Scattering of EC beams by turbulent density fluctuations and its impact for DEMO

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KDII#8 Progress meeting

Outline

Task description

Task description for 2020

Actual task description

- Carry out poloidal scan for launch position
- Use more physics-oriented way to illustrate results

To finish the project

- Assess the necessary power to mitigate NTMs

Working at the moment
Finished

Background and 2019

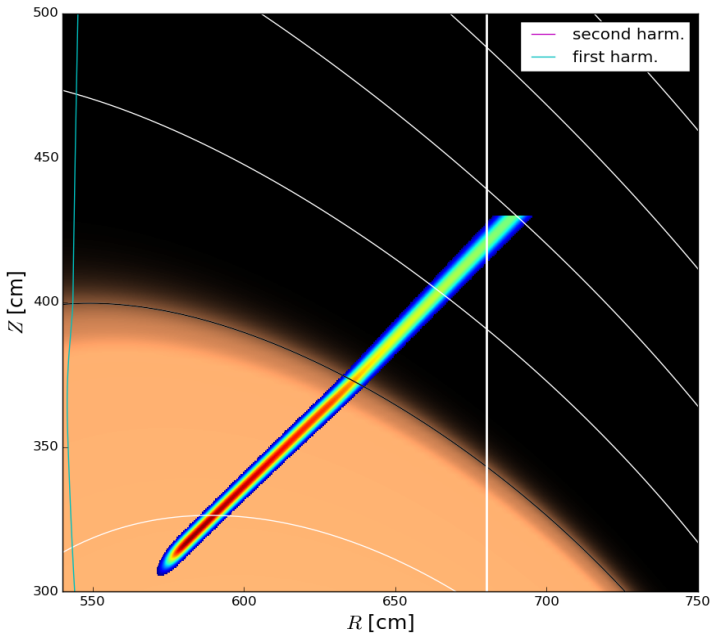
EC waves in tokamaks

EC heating and current drive well-localized

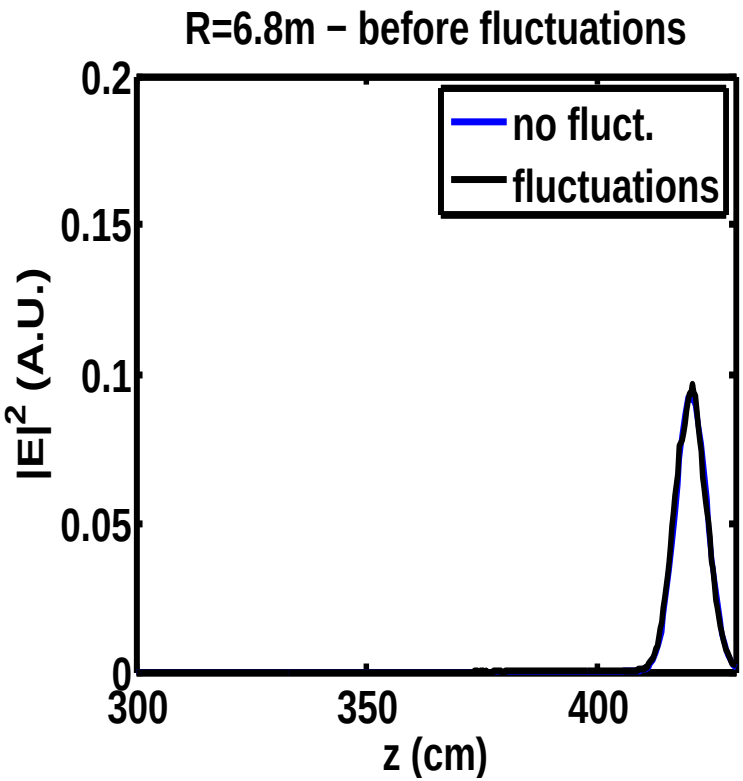
→ (Real-time) control of MHD instabilities (in particular NTMs)

- Turbulent **edge density fluctuations might spoil** the localization
- The broadening predicted to scale unfavorable with the machine size
- Numerical tool WKBeam used to study this

Beam-broadening in ITER

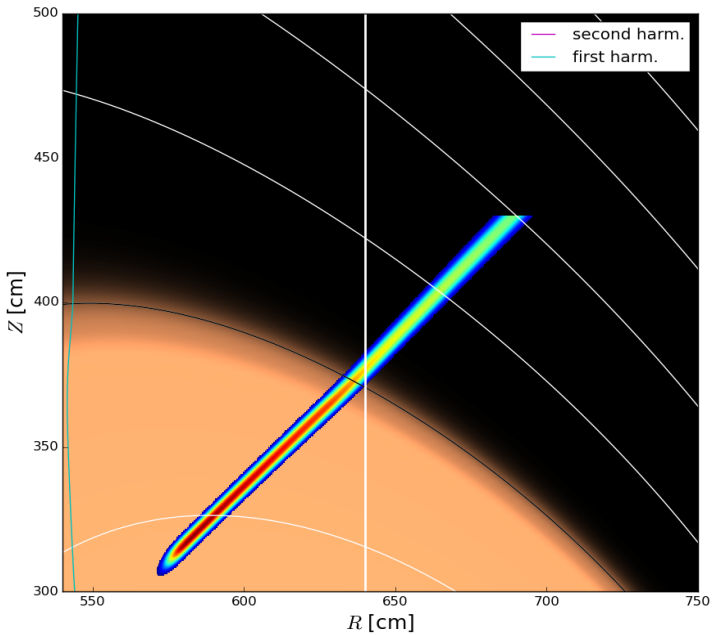


EC beam w/o fluctuations in ITER



Cross-section of beams w/ and w/o fluctuations

Beam-broadening in ITER



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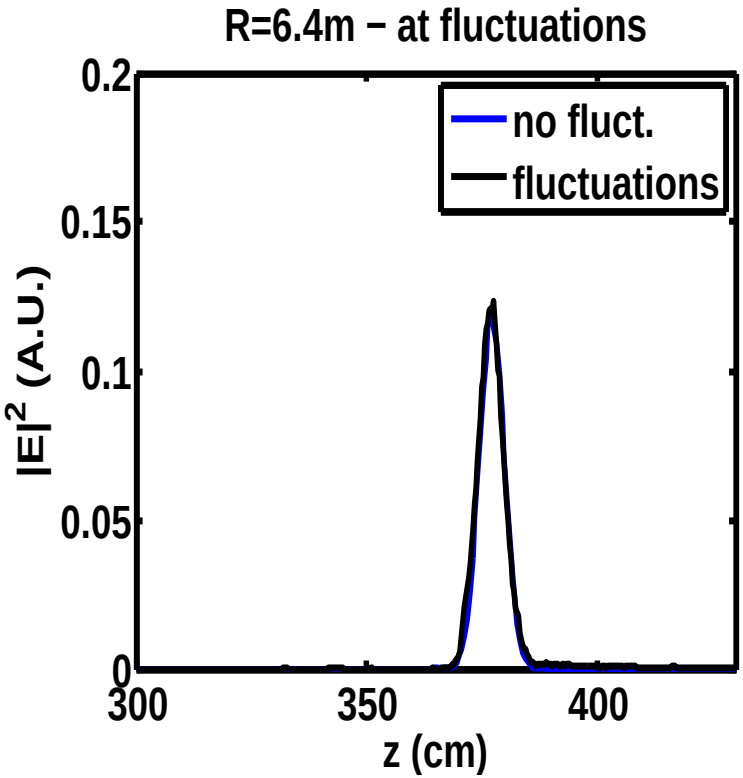

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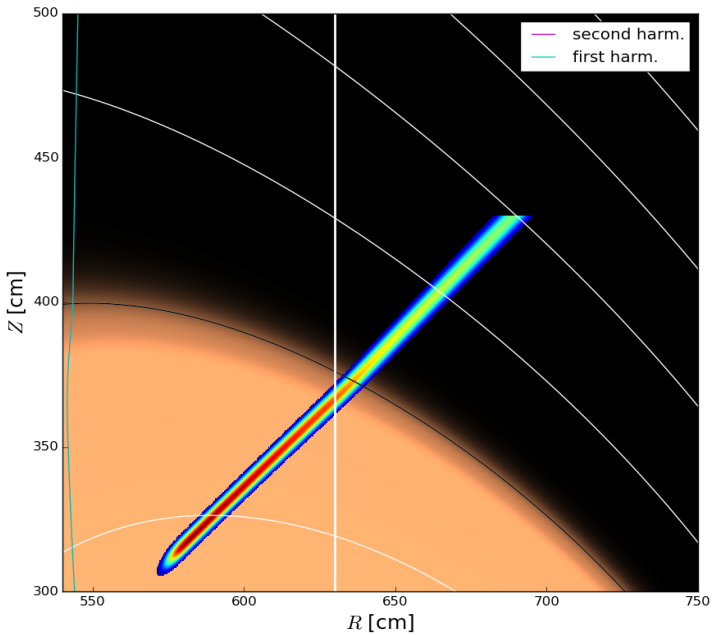

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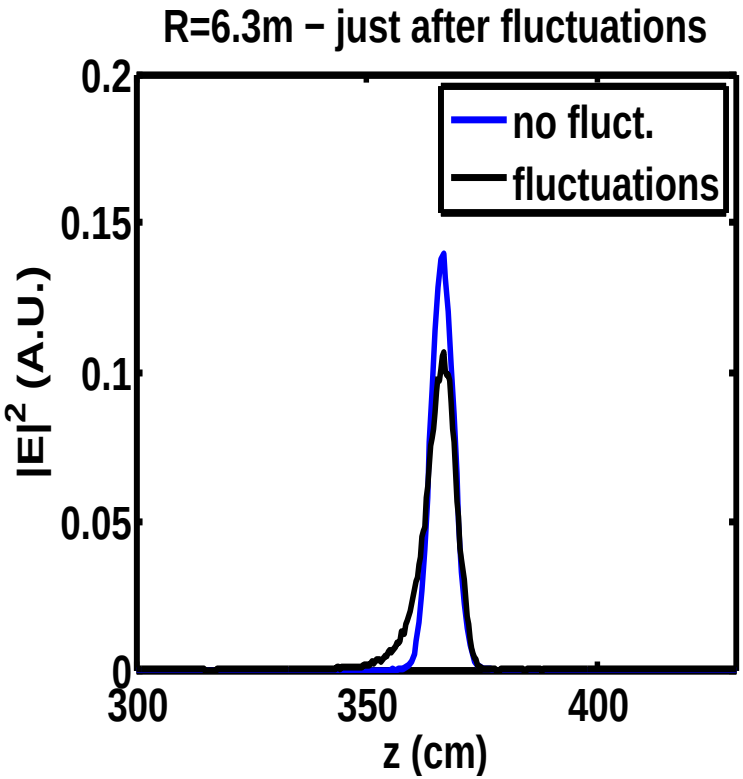

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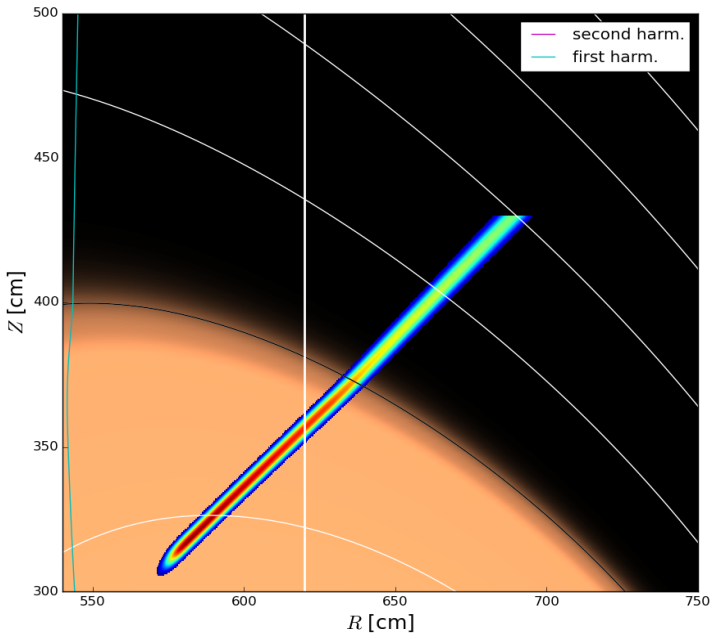

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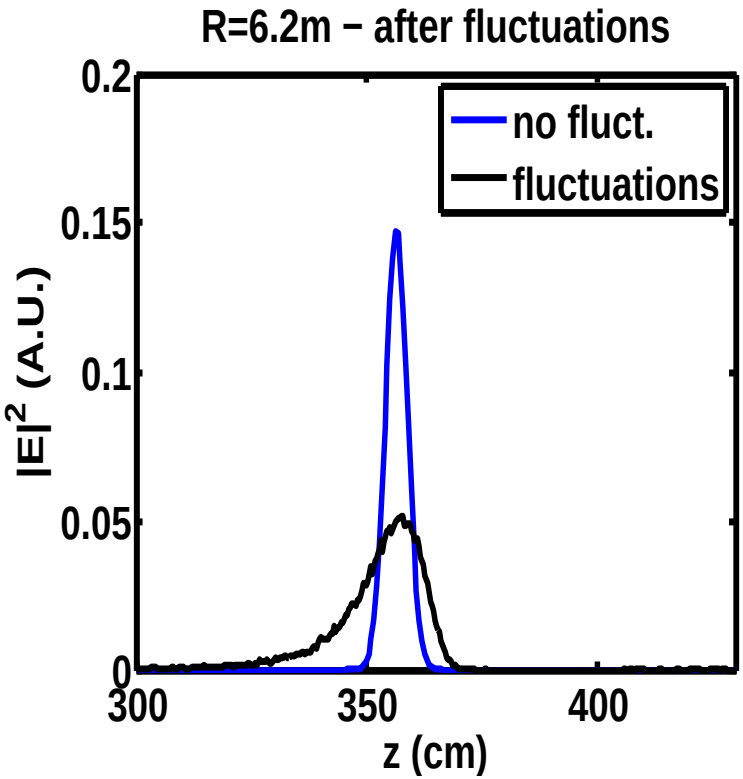

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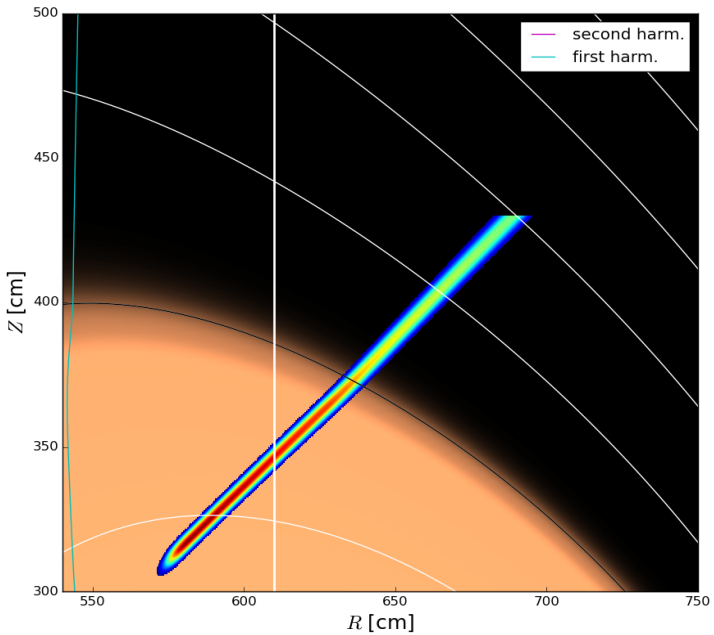

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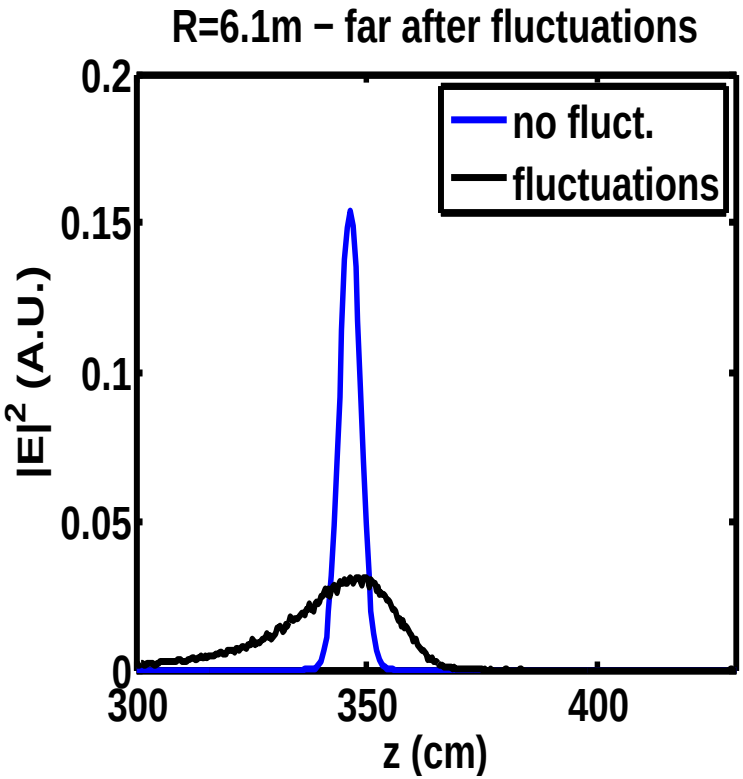


Cross-section of beams w/ and w/o fluctuations

EC waves in DEMO

EC system planned at equatorial port

→ Beam traveling through outer midplane, short propagation in turbulent layer

- Beam enters plasma at the peak of fluctuations (explained below)
- Long propagation after fluctuations

→ Numerical assessment necessary

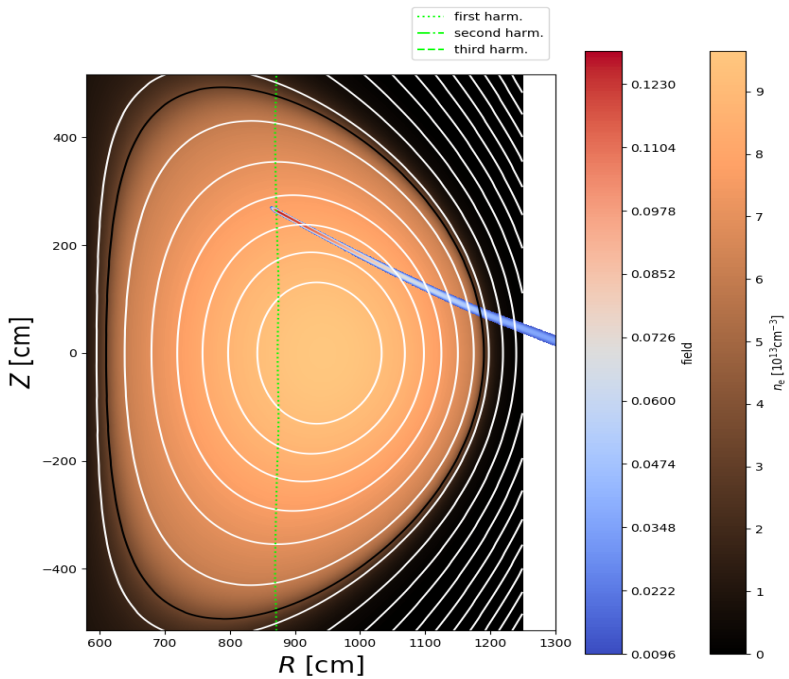
- In this presentation, design of DEMO1 2018 considered
- Differences to 2019 design insignificant **for EC broadening**

DEMO studies 2019

EC beam modeling

WKBeam model based on TORBEAM inputs

- Inputs from earlier TORBEAM analysis
- Fluctuation model identical to ITER
- Note strong effect of warm electrons!



EC beam in DEMO (no fluctuations)

DEMO lies in diffusive regime

EC transport is diffusive in DEMO

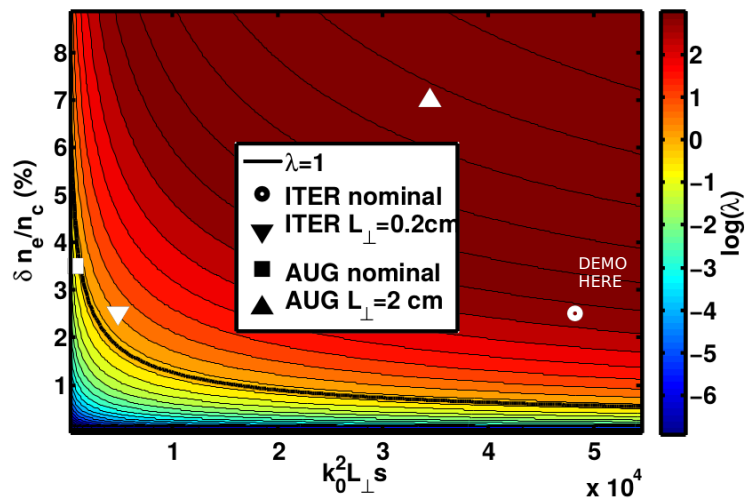
- Using 0D parameters, possible to estimate the transport regime[1]
  - $\delta n_e/n_c$ ≈0.3, $L_\perp$ ≈1-3cm
  - $\Delta\ell$ ≈20cm → $k_0^2 L_\perp \Delta\ell$ ≈5e4 → $\lambda_O \gg 1$

→ DEMO lies deeply in the diffusive regime, EC broadening expected

plasma parameter in the turbulent region. Then we can write an estimate for λ_α which can be evaluated for a given tokamak scenario without need of ray- or beam-tracing calculations. That is,

$$\lambda_\alpha \approx \sqrt{\frac{\pi}{2}}\frac{1}{n_\alpha}\left[\frac{\delta n_e}{n_c}\right]^2_{\rm rms}(k_0^2 L_\perp \Delta\ell)\begin{cases}1, & \alpha = O,\\ \omega^2/(\omega+\omega_{\rm ce})^2, & \alpha = X,\end{cases} \tag{15}$$

and we have introduced the cut-off density $n_c = n_e(\omega/\omega_{\rm pe})^2$.

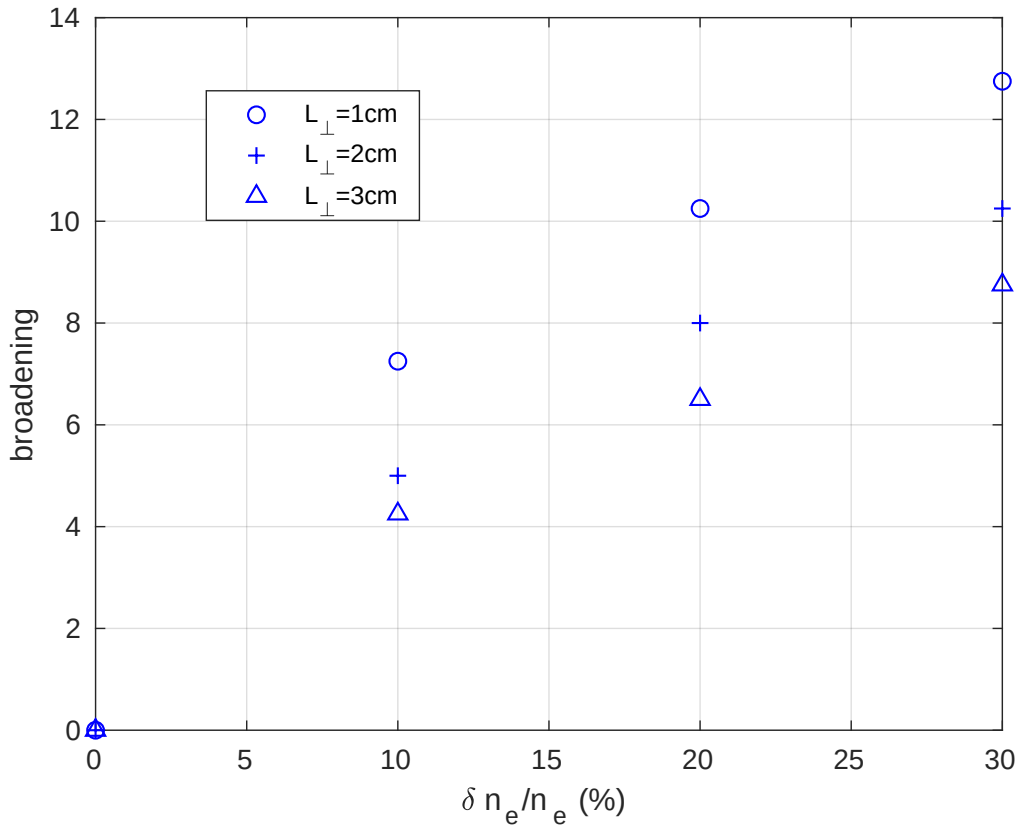


Transport regimes in AUG, ITER, and DEMO

[10] A. Snicker *et al., [Nuclear Fusion 58 (2018)]*

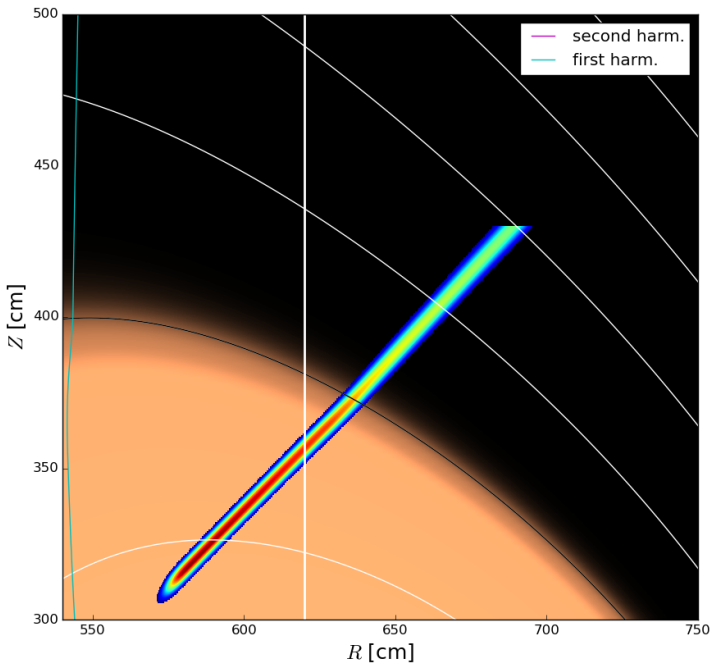
Dependency on fluctuation amplitude and correlation length

- Run 30k rays for the scans
- Scanned F and $L_\perp$
- Broadening defined as the relative increase in FWHM of deposition profile
- Single 1MW beam considered, no overlapping of the beam lines!



Explanation for the large broadening

- Distance in the transport layer comparable to ITER ($\approx$ 20cm)
- Distance from the transport layer (δs) to resonance surface plays a key role
  - In ITER, δs<1 m
  - In DEMO, δs>2 m
  - Beam has loads of time to diffusive
  - Possible solutions: upper port, resonance layer towards low field side...



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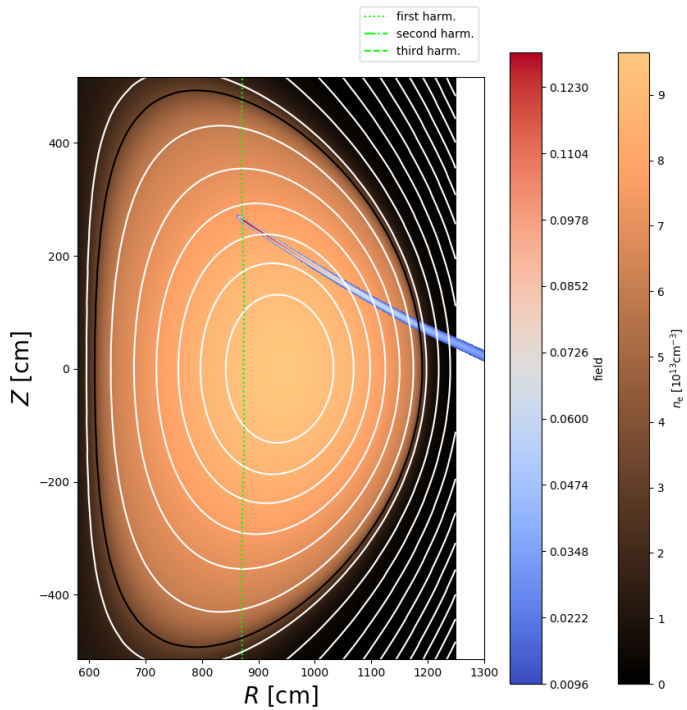

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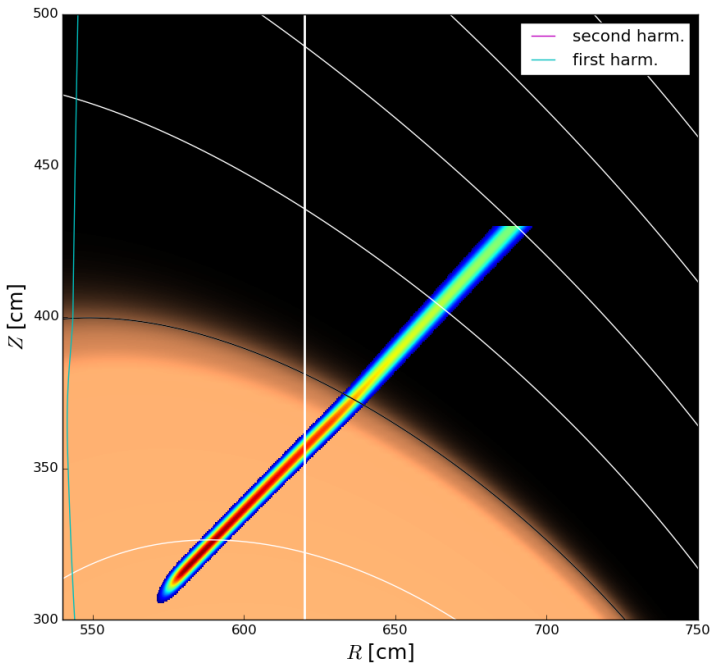

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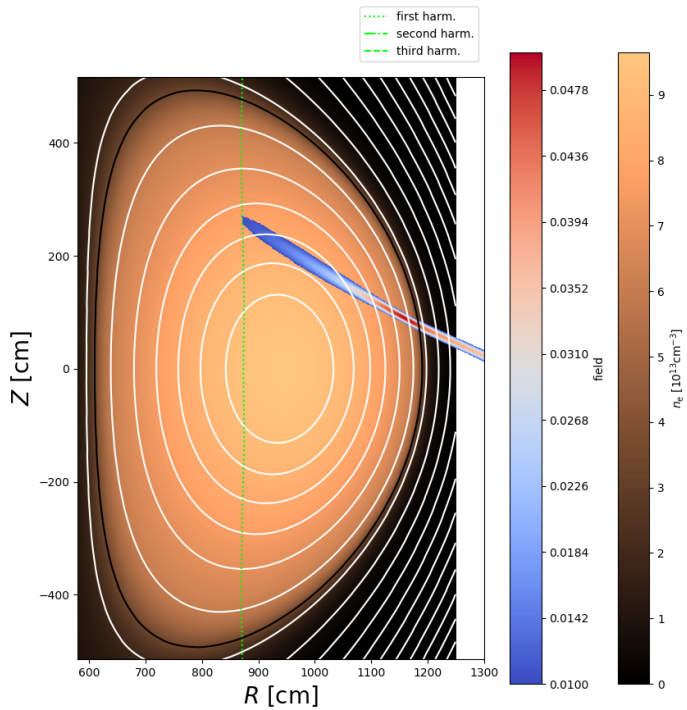
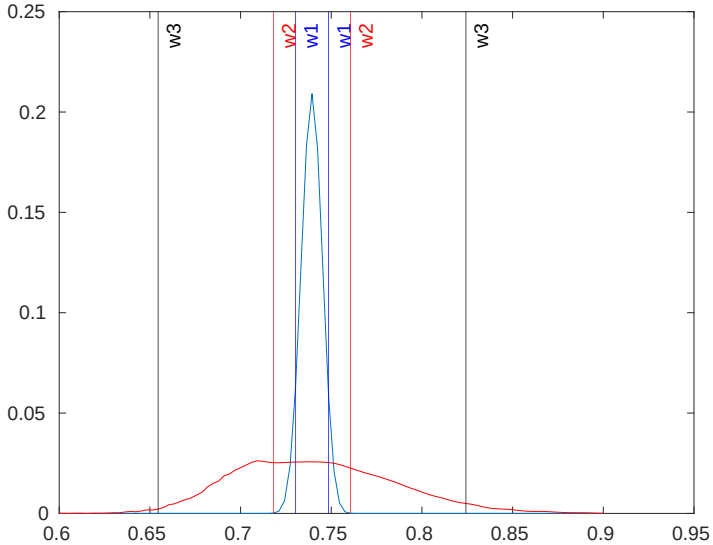


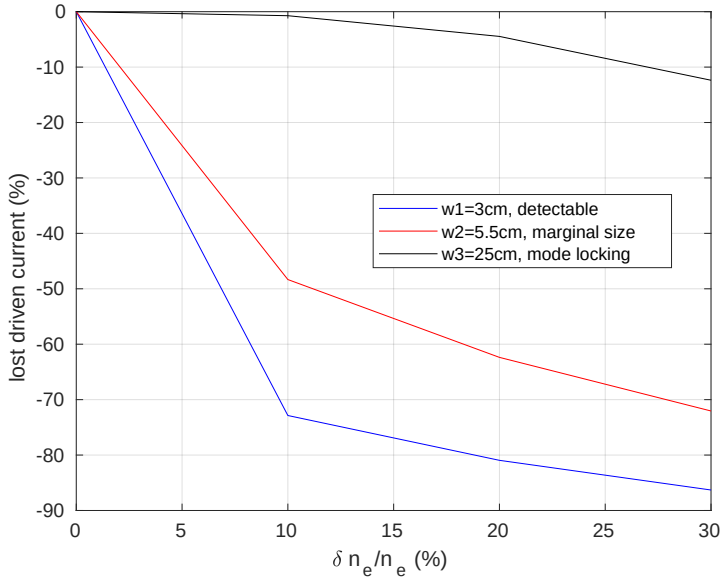
EC beam with fluctuations (20%, 2cm) in DEMO

DEMO studies 2020

From beam broadening to lost current

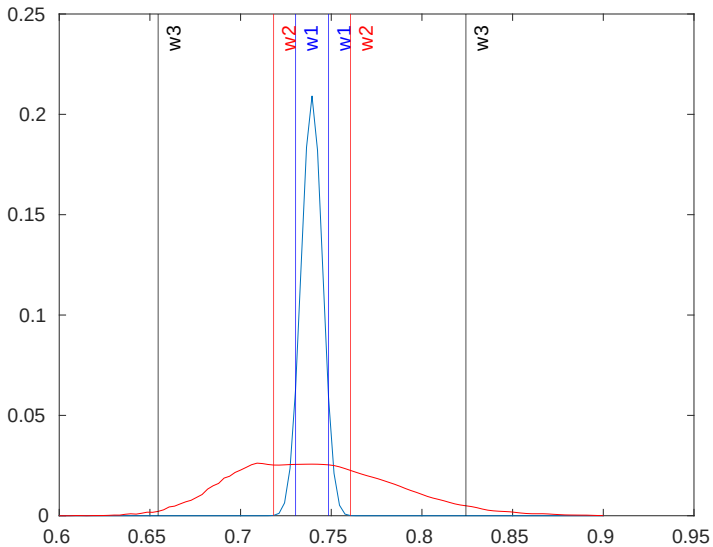
- NTMs are mitigated by current driven inside the island
- Beam broadening might be optimal way to illustrate this
- Instead, integrate the current inside a radial domain (idea proposed by O. Sauter)
- Three scales: i) detectable size (3cm), ii) marginal size/fastest growing (5-6cm), and iii) locked mode (25cm)

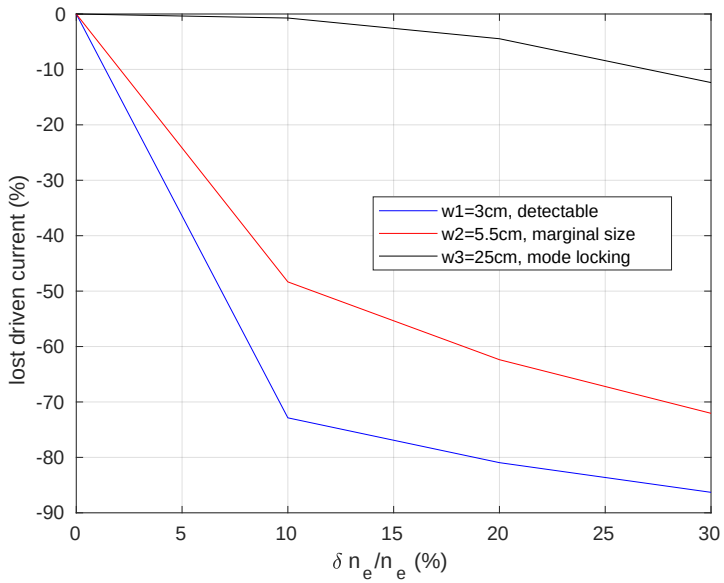




What does this imply?

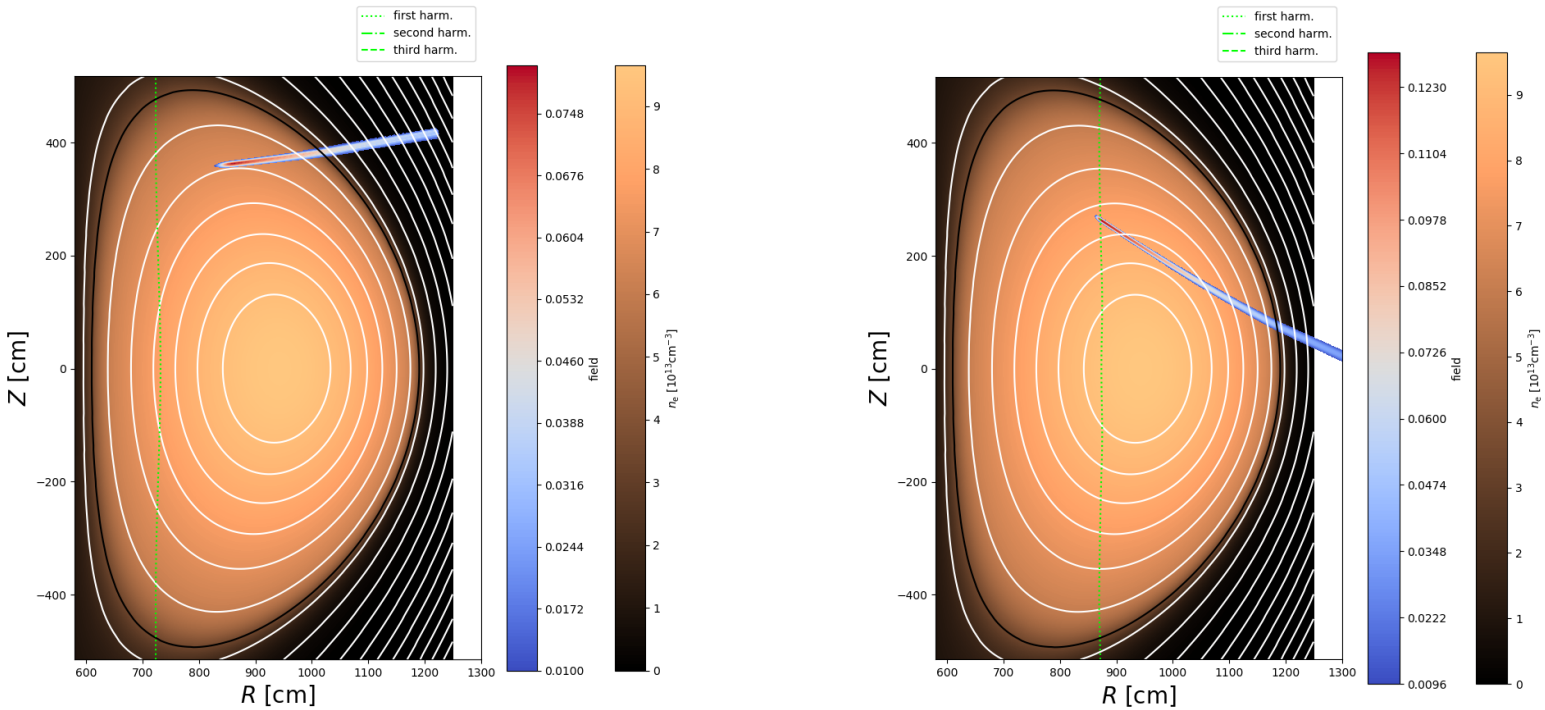
- With larger islands, still effective current drive
- For DEMO, rather steep curve of dw/dt vs. w
- Hence, there is SOME hope to control larger islands
- Conclusion, need some numbers (see the item later on)





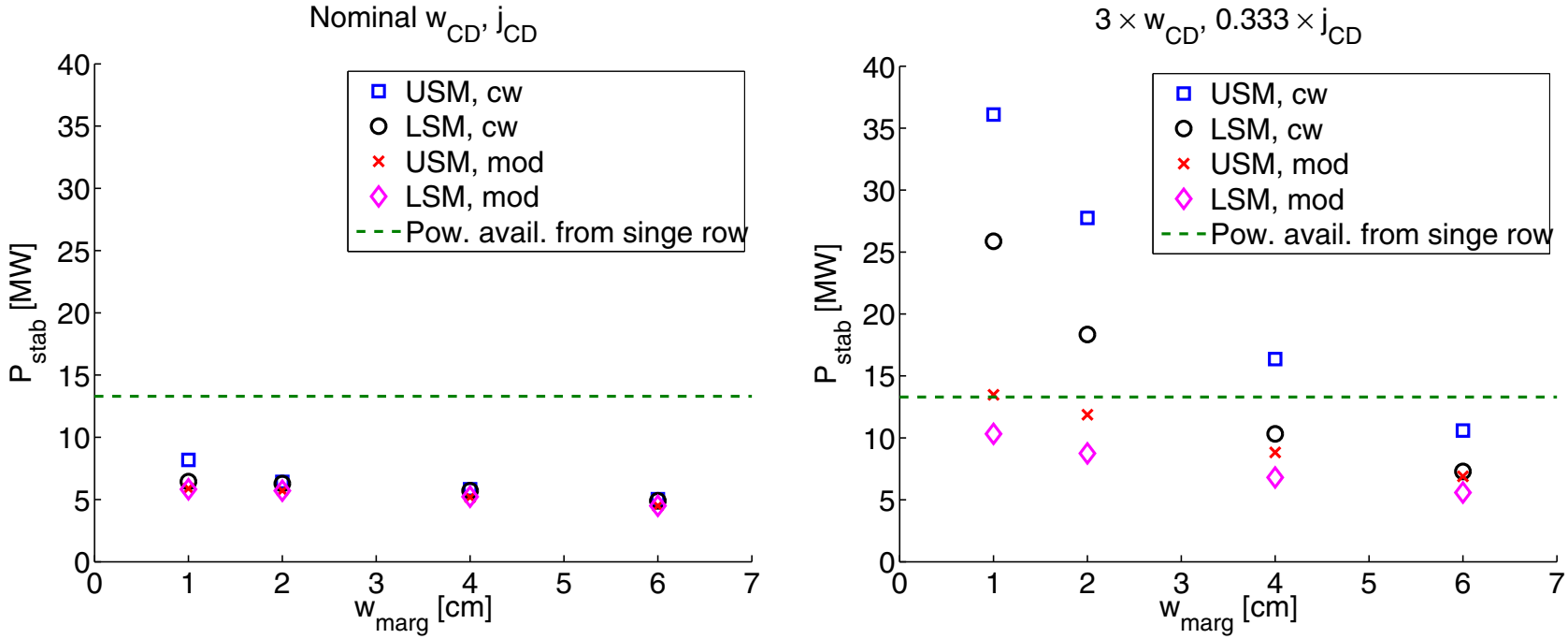
Poloidal scan of the launcher

- Earlier study (using TORBEAM) used ITER-like launcher position
- Take beam parameters of that study, modify launching angles
- Study the lost current/beam broadening from this position
- Status: received the position a week ago, currently starting simulations



Implication of the broadening to ITER NTM control

- Power of 10 MW (nominal 20MW) not enough to stabilize the mode with 3xw_{CD} for all w_{marg}
- Even in the most unfavourable case, 10 MW is enough if EC power modulated
- Status for DEMO, only started playing around with parameters...



Thank you for your attention!

Any questions?