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 2D tungsten wire calorimeter has been developed and installed to assess the actual beam profile entering the tokamak and align beam modeling with actual performance
- A Neutral Particle Analyzer is being installed to provide the first direct measurement of fast ion confinement on LTX-β, with calibration underway
- A realignment of the NBI to a larger tangency radius has just been completed to maximize beam coupling, first measurements and documentation of improved performance expected with 2025 experimental campaign

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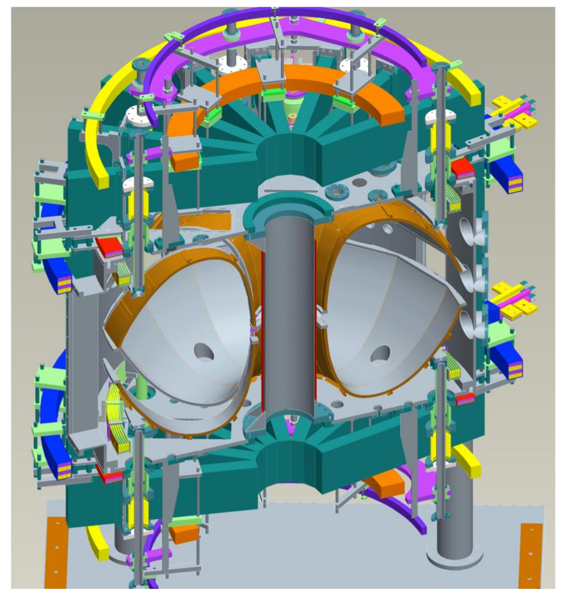
Motivation

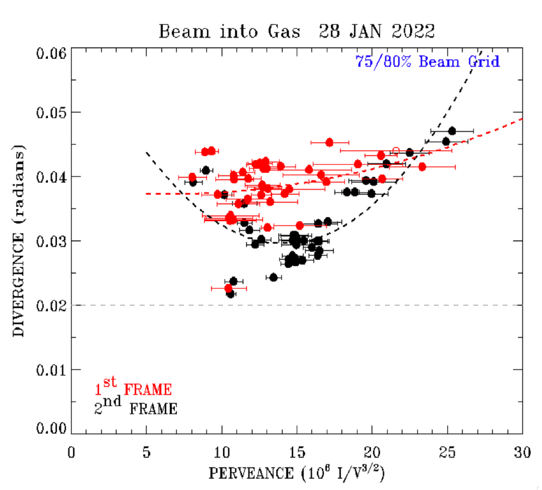
Maximum Parameters		LTX	LTX-β
Major/Minor Radius	R/a	40/26 cm	
Toroidal Field	B_T	0.18 T	0.3 T
Plasma Current	I_p	85 kA	135 kA
Flattop Duration	t_{flat}	~15 ms	~35 ms
Electron Temperature	T_e	~250 eV	~400 eV
Ion Temperature	T_i	~100 eV	~200 eV
Energy Confinement	τ_E	~2 ms	~5 ms
Neutral Beam Current	I_{nbi}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



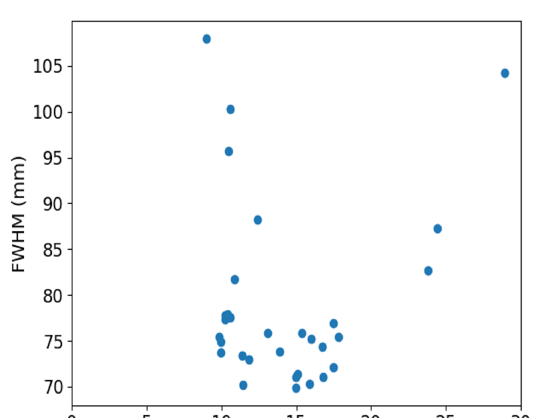
Neutral beam injection provides access to numerous investigations:

- 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-direct measure of beam performance is desirable via wire calorimeter measurement of beam footprint per discharge [3]



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

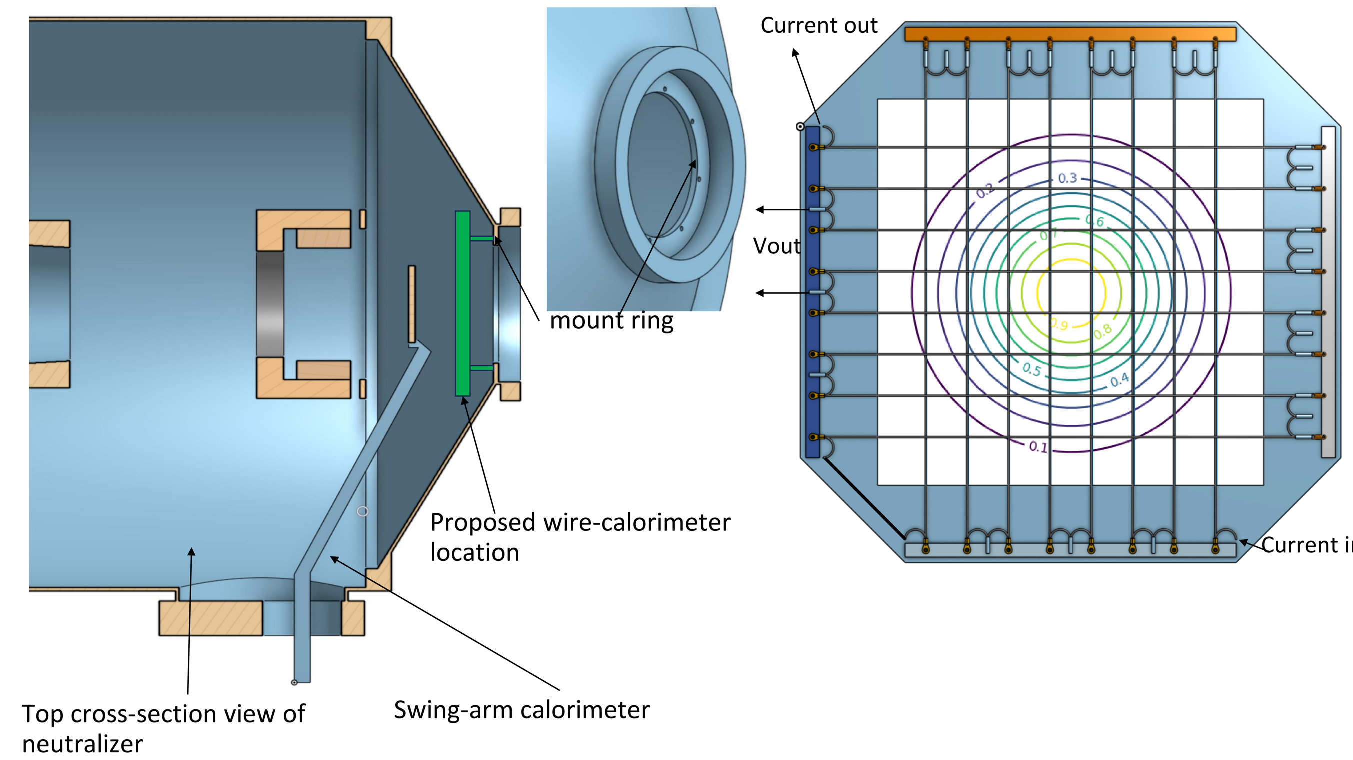


Calorimeter thermocouple data optimization of beam

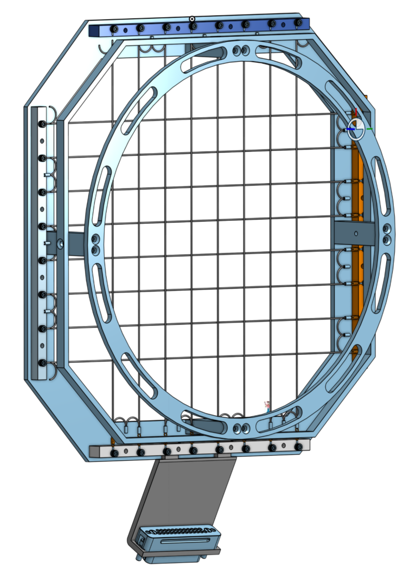
- Access to the beam profile and fast ion energy distribution with the newly installed wire calorimeter and NPA diagnostics will significantly increase data available for modeling and understanding of improved beam coupling of newly realigned NBI

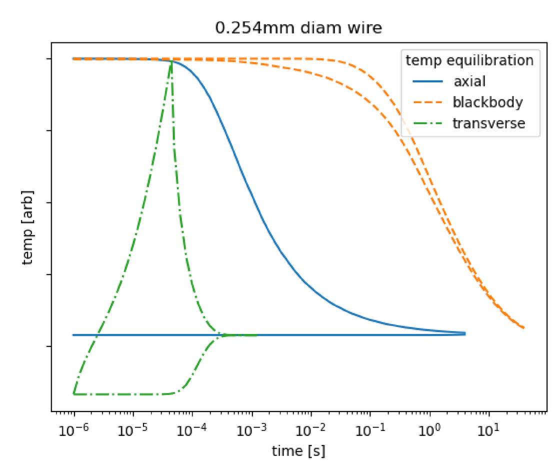
APS DPP Oct 2024

2D Tungsten Wire Calorimeter



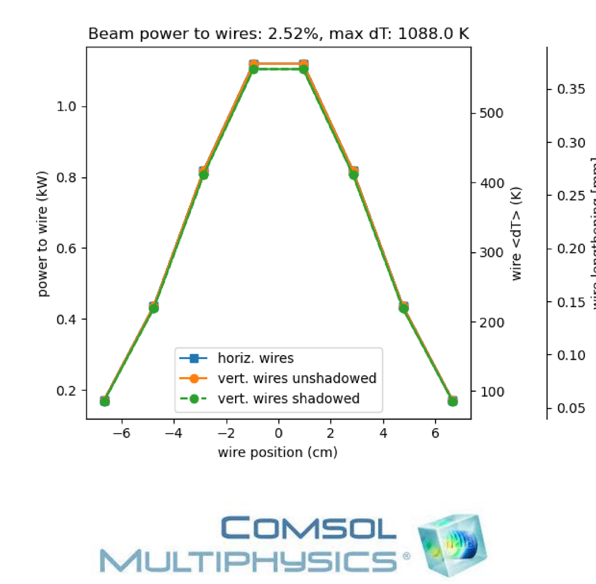
- Space along beamline into vessel extremely limited, mounted just inside neutralizer
- Conveniently unused mount ring, no modifications to tank are necessary
- Wiring through 4" port at tank bottom (not shown)
- Design to fit through 12" conflat on tank side
- Many positives:
  - Naturally beam-normal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

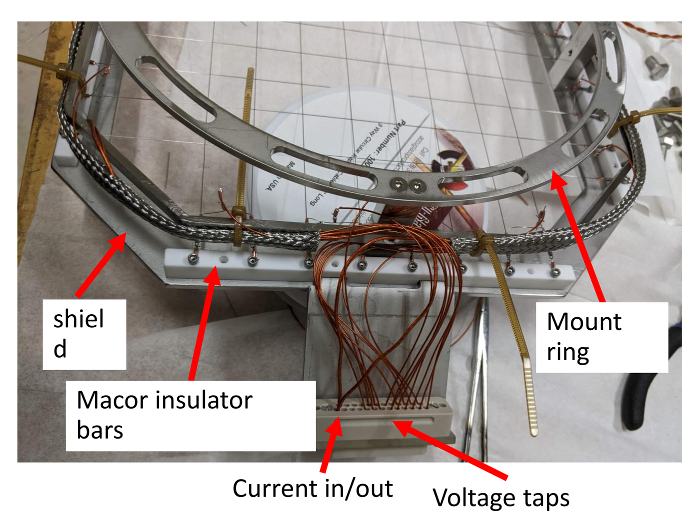




.254 mm wire analysis

- 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



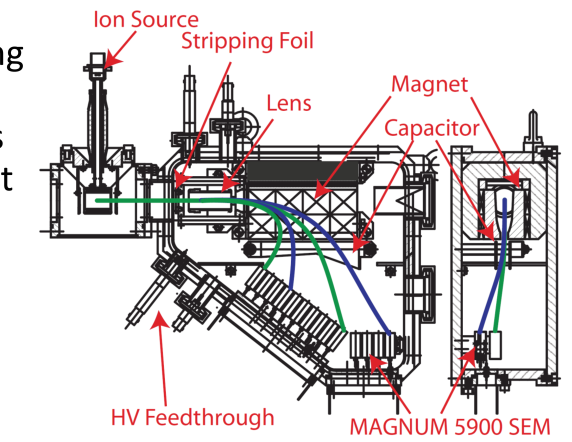


- Stainless steel construction provides rigidity and shielding of sensitive components from beam path
- Micor insulation bars used to isolate wire from frame
- PEEK 25 pin connection allows for easy detachment in case of upgrade or maintenance requirements
- 20 AWG current leads and 28 AWG voltage taps 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

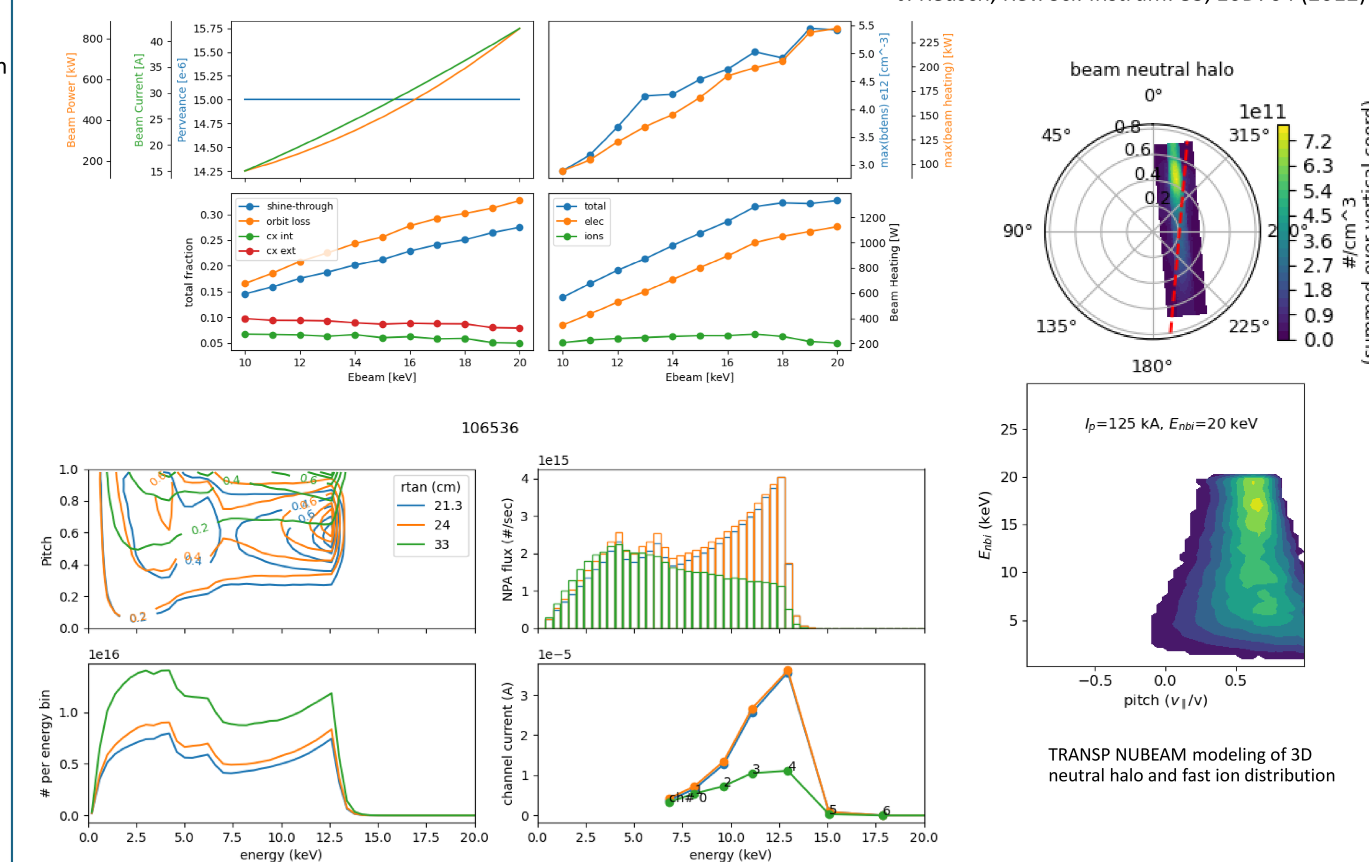
Installation on exit port of LTX NBI neutralizer tank

Neutral Particle Analyzer

- TRANSP NUBEAM modeling predicts increasing heating over available energy range despite increasing first-orbit and shine-through losses
- NPA will provide first direct observation of fast ion population energy distribution in LTX-β
- Suitable NPA on loan from MST
  - Energy range up to 35 keV with 10 keV variable offset
  - Energy resolution 2-4 keV
  - Time resolution 10 μs



J. Reusch, Rev. Sci. Instrum. 83, 10D704 (2012)



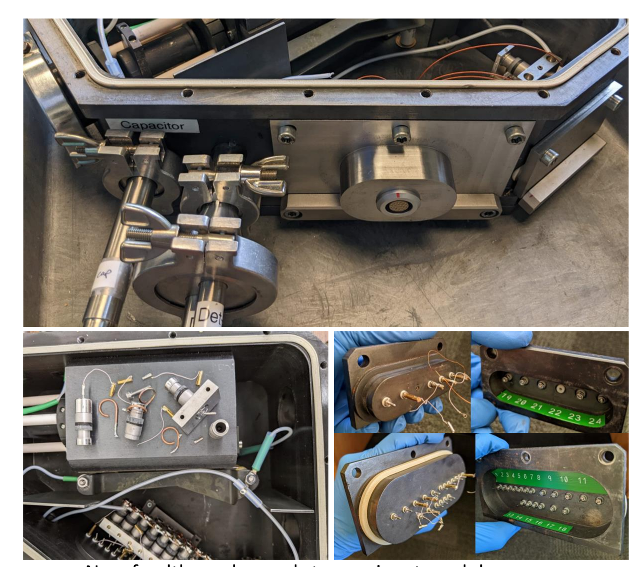
- Larger beam tangency produces higher pitch fast ion population and overall larger population due to better confinement and lower first orbit losses
- NPA signal relies on charge exchange with neutrals; Low neutral inventory of LTX-β plasmas (particularly in core) would lead to an edge-dominated and overall low signal levels on NPA

$$\Gamma_{NPA} = \int_L n_0 n_{fi} \langle \sigma v \rangle_{cx} \delta(\gamma - \gamma_c)(1 - f_r) dl$$

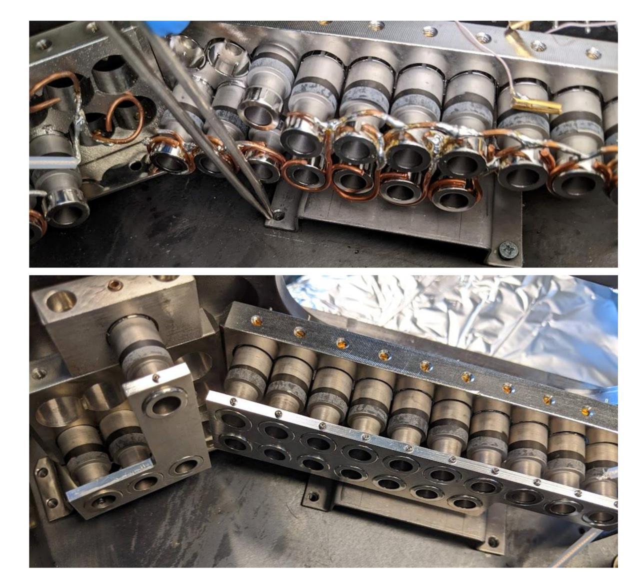
- By utilizing the neutral halo created by NBI, NPA signal increases and becomes more sensitive to fast ion population in the core

Refurbishment and Calibration

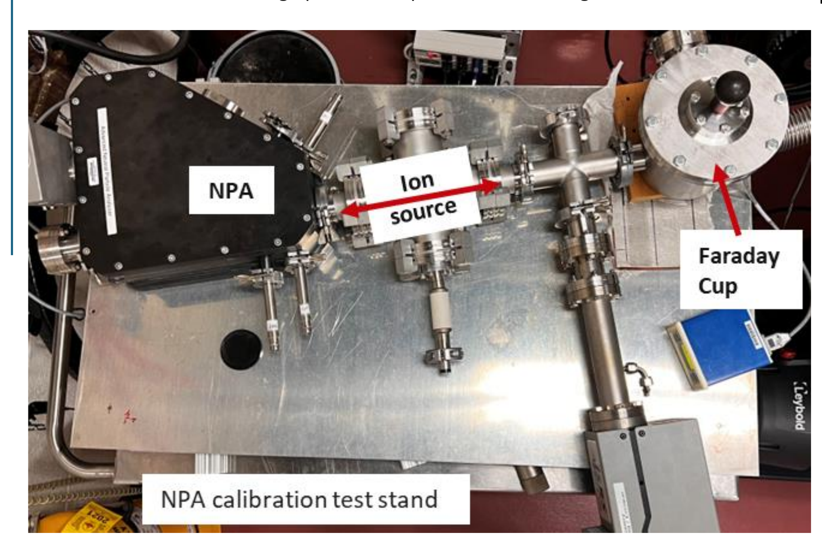
- Repairs are complete on NPA channeltron arrays and wiring
- Rewiring of high voltage power supply complete and approved by PPPL electrical safety
- Currently on stand for calibration
- Calibrated via voltage scan of ion source, with channeltron array signals compared to faraday cup
- Ready to install on LTX-β



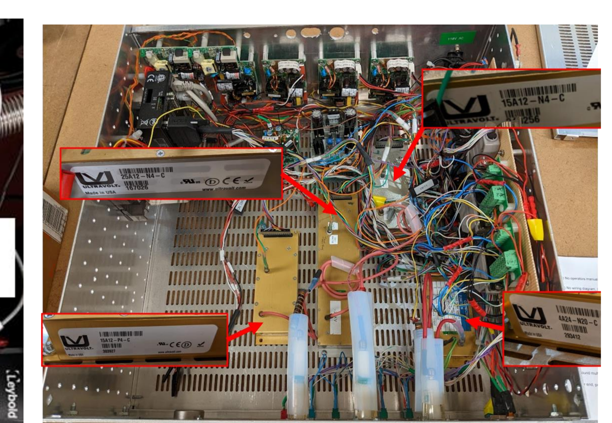
New feedthrough panels to repair external damage



Repairs to internal channeltron high voltage wiring



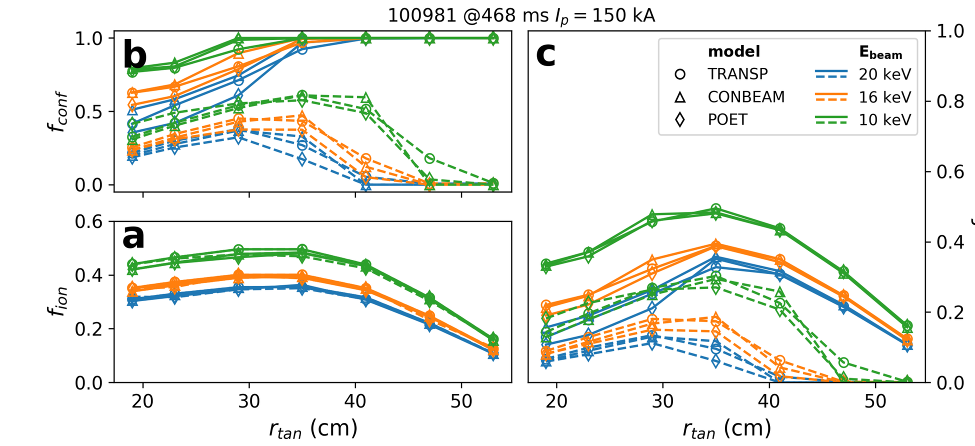
NPA calibration test stand



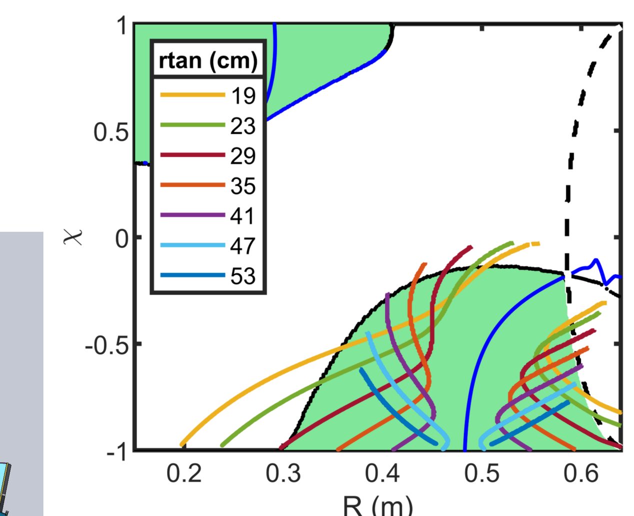
Rewiring and modifications to NPA high voltage power supply

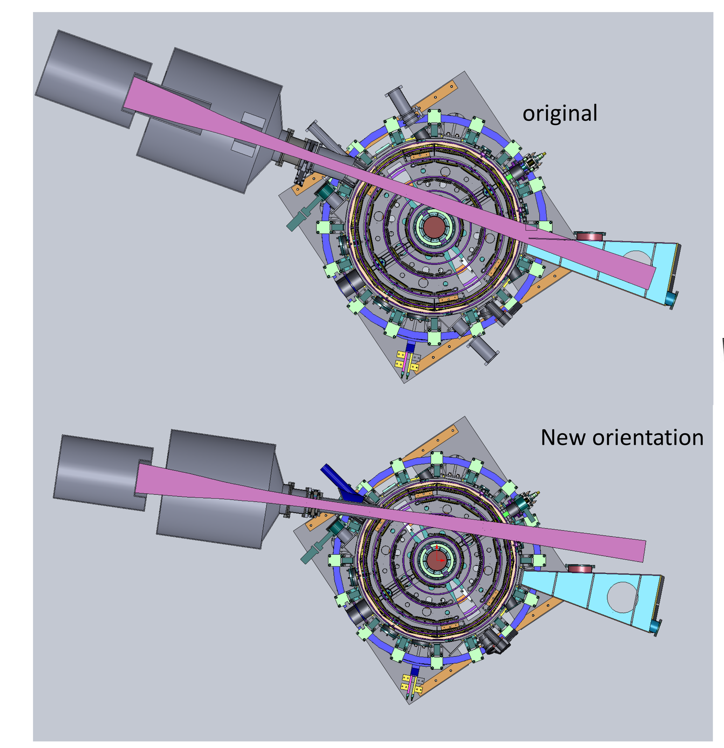
NBI Realignment

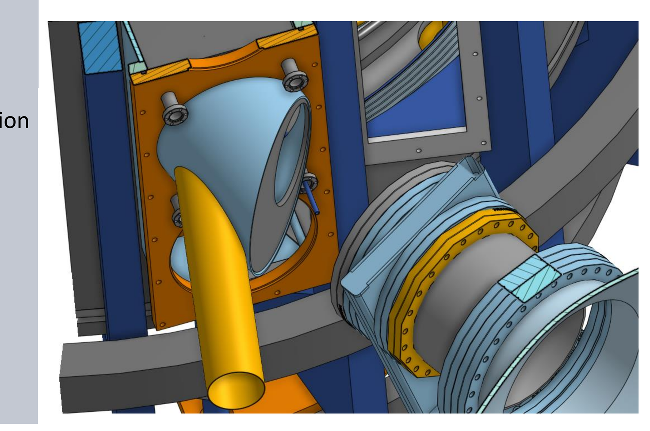
- Modeling suggests an optimal injection tangency radius of 35 cm for a co-Ip injected beam [4]
- This balances increases to coupling due to deposition onto high pitch orbits and decreases via reduced ionization as beam path approaches the plasma edge



- NBI tangency radius scan for both co-injected (solid) and counter-injected (dashed) scenarios. Good agreement between three models showing optimal r_{tan} ~35 cm
- Confinement of ionized fraction goes to unity at large r_{tan} for co-inj ions as pitch deposition shifts further into confined region







- Realignment requires complete redesign of porthole interface
- Optimal tangency radius of 33 cm chosen, beyond which scrape off on injection port sides reduces the injected fraction
- New port installed, LTX-β pump-down and NBI operation expected by end of 2024

Conclusions

- Fueling via NBI is a major research focus of LTX-β to sustain the plasma in low-recycling discharges
- Implementation of a tungsten wire calorimeter is ready to take data and provide beam profile measurements of the injected beam power
- A Neutral Particle Analyzer is being calibrated and will be installed to provide the first direct measure of the fast ion population energy distribution in LTX-β
- Realignment of the NBI to a larger tangency radius (from 19 cm to 33 cm) will improve beam coupling and maximize fueling within the restrictions of the available NBI energy range and machine geometry
- Scan QR code for link to drive containing LTX-β talks and posters

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)

[4] W. Capecchi *et al* 2021 Nucl. Fusion **61**, 126014