Primary electron analysis to improve the negative ion uniformity toward ITER-class long-pulse and high power negative ion sources

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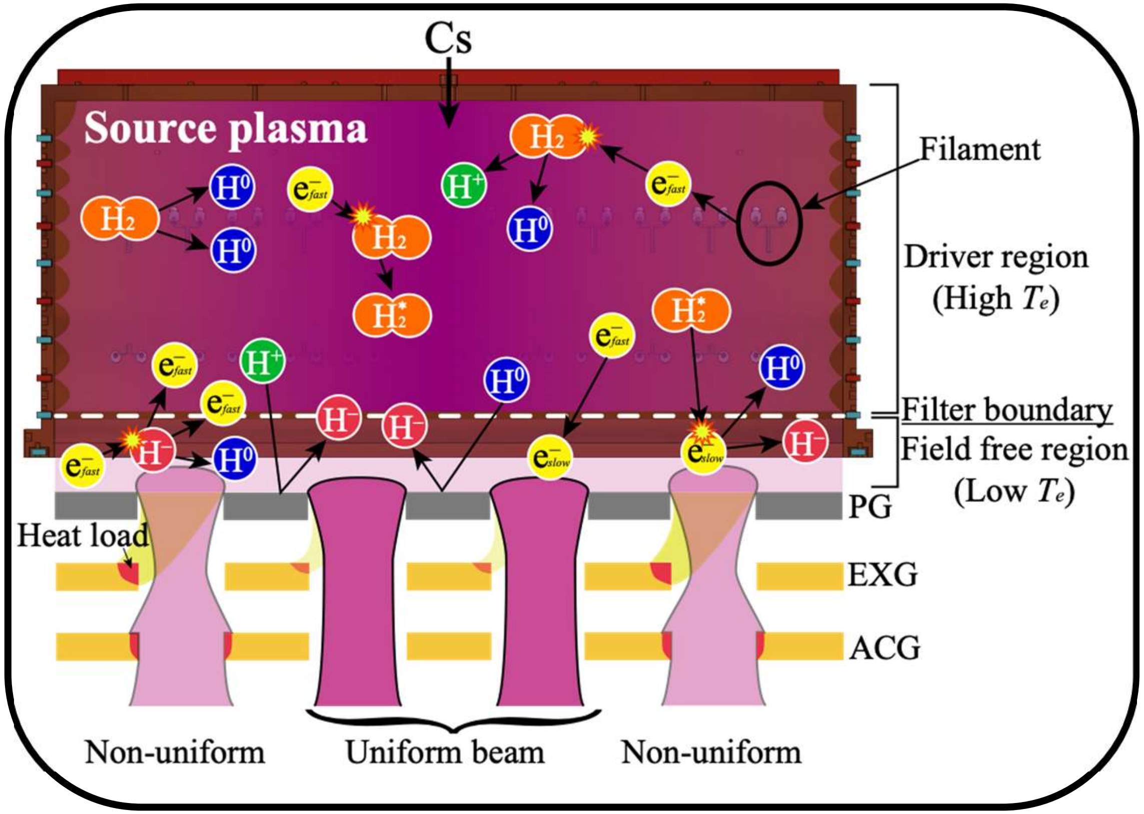
Background

In the neutral beam injection (NBI) system for JT-60SA, ITER, and DEMO, **long-pulse** and **large current** negative ion sources are required.

	JT-60U	JT-60SA	ITER
Energy [MeV]	0.35 ⇒	**0.5**	**1.0**
Pulse [sec]	30 ⇒	**100**	**3600**
Current [A]	13 ⇒	**22**	**40**

One of the common issues for large negative ion sources is the non-uniformity of negative ion current caused by non-uniformity of plasma.

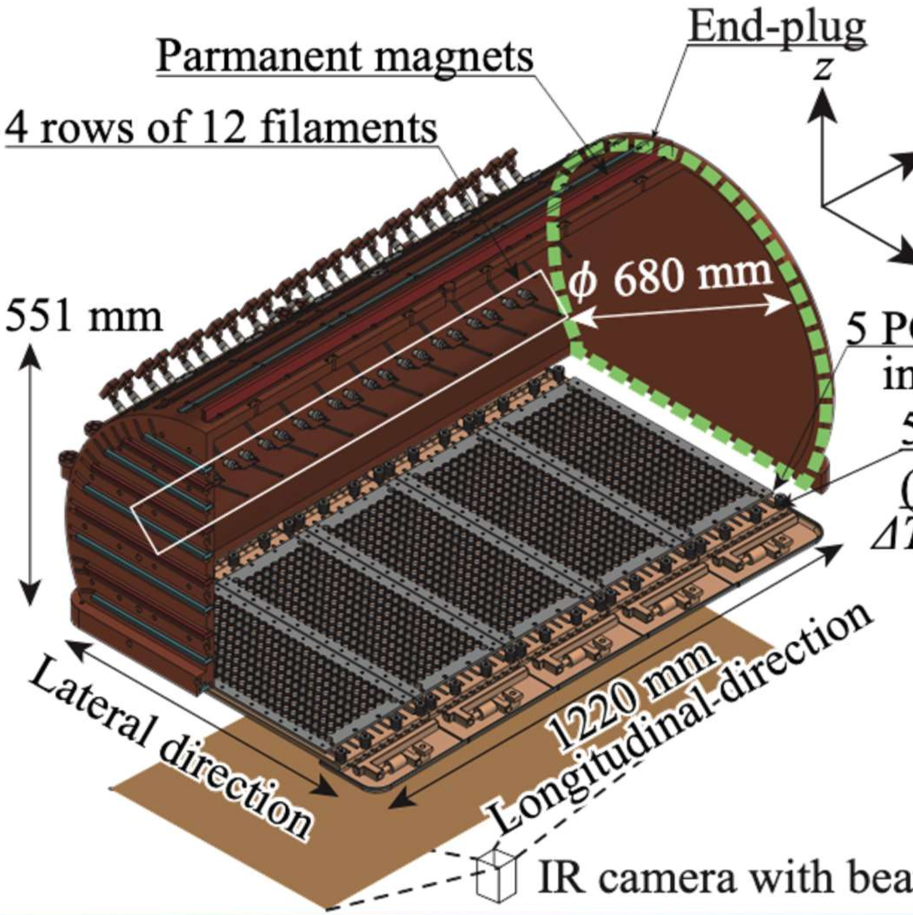
Overview of the large negative ion source

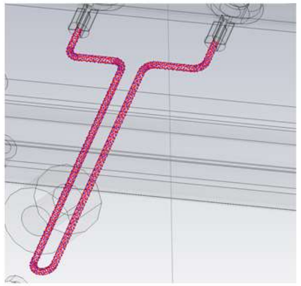


The magnetic field configuration to improve the negative ion current is investigated by using a three-dimensional electron simulation.

Experimental setup & numerical simulation

"KAMABOKO" ion source
Semi-cylindrical shape for efficient plasma confinement





<u>3D electron trajectory analysis</u>

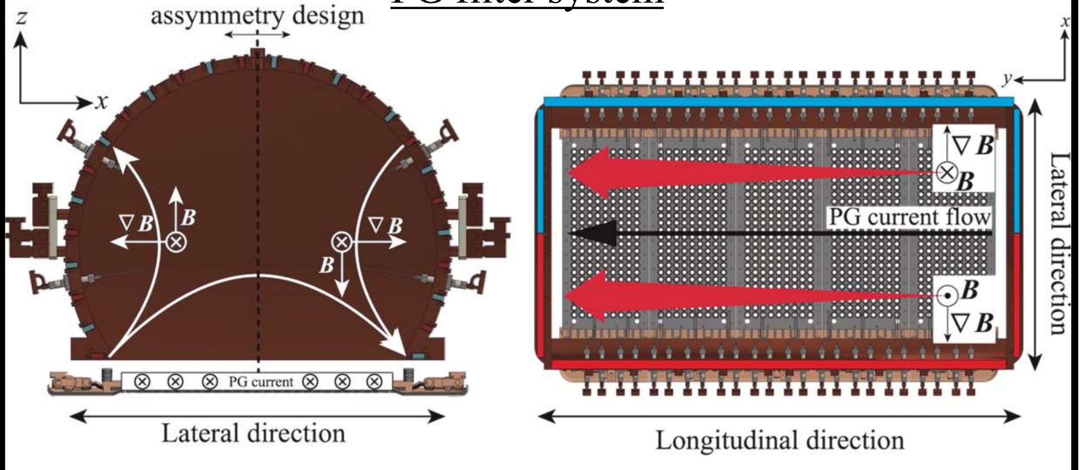
- Code: CST Studio TRK solver
- Potential information (assuming the plasma)
  - All components: 0 V
- Magnets
  - Chamber (B_r = 1.08 T)
  - EDM (B_r = 0.905 T)
- Energy of electrons: 70 eV
- Number of filaments: 48 filaments

This simulation neglected the following effects.

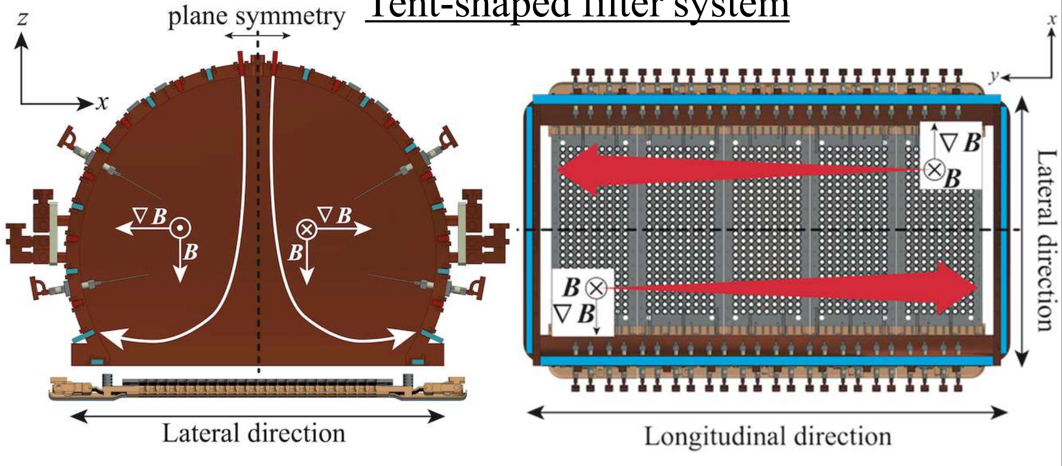
Collision, ionization, magnetic field produced by filament current, sheath, and space charge effect.

History of magnetic filter geometry

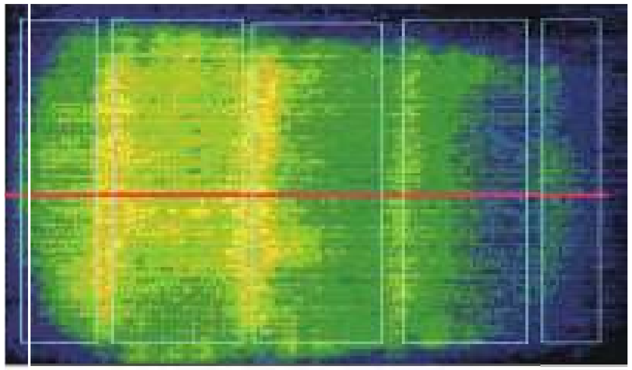
PG filter system

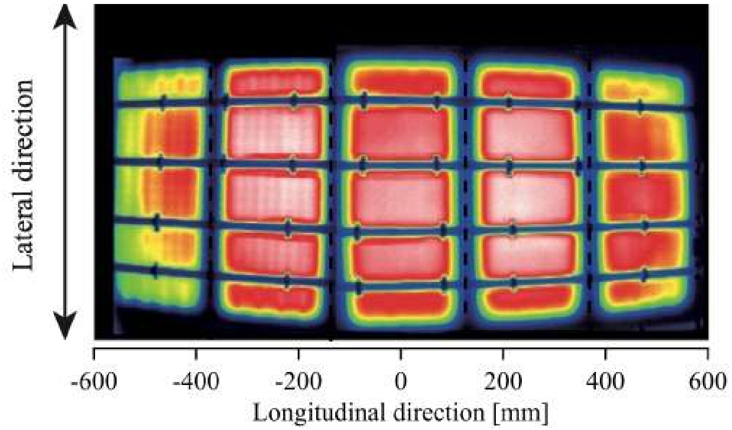


Tent-shaped filter system



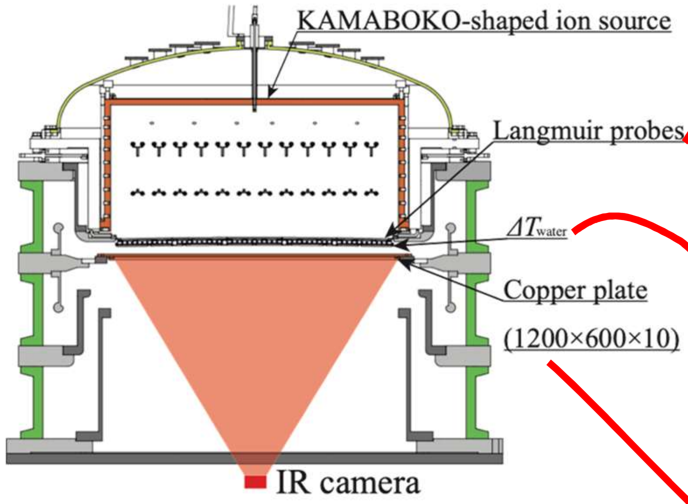
[1]A. J. T. Holmes *et al*., Rev. Sci. Instrum. **65(4)**, 1153 (1994). [2] M. Hanada *et al*., Rev. Sci. Instrum. **77(3)**, 03A515 (2006). [3] H. Tobari *et al*., Rev. Sci. Instrum. **79(2)**, 02C111 (2008). [4] M. Yoshida *et al*., Rev. Sci. Instrum. **85(2)**, 02B314 (2014).

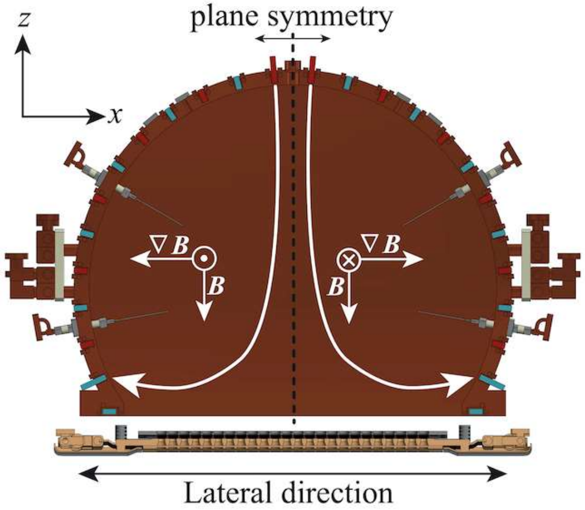




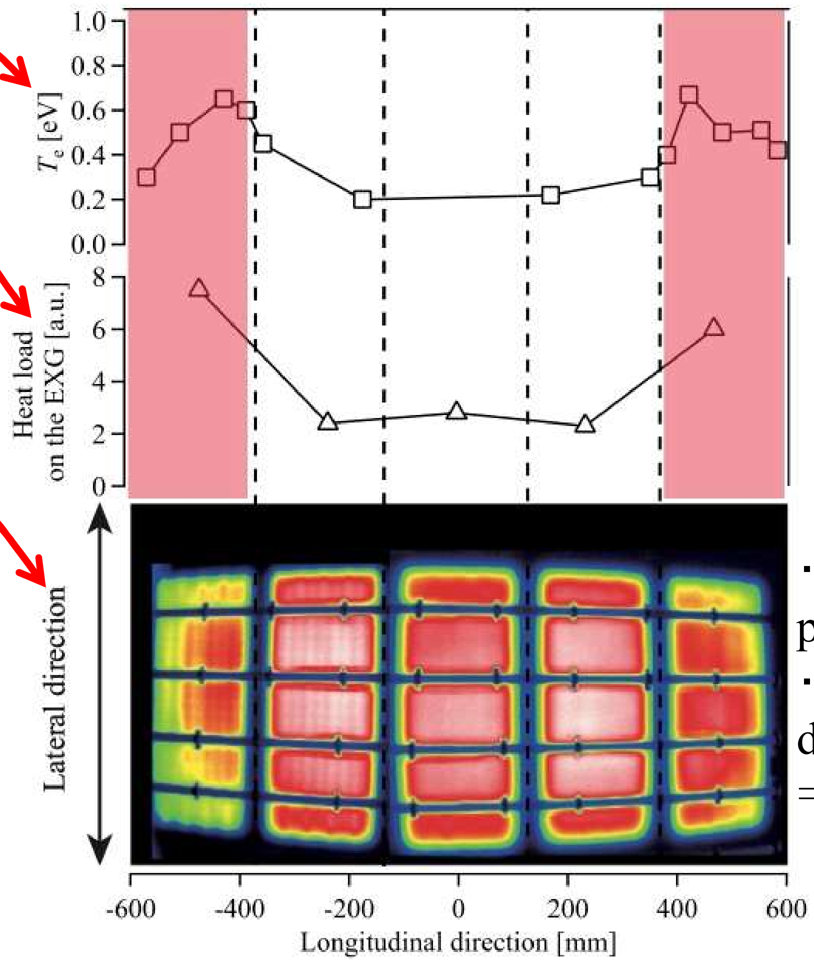
Uniformity of the extracted negative beam was much improved. However, ion production on the edge segments is insufficient.

Experimental investigation of non-uniformity





(Results w/ tent-filter)



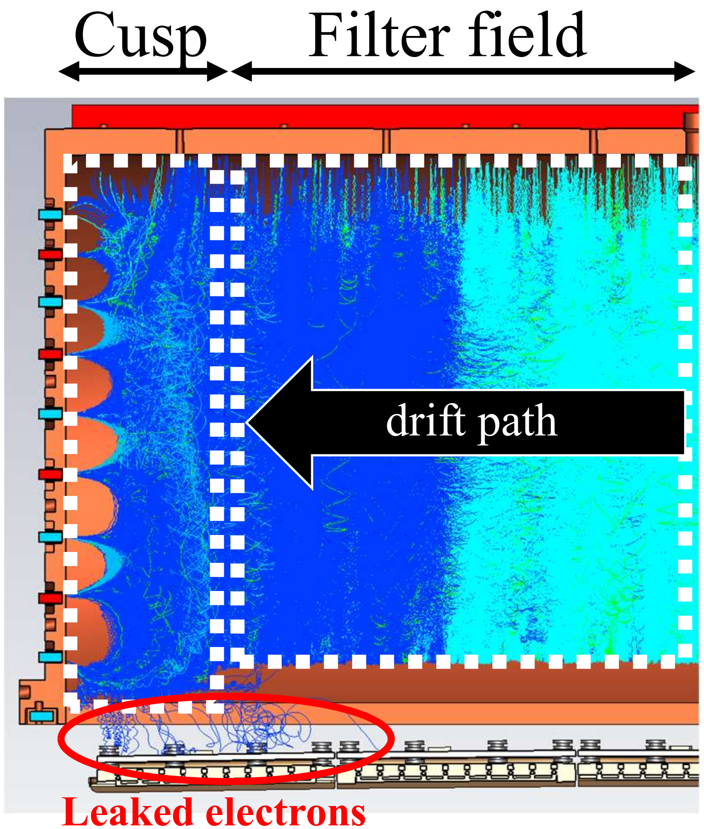
Higher T_e

Higher heat load

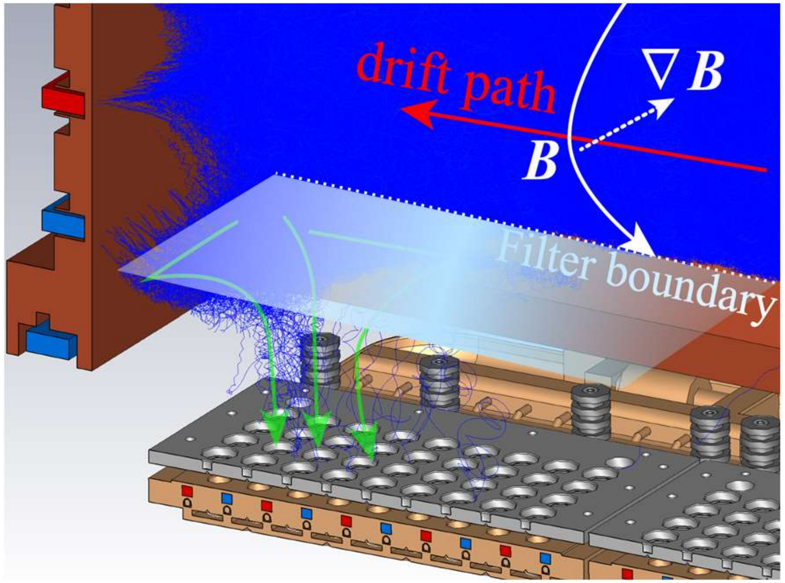
- Poor negative ion production rate
- High negative ion destruction rate

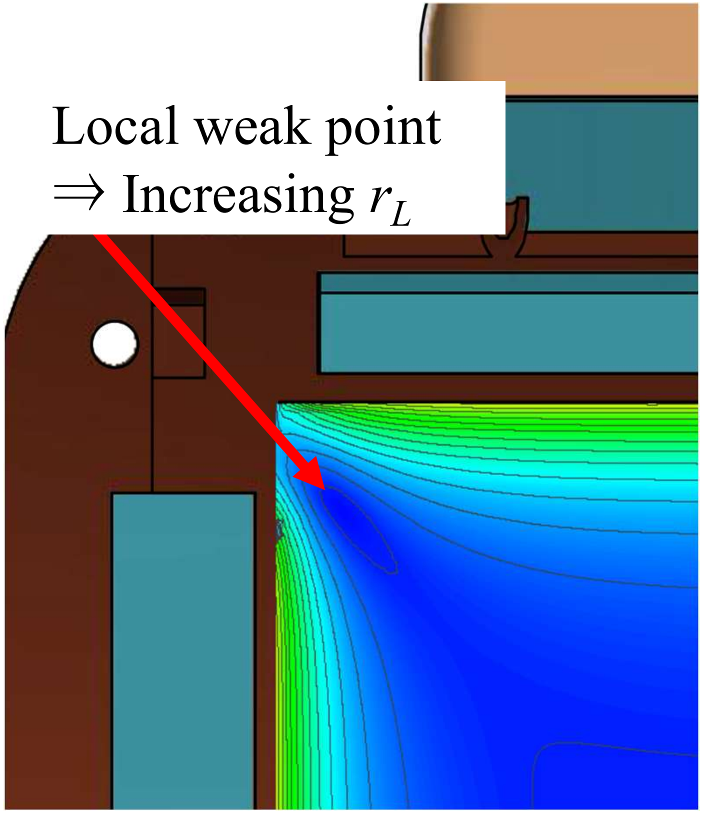
⇒ **spatial non-uniformity**

Two major causes of electron leakage to PG



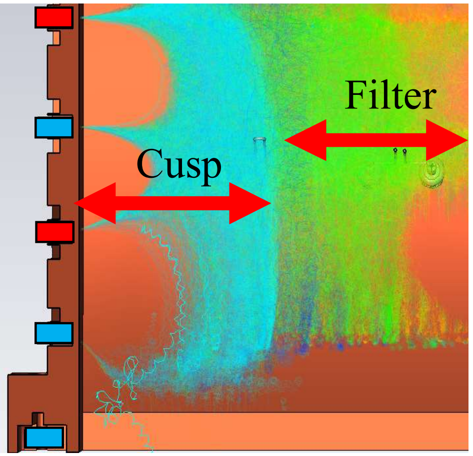
Each color is corresponding to each filament group.

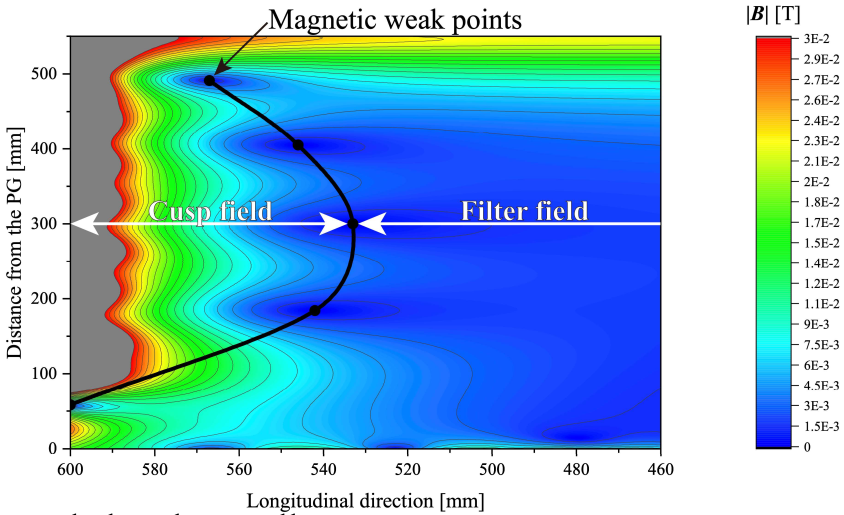




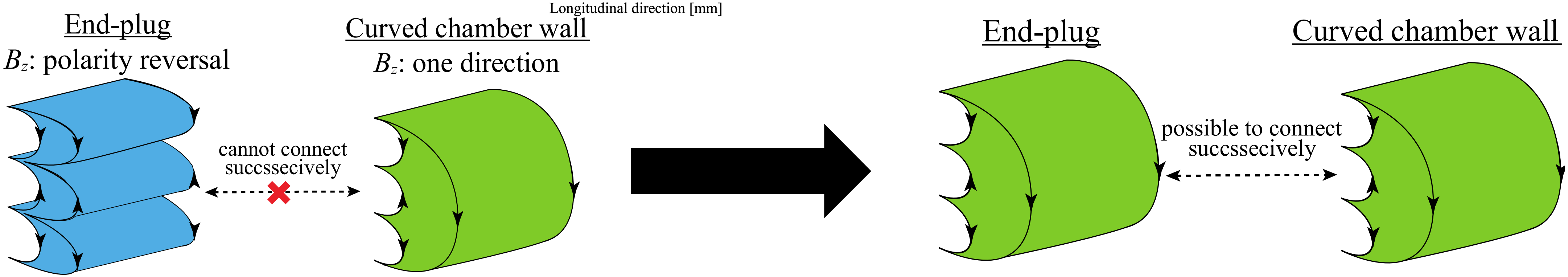
1. **Electrons around the end-plug are affected by not the filter field but the cusp field.**
2. **The magnets arranged with 90 degrees of angle induce the local magnetic weak point near the corner.**

1. Cusp-Filter junction near the end-plug





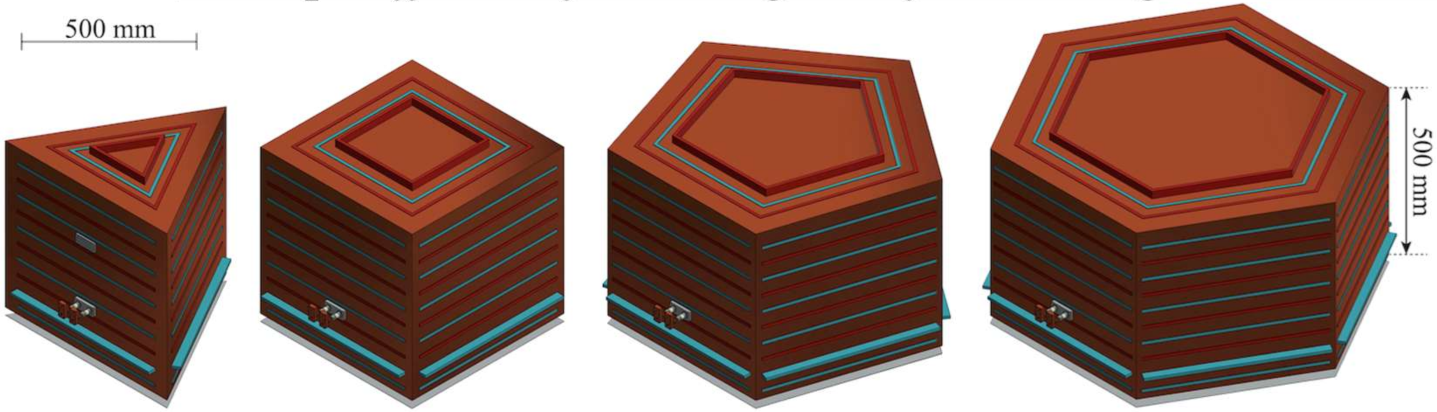
Cusp magnets mounted on the end-plug diminish the filter field strength in the vicinity of that.

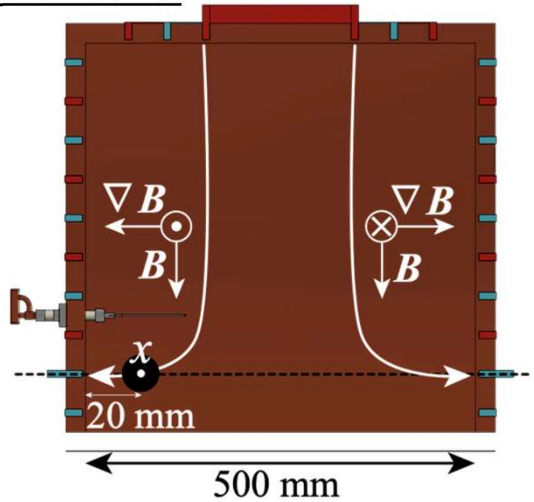


Avoiding the intermixing of different kinds of magnetic field structures is one of the key points for magnetic filter field design.

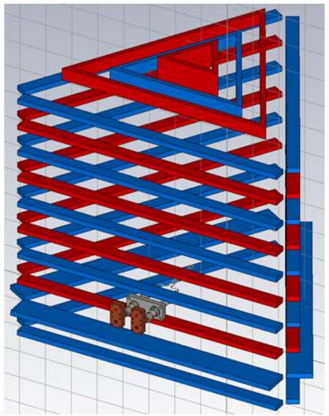
2. Verification of electron leakage from the corner

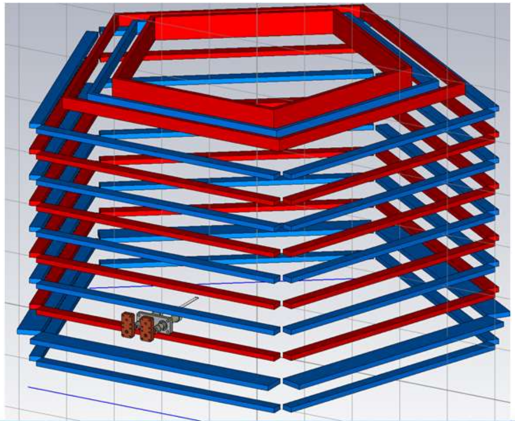
How much more does the connection angle of the magnets have to be opened to keep sufficient filter magnetic field strength at the chamber corner?





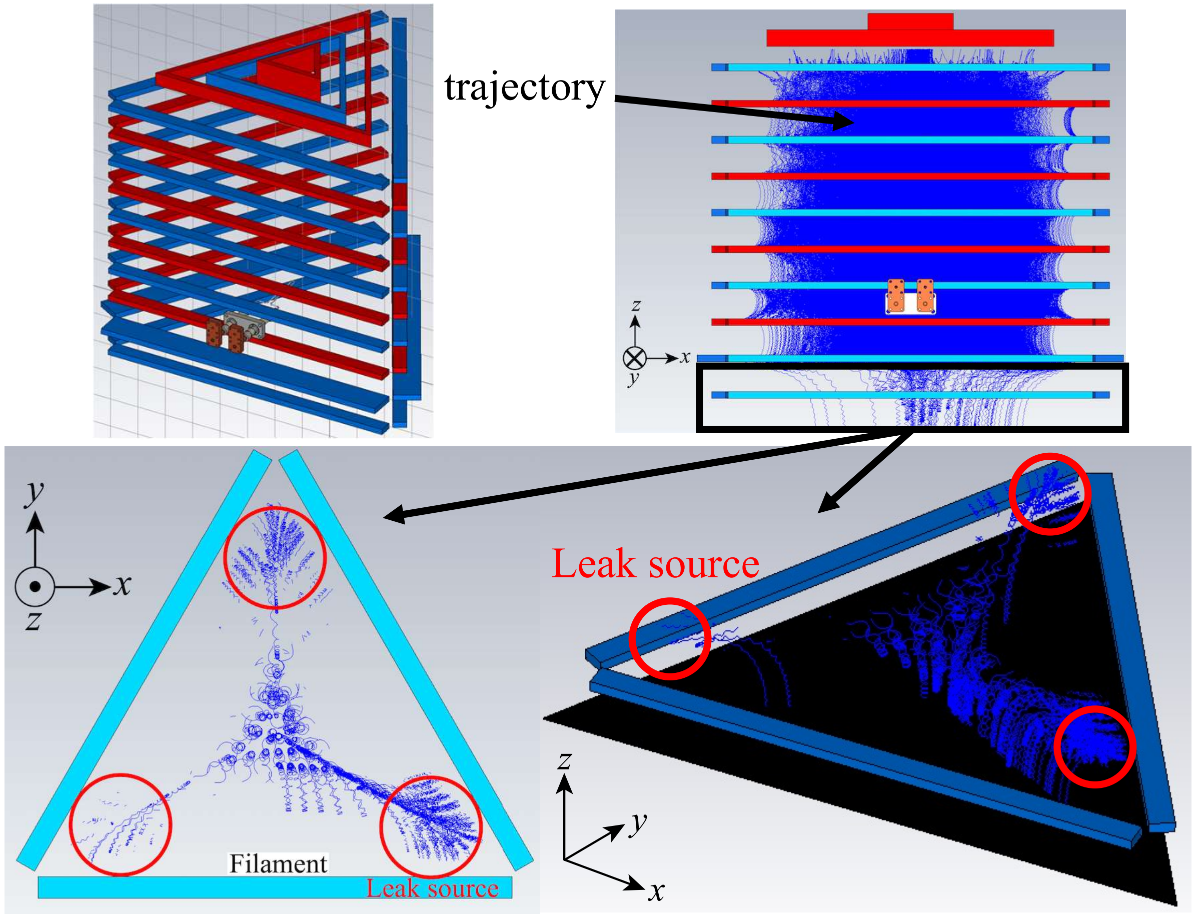
Simulation conditions
Chamber: polygon cross-section (triangle to nonagon)
A side length, height: 500 mm
Filter field: tent-shaped for every direction
Number of emitted electrons: 5000



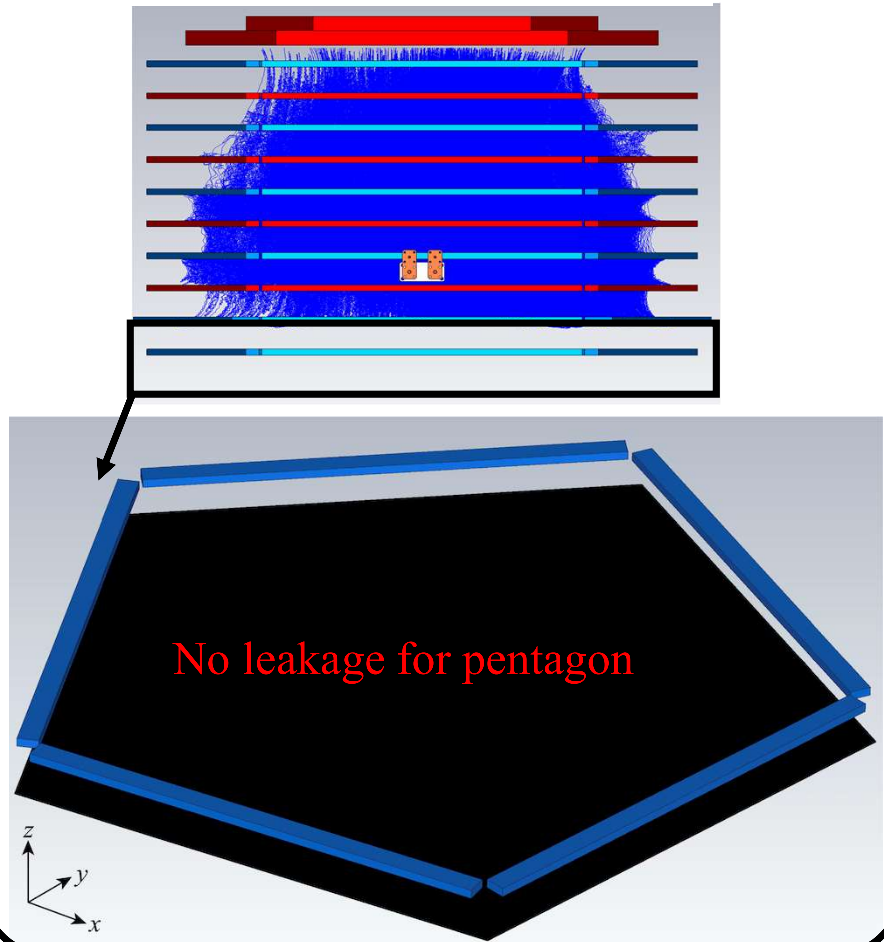


2. Verification of electron leakage from the corner

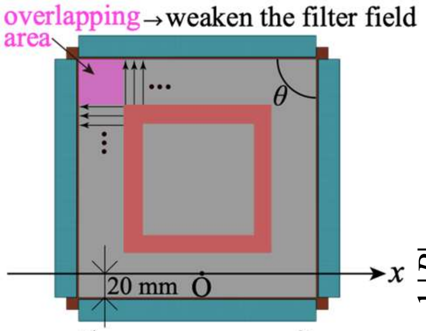
Leaked case (triangle)

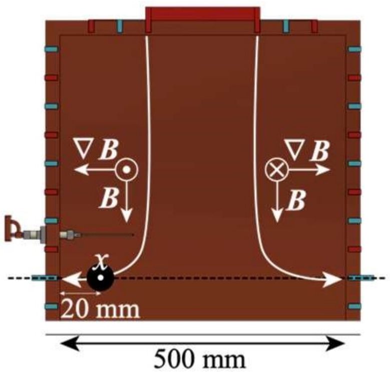


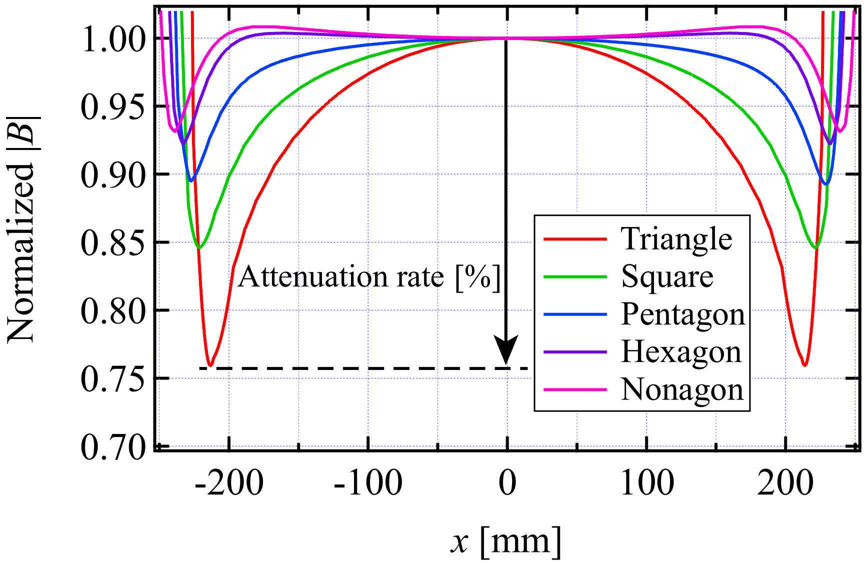
No-leak case (pentagon)

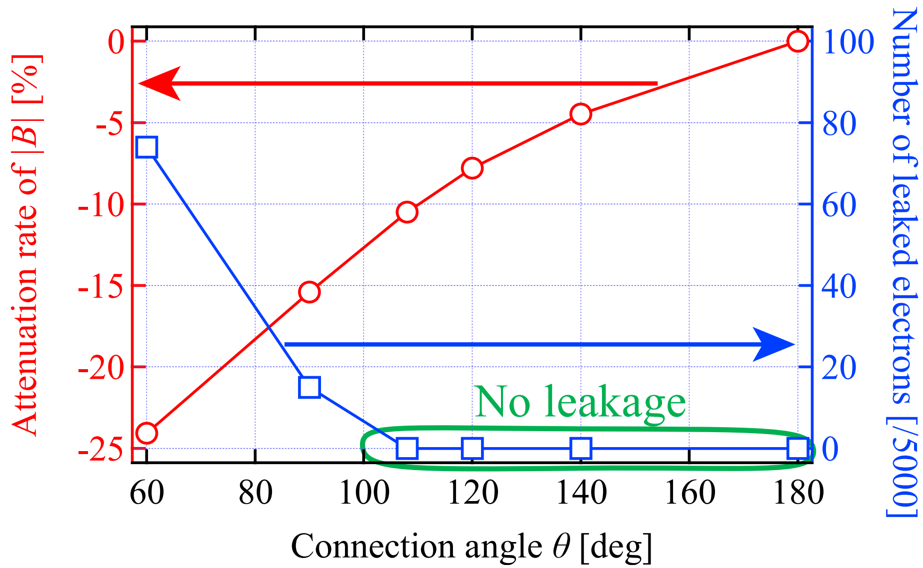


2. Verification of electron leakage from the corner







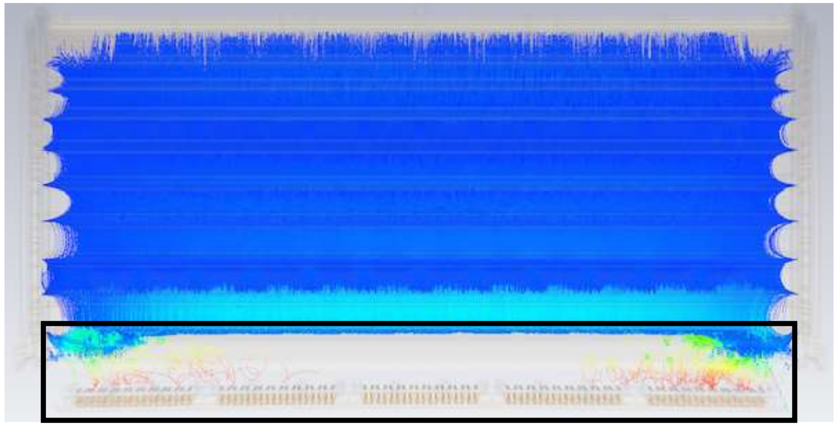


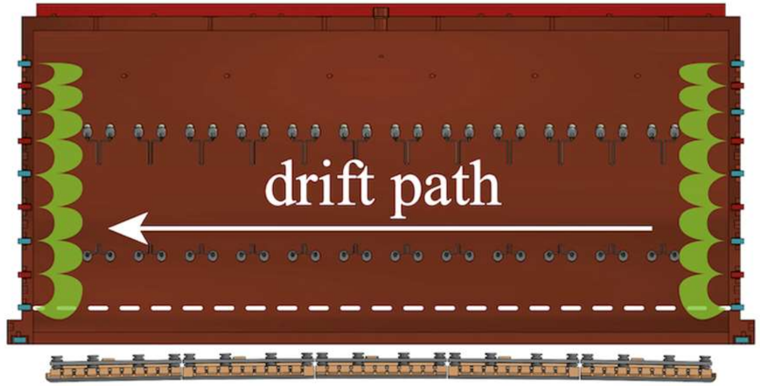
The wider connection angle (>108 deg) is preferable from the point of view of the local magnetic weak point to reduce the fast electron leakage to PG at the corner.

Proposed solution: Eclair-shaped

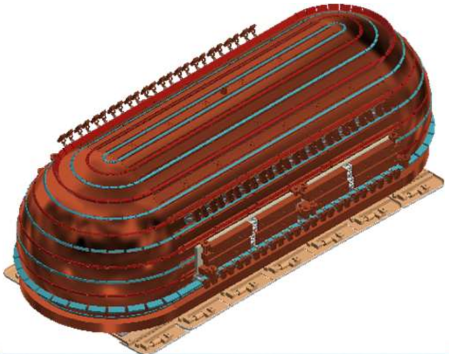
The ideal configuration we consider is a continuous magnetic filter for the whole circumference in the Eclair-shaped source chamber.

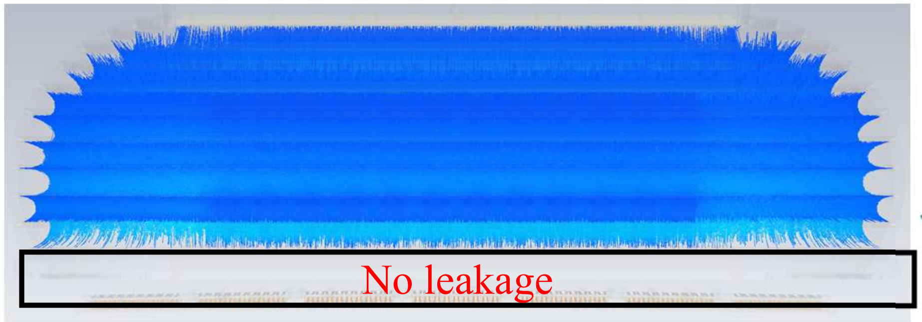
KAMABOKO w/ tent



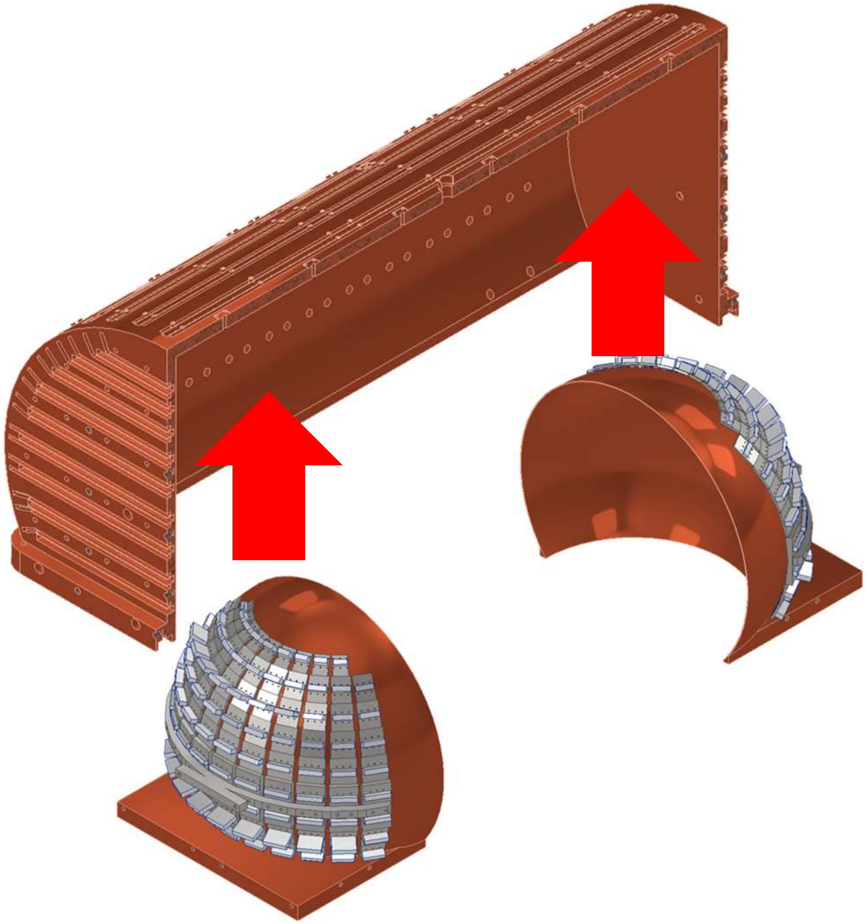


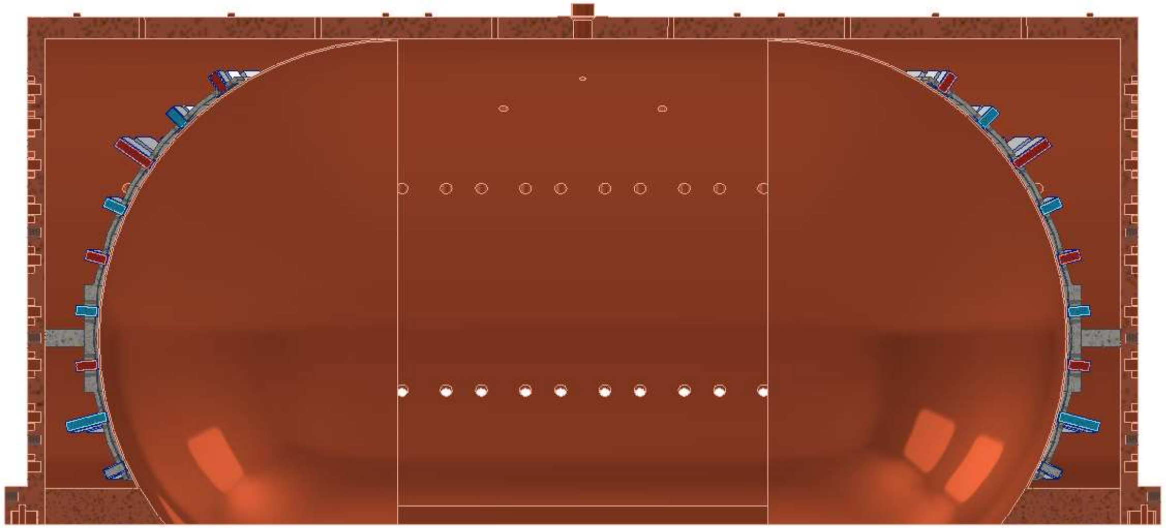
Eclair w/ tent





Future works: verification test





The miniaturized Eclair-shaped source chamber will verify the feasibility of the uniform negative beam extraction.

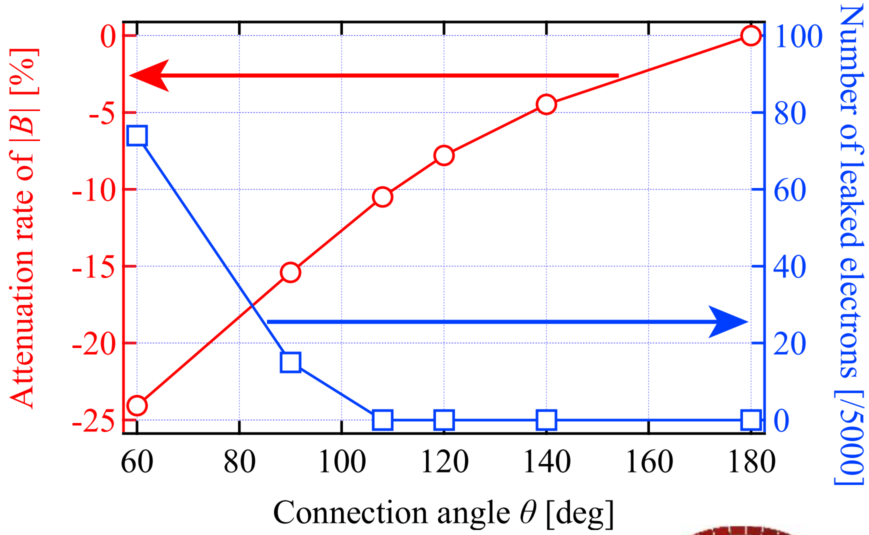
- ✓Electron convection
- ✓Loss-less configuration for fast electrons
- ✓Uniform parent particle production

Summary

Research target

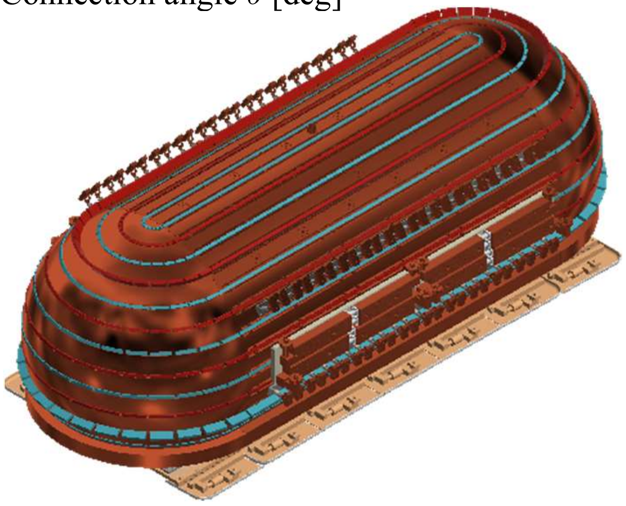
Improving the **non-uniformity** of negative ion extraction

⇒Possible cause: Fast electron leakage from driver to PG



Countermeasures

- Tent-shaped filter for whole circumference
- Wider connection angle



Our proposal: Eclair-shaped source chamber with tent-filter field

Expected results

- Uniform negative ion production and extraction
- Reduction of co-extracted electron current