A 60 GHz ECR Ion Source For the Beta Beams

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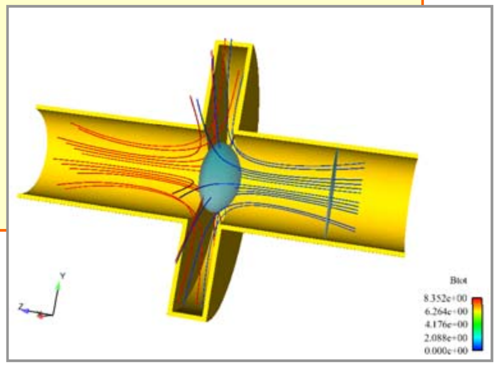
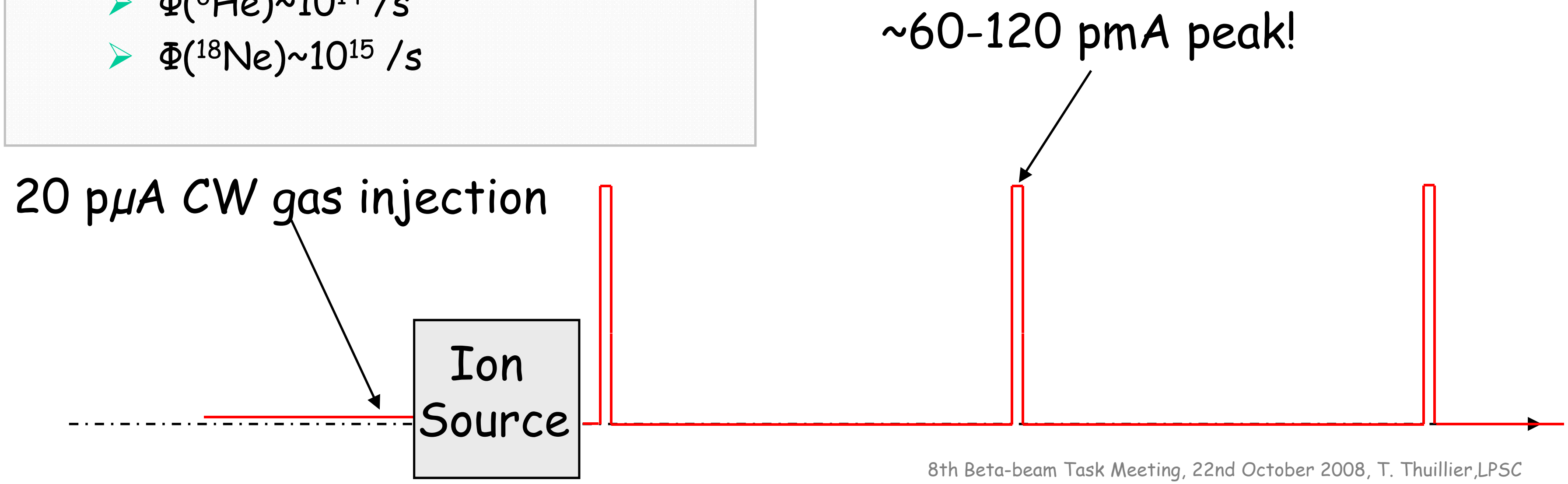
1. Preglow experiments during FP6
2. Preglow Simulation with IAP and 37 GHz experiments
3. Insight from FP6 and summary of possible Ion Source scenarii
4. First 60 GHz source design (CUSP)
5. Other Prospects



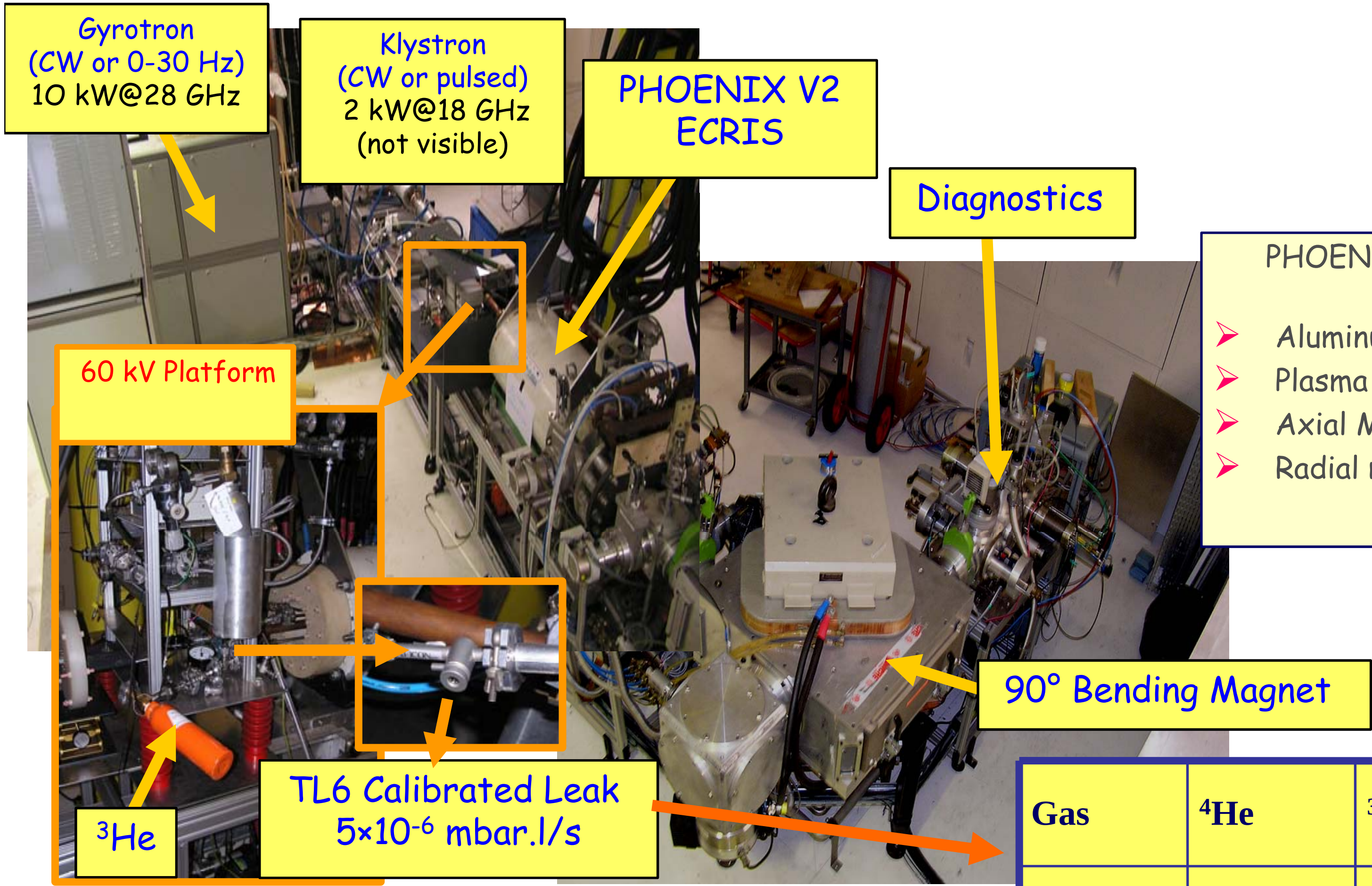
0. Ion source R&D initial specifications for Beta Beams

- Source near to the target
  - Highly radioactive environment
  - Source activation
  - Last as long as possible (~1 month)
- Short Half lives :
  - $\tau\,(^{6}He)=0.807$ s
  - $\tau\,(^{18}Ne)=1.67$ s
  - Fast ionization and extraction
- Fluxes expected from target:
  - $\Phi(^{6}He)\sim10^{14}$ /s
  - $\Phi(^{18}Ne)\sim10^{15}$ /s

- Bunch ions in range 10-25 Hz
- Pulse width < 50-100 μs
- <u>As efficient as possible</u>
- Multicharged Ions prefered
- 1+ source not excluded



o Bunching efficiency study with the Phoenix V2 ECR Ion Source



Phoenix V2 ECRIS on its test bench

PHOENIX V2 Main parameters

- Aluminum plasma chamber
- Plasma Volume ~ 0.7 Liter
- Axial Mirror : 1.6-0.4-1.35 T
- Radial mirror : 1.3 T

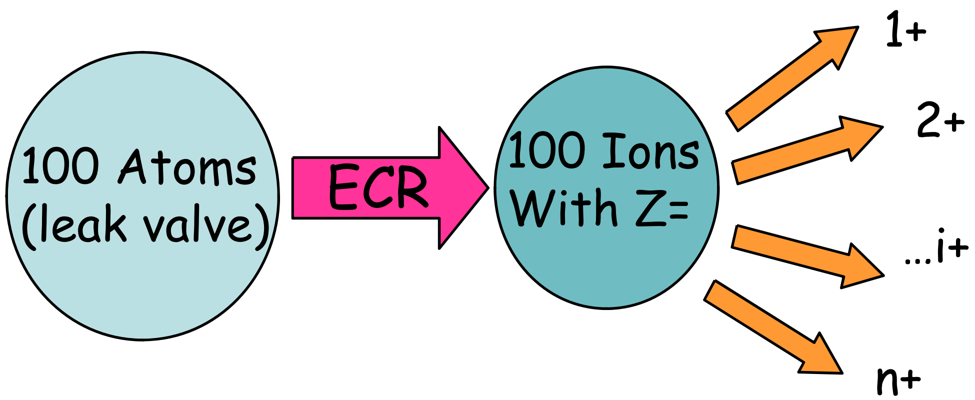
Gas	^{4}He	^{3}He	^{22}Ne
Atoms/s	~1.2x10^{14}	~1.6x10^{14}	~5.1x10^{13}

1. Ionisation Efficiency in C.W. experiments (18 GHz)

^{3}He experiment :

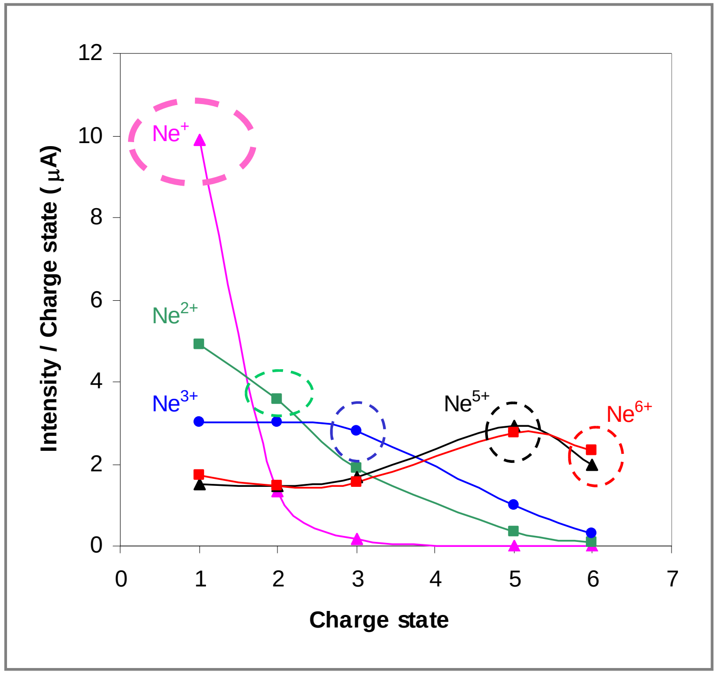
- O_2 Buffer Gas
- Global Ionisation Efficiency is **100 %**
- <u>99% of $^{3}He+$</u>

These C.W. efficiencies give the maximum physical values achievable for bunching efficiencies

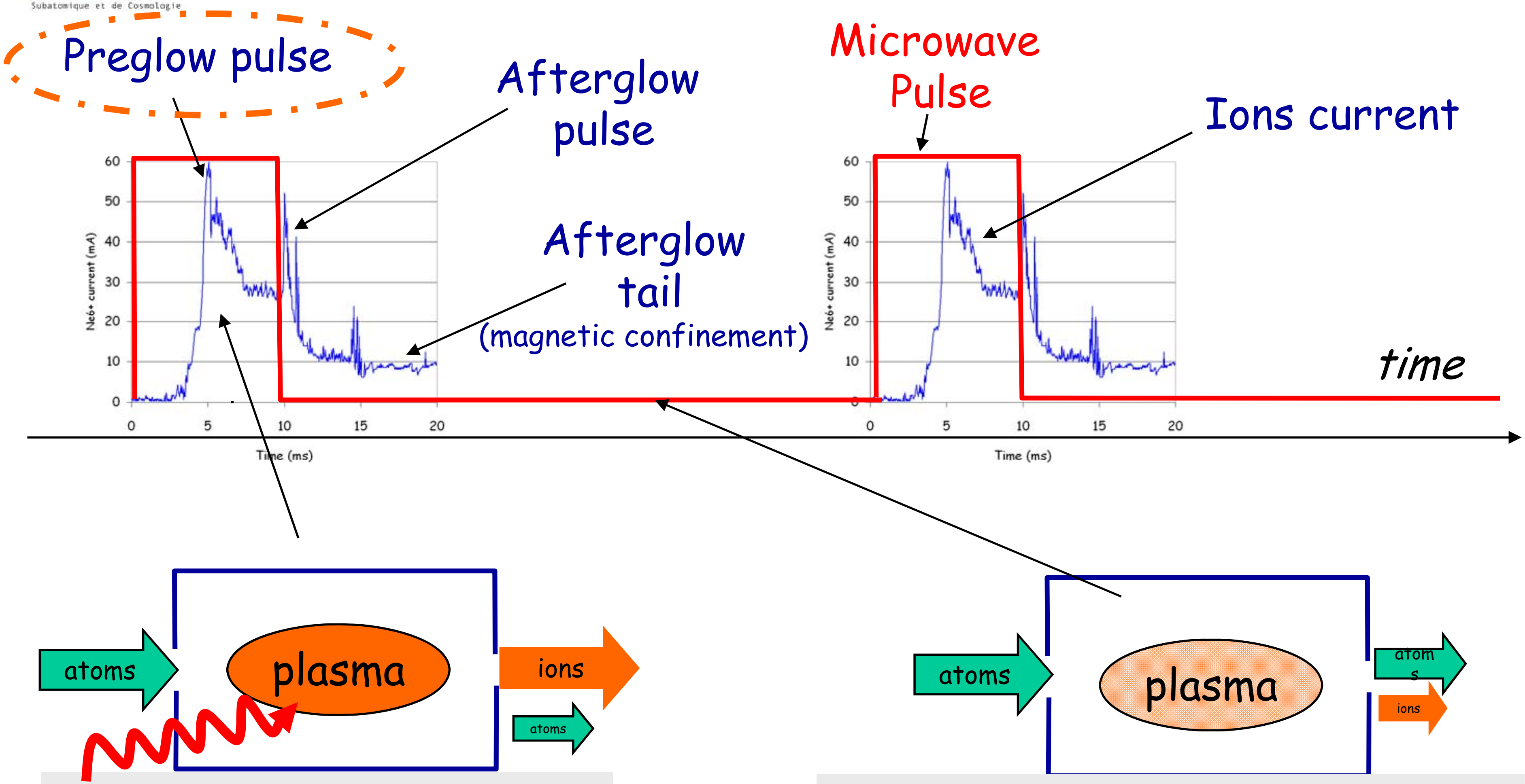


^{22}Ne experiment :

- ^{4}He Buffer Gas
- Global Ionisation Efficiency is **100 %**
- ~20-30% max. on one optimized charge state (3+ to 6+)
- ~<u>60-80% expected for charge 1+ optimized</u> (only estimated)



1. Ions bunching in an ECR Ion Source



During RF pulse, plasma ionizes atoms => Beam extracted

between RF pulses, plasma decays ± rapidly, depending on the magnetic field confinement

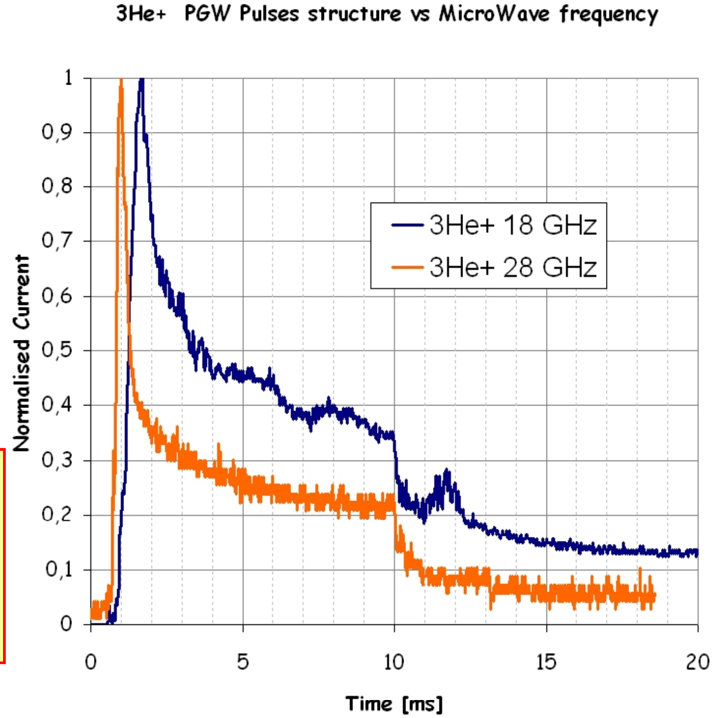
We focused our attention on the Preglow peak, a new fast unexpected phenomenon

1. He & Ne Preglow study at 18&28 GHz

- Difficult experiments but very instructive
- Contamination of Neon peaks with C,N,O and Ar ions rendered data analysis very difficult
- Nevertheless, order of magnitudes have been measured :

He+	18 GHz	28 GHz
FWHM	600-1200 μs	100-300 μs
Efficiency in the whole peak	~5-10%	~1-3%

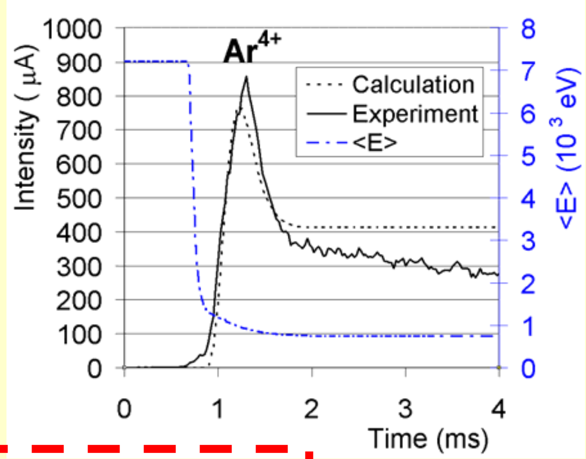
Efficiencies must be Improved!

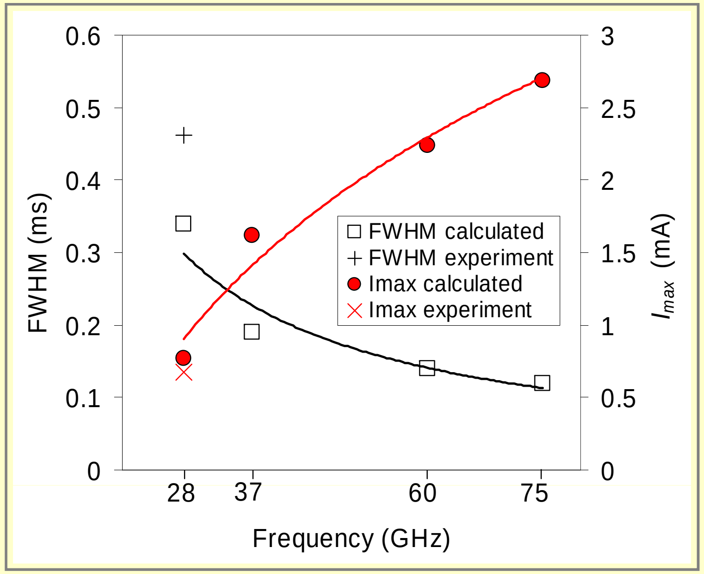


Ne2+ (example)	18 GHz	28 GHz
FWHM	900μs	350 μs
Efficiency in the whole peak	~3%	~5%

- FWHM decreases with ECR Frequency
- The lower He efficiency for 28 GHz comes from:
  - a too low magnetic confinement
  - a space charge limitation of ion extraction (Child Langmuir)

- The experimental Preglow study is quite well reproduced by a simple 0 dimension plasma model developed at IAP (DOI: 10.1109/TPS.2008.927292)
- Based on the 18 & 28 GHz experiments, the model enables to simulate a 60 GHz plasma
- As observed in experiments, the peak FWHM is expected to decrease with the ECR frequency increase
  - FWHM (60 GHz)~ 100 µs



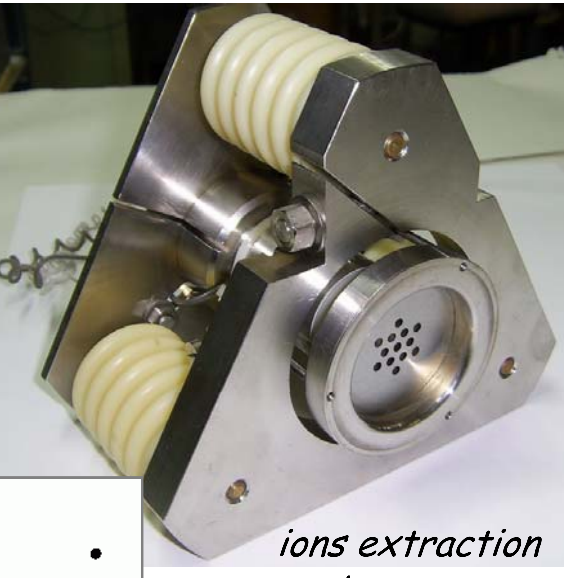


ex. of prediction for Ar4+ Preglow

- Helped with :
  - 100 kW microwave pulse
  - 100 kV extraction voltage
  - A high magnetic confinement
- At 60 GHz The peak currents are expected to increase by a factor 3 to 10

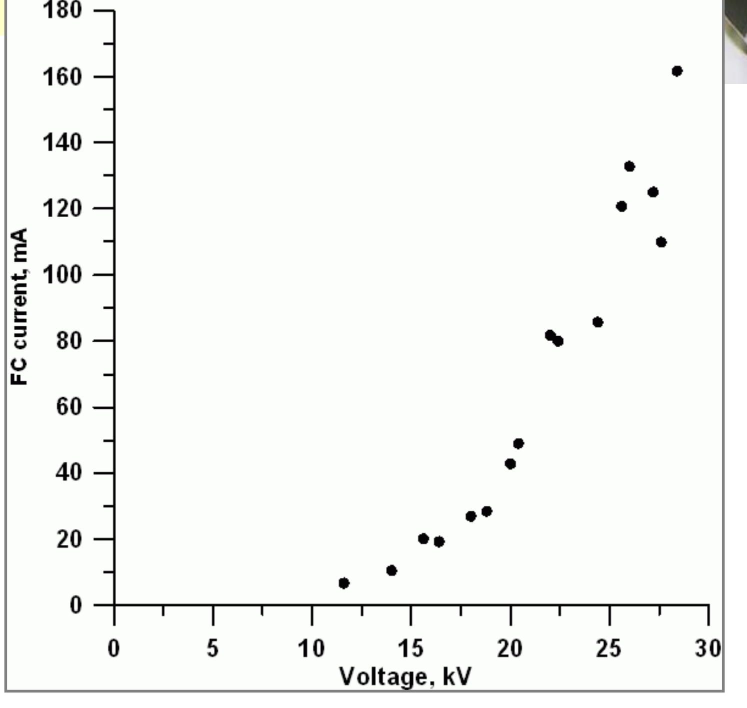
2. High Current Extraction from IAP CUSP (37 GHz)

- Multi-holes extraction
  - 13 holes Ø2 mm
  - Ø20 mm beam
- 150 mA extracted @ 30 kV



ions extraction system

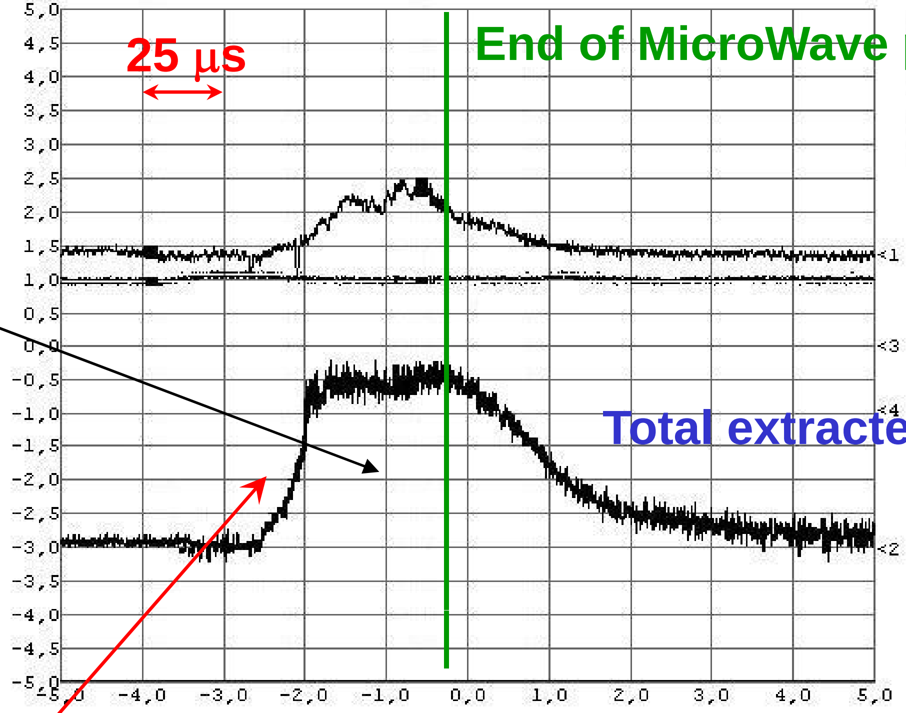
Multi-hole ions extraction electrodes



2. Short Pulse extraction from IAP CUSP (37 GHz)

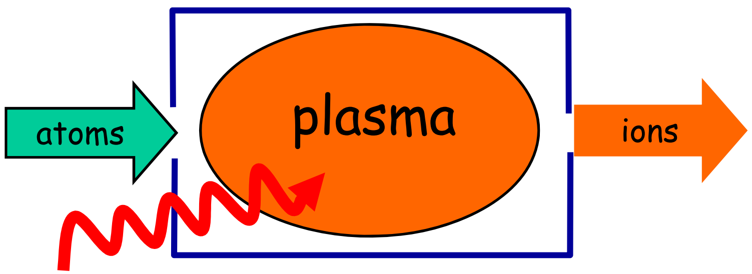
Gyrotron 37.5 GHz, 100 kW
Cusp trap with 25 cm effective length
Working gas is He

75 μs peak

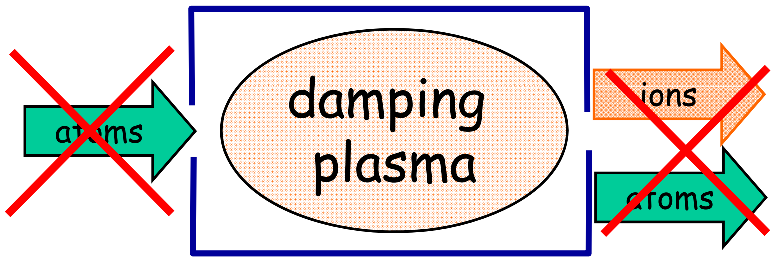


Rising time of total extracted ion current is ~15 μs !!!

- RI gas may be pumped or extracted between RF pulses
  - Pulsed valve at injection
  - Iris (camera like) at extraction or Electrostatic electrode



During RF pulse,
plasma ionizes atoms



After RF pulse,
Ion extraction continues
RIB gas can be pumped through
Plasma electrode

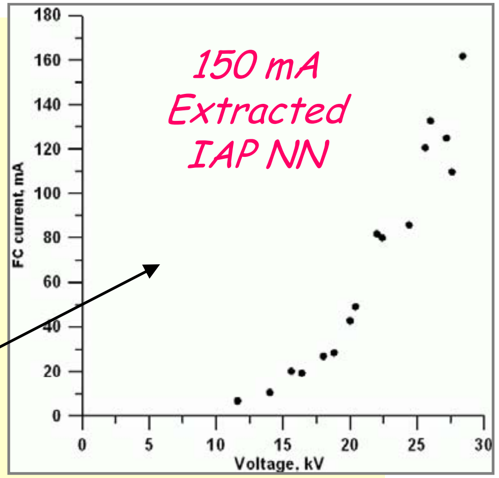
3. Ions source Volume and Ion extraction constraint

- Buffer gas flow
  - To ensure high density plasma condition
  - At 60 GHz : n_e~4.10^{13} /cm^3 => ~10^{16} e^-/litre >> RIB flux
- But the higher the buffer gas flow... the higher the total extracted current
- ...And the more difficult the extraction system design

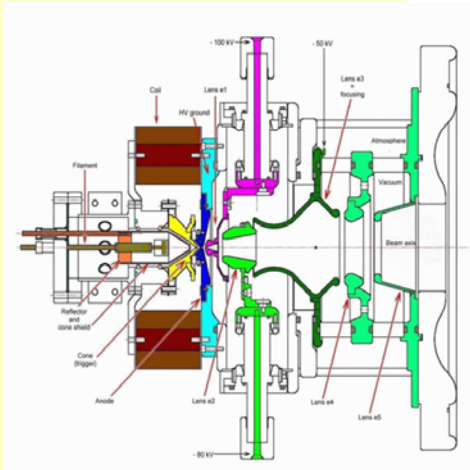
- A small plasma volume is necessary
  - Volume << 1litre
- A high voltage extraction system is mandatory
  - 100 KV
  - Very short accelerating GAP

3. Summary of possible Ion Sources scenarii

- High confinement ECRIT at 60 GHz
  - Pulse time structure (~100 μs)
  - Ionization efficiency
  - High charge state
  - Plasma Volume < 1 litre ..?
  - Total extracted current?



- A mirror or CUSP trap @ 60 GHz
  - High current extraction measured at IAP Nijni Novgorod
  - Short pulses (<100 μs)
  - Medium charge state
  - Ionization efficiency?
- A duoplasmatron ?
  - Pulse Time structure OK
  - High Current extraction OK
  - Pressure in the source…1 mbar (PBM!)
  - Ionization efficiency ??

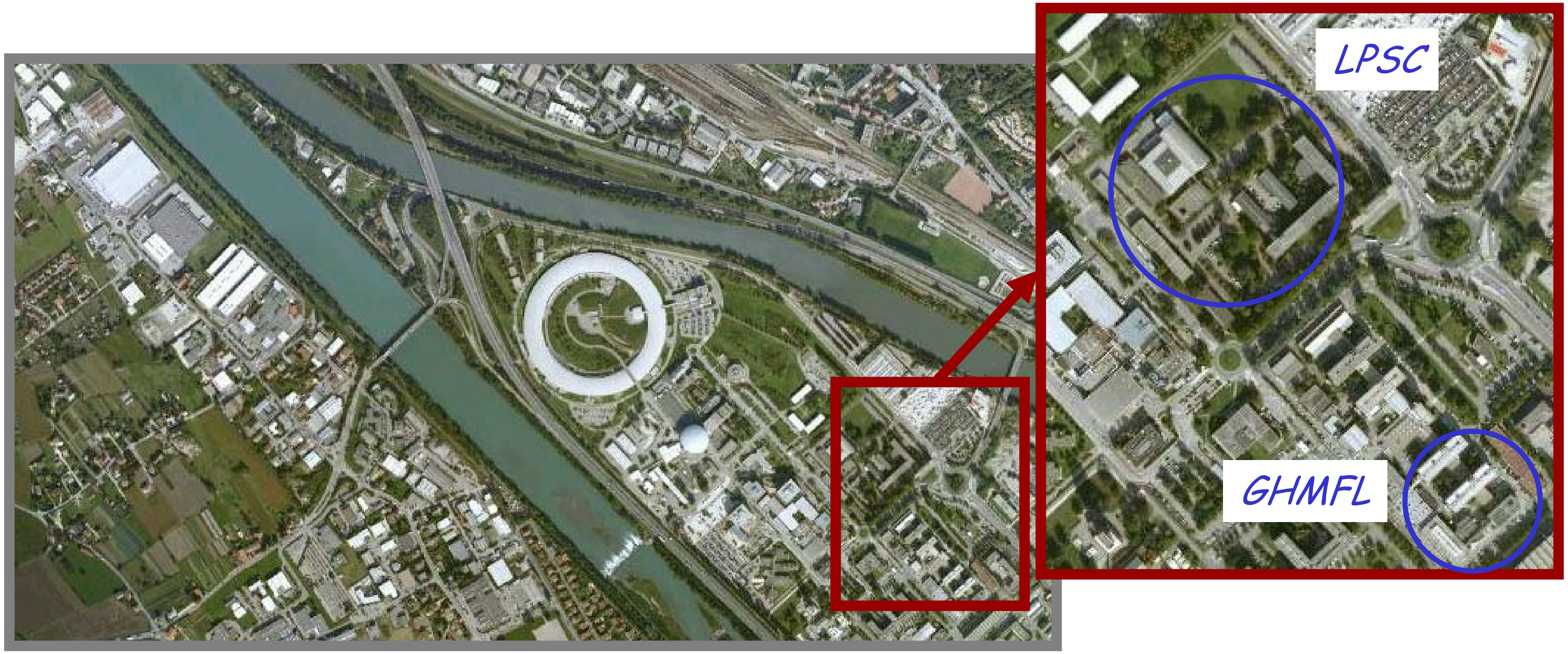


LPSC duoplasmatron

Difficult to choose…each trail is of interest for the project!

3. The 60 GHz R&D program of LPSC

- Build & test prototypes of 60 GHz magnetic structures
- Collaboration with the Grenoble High Magnetic Field Laboratory (GHMFL)
- Design and build copper based prototypes to be tested in GHMFL
- Fast CAD, fast building

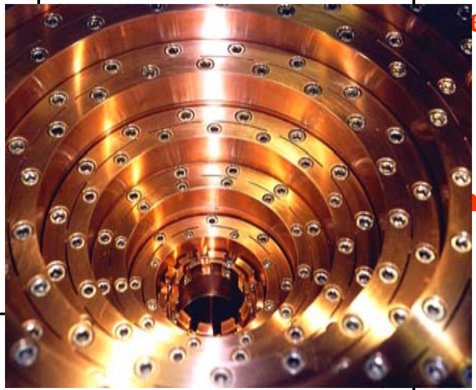


Grenoble Scientific Polygon

Grenoble High Magnetic Field Laboratory

Staff

16 permanent researchers
8 post docs
7 PhD
40 technical staff

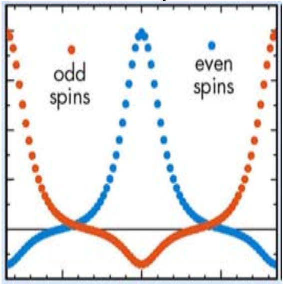


Research

Condensed matter

etals

Superconductors
Semiconductors
Magnetic materials



nophysics

Biochemistry and soft matter

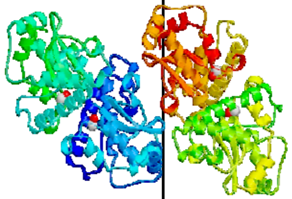
Structural studies
Magneto-science

Applied Superconductivity

Superconductor development
Magnet development

Magnetohydrodynamics

Basic studies
Technological
studies



Instrumentation under magnetic fields

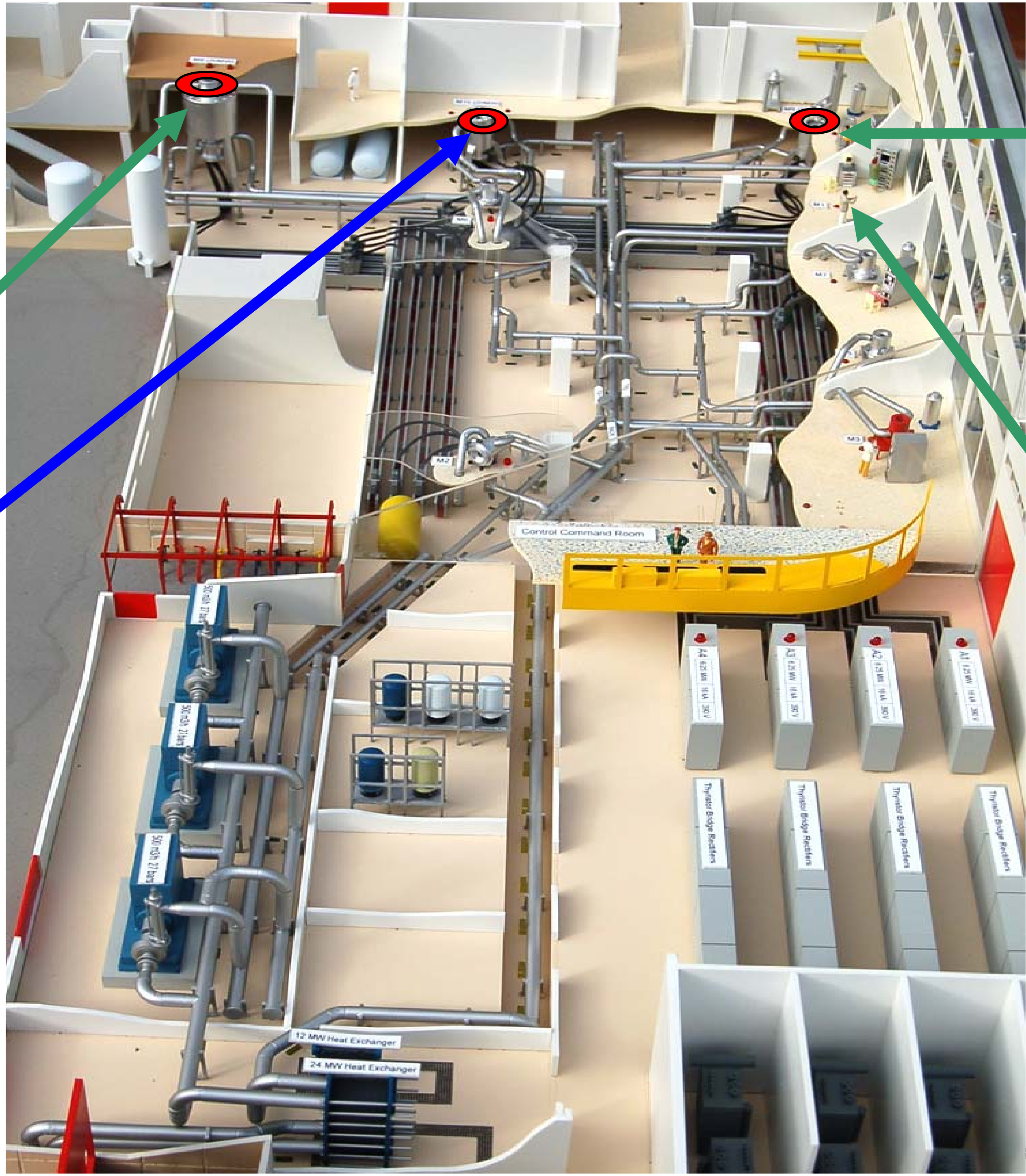
Specific technics

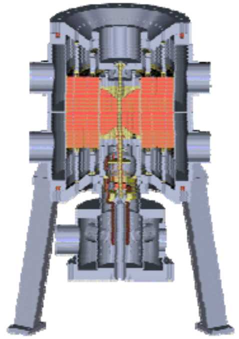
Magnetic field up to 32 T
Low temperatures (> 20 mK)
High pressure (up to 10 kbar)
High field EPR
High field NMR

➔*RESEARCH PROPOSAL FOR MAGNET TIME*
Deadline for 2nd semester 2007
May 25th, 2007

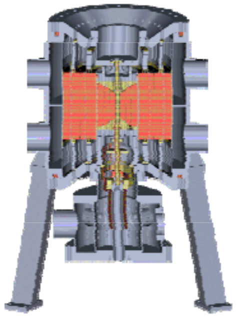
http://ghmfl.grenoble.cnrs.fr/

20 T /160 mm





32 T /34 mm
(34 T May 2007)



28 T/50 mm

10 MW 25 T
Sept 2007

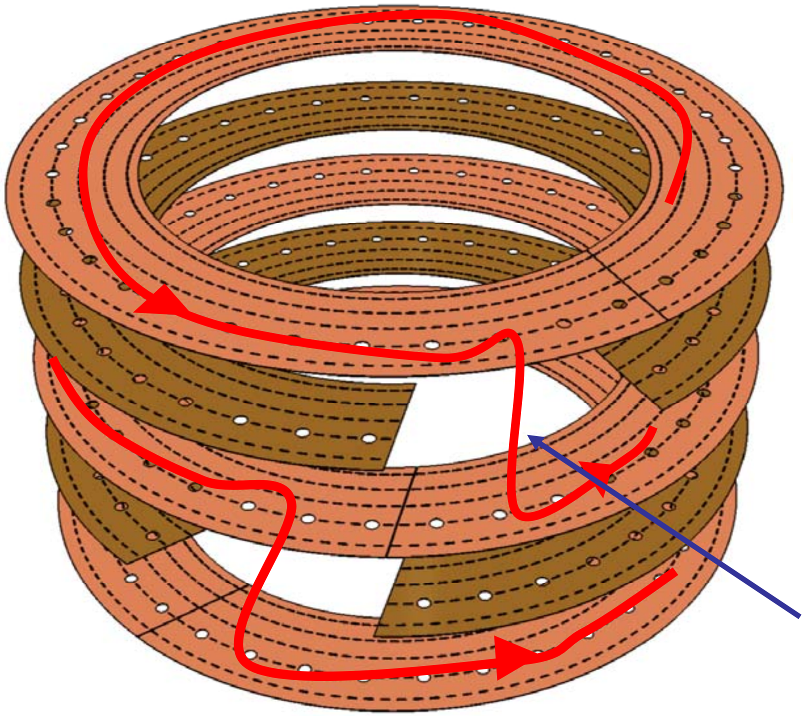
GHMFL

Magnet Technology

GHMFL

Bitter

Widely used in main high field labs



~ 1000 electric contacts under variable pressure with B

Helix

Longitudinally or Radially cooled

Developed at the GHMFL

~ 10 contacts independant of B

➔ Improved field stability

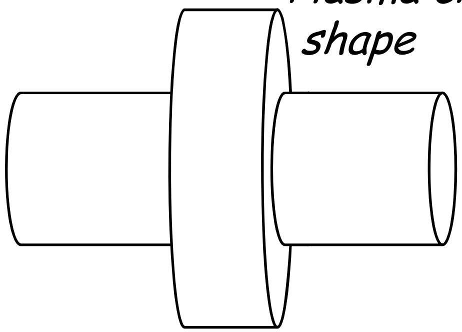
Electrical discharge machining

4. First 60 GHz Prototype - Specifications

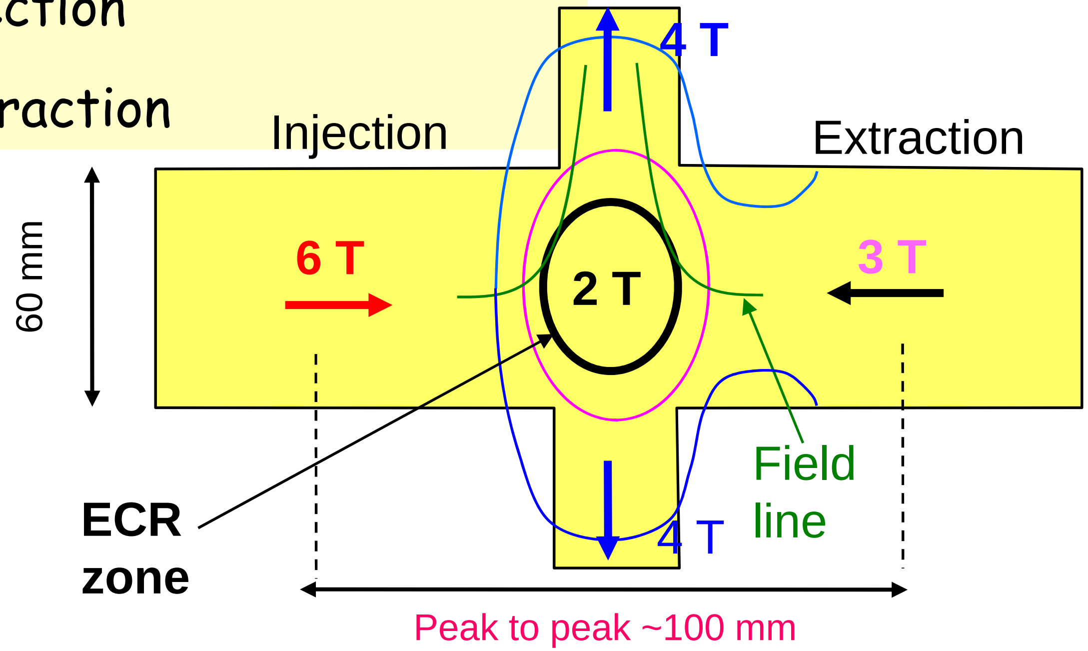
o 60 GHz Magnetic CUSP specifications:

- Compact source (~100 mm long)
- 2,1 Tesla <u>closed ECR surface</u>
- 4 Tesla radial confinement
- 6 Tesla at injection
- 3 Tesla at extraction

Plasma chamber shape



Vchamber~38 cl



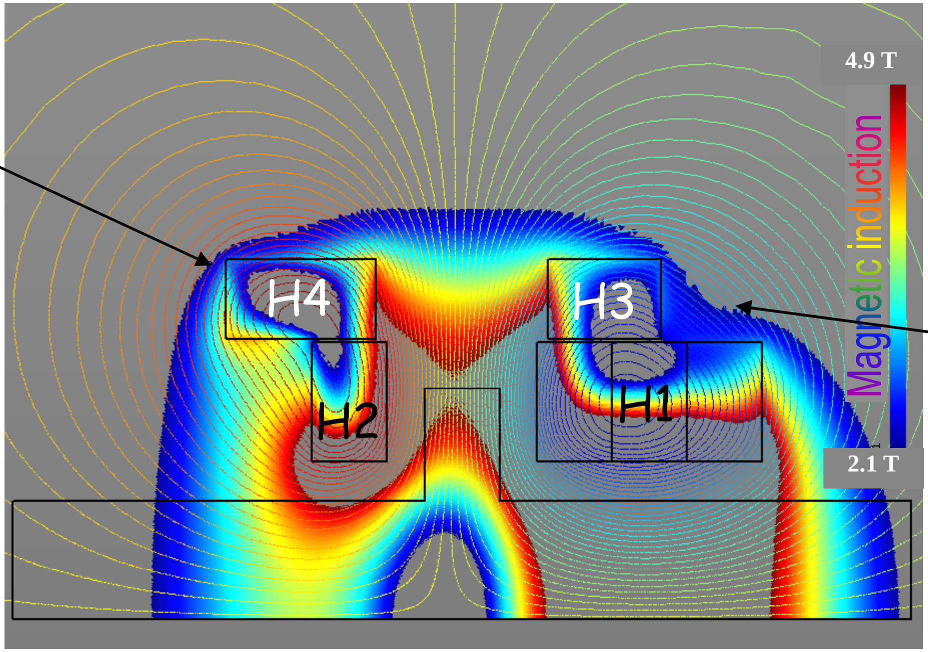
Plasma Volume~ 20 cl

4. CUSP - Magnetic Simulation

o 2D Simulation

- Fast RADIA* calculations to study coils geometry
- Getdp** to adapt coil geometry to Helix techology

Extraction coils H2+H4



Injection coils H1+H3

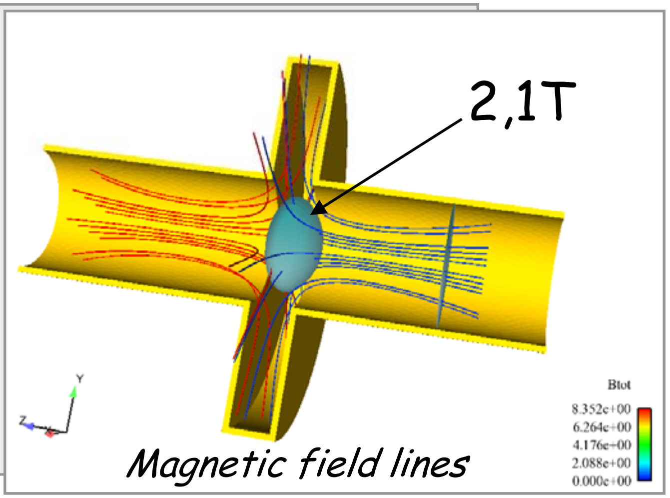
- Solution with 4 helices : H1,H2,H3,H4
- H1 has 3 helix spiral pitches

* Mathematica package (ESRF) ** Liege University

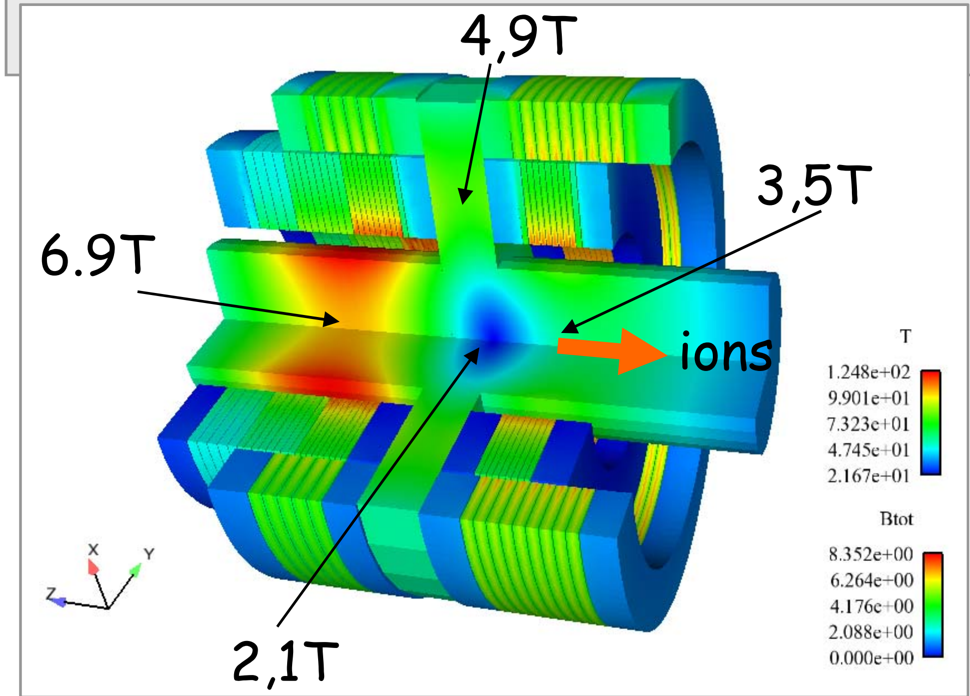
Laboratoire de Physique Subatomique et de Cosmologie

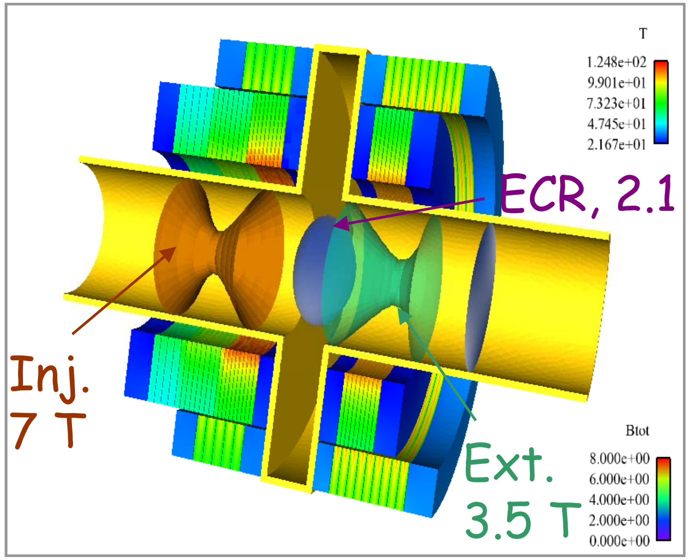
4. CUSP Magnetic Simulation

- 3D Simulation with Getdp
  - Exact geometry from CAD
  - Magnetic Field
  - Thermal study
  - Mecanical stress



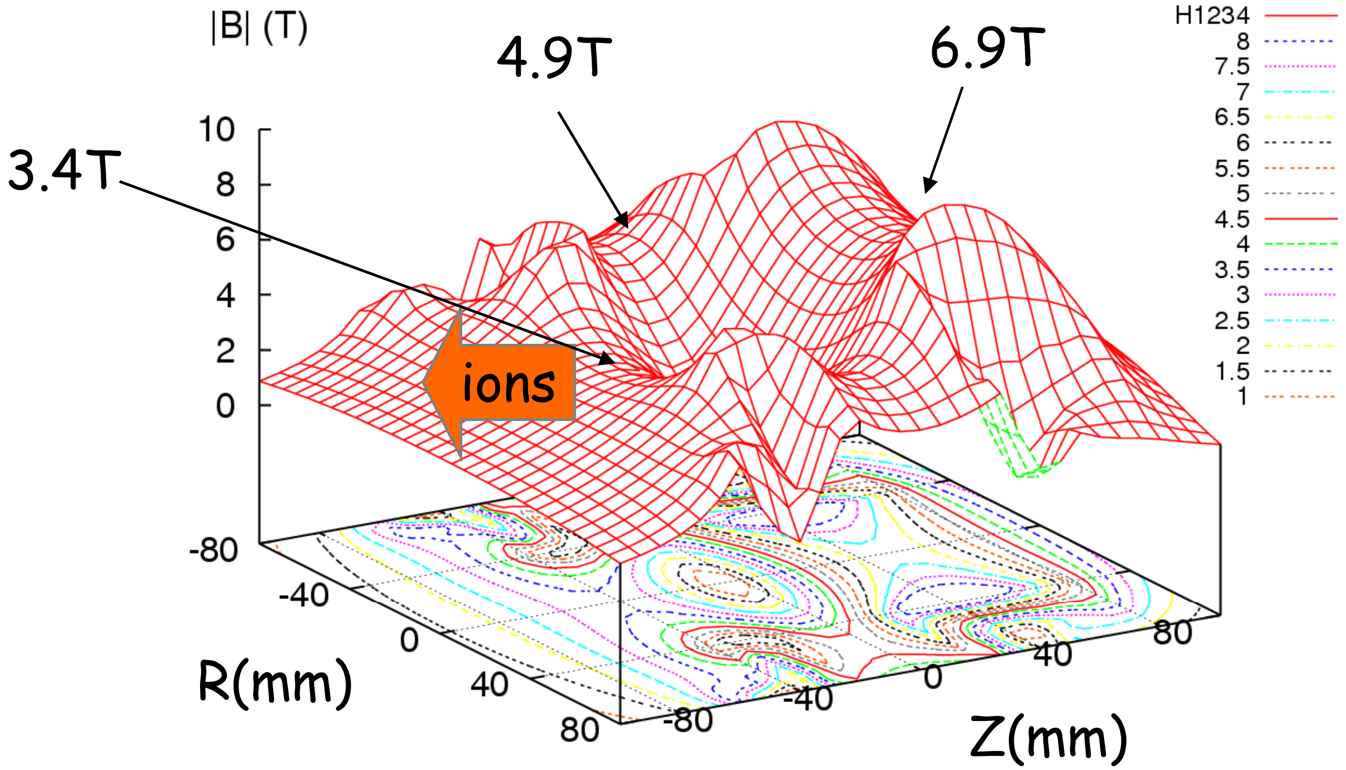
Magnetic field lines

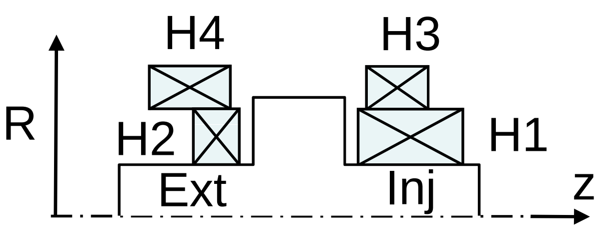




Magnetic Field Above expectation

(R,Z) plane, |B| surface

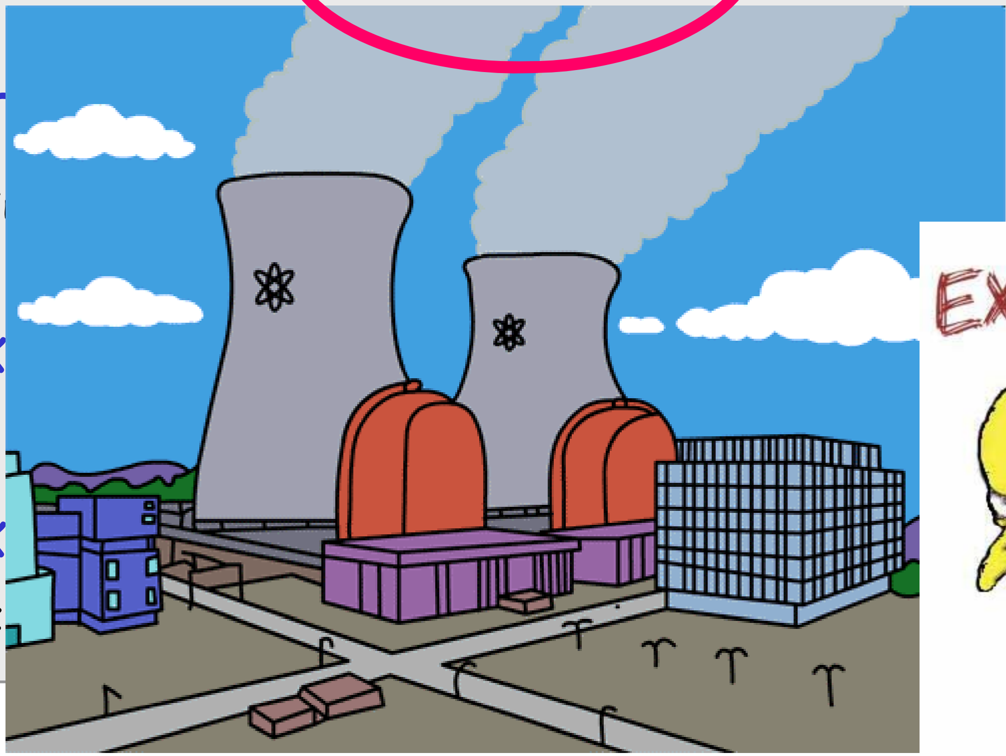




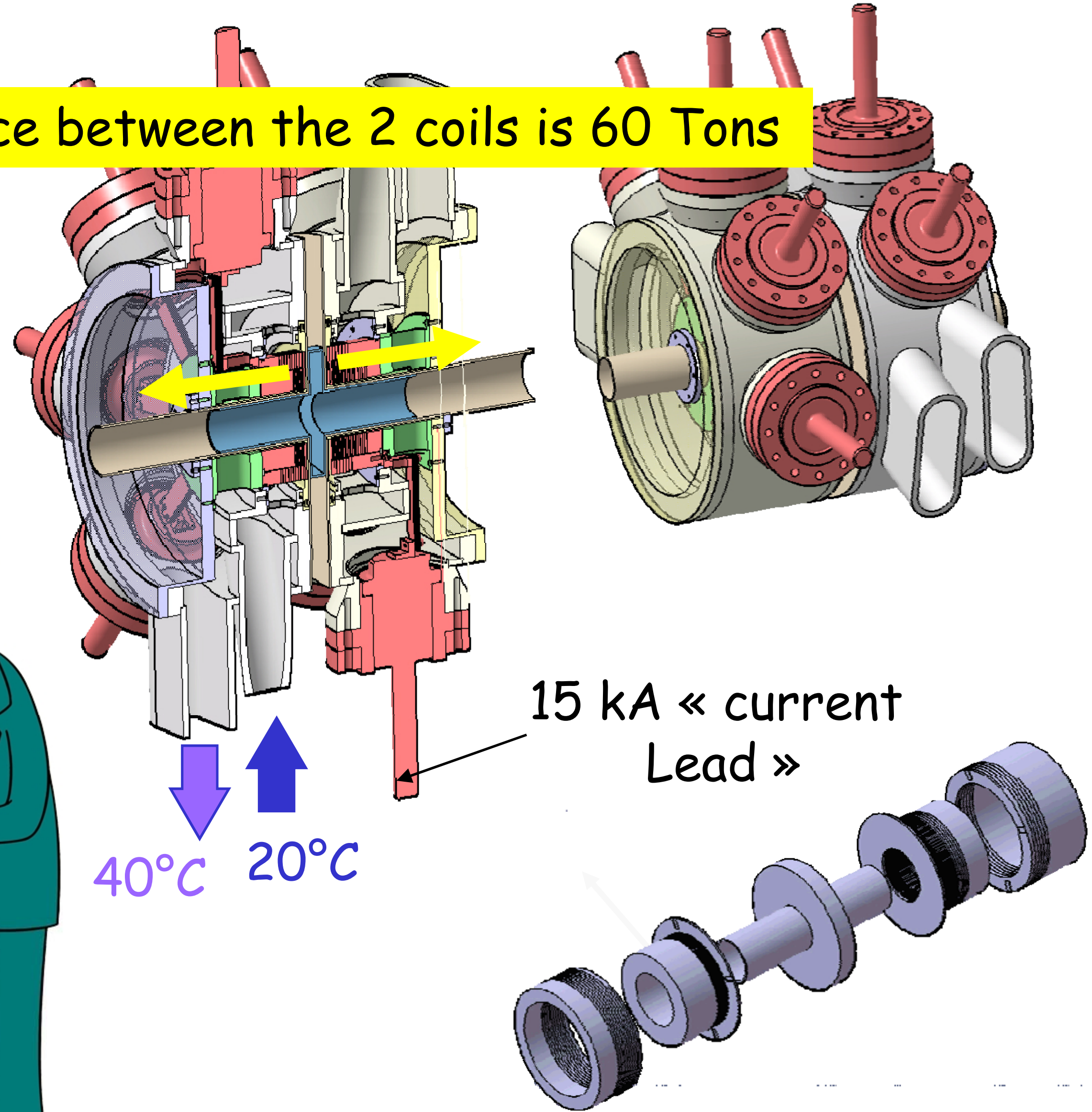
- 6,9 T injection
- 3,4 T ion extraction
- 4,9 T radial mirroir

4. CUSP – order of magnitudes

- Current : 30 kA
  - Max density in 2 mm pitch helix part : J~650 A/mm^2
- Electrical Power : P~ 5 MW
- Wat
  - P_i
- Max
- Max
  - <<

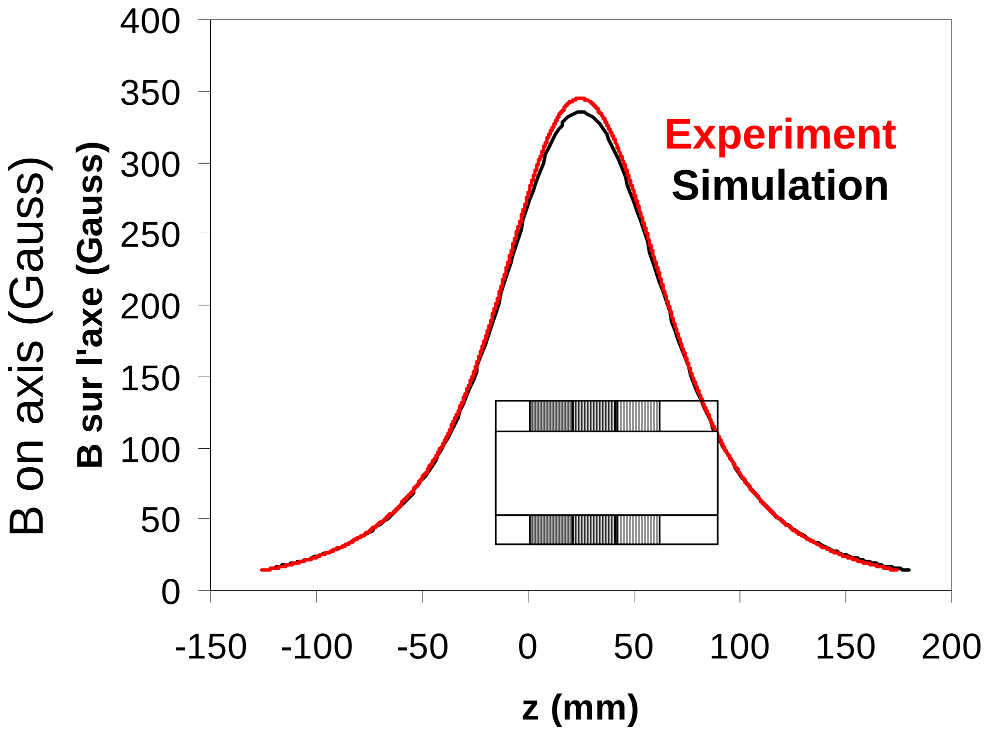


4. CAD Design


Force between the 2 coils is 60 Tons
15 kA « current Lead »
40°C
20°C

o Scale 1 Aluminum model of Coil H1

H1 Aluminum model



- Tested at 140 A (low current)
- Magnetic field measurement
- Comparison with simulation : dB/B~3%
- Magnetic structure validated : OK to build Copper Coils

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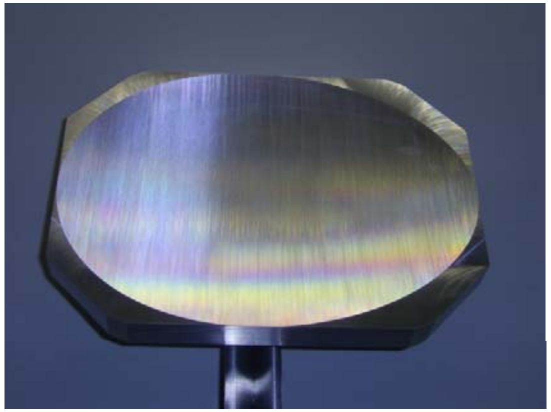
5. 60 GHz Gyrotron

- Order to be placed this year
- Technical specification :
    - 100 kW / 50-10000 μs pulse / 25 Hz
- Collaboration with IAP under discussion
- Delivery expected end 2009



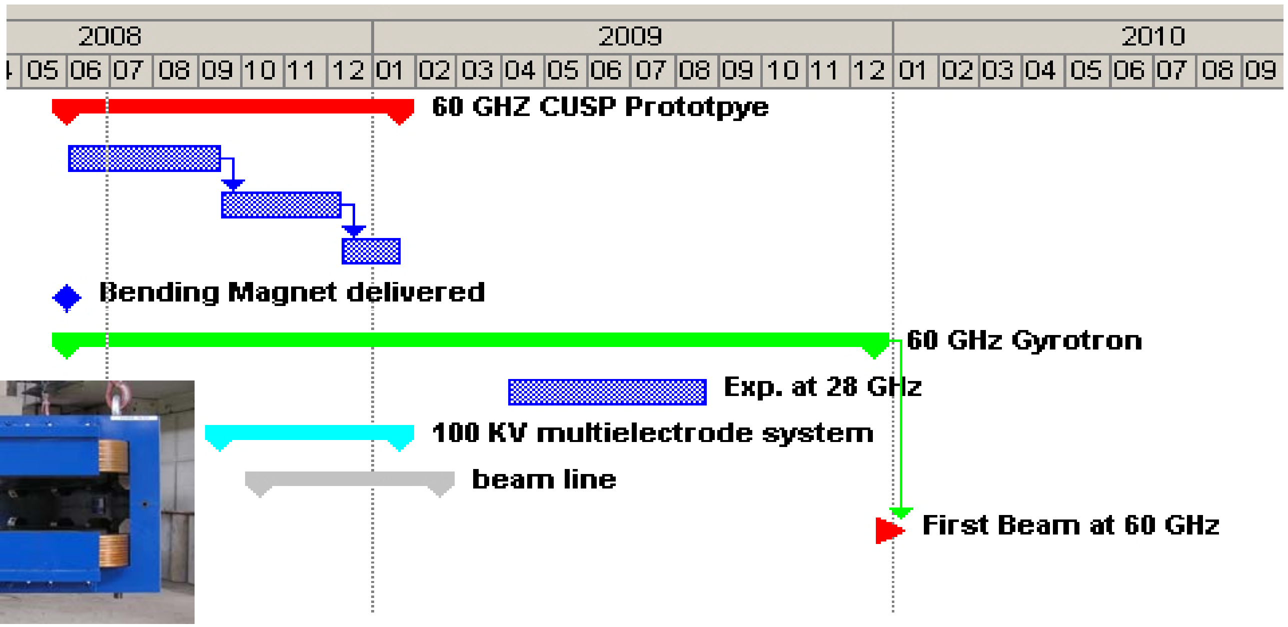
IAP Focusing Lens

Gycom Gyrotron frame

Gycom Gyrotron
53 GHz
100 kW

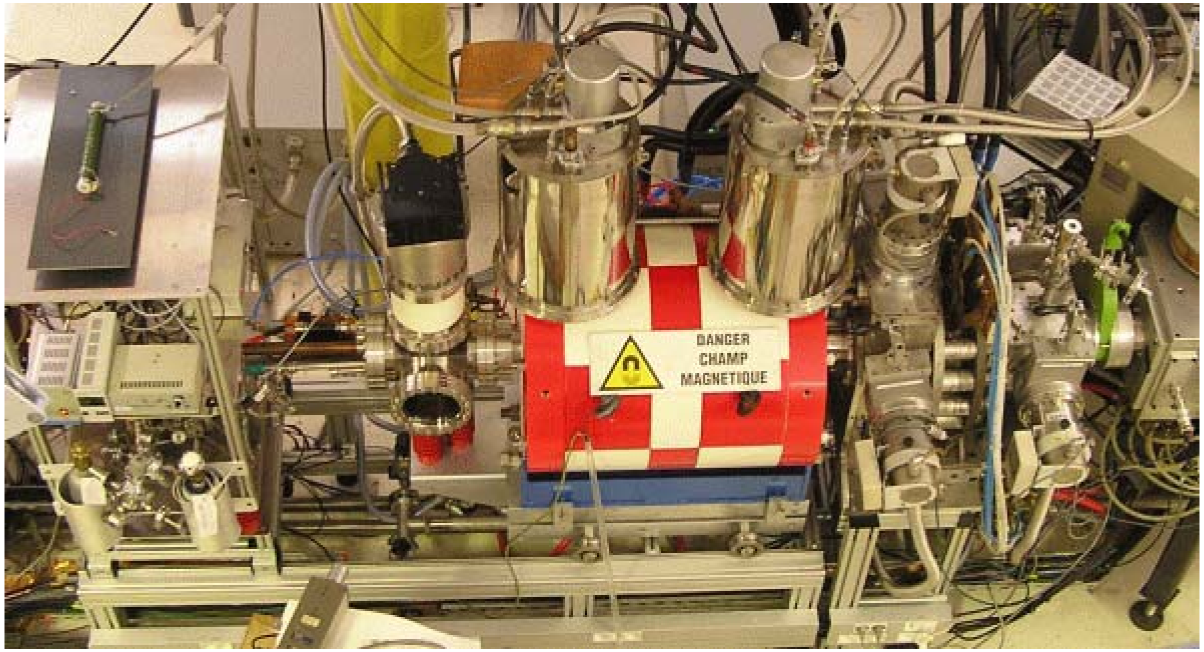
5. Planning

- CAD design under progress
  - Validation expected for 10/2008
- Mechanical parts machining
  - Expected for 12/2008
- Magnetic Structure Assembly for 01/2009
  - Deliverable of Eurisol beta beam contract, task 9



5. Additional perspective: A-PHOENIX

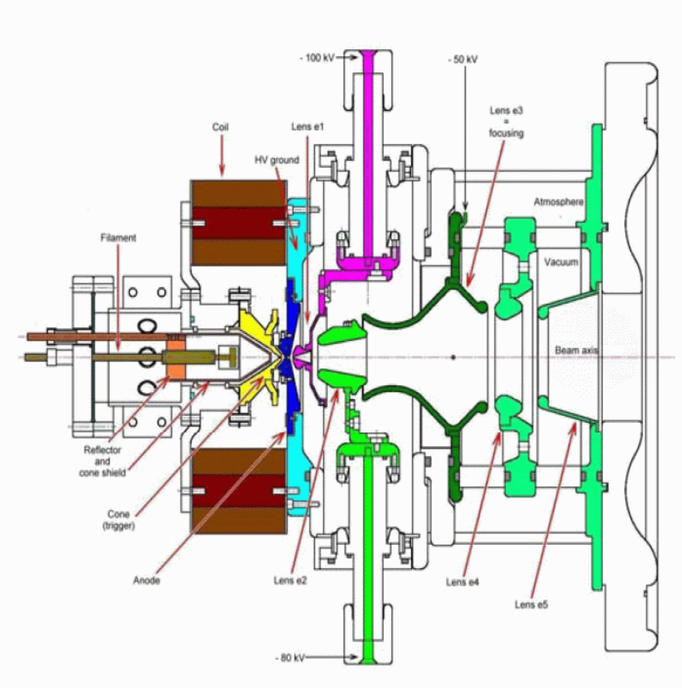
- Test with A-PHOENIX in ECRIT mode (Afterglow)
  - Classicle compact Min-B ECR Ion Source
  - 3 Tesla axial Mirror
  - 1.55-2 Tesla radial mirror
  - 28 GHz experiments
  - Study Bunching efficiency



5. Additional perspectives : Duo-plasmatron

- Waiting for the 60 GHz gyrotron availability, other tests can be done

=> Study the ionization efficiency of a duo-plasmatron
  - LPSC has several duo-plasmatrons (GENEPI,GUINEVERE)
  - A duo-plasmatron can be tested on the 60 GHz bench
  - High current , short pulse, 1+ beam
  - Ionization efficiency?
  - Gas pressure in the source?



LPSC duoplasmatron