

Pegasus-III Experiment

Solenoid-Free Startup in the Pegasus-III Experiment

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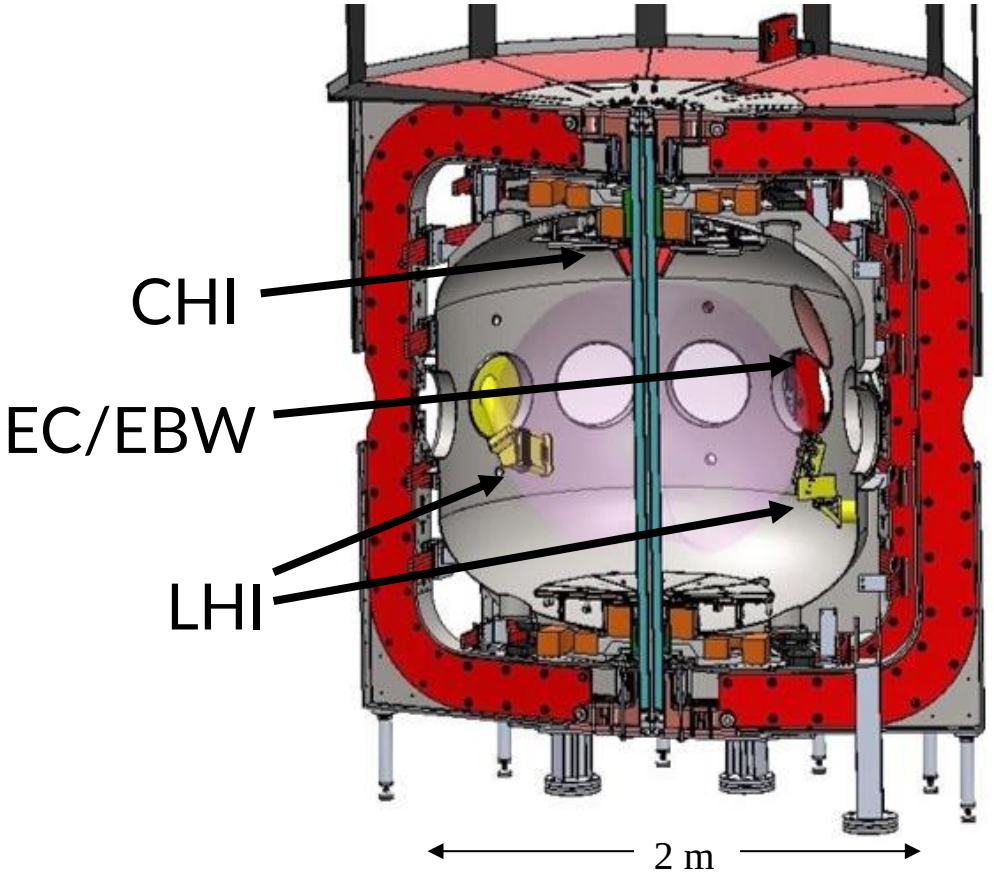
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Pegasus-III is Addressing Need for Solenoid-Free Startup

- Future tokamak designs call for minimal or no solenoid, critical for ST designs[1,2]
- New Pegasus-III Experiment[3] began operations in July 2023
  - Advanced Local Helicity Injection (LHI)
  - Floating Coaxial Helicity Injection (CHI)
  - Microwave assist, sustainment and startup
- Research program provides predictive understanding of solenoid-free techniques
  - Extrapolatable techniques to MA-class advanced tokamaks, spherical tokamaks

JP12.65, JP12.65-74

Solenoid-free Pegasus-III facility



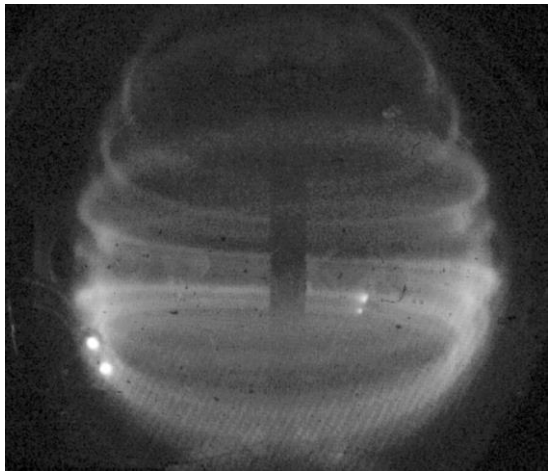
[1]J.E. Menard et al., Nucl. Fusion 56, 106023 (2016)
[2]J.E. Menard, Phil. Trans. R. Soc. A 377, 20170440 (2019)
[3]A.C. Sontag *et al.*, IEEE Trans. Plasma. Sci. **50**, 4009 (2022)

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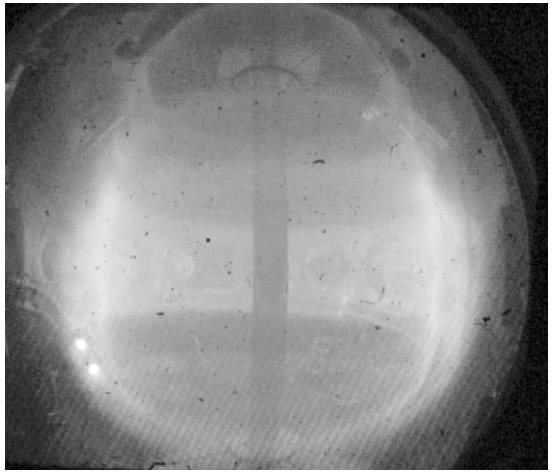
LHI initiates tokamak-like plasma

Fast Camera Images of LHI Stages on Pegasus-III



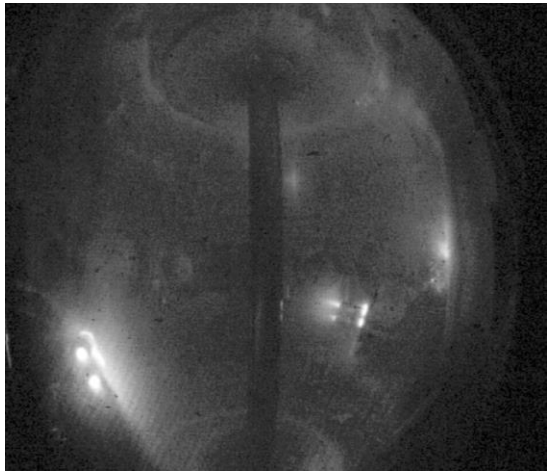
$I_p \approx N_{turns} I_{inj}$

1. Injected current follows helical $\vec{B}$



$I_p \gtrsim N_{turns} I_{inj}$

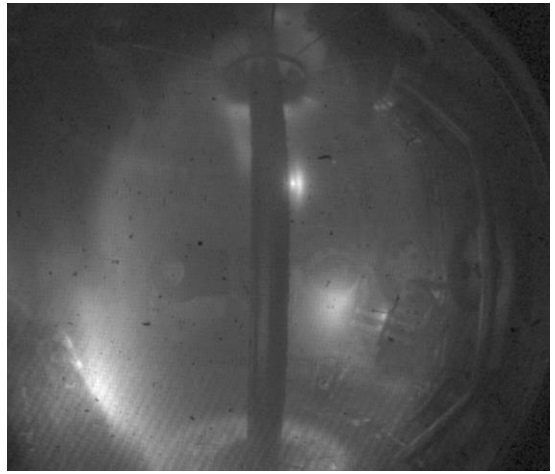
2. Current streams go unstable, reconnect



$I_p \gg N_{turns} I_{inj}$

3. Plasma relaxes to a "tokamak-like" state

Majority of magnetic energy is in axisymmetric mode



$I_p \neq 0, I_{inj} = 0$

4. Tokamak plasma remains after injector shutoff

JP12.67, JP12.71

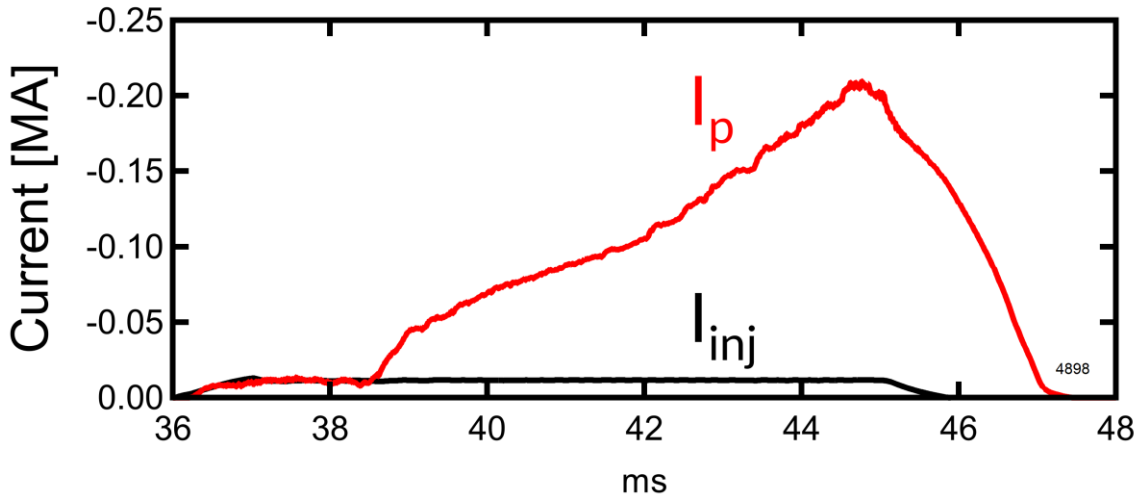
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Extending LHI physics to B_T > 0.15 T

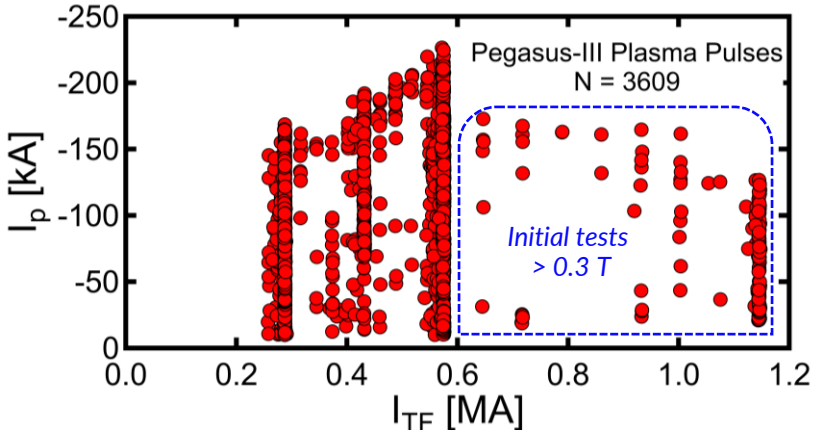
- New 4 cm^2 injector systems reliably operate at B_{inj} = 0.33 T
  - Consistent with low-I_p Pegasus HFS injectors at R_{inj} = 0.17 m
- High-I_p scenarios established
  - 0.23 MA at 0.3 T
  - 0.13 MA at 0.6 T to date
- Relaxation more challenging
  - Expected with increased B_T from pitch angle considerations
  - Revised LFS injector geometry considered

JP12.65, JP12.66

0.2 MA LHI Plasma; I_p/I_{inj} = 18



$I_p(I_{TF})$ Attained in Pegasus-III Operations



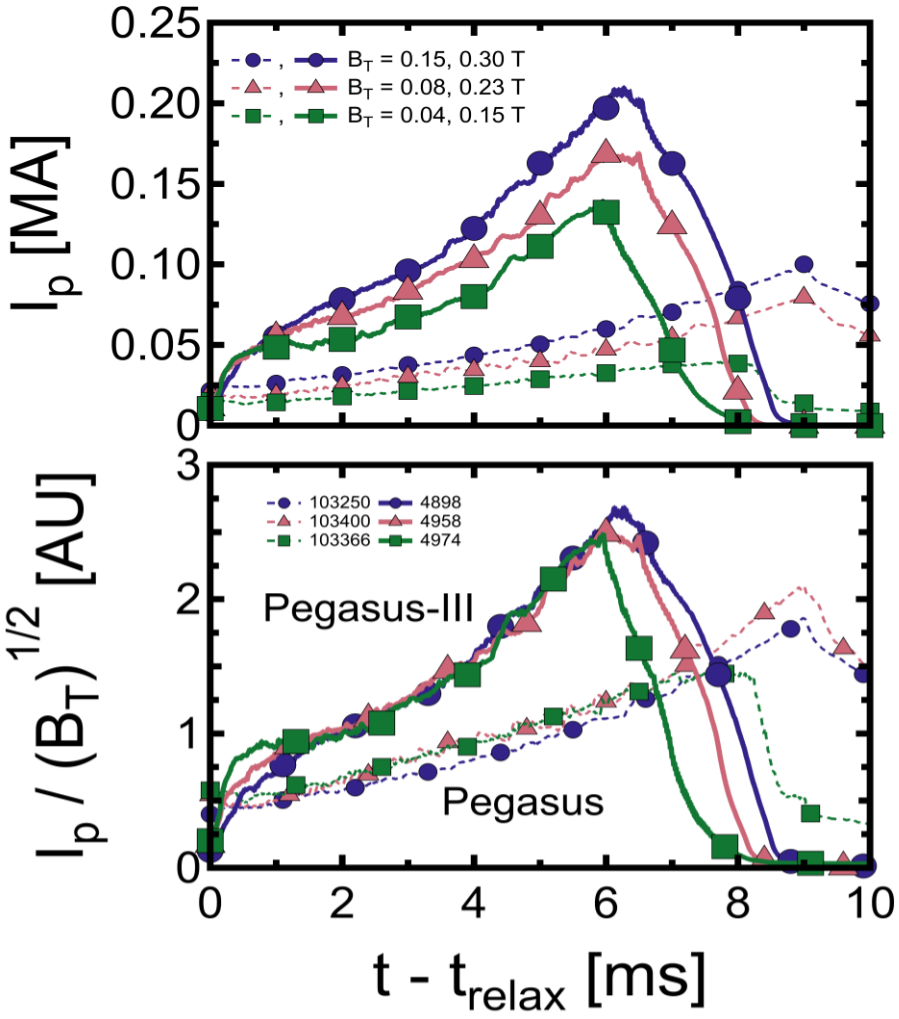
Experimental tests of Taylor limit extended with new capabilities

- Taylor relaxation limits maximum I_p
  - System driven to minimum energy state that conserves K

Taylor Limit: $$I_p \leq \sqrt{\frac{1}{2\pi R_{inj} w_{inj}} \frac{\Psi_T I_{inj}}{B_{p,inj}/I_p}}$$

- Experimental limits
  - $\sqrt{B_T}$ scaling expanded via experiments on Pegasus, Pegasus-III
  - $\sqrt{I_{inj}}$ expanded via power systems
  - $\sqrt{1/w_{inj}}$ varied via injector ΔR_{inj}

$$I_{TL} \propto B_T^{1/2}$$



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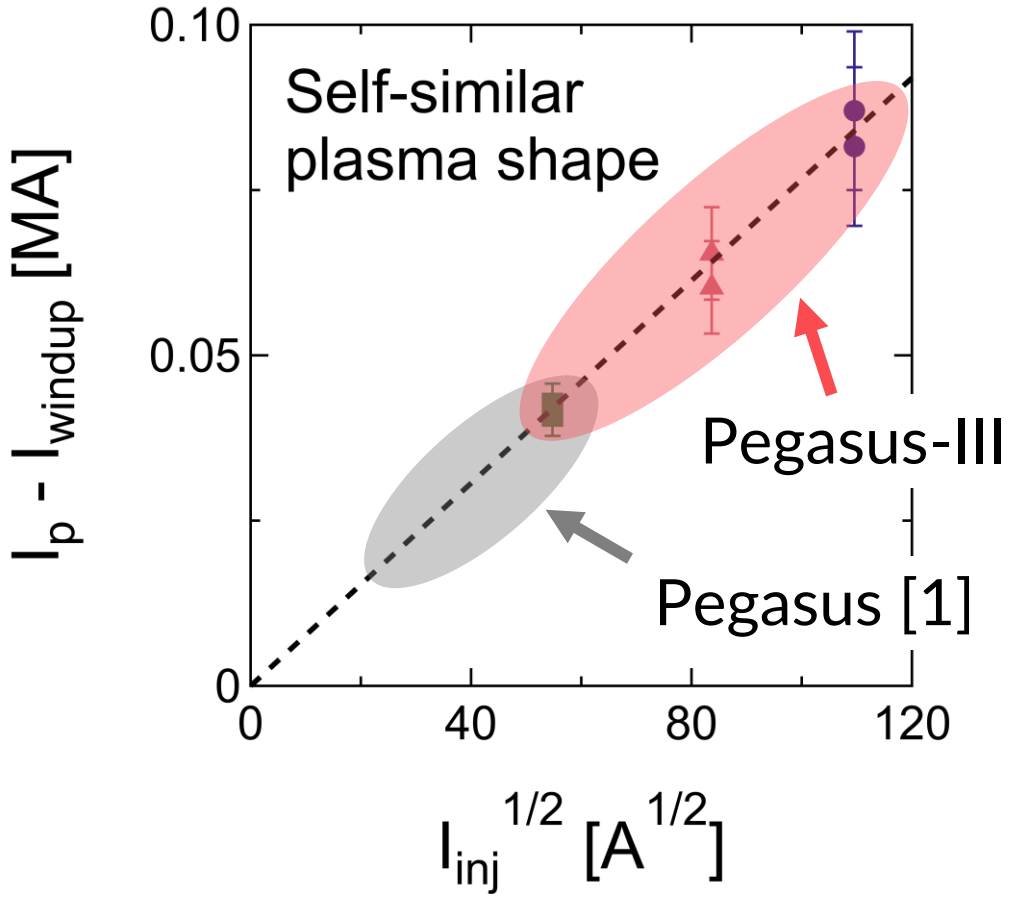
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I_p follows expected $I_{TL} \propto \sqrt{I_{inj}}$ scaling for self-similar plasma shapes



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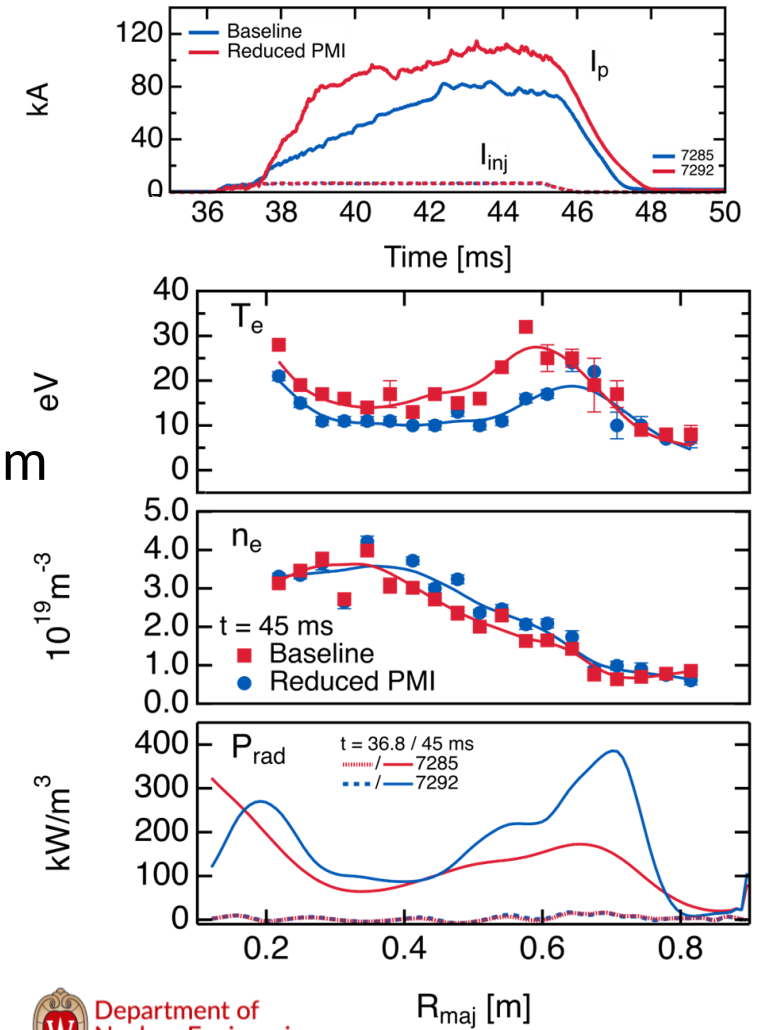
[1] D. J. Battaglia *et al.*, *Nucl. Fusion* **51**, (2011).

Enhanced and upgraded diagnostics explore PMI impact

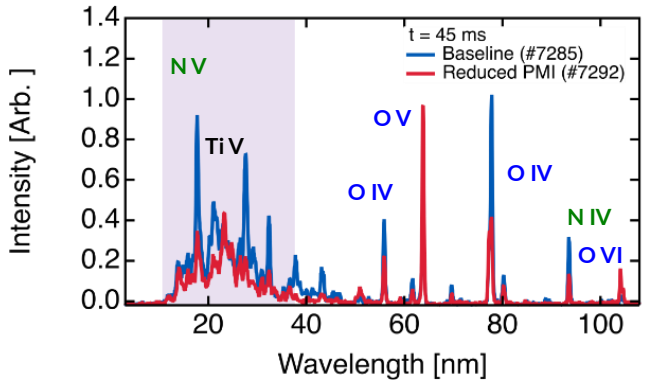
- Impurity diagnostic suite[1] fielded to constrain impurity transport modeling
  - 32 channel AXUV diode array
  - SPRED VUV spectrometer
  - Visible spectrometer
  - Initial measurements identify Ti from injector-limiter PMI as source
- Commissioned magnetics for equilibrium reconstruction, low-f (<200 kHz) MHD measurement[2]
- Systems under development for microwave, ion dynamics studies

JP12.68, JP12.69, JP12.70, JP12.72

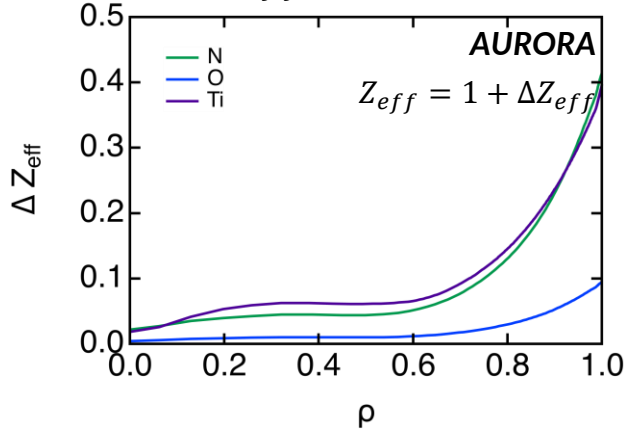
PMI Impact on I_p



SPRED Spectrum



Modeled Z_{eff} Contributions



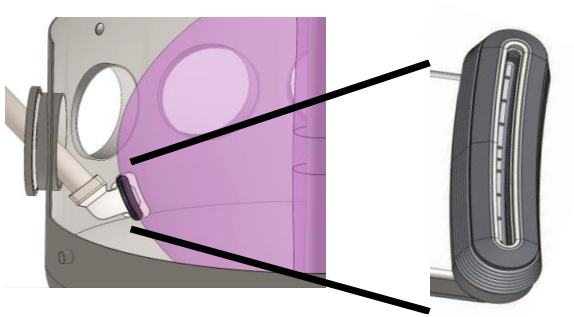
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[1]Rodriguez Sanchez *et al.*, RSI **95**, 083525 (2024)
[2]Reusch *et al.*, RSI **95**, 093518 (2024)

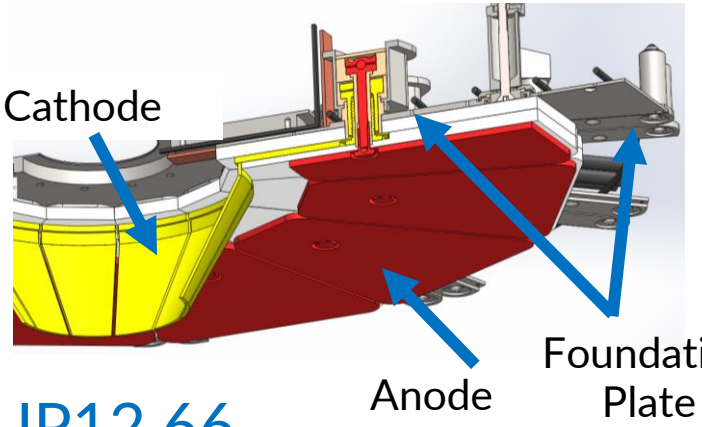
Initial circular injector campaign leads to CHI/non-circular operations

Installation in Progress

Advanced Non-circular Injector in PEGASUS-III



Novel CHI system



JP12.66

2025

SAMI (EBE) installed



UNIVERSITY of York

28 GHz microwave injection for EBW/EC

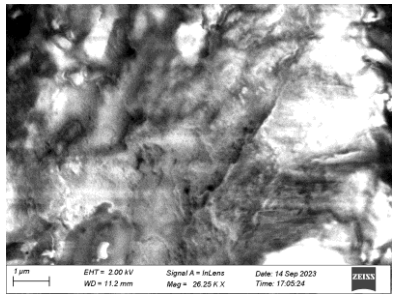


JP12.72, JP12.73

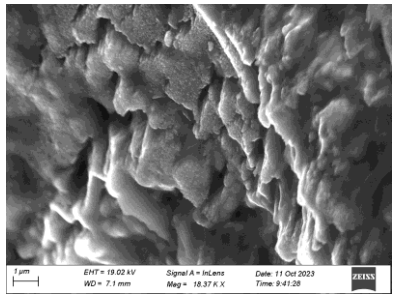
New initiatives:

Affects of **materials** choices on component lifetimes being studied: **Mo frustum shield**

Before Use



After Use



Open and FAIR Fusion for Machine Learning Applications

MIT PSFC Plasma Science and Fusion Center

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The HDF Group

JP12.74

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First Pegasus-III run campaign extended LHI to High B_T

- Pegasus-III - solenoid-free startup for tokamaks
  - **Solenoid-free** A ~ 1 spherical tokamak
  - Increased B_T capability to 0.6 T; new divertor coils
  - LHI in operation, next – CHI, microwave sytems
- 2023-24 campaign extended LHI from 0.15 → 0.6 T
  - Validated Taylor limit scalings for B_T, I_{inj} in expanded operating space (B_T < 0.3 T)
  - I_p consistent with injector capabilities; projects to 0.3 MA
  - Scenarios for microwave design optimization studies
- Expanded diagnostic suite supports detailed physics studies
  - Magnetics, Thomson scattering, impurity quantification/dynamics, EBE systems fielded
  - Ion-channel diagnostics in development (NPA, DNB/CHERS)
- Improvements in TF joint assembly, new non-circular LHI and CHI installs underway



Reprints:

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Posters Tues PM – JP12.00065-74

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