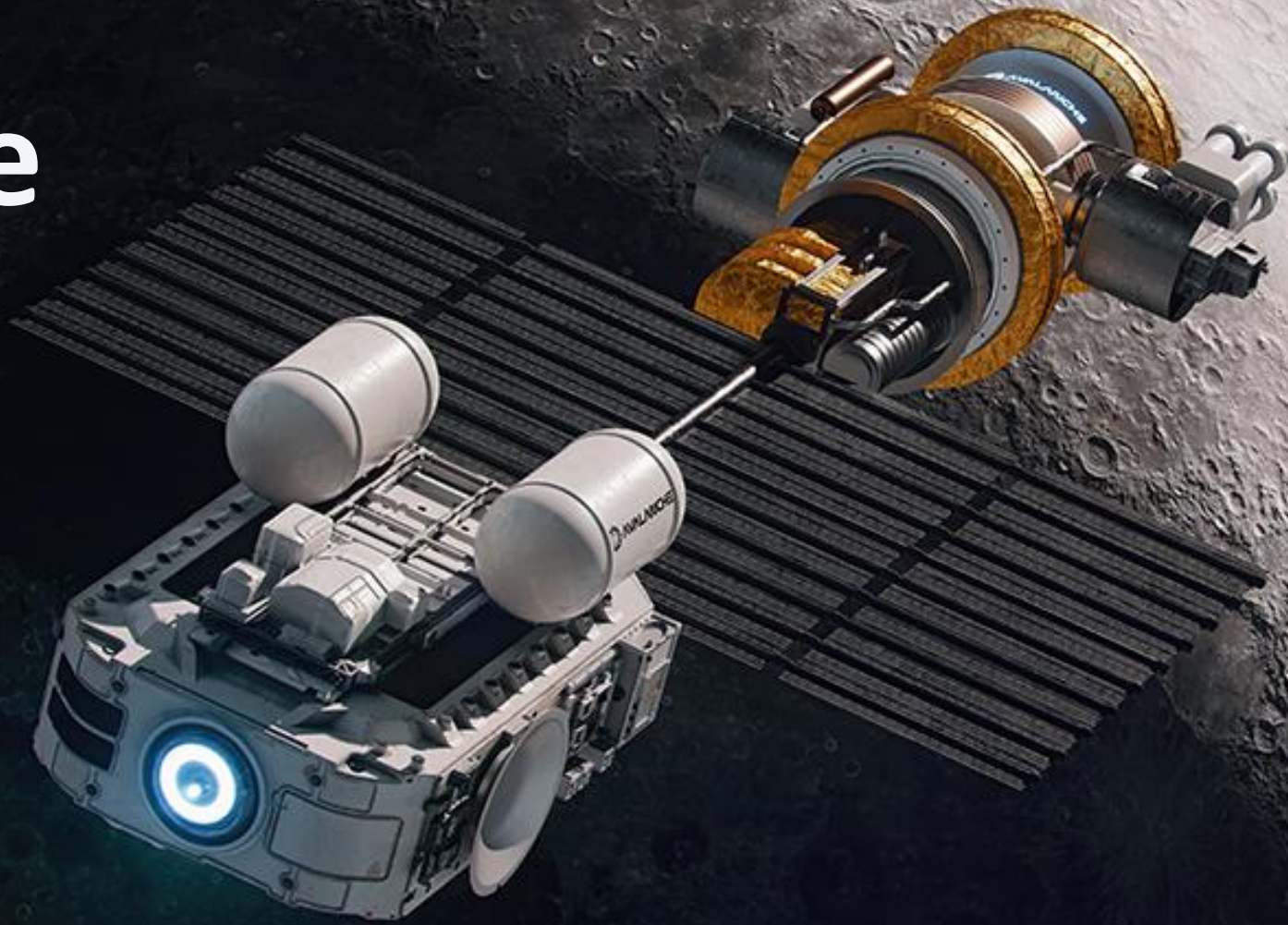


# Avalanche Fusion

The Orbitron – Use of Magnetostatic and  
Electrostatic Confinement

Robin Langtry (rlangtry@avalanche.energy)

CWFEST 2025



# Agenda

- A) Update on Orbitron fusion core science program
  - 1) 300 kV Feedthrough Development
  - 2) Taming Plasma Instabilities & Recent Plasma Density Breakthrough
- B) Proposal for a micro-Fusion Prototypical Neutron Source (uFPNS) to advance tritium breeding and material science
- C) Overview of FusionWERX test facility: A “commercial windtunnel-like test facility for developing and qualifying fusion technologies”

# Fusion Reactor Size determines Capital, Headcount and Development Speed

Built in years, iterate in months, civil engineering project

## Application: Grid

Most approaches are thermonuclear.

Reactor size varies from house to warehouse scale

Capital costs to commercial operations >\$1B

Headcounts 100's to 1000's of people

Estimated first commercial operations >6 years



Built in weeks, iterate in days, mass produce at factory scale

## Application: Mobility and Distributed Energy

Avalanche is developing world's smallest fusion microreactor.

Capital costs to commercial operations <\$1B

Headcount <200 of people

Estimated first commercial operations <6 years

Plasma core (right) is called an Orbitron



1GW



10's MW

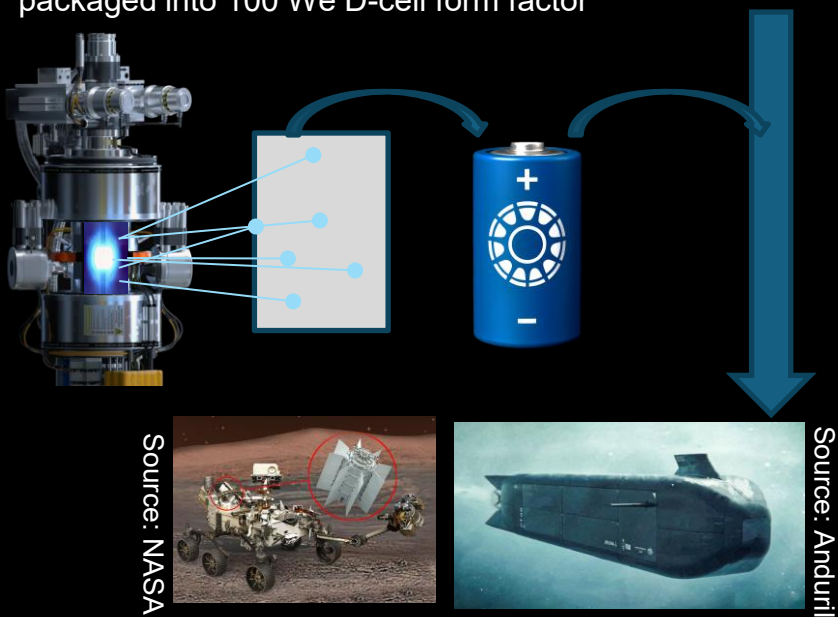


10's kW

# Product Roadmap

## 100's W to 1 kW

Radioisotope Power Systems aka "Nuclear Batteries"  
Neutrons from **Low Performance Fusion Machine**  
make Po-210 (138 day half-life) which is then  
packaged into 100 We D-cell form factor

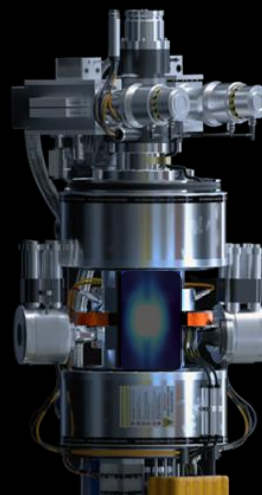


Neutron flux ( $\text{n/s-cm}^2$ ) determines rate we can make isotopes  
and defined as source strength ( $\text{n/s}$ ) / surface area ( $\text{cm}^2$ )

Small compact fusion machines can generate large neutron  
fluxes for irradiation testing and isotope production at much  
lower cost than large reactors

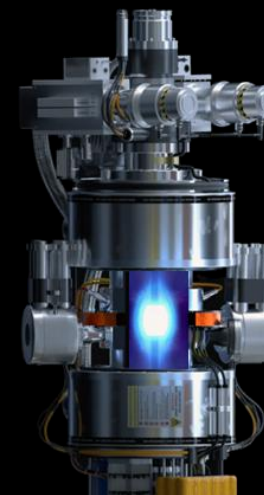
## 100 kW

**Medium Performance Fusion Machine**  
Ex: 50 cm Plasma Diameter operating at  
low plasma density  $1\text{E}13 / \text{cm}^3$



## 1 MW

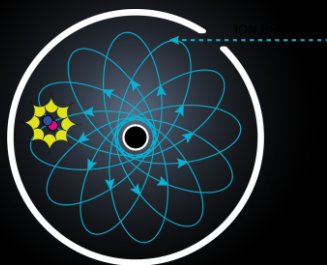
**High Performance Fusion Machine**  
Ex: 50 cm Plasma Diameter operating at  
high plasma density  $1\text{E}14 / \text{cm}^3$



# How It Works

Fusion plasmas need three things: high energy to fuse, high density to fuse a lot, and a long confinement time to make it meaningful.

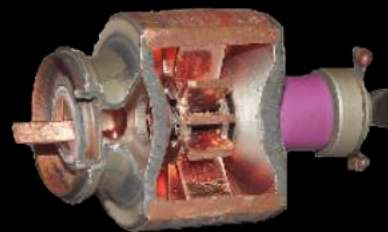
## Orbitrap Technology



Orbitrap-type geometries trap ions in self-intersecting, elliptical orbits with high-voltage electrostatics.

+

## Magnetron Technology

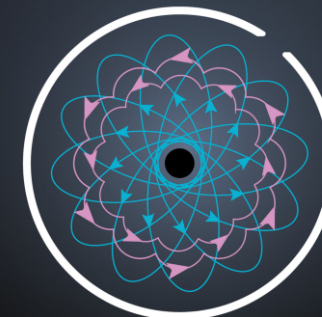
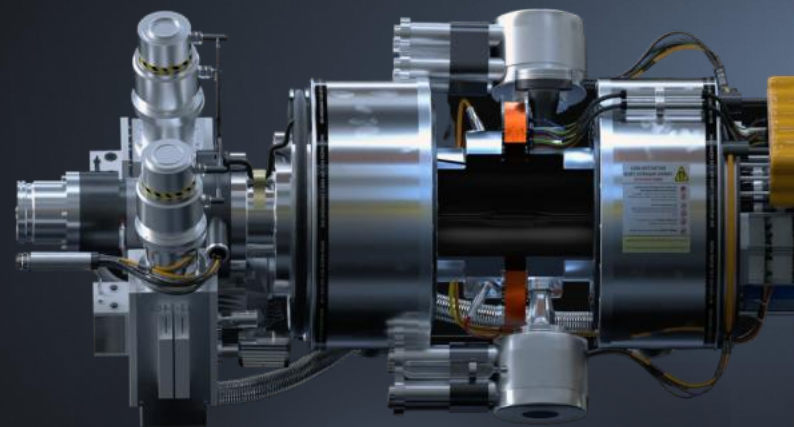


Smooth-bore magnetron architectures trap electrons in cycloidal orbits with magnetic fields.

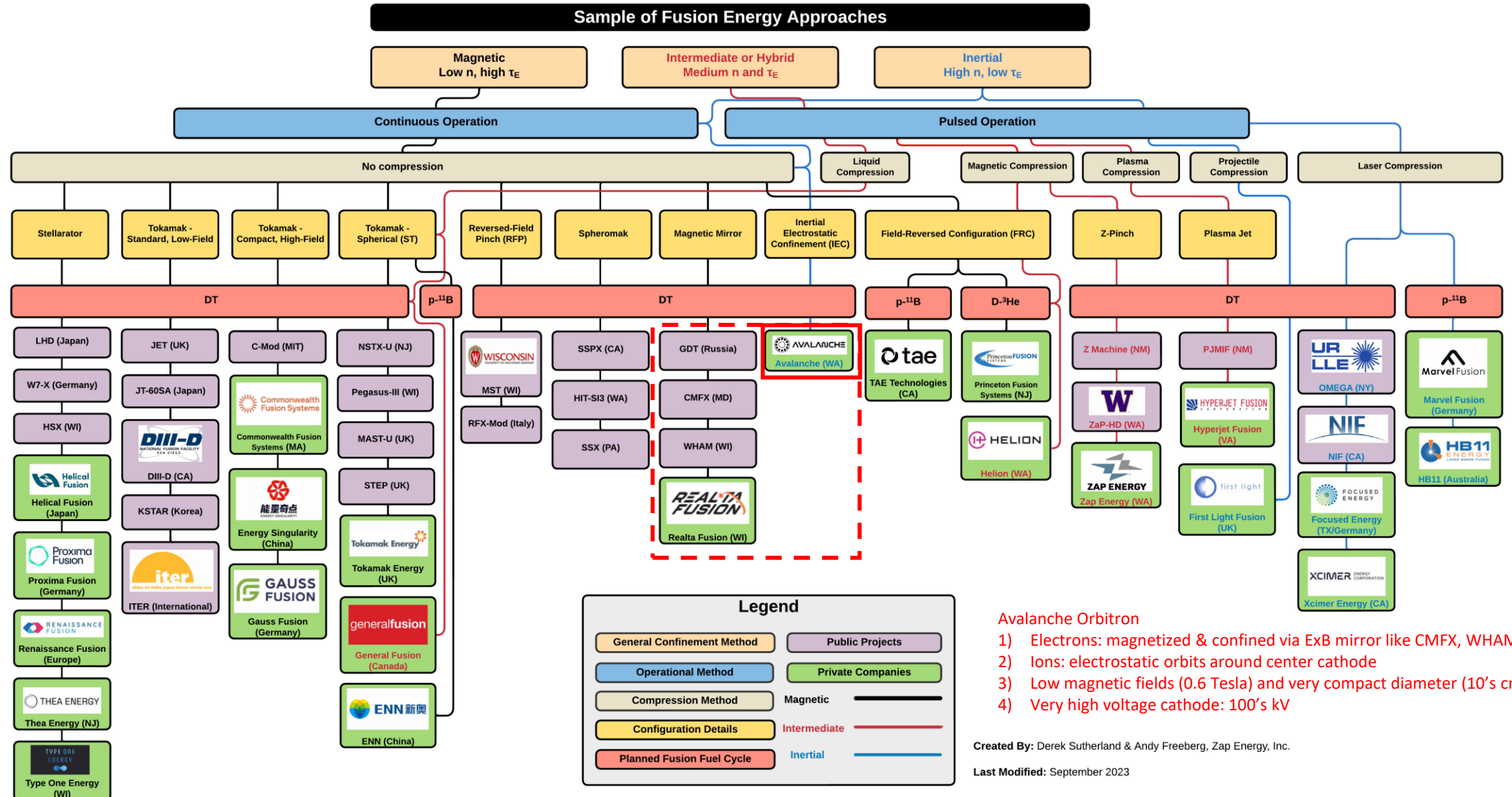
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## Orbitron

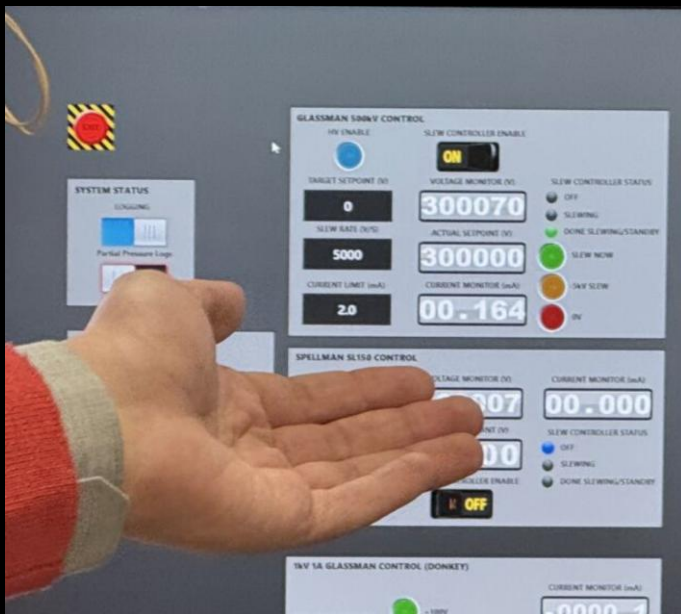
### Fusion Microreactor



Combining an orbitrap and magnetron, increasing voltage up 100's of kV, operating in a deep vacuum conditions co-confines high-speed ions & electrons for useful fusion.



# Recent Technical Milestones: 5 MV/m



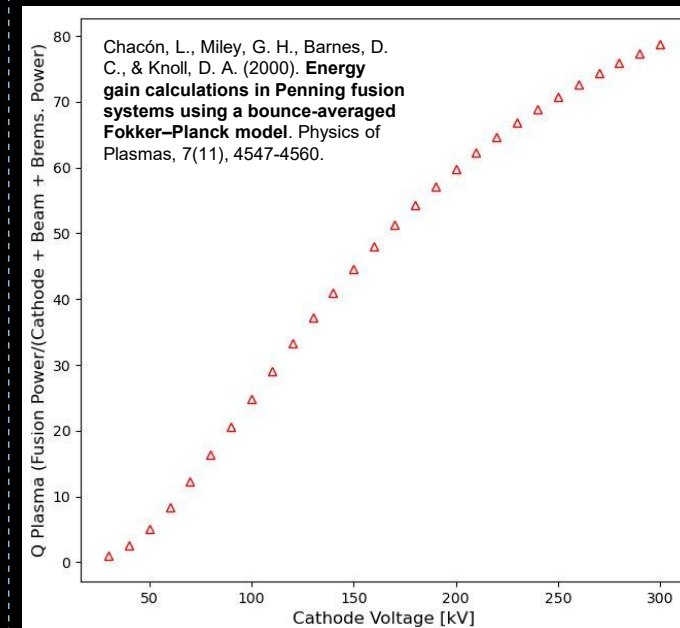
## 300 kV High Voltage

300,000 Volts at 0.164 mA = 42 Watts in a compact 12 cm diameter vacuum



## Test Fail Fix

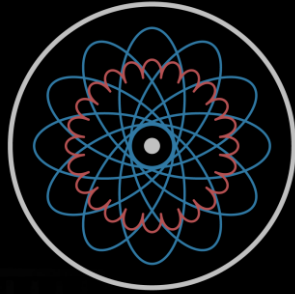
Hard fought! We learned a ton building testing and failing high voltage deep vacuum feed throughs.



## 300 kV means Efficient $Q>1$

300 kV a major Avalanche Series A technical milestone and key enabler for efficient  $Q>1$  Magneto-electrostatic fusion.

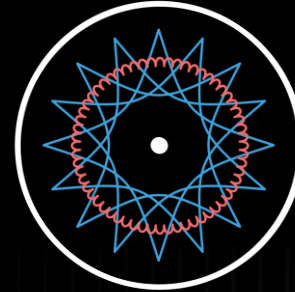
## Electrostatic



- Large ion orbits  
Very high fusion plasma  $Q > 50$  ( $\rho^* > 0.9$ )
- Limited magnetic field strength → low density → low power output.
- Even with co-confinement with electrons, suffers an m1 rotational mode preventing target densities.

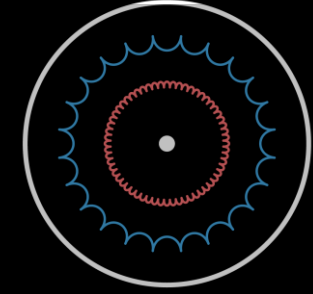
## Hybrid Magneto-electrostatic

Highly rotating, large ion orbits



- Moderate ion orbits ( $0.2 < \rho^* < 0.9$ )
- Complex orbits– not purely electrostatic or cycloidal.
- Likely can still be JxB shear stabilized to kill instabilities and turbulence, but unclear at what  $\rho^*$  this becomes too small.
- Does not require as high voltage as Centrifugal Mirror (100kV – 1 MV).
- Potentially highest performing approach to compact fusion, but requires improvements in plasma Q modeling and experimental data.

## Centrifugal Mirror

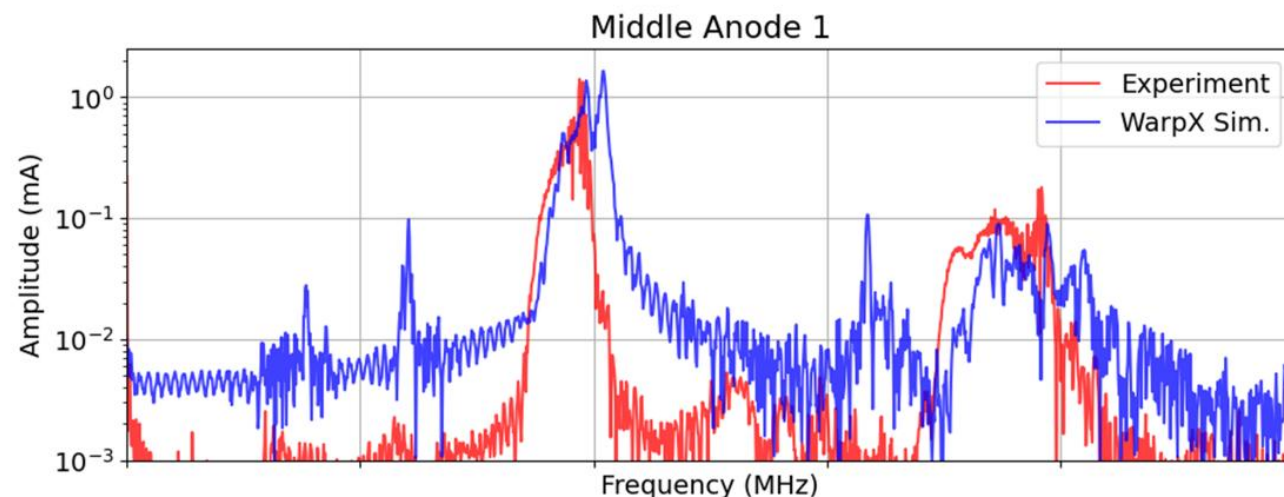
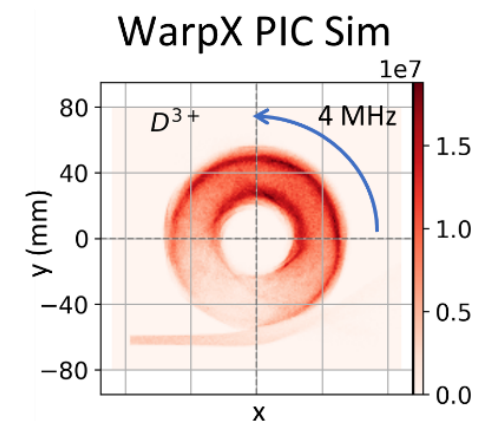
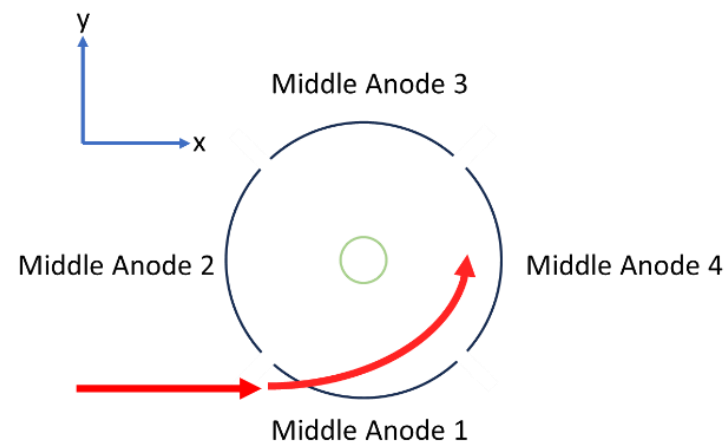
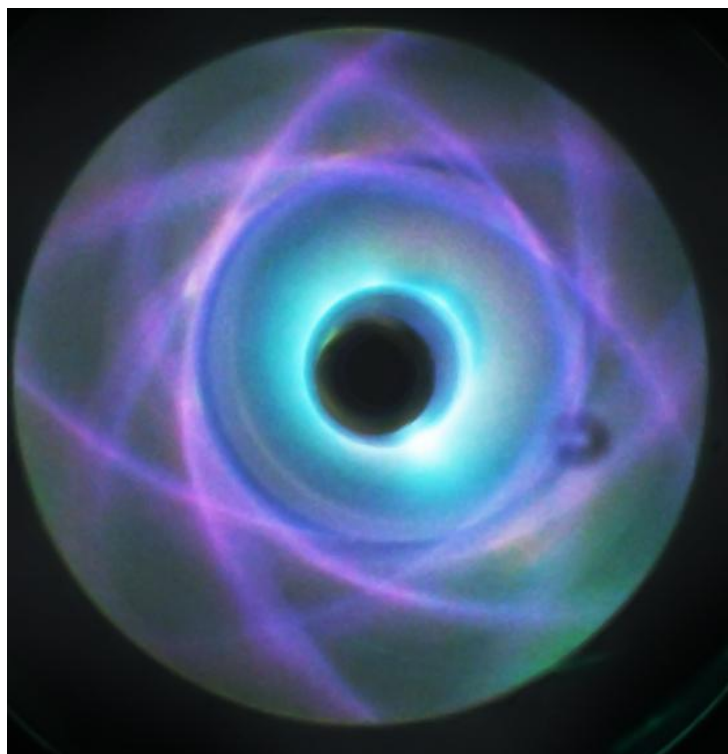


- Small cycloidal ion orbits ( $\rho^+ < 0.2$ )
- Plasma behaves more like fluid which introduces JxB rotational force term creating shear.
- Shear kills instabilities and turbulence, results in low particle diffusion to walls (e.g. classical diffusion), long confinement time and less power to maintain.
- Additional power for JxB and axial losses mean lower fusion plasma Q, main disadvantage is requiring very high voltages – 500kV to 5 MV for  $Q = 1-10$ .

$\rho^* = \text{Ion orbit radius} / \text{Characteristic device radius}$

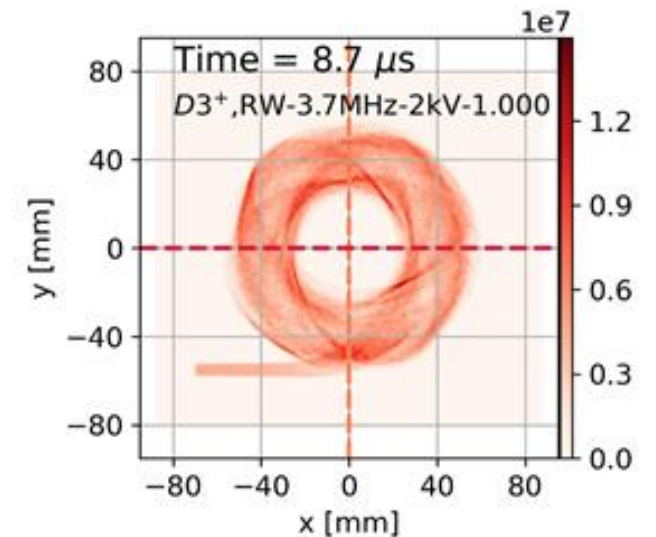
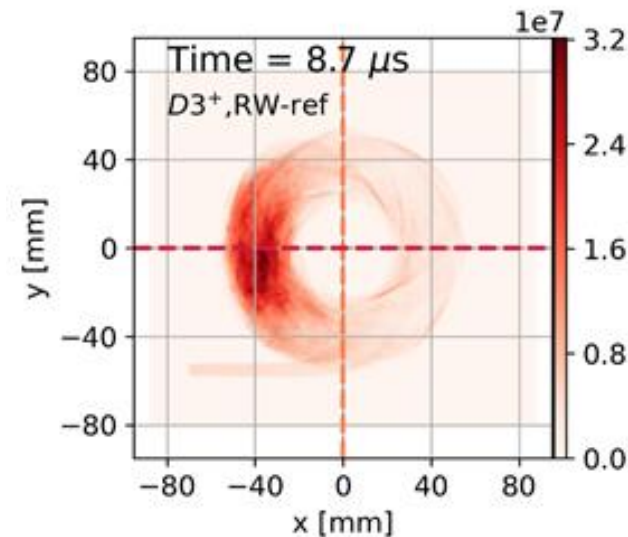
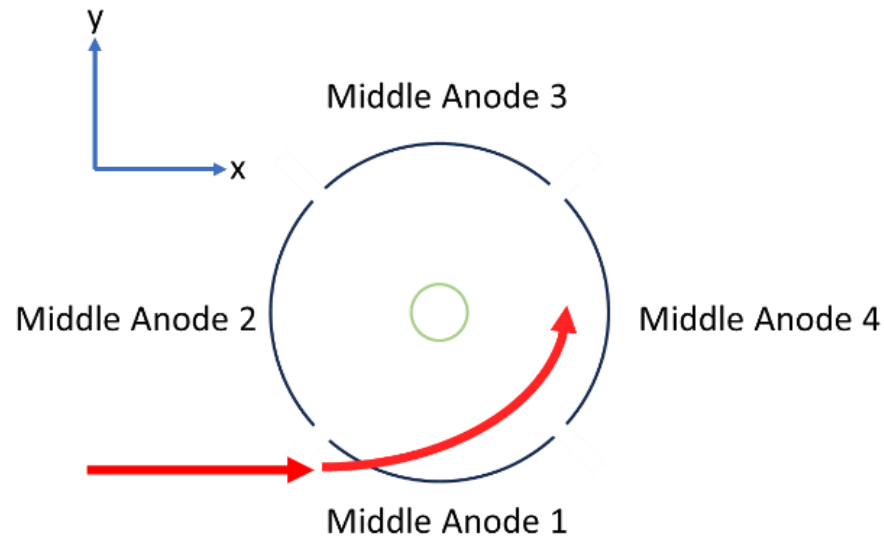
# Measured and Simulated Ion Plasma Stability and Density Limit due to Rotating m1 mode at $1\text{E}8\text{ ions/cm}^3$

Low-light astronomical camera snapshot of  $\text{D}_3^+$  ion beam injection and orbits in purple (not visible to human eye)

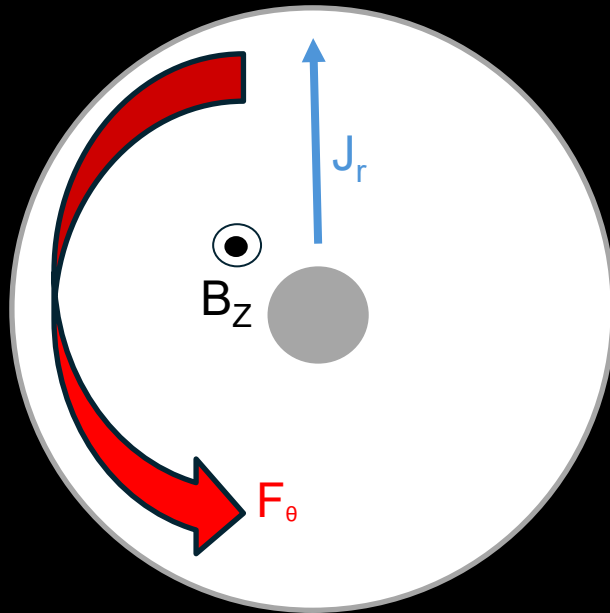


# Ideas Explored: Torque plasma and use shear to suppress plasma instabilities to push density higher in experiments

Example: WarpX Simulations without (middle) and with (right) a “rotating wall” i.e. rotating electric field of 2 kV and rotating at a frequency of 3.7 Mhz torquing the plasma and showing the suppression of the ion rotating mode (clumping of ions on left) and thus reducing ion “transport” and losses to the walls.



# Plasma Stability Breakthrough and Record Density in very Compact Fusion Machine



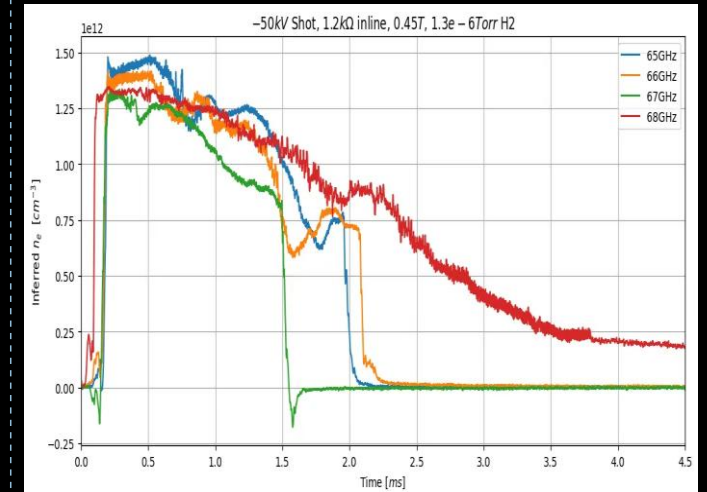
## Pulsed Cathode Torque

Rapidly spinning up plasma generates shear stabilization suppressing modes & turbulence. Inspired by Russian PSP-2 Experiment (1980)



## JYN Fusion Machine

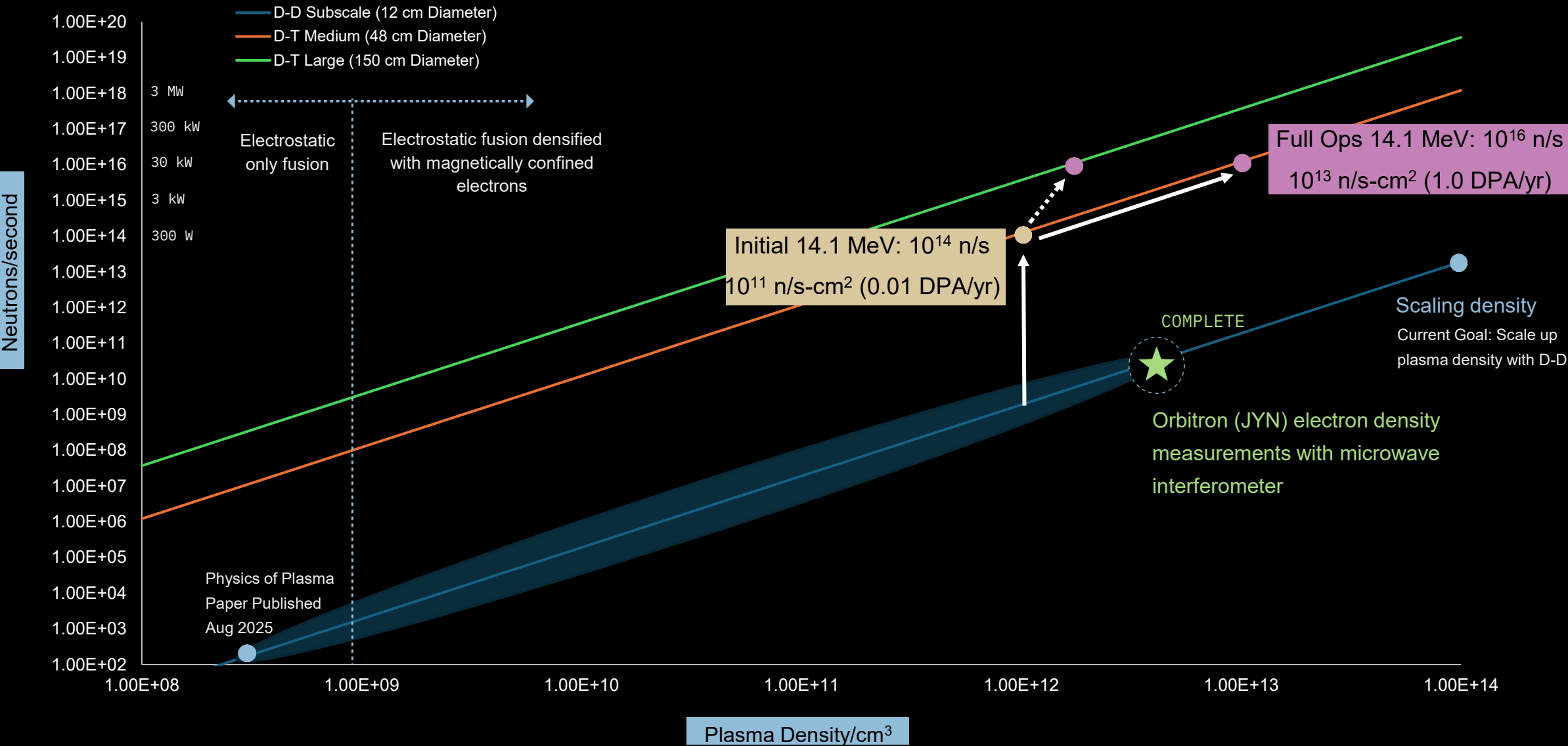
6 cm plasma radius at 100 kV 300 Amp pulsed operating at 0.45T centerline with 4.5T superconducting magnets and mirror ratio of



## Measured Low to Mid $10^{12}$ /cm<sup>3</sup> Shear Stabilized Plasma Densities

Possibly a record magneto-electrostatic density for such a small 12 cm diameter device

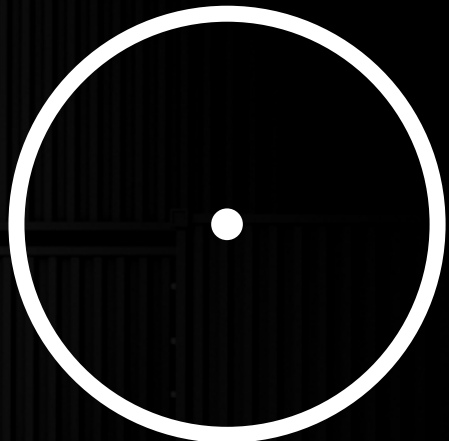
# Fusion Rate Roadmap for uFPNS & FusionWERX



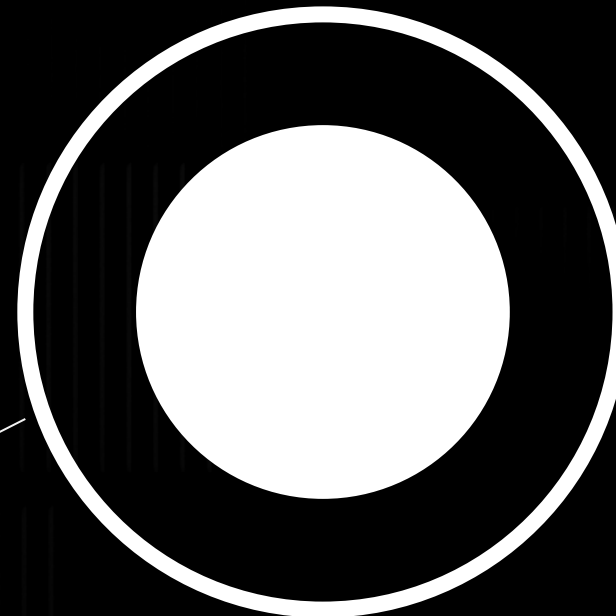
# Comparison of machines

(plasma cores)

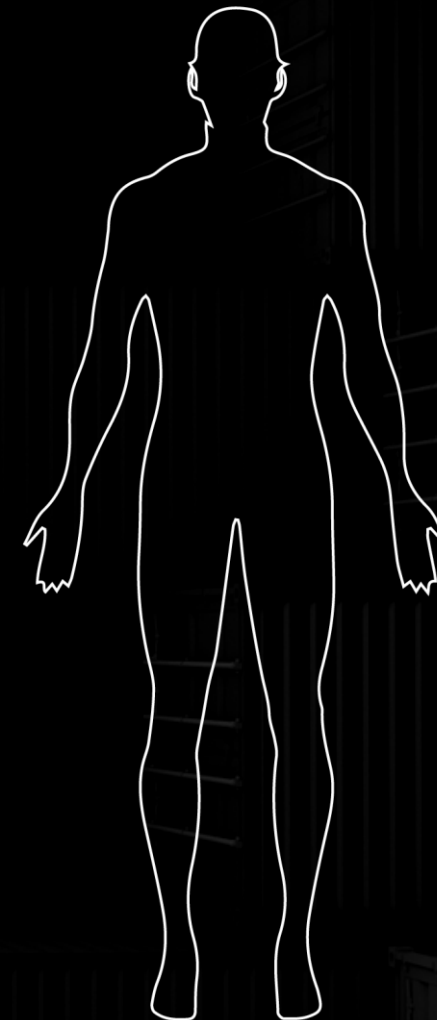
- Few machines have use shear to shrink device size
- Jyn architecture is rivaling peak performance of multi-decade programs already.
- Jyn is the smallest fusion machine to ever achieve these densities, using shear or otherwise.



Device: MCX<sup>1</sup>  
**Entity:** University of Maryland  
**Status:** Retired  
**Radius<sub>chamber</sub>:** 36.1cm  
**Radius<sub>cathode</sub>:** 3.8cm  
**Peak Density:**  $1 \times 10^{14}$  ions/cm<sup>3</sup>



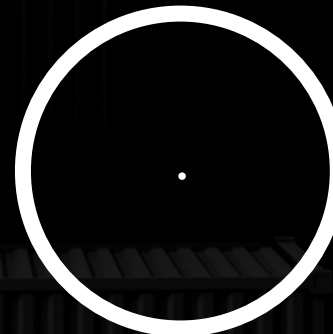
Device: PSP2  
**Entity:** Budker Institute (USSR)  
**Status:** Retired  
**R<sub>cathode</sub>:** 0.32cm  
**R<sub>chamber</sub>:** 5.5cm  
**Peak Density:**  $1 \times 10^{12}$  ions/cm<sup>3</sup>



Device: Jyn 1  
**Status:** In Operation - improving  
**Entity:** Avalanche  
**Radius<sub>chamber</sub>:** 5.5cm  
**Radius<sub>cathode</sub>:** 0.32cm  
**Peak Density:**  $5 \times 10^{12}$  ions/cm<sup>3</sup>



Device: Jyn2  
**Status:** In Fabrication  
**Entity:** Avalanche  
**Radius<sub>chamber</sub>:** 10cm  
**Radius<sub>cathode</sub>:** 0.32cm  
**Peak Density:** TBD



Device: \*Stardust  
**Status:** In Design  
**Entity:** Avalanche  
**Radius<sub>chamber</sub>:** 25cm  
**Radius<sub>cathode</sub>:** 0.32cm  
**Peak Density:** TBD

August 2025

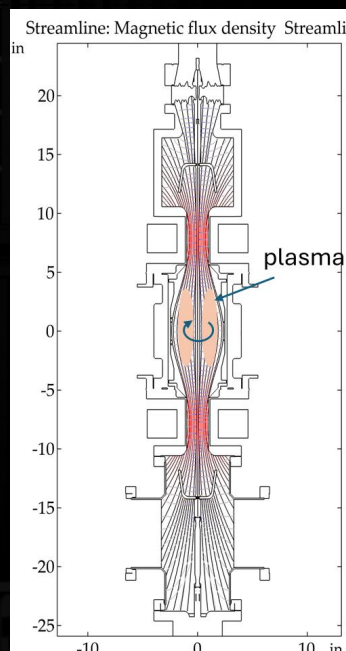
<sup>1</sup> – CFMX has replaced CMX at the University of Maryland but has yet to meet CMX peak density value.

## Purpose of Experiment Campaign

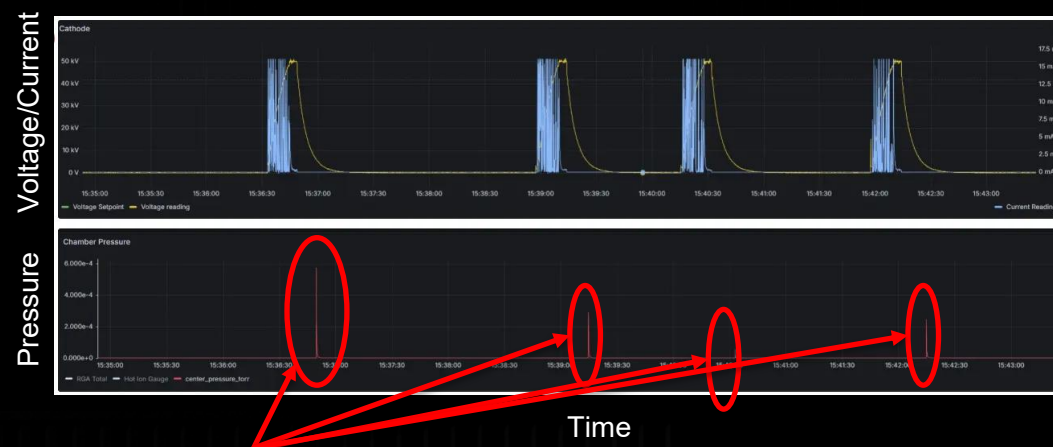
Get >1keV ion temperatures in a dominantly hydrogen plasma

### What were doing

We have achieved large plasma density. We are now trying to raise plasma temperature by attaining  $V_{\text{cathode}} \sim 30\text{kV}$



### First Challenge Encountered



Correlated with every discharge on JYN is a large pressure spike in the 100s uTorr. This is a sputtering avalanche reaction. Current theories including sputtering of surface contaminants (water) or cathode material. This limits our cathode voltage. PSP-2 and MCX also encountered this.

### Plan to Overcome

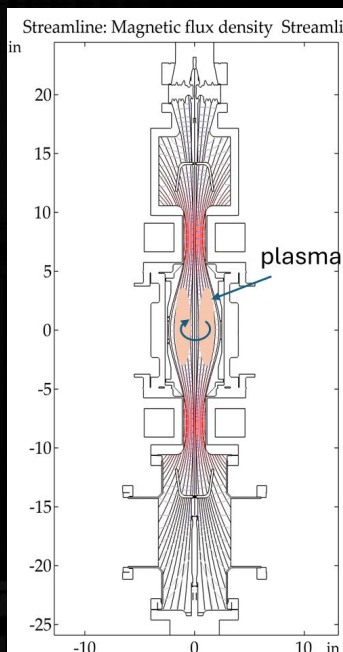
- Geometry changes to cathode & anode to move plasma away from walls
- Improved pumping paths
- Higher Temp. Bakeout between vacuum breaks 150C
- Gas puffing to manage neutral gas loads during a shot

## Purpose of Experiment Campaign

Get >1keV ion temperatures in a dominantly hydrogen plasma

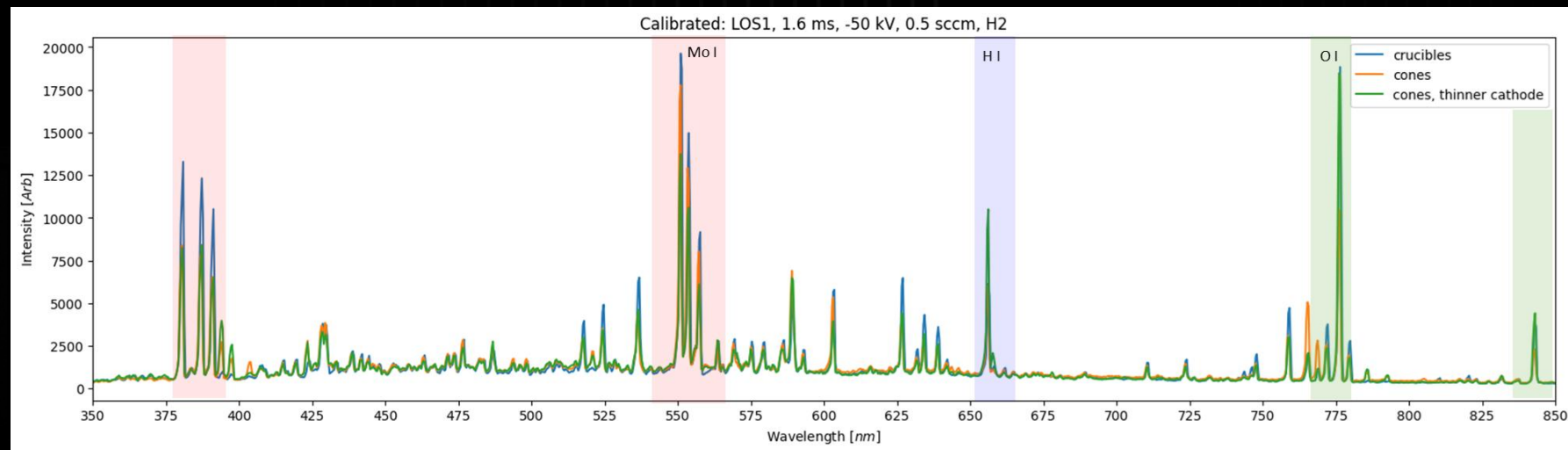
### What were doing

We have achieved large plasma density. We are now trying to raise plasma temperature by attaining  $V_{\text{cathode}} \sim 30\text{kV}$



-3 Design iterations ( $\cong 1$  per week) from Sept 15 to Oct 10 reduced Molybdenum sputtering from cathode and made Oxygen the dominant impurity OES line

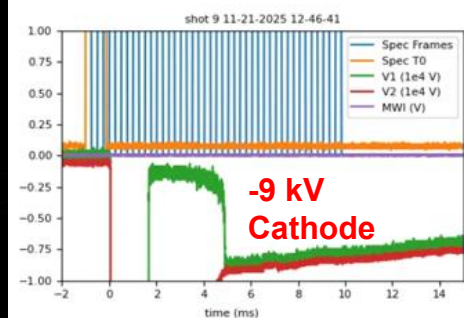
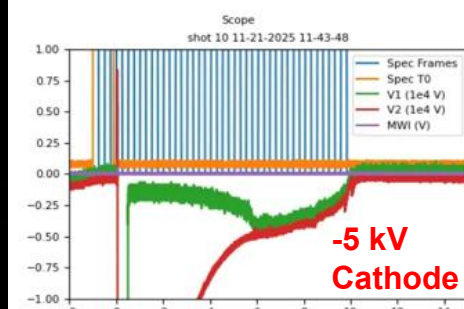
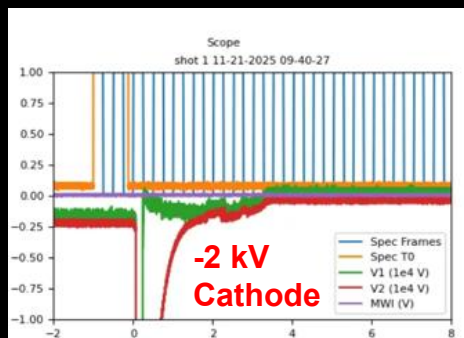
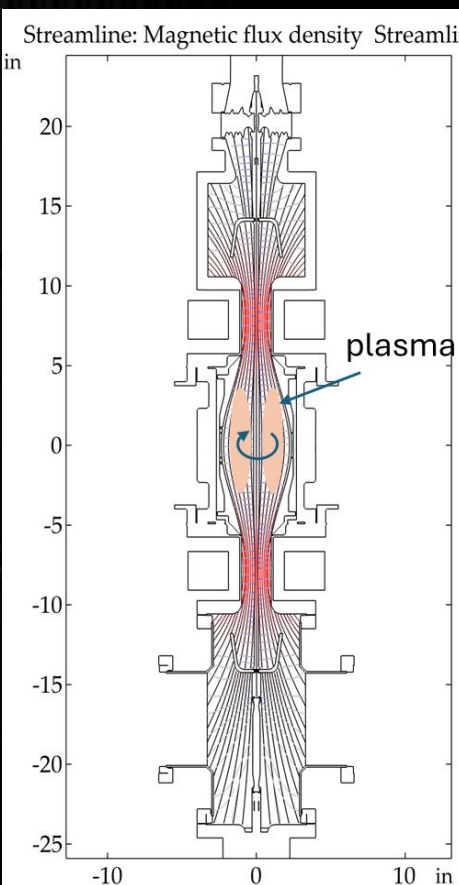
- Oxygen from water is likely playing a roll as well in Mo sputtering
- Follow on Step: Implement improvements to eliminate water and reduce pressure pulse during shots over next couple weeks



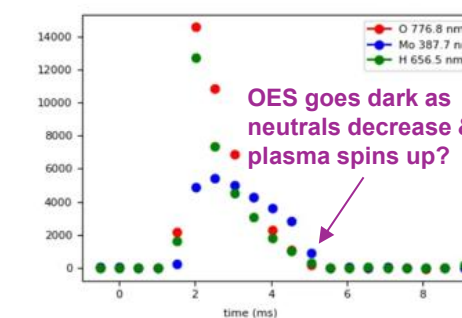
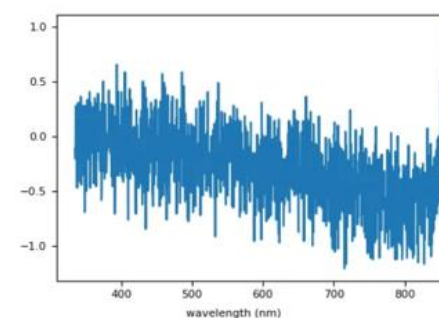
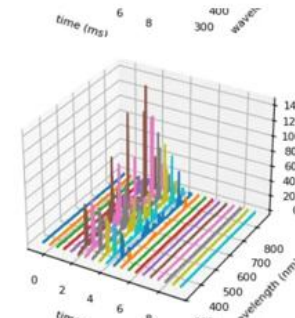
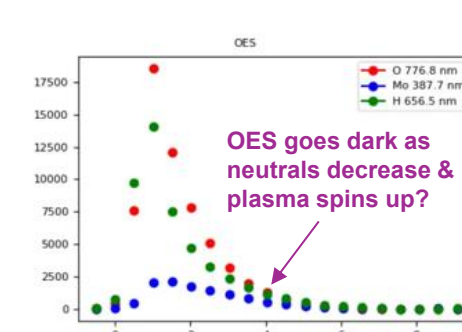
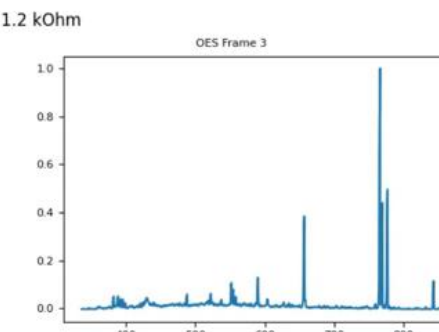
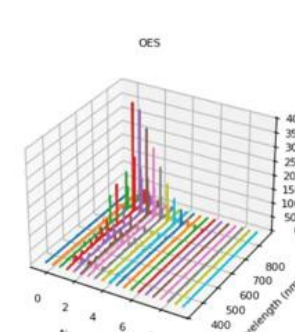
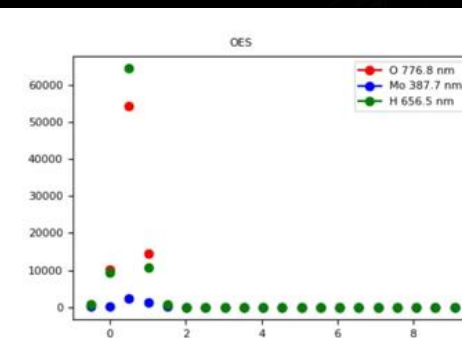
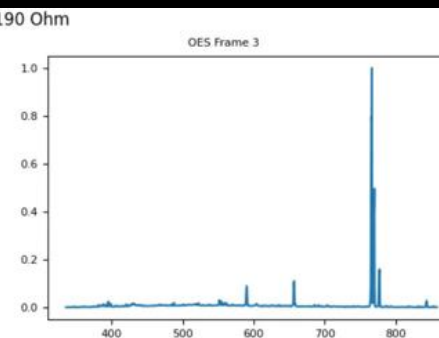
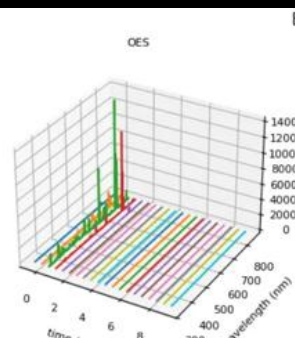
## Purpose of Experiment Campaign

Get >1keV ion temperatures in a dominantly hydrogen plasma

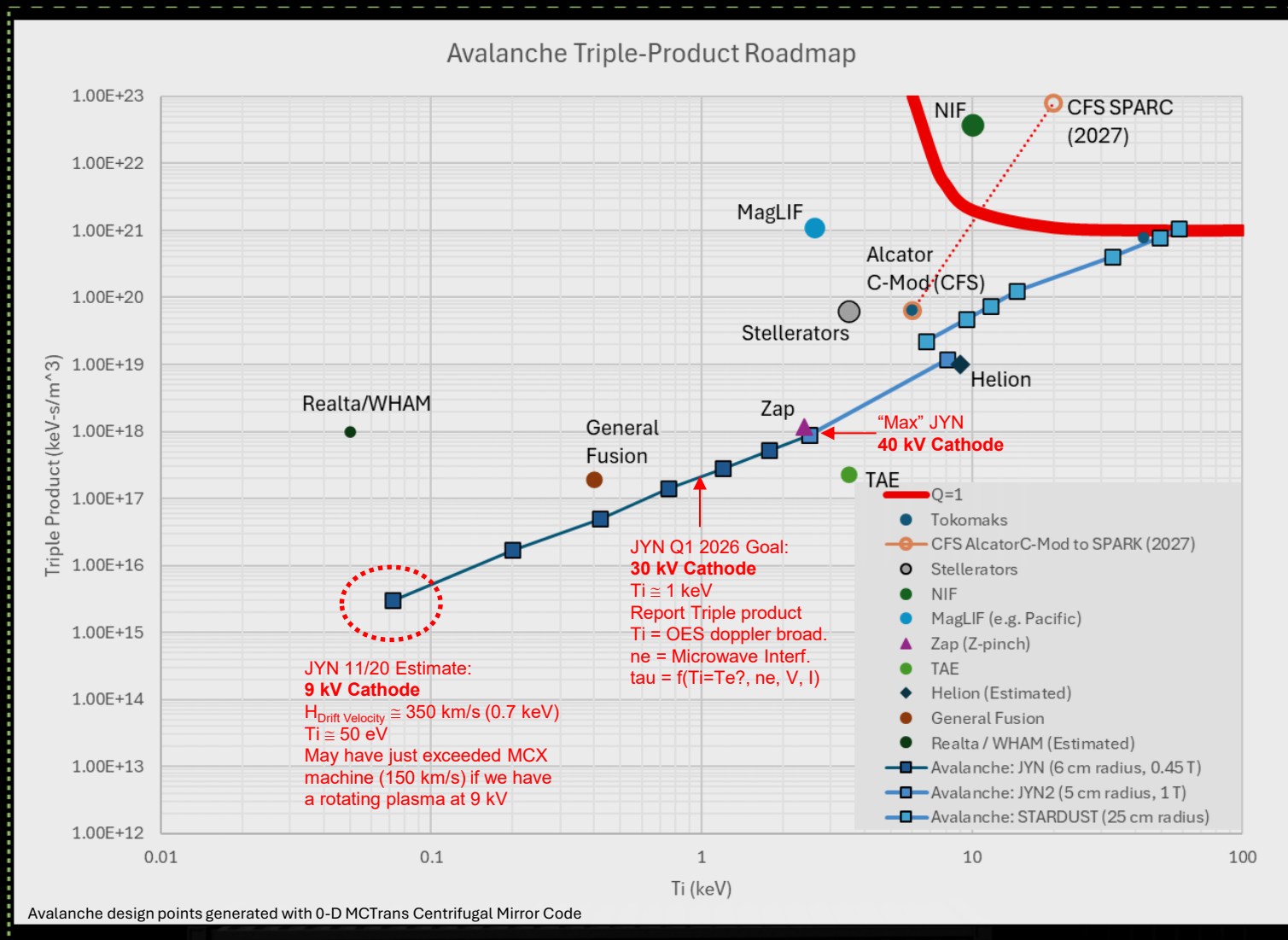
- Moved Anode away from plasma
- Steady increase in voltage across plasma with successive shots
- OES goes dark – may need more sensitive OES camera or dope plasma with He or H gas puffs to get back H-alpha (656.5 nm)



Plasma Shots: Increasing cathode voltage & shot length

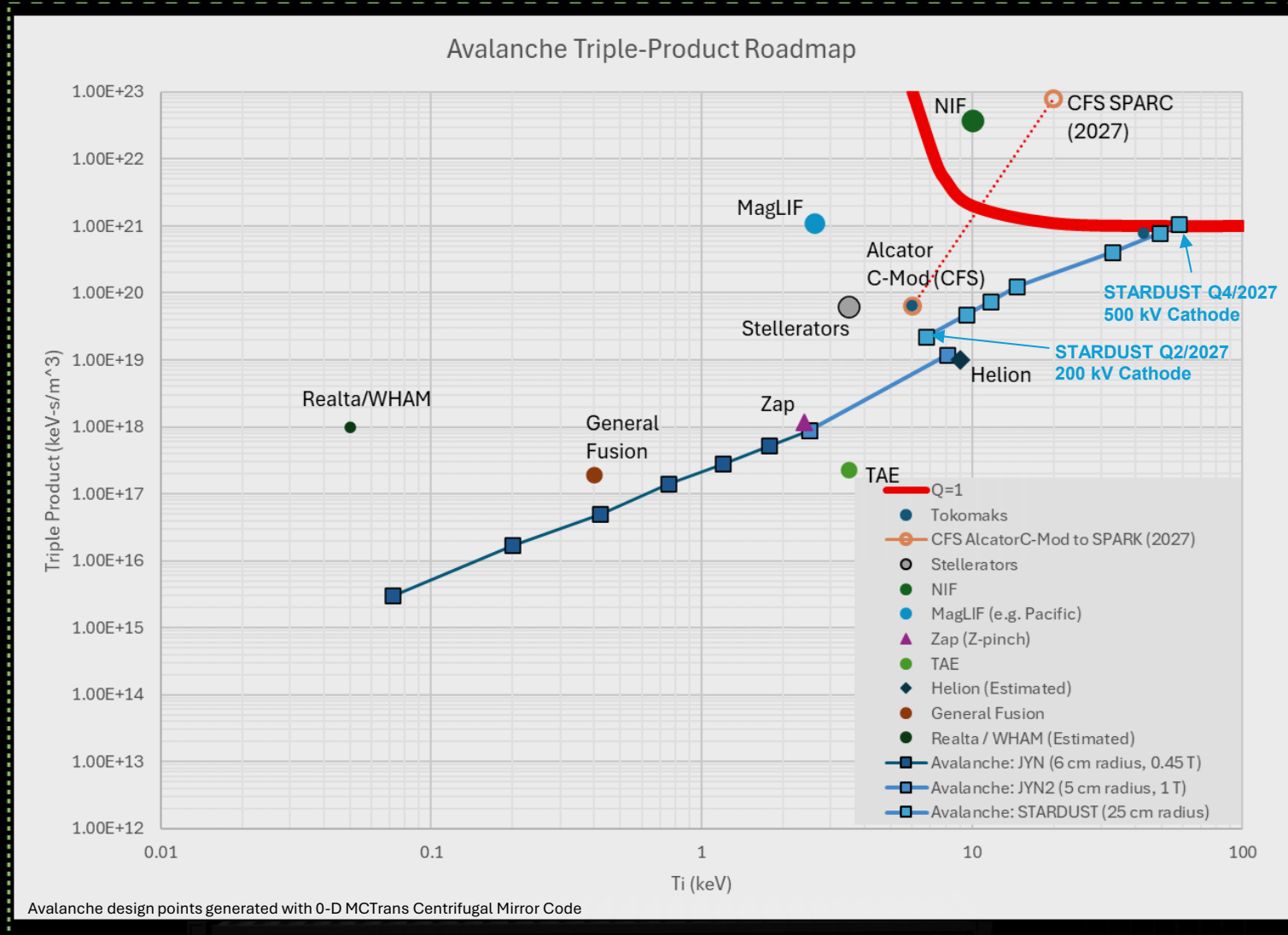


## Fusion Triple Product Development Path



# Planned DoW DIU Prototype 2027 (“STARDUST”)

## Fusion Triple Product Development Path



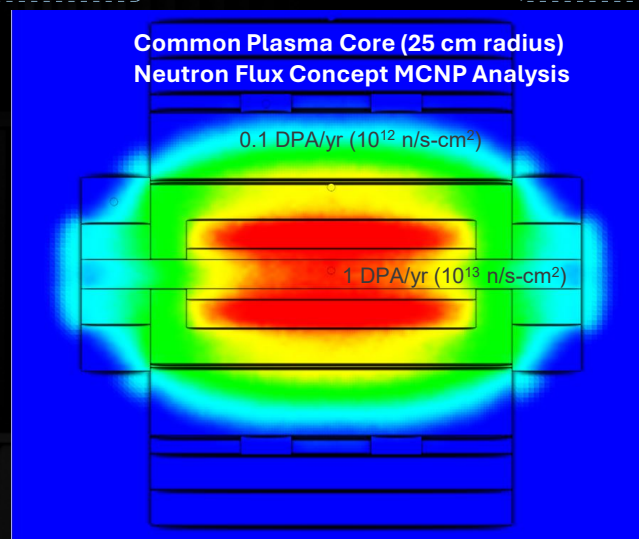
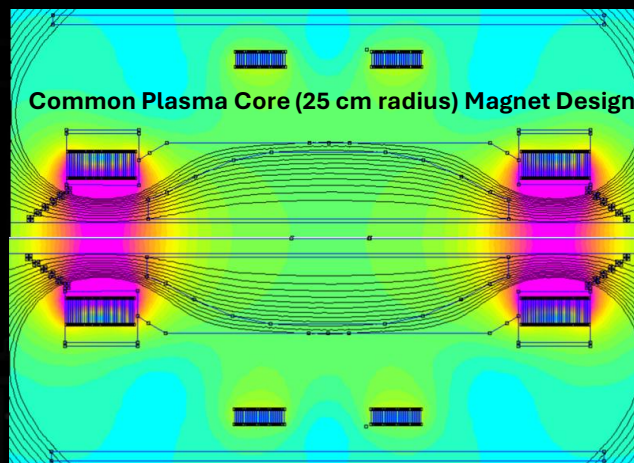
### JYN Experiment

- Small 6 cm radius allows rapid prototyping & capital efficient path to learning and solving neutral gas management in magneto-electrostatic mirrors

### “STARDUST” Experiment

- Incorporate key learnings from JYN on neutral gas management
- Exceed previous records set by PSP-2 machine: 400 kV Cathode, Ti = 20 keV & tau = 0.1 ms (limited by neutral gas charge exchg)
- Low neutral gas load and larger 25 cm radius increases confinement time (tau) to sufficient Q>1 triple products
- Basis for a world class neutron source 10<sup>16</sup> n/s for tritium breeding and fusion materials development

# Common Plasma Core “STARDUST” Concept



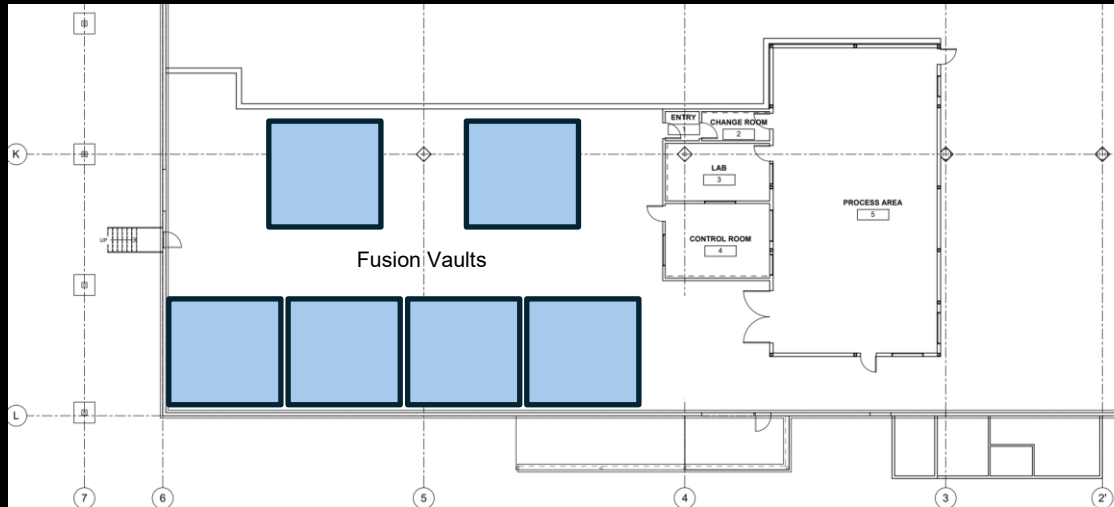
| Parameter with D-T Fuel                               | FusionWERX<br>Neutron Source | Q=1<br>Demonstrator | uFPNS<br>(1 DPA/yr) |
|-------------------------------------------------------|------------------------------|---------------------|---------------------|
| Device Radius (m)                                     | 0.25                         | 0.25                | 0.25                |
| Plasma Length (m)                                     | 1                            | 1                   | 1                   |
| Plasma Radius Min (m)                                 | 0.1                          | 0.02                | 0.1                 |
| Exhaust Radius (m)                                    | 0.11                         | 0.05                | 0.05                |
| B Field Throat (T)                                    | 5                            | 5                   | 5                   |
| B Field mid-plane (T)                                 | 0.95                         | 0.5                 | 1                   |
| Operating Voltage (kV)                                | 300kV                        | 500kV               | 500kV               |
| Ti (keV)                                              | 7                            | 55                  | 23                  |
| Te (keV)                                              | 3.5                          | 26                  | 10                  |
| $\rho^*$                                              | 0.191                        | 0.658               | 0.33                |
| Density (/m <sup>3</sup> )                            | 4.00E+19                     | 3.00E+18            | 3.00E+19            |
| Plasma Beta (%)                                       | 19%                          | 39%                 | 33%                 |
| Alfven Mach Number                                    | 1.02                         | 1.09                | 1.21                |
| Particle Flux (/s from MCTrans)                       | 5.70E+18                     | 1.60E+16            | 1.20E+18            |
| Plasma Neutral Density (/m <sup>3</sup> from MCTrans) | 2.00E+13                     | 5.70E+11            | 5.60E+12            |
| $P_{\text{plasma}} / P_{\text{vacuum}}$               | 1.39E-04                     | 3.83E-04            | 3.83E-05            |
| Required Vacuum Pressure (Torr)                       | 4.5E-06                      | 4.6E-08             | 4.5E-06             |
| Magnet Cost (\$)                                      | \$4,874,599                  | \$4,874,599         | \$4,874,599         |
| Duty Cycle                                            | 0.25                         | 0.06                | 0.80                |
| Tritium Consumption (g/yr)                            | 0.1                          | 0.0053              | 1.3                 |
| Triple-Product (keV-s/m <sup>3</sup> )                | 6.00E+19                     | 1.00E+21            | 4.00E+20            |
| Neutron Yield (n/s)                                   | 2.1E+15                      | 5.8E+14             | 1.0E+16             |
| Est. Cathode Neutron Flux (n/s-cm <sup>2</sup> )      | 2.1E+12                      | 5.8E+11             | 1.0E+13             |
| Est. Anode Neutron Flux (n/s-cm <sup>2</sup> )        | 8.3E+11                      | 2.3E+11             | 4.1E+12             |
| Power In (W)                                          | 114000                       | 1640                | 46600               |
| Efficiency (n/J)                                      | 1.8E+10                      | 3.6E+11             | 2.2E+11             |
| Oper. Cost (\$/yr, tritium+power+magnets/1 yr)        | \$4,923,639                  | \$4,875,509         | \$4,958,307         |
| Qsci                                                  | 0.051                        | 1.01                | 0.63                |

Open Source MCTrans 0-D code used to estimate plasma parameters <https://github.com/ianabel/MCTrans>

# FusionWERX: A “Wind-Tunnel” for Fusion



FusionWERX in Richland, WA, USA is a first-of-its-kind commercial-scale testing facility for advanced fusion technologies



Offering access to private companies, universities, national laboratories and public-private consortia working to accelerate the path to commercial fusion power



FusionWERX will operate under a broad-scope radioactive materials license with most advanced tritium handling capacities available in the private sector when fully licensed and operational.

Incubating a number of revenue generating businesses and also technology development partnerships at FusionWERX

Avalanche Defense/Space Q>1 Test Program and Prototype Qual.

# It's Time to Build Fusion!

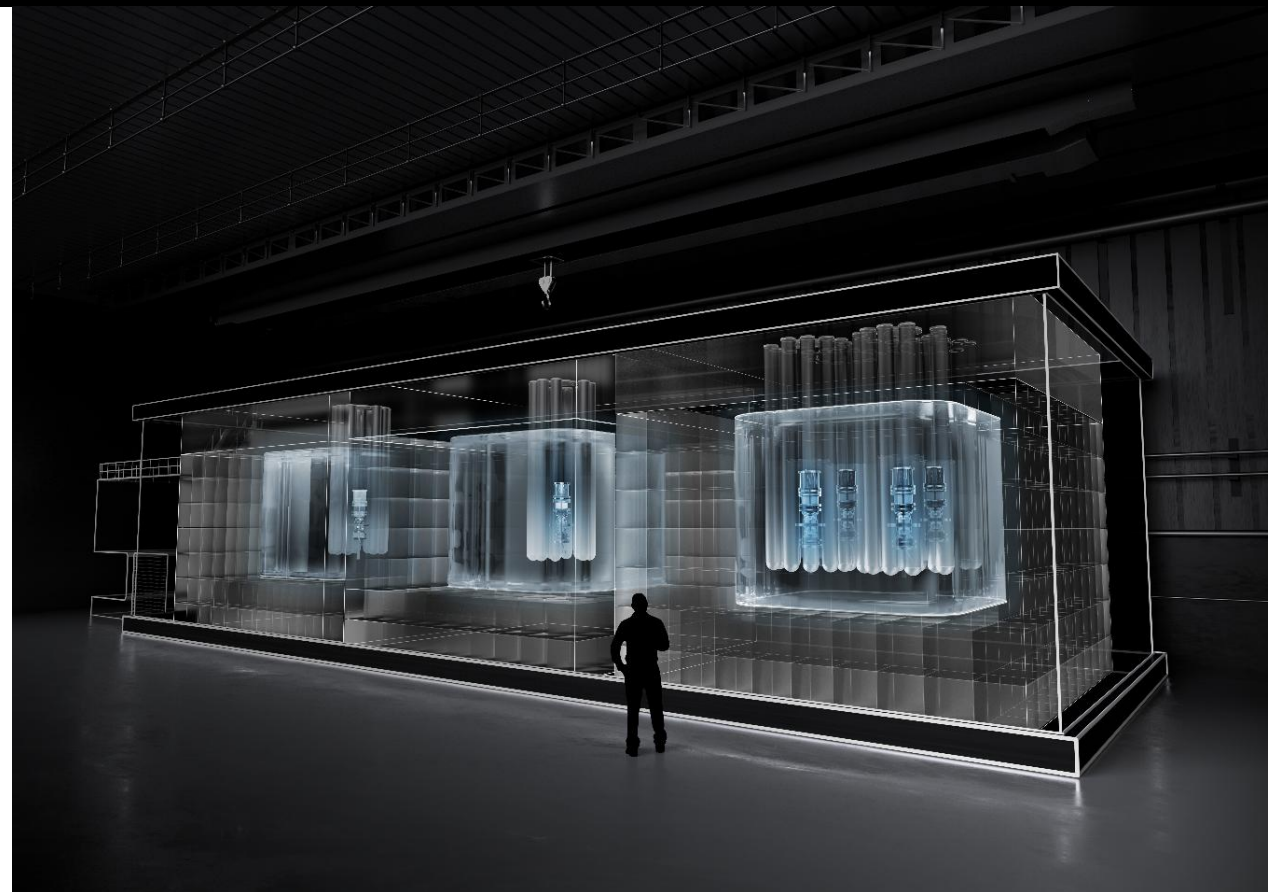
A) We've pushed the plasma physics of Orbitrons far enough that when scaled up by voltage and diameter operating with tritium they can be world class neutron sources

B) FusionWERX in Richland, WA is going to be a world class test facility for advancing fusion technologies and growing the supply chain and workforce.

C) FusionWERX is already supported by \$10M WA State Green Jobs award. **Putting together the private capital and joint development agreements right now (Reach out!)**

D) FusionWERX will be comprised of:

- A broad scope radioactive materials handling license
- World class tritium handling capability up to 10 grams
- **uFPNS** neutron sources capable of up to  $10^{16}$  n/s generating 14.1 MeV neutron fluxes of  $10^{13}$  n/s-cm<sup>2</sup> and 1 DPA/yr OR thermal neutron fluxes of  $\cong 10^{13}$  n/s-cm<sup>2</sup>
- Open to fusion companies, labs and universities to develop technologies or qualify hardware
- **Operating on flexible commercial IP terms (No CRADA's, unless you want to ...)**



# Orbitron Fusion

Small scale fusion for mobility and distributed energy applications





**Thank you.**  
reachout@avalanche.energy



AVALANCHE

# Why Washington State / Richland is ideal for Fusion

## Washington

### Innovative spirit

- Aerospace / Adv Mfg (Boeing, Blue Origin, Paccar)
- Technology (Microsoft, T-Mobile, Expedia)
- Commerce (Amazon, Costco, Starbucks)
- Fusion hub (Avalanche, Helion, Zap, KF, UW, WSU)

### Regulatory support

- Agreement State
- DOH leads in US fusion regulatory expertise
- X-ray, emissions & materials licensing under one roof

### Legislative / Policy support

- Murray & Cantwell are fusion advocates
- Governors Inslee & Ferguson are fusion advocates
- WA Nuclear Caucus support
- Legislature streamlined fusion facilities permitting
- Legislature defined fusion energy as a project of “statewide significance”
- WA Green Jobs program & funding innovation

## Richland, Washington

### Nuclear hub

- Manhattan project legacy
- Hanford / PNNL
- Columbia Generating Station
- Washington State University / Tri-Cities

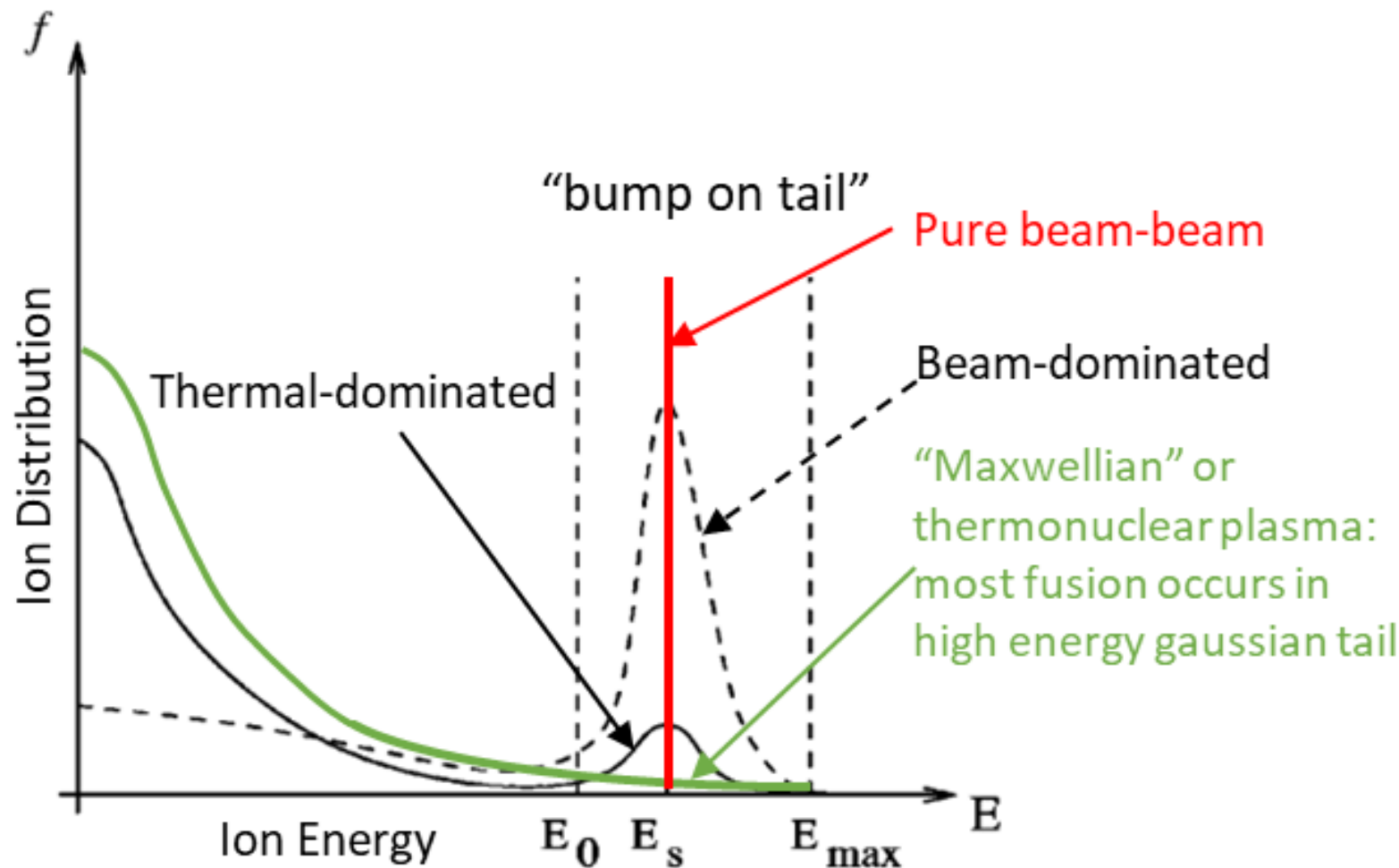
### Collaborative environment

- Tri-Cities Development Council (TRIDEC)
- Port of Benton

### Skilled workforce

- Nuclear, mechanical, electrical engineers
- Nuclear technicians
- Scientists and researchers
- Health physicists and safety officers
- Tritium handling expertise
- Particle accelerator expertise
- Apprenticeship & training programs

# Magneto-electrostatic fusion: non-Maxwellian and $Q > 1$



## Energy gain calculations in Penning fusion systems using a bounce-averaged Fokker-Planck model

L. Chacón<sup>a)</sup> and G. H. Miley  
*University of Illinois at Urbana-Champaign, 103 South Goodwin Avenue, Urbana, Illinois 61801*

D. C. Barnes and D. A. Knoll  
*Los Alamos National Laboratory, Los Alamos, New Mexico 87545*

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In spherical Penning fusion devices, a spherical cloud of electrons, confined in a Penning-like trap, creates the ion-confining electrostatic well. Fusion energy gains for these systems have been calculated in optimistic conditions (i.e., spherically uniform electrostatic well, no collisional ion-electron interactions, single ion species) using a bounce-averaged Fokker-Planck (BAFP) model. Results show that steady-state distributions in which the Maxwellian ion population is dominant correspond to lowest ion recirculation powers (and hence highest fusion energy gains). It is also shown that realistic parabolic-like wells result in better energy gains than square wells, particularly at large well depths ( $> 100$  kV). Operating regimes with fusion power to ion input power ratios ( $Q$ -value)  $> 100$  have been identified. The effect of electron losses on the  $Q$ -value has been addressed heuristically using a semianalytic model, indicating that large  $Q$ -values are still possible provided that electron particle losses are kept small and well depths are large. © 2000 American Institute of Physics. [S1070-664X(00)00711-4]

