Advanced Fusion Fuels in an Inertial Electrostatic Confinement Device

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Why Fusion?

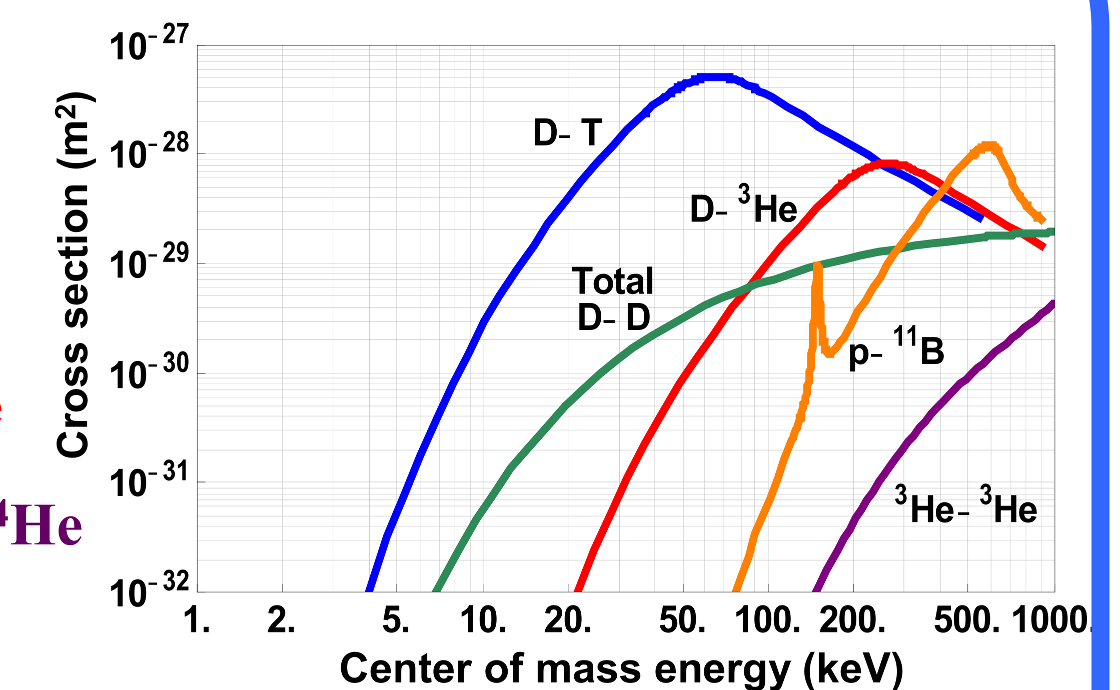
- **Shares advantages of fission:** no greenhouse gas emissions, and abundant energy per gram of fuel.
- **But also:** much less and shorter-lived radioactive waste, inherently safe from meltdowns, and fewer proliferation risks.
- **Hurdle:** overcoming repulsion between positive nuclei → need very high energies, temperatures **~10^8-10^9 degrees!**
- **Huge technical challenge:** likely only a long term solution. Energy breakeven is close, but much progress still needed to make a reliable and economically attractive reactor.

Fusion Fuels

1st Generation
- $D + T \rightarrow n + {}^4He$
- $D + D \xrightarrow{50\%} n + {}^3He$
- $\xrightarrow{50\%} p + T$

2nd
- $D + {}^3He \rightarrow p + {}^4He$

3rd
- ${}^3He + {}^3He \rightarrow 2p + {}^4He$
- $p + {}^{11}B \rightarrow 3\times{}^4He$



p = proton (hydrogen-1); D = deuterium (hydrogen-2); T = tritium (hydrogen-3); ${}^3He$ = helium-3; ${}^4He$ = helium-4; ${}^{11}B$ = boron-11; n = neutron.

- ***Why Advanced Fuels?***

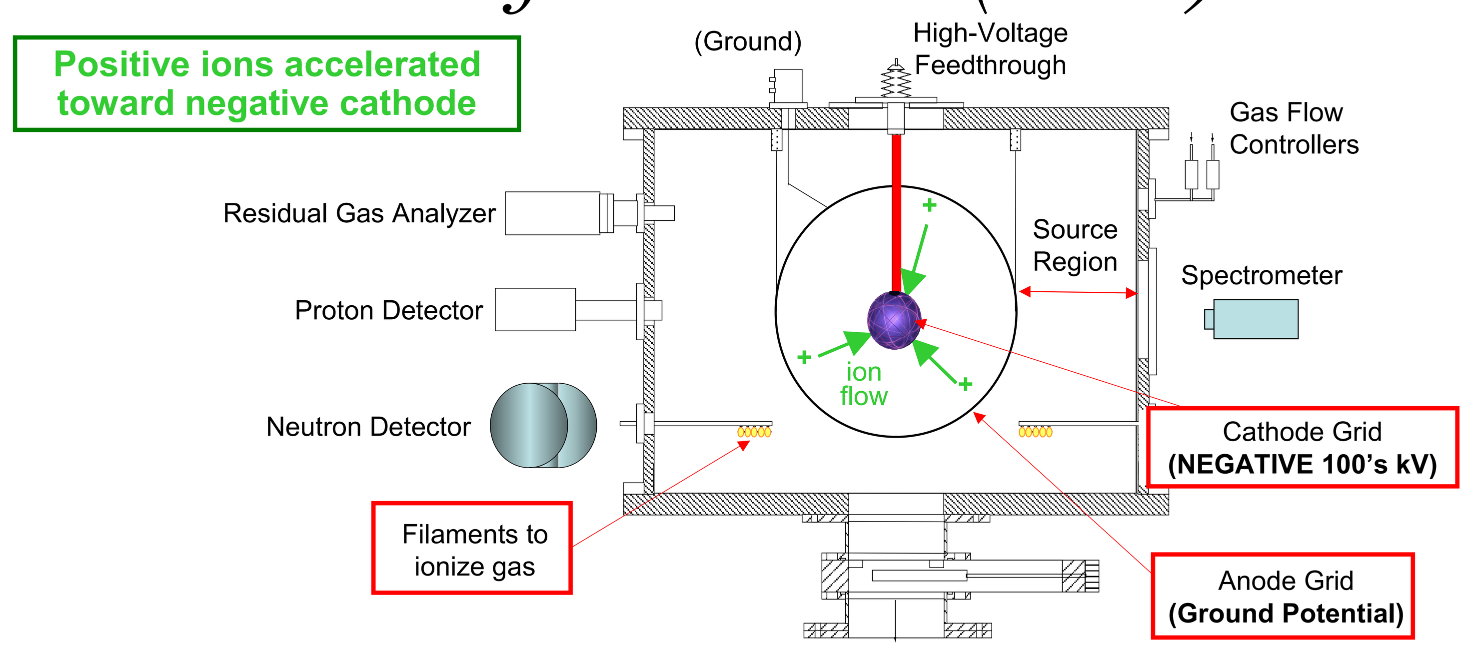
Nuclear power without radioactivity!

Neutron rate per watt (incl. main side reactions)	
Reaction	Neutrons/second
D-T	4×10^{11} *(14.1 MeV)*
D-D	9×10^{11} *(2.45 MeV)*
D-³He	2×10^{10} *(2.45 MeV)*
³He-³He	negligible
p-¹¹B	negligible

Number in brackets indicates neutron energy

- D-T reaction is easiest, but: many high-energy neutrons
  → wall damage & radioactivity
  → complicates reactor design
- Advanced fuels produce fewer & lower-energy neutrons
  → harder confinement physics but easier, cheaper engineering
- Tritium is also radioactive, must be bred; ${}^3He$ availability is an issue, but other fuels are **plentiful and stable.**

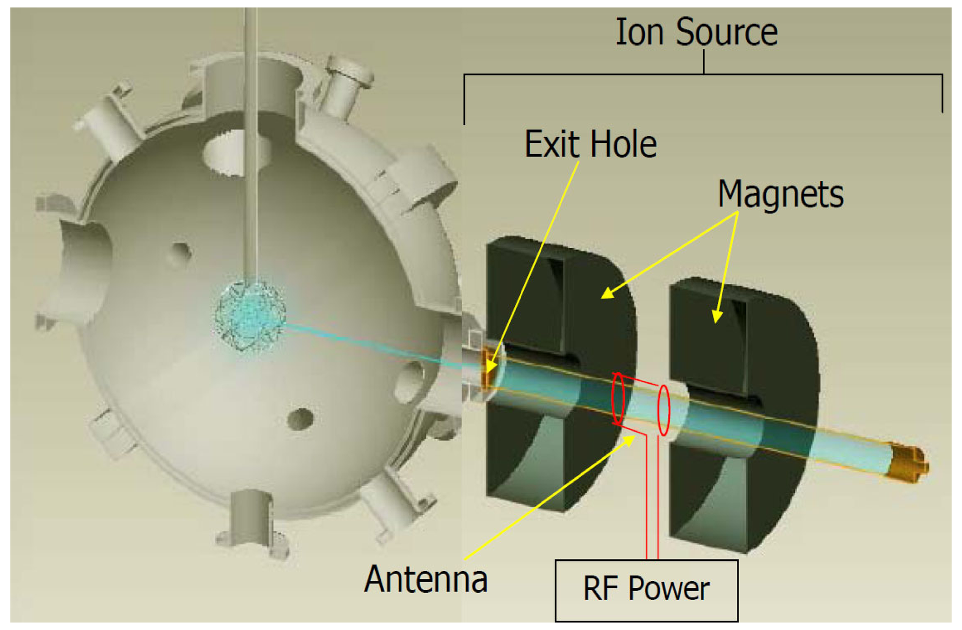
Inertial Electrostatic Confinement (IEC)



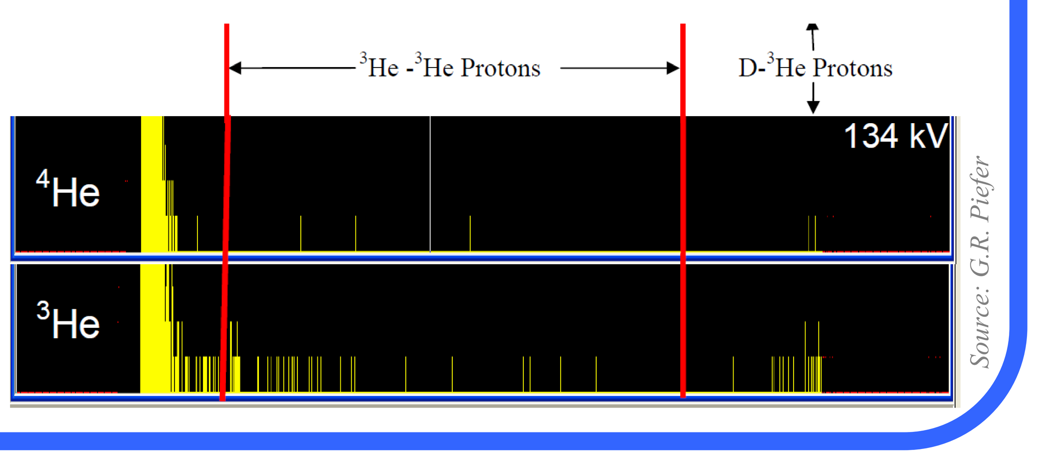
- Most fusion concepts: bulk plasma (ionized gas) is thermally heated → only few particles reach fusion-relevant energies.
- IEC devices directly accelerate ions, so they are **better suited for studying advanced fuel reactions** requiring high energies.
- UW IEC Group runs D-D and D-${}^3He$ routinely. Research is building on previous work with ${}^3He$-${}^3He$, trying to extend the developed techniques to p-${}^{11}B$.
- **Caveat**: IEC gridded devices achieve steady-state fusion easily, but not near energy breakeven. However, spin-off concepts such as the Polywell™ may result in a viable advanced fuel reactor.

Previous Work

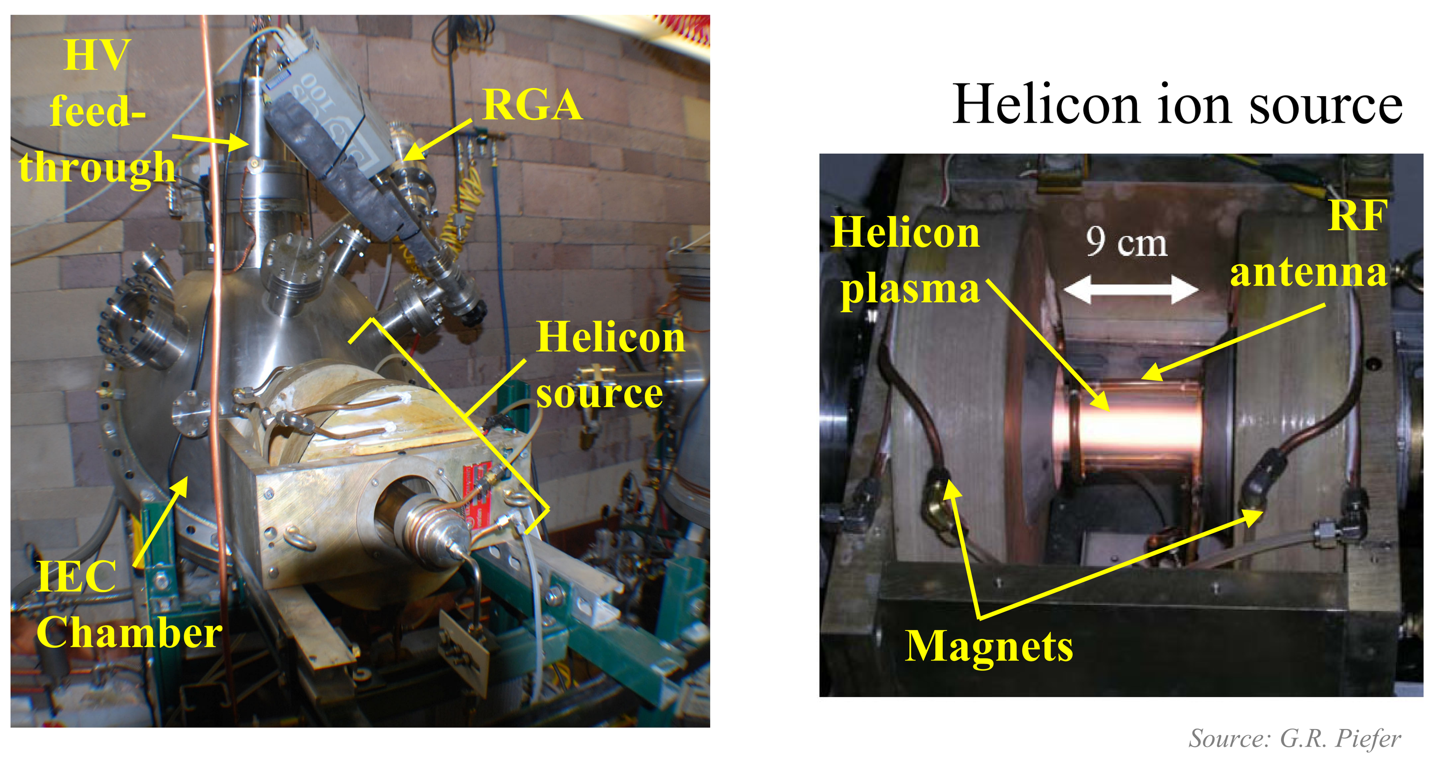
- Piefer (2006): **${}^3He$-${}^3He$ protons first detected** in an IEC experiment: HELIOS, a spherical device, designed to operate at ~0.2 mTorr using an external helicon ion source.



- The current record ${}^3He$-${}^3He$ rate is 1.1×10^3 reactions/sec at -134 kV cathode voltage and 25 mA meter current.

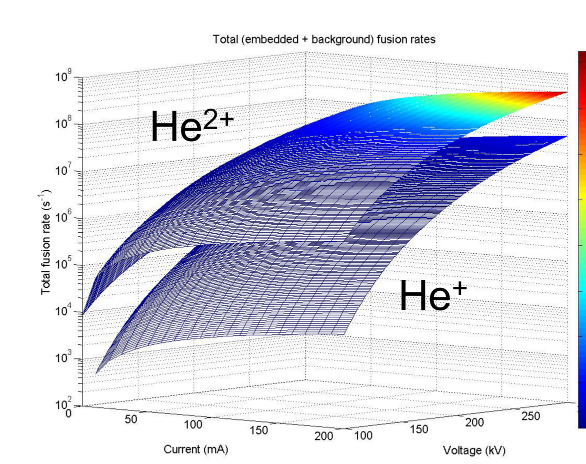


Experimental Setup



Research Underway

- IEC Group recently upgraded to a **300 kV power supply**.
- HELIOS high voltage feed-through, grid and stalk are being modified to allow for experiments at **200 kV & beyond**.
- An ion extraction system and a more efficient antenna are to be implemented on the helicon source to **achieve higher currents**.
- An electron cyclotron resonance (ECR) ion source producing He^{2+} ions is under consideration, in order to **double ion energies**.



- Most boron precursors are highly toxic, but potential sources are being studied for future **p-${}^{11}B$ experiments**.

Summary & Conclusions

- Advanced fuels are very attractive for **reliable, economical** and **radioactivity-free** operation of nuclear fusion power.
- IEC devices provide a simple, unique way to **study advanced fuels for fusion**.
- A campaign is underway to **expand the capabilities of the IEC facilities at UW-Madison**, with the goal of extending the previous ${}^3He$-${}^3He$ work to p-${}^{11}B$ fusion reactions.

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