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A Framework for Predicting the Performance of A304L SS Laser Welds with Stochastic Reduced Order Models

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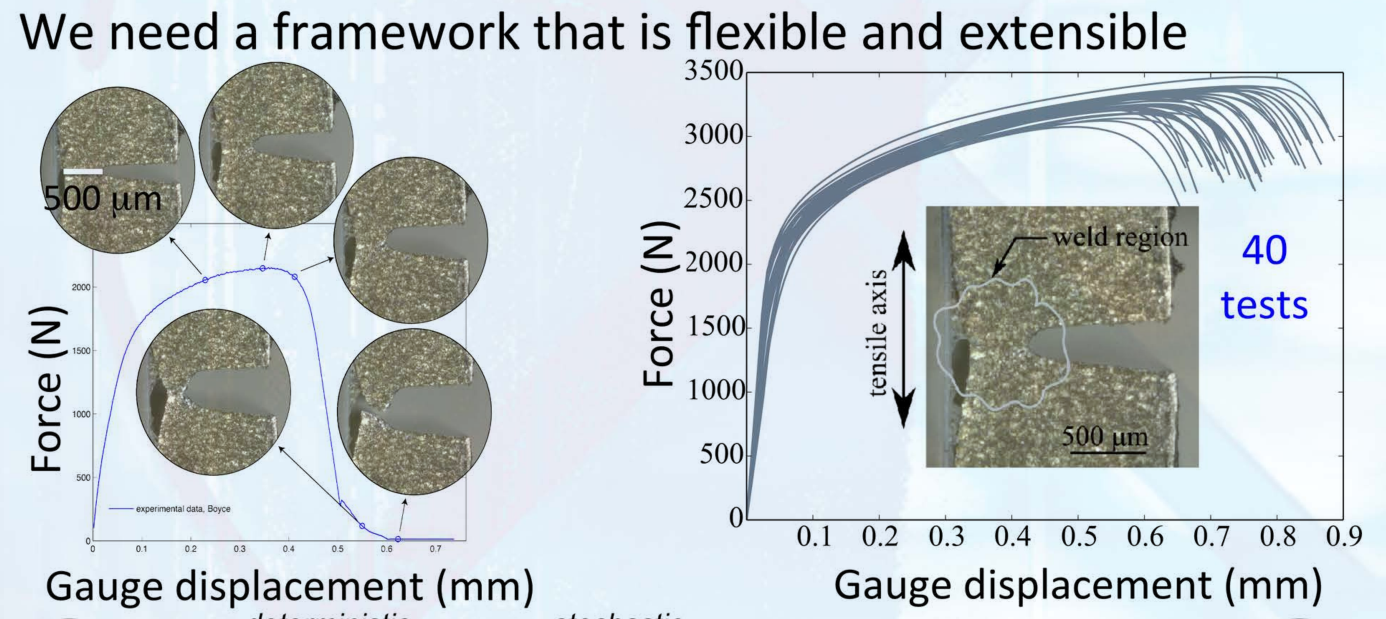
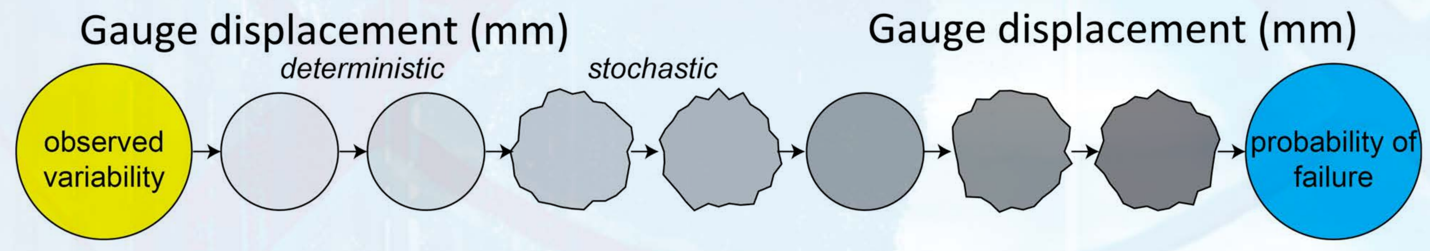
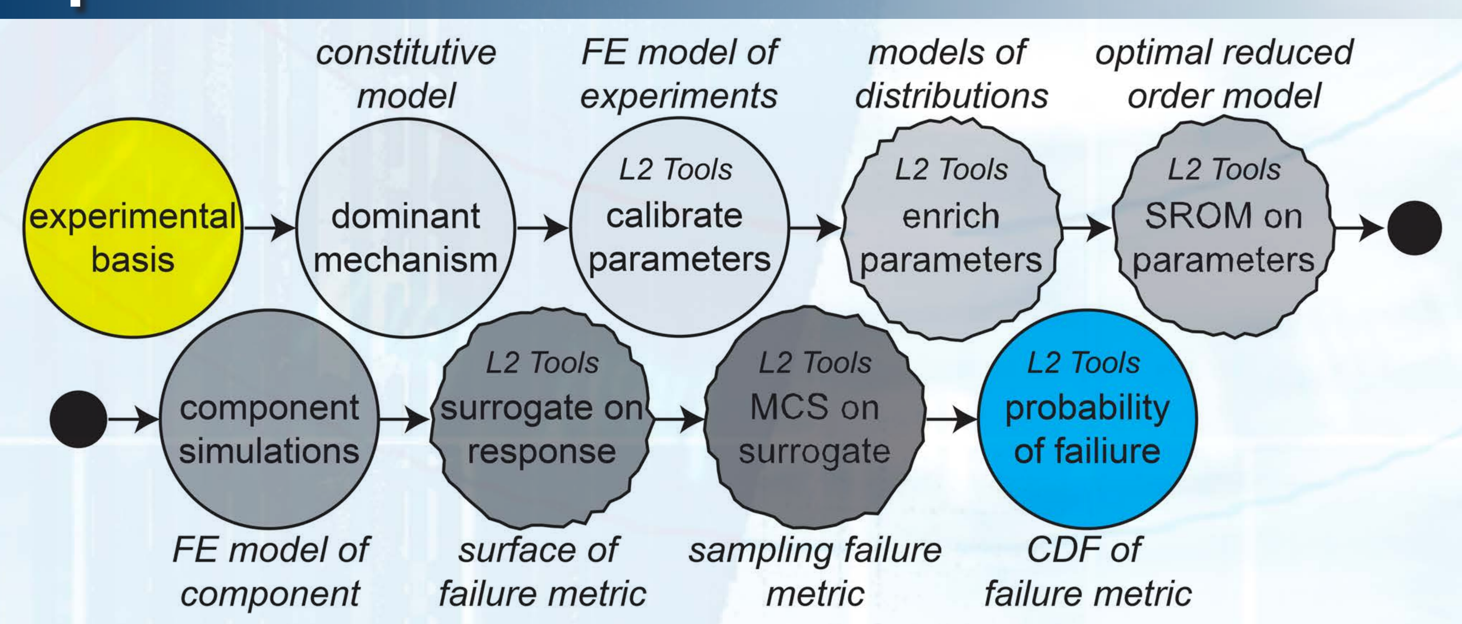
We Need a Framework for Prediction

- Nuclear safety is governed by the performance of 304L welds
- Observe geometric/material variability in laser welds
- Need to determine impact of variability on performance
- Capture tail of cumulative distribution function (CDF)
- We need a framework that is flexible and extensible





Components of Stochastic Framework



Calibration of Stochastic Parameters

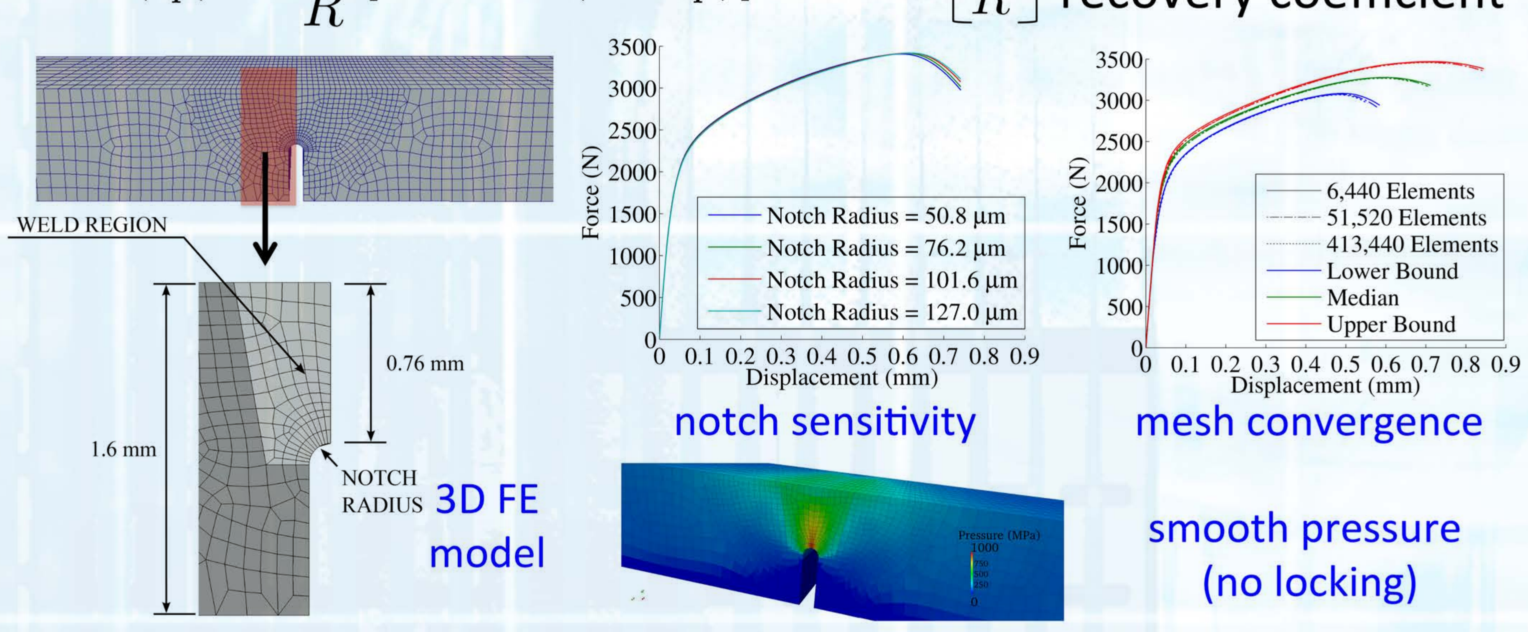
Model calibrated to the 40 available experiments using DAKOTA

$$\sigma_y = Y + \kappa \qquad \dot{\kappa} = [H - R\kappa]\,\dot{\epsilon}_p$$

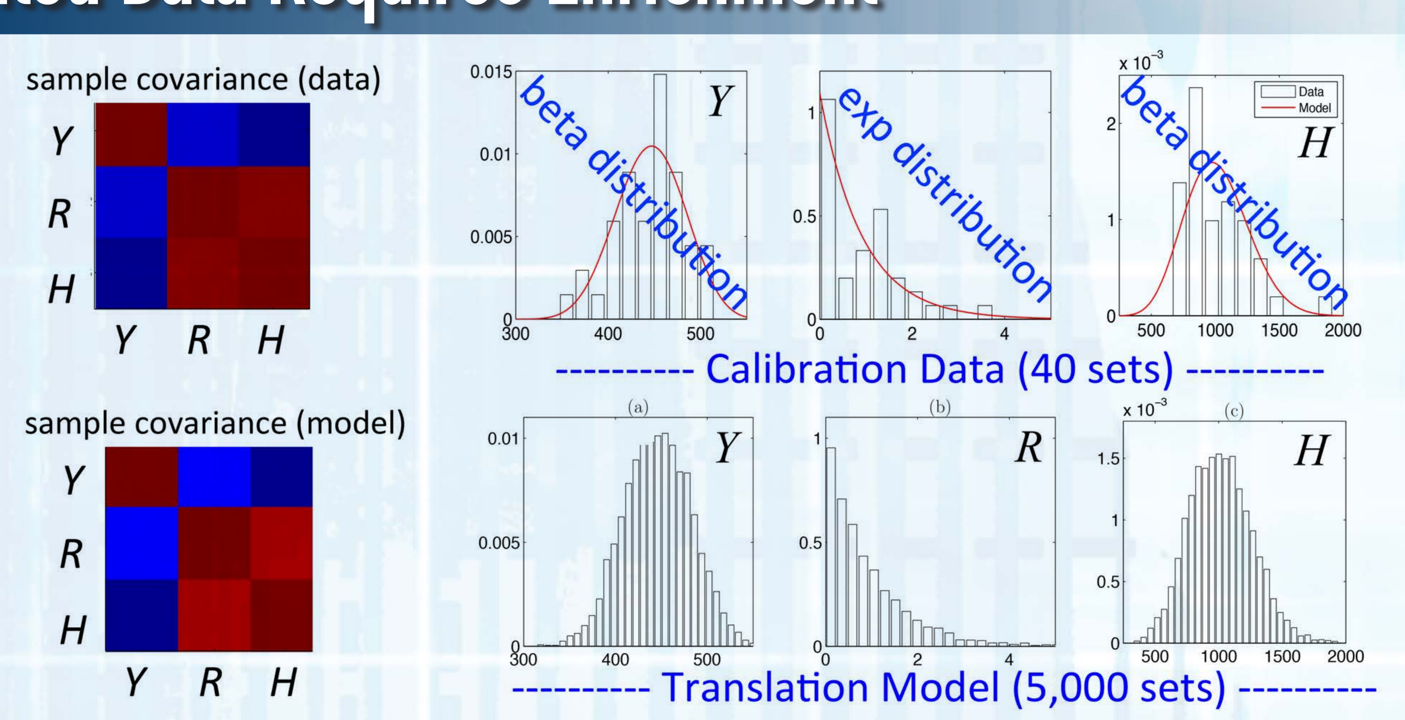
$$\kappa(\epsilon_p) = \frac{H}{R}\left[1 - \exp(-R\epsilon_p)\right]$$

$$\boldsymbol{\Theta} = \begin{bmatrix} Y \\ H \\ R \end{bmatrix}$$

- Y: initial yield stress
- H: hardening (linear)
- R: recovery coefficient



Limited Data Requires Enrichment

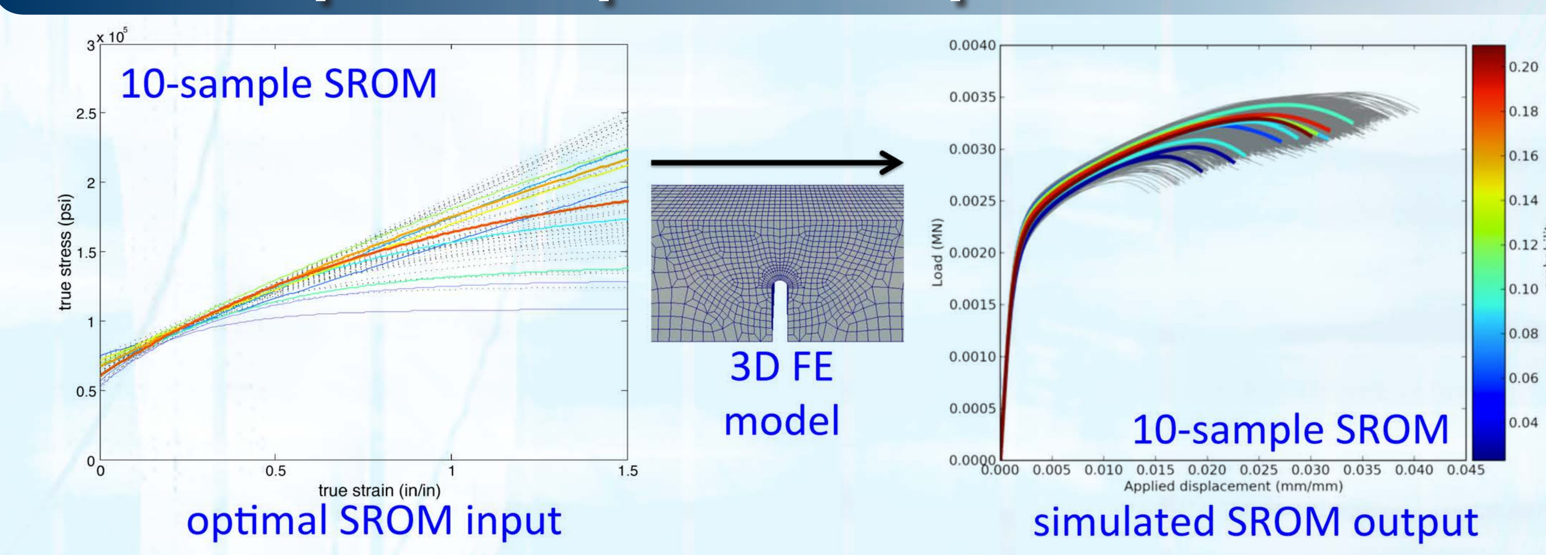


Stochastic Reduced Order Model (SROM)

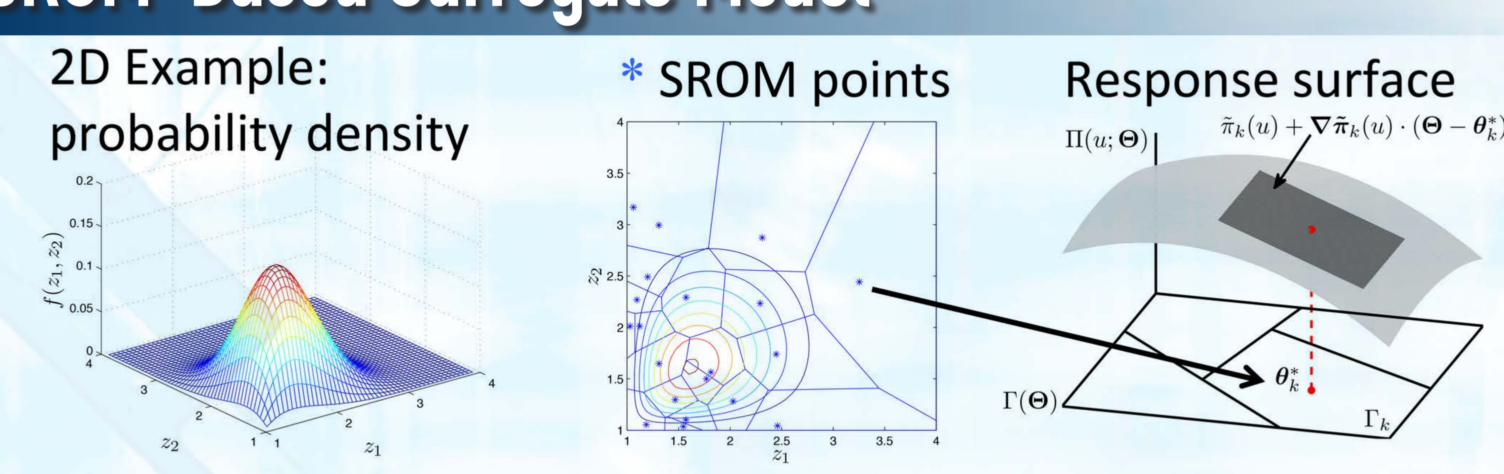
We choose to represent the uncertain input with a discrete random variable $\tilde{\Theta}$. The SROM is defined by the collection $(\tilde{\theta}_k, \tilde{p}_k)$ $k = 1, \ldots, m$ that minimizes an objective function of the form:

$$\underbrace{\max_{1\le r\le \bar{r}} \max_{1\le s\le d} \alpha_{s,r}|\tilde{\mu}_s(r) - \hat{\mu}_s(r)|}_{\text{moments}} + \underbrace{\max_{x} \max_{1\le s\le d} \beta_s|\tilde{F}_s(x) - \hat{F}_s(x)|}_{\text{cumulative distribution}} + \underbrace{\zeta_{s,t} \max_{s,t}|\tilde{c}(s,t) - \hat{c}(s,t)|}_{\text{correlation}}$$

SROM Output, "Component" Response



SROM-Based Surrogate Model

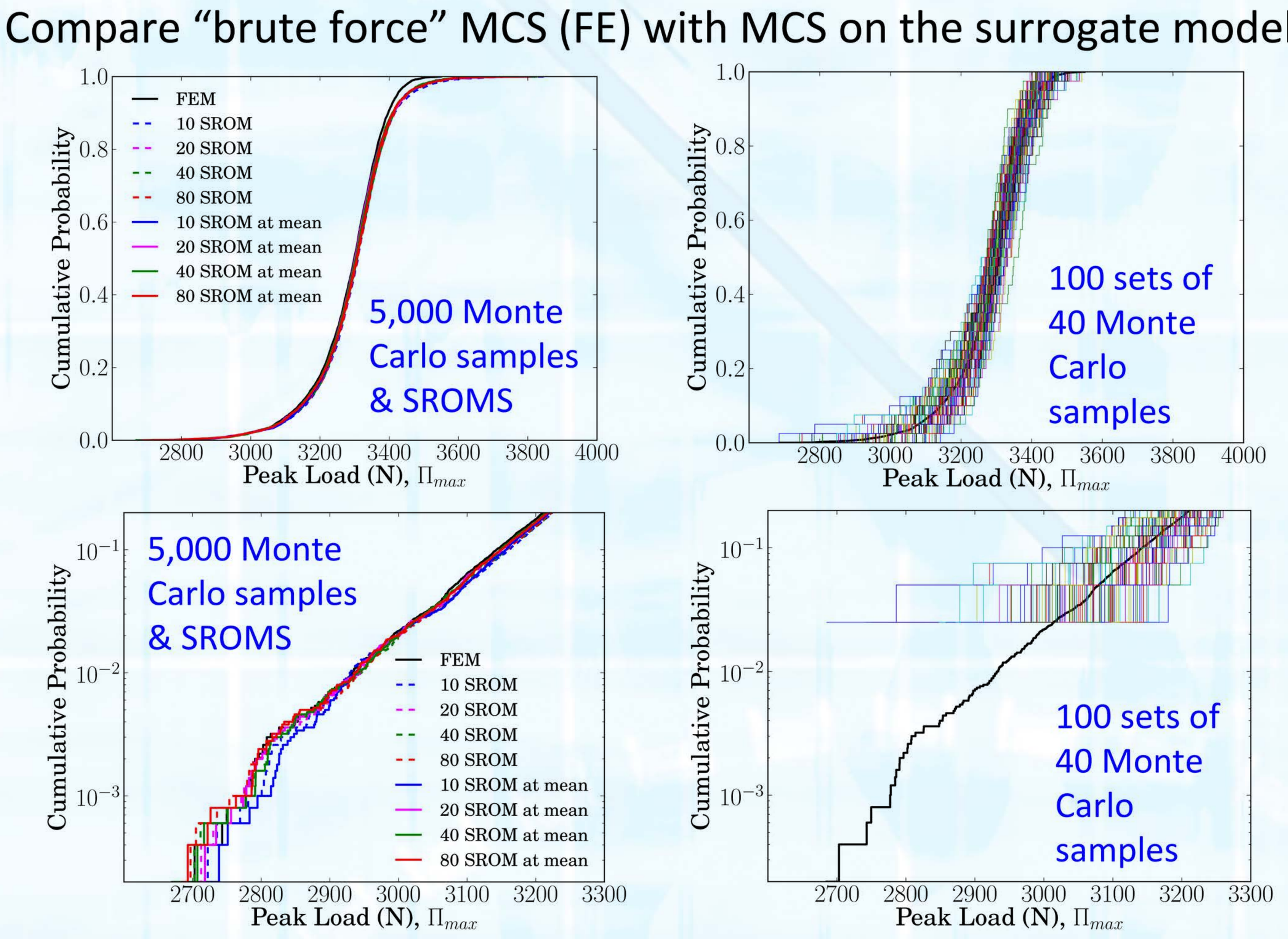


A response surface is constructed using a series of hyper-planes described with a first-order Taylor approximate:

$$\tilde{\Pi}_L(u;\boldsymbol{\Theta}) = \sum_{k=1}^{m} 1(\boldsymbol{\Theta} \in \Gamma_k)\,[\tilde{\pi}_k(u) + \nabla\tilde{\boldsymbol{\pi}}_k(u)\cdot(\boldsymbol{\Theta} - \boldsymbol{\theta}_k^*)]$$

MCS on SROM-based Surrogate Yields Tail in CDF

Compare "brute force" MCS (FE) with MCS on the surrogate model



For a linear response surface, 10-sample SROM = 40 calculations

Summary of Findings

- We cannot afford "brute force" Monte Carlo Simulation (MCS)
- Developed framework for constructing and applying SROMs
- SROM-based surrogate accurately captures the tail of the CDF
- SROM-based surrogate is superior to "brute force" MCS

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