EUROfusion

Tangential phase-contrast imaging diagnostic

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Phase-contrast imaging on JT-60SA

- First real opportunity to study turbulence and turbulent transport, and validate models, in a reactor-grade device
- PCI is a powerful technique that can measure $\delta n/n \sim 10^{-5}$ in the range $0.06 < k\rho_i < 12$ (and potentially beyond: ITG/TEM/ETG) in all regimes and in the whole plasma, with high spatial resolution in the center and at the edge
- Direct spatial imaging means complex spatial structures such as zonal flows, avalanches and streamers can be resolved
- Gyrokinetic modelling support proposed in parallel, with comparisons mediated by a synthetic diagnostic
- JT-60SA offers a very favorable configuration, the technique is well understood ⇨ the project is feasible and carries low risk

Outline

- Motivation
- Principles of (tangential) PCI
- Design criteria
- Proposed layout and implementation
- Status of project
- Summary and outlook

Motivation

- ITG/TEM (plus resistive MHD, plus possibly ETG) turbulence deemed responsible for anomalous transport, regulated by zonal flows - all still not fully understood
- We must validate the models.
  Unique opportunity to advance the understanding of microturbulence and anomalous transport in truly reactor-grade conditions, in a variety of regimes, with strong theory support

Principles of PCI

- PCI is an internal-reference interferometer: measures line-integrated density but only by manipulating and recombining beam components
- It is more sensitive than an interferometer ($\int \delta n \, dl \sim 10^{14}$ m^{-2}) but cannot measure *absolute* phase shift (long wavelength cutoff ≈ size of beam)
- An image is created across the beam, and spatial resolution is limited only by the number of detector elements

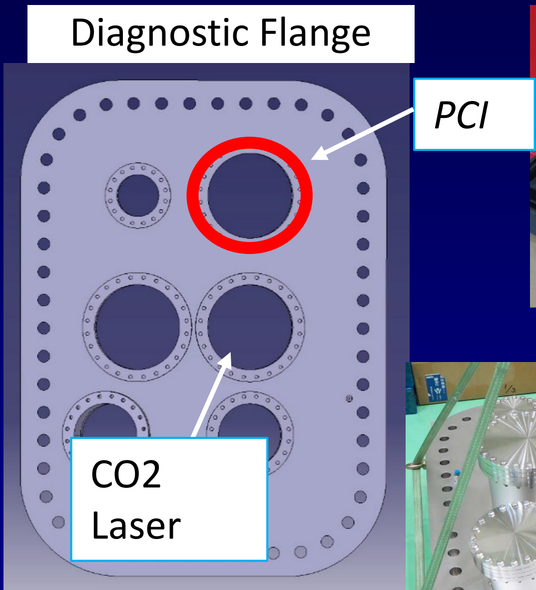
Principles of TPCI

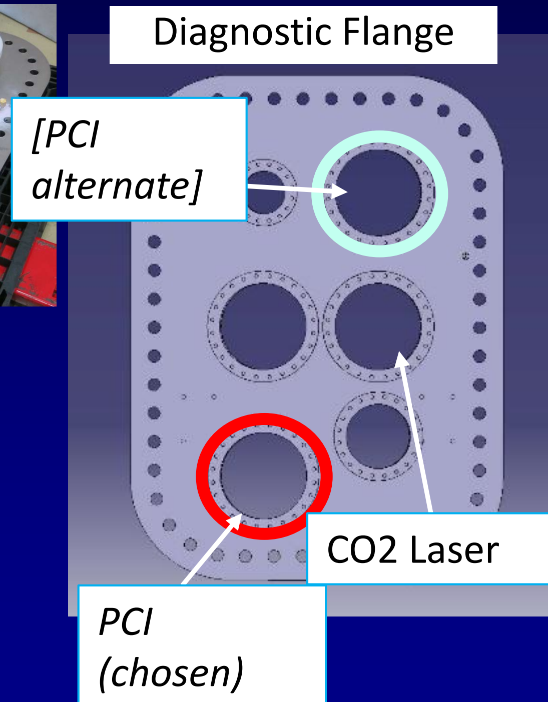
- At each location, signal contribution comes from one wave-vector direction: **k** $\propto$ **B**x**k**$_0$.
  Selecting **k** direction (by optical manipulation) imposes spatial selection rule, which is effectively restrictive only in the case of tangential propagation
- In JT-60SA, best spatial localization is achieved near the magnetic axis and in the pedestal (on the HFS)

Design criteria: beam geometry

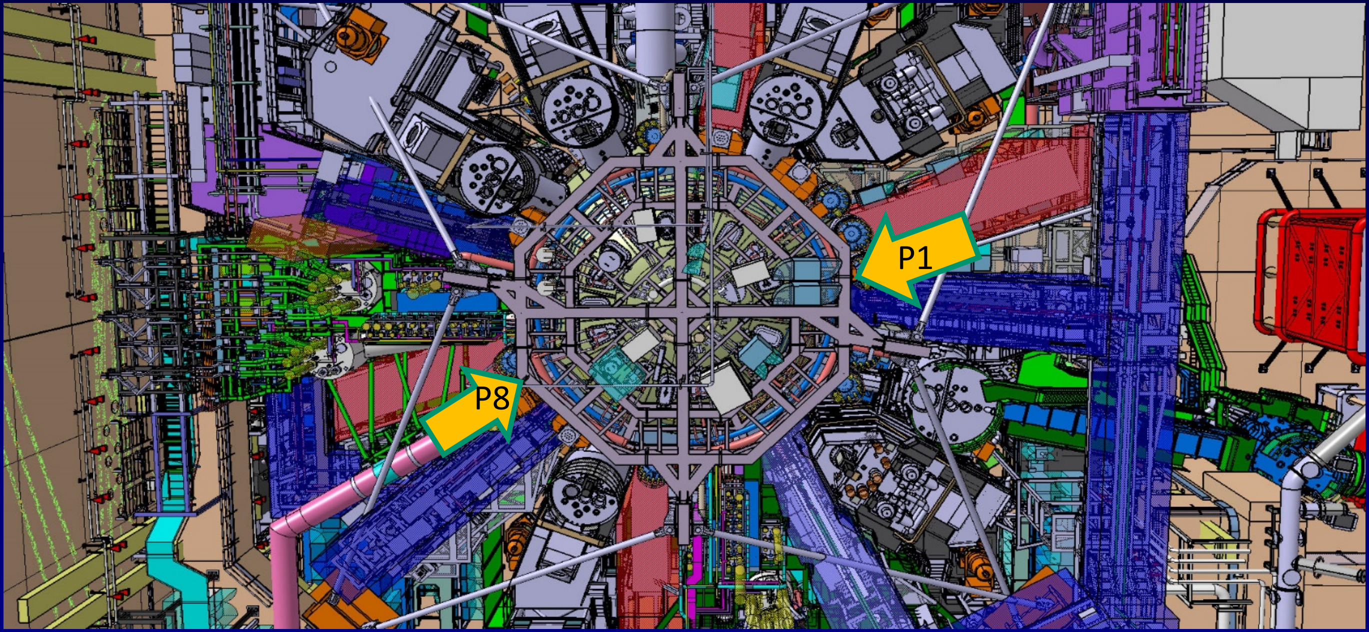
P8 (entry)

P1 (exit)



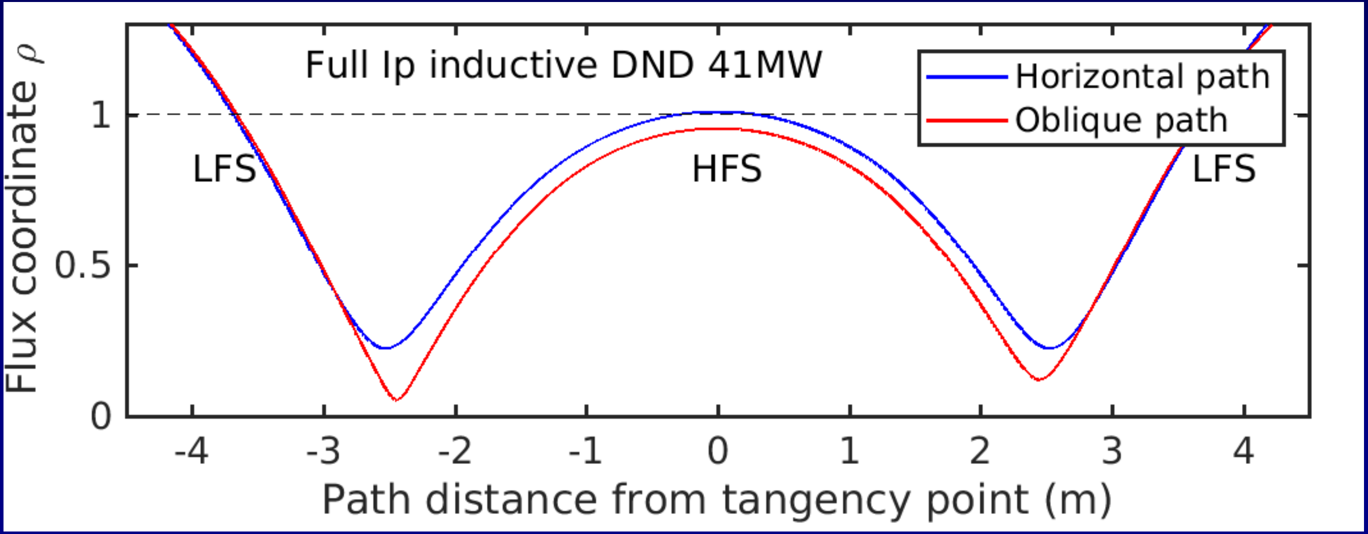


Design criteria: beam geometry

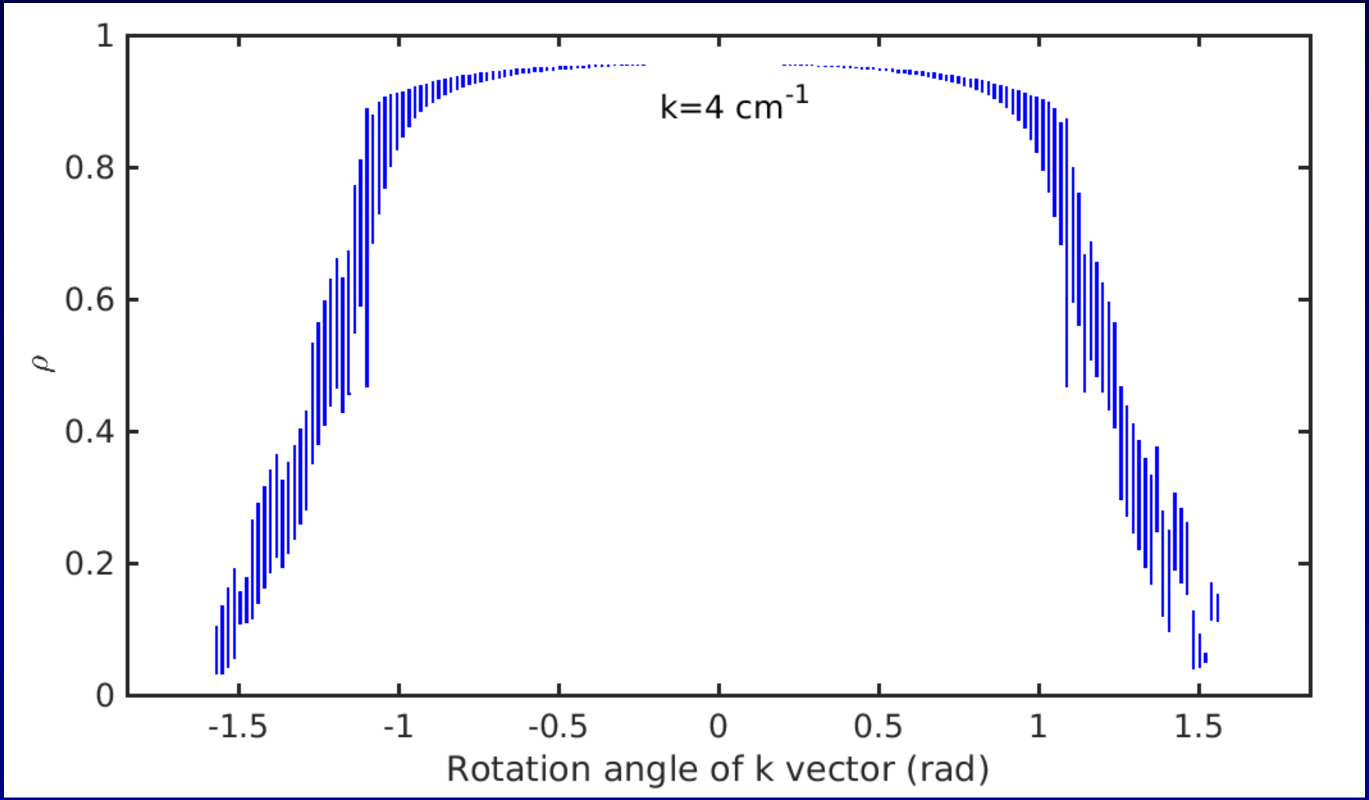


Dedicated oblique path is best

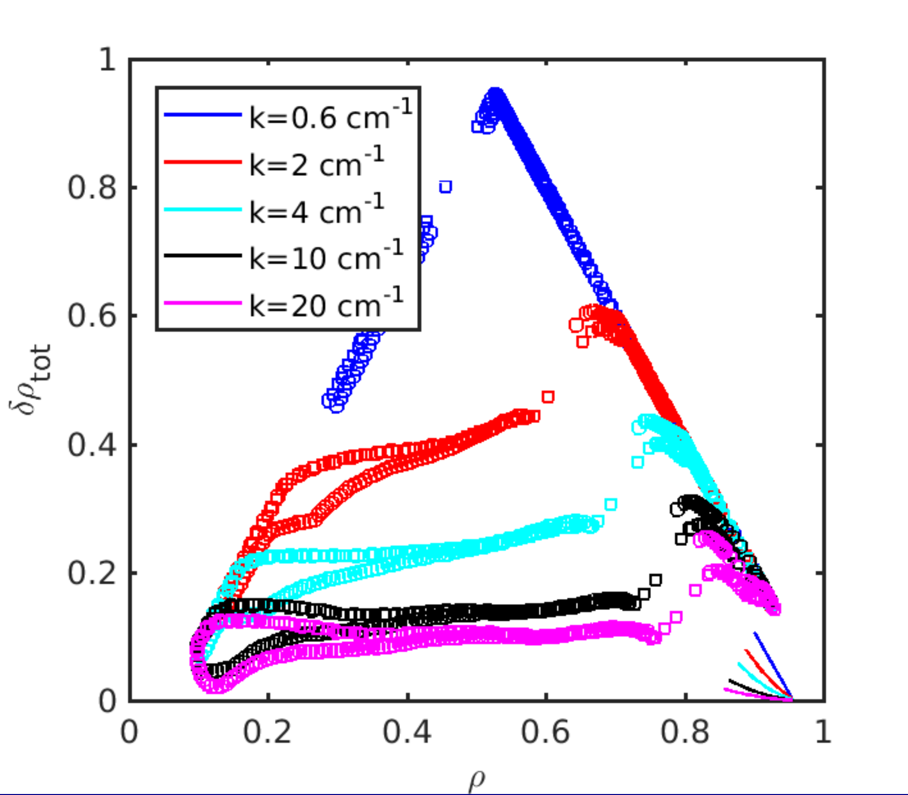
- Largest possible beam size desired (access longer wavelengths)
- Proposed ports are compatible with 18-cm beam
- Oblique path is better: covers HFS edge and gets closer to axis (both with high resolution)



Good localization



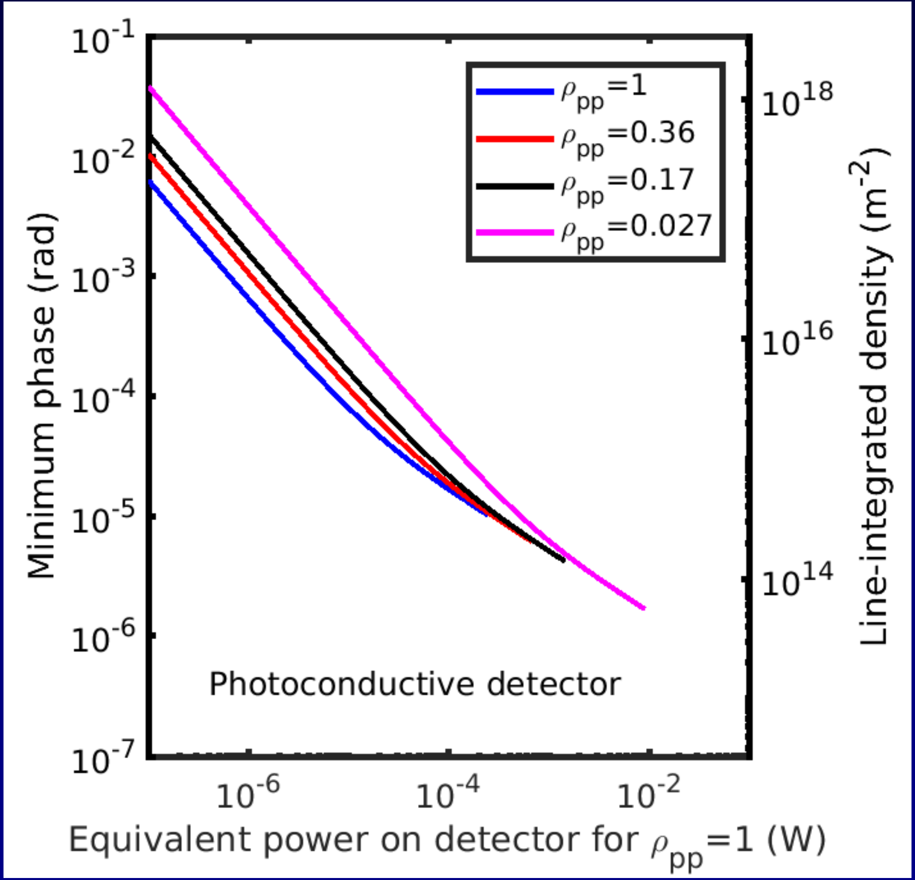
Localization improves with increasing k



k direction: predominantly k_ρ in center, k_ρ and k_θ in two separate edge measurements

S. Coda, A. Iantchenko, K. Tanaka, and S. Brunner, Proc. 46th EPS Conf. On Plasma Physics, Milan, Italy, Europhys. Conf. Abstr. 43C (2019) (P2.1013)

Sensitivity is crucial



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

Gyrokinetic modelling (GENE)

- Indications from GENE runs, aided by synthetic diagnostic, are that TPCI is well placed to detect the relevant modes
  - see presentation by A. Iantchenko (next)

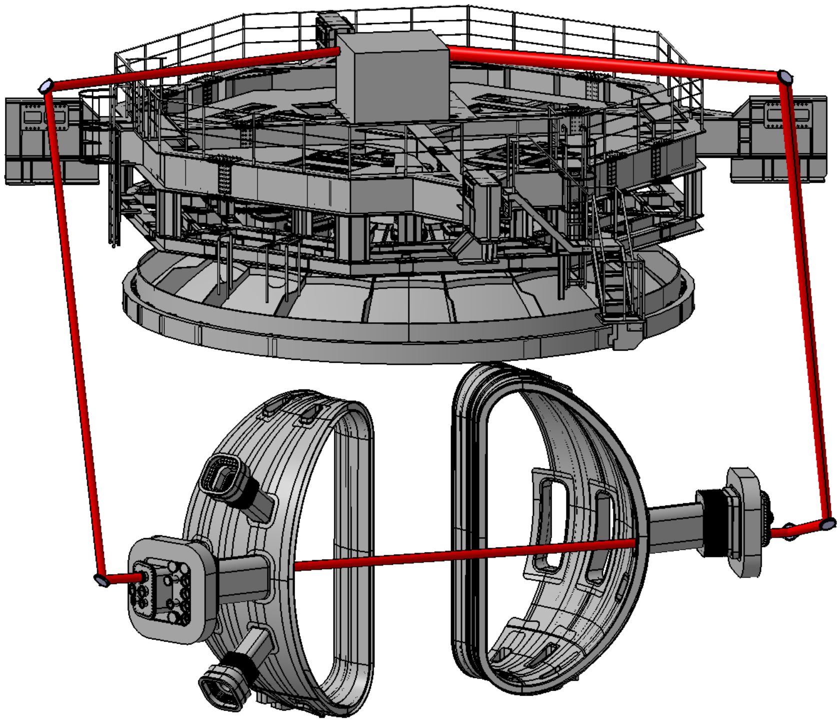
A. Iantchenko, G. Merlo, S. Coda, and S. Brunner, Proc. 46th EPS Conf. On Plasma Physics, Milan, Italy, Europhys. Conf. Abstr. 43C (2019) (P2.1098)

Hardware layout

- Beam generation
  - CO_2 laser of ~100 W power
  - Beam expansion by telescopic arrangement
  - Relay mirrors all off-vessel (max 32-cm diameter)
- Vacuum interfaces
  - ZnSe windows
- Beam collection
  - Relay mirrors all off-vessel (max 45-cm diameter)
  - Reflective-refractive focusing and imaging system

Hardware layout

- Only 5 relay mirrors are necessary



Status: completed design

- Optical and mechanical layout finalized
- Neutron + gamma shielding, fire-safety beam shielding planned
- Lasers, detector (with automated LN_2 cooling), electronics and acquisition included in design

Planned activities for 2021 and beyond

- 2021 is a “keep-in-touch” year with focus on the compilation of complete engineering specifications and purchasing indications
- Pending funding, procurements and construction can proceed from 2022
- Hiring of dedicated staff will be required
  - a postdoc and a graduate student are envisioned – with first data possible from 2024
  - construction can be accelerated if needed

Summary and outlook

- Tangential PCI system ready to be built 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 ($k=2-10\ cm^{-1}$)
- Can be operational on the 2024 horizon