Progress and Next Steps at TAE

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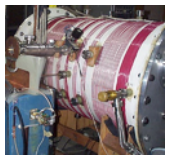
Historical and future program overview

Continual progress towards advanced beam-driven FRC fusion

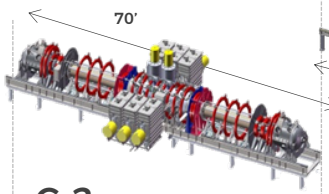
Major development platforms integrate then best design

- incremental bases for rapid innovation

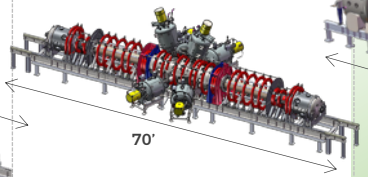
Copernicus entering phased sequence of reactor performance experiments



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



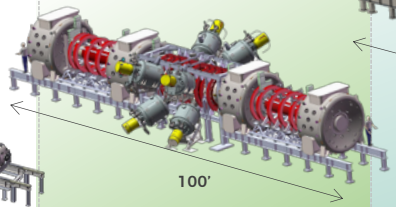
C-2
First full-scale machine
2009-2012



C-2U
Plasma Sustainment
2013-2015

TAE's current machine

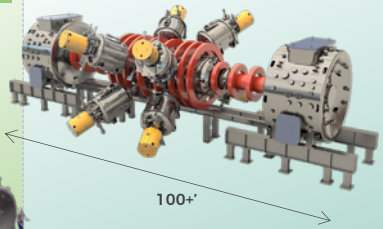
- Performance goals achieved
- Copernicus design protoyping ongoing



Norman (C-2W)
Collisionless Confinement Scaling
2016-2020

TAE's upcoming machine

- First fabrication under way
- Finalizing residual designs
- Commissioning late 2023



Copernicus
Reactor Performance operating on hydrogen plasma
2021+

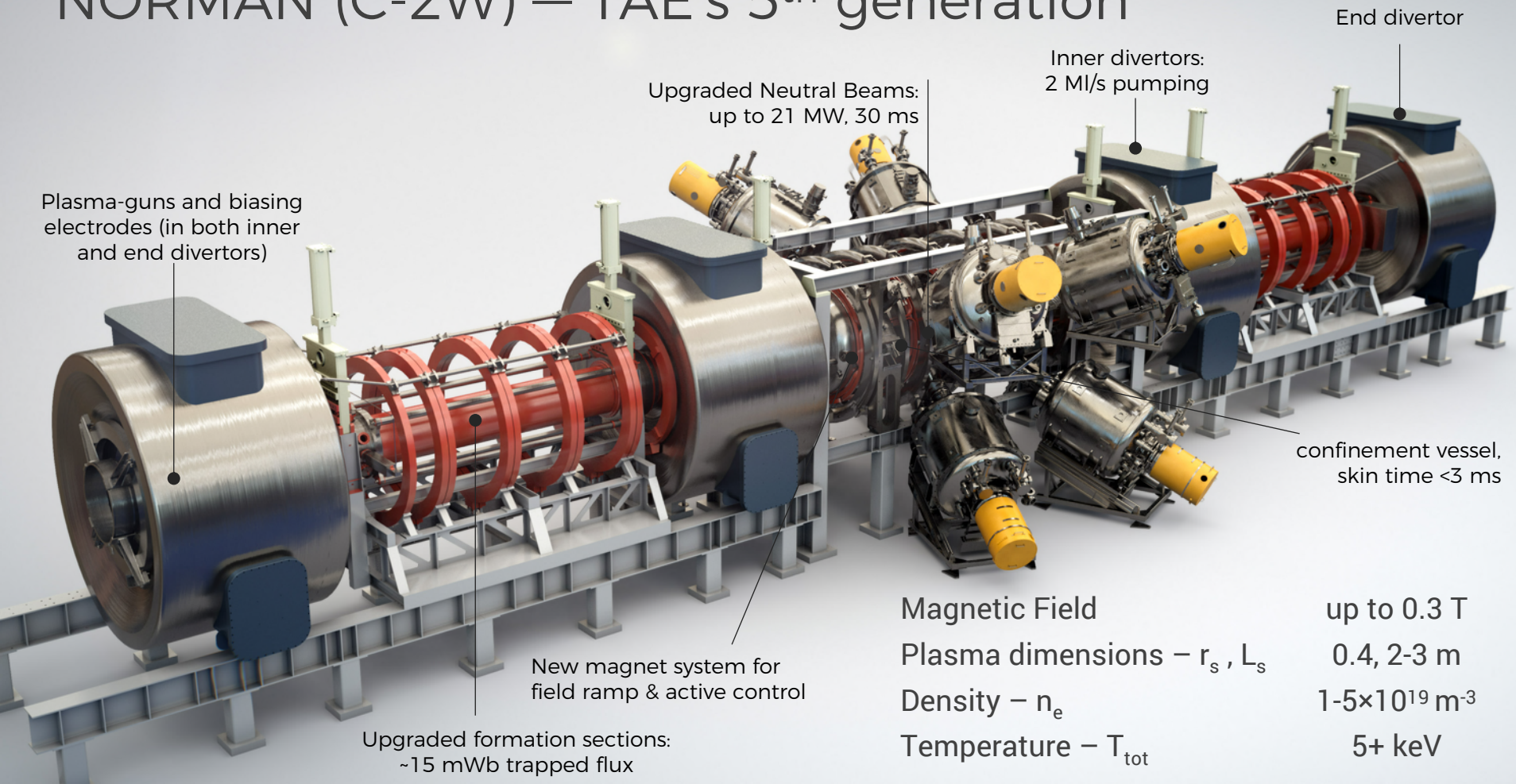
Norman Summary and recent Highlights

Norman goals achieved

Beam driven FRCs explored in fully collisionless regime

- Physics performance goals achieved
  - Sustainment for 30+ ms, limited by stored energy
  - Total temperature over 5 keV, electron temperature up to 1 keV
  - Confinement scaling confirmed in collisionless regime
  - Excellent edge insulation – energy loss per ion/electron pair ~6 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

NORMAN (C-2W) — TAE's 5th generation

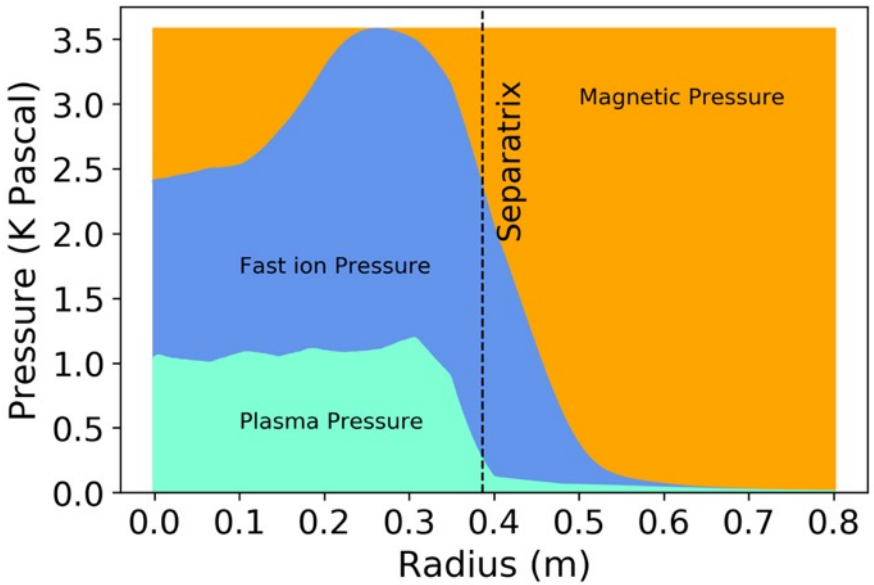


Magnetic Field	up to 0.3 T
Plasma dimensions – r_s , L_s	0.4, 2-3 m
Density – n_e	1-5×10^{19} m^{-3}
Temperature – T_{tot}	5+ keV

Fast ions enable stable beam-driven FRCs

Strong stabilizing impact without any deleterious consequences

Typical Norman Pressure Profile

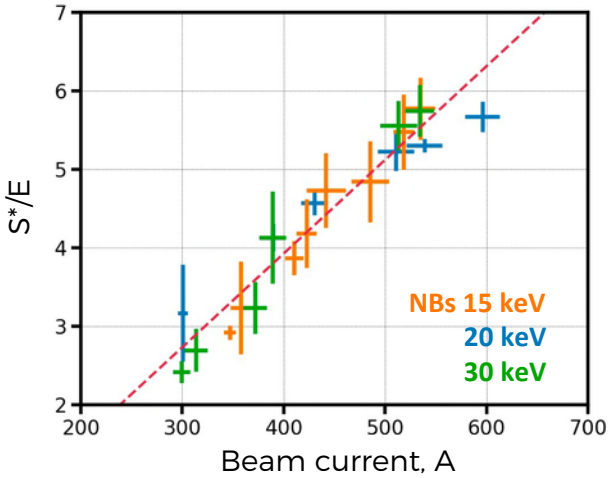


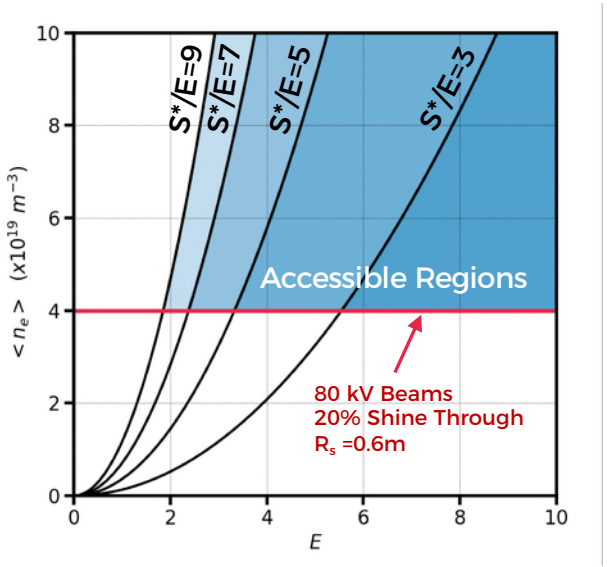
- Dominant fast ion pressure
- Provides enhanced stability
- Expands operating regime
- No fast ion driven deleterious modes
- Large ion orbits and turning points well outside separatrix — $P_{fast} \gg P_{th}$

Fast ion stabilization expands operational domain

Removes any constraining density limit

$S^*=r_s/\delta_i$ and $E=L_s/2r_s$





- Tilt improves with growing fast ion population well beyond historical limit of S*/E ~ 3
- Higher S*/E expands Copernicus design space and provides operating flexibility

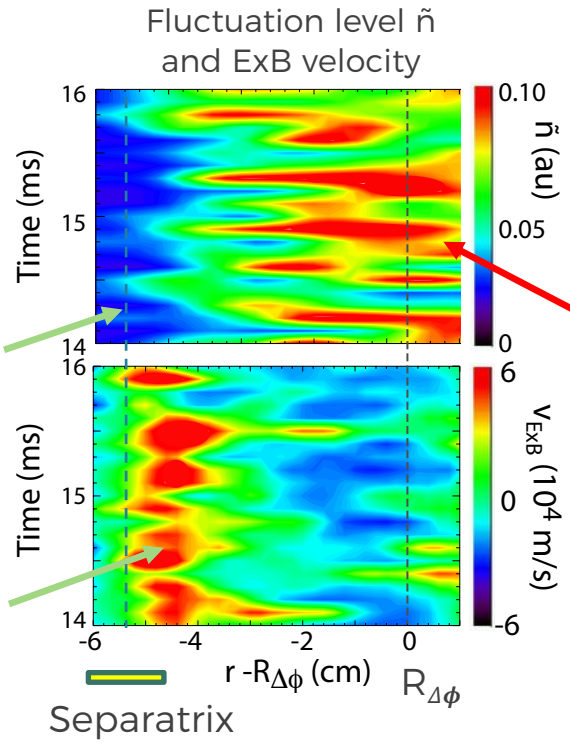
Zonal-flows and turbulence self-organization

First ever observation in FRCs

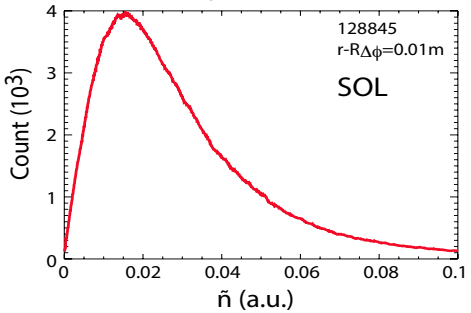
- Quiescent core, turbulence on open field lines
- Zonal-flow shear based transport barrier just outbound of separatrix
- Inward propagation w/ avalanche like features
- Consistent w/ 3D turbulence simulations

Turbulence quenched near separatrix

High Zonal-Flow ExB shear forming barrier near separatrix



Skewed amplitude distribution of ñ indicates transport avalanches in SOL



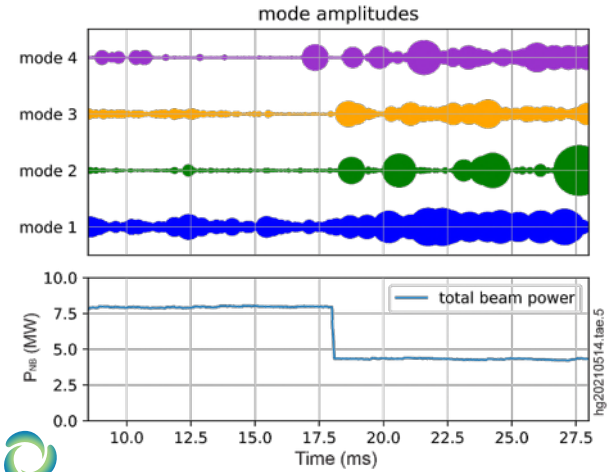
Small "events"

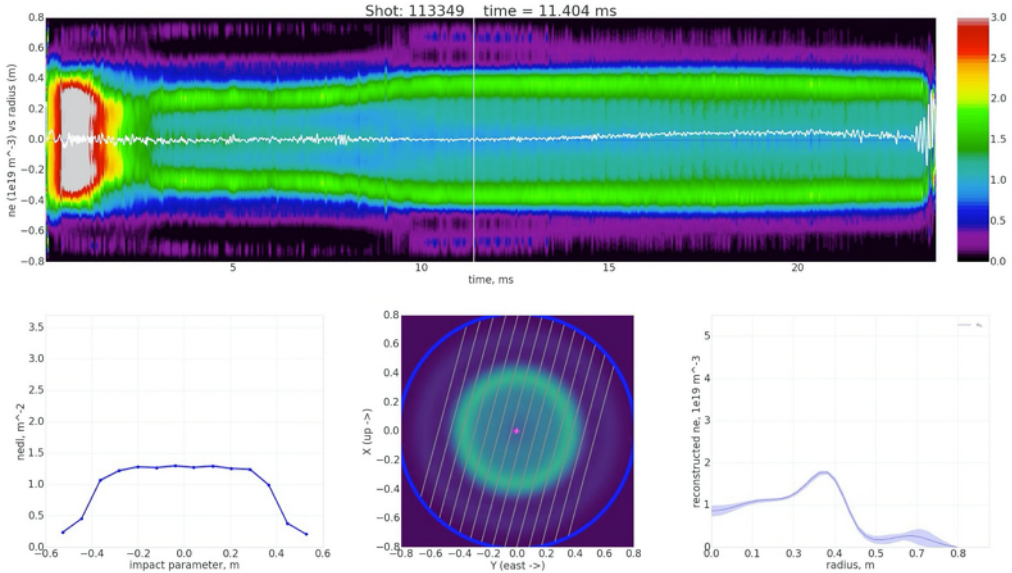
Large "events" (avalanches)

Integrated diagnostics reconstruction

Provides identification of internal plasma perturbations

- Powerful Bayesian tools developed in collaboration with Google infer core mode structures
- Further evidence for stabilization by energetic ions

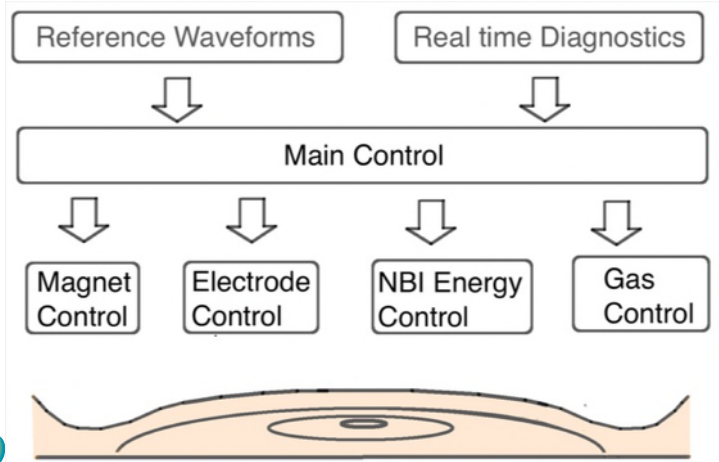


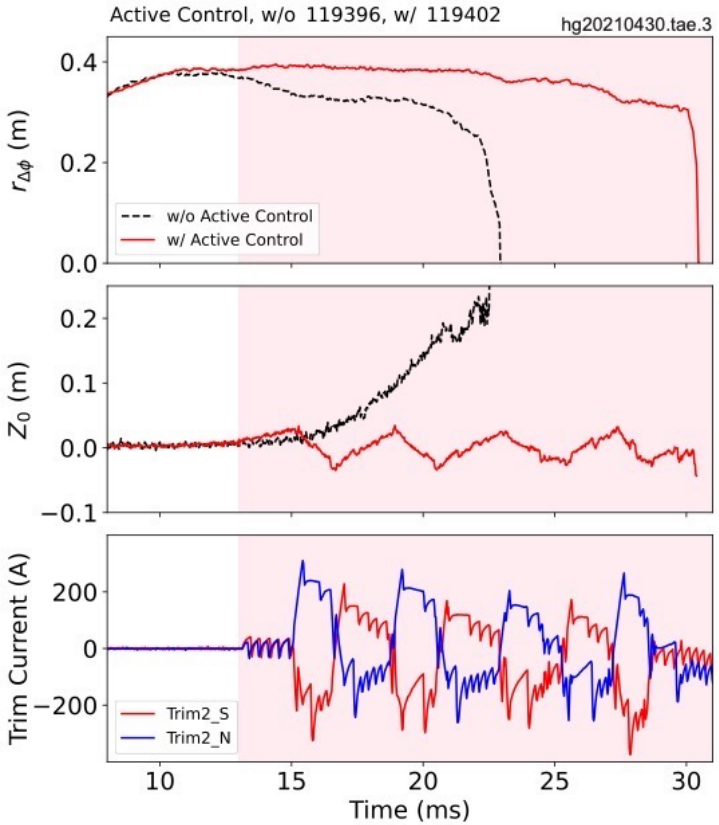


M. Dikovsky, et. al., Physics of Plasmas **28**, 062503 (2021)

Active feedback controls plasma position

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





Under Way . . .

Copernicus

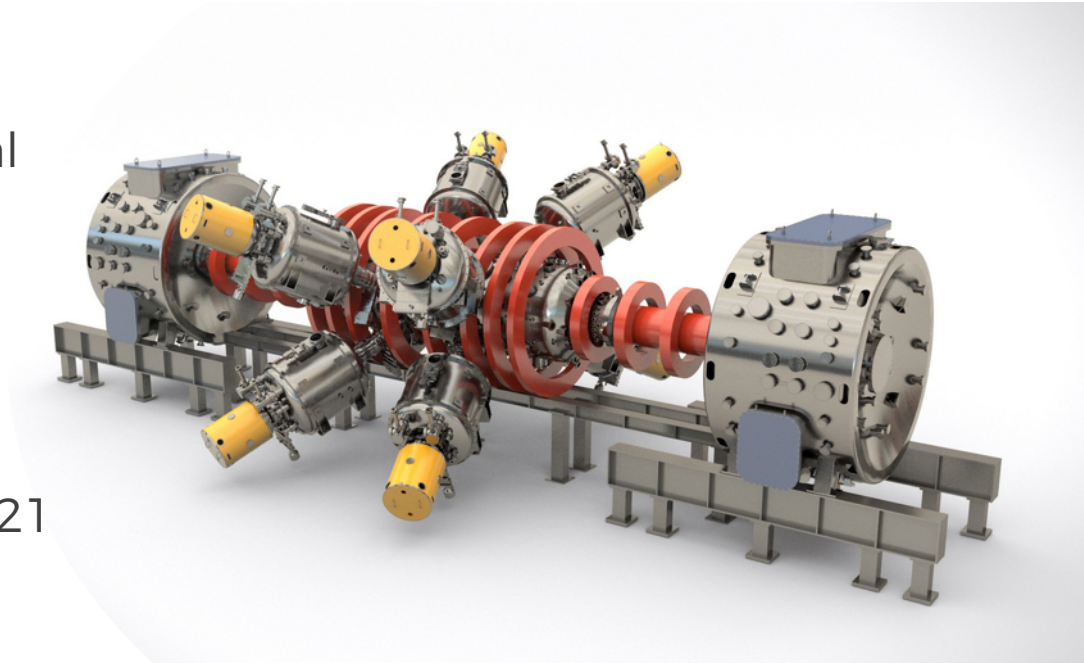
Reactor scale plasma performance platform

Design development ongoing

- 10+ keV ion temperature goal
- Hydrogen only operation

Budget and timing

- $250 MM cap-ex
- First fabrication started in 2021
- Commissioning by late 2023



Beyond Fusion

Spin-off technologies

- Medical – BNCT
- Power management – EVs to grid infrastructure


Thank You