(Magnetic) design of a hollow hexapole applicable to ECR charge breeder to mitigate the plasma contamination by sputtering

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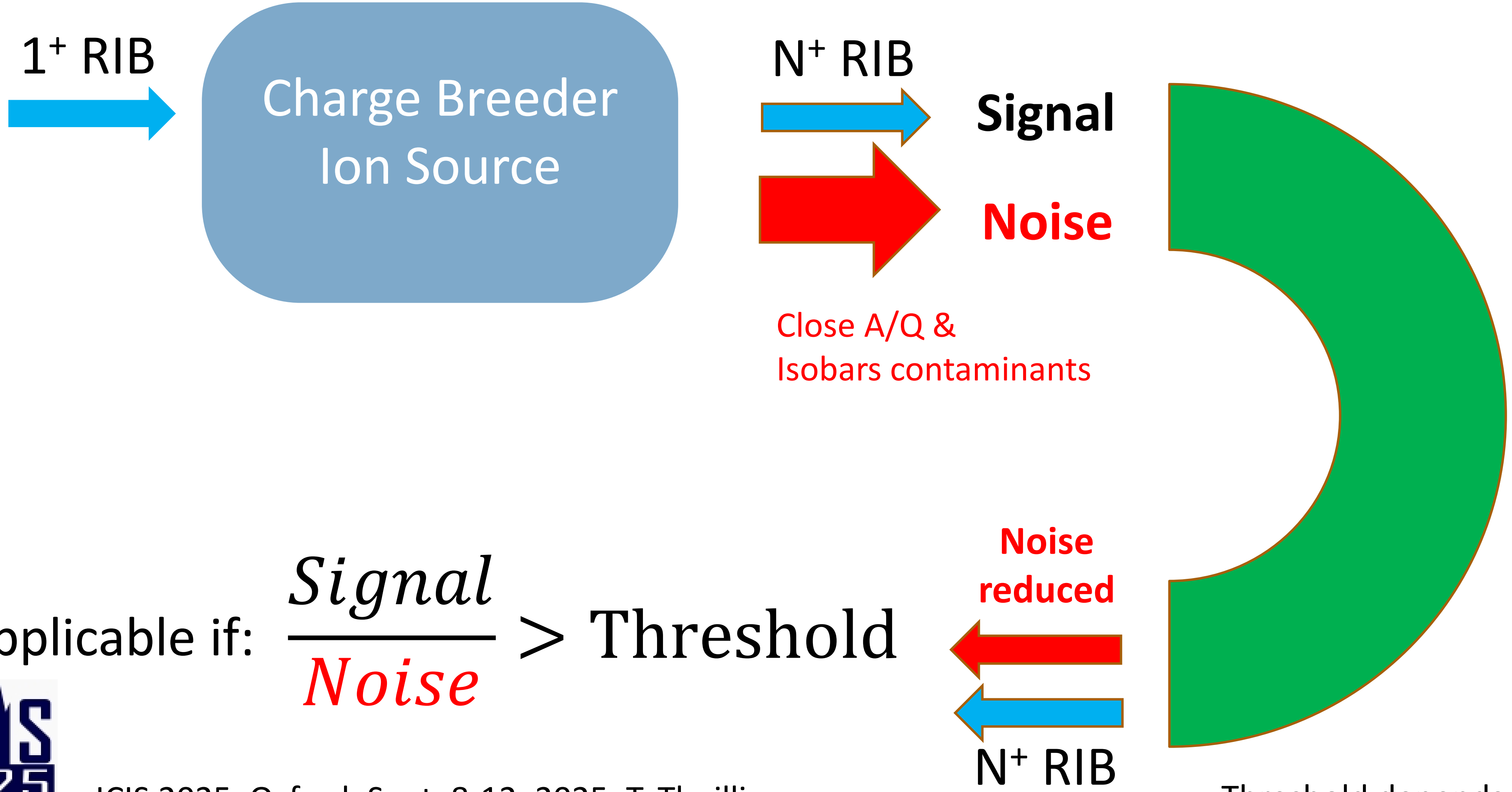
Outline

- Motivation
- Magnetic Design of a Hollow Hexapole
- Monte Carlo Simulation
- Discussion and Prospects

Motivation

Radioactive Ion Beam (RIB) Experiments Require Beam Purity



Process selection

$$\frac{M}{\Delta M}$$

Applicable if: $\frac{Signal}{Noise} > \text{Threshold}$

Threshold depends on the facility

ECR CB Contamination

Wall sputtering
$\sim 10^9 - 10^{10}\ pps$ whole ion spectrum
$\sim 10^4\ pps$ within $\frac{M}{\Delta M} \sim 400$
$\sim 10^2\ pps$ within $\frac{M}{\Delta M} \sim 5000$

Buffer gas
$\sim 10^{16}\ pps$

Gases contaminants
$\sim 10^9 - 10^{13}\ pps$ *whole spectrum*
$\sim 10^4\ pps$ within $\frac{M}{\Delta M} \sim 400$
$\sim 10^2\ pps$ within $\frac{M}{\Delta M} \sim 4000$

1+ signal
up to $10^{13}\ pps$

14 GHz
ECR

Contaminants (noise)

Itotal~1 mA
($\sim 10^{15} - 10^{16}$ pps)

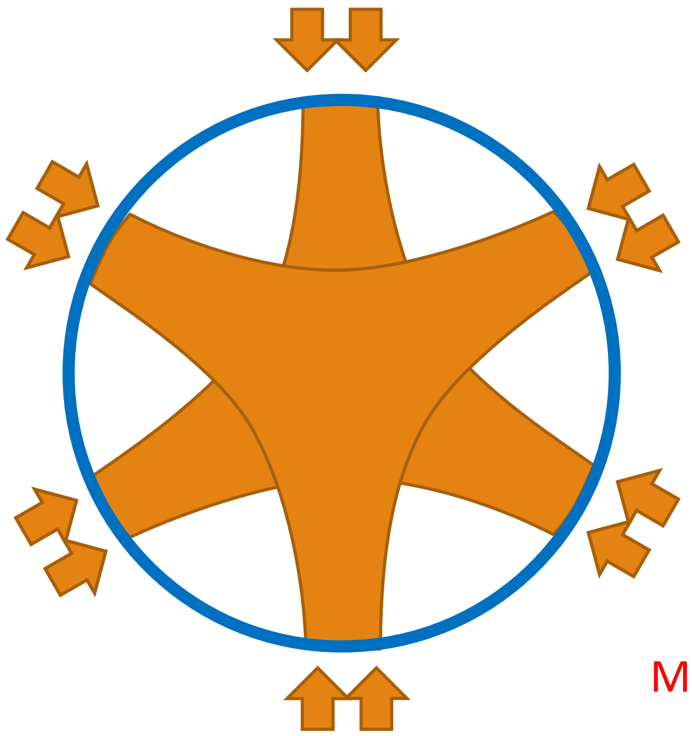
N+ signal

➢ **Signal** to **Noise** ratio is a critical parameter for ECRIS CB at low RIB intensity:

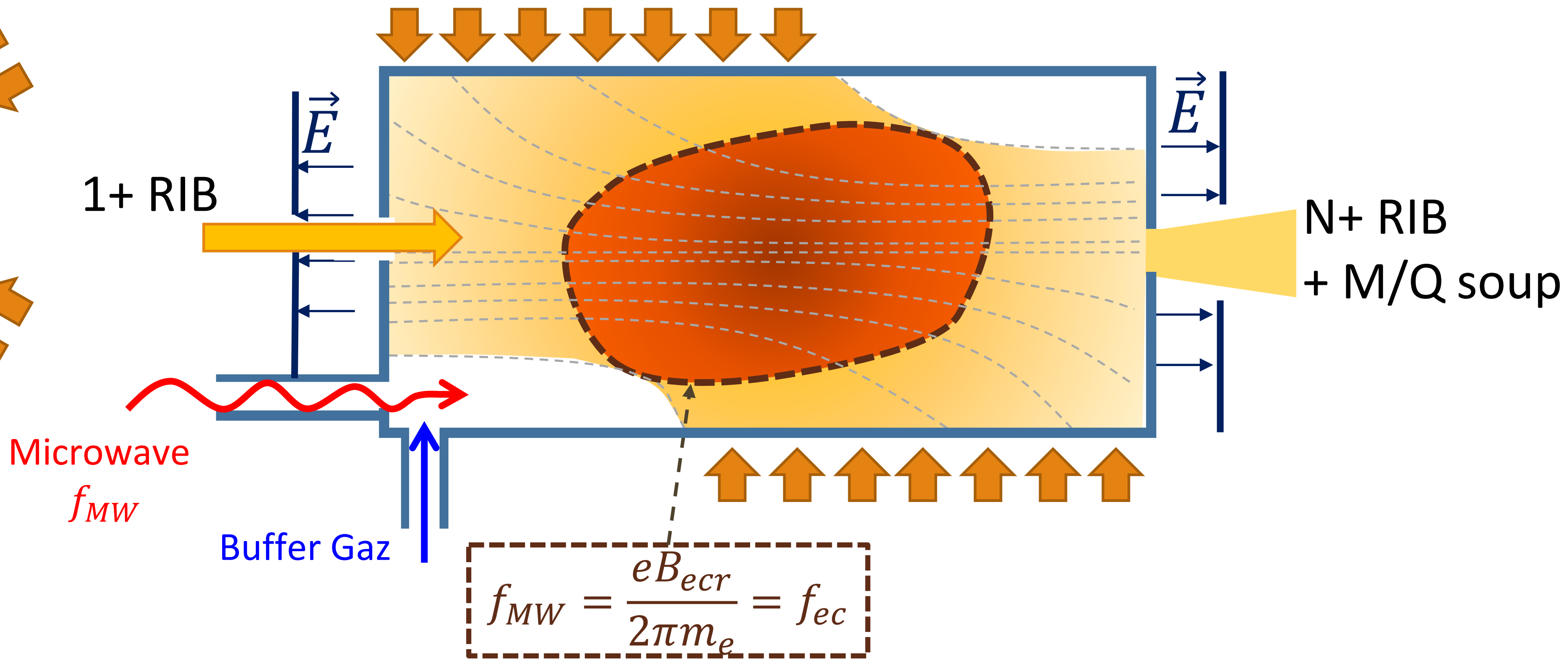
	Signal (pps)	10^2	10^3	10^4	10^5	10^6
For $\frac{M}{\Delta M} \sim 400$	Signal/Noise	0.01	0.1	1	10	100
	N+ RIB fraction	0.9%	9%	50%	91%	99%
For $\frac{M}{\Delta M} \sim 5000$	Signal/Noise	1	10	100	1000	10000
	N+ RIB fraction	50%	91	99%	99.9%	99.99%

CARIBU (ANL) , TRIAC (TRIUMF)

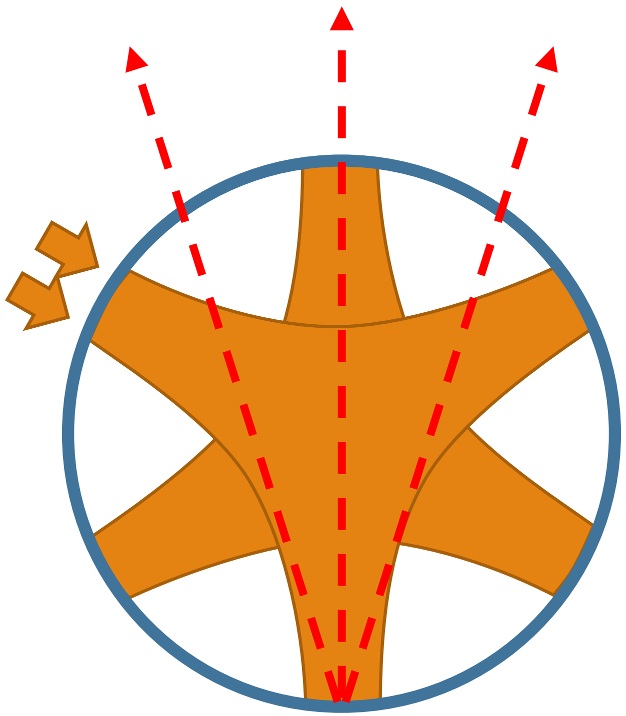
The ions, accelerated by the plasma sheath, sputter the plasma chamber radial walls, expelling the metallic alloy compounds and its impurities

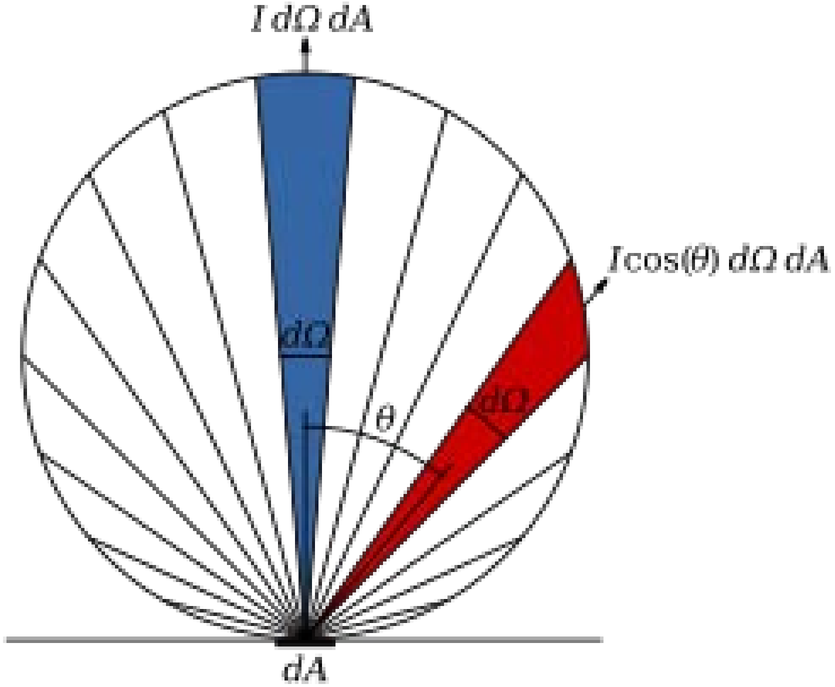


The plasma is hitting the wall following the hexapole field lines



The atoms sputtered radially have a high chance to be ionized on flight passing through the plasma



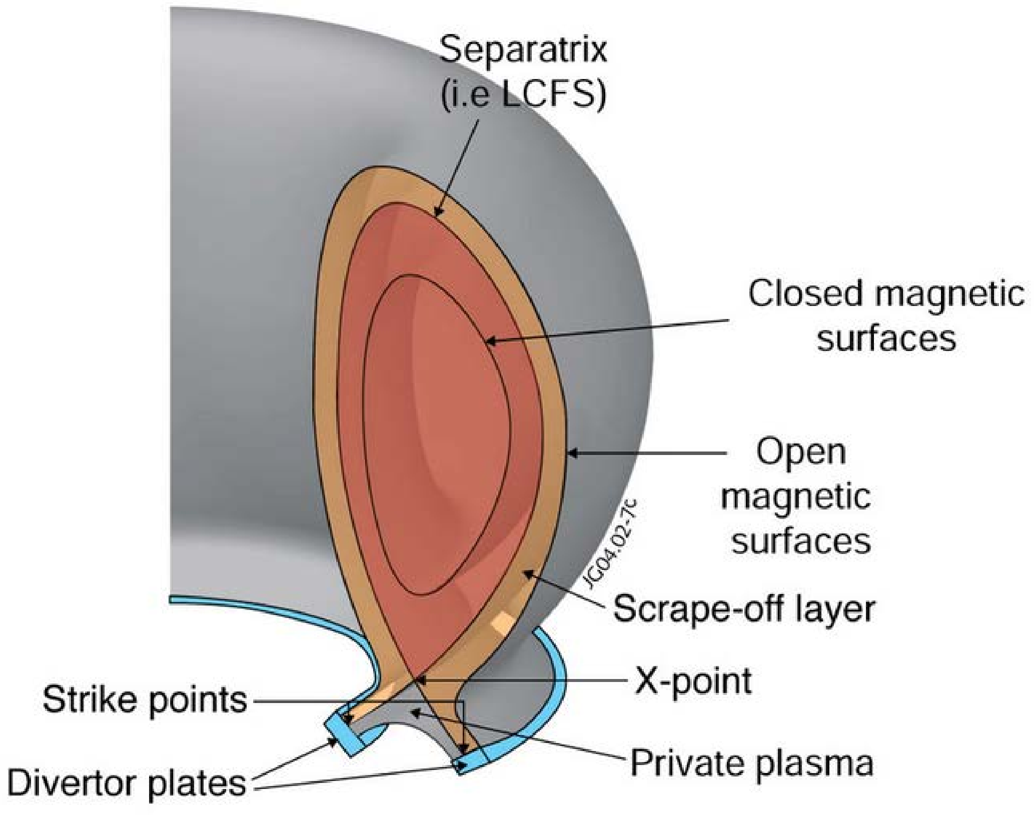


Lambert's cosine law (Wikipedia)

Is there a way to mitigate this phenomenon?

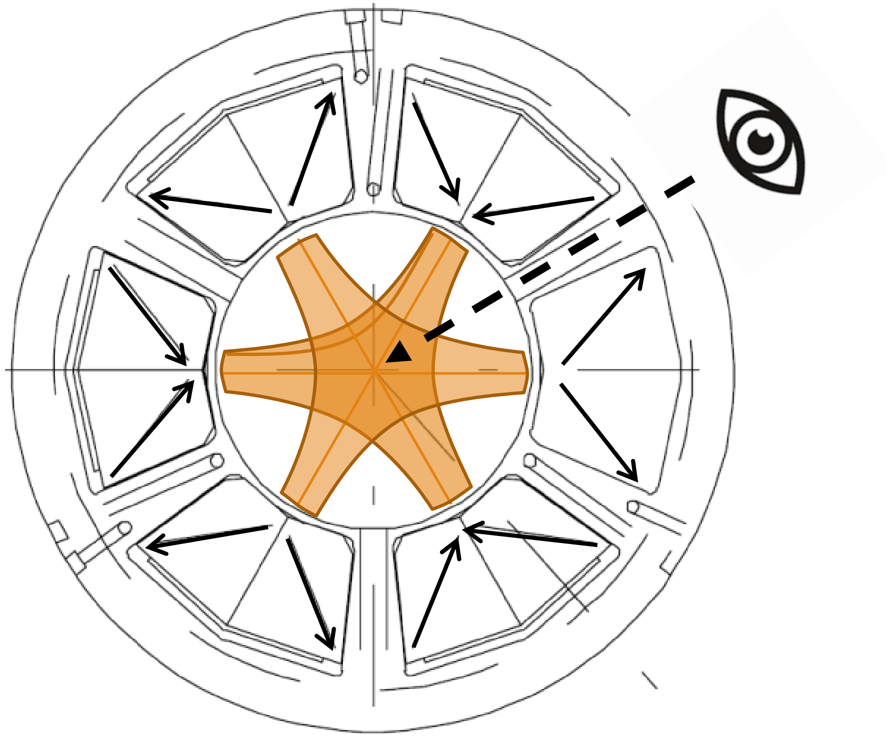
How is contamination mitigated in Tokamaks?

The Ergodic divertor (magnetic limiter) is used to remove impurities from the main plasma through a zero field area

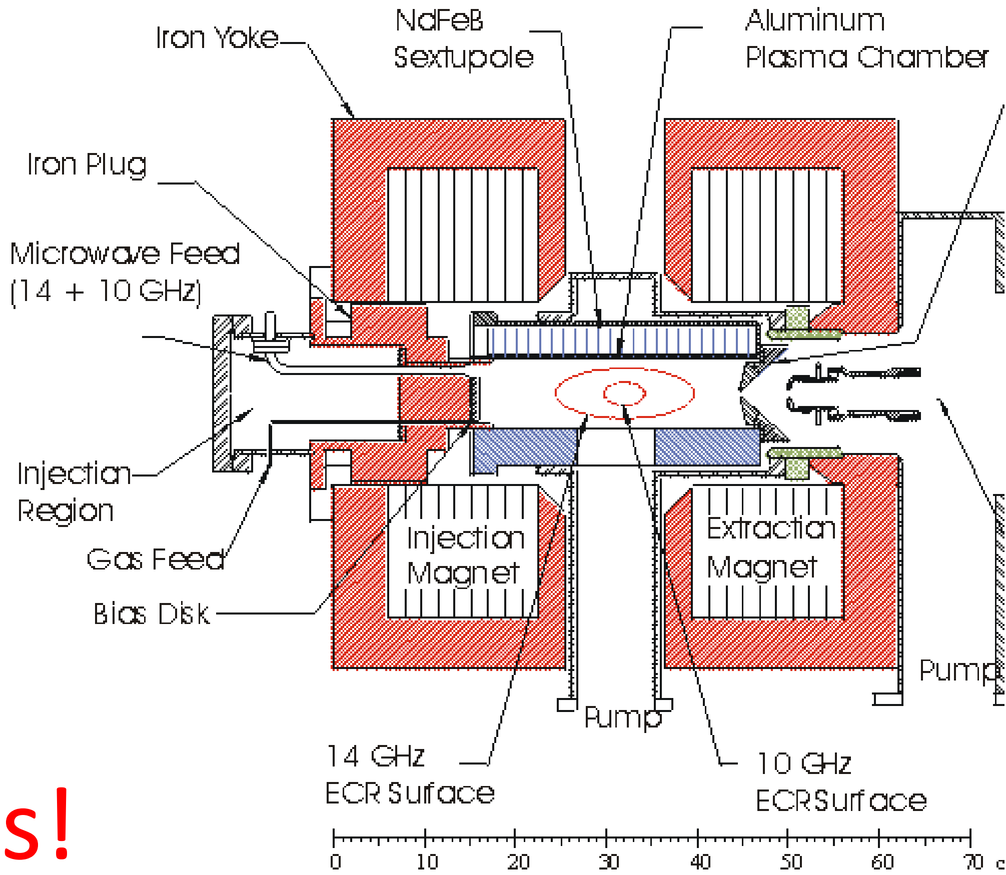


Can holes be made in an ECR hexapole?

A-ECR Design : 6 radial view ports, located where the plasma does not hit the wall

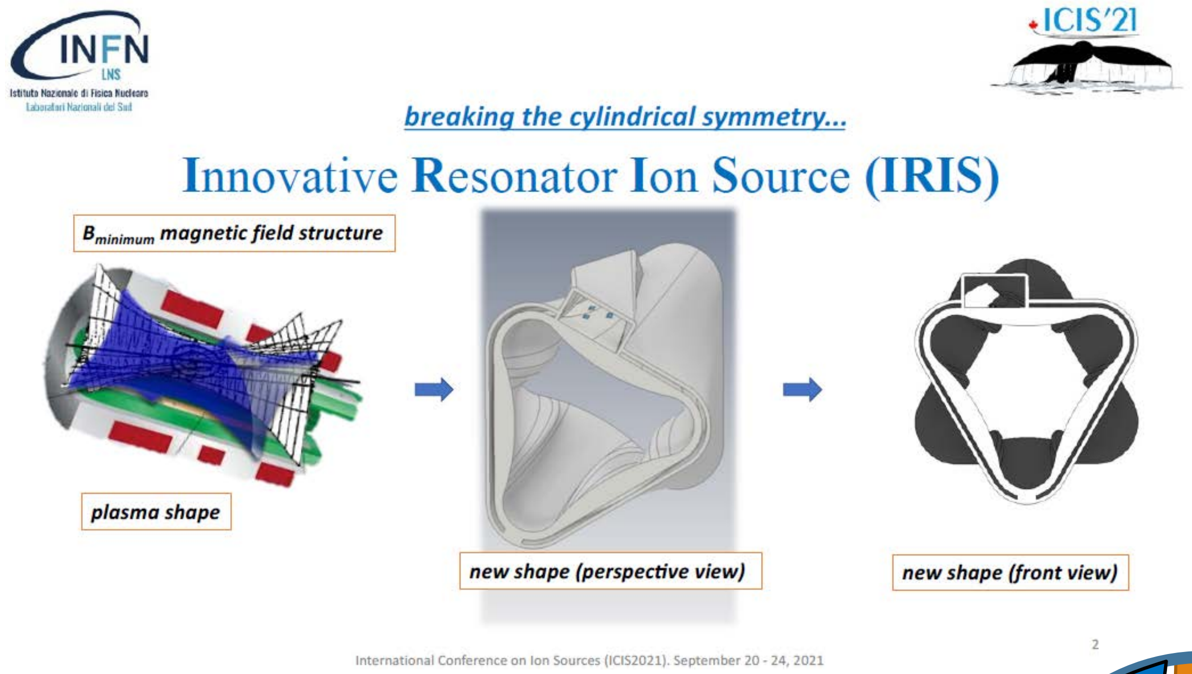


14 GHz LBNL AECR-U Ion Source

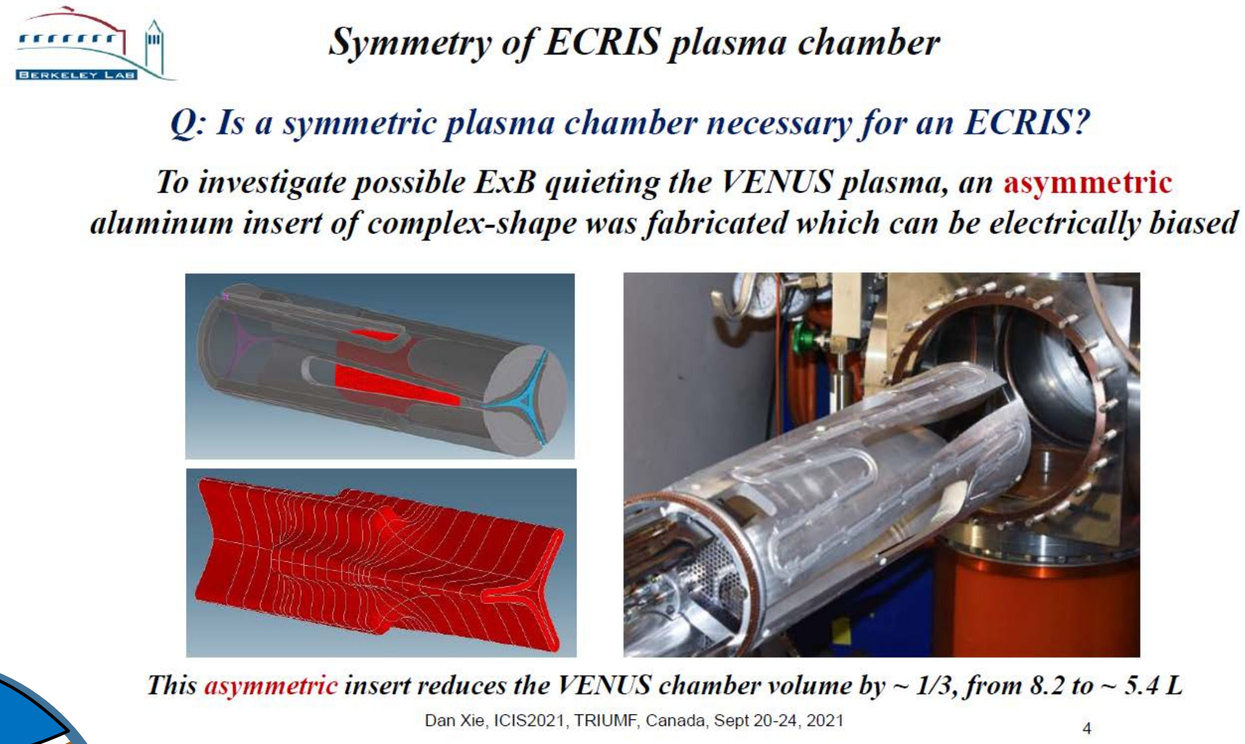


The answer is clearly yes!

Can material be added inside the cylindrical plasma chamber?



G. Torrisi, ICIS21, LNS

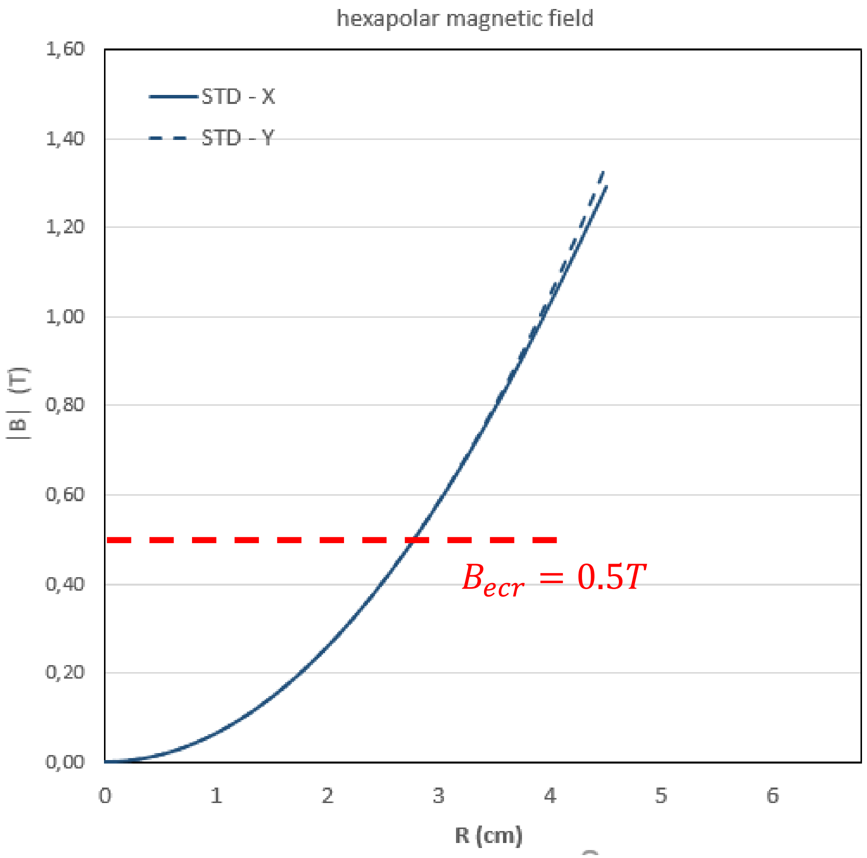


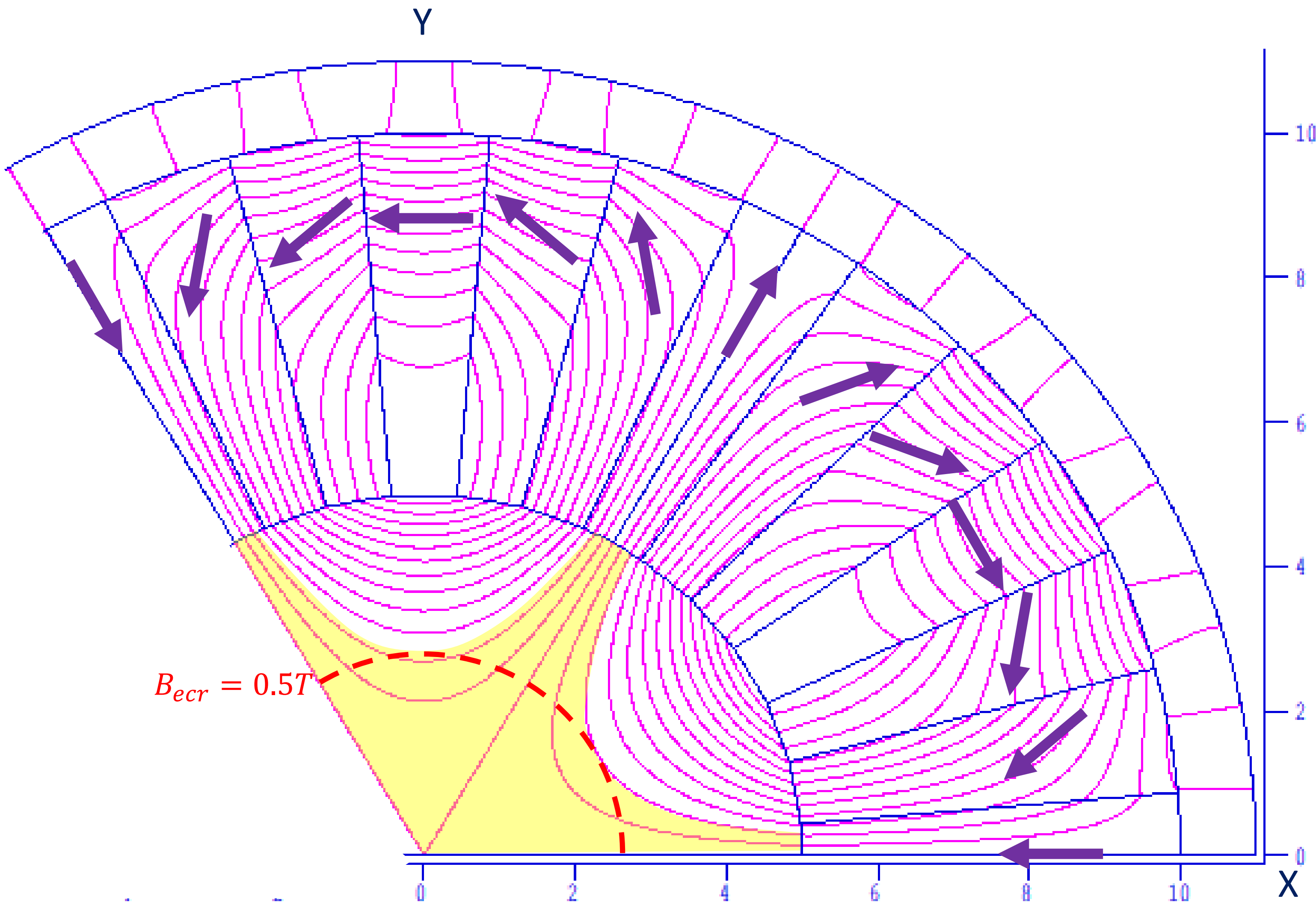
D. Xie, ICIS21,LBNL

Again, the answer is yes !

Recipe for a 14 GHz hollow hexapole

…Start with an up to date HallBach type hexapole

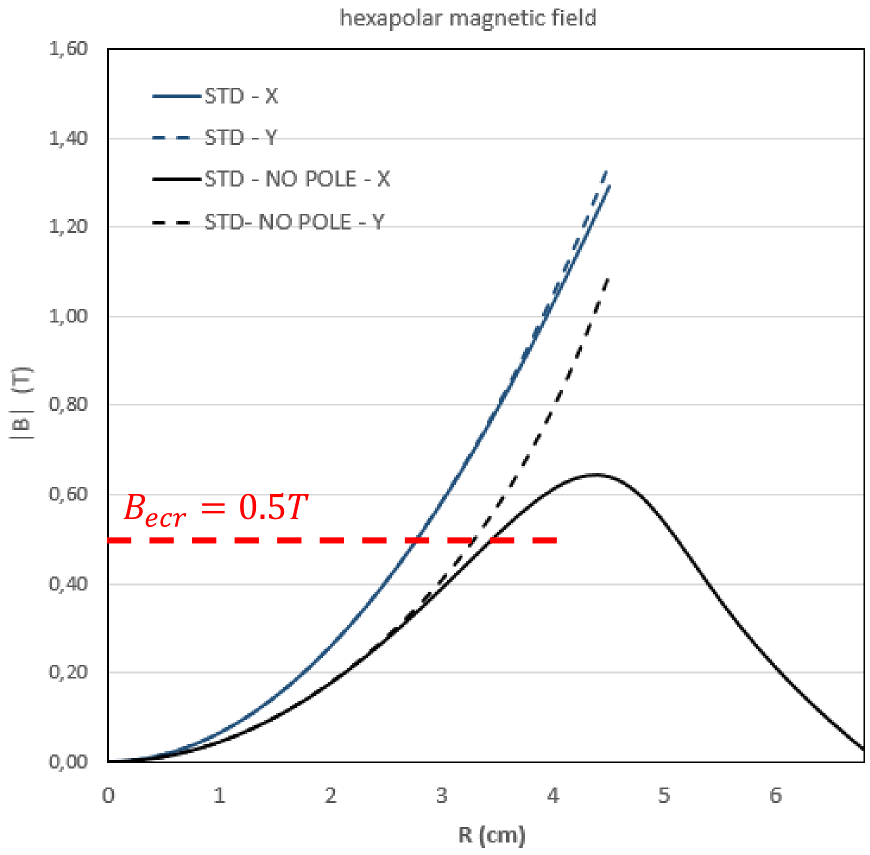


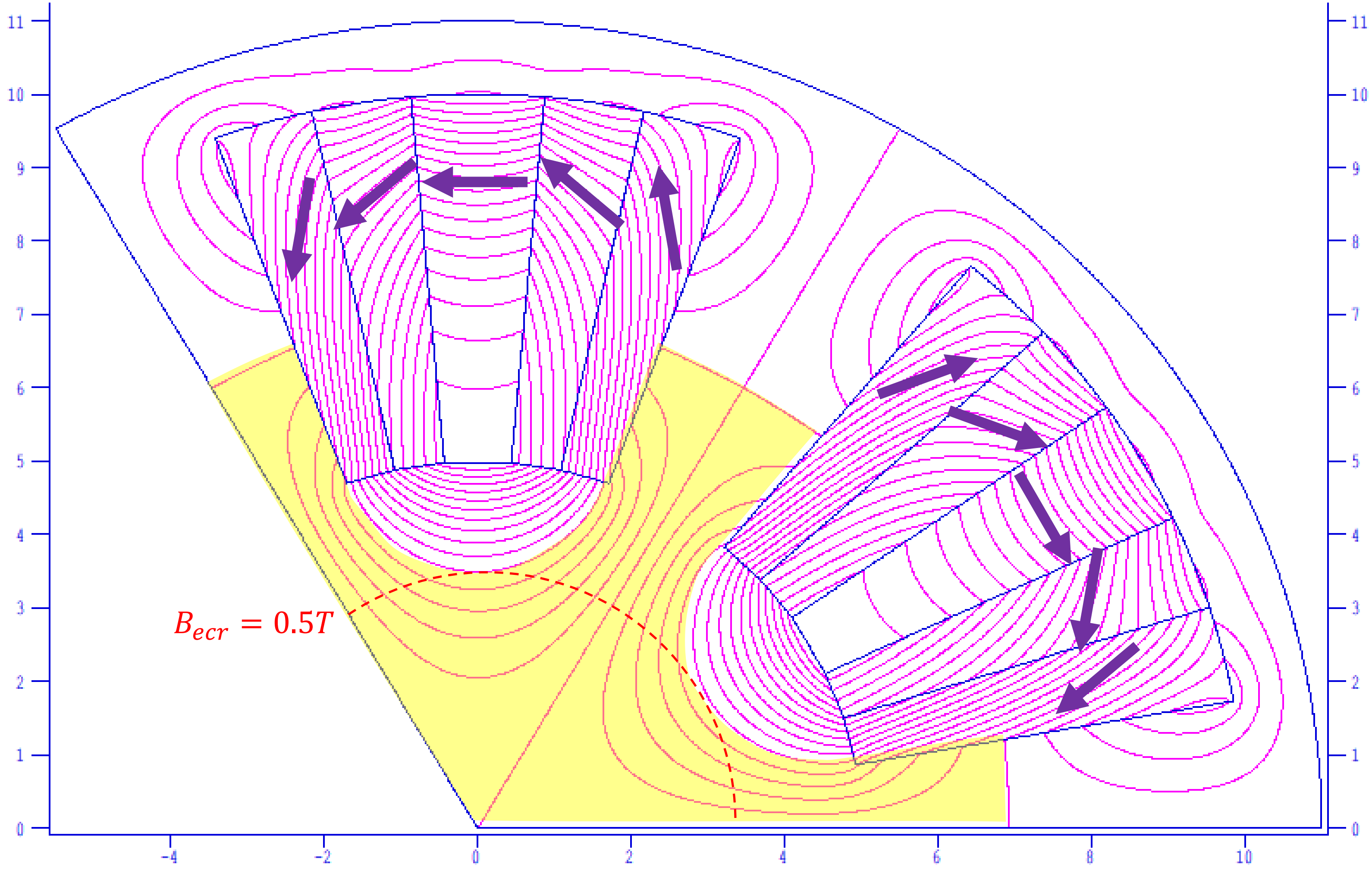


Remove the 0°, enlarge the 90°, shrink the 60° and 30° magnets

✓ Field lines expand radially and hit the wall along $\theta = const$

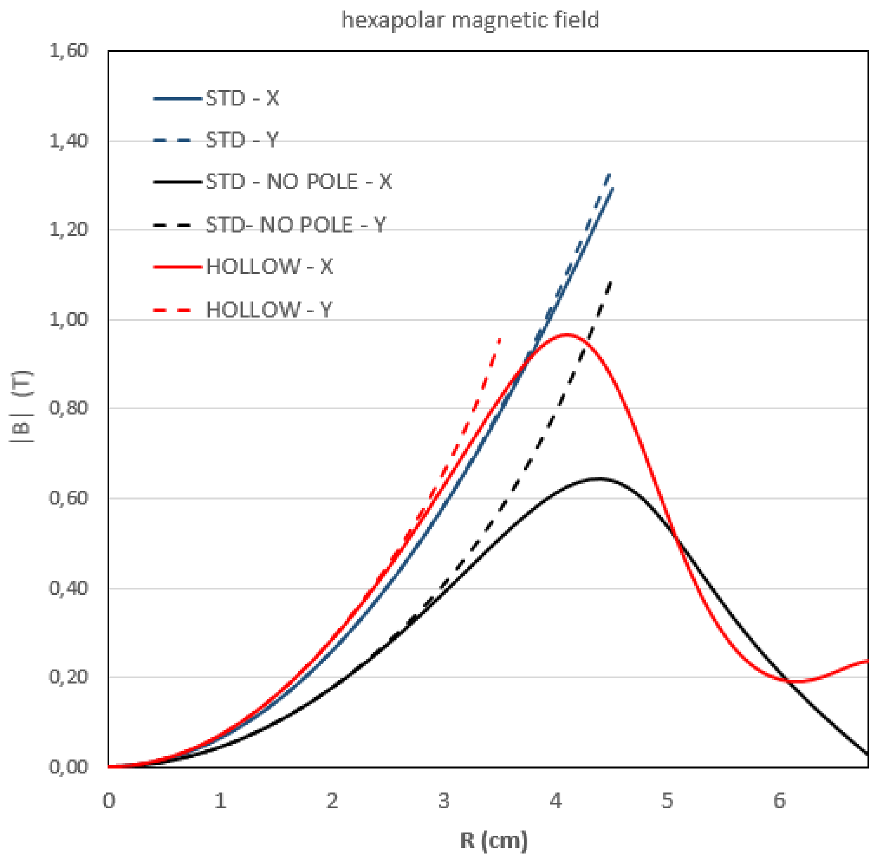
✗ But Radial field is too weak

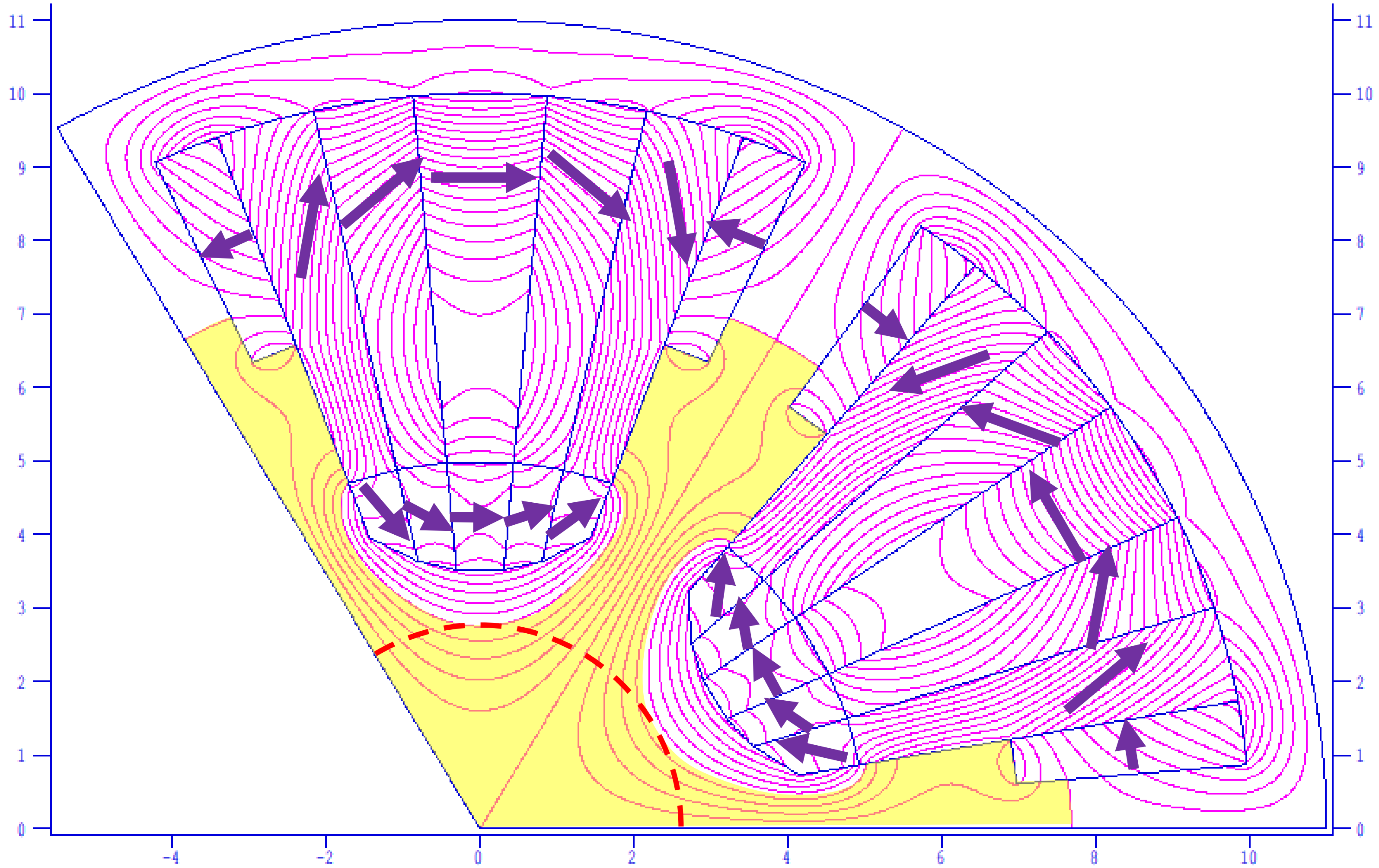




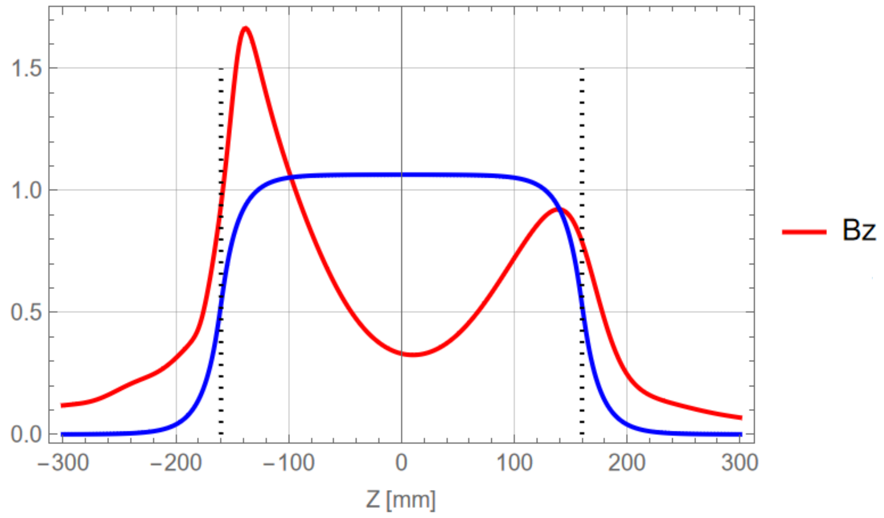
Add magnets where you can et voilà

Add magnets inside the cylindrical plasma chamber
Add extra magnet at large radius => radial confinement ok for 14 GHz



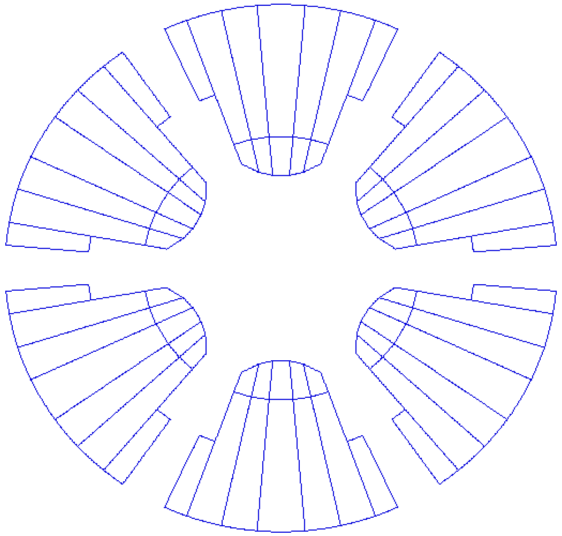


Checking the ions flow to the wall with a Monte-Carlo



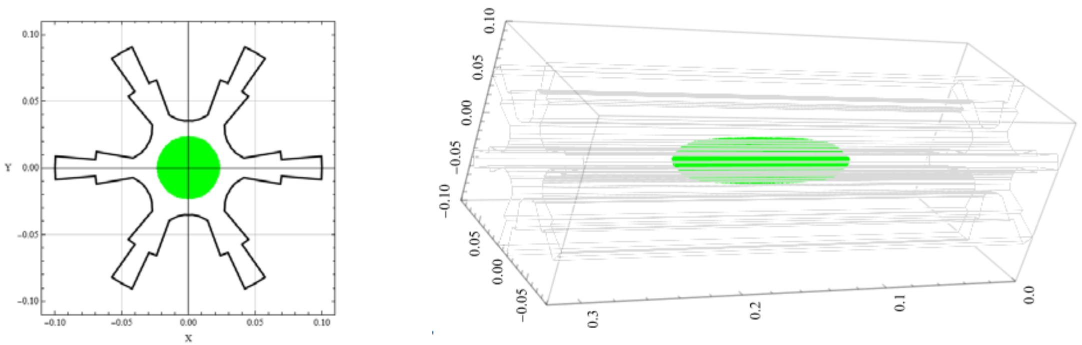
Axial magnetic field (existing PHOENIX CB)

+

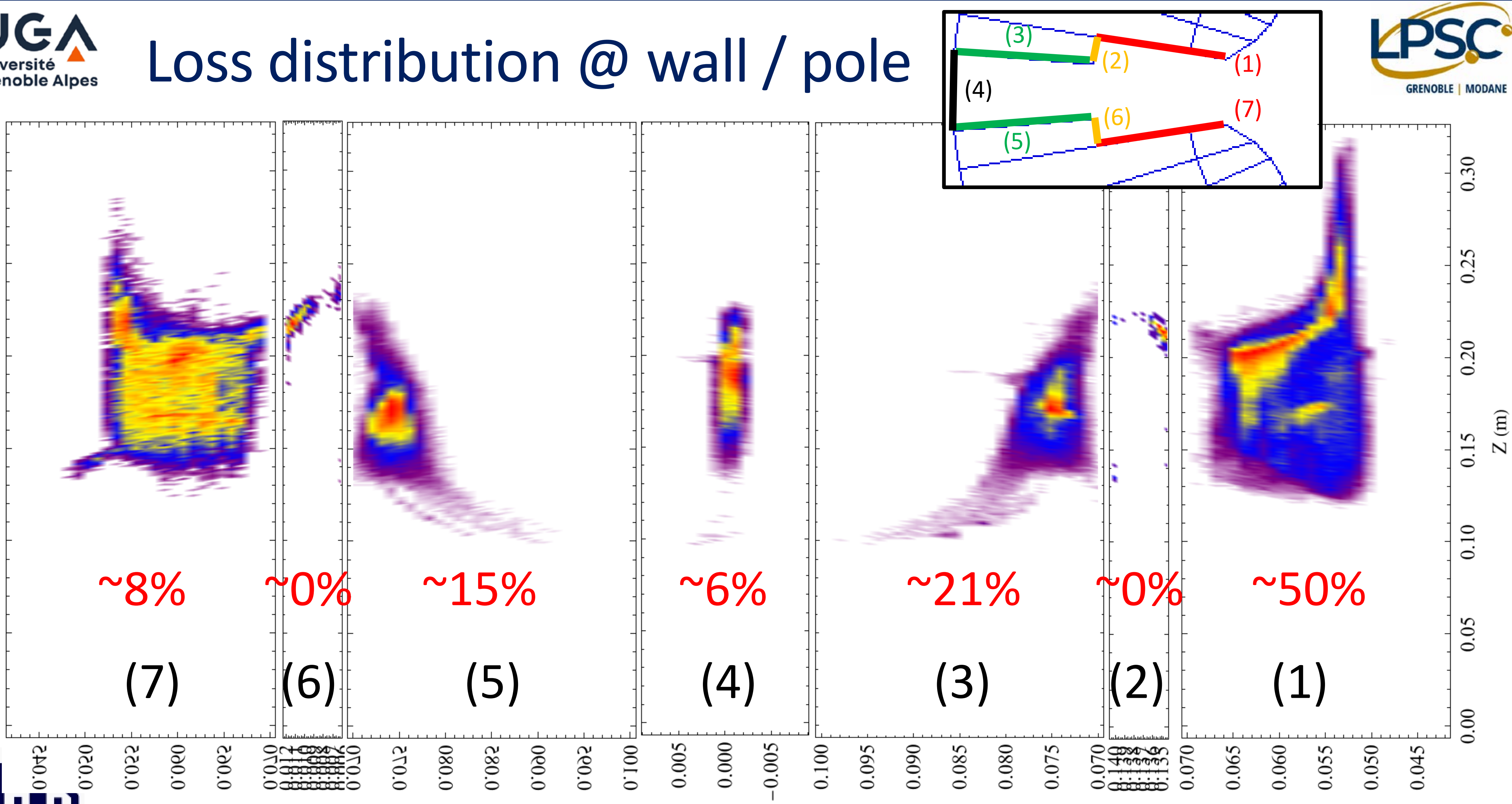


Hollow hexapole for the radial confinement

- He^{2+} Ions generated in the ECR zone volume
- T_{kin}=5 eV, random velocity direction
- Coulomb collision
  - « Forceps Delivery » with $\nu_i \times 10$
- 10^6 particles, 220h CPU time



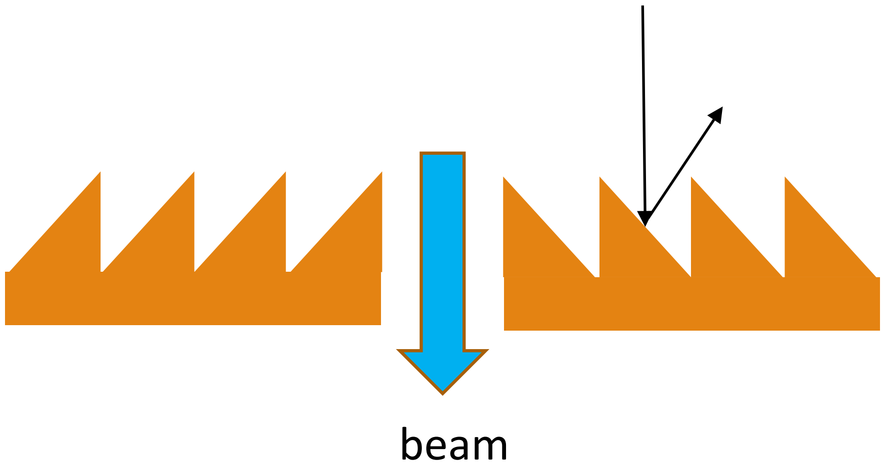
Loss distribution @ wall / pole



What about the extraction and injection flanges?

- Topic not treated here

- A cheap hint: machine the injection and extraction metallic surfaces to form concentric edges that will force the mean sputtered atom direction away from the dense plasma



Discussion and Prospects

- The hollow hexapole design appears applicable to 14 GHz ECR charge Breeders
- The ions simulated are well crashing in the hollowed hexapole part
- The ion hitting locations at wall are not symmetric with respect to the hexapole poles axis
  - ➢ magnetic Field Gradient Drift force?
- This structure has the potential to reduce significantly the atom yield sputtered toward the plasma
- Prospect 1: generate sputtered atoms from the obtained density at wall and assess the % of on-flight ionization through the ECR zone. Compare the results with an equivalent simulation using a standard hexapole.
- Prospect 2: Add electrons, find a self-consistent plasma solution including the plasma potential. Re-process the sputtered trajectories accordingly.

Thank you for your attention!