Supported by Office of Fusion Energy Sciences Office of Science

(Preliminary assessment of)
Recycling and particle fluxes in NSTX

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NSTX Liquid Lithium Divertor Design Meeting
24 April 2007
Princeton, NJ

Motivation

Based on measurements available in NSTX…

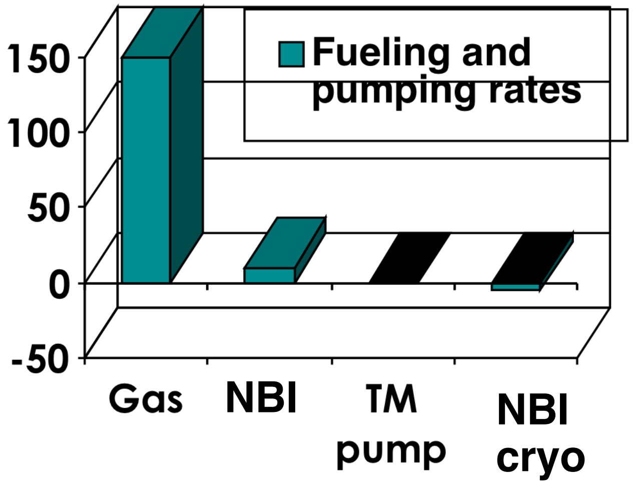
- Assess poloidal distribution of fueling sources
- Assess relative role of lower, upper divertor and “main chamber” recycling

- Provide input in liquid lithium divertor (LLD) module design
  - ✓ Input for 0D modeling
  - ✓ Assess optimal LLD module location and size
  - ✓ Assess expected impact of LLD on particle inventory

- Apply developed analysis to FY2006 LITER lithium evaporator experiments
  - ✓ Analyze ion source change in LITER experiments
  - ✓ Assess particle balance

Large effort!

Main fueling source and sink in NSTX are walls (including divertor)



NSTX fueling source

- Gas injection: low field side (LFS, top + side) and high field side (HFS, midplane + shoulder), divertor. D_2, He, injected at S = 20 - 100 Torr l /s.
- Neutral beam injection system: three beams, 60 - 100 keV, 6-7 MW, fueling rate: S < 4 Torr l / s
- Supersonic gas injection S = 30 - 130 Torr l / s
- Wall (and divertor)

NSTX pumping

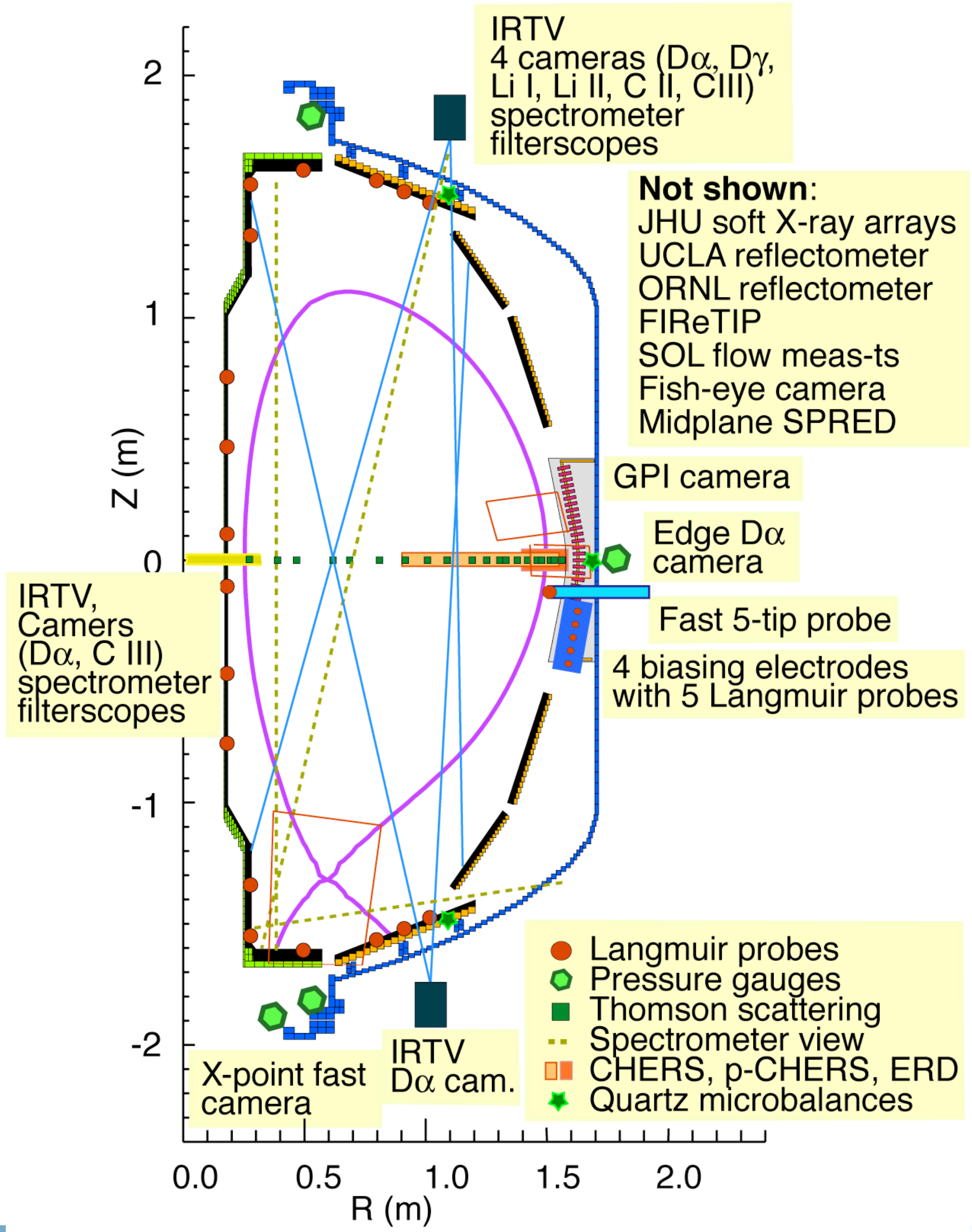
- Turbomolecular pump (S = 3400 l / s)
- NBI cryopump (S = 50000 l / s, in NBI-heated plasmas only)
- Conditioned walls

PFC

- ATJ graphite tiles on divertor and passive plates
- ATJ and CFC tiles on center stack

Particle fluxes measured in NSTX with spectroscopy, probes and pressure gauges

- Deuterium emission
  - Lower divertor Dα camera
  - Lower divertor Dγ camera
  - Center stack midplane Dβ camera
  - Outer edge midplane 4-channel Dβ EIES (PMT) array
  - One channel tangential Dα EIES
  - Calibrated *in-situ* before/after each run year with a LabSphere radiometric standard
- Neutral pressure gauges
  - Not conductance limited
  - Penning gauges in lower and upper divertors
  - Several midplane micro-ion gauges
  - One top micro-ion gauge
- Plasma-wall interaction: 18 tile Langmuir probes
  - I_{sat} routinely available with few ms resolution



S/XB ratio technique is used to infer ionization source from spectroscopic Dα-Dβ measurements

- Technique originally developed by L. C. Johnson & E. Hinnov, and further by A. Kallenbach
- Used for deuterium and impurities

$$\Gamma_{ph} = \int_{x_1}^{x_2} n_i \, n_e \, X \, B \, dx$$

$$\frac{\partial n_i}{\partial t} + \frac{\partial}{\partial x}(v_i \, n_i) = S^{i-1} \, n_e \, n_{i-1} - S^i \, n_e \, n_i$$

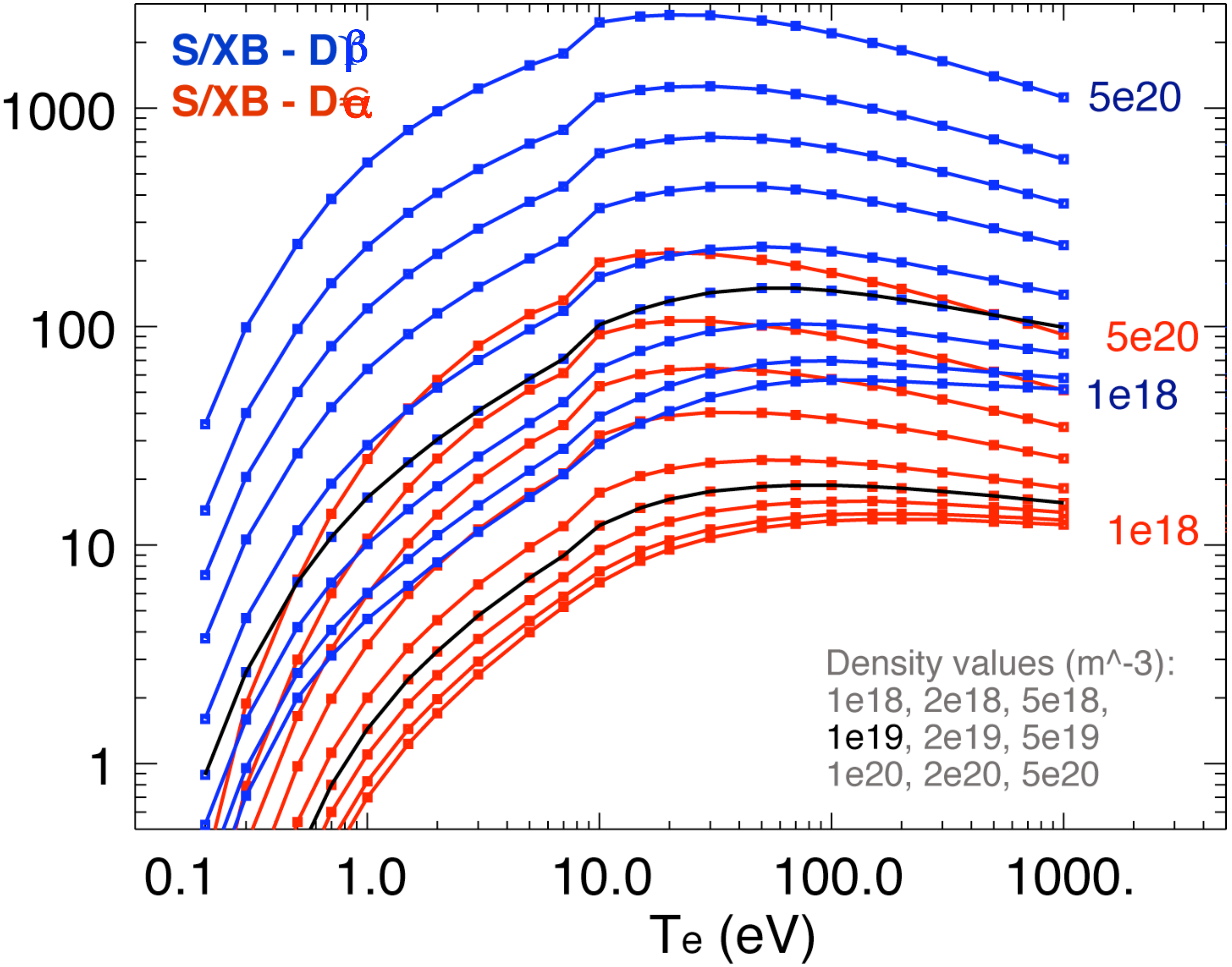
$$\Gamma_{ph} = -\frac{X \, B}{S^i} \left(v_i \, n_i |_{x_1}^{x_2} - \int_{x_1}^{x_2} S^{i-1} n_{i-1} \, n_e \, dx + \int_{x_1}^{x_2} \frac{\partial n_i}{\partial t} \, dx \right)$$

$$\Gamma_i = -v_i \, n_i |_{x_1}^{x_2} + \int_{x_1}^{x_2} S^{i-1} n_{i-1} \, n_e \, dx$$

$$\Gamma_i = \frac{S}{X \, B} \, \Gamma_{ph}$$

- 1D viewing geometry
- x_1- recycling / erosion boundary, x_2 - detector location
- Recombination neglected
- Excitation and ionization occur in the same volume
- Steady-state condition

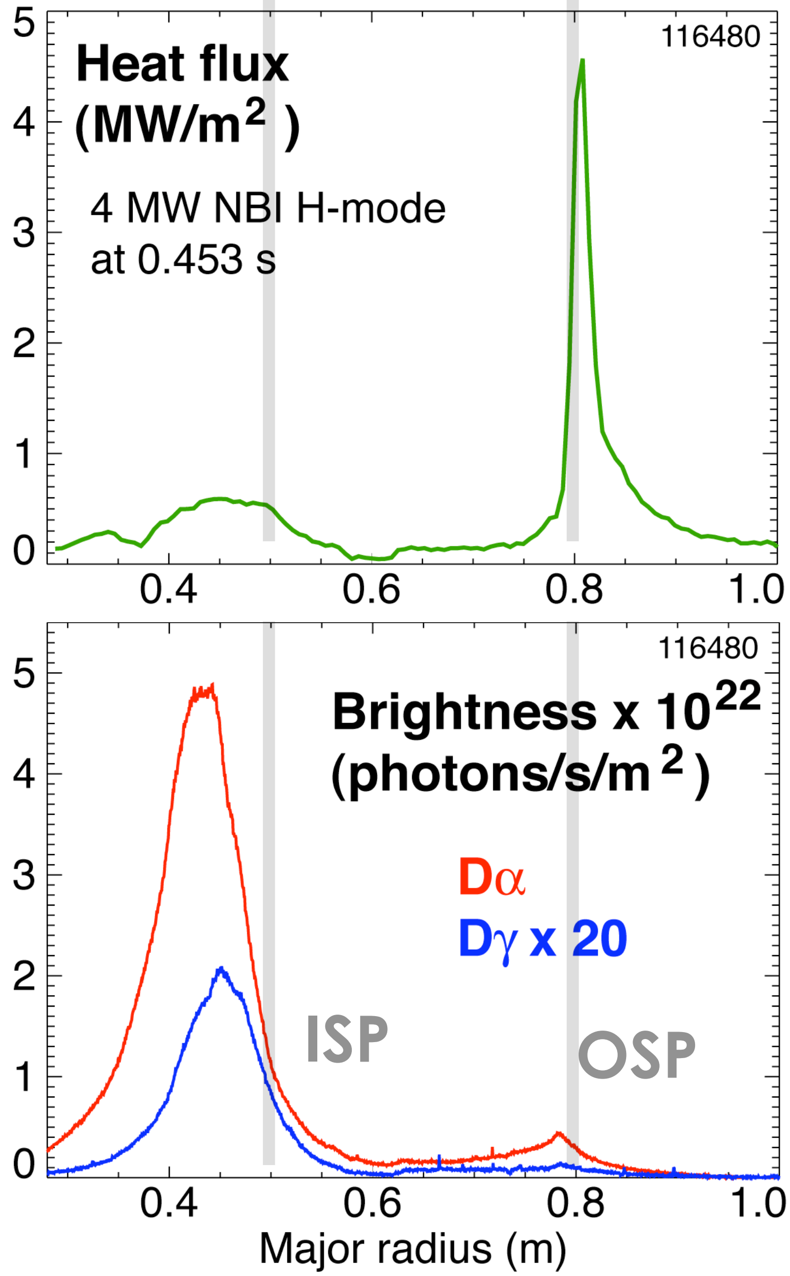
S/XB ratio technique is used to infer ionization source from spectroscopic Dα-Dβ measurements



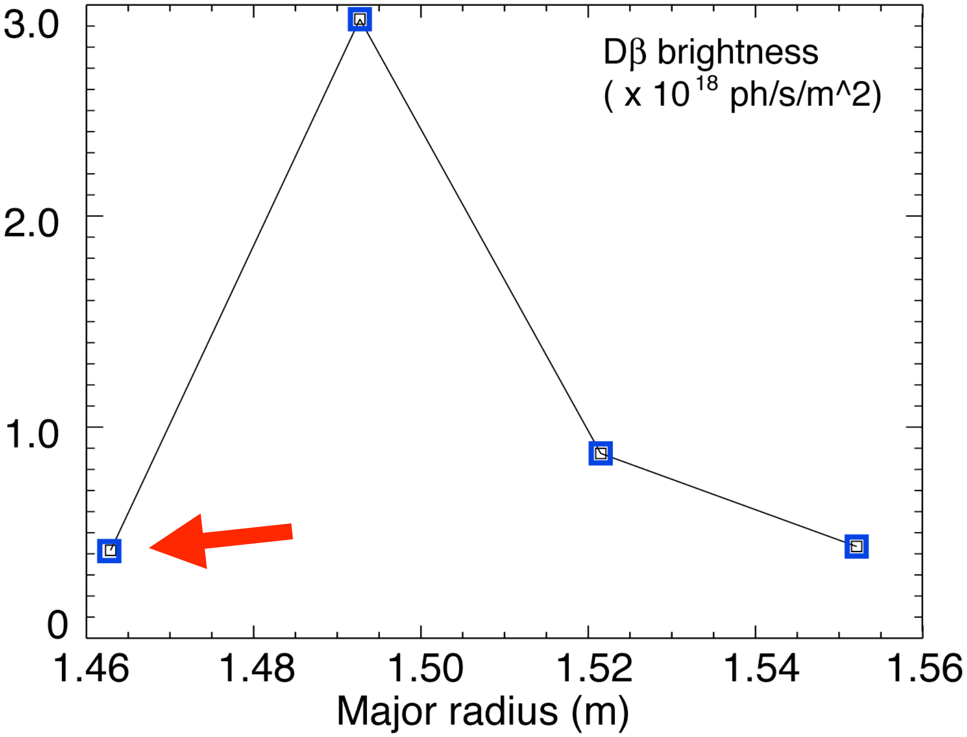
- From ADAS database (courtesy of ORNL Controlled Fusion Atomic Data Center (CFADC))

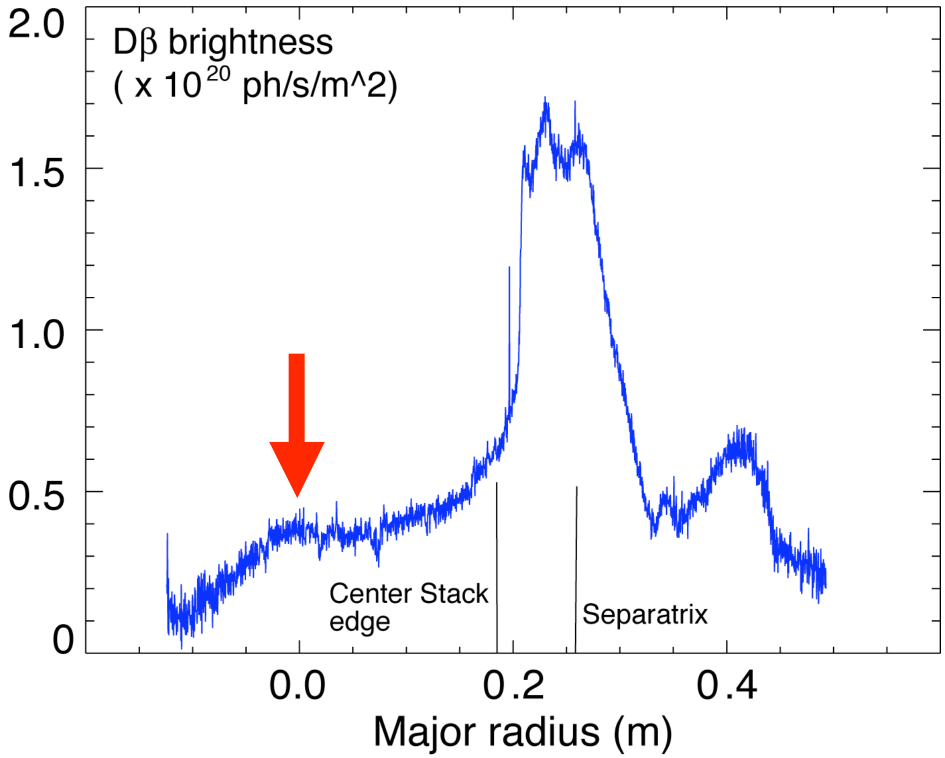
Lower divertor heat flux and deuterium emission profiles

- Reflections in outer divertor small ~ 10 %, in inner divertor higher
- Outer strike point attached - use S/XB ratio of 20 ionizations / Dα photon
- Inner strike point detached, use S/XB ratio of 1-2 ionizations / Dα photon
- Private flux region fluxes not considered
- Future work: use Dγ profile to infer inner divertor sink using recombinations / Dγ photon



Midplane center stack recycling is much higher than outer midplane edge recycling





- Outer SOL Dβ EIES array
  - Too few points for Abel inversion, typically all outside separatrix
  - Take innermost point and use as “radial” view

- Inner SOL Dβ profile from 1D CCD camera
  - Inversion difficult due to reflections / poor background coverage
  - No T_e and n_e measurements in inner SOL
  - Take R=0 value for “radial” view

Atomic and molecular fluxes are inferred from neutral pressure measurements

$$\Gamma_{D_2} = \frac{1}{4} n_{D_2} \bar{v} \qquad \bar{v} = \sqrt{\frac{8kT}{\pi m}} \qquad P = n\,kT$$

$$\Gamma_D = 2 \times \frac{1}{2} \times \Gamma_{D_2} = \frac{1}{4} \frac{P}{kT} \sqrt{\frac{8kT}{\pi m}}$$

- “Standard” way to estimate molecular / atomic fluxes from pressure neutral measurements
- Might be about factor of 2-3 overestimated (from MC simulations and / or kinetic simulations)
- Typical midplane pressure P < 0.1 mTorr, lower divertor P < 1 mTorr

Plasma ion out-flux is inferred from tile Langmuir probes

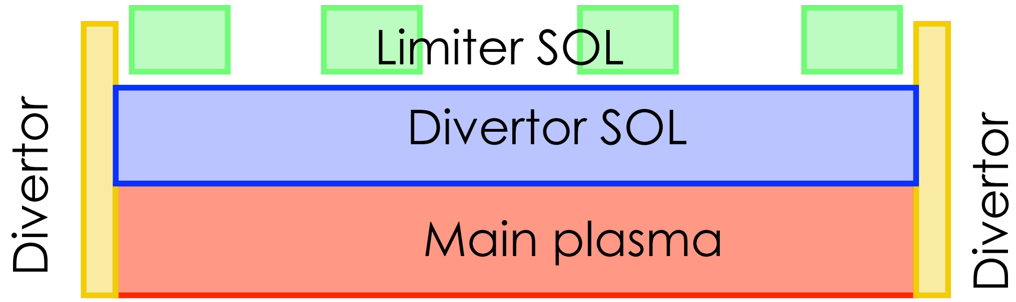
- I_{sat} data available for 2005 and 2006 shots

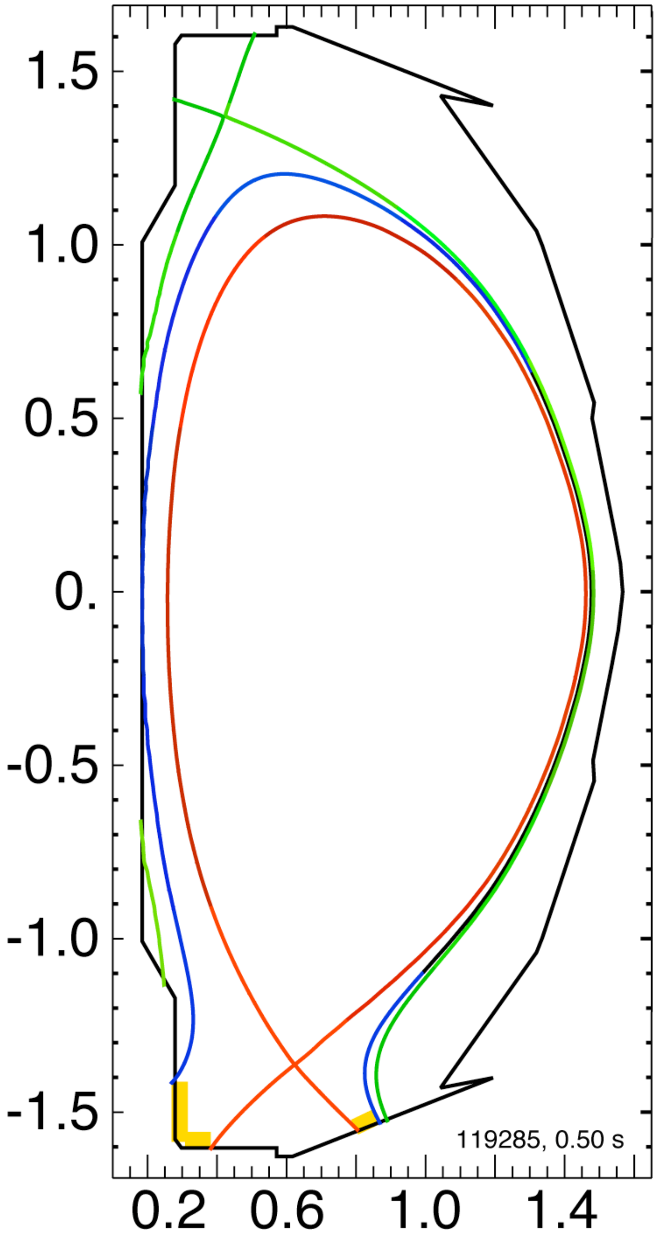
$$j_{sat} = \frac{I_{sat}}{A_{pr} \sin \alpha} \qquad \Gamma_i = j_{sat}/e$$

- Tile Langmuir probes are flush-mounted
- Main computational effort is to calculate α's accurately
- For very shallow angles ($\alpha < 1$–2^o) will use Gunn's probe sheath expansion model
- Inferred fluxes will be used to assess main wall flux according to the "window frame" technique

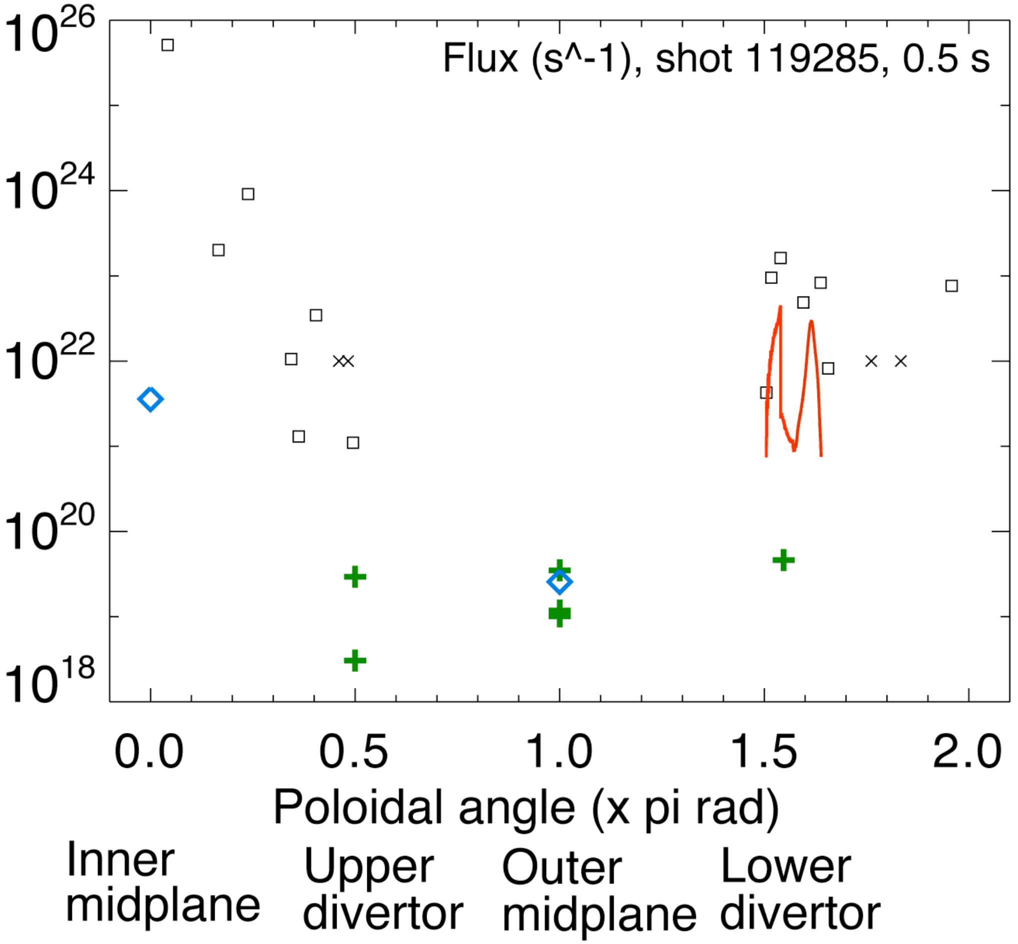
Elements of “window frame” technique used for particle flux analysis in NSTX

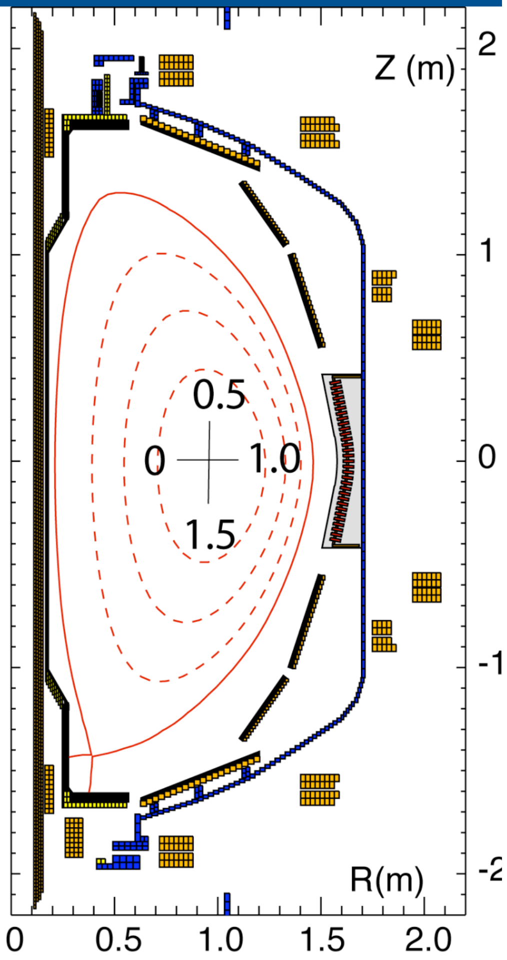
- “Window frame” technique developed by P. C. Stangeby, D. G. Whyte et. al.
- Define “divertor SOL” as region between | | (full line connection from plate to plate)
- Define “main chamber wall” at DivSOL boundary | where connection length abruptly decreases
- Use Langmuir probes to infer plasma flux on main wall
- Use spectroscopy and neutral pressure measurements to infer recycling / neutral fluxes from main wall
- Prescribe smooth poloidal profile for “main wall” based on two point measurements and top stagnation point
- Inner and outer divertor “plates” are shown by |
- Use spectroscopy and neutral pressure measurements to assess recycling / neutral fluxes from divertor
- In NSTX, upper divertor coverage is poor





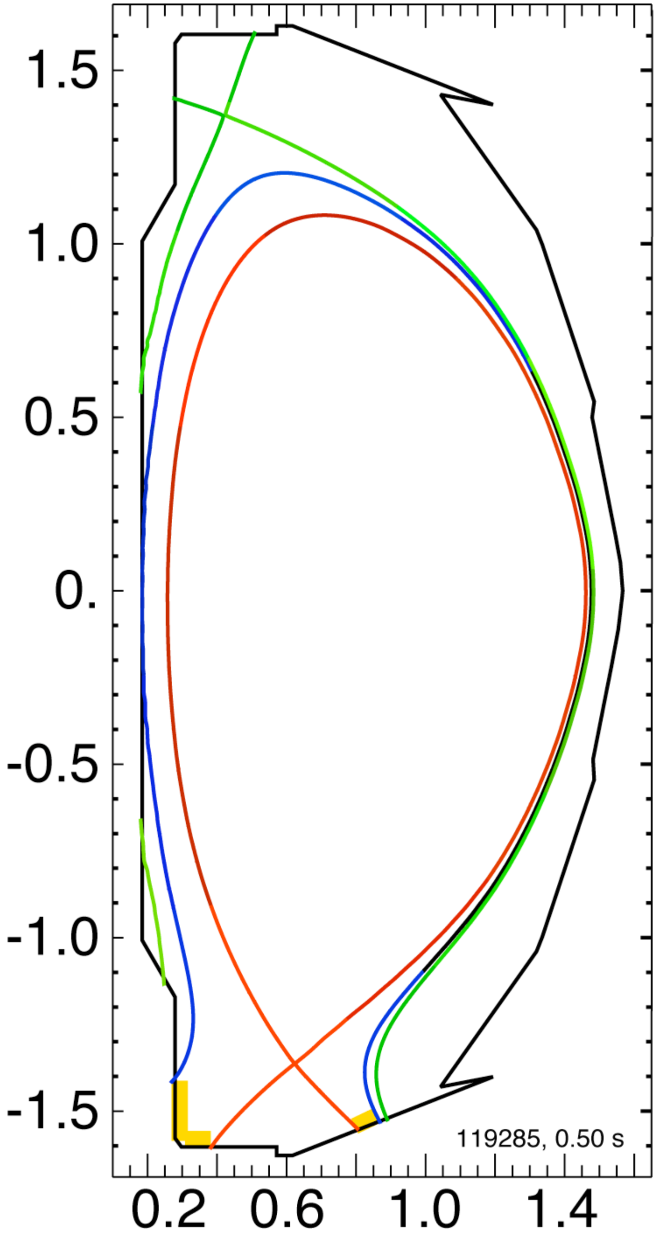
Preliminary result - poloidal distribution of particle fluxes





- Langmuir probe - uncorrected j_{sat} shown (black squares)
- Neutral pressure - green crosses
- Midplane Dβ measurements - blue diamonds, Divertor Dα - red trace

Preliminary results for shot 119285, at 0.3 s and at 0.5 s



MPTS line average density: 3.4e+19

total inner div source is: 1.35e+22

total outer div source is: 8.18e+21

total outer MP source is: 7.59e+20

total inner MP source is: 3.57e+21

MPTS line density: 5.2e+19

Inner div source is: 1.13e+22

total outer div source is: 1.28e+22

total outer MP source is: 6.28e+20

total inner MP source is: 4.45e+21

Questions:

- Is outer divertor SOL in linear regime?
- Inner divertor source is strong - true?

Preliminary conclusions and future work

- In a low-triangularity low-elongation shot (*drsep* ~ -2.0 cm)
  - ✓ Lower divertor *appears* to be a dominant ionization source (x 10) over “main wall” source
  - ✓ Upper divertor *does not appear* to be a significant ionization source
  - ✓ **Results are preliminary**
  - ✓ Implications for **LLD** to be assessed numerically, but looks like LLD should be where outer divertor SOL intersects the divertor plate

- Future work:
  - – Check and clean up calculations
  - – Analyze high κ,δ shots
  - – Compare with particle balance calculations (TRANSP?)
  - – Compare with edge modeling (UEDGE / DEGAS)