Recent Results from the Pegasus Toroidal Experiment

A.J. Redd, J.L. Barr, M.W. Bongard, M.G. Burke, R.J. Fonck,
E.T. Hinson, D.J. Schlossberg, N.L. Schoenbeck, K.E. Thome

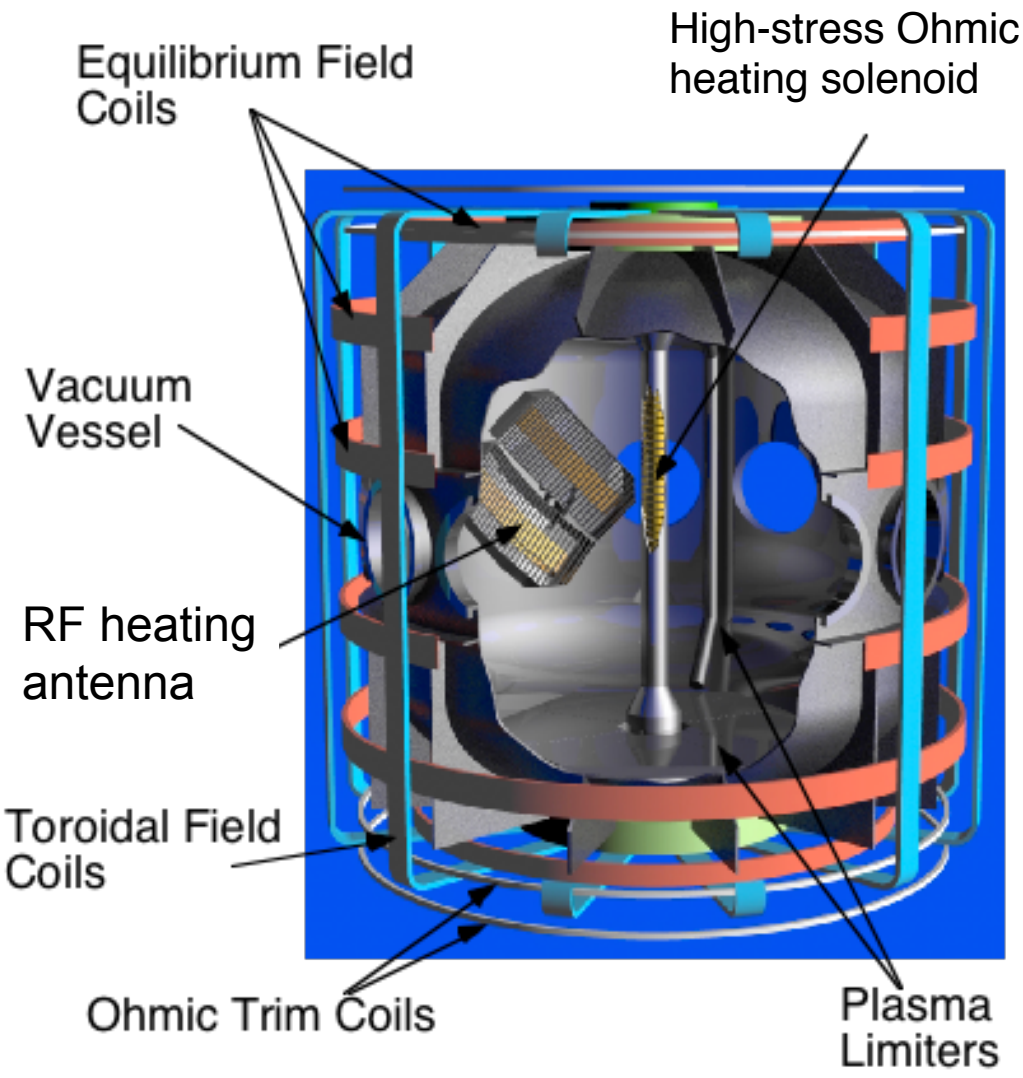
Annual 2011
APS-DPP
Conference

Salt Lake City, UT
Nov 14-18, 2011



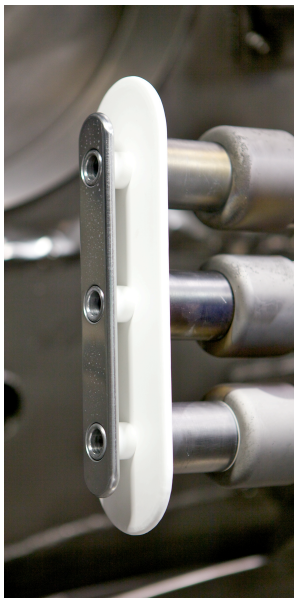


PEGASUS is a Compact Ultralow-A ST



Experimental Parameters

Parameter	To Date
A	1.15 – 1.3
R(m)	0.2 – 0.45
I_p (MA)	≤ .22
I_N (MA/m-T)	6 – 12
l_i	0.2 – 0.5
κ	1.4 – 3.0
τ_{shot} (s)	≤ 0.025
β_T (%)	≤ 25
P_{HHFW} (MW)	0.2

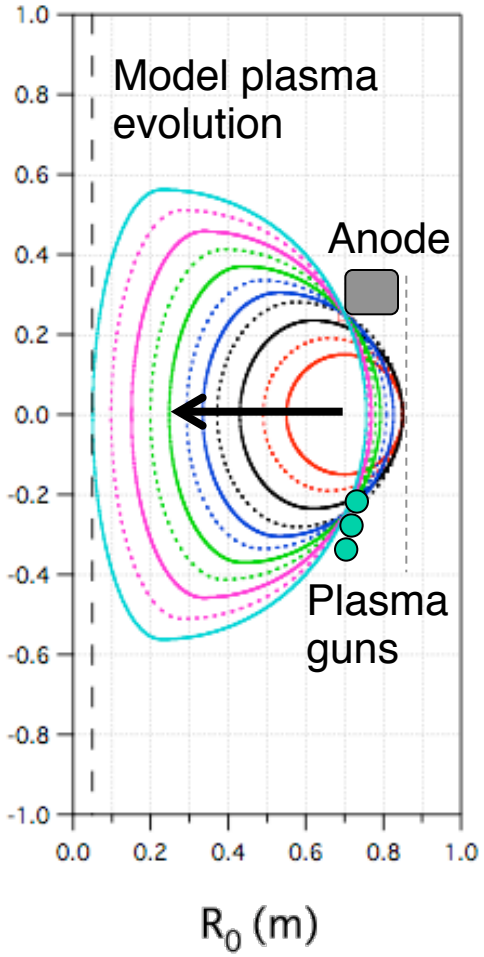


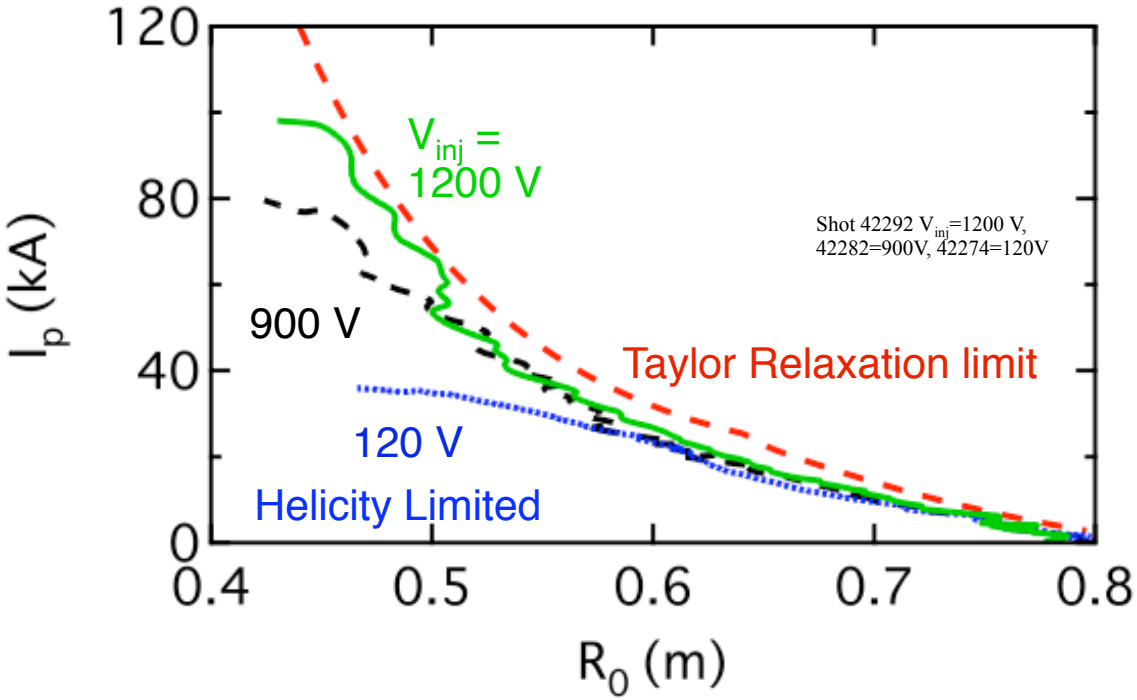
Presently installed injector

A.J.Redd et al., 2011 APS-DPP Meeting, Salt Lake City, UT

THE UNIVERSITY of WISCONSIN MADISON

Plasma performance bounded by Taylor relaxation limit and helicity injection limit





- Taylor limit I_p is ~ $(I_{TF}I_{inj}/w)^{1/2}$
- V_{eff} ~ $V_{inj}A_{inj}/A_{plasma}$
- Need sufficient drive to stay at Taylor limit

A.J.Redd et al., 2011 APS-DPP Meeting, Salt Lake City, UT

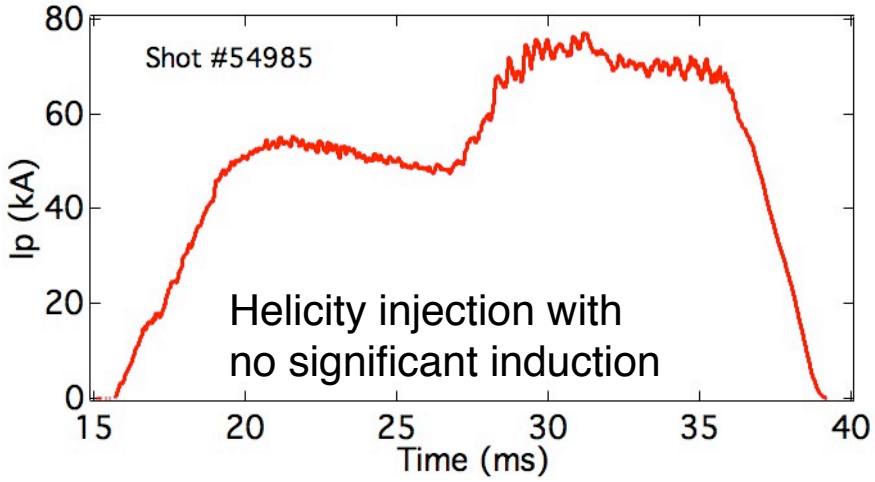
THE UNIVERSITY of WISCONSIN MADISON

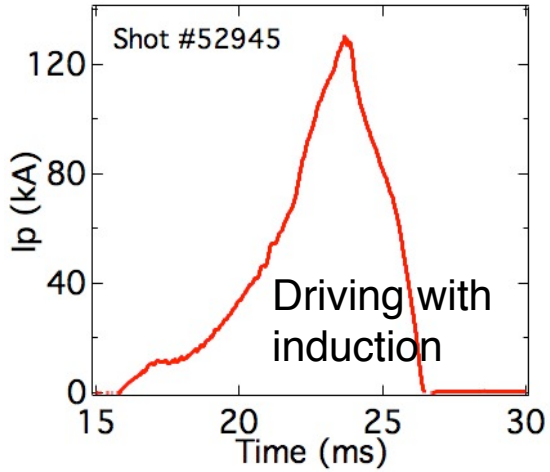
Extend non-solenoidal startup to high I_p

- Goal is to confidently project to mega-amp startup in NSTX-U and beyond.
- Previously, majority of drive from outer-PF induction
  - Radial force balance difficult (plasma decouples from injector)
  - Evolution needs moderate dI_p/dt (but limited induction V-s)
- Now, driving plasma using *only* helicity injection
  - Controlled I_p buildup and sustainment
- Physical understanding of helicity injection improving:
  - Addressing source impedance and J(r) evolution
  - Study confinement at high I_p

THE UNIVERSITY of WISCONSIN MADISON

Pegasus discharges formed and sustained by helicity injection alone





- Demonstrates there is no physical limit on driving plasmas with helicity injection:
  - Studies at low I_p can quantify the helicity injection needed for high I_p
- High-I_p operation will require:
  - Active radial position control, to keep plasma connected to injector
  - Power supply upgrades and injector modification
- Position control and power supply upgrades imminent

THE UNIVERSITY of WISCONSIN MADISON

Combined active plasma guns with passive electrodes to increase drive

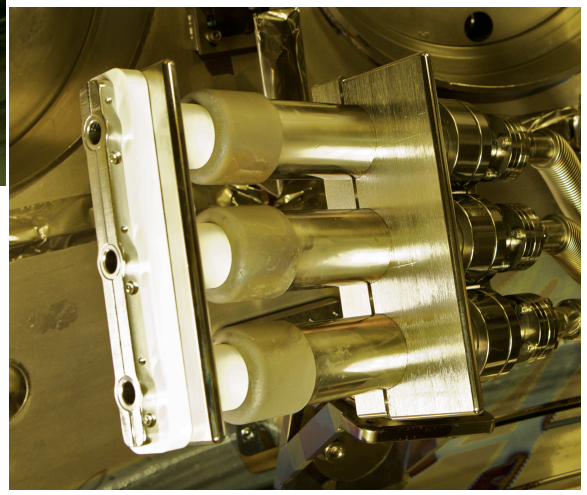
- Extensive electrode area to increase helicity injection
  - Narrow radial width for high Taylor limit on I_p
- Overall reduction in impurity content
  - VB, SPRED, bolometers
  - Plasma performance improved
- Present system promising for high-power ops

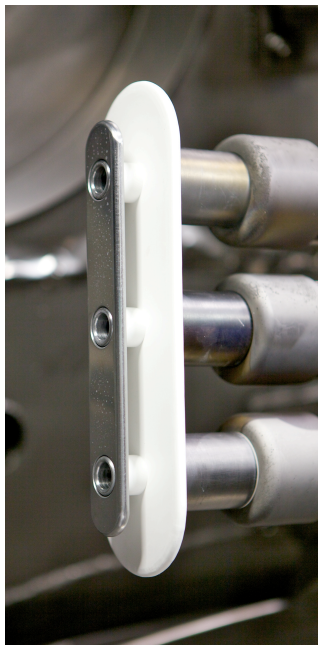
***See PP9.00002 Fonck* et al.**



Last APS: Plasma guns with "slotted" BN caps

Mo electrode with local scraper limiters





Present system:
Mo electrode raised off the BN limiter

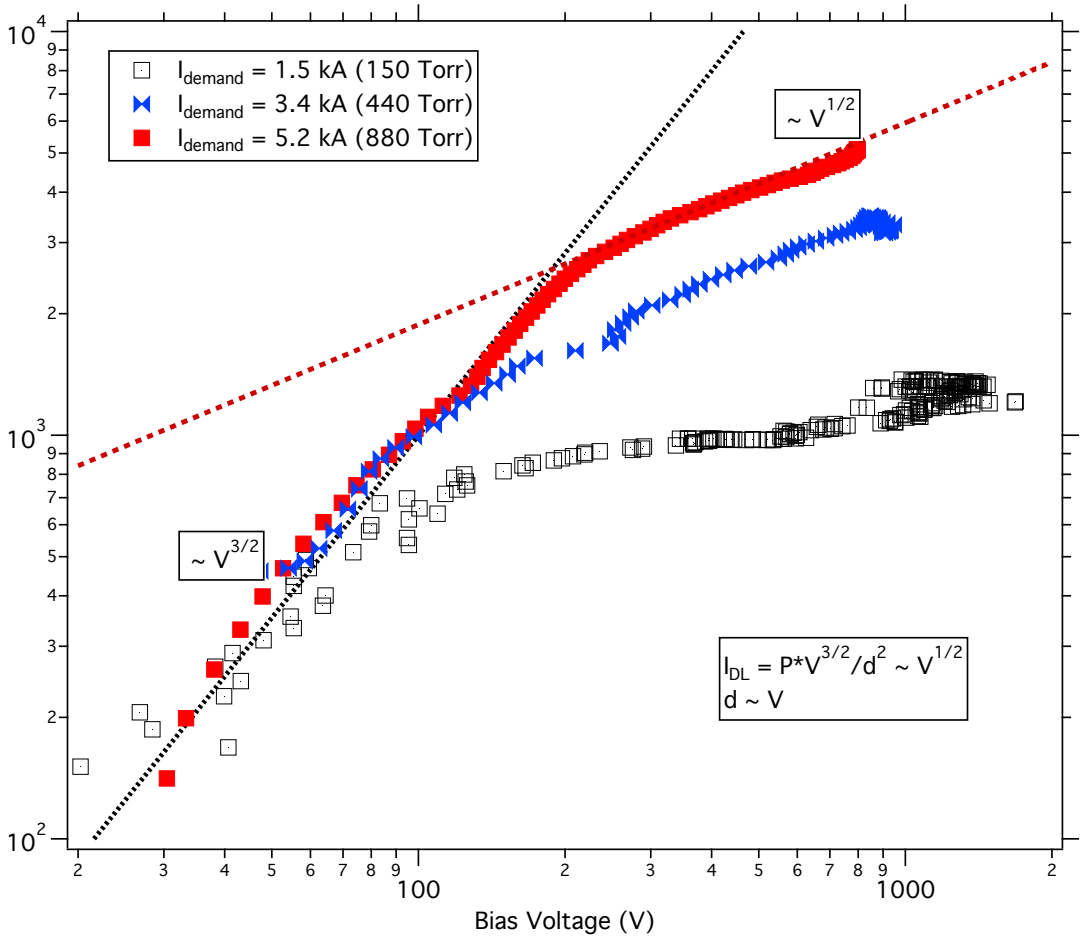
A.J.Redd et al., 2011 APS-DPP Meeting, Salt Lake City, UT

THE UNIVERSITY of WISCONSIN MADISON

Source Impedance Appears to be Governed by Sheath Physics

- Source impedance determines helicity injection rate
- Model for gun drive phase impedance evolving:
  - Initial space charge limitation gives $I_{bias} \sim V^{3/2}$
  - Saturated state is double sheath, giving $I_{bias} \sim V^{1/2}$
  - Predictive model requires n_e
- Electrode impedance is more complex

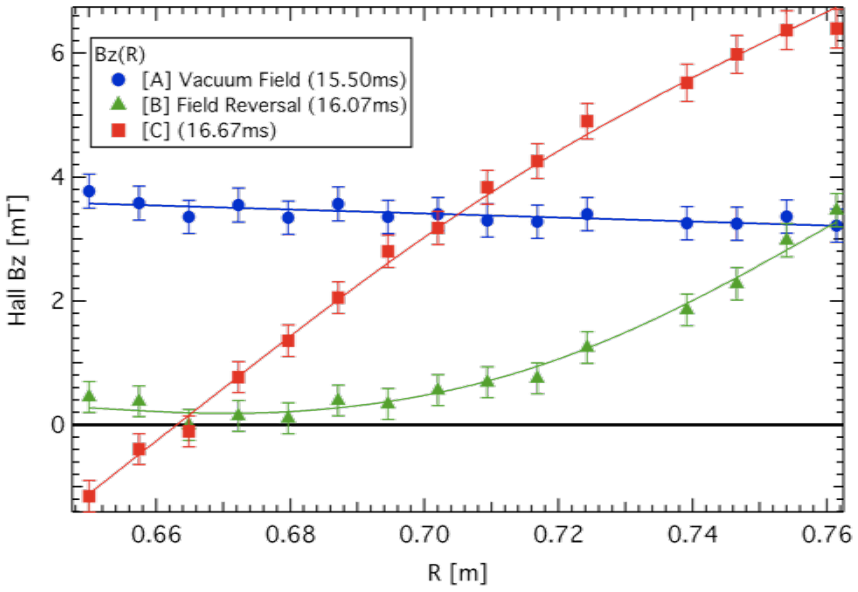
***See PP9.00004 Hinson* et al.**



THE UNIVERSITY of WISCONSIN MADISON

Internal $J_\varphi(R,t)$ Measurements Providing Details on Tokamak Formation via HI

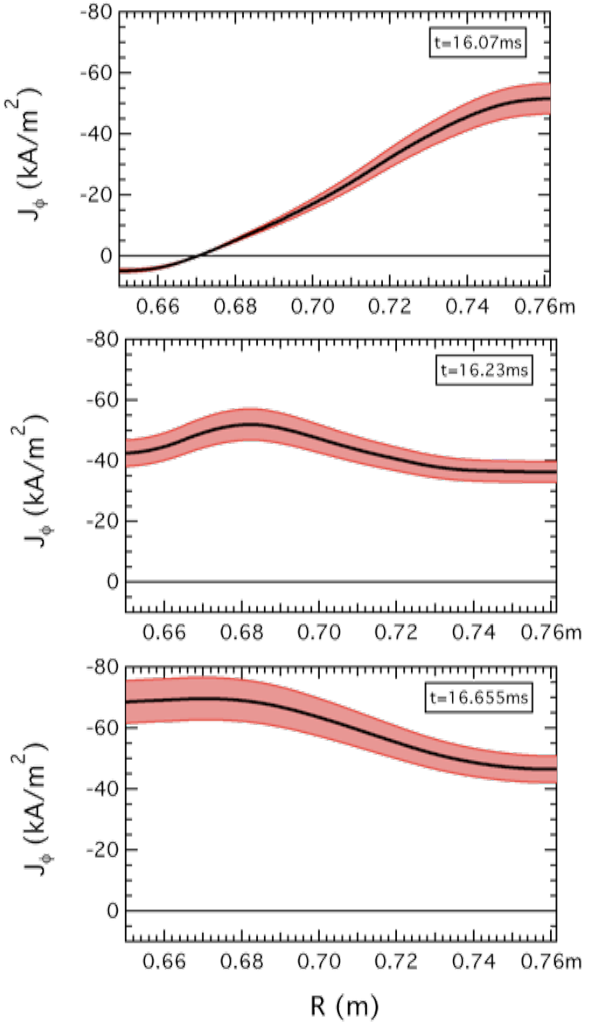
- $B_z(R,t)$ via a Hall probe array confirms the formation of a field null before relaxation:



***See PP9.00005 Barr* et al.**

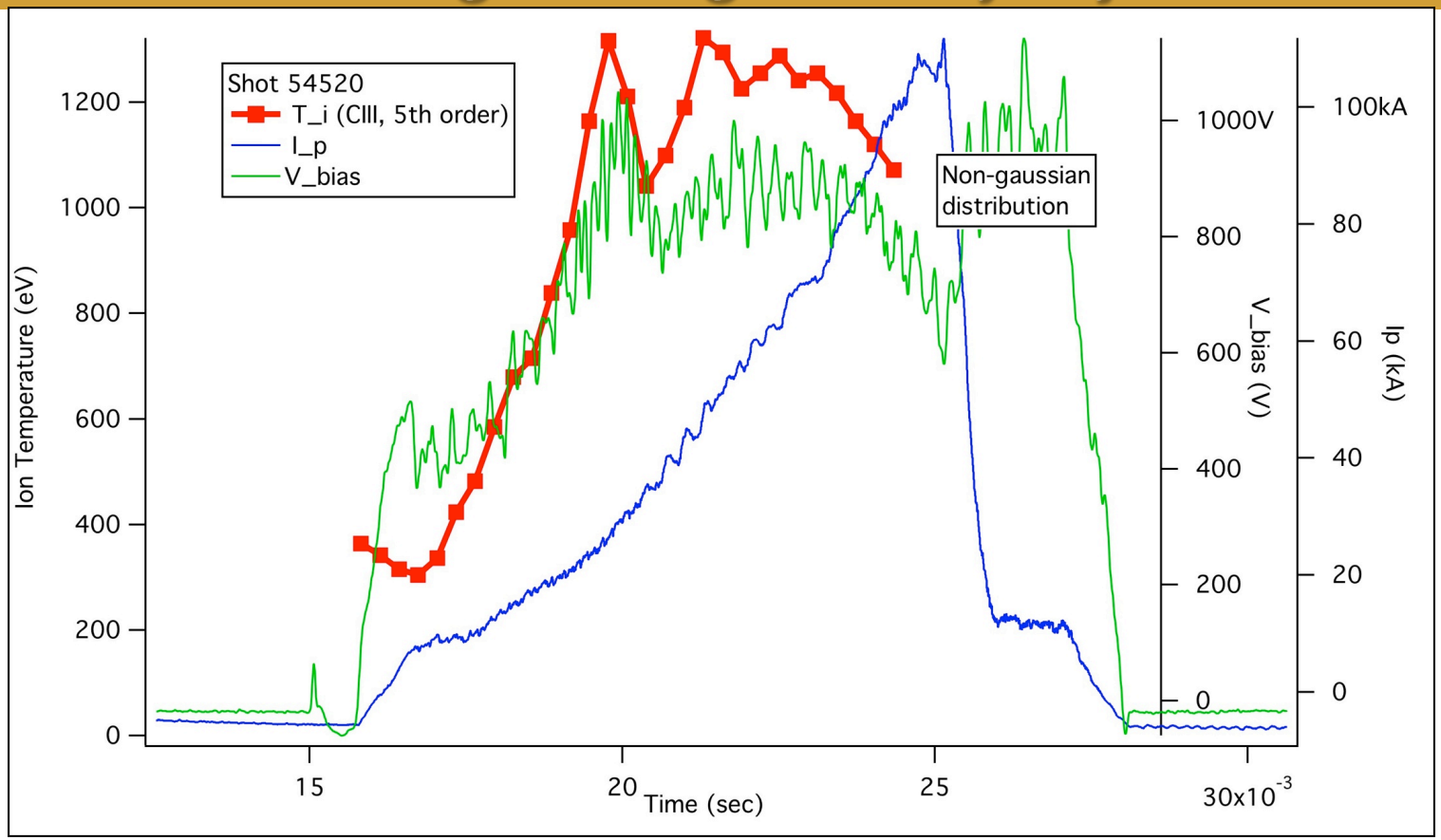
A.J.Redd et al., 2011 APS-DPP Meeting, Salt Lake City, UT

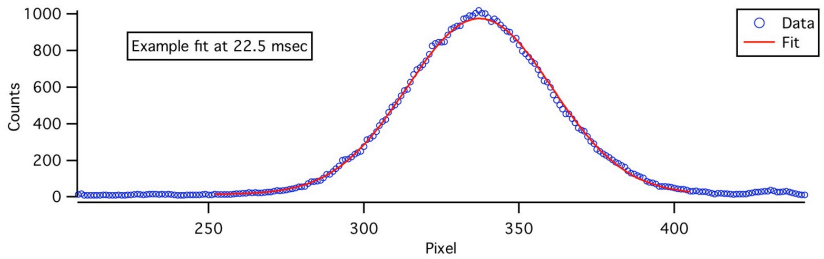
- Initial current profile is very hollow
- Current profile relaxes; current fills into the core
- Tokamak-like current profile forms



THE UNIVERSITY of WISCONSIN MADISON

Passive ion spectroscopy shows strong ion heating during helicity injection





***See PP9.00002 Fonck* et al.**

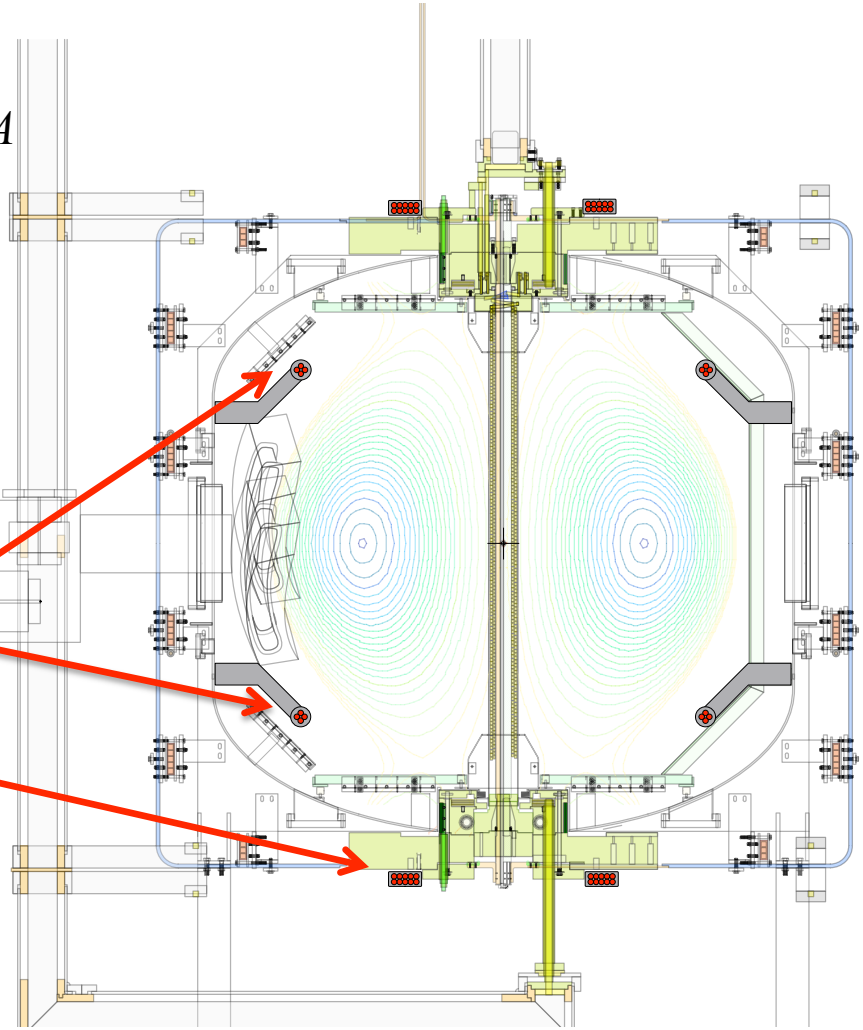
A.J.Redd et al., 2011 APS-DPP Meeting, Salt Lake City, UT

THE UNIVERSITY of WISCONSIN MADISON

Medium-Term Upgrades Will Allow Further Tests of Point-Source Helicity Injection

- Power Supplies, Heating
  - Increased helicity injection power: *3 kV, 15 kA*
  - Double TF current: *increase Taylor limit*
  - Possible HHFW system: *electron heating*
- New electrode deployment
- Expanded PF Coil Set and control
  - Internal coils for radial position control
  - New external divertor coils
  - Implement GA Plasma Control System
- Diagnostic Additions
  - Multipoint Thomson Scattering

See PP9.00007and PP9.00008



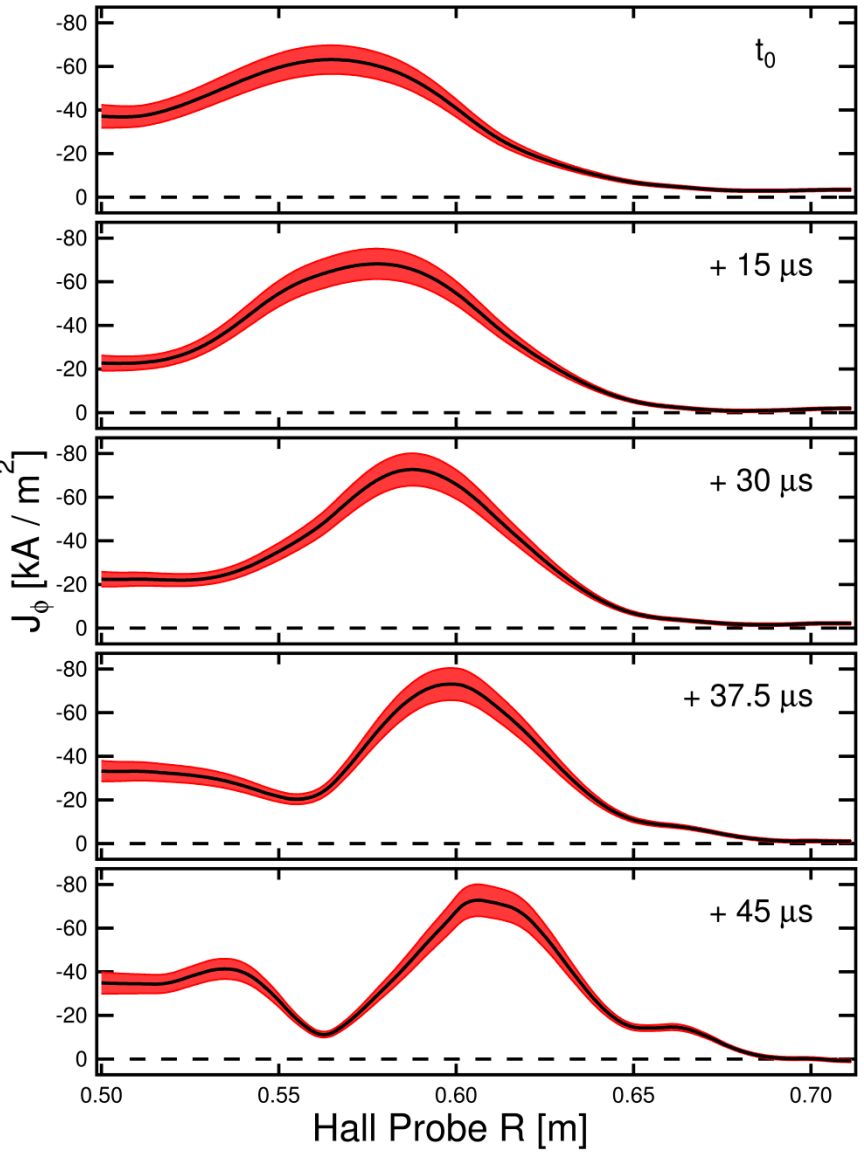
A.J.Redd et al., 2011 APS-DPP Meeting, Salt Lake City, UT

THE UNIVERSITY of WISCONSIN MADISON

ELM Dynamics studied with high time resolution J(R) measurements

- Peeling mode J_{edge} observed
- Propagating filament forms from "current-hole" J_{edge} perturbation
  - Validates formation mechanism hypothesized by EM blob theory
  - v_R comparable to theory
- $I_{filament}$ ~ 100–220 A, < 0.2% of I_p

***See PP9.00003 Bongard* et al.**



A.J.Redd et al., 2011 APS-DPP Meeting, Salt Lake City, UT

Summary

- Helicity injection program in the past year emphasized science understanding and technology development:
  - Address plasma-material interactions and increase helicity injection rate
  - Developing predictive model for source impedance
  - Preliminary current-profile evolution measurements
  - Near-term studies of the confinement and dissipation

- Operation at near-unity aspect ratio allows detailed study of peeling modes (ELM precursors):
  - Current-carrying filaments form, detach, and propagate radially