Experimentally Investigating Fusion Plasma Instabilities Using MeV Proton Emissions

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MeV Proton Emission Diagnostic Motivation

- Proof of concept: advantage in size, cost, and energy resolution
- Successful prototype 3MeV proton detector at the Mega Amp Spherical Tokamak (MAST)
- Measure DD proton fusion rate profile
- Study MHD instability effects on proton rate
Prior Work with DD Charged Fusion Products

- Collimated silicon detectors surface barrier detectors for detecting ions - Strachan (1986) and Lo et al. (1995)
- 3MeV proton energy spectra in conventional tokamaks - Chrien et al. (1983), Heidbrink et al. (1985), and Bosch (1990)
- MAST fast ion diagnostics - Jones et al. (2013), Cecconello, et al. (2014)
- MAST neutron camera (NC) measures same profile using 2.5MeV neutrons

[Original Image Cecconello et al. (2012)]
DD Charged Fusion Product Emissions of Interest

• Primary
  • $D + D \rightarrow P (3\text{MeV}) + T (1\text{MeV})$
  • $D + D \rightarrow N (2.5\text{MeV}) + ^3\text{He} (0.8\text{MeV})$
• Secondary
  • $D + T \rightarrow N (14.1\text{MeV}) + ^4\text{He}(3.5\text{MeV})$
  • $D + ^3\text{He} \rightarrow ^4\text{He} (3.6\text{MeV}) + P(14.7\text{MeV})$

• Dominant signal from beam-plasma fusion events during Neutral Beam Injection (NBI)
• Potential application of proton detector (PD) to study beam ion confinement and heating profile
Note an isotropic DD cross section is assumed
Orbit bundles for central trajectories

Finite acceptance of collimator-detector system

~6 cm
Mechanical probe arm pushes PD towards plasma
Compact Housing: 110mm diameter, 185mm length

Detector assembly

Boron nitride shell
Main housing: detector assembly components

- Energy loss through 0.8\(\mu\)m foil
- Proton 18.4 keV
- Triton 34.6 keV
- \(^3\)He 282 keV

Note: we use silicon surface barrier detectors and not silicon photodiode detectors.
Acceptance of collimator

Acceptance: $9.83 \times 10^{-8}$ (Srm$^2$)

Collimator
Diam. 3.8mm

Detector

Collimator

Detector
Data acquisition schema

3m (not drawn to scale) from detector to preamp was not part of the original design but was an unavoidable constraint caused by the logistics of installation on the mechanical arm.

Canberra 2003BT
Canberra 2111

Preamp

Amp

Peripheral Component Interconnect Express (PCIe) Expansion System
Digitizer

Supermicro 5016I-MTF
Adnaco-S2 PCIe and NI PCI-5105 high-speed digitizer LabVIEW software

Fiber optic cable

Host PC

Silicon Surface Barrier Detector
Ortec CU_014-050-100S

2 Custom connectors (I/O) to enter MAST probe arm

Cables inside MAST probe arm

2 Custom connectors (I/O) to leave MAST probe arm
Signal dependence on Neutral Beam Injection

- Data continuously sampled at 60MHz
- Length of plasma discharge ~ 0.5s
- Signals/ pulses showed clear dependence on neutral beam power
Characteristic particle signals found in data

- **Peak/pulse shapes:**
- Height ~0.6V for P (3MeV)
- Height ~0.2V for T (1MeV)
- Width ~100ns

![Graph showing raw data signal and signal magnification](image)
Example noise signals found within a data channel

Raw Data Time Interval

Raw Data Time Interval

Voltage

Time [ms]

Voltage

Time [µs]
Pulse-height spectra without fitting data

- Search for peaks (within a threshold)
- Determine their pulse height
- Histogram of pulse height

Time Interval [150ms-200ms]

Pulse height [V]

Number of peaks

- Tritons (real)
- Protons (real)
- Simulated pulse 1V

Low energy and noise signals (real)
Peak fitting method to mitigate noise contribution

- Sample set of peaks are chosen, normalized, and used to create a peak fit function
  \[ V = V_0 e^{-c_1(t+t_0)}(1 + \tanh(c_2(t + t_0))) \]
- Data is fitted against quadratic background
Iteratively fit intervals of data within a channel

- Within a time slice:
  - Fix peak positions (width)
  - Vary peak height (to get fit amplitude)
  - Vary background (quadratic)