Empirical model of fast-ion charge exchange emission in MAST

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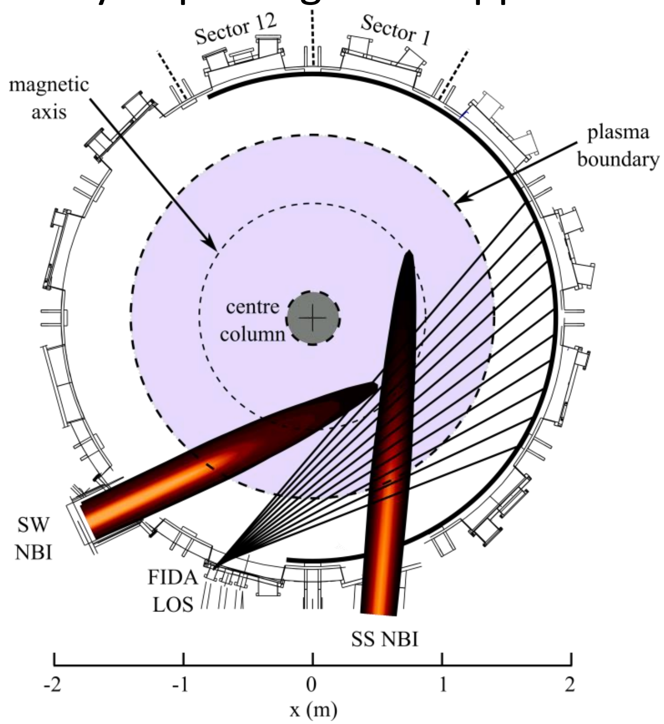
Introduction

- Fast-Ion Deuterium Alpha (FIDA) spectroscopy provides a spatially, spectrally and temporally-resolved measurement of the energetic-ion population in fusion plasmas.
- Based on CX reaction between fast ions and injected beam neutrals:

$$\mathrm{D_f^+} + \mathrm{D_b^0} \rightarrow \mathrm{D_f^{0*}} + \mathrm{D_f^+}$$

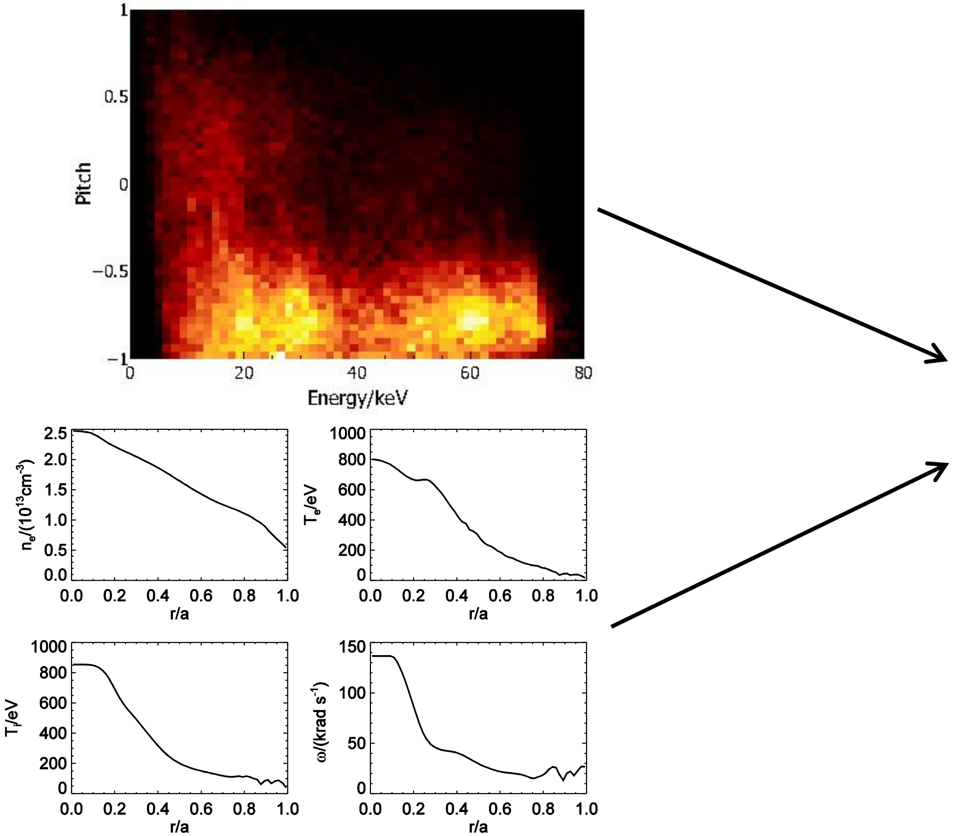
- System installed on the Mega-Amp Spherical Tokamak (MAST) has toroidal and vertical views, sensitive mostly to passing and trapped ions respectively.



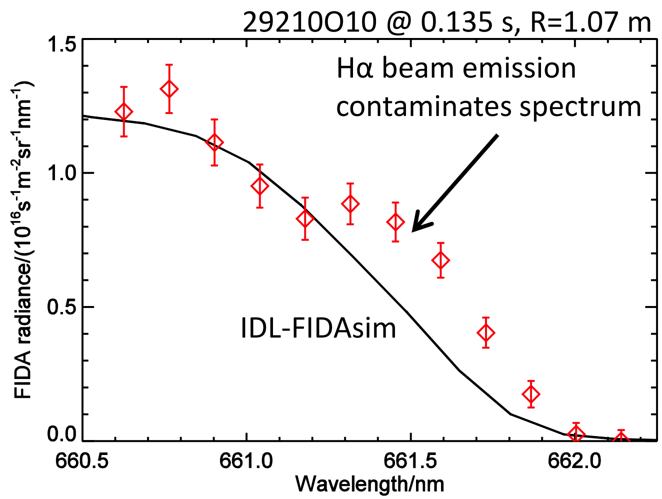
- Useful for studies of energetic-particle transport by MHD instabilities (kink modes, Alfvén eigenmodes, magnetic reconnection).

Objective

- Map synthetic fast-ion distributions from the Monte Carlo NUBEAM module[1] of the TRANSP code[2] to synthetic FIDA spectra for comparison with measurements:



[1] A. Pankin *et al*, Comp. Phys. Comm. **159** (2004), 157 – 184
[2] http://w3.pppl.gov/transp



- The FIDAsim code[3], developed by Heidbrink et al. at UC Irvine/GA:
  - Takes plasma profiles, equilibrium, beam power and fast-ion distribution from TRANSP output.
  - Maps profiles, beam geometry and FIDA sightlines onto grid.
  - Solves collisional-radiative model internally to determine FIDA radiance per marker particle.
  - Sums radiance over marker particles to generate spectra for each viewing chord.

[3] W.W. Heidbrink *et al.*, Commun. Comp. Phys. **10** (2011), 716 – 741

Motivation

- FIDAsim has proven successful in modelling FIDA spectra from DIII-D[4], ASDEX-Upgrade[5] and MAST[6].
- Using the Monte Carlo approach for ~10^6 fast ions + ~10^5 beam neutrals and solving the full collisional-radiative model for each marker is time consuming!
- …although a recent re-write of FIDAsim from IDL to FORTRAN-90 by Benedikt Geiger at IPP Garching has delivered an order of magnitude speed-up[7].

➢ ADAS should provide the required *derived* rate coefficients in a usable format, obviating the need for an internal solver.

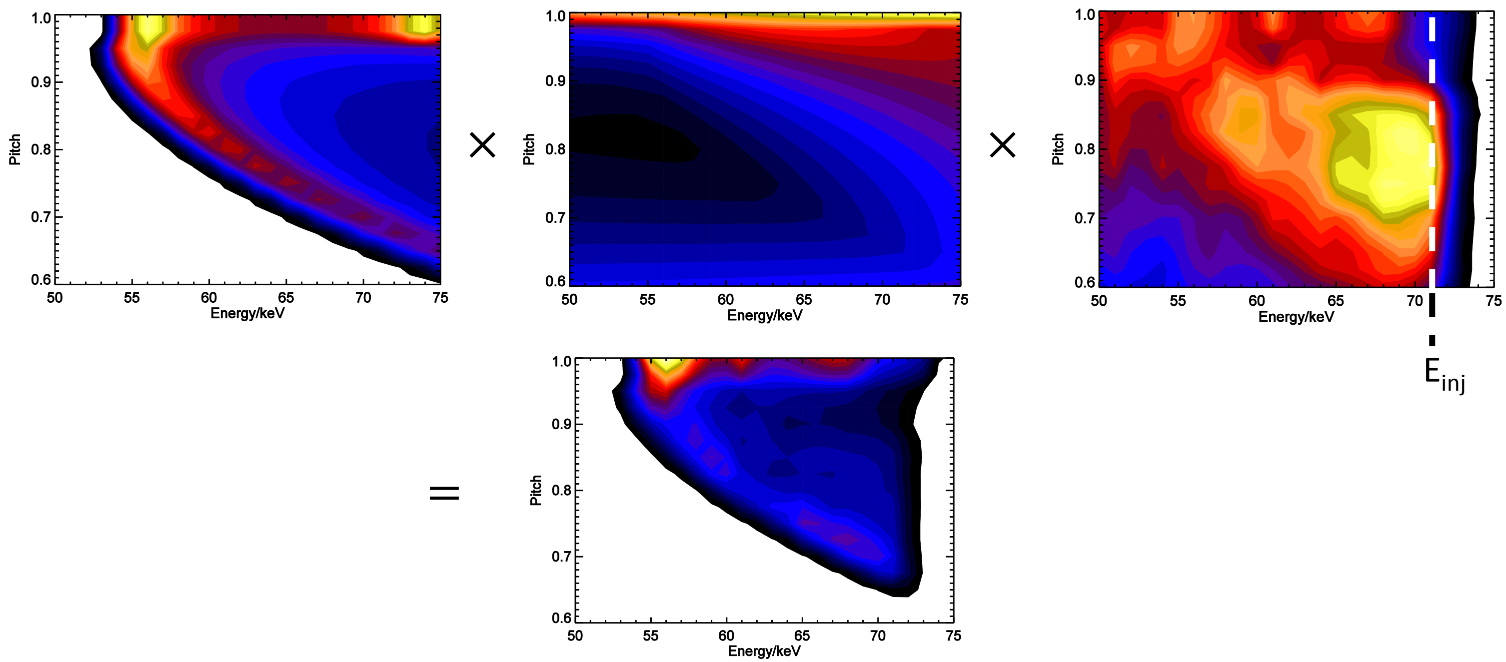
➢ Inspired by development of the NEBULA code for modelling of beam emission in MAST (S.H.).

[4] W.W. Heidbrink *et al.*, Plasma Phys. Control. Fusion **56** (2014), 095030
[5] B. Geiger *et al.*, Rev. Sci. Instrum. **84** (2013), 113502
[6] C.A. Michael *et al.*, Plasma Phys. Control. Fusion **55** (2013), 095007
[7] B. Geiger, *Ph.D. Thesis*, Ludwig-Maximilians-Universitaet, Munich (2012)

Weight functions

- Sensitivity of FIDA measurements has a complicated dependence on velocity space coordinates of fast ions.
- In each view, the sensitivity is parametrised by LOS-beam angle, LOS-field angle and beam-field angle.
- Described most naturally in terms of *weight functions* in velocity space:

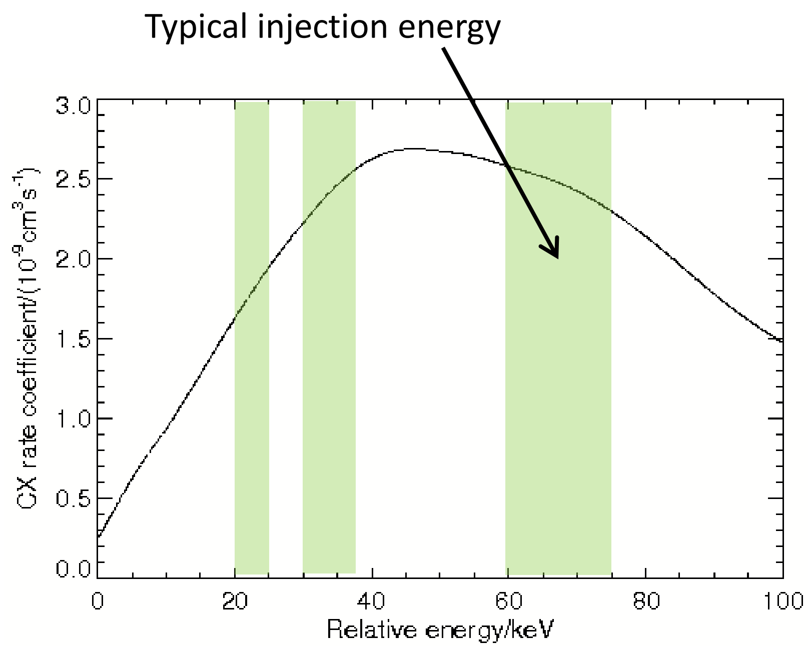
$$I_\lambda = \iint w_\lambda(v_\parallel, v_\perp; \bar{\theta}) f(v_\parallel, v_\perp) dv_\parallel dv_\perp$$

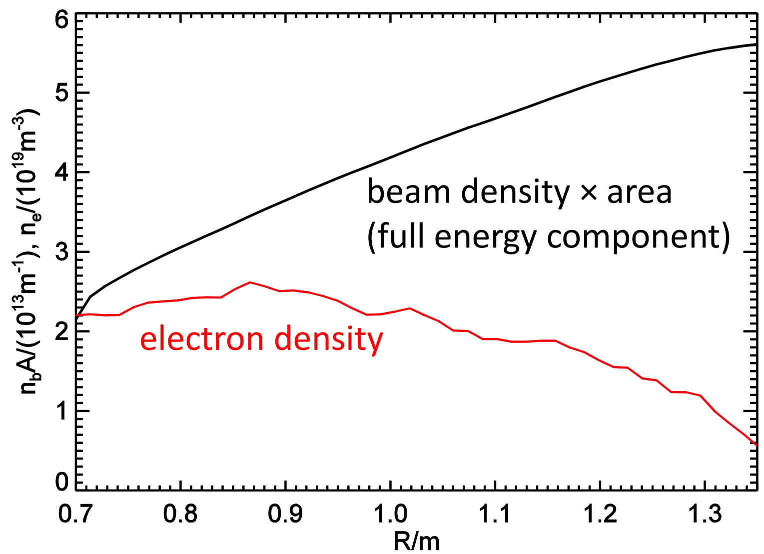


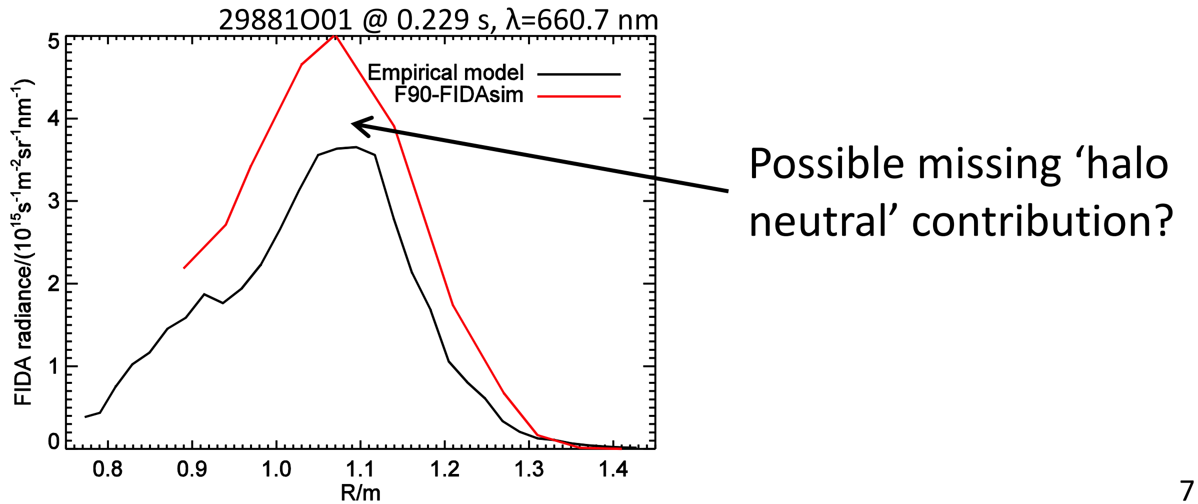
Atomic physics

- Neutral density along beam path obtained after mapping plasma profiles (n_e, T_e) onto path:
  - ADF21 files in /adas home directory interrogated directly by subroutine read_adf21.
  - Pure deuterium plasma (although inclusion of impurities should be straightforward, cf. NEBULA).
- Distribution of excited states (bundle-*n*) in beam determined from local plasma conditions:
  - ADF22 files, generated using ADAS312 and bundled with source code, interrogated directly by subroutine read_adf22.
  - Pure deuterium plasma (although inclusion of impurities should be straightforward).
- CX effective emission coefficient for Balmer alpha (656.1 nm) line:
  - ADF12 file interrogated using ADAS303 to provide look-up table.
  - *n*=2 donor coefficient approximated as 0.25*2s + 0.75*2p donor coefficients.
  - *n*=4 donor coefficient approximated as (0.25 * *n*=3 donor coefficient).
  - Truncated at *n*=4 due to negligible donor density above this level.
- Beam neutral – fast ion relative velocities averaged over narrow range of gyro-angles contributing to signal at each point in velocity space, at each radius.

FIDA emission



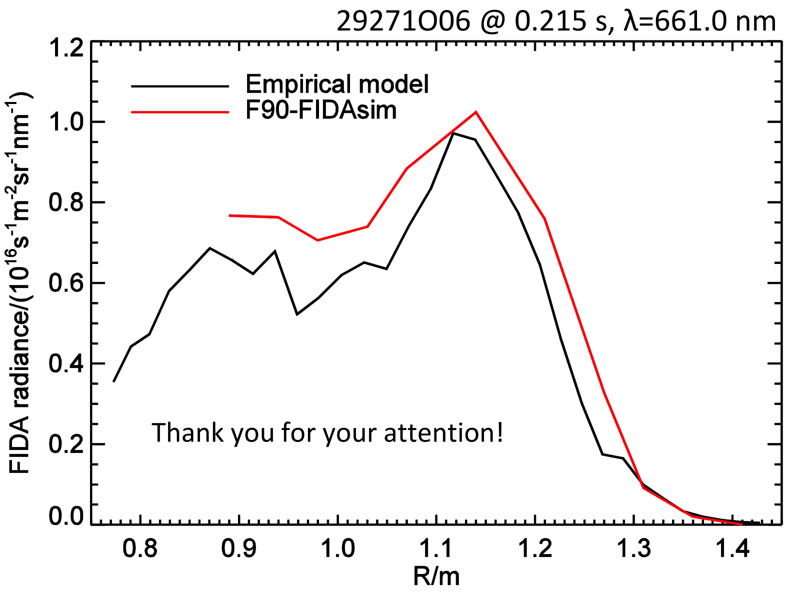




Ongoing work

- Including halo neutral contribution to FIDA CX emission:
  - beam stopping × (CX rate/ionization rate) gives birth rate of halo neutrals at each point along beam.
  - Diffusion of halo neutrals from source taken to reach steady state with ionization.
  - Solution given by sum of Bessel functions convolved with Gaussian beam profile.
  - Easier calculation for CX, since relative velocity = fast-ion velocity.

- Investigating discrepancy of radial profile with respect to data:
  - Modelled profiles shifted inward by approximately 7 cm compared to measurements.
  - Suspect faulty correction for FLR effects (in TRANSP output?).
  - Need to triple-check spatial calibration via beam emission redshift (*in situ* alignment data to be analysed).



Thank you for your attention!