ID: OV/P 1377

Experiments on ST40 towards burning plasma conditions

M Gryaznevich and Tokamak Energy Ltd. Team

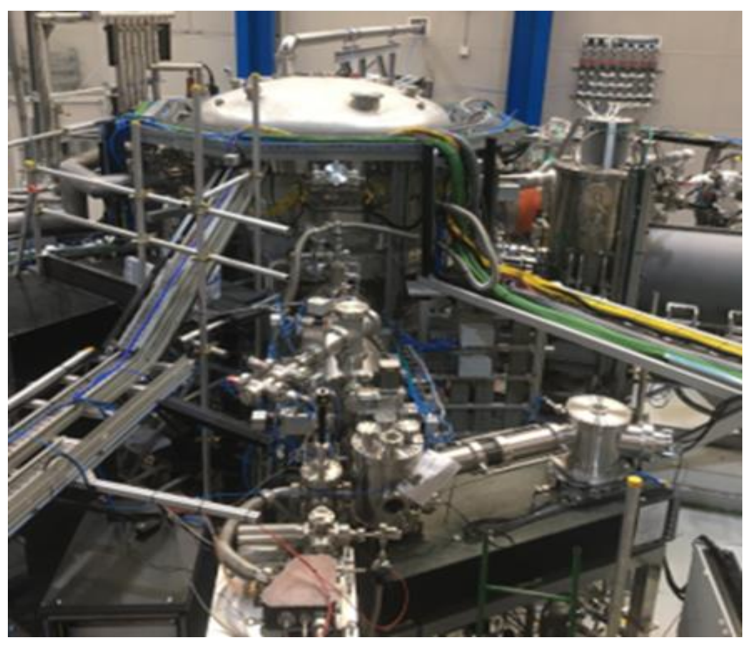
Tokamak Energy Ltd., 173 Brook Drive, Milton Park, Abingdon, UK

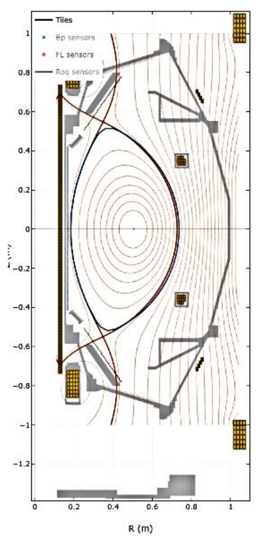
Mikhail.Gryaznevich@tokamakenergy.co.uk

tokamak energy — a faster way to fusion

The combination of the high β, which has been achieved in STs, and high TF that can be produced by HTS TF magnets, opens a path to lower-volume fusion reactors, in accordance with the fusion power scaling ~ $b^2B_t^4V$. High field spherical tokamak ST40 is the first prototype on this path and is now operating.

Present status of ST40

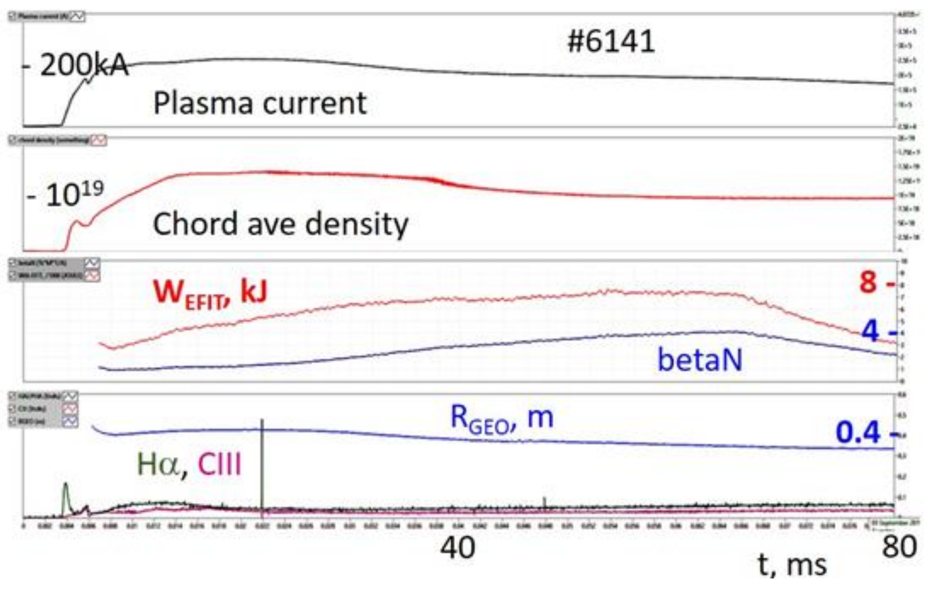




- DND operations possible, HFS Cu passive plates and divertor (Mo) installed

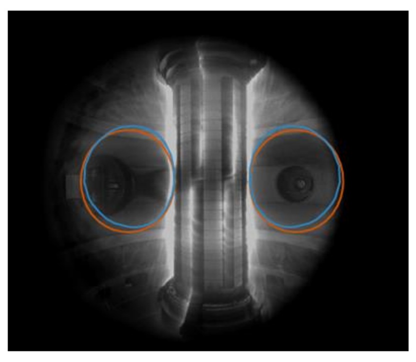
- **B_t = 3T (highest in STs)**, I_p = 2MA, R_0 =0.4-0.6m, R/a=1.6-1.8, κ=2.5
- **2 MW** (up to 5) of **auxiliary heating** (NBI / ECRH, 1MW 25kV and 1MW 50kV **operational**, 3rd NBI ordered, 1 MW gyrotron ordered)
- **P**ellet **I**njector ordered.
- Pulse flat-top **1 sec** at nominal 3T, longer for lower TF.
- LN2 cooling of **Cu magnets** commissioned.
- Bioshield installation completed.
- Experimental campaign has started with 10 keV range temperatures as a goal on the way to **burning plasma conditions**, T_in_e ~ 10 keV x $10^{21}m^{-3}$

First results



First results, 2018-19

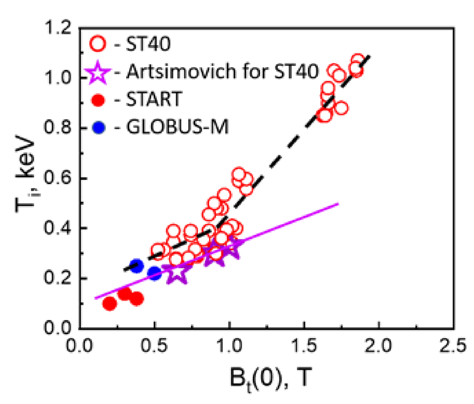
- **OH:** Highest β_N (EFIT) ~ 4, W_{EFIT} ~ 20 kJ – confirmed by diamagnetic loop data



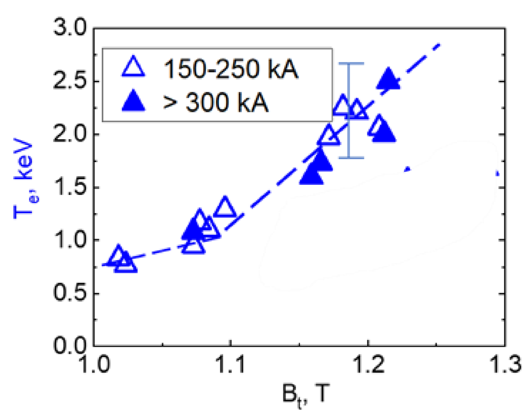
CCD image in visible light overlapped with EFIT reconstruction

Confinement studies in OH:

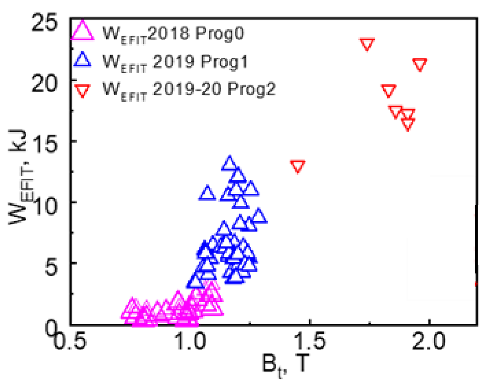
- Sharp improvements in performance with increased toroidal field **above 1 T**



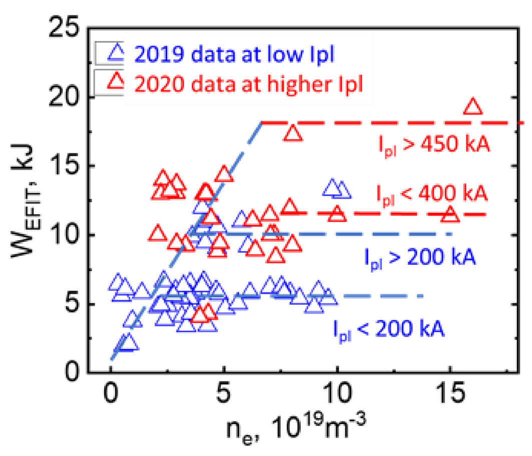
Ion temperature *measured on ST40, START and Globus-M against toroidal field, along with T_i predicted by* ***Artsimovich*** *formula*



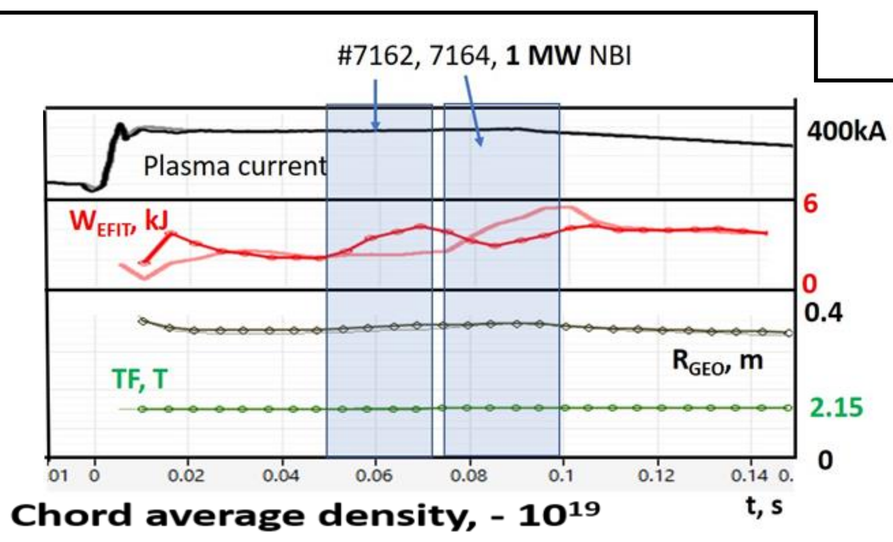
Electron temperature *(SXR spectrometer) shows sharp increase at TF > 1T*

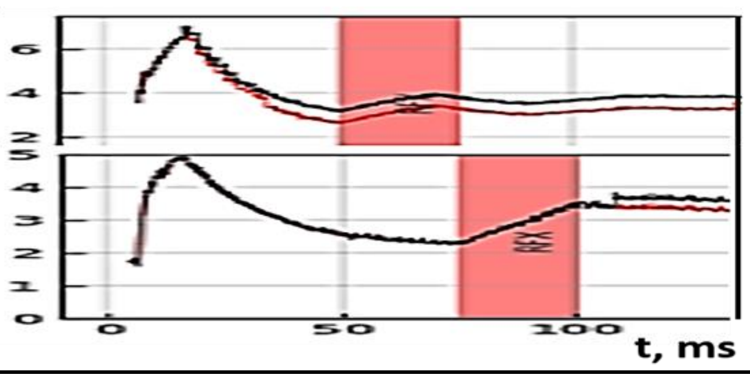


Thermal energy *W_{EFIT} shows sharp increase at TF > 1T*



Saturated Ohmic Mode: *W_{EFIT} saturates at critical density*



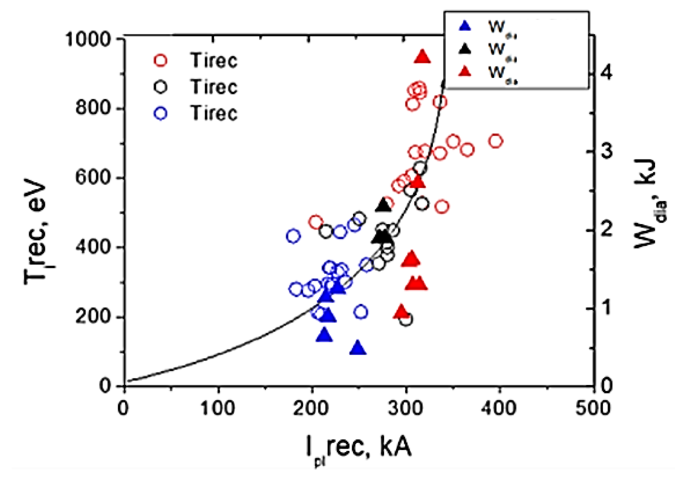


2020 First results with NBI

- 25 keV 1.0 MW NBI: visible increase in plasma density and stored energy
- Increase in T_i from ~ 0.6 keV to ~ 1.2 keV in these shots (NPA data)

Merging/Compression start-up

- It is possible to transfer **magnetic energy** into the plasma **thermal energy** with a very high efficiency (up to 90%), thus using magnetic field **not only for the containment**, but also **for** the plasma **heating** using magnetic reconnections during merging-compression formation.



- According to predictions, heating due to reconnection should be ~ B_{pol}^2, results from ST40 confirm this.

HTS development

2015: ST25-HTS
First full-HTS tokamak
Achieved **0.1 T** @ R 0.25 m
Plasma pulse duration 29 h

DEMO-3, 2019:
Record field in all-HTS magnet
24.4 T @ 21 K

DEMO-4, 2021:

- Exceed **24 T** on centre column @ temperature ~20 K
- TF: ~40 km tape, PF: ~20 km tape
- **16 MJ** stored energy
- Demonstrate scalable quench protection
- Test PF / TF interaction (DC & AC)
- Simulate fusion heating

DEMO-4, ST25-10T
Target **10 T @ R 0.25 m**
Under construction

Conclusions

- **ST40 is operational**, demonstrating advantages of high-field ST.
- Increase in T_e, T_i and W_{therm} with TF has been observed for **TF up to ~ 2 - 3 T in OH operations.**
- **Below 1 T TF**, OH experiments show similar trends as in Neo-Alcator scaling.
- At average densities above *2-6 $10^{19}m^{-3}$* **ohmic saturated mode** has been observed with critical density depending on I_{pl} rather than on TF.
- **First results with NBI** show expected increase in temperature, density and stored energy.
- Merging-compression formation results are in agreement with results of previous studies and predictions.

HTS development

- Significant advances in HTS magnets development.

FUTURE PLANS:

- Long pulses in ST40 with increased I_{pl}, TF and heating power.
- Pumped divertor, LFS passive plates, HFS PI and EBW HFS launch.
- Conceptual design of ST Power Plant module.

28th IAEA Fusion Conference 10-15 May 2021