Options for Er measurements from CXRS on NBI

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Observation optics options

W7X CXRS Summary

CXRS observes line emission from impurity species after charge exchange with a beam neutral.

Intensity --> n_i

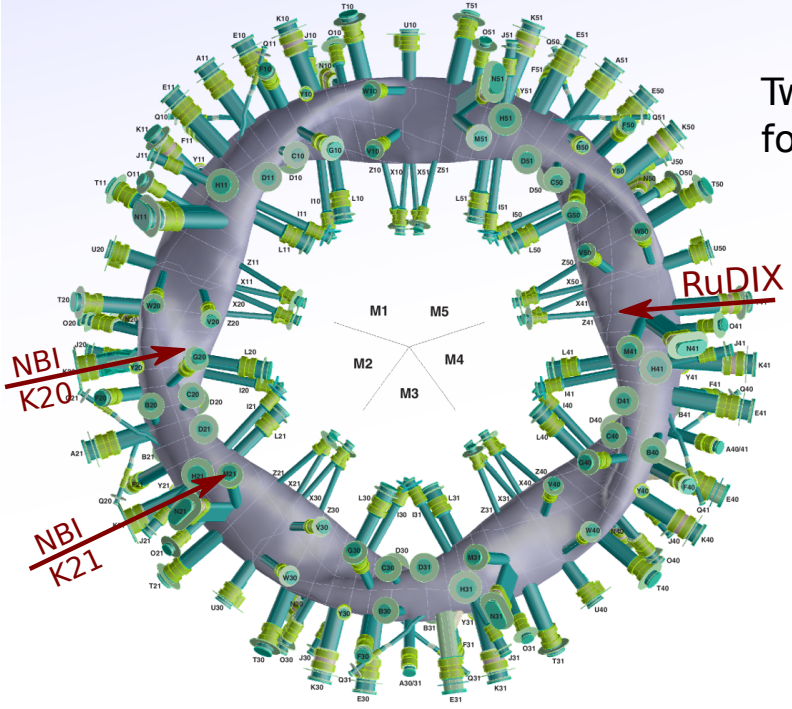
Width (Doppler Broadening) --> T_i

Shift (Doppler Shift) --> $V_\varphi/V_{\theta,}$ V_θ --> E_r

Requirements for E_r:
Generally we think we'll be looking at $|Er| < 50kV/m$ and wanting to see details down to preferably: $\delta Er \sim 2kV/m$,
At the very least: $\delta Er \sim 10kV/m$.

$B_\varphi \sim 2.5T$ so $E_r=2kV/m$ --> $v_\theta \sim 800m/s$.

Expect small values in very core, with most detail in $\rho_N > 0.5$.



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)

Heating Beams (NBI):

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

n_i, T_i can be provided by either, but v_φ / v_θ depends on the viewing geometry.
For W7X v_φ expected to be small, so E_r principally determined by $v_{\theta.}$

Other diagnostics:

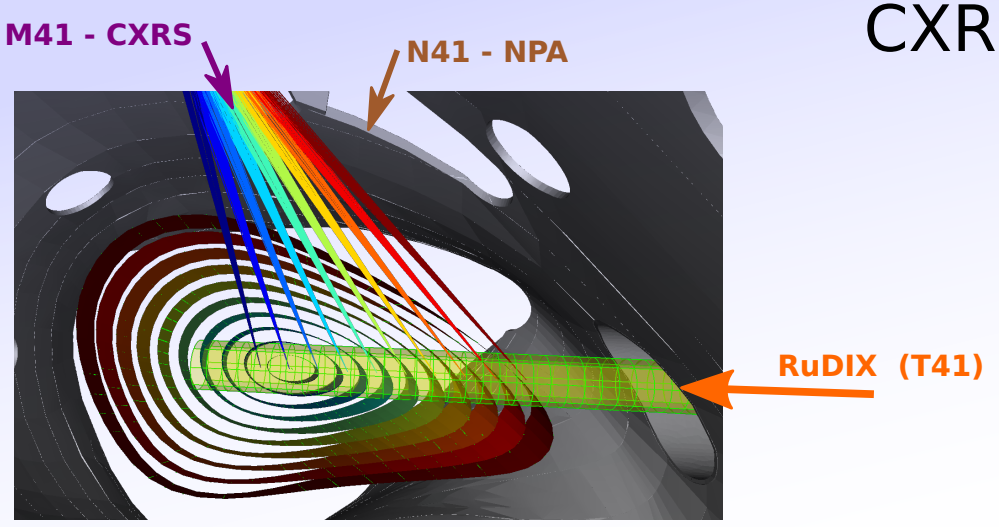
XICS: n_i, T_i, v_θ - line integrated, limited local information in the centre. Available only with Ar puff.
(Probably higher accuracy v_θ measurement (low stat noise) compared to CXRS.)

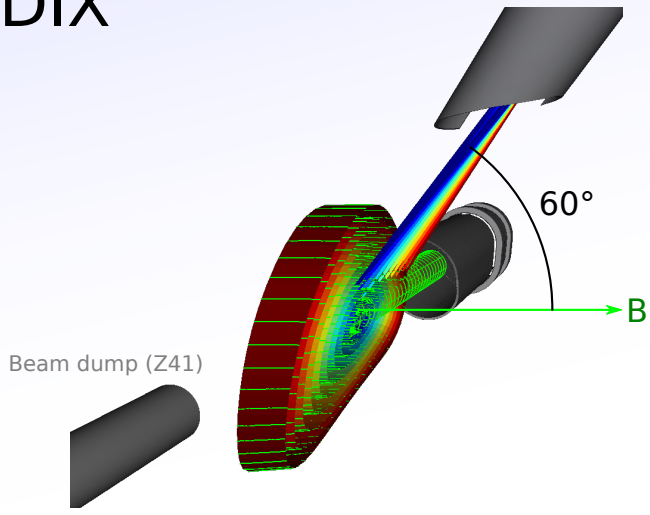
Edge Passive Spectroscopy: T_i, n_i, v_θ/E_r up to $T_e \sim$ few x100eV.

Doppler Reflectometry: Very edge E_r.

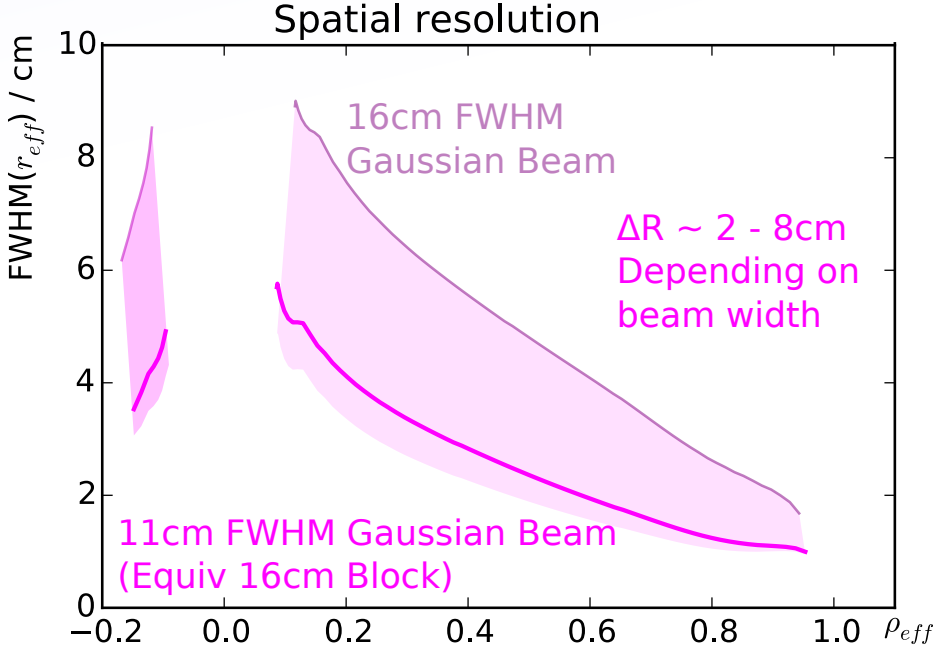
We will have very limited localised Er measurements in core to mid-radius from other diagnostics.

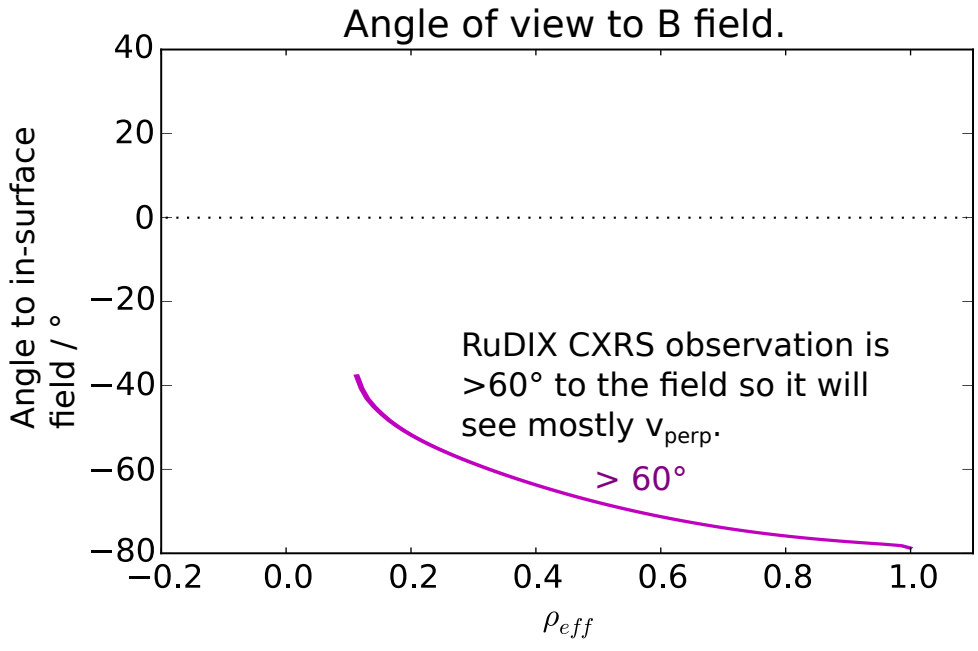
CXRS on RuDIX





Good resolution at edge, very good V_θ/E_r sensitivity. No v_φ measurement.
Near triangular plane central surfaces are approx circular, giving low spatial resolution near core.





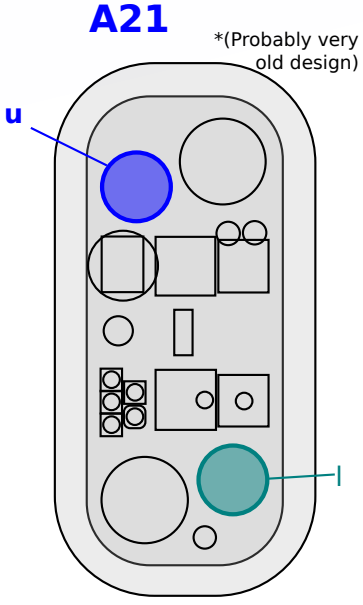
RuDIX CXRS obersation system almost ready (J. Baldzuhn), so will not change.
It's likely that RuDIX will not be ready until at least late in OP1.2.
We cannot rely on this if we want E_r during OP1.2.

W7X NBI Active Spectroscopy Systems

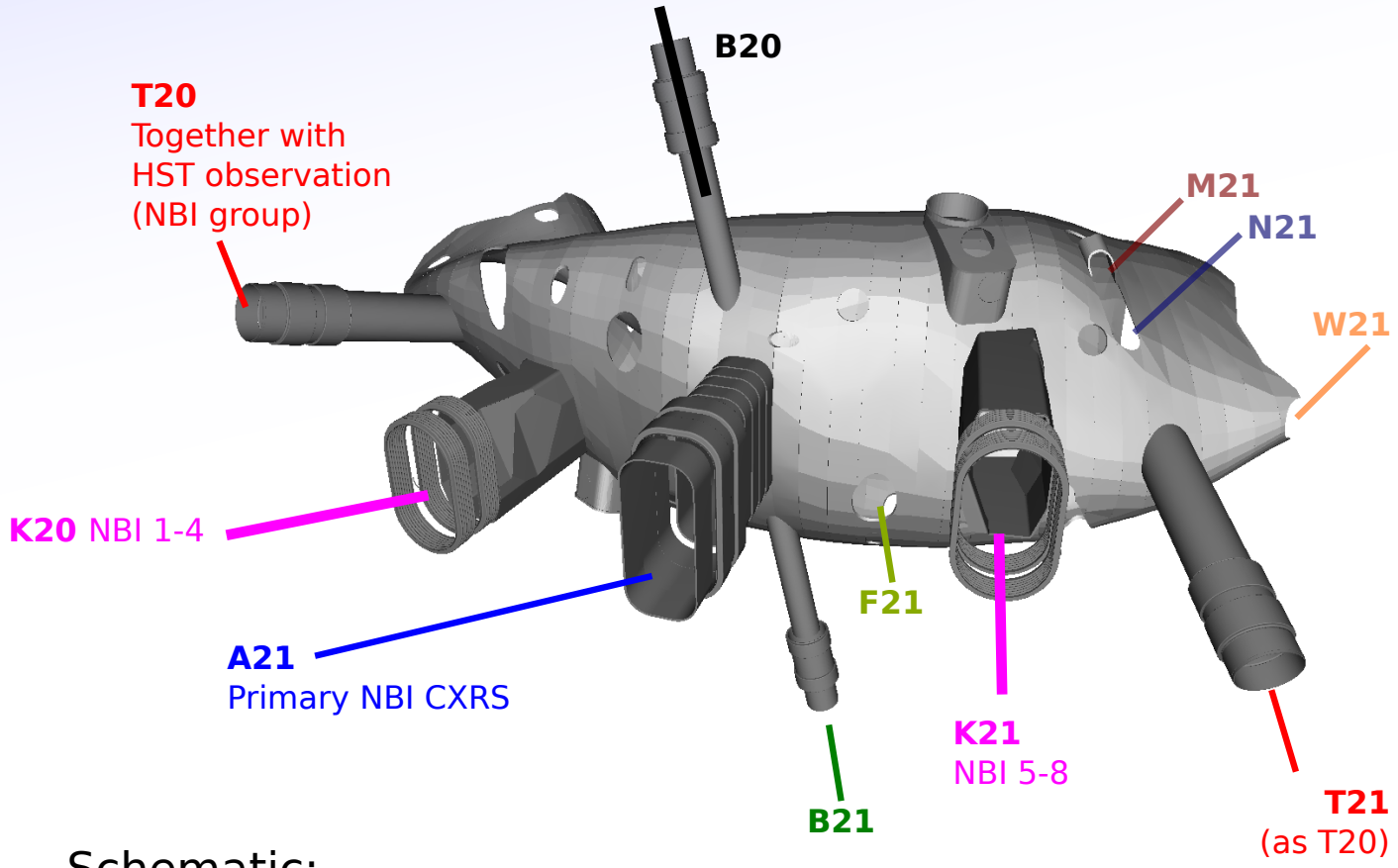
Two systems currently planned:

T2x: Low-resolution BES/CXRS.
~ 5 channels using optics in HST immersion tube.

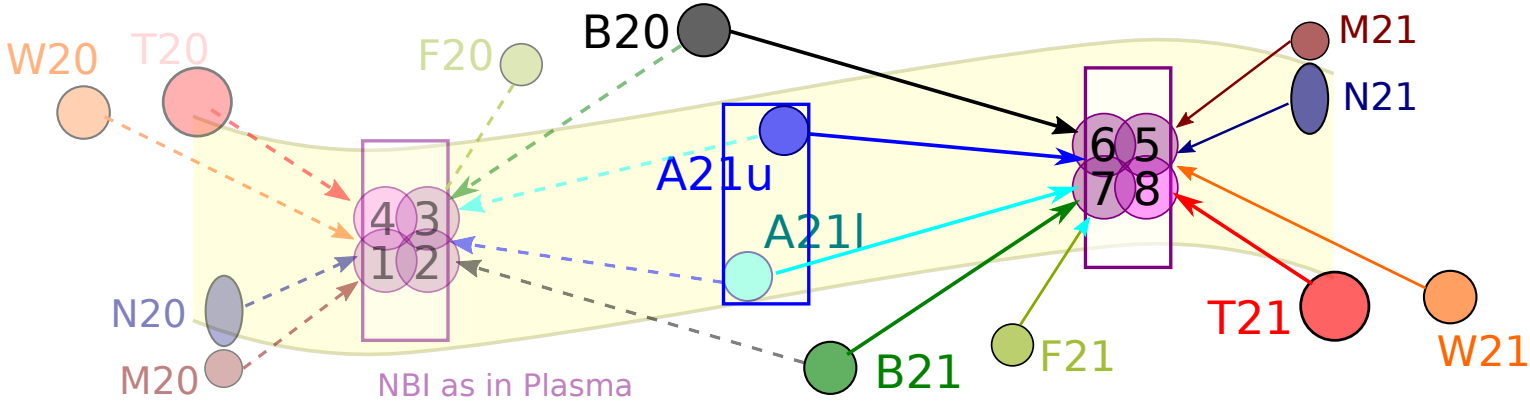
A21: Primary CXRS on NBI.
Two immersion tubes available in A-port for CXRS and later MSE systems.



All ports in the vicinity of K20/21:



Schematic:



NBI CXRS: More ports

NBI:

A21u: Very good resolution, v_φ only. Primary core T_i, n_i system.

A21l: Poor resolution, some v_θ. Better used as above for K20 beams.

T21: Good v_φ, very poor resolution. Probably use for ~5 channels to cross-check.

B20$^{(K21)}$: Very good resolution, Some v_θ/E_r sensitivity. [B20: LiBeam (OP1.2), Visible Spec (?) , Edge Passive Spec (OP 1.2)]

~~**B21$^{(K21)}$: Poor resolution. Better as B21$^{(K20)}$.** [B21: Sniffer Probes, ... +LiBeam??]~~

~~**N21:** Poor resolution [N20: SX Multi-foil N21: visible bulk spec]~~

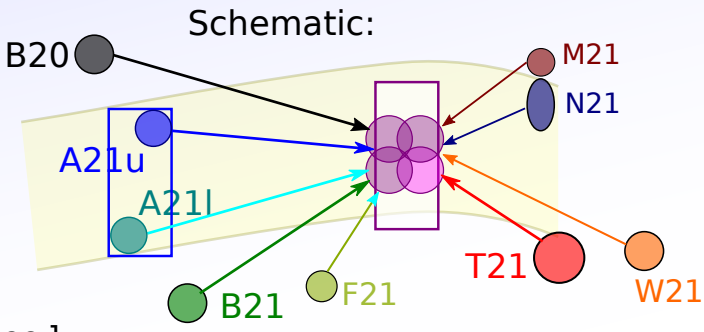
~~**F21:** OK resolution, Good E_r. [F20/21: Video, Hα camera, Div. Thermography]~~

M21: OK resolution. Good E_r. [M20: SX Flexible cam M21: visible bulk spec]

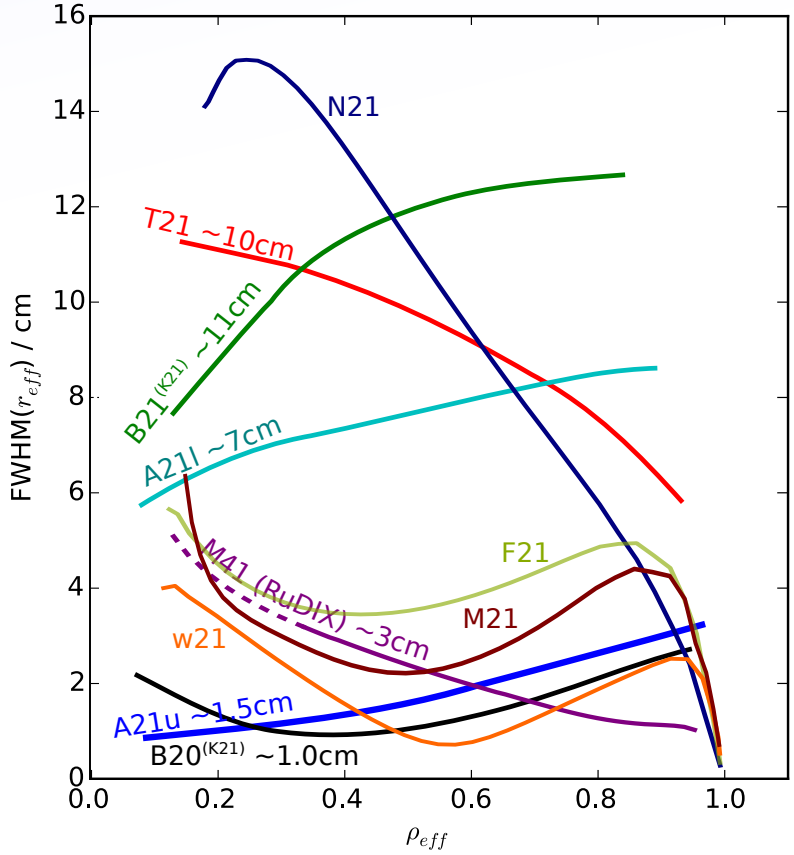
W21: Good resolution, same E_r as B20 [W20: XMCTS (OP?), W21: Bolometry (OP2)]

RuDIX M41: Good edge resolution. Excellent v_θ/Er sensitivity.

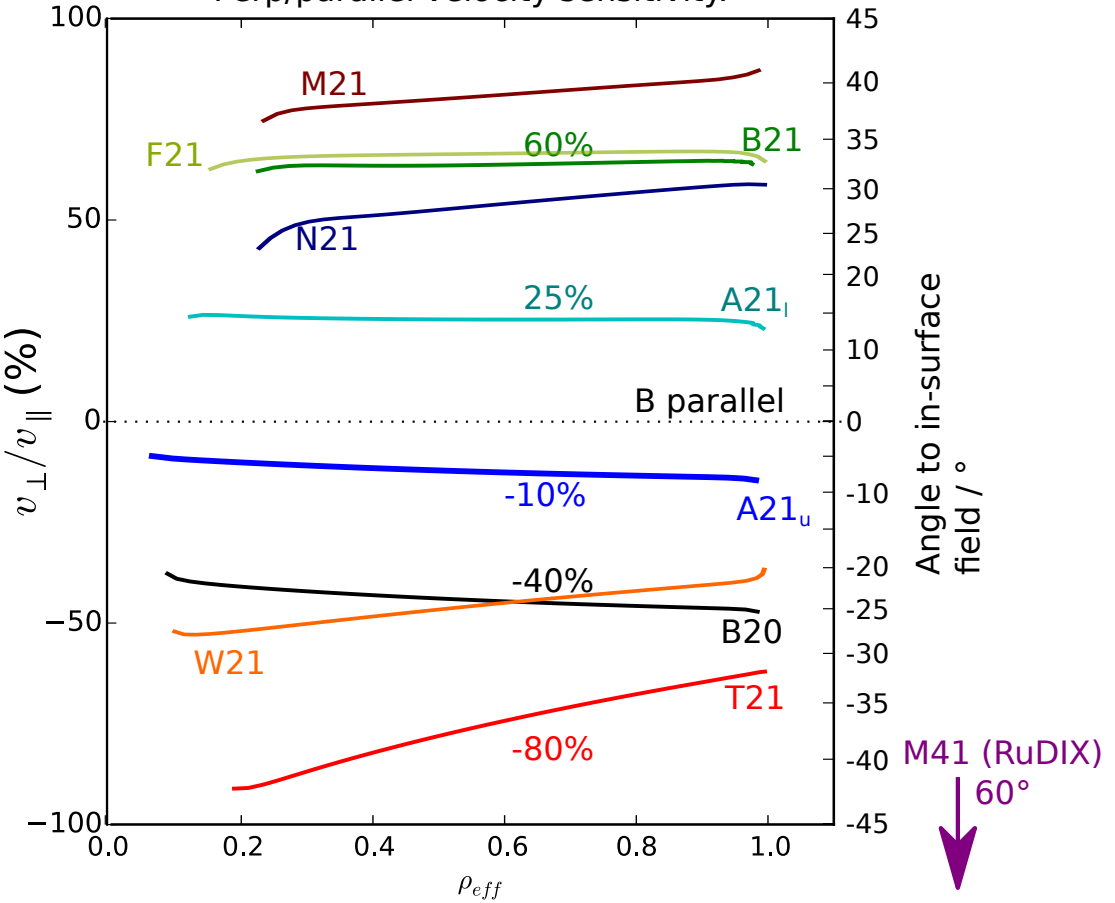
Schematic:



Geometric Spatial Resolution (neglecting focus)



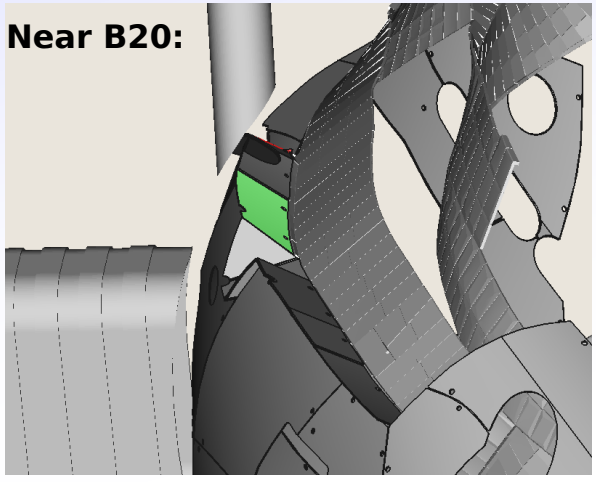
Perp/parallel velocity sensitivity.

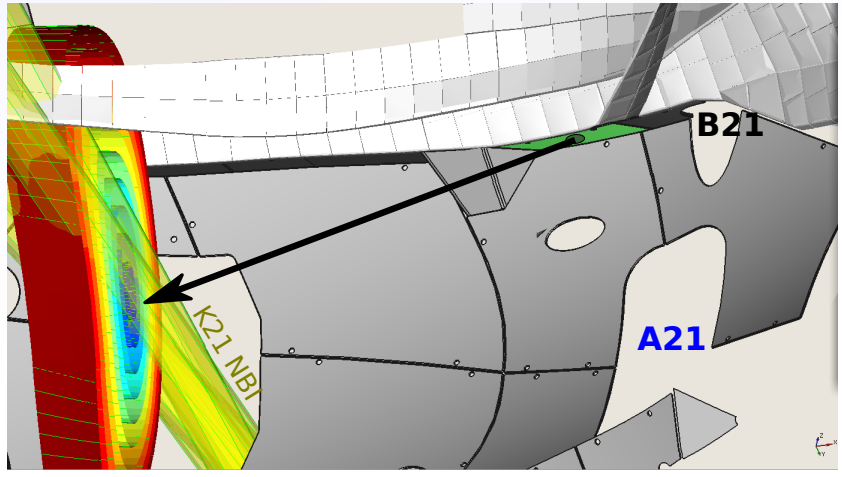


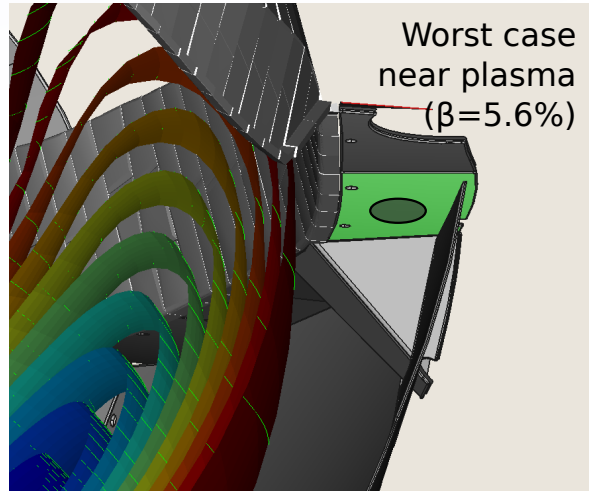
NBI CXRS: Panel options

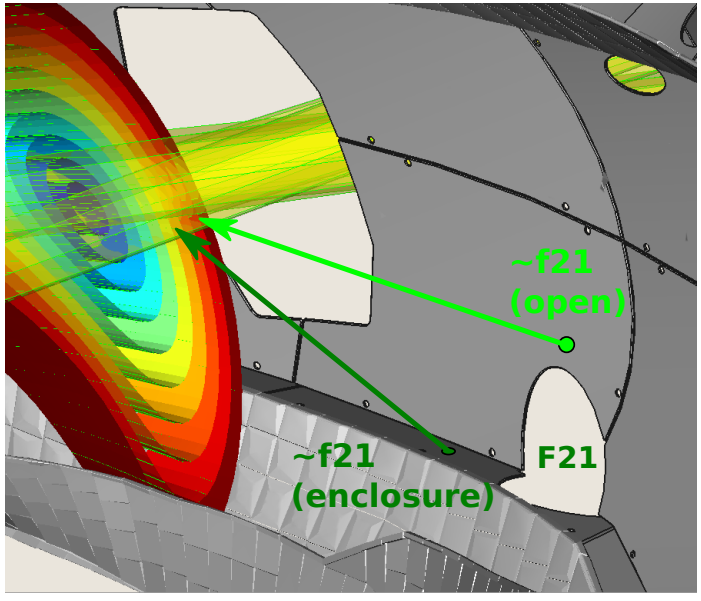
There is also the option of mounting heads in panels instead of ports and routing the fibres to them (All of the AUG CXRS systems are done this way).

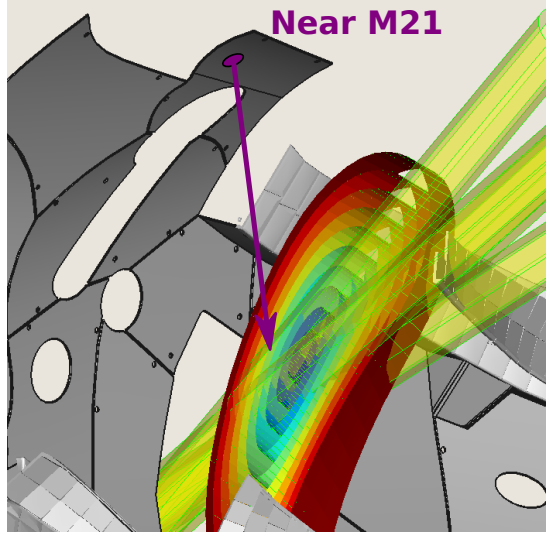
+ Can stay for OP2 when port space is more limitied.
+ Freedom of placement gives generally better resolution.
- Very complicated design/construction.
- Fixed in-vessel components harder to maintain.







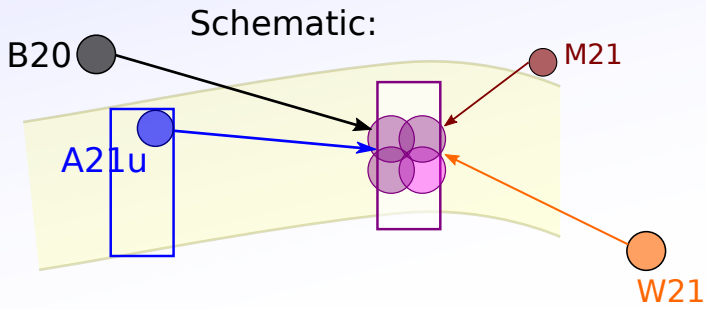


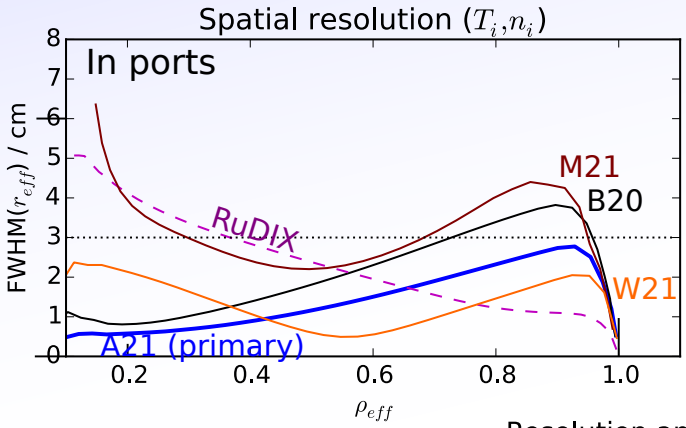


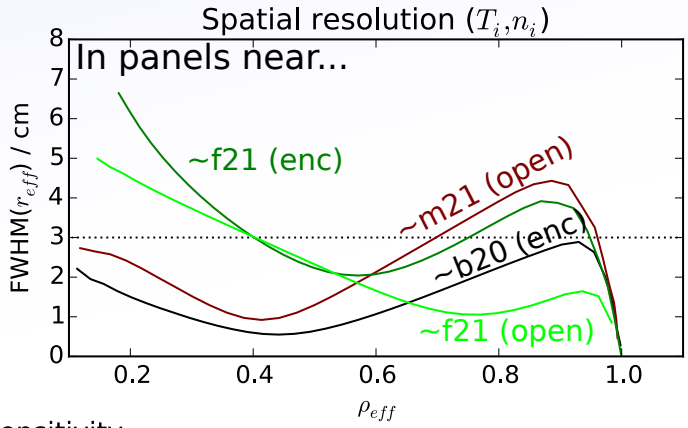
Considerations:
- Is there space behind baffels/enclosure?
- Fibres need to be routed in through a port - probably space in A21 near the main CXRS.
- Requires shutter and its drive routing. (Cable or piezo drive)
- All vacuum compatible components.
- ECRH stay radiation shielding required.
- ... ?

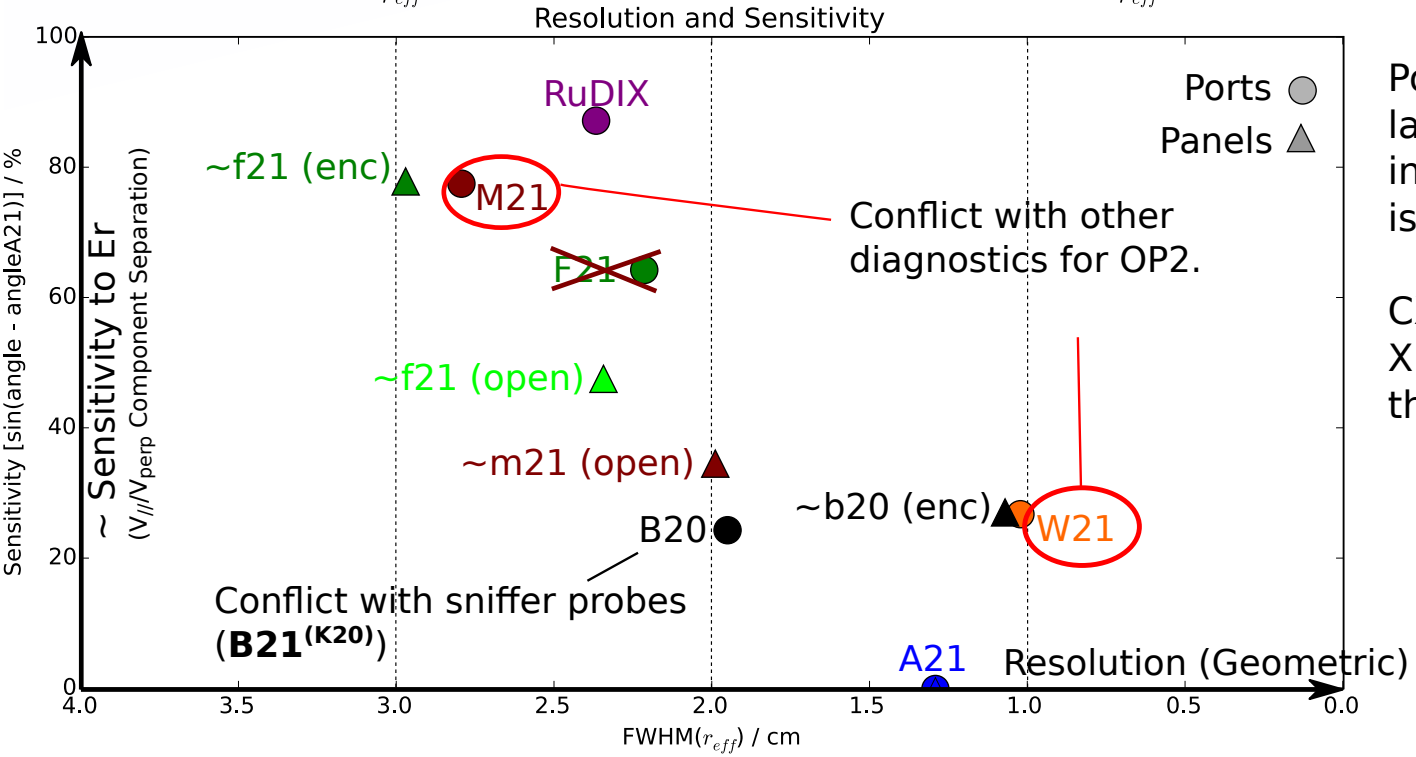
NBI CXRS: Best options

Closer look at highest resolution options:
The A21 system will be the primary NBI CXRS system for ni, Ti, and measures at ~ -7° to the field, so mostly parallel flow.
We are looking for a measurement at an angle to this, to isolate the other component:









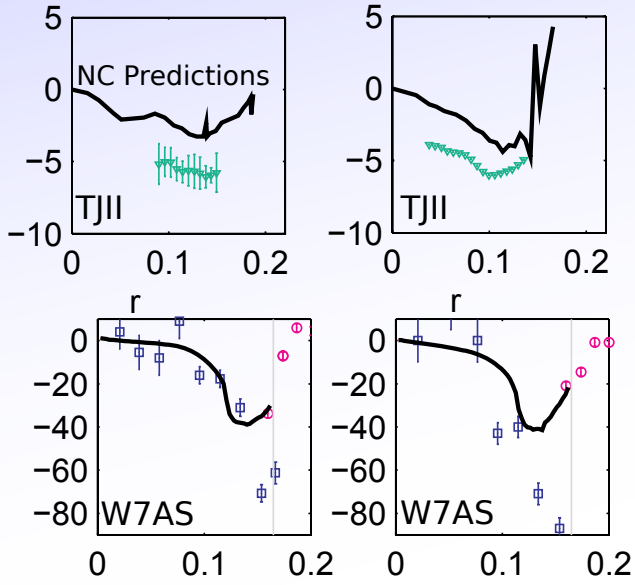
Poor sensitivity is possible to overcome later with better spectrometers / longer integration etc, but spatial resolution is fixed by optics.

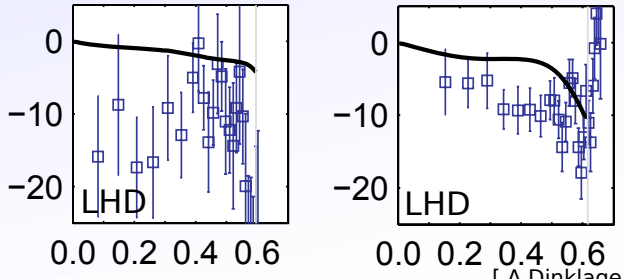
CXRS brings the spatial resolution which XICS can't provide, particularly towards the core.

Port occupancy:
- **A21:** Primary core T_i, n_i system.
- **B21(K20) :** Sniffer probes
- **M21:** Visible bulk spec, **M20:** SX Flexible camera
- **F21, F20:** Video diagnostics - no space.
- **W21:** Bolometry, **W20:** XMCTS

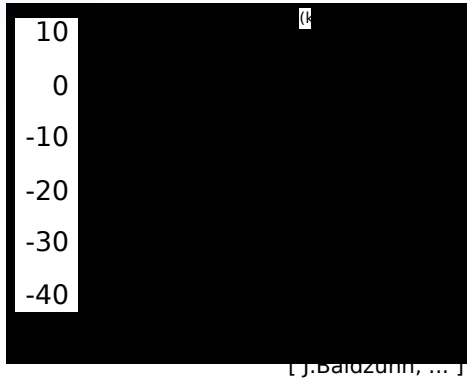
Er Requirements and capability

From other machines, and modelling for W7X, we can get an idea of what sensitivity to Er is required:

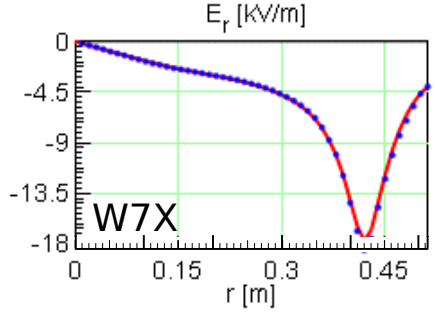




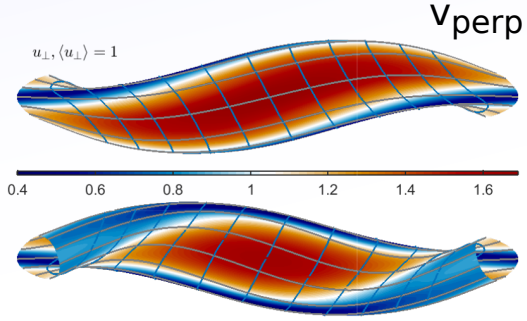
[A.Dinklage ... Nucl Fus 53 2013]

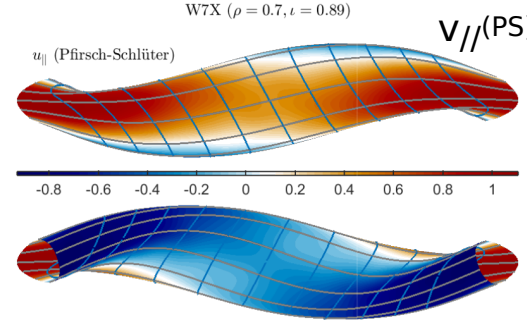


[J.Baldzuhn, ...]



[J.Geiger, ... Status of W7X Modelling ISHW2012]





For Er, generally suspect that we'll be looking at |Er| < 50kV/m and wanting to see details to, at the very least ±10kV/m, preferably ±2kV/m. At B_φ ~ 2.5T, E_r=2kV/m --> v_θ ~ 800m/s.

Use the best spectrometer from ASDEX Upgrade (ITER-like from Jülich, or duplciate their best core system).
- Same NBI and the same minor radius.
- Higher ne attenuates beam in core more.
- Low Carbon content due to W wall, so they use Boron (from Boronisation) - we could also do that, or C might be better.
- ITER Spectrometer: At 1.2x10 ^{20}, C measurements at AUG gives ±5km/s (12kV/m) at 10ms, ±2km/s (5kV/m) at long intergration (~2s, and doesn't help any more) in the core, much better at the edge.
  We would have a factor 2-3 larger errors due to 20° angle. But, our C content should be much large.

XICS will probably give higher time resolution/sensitivity than CXRS for Er but is line-integrated. Integrated analysis of XICS + CXRS will be needed for time + spacial resolution together.

[With thanks to A. Kappatou, R.McDermott]