The Path to High Field Utilization and Beta in the PEGASUS Toroidal Experiment

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2003 APS-DPP Meeting
October 29, 2003
Albuquerque, New Mexico

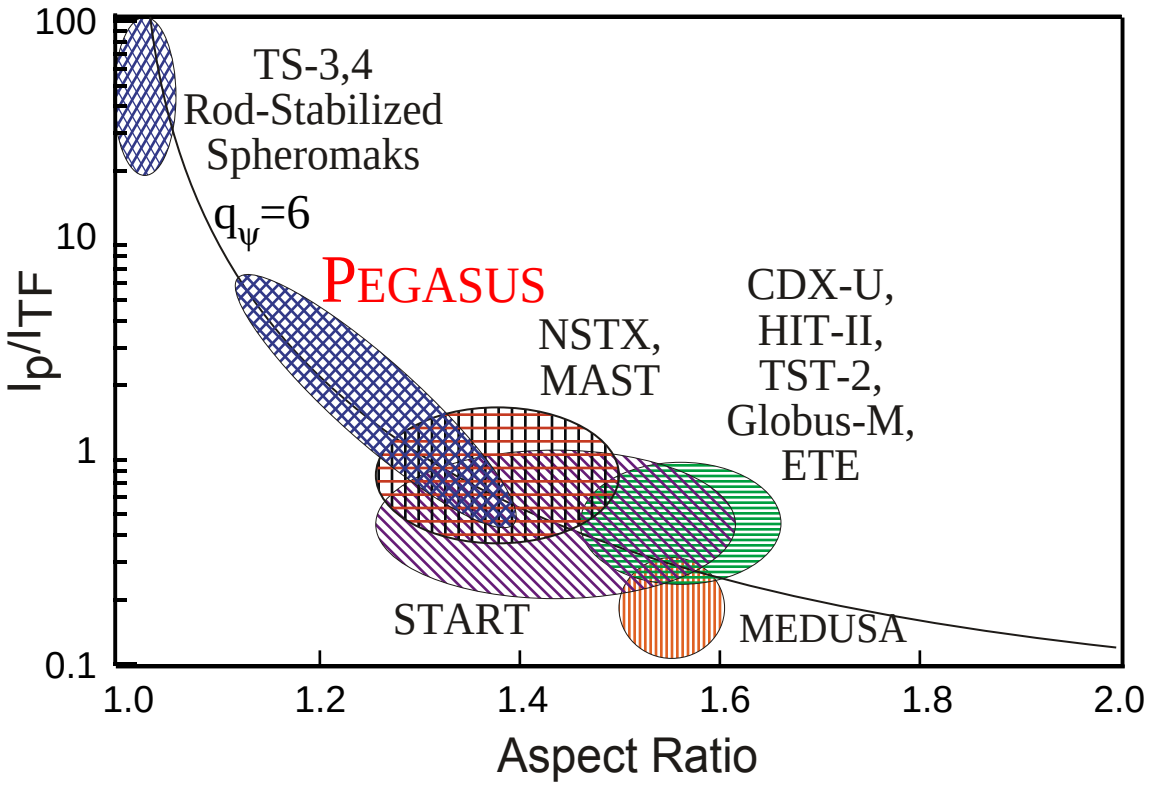
Work supported by U.S. DoE Grant No. DE-FG02-96ER54375





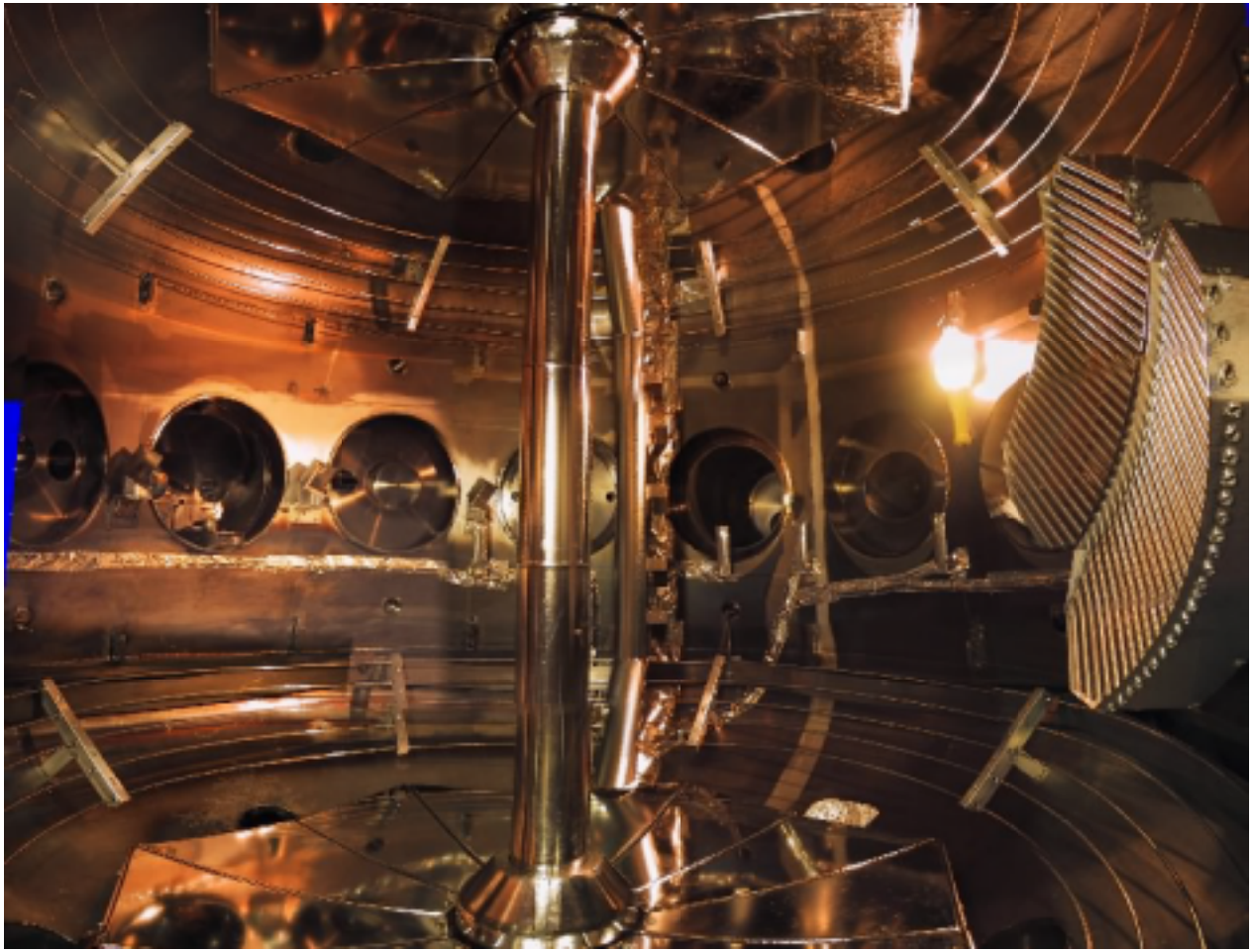
PEGASUS Mission: Explore plasma limits as A→1

- Stability and confinement at high I_p/I_{tf}
- Limits on β_t and I_p/I_{tf} as A→1





PEGASUS has produced high-β_t, ultralow-A plasmas



Vessel Interior

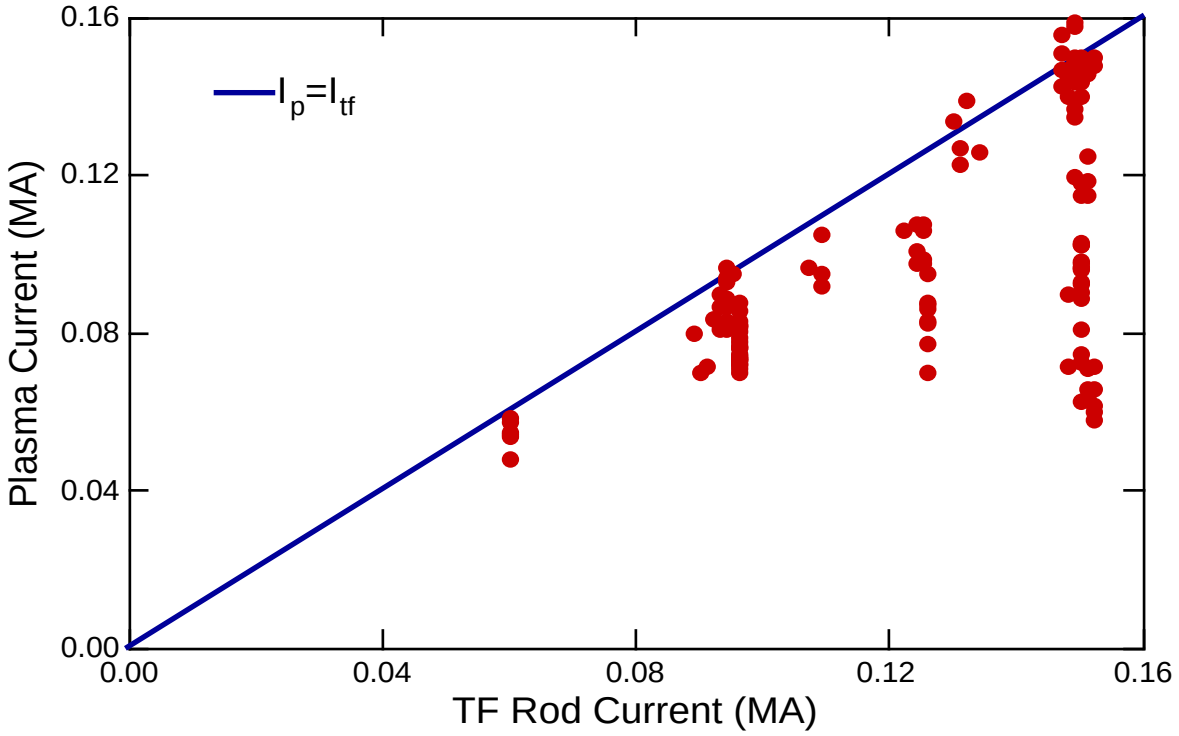
Phase I: Achieved Parameters

A	1.15-1.3
R	0.2-0.45 m
I_p	0.16 MA
I_p/I_{tf}	1.07
I_N	≤ 7 MA/T-m
RB_t	≤ 0.03 T-m
κ	1.4 - 3.7
Δt_{pulse}	0.01-0.03 s
$\langle n_e \rangle$	$1\text{-}5 \times 10^{19}$ m^{-3}
β_t	≤ 25 %
β_N	≤ 5 %-T-m/MA

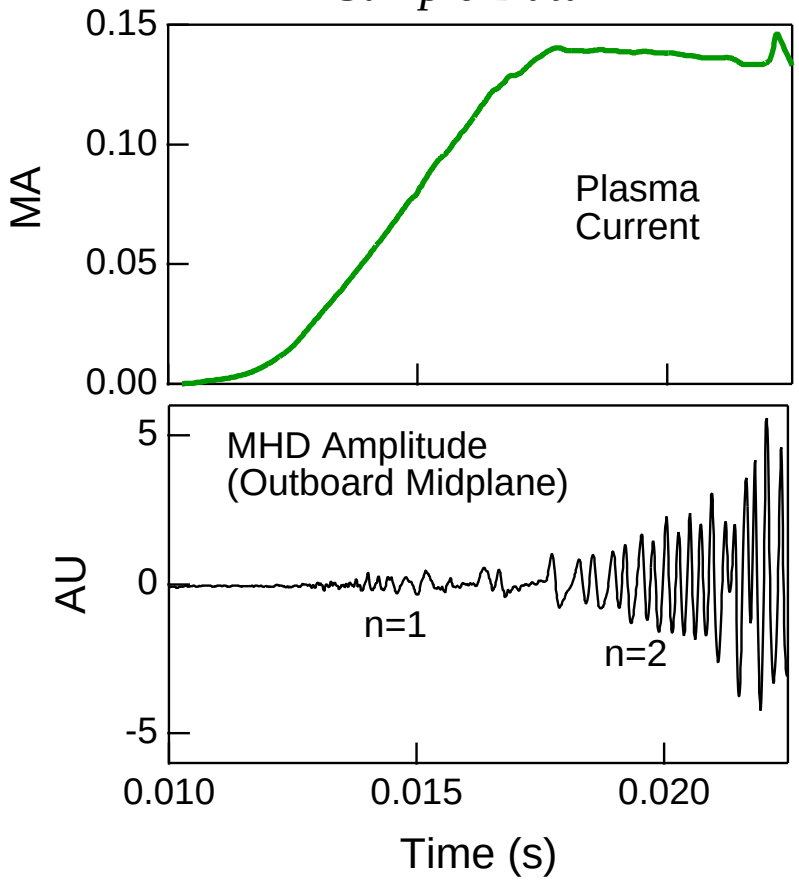
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"Soft limit" of $I_p/I_{tf} \approx 1$ associated with tearing modes

- Limit on I_p/I_{tf} is not abrupt or disruptive
- Resistive MHD instabilities degrade plasma as TF ↓
  - low field + low shear + high dI_p/dt =
    rapid growth of tearing modes and large saturated island widths
- Reduced effective V-s as TF ↓ also plays a role
- External kinks observed at $q_{95} = 5$



Sample Data



Garstka, APS-DPP 2003

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Path to high β_t and I_p/I_{tf}: mitigate early MHD

- $I_p > I_{tf}$ regime accessed via suppression of tearing modes

  - Ohmic heating: $I_p > I_{tf} \Rightarrow$ high β_t, low q

- Approaches and tools to increase I_p/I_{tf}

  - Transiently increase q during startup
    = $B_t(t)$

  - Manipulate current profile
    = V_{loop} control
    = position/shape control
    = $B_t(t)$

  - Reduce η before low-order rationals appear
    = V_{loop} control
    = position/shape control
    = RF heating (HHFW)

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Overview of PEGASUS Phase II upgrades

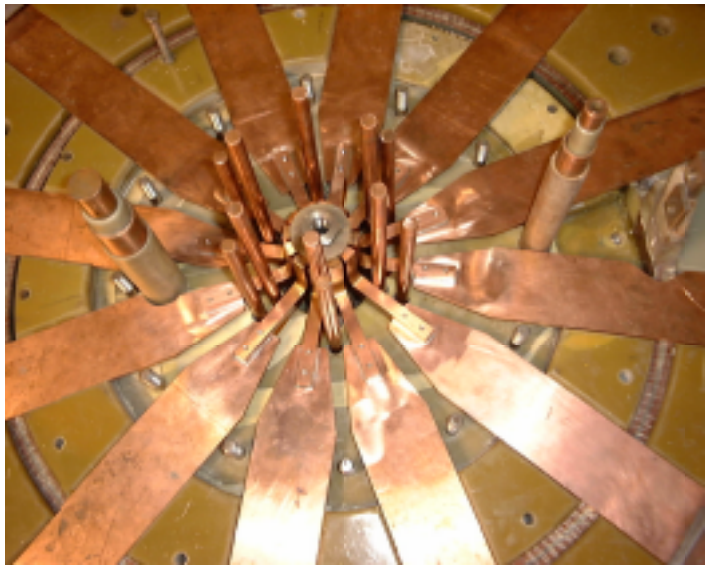
- Power supplies replaced - waveform control now available
  - Switching power amplifiers provide waveform control
    = *with significant help from the HIT group*
  - 6 MJ low voltage electrolytic capacitors installed
  - Stray field "flux catcher" installed for public safety

ABB IGCT
2.8kV@4kA
Steady-State
~ 50 cm long



- Low-inductance toroidal field centerstack installed
  - Provides time-variable TF
  - Maximum B_t increased 3x
  - New TF joint structures implemented

Partially assembled TF joints

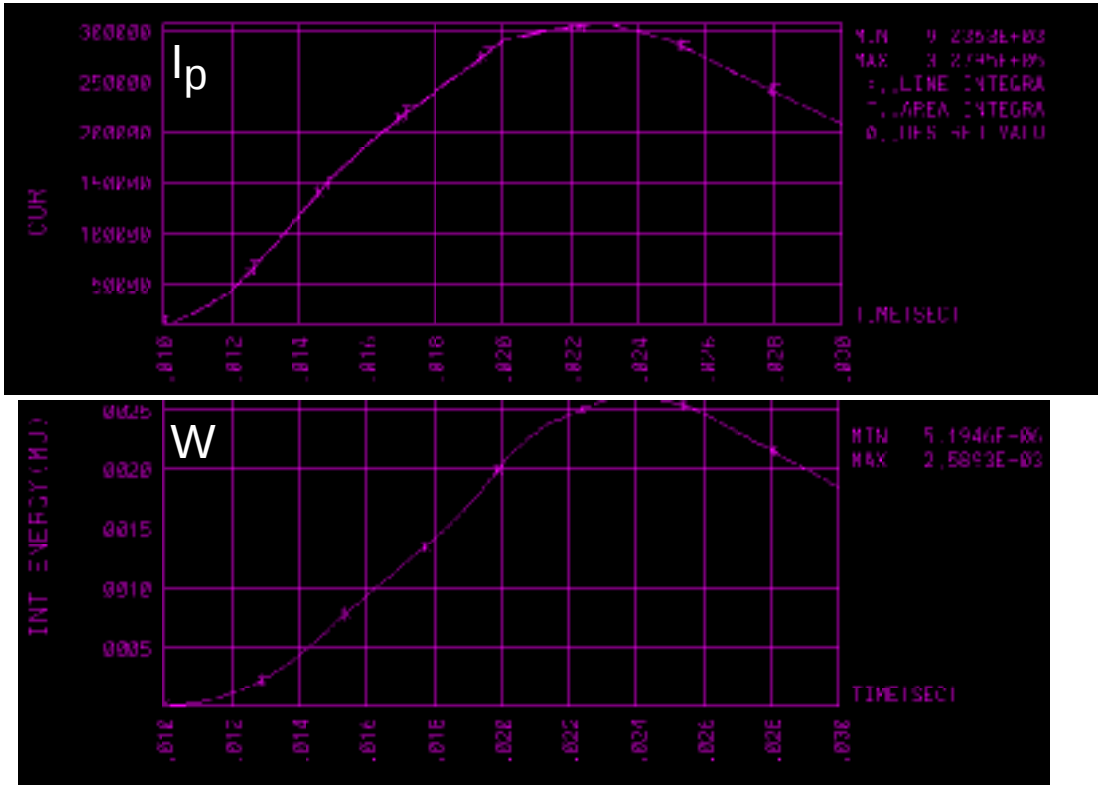


- Lab infrastructure improved or replaced
  - Lab completely rebuilt from "green field"
  - Screen room installed for control and data acquisition
  - New control system and code implemented

QP1.068 - Quinn et al.
QP1.069 - Burke et al.

TSC simulations used to guide exploitation of new capabilities

- TSC model developed for PEGASUS
  - Realistic constraints on coils
  - Detailed wall model
  - Reasonable match to Phase I fiducial plasma
- Initial simulations I_p ~ 0.3 MA
  - dI_p/dt = 20 MA/s
  - All coils within PS limits
  - Stored energy increased 4x over 0.15 MA fiducial
  - Flux swing of 85 mWb matches expectations
- Fast TF rampdown also modeled
  - Provides access to higher β_t
  - Generation of significant J_{edge} and I_p

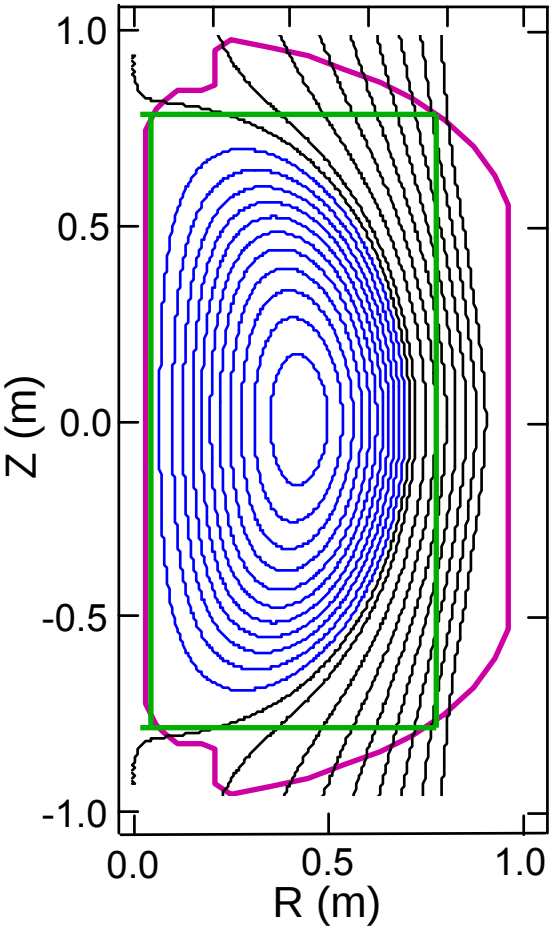


QP1.067 - Eidietis et al.

Stable equilibria exist at $I_p/I_{tf} \approx 2$

- DCON used to evaluate stability of high I_p/I_{tf}
- Initial studies: equilibria with $I_p/I_{tf} > 3$ stable to all modes except resistive interchange
- Further studies to include effects of:
  - Finite beta
  - Diverted configuration
  - Edge currents

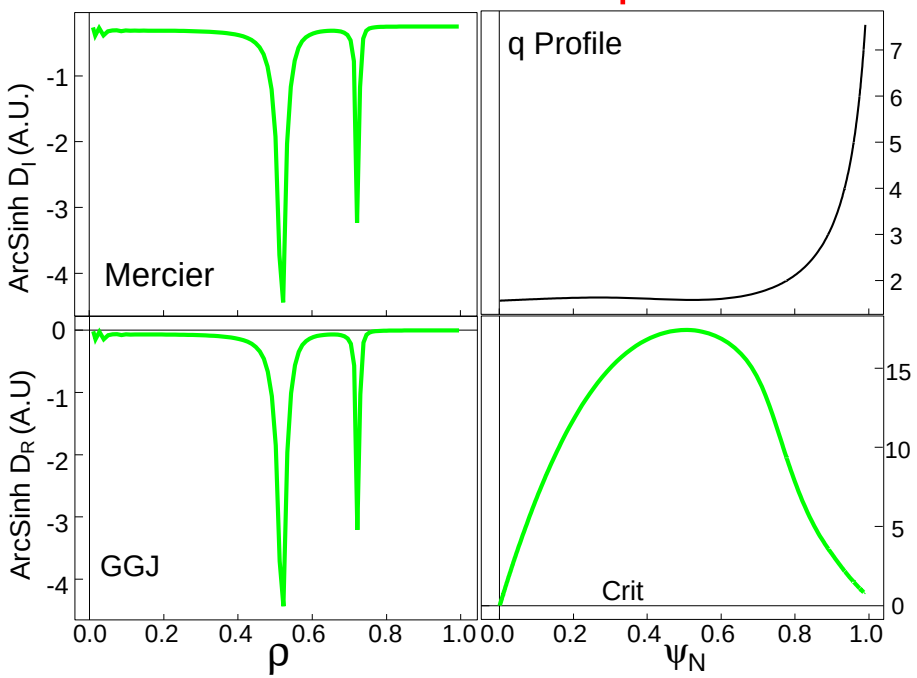
Poloidal Flux



Equilibrium Parameters

I_p	0.29 MA
I_N	12 MA/m-T
I_p/I_{tf}	1.93
l_i	0.59
q_0	1.5
R_0	0.39 m
a	0.34 m
A	1.15
κ	2.2
q_{95}	4.8

DCON Output



QP1.066 - Unterberg et al.

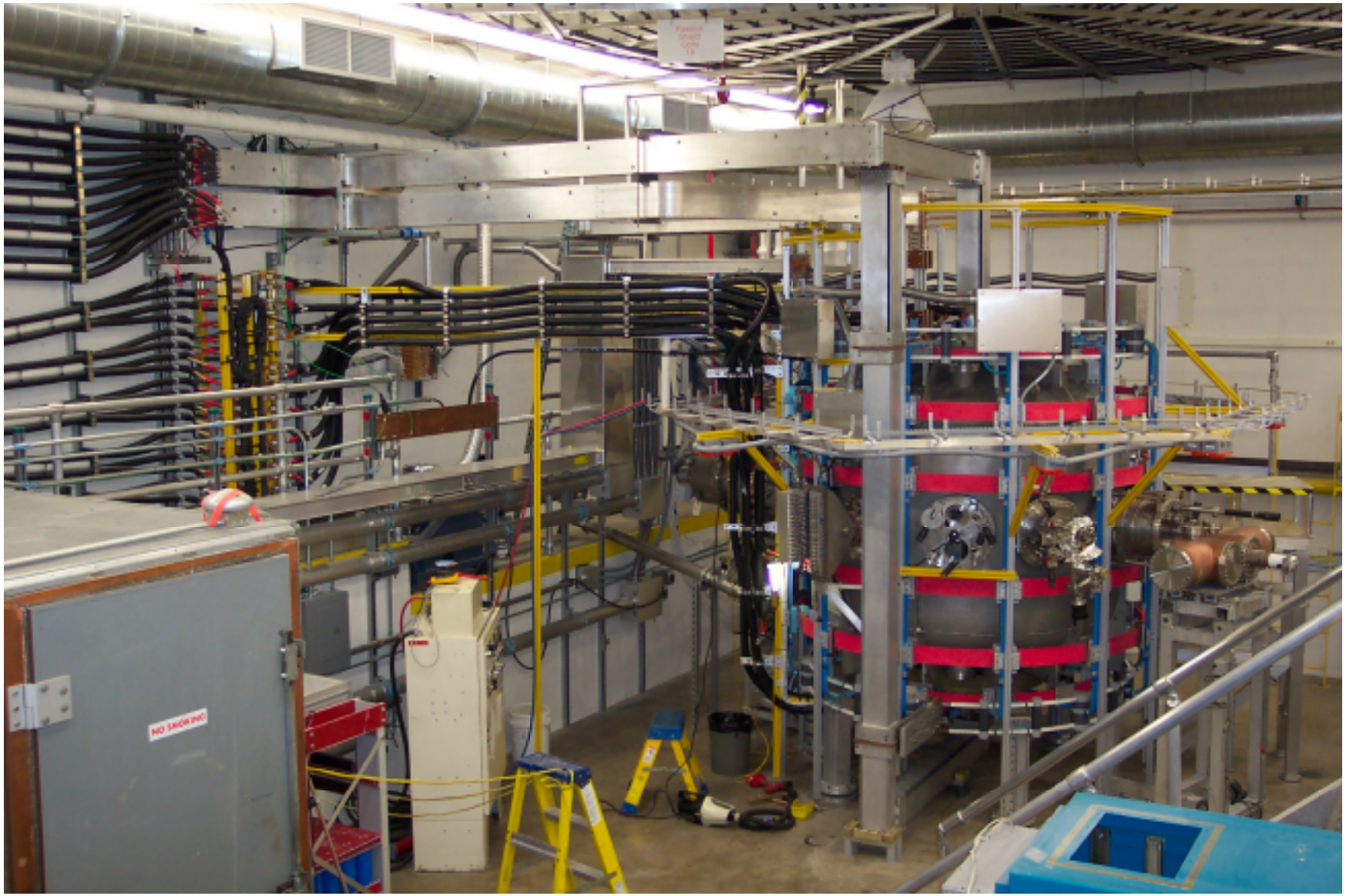
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Capacitor banks installed in outside vault



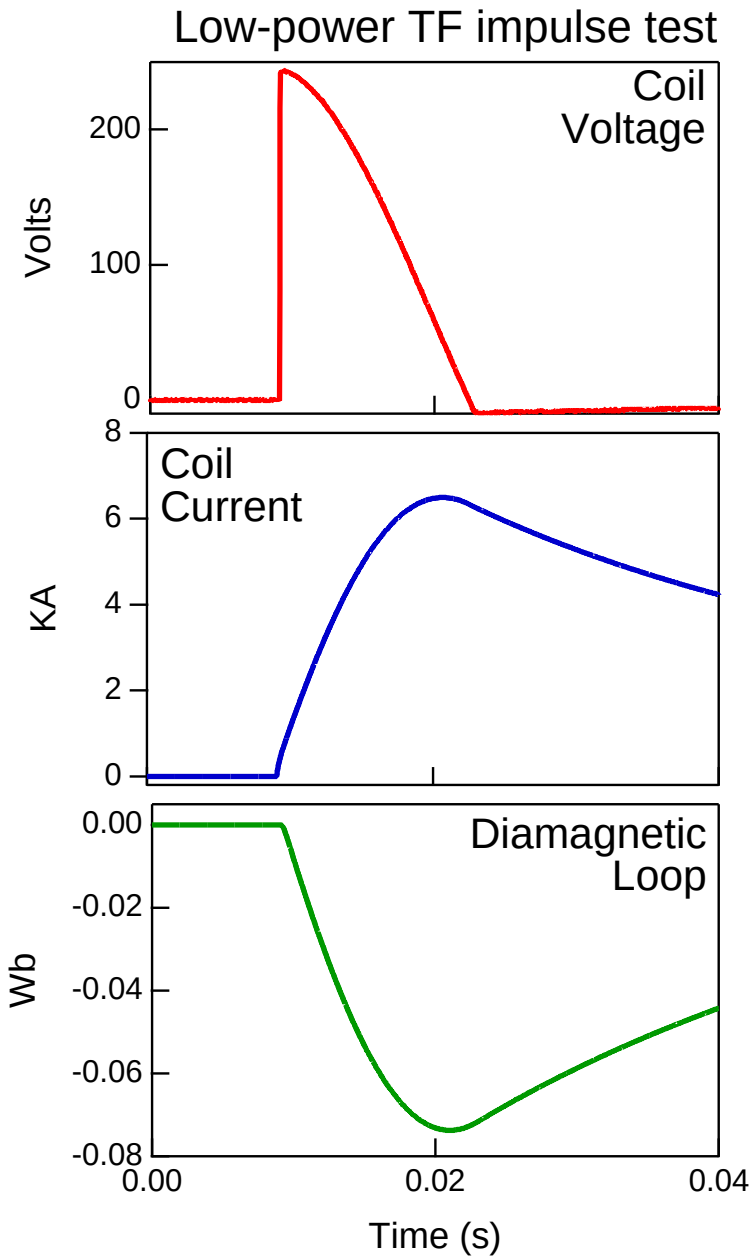


Laboratory reconfiguration is complete



Low power operations have begun

- Currently
  - First power put through new TF coil
  - EF coil packs tested to 15 KA
  - EF buswork improvements implemented
- November-December
  - Continue power / stress / cross-field testing
- December-January
  - Begin deployment of high-power switches
  - Possible low-power plasma ops with hybrid power supplies
- December-February
  - Deployment and testing of high-power programmable power supplies



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Summary

- PEGASUS is an ultra-low A ST with a mission to explore plasma limits as $A \rightarrow 1$
- Phase I of plasma operations has demonstrated high β_t and $I_p=I_{tf}$ ohmically
- Upgrades will increase experimental flexibility and power
- Initial simulations using TSC and DCON indicate a path to stable, high I_p/I_{tf} equilibria
- Lab reconfiguration is complete and power testing has begun

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PEGASUS poster presentations on Thursday morning

QP1.066 - Unterberg
Low-q Operation in an Ultra-Low-Aspect-Ratio Torus

QP1.067 - Eidietis
Modeling PEGASUS Plasmas with TSC

QP1.068 - Quinn
PEGASUS Facility Upgrades

QP1.069 - Burke
Upgraded Diagnostics and Control Systems for the PEGASUS Toroidal Experiment