Future Engineering Challenges in the Particle Physics Sector

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All Engineers Meeting

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U.S. DEPARTMENT OF ENERGY

Fermilab

Mission of the Particle Physics Sector

- Support the US HEP program mission to understand how the universe works at its most fundamental level by:
  - Designing, building, and operating experiments for the Energy, Intensity, and Cosmic frontiers
  - Providing a "home" for most of the Laboratory users that make up the OHEP experimental community
  - Leading a focused, efficient program of detector R&D in collaboration with university researchers and other national labs
  - Hosting a leading theoretical physics program aligned with the three frontiers
- Engineering in the PPD Mechanical Department, the PPD Electrical Engineering Dept and CD Electronics Systems Engineering Dept is critical to carrying out this mission
- CD and PPD Depts also provide Engineering support to the Accelerator sector (eg beam instrumentation, LBNE target design)

The Post Tevatron Era

- Our future involves work toward experiments on three timescales:
  - Near: operate current experiments and construct new experiments (DECam, NOvA, MicroBooNE)
  - Middle: design and develop upgrades to current experiments (CMS) and design future experiments (eg LBNE, Mu2e, SuperCDMS)
  - Middle to Long: develop enabling technologies for future experiments (generic detector R&D). Broad spectrum of efforts for future collider experiments, intensity frontier (Project-X era) and astrophysics.

Experiment Operations

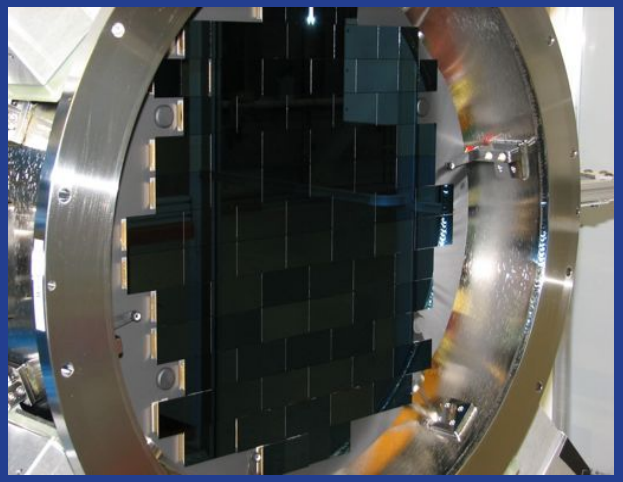
- The end of Tevatron operations means change of operations focus not an end of detector operations:
  1. Operate Intensity Frontier experiments (MINOS, MINERvA, MiniBooNE, SeaQuest)
  2. Operate Cosmic Frontier experiments (CDMS, DES, COUPP)
  3. Support CMS operations
  4. Operate Testbeam
  5. Decommission CDF & D0 (short term)
- Technical support of operations of intensity frontier experiments will increase
- 3 FTE in FY11 on CDF and D0 will decrease slightly in FY12 for decommissioning

Current Projects – Dark Energy Camera (DECam)

- 570M Pixel camera for Blanco telescope at Cerro Tololo in the Chilean Andes. Survey of very distant Supernovae to understand why the expansion of the universe is accelerating
- Fermilab designed CCD packaging, focal plane, mounting structure, LN2 cooling system, camera electronics, test facilities in Lab A
- Construction project will complete in next few months with installation in Chile in progress
- Transition to commissioning and operations support

Blanco Dome at CTIO

CCDs on Focal Plane

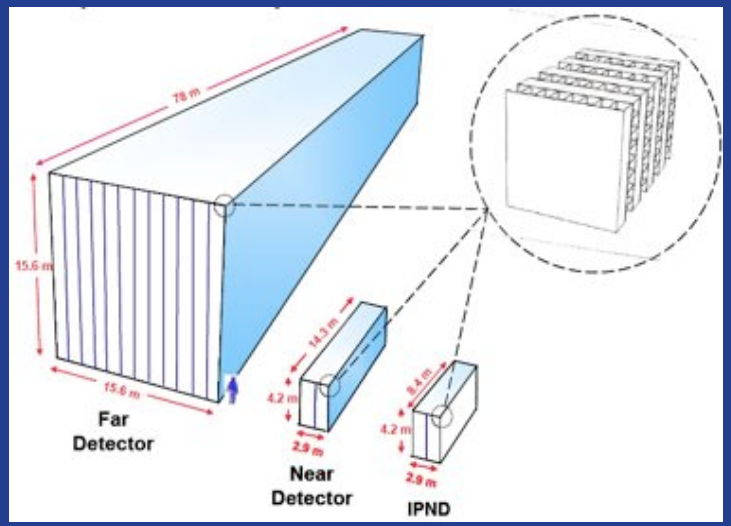


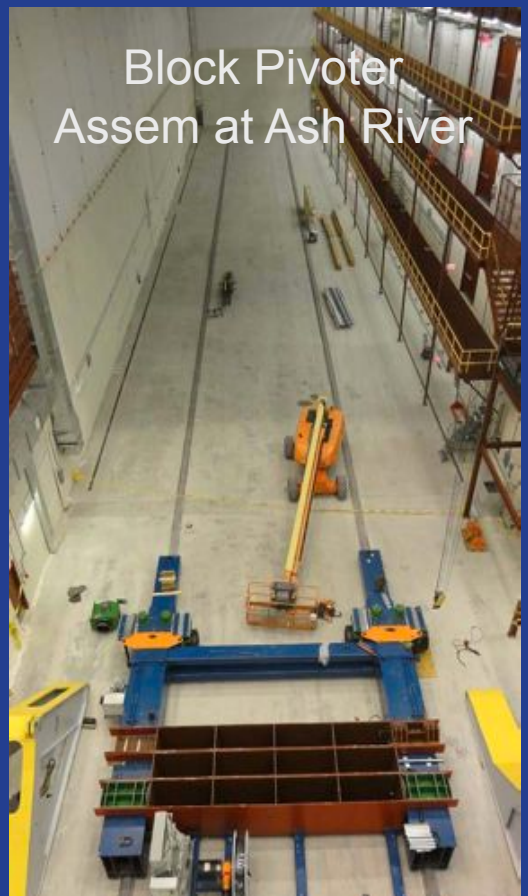
Current Projects (NOνA)

- Neutrino Oscillation appearance experiment using off-axis NUMI beam. About 15kT liquid scintillator far detector in Ash River MN
  - Fermilab responsible for structure design of detector and block pivoter to assemble detector, electronics cooling water system, DAQ (CD), QA on scintilator and PVC extrusions…
- Still significant design tasks – eg final design of near detector
- Construction of far detector gearing up, requires engineering oversight
- Like all projects, will need continuing effort to solve the unexpected

Prototype Near Det.

NOνA Detector Concept

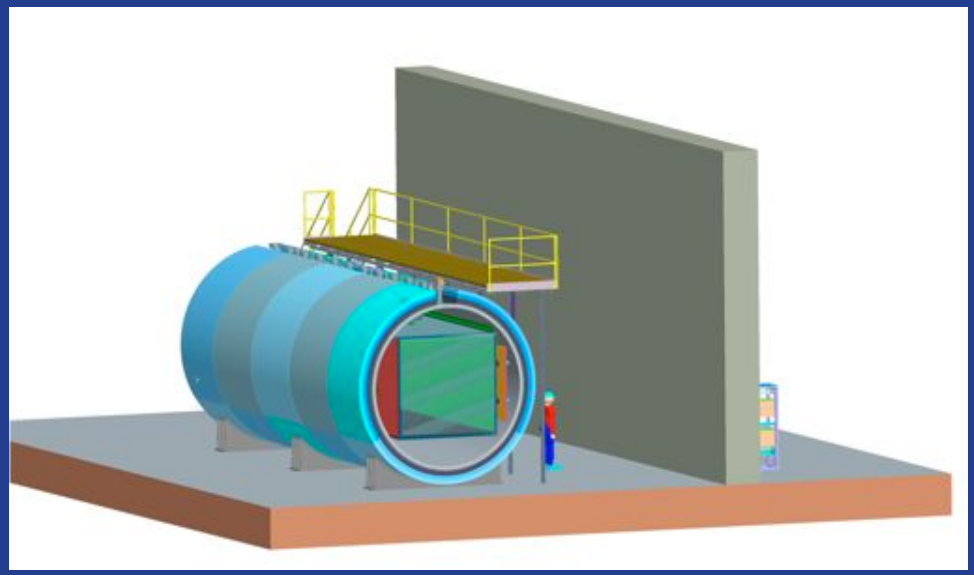




Block Pivoter
Assem at Ash River

Current Projects (MicroBooNE)

- 150T Liquid Argon Time Projection Chamber (TPC) targeted at understanding the MiniBooNE low energy excess
  - Part of LAr TPC development program targeted at 20kT modules for LBNE
- Received CD-2 (baseline approval) and CD-3a (limited construction) this month
- Fermilab: cryogenic system, electronics integration, detector assembly
- Design completion in FY12 with construction starting in FY12



Smaller Scale Projects

- Many smaller scale experiments, particularly in the Cosmic Frontier
- For example: COUPP bubble chambers for Dark Matter searches
  - Several phases at the same time
    - Operation of 4kg chamber at SnoLab (Ontario)
    - Preparing 60kg chamber to deploy at SnoLab
    - Preparing for 500kg proposal
  - Fermilab responsible for pressure vessels, control systems, data acquisition
  - Challenges of very low backgrounds (eg radioactivity of glass windows for outer pressure vessel)

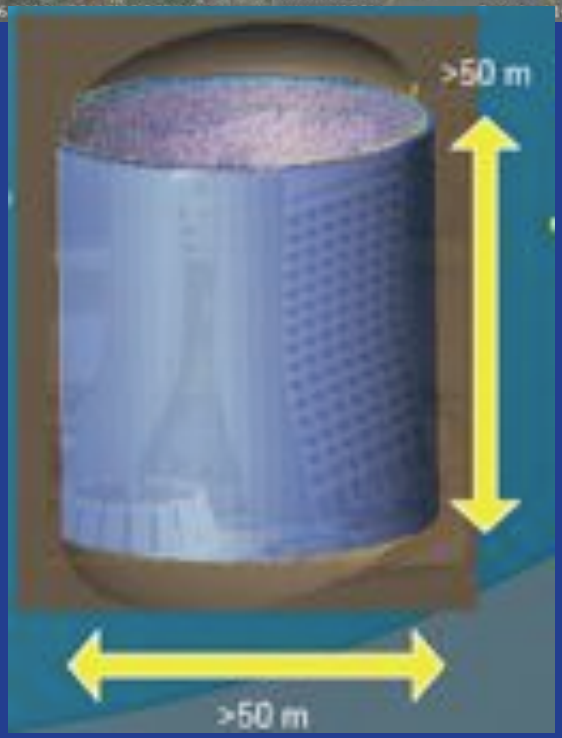
COUPP 4kg Setup at SNOLAB

COUPP 60kg Chamber

COUPP 60kg Experiment test at D0

Future Projects (LBNE)

- Long Baseline Neutrino Experiment
  - Neutrino Oscillations
  - Neutrino Astrophysics
  - Proton Decay
- Two possible detector technologies for far detector:
  - Two 20kT LAr TPCs
  - Two 100kT H_20 Cherenkov detectors
- Major PPD involvement in LAr TPC effort
  - Detector devolpment
  - MicroBooNE
  - Lar30 - 30T membrane cryostat prototype
  - LAr 1 – 1kT prototype
  - Cold electronics development
- Smaller involvement in H_20 detectors
  - Water systems (PPD)
  - PMT procurement (TD)
  - Role will grow significantly if H_2O is chosen



100kT H_2O vs Fermilab HighRise

Liquid-Argon Time Projection Chambers

Status of R&D Program in the US

The first TPCs in the United States:

Yale TPC

Location: Yale University
Active volume: 0.00002 kton
Year of first tracks: 2007

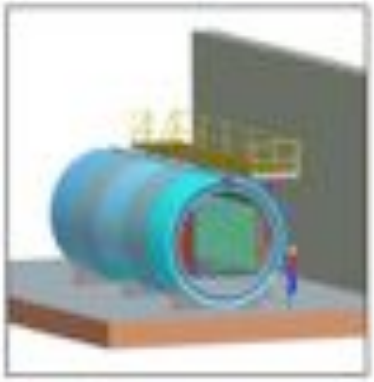
Bo

Location: Fermilab
Active volume: 0.00002 kton
Year of first tracks: 2008

ArgoNeuT

Location: Fermilab
Active volume: 0.0003 kton
Year of first tracks: 2008
First neutrinos: June 2009

MicroBooNE



Location: Fermilab
Active volume: 0.1 kton
Start of construction: 2011

Test stands to improve liquid-argon technology:

Luke

Location: Fermilab
Purpose: materials test station
Operational: since 2008

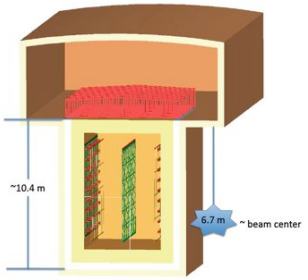
LAPD

Location: Fermilab
Purpose: LAr purity demo
Operational: 2011

LAr35: Membrane Cryostat Prototype

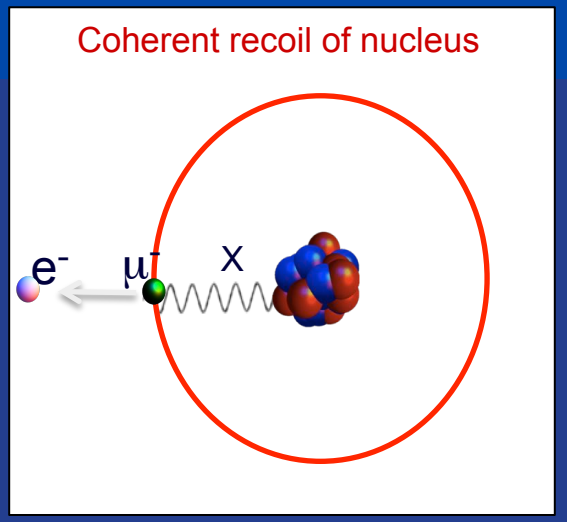
Location: Fermilab
Volume: 0.035kT
Operational: 2012

LAr1: Engineering Prototype

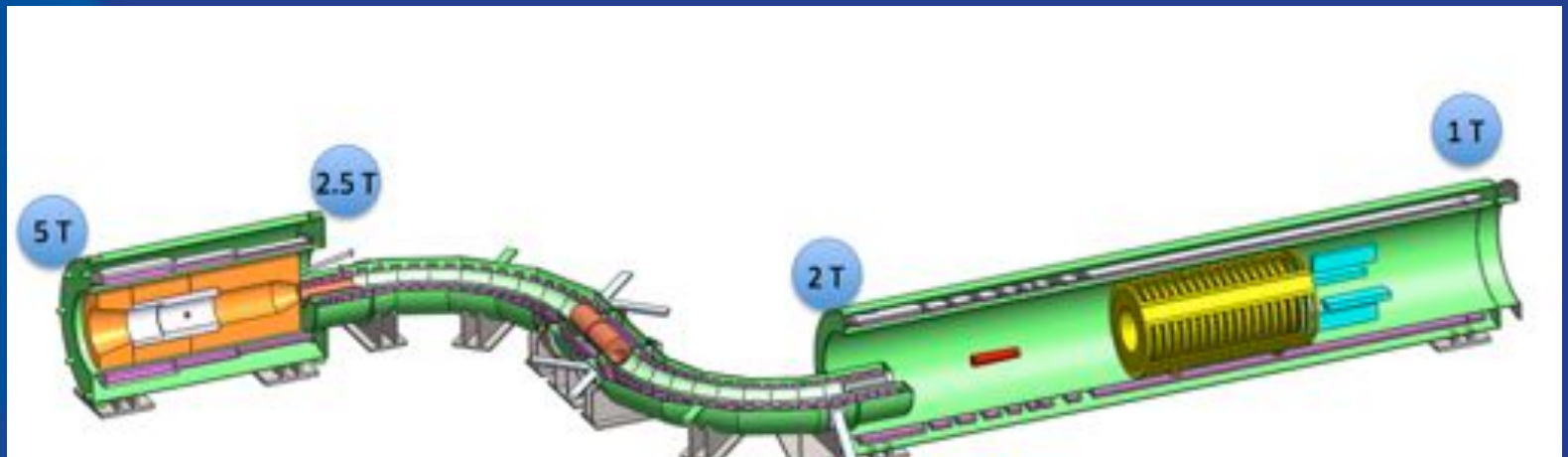


Location: Fermilab
Volume: 1kT
Operational: 2013-14?

Future Projects – Mu2e



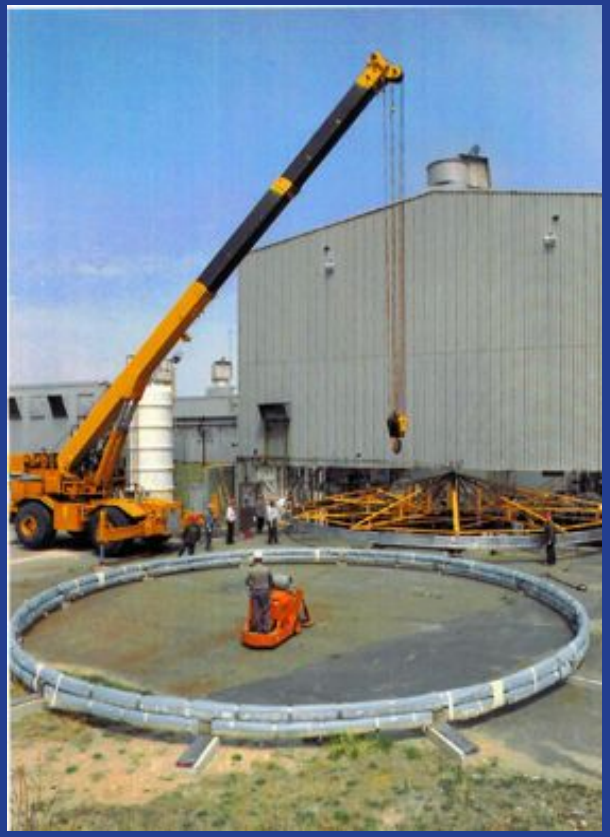
- μ^- to e^- conversion – μ^- converts to an e^- in the field of a nucleus
  - No emission of neutrinos
  - Nucleus remains intact – coherent
  - Signal is a monoenergetic 105 MeV e^-
  - Sensitivity goal <6 X 10^{-17}
- Received CD-0, preparing for CD-1
- Large Fermilab involvement in converting p-bar accumulator and building beamline/target (AD) and muon channel solenoids (TD) – see Stu's talk
- PPD/CD responsibilities: overall project engineering and detector design (straw tracker, cosmic ray veto), DAQ



Future Projects – g-2

- Measure the magnetic moment of the muon
- Higher precision follow up to BNL experiment
- Share accumulator with Mu2e (Muon Campus)
- Move experimental equipment from BNL
  - Ring, coils – very large, difficult logistics
  - Rebuild cryo and control systems for ring magnet coils
  - Still defining roles of organizations

G-2 Coil at Brookhaven



G-2 Experiment at Brookhaven

Coil Transporter?

Detector Upgrades - CMS

- Small improvements/fixes during 2013 shutdown
  - Fixing part of Hadron CALorimeter -> install Silicon Photomultipliers (SiPM)
  - Install another layer (rescope) of Encap MUon detectors
- Two major phases of upgrades to LHC experiments
  - 2017/18 - full design luminosity
  - Early 2020s – even higher intensity
- First phase includes these areas of Fermilab involvement:
  - New HCAL electronics (new QIE ASIC)
  - Replacement of pixel vertex detector, Fermilab involved in forward detector design and potentially new readout electronics (ASIC)
  - Collaboration on development of next generation optical links for Data transfer off of detector
- Second phase much larger in scope (eg whole new tracker)
  - Current activities part of generic detector development include rad hard sensors for pixel detectors, development of ASICs for track triggering

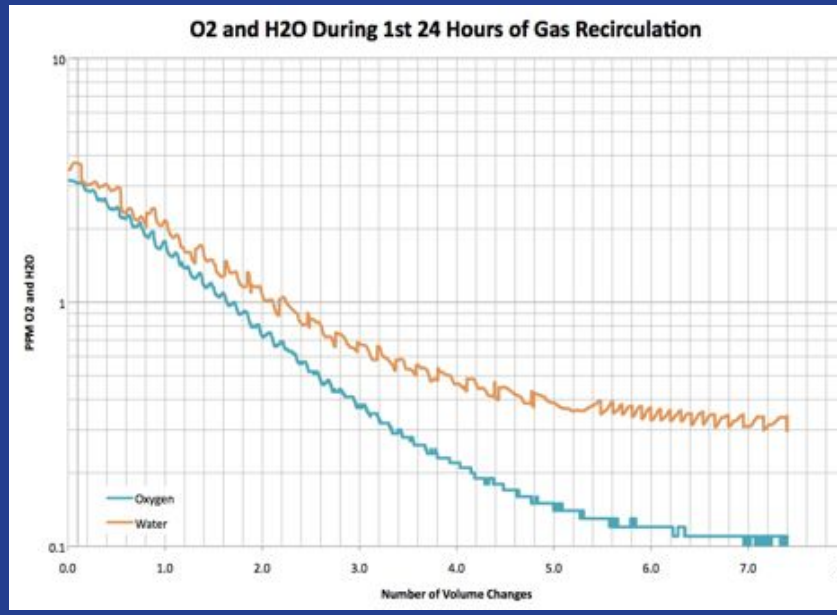
Detector Development – Cryogenic Detectors

- General Lar TPC development for future (eg LBNE)
  - LAr Purity Demonstrator in PC4 – high purity without evacuation
  - Development of TPC electronics to work at cryogenic temps
- LAr for Dark Matter – distillation column in PAB

LAPD 20T Tank

Complete LAPD System

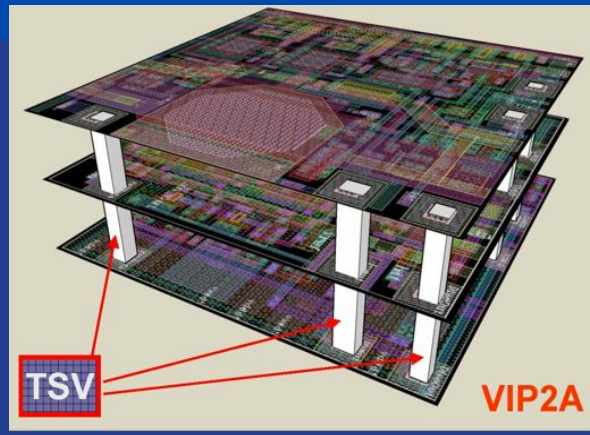
Gaseous Ar: O_2 and H_2O contamination drop with Filtration



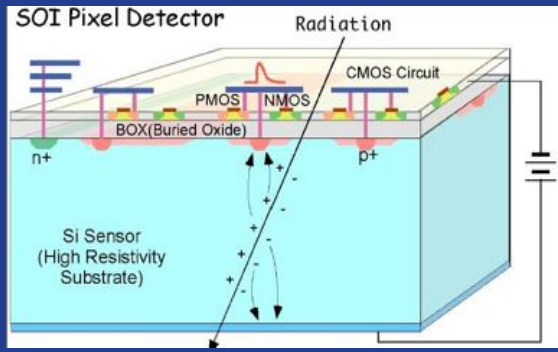
Goal for liquid in ppb scale

Future Detector Development

- ASICs - Development of new integrated circuits for future experiments an ongoing focus
  - 3d Technology – major focus of last 5 years
    - Multiple silicon wafers bonded together
    - Much higher circuit density, small trace lengths
    - Possibility of circuits bonded directly to a sensor layer
  - Possible HEP applications of 3d technology
    - Content addressable memory for LHC triggers (like CDF Silicon Vertex Trigger)
    - Integrated silicon detector, readout and triggering for LHC
    - Integrate Silicon Photomultiplier (SiPM) with electronics
    - Intensity frontier applications not yet explored
- Many other areas of detector R&D:
  - CCDs – eg Low noise readout (PPD/EED and CD/ESE)
  - Solid Xenon for Axion searches
  - Hadron calorimetry – total absorption calorimetry
  - Plastic scintillator – new methods of extruding
- What's your new detector technology idea?
  - Could be evolutionary – improve on an existing concept
  - Could be revolutionary – a completely new way of doing things



3d Pixel Readout Chip



Silicon on Insulator Integrated Senor and electronics

People are the key

- To carry out all of these projects we need skilled engineers and tools to support them
- Ability to complete projects has been limited by availability of mechanical engineers. Need to have more engineers for current work and for labs future
  - Almost no hiring for over a decade!
  - Two new mech engineer hires last year
  - Focus on mentoring of new hires, COOPs and GEM students
  - Use contractors until future projects are secured
- Need technical support staff :
  - New mechanical designers hired in recent years supplemented by contractors as needed
  - Few technician hires for last decade
    - Accommodate operations crews from CDF and D0 operations
    - Be prepared to hire as future projects ramp up

Tools

- CAD tools are as essential for engineers and designers as wrenches and soldering irons for technicians - Need to keep tools up to date
- I-DEAS is being replaced by NX as standard mechanical CAD tool
  - I-Deas being phased out, NX is industry leader (both Siemens)
  - 3D modeling and updated User Interface
  - Use of common parts (both industrial and Fermi specific)
- Lab-wide data management strategy:
  - Teamcenter - Engineering Data Management System
    - CAD models and drawings, engineering notes and analysis, technical specifications and requirements, procedures…
    - Teamcenter and NX will be tightly coupled
  - SharePoint - general Data Management System
    - Presentations, general documentation and correspondence, project files…
- Also looking to consolidate CAD software in the electrical and civil areas
  - Electrical - wide range of needs (simple PC layout to designing ASICs)
  - Just for design of ASICs, need tools from several vendors to get necessary capabilities

NX and Teamcenter Status and Schedule

- NX - About 90 people already trained
  - Design Groups continuing with hands-on training with NX
    - To minimize the start up time
  - Anyone interested in taking training in NX contact Tony Metz
  - NX is available now for training and early adopters
  - I-Deas data (for designated projects) will be converted to NX starting in March
    - Need to clean up this data now
- Teamcenter – Production Hardware and Software installed (includes backup)
  - Two rounds of testing completed with the Development environment - Siemens completing fixes (estimate completion – early November)
  - Once Development is complete; copy configuration to Production (December)
  - Siemens is working on custom Teamcenter training (Training start – December)
  - First pilot project to start in mid-January
  - First major project to be incorporated in March
  - Additional projects added sequentially