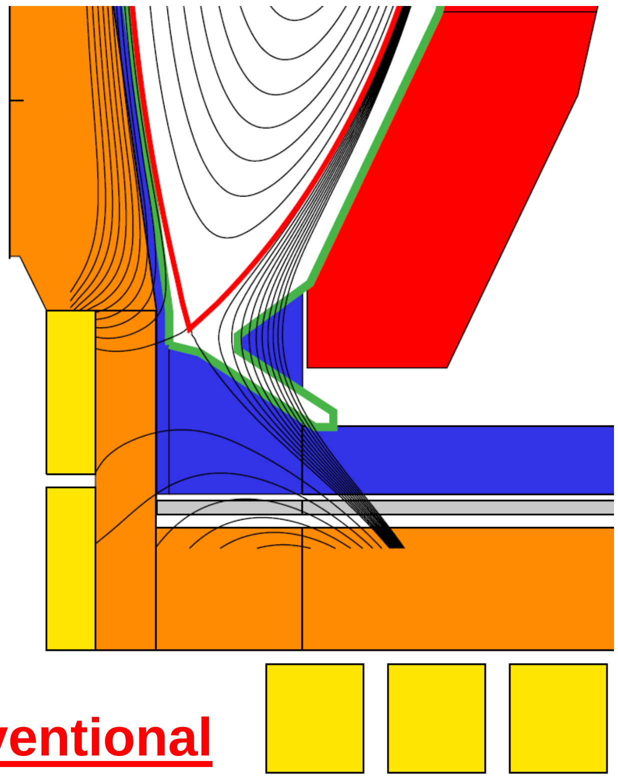
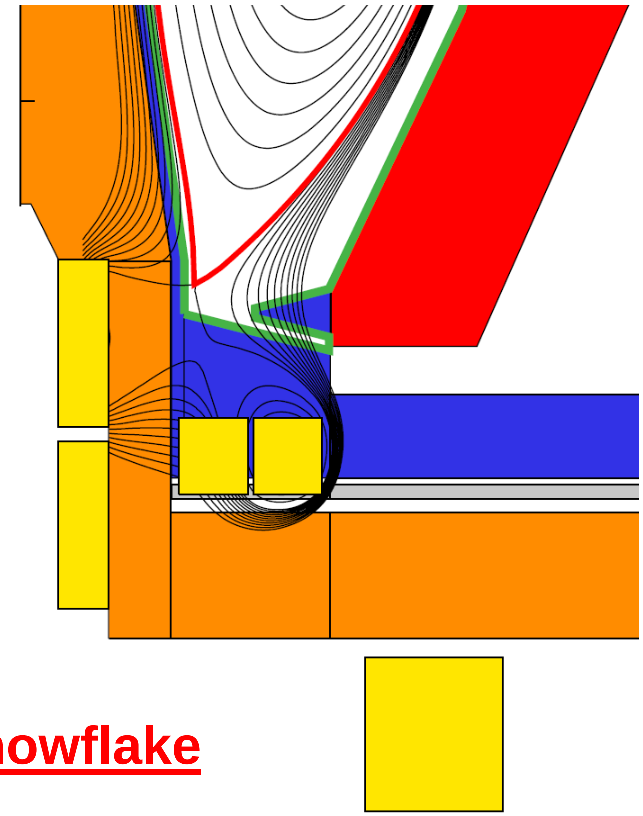
Initial FNSF cryo pumping analysis

Divertor PF coil configurations identified to achieve high δ while maintaining peak divertor heat flux < 10MW/m^2



Field-line angle of incidence at strike-point = 1°



Conventional

- **Flux expansion = 15-25, δ_x ~ 0.55**
- **1/sin(θ_{plate}) = 2-3**
- **Detachment, pumping questionable**
  - Future: assess long-leg, V-shape divertor (JA)

Snowflake

- **Flux expansion = 40-60, δ_x ~ 0.62**
- **1/sin(θ_{plate}) = 1-1.5**
- **Good detachment (NSTX data) and cryo-pumping (NSTX-U modeling)**

- **Will also test liquid metal PFCs in NSTX-U for power-handling, surface replenishment**

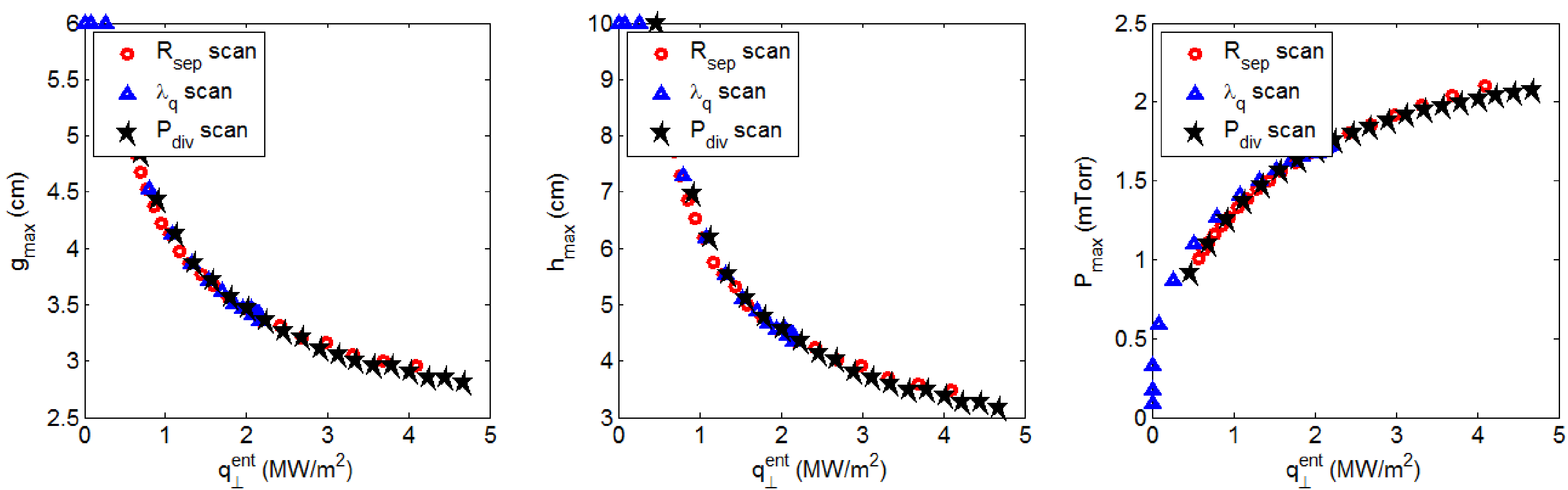
Jaworski - IAEA FEC EX/P5-31

Notes on assumptions

- Same geometry as NSTX-U (not shown here)
  - Pumping in SOL
  - Need to optimize height, length, radius of plenum entrance
- Minimum pumping level needed to remove NBI fueling
  - Assume 80 MW @ 0.5 MeV
  - Beams give roughly 20 A/MW @ 80 keV, so 3.2 MW @ 500 keV
  - Gives a rough estimate of 24 torr-l/s that need to be removed
  - So, pressure of 1 mTorr needed if there's one cryo with the same pumping speed we've assumed for NSTX-U
  - Really, we're assuming CND, so there'd be two pumps with this speed
  - So in all, a (rough) estimate of the needed pressure is 0.5 mTorr
    - Will update based on TRANSP later on
    - PNBI would make this higher (~4x)
    - But we could probably assume higher pumping speeds if we need to

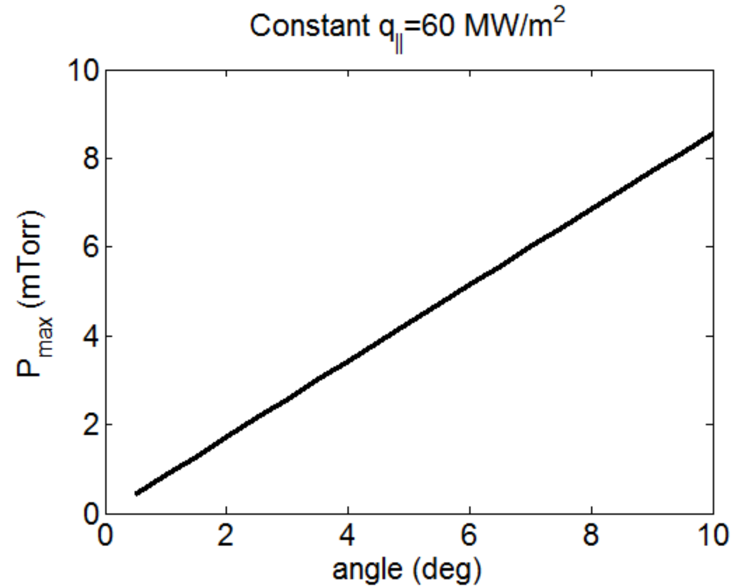
Duct optimization for R_{pump}=1.3 m

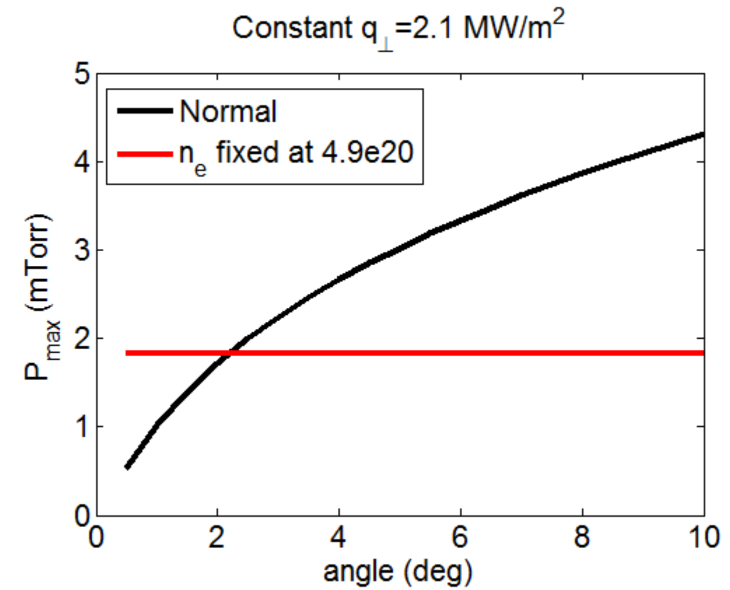
- Exponentially decaying heat flux assumed, based loosely on parameters from the Menard/Brown DEMO talk
  - Assuming T_e=5 eV, due to erosion requirements
- It's actually pretty easy to get to P=0.5 mTorr
- Aiming for 1 mTorr gives a duct with g~4.5, h~7 cm
  - Need ~1MW/m^2 at pump entrance
- Can already see that if PNBI is used this will be harder
  - Need ~5 MW/m^2 at pump entrance to get to 2 mTorr
  - Would probably need to increase pumping speed in that case (or maybe play more with divertor geometry—still want to try vertical target)



Note that $q_\perp$ isn't everything: increasing the field-line angle of incidence makes pumping better

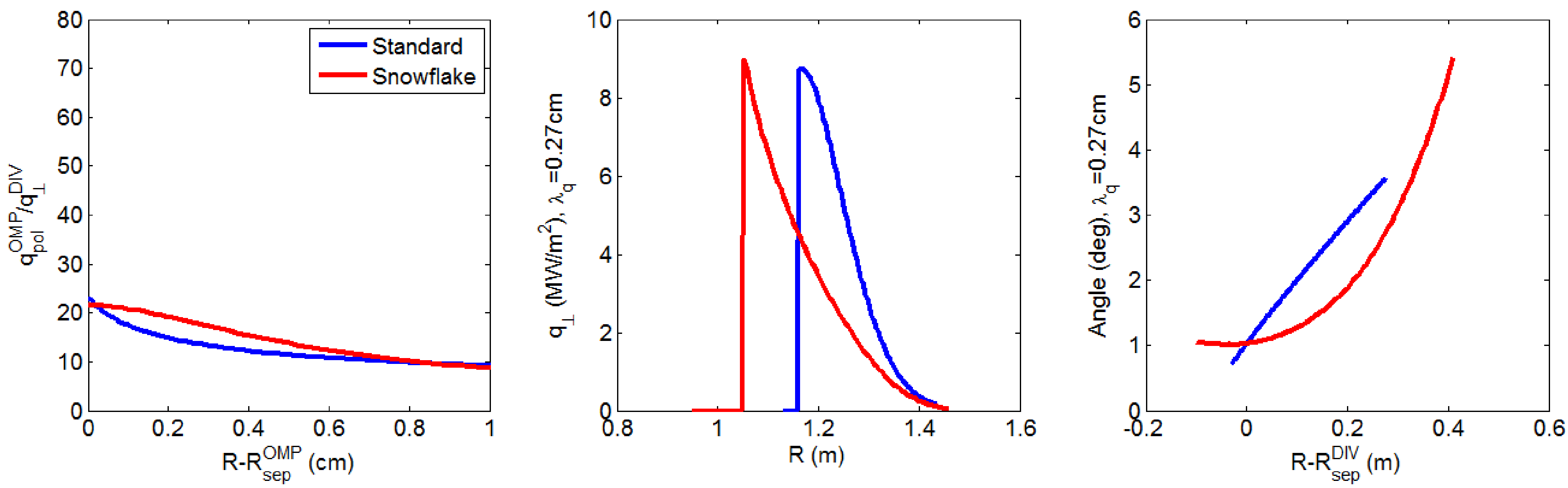
- For fixed angle and T_e the heat flux at the entrance pretty well determines the pumping rate
- Two approaches to testing effect of angle: constant $q_{||}$ or constant $q_\perp$
  - Constant $q_{||}$ relevant to scenario where you use flux expansion to reduce heat flux to manageable levels
  - Constant $q_\perp$ relevant to using other controls (e.g. radiation or input power) to maintain $q_\perp$ at some value to ensure good pumping
- At constant $q_{||}$, increased angle means higher perpendicular flux, which means higher neutral flux and pressure
- At constant $q_\perp$, increased angle means reduced $q_{||}$, which means lower n_e and less ionization of neutrals before they reach pump
  - Confirmed by red curves on bottom plot, where neutral transmission was calculated using a constant plasma density (which is inconsistent with the flux and T_e, but shows that this is a neutral attenuation effect)





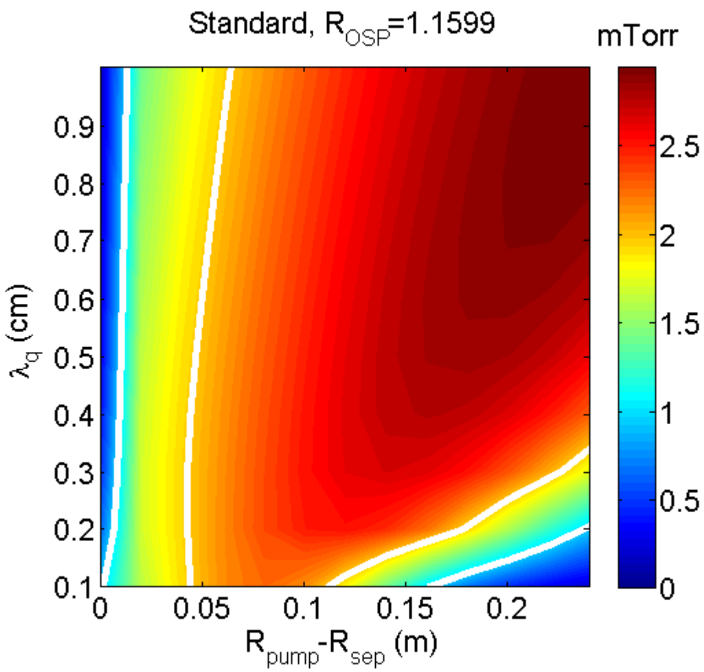
Standard and Snowflake equilibria used to map fluxes onto divertor

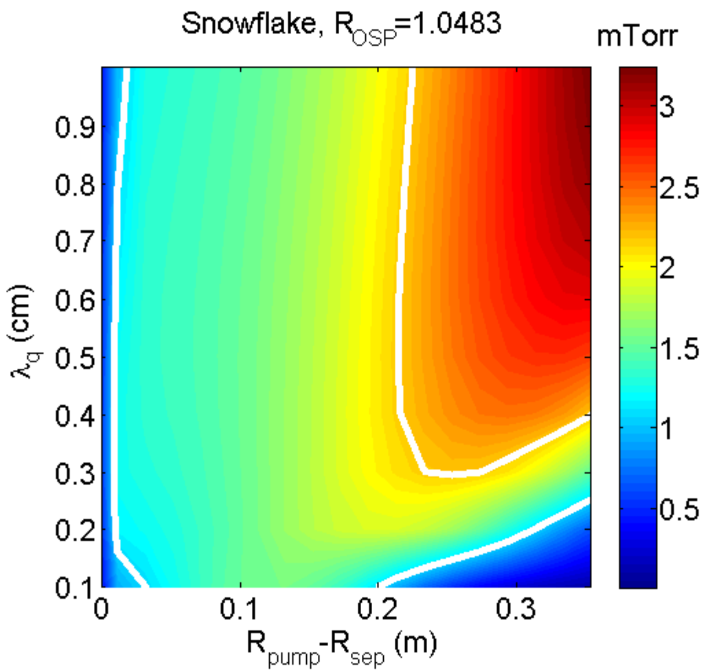
- Flux surface shapes can be found in Menard/Brown DEMO talk
- Both divertors have ~the same geometric heat flux reduction
  - Snowflake gets it through flux expansion, standard through poloidal inclination of target
  - Note that target geometry is different in the two cases
  - Total field angle of incidence is similar at OSP (~1 deg)



Looks like reasonable pumping can be achieved

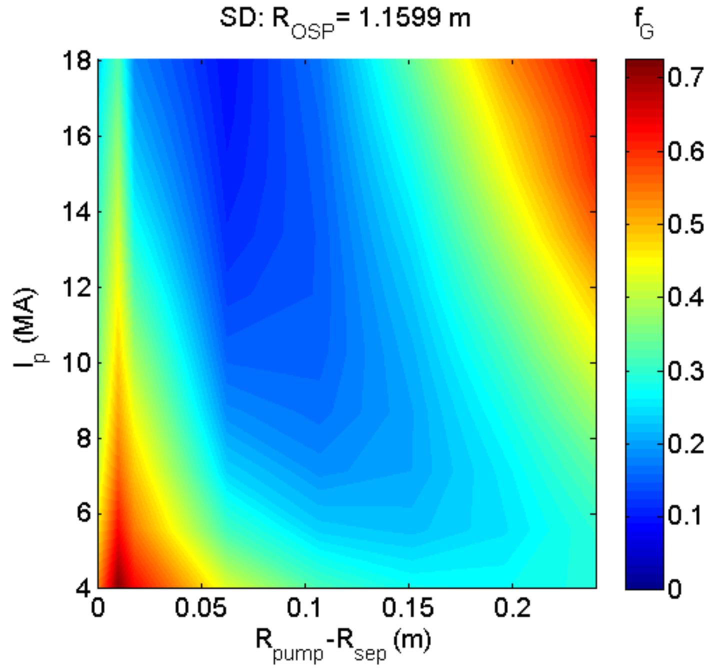
- Assuming Te=5 eV
- Projected pressure shows usual maximum in pump position that varies with SOL width
  - Even though heat flux is higher near OSP, the angle is lower too, so that plasma density is high and ionizes more neutrals
- For λ_q~2.7mm, a pump at R~1.3 looks like its close to optimal for both divertor configurations
- Reaching 0.5 mTorr is easy, and it looks like even 2 mTorr is within reach (one of the white contours, not sure why there are two…)

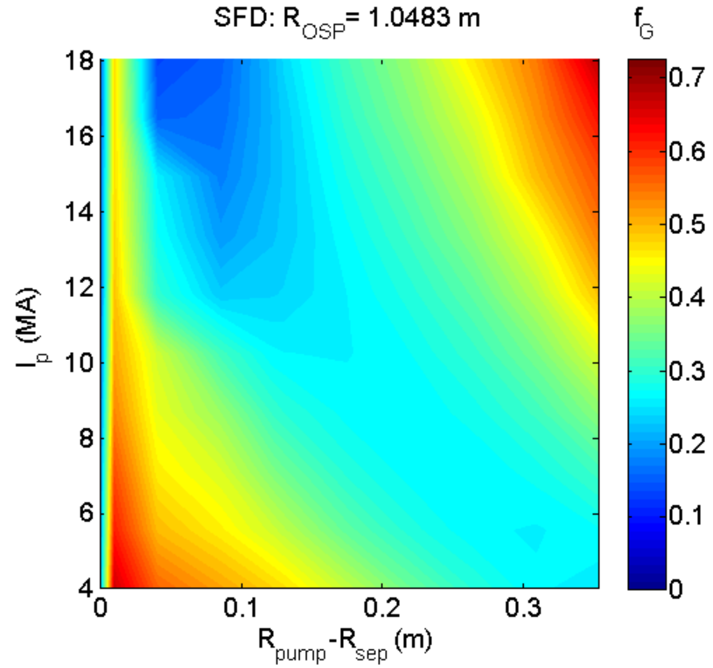




Achievable Greenwald fraction assuming we only have to pump 500 keV beam input

- Eich scaling for SOL width used during I_p scan
- Note that 2-pt model used here doesn't account for radiation
  - E.g., assumes that the full 80% radiated power is in the core
- Can easily reach very low f_G, consistent with pressure plots
- Might be better to move pump inwards a bit, maybe to ~1.25 or even 1.2 to be able to pump high current shots





Achievable Greenwald fraction assuming we only have to pump 150 keV beam input

- Assuming that you need ~4 times the pressure with low energy PNBI
- Can still pump down to reasonable densities (~0.8 GW)
- Contours are pushed out to the right a little bit compared to previous slide, so the R=1.3 pump looks good in this case