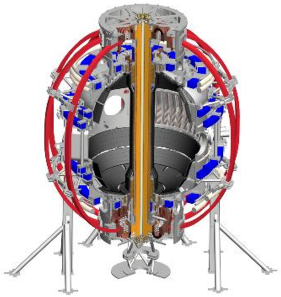
PFCR-WG Update

M.L. Reinke

PFCR-WG Meeting
B-252
9/19/2018



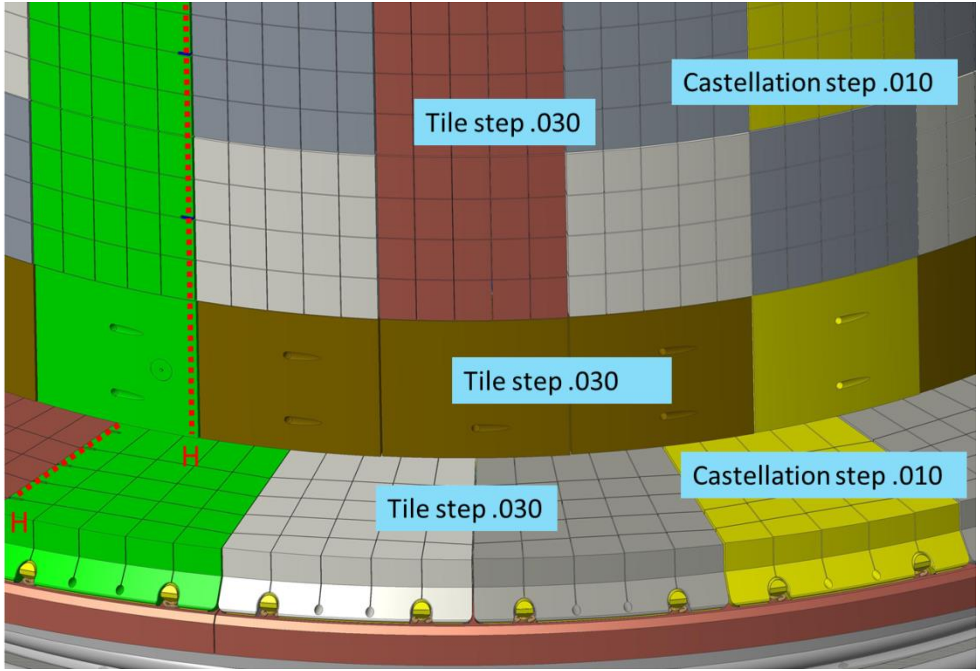
Goals of the Meeting

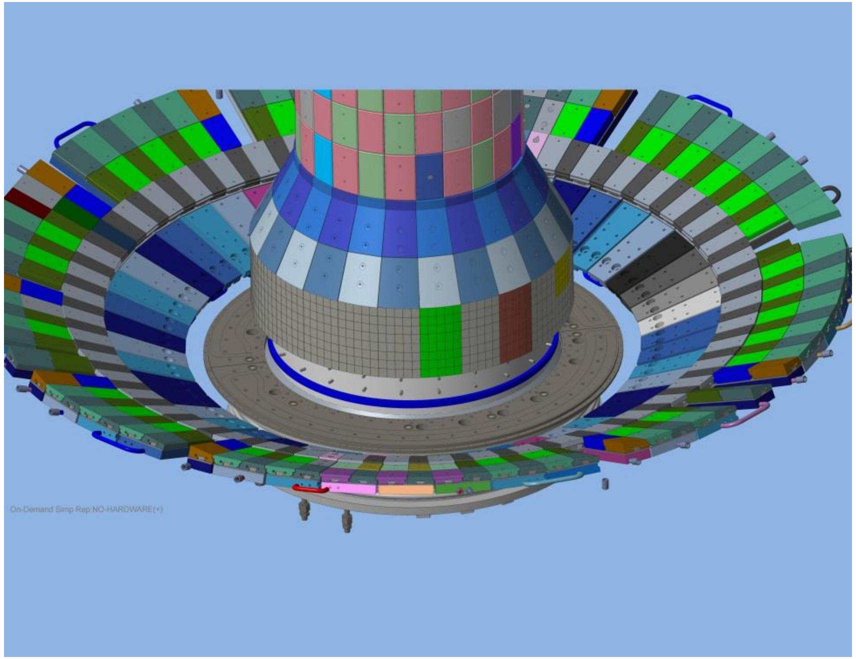
- update on the status of the PFC Engineering activities
- MEMO's remaining for FY18 (very early FY19)
- presentation on 3D Heat Flux from coil misalignments (S. Munaretto – GA)
- discuss status of R18-1 Milestone Work
  – T. Looby (UT-K): Heat Flux Model Validation Using Embedded Thermocouples
- discuss FY19 plans for Working Group

http://nstx-u.pppl.gov/program/working-groups/pfc-requirements-working-group

PFCs Moving to Final Design Review - 9/28

https://sites.google.com/pppl.gov/20180926pfcs-pempfdr/home





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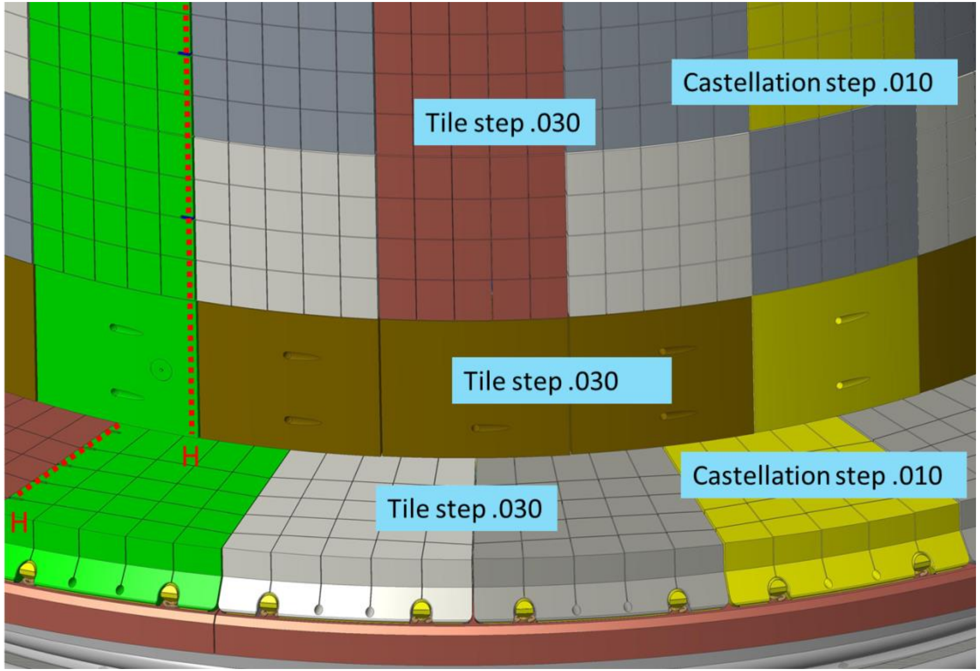

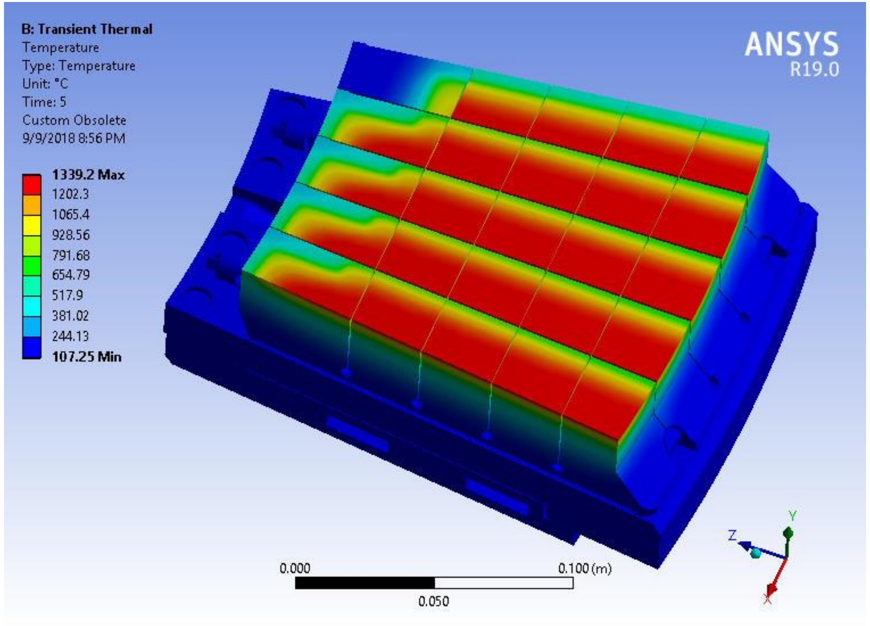

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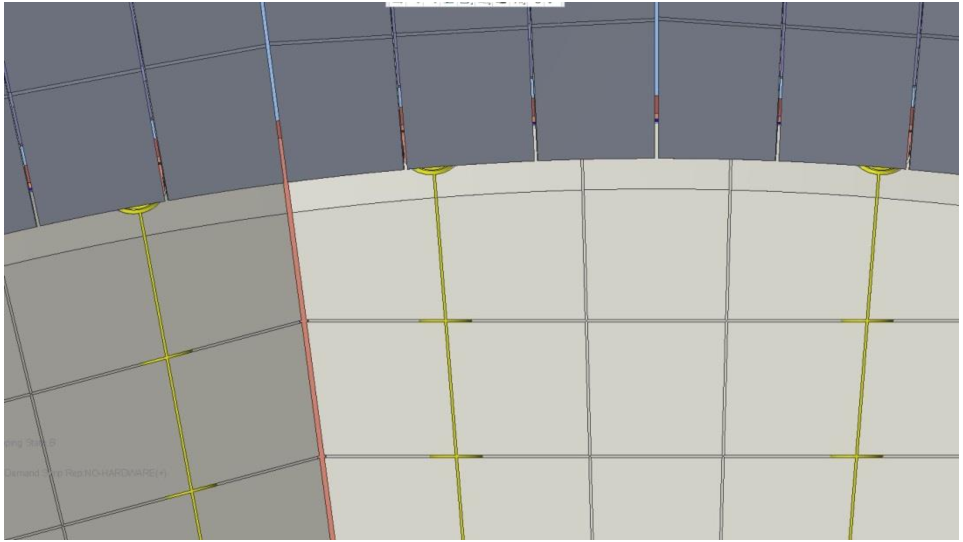
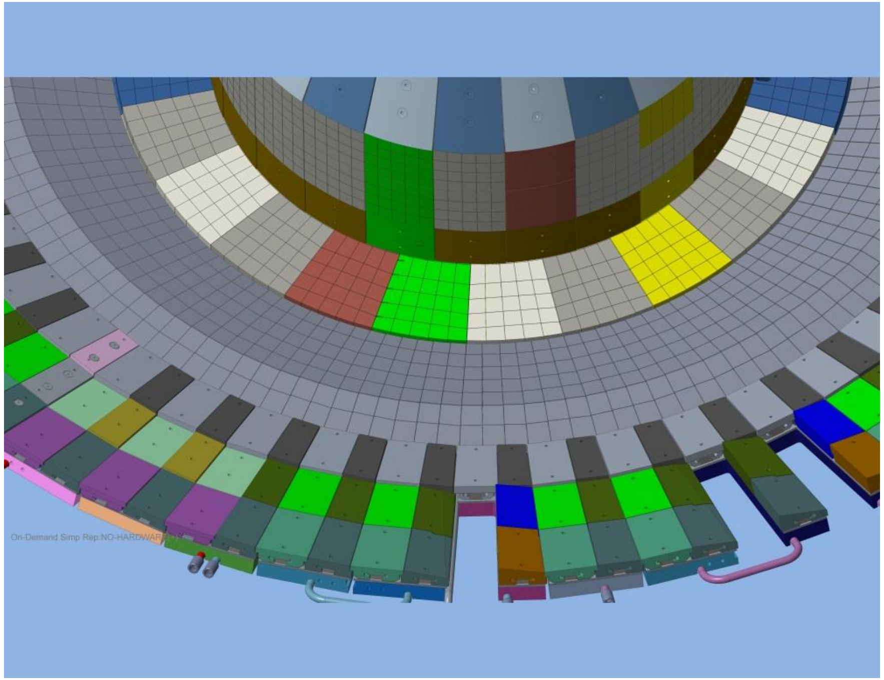




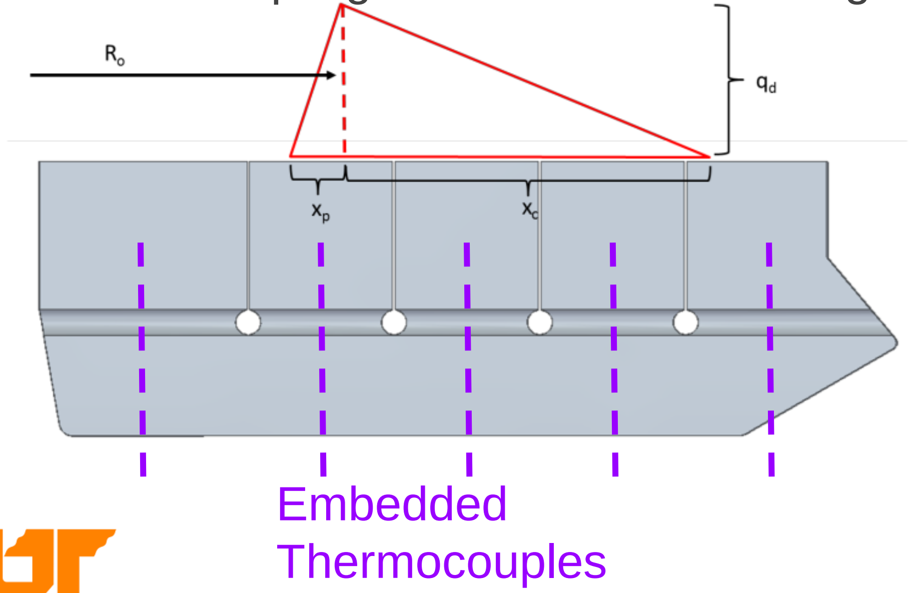
MEMO's to be Completed

- MEMO-007 (Reinke) on the W_PFC heat flux code
- MEMO-022 (Reinke) on the erosion/ablation calculations which fed requirements for shaping, summarized in R18-1 report
- MEMO-023 (Erickson) summary of image based heat flux control
- MEMO-024 (Reinke) final milestone summary, expanding on what was in the R18-1 report, matching to MEMO-014 on goals
- MEMO-025 (Looby) summary of NN work, basically his Master's thesis which is due in early FY19
- Others?

Sub-Surface Temperature Sensing

- UT-K (T. Looby) masters thesis project

Demonstrate how unknown heat flux model parameters can be derived with various sampling mechanisms within a given parameter space.



Simplified Eich Model:

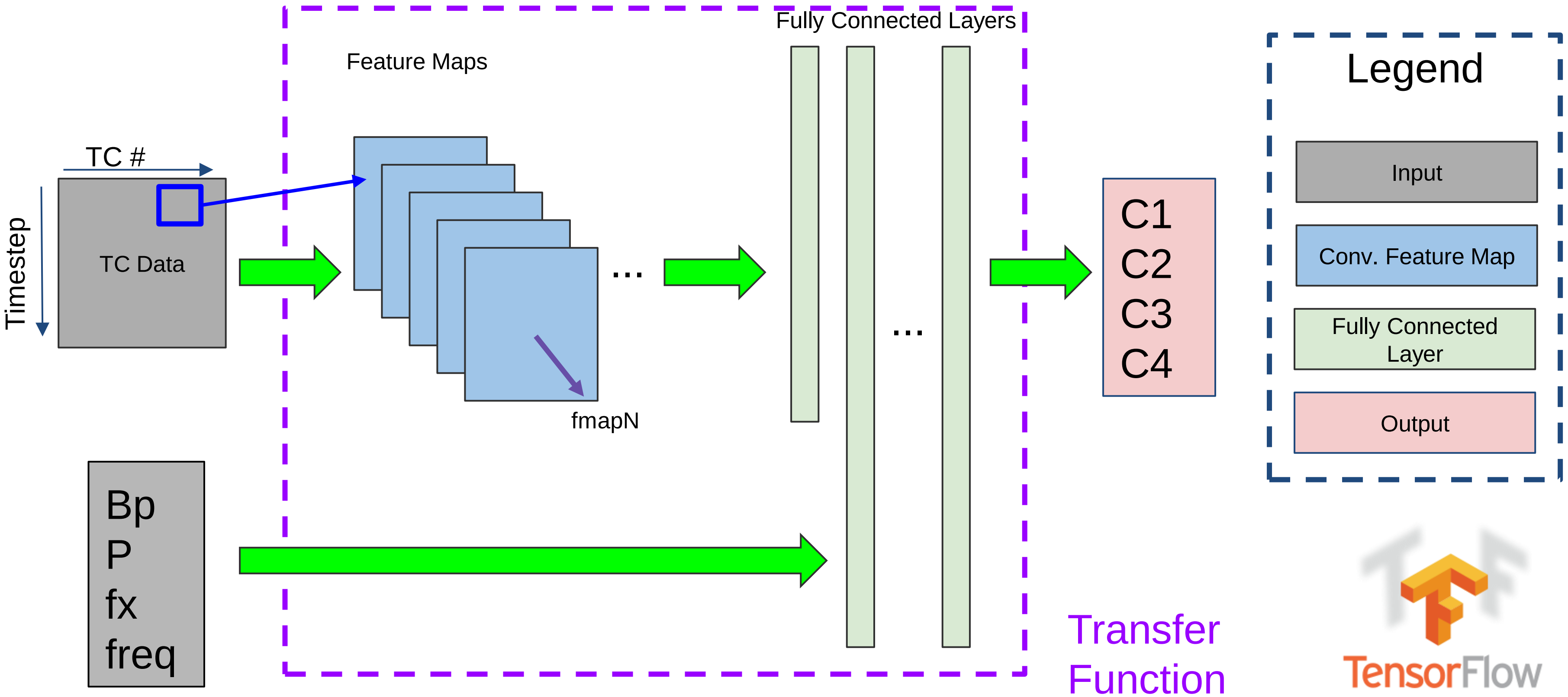
$$x_P = S f_x$$
$$x_C = \lambda_q f_x$$
$$P_{heat} = \int_{R_o - x_p}^{R_O + x_c} q(R) 2\pi R dR$$

$$\frac{S}{\lambda_q} = C_1$$
$$\lambda_q[mm] = C_2 P_{heat}^{C_3} B_p^{C_4}$$

$$0.1 < C_1 < 0.3$$
$$1.0 < C_2 < 2.5$$
$$-0.1 < C_3 < 0.25$$
$$-1.2 < C_4 < -0.5$$

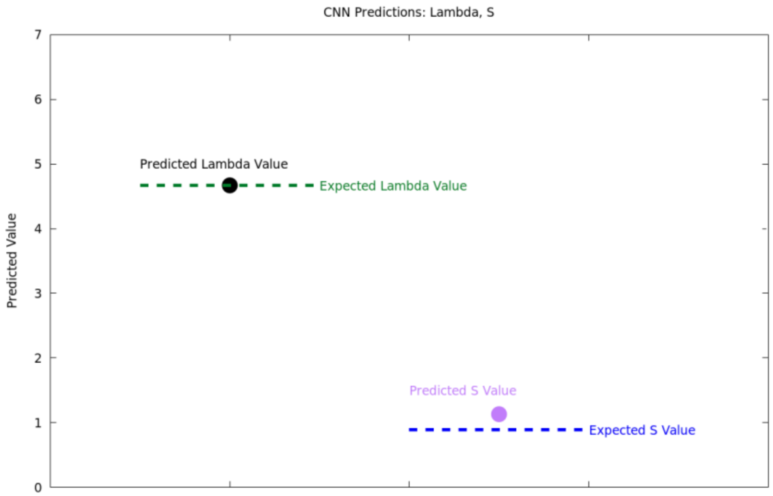
$$0.2 < B_p[T] < 0.6$$
$$0.5 < P_{heat}[MW] < 4.9$$
$$4 < f_x < 30$$
$$46.0 < R_o[cm] < 57.5$$
$$1 < \Delta t\ [sec] < 5$$

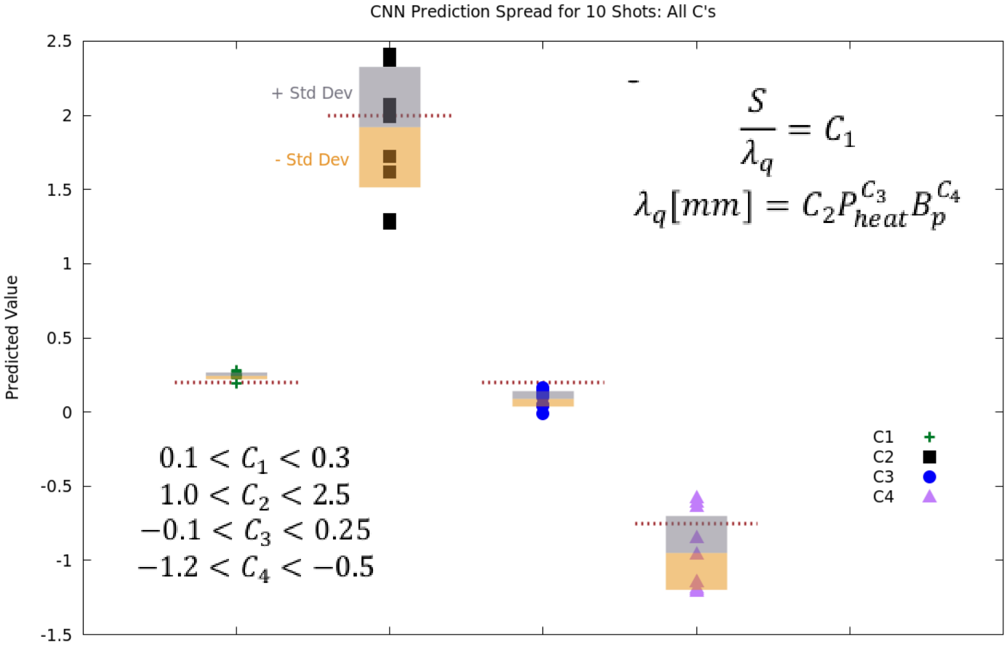
First Neural Network Attempts



TensorFlow

'1-Shot' Analysis gives S, λ_q, Degeneracy for C_1-C_4





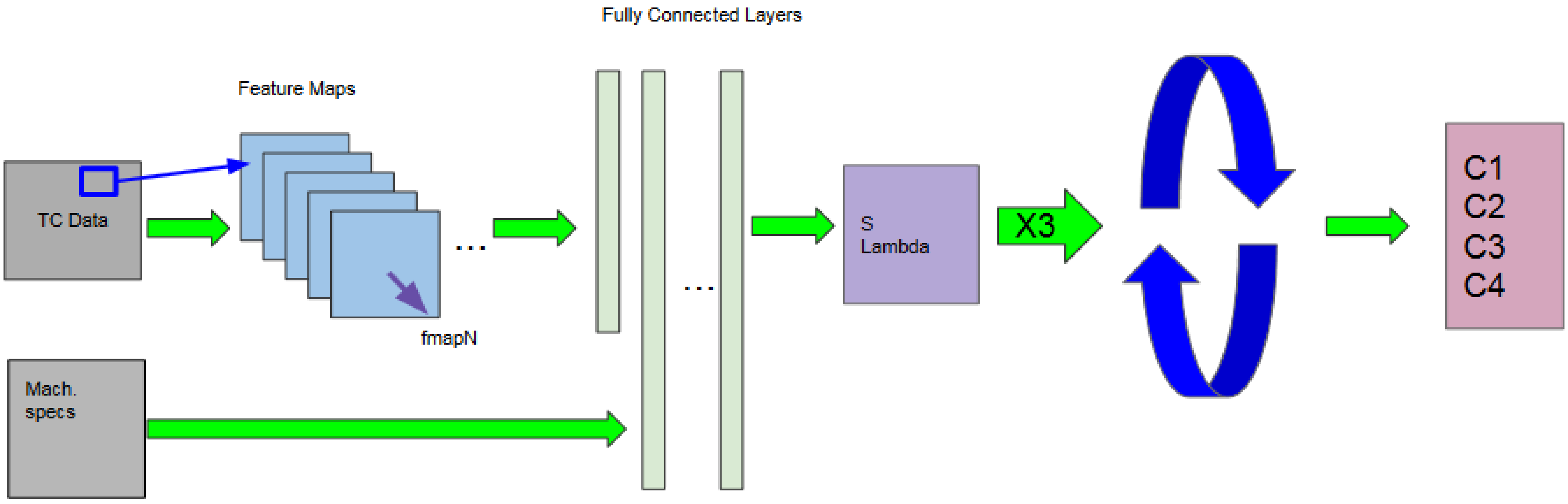
- Possible ƛ Domain [mm]: (1.0836, 25.493)
- Possible S Domain [mm]: (0.10836, 7.6479)

Result led us to explore using 'triplets' to break degeneracy

Problems with Triplet Method, Limits of Use for CNN

- method of training on ‘triplets’ of data to break degeneracy only using NN were problematic
  - Requires large dataset generation, long (few days) training
  - NN was trying to assign meaning to the ordering of triplet
- CNNs’ strength is in pattern recognition, object detection, and computer vision.
  - TC data is an excellent application for CNN pattern recognition.
- NNs are not the best for solving small (non)linear systems
  - e.g. solving system of equations for relating S,λ_q to eng. param.

New Hybrid Model for Solving for C_1-C_4

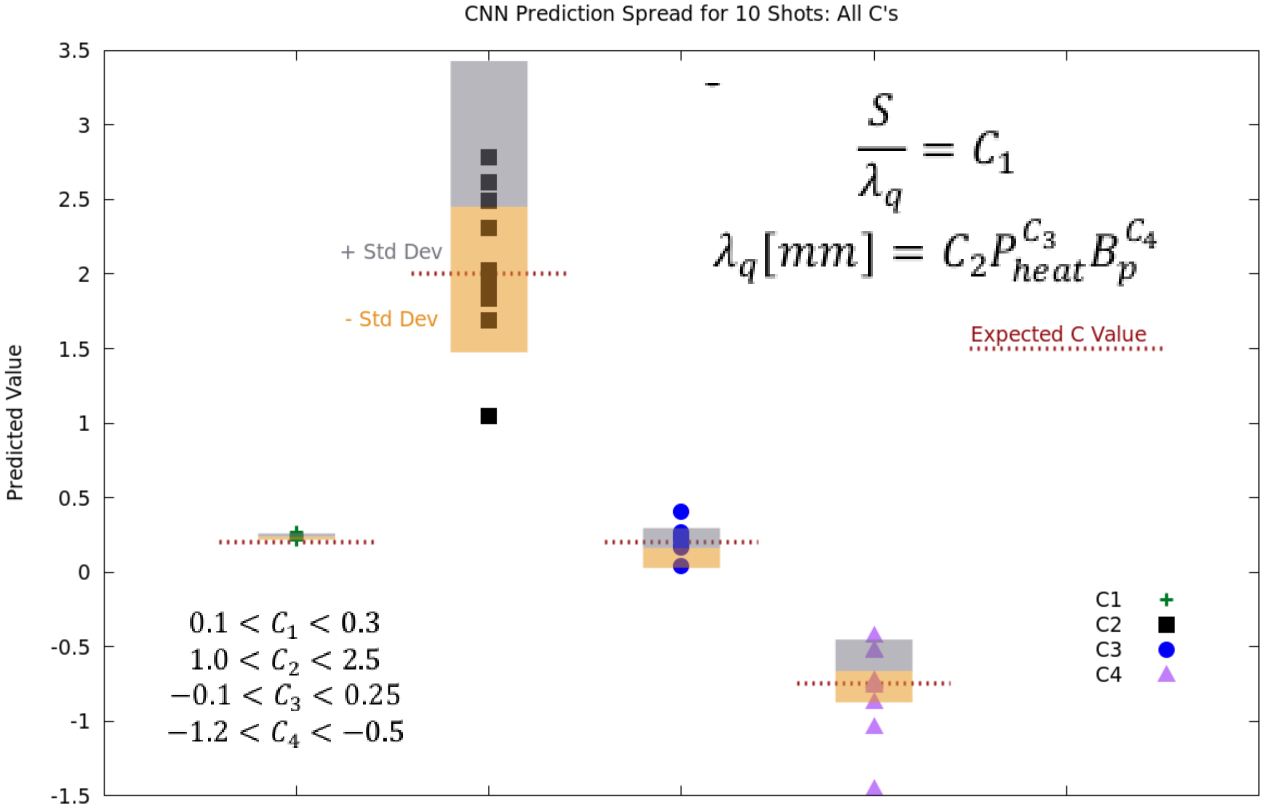


Convolutional Neural Net

Deep Neural Net

Newton's Method
(iterative)

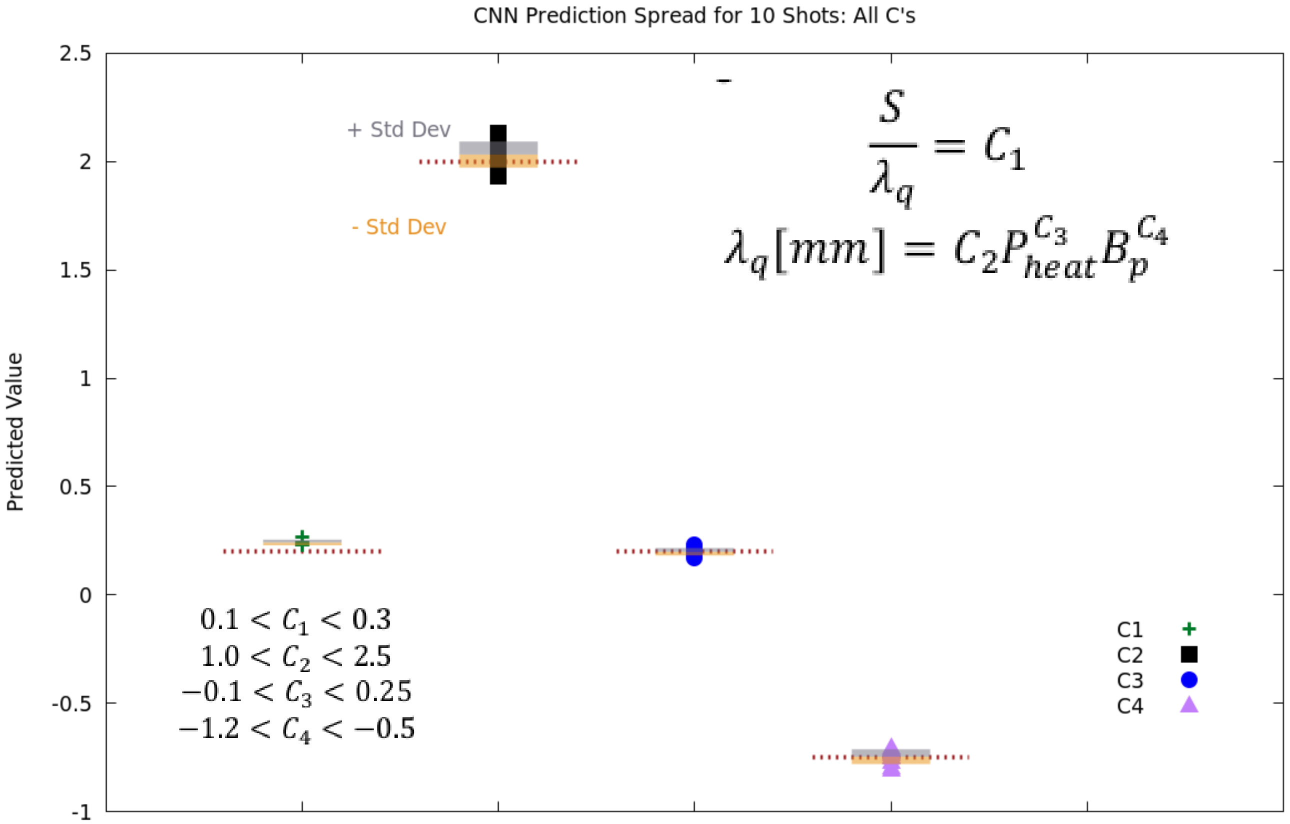
Method Works, But Requires Accurate Training



CNN training 99% accuracy for S, λ_q within 3%

(e.g. 99% of the cases predict S, λ_q within 3 %)

Method Works, But Requires Accurate Training

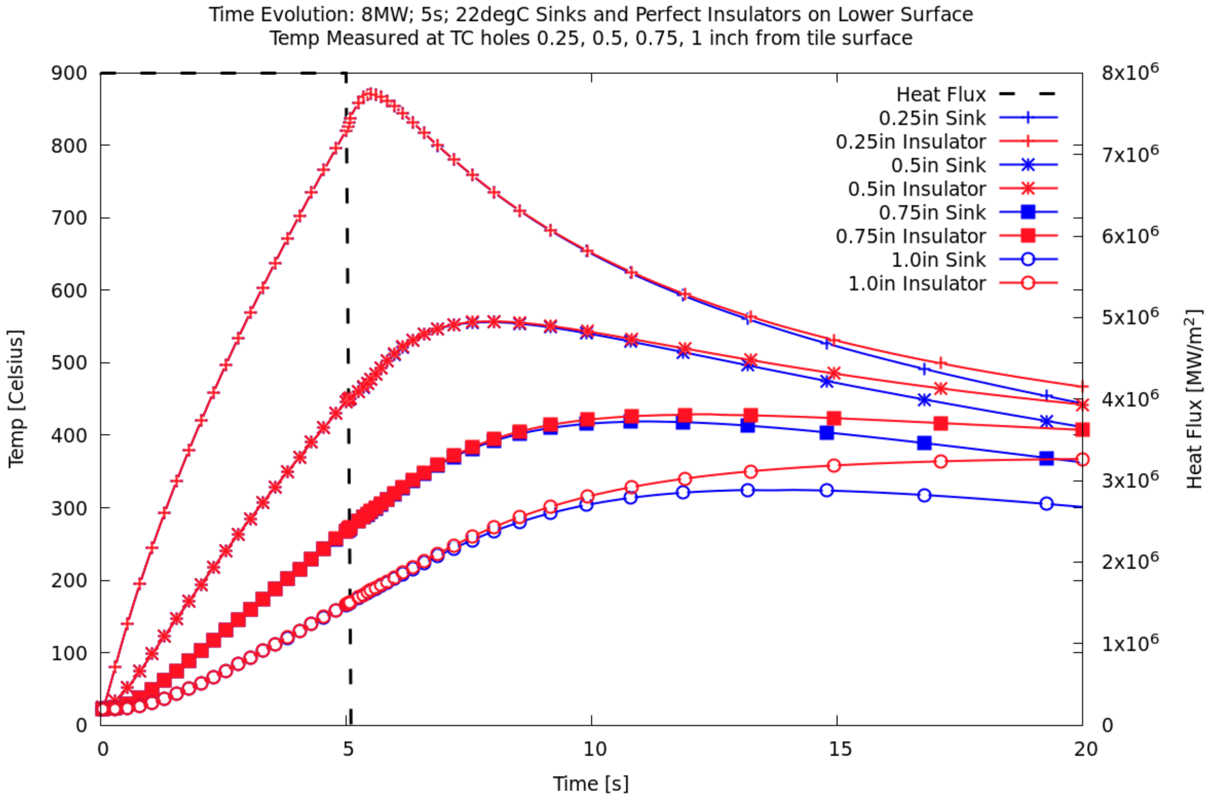


CNN training 93% accuracy for S, λ_q within 0.5%

What happens to this method when systematic errors are including?

Exploring Possible Systematic Errors

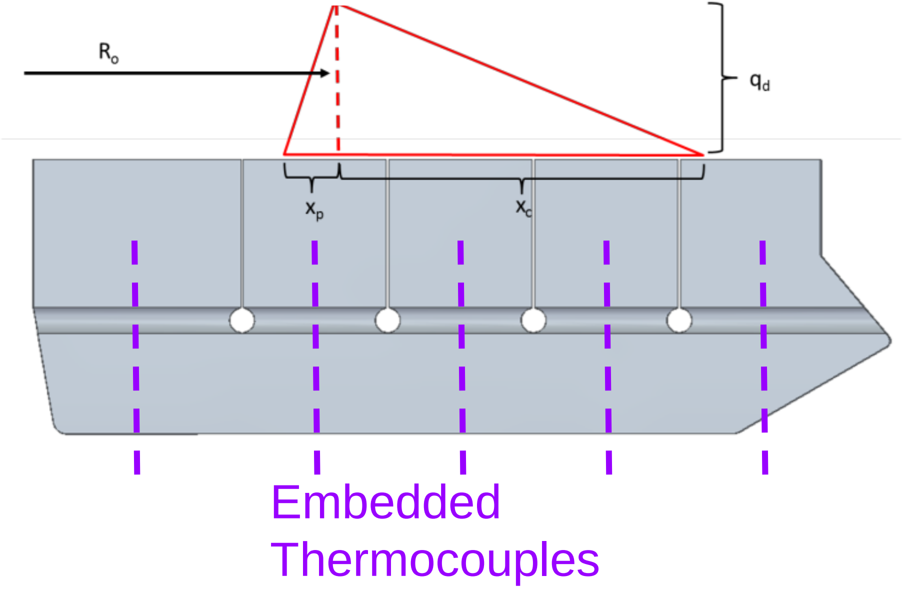
- impact of offsets/problems with TCs?
- impact of model and it’s back-end structure depends on desgin



Generic Solution for Power Law Scalings

$$x_P = S f_x$$
$$x_C = \lambda_q f_x$$
$$P_{heat} = \int_{R_0 - x_p}^{R_0 + x_C} q(R) 2\pi R dR$$

$$\frac{S}{\lambda_q} = C_1$$
$$\lambda_q[mm] = C_2 P_{heat}^{C_3} B_p^{C_4}$$



$$x_p = C_1 C_2 P_h^{C_3} B_p^{C_4} f_x$$
$$x_c = C_2 P_h^{C_3} B_p^{C_4} f_x$$

<u>Take 3 shots, A, B, C</u>

$$C_1 = \left(x_p / x_c\right)_i$$
$$\ln(x_c/f_x) = \ln C_2 + C_3 \ln P_h + C_4 \ln B_p$$

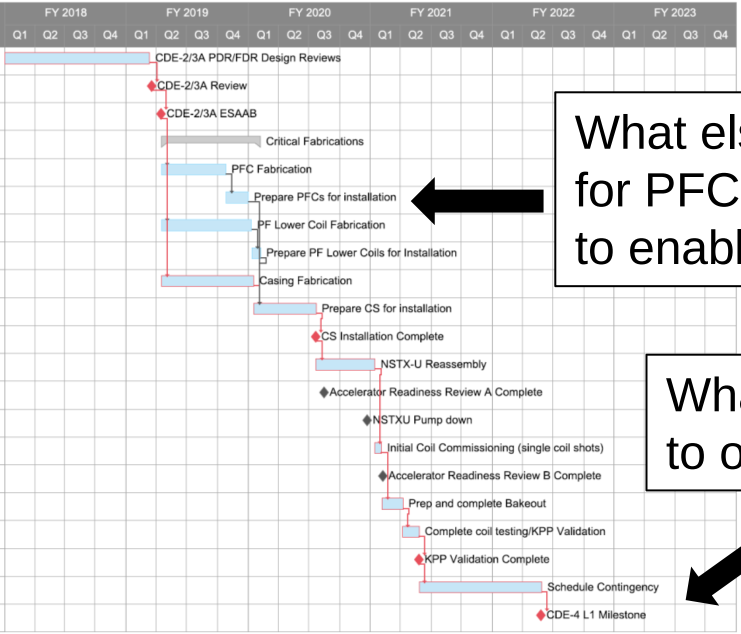
$$\begin{bmatrix} \ln(x_c/f_x)_A \\ \ln(x_c/f_x)_B \\ \ln(x_c/f_x)_C \end{bmatrix} = \begin{bmatrix} 1 & \ln P_{h,A} & \ln B_{p,A} \\ 1 & \ln P_{h,B} & \ln B_{p,B} \\ 1 & \ln P_{h,C} & \ln B_{p,C} \end{bmatrix} \cdot \begin{bmatrix} \ln C_2 \\ C_3 \\ C_4 \end{bmatrix}$$

can extend to arbitrary number of engineering parameters, find LS soln.

Discussion: Focus New FY19 Work?

- post-FDR, is there a purpose to the WG prior to a ramp up to operations (some carryover of R18-1 work into FY19)

Task Name	Start	Finish
CDE-2/3A PDR/FDR Design Reviews	10/02/17	12/10/18
CDE-2/3A Review	12/17/18	12/17/18
CDE-2/3A ESAAB	01/14/19	01/14/19
Critical Fabrications	01/15/19	11/04/19
PFC Fabrication	01/15/19	07/25/19
Prepare PFCs for installation	07/26/19	10/01/19
PF Lower Coil Fabrication	01/15/19	10/10/19
Prepare PF Lower Coils for Installation	10/11/19	11/04/19
Casing Fabrication	01/15/19	10/16/19
Prepare CS for installation	10/17/19	04/20/20
CS Installation Complete	04/20/20	04/20/20
NSTX-U Reassembly	04/21/20	10/12/20
Accelerator Readiness Review A Complete	05/14/20	05/14/20
NSTXU Pump down	09/21/20	09/21/20
Initial Coil Commissioning (single coil shots)	10/13/20	11/02/20
Accelerator Readiness Review B Complete	11/06/20	11/06/20
Prep and complete Bakeout	11/03/20	01/05/21
Complete coil testing/KPP Validation	01/06/21	02/25/21
KPP Validation Complete	02/25/21	02/25/21
Schedule Contingency	02/26/21	02/25/22
CDE-4 L1 Milestone	02/25/22	02/25/22



What else is needed to for PFCs prior installation to enable monitoring?

What is needed prior to operations?

Plans for FY19

- WG will be put on ‘hiatus’ barring any PPPL lead to continue working on scope
  - no new deputy assigned, unless there are ‘takers’
  - Reinke remains as contact point in case Recovery needs input and needs to ramp back up a specific mission
- post PFC FDR, post CDE2/3a timeline and scope for PFCs and any monitoring will be clarified
  - will revisit WG as a vehicle to deliver the operations-related scope in the original charge in mid-FY19

R18-1 Executed Within the PFCR-WG

R(18-1): Develop and Benchmark Operations-Focused Reduced Heat Flux and Thermo-Mechanical Models for use in PFC Monitoring

The NSTX-U Recovery Project will deploy new plasma facing components (PFCs) to meet updated heat exhaust requirements driven by narrower scrape-off-layer widths, increased heating power, and longer pulse durations relative to NSTX. Inter-shot monitoring or intra-shot control of heat flux to PFCs is anticipated for a range NSTX-U operating space, necessitating reduced models that can be run between shots or even in real-time. Monitoring requires a reliable instrumentation suite which can support or contradict model predictions and confirm PFC integrity. The goals of this milestone are three-fold: (1) Develop tools for pre-shot planning and confirmation of post-shot PFC thermal observations which use reduced models to predict time-evolving heat fluxes to shaped PFCs and estimate distances from engineering limits. Assess additional effort needed for implementation of reduced models in PCS. (2) Where feasible, benchmark reduced models against boundary physics (e.g. SOLPS, UEDGE) and finite element analysis (e.g. ANSYS) tools, and validate using experimental data from relevant tokamaks and results from Facility Milestone F(18-1). (3) Evaluate examples of discrete monitoring systems that are sufficient to capture the evolution of the PFCs relative to engineering limits. Compare the ability for different techniques (e.g. thermocouples vs. imaging) and technologies (e.g. near vs. long-wave infrared cameras) to achieve NSTX-U PFC monitoring objectives.

1. ~~define which (additional) parameters need to be specified in an updated requirements document for the NSTX-U PFCs~~
2. facilitate generation of updated requirements utilizing:
   a) available reduced models, empirical scalings, boundary simulations
   b) ultimately, a validated model for specifying heat loads to all plasma facing components for arbitrary NSTX-U scenarios
3. in preparation for operations, develop:
   a) instrumentation plan for intra and inter-shot PFC monitoring
   b) a reduced model for heat loading for pre-shot planning
   c) guidance on how to best integrate monitoring with operations
   d) control, diagnostic requirements for real-time heat-flux control
4. work closely with engineers and analysts to develop and implement requirements