Progress of experimental study on negative hydrogen ion production and extraction

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- Performance of negative-ion-based NBI in LHD
- Research activities for further improvement of N-NBI
- Improvement of negative ion source
  - Engineering approach
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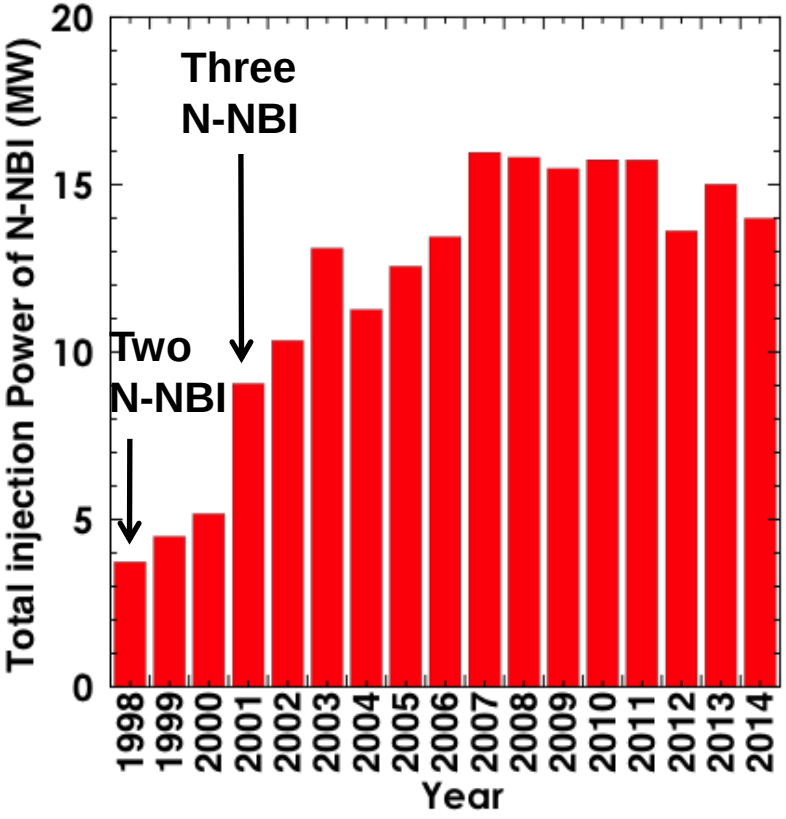
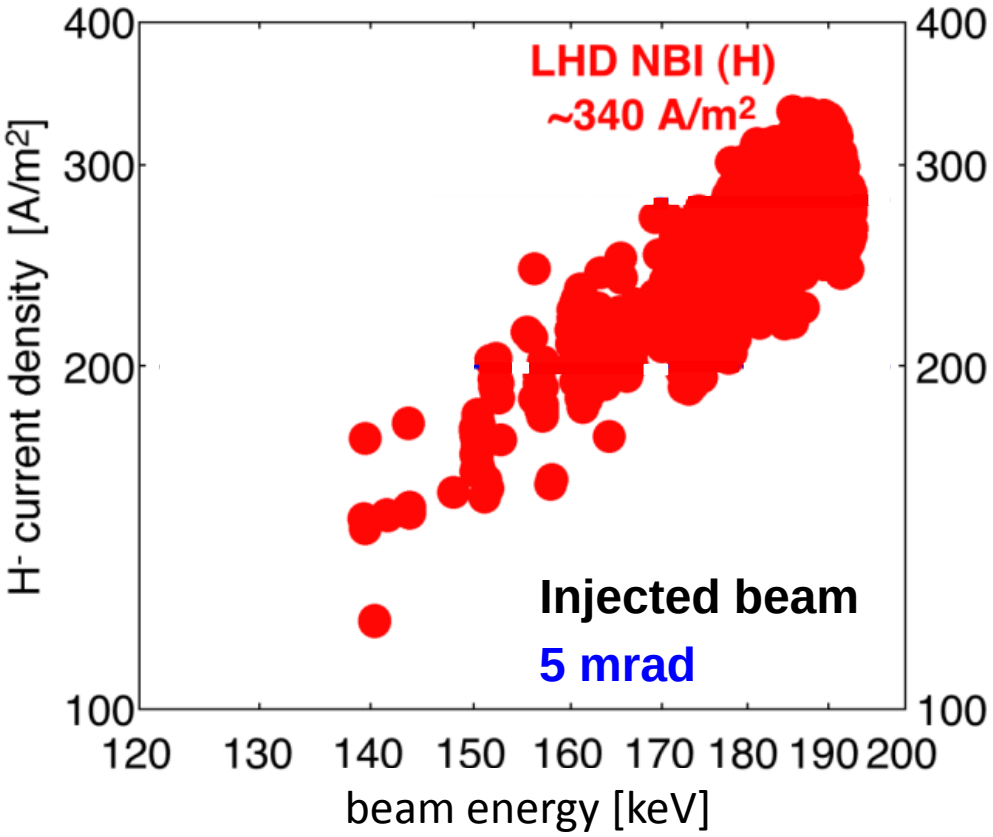
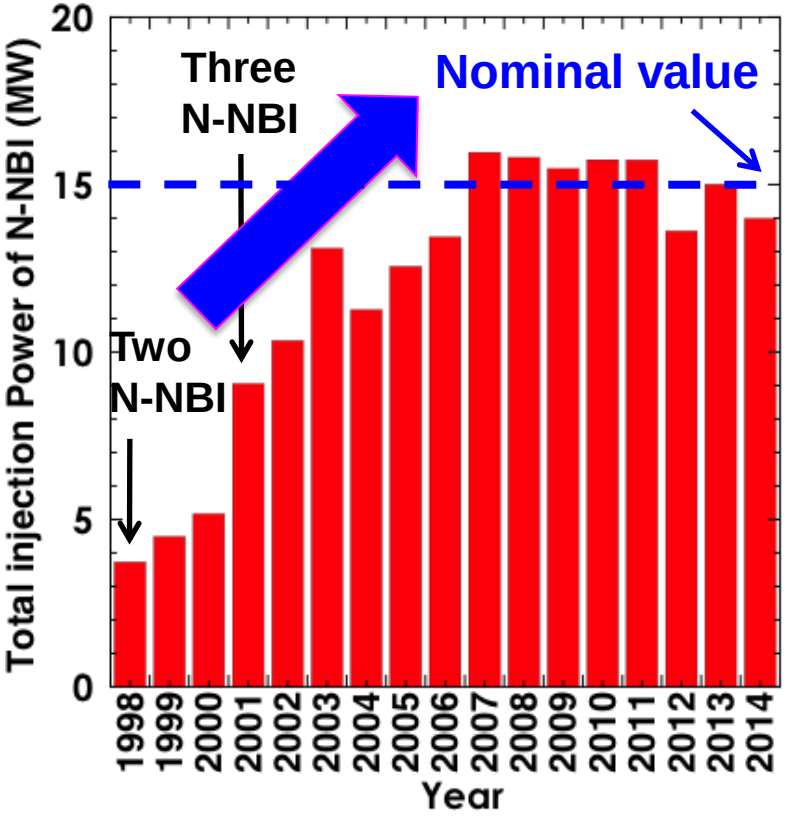
- Summary

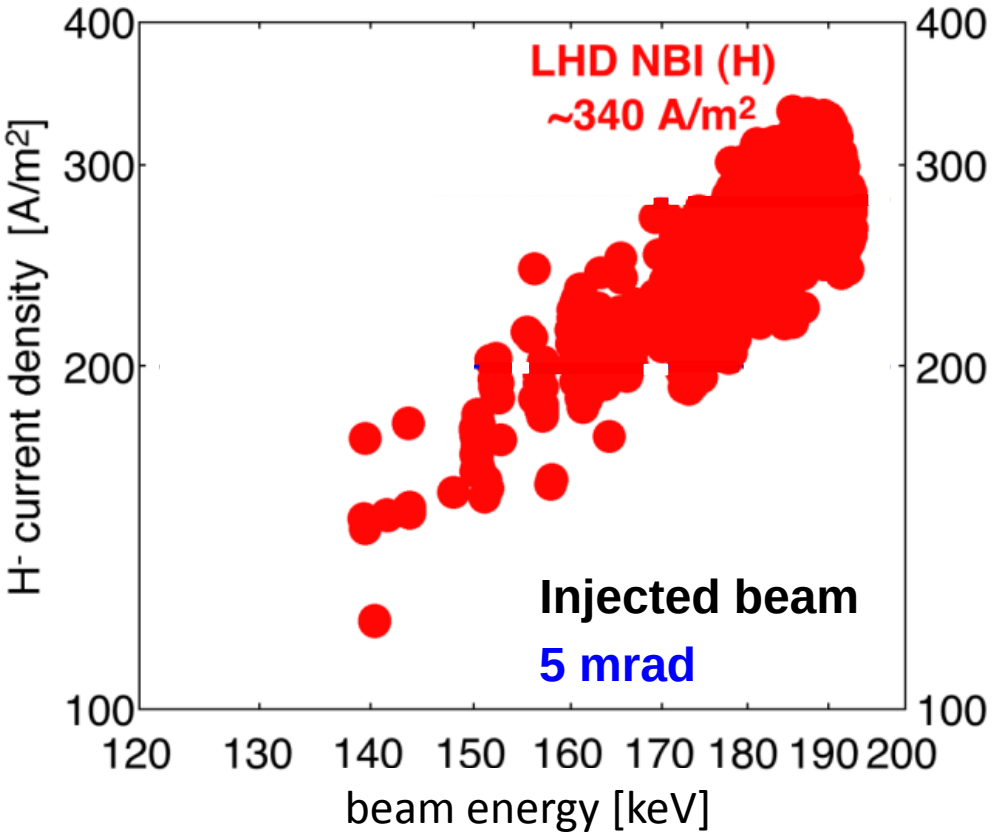
Negative-ion-based NBIs are utilized as main heating device in LHD





Negative-ion-based NBIs are utilized as main heating device in LHD





- Total injection power with N-NBIs has exceeded 15 MW by optimizing caesium dose and beam control.
- The H^- current density has reached 340 A/m^2 with divergence of 5 mrad, and the values are comparable with the targets of ITER NBI.

Research activities for further improvement of N-NBI

Deuterium plasma operation in LHD

- •Negative ion current decreases according to Child-Langmuir law.
- •Co-extracted electron current increases.
- ➔increases heat load on acceleration grids
- ➔degrades voltage holding capability.

Engineering approach

modification of accelerator

➔reduction of grid heat load and improvement of voltage holding capability

Physics approach

measurement of negative ion source plasma

➔clarification of negative ion behavior

Engineering approach

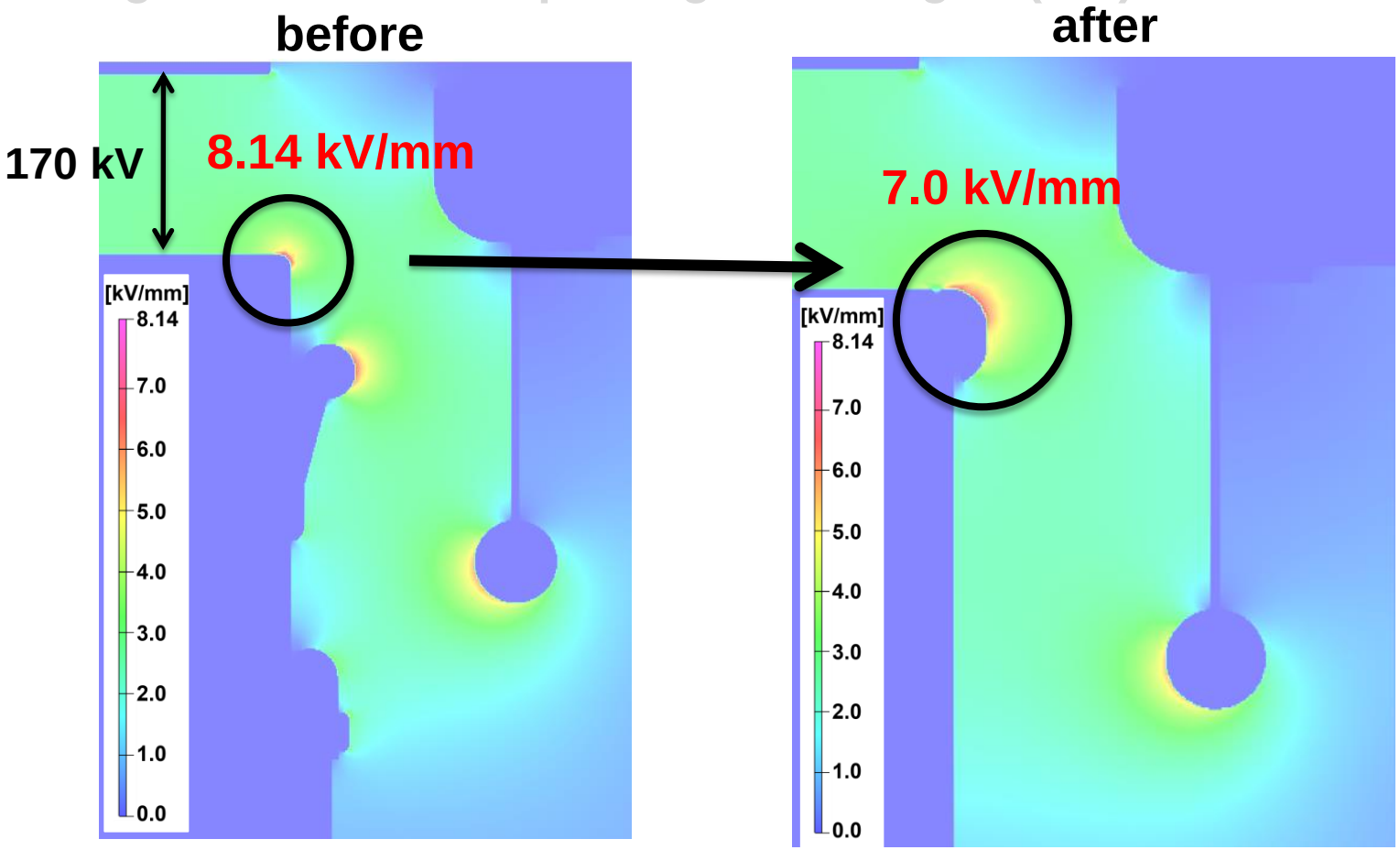
- **Modification of accelerator**

Modification of accelerator

- **Installation of field limiting ring**

  The field limiting ring was installed inside accelerator to moderate the local electric field **(8.14 kV/mm → 7.0 kV/mm)**.

- Change of the hole shape on grounded grid (GG)



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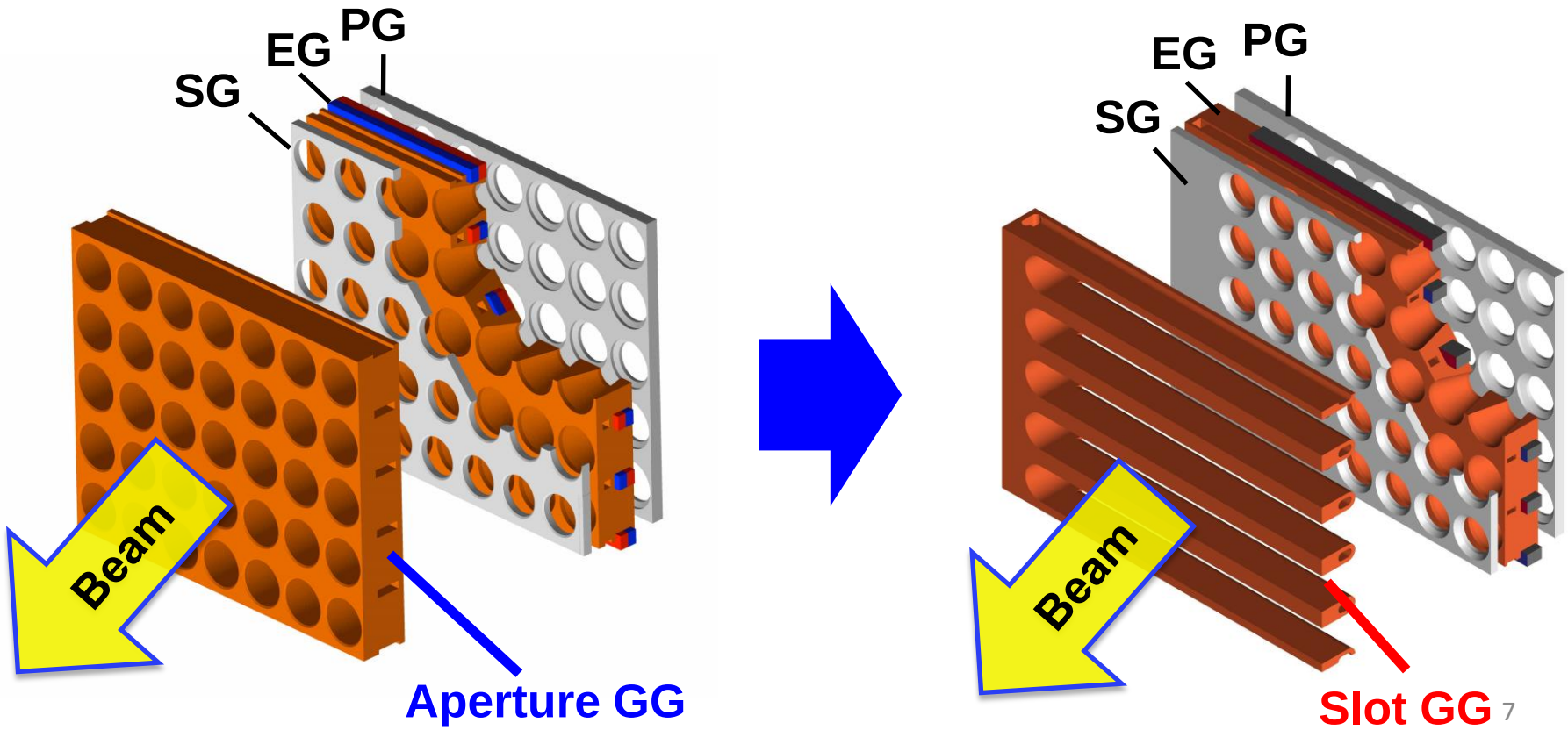
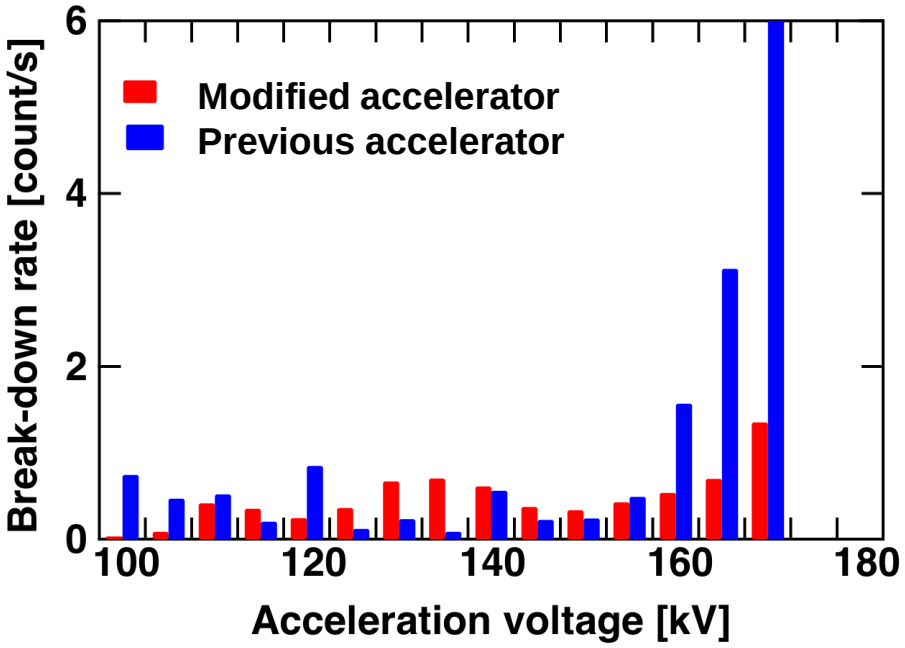
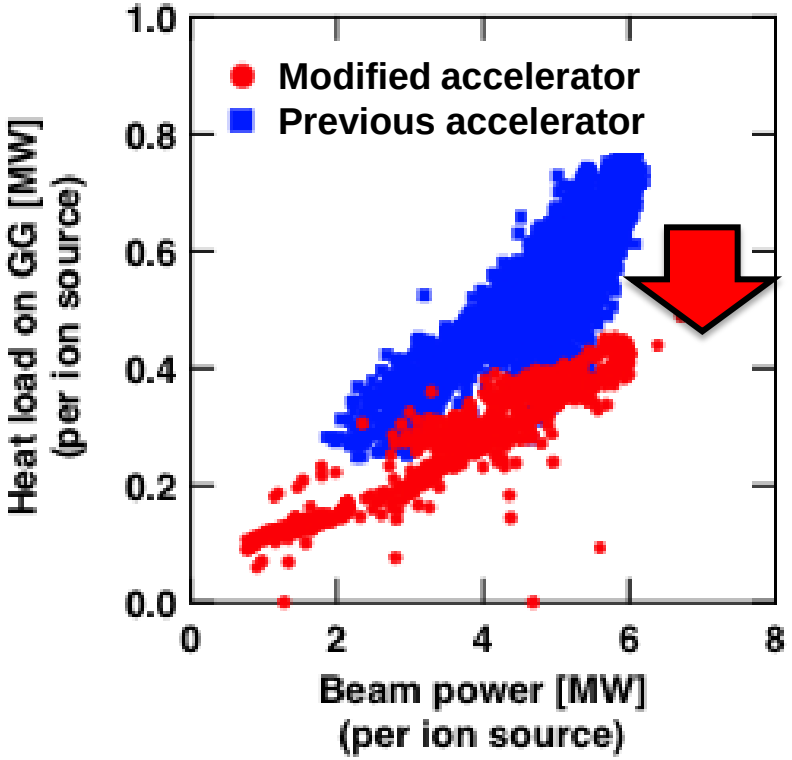


Improved performance of N-NBI in LHD





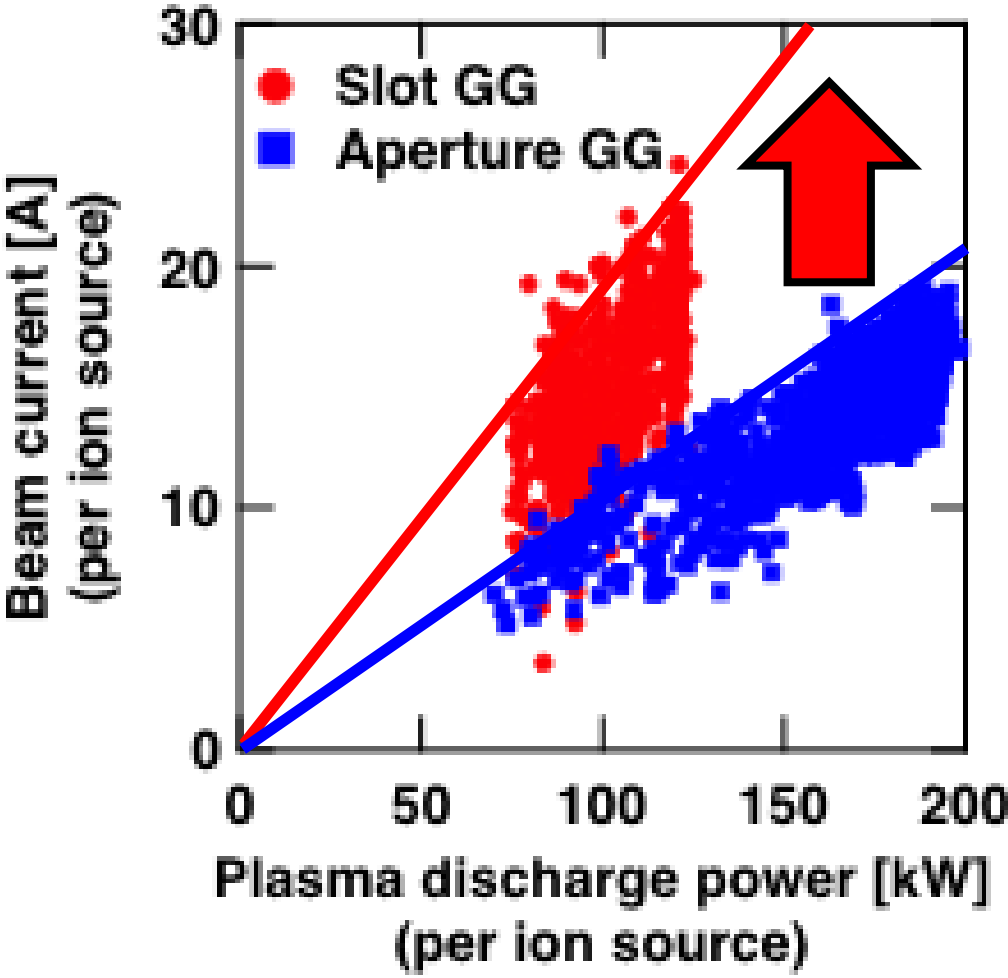
- The voltage holding capability is improved especially **at high acceleration voltage**.
- The heat load on GG is reduced **by 40%**.

[1] M. Kisaki, et. al., Rev. Sci. Instrum. **87**, 02B321 (2016).

H^- production efficiency is enhanced by just modifying the accelerator

H^- production depends on accelerator configuration??

Investigation of source plasma is important to understand the physical mechanism.
(Cs recycling …)



[1] M. Kisaki, et. al., Rev. Sci. Instrum. **87**, 02B321 (2016).

Physics approach

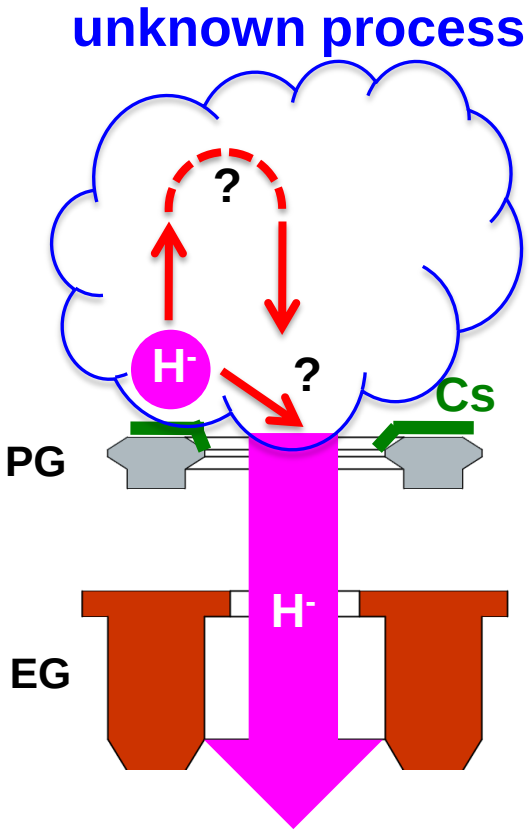
- **Clarification of extraction process of H^-**

Extraction process of H^- has not been clarified yet

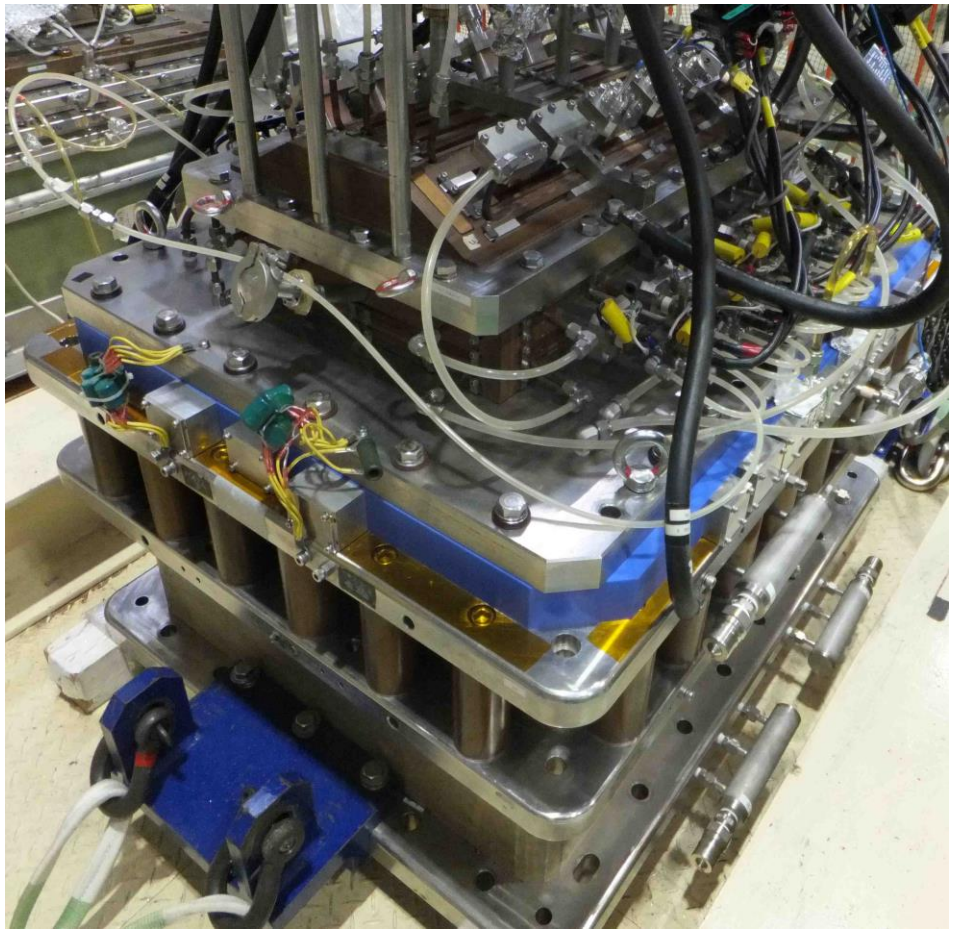
- H^- is produced on the surface of grid metal with Cs seeding.

  Investigation of H^- dynamics in order to clarify the extraction process of H^-

  Improvement of H^- extraction efficiency



NIFS-R&D Negative Ion Source



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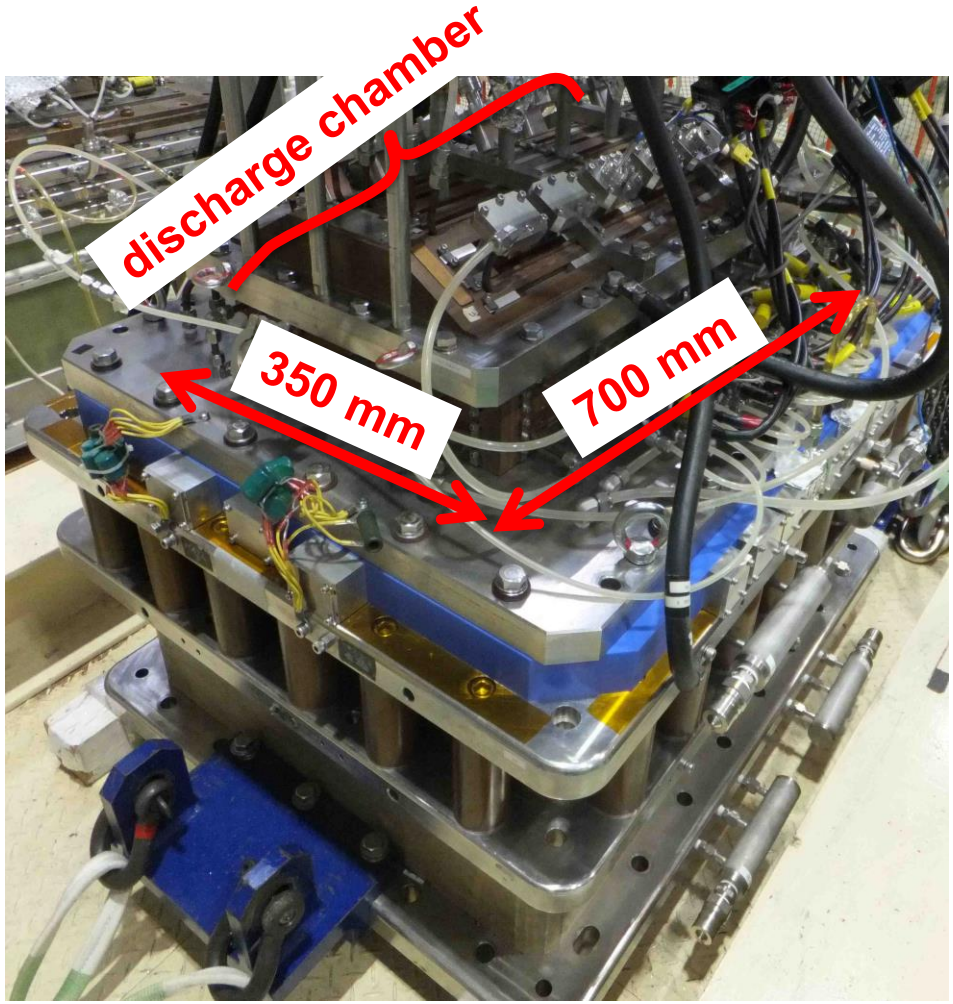

Discharge chamber:

- filament-arc discharge
  with Cs seeing
- 1/2 volume of LHD N-NBI

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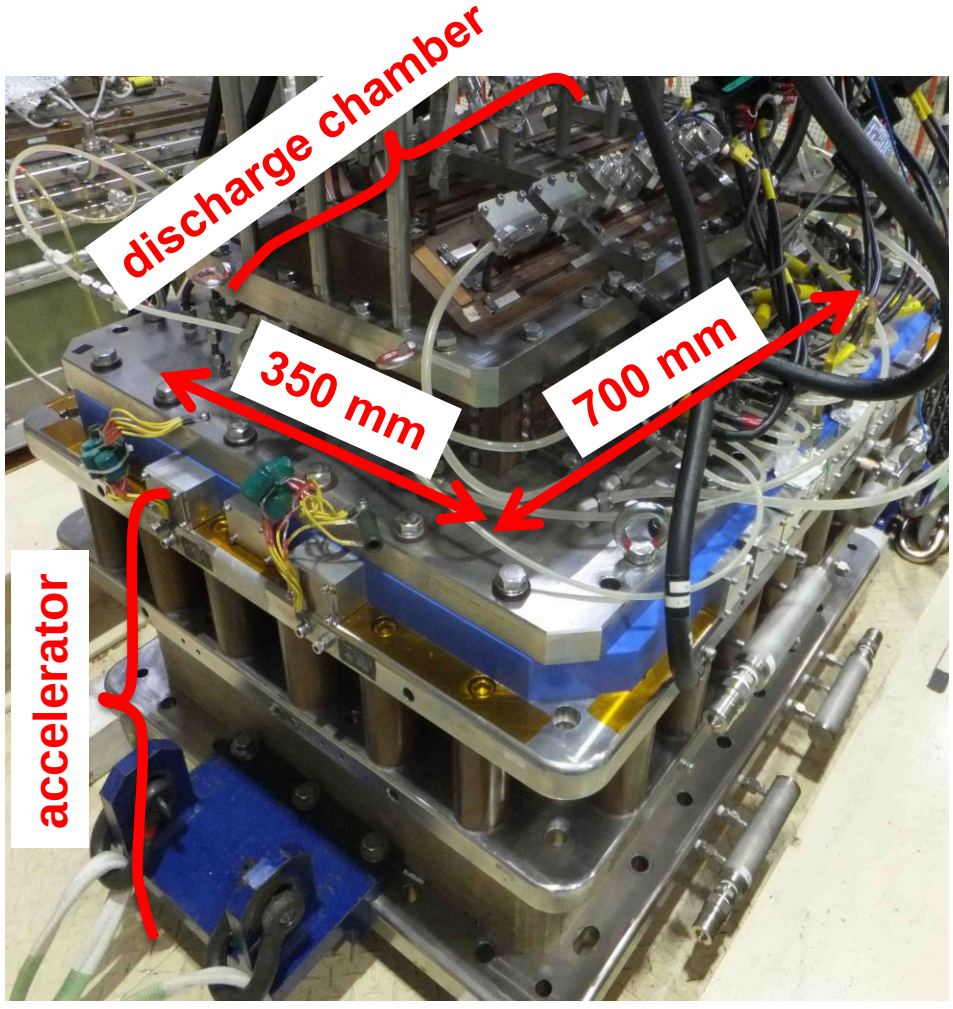
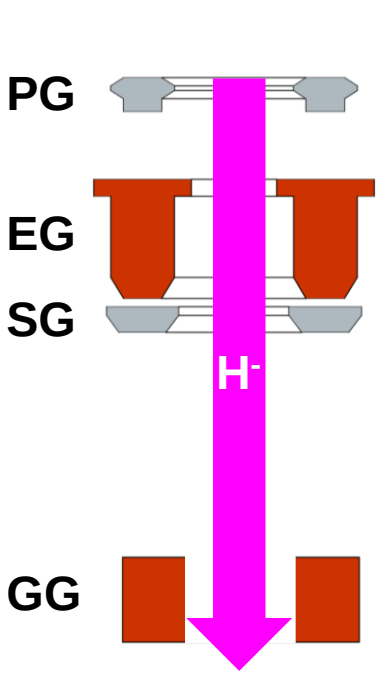
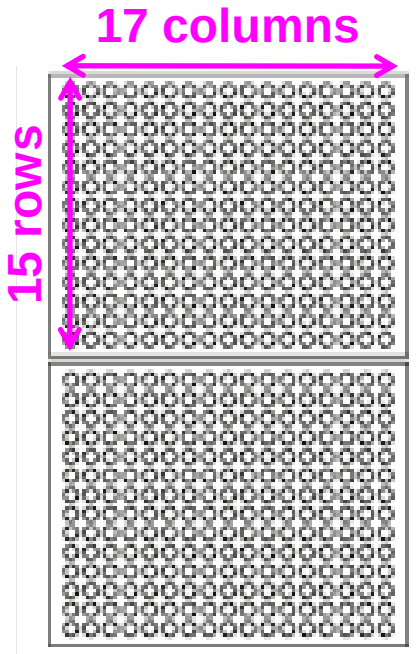


Discharge chamber:

- filament-arc discharge **with Cs seeing**
- 1/2 volume of LHD N-NBI

Accelerator:





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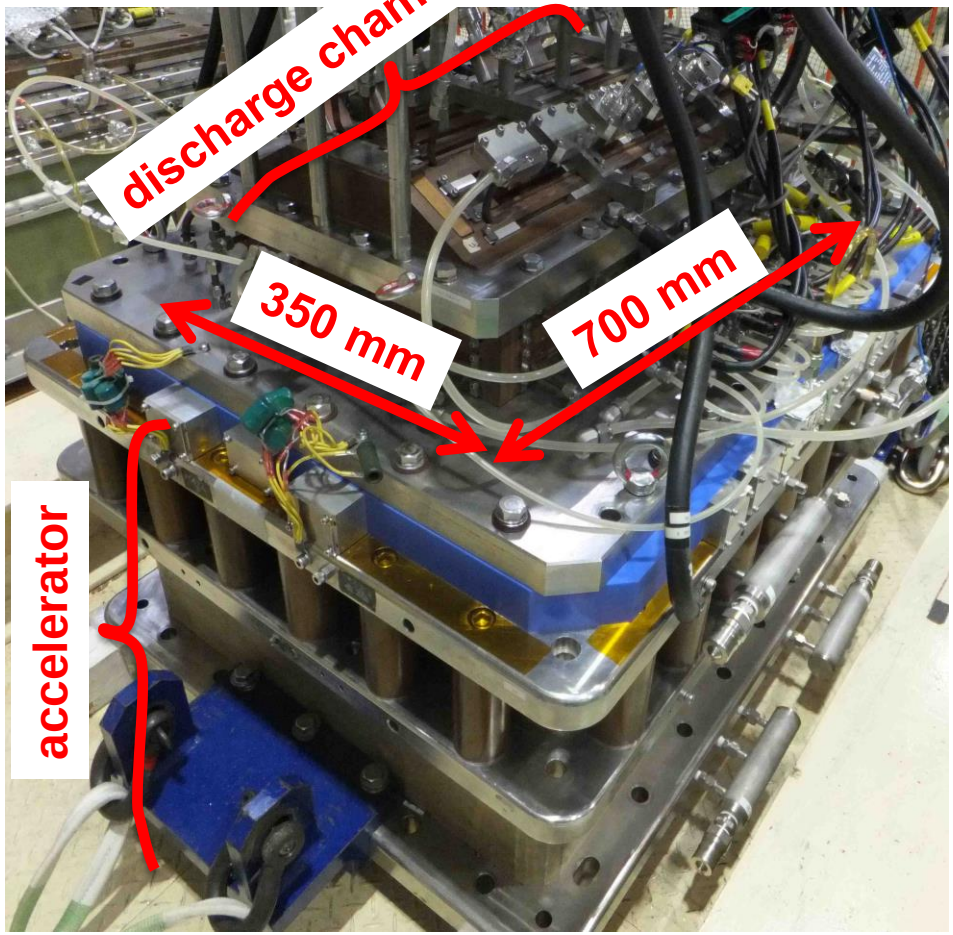

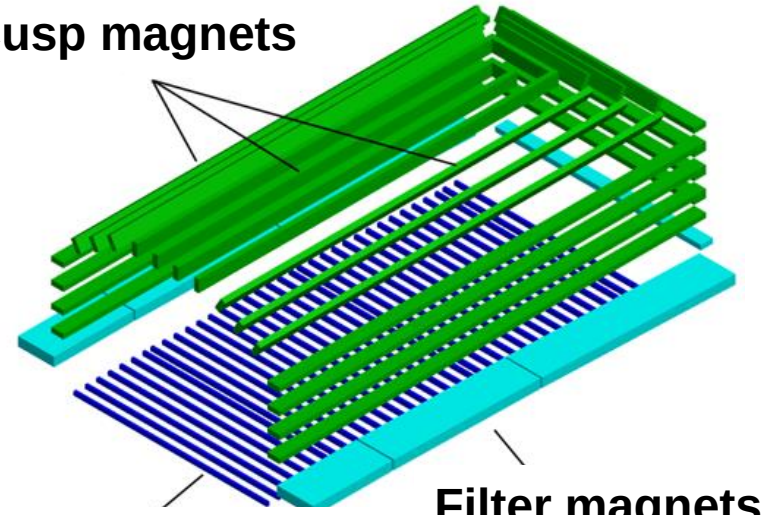

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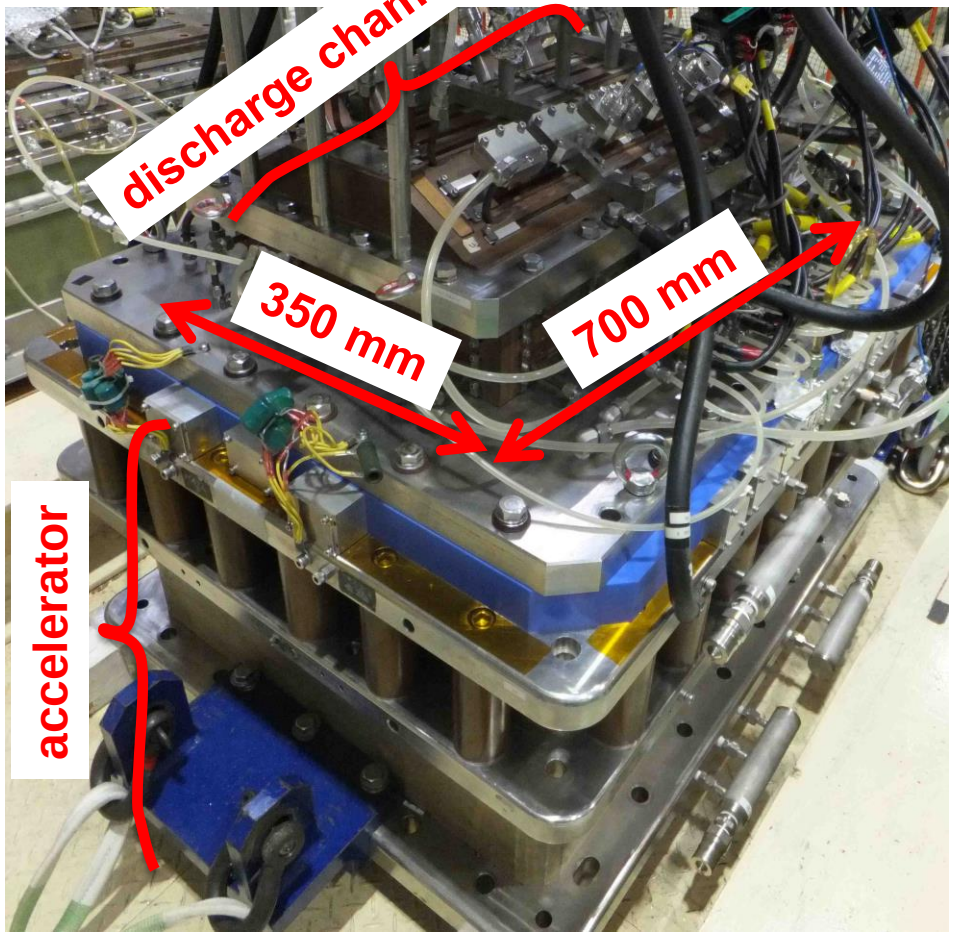
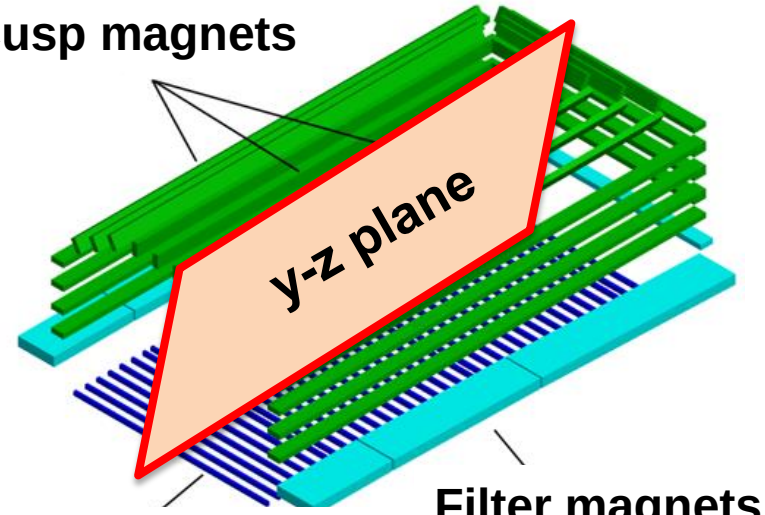
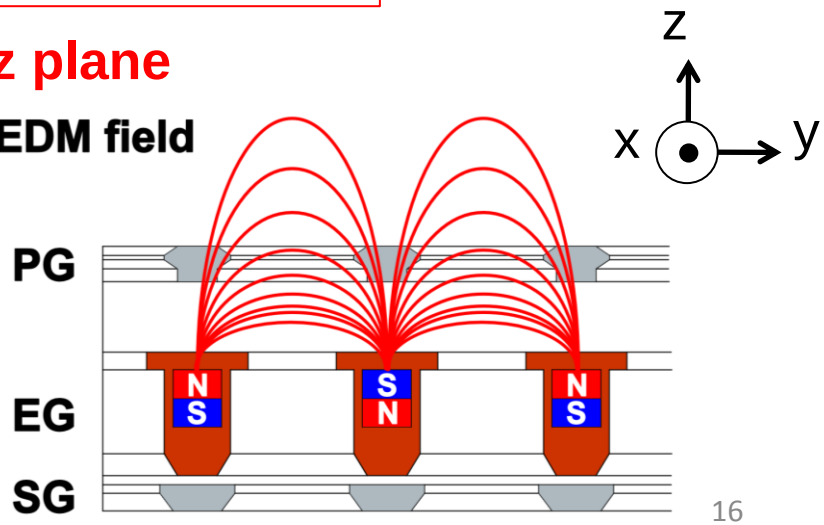




Electron deflection magnets (EDM)

y-z plane



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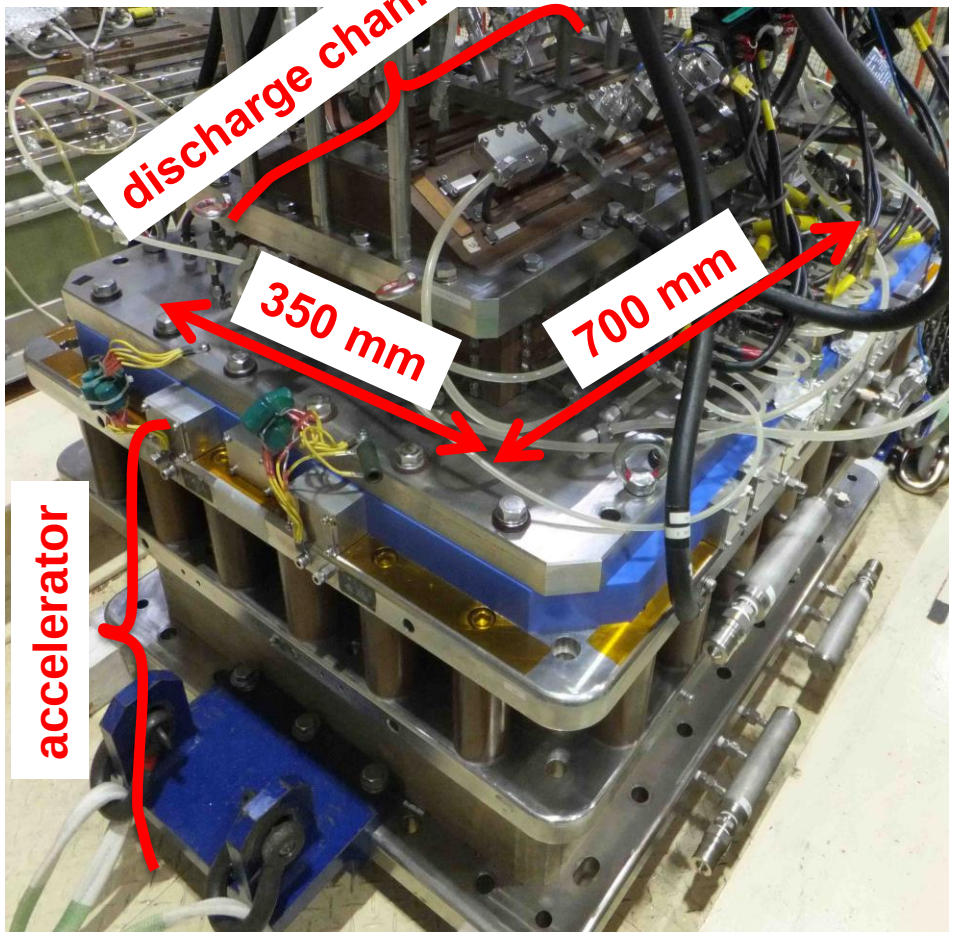

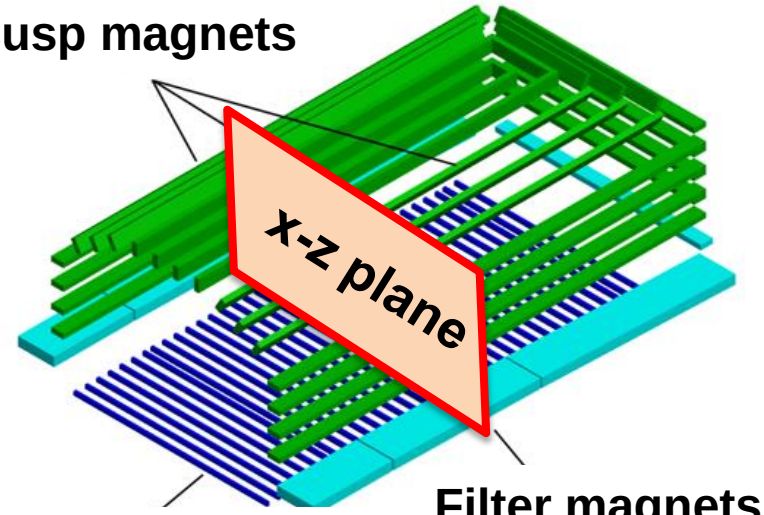

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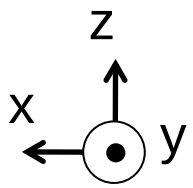
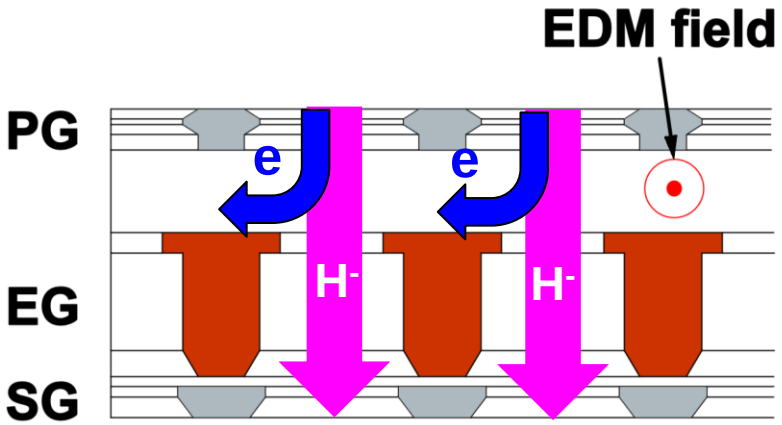
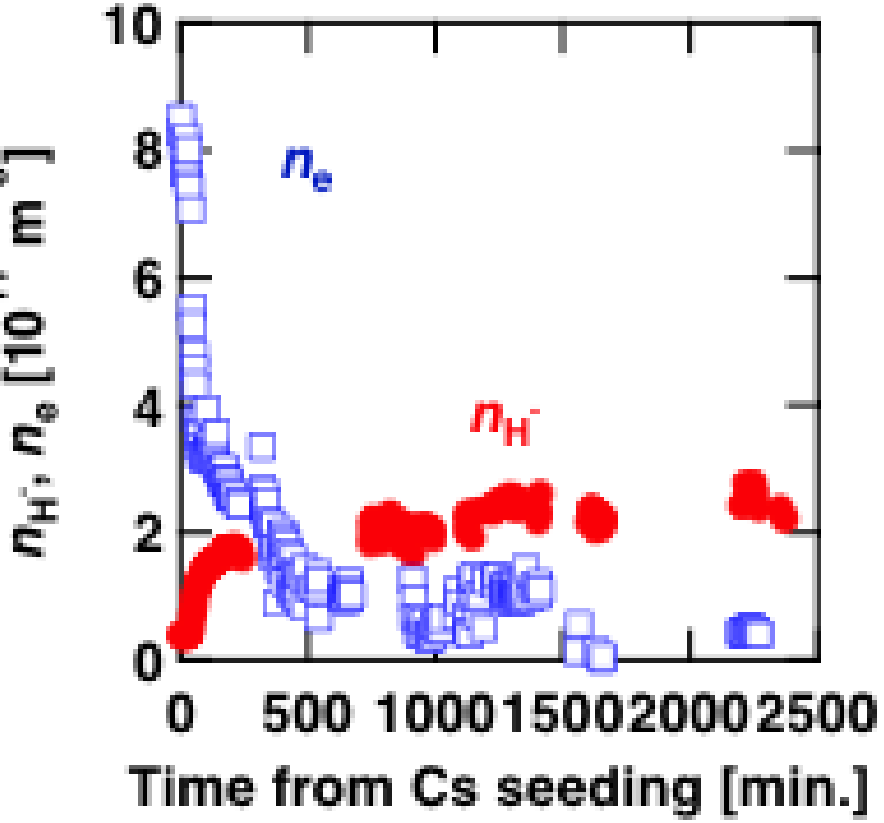




Formation of negative-ion rich plasma was found



[2] Y. Takeiri, et. al., AIP conf. proc. **1655**, 060004 (2015).

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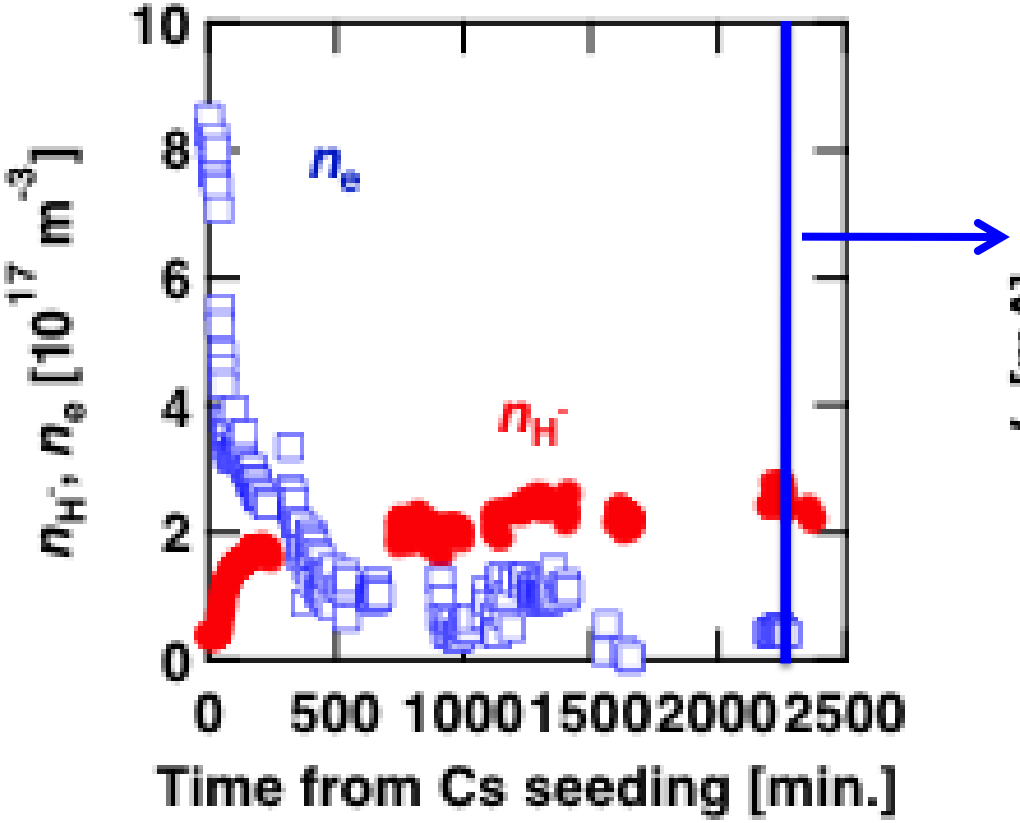
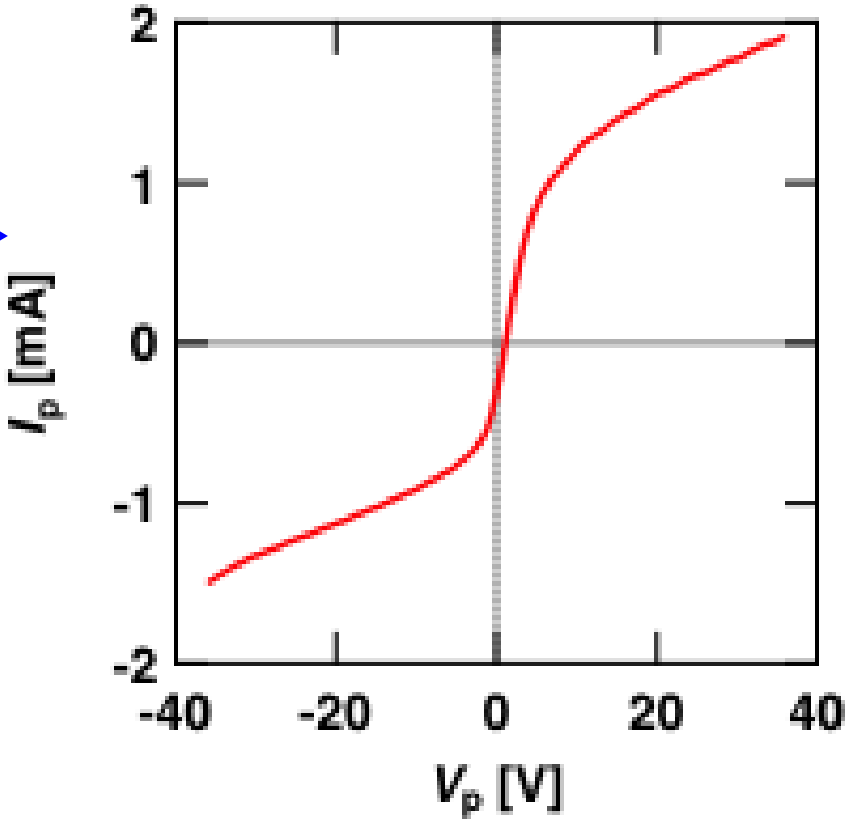
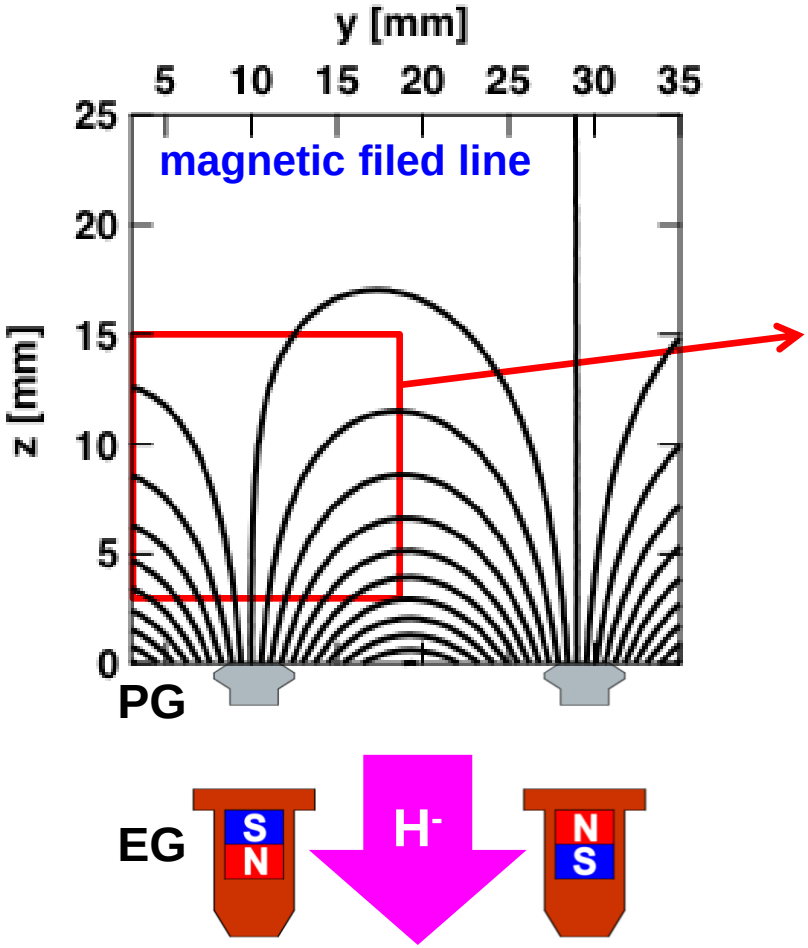




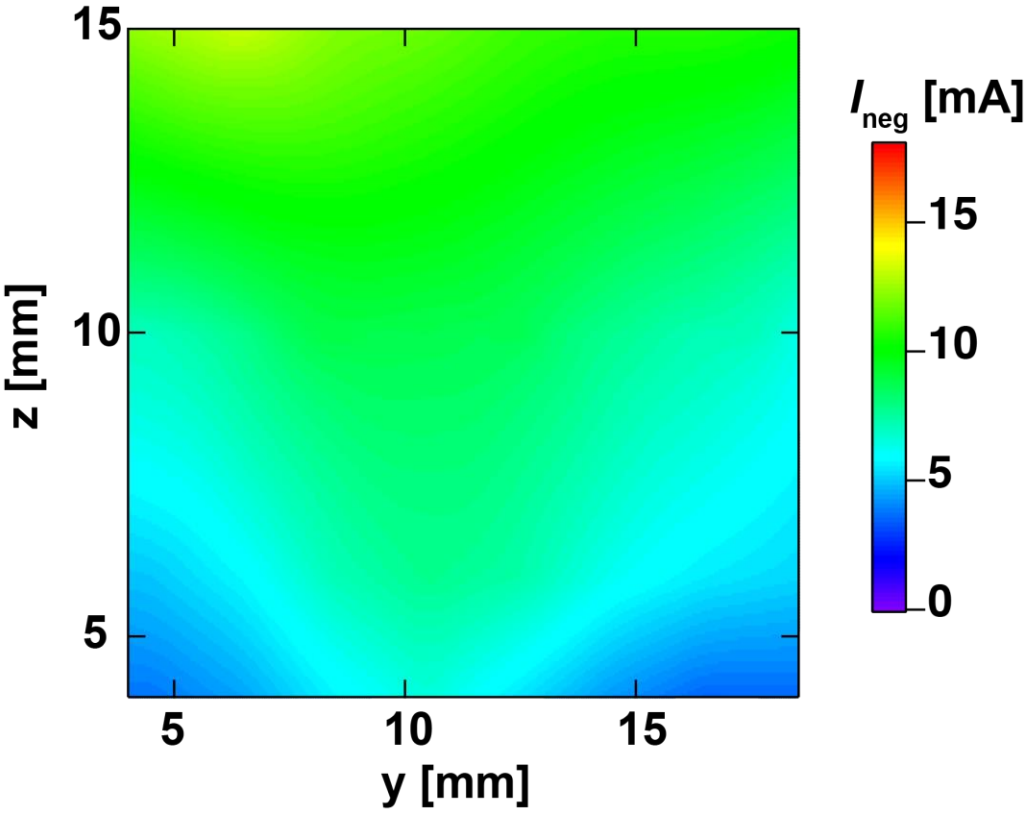
- At later phase of Cs conditioning, Langmuir probe signal became symmetric.
- What causes formation of negative-ion rich plasma?

[2] Y. Takeiri, et. al., AIP conf. proc. **1655**, 060004 (2015).

EDM field plays an important role in suppression of electron near PG

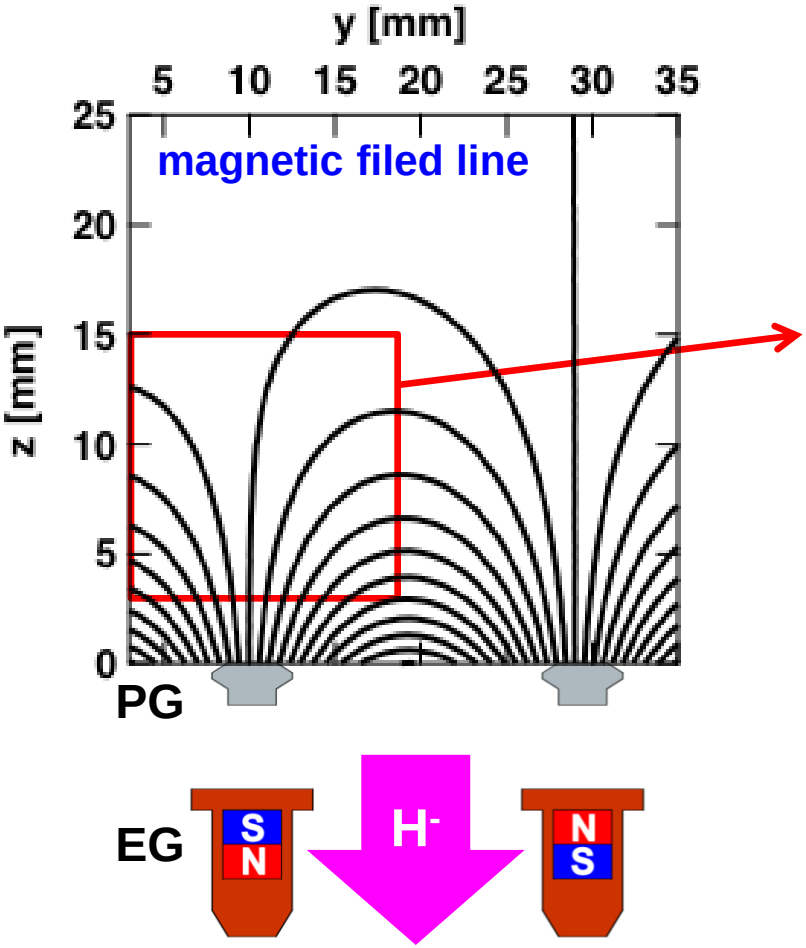


Langmuir probe measurement



$$I_{neg} = I_{H^-} + I_e$$

EDM field plays an important role in suppression of electron near PG



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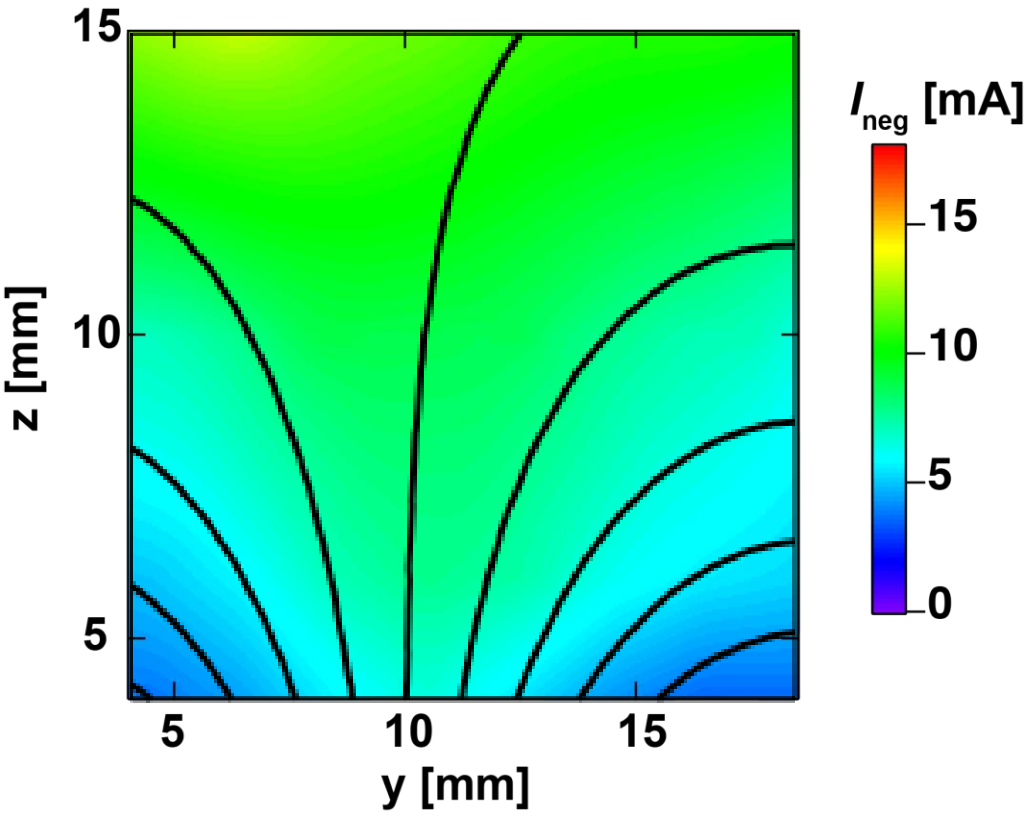

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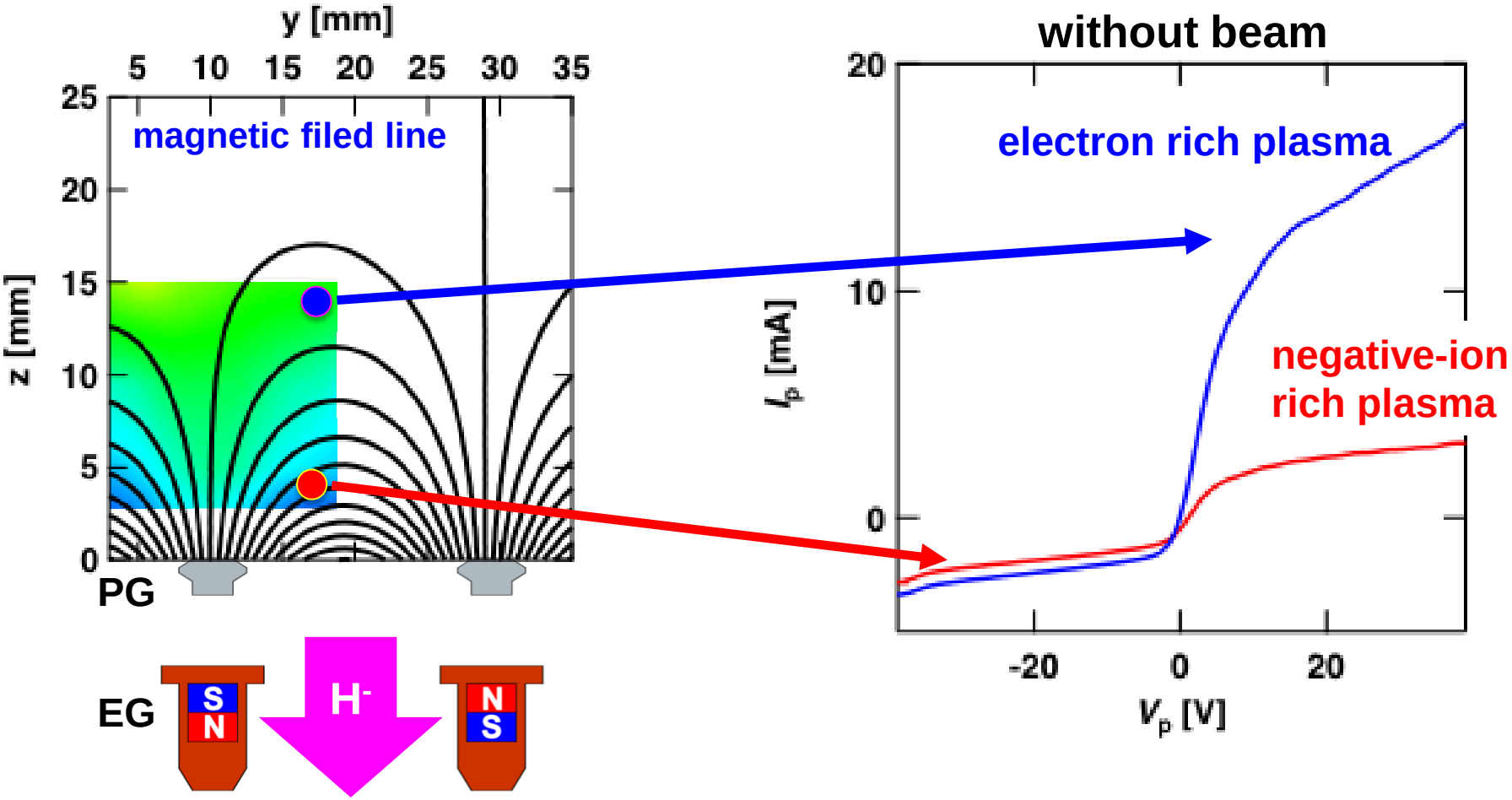
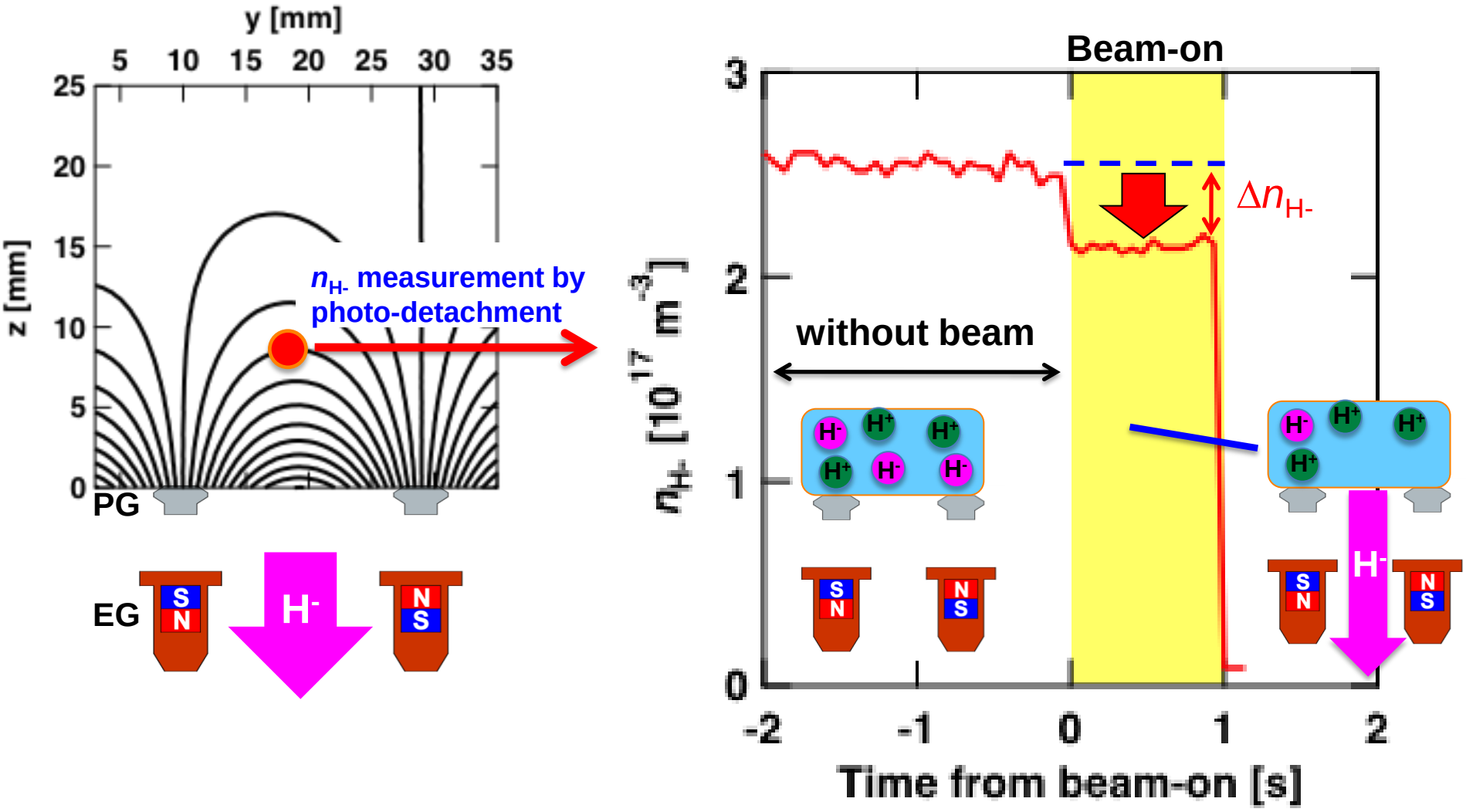


- Negative-ion rich plasma is formed near PG aperture.
- What happens in negative-ion rich plasma with beam extraction?

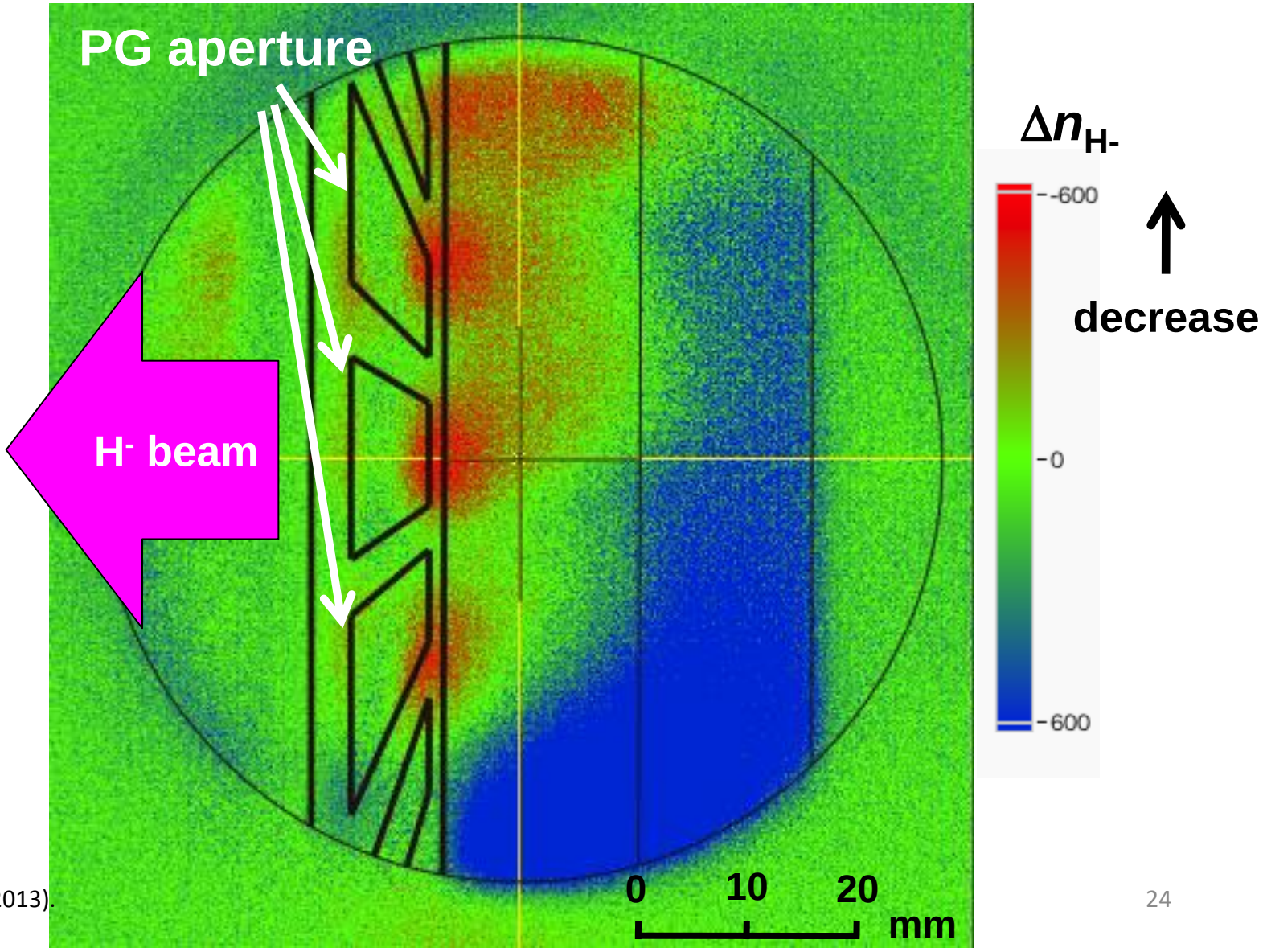
Response of H⁻ to beam extraction



spatial distribution of H⁻ response?

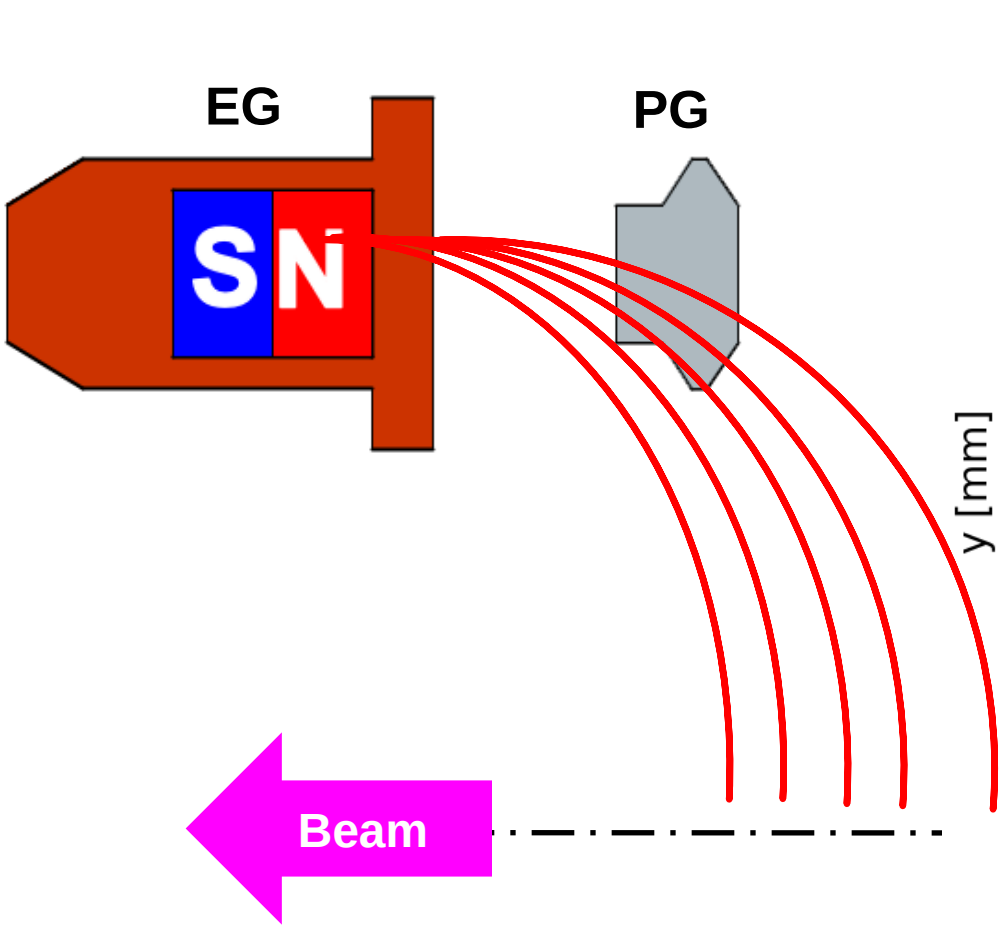
[3] K. Tsumori, et. al., Rev. Sci. Instrum. **87**, 02B936 (2016).

n_{H^-} decreases on widespread area above PG apertures

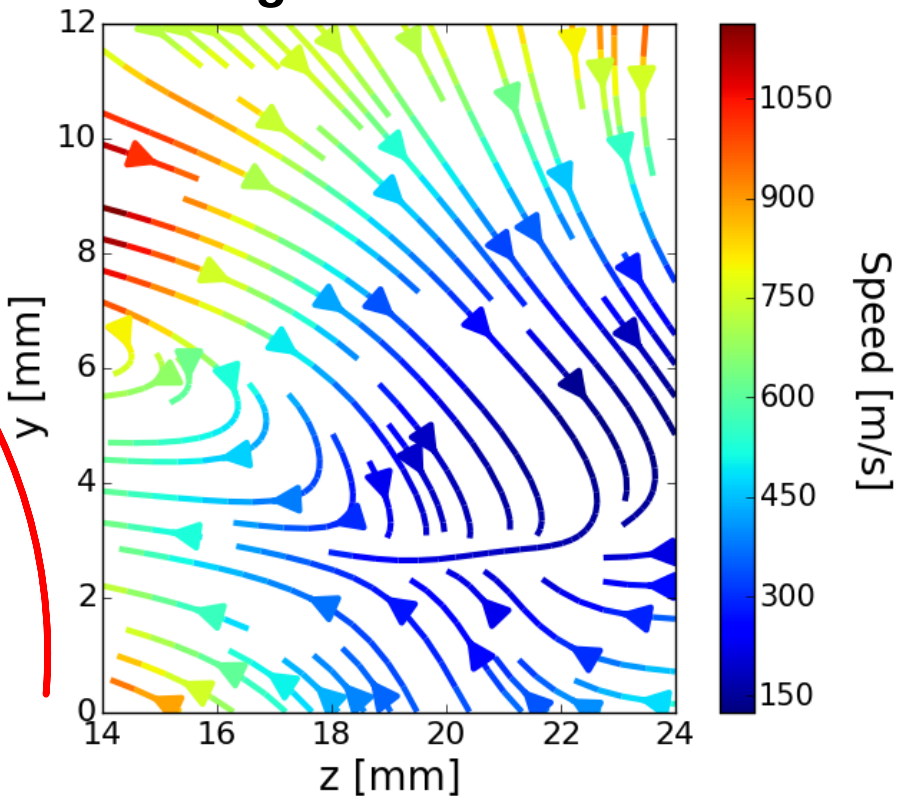


[4] K. Ikeda, et. al.,
New J. Phys. **15**, 103026 (2013).

Extraction process of H^- was clarified for the first time



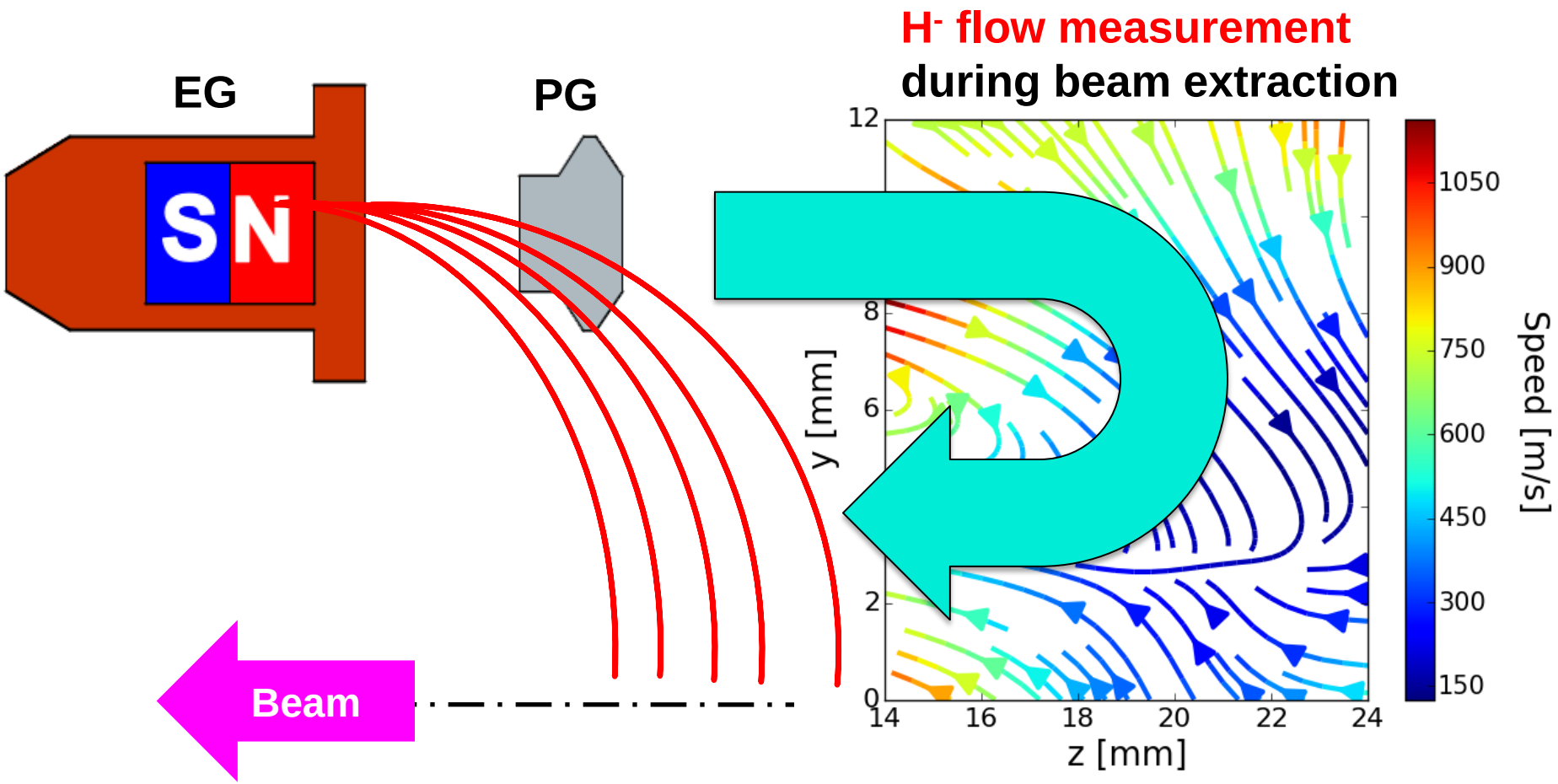
H^- flow measurement during beam extraction



Directional photo-detachment measurement revealed the H^- flow structure.

[5] S. Geng, et. al., Fusion Engineering and Design (to be submitted).

Extraction process of H^- was clarified for the first time



The surfaced produced H^- is mainly extracted after the process of spreading over the bulk plasma.

➔The enhancement of n_{H^-} in region away from PG is also important.

[5] S. Geng, et. al., Fusion Engineering and Design (to be submitted).

Summary

Dedicated experiment were conducted in order to develop high performance negative ion source.

◆Engineering approach

- **Voltage holding capability was improved and heat load on the GG was reduced.**
- **H^- production efficiency was improved by just modifying the accelerator.**

◆Physics approach

- **Electron transport to PG aperture is suppressed by EDM field**
- **Negative-ion rich plasma is formed inside the loop of EDM field.**
- **Extraction process of H^- was experimentally clarified for the first time.**