



Equilibrium & Stability Analysis of PEGASUS Plasmas



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Overview

- **Equilibrium analysis with new code**

- Grad-Shafranov solver coupled to Levenberg-Marquardt least squares fit
- robust & flexible, at expense of speed

- **Implementation**

- wall current modeling
- uncertainty analysis

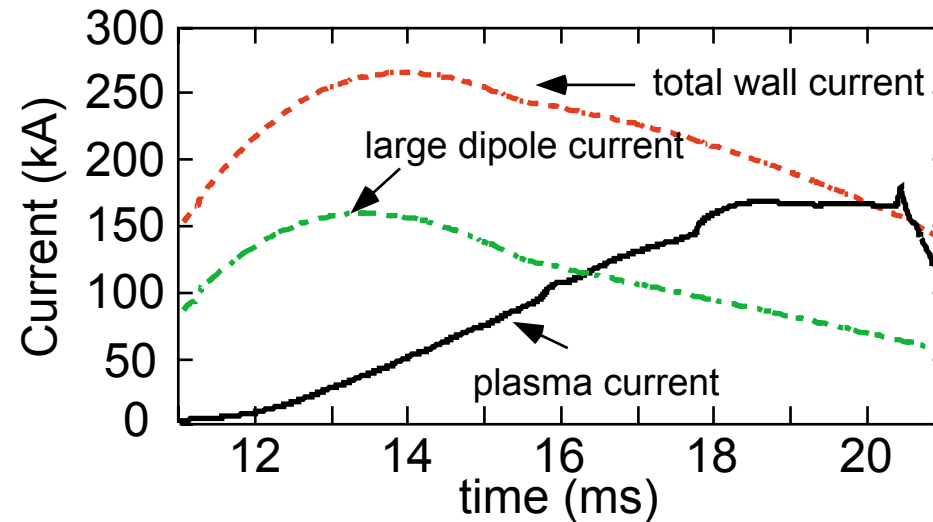
- **OH plasma characteristics**

- high- β , low-A plasmas accessed
- MHD
 - large 2/1 modes with low central shear*
 - external kink modes at higher I_p*

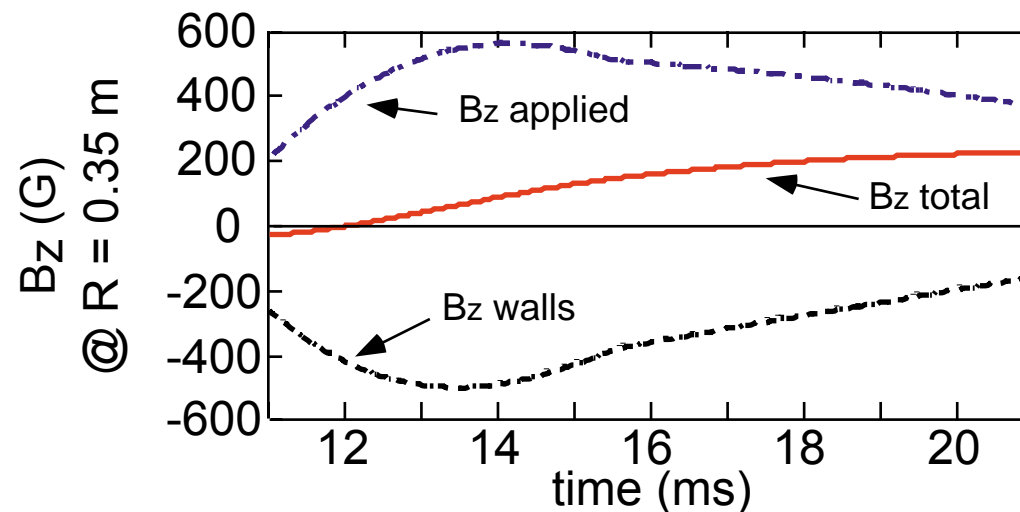


Equilibrium Analysis Accounts for Induced Wall Currents

- $I_{\text{wall}} > I_{\text{plasma}}$ throughout shot
 - large dipoles are most significant



- **Applied field must balance wall field**
 - necessary for breakdown and radial position control

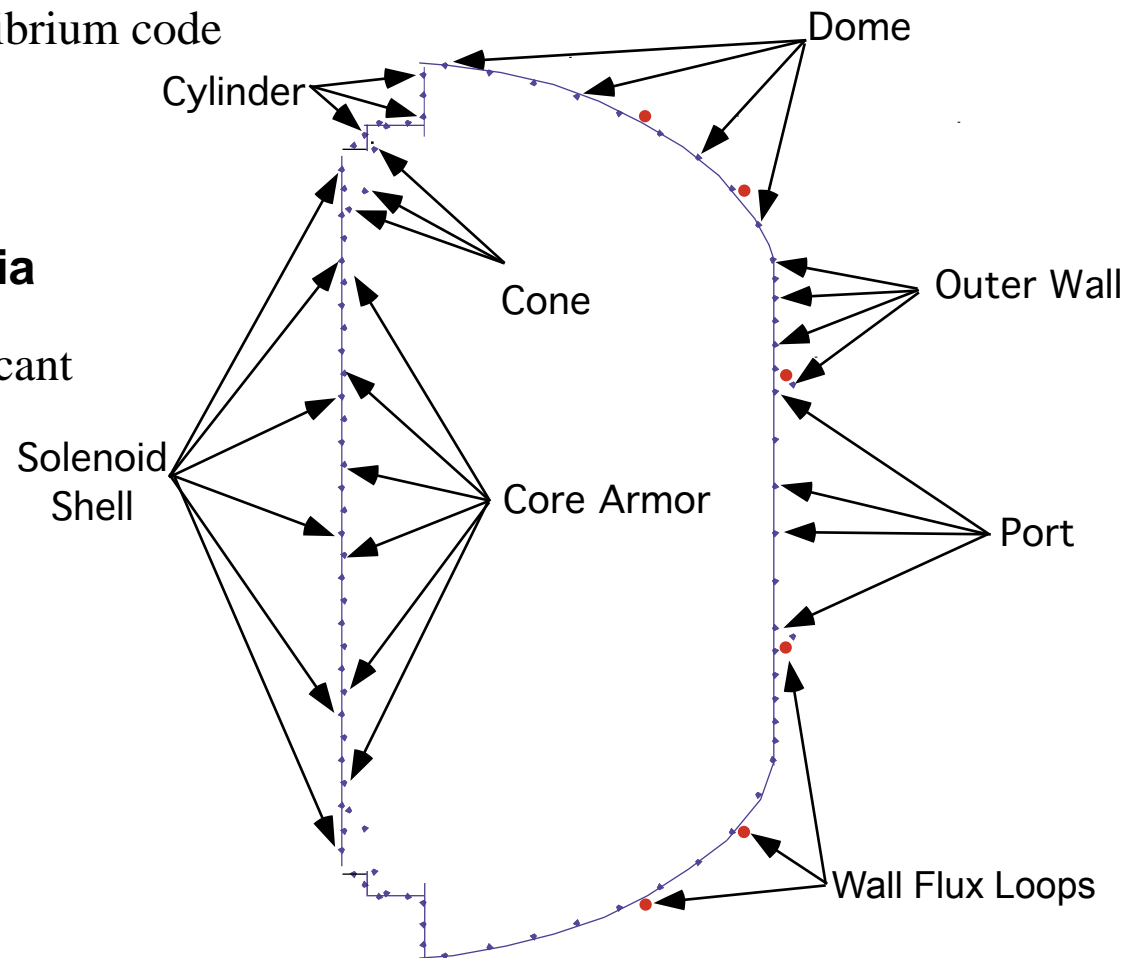




Wall Currents are Fit by Equilibrium Code

- **Wall modeled as 91 current filaments**
- **Filaments grouped into coil packs**
 - coil pack currents are fit by equilibrium code

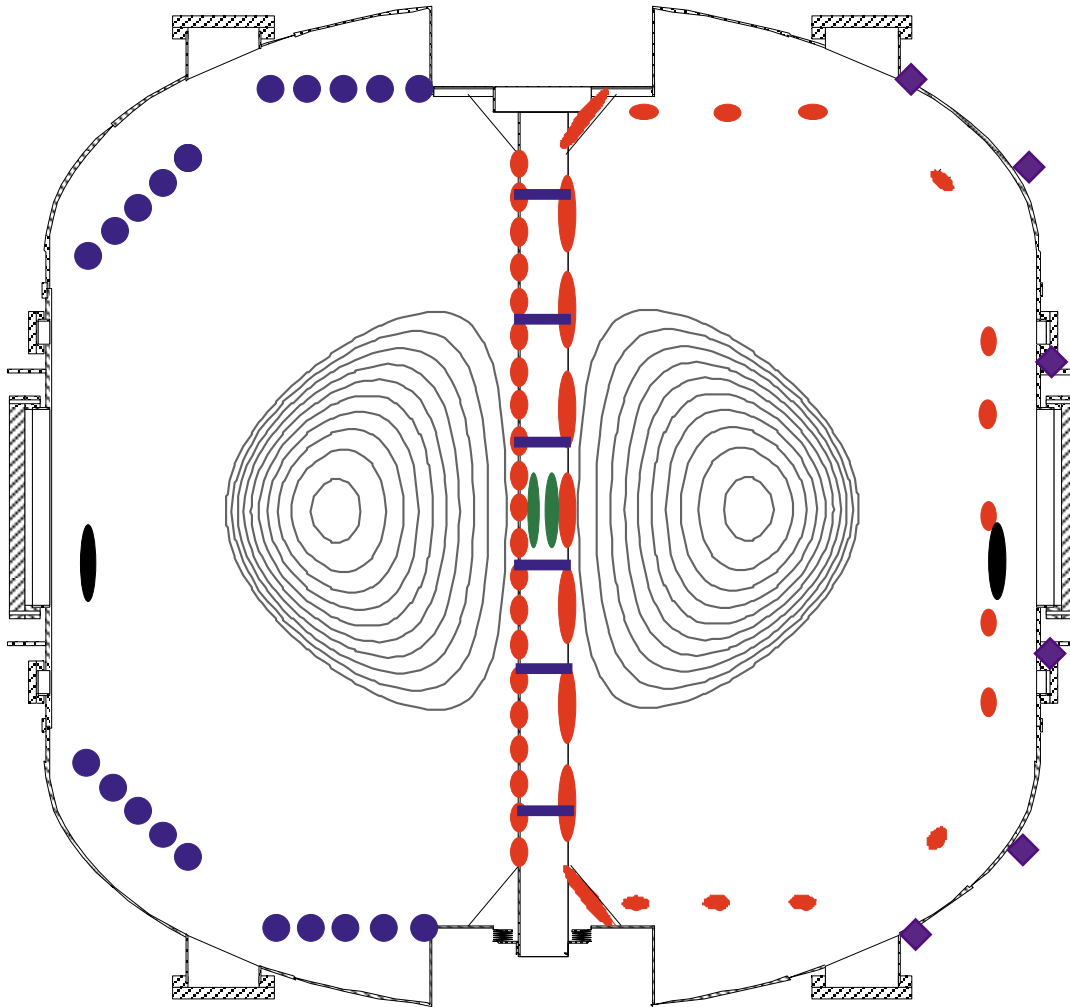
- **Coil pack currents constrained via wall-mounted flux loops**
 - dome and outer wall most significant
 - 2 loops on dome, 1 on outer wall





Addition of Magnetic Diagnostics

Current Magnetics Arrangement



Not shown:

- Plasma Rogowski Coils (2)
- Diamagnetic Loops (2)
- Diamagnetic Compensation Loop
- Internal B_{tan} Coils (15) [constrain wall currents]

Before Upgrade

- Poloidal Mirnov Coils	(13)
- Flux Loops	(6)
Total	(19)

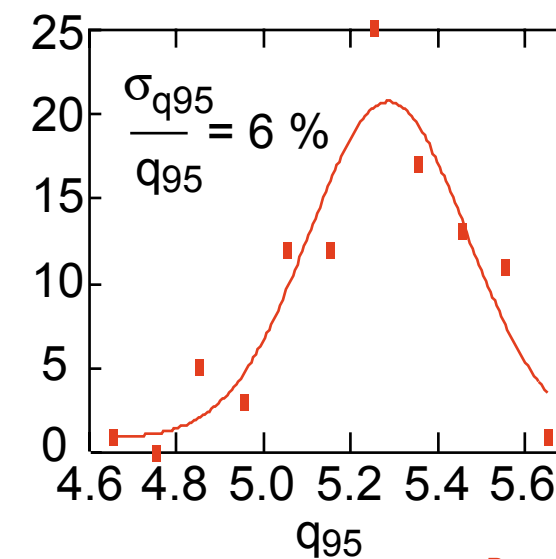
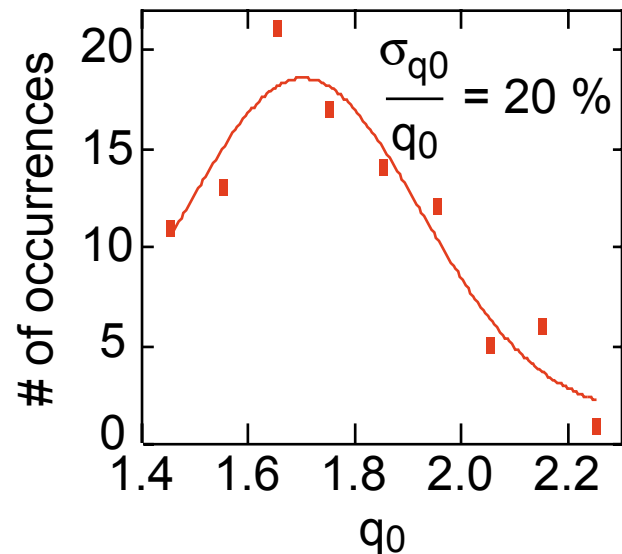
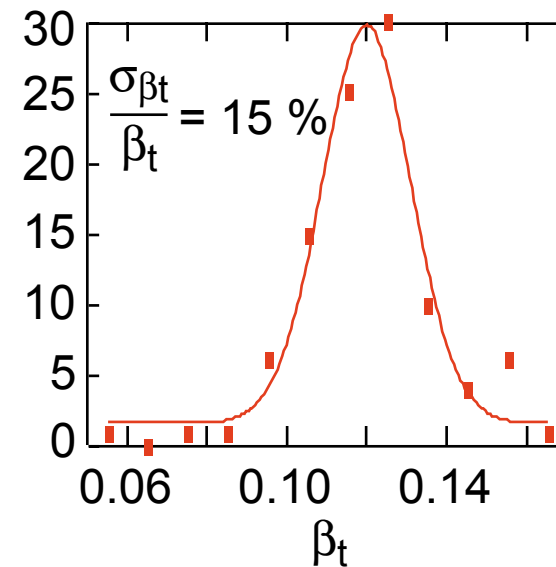
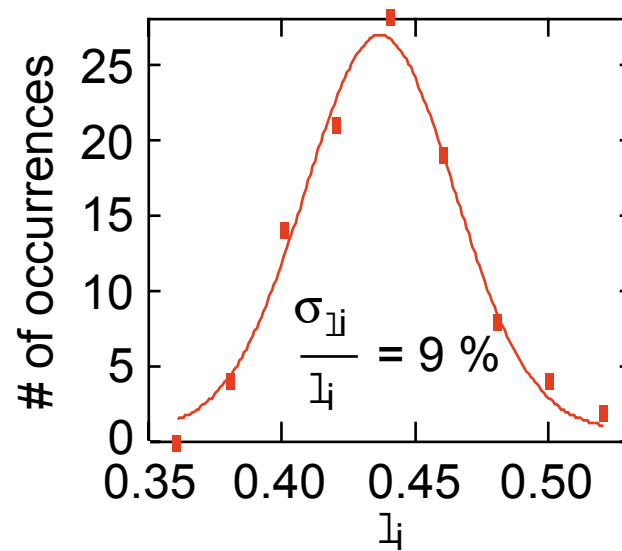
After Upgrade

● Flux Loops	(26)
● Poloidal Mirnov Coils	(22 + 21)
● LFS Toroidal Mirnov Coils	(6)
● HFS Toroidal Mirnov Coils	(7)
◆ External Wall Loops	(6)
Total	(88)



Equilibrium Accuracy Increased with Upgraded Magnetics

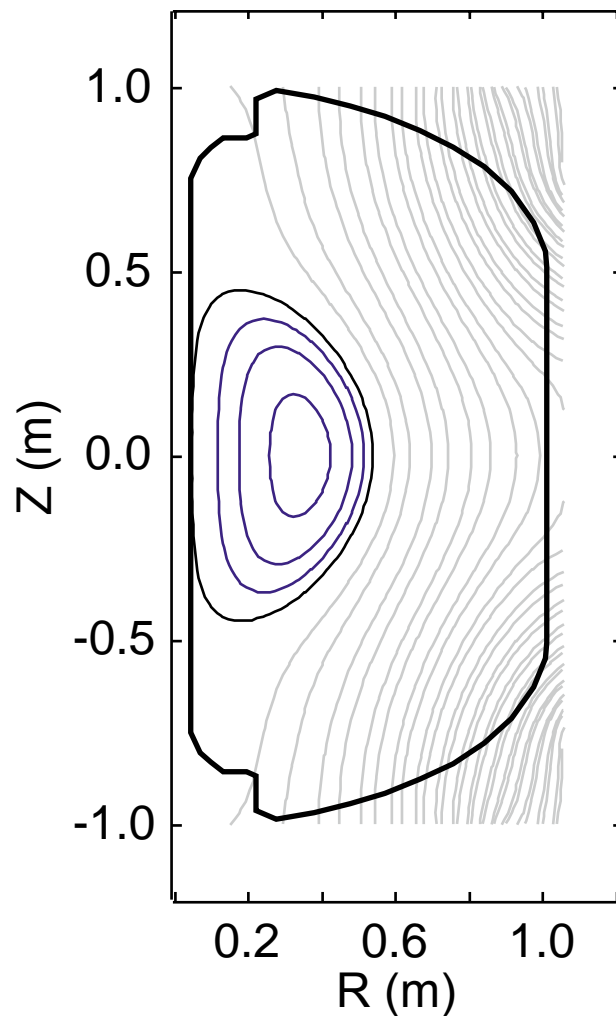
- **Upgraded magnetics provide good constraint**
 - Monte Carlo analysis to estimate fit parameter uncertainty





Equilibrium Reconstruction Shows High β_t for Fully Formed Plasmas

Poloidal Flux Plot

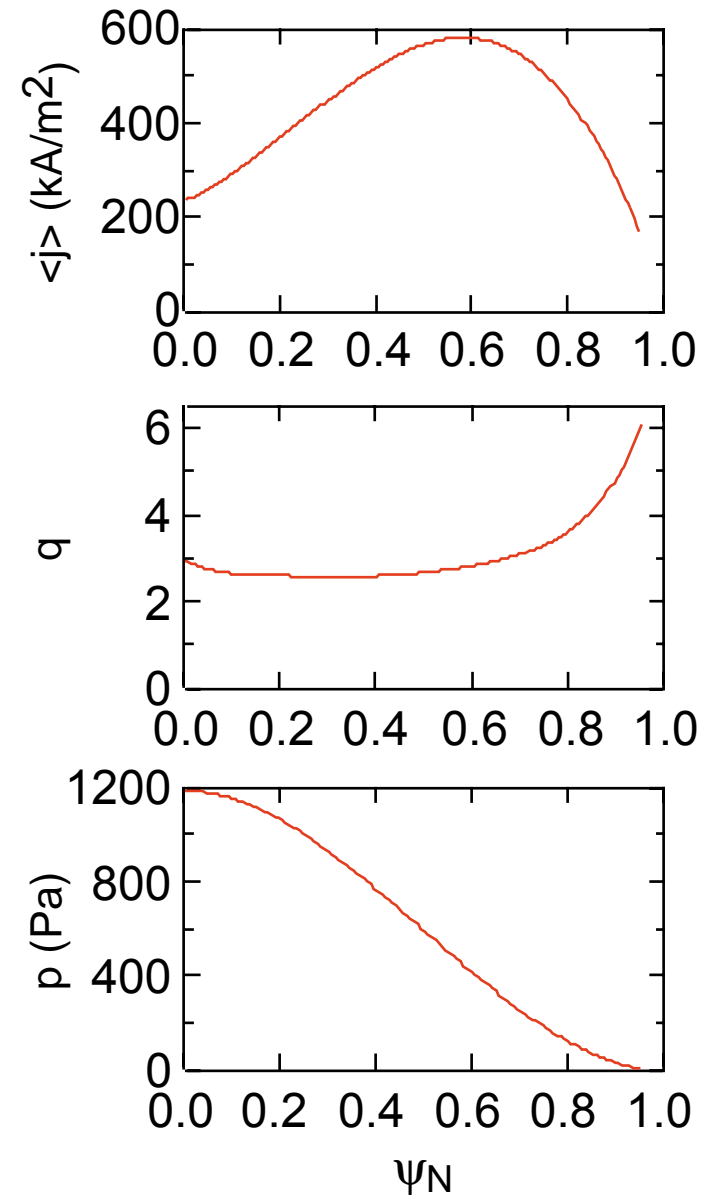


Shot
13064

I_p	151.4 kA
R_0	0.305 m
a	0.249 m
A	1.22
κ	1.8
B_t (axis)	0.1 T
β_t	16%
I_i	0.35
q_0	2.8
q_{95}	6.2

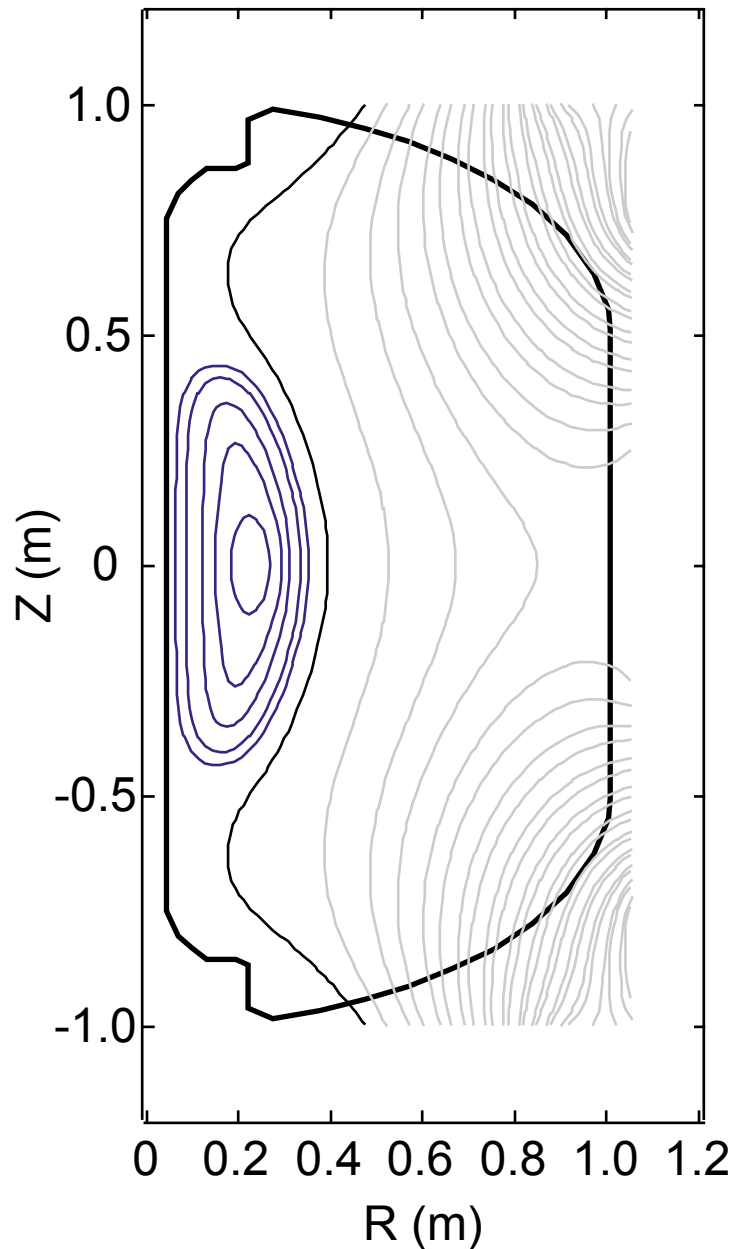
Constraints:

Rogowski Coil
15 Flux Loops
3 B_p Coils
Diamagnetic Loop



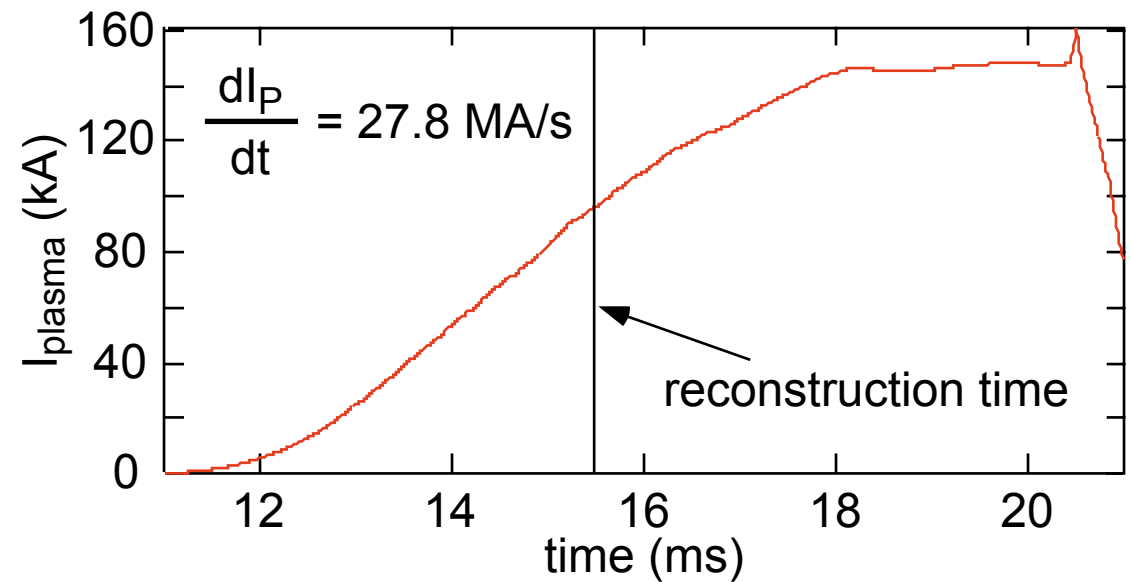
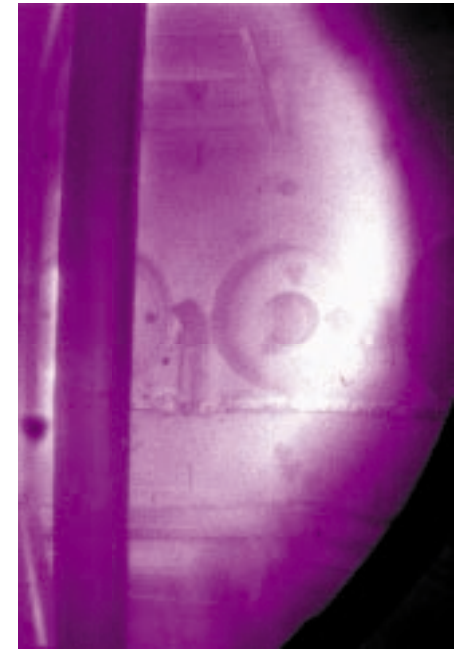


High Elongation Observed During Current Ramp



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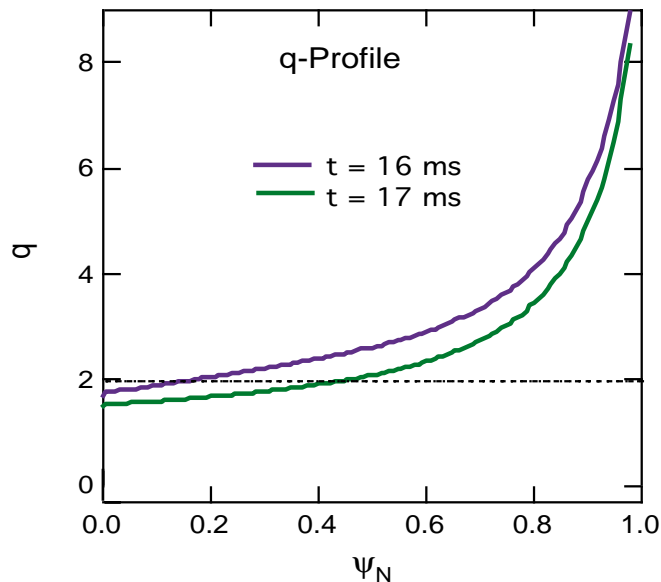
I_p	93.8 kA
R_0	0.203 m
a	0.147 m
b	0.436 m
A	1.38
κ	3.0
β_t	0.1 %
I_i	0.20
q_0	3.8
q_{95}	13.1



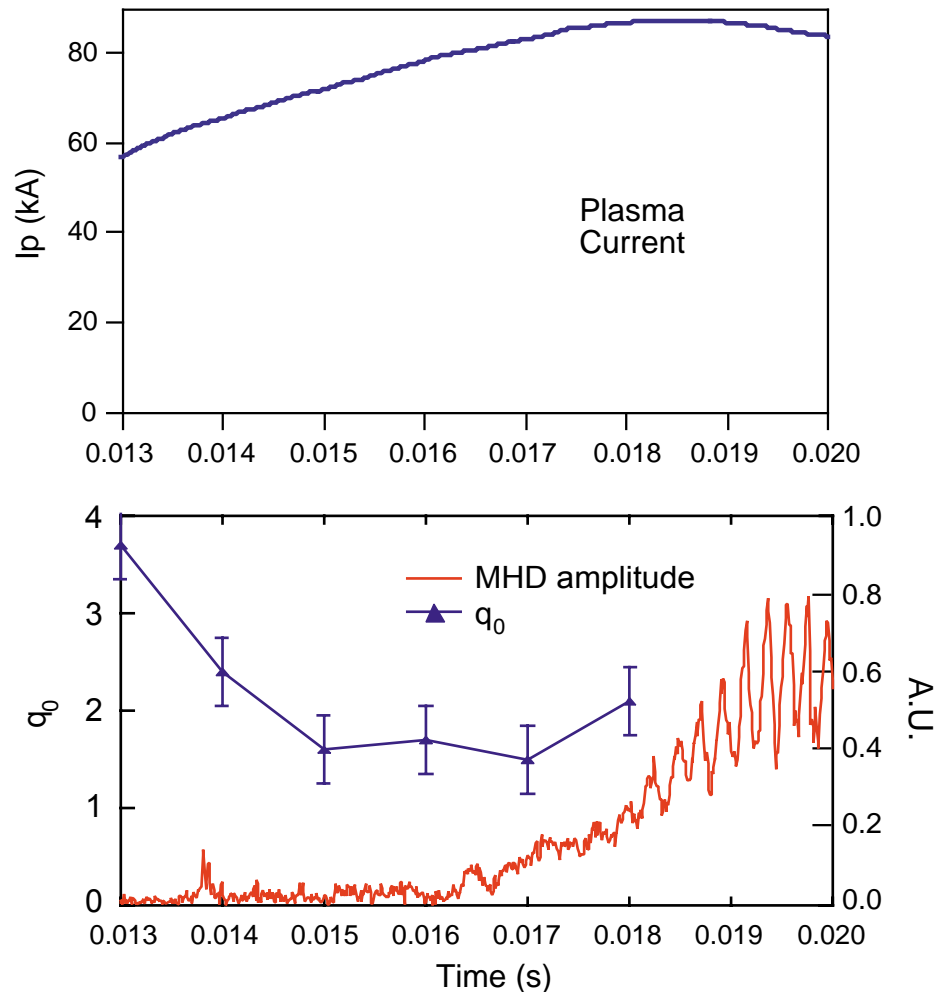


Growth of Large Tearing Mode Correlates with q_0 Behavior

- **Growth of 2/1 mode observed soon after q_0 passes through 2**
 - often appears to constrain discharge evolution
- **q_0 constrained by equilibrium fit to external magnetics**
 - 2D SXR camera will provide better constraint



- **Broad low-shear region gives mode large radial extent**

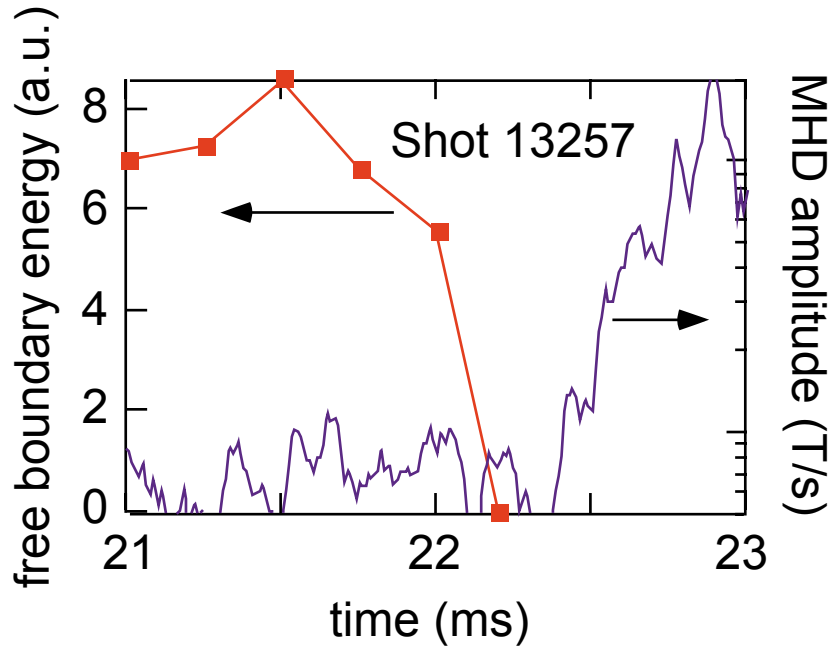


* RP1.034 MHD Activity and Analysis at Near-Unity Aspect Ratio in Pegasus
G. Garstka, et al.

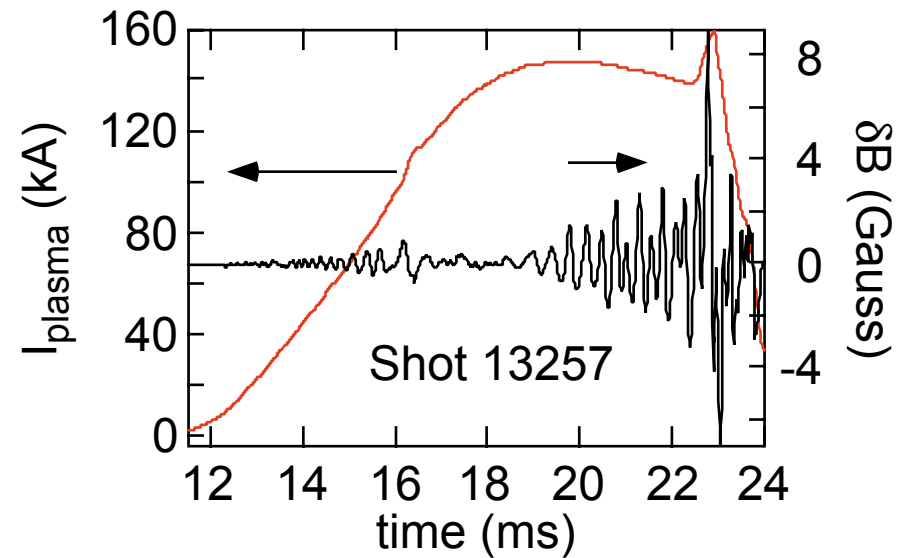
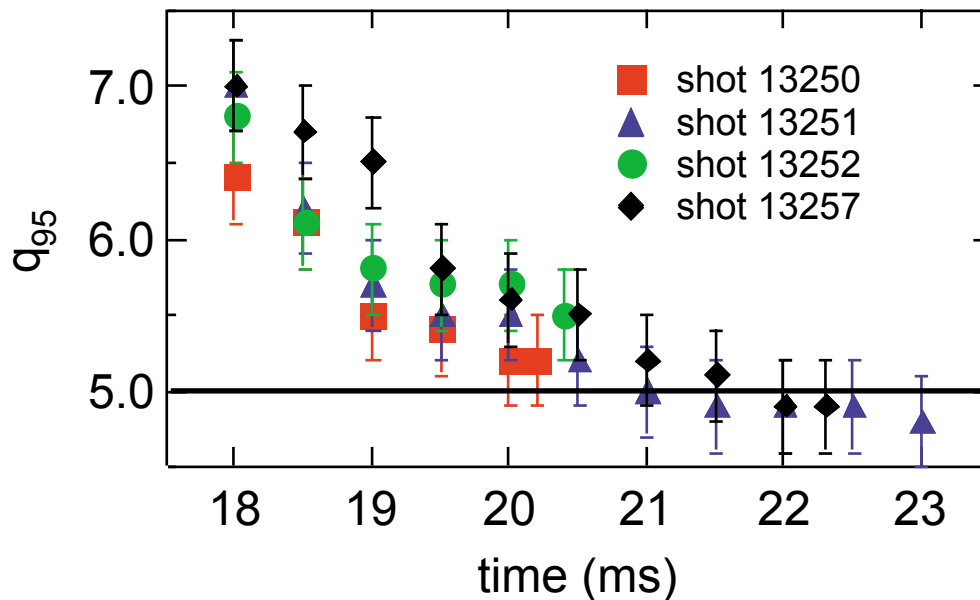




q_{95} Behavior and DCON Analysis Suggest Edge Kink Mode



- 2/1 suppressed by large \dot{I}_p and increased V-s
- free boundary energy $\rightarrow 0$ as $q_{95} \rightarrow 5$
- disruption immediately follows





Low-A Stability Limits Under Investigation with DCON

- **Edge kink limits currently being explored**
 - q_a limit expected to increase as $A \rightarrow 1$
 $q_{95}/q_0 > 2$ is high-A limit (Sykes-Wesson)

- **First scan gives $q_{95}/q_0 > 3$ as limit**

- Constraints:

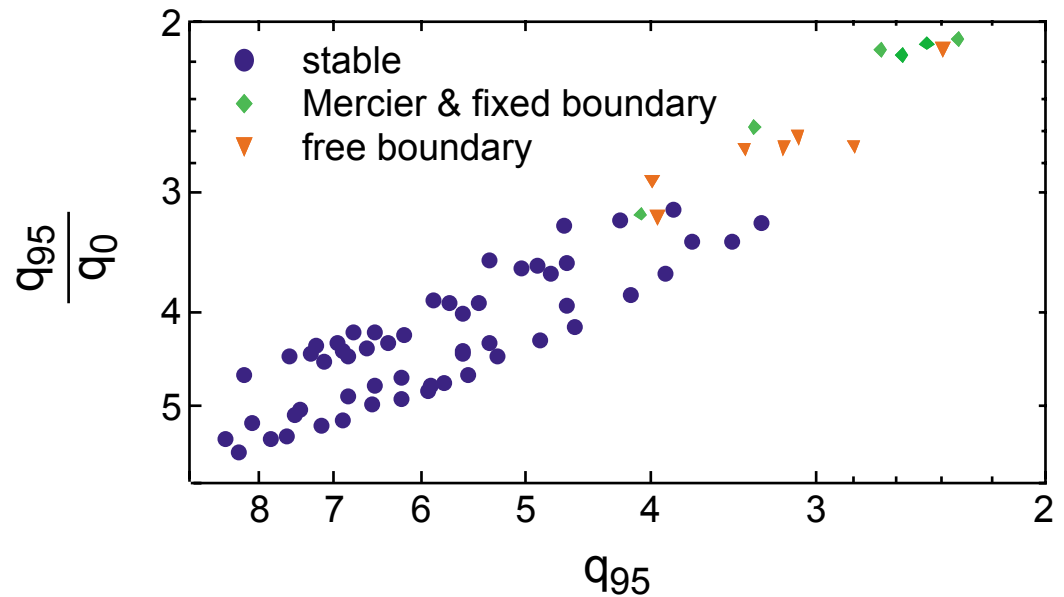
$$I_p = 120 \text{ kA}$$

$$R_0 = 35 \text{ cm}$$

$$q_0 > 1$$

$$\beta_t < 0.5\%$$

$$A \sim 1.15$$



- **More extensive scan in progress**





Summary

- **Equilibrium analysis is an essential tool for PEGASUS**
 - I_i , β , q_a , q_0 , etc.
 - input to stability codes
- **PEGASUS has entered designed operational regime**
 - high- β , high- κ achieved
- **Tearing modes and external kinks encountered**
 - theoretical exploration of parameter space begun