Abstract

Outline

- **Pegasus is a mid-size ST built to explore $A \rightarrow 1$**

- **Plasmas exhibit low-A characteristics**
  - High β_t, I_N, β_N via OH heating
  - High I_p/I_{tf}
  - low l_i

- **Characteristics of High I_p/I_{tf} Operation**
  - Large scale internal MHD limit on I_p/I_{tf}
  - External Kink at q_{95}=5

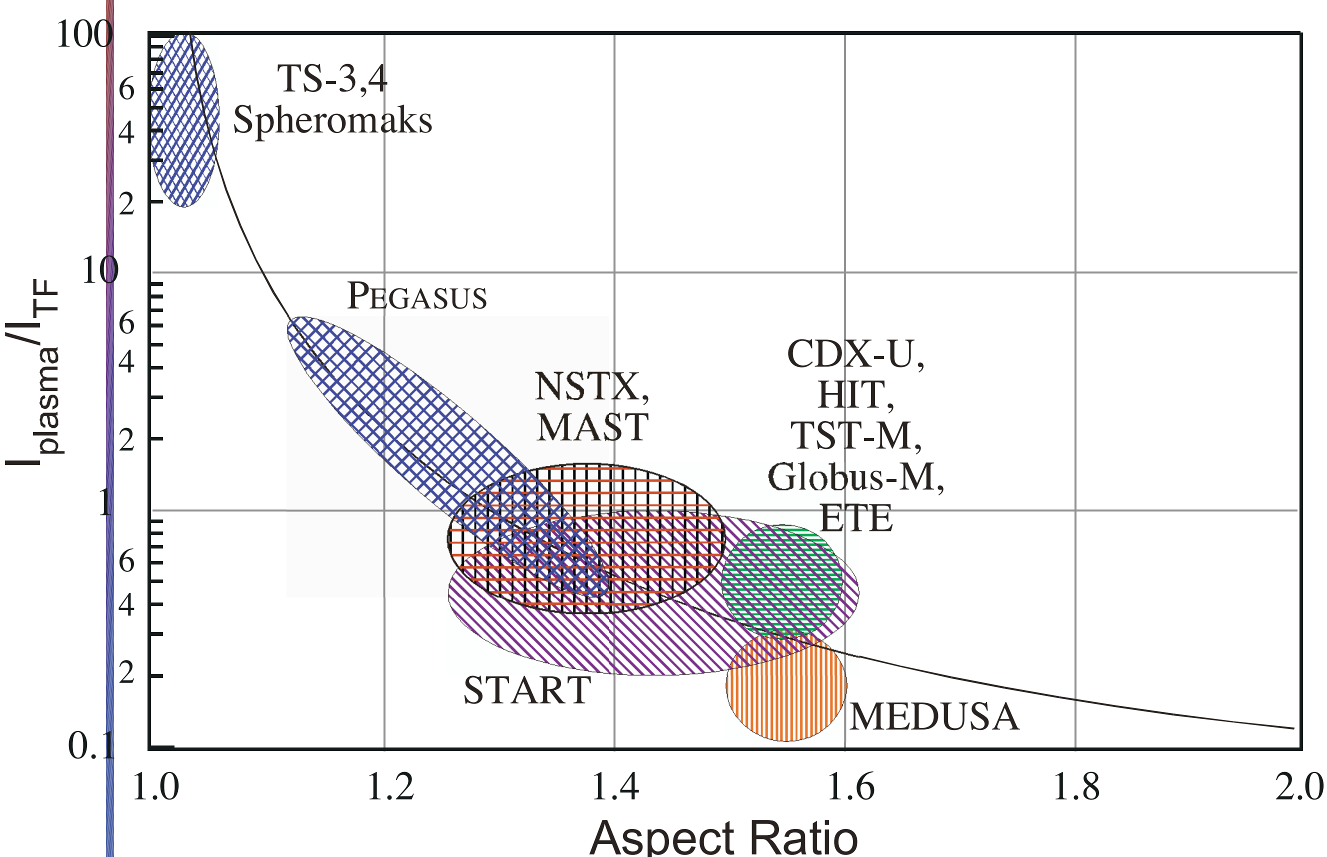
- **Upgrades to increase access to high I_p/I_{tf}, β_t regime**
  - Increased V-sec.
  - Position and shape control
  - B_{TF} versus time

Role of PEGASUS in Fusion Community

Mission Statement

An extremely low-aspect ratio facility exploring quasi-spherical high-pressure plasmas with the goal of minimizing the central column while maintaining good confinement and stability.

- *Stability at very high TF utilization (I_p/I_{TF}) > 3, ($\beta \approx 1$)*
- *Relaxation stability at tokamak/spheromak boundary for $A \rightarrow 1$*
- *Access high-β_t at extreme I_N w/o conducting shell*

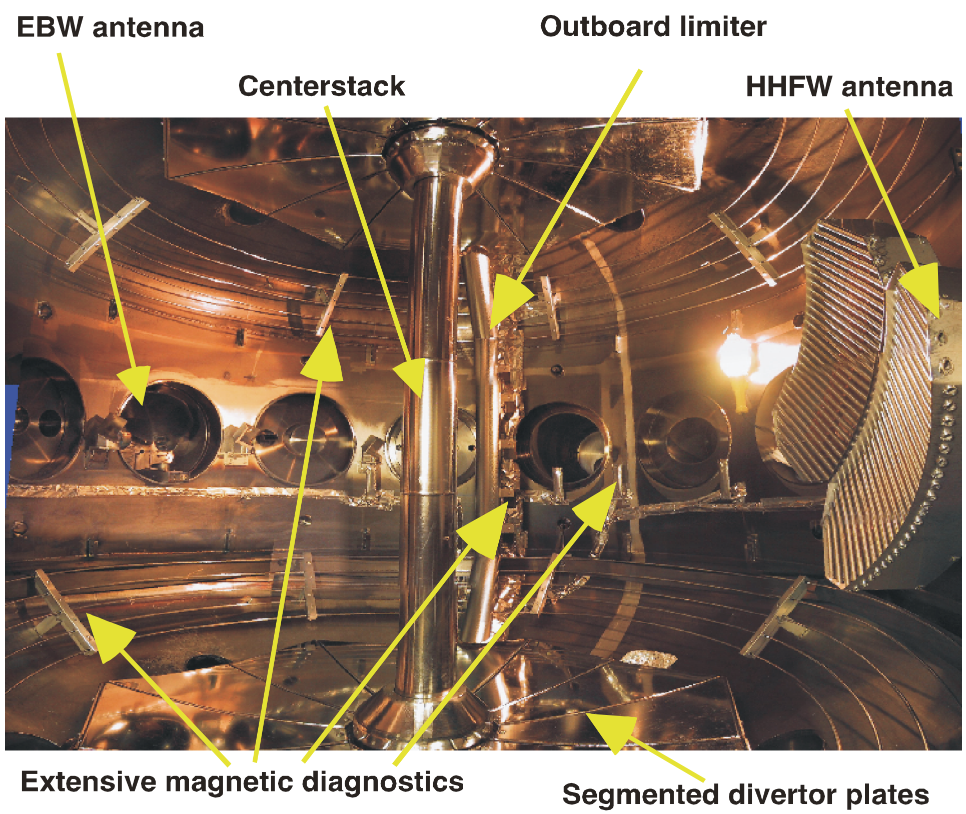


Machine Parameters

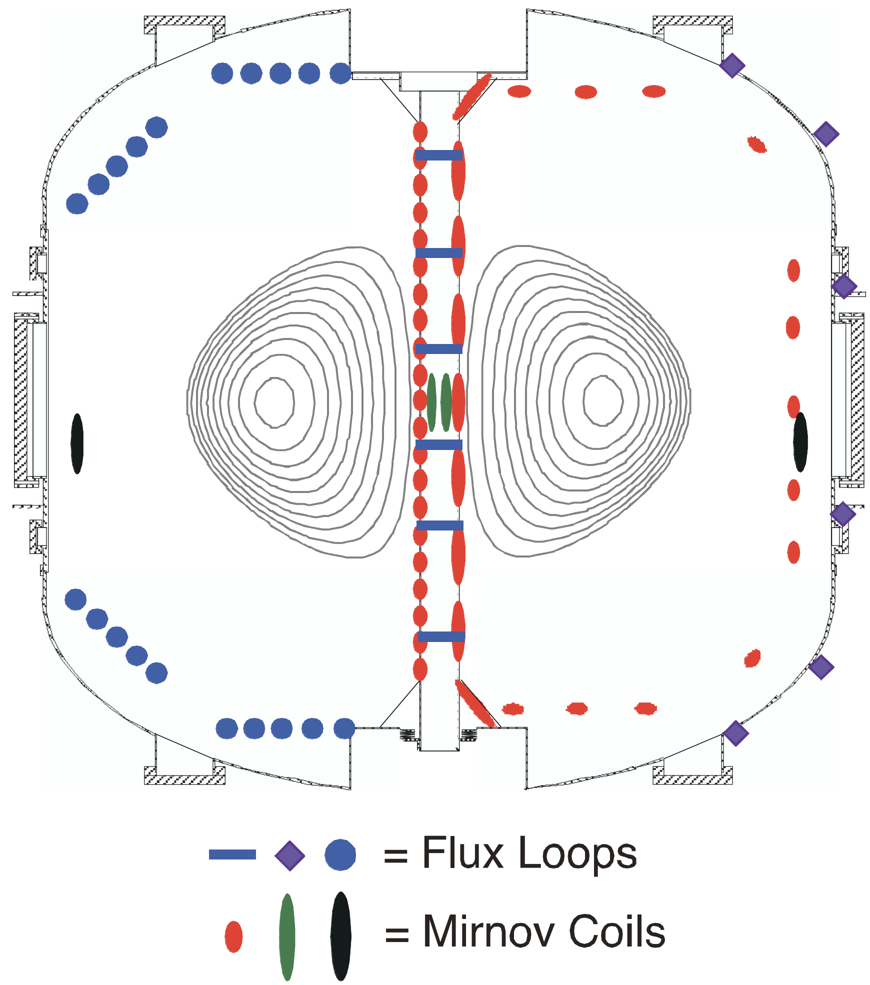
-A ~ 1.1 - 1.3	**-R ~ 0.2 - 0.45 m**	**-Δt_{pulse} ~ 10 - 30 msec**
-I_p ≤ 0.15 MA	**-B_t < 0.30 T**	**-K ~ 1.5 - 3.7**

Diagnostic Set for Reconstructions and Mode Analysis

Composite Photograph of Vessel Interior



Schematic of Magnetic Diagnostics



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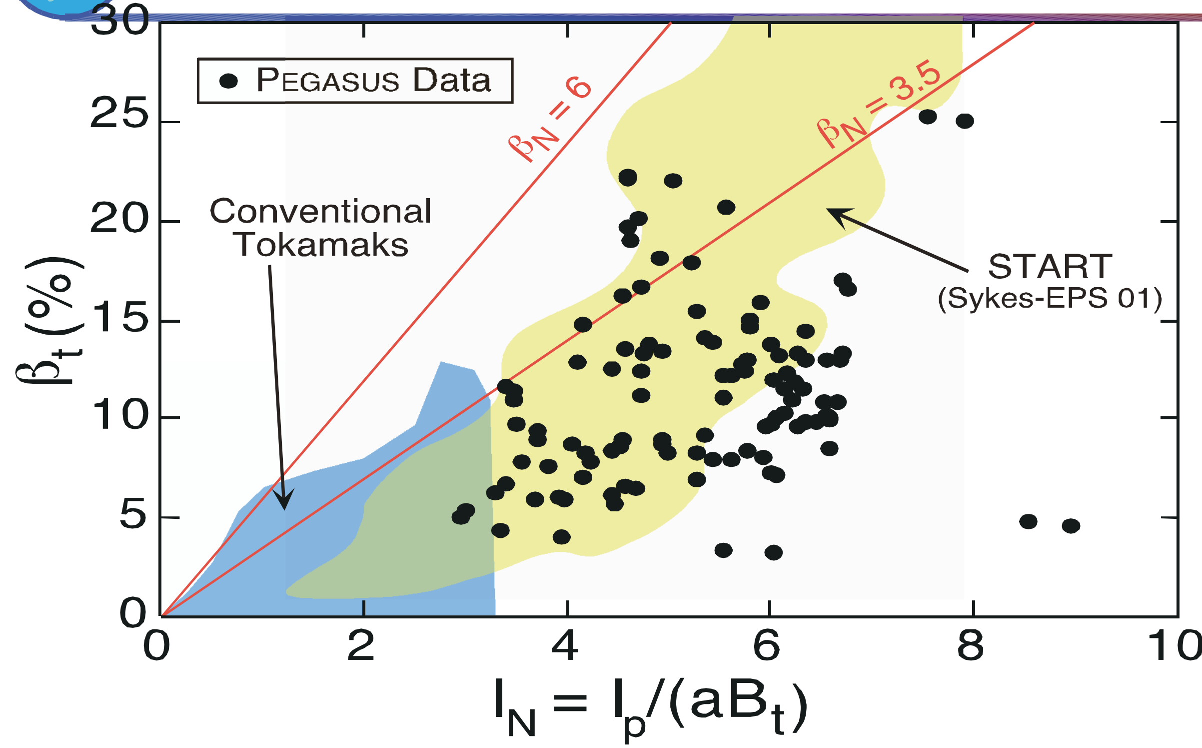
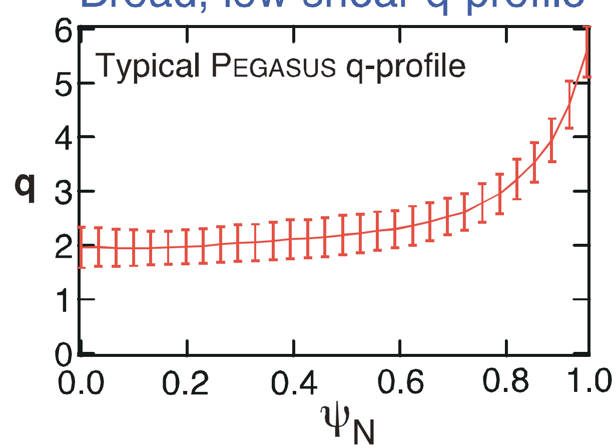
Plasmas Show Low-A ST Characteristics

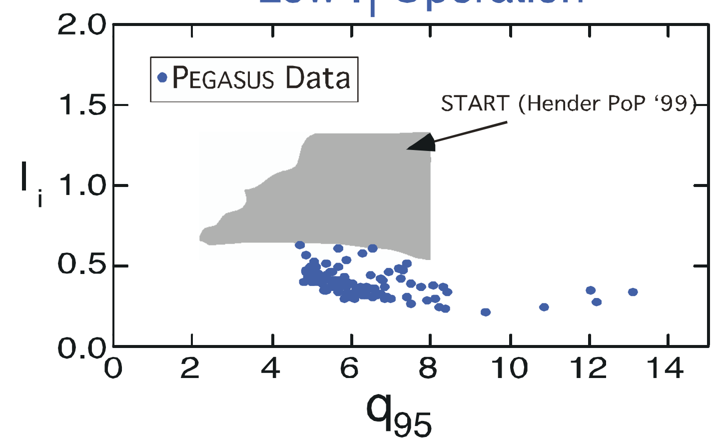


- **Typical discharge parameters**
  - β_t > 10%
  - β_N > 4
  - I_p/I_{TF} ~ 1
  - I_N ~ 6
  - n_e ~ n_{GW}
  - κ > 2
  - *MHD: 2/1, 3/2, IREs, DTMs*

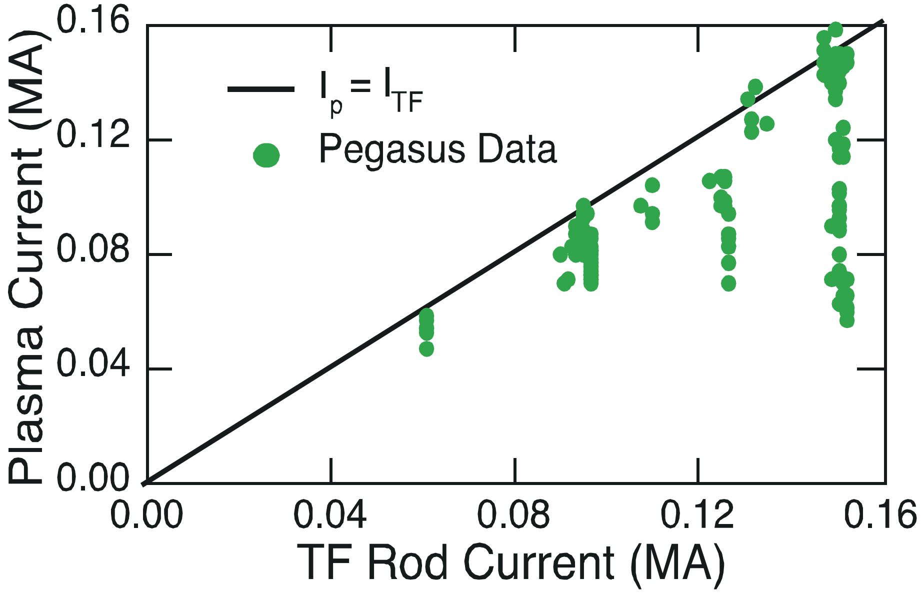
Broad, low shear q-profile



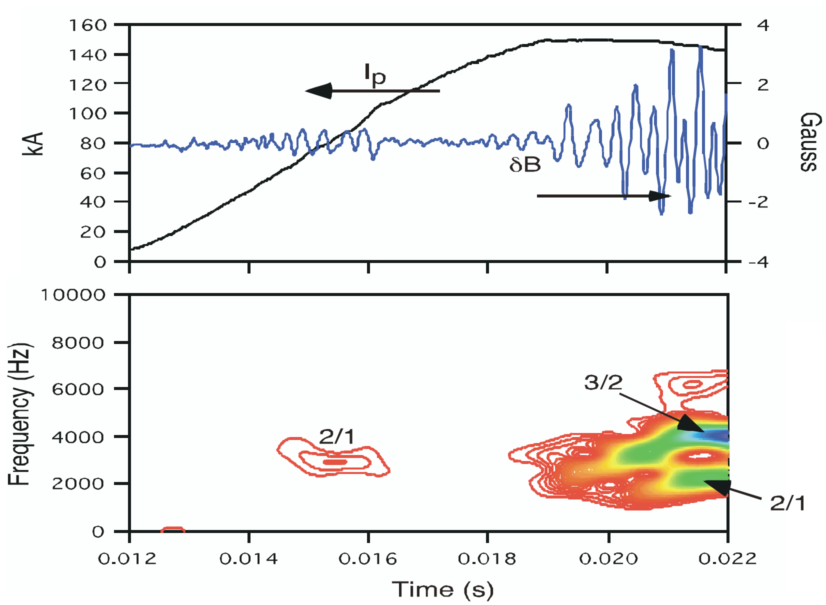
Low l_i Operation



High Toroidal Field Utilization Achieved

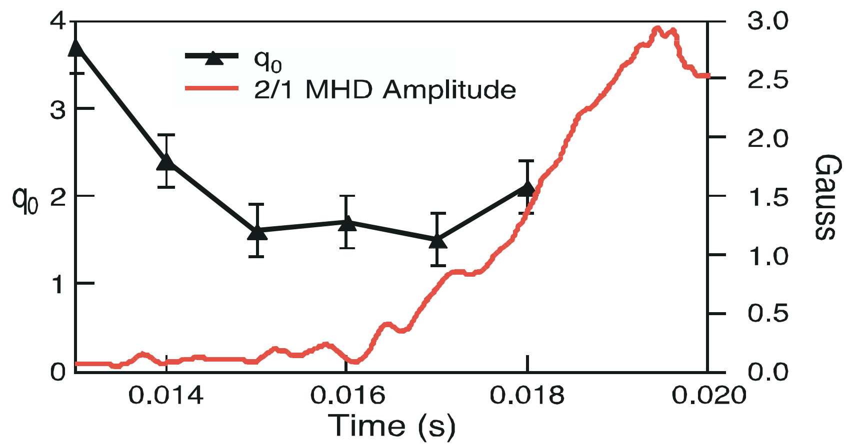


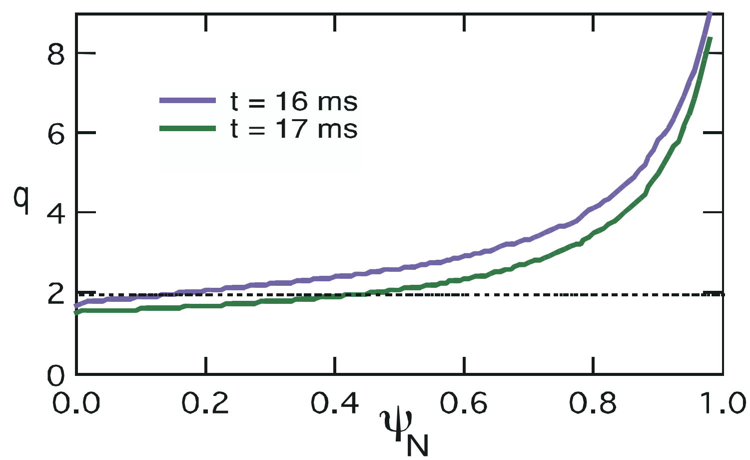
- I_p/I_{tf} = 1 routinely achieved
- I_p/I_{tf} “soft“ limit due to:
  - Large scale internal MHD
  - V-sec. availability as B_{tf} is lowered



- Resistive modes seen in most discharges
- Characterized as 2/1 and 3/2 modes
  - seen as $q_{50} < 2$ and 1.5, respectively

Soft Limit Inhibited by Rational Surface Location and Shear





- **Large internal modes degrades plasma**
  - Rollover in I_p
  - High $C_E \Rightarrow$ poor flux consumption, low τ_E
  - Estimated large island width, w > 10 cm
- **Heuristic analysis predicts $q_0 \approx 2$ limit**
  - $\frac{I_p}{I_{TF}} \sim \frac{1}{A^2}\frac{1}{q_0}\left(\frac{1+\kappa^2}{2}\right)$
  - For Pegasus@$q_0 \approx 2$: A~1, κ ~ 1.7
  - Hence $I_p/I_{tf} \approx 1$
- **Optimization of q-profile leads to less virulent modes**
- **Magnetic shear also mitigates MHD**

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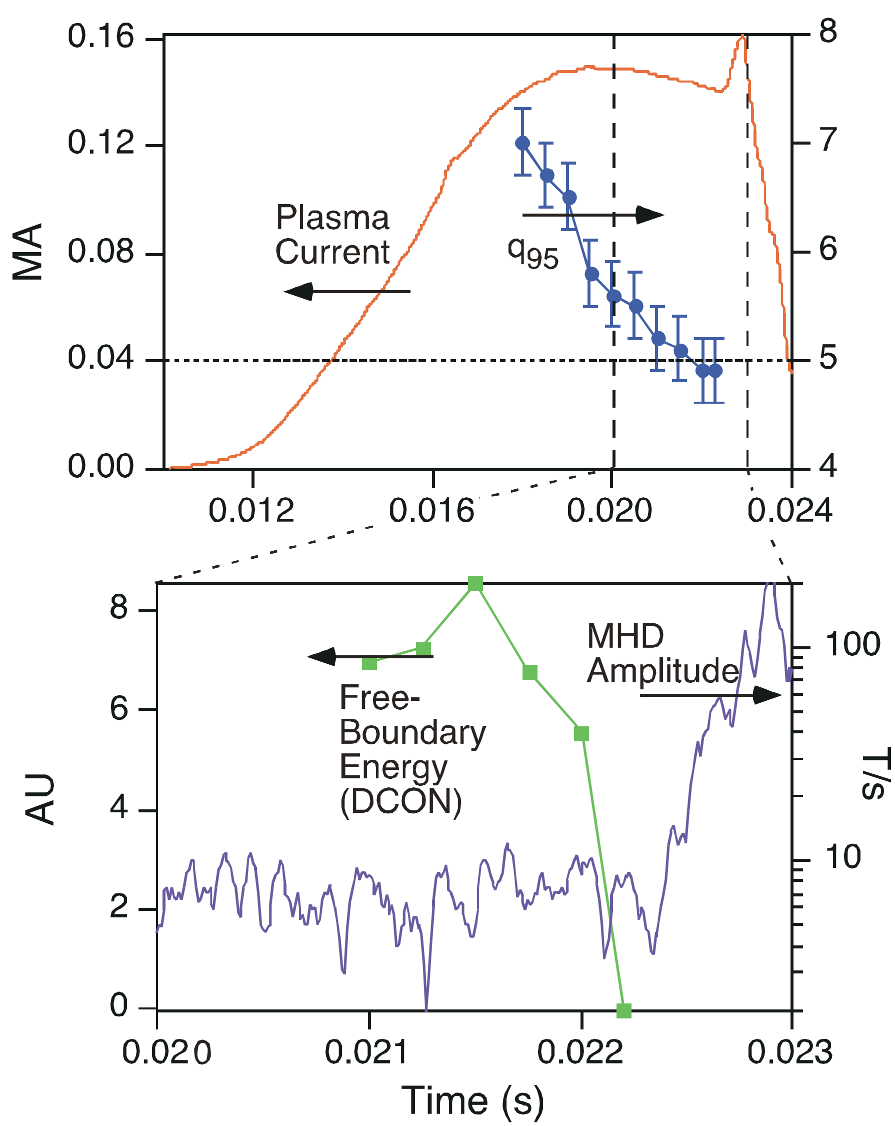
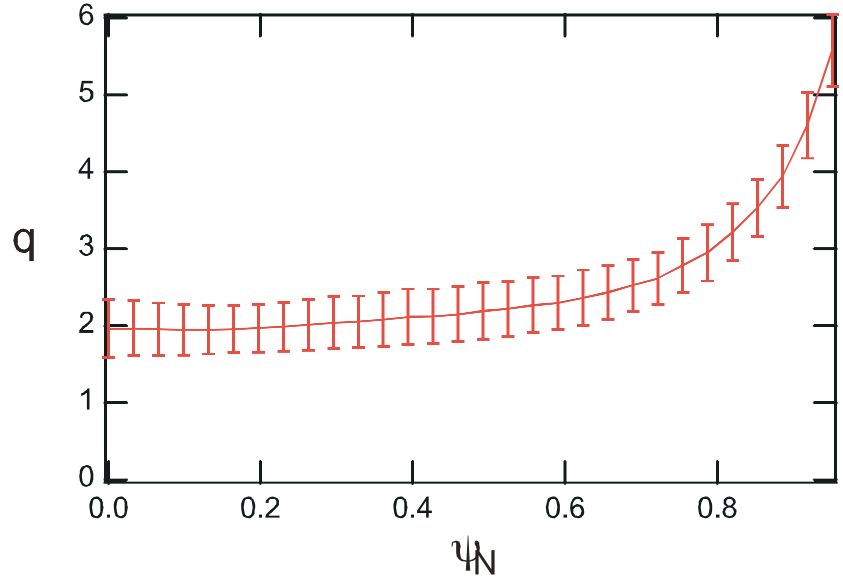
High q_{95} external kink limit observed



- **n=1 observed prior to disruption**
- **Associated with edge kink limits**
  - Oscillations not observed until $q_{95} \approx 5$
- **DCON predicts external kink at mode onset**
- **Consistent with theory expectation**
  - As $A \rightarrow 1$, unstable q_a increases
  - Roles of finite β, low l_i under study

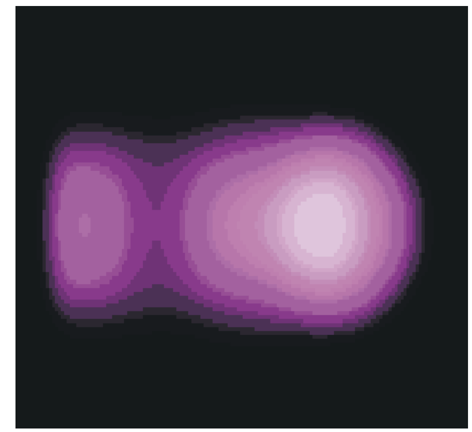
SXR Image Data Provides Internal Constraint for Determination of $q(\psi)$

- Confirms wide region of low shear in plasma interior

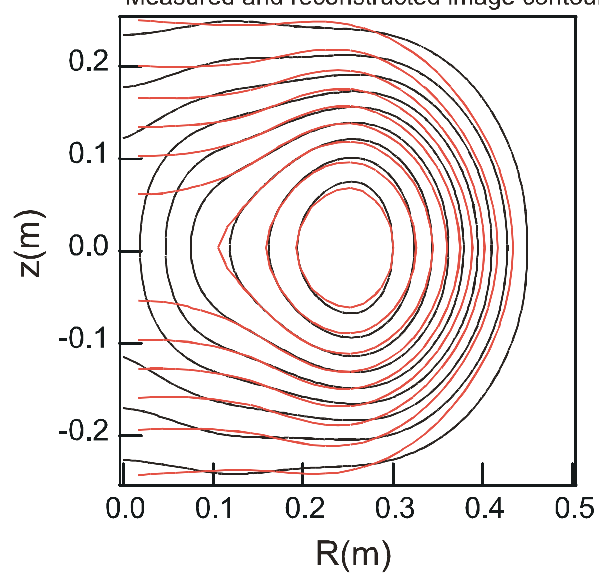


- External magnetics constrain plasma boundary
- SXR image provides internal constraint

Smoothed tangential PHC X-ray image



Measured and reconstructed image contours



Access to High I_p/I_{tf}, β_t Operation

- **Suppression of large internal MHD modes**
  - Vary $q(\psi)$
  - Lower η before $q(\psi)$ approaches low-order rational mode surfaces
  - Tools: increase V-sec. and duration, time-varying B_{tf}
- **Expand access to external kink modes studies**
  - Plasma time evolution, shape
  - Edge conditions
  - Tools: flexible poloidal field system, divertor activation
- **Access to very high β_t regime for stability analysis**
  - OH access and HHFW heating availible

Summary

- **Pegasus is a mid-size ST built to explore A → 1**

- **Plasmas exhibit low-A characteristics**
  - $\beta_t > 10\%$, $I_N \sim 6$, $\beta_N > 4$ via OH heating
  - $I_p/I_{tf} \sim 1$
  - $l_i \sim 0.4$

- **Characteristics of High I_p/I_{tf} Operation**
  - Large internal tearing modes contribute to $I_p/I_{tf} \sim 1$
  - External kink observed at $q_{95}=5$

- **Upgrades to increase access to high I_p/I_{tf}, β_t regime**
  - Increased V-sec.
  - Position and shape control
  - B_{TF} versus time

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Access to High I_p/I_{tf}, β_t Operation

- **Manipulate q-profile:** suppression of large internal modes
- **Lower η during plasma formation:** suppression of large internal modes
- **Manipulate edge current:** Expand access to external kink modes
- **Access to very high β_t regime for stability analysis**

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Facility Upgrades for Further Low-A Studies

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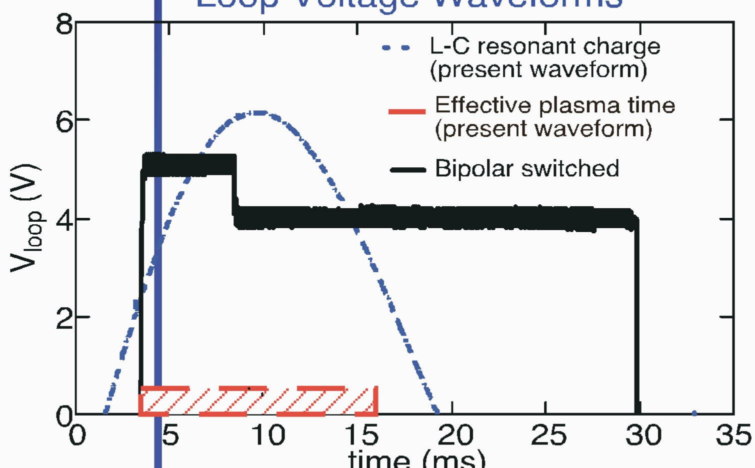
- **Ohmic System:** increased V-sec and pulse length
- **Toroidal Field:** increased at startup, and time-variable
  - *Low inductance center rod installed*
- **Equilibrium Field:** flexible shape and position control
  - *U. of Washington collaboration*
- **Activate Divertor Coils:** edge separatrix
- **HHFW:** RF heating power

Present and New
Loop Voltage Waveforms



TF Waveform
with Fast Rampdown