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Perspectives in Particle Physics

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DIS 2015

1 May 2015

Perspectives on Particle Physics today

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

US High Energy Physics Strategic Plan: P5

The P5 report completed in 2014 outlines a strategic plan for U.S. High Energy Physics that is executable over 10 years and prepared in the context of a 20-year global vision.

- Note: P5 Plan does not include Heavy Ions, JLab, NLDBD but does include Astroparticle physics, DM, and DE

The plan was formulated by a panel of 25 scientists

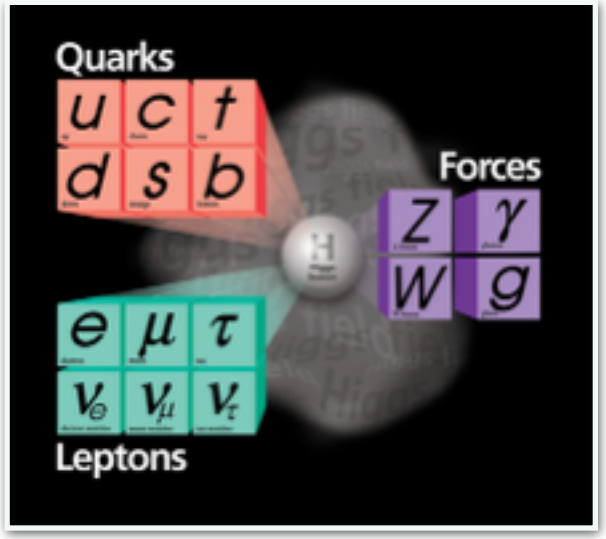
5 international members from Canada, Europe, Japan took part in the panel process

Chaired by Steve Ritz (UCSC)

"Particle physics is global. The United States and major players in other regions can together address the full breadth of the field's most urgent scientific questions if each hosts a unique world-class facility at home and partners in high-priority facilities hosted elsewhere." (P5 report)

Particle Physics Science Drivers

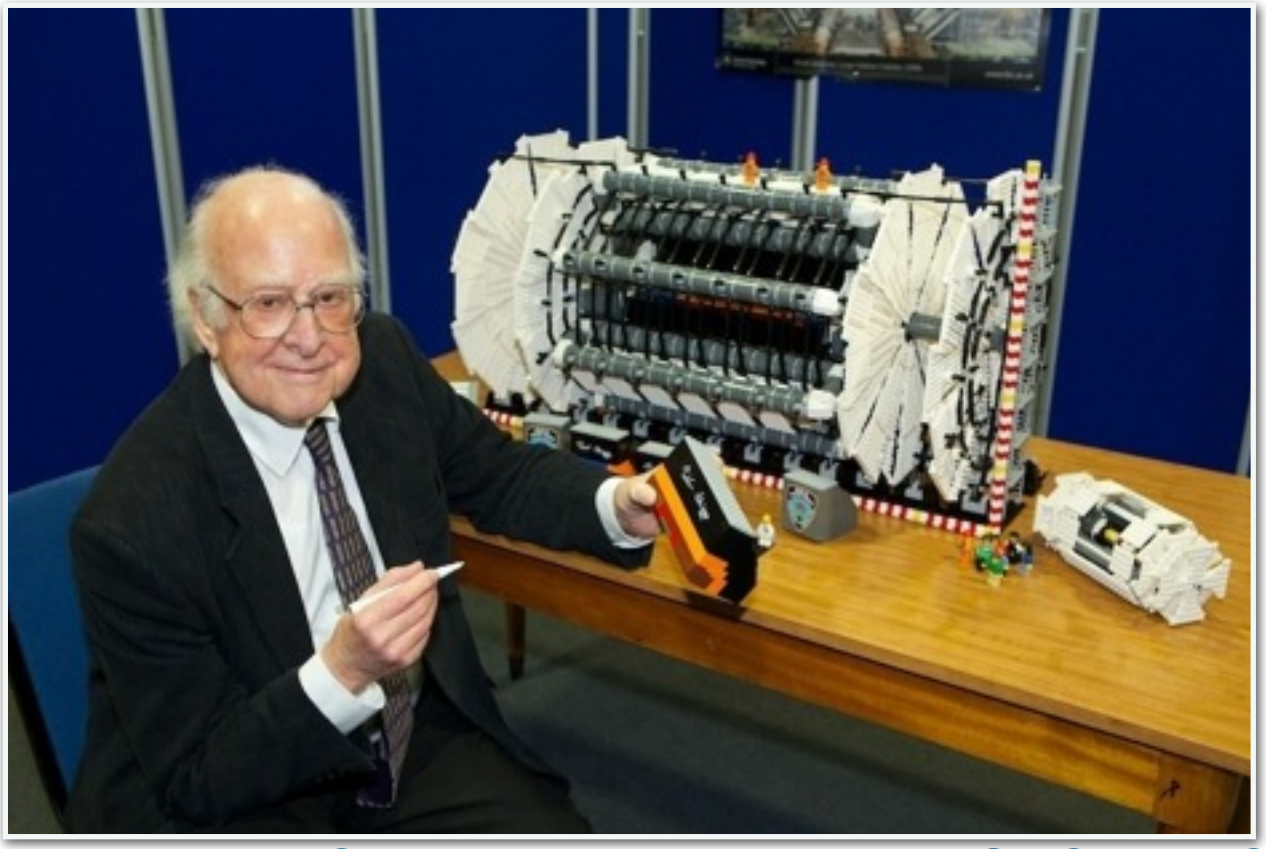
- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation
- Explore the unknown: new particles, interactions, and physical principles



- What is the P5 Plan telling us:
  - Continue U.S. commitment and leading roles in the LHC
  - Build a neutrino program at Fermilab that will attract the world community
  - Continue U.S. leading efforts in dark matter, dark energy, and cosmic microwave background
  - Invest in the accelerator and detector technologies that we will need in the future

  (by no means a complete list)

Use the Higgs boson as a new tool for discovery



More than 1000 U.S. scientists collaborate on CMS/ATLAS

The planned LHC and HL-LHC program extends until 2035.

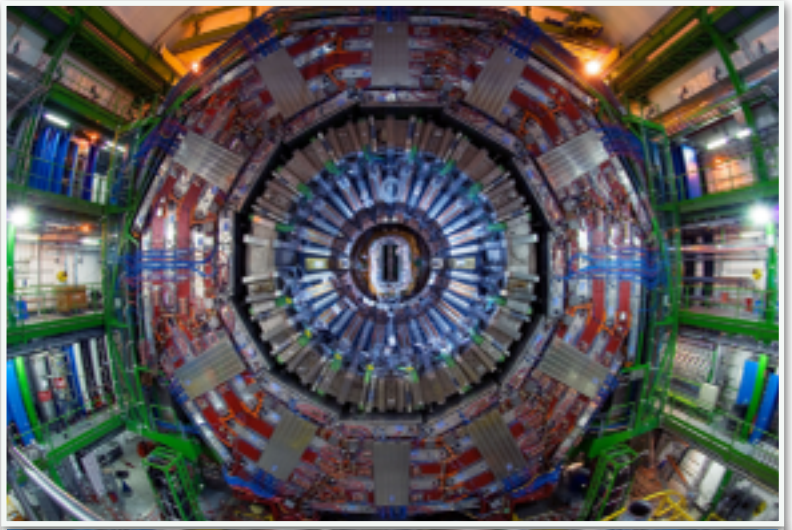
U.S. Participation in the LHC

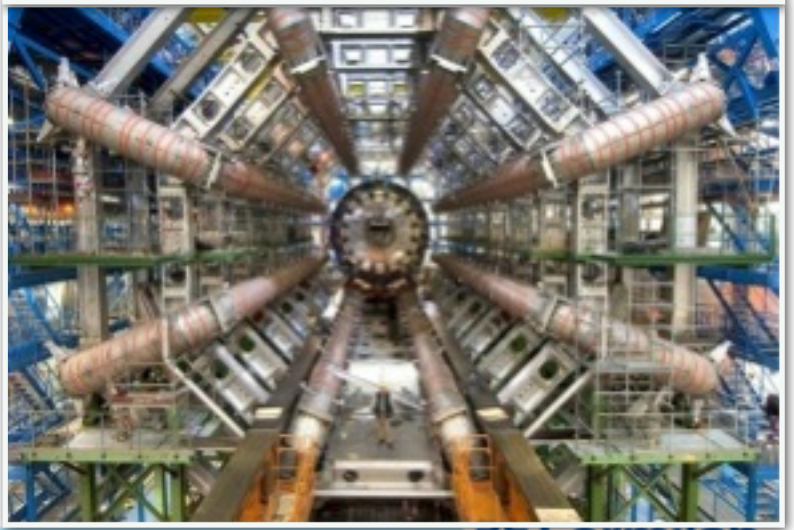
- LHC is expected to be a part of the U.S. program for next ~20 year.

- **LHC will resume operations in May–June 2015 at collision energies of 13 TeV**
  - Increase the reach of searches for new physics
    - **SUSY, DM, and extra dimensions**

- **U.S. active in the Phase-1 upgrades of the ATLAS and CMS detectors (now-2018)**
  - construction has begun

- **High luminosity to LHC will extend the discovery potential (HL-LHC 2025-2035)**
  - Increase LHC luminosity by a factor of 10
  - Explore new physics and new dynamics for *W/Z*, top, and Higgs at TeV energies
  - Discussions ongoing on the U.S. in the HL-LHC detector upgrades



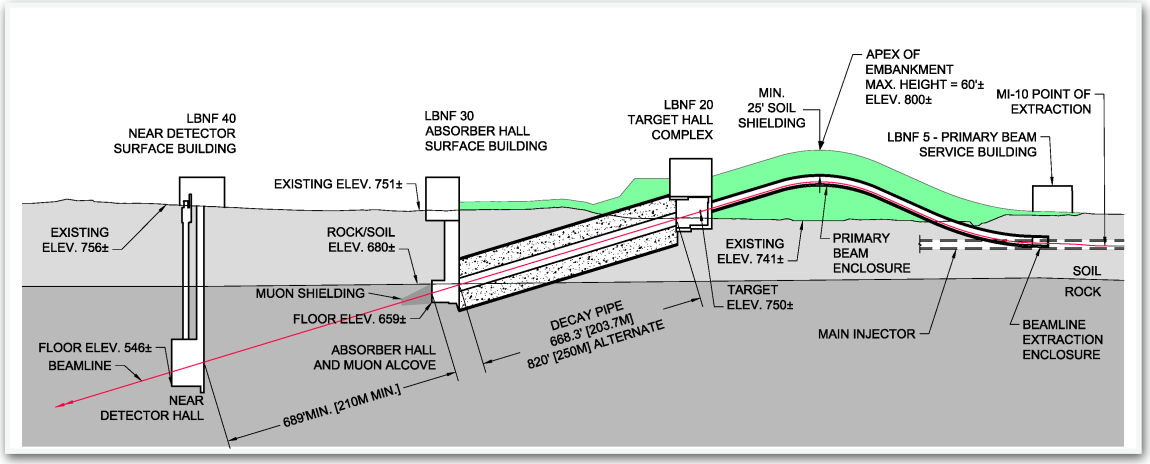


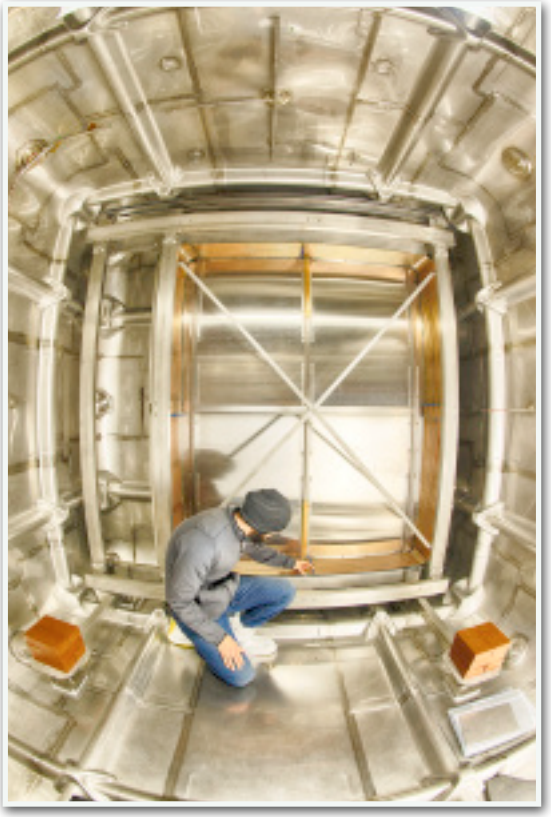
The High Luminosity LHC Upgrade

- Major R&D goal: Design the next generation interaction region quads for the LHC. (LARP Program)
  - The original IR quads, which Fermilab built, will reach their end of life due to radiation damage in perhaps ten years.
  - Increased luminosity demands large aperture quadrupoles at comparable gradients.
    - Larger aperture leads to much higher magnetic fields at the coils.
    - NbTi will not meet the needs.
- US Acc. R&D(LARP) focus is Nb_3Sn IR quadrupole magnets.
  - Builds on the development of the Nb_3Sn strand and cable technology from the High Field Magnet R&D program

Looking ahead: **Future high energy colliders** will be expensive and complex. *Optimization studies will be key* to lowering the construction cost and maximizing the operating efficiency. Optimized superconducting magnet design both in field intensity and manufacturability will require R&D for a very high-energy proton-proton collider. For e^+e^- colliders, more efficient RF sources as well as much higher accelerating gradients could lower operating costs.

Pursue the physics associated with neutrino mass





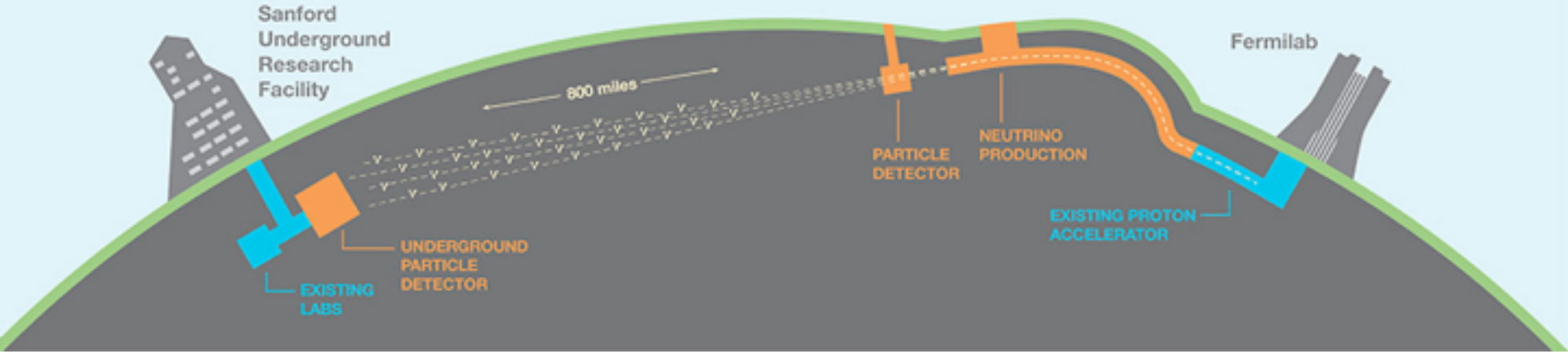
Long Baseline Neutrino Facility (LBNF)

- P5 Recommendation
  - 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 [of the report]. LBNF is the highest-priority large project in its timeframe.

Fermilab has taken on this challenge to become the accelerator center for neutrino science that can engage the worldwide community.

Neutrinos go global into the 2020s

DUNE experiment 750 scientists from 23 countries



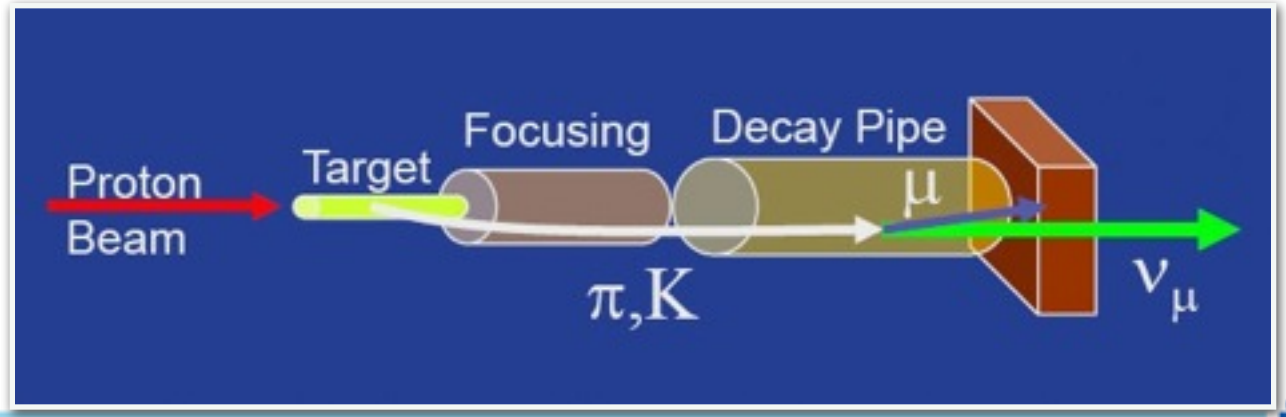
- Long Baseline Neutrino Facility (LBNF) - A Global Next Generation Facility for Neutrino and Underground Science
  - an intense beam of neutrinos produced at Fermilab in Illinois are sent to the Deep Underground Neutrino Experiment (DUNE) at the Sanford Underground Research Facility in South Dakota.
  - for the first time in its history the U.S. will host a large scale science facility that is international (global) from the start.

High level agreement on scope by collaboration

- A (staged) 40 kiloton liquid argon detector 1300 kilometers from Fermilab at the 4850 level at Sanford facility S.D.
- The first 10 kiloton detector underground as soon as possible
- A high precision “near” detector on the Fermilab site
- Exposed to 1.2 MW tunable energy neutrino beam produced by the PIP-II upgrade at Fermilab.

Neutrino beams from accelerators

- Fermilab already makes the world's most powerful neutrino beams.
- There are plans to significantly increase the beam power in the future.



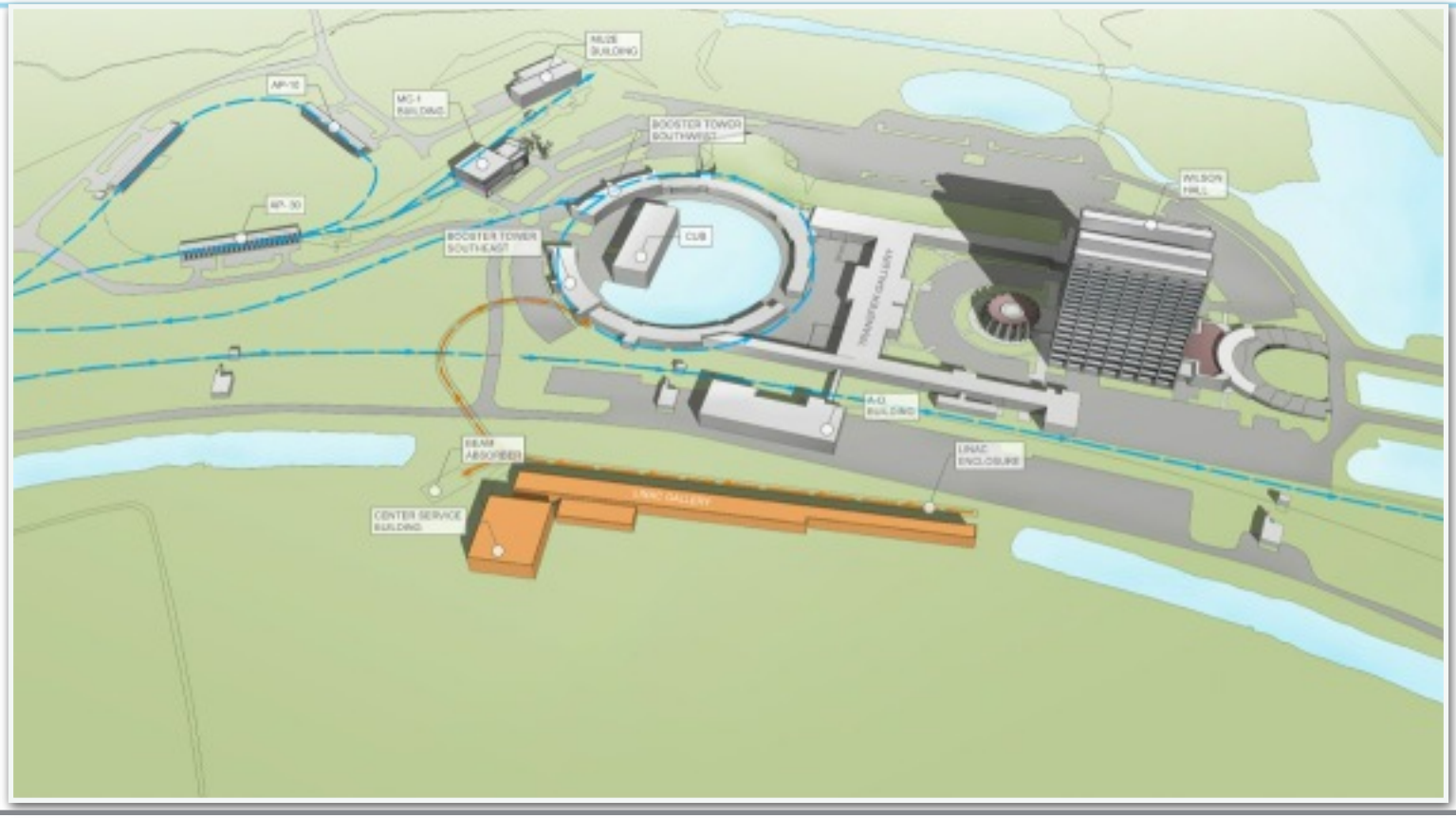
PIP-II accelerator upgrade at Fermilab

P5 Recommendation 14:

> "Upgrade the Fermilab proton accelerator complex to produce higher intensity beams. R&D for the Proton Improvement Plan II (PIP-II) should proceed immediately, followed by construction, to provide proton beams of > 1 MW by the time of first operation of LBNF"

- PIP-II will allow Fermilab to maintain the lead with the most powerful neutrino beam in the world
- R&D for PIP-II is well along…a start-of-the-art superconducting linear accelerator using SRF technology developed at Fermilab

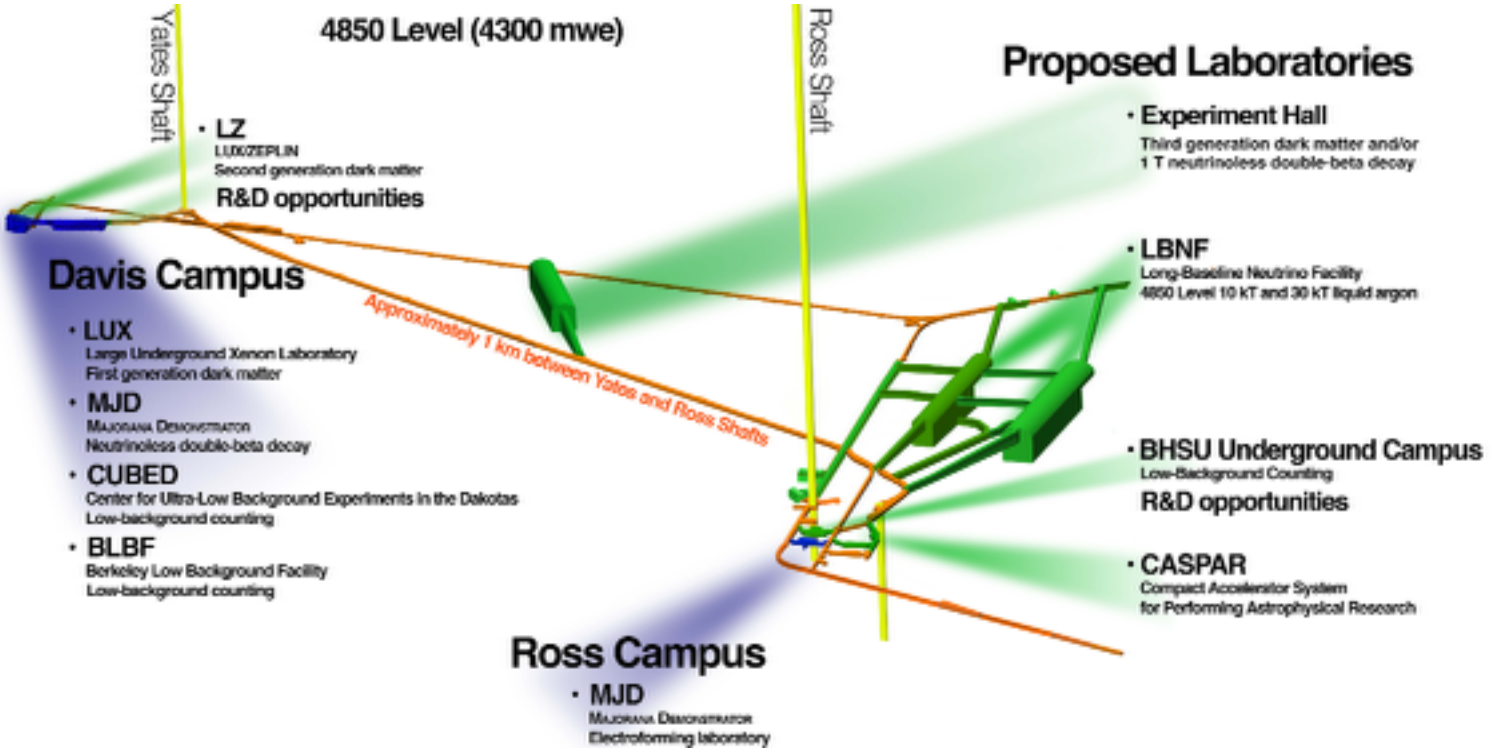
PIP-II Site Layout (provisional)



R&D opportunities: For the Intensity Frontier, the neutrino physics performance measure is: MW•Ktons•beamtime/yr
so *producing higher beam power has significant leverage*. Beam stability at synchrotron injection energies combined with higher power targets could have large benefits, motivating investments in the IOTA R&D facility and MW Targetry.

LBNF Caverns at the Sanford Underground Research

- Currently the Yates shaft serves the LUX and Majorana Demonstrator experiments in the Davis Campus area
- Ross shaft rehab (funded by South Dakota) ~50% complete



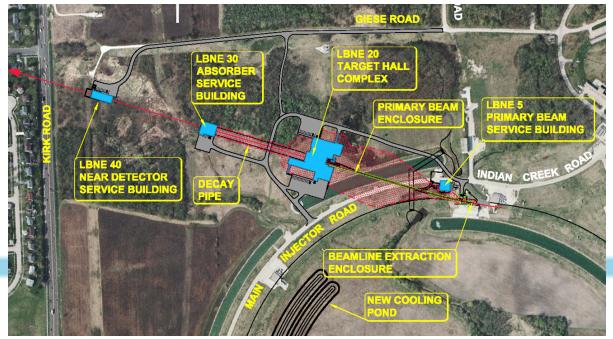
Ross shaft rehab

- South Dakota legislature just appropriated another $4M
- Working two 12 hour shifts/day in order to be done by 2017

LBNF major components:

- **Far site detector infrastructure at the Sanford Underground Research Facility:** (planning for CD2a/CD3a approval of major far site infrastructure in November 2015)
  - Surface cryogenics in a new building next to the Ross headframe
  - Utilities (including liquid nitrogen and argon) passing down the Ross shaft
  - Caverns and drifts on the **4850 foot level** (and below)
  - CF utilities, cryogenics, and LAr purification in a central cavern
  - Four detector pits with 10 kiloton fiducial cryostats
  - Laydown space for installation

– **Beam Line at Fermilab**:



The LHC model for LBNF/DUNE

We are adapting the LHC model, with an international detector collaboration, a host lab providing infrastructure, and appropriate international oversight bodies

- The detector project(s) are led by the DUNE collaboration, with appropriate oversight by stakeholders (including DOE)
- The LBNF facility infrastructure is a DOE/Fermilab project, in collaboration with international partners
- Additional coordination and oversight is provided by:
  - International Advisory Cmte (regional funding agency reps, forming now)
  - Resource Review Board (to be formed later this year)
  - Experiment-Facility Interface Group (operating since Jan 2015)
  - Long Baseline Neutrino Committee (formed last month)

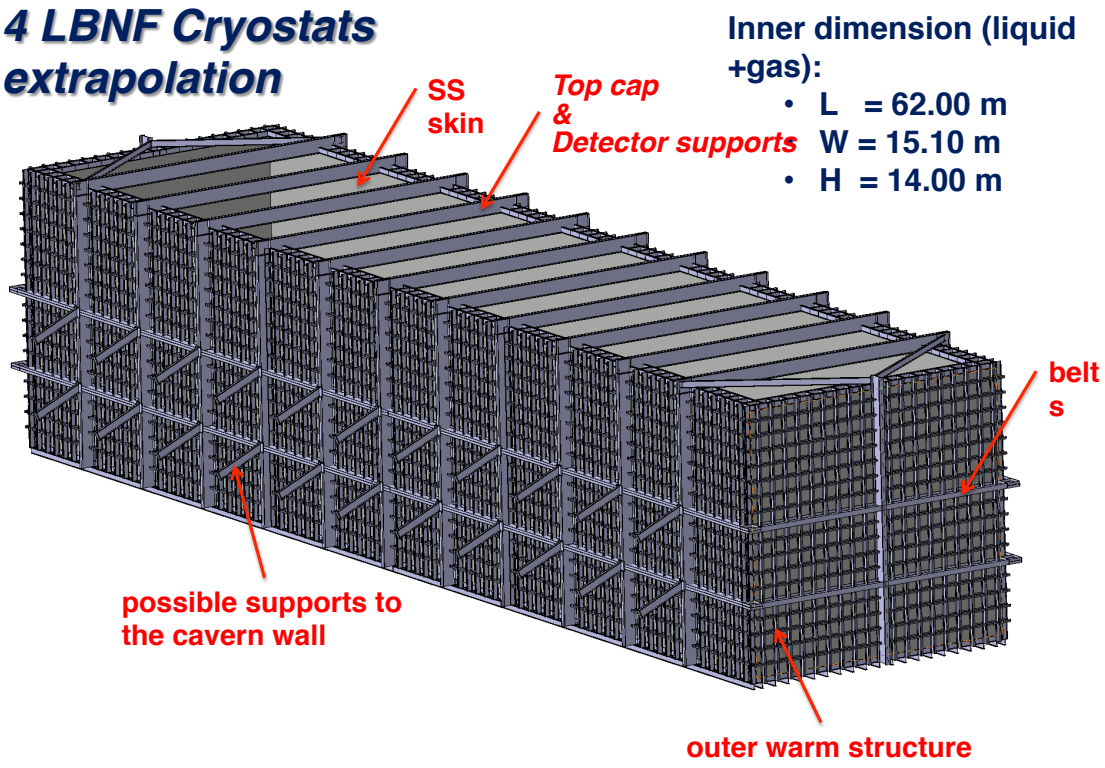
CD-1-R Internal Milestones

★	**18 March**	**DUNE Technical Coordinator Named** ✔
★	**24 March**	**Task Force Conveners Named** ✔
★	**31 March**	**CD-1 Document Scope Defined** ✔
★	15 April	Zeroth-order Draft of CD-1-R Documents ✔
★	16-18 April	First DUNE Collaboration Meeting ✔
★	19 April	First full LBNC Meeting ✔
★	5 May	First CD-1-R draft for review by project office
★	19 May	CD-1-R documents posted for Director's Review
★	2-3 June	Director's Review
★	22-23 June	Fermilab PAC
★	6-8 July	DOE CD-1 Review

November 1st week CD2a/CD3a……construction start FY17 goal

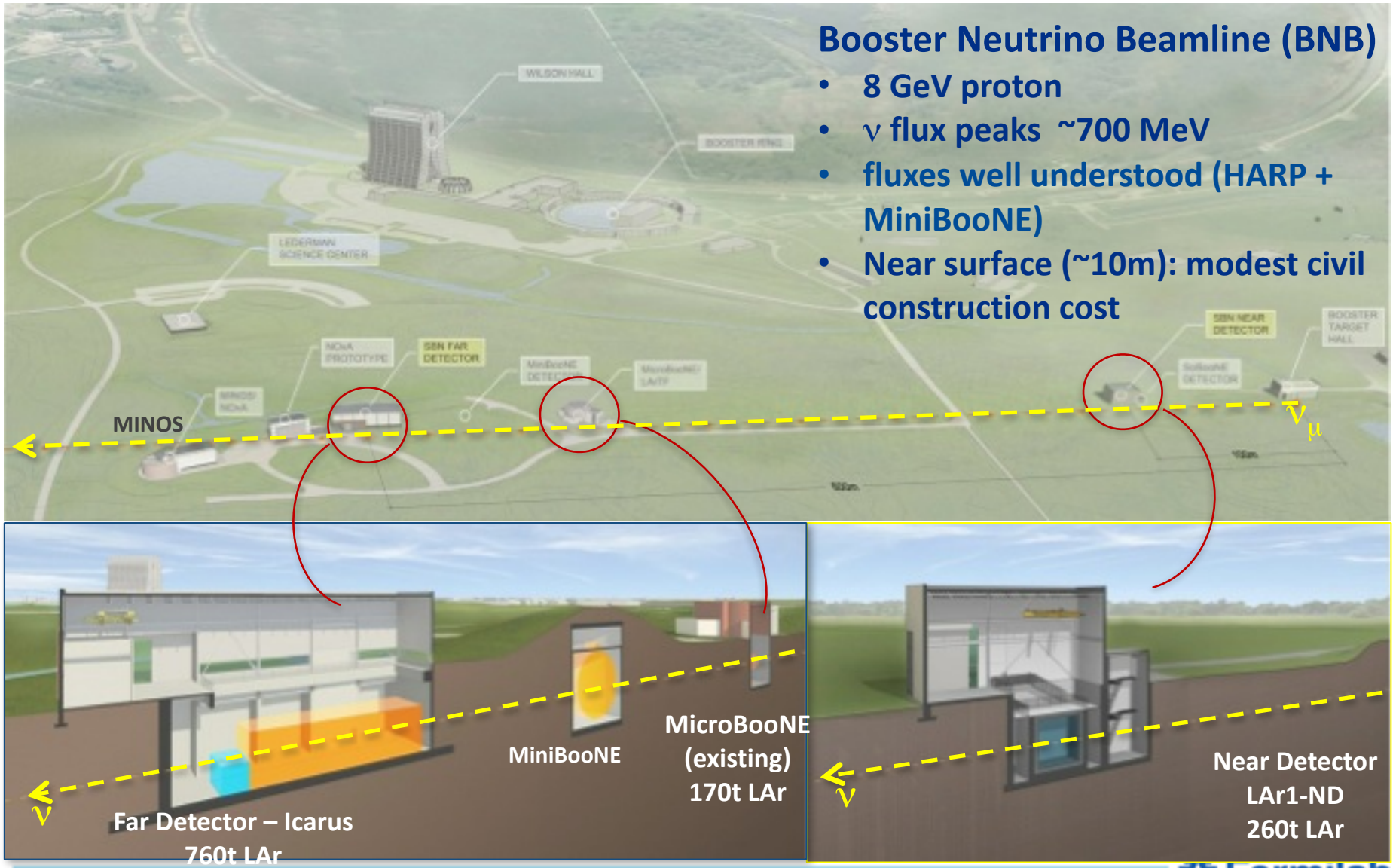
Development for LBNF/DUNE

Development of the large scale prototypes are critical for the detector. It is a large extrapolation to get to 10KT fiducial volume.



LAr = 17'432 tons (95% liquid)

One SBN Program - Three LAr-TPC Detectors



SBN Far Detector: ICARUS-T600

- ICARUS-WA104 collaboration: refurbish at CERN w/new cryostats and electronics, upgraded light detection
  - ✓ Move from Gran Sasso to CERN Dec 2014
  - ✓ Refurbishing started

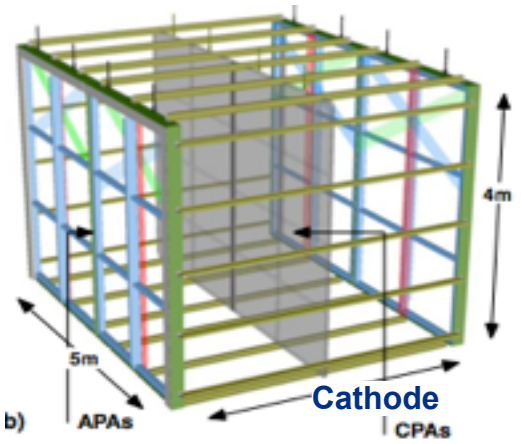
  Schedule: TPCs delivered to FNAL in new cryostats when new building is available, currently foreseen as early 2017
- For surface operation need improved cosmic rejection:
  - Improved light detection, external cosmic tagger system
- CERN-INFN collaborative effort to refurbishment:
  - MOU signed covering all work up to shipment to Fermilab
- CERN leadership on cryogenics

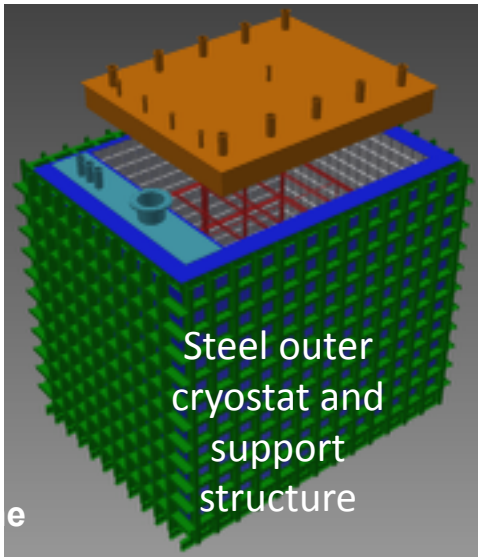
First TPC leaving LNGS

First TPC in Cleanroom at CERN

SBN Near Detector: LAr1-ND

- Build on experience from ICARUS, MicroBooNE, LBNE 35ton prototype, and based LBNE designs
- Opportunity for prototyping DUNE designs or developing alternative system designs
  - e.g. test-bed for light collection concepts
- International collaborative efforts on detector:
  - TPC: Five universities (US NSF + UK STFC)
  - TPC Electronics: BNL (DOE) + Columbia (NSF requested)
  - Laser calibration: Bern (SNSF, AEC)
  - Cosmic Tagger: Bern
- CERN + Fermilab collaborating on cryostat and cryogenics
  - Establish teams for LBNF infrastructure
- Installation in 2017





MicroBooNE

- detector has been fully installed in the Booster neutrino beamline

- The project is complete
- detector commissioning is in full swing
- initial cool-down is starting

Ongoing Neutrino Program beyond Fermilab

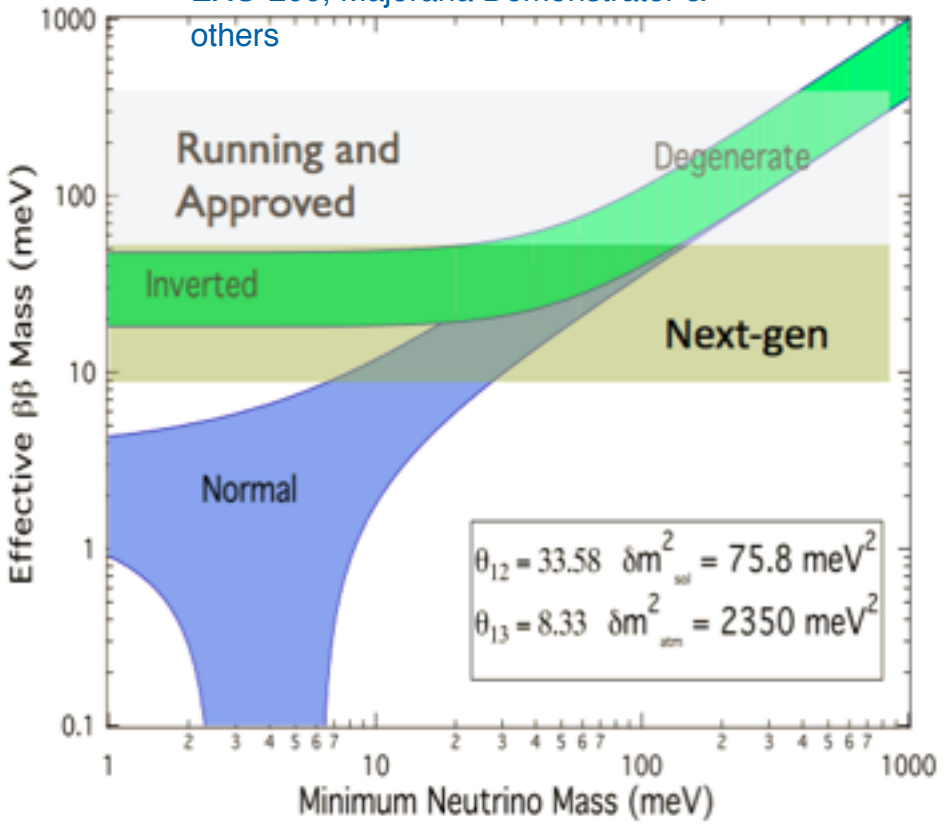
Daya Bay – precise determination of θ_{13}

SuperK/T2K:
long-baseline oscillations
atmospheric neutrinos
+ proton decay
+ supernova search

Neutrino mixing/masses,
Lepton number non-conservation…

with U.S. participation

Neutrinoless double-beta decay expts.
EXO-200, Majorana Demonstrator & others

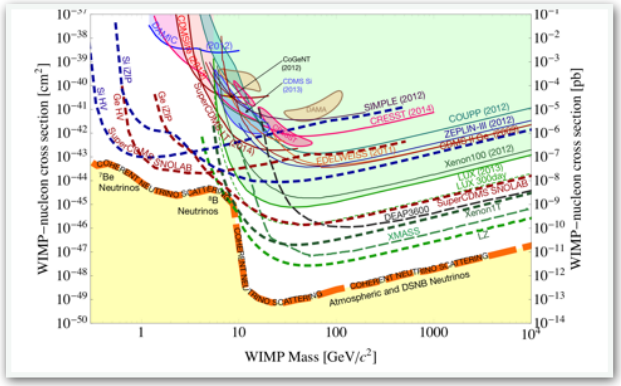


In US, NP is “steward” of NLDBD.
NSAC has been charged to id criteria for next generation.

Identify the new physics of dark matter

- Lots of results coming out from current experiments.
- Moving towards 2nd generation Dark Matter direct detection

AMS

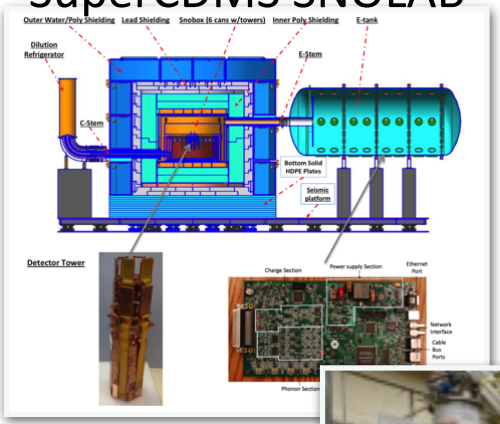


DM program: **ADMX-IIa, COUPP-60/PICO, DarkSide-50, LUX, XENON100/1T, SuperCDMS-Soudan, CoGeNT, DRIFT-II, DMTPCino, MiniCLEAN,PICASSO, ADMX-HF**

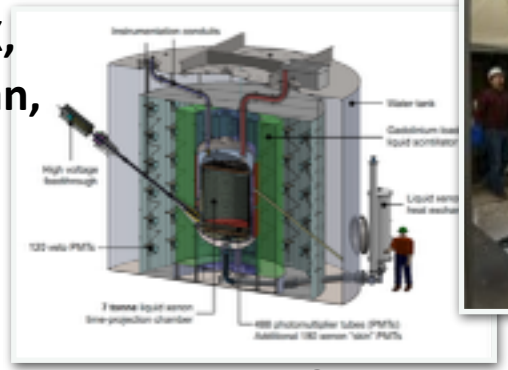
Upcoming G2 DM: **ADMX-G2, LZ, SuperCDMS-SNOLAB**

+ Coordinated R&D

SuperCDMS SNOLAB



G2 DM



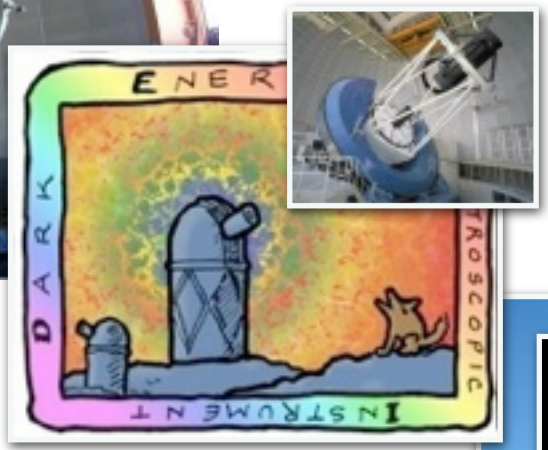
LZ at SURF

ADMX

Fermilab

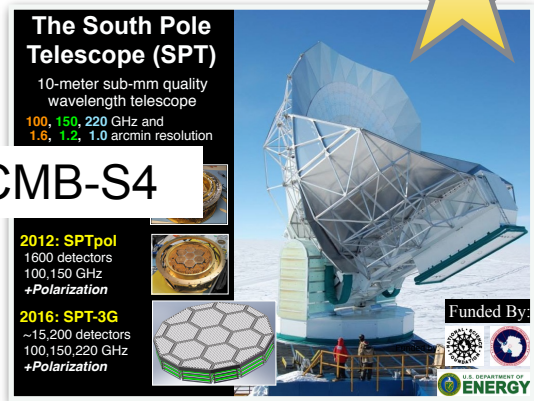
Understand cosmic acceleration: dark energy and inflation

DES



DESI - in 2018

CMB-S4



Explore the unknown: new particles, interactions, and physical principles

g-2 arriving at Fermilab from BNL

Muon Program

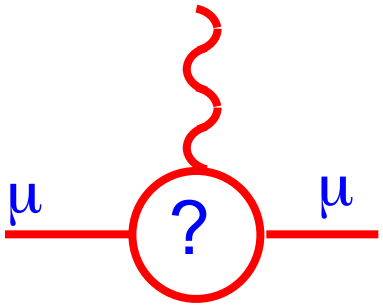
P5:

Recommendation 22: Complete the Mu2e and muon g-2 projects.

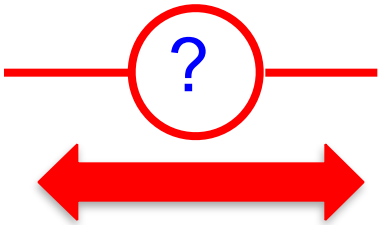
Fermilab response

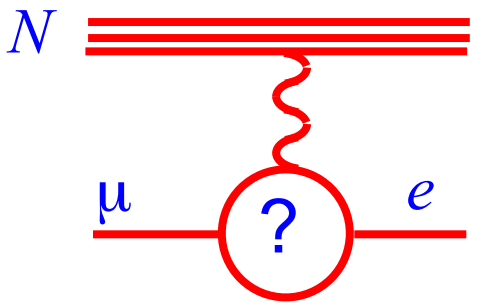
Exploring the unknown with muons

- Muons provide a unique tool for exploring the unknown
  - Fundamental particle with relatively large mass (200x m_e)
  - Can be produced in copious amounts (10^{10} μ / s)
  - Have a long but finite lifetime



Measure muon g-2 to 100 parts per billion





Search for charged lepton flavor violation to single event sensitivities of 10^{-17}

Large synergy with the LHC and neutrino physics programs and potentially large reach beyond LHC and LBNF capabilities

Muon g-2

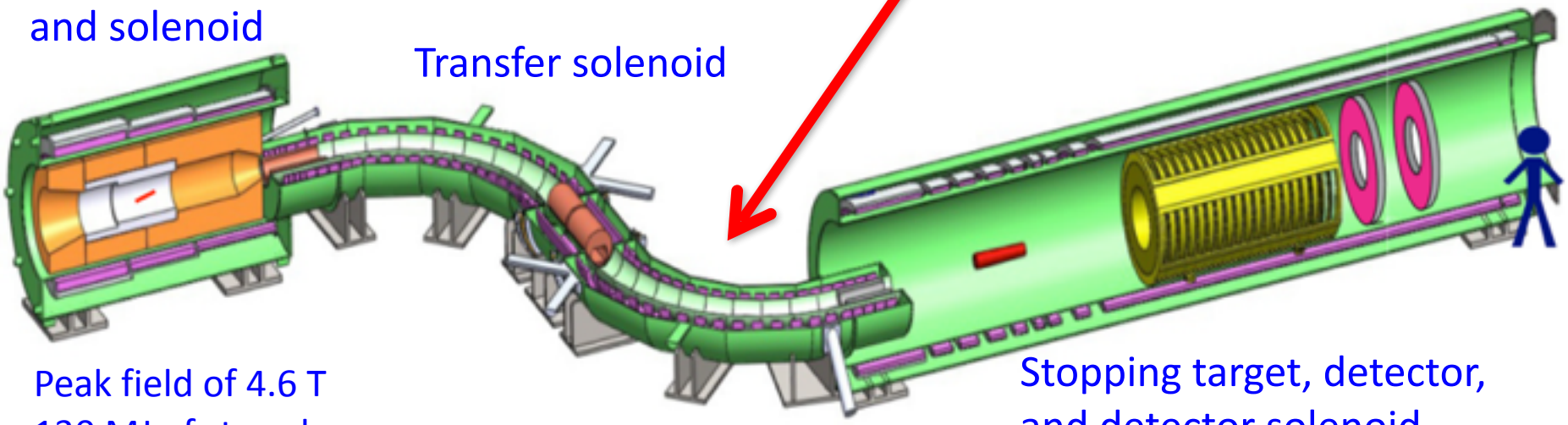
- Magnet reassembly complete at Fermilab
- First pump down / cool down / power up cycle beginning
- Project approval in early summer; first beam anticipated in 2 yrs
- Will have a BNL size data set in 2017 and 20x BNL stats by 2019

Mu2e

- Ground breaking for new experimental hall in April 2015
- first beam expected 2020

Production target and solenoid

Transfer solenoid



Stopping target, detector, and detector solenoid

Peak field of 4.6 T
130 MJ of stored energy
70 km conductor and 45 ton cold mass
8 kW power on production target
~100k readout channels
700 MB/s coming off detector, 5 pb to tape per year

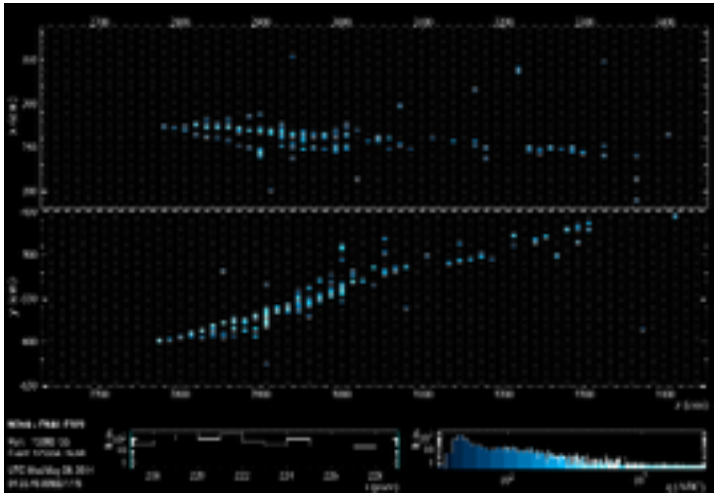
There is more to particle physics than in P5

- There is a ongoing broad physics program at accelerator facilities (Fermilab, JLAB, BNL and TRIUMF) as well as through international collaborations at CERN, KEK, JPARC, BES.

Fermilab Operations Summary April 2015

Experiment	Beam	POT Request	POT Delivered
MiniBooNE-DM	*BNB*	*1.5E20*	*1.9E20*
MINOS+	*NuMI - ME*	*18E20*	*4.8E20*
MINERvA	*NuMI - ME*	*6E20 (ν) 12E20(νbar)*	*4.8E20 (ν)*
NOvA	*NuMI - ME*	*36E20*	*2.5E20*
MicroBooNE	*BNB*	*6.6E20*	*N/A*
SeaQuest	*SY120*	*5E18*	*7.0E17*

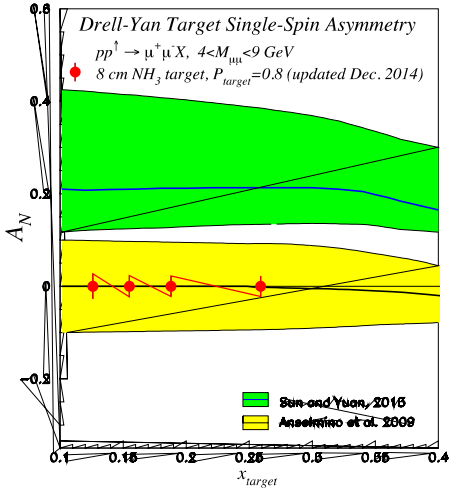
Event in NOvA

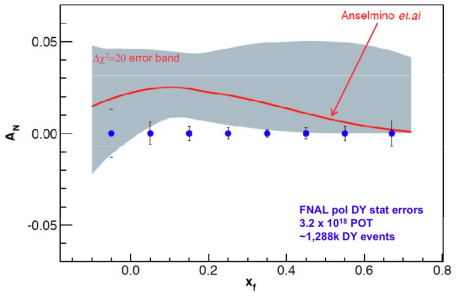


- There are also many vital particle physics programs funded in the U.S. through Nuclear Physics.
- And a number of astroparticle physics initiatives…

Reestablishing spin at Fermilab

- **E-1039: SeaQuest with polarized target**
  - Stage-1 approval
  - sensitive to Sivers TMD for sea quarks
  - hint for substantial role of sea quark Sivers effect in SIDIS data
  - LANL and UVa will provide polarized proton (NH3) target by 2016
  - production running in 2017
- **E-1027: SeaQuest with polarized beam**
  - Stage-1 approval
  - sensitive to beam valence quarks at high-x
  - large effects → sign, size, and maybe shape of Sivers TMD





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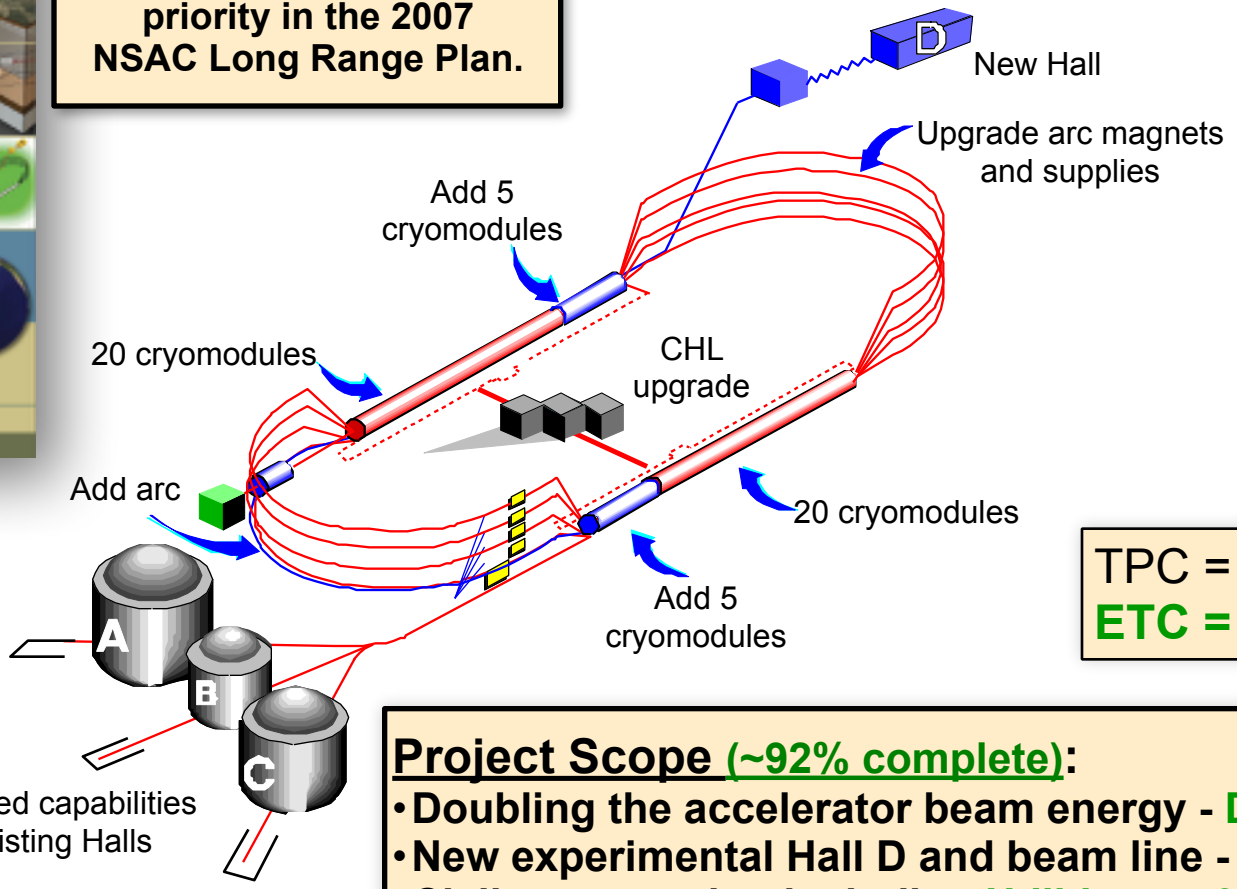
JLAB: 12 GeV Upgrade Project

Completion of the 12 GeV CEBAF Upgrade was ranked the highest priority in the 2007 NSAC Long Range Plan.

Upgrade is designed to build on existing facility: vast majority of accelerator and experimental equipment have continued use.



TPC = $338M
ETC = ~$26M

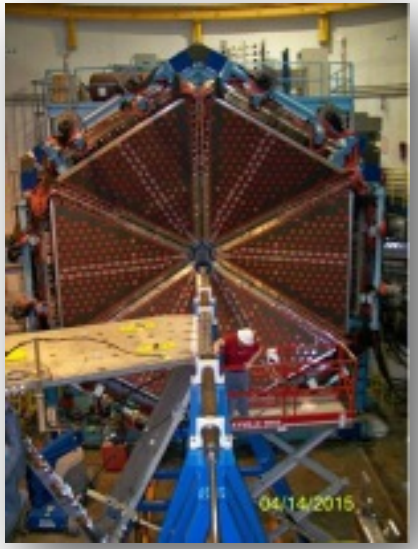
Project Scope (~92% complete):

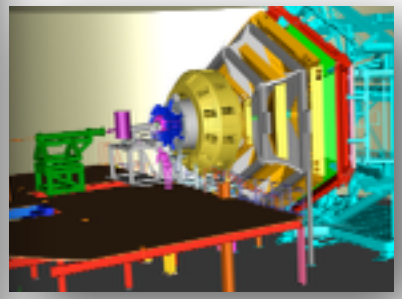
- **Doubling the accelerator beam energy - DONE**
- **New experimental Hall D and beam line - DONE**
- **Civil construction including Utilities - ~97%**
- **Upgrades to Experimental Halls B & C - ~80%**

Maintain capability to deliver lower pass beam energies: 2.2, 4.4, 6.6….

12 GeV Scientific Capabilities

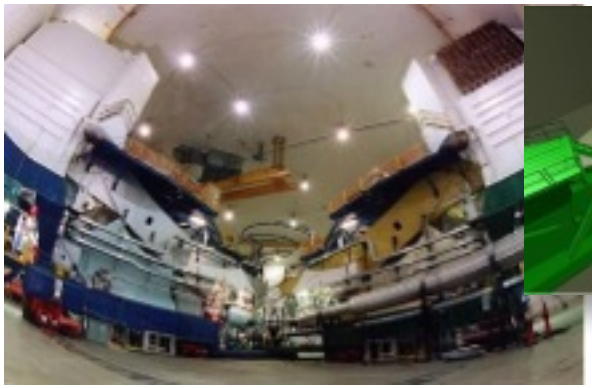
Hall B **– understanding nucleon structure via generalized parton distributions**





Hall D **– exploring origin of confinement by studying exotic mesons**

Hall A **– form factors, future new experiments (e.g., SoLID and MOLLER)**



Hall C **– precision determination of valence quark properties in nucleons/nuclei**

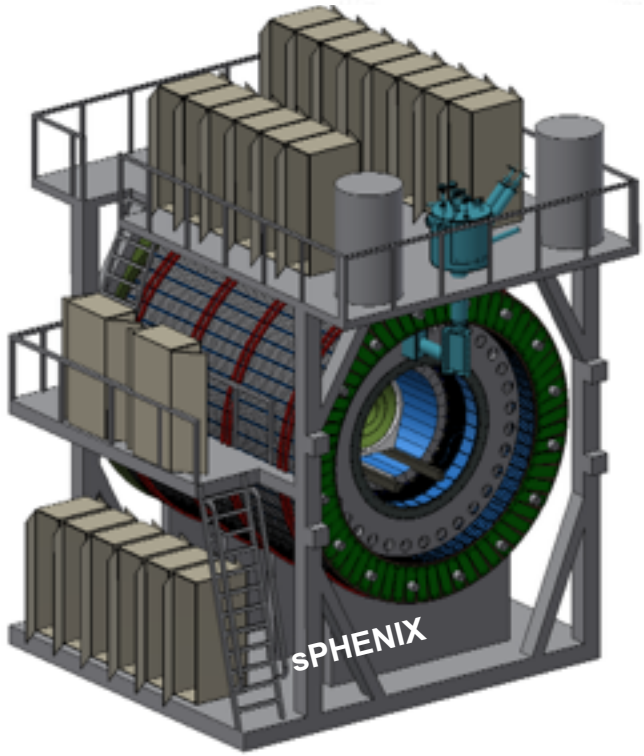
Completing the RHIC science mission at BNL

Status: RHIC-II configuration is complete

- Vertex detectors in STAR (HFT) and PHENIX
- Luminosity reaches 25x design luminosity

Plan: **Complete the RHIC mission** in 3 campaigns:

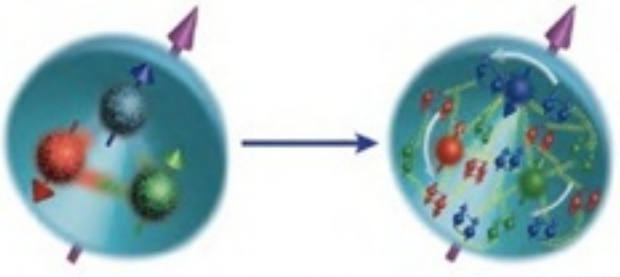
- **2014–17: Heavy flavor probes of the QGP using the micro-vertex detectors;**
  Transverse spin physics
- *2018: Install low energy e-cooling*
- **2019/20: High precision scan of the QCD phase diagram & search for critical point**
- *Install sPHENIX*
- **Probe QGP with precision measurements of jet quenching and Upsilon suppression**
- **Spin physics and initial conditions at forward rapidities with p+p and p+A collisions ?**
- *Transition to eRHIC*



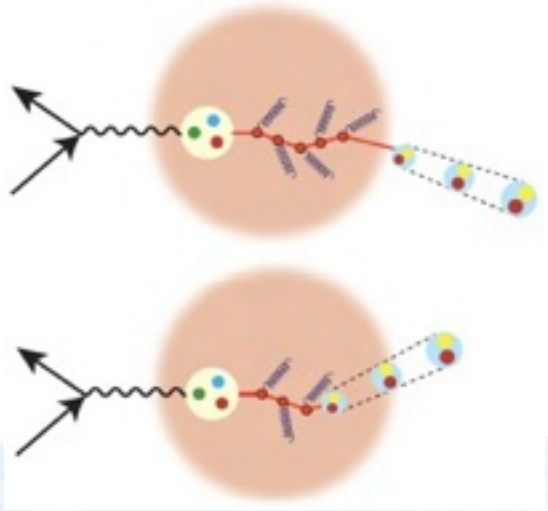
RHIC remains a unique discovery facility

EIC will be a QCD laboratory

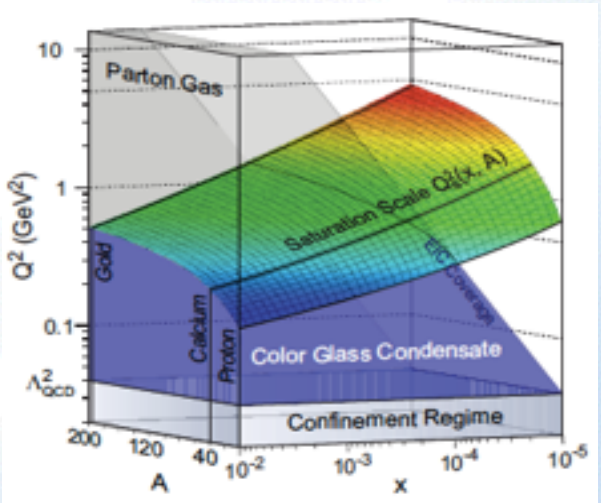
Gluon and sea quark structure of the proton, or what gives matter (most of) its mass ?



Use the nucleus as a fm-scale vertex detector to probe confinement



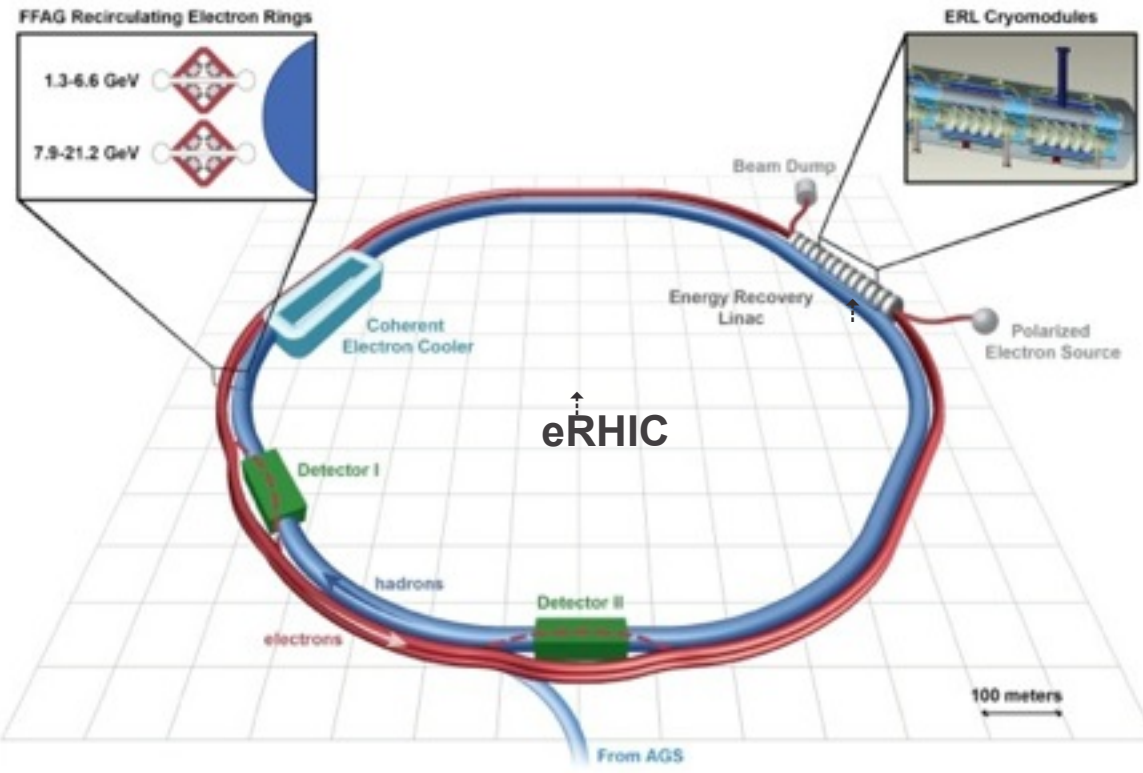
Is there a universal saturated gluon ocean (CGC) at low x ?



eRHIC Design

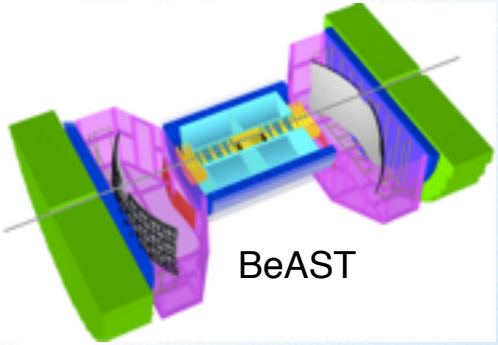
eRHIC ERL + FFAG ring design @ $10^{34}/cm^2s$

Up to 21.2 GeV e^- + 255 GeV p or 100 GeV/u Au



When completed, eRHIC will be the most advanced and energy efficient accelerator in the world

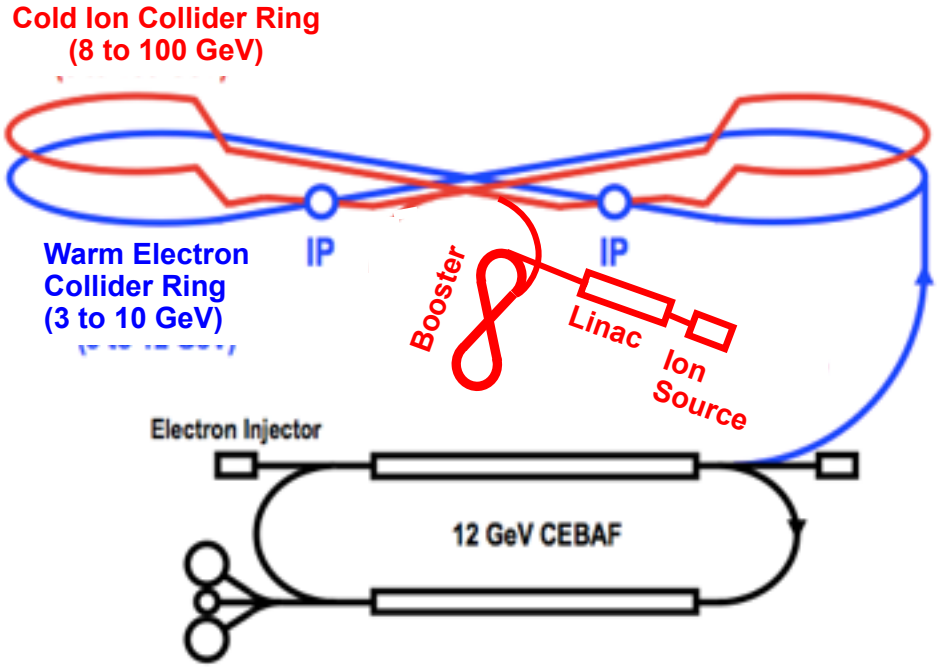
Detector Options



Jefferson Lab Mission: MEIC

JLab MEIC Figure 8 Concept

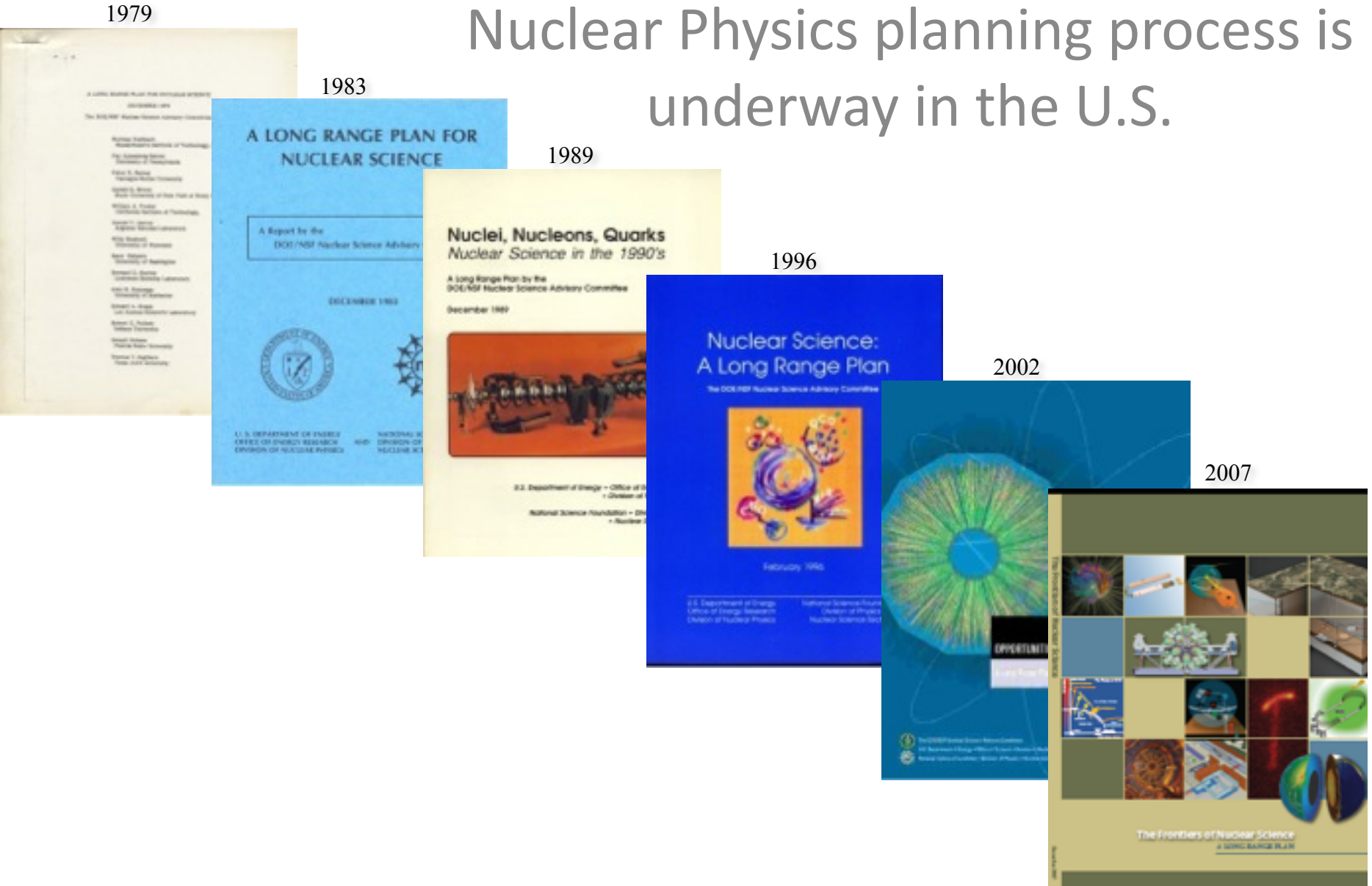
- **Initial configuration**:
  - 3-10 GeV on 20-100 GeV ep/eA collider
  - Optimized for high ion beam polarization:
    - polarized deuterons
  - Luminosity:
    - up to above 10^{34} e-nucleons cm^{-2} s^{-1}
  - Fully integrated 4π detector
    - 3×10^{-4} resolution for beam fragments
- **Low technical risk with modest R&D**
  luminosity performance assured
- **Upgradable to higher energies**
  up to 250 GeV protons + 20 GeV electrons
- **Flexible timeframe for Construction**
  consistent w/running 12 GeV CEBAF
- **Thorough cost estimate completed**
  presented to NSAC EIC Review
- **Cost effective operations**



→ Fulfills White Paper Requirements

The 2015 NSAC Long Range Plan

Nuclear Physics planning process is underway in the U.S.



NSAC Long Range Plan Schedule

- ✓ Charge delivered at 24 April NSAC Meeting
- ✓ LRP Working Group formed in early June ~ 60 members
  - NuPECC and ANPhA observers.
- ✓ Community organization last summer
- ✓ DNP town meetings in the July/September
- ✓ Joint APS-DNP-JPS Meeting Oct 7-11, 2014
- ✓ Working Group organizational meeting Nov 16, 2014
- ✓ White papers by end of January to have greatest impact
- ✓ Cost review of EIC – Report at April 3 NSAC meeting
- ✓ Most of text of report assembled by April 10.
- ✓ Resolution meeting of Long Range Plan working group April 16-20, 2015.
- Resolutions embargoed as final report is completed
- Draft report reviewed by external wise women and men.
- Consideration by NSAC in July NSAC meeting
- LRP final report due October 2015

Summary

- The U.S. Particle Physics community has agreed on a prioritized plan for facilities and projects for the coming decade.
  - We are working to execute the plan.
  - There is still room for smaller projects and R&D.
- The neutrino program in the U.S. is making great strides towards becoming a global neutrino platform.
- The U.S. Nuclear Physics community is completing their Long Range Planning process.

- The future seems bright for particle physics around the globe.
  - We should have a broad and diverse program.
  - The LHC will be recording collisions at 13TeV very soon!
  - What else is around the corner?

Thank you

- Many thanks to Greg Bock, Brendan Casey, Markus Diefenthaler, Don Geesaman, Andy Lankford, David Lissauer, Nigel Lockyer, Joe Lykken, Krishna Kumar, Hugh Montgomery, Bob Tschirhart and to the P5 panel for their input into this presentation.

- Special thanks to Jon Rosner and Steve Ritz for their critical roles in pulling the P5 plan together.

- Thank you to the organizers for asking me to give my perspectives. Apologies to the projects and programs that were omitted due to time constraints.