Status of US planning towards an e^+e^- Higgs Factory

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U.S. support for a Higgs Factory

- The 2014 U.S. Particle Physics Project Prioritization Panel (P5) identified five compelling science drivers for the field.
  - "*Use the Higgs boson as a new tool for discovery*" was one of them.
  - That panel went on to comment in its report: "*An e+e- collider can provide the next outstanding opportunity to investigate the properties of Higgs in detail*"
- The strong support of U.S. community in a Higgs Factory is reflected in the breadth of contributions towards Snowmass and the subsequent P5 process.
- The 2021 Snowmass process emphasized strong support for the next generation e^+e^- collider, noting that:

  "The e+e− colliders are the vehicle that will enable a high-precision physics program in the EW sector by increasing the precision of SM measurements. ***The physics case for an e+e− Higgs factory is compelling, and the program is possible essentially with current technology****.*
- The current P5 process is underway, with its final report expected in December 2023. We expect the current P5 to offer its strong support for a Higgs Factory and the U.S. involvement in the next generation e+e- collider.

U.S. advocacy for an e+e- Collider

- The ALCC (Americas Linear Collider Committee) has long advocated for the ILC in Japan. In its statement to P5 in April 2023, ALCC noted:

  *"**the ALCC urges P5 to move the Higgs factory forward as a global project by assigning the idea of an e+e− Higgs factory high priority**, initiating a global discussion of the technology choice and cost sharing, and offering the option of siting the Higgs factory in the U.S."*

  - U.S. groups have extensively contributed to developments leading to TDR for ILC (SID & ILD).

- Leading up to the P5 process, a bottom-up community interest has emerged in strong support of FCC.
  - Extensive R&D efforts already underway at several institutes toward CLID/IDEA/ALLEGRO.
  - Following the 2020 update of the European Strategy, DOE and CERN signed an agreement for cooperation in the FCC Feasibility Study.

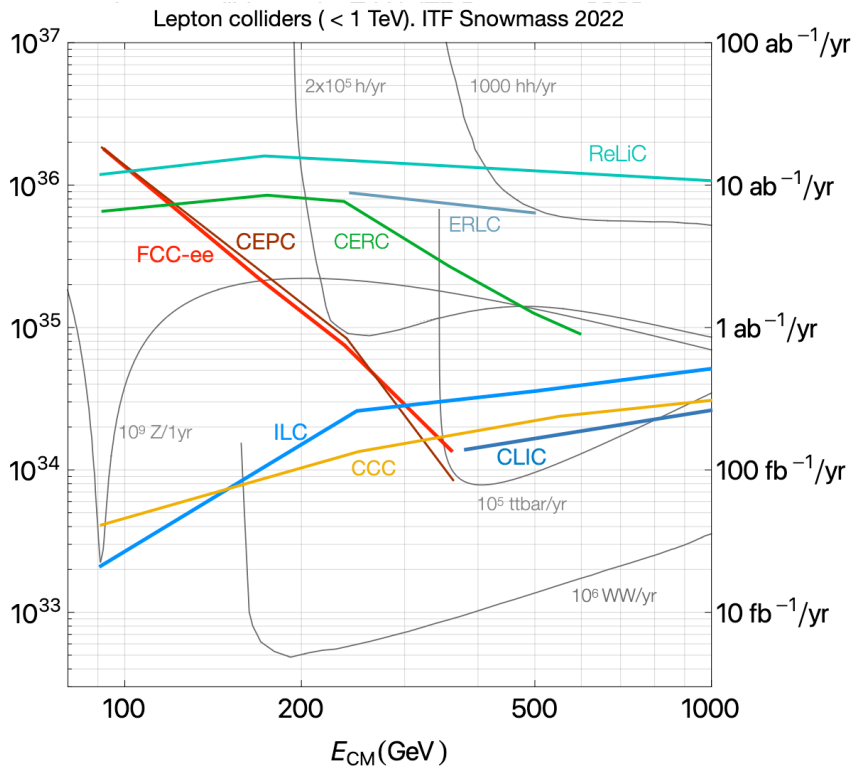
- R&D toward a demonstrator for Cool Copper Collider (C^3) based on normal conducting technology operating at LN2 is moving forward at SLAC.
  - 4 (8) km footprint, 70 MeV/m, 250 (550) GeV initial starting point.
  - Detector requirements for C^3 highly overlap with those for ILC & FCC detector.

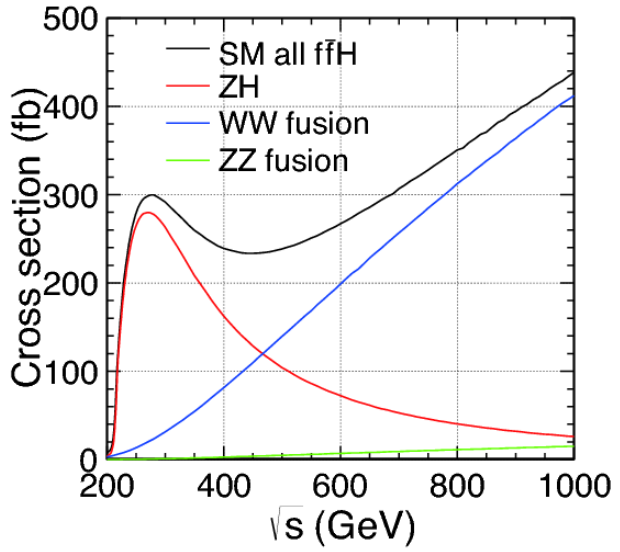
U.S. institutes with ongoing effort/interests

- Universities and National Labs with existing interests/efforts in e+e- Collider (60+ institutes):
  - **Argonne**, Arizona, Brandeis, **Brookhaven**, Brown, Boston, Caltech, Carnegie Melon, Colorado, Colorado State, Columbia, Cornell, Duke, Florida Tech, Florida, **Fermilab**, Florida State, Hawaii, Indiana, Iowa, Iowa State, **Jefferson Lab**, Johns Hopkins, Kansas State, **LBNL**, Louisiana State, Maryland, U Mass Amherst, Michigan, Michigan State, MIT, Mississippi, Nebraska, New Mexico, Northeastern, Northern Illinois, Notre Dame, **Oak Ridge**, Oregon, Pennsylvania, Pittsburgh, Princeton, Purdue, Riverside, Rochester, **SLAC**, Stony Brook, Syracuse, Texas Arlington, Texas Austin, Texas Tech, Tufts, UC Berkeley, UC Davis, UC Irvine, UC Los Angeles, UC Santa Barbara, UC Santa Cruz, Virginia, Washington, Wayne State, Wisconsin, Yale
- Resource pool expected to grow with time
  - Significant pool of resources/expertise, primarily engaged in the ongoing LHC/HL-LHC program, who can seamlessly transition and contribute to the next generation Higgs Factory collider at the conclusion of the ongoing HL-LHC upgrades.
  - Significant overlap, synergies and (physics/detector) interests amongst the ILC, FCC and C^3 communities to warrant a strong collaboration while waiting for a collider decision.

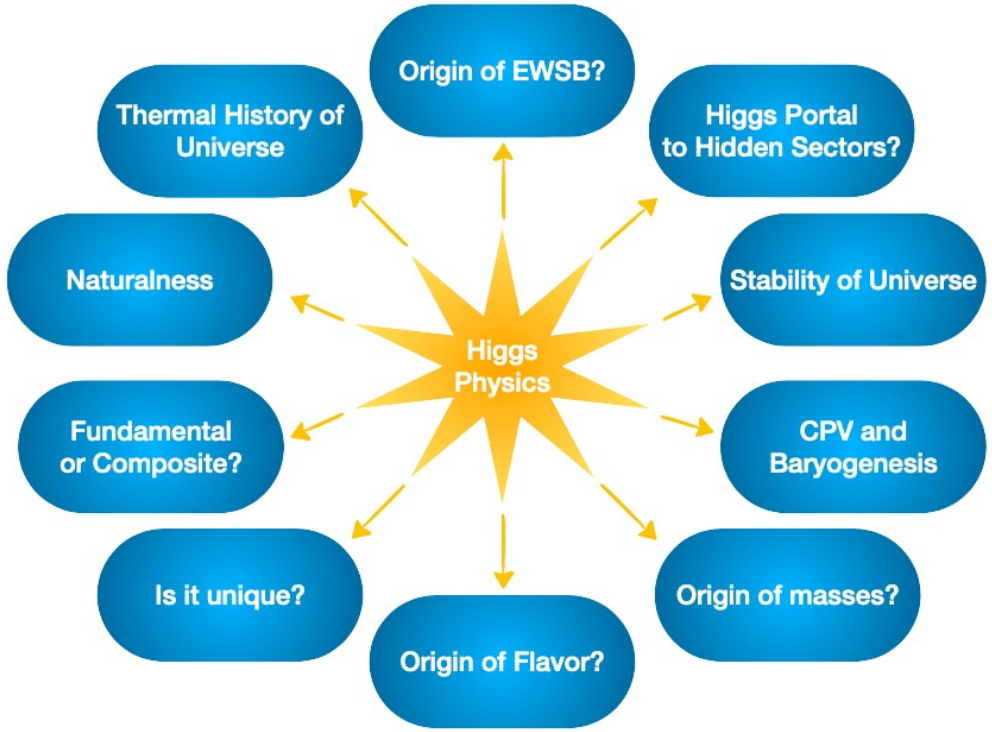
Exploiting synergies

- While circular and linear colliders have their respective advantages, they bear significant commonalities.
- Common benchmark physics processes provide an opportunity to exploit synergies:
  - Higgsstrahlung at E ~250 GeV allows exploitation of a well measured recoil Z to make precision measurements of the Higgs boson properties.
  - WW fusion process indispensable for electroweak precision physics.
- The U.S. LC and CC communities united their efforts to put forward a common proposal to P5.
  - Critical for the community to work together exploiting synergies, especially given that only one of the collider options is likely to move forward.





Higgs at Snowmass

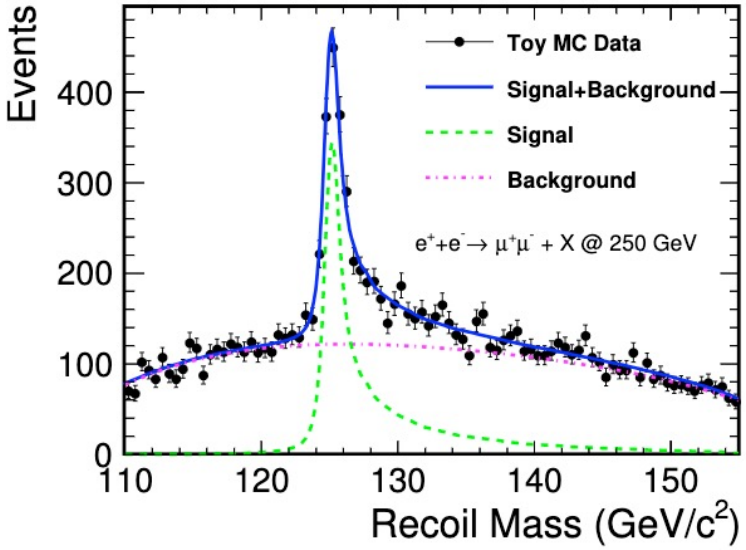


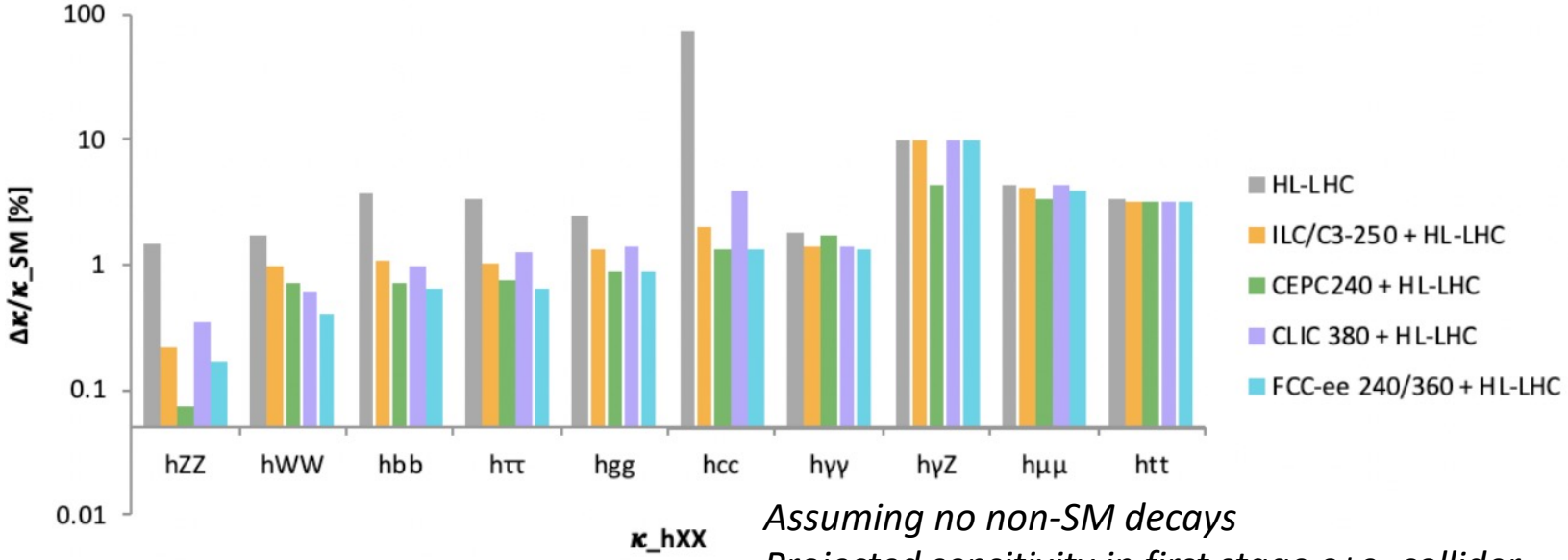
The Higgs Boson, as the keystone to the SM, is connected to numerous fundamental questions that can be investigated by studying in detail

- [many as part of the proposed Higgs Factory programs]
- Snowmass Report, Topical Group on Higgs Physics, https://arxiv.org/pdf/2209.07510.pdf

Higgs at Snowmass

- ❖Precision Higgs measurement was a strong focus topic at Snowmass and an important justification for pursuing e+e- Higgs Factory.
- ❖Precision model-independent measurement of Higgs width using ZH recoil events
  - Leading to model independent Higgs partial width and coupling measurements.
  - Performance similar amongst various collider options
  - Polarized beam at linear collider (2 ab^{-1}) show comparable performance to FCC-ee (5 ab^{-1})





Assuming no non-SM decays
Projected sensitivity in first stage e+e- collider

Software Support

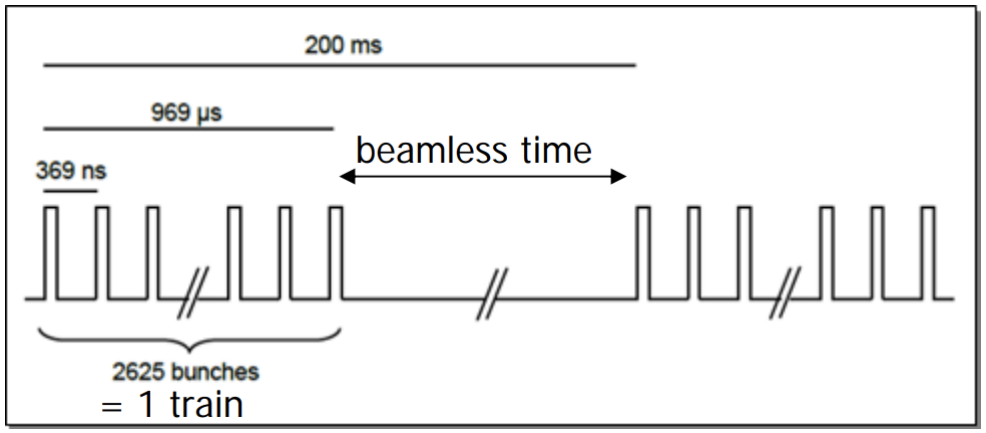
- While we agree with the prioritization of benchmark physics processes as laid out by ECFA, we must be able to support other ongoing studies:
  - Ongoing studies at Z-pole (*b* and τ factory!), WW (EW and top precision measurements), light and top Yukawa couplings, Higgs self-couplings, rare/exotic decay modes and other studies accessible only at higher energies. This helps to add value to the ECFA planned studies.
- Software tools and related support are essential to allow contributions to physics studies and in turn detector optimizations.
- Close coordination with ECFA WG2 and FCC software team, building on the developments in Key4HEP is essential. U.S. has significant pool of expertise to engage here.
- U.S. interests in the near-term leverage expertise at the LHC and focus primarily on:
  - Immediate Near Term (starting now):
    - Generators, fast/full simulation, framework and reconstruction software to support developments within the Key4HEP framework for detector design and optimizations.
  - Medium Term:
    - Forward looking R&D, exploiting ML and GPUs for simulation and reconstruction to exploit the latest technologies for intelligent and faster reconstruction/analysis.
  - Longer Term:
    - Contribute to the next generation software and beyond-exascale computing architectures, leveraging from the U.S. experience, to support FCC simulation and other software needs.

Detector R&D

- Funded R&D efforts of interest to e+e- already ongoing in U.S in several areas, as part of efforts in SiD/ILD for ILC or for IDEA and ALLEGRO for FCC-ee.
  - Significant overlap in detector concepts amongst the e+e- collider options.
- U.S. Higgs Factory coordination group, bringing together the ILC, FCC and C^3 communities, have organized themselves along technological themes:
  - A community driven bottom-up proposal has been developed, documenting the interests and expertise of the U.S. groups. This was submitted to P5 for their consideration : https://arxiv.org/abs/2306.13567
  - This proposal also served as a starting point for discussions with the DRD groups: Coordinators are actively engaging with the ongoing DRD efforts and are in direct communication with the DRD group convenors.
- In addition, high level discussions are ongoing between DOE and CERN to enable cooperation in DRD projects.
  - There already exists strong collaboration in many focused R&D topics between U.S. and European groups. Important to support and strengthen this.

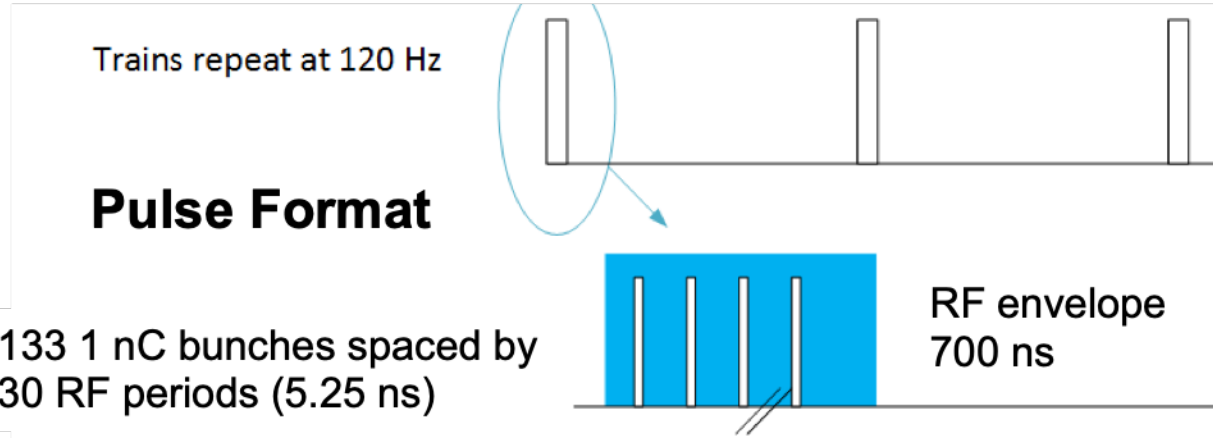
Focused efforts for Linear Collider option

ILC timing structure



1 ms long bunch trains at 5 Hz
308ns spacing

C^3 timing structure



- **Joint simulation/detector optimization effort with ILC groups**
- **Common US R&D initiative for future Higgs Factories 2306.13567**

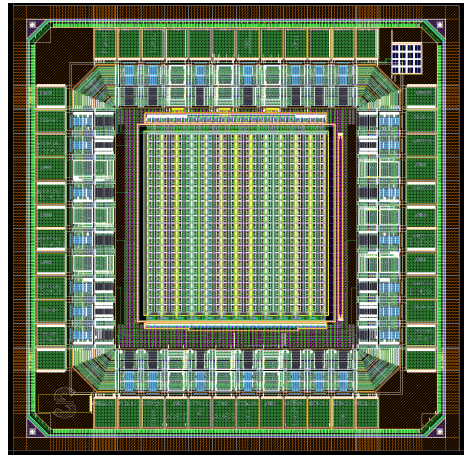
ILC/C^3 timing structure: Fraction of a percent duty cycle

- **Power pulsing possible**, significantly reduce heat load
  - Factor of 100 power saving for FE analog power
- Tracking detectors **don't need active cooling**
  - Significantly reduction for the material budget

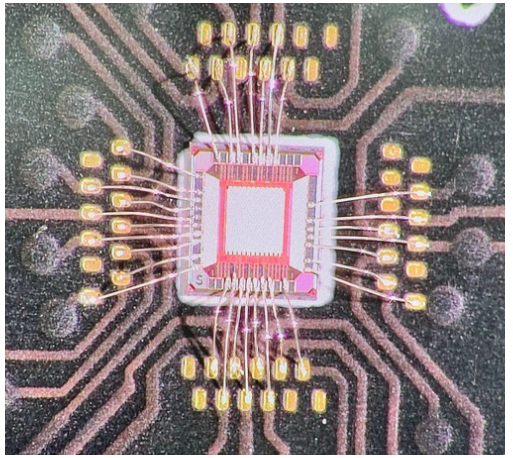
Need for investments in detector solenoid: US with a strong record in magnet technology can potentially contribute.

Solid State

- Significant expertise in several U.S. Labs and institutes
  - Pixel and Strip design, fast timing and 4D concepts
  - Low mass mechanics, power management
  - Continuous beams (FCC) puts demands low-power, cooling.
- Significant interests in monolithic CMOS technology
  - EIC is developing MAPS based tracking detector following ALICE ITS3 based on 12” wafer, 65 nm TowerJazz.
  - Basis of tracker & calorimeter readout in all e+e- detector concepts.
  - Provides increase density for circuits, Low power (20 mW/cm^2), Low mass (0.05% Xo/layer), superior spatial resolution (3 μm hit precision),
  - SLAC developing prototypes as part of CERN ITS package WP1.2 (=DRD3) and will focus on improving timing resolution.
  - Strong interests in U.S. to build on expertise to develop cost-effective vertex/tracker and EM calorimeter readout designs.



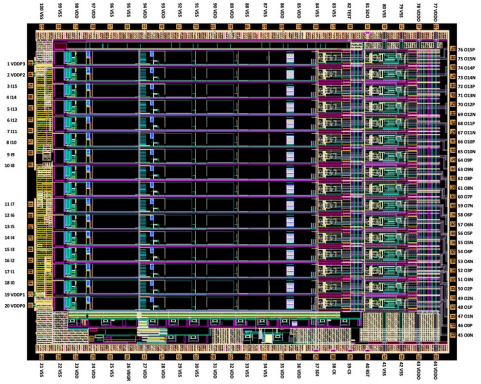
Layout of MAPS (SLAC prototype)

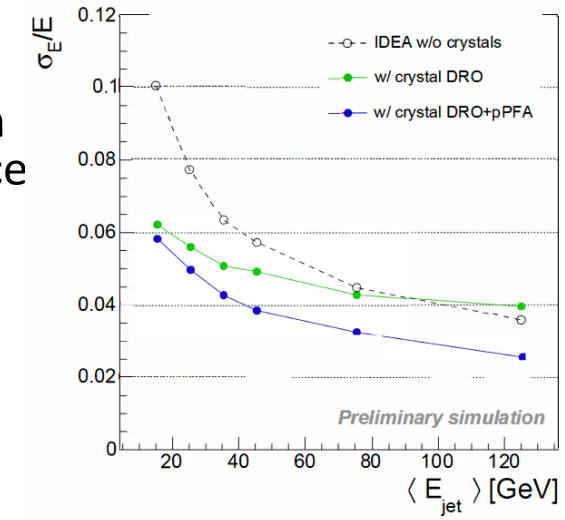


Calorimetry

- U.S. groups have been deeply engaged for decades in Calorimetry
  - Strong collaboration with Europe for decades in LHC, neutrino projects, etc. The U.S. wants to further build on that collaboration.
  - Experience in the U.S. can be exploited for manufacturing low-noise, high resolution calorimetry suitable for particle flow algorithms targeting e+e- experiments.
- Thrust areas where U.S. has and can continue to play key roles:
  - Cryo Front End electronics for Liquified noble gas calorimeters
    - Superior (~5x) SNR with cold electronics, coupled with fine segmentation (12 layers compared to 4 in current ATLAS) provides superior performance
  - Hybrid dual readout calorimeter
    - Segmented homogenous crystal EM calorimeter with SiPM readout and a Cerenkov/Scintillator fiber with time-domain readout for hadronic calorimeter, with fine long/trans segmentation
      - Hybrid mechanism has the potential to achieve 3-4% jet energy resolution for 50-150 GeV jets while maintaining superior EM resolution.
  - Si-W EM calorimeter with MAPS readout, Scintillating Tile with SiPM readout for Hadronic calorimeter, in part

180 nm design for DUNE





Other Detector R&D areas

- Gaseous Detectors:
  - MPGD facility, high resolution/fast timing detectors with eco-friendly gases
- Particle ID:
  - Dedicated TOF detectors using LGADS to improve π/K separation
- Readout/ASIC developments:
  - 28 nm developments, coping with high rates, density, power, …
- Trigger/DAQ:
  - on-detector real-time data processing
- Quantum:
  - Explore engineered materials that can improve efficiencies via doping
- In addition, we have a dedicated group to address the software needs.
- U.S. groups eager to get engaged in this process and collaborate with Europe, awaiting P5 process to conclude and funding to enable this engagement. We are hopeful of a limited level of funding support beginning 2024 and ramping up in subsequent years.

Moving forward

- We expect the Higgs Factory to be the next high priority Energy Frontier project following the completion of HL-LHC.
  - FCC-ee, ILC and C^3 all have challenges.
  - Comparable approval timelines for ILC and FCC were advocated by the proponents during the recent P5 town hall meeting at BNL.
  - This makes it essential for these communities to coordinate on detector technologies targeting these projects, at least for the next few years until respective project approval.
- We are waiting for P5 process to conclude, Report is planned to be released Dec 7-8, 2023.
  - We look forward to a strong support for a U.S. program in the next generation Higgs Factory. In anticipation for that, we are developing a prioritized list of short-term activities, identifying resources and preparing our ask to the agencies.
- Active engagement with DOE already underway. We have also begun the process to engage NSF to seek their support as it is equally vital for a nationally and internationally coordinated U.S. participation in a Higgs Factory.

A final comment

- Each geographical region has their own well-defined process for laying out the vision of the High Energy physics program.
  - The European Strategy, mandated by CERN council, aids to define the process in Europe.
  - The US has its Snowmass/P5 community driven process.
  - Japan and other countries have their own process as well.
- However, it is clear that no country, or even continent, can embark on a multi-billion dollar project by themselves.
  - Funding is not the only issue; resources and expertise are distributed as well.
  - Collaboration and pooling resources is critical and serves to strengthen the global program.
    - A faster track to answering the physics questions.
  - Tevatron, LHC, DUNE, …. They are all international collaborations!
- Thanks for engaging the U.S. in the ECFA process.
  - It was also a pleasure to see a strong European participation in the Snowmass process.
  - We need to continue to strengthen this collaboration (+Asia) and agree on a common global vision for the program.

U.S. Higgs Factory Coordination Group

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- Readout/ASICs: J. Gonski, J. Hirshchauer
- Trigger/DAQ: Z. Demiragli, J. Zhang
- Particle ID: M. Artuso, G. Wilson, Z. Ye
- Quantum: M. Demarteau, C. Pena, S. Xie
- Software: H. Gray, O. Gutsche, J. Strube
- ex-officios: J. Brau, A. Canepa, D. Denisov, S. Eno, P. Grannis, K. Jakobs, A. Lankford
  - plus representation from DOE and CPAD.
- Chair: S. Rajagopalan