Progress on a New RF Plasma Generator – a fusion material science R&D

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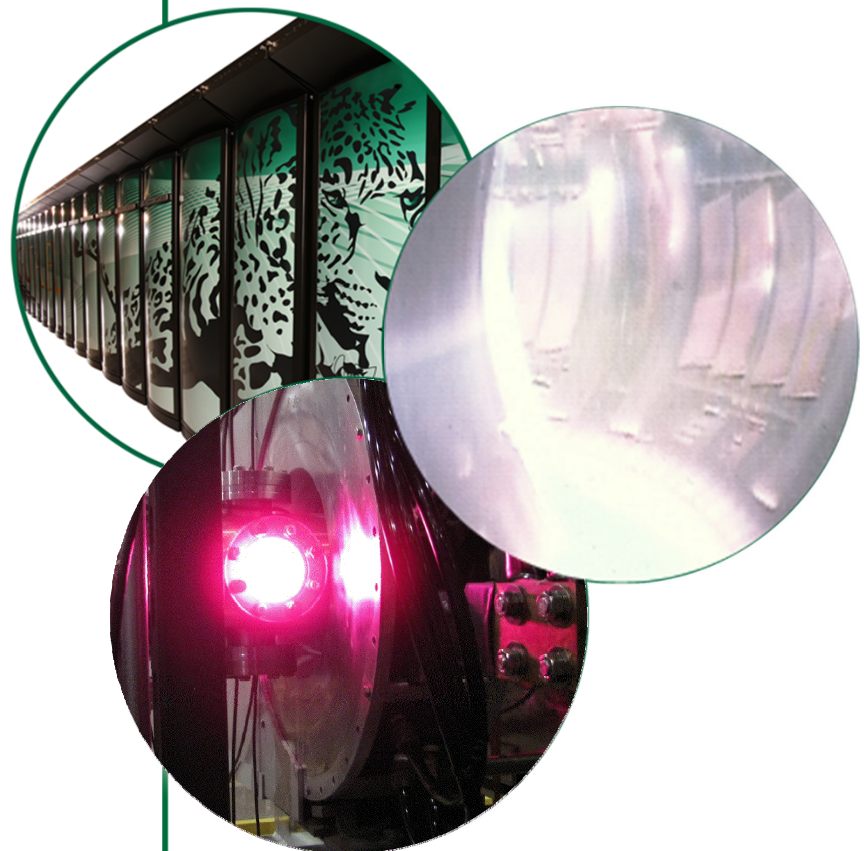

Fusion Energy: Progress and Promise
FUSION POWER ASSOCIATES
33rd Annual Meeting and Symposium

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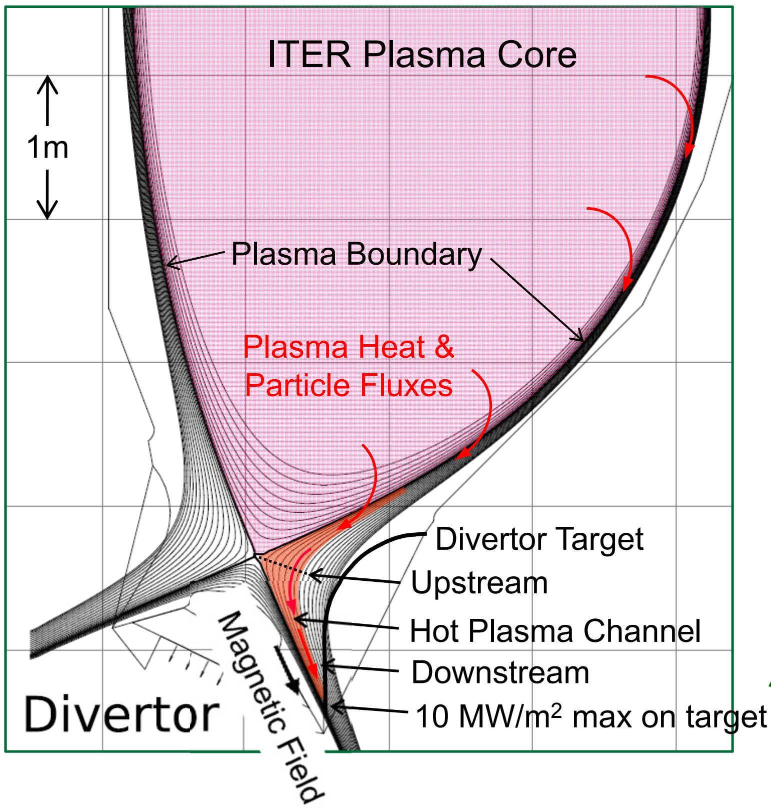
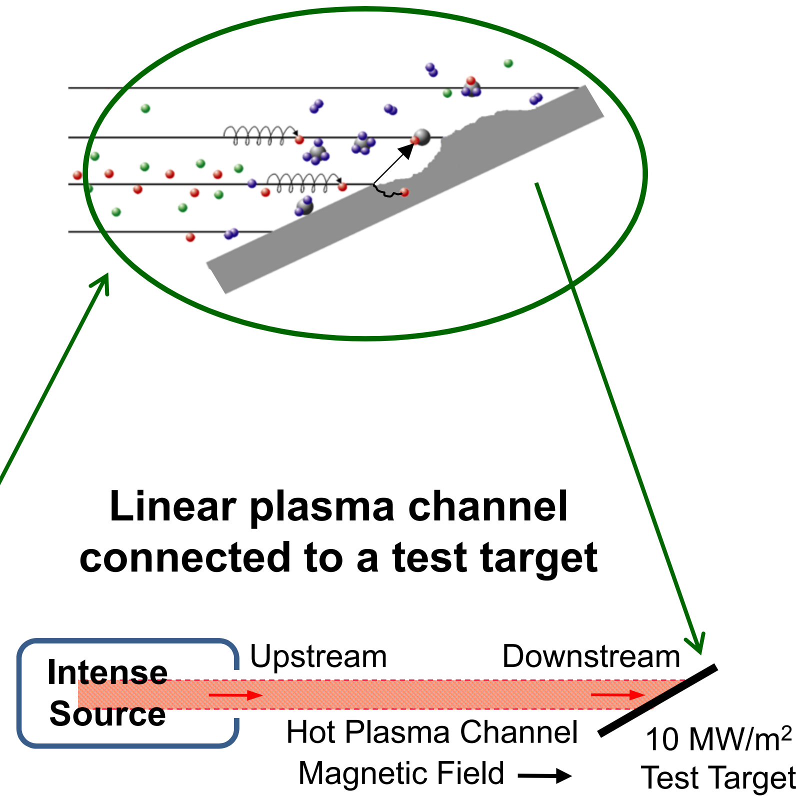
Capitol Hill Club
Washington, DC 20003

Plasma source goal: produce high-recycling, strongly coupled PMI regime, guided by ITER divertor plasma

ITER divertor channel



High-recycling, strongly coupled PMI regime



What source plasma parameters are required?

Managed by UT-Battelle
for the U.S. Department of Energy

Super-extended divertor tests aim to reduce peak heat flux while improving particle control

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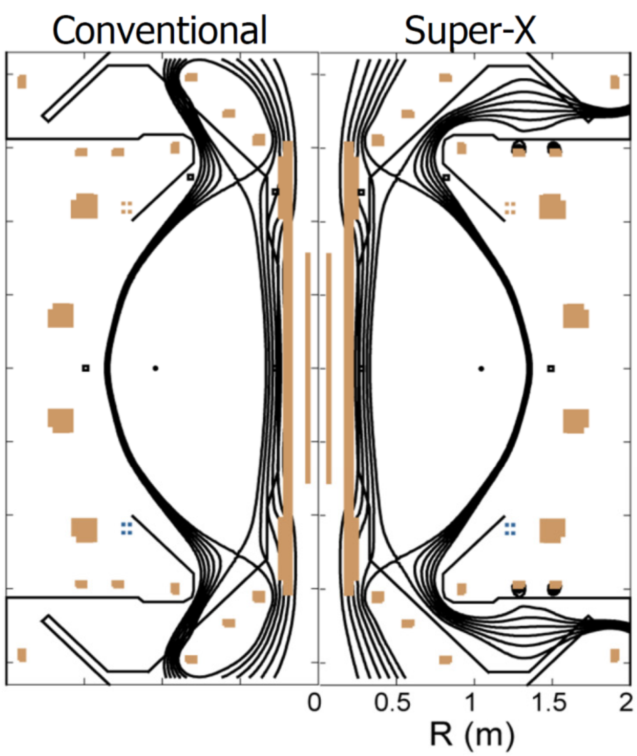
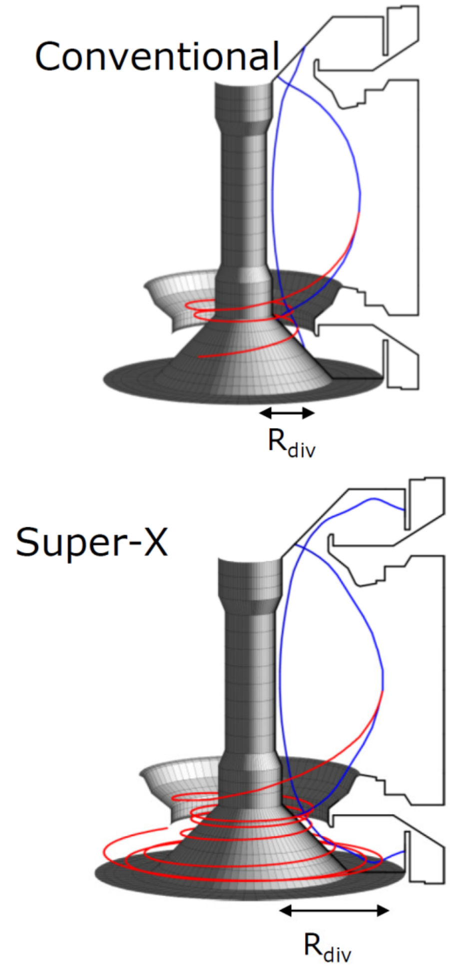
MAST Upgrade divertor

Both super-X and conventional divertor operation are possible.

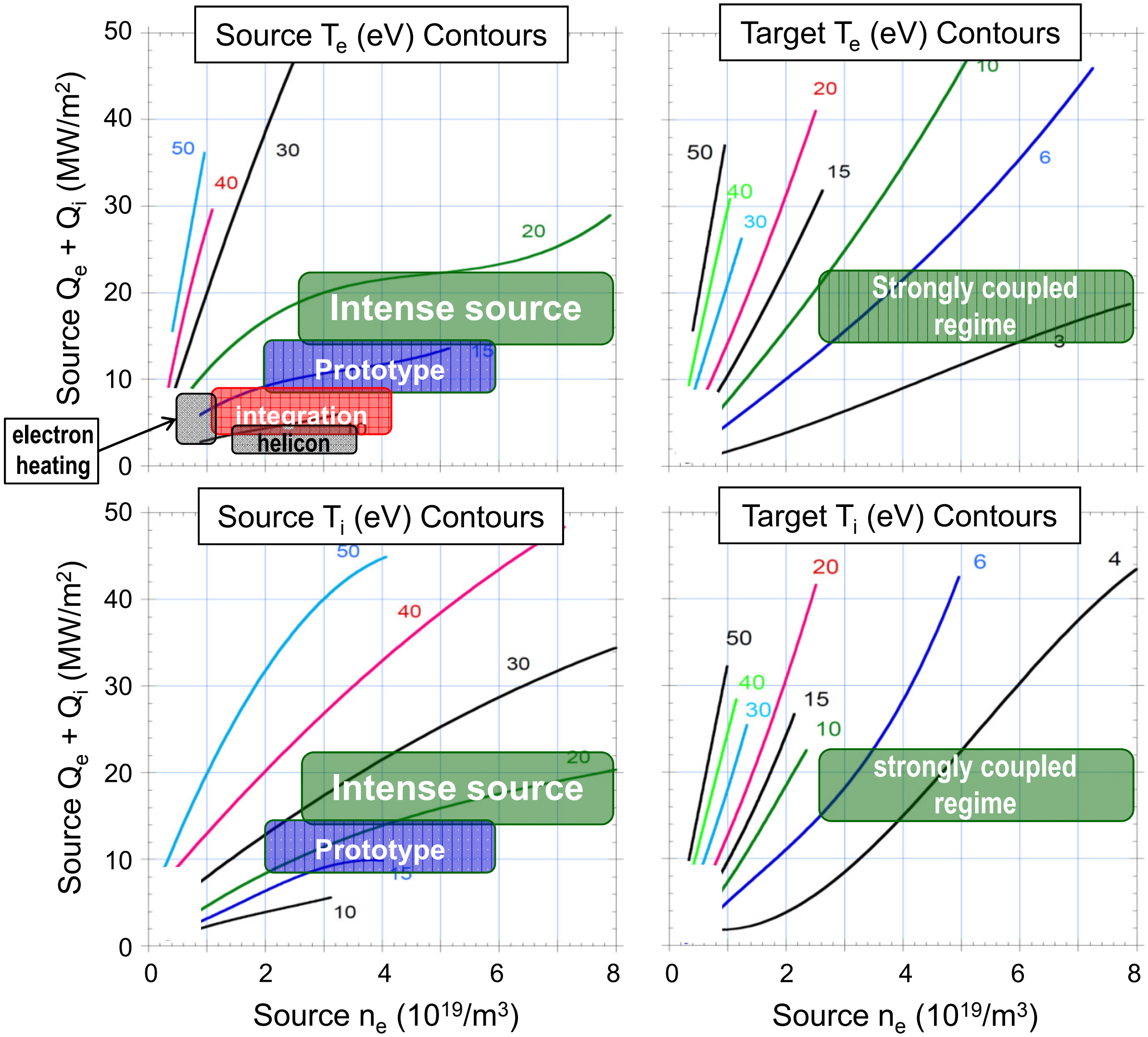




Valanju et al Phys. Plasmas 2009

A companion challenge: lifetime divertor surface material evolution under manageable plasma heat fluxes

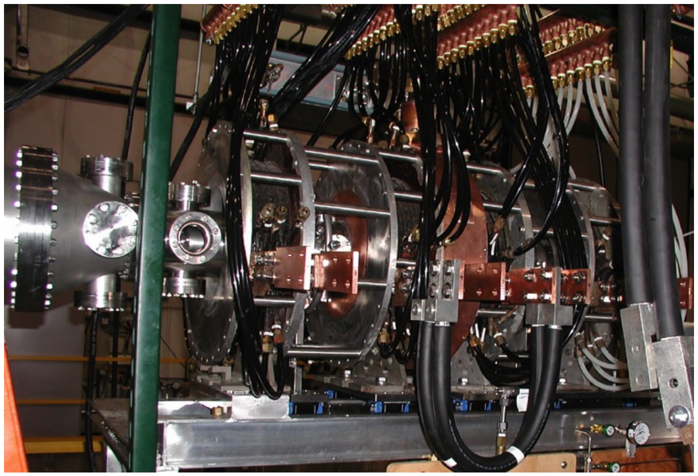
Required source parameters & research

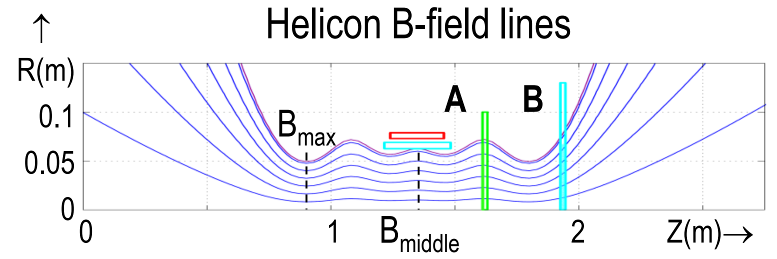


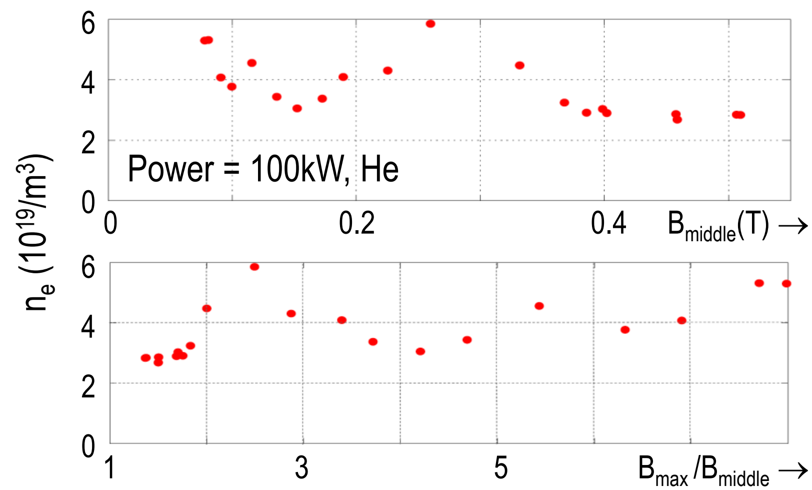
- Strongly coupled PMI regime
- Simulations of required 10-cm source plasmas @ 3m:
  - T_e, $T_i \leq$ 25–35eV,
  - n_e = 4–8x10^{19}/m^3,
  - Q ~ 20 MW/m^2
- Prototype high intensity source experiment to obtain the needed experimental data base
  - T⇒10–30eV,
  - n_e=2–6x10^{19}/m^3
- Physics integration experiment to test combination of helicon & electron heating
  - T_e = 10–15eV

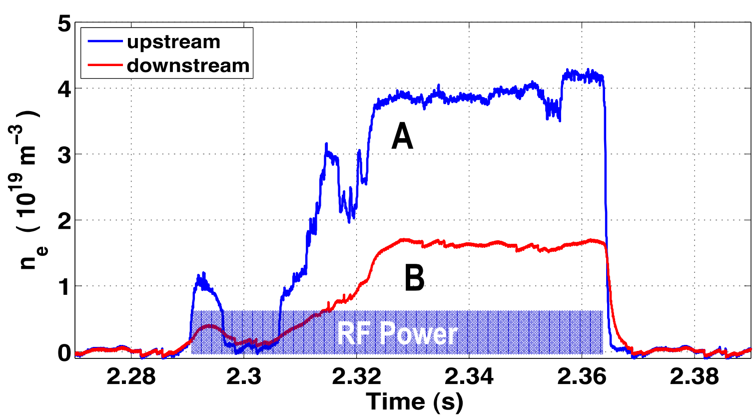
0.3 full-power-year operation in this condition would deliver the estimated divertor plasma heat and particle fluences of ITER life.

Building block: Large, high-density helicon



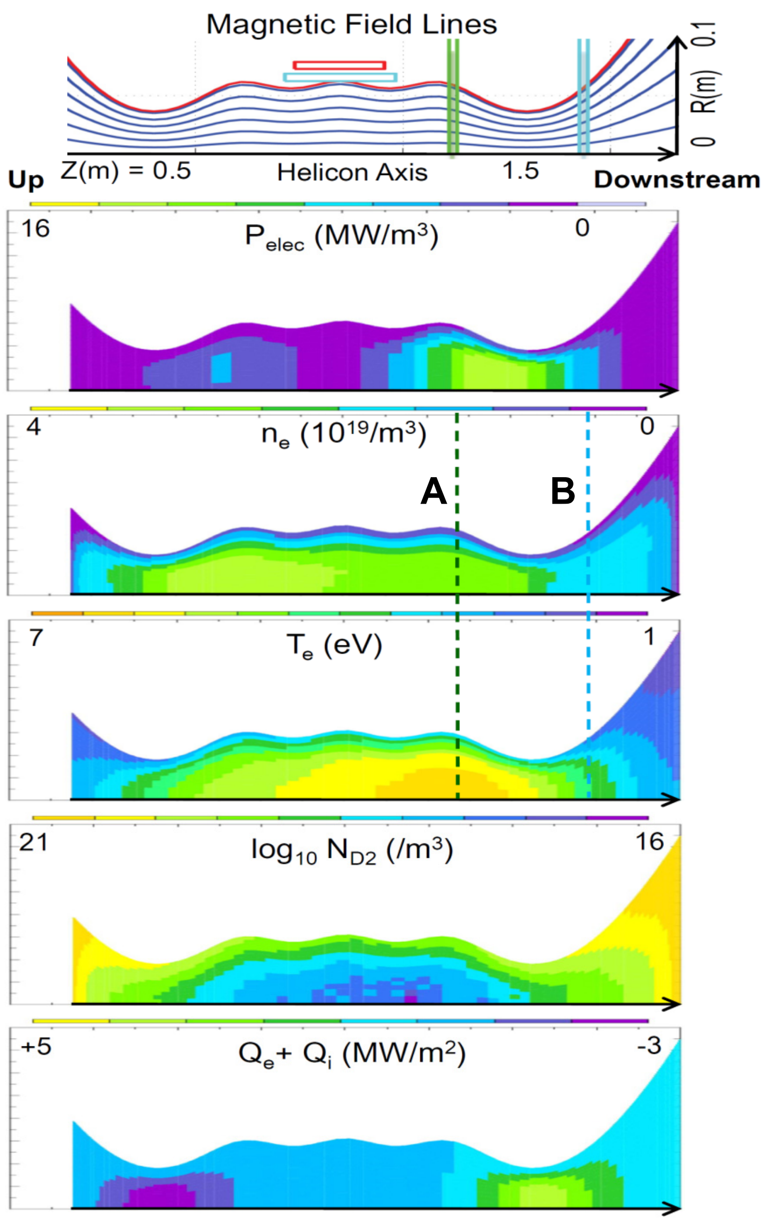






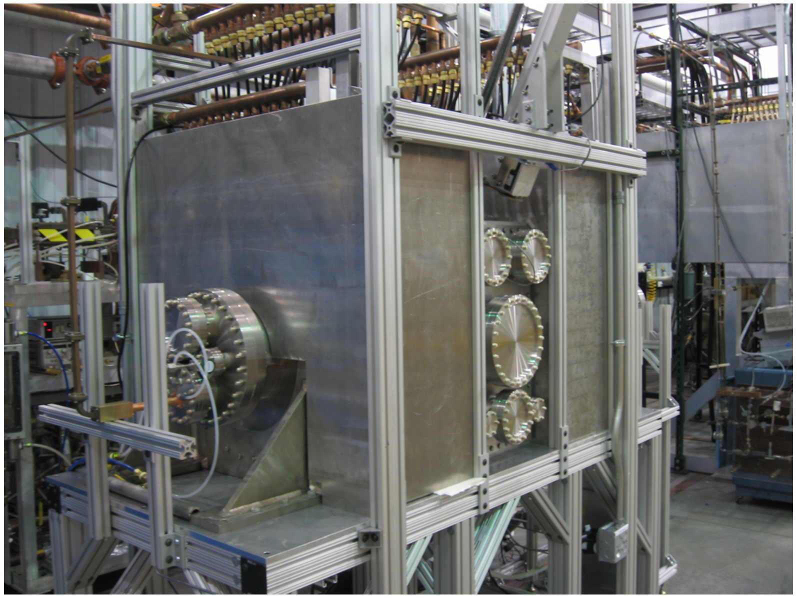
- **Plasma diameter = 12 cm**
- **n_e found to maximize at (He)**
  - B_{middle} ~ 0.07T & 0.3T
  - B_{max}/B_{middle} ~ 2.5 & 6.7
  - $n_e \leq 6 \times 10^{19}/m^3$
- **Injected power ≤ 90kW (D)**
  - $n_e \leq 4 \times 10^{19}/m^3$ (70kW, 1150 sccm)
- **Stationary condition in plasma-neutrals-wall surface interaction time scales**

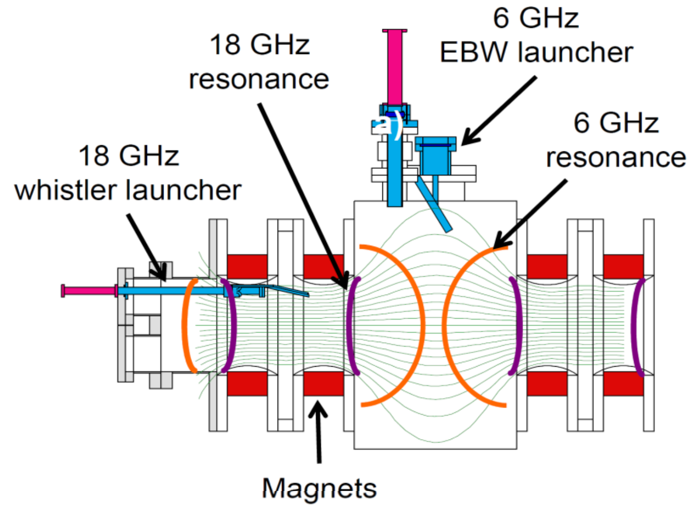
Advanced simulations of helicon plasmas led to new understanding

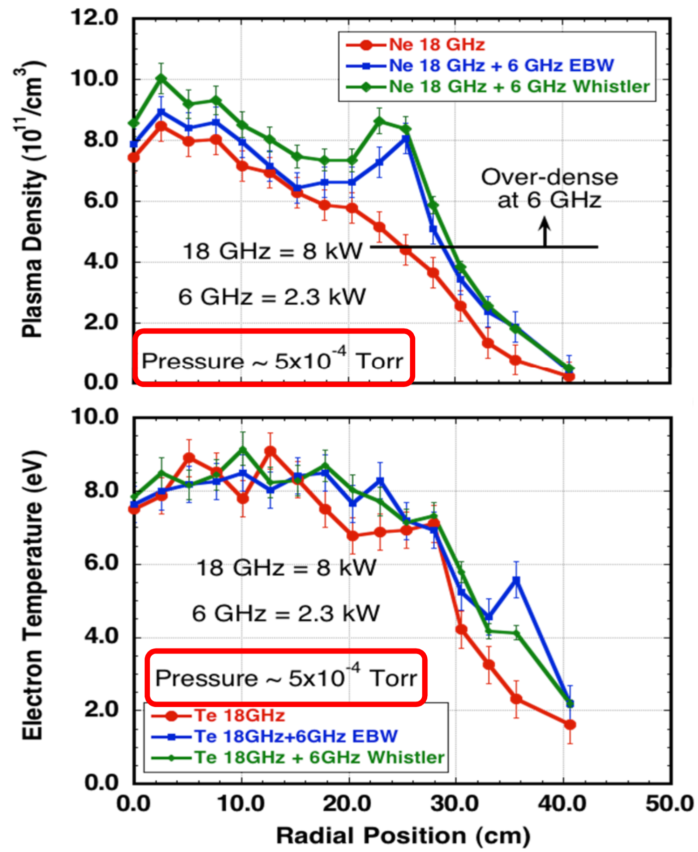


- SOLPS (B2-Eirene) (Jülich; Garching; U. Paris)
  - Models for plasma-neutrals-wall interactions
  - Kinetic Monte Carlo D^0 and D_2 statistics
  - Adapted from tokamak to linear configuration
  - New advance in simulating linear system
- Helicon device and operation conditions
  - Up to 90 kW RF power injected (P_{inject})
  - 1200 sccm gas injection, 40 mTorr prefill
  - Added model for electron heating (P_{elec})
- Match n_e and T_e data @ **A & B** (P_{inject}=70kW)
  - $n_e = 3 \times 10^{19}/m^3$, T_e = 5-6 eV @ **A**
  - Adjust P_{elec}(40kW) & downstream plasma flow
- **Inferred from best match:**
  - D_2 depleted by $\sim 10^{-4}$ at plasma center
  - Strong fueling recycled from upstream
  - Helicon $Q_{max} \sim 3MW/m^2$; $P_{plasma} / P_{inject} \sim 14\%$

Building block: electron heating in over-dense mirror plasmas





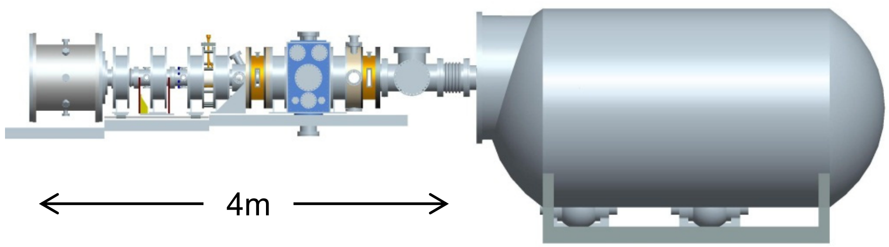


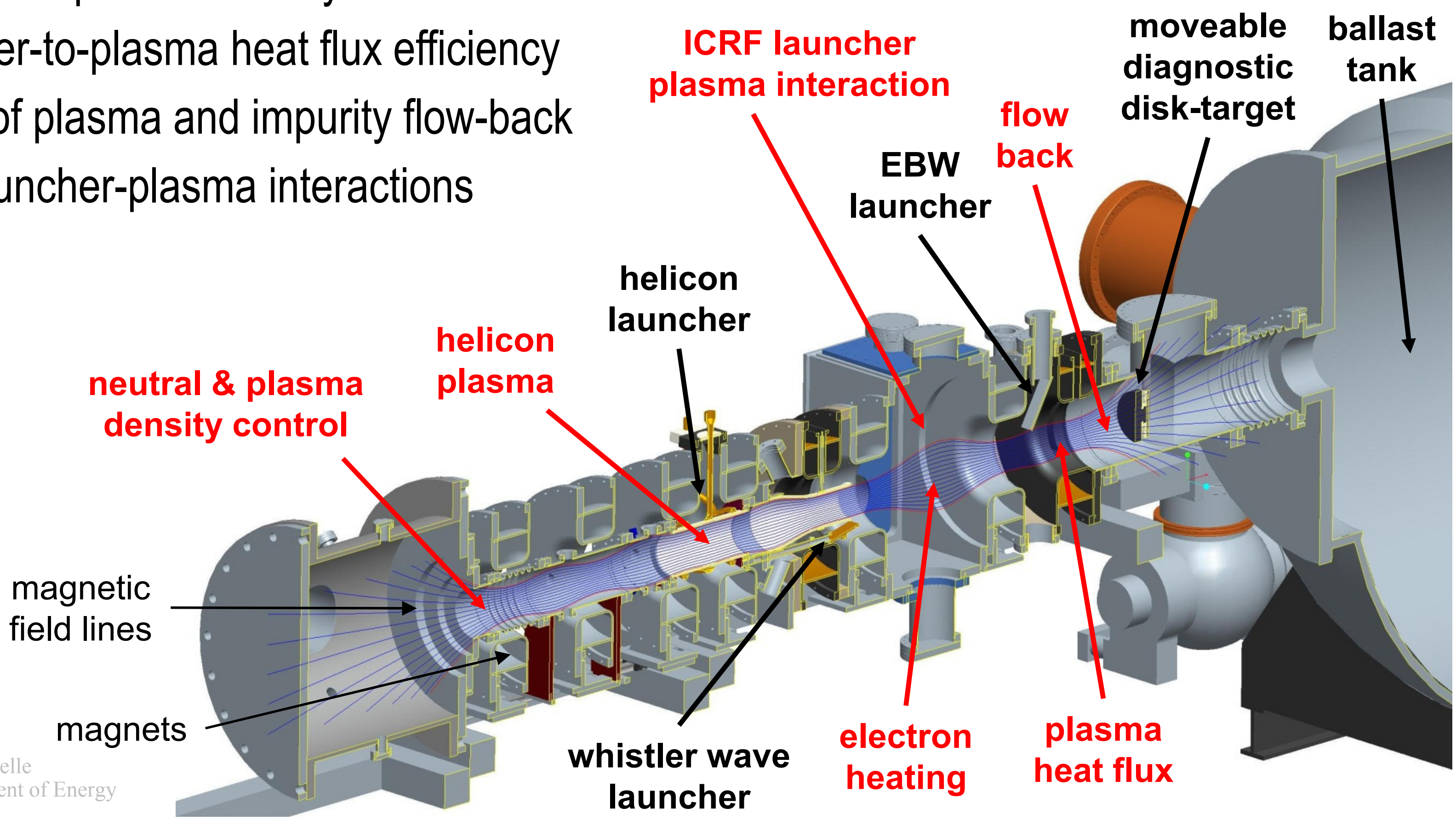
- Tested whistler and EBW launching and absorption at modest fields and densities
- Demonstrated absorption and density increase in over-dense plasmas
- Heating affected by neutral pressure

Integration objectives, capabilities, and research

- **Investigate the addition of <u>electron heating</u> to <u>helicon plasma</u>**
  - Heating of helicon plasma electrons
  - Effects back on helicon plasma production
  - Neutral and plasma density control
  - RF power-to-plasma heat flux efficiency
  - Effects of plasma and impurity flow-back
  - ICRF launcher-plasma interactions

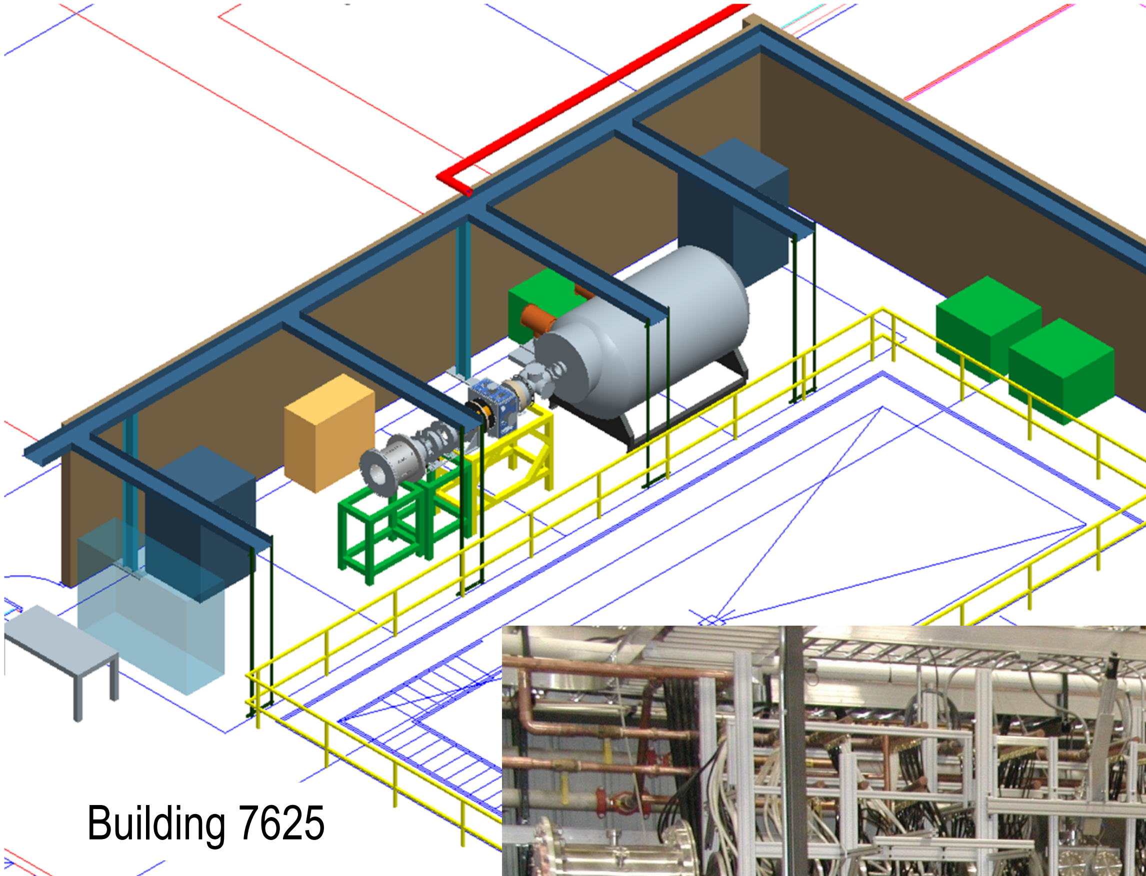
(helicon + electron heaters)

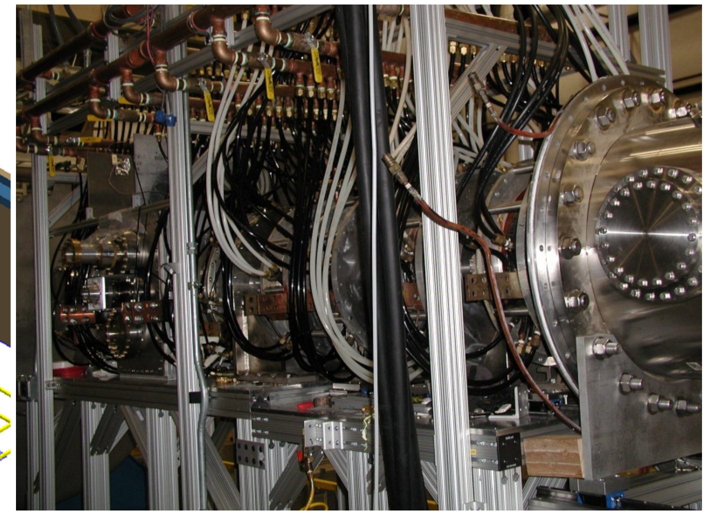


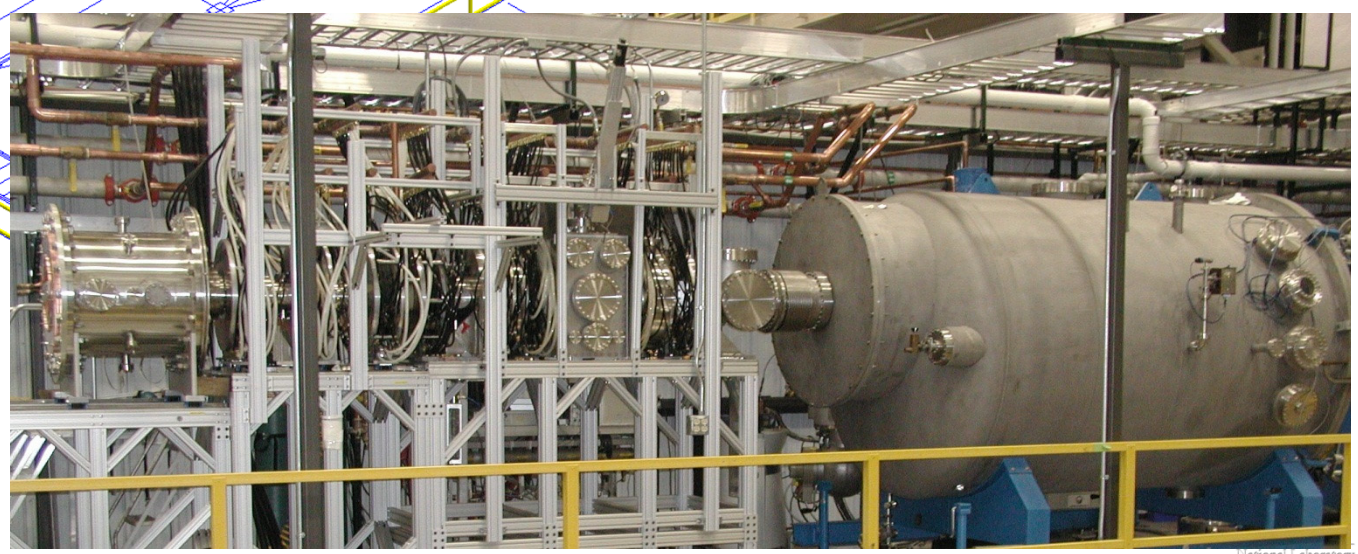


Integration test (PhIX) assembly and facility

- **Assembly completed in September, 2012**



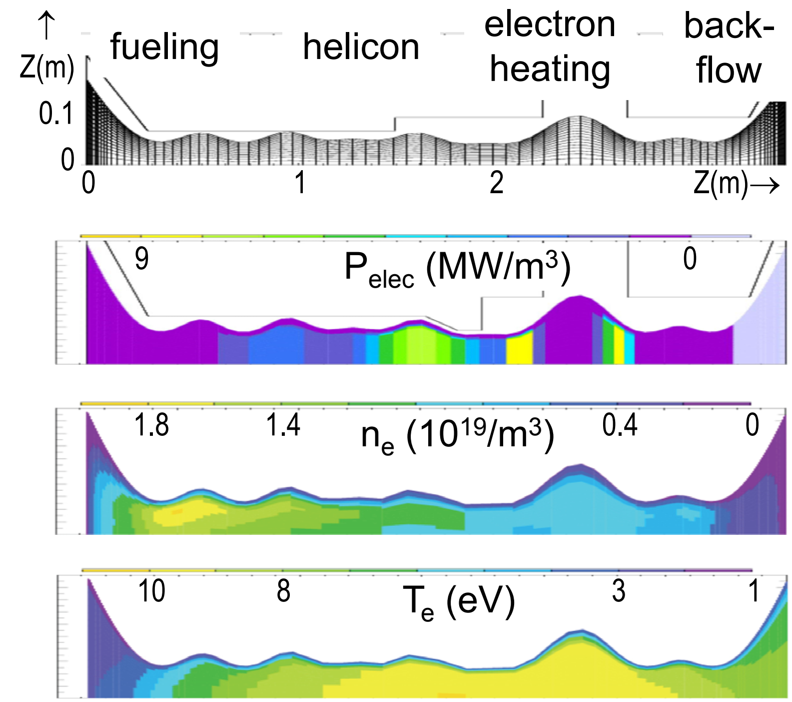


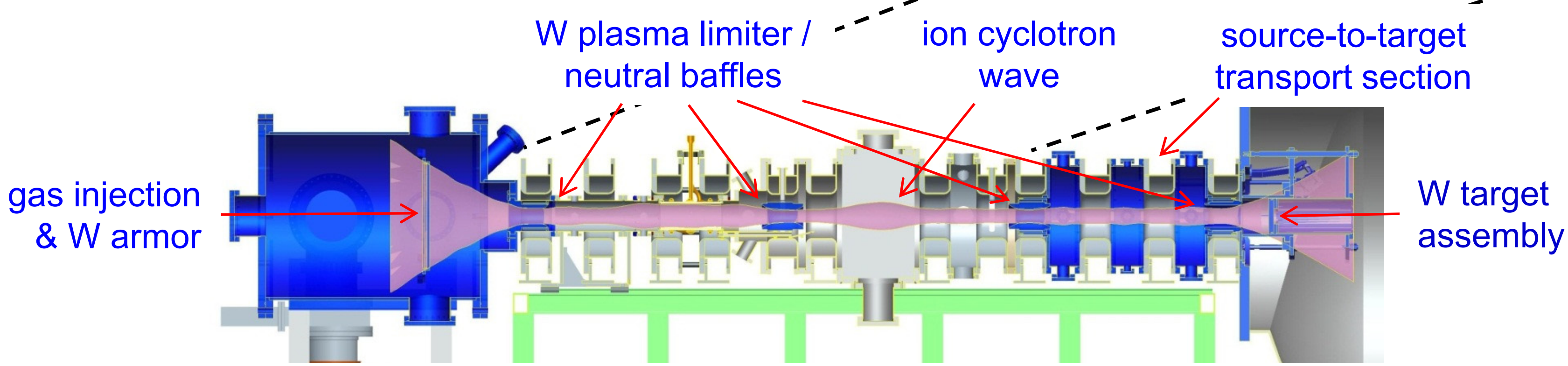


Stepping from Integration to Prototype experiment

- **Simulation under way for Integration test**
- **Add whistler and EBW heating (20 kW)**
- **Extend to Prototype**
  - **Source fueling and power handling**
  - **Plasma boundary & neutral pressure**
  - **Ion heating (revive Archimedes RF supply!)**
  - **Plasma & neutrals flow to target & back-flow**
  - **Target particle recycling & impurity control**

Integration simulation

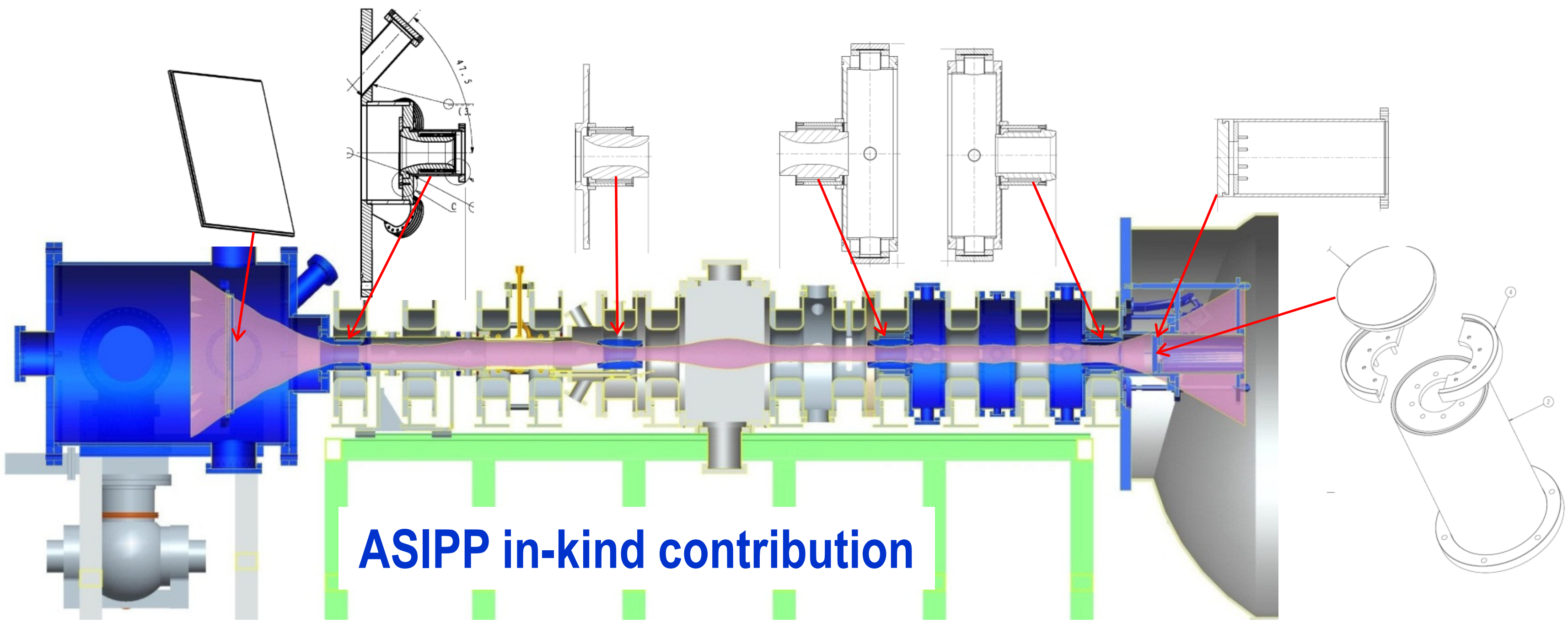




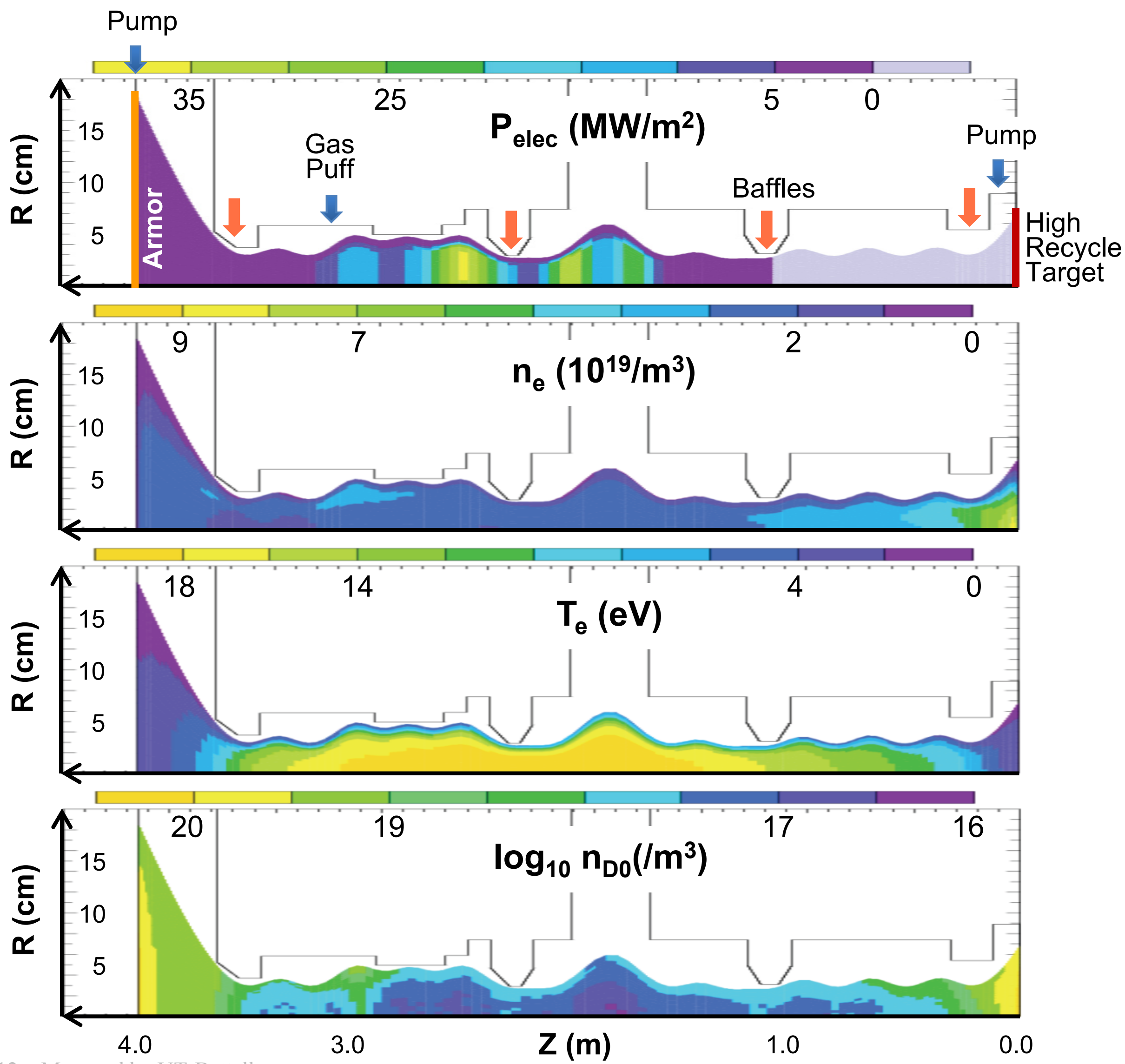
Prototype High Intensity Source Experiment (PHISX)

ASIPP-ORNL collaboration on Prototype

- Critical new components: CAD concept → 3D models → fab drawings → fabrication → inspection → shipping (early FY13)
- Include all-tungsten plasma facing components (armor, limiter-baffles, targets)
- Enable proof-of-principle experimentation on new high intensity plasma source
  - Capable for up to 15 MW/m^2 peak thermal plasma heat flux, up to 1-s
- Experimental research collaboration, involving US and CN researchers

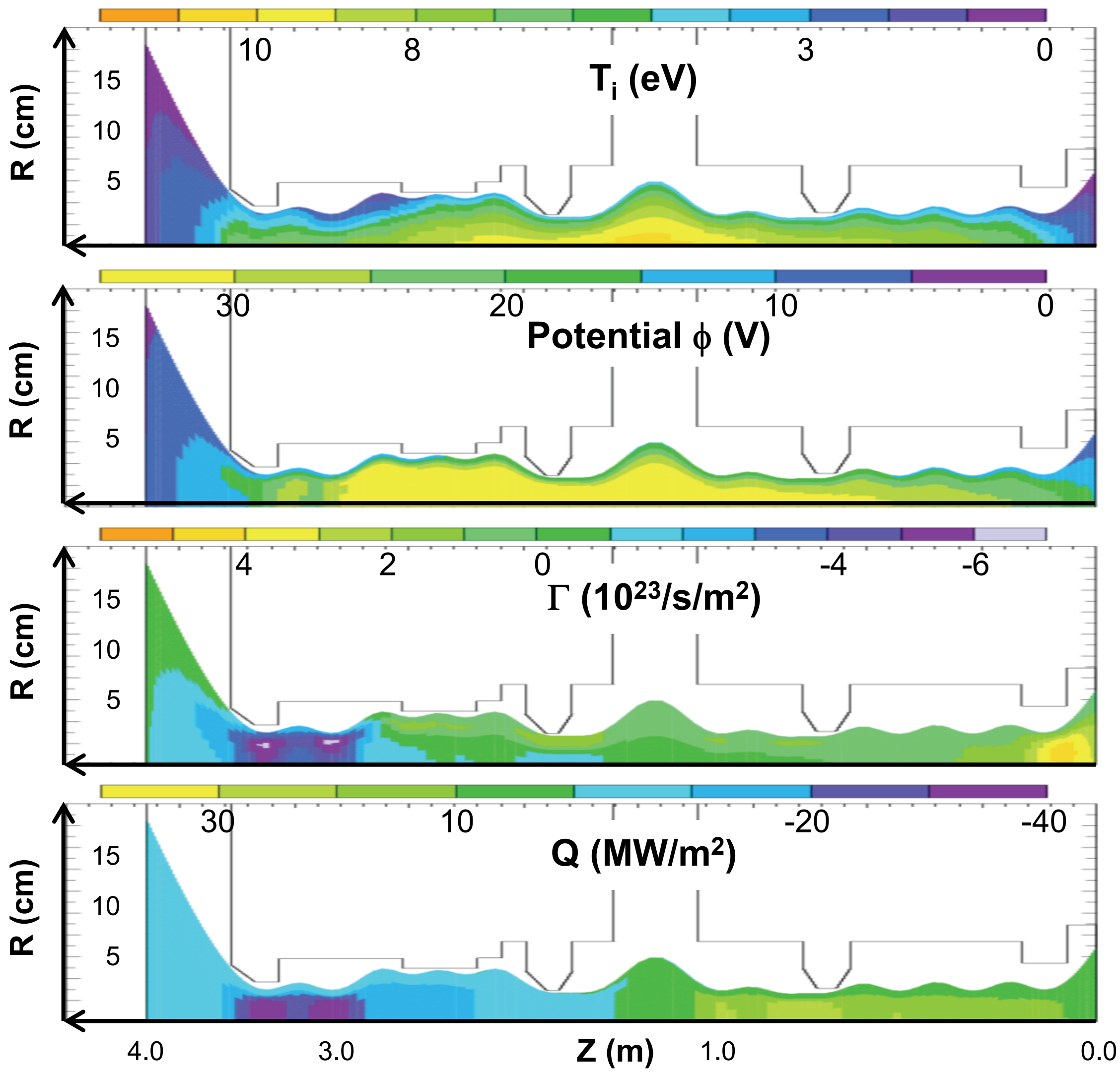


Physics questions of interest to PHISX – I (3600 sccm, helicon gas puff)



- Fueling & pumping locations?
- How to raise target density toward 10^{21}/m³?
- dT_e/dz dominated by parallel heat diffusivity?
- Neutrals depleted in source region; is fueling dominated by particle recycling from target and armor?

Physics questions of interest to PHISX – II (3600 sccm, helicon gas puff)



- Contribution of $d\phi/dz$ to ion heating?
- Benefits of ICRF heating (~50kW absorbed, T_i ~ 50eV)?
- How to raise Γ toward 10^{24}/s/m² and Q toward 20MW/m² on target?
- How to maintain RF power absorption over ranges:

  $n_e = 1 – 4\times10^{19}/m^3$ and T = 5 – 20eV?

Summary – new plasma source research

- Intense plasma source will enable required testing of PMI/PFC options at much reduced cost and time
- Determined required plasma source parameters
- Roadmap:
  - High density Helicon
  - Over-dense plasma electron heating
  - Integration (FY13)
  - Physics prototype experiment (ASIPP-ORNL collaboration)