

Research Opportunities at Fermi National Accelerator Lab (FNAL)

31 March, 2014

Erik Ramberg

Fermilab





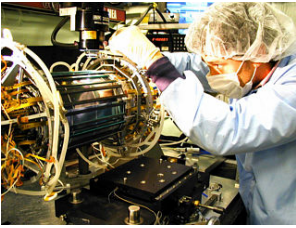


Fermi National Accelerator Laboratory is 2.5 square kilometers in Batavia, Illinois, (about 50 kilometers west of Chicago)





The European CALICE hadron calorimeter being installed at the Test Beam Facility



Building a silicon vertex detector at the Silicon Detector Facility



Liquid Argon Test stands at Proton Assembly Building



NUMI Underground Facility, with MINERVA detector in background

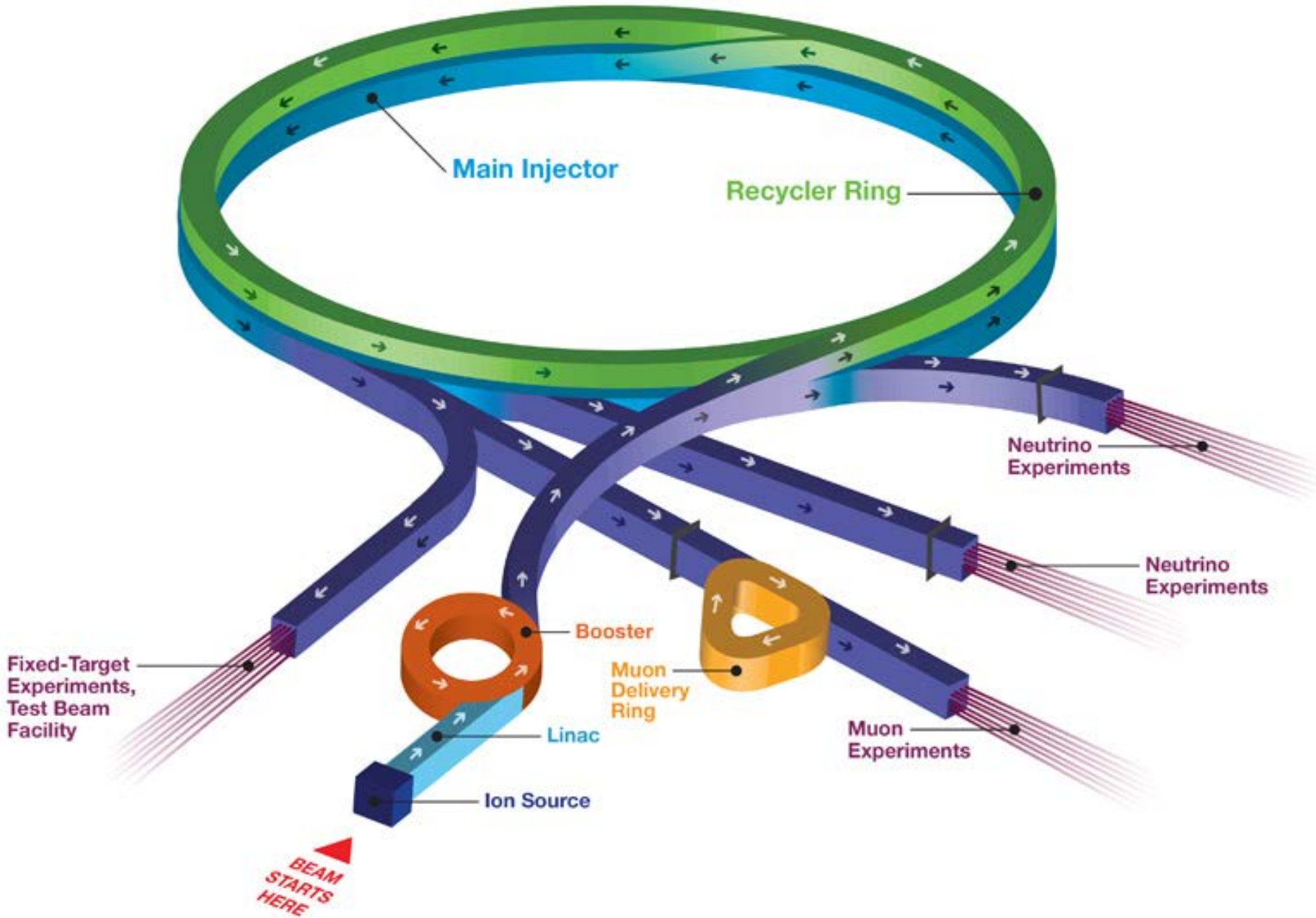


D0 Experiment. One of two Tevatron collider detectors, now used for liquid Argon R&D

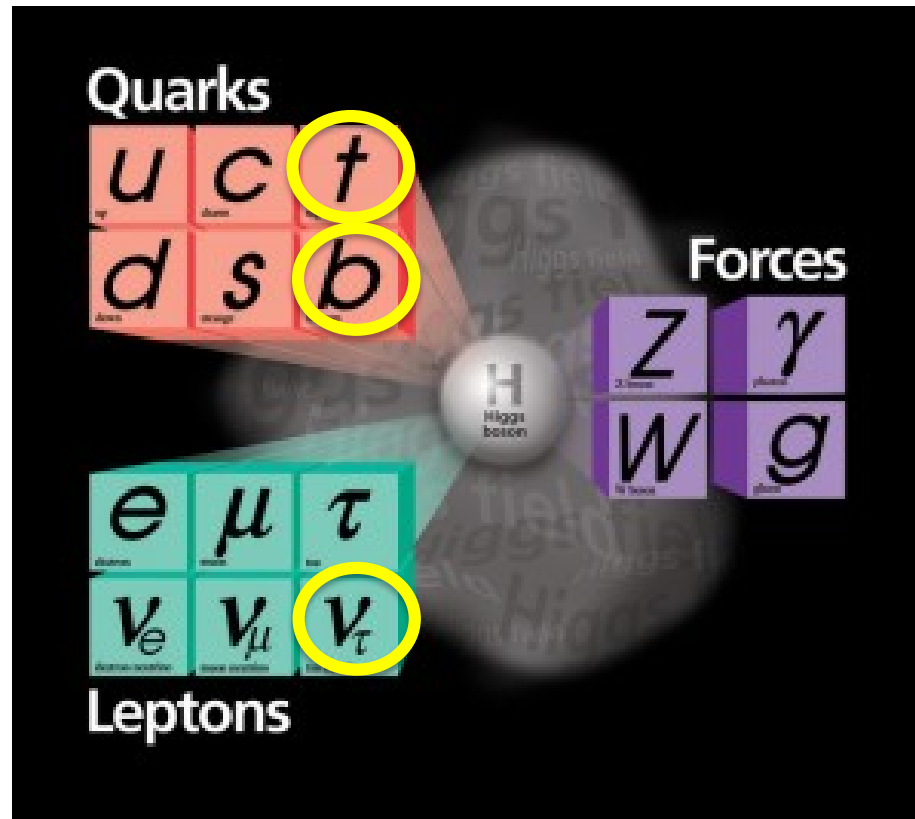


CDF Experiment. One of two Tevatron collider detectors. Now used for accelerator research

Fermilab Accelerator Complex



Standard Model of Particle Physics:



But what about: Dark Matter ? Dark Energy ? Inflation ?

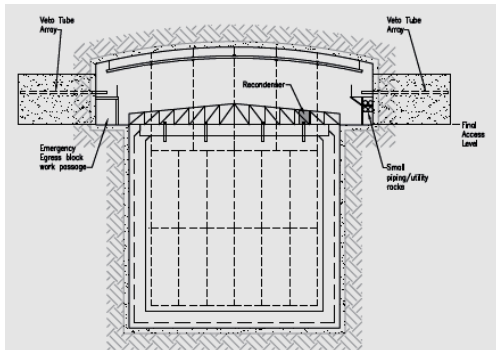
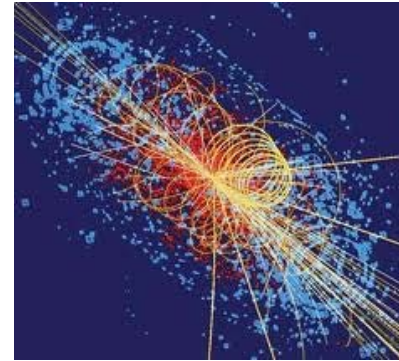
The Fundamental Physics Research Program at Fermilab

- ***New Particles***
Partners of Higgs Boson
New Supersymmetric particles
- ***New Forces***
Lepton Flavor Violation (e.g. $\mu \rightarrow e$)
Baryon Number Violation ($n \rightarrow \bar{n}$ oscillations)
- ***New properties of matter***
Neutrino/anti-neutrino asymmetries
Neutrino magnetic moment
- ***New dimensions***
e.g. super-symmetric amplitudes via EDM's
Warped dimensions via kaon decays
- ***New technology***
Muon based neutrino factory
3-dimensional integrated circuits
Accelerator driven nuclear reactions

Examples of technology challenges in the 'Frontiers' of High Energy Physics that Fermilab is addressing

'Energy Frontier' :

In an upgrade to the LHC detectors, vertex sensors and triggers will need to withstand a flux of 10^{16} particles/cm²

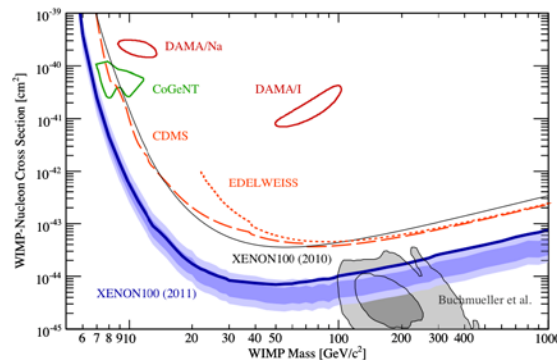


'Intensity Frontier':

As an alternative to huge water Cerenkov neutrino detectors, the U.S. program is advancing neutrino detector research with large volumes of Liquid Argon

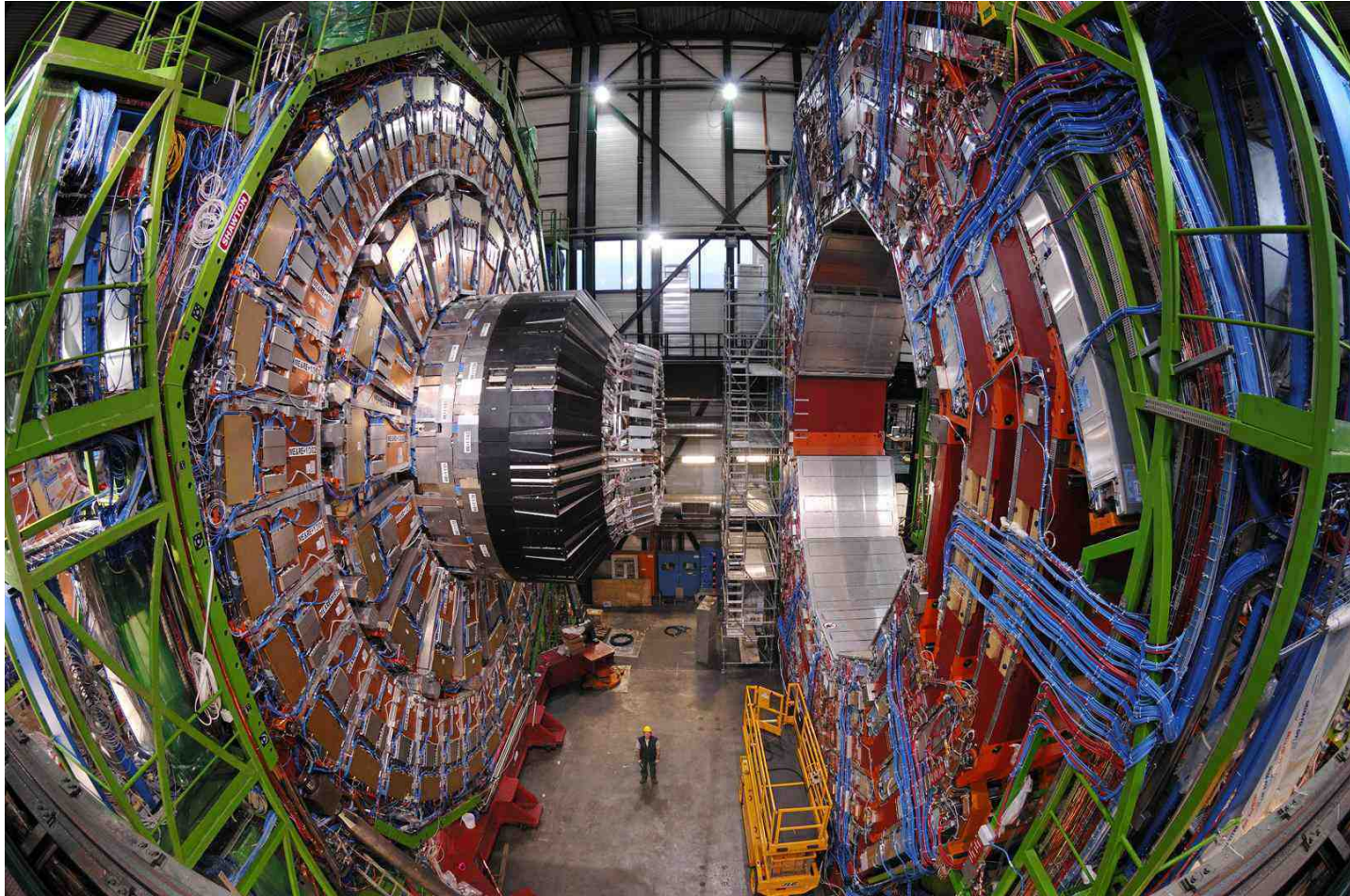
'Cosmic Frontier':

We need to reduce background rates in dark matter detectors down to a level of 1 nuclear recoil per ton per year



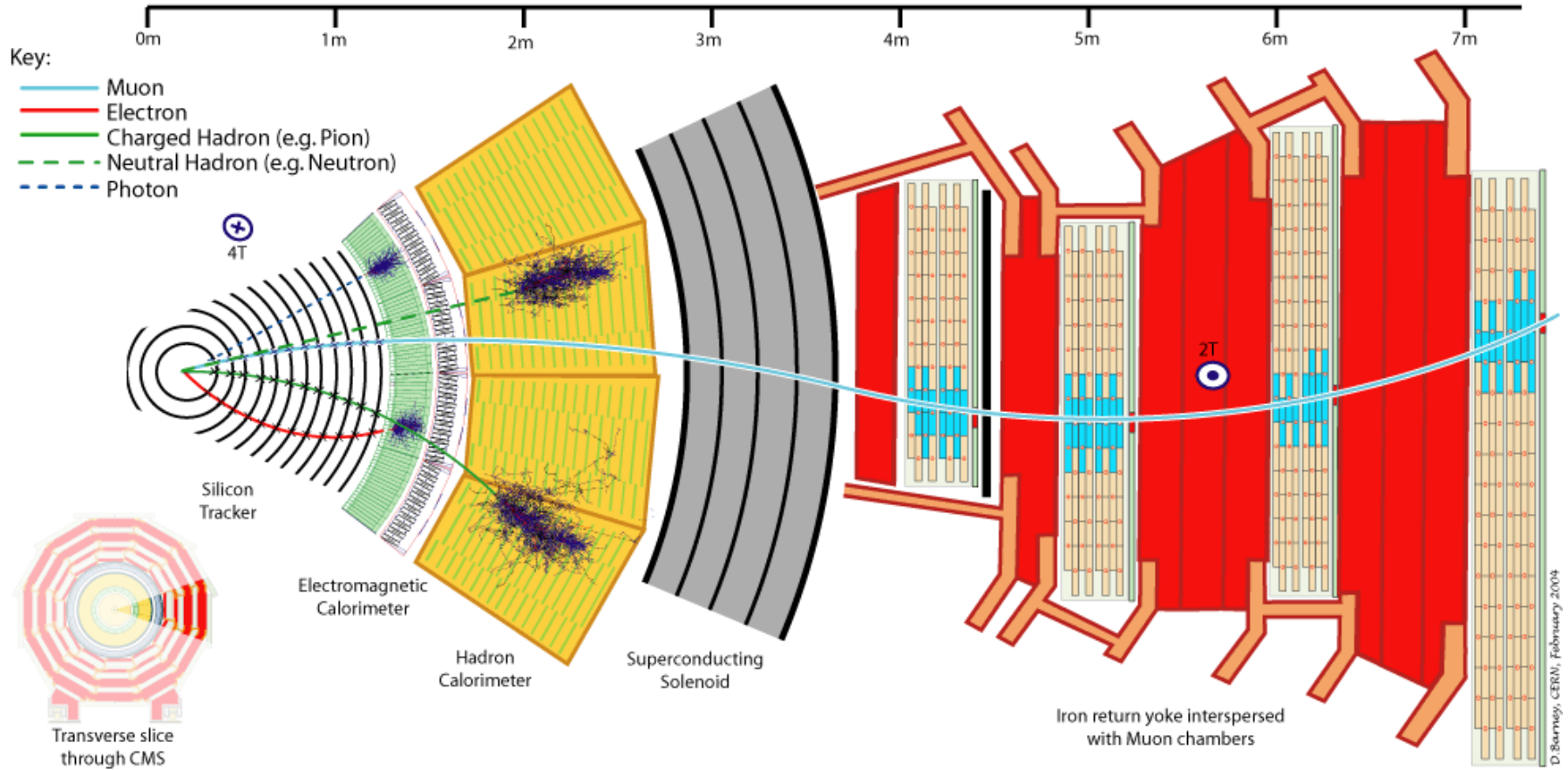
Energy Frontier Research

The Energy Frontier - CMS Detector



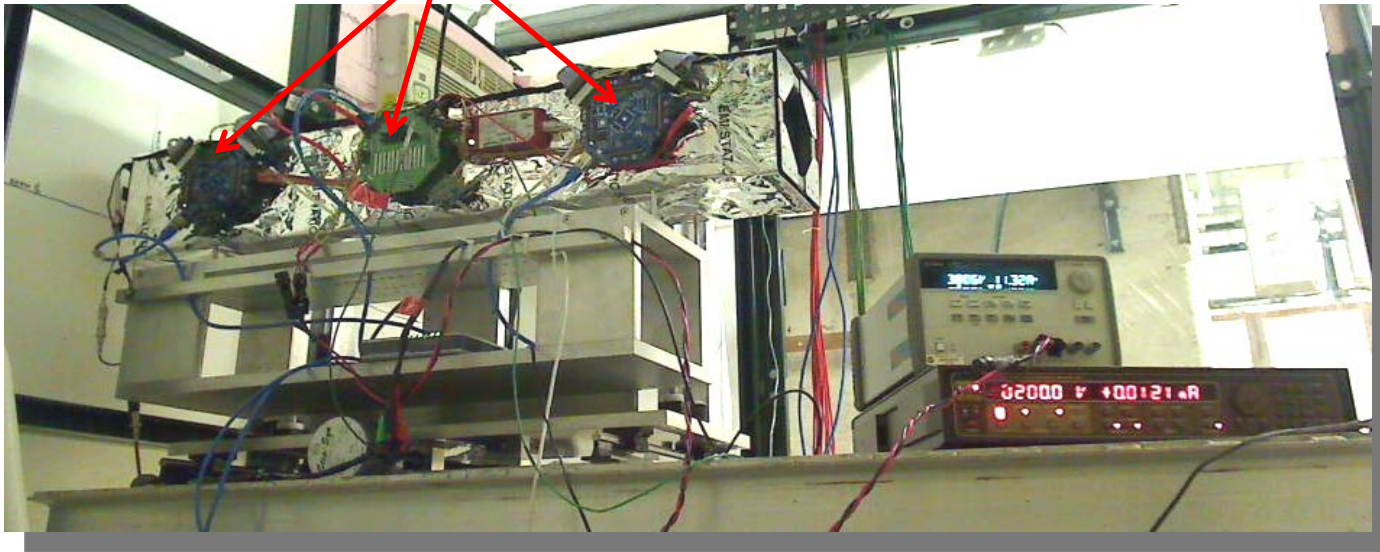
Co – discovery collaboration of Higgs Boson, at LHC

Particle tracks and showers in CMS



Fermilab Test Beam Pixel Telescope and Custom DAQ

CAPTAN STACK

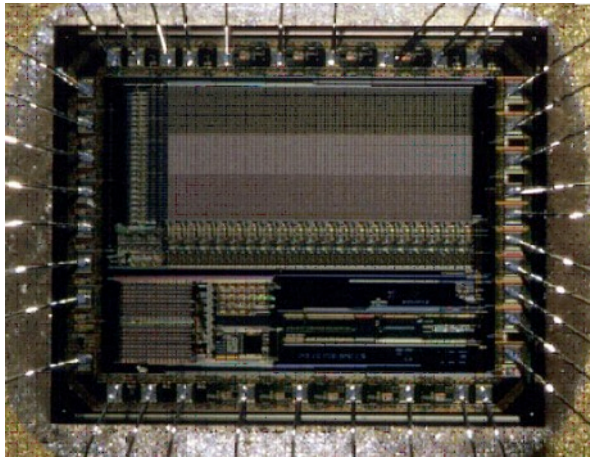


CAPTAN DAQ, developed by Fermilab Computing Division, is reading out data from silicon detectors left over from construction of CMS

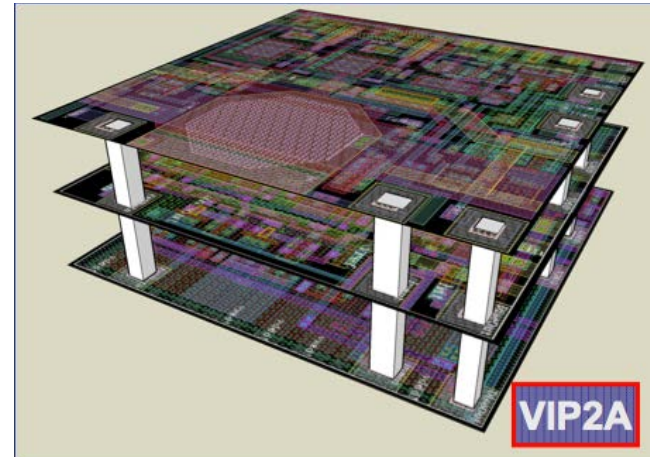
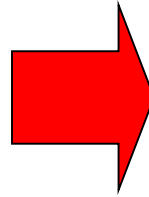
Telescope consists of X Y X' Y' layers, with 5 micron accuracy

Used for testing efficiencies of new sensors – like diamond detectors!!

3-Dimensional Integrated circuit program



Conventional Monolithic
Active Pixel Sensor



3 tier 3D stack for FNAL ILC vertex
chip, fabricated by MIT-LL

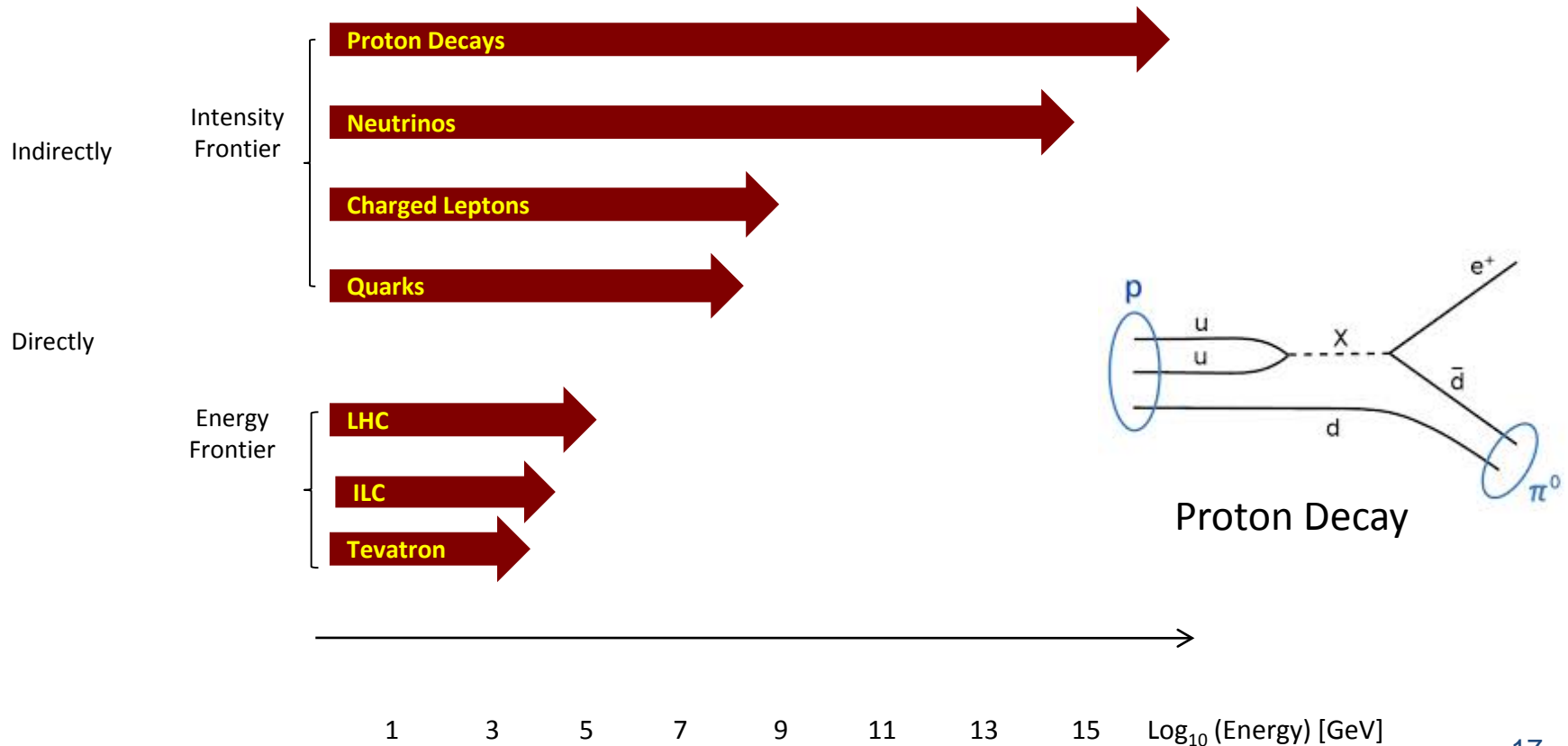
-Fermilab has led the formation of a large international group addressing this new technology for particle physics.

The thin layer to layer communication path makes these circuits very fast and noise free and low power

Intensity Frontier at Fermilab

The Farthest Reach in Mass is through Rare or Forbidden Processes, not through Center-of-Mass Energy

Experimental reach (model dependent)



LBNE (Long Baseline Neutrino Experiment)

Scientific Motivations:

- **Explore 3x3 model of ν mixing**
 - Broad band beam and high resolution detector
 - CP violation and mass hierarchy
- **Atmospheric neutrinos**
 - Independent ν source, can determine mass hierarchy, and others
- **New ν physics**
 - Sterile ν , non-standard interactions, other
- **Proton Decay**
 - Test fundamental but unexplained conservation of baryon number
 - Grand Unified Theories predict specific decay modes, lifetimes, branching ratios
- **Astrophysics**
 - Supernova burst ν

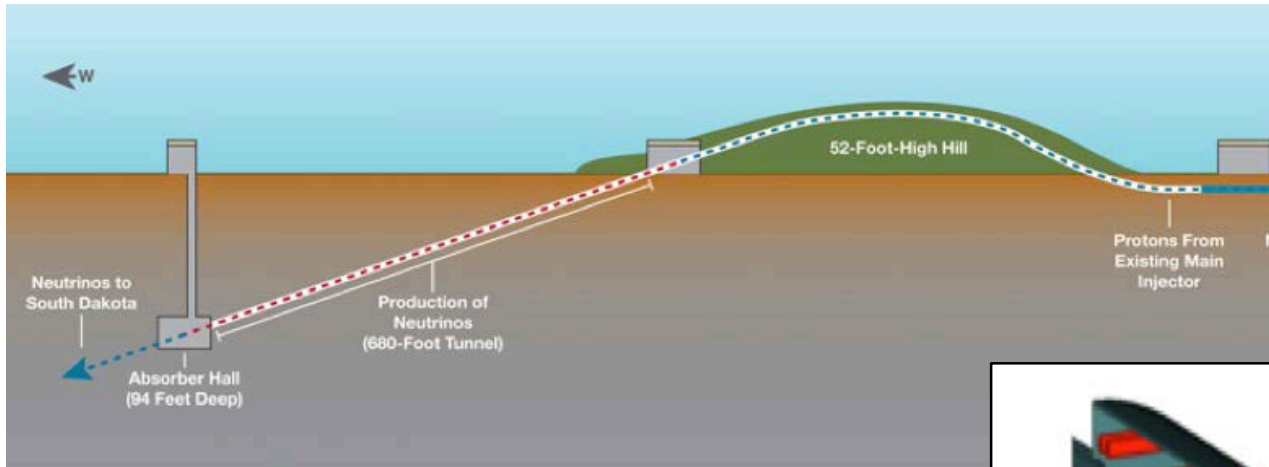
- *What is the mass hierarchy?*

_____ normal? or _____ inverted?

- *Is $\theta_{23} = 45^\circ$?*

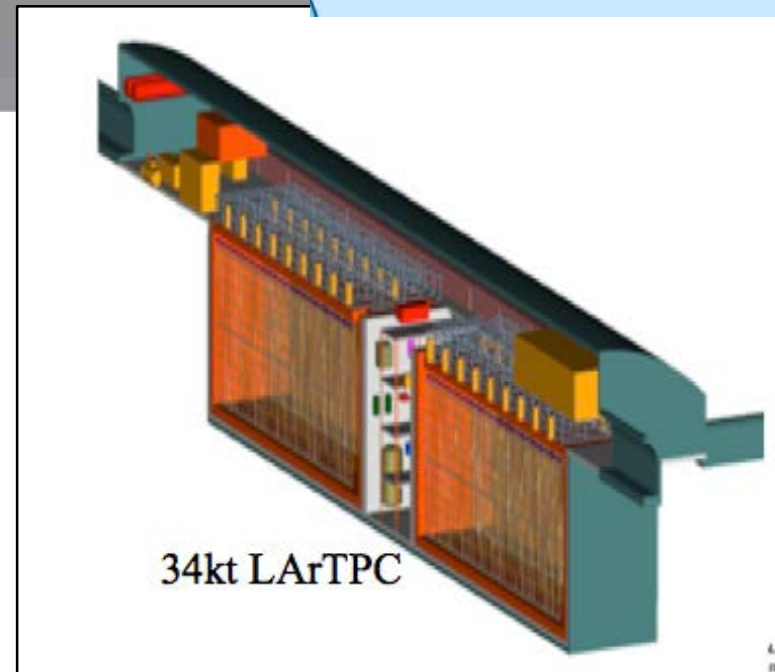
- *Is CP violated? $P(\nu_\alpha \rightarrow \nu_\beta) \neq P(\bar{\nu}_\alpha \rightarrow \bar{\nu}_\beta)$?*

Plan for LBNE Beamline and Far Detector



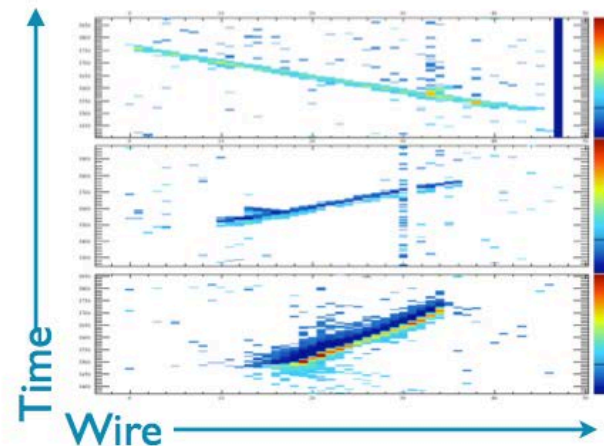
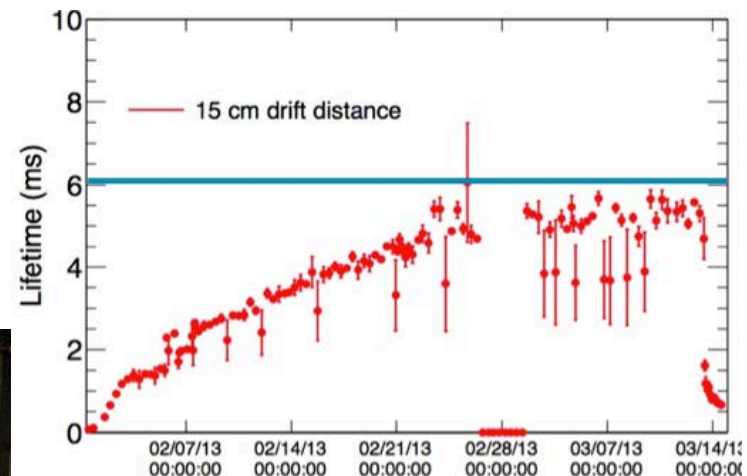
Long Baseline Neutrino Experiment:

- 1500 kilometer baseline
- Beam is pointed into the ground towards South Dakota
- neutrinos oscillate their flavor at this distance
- Eventually 2.2 Mwatt beam
- 34 kton Liquid Argon detector



Progress in Liquid Argon R&D: Demonstration of Efficient Charge Collection

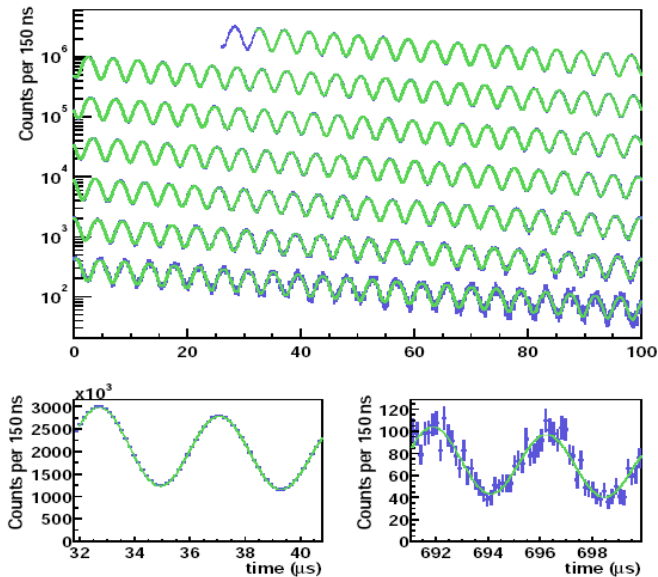
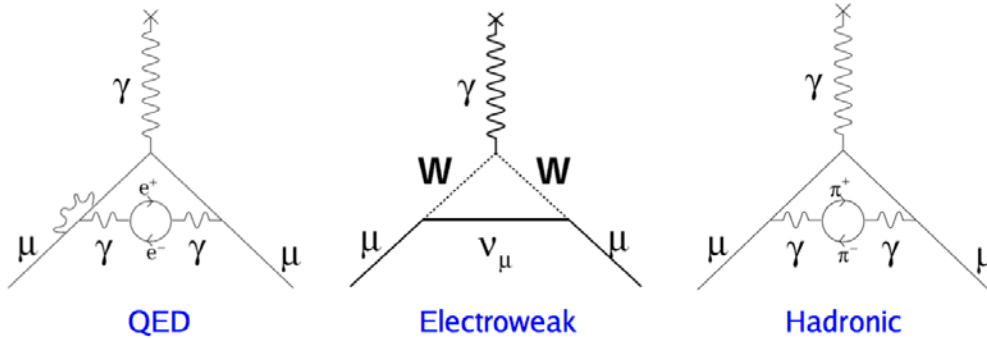
- 'Liquid Argon Purity Demonstrator' has demonstrated high purity in a non-evacuated 30 ton volume.
- Now instrumented with the longest TPC in the U.S. (2.5 meters)



Intensity Frontier: Muon Physics

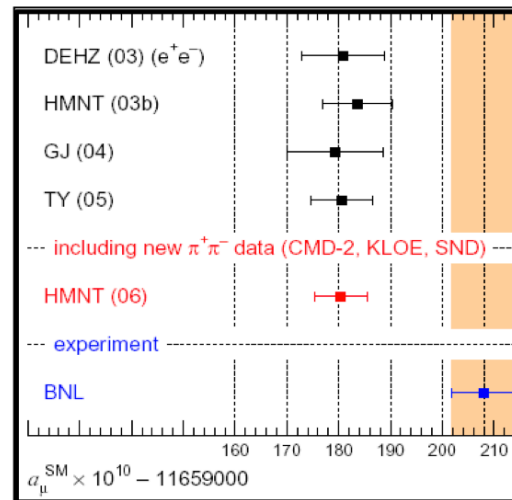
Muon Anomalous Magnetic Moment (g-2)

Why measure the muon magnetic moment? $a_\mu = \frac{g-2}{2}$



● BNL $a_\mu(\text{exp}) = 116\,592\,080(63) \times 10^{-11}$

Theory evaluation stable!



3σ discrepancy between theory and measurement at BNL.

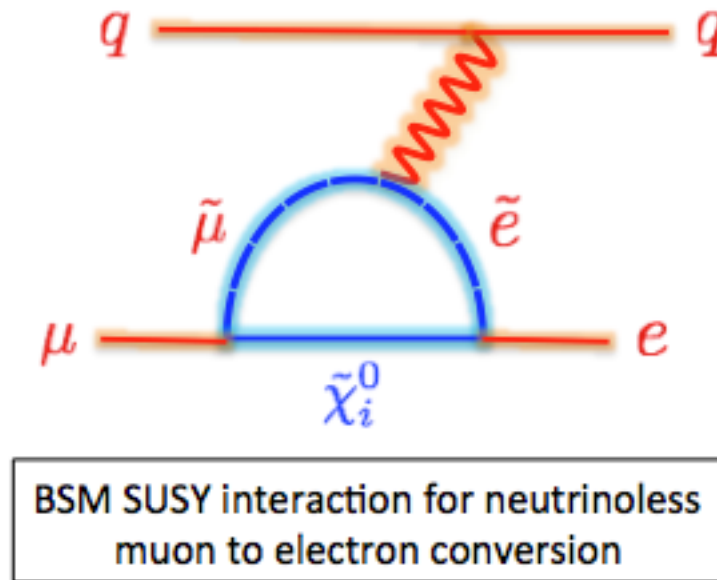
Making the Move: BNL \rightarrow FNAL



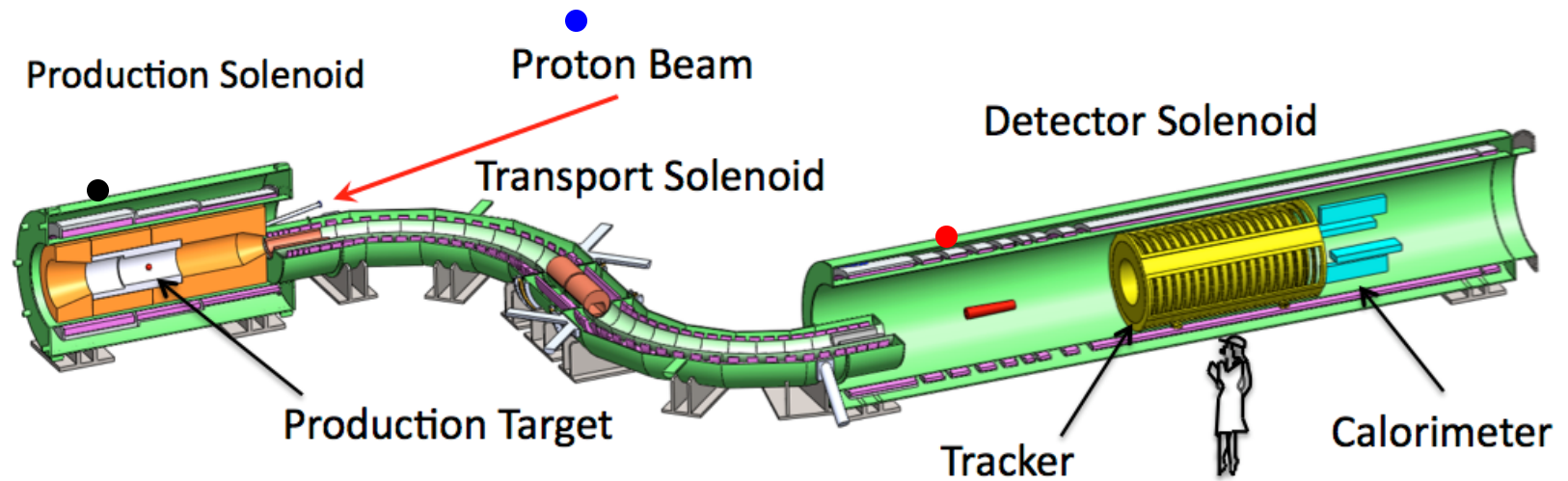


$\mu \rightarrow e$ Conversions:

- The search for 'charged lepton flavor violation', or CLFV, is planned for Fermilab's future:



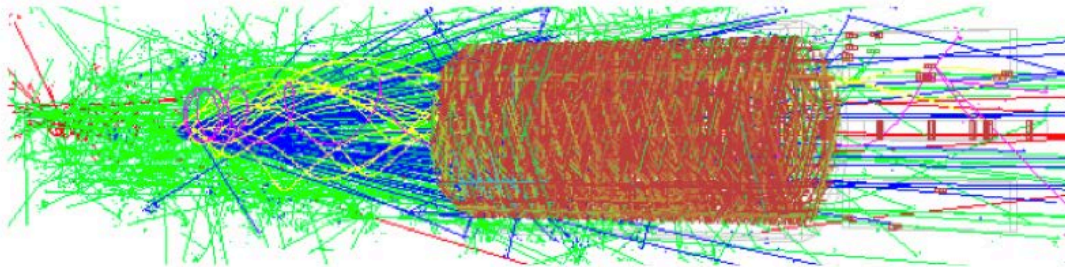
Muon Beam Line and Mu2e Detector



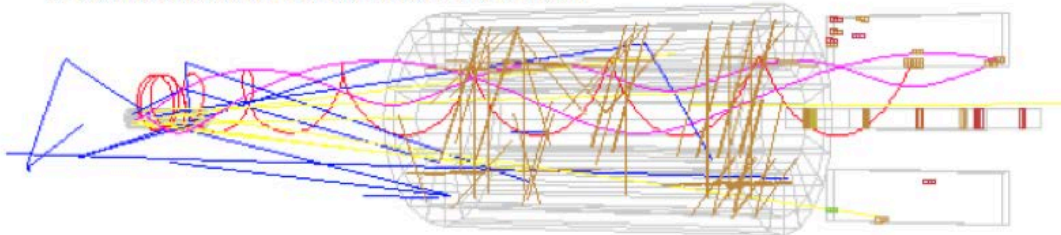
- Production Target
 - Proton beam strikes target, producing mostly pions
- Production Solenoid
 - Contains backwards pions/muons and reflects slow forward pions/muons
- Transport Solenoid
 - Selects low momentum, negative muons
- Capture Target, Detector, and Detector Solenoid
 - Capture muons on Aluminum target and wait for them to decay
 - Detector blind to ordinary (Michel) decays, with $E \leq \frac{1}{2}m_{\mu}c^2$
 - Optimized for $E \sim m_{\mu}c^2$

Importance of timing in Mu2e

500 - 1695 ns window

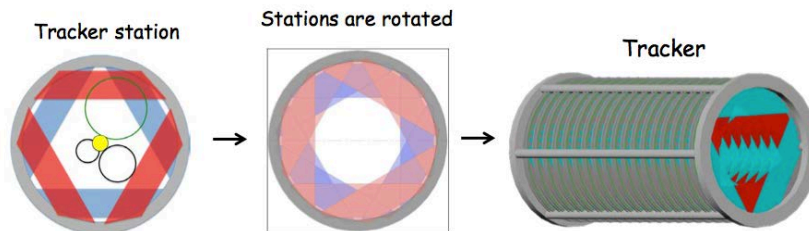


± 50 ns around conversion electron



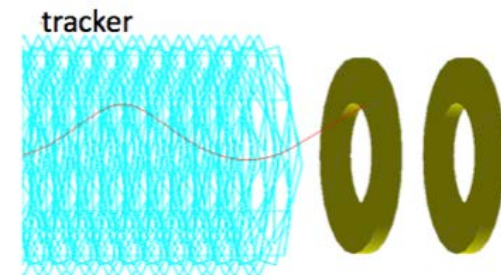
Mu2e Tracker

- 21600 Straws
- 12.5 μm wall straws in vacuum
- 100 kHz per straw



Straw tube tracker only
accepts large radius tracks

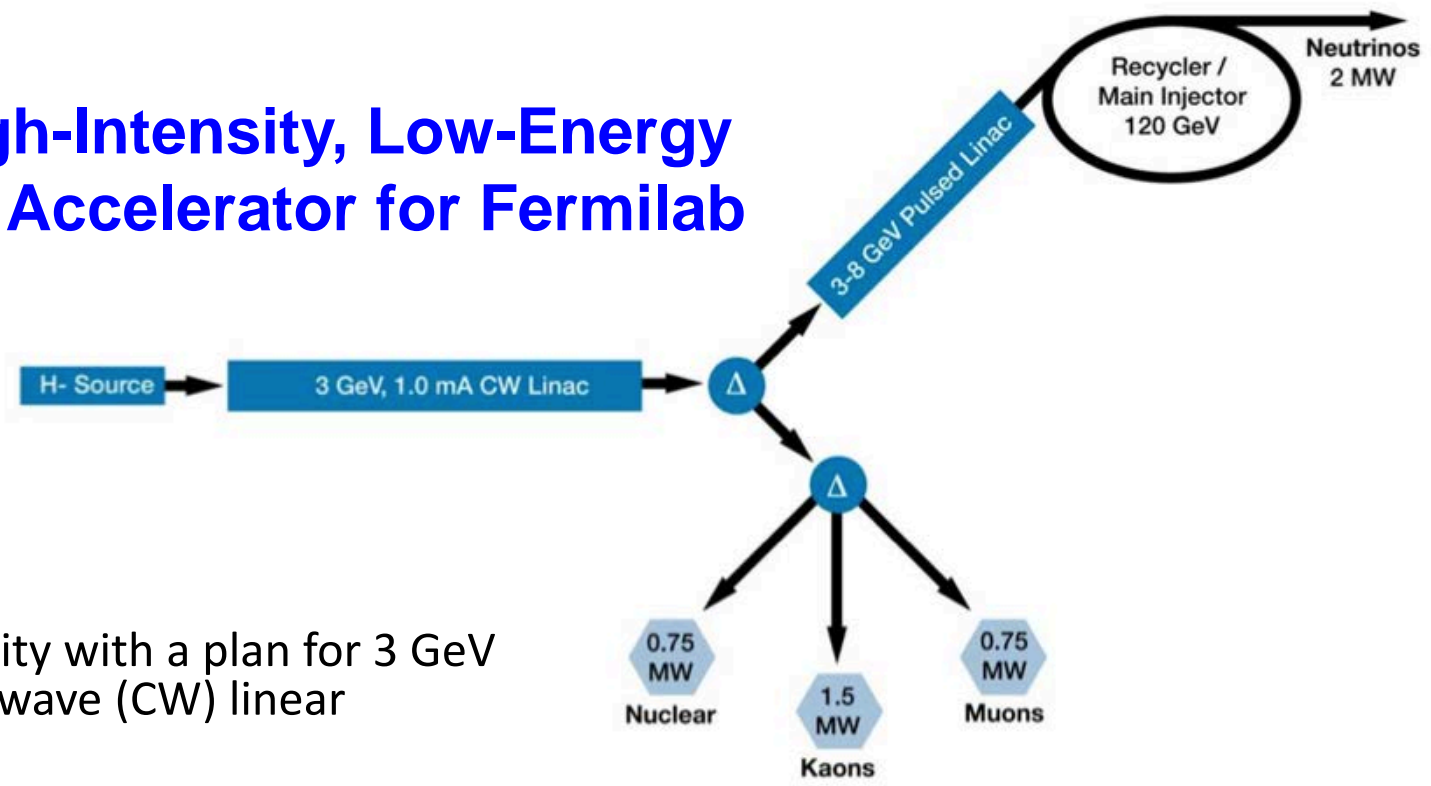
Two disks separated
by $\frac{1}{2}$ wavelength



Two disks of hexagonal LYSO
crystals for independent
measure of timing and energy

Accelerator Research at Fermilab

A New High-Intensity, Low-Energy Front-End Accelerator for Fermilab



- Unique facility with a plan for 3 GeV continuous wave (CW) linear accelerator
- Has a staged approach
- Increases Fermilab low-energy proton flux by x100, with flexible timing patterns. Ideal for rare decay experiments
- Experiments run simultaneously at 3 GeV, and 60-120 GeV

- Delivers 2+ Mwatts to LBNE
- Can serve as front end for neutrino factory or muon collider
- Centerpiece of a world-leading Intensity Frontier program
- Crucial time now for R&D ongoing with international collaborations

Illinois Accelerator Research Center

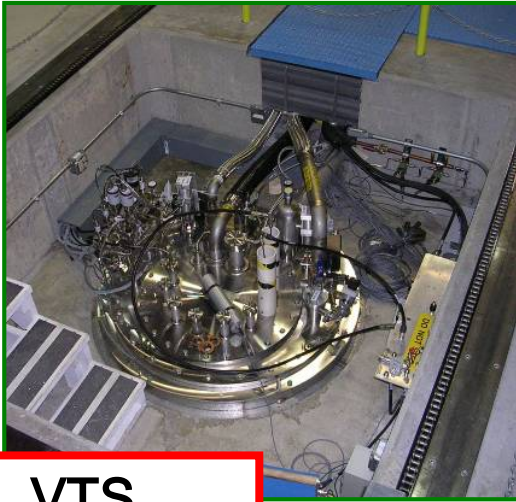


- A partnership between Department of Energy and the State of Illinois
 - To encourage and enable Fermilab to work closely with industry and universities to solve problems of national importance
 - To develop new accelerator technology-based products and high tech industries in the U.S. and in Illinois
 - To promote education in accelerator science & technology

FNAL Superconducting Radio Frequency (SRF) Accelerating Cavity Research



VTS



Cavity tuning machine



HTS



Final Assembly

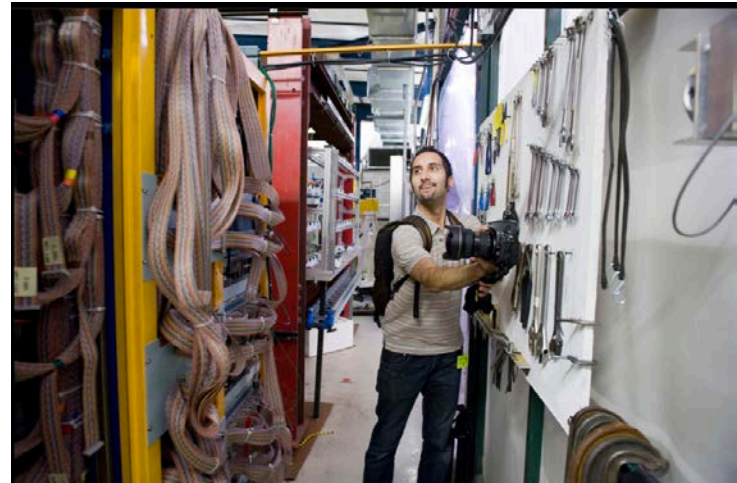


String Assembly

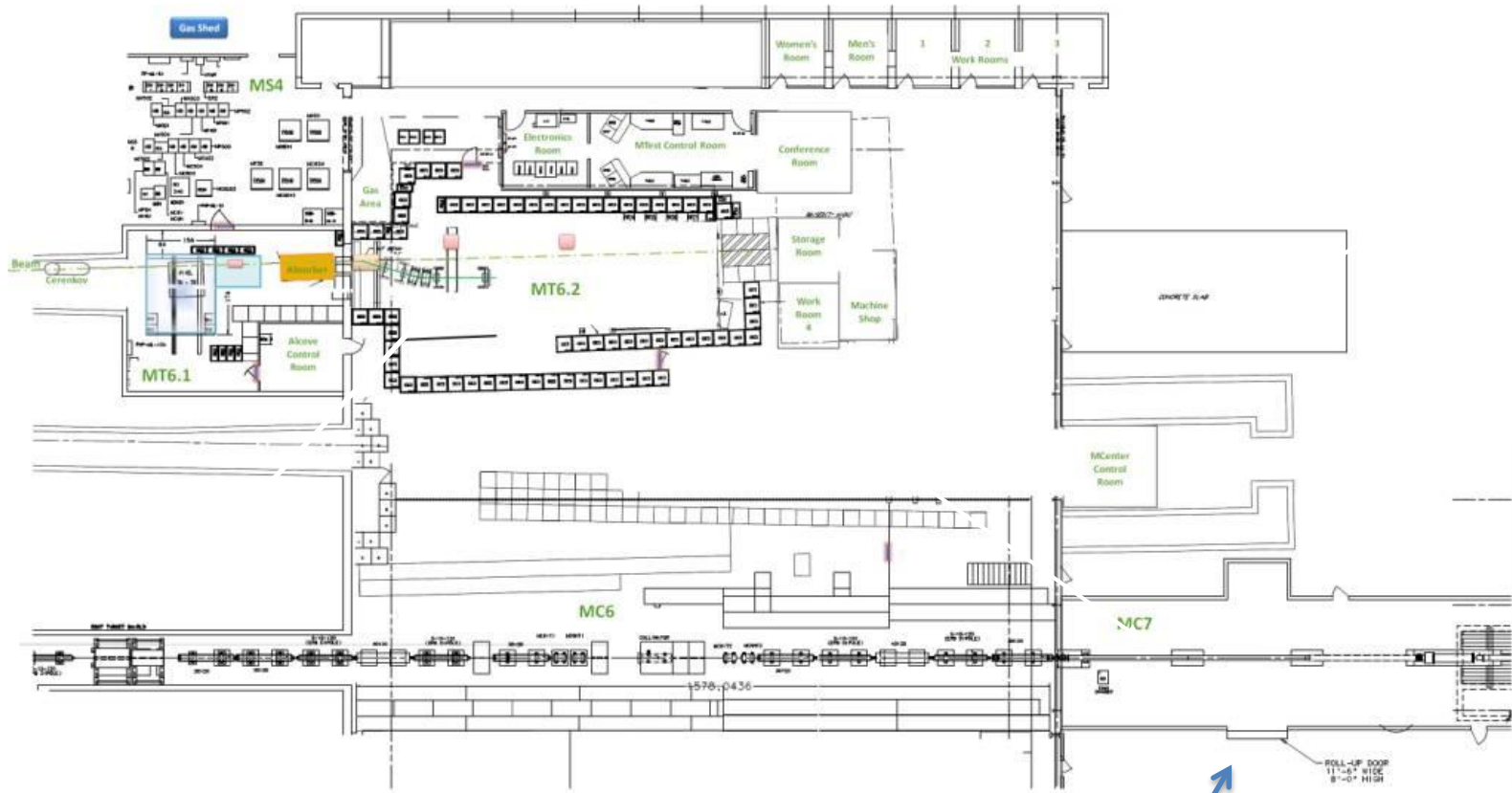


Detector Testing at Fermilab

Fermilab Test Beam Facility (FTBF)

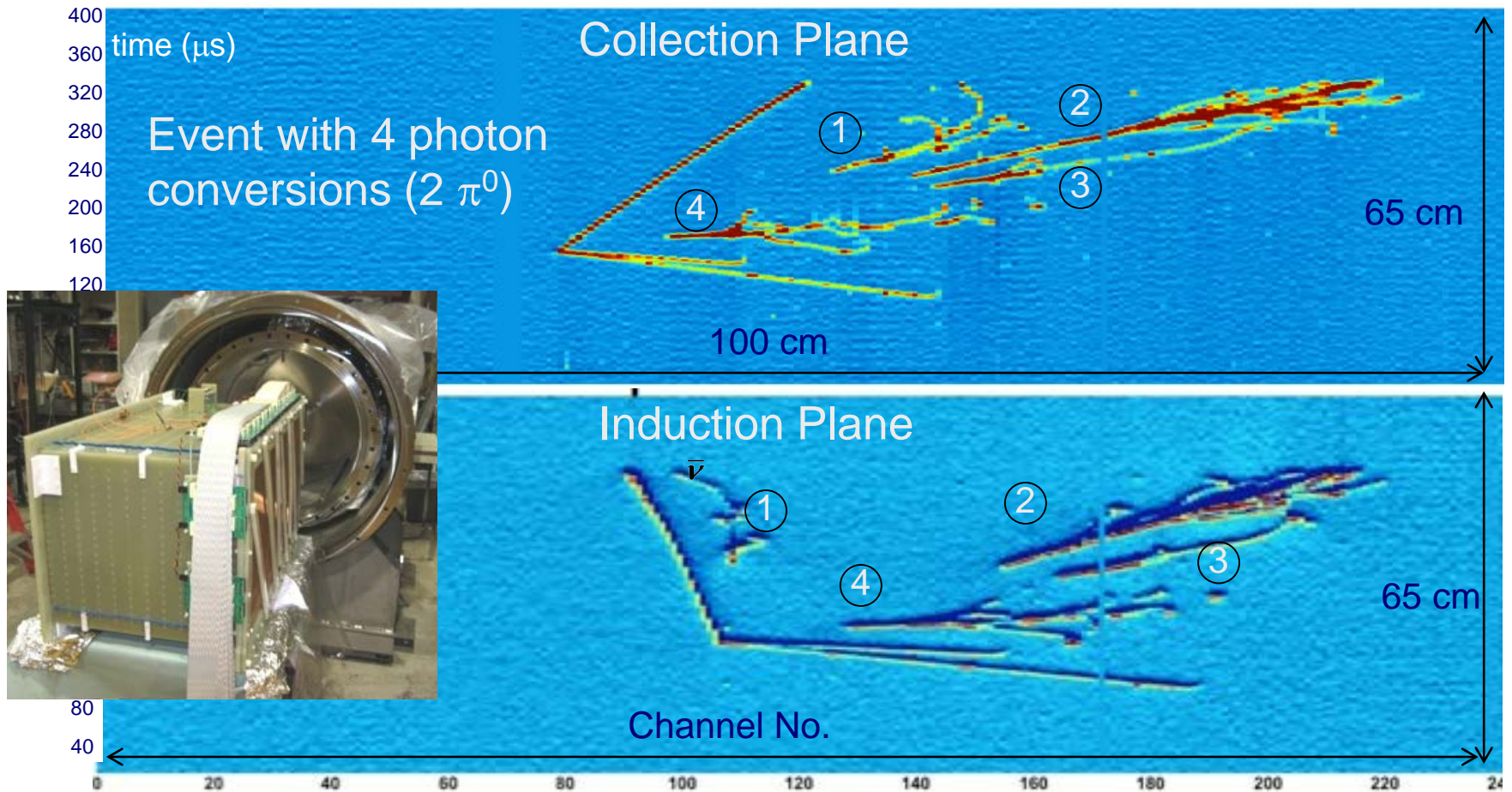


Layout of the current facility



New facility being developed here

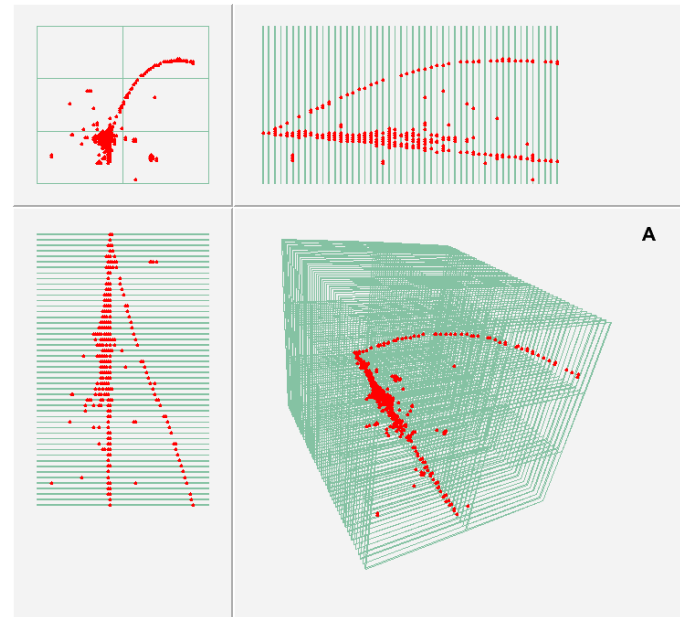
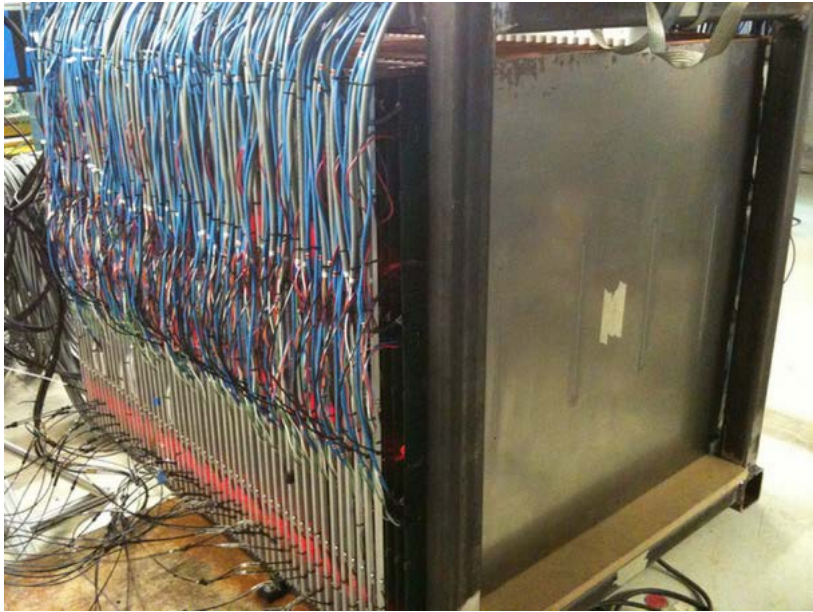
ArgoNeuT in NuMI beam (2009 – 2010)



Invaluable data set: 1000's of ν interactions in Argon

arxiv 1111.0103 : Measurements of Inclusive Muon Neutrino Charged Current Differential Cross Sections on Argon – J. Spitz (Yale) Thesis (uses automated reconstruction)

Digital Hadron Calorimeter (ANL) at Fermilab's Test Beam



- This test device has more channels (400K) than CMS + ATLAS + LHCb calorimeters combined
- Argonne National Lab designed and built this wonderful calorimeter
- Fermilab designed the readout chip and trigger modules
- May pave the way for a pointing calorimeter for high intensity decay experiments

Summer Internship at Fermilab

Summer Internships



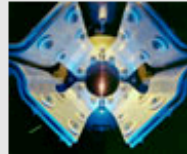
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CCI - Community College Internships



For community college students

IPM - Internship for Physics Majors



For foreign students in US & non-US universities & majoring

in physics.

Italian Students - INFN and ISSNAF



For Italian physics & engineering majors

Lee Teng Undergraduate Internship



For juniors and exceptional sophomores in U.S. institutions

when applying .

PARTI - Physics of Accelerators and Related Technology for International



For physics & eng. majors in former U.S.S.R. countries

SIST - Summer Internships in Science and Technology



For majors in physics, elect. & mech. eng. and CS in 4-year U.S.

colleges

SULI - Science Undergraduate Laboratory Internship



For U.S. citizens from 4 and 2-year institutions & majoring in physics



Science Undergraduate Laboratory Internships (SULI)

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Eligibility

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Eligibility for the SULI program requires that all applicants:

- Must be currently enrolled as a full-time undergraduate student at an accredited institution, and also have completed at least one year as a matriculating undergraduate student at the time of applying (additional undergraduate credits obtained prior to enrollment cannot be applied to meet the minimum one-year completion requirement). Applicants who will complete their undergraduate degree prior to starting their internship may apply as a "Graduating Senior", if (1) the applicant has not yet started a program of graduate study and will not matriculate as a graduate student prior to completing the SULI term, and (2) the time period between receipt of an undergraduate degree and starting the SULI term is less than one year. Community college students are eligible to apply.
- Must have an undergraduate cumulative minimum Grade Point Average (GPA) of 3.0 on a 4.0 scale for all completed courses as a matriculating student.
- Must be 18 years or older at the time the internship begins.
- Must be a United States Citizen or Permanent Resident Alien at the time of applying.

Proof of U.S. Citizenship or Permanent Resident Alien status will be requested at the time an internship offer is accepted. Acceptable form of proof of U.S. Citizenship includes, but is not limited to, a Certified Birth Certificate, an U.S. State Government Issued Enhanced Drivers License, U.S. Passport, U.S. Passport Card, Naturalization Certificate, Certificate of Citizenship, Consular Report of Birth (of U.S. citizen) Abroad, or Certification of Birth. Permanent Resident Aliens must hold an active United States Permanent Resident Card.

- Must have earned a high school diploma or General Education Development (GED) equivalent at the time of applying.

Proof of an earned High School diploma or for passing all five GED tests required to achieve a Certificate of General Educational Development should be provided on the applicant's undergraduate transcripts.

Additional Eligibility requirements:

- Applicants are limited to participation in the SULI program to no more than two internships.
- Applicants can apply to the SULI program a maximum of three times.

Example topics for SULI/IPM program

- Scintillator-photomultiplier tube calibration and noise reduction for the Neutron Incident Calibration Experiment using cosmic rays
- Design of a Silicon on Insulator Pixel Detector using a Charge Sluice
- Measuring Longitudinal Bunch Shape in the Fermilab Linear Accelerator with a Feschenko Bunch Shape Monitor
- Investigating the NuMI beam focusing uncertainties for MINERvA flux
- Muon g-2 Straw Drift Chamber Tracking Detectors

Lee Tang Accelerator Internship



Illinois Accelerator Institute

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2014 Internship



Applications now open for summer 2014
 Applicants must be full time students in a U.S. University
 (http://iaai.fermilab.gov/apply.html)

Offered by the Illinois Accelerator Institute, the Lee Teng Undergraduate Internship in Accelerator Science and Engineering offers research summer internships for undergraduate students awarded in four year U.S. institutions. This program has been developed to attract undergraduate students into the exciting and challenging world of particle accelerator physics and technology.



Color Flyer
(Please Circulate)

[Other internship opportunities at](#)

2013 Interns and Projects

[Argonne National Laboratory Interns](#)

Fermilab Interns and Projects

(Click on link below to see interns paper on the project)

Intern	University	Mentor	Project
Reynier Cruz-Torres	University of Florida	Charles Thangaraj, Bob Zwaska	Microwave Measurement of eCloud Using Resonant Cavity Technique in the Main Injector
Yiqing Ding	Purdue University	Katsuya Yonehara, Maria Leonova	Test of Dielectric Materials in RF Cavity for Muon Accelerator
Tegan Johnson	Otterbein University	Duncan Scott	Tomographic Studies of Longitudinal Phase Space
Christopher Lynn	Swarthmore College	Tanaji Sen, Philippe Piot	An Update to the Mathematica Package PCR for Simulation of Planar Channeling of Electrons
John Nocita	Kalamazoo College	Amber Johnson, John Diamond	Measurement of Transverse Emittance in ASTA at Fermilab

Thanks! Any Questions

