NSTX-U Divertor Simulation

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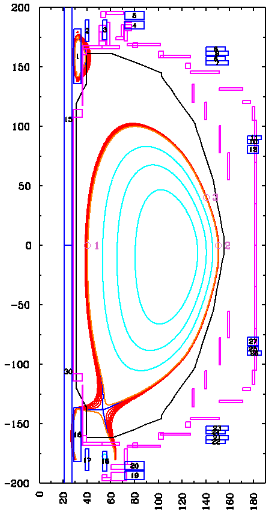
Outline

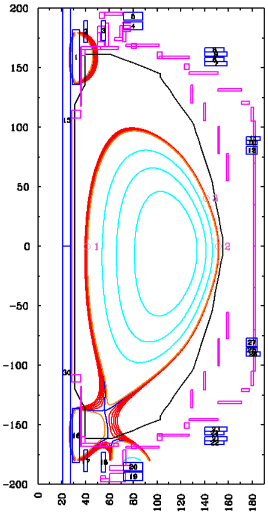
1. CORSICA equilibria
2. SOLPS simulation
3. Future work

CORSICA

- Plasma equilibria with Standard Divertor(SD) and X Divertor(XD) and their properties.
- PF coil currents
- Various divertor geometries.

Equilibria with SD and XD





Plasma properties

	SD	XD
I_{plasma}, B_{tor}	1.103, 0.742	1.107, 0.735
R, a, R/a	0.953, 0.551, 1.729	0.963, 0.550, 1.749
β_{norm}	4.387	4.671
q_{95}	6.099	5.566
elongation 95(edge)	2.068 (2.168)	1.993 (2.124)
U. triangularity 95(edge)	0.260 (0.278)	0.269 (0.289)
L. triangularity 95(edge)	0.475 (0.733)	0.468 (0.665)

Coil currents (for XD)

#	Name	ic	wgt(svec)	I(MA)	rc	zc	drc	dzc	nrc	nzc	MA/m2	MW
1	PF1a	1	1.0d+00	0.423	0.319	1.591	0.061	0.458	1	10	15.252	0.518
2	PF1b	0	1.0d+00	0.000	0.400	1.804	0.034	0.181	2	2	0.000	0.000
3	PF1c	0	1.0d+00	0.000	0.550	1.814	0.037	0.166	2	2	0.000	0.000
4	PF2a	2	1.0d+00	0.042	0.799	1.853	0.163	0.068	3	1	3.813	0.032
5	PF2b	2	1.0d+00	0.042	0.799	1.933	0.163	0.068	3	1	3.813	0.032
6	PF3a	3	1.0d+00	-0.047	1.483	1.570	0.163	0.034	1	1	-8.546	0.151
7	PF3b	3	1.0d+00	-0.047	1.494	1.536	0.186	0.034	1	1	-7.478	0.133
8	PF3c	3	1.0d+00	-0.047	1.483	1.651	0.163	0.034	1	1	-8.546	0.151
9	PF3d	3	1.0d+00	-0.047	1.494	1.617	0.186	0.034	1	1	-7.478	0.133
10	PF4a	0	1.0d+00	-0.000	1.795	0.871	0.092	0.034	2	1	-0.000	0.000
11	PF4b	0	1.0d+00	-0.000	1.806	0.905	0.115	0.034	2	1	-0.000	0.000
12	PF4c	0	1.0d+00	-0.000	1.795	0.807	0.091	0.068	2	1	-0.000	0.000
13	PF5a	4	1.0d+00	-0.142	2.012	0.649	0.136	0.069	2	1	-15.290	1.100
14	PF5b	4	1.0d+00	-0.142	2.012	0.575	0.136	0.069	2	1	-15.290	1.100
15	OH	0	1.0d+00	0.000	0.242	1.060	0.069	2.121	1	40	0.000	0.000
16	PF1a	0	1.0d+00	0.390	0.319	-1.591	0.061	0.458	1	10	14.058	0.440
17	PF1b	0	1.0d+00	0.000	0.400	-1.804	0.034	0.181	2	2	0.000	0.000
18	PF1c	0	1.0d+00	-0.077	0.550	-1.814	0.037	0.166	2	2	-12.406	0.132
19	PF2a	0	1.0d+00	0.125	0.799	-1.933	0.163	0.068	3	1	11.298	0.284
20	PF2b	0	1.0d+00	0.125	0.799	-1.853	0.163	0.068	3	1	11.298	0.284
21	PF3a	5	1.0d+00	-0.068	1.494	-1.617	0.186	0.034	1	1	-10.656	0.270
22	PF3b	5	1.0d+00	-0.068	1.483	-1.651	0.163	0.034	1	1	-12.178	0.307
23	PF3c	5	1.0d+00	-0.068	1.494	-1.536	0.186	0.034	1	1	-10.656	0.270
24	PF3d	5	1.0d+00	-0.068	1.483	-1.570	0.163	0.034	1	1	-12.178	0.307
25	PF4a	0	1.0d+00	-0.000	1.795	-0.871	0.092	0.034	2	1	-0.000	0.000
26	PF4b	0	1.0d+00	-0.000	1.806	-0.905	0.115	0.034	2	1	-0.000	0.000
27	PF4c	0	1.0d+00	-0.000	1.795	-0.807	0.091	0.068	2	1	-0.000	0.000
28	PF5a	4	1.0d+00	-0.142	2.012	-0.649	0.136	0.069	2	1	-15.290	1.100
29	PF5b	4	1.0d+00	-0.142	2.012	-0.575	0.136	0.069	2	1	-15.290	1.100
30	OH	0	1.0d+00	0.000	0.242	-1.060	0.069	2.121	1	40	0.000	0.000

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Total PF power =     7.845 MW, Total PF MA-m =     6.644 =     0.85 times Plasma MA-m =     7.800
TF cur =        3.536 MA,      11.489 MA/m2; B=      2.259 at rTF =       0.313
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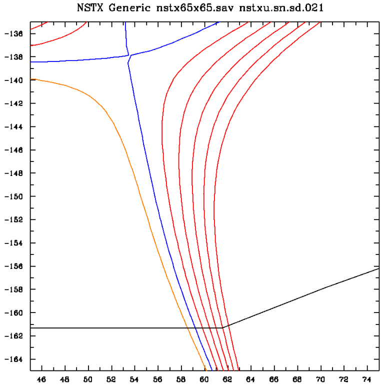
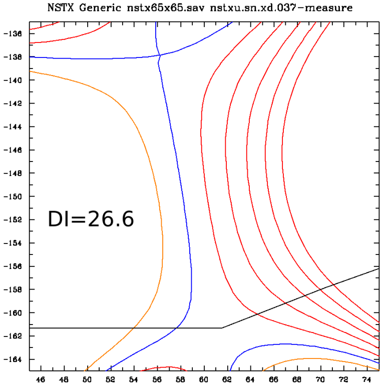
Coil current limits

coil	PF1a	PF1b	PF1c	PF2	PF3	PF4	PF5
I_{min}(MA)	-0.512	0	0	-0.308	-0.48	0	0
I_{max}(MA)	1.216	0.416	0.32	0.42	0.36	0.544	1.632

In addition to the table above (S. Gerhardt email, March 2014), we were told the following:
- "PF1Bs will not have a power supply for some time" by J. Menard 21 Feb. 2015
- "strongly discourages use of the PF4 coils at all" and "Make sure that the ratio PF-3/PF-5 never drops beneath about 0.2 or so (and that PF-3 is always in the pushing direction)." by S. Gerhardt 27 Feb. 2015
- "The PF1aU coil has been taken out of service for the remainder of this year's run campaign, and experimental proposals have been modified to use PF2 for similar plasma shape control." by PPPL 12 Jul. 2016

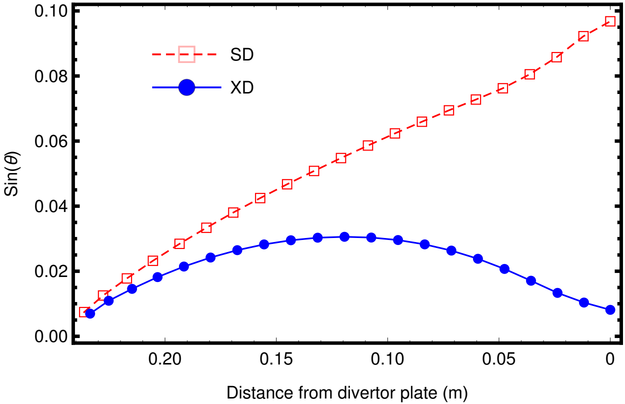
Divertors: Standard and X





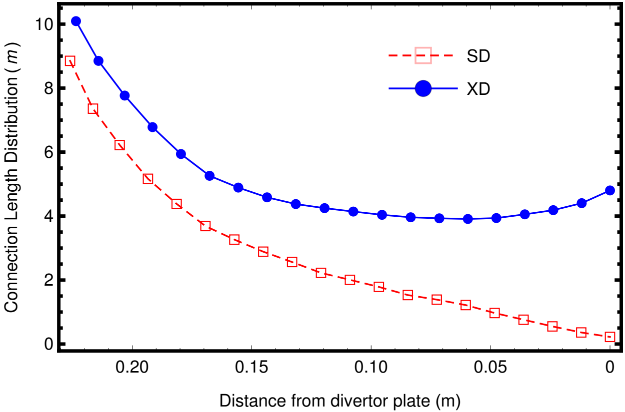
We managed to maintain similar core plasma shapes and main X-point locations while creating different types of divertors. The X-divertor shown has the maximum flaring effect.

Poloidal flaring: total field angle



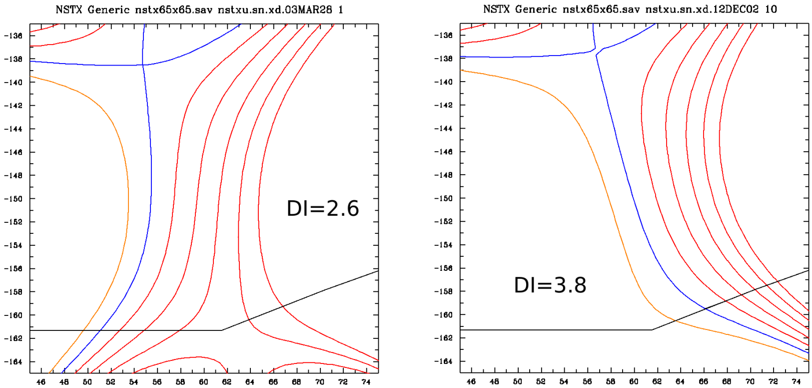
The second X-point weakens the poloidal field (increases flux expansion) near the target, resulting in an ever-shallower field angle.

Poloidal flaring: connection length



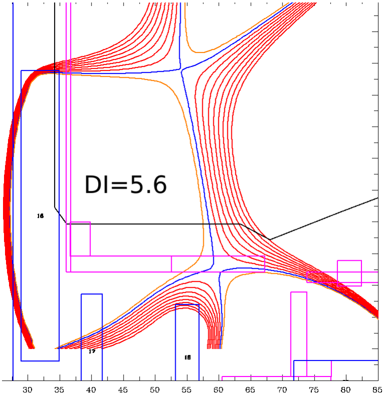
As a result the total field becomes more toroidal like as it approaches the target, which largely increases the connection length within the neutral buffer layer.

More X-divertors: sweeping the divertor leg



We also managed to sweep the divertor leg to move the strike point location along the divertor plate. Therefore we can help accommodate diagnostic positions.

More X-divertors: extending the divertor leg



These serve as comparison cases to the optimal X-divertor to demonstrate the importance of flaring effect.

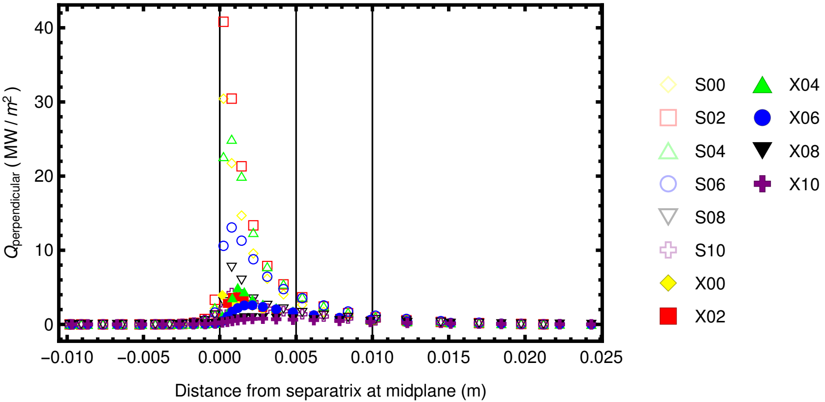
SOLPS

- Simulation parameters
- Simulation results: $Q_{\perp}$, $Q_{/\!/}$, P_{total}, and T_e profiles

Parameters

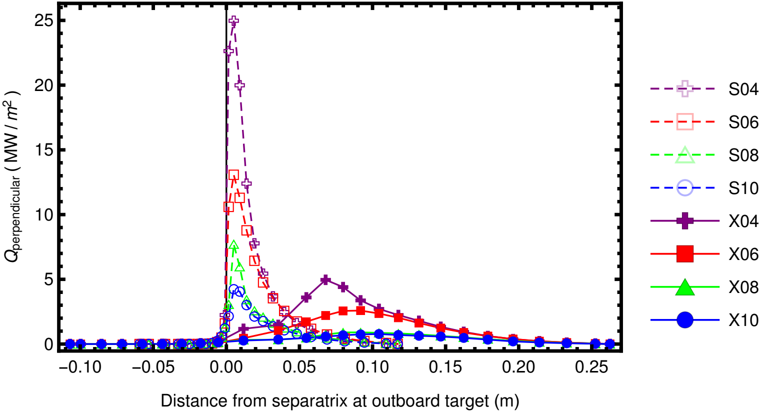
- Counter-directed I_{plasma} and B_{tor}
- SOL power: 1.5 MW for both ions and electrons at the core boundary. Calculated SOL power: 2.87-2.88 MW for SD and 2.84-2.88 MW for XD
- Gas-puff scan: 0, 2, 4, 6, 8, 10 $\times 10^{21}$particles/second

Results: power SOL width



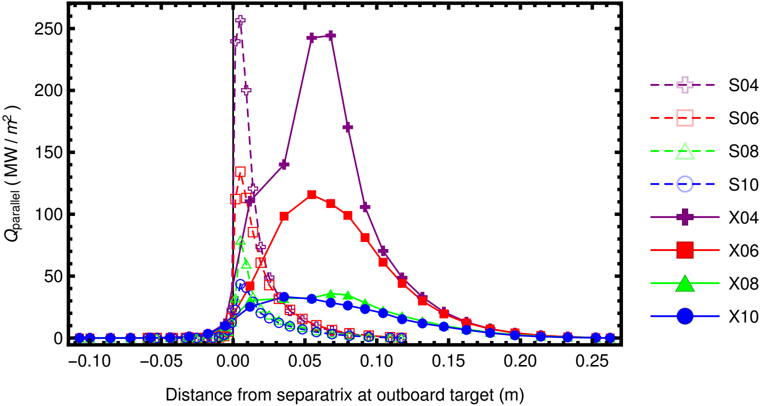
By mapping the target $Q_\perp$ profile upstream to outboard midplane, we estimate the power SOL width ~ 3mm

Results: $Q_\perp$ at the outboard target



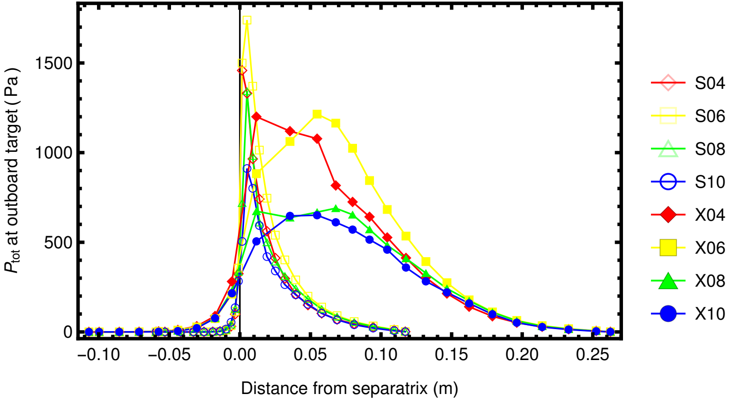
At the same gas-puff rate, the $Q_\perp$ is more spread out and the peak value is much lower for the XD compared to the SD.

Results: $Q_{/\!/}$ at the outboard target



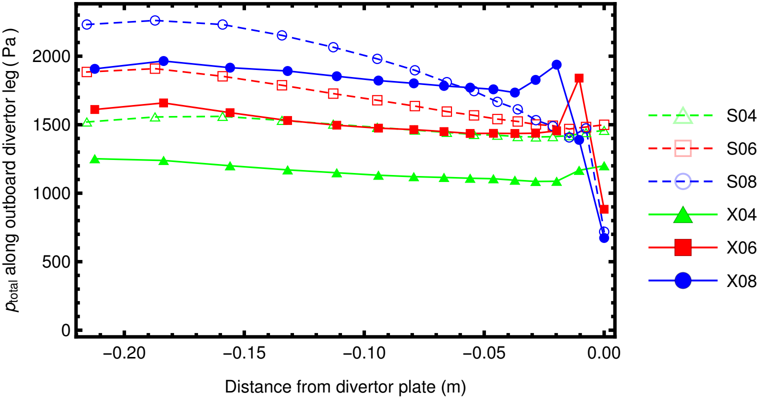
For high gas-puff rates, especially $8 \times 10^{21}\,/s$ (green curve), $Q_{/\!/}$ has a lower peak value for the XD than for the SD, which indicates that radiation is stronger in the XD geometry.

Results: p_{total} at the outboard target



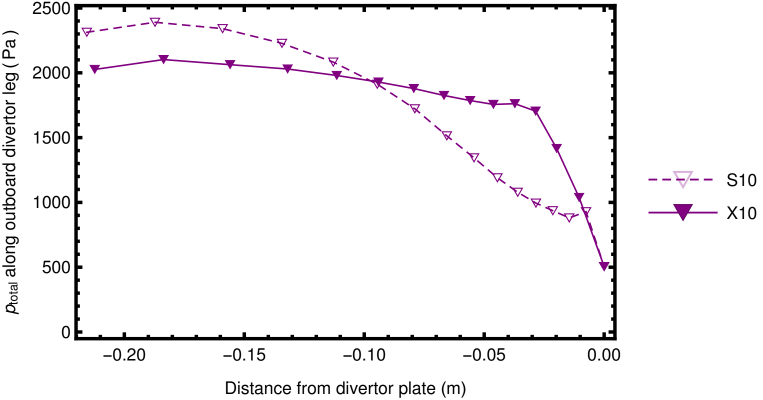
For all gas-puff rates, P_{total} has a lower peak value for the XD than for the SD.

Results: p_{total} along the divertor leg: detachment



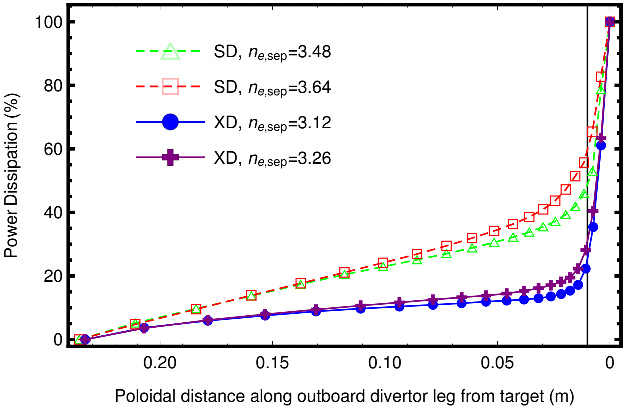
Detachment, indicated by a drop of P_{total} in the poloidal direction, happens for the XD at a lower gas -puff rate $6 \times 10^{21}/s$ than for the SD.

Results: p_{total} along the divertor leg: detachment

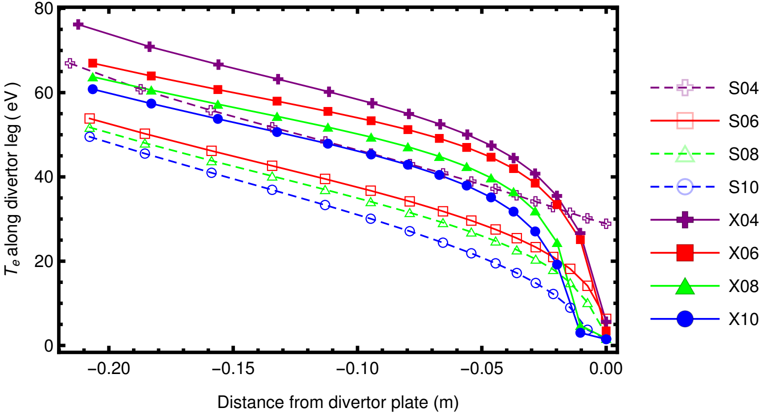


At gas -puff rate $10 \times 10^{21}/s$ both SD and XD are detached. However, the XD is better at keeping the detachment front near to the target.

Results: power dissipation along the divertor leg



Results: T_e along the divertor leg



Remark: For the same gas-puff rate, SD and XD have similar T_e downstream, but instead the XD has a higher T_e upstream.

Results: $n_{e,sep}$ at outboard midplane

gas rate ($10^{21}/s$)	$n_{e,sep}$ ($10^{19}m^{-3}$), SD	$n_{e,sep}$ ($10^{19}m^{-3}$), XD
0	1.422	1.361
2	2.007	1.828
4	2.616	2.353
6	3.198	2.789
8	3.641	3.120
10	3.880	3.377

The outboard midplane electron(plasma) density at the separatrix in the SD case is consistently higher than that in the XD case. Therefore, when we compare the two divertor cases with the same midplane density, instead of the same gas-puff rate, the XD case will have a higher gas-puff rate, which will make the results look better.

Future work

- Prepare for the first experiment
- Do a better resolved gas-puff scan in order to compare SD and XD at the same upstream n_e which will show more remarkable results for XD.
- Study other XD geometries (sweeping and extending divertor legs)