MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Validation of edge modeling codes

Wendelstein 7-X

V. R. Winters (on behalf of TFII/III)

EUROfusion

List of selected OP2.1 Proposals on edge modeling validation

- Disclaimer: many proposals dealing with edge modeling validation can also be discussed in the framework of other deliverables in this workshop! Below is just a sample of relevant proposals.

alkn_003	Characterization of edge topology and PFC heatload analysis in high current scenarios
alkn_004	Beta effects on edge topology and PFC heatloads in paradigm configurations
caki_017	Destabilization of detachment in standard configuration
caki_018	Validation of transport models using new spectroscopic fluctuation measurements
ebf_002	Profile diagnostics exploitation for SOL and upstream characterization
flr_004	Validation of numerical modelling of edge transport and exhaust
geiger_006, 008, 009	Change of boundary topology and heatload distribution with β
sxu_001,002	β effects on detachment threshold and edge impurity transport -> shifted to OP2.2
tid_003	Impurity transport studies using 15N injections -> shifted to OP2.2

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Field line diffusion/EMC3-Lite/ HINT/ VMEC + Extender validation

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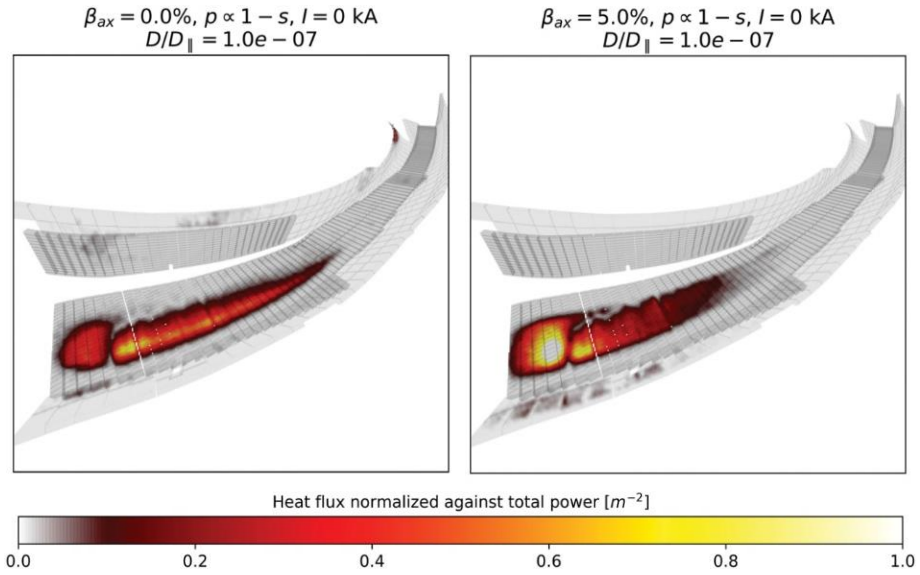
ERO2.0/ WallDyn3D validation

FLD calculations from HINT equilbria show β effects on heatload distribution, but at lower β than expected

Courtesy: A. Knieps

Anisotr. Diffusion prediction

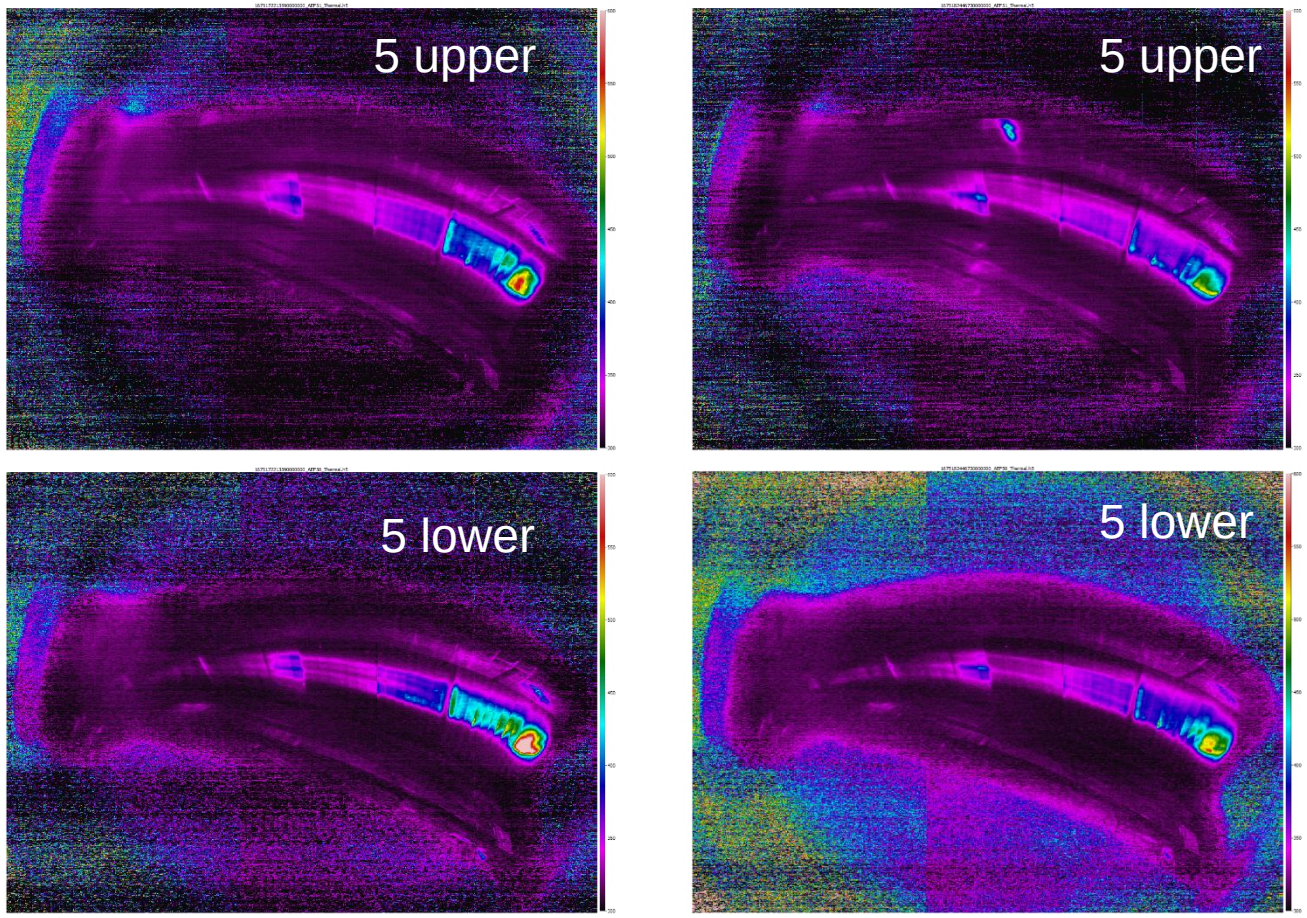


IR cameras show similar trend as simulations predict, but changes might happen at lower beta than expected (profile analysis pending for proper on-axis beta calculation)

Divertor IR observations at 4 s

20230131.040

20230131.054 ($\beta_{vol} \approx 0.5\%$)

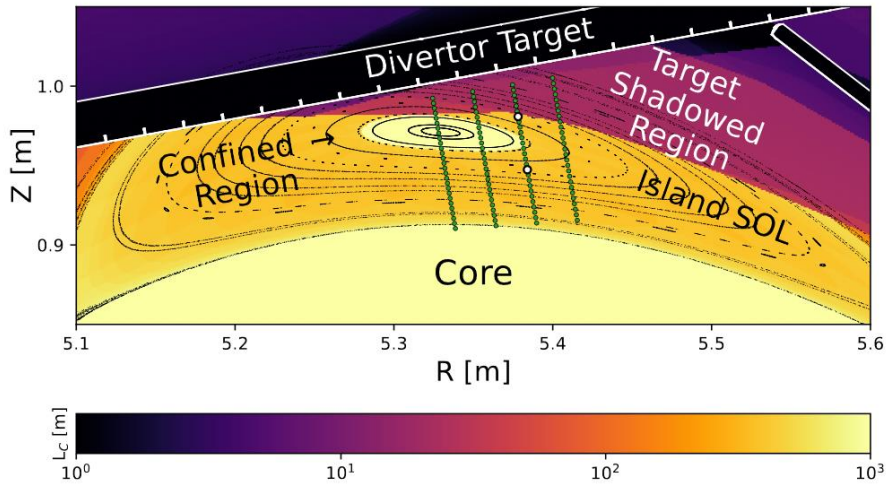


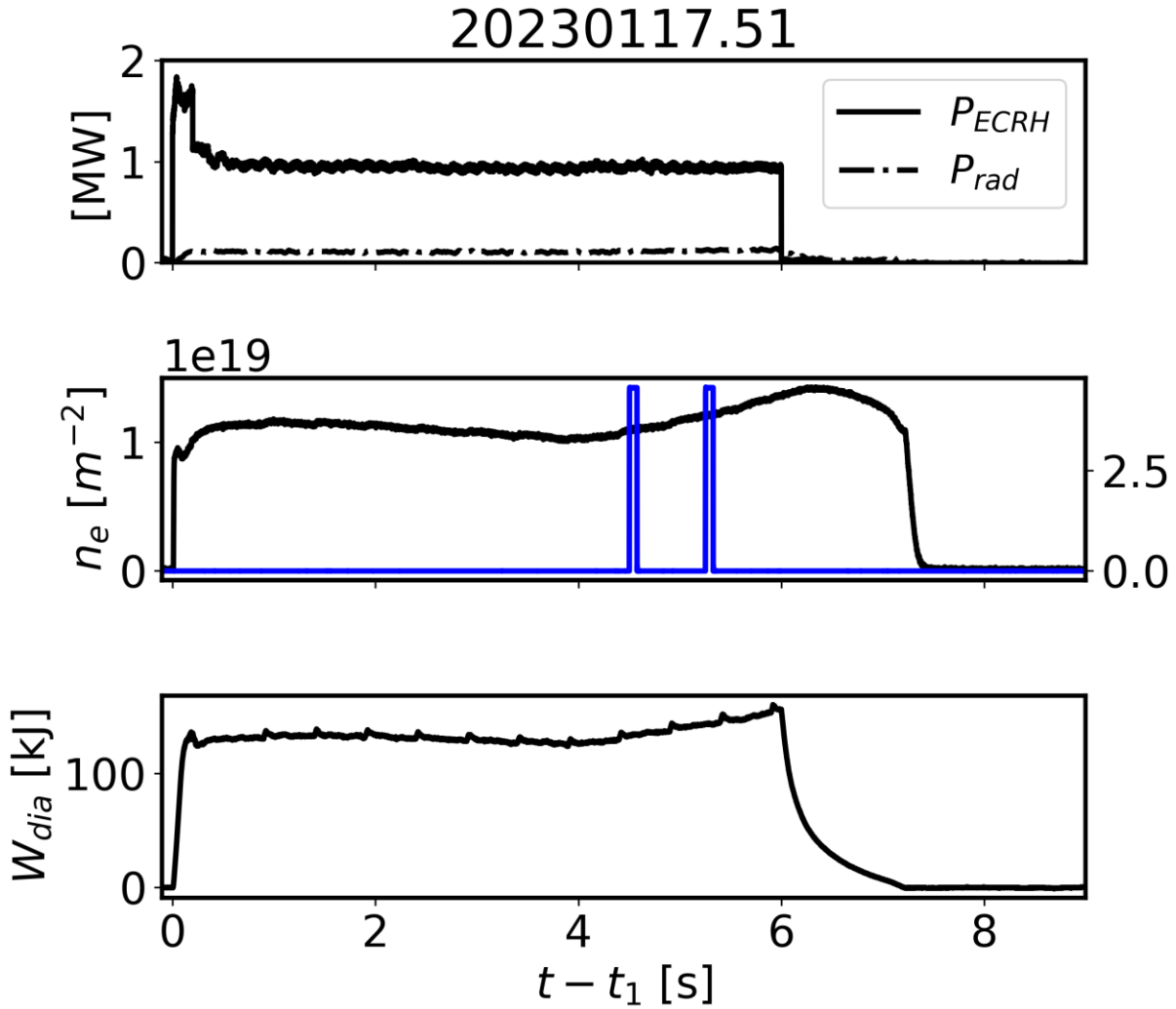
Images courtesy of Yu Gao

EMC3-Eirene validation: Comparison of He-beam profiles

Courtesy: N. Maaziz, E. R. Flom

- Experimental He-beam profiles from OP2.1 were compared in detail to EMC3-Eirene modeling results.
  - Multiple He-beam profiles averaged under similar conditions (20230117.51 & 52) – noise reduction
- **Detailed assessment on the impact of the choice of anomalous parameters on T_e, n_e profiles**





E. Flom et al 2023 Nuclear Fusion - Submitted

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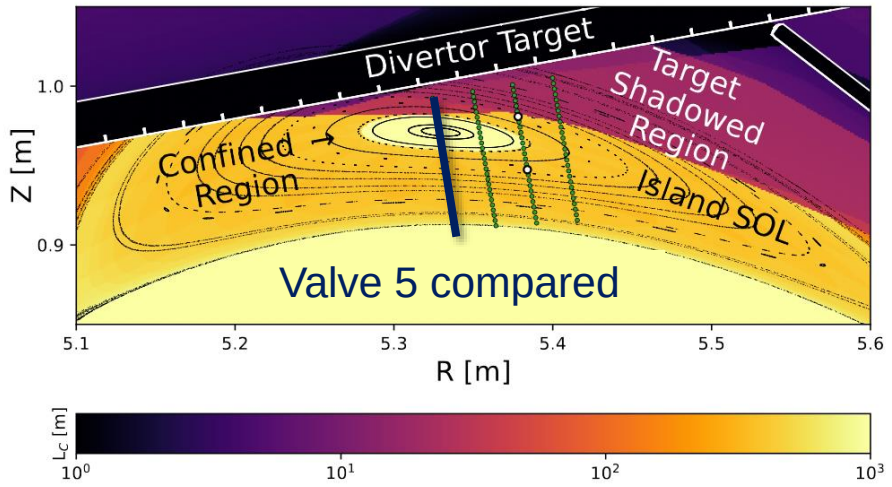

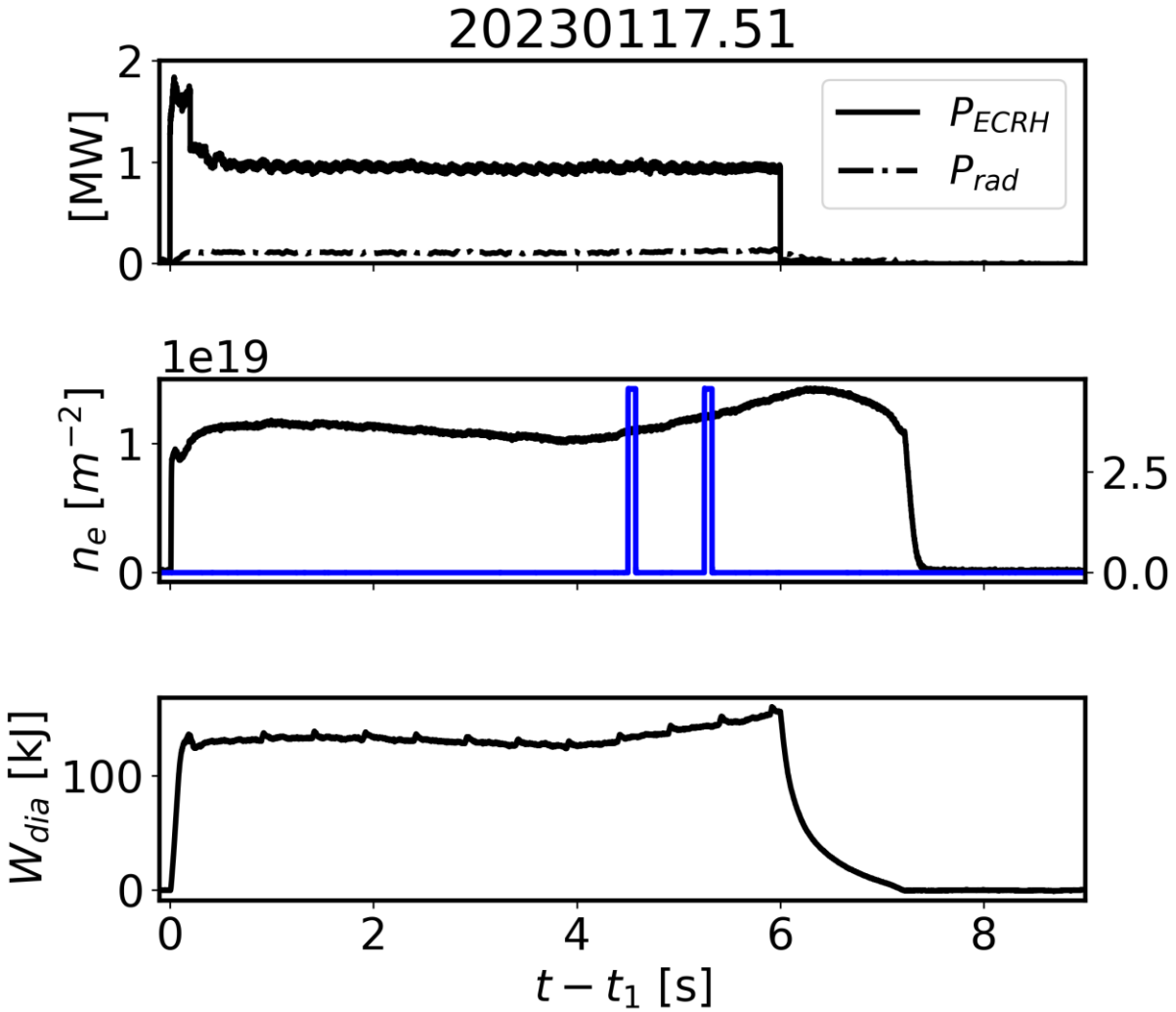

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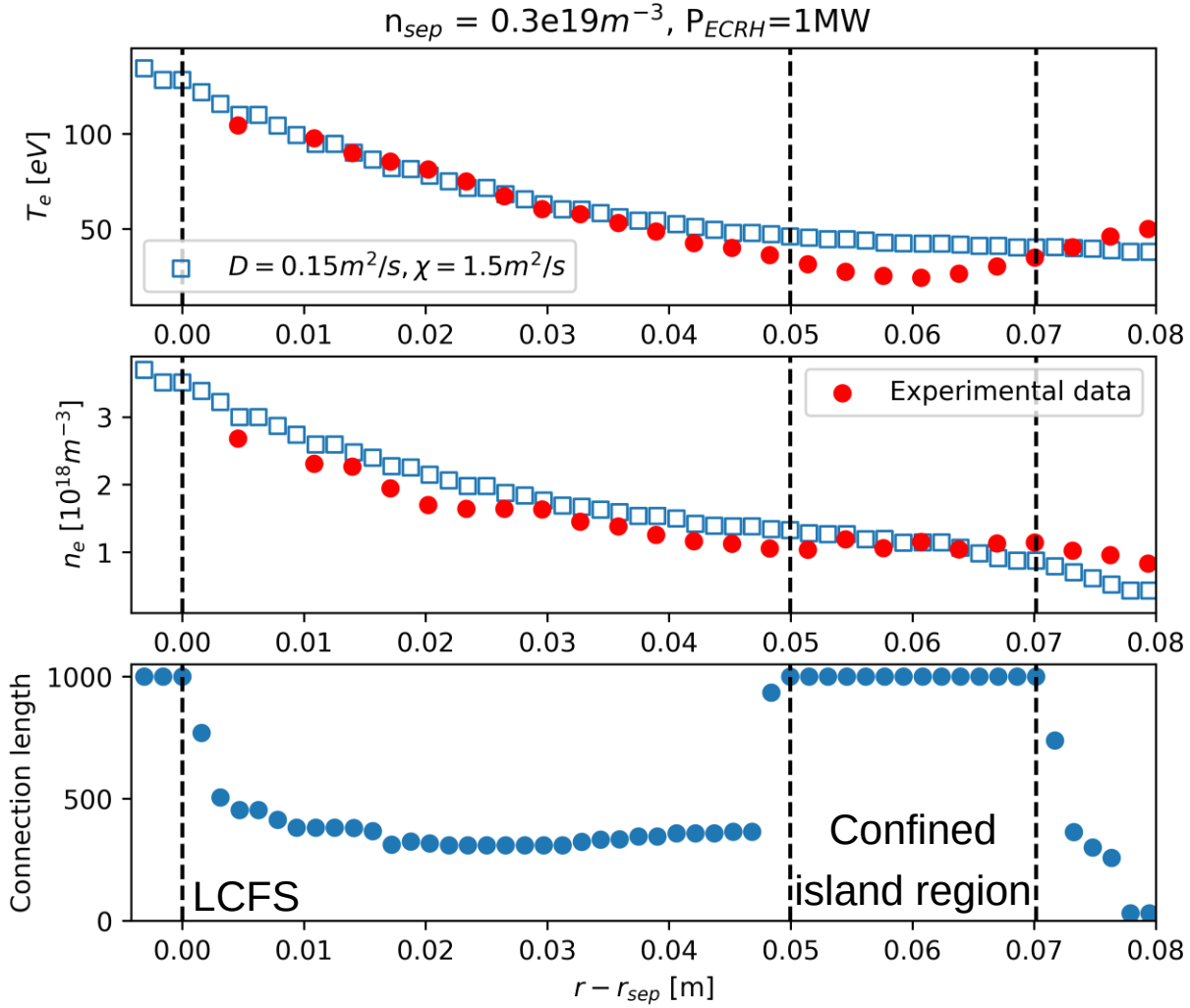
- Density fall-off length requires very low anomalous diffusion coefficients
  - $D = 0.15$ m^{2}s^{-1}
  - Consistent with MPM measurements[1] ✓
- Assuming anomalous heat diffusion $\chi_\perp = 3D_\perp$ leads to large overestimations of T_e at LCFS
  - $\chi_\perp = 10D_\perp$ matches both T_e and n_e fall-off lengths ✓



[1] C. Killer et al, *Nucl. Fusion* **61** (2021) 096038

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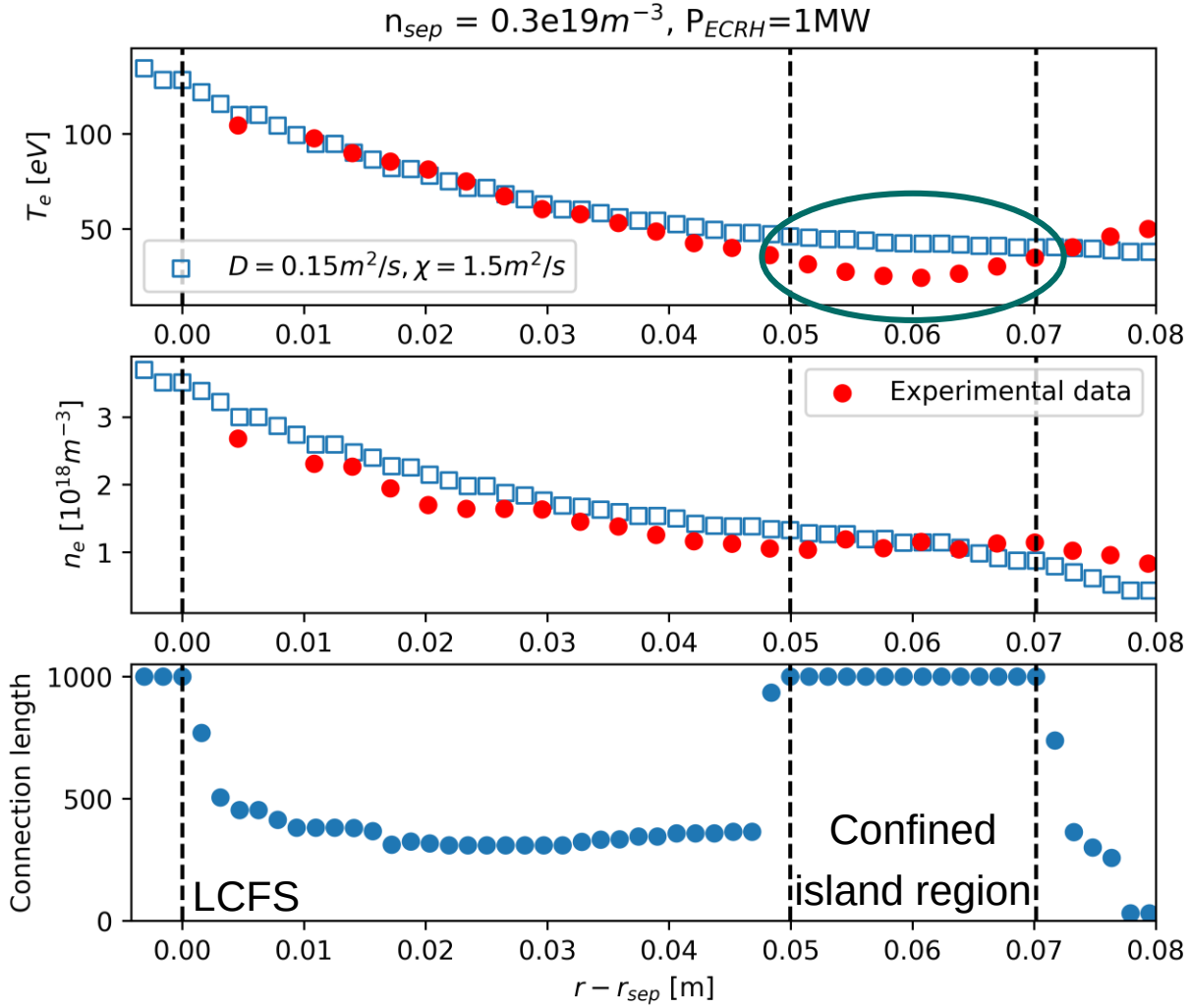
- Hollowness in confined island region not captured using uniform transport coefficients[2] X



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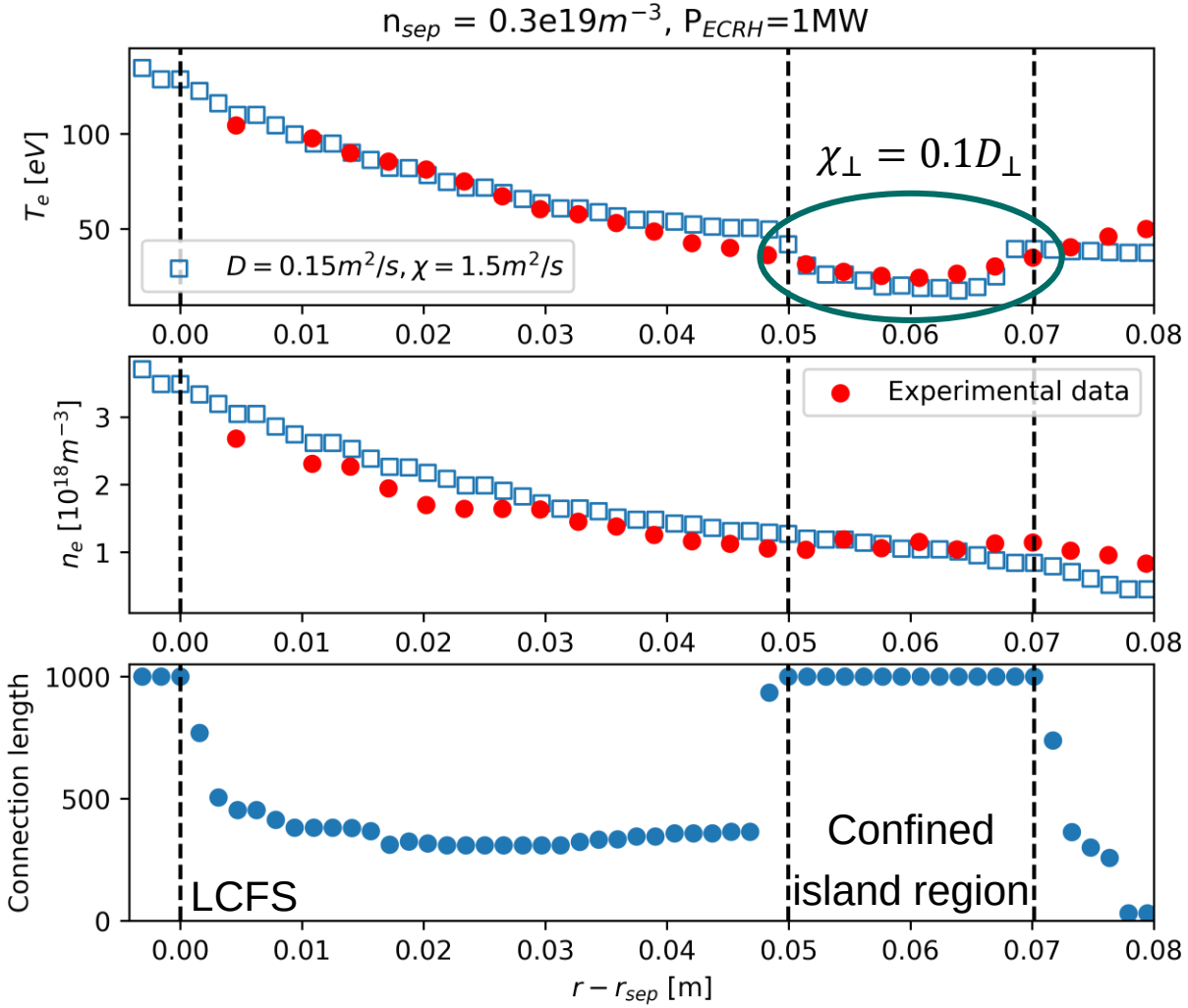
- Hollowness in confined island region not captured using uniform transport coefficients **X**
- Reducing $\chi_\perp$ by a factor 100 inside confined island region leads to a similar hollow T_e profile measured by He-beam



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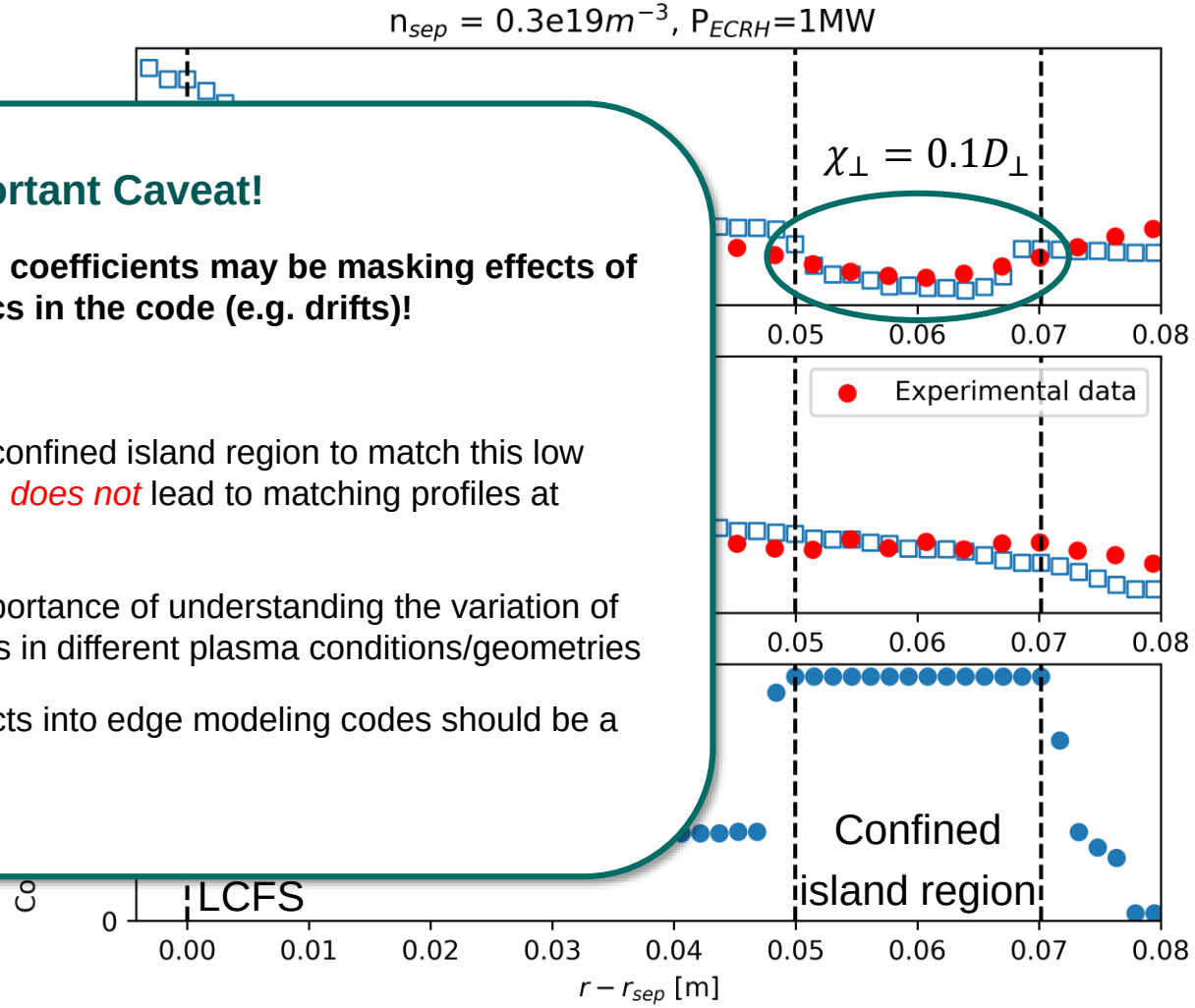
- Hollowness in confined
  using uniform transport
- Reducing $\chi_\perp$ by a factor 1
  region only leads to a similar hollow T_e profile measured by He-beam

Important Caveat!

Using non-uniform transport coefficients may be masking effects of missing physics in the code (e.g. drifts)!

- This reduction of $\chi_\perp$ in the confined island region to match this low density, low power program *does not* lead to matching profiles at higher density
- This work highlights the importance of understanding the variation of SOL turbulence and/or drifts in different plasma conditions/geometries
- Implementation of drift effects into edge modeling codes should be a priority



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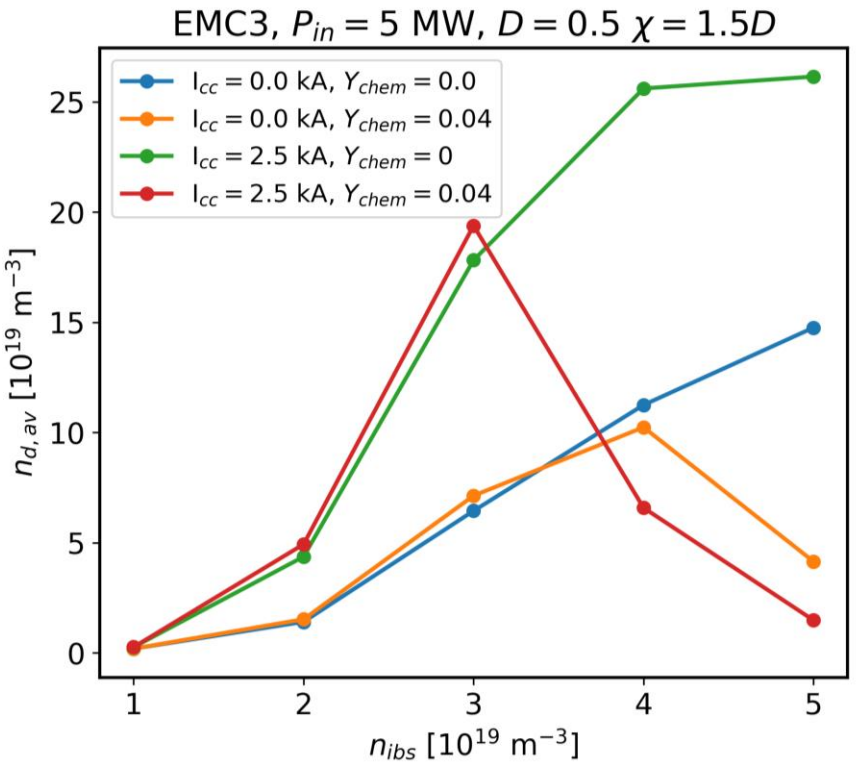
EMC3-Eirene validation: effect of control coil current on density build-up

- Ratio of ∥- to ⊥- transport is highly sensitive to the **magnetic field line pitch, Θ, within the island**[3]:

$$\Theta = 2a\sqrt{\frac{\iota' b_{rm}}{Rm}}$$

- b_{rm} is the radial resonant field component (increases w/ $+I_{cc}$)

  → Larger Γ_{recyc} to target (predicted by EMC3-Eirene) for $+I_{cc}$ (at low f_{rad})



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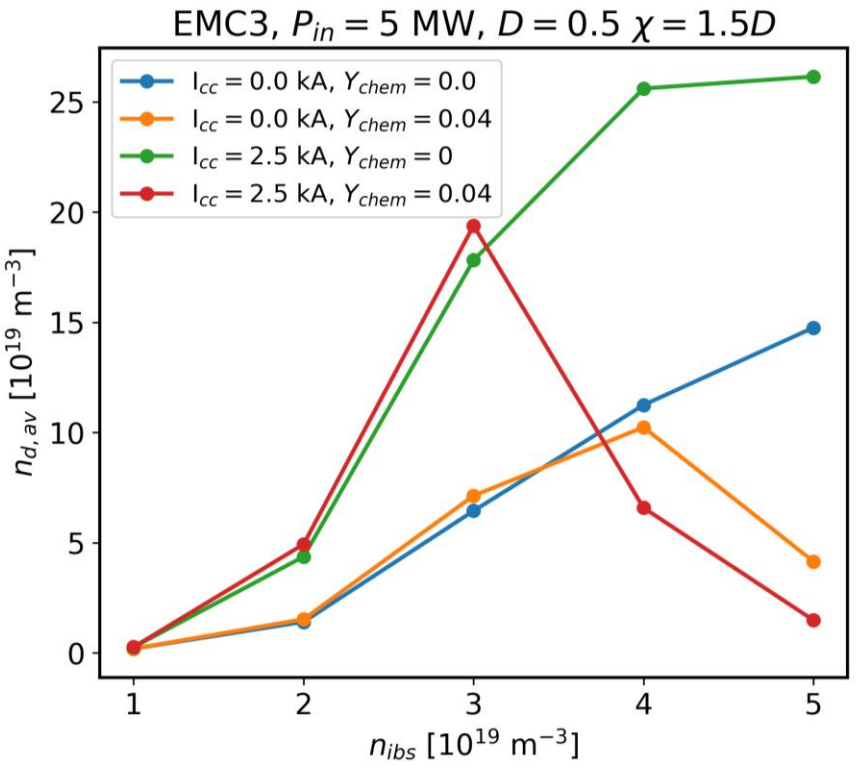
- No direct downstream density measurements at strikeline in OP2.1 with I_{cc} (LPs, H-alpha were not yet ready)

- But: we may have some indirect indications!



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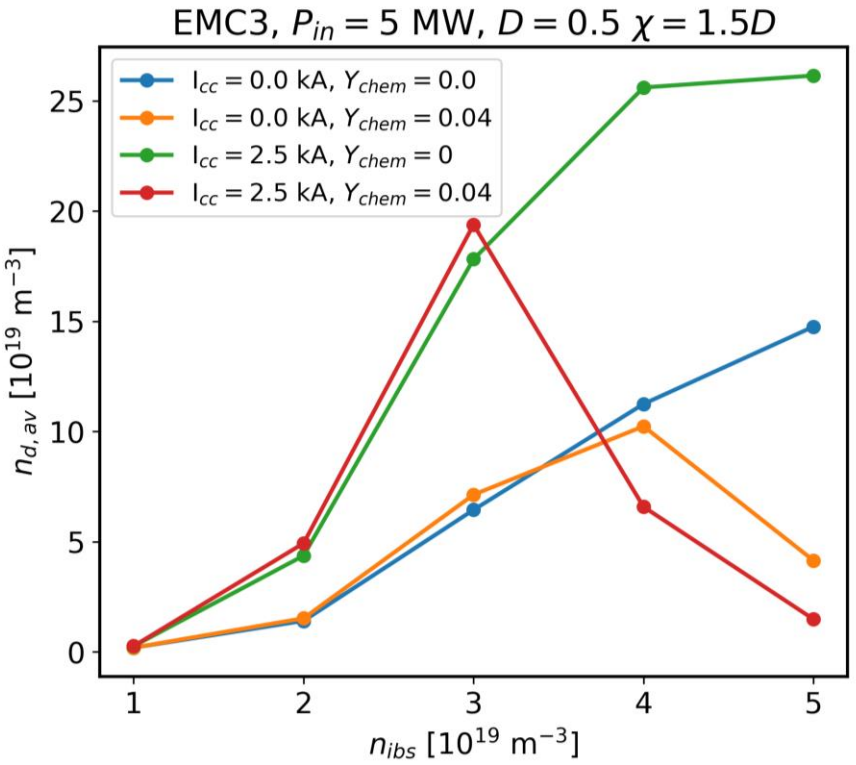

- Carbon source = $Y_{chem}\Gamma_{recyc}$
- If we assume divertor retention is similar for all I_{cc}:

  → $n_{c,CXRS} \propto \Gamma_{recyc}$ at a given $n_{separatrix}$

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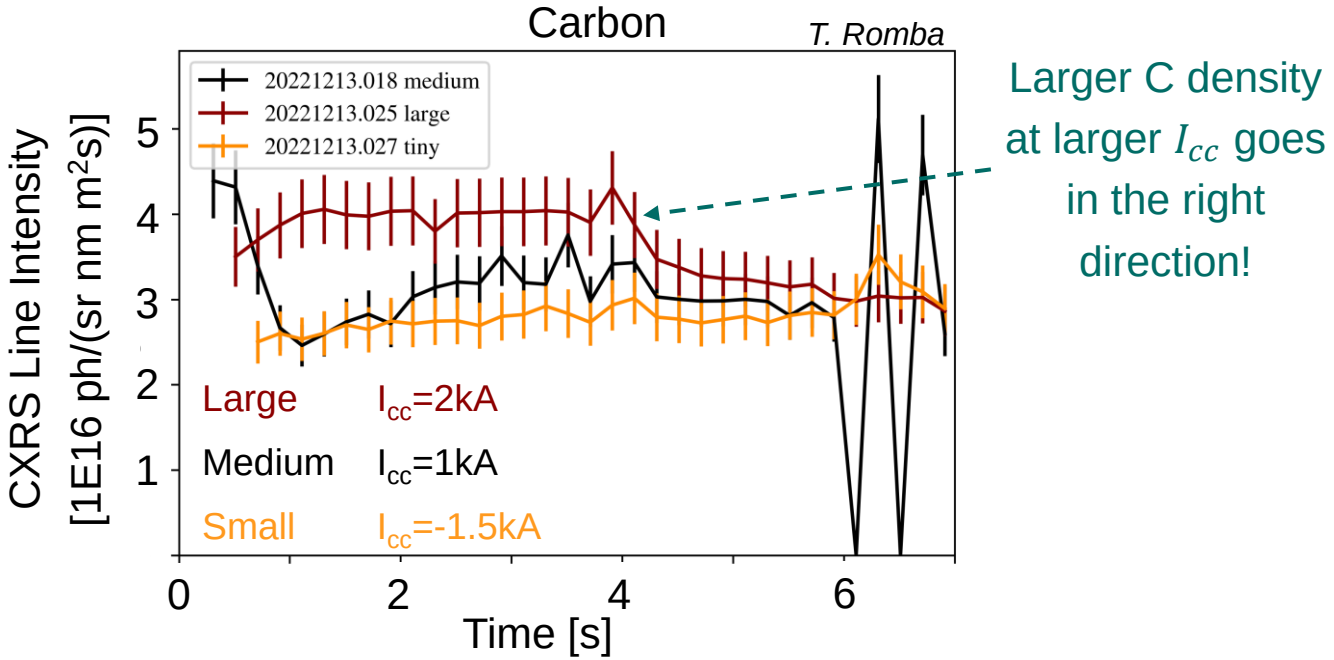
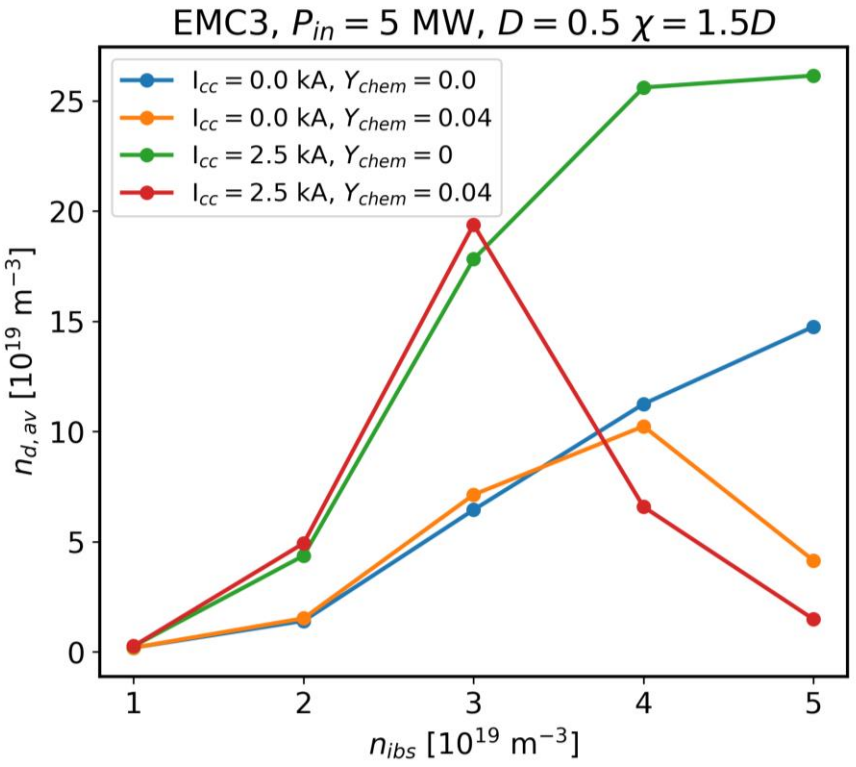


Larger C density at larger I_{cc} goes in the right direction!



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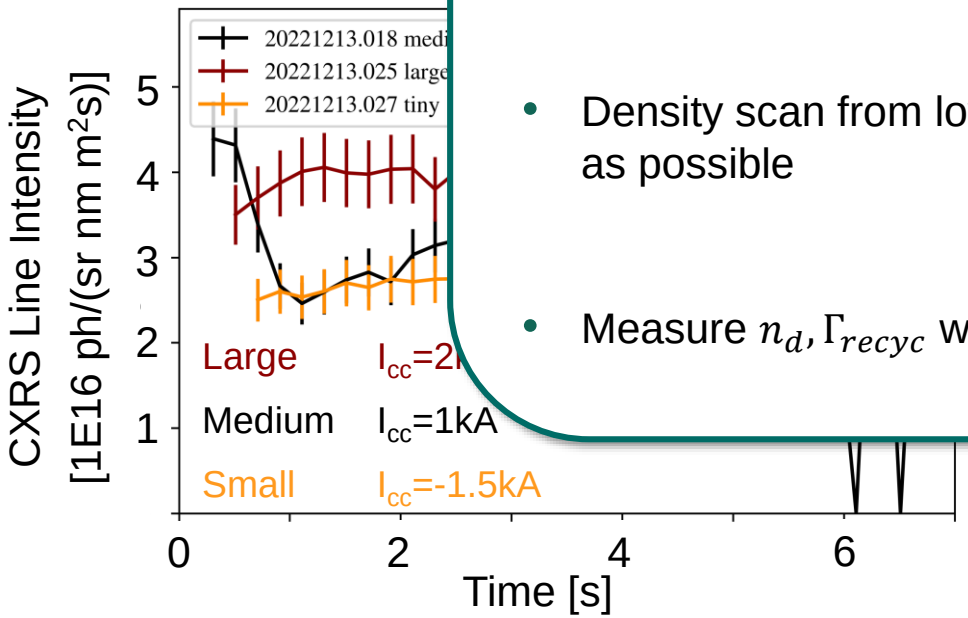
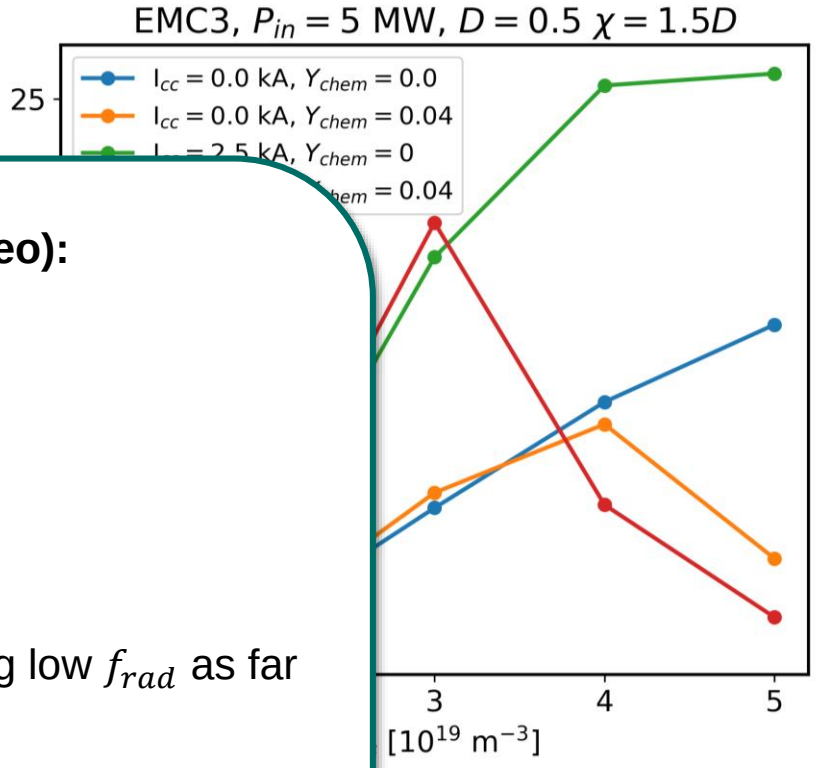


New proposal idea for OP2.2 (V. Perseo):

- Newly boronized, high P_{ECRH} programs
- For each program, a constant I_{cc}
- Density scan from low to high density, maintaining low f_{rad} as far as possible
- Measure n_d, Γ_{recyc} with divertor LPs, Stark Broadening, H-alpha



$_{recyc}$

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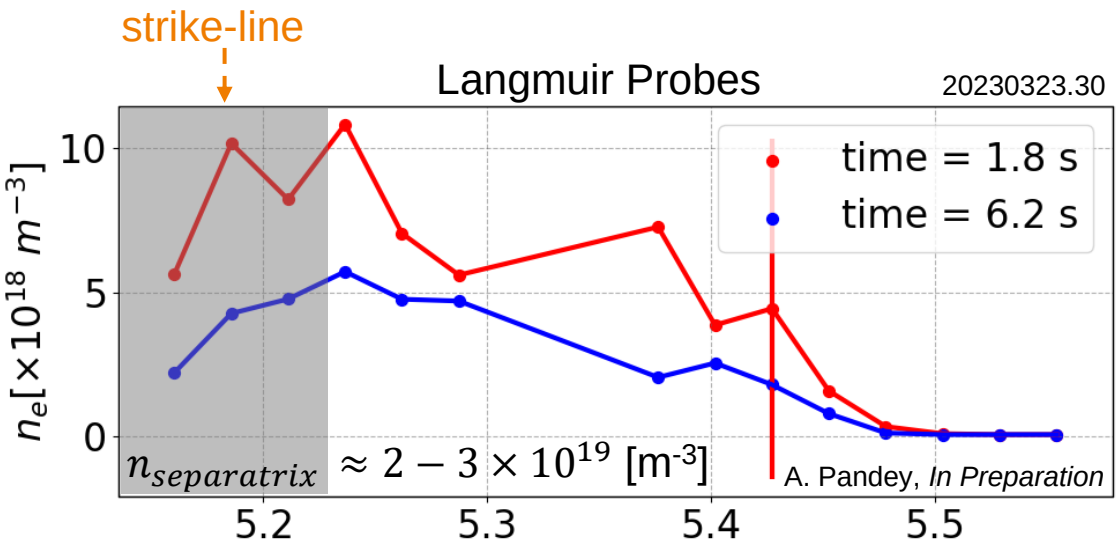
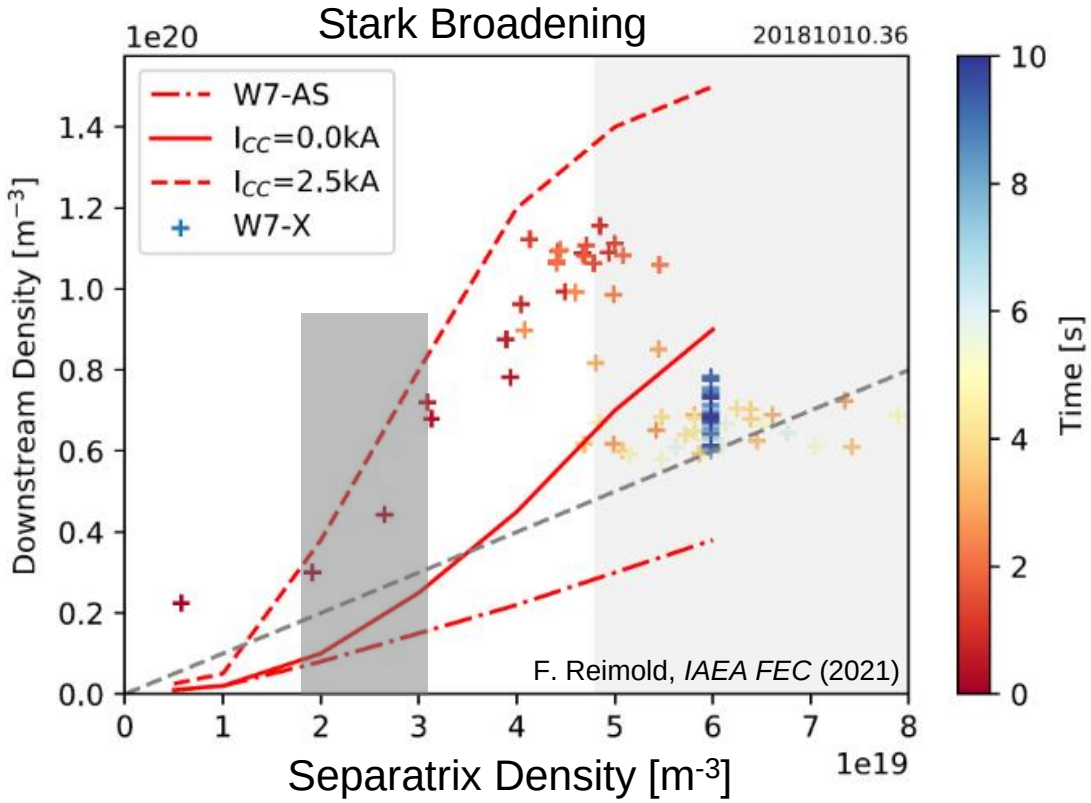
EMC3-Eirene validation: what is our downstream density??

- Divertor Langmuir Probes consistently measure lower n_e than spectroscopic techniques

  → large difference: factor of 5 to 10!

  → spectroscopic measurements agree more with EMC3-Eirene calculations





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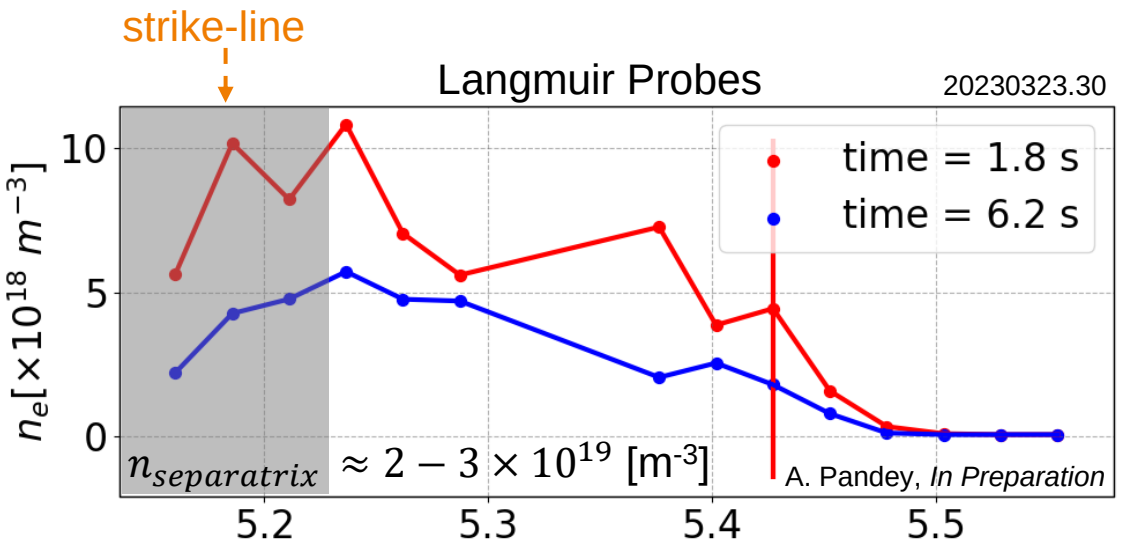
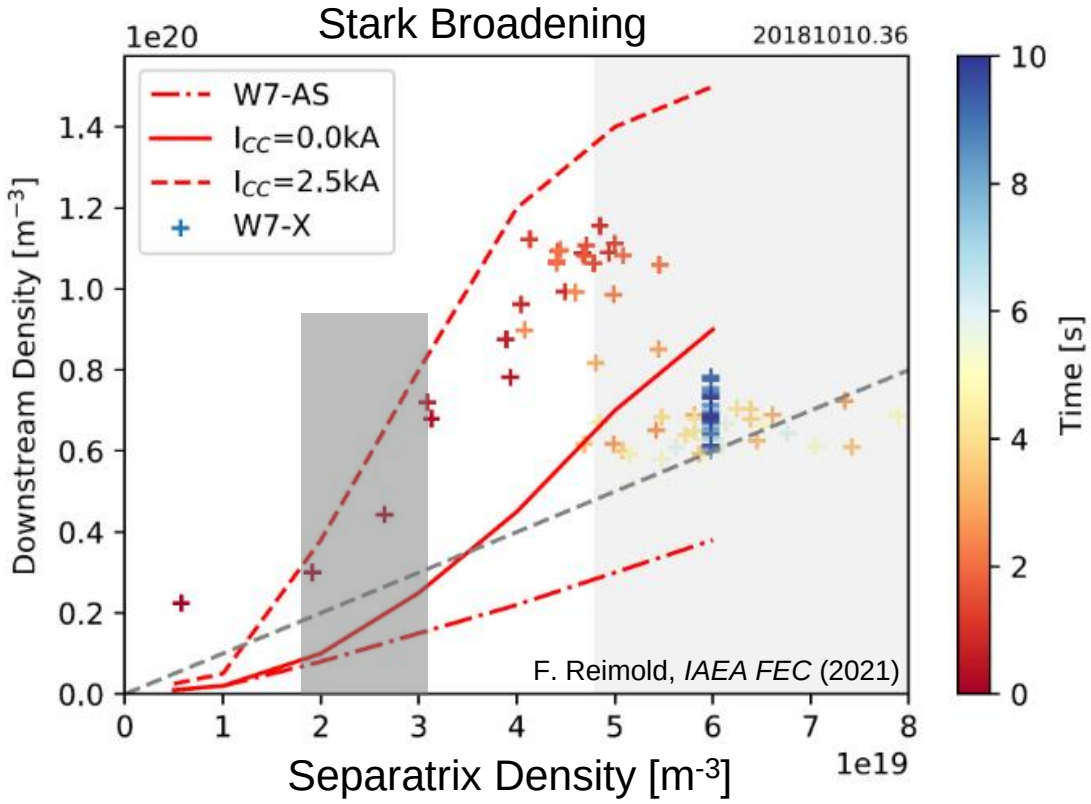
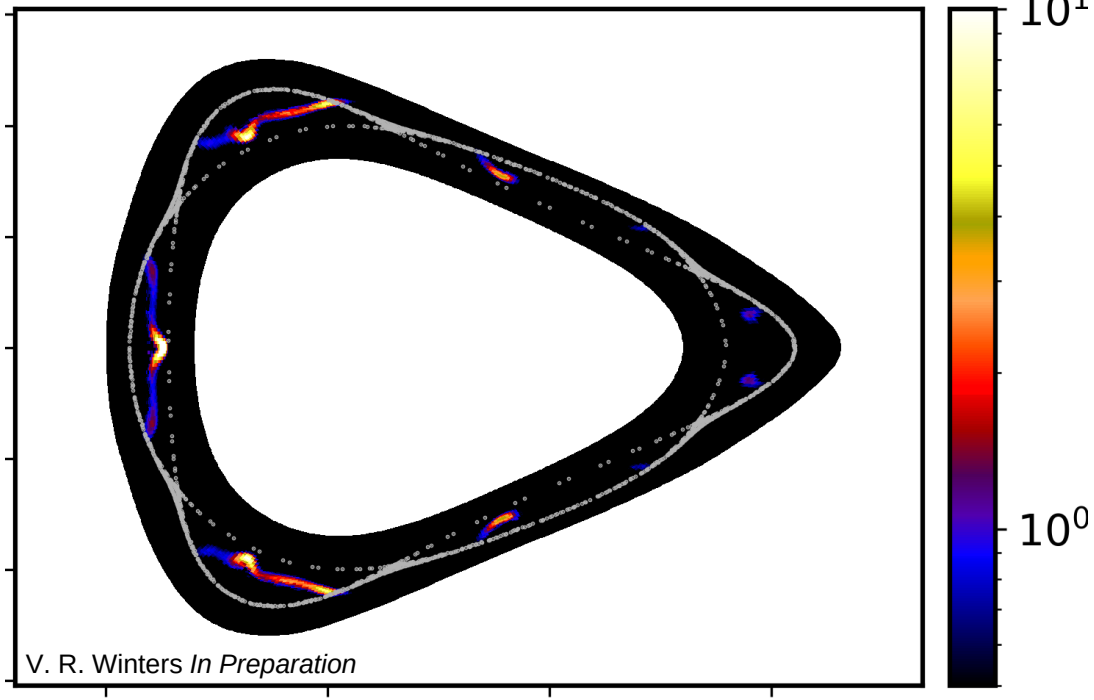




- However: pop-up LPs are consistent to previous OP1.2 measurements
- These discrepancies should be investigated in the next campaign!

EMC3-Eirene validation: Radiation pattern shows consistency, but some qualitative differences remain

„Low Iota“ P_{rad} Distribution (EMC3-Eirene)



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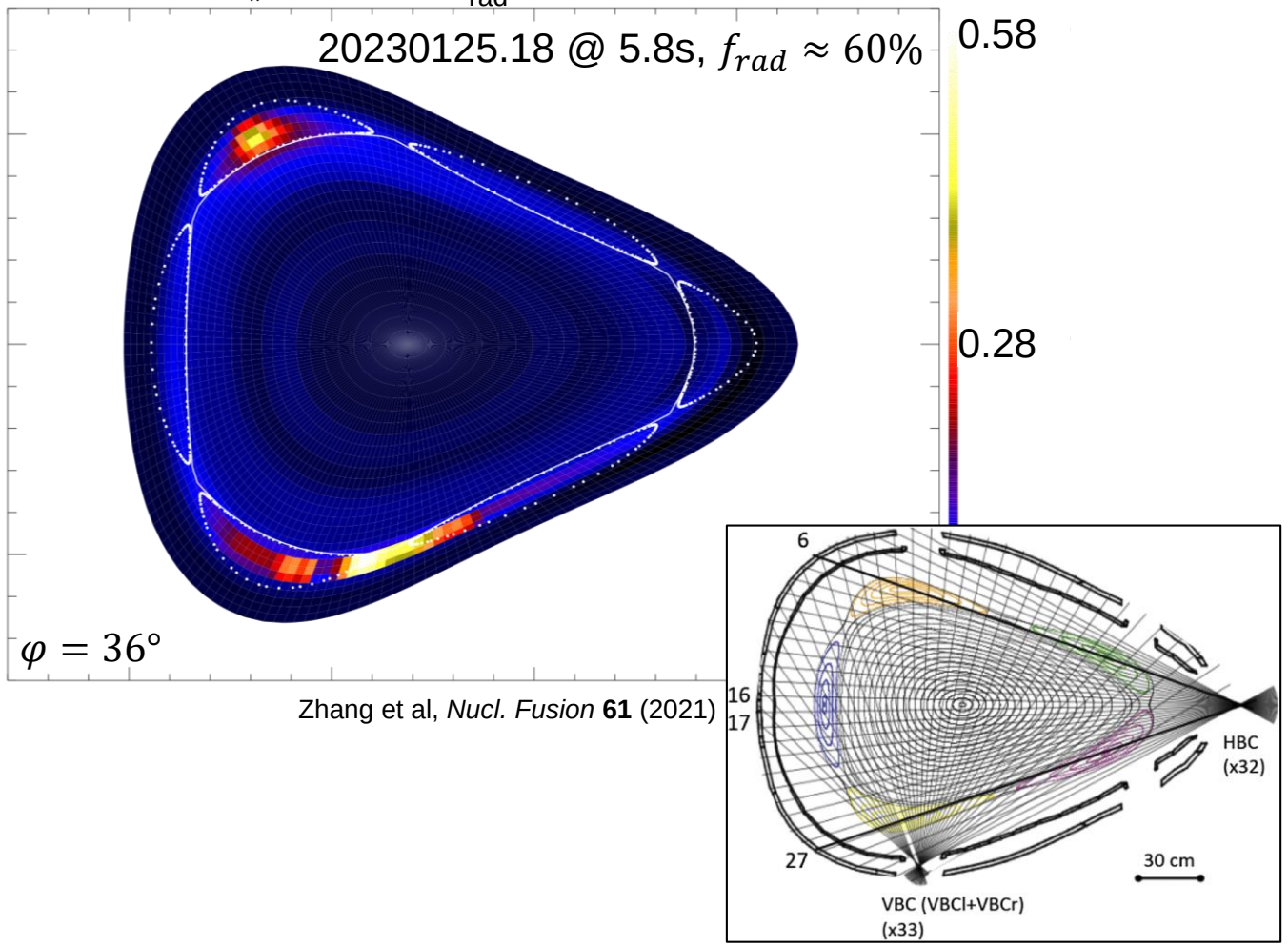

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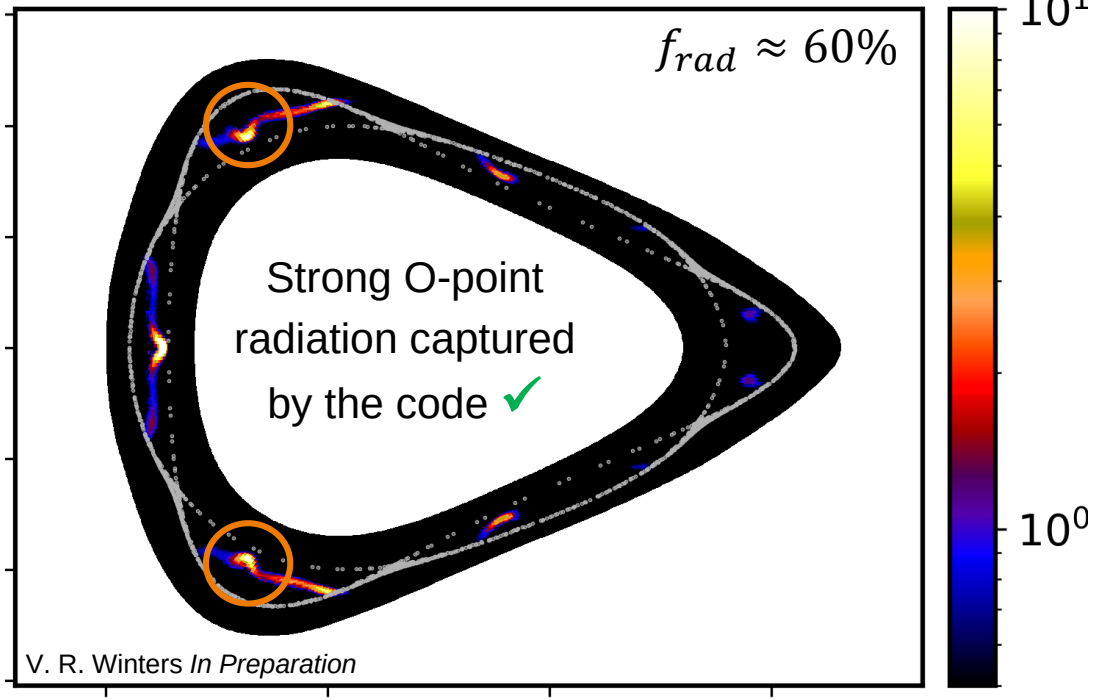

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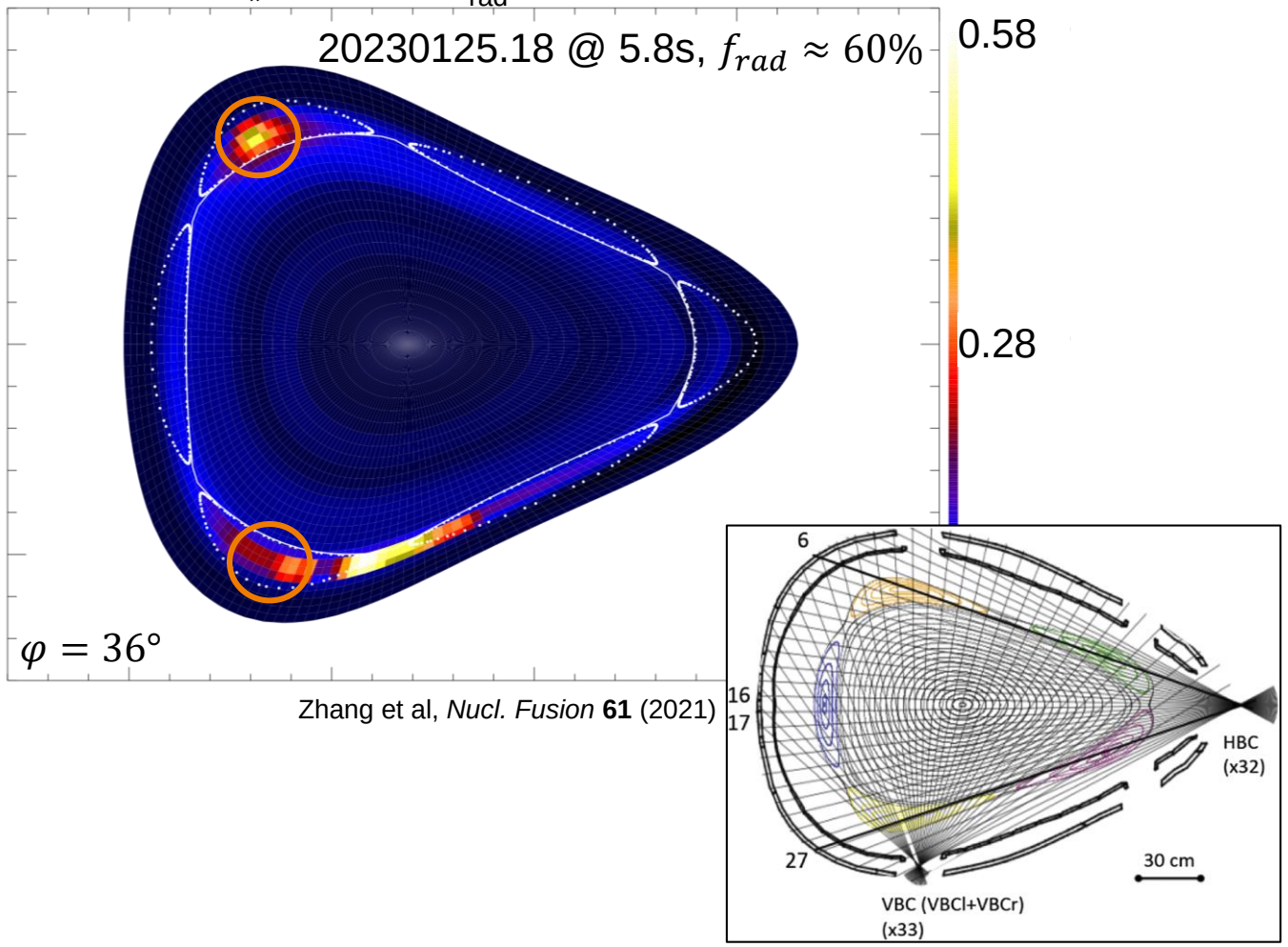

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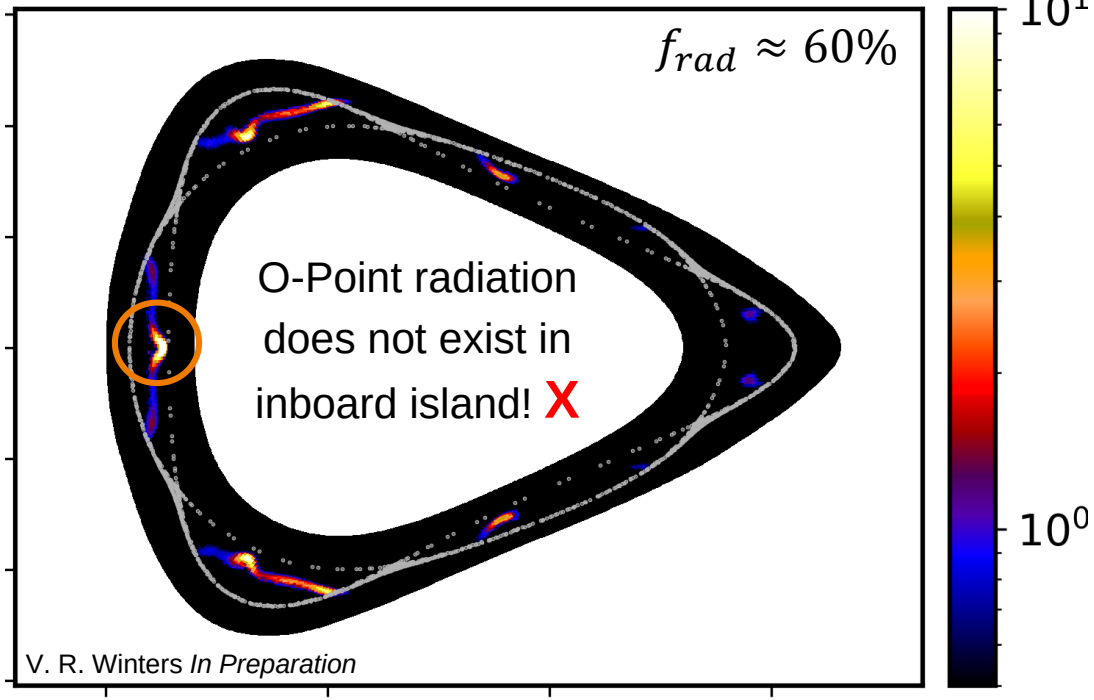

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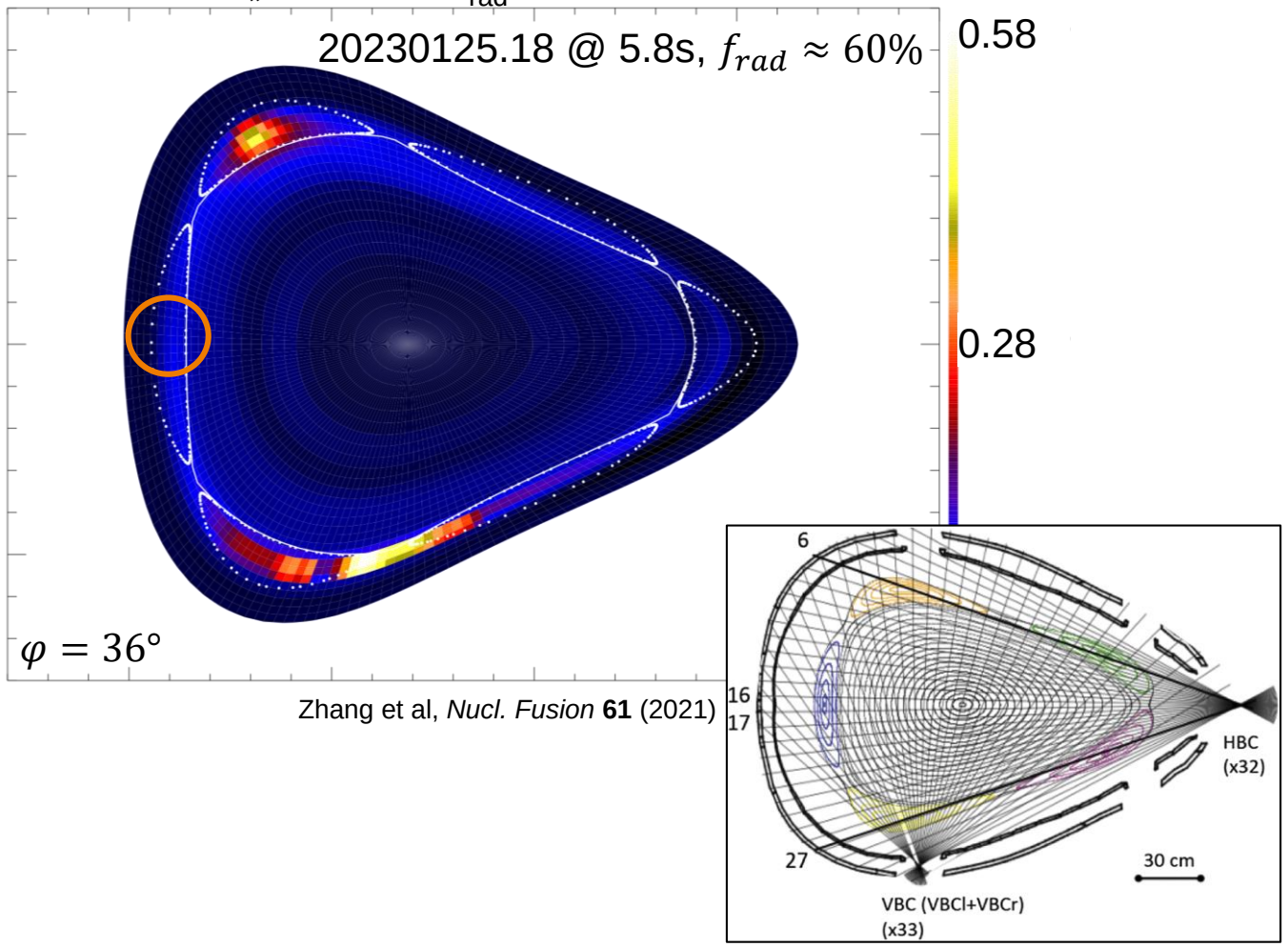

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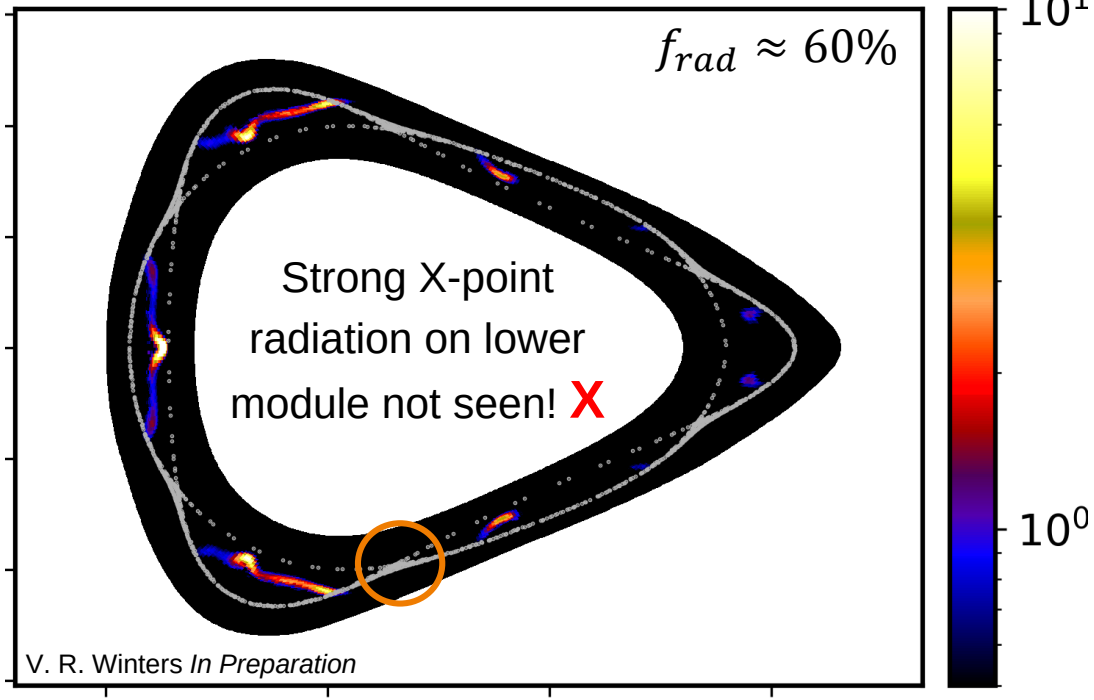

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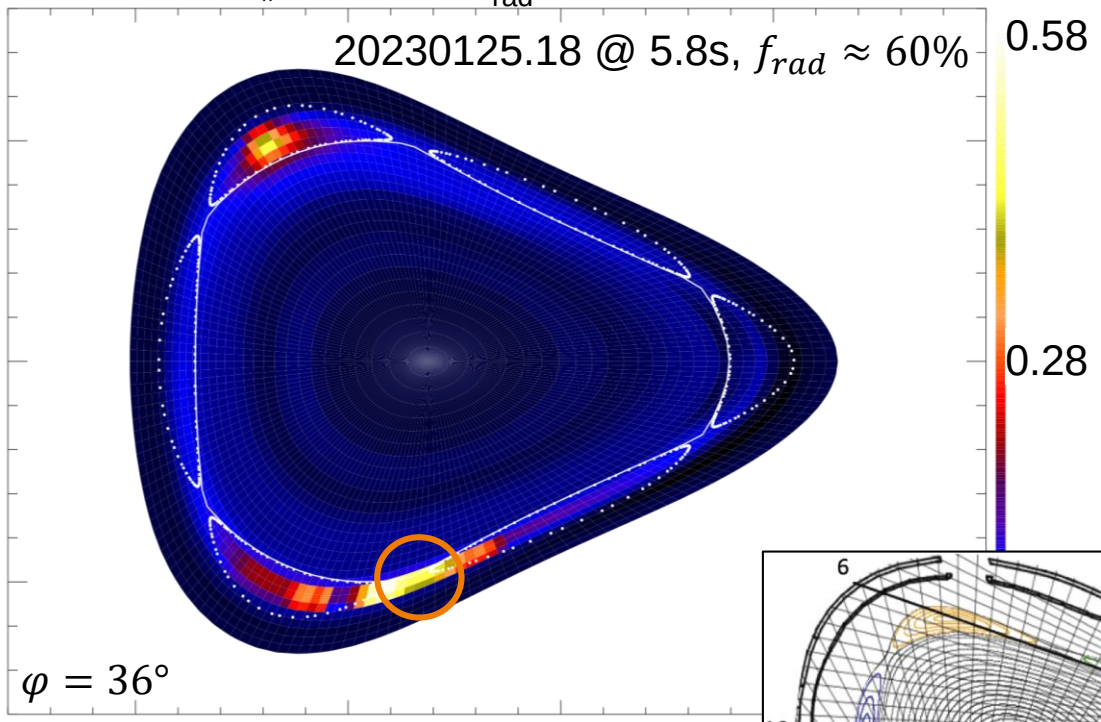

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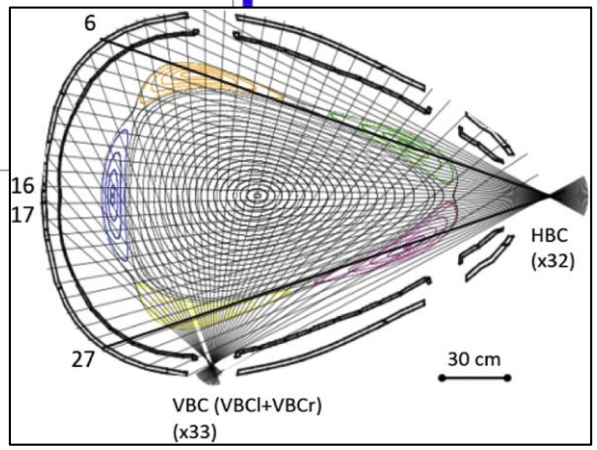

- Additionally, significant up/down asymmetries are seen (likely drifts), which are not captured with our current modeling. We assume up/down symmetry in the symmetry plane
- Origin of X-point radiation in low iota to be investigated by D. Zhang (PSI-26)

Topics which I will not get into, but are nonetheless important

- Up/down asymmetries in the target heat load pattern, likely due to drifts (D. M. Kriete talk, TF-III)
  - Mismatch in toroidal distribution of strike line width in EMC3-Eirene (see: D. Bold *Nucl. Fusion* **62** (2022) for OP1.2b analysis)
- Validation of toroidal current/control coil current effects on heat load pattern (Y. Gao talk TF-II, also see: Y. Gao *Nucl. Fusion* **59** (2019))
- Local validation EMC3-Eirene results of impurity fractional abundance/transport effects in the divertor (F. Henke, D. Gradic talk TF-II)
- EMC3-Eirene validation of neutral transport and pumping in the subdivertor region (see: D. Boeyaert *PPCF* (2023) accepted for OP1.2b analysis)
- Effects of error fields on local comparison to EMC3-Eirene modeling

How should we move forward in OP2.2?

- Overall, we have seen that our edge codes can reproduce *gross, qualitative* features observed in experiment
- However, detailed matching (profiles, radiation patterns) remains elusive
  - Detailed matches (via non-uniform transport coefficients, etc.) might be masking missing physics – we must be careful in our conclusions here
- Significant SOL characterization was not possible in OP2.1 (lack of import SOL diagnostics! Divertor LPs, H-alpha cameras, Alkali metal beam, etc)
  - New proposal should be developed to obtain as consistent as possible SOL characterization

- Imperative: code development must be prioritized!
  - EMC3-Eirene – inclusion of drifts
  - Further development of 3D SOL turbulence codes (BOUT++, GENE-X, GRILLIX …)
  - Simultaneous development of non-MC based SOL fluid codes (e.g. BOUT++ → D. Bold)