A Charged Fusion Product Diagnostic for a Spherical Tokamak

Proposal Defense

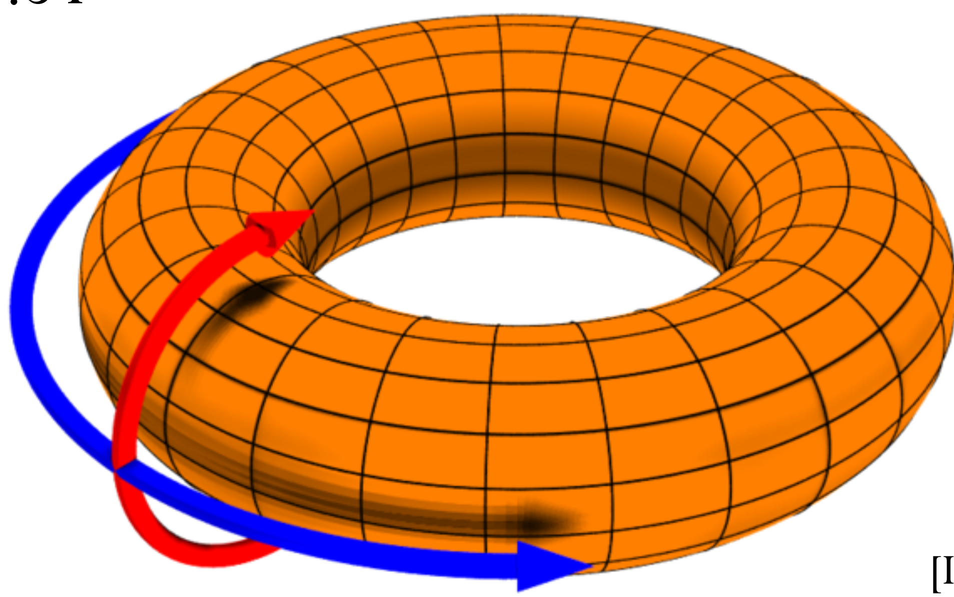
Ramona V Perez

Outline

1. Background
2. Experimental Design
   1. Mechanical Design
   2. Simulations
   3. Electronic & Data Acquisition Design
3. Data Collection
4. Data Analysis
5. Timeline

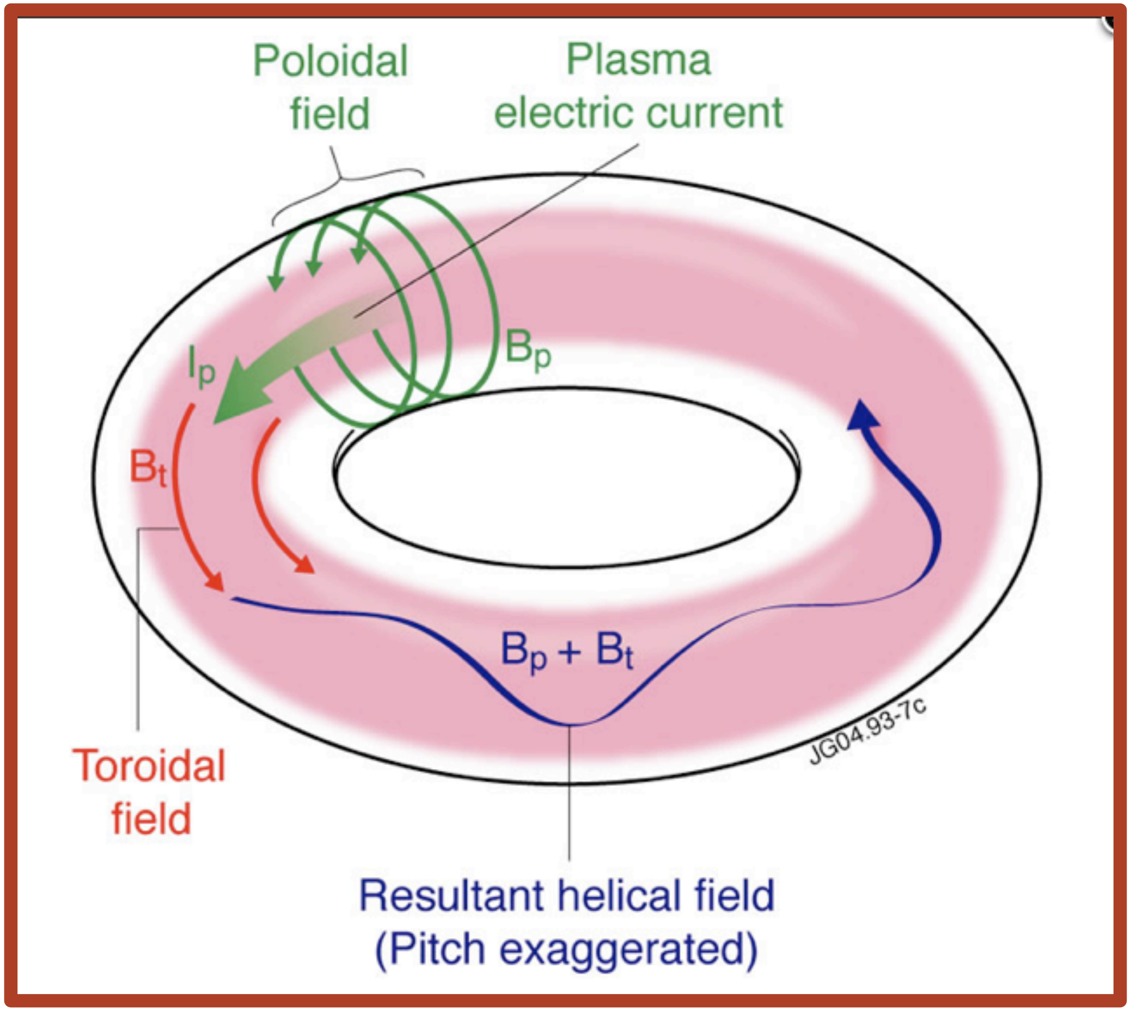
Confined Plasma

- Poloidal & toroidal direction
- Temperature 10^8 K
- Magnetic field .5T

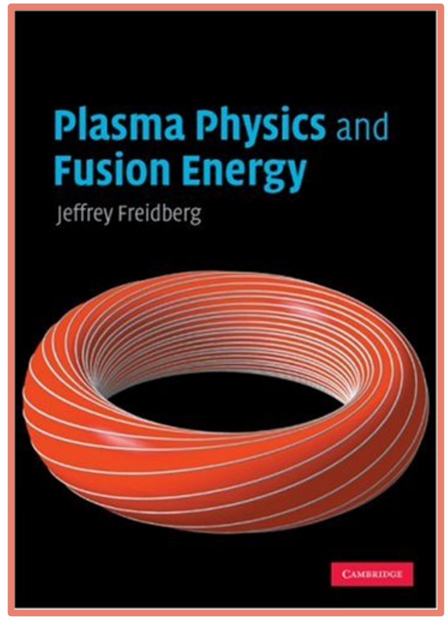


[Image 1]

Confined Plasma

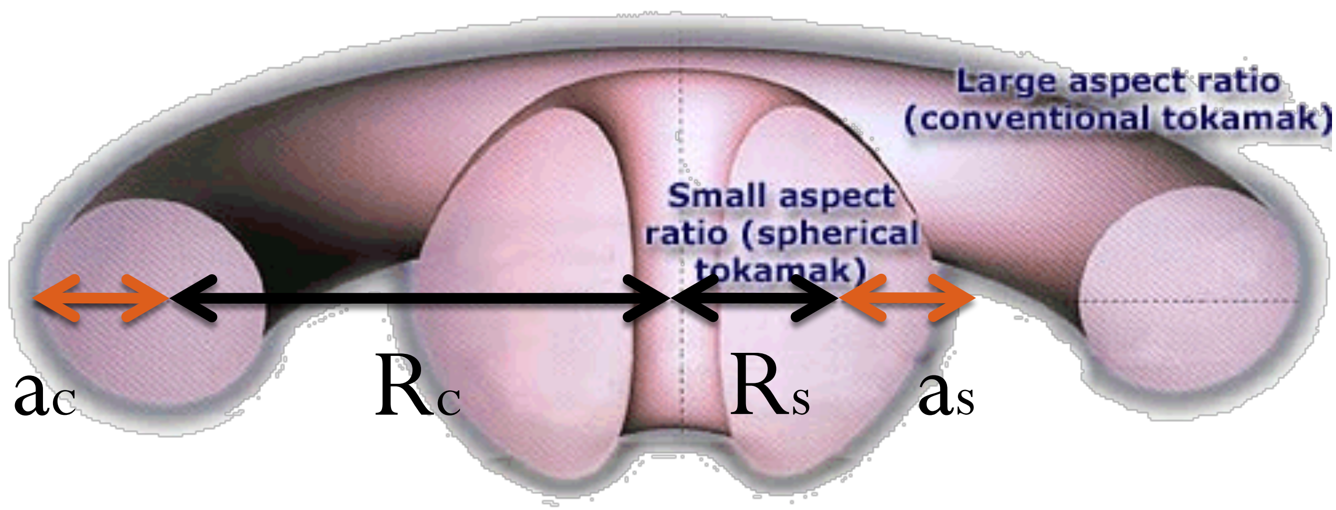


[Image 2]



[Image 3]

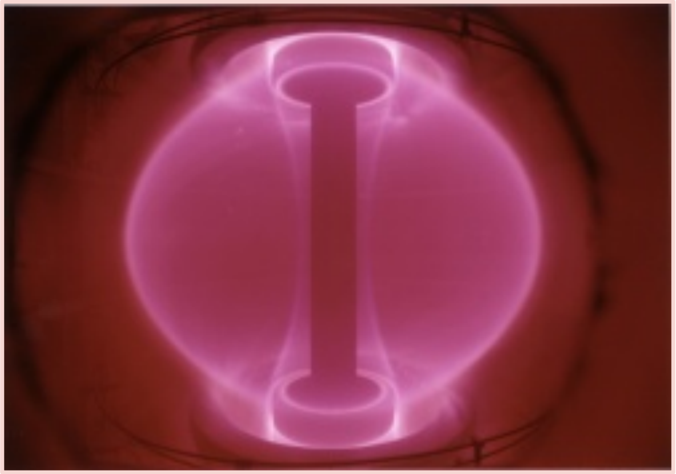
Spherical Tokamak



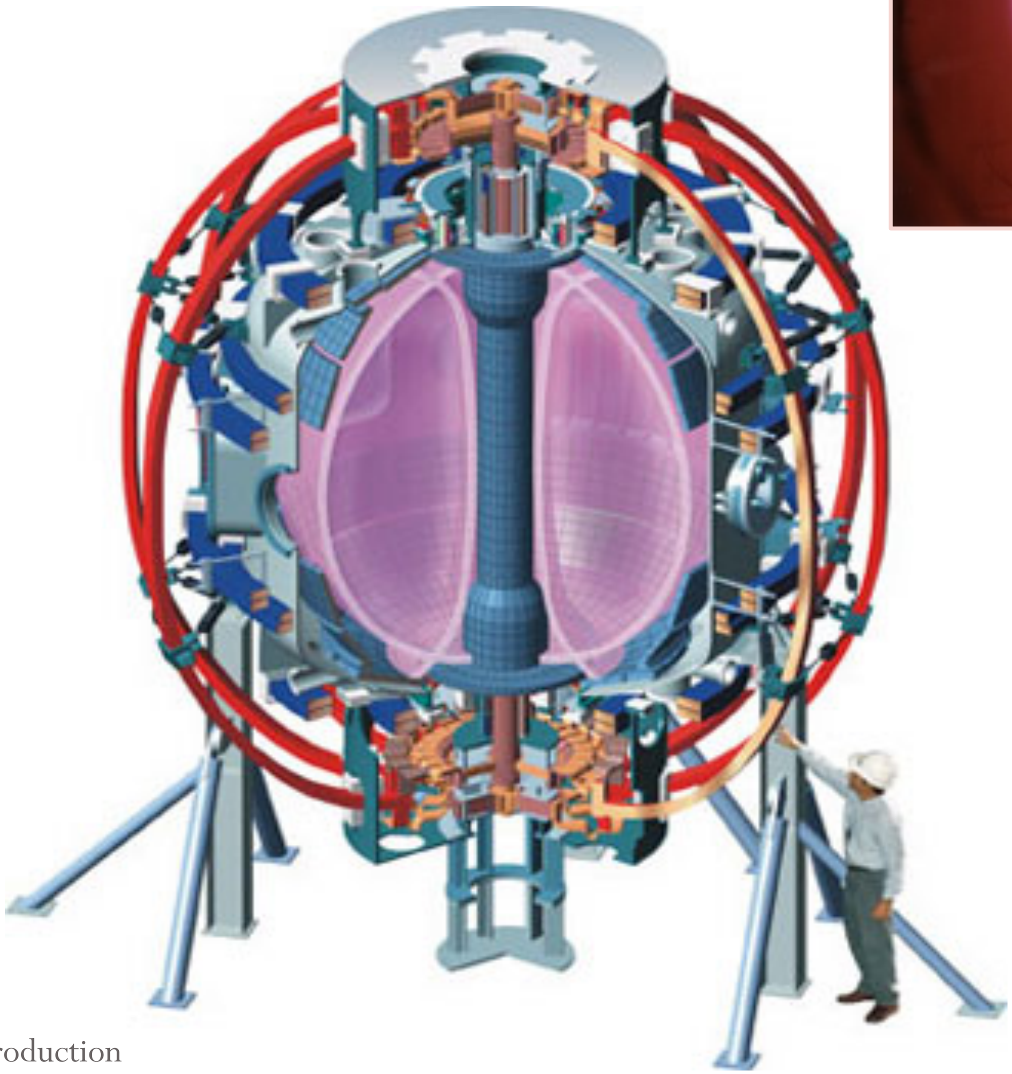
Aspect Ratio: R/a

[Image 4]

NSTX and MAST

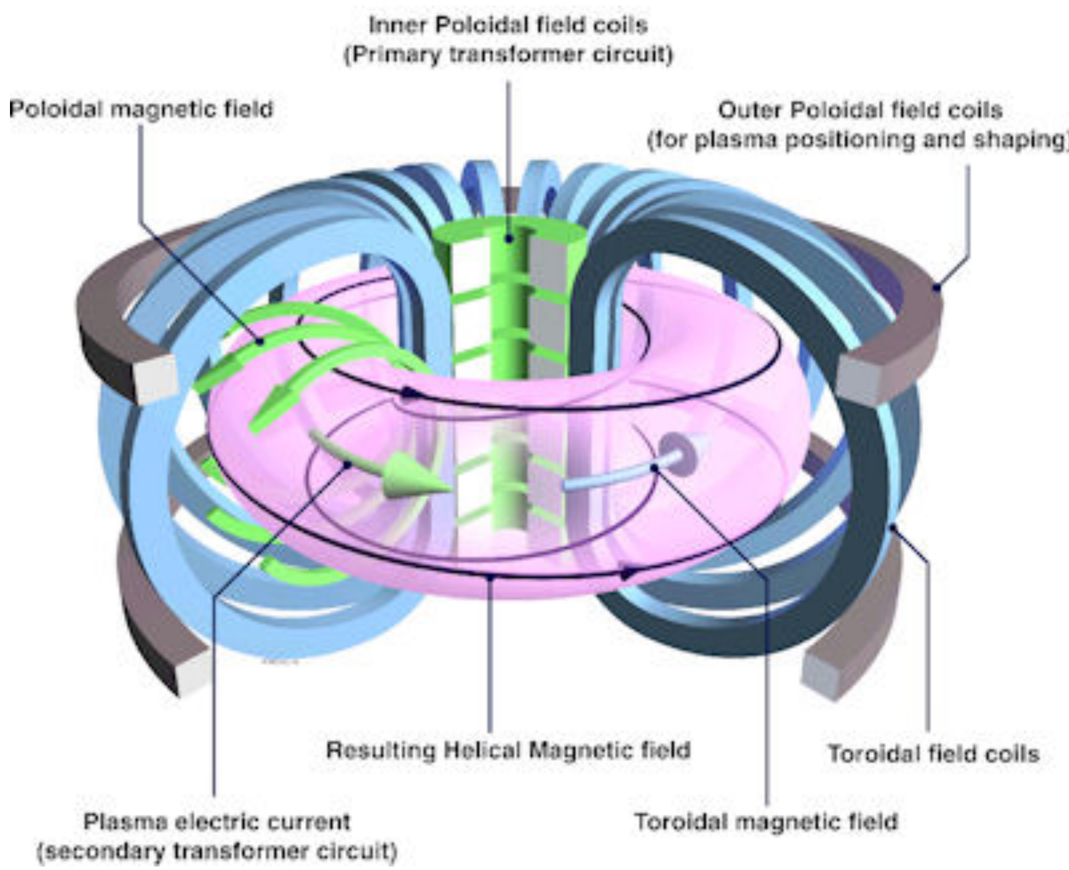


[Image 6]



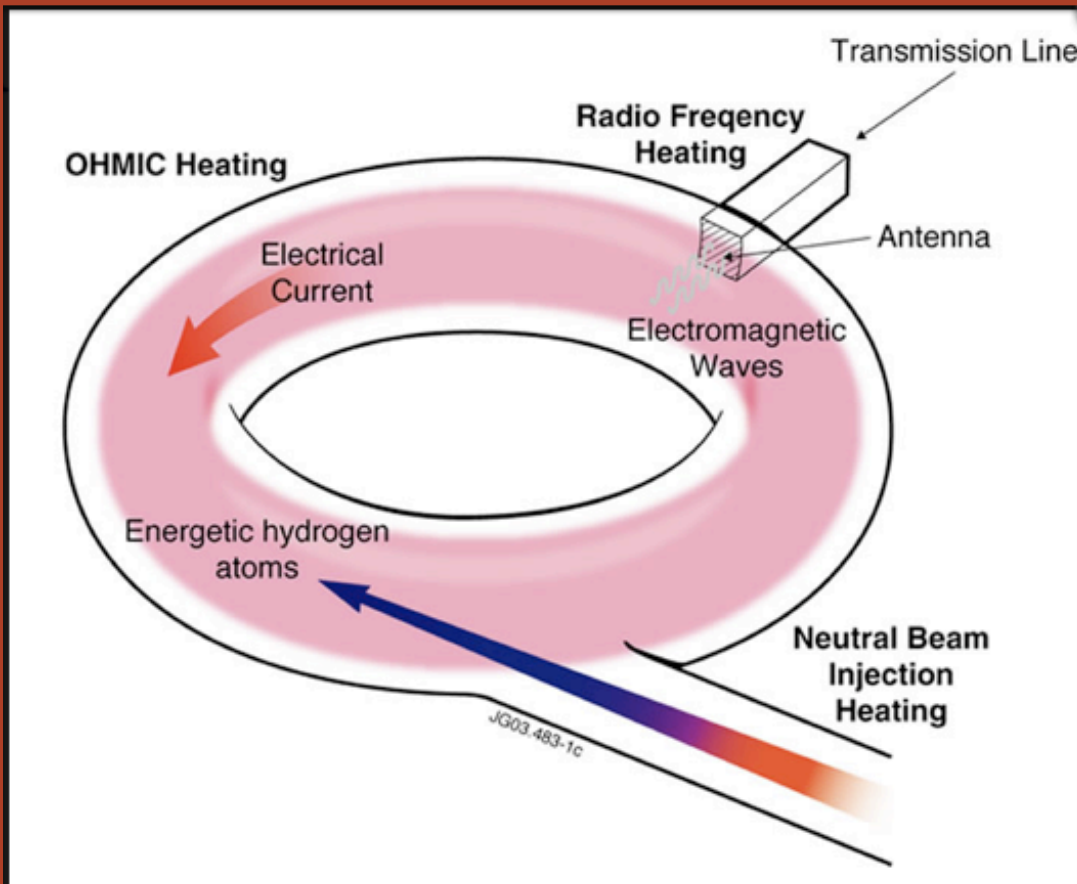
[Image 5]

Tokamak Field Coils



[Image 7]

Heating Methods



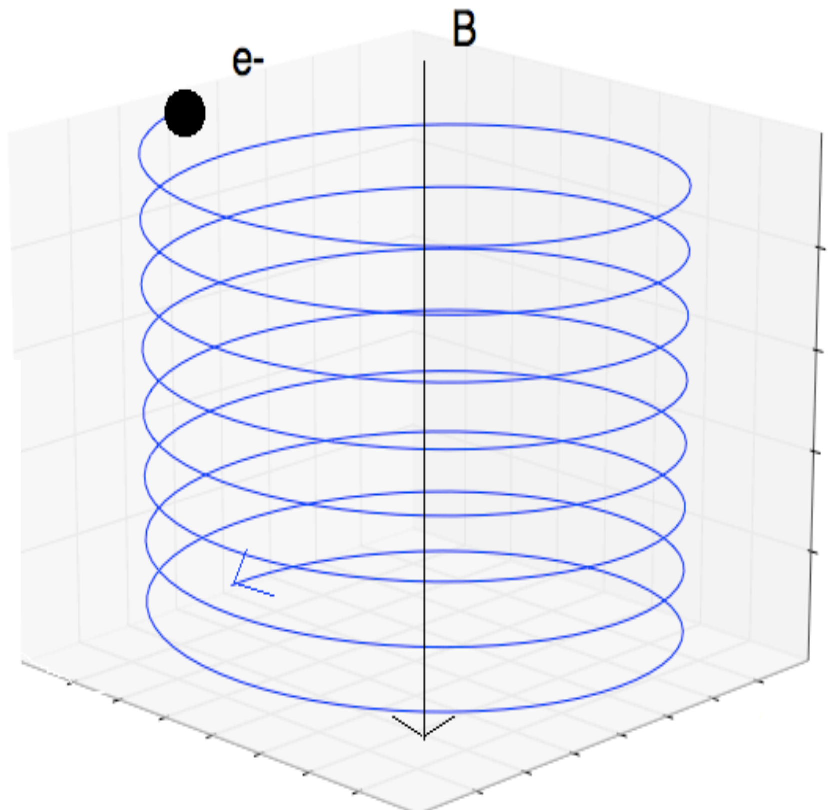
- Ohmic heating (induced current)
- **Neutral-Beam Injection (NBI)**
- Radio Frequency (RF) (oscillating electromagnetic waves)

[Image 8]

Particle Motion

- How do particles move in these magnetic fields?

$$Radius_{gyro} = \frac{mv_{\perp B}}{|q|B}$$



Fusion Reactions

- Primary reactions

  $D + D \rightarrow P(3MeV) + T(1MeV)$

  $D + D \rightarrow He^3(0.8MeV) + N(2.5MeV)$

- Secondary reactions

  $D + T \rightarrow N(14.1MeV) + \alpha(3.5MeV)$

  $D + He^3 \rightarrow \alpha(4.6MeV) + P(13.7MeV)$

DD Reaction

- Energy investment to facilitate nuclear reactions

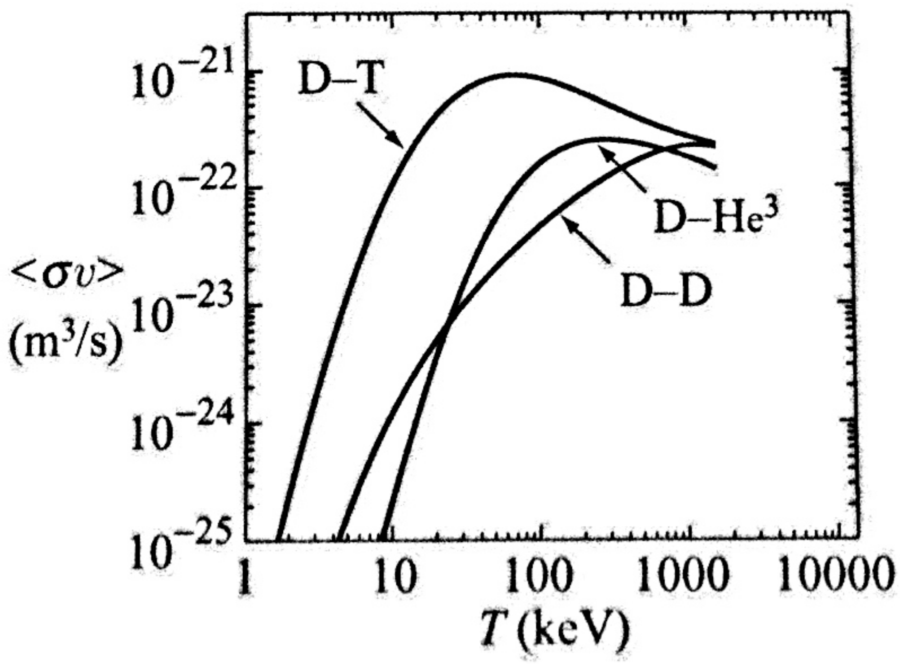


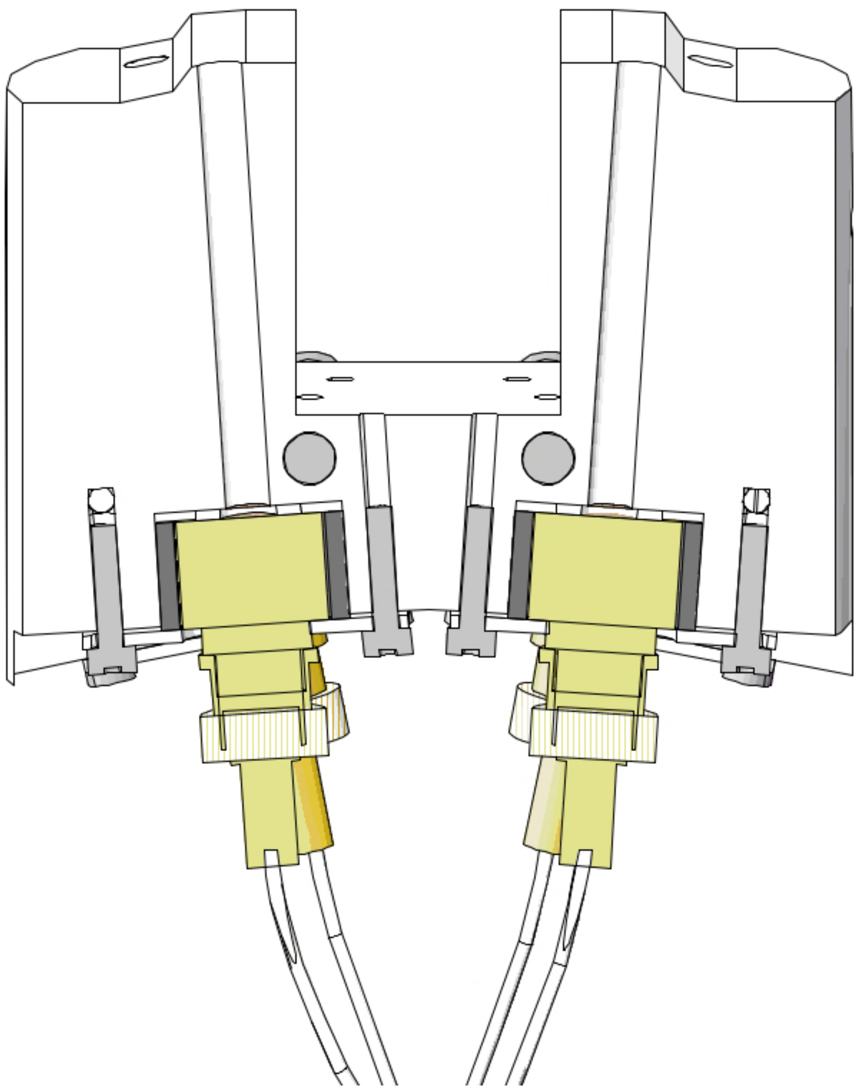
Figure 3.11 Velocity averaged cross section (i.e., $\langle \sigma v \rangle = R_{ij}/n_i n_j$) for the D–T, D–He^3, and D–D fusion reactions as a function of temperature.

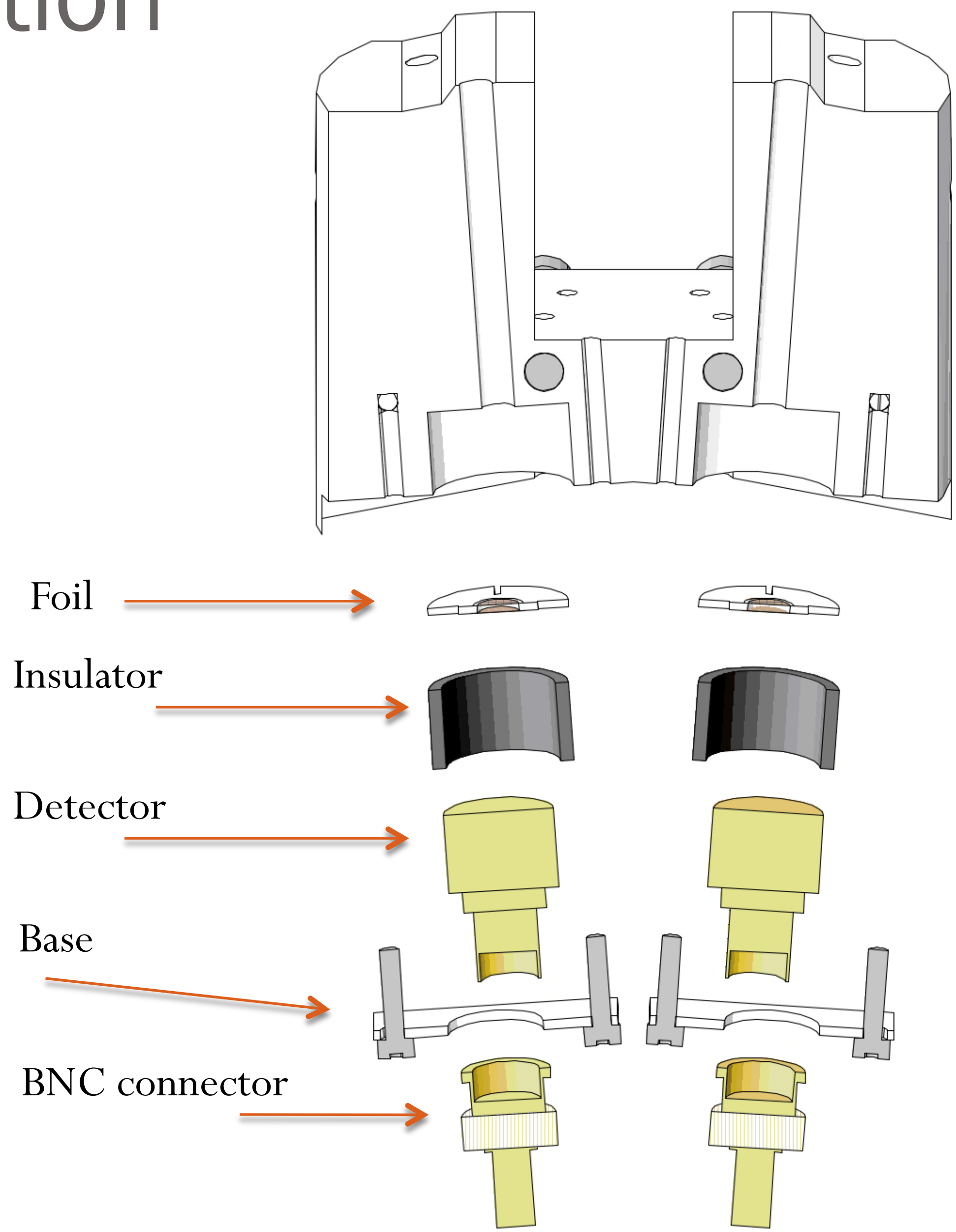
[Image 10]

Research Objective

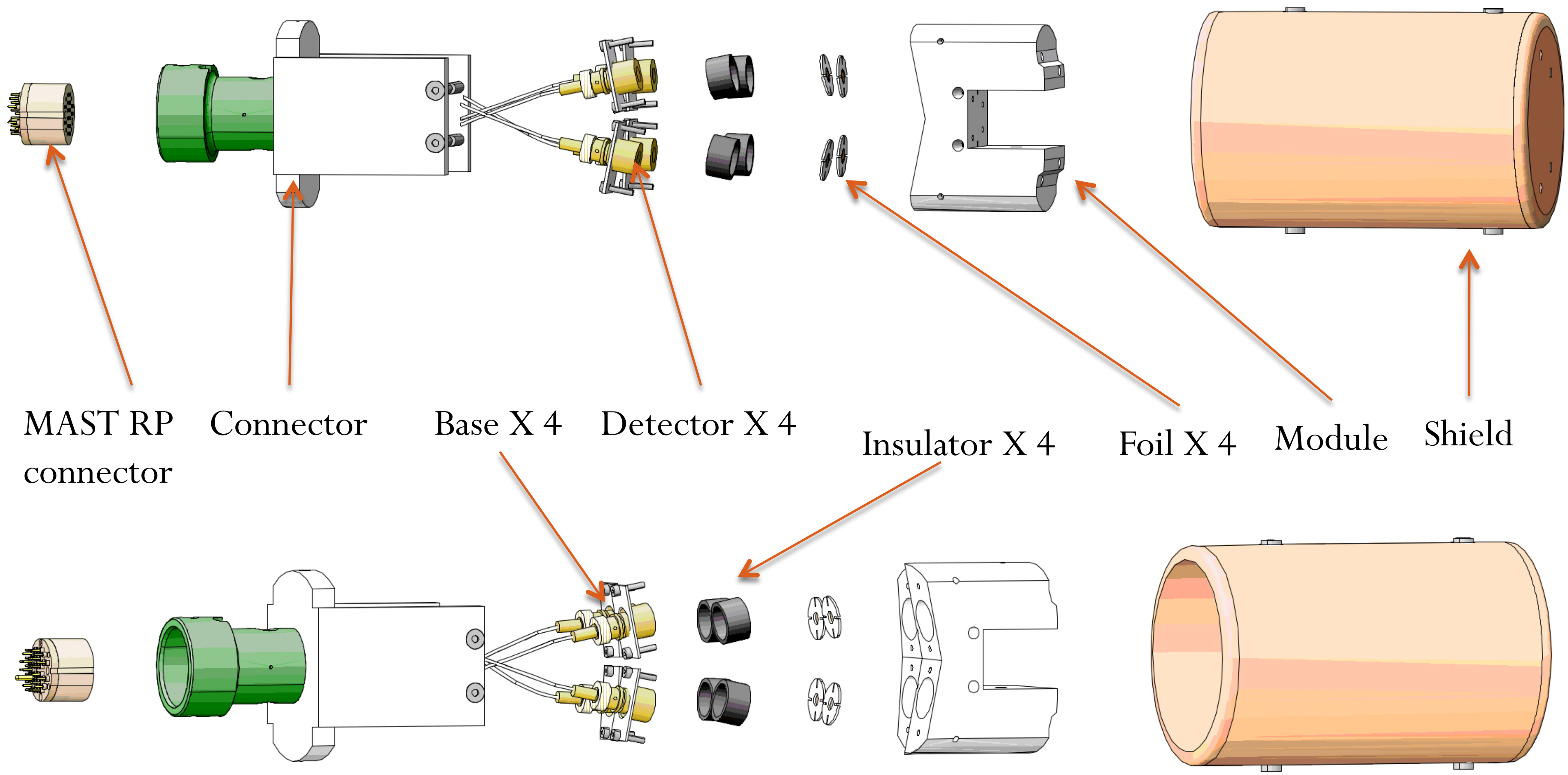
- Determine emission profile
  - Where are the d(d,p)t reactions taking place in the plasma?
  - At what rate are these d(d,p)t reactions taking place in the plasma?
- MHD instabilities
- Provides foundation for future work with spherical tokamaks

Module Cross Section

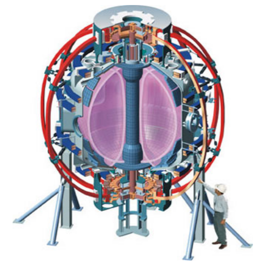


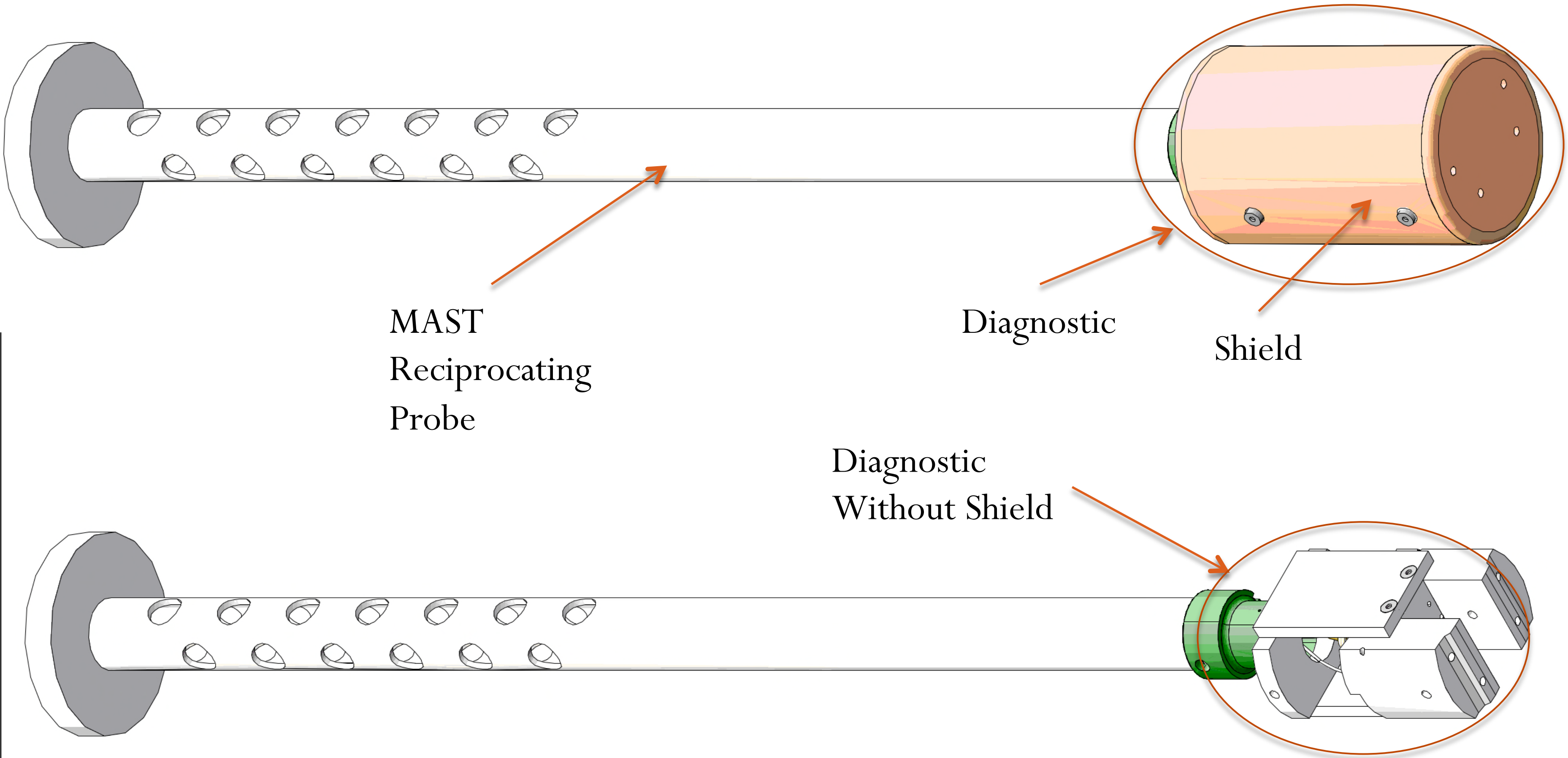


Total Exploded View

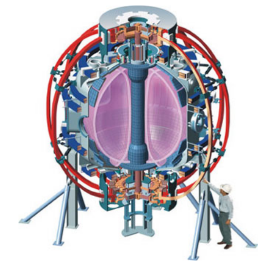


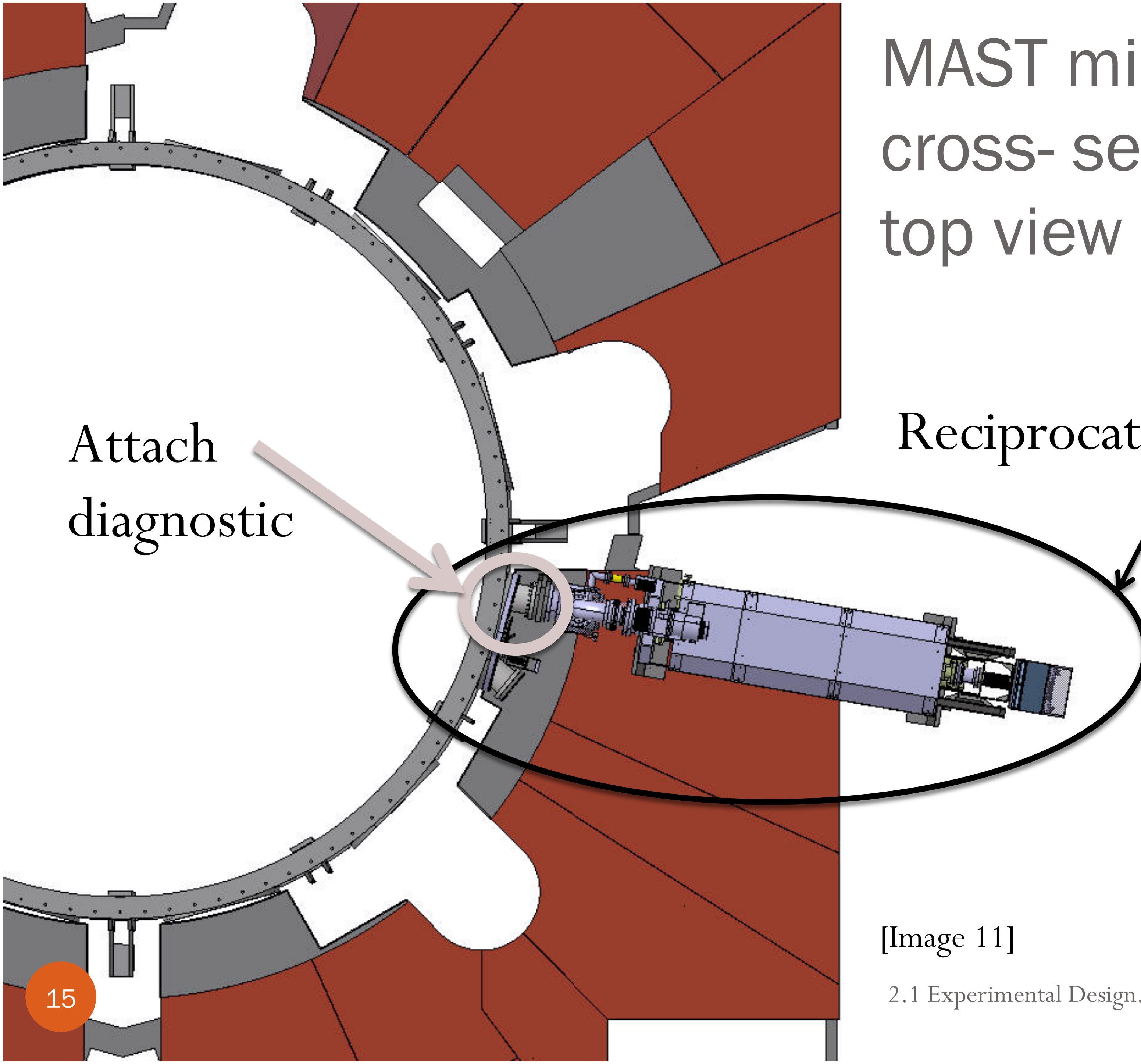
Total Assembled View





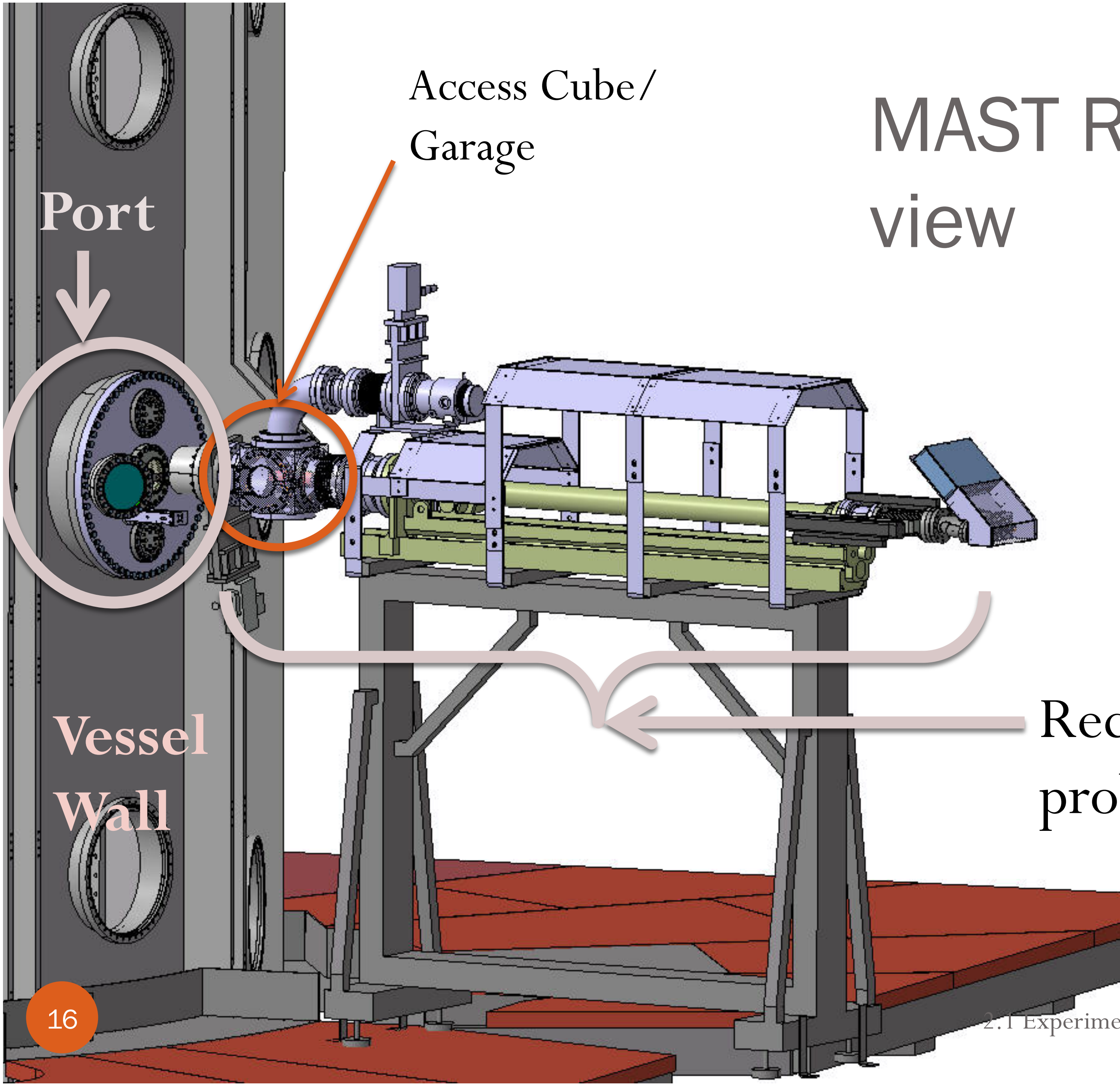
MAST mid-plane cross- sectional top view





[Image 11]

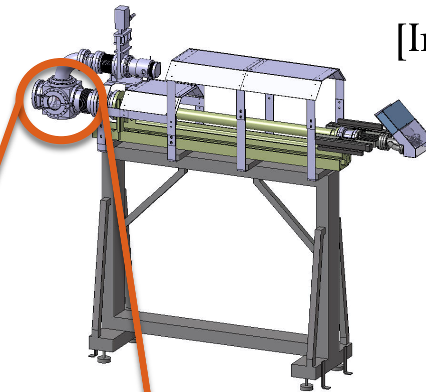
MAST RP side view



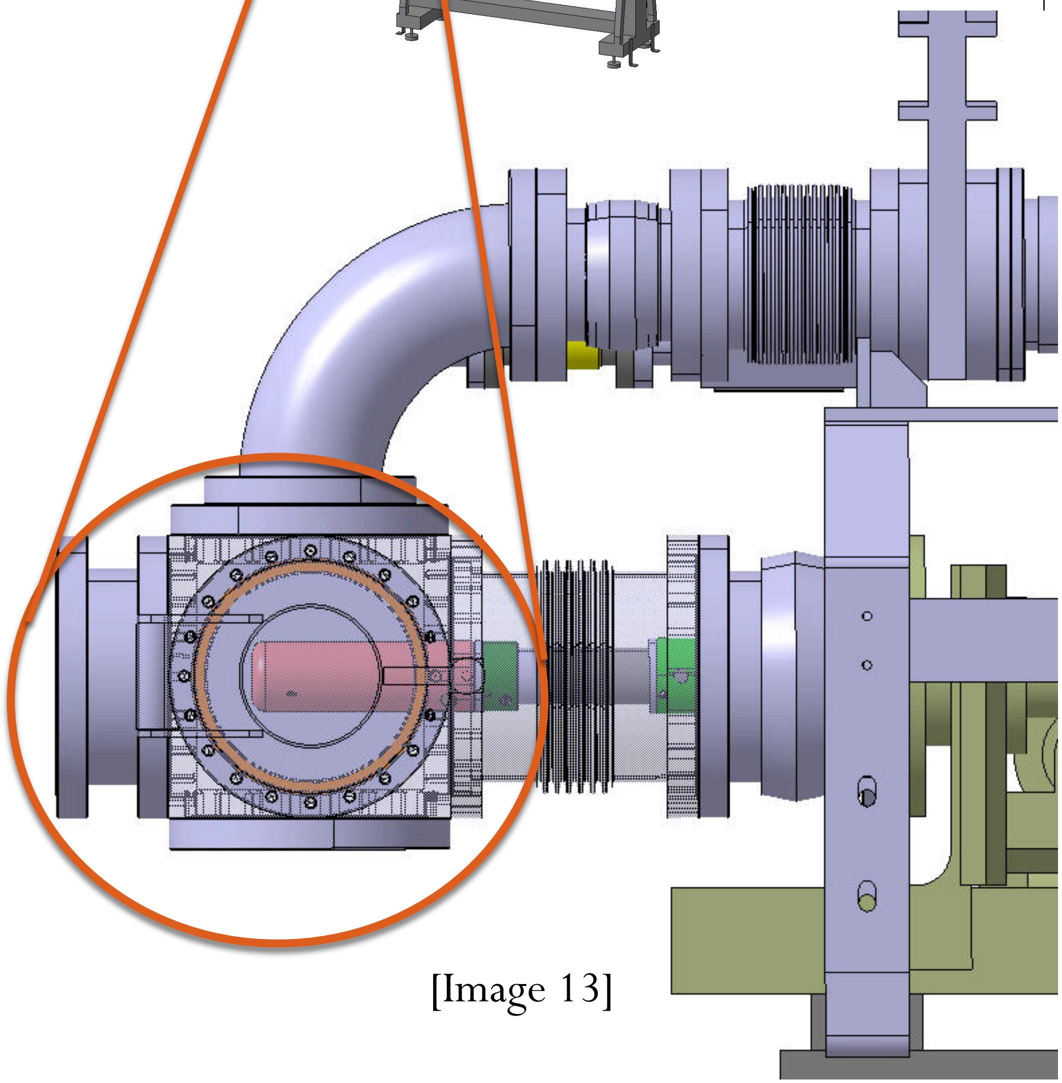
[Image 12]

MAST RP Access Cube

- Clearance Diameter: 148mm
- CFPD Diameter: 111mm
- Clearance Length: RFEA Diagnostic 185mm + few cm
- CFPD Length: 201.7mm = 185mm + 1.7cm



[Image 14]



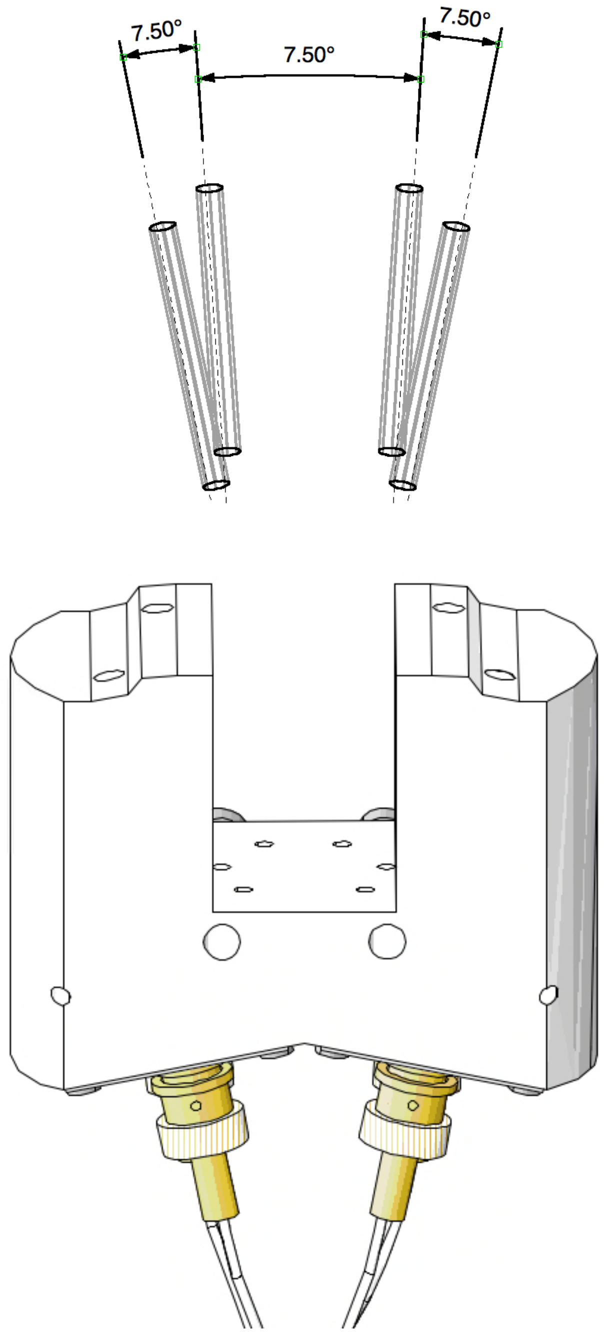
[Image 13]

2.2 Simulations

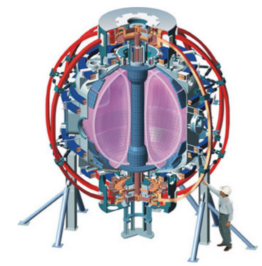
- Orbit Code
- Recreate particle trajectory, or orbit, backwards in time

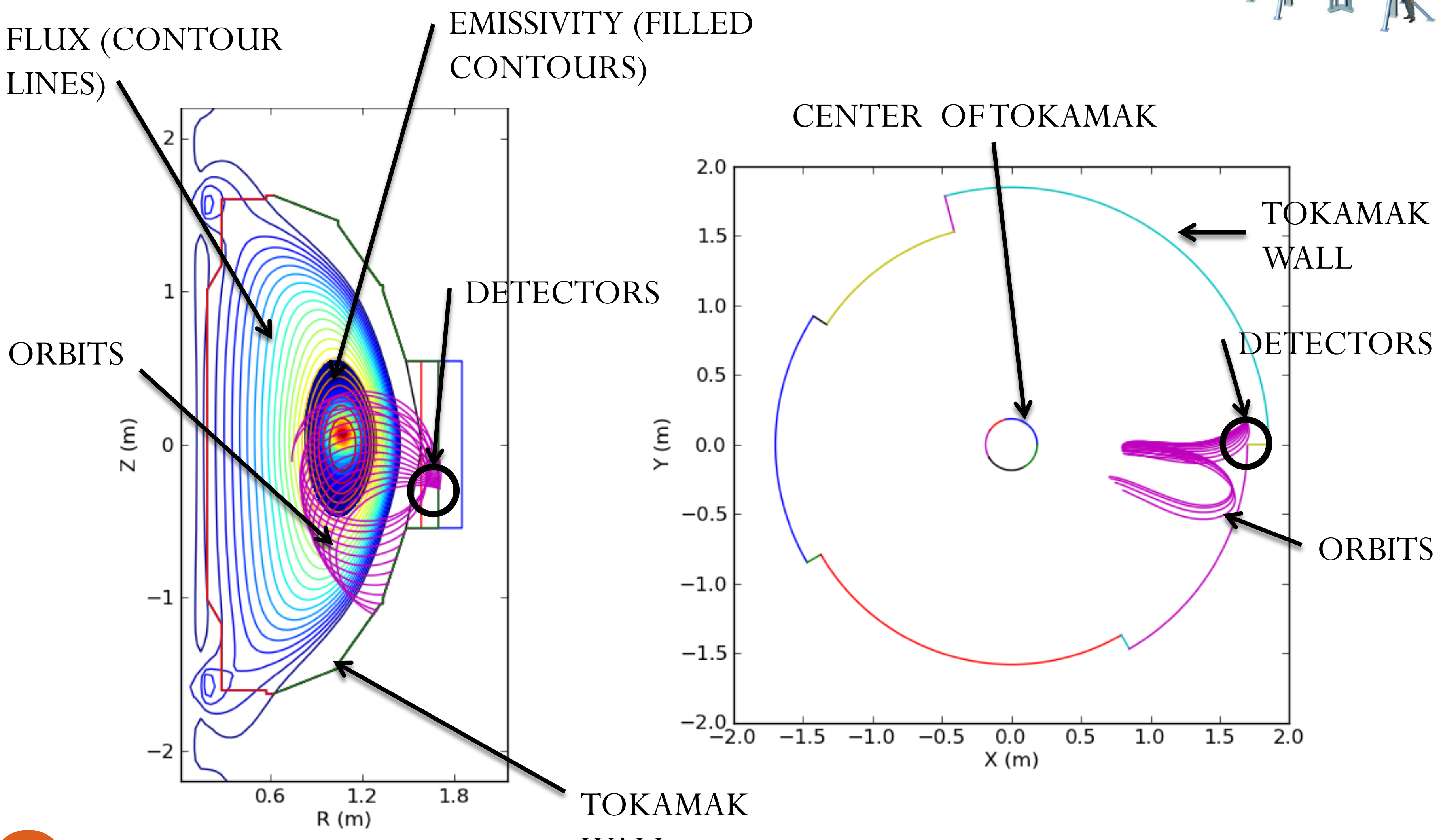
$$\epsilon_{sim} = \frac{\sum_{n=1}^{N_{det}} S_n}{\sum_{n=1}^{N_{total}} S_n}$$

$S_n = emissivity\ for\ event\ n$



Particle Orbits





Flux Surfaces

- Constant pressure
- Constant temperature

$$\epsilon_{sim} = \frac{\sum_{n=1}^{N_{det}} S_n}{\sum_{n=1}^{N_{total}} S_n}$$

$$S_n = emissivity\ for\ event\ n$$

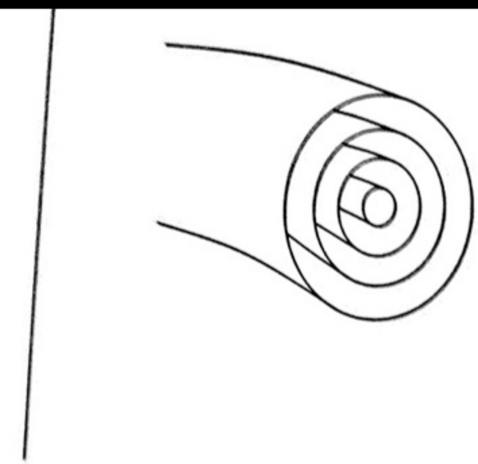
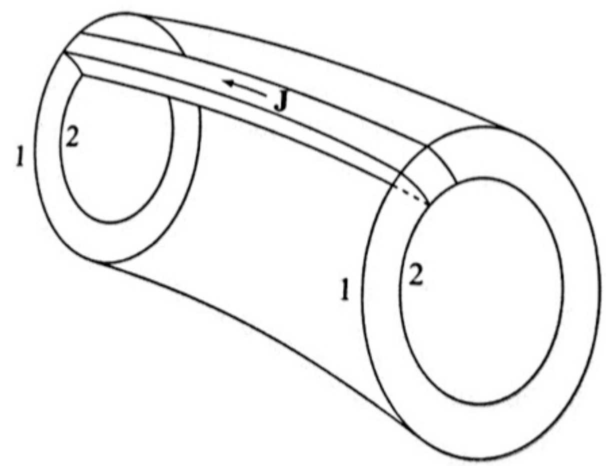


Figure 11.8 Contours of constant pressure in a well-confined toroidal equilibrium.



[Image 15]

Figure 11.9 Two flux surfaces, 1 and 2, at two different toroidal locations showing that the current flows between and not across them.

MAST Neutron Camera

Rev. Sci. Instrum. **81**, 10D315 (2010)

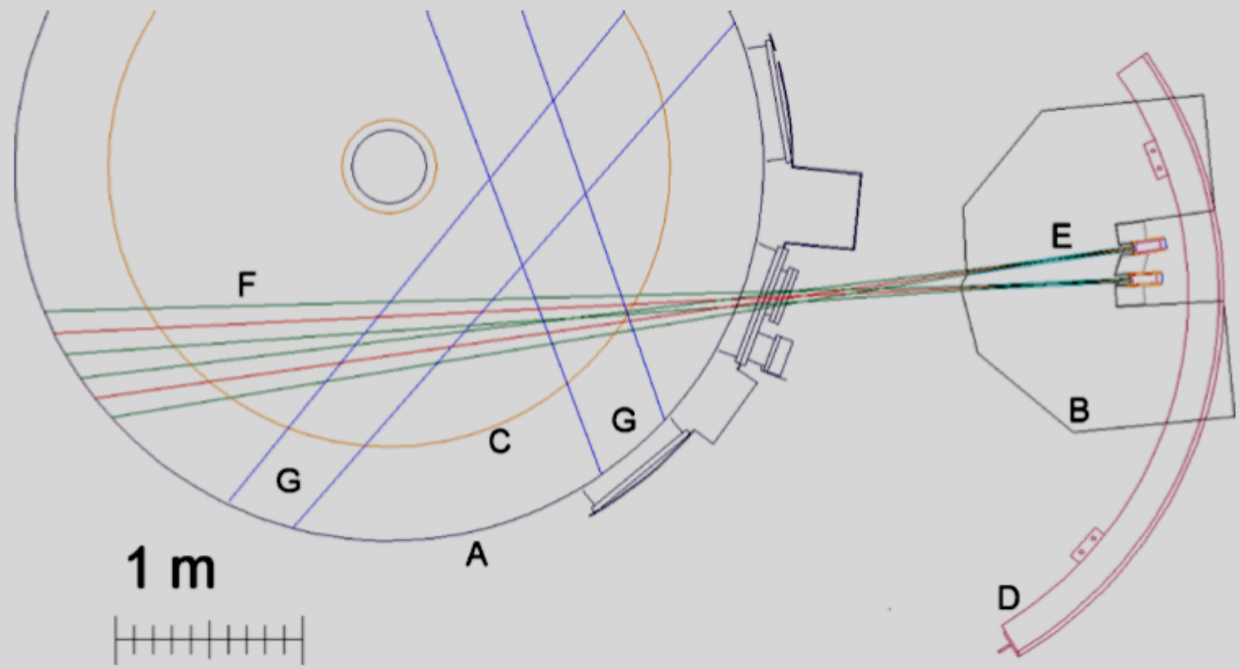
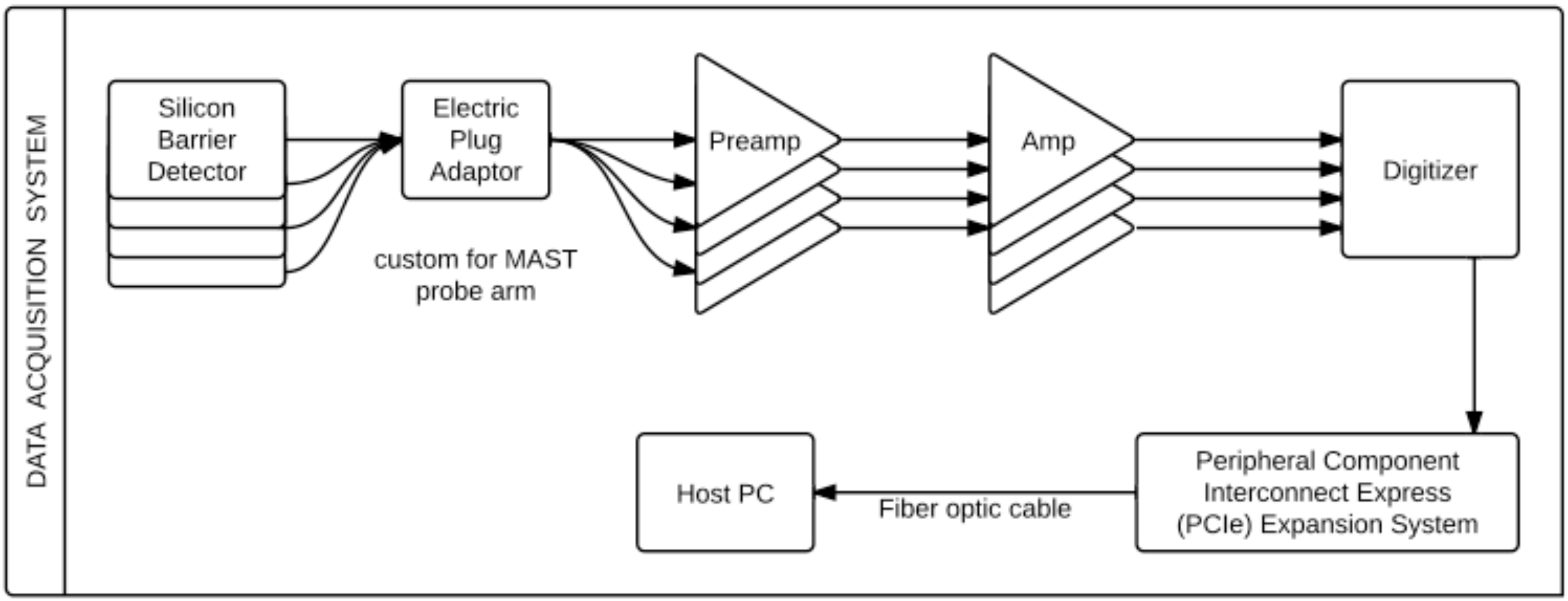
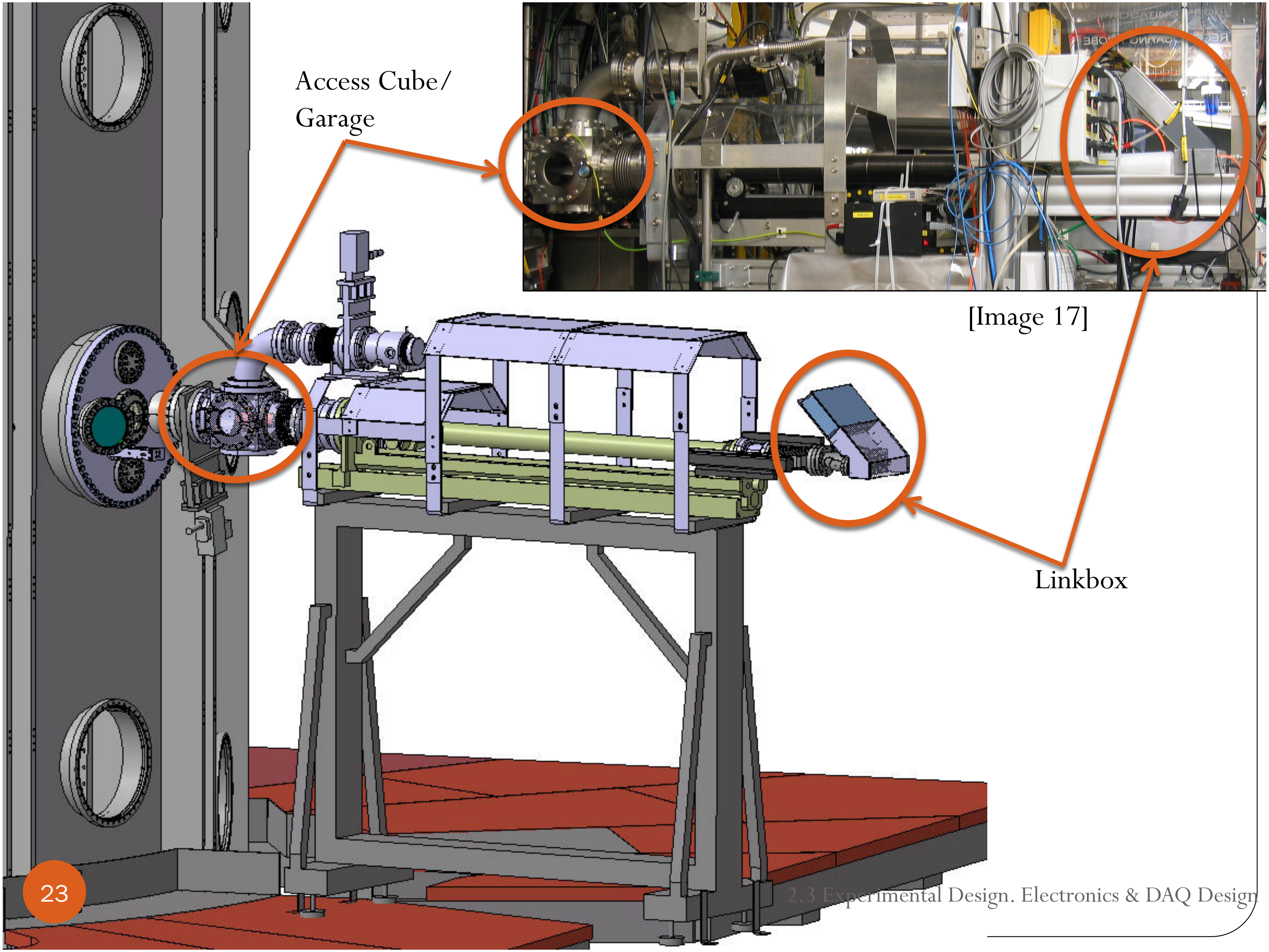


FIG. 2. (Color online) Top view of MAST equatorial plane and of the prototype NC (right). (a) Vessel, (b) neutron shielding, (c) plasma boundaries, (d) rail, (e) lines of sight, (f) fields of view, and (g) NBI beams.

[Image 16]

2.3 Electronics & DAQ Design

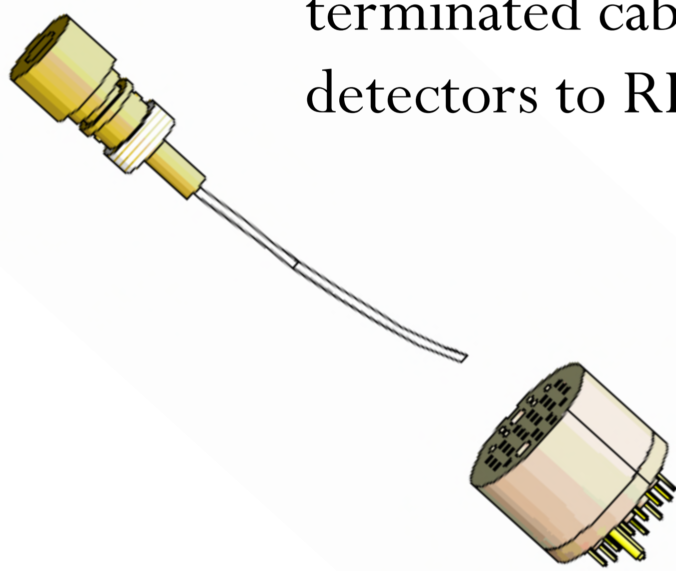


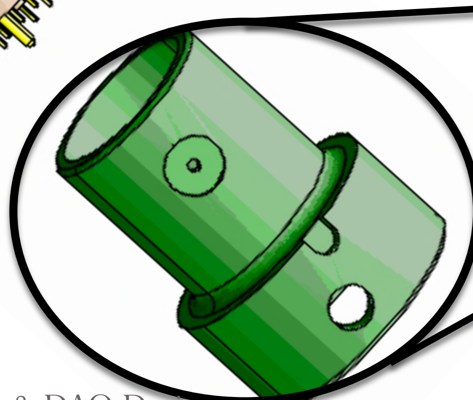


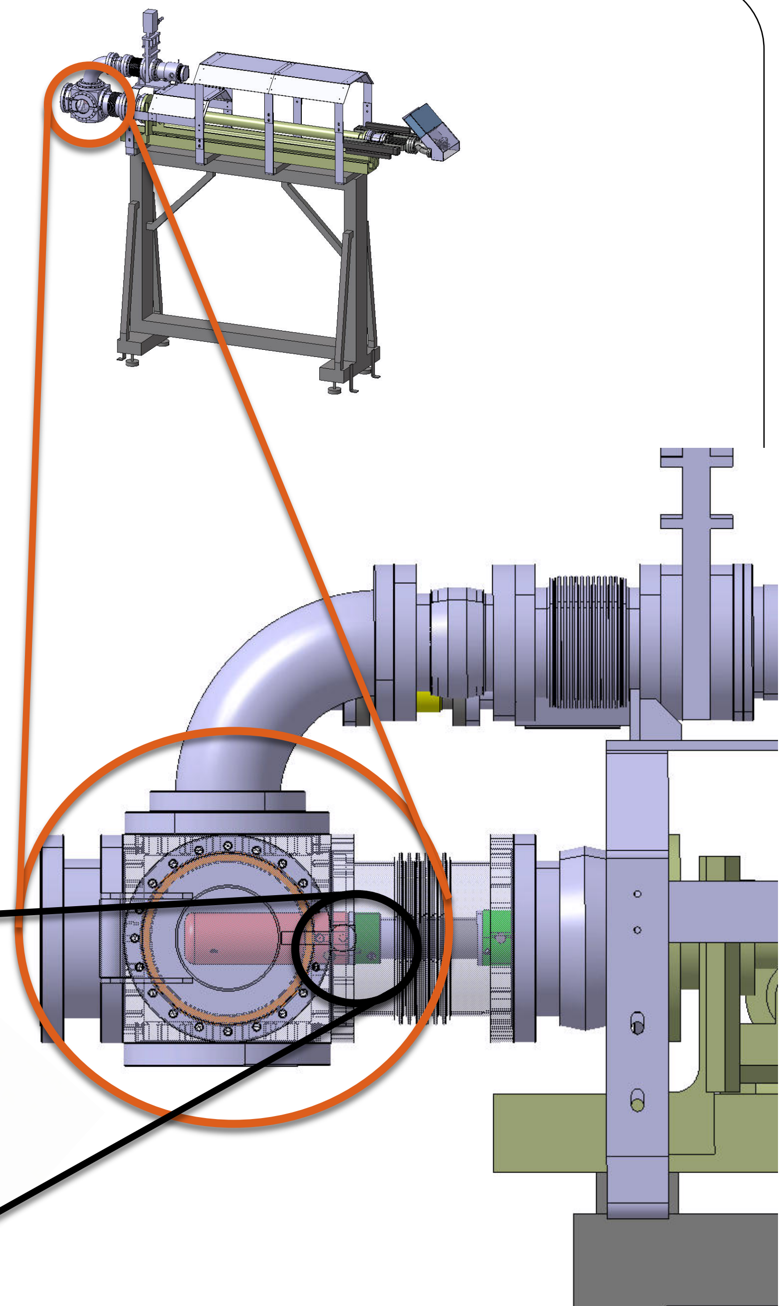
[Image 17]

MAST RP Access Cube

- MAST will connect non terminated cable ends from detectors to RP connector



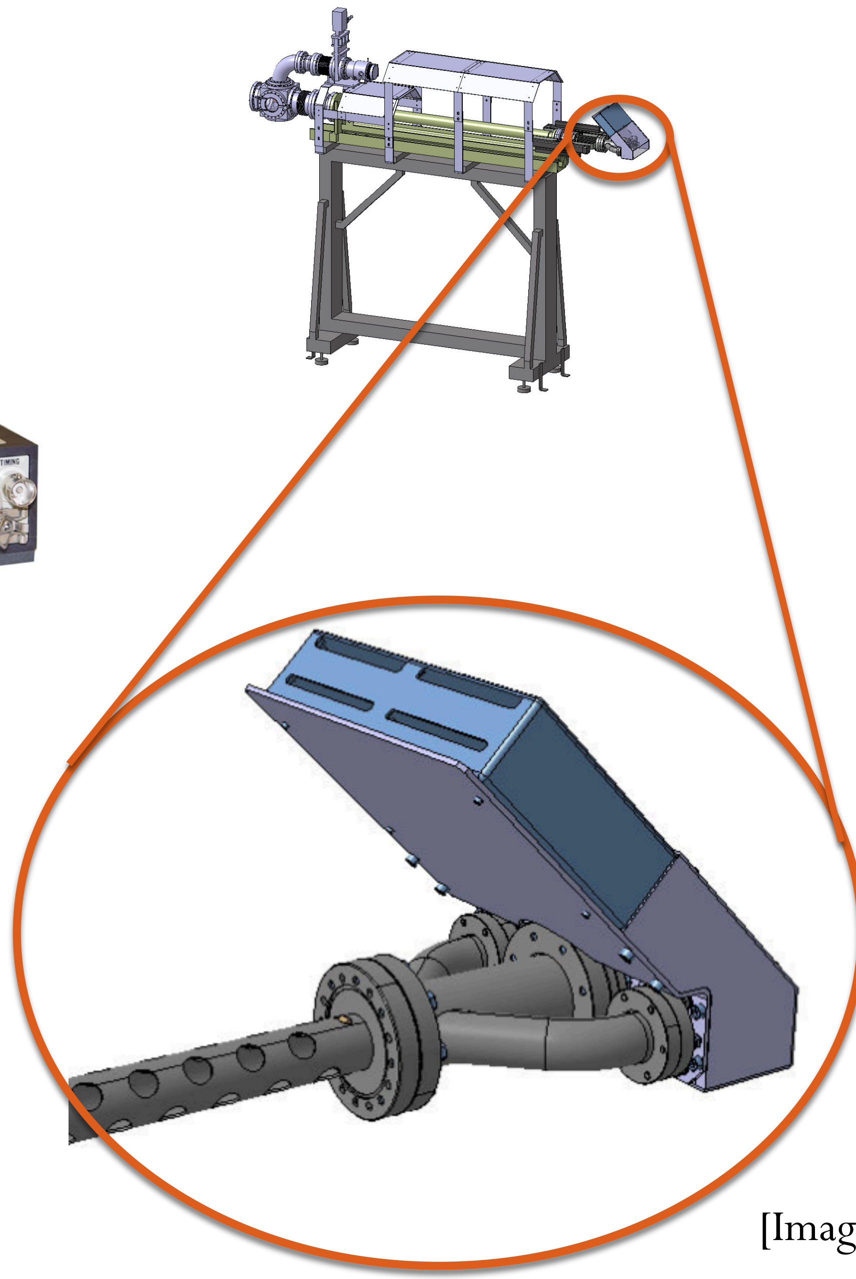




MAST RP Linkbox

- 4 preamplifiers stored inside linkbox

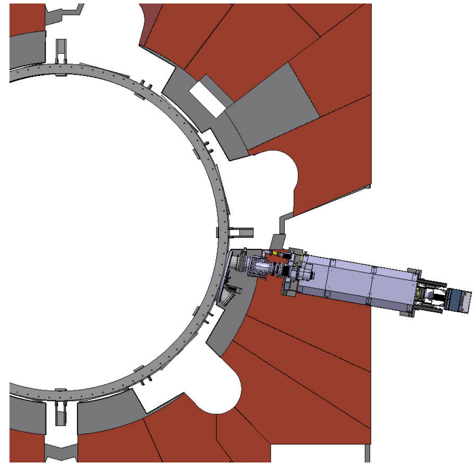
- MAST will connect non terminated cable ends from preamplifiers to RP
- Bias supply and power supply cables to preamp will run into linkbox

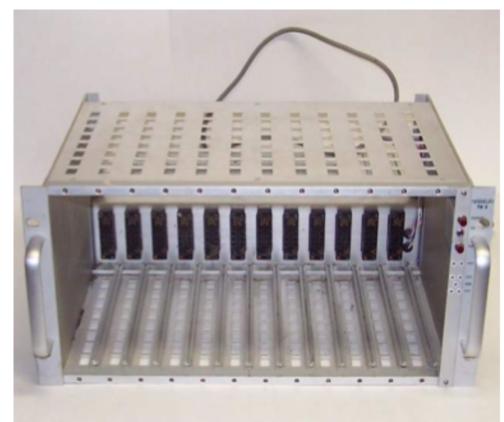


[Image 18]

Hardware Storage

- 10m from MAST RP
  - 4 amplifiers
  - 1 NIM BIN
  - 1 rack mount computer
  - 1 PCI extension box
  - 4 power supplies for detector bias Voltage

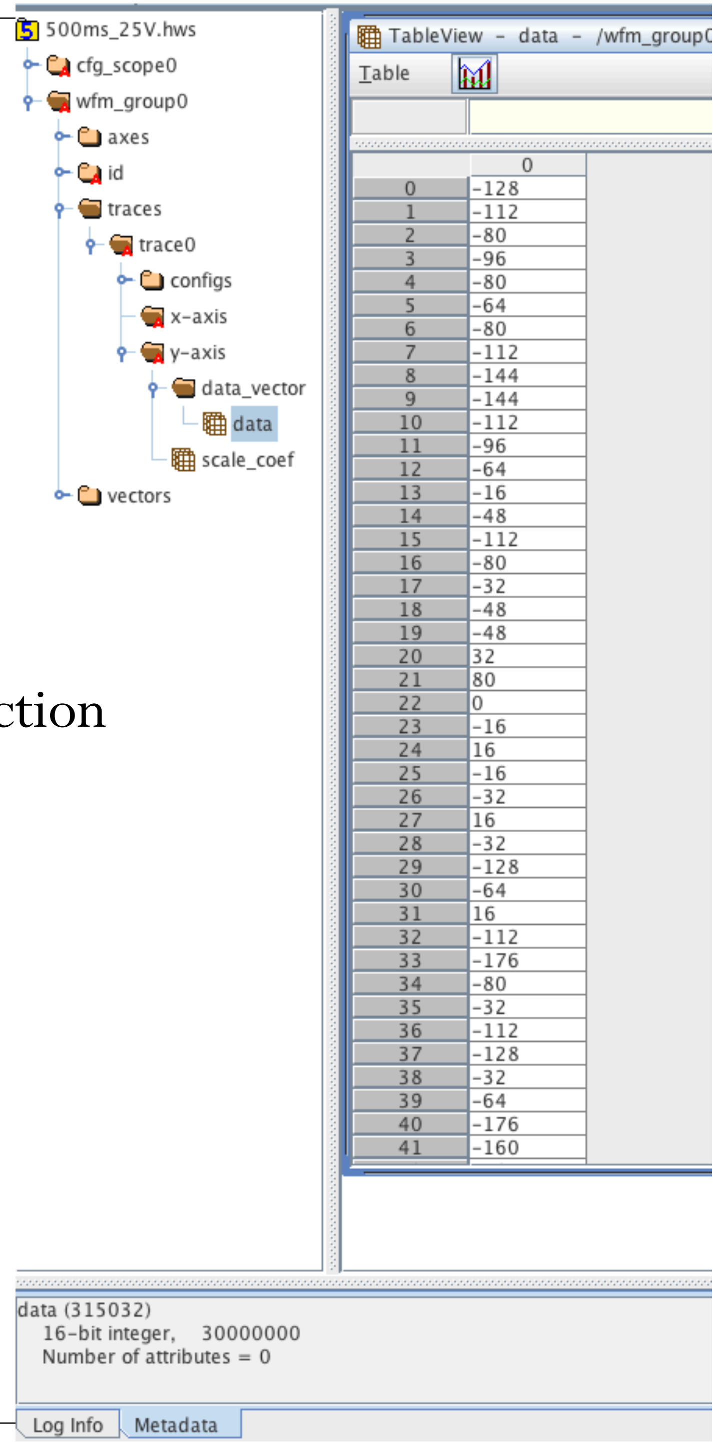




[Images 19-23]

Data Files (HDF)

- Data file sizes
  - 23MB per channel per shot
  - 92MB per shot for all channels
  - 46GB for 10 days (2 weeks) data collection
  - 92GB for 4 weeks data collection
- Data Storage
  - 150GB onsite rackmount computer
  - 800GB FIU host computer

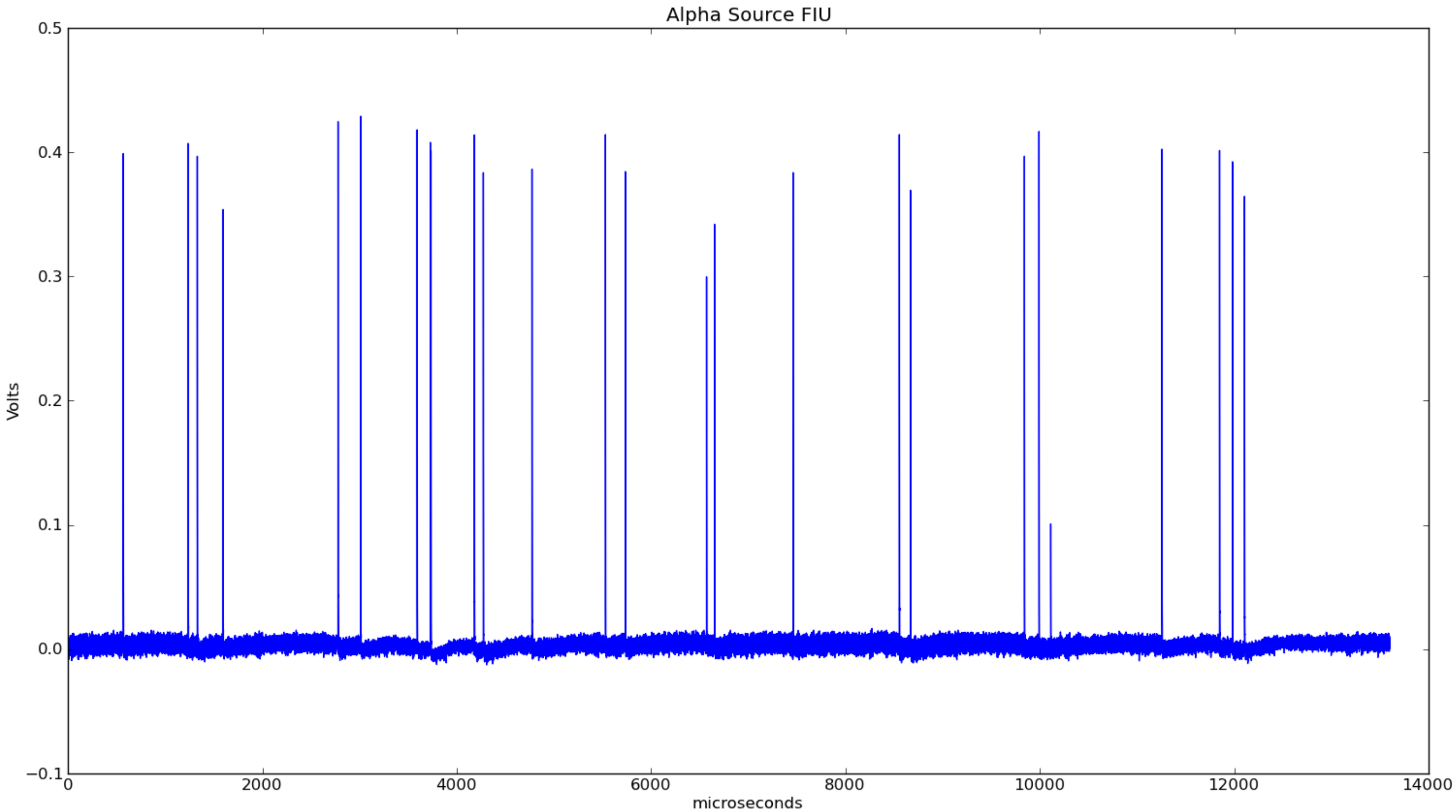


3. Data Collection: *Round 2*

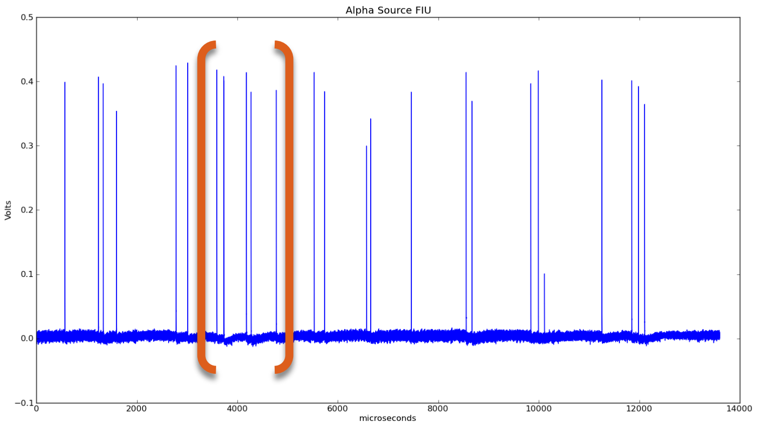
- Initial noise diagnostics and Electrical Design Review
  - January/March 2013
  - The Mega Amp Spherical Tokamak (MAST) at in the Culham Centre for Fusion Energy (CCFE) in the United Kingdom
- Diagnostic installation and subsequent data collection
  - May/ June 2013
  - The Mega Amp Spherical Tokamak (MAST) at in the Culham Centre for Fusion Energy (CCFE) in the United Kingdom

4. Data Analysis

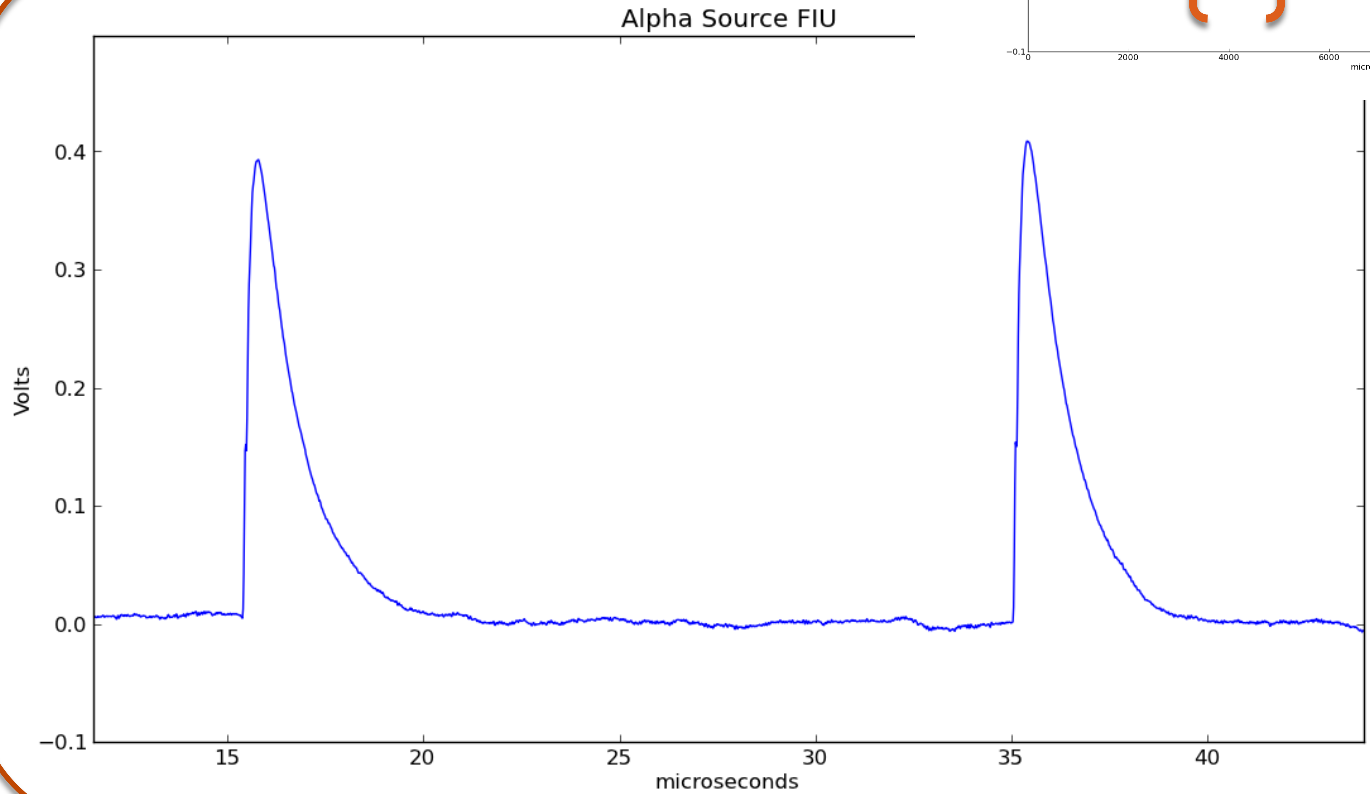
- Example of pulse signals, 5.5 MeV alpha particles



Find Peaks

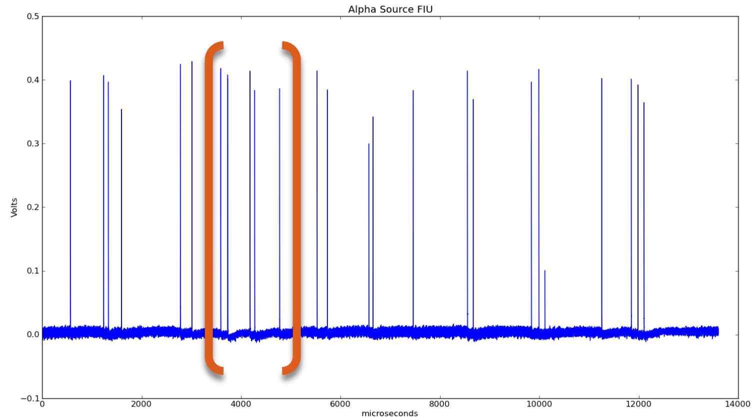


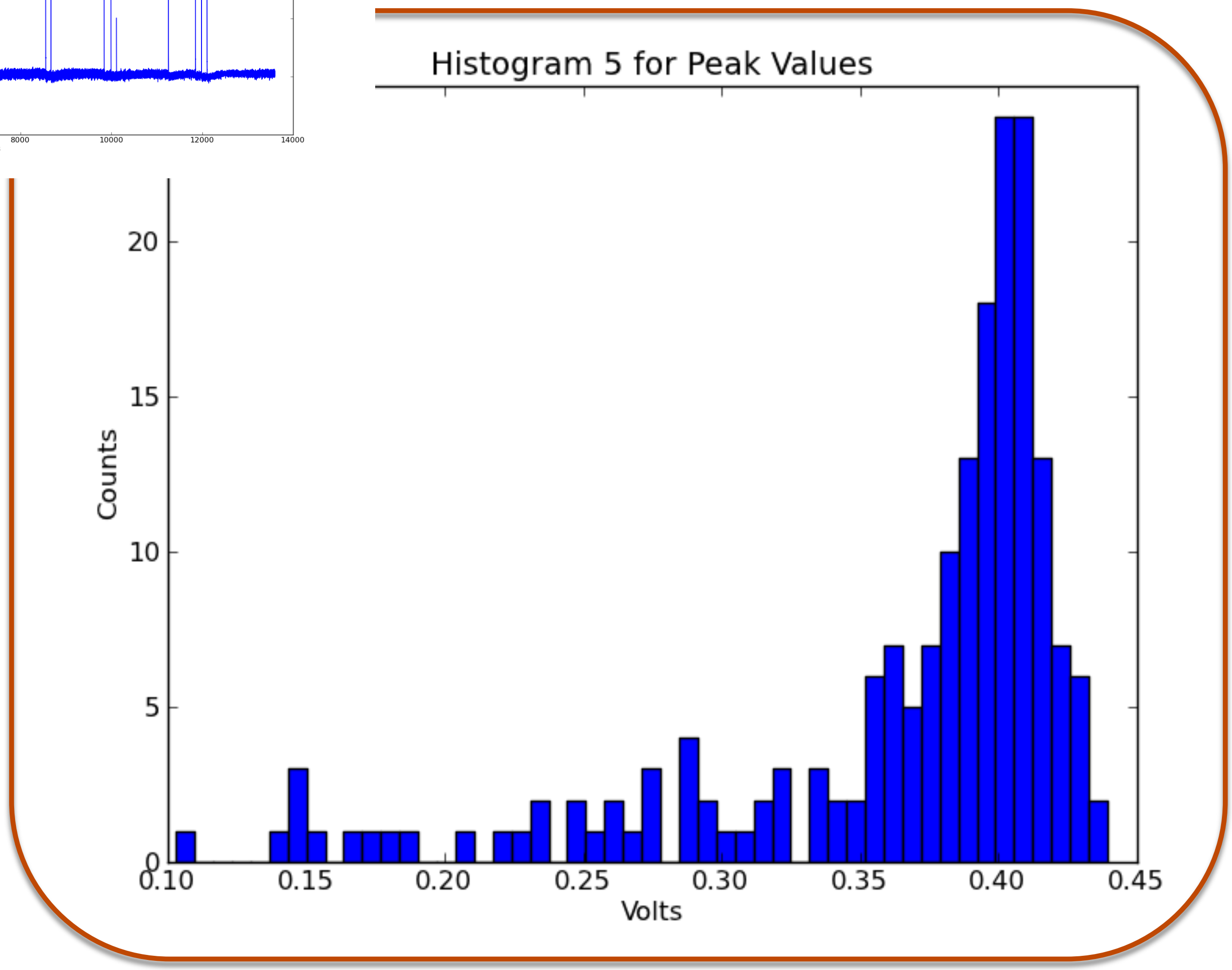
Alpha Source FIU
Volts
microseconds



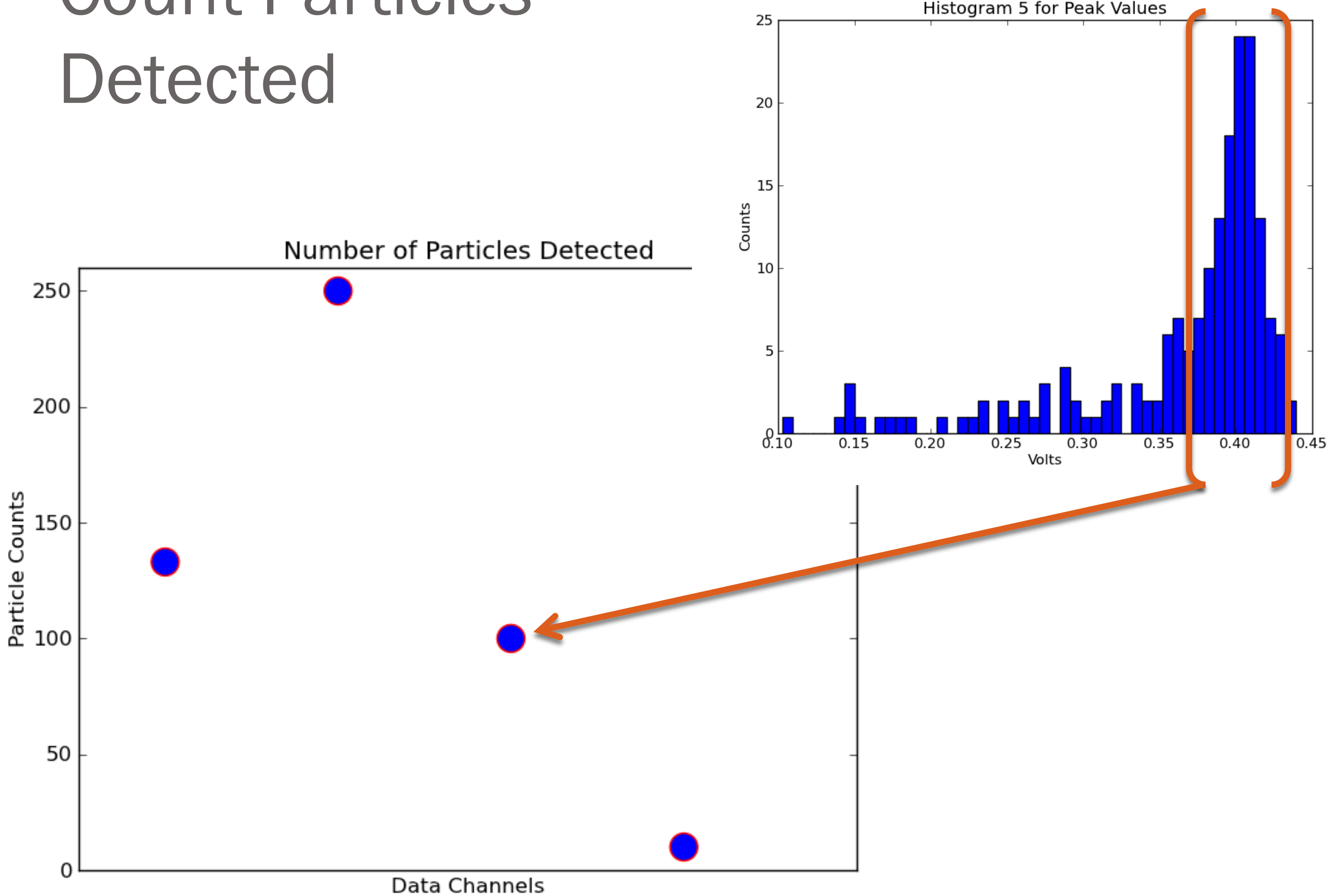
Alpha Source FIU
0.4
0.3
0.2
0.1
0.0
−0.1
Volts
15
20
25
30
35
40
microseconds

Bin Peaks

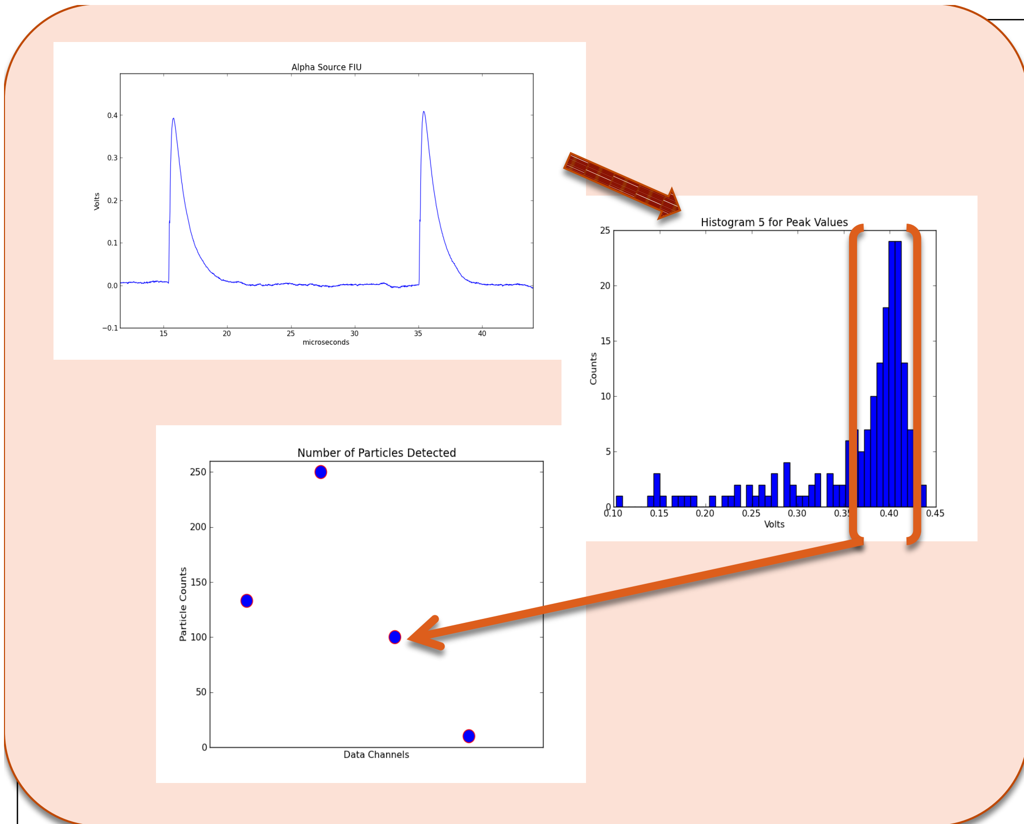

Alpha Source FIU
Volts
microseconds
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
0
2000
4000
6000
8000
10000
12000
14000


Histogram 5 for Peak Values
Counts
Volts
0
5
10
15
20
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

Count Particles Detected



Emissivity



- Ratio of particles detected (counted) and MAST global yield rate proportional to below expression
- Simple models of emissivity will be fitted to data

$$\epsilon = \frac{\int A(\theta)d\theta \int_{orbit} S(\vec{r})dl}{2\pi \int_V S(\vec{r})dV}$$

$$S(\vec{r}) = emissivity\ at\ position\ \vec{r}$$

$$A(\theta) = effective\ detector\ opening\ for\ entry\ angle\ \theta$$

5. Tentative Timeline

TERM	GOALS
SUMMER 2012	Diagnostic design/ assembly/ testing
FALL 2012	Continue summer goal, apply for 2014 fellowship
SPRING 2013	Initial testing & Electrical Design Review at MAST
SUMMER 2013	Diagnostic installation and data collection
FALL 2013	Data analysis, dissertation, apply for 2015 fellowship
SPRING 2014	Data analysis, dissertation
SUMMER 2014	Write paper for publication, dissertation
FALL 2014	Dissertation defense, submit paper for publication

References- Images

- Unreferenced images are created by author

1. An image depicting the poloidal (red, called theta) direction and the toroidal (blue, called phi) directions. 13 September 2006. Made in POV-Ray by Dave Burke. PNG File.
2. European Fusion Development Agreement (EFDA). Magnetic fields in a tokamak. 2012. Garching, Germany. EFDA: Fusion. 08/01/2012. <http:// www.efda.org/fusion/focus-on/plasma-heating-current-drive/ohmic-heating/>
3. Jeffrey Freidberg. Cover. Plasma Physics and Fusion Energy. Cambridge University Press, 2008.
4. Spherical Tokamaks Image. 2009. Abingdon, Oxfordshire, UK. Culhman Centre for Fusion Energy: Research. 08/01/2012. <http:// www.ccfe.ac.uk/st.aspx>
5. Princeton Plasma Physics Laboratory. National Spherical Torus Experiment. Princeton, New Jersey. Alternative Energy Action Now. 09/01/2012. <http://www.alternative-energy-action-now.com/ spherical-tokamak.html>
6. Spherical Tokamaks Image. 2009. Abingdon, Oxfordshire, UK. Culhman Centre for Fusion Energy: Research. 08/01/2012. <http:// www.ccfe.ac.uk/st.aspx>
7. Coils image
8. European Fusion Development Agreement (EFDA). Heating of JET Plasmas. 2012. Garching, Germany. EFDA: Fusion. 08/01/2012. http://www.efda.org/fusion/focus-on/plasma-heating-current-drive/ohmic-heating/
9. Fig. 1. Fundamental quantum mechanical phenomena. 2012. Victoria Stafforda Psychic Investigation. 09/20/2012. <http:// victoriastaffordapsychicinvestigation.wordpress.com/2012/07/01/line-19-a2a-semiconductor-heterostructures-schrodinger-quantum-confinement-5g-wow-seti/fig-1-fundamental-quantum-mechanical-phenomena-a-electron-reflection-and-interference-b-tunneling-effect-c-e-quantum-confinement/>

References- Images

10. Cross-section image
11. Cross-sectional mid-plane view of MAST. CAD image created by the Culham Centre for Fusion Energy's MAST Drawing Office. 2012. PDF File.
12. Side View of Assembled MAST Reciprocating Probe. CAD image created by the Culham Centre for Fusion Energy's MAST Drawing Office. 2012. PDF File.
13. MAST Reciprocating Probe Access Cube. CAD image created by the Culham Centre for Fusion Energy's MAST Drawing Office. 2012. PDF File.
14. Side View of MAST Reciprocating Probe. CAD image created by the Culham Centre for Fusion Energy's MAST Drawing Office. 2012. PDF File.
15. Figure 11.8 and Figure 11.9. Page 262, 2007. Plasma Physics and Fusion Energy. Jeffrey Freidberg. Cambridge University Press, 2007.
16. Cecconello *et al.* FIG 2. MAST Neutron camera schematic. Rev Sci Instrum. **81**, 10D315 (2010).
17. Scott Y. Allan. MAST Reciprocating Probe. Culham Centre for Fusion Energy. 2012. JPG File.
18. Linkbox MAST Reciprocating Probe. CAD image created by the Culham Centre for Fusion Energy's MAST Drawing Office. 2012. PDF File.
19. Please ask for user manual, CANBERRA 2111 Timing Filter Amplifier.
20. Please ask for user manual, ADNACO S2 Fiber Optic PCI Bus Extender.
21. Please ask for user manual, SuperMicro 50161 MTF 1U Rackmount Server.
22. Please ask for user manual, CANBERRA 3002D 0-3 kV H.V. Power Supply.
23. Please ask for user manual, Tennelec TB-3 NIM BIN with TC-911 Power Supply System.

References

1. J. A. Bittencourt, *FUNDAMENTALS OF PLASMA PHYSICS*. Springer Science + Business Media, LLC, 3rd Edition, 2004.
2. W. U. Boeglin, R. Valenzuela Perez, D. S. Darrow, Rev. Sci. Instrum. **81** (2010) 10D301
3. Hans-Stephan Bosch, Rev. Sci. Instrum. **61**, 1699 (1990)
4. L. F. Delgado-Aparicio, et. al., J. of Appl. Phys. **102** (2007) 073304
5. Jeffrey Freidberg, Plasma Physics and Fusion Energy. Cambridge University Press, 2007.
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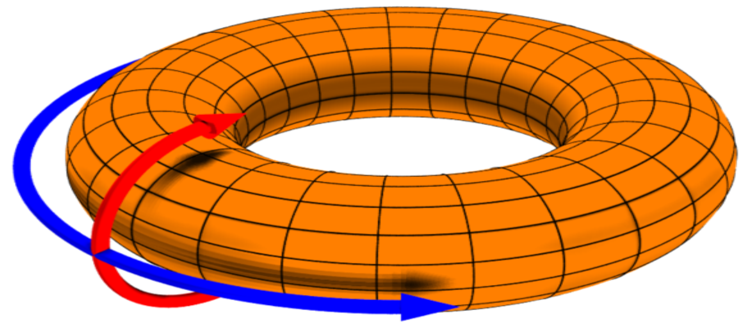
7. J. D. Strachan, Rev. Sci. Instrum.**57**, 1771 (1986)
8. S. J. Zweben, Rev. Sci. Instrum.**57**, 1774 (1996)
9. S. J., Zweben, et al., Nucl. Fusion **35**, 893 (1995)

Thank you for your time!

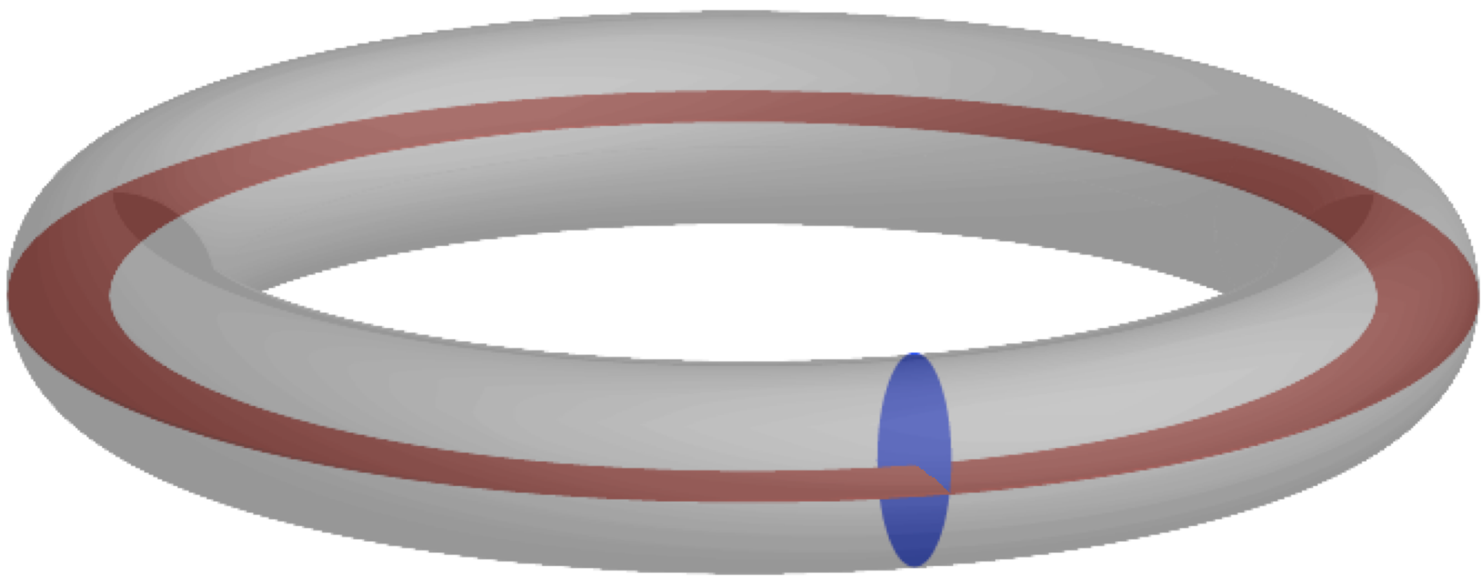
Questions

Magnetic Flux

- Red surface: poloidal
- Blue surface: toroidal

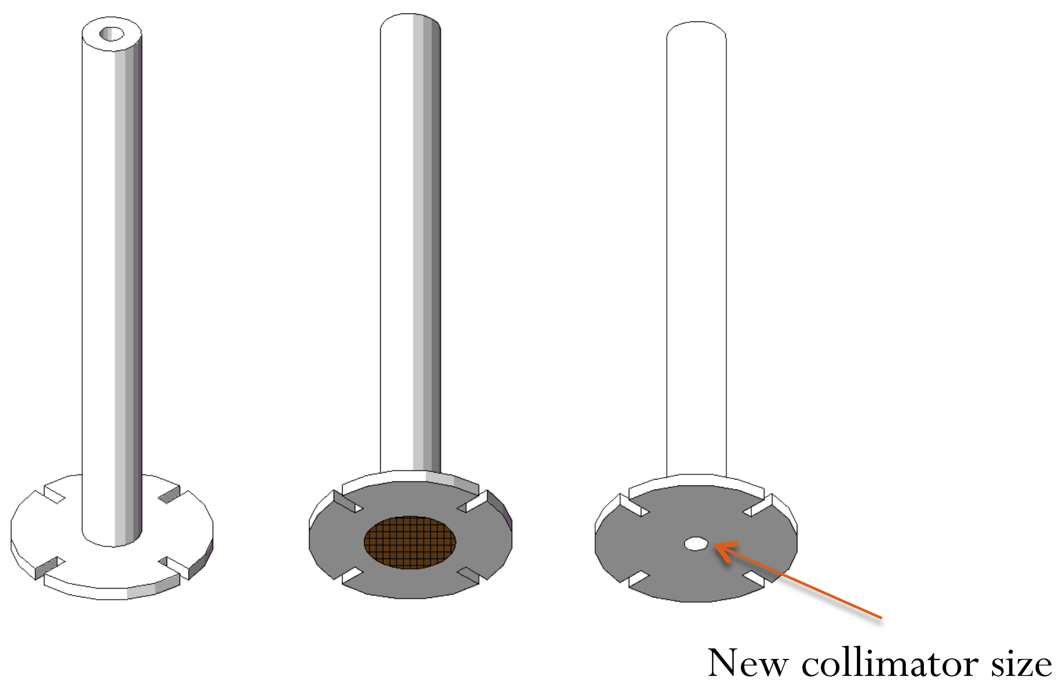


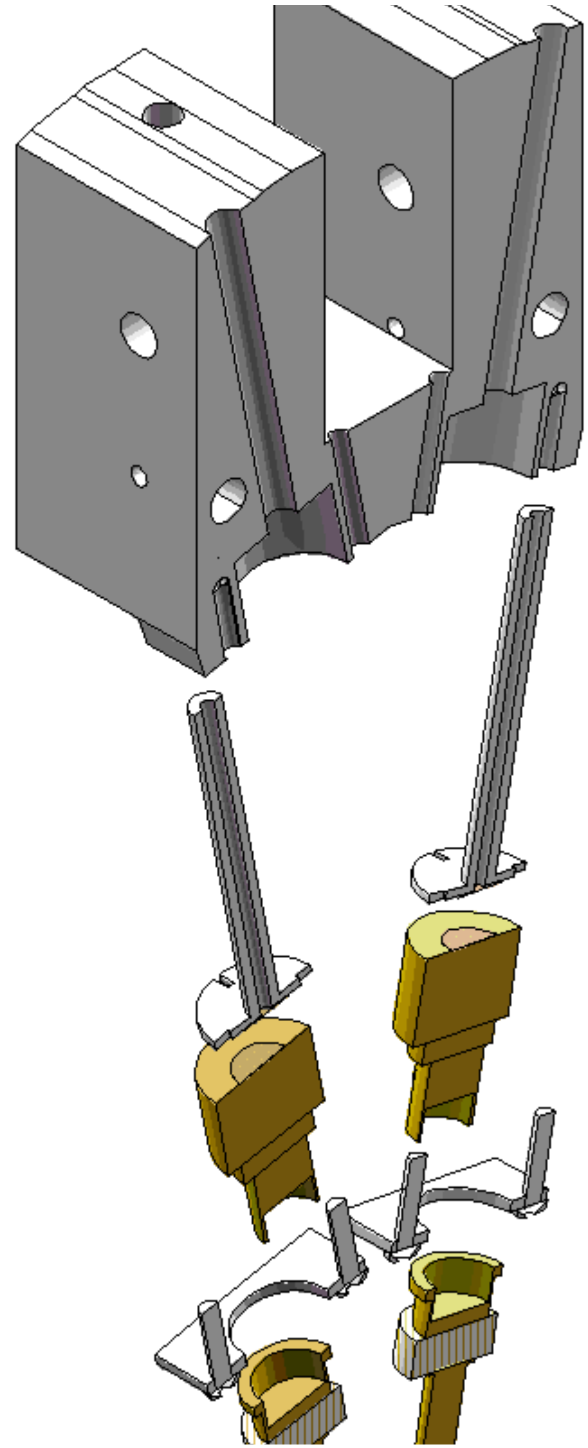
[Image #]



[Image #]

Alternate Washer to Change Collimator Size



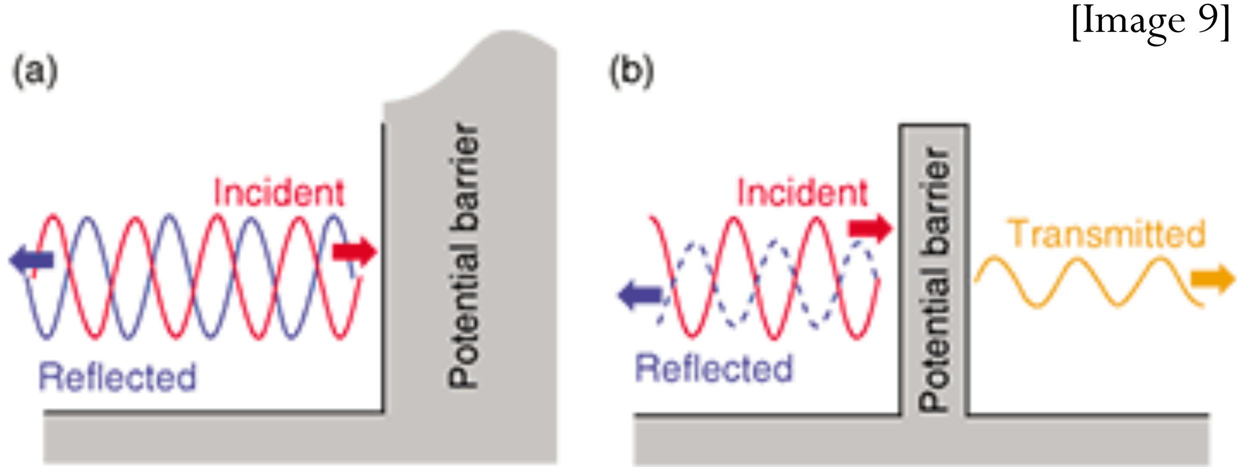


Tokamak

- Facilitate nuclear reactions

$$Potential_{Coulomb} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r}$$

[Image 9]



Gyro radius

$$Radius_{gyro} = \frac{mv_{\perp B}}{|q|B}$$

$$m\frac{dv_{\perp B}}{dt} = qv_{\perp B} \times B$$

$$m\frac{dv_{\perp B}}{dt} = \frac{mv^2_{\perp B}}{Radius_{gyro}}$$

Collimator

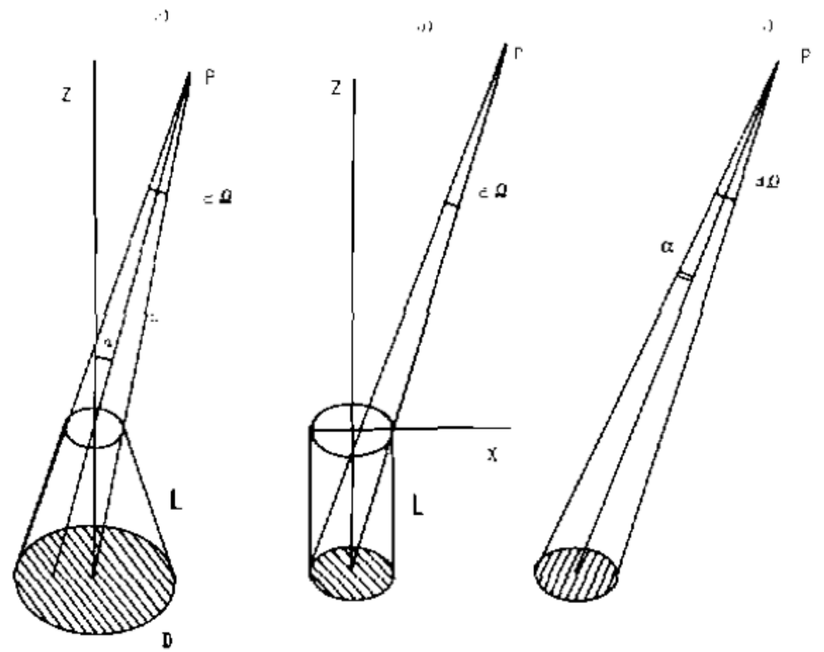
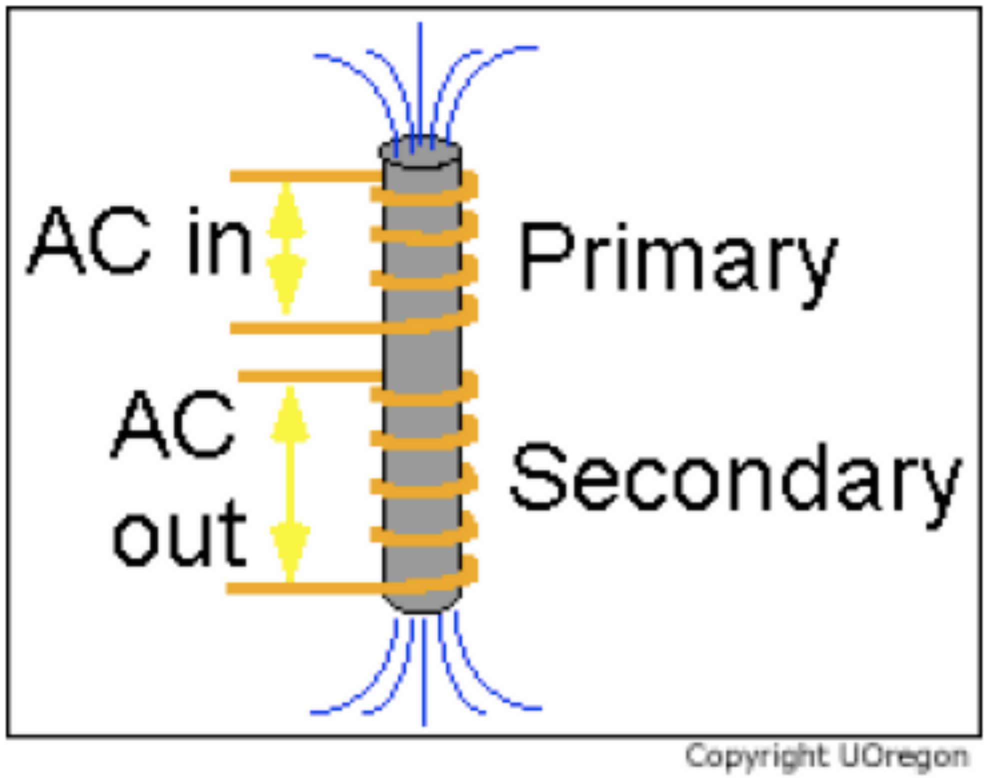


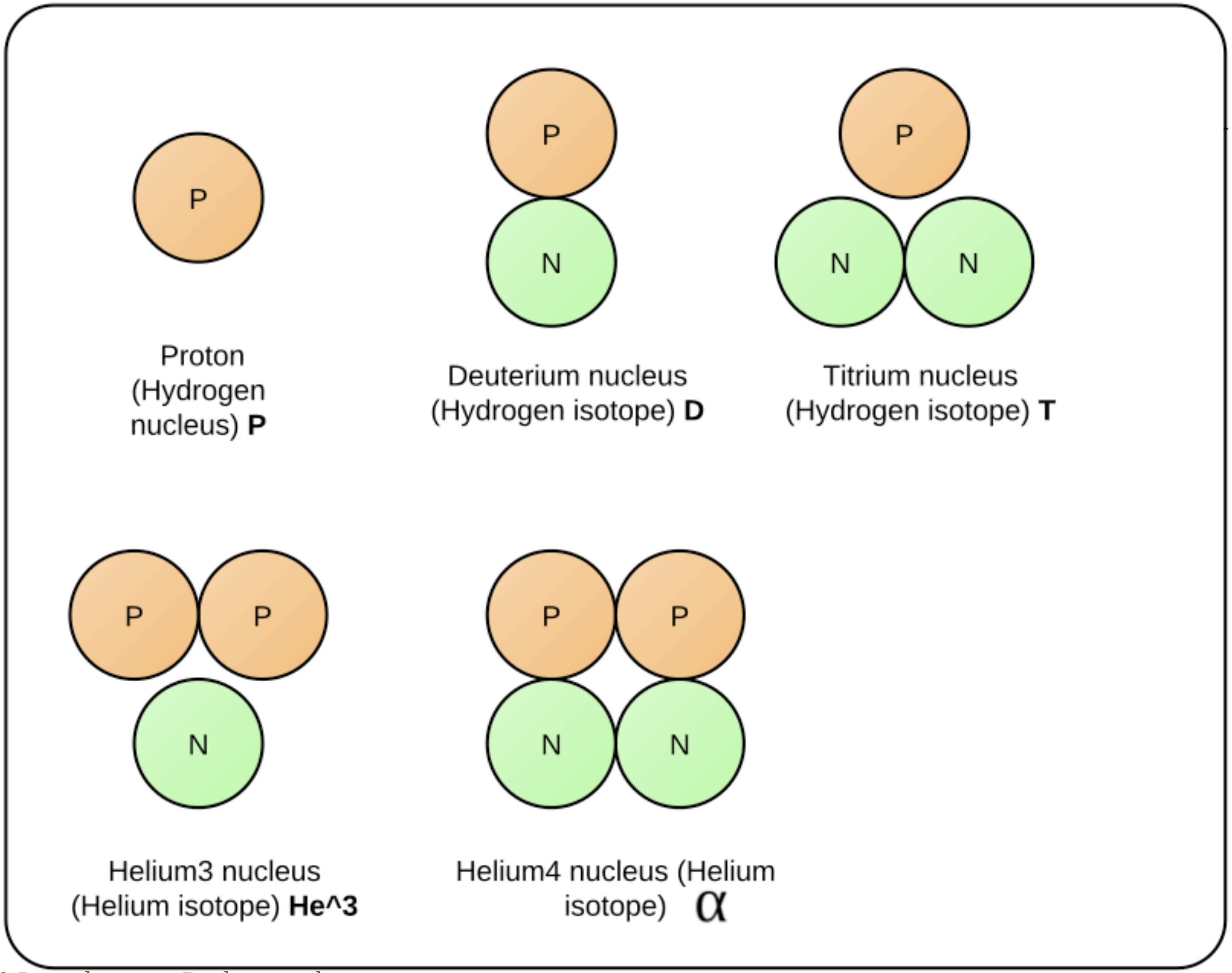
Fig. 1. Solid angle subtended by a detector of area D without (right) and with a cylindrical (middle) and a conical (left) collimator.

[Image #]

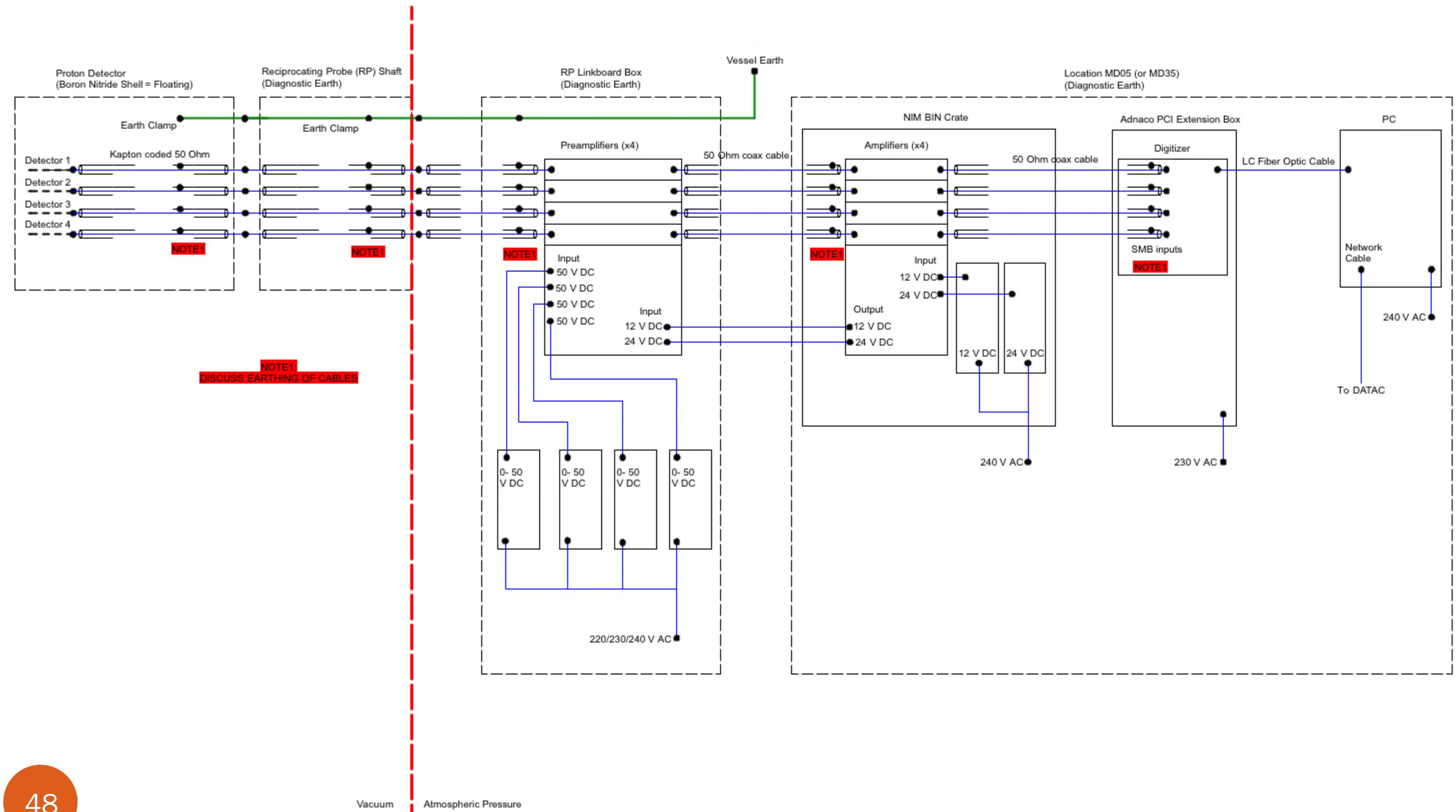
Transformer



[Image #]


P
Proton
(Hydrogen
nucleus) **P**
P
N
Deuterium nucleus
(Hydrogen isotope) **D**
P
N
N
Titrium nucleus
(Hydrogen isotope) **T**
P
P
N
Helium3 nucleus
(Helium isotope) **He^3**
P
P
N
N
Helium4 nucleus (Helium
isotope) α

Electronics Schema



Module Exploded View with Bases