Point-source helicity injection for ST plasma startup in PEGASUS

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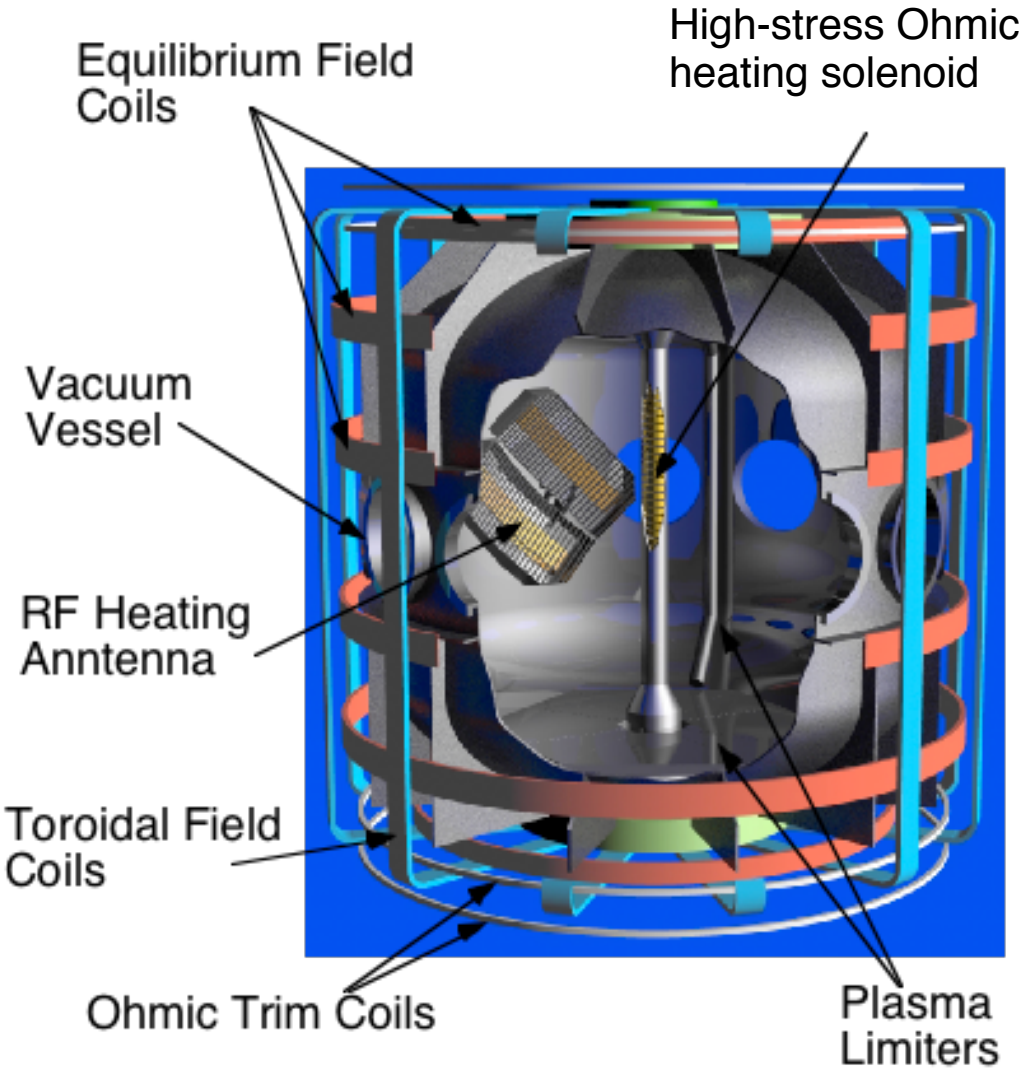
Atlanta, GA USA

PEGASUS Toroidal Experiment

PEGASUS helicity injection talk outline

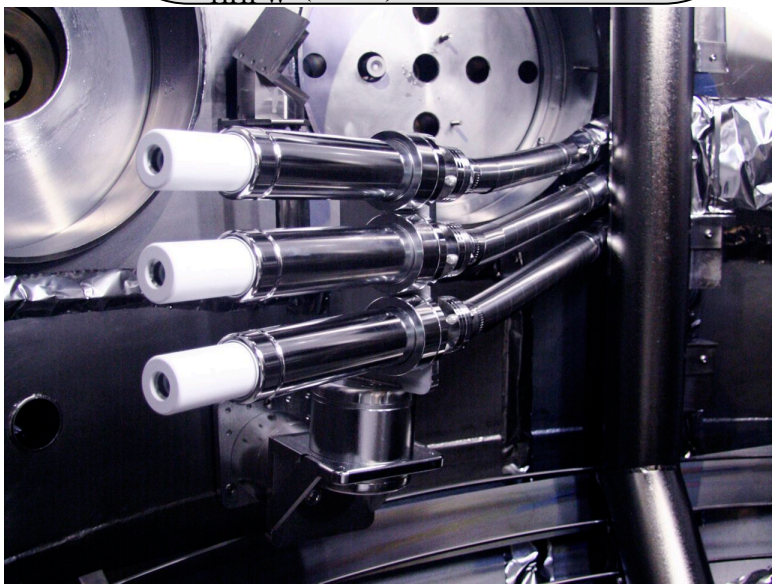
- The PEGASUS Toroidal Experiment
- Helicity injection in PEGASUS
- Testing max I_p theoretical scalings
- Summary

Pegasus is a Compact Ultralow-A ST



Experimental Parameters

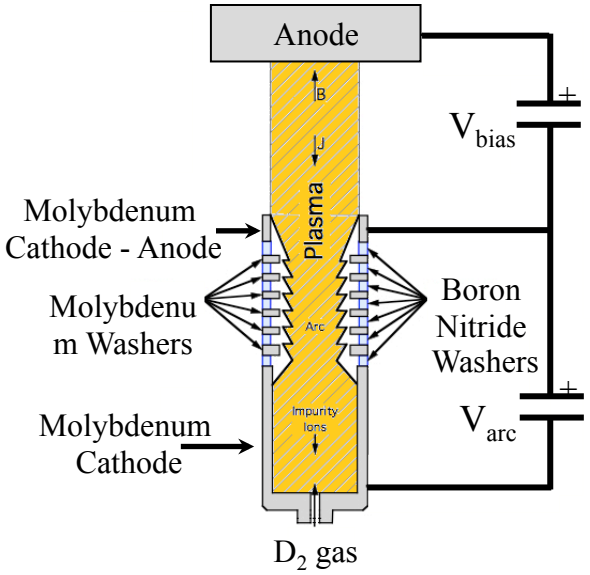
Parameter	To Date
A	1.15 – 1.3
R(m)	0.2 – 0.45
I_p (MA)	≤ .21
I_N (MA/m-T)	6 – 12
l_i	0.2 – 0.5
κ	1.4 – 3.7
τ_{shot} (s)	≤ 0.025
β_t (%)	≤ 25
P_{HHFW} (MW)	0.2

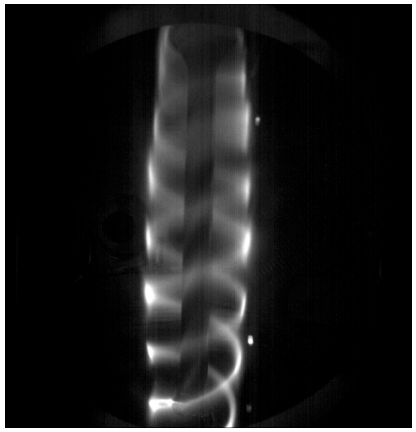


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Local Plasma Current Sources + Helical Vacuum Field Give Simple DC Helicity Injection Scheme

- Current is injected into the existing helical magnetic field
- High I_{inj} & modest B ⇒ filaments merge into current sheet
- High I_{inj} & low B ⇒ current-driven B_θ overwhelms vacuum B_z
  - Relaxation via MHD activity to tokamak-like Taylor state w/ high toroidal current multiplication





Reduced B_z



B_T=10 mT, B_z = 5 mT

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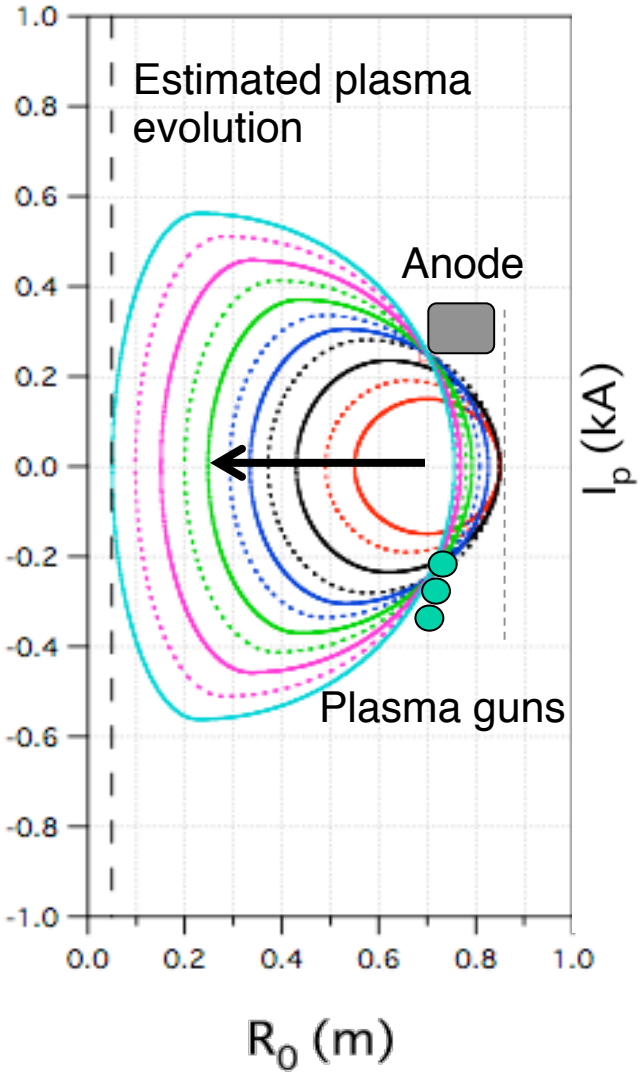
Driven helical filaments can relax to an axisymmetric tokamak-like state

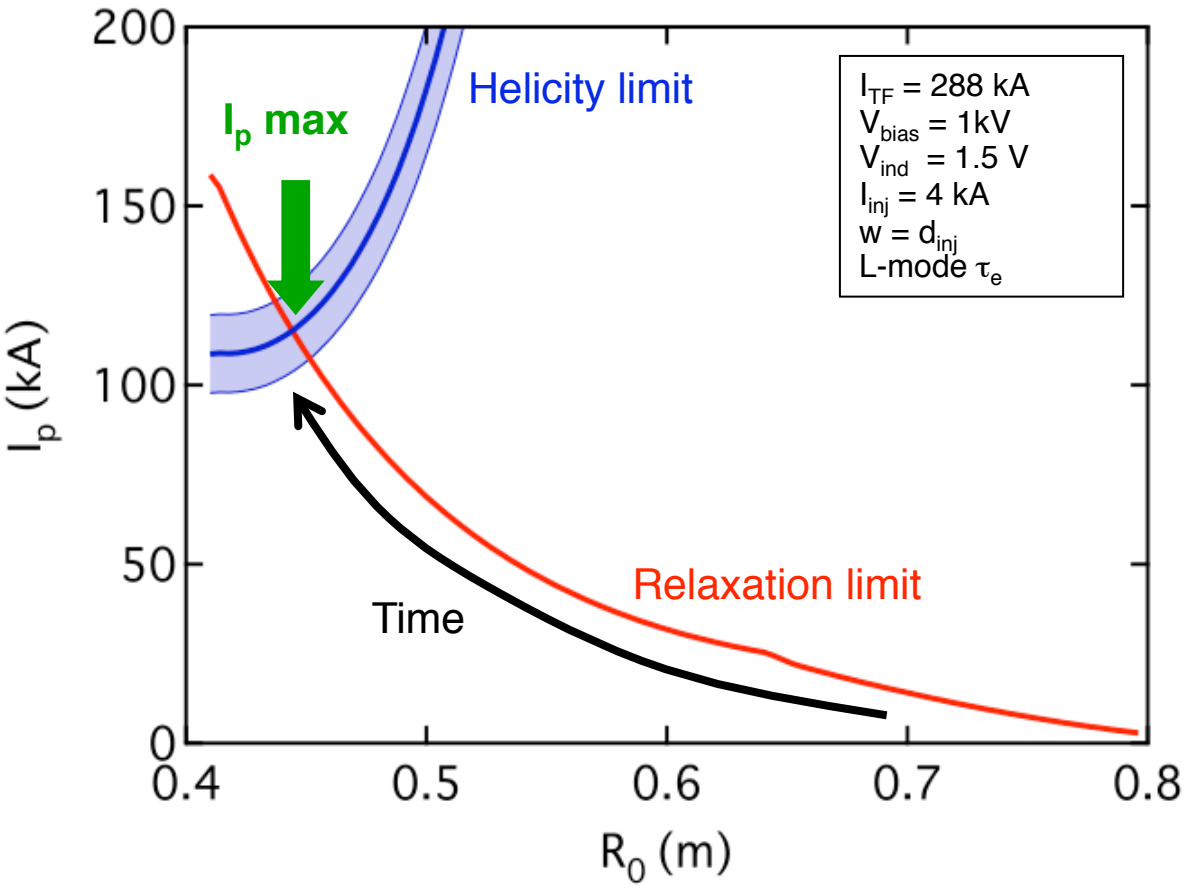
- Driven helical filaments are strongly unstable
  - Relax into the axisymmetric tokamak-like state
- Tokamak-like equilibrium satisfies a set of conditions
  - Radial force balance
  - Helicity/power balance
  - Kink stability: edge q > 3
  - Taylor relaxation current limit
- Max I_p determined by dK/dt and Taylor relaxation limit:

$$I_p \leq f_G \left[\frac{\varepsilon A_p I_{TF} I_{inj}}{2\pi R_{edge} w} \right]^{1/2}$$

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Maximum I_p achieved when helicity input is sufficient to reach the relaxation limit

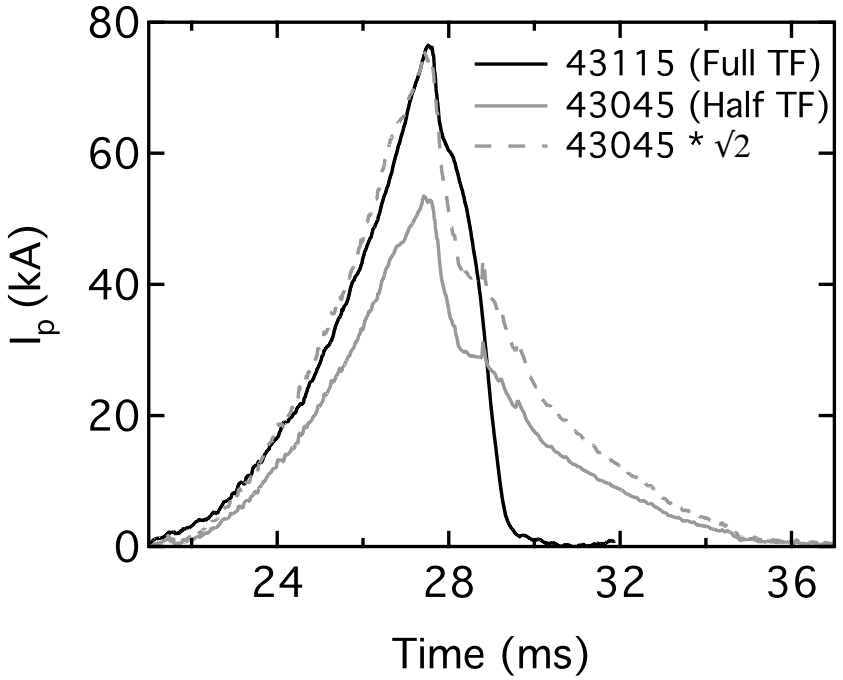


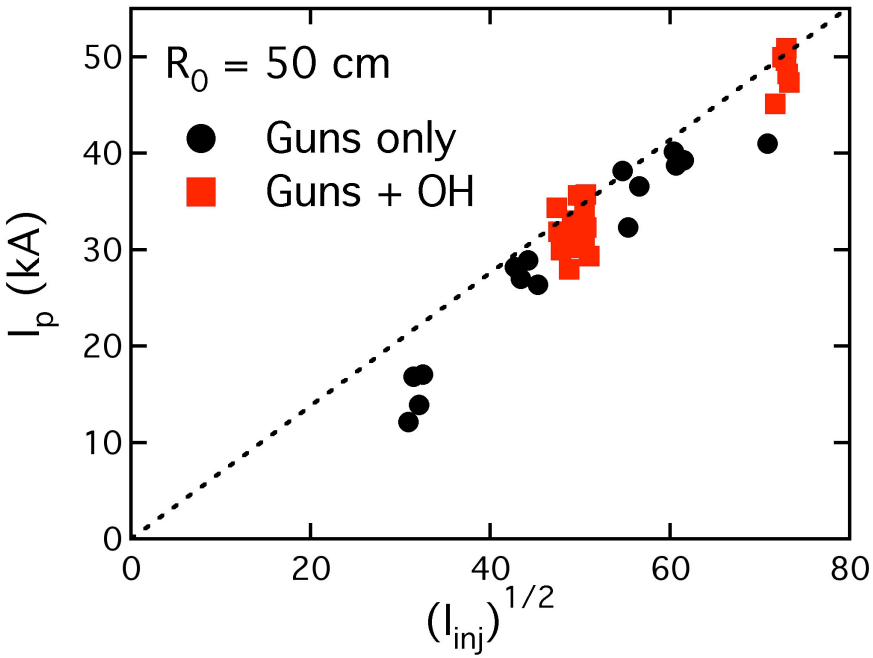


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Experiments confirm relaxation limit scalings with I_{TF} and I_{bias}

- Predicted relaxation limit I_p scales with $(I_{TF}I_{bias})^{1/2}$
- Experimental I_p consistent with these scalings:



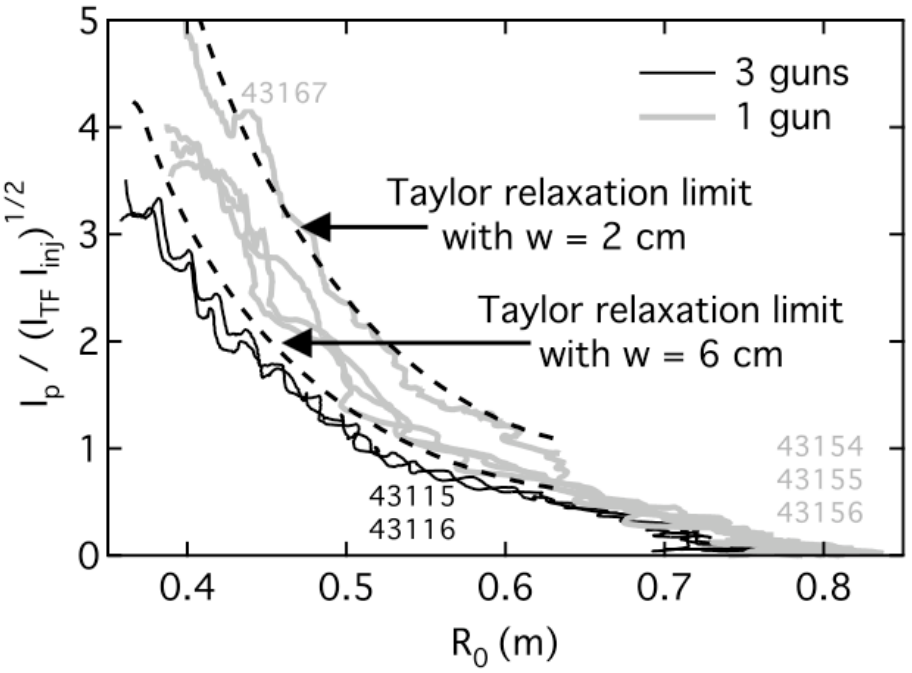


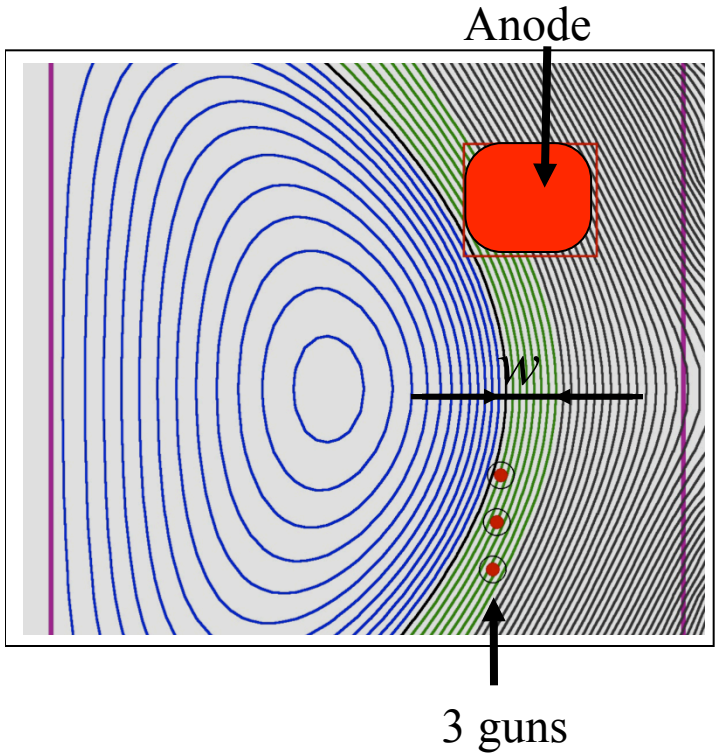
Note: adding solenoid induction does not allow driven I_p to exceed the Taylor relaxation limit

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Experiments demonstrate dependence on the width of the driven current layer

- Relaxation current limit scales as $w^{-1/2}$
- One-gun discharges had higher limits than corresponding three-gun cases, indicating the gun array was misaligned:

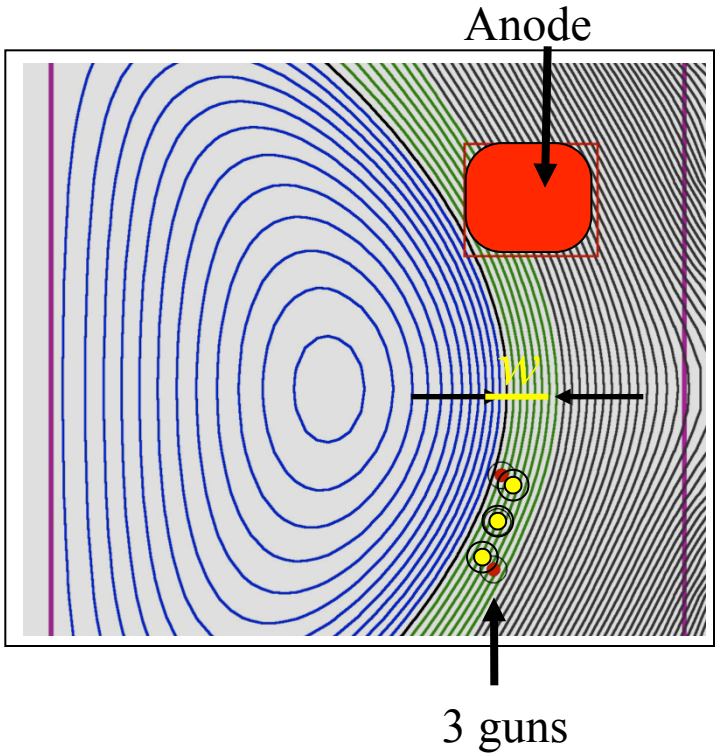


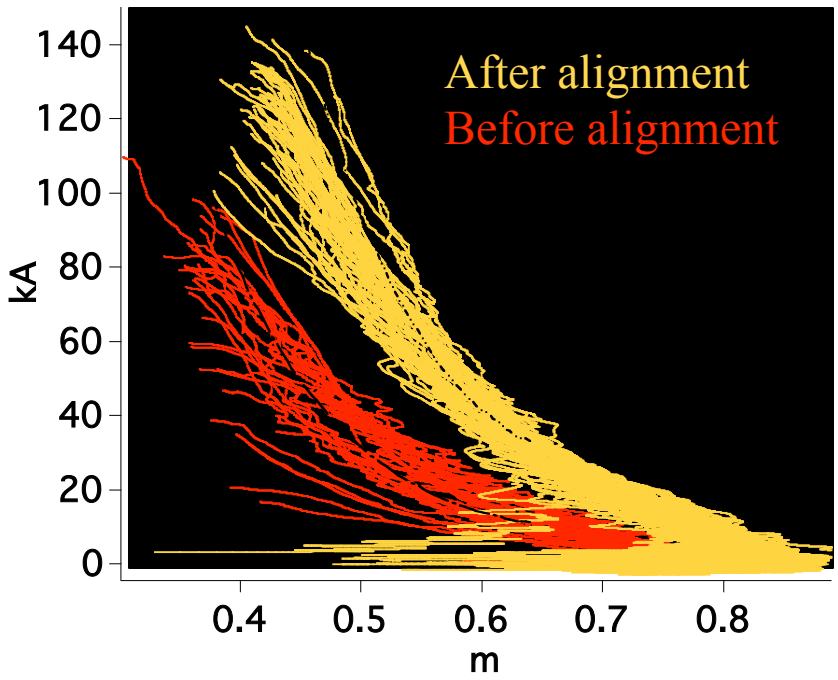


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Gun array was realigned to reduce w, significantly increasing relaxation limit

- Changing the tilt of the gun array increased the max I_p by a factor of 1.5-1.7, implying a factor-of-3 change in *w*.
- In this configuration, have achieved I_p > 170 kA.

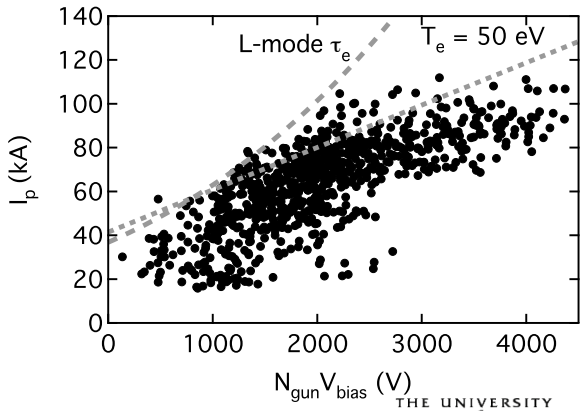




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Further development of gun startup needed to achieve high I_p

- PEGASUS non-solenoidal startup goal is 0.3-0.4 MA
  - Characterize confinement/dissipation in driven plasma
  - Access high I_p/I_{TF}, high β regimes
- This will involve:
  - Increase TF: increase Taylor limit, improve confinement
  - Increase gun current: increase Taylor limit
  - Bigger/improved plasma guns: higher helicity injection rate
  - Test augmenting the guns with shaped electrodes
- Outstanding issues:
  - What sets the bias impedance Z_{inj}?
  - Is the confinement/dissipation stochastic?
  - What sets the width *w* of the driven region?



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PEGASUS Summary: Creating High-I_p Non-Solenoidal Discharges & Enabling high-I_N study

- Making progress with non-solenoidal startup
  - I_p up to 170 kA using helicity injection and outer-PF rampup
  - Using understanding of helicity balance and relaxation current limit to guide hardware and operational changes
    - Outstanding physics questions: λ_{edge}, Z_{inj}, confinement, *etc.*
  - Ultimate goal is 0.3-0.4 MA non-solenoidal current

- High-I_p non-solenoidal startup enables exploration of high I_N, β_T operating space
  - $I_p/I_{TF} > 2$, $I_N > 14$ achieved
  - Extend to high I_p, n_e for high β_t

