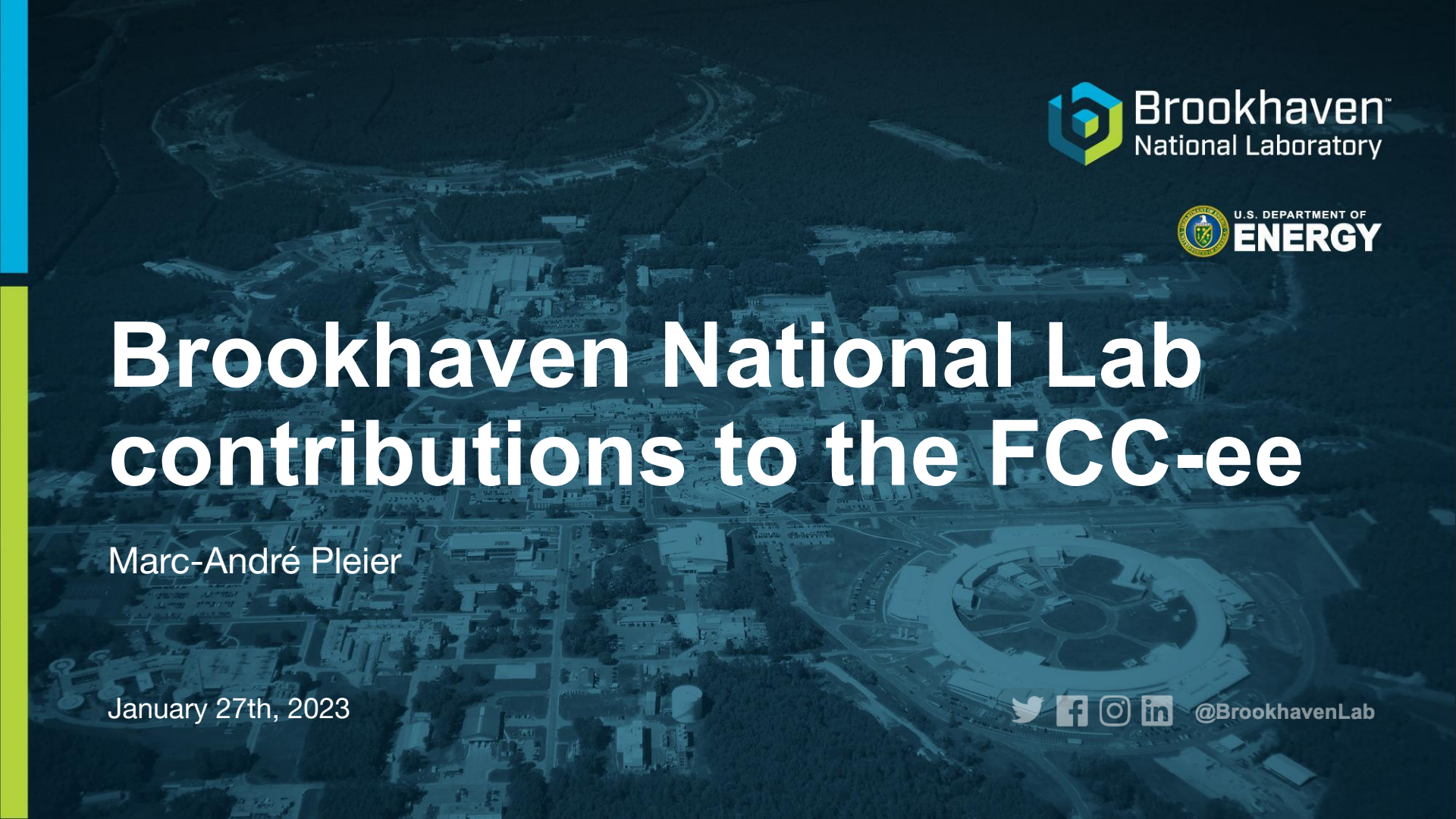


Brookhaven National Lab contributions to the FCC-ee

Marc-André Pleier

January 27th, 2023

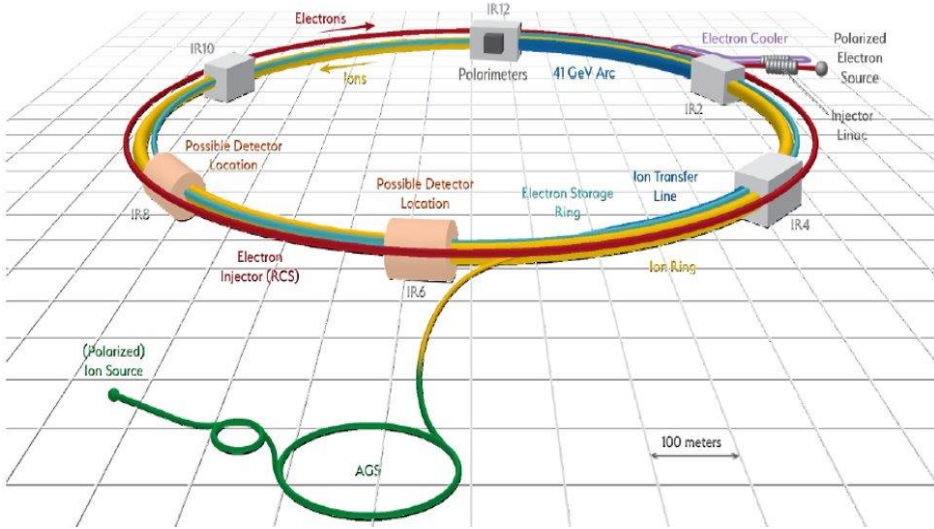
@BrookhavenLab

About BNL

- Physical Assets
  - ~5300 acres (~21km^2)
  - 300 buildings
- People
  - ~2600 staff
  - Lab supported:
    - 500 students
    - 4,400 guests/users, including remote
- Multidisciplinary laboratory
  - 7 Nobel Prizes

Inside BNL

- Environment, Biology, Nuclear Science & Nonproliferation
- Energy and Photon Sciences
- Computational Science Initiative
- Nuclear and Particle Physics
  - Collider-Accelerator Department
  - Physics Department
- Electron-Ion Collider Project
- Advanced Technology Research Office
  - Instrumentation Division
  - Superconducting Magnet Division
  - Accelerator Facilities Division



EIC Double Ring Design Based on Existing RHIC Facility

In March: SRF meeting in the US focused on EIC and FCC-ee

High Energy Physics Program

- ATLAS experiment at CERN
  - Lead Lab for US ATLAS collaboration of 800 US scientists & strong participation in ATLAS research
  - Leading US ATLAS Ops program, hosting Tier 1 computing center
- Neutrino Program at Fermilab
  - Proto-DUNE detector with BNL-developed cold electronics
  - Studying properties of neutrinos with short-baseline experiments
- Belle II experiment at KEK
  - Lead Lab for U.S. Belle II experiment in Japan
- Rubin Observatory
  - Commissioning the experiment in Chile
  - Developing computing and software for data analysis
- Theory
  - neutrino and colliders physics, (g-2) value calculations

Assembly of muon system at CERN

Tier 1 center in new building at BNL

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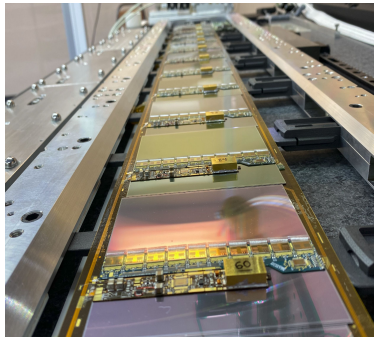
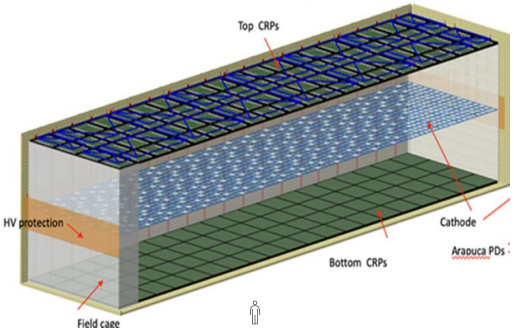
Enabling the Future of the Field

- Energy Frontier
  - Hosting project office for ~$250M ATLAS upgrade & building magnets for HL-LHC upgrade
  - Developing HL-LHC physics program
  - Developing future colliders program
    - Higgs factory and next energy frontier collider
- Intensity Frontier
  - Strongly contributing to DUNE experiment
    - Studies of neutrinos, supernovas, and proton decay
    - Leading DUNE Module 2 activities
  - Studying CP violation with Belle II experiment
- Cosmic Frontier
  - Soon to analyze unique Rubin Observatory data
  - Building LuSEE-Night mission to the far side of the moon
- Leading Technologies Developments for Particle Physics
  - Computing and software
  - Detectors and electronics
  - Accelerators R&D, including superconducting magnets
- Actively participating in Snowmass & P5 Town Halls
  - BNL: Energy, Instrumentation, Computational Frontiers, Apr 12-14
  - SLAC: Underground, Accelerator, Theory Frontiers, Community Engagement, May 3-5

HL-LHC magnet testing at BNL



ATLAS silicon assembly at BNL



DUNE Module #2 design

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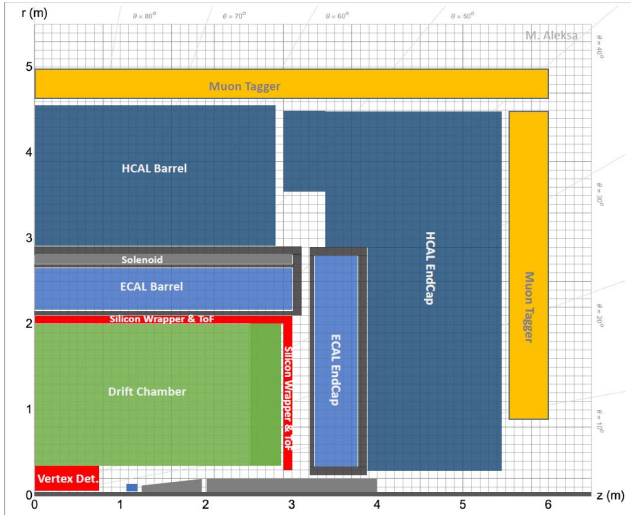
Future Higgs Factory Research at BNL

Laboratory Directed Research and Development Program

- Covers three year period (10/22-9/25)
- Augments FCC accelerator studies at BNL
- Leverages expertise across BNL (Theory, Belle II, ATLAS (& CMS), IR Magnets)
- Study FCC-ee detector development and optimization…
  - With focus on tracking and timing detectors,
  - noble-liquid based calorimetry, and
  - data-acquisition architecture
- …using Higgs boson property studies…
  - Higgs decay into charm quarks
  - Higgs self couplings (& other BSM HH couplings, EFT)
  - Higgs to invisible / dark sector
- …and Interaction Region magnet design constraints
- Build FCC-ee community in the US



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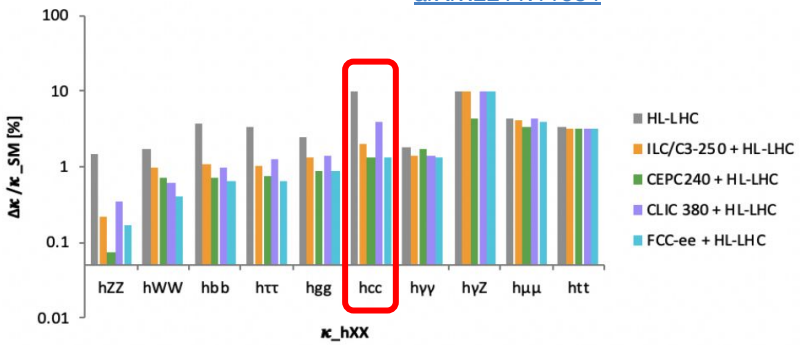
Higgs H→cc Studies

Flavor physics: great attention due to anomalies
- Access to Higgs couplings to 2nd generation quarks is unique opportunity for lepton colliders wrt. LHC
  - FCC-ee can significantly improve on the knowledge of H-c coupling over expected HL-LHC results

Plans to study c-tagging algorithms
- Stepping stone: available algorithms for lepton colliders
- Expand to ML and tracking+timing detector optimization
  - precision vertexing, low material budget, ps timing
- Start from Z→bb/cc and extend to H→cc

Group expertise:
- b/c tagging at LEP-II and Belle-II
- Tracking and Timing detectors (4D, 5D)
  - Pixel/strip trackers, MAPS, (AC-)LGADs
- Synergy with ATLAS, EIC, Belle-II and Theory
- ML algorithms
- Trigger and DAQ at LHC

arXiv:2211.11084



Starring:

Haider Abidi
Viviana Cavaliere
Angelo Di Canto
George Iakovidis
Robert Szafron
Alessandro Tricoli

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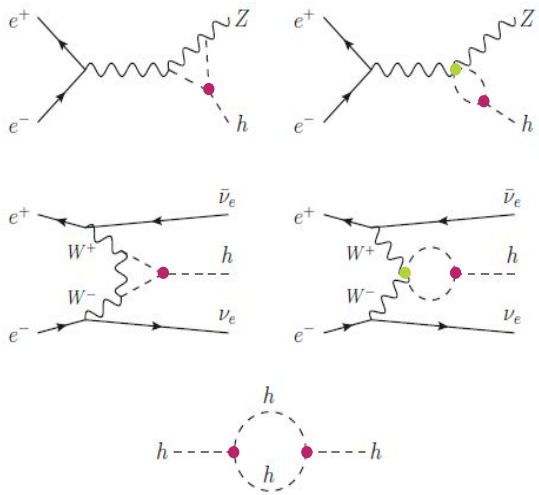
Higgs self-coupling Studies

Long-standing contributions to searches for HH production at the LHC, both at ATLAS and CMS

FCC-ee Interests: Indirect determination of the Higgs self-coupling, other BSM HH couplings, EFTs

- Measure ZH,Z→cc cross section
  - New dedicated study at the FCC-ee, needed for the self-coupling measurement
  - Synergy with H→cc, charm tagging work in the BNL group
- Study other rare couplings with two Higgs bosons (for example, κ_{2V})
  - Start with κ_λ, κ_{2V} variations, eventual connection to EFT studies
  - κ_{2V} bonus: can measure HHZZ and HHWW couplings separately (unlike in VBF HH production at the LHC)



Starring:

Elizabeth Brost

Abraham Tishelman-Charny

Robert Szafron

Higgs H→invisible Studies

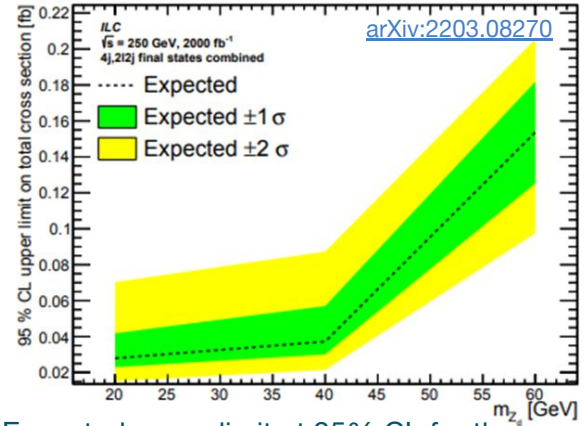
Group involved in dark sector state searches with ATLAS

- Visible dark sector states such as exotic Higgs decays, $H \rightarrow Z\,(Z_d)Z_d \rightarrow 4l+X,\ 2l2j$, Z_d = dark sector vector boson
- Invisible dark sector states, such as H → invisible, in ZH, VBF or monojet production channels, combination of various H → inv searches, with interpretation in the Higgs portal model etc.
- Projections of ATLAS VBF H → inv for HL-LHC

Snowmass: contribution to ILC prospects of $H \rightarrow Z_d Z_d$ in 4l, 2l2j, 4j final states at sqrt(s) = 250 GeV

Plan to study H → inv at the FCC-ee

- As benchmark channel for FCC-ee detector performance optimization for searches for dark sector states
- Direct contribution for the search of H → invisible at the FCC-ee. Aim to significantly improve upon the BR limit if no excess observed
- We would like to join (or develop) a collaboration with other groups with similar interests



arXiv:2203.08270

Expected upper limit at 95% CL for the cross section of $H+Z \rightarrow Z_d Z_d + Z \rightarrow 4j,\ 2`2j+Z$ at ILC

Starring:

Kétévi Assamagan
Diallo Boye
Scott Snyder
Robert Szafron
Christian Weber

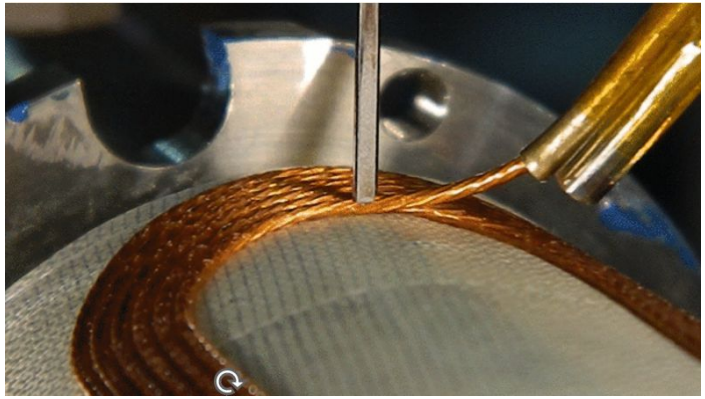
Brookhaven National Laboratory

Interaction Region magnet design

BNL's Superconducting Magnet Division involved in areas of Interaction Region magnet design and Machine Detector Interface

- BNL Direct Wind magnet production technology suitable for producing the main IR quadrupoles
  - only practical way to introduce FCC-ee IR corrector magnets
  - significant design challenges to resolve for implementing the required anti-solenoid coils for detector field compensation while maintaining the desired experimental acceptance

- Enhance collaboration with the FCC-ee IR design team



BNL Direct Wind in Action Closeup View

Starring:

Brett Parker

Conclusion

- BNL has excellent synergies in physics, accelerators and detectors in support of high energy physics
- Excited to deepen BNL's contribution to FCC-ee
- Building FCC-ee community in the US

Starring:
The US community
& international partners

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BACKUP