Comments About Varied IEC Approaches to Fusion Power

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Abstract

IEC Fusion concepts can be broadly categorized as either ion injected or electron injected. Current gridded IEC neutron sources are typically ion injected while Polywell-type concepts use electron injection with magnetic assistance. There are advantages/disadvantages to both, the primary objective being to create a potential well trap with sufficient depth and volume to confine high energy ions at reasonable density and with a good confinement time consistent with the Lawson criterion. In this presentation various IEC concepts intended to achieve these goals will be discussed. The coverage will largely come from Reference [1].

References

[1]. G. H. Miley and S.K. Murali, Inertial Electrostatic Confinement (IEC) Fusion, Springer Press, N. Y. 2014

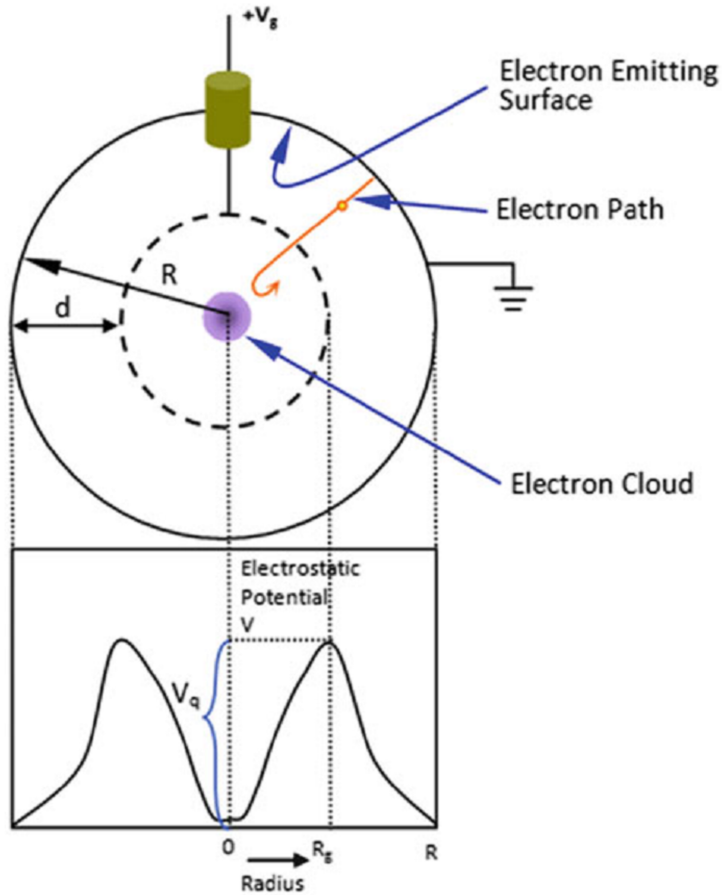
Some examples of electron injected IECs

Elmore et al.

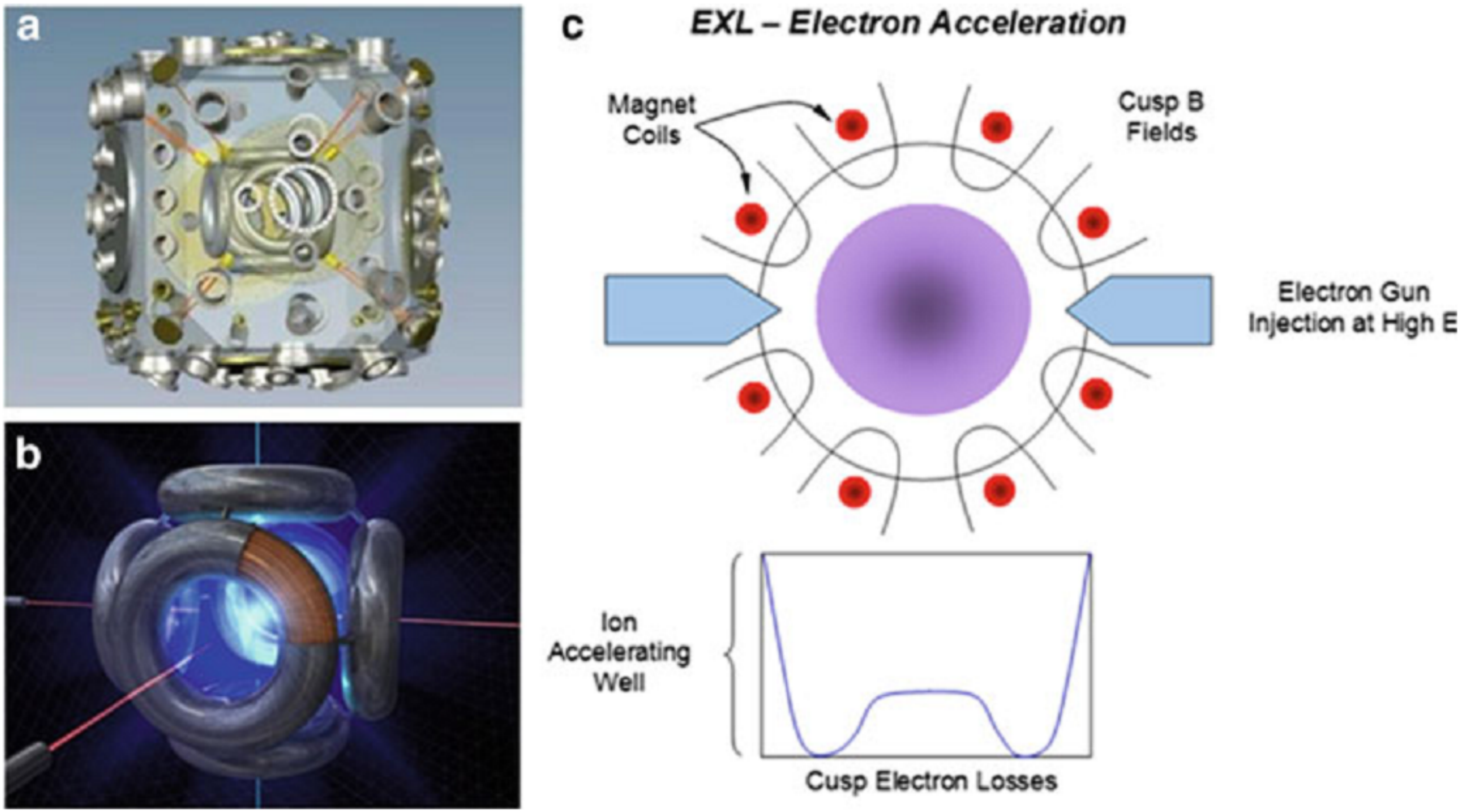
Polywell

Penning trap

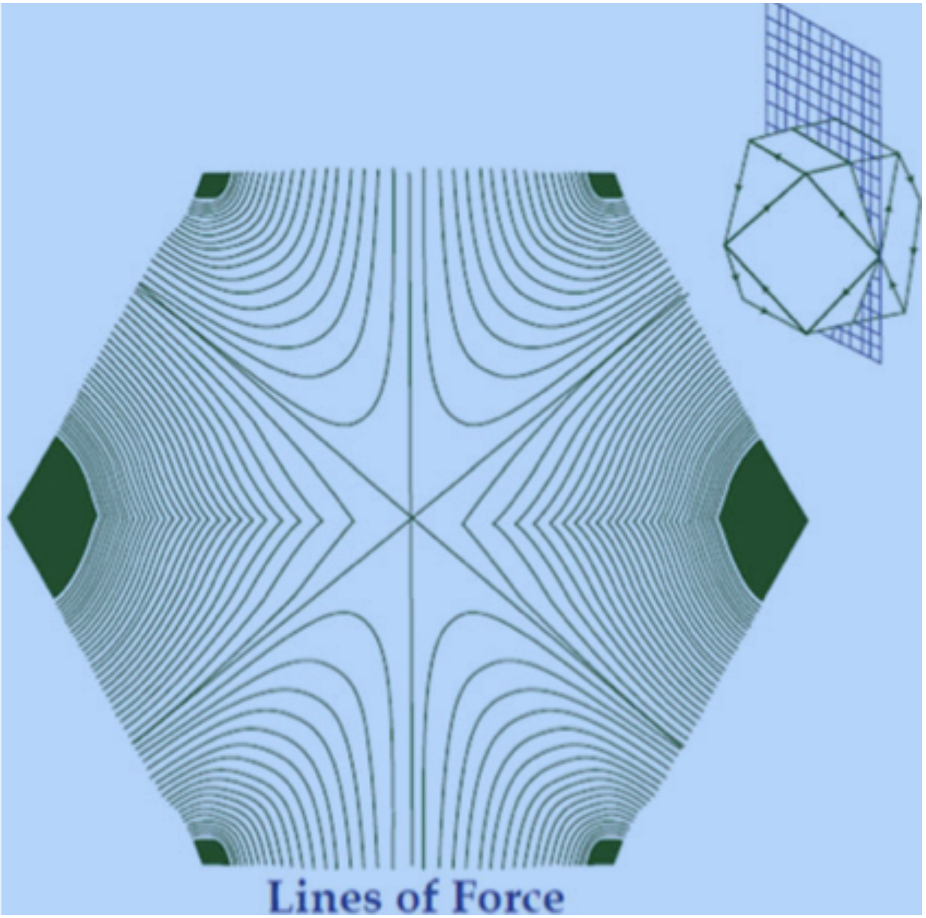
Schematic representation of the"electron-injected" spherical device analyzed by Elmore et al.



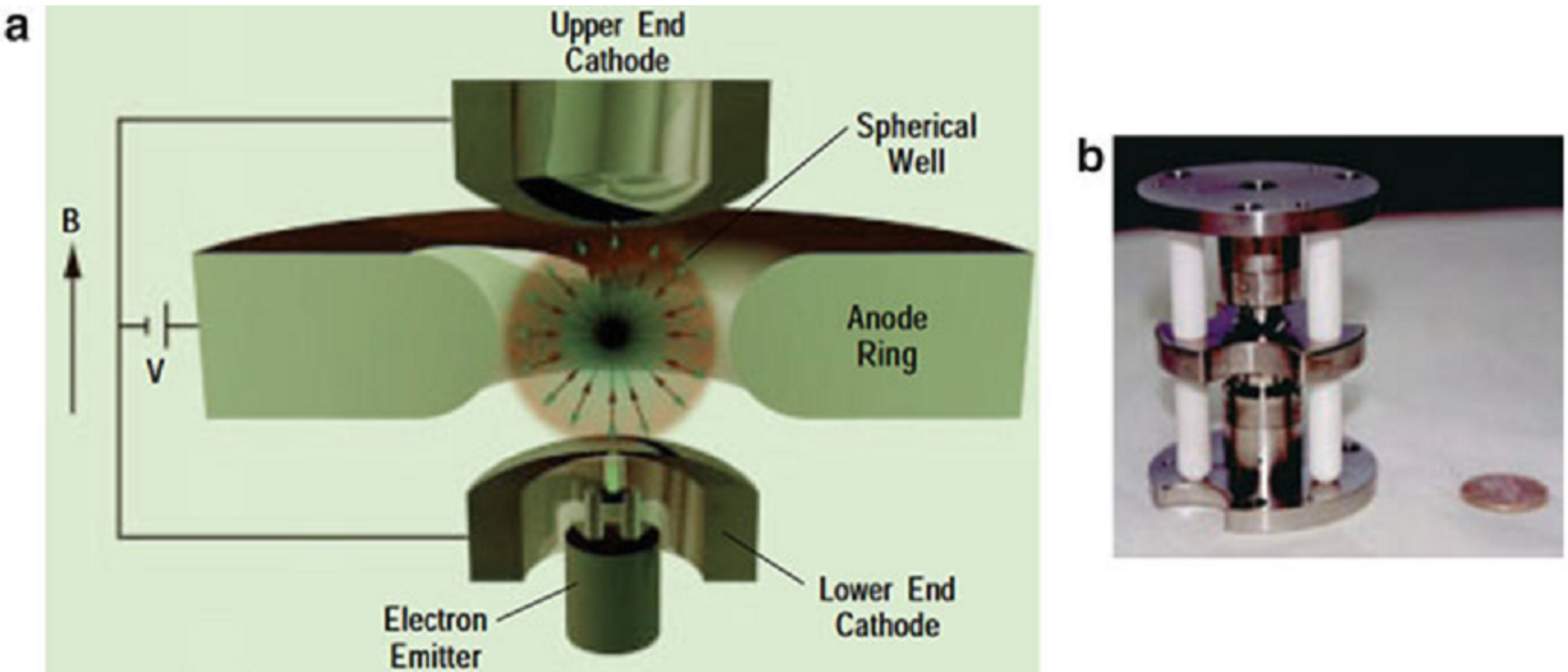
Bussard Polywell prototype design. (b) Picture of the cusp field confining the plasmaand electrons being injected into the cusp fields. (c) The basic principle of operation showing the ions accelerating in the cusp fields generated by the magnet coils



Polywell Fields



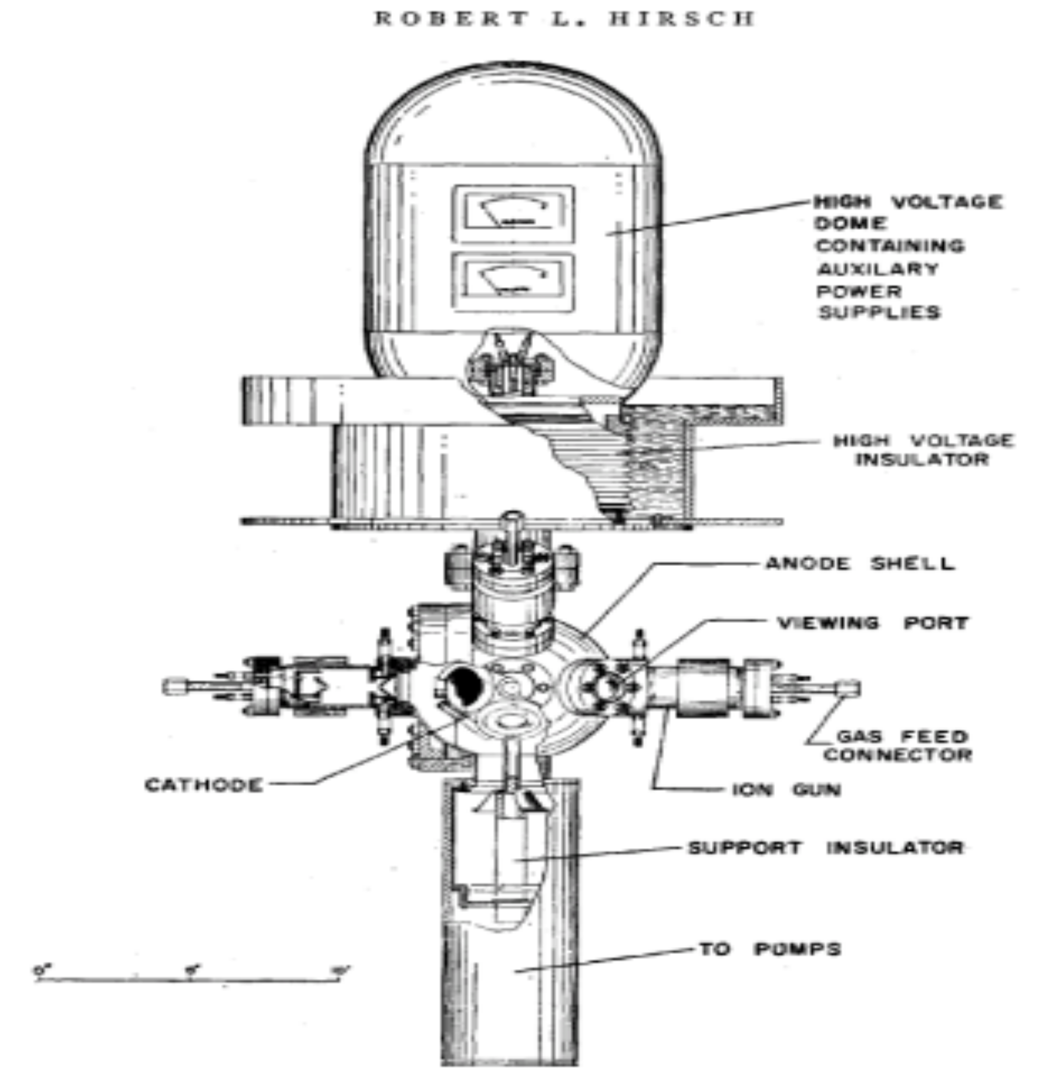
(a) Schematic representation of the ***Penning trap*** showing the effective spherical well boundary and the reflected electron trajectories. (b) The trap used in the Penning trap experimentsat Los Alamos National Lab. The quarter is placed next to the device for scaling.



Some Ion Injected Concepts

Hirsch 6 gun experiment
SIGFE
multi-grid IEC
others

Hirsh and Farnsworth's "historic" early IEC ion injection experiment



Normalized ion density as a function of radius (for $K_+ = 0.7$, $\lambda_+ = \lambda_{+max} = 0.45$)

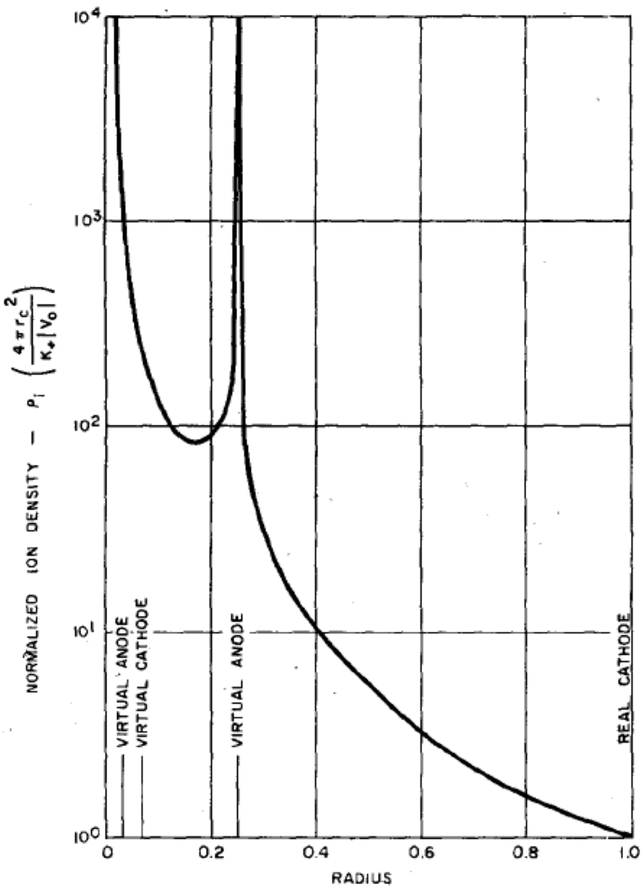
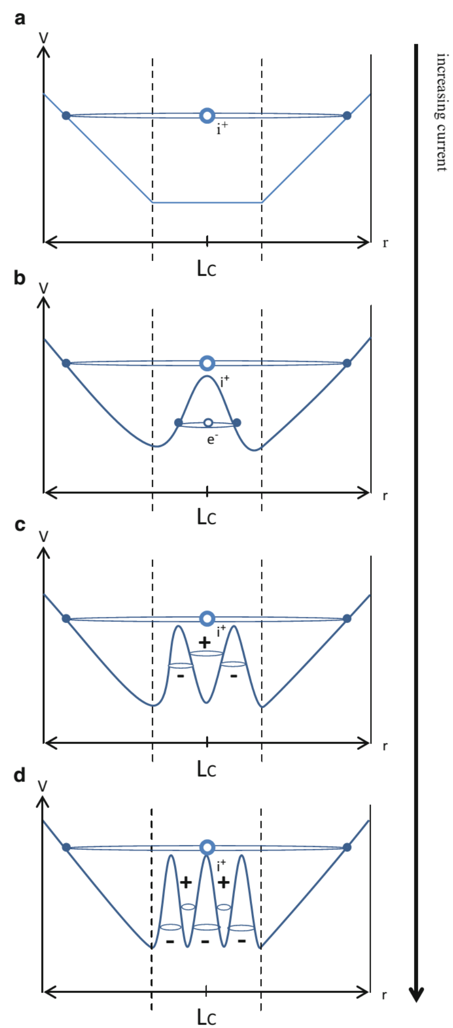
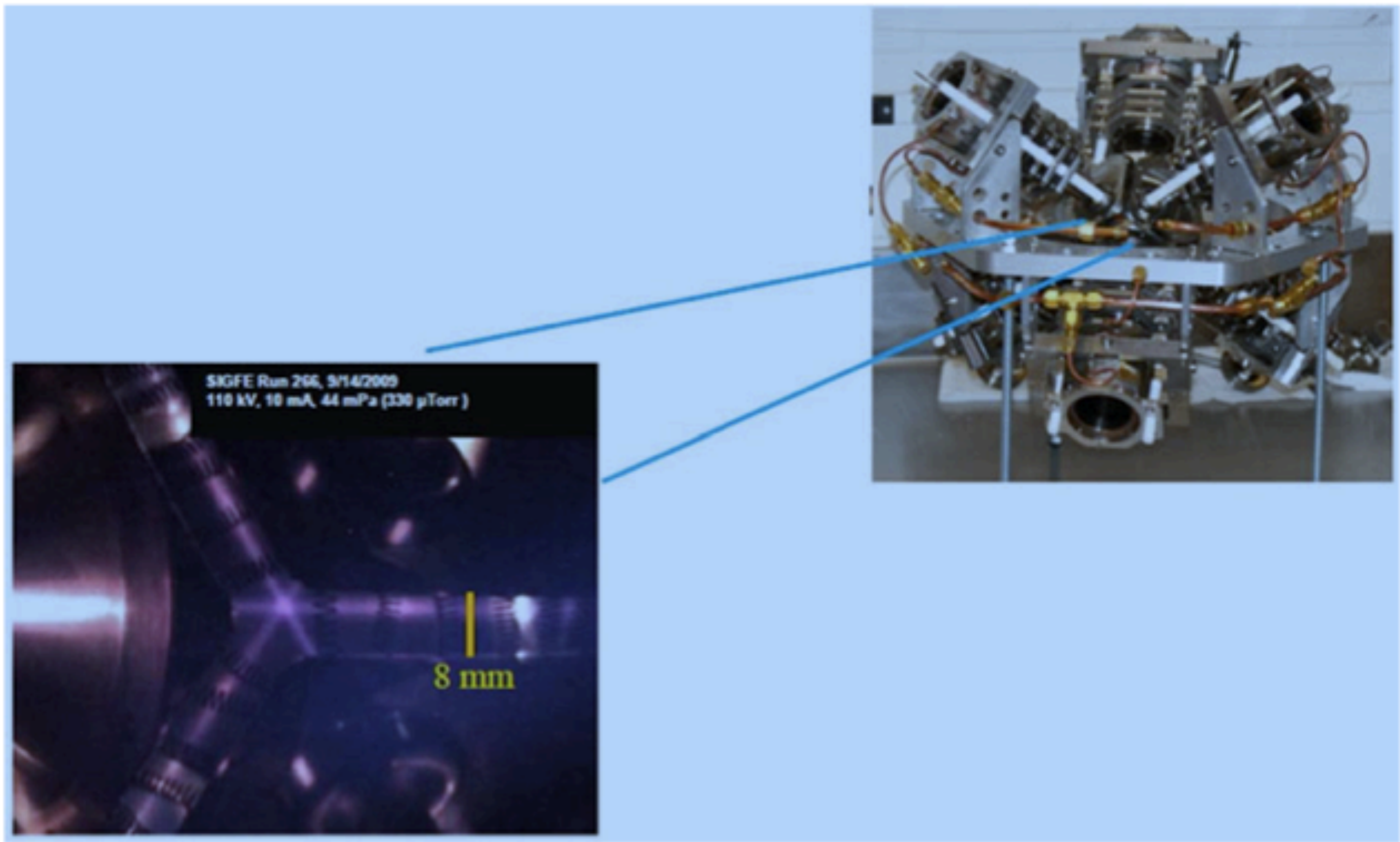


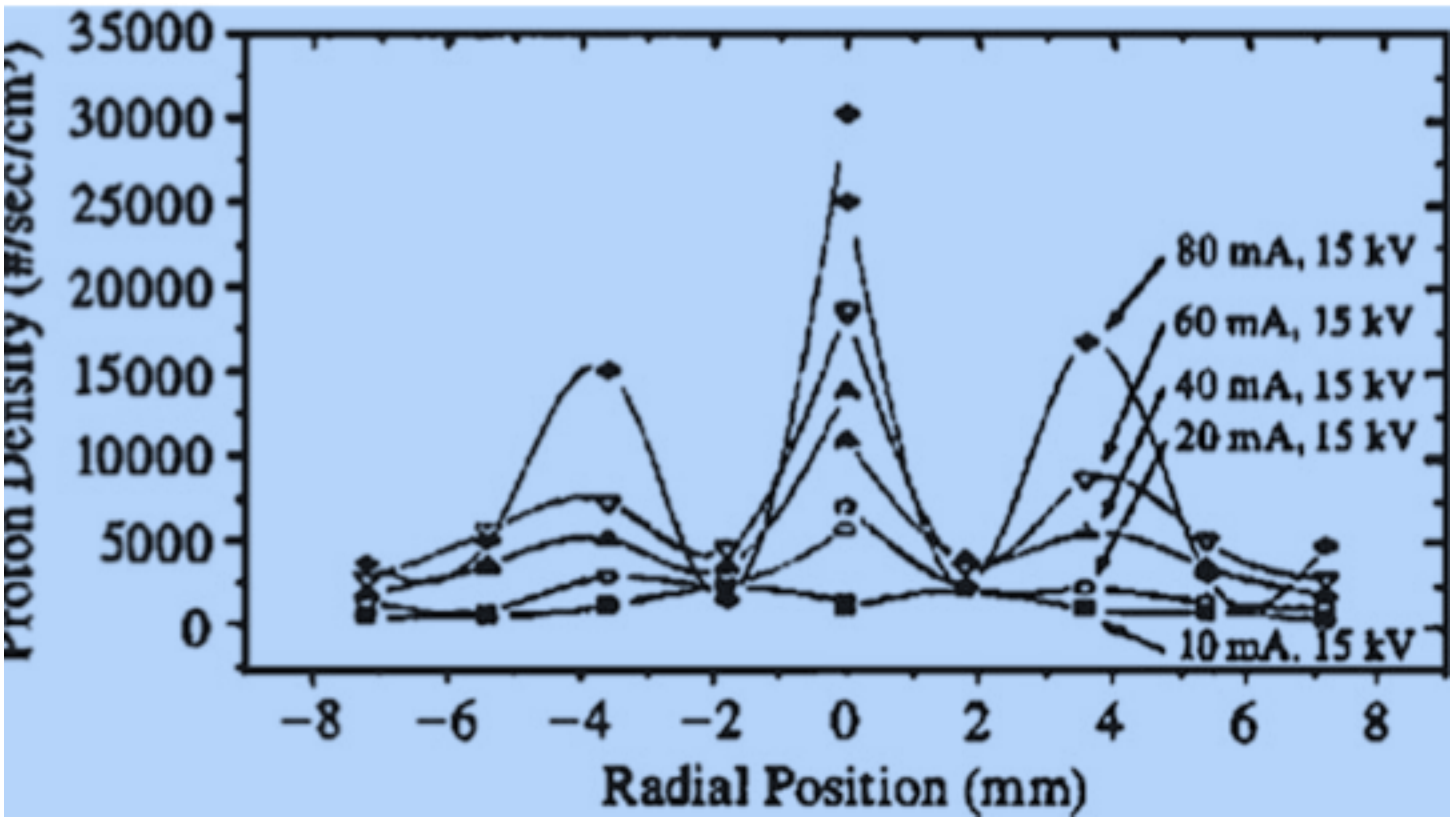
Illustration of the formation of multiple potential wells in a spherical IEC as a function of increasing current in going from (a) to (d).



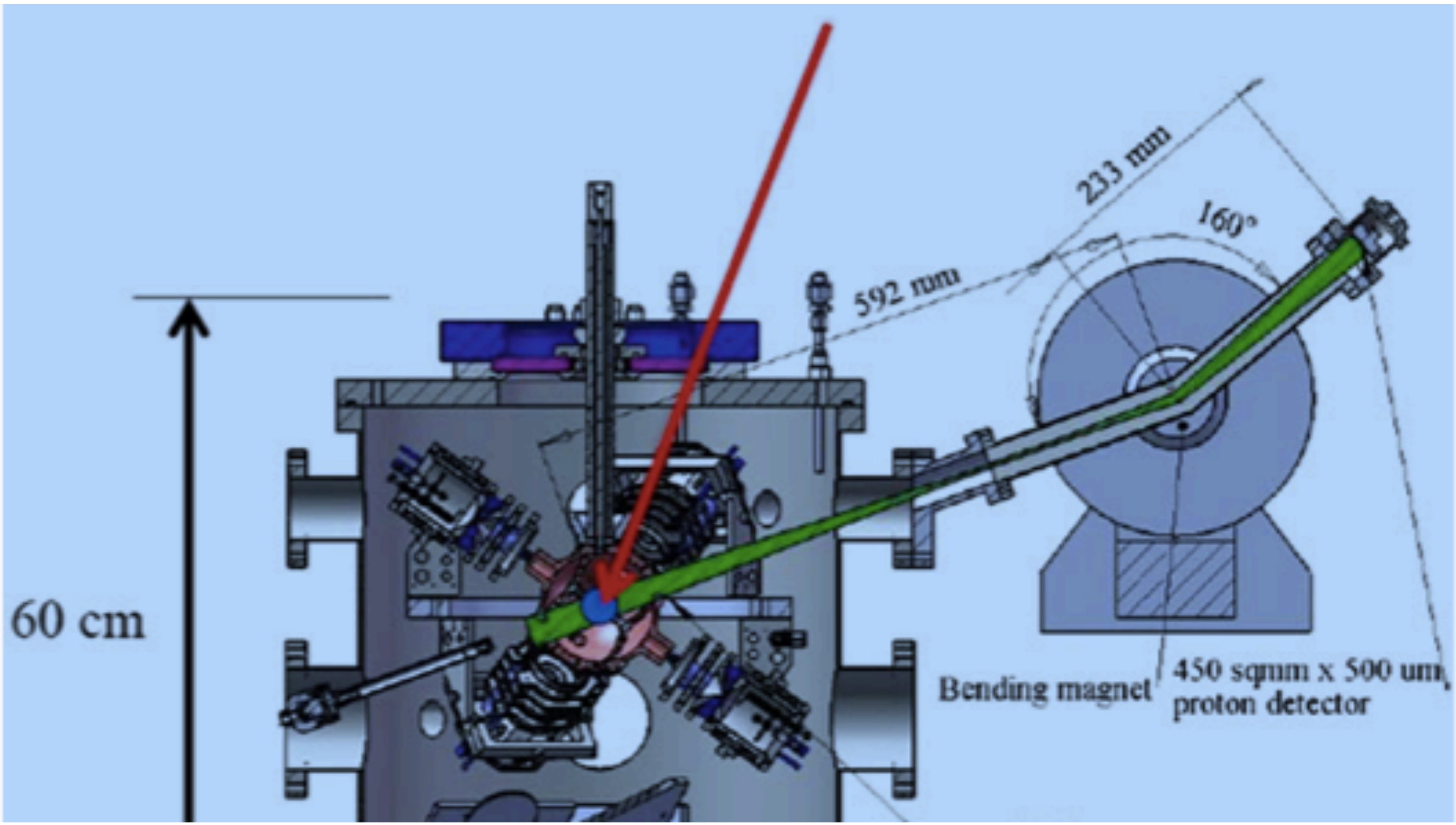
The Six Ion Gun Fusion Experiment (SIGFE) device



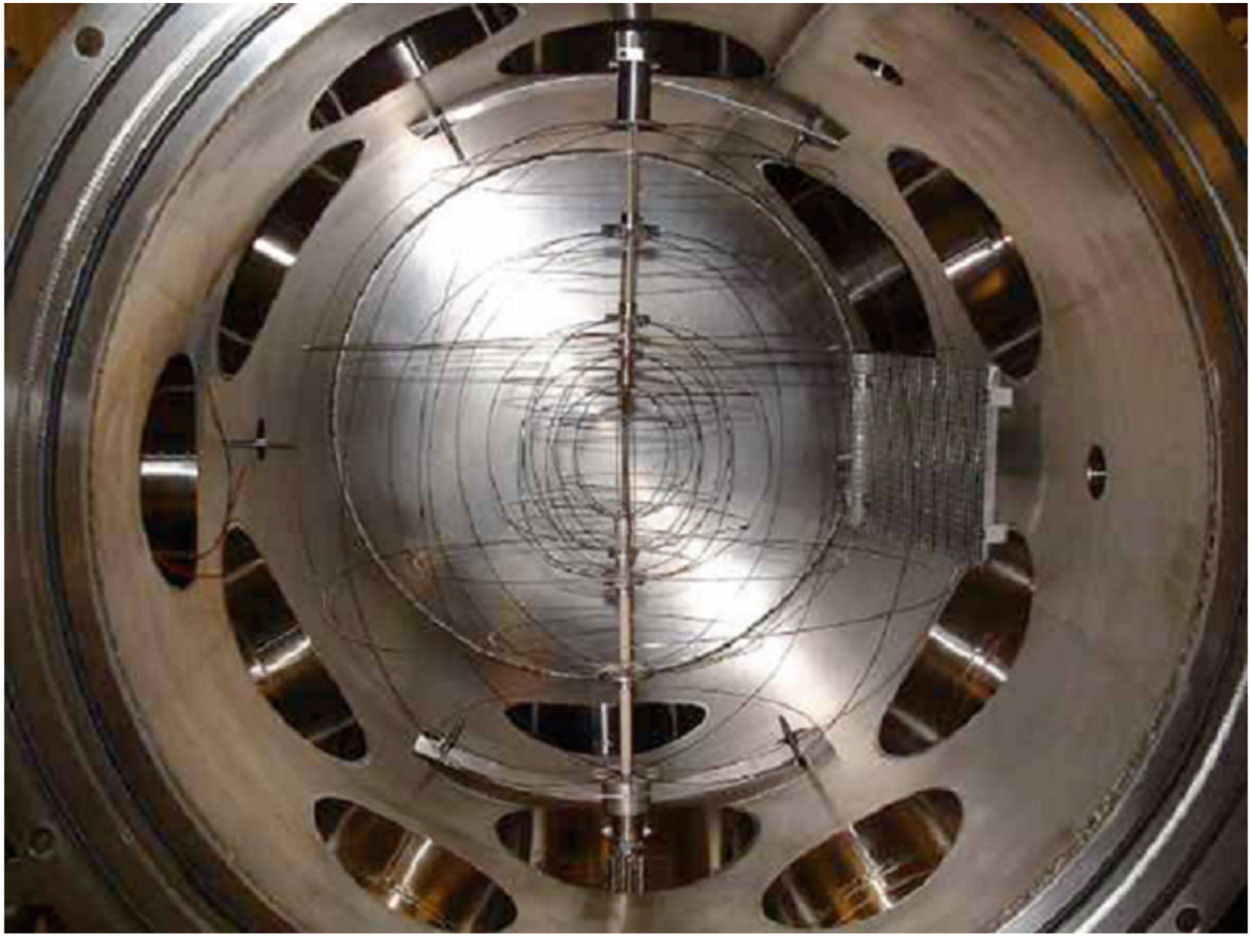
Measurement of the potential well structure using a collimated proton detector



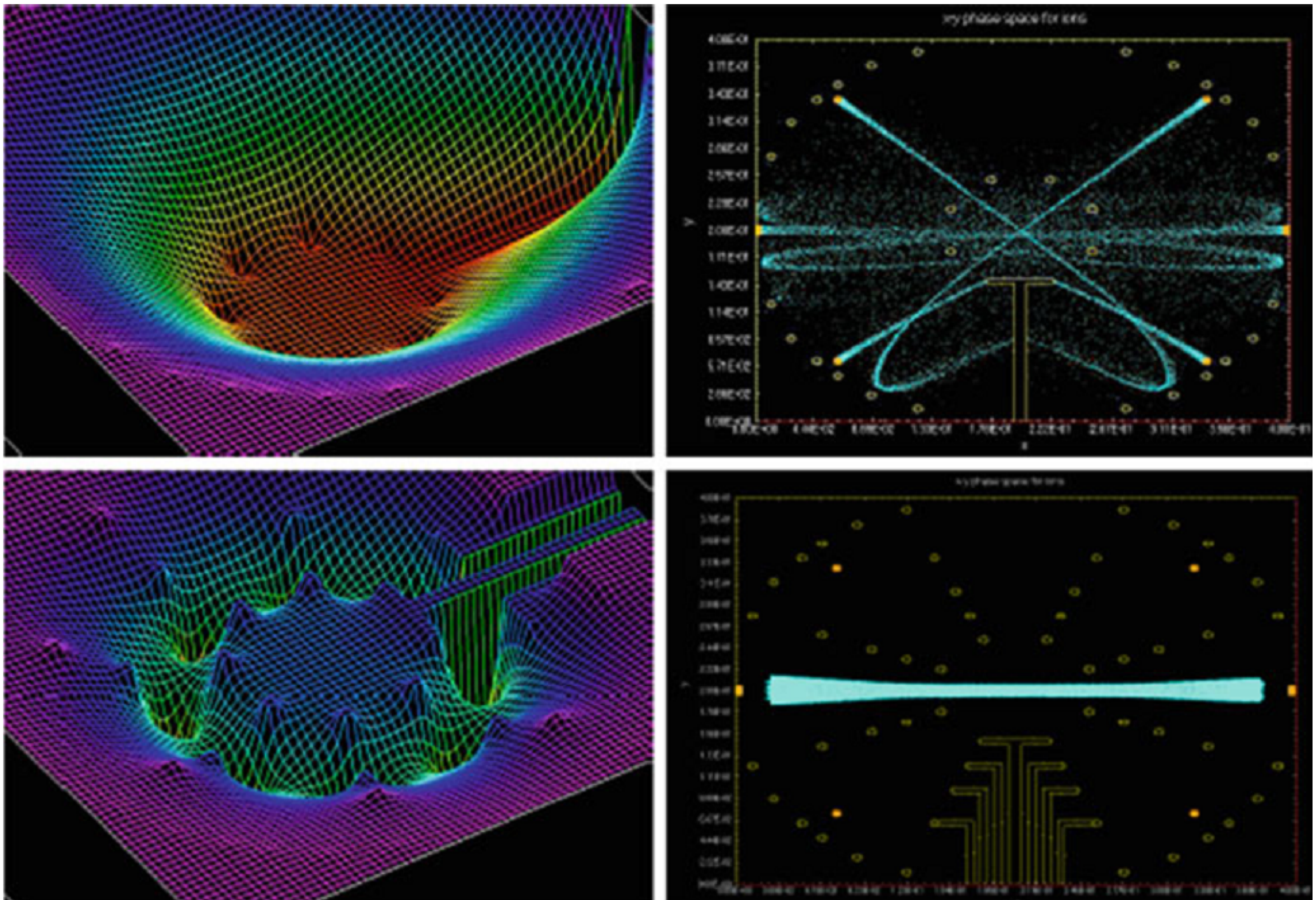
The SIGFE with a bending magnet to reduce x-ray noise while studying the protons from D–D reaction at the cathode center



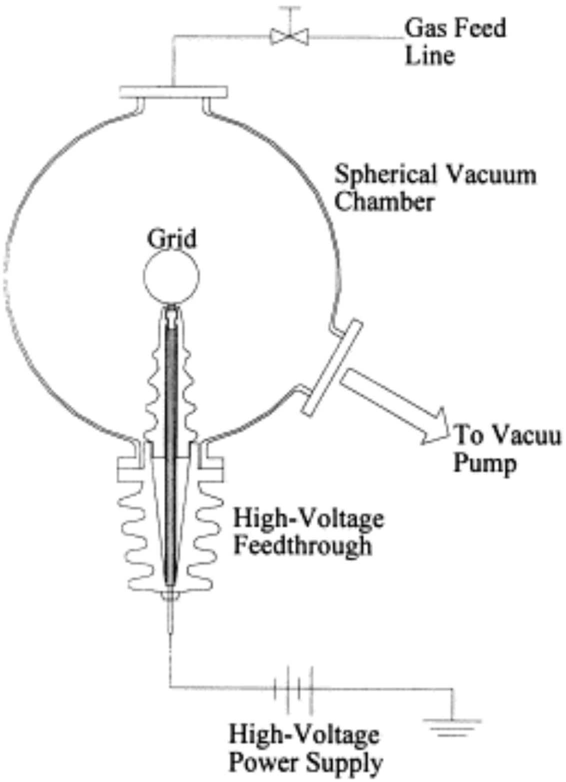
The multi-grid IEC in the vacuum chamber

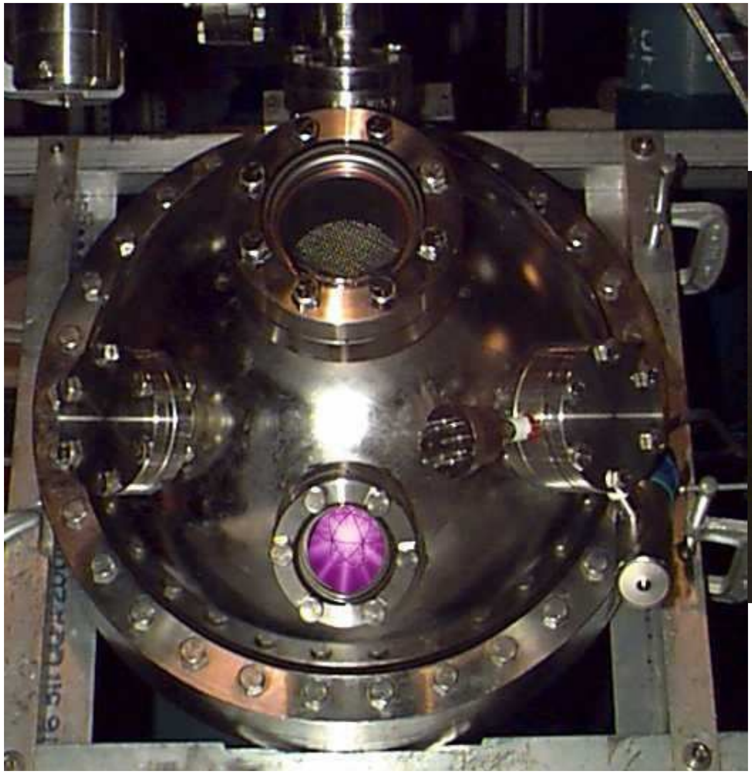


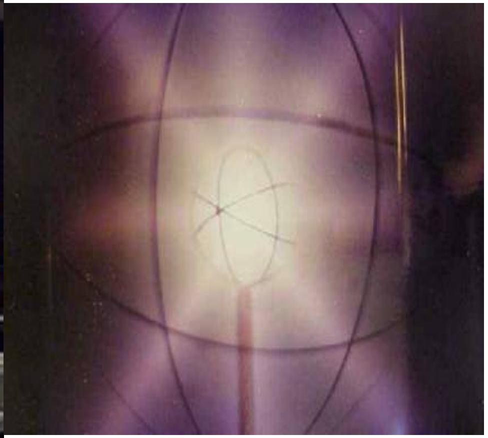
Single cathode grid and stalk produce a highly defocusing beam line (top left) resulting in chaotic ion paths terminating on the grid (top right). Additional grids shield this effect (bottom left)and greatly extend ion lifetime (bottom right). These particle simulations used a commercial particle-in-cell (PIC) code



Examples of a spherical IEC at the University of Illinois

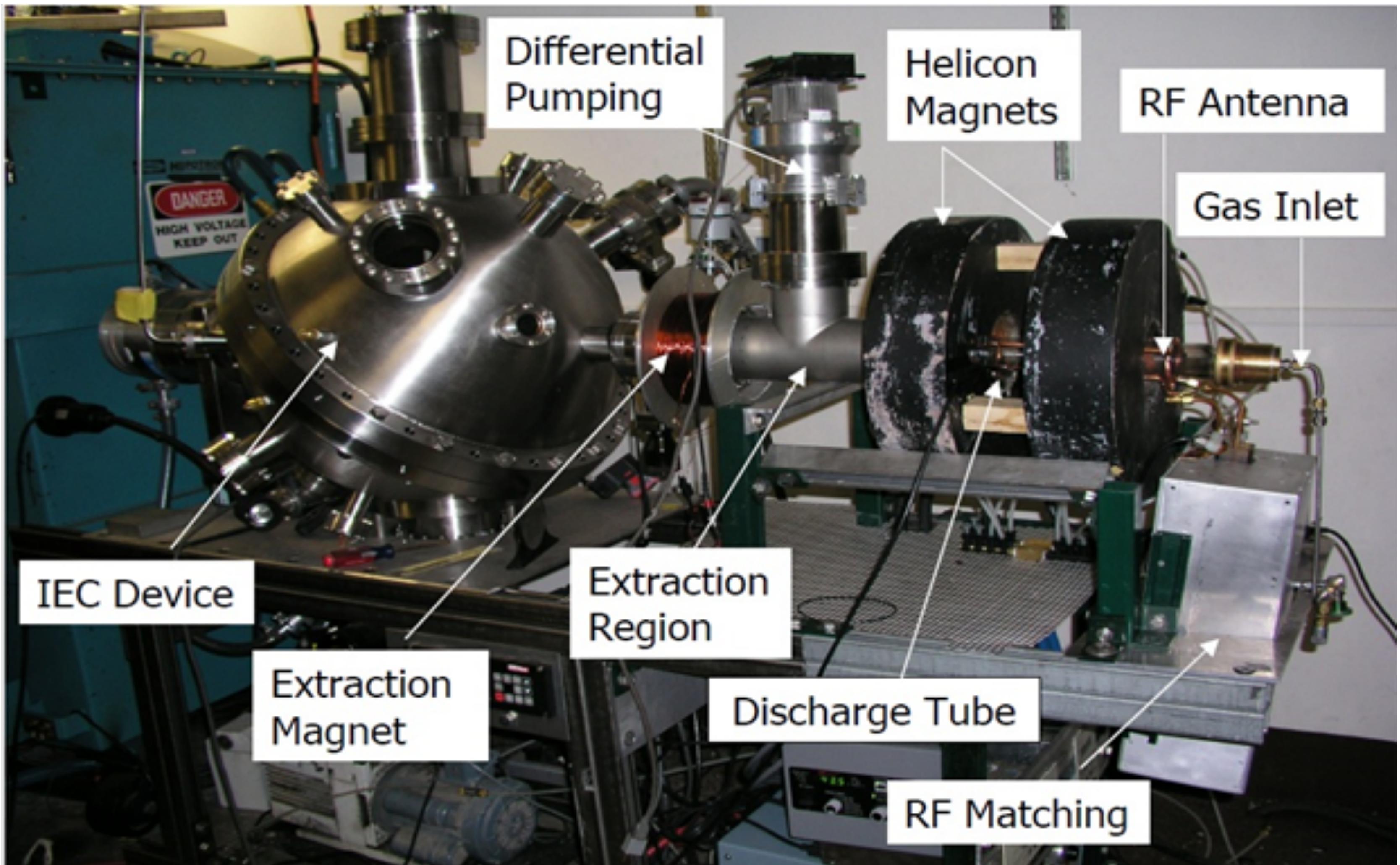




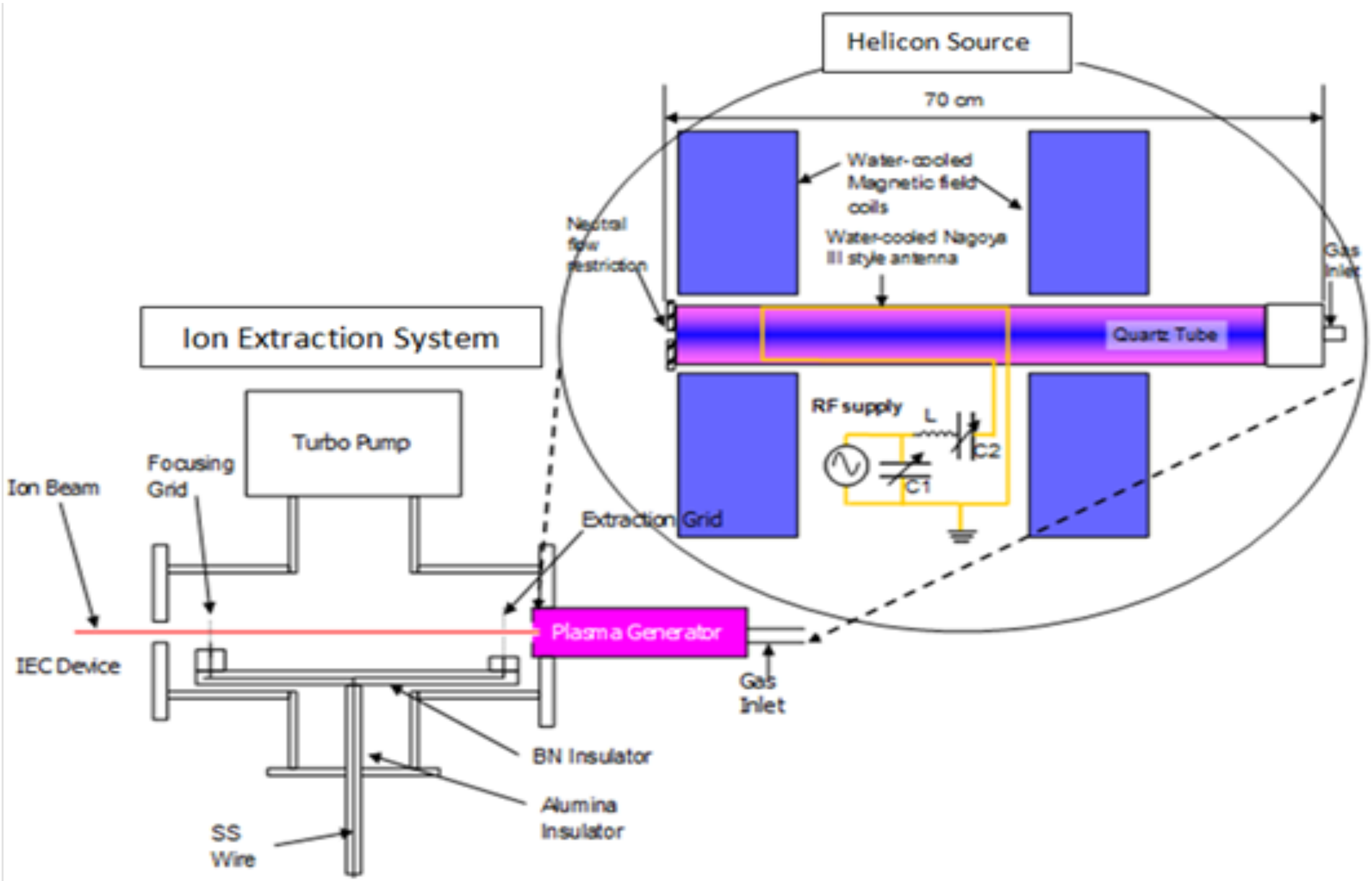


IEC system with a radio frequency ion gun

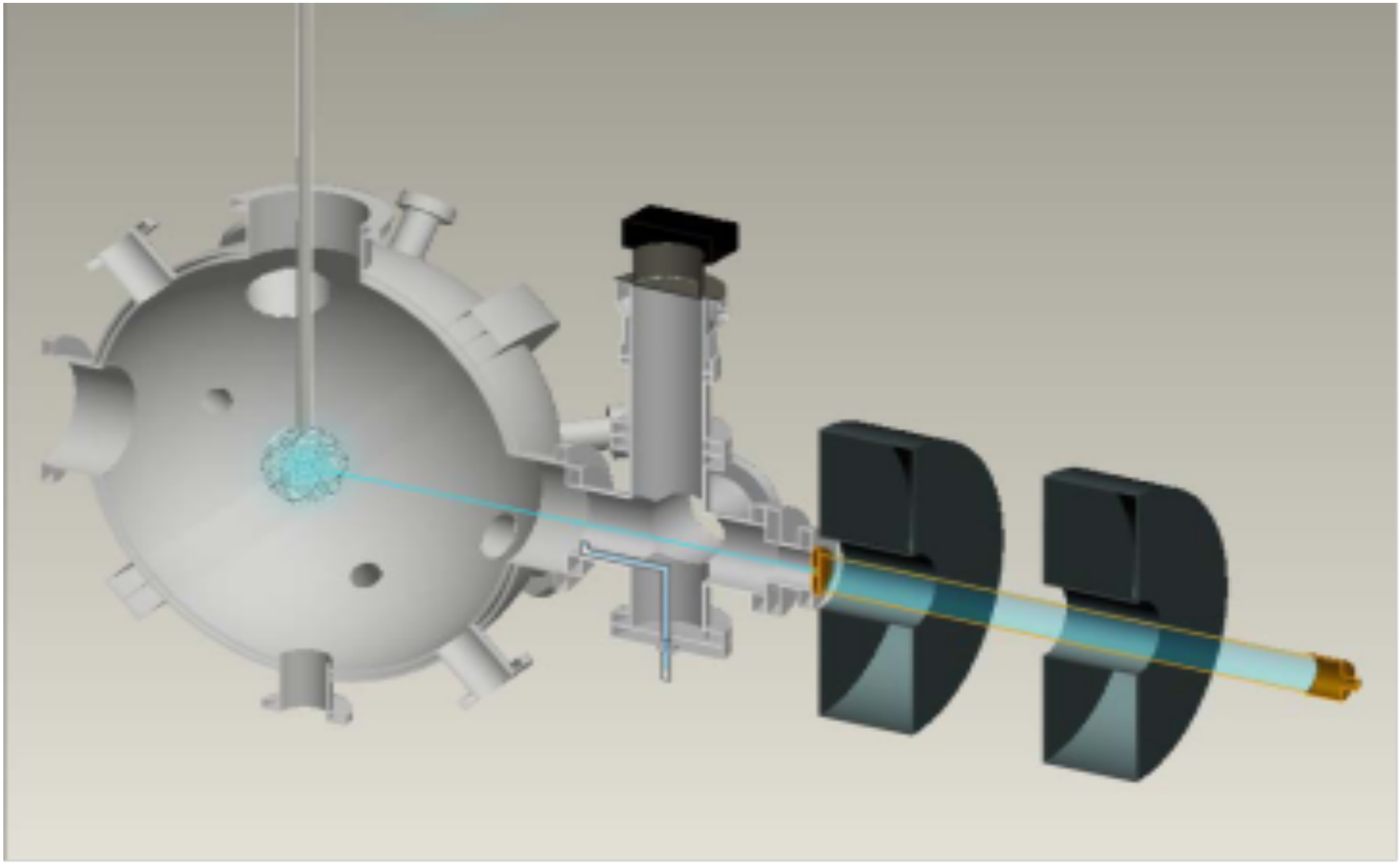
Ion source mated to the University of Wisconsin Madison IEC



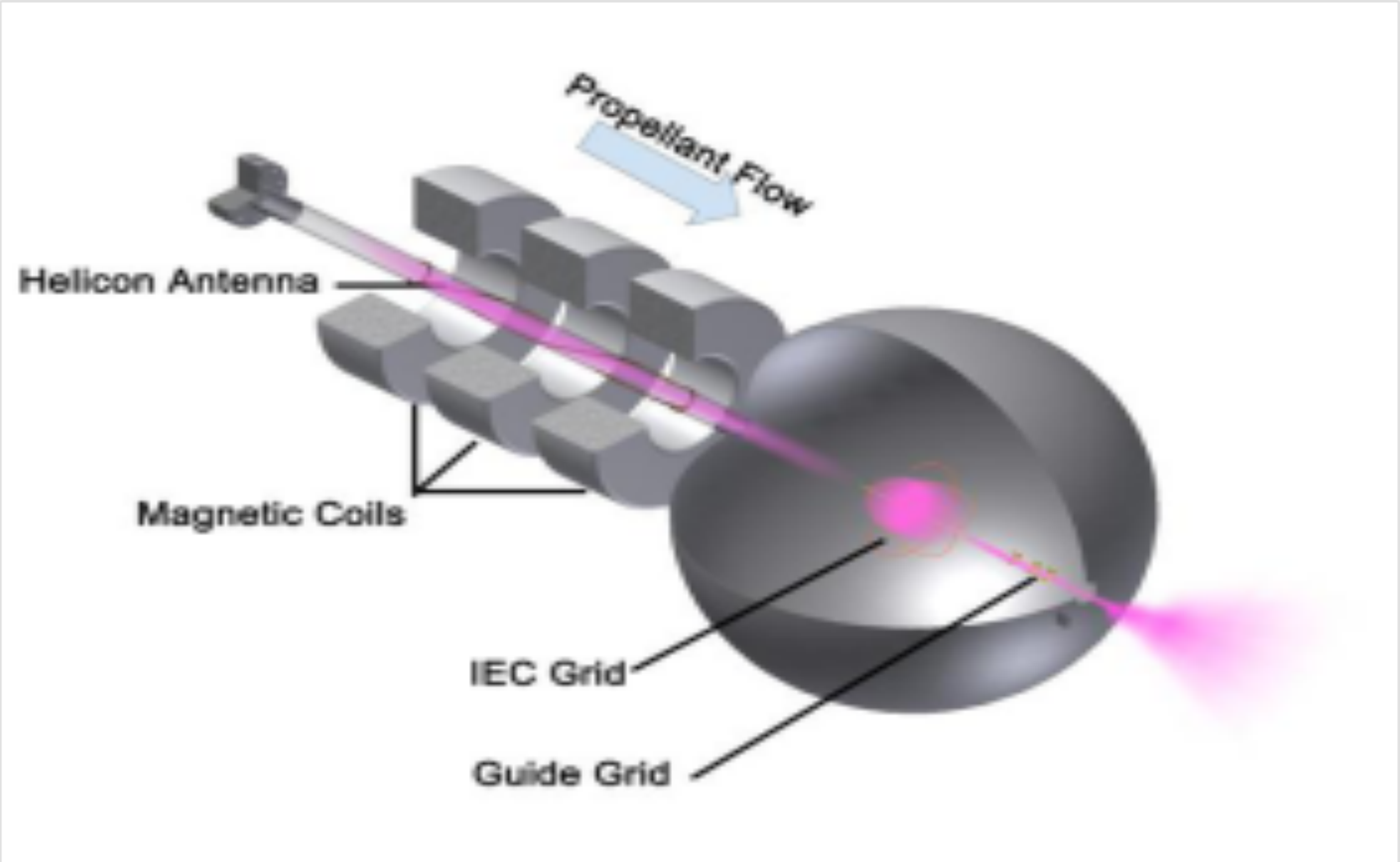
Helicon source and the ion extractor system



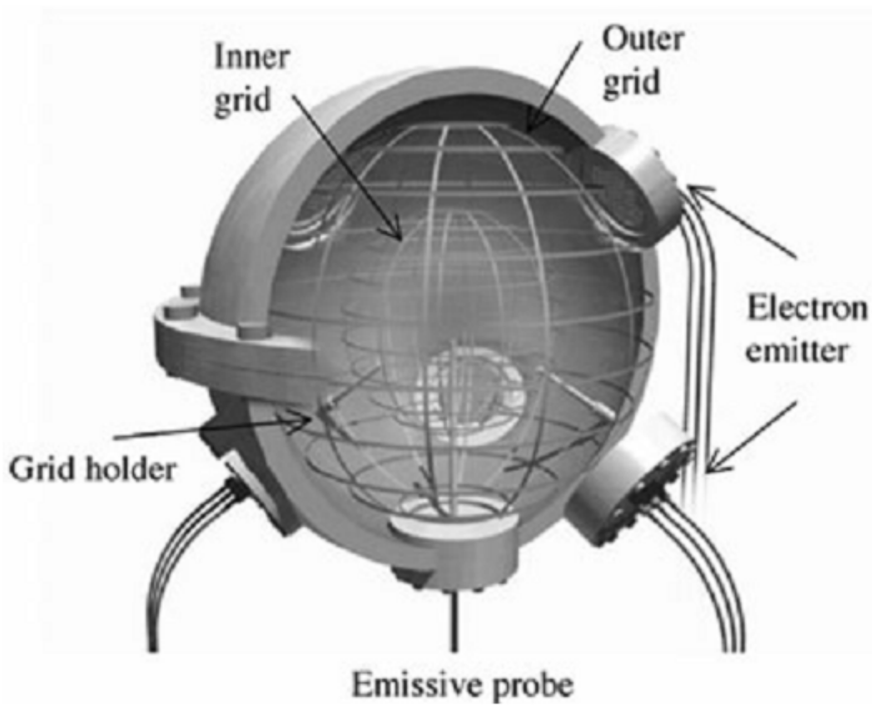
3He ion source for use in 3He – 3He fusion rate studies at the University of Wisconsin

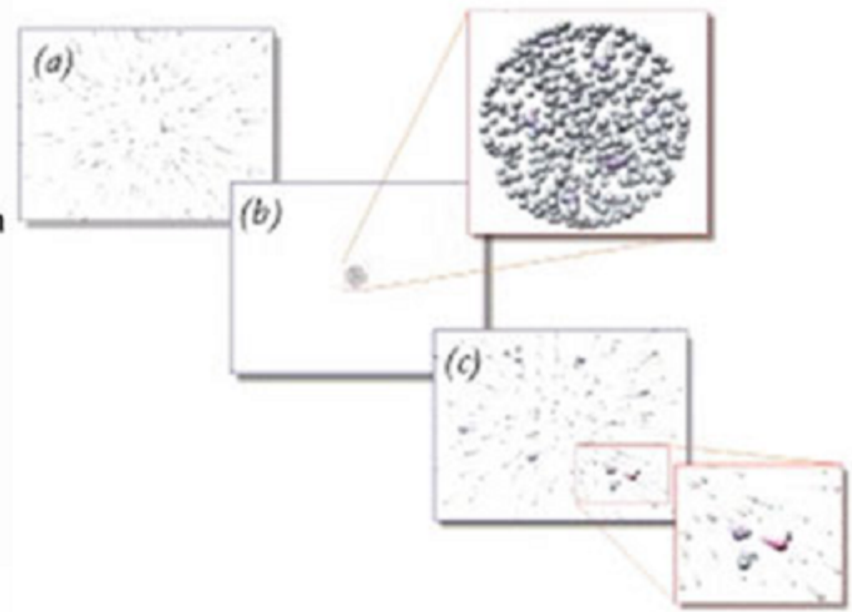


Schematic of the HIIPER concept

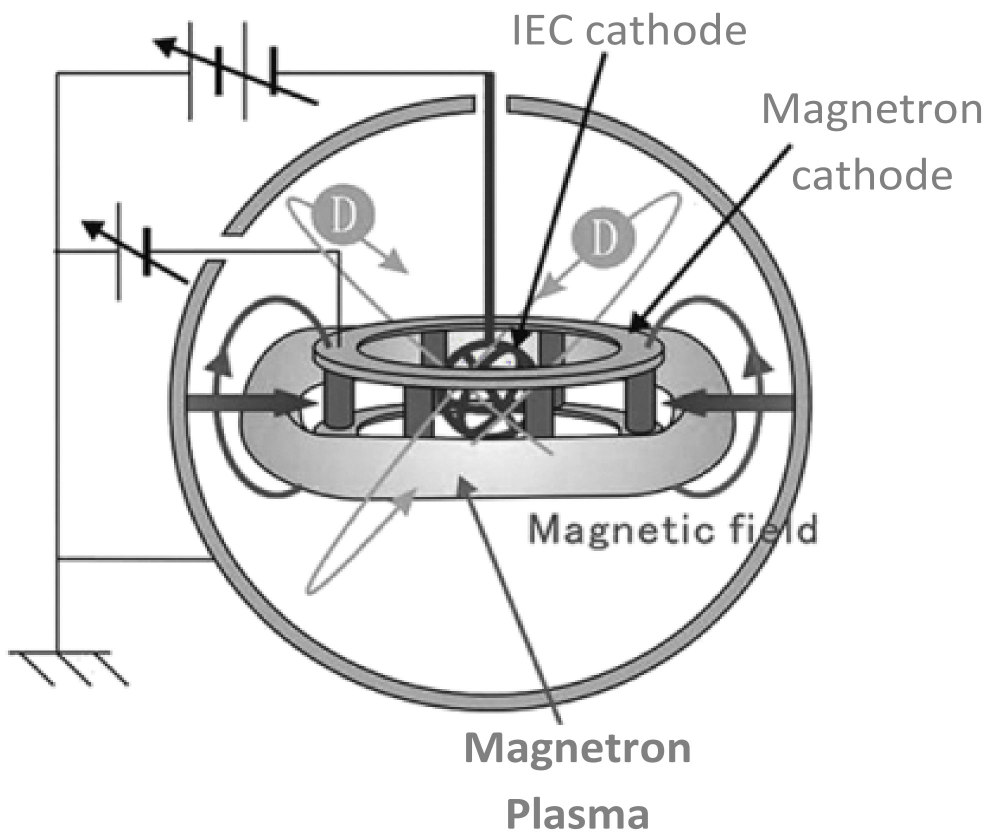


Intense neutron source-electron (INS-e) device demonstrating the ***POPS concept*** at the Los Alamos National Lab. (a) Particles distributed spatially around the cathode but converged in velocity space. (b) Particles converging in space by distributed in velocity space. (c) Half a period later the particles return back to their original spatial distribution



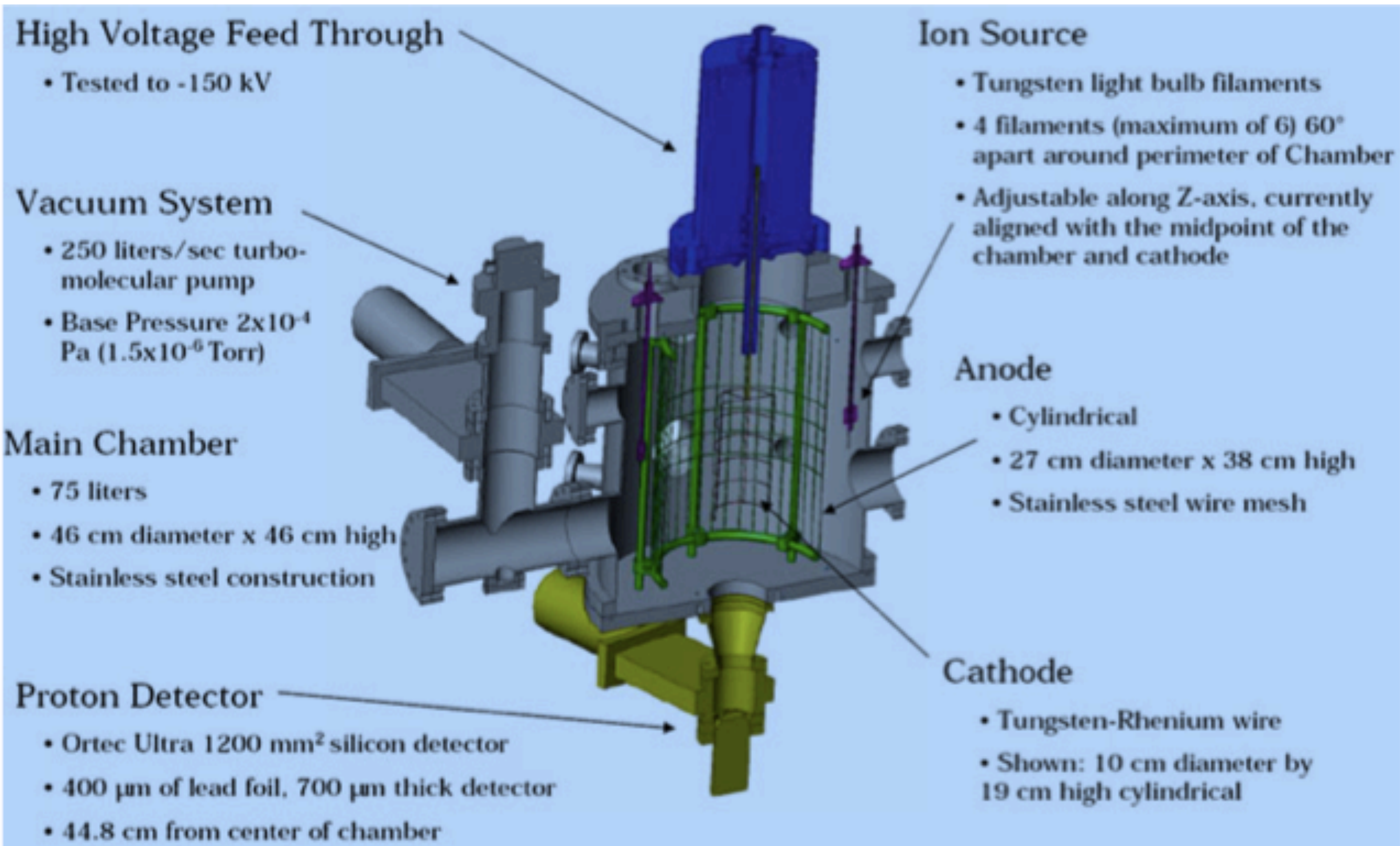


Schematic for electrode arrangement in a RS-MIS ion source driven IEC device

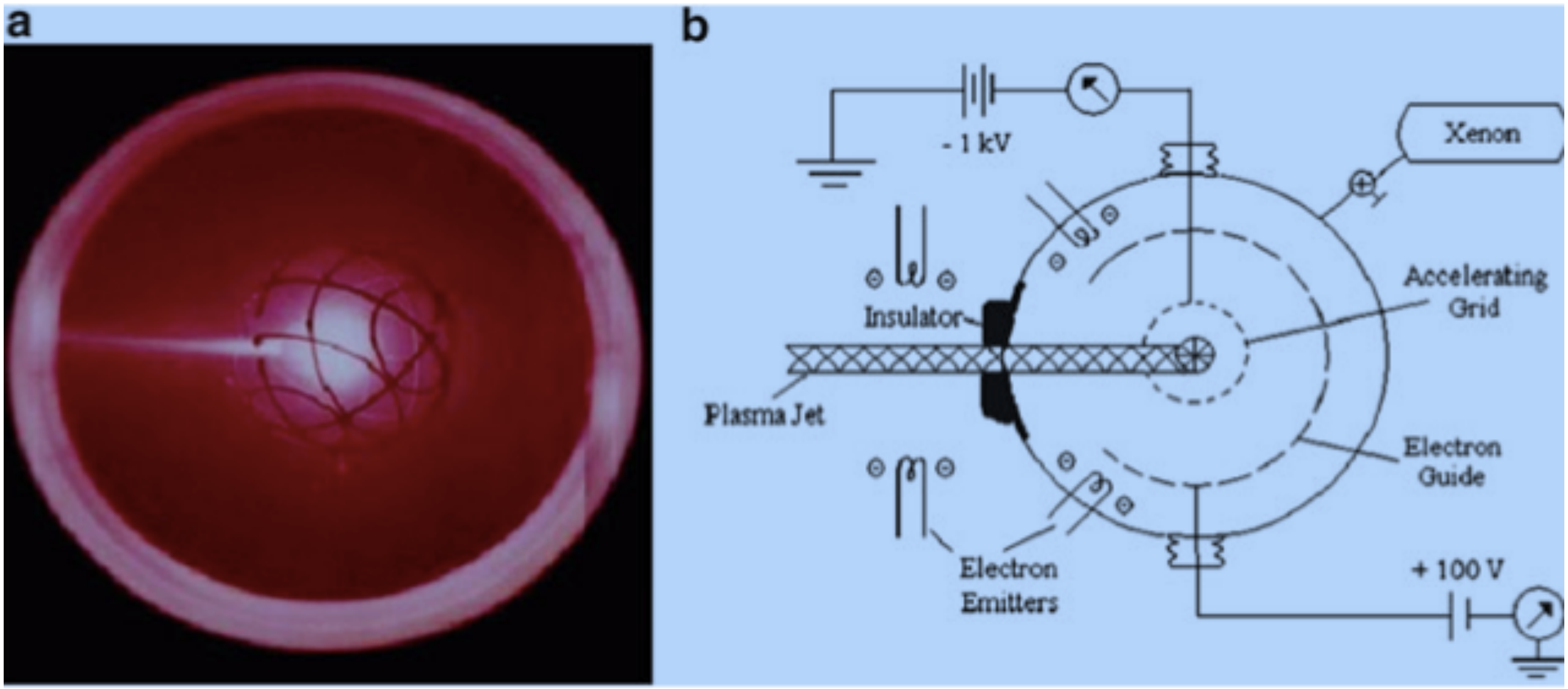


Cylindrical and other Geometries

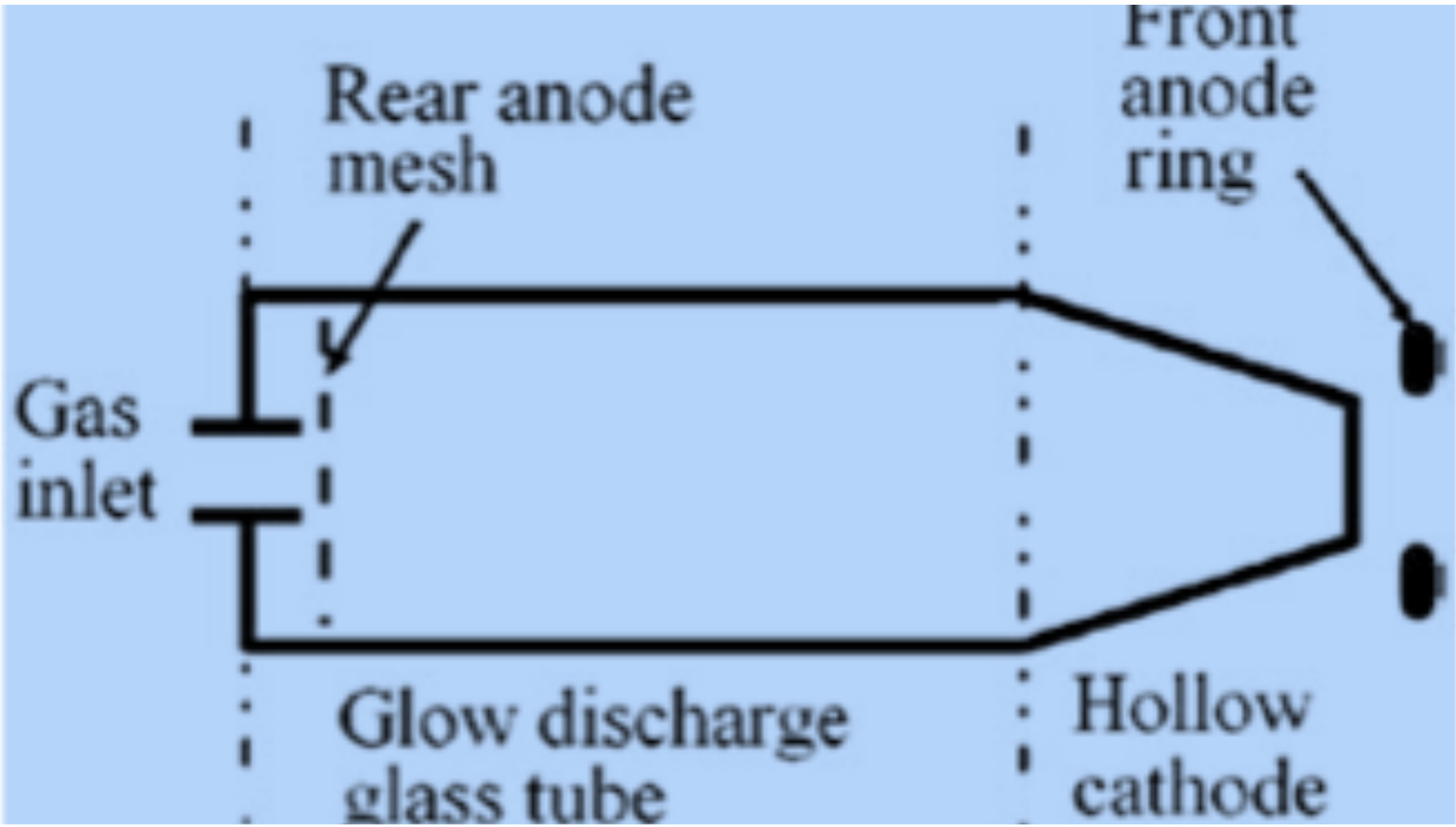
Components and diagnostics of the 3He Cylindrical Transmutation Reactor (3HeCTRE)



(a) Jet operational mode in experimental IEC device. (b) Jet setup



The charge exchange thruster



Dipole reactor propulsion scheme

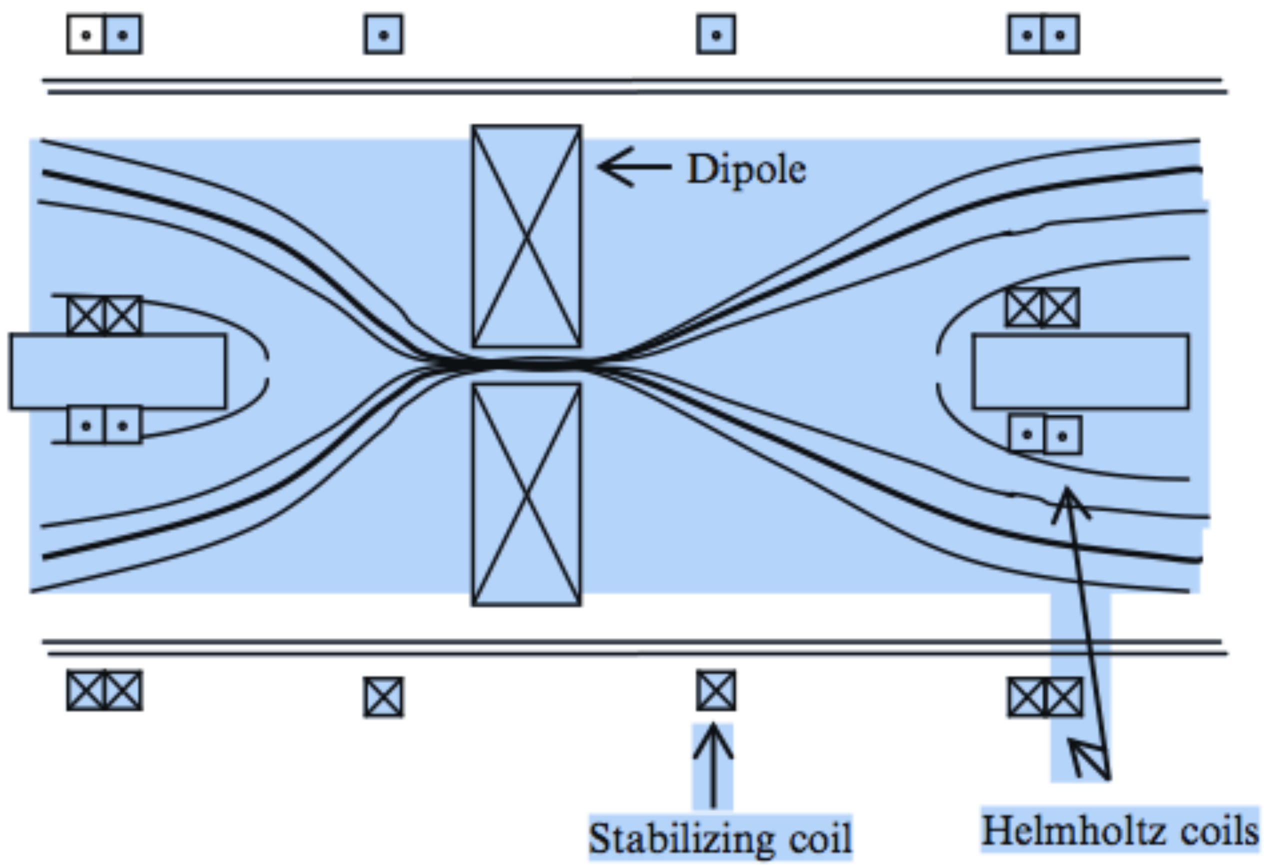


Illustration of a three-unit MCSA device

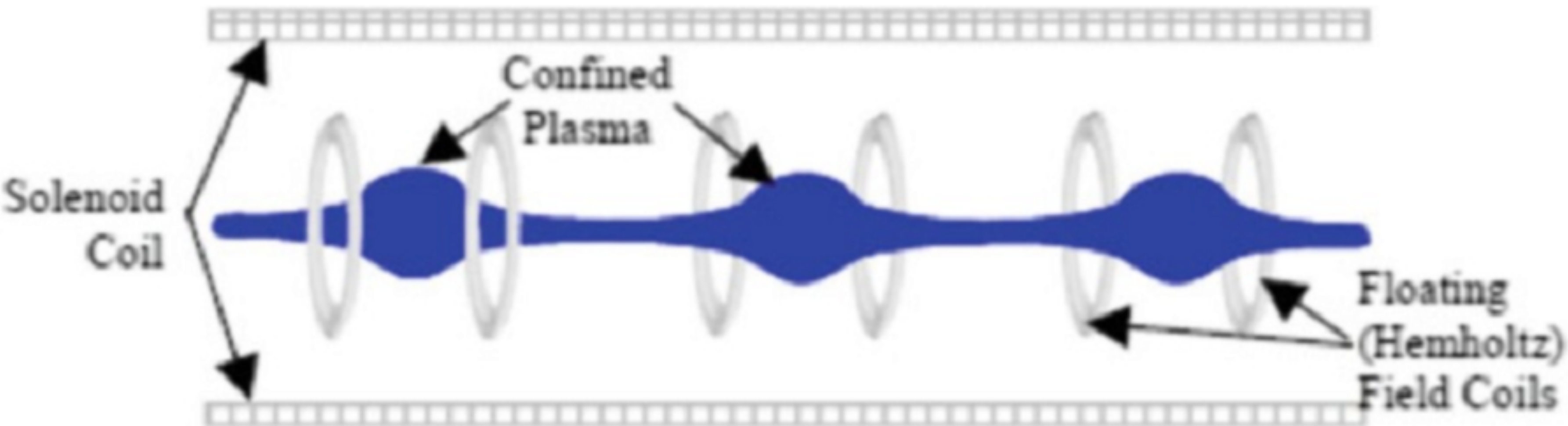
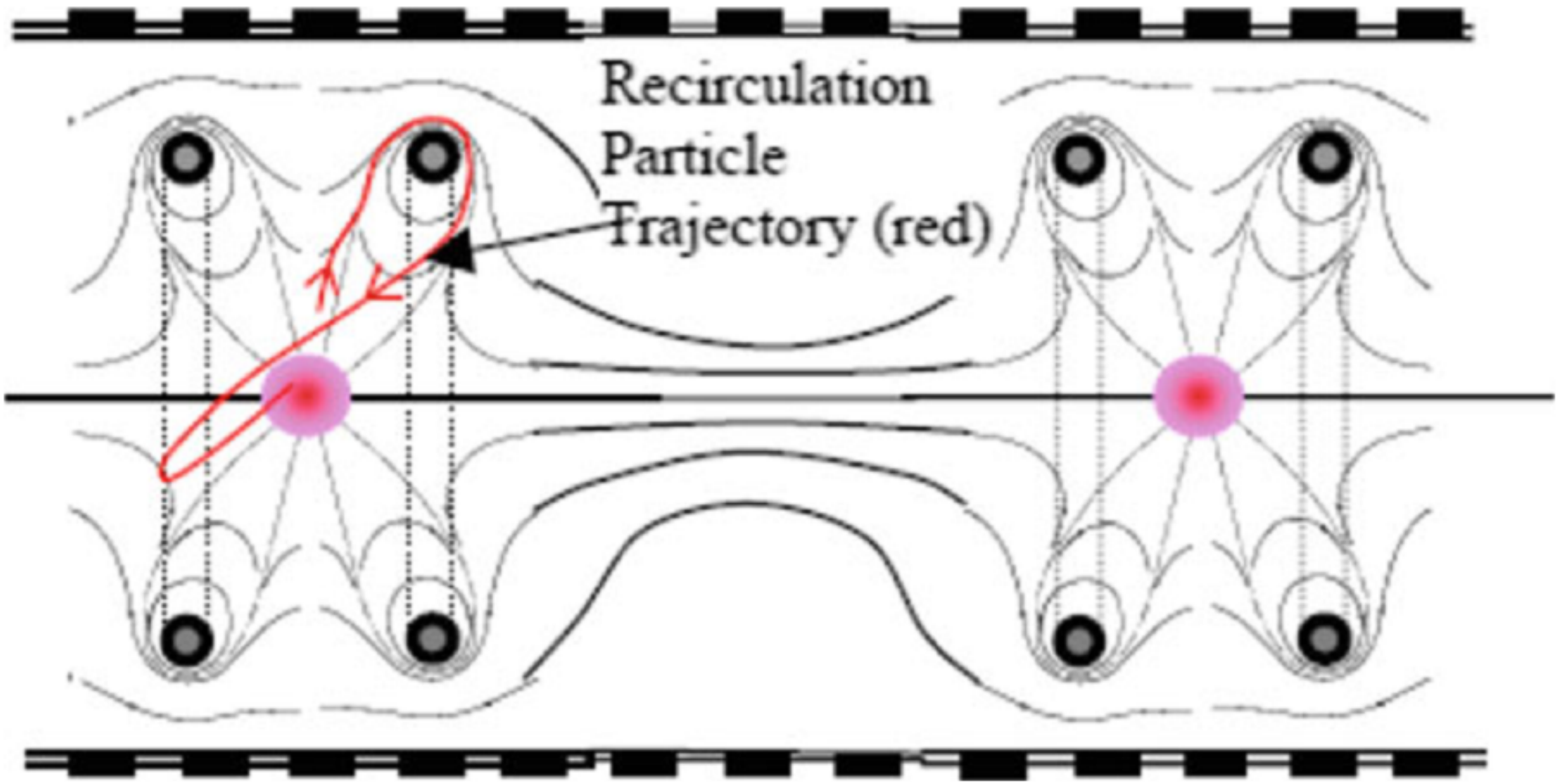
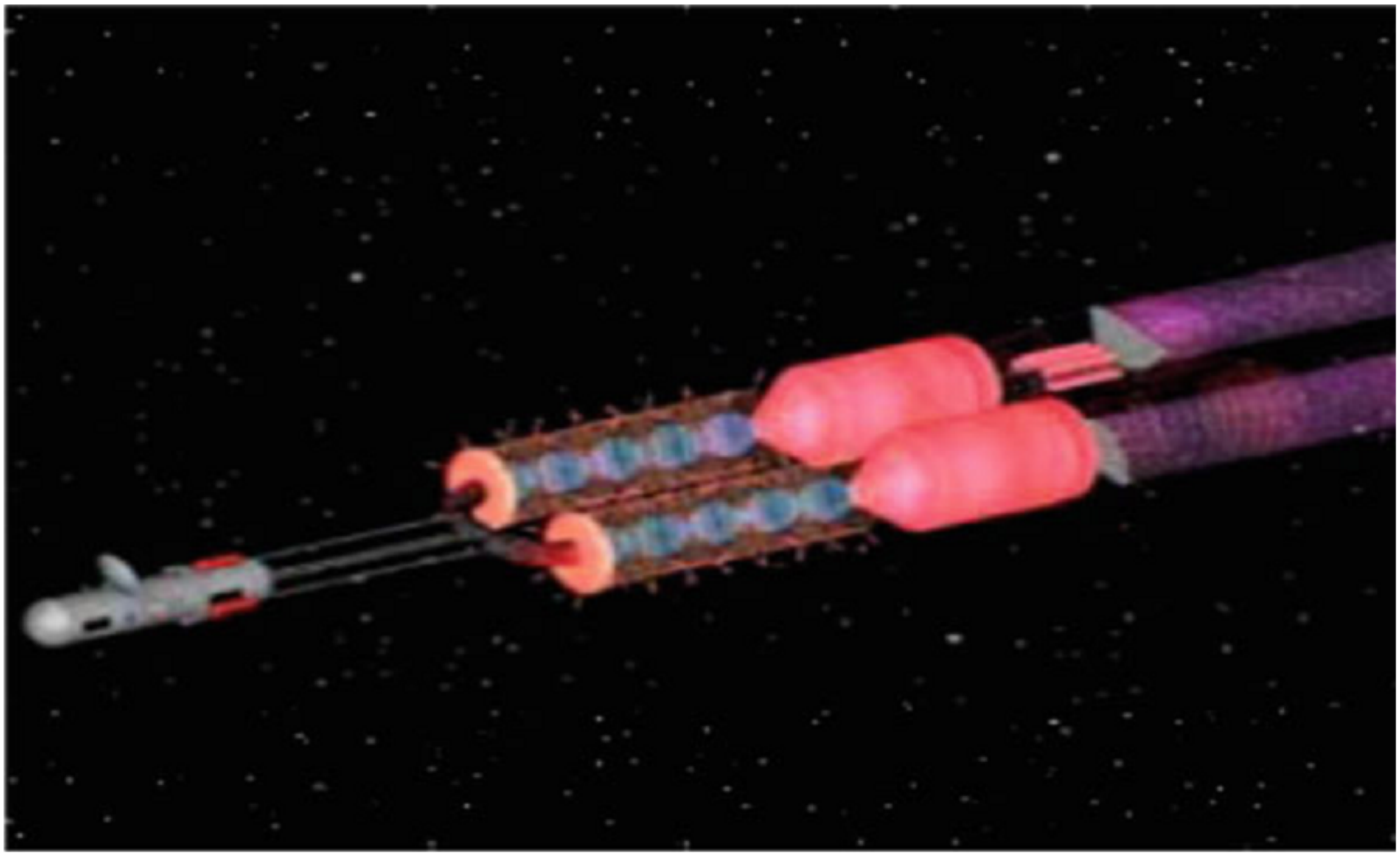


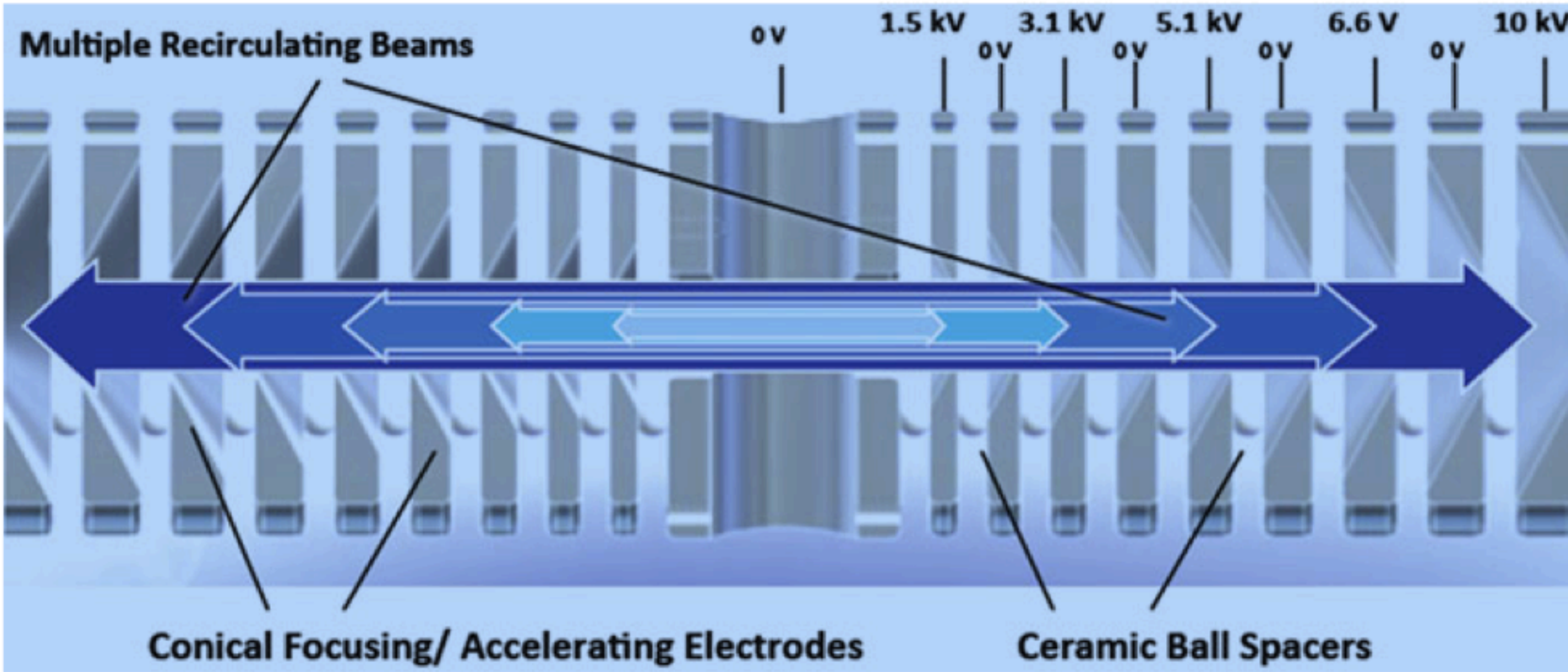
Diagram of belt cusp fields and particle recirculation



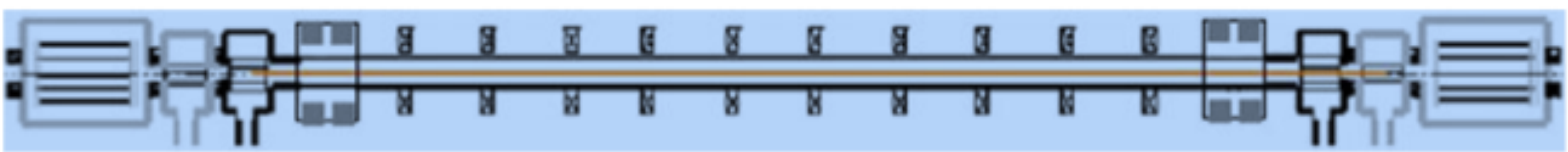
The Fusion II Spaceship, a 750 MWe IEC fusion-powered manned spacecraft with ion thruster propulsion



The prototype MARBLE-1

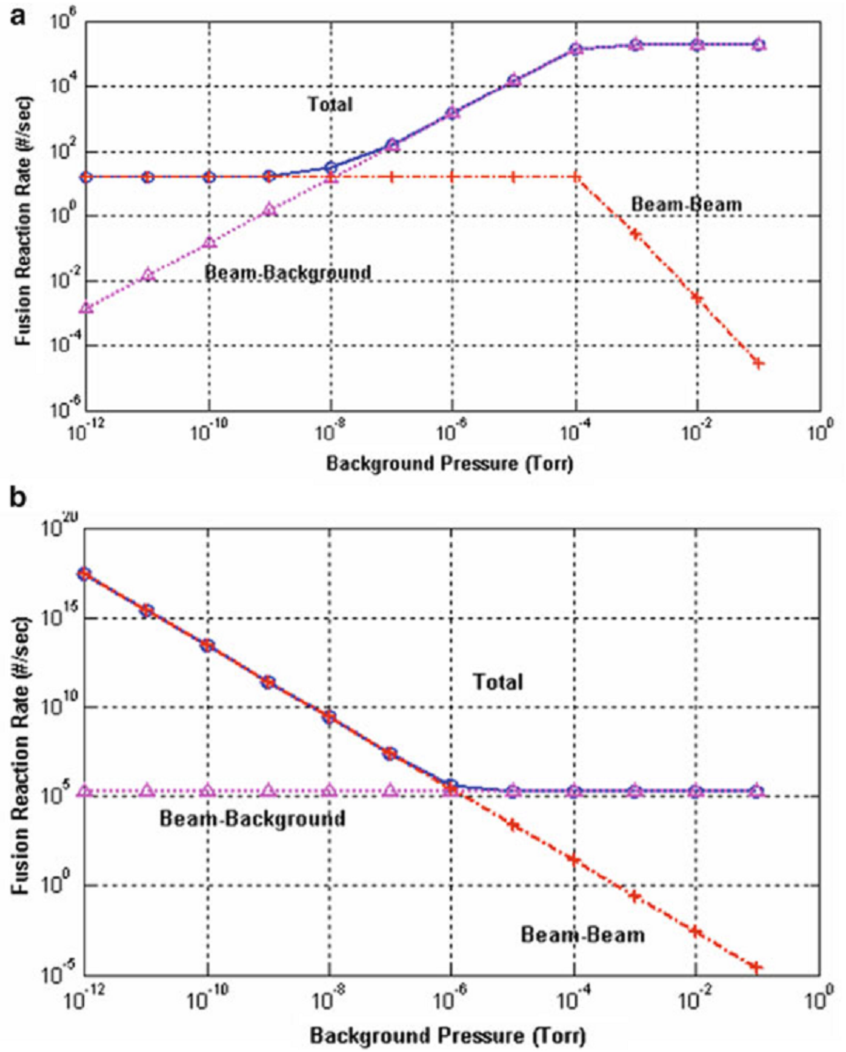


A conceptual drawing of the counter-streaming linear IEC generator



Comments about reactor issues

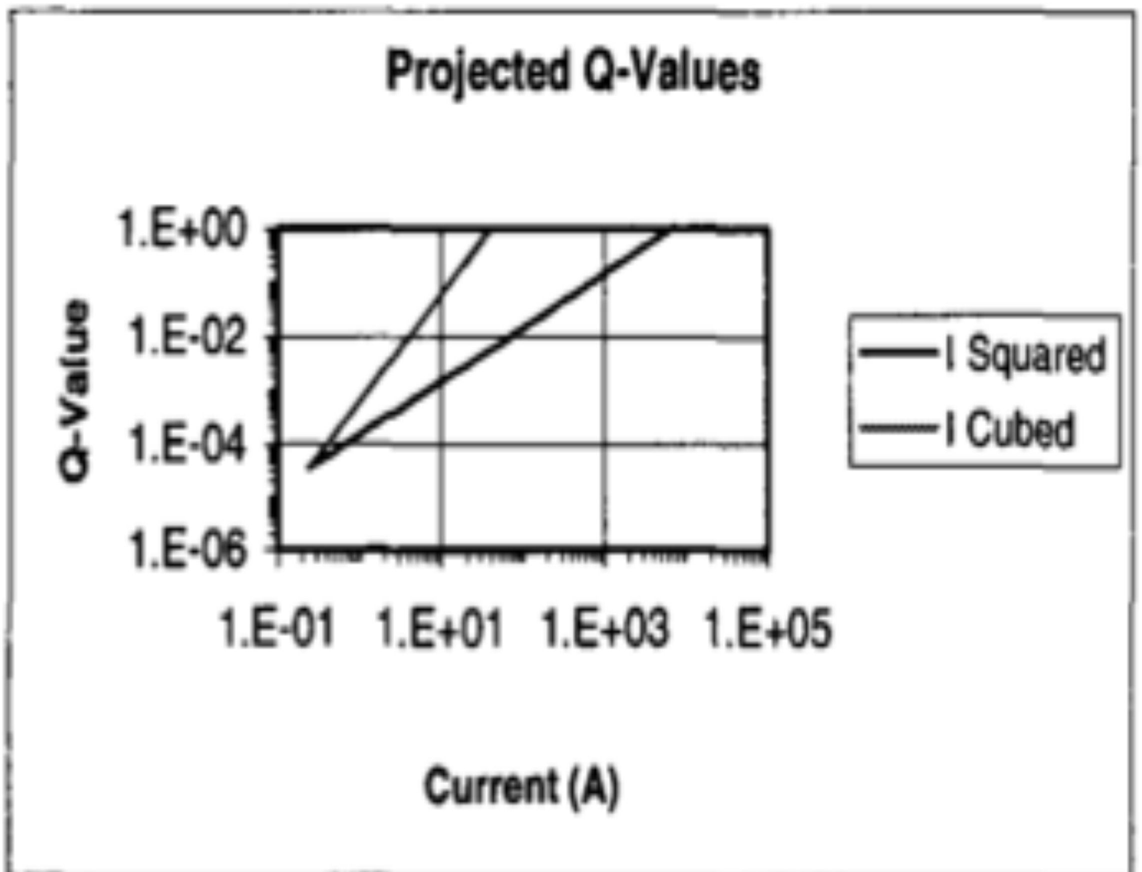
Fusion reaction rates for beam–beam and beam–background contributions. Resultsshown are for confinement limited (a) and charge exchange limited (b) operations as a function of background pressure



Scaling issues

$$\text{Total Reaction Rate} = \left(\frac{I\cdot\gamma}{2\cdot\pi\cdot r^{2}\cdot v(R)\cdot e}\right)^{2} <\sigma\, V(r)> \; V$$

Projected Q-values vs. cathode current for a scaled-up IEC reactor.

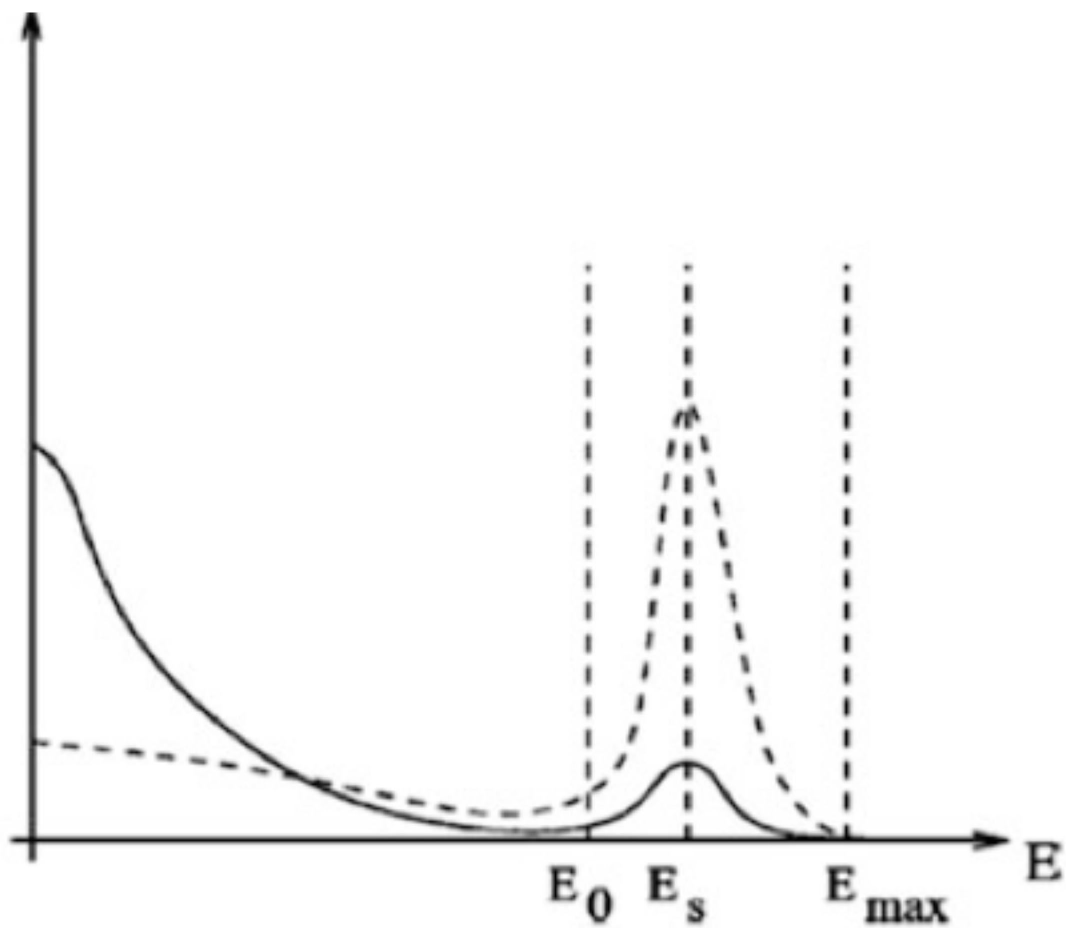


Comparison of Semi-analytic and BAFP Code Results

Table 13.1 Comparison of analytical and numerical estimates of Q-values in a beam-dominated solution for a 50 kV square well

Analytical	Energy gain, Q (semi-analytic)	BAFP
With co-moving ions, Nevins [3]	~0.21	NA
Without co-moving ions, Barnes et al. [4]	~1.3	~1

Sketch of two opposite limits of the beam- Maxwellian equilibrium. The solid line corresponds to a case in which the Maxwellian population is dominant, and the dashed line corresponds to a case in which the beam contribution is dominant



Concluding comments

In addition to numerous potential applications (NAA, medical isotopes, material testing ...) the IEC may ultimately lead to a small economic fusion reactor.

The variety of configurations for both electron and ion injected concepts offer multiple potential routes to a fusion reactor.

Thanks for your attention

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