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The Road Ahead at TAE

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43rd FPA ANNUAL MEETING

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TAE's path towards commercial fusion

Major development platforms integrate then best design

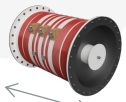
- incremental bases for rapid innovation

Copernicus entering phased sequence of experiments in 2024-26

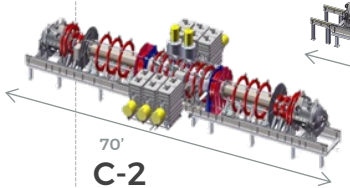
DaVinci demo plant around end of decade

TAE's next machine
- In final design
- Construction 2022+
- First ops in 2024
- Viability of net energy 2025

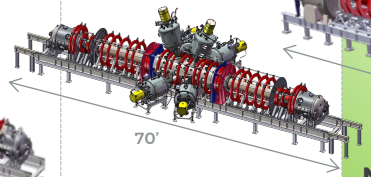
Proof of Concept
- up to 6 keV total T
- Full active feedback
- Macro-stability



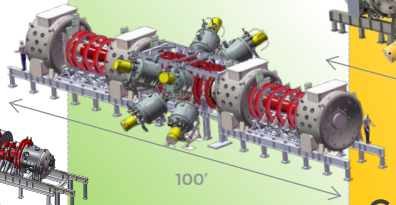
A, B, C-1
Early development steps
1998 – 2000s



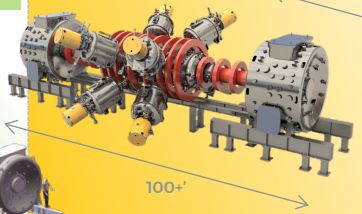
C-2
First full-scale machine
2009-2012



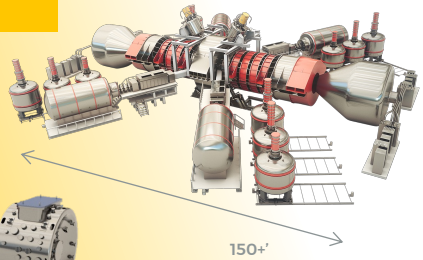
C-2U
Plasma sustainment
2013-2015



Norman (C-2W)
Collisionless Confinement Scaling
2016-2024



Copernicus
Reactor performance operating on hydrogen plasma
2022-2026



Da Vinci
First integrated Demo Plant to begin ops in late 20's and fueled with H-B[11]
2023+ onward

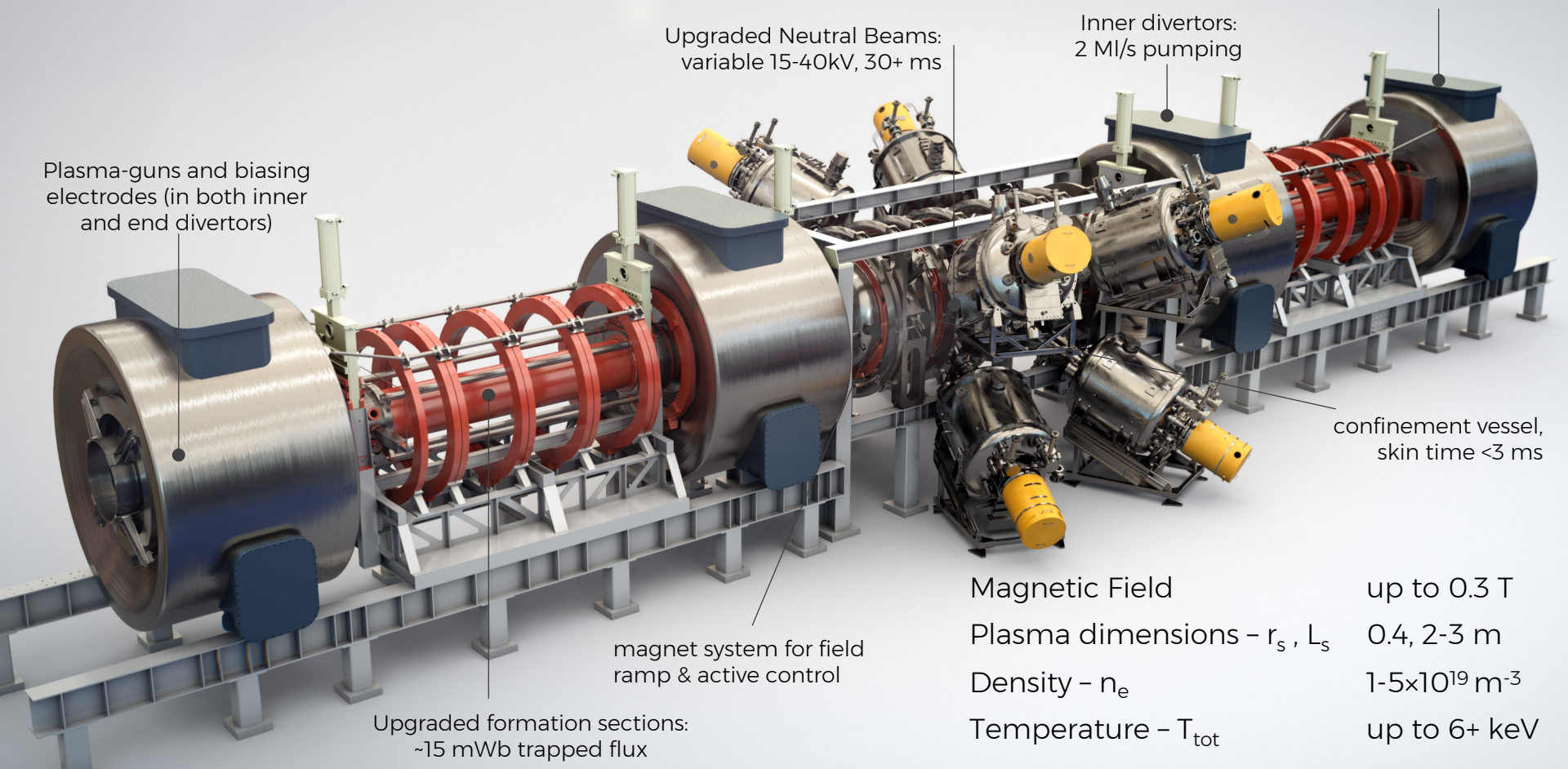
Recent Highlights on Norman

Goals for Norman

Explore beam driven FRCs in fully collisionless regime

- Demonstrate ramp-up and sustainment for times well in excess of characteristic confinement and wall times
- Explore energy confinement scaling over broad range of parameters
    - core and edge confinement scaling and coupling
    - consolidated picture between theory, simulation and experiment
- Develop and demonstrate active plasma control

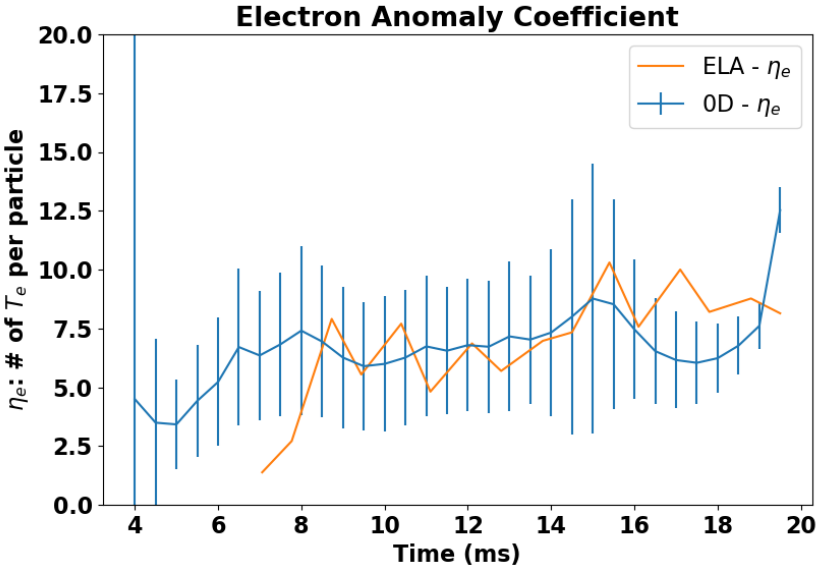
NORMAN — TAE's 5th generation



Magnetic Field	up to 0.3 T
Plasma dimensions – r_s , L_s	0.4, 2-3 m
Density – n_e	$1\text{-}5\times10^{19}\ m^{-3}$
Temperature – T_{tot}	up to 6+ keV

Norman divertors provide excellent edge insulation

Energy loss per electron/ion pair near theoretical minimum



see - Pastukhov V.P. 1974 Nucl. Fusion **14** 3

Flaring magnetic fields

- limit debye sheath voltage at the material boundary
- minimize cold electron back streaming

Extensive vacuum pumping

- evacuates cold gas – minimized cold ion population

Bias electrodes improve stability and transport

Electron energy loss per ion near ideal level

- measured by energy analyzers in outer divertors
- indicates parallel losses in **convective regime** $\frac{q_{\parallel}}{n} \sim T_e^{\frac{3}{2}}$
- $\boldsymbol{\eta_e \sim 6 - 7}$ near ideal ambipolar electron confinement

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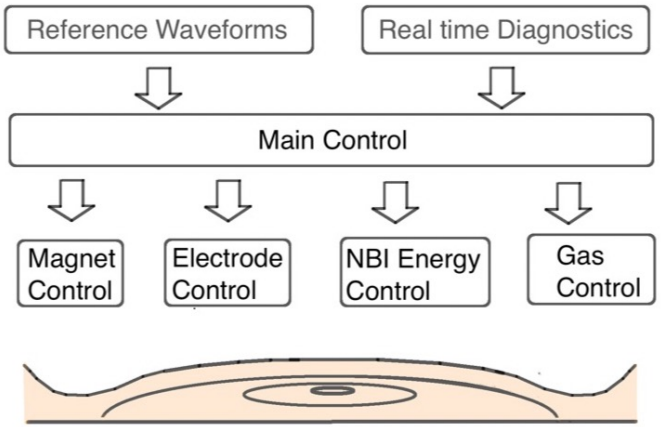
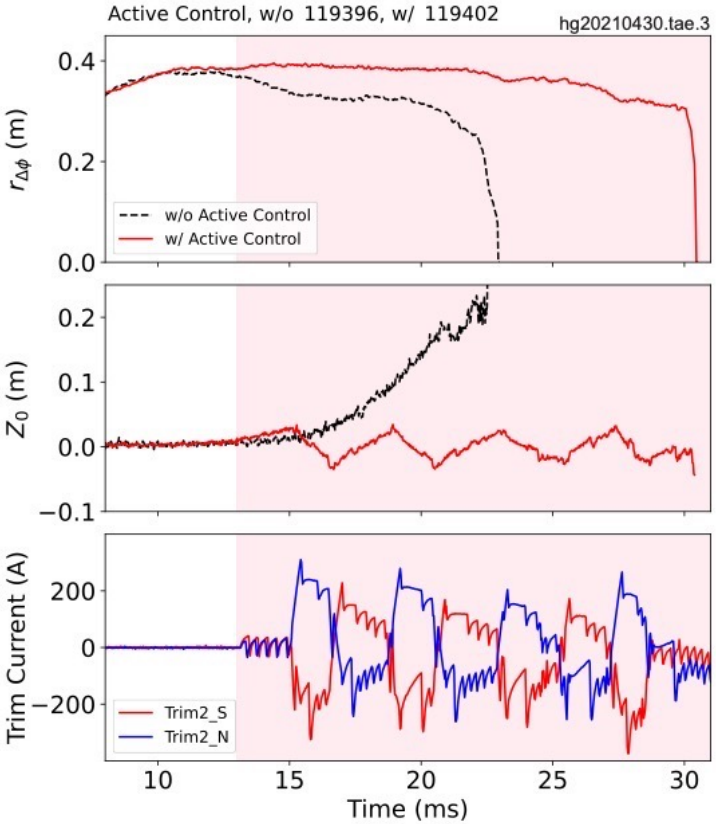
Active feedback controls plasma position

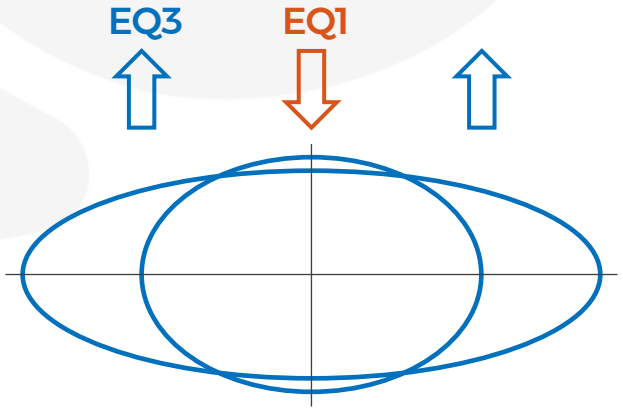
- Axial and radial/azimuthal position control with real-time feedback
- System capable of controlling several additional actuators

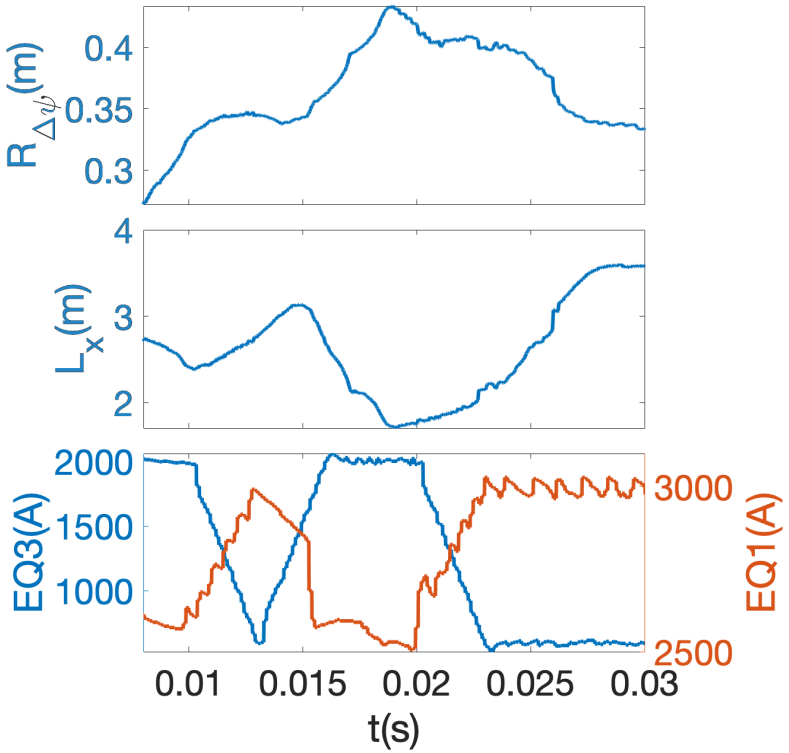




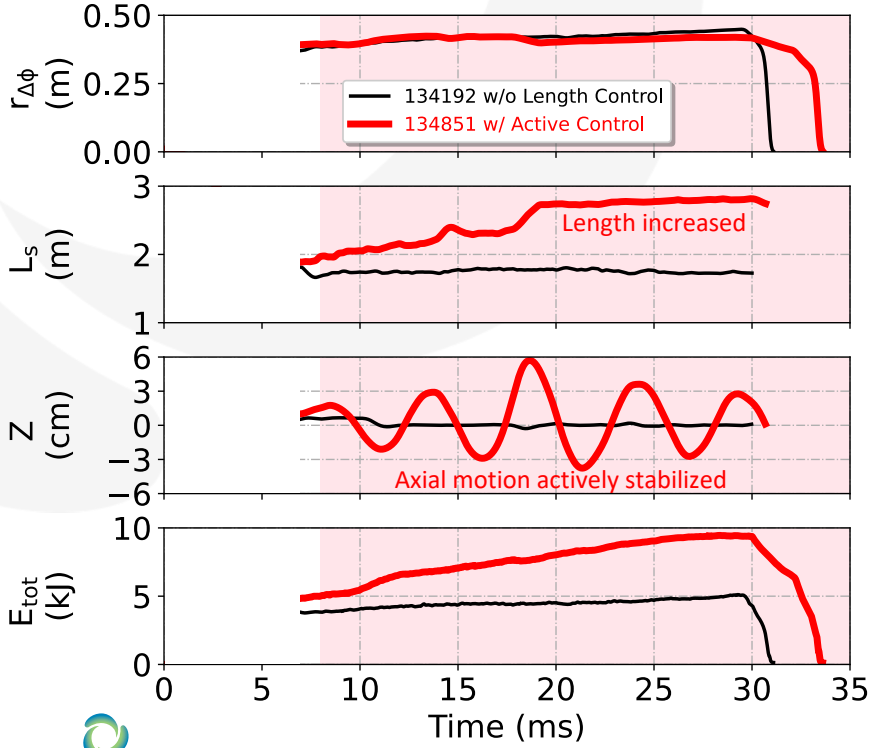
Active feedback control — plasma shape

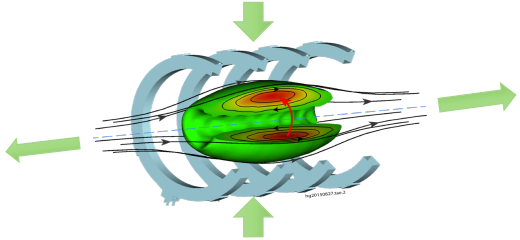
- Length no longer determined by intrinsic processes
- Elongation responds to external fields





Active-feedback control of plasma length expands Copernicus design space





- Beam injection helps to break an intrinsic coupling between FRC density and length ($S^*/E < 3$)
- Active-feedback, real-time magnetic control implemented to independently control plasma length
- Improves operating flexibility and enables broader options for future machines

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Norman goals achieved

Beam driven FRCs explored in fully collisionless regime

Physics performance goals achieved

- Macro-stability and sustainment for 40+ ms, limited by stored energy
- Total temperature over 6 keV, electron temperature up to 1 keV
- Confinement scaling confirmed in collisionless regime
- Excellent edge insulation – energy loss per ion/electron pair ~6-7 T_e

Technology development goals demonstrated

- Millisecond-scale ramp-up and heating
- Real-time active feedback with
  - tunable beam system – 15-40 keV within 100s of micro-seconds
  - stability and transport control via end-biasing
  - position and shape control via trim and saddle-coils

Next Step

Copernicus

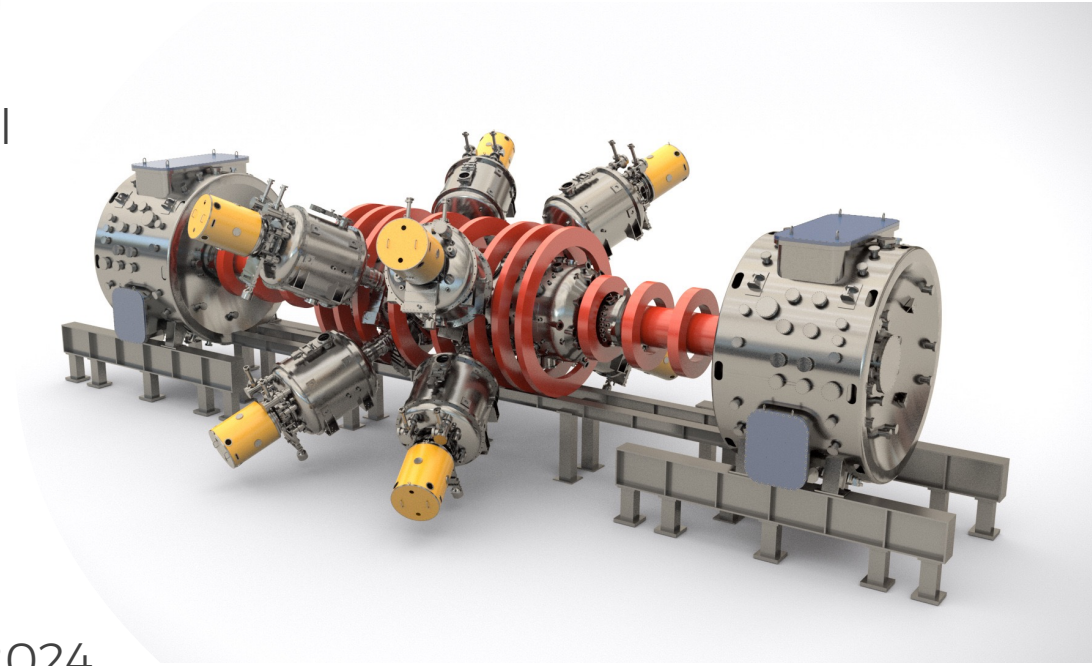
Reactor scale plasma performance platform

Design established

- 10+ keV ion temperature goal
- Hydrogen only operation
- 2-3 sec pulse length

Budget and timing

- $250+ MM cap-ex
- Fabrication under way
- Commissioning and ops by 2024



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Copernicus site is under construction

- 100,000 sqft Copernicus lab site in Irvine
- Estimated building completion April 2023

Beyond Fusion

Spin-off technologies

From fusion power supplies to power management

Automotive & Grid Stabilization

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Power Solutions for

eMOBILITY

Energy Storage

Motor

Power Generation

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Power Technology for

CLEAN FUSION

Residential, Charging, Storage & Grid Stabilization

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Power Solutions for

GRID AND STORAGE

Solar Thermal

Residential

Energy Storage

From fusion beams to targeted radiation oncology

Beam technology adapted to compact epithermal neutron sources

- BNCT (boron neutron capture therapy) – existing cancer treatment, but only available at research sites with a nuclear reactor
- 3x efficacy of x-ray & proton treatments
- First clinical system delivered in 2021
- **First human patients treated in October 2022**
- Growing order book in Asia, EU, US

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Thank You