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Outlook for US HEP and the P5 Plan

Joe Lykken

US LHC Users Association Annual Meeting

11/14/2014

Two years ago…

- US HEP community divided
- Many ideas, ambitions, but no actionable plan to realize them
- Even by Washington standards our field looked dysfunctional
- Budget extrapolations grim

One year ago: US HEP community comes together

- Successful Snowmass community process
- Clarifies the physics landscape
- Realization that if we don't hang together we will surely hang separately

6 months ago: P5 plan rollout

Building for Discovery

Strategic Plan for U.S. Particle Physics in the Global Context

- A strategic plan for US HEP maximizing opportunities for breakthrough science
- Explicit prioritization, hard choices made within realistic budget scenarios
- Clear actionable recommendations
- US HEP community unified behind the report: 2331 signatures on letter sent to Secretary Moniz

Strong support for P5 plan at DOE

As we plan for the future, the P5 report recommendations and the strong community support for them are forefront in our considerations.

Sincerely,

Patricia M. Dehmer
Acting Director, Office of Science

cc: Dr. Nick Hadley
Dr. Ian Shipsey
Dr. Raymond Brock

P5 plan in a nutshell

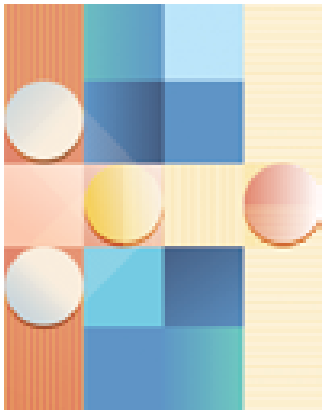
Recommendation 1: Pursue the most important opportunities wherever they are, and host unique, world-class facilities that engage the global scientific community.

Recommendation 2: Pursue a program to address the five science Drivers.

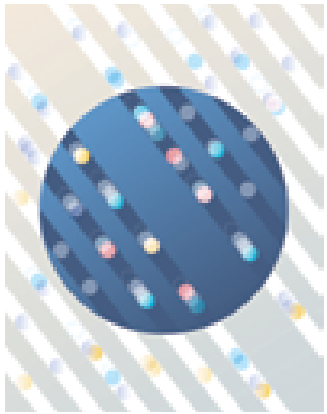
P5 Science Drivers

Five intertwined scientific Drivers were distilled from the results of a yearlong community-wide study:

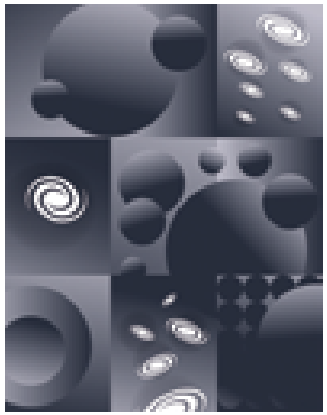
- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation
- Explore the unknown: new particles, interactions, and physical principles



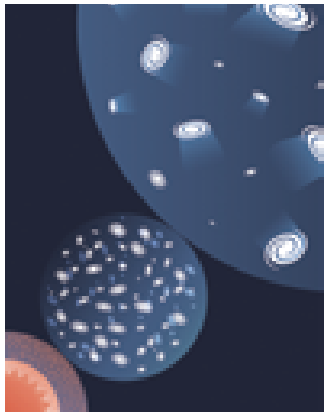
Higgs boson



Neutrino mass



Dark matter

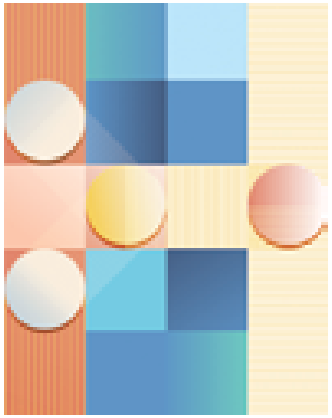


Cosmic acceleration

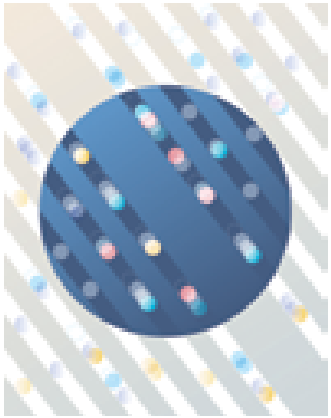
Explore the unknown

The Science Drivers are NOT Prioritized

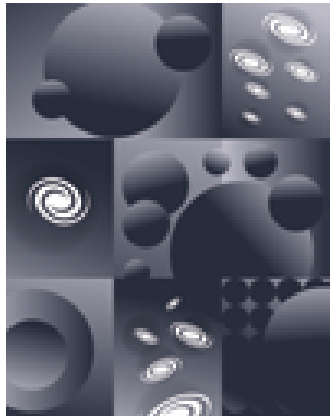
- Our job is to uncover physics beyond the Standard Model
- But no one knows for sure what this physics is or where it will turn up first
- A multi-pronged experimental effort pursuing all five science drivers is the optimal strategy



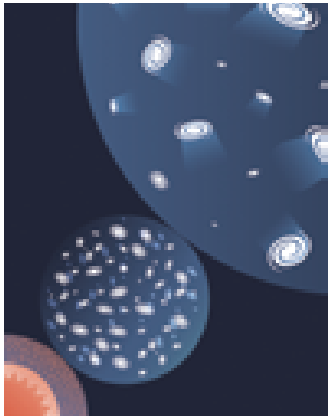
Higgs boson



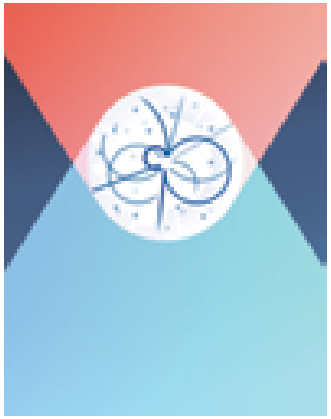
Neutrino mass



Dark matter



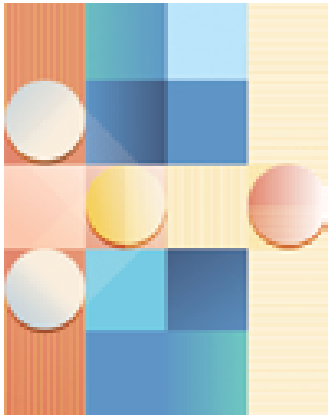
Cosmic acceleration



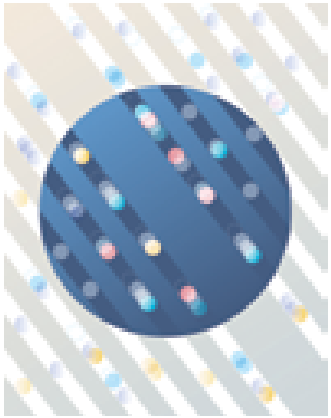
Explore the unknown

The Science Drivers are NOT Prioritized

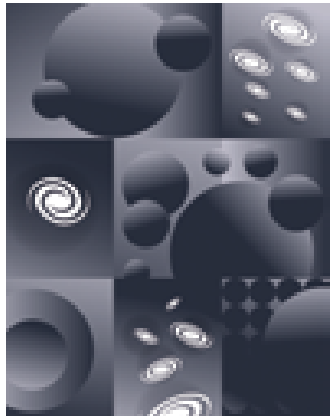
- Furthermore the drivers are all related in deep ways, some of which we already suspect and probably in other ways beyond our current understanding
- Discoveries or constraints from one front will inform what we need to do on others
- Ultimately the clues from many fronts will allow some smart young people to sketch the new big picture



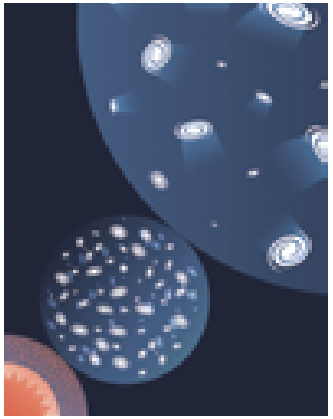
Higgs boson



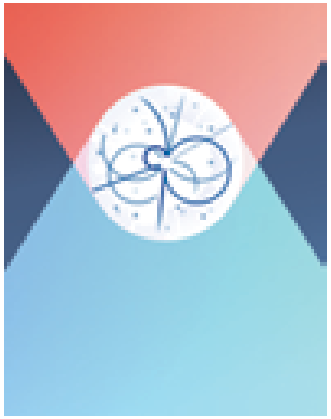
Neutrino mass



Dark matter



Cosmic acceleration



Explore the unknown

Example: Higgs Connections

- Higgs and Supersymmetry?
- Does the Higgs field destabilize the vacuum?
- How does the Higgs talk to neutrinos?
- Is there a Higgs portal to dark matter?
- Is the Higgs sector responsible for baryogenesis?
- Extra credit: Is the Higgs related to inflation or dark energy?

We live in interesting times

- Higgs is a huge discovery - a completely new kind of beast
  - Need to study with as much precision as possible
- LHC higher energy run will be enlightening and exciting!
  - Anything new will be a revolution
- Dark matter direct detection could be around the corner
  - The most interesting region being probed soon
- Surprises have been plentiful (neutrinos, dark energy), and this may continue
- Many reasons to think that we are on the edge of huge discoveries
- Need to plan for success and our longer term future

P5 priorities: Build for the Future

Recommendation 4: Maintain a program of projects of all scales, from the largest international projects to mid- and small-scale projects.

Recommendation 5: Increase the budget fraction invested in construction of projects to the 20%–25% range.

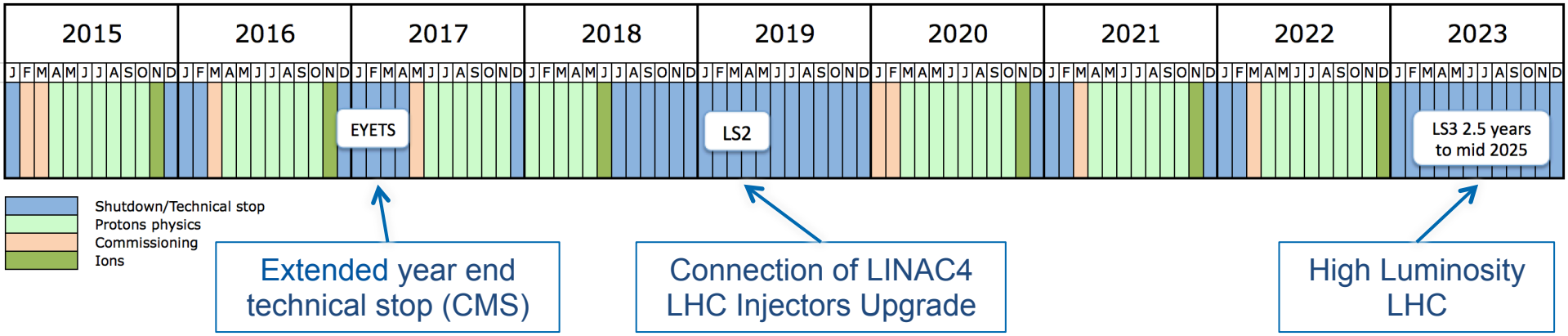
- Needed for US HEP to have a viable future
- Just a few years ago, project fraction < 10%
- Painful adjustment period, squeezes research, operations, and long-term R&D
- But new initiatives also give us leverage to attract more resources

P5 priorities: LHC

Recommendation 10: Complete the LHC phase-1 upgrades and continue the strong collaboration in the LHC with the phase-2 (HL-LHC) upgrades of the accelerator and both general-purpose experiments (ATLAS and CMS). The LHC upgrades constitute our highest-priority near-term large project.

- This is a huge commitment by the US HEP community
- It will be a heavy lift, especially on the NSF side
- But we have to make it happen

the next 10 years



- present LHC will reach its limits in the early 2020s
  - radiation hardness of magnets (lifetime)
    - e.g. triplet and cleaning insertions to be changed in any case
  - cooling and cryogenics (limit at 1.75 10^{34} $cm^{-2}s^{-1}$)
  - radiation and R2E
    - shielding and removing equipment from the tunnel (superconducting link and cold powering)
- HL-LHC goal: 3000 fb^{-1} within twelve years (run until mid 2030s)
  - integrated luminosity of 250 fb^{-1} per year, about ten times present LHC
  - peak luminosity of 5 10^{34} $cm^{-2}s^{-1}$ with levelling (140 events per crossing!)
    - need availability and reliability!

High Luminosity LHC

P5 priorities: Neutrinos

Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.

Recommendation 13: Form a new international collaboration to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S. To proceed, a project plan and identified resources must exist to meet the minimum requirements in the text. LBNF is the highest-priority large project in its timeframe.

- Another huge commitment by the US HEP community
- Basically asks Fermilab to do for neutrinos what CERN did for LHC
- It will be a heavy lift, especially on the international side
- But we have to make it happen

P5 plan in a nutshell

- Continue our commitment and leading roles in the LHC
- Build a neutrino program that will attract the world community for decades to come
- Continue leading efforts in dark matter, cosmic surveys, and CMB
- Invest in the accelerator and detector technologies that we will need in the future

It is a feature of this plan that the major components reinforce each other

P5 Headline: Particle Physics is Global

- This was not highlighted in previous HEPAP reports
- US HEP plan needs to make sense in the context of global HEP
- US involvement in LHC seen as a successful example of international collaboration
- International partnerships of growing importance in US science, HEP seen as leading the way

Three Regions in World: Europe, Americas & Asia

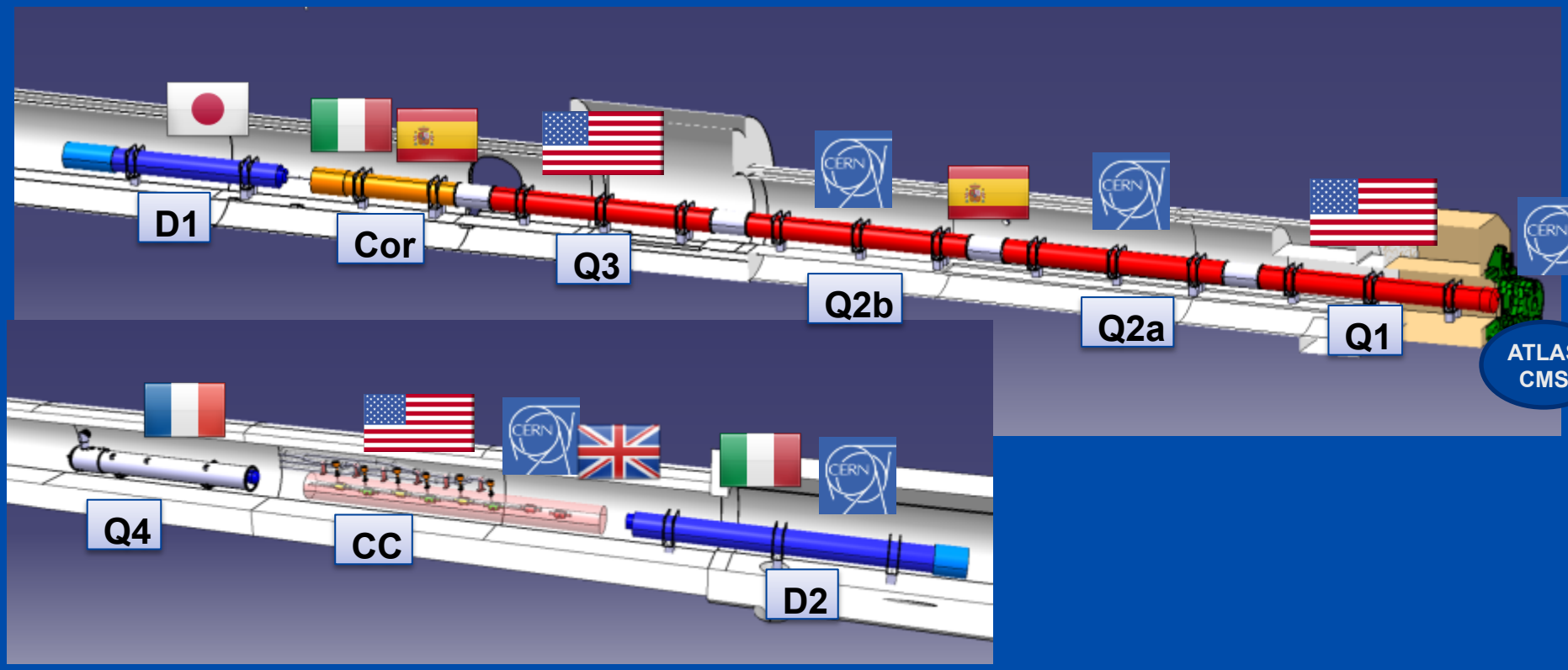
National and regional ambitions in a global context
We will have to solve problems together and be well coordinated

European strategy

- Highest priority is exploitation of the LHC including luminosity upgrades
- Support at CERN for European involvement in neutrino experiments in the US

- **Combination strengthens the US-European partnership for HEP**
- **Note the strong CERN-Fermilab partnership is key here**

Good Example of International Collaboration



Baseline design of HL-LHC Interaction Region (Bordry)

Higgs discovery and future colliders

- Higgs discovery motivates a precision Higgs factory…not going to make three….
- China wants to build a Higgs factory
- Europe wants to build a Higgs factory
- ILC higher energy (500 GeV), both beams polarized, mature design & machine ready to go
- Strategy for FCC and CECP is however attractive: an attractive growth path just as LEP grew into LHC.
- Absence of other low hanging fruit at LHC so far motivating ideas for a ~100 TeV pp machine

FCC Overview

FCC-hh hadron collider with 100TeV proton cms energy

~16 T ⇒ 100 TeV *pp* in 100 km
~20 T ⇒ 100 TeV *pp* in 80 km

FCC-ee a lepton collider as a potential intermediate step

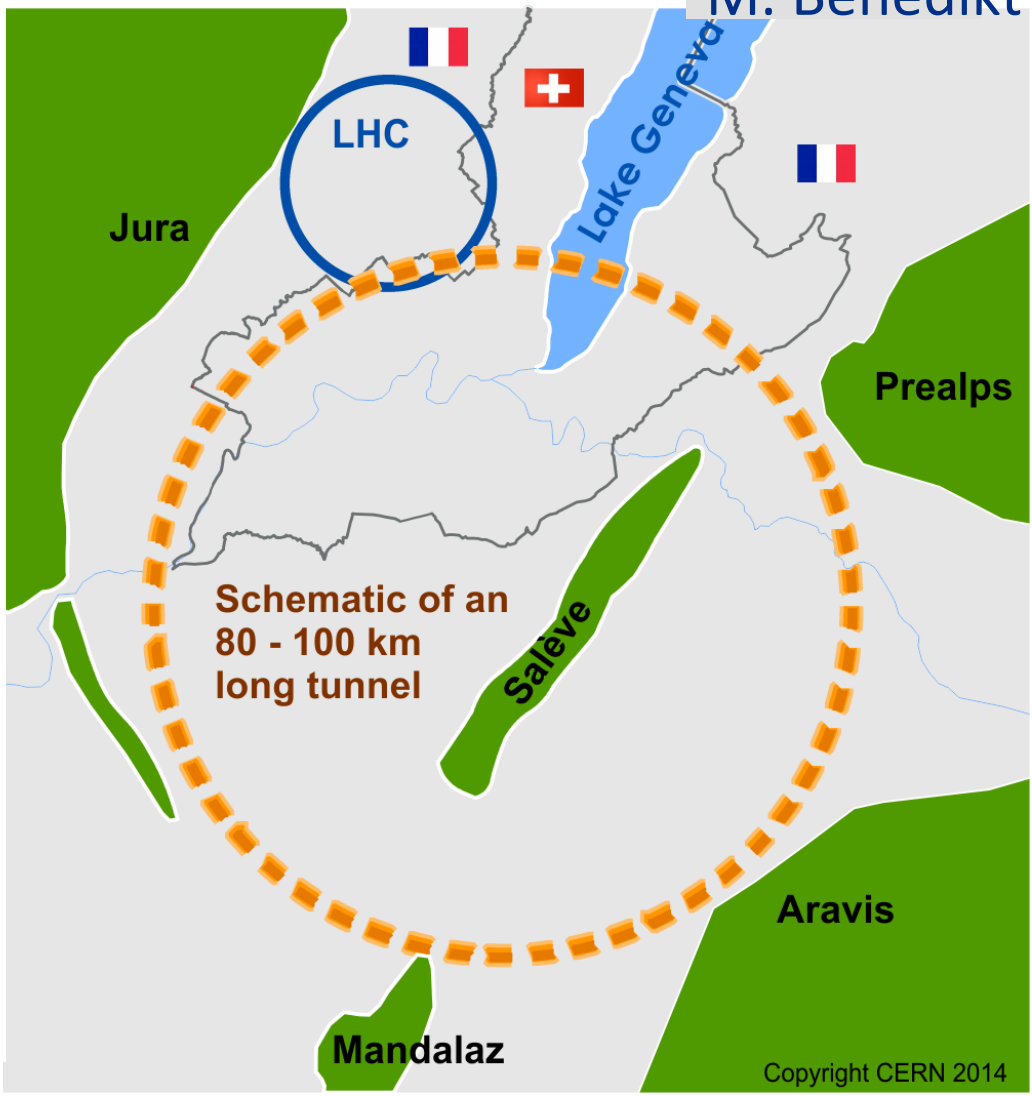
FCC-eh lepton hadron option

International collaboration

Site studies for Geneva area

CDR for EU strategy update in 2018

M. Benedikt



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FCC Kick-off Meeting

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The CEPC-SppC Kick-off Meeting in Beijing

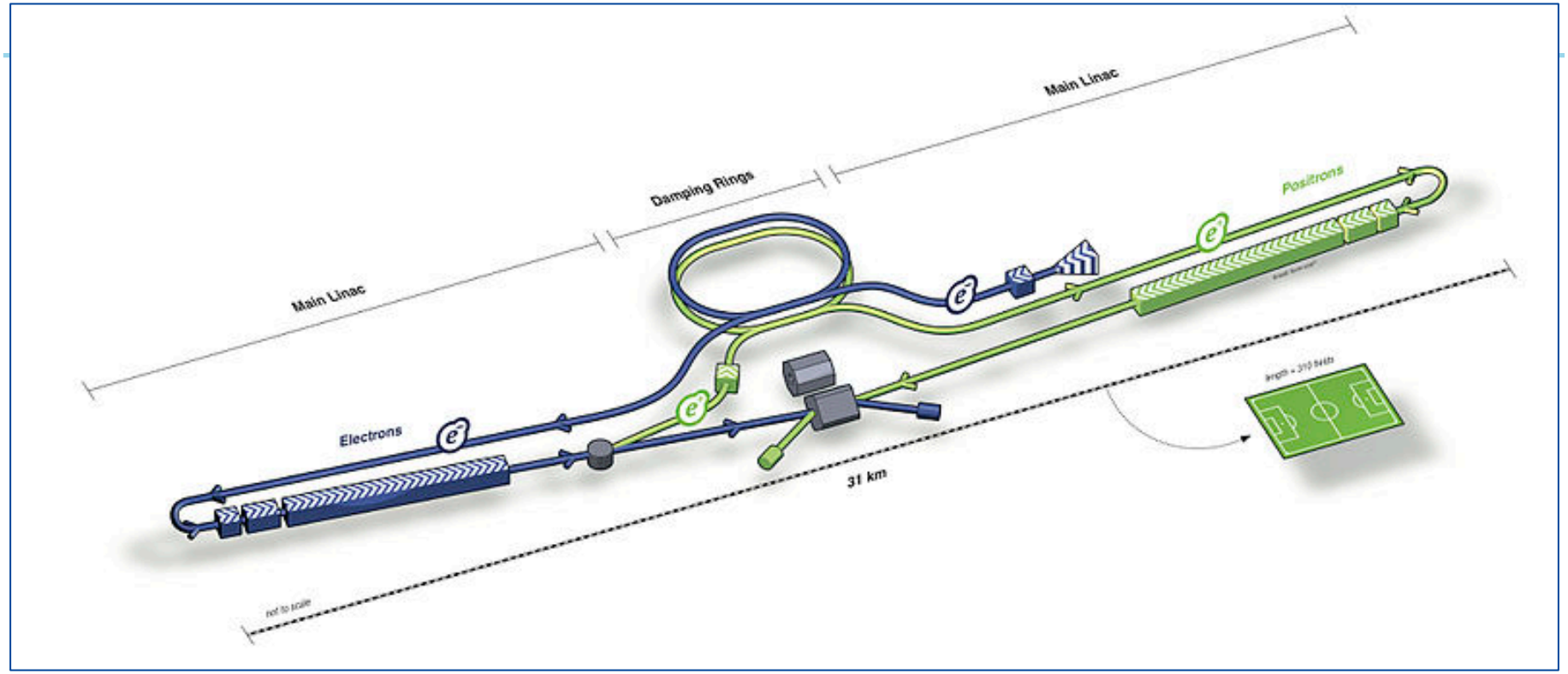
- The Chinese CEPC+SPPC Study Group kick-off meeting took place Sept. 13-14 in Beijing
- Participation by over 120 physicists from 19 domestic institutes
- Domestic accelerator, theoretical and experimental physicists were organized

CEPC – Site Investigation

300 km from Beijing

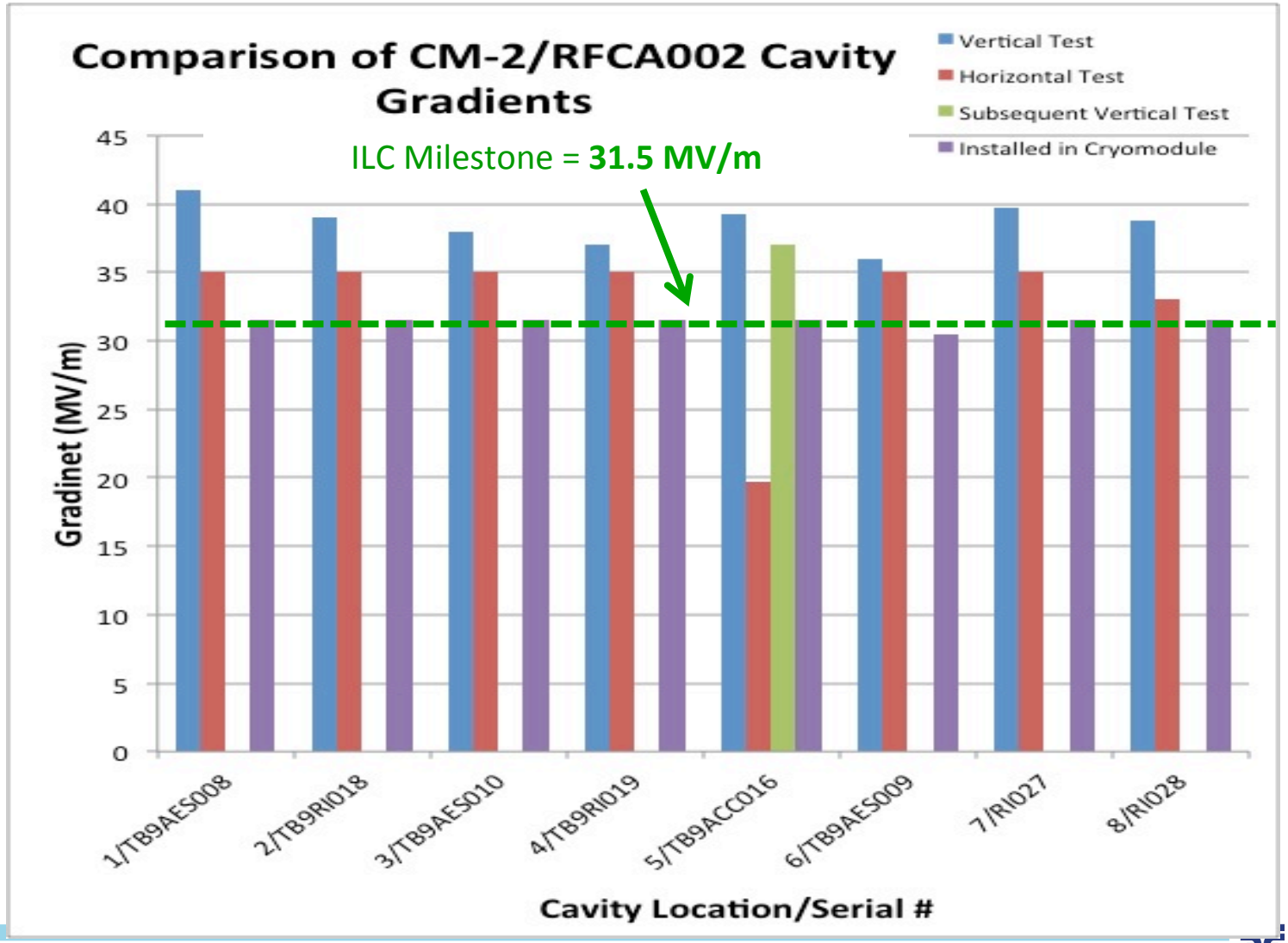
3 hours by car; 1 hours by high speed train

International Linear Collider



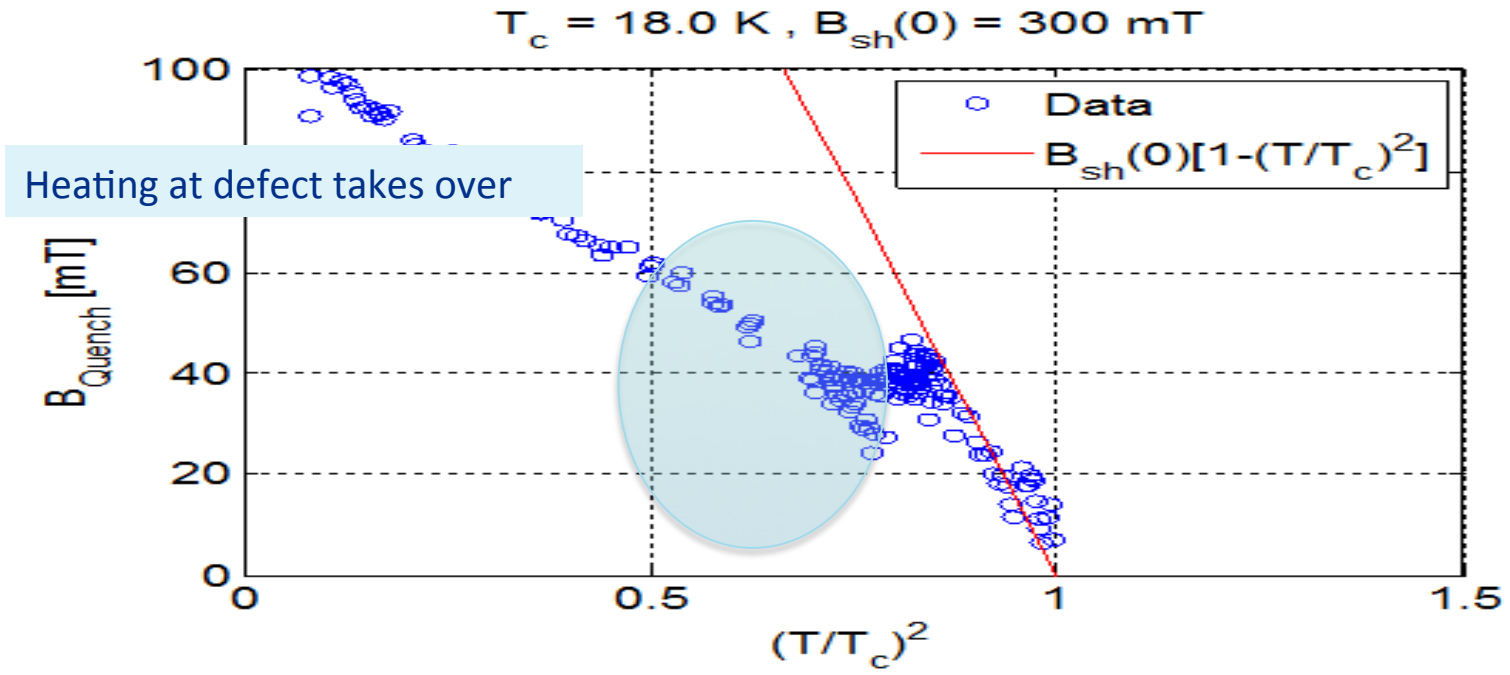
- **ILC or International Linear Collider is e^+e^- linear collider with the following main parameters**
  - Center of mass energy 500 GeV – upgradable to 1 TeV
  - **Luminosity >** 10^{34} $cm^{-2}s^{-1}$
- **Waiting for Japanese government to decide if they want to host**
- **If it goes ahead in Japan, US and Europe HEP will want to help**

Fermilab cryomodule operates at full ILC gradient



Long-term goals R&D program: 60 MV/m → 90MV/m

- Using high power RF (MW) with short pulses, Cornell recently demonstrated (for T>6K) Nb3Sn follows the expected superheating field of the 18K superconductor.
- When extrapolated to 2K this leads to surface magnetic fields of 300 mT as compared to Nb superheating field of 200 mT.
- These results suggest that a well prepared Nb3Sn cavity with optimal shape will capable of reaching 80-90 MV/m and high Q (due to higher Tc of Nb3Sn)
- With intense R&D, such new materials can outperform Nb.



P5 likes Particle Astrophysics

Five science drivers:

- Higgs boson
- Neutrino mass
- Dark matter
- Cosmic acceleration
- Explore the unknown

Particle Astrophysics experiments address all but the first

Many experiments address more than one

Report supports expanded dark matter program, new cosmic surveys, and a new multi-agency program in CMB

WIMPS dark matter candidates

- Three ways to find WIMPS….all three being pursued
  - Produced in colliders
  - Direct detection
  - Indirect detection from annihilation

Worldwide WIMP Searches (slides thanks to Elena Aprile)

US: Dark Matter after P5 and G2 “Downselect”

DOE and NSF released their G2 plans on July 7

- Responds to P5 recommendation of expanded G2 program
- Expanded funding not yet available

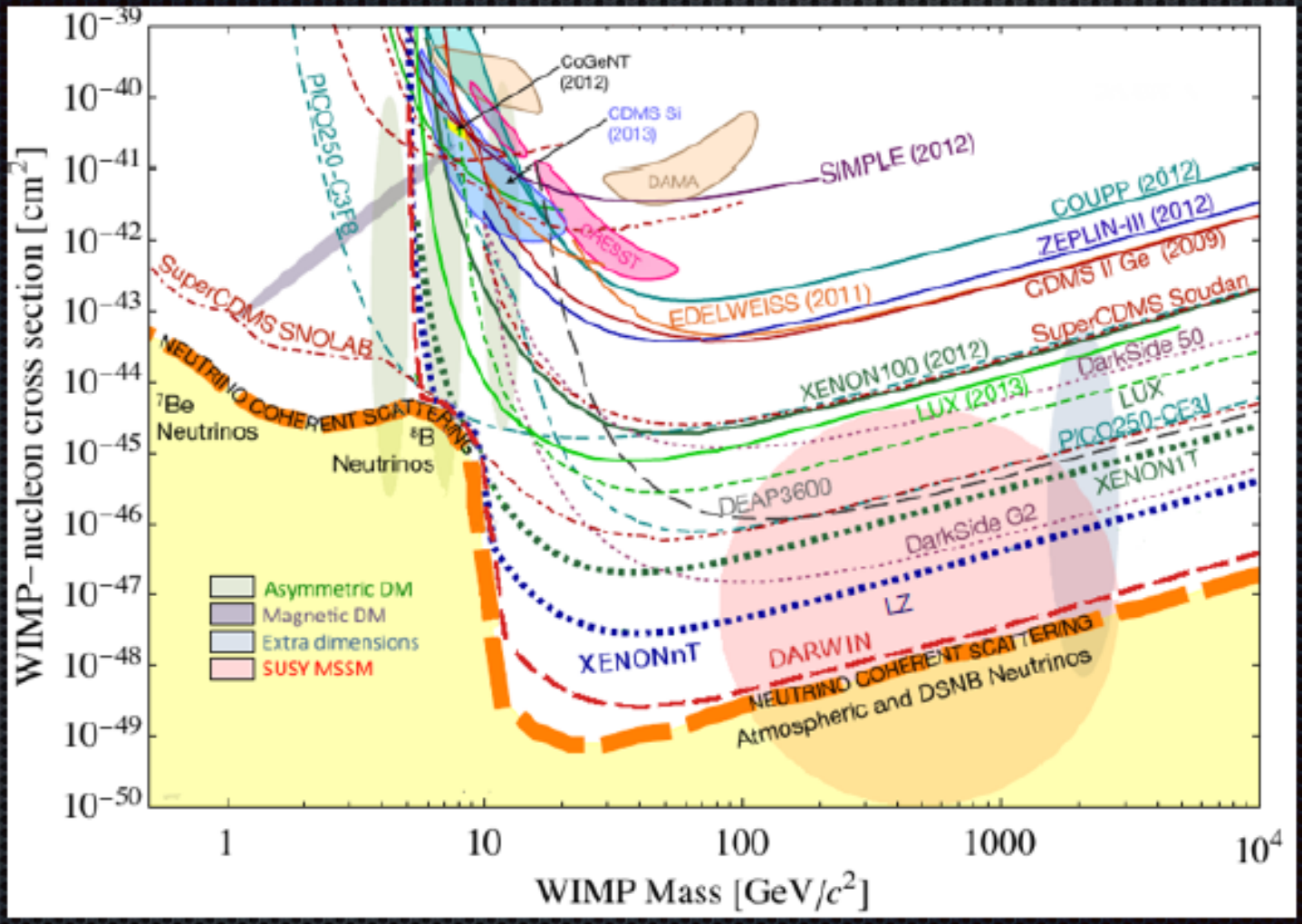
SuperCDMS and LZ are selected for (slow start) construction

ADMX (axion search) is approved; now operating

PICO and DarkSide:

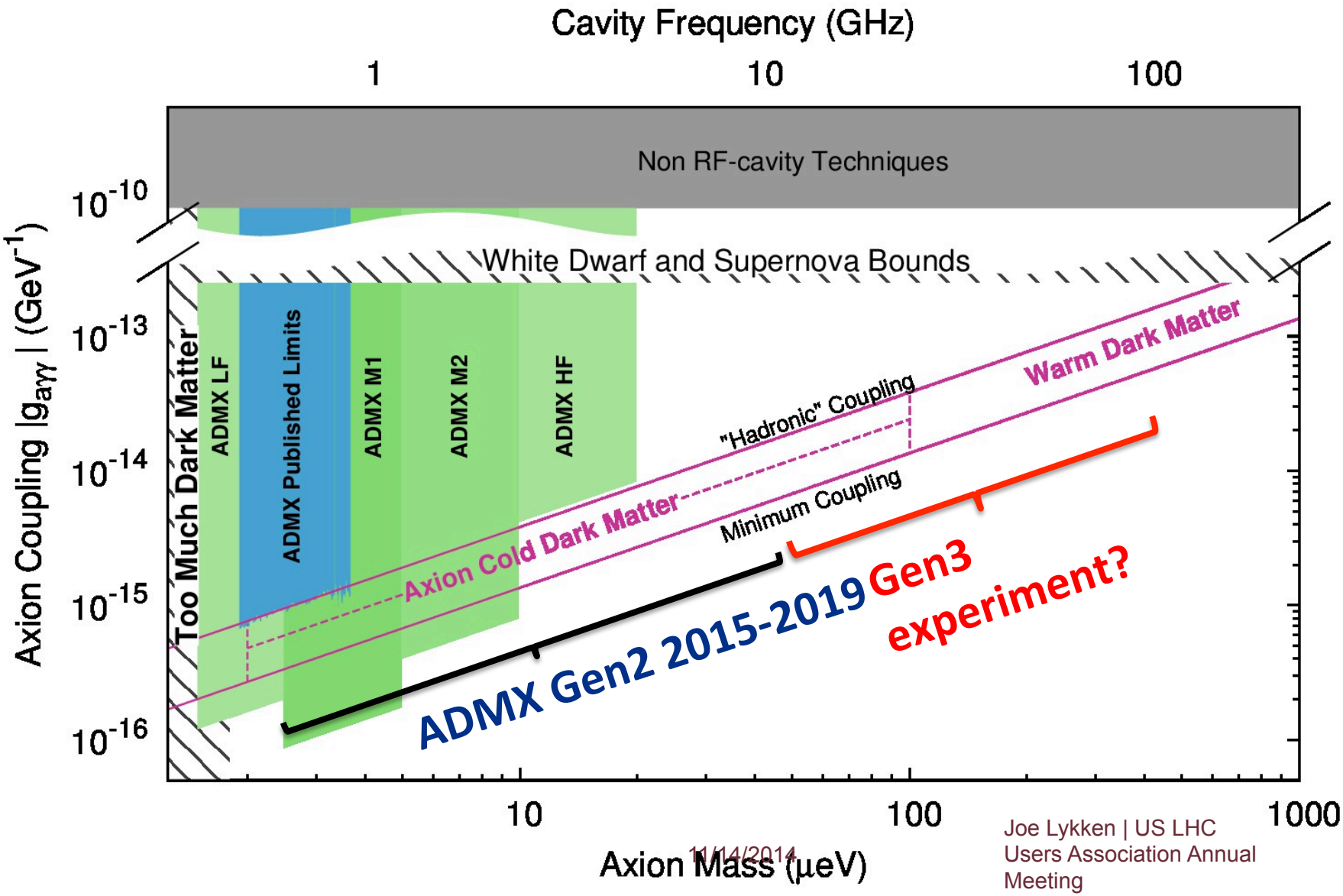
- Operations of current G1 experiments will be supported; importance to G3 is recognized
- Should be an R&D program leading to G3, but not yet funded

Projected Sensitivity of Next Generation Experiments



Axion Dark Matter Experiment

Goal: cover preferred axion mass region from 500 MHz – 10 GHz

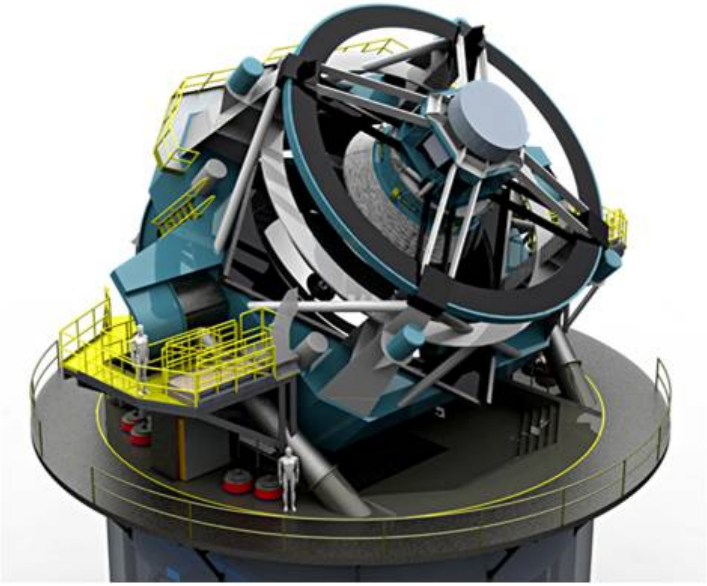


LSST…moving ahead

Like DES but with 10x survey speed, 100x total size

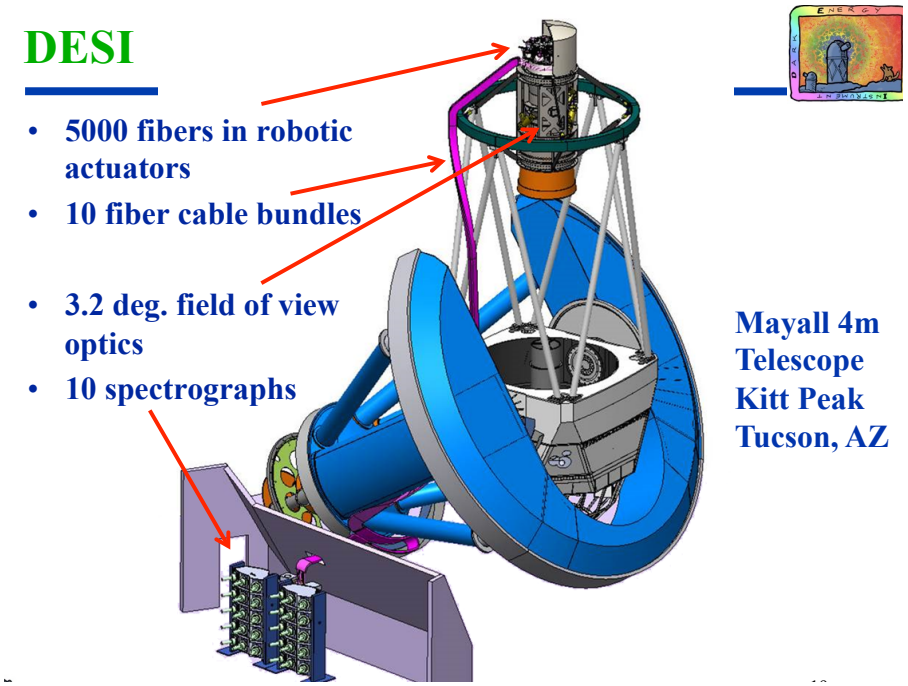
Received DOE CD3a, NSF MREFC approval

Project is starting; expect operations to begin in 8 years



DESI (Dark Energy Spectroscopic Instrument)

- **Science goal:** measure the cosmic distance scale over nearly the entire age of the Universe, constrain neutrino masses and inflation.
- **Technical challenge:** 1m diameter lenses, 5000 robotic fiber positioners
- **FY14 highlights:** 1st Spectrograph ordered, optical design finalized, 1st lens orders placed, fiber positioner selected, passed CD-1 review



Partnerships (currently forming):

DOE Labs: LBNL,FNAL,SLAC,ANL,BNL

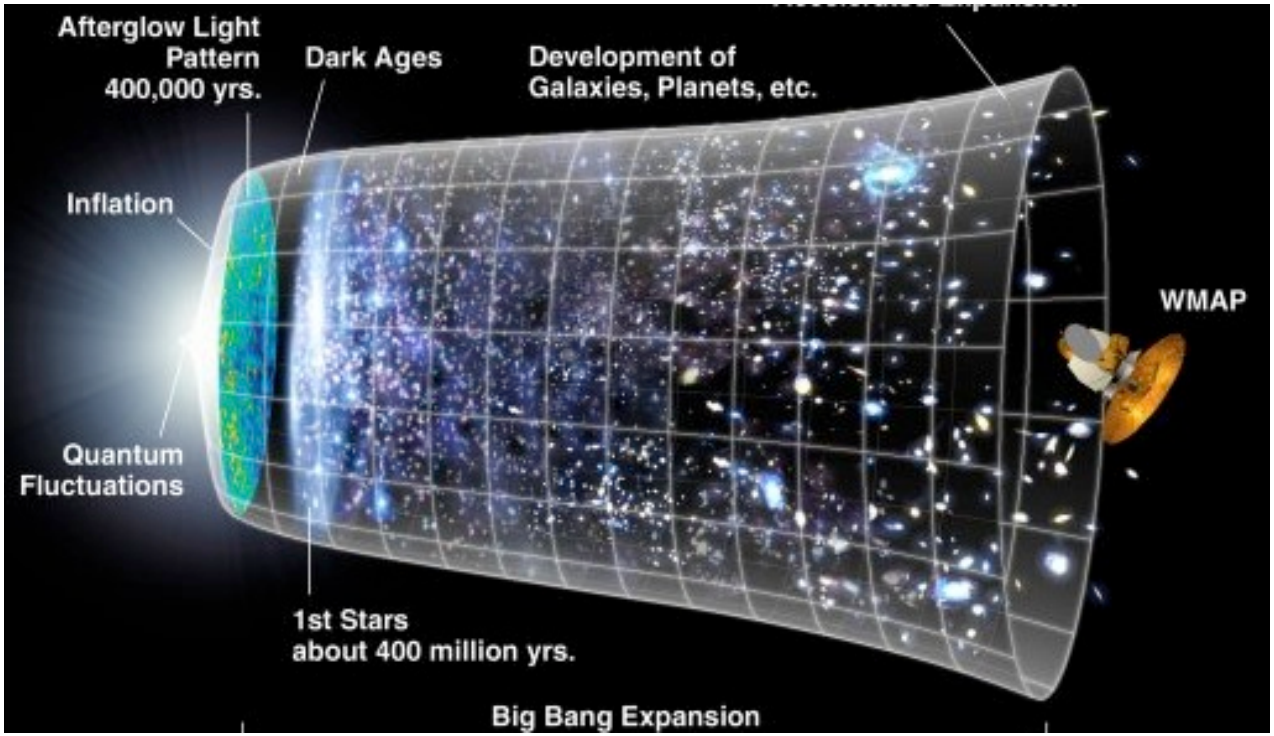
US Universities: 21

International Institutions: 19

New in P5: Cosmic Microwave Background (CMB)

"Support CMB experiments as part of the core particle physics program. The multidisciplinary nature of the science warrants continued multiagency support."

Program will map anisotropy of polarization in primordial radiation at high resolution over wide area of sky



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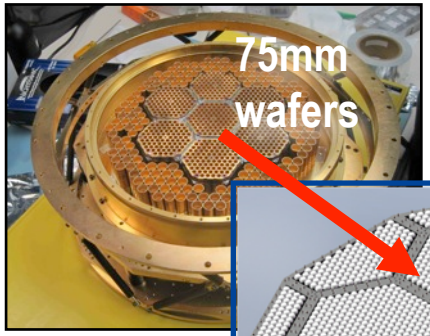
CMB from SPTpol to SPT-3G to Stage-4

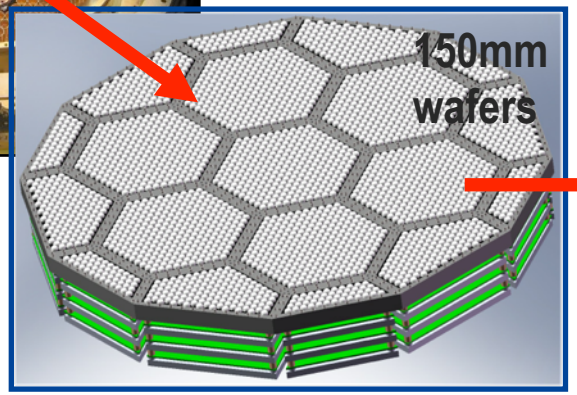
Currently under development: SPT-3G; wide-angle, high-resolution, multi-band survey of CMB polarization anisotropy

Primary technical challenge: increase survey speed with bigger superconducting detector arrays and cameras

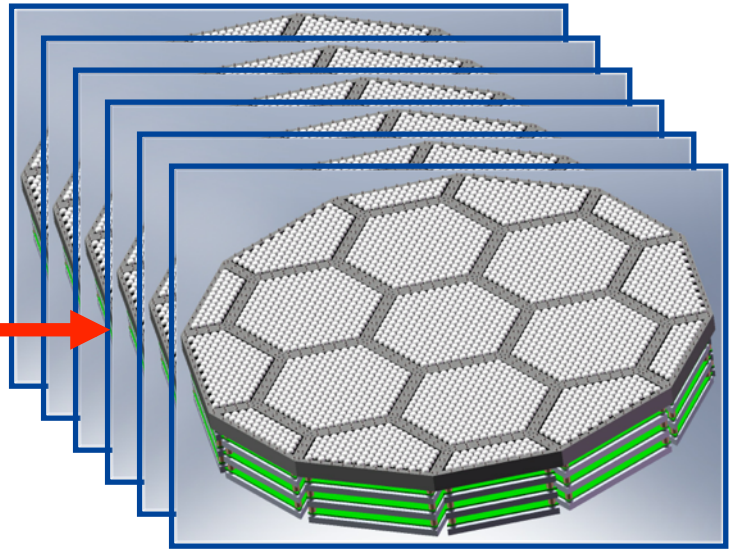
Stage-2
2012: SPTpol
1600 detectors



Stage-3
2016: SPT-3G
15,200 detectors



Stage-4
2020+: CMB-S4
~500,000 detectors



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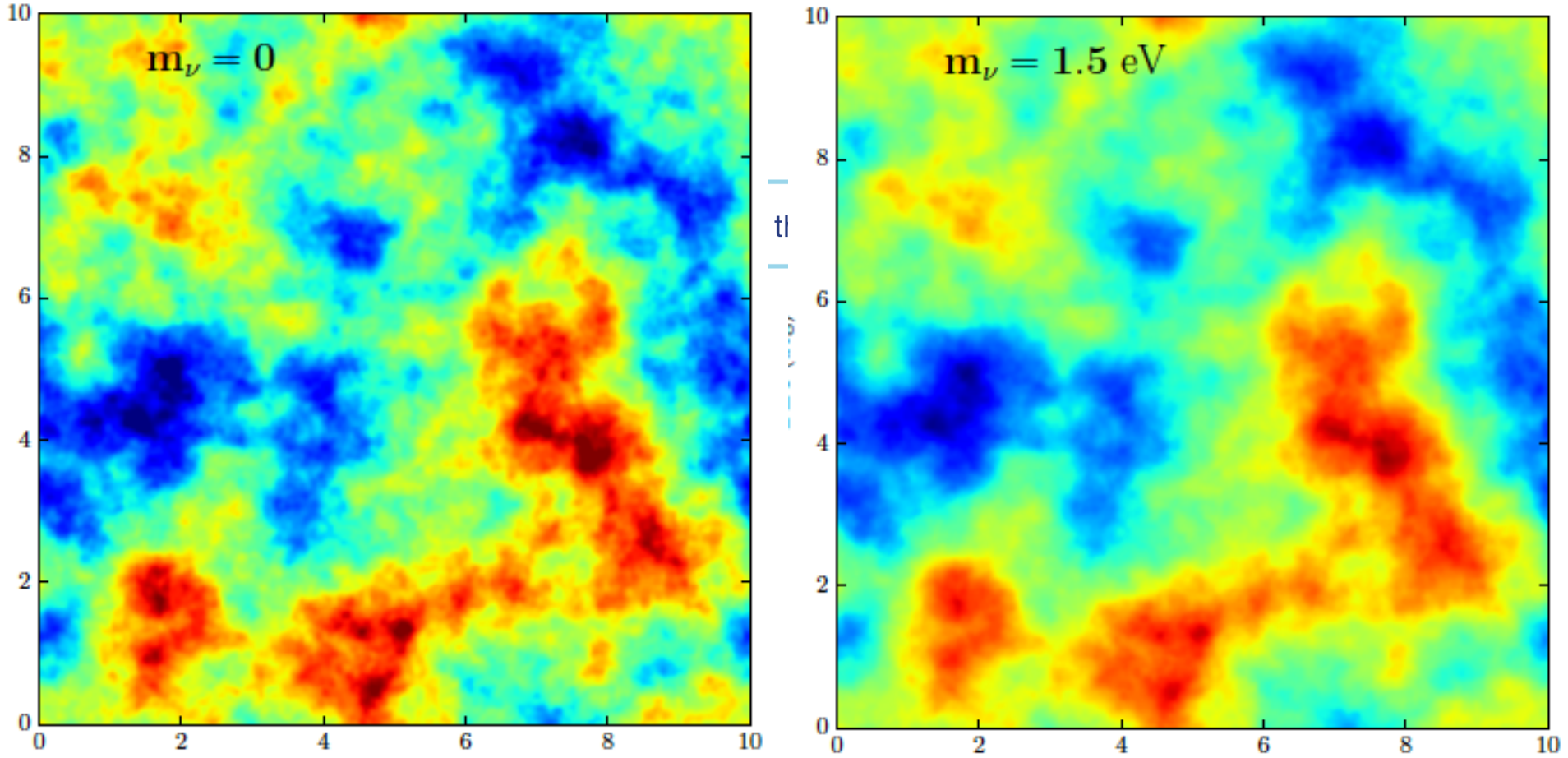
Neutrinos mass and cosmic structure



Simulated maps of the gravitational potential that will be made by observing the distortions produced by gravitational lensing of relic radiation. Massive neutrinos produce a universe with shallower gravitational potential wells

What's happening at Fermilab?

- New senior management
  - Some imported (Canada, Cornell)
  - Some home grown

What's happening at Fermilab?

- New Neutrino Division
  - Grow neutrino program in its own division
    - Gina Rameika is ND head
  - CMS anchors the Particle Physics Division
    - Patty McBride is PPD head

What's happening at Fermilab?

- Aligning with P5 priorities:
  - Project X is gone
  - MAP program winding down
  - No nuSTORM, no ORKA

What's happening at Fermilab?

- Aligning with P5 plan on neutrinos:
  - Encourage formation of a new international collaboration to build large liquid argon detectors at the Sanford Lab in SD
  - Redirecting resources towards creating a megawatt neutrino beam (PIP-II) for LBNF
  - Redirecting resources towards a short baseline neutrino program that advances liquid argon R&D

LBNF and a new international collaboration

- June: CERN Medium-Term Plan (MTP) approved…5 year plan with next year's budget defined…$60M for neutrinos
  - Aimed at neutrino platform to assist with program in US
  - Investment in infrastructure outside CERN allowed
  - No funds for a CERN neutrino beam for at least 5 years
- June 21-22: APPEC Paris meeting…European neutrino physicists & agencies met to discuss future
  - Strong support for accelerator-based neutrinos in US & Japan
- Next meeting at Fermilab in spring 2015
- July 14: Jim Siegrist hosted a meeting at Fermilab of funding agencies….UK, Italy, CERN, India, Brazil, Japan
  - Discussed adapting LHC governance model to LBNF
  - Launch working group to develop international PMP

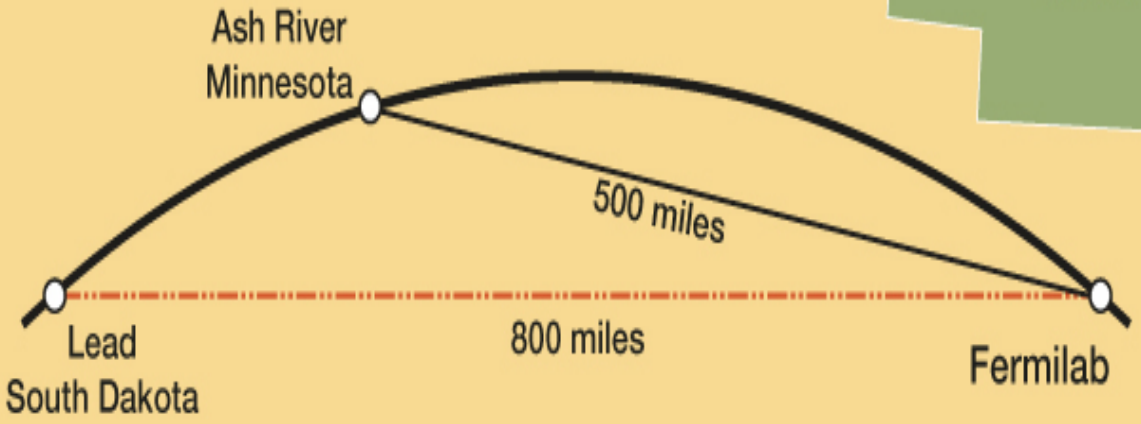
LBNF and a new international collaboration

- July 21-22 Neutrino “summit” at Fermilab
  - Facilitated by Rob Roser and Ken Long
  - World neutrino community represented
  - Recommended creation of Interim International Executive Board (iIEB) to move forward on forming a new collaboration
- Sept. 23-24 First meeting of iIEB at Fermilab
  - Discussed scientific strategy for new experiment
  - Agreed to begin draft LOI aimed at January Fermilab PAC
- Oct 20 Phone meeting of iIEB
  - Agreed on Sanford lab as underground site
  - Agreed to call two open PI meetings to form new collaboration:
    - Dec 5 at CERN
    - Dec 12 at Fermilab

Straight Through the Earth

MINOS	Soudan Mine, MN	2340 ft deep
NOvA	Ash River, MN	Surface level
LBNE	Homestake Mine, SD	4850 ft deep

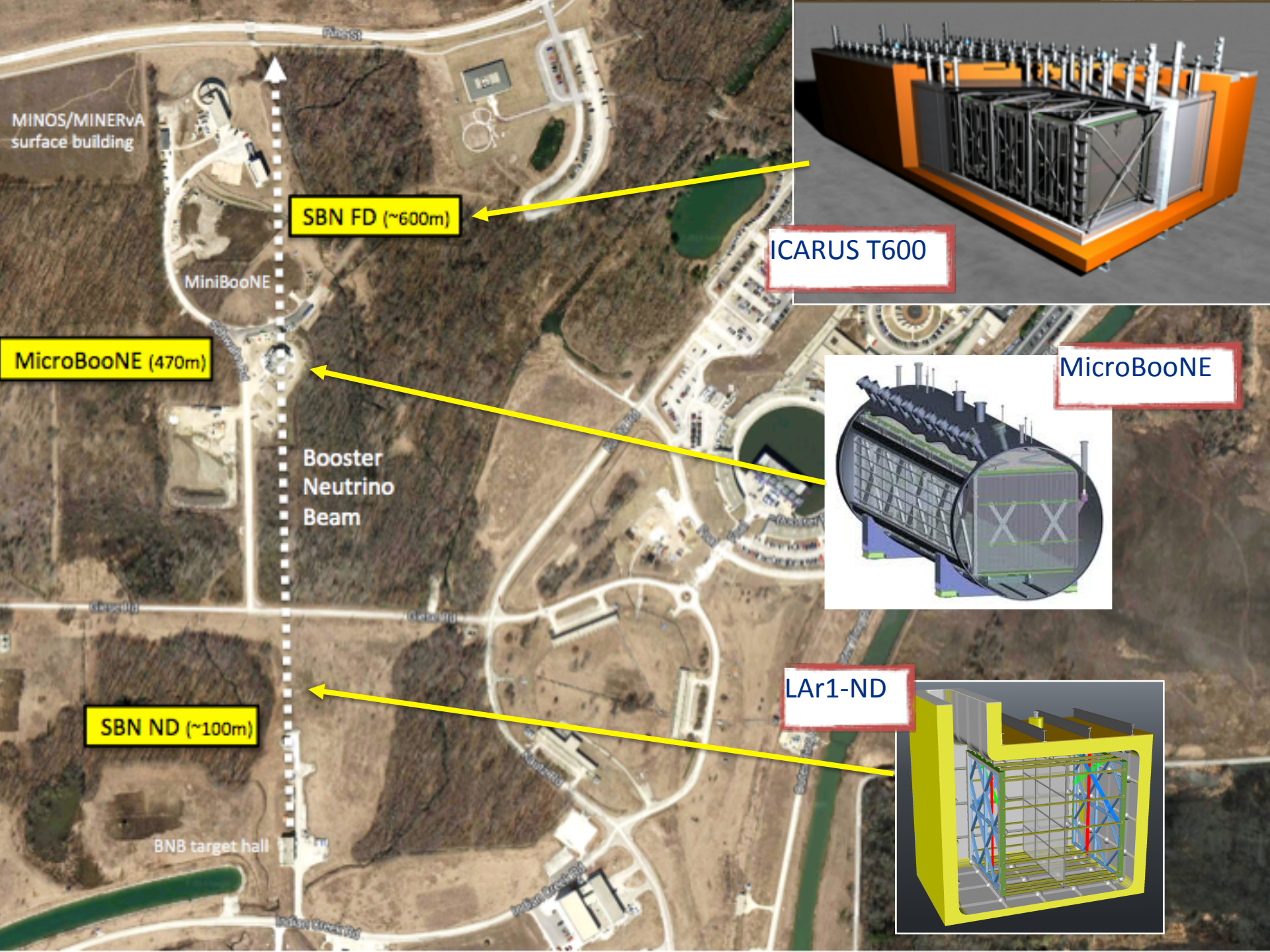
40 fiducial tons liquid argon deep underground



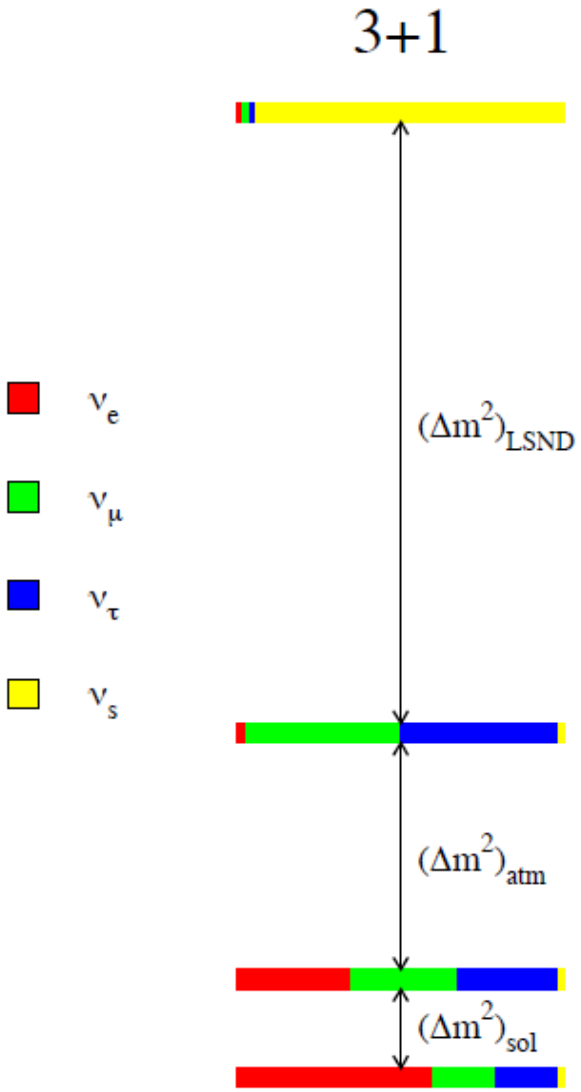
Short Baseline Neutrinos (SBN) at Fermilab

- MicroBooNE experiment begins data taking in a few months
- LAr1-ND recommended as near detector test experiment by Fermilab PAC, R&D towards LBNF detectors
- ICARUS detector coming to Fermilab in 2017 after refurbishing at CERN

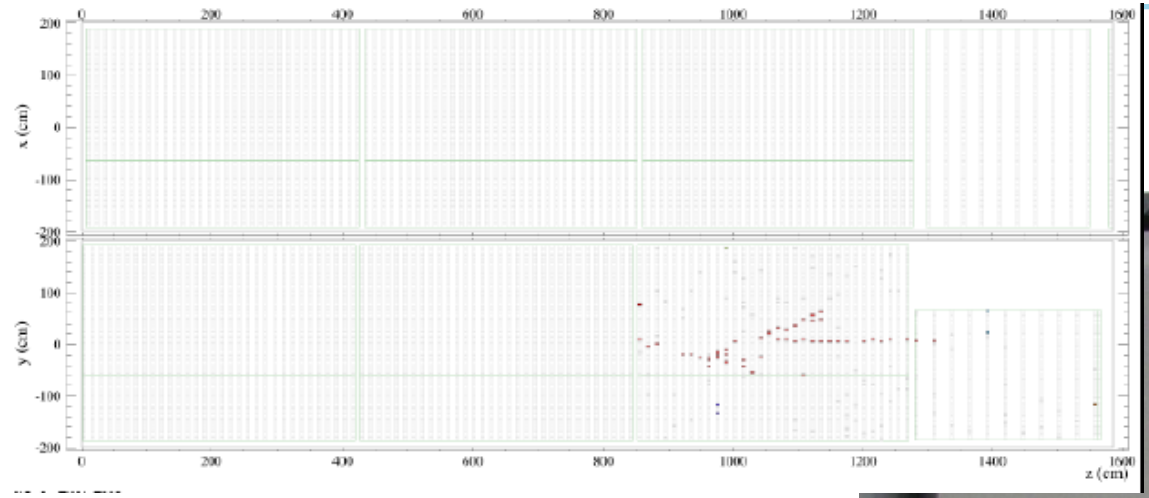
Why is this man smiling?


MINOS/MINERvA
surface building
SBN FD (~600m)
MiniBooNE
MicroBooNE (470m)
Booster
Neutrino
Beam
SBN ND (~100m)
BNB target hall
ICARUS T600
MicroBooNE
LAr1-ND

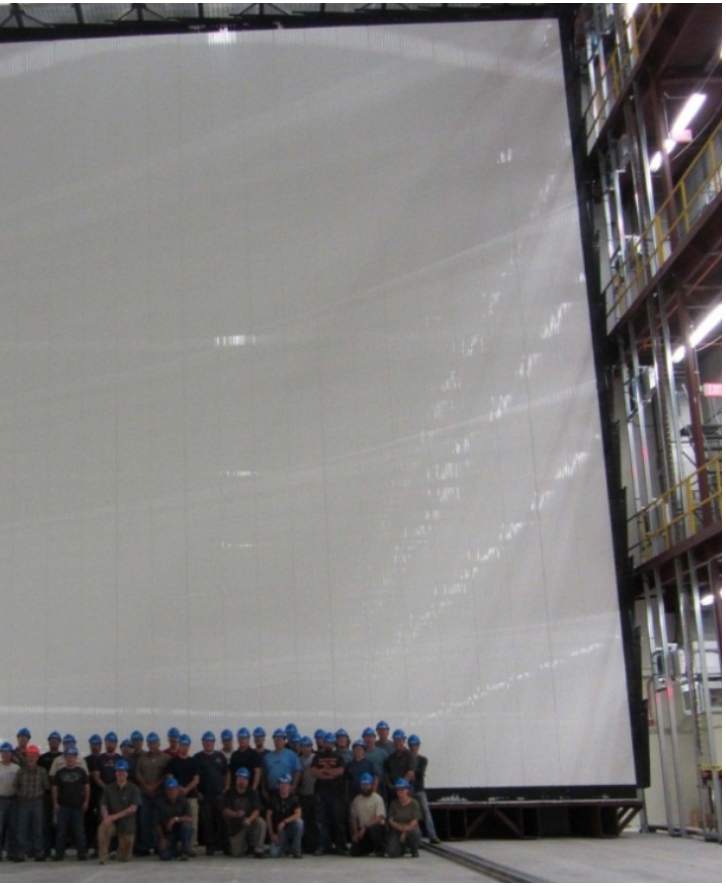
Sterile Neutrinos?



Near & Far Detector up and running : NOvA



Data taking data started



Working toward 700 kW for neutrinos

Fermilab

Muon g-2

- **Science goal:** Measure g-2 of the muon four times more precisely than previous experiments to search for new physics
- **Technical challenge:** Obtaining high field uniformity, delivering new muon beam, measuring muon spin precession to sub-ppm
- **FY14 highlights:** Ring transport from BNL; building complete; cryo plant began construction

Status: Magnet cold and powered next Spring

Operations start: March 2017

Initial run duration: 2-3 years

Partnerships

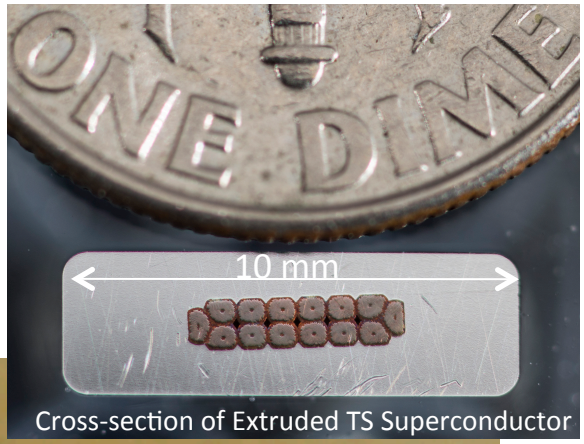
DOE labs: ANL, BNL

U.S. universities: 16

International: 8 countries, 17 institutions

Mu2e

- **Science goal:** Discover charged-lepton-flavor-violation by improving sensitivity by 10^4
- **Technical challenge:** Design and fabricate unique superconducting solenoid system and world's most intense muon beam
- **FY14 highlights:** Completed conductor R&D for procurement (CD-3a), solenoid reference designs, and specified detector technologies



Cross-section of Extruded TS Superconductor


Straw drift-tube for tracker: 5mm diameter, 15 μm walls

Status: CD-2/3b approval expected soon

Operations & Commissioning: 2020

Initial run duration: 5 years

Partnerships

DOE labs: ANL, BNL, LBNL

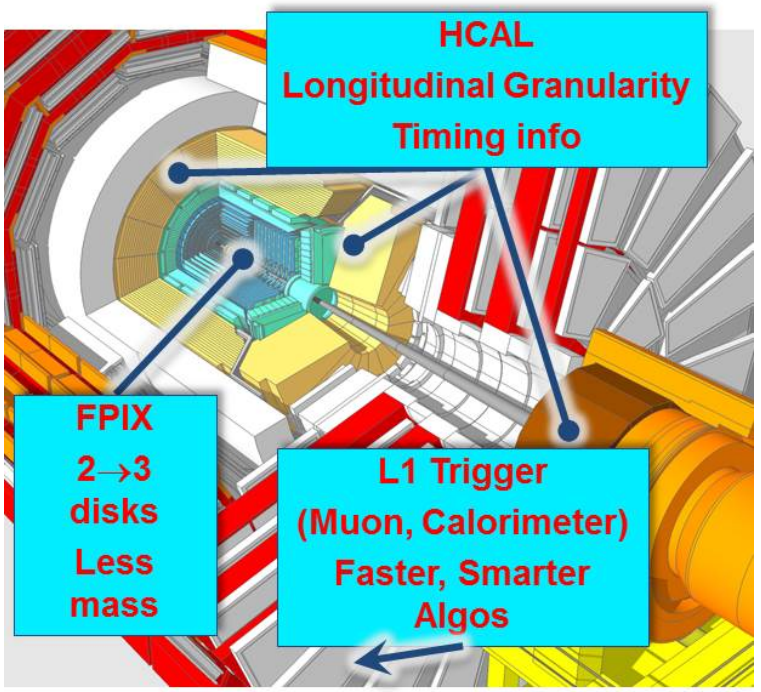
U.S. universities: 16

International: 3 countries, 8 institutions

US CMS Phase I Upgrades

Higgs Boson, Dark matter,
Explore the unknown

- **Science goal:** Exploit the opportunity at the LHC to explore the Energy Frontier
- **Technical challenge:** Create new HCAL front end and backend, Forward Pixel, and L1 Trigger system within the constraints of the LHC schedule while simultaneously operating the current detector
- **FY14 highlights:** Completion of design/prototype phase and Initiation of the fabrication phase



TPC: $42.7M

Status: CD-2/3 approved!

Agencies: DOE, NSF

DOE labs: FNAL

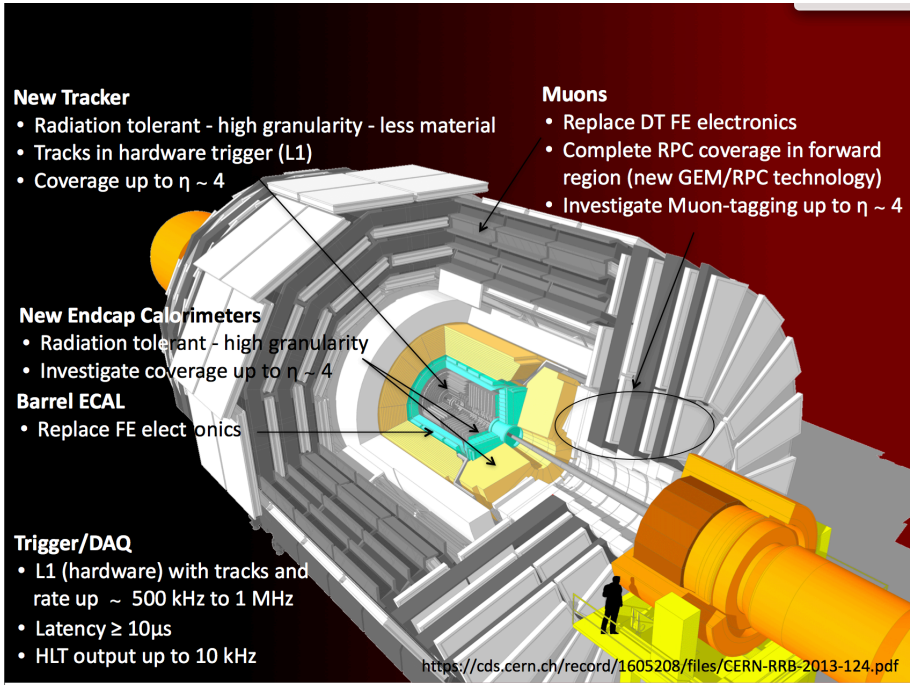
U.S. universities: 30

International: CERN + 130 institutes

US CMS Phase 2 Upgrades

Higgs Boson, Explore the unknown

- **Science goal:** Discovery of new physics, measurement of Higgs boson properties
- **Technical challenge:** Design of a silicon tracker integrated with a L1 trigger and an endcap calorimeter to operate in the high luminosity environment of the HL-LHC.
- **FY14 highlights:** Start up of the Phase 2 R&D program.



TPC: Scope to be negotiated

Status: R&D begun; CD-0 in FY16

Partnerships: DOE, NSF MREFC?

DOE Labs: FNAL

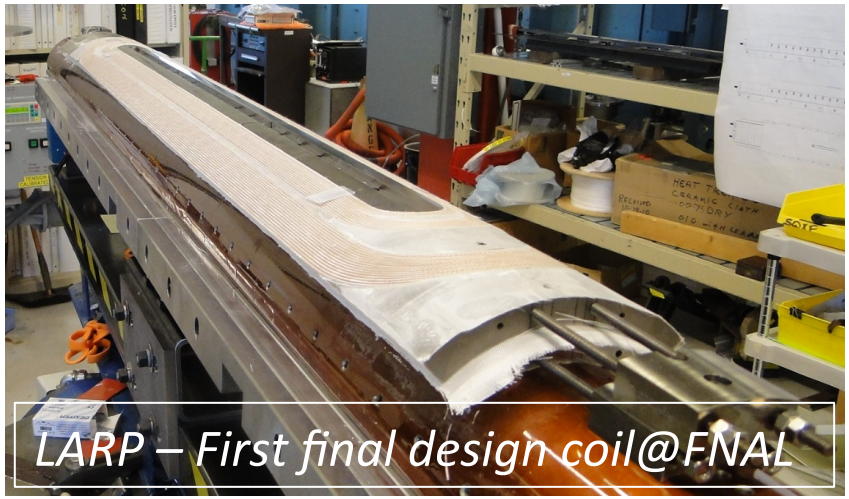
U.S. universities: 47

International: CERN + 130 institutes

Fermilab

LARP/HL-LHC

- **Science goal:** Contribute with leading-edge technology (Nb_3Sn magnets and possibly crab cavities) to the HL-LHC
- **Technical challenge:** Develop first accelerator-quality Nb_3Sn focusing quadrupoles.
- **FY14 highlights**: Consistently reached 170 T/m in recent models. Essential means to high luminosity for LHC.



LARP – First final design coil@FNAL

TPC: LARP $48M

HL-LHC scope to be negotiated

Status: pre-CD-0 (LARP Phase)

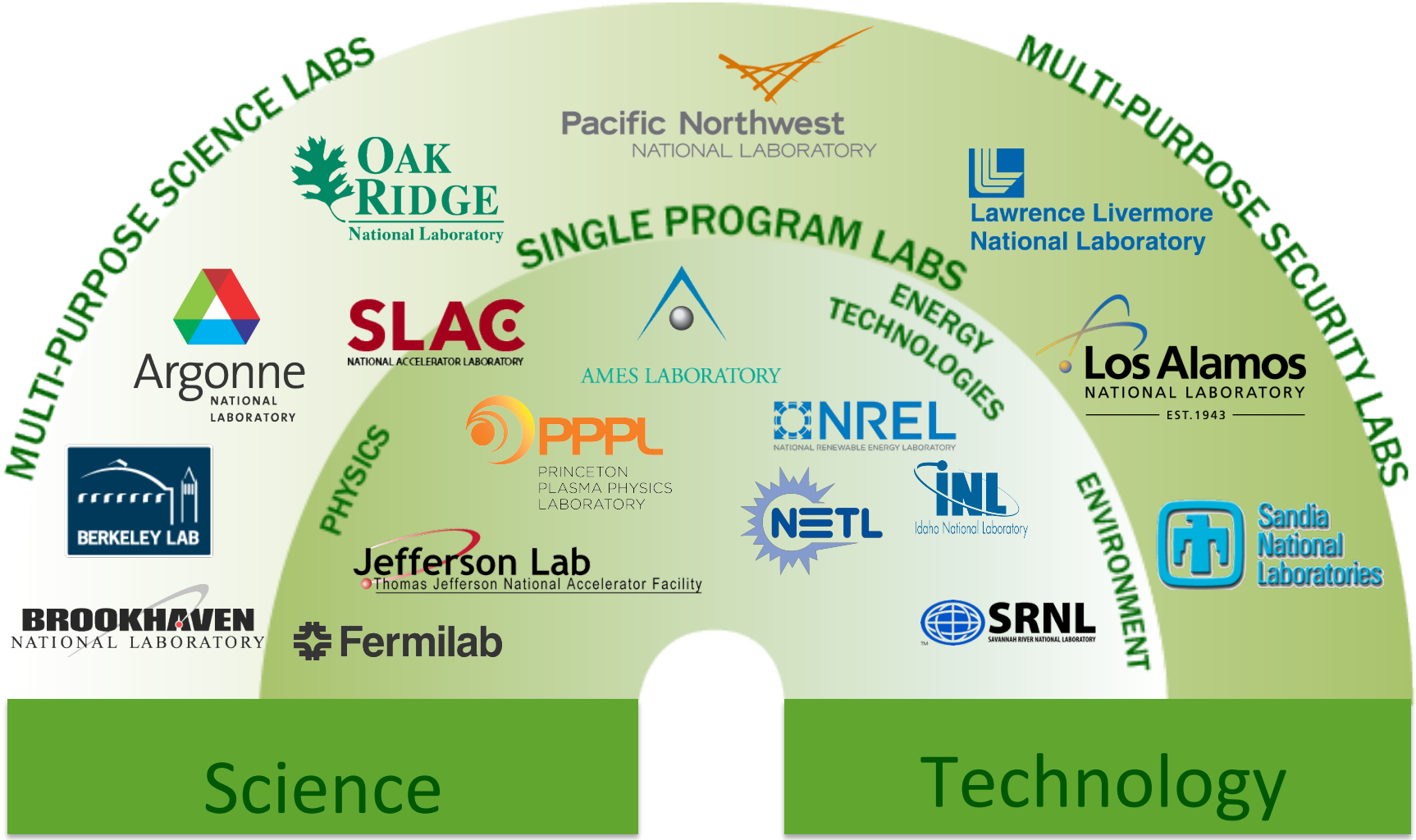
Partnerships

DOE labs: BNL, LBL, SLAC

U.S. universities: ODU (JLab)

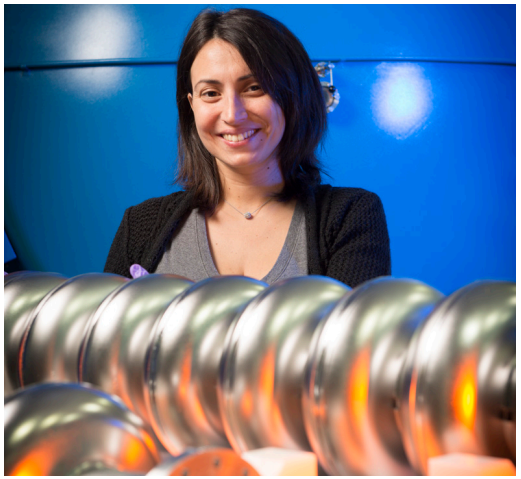
International: CERN

The National Labs as Networks



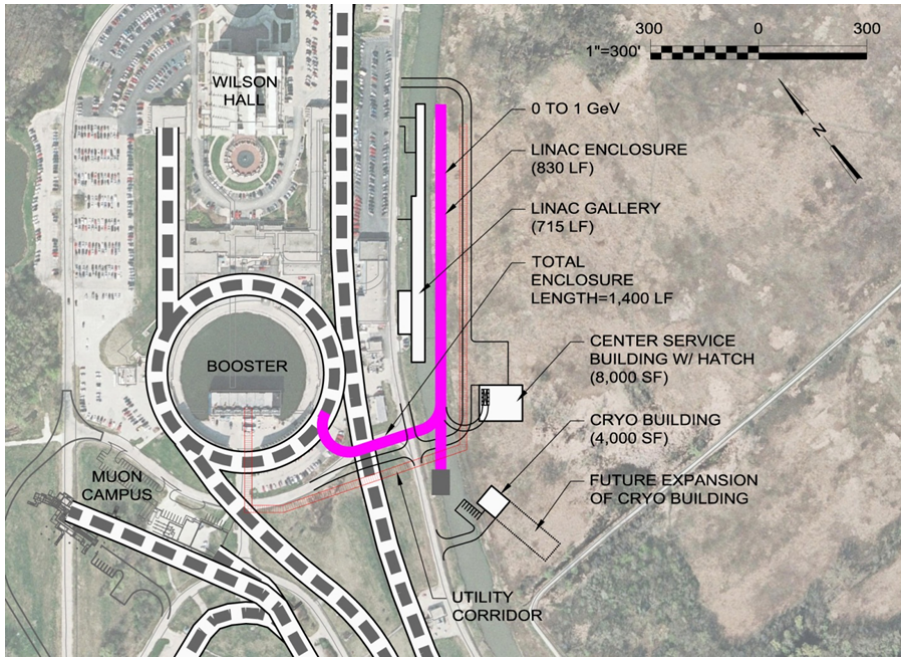
The National Labs as Networks - Example: LCLS-II

- Fermilab, Argonne, Jefferson Lab, and Berkeley Lab all working to build the next generation LCLS-II light source at SLAC
- Fermilab's leading expertise in superconducting accelerator technology (SRF cavities and cryomodules) is essential
- Highest gradient cryomodule in the world is at Fermilab
- Highest Q cavities in the world are at Fermilab



The National Labs as Networks - Example: LCLS-II

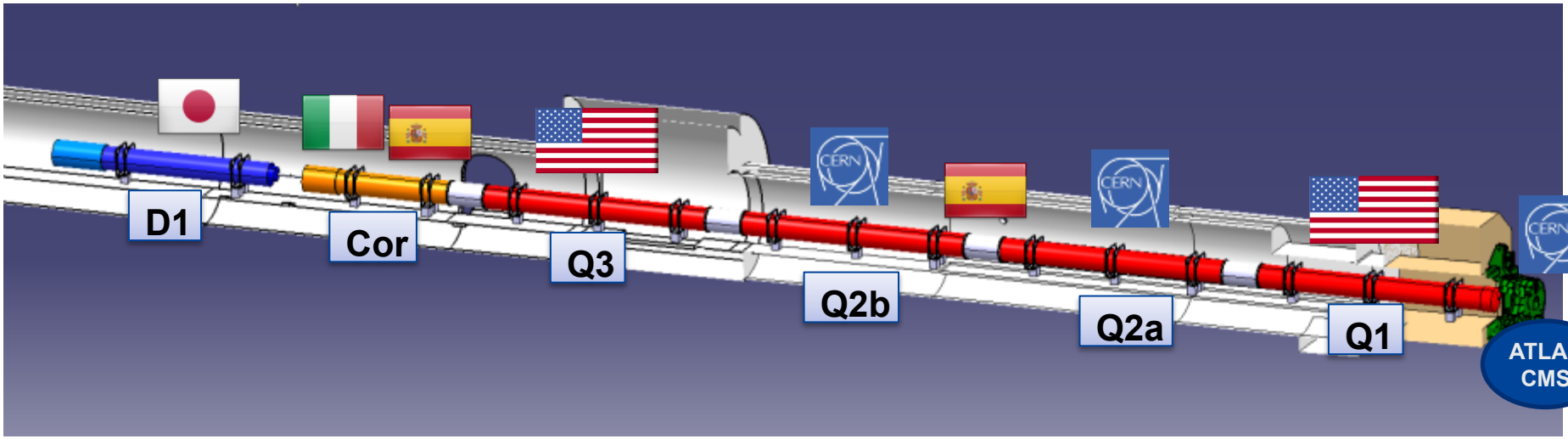
- Fermilab technical capability developed for ILC now enables the highest priority project of the DOE Office of Science
- After LCLS-II is done, keep building cryomodules, but now they are for the PIP-II accelerator upgrade at Fermilab
- Enables the world's most powerful neutrino beam



Fermilab

The National Labs as Networks - Example: HL-LHC

- Fermilab, Argonne, and Berkeley Lab all working on HL-LHC accelerator upgrades
- Part of a larger international network of labs



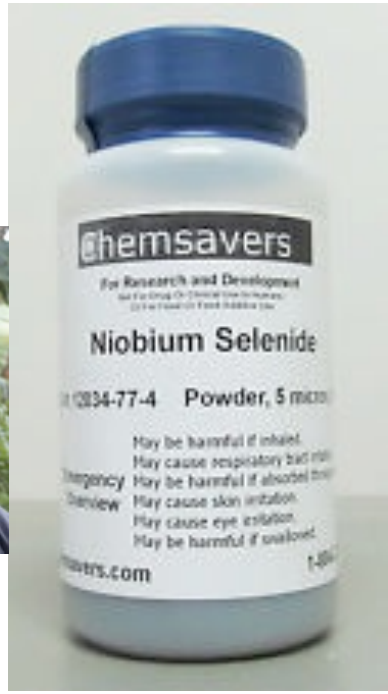
Trivia Question

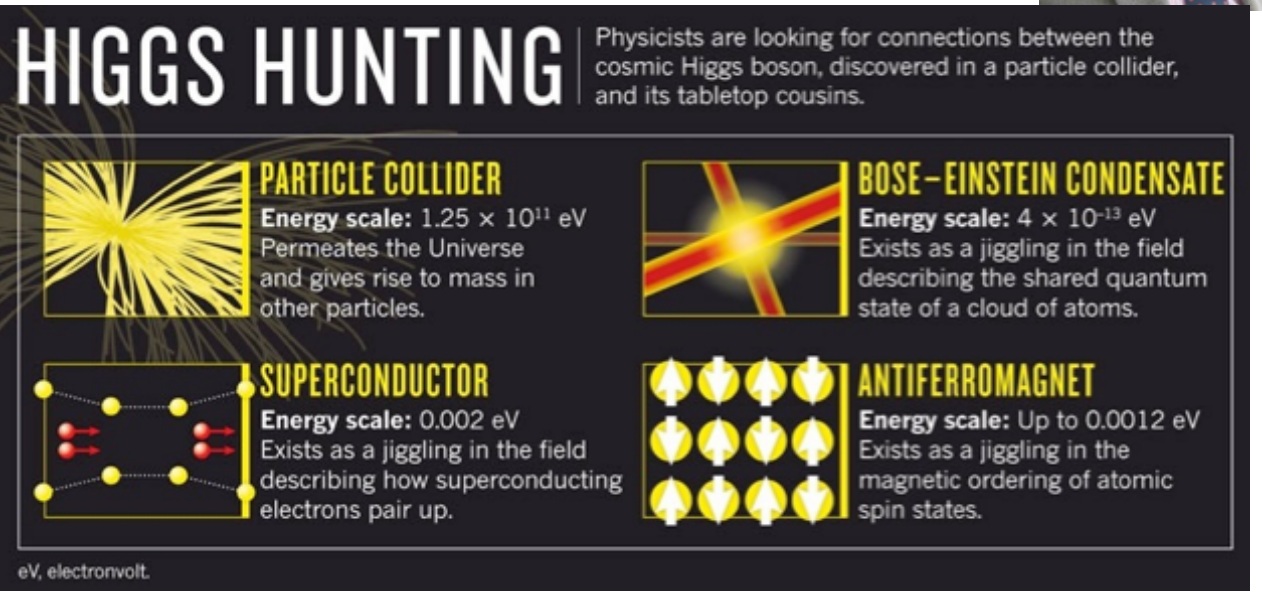
What do these two people have in common?

Lab Director Peter Littlewood

Lab Director designate Fabiola Gianotti

Answer: They both discovered a Higgs boson





Peter Littlewood and Chandra Varma discovered a Higgs “radial” mode in niobium selenide superconductor, 1981

The future has begun