HetGP: Multi-fidelity emulation with varied statistical precision

Raymond Ehlers[1] in collaboration with Simon Mak[2], Irene Ji[3]

Bayesian UQ meeting, 9 April 2025

[1]Lawrence Berkeley National Lab/UC Berkeley
[2]Duke University
[3]SAS

raymond.ehlers@cern.ch

BERKELEY LAB

Berkeley
UNIVERSITY OF CALIFORNIA

Multi-fidelity emulation

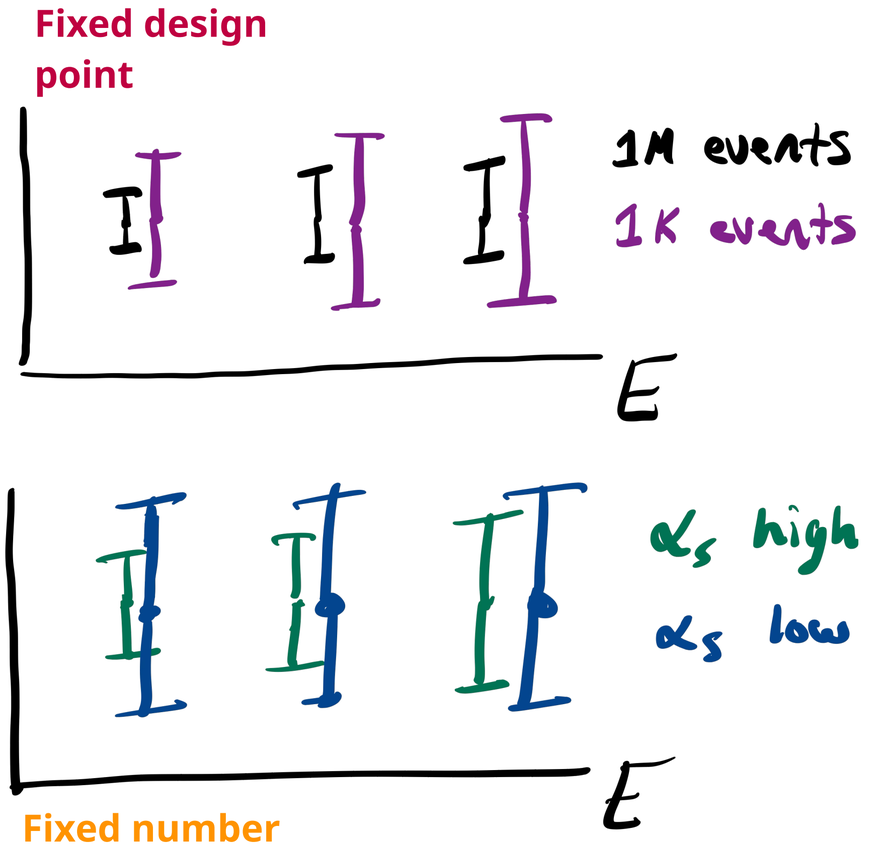
Monte Carlo simulations

- Computation time is a limiting factor for understanding HI collisions
- Expensive simulations → run limited simulations over parameter space, utilize surrogate model (i.e. Gaussian process emulation)

How to vary and account for fidelity?

- Imaging we're simulate events a measurement…
- How to maximize fixed computational budget?
- Considerations:
  - **Varied statistical precision** (trades off with # of design points)
  - **Physics evolves across parameter space** (better precision for fixed computation time)
- Precision varies as function of energy

➡ How can we we use this information?



HetGP: Multi-fidelity method for varied statistical precision

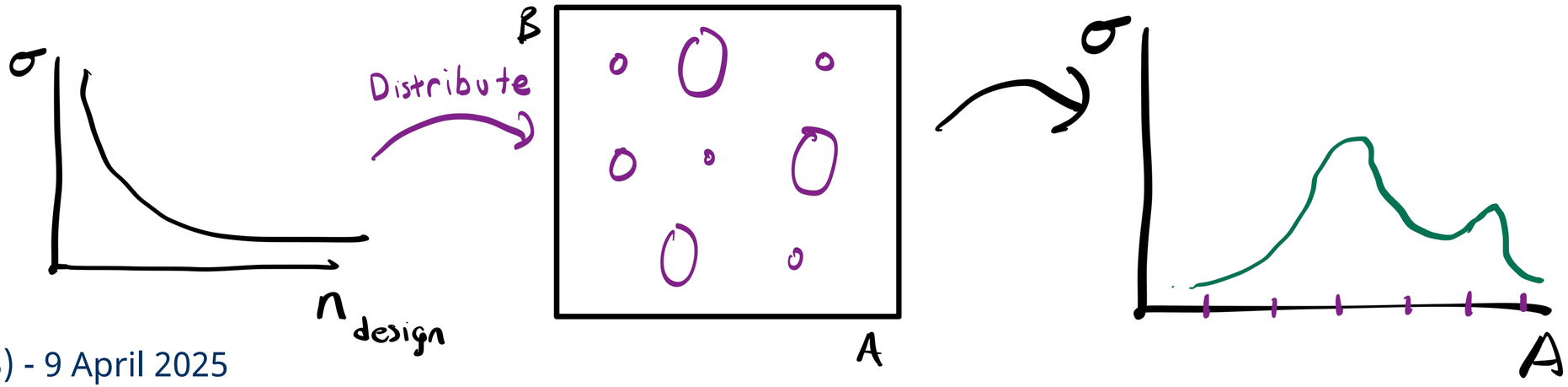
- Key concepts: 1) **multi-fidelity design**, and 2) **fidelity aware Gaussian Process Emulator**

Multi-fidelity design

- Method to allocate design points + their precision
- Design based on multi-mesh method:
  Yuchi et al, Journal of Mechanical Design, 2023
- Two key modifications:
  - For a fixed computing budget, **determine optimal precision per design point**
  - Assign precision to design points such that **close design points have different precision**

HetGP: Deep heteroskedastic GP

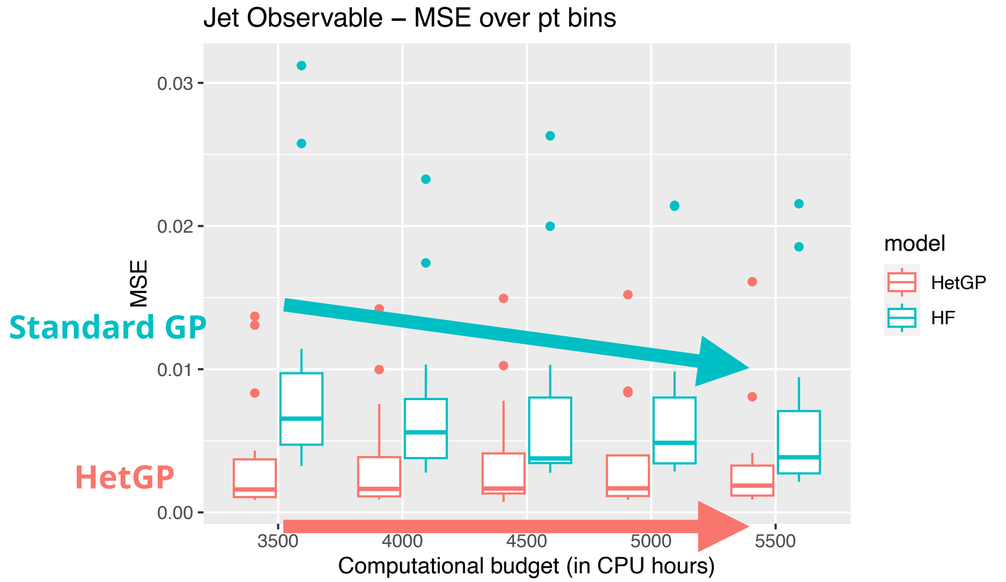
- Heteroskedastic: Data with varying precision
- **Fidelity is explicitly included in GP training**
- Implemented with R package, compared to standard GP

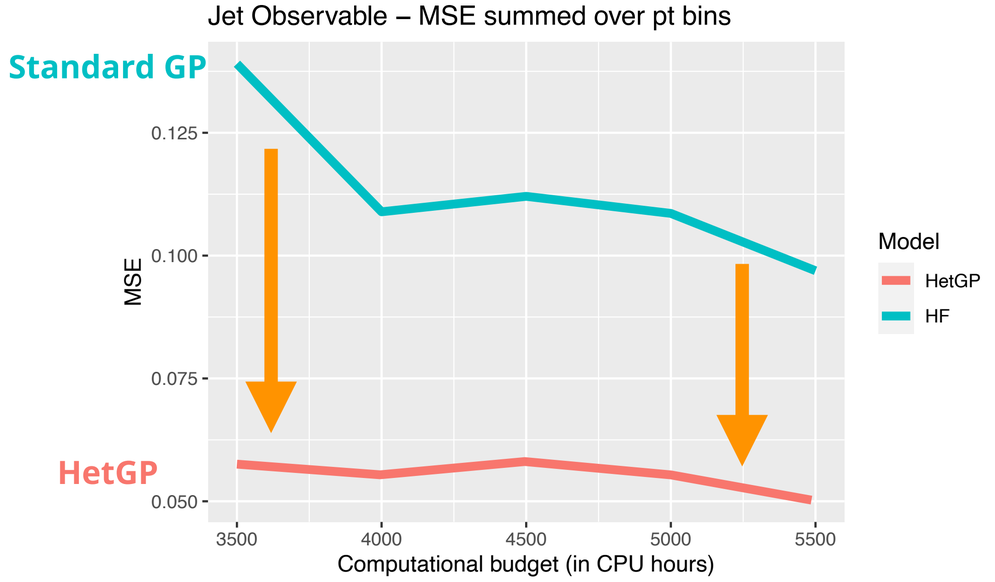


HetGP: Multi-fidelity method with varied statistical precision

- Intuition: **Low fidelity provides rough estimate, higher fidelity refines**
- **Consistently outperforms standard high-fidelity GP** at fixed budget

➡ **We're using with statistical precision, but can be applied to other multi-fidelity cases**





Backup

Hadron vs jet