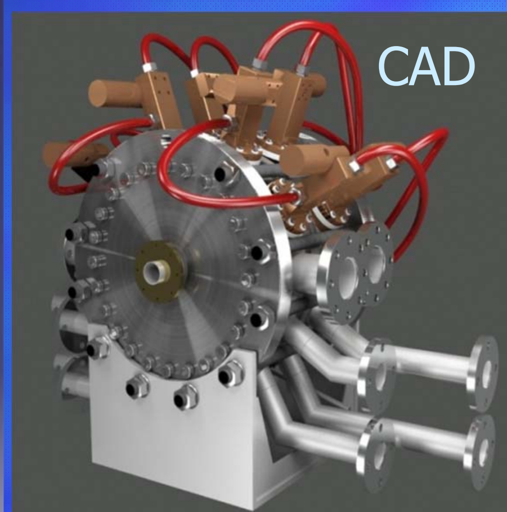


2 sub-assemblies



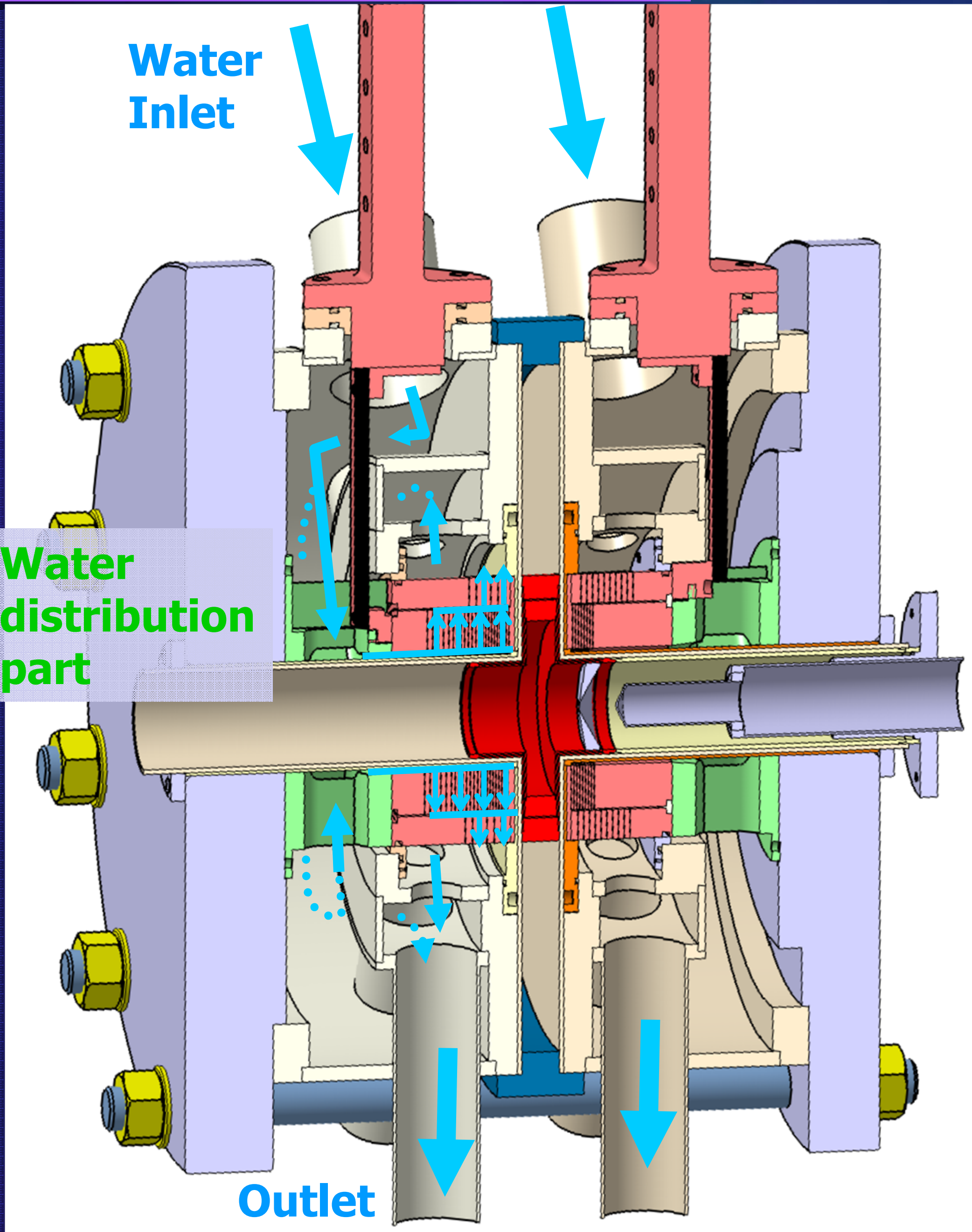


Extraction Flange

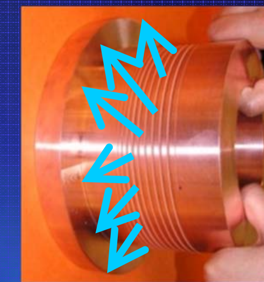


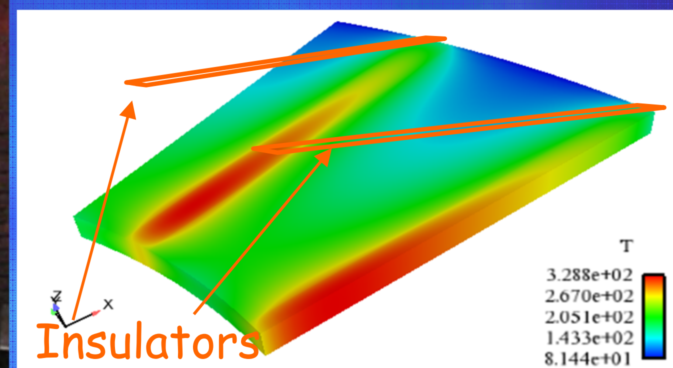
- Characteristics
  - Diameter 620 mm
  - Length 480 mm
  - 600 kg
  - 30 tons Repel force

Radial cooling of the helices



- Water cooling
  (deionized water)
  - Water cooling flow ~ 30 l/s
  - Pin = 27 bars ; Pout = 4 bars
  - Tinlet = 20 °C, Toutlet = 40 °C



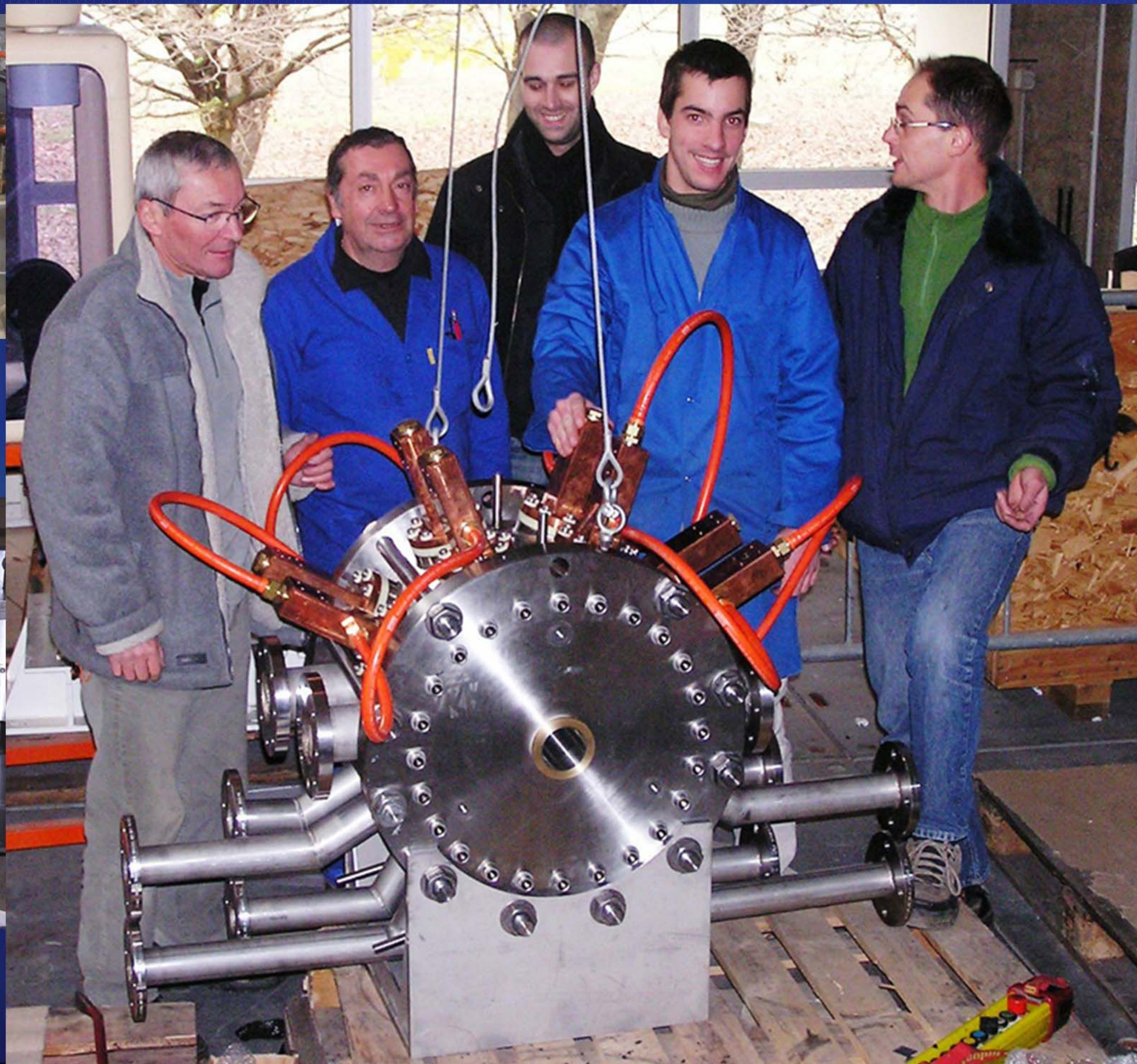


10 % of the total surface

- Worth case (thinner pitch of H1)
  - I = 30000 A
  - Empty space : 1.7 mm
  - Copper thickness : 2 mm
  - Tmean = 180 °C, Tmax = 330 °C

SEISM prototype assembly

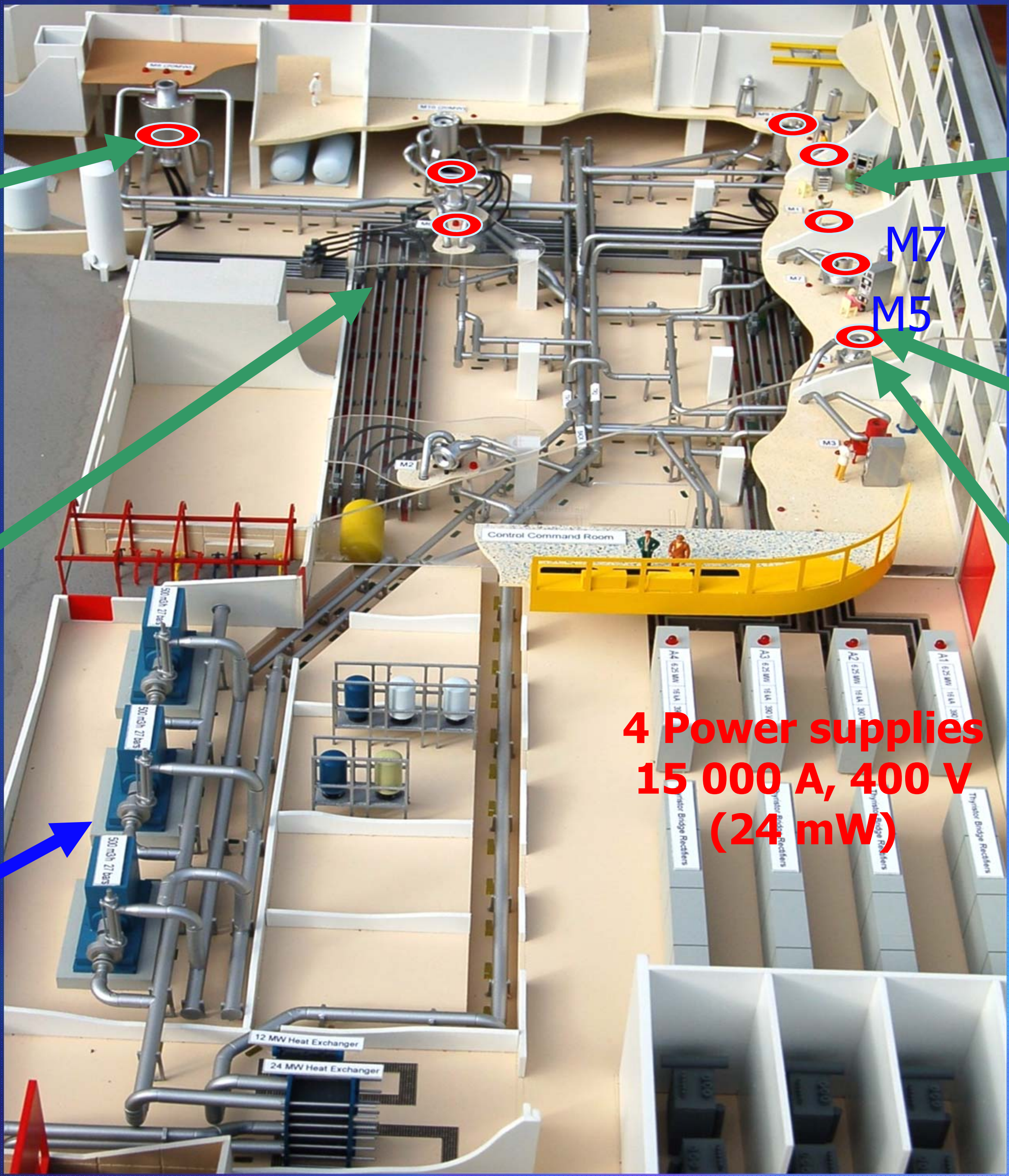




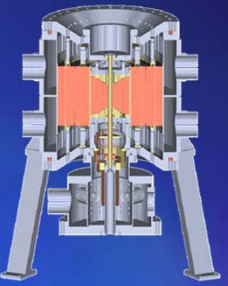
LNCMI : a place to perform experiments

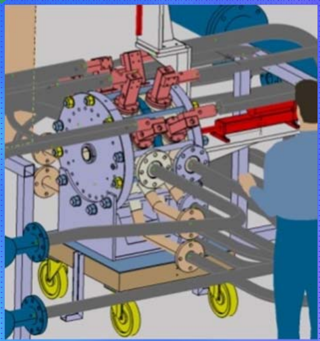
19 T /160 mm

Cooling
1000 m3/h
deionized water



34 T /34 mm

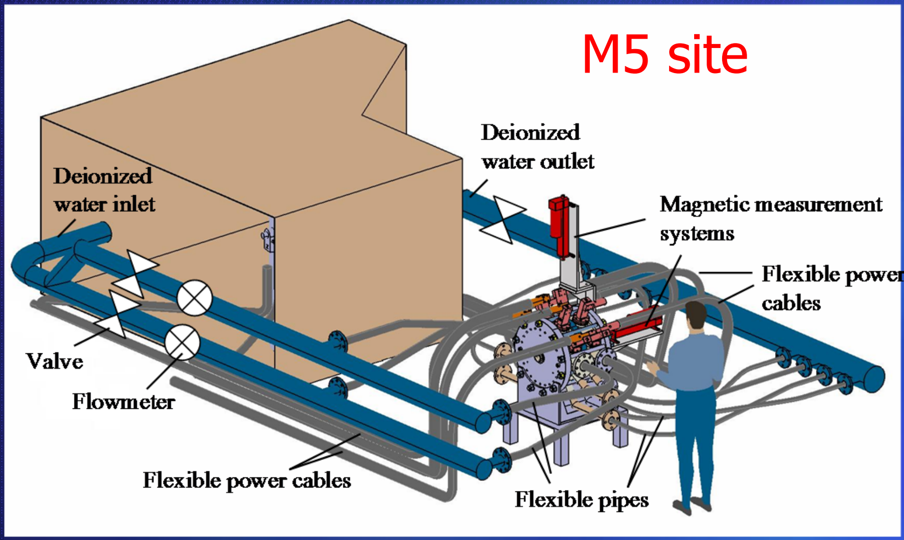


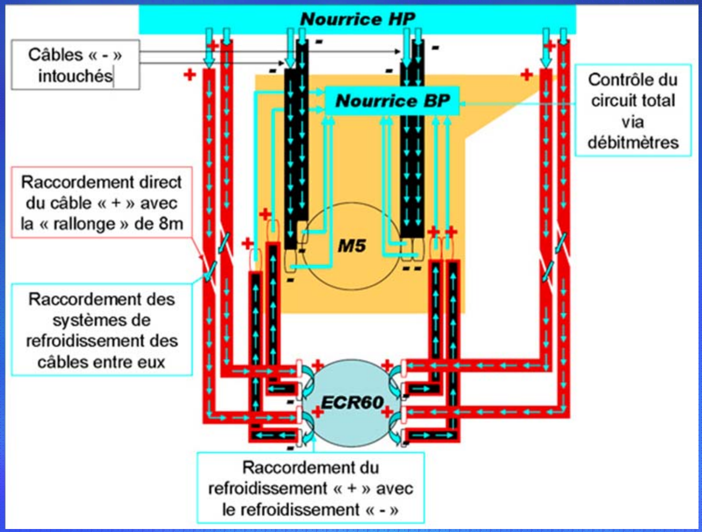


28 GHz 15000 A
2.5 MW
60 GHz 30000 A
6 MW

SEISM prototype setup on the M5 site

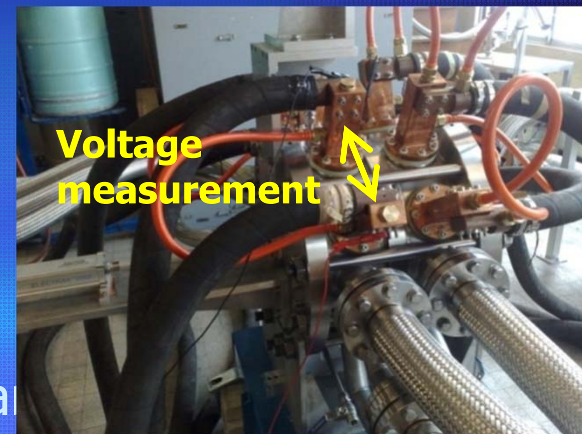
- M5 site adaptation for SEISM
  - Parallel hydraulic circuit (~ 50 l/s from 150 l/s)
  - Serial electrical connexion with M5 (impedance matching)



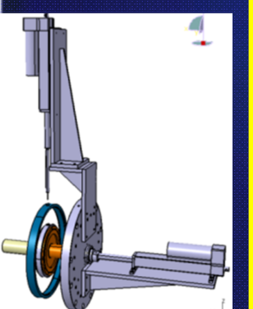


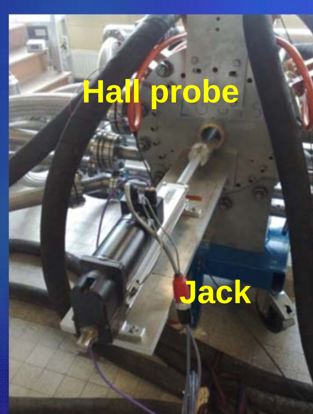
SEISM magnetic field measurements principles

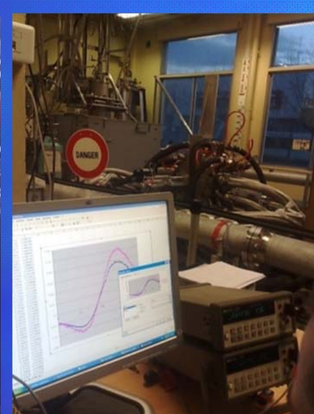
- Helices temperature monitoring
  - Resistance variation with T, R=R0(1+α*ΔT), Copper (α= 0.0036)
    - R0 = 3 mΩ at 10 °C (SSI Hall temperature in winter...)
  - R=U/I = R0(1+α*ΔT) → ΔT
    - Voltage measured during operation
    - Intensity given by LNCMI supplies

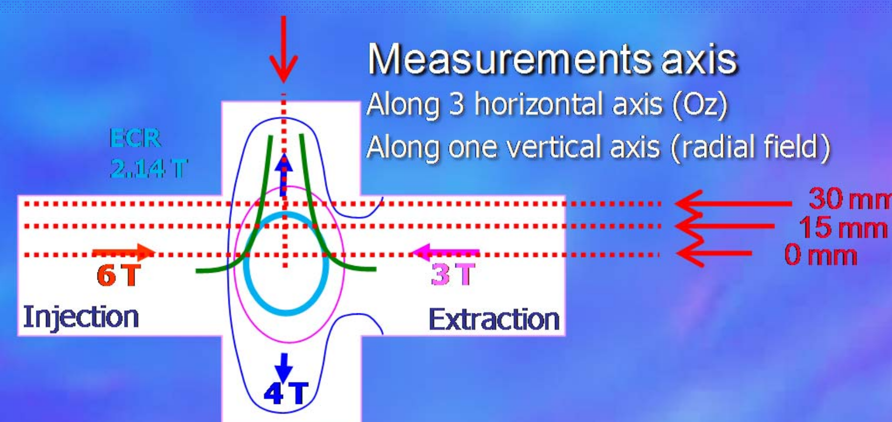


- Automated magnetic induction measurements
  - Tesla meters, axial and radial Hall probes on specific sta
  - probes movements with jacks – steppers 1 mm / 300 mm
  - Labview control



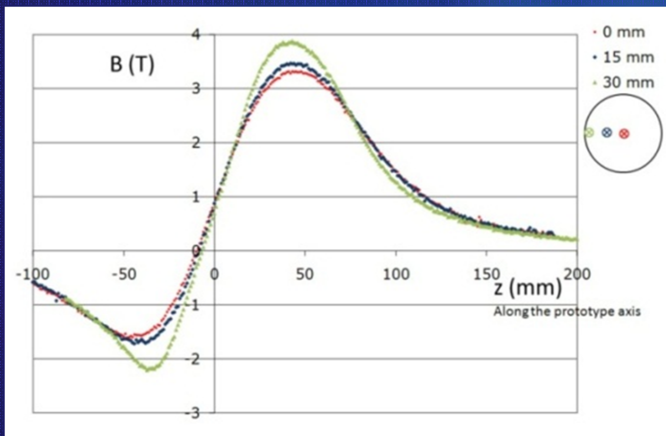


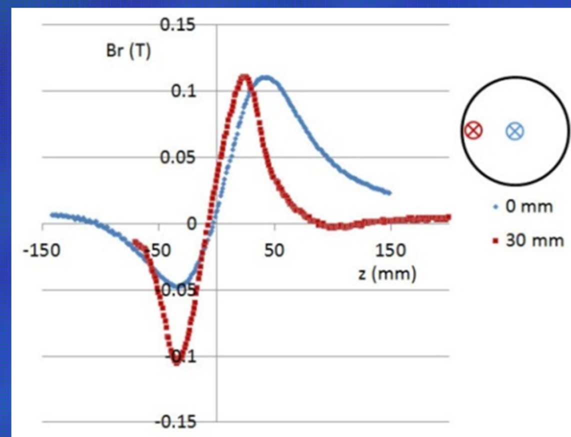




Magnetic field measurements results

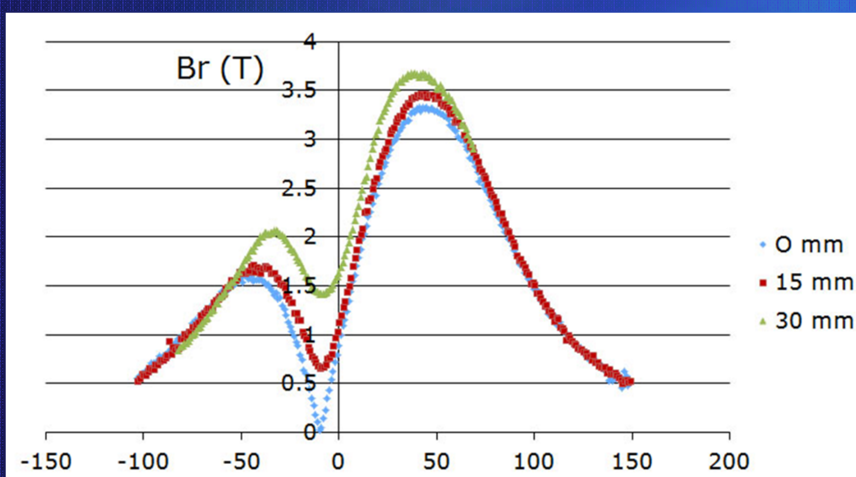
- Axial magnetic field induction from 1500 up to 15000 A
  - Axial and radial measurements three axis of the prototype (0, 15 and 30 mm)





15000 A measurements

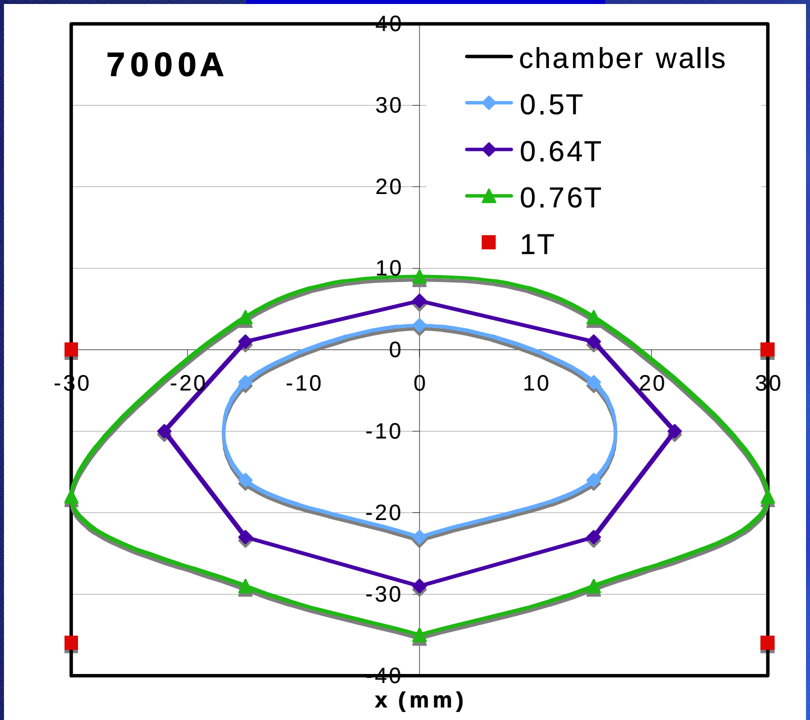
- Magnetic field induction norm



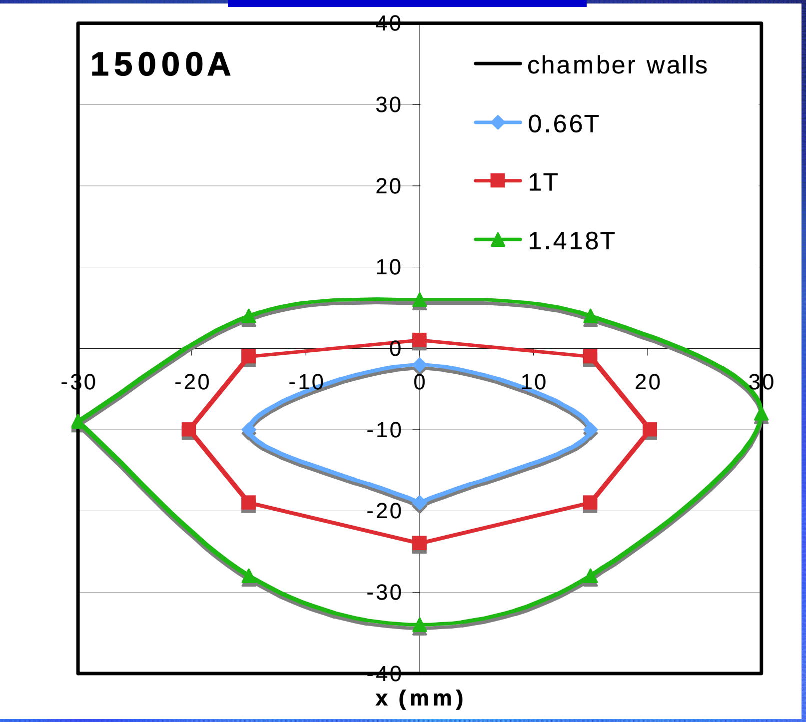
- Expected results (and obtained)
  - Axial symetry of the magnetic field
  - Linear increase of B with intensity
- Unexpected results
  - 10 mm shift of the maxima
  - Lower amplitude on the extraction side
  - No impact on the plasma characteristics

Iso-B for resonance zones

14 GHz



28 GHz



28 GHz (1T) ECR zone closed at about 12000 A

The 60 GHz closed ECR zone should be obtained at 26000 A

Plasma experiments are already 'magnetically' possible at 28 GHz using two LNCMI current supplies

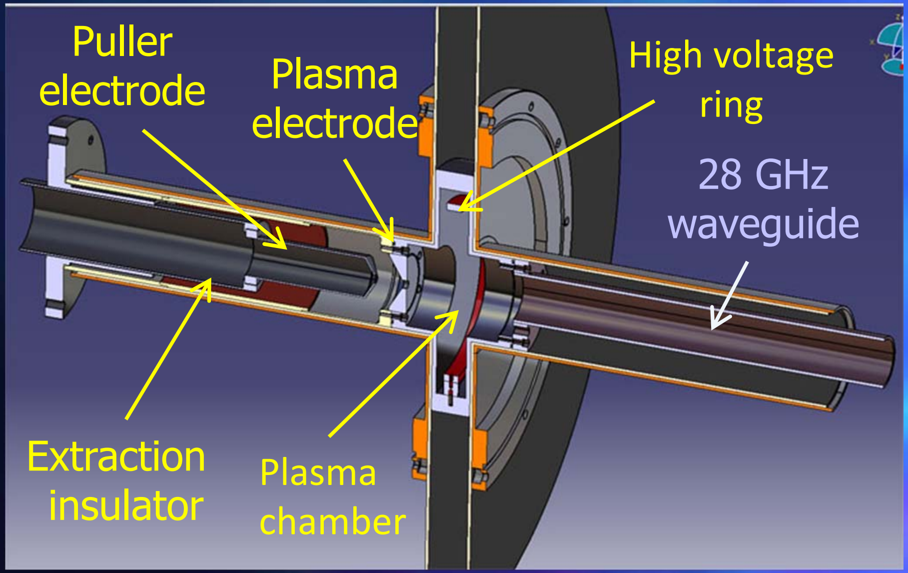
Phase 1 of this project is a success

Application for magnet time

Accepted for 20 days

Characterization of ion beams extracted from a 28 GHz ECR plasma in a split magnet

- To progress towards 60 GHz ECR operation of the ECRIS
  - Simple beam line : magnetic spectrometer and beam characterization devices
  - 10 kW 28 GHz gyrotron available from LPSC
  - A lot of safety issues (Microwaves, X rays, High voltage...)
- After beam measurements (a few weeks)
  - Terminate magnetic field measurements from 15000 up to 30000 A
  - If gyrotron available : 60 GHz experiments



Inside ECRIS 28 GHz prototype design

Efficiencies and currents expected ...?

- Fast ionization, efficient ionization
  - High density necessary
  - High ECR frequency (60 GHz) and high power density
  - 60 GHz : cut-off density 4.46×10^{13} ions/cm^3 to be compared with 2×10^{10} ions/cm^3 He ...(5×10^{12} in a 0.25 l (plasma): 2×10^{10} ions/cm^3 (ratio ~ $4.5\ 10^{-4}$)
  - Multi-Ampères source !!!! Certainly avoid multi charged ions...
    - High intensity beam line will be required (mandatory...)
    - But good news from Russia

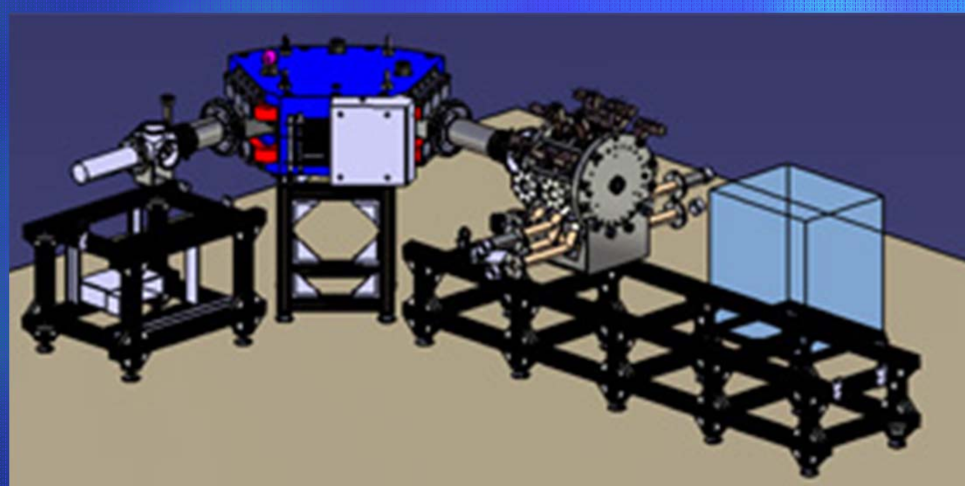
8th International Workshop 'Strong Microwaves and Terahertz Waves Sources and Applications'
July 9 - 16, 2011 Nizhny Novgorod, Russia

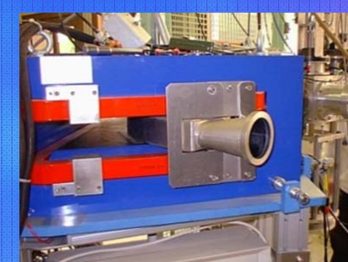
1.6 mm extraction hole leads to 80% efficiency for He^+ and only 300 mA total current

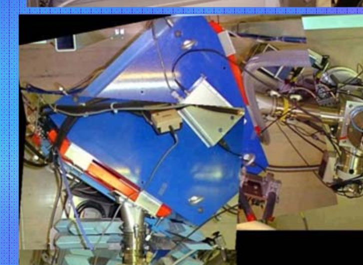
"Gas utilization efficiency optimization for short-pulsed ECR ion source"
I. V. Izotov, V. A. Skalyga, V. G. Zorin (IAP Nizhny Novgorod)

LNCMI site preparation for future experiments

- Design of the High intensity beam line
  - Vacuum components (turbo pumps, chambers, tubes…) ordered
  - Stands ordered
  - Magnetic spectrometer current supply operational
  - LNCMI installation in M3 rather problematic…
    - Concrete foundation slab resistance … (Magnet > 2 tons)…
    - Layout
    - Magnetic fringing fields from other magnets and prototype (for gyrotron)
    - A lot of safety issues (HV, MW, X rays…)





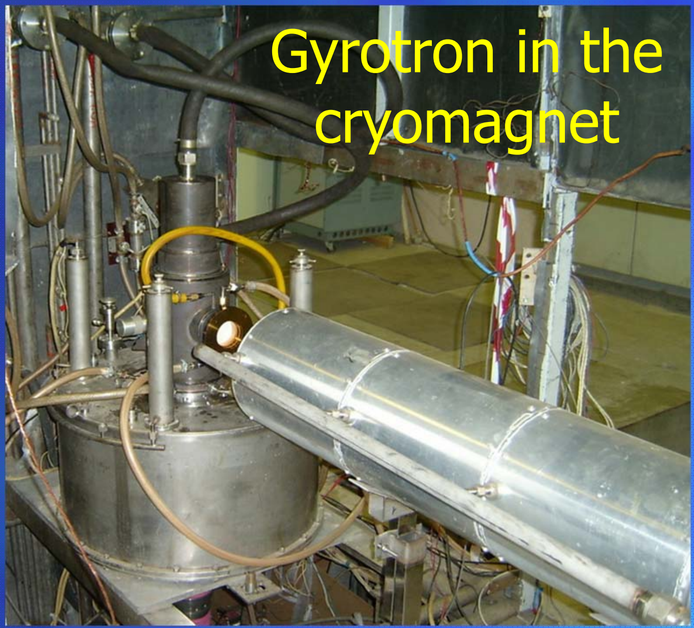


60 GHz gyrotron

- Pulsed 60 GHz 300 kW gyrotron manufactured by **GYCOM**

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

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

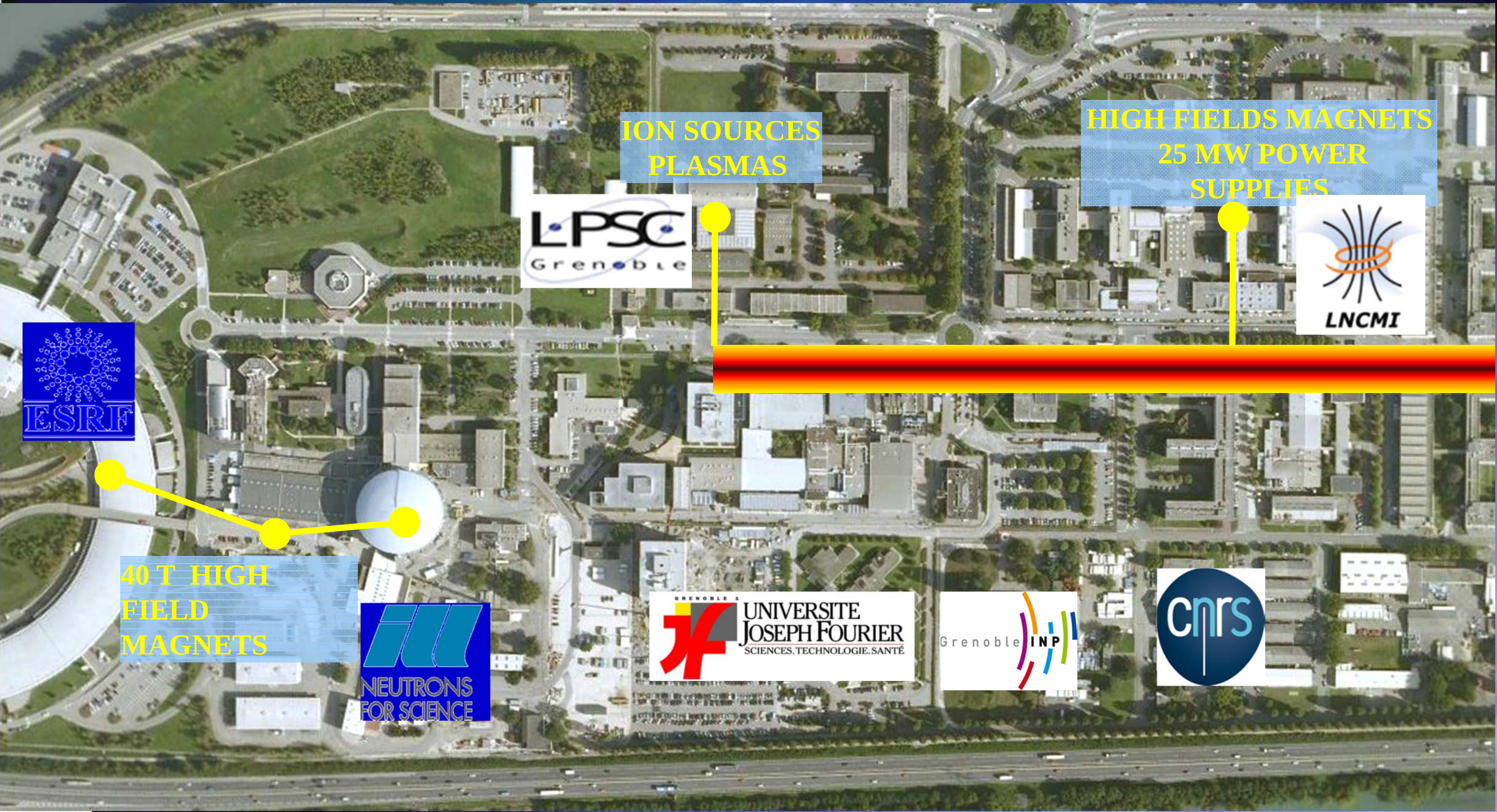


Delivery at Grenoble spring 2012

Project #3965
Design, Manufacturing and Tests of Short Pulse ECR Multi-Charged Ion Source Prototype with High Ionization Efficiency

Eqipex 2011 under preparation

Superconducting bus from LNCMI to LPSC (4*15000 A) allowing future ECRIS R&D
28 and 60 GHz ion sources for SPIRAL2



Thank you !

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