Abstract

MHD equilibrium reconstruction on the Pegasus Toroidal Experiment is the major tool used to characterize the plasma across varied operational regimes. Reconstructions are complicated by the presence of wall currents. Since the vacuum vessel can carry currents comparable to the plasma current for much of the shot duration, vessel current estimates are constrained by an array of external flux loops. The characteristics of plasmas produced by helicity injection by plasma guns are of particular interest. Reconstructions of these plasmas indicate that the current profile J(r) is relatively hollow, as expected in cases where current is driven at the edge. This gives rise to reverse magnetic shear in the core region. In contrast, purely ohmically driven plasmas typically exhibit peaked J(r) profiles and minimal magnetic shear in the plasma interior. In the near future, data from a new 2D soft X-ray camera will be incorporated as a measurement of flux surface shape which provides a constraint on the current profile.

*Work supported by United States Department of Energy Grant DE-FG02-96ER54375.

Outline

- MHD equilibrium reconstruction is an important tool for Pegasus
  - Determines global plasma parameters
  - Characterizes plasmas across varied operational regimes
  - Provides information for stability analysis

- Magnetic diagnostics provide fitting contraints
  - Flux loops and $\dot{B}$ coils on inboard and outboard sides of plasma

- Induced vacuum vessel currents are taken into account
  - Wall currents can be comparable to plasma current
  - Axis-symmetric current filament model used for 1st order correction
  - Final wall-currents constrained by wall loops in the equilibrium fit

- Reconstructions help characterize helicity injected plasmas
  - Extremely hollow current profile
  - Large reverse shear near core
  - Exhibit vertical asymmetry about the mid-plane

- In contrast, ohmic plasmas are characterized by
  - Peaked current profile
  - Minimal magnetic shear in the plasma interior

Equilibrium Reconstruction an Important Tool for PEGASUS

Motivation

- MHD equilibrium solver determines global plasma parameters
- Characterization of various operational regimes important for pegasus experiments
- can help to define ST stability limits for various system configurations

Description

- Iterative process: Grad-Shafronov solution decoupled from χ^2 minimization
  - Guass-Seidal multigrid relaxation on 2-D grid?????
- Full solution of Grad-Shafranov equation at each iteration
- Minimizes χ^2 subject to diagnostic measurement constraints
  -via Levenberg-Marquardt method

Implementation

- IGOR Pro routine interfaced to an ANSCI C G-S solver
- Has been validated against TokaMac

Magnetic Diagnostic Layout for PEGASUS

Inboard Measurements

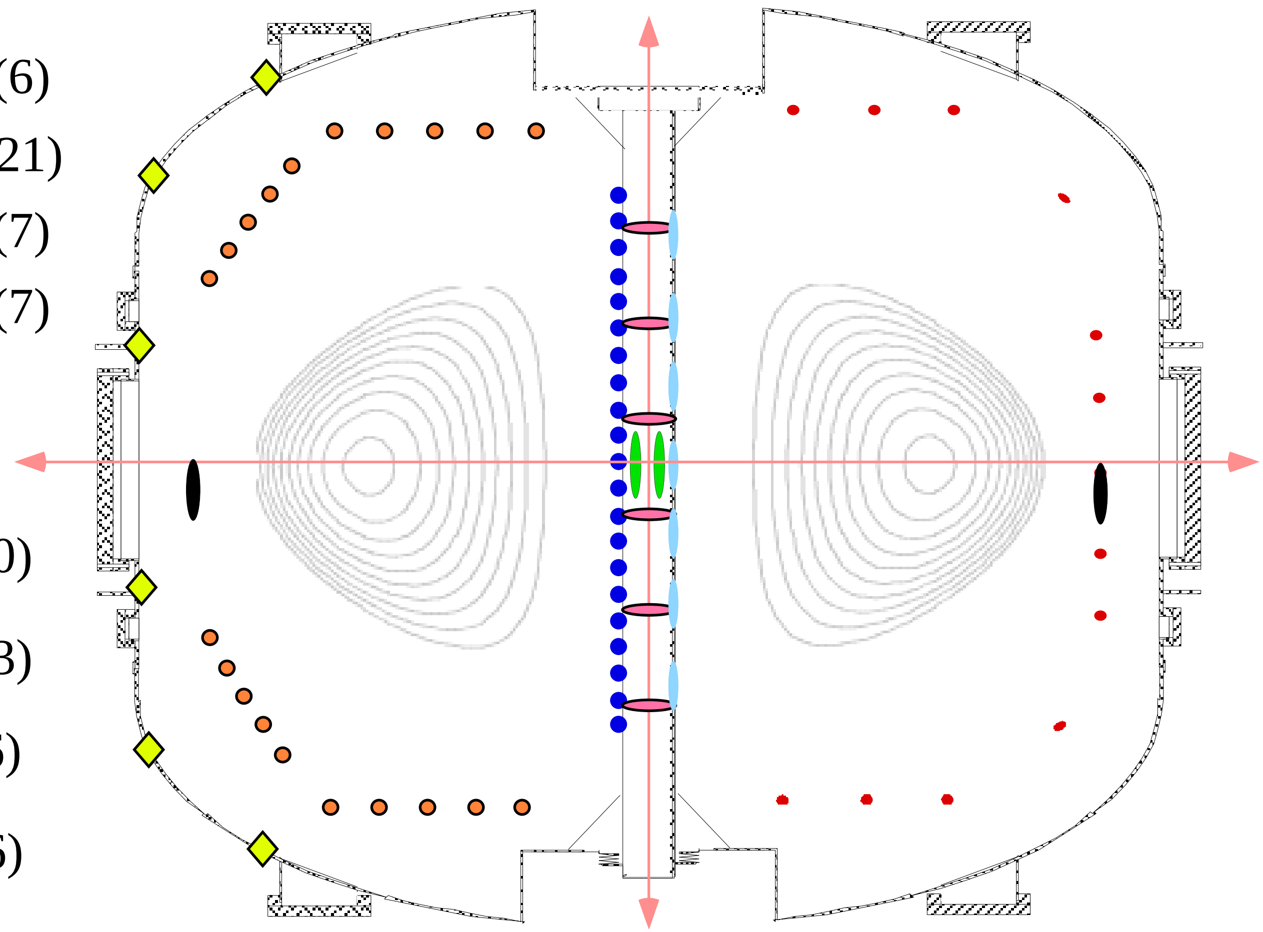
- Core Flux Loops (6)
- High Resolution Mirnovs (21)
- Low Resolution Mirnovs (7)
- HFS Toriodal Mirnovs (7)

Outboard Measurements

- Flux Loops (20)
- Poloidal Mirnovs (13)
- LFS Toroidal Mirnovs (6)
- Ext Wall Loops (6)

Not Shown

- Plasma Rogowski Coils (2)
- Diamagnetic Loops (2)
- Diamagnetic Compensation Loop

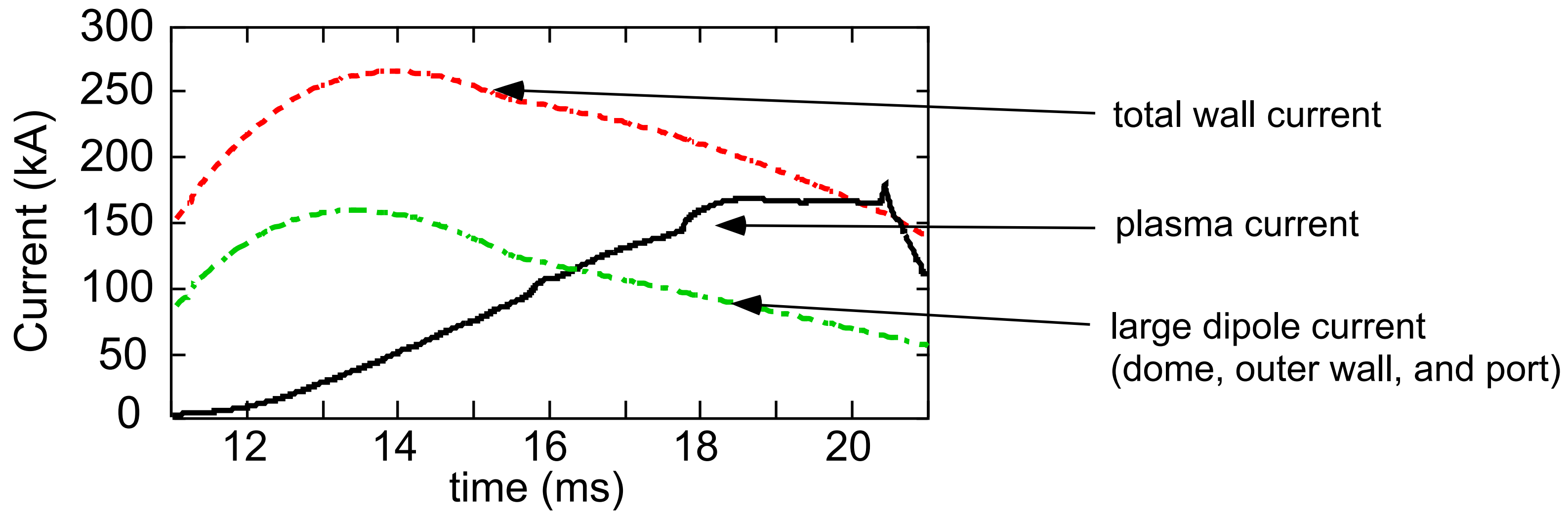


Current Magnetics Arrangement

Wall Currents are Significant During Start-up

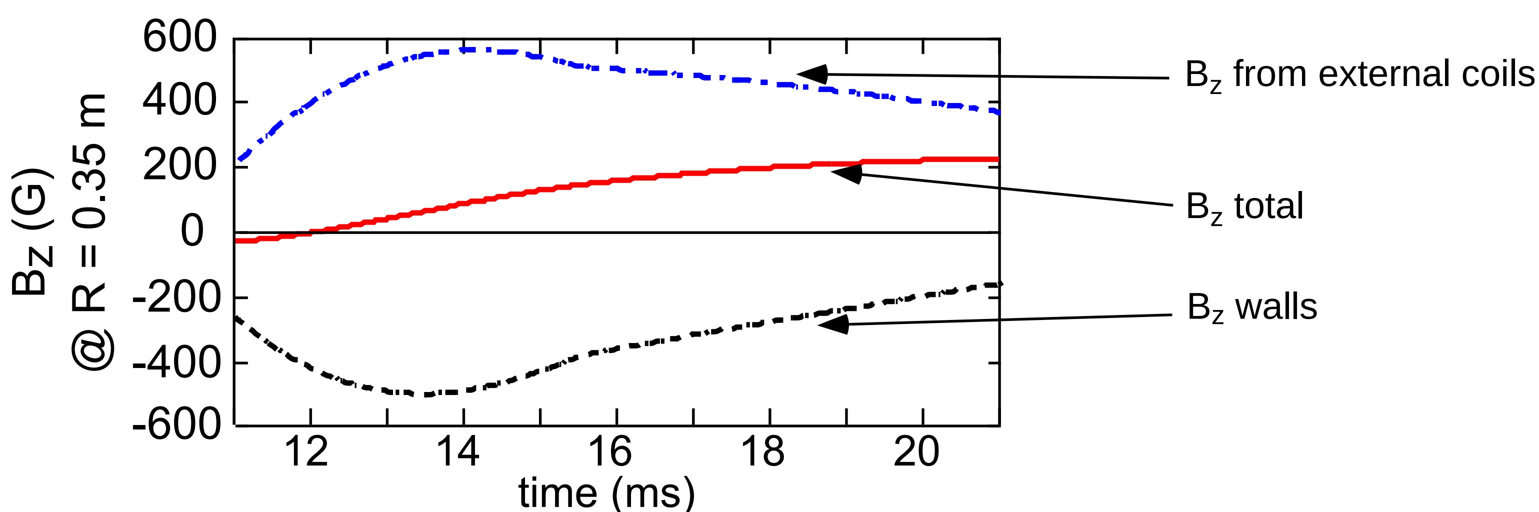
Total current induced in wall is comparable to Ip throughout shot

- dome, outer wall, and ports have largest dipole



Induced wall currents strongly affect B_Z at early times

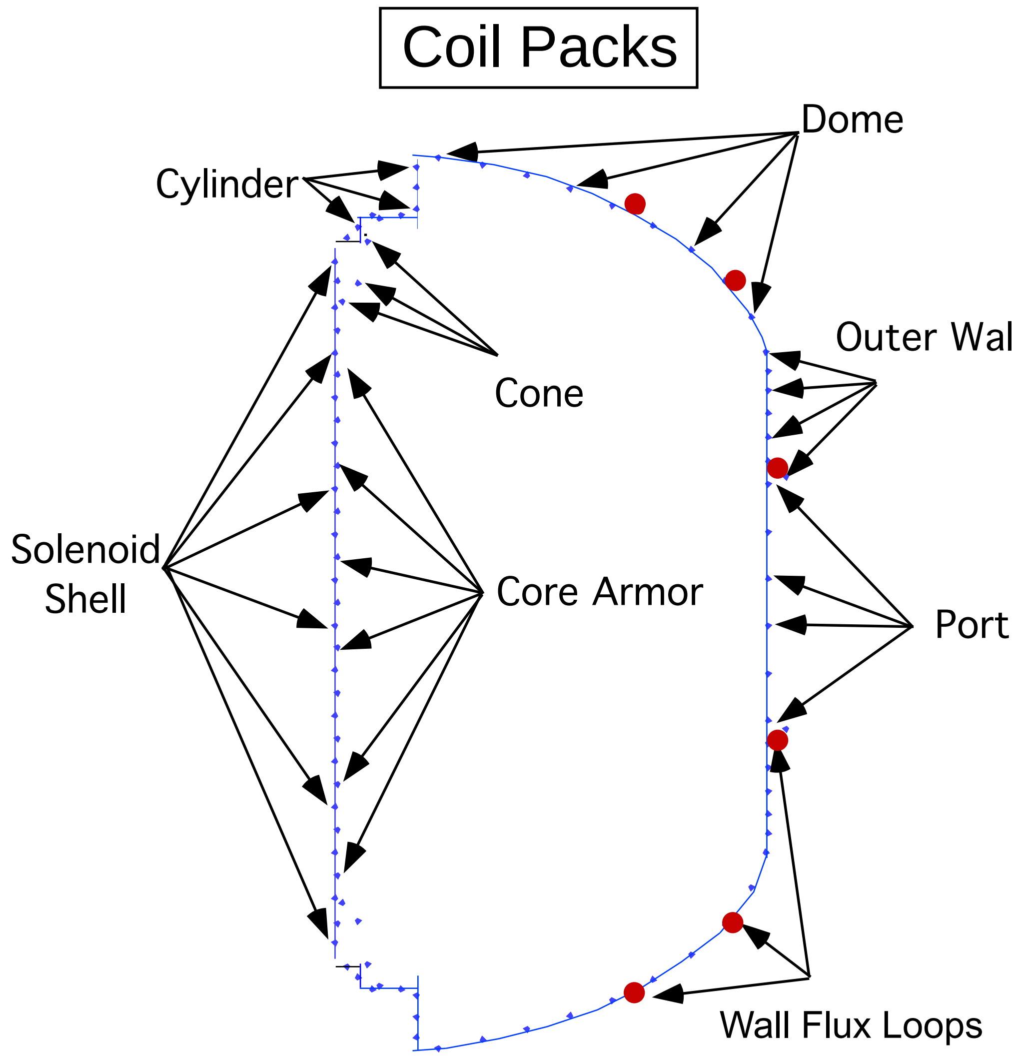
- field due to walls roughly equal to coil field at start-up



Resistive Vacuum Vessel Modeled as Axis-symmetric Current Filaments

Wall modeled as 91 individual axis-symmetric current filaments

- Similar behavior in 7 sections of vacuum vessel
  - filaments grouped into coil packs



Coil packs constrained by wall loops

- dome & outer wall most significant
- 2 loops on dome; 1 on outer wall

Wall currents found by integrating differential circuit equations

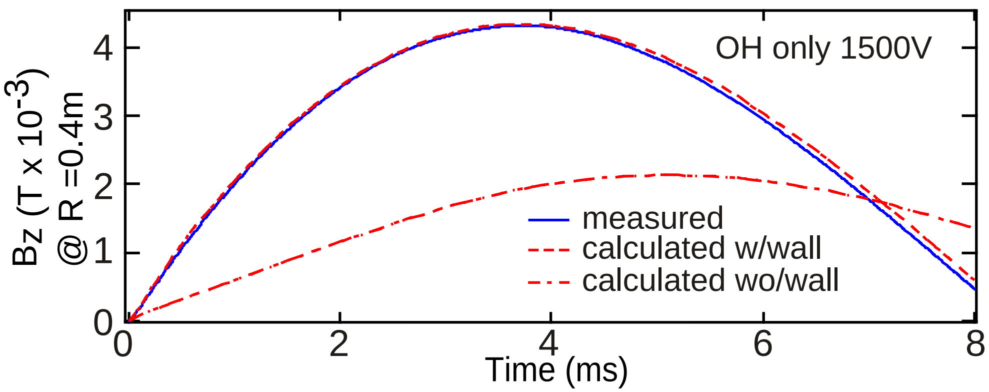
- coupled filaments described by

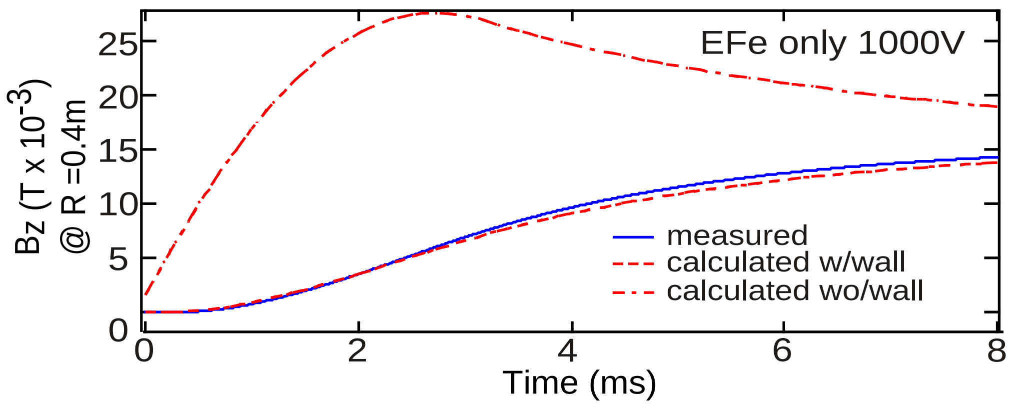
$$\overline{M} \bullet \frac{d\overline{I}}{dt} + \overline{R} \bullet \overline{I} = \overline{V}$$

- induction matrix (M) determined by self and mutual inductances

Wall Model Calibrated with $\dot{B}$ Probe Measurements

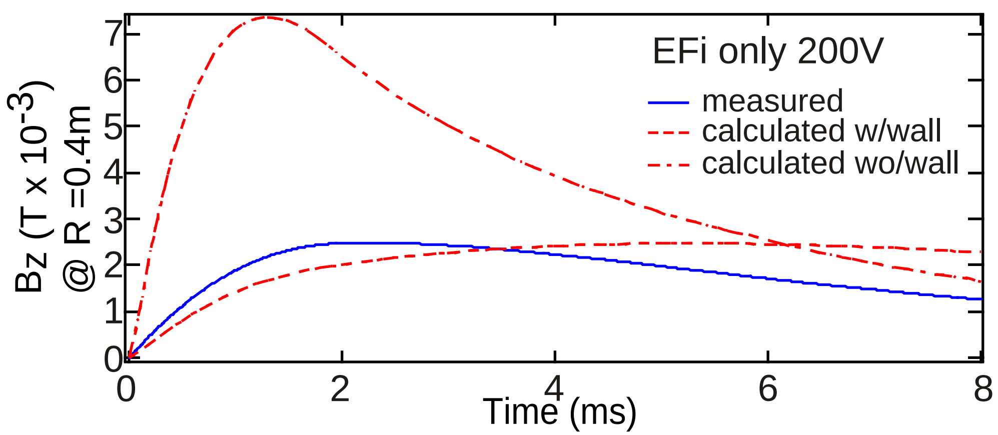
Predicted OH and EF coil values match measured data well





Predicted values for internal trim coils show more deviation

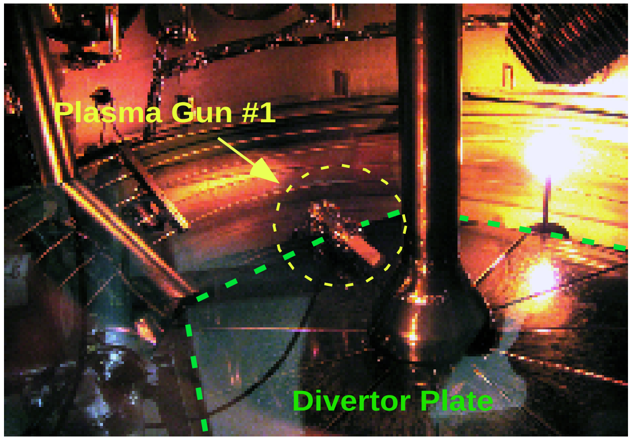
- Port structures with time varying inductance couple strongly to internal coils
- Model still provides low order correction



Plasma Guns are a Helicity Injection Source

Initial experiments with 2 guns

- Placed above lower divertor
- Ro = 27 cm (~)
- 180° apart

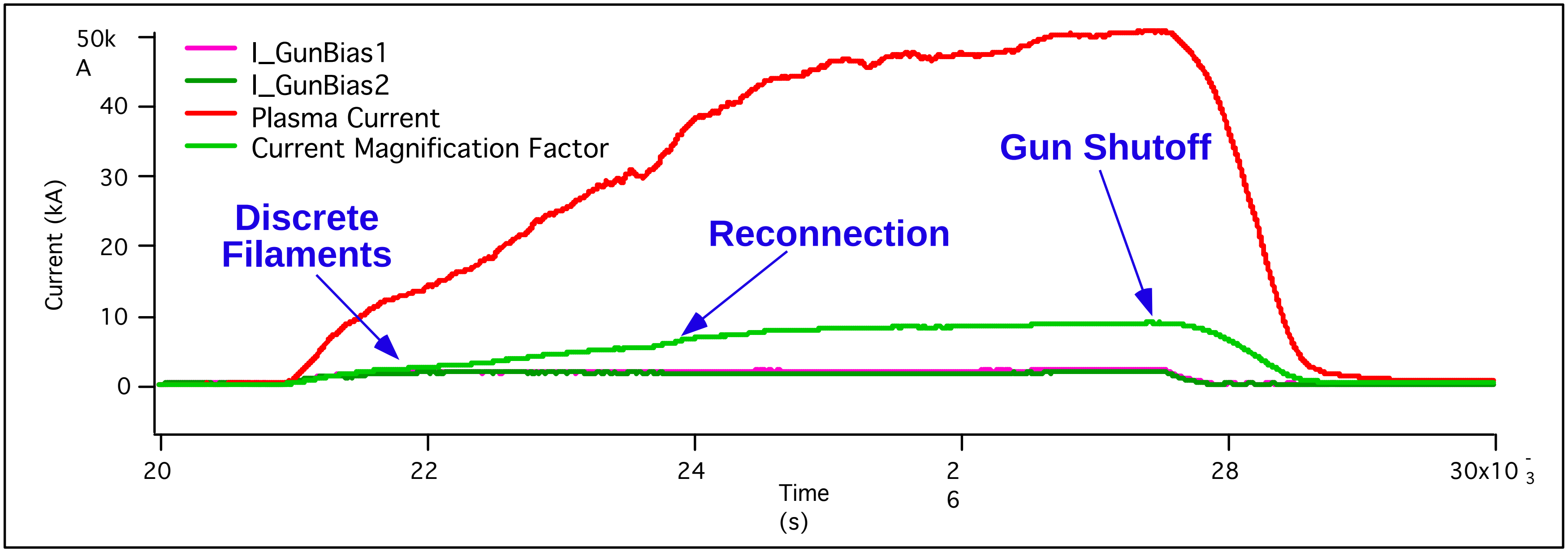


Max $I_\phi \approx 50$ kA

Current multiplication ~ 15-20 routinely achieved

Toroidal current evolution has two distinct phases:

1) Simple magnetic geometry stacking of current stream
2) Increased current magnification as streams reconnect



Future Work

Guns

- Develop a multi-point probe to measure local magnetic fields and further constrain gun equilibria
- Explore plasma evolution of mid-plane helicity injection source
- Compare evolution of lower and mid-plane gun plasmas
- Data for DCON analysis

Ohmic

- High normalized current evolution
- Map the kink stability boundary
- Explore targets for EBW and HHFW heating
- Verify the PCS system
- Continue DCON analysis

Summary

- MHD equilibrium reconstructions characterize plasmas in PEGASUS
  - Determines global plasma parameters
  - Provides information for stability analysis

- Magnetic diagnostics provide equilibria fitting contraints
  - Approximately 20 diagnostics used in a fit

- The vacuum vessel transient wall currents have been taken into account
  - The final wall current values are constrained by wall flux loop measurements in the equilibrium fit

- Reconstructions of gun plasmas help to characterize helicity injected plasmas
  - *Extremely hollow current profile*
  - *Large reverse shear near core region*
  - *Exhibit asymmetry about the mid-plane axis*

- In contrast typical Pegasus Ohmic plasmas are characterized by the following...
  - *Peaked current profile*
  - *Minimal magnetic shear in the plasma interior*

Reprints