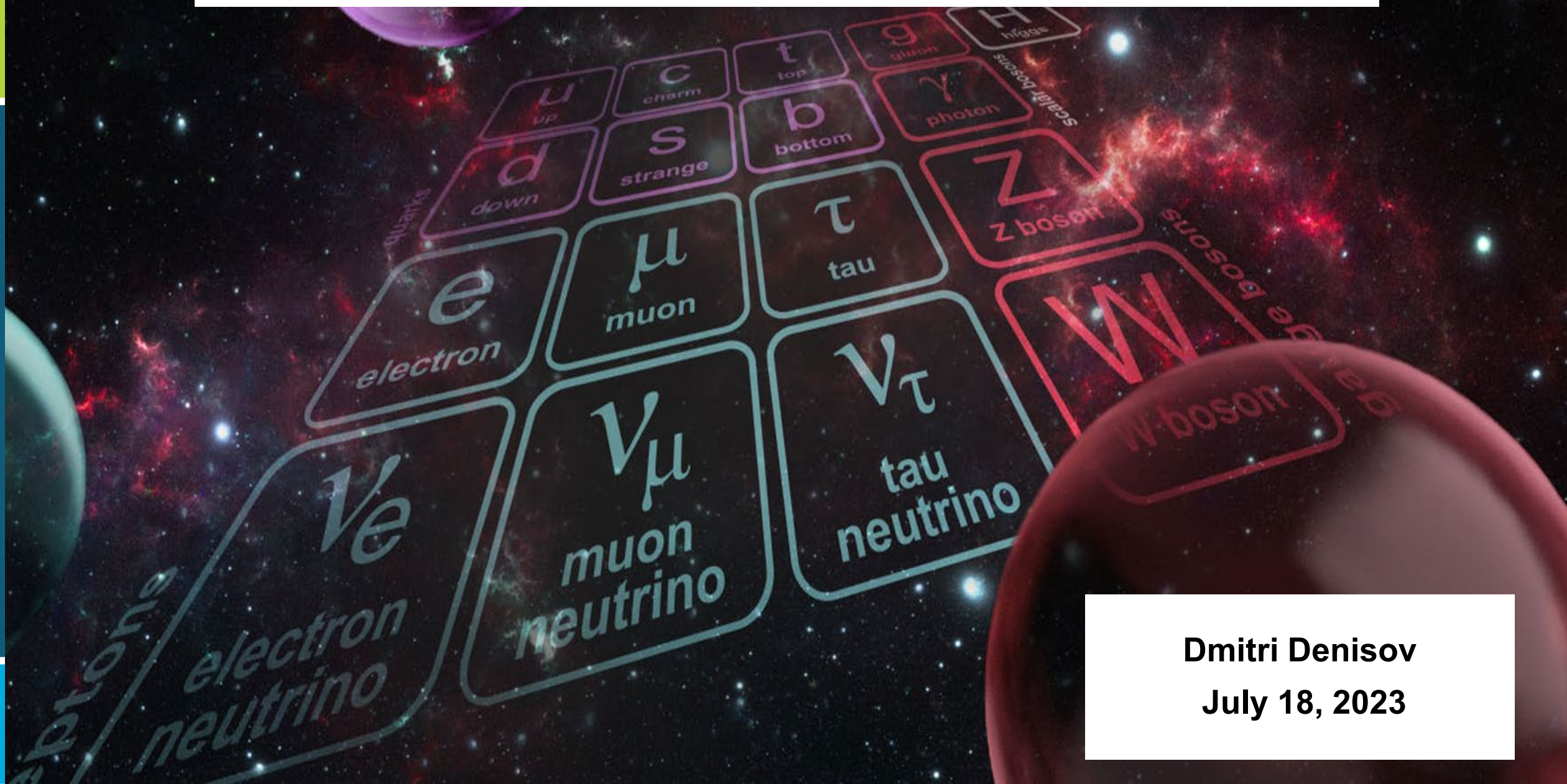


# BNL High Energy Physics Program

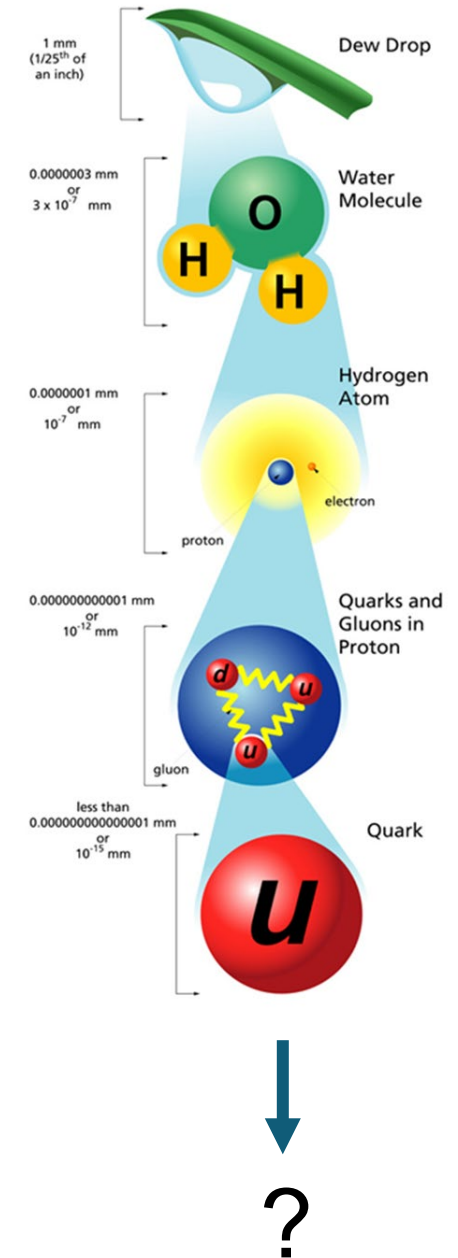


Dmitri Denisov

July 18, 2023

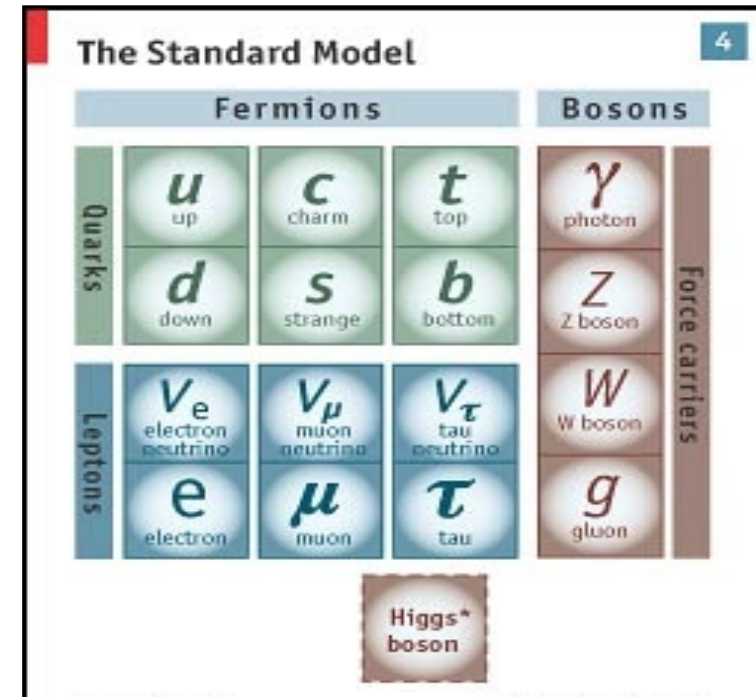
# High Energy Physics Mission

- To understand world at smallest and largest distances accessible
  - What is inside quarks and gluons?
  - What is the Higgs boson?
  - What is dark matter and dark energy?



# High Energy Physics (HEP)

- Standard Model is the theory of elementary particles and interactions
  - Describes majority of phenomena in Nature
  - Makes everything of a small number of objects
    - Quarks and leptons
  - Forces are carried by
    - photon - electromagnetic
    - gluons - strong
    - W/Z bosons - weak
  - Higgs boson provides mass
  - Accurate to a very high precision
    - Better than  $10^{-10}$
- Addresses 1000's of years hunt of mankind to understand
  - What everything around us is made of



- But our current understanding is incomplete
  - Can't explain observed number of quarks/leptons
  - Model parameters can't be predicted
- Nothing is "wrong" with the Standard Model
  - The goal is to define the limits of applicability and find what lies beyond

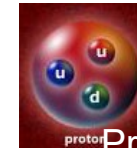
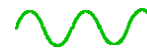
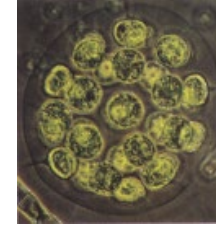
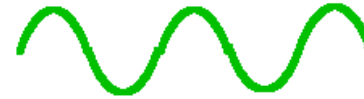


# Why High Energy and Why Colliders

- Accelerators are built to study the Nature smallest objects

$$\text{Wavelength} = h/E$$

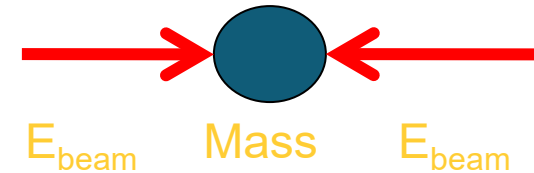
$\sim 2 \cdot 10^{-18} \text{ cm}$  for LHC



- Accelerators convert energy into mass

$$E = mc^2$$

Objects with masses up to  
 $\text{Mass} = 2E_{\text{beam}}$  could be created



# BNL High Energy Physics Current Program

## ATLAS experiment at CERN

Lead Lab for U.S. ATLAS collaboration of 800 US scientists  
Leading US ATLAS Operations program and 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

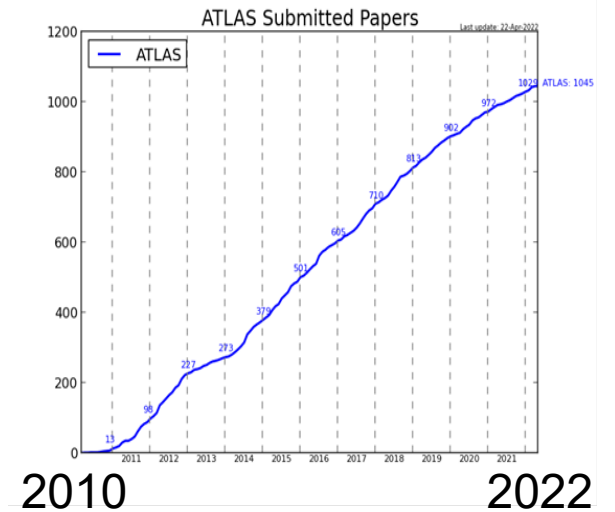
## Theory

Fundamental progress on (g-2) value calculations  
Exciting new developments in neutrino and colliders physics

Assembly of muon system at CERN



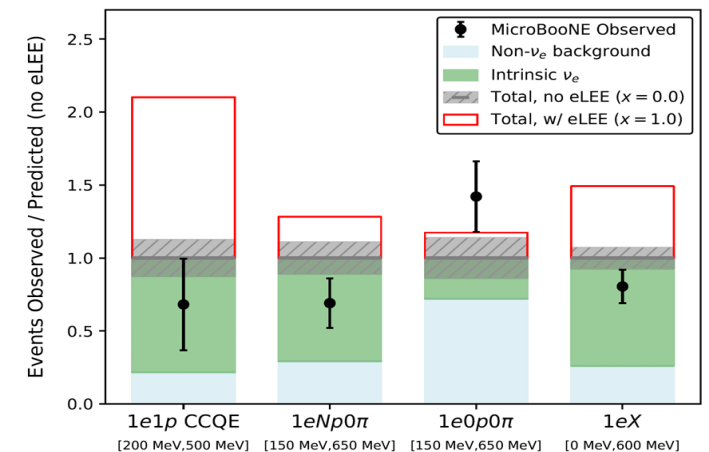
ATLAS published over 1000 papers



Tier 1 center in new building at BNL



Exclusion of sterile neutrinos



# BNL HEP Program - Enabling Future of the Field

## Energy Frontier

- Hosting project office for \$280M high luminosity ATLAS upgrade
- Building magnets for the LHC upgrade
- Developing computing and software for effective HL-LHC data management

HL-LHC magnet testing at BNL



ATLAS silicon assembly at BNL



## 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

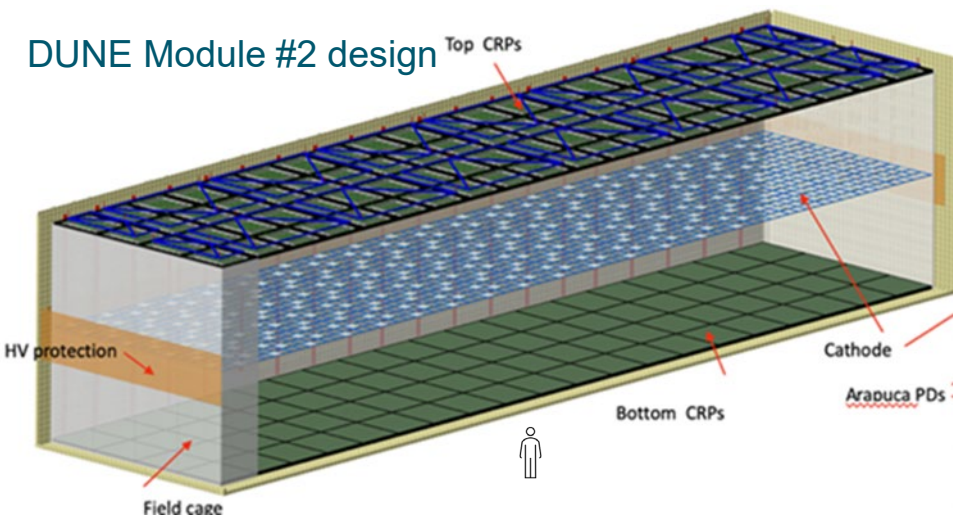
## Cosmic Frontier

- Soon to analyze unique Rubin Observatory data
  - Understanding Universe expansion
- Building LuSEE-Night mission to the far side of the moon
  - To detect, for the first time, "Dark Ages" signal from the early Universe

## Leading Technologies Developments for Particle Physics

- Computing and software
- Detectors and electronics
- Accelerators R&D including superconducting magnets

Actively participating in the field long term future planning aka Snowmass and P5



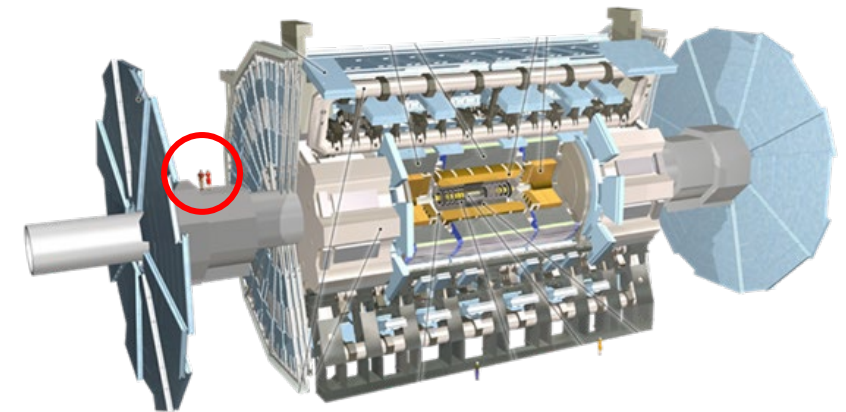
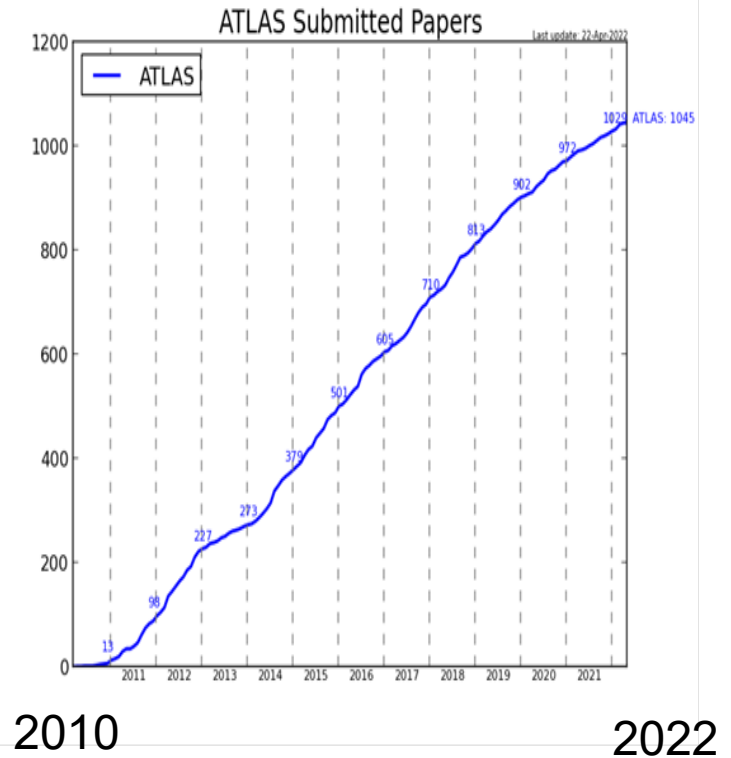


# Energy Frontier

- ATLAS is the largest BNL HEP experiment and the largest experiment in the world:
  - Key responsibilities with commensurate leadership positions in Physics, Operations, Computing, Software, Trigger, Upgrade
  - Strong presence at CERN
- Higgs & Electroweak Symmetry Breaking in diboson final states is primary physics expertise
  - Convenorships of physics group and sub-groups
  - Strong ATLAS publication record

## Looking forward

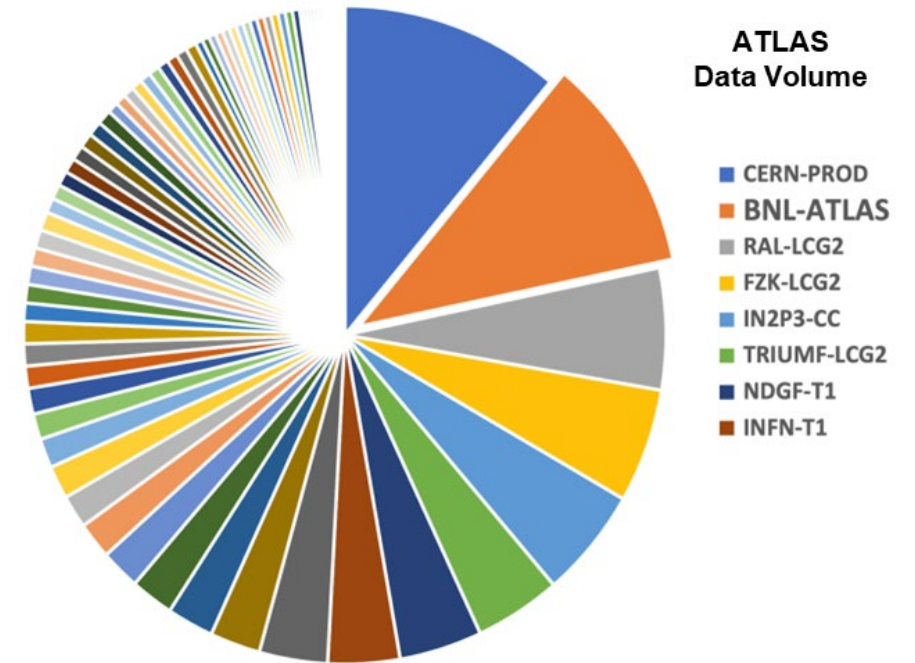
- Engaged in Higgs factories efforts
- Magnet technologies and detectors developments



# U.S. ATLAS Operations

- BNL is coordinating US ATLAS Operations program
- LHC is finishing its second long shutdown preparing for its next data taking operations
  - Run 3 beams started last month!
- BNL leading ATLAS commissioning efforts
- BNL Tier-1 contributes 23% of the required ATLAS computing capacity
- Continued R&D for HL-LHC phase in collaboration with others
- BNL leads the ATLAS-wide core software and distributed computing efforts

ATLAS Data Storage

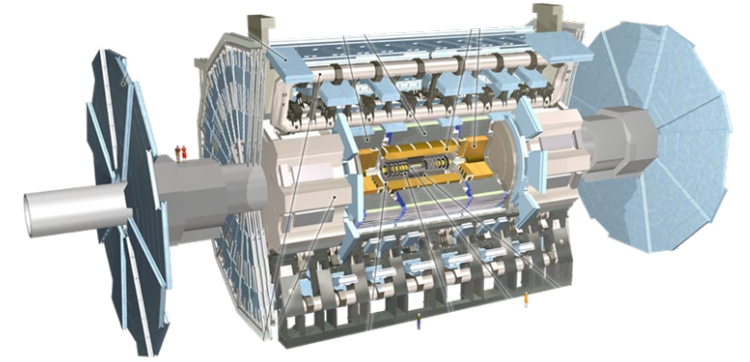




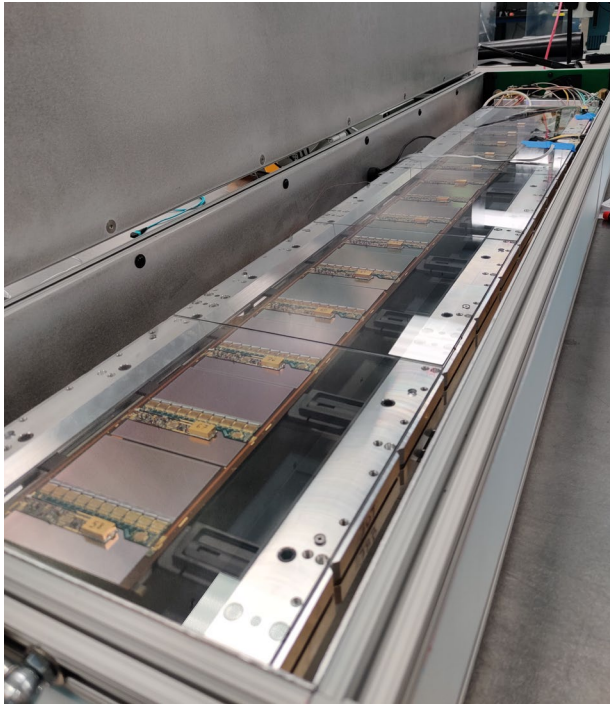
# U.S. ATLAS HL-LHC Upgrade Project

Leading U.S. ATLAS upgrade project

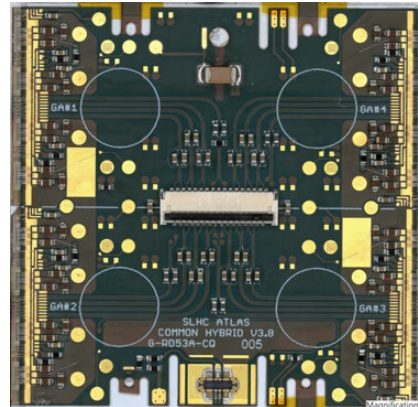
- Joint project between DOE and NSF
- Total cost is ~\$300 million



Fully assembled 28-module silicon strip prototype stave in cold box in BNL clean room.



First prototype pixel quad module assembled at ANL



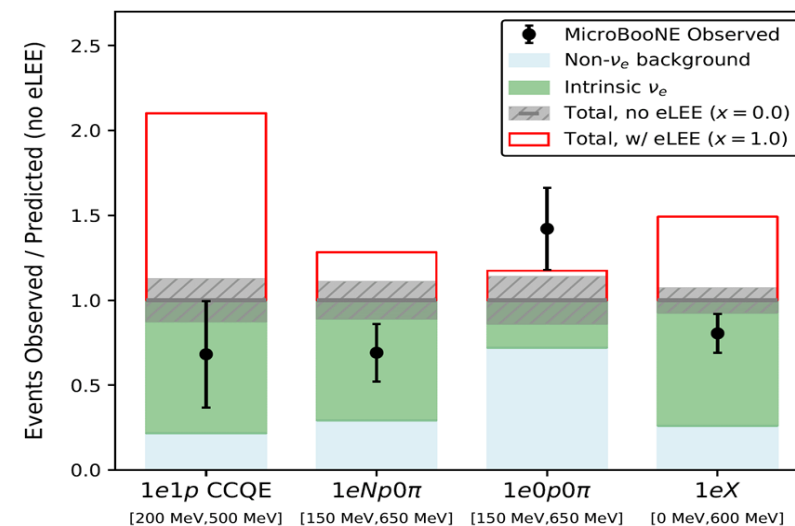
Clean room at SLAC for pixel inner system detector assembly.



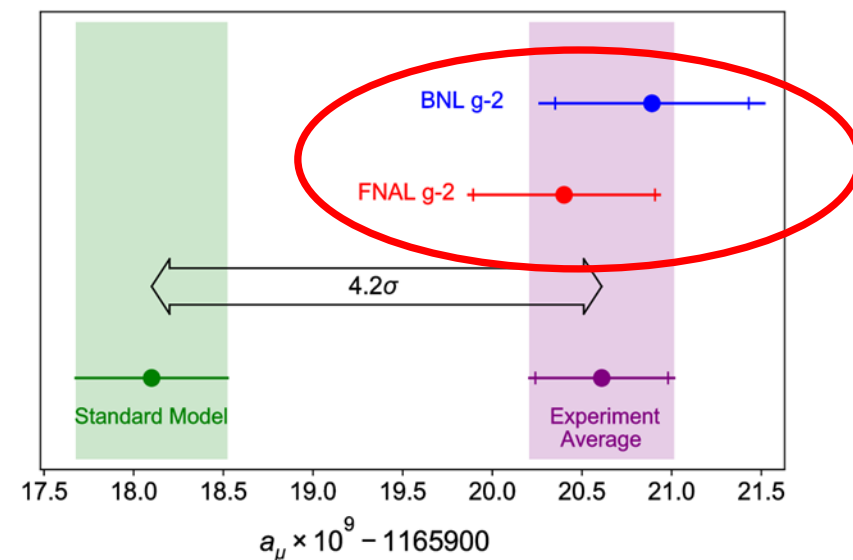
# Intensity Frontier

- Neutrinos
  - Leading several areas of DUNE project
    - Key contributions to DUNE design
    - Updates to DUNE oscillation analysis
  - Active participation in short baseline neutrino program at Fermilab
- Heavy flavor
  - Leading U.S. Belle II operations including computing
  - Research efforts making impact on Belle II analysis
- g-2
  - Constructed electrostatic quadrupoles
  - Delivering key beam and spin dynamics systematics uncertainties
  - Contributed significantly to g-2 result

Exclusion of sterile neutrinos



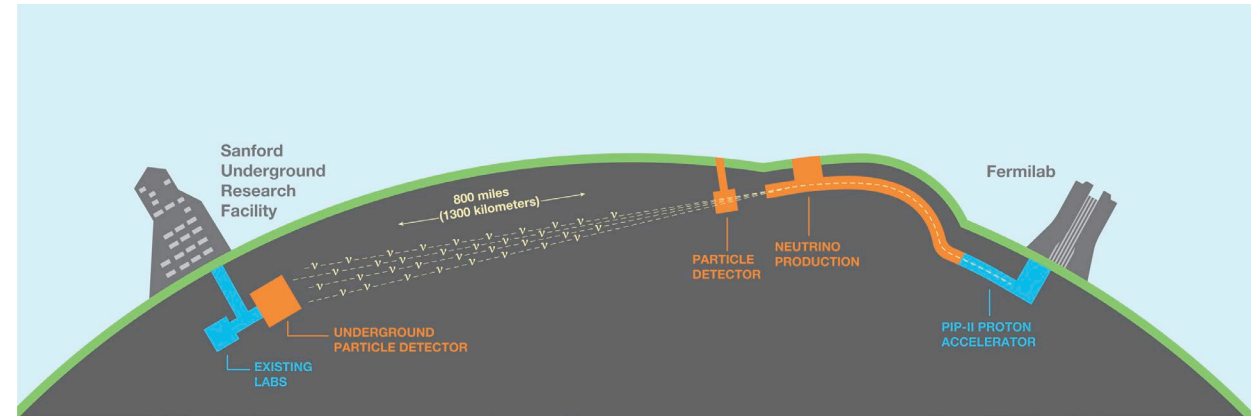
New g-2 result



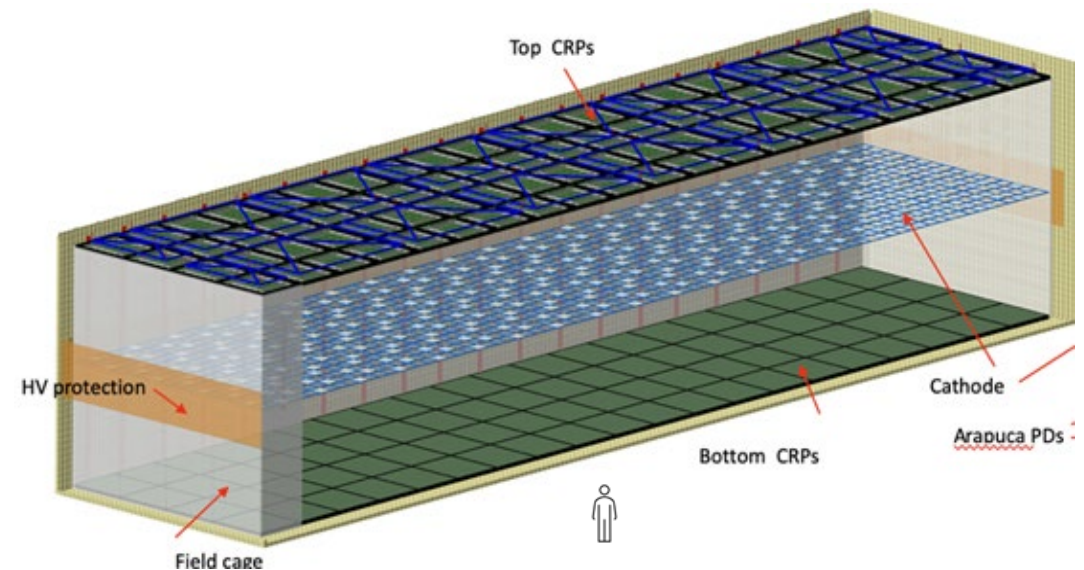
# BNL and DUNE Project

- Far Detector 1 (Horizontal Drift)
  - Major effort in cold electronics
  - Lead HV system developments
  - Leading installation planning
- Far Detector 2 (Vertical Drift)
  - Co-leading international Vertical Drift project
  - Leading R&D on anode readout, HV and cold electronics
  - Leading US contributions to HV, cathode readout planes and installation

LBNF/DUNE



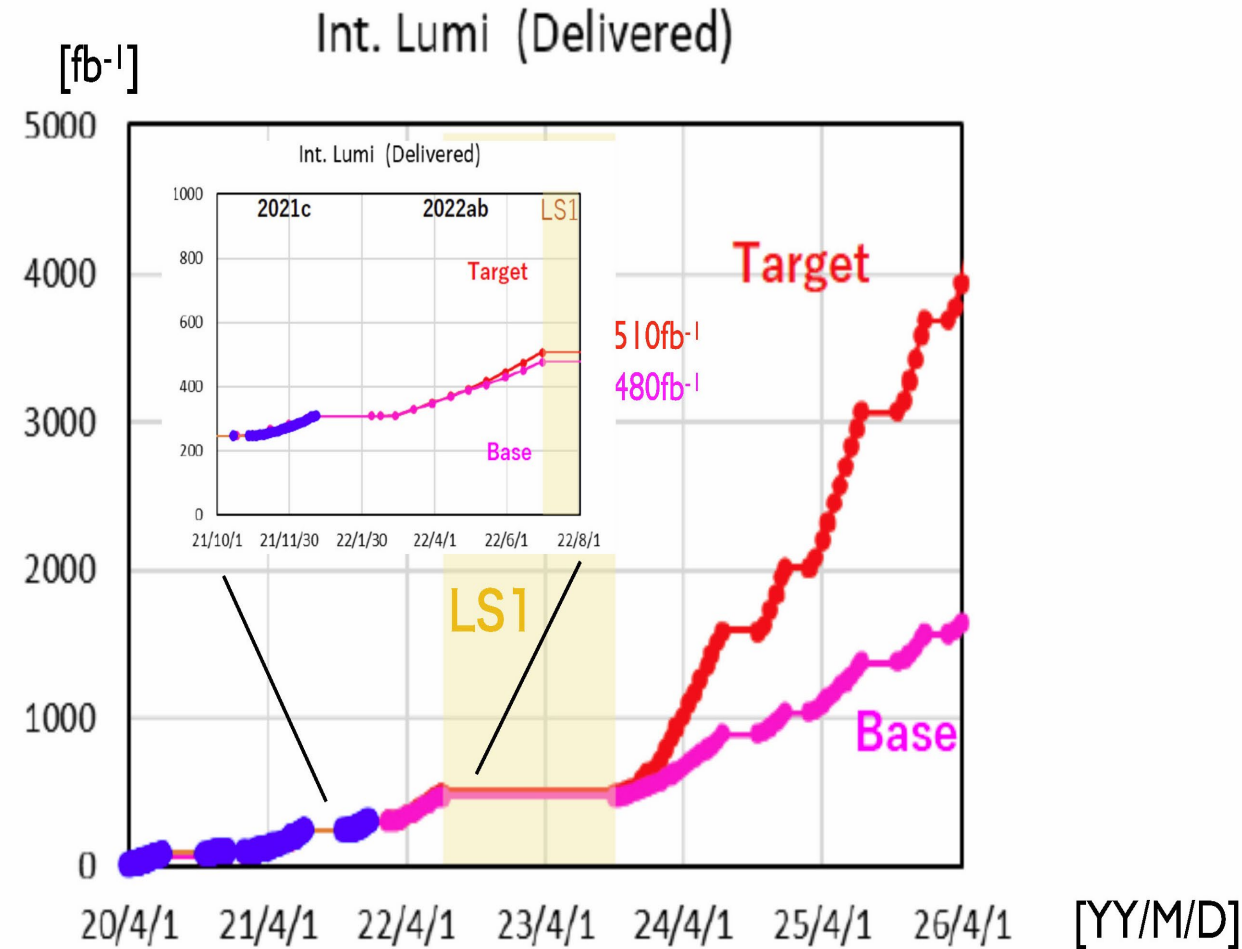
DUNE 2<sup>nd</sup> Detector





# Belle II Research and Operations

- BNL is leading Belle II US program
- With data sample expected by Summer 2022 ( $\sim 700 \text{ fb}^{-1}$ )
  - World-leading measurements of mixing and charge parity violation in charm decays
- Stable operations of Tier 1 computing site, prompt calibration center, conditions database
- Must capitalize on excellent Belle II potential and U.S. long term investments



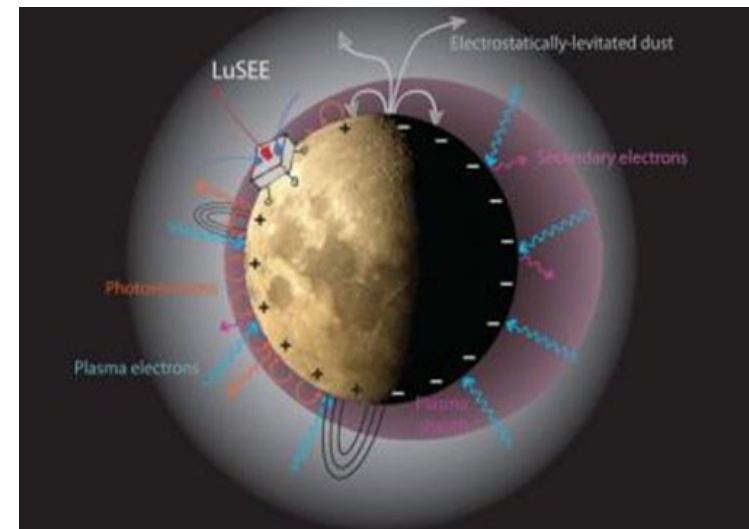
# Cosmic Frontier at BNL

- Rubin Observatory
  - Successfully delivered optical camera
  - Engaged in commissioning and operations
    - Close cooperation with SLAC
  - Major roles in Dark Energy Science Collaboration
- LuSEE-Night MIE project and science program
  - The experiment to study “Dark Ages” of the Universe with the detector on the far side of the moon
  - Close cooperation with NASA and University of California Berkeley
  - Science collaboration led by BNL

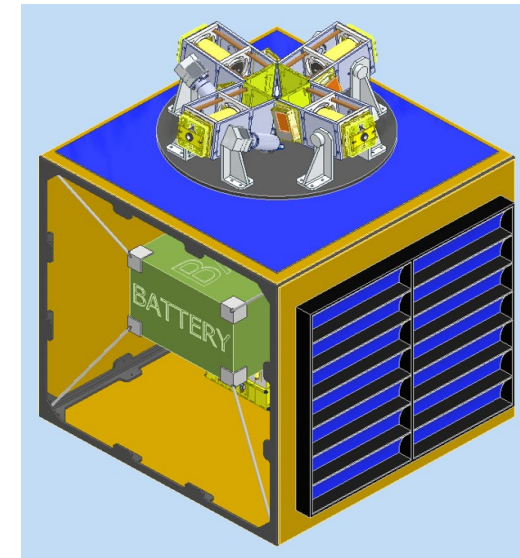
Rubin Observatory



LuSEE-Night on the moon



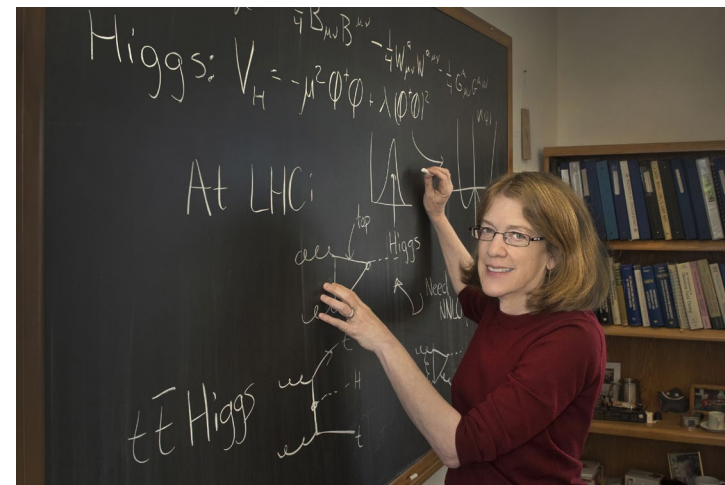
LuSEE-Night DOE



# High Energy Theory

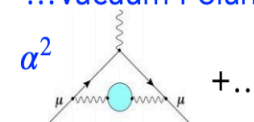
Sally Dawson leads theory group

- High energy frontier
  - Precision QCD, calculations for the LHC (Higgs physics)
  - Development of new techniques for higher order calculations
- Intensity frontier
  - Precision studies of long baseline  $\nu$  data
  - Probes of  $\nu$  cross sections with ultra high energy  $\nu$  telescopes
  - Dark matter models with light mediators
- Lattice
  - g-2, weak interaction matrix elements
  - Heavy flavor
  - Development of numerical algorithms
  - Machine learning improvements
  - Nucleon structure
- Strong community leadership in g-2 theory initiative, Snowmass working groups, DUNE working groups



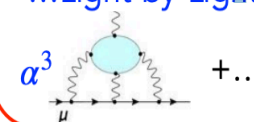
Hadronic...

...Vacuum Polarization (HVP)



$6845 (40) \times 10^{-11}$   
[0.6%] 0.37 ppm

...Light-by-Light (HLbL)



$92 (18) \times 10^{-11}$   
[20%] 0.15 ppm

Numbers from Theory Initiative Whitepaper



# Detector R&D

- Leading developments of new ideas for next generation of HEP experiments
- LGADs: several new designs and device implementations. Monolithic AC-LGAD
  - Combines particle sensing with readout electronics in a single device, using commercial CMOS processing for integrated circuits
- ASIC R&D: focus on extreme environments and new technologies
  - Cryogenic environment
- LAr research
  - Key measurements of LAr properties for DUNE
- FELIX/DAQ
  - Used by ATLAS, ProtoDUNE, DUNE, sPHENIX
- Developing 21 cm detection technologies
  - Noise source installed and drone calibration procedure developed

New LAr research facility



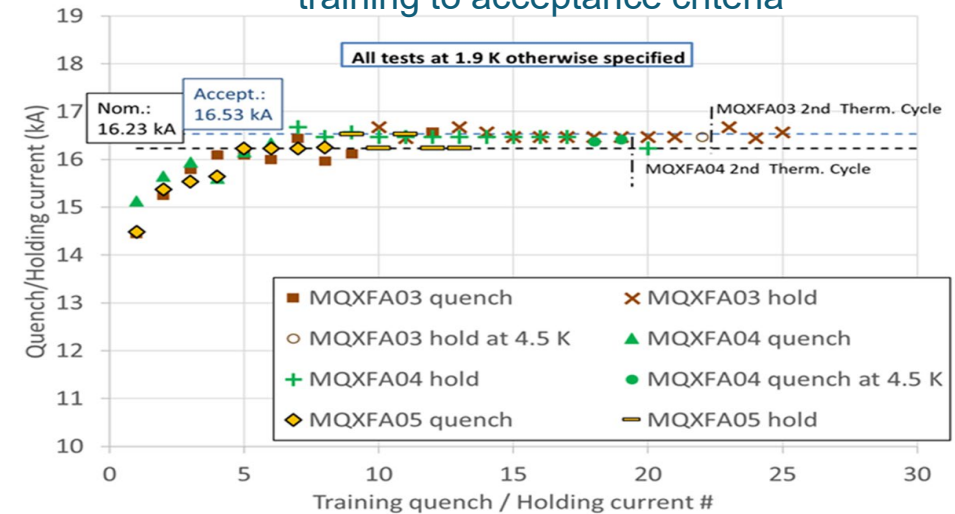
21 cm detector prototype – test bed for LuSEE-Night



# Accelerator Research

- Working with US and global partners to develop magnets technology to meet the future needs of HEP
  - Magnet Development Program
    - Design of high field magnets
- Key partner in HL-LHC magnets project
  - Quadrupole magnets for HL-LHC
  - Building coils, testing magnets
  - Close cooperation with Fermilab and LBL
- Construction of EIC at BNL has deep synergies with HEP accelerators

Pre-production magnet training to acceptance criteria



Coils produced at BNL





# BNL Computing and Software Activities

NSLS I building re-purposed

- Just finished move to a new state of the art facility
  - Host computing for ATLAS, Belle II and many other experiments
  - One of the largest computing centers in the world
- Strong team in software developments
  - AI/ML tools development
  - Software for distributed computing, including cloud computing
  - Development of quantum computer-based codes for unique calculations





# P5 Proposals BNL is Deeply Engaged

- DUNE upgrades
  - Physics and modules 3 and 4 upgrade
- Higgs factory
  - Currently mainly with FCC due to our close connections with CERN
  - Excited about US based options
- Muon collider
  - Unique expertise in accelerator and detectors
- Proton Electric Dipole Moment experiment at BNL
  - Unique way for exciting science using infrastructure built for HEP decades ago
- Forward Physics Facility at CERN
  - Neutrinos and energy frontier, dark matter and more
- PIONEER
  - Small scale experiment with deep science connection to HEP fundamental principles
- LHCb
  - Have experts in both physics and detectors, upgrade starts after HL-LHC projects
- Small scale proposals for accelerators, detectors, computing and related R&D

# BNL High Energy Physics Program

- Strong program with excellent potential
  - Engaged with multiple US National Laboratories
  - 100's of US universities
  - Strong international cooperation with Europe, Asia and Africa
- Played major role in recent fundamental discoveries
  - World heaviest particle, the top quark
  - The most recently discovered elementary particle – the Higgs boson
- Exciting program for decades to come
  - At the energy, intensity and cosmic frontiers

We are excited about more partners joining our high energy physics program and will be glad to discuss opportunities to cooperate