NSTX

Fusion Energy Sciences

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Modeling core impurity reduction via divertor gas injection in NSTX

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Plasma Facing Components
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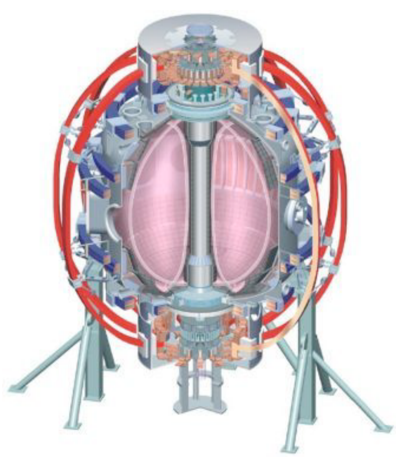
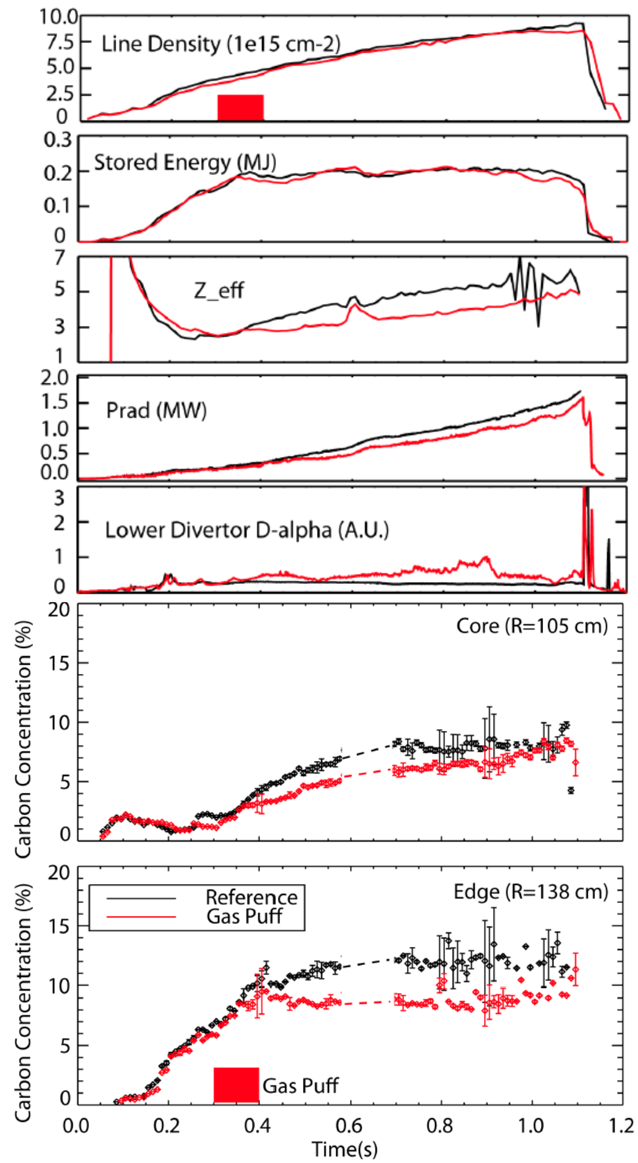


In NSTX, lithium conditioning led to impurity accumulation

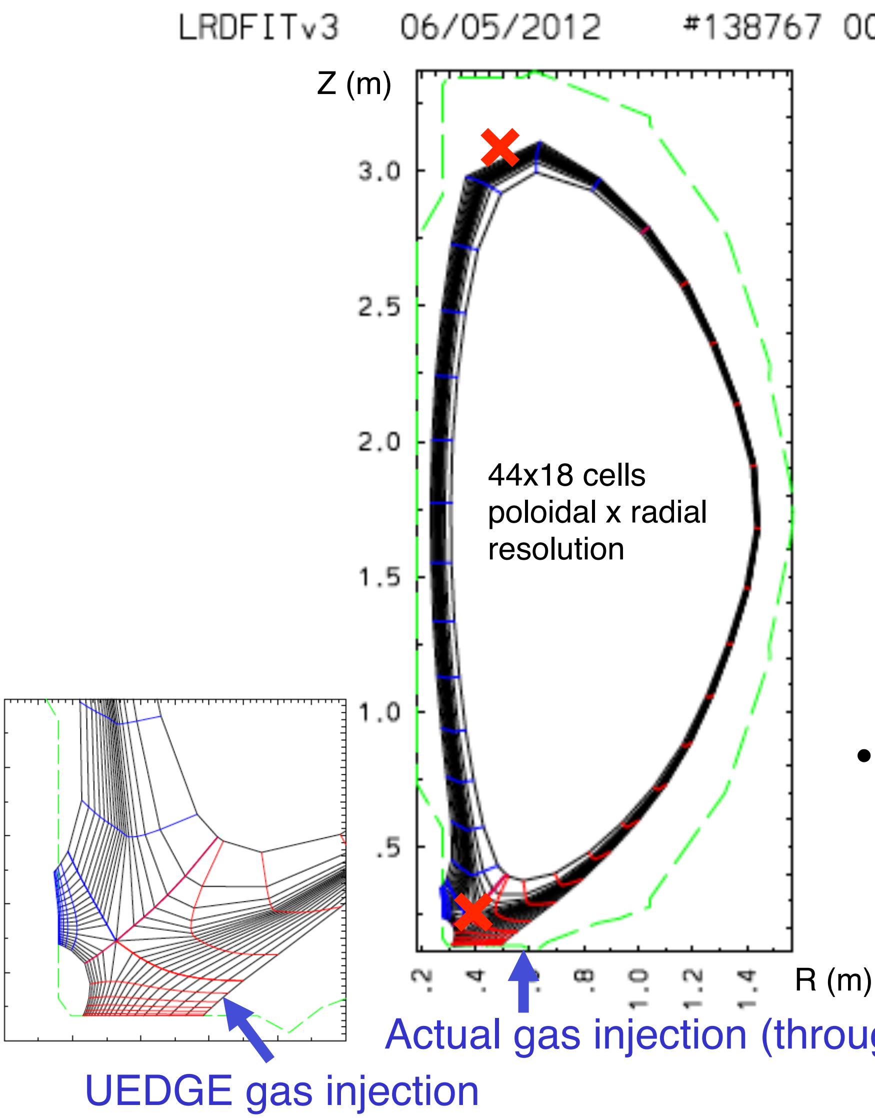
- Lithium conditioning → impurity accumulation
  - Lithium-induced edge stabilization suppresses ELMs, allowing accumulation
- High impurity concentration can be problematic
  - P_{rad} up to 2 MW (largely due to high-Z impurities)
  - Lack of density control
  - Z_{eff} increase → resistivity increase
- Impurity control techniques on NSTX
  - ELM triggering with resonant magnetic perturbations (RMPs) [Canik PRL 2010]
  - Control plasma-wall interaction during startup phase
  - Partially detached divertor scenarios (gas puff, impurity seeding, snowflake)
  - **Deuterium gas puffing [Scotti APS 2010]**

Divertor deuterium puffing on NSTX reduced impurity concentration by up to 30%

- ~20 torr-l injected in 0.1 sec
  - Core plasma retains desirable properties
  - Outer divertor remains attached
  - Carbon concentration reduced 30%
- Deuterium puffing might…
  - Reduce sputtered influx
  - Modify parallel impurity transport
    - Divertor impurity retention
    - Other?



The UEDGE 2D fluid transport code is used to study effects of gas puffing on carbon transport



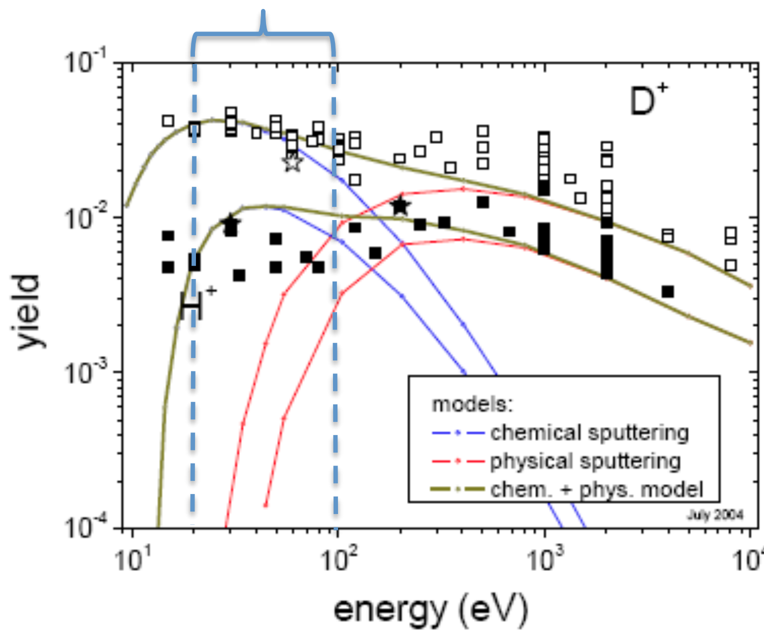
- Multi-species carbon model (C^{1+} - C^{6+})
- 0.96 < psi < 1.028 → ~6 mm SOL
- D_{perp} = 0.5 m^2/s, $\chi_{i,e}$ = 1.5 m^2/s
- Target recycling is 90% [Canik PoP 2011]; Wall recycling is 100%
- Zero flux BC for neutral D and C at core
- Fixed core flux of D^+
- No drift effects
- Inward carbon pinch, v_{pinch}=-25 m/s

- **Scan from 0 to 1200 atom-amps continuous D injection**
  - Experimental rate is 2000 A for 0.1 s

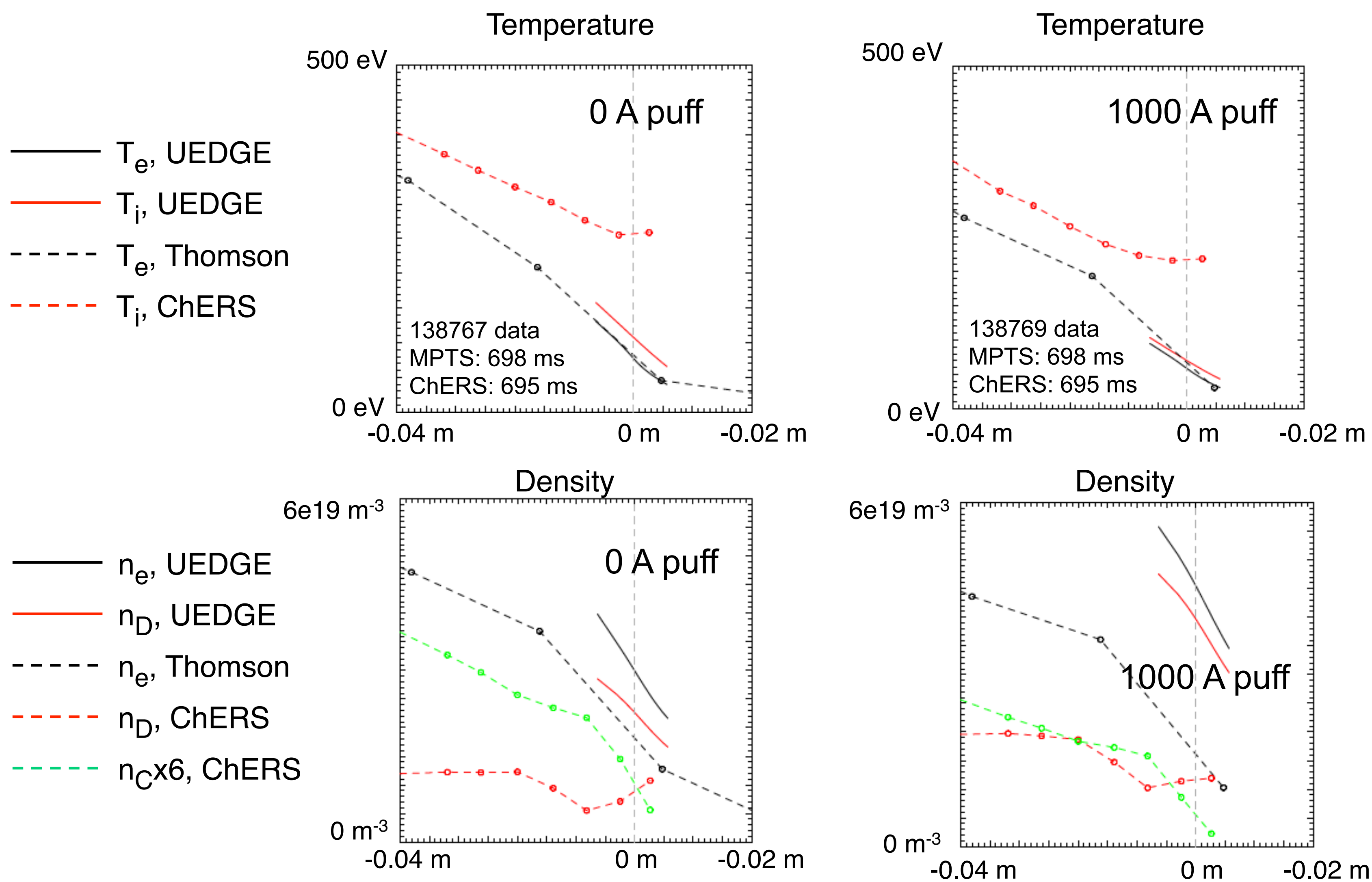
UEDGE includes physical and chemical carbon sputtering

- UEDGE includes physical and chemical sputtering of carbon
  - Physical and chemical sputtering models are from DIVIMP (U. Toronto)
  - Actual NSTX vessel wall is far from outer UEDGE boundary
    - Sputter yield reduced 10x at outer UEDGE boundary
  - T_{target}=500 K and T_{wall}=300 K assumed for all gas puff rates
    - Experimental T_{target} drops from ~600 K to ~400 K
- Lithium coating effects are not modeled
  - Complicated Li-C-D-O interaction still under investigation [e.g., Scotti PSI 2012]
- C-C and Li-C sputtering not included

Reducing energy from 100 to 20 eV, chemical sputtering goes up and physical sputtering goes down.

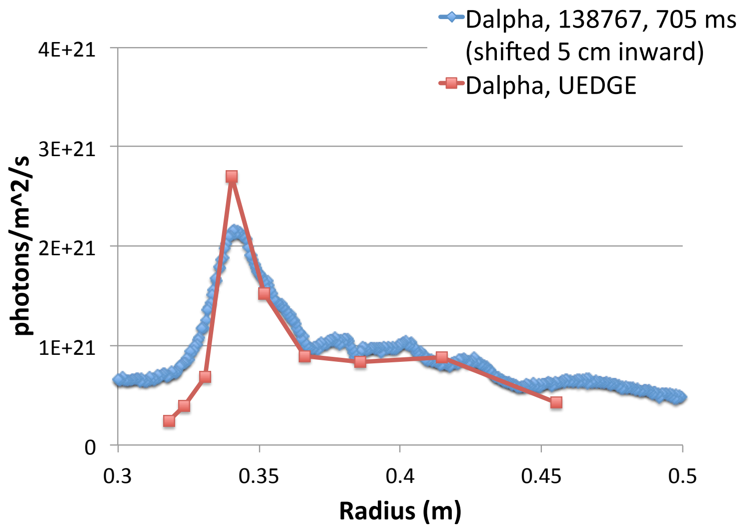


Midplane T_e matches well; T_i, n_e, n_i, not well-matched

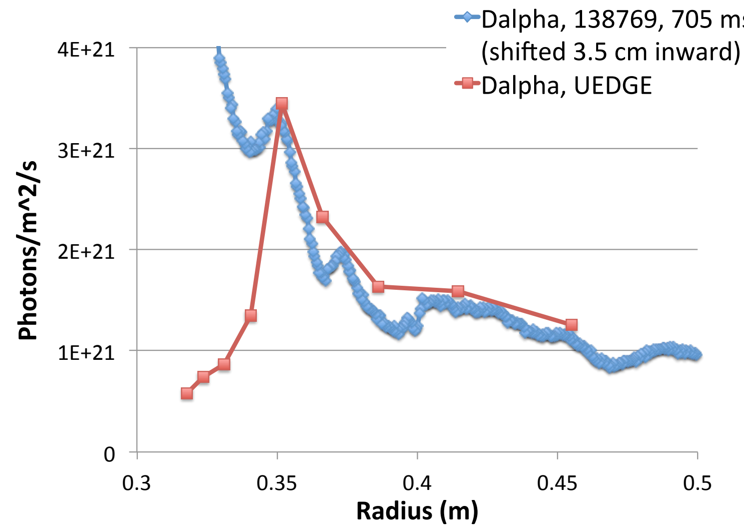


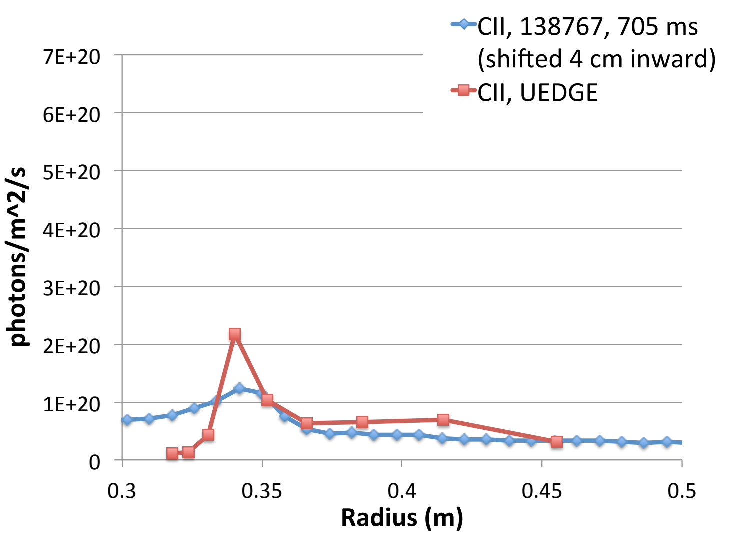
Outer divertor D_α profiles show good agreement; UEDGE CII profiles with large injection are too high

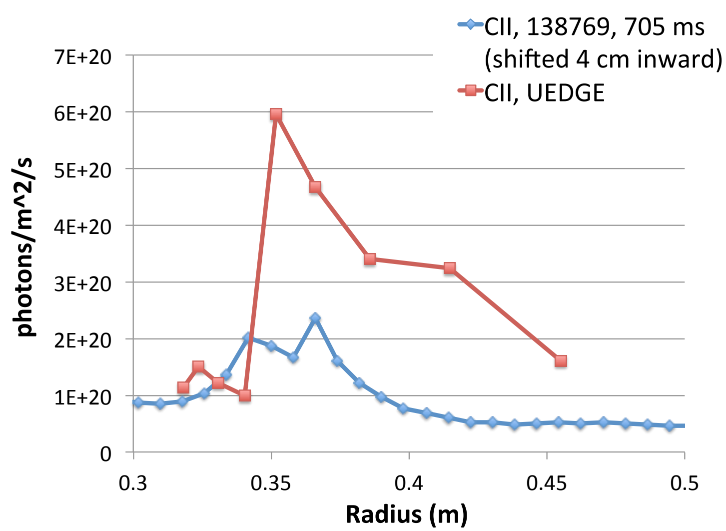
0 A puff



1000 A puff

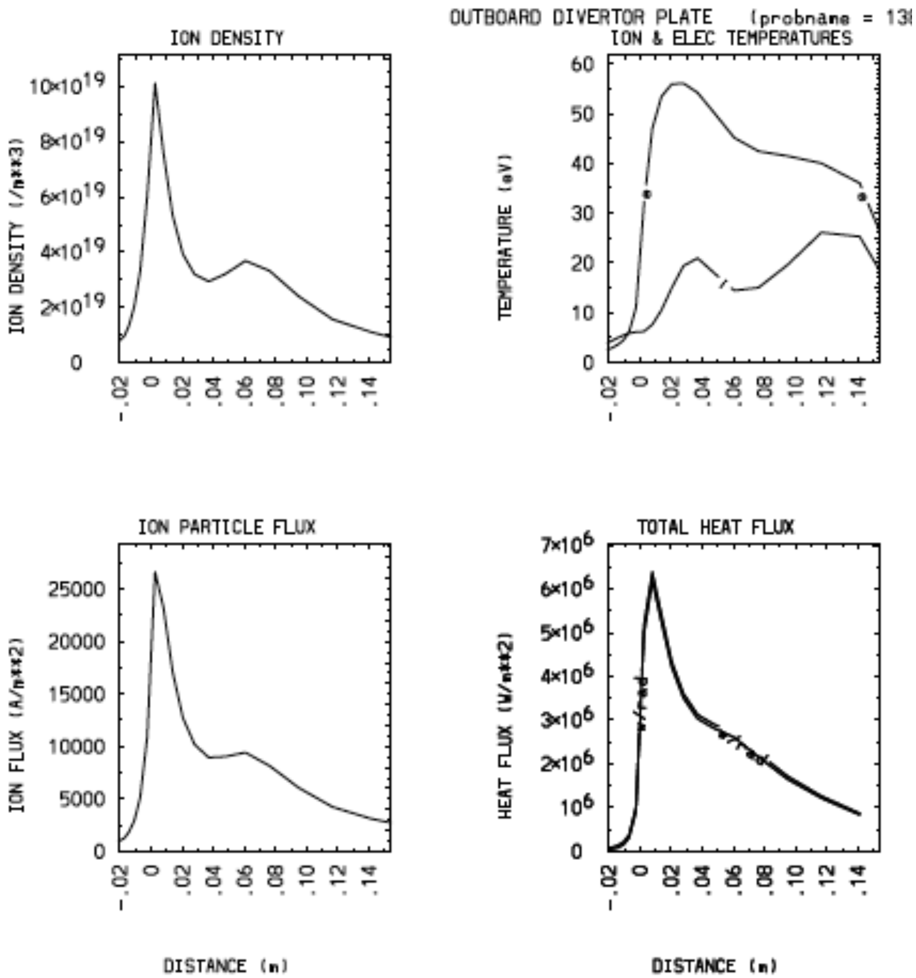




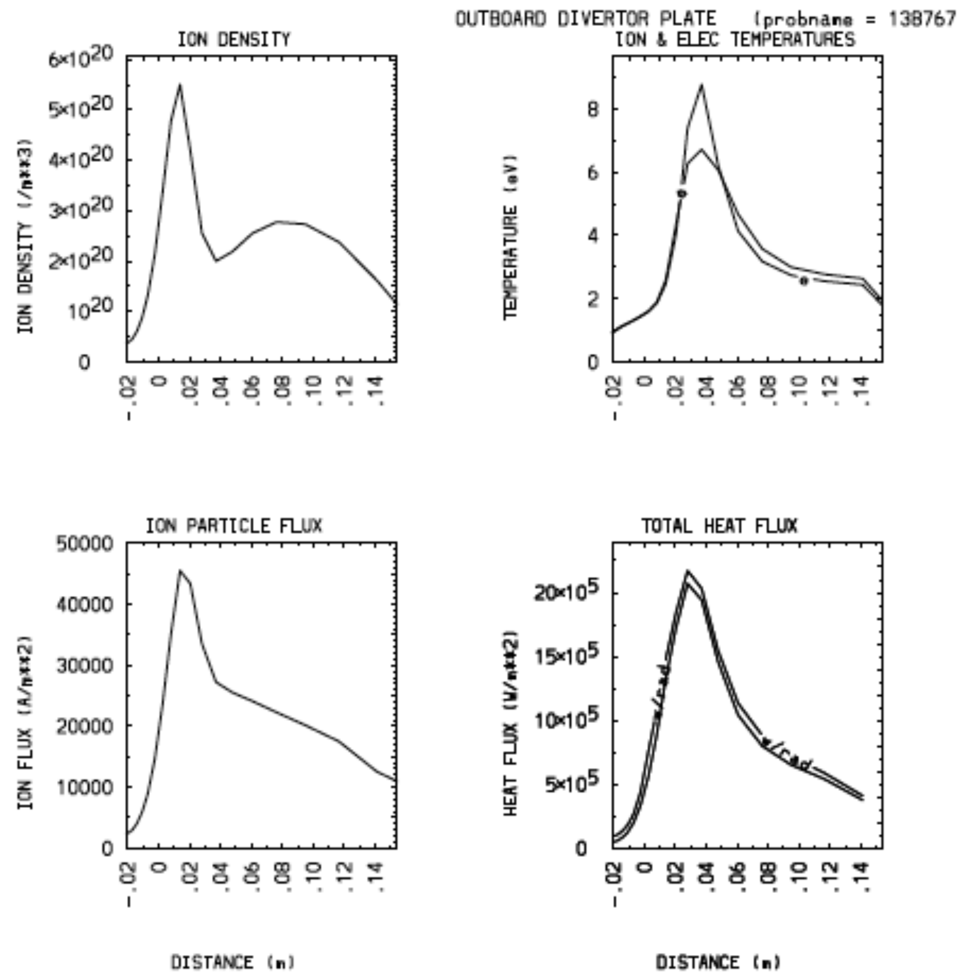


Outer divertor sees large temperature and heat flux reduction with 1000 A injection

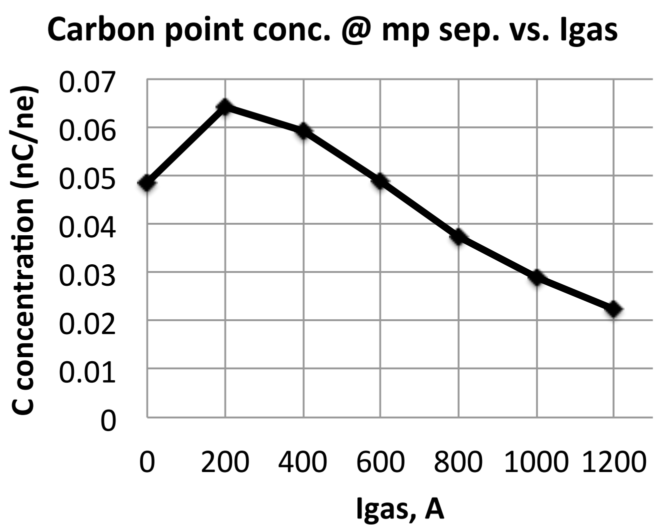
No injection



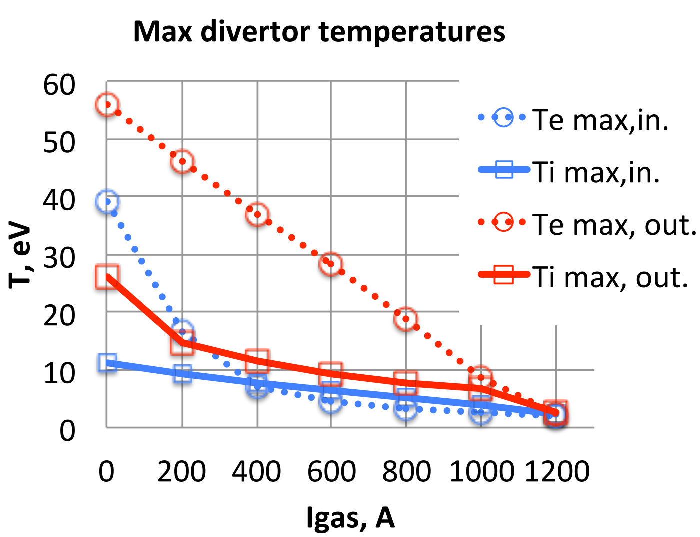
1000 A injection



Carbon concentration is reduced with increasing deuterium gas injection

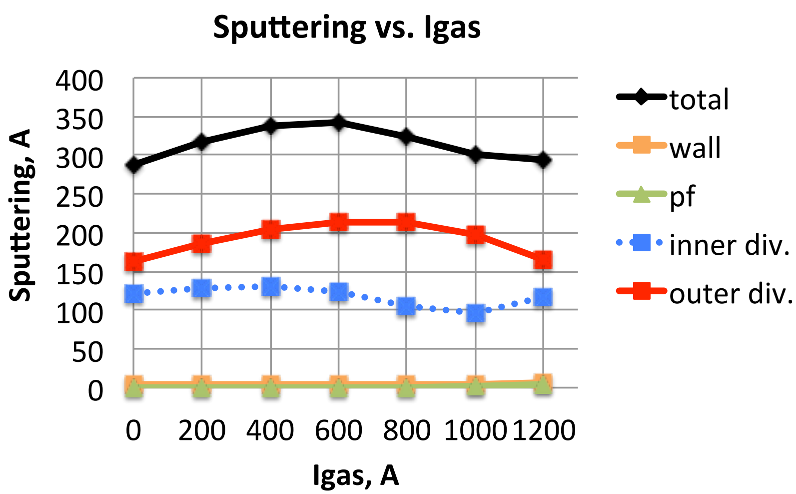


- Carbon concentration at the midplane separatrix is reduced by over 50% with 1200 A puff

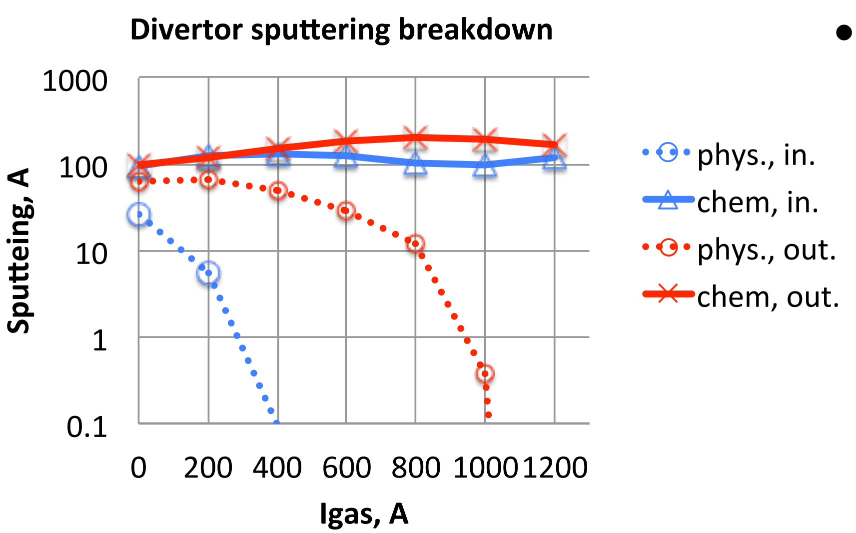


- Divertor temperatures are reduced dramatically

Total sputtered flux remains nearly constant

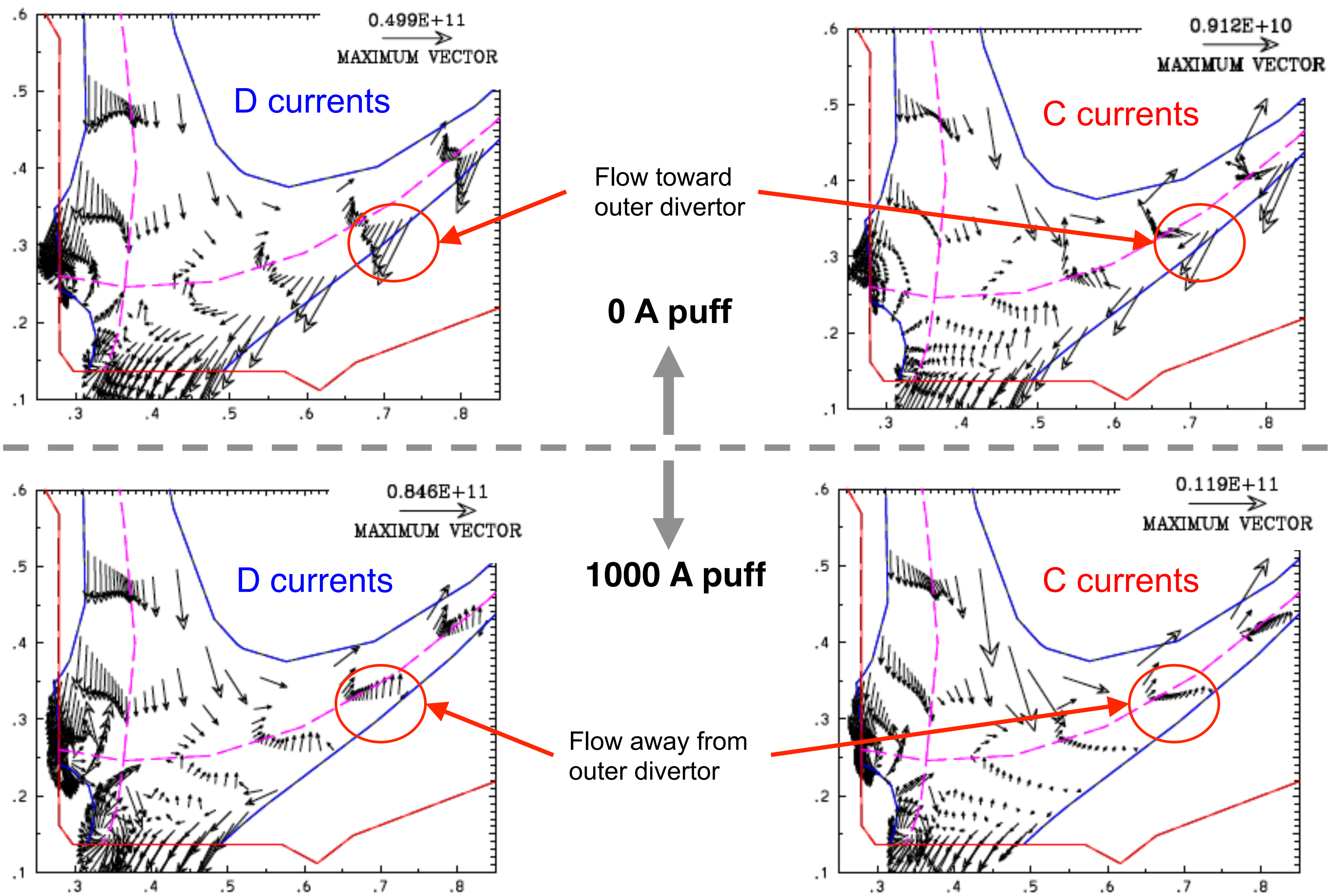


- Sputtered flux is dominated by inner and outer divertor sources



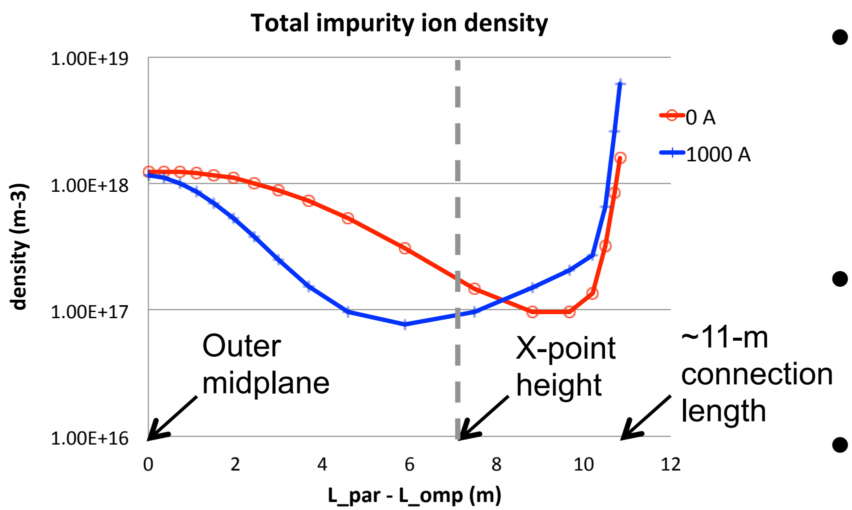
- Physical sputtered flux drops, but chemical sputtered flux rises

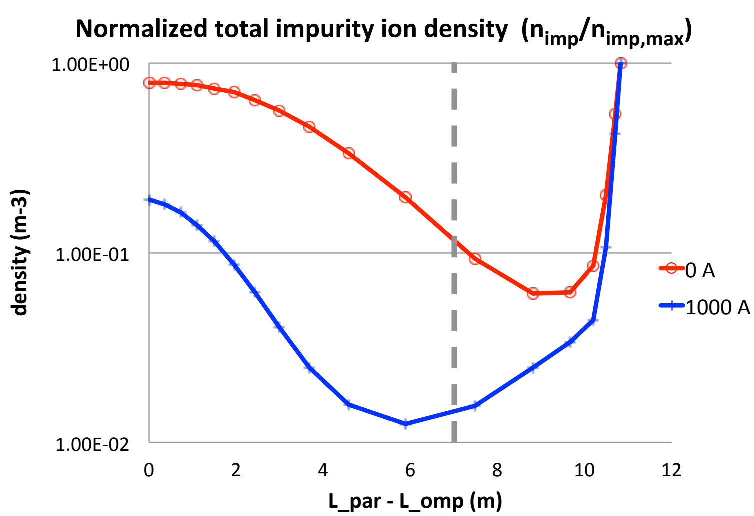
D gas injection causes D and C flow away from outer divertor



Total impurity density near the X-point is reduced with deuterium gas injection

Data is plotted along a field line on the 2 mm flux surface.

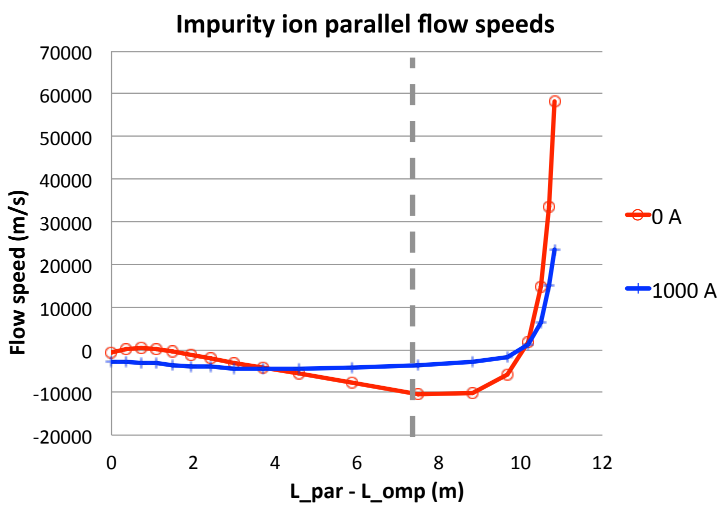


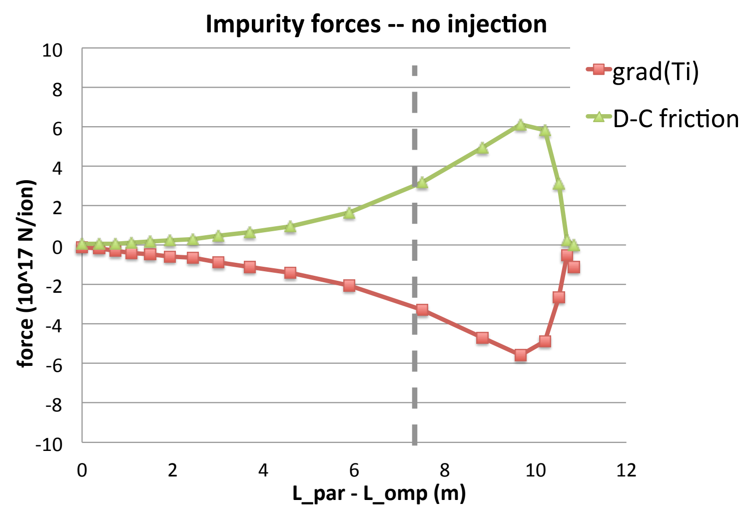


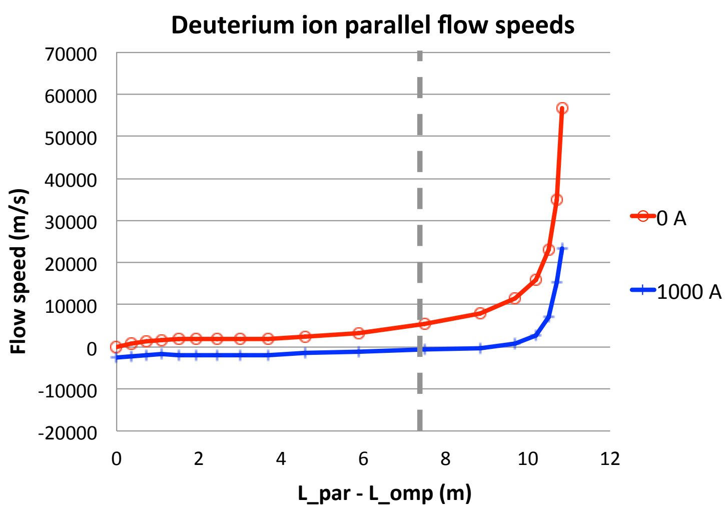
- n_{imp} rises at outer target, but falls (slightly) at outer midplane
- n_{imp} at X-point height is reduced
- $n_{imp}/n_{imp,max}$ shows large relative reduction
  - Divertor retention?

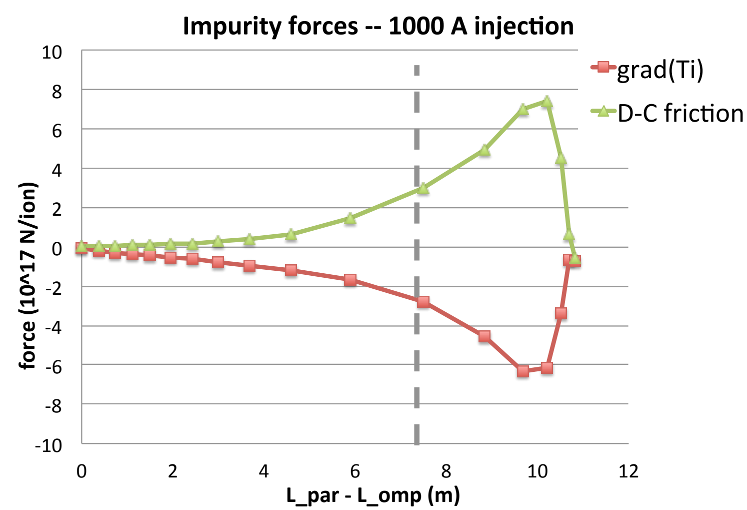
Deuterium gas injection prevents carbon flow stagnation near outer midplane

Data is plotted along a field line on the 2 mm flux surface.









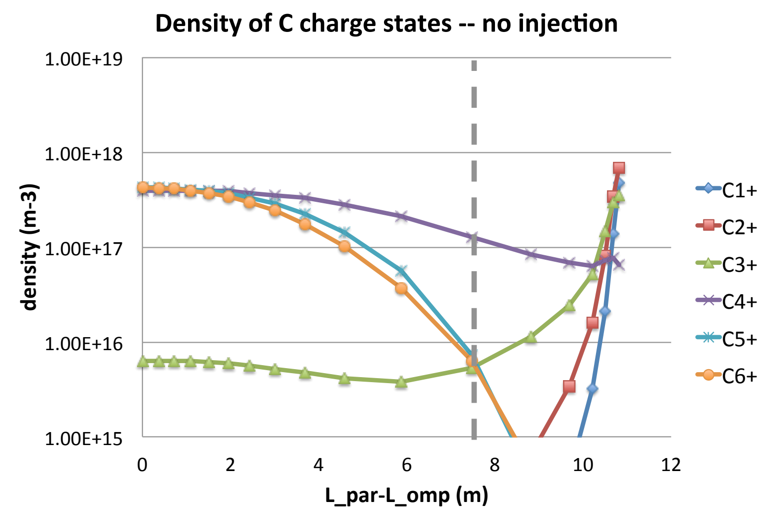
Conclusions

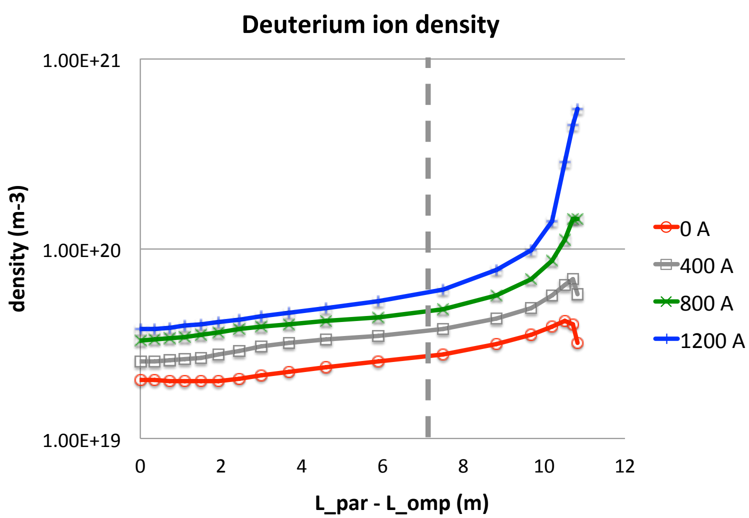
- UEDGE gas puff study shows carbon impurity reduction with divertor deuterium gas injection
  - Observed reduction trend is consistent with experiment
  - Reduction seems related to “flow-through” of C past outer midplane
    - Carbon buildup at outer midplane is prevented
  - Reduction of carbon source is not seen
- Simulations could be improved in future work
  - Double null grid would give larger SOL and include upper divertor physics
  - More closely matching midplane profiles and divertor spectroscopy would increase confidence

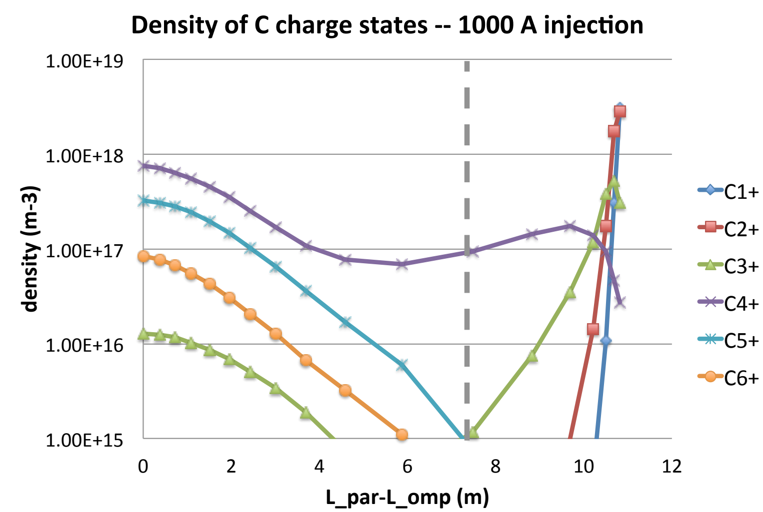
Backup slides

D and C profiles…

(Abscissa is the distance from the outer midplane along a field line on the 2 mm flux surface.)

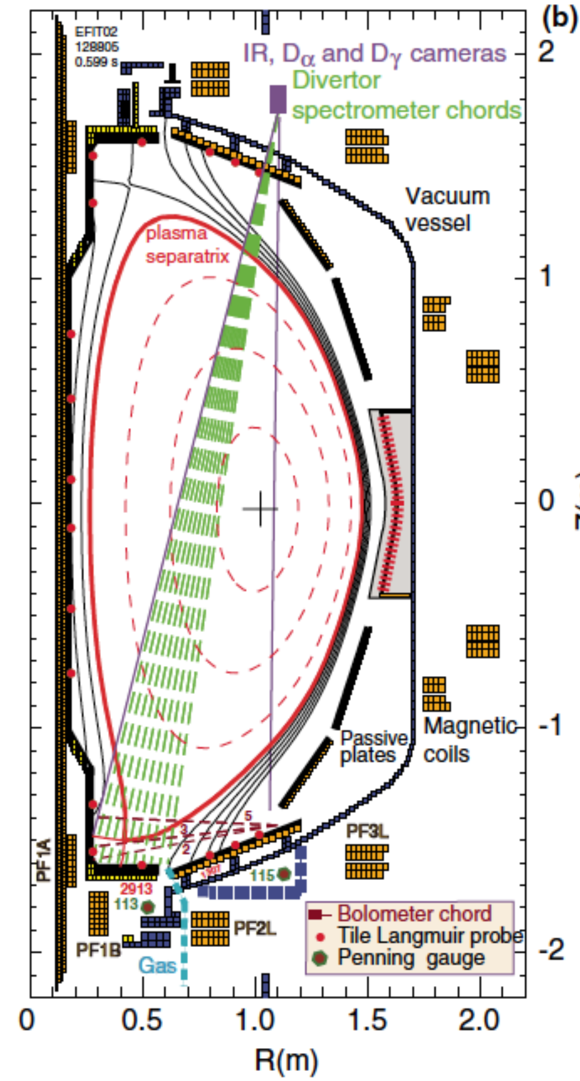






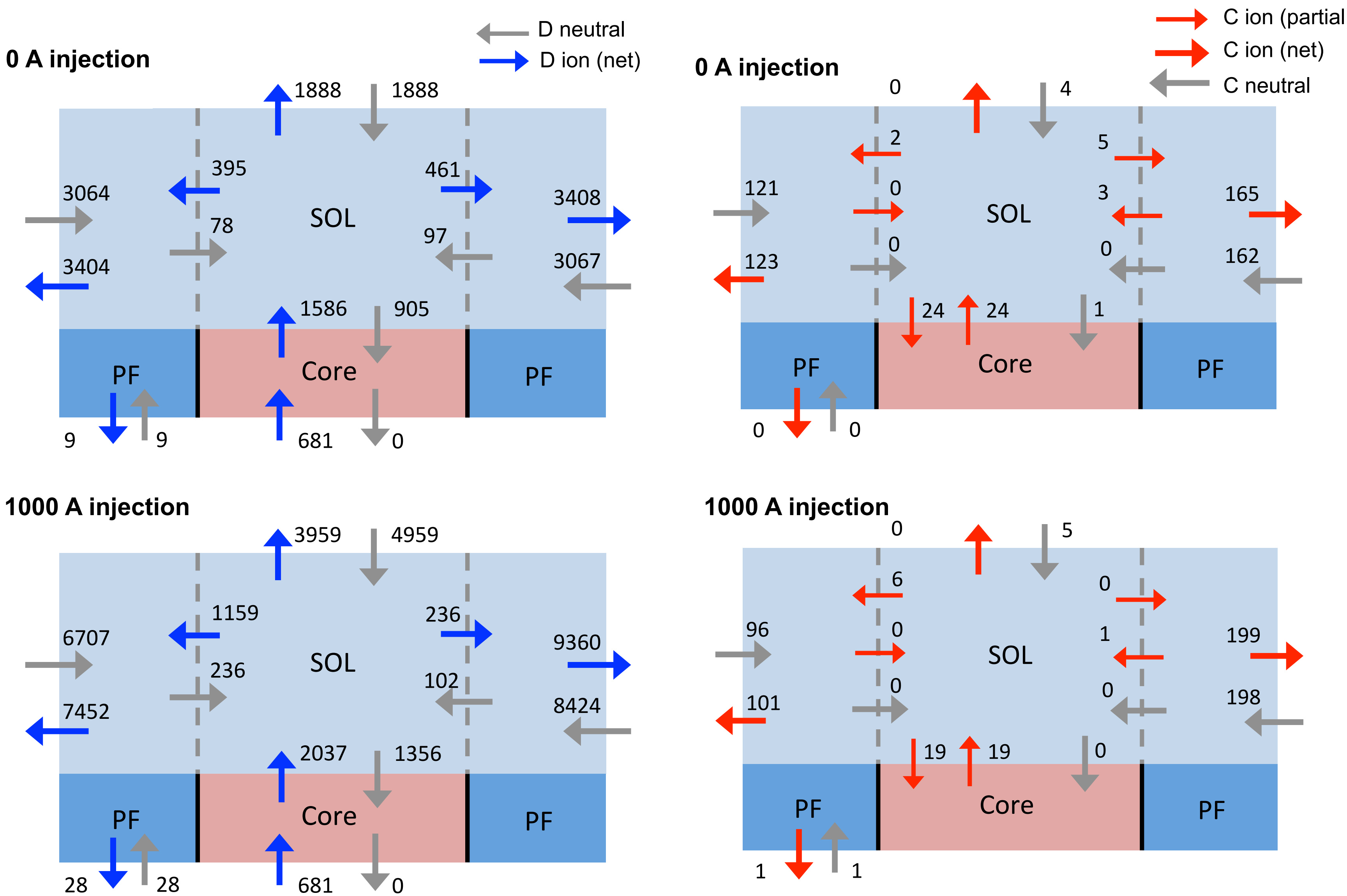
Divertor diagnostics include IR and visible cameras, divertor spectrometry, and tile Langmuir probes

- IR camera used to determine heat flux
- Visible cameras can be filtered to provide D_α data
- Langmuir probes provide sparse data
  - Other comments???



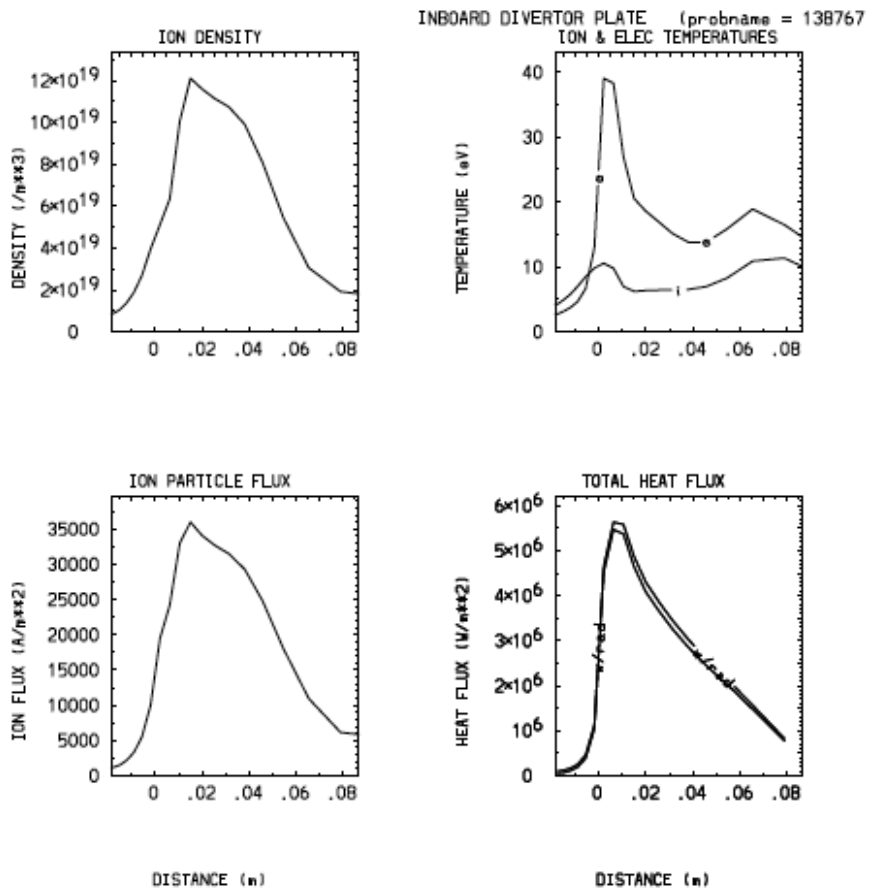
[Soukhanovskii NF '09]

With deuterium injection, recycling increases dramatically, but changes to C transport are more subtle

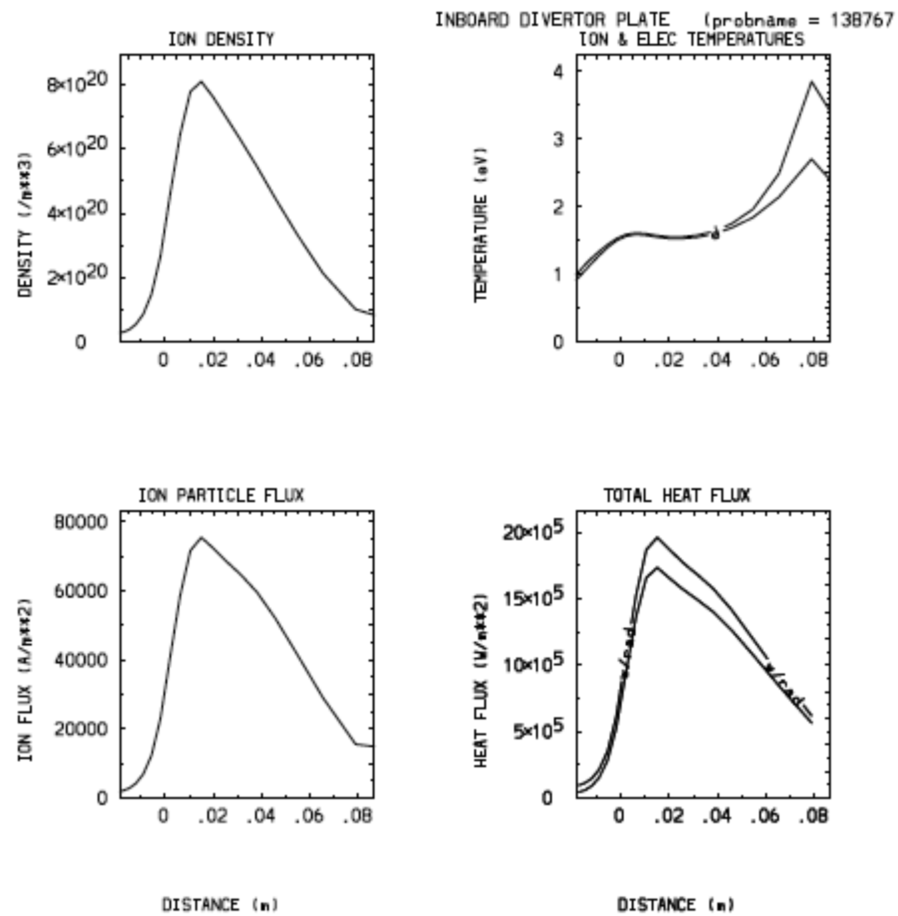


With 1000 A injection, inner divertor temperature and heat flux fall dramatically

0 A injection

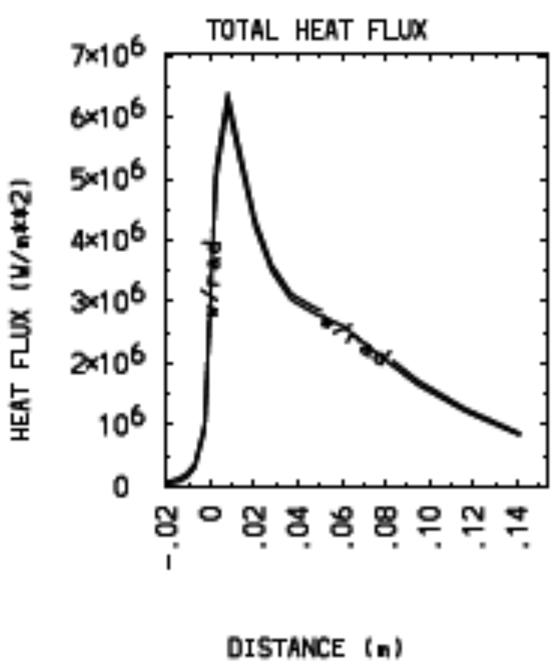


1000 A injection

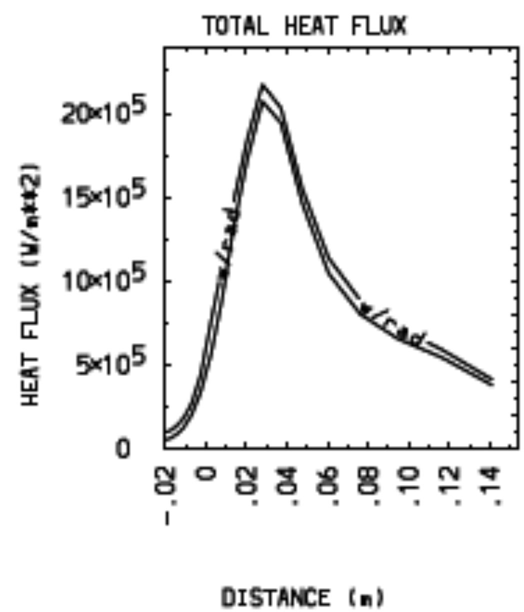


Heat flux comparison…

0 A puff



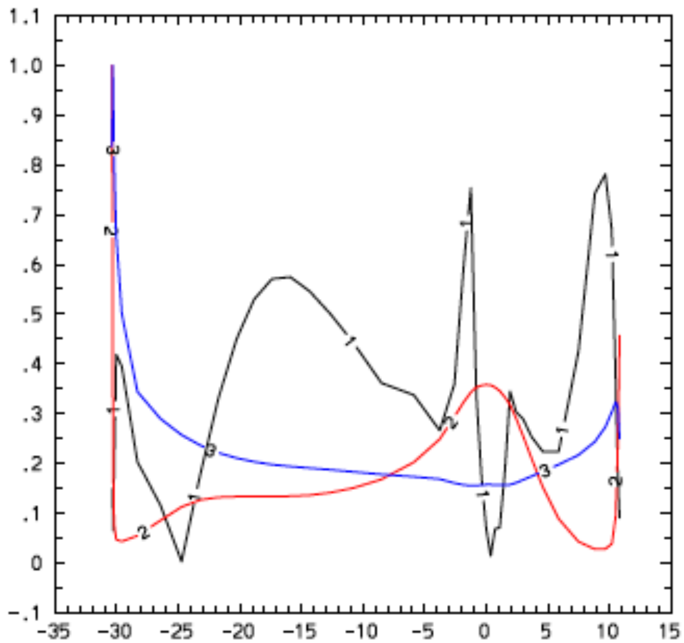
1000 A puff



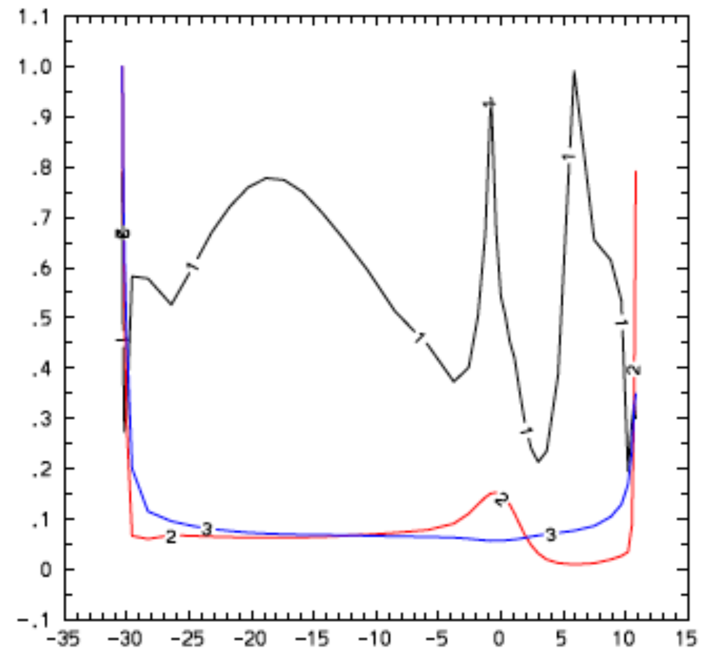
Igas (A)	P_SOL (MW)	Pdiv_in (MW)	Pdiv_out (MW)	Pwall (MW)	Prad
0	3	0.44	0.95	1.51	0.22
1000	3	0.27	0.37	1.92	0.50

Assessment of radial impurity current

0 A



1000 A



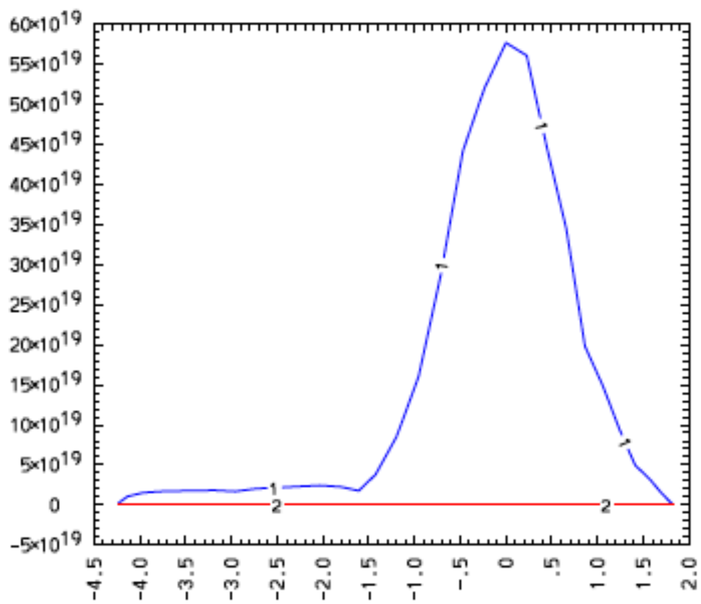
1. (Black) Poloidal impurity current (into a cell) / total current (into a cell)
2. (Red) Impurity ion density
3. (Blue) Deuterium ion density

Abscissa is poloidal distance from outer midplane. Data is plotted for the 2 mm flux surface (iysptrx+6) are plotted.

```
1. plot fpc(1:nx)/ftc(1:nx) ltmp(1:nx,iy)-ltmp0
2. plot nimp(1:nx)/max(nimp(1:nx)) ltmp(1:nx,iy)-ltmp0 color=red
3. plot ni(1:nx,iy,1)/max(ni(1:nx,iy,1)) ltmp(1:nx,iy)-ltmp0 color=blue
```

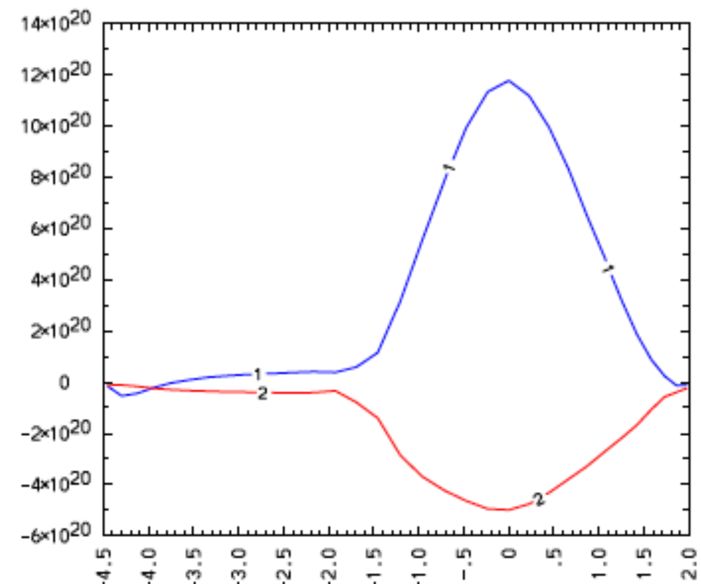
Radial deuterium fluxes, 0 A

Core flux



1: plot fniy(ixpt1+1:ixpt2,0,1) lpol(ixpt1+1:ixpt2,0)-lpol0 color=blue
2: plot fngy(ixpt1+1:ixpt2,0,1) lpol(ixpt1+1:ixpt2,0)-lpol0 color=red

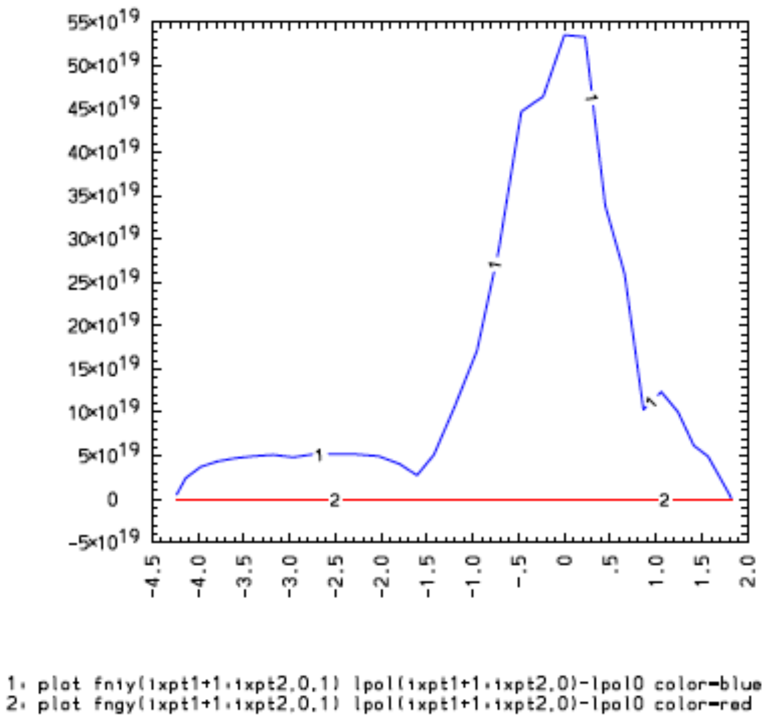
Separatrix flux



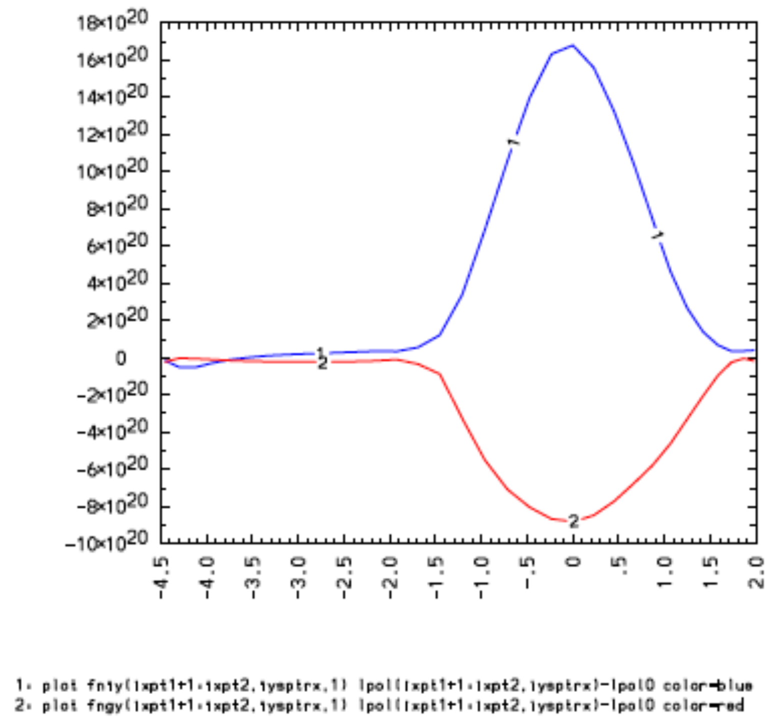
1: plot fniy(ixpt1+1:ixpt2,iysptrx,1) lpol(ixpt1+1:ixpt2,iysptrx)-lpol0 color=blue
2: plot fngy(ixpt1+1:ixpt2,iysptrx,1) lpol(ixpt1+1:ixpt2,iysptrx)-lpol0 color=red

Radial deuterium fluxes, 1000 A

Core flux



Separatrix flux



Neutral gas density …