MPEX Diagnostics

T.M. Biewer, T. Bjorholm, G.T. Boyd, J.F. Caneses, D. Elliott, T. Gray, W. Sides

Oak Ridge National Laboratory

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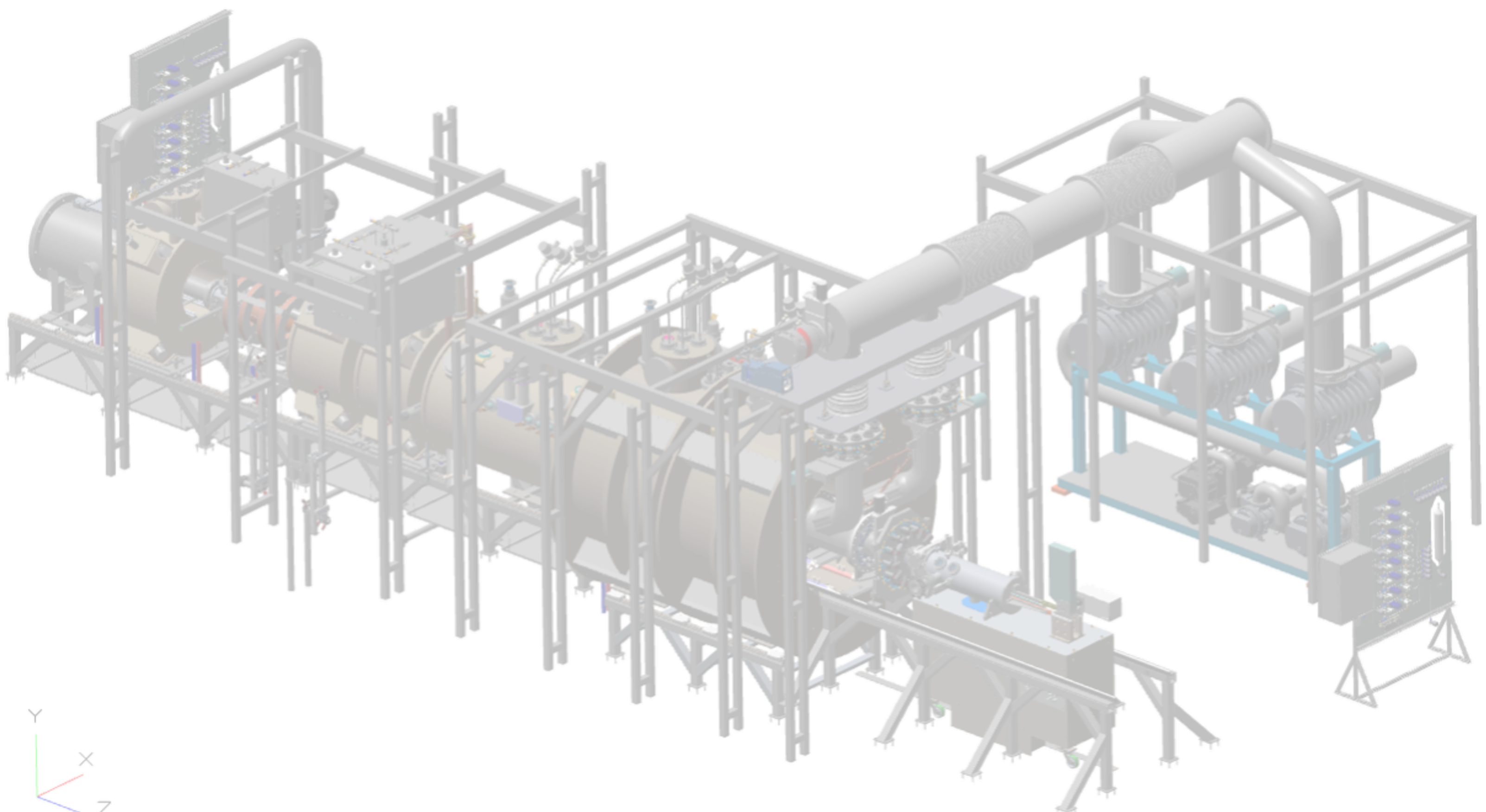
Outline: MPEX Diagnostics (15+5 minutes)

- Design Overview of Diagnostics (10 min)
- Progress since 1st MURF (5 min)
- Summary



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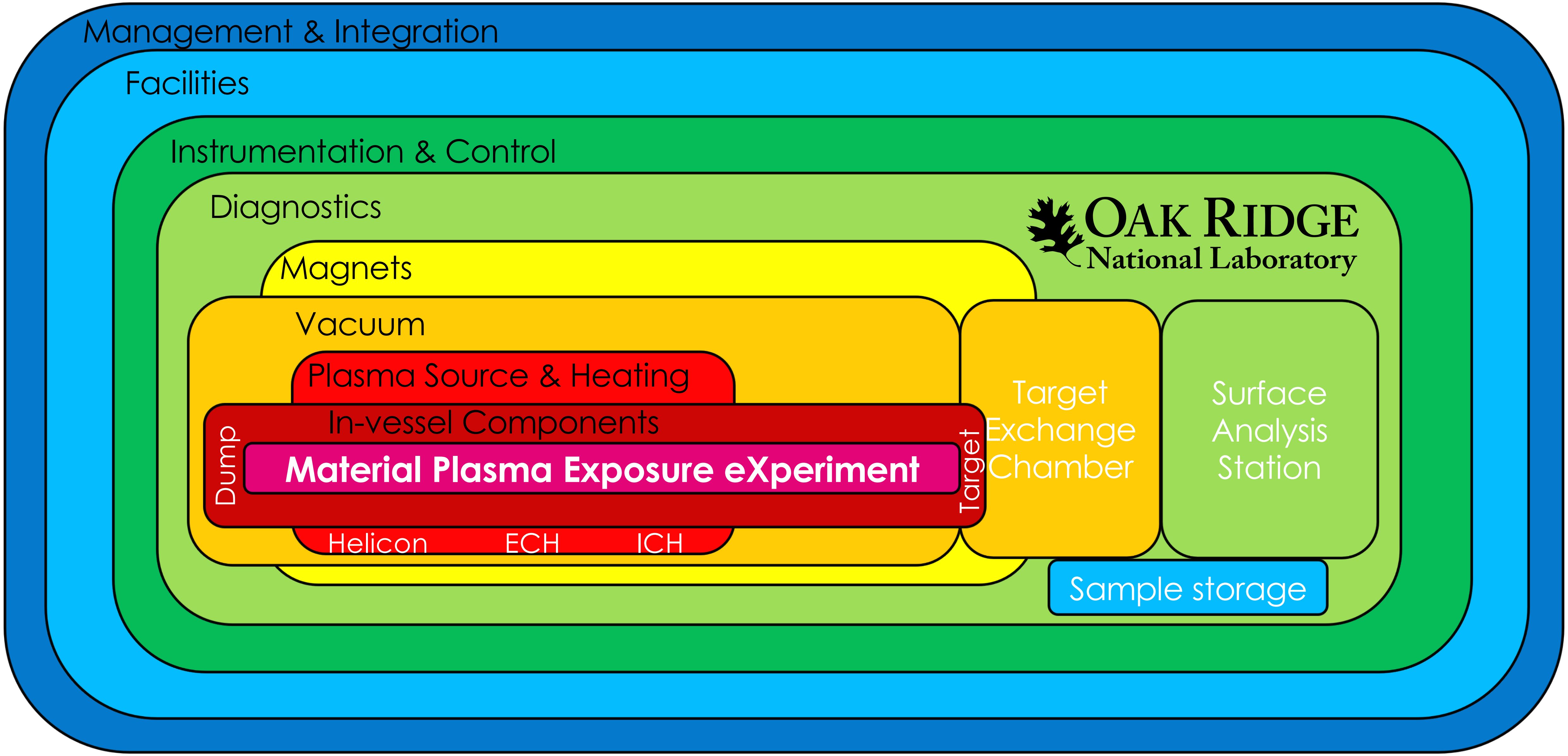
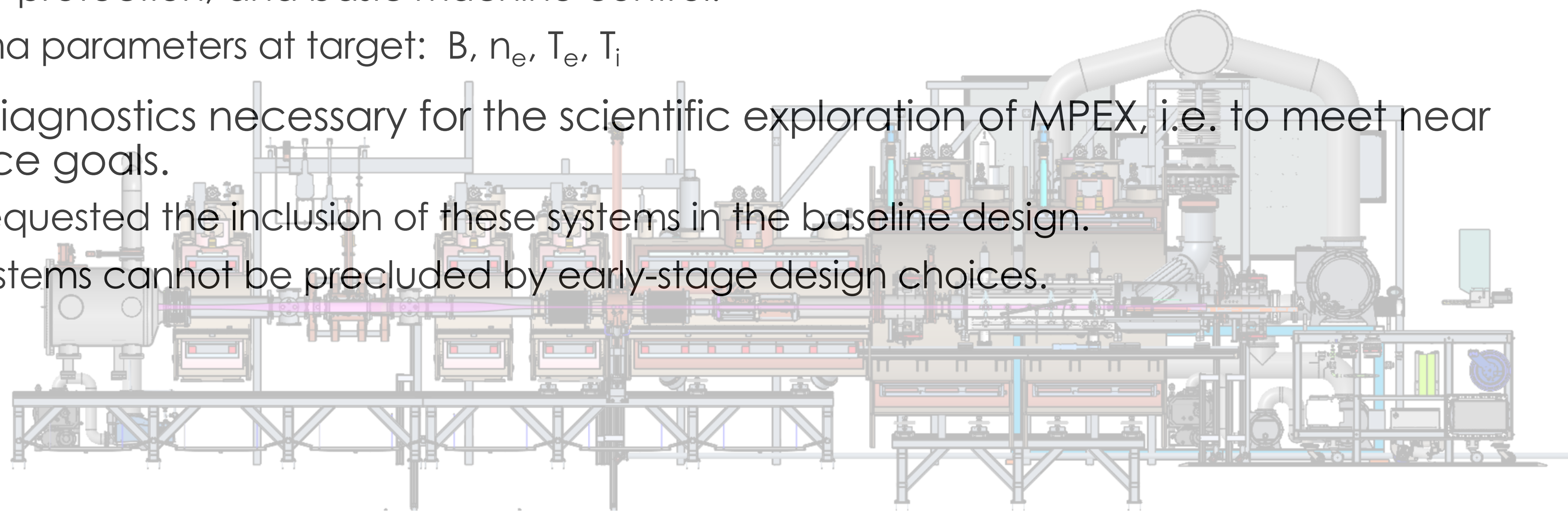
MPEX Project interdependencies



Design Overview of MPEX Diagnostics System

- The Diagnostics Systems cover **all diagnostics for the scientific exploration of MPEX**.
  - machine protection
  - basic machine control
  - advanced plasma control
  - evaluation and physics studies

- **Phase I**: Those Diagnostics necessary to demonstrate “first plasma” milestone
  - Machine protection, and basic machine control.
  - D_2 plasma parameters at target: B, n_e, T_e, T_i
- **Phase II**: Diagnostics necessary for the scientific exploration of MPEX, i.e. to meet near term science goals.
  - D.O.E. requested the inclusion of these systems in the baseline design.
  - These systems cannot be precluded by early-stage design choices.



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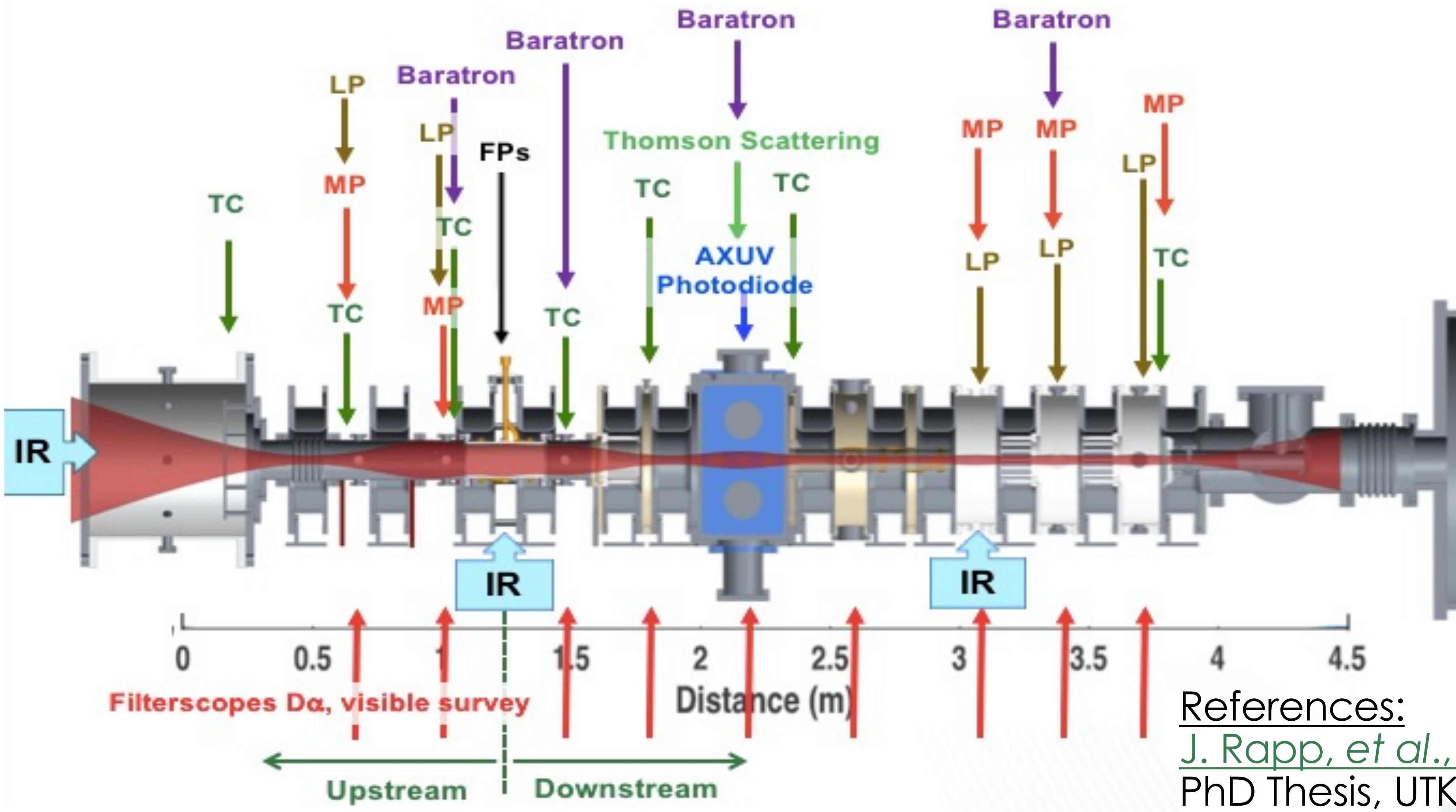
The diagnostic portfolio of Proto-MPEX has been described in a variety of publications and PhD theses.



Legend:
FP = Fluoroptic Probe
IR = InfraRed camera
LP = double Langmuir Probe
MP = Mach Probe
TC = ThermoCouple

AXUV Photodiode
Baratron
Filterscopes
Thomson Scattering

Bolometers
Fast Camera Imaging
Optical Emission Spectro.
SXR Photodiode
μ-wave diodes

References:

J. Rapp, *et al*., Fus Sci Tech, **75**, 654, 2019
PhD Thesis, UTK 2018, M.A Showers
PhD Thesis, UTK 2019, N. Kafle
PhD Thesis, UTK 2020, H.B. Ray
PhD Thesis, UTK 2021, C.J. Beers

Many diagnostics will move from Proto-MPEX to MPEX resulting in significant cost savings for Phase I

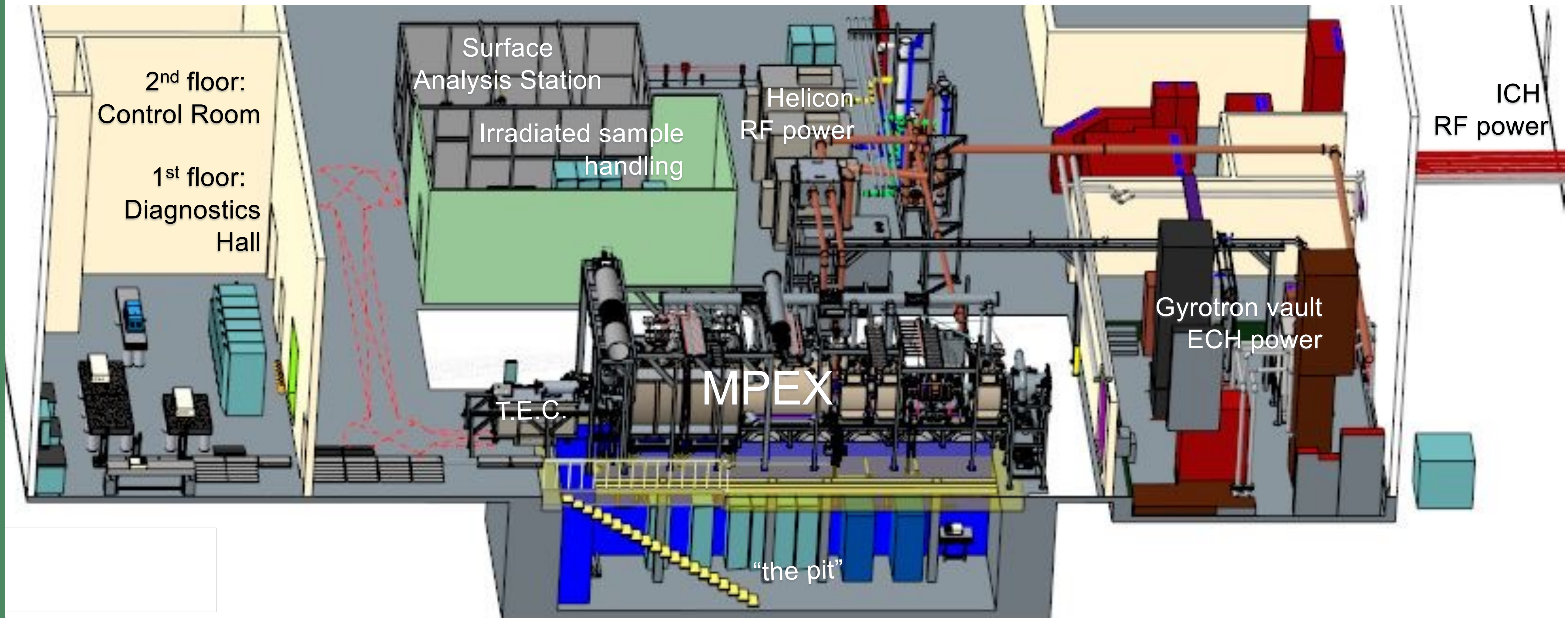
Phase I: "first plasma"

Diagnostic
OES-HiRes
OES-Survey
Baratrons
Thomson Scattering
Pyrometer
Visible Cameras
IR Camera
Filterscopes
RGA
TC/Flouroptics

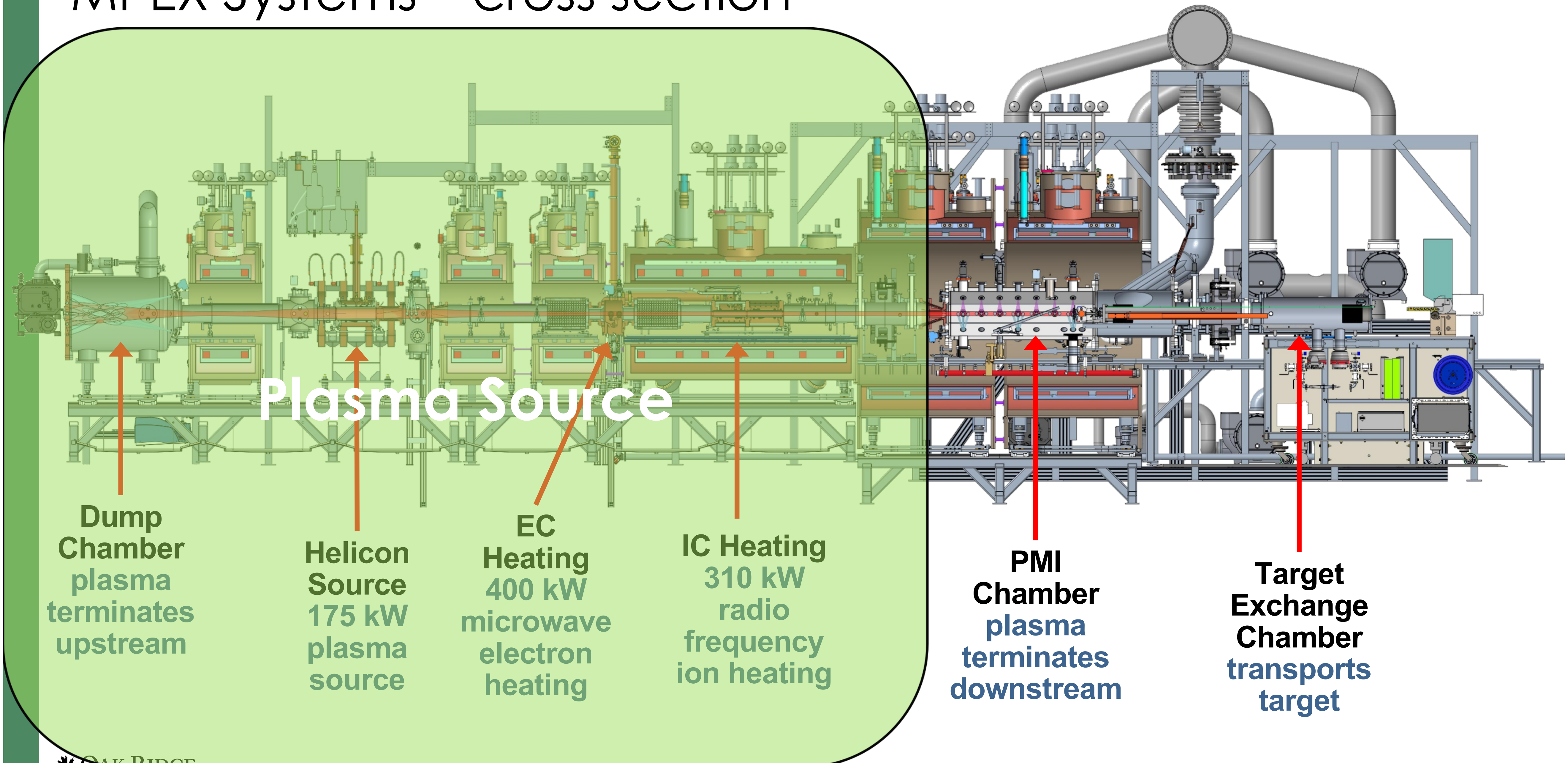
Phase II: to meet science goals

Diagnostic
Surface Analysis Station
Thomson 2, 3
TALIF
CO_2 Interferometer
Bolometers
IR Camera 2, 3, …
Microwave Diodes
AXUV/SXR Diodes
LIBS/LIDS/LIAS

Current Design of MPEX Facility

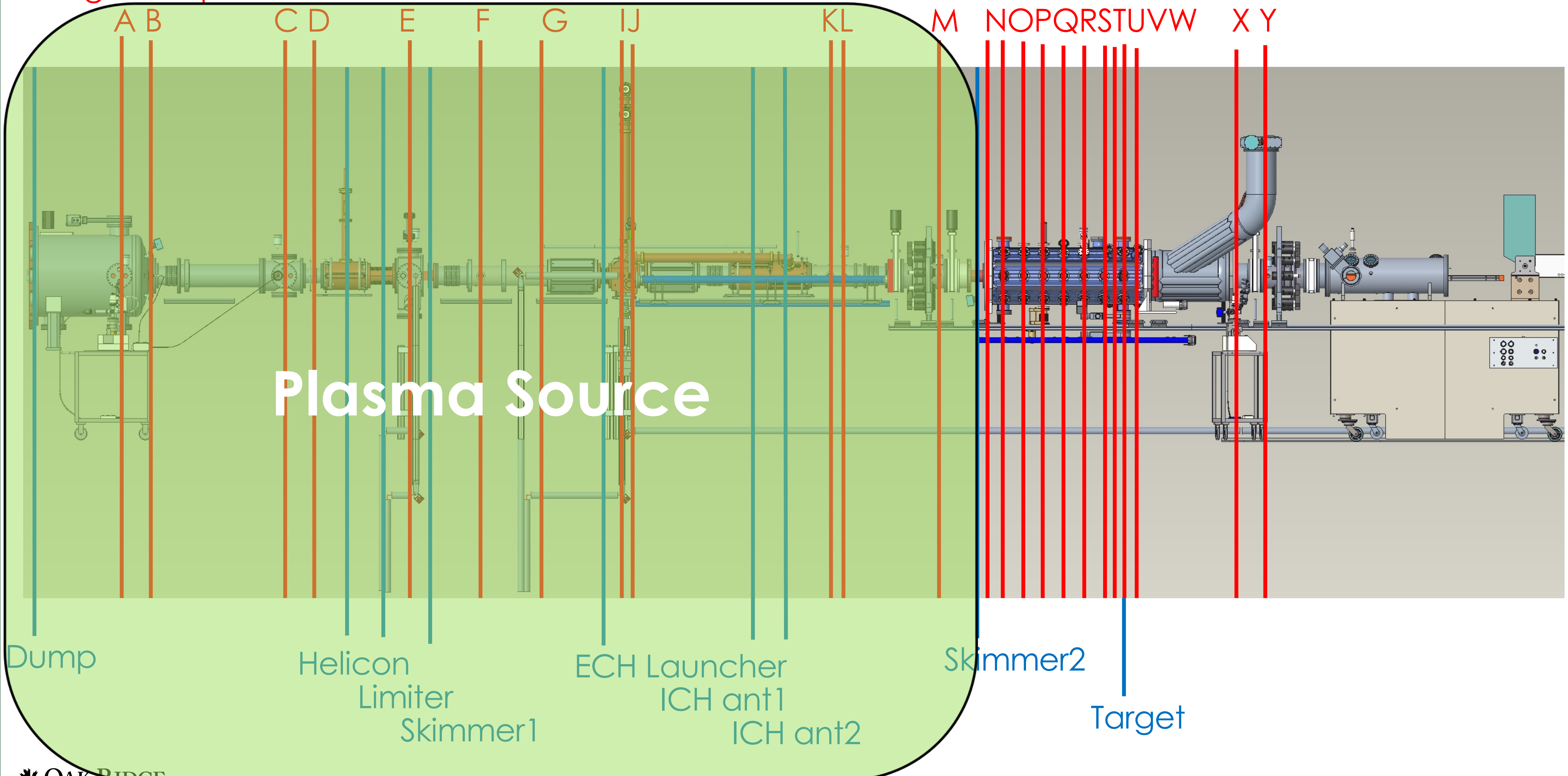


MPEX Systems – cross section

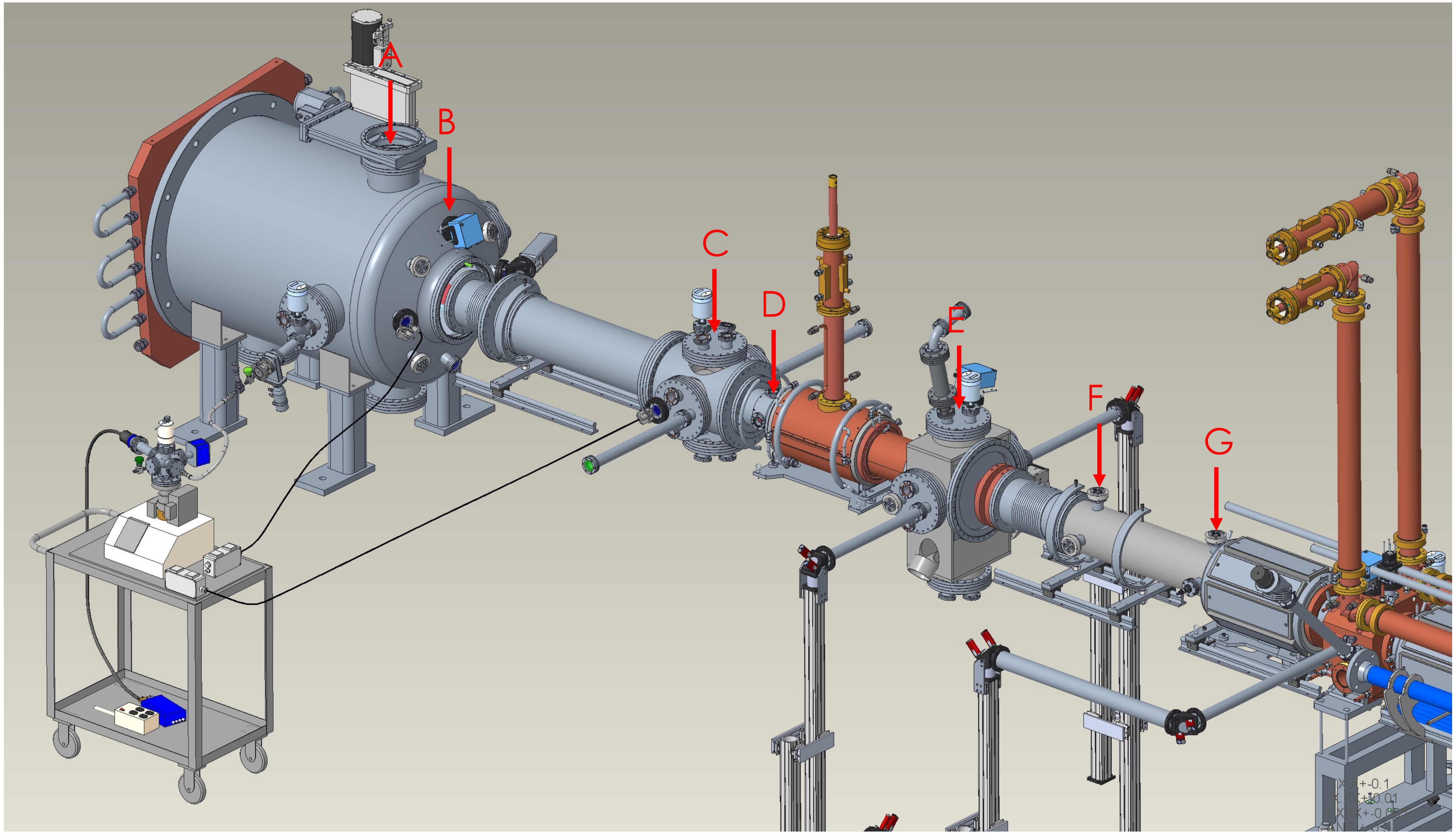


MPEX diagnostic port planes

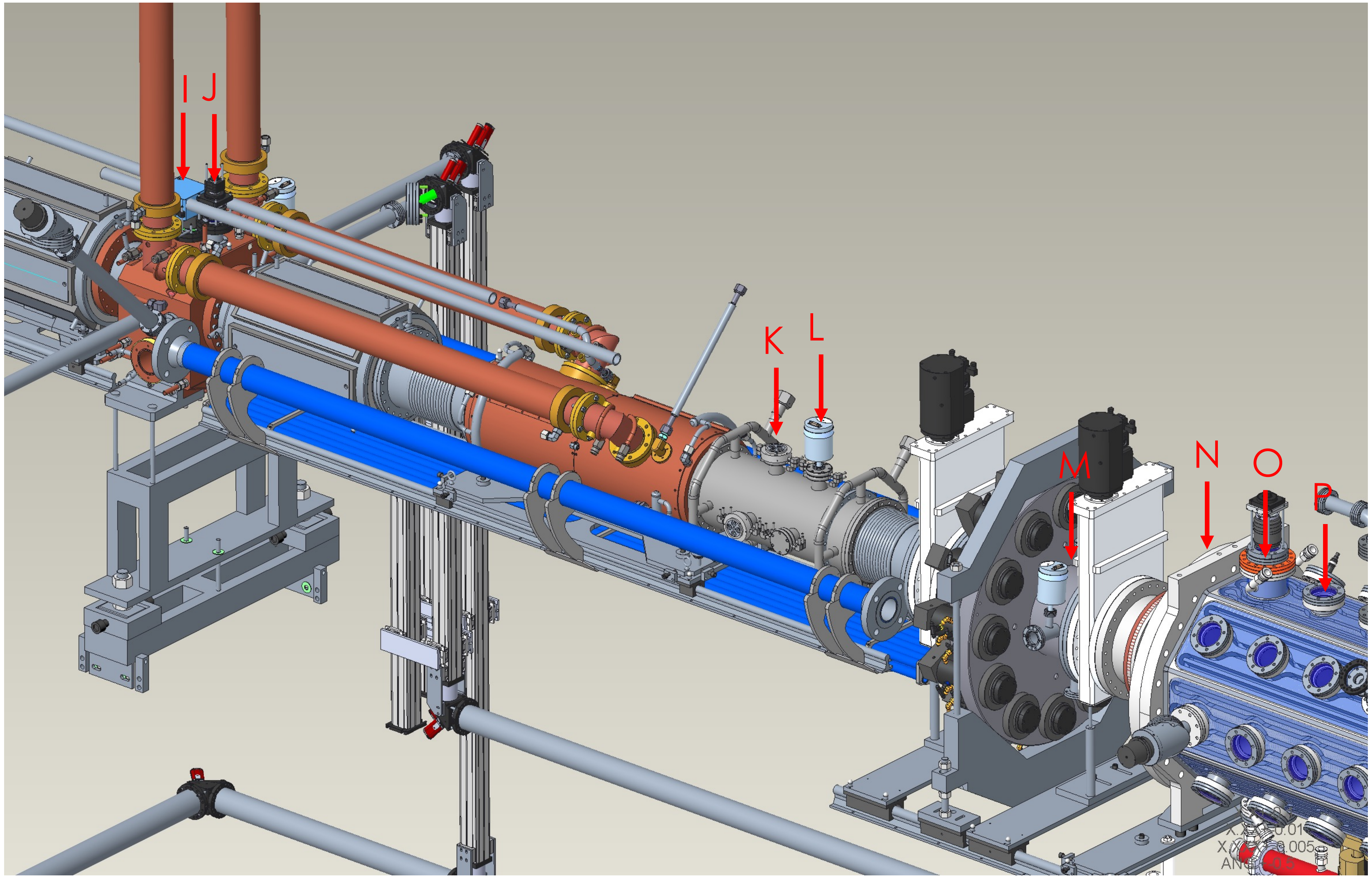
Diagnostic planes:



MPEX dump and helicon regions



MPEX ECH and ICH regions



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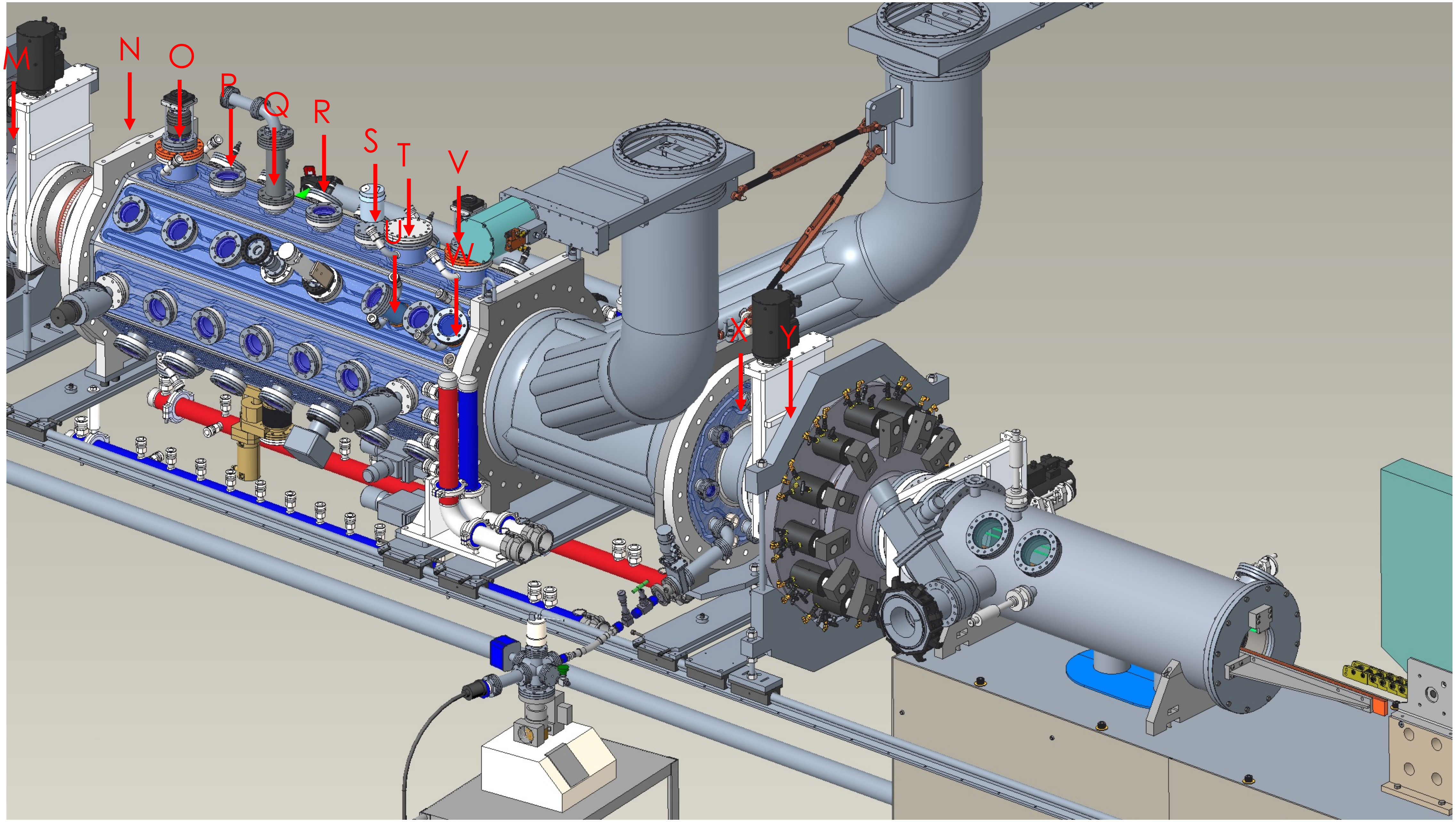
MPEX PMI region



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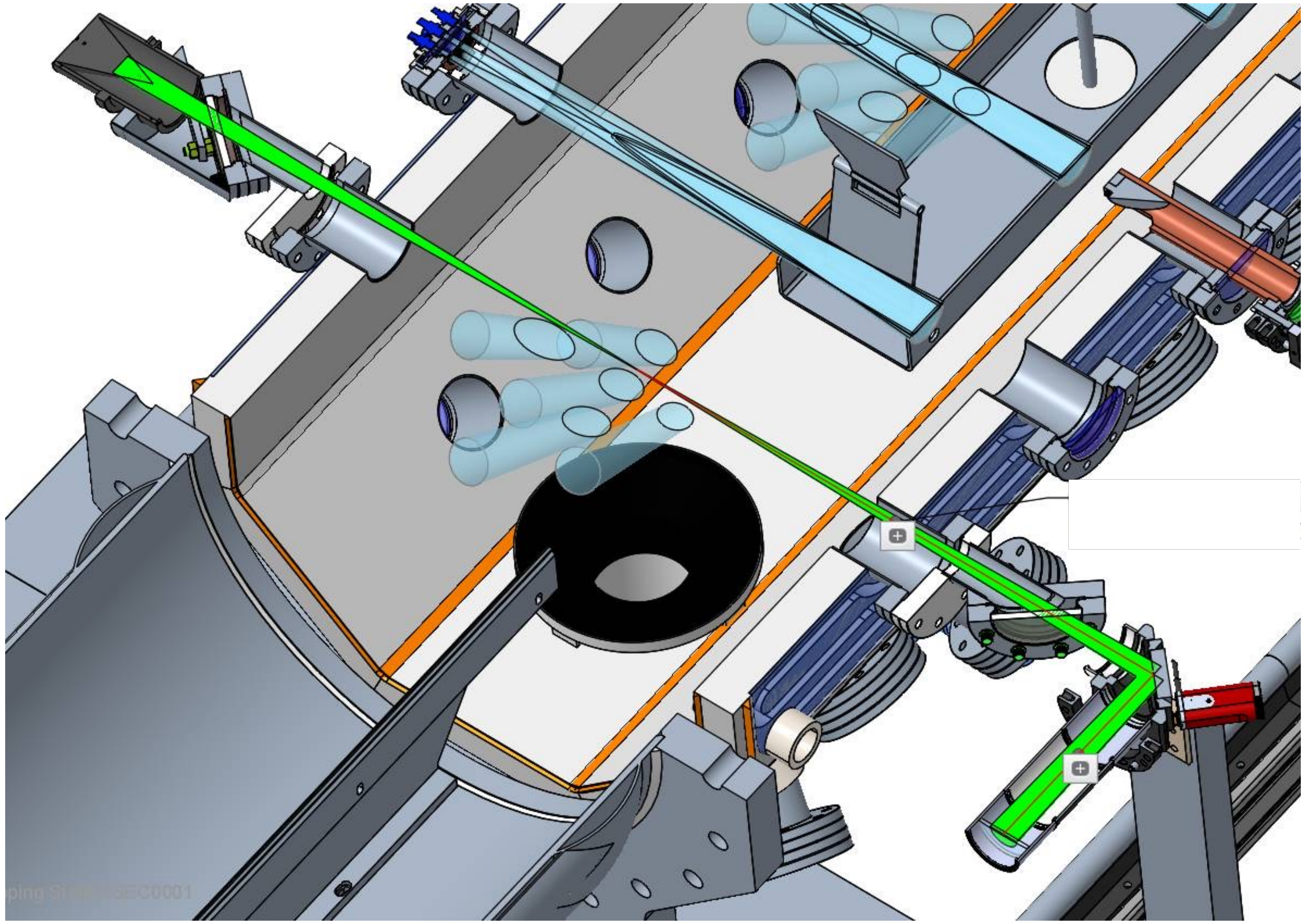
Thomson Scattering

- Based on hardware used on Proto-MPEX to demonstrate EBW heating physics
  - T.M. Biewer, et al., RSI, 2016
  - N. Kafle, et al., RSI 2018
  - T.M. Biewer, et al., Phys. Plasmas, 2018
- QuantaRay Pro350 2 J Nd:YAG laser
  - Frequency doubled to 532 nm
  - 10 Hz measurement rate
  - 10 ns Measurement interval
- Single laser could be used in multiple passes, as on Proto-MPEX
- Princeton Instruments intensified camera and Kaiser Optical Holospec f1.8.
- **1 region in phase I**, 2 additional regions in phase II.



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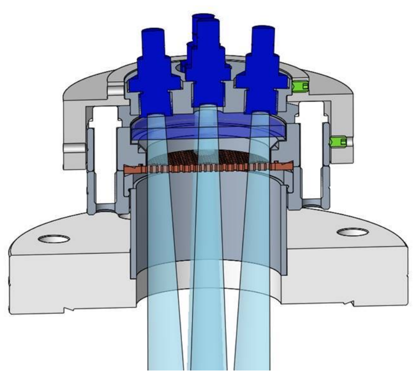
Optical Emission Spectroscopy

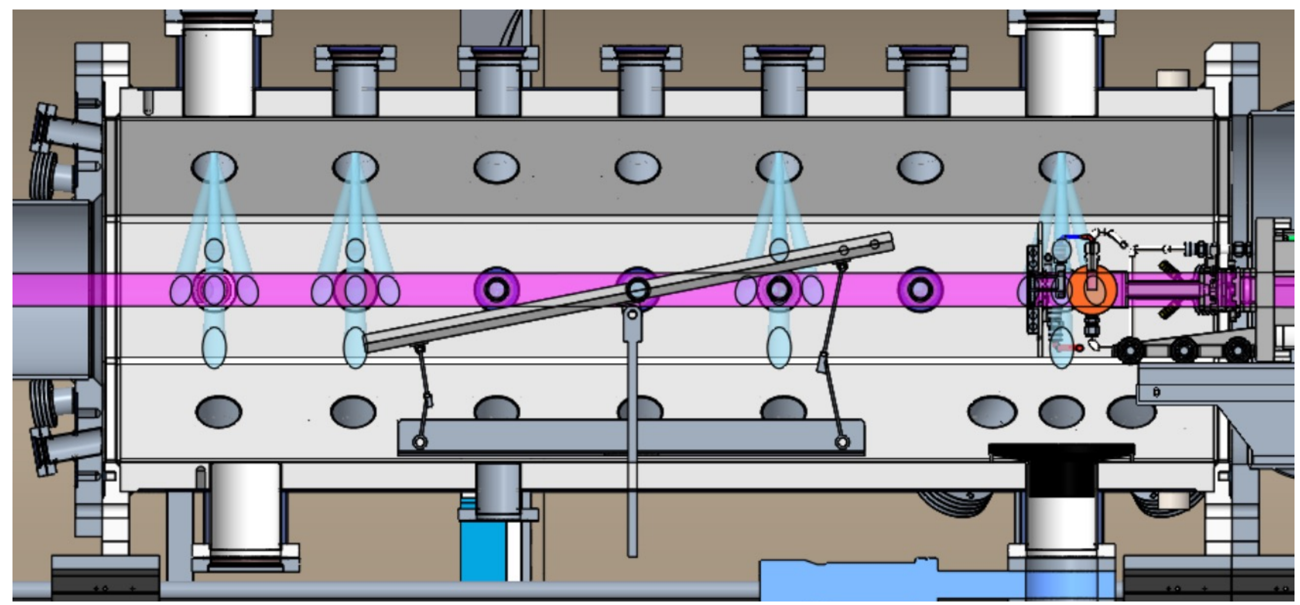
Survey

- Ocean Optics HR4000 compact spectrometer from Proto-MPEX
  - Easy expansion to additional channels
- Identify impurity species, good for target material tracking
- Important diagnostic for safety and operational control
  - Unknown impurities can be an early warning sign
  - Appearance of different species indicates changes in bulk plasma conditions.



High Resolution

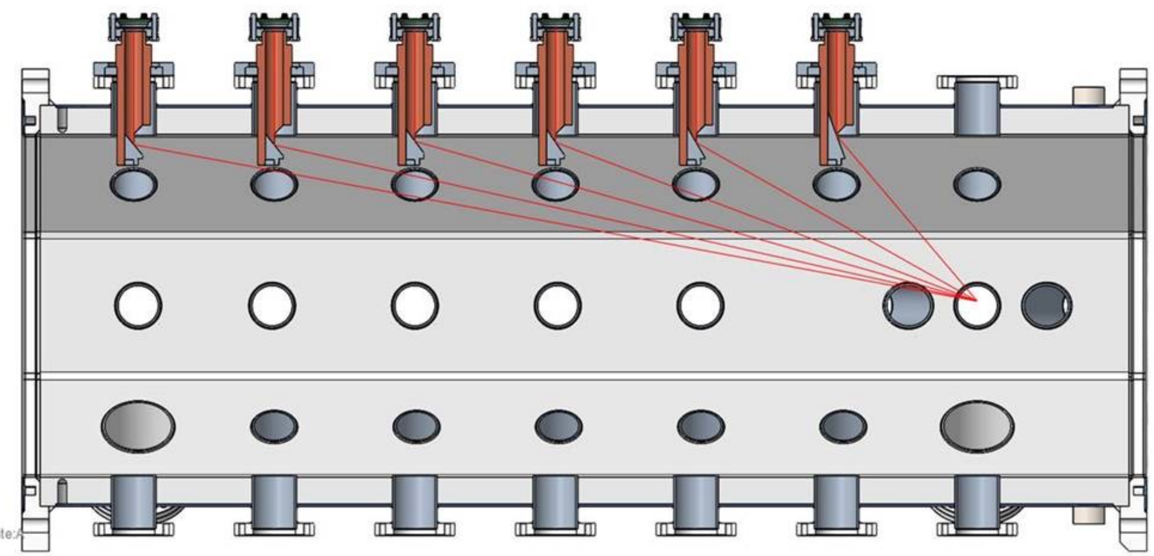
- McPherson 1m 2051 spectrometer from Proto-MPEX
- PI PhotonMax 512b EMCCD detector
- Doppler measurements for T_i and v_i, with inversion if necessary
  - C.J. Beers, et al., Phys Plasmas, 2018
- Ar II trace impurities for ion measurements

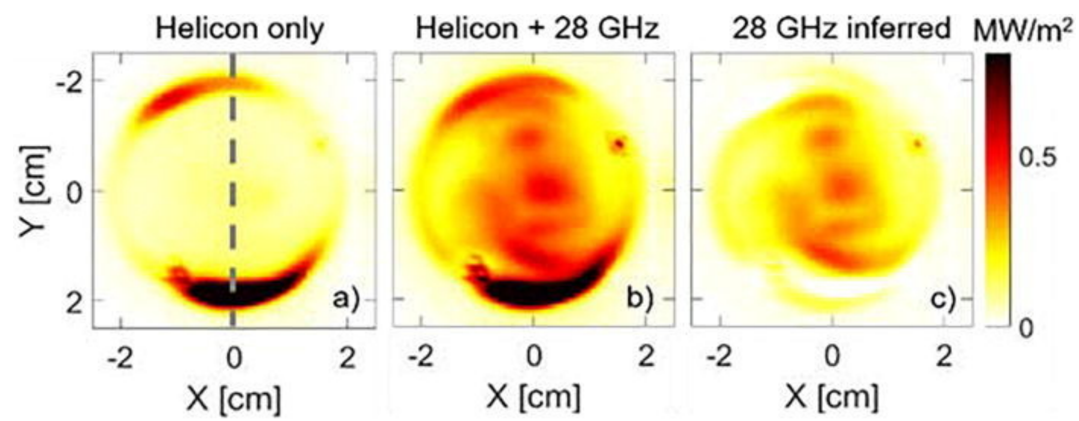


IR camera for thermal imaging of heat flux on target

- FLIR A655SC IR Camera used extensively on Proto-MPEX
  - Heat load monitoring on the target
  - M. Showers, et al., RSI, 2016
  - M. Showers, et al., Phys Plasmas, 2018
  - C. Lau, et al., Phys Plasmas, 2019

- Periscope design allows for flexibility of installation
  - 1 camera for phase I, additional cameras for phase II



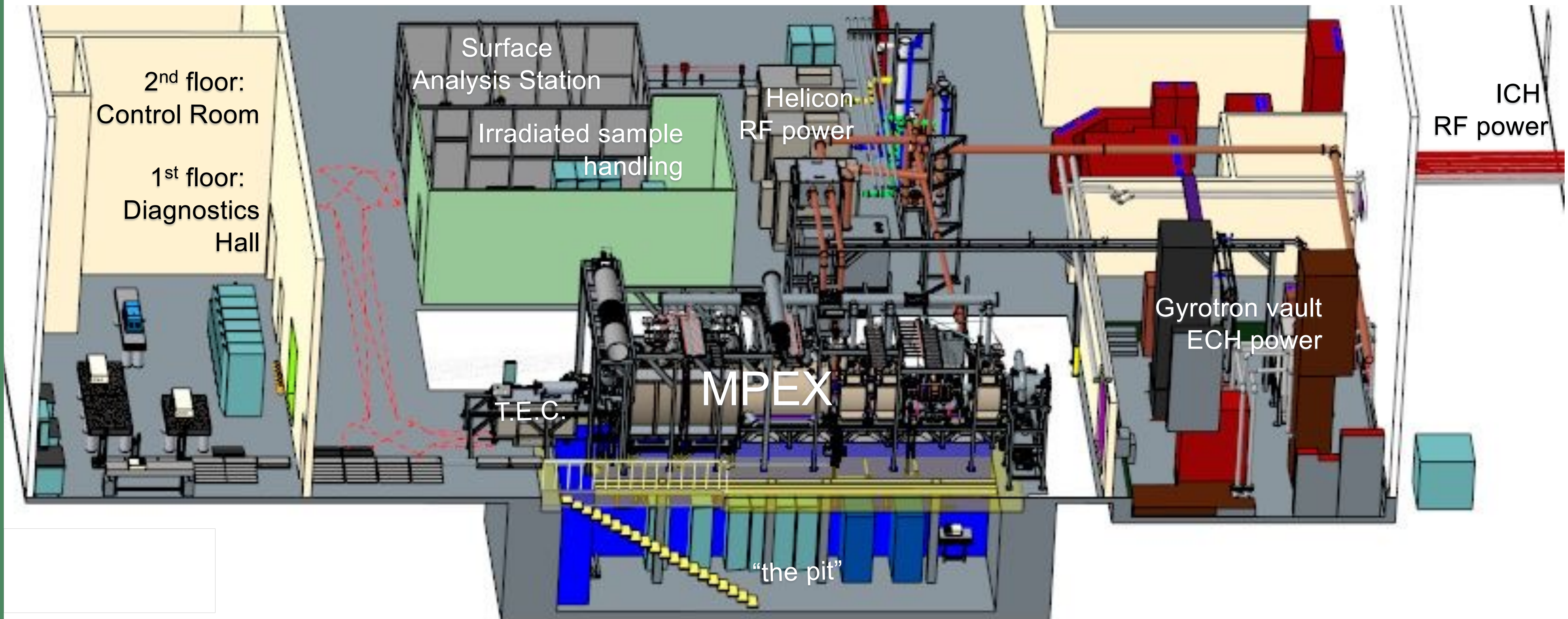


MPEX required measurements classified by role

Measurement	Parameter	Role	Range	Time resp.
Helicon window temperature	T_{hel}	1.a1	20–500°C	>1 Hz
ICH window temperature	T_{ICH}	1.a1	20–500°C	>1 Hz
Skimmer temperature	T_{skim}	1.a1	20–500°C	>1 Hz
Limiter temperature	T_{lim}	1.a1	20–2500°C	>1 Hz
Dump plate temperature	T_{dump}	1.a2	20–2500°C	>1 Hz
Ave. Target temperature	T_{tar}	1.a2	20–2500°C	>1 Hz
Target Heat Flux distribution	Q_{tar}	1.b	0–40 MW/m^2	>10 Hz
Dump Heat Flux distribution	Q_{dump}	1.b	0–20 MW/m^2	>10 Hz
Target Particle Flux	G_{tar}	1.b	10^{22}–10^{25} particles/m^2	>100 Hz
Dump Particle Flux	G_{dump}	1.b	10^{21}–10^{24} particles/m^2	>1 Hz
Magnetic field (SC windings)	B	1.b	0.01–5 T	>1 Hz
Magnetic field (Cu windings)	B	1.b	0.01–5 T	>1 Hz
Total Neutral Gas pressure	P_0	1.a2	10^{-7}–100 Pa	>1 kHz
Helicon Power	$P_{helicon}$	1.a2	0–20 kW	>1 kHz
ICH Power	P_{ICH}	1.a2	0–500 kW	>1 kHz
ECH Power	P_{ECH}	1.a2	0–500 kW	>1 kHz
Stray microwave power	P_m	1.a2	0–500 kW	>1 kHz
Soft X-ray monitoring	P_{SXR}	2		>10 kHz
Radiated Power	P_{rad}	2	1–1000 kW	>100 Hz
Line-averaged electron density	∫(Ne*dL)/dL	1.a2	10^{18}–10^{22} m^{-3}	>1 kHz

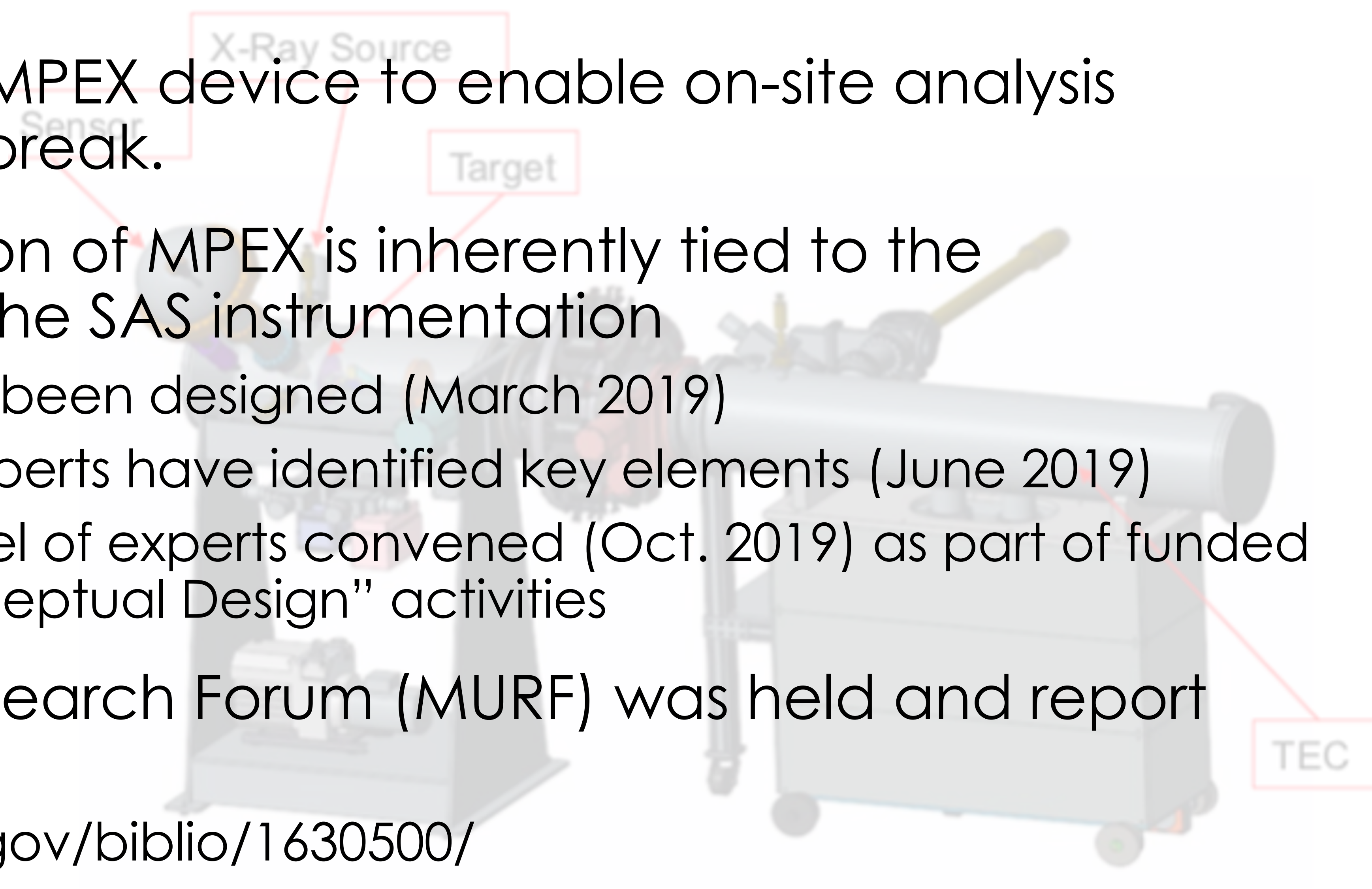
Measurement	Parameter	Role	Range	Time resp.
Plasma dynamics	D_{alpha}	2		100 kHz
On-axis Electron Temperature	$T_e(0)$	1.b	1–50 eV	>1 Hz
Electron Temperature profile	$T_e(r)$	2	1–50 eV, >10 radial points	>1 Hz
On-axis Electron Density	$n_e(0)$	1.b	10^{18}–10^{22} m^{-3}	>1 Hz
Electron Density profile	$n_e(r)$	2	10^{18}–10^{22} m^{-3}, >10 radial points	>1 Hz
Line-averaged Ion Temperature	∫(Ti*dL)/dL	1.b	1–50 eV	>10 Hz
Ion Temperature profile	$T_i(r)$	2	1–50 eV, >5 radial points	>10 Hz
Neutral Gas density	n_0	2	10^{18}–10^{22} m^{-3}	
Plasma Flow	V	2	0–100 km/s	>1 Hz
Impurity Species Monitoring	n_Z	2	Spectral line emission	~1 Hz
Impurity Species Monitoring	P_Z	2	1–100 amu	~1 Hz
In-vessel imaging	TV	1.a2	Camera coverage of critical areas	>1 kHz
Target Surface imaging		2	Features ~<10 mm × 10 mm	
Target Surface erosion		2	Feature height ~<100 nm	
Window transmission	T_{win}	1.a2	0–100%	~1 Hz

Current Design of MPEX Facility



The **Surface Analysis Station** is a key element of the MPEX Science Mission.

- Co-located with MPEX device to enable on-site analysis without vacuum break.
- The science mission of MPEX is inherently tied to the sophistication of the SAS instrumentation
  - Concept SAS has been designed (March 2019)
  - ORNL panel of experts have identified key elements (June 2019)
  - International panel of experts convened (Oct. 2019) as part of funded "advanced Conceptual Design" activities
- 1st MPEX Users Research Forum (MURF) was held and report published
  - https://www.osti.gov/biblio/1630500/



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Recommendations from 1st MURF

- Experiments in MPEX should strive to take advantage of the range of measurement capabilities: *in situ, in vacuo,* and *ex situ* at ORNL.
- A single "do all" SAS design is not required.
- Arrive at a reasonable instrumentation package for a "first generation (single) SAS" that will be incorporated into the MPEX facility baseline project design and cost.
- The prioritized instrumentation package should include:
  - a scanning electron microscope (SEM) to image
  - surface morphology with energy-dispersive X-ray (EDX) analysis to examine surface composition,
  - a compact high-energy, light ion beam for Nuclear Reaction Analysis (NRA) to study presence/retention of light isotopes,
  - and laser induced break-down spectroscopy (LIBS) to enable moderate depth profiling of static retained gases.
- FIB/SEM capability inclusion warrants further discussion.

Summary

- The Diagnostics WBS covers **all diagnostics for the scientific exploration of MPEX**. They include:
  - Diagnostics which are needed **for machine protection** as well as **basic and advanced plasma control,**
  - **Surface analysis diagnostics co-located with the MPEX facility**, which may be utilized to examine material samples after plasma exposure.
- A baseline diagnostic set is planned based on Proto-MPEX.
- Additional ports have been incorporated in the baseline design to enable future diagnostic upgrades and expansion