Setup and Initial Operation of a 28 GHz long pulse gyrotron for EBW startup experiments on MAST

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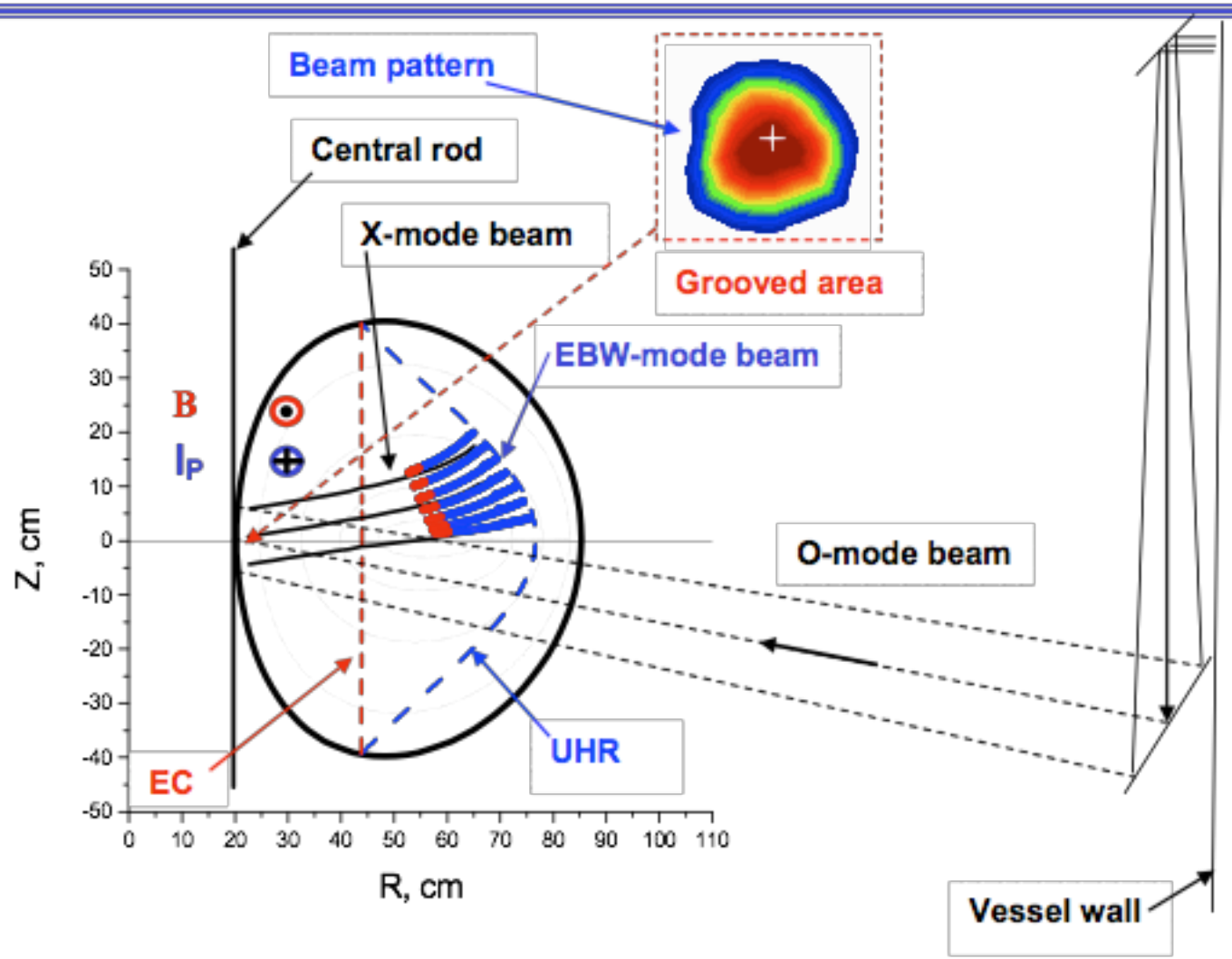
Higher power EBW/Startup Experiments on MAST

- Higher power, longer pulse length desired to expand experimental capability
- Recondition older gyrotron from ORNL
- Upgrade a gyrotron socket at MAST
- Condition the gyrotron
- Fine tune the waveguide system
- Perform initial EBW experiments on MAST

Previous Capability

- 28 GHz 100 kW, 90 ms pulsed gyrotron
- Long 40 mm waveguide run with several radius bends
- Mode converting launcher
  - Outside O-mode
  - Polarization rotating reflector on center stack reflects X mode

EBW Start-up Scheme



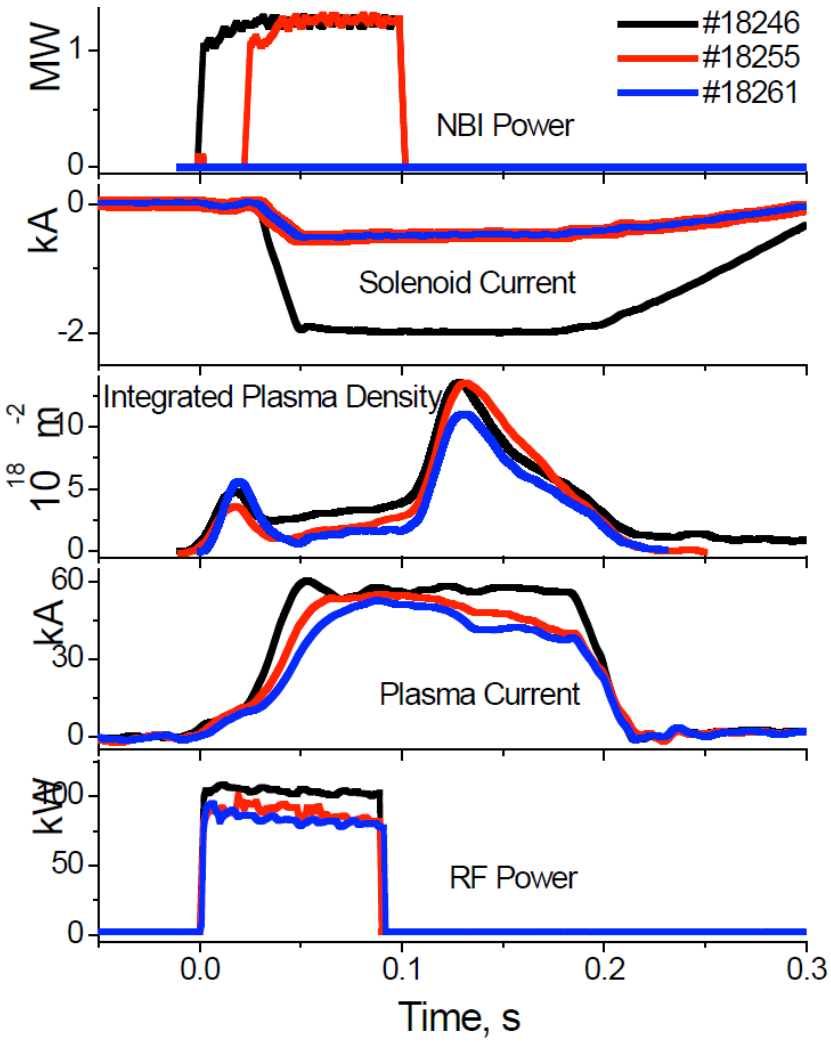
Ray-tracing modelling (poloidal view) of the EBW CD plasma initiation. The RF beam pattern, as measured at low power, is well within the grooved area of the graphite mirror-polarizer.

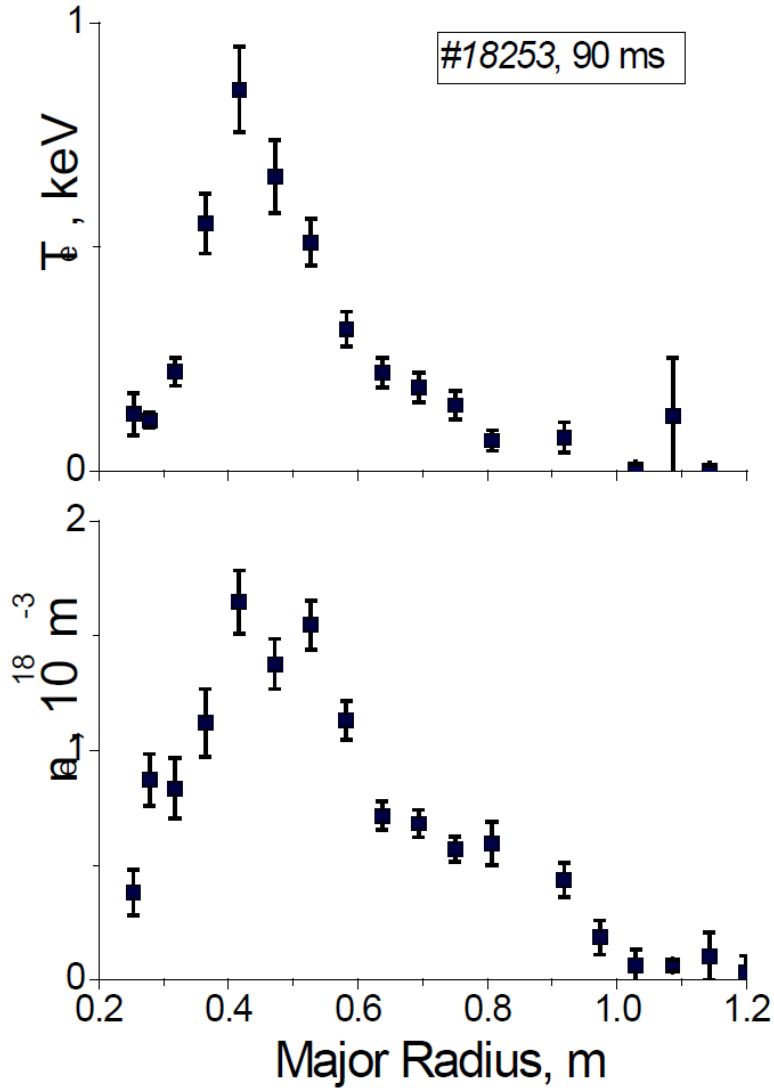
Previous experimental results

- Shevchenko & Saveliev reported on EBW assisted plasma startup on MAST
- 28 GHz 100 kW, 90 ms power
- Achieved 33 kA plasma current with no solenoid flux
- Achieved 56 kA with small solenoid blip
- Optimized vertical plasma shift to suppress negative pressure driven currents

2007 Results

Start-up with Limited Solenoid Assist





*EBW plasma current start-up with **limited solenoid assist**.*

V. Shevchenko et al, *MAST Forum, 13 -14 Feb 2008, Culham, UK*

MAST

UKAEA

Fusion Working with Europe

28 GHz CW gyrotrons

- Several 28 GHz CW gyrotrons were used on EBT, RFTF, ATF and other applications at ORNL in past years
- Vacuum conditions are acceptable but need some re-conditioning
- The long pulse power capability is estimated to be 350 kW

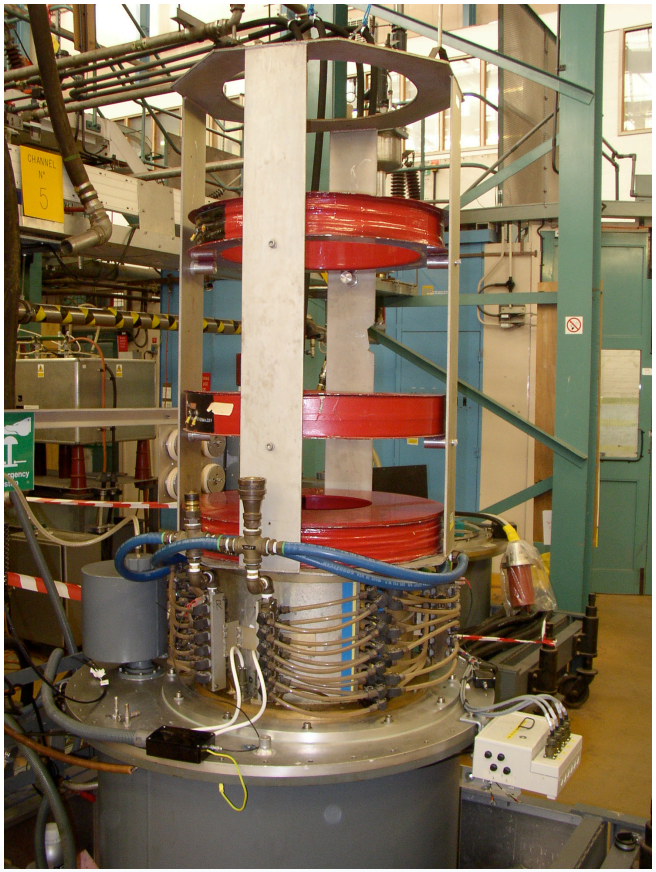
Low power CW conditioning

- CW testing of several gyrotrons has been performed on a low power test stand
- -45 kV, 1 A beam
- Typically 10 kW cw output
- Can run for hours to restore vacuum conditions

Gyrotron conditioning at ORNL

- High power, short pulse testing was planned
- Equipment moved and re-connected
- Gyrotron installed and all systems checked out
- Problem with HV transformer limited testing

Socket modifications at MAST



- Existing 60 GHz oil tank used
- Magnet replaced
- Collector magnet
- Most other controls re-used but isolated

MAST 28 GHz Installation

- Gyrotron installed in July
- Controls check-out through early September
- Plasma operations mid-September

Improved HV safety for Controls

- New magnet power supplies
- All controls were isolated by analog fiber optic links

Controls checkout

- HVDC Power supply restarted after 2 years off
- Water system, PLC, other systems upgraded

Gyrotron conditioning at MAST

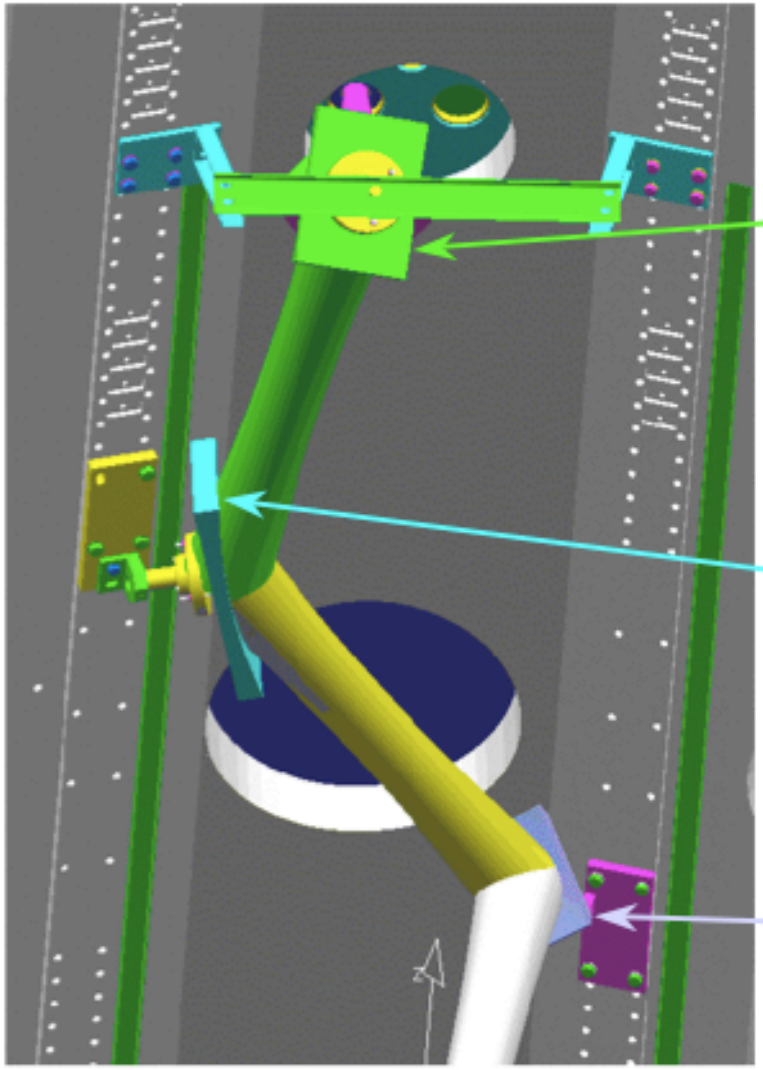
- The gyrotron was operated into a dummy load for ~ 2 weeks
- Short repetitive pulses at reduced pulse length and beam current
- Arcing in gun area a problem if parameters were pushed too fast
- Eventually, fairly reliable operation at ~160 kW was achieved and plasma experiments commenced

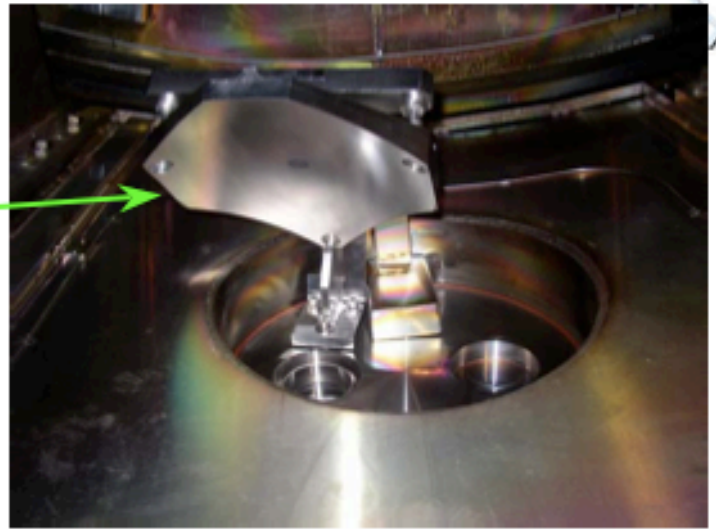
Waveguide configuration

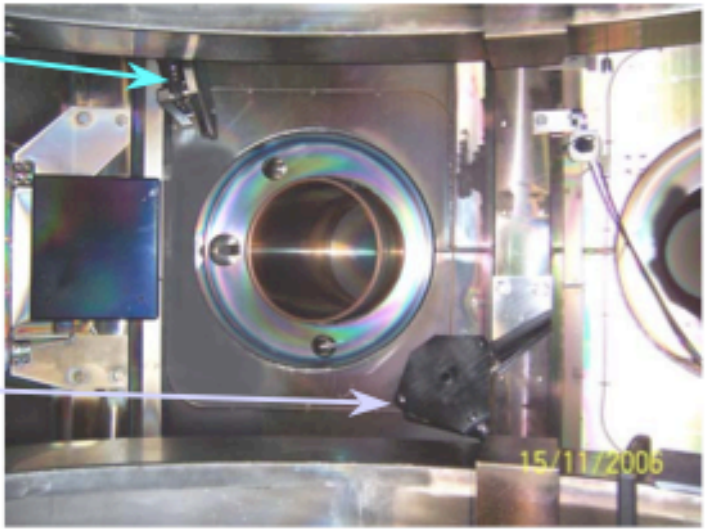
- 63.5 to 40 mm downtaper
- Reflected power monitor
- TE02-TE01 ripple wall converter
- Corrugated radius bend
- Long run
- K-spectrometer
- Calorimeter load or second radius bend
- Several more bends and long runs
- TE01-TE11-HE11 mode converters

28 GHz Launcher

MAST



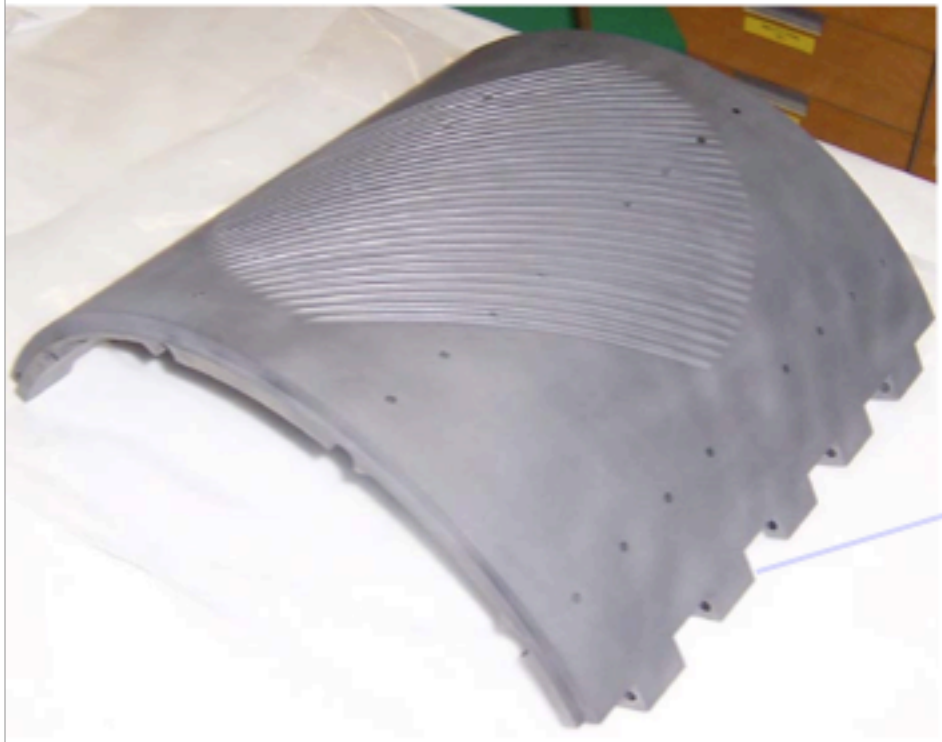


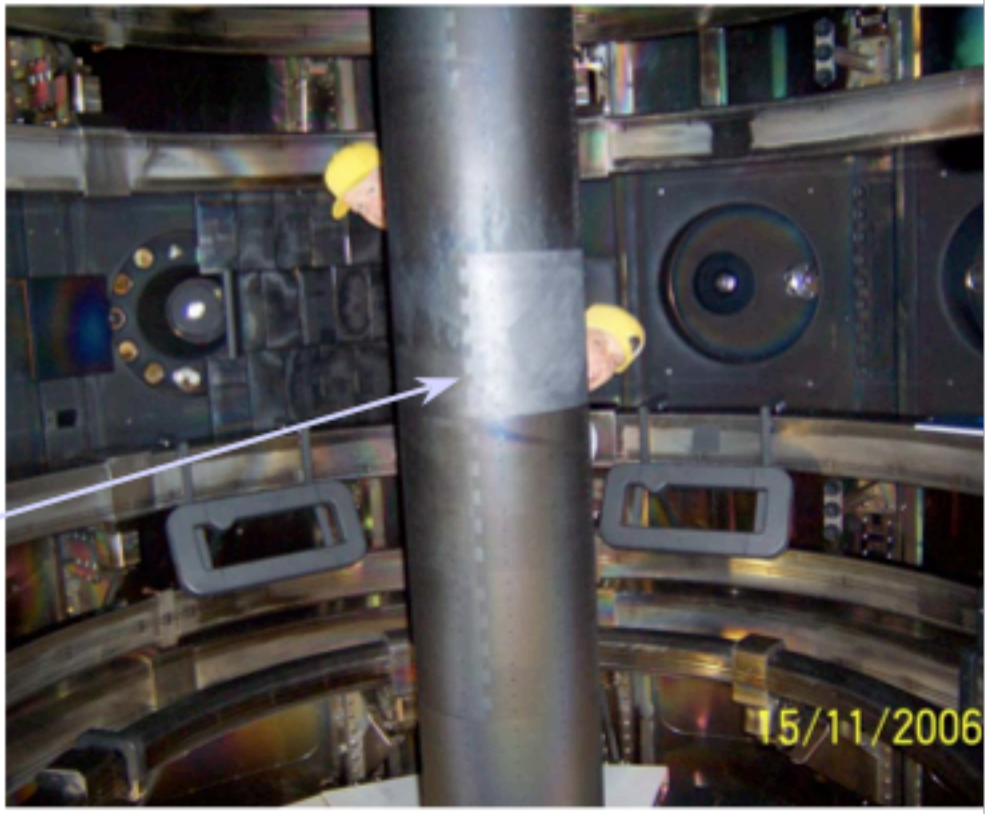


In-vessel mirrors of the 28 GHz launcher

Mirror-Polarizer in MAST

MAST





Graphite tile with grooved mirror-polarizer

Mirror-polarizer on the central rod in the MAST vessel

Initial operation into MAST

- 2 week experimental campaign conducted
- Time limited by continued check-out of new controls and conditioning of gyrotron
- Some experiments were successful in generating a modicum of plasma current

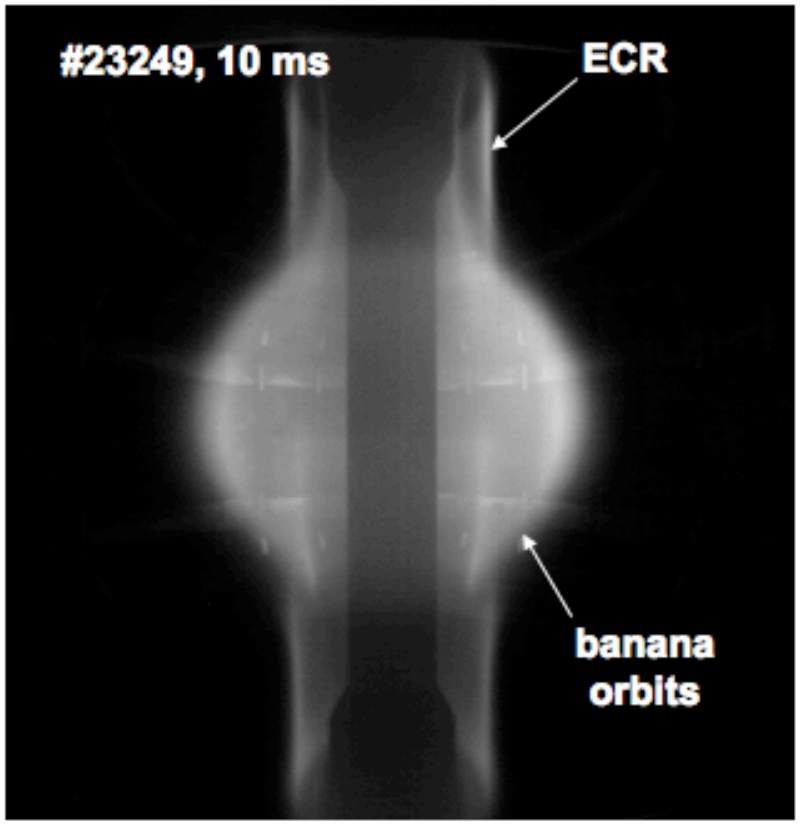
Waveguide improvements

- Reconfigure mode converter, first bends, bellows
- Looked at various sections of waveguide
- Looked at torus window
- Other tests envisioned to localize arcing
- CW Gyrotron mode purity and issue?

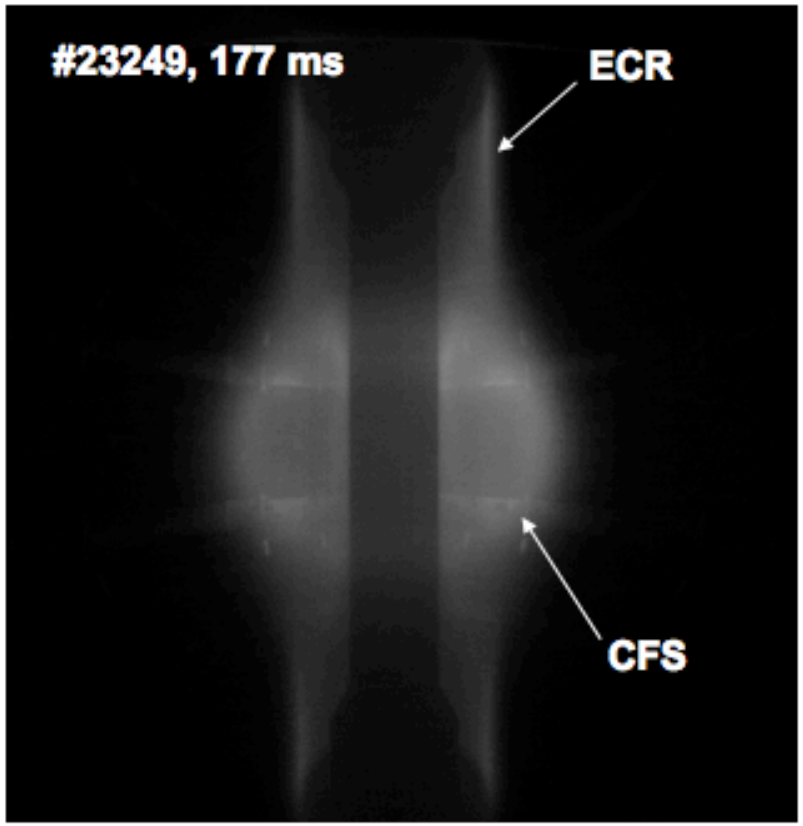
Experimental results

- 24 kA plasma current quoted in experimental logs by Vladimir
- Poor MAST vacuum conditions
- Gyrotron pulse length limited by waveguide arcing
- Good operating results with the gyrotron into a dummy load with a short run of waveguide

Plasma Images



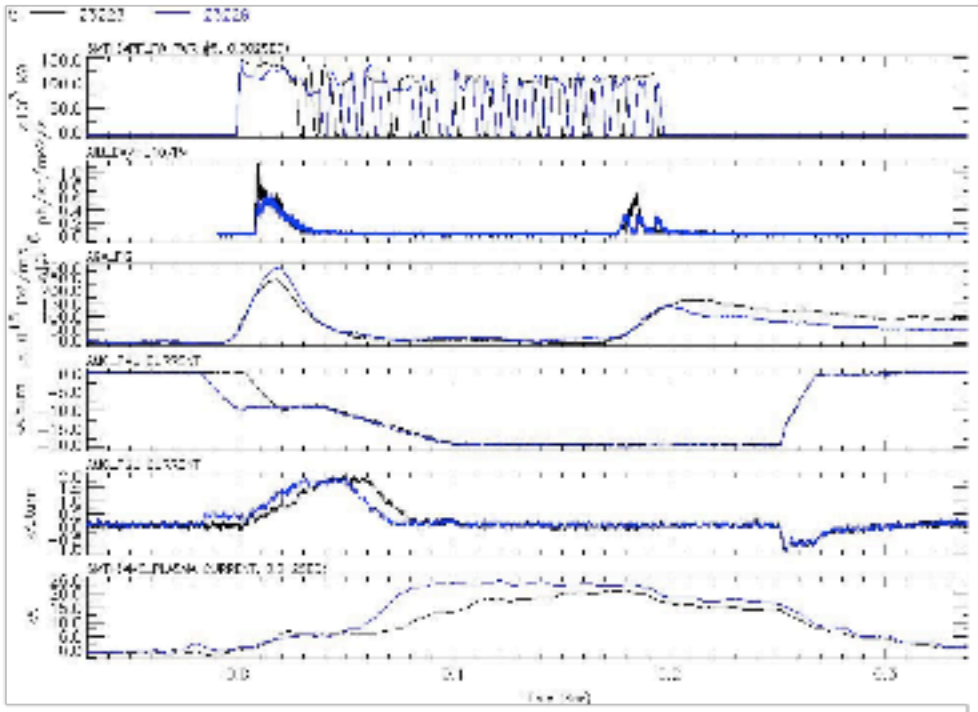
Plasma image at the beginning of 100 kW RF injection. EC resonance and banana orbits of fast electrons are clearly seen.



Plasma image at the end of the RF pulse after additional gas puffing. Closed flux surfaces (CFS) are fully formed.

Main stages of plasma formation are the similar to the previously developed scenarios

Optimized Up-Down Shift



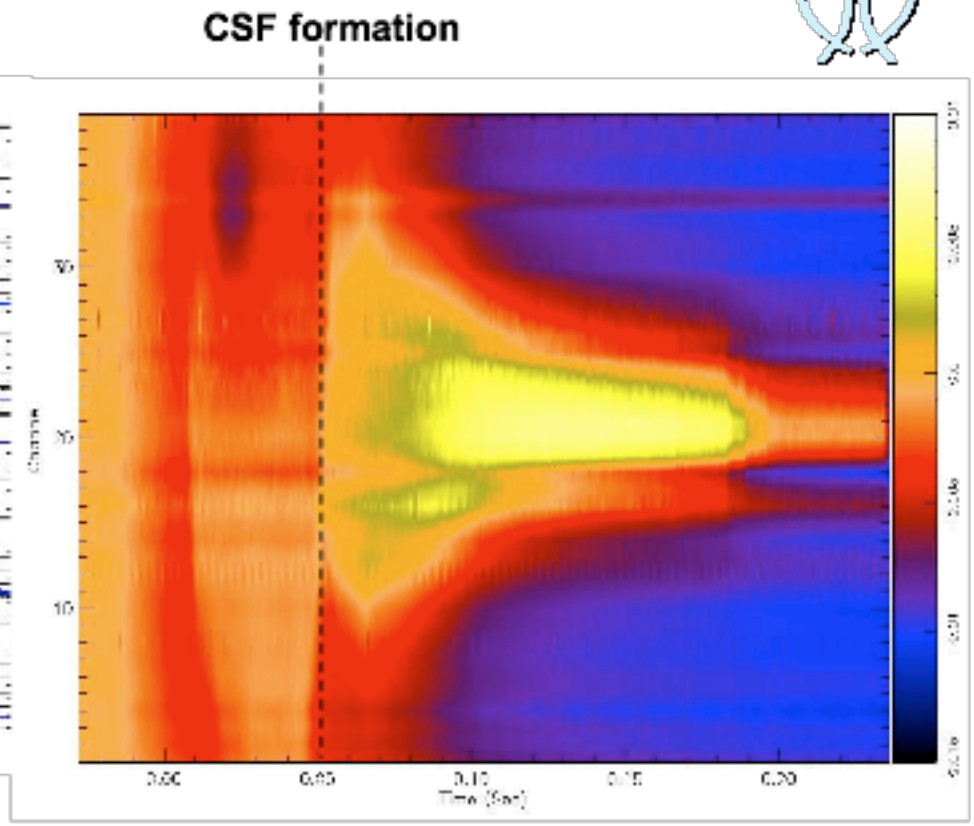


Figure illustrates how critical is the timing of the Up/Down shift for the formation of closed flux surfaces (CFS).

Contour map of the vertical component of the magnetic field measured at the central rod. CFS are formed at ~ 50 ms. Note the structure of the field immediately after CFS formation.

New scenario based on Up/Down shift strategy has been developed with lower Bv and Br

Plans for next operational campaign

- Concentrate on solving the waveguide arcing
- Raise gyrotron power to highest achievable with reasonable reliability
- Operate during “prime” MAST vacuum conditions
- Investigate long-pulse regimes where current & density profiles stabilize

Possible upgrades

- Additional 28 GHz gyrotrons
- Higher power 18 GHz gyrotron
- Outside O-X-EBW launcher