Measurement of the Hard X-ray Emission Spectrum from MST

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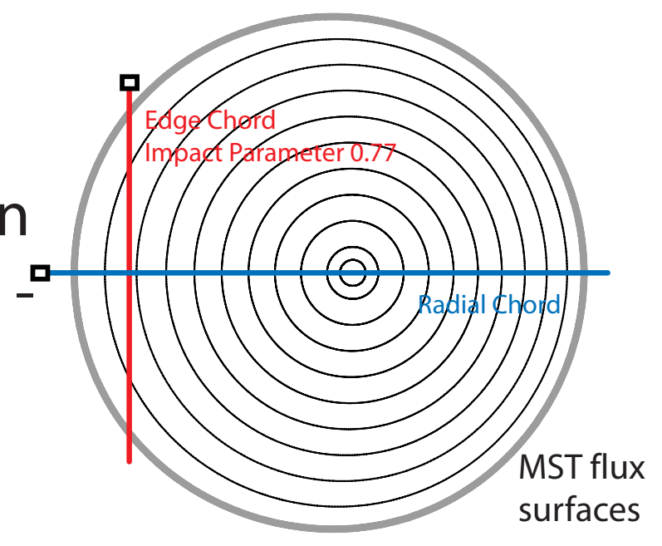
When used in conjunction with the CQL3D code, X-ray spectra and flux allow estimates of fast electron population and diffusion coefficient.

Using new solid state materials - compact, flexible and low maintenance high energy X-ray diagnostics are possible with low cost.

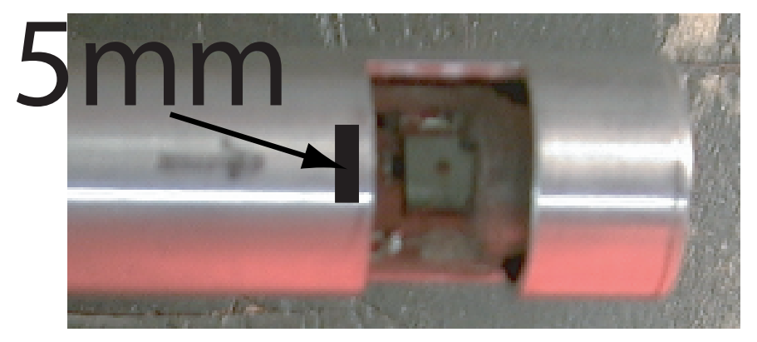
INTRODUCTION:

Cadmium-telluride (CdTe) X-ray detectors in the 5-150KeV energy range have been used to measure the hard X-ray spectrum on MST for a range of plasma parameters. A direct digitization proceedure has been used to measure the X-rays rather than the conventional energy discrimination and counting. This allows a simpler hardware setup with flexible energy and time binning with no increase in cost. Modelling using the CQL3D Fokker-Planck code gives estimates for the fast electon population and diffusion coefficient.

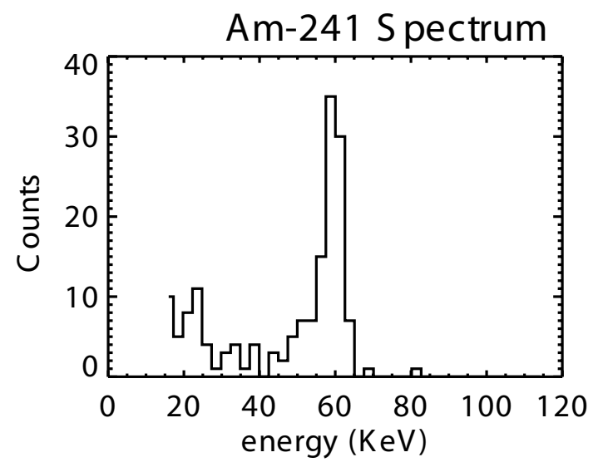
HARDWARE SETUP:



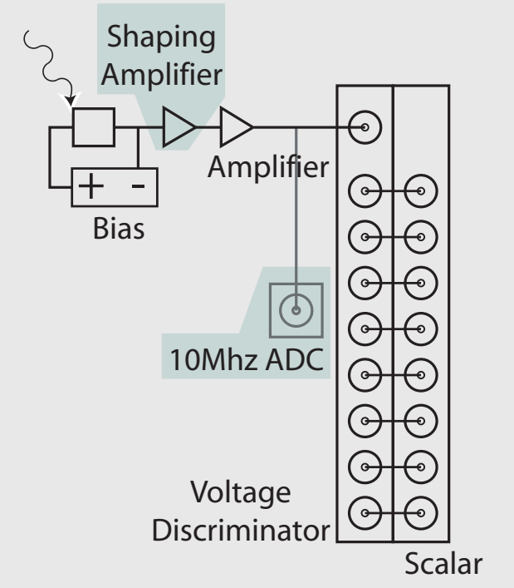
Line integrated measurements have been made using a radial chord and an edge chord, as shown on the right. The CdTe detector itself is compact - typically 10mm x 10mm x 2mm. An image of the detector is shown below:



Energy resolution:
~ 5KeV - 150KeV
~7% resolution.



DIRECT DIGITIZATION SIMPLIFIES THE HARDWARE SETUP



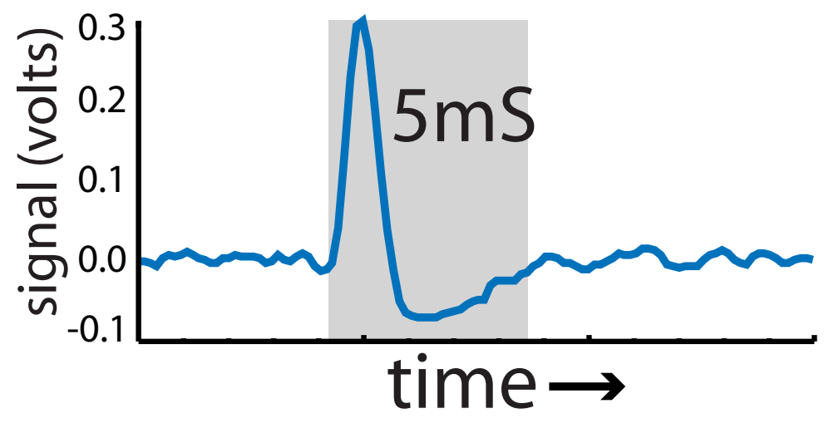
The detector is biased to 200V, and current pulses are amplified using a transconductance amplifier. The pulse output is then processed through a standard shaping amplifier. Conventionally the pulses are then subjected to an energy discriminator and counter array of some sort. We have switched to a direct digitization method.

DIRECT DIGITIZATION GIVES BETTER CONTROL OF FITTING AND BINNING DATA

Flexible binning in time or energy, depending on flux rates the balance between time resolution and energy resolution can be adjusted dynamically.

Better noise immunity and pile up detection. Noise and Pile up events are identifiable - often not so for counters. A higher level of pile up can be tolerated allowing the maximum flux.

Cost effective - costs the same as counter/discrimination combination.



Using 10Mhz sampling time the fast pulses are well resolved. Their shape is very distinguishable from noise.

Any given time history is scan for pulses and events are stored with a time and energy.

MEASUREMENTS MADE ON MST:

Measurements have focused on 4 discharges types:
Low and high current standard plasmas
Low and high current Pulsed Poloidal Current Drive (PPCD) plasmas

Measurements are consistent with higher confinement for PPCD plasmas.

In PPCD plasmas a poloidal current is driven in the conducting shell. This modifies the toroidal magnetic field which in turn induces a poloidal electric field in the plasma. The field is chosen to flatten the current profile - thus forcing the plasma into a minimum energy state, reducing magnetic activity and in improving confinement.

CQL3D MODELLING:

CQL3D is a quasi-linear 3 dimensional Fokker-Planck code and has been used to model the MST plasma conditions.

The code is a major test of the consistency of the major plasma diagnostics

DESCRIPTION OF CODE:

Evolves full distribution functions on collisional and transport times.
Full radial diffusion of distribution functions - $f_{e,i}(r,v_\perp,v_{||},t)$
Has toroidal symmetry, non-circular plasmas,
Is coupled to RF, NB and pellet codes.

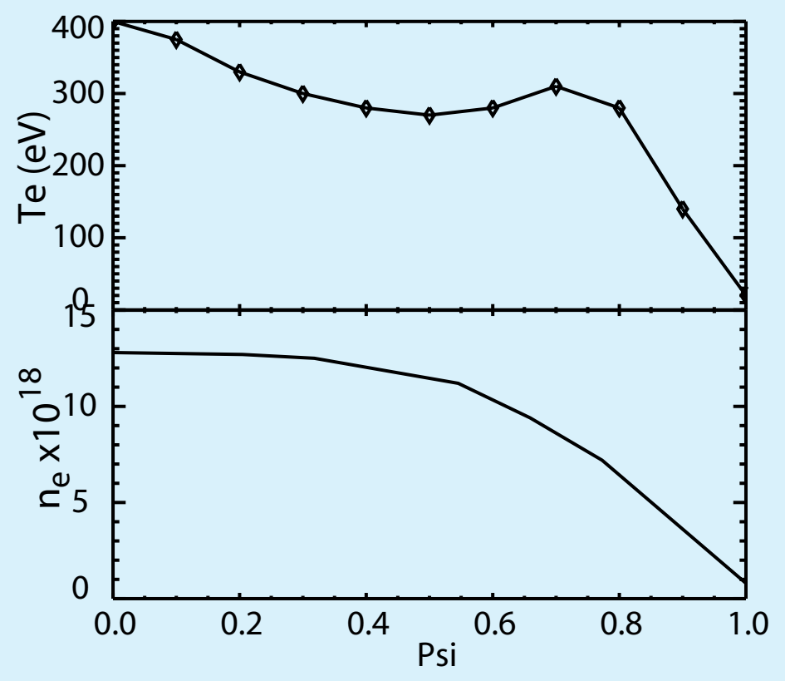
MODELLING MST PLASMAS:

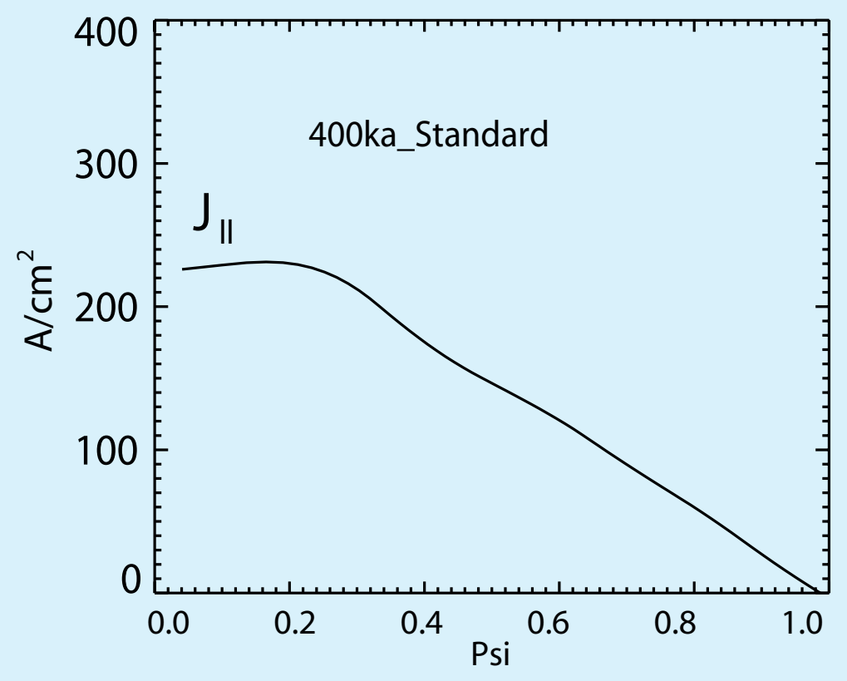
Inputs: Electron density and temperature profiles (n_e, t_e) are input to the code. Parallel electric field ($E_{||}$) and diffusion coefficient (D) are modified to fit the data for a range of Z_{eff}.

Outputs: X-ray spectra, full electron distribution, constrains diffusion coefficients and Z_{eff}.

STANDARD PLASMA

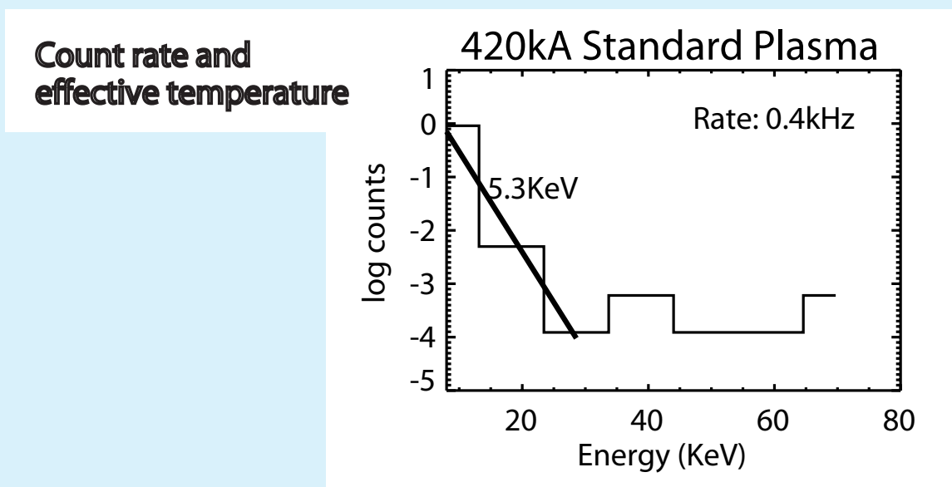
X-rays not typically seen for standard plasmas
Only seen during high current plasmas.



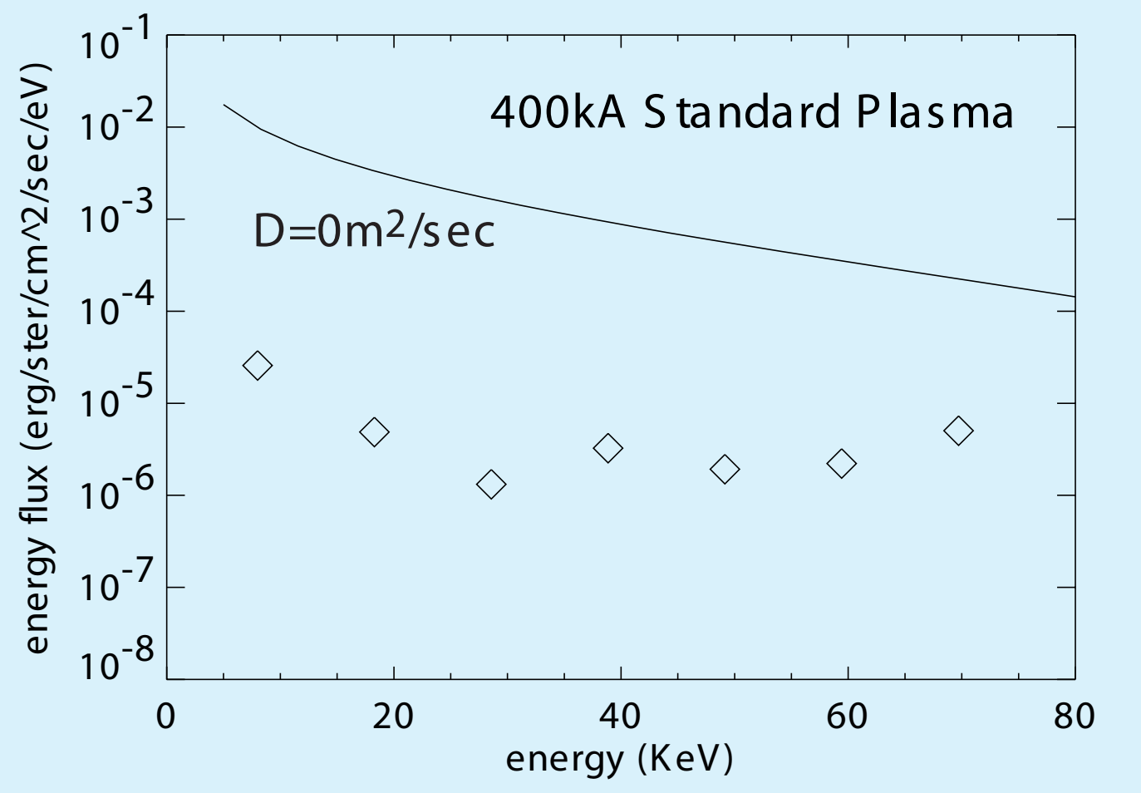


PLASMA CONDITIONS

Plasma current: 420kA
Core temperature: 400eV
Density: 1 x 10^{19} m^{-3}



ABSOLUTE ENERGY FLUX FOR HIGH CURRENT STANDARD PLASMA (0.4 kHz flux):

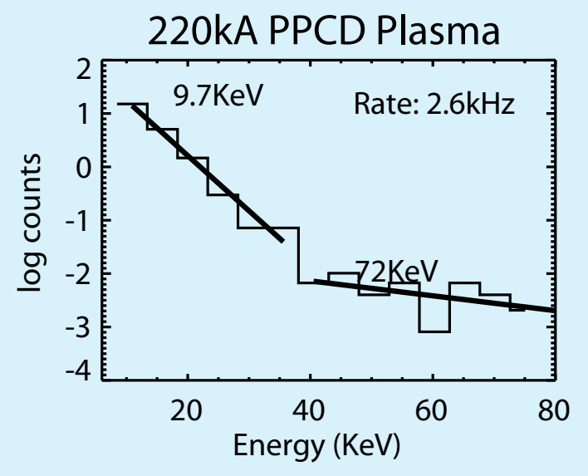


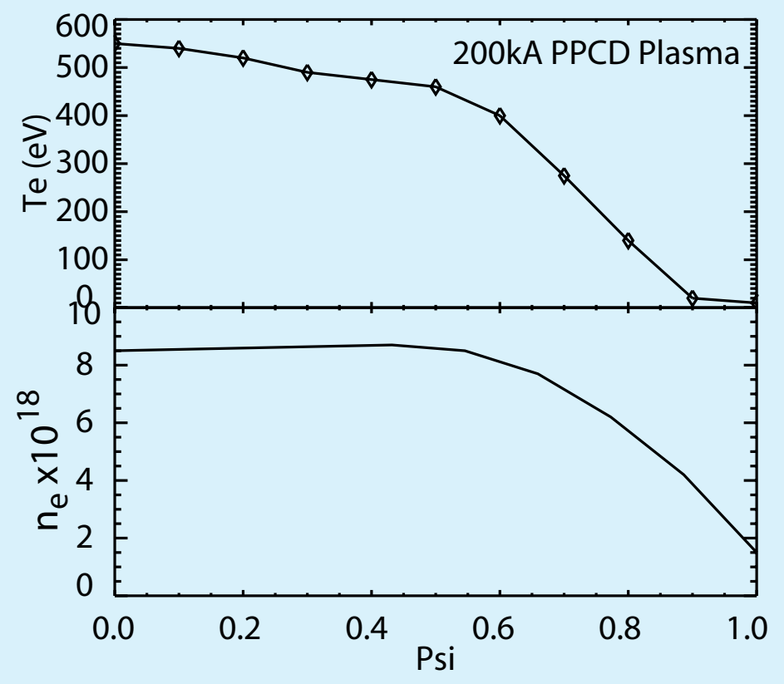
PPCD PLASMA

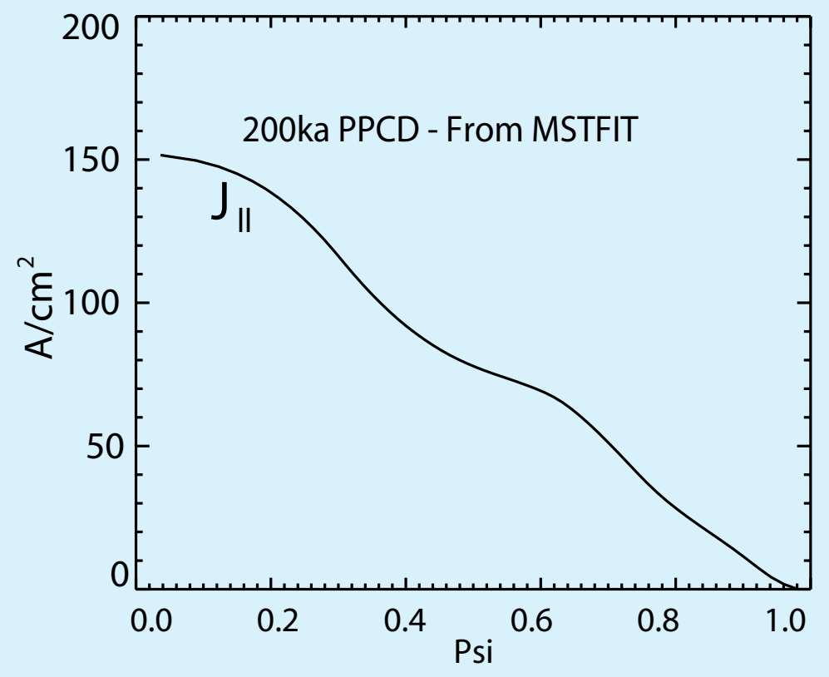
X-rays usually seen during PPCD plasmas

The data strongly supports the thesis that there is better fast electron confinement during PPCD Plasmas

Parallel electric field is lower during PPCD discharges
Yet flux goes up.
Modelling supports this.



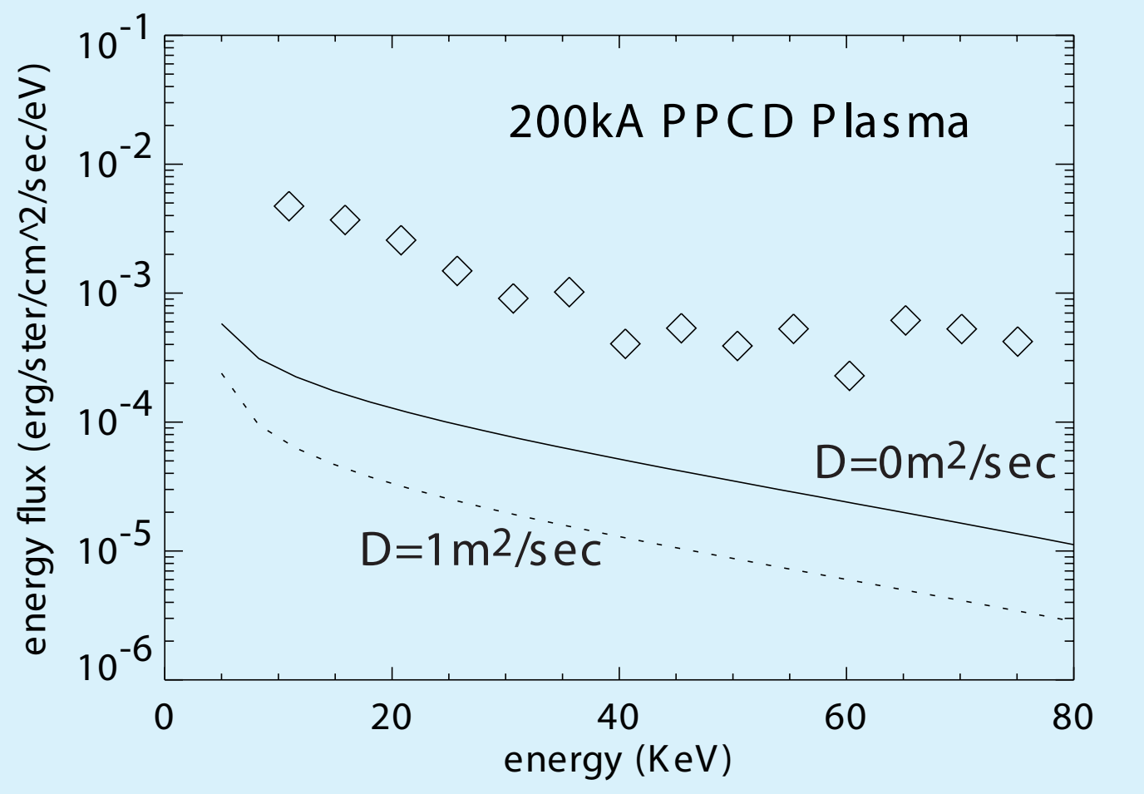




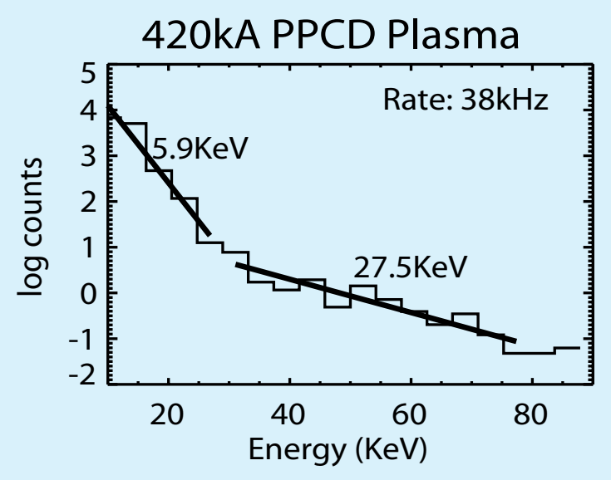
PLASMA CONDITIONS

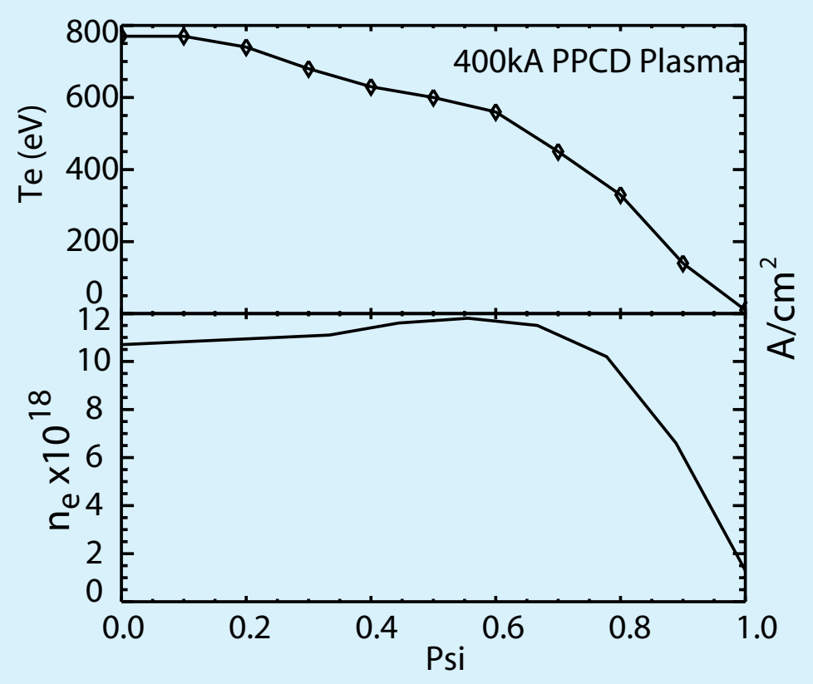
Plasma current: 220kA
Core temperature: 550eV
Density: ~1 x 10^{19} m^{-3}

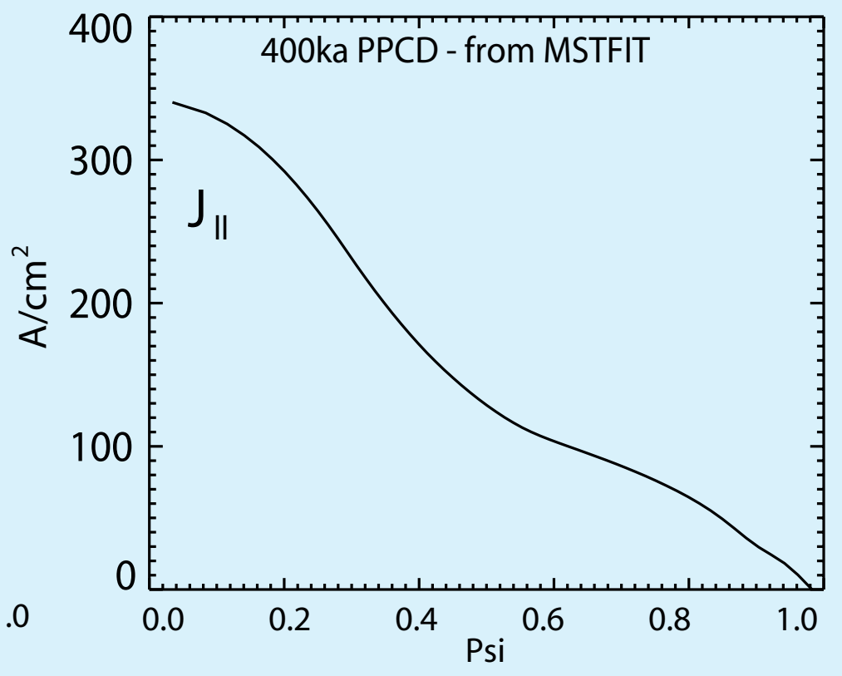
ABSOLUTE ENERGY FLUX FOR LOW CURRENT PPCD PLASMA (2.6 kHz flux):



The flux during high current PPCD discharges is two orders of magnitude higher than for corresponding standard plasmas.



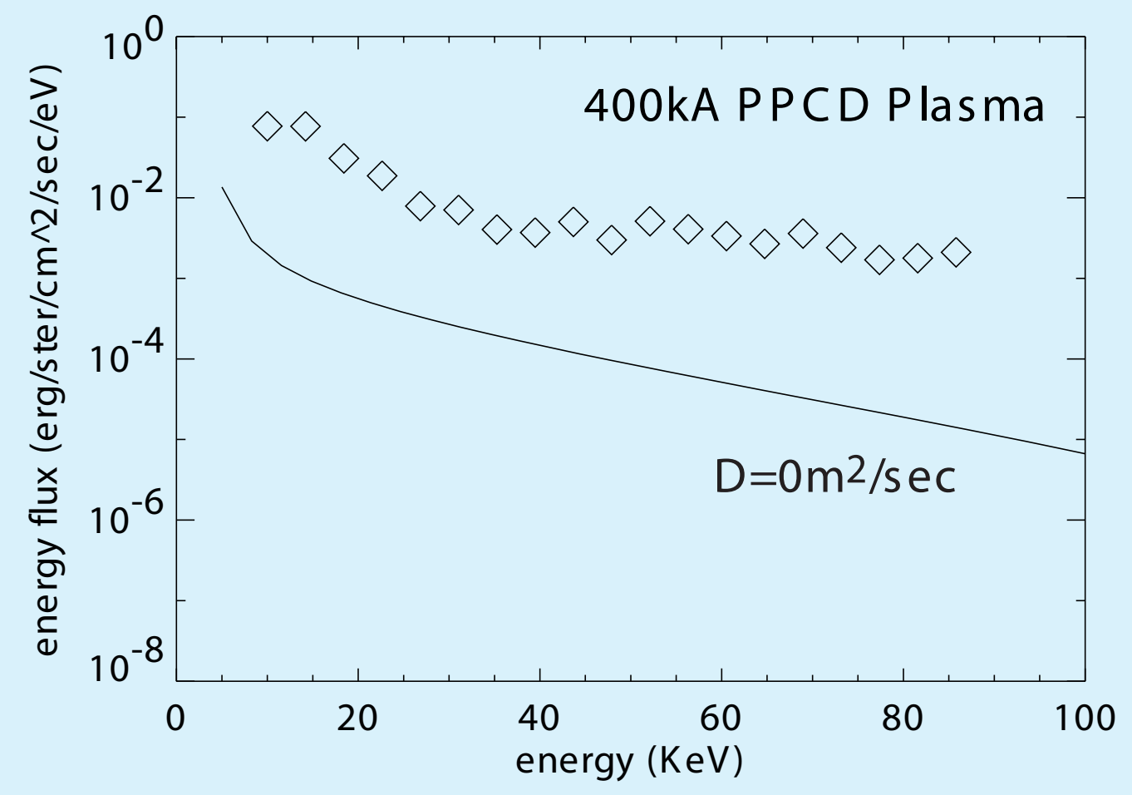




PLASMA CONDITIONS

Plasma current: 420kA
Core temperature: 800eV
Density: 1 x 10^{19} m^{-3}

ABSOLUTE ENERGY FLUX FOR HIGH CURRENT PPCD PLASMA (38 kHz flux):



MODELLING METHODOLOGY:
The code inputs the parallel electric field, and evaluates the current density from this for the plasma parameters entered.

Work is still at an early stage - for example the diffusion coefficent at present is constant for all energies.

KEY RESULTS from Modelling:

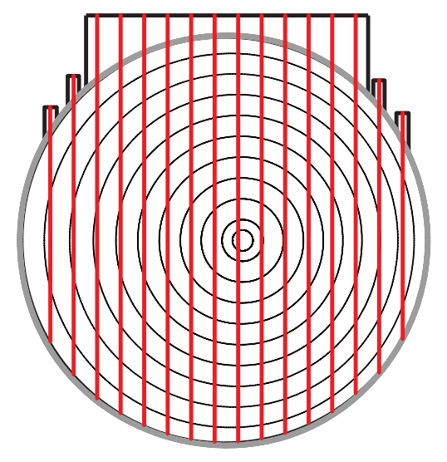
The code does remarkably well at determining the *absolute* energy flux. Initial results agree to approximately one order of magnitude.

Modelling matches PPCD data best with negligible diffusion coefficient.

Initial estimates give the resistivity in the core for high current PPCD plasmas at approx. twice Spitzer.

FUTURE WORK

The current system is being expanded to a 16 channel system. This will allow profile information to be collected. Newer cadmium-zinc-telluride (CdZnTe) detectors will be used.



More chords, as shown on the left will help to determine the diffusion coefficient.

Longer sampling time ADCs will be installed - a 16 channel VME based system will process the locally after each plasma and store just the time and energy of X-ray events on the main data system.

Ensembling will be used to examine X-ray activity during sawtooth cycle.

Radial diffusion during RF heating will be modelled and compared to experiments.
Modelling efforts will continue, both via further developments with the code and improvement of measured data input to the code.

CONCLUSIONS:

Direct digitization has been used with CdTe X-ray detector to measure X-ray flux during Standard and PPCD plasmas

Energy flux highest during PPCD plasmas - more evidence for improved electron confinement from code - low diffusion coefficient is needed to match measured energy flux rates.

Runaway electrons present during PPCD plasmas suggests good flux surfaces.

Modelling via CQL3D matches well with measurements. Absolute energy fluxes have been computed and are within an order of magnitude of measured fluxes. This work is ongoing.

Using the code to model the data estimates for the high energy electron distribution can be made.

Initial estimates for resistivity twice Spitzer for high current PPCD plasmas.

ACKNOWLEDGEMENTS:

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Special thanks to the MST for all their help.