Abstract

The operational space of the PEGASUS Toroidal Experiment will be significantly expanded by recent upgrades: shape and position control, increased and time variable toroidal field, increased ohmic flux, and loop voltage control. The Tokamak Simulation Code (TSC)[1] is used to model plasma evolution in a number of scenarios in order to determine accessible paths to high I_p/I_{TF} and β_t. Various startup scenarios and fast toroidal field rampdown are under study. The focus of the startup studies is optimization of the loop voltage waveform and plasma position during the current ramp. Fast TF rampdown is a tool that may allow access to high I_p/I_{TF} and β_t, but which could have deleterious effects on stability if overdriven. Initial studies show that a 50% TF rampdown in 3 ms increases β_t by a factor of 4 while keeping β_p relatively constant, and drives parallel edge current that reduces ℓ_i and q_{95}.

[1]S.C. Jardin, J.L. DeLucia, N. Pomphrey, J. Comput. Phys. **66**, 481 (1986).

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Motivation

- The PEGASUS Toroidal Experiment has undergone significant upgrades to power and control systems[1].

- Phase II goals include:
  - I_P up to ~ 0.3 MA
  - $I_P/I_{TF} > 2$
  - High b_{Tor}
  - Extremely Low Aspect Ratio (1.1)

- Preliminary TSC studies begun to explore viable paths

[1] See posters: QP1.068, QP1.069

Outline

1. Building PEGASUS TSC Model
2. Discharge Simulation Using Enhanced OH and EF Capabilities
3. Simulation of Toroidal Field Rampdown Using Enhanced TF Capabilities
4. Conclusions



Building PEGASUS TSC Model



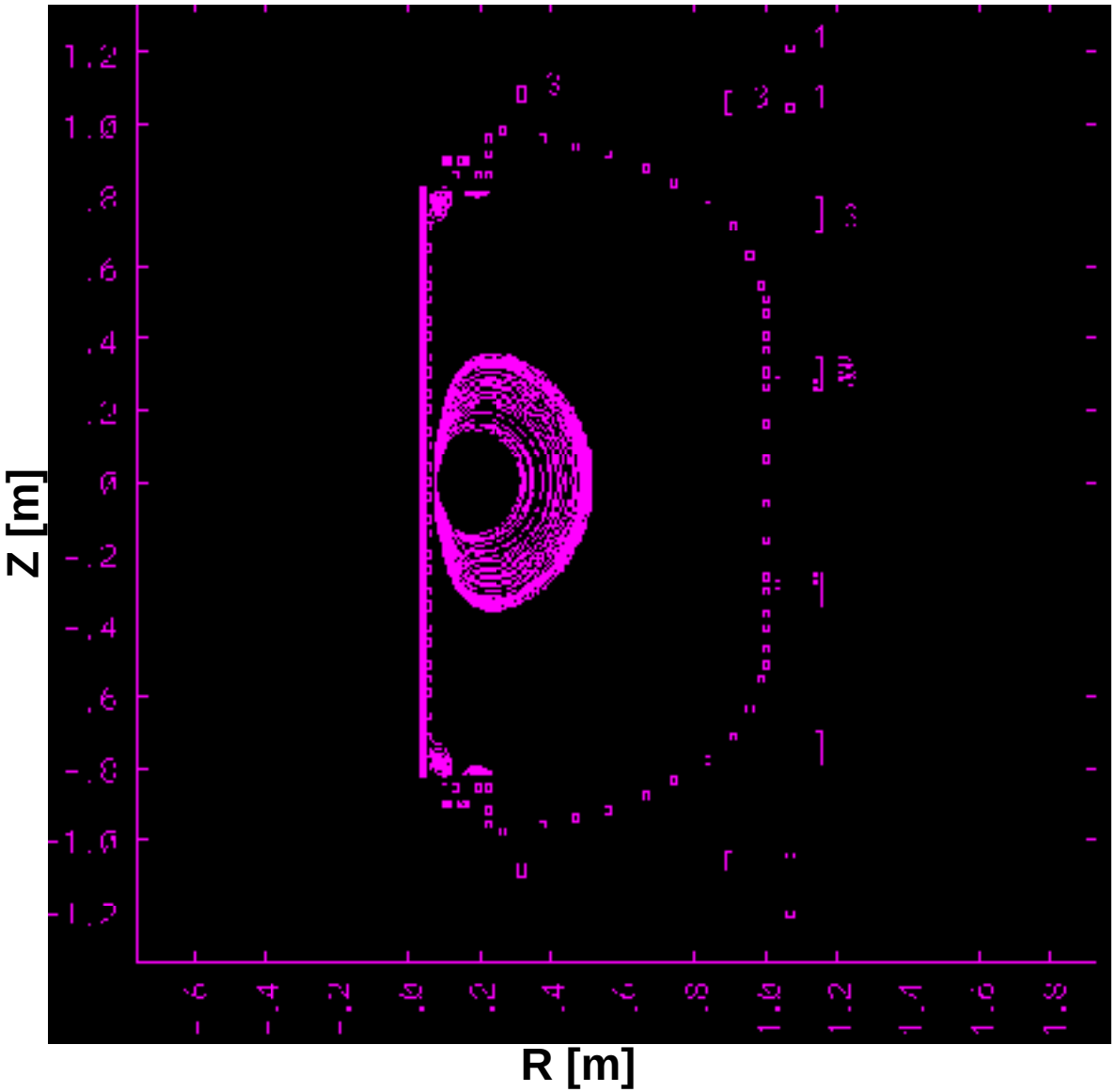
Overview: Tokamak Simulation Code[1]

- Models evolution of axisymmetric tokamak plasma on several time scales
- Circuit equations, effects of induced currents in conducting walls included
- Arbitrary transport model (Coppi-Tang used for this study)
- Realistic feedback control system modeling

[1]S.C. Jardin, J.L. DeLucia, N. Pomphrey, J. Comput. Phys. **66**, 481 (1986).

Establishing PEGASUS TSC Model

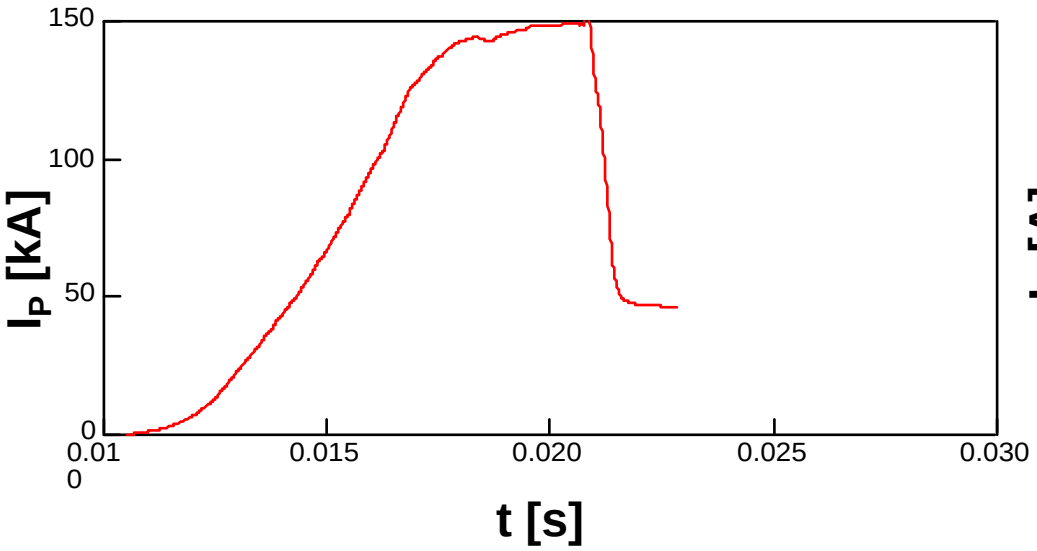
- Walls & coils modeled as discrete coils
  - Continuous conducting wall
- Z symmetry assumed
- Calibration to shot #13064:
  1. Preprogrammed actual OH, EF, TF currents
  2. Compared macroscopic plasma properties at peak I_p (t = 20ms)
  3. Primary interest in matching I_p evolution



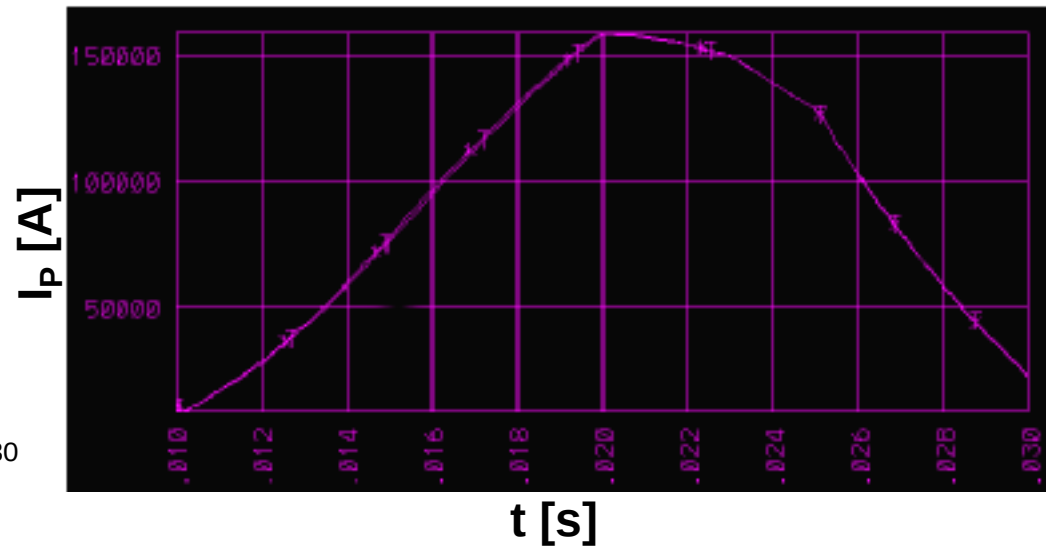
Comparison of Actual to Simulated Plasma Parameters

- Achieve similar maximum I_p on equivalent time scales

Shot 13064



TSC Simulation



- Internal energy, ℓ_i both within ~ 20% actual values at t = 20ms
- Maximum T_e ~ 200 keV, near estimates



Enhanced Discharge Simulation

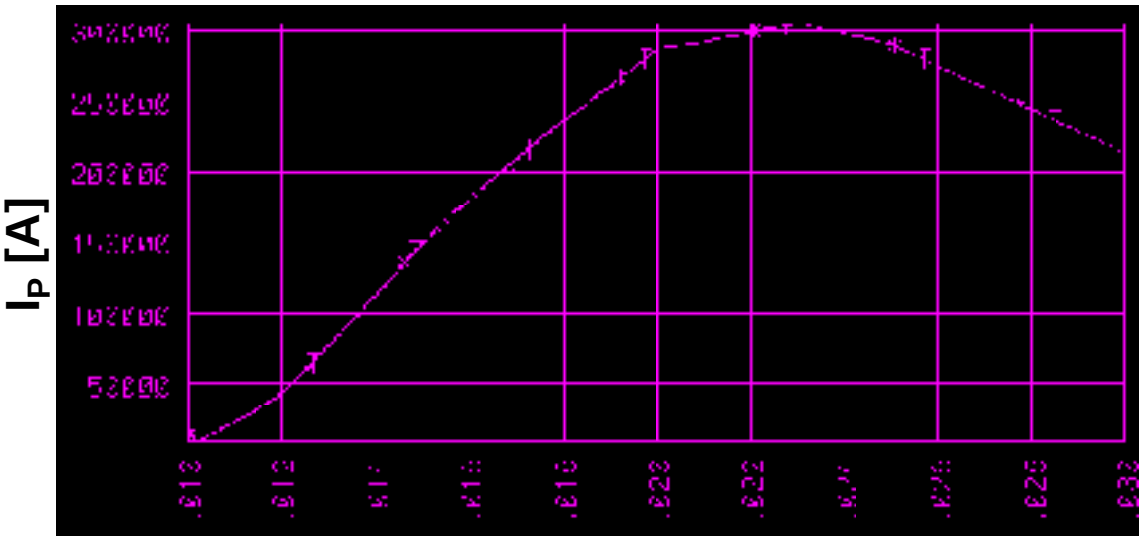


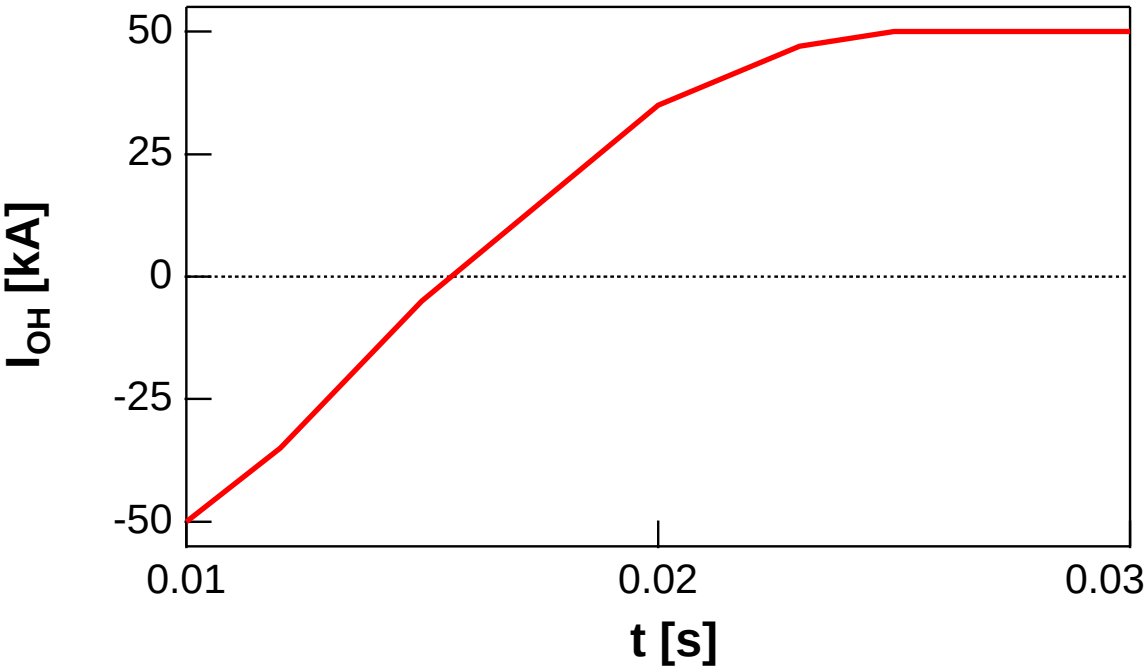
Enhanced PEGASUS Capabilities

- Upgraded OH power systems provide:
  - Improved OH waveform control
  - Increased V-s
  - **PEGASUS capable of I_p ~ 0.3 MA**
- Upgraded EF power systems provide:
  - Improved EF waveform control
  - Independently controlled coilsets
  - **Larger, shaped plasmas accessible**
- Use TSC simulations to guide exploitation of these new tools

TSC: 300 kA I_p Achievable with Available V-sec

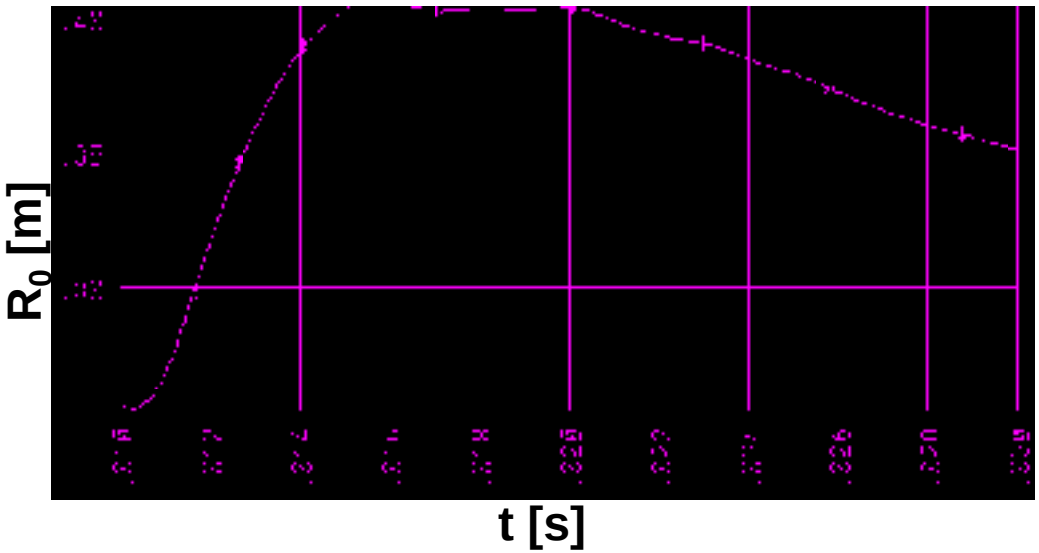
- TSC shows 0.3 MA ramp in 12ms
- $B_\phi = 0.15$ T
- Required ohmic waveform within capability of new power system

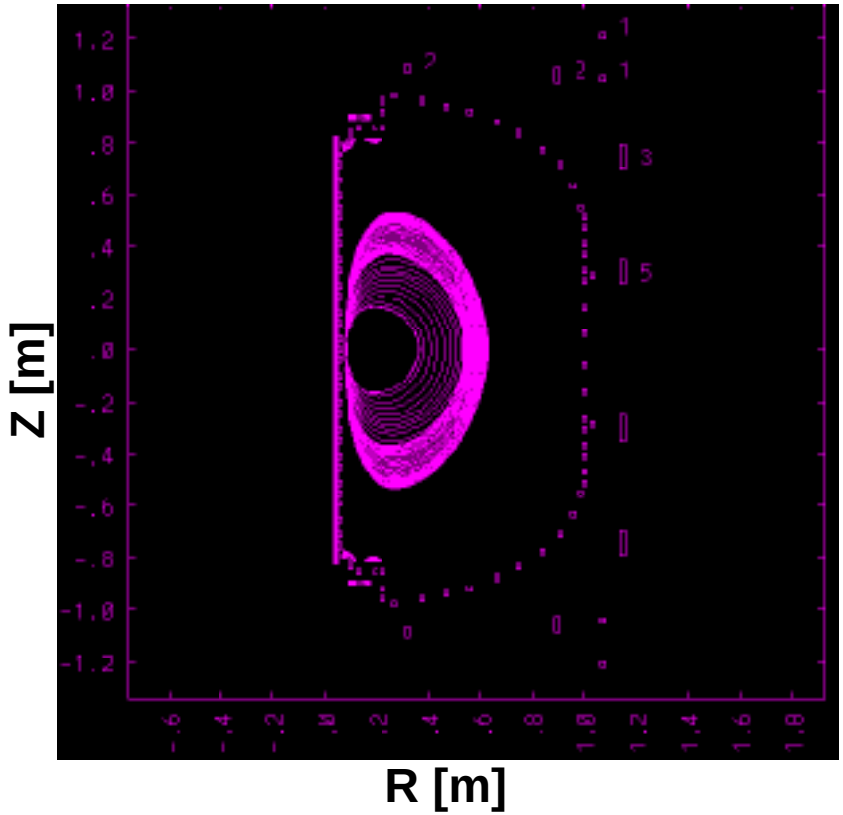




Larger Plasmas Accessible

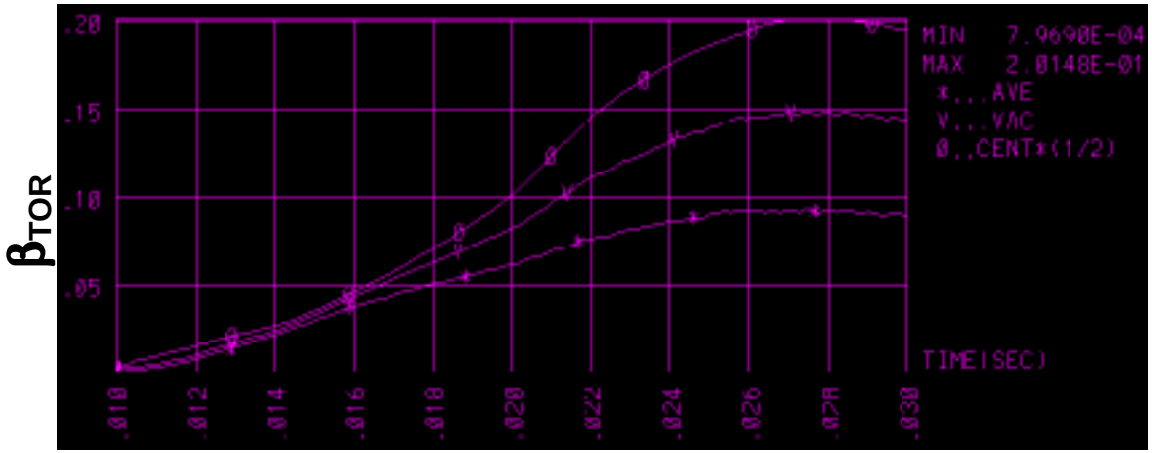
- Flexible EF coils and power supplies should provide greater plasma size control
  - Previously restricted to $R_0 < 0.35$ m
  - $R_0 \sim 0.40$-0.45m allows access to lowest $A \sim 1.14$



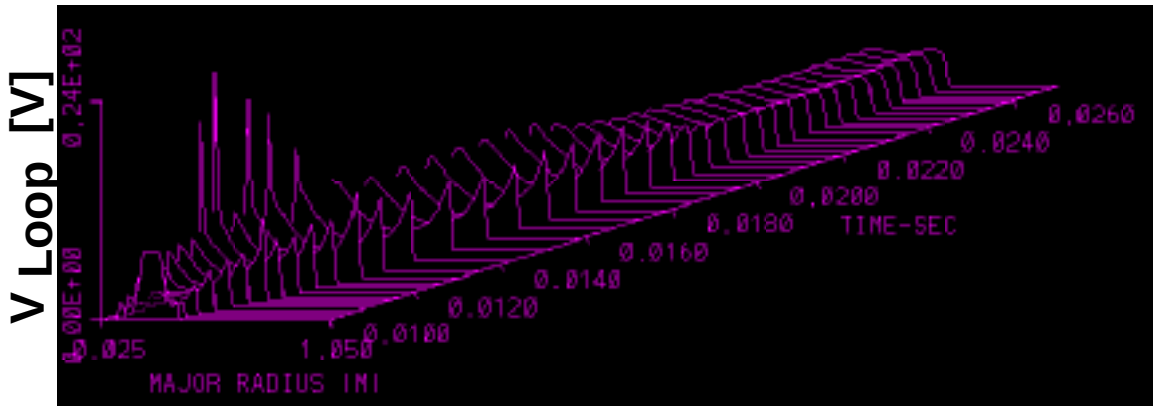


Sample Plasma Properties

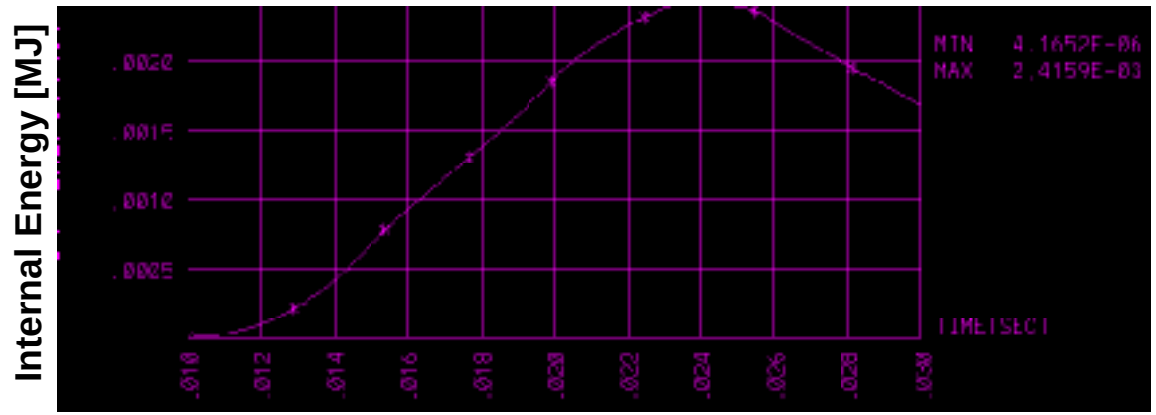
- β_{Vac} ~ 15% predicted at B_ϕ ~ 2x typical



- Loop Voltage



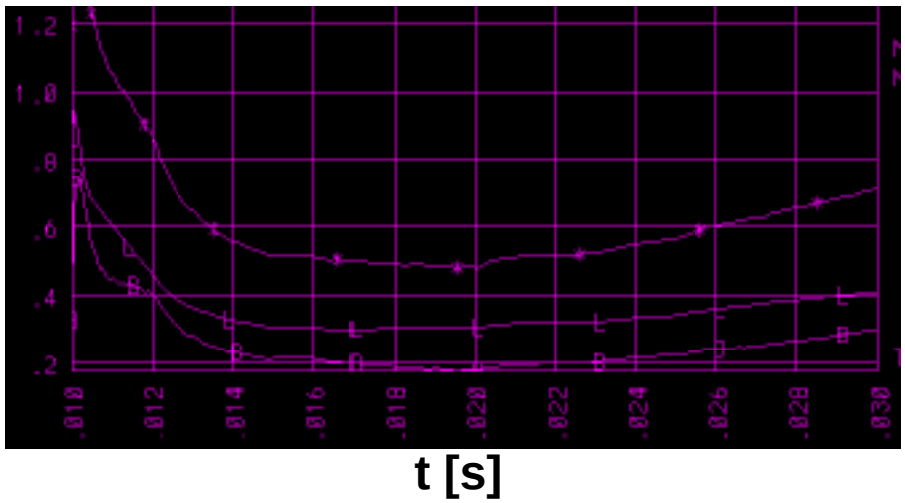
- Internal energy
  - Increased 4x over Phase I reference shot

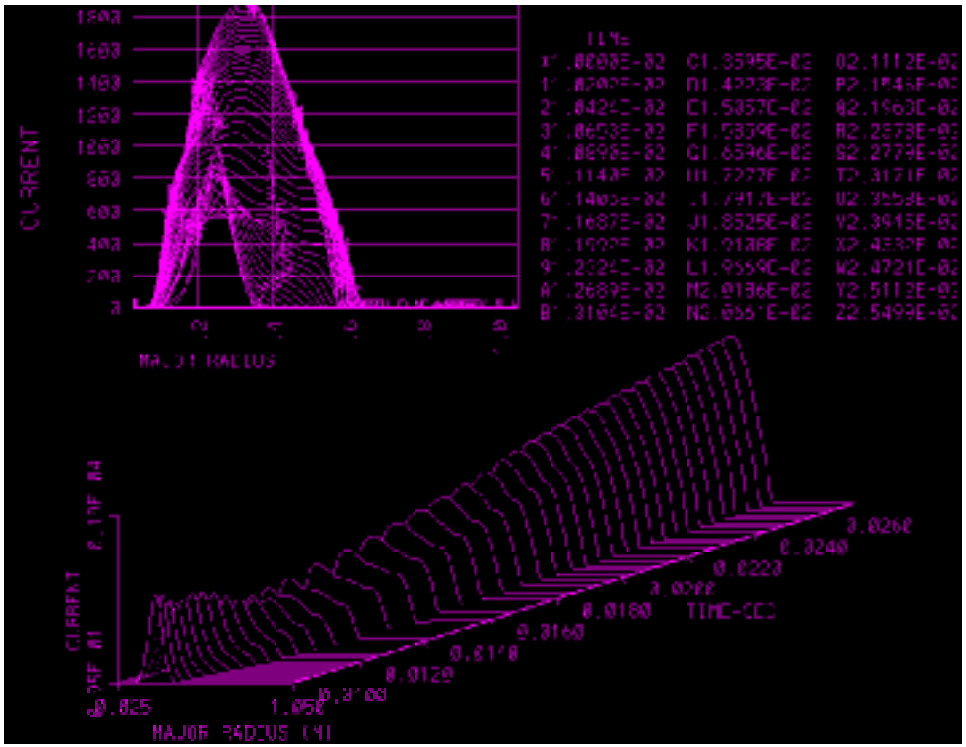


t [s]

Current Profile

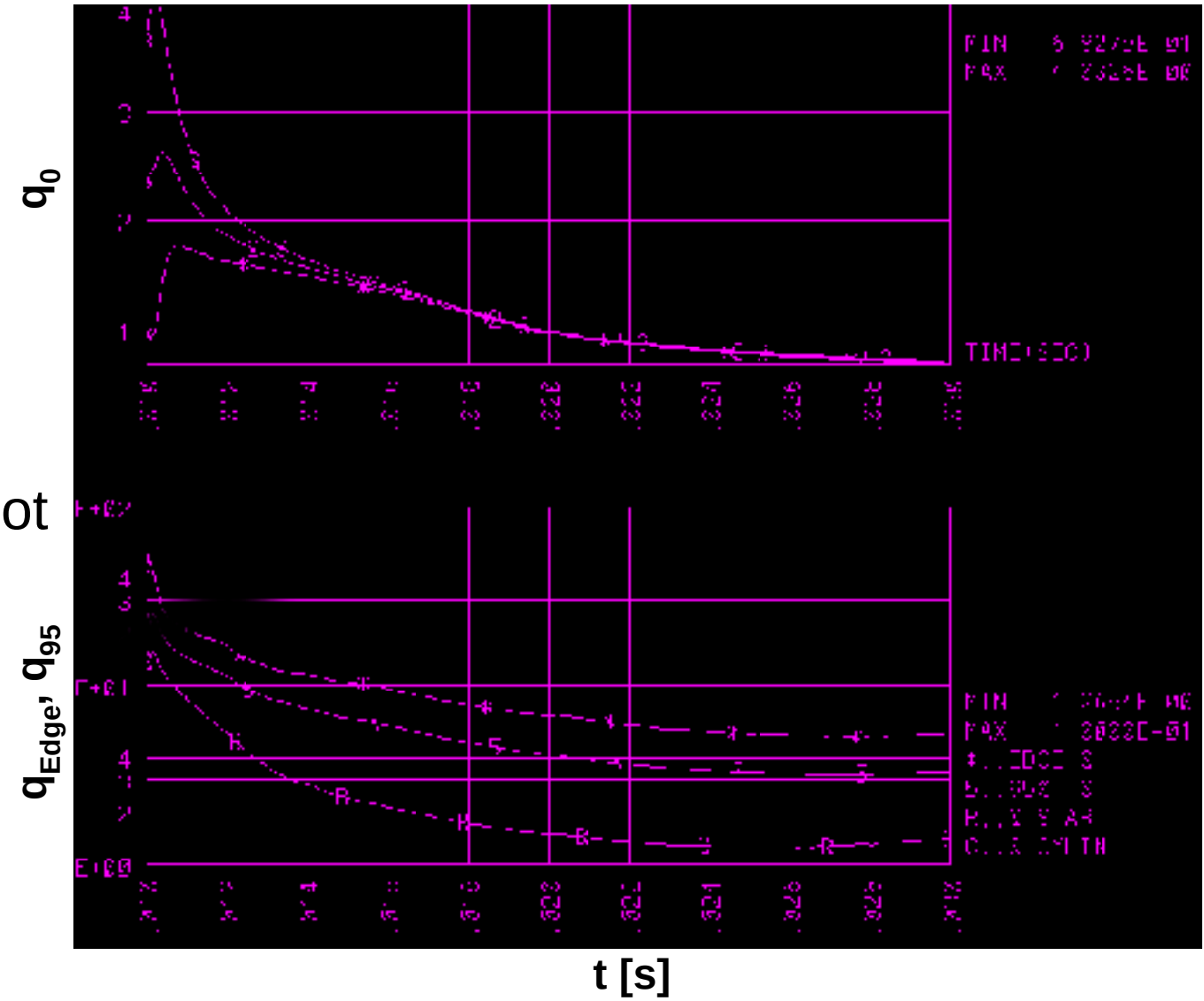
- Current profile typical of ohmic plasma
- Maximum $\ell_i \sim 0.7$





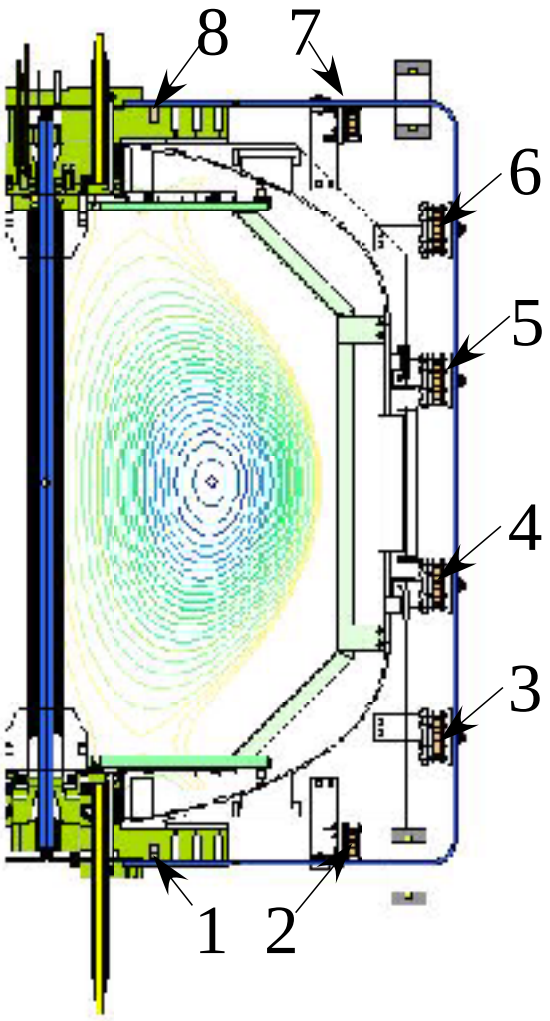
q Evolution

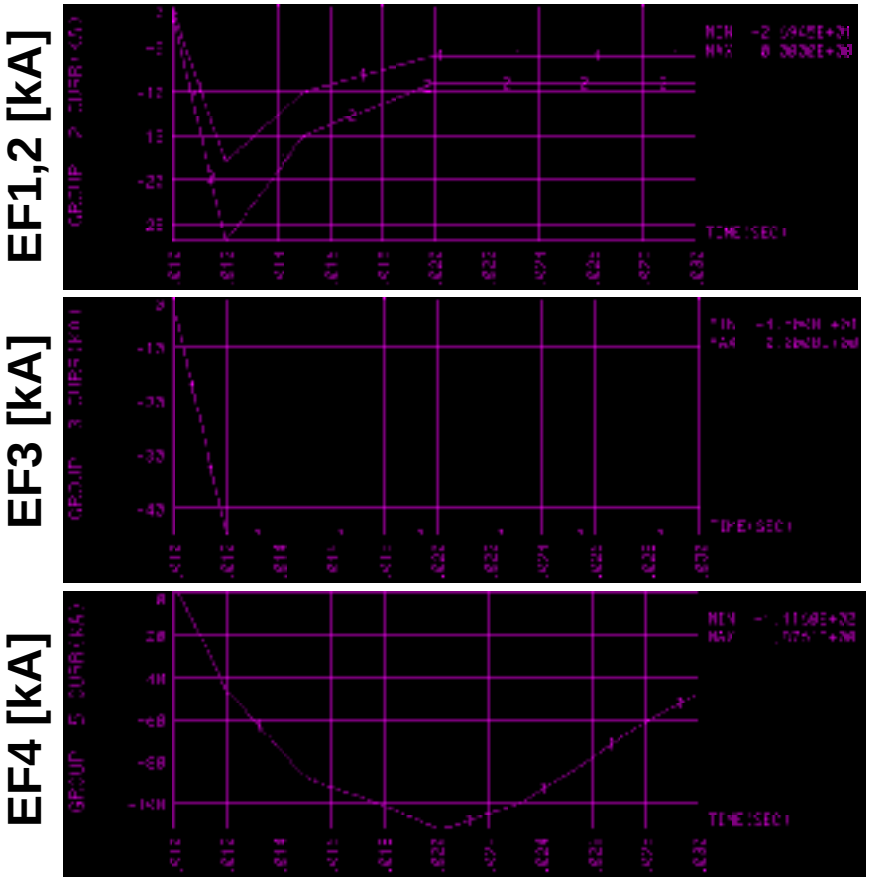
- $q_{0min} \sim 0.8$
- $q_{95} > 3$ throughout shot



EF Coils Within Design Parameters

- Design: All EF coils up to 20kA/turn







B_{TOR} Rampdown Simulation



Toroidal Field Rampdown

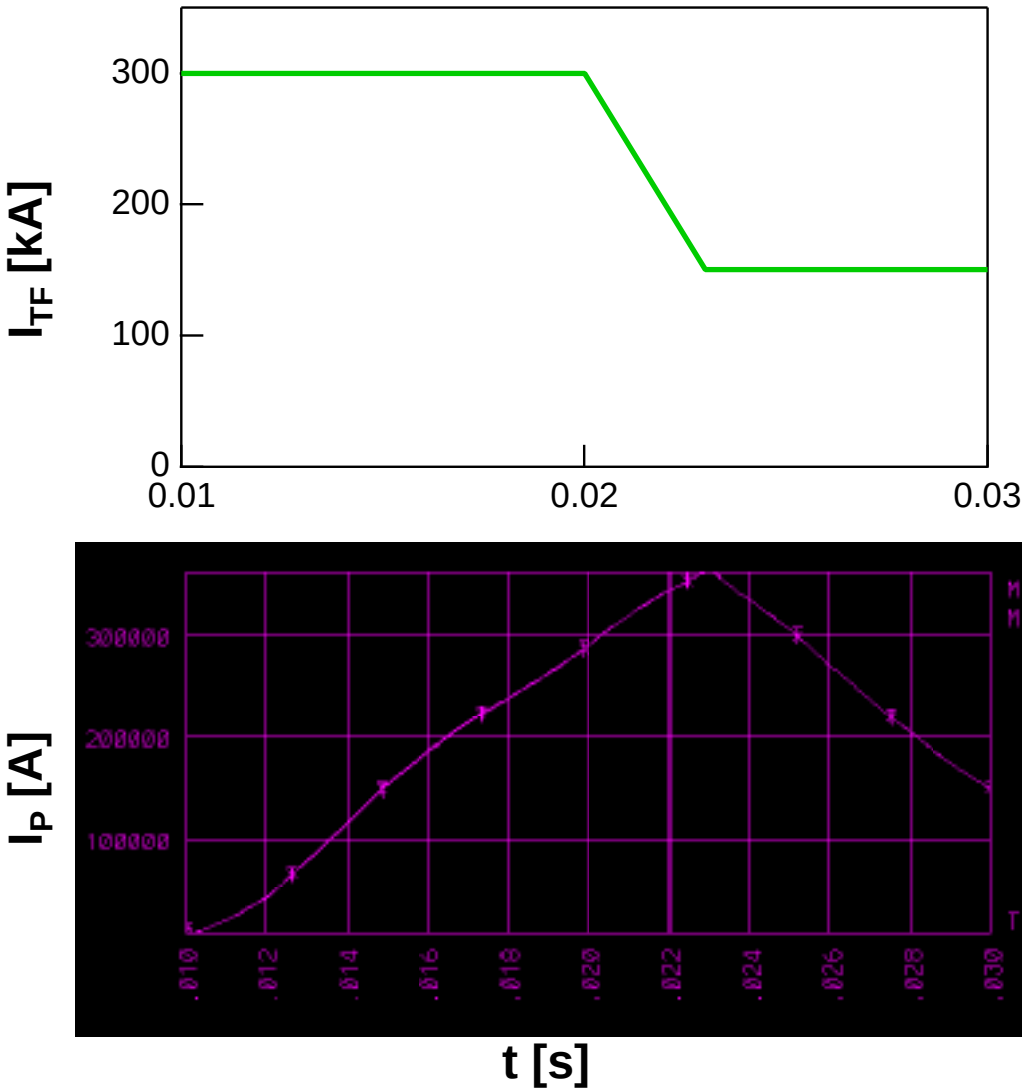
- Rapid B_{Tor} rampdown at high I_p allows access to:
  - $I_p/I_{TF} > 2$
  - High β_{Tor}

  with internal MHD suppression at startup

- Two enhancements now enable PEGASUS to ramp down :
  - Low-inductance TF coils
  - Better TF current waveform control

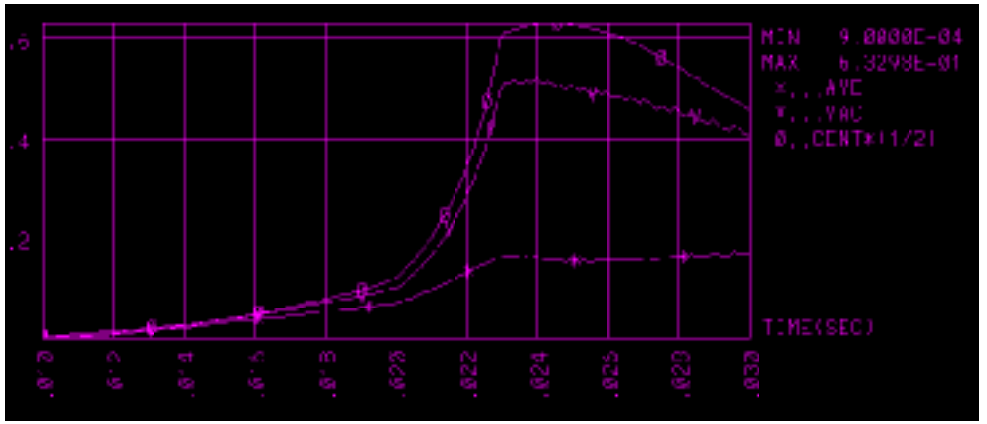
TF, I_p Current Evolution

- TF rod current ramped down 300-150 kA in 3 ms
- Rampdown coincides with I_p peak
  - Drives ~ 50 kA I_p
- I_p/I_{TF} > 2 achieved

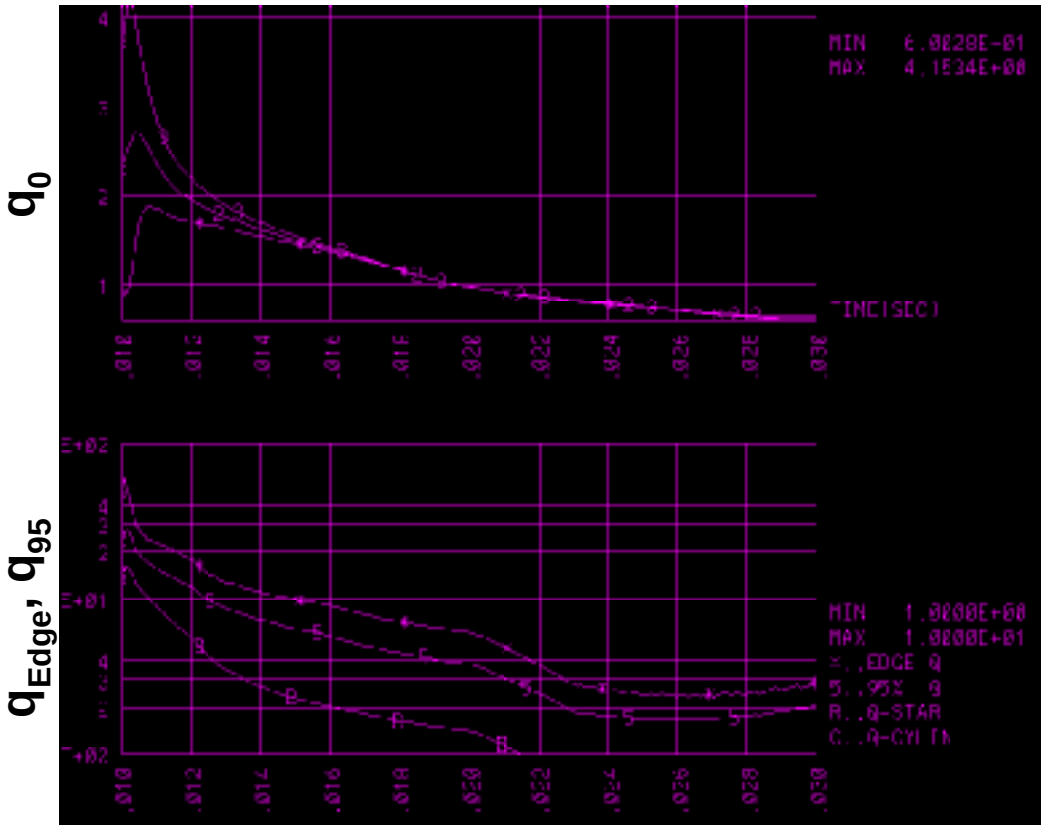


β_{Tor} and q Evolution

- Significant increase in β_{Tor} from rampdown (e.g. 15-40%)



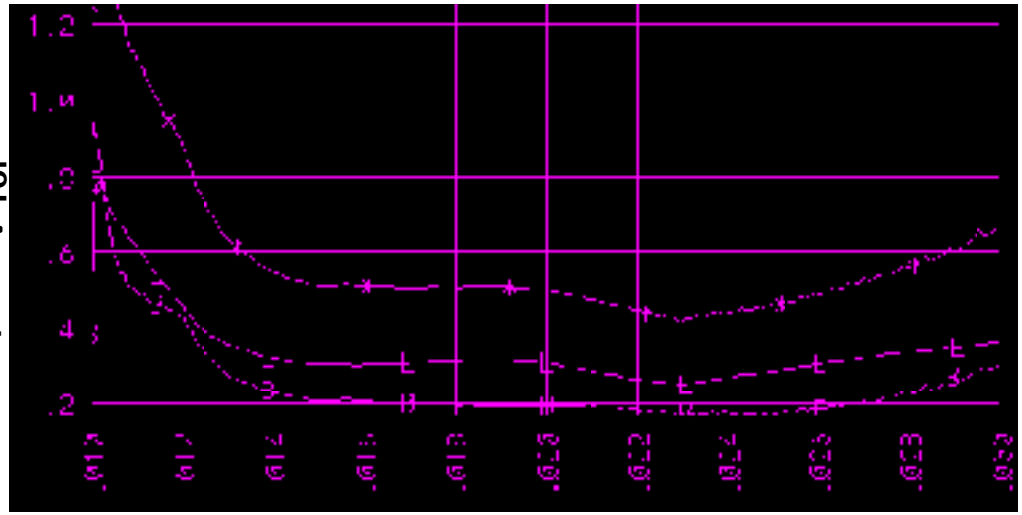
- For these initial simulations, q_{95} falls below 3
  - Further manipulation of plasma shape may be required
  - Divertor coils not activated
  - Necessary to cross-compare with DCON equilibria to explore avenues to accesiblility[1]

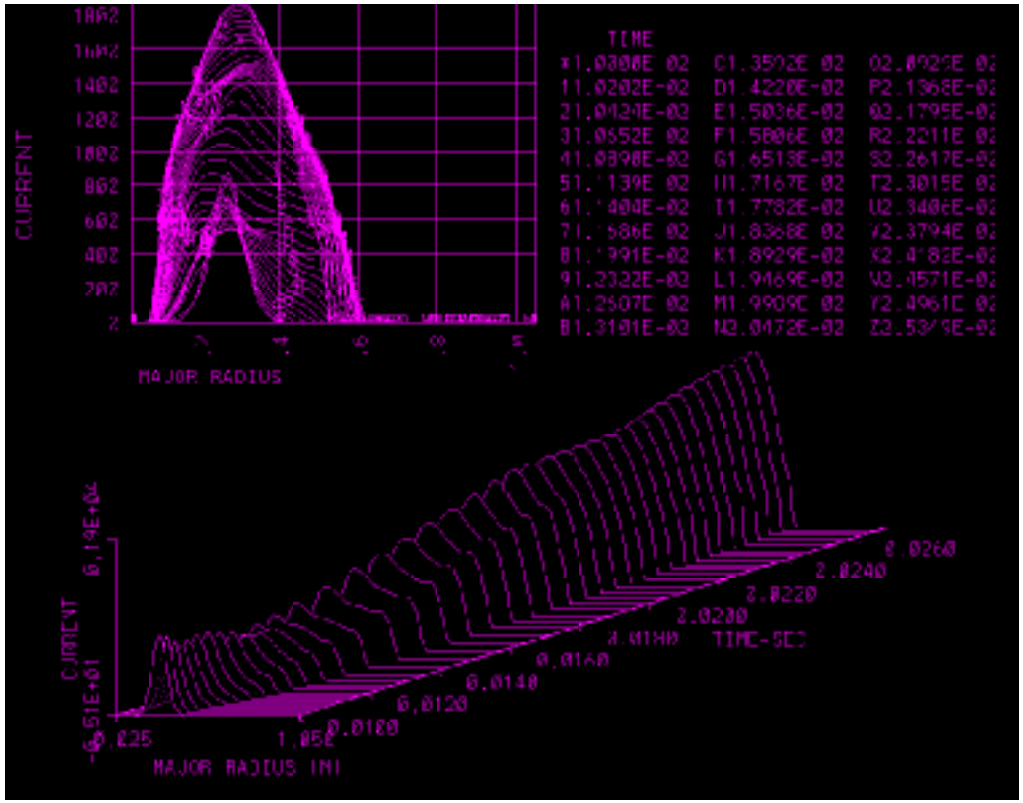


[1] See poster QP1.066

Plasma Current Profile

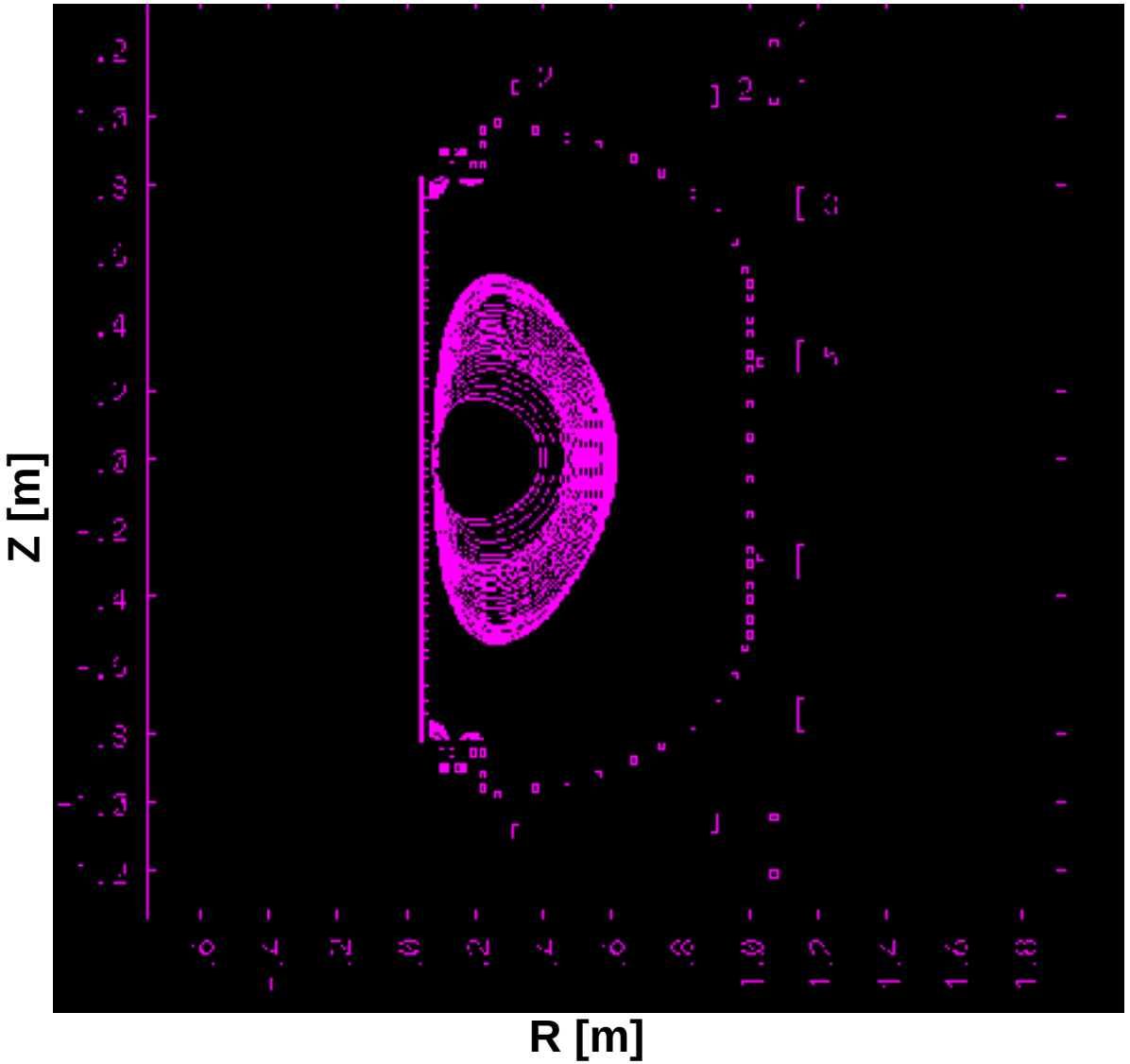
- Broadened l_p profile during rampdown causes ℓ_i to drop
  - Current driven at edge





Shaping Due to Rampdown

- Rampdown increases elongation



Conclusions

- Initial TSC model for PEGASUS established
  - *Useful to guide exploitation of new experimental capabilities*
- Initial TSC simulations indicate Phase II PEGASUS able to achieve:
  - I_p *up to ~ 0.3 MA*
  - $R_0 > 40$ *cm*
  - $I_p/I_{TF} > 2$ *via Toroidal Field Rampdown*
  - *Increased* β_{Tor} *via Toroidal Field Rampdown*

Reprints