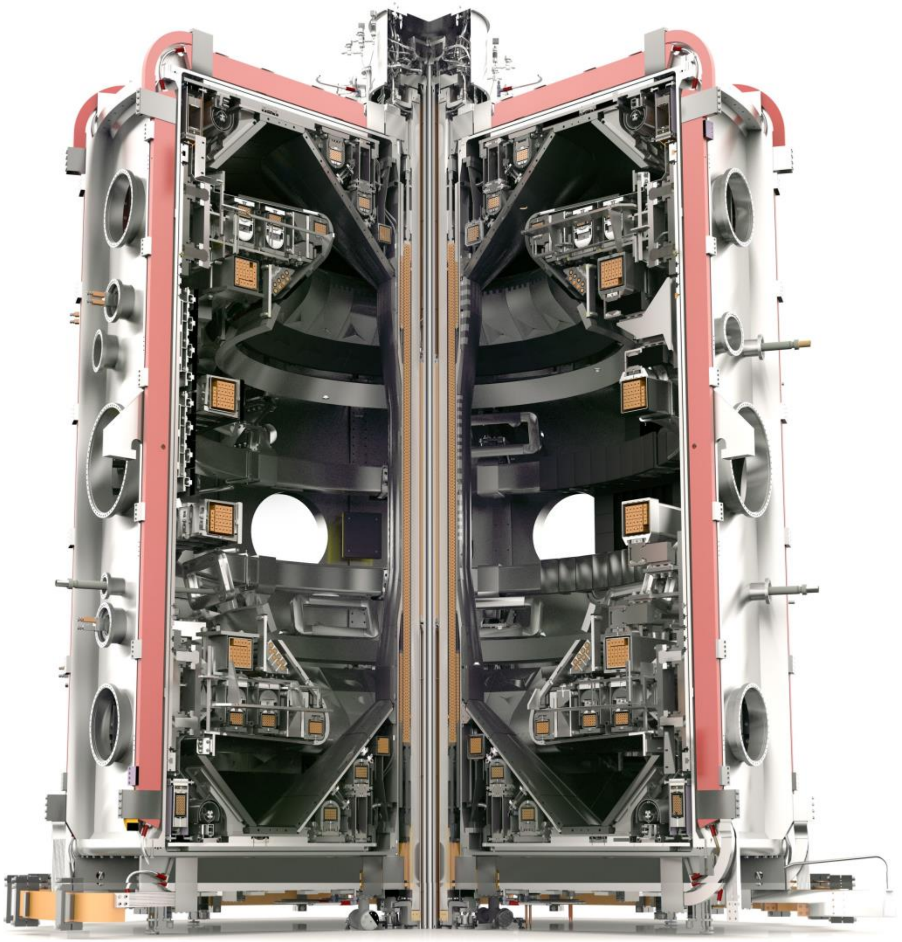
# MAST Upgrade: Status, plans and complementarity with NSTX-U

Andrew Kirk

# Contents

1. Introduction
2. Timeline and project progress
3. 1st physics campaign
4. NSTX-U Complementarity



# MAST Upgrade: Introduction

**Increased TF**
*Improved confinement*

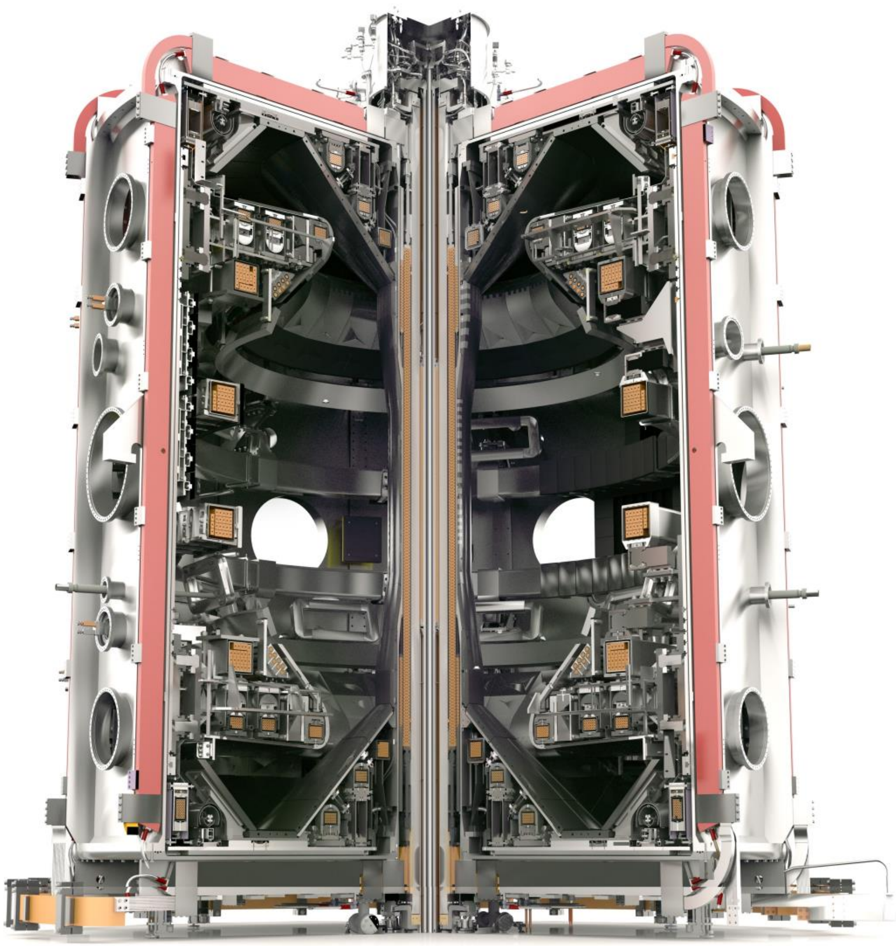
**New Solenoid**
*Greater $I_p$, pulse duration*

**19 New PF Coils**
*Improved shaping*

**Super-X Divertor**
*Improved power handling*

**Off-Axis NBI**
*Improved profile control*

## MAST Upgrade ("core scope")



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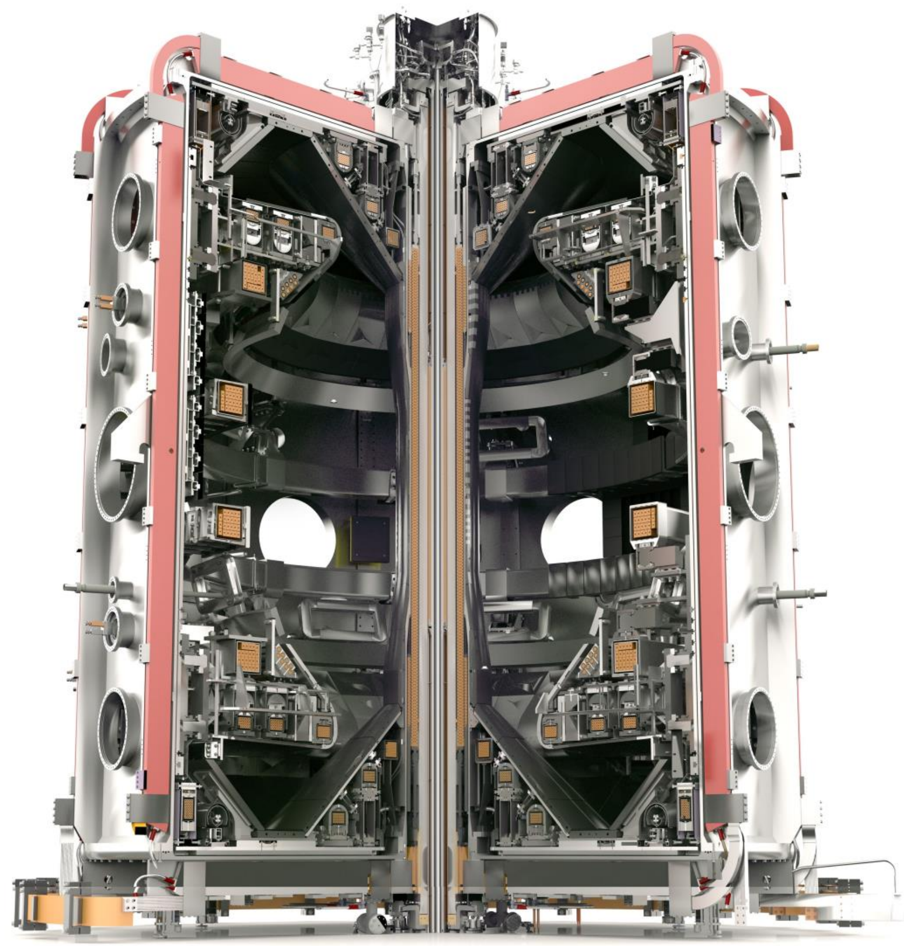
**Cryoplant**
*Divertor particle control*

**Double NBI Box**
*Increased auxiliary heating*

## MAST Upgrade after Stage 1



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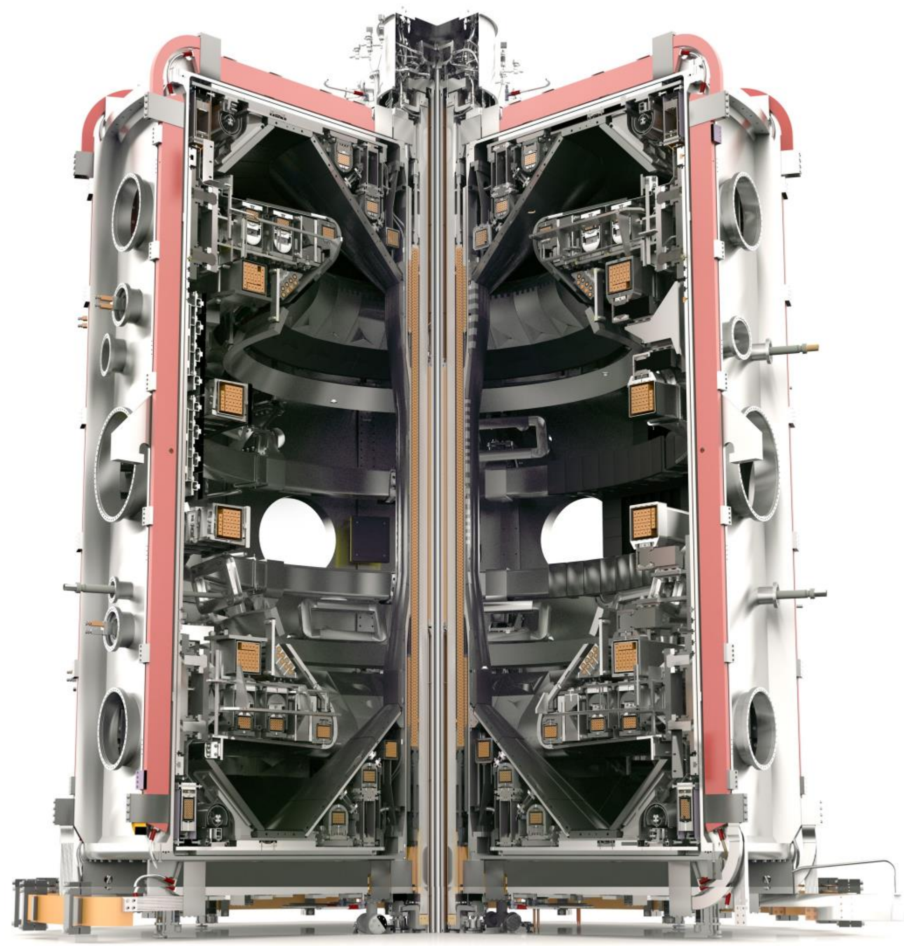
## MAST Upgrade after Stage 2



**4th NBI source** | **EBW** | **Pellet injector**

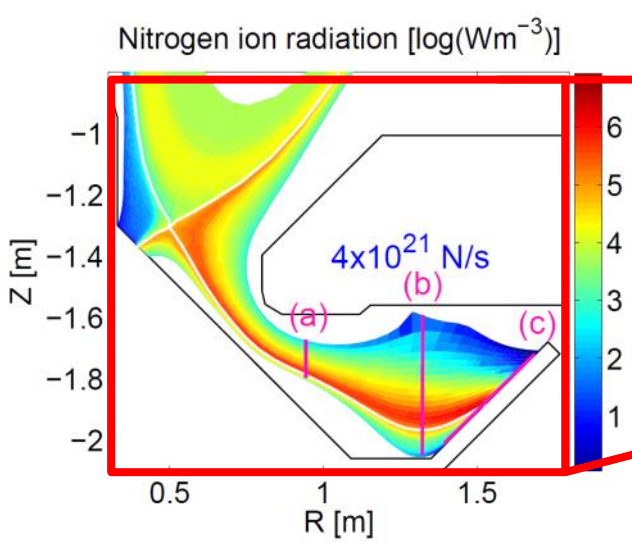
# MAST Upgrade: Introduction

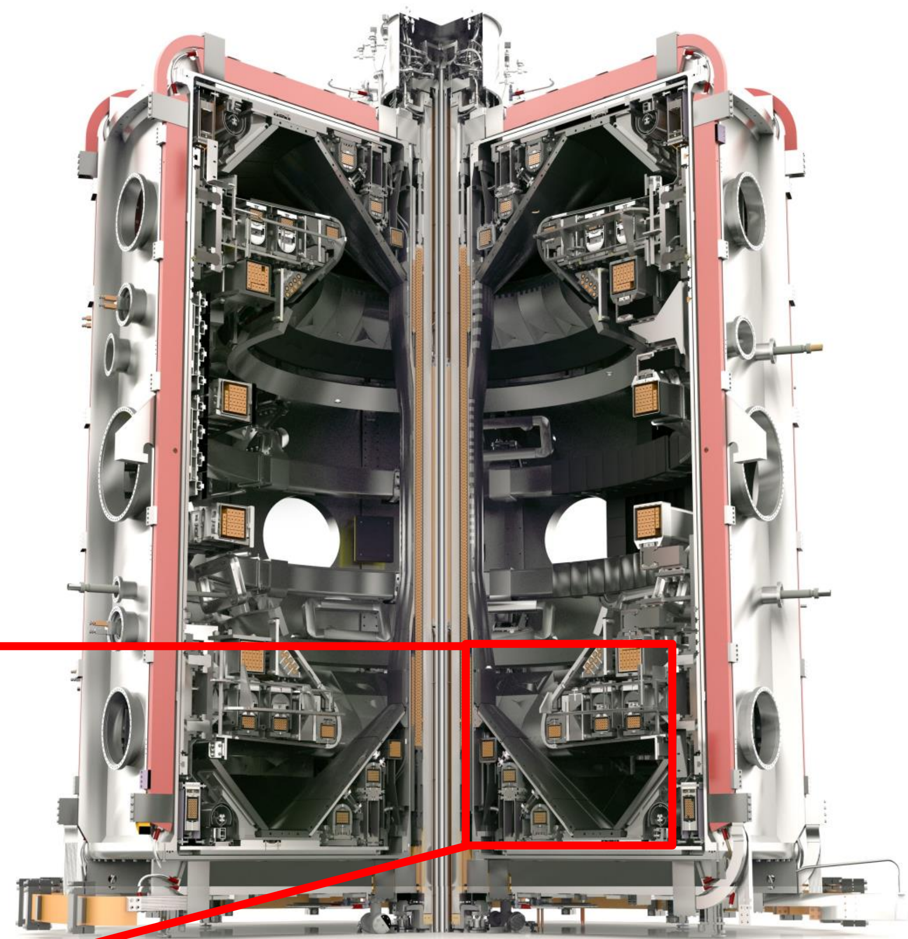
**MAST Upgrade** has 3 primary objectives, namely to contribute to:

1) Developing novel exhaust concepts

2) Knowledge base for ITER
(e.g. understanding and controlling ELMs with 3D fields)

3) Feasibility of spherical tokamak as fusion Component Test Facility

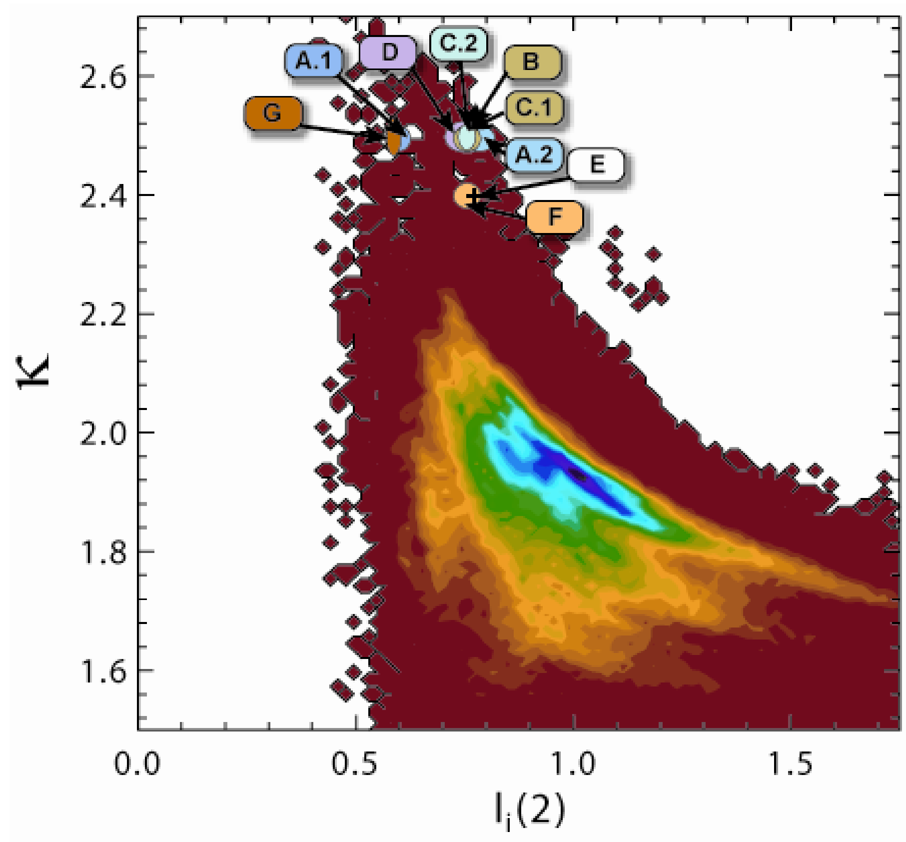


# MAST Upgrade: Introduction

- MAST-Upgrade will have expanded operational space
  - Maximum plasma current increased from 1.3MA to 2.0MA
  - Lower main chamber neutral pressure
    - Lower $n_e$, higher $T_e$ edge pedestal
  - Higher elongation, triangularity

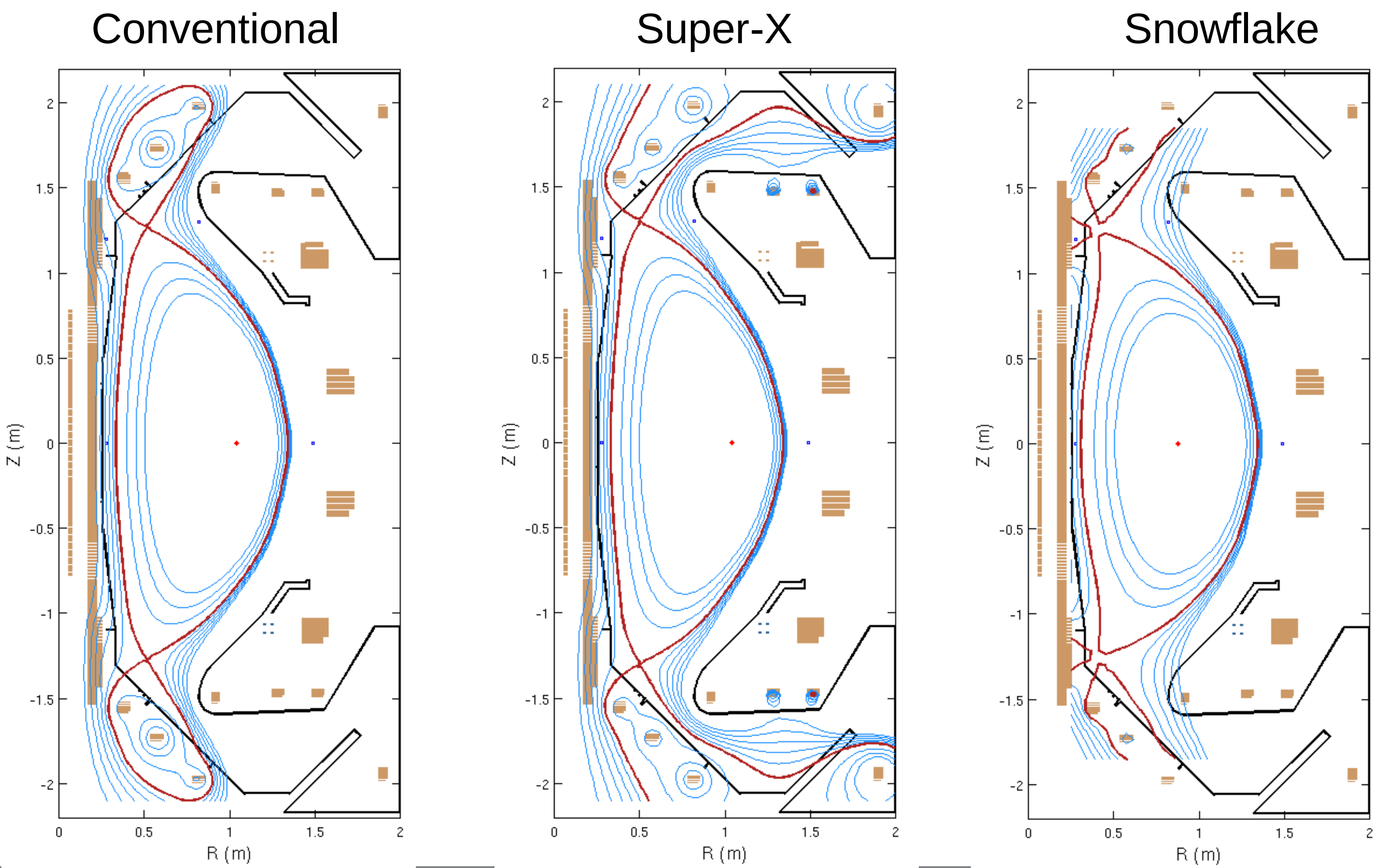
- Very flexible magnetic geometry
  - “Conventional”, Super-X and snowflake divertor configurations possible



CCFE CULHAM CENTRE FOR FUSION ENERGY

# MAST Upgrade: Introduction

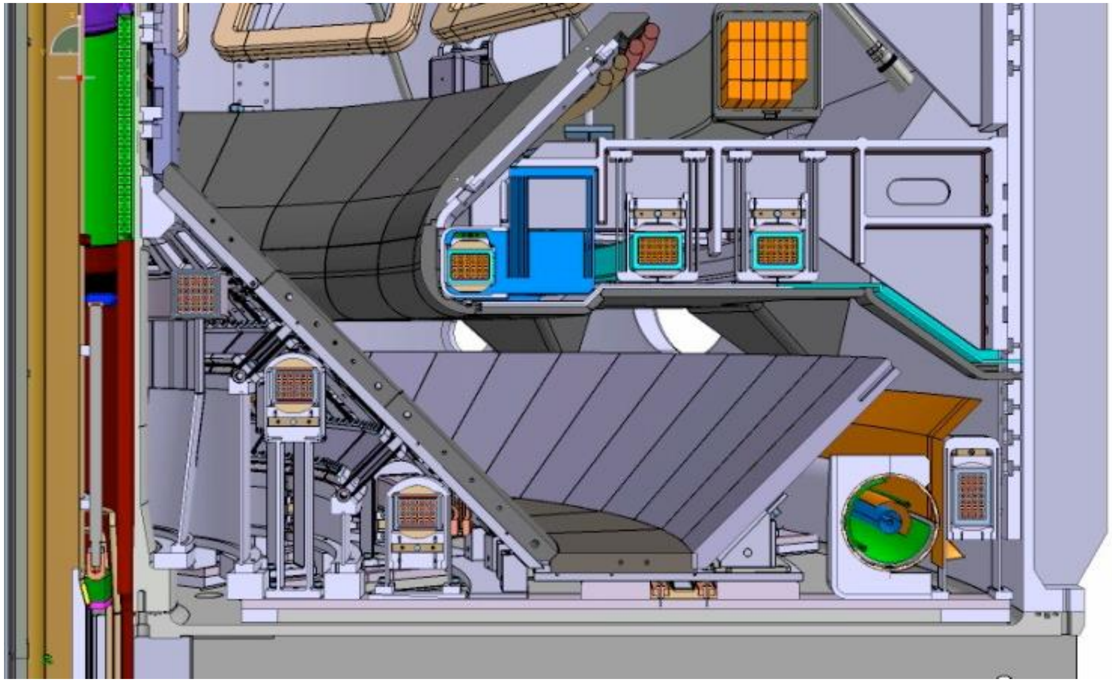
Flexible poloidal field coil set allows for a wide variety of magnetic geometries



# MAST Upgrade: Introduction

- Divertor physics programme will focus on studying the Super-X divertor configuration*
  - Larger $R_{div} \rightarrow$ larger wetted area
  - Lower poloidal field in divertor $\rightarrow$ larger $L_{||}$
  - Lower toroidal field in divertor chamber $\rightarrow$ lower $q_{||}$

} Larger SOL volume



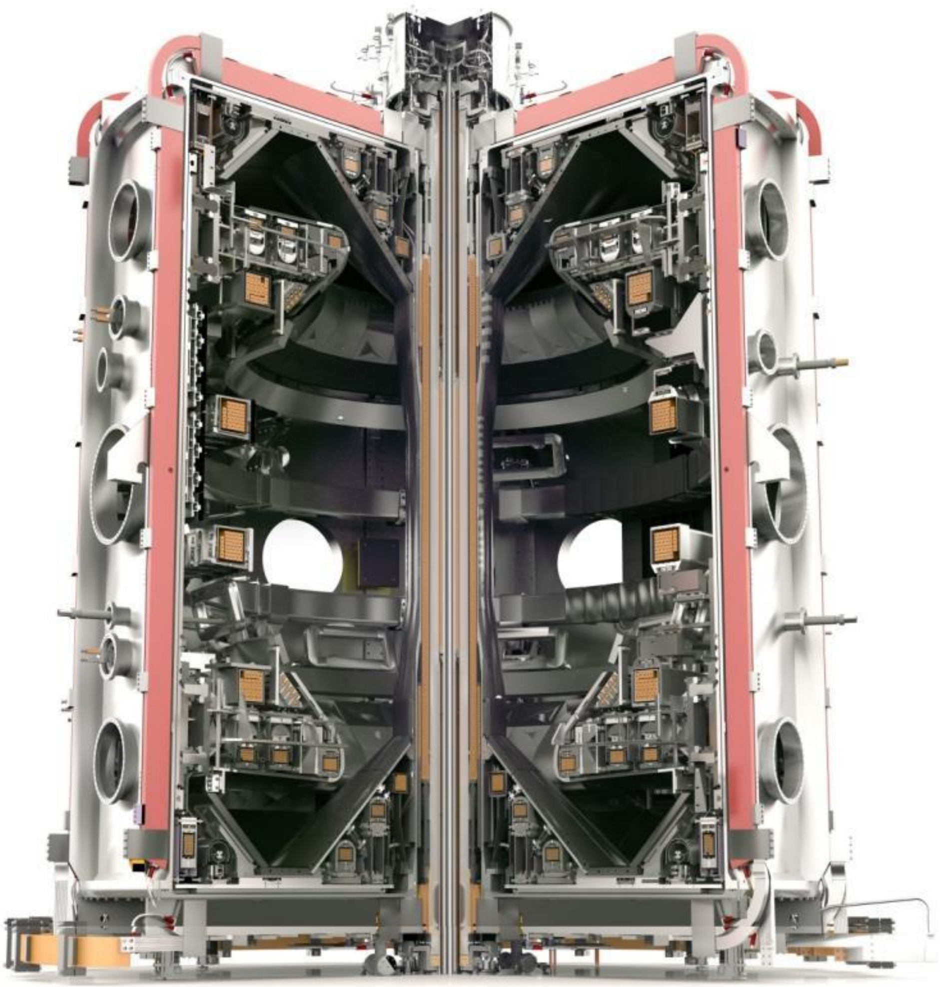
*Valanju et al., Phys. Plasma 16, 056110 (2009)

# MAST Upgrade: Introduction

MAST Upgrade Overview:

| Parameter / System | Upgrade |
|---|---|
| Toroidal Field | Increased from 0.5 to 0.8T (at R = 0.8m) |
| Plasma Current | Increased from 1MA to 2MA |
| Pulse Length | Increased from 0.5 to 5s |
| In-vessel Coils | Increased from 10 to 20 |
| Ex-vessel PF  Coils | Increased from 1 to 4 |
| NBI injection | 2 on-axis beams reconfigured to 1 on-axis, 1 off-axis |
| Divertor | Fully reconfigured for advanced scenario operation |

=> Result, 90% of the Load Assembly is new (only vacuum vessel and a few coils re-used)



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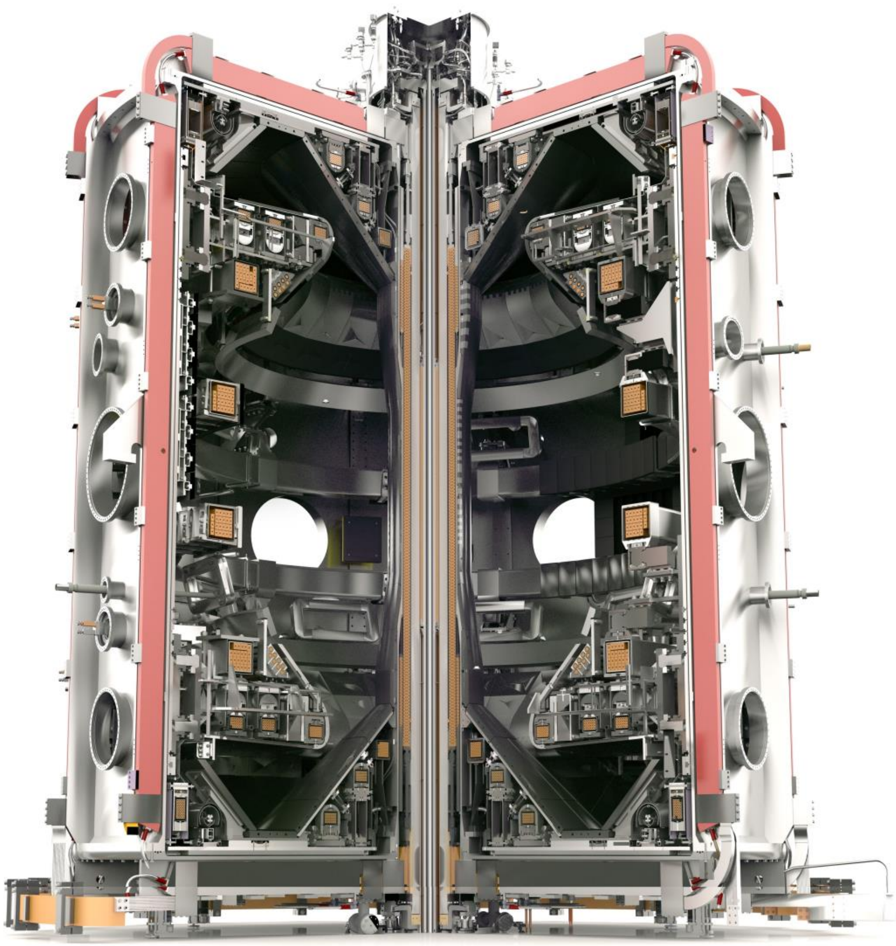


# Timeline

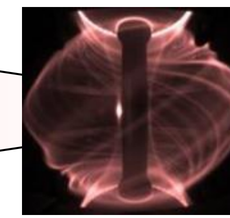
*Conceptual Design*

*Scheme Design*

*Detailed Design*

*Construction*

*2008 2009 2010 2011 2012 2013 2014 2015 2016 2017*



*Jan 2008, MAST-U + Super-X Divertor, Scoping studies and Conceptual Design started*

*April 2010, MAST-U Construction Approved*

*Oct 2013, MAST Operations finish, Strip out starts*

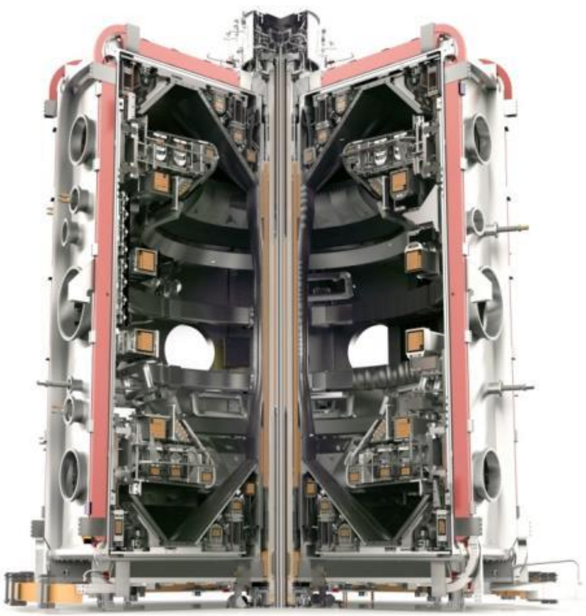
*March 2014, MAST-U rebuild underway*

*Dec 2016, Based on revised budget latest Pump down projection, Start of Integrated commissioning*

*Mid 2017, First MAST-U Plasma*

# Progress Summary

## MAST-U Load Assembly - Modular Construction



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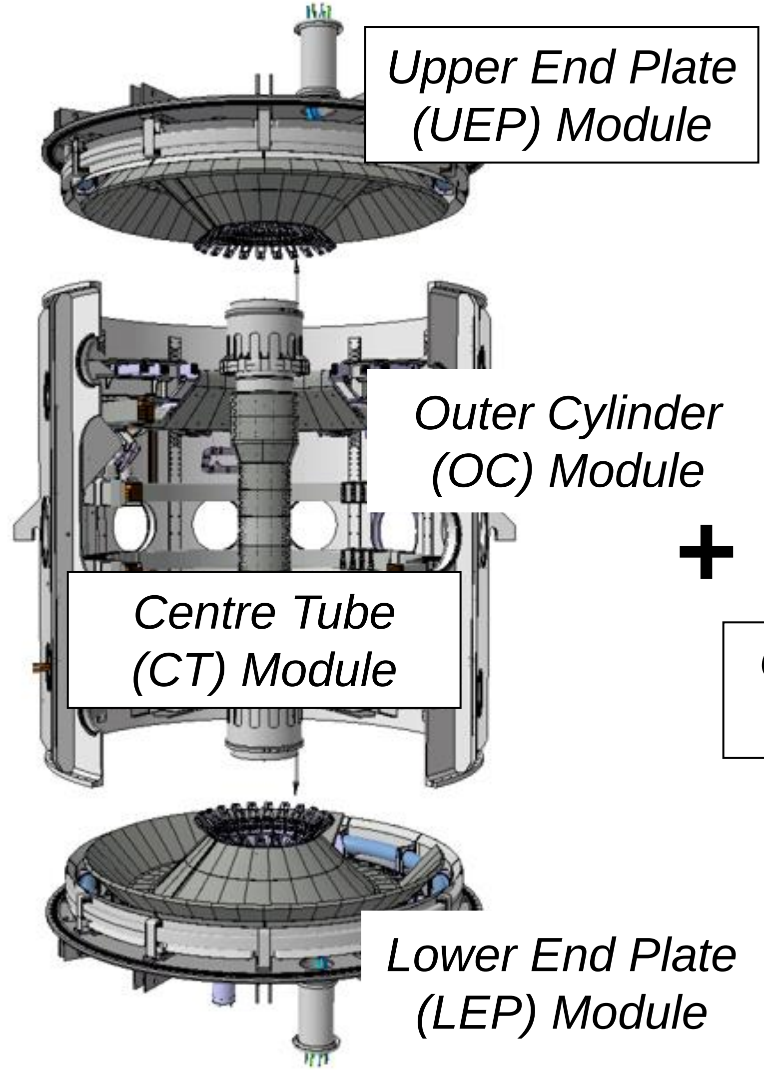


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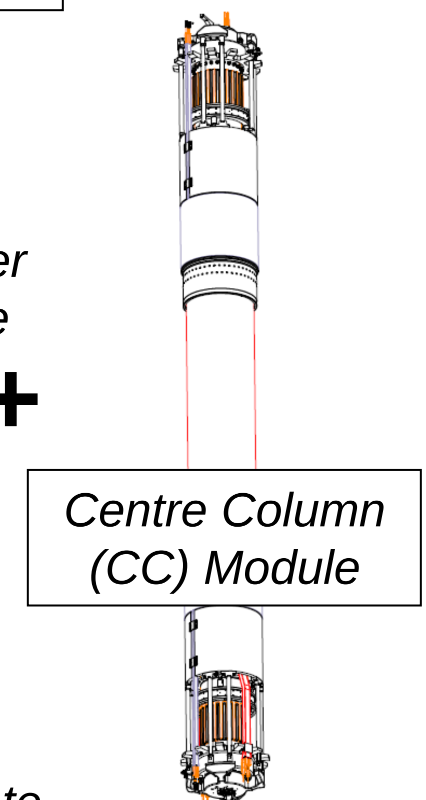


# Build Progress

Lower divertor cassette - 90% complete

Centre tube module - 40% complete

# Build Progress

Lower end plate - 40% complete

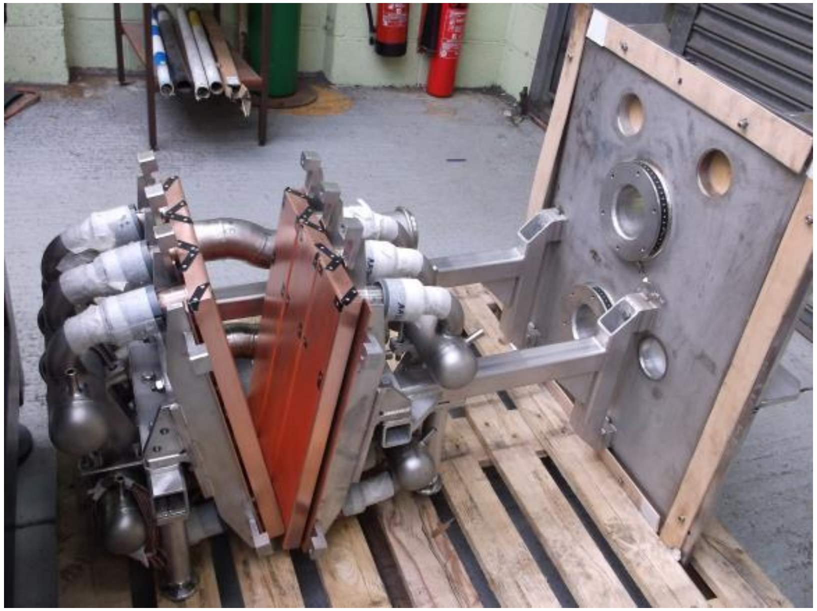
Solenoid - complete

# Build Progress


Outer cylinder –
PF coil and embedded diagnostics - 75% complete

# NBI Progress

NBI bend magnets
– 80% complete



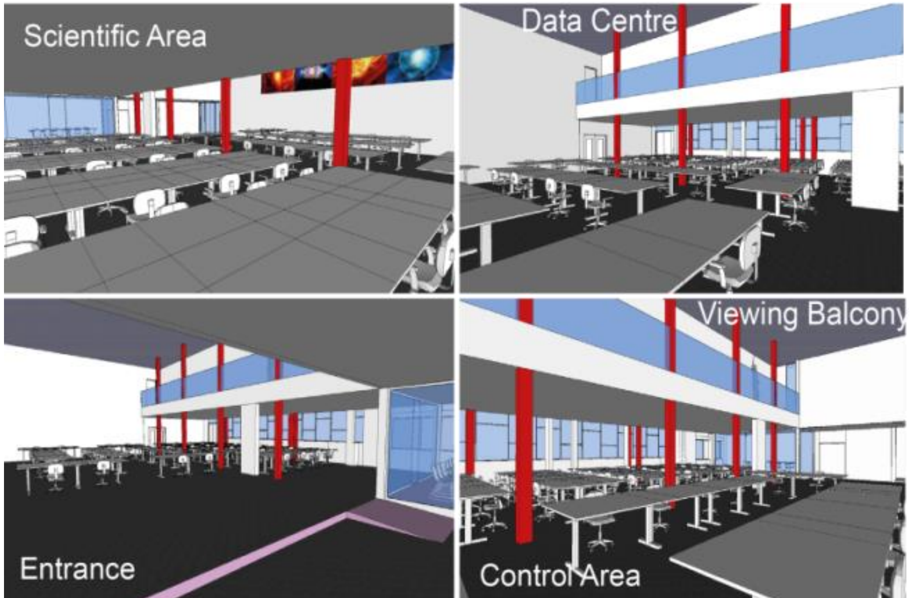
NBI ion dumps
– 80% complete

# Power supplies

Toroidal field power supplies
– Installed and ready for local commissioning

Poloidal field and divertor power supplies
– Installation 75% complete

# New control room




Construction underway

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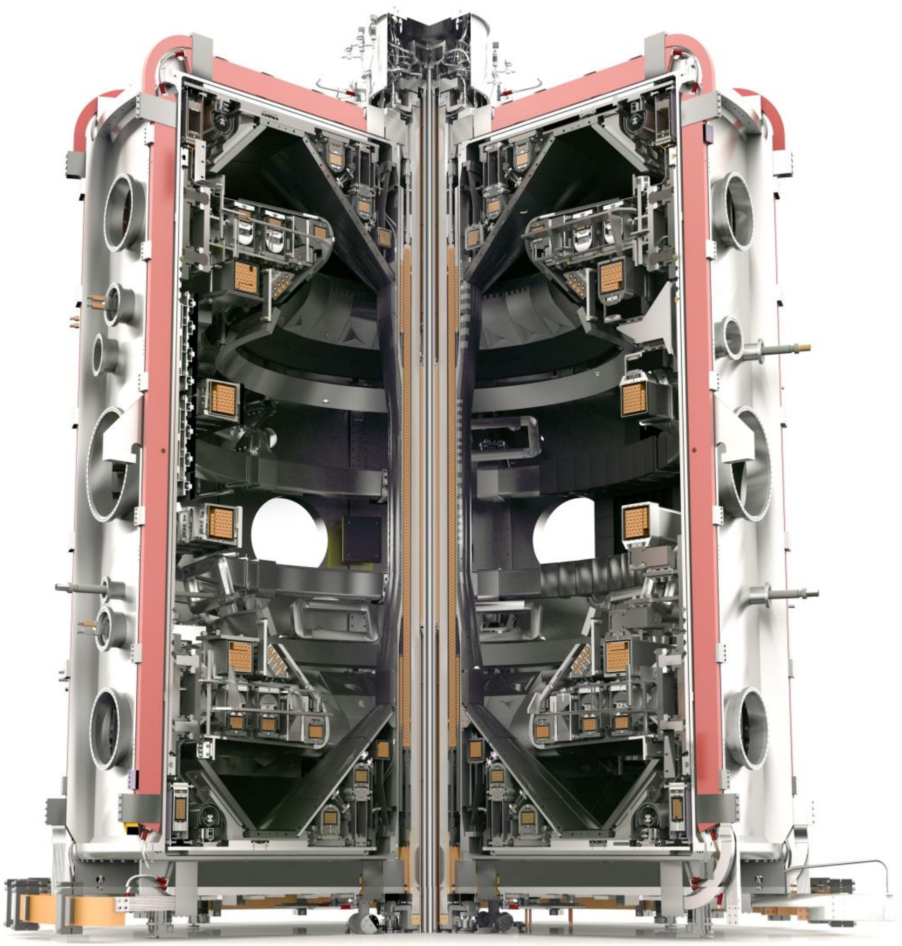


# $1^{st}$ campaign operating constraints

- Water cooled centre column reduces $I^2t$

  P1: $I^2t$ = 1500 $kA^2s$ (3000 $kA^2s$ Galden)

  TF: 40 000 $kA^2s$ (50 000$kA^2s$ with Galden)
  -> pulse duration ~ 1.8s (based on MAST scenarios)
  However likely that it will be core MHD (q<1) that will limit shot duration

- Coil current limits to avoid lifetime limiting shots during $1^{st}$ campaign
  P1 current limit +/- 45 kA (55kA max)
  TF current = 100 kA (135 kA max)

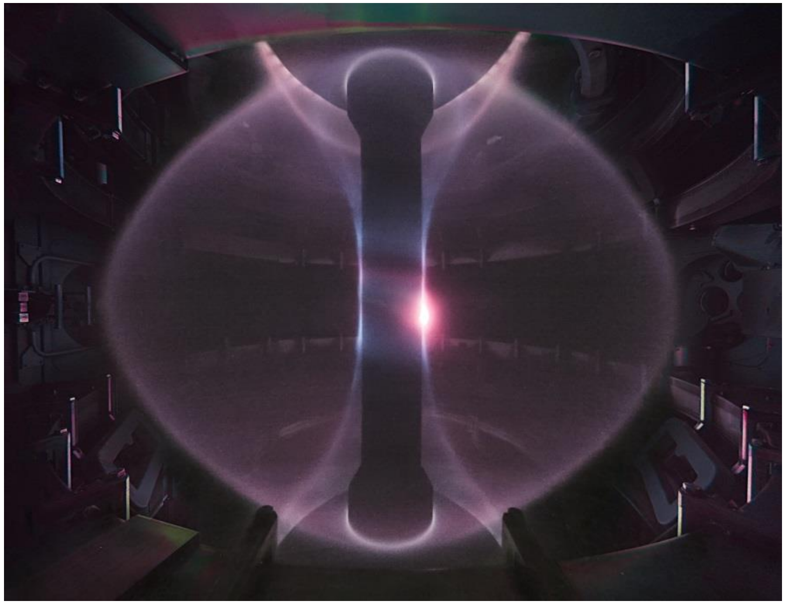
- NBI power supply and machine protection limits
  NBI pulse length 2s
  NBI power/PINI 2 MW

- No Cryoplant
  Non stationary density

# Diagnostics

Plan to have similar set of diagnostics as on MAST available at Day 1

- MAST-U will retain diagnostic capabilities
  - 130 point, ~1cm resolution Thomson scattering
  - Extensive beam spectroscopy
    - Charge-exchange recombination spectroscopy
    - Motional Stark Effect
    - Fast Ion $D_\alpha$
  - Wide-angle high speed imaging

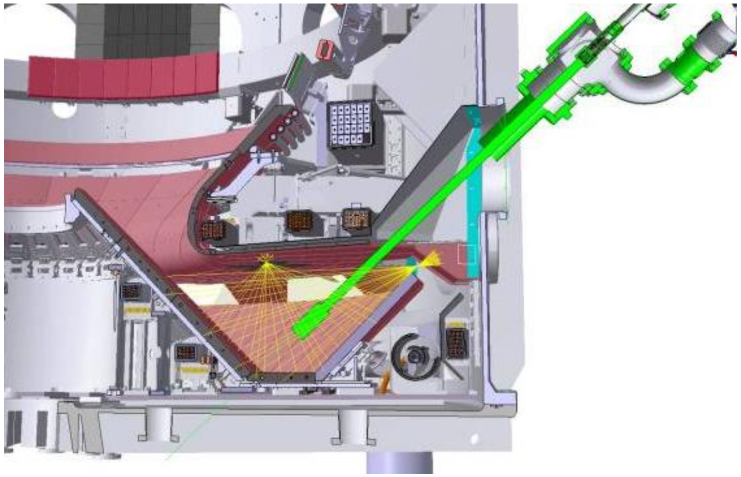


- Divertor diagnostics will be extended and enhanced

# New Divertor Diagnostics

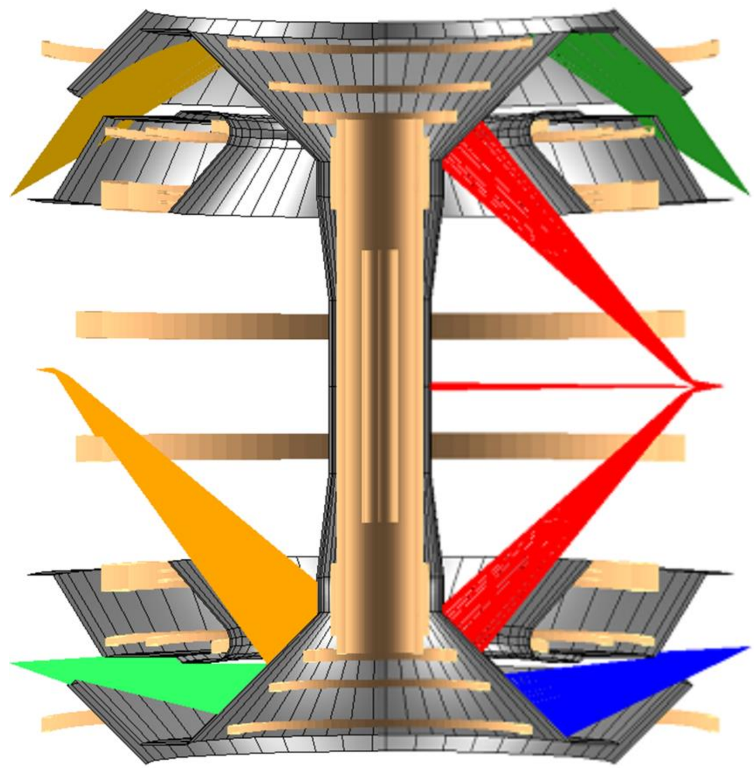
- Extensive Langmuir probe coverage
  - Strike points will be monitored in a wide range of magnetic configurations
- Thomson scattering will be used to measure $n_e$, $T_e$ in the divertor chamber
  - Measurements at 16 locations along laser path
  - Monitor parallel pressure balance $\rightarrow$ detachment physics
  - Benchmarking Langmuir probes and spectroscopy
- Radiated power in main chamber and divertor will be monitored using gold foil bolometer arrays
  - 32 channels in main chamber
  - 32 channels in divertor

# New Divertor Diagnostics



Divertor reciprocating probe will be used to measure fluctuations in the Super-X divertor chamber

Divertor strike points will be monitored by IR and filtered visible cameras



# Priorities for first physics campaign

Experimental proposals in the following two areas will be given priority for the first physics campaign

**Scenario development:**

MAST-U is effectively a new machine and so we will need to establish new scenarios that can be used by other areas.

Need to understand

1) intrinsic error fields in MAST-U
2) H-mode access in conventional and Super-X divertor configuration
3) on vs off-axis neutral beam heating and current drive

**Exhaust:**

Experiments that exploit the new features in MAST-U namely a closed conventional divertor allowing detachment studies and experiments comparing a super-X and conventional divertor configuration.

In addition to involvement in these areas, in future campaigns there are a wide range of other topics that we would welcome collaborators to lead

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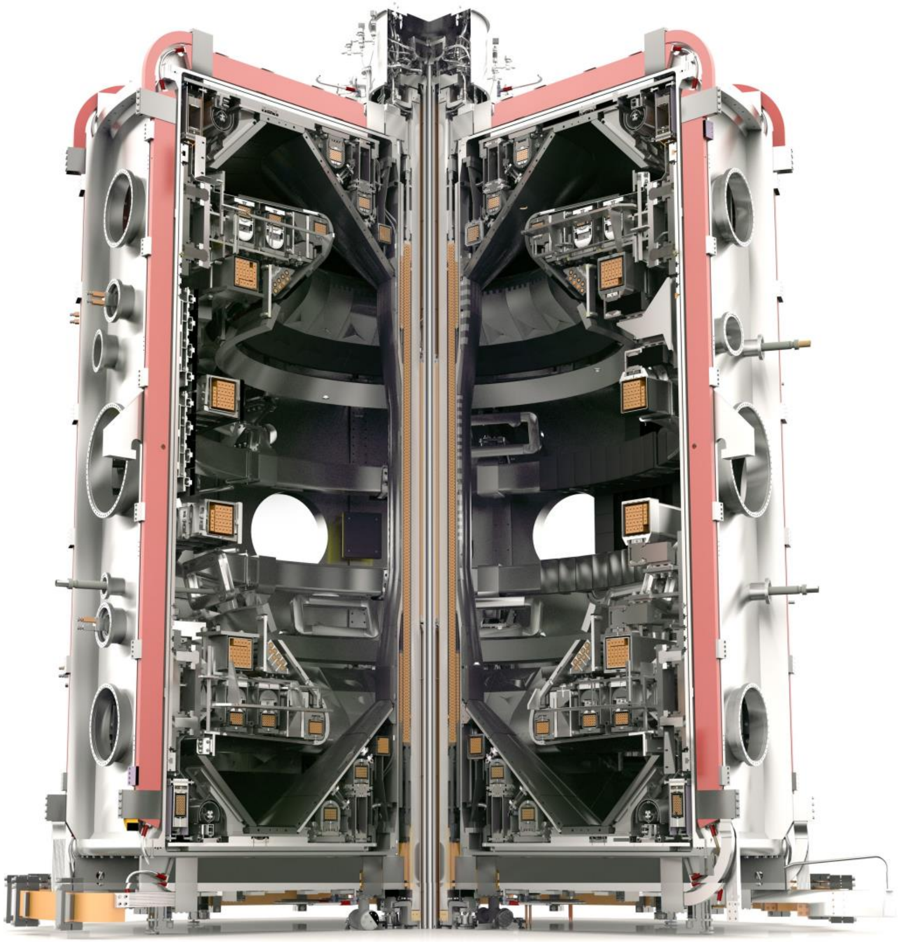

# Participation in NSTX-U

In 2015 involvement will have to be limited due to budget restrictions, however, we will bid for EuroFusion funds for further experiments in 2016

For 2015 we would like to propose experiments on

1) Joint pedestal experiment on the effect of seeding on pedestal structure (Beurskens, Giroud, Saarelma and Leyland)

2) Scenario development – restart studies

For 2016 we would like to discuss involvement in fast particle studies

# Opportunities for collaboration

Due to a restructuring of priorities at CCFE we are seeking an ever increasing contribution from external collaborators, many of which would be greatly improved with comparisons on NSTX-U , some ideas are:

**Core turbulence:** Turbulence studies, exploiting the higher field and the upgraded BES system and a possible DBS system.

**Fast particle physics:** effect of on and off-axis beams on TAE drive, fishbones etc using improved diagnostics including a Fast ion loss detector

**Rotation studies:** NTV studies using in vessel RMP coil set

# Summary

• MAST-U build now well underway
  - some delays due to technical and budget issues
  - first plasmas due mid 2017

• The machine will offer many interesting divertor configurations
  - super-X, conventional, snowflake

• Many similarities with NSTX-U, which we think should be exploited and we welcome collaborators to lead some of the research activities