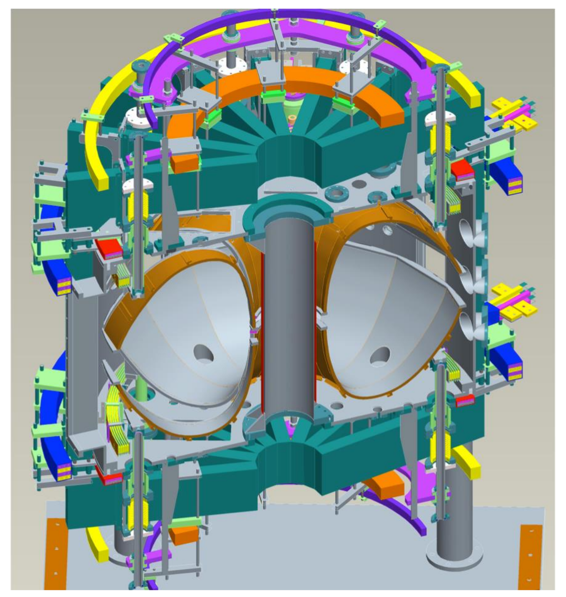
Summary

- The Neutral Beam Injector (NBI) installed on the Lithium Tokamak Experiment Beta (LTX-β) continues to result in beam heating observations below that expected by TRANSP NUBEAM and other modeling.
- Available experimental data on beam performance shows no obvious discrepancy from model inputs
- A scan of beam voltage and current to measure beam divergence revealed an incompatibility between the assumption of full acceleration grid utilization and a real beamlet divergence value
- To assess the actual beam profile entering the tokamak and align beam modeling with actual performance, a 2D tungsten wire calorimeter has been developed
- To limit deflection of the horizontal wires during repeated heating/cooling of the wires, a tensioning system was implemented
- Development and construction of the diagnostic will be presented, with first data expected within the next month

This work was supported by the U.S. D.O.E. contracts DE-SC0019006 and DE-AC02-09CH11466.

Motivation

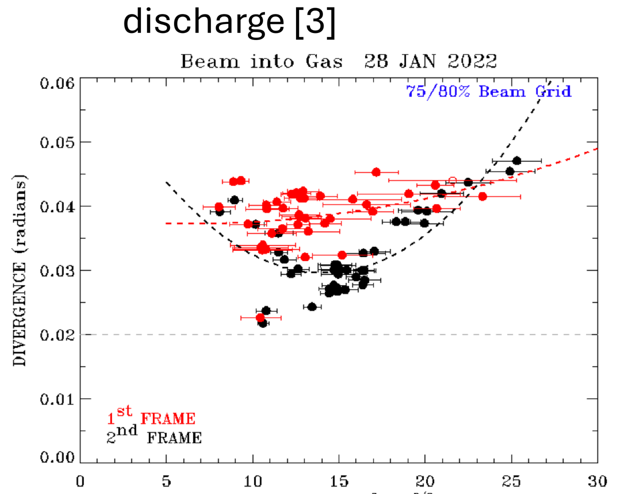
Maximum Parameters		LTX	LTX-β
Major/Minor Radius	R/a	40/26 cm	
Toroidal Field	B_T	0.18 T	0.3 T
Plasma Current	I_p	85 kA	135 kA
Flattop Duration	t_{flat}	~15 ms	~35 ms
Electron Temperature	T_e	~250 eV	~400 eV
Ion Temperature	T_i	~100 eV	~200 eV
Energy Confinement	τ_E	~2 ms	~5 ms
Neutral Beam Current	I_{nbi}	-	~35 A
Neutral Beam Energy	E_{nbi}	-	13-20 keV
Neutral Beam Duration	t_{nbi}	-	5-10 ms



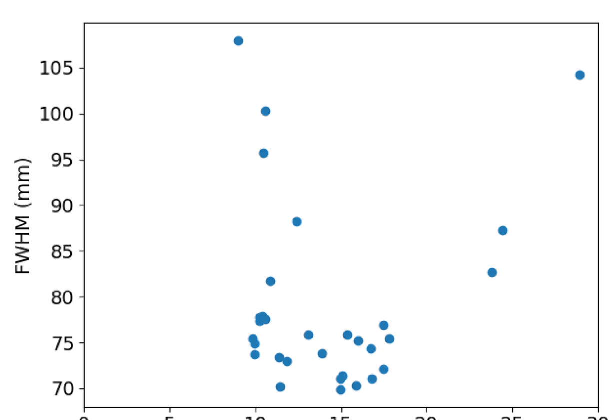
Neutral beam injection provides access to numerous investigations:

- LTX- β provides testbed for study of energetic particles (EPs) in low-recycling boundary plasmas
- Flat T_e profiles observed in LTX [1] and LTX-β remove (or diminish) temp-gradient modes
- Fueling essential for plasma sustainment during low-recycling phase (no gas puffing)
- Auxiliary heating probes energy scaling in low-recycling plasmas
- First beam heating of a flat-temperature profile observed [2]

- Beam optimization in 2022 resulted in data consistent with CHERS
- Energy to calorimeter consistent with original operation
- Some questions remain regarding beam geometry
- CHERS peak fitting suggested < 0° beamlet divergence
- Under filling of HV grid used to explain, but a direct measure of beam performance is desirable
- Wire calorimeter can give direct measure of beam footprint during discharge [3]



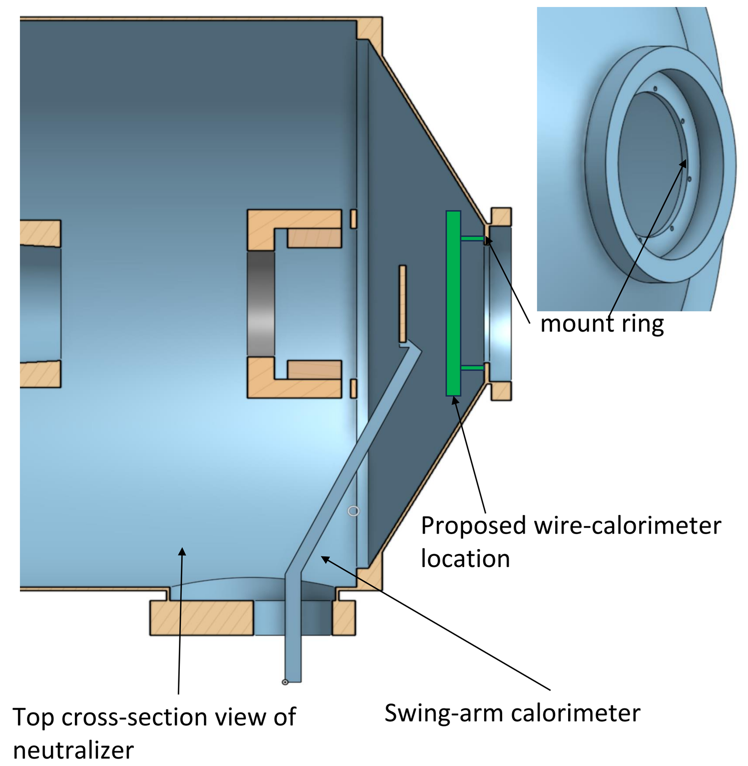
Beam into gas divergence data for 1st/2nd half of beam pulse



Calorimeter thermocouple data optimization of beam

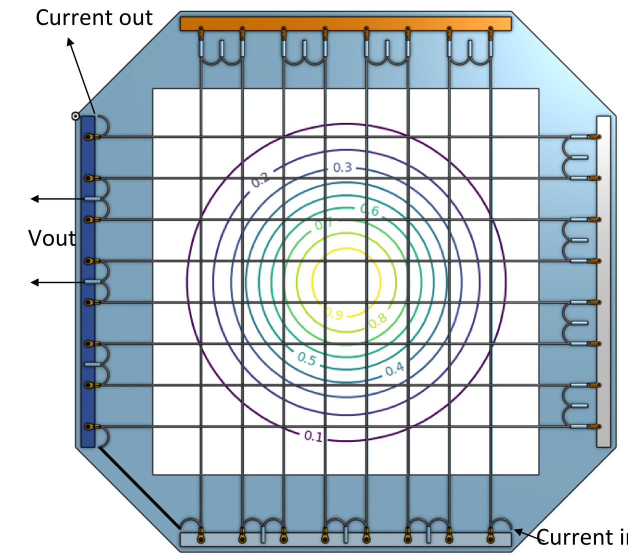
HTPD Apr 2024

Design and Modeling

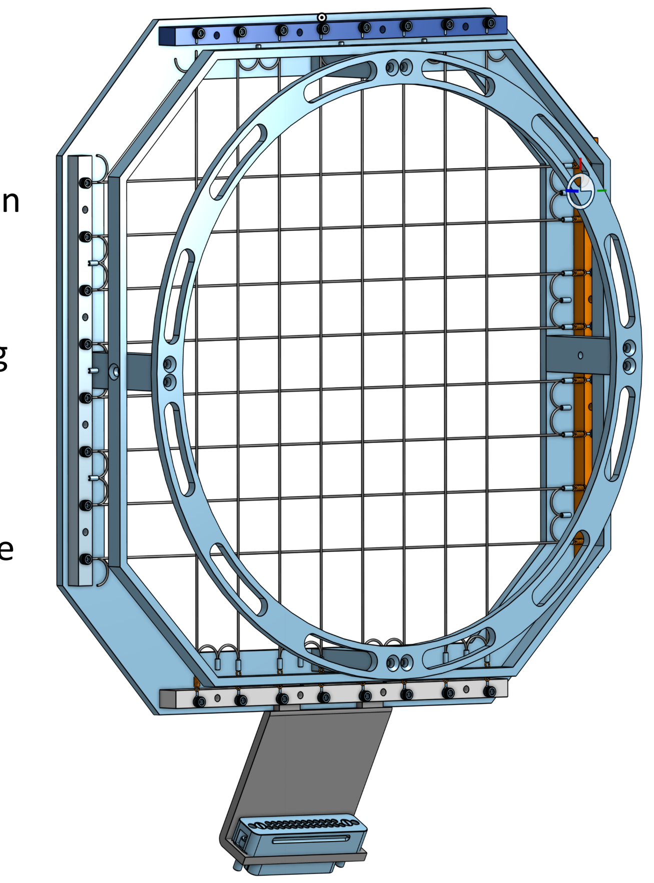


- Space along beamline into vessel extremely limited, plan to mount just inside neutralizer
- Conveniently unused mount ring, no modifications to tank are necessary
- Wiring through 4" port at tank bottom (not shown)
- Design to fit through 12" conflat on tank side
- Many positives:
  - Naturally beam-normal
  - Doesn't require machine vent to access
- Potential drawbacks
  - Residual ion fraction could cause vertical asymmetry (but easy to determine and account for)

Wire-calorimeter final design



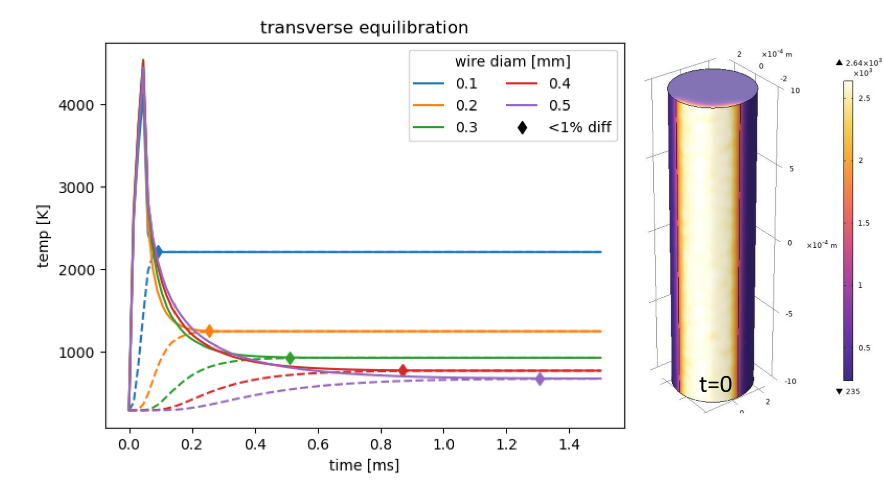
- 8x8 grid of 0.01" diameter tungsten wire with 0.75" spacing
- Spring tensioned on top and right
- Crimp connections for springs, ring terminals, Vout
- Small enough to fit through 12" conflat bore
- Modular build using individual wire segments crimped together
  - Easier repair
  - A relaxed connection between adjacent wires puts spring tension in alignment with wire



Thermal Equilibration Timescales

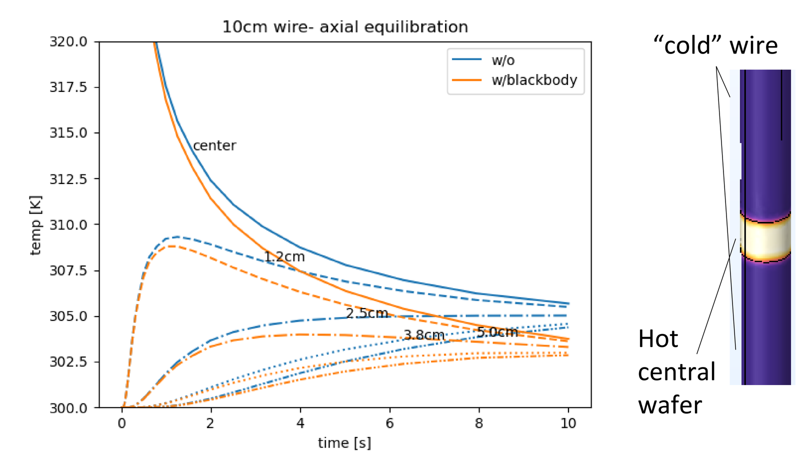
Transverse

- Surface heating applied to one quadrant of wire for first few frames of simulation
- After heating turns off wire allowed to equilibrate, temp measured on front/back surface
- Equilibrates on timescale of milliseconds



Axial

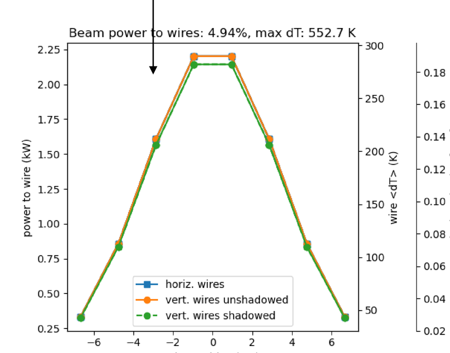
- Very hot central "wafer" started with Twall + 1000 deg allowed to equilibrate into 10 cm wire
- Including blackbody lowers wire temp, but only a few degrees after 10s
- Equilibrating back to Twall (=300deg here) instead of equal temperature along wire
- Equilibrates on timescale of seconds

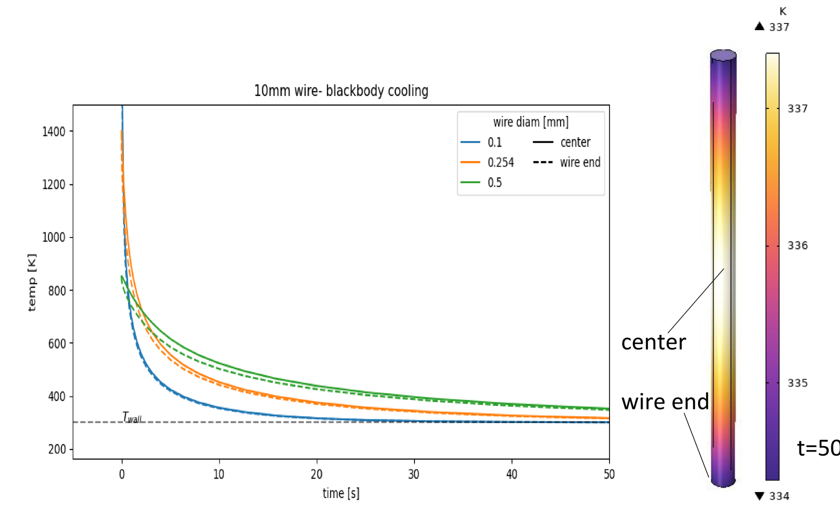


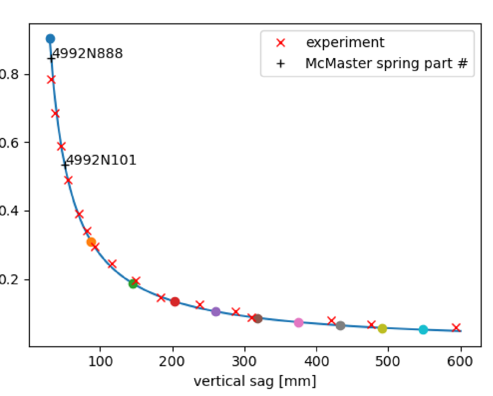
Blackbody

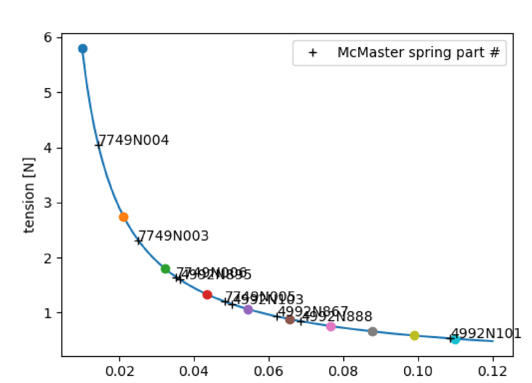
- Initial temperature using present beam parameters vs wire diameter
- Wires cool to wall temp on timescale of ~1 minute (won't limit shot cycle)

Wire diam [mm]	Max dT [K]
.1	2750
.254	1100
.5	550







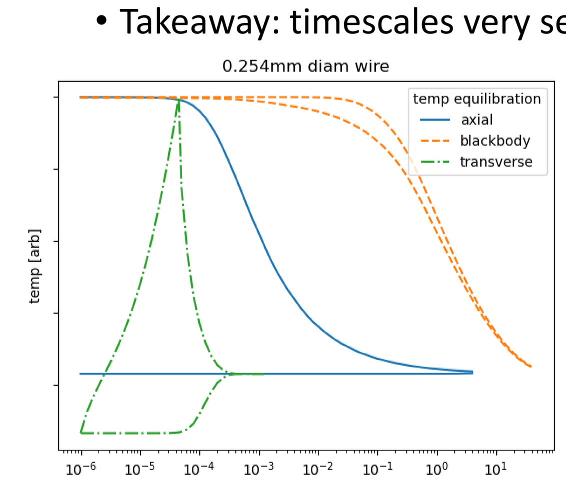


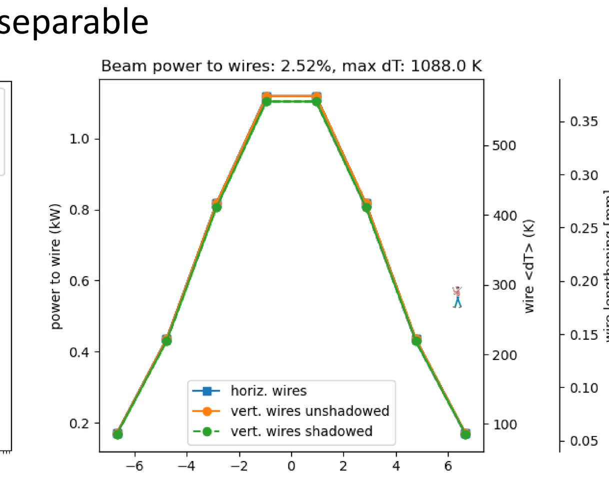
Spring selection

- Catenary experiment used to validate predicted vertical sag in wire vs tension of spring under max load

.254 mm wire analysis

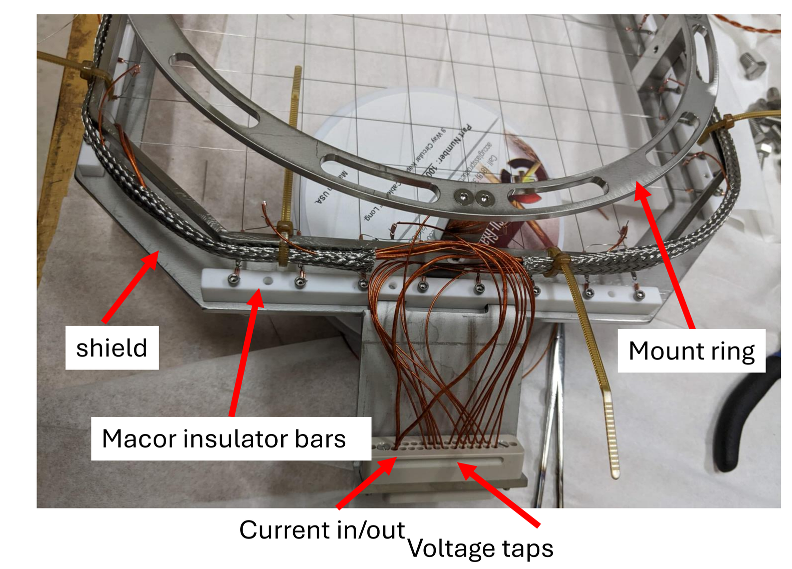
- Max dT to wire center ~1000 deg
- Transverse heating timescale negligible (< 1ms including heating phase)
- Axial (10 cm wire here) nearly accomplished after 0.1 s before blackbody does much of anything
- Takeaway: timescales very separable

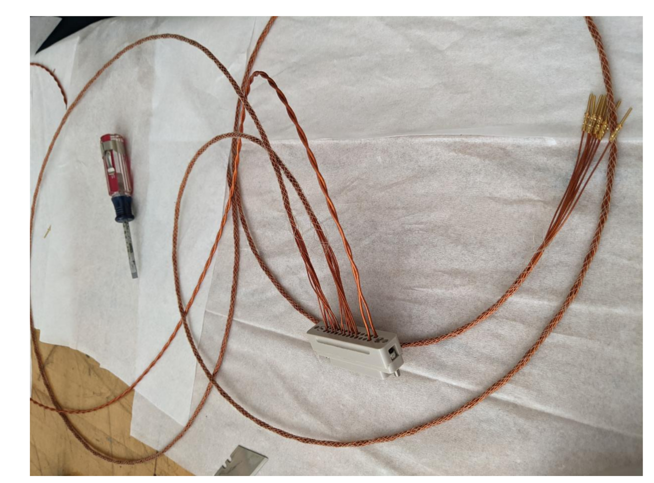




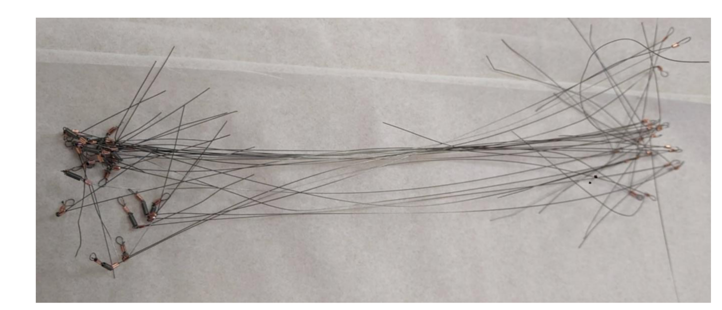
Construction

- Stainless steel construction provides rigidity and shielding of sensitive components from beam path
- Micor insulation bars used to isolate wire from frame
- PEEK 25 pin connection allows for easy detachment in case of upgrade or maintenance requirements





Custom Kapton wiring assembly for in-vacuum wiring to vacuum feedthrough



Each transverse wire length created individually and mechanically joined during assembly at V_{out} locations

Installation on exit port of LTX NBI neutralizer tank

- 20 AWG current leads and 28 AWG voltage taps via custom cabling from Lesker 25 pin DSUB vacuum feedthrough port
- Constant current source provided by Rigol DP831A programmable DC power supply
- 17 channels digitized on NI PXI-6250 DAQ

Initial Data

Forthcoming pending resolution of vented maintenance phase!

References

[1] D.P. Boyle et al 2017, PRL **119** 015001 (2017)
[2] D.P. Boyle *et al* 2023 *Nucl. Fusion* **63** 056020
[3] J.B. Titus *et al Rev. Sci. Instrum.* **92**, 053520 (2021)