Recent developments and electron density simulations at the ATOMKI 14.5 GHz ECRIS

S. Biri, R. Rácz, Z. Perduk, I. Vajda and J. Pálinkás

Institute of Nuclear Research (ATOMKI), Hungary, H-4026 Debrecen, Bem tér 18/c

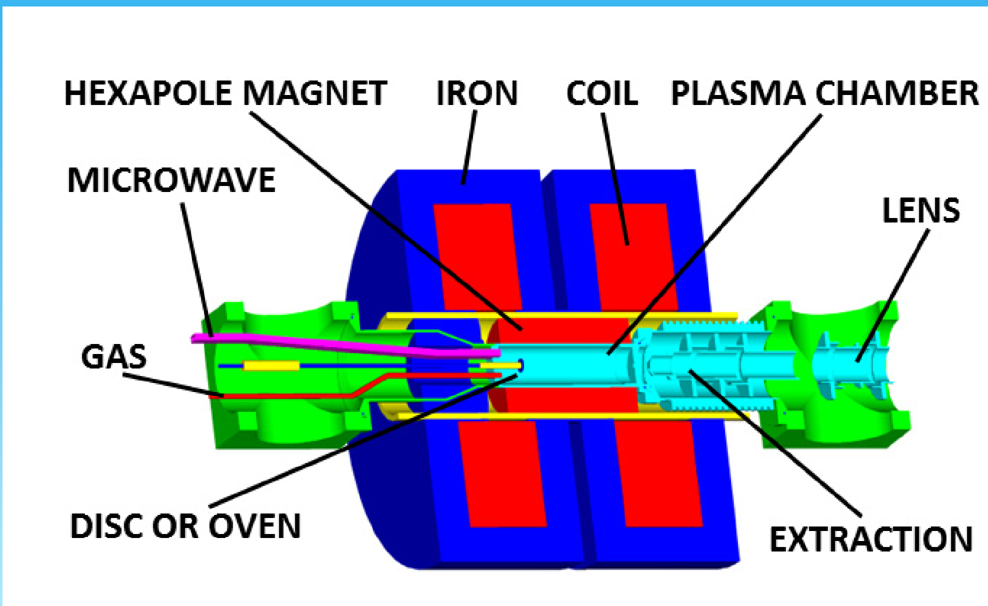
University of Debrecen, Hungary, H-4010 Debrecen, Egyetem tér 1.

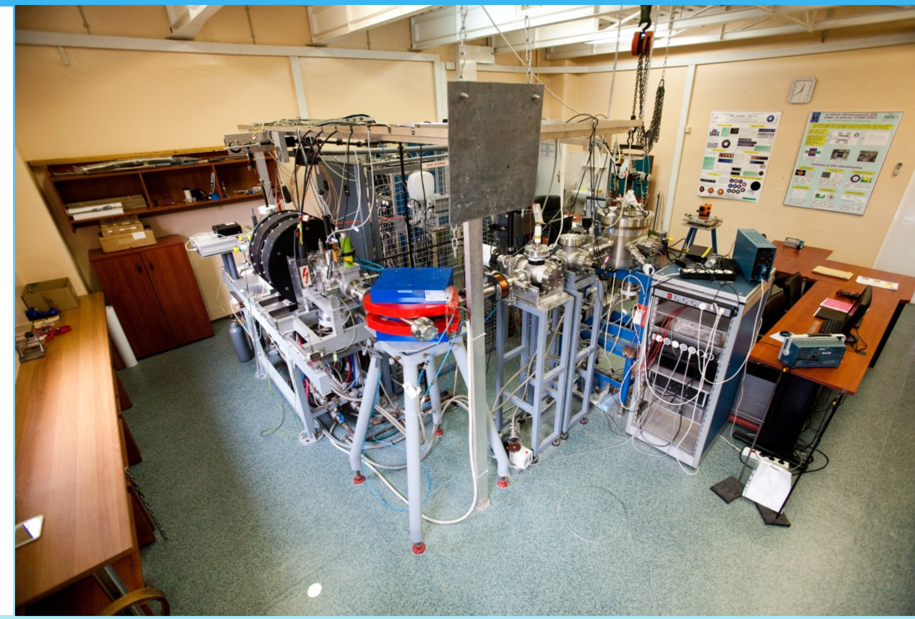
Summary

1. Magnetic trap upgrade and other developments
   - ❑ Hexapole change
   - ❑ New iron plugs
   - ❑ Ions from solids
   - ❑ New control system

2. Simulation of the ECRIS electron cloud
   - ❑ TrapCAD summary and upgrades
   - ❑ Initial conditions
   - ❑ General results
   - ❑ Filtering by energy and position : specific results

The ATOMKI-ECRIS: 1992-2012





Main features:

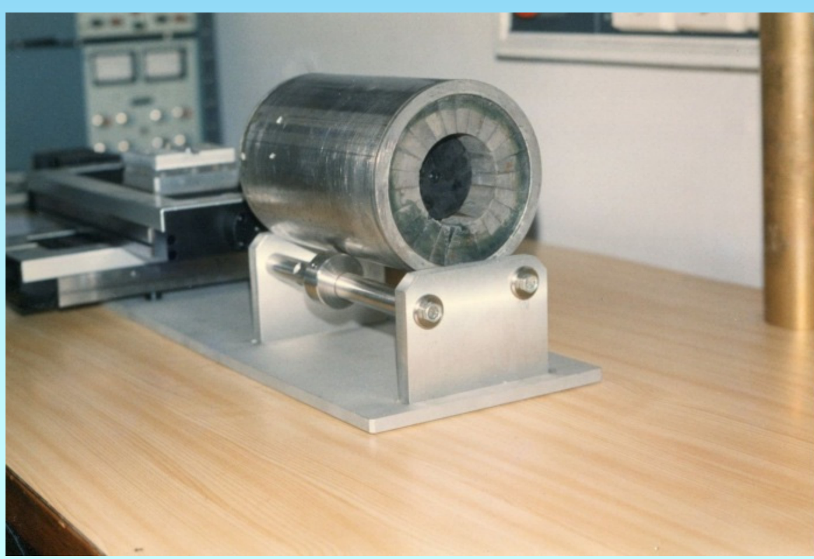
- 14.5 GHz (1000 W)
- 8…12 GHz (20 W)
- Room-temperature coils
- NdFeB hexapole
- Platform voltage: 50 V – **30 KV**
- No post-acceleration

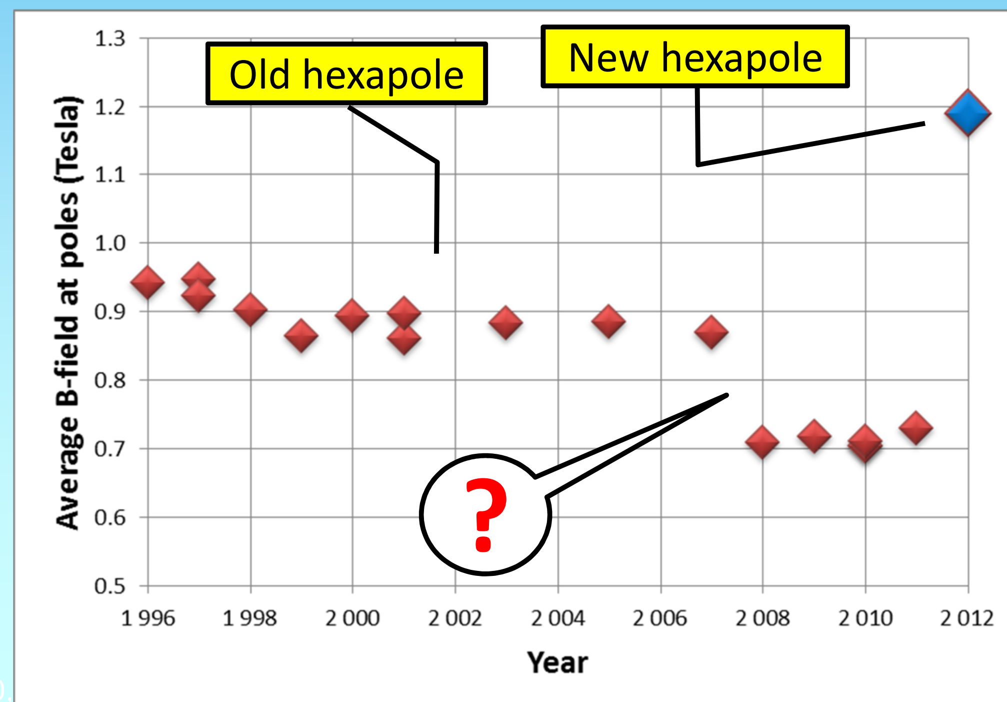
Applications / research topics:

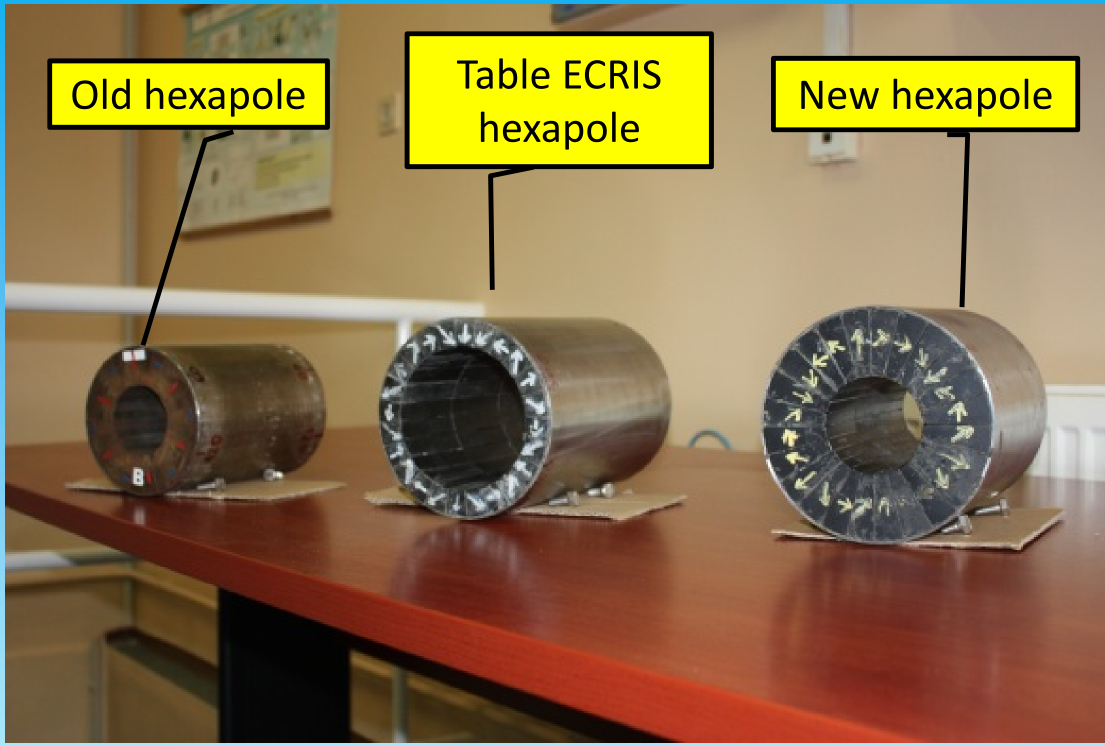
- Plasma diagnostics
- Atomic physics (ion guiding)
- Industrial application (surface mod)
- Medical applications (surface mods)
- New materials (X@C60)

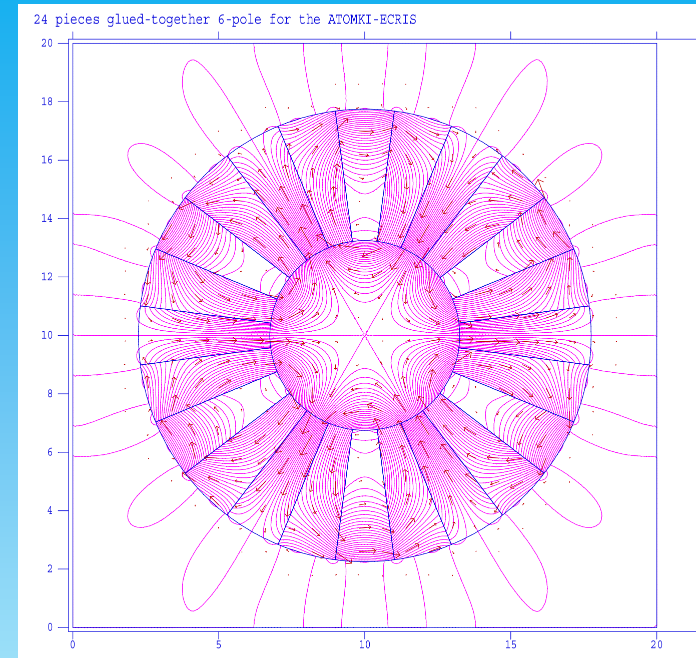
Magnetic system upgrade 1: changing the hexapole

- 1996: first hexapole: **0.95 Tesla** in the chamber (R=29 mm)
- 1996-2007: about **2%** decrease year by year.
- 2008: un-understable sudden decrease: **0.7 Tesla** only! (R=29 mm)
- 2008-2012: the ECRIS mainly operated at lower frequencies (8…12 GHz).
- 2012: new hexapole: **1.2 Tesla** in the chamber





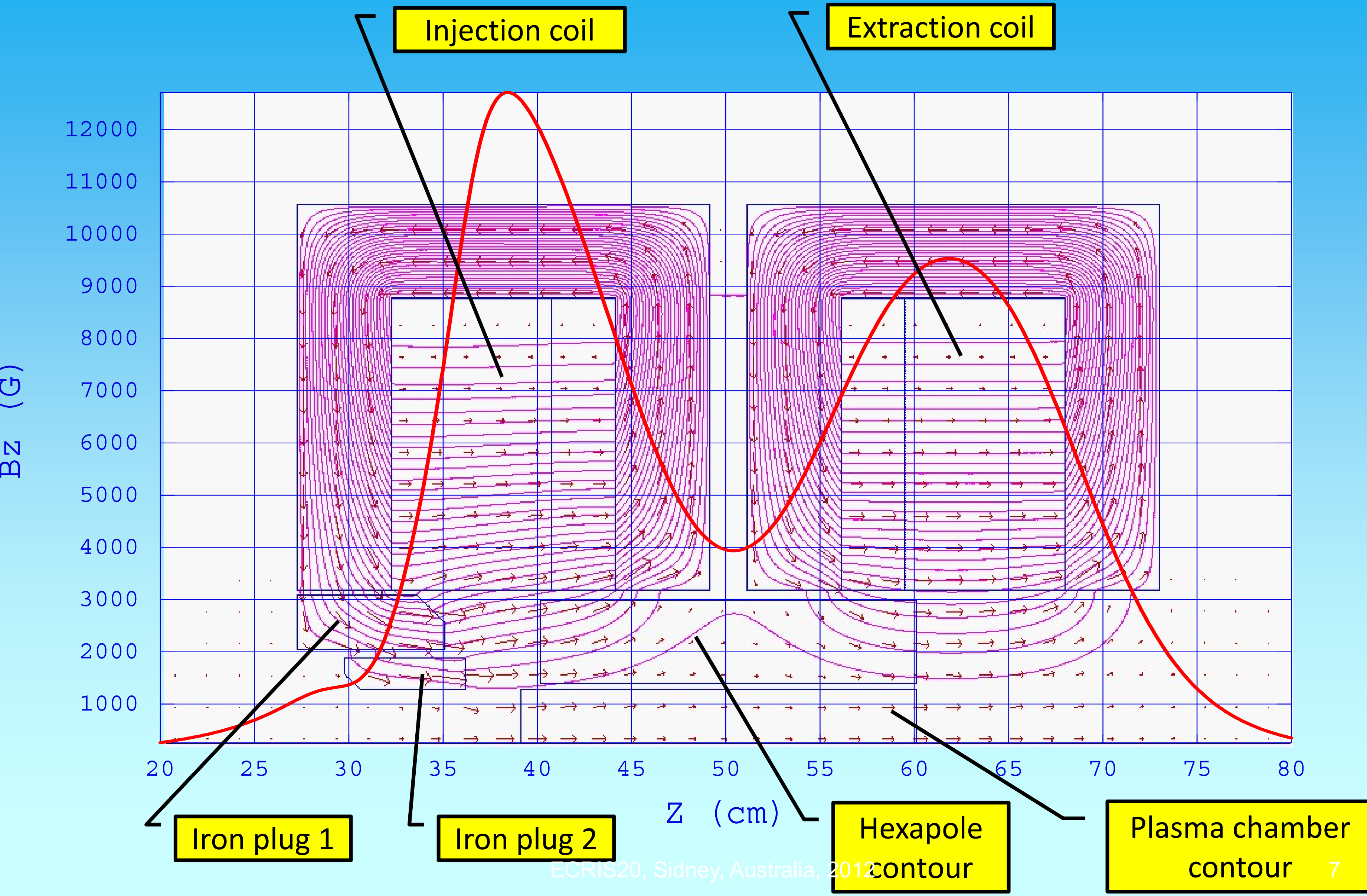


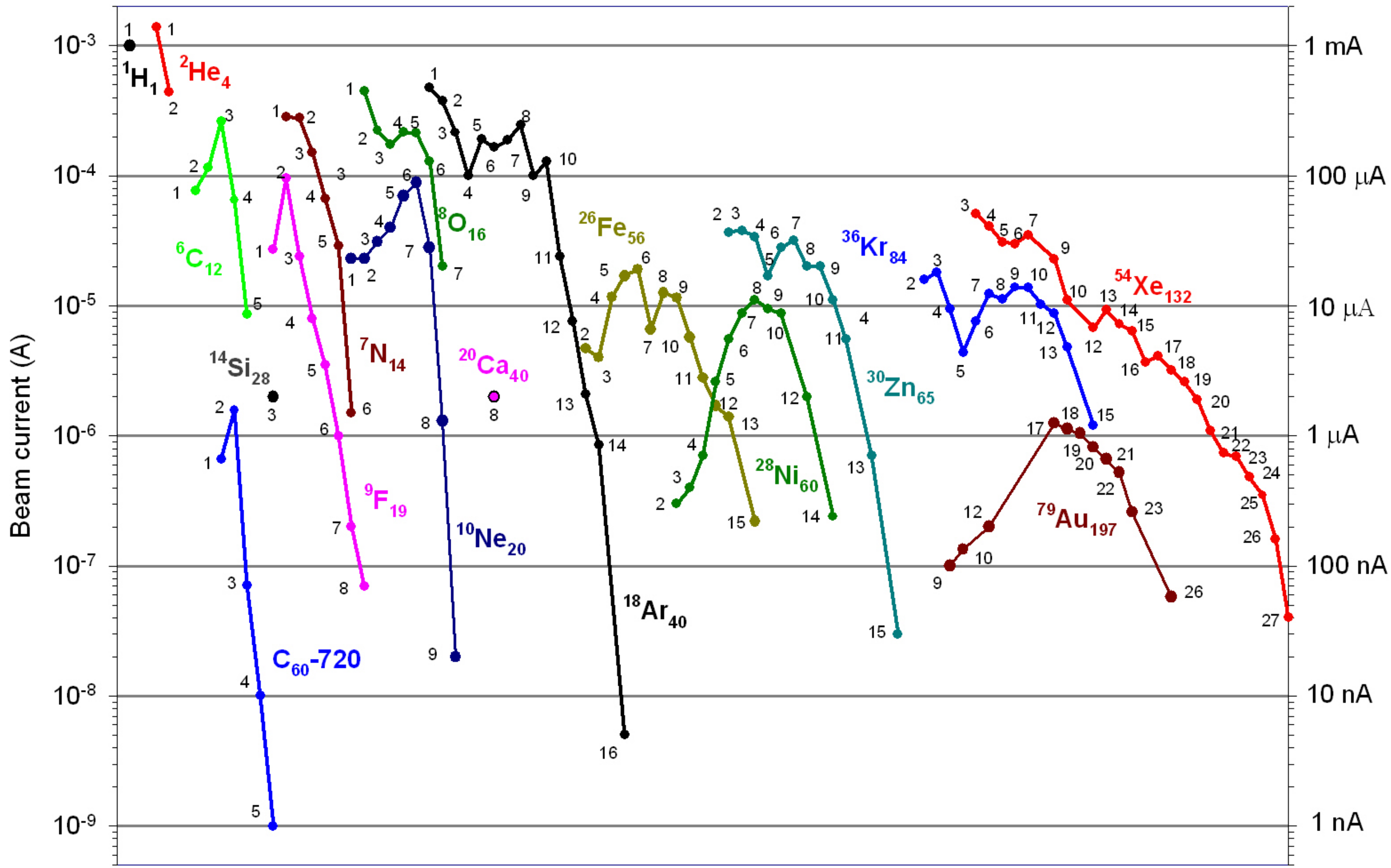


	Material	Segments	Length (mm)	ID (mm)	OD (mm)	B-field at R=29 mm (Tesla)
Old hexapole	NdFeB (490i/400i)	24	200	65	135	0.95 (0.7)
New hexapole	NdFeB (N45H)	24	200	65	**155**	**1.2**

Magnetic system upgrade 2: new iron plugs

- the soft iron magnetic plugs at the injection side were re-designed, manufactured and installed.
- to increase the peak magnetic field at the injection side **inside** the plasma chamber as high as possible.
- to minimize the force to the plugs and thus to minimize the opposite direction force to the basic structure of the ion source.
- now the peak axial magnetic field at the injection side is almost 1.3 Tesla


Injection coil
Extraction coil
Bz (G)
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
20
25
30
35
40
45
50
55
60
65
70
75
80
Z (cm)
Iron plug 1
Iron plug 2
Hexapole contour
Plasma chamber contour

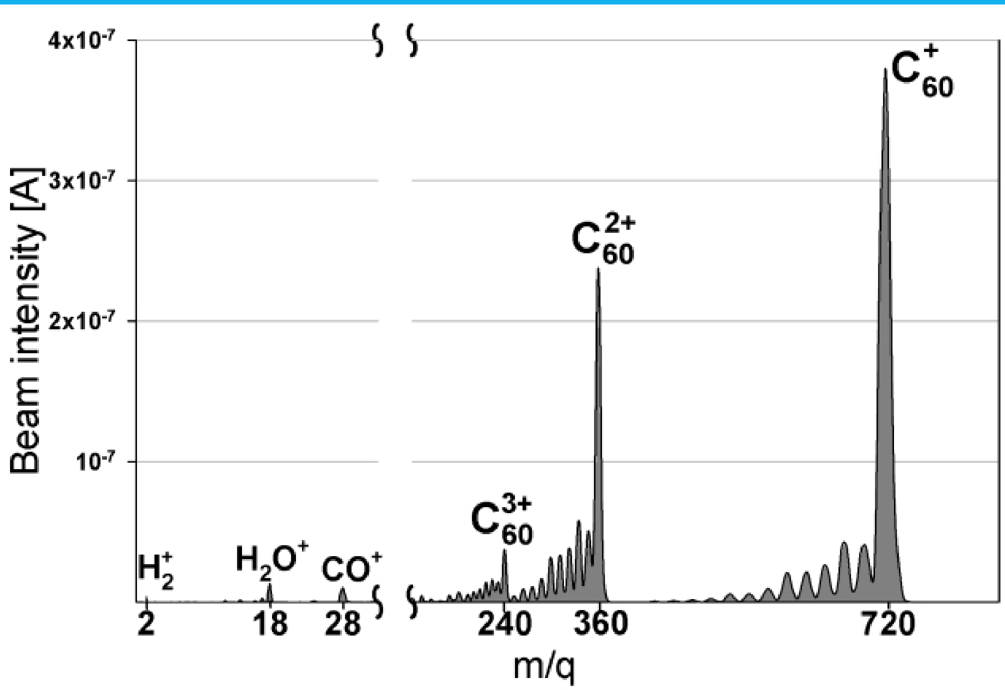

Beam current (A)
10-3
10-4
10-5
10-6
10-7
10-8
10-9
1 mA
100 μA
10 μA
1 μA
100 nA
10 nA
1 nA
1H1
2He4
6C12
14Si28
7N14
9F19
8O16
10Ne20
20Ca40
18Ar40
26Fe56
28Ni60
30Zn65
36Kr84
54Xe132
79Au197
C60-720

New beams from solids

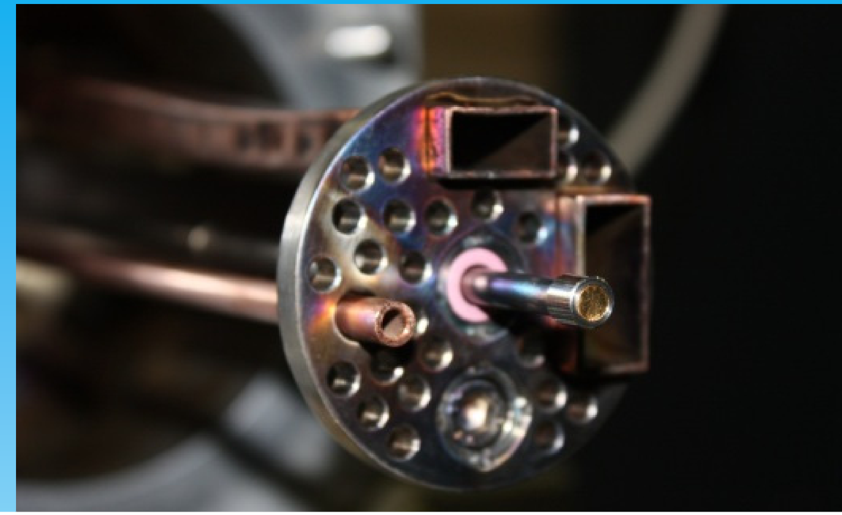
Challenge:

Some of our users (materials physicists, dentists) require „unusual” beams, like:

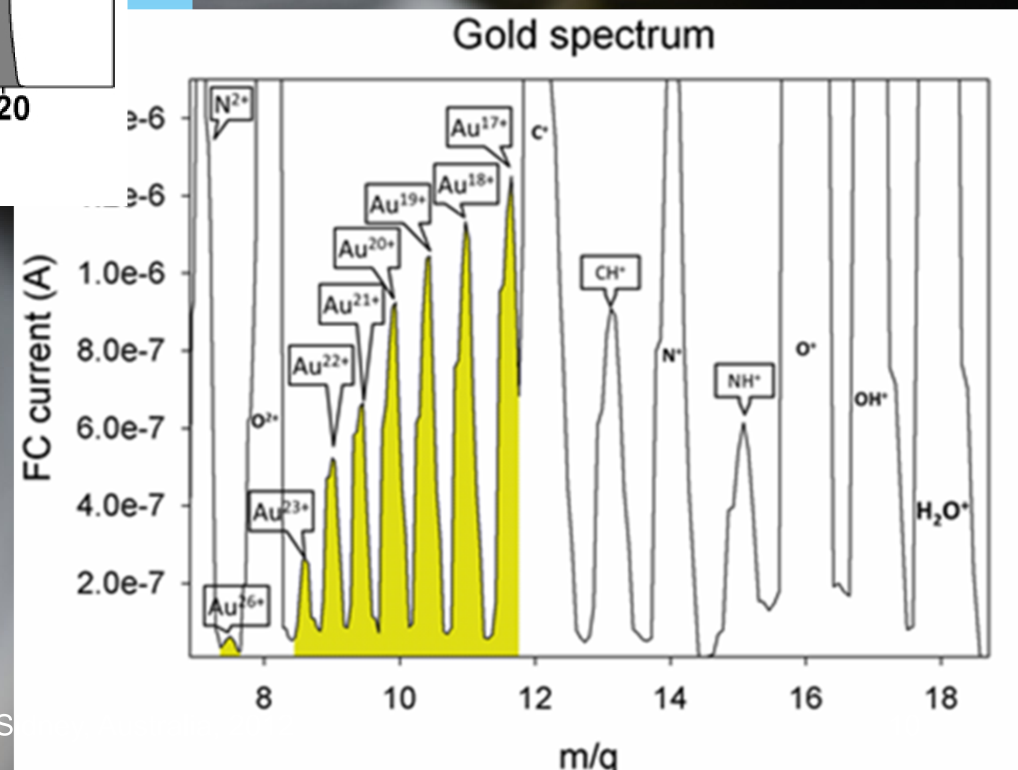
- Fullerene: routinely used
- Gold: sputtering, first result are promising
- Calcium: sputtering, argon mass difficulty
- Silicon: grinded, mixed with carbon powder (SiH_4 better?)



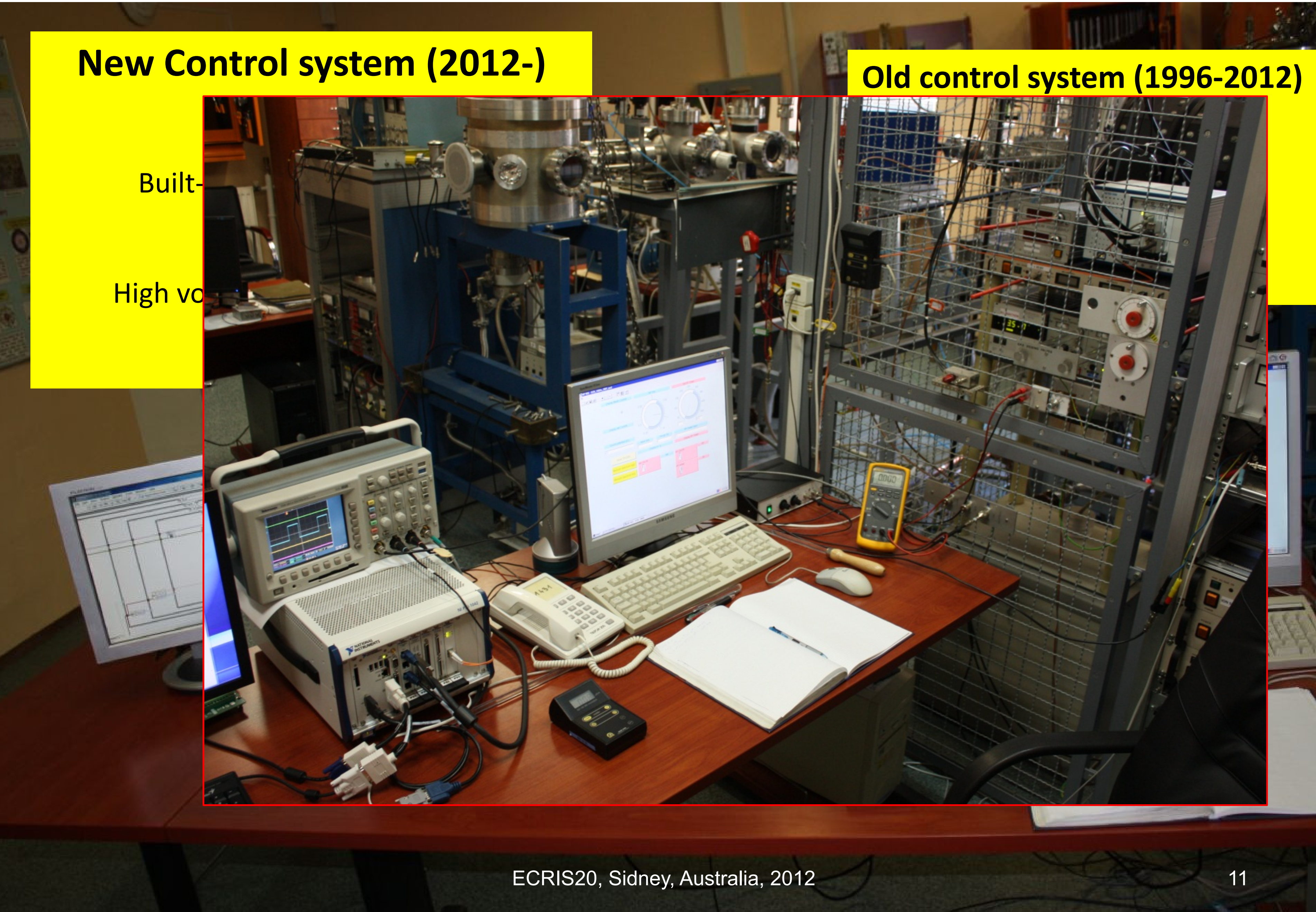
Beam intensity [A]
4x10^-7
3x10^-7
2x10^-7
10^-7
H2+
H2O+
CO+
C60 3+
C60 2+
C60 +
2
18
28
240
360
720
m/q



ECRIS20, S



Gold spectrum
FC current (A)
e-6
e-6
1.0e-6
8.0e-7
6.0e-7
4.0e-7
2.0e-7
N2+
O2+
Au26+
Au23+
Au22+
Au21+
Au20+
Au19+
Au18+
Au17+
C+
CH+
N+
NH+
O+
OH+
H2O+
8
10
12
14
16
18
m/q

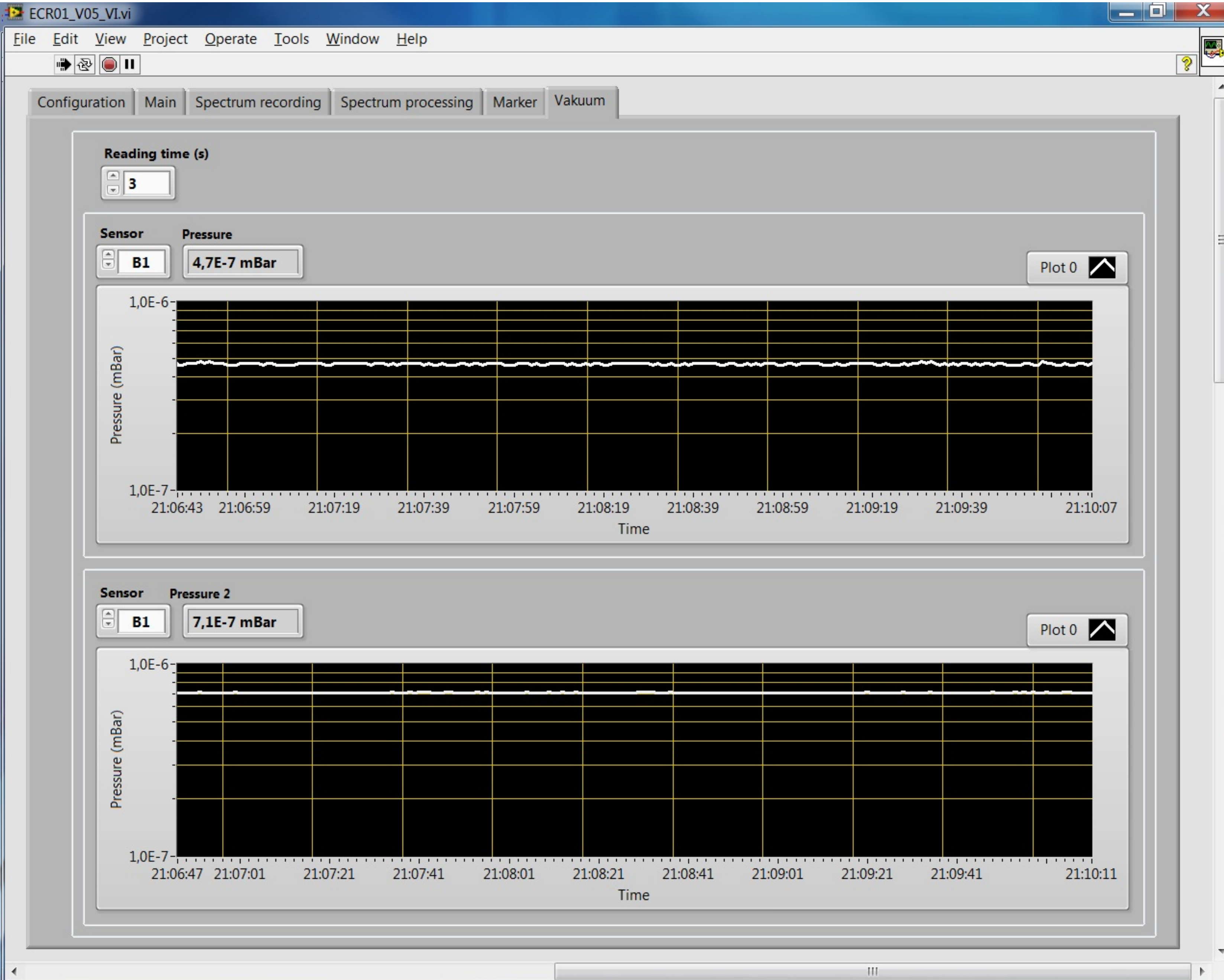


New Control system (2012-)

Built-

High vo

Old control system (1996-2012)



ECR01_V05_VI.vi
File Edit View Project Operate Tools Window Help
Configuration Main Spectrum recording Spectrum processing Marker Vakuum
Reading time (s)
3
Sensor
Pressure
B1
4,7E-7 mBar
Plot 0
1,0E-6
1,0E-7
Pressure (mBar)
21:06:43 21:06:59 21:07:19 21:07:39 21:07:59 21:08:19 21:08:39 21:08:59 21:09:19 21:09:39 21:10:07
Time
Sensor
Pressure 2
B1
7,1E-7 mBar
Plot 0
1,0E-6
1,0E-7
Pressure (mBar)
21:06:47 21:07:01 21:07:21 21:07:41 21:08:01 21:08:21 21:08:41 21:09:01 21:09:21 21:09:41 21:10:11
Time

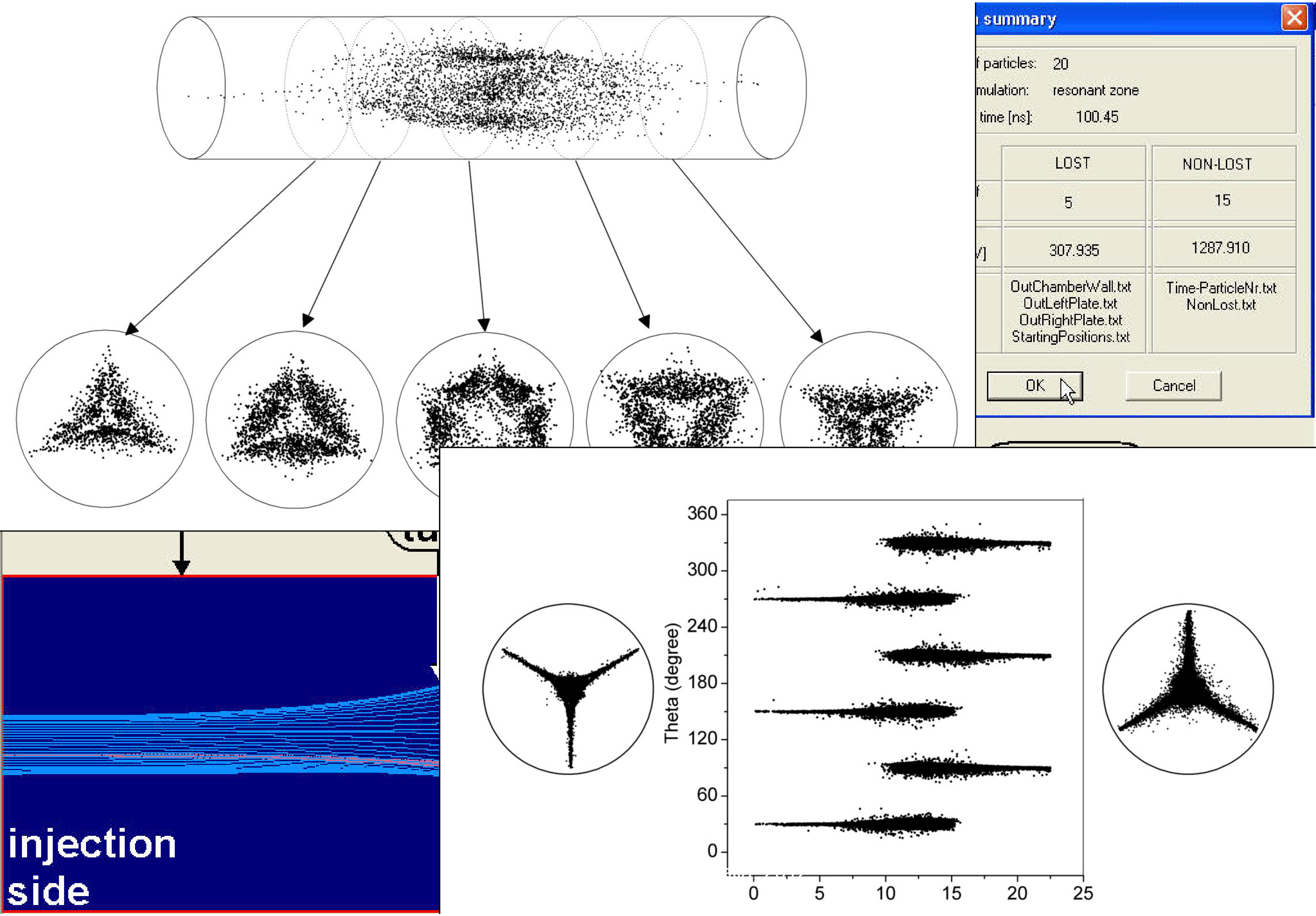
Summary

1. Magnetic trap upgrade and other developments
   - ❑ Hexapole change
   - ❑ New iron plugs
   - ❑ Ions from solids
   - ❑ New control system

2. Simulation of the ECRIS electron cloud
   - ❑ TrapCAD summary and upgrades
   - ❑ Initial conditions
   - ❑ General results
   - ❑ Filtering by energy and position : specific results

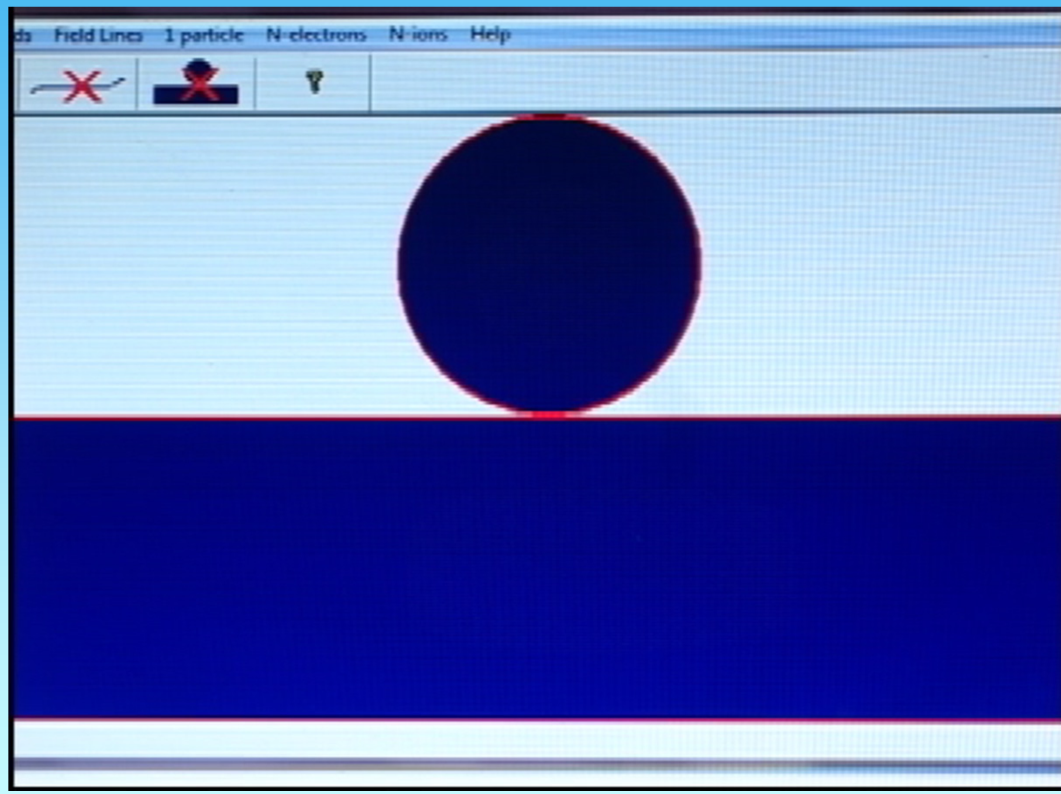
ECRIS plasma electrons simulation

- TrapCAD code: since 1994…
- More than 20 users
- „Multiple-one-particle” code
- Realistic magnetic field (2D-3D)
- Stochastic ECR heating
- Magnetic field: PoissonSuperfish
- Only electrons
- Plasma potential not included
- Collisions not included



summary
f particles: 20
mulation: resonant zone
time [ns]: 100.45
LOST
NON-LOST
5
15
307.935
1287.910
OutChamberWall.txt
OutLeftPlate.txt
OutRightPlate.txt
StartingPositions.txt
Time-ParticleNr.txt
NonLost.txt
OK
Cancel
injection
side
Theta (degree)
360
300
240
180
120
60
0
0
5
10
15
20
25

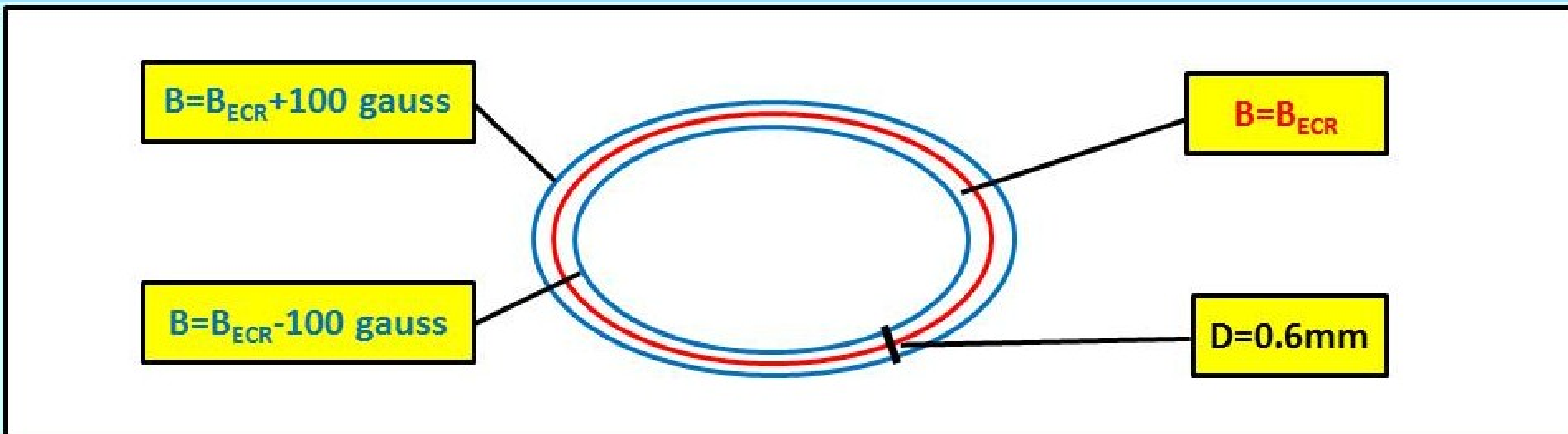
TrapCAD: cloud from 50000 elektrons



ECRIS electrons simulation

- Improved magnetic trap = time to re-calculate
- Magnetic field: PoissonSuperfish

- TrapCAD recent upgrades:
  - the initial electron density on the surface of the resonance zone is much more equal than before
  - the surface may have a thickness
  - faster runnig



Initial conditions

Geometry. Cylindrical plasma chamber of the ATOMKI-ECRIS, D=58 mm, L=210 mm.

Magnetic field. New hexapole, new plugs, PoissonSuperfish. Mesh size 1 mm.

Electrons.

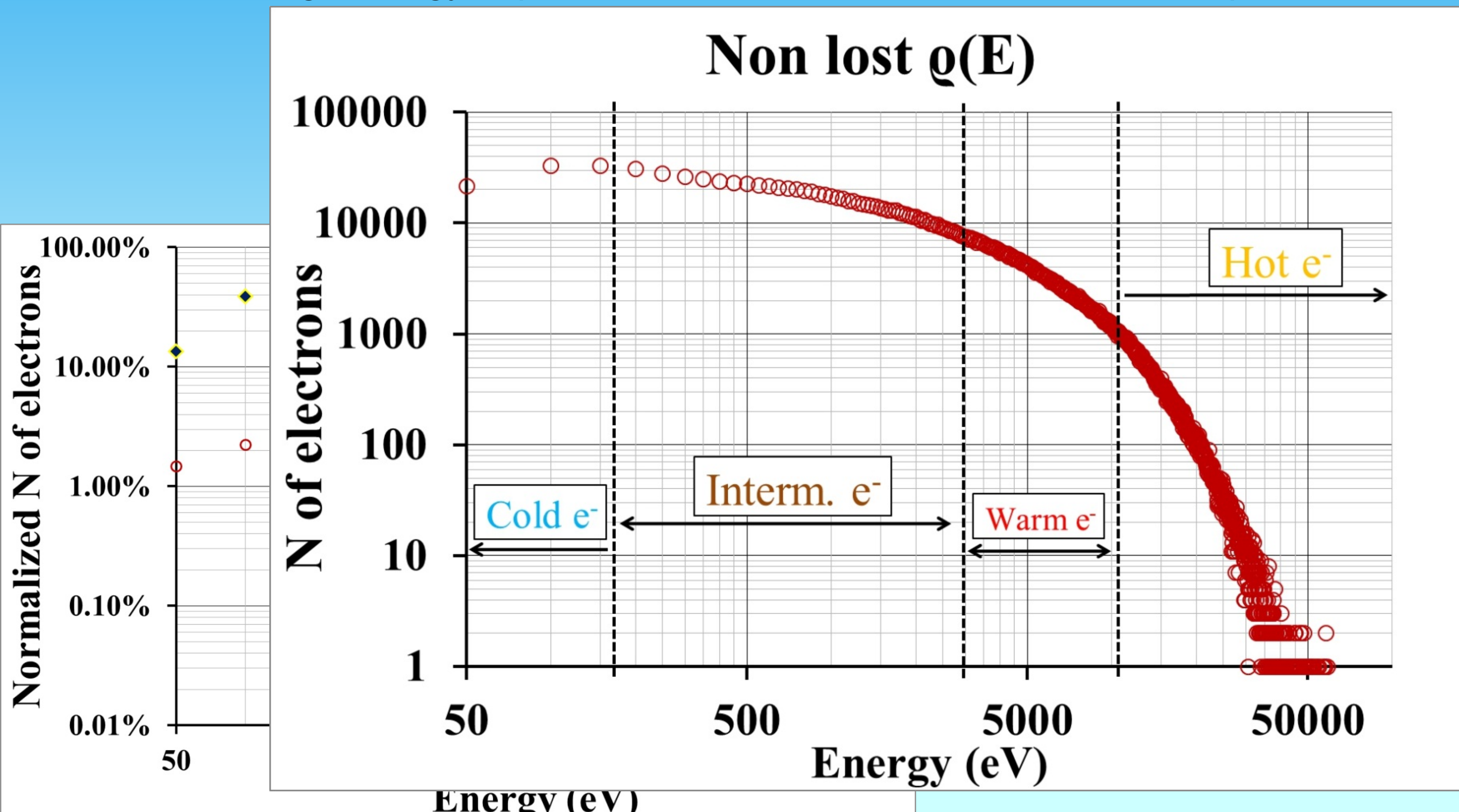
- 3 million electrons, resonance surface (B=5200 gauss, f=14.5 GHz)
- Thin layer: 100 gauss difference from Becr: B=5100…5300 gauss
- D=0.6 mm thickness
- Energy: random between 1-100 eV, both components

Microwave. 14.5 GHz, 1000 watt, circularly polarized plane wave

Simulation time. 200 nanoseconds, CPU time 127 hours

General results

Non-lost (plasma) electrons: 49% (1.46E6)
Lost (on walls) electrons: 51%
Average energy of plasma electrons: increased from 100 eV upto 3330 eV.

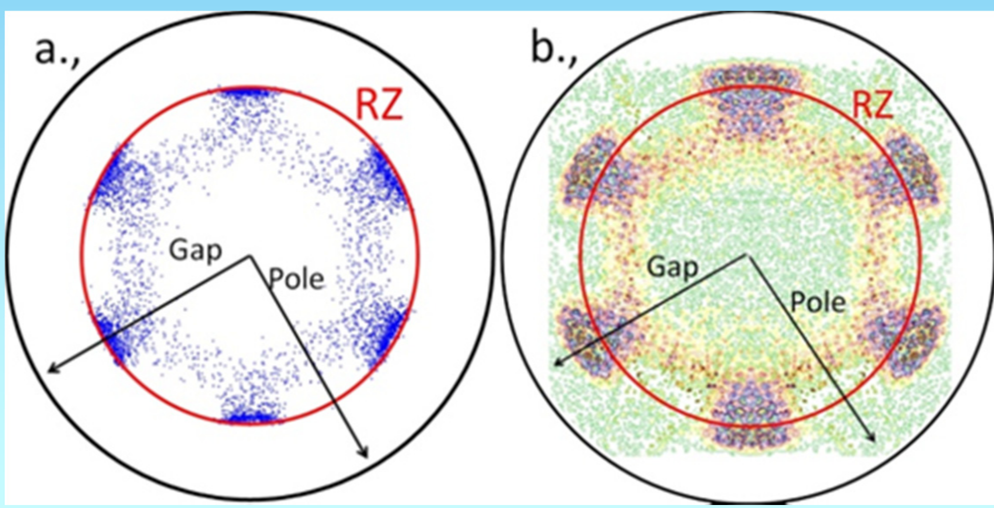


R. Rácz. S. Biri, J. Pálinkás, Plasma Sources Sci. and Tech. 20 (2011) 025002(7):

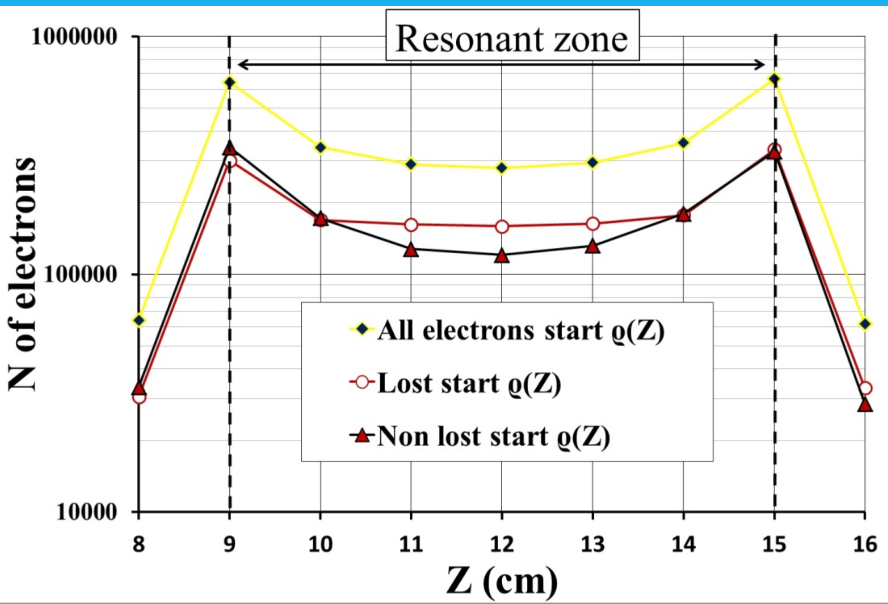
- E<200 eV: **cold** electrons
- 200 eV < E < 3 KeV: **intermediate** electrons
- 3 KeV < E < 10 KeV: **warm** electrons
- E>10 KeV: **hot** electrons.

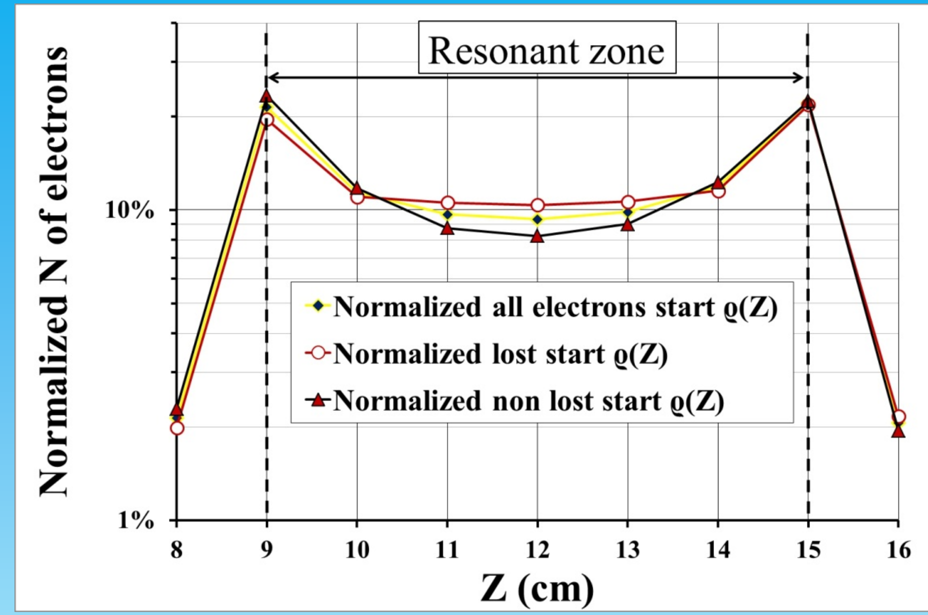
By comparing the simulation results with X-ray photos of the argon ions there is a correlation between the spatial position of these two particle clouds.

Based on this result, any spatial information obtained for the warm ***electrons*** can be used for the plasma ***ions***.



Left: computer simulation of the warm electron cloud of a 14.3 GHz plasma. Right: X-ray photo of a 14.5 GHz argon plasma.

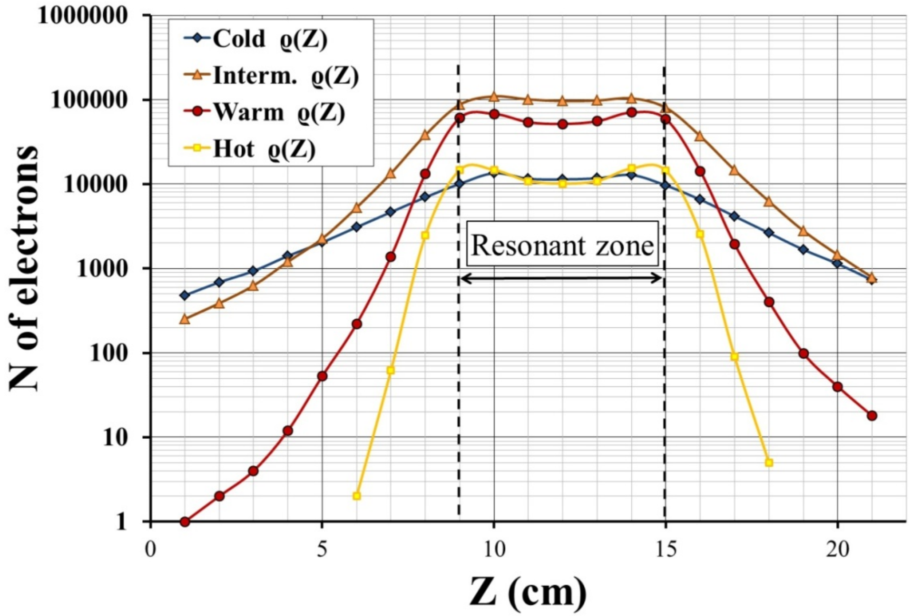


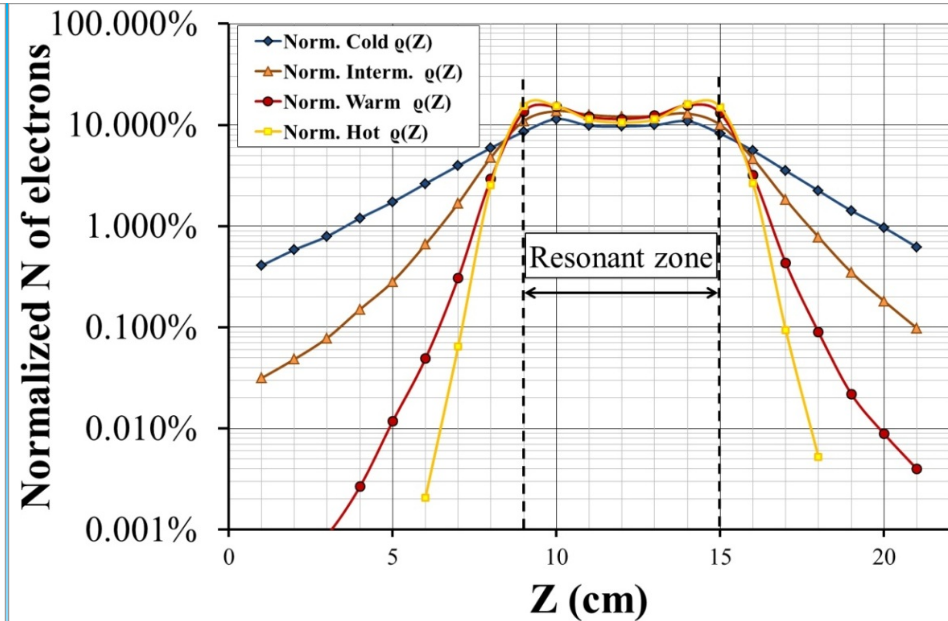


Results 1.

Starting positions of the non-lost and lost electrons

At the middle plane more electrons lost than from other positions. (Six lost arms are here, wall is closer, etc.)





Electron density distribution along the plasma chamber axes (z-axes).

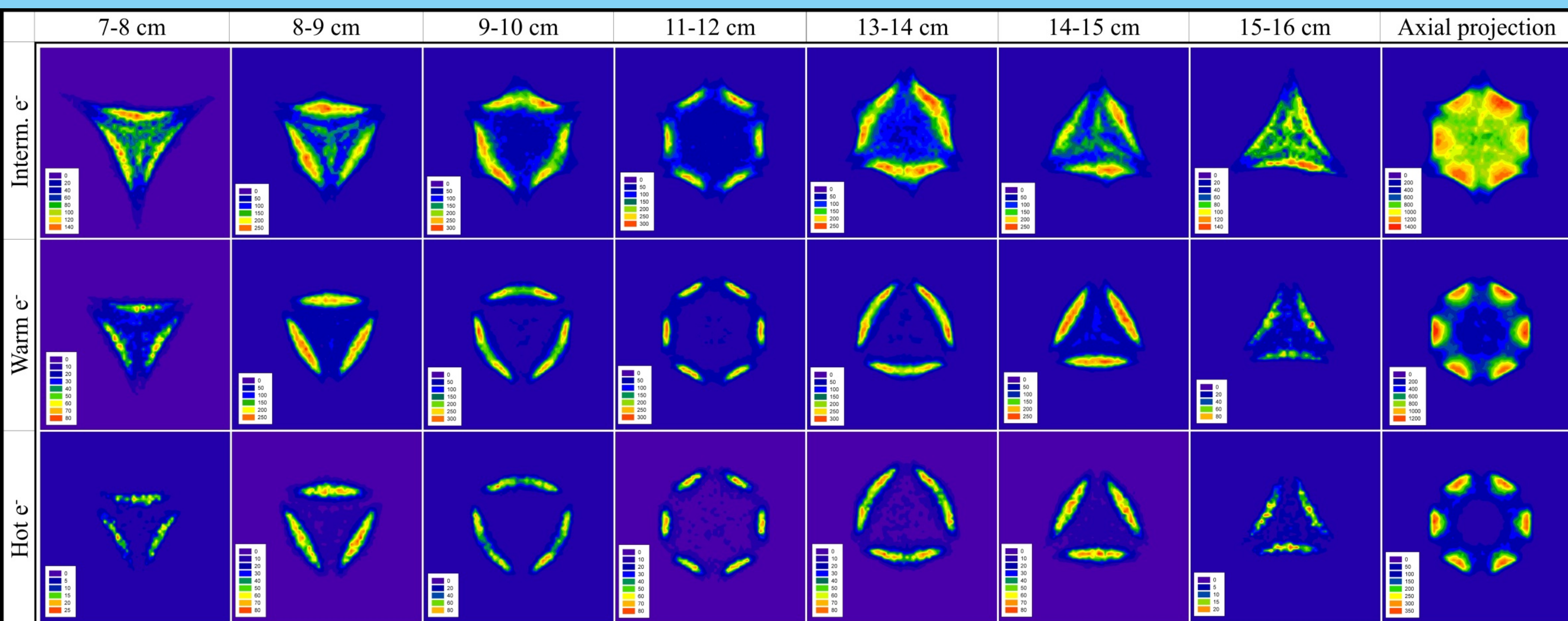
Normalized electron density distribution along the plasma chamber axes (z-axes).

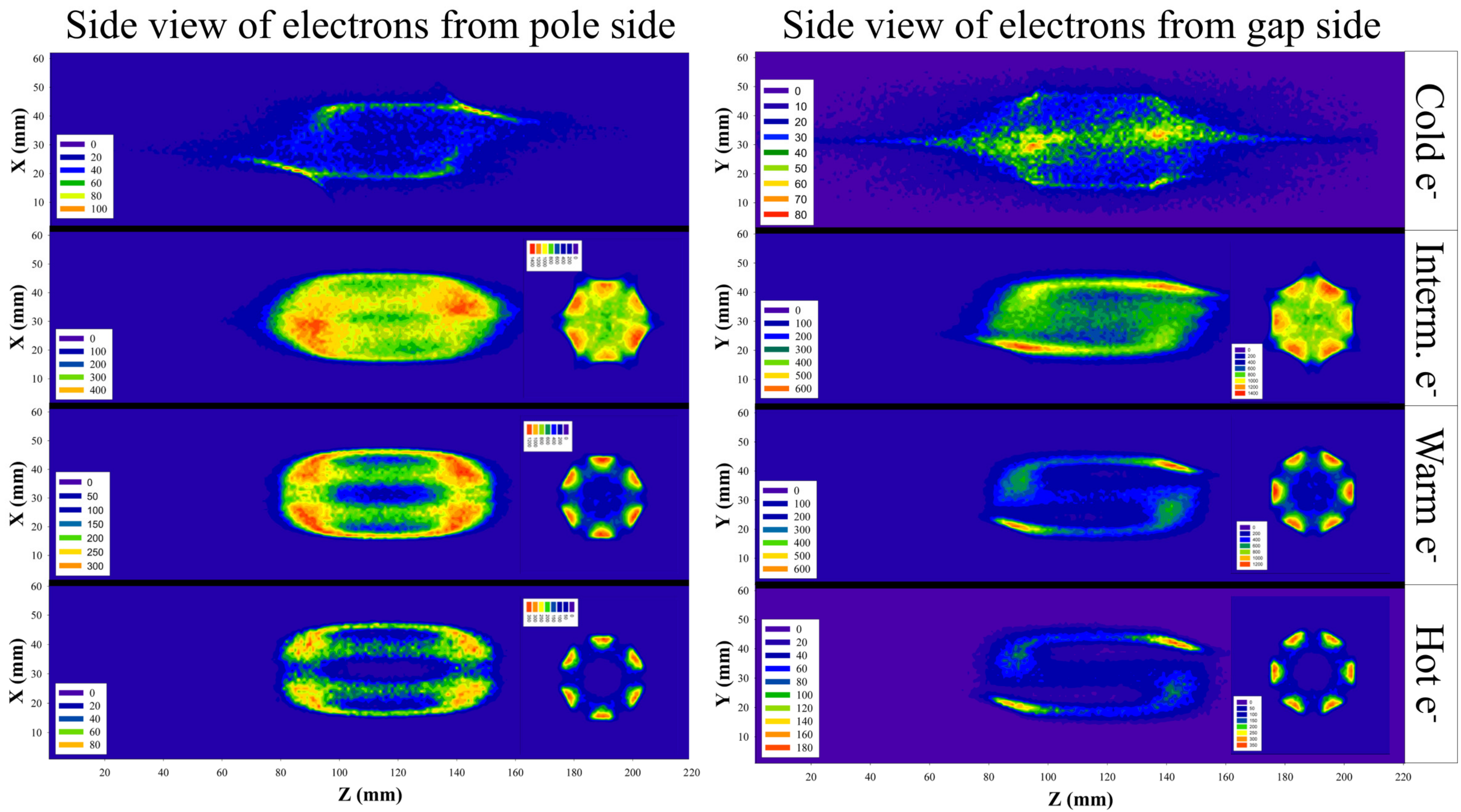
- the final energy and positions of all the electrons are saved
- non-lost electrons are filtered by their energies
- significant difference between the 4 electron populations
- cold electrons are found all along the plasma chamber
- warm (ionizing) electrons concentrate much more around the RZ
- even much less hot electrons outside the RZ

For all energy components: electrons separate into a high density inner plasma surrounded by a lower density halo (same observation also by others)

Plasma slices

- To get 3D-impression about the main component of the plasma
- one centimeter thick plasma-slices
- intermediate, warm, hot electrons
- Z=11-12 cm middle plane of the plasma chamber
- 8-9 and 14-15 cm positions: two ends of the RZ
- right column: the superposition of all the plasma slices




Side view of electrons from pole side
Side view of electrons from gap side
Cold e⁻
Interm. e⁻
Warm e⁻
Hot e⁻
X (mm)
Y (mm)
Z (mm)

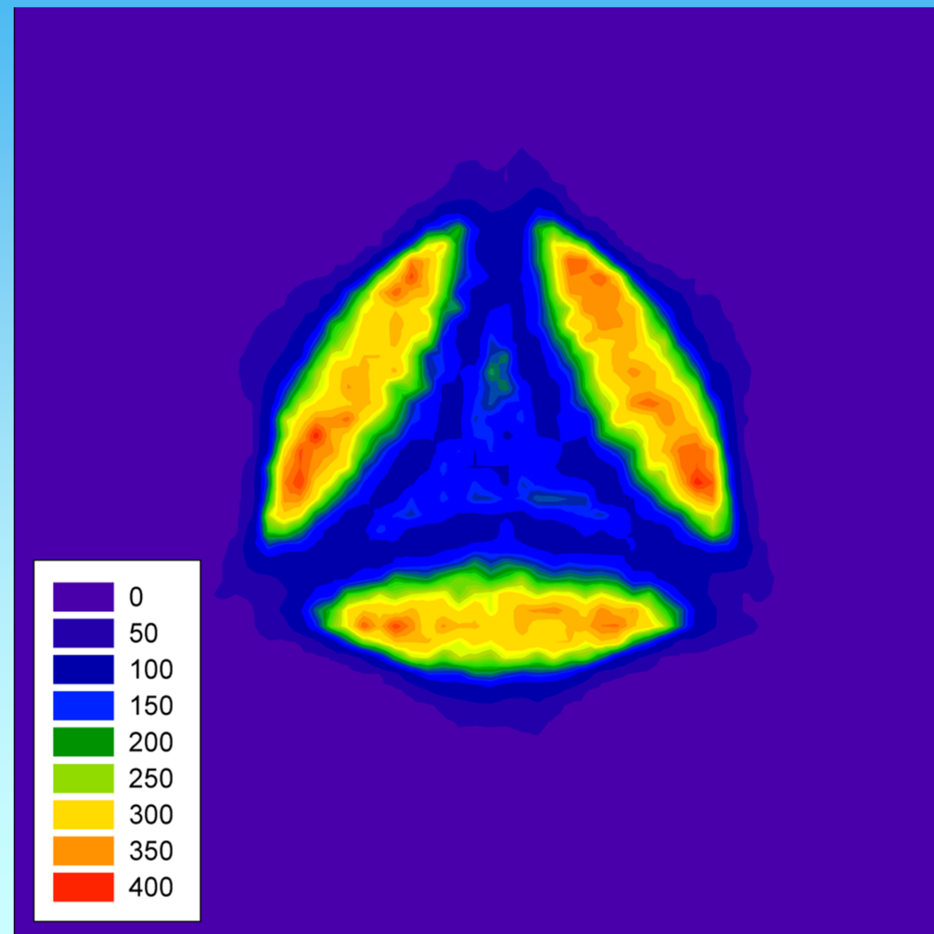
Input data for extraction codes?

The extraction "third" of the plasma chamber …

Z-positions: 13-21 cm, 3-10 KeV warm electrons

1. Individual ions can be started from the appropriate x-y-z coordinates where the ion density (warm electron density) is the highest.

2. Or: to construct a 3D density matrix by the TrapCAD output files (number of electrons in each cubic mm) and to use the position-dependent density values for the ions extraction simulations.



Summary

1. Magnetic trap upgrade and other developments
   - ❑ Hexapole change
   - ❑ New iron plugs
   - ❑ Ions from solids
   - ❑ New control system

2. Simulation of the ECRIS electron cloud
   - ❑ TrapCAD summary and upgrades
   - ❑ Initial conditions
   - ❑ General results
   - ❑ Filtering by energy and position : specific results

Thank you for your attention !