US Higgs Factory Coordination Consortium (US HFCC) : AI/ML, Integrated Detector Concepts, Microelectronics (AIM) Group

L2 : Jim Hirschauer (FNAL), Julia Gonski (SLAC)
L3 : Liza Brost (BNL), Lukas Gouskos (Brown), Jennet Dickinson (Cornell), Tim Andeen (UT Austin)

ML4FE Workshop
21 May 2025

Outline

- Overview of **US Higgs Factory Coordination Consortium** (HFCC)
- Overview of **AI/ML, Integrated Detector Concepts, Microelectronics (AIM) Group** of HFCC
- Community **Detector Design/Optimization “Challenge"**
- **Summer 2025 Workshop** to Kick-off Detector Design/Optimization “Challenge”

US e+e- Higgs Factory Coordination Consortium

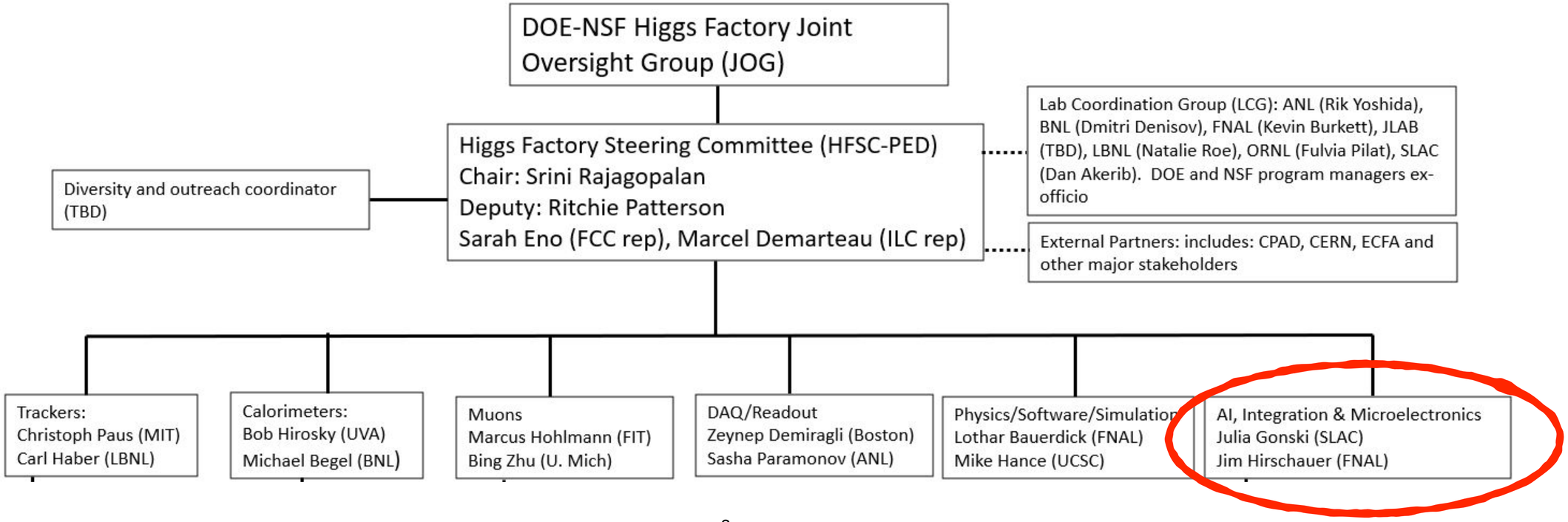
Charge:

- Physics and technical feasibility studies for future e+e- Higgs factory
- Stewardship and prioritization of national R&D
- Pre-project R&D plan
- Software and computing framework
- Funding model to support R&D
- Collaborate with partners (CPAD, ECFA, DRD)

Recent activities:

- Input to ESPP (https://arxiv.org/abs/2504.05395)
- Deployment of FY25 and planning FY26 R&D funding
- Annual US HF/FCCee Workshop at FNAL/ANL
  - https://indico.fnal.gov/event/67484/

https://us-fcc.web.cern.ch/



AIM Overview

- Focus on **cross-cutting topics** :
  - AI / ML
  - Integrated Detector Concepts
  - Microelectronics

- Critical to maintain **strong connections with**
  - HFCC Subdetector L2 areas
  - HFCC Software / Computing
  - HFCC TDAQ
  - International efforts
  - US R&D community in AI/ML and Microclectronics

- **AIM evolved from "Readout/ASICs"** group for the Higgs Factory P5 costing exercise
  - https://arxiv.org/pdf/2306.13567

Recent meetings:

- November 2024 : HFCC Strategy Meeting at Stony Brook U
  - https://indico.bnl.gov/event/24922/
- December 2024 : US HFCC Planning Meeting at SLAC
  - https://indico.slac.stanford.edu/event/9297
- April 2025 : Annual US HF/FCCee Workshop at FNAL/ANL
  - https://indico.fnal.gov/event/67484/

AI/ML

- ***L3: Jennet Dickinson (Cornell)***
- **Potential Work Packages:**
  - AI/ML in on-detector hardware – coordinate with AIM Microelectronics
  - AI/ML in off-detector hardware
  - Algorithm development and optimization: data compression, feature extraction, classification, anomaly detection, etc.
  - AI/ML for detector optimization – coordinate with AIM Integrated Detector Concepts
- **Existing Work/ US Expertise**
  - AI-ASIC development (UT Austin, Cornell, UChicago, UIC, JHU, FNAL, LBNL, SLAC, ANL, BNL, ORNL)
  - Differentiable programming-based ML detector optimization (SLAC)
  - Embedded FPGAs (SLAC, LBNL)

Connection to ML4FE:

- ML models suitable for deployment in low-power, low-latency, rad-tolerant hardware for ML on FE.

Integrated Detector Concepts

- ***L3s: Liza Brost (BNL), Loukas Gouskos (Brown)***
- Critical to coordinate with partners – especially HFCC Software/Computing and International efforts.
- **Potential Work Packages:**
  - Physics studies: strategy, develop/streamline existing SW frameworks, execution
  - Design and optimization of whole-detector concepts – coordinate with AIM AI/ML
  - Integration of subsystem capabilities (e.g. fast timing)
  - Whole-detector data simulation (e.g. for TDAQ bandwidth studies)
- **Existing Work/ US Expertise**
  - Leadership of FCC PED studies for physics benchmarks (BNL, Brown, Maryland, MIT, SLAC, etc)
  - Key4HEP software development (Princeton)

Connection to ML4FE:

- Realistic (digital) data from simulations of integrated detectors
  - Analog data / waveforms come directly from HFCC subdetector L2 areas — facilitated by AIM
- Realistic data volumes for optimizing compression/selection on FE.

Microelectronics

Connection to ML4FE:
- Develop low-power, low-latency, rad-tolerant hardware needed for ML on FE.

- ***L3: Tim Andeen (UTexas Austin)***
- **Community-driven Work Packages (tentative):**

Research Area	**Ongoing and future effort**
AI/ML in ASICs, intelligence on detector	UTAustin, UChicago, Cornell, UIC, UIUC, JHU, Kansas, ANL, LBNL, BNL, FNAL, SLAC, ORNL
Common IP for future MOSFET process nodes (28 nm e.g.)	LBNL, BNL, FNAL
3D / hybrid integration	USSC, LBNL, BNL, FNAL
Silicon photonics	ANL, LBNL, FNAL
High data density (including fast optical links	UPenn, ANL, LBNL, FNAL
Novel materials / devices	LBNL, FNAL
Novel design tools : open source, automated, AI/ML enhanced	UPenn, LBNL, BNL, FNAL, HEPIC
MAPS, 4D/5D sensor + ASICs, electronics for precision timing (now covered in Tracker L2 area)	UMichigan, ND, Oregon, UCSC, ANL, LBNL, BNL, FNAL, SLAC, ORNL

FY24 HFCC Funding

https://us-fcc.web.cern.ch/

- Scope/Priorities for FY24 were laid out during the P5 process prior to the formation of the HFCC organization.
- Following the successful P5 process, DOE authorized $450k (late FY23) for FY24 R&D.
- The following **FY24** activities (**total $261k**) were subsequently approved and funded:
  - +50k for workshops and travel, Remaining carried over to FY25.

MAPS (Napa p2 development)	SLAC	50k
Design of test structures for testing MAPS	FNAL	60k
TCAD simulations	FNAL	15k
Setup to study gas mixtures for straw tubes	Michigan	40k
Purchase of wires for gaseous tracker R&D	BNL	16k
Investigation of eco-friendly gases	FIT	16k
Design for integration of cold electronics in LAr demonstrator modules	BNL	28k
Study of low power 28nm TDC	Amherst	10k
Key4HEP software development	Princeton	26**k**

FY25 HFCC Funding

https://us-fcc.web.cern.ch/

- Each L2 coordinator presented a prioritized request following a bottom-up process and input from the community/L3 coordinators.
- Highest priority given to supporting software/simulation efforts:
  - Identified as a priority by all L2 during the cross-cutting session at SLAC meeting
- Several activities were deemed important and high priority across all areas
  - Limited funding could only allow support for a few focused low-budget activities.

Simulation and Analysis Tools support	Princeton	63k
Key4HEP support/development	LBNL	67k
Software workshops, training events	FNAL	50k
Prototype Straw tracker development Michigan 60k	Michigan	60k
Engineering design for analog FE for Dual Readout crystal matrix	FNAL	50k
Endcap design work on LAr turbine structures and associated PCB	Arizona	50k

Critical connection : FCC-ee Detector Simulation Support

- **FCC-ee detector simulation support** provided by funding for US HFCC Software and Computing
  - Ianna Osborne (Research Software Engineer, Princeton)
  - Tools for user friendly simulation in FCCSW
  - Simulation configurations and production workflows
  - Detector geometry development
  - FCCSW and key4hep integration

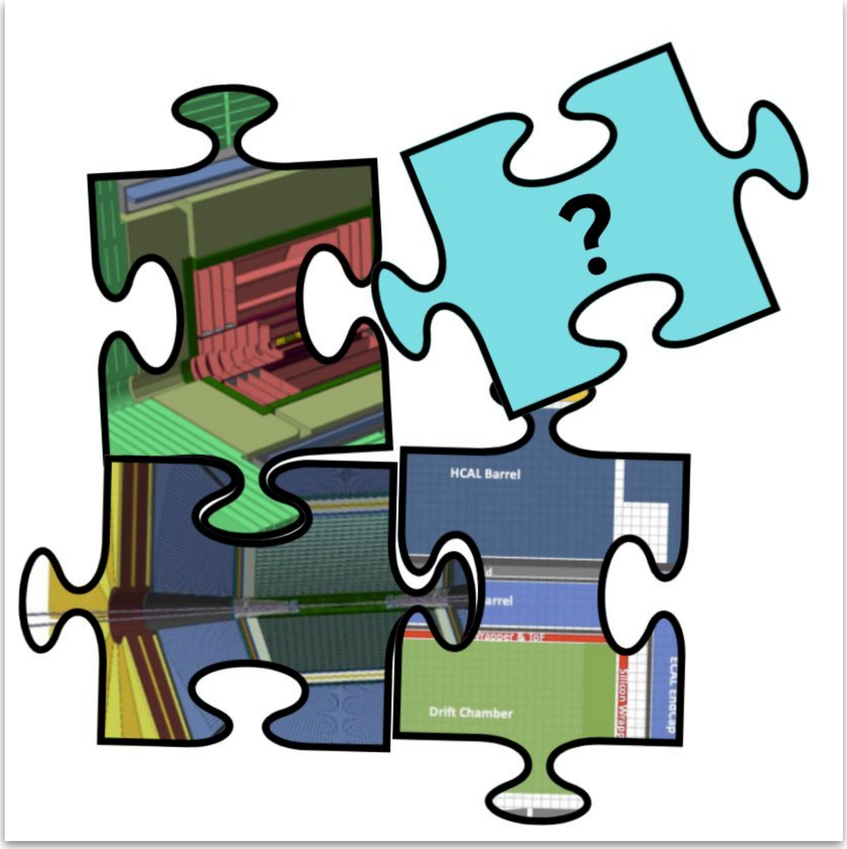
- Short term plan
  - Skeleton plugin creator — e.g. python scripts to generate key4hep-compliant C++ code
    - https://github.com/ianna/DualTestBeam/blob/master/scripts/mktransformer.py
  - Documented detector simulation demonstration / tutorial
    - Building on tutorials from April 2025 FNAL/ANL HF/ FCC-ee workshop
  - Performance profiling of geometry descriptions (e.g. dual readout calo)

Connection to ML4FE:
- Come work with HFCC and Ianna to co-develop realistic simulated HF data — ensuring that simulation is optimized for ML4FE models.

Community Detector Design/Optimization Challenge

Physics studies for full-detector concepts

- **Goals:**
  - Inspire the US community to contribute to **international efforts** for Integrated Detector physics studies
  - Lower the barrier to entry for new groups
  - Inspire new optimization and design ideas, both of which are key deliverables for AIM and US HFCC-PED.



Community Detector Design/Optimization Challenge

- **Determine common physics benchmarks**
  - E.g. SM & BSM Higgs, long-lived particles, flavor benchmarks, [your favorite process here]
  - Provide configs/Madgraph processes
- **Build infrastructure**
  - Need set of baseline Delphes cards for all (sub)detector concepts
    - + recent sub-detector improvements? Create a list/spreadsheet of available cards
    - + where are Delphes simulations adequate vs. where we need separate (full-sim) samples?
  - Simple analysis scripts to determine performance metrics (eg. search sensitivity, object resolution)
    - Where to host information (HFCC websites, git, Zenodo)?
  - Final deliverables for “judging” (eg. displaced vertex reconstruction, Higgs coupling sensitivity, etc.)
- **Very very preliminary timeline**
  - Planning / work-workshop summer 2025
  - Launch competition by end of FY25, with deadline at US HFCC/FCC workshop in ~spring 2026?

Slide from Liza Brost

First step for “challenge” : workshop this summer

- **Work-workshop (do we have a better word for this?)**
  - An excuse to sit together and get actual work done, rather than listen to talks
  - Have parallel tracks / work groups accessible for ~everyone (newcomers to experts)
- **Goals (not in any particular order):**
  - Make it easier for new groups to ramp up on FCC work
  - Build US community
  - Synergies with international effort - create results that can be presented in international meetings, contribute to DRDs
  - Set up for the AIM full-detector optimization challenge
  - Clear deliverables ↓
- **Example deliverables**
  - Lightning talks slide at the end of the week - everyone will show one plot or one slide on their progress
  - Datasets on Zenodo
  - Example analysis that runs (can be varied per work package)
  - Preliminary on-detector ML models

Slide from Liza Brost

First step for “challenge” : workshop this summer

Example work-work to work on during the work-workshop

-- not an exhaustive list, and we would pick a handful to focus on during the workshop, based on community interest

- FCC software tutorial (for newcomers)
- MC generation - running Madgraph? Whizard? and combining it with Pythia
  - What can be done to improve the current state of the art, what can be turned on/off, impact of changing the parton shower
  - => feedback to theorists
- Jet algorithms
  - Also tagging?
- Digitization
  - Calorimeter focus - have an example figure of merit (jet energy resolution?)
- Detector design studies
  - Change detector parameters, see impact on physics process (vertexing, flavor-tagging,

ML-based FE processing is possible

◉ Development of first on-detector ML models

Slide from Liza Brost

Summary

- **US HFCC** is coordinating e+e- Higgs Factory and FCC-ee US efforts
  - Funding is available and expected to increase

- **AI/ML, Integrated Detector Concepts, Microelectronics (AIM)** Group of HFCC is coordinating HF-focused ML4FE efforts
  - Ideal place to obtain realistic digital and analog data for optimizing and training your next ML4FE project!

- Community **Detector Design/Optimization “Challenge"** and Summer 2025 Workshop
  - Come work with us to co-design (a) your next ML4FE model and HW architecture and (b) integrated HF detector concepts.