Pegasus-III
Experiment

Pegasus-III Vacuum and Neutrals: Titanium is addicting

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Nuclear Engineering
& Engineering Physics
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Pegasus - III overview

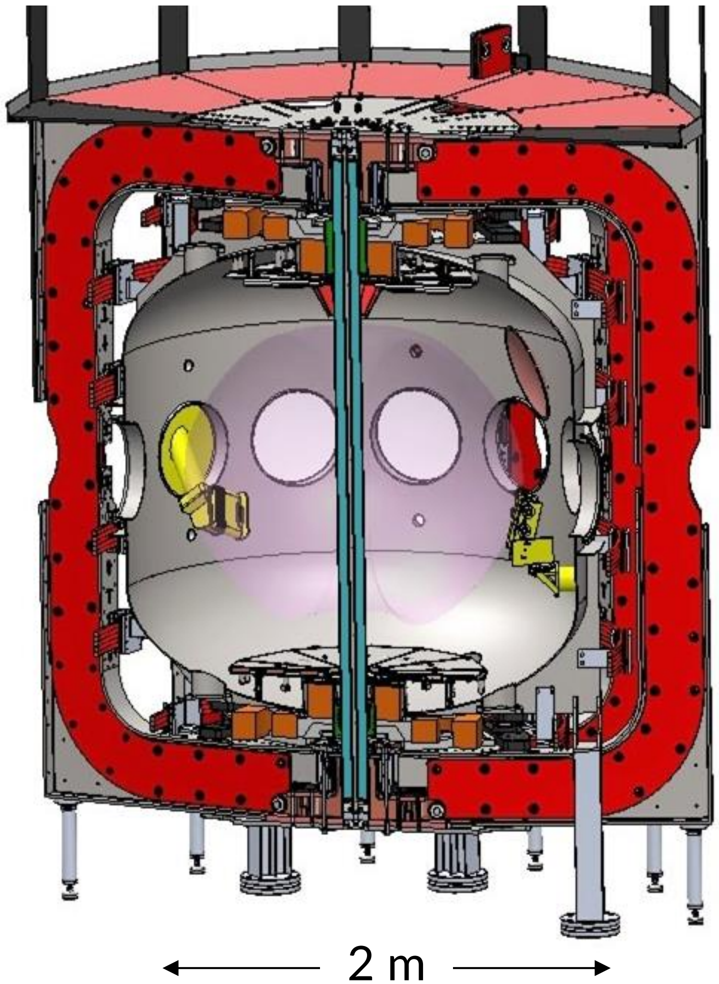
GOAL: investigate the fundamental physics of non-solenoidal spherical tokamak startup and develop power plant relevant technologies

Pegasus startup systems:

- Local Helicity Injection (LHI)
- Coaxial Helicity Injection (CHI)
- Microwave assist and sustainment

Pegasus-III Parameters	
Major Radius	0.48 m
Aspect Ratio	1.22
Magnetic Field	0.6 T
Plasma Current	0.3 MA
Density	~10^{19} cm^{-3}
Electron Temperature	~50 eV

Pegasus-III [1]
(P-III)



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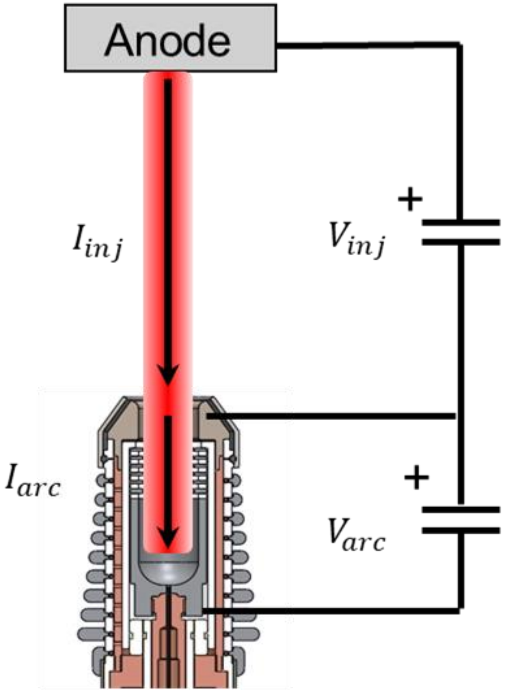
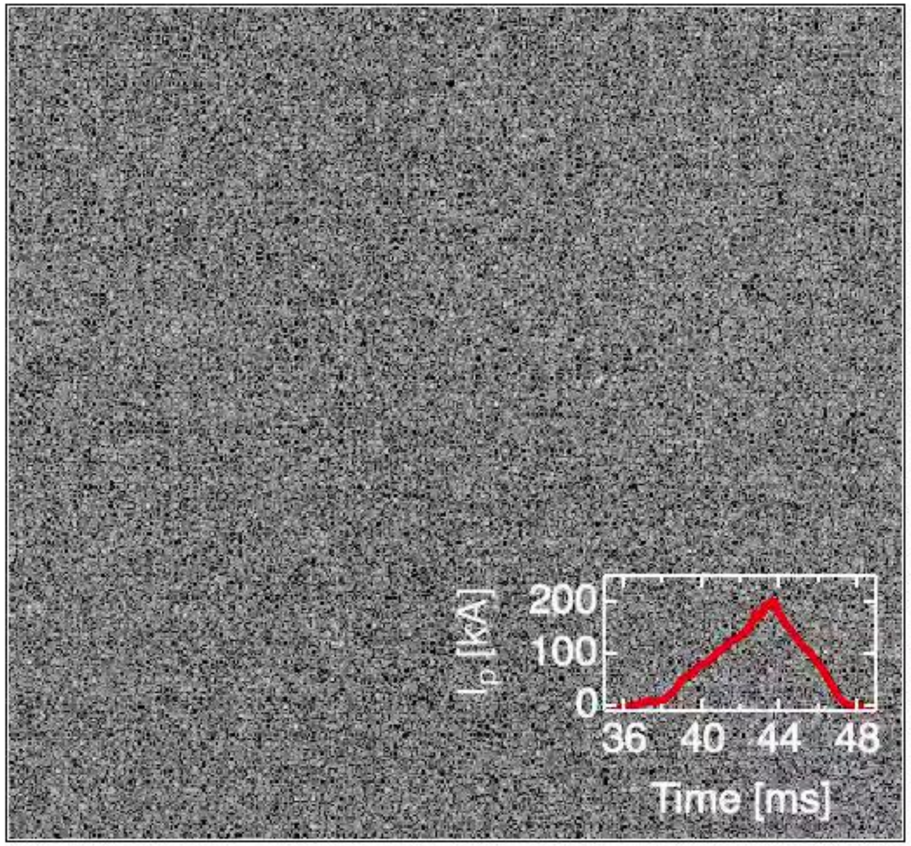
[1] A. C. Sontag et al., The New PEGASUS-III Experiment, IEEE Trans. Plasma Sci. **50**, 4009 (2022).

Local Helicity Injection

- Active arc sources
- Current streams extracted follows vacuum field lines
  - Magnetic instabilities relax the system to minimum magnetic energy state while conserving total helicity



Pegasus LHI injector system conceptual schematic[2].



Video of Pegasus-III plasma discharge.

[2] M. W. Bongard et al., Advancing local helicity injection for non-solenoidal tokamak startup, Nucl. Fusion **59**, 076003 (2019).

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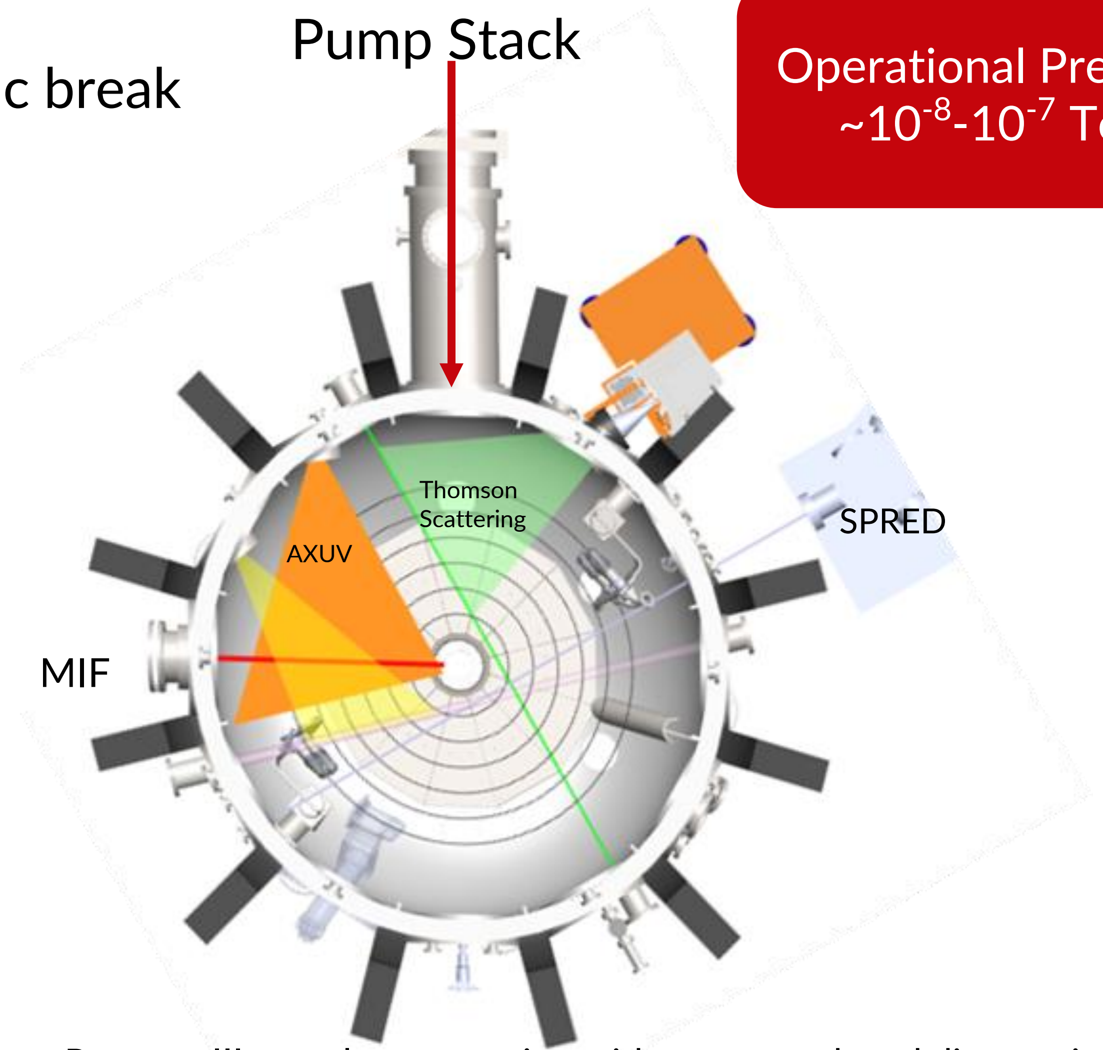
Tech Specs of Pegasus Vacuum

- Total vessel volume ~5200 L
- Walls are ¼ inch Stainless Steel with ceramic break at bottom joint
- Roughing pump
  - ~10^{-3} Torr
- Turbomolecular pump (TV1001 Navigator)
  - $1*10^3$ TL/s N2
- Cryogenic pump (CT-10)
  - $3*10^3$ TL/s N2
  - $9*10^3$ TL/s H20,
  - $5*10^3$ TL/s H2
- Titanium Gettering (sourced from National Electrostatics Corp.)
  - ~$5*10^4$ TL/s H2

Operational Pressure ~10^{-8}-10^{-7} Torr



Pegasus-III vessel cross section with pump stack and diagnostics sight lines.

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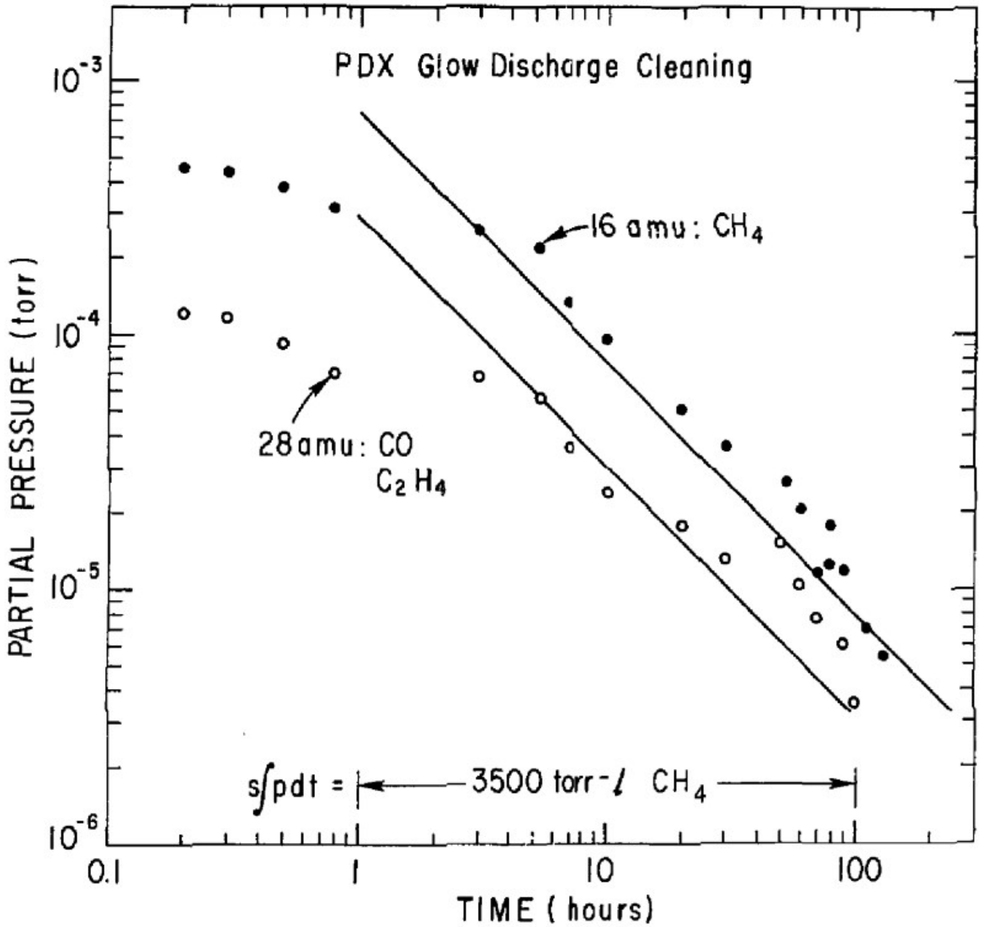
Vacuum Conditioning

- Glow discharge to condition the walls
- ~100 hours glow discharge[3]
  - 20 hours Hydrogen glow on un-gettered walls
  - 100 hours Helium glow
  - This is beneficial because the extended UV exposure can liberate water absorbed in the walls
    - To this end, just running a plasma can be really helpful
    - Generally, a dozen high current plasma shots to be good for wall conditioning
- Injector conditioning also required for optimal operations
  - Few dozen discharges, slowly walking up V inject to condition injector surfaces

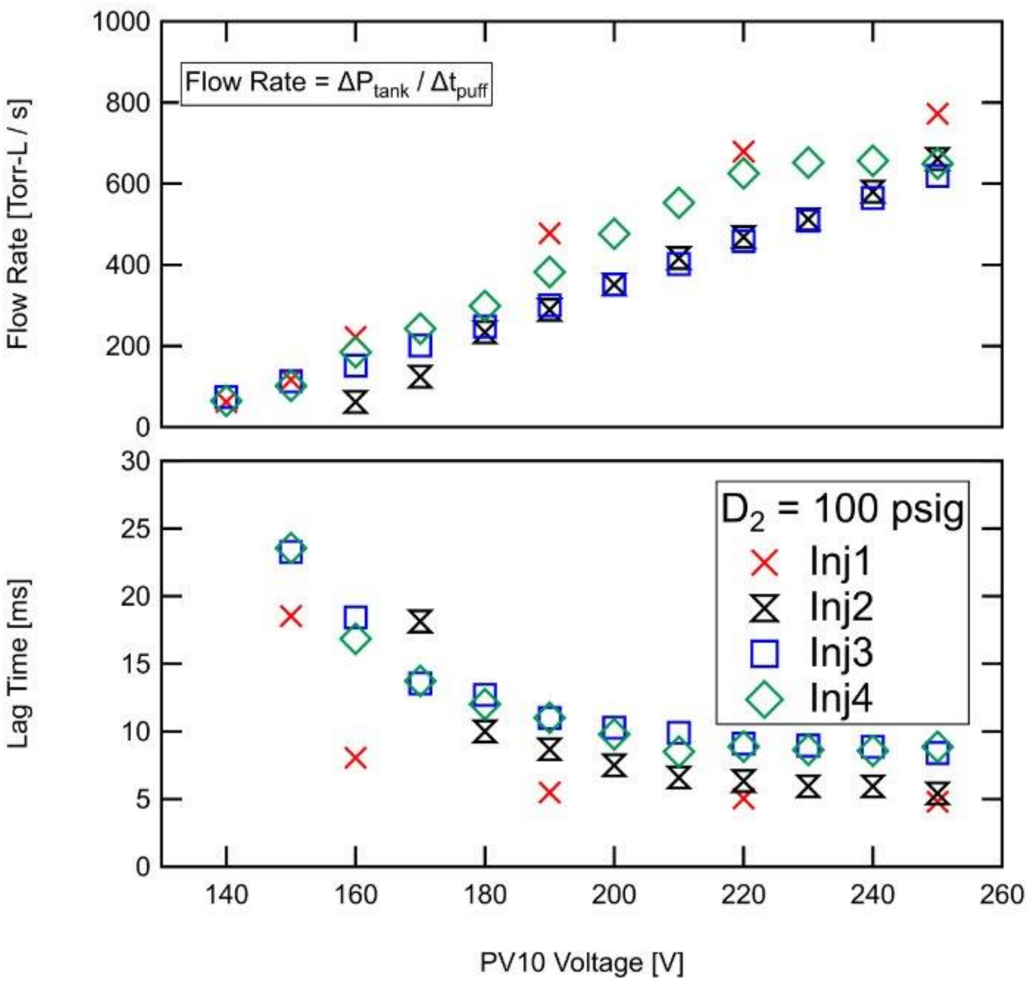


Partial pressure measurements over glow discharge duration on PDX[3].

[3] H. F. Dylla, S. A. Cohen, S. M. Rossnagel, G. M. McCracken, and Ph. Staib, Glow discharge conditioning of the PDX vacuum vessel, Journal of Vacuum Science and Technology **17**, 286 (1980).

Fueling

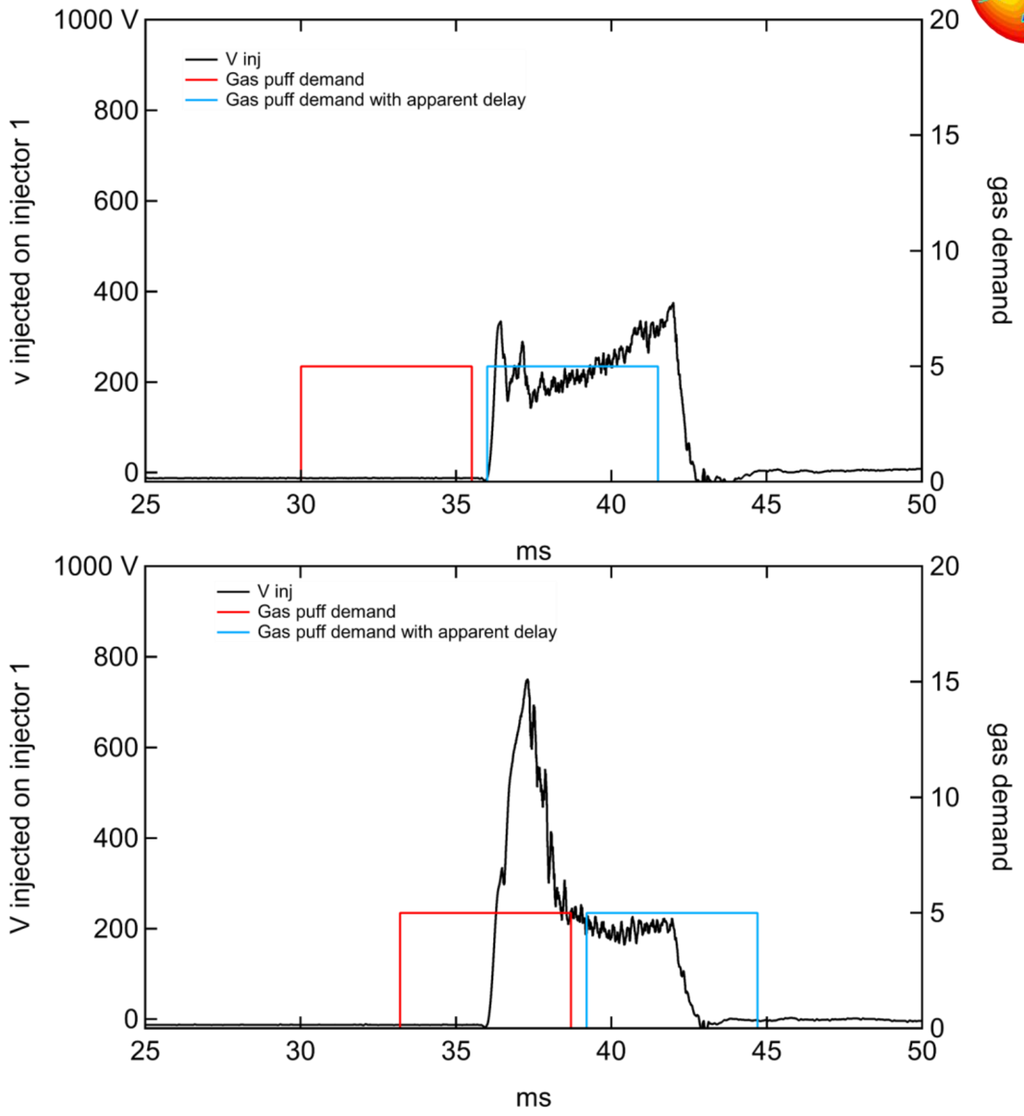
- Predominantly operate with D2
  - Occasionally will run with other gases or with auxiliary fueling of other gases to test impurity diagnostics
- Most of the fueling comes from the helicity injectors themselves
- About ~5 Torr of gas fueling for each shot
  - PV10's control gas flow into the injector arc chamber
  - Increased throughput
  - ~400 Torr L/s
- Fuel low field side and high field side available



Gas flow and lag time as a function of applied voltage for PV10 characterization.

Fueling Impact on V injected

- More gas means more impedance
  - Direct knob for V injected control
- V injected is proportional to V effective
  - All things being equal, knob for plasma current
- Auxiliary fueling on both the LFS and HFS allow for density and edge impedance control



Effect of gas puff timing on V inj.

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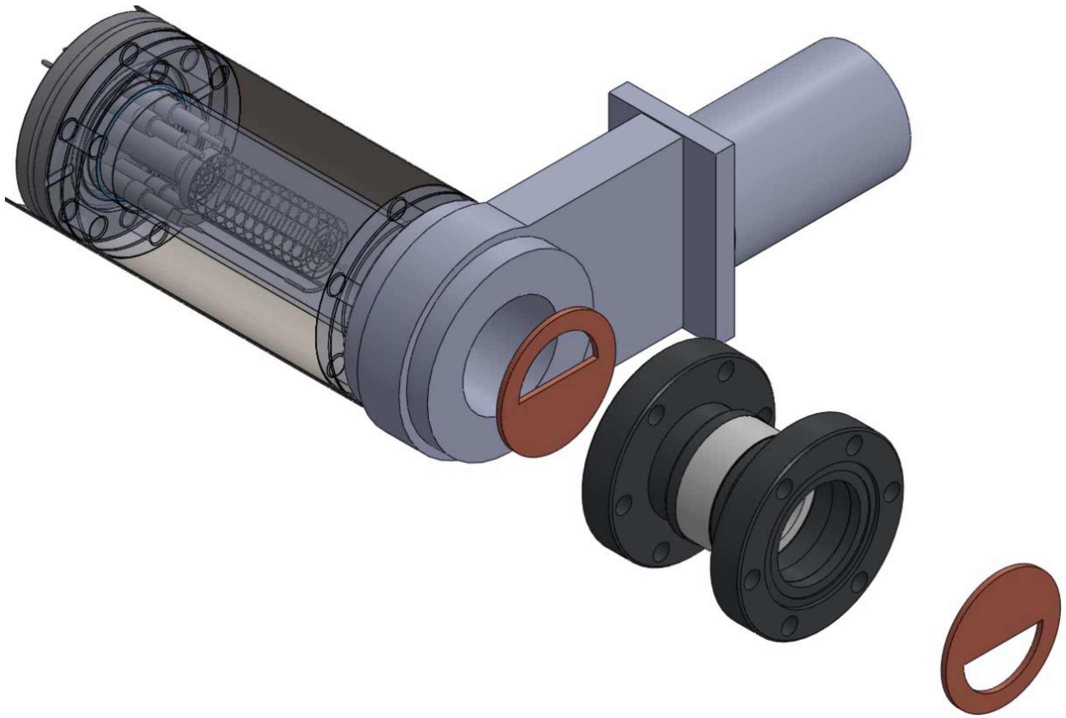
Vacuum and neutral diagnostics

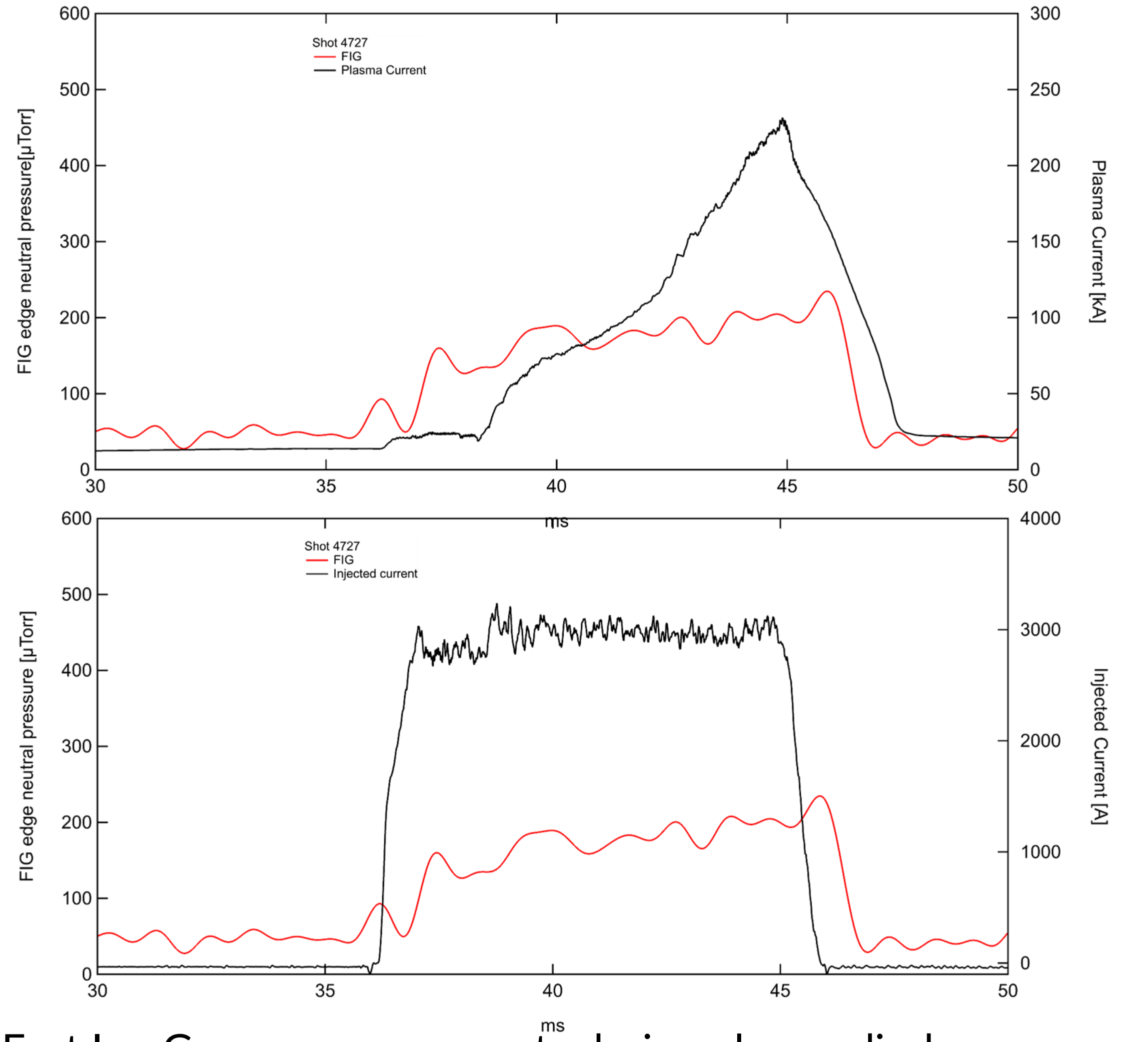
- Tank Ion Gauge
  - Low time resolution tank pressure measurements for intershot evaluation
- Capacitive Manometers
  - Measures fueling plenum
- RGA
  - Primarily to evaluate leaks or vacuum conditions post vent
- Fast Ion Gauge
  - Supposed to be high time resolution
  - Half moon gaskets minimize UV pickup



Fast ion gauge designed deployment.

Edge neutral pressure measurements

- Edge neutral pressure during plasma discharge ~200 μtorr
- ~$5.55*10^{17}$ m^{-3} neutral density vs ~10^{19} m^{-3} electron density
  - This is about 1%
  - Low neutral density
- Intershot gas needed to pump 5 torr liters
  - YAY that is about what we fueled with!



Fast Ion Gauge measurements during plasma discharge.

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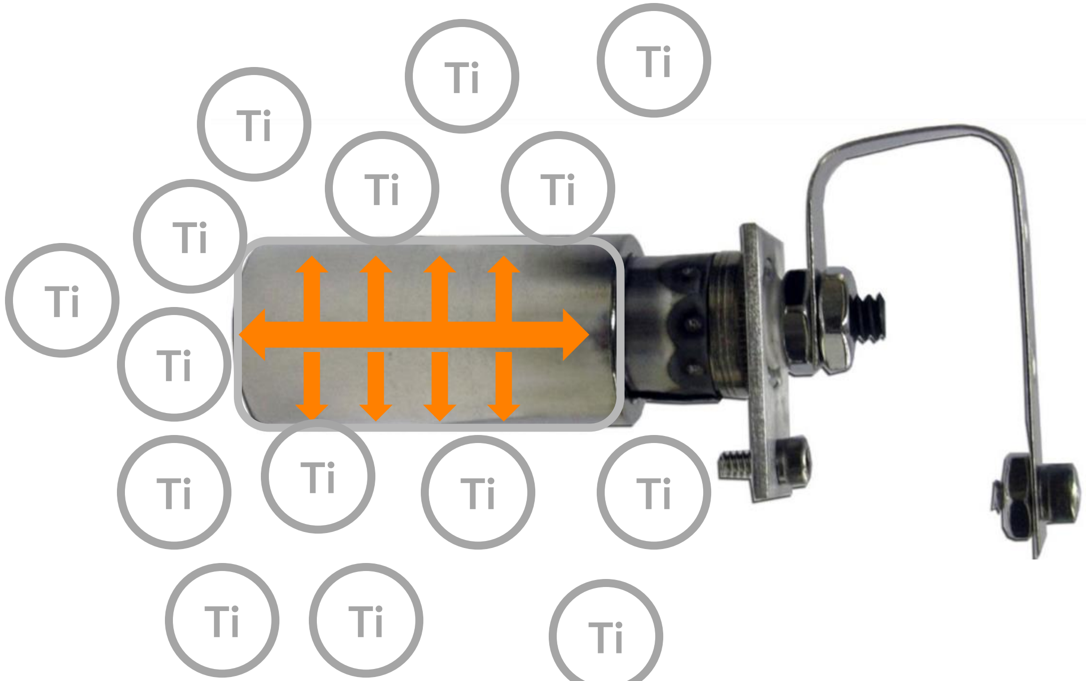
Titanium Gettering

- Pegasus employs continuous titanium gettering
- Sublimated titanium coats ~80% of plasma facing components
- assists in pumping nitrogen, oxygen, and hydrogen
- CON: continuous gettering provides a source of ~10^{13}-10^{14} particles total for the whole discharge
  - about 10^{15} particles per second



Titanium getter sublimators[4].

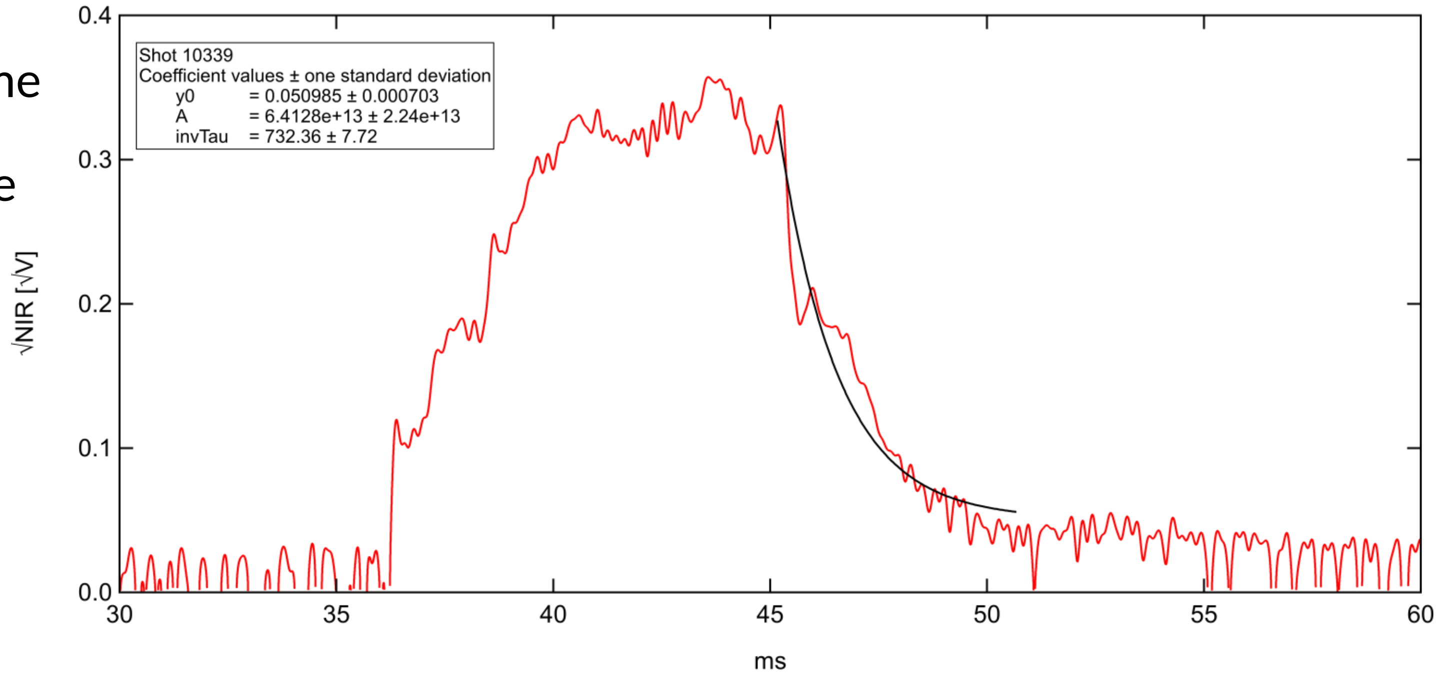
[4] Vacuum Components: Titanium Sublimators, (2021).

Historically we have assumed low recycling rates

- R < 0.8 Phase II
- From interferometer measurements and estimated electron confinement times from reconstructions[5]
  - assumed particle confinement time is 1 ms
  - Same as energy confinement time

$$\tau_p^* = \frac{n_e}{\frac{dn_e}{dt}} = \frac{\tau_p}{1-R}$$

P-III recycling coef. 0.99



Near Infrared signal trace with fit exponential decay.

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[5] K. Thome, *Improved Density Control in the PEGASUS Toroidal Experiment Using Internal Fueling*, https://pegasus.ep.wisc.edu/wp-content/uploads/sites/1310/2020/01/KET_APS12.pdf

In summary…

- Pegasus-III has good vacuum
  - Consistently operating in 10^-8 torr
  - TITANIUM GETTERING
- Decent vacuum/neutral diagnostics
  - Redeploying a D alpha signal
  - FIG has some noise pick up
- Low neutral density
  - ~1% electron density
- Higher recycling coefficient
  - 0.99 compared to 0.8 from Phase II ohmic discharges

References

[1] A. C. Sontag et al., The New PEGASUS-III Experiment, IEEE Trans. Plasma Sci. **50**, 4009 (2022).

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