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A phase-contrast-imaging core fluctuation diagnostic and first-principles turbulence modeling for JT-60SA

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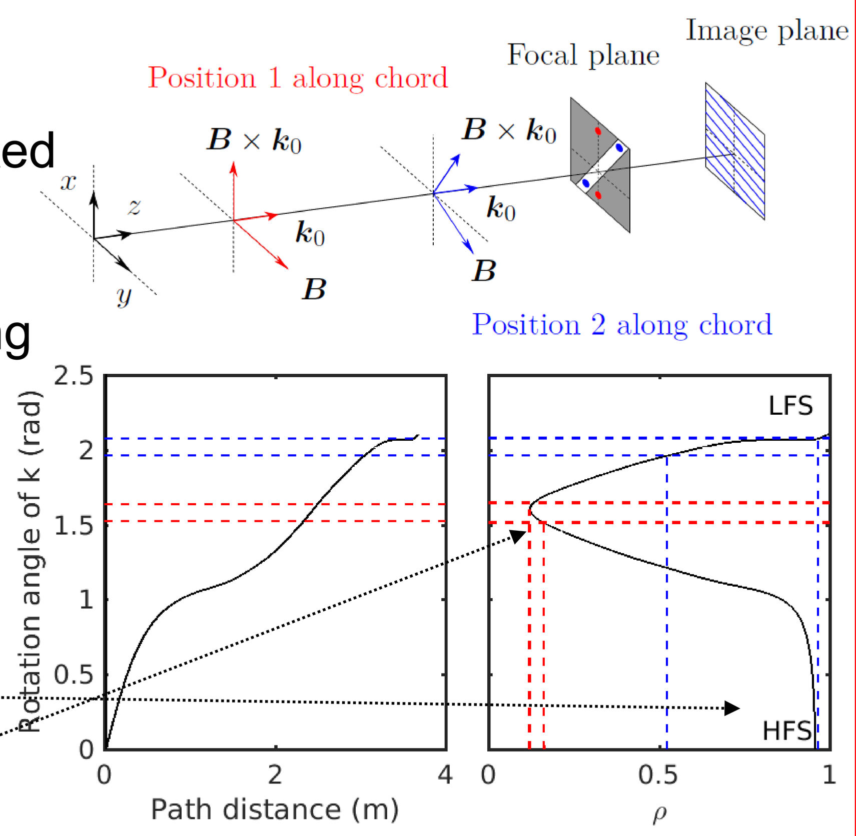
Motivation and highlights

- JT-60SA [1,2] presents a unique opportunity to study turbulence and validate models in a reactor-grade device
- PCI [3,4] is a powerful technique that can provide full δn profile, with $\delta n/n \sim 10^{-5}$ sensitivity, in the range $0.06<k\rho_i<12$ (potentially beyond: ITG/TEM/ETG), with high spatial resolution in the center and at the edge
- Both k_ρ and k_θ wave vectors at the edge, mainly k_ρ in the center
- Suited for detection of complex spatial structures such as zonal flows
- Comparisons with gyrokinetic modelling mediated by a synthetic diagnostic

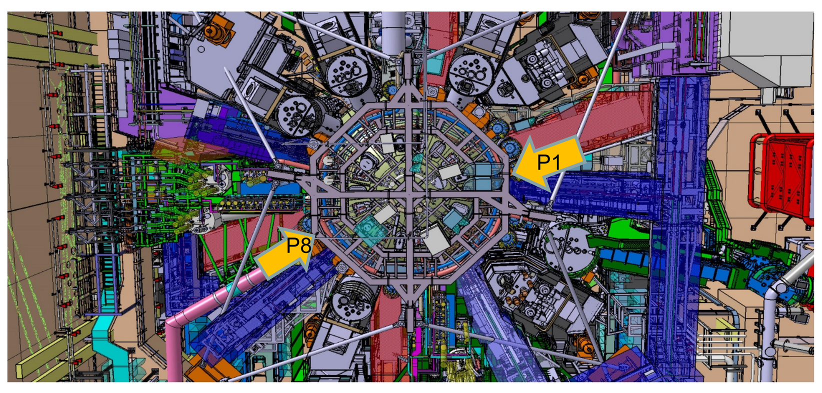
Experimental technique

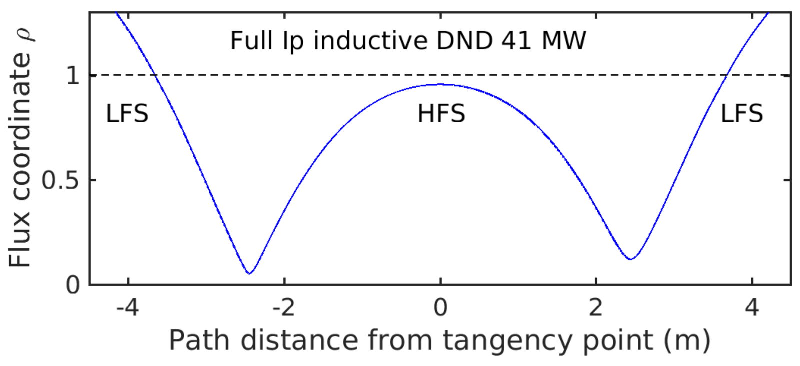
- Internal-reference, laser-based interferometer: images line-integrated density fluctuations in plane perpendicular to beam
- Localization is achieved by selecting **k** direction, which must be locally oriented along $\mathbf{B}\times\mathbf{k}_0$ [5]
- Good localization near tangency point because $\mathbf{B}\times\mathbf{k}_0$ varies rapidly, and $d\rho/dl=0$ enhances effect (HFS edge in our geometry)
- $d\rho/dl=0$ also on the magnetic axis, so localization there is good too

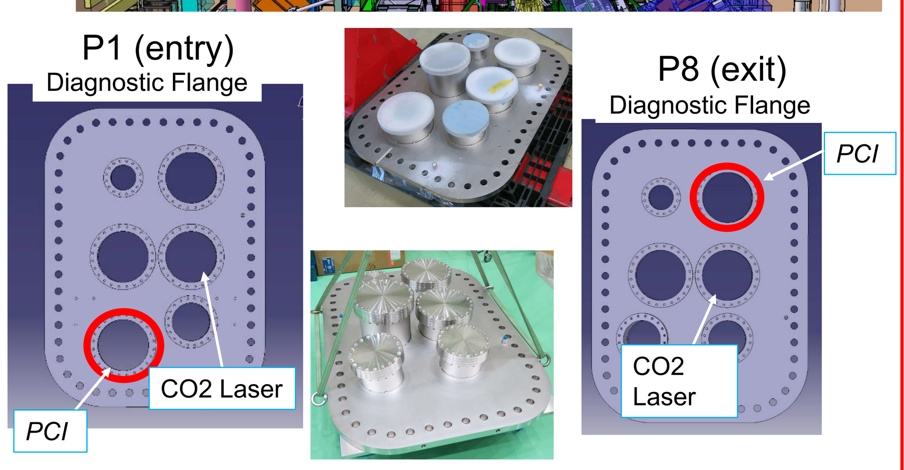


Design criteria

- CO_2 laser wavelength 10.6 μm
- Tangential port assemblies P1 and P8 can fit 18-cm beam
- Chosen path resolves just inside LCFS and near magnetic axis

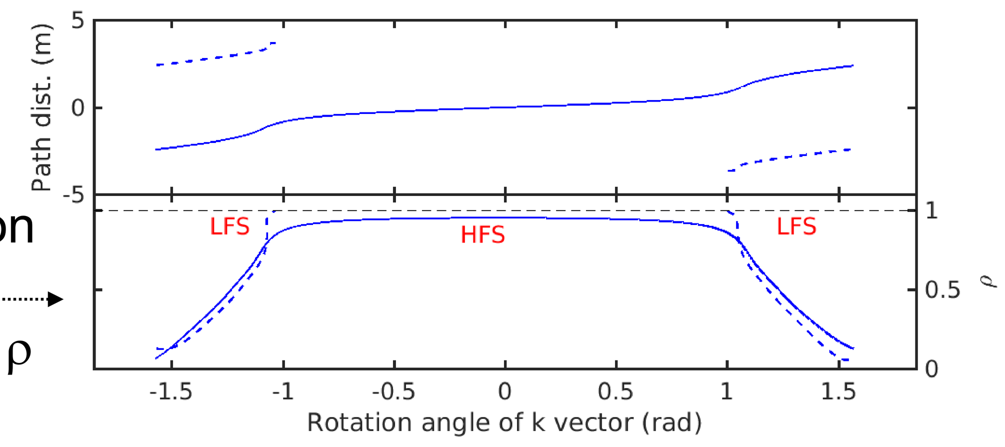


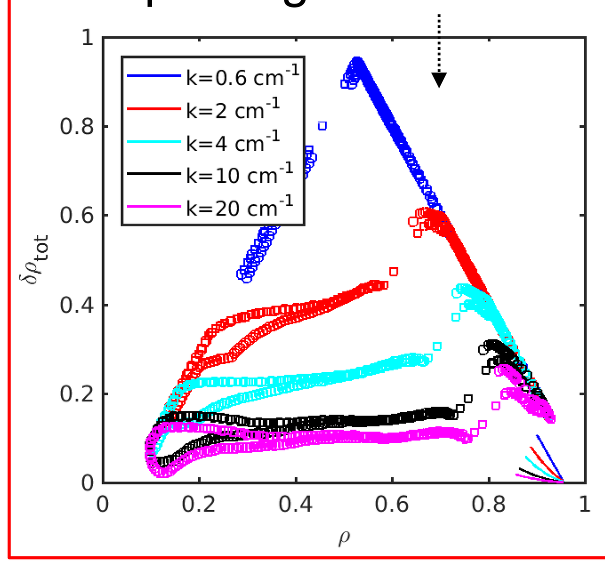


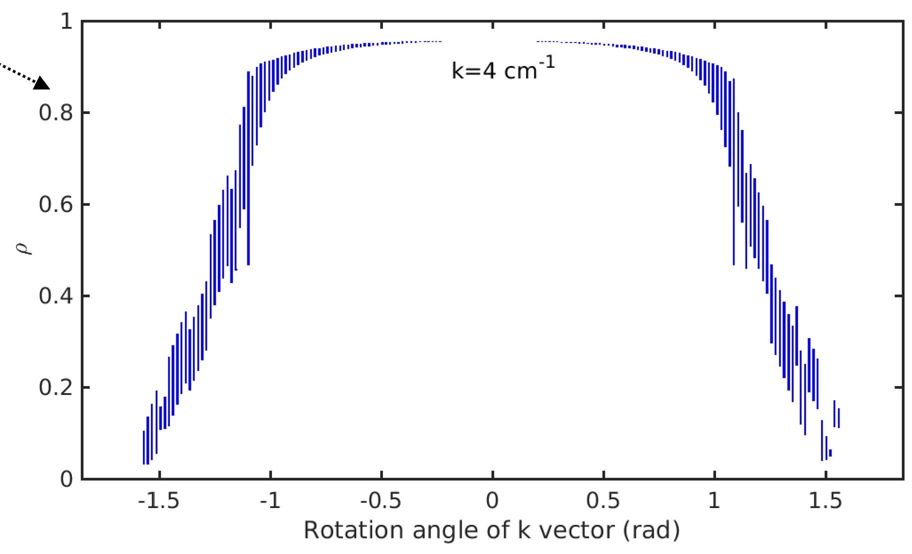


Spatial localization

- Measurement location vs **k** direction is partially double-valued: no localization loss in our geometry as two locations have same ρ
- k-dependent but well-known transfer function
- Good aggregate localization, improving with k



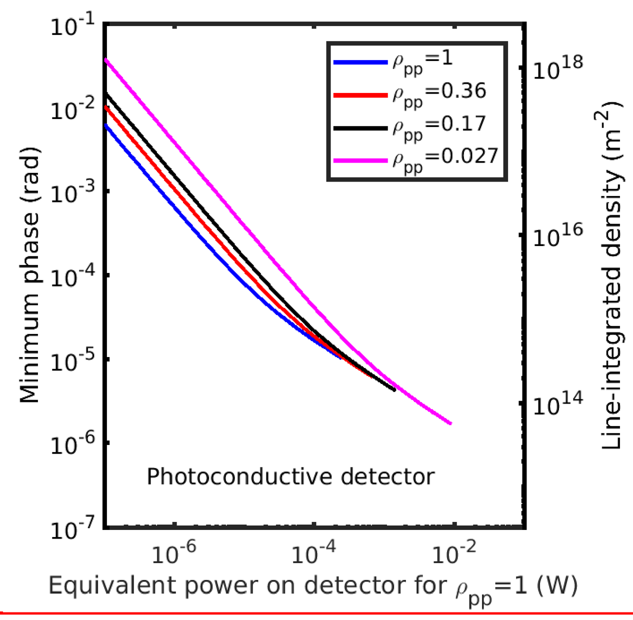




- Mainly k_ρ in center, k_ρ and k_θ at edge

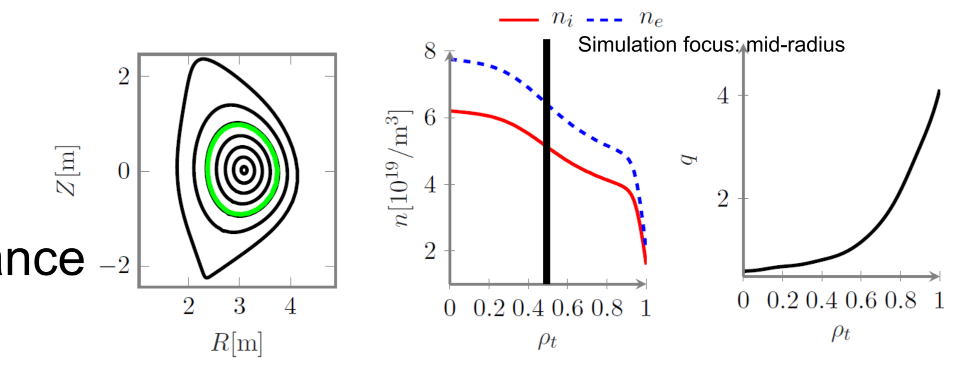
Sensitivity

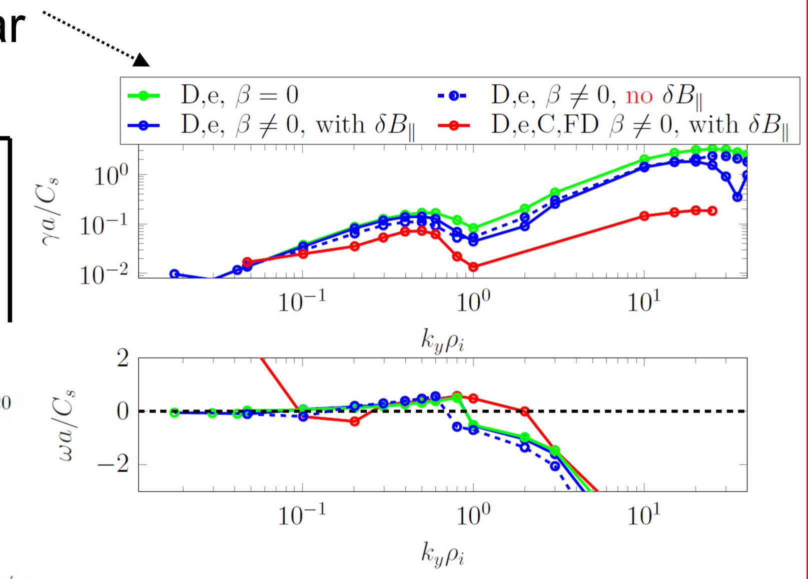
- Improves with laser power
- Depending on integration length, densities as low as 10^{15} m^{-3} can be measured



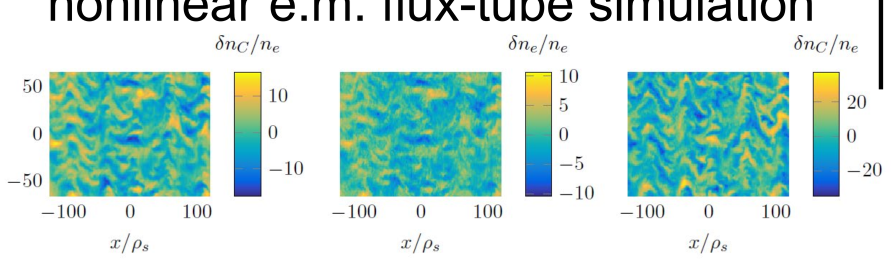
Gyrokinetic modelling

- GENE code [6]
- Scenario 1: DND 41-MW full current
- Linear analysis shows importance of retaining full physics, esp. impurities, e.m. effects
- ETGs could be important but nonlinear ETG/ITG interaction appears minor

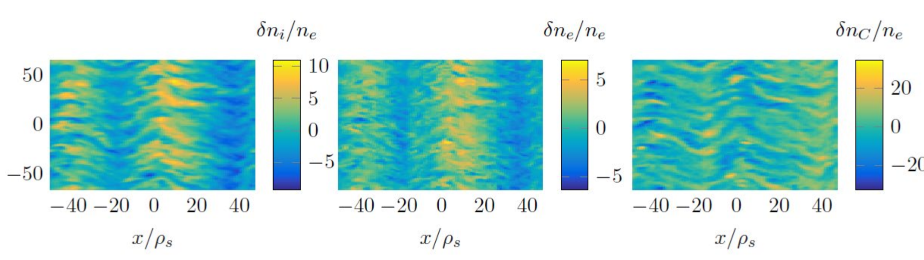




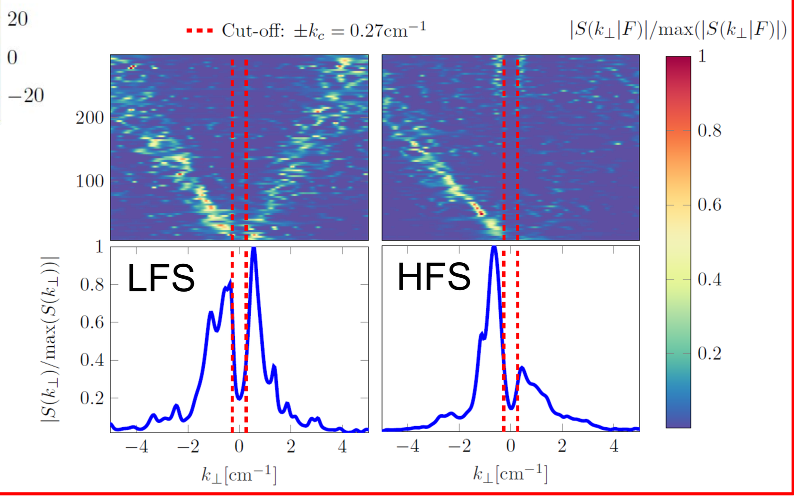
Unfinished (non-steady-state) nonlinear e.m. flux-tube simulation



Complete electrostatic simulation

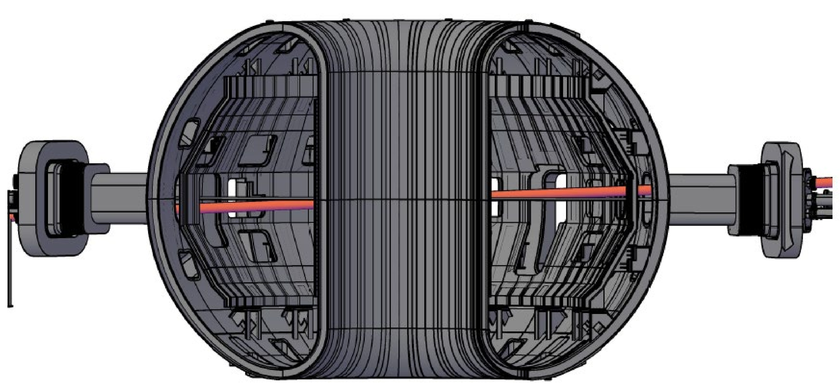


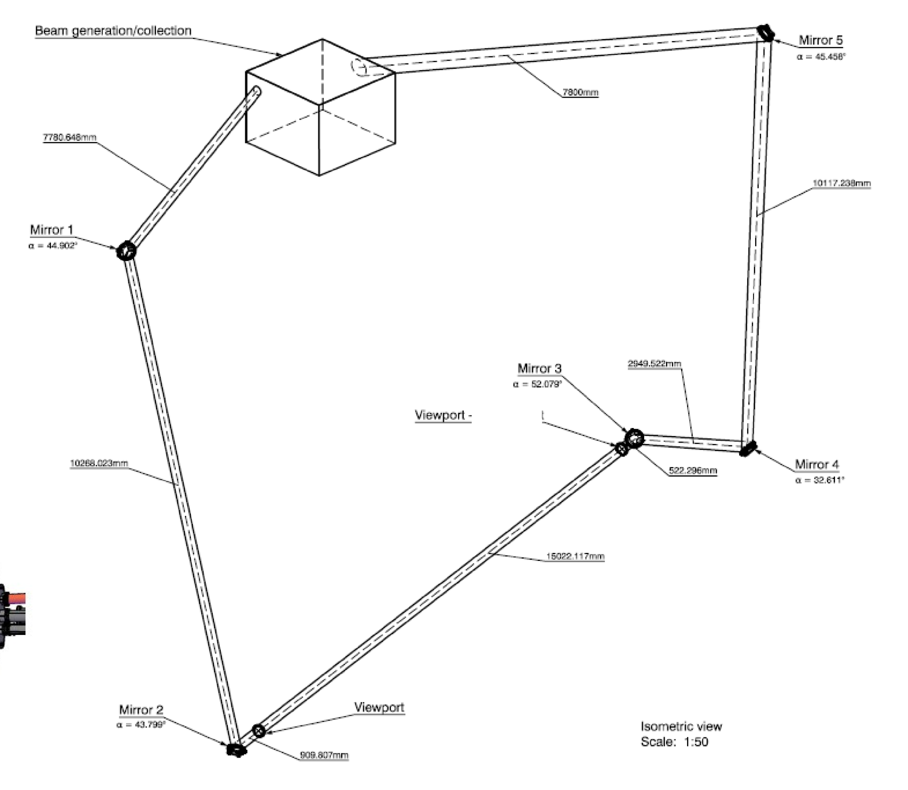
Synthetic TPCI diagnostic



Hardware layout

- Beam-generation and detection equipment above vessel
- Simple with no optics on the vessel





Conclusions

- Tangential PCI system planned for JT-60SA, would likely provide first deep insight into turbulence in reactor environment and usher in the next level of model validation
- Measures full profile in all plasma conditions
- 1 MHz bandwidth, $0.33<k<20$ cm^{-1}, $\int\delta n\, dl>10^{14}$ m^{-2}
- $\Delta\rho<0.1$ (axis + edge), 0.4-0.1 at mid-radius (k=2-10 cm^{-1})

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Swiss Plasma Center

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