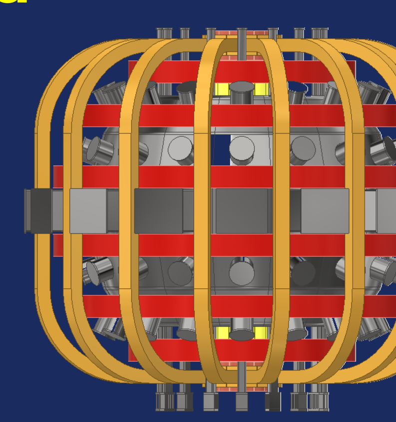
Optimization design of Poloidal field system, Equilibrium and Divertor of the EHL-2 Spherical Torus



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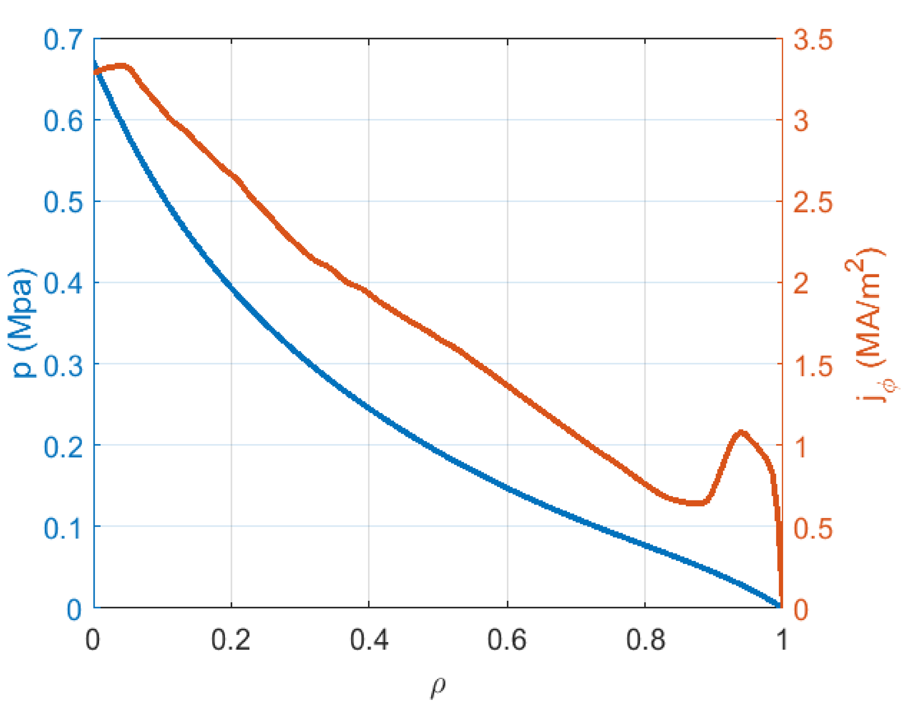
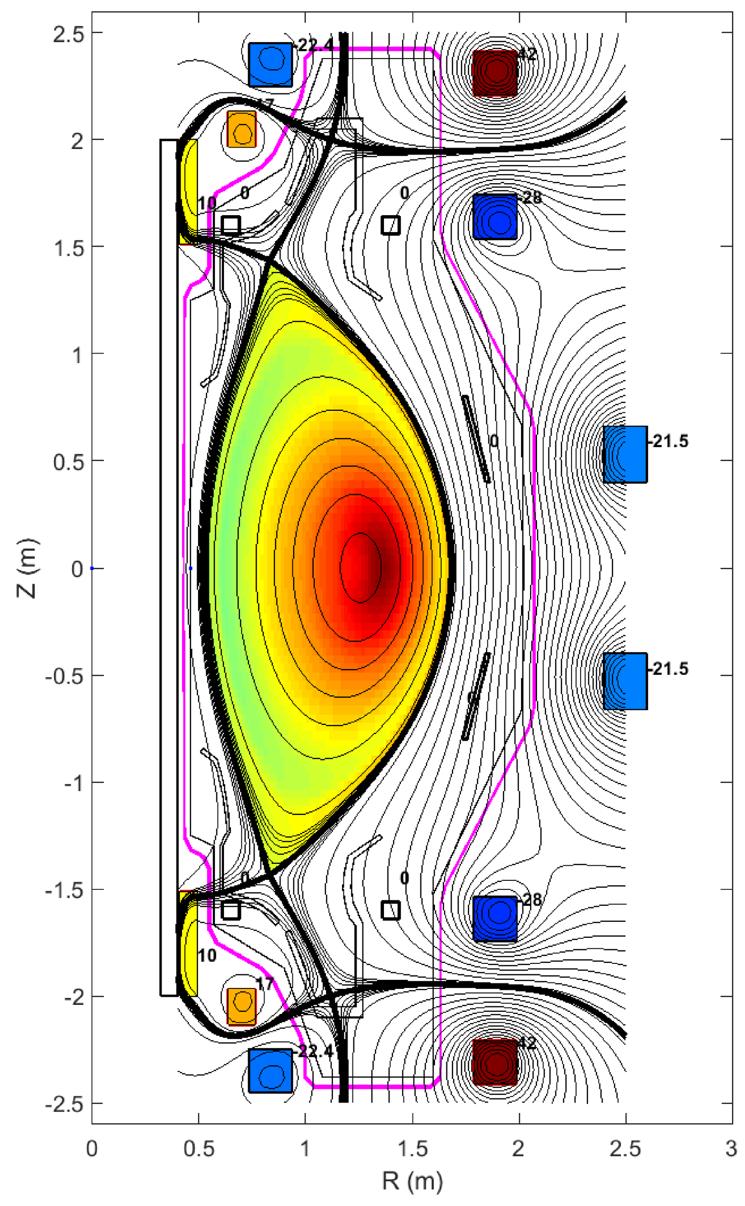
ABSTRACT

The EHL-2 (ENN He-Long 2) project is a spherical torus (ST) facility designed to investigate proton-boron (p-11b) fusion plasmas under extreme conditions, aiming for ion temperatures above 30 keV and densities near $10^{20}m^{-3}$. This study presents an integrated optimization of the poloidal field (PF) system, plasma equilibrium, discharge scenarios and divertor physics design to ensure stable and safety X-point target (XPT) divertor equilibrium operation. With iterative equilibrium reconstruction and discharge design, a robust 3 MA discharge was developed, demonstrating stable multi-X point configurations throughout the flat-top phase. The redesigned PF system, accounting for engineering constraints, enables stable XPT divertor operation. The divertor physics design demonstrates that partial detachment can be achieved when the outboard midplane (OMP) separatrix density reaches 1.8×10^{19} m^{-3}. These results establish a solid basis for future experimental exploration of advanced operating regimes in EHL-2 and provide guidance for the development of aneutronic fusion concepts.

I. PF system and Equilibrium

Optimization of Poloidal field coil system and X-point target divertor configuration equilibrium based on the current density (J) and pressure (p) profiles are derived from a high-ion-temperature operational regime

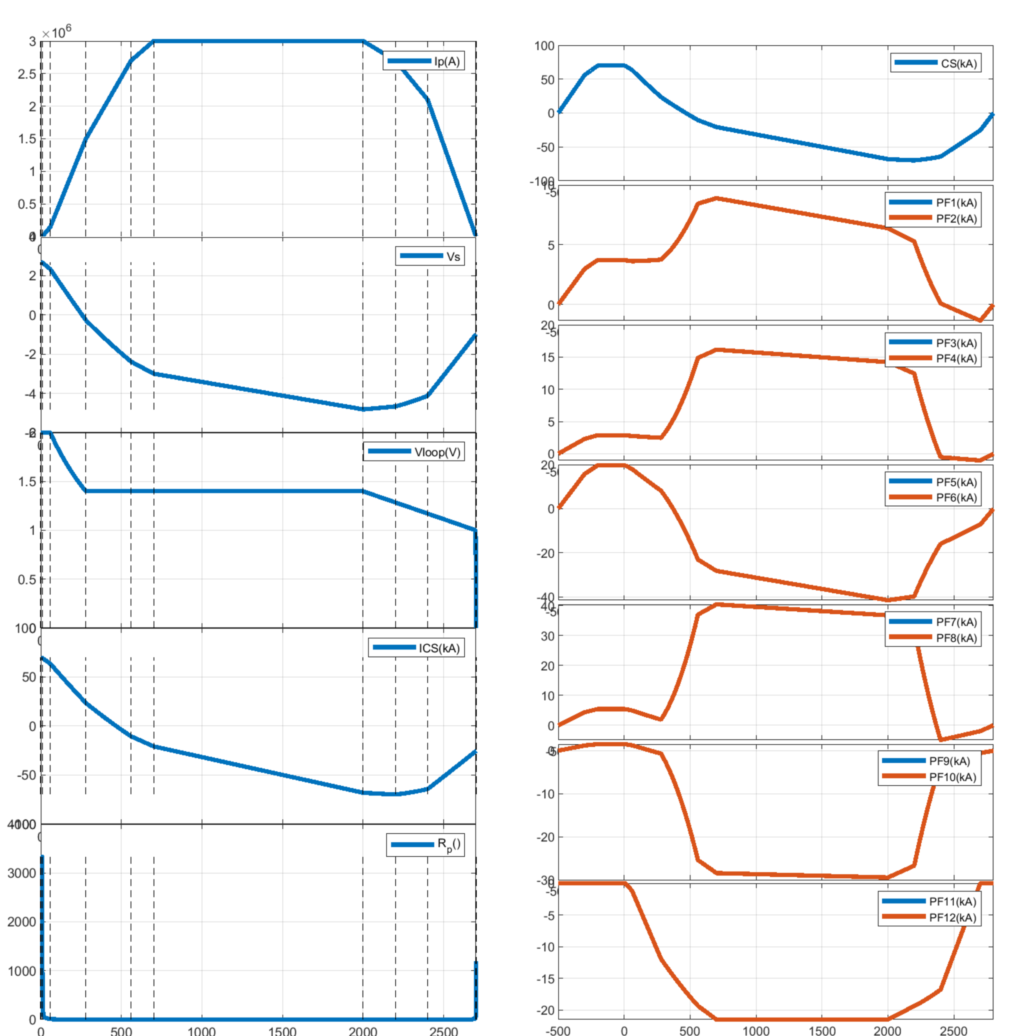


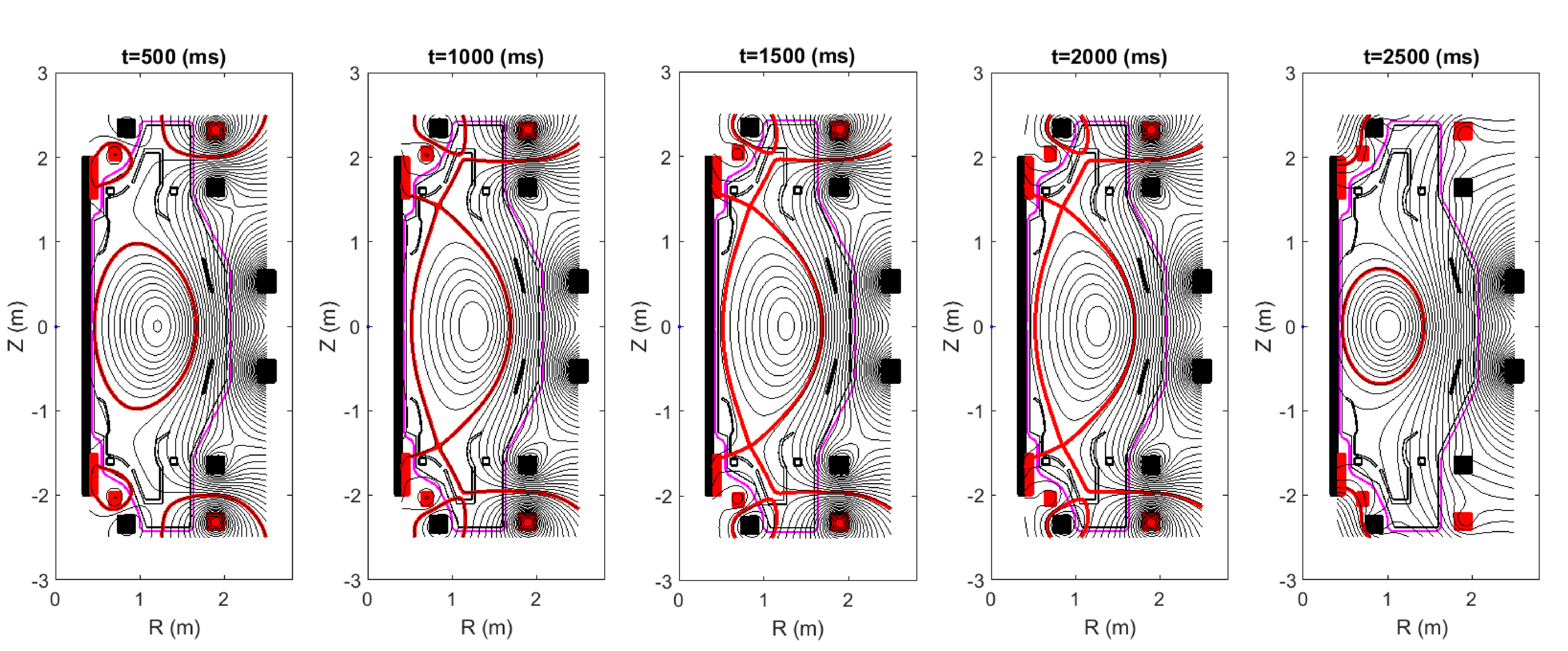


lables	Xcenter (m)	Ycenter (m)	W(m)	H(m)	NX	NY	N	Angle	IexMax(kA)	J (A/mm2)
CS	0.360	0.000	0.080	4.000	4	75	300	90	70	65.63
PF1	0.450	1.756	0.080	0.488	4	18	72	90	17	31.35
PF2	0.450	-1.756	0.080	0.488	4	18	72	90	17	31.35
PF3	0.700	2.050	0.126	0.166	6	8	46	90	12	26.39
PF4	0.700	-2.050	0.126	0.166	6	8	46	90	12	26.39
PF5	0.835	2.350	0.200	0.200	6	6	34	90	35	29.75
PF6	0.835	-2.350	0.200	0.200	6	6	34	90	35	29.75
PF7	1.890	2.310	0.200	0.200	6	6	34	90	35	29.75
PF8	1.890	-2.310	0.200	0.200	6	6	34	90	35	29.75
PF9	1.890	1.640	0.200	0.200	6	6	34	90	35	29.75
PF10	1.890	-1.640	0.200	0.200	6	6	34	90	35	29.75
PF11	2.500	0.530	0.200	0.260	6	8	46	90	35	30.96
PF12	2.500	-0.530	0.200	0.260	6	8	46	90	35	30.96
PF13	1.400	1.600	0.080	0.080	2	2	4	90	16	10.00
PF14	1.400	-1.600	0.080	0.080	2	2	4	90	16	10.00
PF15	0.650	1.600	0.080	0.080	2	2	4	90	16	10.00
PF16	0.650	-1.600	0.080	0.080	2	2	4	90	16	10.00
PF17	1.800	0.600	0.020	0.400	1	1	1	105	4	0.50
PF18	1.800	-0.600	0.020	0.400	1	1	1	75	4	0.50

II. Stable XPT Divertor Discharge

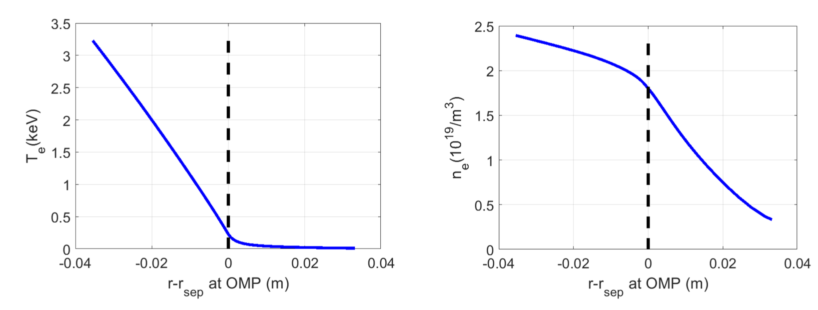
- ECRH pre-ionization allows achieving 3 MA with reduced volt-seconds
- The stability of the X-point target (XPT) configuration can be ensured by a precisely optimized null field
- The secondary X-point position remains relatively stable during the flat-top phase

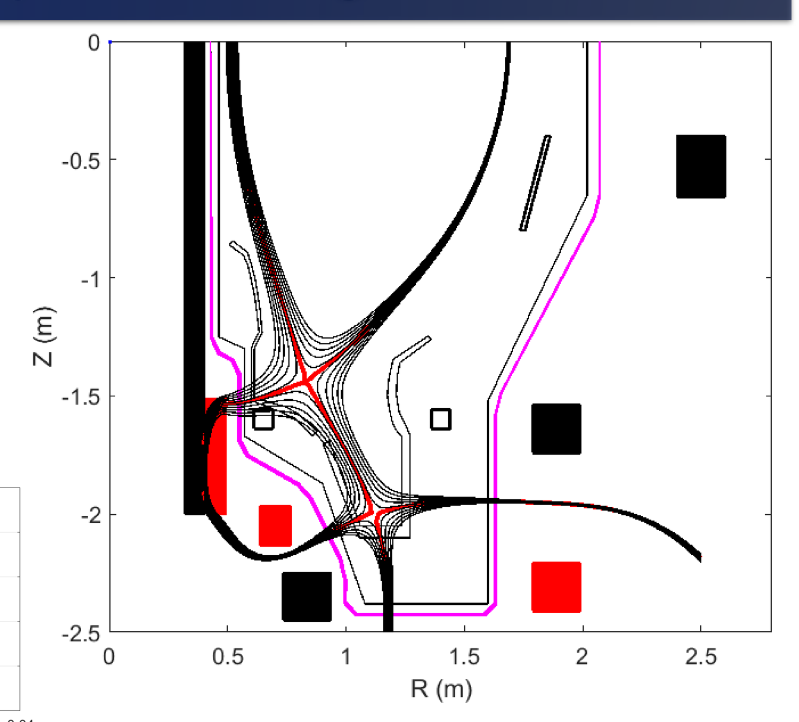




III. Closeure Divertor Physics Design

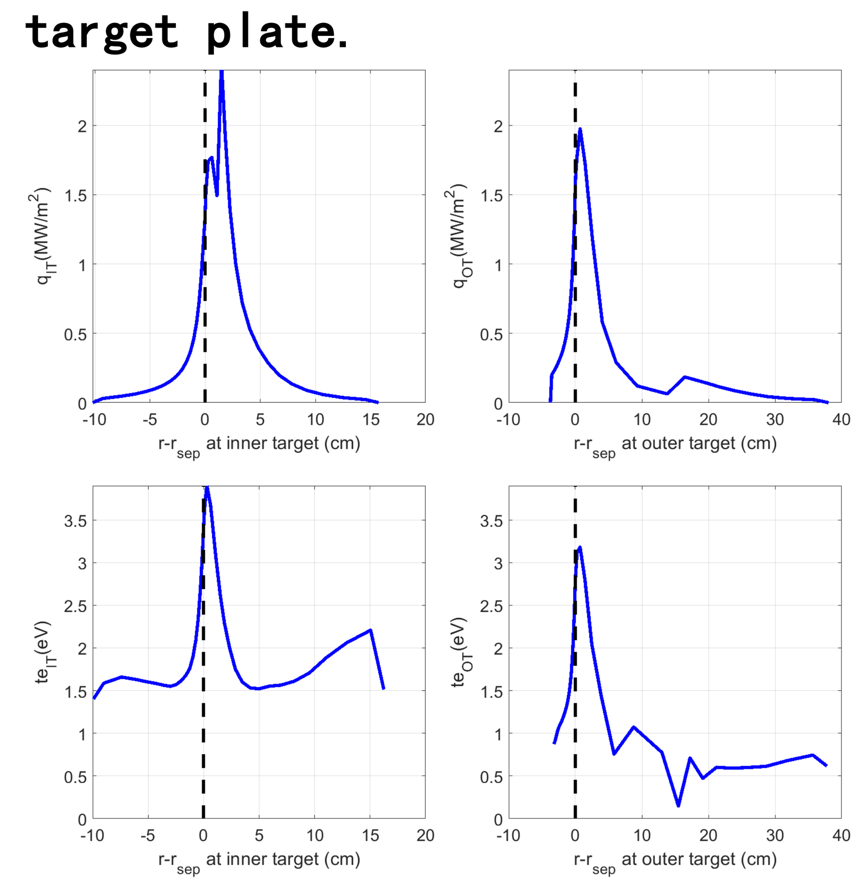
- CFC is the preferred material for the first wall and divertor
- Closure with X-Point Target divertor has been optimized and evaluated for different upstream density

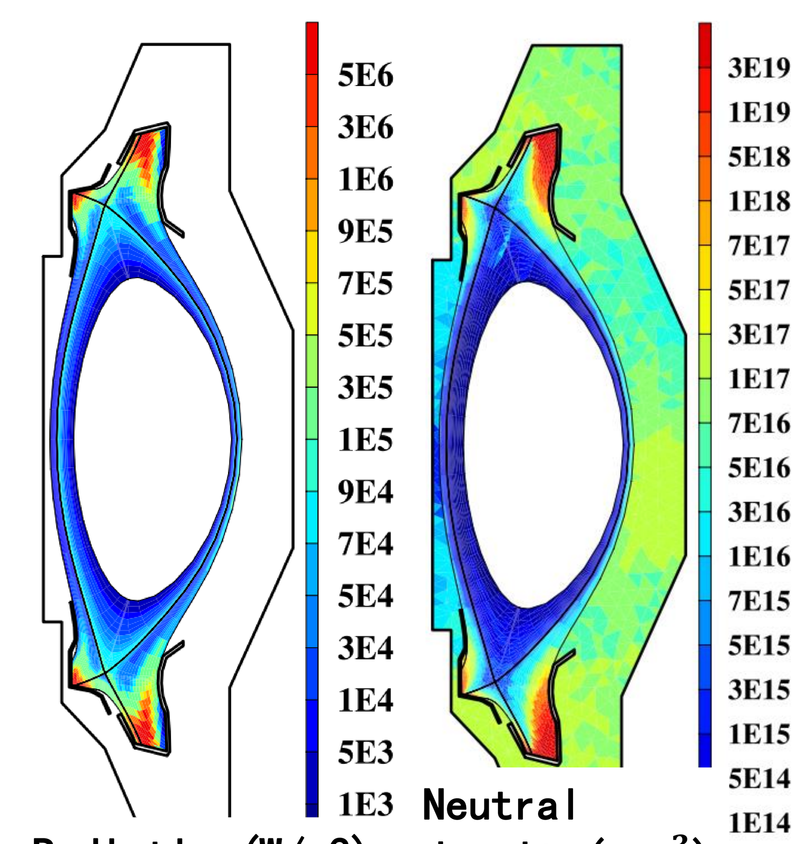




- Electron temperature and density profiles at the outer target plate
- In the present SOLPS-ITER simulation the energy flux entering SOL is 20W and three species H, B and C are included.

The V-shaped geometry has good divertor closure, which can effectively restrict the aggregation of neutral particles in the divertor area, increase radiation power, reduce the corresponding heat flux and electron temperature of the divertor target, and suppress impurity sputtering of the target plate.





Radiation (W/m3) Neutral density (m^{-3})

IV. Conclusion and Discussion

- An integrated optimization of the poloidal field (PF) system, plasma equilibrium, divertor physics and discharge scenarios has been carried out for the EHL-2 spherical torus
- Discharge with stable XPT divertor configuration at flat-top is given.
- The optimized V-shaped divertor geometry improves closure and facilitates detachment, ensuring controllable heat loads under high-power operation.
- Additional density scans at the OMP are needed to systematically determine the detachment onset conditions and their dependence on key plasma parameters.

Reference

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