2-D Divertor Design Calculations for the NHTX

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Predictions of divertor plasma characteristics in NHTX

- Introduction to NHTX
- Code description
- Parameter scans with simple divertor plates
  - Single configuration:
    - Power scan from 10-50 MW at neped ~ 1.5e20
    - Density scan from 7.5e19 - 3e20 at P=30 MW
    - Recycling scan from 0.9-0.99
    - Impurity radiation scans for carbon, neon, argon
  - Calculations for three other configurations
- Potential solutions
  - Conventional vertical target
  - IFS "Super-X" Divertor (UT-Austin)
- Discussion and conclusions

NHTX can lead the field in the integration necessary for successful CTF/FDF & Demo

	R (m)	a (m)	P (MW)	P/R (MW/m)	P/S (MW/m^2)	Pulse (s)	I_p (MA)	Species	Comments
JT-60SA	3.01	1.14	41	14	0.21	100	3.0	D	JA-EU Collaboration
KSTAR	1.80	0.50	29	16	0.52	300	2.0	H (D)	Upgrade Capability
LHD	3.90	0.60	10	3	0.11	10,000	–	H	Upgrade capability
SST-1	1.10	0.20	3	3	0.23	1000	0.2	H (D)	Initial heating
W7-X	5.50	0.53	10	2	0.09	1800	–	H	30MW for 10sec
NHTX	**1.00**	**0.55**	**50**	**50***	**1.13**	**1000**	**3.5**	**D (DT)**	**Initial heating**
ITER	6.20	2.00	150	24	0.21	400-3000	15.0	DT	Not for divertor testing
Component Test Facility Designs									
CTF (A=1.5)	1.20	0.80	58	48	0.64	weeks	12.3	DT	2 MW/m^2 neutron flux
FDF (A=3.5)	2.49	0.71	108	43	1.61	weeks	7.0	DT	2 MW/m^2 neutron flux
Demonstration Power Plant Designs									
ARIES-RS	5.52	1.38	514	93	1.23	months	11.3	DT	US Advanced Tokamak
ARIES-AT	5.20	1.30	387	74	0.85	months	12.8	DT	US Advanced Technology
ARIES-ST	3.20	2.00	624	195	0.99	months	29.0	DT	US Spherical Torus
ARIES-CS	7.75	1.70	471	61	0.91	months	3.2	DT	US Compact Stellarator
ITER-like	6.20	2.00	600	97	0.84	months	15.0	DT	ITER @ higher power, Q
EU A	9.55	3.18	1246	130	0.74	months	30.0	DT	EU "modest extrapolation"
EU B	8.60	2.87	990	115	0.73	months	28.0	DT	EU
EU C	7.50	2.50	794	106	0.71	months	20.1	DT	EU
EU D	6.10	2.03	577	95	0.78	months	14.1	DT	EU Advanced
SlimCS	5.50	2.12	650	118	0.90	months	16.7	DT	JA
CREST	7.30	2.15	692	95	0.73	months	12.0	DT	JA

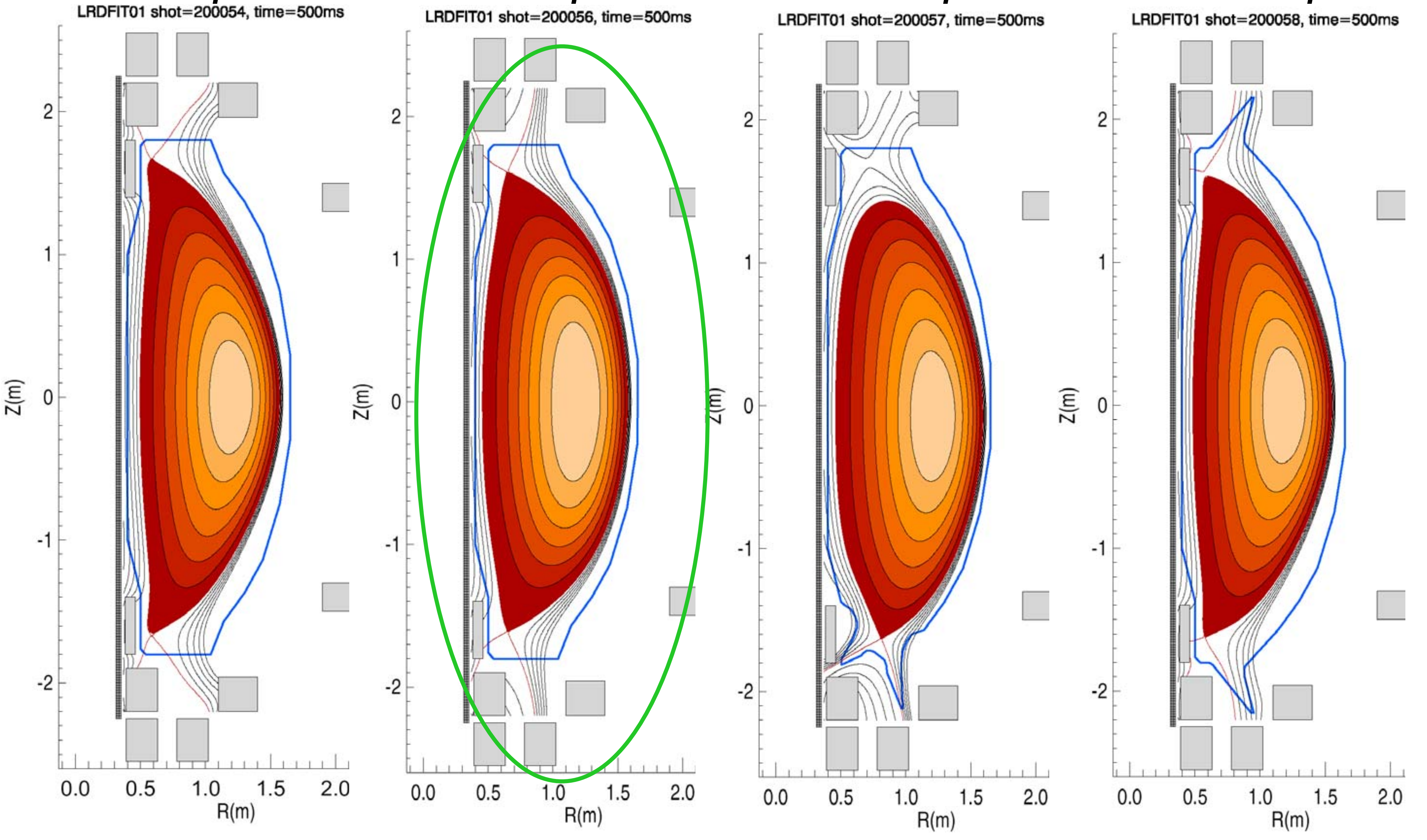
NHTX mission: "To study the integration of high-confinement, high-beta, long-pulse non-inductive plasma operation with a fusion-relevant high-power plasma-boundary interface."

SOLPS is used to calculate SOL plasma properties

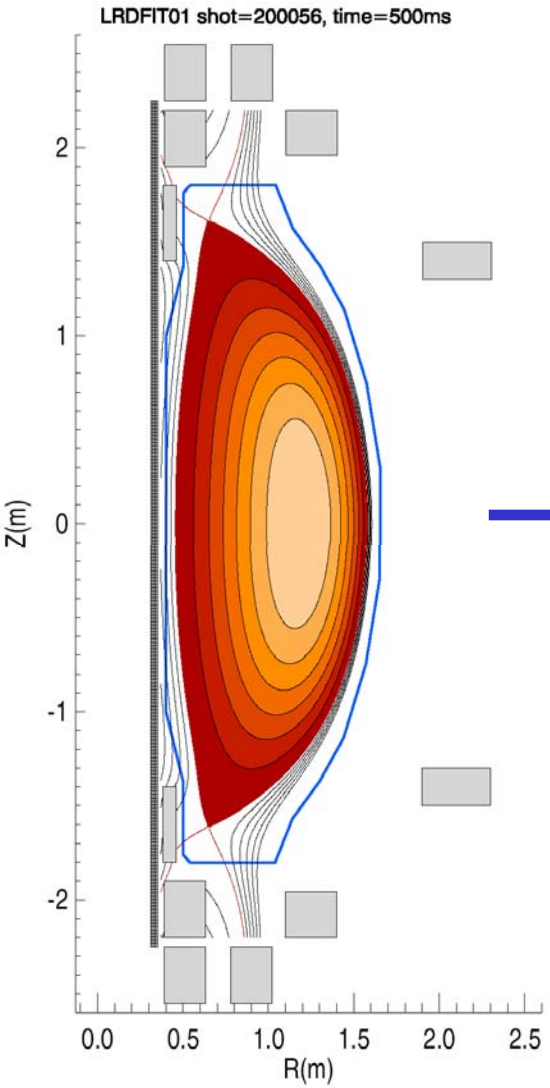
- SOLPS: Scrape Off Layer Plasma Simulation
  - 2D plasma fluid code (B2.5)
    - Plasma transport through SOL to targets
  - Monte Carlo neutrals code (Eirene)
    - Takes wall fluxes, returns neutral sources to B2
  - Two are coupled via
    - Atomic processes (ionization, recombination)
    - Plasma-wall process (recycling, sputtering)
- Plasma transport assumptions
  - Classical in parallel direction
  - Cross-field transport coefficients D, χ = 0.4, 1.6 m^2/s
- Core boundary conditions
    - Input power fixed to values between 10 and 50 MW
    - Density fixed between $7.5x10^{19}$ and $3.0x10^{20}$ m^{-3}
- Targets Recycling coefficients set to 0.90-0.99 (1 elsewhere)

2-D SOL and divertor calculations completed for four different configurations

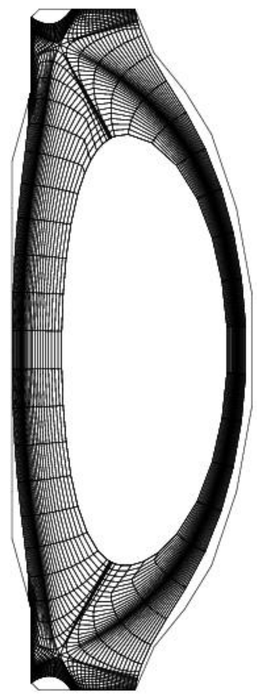
DN f_{exp} ~ 21 | **DN f_{exp} ~ 10** | **LSN f_{exp} ~ 5** | **DN slot f_{exp} ~ 25**



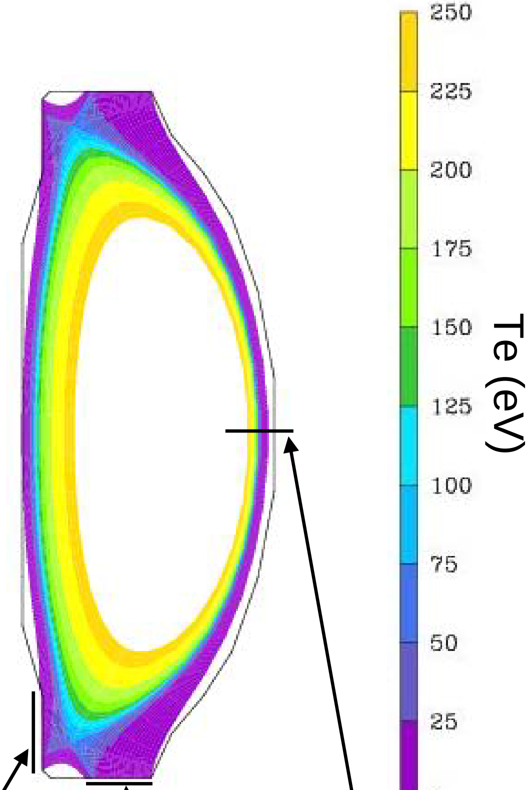
Comparison of Equilibrium to Computational Grid



2D quantities calculated…



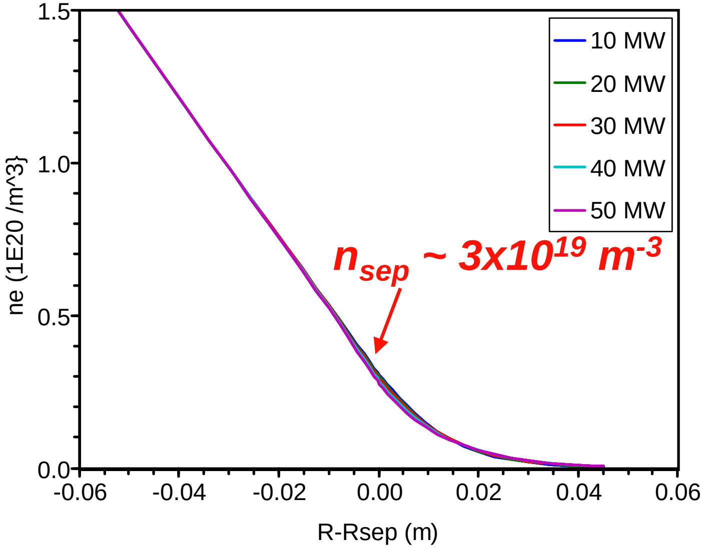
96 x 36 grid



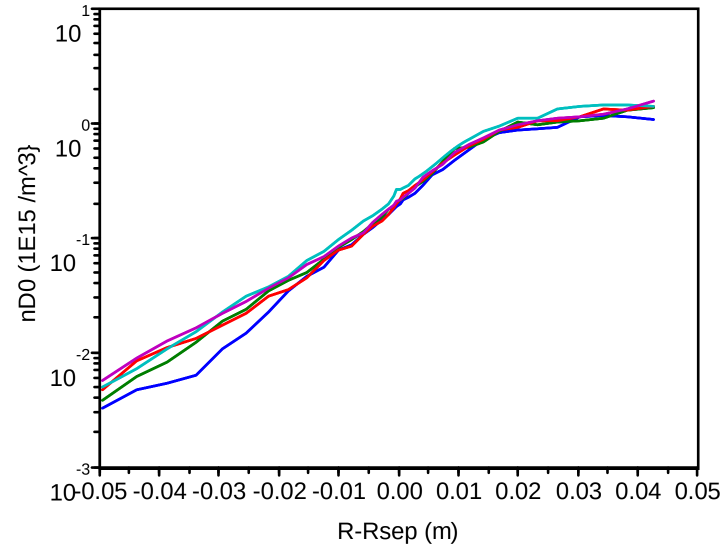
1D quantities plotted along left and right targets, midplane

Midplane profiles at fixed core density, P = 10 – 50 MW

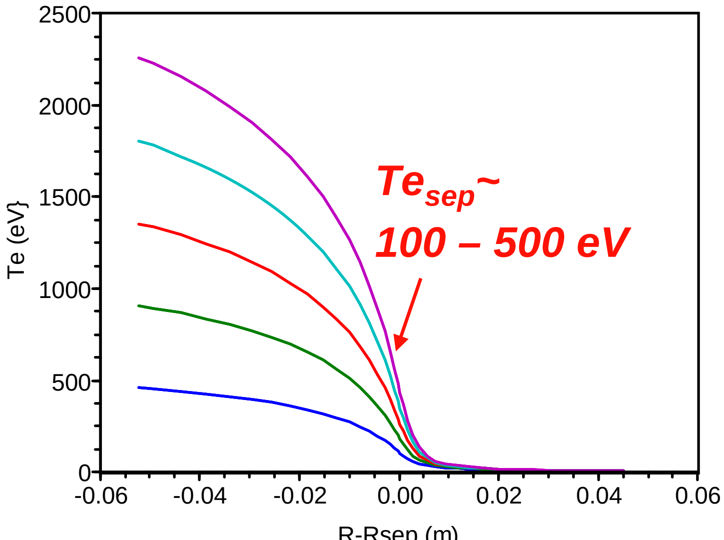
Midplane Electron Density



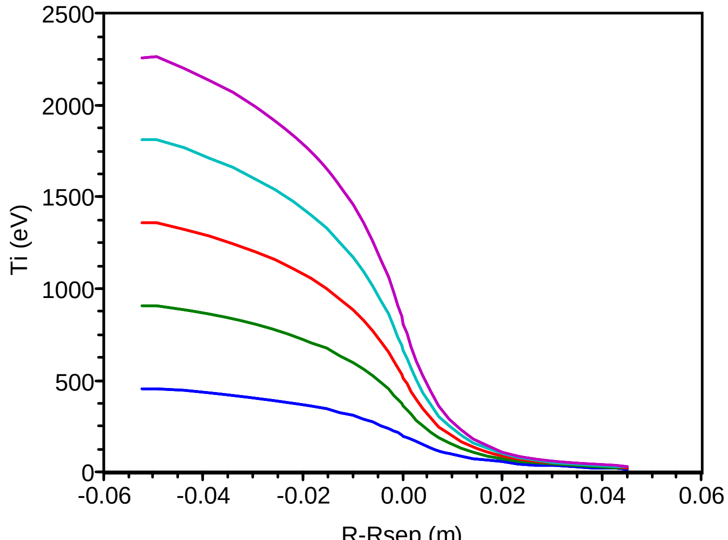
Midplane Atomic Density



Midplane Electron Temperature



Midplane Ion Temperature



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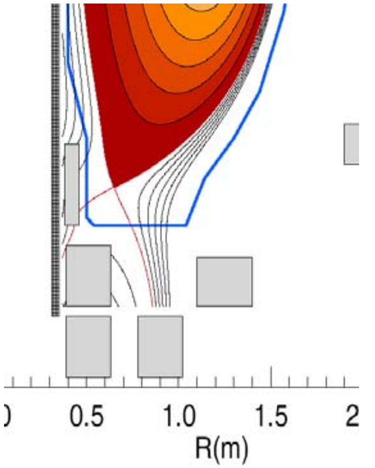
n_{core} = 1.5e20

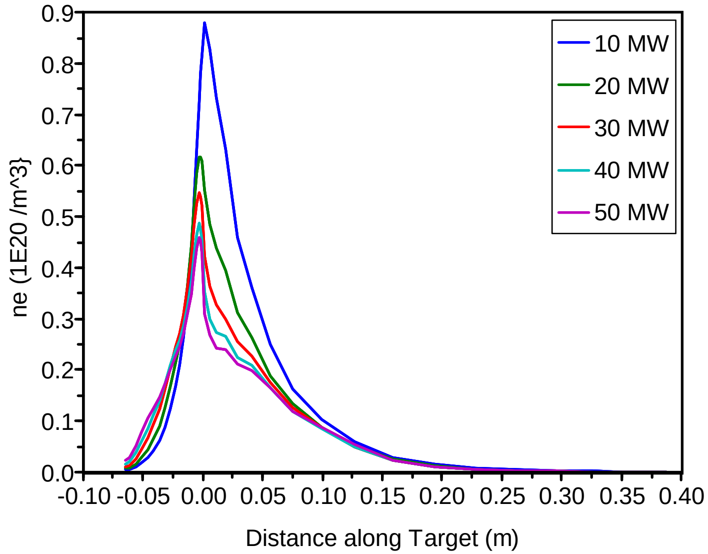
R = 0.95

Pure D Plasma

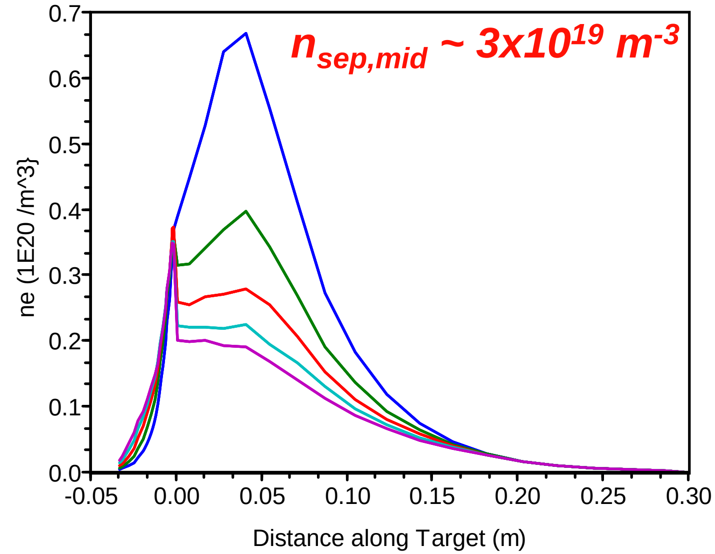


SOL plasma is sheath-limited near separatrix: T, n ~ midplane values

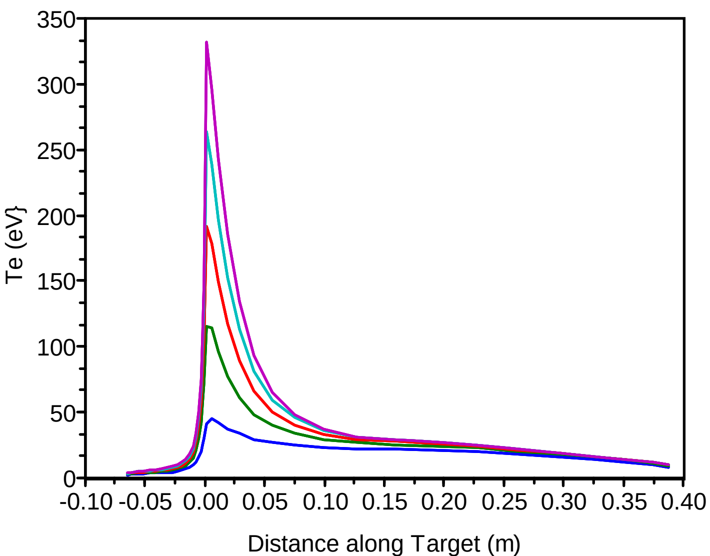
Electron Density Left Divertor



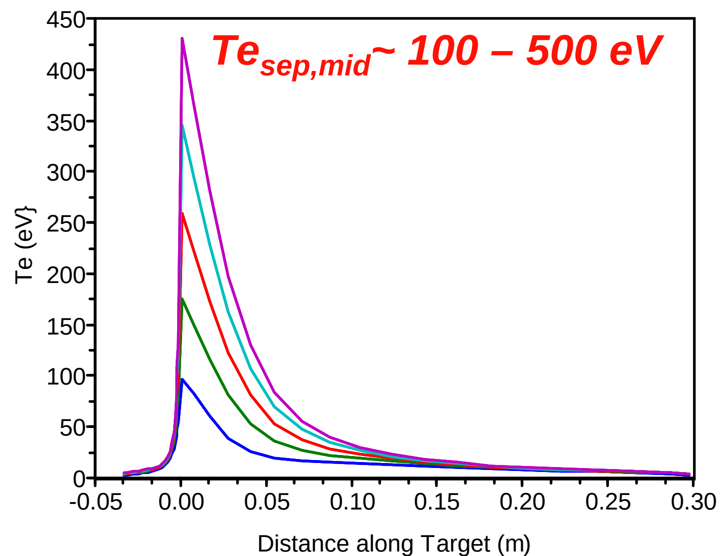
Electron Density Right Divertor



Electron Temperature Left Divertor



Electron Temperature Right Divertor



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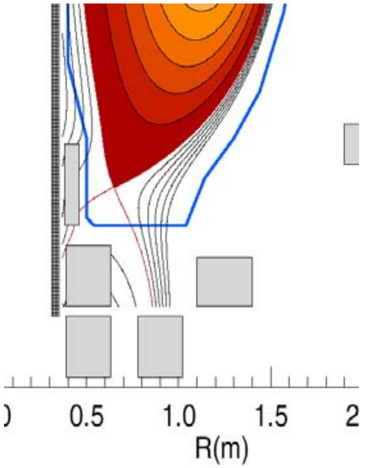
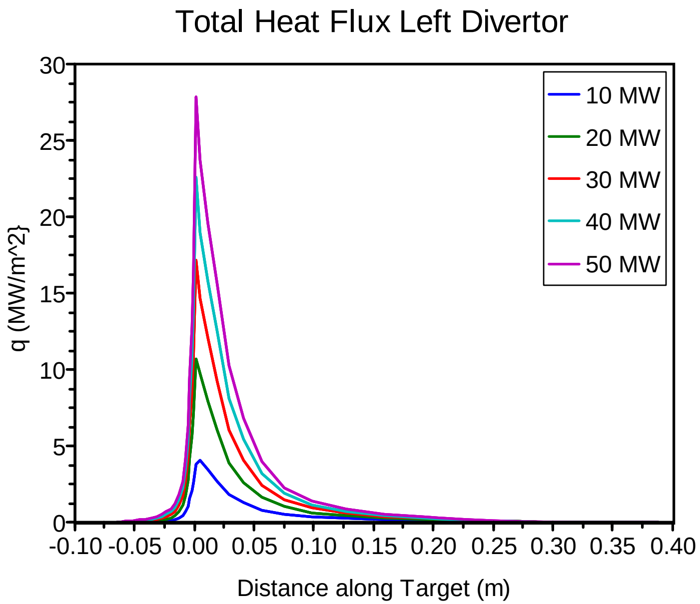
n_{core} = 1.5e20

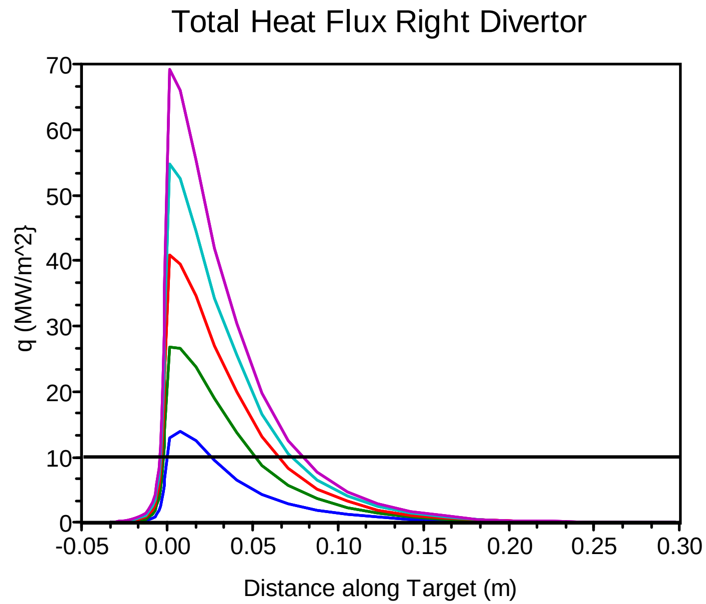
R = 0.95

Pure D Plasma



Total heat flux is up 70 MW/m^2 at outer target





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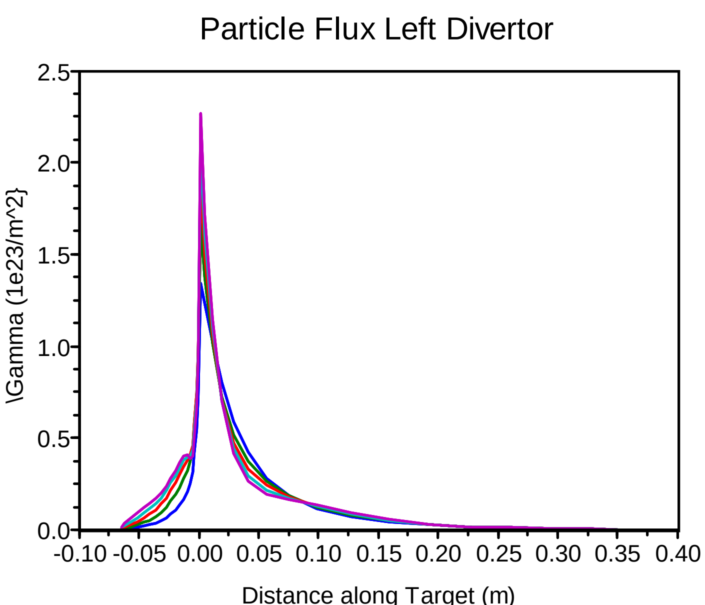
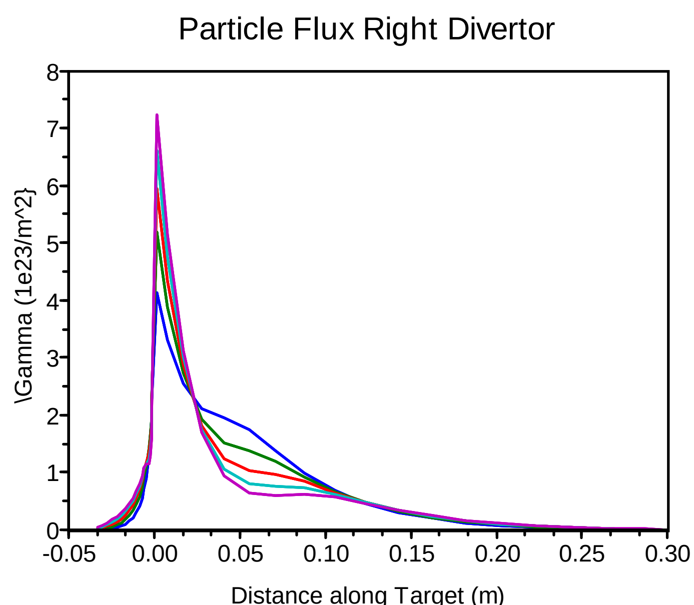
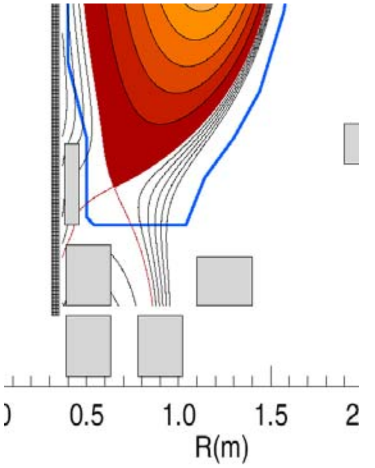
R = 0.95

Pure D Plasma

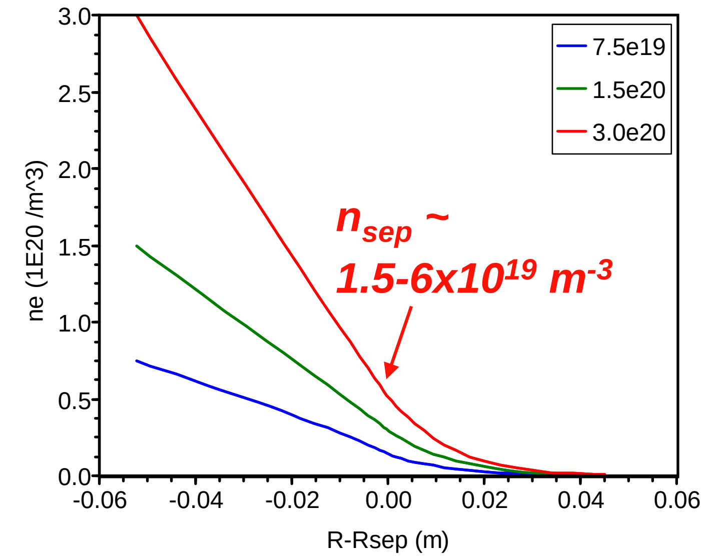




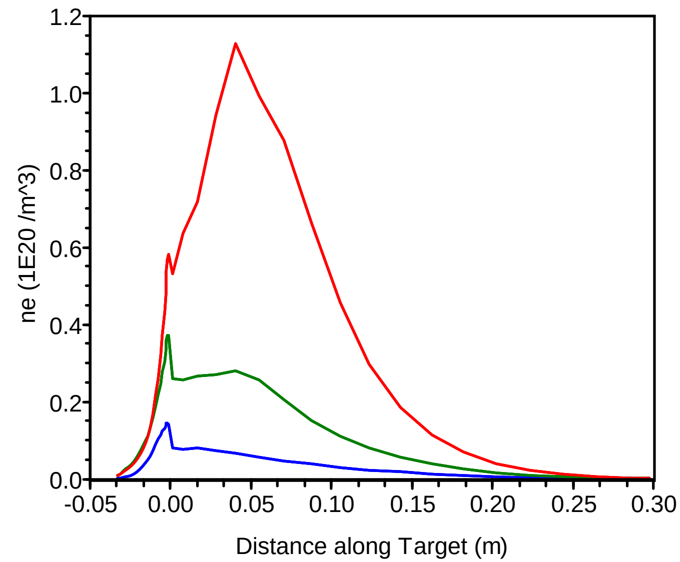


Density scan:
Midplane, target profiles at fixed P (30MW), n_{core} = 0.75-3.0e20

Midplane Electron Density



Electron Density Right Divertor



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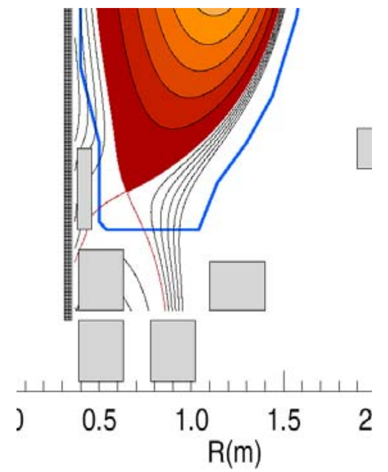
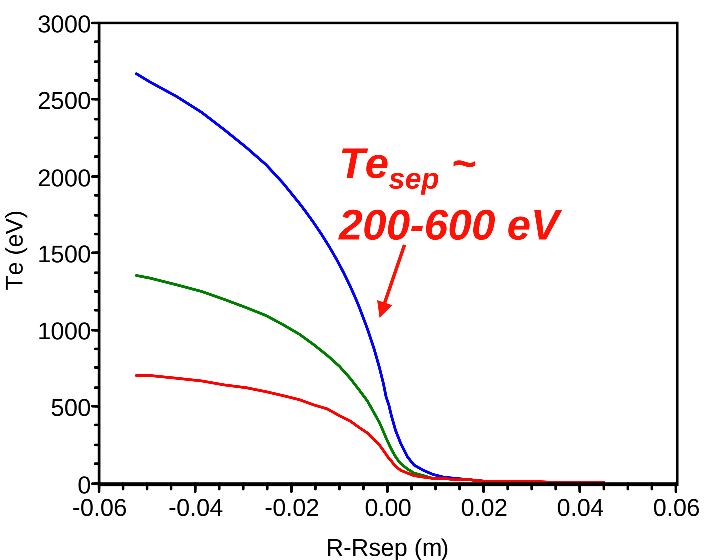
P = 30MW

R = 0.95

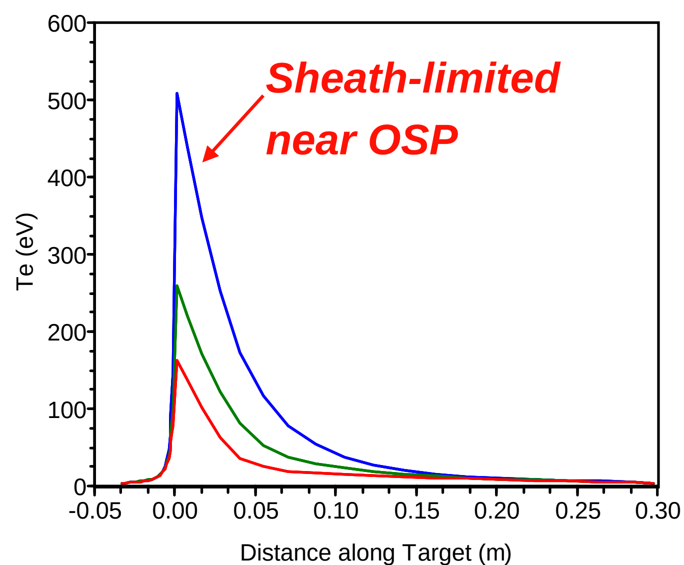
Pure D Plasma



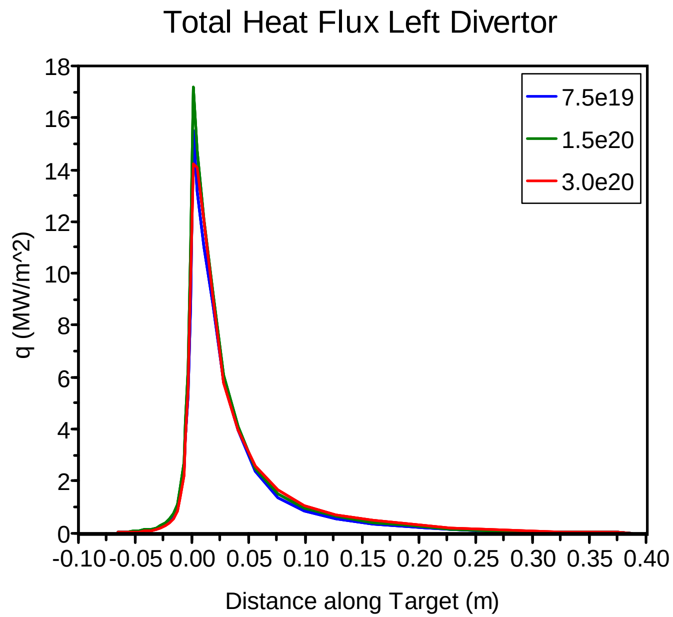
Midplane Electron Temperature

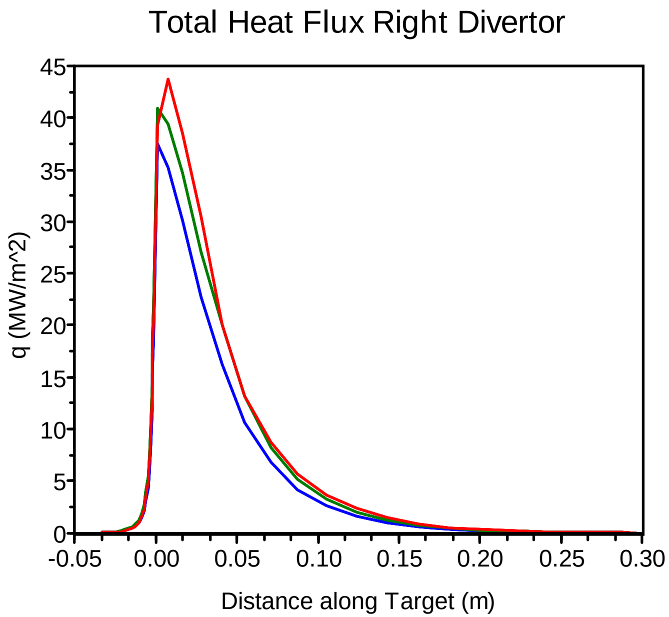


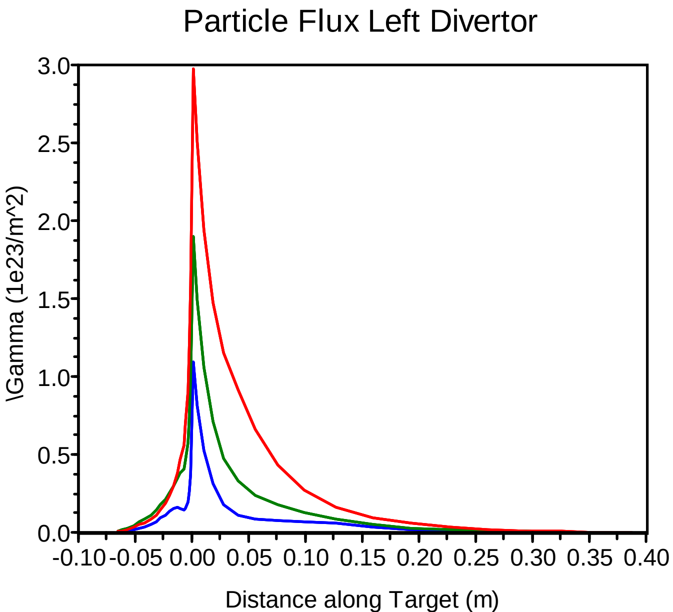
Electron Temperature Right Divertor

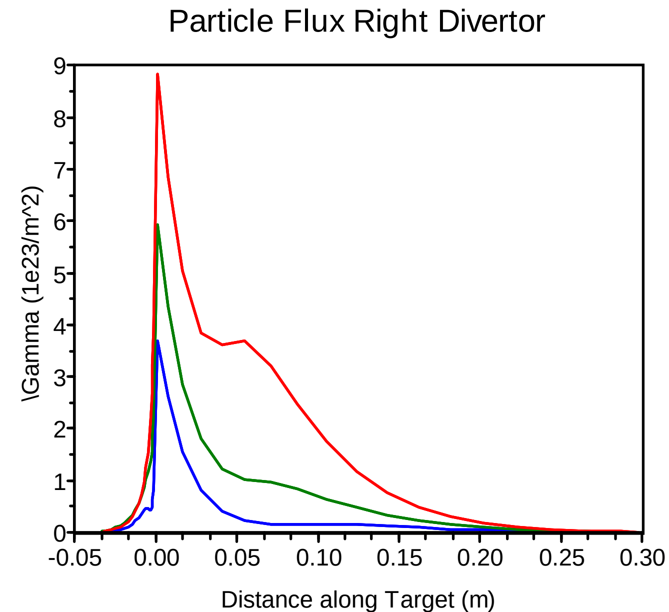


Peak heat flux is fairly insensitive to separatrix density









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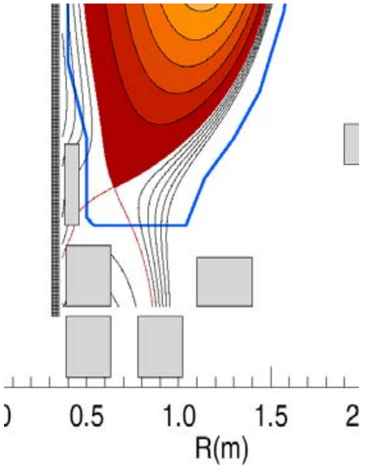
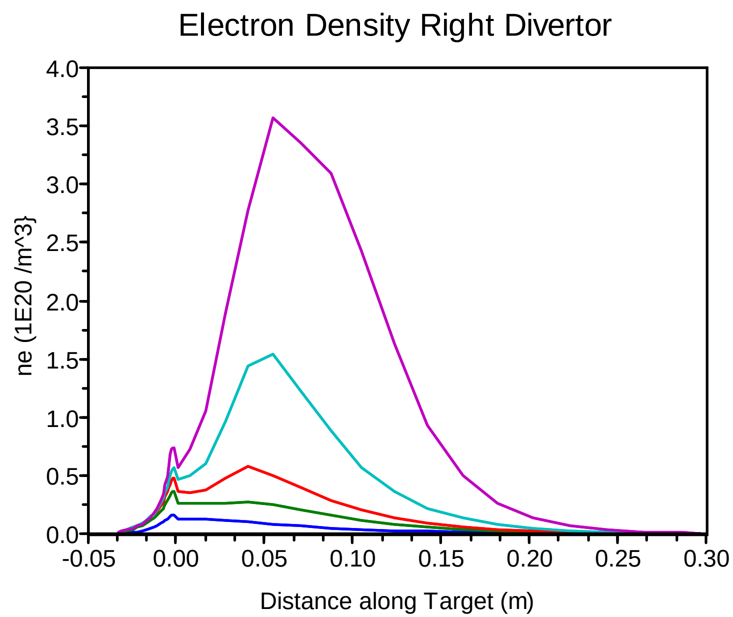
P = 30MW

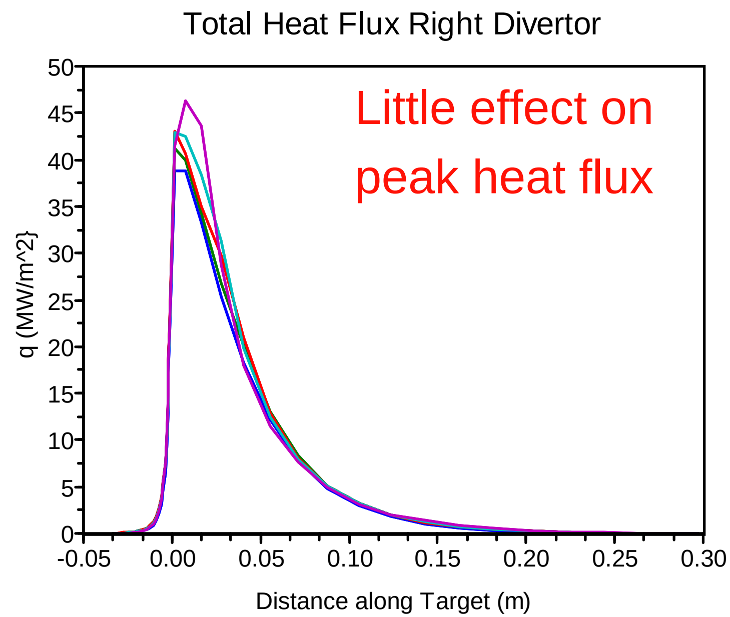
R = 0.95

Pure D Plasma



Recycling scan: Away from OSP, divertor moves towards high-recycling regime





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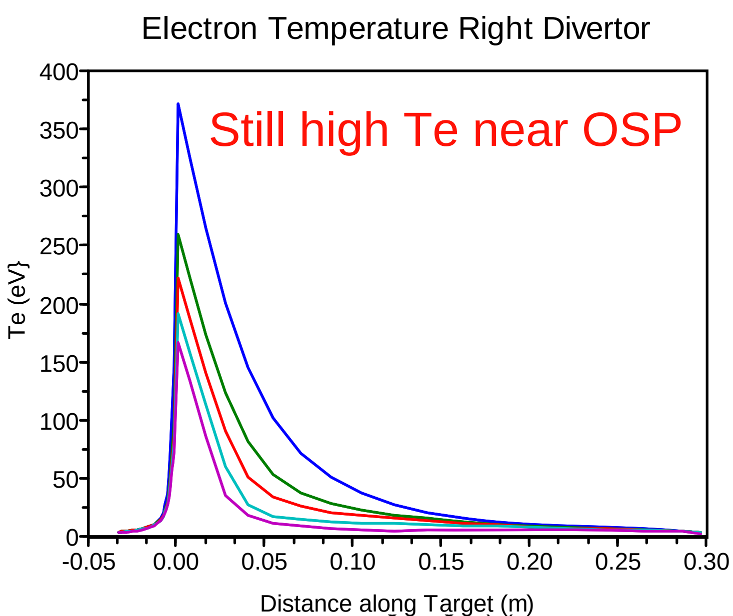
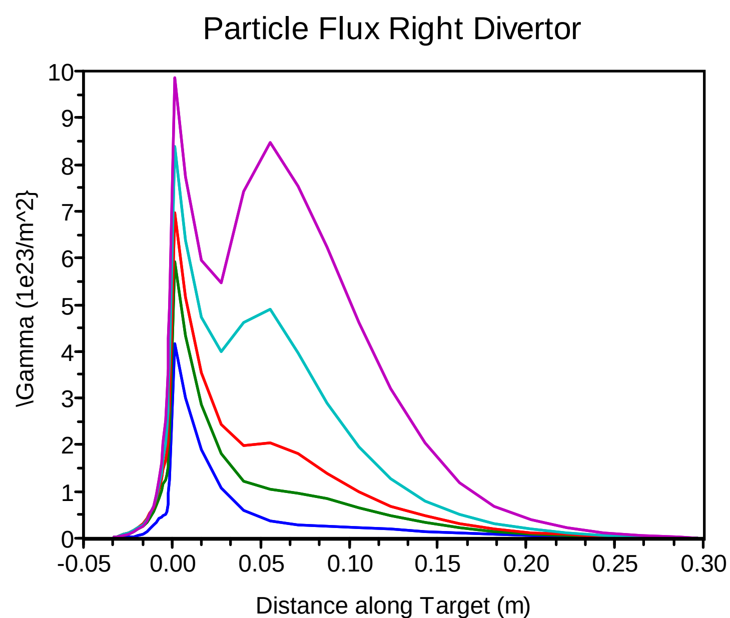
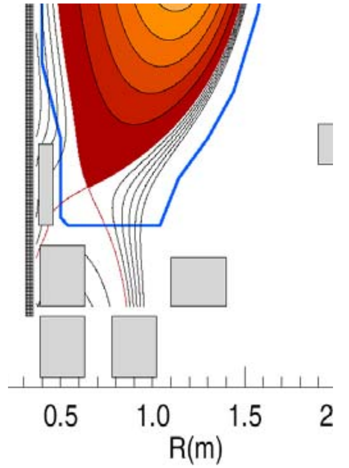
P = 30MW

n_{core}= 1.5e20

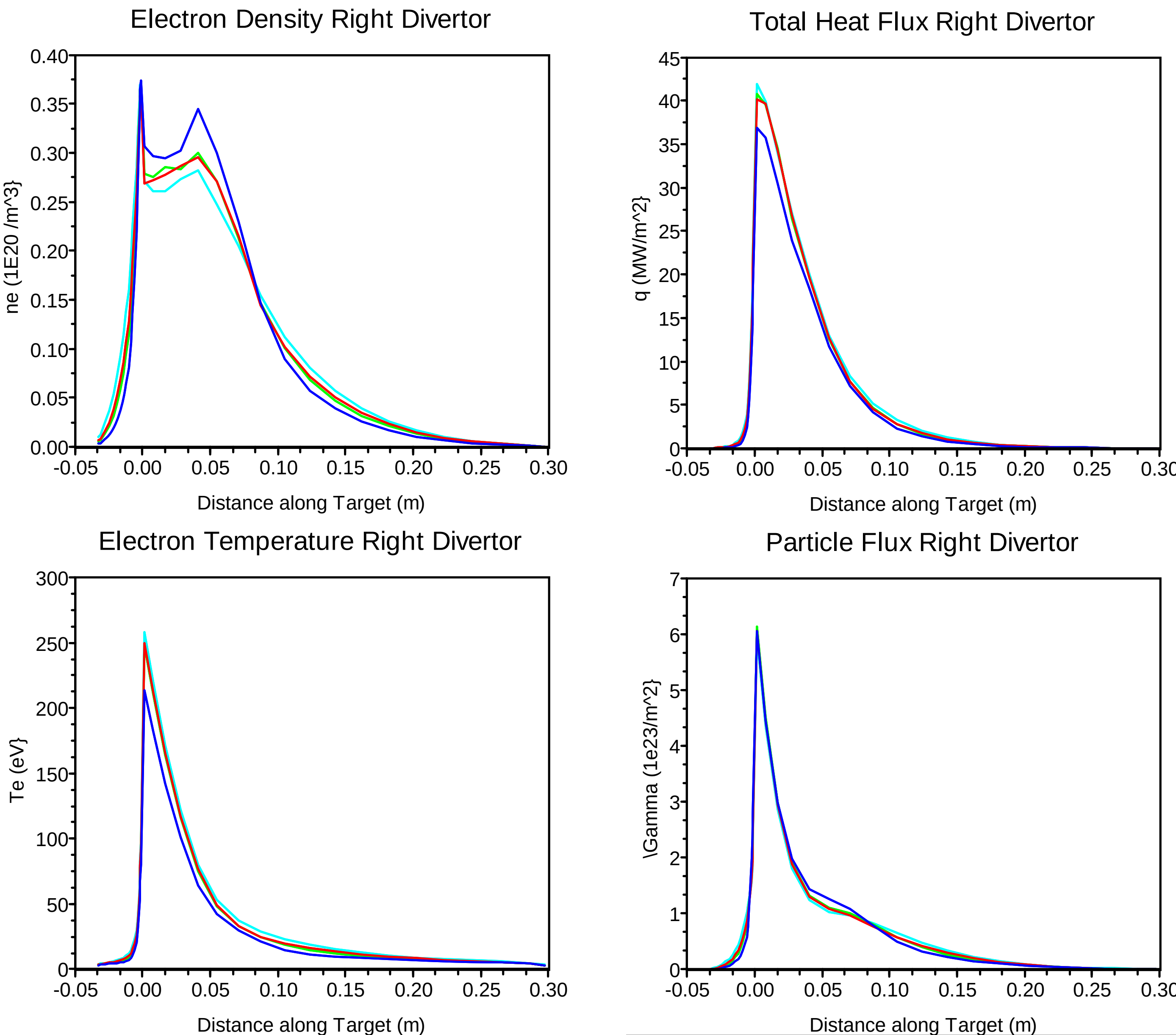
Pure D Plasma







Adding impurities:
SOL radiation is limited at these Te, ne



Radiated power with 4% concentration:

P^{rad}_{C} = 1 MW

P^{rad}_{Ne} = 1 MW

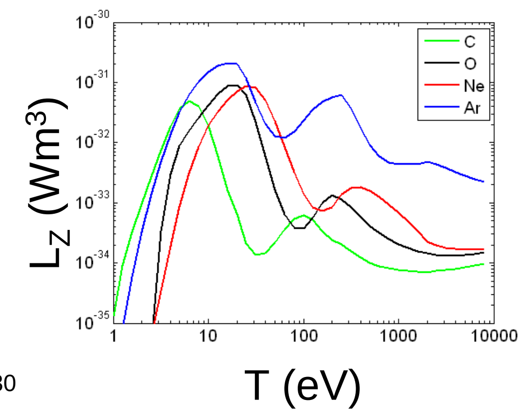
P^{rad}_{Ar} = 4 MW

Impurity concentration f: $n_Z = f*n_e$

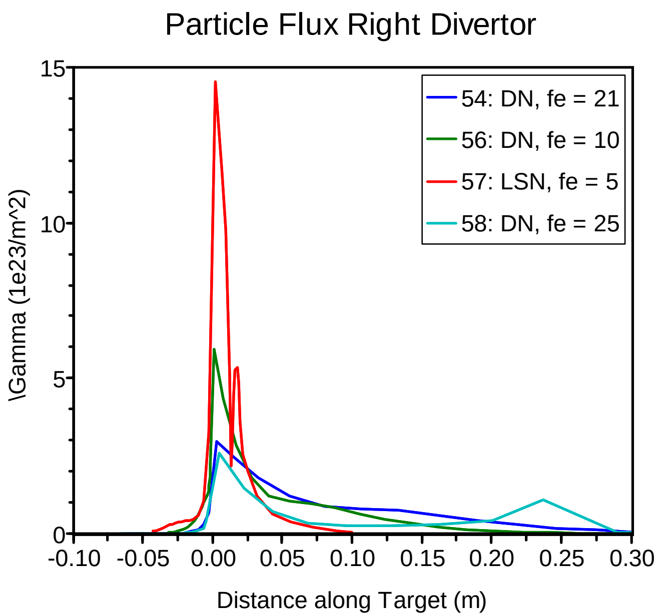
4% in all cases

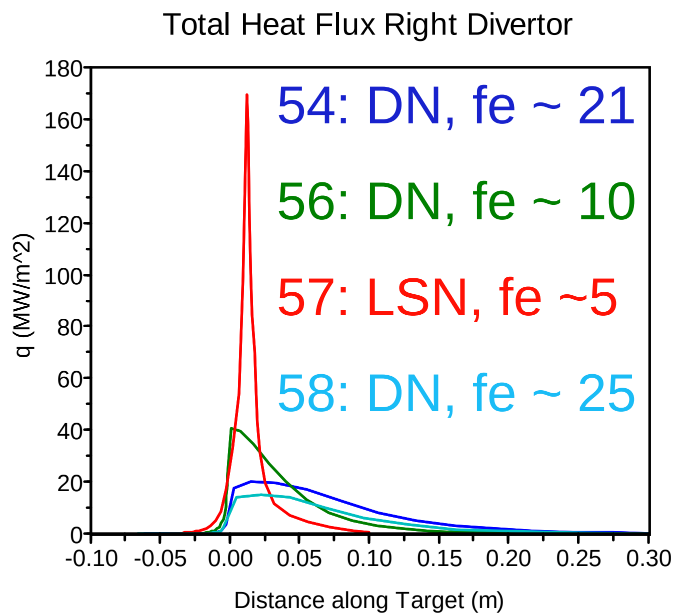
Radiated power:

$p_{rad} = L_Z n_e * n_Z$



Configuration Scan:
Geometry strongly affects heat flux, divertor parameters

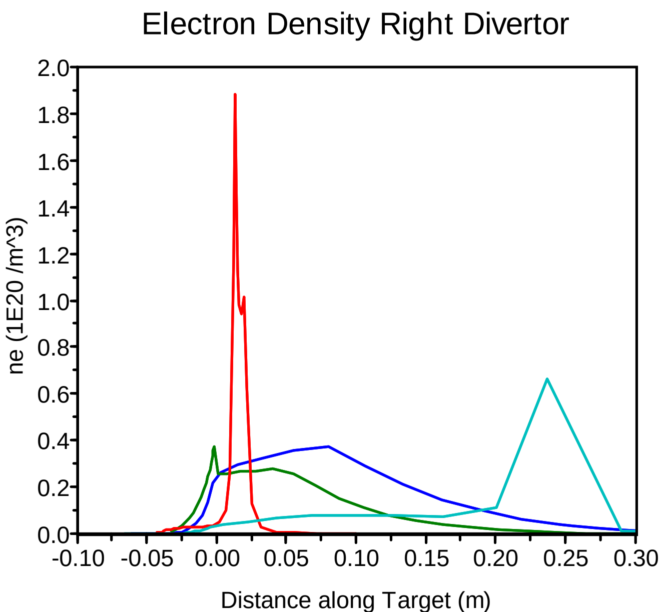


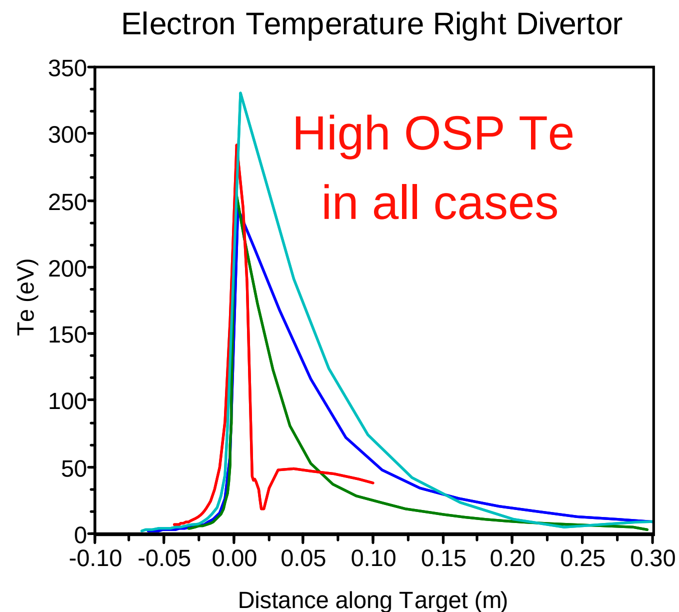


P = 30MW

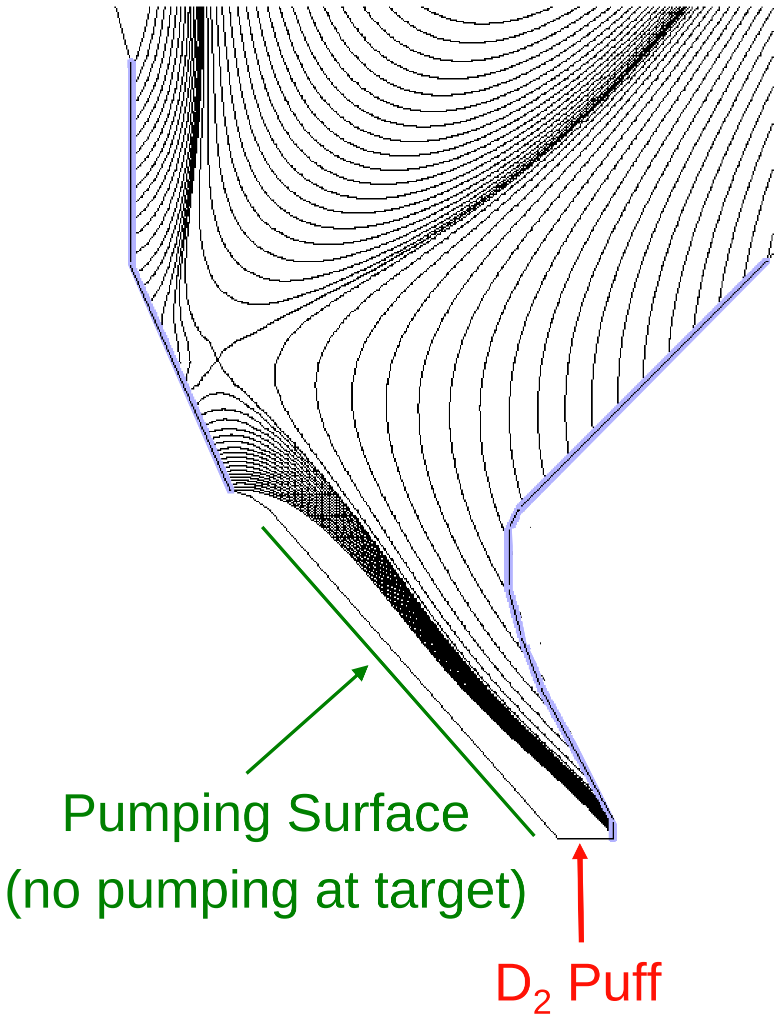
n_{core}= 1.5e20

R = 0.95





Conventional Solution: Vertical Target

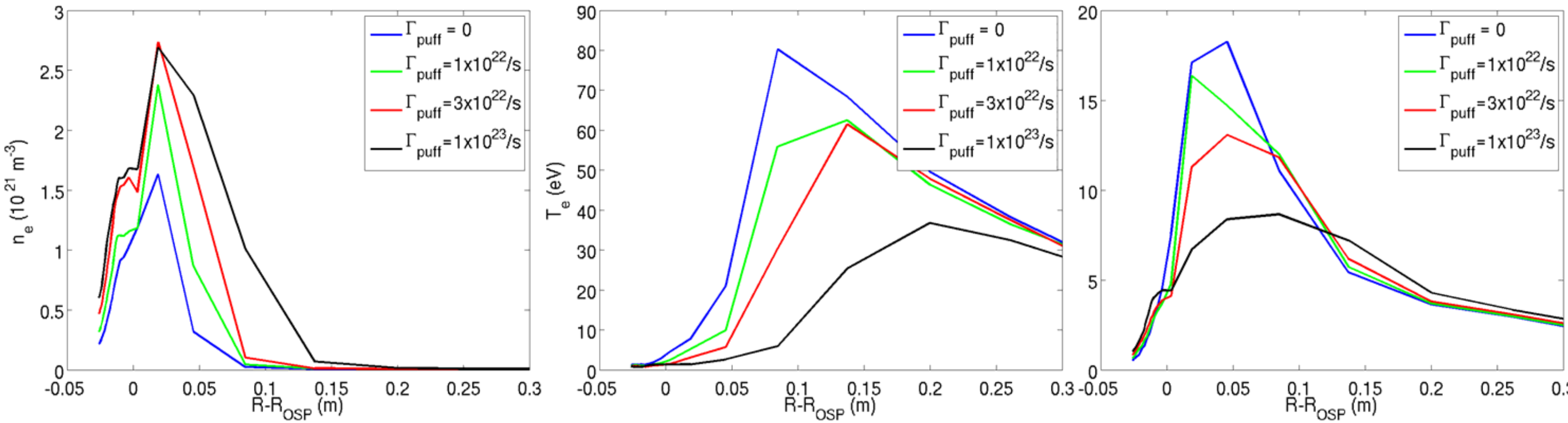


- Geometric benefits maximized
  - Highest flux expansion magnetic configuration (also DN)
  - Plate tilted to 1 degree wrt **B**
    - Maximize wetted area
  - Neutrals directed towards separatrix
  - Gas puffed into divertor
    - Raise density, get out of sheath-limited regime

- Carbon is sputtered from targets
  - Self-consistent impurity radiation
  - "Optimistic" radiator (production at targets, temperature at which it radiates good for radiating divertor)

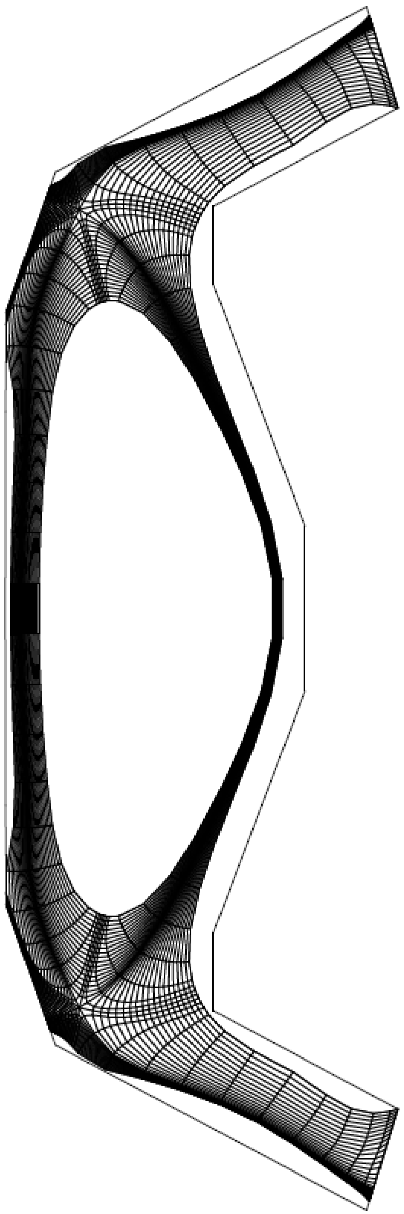
Profiles at Vertical Target: Core density 1.5e20, P=50 MW

Electron Density (10^{21} m^{-3}) — Temperature (eV) — Heat Flux (MW/m^2)



- Profiles shown for different levels of gas puff
- As puff increases, n_e is increased, T goes down
  - Achieve detachment near strike point
  - Up to 15 MW radiated power (Z_{eff} = 1.4 in core)
- Heat flux can be brought down to < 10 MW/m^2
  - But this is at high gas throughput
  - Power is split between two divertors (due to double null)
    - Effective P/R is more like 25 (MW/m)
    - Better test is using SN configuration

SOLPS Modeling of NHTX with a Super-X Divertor



- Strategy: move targets to higher R
  - Decrease P/R
  - Increase connections lengths

  *M. Kotschenreuther, P. Valanju, S. Mahajan, APS-DPP07

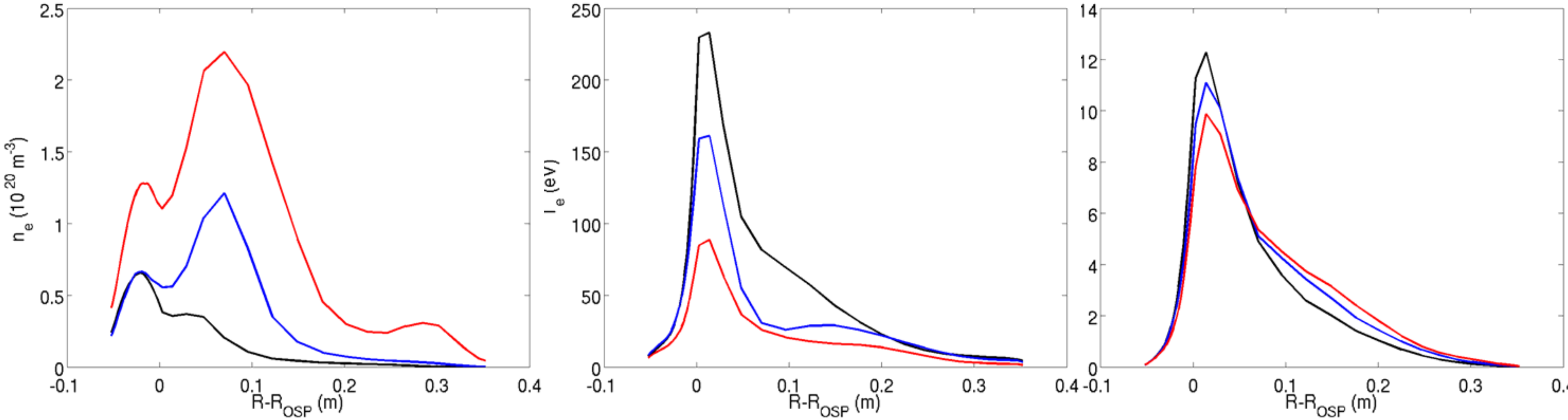
- Core density = 7.5e19 to 3.0e20
- Input power = 50 MW

- Pure deuterium plasmas
- Pumping at plates

- Somewhat pessimistic scenario
  - No impurity radiation
  - Likely to be sheath-limited
    - Low density divertor from target pumping
    - Neutrals directed away from separatrix

SOLPS Modeling of NHTX with a Super-X Divertor

Electron Density (10^{21} m^{-3}) Temperature (eV) Heat Flux (MW/m^2)



- Peak heat flux can be brought down to < 10 MW/m^2
  - Equivalent standard divertor: 34 MW/m^2
  - Could allow operation at low edge density
- "Less" sheath-limited
  - Te still high near separatrix, but much lower than the equivalent standard case (~400 eV for the blue curve)
  - Closer to radiating divertor

Discussion and Conclusions

- NHTX allows a wide operational range of heat fluxes for PFC evaluation
  - Can be varied by a factor of ~ 10
  - Heat flux can be very high – well above 10 MW/m^2
- Results illustrate the challenge of high heat flux boundary
  - Modeling of standard open divertors shows unacceptably high target temperature, little control over heat flux
  - High temperature, low density makes impurity radiation inefficient
- Two possible solutions have modeled
  - Vertical target can reduce heat flux below 10 MW/m2 with strong gas puff
  - Super-X Divertor is effective in controlling heat flux even in sheath-limited regime