# Tangential phase-contrast imaging diagnostic for JT-60SA

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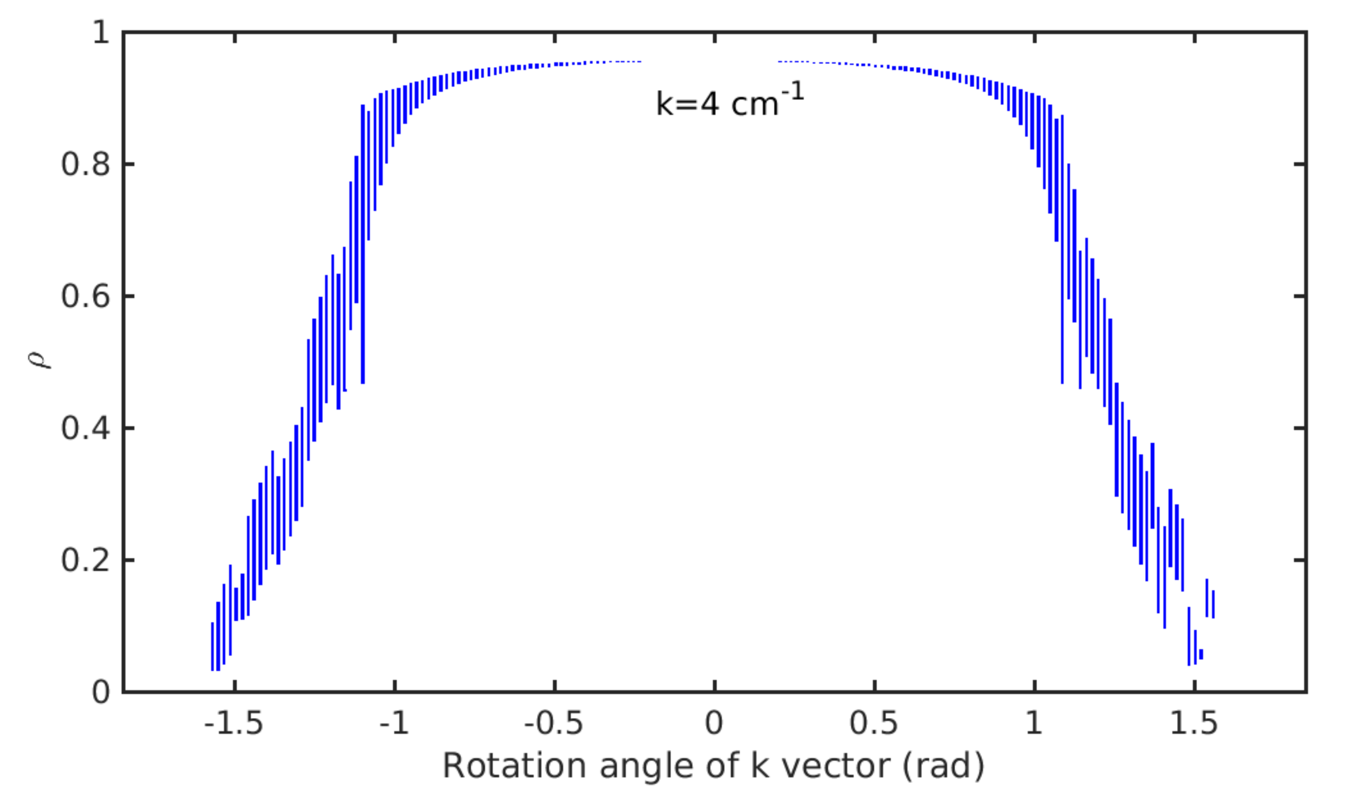
# Phase-contrast imaging on JT-60SA

- Will provide localized density fluctuation measurements across the minor radius and in all plasma regimes
  - $\delta n/n \sim 10^{-5}$, $0.06 < k\rho_i < 12$ (ITG/TEM/ETG)
  - high spatial resolution in the center and at the edge (very favorable configuration on JT-60SA)
- First real opportunity to study turbulence and turbulent transport, **and validate models**, in a reactor-grade device
- Gyrokinetic modelling support proposed in parallel, with comparisons mediated by a synthetic diagnostic (ongoing GENE work)
- Europe/NIFS collaboration, with Japanese funding (JSPS) already secured

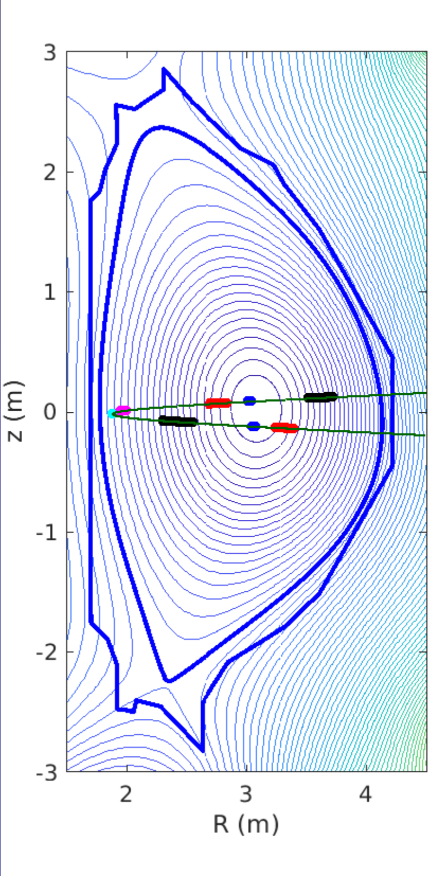
S. Coda et al, Nucl. Fusion **61**, 106022 (2021), DOI:10.1088/1741-4326/ac2081

# Radial localization




A rotating filter allows sampling the entire profile vs time within a shot

# Localization on the flux surface




- While well-localized in ρ, at mid-radius the measurement picks up signal from both the HFS and LFS
- HFS and LFS can be resolved separately by doubling the detection system (splitting the transmitted beam to create two separate images)

# Hardware layout

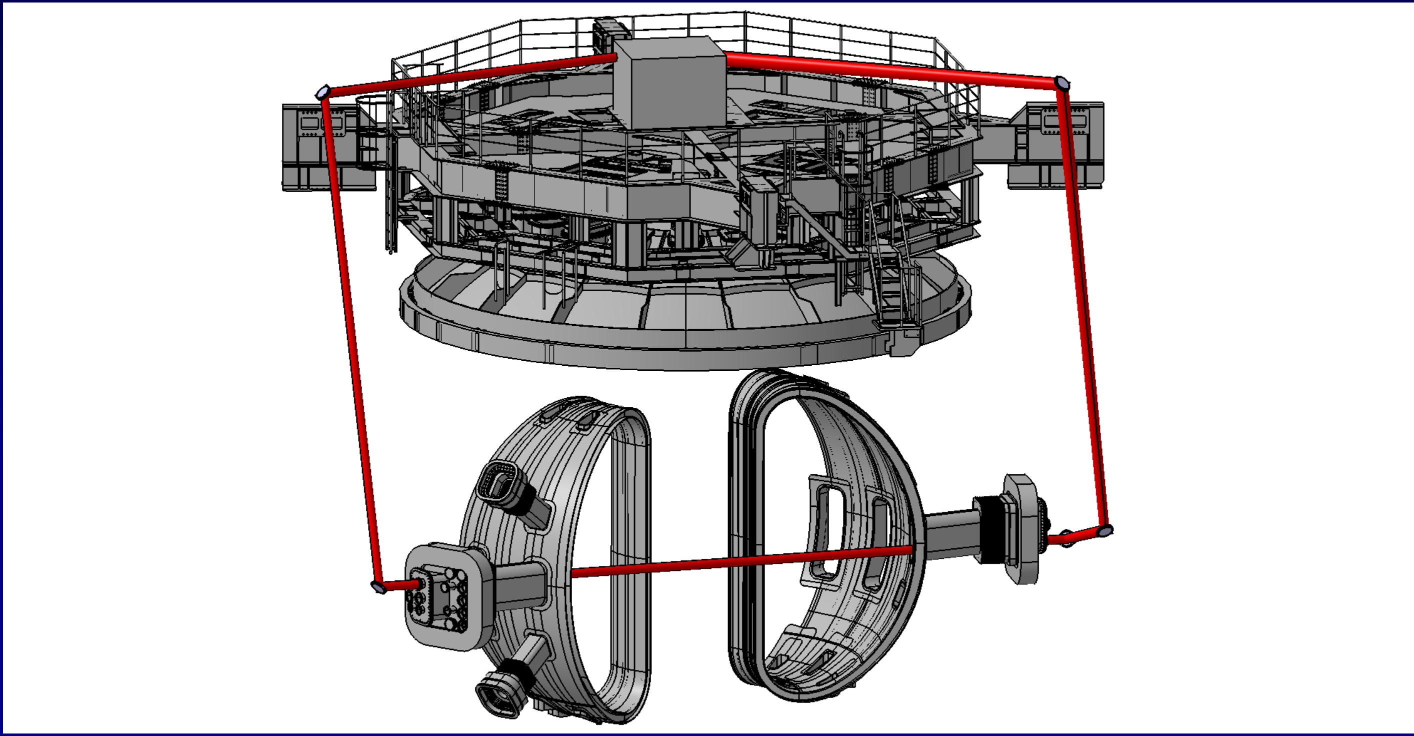
- Beam generation
  - $CO_2$ laser of ~60-100 W power
  - Beam expansion by telescopic arrangement
  - Relay mirrors all off-vessel (max 32-cm diameter)
- Vacuum interfaces
  - ZnSe windows
- Beam collection
  - Relay mirrors all off-vessel (max 45-cm diameter)
  - Reflective-refractive focusing and imaging system: **must be close to vessel since scattered components diverge rapidly**

# Hardware layout

- Neutron + gamma shielding, fire-safety beam shielding planned
- Automated $LN_2$ cooling included in design
- Mechanical vibrations are **not** a cause for concern. DIII-D and TCV have optics mounted on vessel and feedback focusing system counteracts vibrations very effectively

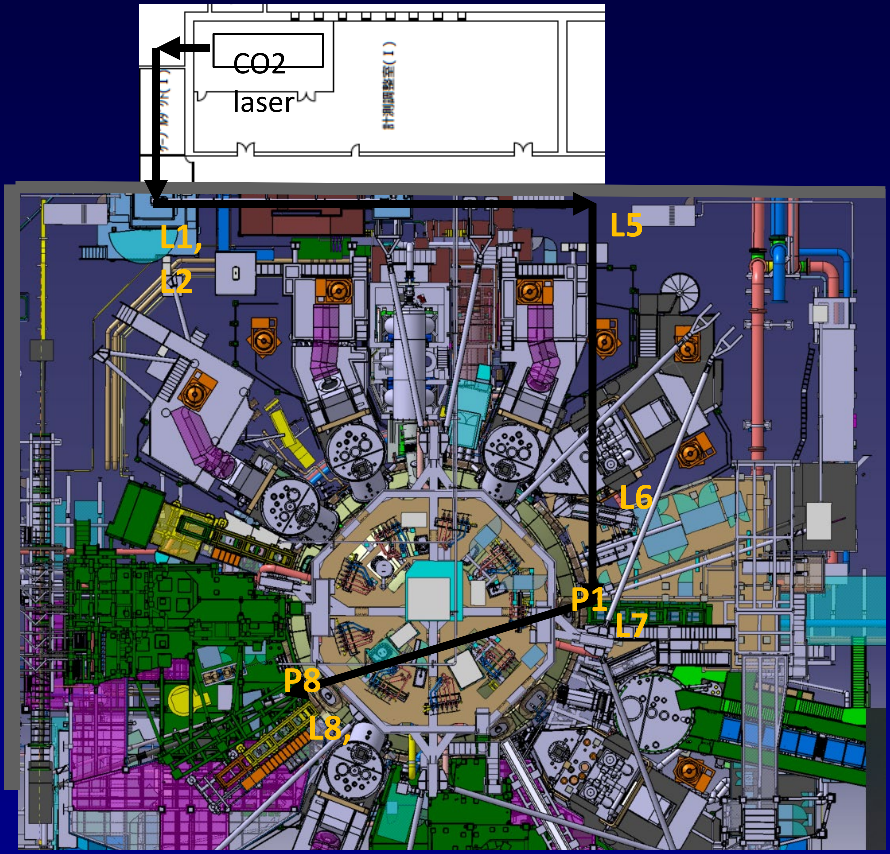
# First design

- Based on assumption that upper stage could be used
- Design essentially completed in early 2021

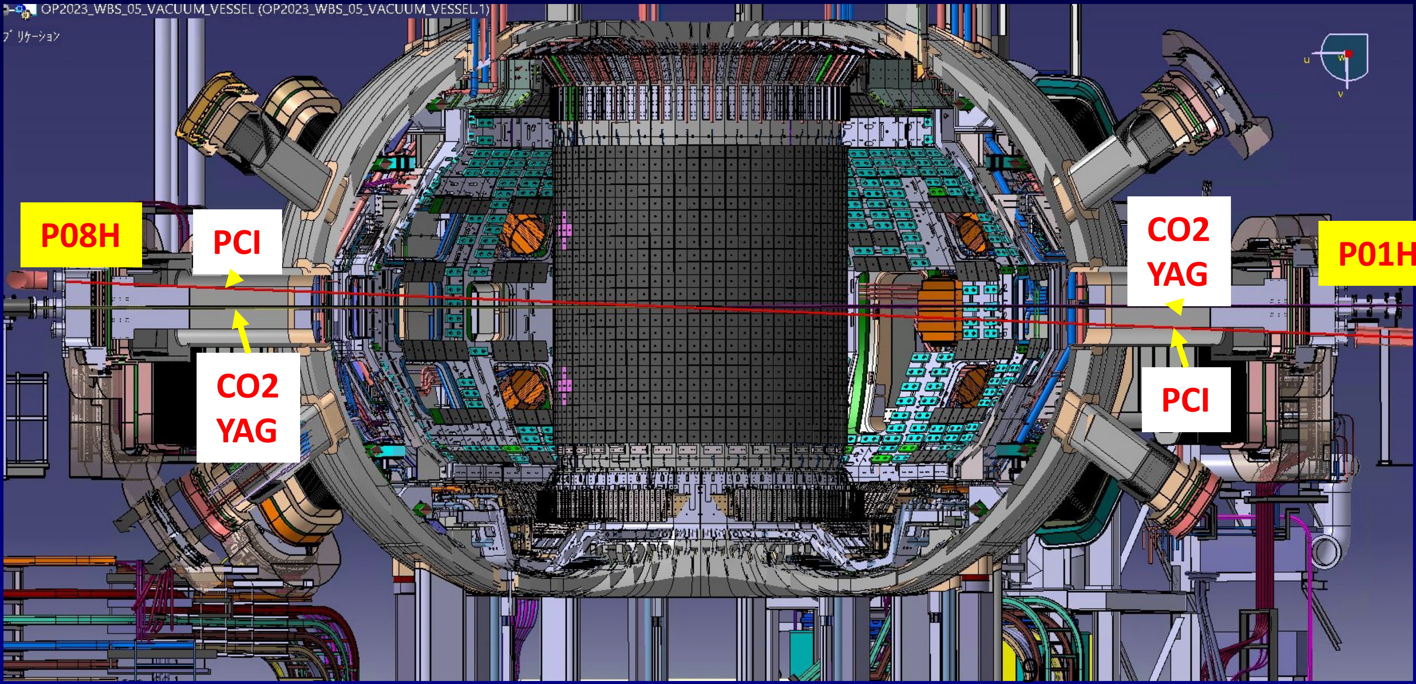


# 2021: updated layout

- New QST preference is to avoid upper stage, and to keep laser system outside torus hall for easier maintenance
- Data acquisition in basement: reduced radiation environment

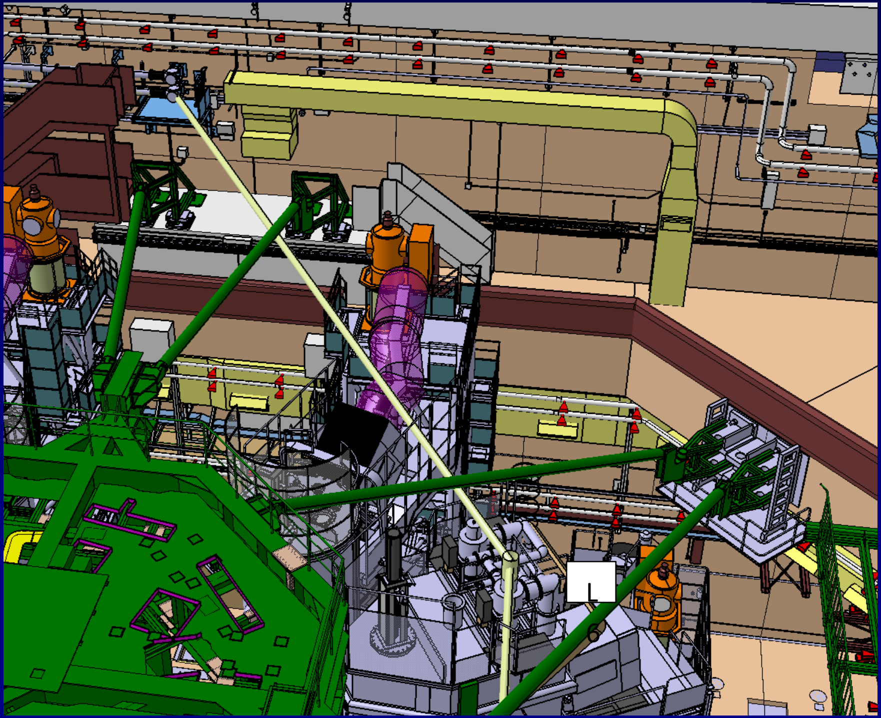


# Optical-path design underway



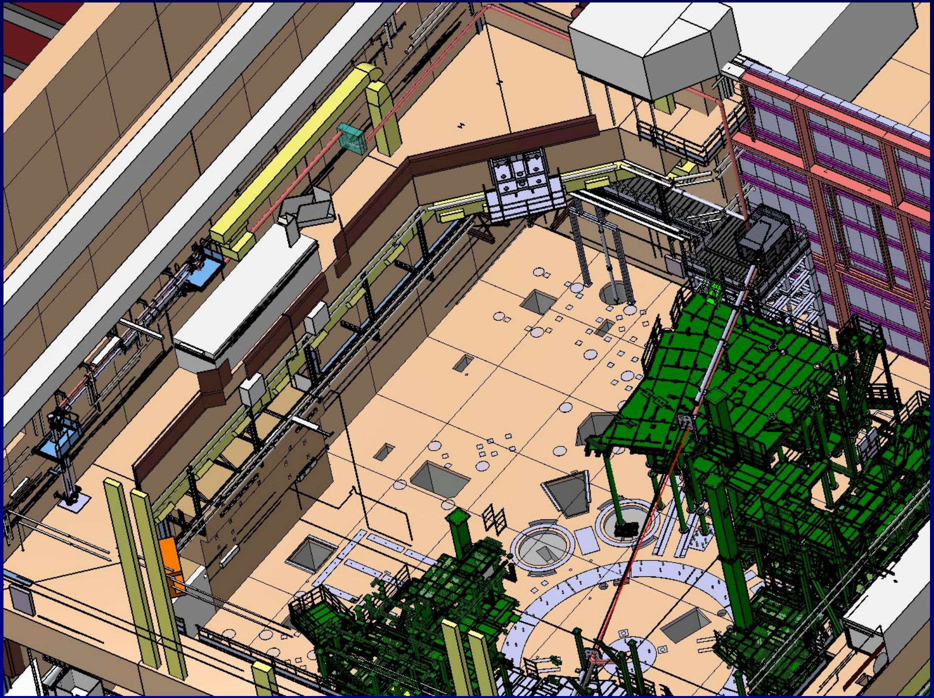
# Optical-path design underway

- EPFL-SPC has proposed several alternatives for each segment of the optical path
  - e.g. this example to shorten the path and minimize the number of optics



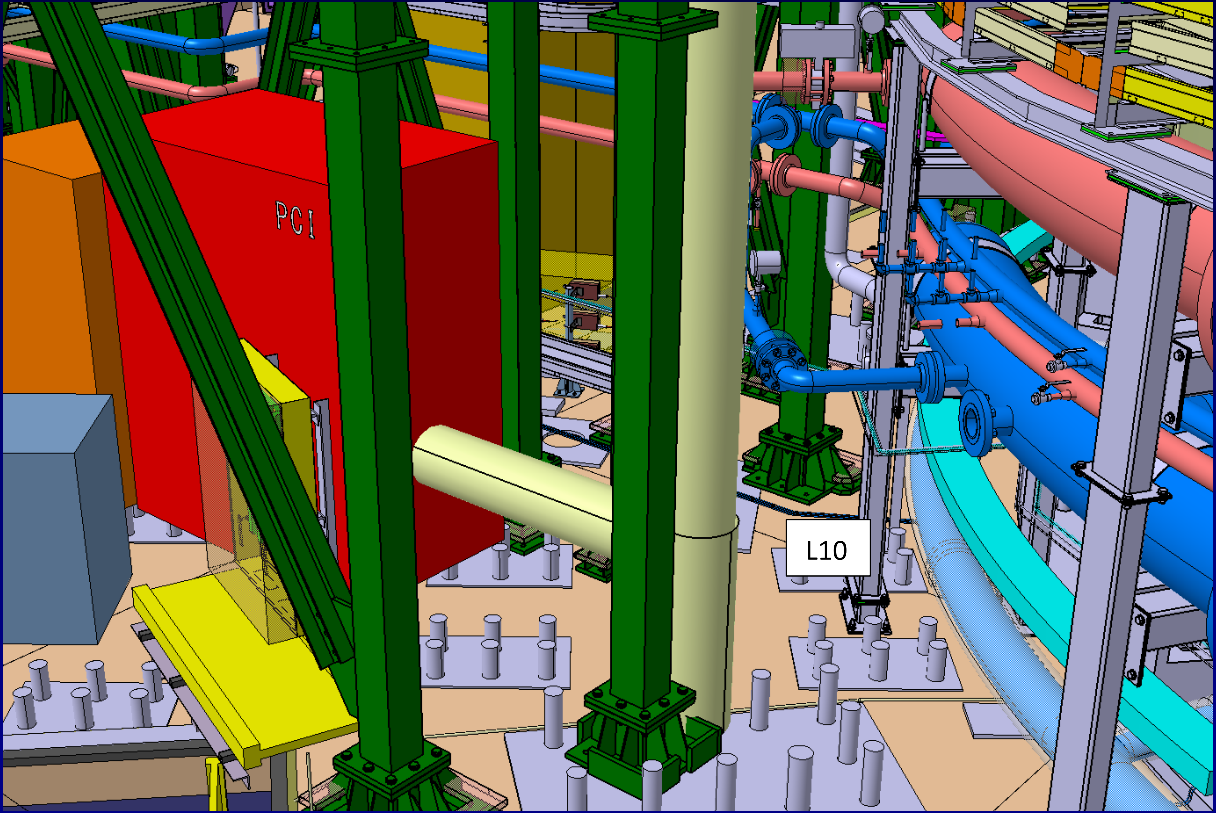
# Optical-path design underway

- QST has opted for a more conservative design, hugging the walls as much as possible, to avoid conflicts with cranes and other structures
- Longer path but no major concerns
- Path is now being optimized and finalized and final approval from QST will be sought shortly



# Optical-path design underway

## Detection box



# Gyrokinetic simulations

- Ongoing, first very complex GENE nonlinear flux-tube simulation of high-$\beta$ (DND) scenario (A. Iantchenko)
  - Gradients in the nominal scenario are too small to match the heat flux
  - Difficult navigation to avoid non-zonal transition and high-amplitude oscillation caused by fast ions
  - Synthetic diagnostic developed for TPCI (paper submitted)
  - Lengthy convergence studies approaching the end ⇨ publication to be submitted soon

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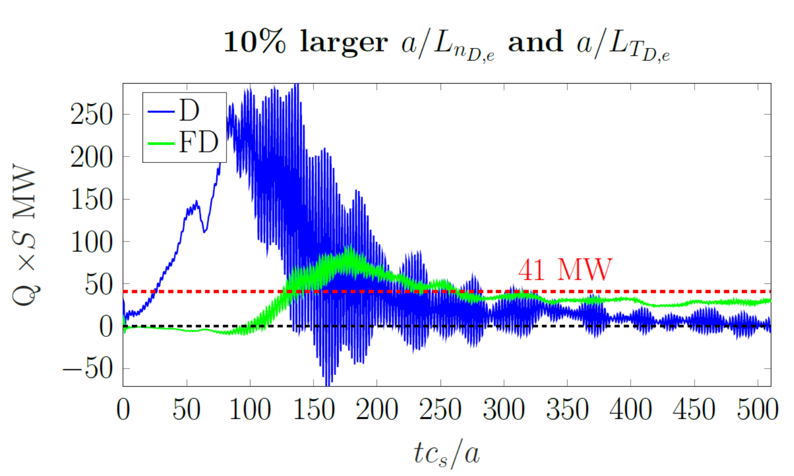

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- Equivalent study of scenario 2 (full Ip inductive SND) started (S. Mazzi, to be continued by other SPC personnel in view of completion in 2023)

# Current status and planning

- Detailed mechanical and optical design (including all mirror boxes, supports, tubing, etc.) to be completed (2022) after final agreement on optical path
- Complete costing to be delivered along with design
  - Budget sharing envisioned between NIFS and Euratom
  - Procurements have begun on the NIFS side (LN2 filling station)
  - NIFS also proposing reuse of LHD equipment (detectors, etc.)
  - Euratom share of hardware budget estimated at 250 k€
- All procurements can start in 2023, and installation would be *possible* in 2024
- Hiring of dedicated staff will be required
  - a postdoc and a graduate student are envisioned
  - construction can be accelerated if needed

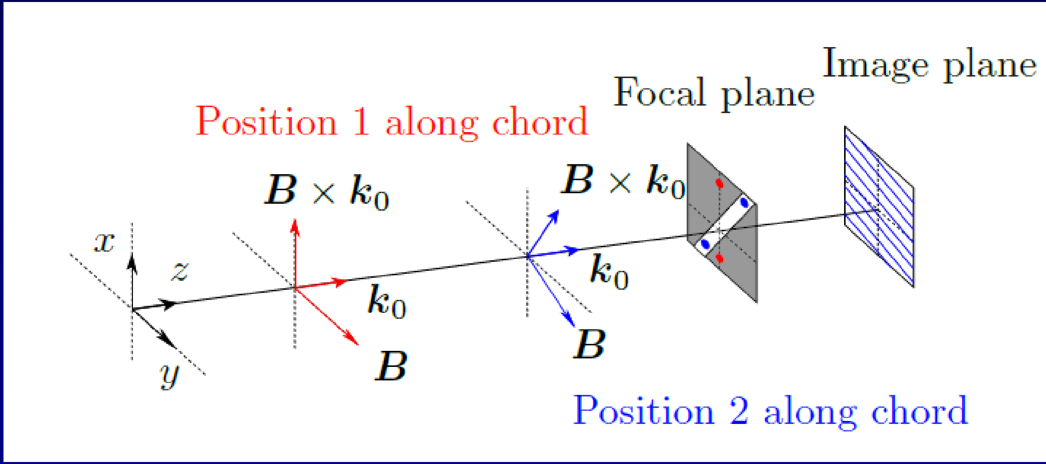
# ADDITIONAL SLIDES

# 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
- Localization *along* the beam is achieved in a tangential-launch geometry by selecting the direction of the measured wave vector (by optical filtering)

# How is spatial localization achieved?

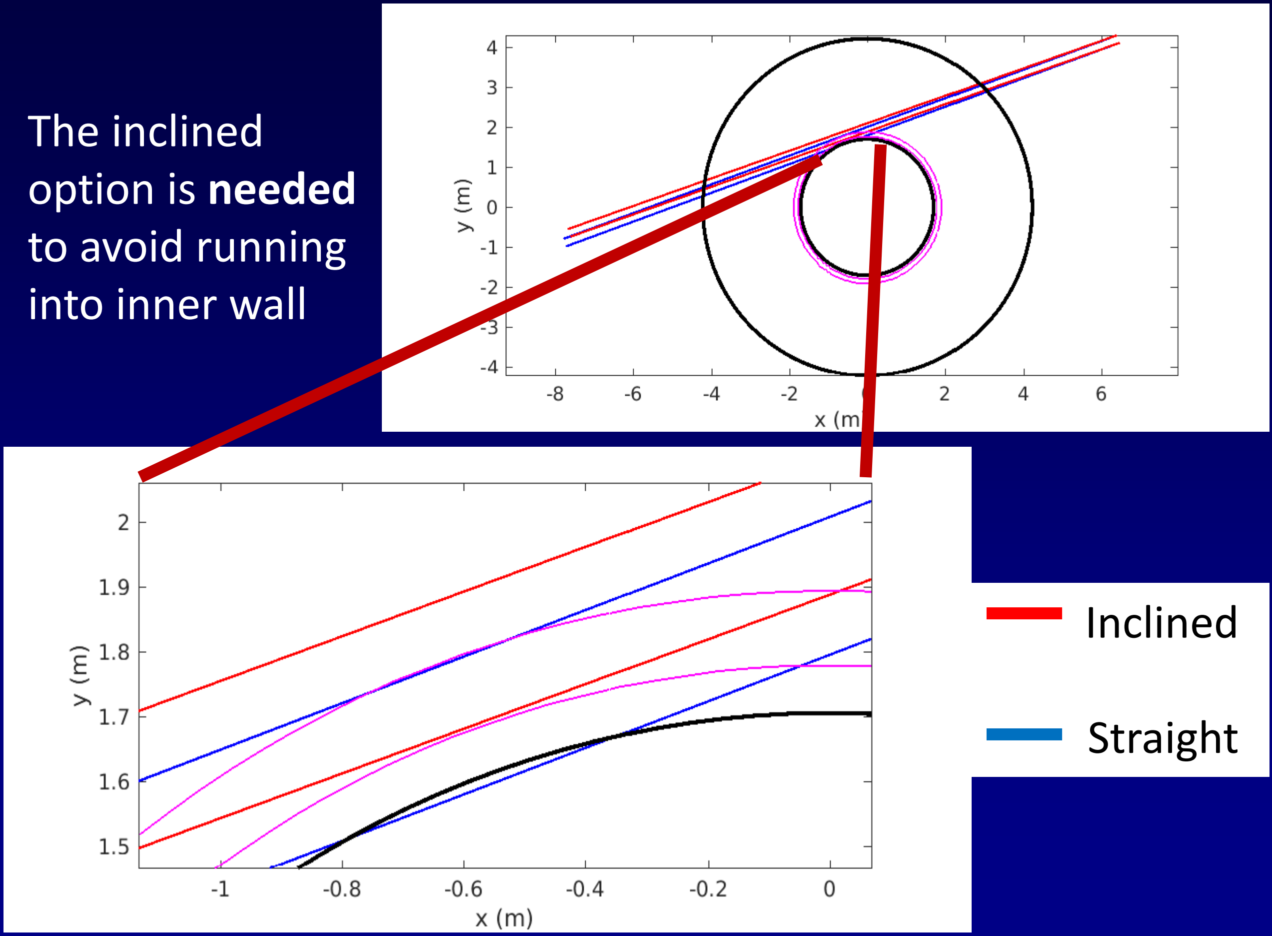
- At every location, measurement selects wave vectors that are perpendicular to the magnetic field (since $k_{par}$~0) and to the laser beam (else canceled by integration), i.e.
  **$k \propto B \times k_0$**
- Selecting the direction of **k** by spatial filtering, we select a spatial location



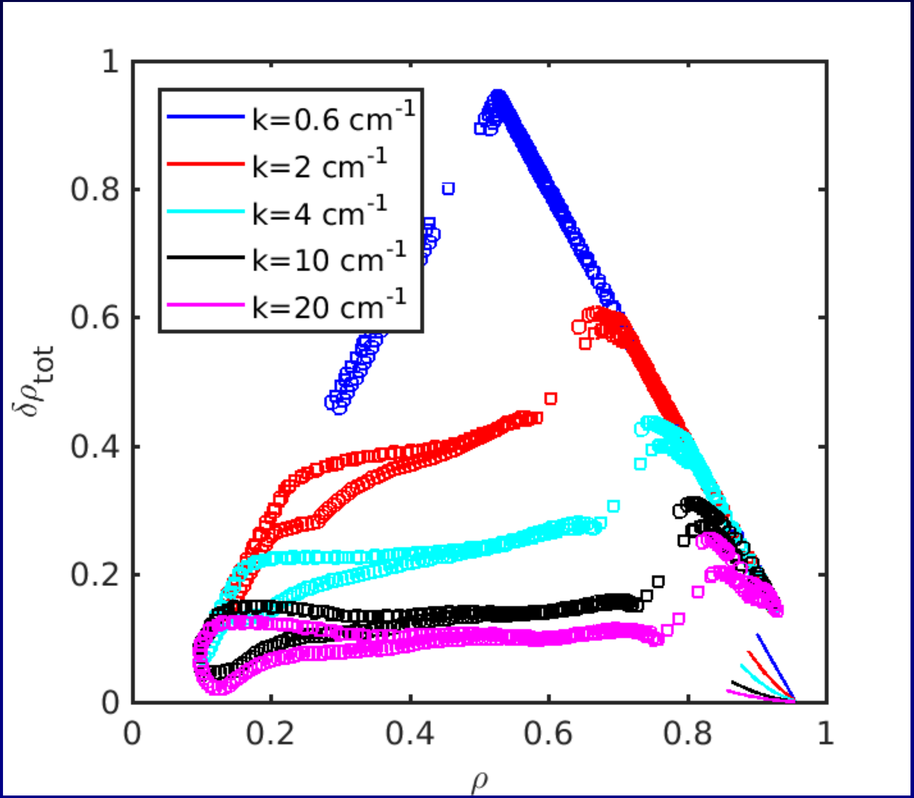

- In JT-60SA, best spatial localization is achieved near the magnetic axis and in the pedestal (on the HFS)

# PCI port choice

The inclined option is **needed** to avoid running into inner wall

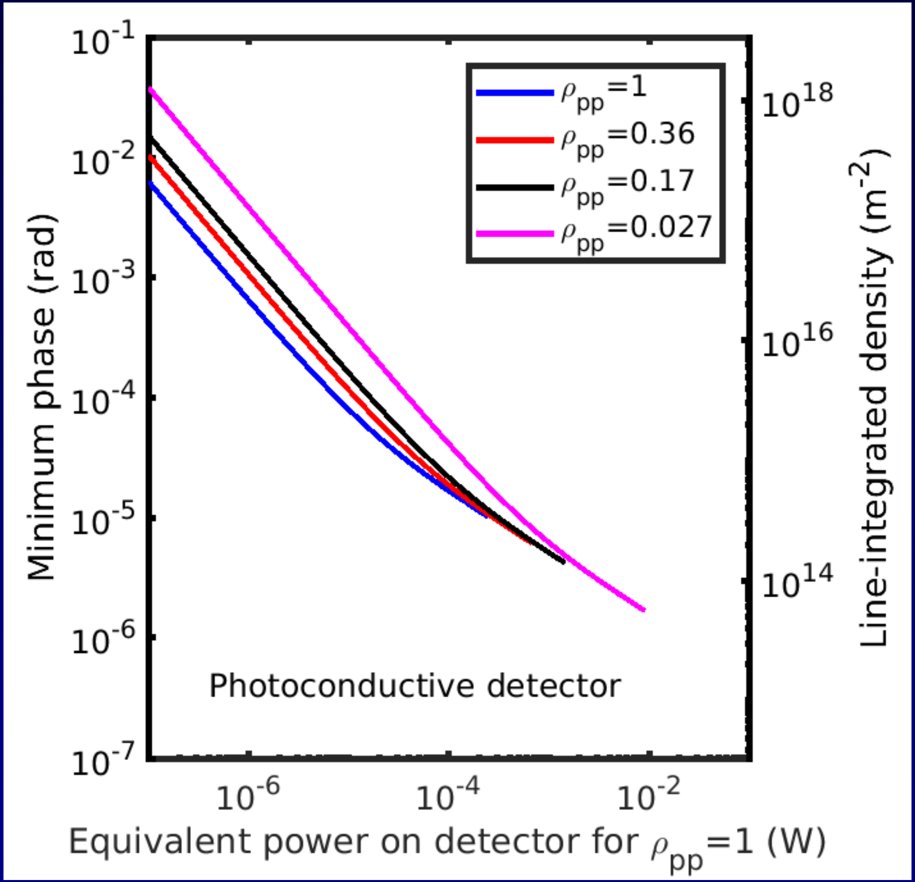


# Localization improves with increasing k




**k** direction:
predominantly $k_\rho$ in center,
$k_\rho$ and $k_\theta$ in two separate edge measurements

# Sensitivity is crucial

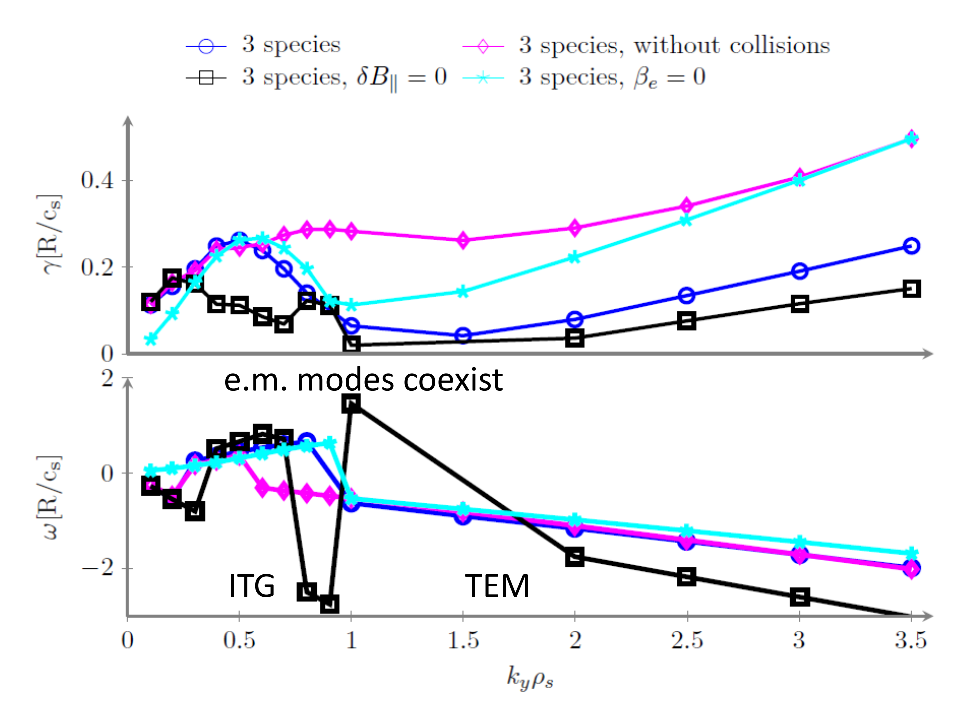



Depending on integration length, densities as low as $10^{15}$ $m^{-3}$ can be measured

# Gyrokinetic modelling (GENE)

Linear analysis shows importance of retaining full physics, including impurities, collisions, e.m. effects

ETG appear minor in this scenario




A. Iantchenko et al, paper in preparation

# Gyrokinetic modelling (GENE)

## Synthetic diagnostic for direct comparison with data