Charge Exchange Recombination Spectroscopy (CXRS) on the Neutral Beam Injection (NBI)

(Ladungsaustauschspektroskopie am Neutralheizstrahl)

Impurity Group Meeting 16.12.16

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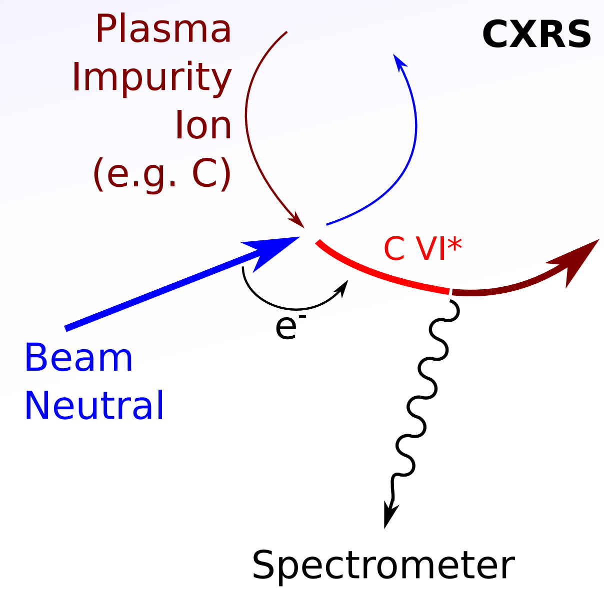
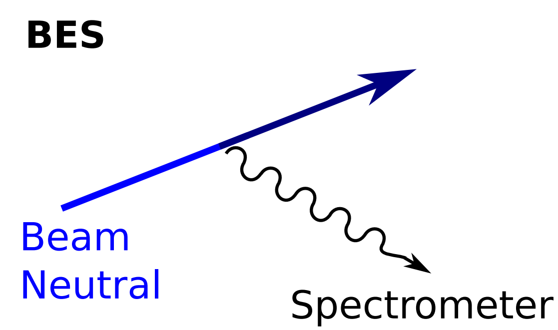
- CXRS Principle
- Neutral injection at W7X
- Diagnostic Overview
- Expected Capabilites

CXRS Principle

Charge Exchange Recombination Spectroscopy (CXRS) physics:
1) Neutral beam particles donate electrons to impurity/plasma ions.
2) Impurity ion left in excited state, emits photon.
3) Spectrum of collected photons give:
   - Impurity Densities (n_Z)
   - Impurity Temperature ~ Ion temperature (T_i)
   - Impurity Bulk Velocity --> Radial Electric Field (E_r)
     + Toroidal Rotation (ω_φ)



+Beam Emission Spectroscopy (BES):
Direction observation of beam neutral emission gives beam density n_b, beam deposition and spatial calibration of optics.

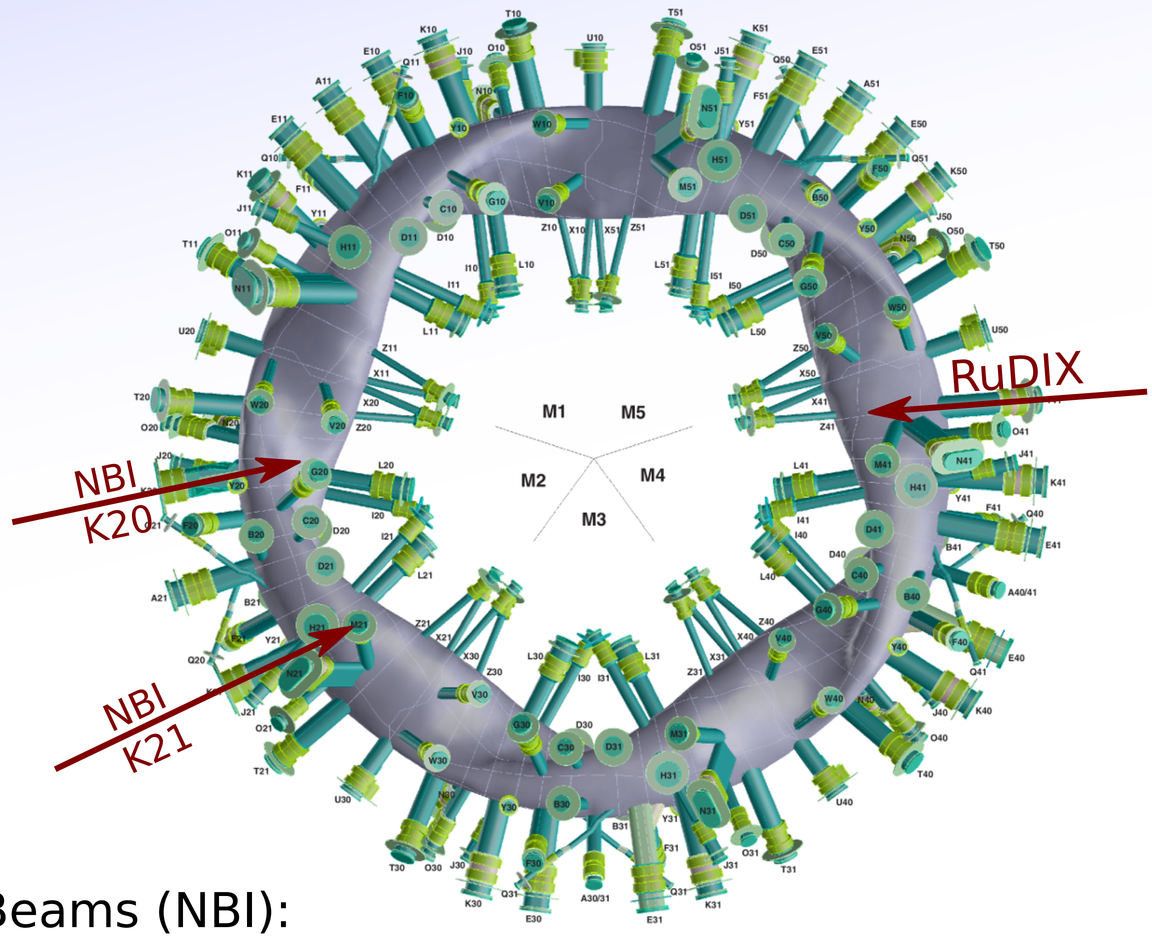


Only diagnostic to give core measurements of:
Core local impurity densities n_z (other than Argon)
Toroidal rotation w_φ
Beam density/deposition n_b

Supplements XICS with localised measurements of:
T_i: Localised measurements.
E_r: Localised across most of profile.

W7X Neutral Beams

Two neutral beam systems foreseen for W7X:



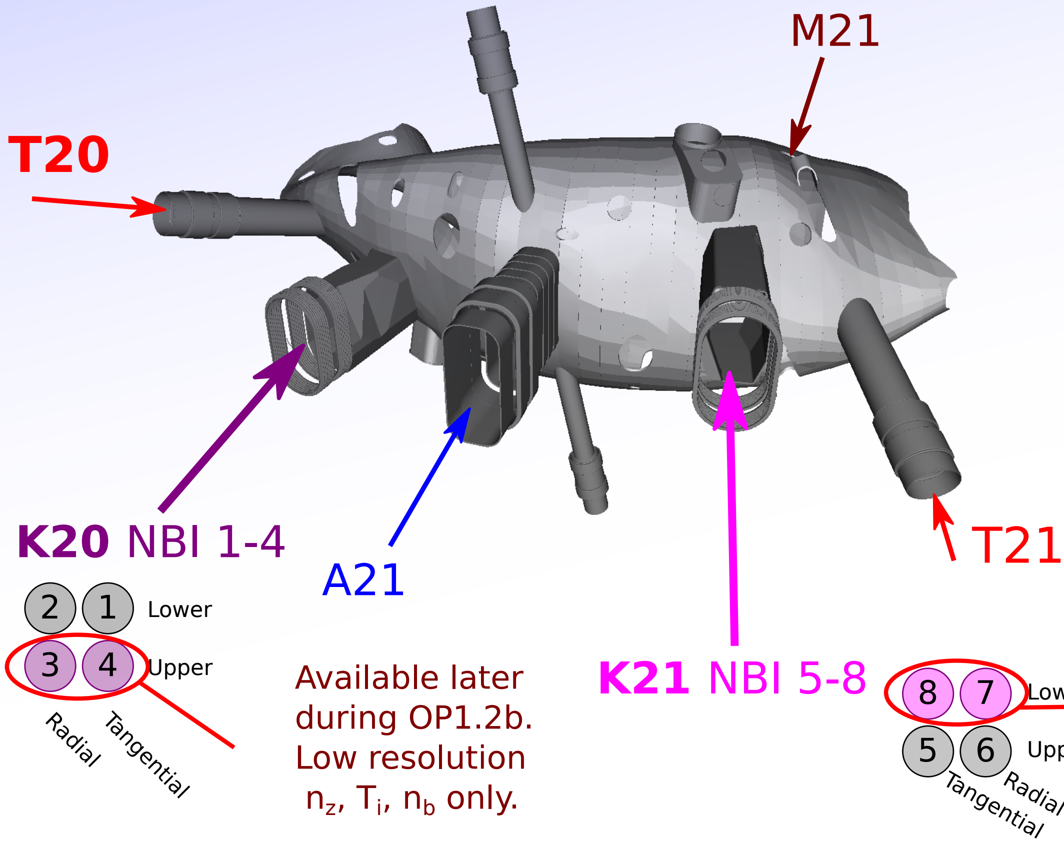
Diagnostic Beam (RuDIX):

(Module 4)
Can run effectively continuously
(pulsed at low duty cycle)
Low-current (less perturbative)
Available from OP2 (at the earliest)

Heating Beams (NBI):

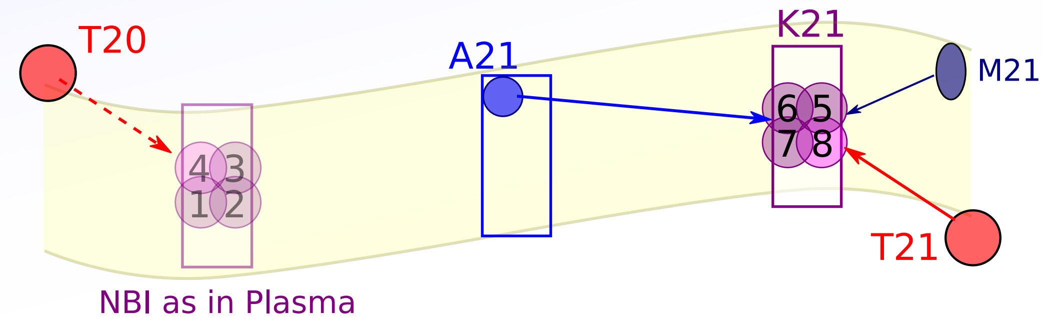
(Module 2)
Max 10 seconds per box (7.5s for H, 10s for D)
Very perturbative (>1MW)

CXRS on the NBI



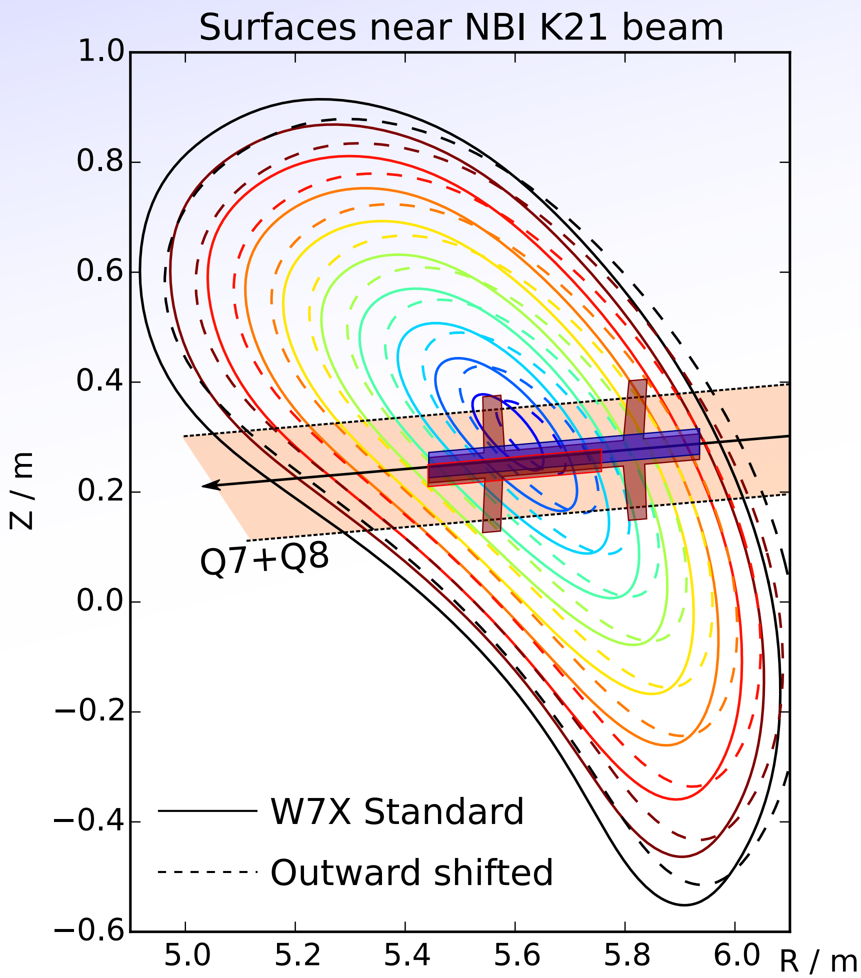
Available later during OP1.2b. Low resolution n_z, T_i, n_b only.

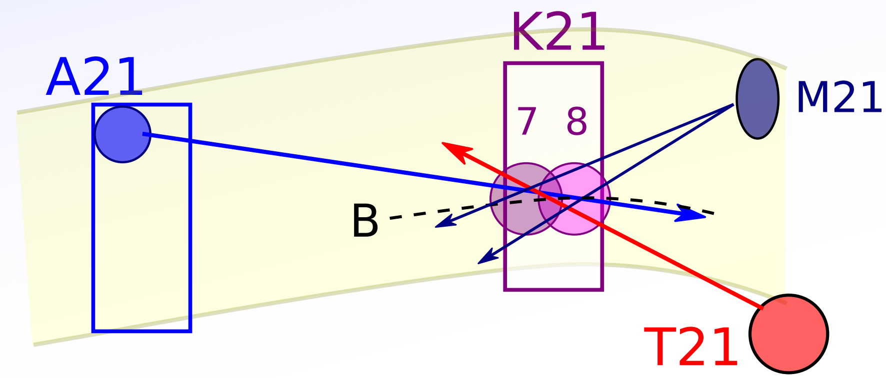
First beams to be available.
OP1.2b (maybe end of OP1.2a)
Full resolution n_z, T_i, n_b, E_r.

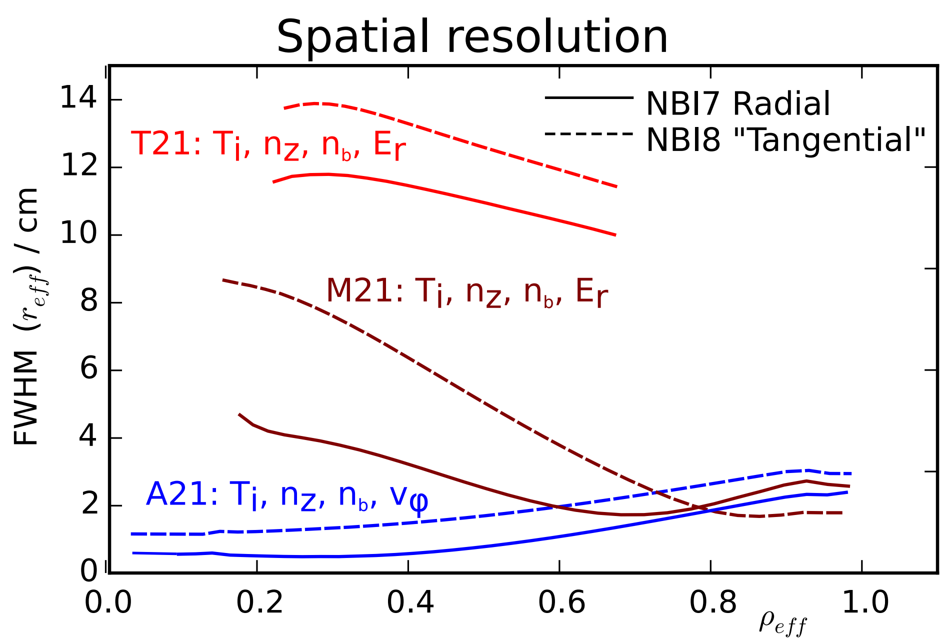


AEA21: High resolution, toroidally viewing system. 80 channels. OP1.2b+
AEM21: 45° to toroidal. Primarily for Er. 80 channels. OP1.2a+
AET20/21: Low resolution overview/cross-check. -45° to toroidal. 8 channels / box. OP1.2a+

Spatial Resolution







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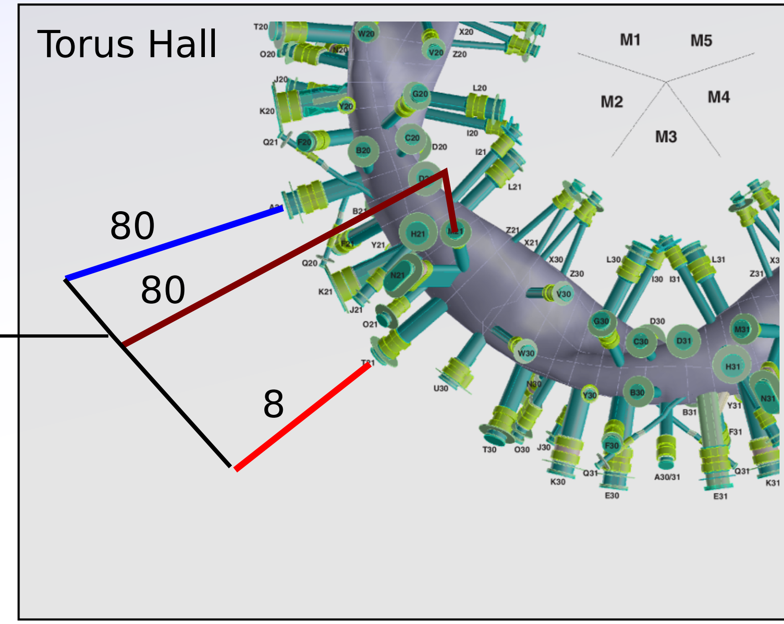
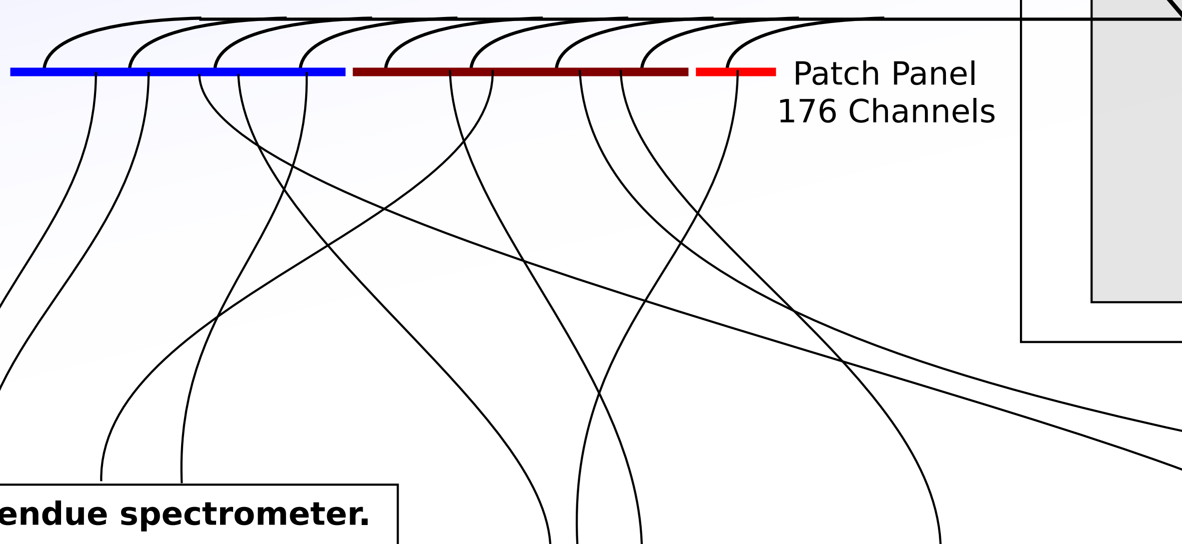
System Components

Three primary spectrometers measuring total 90 channels.
Flexibility for which impurity is to be measured at which radial position and which view angle.





High-etendue spectrometer.

3x Fixed wavelength:
- **H** + Beam Density
- **C_VI**
- **He_II**

~30 channels

OP1.2a

ASDEX Upgrade Spectrometer 1.

Variable wavelength:
B, N, C, (Ar, O)

~30 channels

OP1.2a/b

ASDEX Upgrade Spectrometer 2.

Variable wavelength:
FIDA, **B, N, C, (Ar, O)**

~30 channels

OP1.2a/b

NIFS Dual Channel Spectrometers

He/H studies.

~30 channels

OP1.2b

Emission Lines

The optics, fibres and CCD sensitivity should reasonable signal from 400 - 800nm.
Collected lines observed or mentioned in the CXRS literature:

297.6 O_VIII	Not with the main system, but we could try something if these were really desirable. (297.6 – 388.7)
298.2 B_V	
343.0 F_IX	
343.3 C_VI	
344.9 Ar_XVIII	
348.8 O_VIII	
388.7 N_VII	
434.1 O_VIII	
436.5 Ar_XVI	Will look for this. Might see something.
452.45 S_XIV	
468.58 HeII	Fixed range. Always available.
479.3 Ar_XVII??	
494.46 B_V	Selectable. Very likely to work.
524.9 NeX	Fixed range. Always available.
529.06 C_VI	Fixed range. Always available.
541.152 HeII	
566.94 N_VII	Selectable. Very likely to work.
570.2 S_XIV	
606.8 O_VIII	Selectable. Possible for high O content. Measured at JET, but not enough signal at AUG.
608.5 N_VII	
656.01 HeII	
656.28 HI	Fixed range. Beam density + FIDA etc.
706.8 S_XIV	
771.7 C_VI	
792.7 N_VII	

Expected Performance

W7X CXRS based on the very succesful CXRS on ASDEX Upgrade:

- Same NBI
- Same spectrometers (steal one and use their design for two more)
- Same fibres.
- Same Ion temperatures (T_i).
- ~Same plasma cross-section (50-60cm core-edge).

Up to 4x higher electron density (n_e) so:

- Lower signal in core (NBI attenuation)
- Much higher background (Bremsstrahlung)
- Higher impurity density (for the same concentration)

- Much lower velocities (E_r) and higher sensitivity/accuracy required (> 5x better).

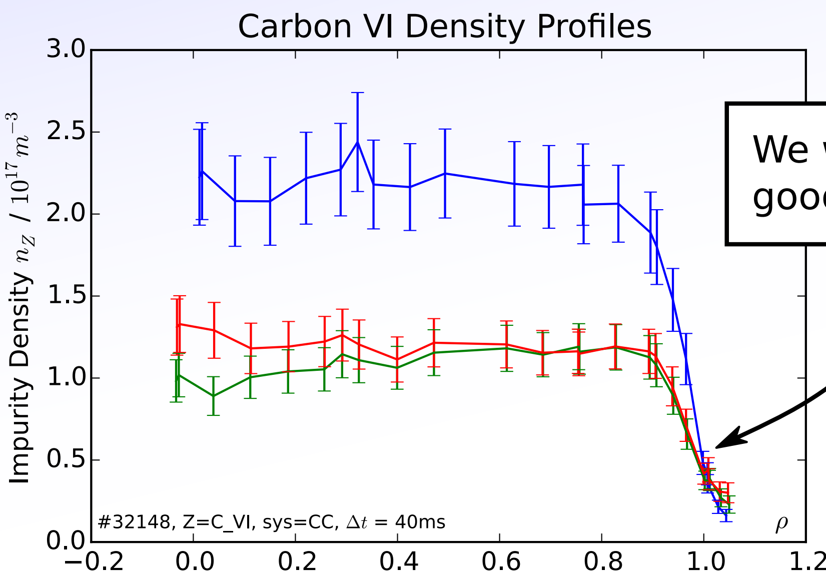
+ Slower typical dynamics (time resolution 100ms instead of 10ms is still useful).
+ Expect higher carbon content (AUG has W wall), but other impurities will be similar.

Performance at AUG

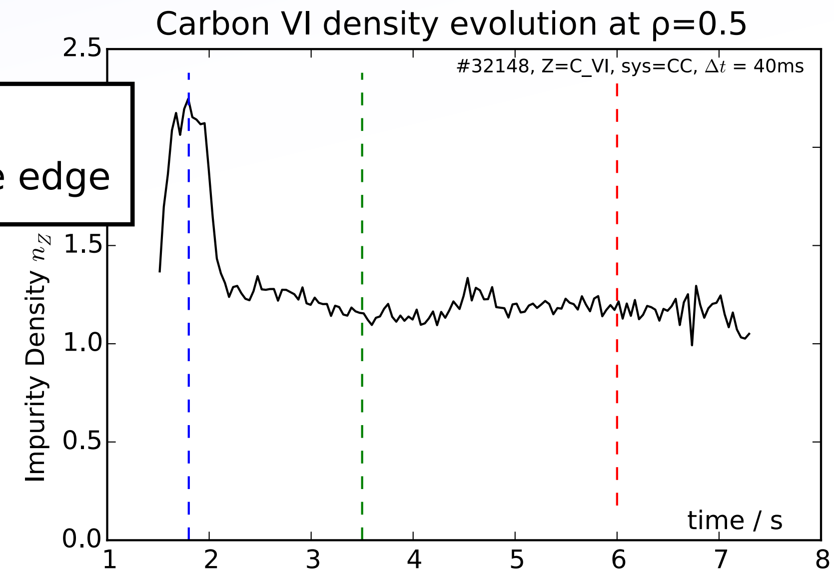
At ASDEX Upgrade, they routinely measure He II, B V, C VI, N VII and produce n_Z profiles whenever the concentration is above ~0.2% n_e.

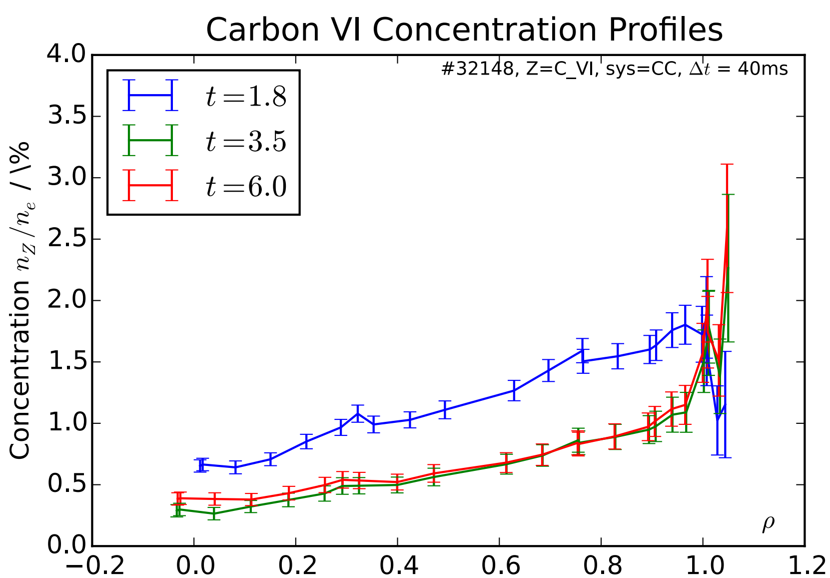
Some examples:

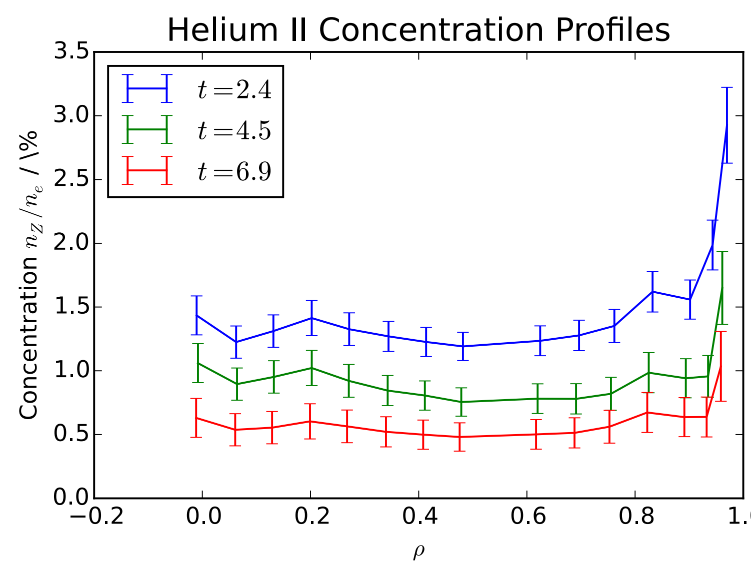
1) From the fixed Helium and Carbon channels of the high-entendué spectrometer at Δt = 40ms:



We will not have such good resolution at the edge



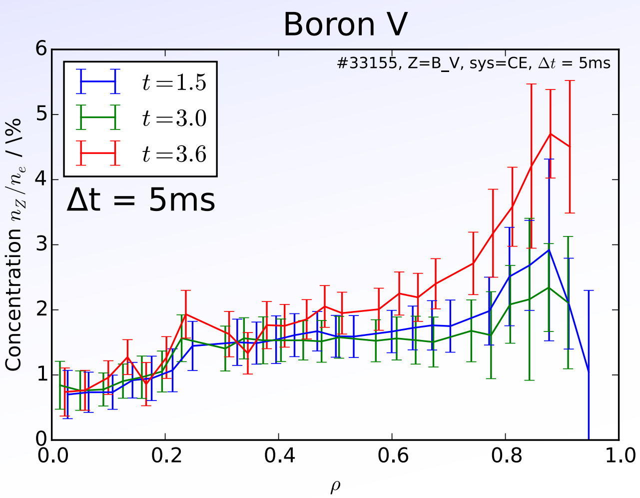


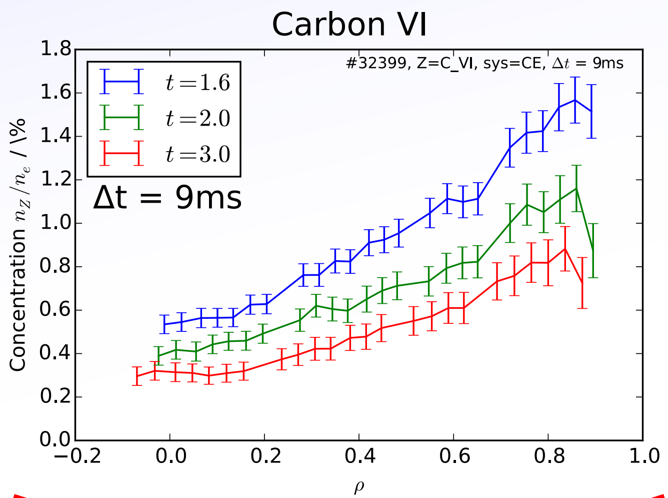


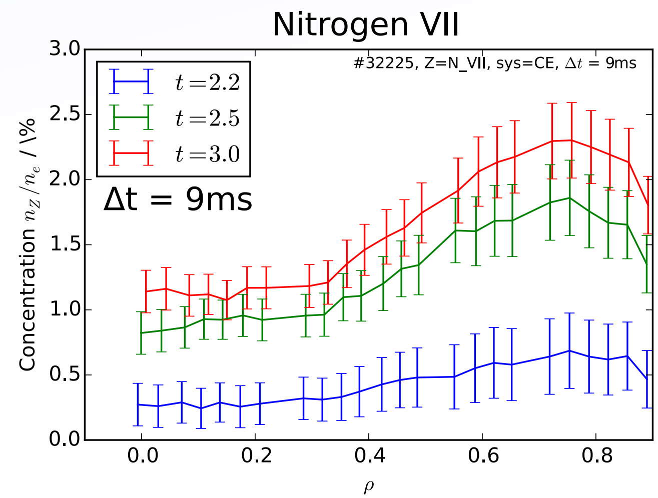
Performance at AUG

Some examples:

2) From the variable wavelength ASDEX Upgrade spectrometers at Δt = 5-9ms:





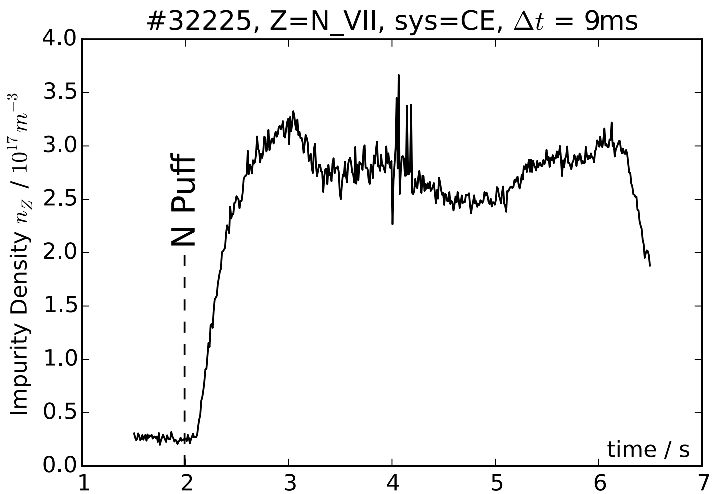


Boron: "*After a boronization we have about 1% B in the machine, which drops to about 0.5% in about a day and then stays at 0.5% for at last a week.*"

~~**Carbon:** "*C after a boronization is <0.1% and returns to a more or less steady 0.2-0.35% within about a day after a boronization..*"~~

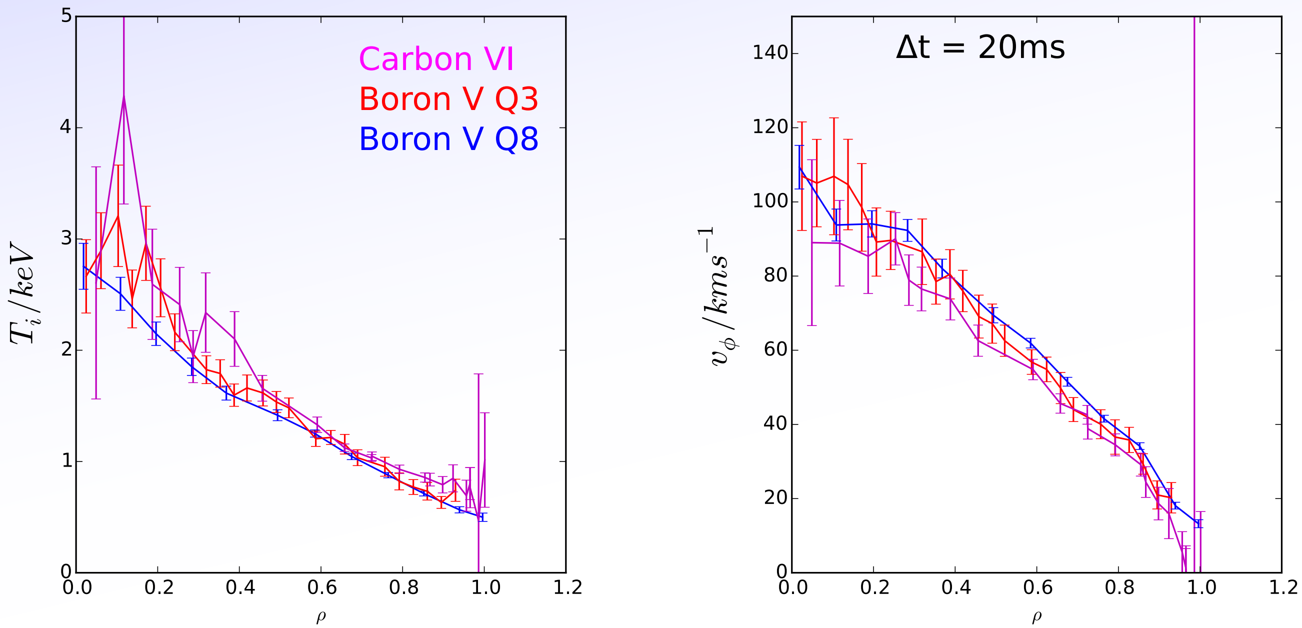
Irrelevant to W7X

Nitrogen: Generally only when puffing *N for seeding experiments.*



Performance at AUG

The systems all also provide regular T_i and v_φ measurements:



Temperature measurements are generally very reliable and match between each species.

It's not clear how useful the v_φ/v_θ measurements will be at W7X given the much smaller values in Stellarators.
The AUG systems can typically resolve δv=±10km/s in the core and ±1km/s at the edge for Δt = 3ms - 10ms.
Much longer time integration at W7X might help here.

Summary

CXRS systems at W7X should provide:

n_z: Impurity density profiles of Helium, Carbon, Boron, Nitrogen.

- At least profile shapes and time evolution. Absolute values too, but this will be harder to get right.
- We will try to look at Argon and Oxygen, but do not know if these will work.

T_i: Routine provision of Ti profiles should not be difficult for the main species.

n_b: Beam density / attenuation for all beams.

E_r: Maybe, at least to ±10kV/m but hopefully better.

Δr_{eff} < 3cm but hopefully down to ~1cm in core.
Δt ~ 10 - 100ms. Faster might be possible but will depend on signal level and electron density.

- **Only with NBI!** We will try beam modulation / small blips but this will still have an effect on the plasma.

The design is still in progress and I still need input on what to optimise for with regard to impurity densities.
Please tell me what is needed/desired...

- What is most important - Good time resolution, spatial resolution or small uncertainties?

- Is profile shape useful without absolute density values?

- How useful would it be to look at Argon XVI and XVIII?