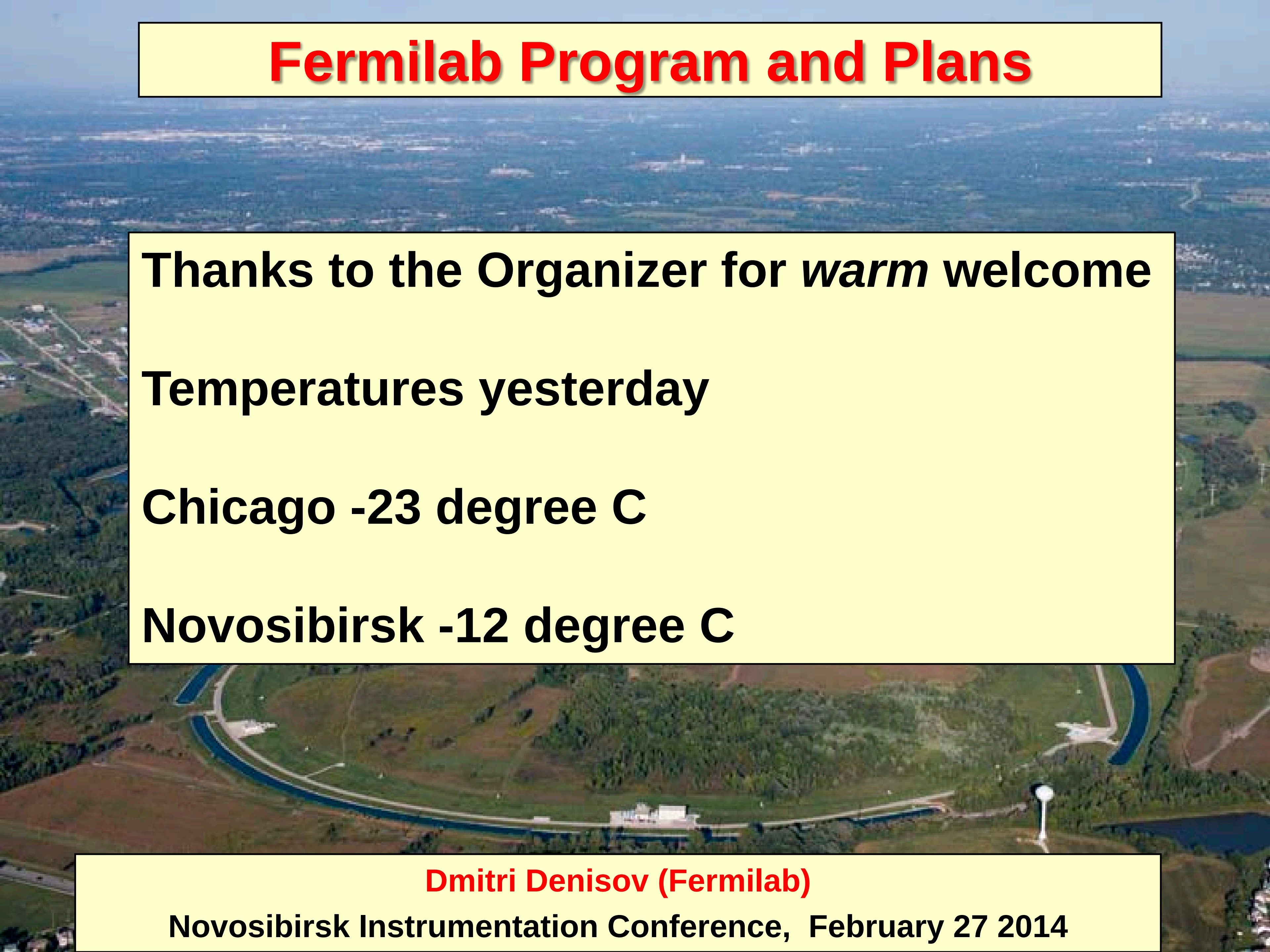
Fermilab Program and Plans



Thanks to the Organizer for *warm* welcome

Temperatures yesterday

Chicago -23 degree C

Novosibirsk -12 degree C

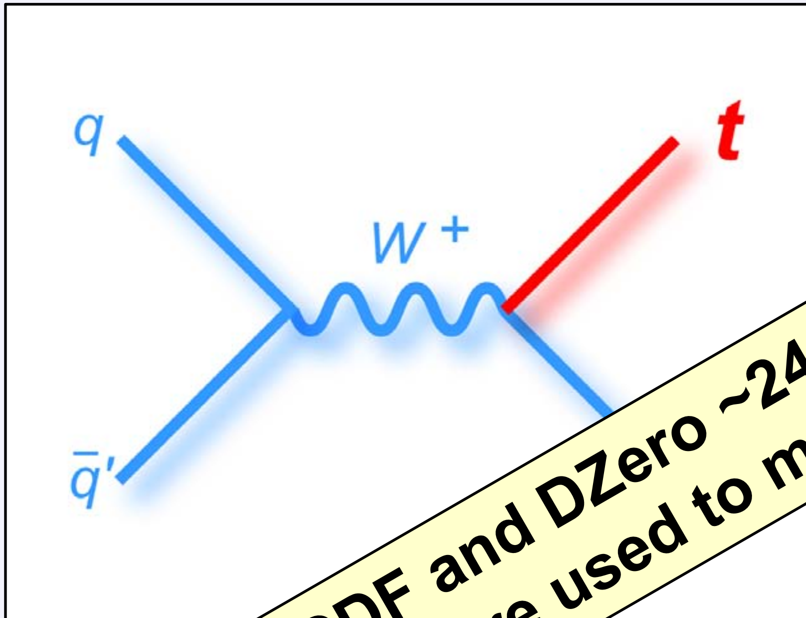
Dmitri Denisov (Fermilab)

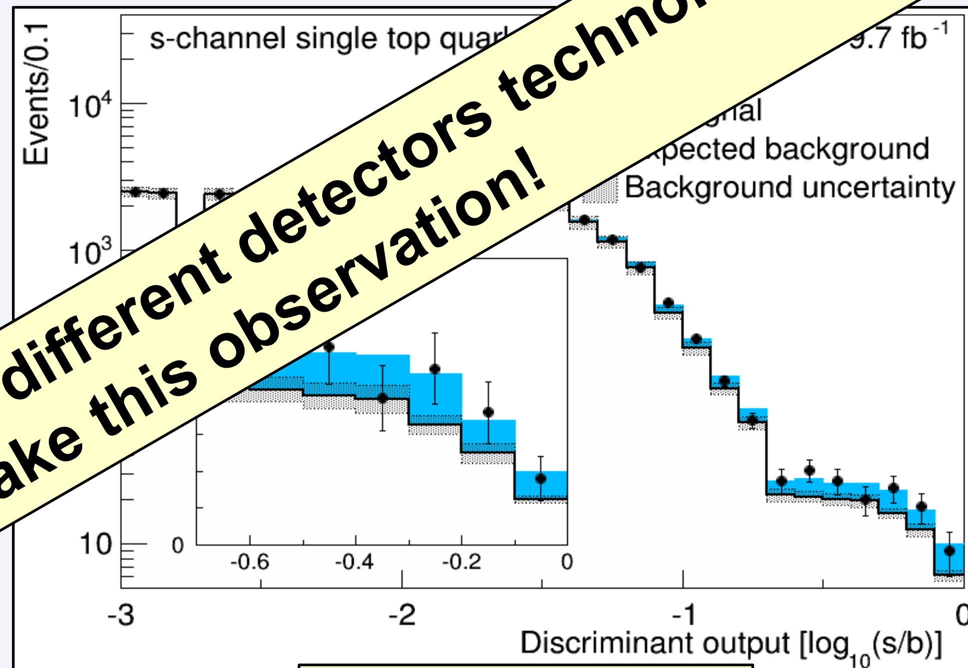
Novosibirsk Instrumentation Conference, February 27 2014

FERMILAB-PUB-14-031-E

Observation of *s*-channel production of single top quarks at the Tevatron

T. Aaltonen[†,21] V.M. Abazov[‡,13] B. Abbott[‡,116] B.S. Acharya[‡,80] M. Adams[‡,98] T. Adams[‡,97] J.P. Agnew[‡]
G.D. Alexeev[‡,13] G. Alkhazov[‡,88] A. Alton[‡ii,31] S. Amerio[†vv,39] D. Amidei[†,31] A. Anastassov[†v,15] A. A…





Between CDF and DZero ~24 different detectors technologies are used to make this observation!

6.3 σ significance

February 24, 2014

FOR IMMEDIATE RELEASE

For images and graphics, please click this link:
www.fnal.gov/pub/presspass/press_releases/2014/Top-Quark-Puzzle-20140224-images.html

Scientists complete the top quark puzzle

Scientists on the CDF and DZero experiments at the U.S. Department of Energy's Fermi National Accelerator Laboratory have announced that they have found the final predicted way of creating a top quark, completing a picture of this particle nearly 20 years in the making.

Talk Outline

- **Planning future particle physics projects in US**
  - **Snowmass and P5 Process**
- **Outcome of the "Snowmass process"**
  - **Main questions for particle physics**
- **Fermilab accelerators and experiments**
- **Future projects**
- **Conclusions**

Selection of Projects in US - 5 Steps Process

- **Step 1**
  - Groups of scientists develop proposals for future projects/experiments
- **Step 2**
  - "Snowmass" community wide process discusses proposals, evaluates physics reach and costs and summarizes outcome in a written form
  - Organized by Division of Particles and Fields (DPF) – professional organization, not Laboratories or NSF (National Science Foundation) or DOE (Department of Energy)
- **Step 3**
  - P5 committee (Particle Physics Projects Prioritization Panel) is formed consisting of ~25 scientists representing all areas of particle physics
  - The committee recommends priorities for funding based on available funds and expected cost of the projects
- **Step 4**
  - HEPAP (High Energy Physics Advisory Panel) appointed by DOE reviews the P5 proposal and recommends it to be considered by DOE/NSF
- **Step 5**
  - DOE/NSF fund recommended projects (based on available funds)

Snowmass 2013

- The DPF Charge for "Snowmass 2013"

  "To develop the community's long term physics aspirations. Its narrative will communicate the opportunities for discovery in high energy physics to the broader scientific community and to the government"

- Organized around Frontiers
  - Energy, Intensity, Cosmic, Instrumentation, Facilities (mainly new accelerators), Education and Outreach, Theory

- Time scale for proposals is ~10 years, taking into account ~20 years time span

- Process continued for about a year (since late 2012) and culminated in ~10 days community meeting at the University of Minnesota late July 2013
  - "Snowmass" is the name of the village in Colorado where similar exercises have been done in the past

Snowmass 2013

Snowmass on the Mississippi a.k.a CSS 2013

Log in

Quick Links

- TWiki registration
- Pre-meetings
  - Community Planning Meeting
  - All pre-Snowmass Meetings
- Colloquium questions
- Big Questions (Quantum Universe)

Groups

- Energy Frontier
- Intensity Frontier
- Cosmic Frontier
- Frontier Capabilities
- Instrumentation Frontier
- Computing Frontier
- Education and Outreach
- Theory Panel

Google Search

snowmass2013.org

WWW

Community Summer Study 2013

(Snowmass on the Mississippi) *Minneapolis, 7/29 - 8/6 2013*

The American Physical Society's Division of Particles and Fields is pursuing a long-term planning exercise for the high-energy physics community. Its goal is to develop the community's long-term physics aspirations. Its narrative will communicate the opportunities for discovery in high-energy physics to the broader scientific community and to the government.

SNOWMASS ON THE MISSISSIPPI

Minnesota Information and Registration webpage

Follow this link to a preliminary agenda

Conveners, to request room for parallel sessions use this link Request rooms

COLLOQUIUM QUESTIONS

BIG QUESTIONS FOR OUR UNIVERSE.

LATEST NEWS

- July 24 update: list of questions for the colloquia at CSS2013 are posted
- May 7 Update: The Snowmass Young Physicists Career and Science Aspirations Survey is now online. Please encourage students and postdocs to respond. http://tinyurl.com/snowmassyoung

Snowmass process is over with final reports available on arXiv

Outcome of Snowmass - Big Questions

1. How do we understand the Higgs boson? Why does it condense and acquire a vacuum value throughout the universe? Is there one Higgs particle or many? Is the Higgs particle elementary or composite?

2. What principle determines the masses and mixings of quarks and leptons? Why is the mixing pattern apparently different for quarks and leptons? Why is the CKM CP phase nonzero? Is there CP violation in the lepton sector?

3. Why are neutrinos so light compared to other matter particles? Are neutrinos their own antiparticles? Are their small masses connected to the presence of a very high mass scale? Are there new interactions invisible except through their role in neutrino physics?

4. What mechanism produced the excess of matter over anti-matter that we see in the universe? Why are the interactions of particles and antiparticles not exactly mirror opposites?

Big Questions - Continues

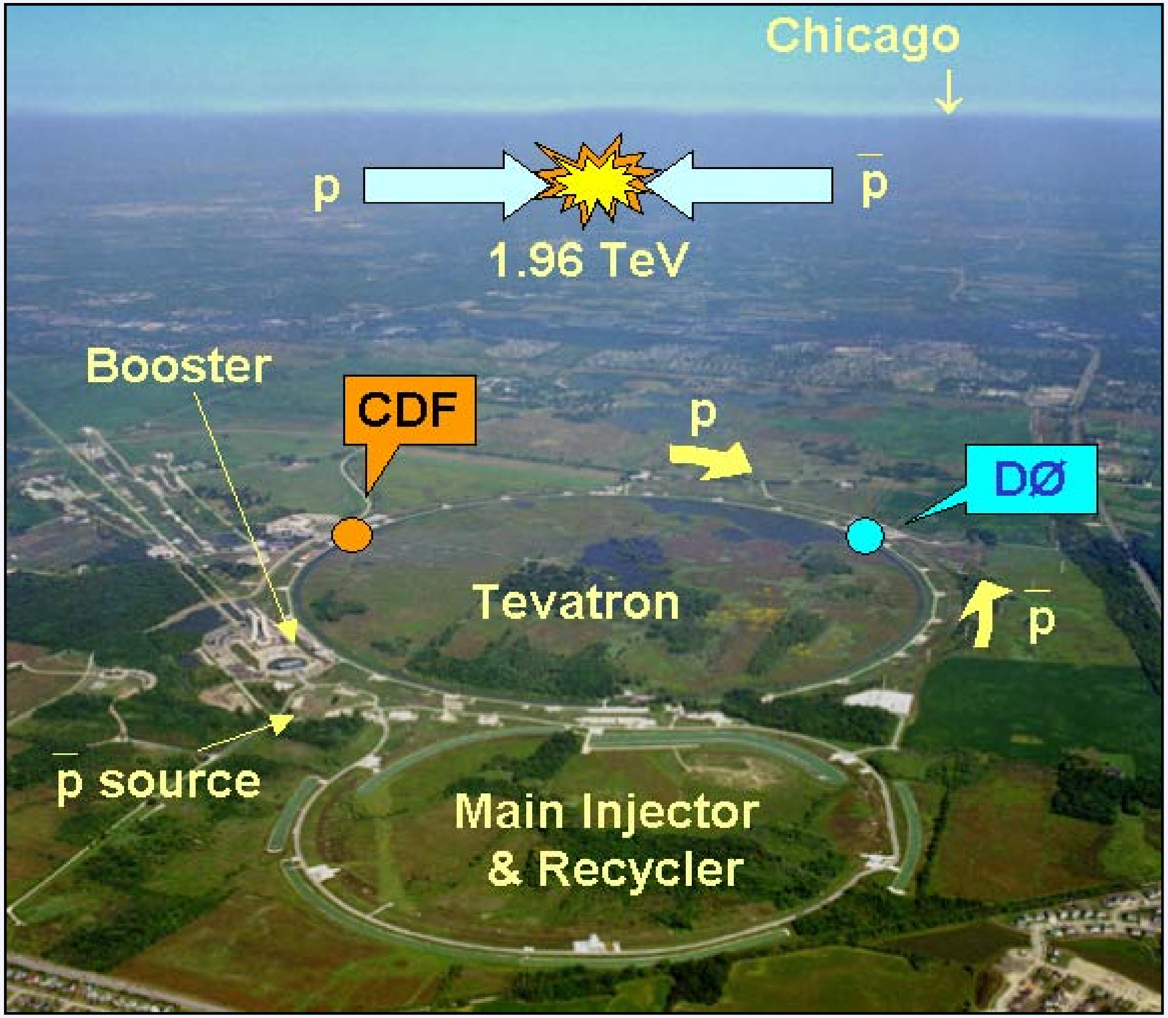
5. Dark matter is the dominant component of mass in the universe. What is the dark matter made of? Is it composed of one type of new particle or several? Are the dark matter particles connected to the particles of the Standard Model, or are they part of an entirely new dark sector of particles?

6. What is dark energy? Is it a static energy per unit volume of the vacuum, or is it dynamical and evolving with the universe? What principle determines its value?

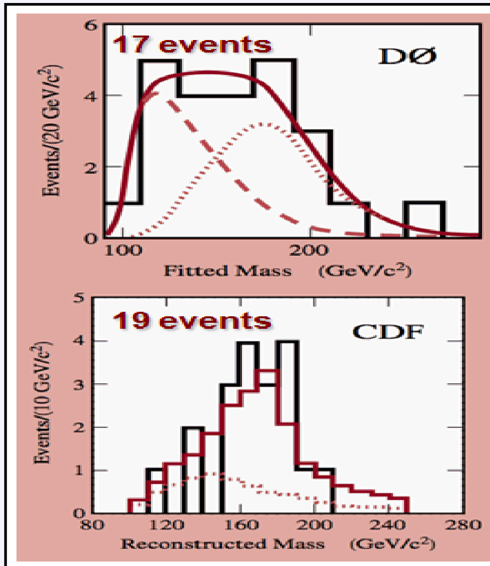
7. What did the universe look like in its earliest moments, and how did it evolve to contain the structures we observe today?

~20 projects are under discussion by P5 committee
Report is expected in May 2014

Tevatron program

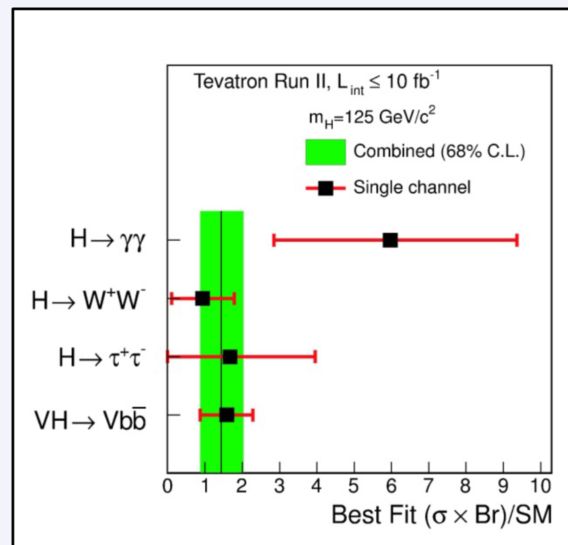


Top Quark Discovery

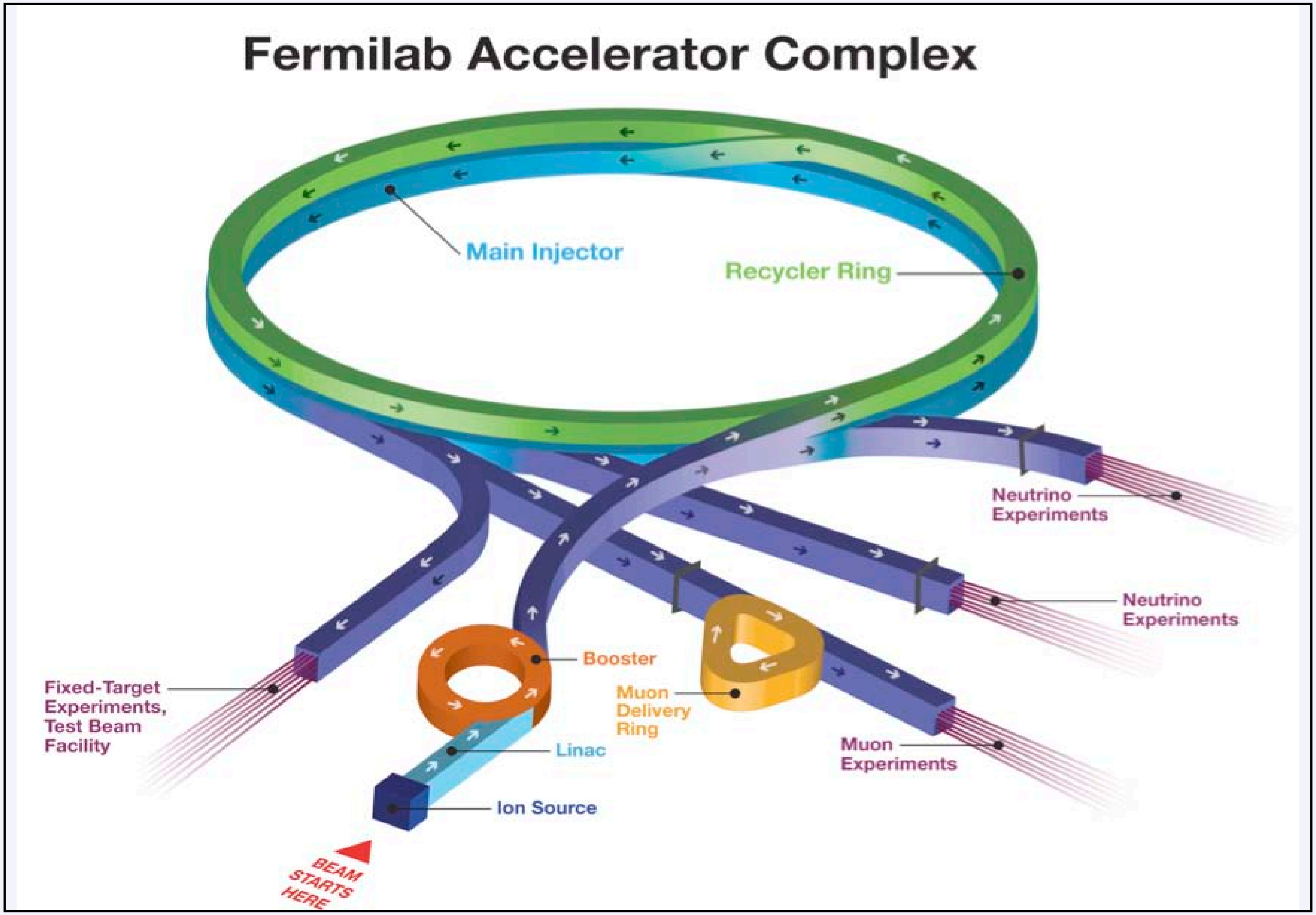


1995, CDF and DØ experiments, Fermilab

Higgs Boson Evidence

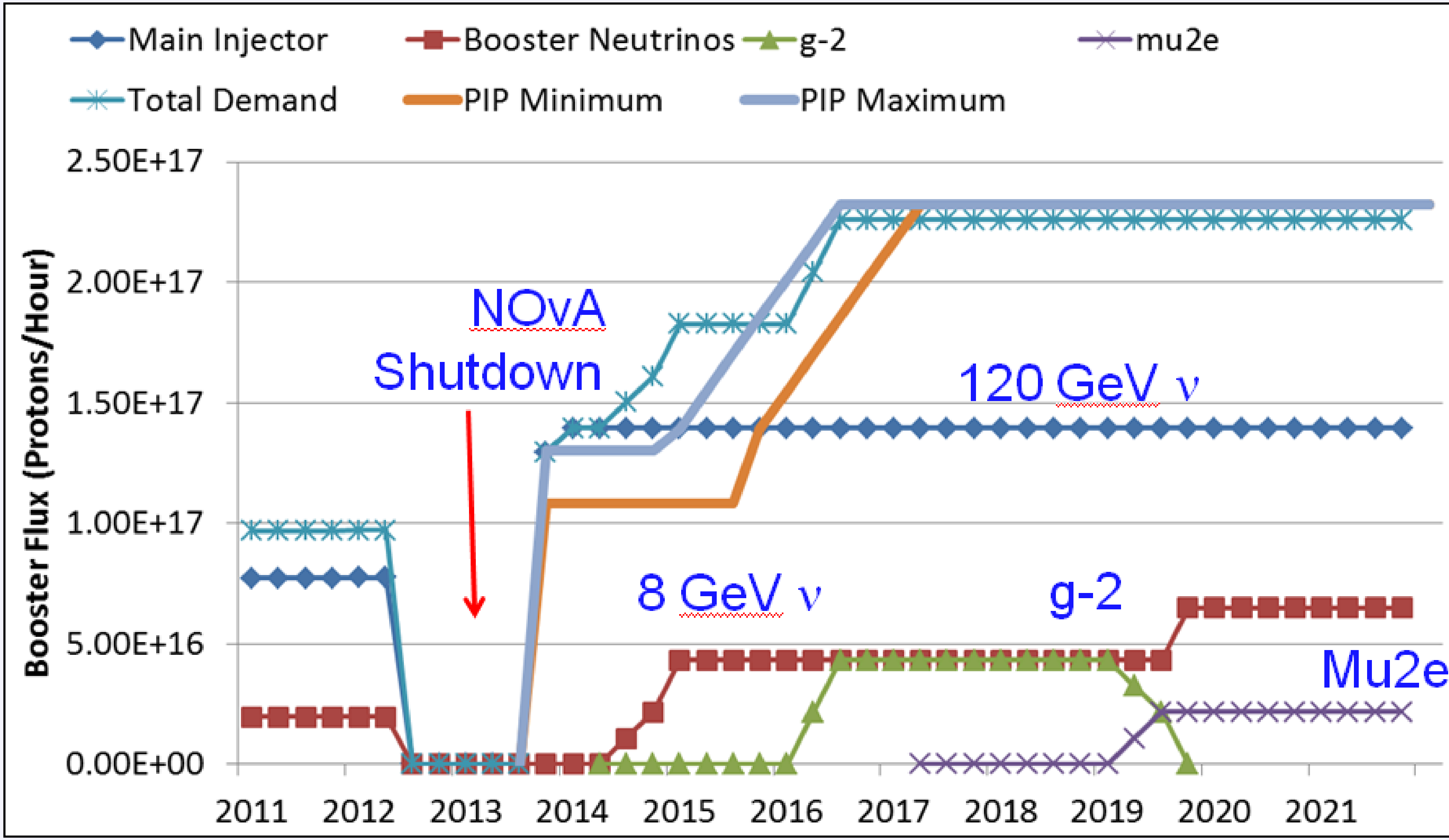


- From the top quark discovery to Higgs boson evidence – 25 years program
- Over 1000 papers cementing Standard Model



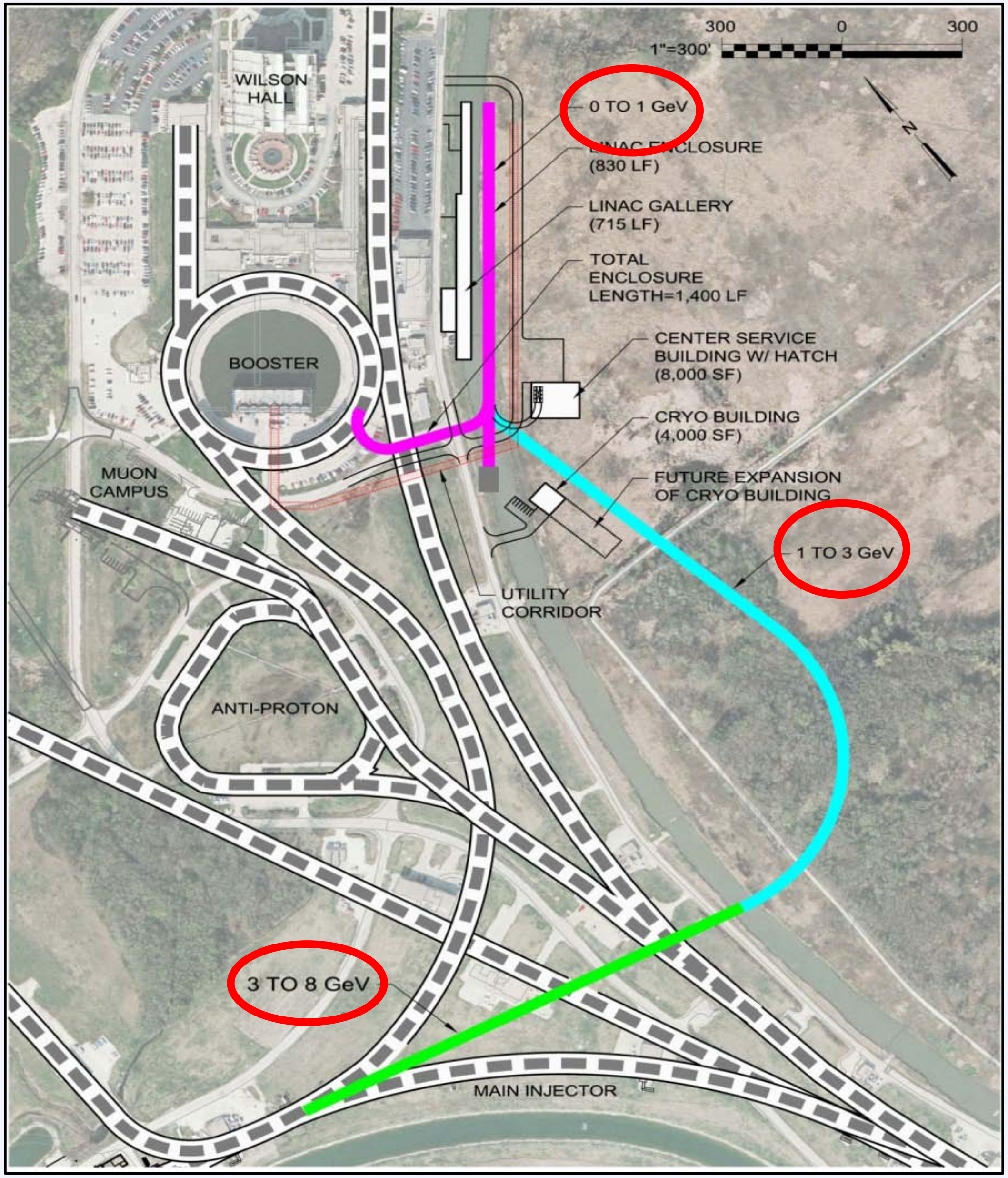
- 8 GeV proton booster - MicroBooNE neutrino experiment
- Main Injector 120 GeV: MINOS, MINERvA, NOvA – neutrino experiments
- Fixed Target: SeaQuest, Test Beam Facility – nuclear structure and test beams
- Future muon experiments: g-2, Mu2e

Beams Delivery Plans



- For the next ~7 years accelerator complex is focusing on delivering beams to
  - Neutrino, fixed target, high intensity muon beams and test beam experiments

Next Accelerator Upgrade



- **Multi-MW proton linear accelerator with flexible beam structure based on SCRF technology:**
  - **1 MW at 1 GeV, more at 3-8 GeV**
  - **>2 MW to neutrino program at 120 GeV**
- **Could serve multiple experiments over broad energy range**
- **Platform for future neutrino and muon facilities (including muon collider)**

Studies of the Neutrinos

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix} c_{12} & s_{12} & 0\\ -s_{12} & c_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}1 & 0 & 0\\ 0 & c_{23} & s_{23}\\ 0 & -s_{23} & c_{23}\end{pmatrix}\begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta}\\ 0 & 1 & 0\\ -s_{13}e^{-i\delta} & 0 & c_{13}\end{pmatrix}\begin{pmatrix}1 & 0 & 0\\ 0 & e^{i\alpha/2} & 0\\ 0 & 0 & e^{i\alpha/2+i\beta}\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

$\Delta m_{21}^2 = 7.54\,^{+0.26}_{-0.22} \times 10^{-5}\ \mathrm{eV}^2$

$|\Delta m_{32}^2| = 2.42\,^{+0.07}_{-0.11} \times 10^{-3}\ \mathrm{eV}^2$

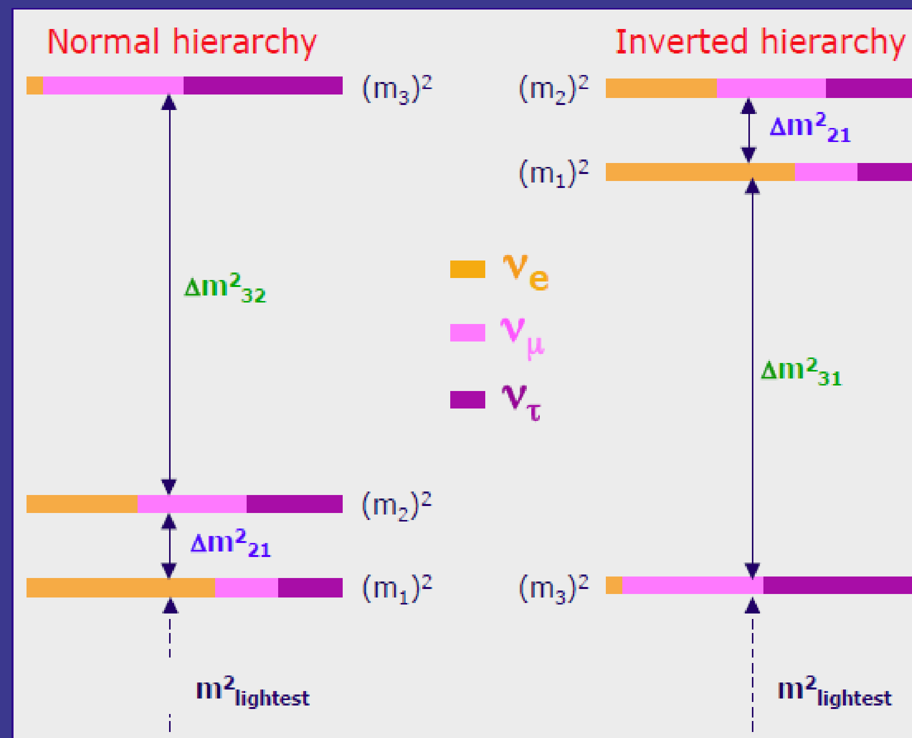
$m(\nu_e) < 2.3$ eV (95% CL)

$\theta_{12} = 33.6\,^{+1.1}_{-1.0}$ deg

$\theta_{23} = 38.6\,^{+2.4}_{-1.4}$ deg

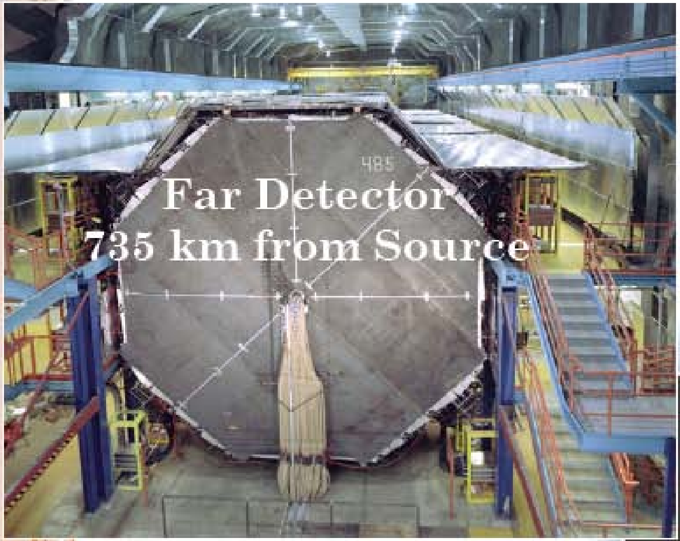
$\theta_{13} = 9.0\,^{+0.4}_{-0.5}$ deg

$m_{lightest}$ = ?
sign Δm_{32}^2 = ?
δ = ?



- Neutrinos remain one of the most puzzling particles of the Standard Model
- Studies of its properties, including mixing matrix parameters, could shed light on many interesting topics, including matter-antimatter asymmetry of the Universe

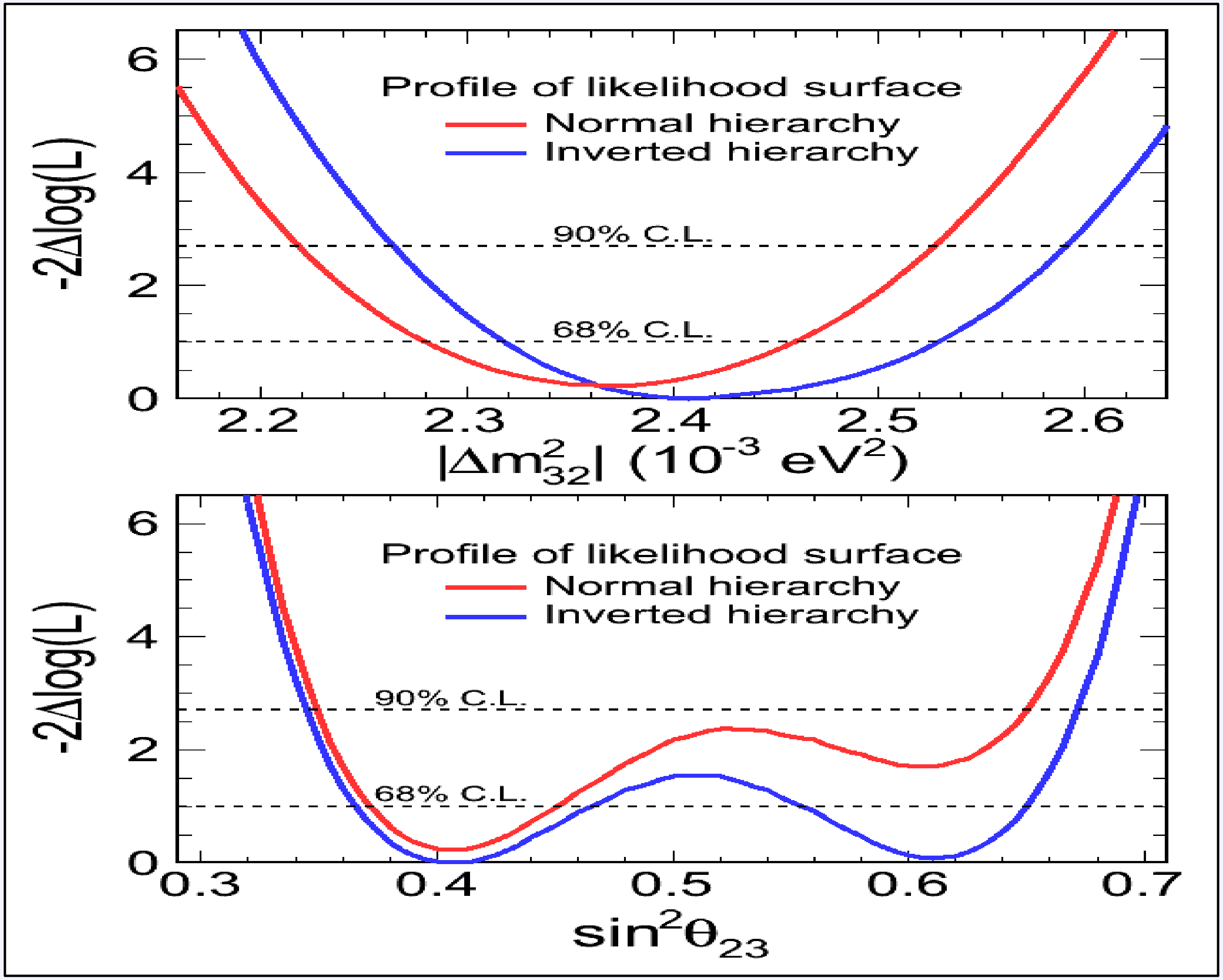
THE MINOS EXPERIMENT



- Long-baseline neutrino oscillation experiment
- Neutrinos from NuMI beam line
- L/E ~ 500 km/GeV
- atmospheric Δm^2

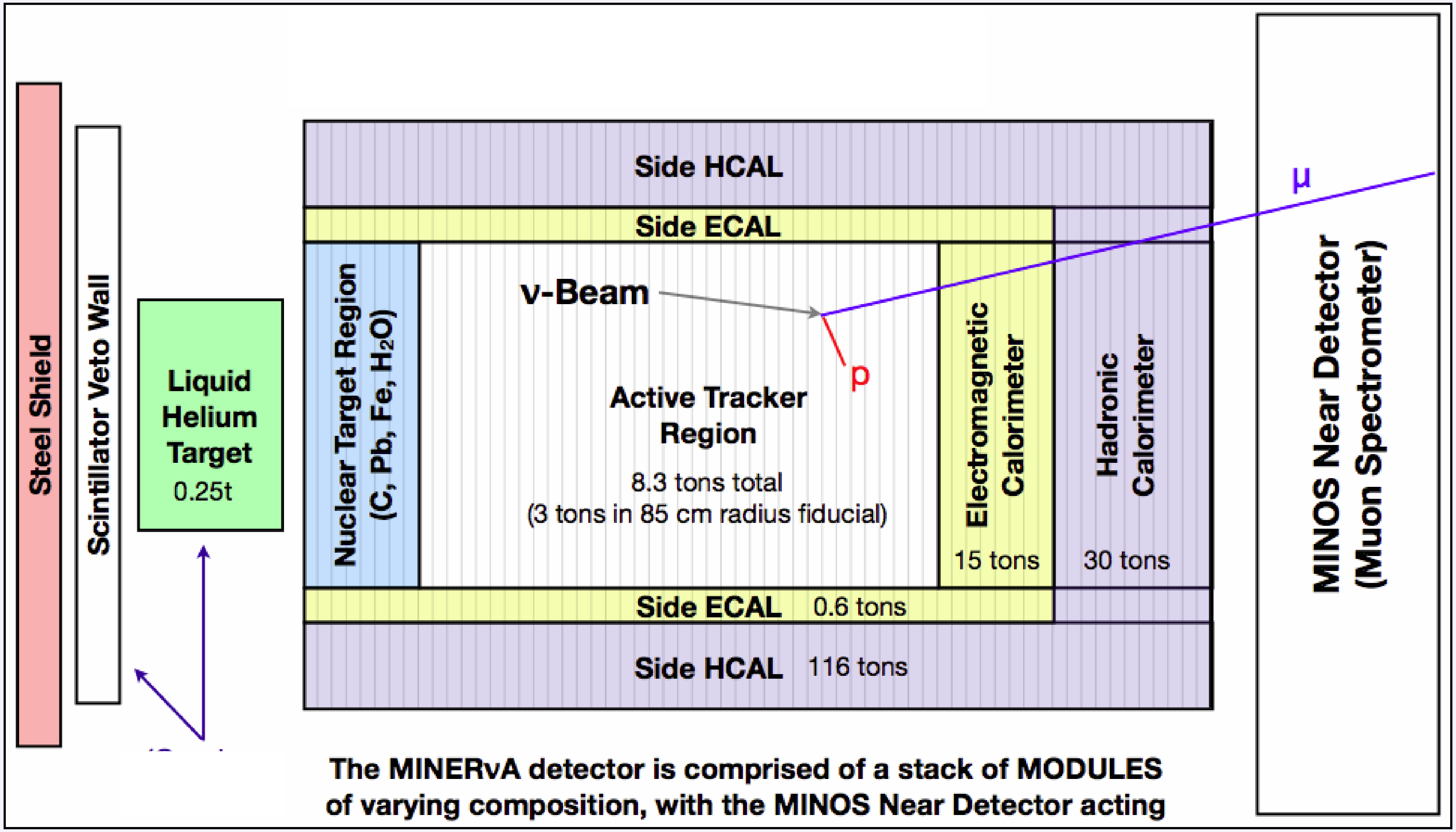
- Two detectors mitigate systematic effects
  - beam flux mis-modeling
  - neutrino interaction uncertainties

Recent MINOS Results



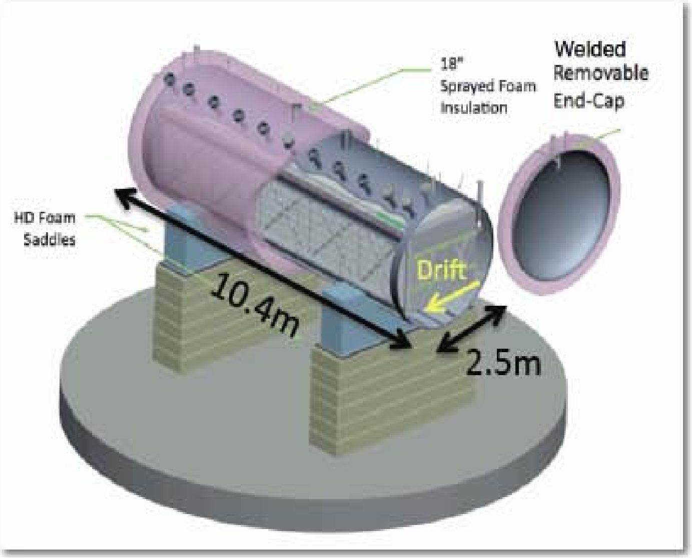
- Approaching sensitivity for mass hierarchy and CP violation in neutrino mixing
- Measured that speed of neutrino is not faster than a speed of light…

MINERvA Experiment



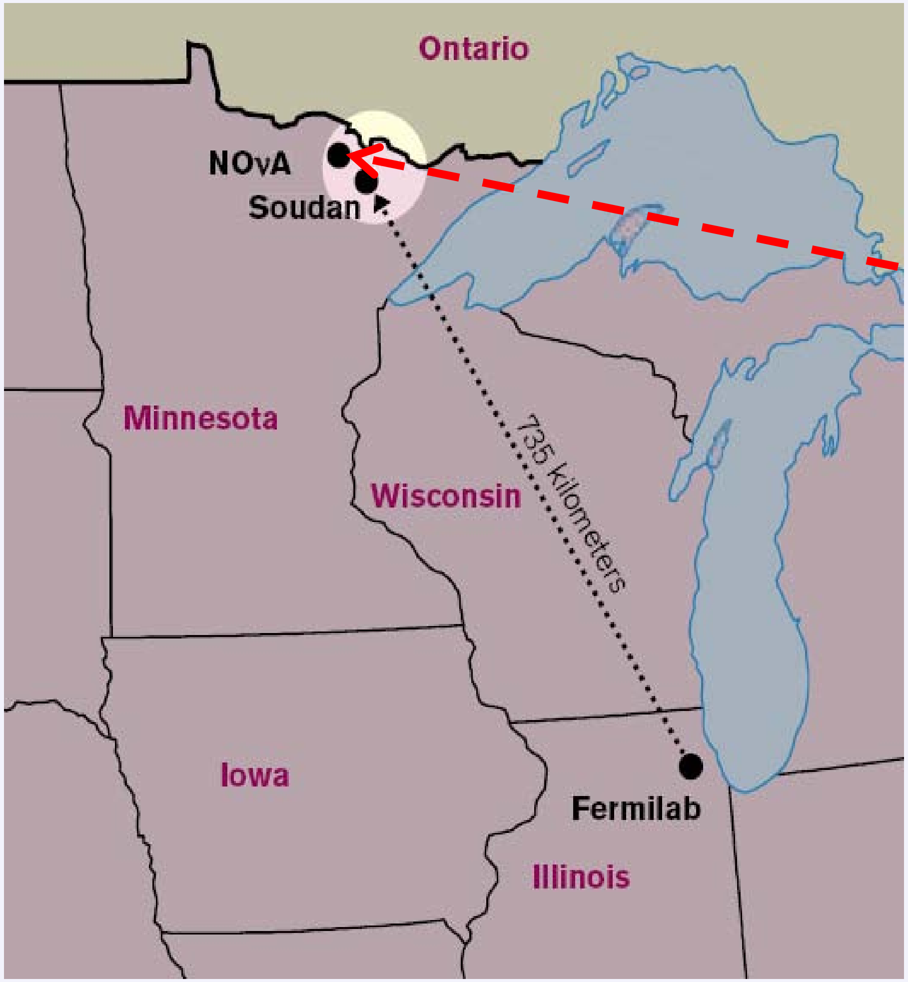
- MINERvA (just in front of MINOS) is studying neutrino interactions in unprecedented detail on a variety of different nuclei – He,C,CH2,H2O,Fe,Pb
- Important information for all neutrino based experiments

MicroBooNE

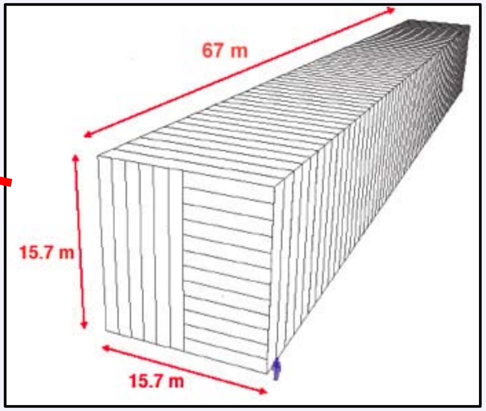


- 170 ton LAr TPC
  - *same beam & location as MiniBooNE*
  - *new detector technology*
- goals:
  - *MiniBooNE excess events*
  - σ_ν *measurements in argon*
  - *R&D for future LAr TPCs*

NOvA Experiment at Fermilab

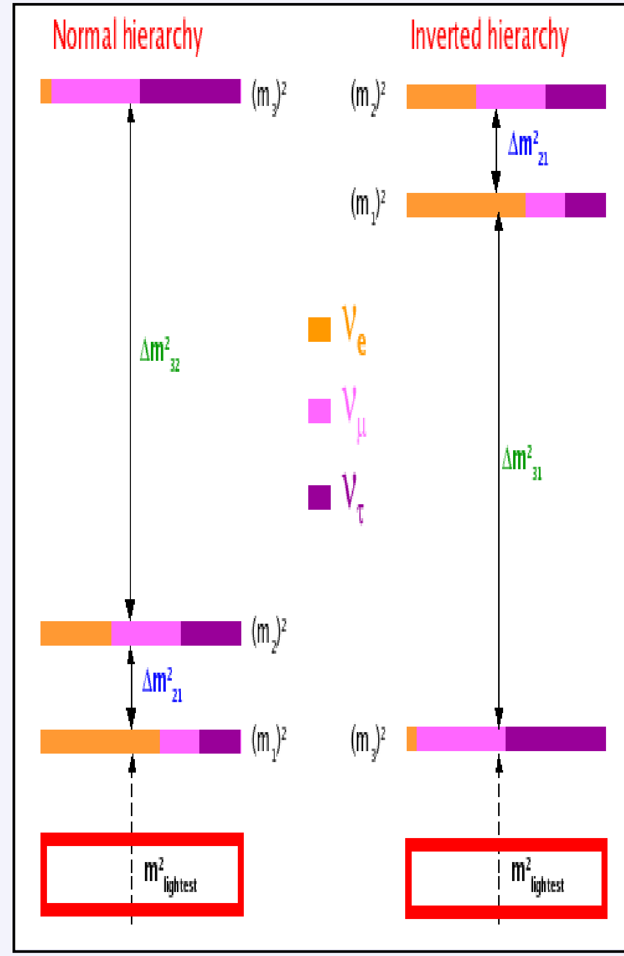


Plastic extrusion with liquid scintillator and WLS fiber with APD readout



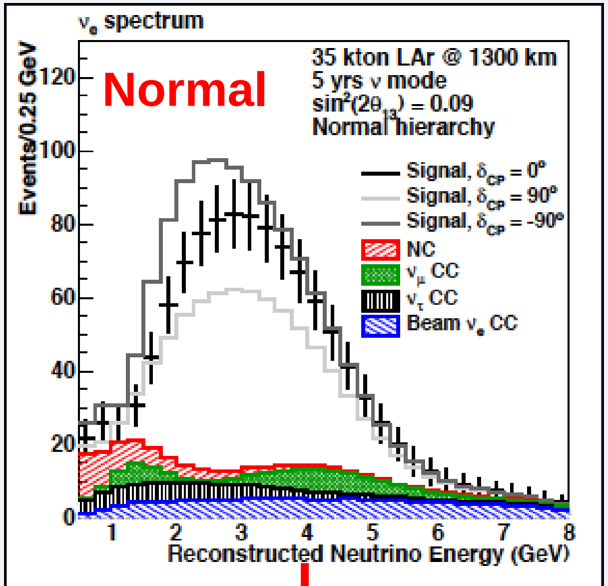
- “Off axis” neutrino experiment with 15 kton far detector and 300 ton near detector: 3σ mass hierarchy sensitivity
- Will start data collection this summer

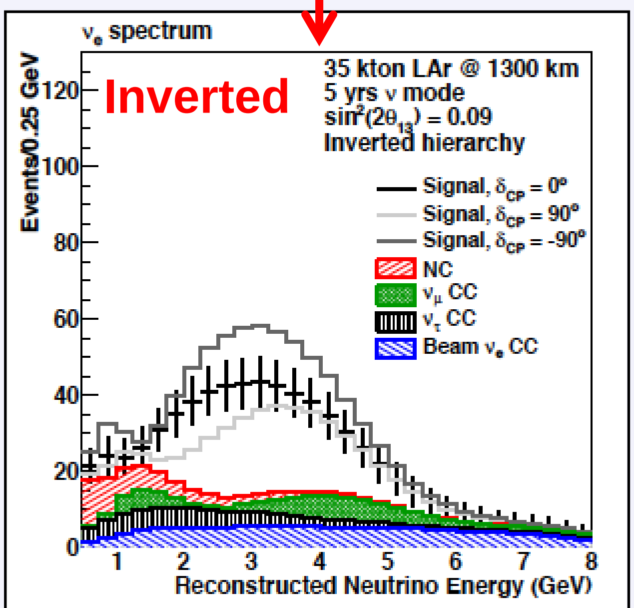
Long Baseline Neutrino Experiment - LBNE

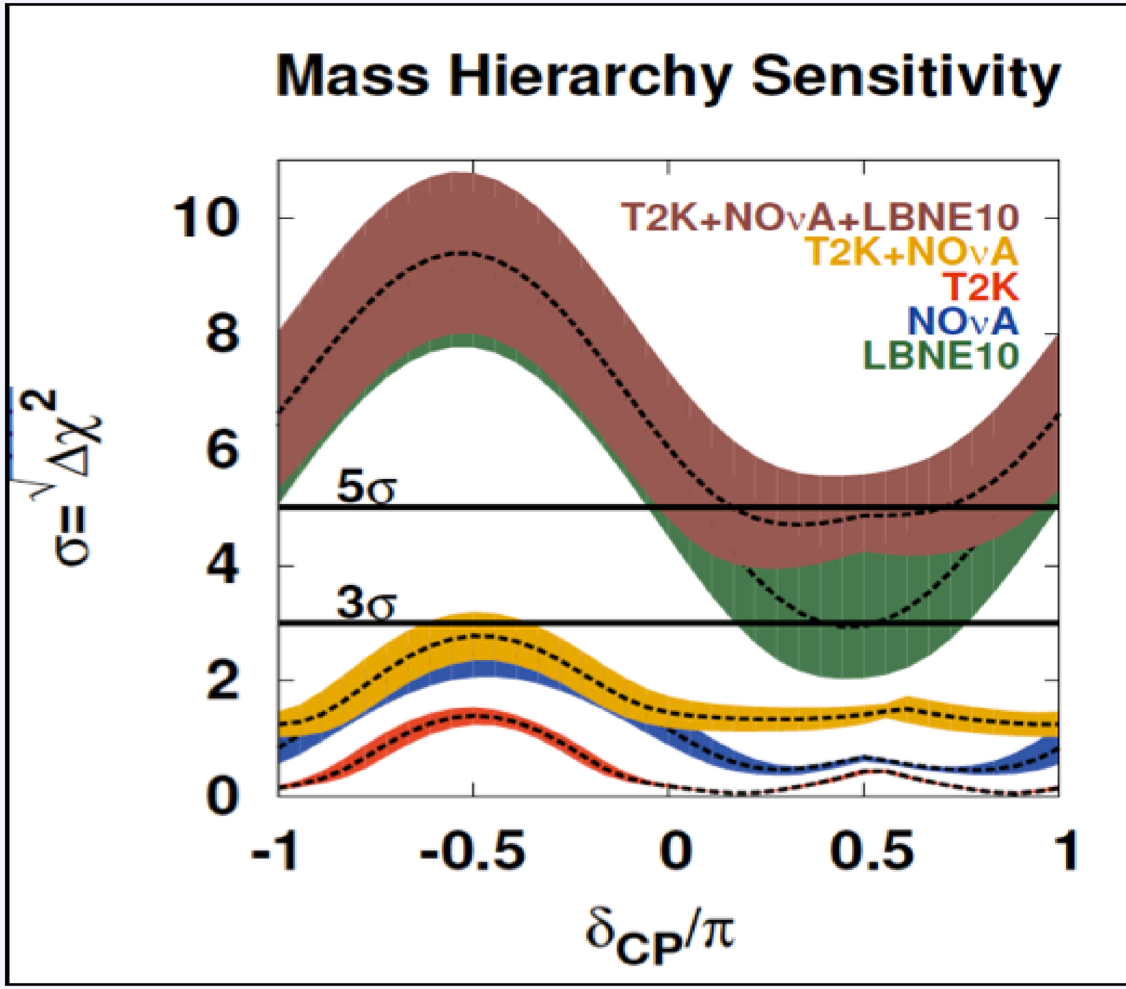


- **LBNE is LAr ~30kton experiment deep underground using neutrino beam from Fermilab – proposal for now**
- **Goals: neutrino mass hierarchy and CP violation as well as supernova detection and proton decay (up to 10^{35} years)**

Long Baseline Neutrino Experiment - LBNE

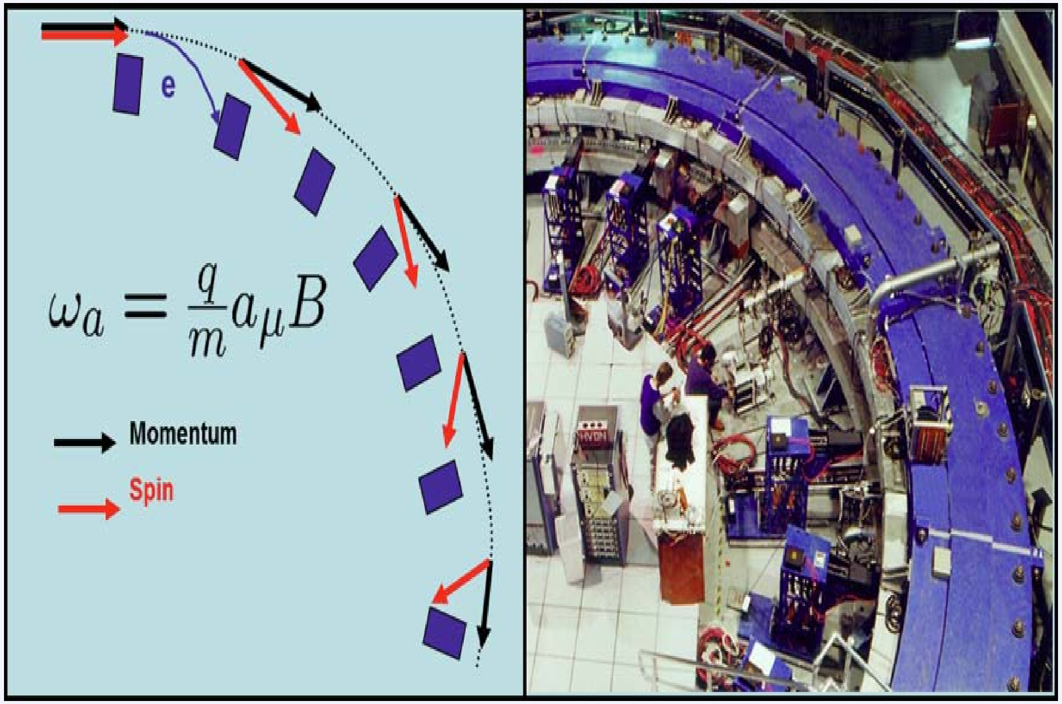


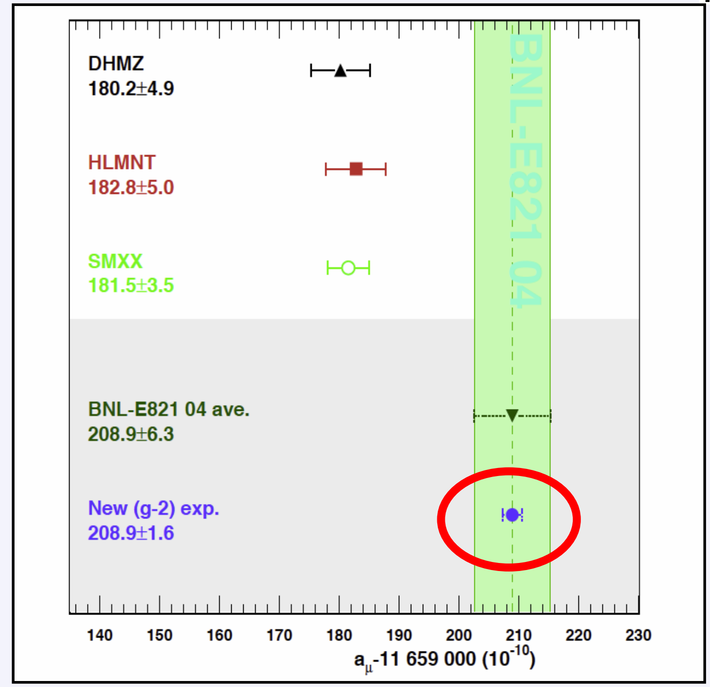




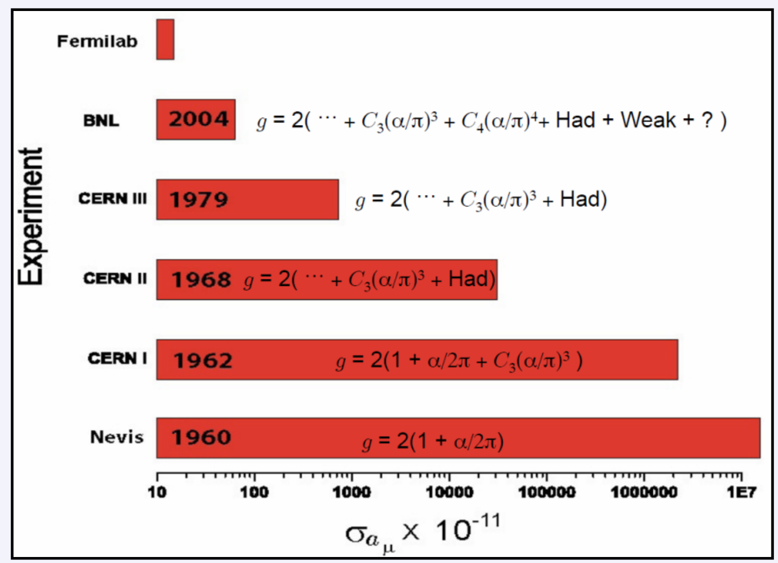
- Superior option to resolve mass hierarchy
- Find proton decay up to lifetime of 10^{35} years
- Detect supernova neutrinos

Muon Magnetic Moment g-2 experiment



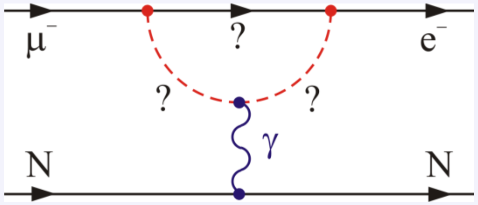


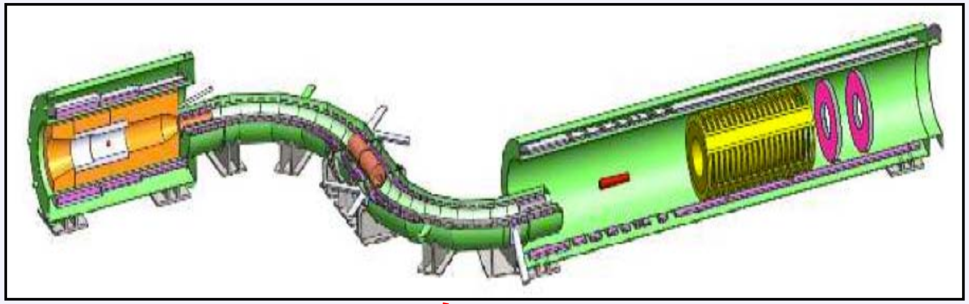
- Puzzle of ~3σ from BNL 2004 result
  - New physics?
  - Experimental effect?
- Coil moved to Fermilab in 2013
  - Higher intensity beam
  - Better systematics
- ~4 times better accuracy
- Start data collection in 2017

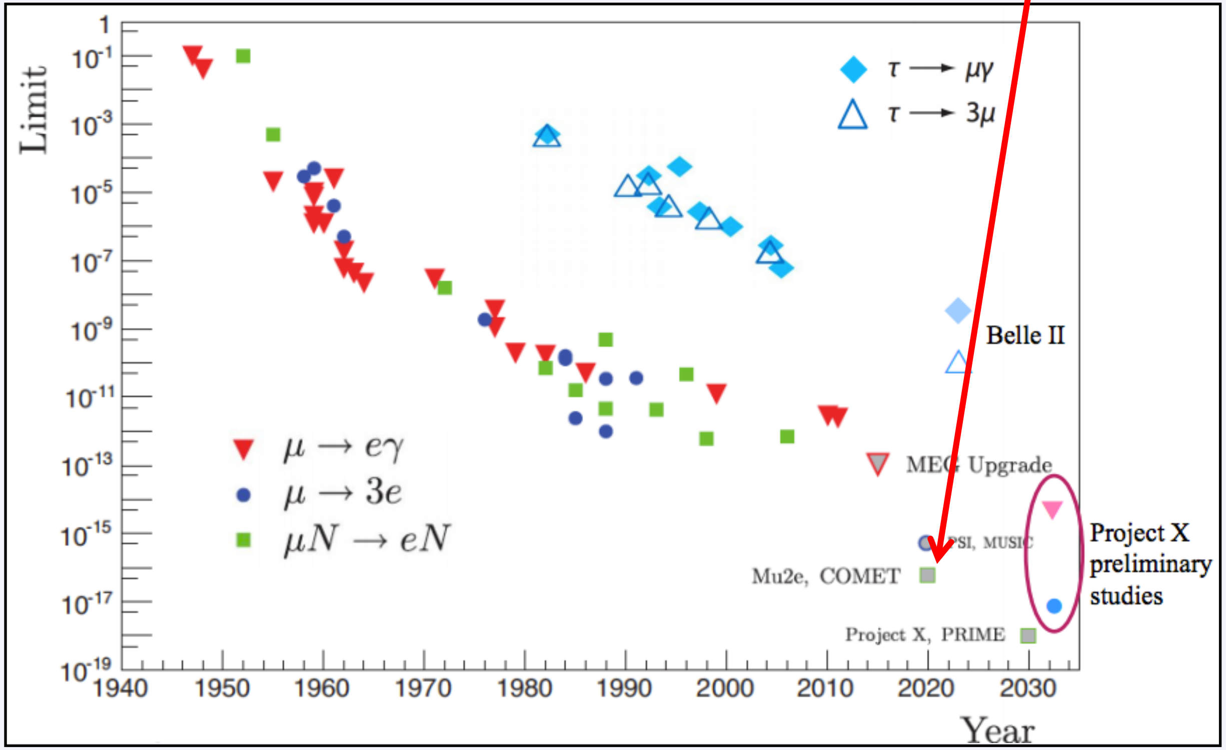


Lepton Flavor Violation: Mu2e

- New experiment Mu2e at Fermilab
  - High intensity muon flux stopped on a nuclear target
- Monochromatic electron emission from μ to e conversion
  - ~4 orders of magnitude improvement vs today's limits

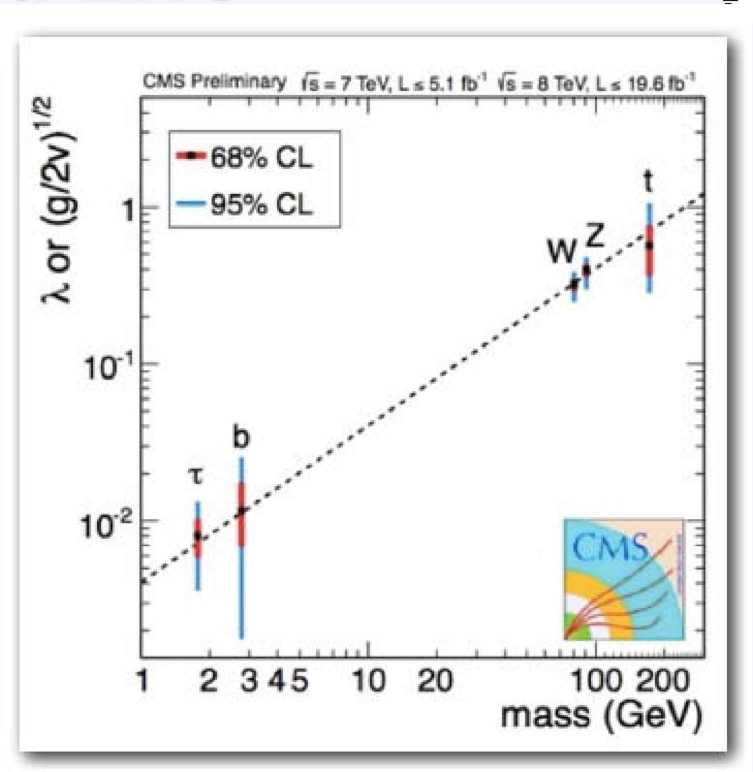




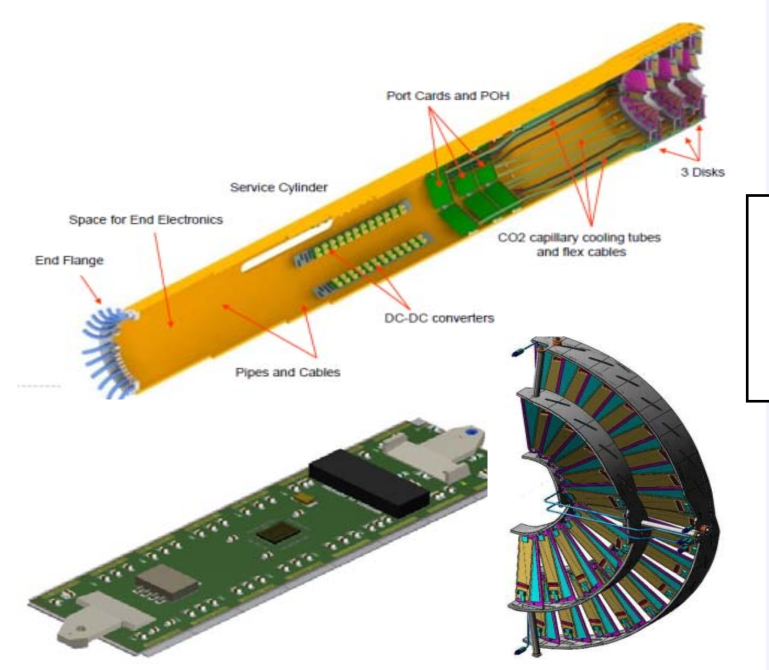


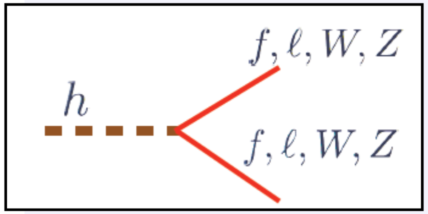
Fermilab and LHC

- **Fermilab is actively involved in LHC program: CMS and LHC upgrades**
- **Critical to study of all properties of the Higgs**
  - **Mass, width, spin, couplings, etc.**
- **Search for new particles and interactions**



Forward Pixel Detector

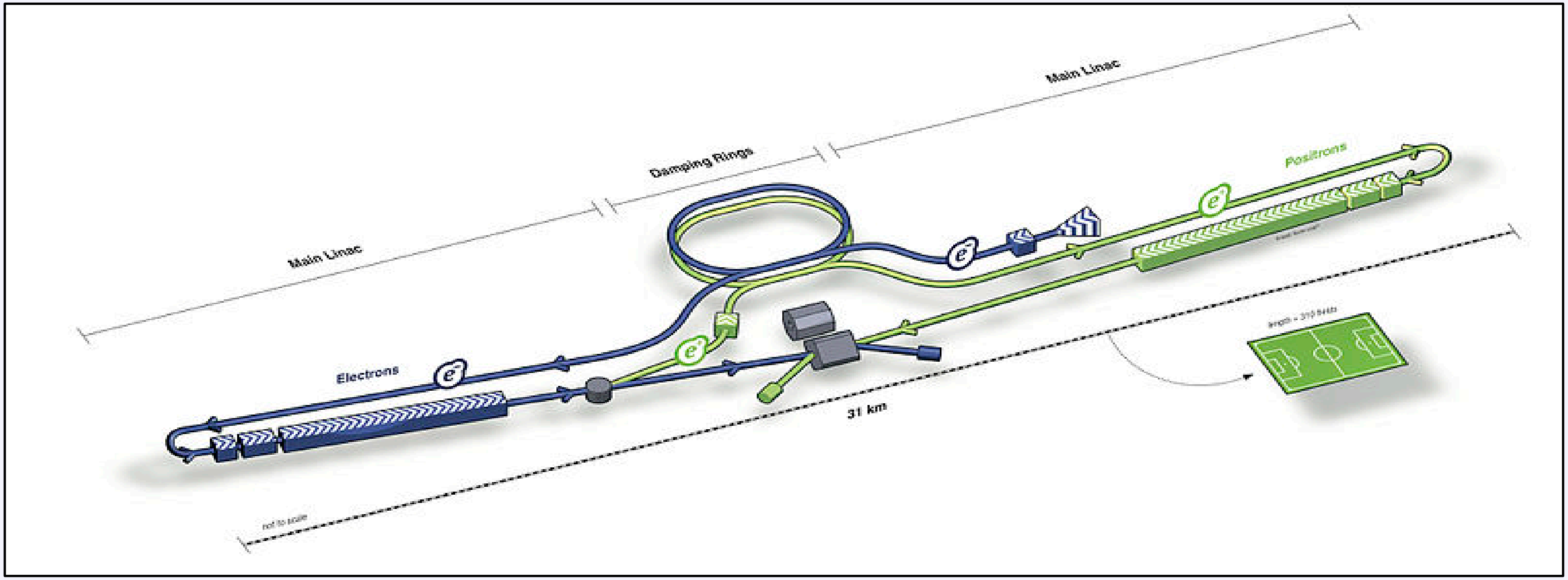




- New detector technologies are critical for "high luminosity LHC"
  - ~$5 \cdot 10^{35}$ $cm^{-2}sec^{-1}$ and above
- Fast, radiation hard detectors needed

US Participation in ILC (in Japan)

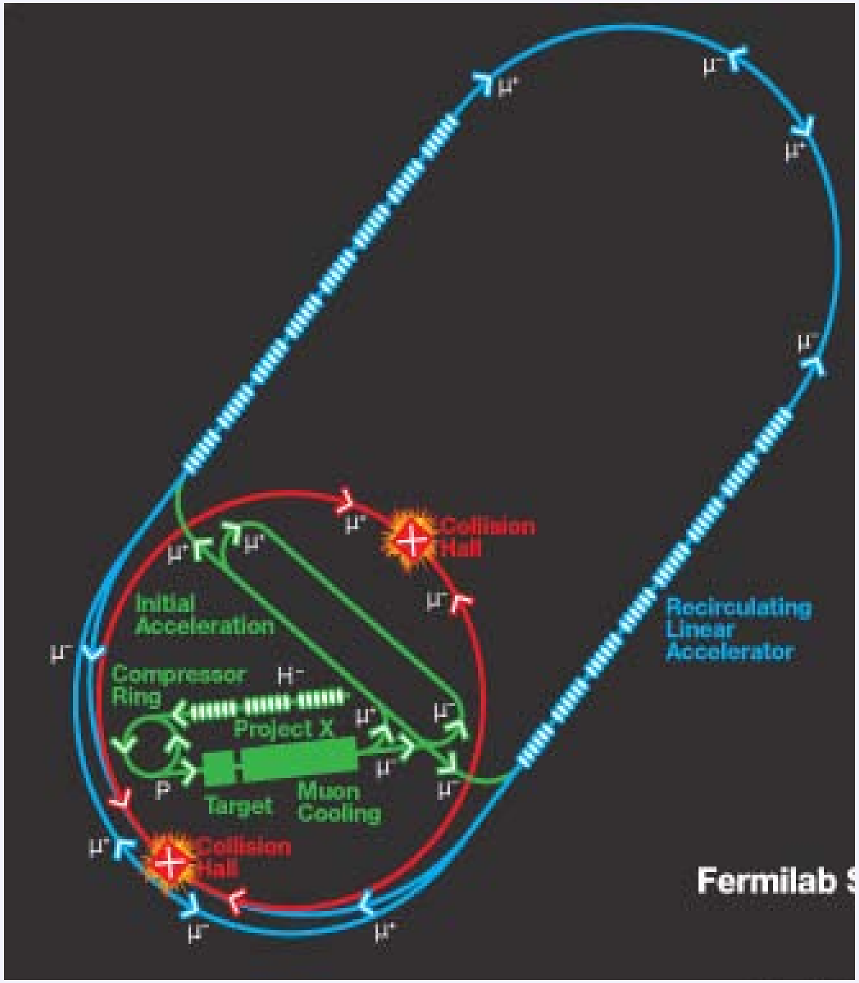
- U.S. accelerator community is capable to contribute
  - Supported by strong physics case
- ILC design is technically ready to go
  - TDR incorporates U.S. contributions to machine physics & technology
    - SCRF, high power targetry (e^+ source), beam delivery, damping rings, beam dynamics
- Important that there is an upgrade path of ILC to higher energy & luminosity (> 500 GeV, > 10^{34} $cm^{-2}s^{-1}$)



Muon Collider

- **Muons do not have high synchrotron radiation making circular accelerator viable for multi TeV energies**
  - **Muons are unstable with life-time of 2 μs**
- **Main accelerator challenge**
  - **To make large number of muons quickly and then "cool" them to focus into small diameter beams to collide**
- **Another issue are decays and irradiation by electrons from muon decays**
  - **and neutrinos irradiation!**
- **Active program in US, while many technical challenges exist**
  - **Maximum energy is ~10 TeV**

2x2 TeV



Fits on Fermilab's Site

VLHC – 100 TeV Hadron Collider

- **While "post-SSC effects" still present in US, there are re-newed discussions of ~100 TeV and ~100 km long circular pp hadron collider**
  - **Especially if full energy LHC will not bring new physics**
  - **33 TeV energy collider did not get support at Snowmass, while 100 TeV did**
- **Technically feasible option**
  - **100's of km of underground tunnels near Chicago**
  - **Accelerator technology is similar to Tevatron, SSC and LHC**
- **Snowmass conclusions recommend to increase efforts on VLHC accelerator/physics/detectors development**

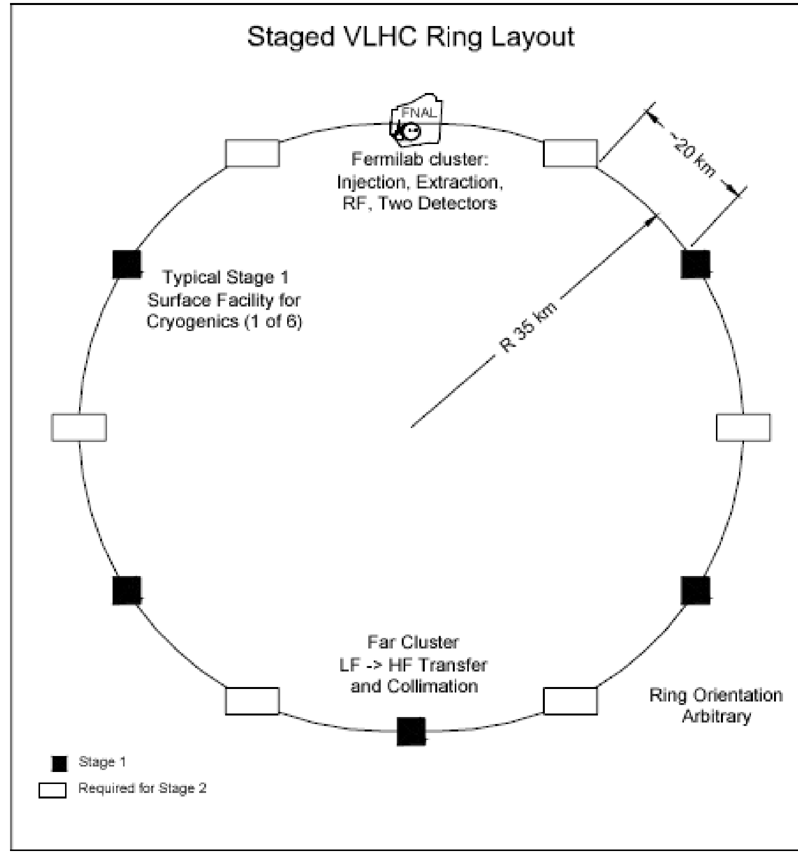
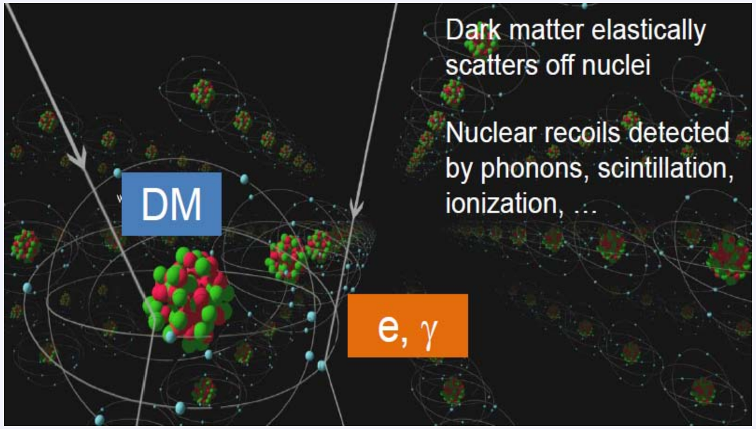


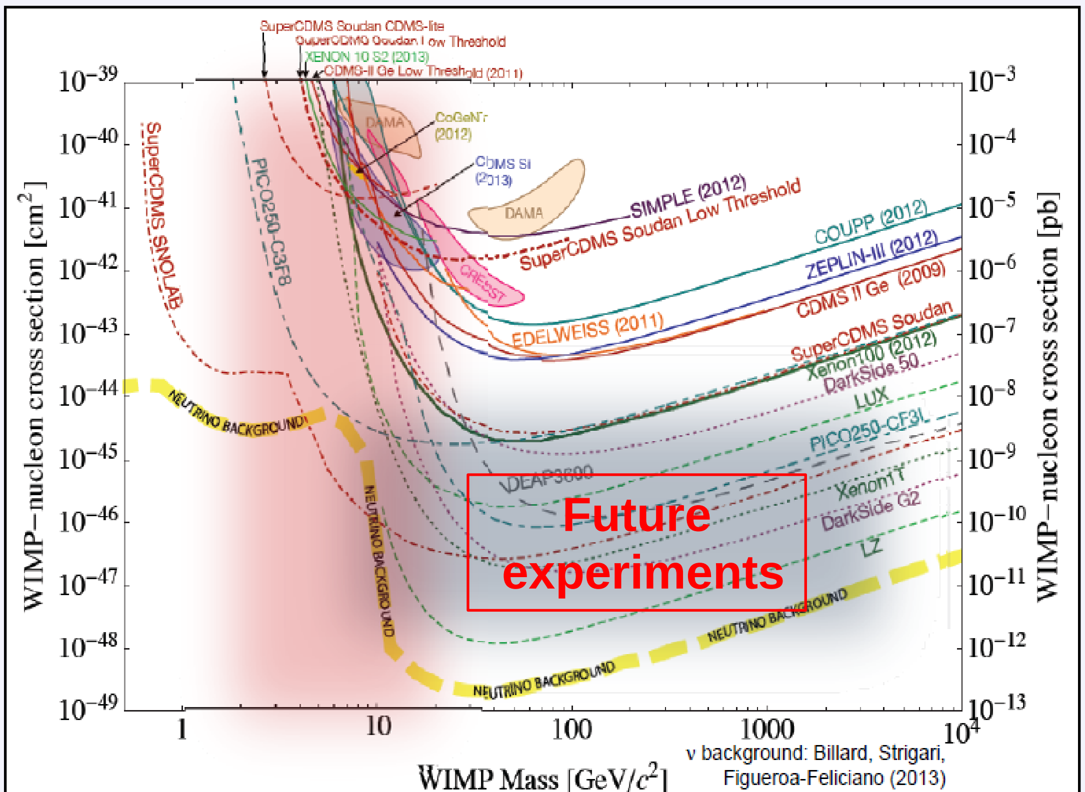
Table 1.1. The high-level parameters of both stages of the VLHC.

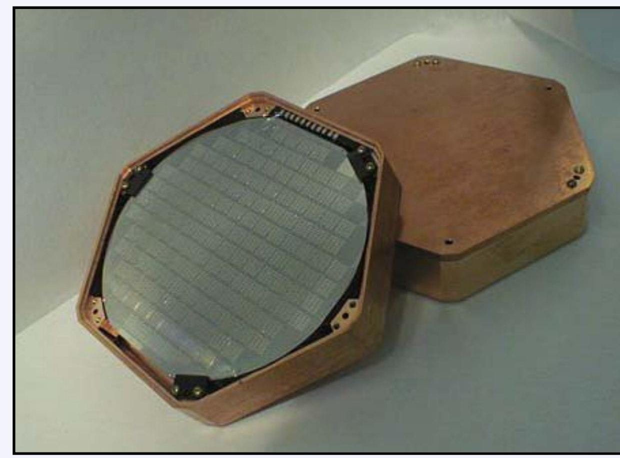
	Stage 1	Stage 2
Total Circumference (km)	233	233
Center-of-Mass Energy (TeV)	40	175
Number of interaction regions	2	2
Peak luminosity ($cm^{-2}s^{-1}$)	1×10^{34}	2.0×10^{34}

Dark Matter Direct Detection



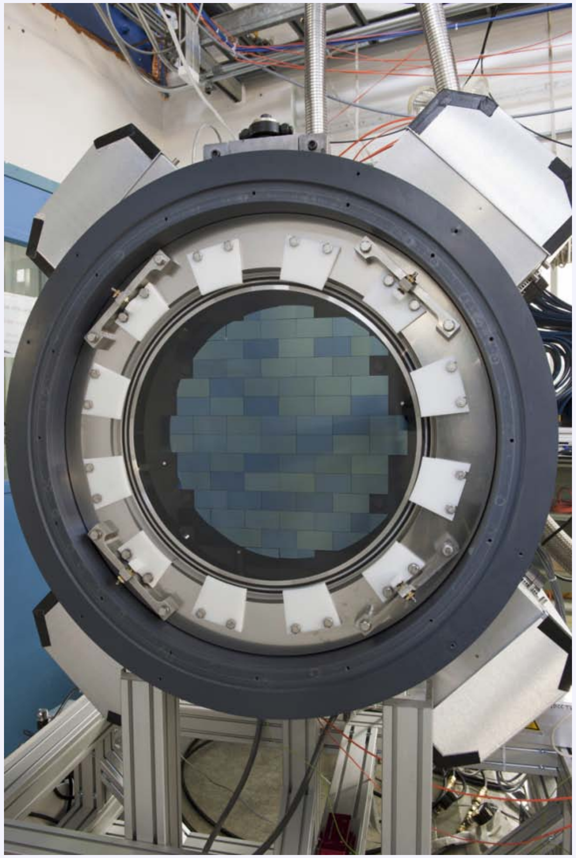
- Many models expect dark matter to consist of heavy WIMP particles
- Multiple methods used to detect elastic scattering of WIMPs: ionization, scintillation, phonons. Results mixed…
- Fermilab is actively involved in CDMS experiment in Soudan mine





Fiducial volume is 75% of the crystal
9 kg currently operating at SuperCDMS Soudan
200 kg planned for SuperCDMS at SNOLAB

Dark Energy Survey - DES

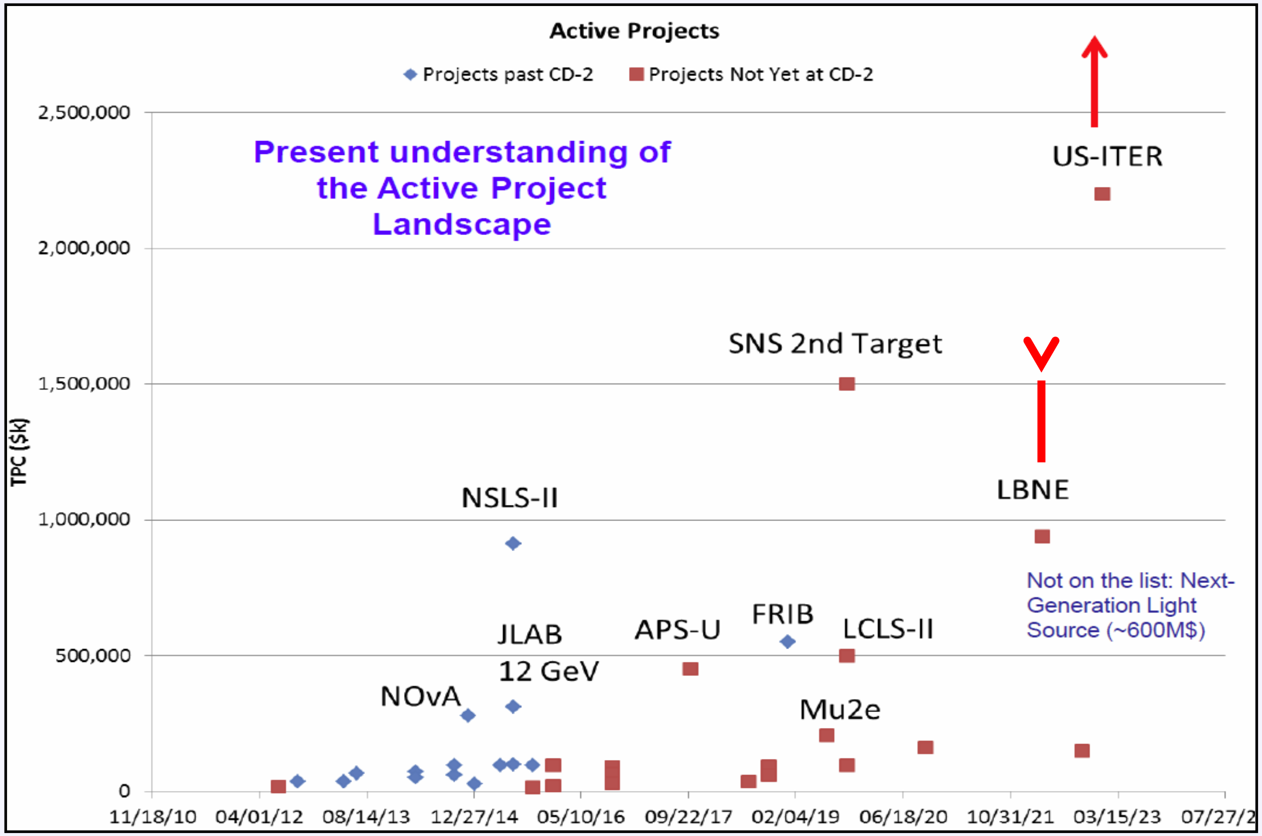


One of the first DES pictures!

- **DES goal is to create scans of night sky using 4 meters telescope and 570 megapixels camera (camera made at Fermilab)**
  - **Located in Chile**
  - **Started data collection in September of 2013, very large data volumes**
- **Major scientific areas: studies of dark matter, dark energy, supernova, solar system survey and many other topics**

And What About "Super" Projects

- Any new large accelerator has price tag of "many billions"
- Even large detectors, like ATLAS/CMS/LBNE , cost in excess of a billion dollars
- Such projects were affordable in the past
  - Cost of the *first* Fermilab accelerator in today's dollars is ~$4 billion
- Recent history shows that "any project has to be below ~$1 billion"



Current and Planned Fermilab Experiments

							Project: from CD-0 to CD-4			Operations		
Project	**FY2006**	**FY2007**	**FT2008**	**FY2009**	**FY2010**	**FY2011**	**FY2012**	**FY2013**	**FY2014**	**FY2015**	**FY2016**	**FY2017**
Energy Frontier												
Tevatron												
CDF/DZero												
LHC CMS			CD-4				**CD-0**	**CD-1**	CD-2/3			
LHC Machine			CD-4						CD-0/1	CD-2/3		
Intensity Frontier												
Linac/Booster/MI												
Testbeam												
MiniBooNE												
MINOS												
MINERvA	CD-0	**CD-1/2/3a**	**CD-3b**		**CD-4**							
NOvA	CD-0	**CD-1**	**CD-2**	**CD-3a**						**CD-4**		
MicroBooNE					CD-0/1	CD-2/3a	CD-3b		CD-4			
Muon g-2							CD-0	CD-1/3a	CD-2/3b		CD-4	
Muon (AIPs, GPPs)												
Mu2e					CD-0		CD-1	CD-3a	CD-2/3b	CD-3		
LBNE					CD-0			CD-1		CD-3a	CD-2	CD-3b
Project X									CD-0	CD-1		
Cosmic Frontier												
DE Cam	**CD-0**		**CD-1/2/3a**	**CD-3b**			CD-4					
Gen2 Dark Matter							CD-0		CD-1	CD-2		
Infrastructure												
SLI				**CD-0**		CD-1			**CD-2** **CD-3**		CD-4	

Concluding Remarks

- Particle physics in US is undergoing changes after shutdowns of SLAC B factory and Fermilab Tevatron over last 5 years
- Snowmass process created well documented list of exciting proposals for new accelerators and experiments
- Most probable accelerator projects for this decade
  - New Fermilab linac, ILC and LHC high luminosity upgrades
- Large new upgrades/experiments planned at Fermilab
  - g-2, Mu2e, LBNE, ATLAS/CMS upgrades, dark matter searches
- P5 process is progressing to set priorities for the coming ~10 years
- Wide range of test beams is available for detector studies

There is wealth of experience at Fermilab in both accelerators and detectors and interesting program ahead