Overview of Kyoto Univ. Research and Preliminary Results from a New Device Driven by a Built-In Ring-Shaped Ion Source

IEC2009
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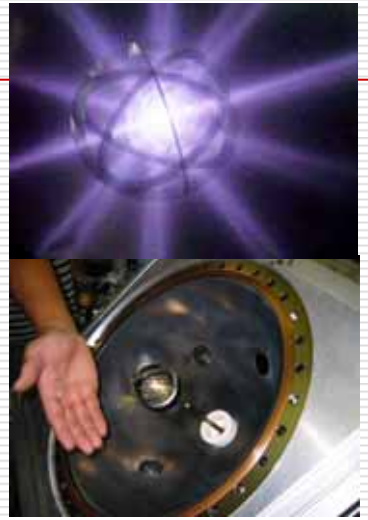
Inst. Advanced Energy, Kyoto Univ.

**Inst. Sustainable Science, Kyoto univ.*

KU IEC Research History



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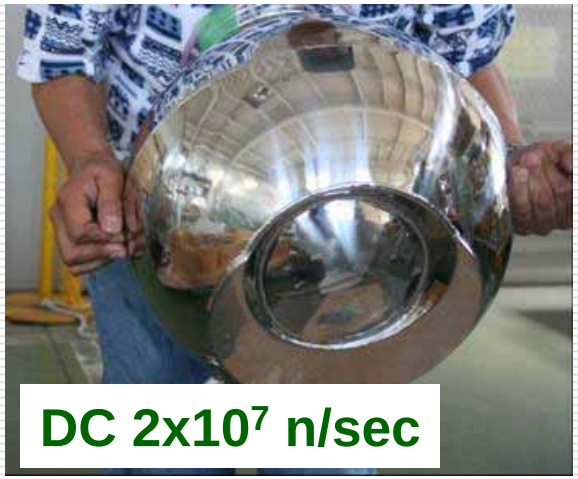
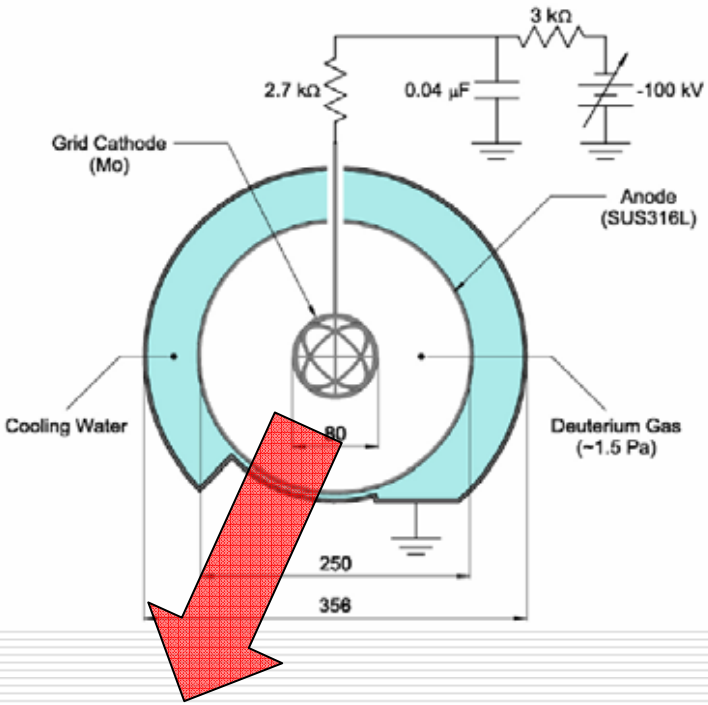
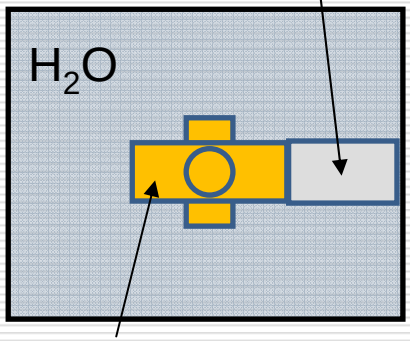
- **1997: First experiment (single-grid glow-driven IEC).**
- **2000: Dependence on D2 gas pressure studied in C-IEC driven by ECR ion source.**
- **2006: 25-cm dia. IEC neutron source for landmine detection.**
- **2008: 2-D time-independent code showed agreement with experimental I-V.**
- **2009: Neutron beam production by C-IEC with collimator.**

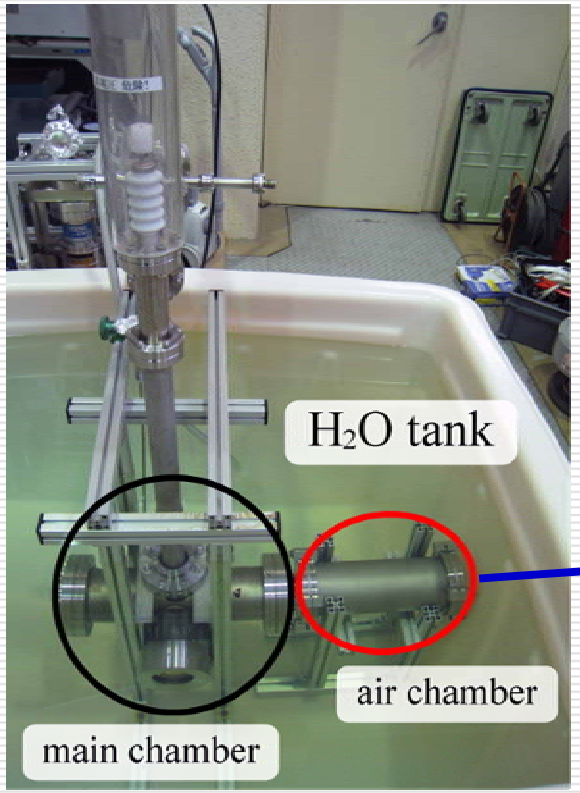
Neutron Beam Production by C-IEC

IEC for LM Detection





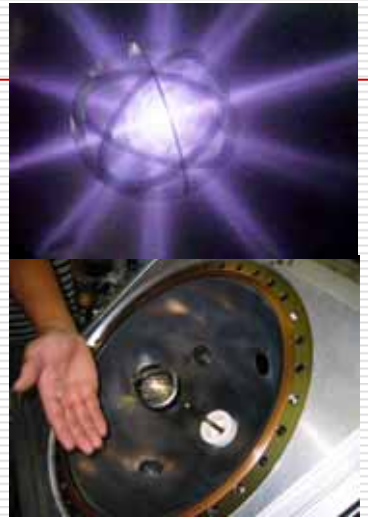




Neutron beam

will be presented by K. Nonborio, Mon Afternoon

KU IEC Research History



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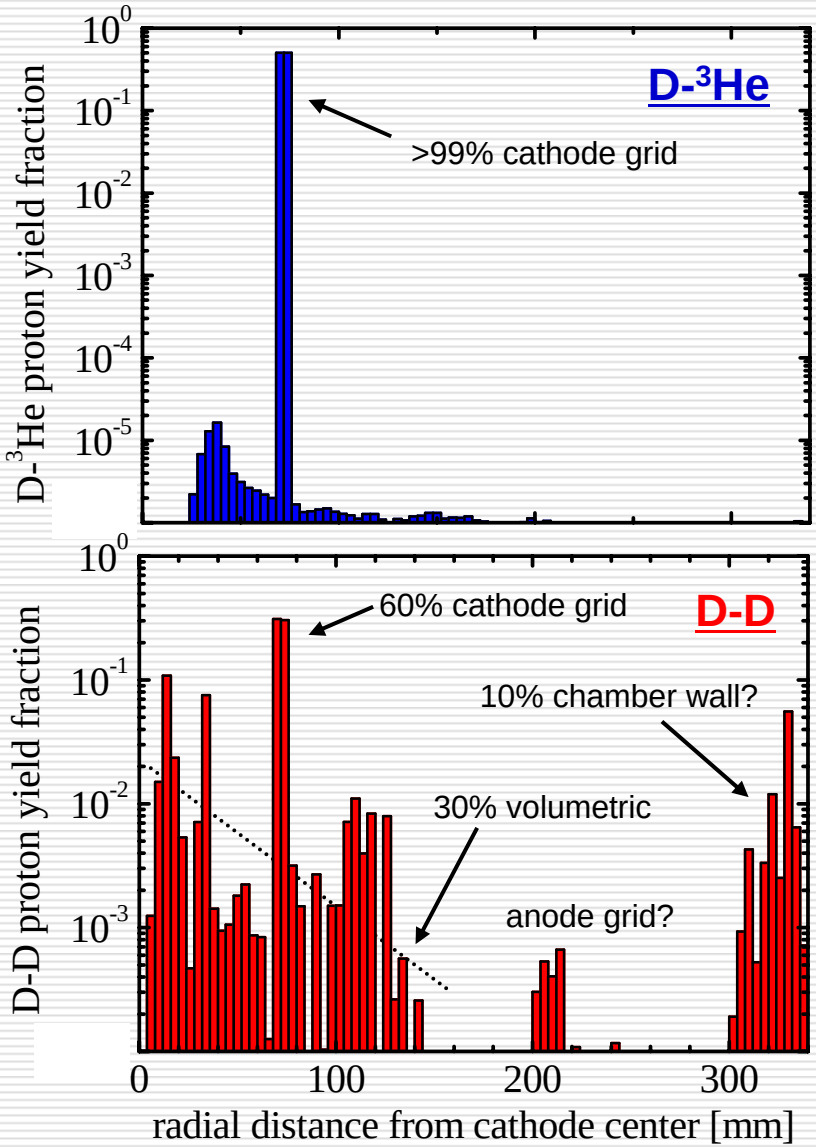
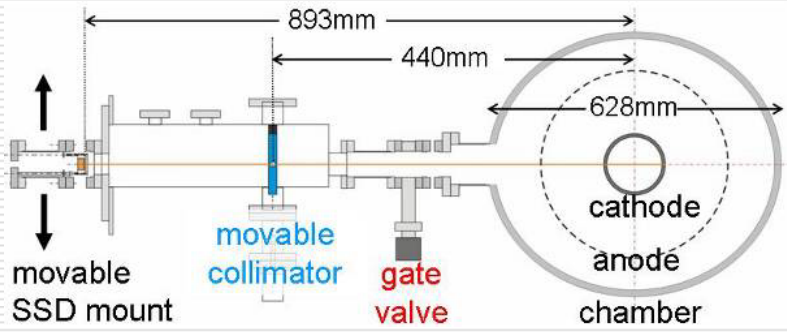
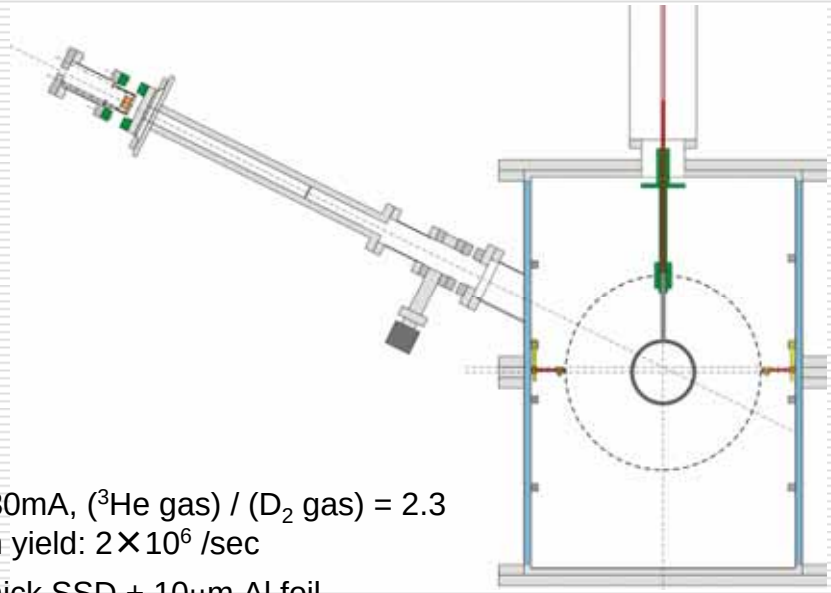
Proton Birthplace Distribution



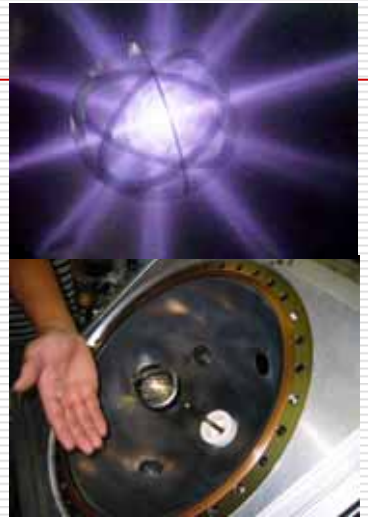




60kV, 30mA, (^{3}He gas) / (D_2 gas) = 2.3
neutron yield: 2×10^6 /sec

2mm-thick SSD + 10μm Al foil
counting time: 1,000sec
max. count rate: (D-D) 32/sec, (D-^{3}He) 0.14/sec

KU IEC Research History



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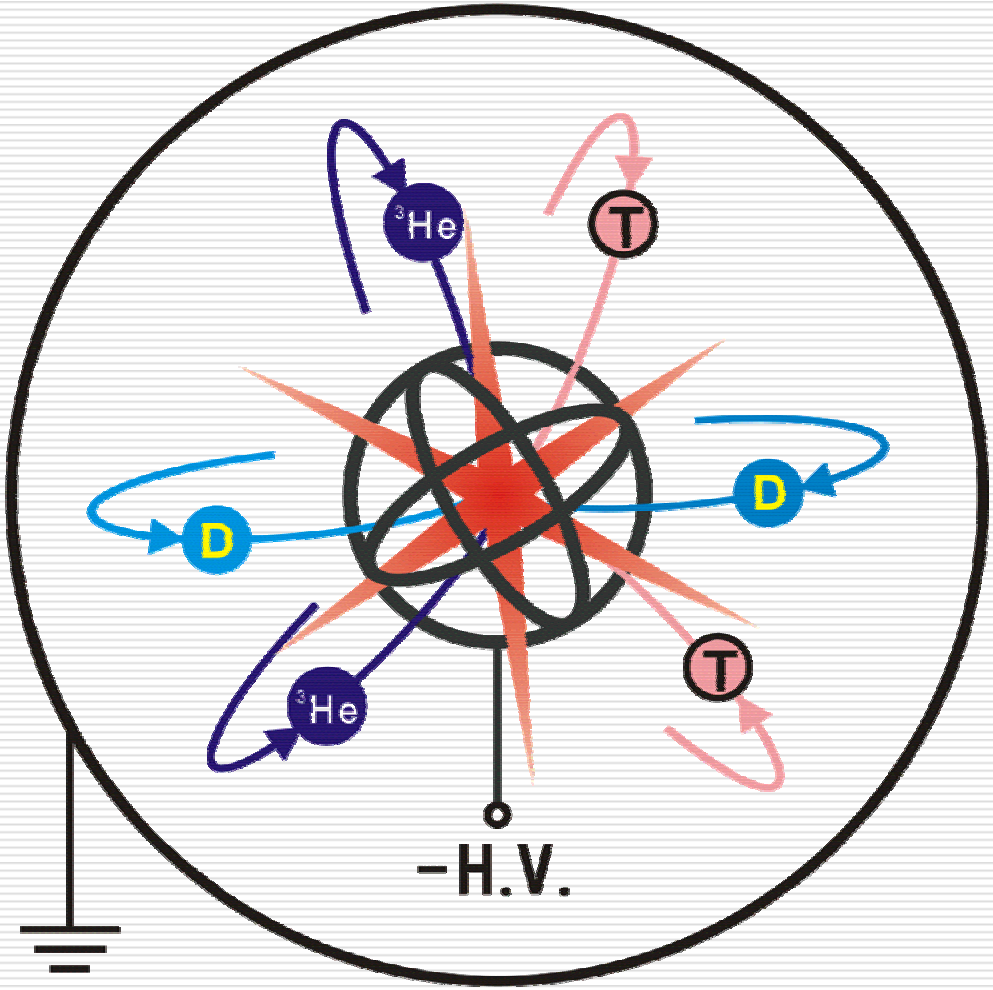
Fusion Paths in Glow-Driven IEC



beam - beam

most preferable but negligible

beam - gas

dominant for D-D

beam - grid

dominant for D-^{3}He

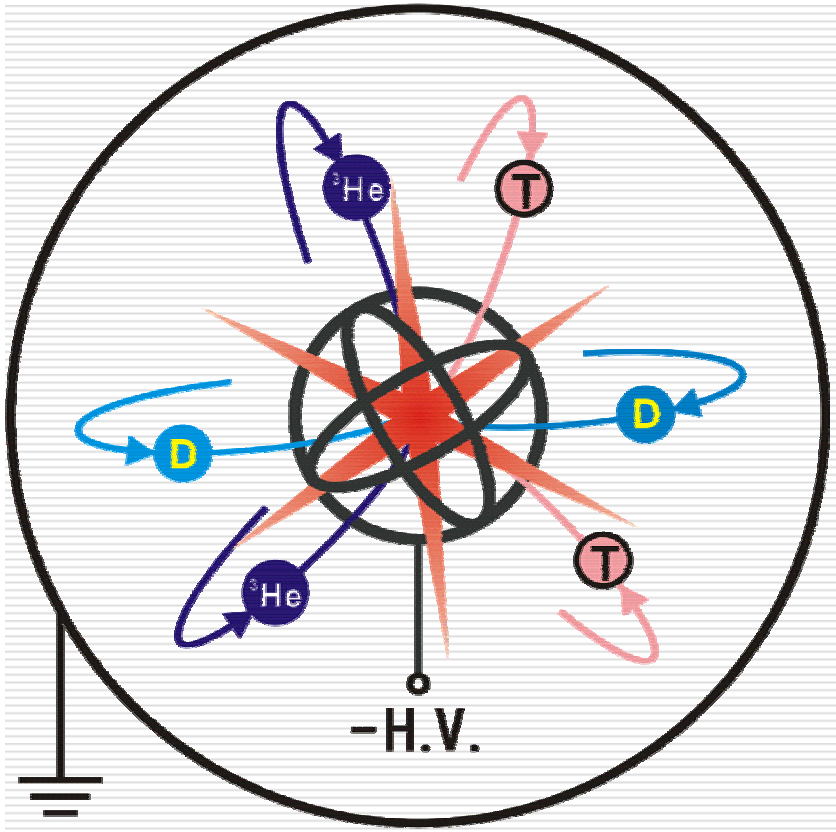
neutral- chamber

Advantage over solid-target neutron generators:

The use of gas-target enables high power input.

Problem to be Coped With

~ 1 Pa required for glow-discharge IEC



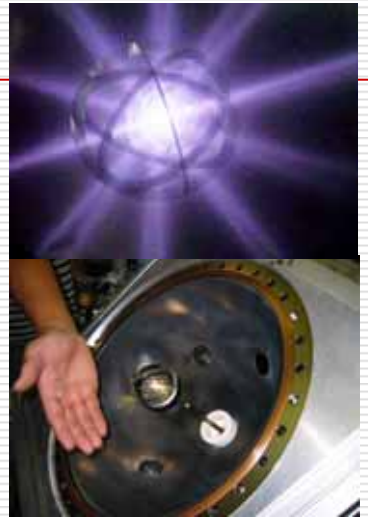
- **Low efficiency**

  e.g. 12 kW for 1×10^9 n/sec (DD)

- **Rapid loss of ions due to CX collisions**

  - ✓ **diverse & low energy**
  - ✓ **short mean free path**

KU IEC Research History



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- 1997: First experiment (single-grid, glow-driven).
- 1998: Triple-Grid IEC.
- 1999: Laser induced fluorescence method.
- 2000: Doppler-shift spectroscopy.
- 2002: Study of magnetron ion source started.
- 2003: 1-D time-domain code showed agreement with experimental P-V.
- 2005: NPR dependence on D_2 gas pressure studied in C-IEC driven by ECR ion source.
- 2006: 25-cm dia. IEC neutron source for landmine detection.
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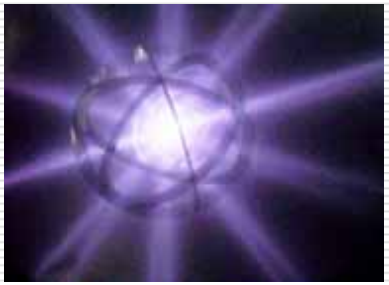
- 2009: Double-grid IEC.
- 2009: IEC driven by ring-shaped magnetron ion source.

How Can We Improve NPR / Power ?

- **What we accelerate in IEC device are ions & electrons.**



>90% in glow-driven device.

Power consumption by ion acceleration never exceeds 50% even in ion-source-driven IEC.

➡ **ER-IEC by double-grid arrangement**

- **σ_{fusion} / σ_{CX} will limit NPR / Power as long as we stay in beam-gas collision regime.**

Beam-beam or beam-target would be the solution.

➡ **RSMIS-IEC for BM-BM study**

Double-Grid ER-IEC

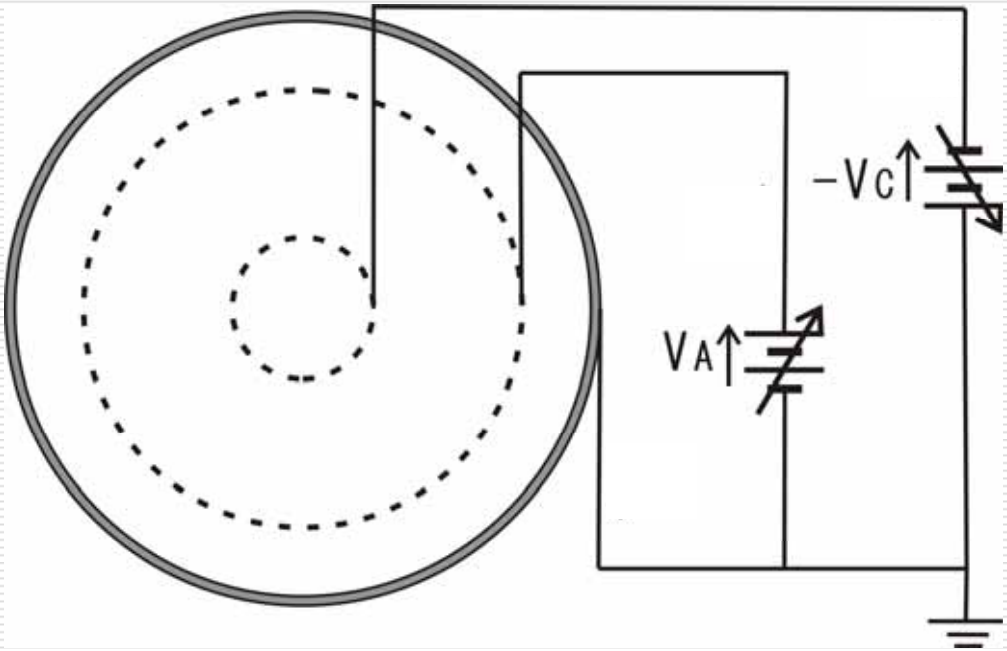
will be presented by **T. Kajiwara, Tue Morning**

- **Energy recovery from escaping electrons**

  (Chamber serves as depressed collector)

for reduction of:

- ✓ **input power**
- ✓ **X-ray emission**



- **Doubled voltage (Va + Vc)**

RSMIS-IEC: Objective

To investigate experimentally…

beam-beam colliding fusion regime in IEC

- **show I^2-dependence of fusion rate?**
- **lead to a drastic enhancement in fusion rate per input power?**

Development of a new IEC-based scheme;

- **first observation of dominant I^2-dependence**

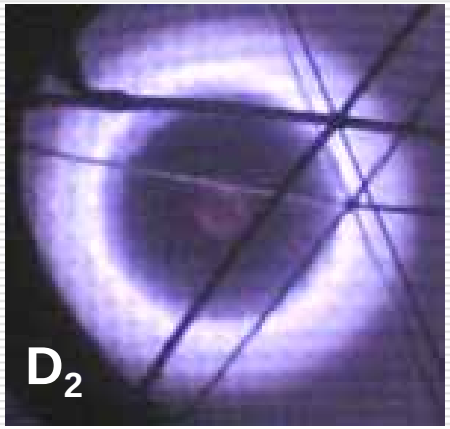
Requirements for BM-BM Collision

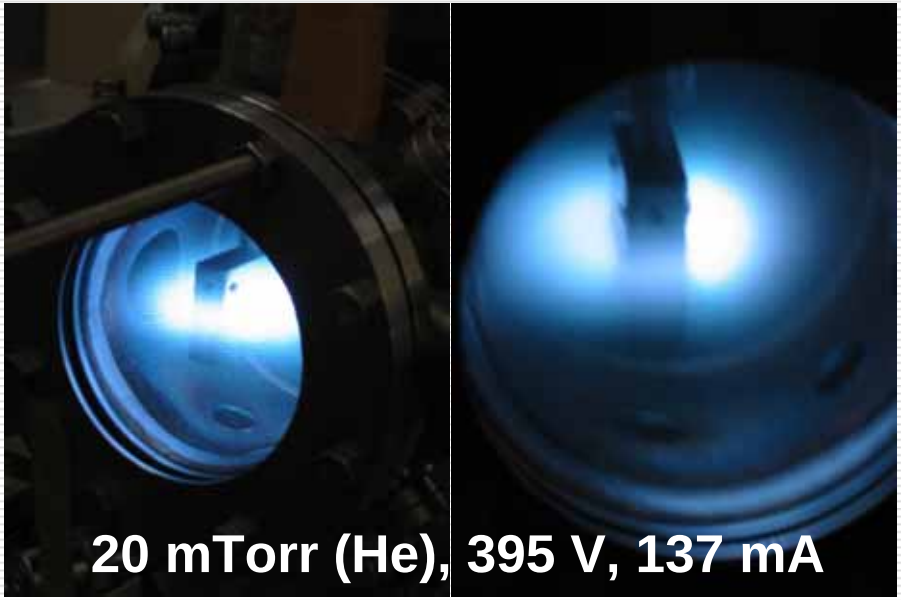
High beam density at center….as high as gas density

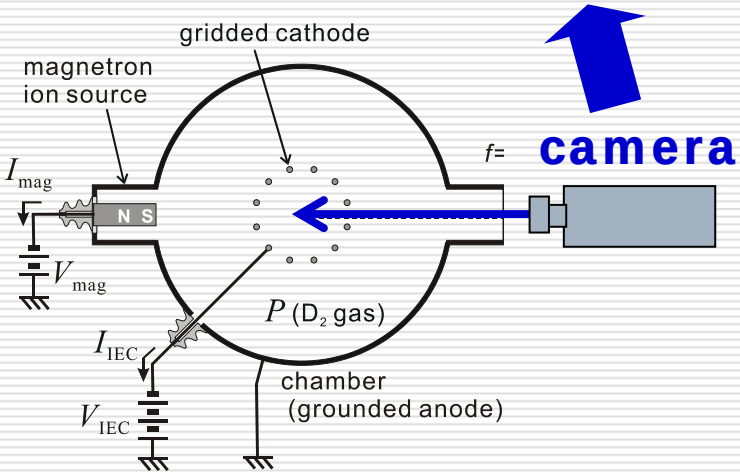
- ✓ **significant recirculation of ions**
  - ➢ **birthplace of ions at negative potential**
- ✓ **MFP much longer than device size**
  - ➢ **gas pressure <10 mPa**
- ✓ **spherical focus of ions is most preferable**
  - ➢ **6 or much more ion sources?**

The Idea Comes Out Of ....

DC magnetron discharge







Kyoto U. (2006)

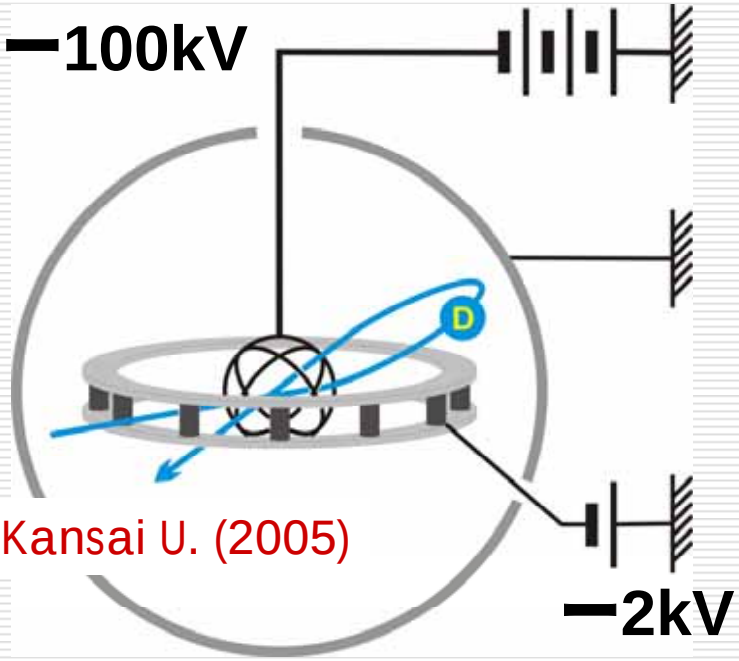
1 mPa accessible by use of permanent magnets,

no need of differential pumping

though the current is very low.

<0.1 mA… 10 times higher current is needed…

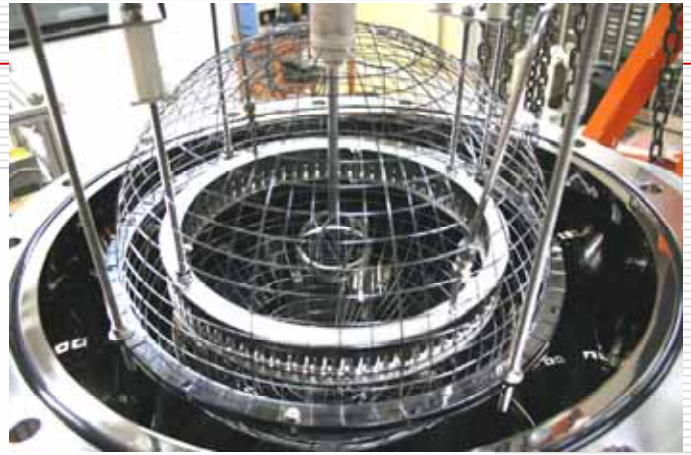
Ring-Shaped Magnetron Ion Source

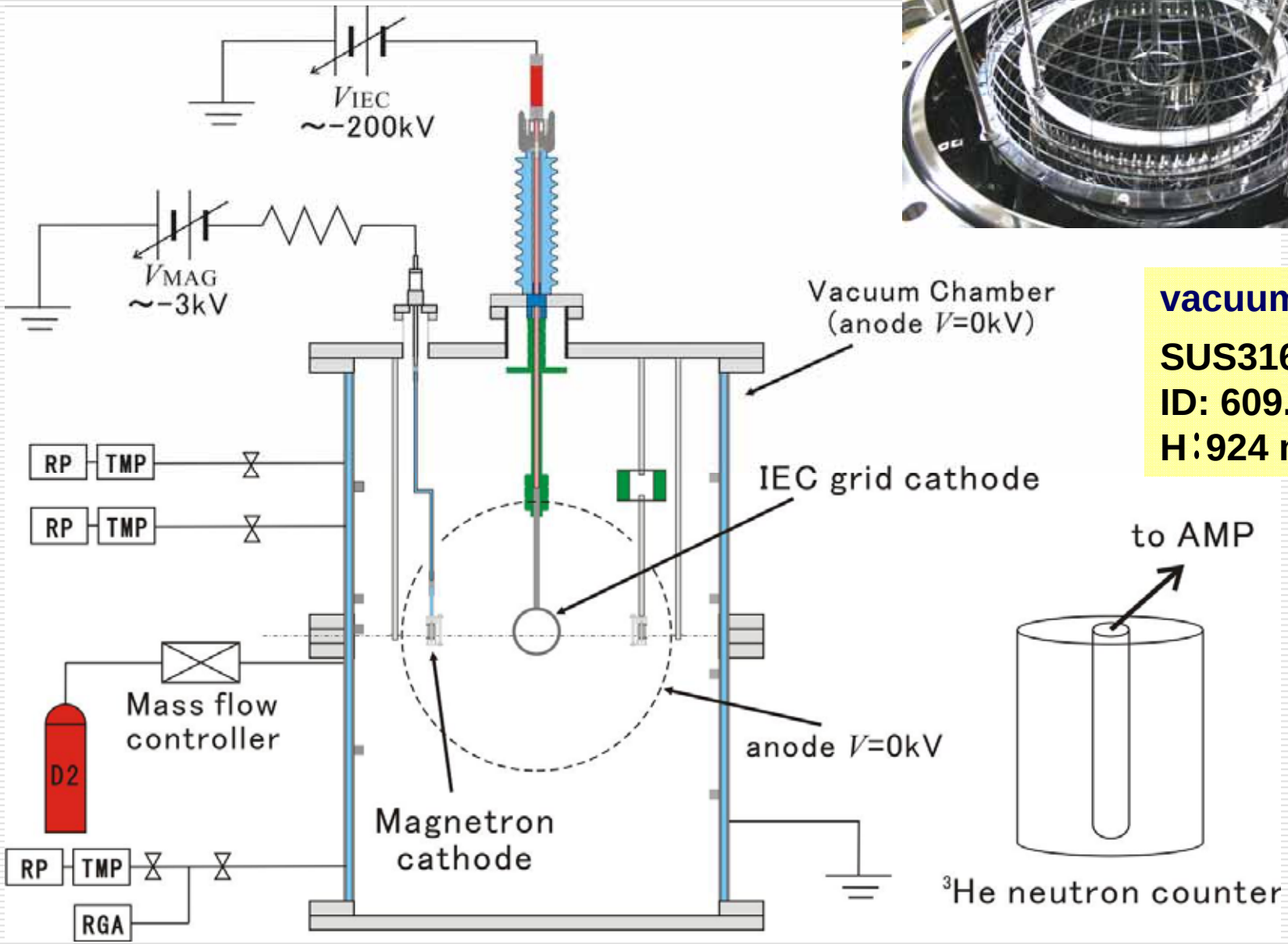


Kansai U. (2005)

- **~1mA expected**
  - **use of single larger ring,**
  - **i.e. longer circumference**
- **<10mPa accessible**
- **radial focus of ions**
  - **not spherical… but still better than head-on collision of linear beams**
- **preferable birthplace of ions**
  - **- at negative potential,**
  - **- normal with respect to the HV feedthrough**

Experimental Setup

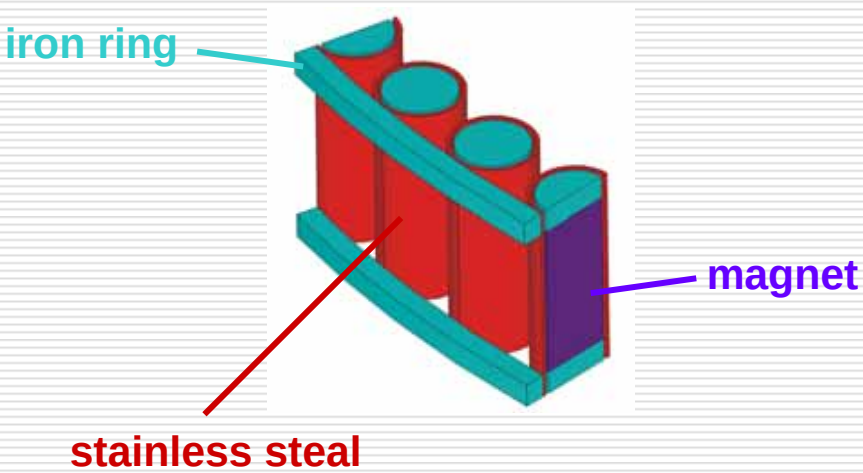


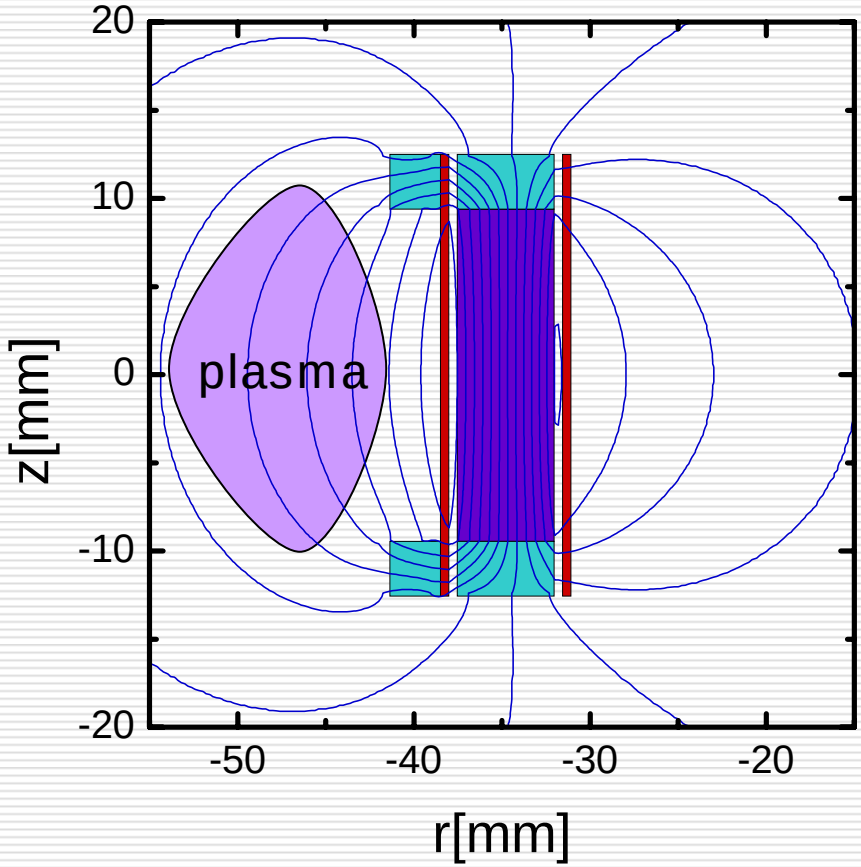


vacuum chamber

SUS316
ID: 609.6 mm
H: 924 mm

Experimental Setup (contd.)





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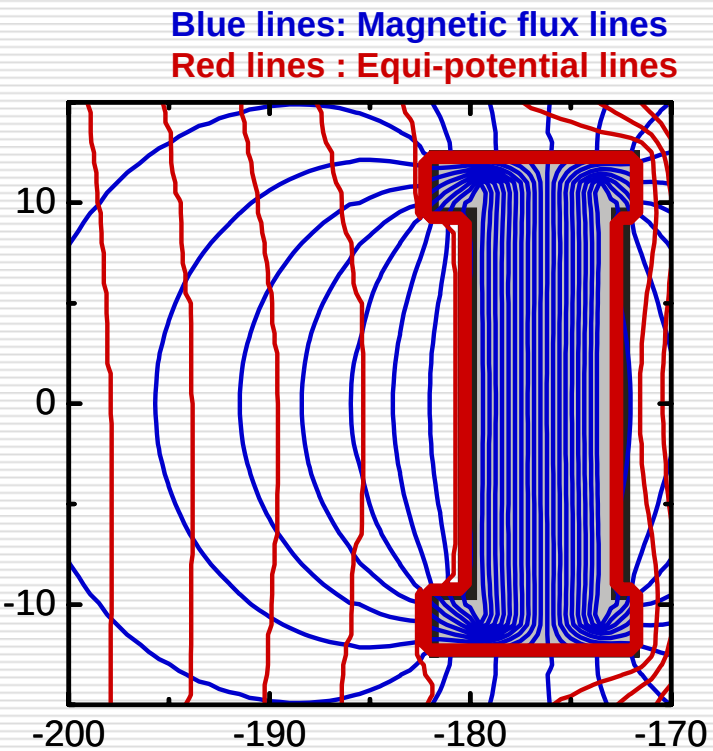
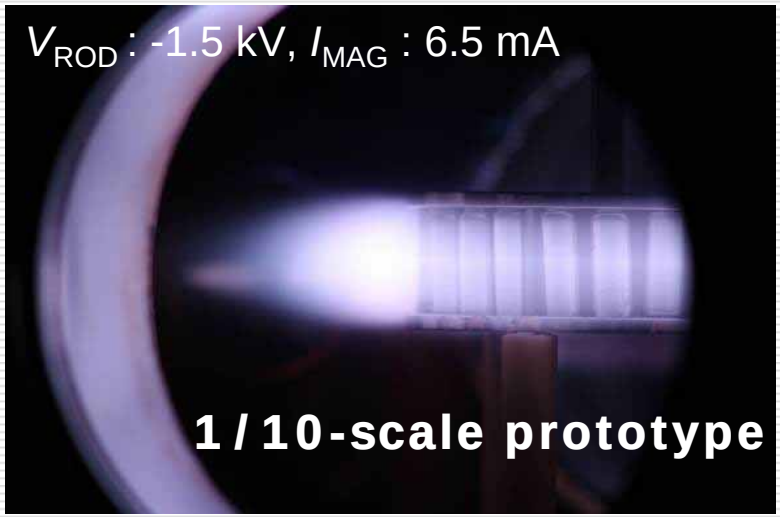
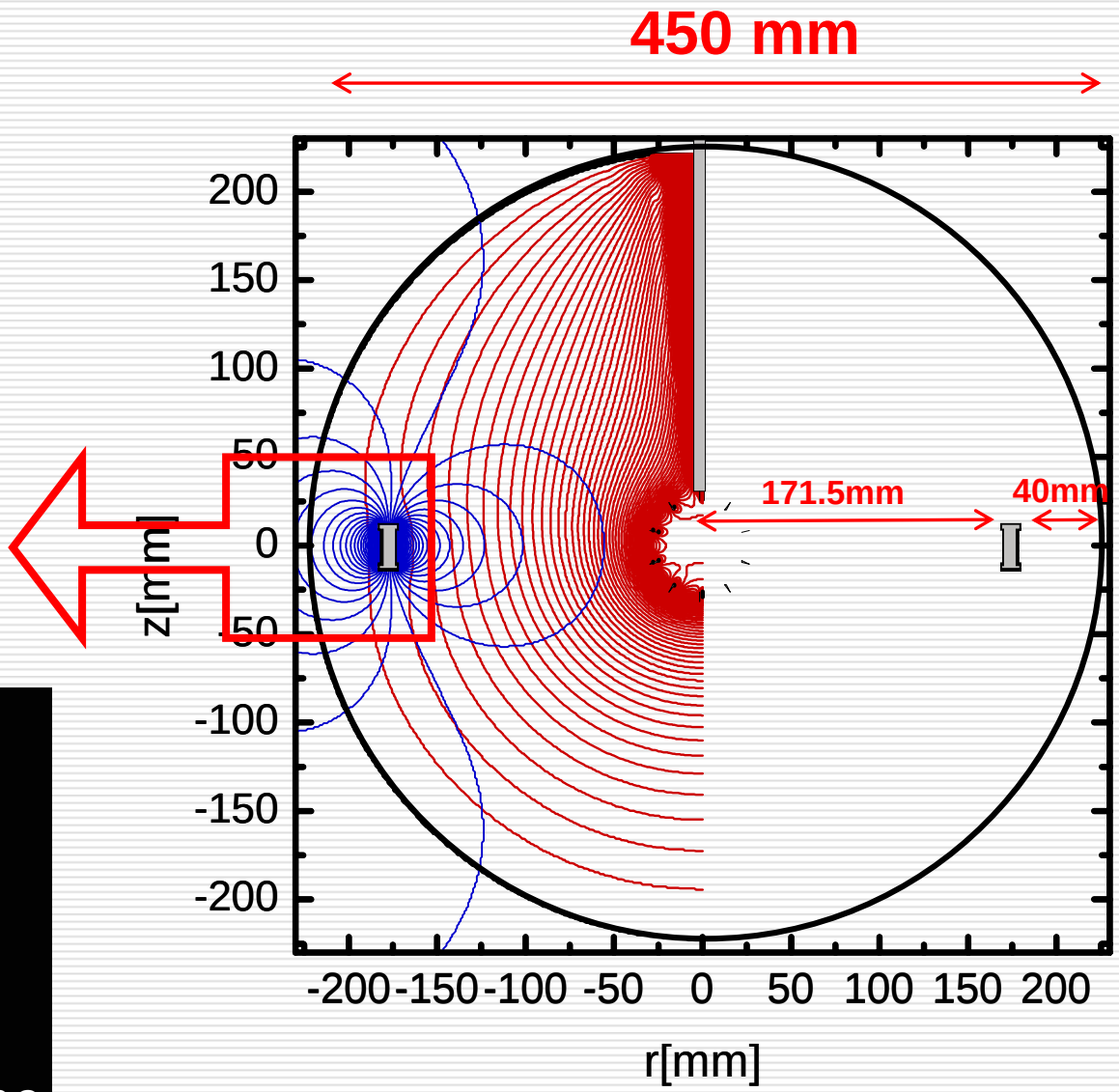
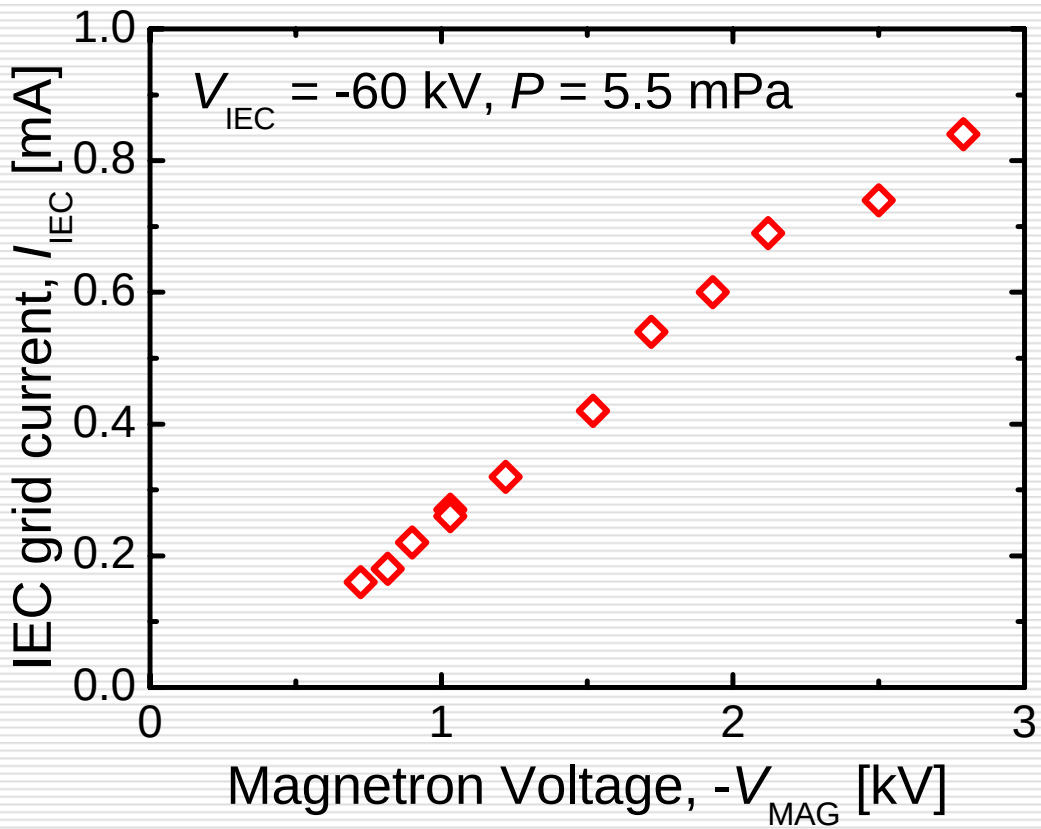
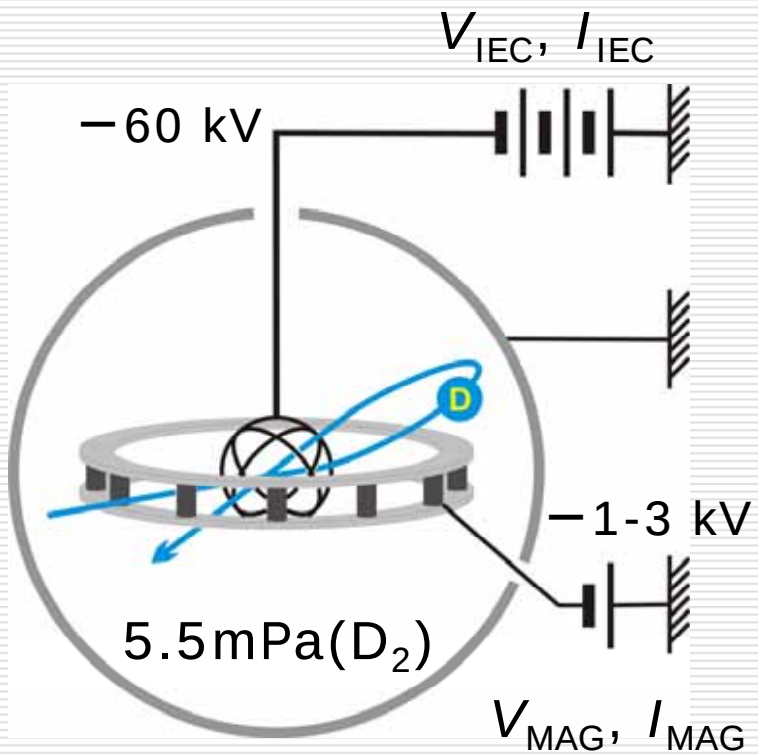






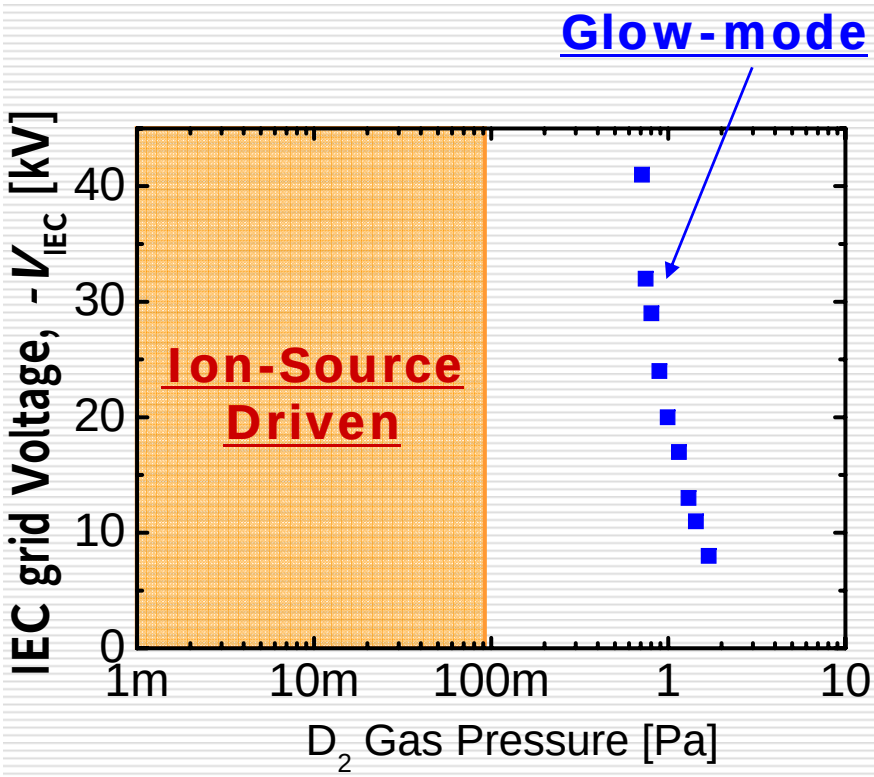
Operational Pressure & Current

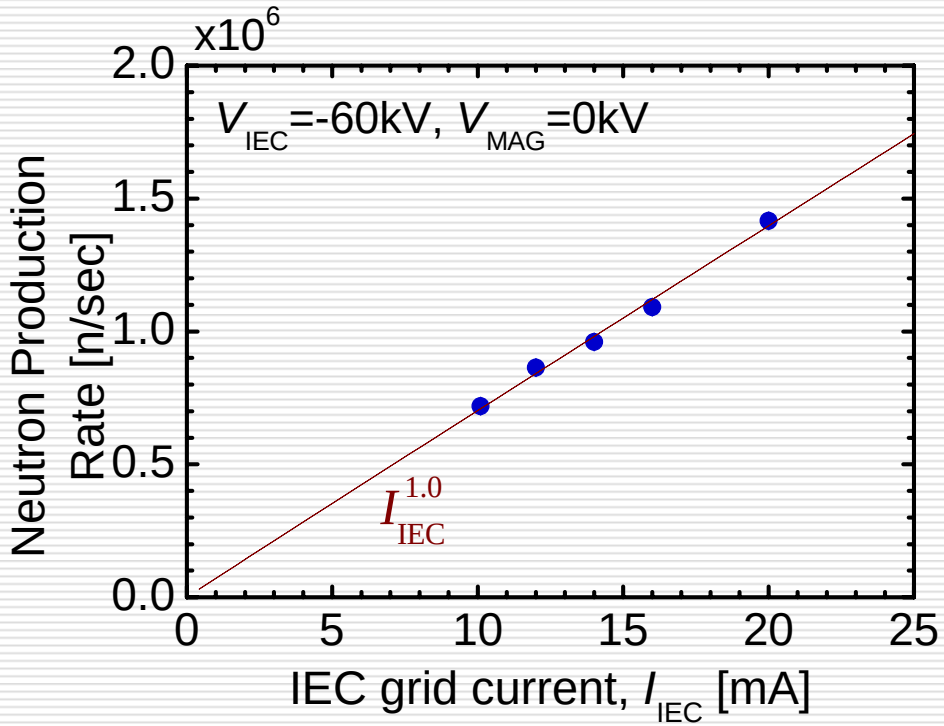




- I_{IEC} can be varied by changing V_{MAG}
- 0.1-0.9mA @5.5mPa

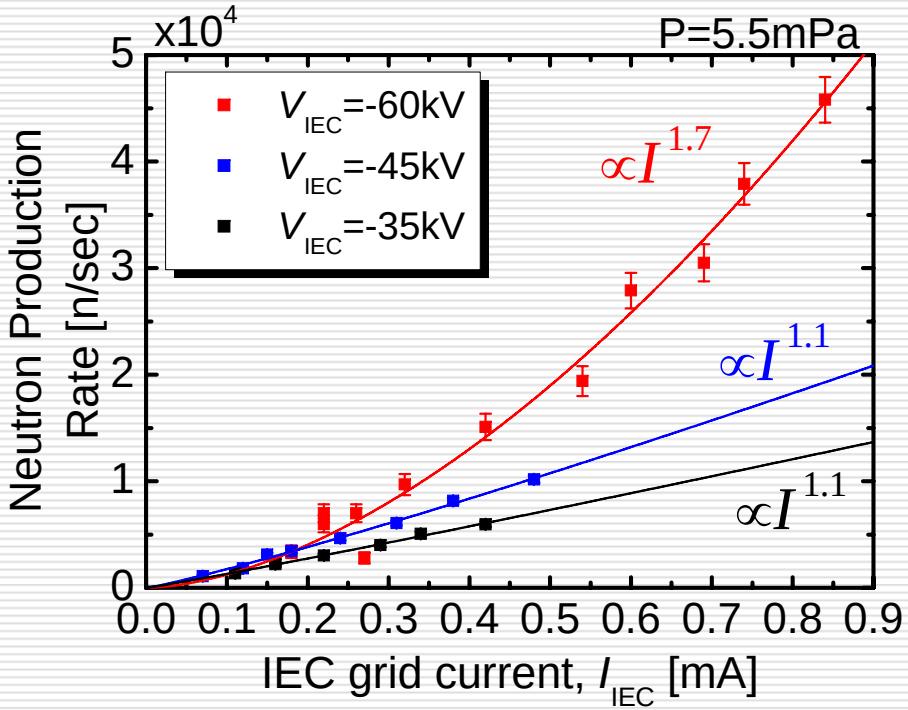
Glow-Mode Operation (V_{MAG} = 0)

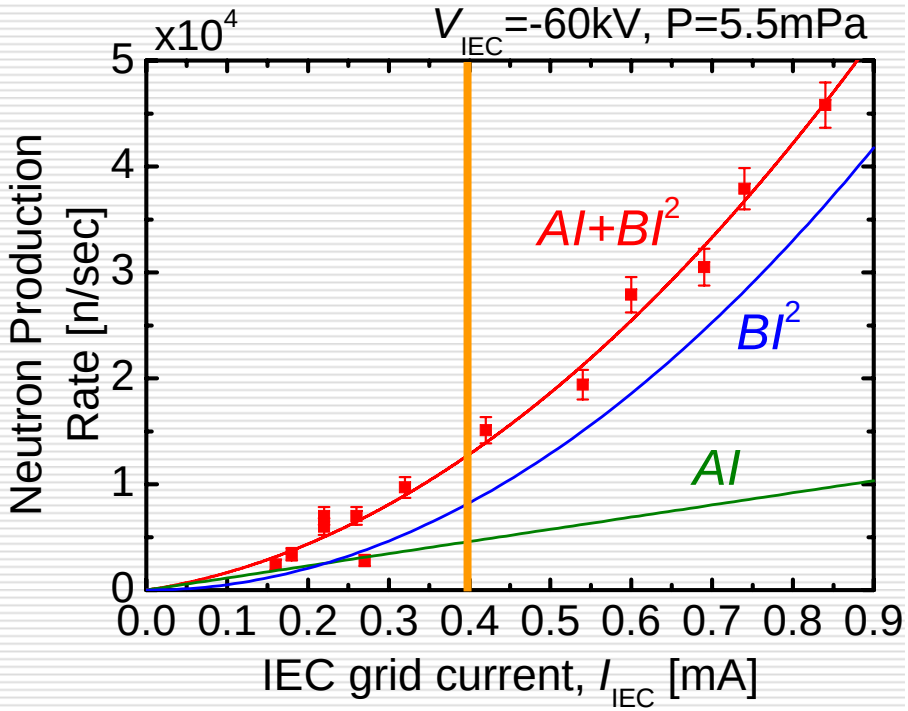




- Glow mode: >700mPa
- $dN/dt \propto I^{1.0}$ @V_{IEC}=-60kV

Neutron Yield vs. Current

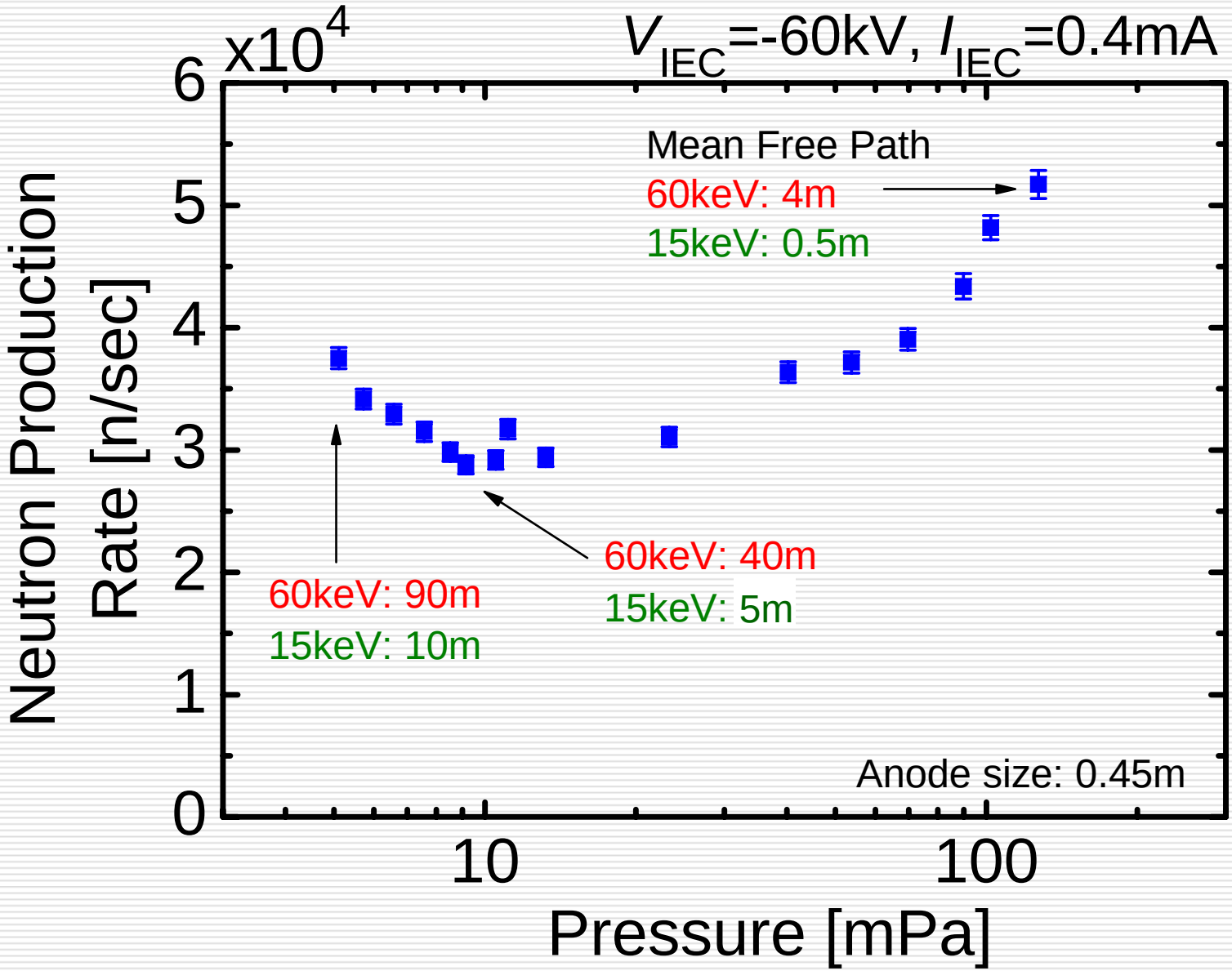




- $dN/dt \propto I^{1.7}$

  @5.5mPa, V_{IEC}=-60kV, I_{IEC} = 0.1-0.9 mA

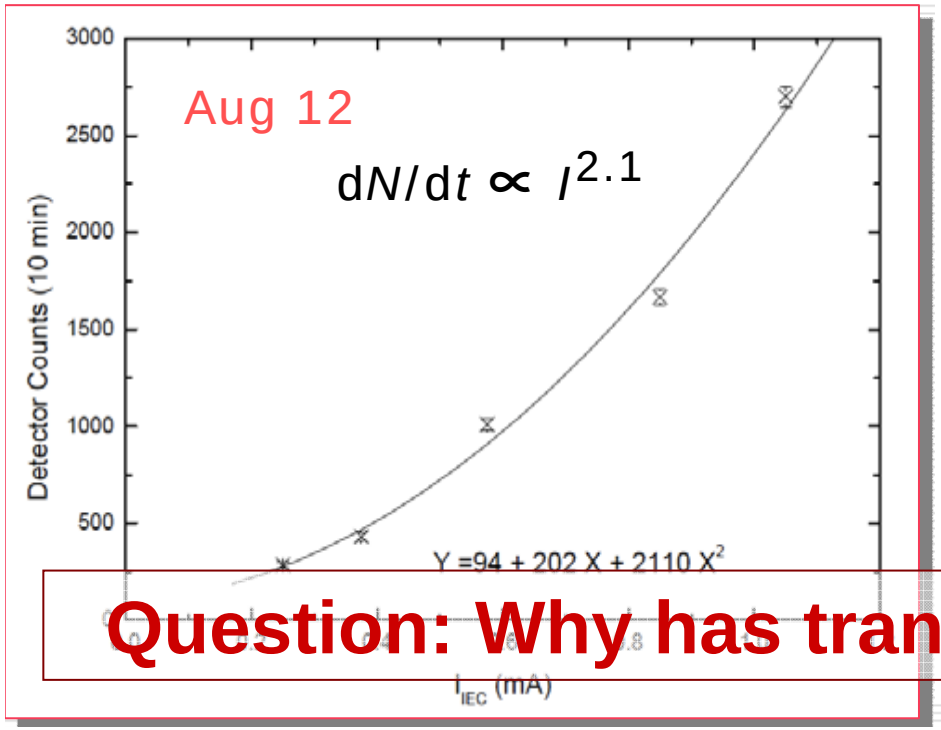
Neutron Yield vs. Pressure



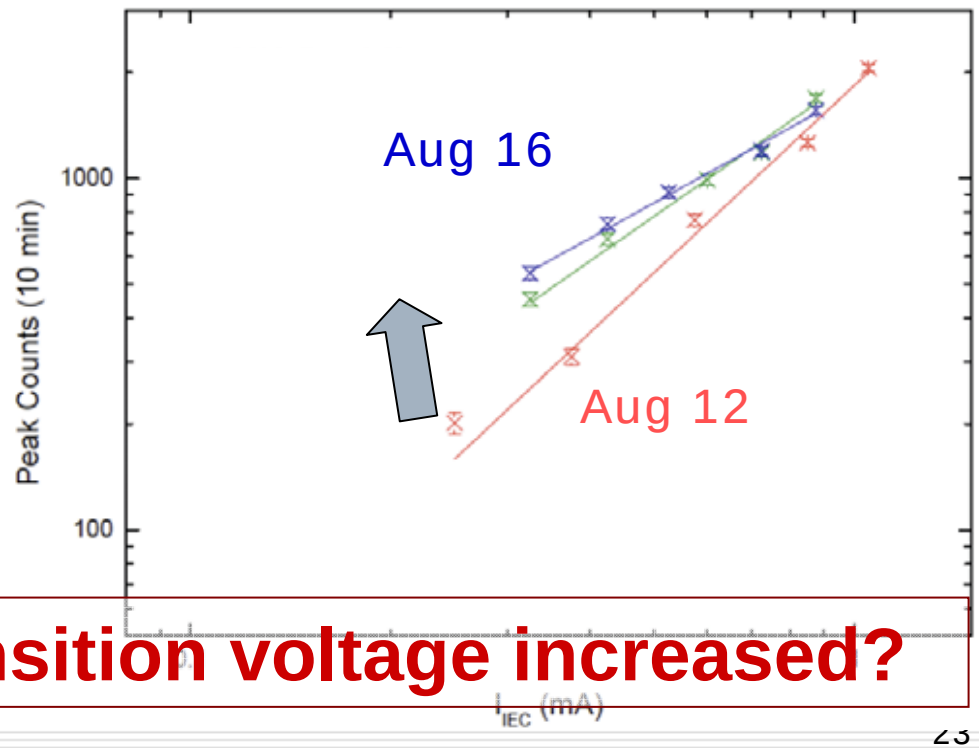
The I^2-Dpendence is Seen Only Temporary

- After half a year pause of operation, we lost the I^2-dependence at 60kV.
- We pushed the voltage up to 80kV, then the I^2-dependence appeared again,
- but only temporary... We lost the I^2-dependence again in 4 days.

80kV, 5.2mPa, 0.2-1.0 mA



80kV, 5.2mPa (3 different days)



Question: Why has transition voltage increased?

Summary

- The newly developed device
  - extended the accessible pressure very much (1mA@5mPa),
  - produces a single ring-shaped ion source inside the anode, and
  - provides radial focusing of the ions.
- Experimental n-output showed dependence on current,
  - to the power of 1.7 @60kV, 5.5mPa, 0.1-0.9mA
  - to the power of 2.1 @80kV, 5.2mPa, 0.2-1.0mA
- The n-output turned out to increase as the pressure decreases, for low pressure below 10mPa.
- Both of the above results are very indicative of the envisaged beam-beam colliding fusion regime,
- though these phenomena are seen only temporary (e.g. a couple of days), possibly due to increasing beam-grid contribution.

Conclusion & Future Plans

We have *touched* the I^2-dependence for the first time, that brought out many things to do...

- Determination of spatial distribution of fusion reaction by means of collimated proton measurements,
- Refinement of anode and cathode geometries for a better confinement of ions,
- Numerical studies,
- Upgrade for a higher current (e.g. ~10mA)

  ...not by further larger ring.