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

(Ladungsaustauschspektroskopie am Neutralheizstrahl)

Impurity Group Meeting 16.12.16

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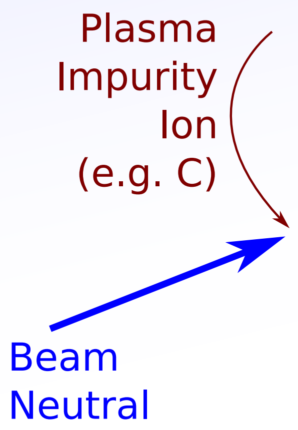
- CXRS Principle
- Neutral injection at W7X
- Diagnostic Overview
- Expected Capabilites

CXRS Principle

Charge Exchange Recombination Spectroscopy (CXRS) physics:



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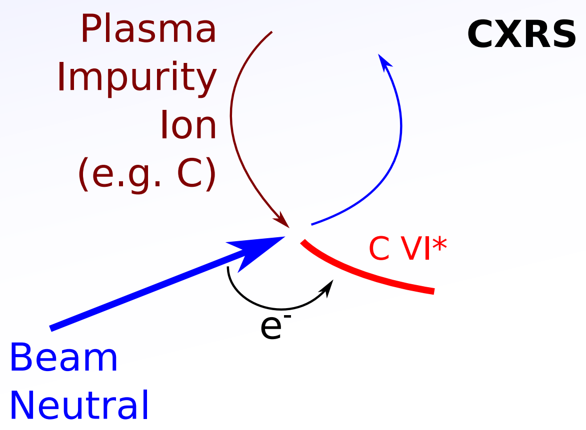

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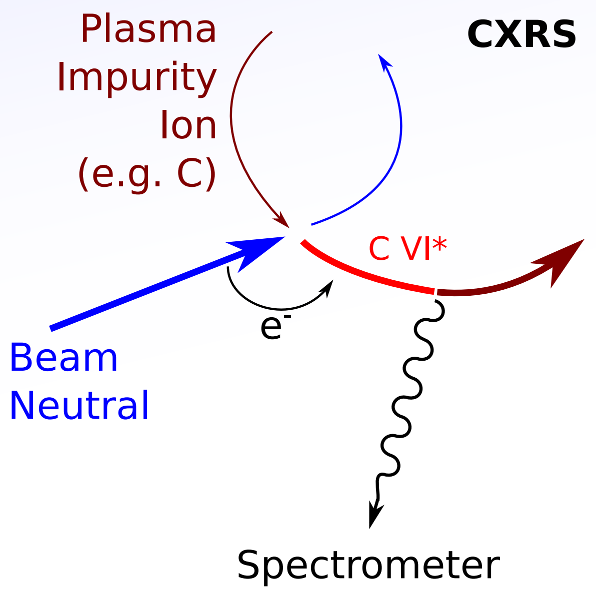
2) Impurity ion left in excited state, emits photon.
3) Spectrum of collected photons give:
   - Impurity Densities (n_Z)
   - Impurity Temperature ~ Ion temperature (T_i)
   - Impurity Bulk Velocity --> Radial Electric Field (E_r) + Toroidal Rotation (ω_φ)



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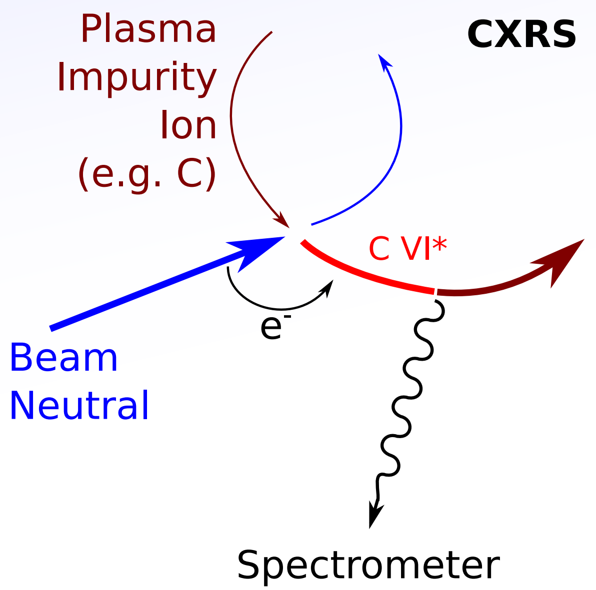
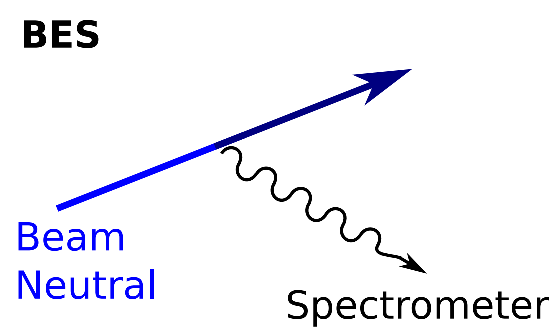


+Beam Emission Spectroscopy (BES):

Direction observation of beam neutral emission gives beam density n_b, beam deposition and spatial calibration of optics.



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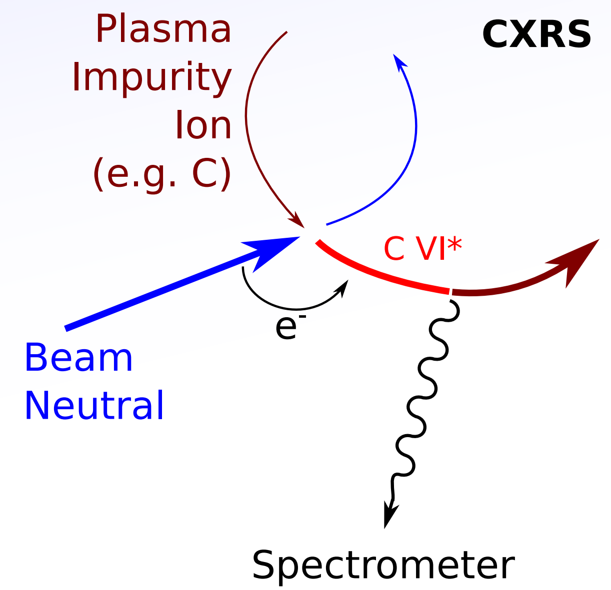

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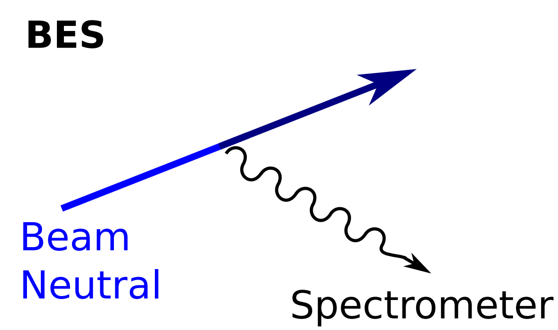


Only diagnostic to give core measurements of:

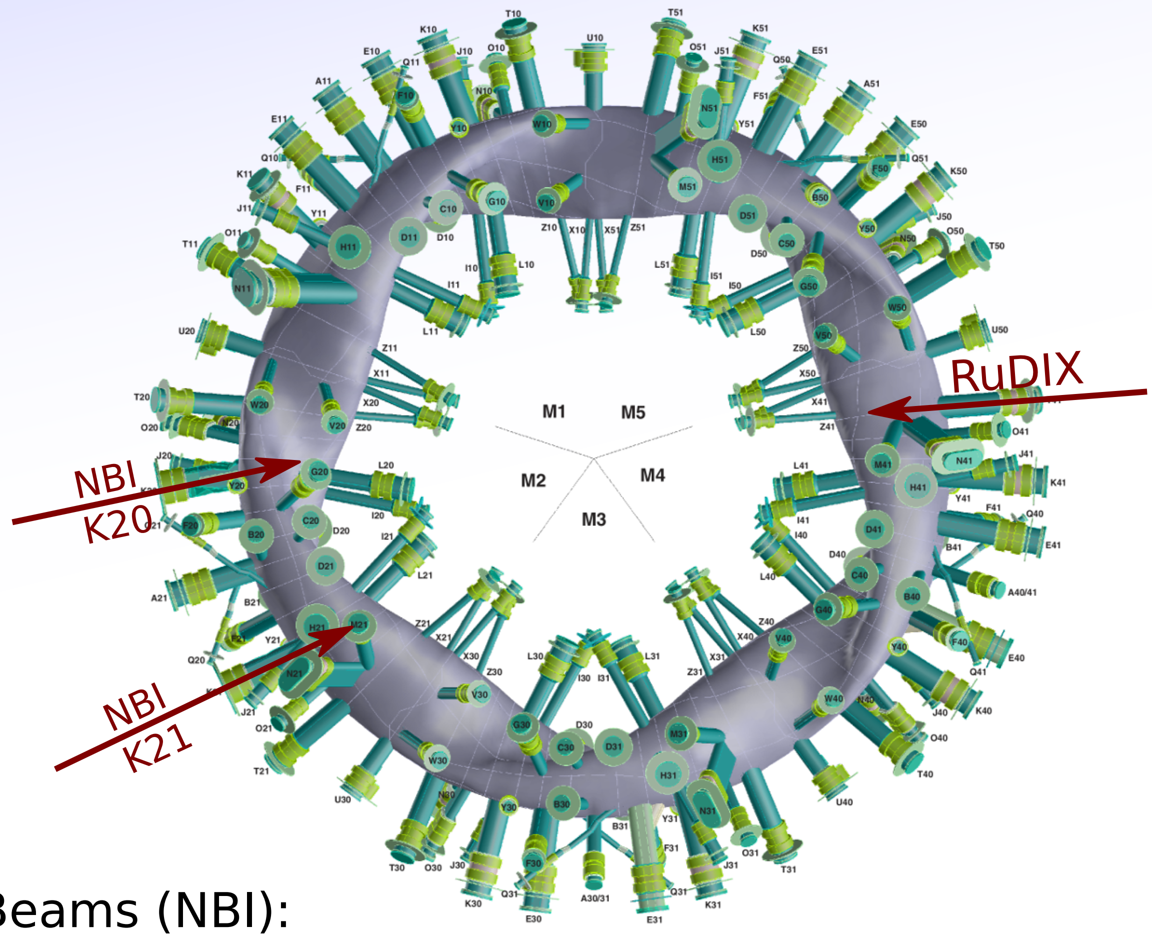
Core local impurity densities n_z (other than Argon)
Toroidal rotation w_φ
Beam density/deposition n_b

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:



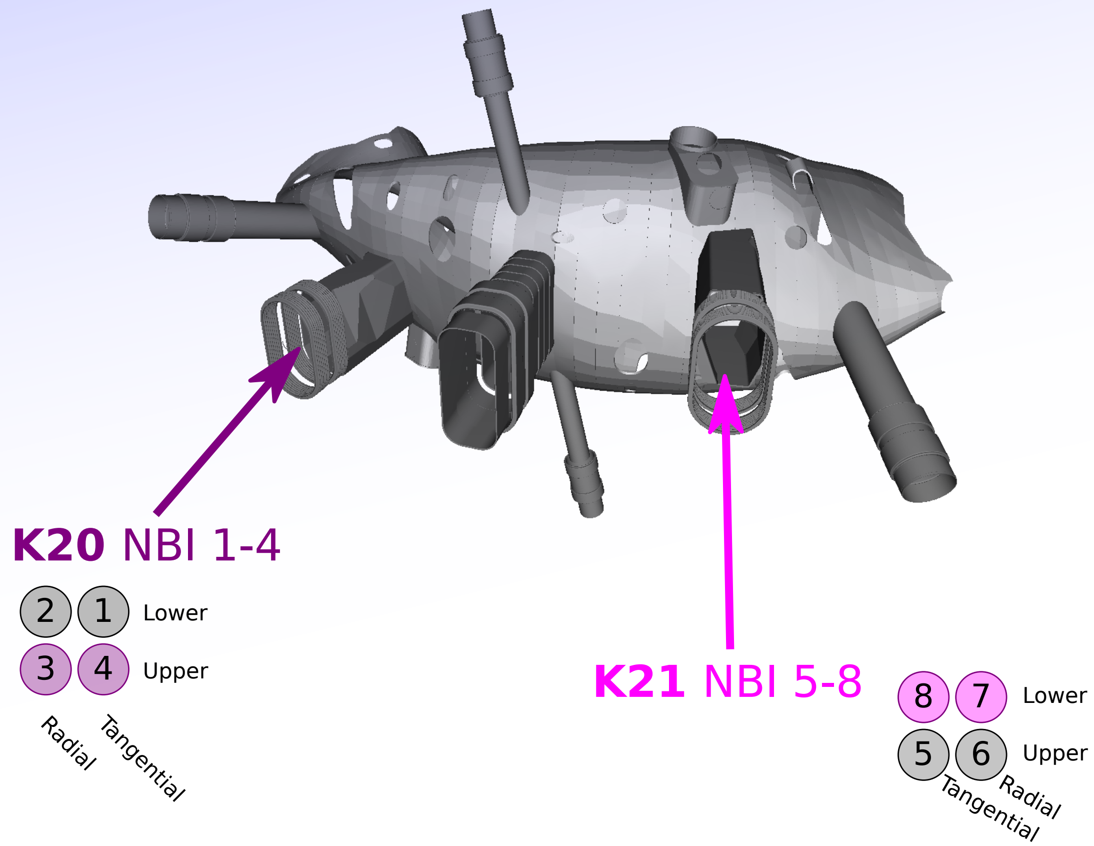
Diagnostic Beam (RuDIX):

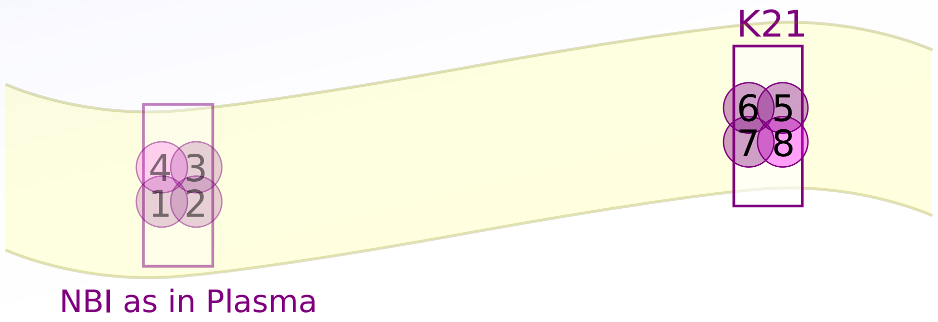
(Module 4)
Can run effectively continuously
(pulsed at low duty cycle)
Low-current (less perturbative)
Available from OP2 (at the earliest)

Heating Beams (NBI):

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

CXRS on the NBI





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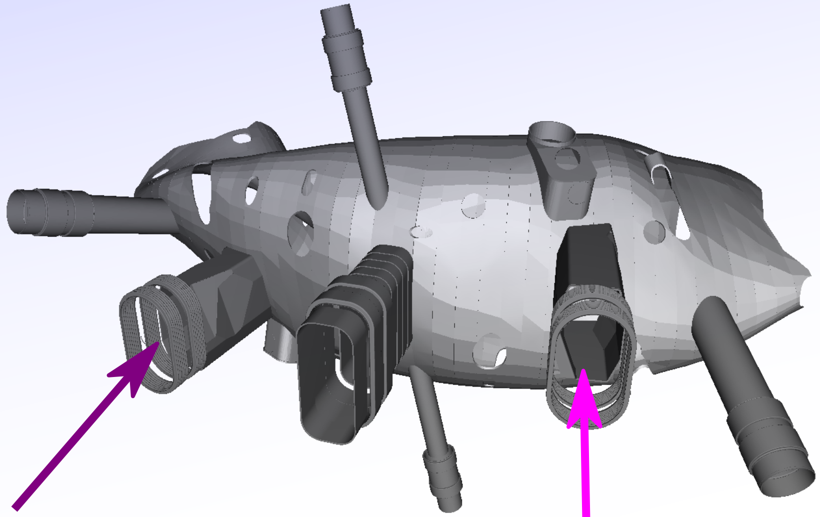
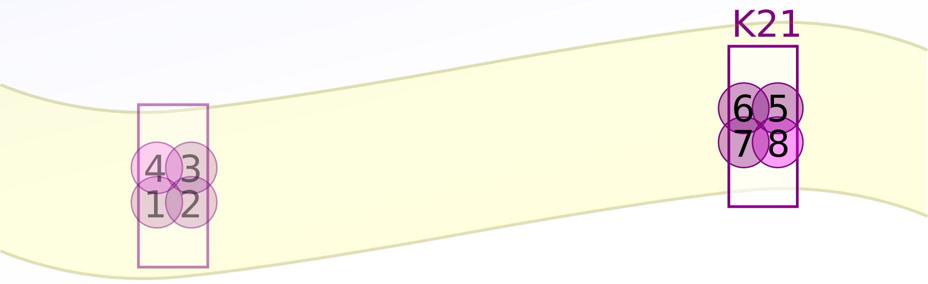
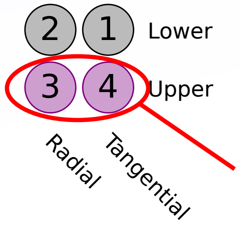


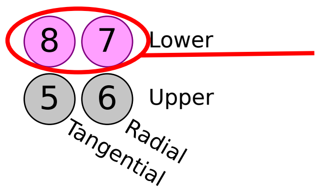


K20 NBI 1-4



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

K21 NBI 5-8



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

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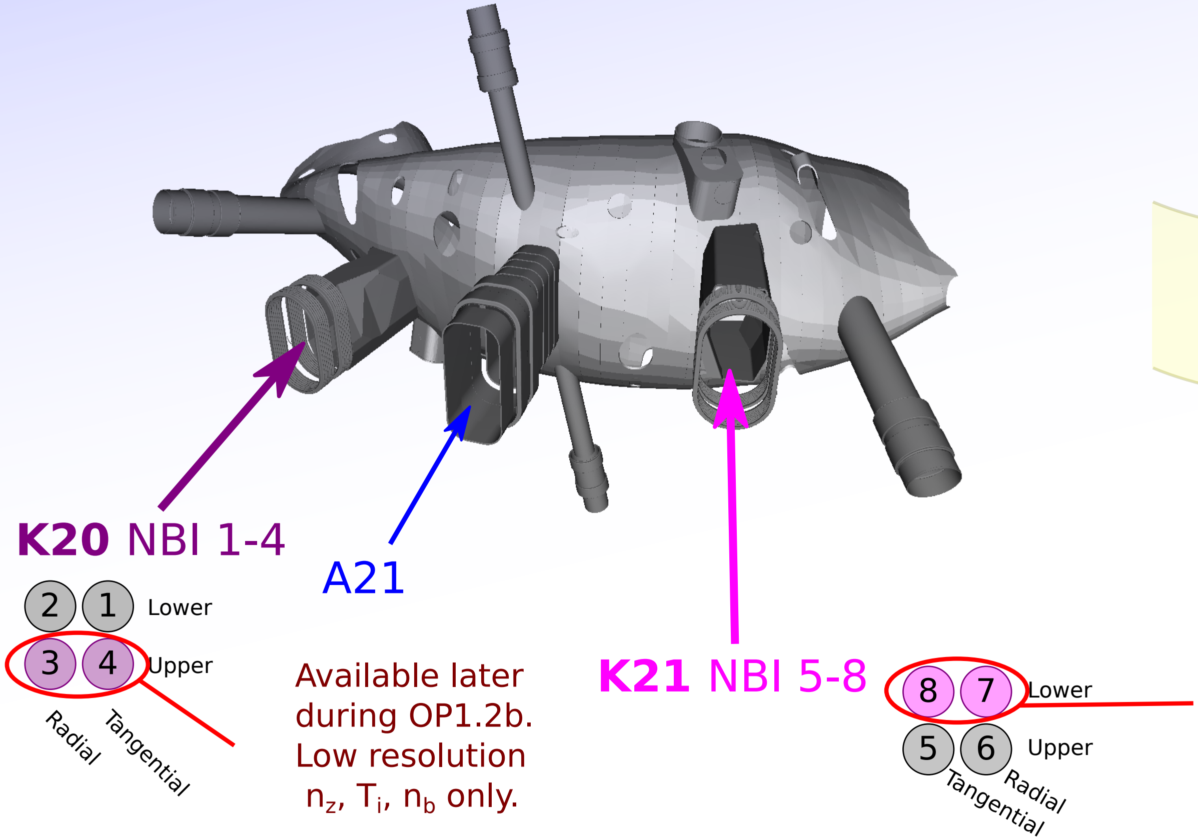

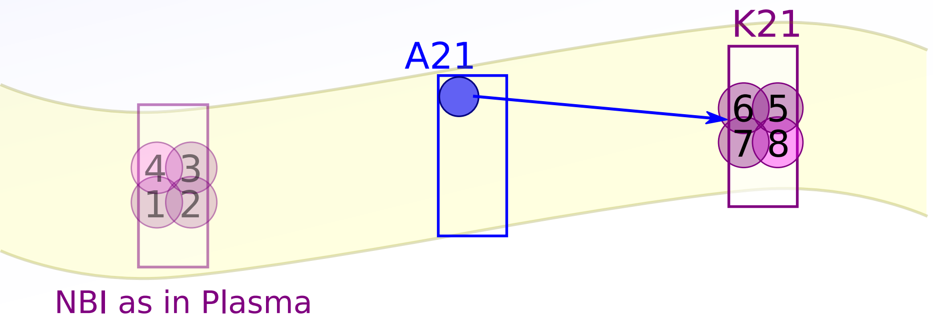

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AEA21: High resolution, toroidally viewing system. 80 channels. OP1.2b+

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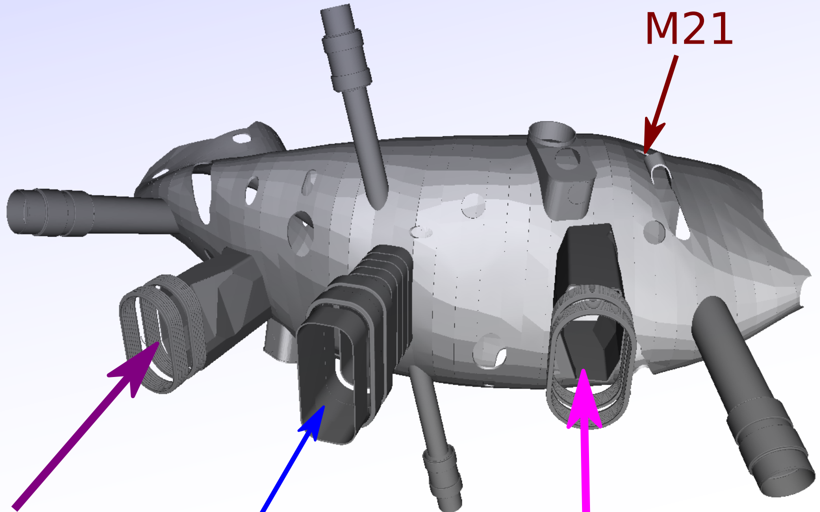

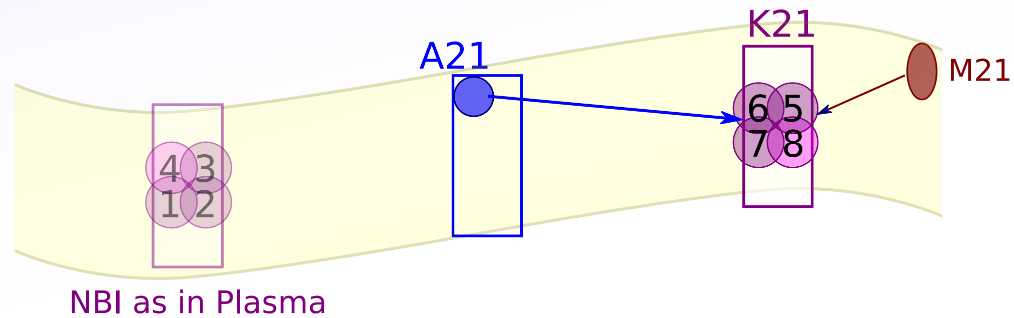

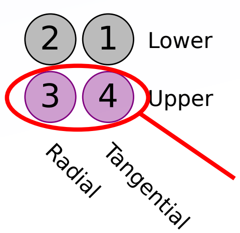

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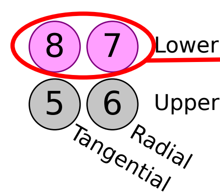

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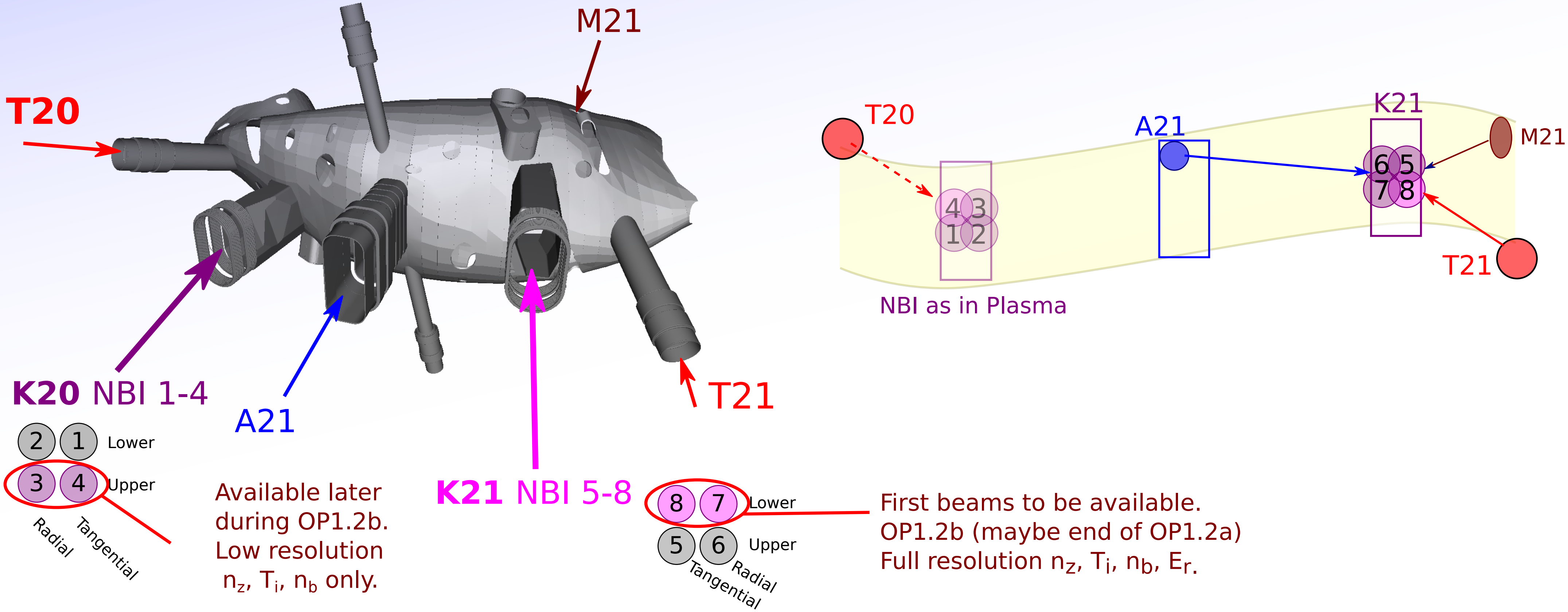
CXRS on the NBI



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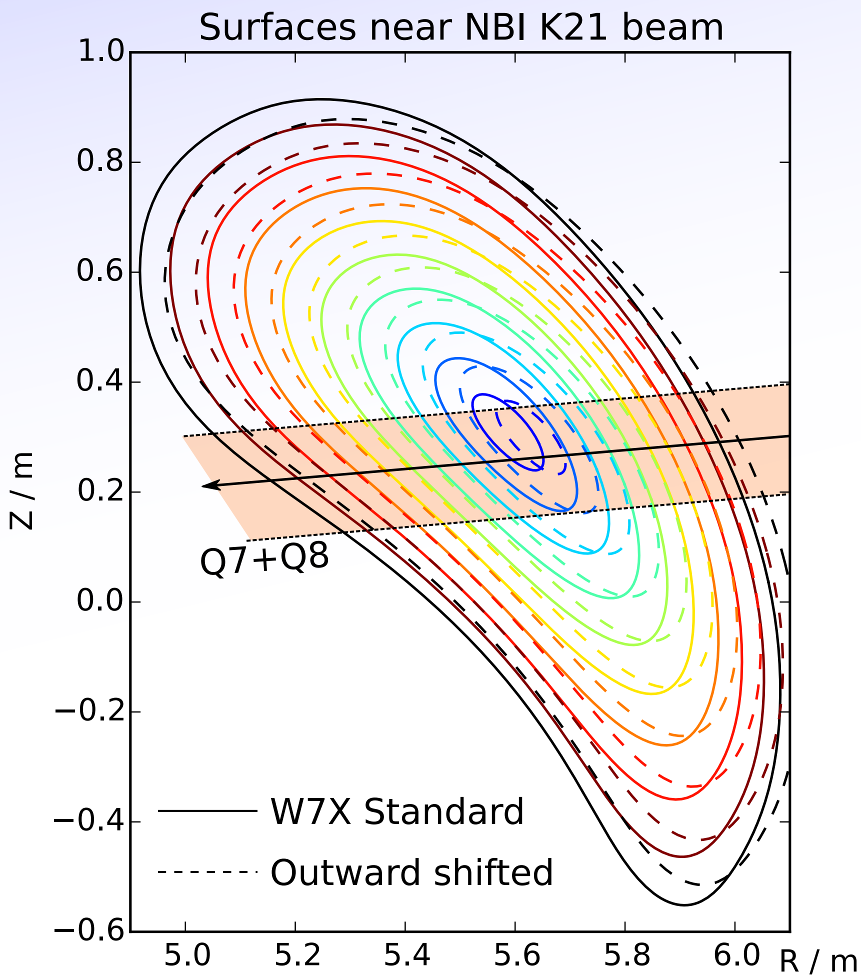
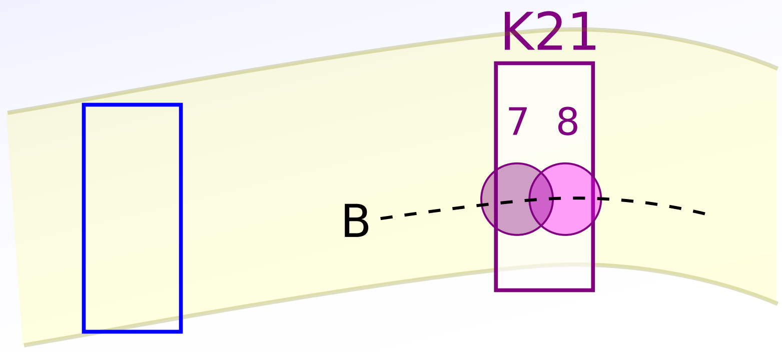
AET20/21: Low resolution overview/cross-check. -45° to toroidal.	8 channels / box.	OP1.2a+

Spatial Resolution





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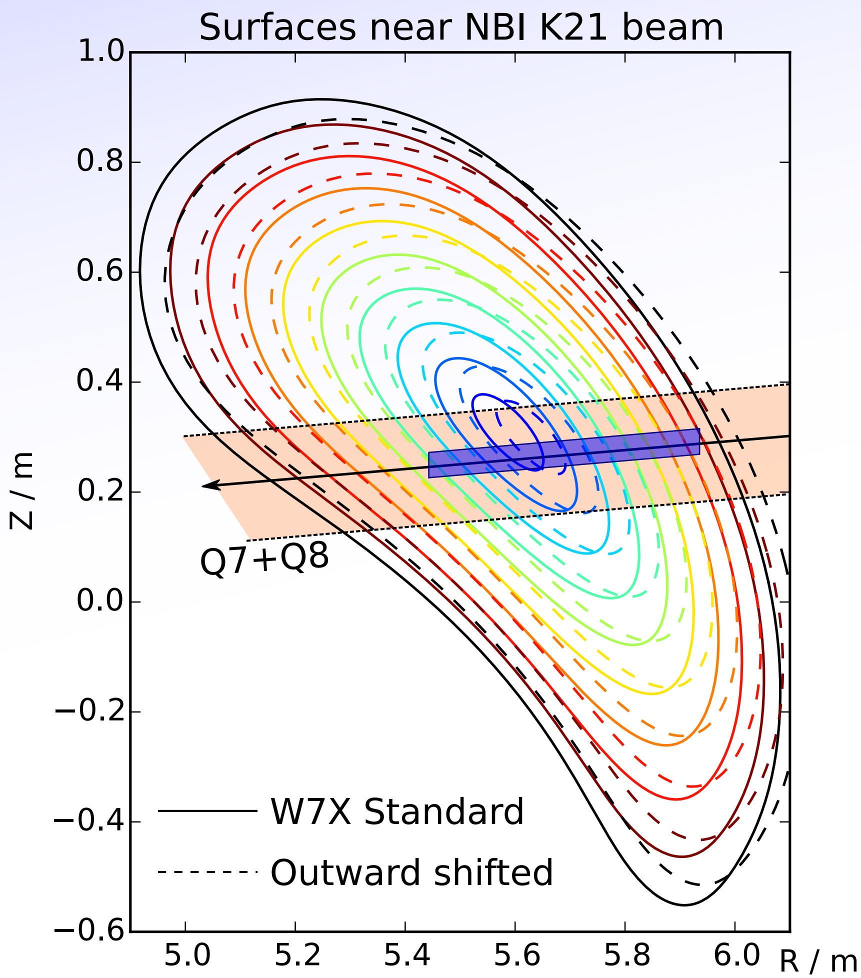

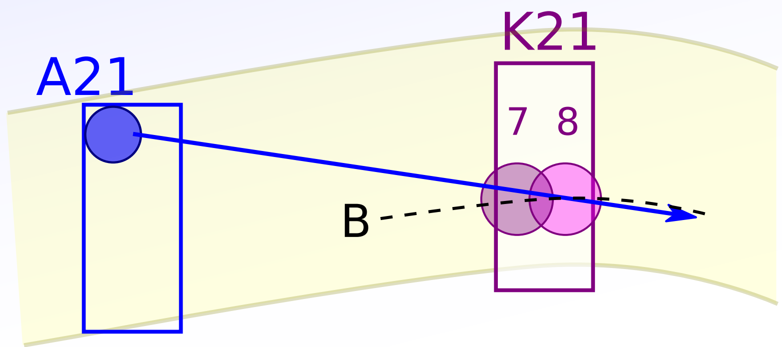

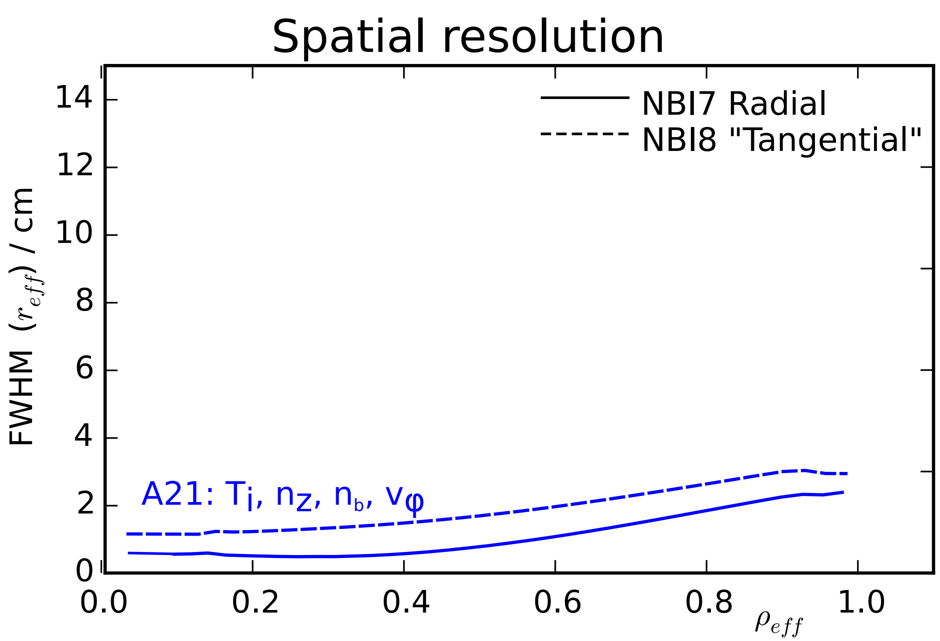

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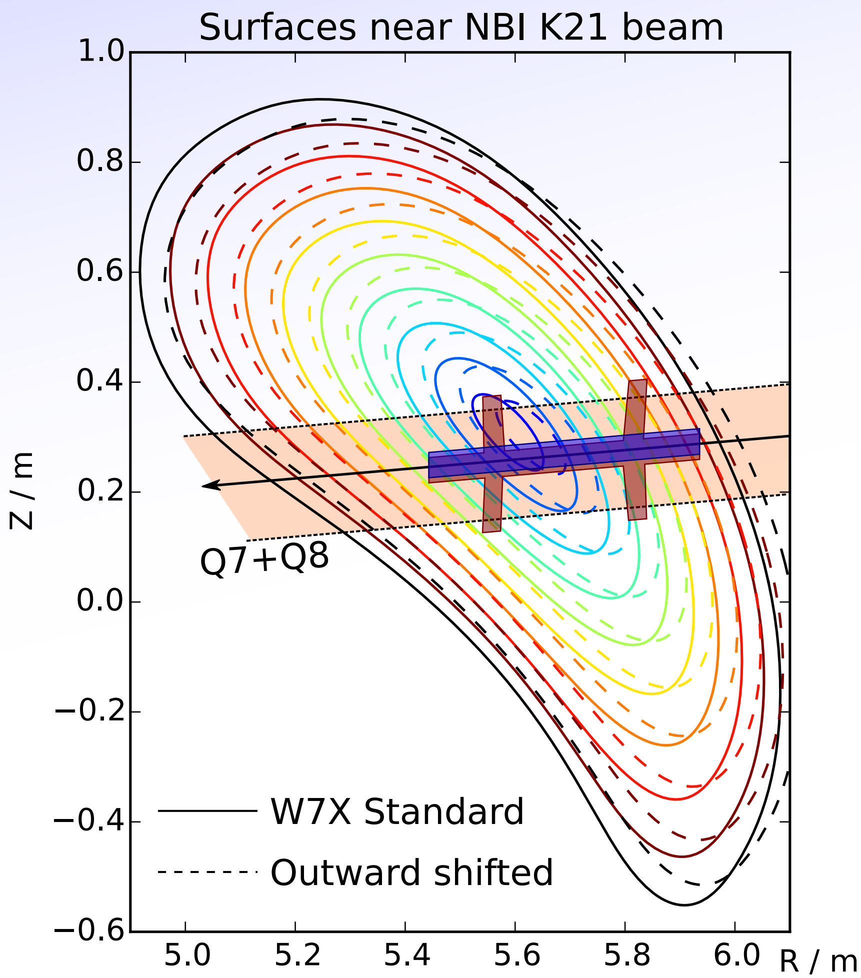

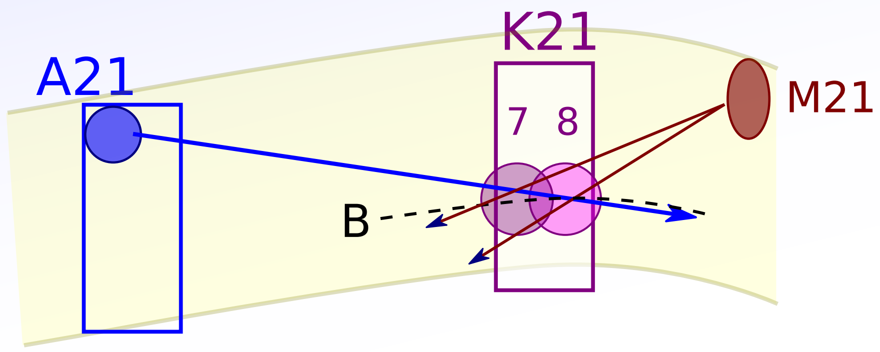

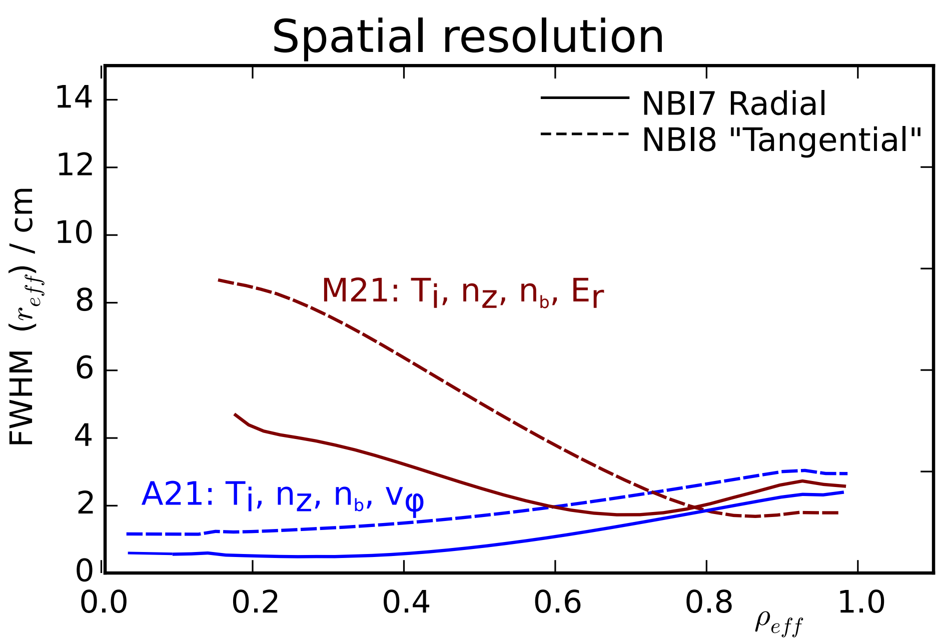

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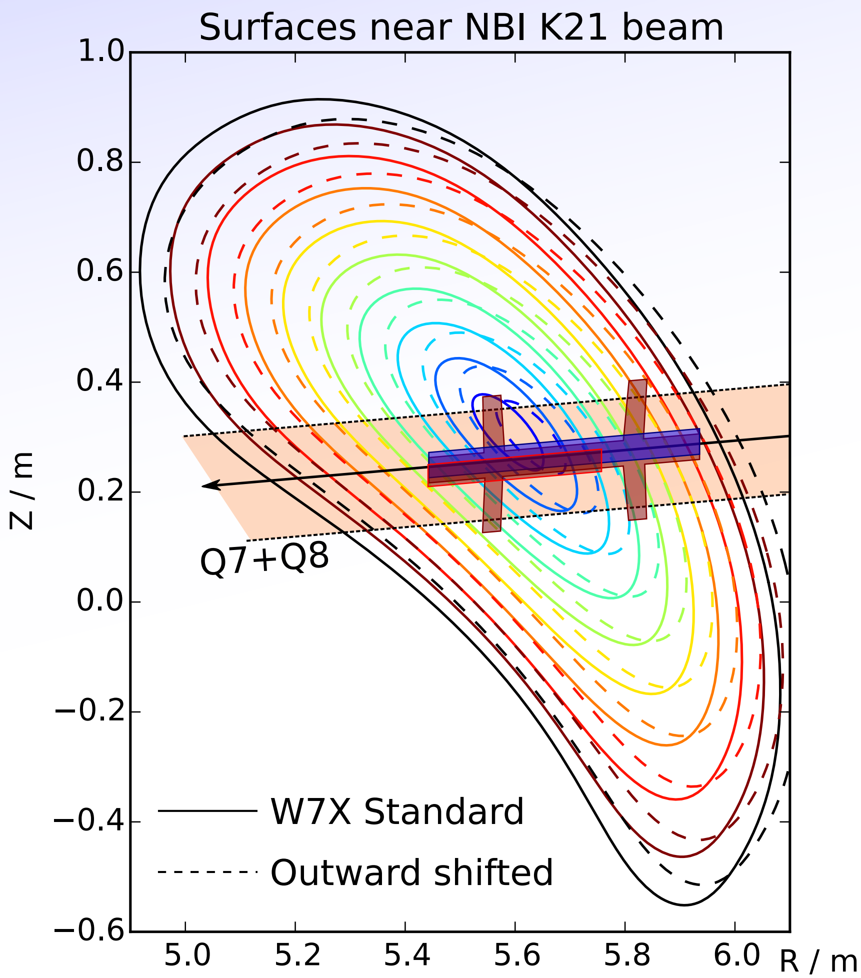

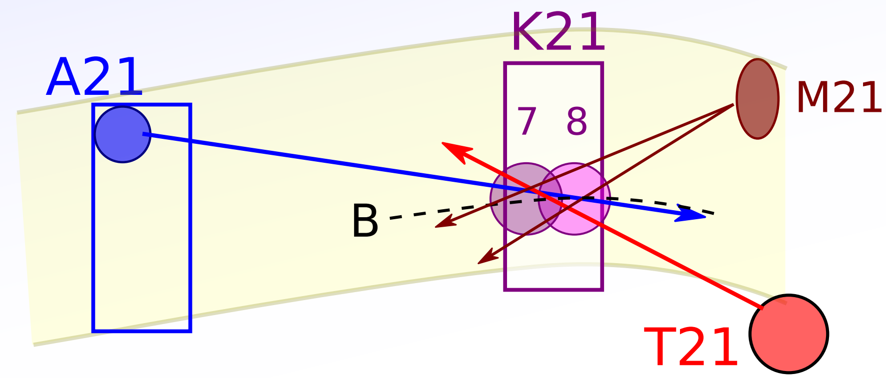

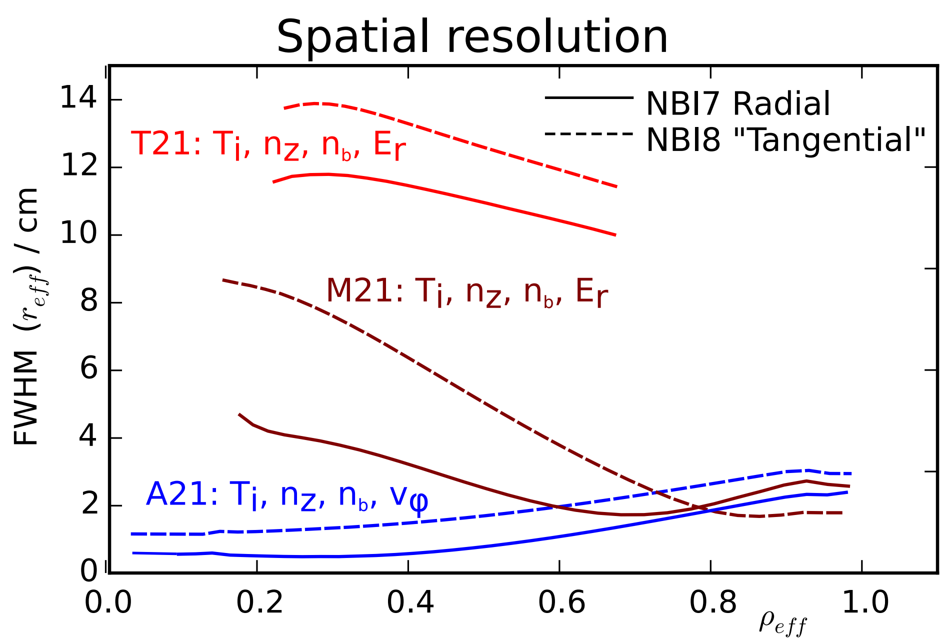

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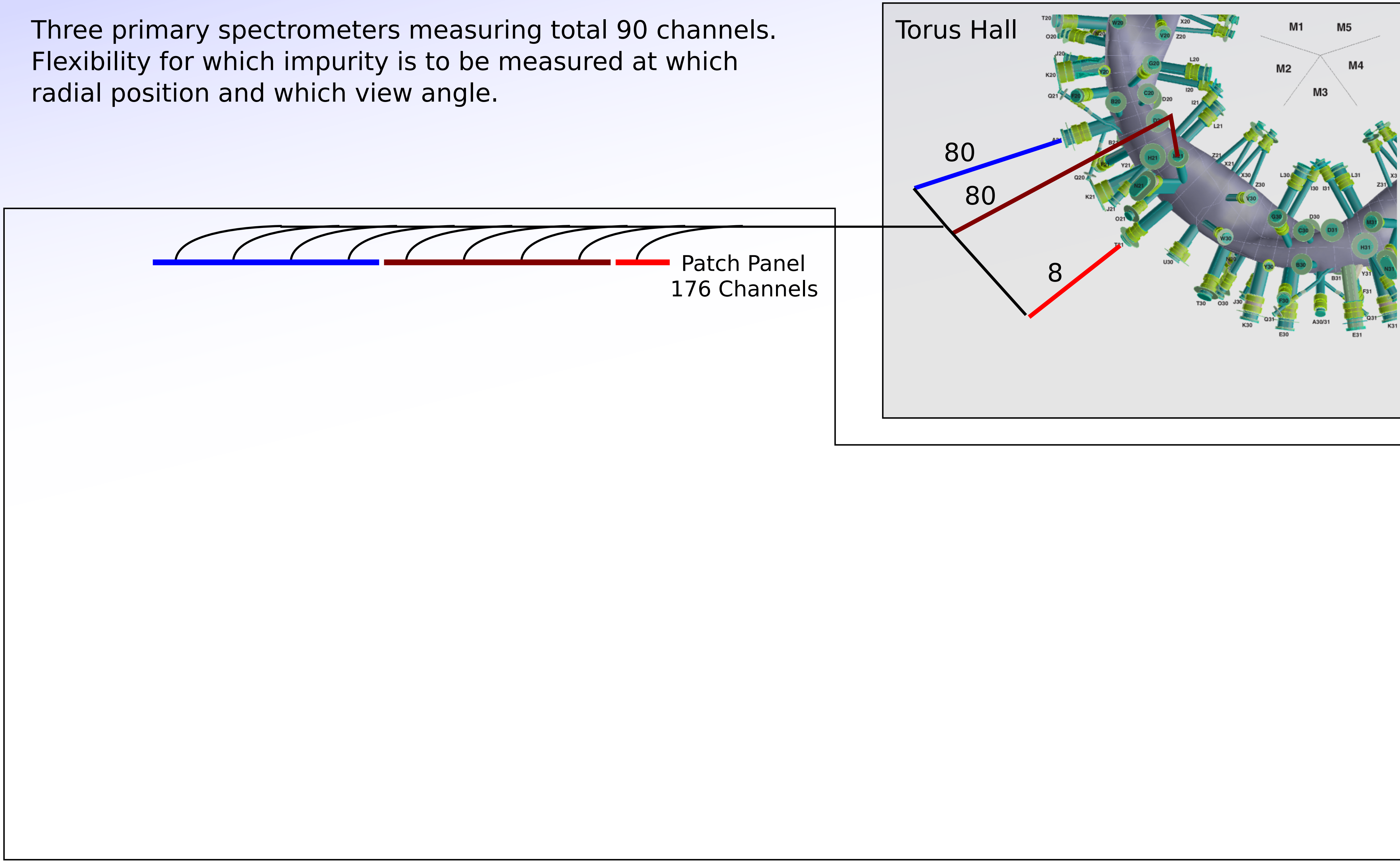
Three primary spectrometers measuring total 90 channels.
Flexibility for which impurity is to be measured at which radial position and which view angle.



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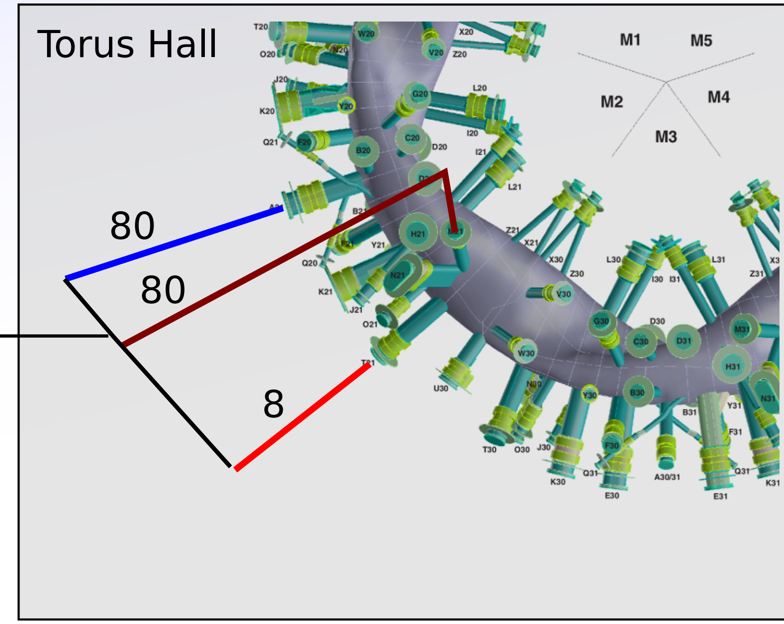

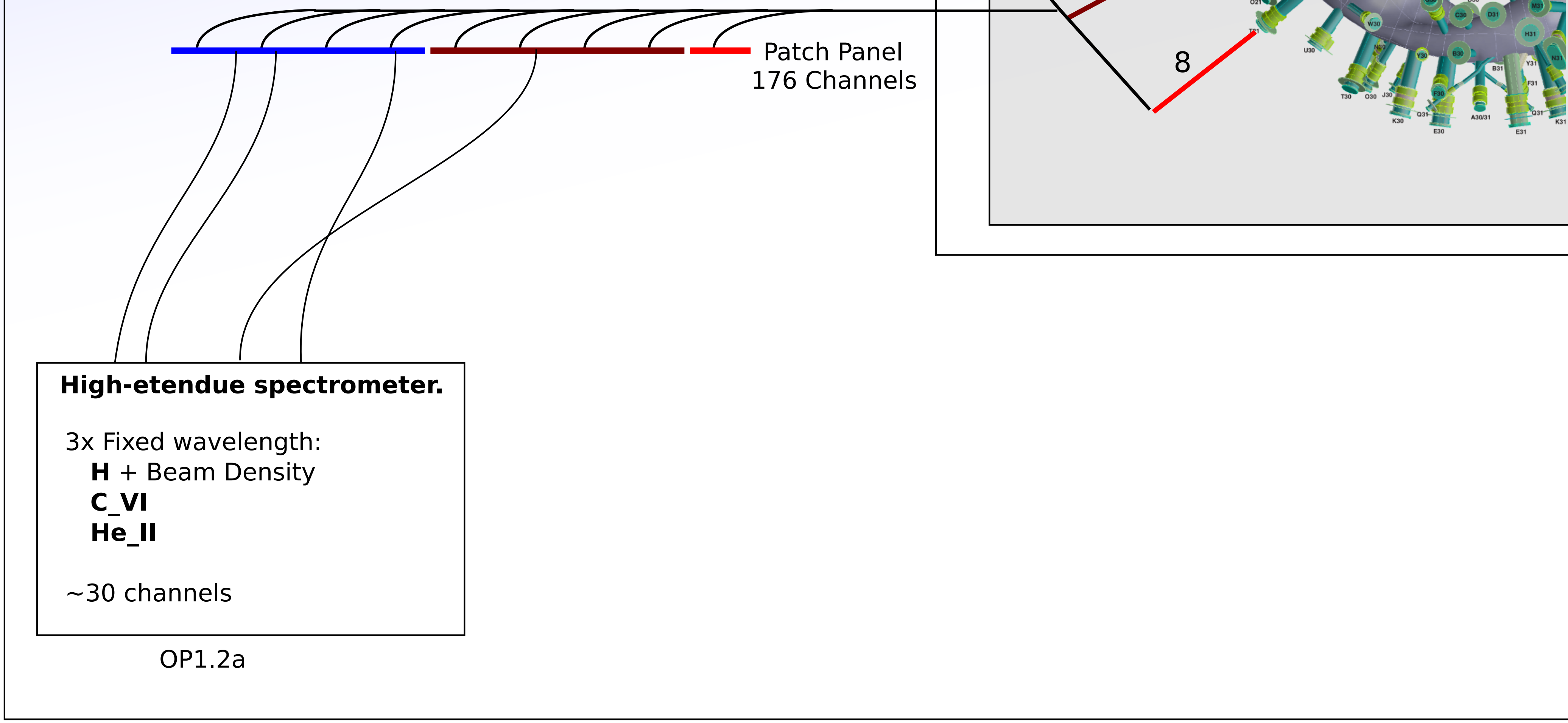

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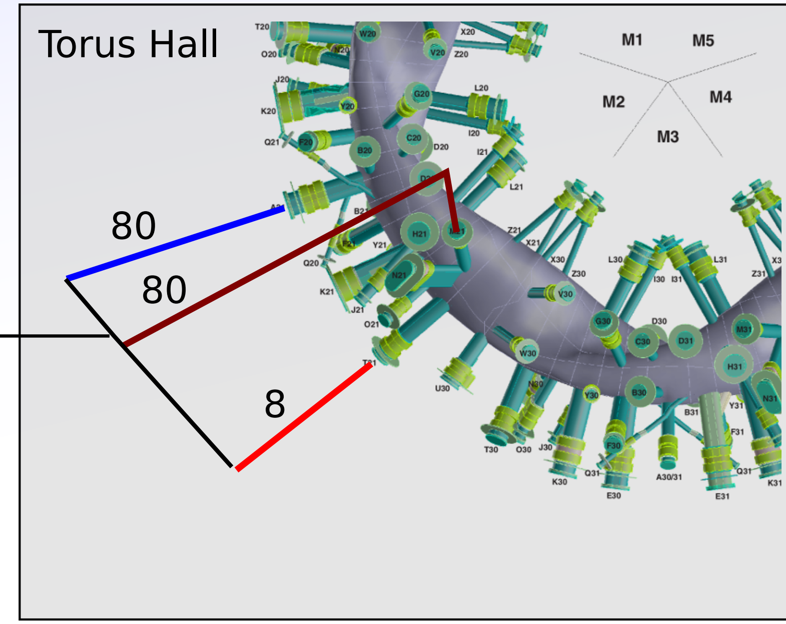

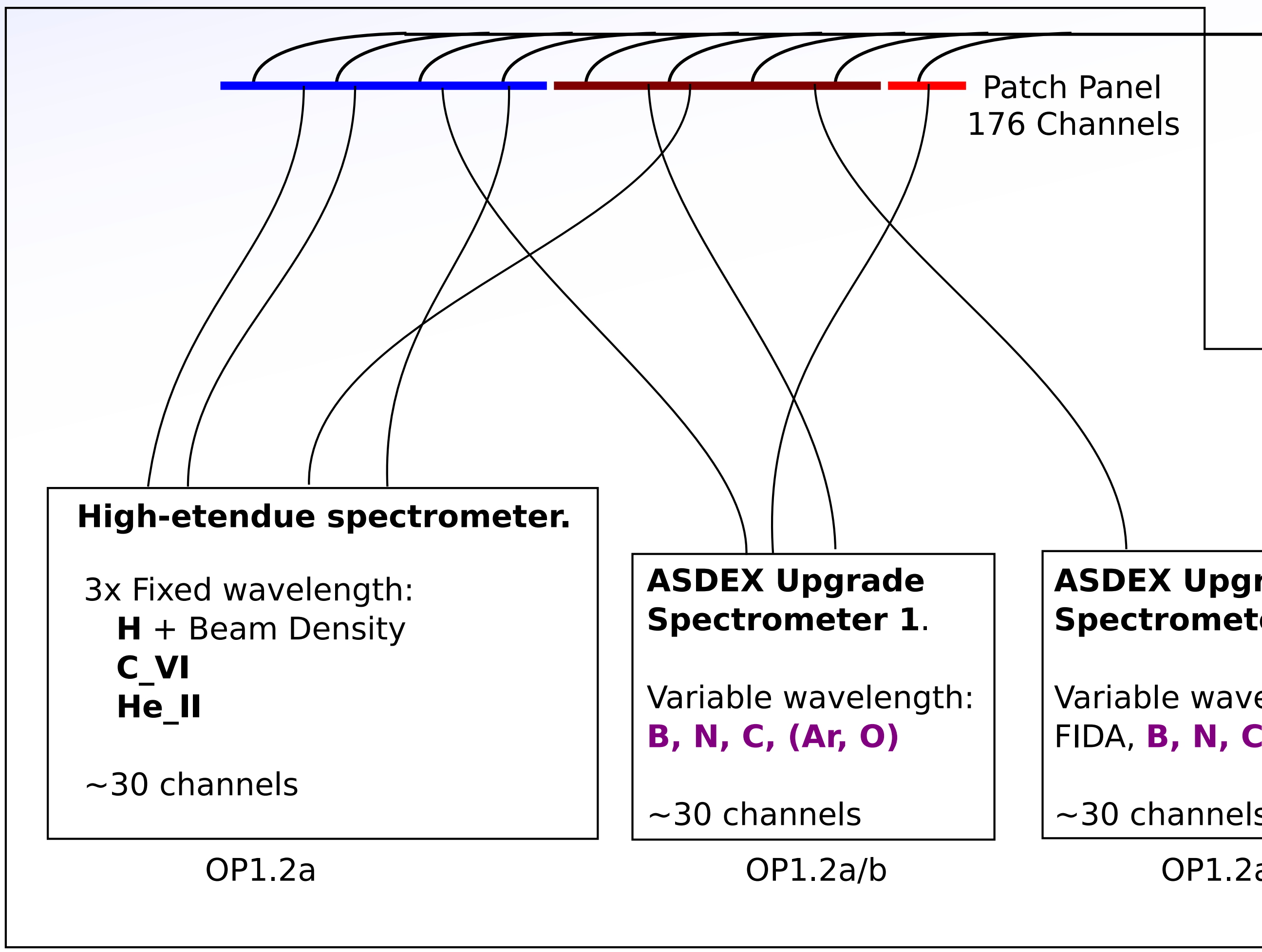

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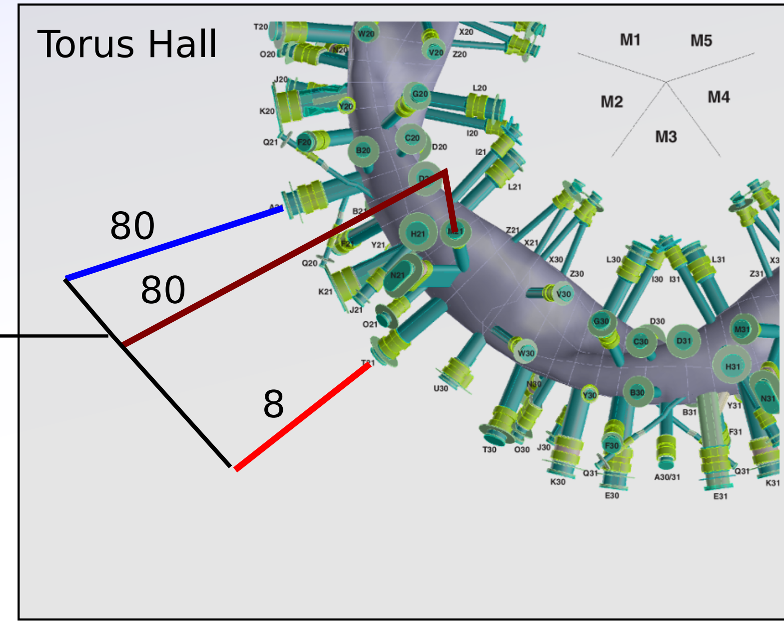

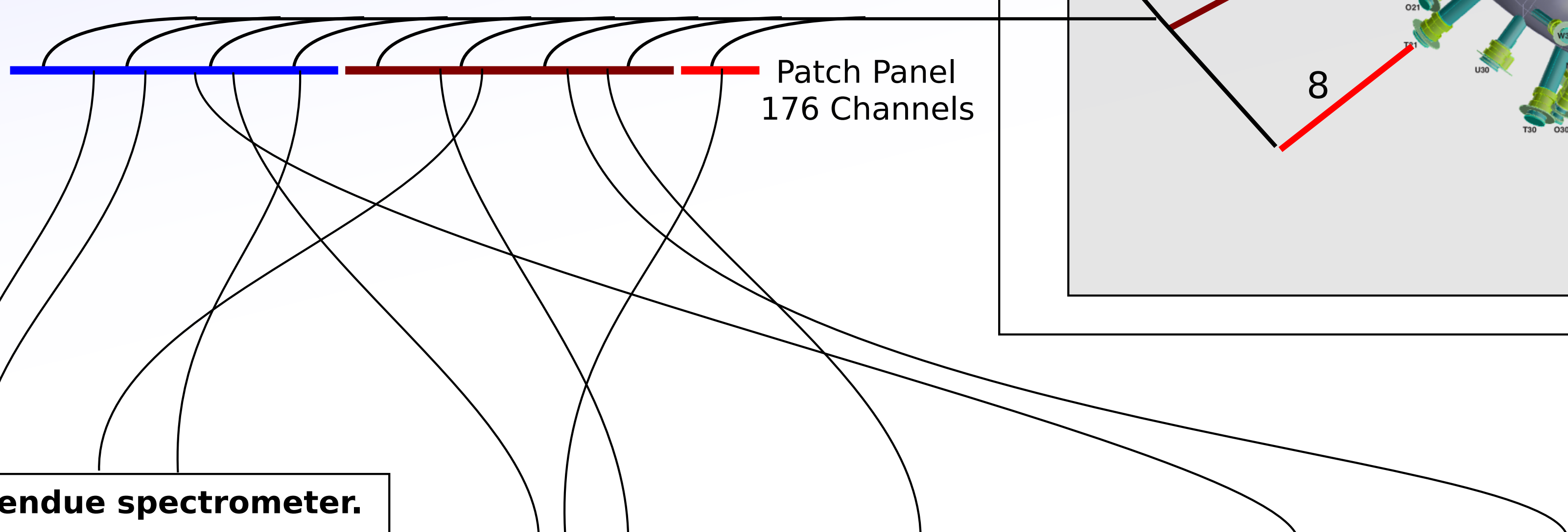

High-etendue spectrometer.

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
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
452.45 S_XIV
468.58 HeII
479.3 Ar_XVII??
494.46 B_V

524.9 NeX
529.06 C_VI
541.152 HeII
566.94 N_VII
570.2 S_XIV
606.8 O_VIII
608.5 N_VII
656.01 HeII
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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).

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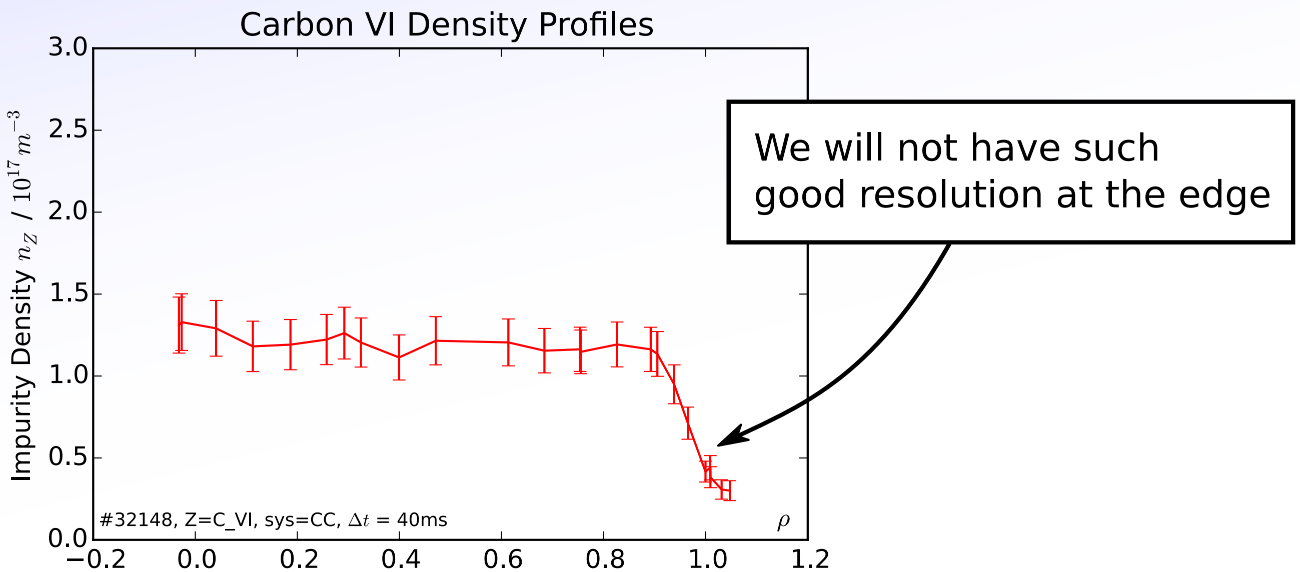
Performance at AUG

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:



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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.

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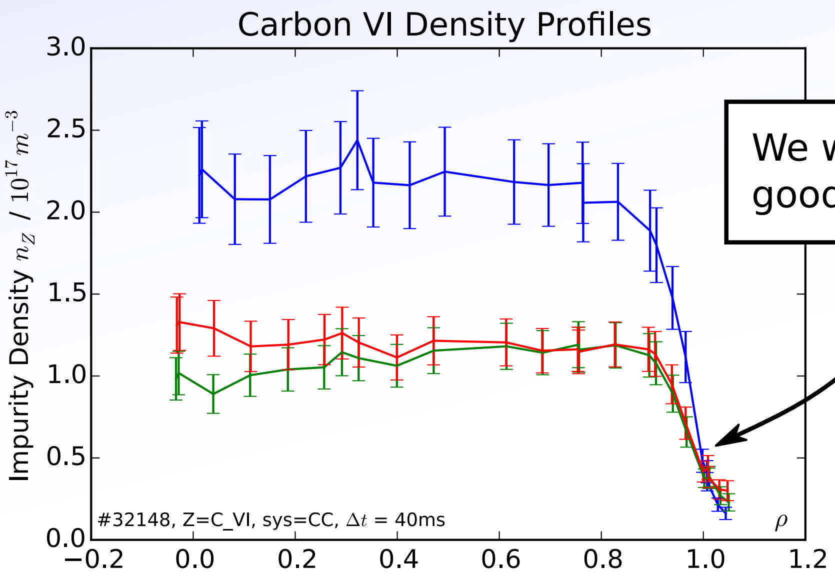

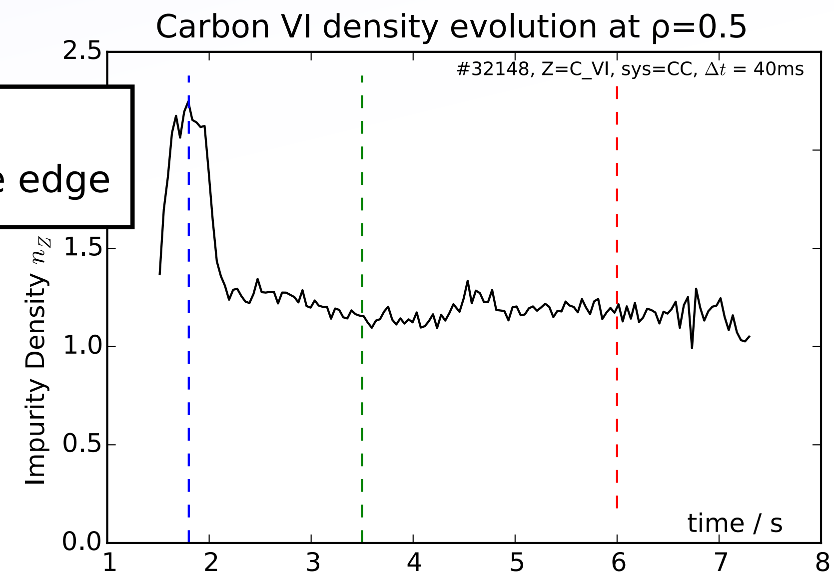

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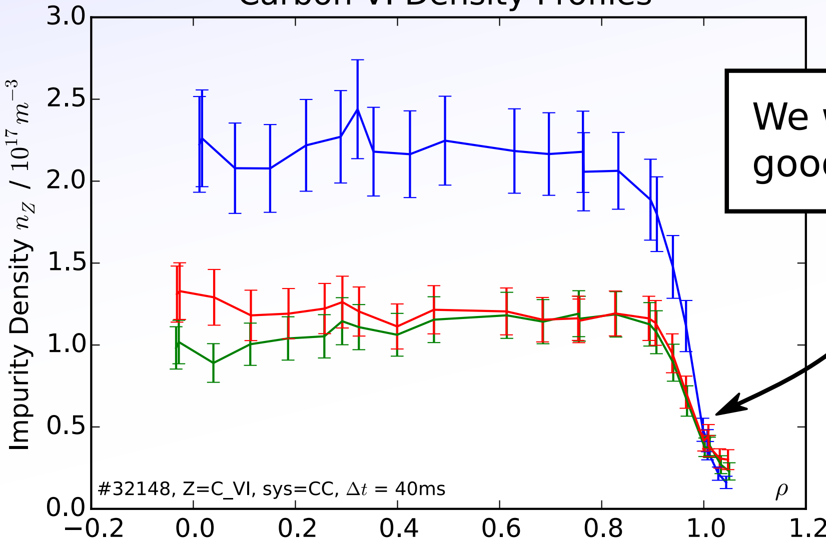
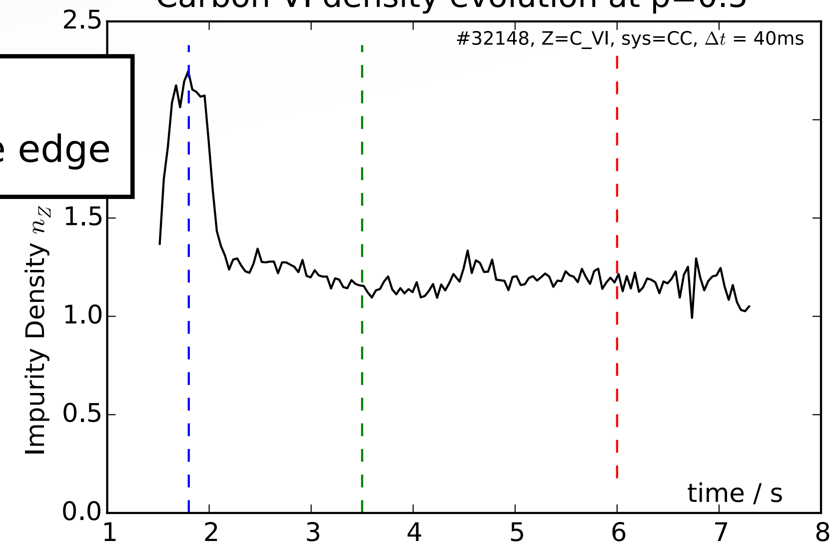
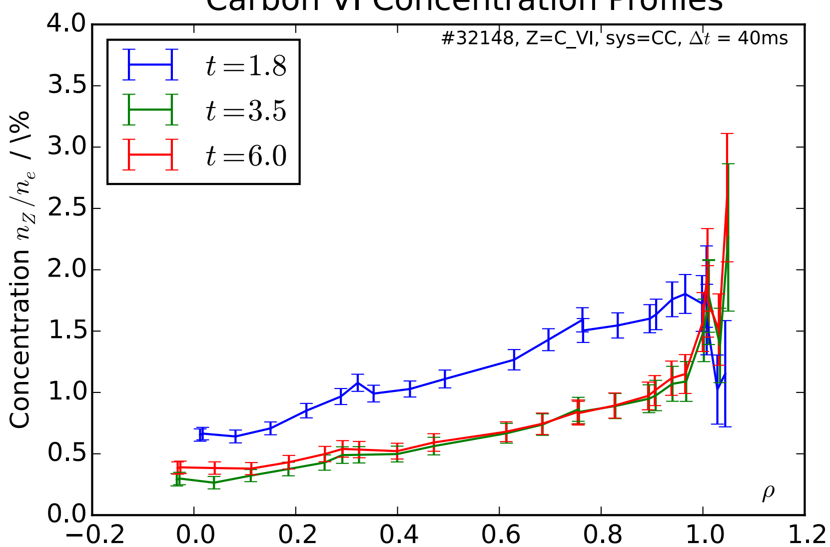
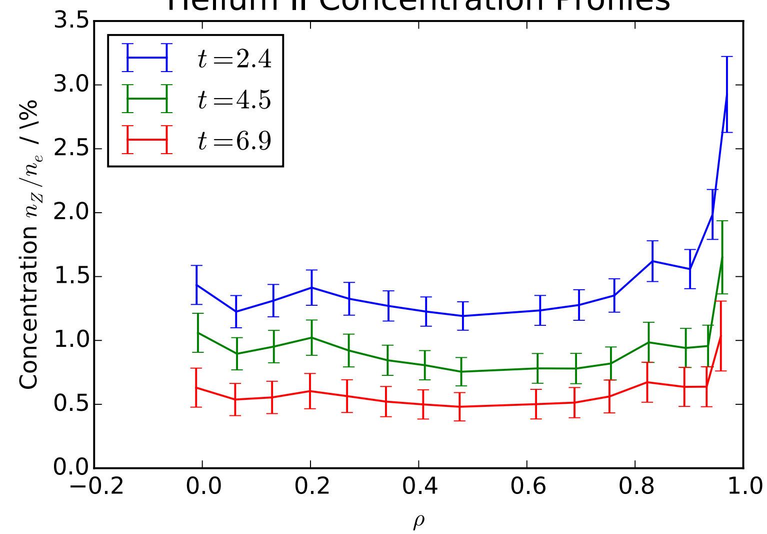


We will not have such good resolution at the edge







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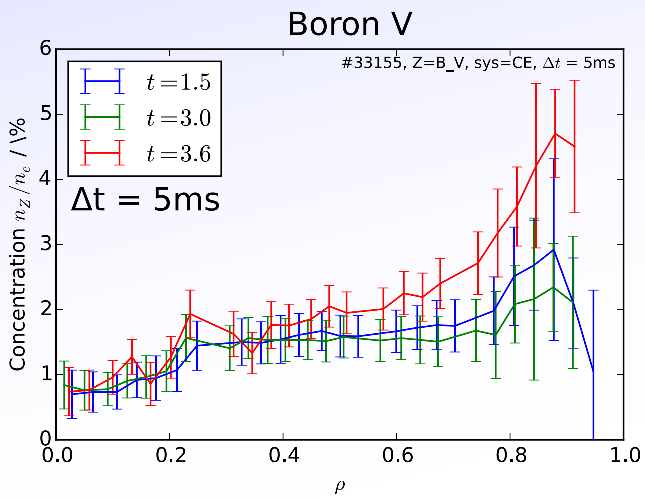
2) From the variable wavelength ASDEX Upgrade spectrometers at Δt = 5-9ms:



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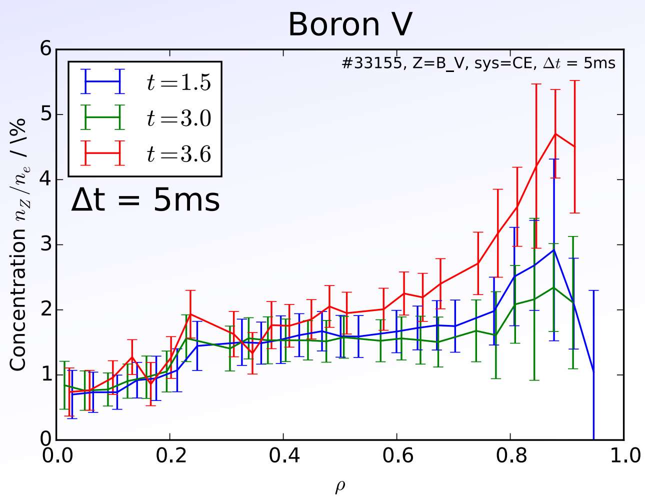

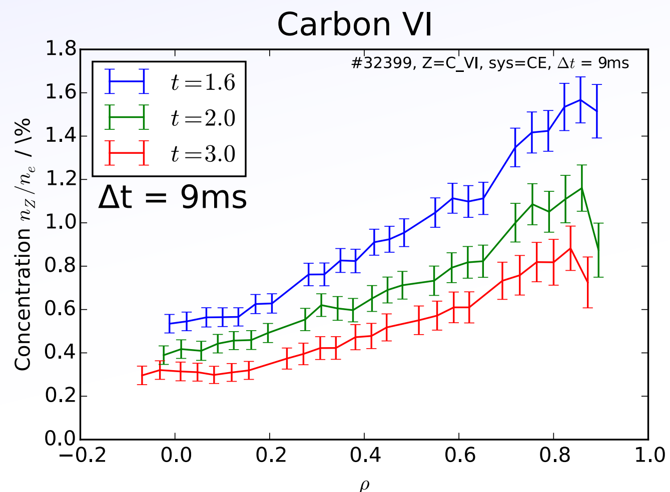

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Irrelevant to W7X

Performance at AUG

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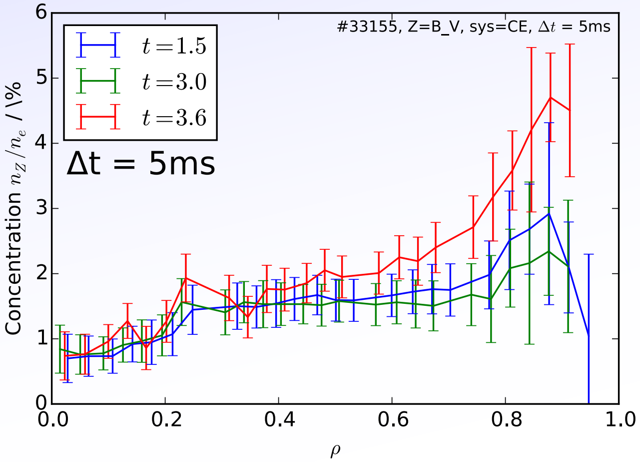
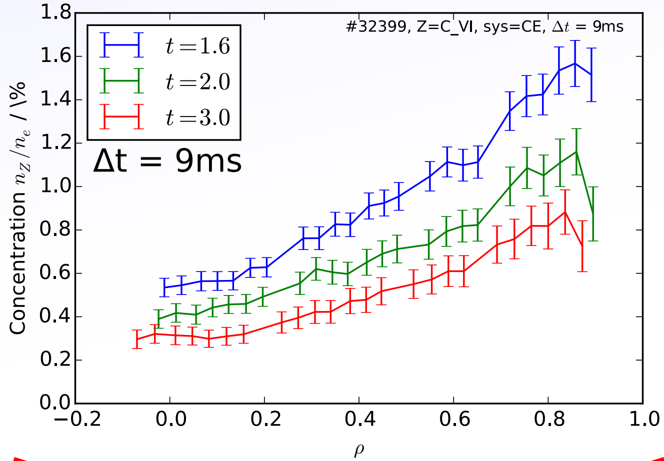
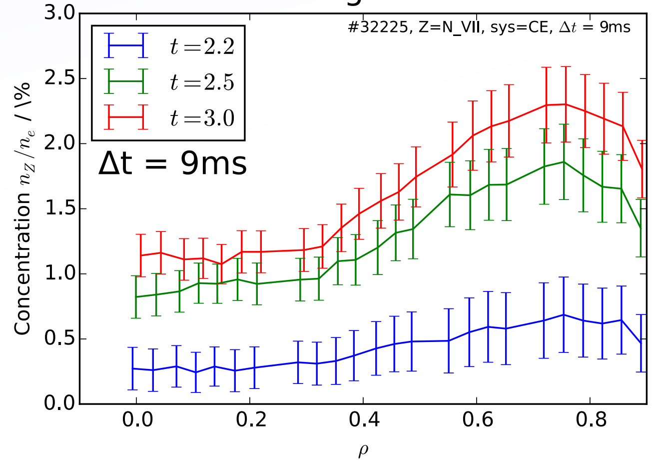
Boron V



Carbon VI



Nitrogen VII



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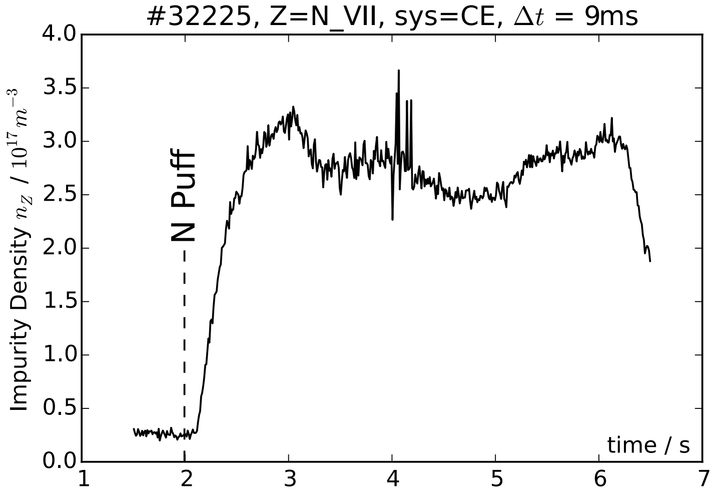
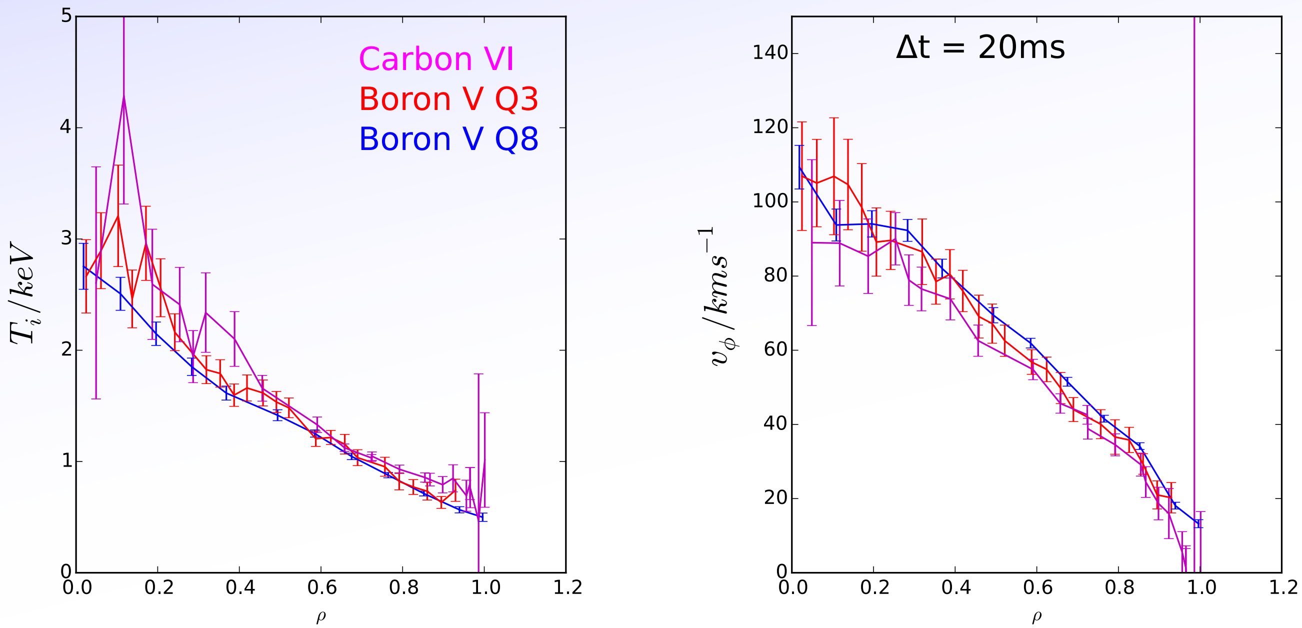
Nitrogen: Generally only when puffing *N for seeding experiments.*



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 Carbon, Boron, Nitrogen. Helium with some work.
- 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.

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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?