SXD Configurations for NSTX-Upgrade

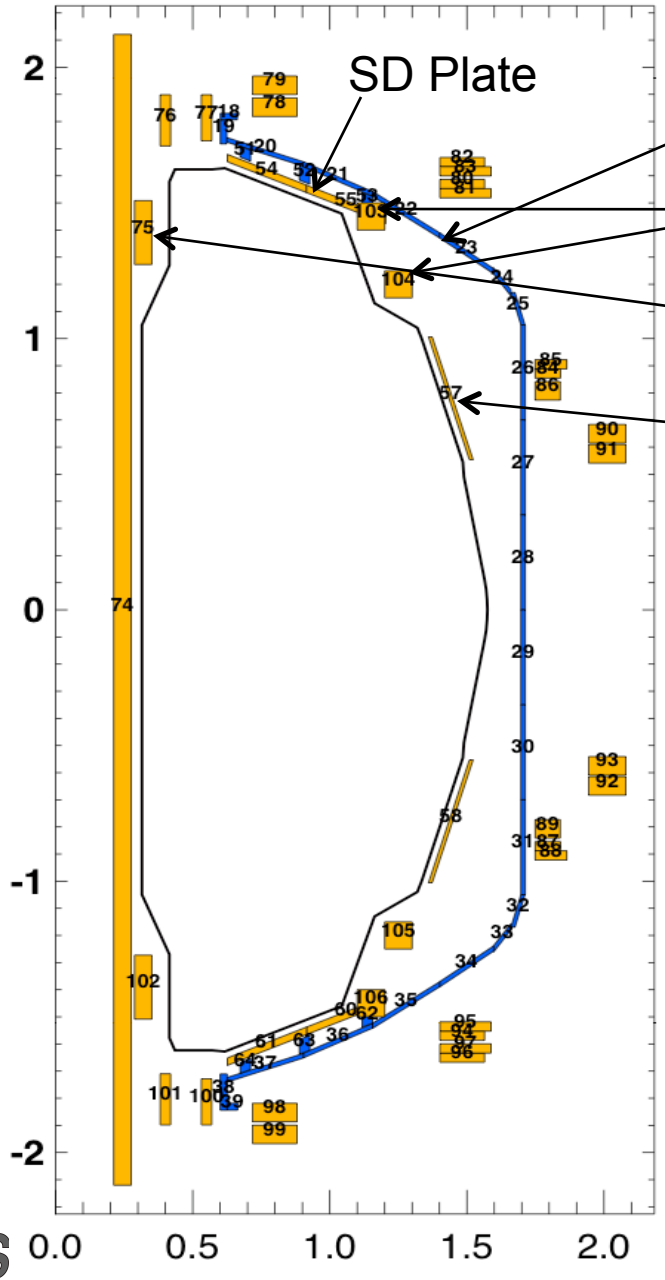
UT-PPPL Teleconference

15 Jan 2009

Goals

- Present some Super-X divertors (SXD) for NSTX-Upgrade
- Determine design changes (if any) required for the center-stack upgrade divertor coils to accommodate SXD
  - Short answer: none are *required*, but …
  - Some minor changes (consistent with constraints) may be desirable
- Demonstrate flexibility of SXD coils to make:
  - Standard Divertor (SD) to SXD as well as Multi-X divertors
- Discuss emerging coil optimization targets and "knobs"
- Discuss synergy of SXD with Lithium divertors

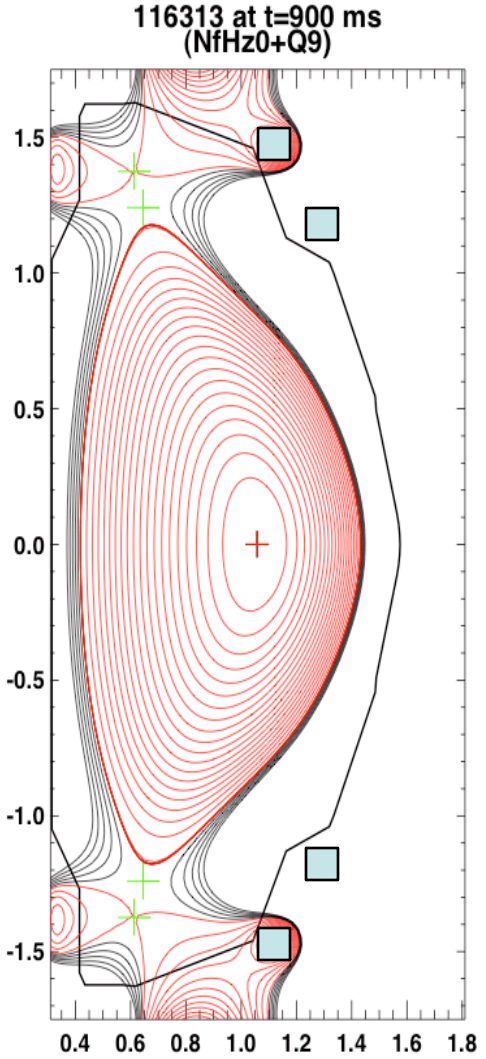
NSTX Starting Point



SXD Coil	Total kA
PFX1U-104	175
PFX2U-105	-175

Note: All today's results are for Ip=1 MA, BT=0.5T

We will change them to Ip=2 MA, BT=1T

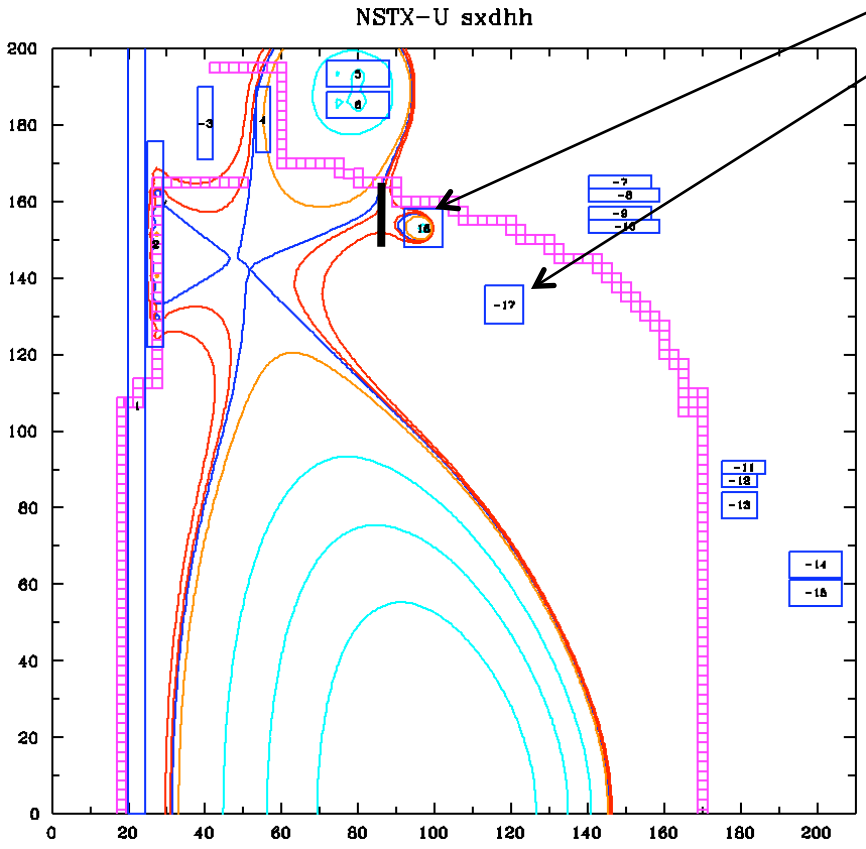


SXD-like NSTX-U

Constraints (from J. Menard)

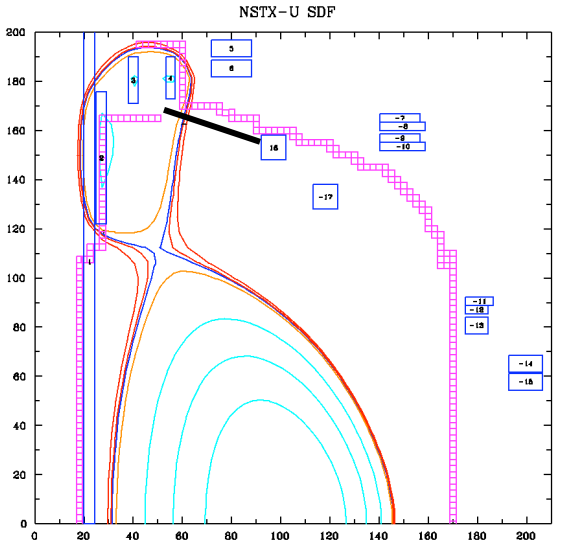
- Keep all coils **outside vacuum vessel** unchanged (Fine for SXD design)
- **Inner stack vertical**: PF1A coil radius is fixed (75, 102), but you can change vertical position and extent - or have 2 coils if you need them.
- **Inner stack radial**: You can move closer to the midplane if needed, but too close would be undesirable. (We did not need to move closer to midplane)
- PF1B, C are fixed (76, 77, 100, 101). They don't fit anywhere else. (Fine)
- You **can add internal coils, move passive plates etc**. inside the vessel
- **Internal coils**: best to have them near the vessel for mounting purposes
- The 4 internal coils shown (103-106) can be moved, deleted, etc.
- **Bottom line: NSTX-U SXD design can comfortably obey all constraints**

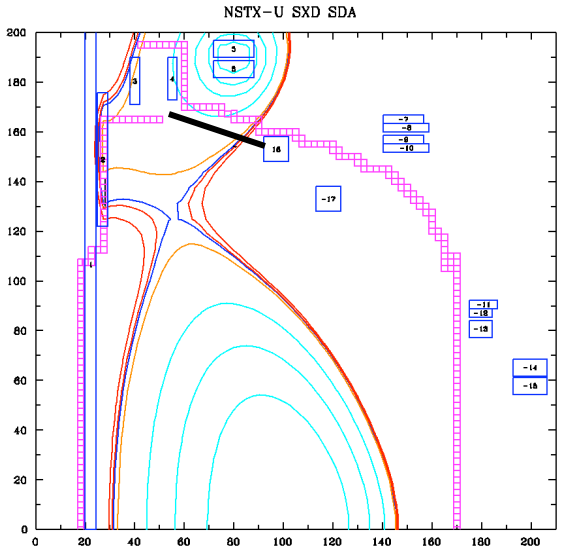
First SXD case (with CORSICA)



- Only two in-vacuum coils
  - Same as NSTX starting point
  - Coil currents lower than NSTX starting point, core plasma same
- Flux expanded near outer plate
- No center stack change needed
  - Need not reduce center stack radius
  - Optional vertical splitting of PF2 into two parts gives a bit more control
- Low MA-m (1.17) & coil currents
  - Is ~ 100 kW ok for in-vacuum PFs?
  - Is per turn ~ 5 kA ok for feedthrough?

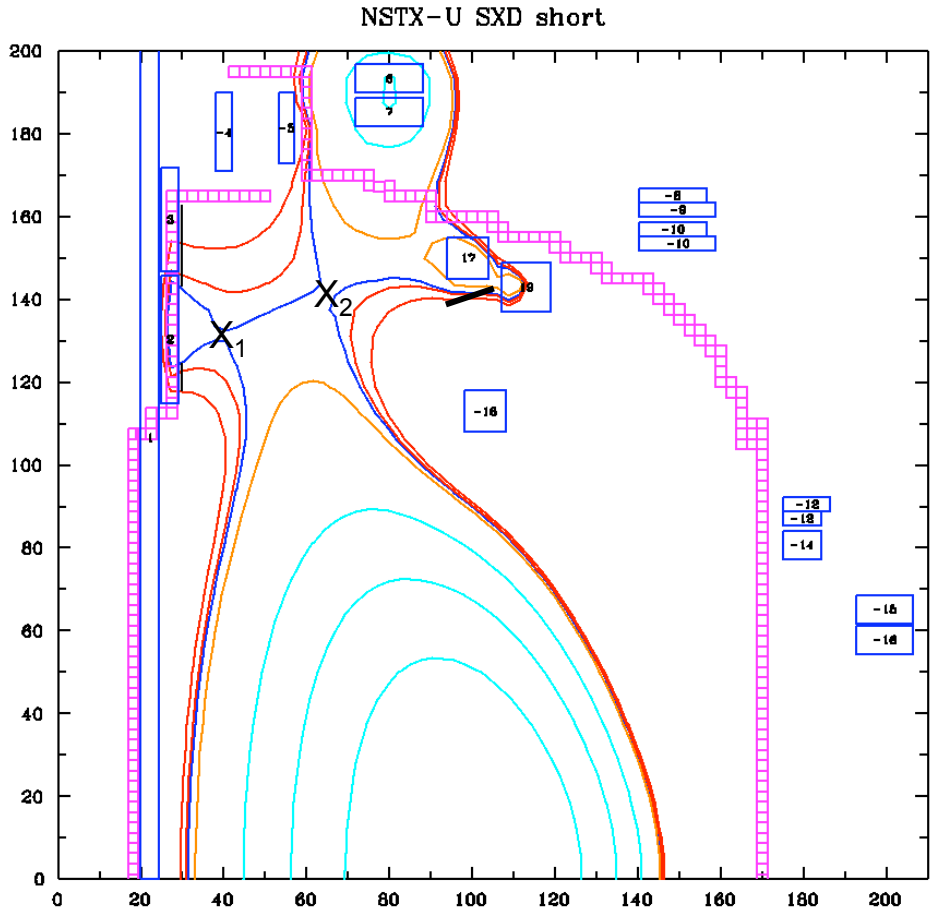
SD sequence with SXD coils (flexibility)





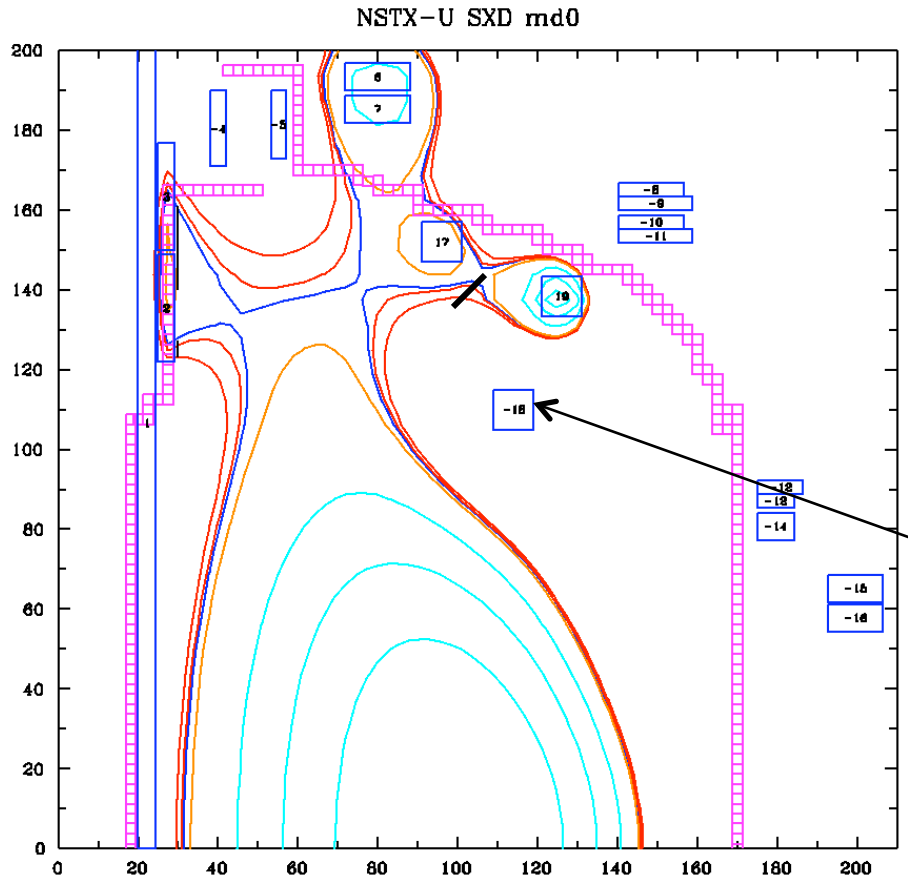
- SXD coils can support a big range from SD to SXD
  - 2 shown, we have many more
- Can move over whole SD plate
  - While keeping core fixed
- Can also produce multiple-X
  - Includes snowflakes
- Configurations are “robust”
  - Topologies do not change with small changes in PF coil currents

Intriguing "Rabbit" SXD?



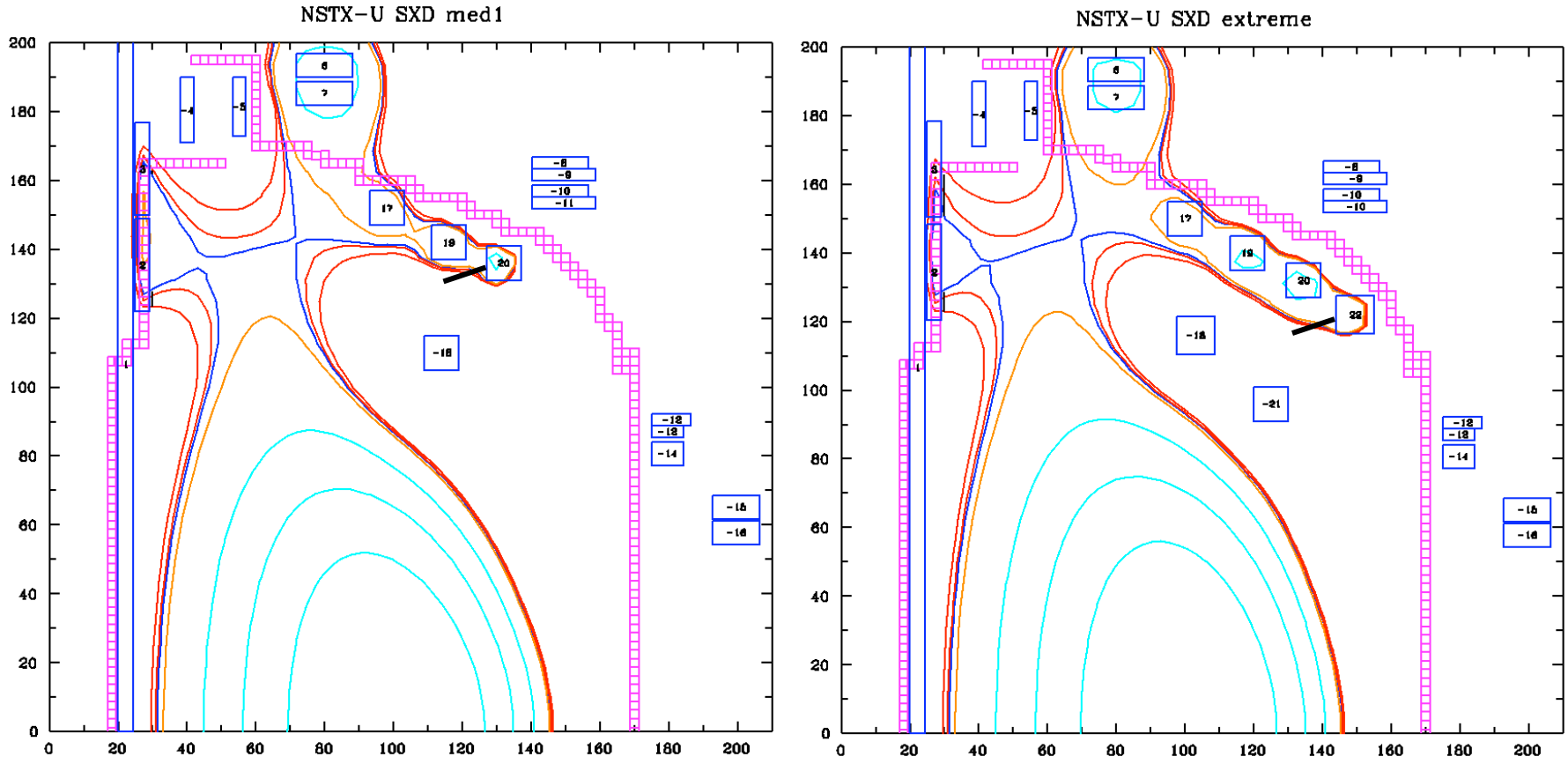
- Split the main X into 2 Xs
- Separately pull X1 inward for higher triangularity, and …
- Pull X2 outward for big SXD R
- This separation avoids the conflict between these 2 goals
- Conflict reduction leads to 25% lower SXD coil currents!
- The 2 Xs need good alignment
  - Just like snowflake or double-null

Extending SXD R is easier for “Rabbit”



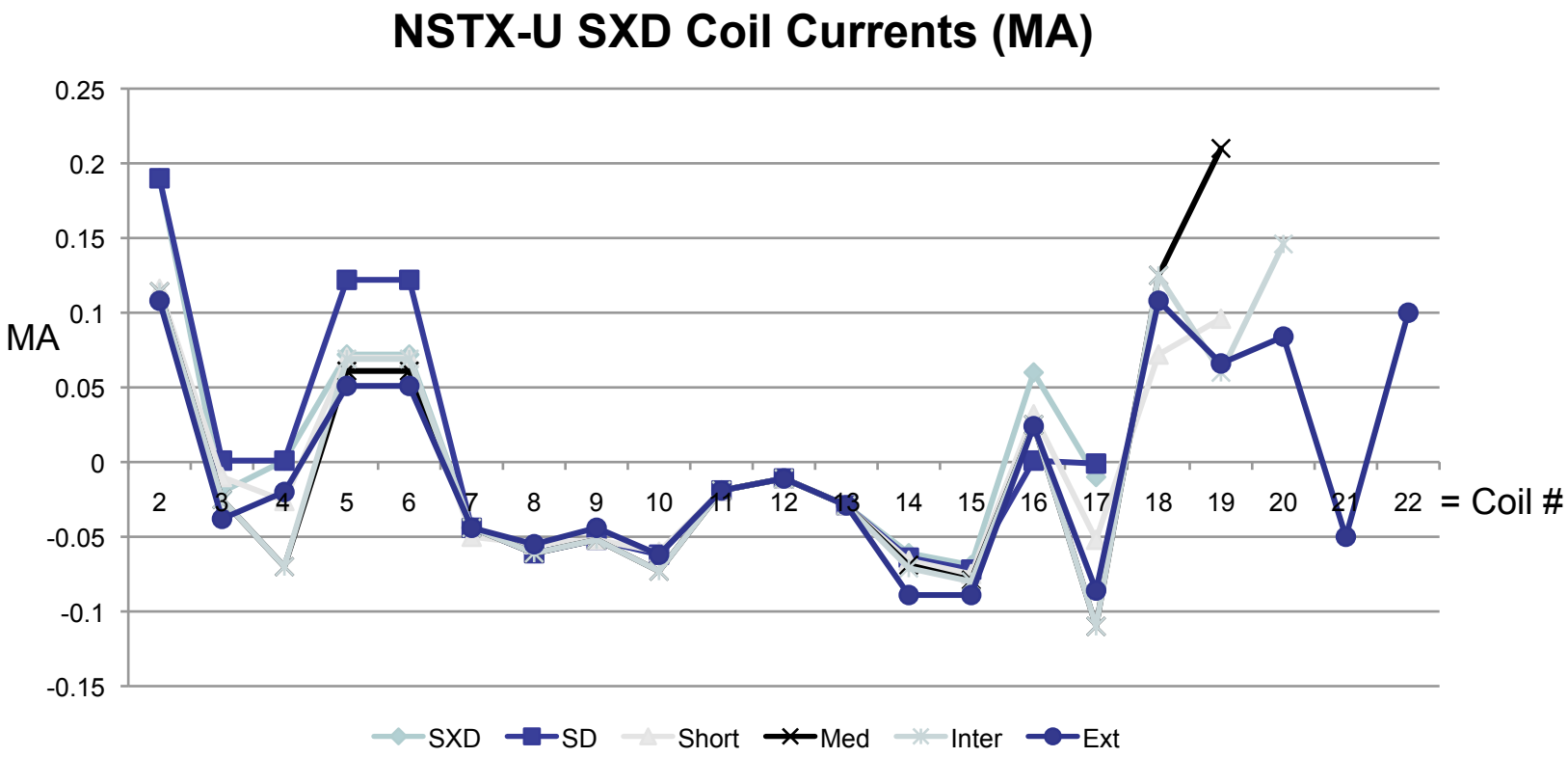
- In NSTX-U, the rabbit SXD makes it easier to extend the outer leg while keeping high triangularity and low coil currents
- We *may* be able to move this coil further out – nearer to vacuum vessel. Needs further investigation.

Extreme extending of SXD "Rabbit" R



- Though not shown here, we can (& will) get much higher flux expansion in the long SXD leg for these cases (work in progress)
- The net MA-m do not increase much with the extra coils

Coil currents for NSTXU-SXD cases



Total MA-m/ Plasma MA-m =	1.17	1.19	1.31	1.24	1.26	1.45

- Total MA-m comparable to SD, minimized by moving coils
- These cases are not yet optimized for currents (by moving coils)

SXD and Lithium Synergy - 1

- **Lithium could increase the need for an SXD**
  - Li *reduces* edge density, possibly smaller SOL width
  - So power exhaust is *more challenging* with Li
  - Plasma temperatures at the divertor plate could be much higher (sheath limited regime, plasma “burns through”)
  - Neutral density low - He exhaust much more difficult(?)
  - **SXD - allows plasma to operate in the partially detached regime for much *lower density* & *higher power* than SD**
  - SXD takes care of power exhaust, plasma temperature, neutral pressure issues

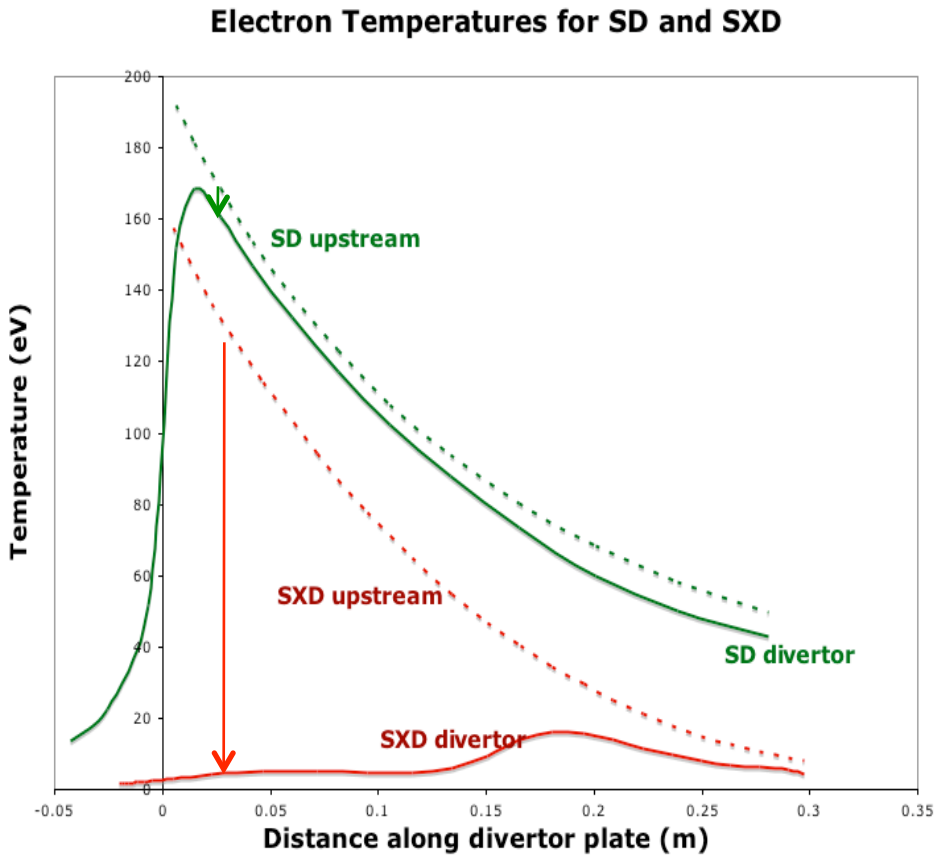
Super-X Divertor (SXD) is partially detached - Standard divertor is sheath limited

SOLPS analysis for CTF/CFNS:

- **Standard divertor - exhausted high power plasma is "sheath limited"**
  - very hot and damaging
  - Very low neutral pressure and helium exhaust
- **SXD - divertor is "partially detached"- T < 10- 20 eV**

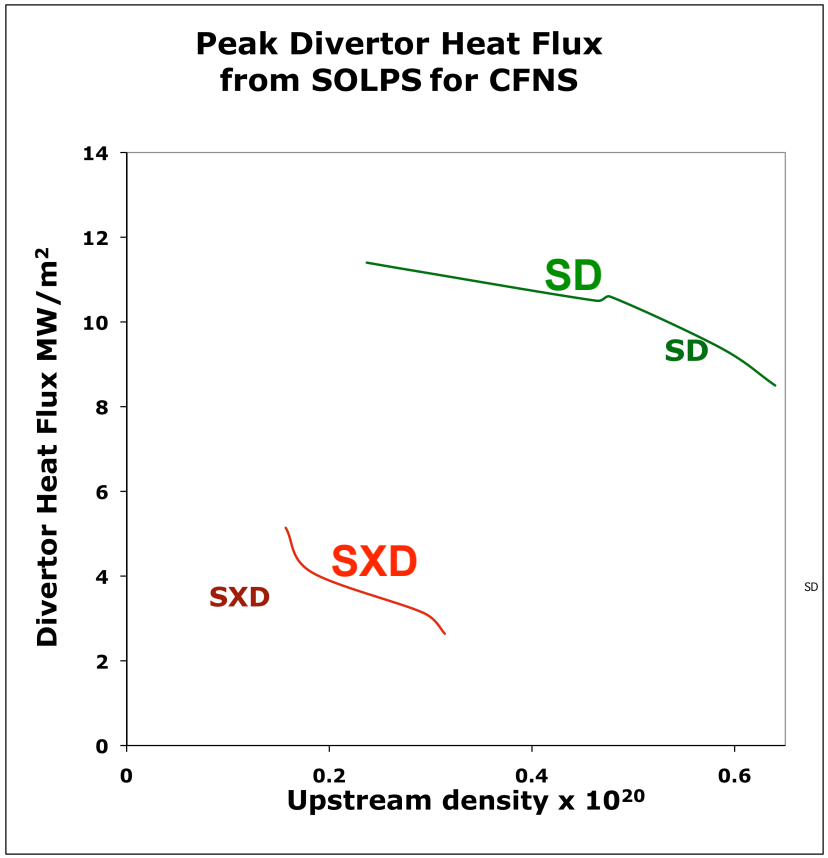
SXD: ~ 4 MW/m^2

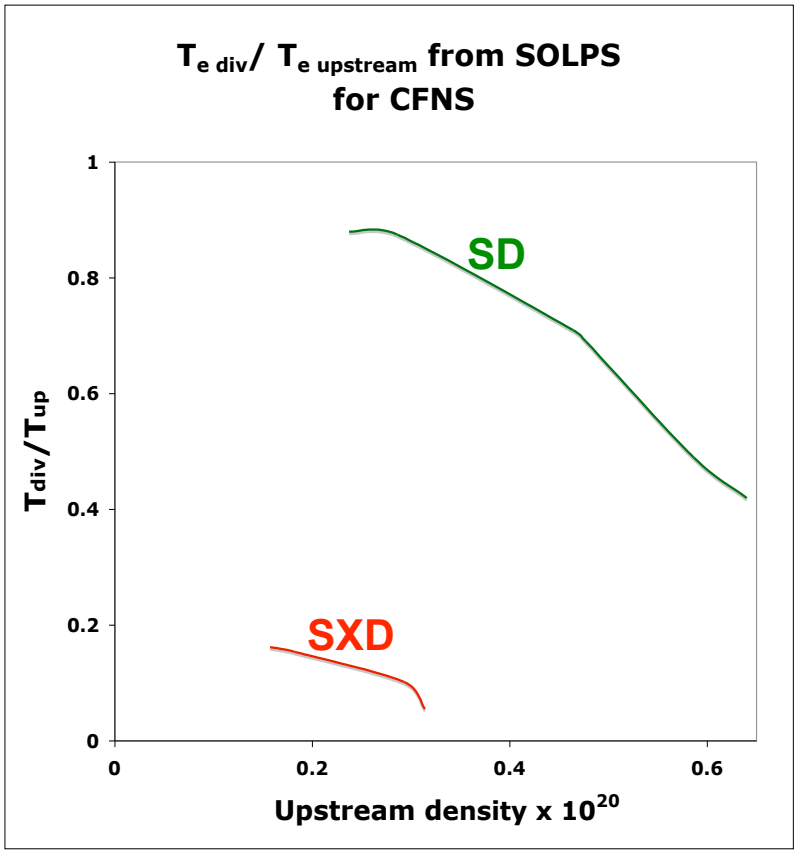
SD: ~ 11 MW/m^2



SOLPS Calculations by John Canik ORNL

Superior SXD performance at low SOL plasma edge density





SOLPS Calculations by John Canik ORNL

SXD and Lithium Synergy - 2

- **An SXD could enhance Li benefits**
  - Long divertor throat could help prevent impurities generated at the divertor plate from entering plasma
  - Add Li plate at SXD strike point - several possible advantages
    - Even lower recycling
    - A Li-soaked divertor plate for a CTF/CFNS/reactor could be designed to be self-replenishing - so ELM erosion from large ELMS might become tolerable (?)

Conclusions & Further Action Items

- **Initial SXD scoping study is very encouraging**
- **Many SXDs possible for NSTX-U within constraints**
- **Total MA-m of SXD coils comparable to SD case**
- **NSTX-SXD topologies "robust" vs coil currents**

Next tasks:

- **Select a "base" SXD design from the many possible**
- **Refine optimization targets & constraints**
- **SOLPS & Li-related calculations for SXD**