# Current and Future HEP Program in the U.S.

Nigel Lockyer

April 22, 2021

# Outline of HEP Activities from following DOE labs

- Brookhaven National Lab
- Argonne
- Berkeley
- SLAC
- Fermilab

## Secretary of Energy Jennifer Granholm

# High Energy Physics at BNL

**ATLAS**

- Lead lab for U.S. ATLAS team of 800 scientists
- Successfully completed U.S. ATLAS Phase I upgrade
- Host for $250 million high luminosity ATLAS upgrade

**Building magnets for HL-LHC upgrade**

**Neutrino Program at Fermilab**

- Operation of Proto-DUNE detector with BNL-developed cold electronics, developing options for 2nd detector
- Addressing low energy excess neutrino anomaly via short-baseline experiments

**Belle II**

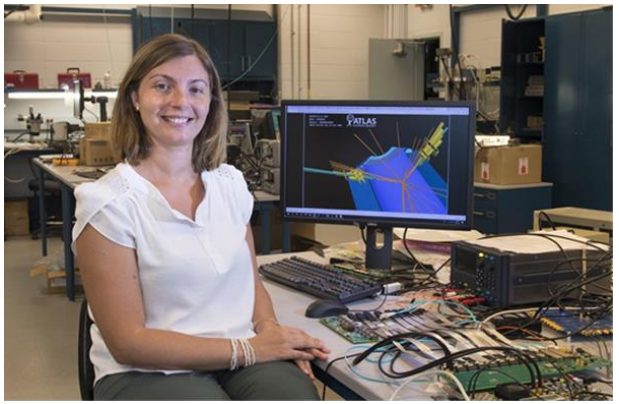
- Lead lab for U.S. Belle experiment, Host computing center

**Vera Rubin Observatory - LSST**

- Completed constructing CCD sensors
- Supporting camera testing and assembly at SLAC

**Theory**

- Fundamental progress on definitive calculation of hadronic contributions to muon (g-2)



Viviana Cavaliere from BNL works on Higgs studies at ATLAS

LSST CCD sensors assembly at BNL

Fermilab

# High Energy Physics at BNL: Looking Forward

**Energy Frontier**

- Deliver U.S. ATLAS and high field magnet upgrade projects for HL-LHC
- Building computing and software required for effective HL-LHC data management

**Intensity Frontier**

- Enabling DUNE experiment
  - Studies of neutrinos, supernova explosions, and proton decay
- Studying CP violation with Belle II experiment

**Cosmic frontier**

- Analysis of unique Vera Rubin data
  - Understanding Universe expansion

**Leading Technologies**

- Key R&D activities in software, detectors, computing, superconducting magnets, and accelerators

**Snowmass planning process**

- BNL scientists are leading Energy, Neutrino Frontiers and Education and Outreach efforts
  - And participate in various study groups


Building and testing superconducting magnets for HL-LHC upgrade

New 21cm large telescope array is among BNL led proposals for Snowmass

Fermilab

# Accelerator activities at Argonne

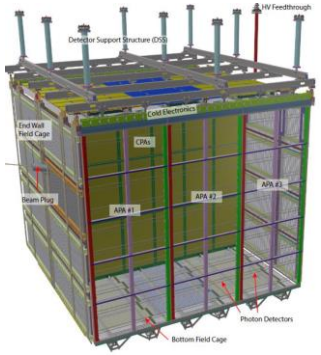
- The Argonne Accelerator Institute (AAI) is an umbrella organization for coordinating accelerator activities
- Argonne accelerator facilities supported by three offices in the DOE Office of Science: BES (APS), NP (ATLAS) and HEP (AWA).
- Argonne has almost every area of accelerator science and technology with relevance to HEP
  - Electron storage rings (damping rings)
  - Hadron beams (Intensity Frontier)
  - Superconducting RF (PIP-II)
  - Normal and superconducting undulators (damping rings, polarized e+)
  - Advanced accelerators (Future Linear Collider)
- Unique infrastructure (e.g. SRF and magnet labs)

# Accelerator activities at Argonne

- **APS Division.**
  - APS Upgrade will be the most sophisticated electron storage ring ever built.
  - Storage Ring Physics (M. Borland)
  - Physics and design of an x-ray FEL oscillator (XFELO) (R. Lindberg)
  - Diamond optics towards an x-ray optical cavity (KJ. Kim/Y. Shvyd'ko)
  - Superconducting undulators (Y. Ivanyushenkov )
  - Simulation code development (M. Borland)
- **PHYS Division.**
  - Operation of the nuclear physics ATLAS user facility (B. Mustapha)
  - Superconducting RF development (M. Kelly)
  - Accelerator-based research on radioisotopes (J. Nolen)
- **EOF Division**
  - Accelerator-based research and production of radioisotopes (S. Chemerisov)
- **HEP Division.**
  - Operation of the Argonne Wakefield Accelerator Facility (J. Power)
  - Advanced Accelerator R&D: Structure Wakefield Acceleration and Phase Space Manipulation. (P. Piot)
- **AAI (joint accelerator activities) (J. Byrd)**
  - SRF Gun project (J. Byrd/P.Piot) APS, PHYS, HEP
  - Linac Extension Area Facility (A. Zholents) APS,HEP
  - Collinear Wakefield Accelerator R&D (A. Zholents) APS,HEP
  - Shared resources across accelerator groups (J. Byrd) APS, HEP
  - AAI sponsored joint appointments (J. Byrd)

# A Sample of Activities at Argonne HEP

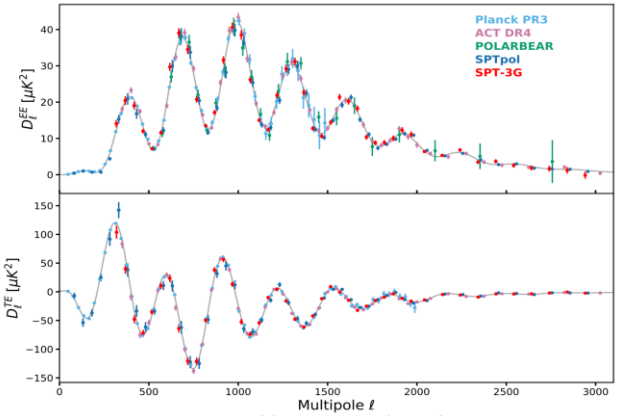
## DUNE/ProtoDUNE




## Argonne 4T facility

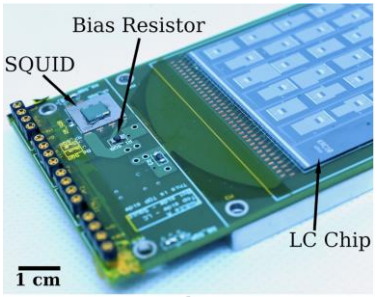

## g-2 field (cross-)calibration

2018 SPT-3G

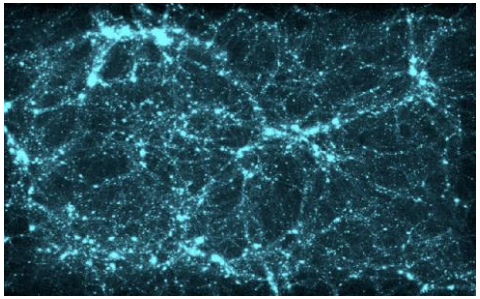



Dutcher et al. https://arxiv.org/abs/2101.01684
Submitted to Physical Review D

## Cosmic simulation



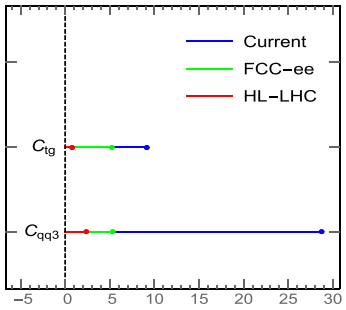

Technology for CMB-S4



*Particle distribution in the Last Journey simulation showing a small sub-volume (~1/100,000 of the total volume).*

## ATLAS ITk pixels

## Theory: SMEFT coefficients



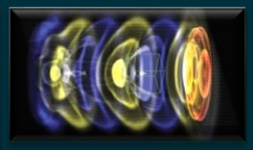
# HIGHLIGHTS OF ACCELERATOR R&D AT BERKELEY LAB

## LASER-PLASMA ACCELERATION, EXASCALE MODELING AND HIGH FIELD MAGNETS

### Exascale project for accelerator modeling

Open standard for particle and mesh data

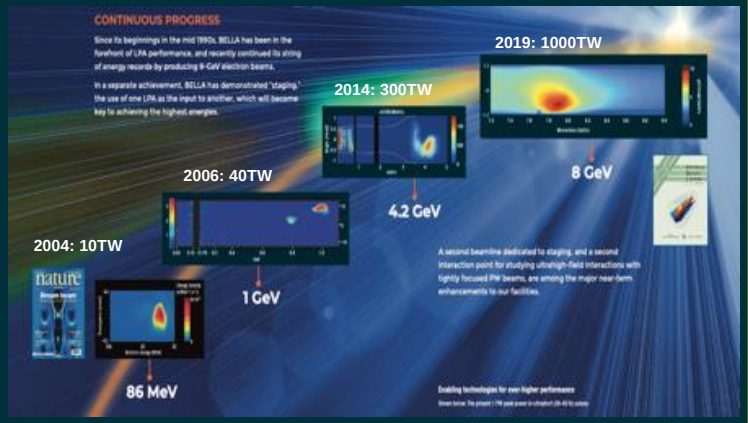
- "Virtual accelerators"
- Simulations
- Machine learning



CAMPA Consortium for Advanced Modeling of Particle Accelerators

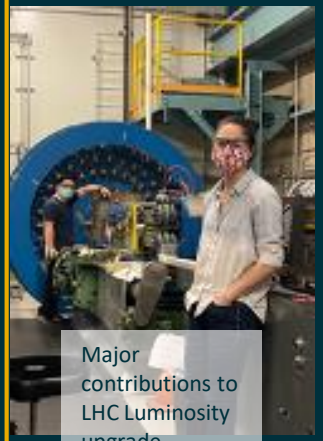
### Compact laser-plasma accelerators




Record electrons energies with ultra-high gradient acceleration, Beamline projects underway for staging and LaserNetUS, applications in rad bio, materials, radiography, …


**Next big step: kBELLA High average power laser facility to secure US leadership**

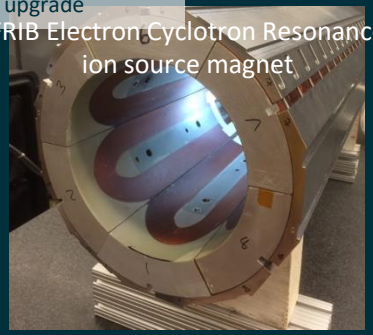
### High field magnets for DOE SC



Major contributions to LHC Luminosity upgrade

MDP: Magnet R&D for future colliders

FRIB Electron Cyclotron Resonance ion source magnet



BERKELEY LAB

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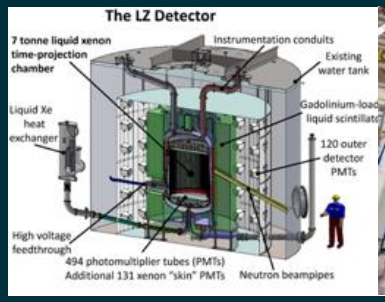
# COSMIC FRONTIER PHYSICS AT BERKELEY LAB

Completed DESI and LZ, new instruments for discovery in Dark Energy and Dark Matter, and launching CMB-S4

LZ: 20x increased sensitivity to dark matter

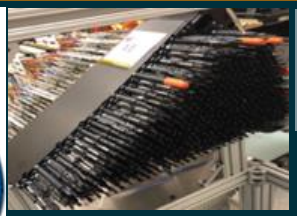



Outer Cryostat tested and being installed at SURF

Water Tank with PMTs installed

CD-4 awarded in September 2020; First science run in 2021

DESI: 20x increased precision in dark energy , + large scale structure and neutrino masses



Final production petal, with fiber positioners

12-ton corrector installed on the Mayall telescope

First light through corrector

CD-4 awarded in May 2020; five year survey starting this month

CMB-S4: most sensitive map of the early Universe

CMB-S4 will comprise an array of 18 telescopes with 500,000 superconducting microwave detectors located in Chile and the South Pole

CD-0 awarded in 2019; LBNL selected as lead lab in August 2020

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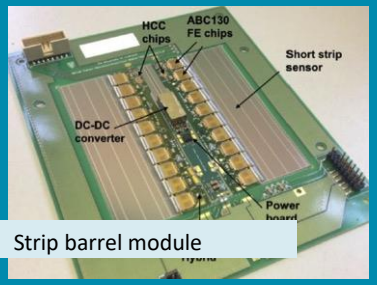
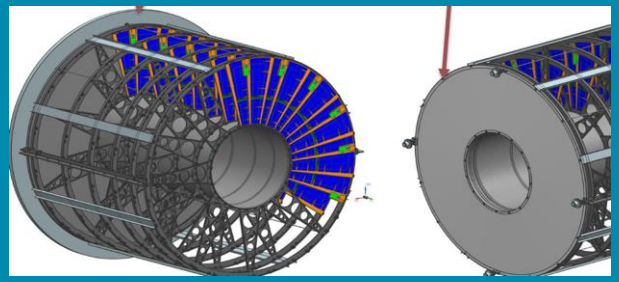
# LBNL CONTRIBUTIONS TO THE ENERGY AND INTENSITY FRONTIERS

## LHC: Contributing to ATLAS Si Strip and Pixel detectors and Global Mechanics




Strip barrel module

Pixel readout chip

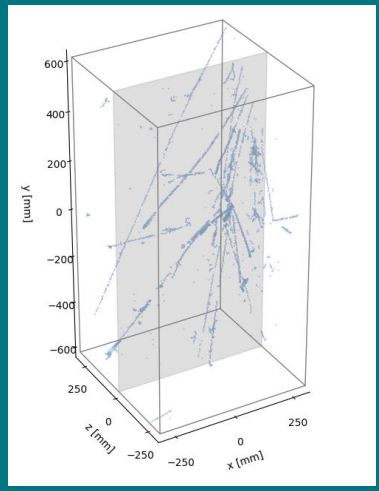


Upgraded LBNL Composites Facility will support fabrication of Global Mechanics

## LBNL leads the LAr TPC Near Detector for LBNF/DUNE


Developed cryogenic pixelated readout ASIC (LArPix) for improved pattern recognition and tracking capabilities

**Dan Dwyer**
ECA Awardee and LAr TPC L2 Lead




Module 0 Demonstration of LArPix v2 readout ASIC

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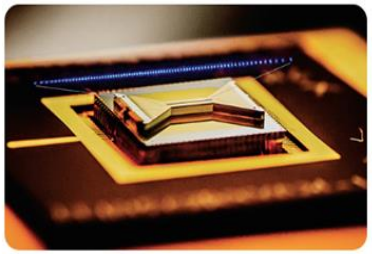
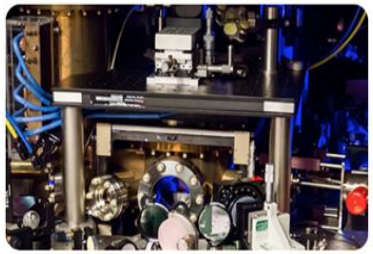
QUANTUM SYSTEMS ACCELERATOR

Catalyzing the Quantum Ecosystem

Harnessing Quantum



Programming Quantum

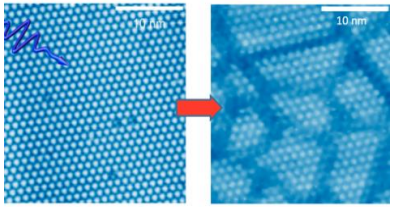


Engineering Quantum

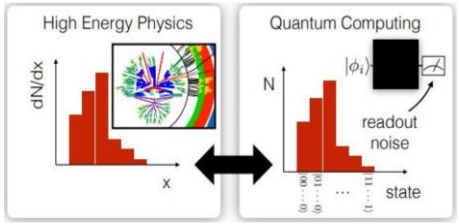
Engaging Quantum

## LBNL QUANTISED QUEST PROGRAM

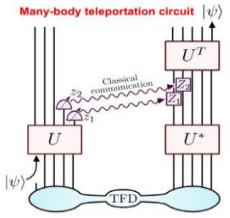
Quantum Sensing For Dark Matter




Quantum Materials for Dark Matter




Quantum Computing For HEP




Quantum Information Theory

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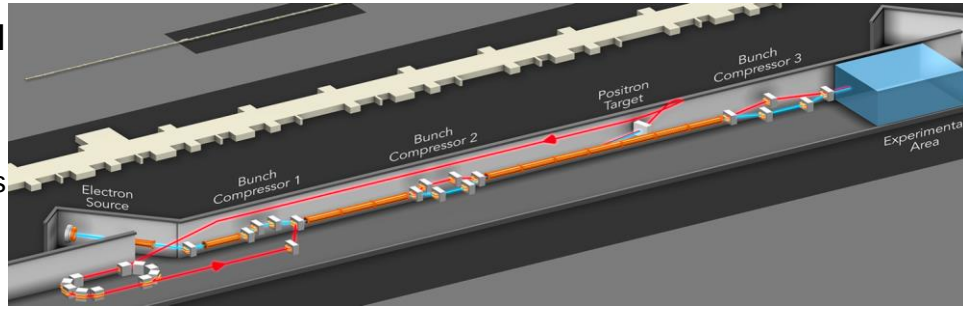
# The Facility for Advanced Accelerator Experimental Tests II (FACET-II) is a National User Facility based on high-energy beams and their interaction with solids, plasmas and lasers


- **Construction is complete**
- **Accelerator commissioning is ongoing**
- **Science program: 2021-2026**

- Milestones in the DOE Advanced Accelerator Strategy Report define important areas of focus for the FACET-II facility:
  - preservation of beam quality and emittance, identifying techniques for positron acceleration in plasmas, developing plasma injectors as sources of ultra low-emittance beams.
- Machine Learning techniques will be leveraged to understand the complex beam dynamics of ultra-short bunches.
- FACET-II will train the next generation of leaders in accelerator physics.
- Results of the FACET-II science program will define a future demonstration facility FACET-III. FACET-III will focus on 1-2 long term R&D initiatives with high impact: supporting the DOE PWFA roadmap and beam physics of ultrashort bunches

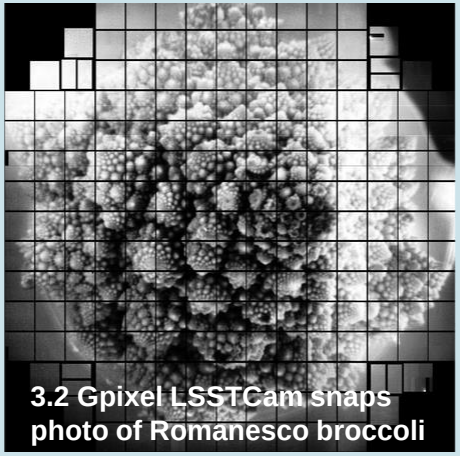



FACET-II is developing advanced concepts to increase accelerator performance by factors of 10-1,000.

# Probes of Dark Energy and Dark Matter at SLAC

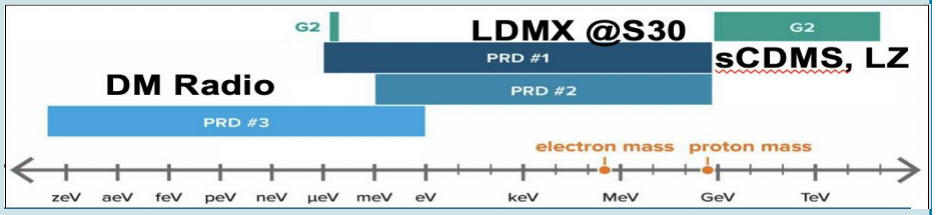
**Vera Rubin Observatory will perform 10-year Legacy Survey of Space and Time**

- LSSTCam Nears Completion with CD-4 review planned for May 2021
- Camera commissioning is underway in Chile
- Rubin U.S. Data Facility to be sited at SLAC
- Dark Energy Science Collaboration prepares for data



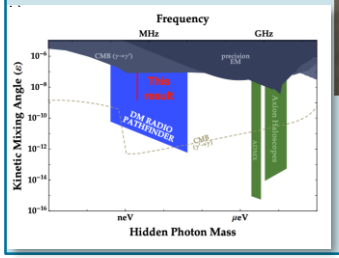


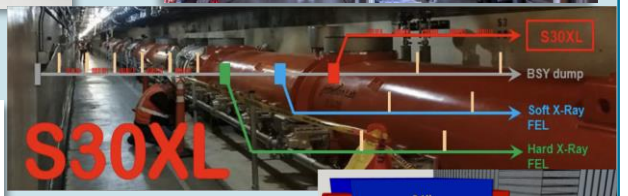
**Leading Dark Matter exploration for WIMPS &**



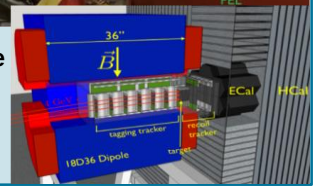



**Harnessing QIS to search for Axions with**



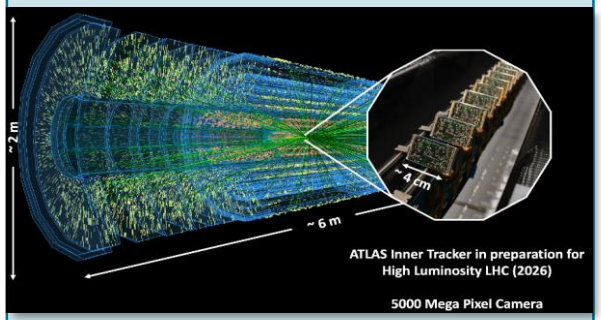




**Constructing beamline to deliver CW nA 4-8 GeV e- from LCLS-II SRF to Light Dark Matter eXperiment**



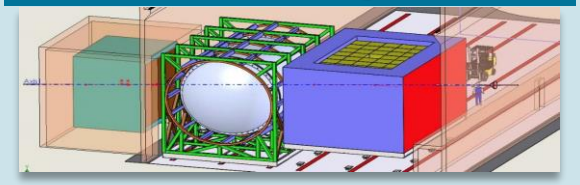
# SLAC plays key role in broad suite of P5 projects and innovative instrumentation

## ATLAS

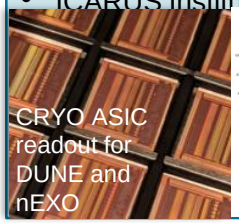


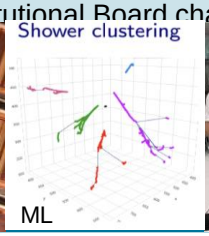

- Pixel lead for U.S. ATLAS
- Assembly site of Inner Tracker pixel detector
- Inner Tracker pixels and global mechanics
- Leading role in defining Higgs self-couplings measurements

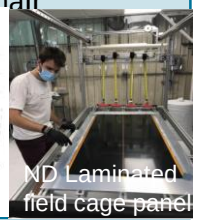
## Neutrino Program



- DUNE Near Detector technical coordination & engineering leadership
- ND Segmented LArTPC prototyped and tested at SLAC Liquid Noble Test Facility
- ND full-scale demonstrator to be constructed @SLAC
- DUNE-PRISM concept adopted by collaboration
- ICARUS Institutional Board chair

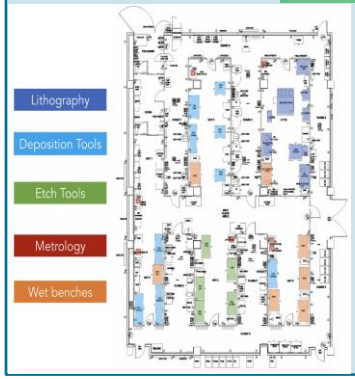



## CMB-S4 + QIS






Construction of Detector MicroFabrication Facility for CMB-S4 detector fab and as Quantum Foundry for Q-NEXT National QIS Research Center

# International engagements

Italy Consul General visit, March 15

"We were so impressed with US-Italy relationship in many scientific collaborations from mu2e to ICARUS and DUNE, from PIP-2 to the new SQMS Center "

— *Consul General Thomas Botzios*


Fermilab-CERN signature ceremony of the MOU for a participation in the HL LHC Upgrade project, March 23

"This is another important milestone on our cooperation on the HL-LHC --- we are very proud of the work we do together with Fermilab, and we look forward to many more accomplishments."

— *Fabiola Gianotti*

CRADA No. FRA-2020-0008 Annex A

INTERNATIONAL

COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENT

FOR

BASIC SCIENCE COOPERATION

(HEREINAFTER "CRADA") NO. FRA-2020-0008

BY AND AMONG

FERMI RESEARCH ALLIANCE, LLC
UNDER ITS U.S. DEPARTMENT OF ENERGY CONTRACT
NO. DE-AC02-07CH11359
TO MANAGE AND OPERATE
FERMI NATIONAL ACCELERATOR LABORATORY
(HEREINAFTER "LABORATORY")

AND

TEL AVIV UNIVERSITY

Fermilab-Tel Aviv University, signed an i-CRADA, March 18

"Fermilab – Tel Aviv University collaboration on R&D activities for Sub-Electron-Noise Skipper-CCD Experimental Instrument (SENSEI; or Skipper-CCD) for pursuing dark matter searches in particle physics"

— *Nigel Lockyer*

**Science & Technology agreements – 10**
**I-CRADAs – 17**
**Multi-institutional MOU (SBN) - 1**

**Under discussion - 7**
**In planning - 2**



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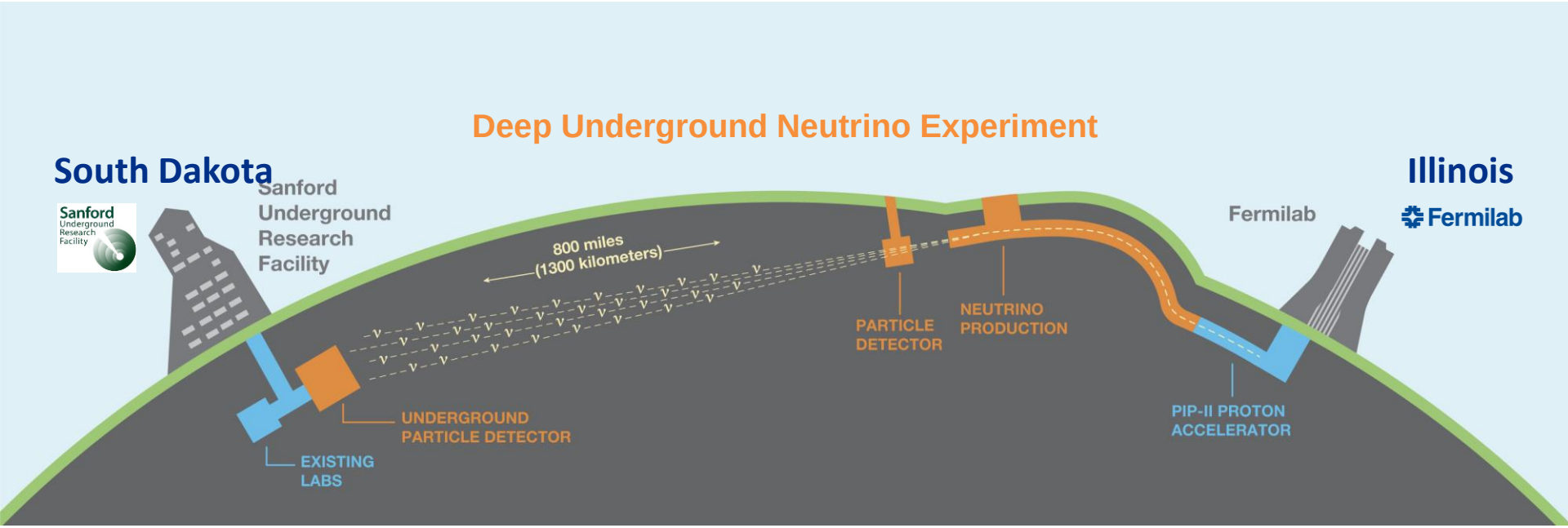
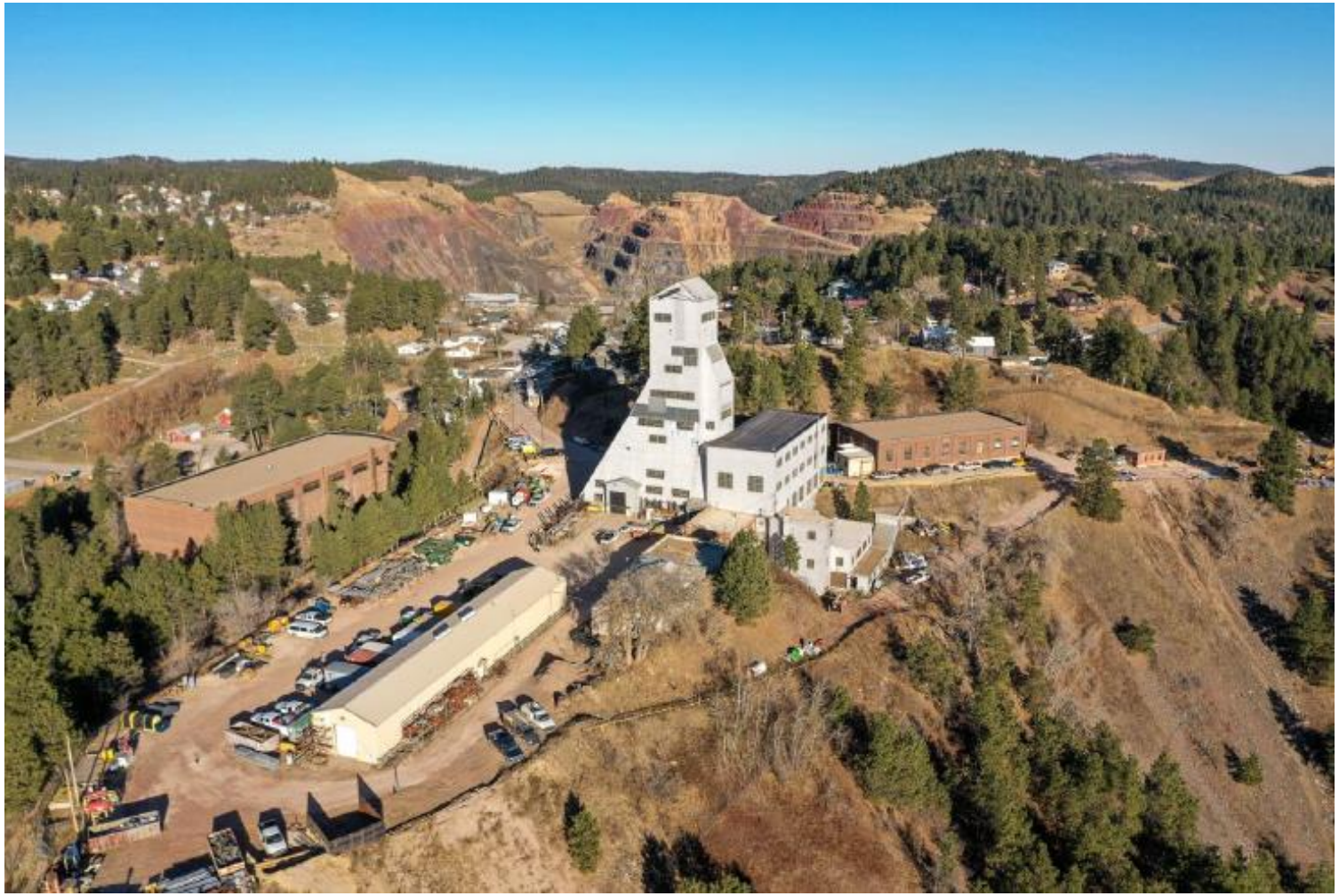
# LBNF/DUNE Overview

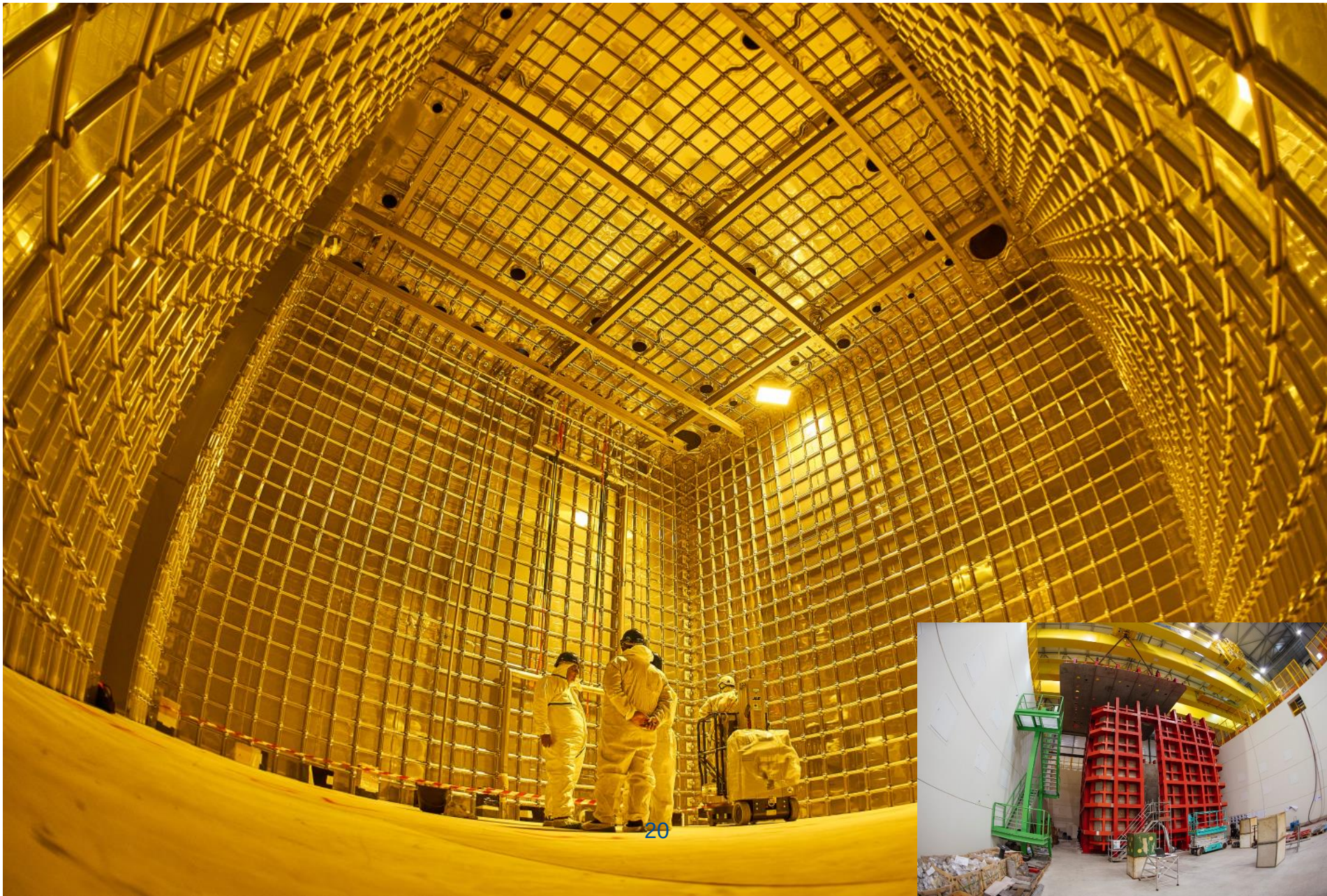



***LBNF will enable the United States to host the global high energy physics community to advance world class science into the fundamental nature of matter***

# Homestake Mine :Sanford Underground Research Facility home of Nobel Prize winning neutrino oscillation/solar neutrino puzzle experiment of Ray Davis

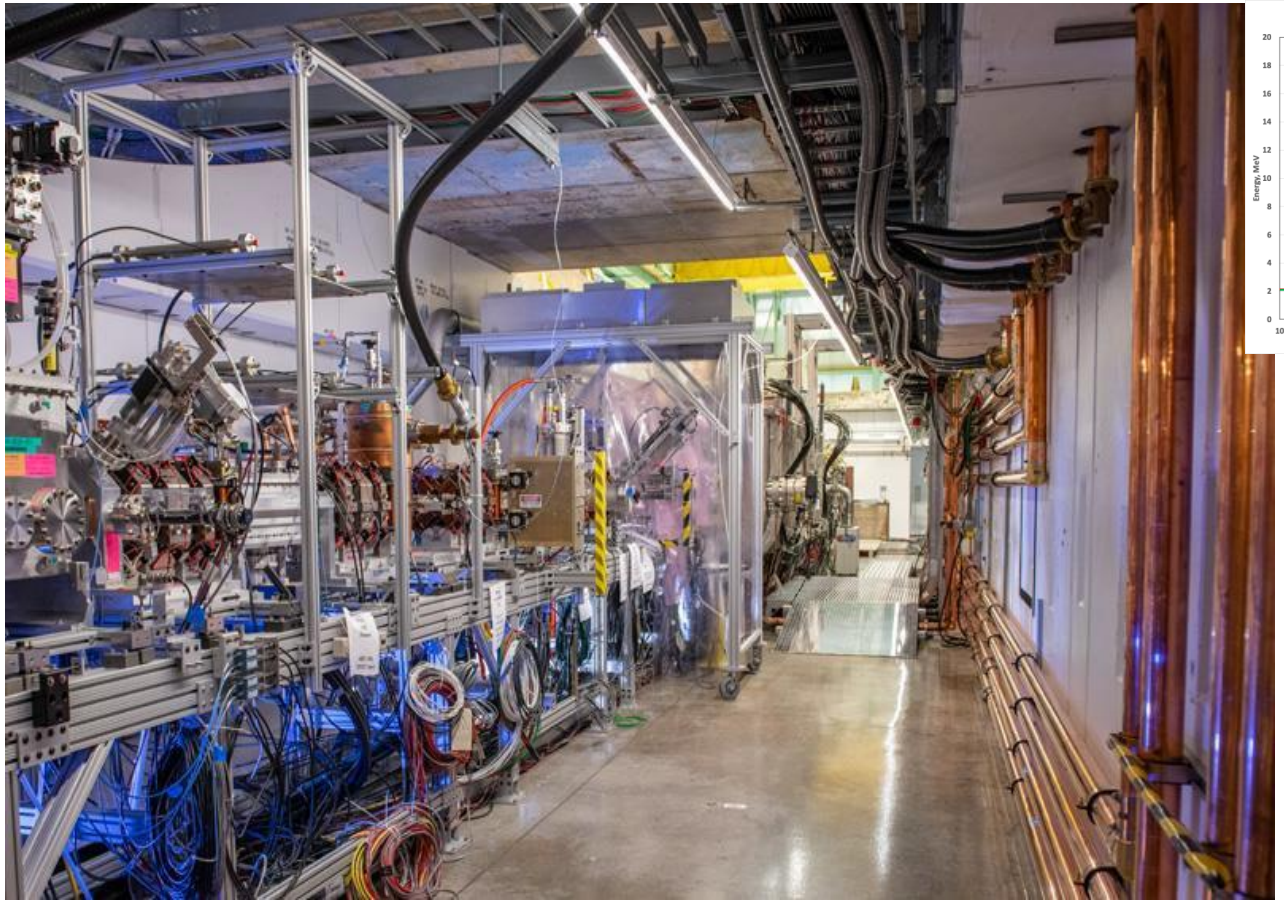


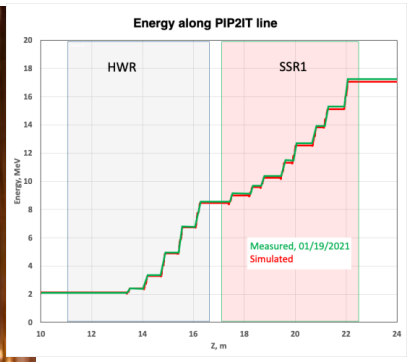
# Fantastic ProtoDune performance at CERN



# PIP-II gets CD-2 (baseline approved)

# PIP-II Cryomodules accelerate beam to 17 MeV!

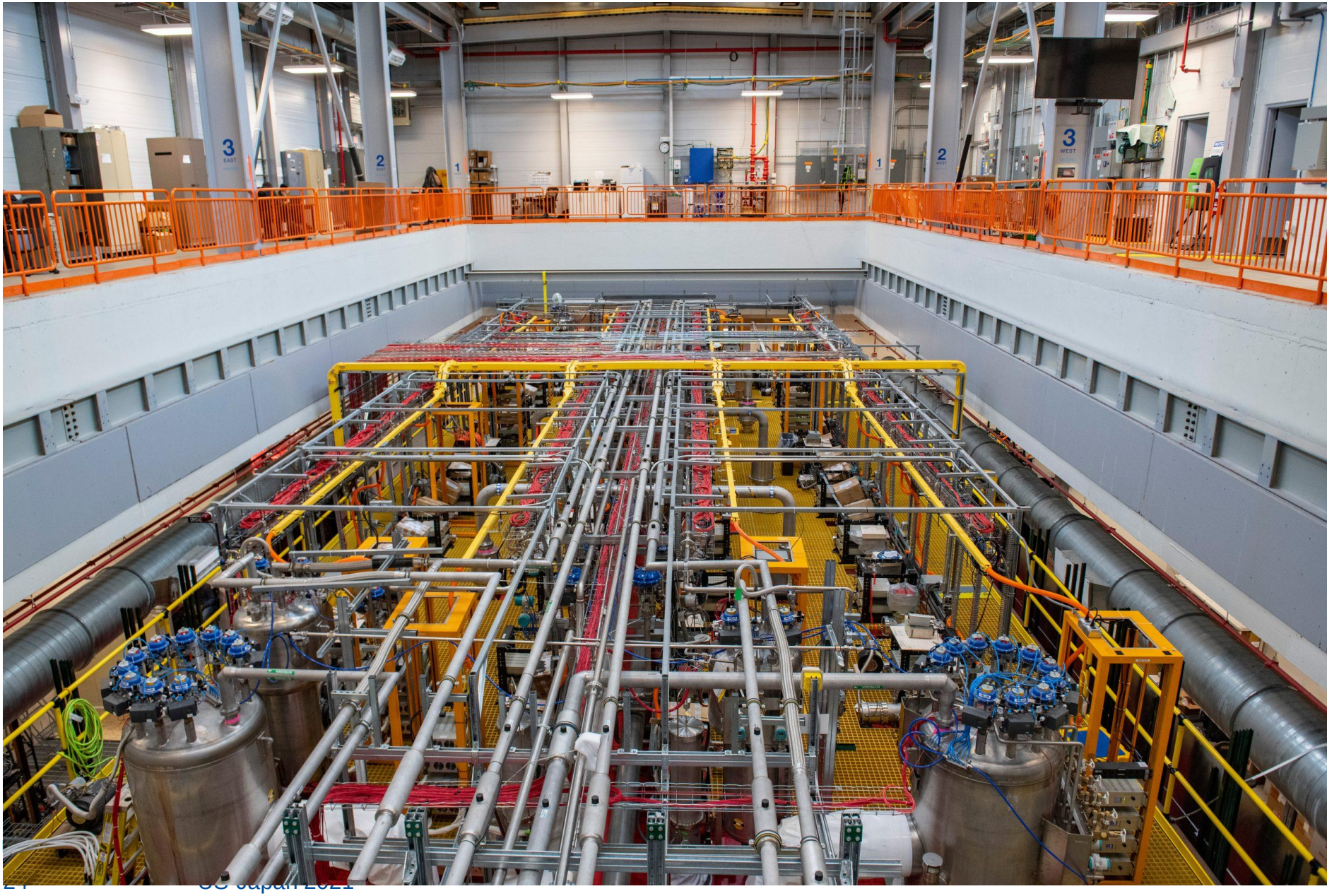




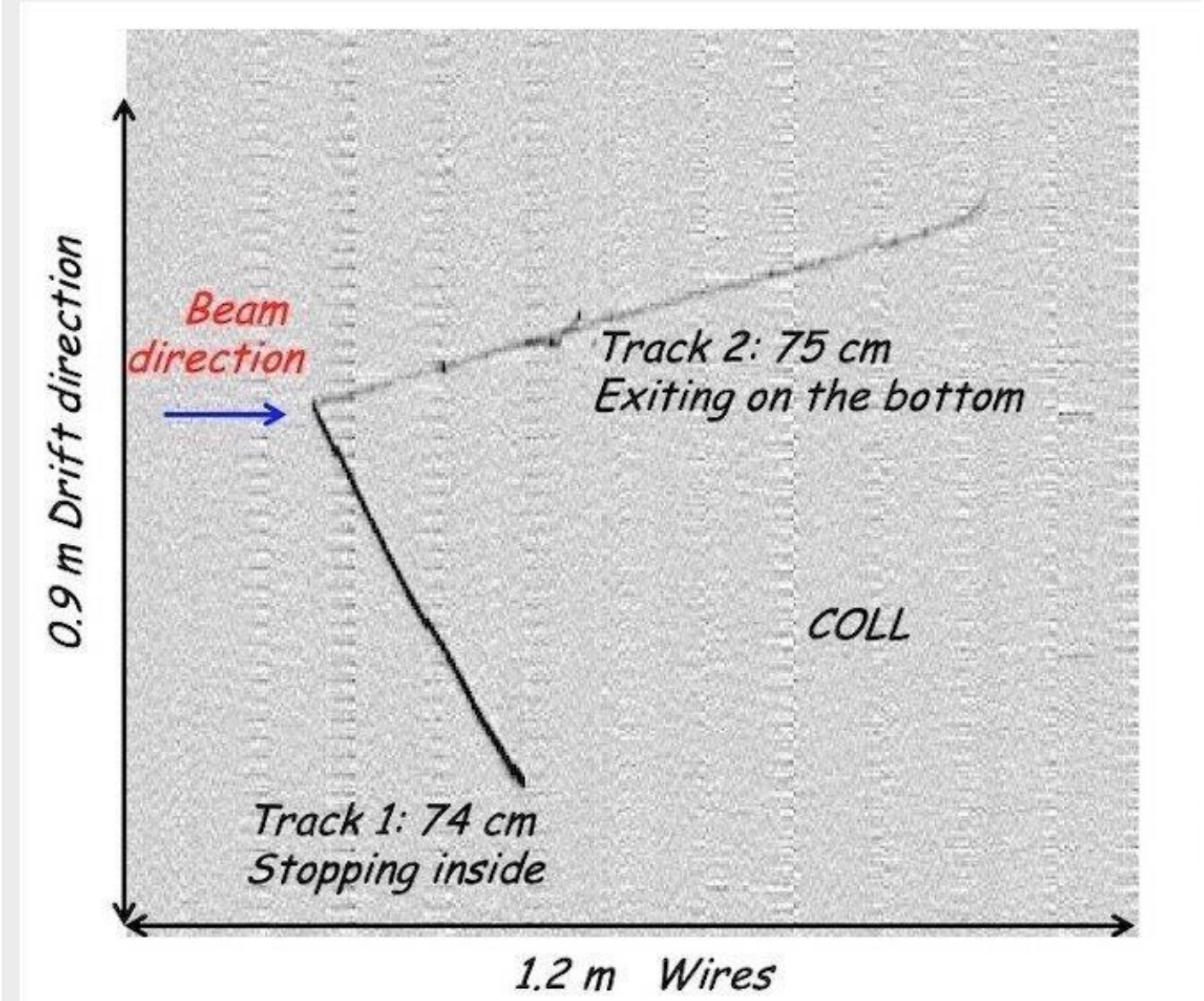

***Significant Milestone: SRF cryomodules and accelerator systems demonstrate solid performance.***
***International partners' deliverables seamlessly integrated.***

# PIP-II Cryogenic Plant Building – 30 March 2021

# ICARUS Detector Short Baseline Neutrinos



# First Beam Neutrino event for Icarus

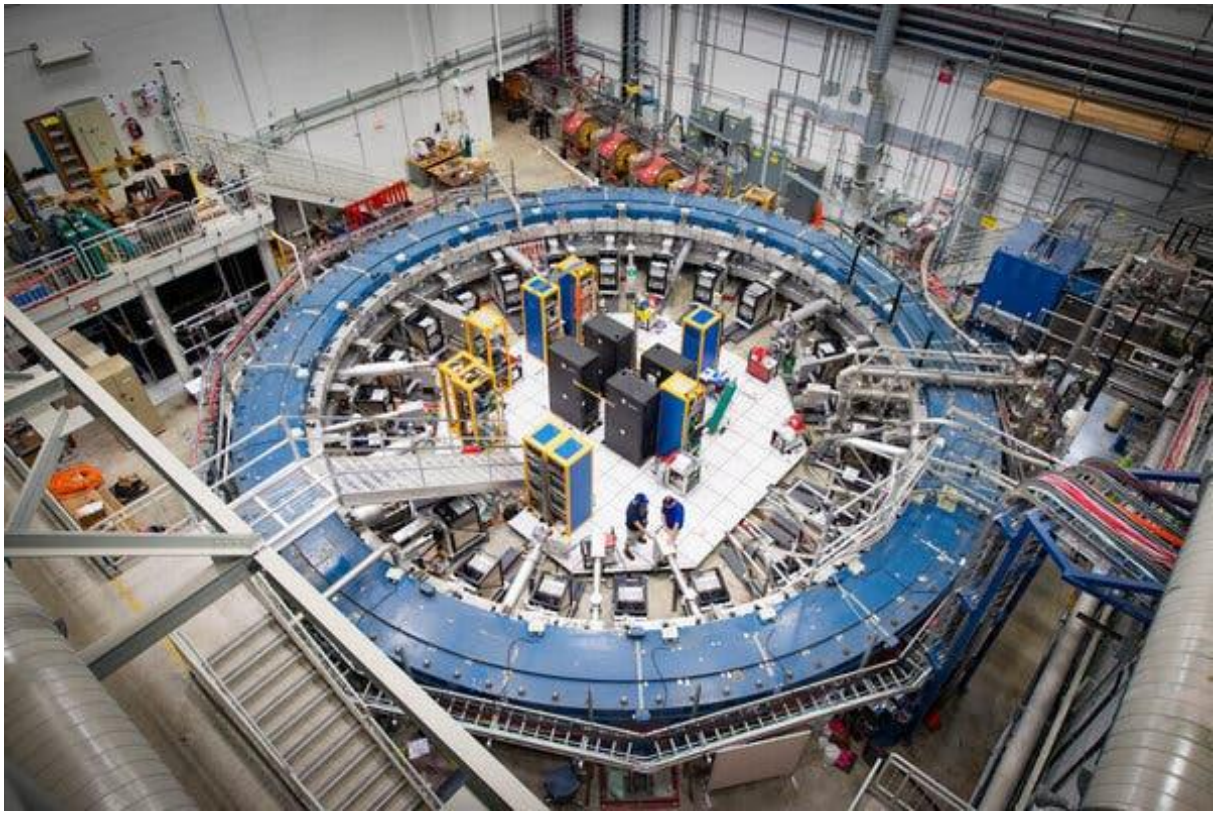





Fermilab

# NYT

Dennis Overbye



World-wide media reach was 5.2 billion people

Evidence is mounting that a tiny subatomic particle seems to be disobeying the known laws of physics, scientists announced on Wednesday, a finding that would open a vast and tantalizing hole in our understanding of the universe.

# It is a world-wide effort

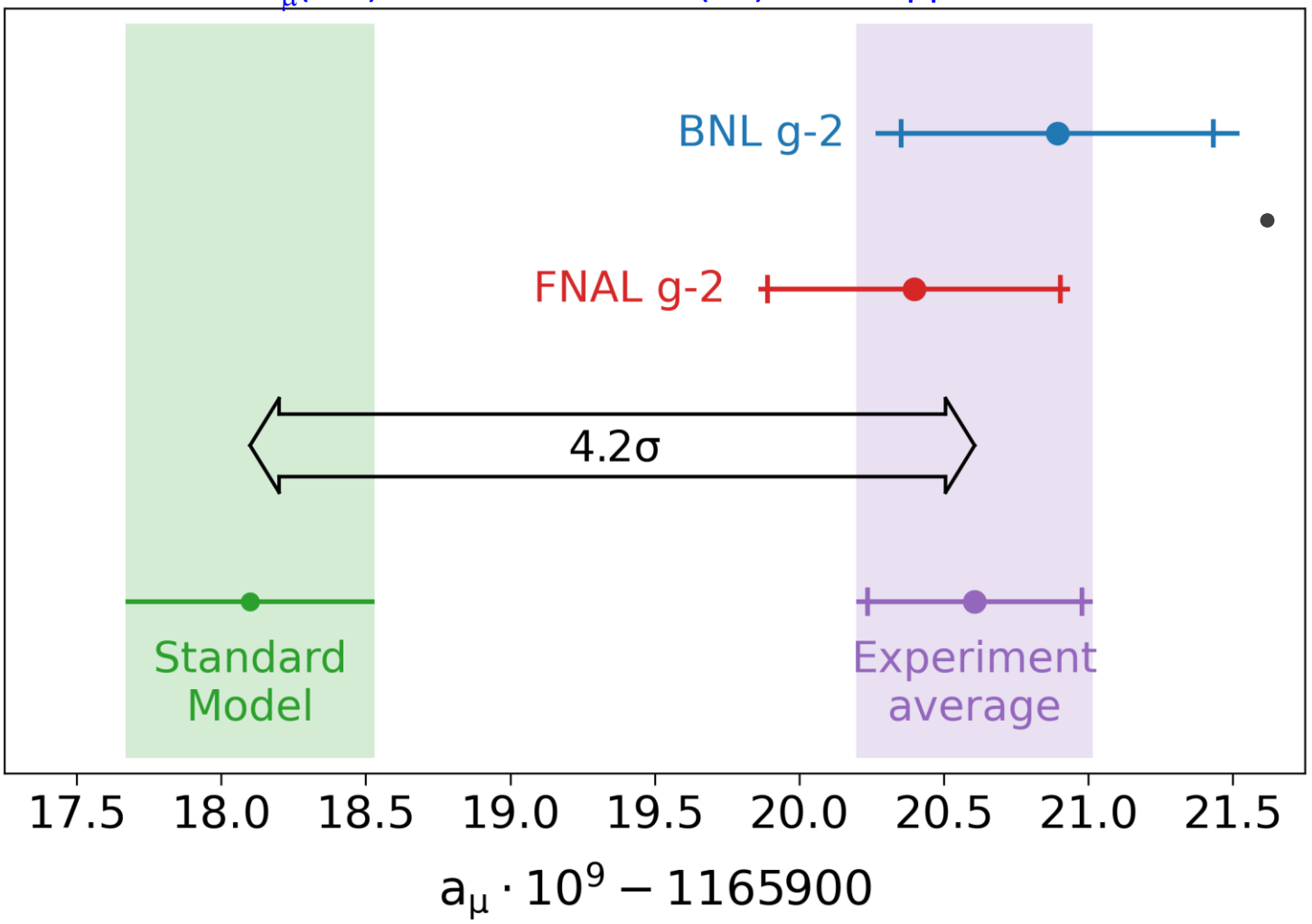
- Muon g-2 experiment: 237 members, 42 institutions across 7 countries
- **Theory community** that published the result on the prior page: 132 authors, 79 institutions across **20 countries**
- Many other accelerator-based expts have provided inputs to theory **5 countries**
  - Babar at SLAC (Stanford)
  - KLOE (phi-factory) in Italy
  - CMD/SND in Russia
  - Belle in Japan
  - BES in China

**Some of the theorists**

**Some of the experimentalists**

# Comparison to SM prediction

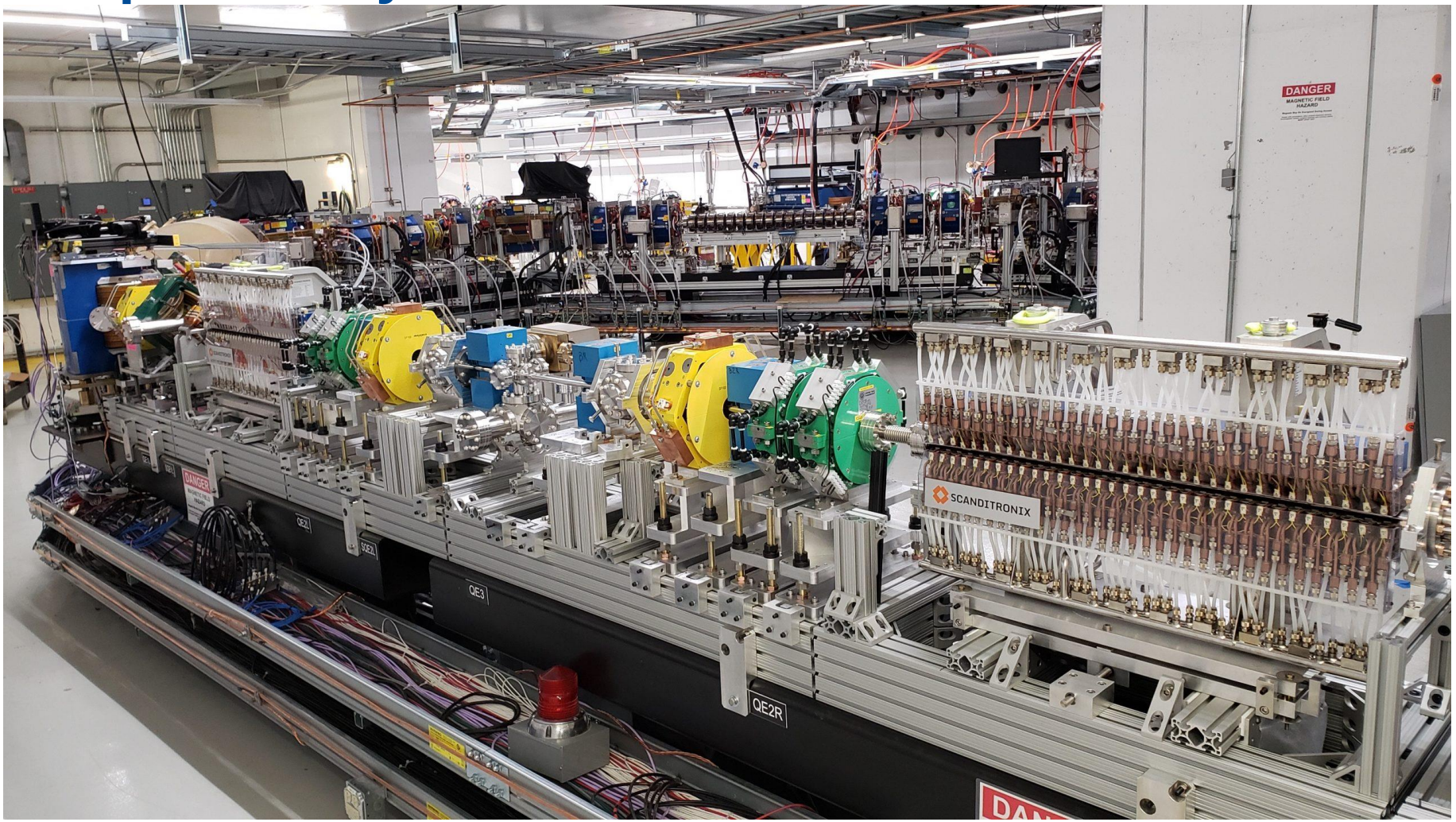
$a_\mu$(SM) = 0.00116591810(43) → 368 ppb




- Individual tension with SM
  - BNL: 3.7σ
  - FNAL: 3.3σ

$a_\mu$(Exp) - $a_\mu$(SM) = 0.00000000251(59) → 4.2σ

# Coolest beams in town (stored a single electron)
# Unique facility dedicated to R&D




## 32 quadrupoles from JINR (Dubna) thank you

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# ILC High Gradient/High Q Low Cost Cryomodule

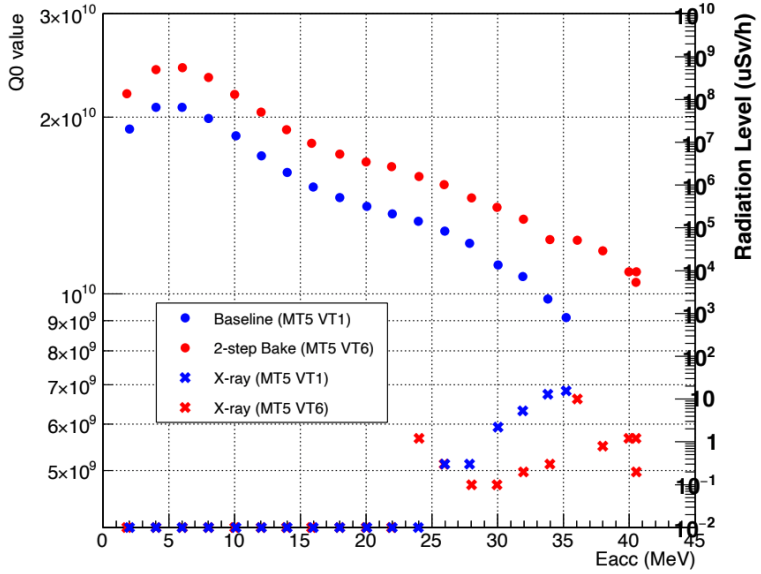
## High gradient/high Q cryomodule – ILC cost reduction

- High gradient – high Q cryomodule collaboration work ongoing, goal $E_{acc}$ > 40 MV/m with Q > 1e10
  - 5 cavities qualified for the cryomodule with $E_{acc}$ > 40 MV/m
  - Cavity treatment based on recent high gradient SRF R&D (cold EP, 2-step bake)
  - Rebuild of first SRF module assembled at FNAL in ~2007 (disassembly has started – see image)
- Collaboration includes FNAL, JLab, Cornell, KEK, DESY, Saclay, TRIUMF…
  - ILC cost reduction funds; outside US labs contribute in-kind on different aspects, from magnetic shielding, to surface treatments, to cryomodule and components design


Fermilab Jefferson Lab DESY. cea Cornell University Founded A.D. 1865 KEK-JAPAN Argonne National Laboratory TRIUMF

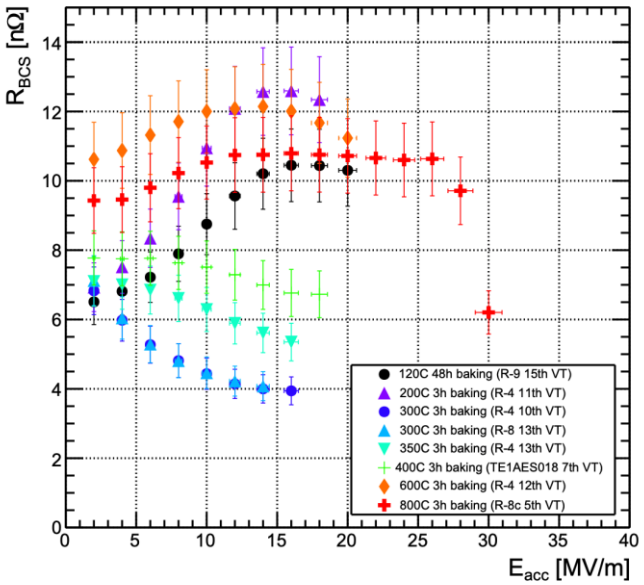
# Fermilab-KEK Collaborative SRF R&D Efforts

- Fermilab and KEK SRF scientists share methods and results, and exchange cavities to further SRF R&D – joining efforts brings faster progress than working separately




*KEK demonstration of $Q_0$ and $E_{acc}$ improvement via 2-step bake developed at Fermilab*

K. Umemori, Snowmass 2021, AF07
A. Grasselino et al., arxiv:1806.09824 (2018)




*KEK building on mid-T bake developed at Fermilab to simpler, high performance furnace treatment*

H. Ito et al, arxiv:2101.11892 (2021)
S. Posen et al., Phys. Rev. Applied 13, 014024 (2020)

# Thanks very much to DOE, Natalie Roe, Joanne Hewett, Dmitri Denisov, and Rik Yoshida