Capturing FCC-ee for BNL

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June 1st 2022

FY2023 NPP LDRD Type A Proposal

Proposal title: Capturing FCC-ee for BNL

Primary Investigator: Marc-André Pleier

Other Investigators: Kétévi Assamagan, Michael Begel, Liza Brost, Viviana Cavaliere, Hucheng Chen, Angelo Di Canto, George Iakovidis, Paul Laycock, Scott Snyder, Robert Szafron, Alessandro Tricoli

Indicate if this is a cross-directorate proposal. Yes ___ No _X_

If yes, identify other directorates/organizations:

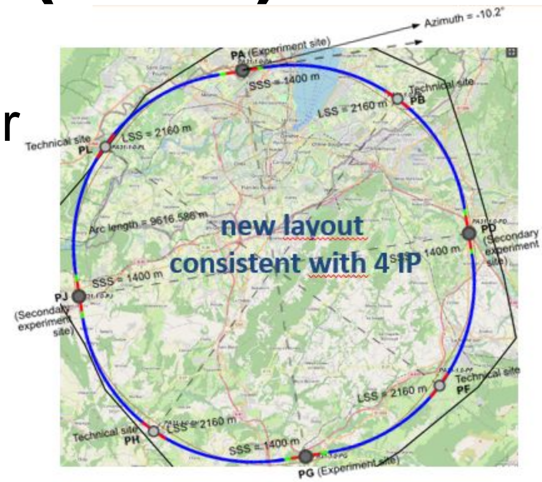
Program: Specify which program - HEP

Proposal Term: 3 years From: Oct 1st 2022 To: Sept 30th 2025

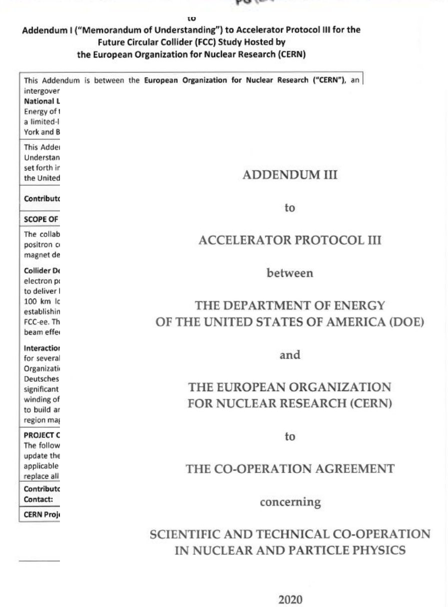
Total funding per year in FY23, FY24 and FY25: $500k each year.

The Future Circular Collider (FCC)

- "**An electron-positron Higgs factory is the highest-priority next collider**…Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage."
  [2020 Update of the European Strategy for Particle Physics]



- Addendum to **DOE-CERN coop agreement and CERN-BNL MoU are in place** since 2020 for FCC accelerator feasibility study



Addendum I ("Memorandum of Understanding") to Accelerator Protocol III for the Future Circular Collider (FCC) Study Hosted by the European Organization for Nuclear Research (CERN)

This Addendum is between the European Organization for Nuclear Research ("CERN"), an

ADDENDUM III

to

ACCELERATOR PROTOCOL III

between

THE DEPARTMENT OF ENERGY
OF THE UNITED STATES OF AMERICA (DOE)

and

THE EUROPEAN ORGANIZATION
FOR NUCLEAR RESEARCH (CERN)

to

THE CO-OPERATION AGREEMENT

concerning

SCIENTIFIC AND TECHNICAL CO-OPERATION
IN NUCLEAR AND PARTICLE PHYSICS

2020

- "ICFA reconfirms the international consensus on the importance of a **Higgs Factory as the highest priority** for realizing the scientific goals of particle physics."
  [International Committee for Future Accelerators, April '22]

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Overview

- **Optimize the FCC-ee detector design**(s) based on our physics expertise and interests, establishing an FCC-ee physics program at BNL
  - physics → detector → s/w & computing → discovery
  - Leverage physics leadership in ATLAS, using the Higgs boson as a new tool for discovery and exploring the unknown
  - Leverage Physics Dept expertise in optimizing tracking and timing detectors, noble-liquid based calorimetry, and DAQ architecture
  - Leverage expertise from OMEGA, HET, EDG, NPPS
- European Strategy in 2026 with decision on next facility
- Snowmass wrapping up in US and P-5 starting
- Synergistic with CERN-RD LAr collaboration (Begel, Chen, Ma, Pleier) and CERN-RD LGAD collaboration (Giacomini, Tricoli)
- This LDRD helps establish the BNL leadership needed to **capture US host laboratory role for a future FCC-ee experiment**

Approach

- Hire 2 FTEs = three post-docs (partly on ATLAS); can kick-start effort with existing person-power while hiring
- Study three complementary physics cases…
  a. Higgs decay into two charm quarks (not observable at HL-LHC!): Post-doc 1, Begel (jets), Cavaliere (Higgs), Di Canto (charm@Belle-II), Laycock (s/w), Szafron (theory), Tricoli (Higgs)
  b. Higgs boson coupling to itself (poorly constrained at HL-LHC!): Post-doc 2, Brost (Higgs), Laycock (s/w), Pleier (Multi-V), Szafron (theory)
  c. New Physics discovery (so far none at the LHC!): Post-doc 3, Assamagan (Higgs/DM), Laycock (s/w), Snyder (Higgs/DM), Szafron (theory)
- …and how they guide detector layout & optimization
  a. tracking and timing detectors: Iakovidis, Tricoli
  b. noble-liquid based calorimetry: Begel, Chen, Pleier
  c. DAQ architecture: Begel, Brost, Cavaliere, Chen
- Leverage relationships with domestic and intl. institutions to build a strong FCC-ee team

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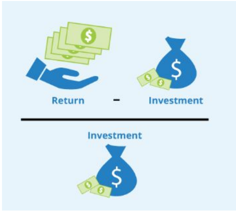

Return on Investment

- Expect U.S. to invest $250-500M per FCC-ee detector, followed by a ~$20M/year operations program and detector upgrades; need for appropriate computing infrastructure (Tier 1), core and reconstruction s/w, …
  - synergistic with CAD, ATRO efforts (e.g. ongoing FCC-ee collider- and interaction-region magnet design efforts)
- Take on long-term HEP intellectual leadership beyond Snowmass/P5 & HL-LHC program
- Enhances nurturing scientific community, in particular developing a diverse, equitable, and inclusive workforce (e.g. African School of Fundamental Physics and Applications pipeline) and workplace, and mentoring of early career researchers
- Strengthens the group’s external relations with universities and global collaborators

Summary

- Jump-start FCC-ee physics and detector program at BNL through a collaboration of EDG, HET, NPPS & OMEGA, hiring three post-docs (each one shared with ATLAS)
- Ultimate Goal is to capture US host laboratory for one FCC-ee detector
- Return on Investment: $$$, intellectual, DEI, community

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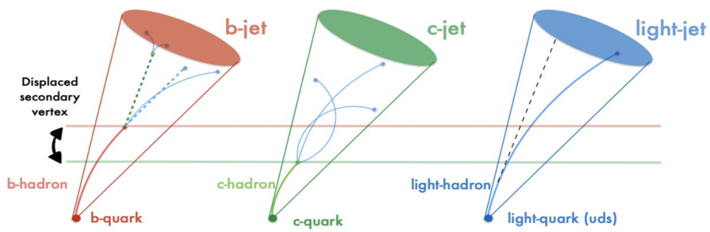
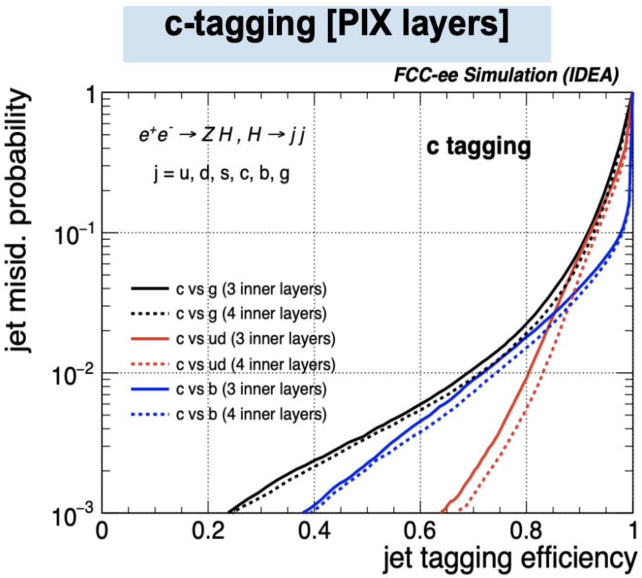
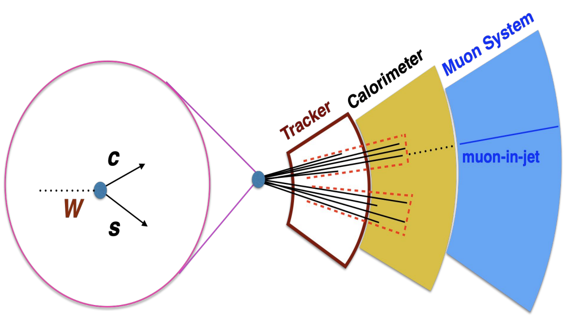
Backup

Higgs coupling measurements @FCC-ee: charm tagging

- Typical precision from HL-LHC: 1.5-4%--> limited by systematic uncertainties
  - To improve our understanding of the Higgs sector and search for O(%) deviations induced by BSM physics **we need to go (sub-)percent level**
- Flavour tagging essential for the Higgs sector at FCC-ee:
  - (HL-)LHC can access 3rd gen. couplings and a few of 2nd generation
  - Measure Higgs particle properties and interactions in challenging decay modes: e.g. cc, WW where W->cs
- Expect H->bb with 0.3% uncertainty on event rate and H->cc with 2.2% uncertainty:
  - **Sensitivity very dependent on vertex detector design and the flavour-tagging algorithm.**
- **Propose to work on charm-tagging to improve the uncertainty on H->cc and H->WW by looking at the hadronic channel where W->cs.**
  - Potentially use Graph Neural Networks to construct a Multi-output discriminant to distinguish c-jets from b-jets and light-jets, or using differentiable programming to get straight to flavour-tagging (effectively combine ML-tracking and ML-flavour tagging).
- **An efficient charm (and b) tagging could give the possibility to measure the magnitude of the CKM element Vcb directly from W->bc decays**







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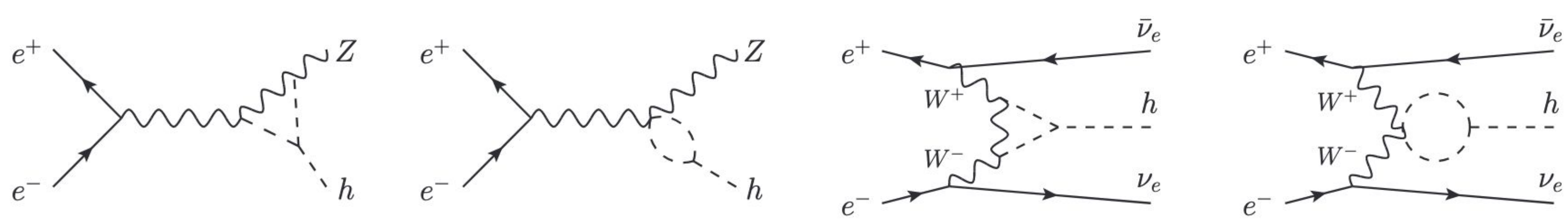
Higgs self-coupling @ FCC-ee

- **Expected precision @ HL-LHC, from direct and indirect constraints: 50%**
- **Is 50% enough?**
  - Depends which models you would like to study
  - “The goal for future machines beyond the HL-LHC should be to probe the Higgs potential quantitatively. This requires at least **gold** quality precision for the self-coupling parameter…”
- **Can extract self-coupling constraints from ZH and WW→H cross section measurements at FCC-ee (requires ~240 GeV and ~350 GeV runs)**

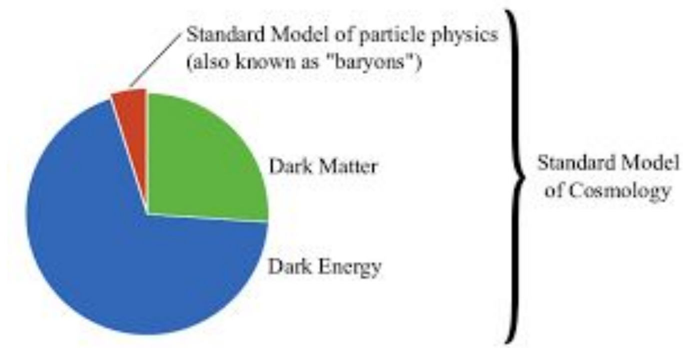
What precision do we need on the Higgs self-coupling?

- **Bronze (100%):** sensitive to models with the largest new physics effects
- **Silver (25-50%):** can exclude a physical hypothesis with realistic deviations in the Higgs self-coupling
- **Gold (5-10%):** sensitive to a broad class of loop diagram effects… could complement measurements on new particles that could be discovered at the HL-LHC.
- **Platinum (1%):** sensitive to typical quantum corrections to the Higgs self-coupling generated by loop diagrams.

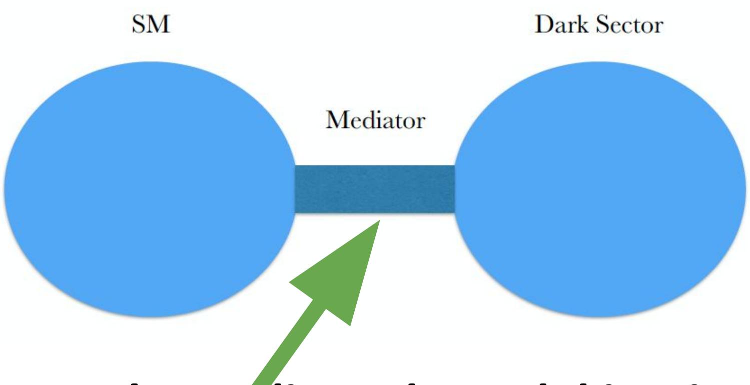
HH White Paper 2018 arXiv:1910.00012



Dark Sector as "New Physics" beyond the SM



Dark Matter could just be one example of Dark Sector State



Weak couplings through kinetic mixing, Higgs or mass mixings

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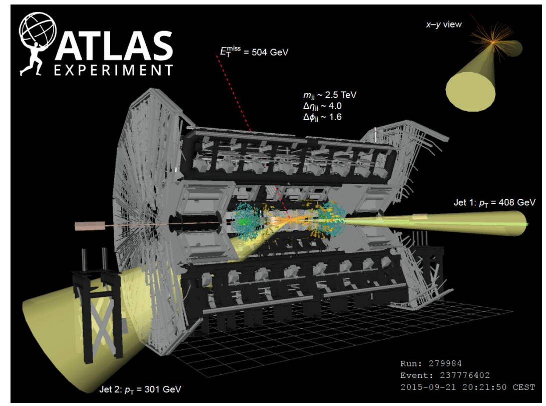
Classic signature at LHC: VBF H⟶ Invisible

Upper bound branching ratio (BR) ~10%

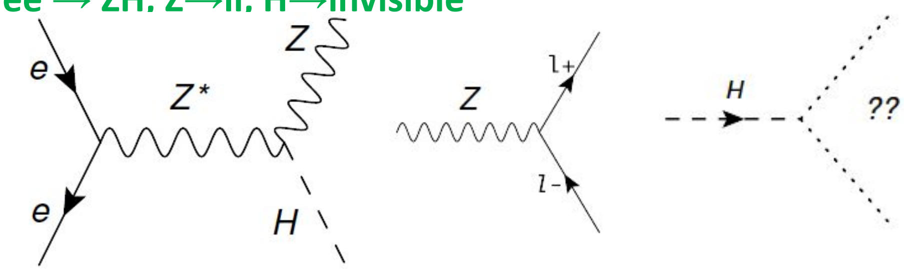


BNL leadership in LHC searches

Less hadronic backgrounds at FCC-ee

Promising channel @FCC-ee:

ee ⟶ ZH. Z⟶ll. H⟶invisible



- **Improved BR limit to < 1.5%**
- **Or discovery & precision measurement of width**
- **In case of discovery of H⟶ invisible, search for other dark sector states, e.g. H ⟶ Z_d Z_d ⟶ 4l**