ARIES Town Meeting
Panel Discussion

Comments on "New device contributions to edge physics benchmarking"

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PMI impact on development paths

(One physicist's overly simplistic interpretation…)

ITER Demo

Fastest (?), highest risk

ITER Demo
FNSF/CTF

Addition of FNSF → fast with lower risk, increased cost (?)

ITER Demo
PMI/FNSF/CTF

PMI mission in FNSF further reduces risk, but is unavoidably slower

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ITER Demo
PMI → FNSF/CTF

Dedicated PMI facility is lowest risk, but could be slowest? Costliest?

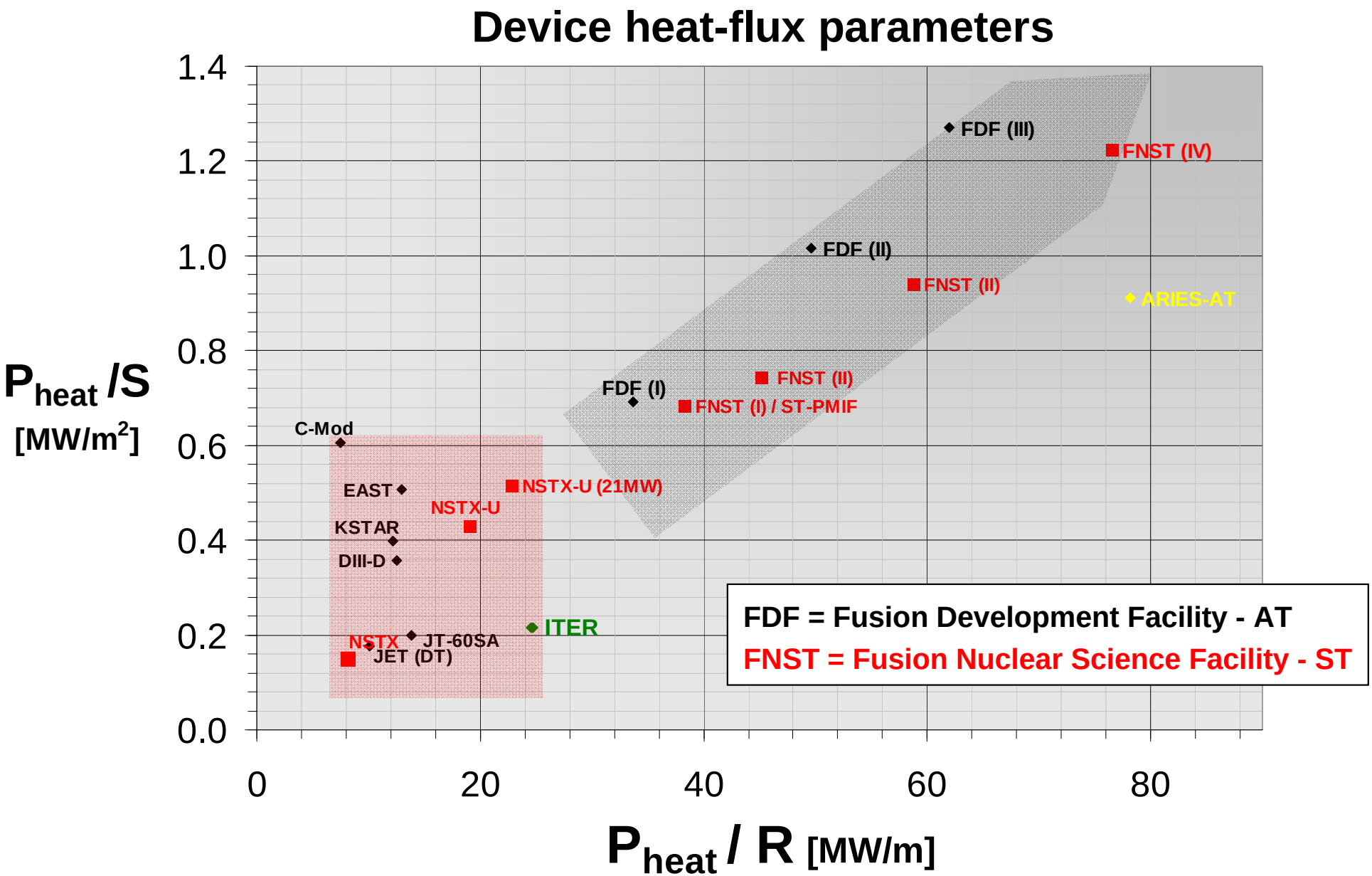
Is dedicated PMI facility needed?

Is a dedicated (non-nuclear) PMI integration facility needed?

- Proponents argue that combination of 3 capabilities needed: high edge power density + long pulse + hot walls
  - This combination **is** unique and necessary, and it does not appear in any planned experiments short of FNSF/CTF or Demo
  - Hot wall critical for assessing long-pulse retention/diffusion and FNSF/reactor relevance (for high thermal conversion efficiency)
  - **Do sufficient models of these long-time-scale processes exist?**

- Independent of facility, need agreement on what physics, operational, and first-wall material parameters must be met for reasonable extrapolation to FNSF, Demo:
  - Heat-flux width: turbulent cross-field + 3D B-field edge transport
    - Pedestal/SOL ν^*, β, Mach #, Er shear, … = ?
  - Power across LCFS required for H-mode access + high $f_{radiation}$
    - Can depends sensitively on wall conditions – are there models for this?
  - Time-scales for "equilibration" between plasma and wall
  - What materials and wall temperatures, and in which configurations

U.S. facilities + EAST/KSTAR will access edge power loads approaching 1st phase of FNSF operation



Modeling and experiments need to address range of potential solutions to the PMI challenge

- High radiated power fraction
- Geometrical changes
  - Very tangential surfaces
  - Snowflake, X/Super-X divertor
- Stellarator-like edge, ergodicity
- Liquid surfaces

Hot walls essentially *absent* in existing program

Can we do more in existing facilities and simulation?

	P/S [MW/m2]	P/R [MW/m]	Divertor heat flux mitigation	Pumping	Warm/hot divertor	Warm/hot walls	Pulse length
FNSF	1	50		Likely cryo	Up to 700C	Up to 700C	Up to 10^6 s
ASDEX-U	0.3	12	Ar/Ne/N2 radiation, RMP	Cryo			5-10s
C-Mod	0.6	8	Ar/Ne/N2/CD4 radiation	Cryo	500C W planned		5
DIII-D	0.35	13	Ar/Ne, Snowflake, RMP	Cryo			10
EAST	0.5	13		Cryo	Hot divertor?	500C W walls?	400
JET	0.2	10	Ar/Ne/N2 radiation	Cryo			20-60
JT60-SA	0.2	14		Cryo			100
KSTAR	0.4	12		Cryo			300
LTX			Limiter plasma	Li		500C Mo walls	< 0.1
MAST-U	0.3	13	Super-X divertor, RMP	Cryo			4
NSTX	0.15	8	Snowflake/X-divertor, RMP	Li	300C Mo (LLD)		1-2
NSTX-U	0.5	22	Snowflake/X-divertor, RMP	Li?	300C Mo (LLD)??	300C Mo walls??	5

A broad range of power and particle control strategies are/will be tested

(but need tests of high f_{rad} at high at P/S, P/R)

Need to expand work on hot divertor

Need to *initiate* work on hot walls

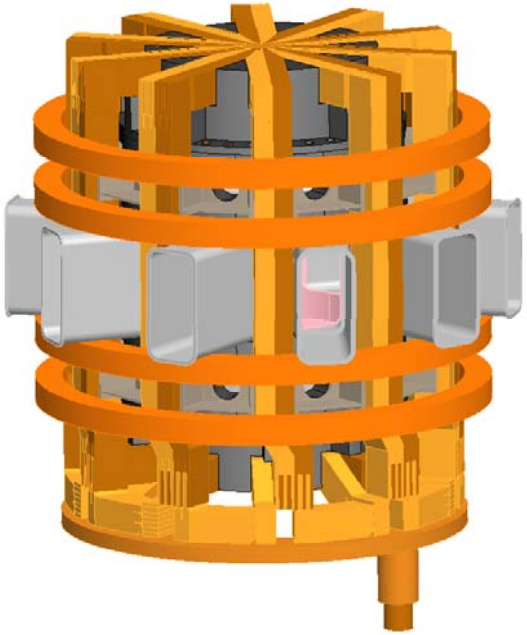
Is hot divertor/wall + long-pulse (for equilibrated PWI) most important linkage?

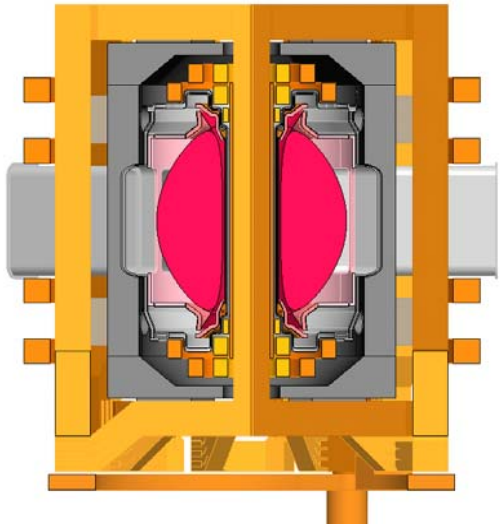
Do FNS facilities have sufficient flexibility and heating power (w/o DT) to perform PMI mission?

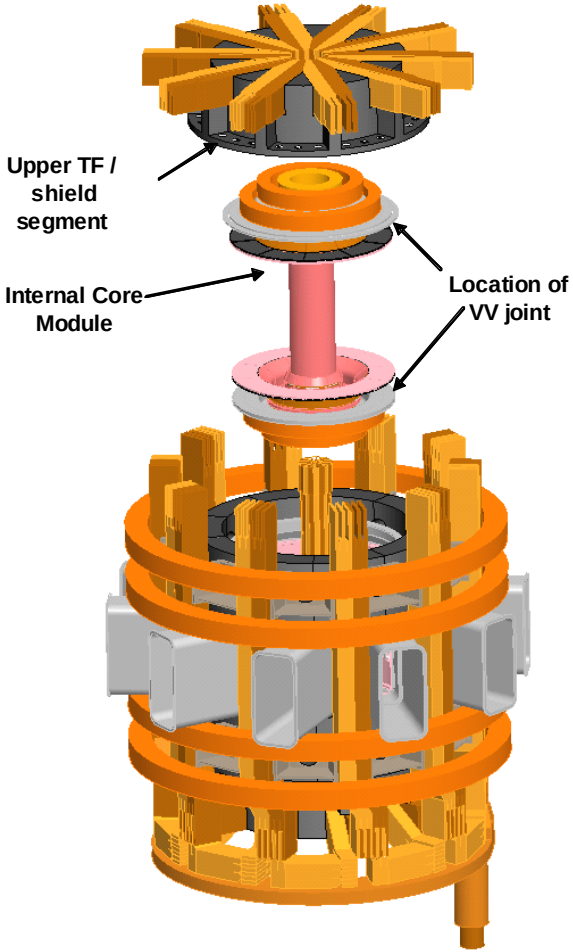
- Considerations for using FNSF for PMI mission:
  - Both PMI and FNSF facilities aim to be modular for maintenance, component replacement
    - Main issue is larger size and activation of FNSF → larger cost, time?
    - FNSF will be less flexible – question is how much?
  - Like ITER, have initial phase w/ H/He to reduce activation?
    - Operate as long as needed to solve PMI problems?
  - Could FNS facility add more P_{aux} to make up for larger size?
    - Is factor of 2 increase in P_{aux} cheaper/faster than separate facility?
  - Initially operate w/ smaller vessel & plasma to increase P/S?

Backup

A ~ 2 with Steady State Cu Coils is an Attractive Option for PMI facility







P/S $\leq$ 1MW/m^2, P/R $\leq$ 50MW/m, 10^3-10^6s pulse, $T_{wall} \leq$ 700C, NBI for H&CD

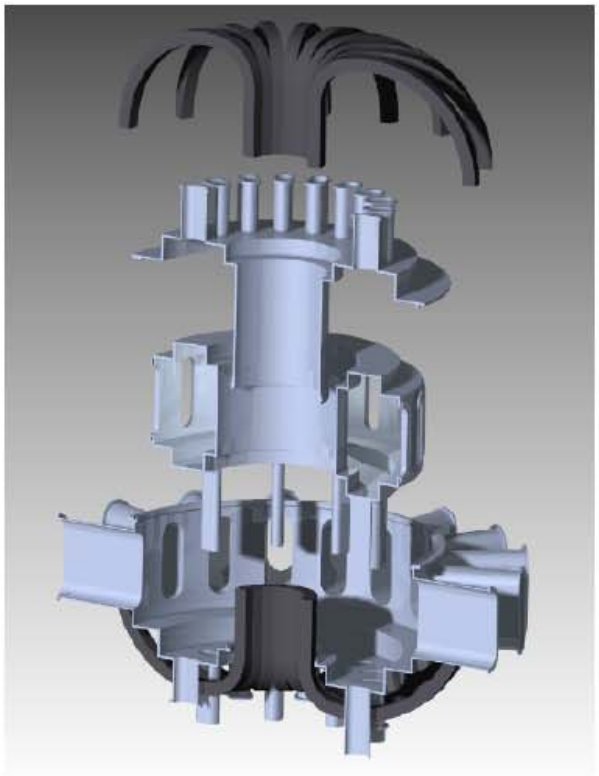
Good radial and tangential access at all elevations

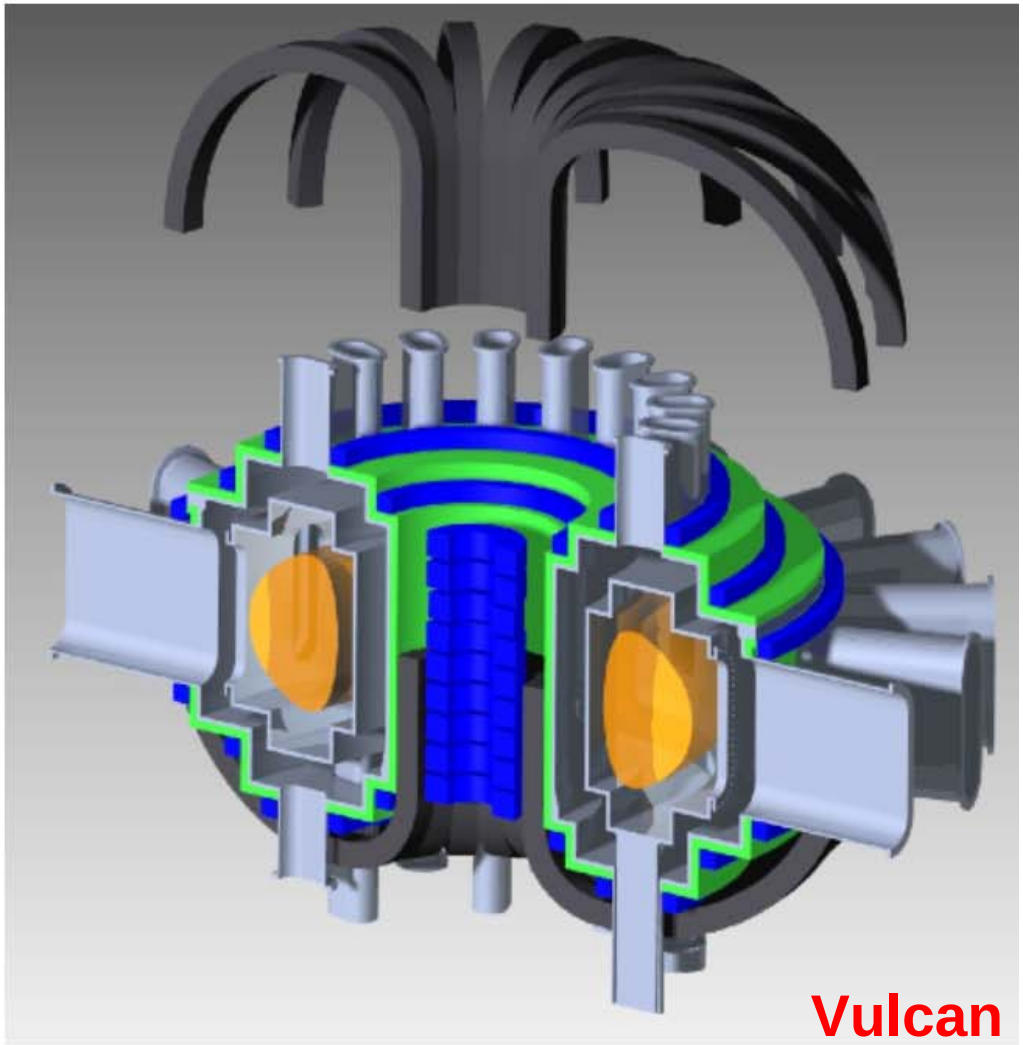
Vertical access allows change-out of divertor and associated shaping coils

50cm shield fits easily, provides hands-on external access after extensive D operation

NHTX

A ~ 4 with Demountable Hi-Tc Coils & Steady-state Current drive is Being Explored





Demountable high-T SC coils
- “Detach & lift” interior maintenance & upgrades
- Interior PF coils for control

Continuous operations at minimum electrical power using SC + low-resistance joints + LHCD

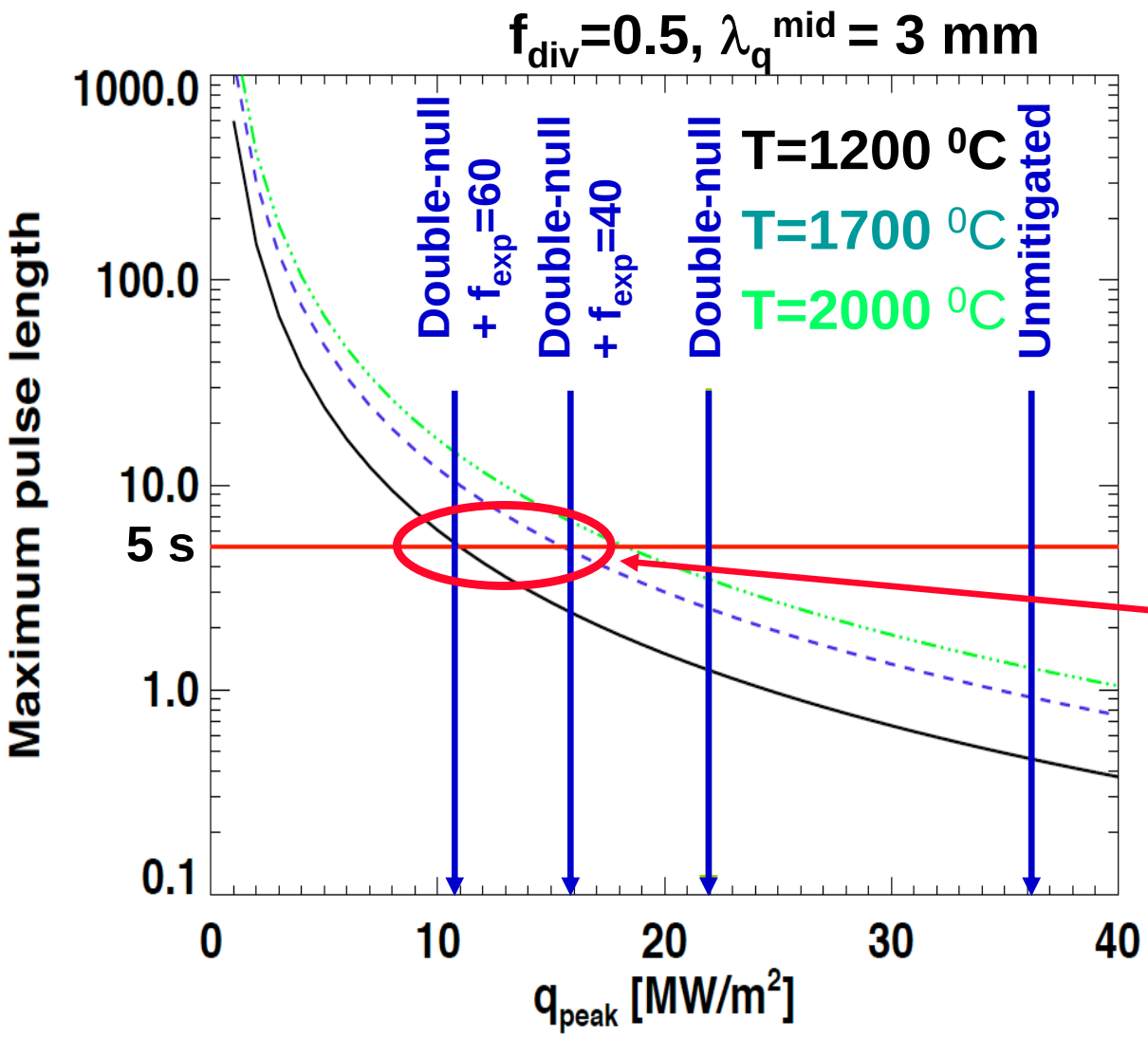
PMI risks at long pulse, high heat flux, high T_{wall}

- Erosion → unacceptably short component lifetimes (e.g., due to sputtering from radiating impurities)
  - Re-deposition results in surfaces with poor thermal contact that flake off, cause disruptions
- T_{wall} controls H diffusion/retention → large accessible fuel inventory in surfaces affects long-pulse n_e control
- Dust accumulation, T retention may pose safety risk
- All solutions to these challenges must also achieve:
  - Consistency with high-performance core plasma
  - Survival during transient high-heat-flux events

Roles of facilities in testing solutions, reducing risks

- Theory: suggest innovations in geometry, materials; predict and understand results of experiments
- Test stands
- PMI: develop understanding of basic PMI properties
- PFC: develop/qualify new technologies (high pressure He cooled divertors, liquid surfaces, …)
- Existing, planned experiments: sieve concepts at short pulse and/or low power and/or cool walls
- PMI Integration Facility: test concepts at long pulse, high power, and hot walls

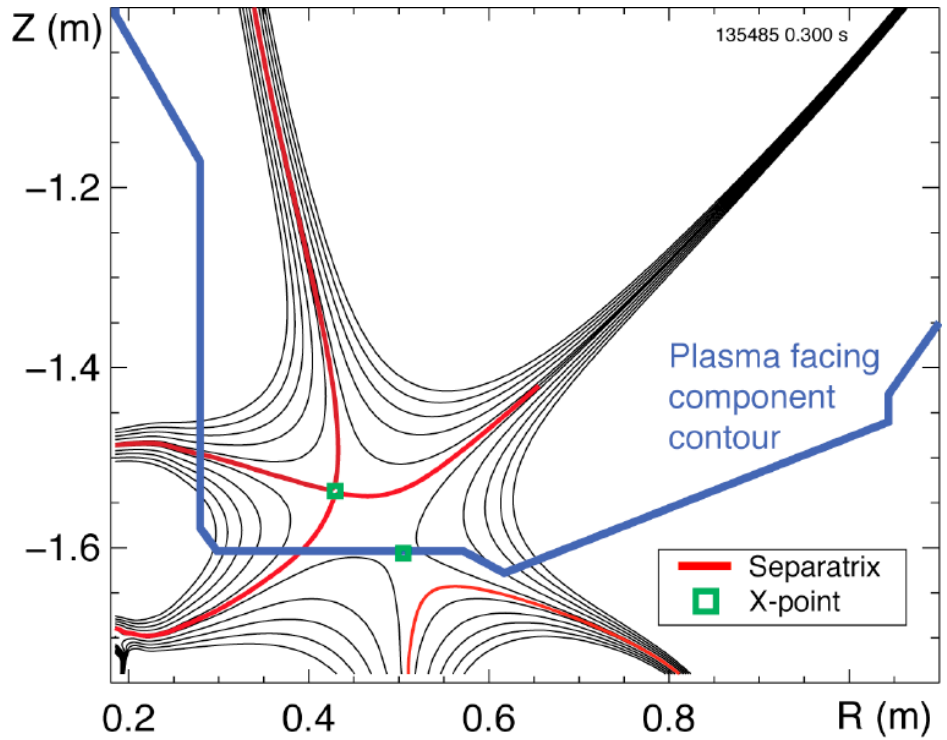
NSTX Upgrade: High current = 2 MA, high P_{NBI} scenario requires extra flux expansion for 5s pulse



- High-current LSN case 2 MA, n/n_{GW}=0.5, P =15 MW (e.g. 10 MW NBI and 5 MW RF)
- Actual scenarios can use n/n_{GW}=0.7-1, which is expected to widen the SOL
- Using DN and increasing flux expansion (e.g. SFD) would just manage for 5s
- Molybdenum tile for higher temperature being considered for 2011-2012

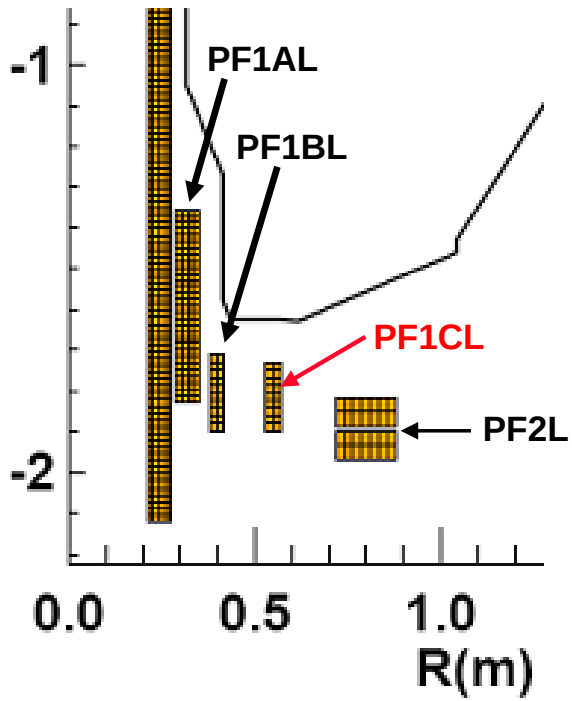
NSTX Pursuing Options for Handling Divertor Heat Flux in Upgrade Scenarios

- Thermal loading on divertor outer strike point a key issue at full power (i.e. P_{NBI} = 10 MW and P_{RF} = 5 MW) for 5 sec
- Developing high flux-expansion double-null configurations required:
  - Snow-flake divertor (SFD) promising
  - Advanced control of divertor
- Considering installing molybdenum divertor tiles for FY11-12



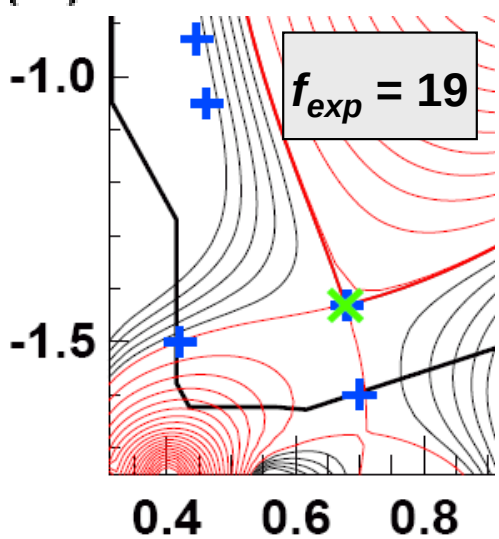
SFD demonstrated in NSTX: high flux expansion ~ 50 and reduced peak heat flux (PRL in preparation)

Additional divertor PF coils for new center-stack to provide improved divertor configuration control

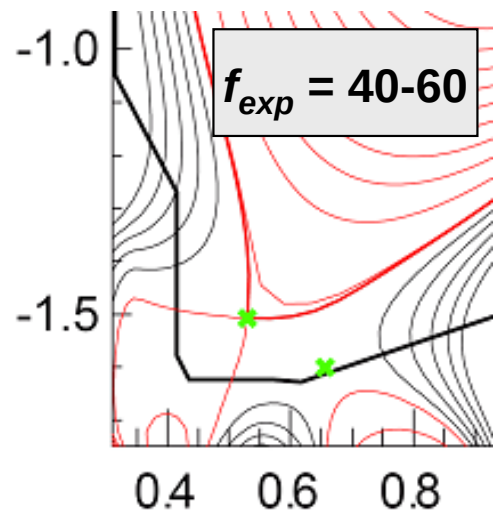


Combination of PF1A,B,C + PF2 enables flux expansion variation with fixed X-point height and strike-point location:

Also supports **very high flux expansion "snowflake" divertor**



Conventional divertor



Snowflake divertor