Centre for Energy Research

Fusion Plasma Physics Department

Beam Emission Spectroscopy

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Please note:

The Hungarian fusion team is **not Wigner RCP** anymore.

We belong to **Centre for Energy Research** (”EK” for short, www.ek-cer.hu/en).

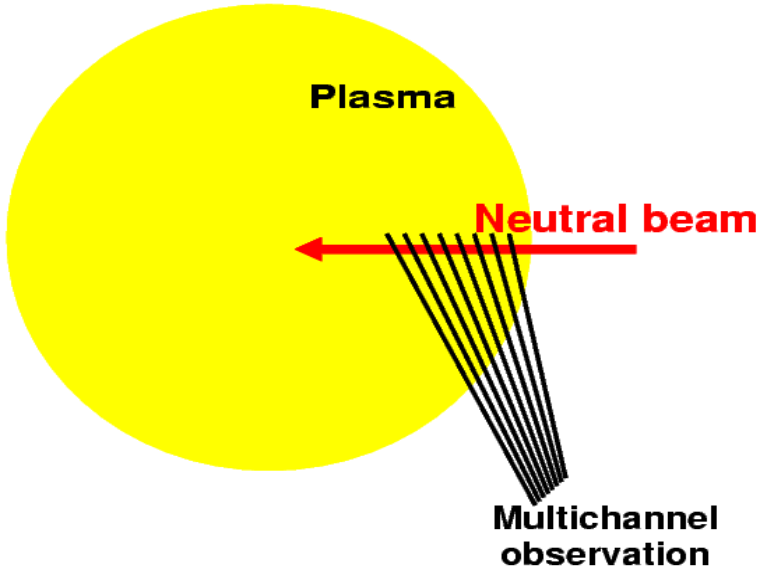
EK is also the EUROfusion beneficiary from FP9 onwards.

EK is made up of the *Atomic Energy Research Institute* (AEKI), the *Institute of Technical Physics and Materials Science* and the *Institute for Energy Security and Environmental Safety*.

Our team is the **Fusion Plasma Physics Laboratory** (department) in AEKI.

Beam Emission Spectroscopy

- Collisionally-excited, Doppler-shifted neutral beam fluorescence (visible range)
- ~cm spatial and ~µsec temporal resolution aimed



Two main types

Narrow alkali diagnostics beam

- Few cm width
- Limited penetration (SOL, edge)
- Non-perturbative diagnostic
- Installed on: **JET, AUG, W7-X, KSTAR, EAST, Compass**, **DIII-D**

Applications:

Density profiles up to 100 kHz

Turbulence – SOL and edge

Flows

Fast transient events – ELMs, ELM filaments, LH transition

High power wide heating Deuterium beam

-15-40 cm width

-Deep penetration (core, edge)

-Only beam heated plasma scenarios

- Installed on: **MAST, KSTAR, EAST, DIII-D, LHD, NSTX**

Applications:

2D Turbulence imaging - core and edge

Flows

Fast transient events – ELMs, ELM filaments, LH transition

BES on JT60SA - History

JT60U –

lithium beam was installed and operated – local expertise and interest,

possibly hardware elements

Heating beam BES – turbulence imaging was not installed

Diagnostics feasibility studies for Alkali beam and Heating beam Beam Emission Spectroscopy diagnostics were completed in 2016

The design activity was continued with less effort, but more or less continuously

Asztalos et al: Fusion Engineering and Design 123 (2017) 861–864

Several student posters

Synthetic diagnostic development

Alkali beam - status

JT-60SA team has experience with LI beam operation
Lithium beam is in the Research plan

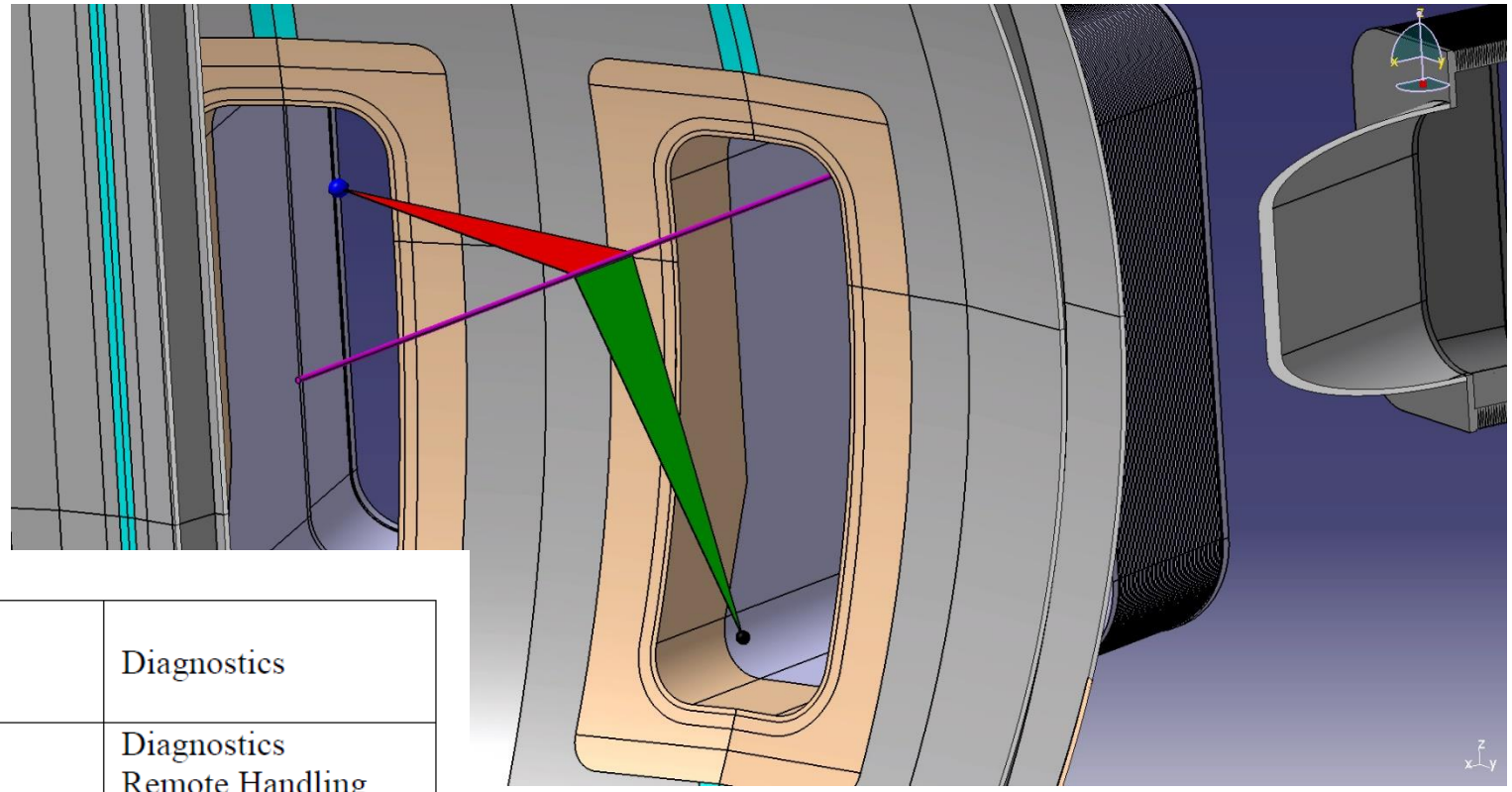
Table D-3: Edge, SOL, Divertor measurements in JT-60SA

Measurement	Diagnostic	Range or Coverage	Time resolution	Spatial resolution or Wave No.	Accuracy	Target
Electron density profile (pedestal / SOL)	YAG laser Thomson scattering system (pedestal)	0.7<r/a<1.1	~ ms	~5 mm	~5%	Type I ELM (f_{ELM} ~10-100 Hz) <1/10 dped
Electron density profile (pedestal)	Li-beam probe	0.8<r/a<1.1	0.01 ms	~1-5 mm	<15%	Type I & grassy ELM (f_{ELM} ~10-500 Hz) <1/10 dped

Japanese conceptual study has been done utilizing the old JT-60U system
Input and information was kindly provided by K. Kamiya in 2015:
It is planned to be developed after the first plasma (2-3 years later)
If there is sufficient fund EU could proceed to the detailed design

Alkali beam – Results of the feasibility study

Green Observation geometry: - Horizontal injection scenario (proposed) P-18
Red Observation geometry: - Toroidal observation scenario (proposed by EK) P-17
2D measurements would be possible

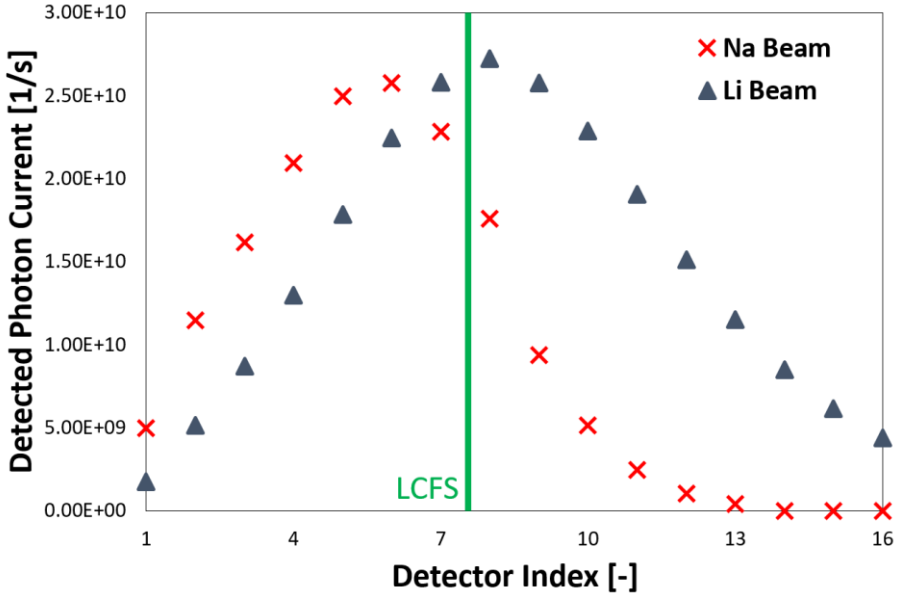


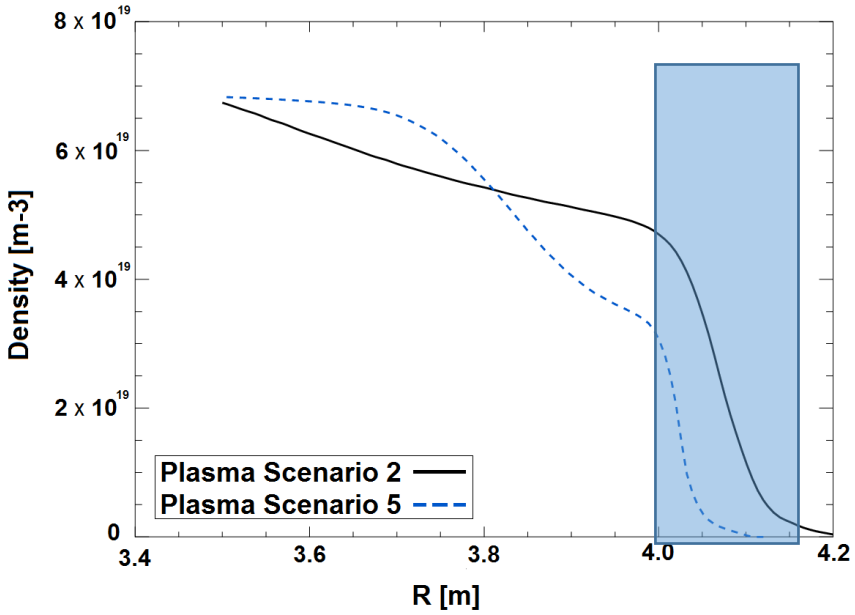
P17	Upper Horizontal Lower	Zeff monitor, MSE	Diagnostics
P18	Upper Horizontal Lower	Bolometer Remote Handling/ Neutron monitor (in port), IR/Visible periscope (divertor), Li-beam probe, Reflectometer Boron gas introduction	Diagnostics Remote Handling Diagnositcs Vacuum Vessel

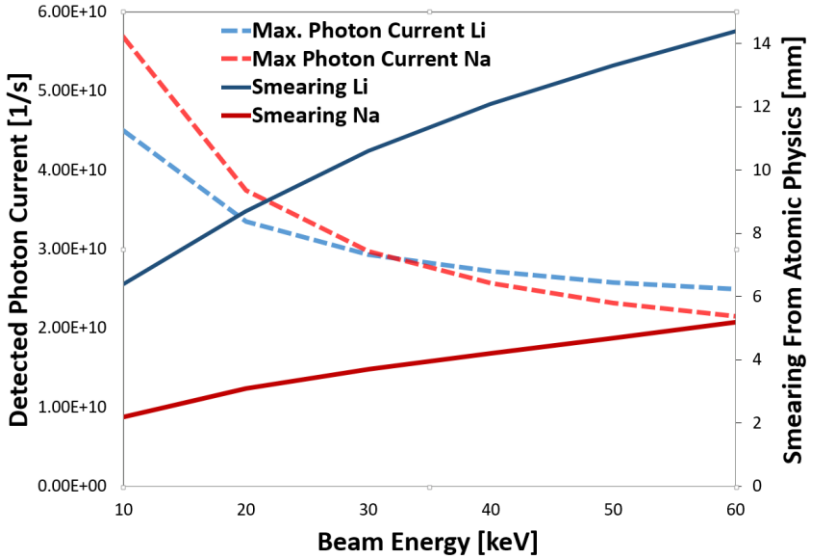
Alkali beam – Results of the feasibility study

Sufficient light for a decent alkali beam diagnostic

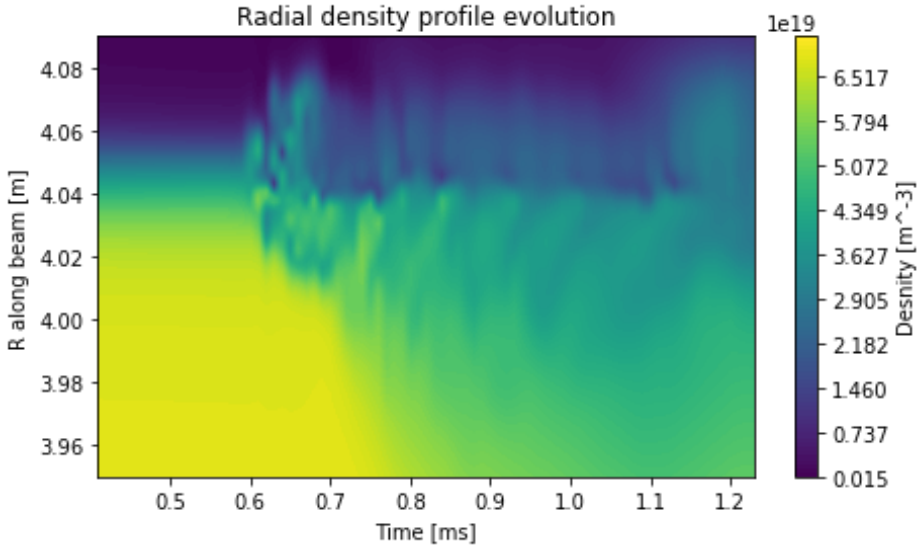
- Using EAST/W7-X beam parameters
- Both Na and Li beam is viable
- Fast profile reconstruction is possible with advanced beam modulation system

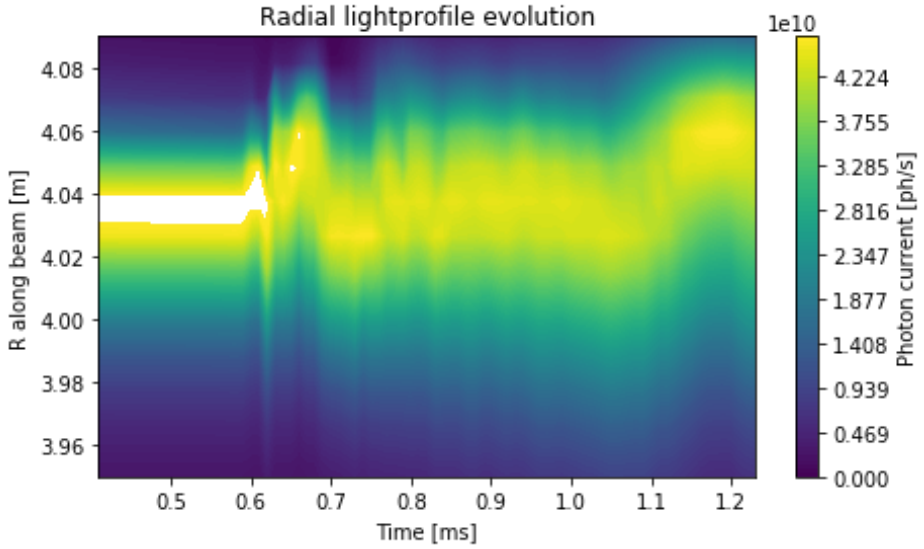




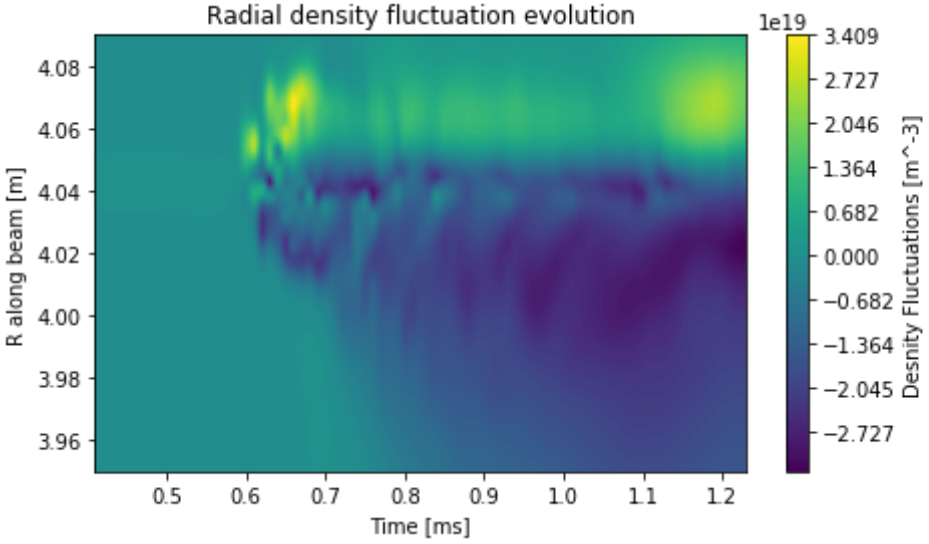


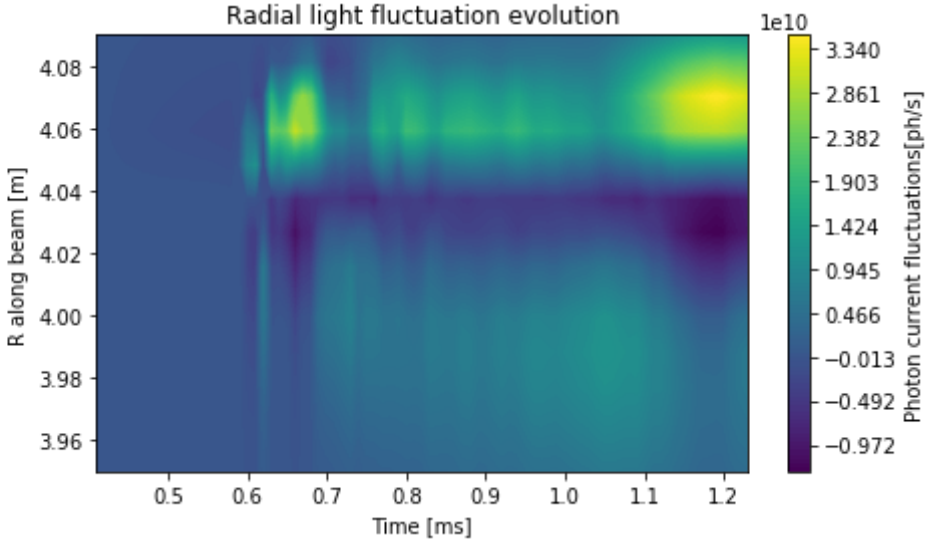
Alkali beam – Physics applications – 2019/2020

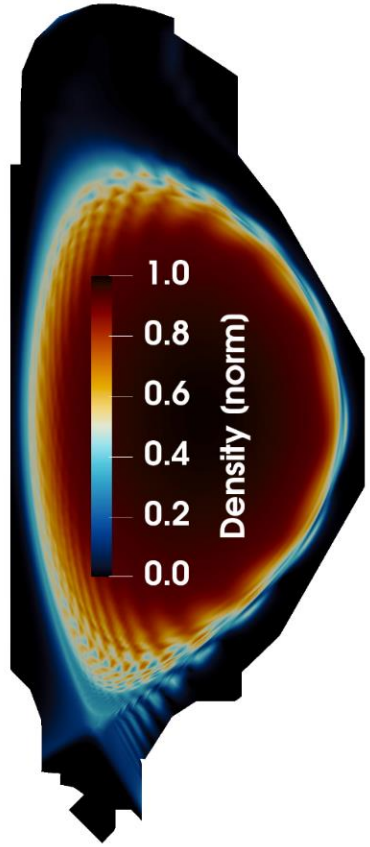




- **ELM simulation with Jorek – pedestal can be resolved as well as the fluctuations**



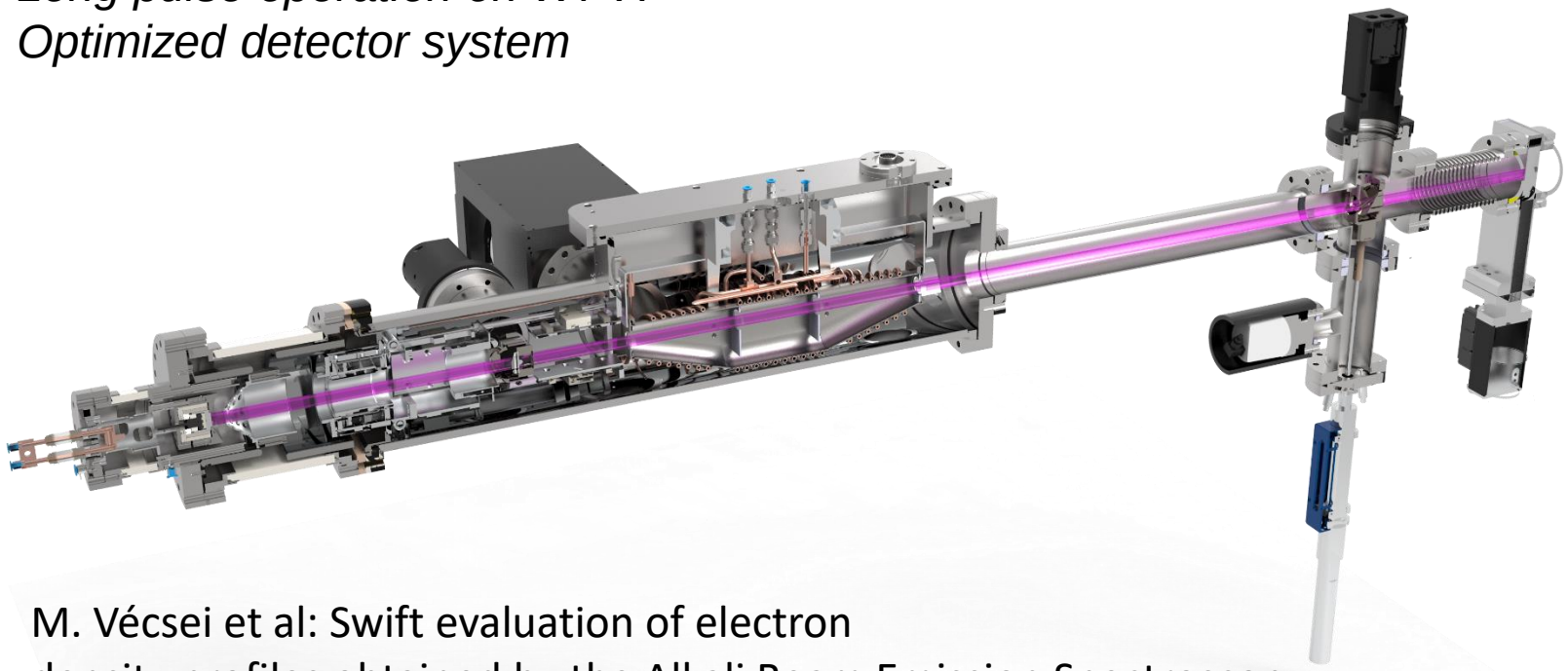


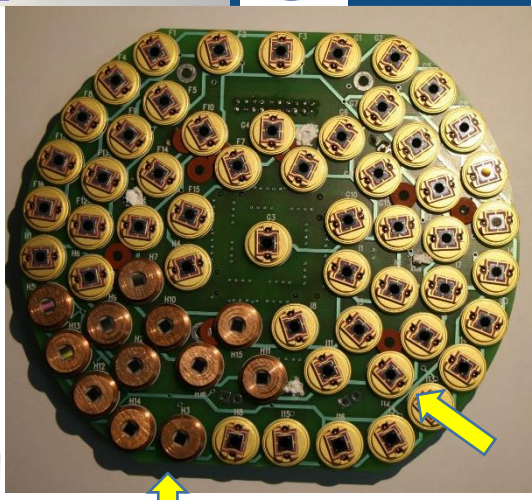


Ors Asztalos,
Stanislas Pamela

Advances in alkali beam technology

Compact design
Upgraded control system
Synchronized beam modulation and observation system
Long pulse operation on W7-X
Optimized detector system





M. Vécsei et al: Swift evaluation of electron density profiles obtained by the Alkali Beam Emission Spectroscopy technique using linearized reconstruction, submitted to Plasma Physics and Controlled Fusion

Real-time reconstruction can also be feasible, if it is required.

5 full systems (injector+observation) built in last 10 years:
COMPASS, KSTAR, EAST, W7-X, ASDEX Upgrade

Advances in alkali beam technology

Alkali beam planned activities: status check on JT-60SA side

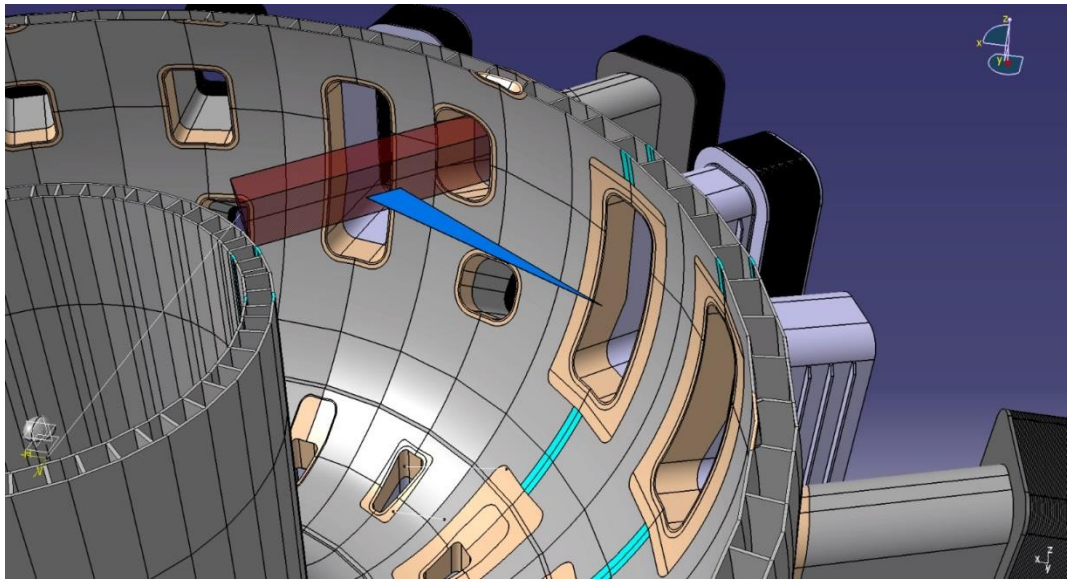
- Discuss the results of the feasibility study with Japanese experts
- Lithium or Sodium beam?
- Which observation port?
- Observation system constraints?
- Our beam or their beam?
- Update the synthetic diagnostics results with the latest modelling results. Which scenarios should we use now?
- Physics driven diagnostics modelling – JOREK and HESEL (SOL turbulence)
- Update a possible project plan and costs

- Deliverables could depend on the answers.

Deliverable – update the feasibility study with the latest scenario calculations
Update the feasibility study with synthetic diagnostics results from JOREK (may be from HESEL)
Project plan and cost estimate for an alkali beam diagnostic
Update the research plan based on the results of the feasibility study

Any step from feasibility to conceptual study requires a few answers and decisions

D-BES – Set-up 8B beam on port 16. Observation on P-17



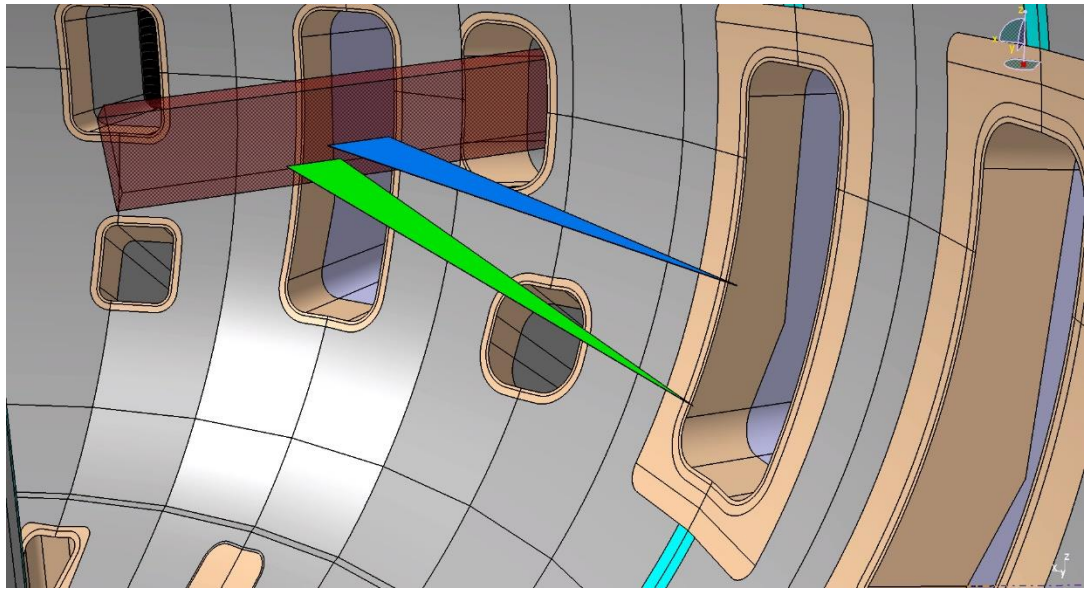
The BES needs large first mirror to collect sufficient light.

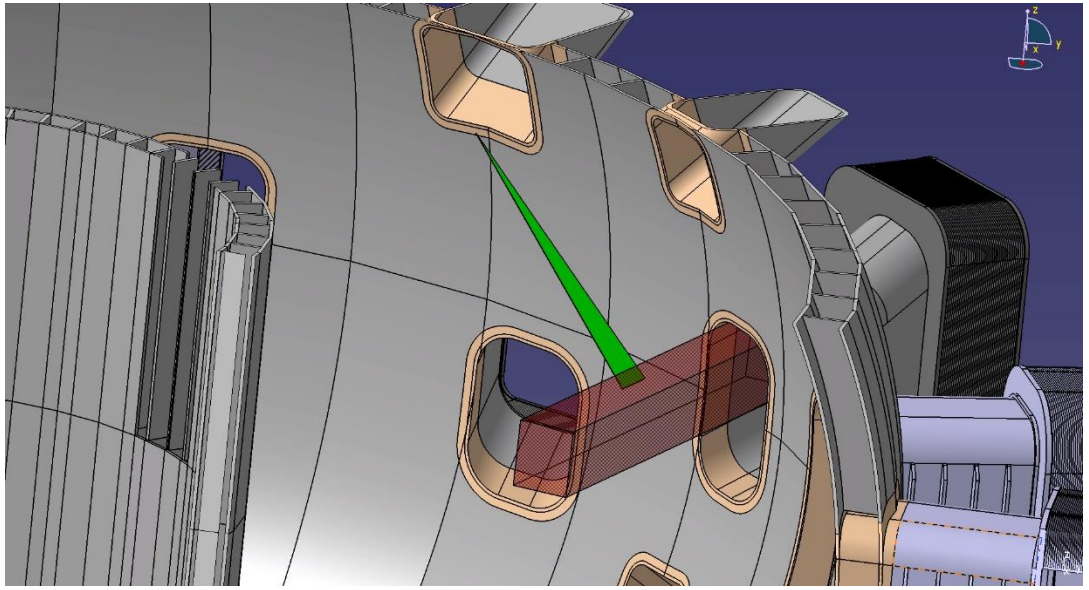
P17	Upper	Cooling water	In-vessel
	Horizontal	Motional Stark effect polarimeter In-vessel coil feeder	Diagnostics In-vessel
	Lower	Cooling water, Liquid He for cryopanel	In-vessel
P18	Upper	Bolometer	Diagnostics
	Horizontal	Remote Handling Neutron monitor, Infrared TV camera (divertor) (TBD), Visible TV camera, Bolometer, Li-beam probe (TBD),	Remote Handling Diagnostics

Table 5-3 List of required turbulence diagnostics

Measurement	Diagnostic	System	k range	Coverage	Spatial resolution	Issues
density fluctuation	Phase contrast imaging	Use the beam of tangential viewing CO_2 laser interferometer	$k\rho_s$=0.1-1 (ITG, TEM, Micro tearing)	Core - Edge	The simplest version is line integrated. Modest local measurements ($\delta\rho$=0.1-0.5) may be possible using a magnetic shear	Effect of mechanical vibration, interpretation of spatially integrated data
density fluctuation	Microwave scattering	Use a heating gyrotron	$k\rho_s$=5-10 (ETG)	Core	Local measurements ($\delta\rho$~0.1) are possible using a tangentially injected microwave	ECE back ground noise, stray radiation
density fluctuation and coherent Er fluctuation from poloidal velocity fluctuation	Microwave reflectometry	Use a diagnostic microwave sources	$k\rho_s$=0.1-1 (ITG, TEM, Micro tearing)	Core - Edge (mainly)	<1cm depending on the density and magnetic field scale length	Requirements of several sources to get spatial distributions
density fluctuation and coherent Er fluctuation from poloidal velocity fluctuation	Beam emission Spectroscopy	Use a heating neutral beam	$k\rho_s$=0.1-0.5 (ITG, Micro tearing)	Core - Edge	~1 cm	SNR for turbulence measurements
density fluctuation	Lithium beam probe	Use a diagnostic beam	$k\rho_s$<0.1 (ITG, Micro tearing)	Edge	Several cm	SNR for turbulence measurements
electron temperature fluctuation	Correlation ECE	Use a heterodyne radiometer	$k\rho_s$<0..5 (ITG, Micro tearing)	core	~1 cm	SNR for turbulence measurements

Feasibility Study results





Synthetic diagnostics was developed to calculate the achievable diagnostic quality to any beam any observation position.
There are possible options for a BES diagnostics
A less optimal position could be still sufficiently good for only edge or core measurements
Physics driven requirements are needed:
What is not good for ITG turbulence can be still OK for larger structures (ELM precursor, MHD modes, etc.)
This is a relatively simple diagnostics.

Heating beam planned activities: status check on JT-60SA side

- Discuss the results of the feasibility study with Japanese experts
- Which observation port is realistic?
- Observation system constraints?
- Which scenarios use the observed beam?
- Update the synthetic diagnostics results with the latest modelling results. Which scenarios should we use now?
- Physics driven diagnostics modelling – JOREK and GENE?
- Update a possible project plan and costs

- Deliverables could depend on the answers.

Deliverable – update the feasibility study with the latest scenario calculations
Update the feasibility study with synthetic diagnostics results from JOREK (may be from GENE)
Project plan and cost estimate for a turbulence imaging BES diagnostic
Update the research plan based on the results of the feasibility study

Any step from feasibility to conceptual study requires a few answers and decisions

FLAP: Fusion Library of Analysis Programs

FLAP

- a program suite for processing large multidimensional datasets
- Originally developed for turbulence and fluctaution analysis
- developed by EK, Python 3.7 + numpy + matplotlib
- core FLAP and data access methods are separate
- filter, slicing, APSD, CPSD, CCF, conditional averaging, …
- plots for 1D, 2D, 3D data objects, slices of objects
- available on GitHub: https://github.com/fusion-flap

Thank you for your attention!