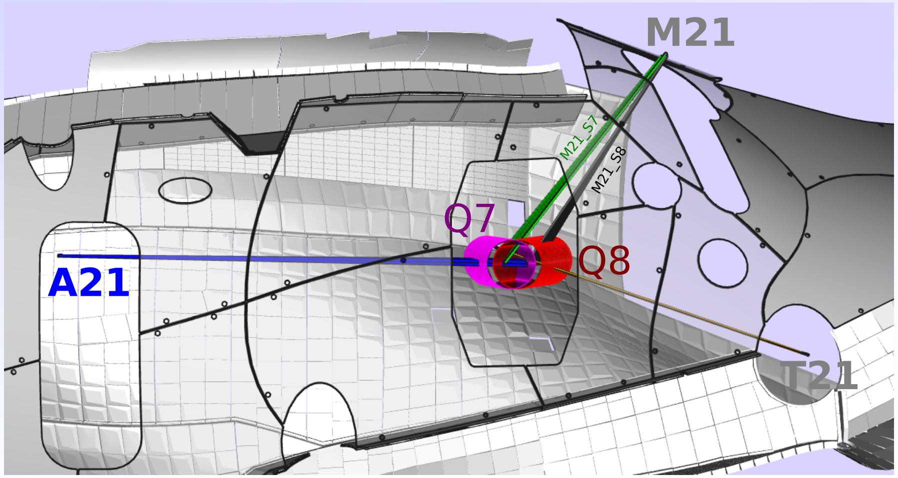
Charge Exchange Recombination Spectroscopy at W7-X.

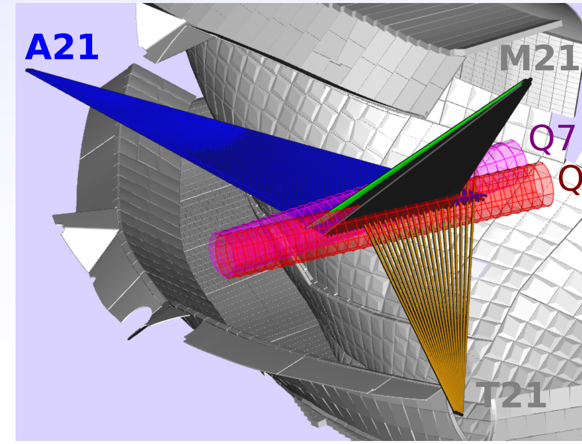
Physics Meeting 29.10.18

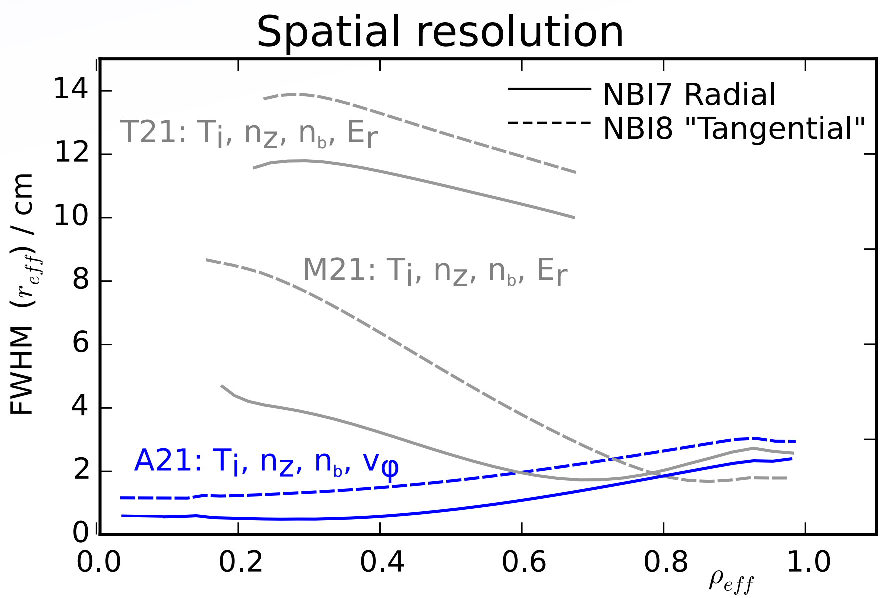
O. P. Ford[1], L.Vanó[1], T. Neelis[3], C. Biedermann[1]
S. Bozhenkov[1], R. McDermott[2], A. Kappatou[2], R. Wolf[1]

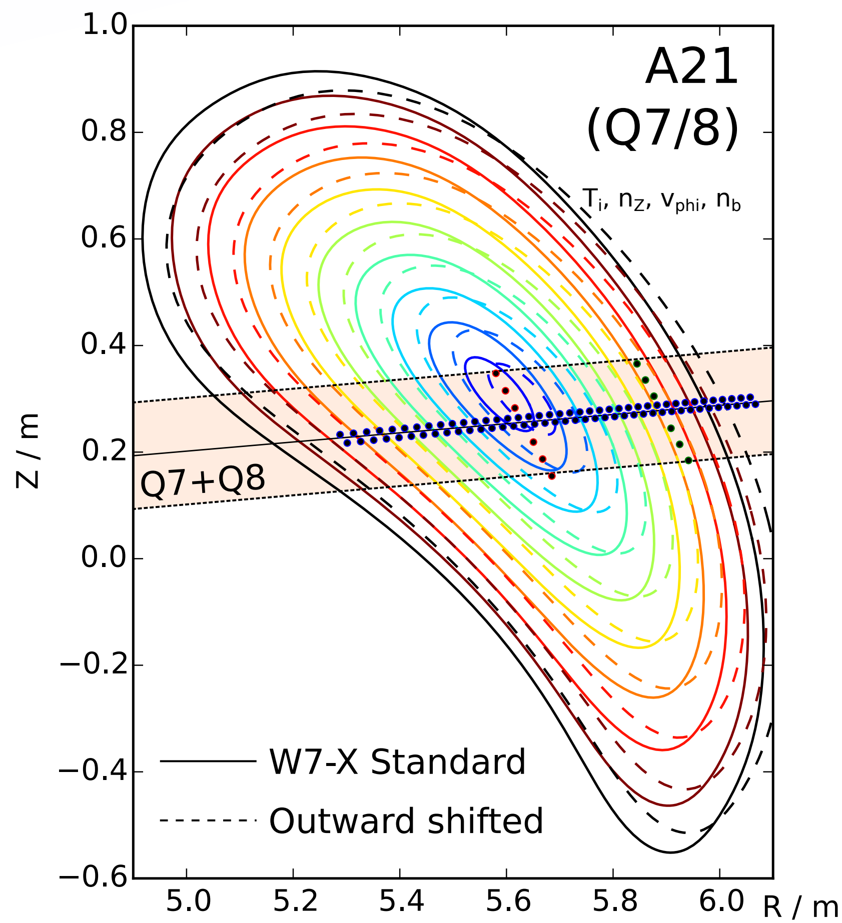
1: Max-Planck Institut für Plasmaphysik, Greifswald, Germany
2: Max-Planck Institut für Plasmaphysik, Garching, Germany
3: TU/e, Eindhoven

Observation Systems







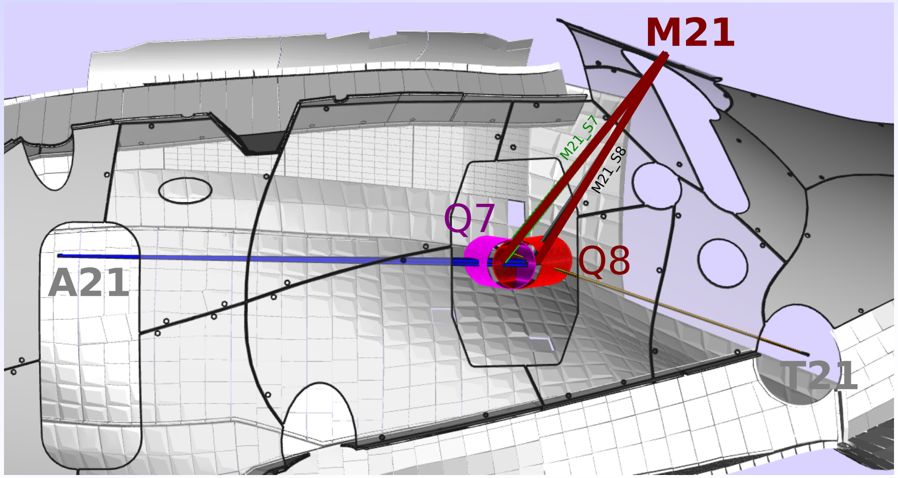


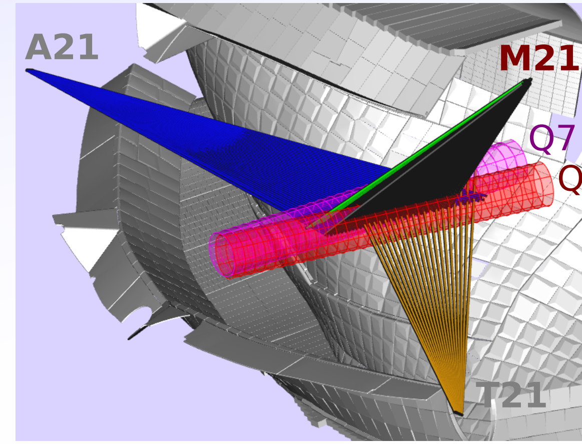
AEA21: High resolution, toroidally viewing system.

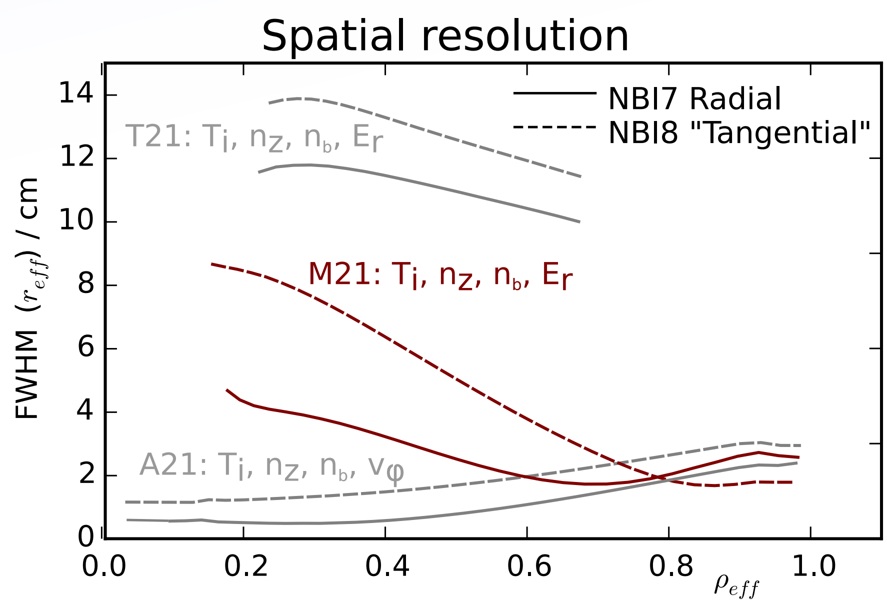
AEM21: 45° to toroidal. Primarily for Er.

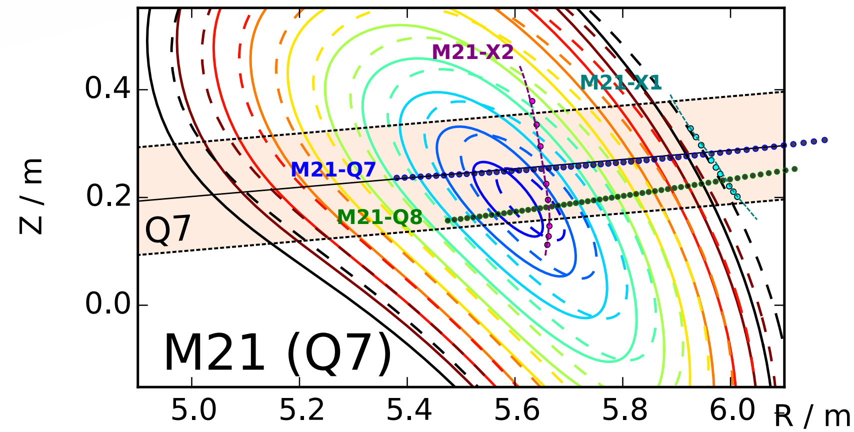
AET21: Low resolution overview/cross-check. -45° to toroidal.

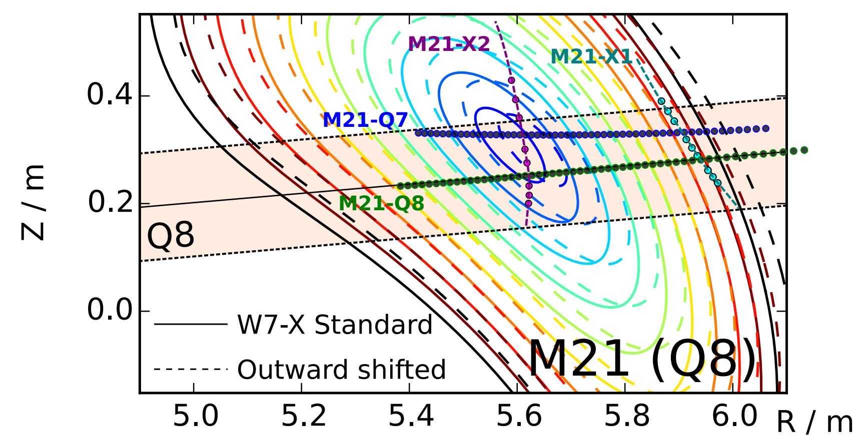
Observation Systems









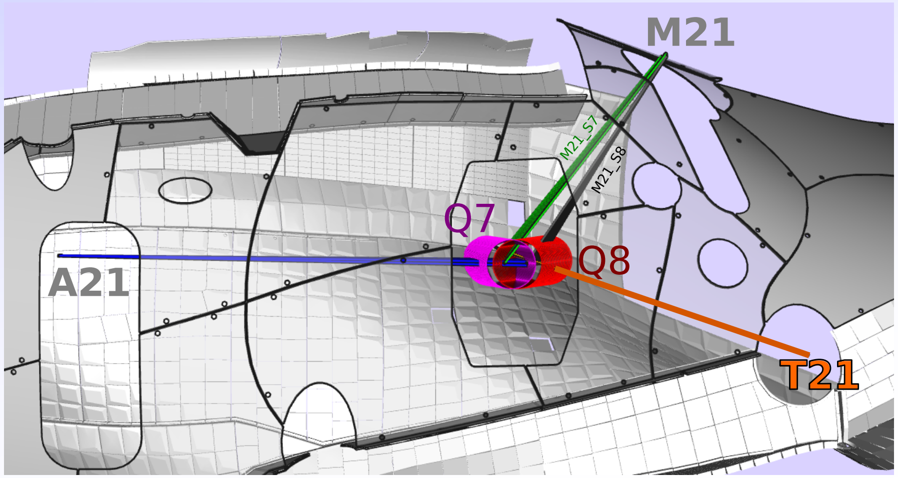


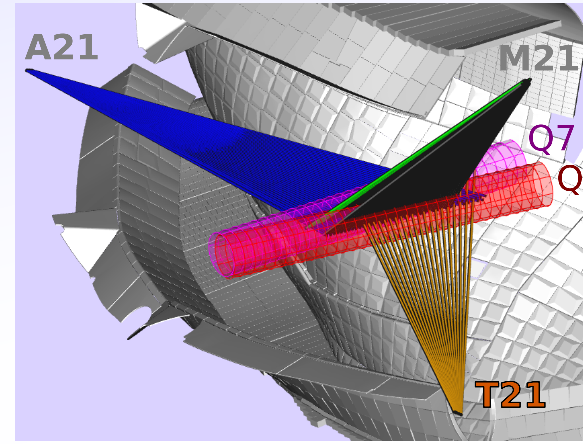
AEA21: High resolution, toroidally viewing system.

AEM21: 45° to toroidal. Primarily for Er.

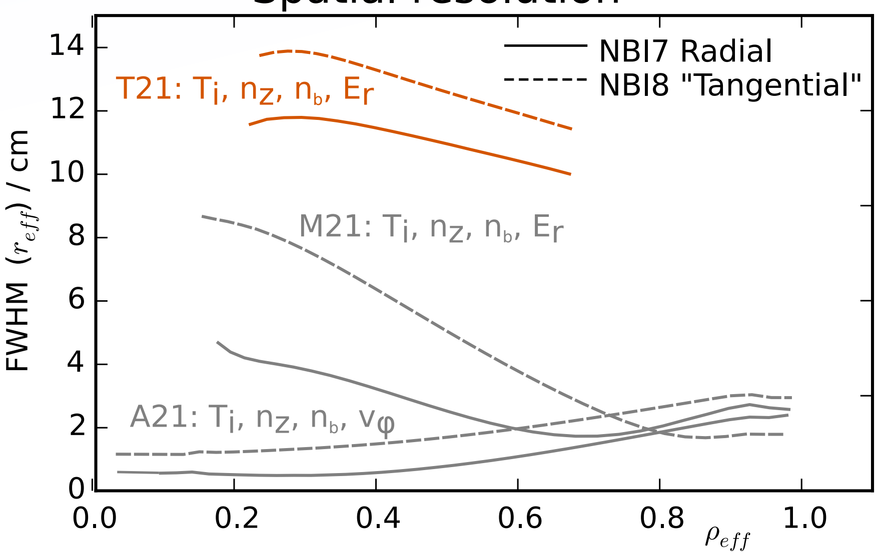
AET21: Low resolution overview/cross-check. -45° to toroidal.

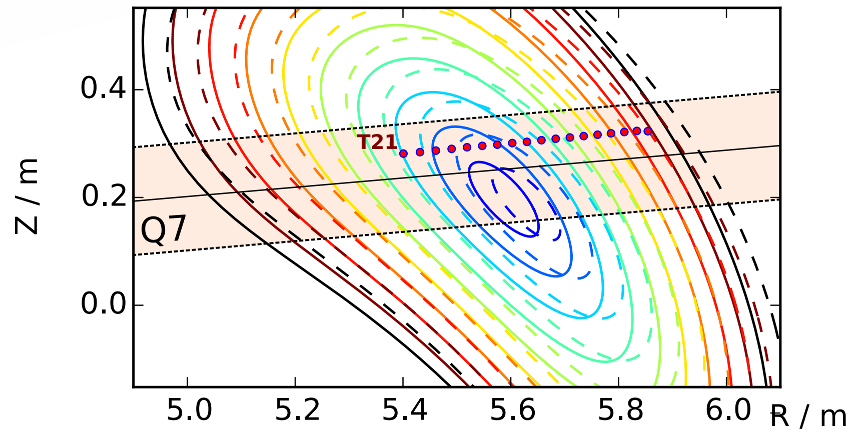
Observation Systems

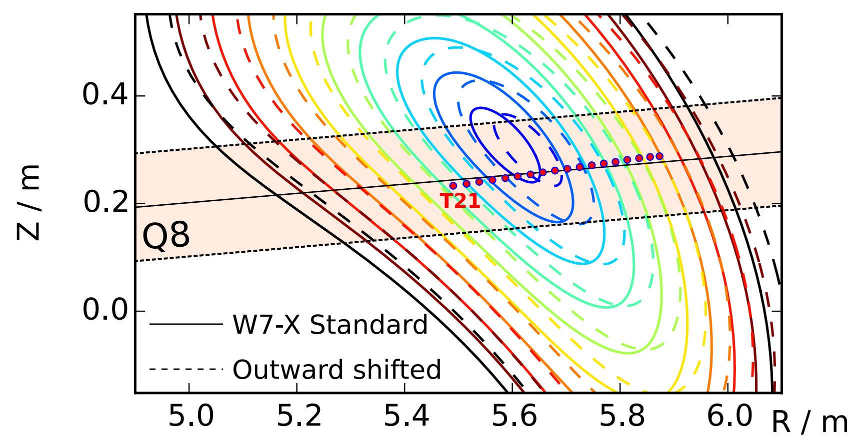




Spatial resolution







AEA21: High resolution, toroidally viewing system.
AEM21: 45° to toroidal. Primarily for Er.
AET21: Low resolution overview/cross-check. -45° to toroidal.

Spectrometers

5 Spectrometers provide 300 measurements, each a mix from A, M and T ports:

ITER-Like Spectrometer (ILS) - Base system, 52 channels:
Red (Halpha) --> n_b and FIDA, maybe one day T_H, n_H, n_e
Green (529nm) --> T_i, n_C, E_r
Blue (468nm) --> n_{He}, but poorly optimised during OP1.2b.

Always available

AUG1 - Secondary impurities 1: 43 channels
Mainly n_O, n_B, n_C and more T_i, E_r.

Variable settings

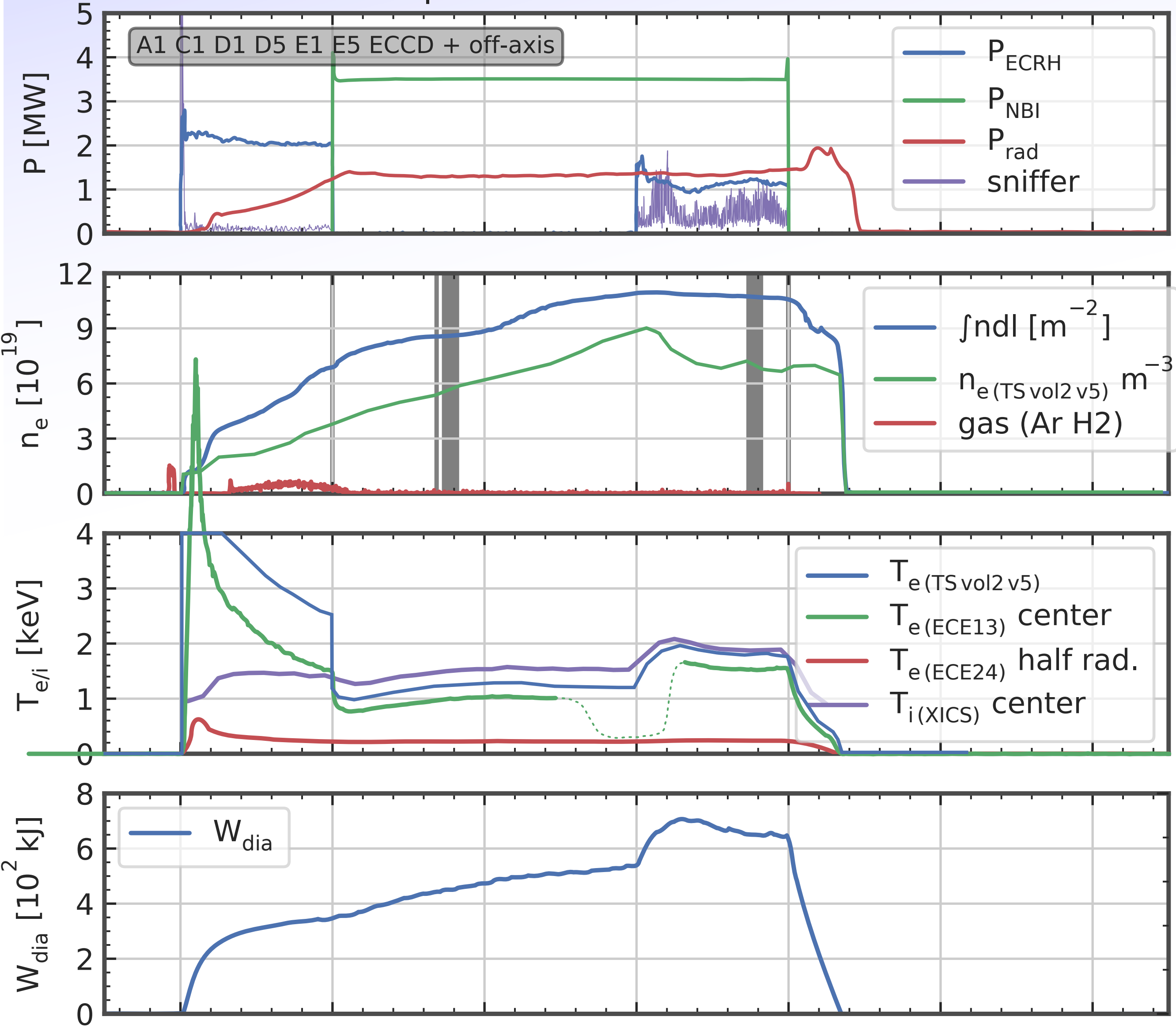
AUG2 - Secondary impurities 2: 37 channels
Injected impurities: B, N, Fe^{23+}, Fe^{24+}, Ar

NIFS He - 30 channels. (K.Ida and M.Yoshinuma)
He/H ratio
NIFS H - 30 channels.
High resolution Halpha for He/H ratio.
But also for BES --> n_b, FIDA, n_H, T_H ...

Avaspec: 1 channel.
Full visible spectrum for active CX line searching.

Example discharge: NBI + O2

W7-X 20181009.034 | UTC: 13:10:00



#20181009.034:

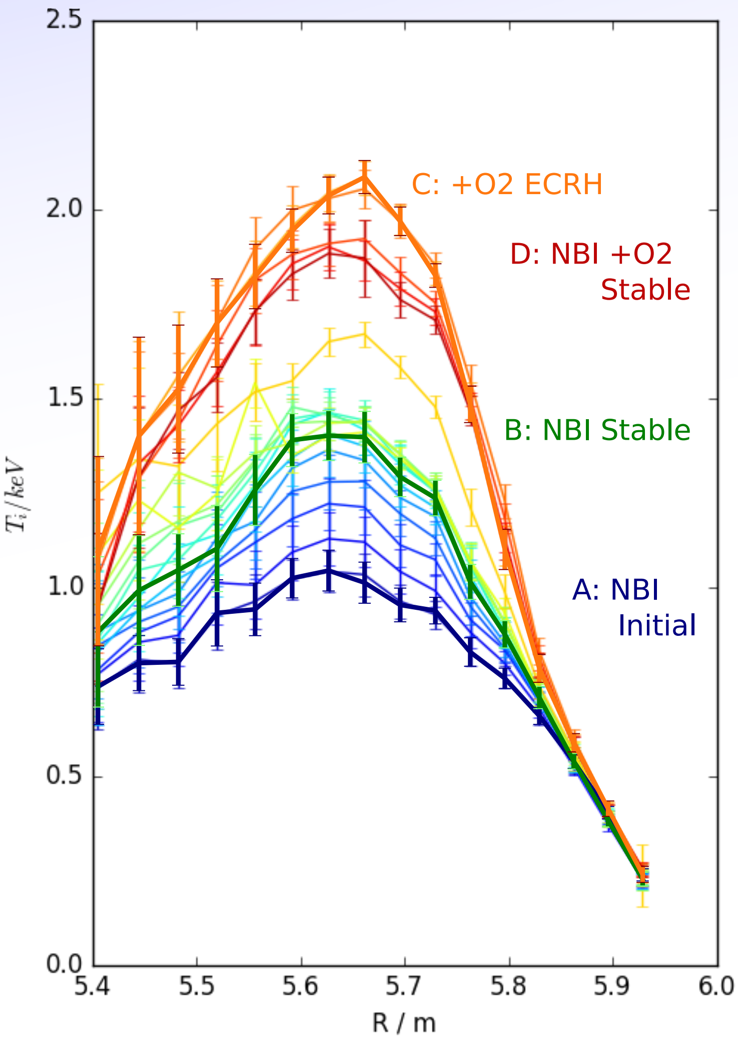
Pure NBI:
- Coupled T_e/T_i,
- Peaked density profile.

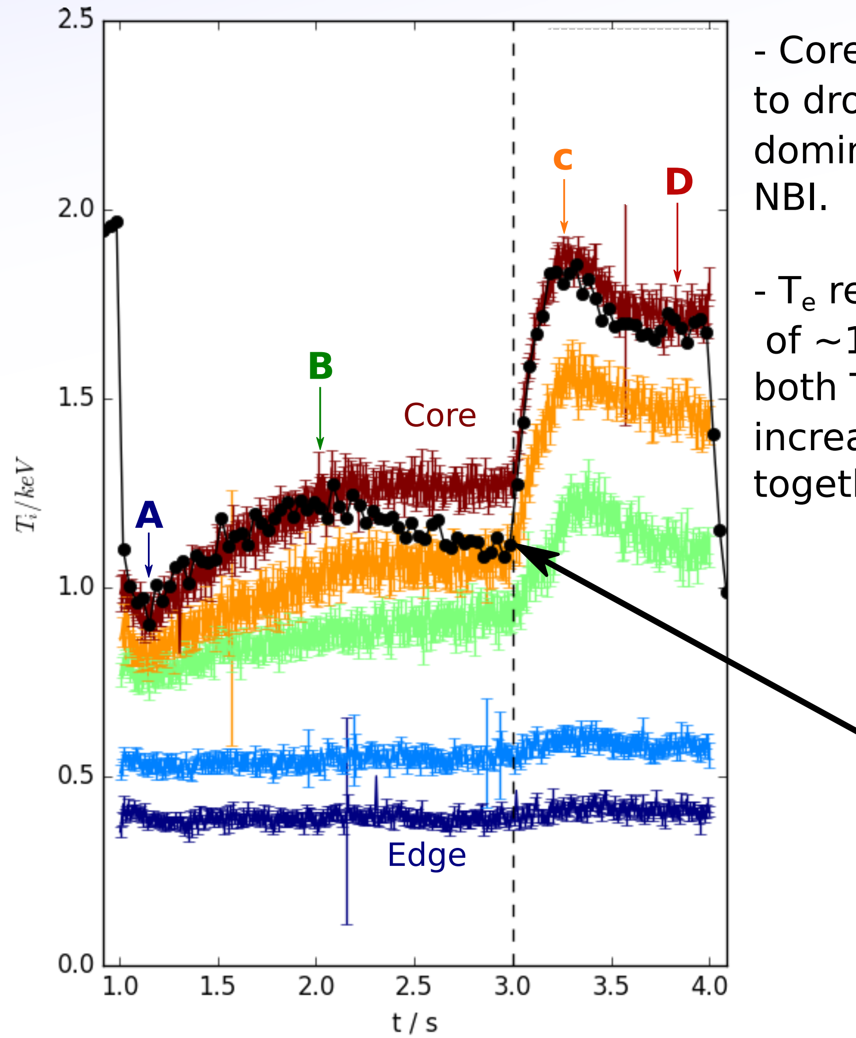
Reintroduce O2 ECRH:
- Increase T_e/T_i together
- Flush core density and impurities?

Route to high performance?

Example discharge: NBI + O2

Base system 'ILS Green': **A12** gives 3/4 full profile, typically at 7.5ms resolution:



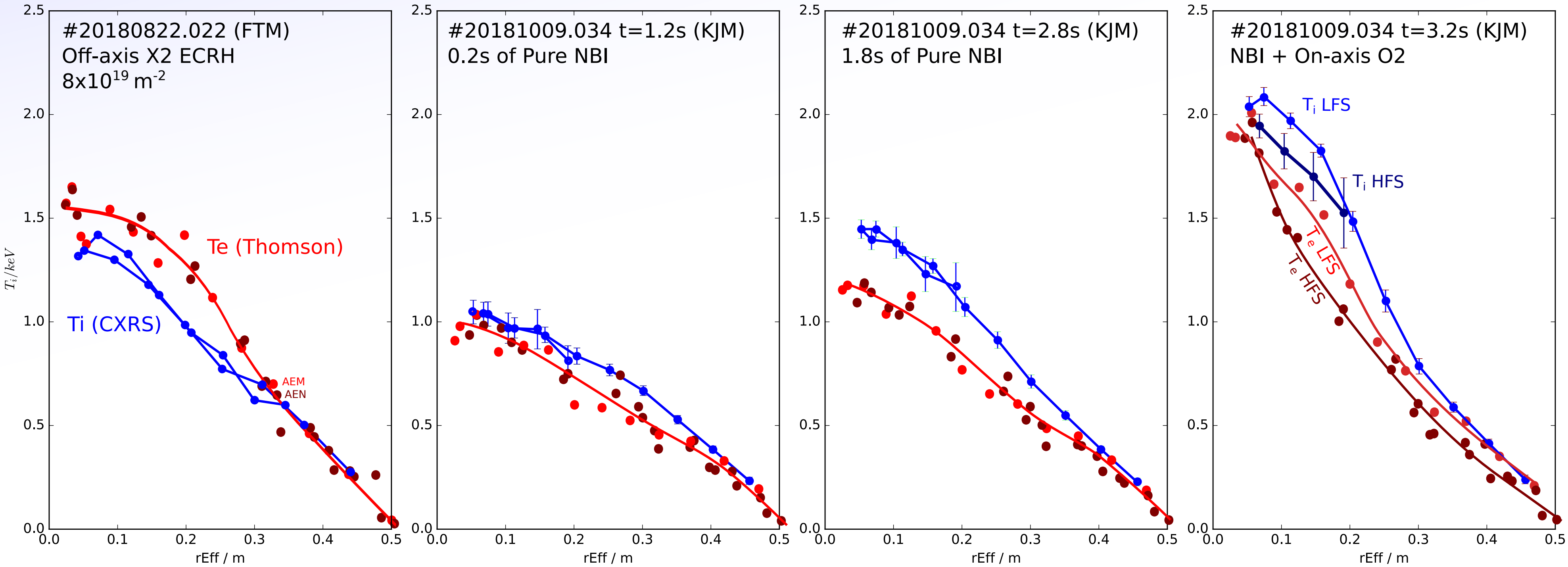


- Core T_e (Thomson) begins to drop below T_i due to dominant ion heating from NBI.

- T_e recovers after addition of ~1MW O2 ECRH and then both T_e and T_i increase dramatically together.

CXRS T_i vs Thomson Scattering T_e

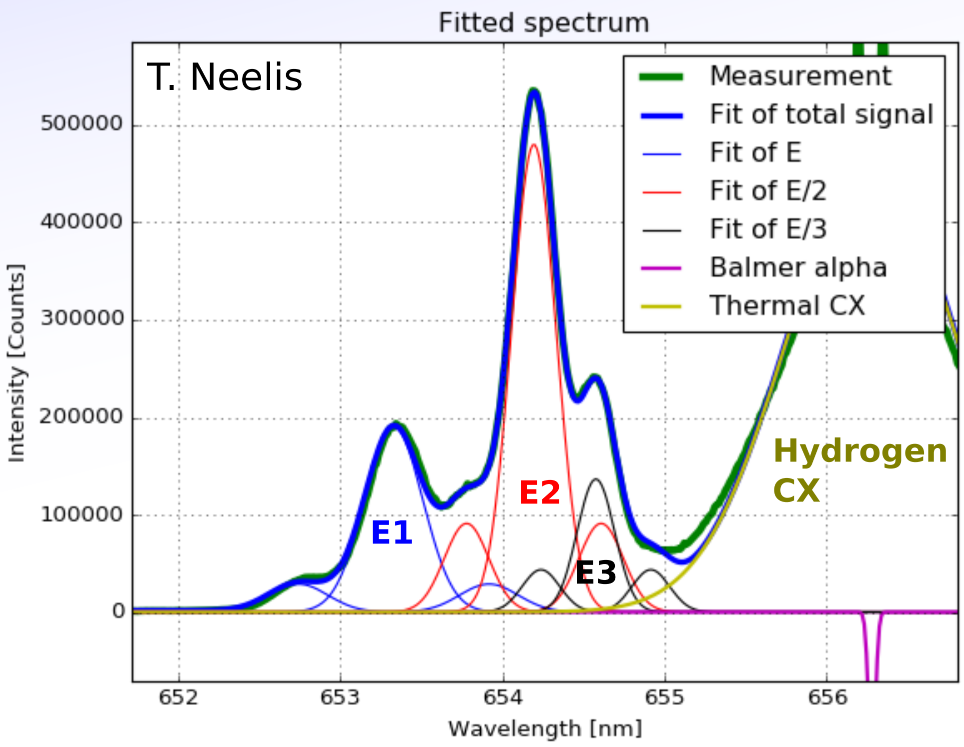
Match to Thomson scattering T_e is usually good for well coupled ($T_e \sim T_i$) plasmas.
T_e/T_i profiles show signs of heating mix effects (but we need to check mapping!)

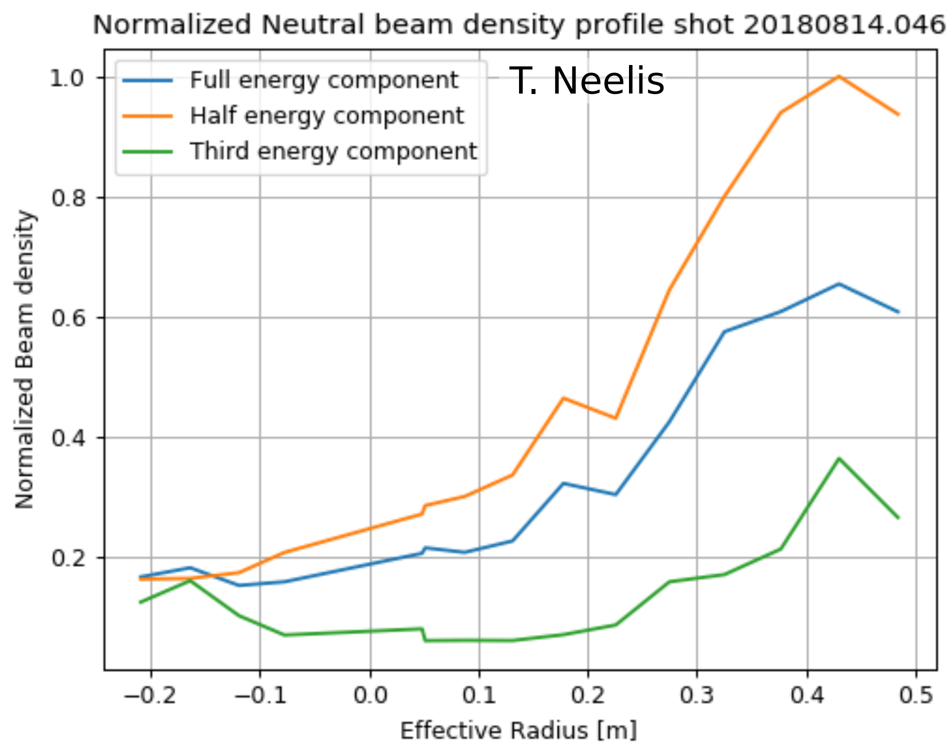


Mapping effects seen on both TS and CXRS HFS vs LFS for highest beta time point (beta=0 VMEC run used here)

Beam Attenuation

Base system 'ILS Red' measures the Hα spectrum - beam emission, Hydrogen CX and FIDA.
Beam attenuation/deposition caluclations and model comparison in progress (T. Neelis)
Very complex spectrum requires detailed modelling:





Beam density decay provides some information about electron density (at Δt ~ 10ms)

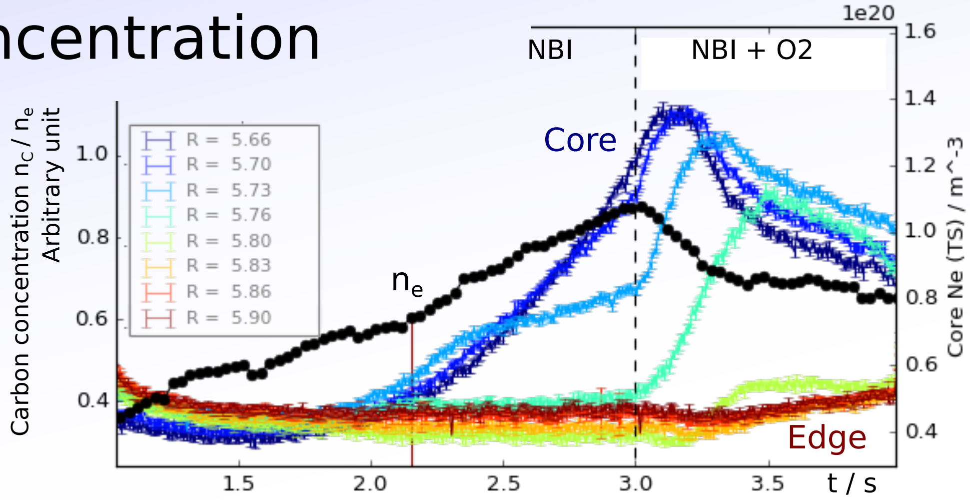
$$I \propto n_e \, n_b \qquad n_b = n_b(0)\, e^{-k \int_0^x n_e(x')dx'}$$

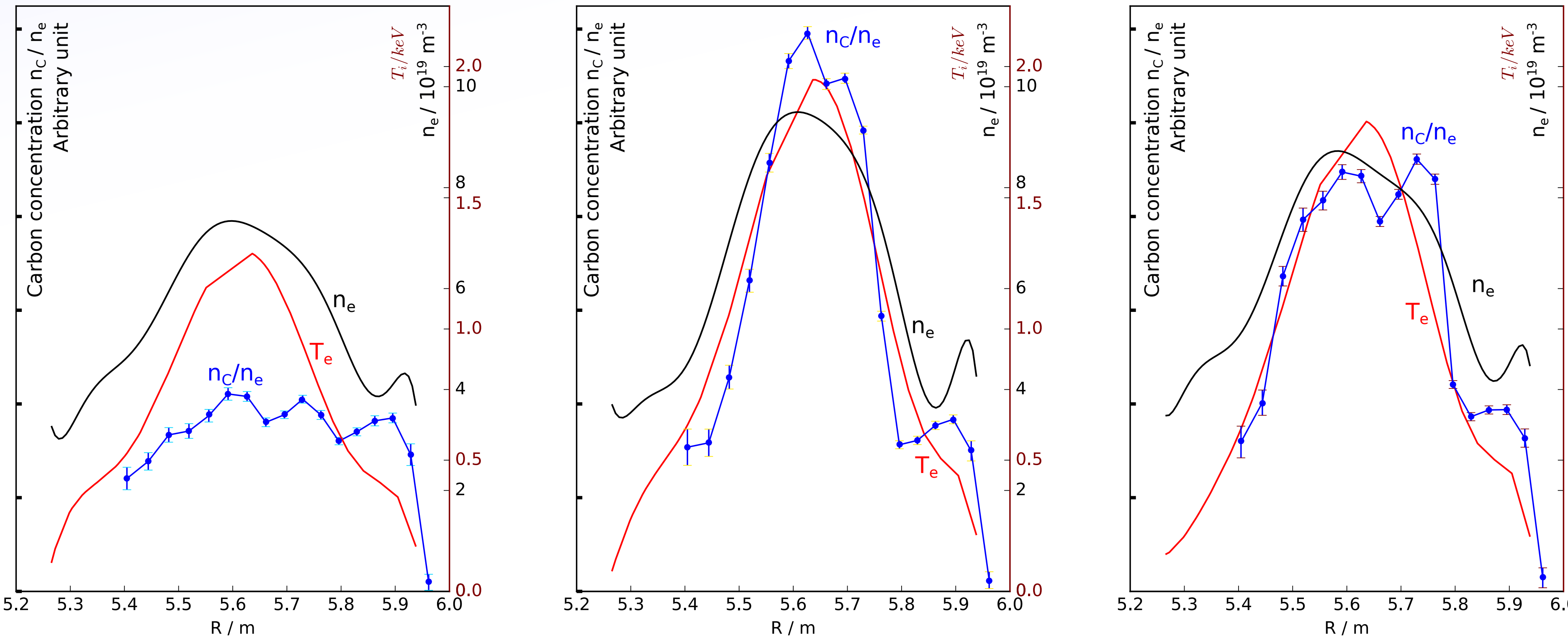
With detailed modelling, the Hα spectrum may allow calculation of the Hydrogen temperature and density (--> n_e, Z_{eff})

Carbon concentration

Base system 'ILS Green' provides carbon impurity density/concentration profile.

Full analysis is on-going (L. Vanó, PhD Project) but approx profiles and temporal changes can be seen from a simplified treatment:



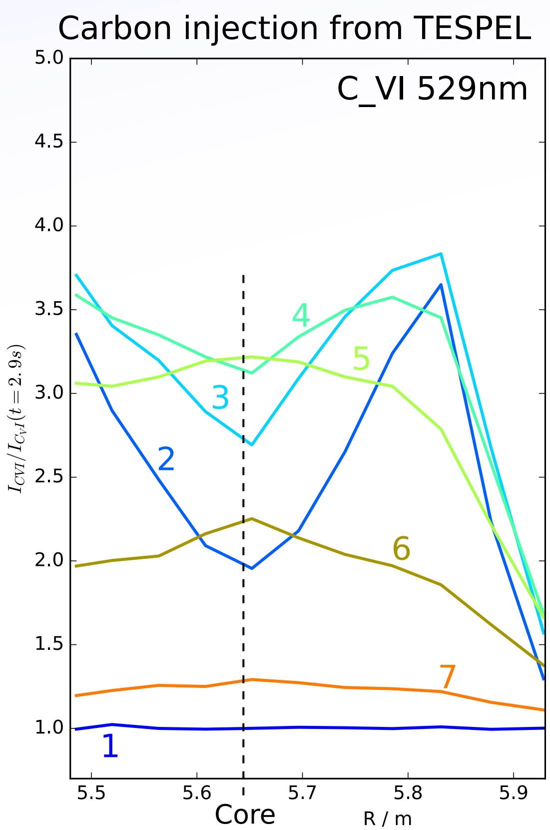


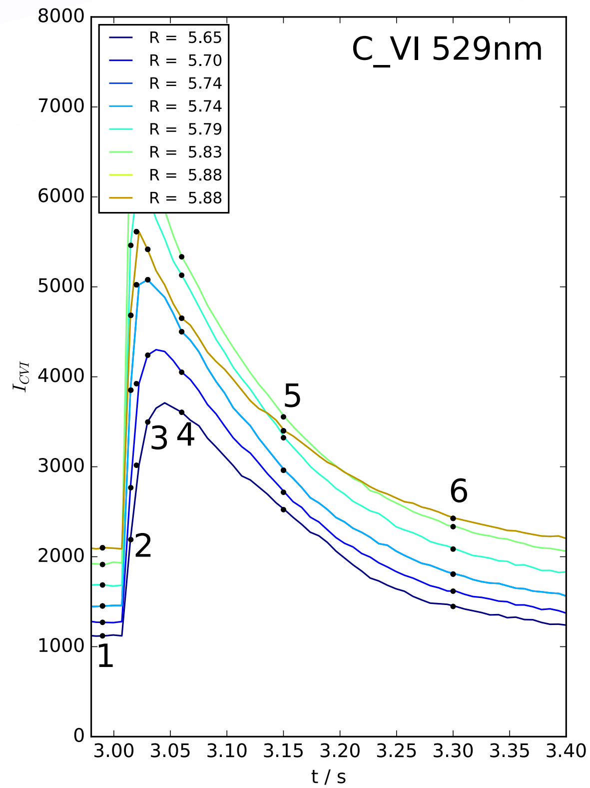
- Pure NBI operation shows strong Carbon peaking inside the steep T_e gradient, after ~ 1sec.
- Addition of O2 ECRH widens and lowers this with some delay.

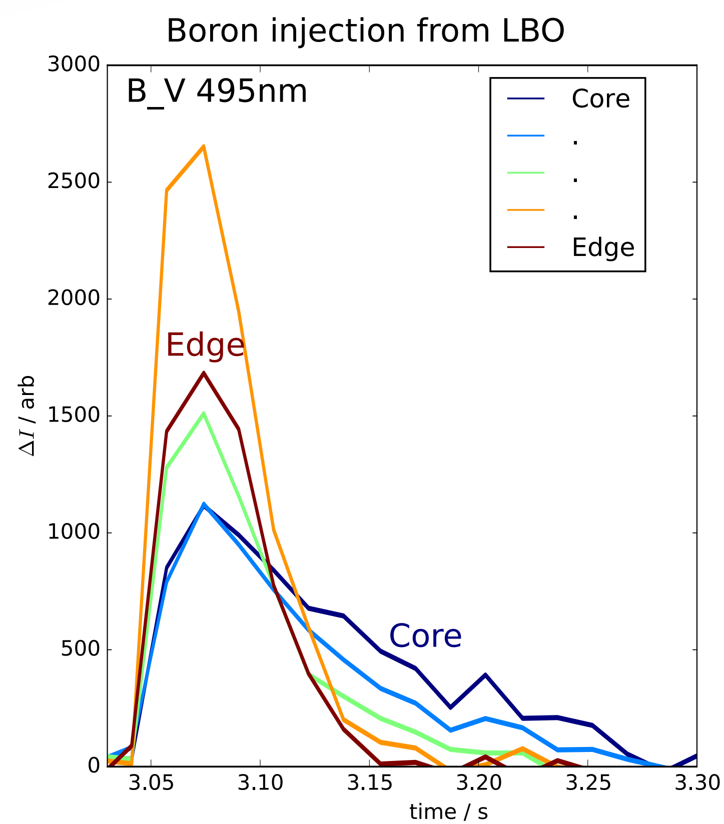
Non-intrinsic impurities

AUG1/2: Variable wavelength spectrometers changed inbetween shots for different impurity lines.

Measurement of injected impurities for impurity transport physics:
- Nitrogren, Neon, Methane (C) from seeding.
- Boron, Iron (Fe^{23+}, Fe^{24+}) from Tespel/LBO.
- Boron from Boron pellet dropper.







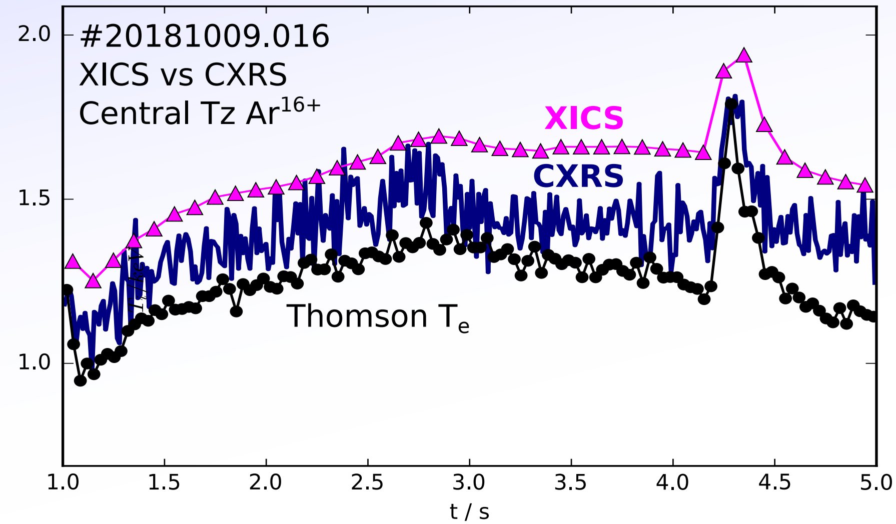
Good Oxygen data were also regularly measured throughout OP1.2b.

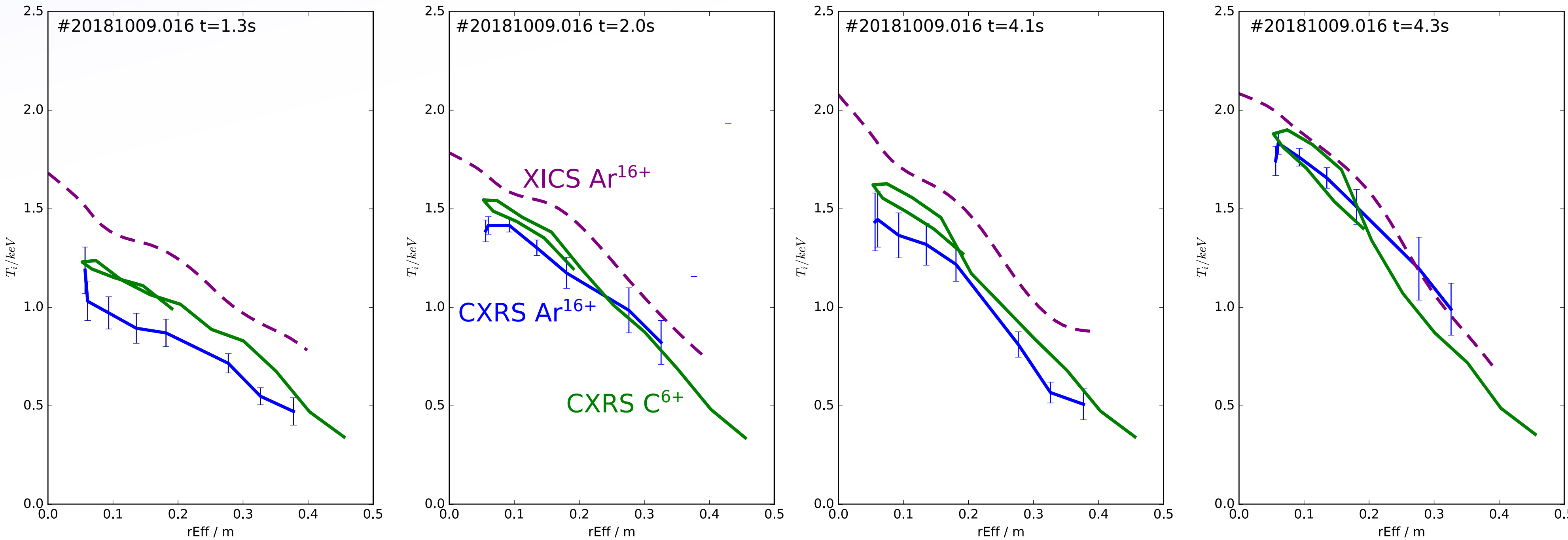
XICS cross-calibration

Argon (Ar^{15+}) for cross-calibration with XICS.
(Ar^{16+} + H --> Ar^{15+*} + p, n=14 - 13, 436.6nm)

- Investigate CXRS XICS T_i discrepancies - Is it T_C vs T_{Ar16+}? or diagnostic?

- Absolute Ar^{16+} intensity to support XICS calibration (if CX cross-sections are OK)





Argon^{16+} CXRS measurements more consistent with Carbon^{6+}. XICS Ar^{16+} usually higher.
Gradients always consistent --> Supports XICS inversions.

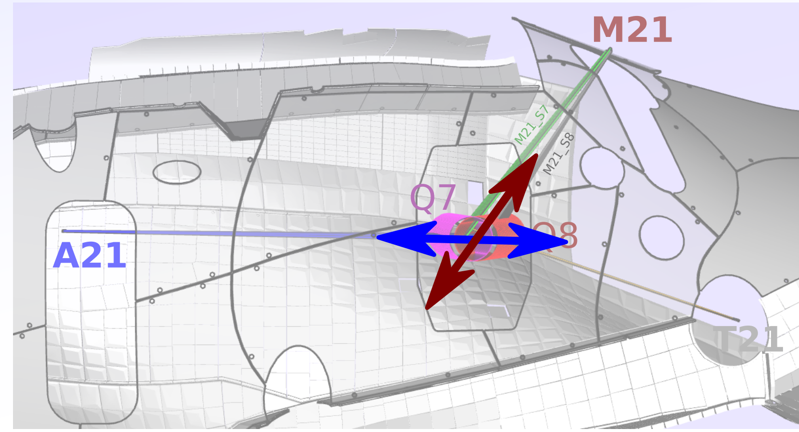
Flow Measurements: Poloidal

Doppler shift of any component gives flow velocity along LOS:

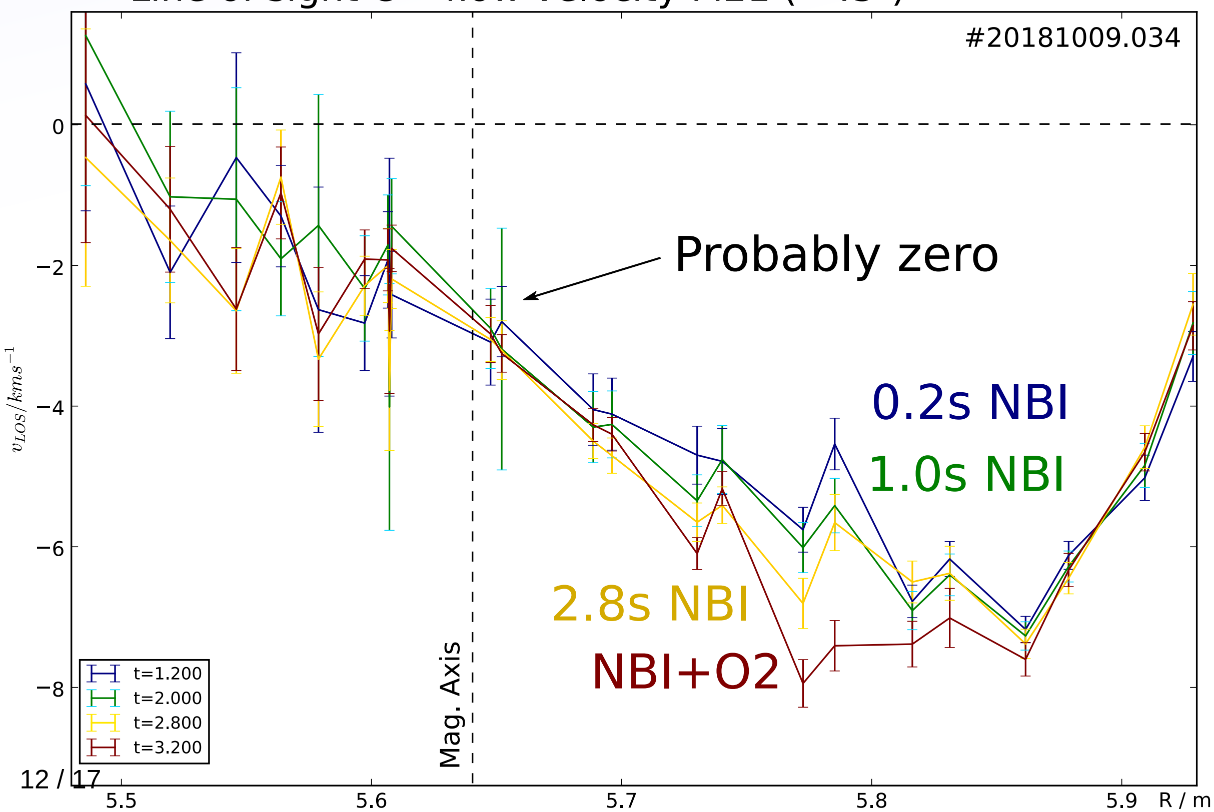
A21 = Toroidal flow.

M21 = Toroidal flow + E_r

Decomposition of velocities into Toroidal bulk flow and E_r have begun.



Line of sight C^{6+} flow velocity M21 (~45°)



Data strongly affected by passive background. OK for standard 20ms blips and for 100ms averging of stationary NBI.

First glance at raw data shows strengthening of -ve E_r with steepening of T_i gradients.

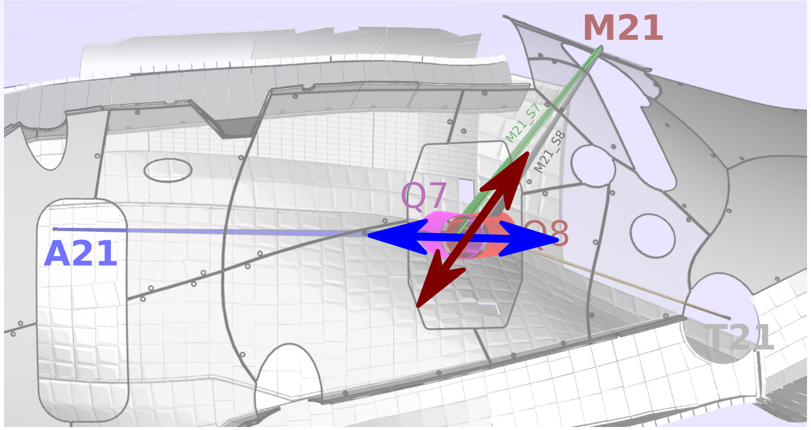
Flow Measurements: Toroidal

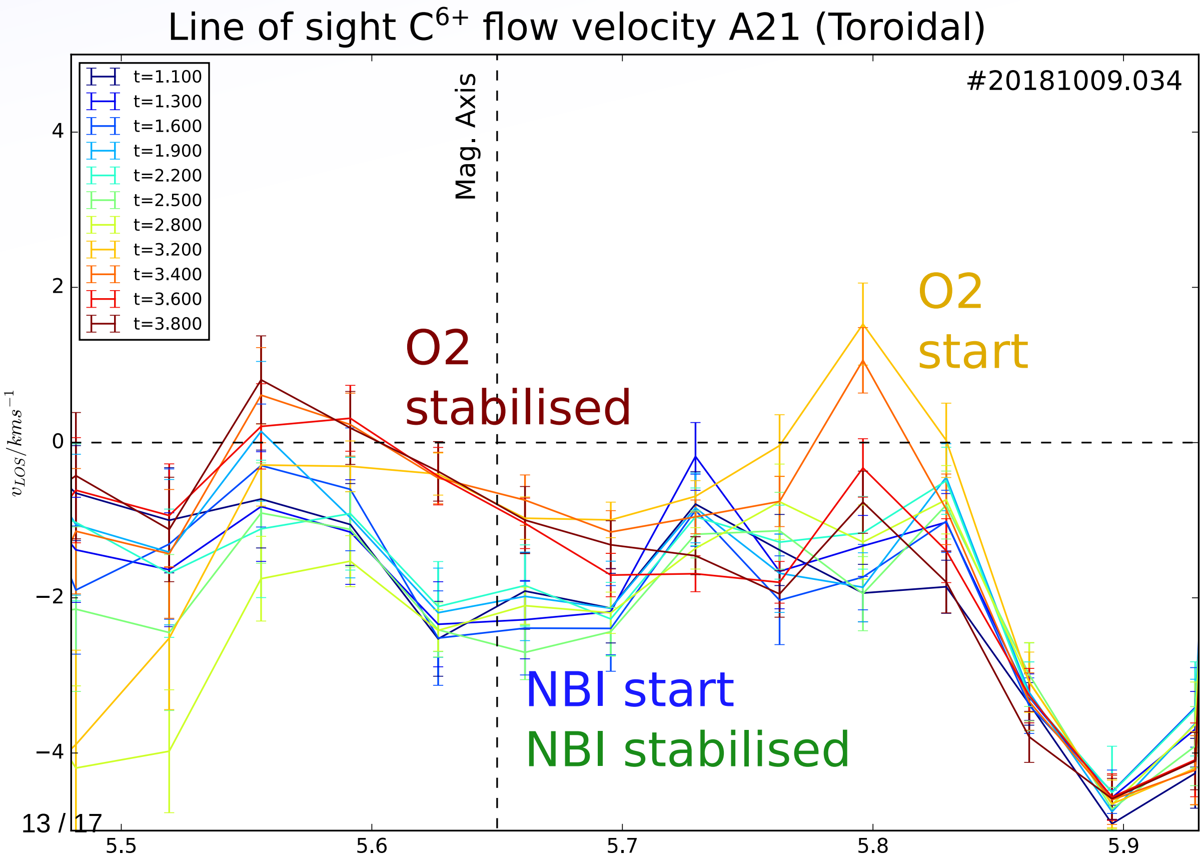
Doppler shift of any component gives flow velocity along LOS:

A21 = Toroidal flow.

M21 = Toroidal flow + E_r

Decomposition of velocities into Toroidal bulk flow and E_r have begun.





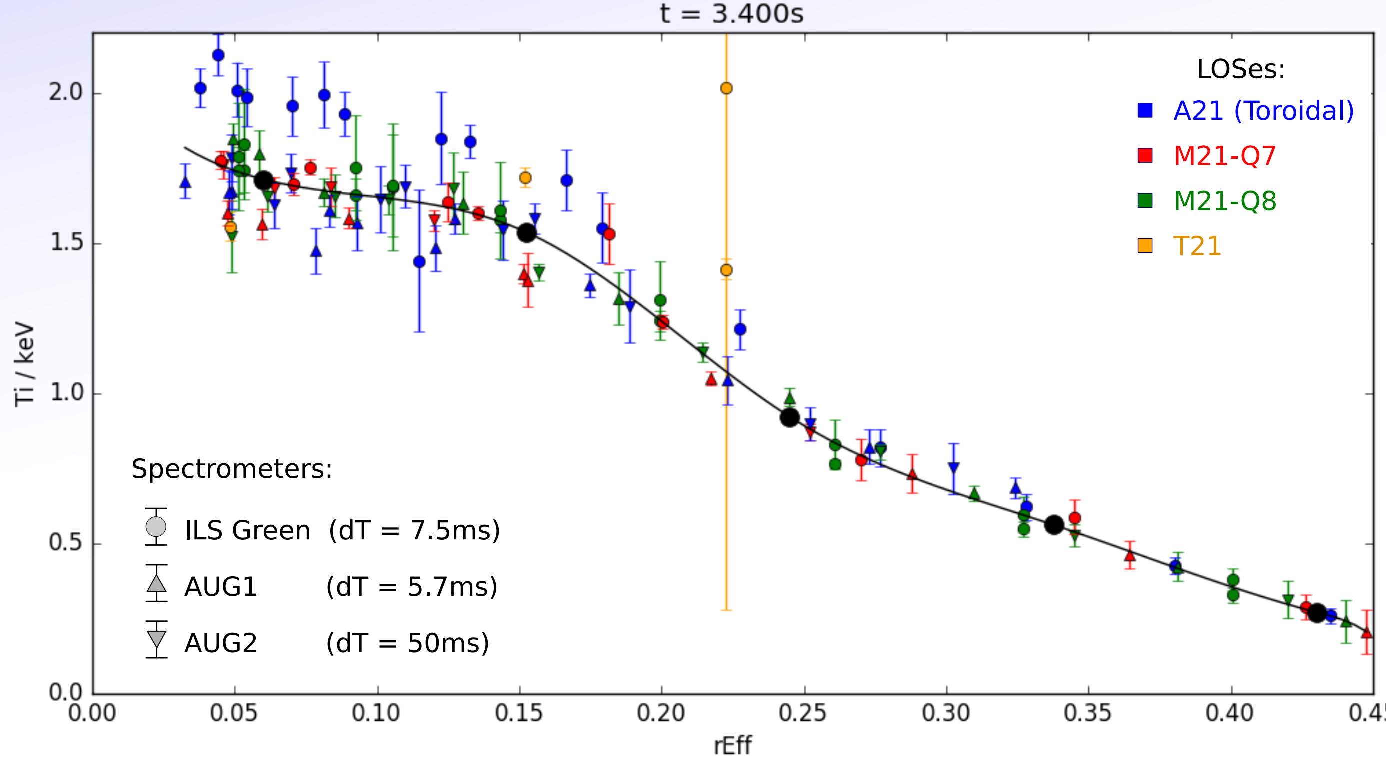
Small changes also visible in toroidal velocity data but not yet fully intrepreted.

- Cross-check wavelength calibration other spectrometers.

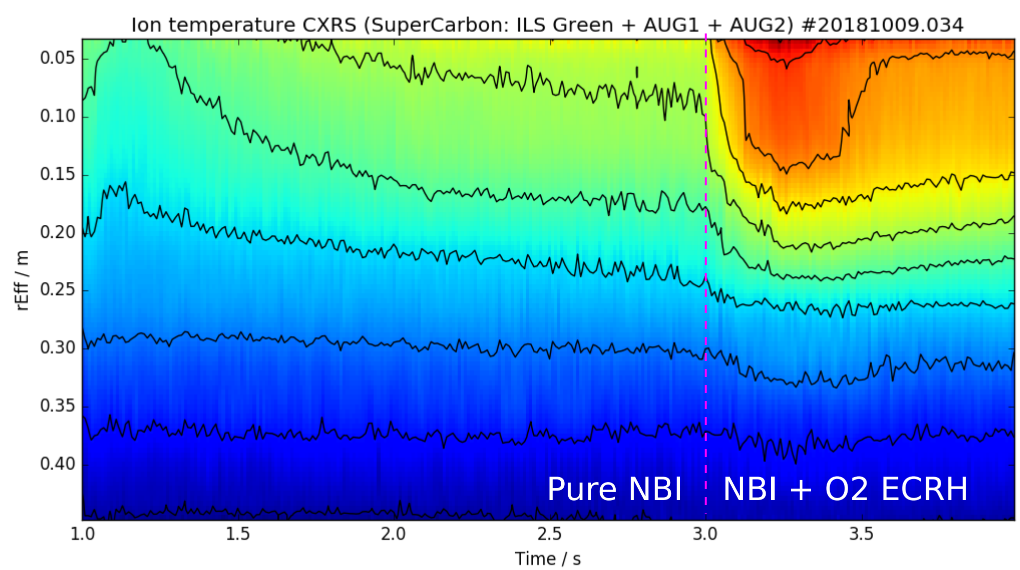
High resolution data

For highest S/N at high spatial resolution, all spectrometers measure C_VI line.

Data from 4 sets of lines of sights, measured by 3 spectrometers at a single time point:

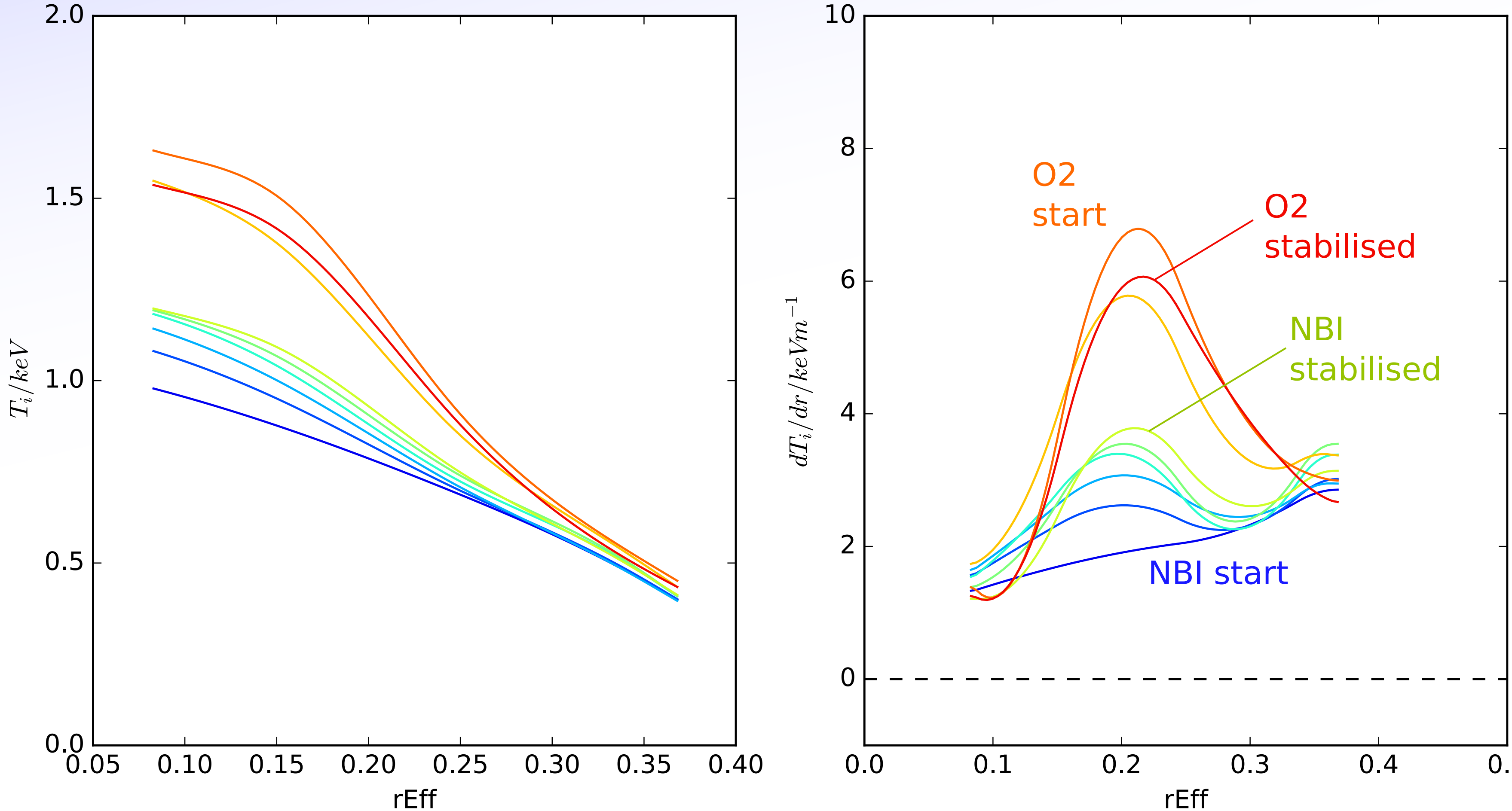


Map of fits for all time points:



High resolution data

With only mild smoothing, good T_i gradients can be derived:



Together with the Thomson Scattering profiles, these will be used to examine the electron and ion transport e.g. in NBI vs ECRH cases and in high-Ti pellet shots.

Summary

- Very successful campaign for CXRS. Almost everything intended was attempted.
  Everything attempted was fairly successful.

- Lots of good data recorded.
- H/W support of other diagnostics:
  NBI Neutraliser spectroscopy, Alkali beam, Passive FIDA

- Analysis tools now being developed and analysis will take a long time, please be patient!
  Unvalidated basic Ti profiles of NBI blips can be processed quite quickly on request.
  See wiki for details and example python script.

- Analysis Projects:
  - NBI Heating/Fuelling characterisation - *Ford, Poloskei, Geiger, Rust.*
  - Beam attenuation/modelling validation - *Neelis, Lazerson, Äkäslompolo*
  - Low-Z impurity transport - *Vanó*
  - FIDA - *Bozhenkov, Äkäslompolo, Geiger*
  - CXRS/XICS comparison and combination - *Ford, Pablant, Langenberg*
  - $T_i/T_e/n_e$ gradients, E_r and transport - *Ford, Bozhenkov*
  - He/H ratio and transport - *Ida, Yoshinuma*
  - Flow decomposition, Er and impurity assymetries - *Ford, Alonso*
  - B, C, Fe injection data - Vanó, *.... Impurity group?*
  - Seeded impurities (N, Ne) - *Reimold*