Overview of Ion Source Characterization Diagnostics in Indian Test Facility (INTF)

M Badyopadhayay, Dass Sudhir Kumar, M. Bhuyan, J. Soni,H. Tyagi, J. Joshi, A. Yadav, C.Rotti, Deepak Parmer, H. Patel, S. Pillai ,A.Chakraborty, DNB & NINB Team.

ITER-India, Institute for Plasma Research,A-29,GIDC-sec-25 Gandhinagar, Gujarat, 382016, India.

16th International Conference on Ion Sources,23-28 August-2015, New York USA

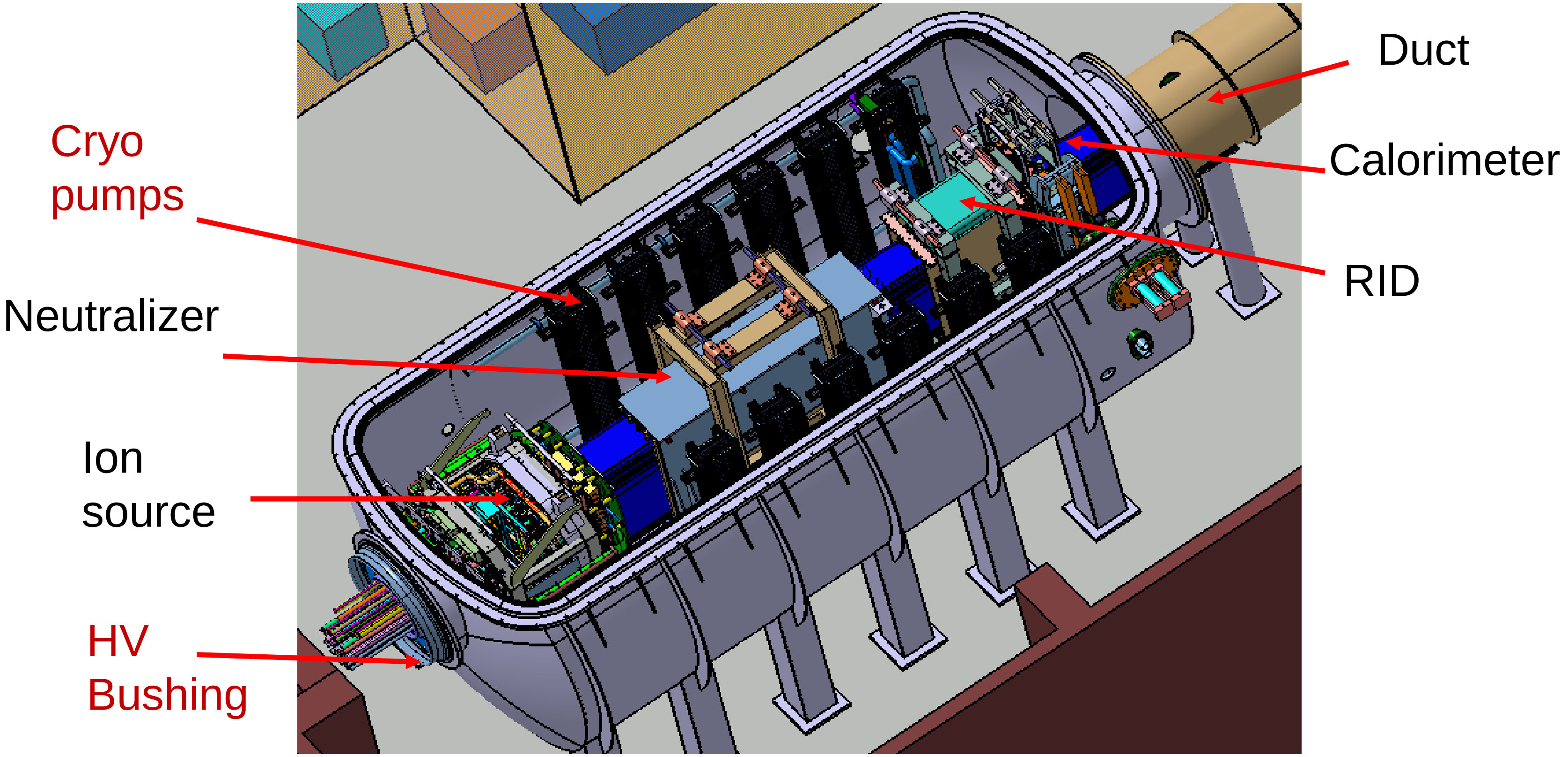
Contents

- **Introduction to INTF**
- **Diagnostics for INTF to characterize Beam Source and corresponding beam**
  - Cavity Ring Down Spectroscopy
  - IR Thermal imaging
  - Probe based diagnostic in Ion source
  - Plasma characterization by RF
  - Doppler Shift Spectroscopy
  - Beam profile with Calorimeter
  - Optical Emission Spectroscopy
  - Beam Tomography.
  - Tungsten Wire Mesh
- **Summary**

Introduction to INTF

Negative Hydrogen Ion source of dimensions **~1.6m * 0.6m,** beam energy of **100kev** & **60A** of extracted & accelerated current.

Beam has to travel **20.67 m** with compatible beam line components. with pulse length of **3s ON-20s OFF** with **5Hz** modulation for **1 Hr.**



The mandate of INTF is to characterize the ITER-DNB beam with full specification

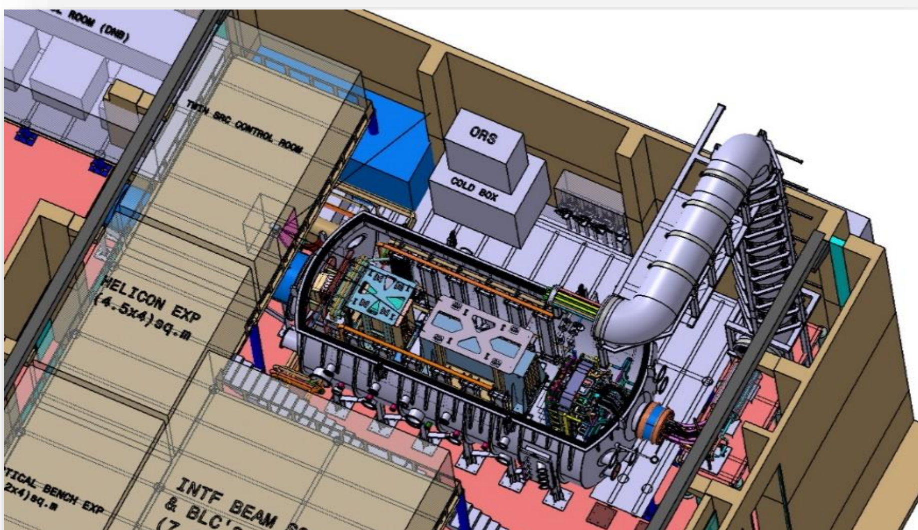
ITER-India

Introduction to INTF(contd)

प्लाज़्मा अनुसंधान संस्थान
Institute for Plasma Research

INTF is a serious effort from IN-DA to test DNB and to explore in the R&D, one of the most important challenges in ITER.

- NBI test bed **(~ 24 m)** with longest beam length =**20.67m**
- BS (to be characterized before sending to ITER) operation.
- Test power supplies using **CODAC** type platform.
- Floor area : **~ 350 m^2** *(Excluding PS area)*
- **1:1** sized BLCs are prototype.
- Vacuum vessel: Cylindrical **ϕ ~ 4.5m**, **L ~ 10 m**
- Duct size: Conical cylindrical **L~13m**
- Pumping system: **12** modular cryo-sorption pumps.



DNB issues - INTF objectives & mandate

The challenges involved in DNB delivery include,

1) **60A** extracted and accelerated H- ion current.

→ **Efficient H- source; Low Stripping** → **Source optimization**

2) Transport for **20.665 m** from the grounded grid of the ion source with **low divergence.**

→ **Excellent accelerator system.** → **Accelerator optimization**

Transport also depends on,

a. **Filter field** effects on beamlet dispersion and deflection.

b. **Bending of grid segments due to expansion** under heat loads.

c. **Beam focussing mechanism** using geometric aiming and aperture offset in presence of PG filter field and space charge repulsion.

3) Integrated beam operation with **Power supplies** using **CODAC** type platform.

4) **Minimum diagnostics to reduce maintenance in nuclear environment in ITER.**

Role of INTF Diagnostics

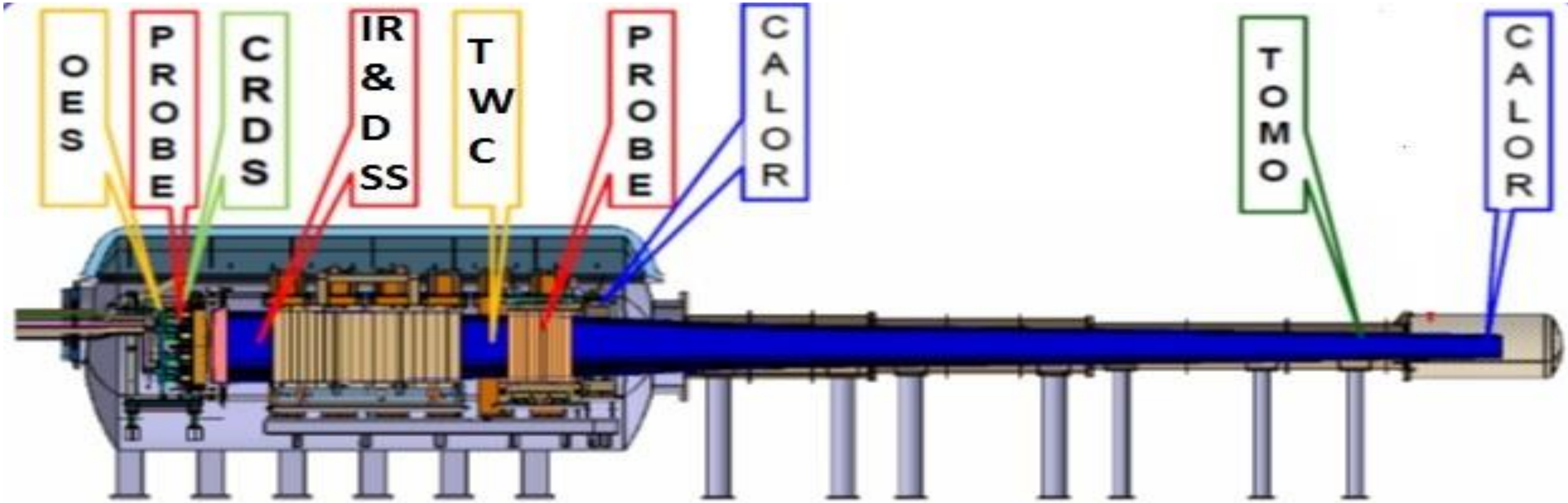
- **Objective of INTF diagnostics:**
  - **To identify optimized operational window of the Beam Source through -Control and Characterization**
  - **Monitor for safe operation through interlocks.**
- **Main systems to control for safe operation (*not discussed in the talk*)**
  - **Vacuum and Gas feed system, Cooling water ,Power supply, Cryogenic system.**

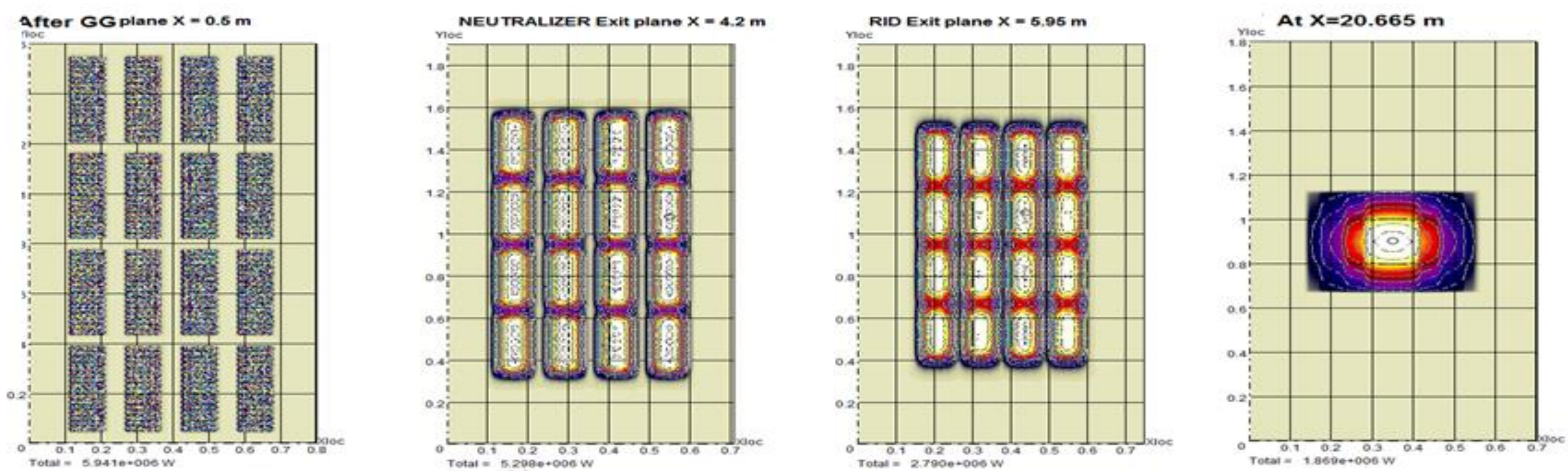
Minimum Diagnostics in DNB (*To reduce Maintenance downtime in ITER*)→ only for protection purpose (electrical, calorimetric and thermocouple based)

- **Beam characterization need to carried out in test bed before being delivered to ITER.**
  1. R&D is required for big negative ion source operation and optimization.
  2. The ion optics for DNB is too complex and its performance @20.67m need to be checked under various operating conditions..
  3. Same would be for the power supplies for integrated operation.

Diagnostics play a big role in INTF

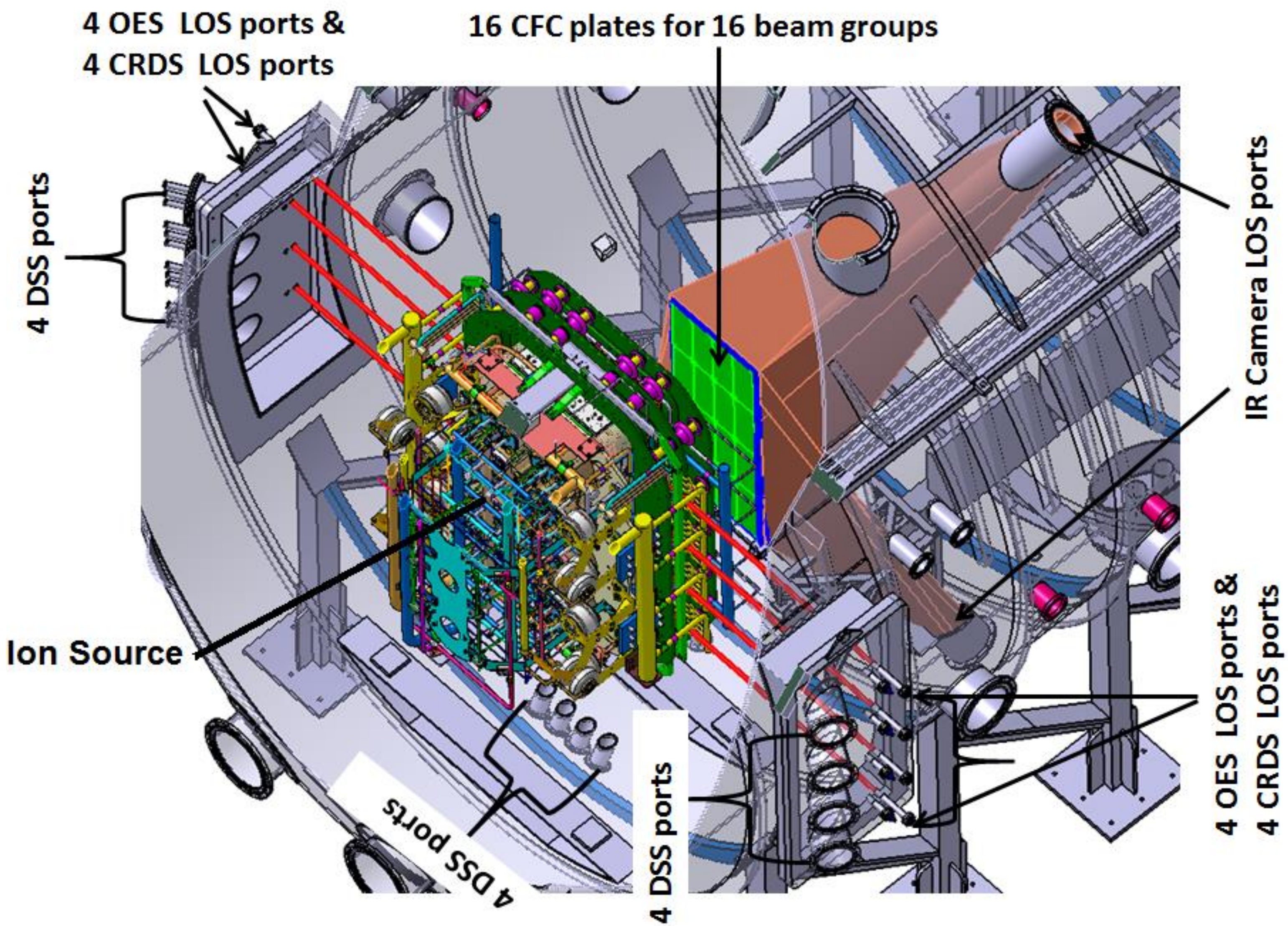
Diagnostics dispersion & Beam foot print





1280 beamlet (4 x 4 beam groups)

Diagnostic line of sights – Beam Source characterization



Diagnostics for Characterization

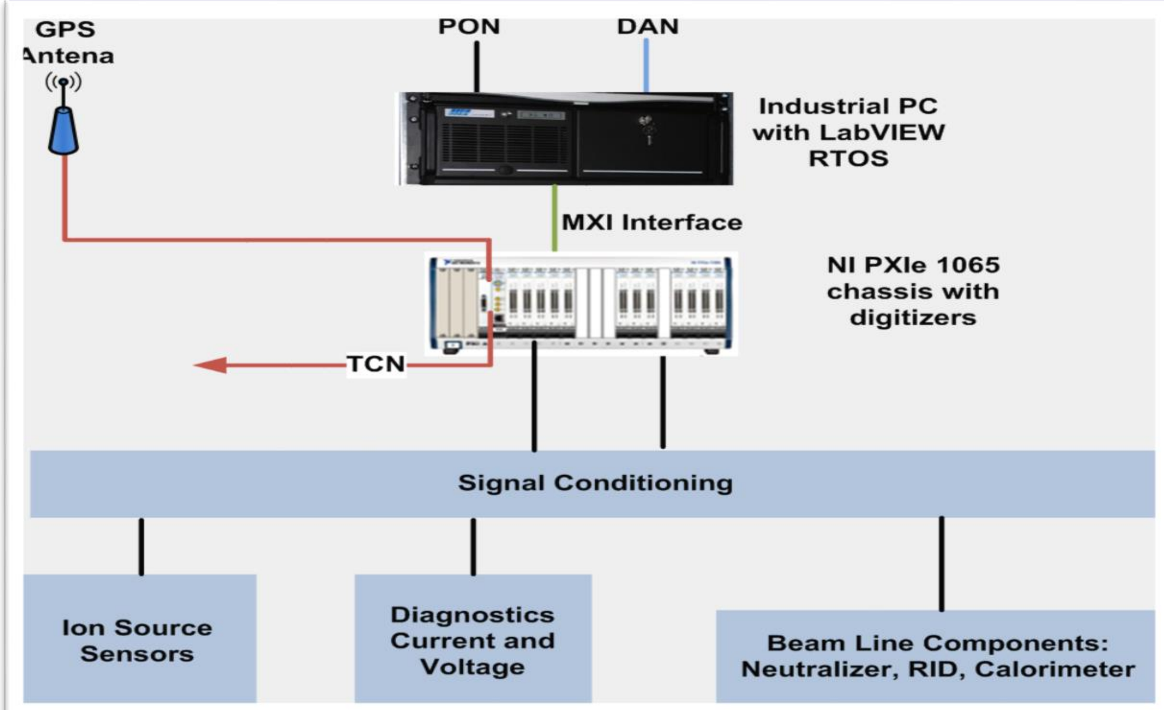
Diagnostics	Location	Measured quantity	Controlled / Monitored parameter
Electrical	• Ion source • RID	• PG current • Bias current. • Probe current. • RID current	• PG filter field. • Co-extracted electron • Plasma density – uniformity • Neutralization efficiency
Optical (Emission, Doppler Shifted, Cavity Ring down)	• Ion source • Beamline	• Balmer lines, Cs line • H-alpha line intensity • CRD signal	• Plasma density and temperature , -ve ion density , Cs density. • Beam energy, div. & stripping
Thermo-couple	V-target	• Surface temperature	• Beam profile
Calorimetry	V-target	• Water temperature	• Beam power
IR Imaging	Perpendicular target	• IR imaging	• Beam profile, beam Divergence & stripping losses
Tomography	• Near Duct	• H-alpha intensity from the beam	• Beam profile Near Duct.

Diagnostics for Monitoring

Diagnostics	Location	Measured quantity	Controlled /Monitored parameter
Vacuum	•Ion source •Vessel	• Gas Press & Flow • Gas composition	•Source plasma parameter. •Neutralization efficiency.
Electrical	•HV deck •Ion source •RID	•Volt. & Current •RF power & matching	•Beam power, uniformity, electron current, focus. • Power on RID panel
Calorimetry	All BLCs, Ion source	•Water temp. • Water flow rate. • Water quality	•Power density. •Beam alignment & uniform • Breakdown level.
Cryo	Cryopump	• Cryogenic flow, temp & Pressure	• Cryopump temp. • Heat load on cryo system
Optical	•Ion source •Beam line	• H-alpha intensity • Cs lines.	• RF power coupling. • Cs amount in plasma.
Thermal	•All BLCs • Cs oven	• Surface temp. • Cs oven temp.	•Beam alignment & profile. • Cs inventory.

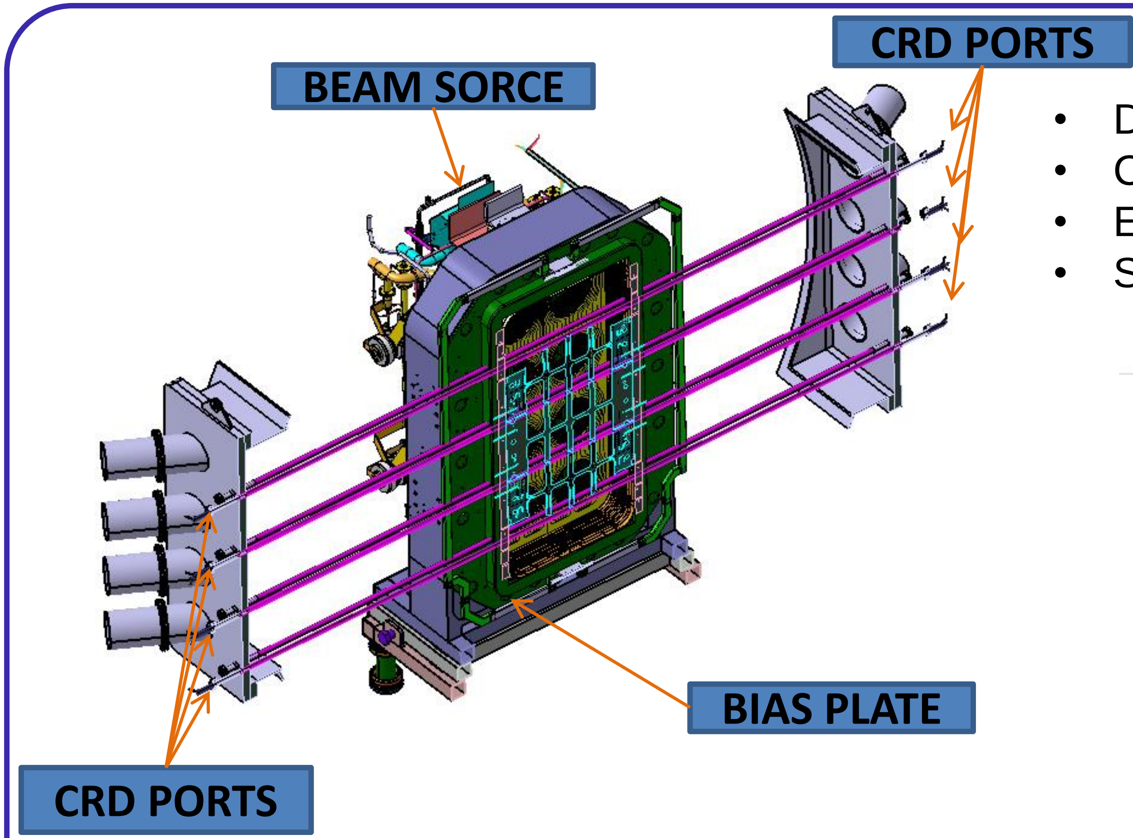
DACS Interface with Diagnostics

	Category of Diagnostics	Interface Method
1	Slow Signals < 20 Sps (e.g. Thermocouples, Pressure transmitters)	Through Siemens S7 plcs, software integrated with EPICS and NI 6225 digitizer cards
2	Fast Signals, in range of KSps (Probe diagnostics, Power supply)	NI 6225 Digitizer cards with Labview RT
3	High Speed Event based DAQ in range of 100 MSps (e.g. CRDS)	Specific hardware from CAEN , integrated with central DACS



Diagnostics System	Acquisition Requirement	
Source Spectroscopy.	8	1 µs
Beam Spectroscopy	12	1 µs
IR Beam dump	40	100µs- 40ms
IR Camera	4	100 fps
CRDS	8	10 ns
Beam tomography	8	1 µs
Probes	10	1 ms

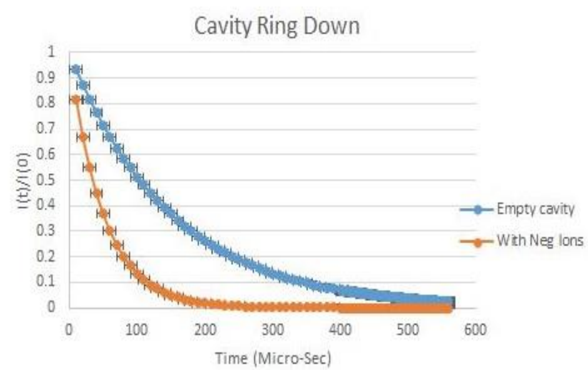
Cavity Ring Down Spectroscopy



ISSUES:

- Deterioration of mirror reflectivity.
- Cavity Misalignment (Vibrations, thermal
- Electrical noise on detection system
- Significant deviation from exp. decay

Line Integrated H-ve Ion density measurement



4 LOS on a vertical plane between Bias-plate and PG.
Each cavity length **~ 5m** with plasma column **0.5m**.
Single **NdYAG** laser beam will be divided into **4** cavity using beam-splitter & bending optics.

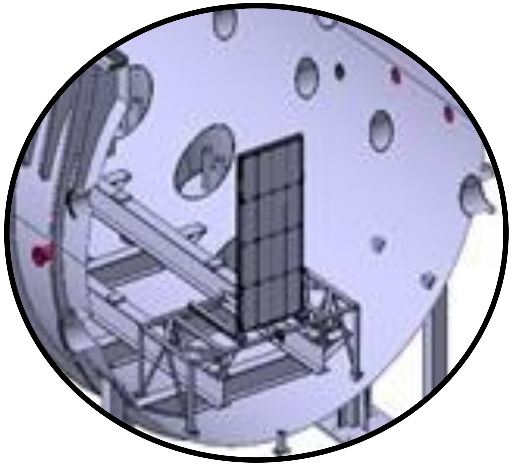
Based on Laser Photo-Detachment Principle $H^- + photon = H + e$

IR Imaging Diagnostics

ITER-India

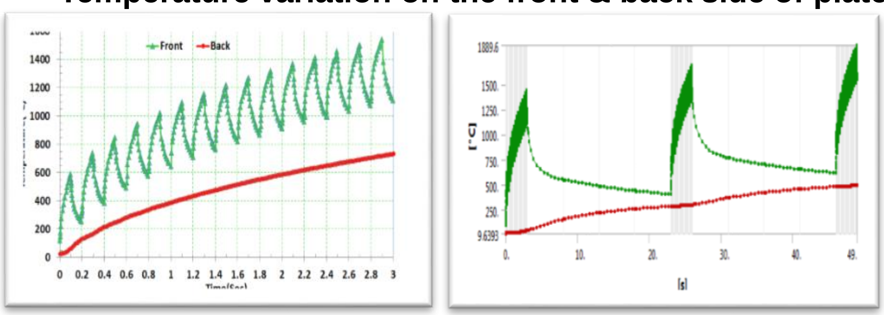
प्लाज़्मा अनुसंधान संस्थान
Institute for Plasma Research

Beam profile & Beam let Divergence for 1280 beam let (in 4 x 4 beam groups)



- The beam dump supposed to handle ~ **6MW** of ion beam power with peak power density ~ **20 MW/m^2** without active cooling.
- The beam dump is proposed to made of **16** carbon fibre composite (CFC) plates.
- Equipped with
  - IR camera,
  - Thermocouple
  - Electrostatic Probe
- Beam profile will be seen from rear side by set of IR cameras → *Overlapping Line of Sight (LOS) for cross-calibration*.

Temperature variation on the front & back side of plate



- Particles impact to dump → Secondary electrons emission → Bias CFC plates

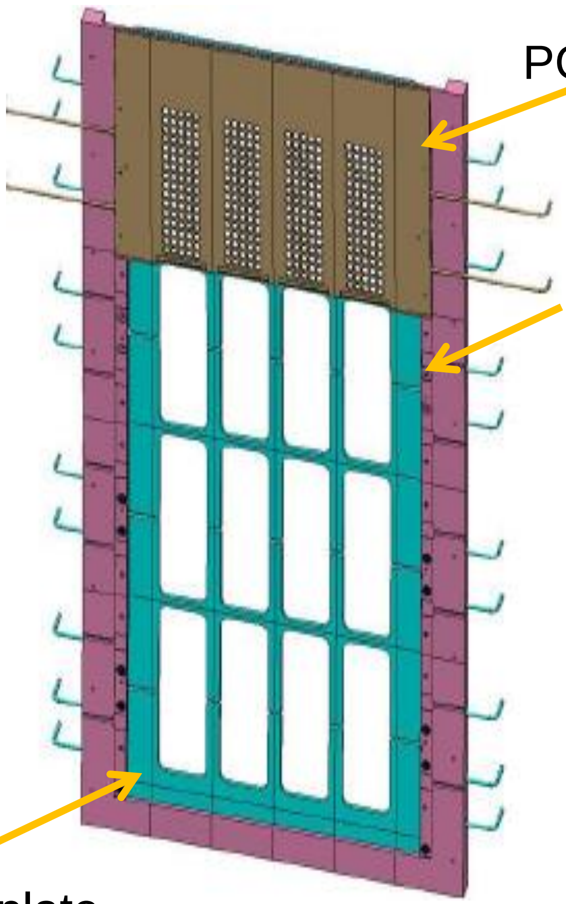
- Beam interaction with background gas

→ Plasma formation near plate → Radiating sheet on front of plate →Impact on visibility → Rear side observation using IR camera (100 to 1500 deg C)

Diagnostics beam dump is optimized using designed by analysis approach, Simulated thermal response of the material under given variable load & material properties.

Electrostatic probes in BS

- ES probes (***Single*** or ***Double*** probe) are separate detachable attachments on ***Bias*** plate.



Doppler shift spectroscopy (DSS)

Preliminary Numbers

Number of Ports & LOS

36 LOS from 12 ports

Doppler spectral shift

for 100 kev beam its ~ 5 nm from 656nm.

Temporal resolution

~1 sec for 1 MHZ ADC and 1024*1024 CCD, Planned to enhance up to 10Hz with binning

Lens Optical Throughput

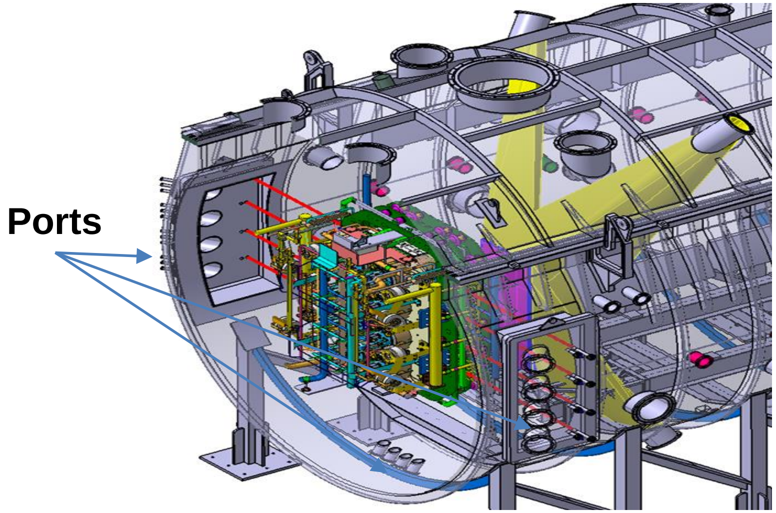
$7.23 \times 10^{-10} m^2 Sr$ at collecting lens of 10mm at 2800mm from source.

Spectrometer throughput

$\sim 3.7 \times 10^{-10} m^2 Sr$ for F no is nearly 750mm it has an entrance throughput that matches reasonably well that of the optical head.

Objectives

Stripping loss of ions *-from stripped ion peak*
Beam divergence*-from line broadening*
Beam uniformity*-intensity comparison from LOS*
Energy distribution of species present *-Doppler shift*
Fraction of species*-Intensity comparison*



View angle w.r.t beam optimized, keeping in mind error in divergence calculation & peak resolution. After trade off angle of 60 degree finalized for DSS.

Plasma characterization by RF electrical parameters

- **Plasma density estimation using electrical parameter in RFG circuit for Inductively coupled plasma sources.**

Plasma loading assuming plasma as single turn secondary to coil.

(Air core transformer model) → plasma density estimation through conductivity tensor

→ Current in coil from calorimetric data of cooling circuit.

Ref- Plasma density estimation of a fusion grade ICP source through electrical parameters of the RF generator circuit
M. Bandyopadhyay, Dass Sudhir and A. Chakraborty, Nuclear Fusion 03, 033017,(2015); DOI: 10.1088/0029-5515/55/3/033017.

- **Physics-Electrical Hybrid Model for Real Time Remote Plasma Characterization & Impedance Matching in RF Plasma Source**

Plasma load using HELIC Code from Dr. Arnush(UCLA) → Power transfer using air core transformer model- → Plasma Density though Power Balance

(Poster presentation in Evening)

Good agreement of calculations with experimental results, Work in Enriching the physics of coupling & minimizing source of possible error on going .

Other Diagnostics

1. **Tungsten Wire mesh calorimeter for qualitative beam profiling.** Tungsten wire thickness design data base created for multiple range of operating power load using thermal analysis.

2. **Neutral Beam Tomography for Beam profiling at duct.** Selection of Inversion algorithm under study.

3. **Optical emission Spectroscopy for plasma & Cs characterization near plasma grid.** Design Ongoing.

Summary

- INTF is an opportunity to explore and overcome the **issues and challenges in ITER - DNB.**
- **Role of Diagnostic in INTF is very important** because ITER does not allow enough diagnostics for characterization.
- Multiple Diagnostics are provisioned for INTF to **characterize Beam Source and corresponding beam**
- In INTF, DNB system including **Power supplies** and **CODAC** based control system will be tested.

Thank you