The Fermilab Research Program

Presentation at
High-Energy Physics Advisory Panel
July 13, 2001

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Research Program Overview

- Tevatron Collider Run 2
  - Discovery potential Higgs, SUSY, Extra Dim.....
  - Precision measurements top, W, B-physics
- Neutrino Oscillation Program
  - MiniBooNE: Key experiment in sorting out the osc. situation
  - NuMI/MINOS: Definitive measurements in the atmospheric osc. region
- LHC Physics with CMS Detector
- Strong flavor physics program into the next decade with BTeV and Kaons
  - Along with possible next generation Neutrinos and other MI120/Low Energy Fixed Target program

Run 2 Program
(Initiated on March 1, 2001)

- Upgraded Fermilab accelerator complex
  Goal is to increase number of available antiprotons/sec
  - New higher intensity 120 GeV Main Injector accelerator
  - New 8 GeV Recycler Ring made of permanent magnets
  - Improved antiproton cooling with both stochastic and electron cooling
  - Time between collisions will decrease from 396 nsec to 132 nsec

- Upgraded D0 and CDF detectors
  - Detectors, trigger, and data acquisition need to handle higher rates
  - Better micro-vertex, silicon tracker systems plus magnetic tracking
    - Detecting b-quark particles key to top, Higgs, and other physics
  - Better "hermetic" coverage ⇒ *"Missing energy" signatures*

- Extended runs from now through 2007-8 with continuous intensity upgrades

Run 2 Large Improvement over Run 1

- Run 2 Luminosity (integrated intensity) Plan
  - Run 2A: $\int L\,dt$ ~ 2 fb-1 by end of 2003
  - Run 2B: $\int L\,dt$ ~ 15 fb-1 by end of 2007
  - all at a cm energy of ~ 1.96 TeV
- Compare this to Run 1 data with
  - $\int L\,dt$ of ~ 0.10 fb-1 at cm energy = 1.80 TeV

All of Run 1 data = 1 week of running in Run 2B

Process $p\bar{p} \rightarrow X\,Y$	Mass Y GeV/c^2	Production sensitivity increase
$t\,\bar{t}$	175	1.4 x 150
W H	120	1.2 x 150
$\tilde{q}\,\tilde{q}$	300	1.8 x 150
$\tilde{g}\,\tilde{g}$	300	2.1 x 150

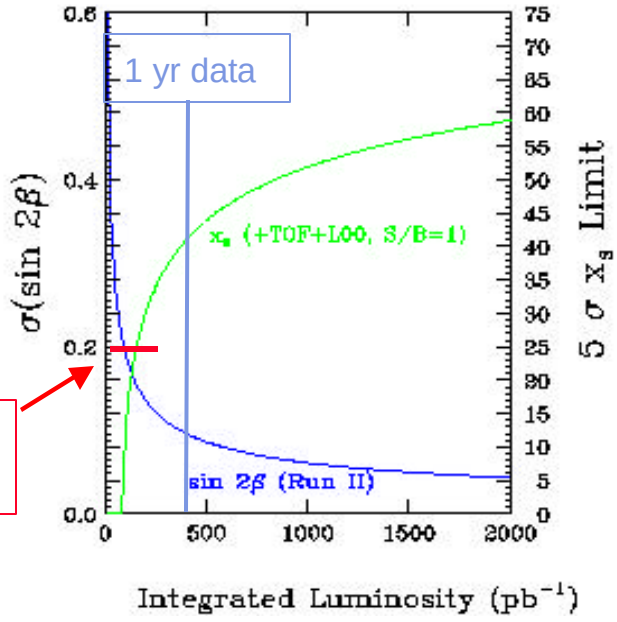
Sensitivity increase of Run 2 vs Run 1 200 - 300

Run 2 Physics

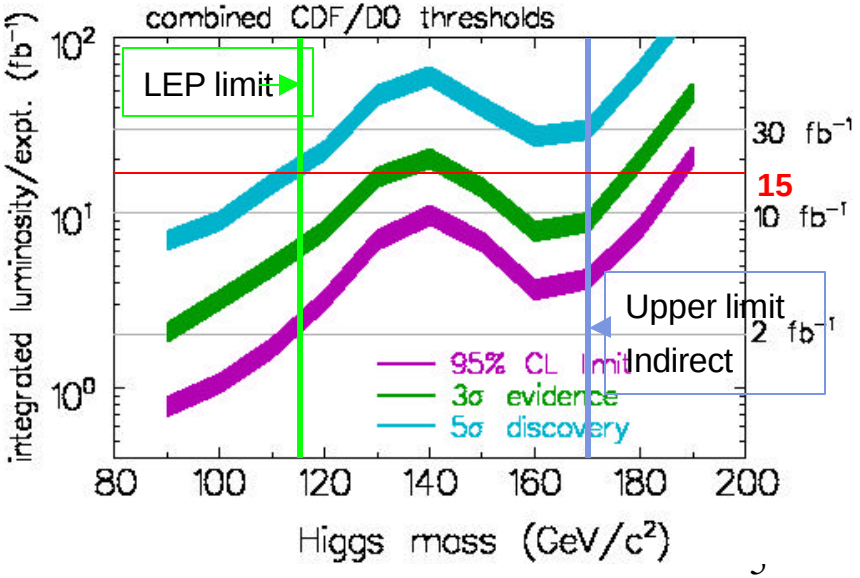
- ***Run 2A* will explore at levels of roughly 40 - 80 times the sensitivity of Run I**
  - B physics: $\delta(\sin 2\beta) \sim \pm 0.05$
    x_s sensitivity to ~ 60
  - Top physics: ~5000 top events
  - Electroweak phenomena:
    $\delta(M_W) \sim \pm 50$ MeV
  - QCD tests: Probe distance scales below *1 milli fermi*
  - Searches: new particle and extra dimensions
    - Is SUSY just around the corner?

New g-2 Result

New BaBar/ Belle result



- ***Physics Potential in Run 2B > 400 ´ that in Run 1***
  - Every factor of two will open up new discovery possibilities
  - Excellent discovery potential
    - Light Higgs
    - Entering farther into the domain of SUSY, extra dimensions .....



Run 2 Status

- Both CDF and D0 have rolled onto beamline
  $\Rightarrow$ Run II started on March 1

- Initial machine and detector tune-up and commissioning
  $\Rightarrow$ During March and April

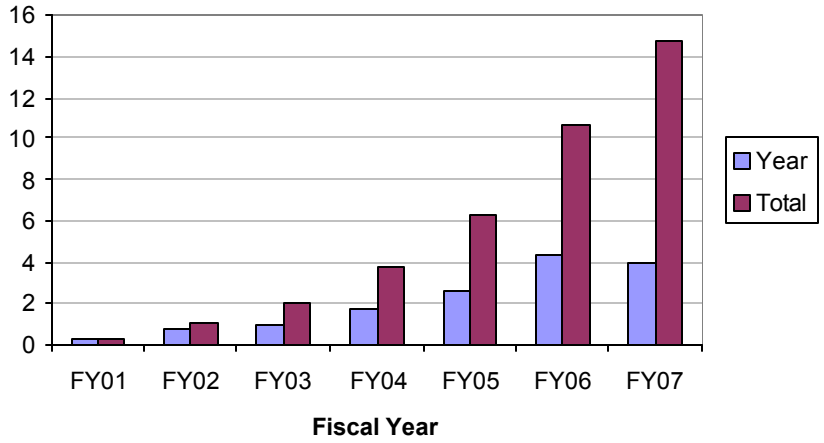
- Collisions for physics during last two weeks of June
  $\Rightarrow$ CDF ~300 nb^{-1} on tape and >$1x10^{30}cm^{-2}s^{-1}$ with luminosity steadily increasing

- Goal is to reach 4 to $5x10^{31}$ luminosity by January
  $\Rightarrow$ Collect integrated luminosity of 200 - 300 pb^{-1} by July,2002

Run 2B Accelerator Upgrade Plans

Goal is to accumulate 15 fb^{-1} by 2007

- Key is to increase the number of antiprotons by x2-3
  - More protons on the antiproton target (x1.8)
    - Slip stacking plus brighter booster
  - Better antiproton collection efficiency
    - Upgrade Li-lens (~x1.5) and increase AP2-debuncher aperture (~x1.5)
  - Better Cooling and antiproton transfer efficiency
    - Including electron cooling in the recycler



Plans for Run 2B Detector Upgrades

- Main problem is radiation damage to silicon trackers and electronics at the ~5 fb^{-1} level
  - Upgrade strategy
    - Short shut-down in ~summer, 2004 for installation (~ 6 months)
    - Replace silicon detectors and electronics with rad hard units
    - Improved triggering
    - Some other upgrades including computing
  - D0 and CDF upgrade projects being set up now
    - Technical Design Reports in Fall, 2001 $\Rightarrow$ Baseline projects by Jan., 2002
    - Start on R&D projects
      - Joint project between CDF and D0 to develop new readout SVX4 chip
      - Begin R&D on sensors
  - Need both detectors to cover the physics
    $\Rightarrow$ Effectively doubles the luminosity

Enormous potential and major discoveries are likely
but we need to reach the Run IIb luminosity goals

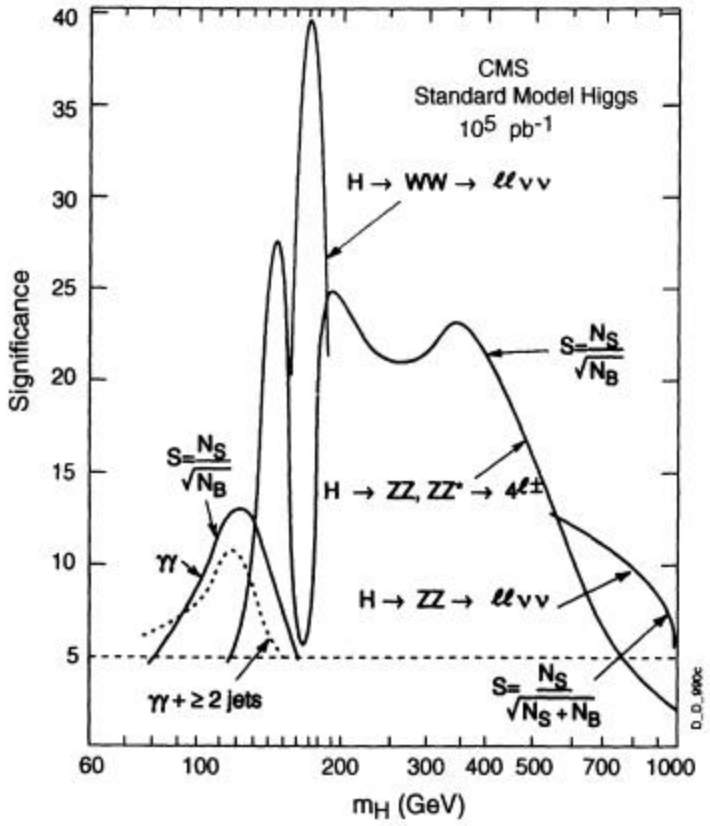
The LHC at Fermilab

Fermilab has a central role in two parts of the US effort on the Large Hadron Collider being constructed at CERN

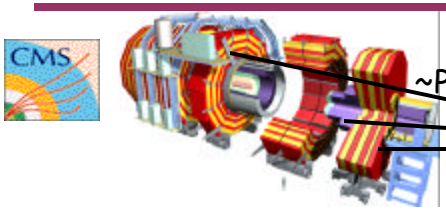
- US LHC Accelerator Project
  - The Project Manager Jim Strait manages a 3-laboratory collaboration building components for the LHC.
- US CMS Project
  - Fermilab is the host lab for the US CMS project.
  - We also are setting up the Tier I center for US CMS computing.

Fermilab participation allows US physicists to take a major role in building the LHC accelerator, building the CMS detector, and doing the science.

- Tevatron Run IIb will go up to ~ 180 GeV
- CMS will cover the range up to ~ 1 TeV: Mainly with $ZZ \rightarrow 4l$



CMS Software and Computing Project at Fermilab



~PBytes/sec

Online System

~100 MBytes/sec

1 TIPS is approximately 25,000 SpecInt95 equivalents

There is a "bunch crossing" every 25 nsecs.
There are 100 "triggers" per second
Each triggered event is ~1 MByte in size

Offline Processor Farm
~20 TIPS

~100 MBytes/sec

Tier 0

CERN Computer Centre

~622 Mbits/sec
or Air Freight (deprecated)

Tier 1

France Regional Centre

Germany Regional Centre

Italy Regional Centre

FermiLab ~4 TIPS

~622 Mbits/sec

Tier 2

Caltech ~1 TIPS

Tier2 Centre ~1 TIPS

~622 Mbits/sec

Tier 3

Institute ~0.25TIPS

Physics data cache

~1 MBytes/sec

Tier 4

Physicist workstations

Physicists work on analysis "channels".

Each institute will have ~10 physicists working on one or more channels

Data for these channels should be cached by the institute server

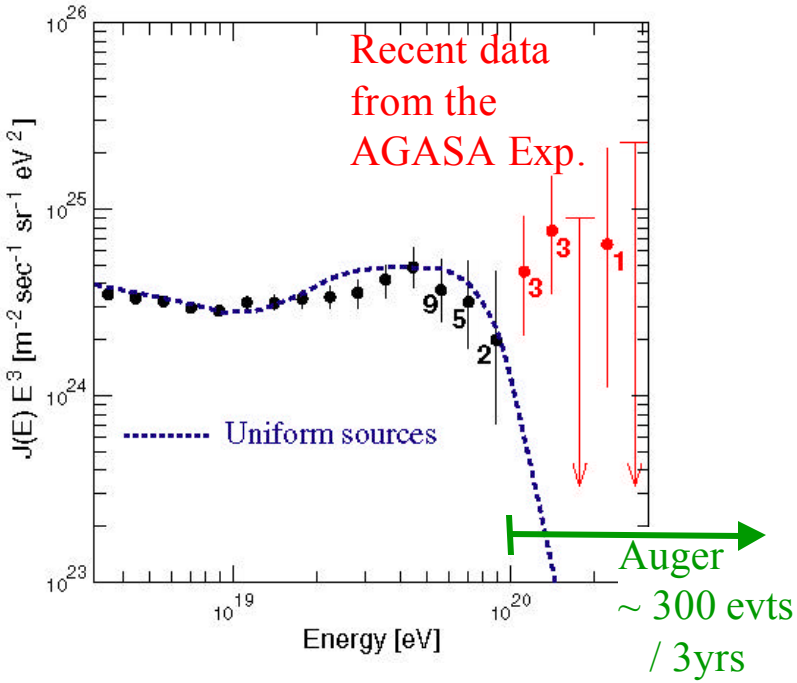
Astrophysics at Fermilab: CDMS, Auger, and SDSS

- Pierre Auger Project

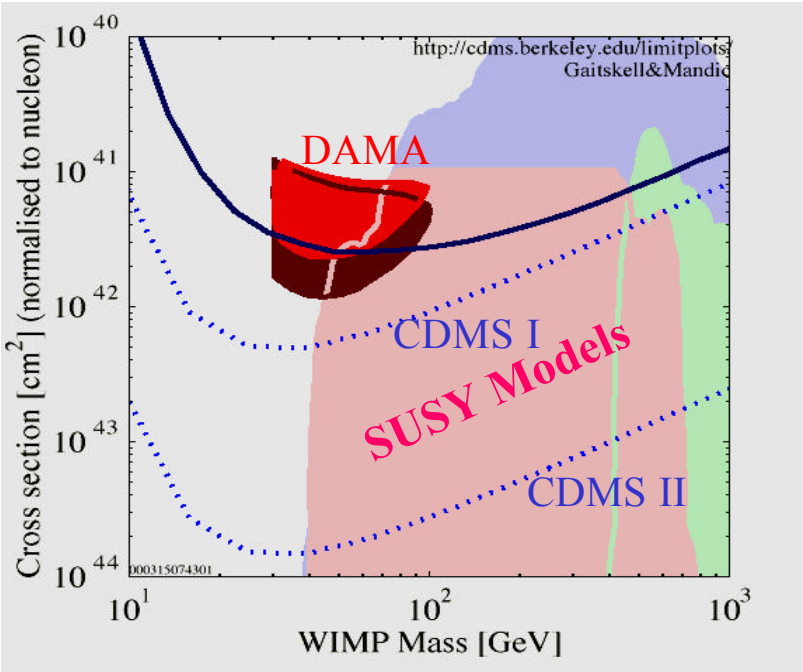
A study of cosmic rays 10^{19} eV - 10^{21} eV

Using very Large Ground Array in Argentina

  - First fluorescence detector complete and operating → 1st events recorded
  - All 40 of the "Engineering Array" deployed.
  - Construction of the full observatory 2002 -2004.

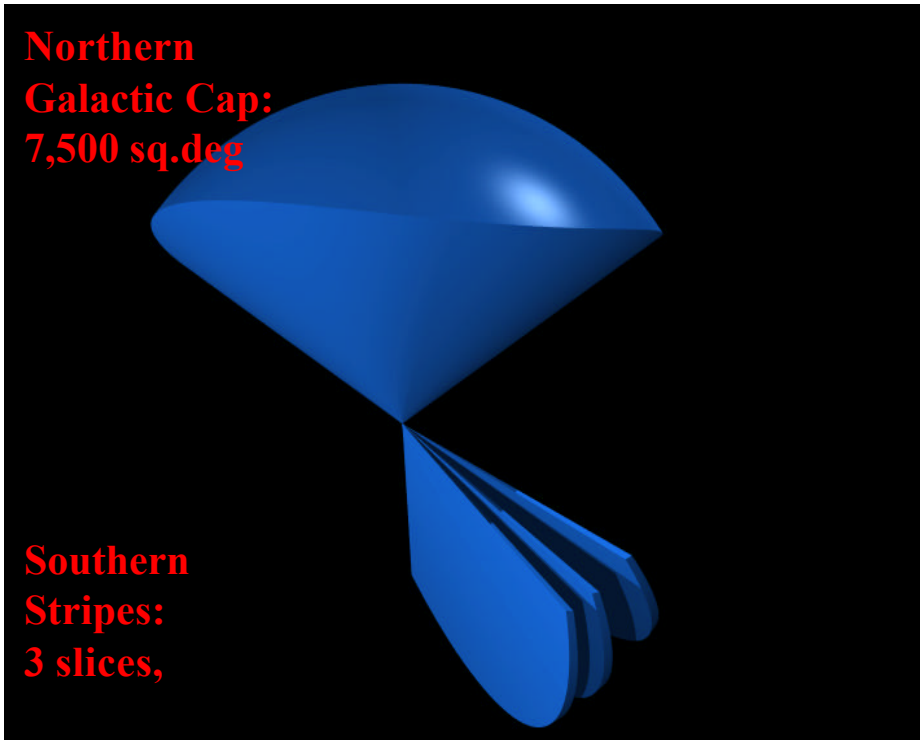


- CDMS (Cold Dark Matter/Wimp Search)
  - Silicon and germanium crystal detectors at cryogenic temperatures (15 mK)
  - CDMS I at Stanford in Summer, 2001
  - CDMS II at Soudan, Minn.(with MINOS) to begin data early in 2002
    - Potential sensitivity 100 times better than current



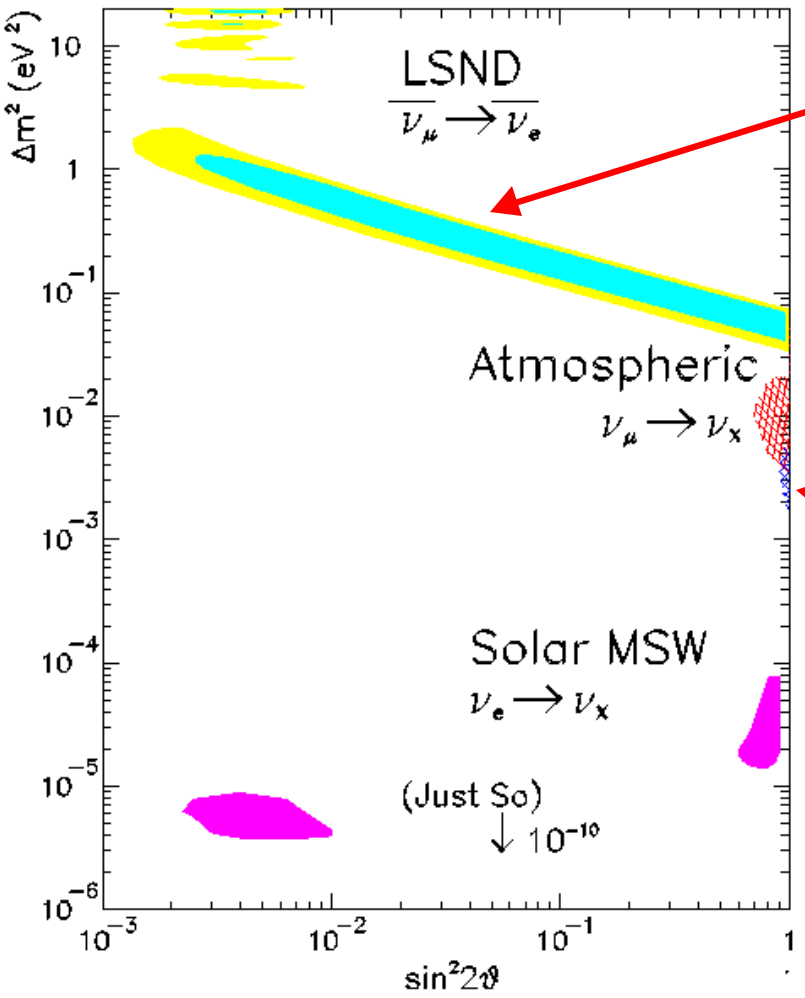
Sloan Digital Sky Survey (SDSS)

- Mapping the universe
  - Large imaging and spectroscopy survey
    - Covering 8000 sq.deg. or about 1/4 of sky
  - Digitize 100 million objects and spectra for million galaxies



- Science Accomplishments
  - Most distant and largest sample of **quasars**.
  - Large sample of **cool stars and brown (methane) dwarfs**.
  - Observation of **weak lensing**
    - This will yield a value for the Ω_m.
  - Large and uniform sample of **galaxy redshifts** gives knowledge of the galaxy luminosity function and properties

Fermilab ν Oscillations Program

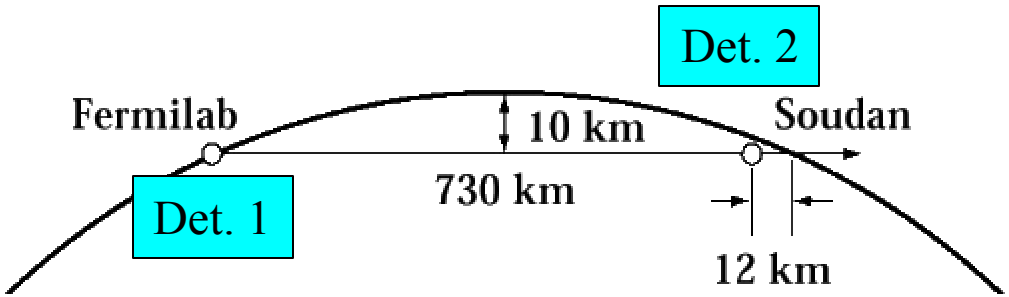


- MiniBooNE experiment:
  - Use neutrino beam from booster to confirm/refute positive LSND signal
  - 1 GeV ν beam from 8 GeV booster to detector at 500m
  - MiniBooNE crucial in understanding ν-osc. pheno.
- NuMI/Minos experiment:
  - Study atmospheric neutrino anomaly with terrestrial beam
  - 3 to 20 GeV ν beam from 120 GeV Main Injector to detector at 738 km (Minnesota)
  - Competition from Japanese K2K experiment and CERN to Gran Sasso (Italy)

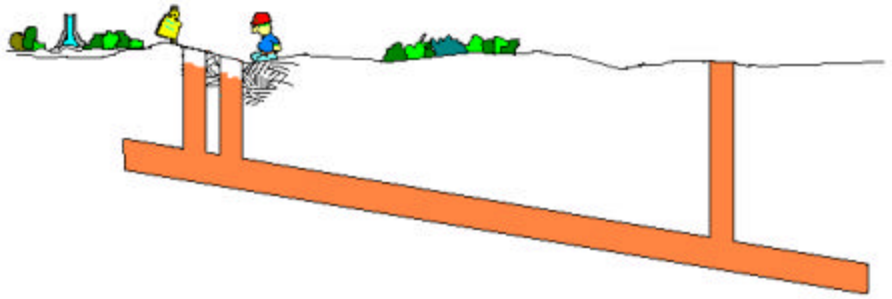
The NuMI/MINOS Experiment

Two Detector Neutrino Oscillation Experiment

- Far Detector (5.4 ktons, magnetized)



NuMI/Minos Project

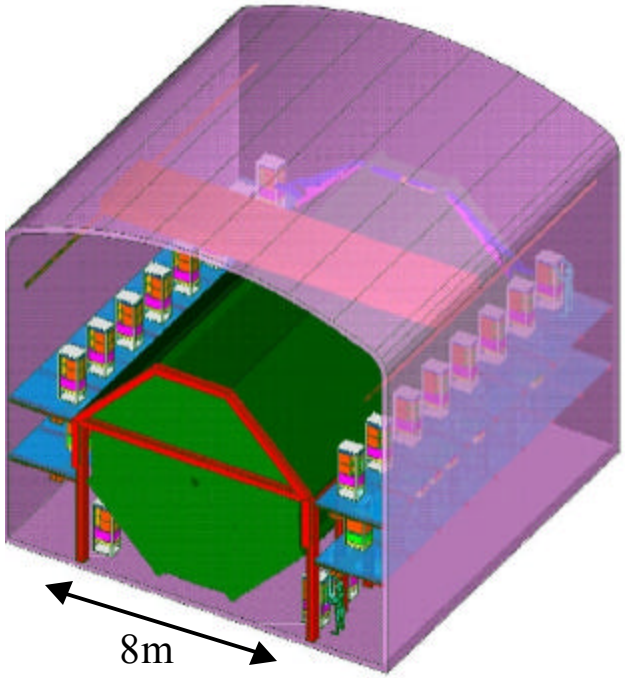


- Start of Soudan (Far Site) Construction 6/99
- Start of Fermilab Construction 3/00
- Start Far Detector Installation 8/01
- Start Near Detector Installation 6/03
- First Beam to Soudan 10/04

At Fermilab

- Submitting a rebaseline for the Project
  - Very difficult construction project at Fermilab
    - Cost and schedule under considerable stress
  - New baseline
    - Restoration of reasonable contingency: add 12 months (Oct.,04) and ~25% to TPC

    (Official DOE CD-4 Start Operations is Sept.05)



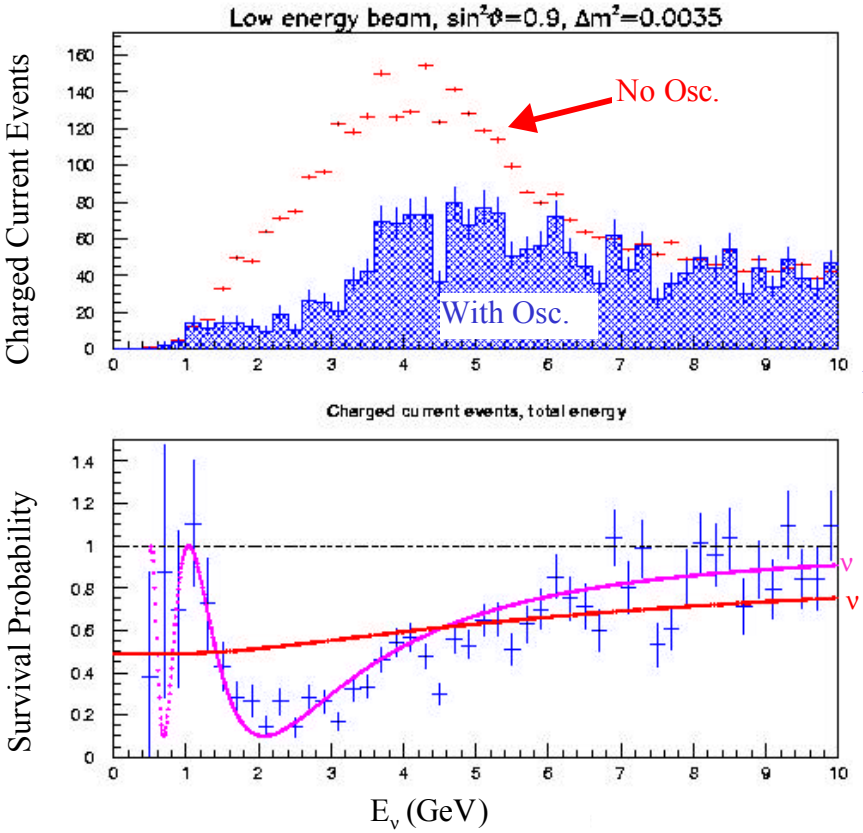
At Soudan, Minnesota

Oscillation effects observable at MINOS

Δm^2 sensitivity (~8x10^{20} pot)

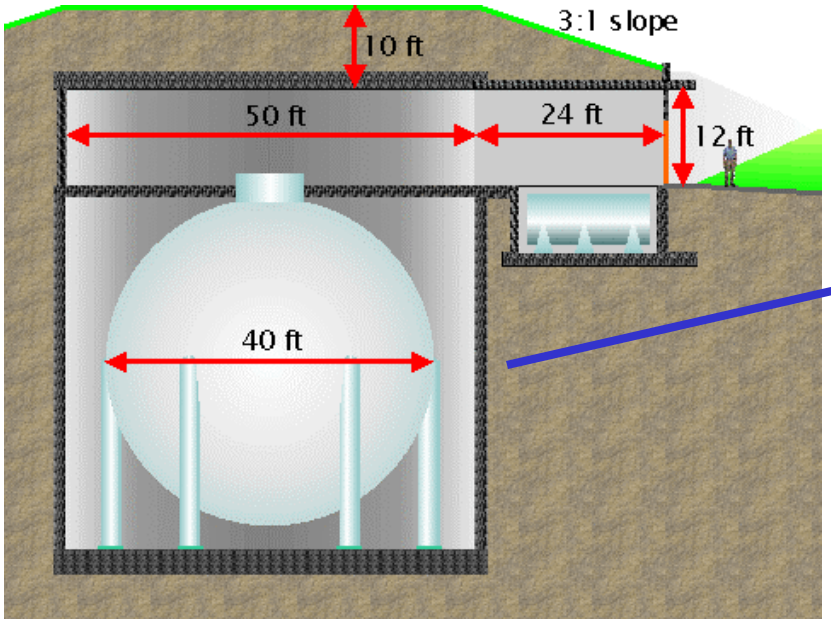
- CC energy analysis at low energy beam
- Includes Statistical & systematic errors

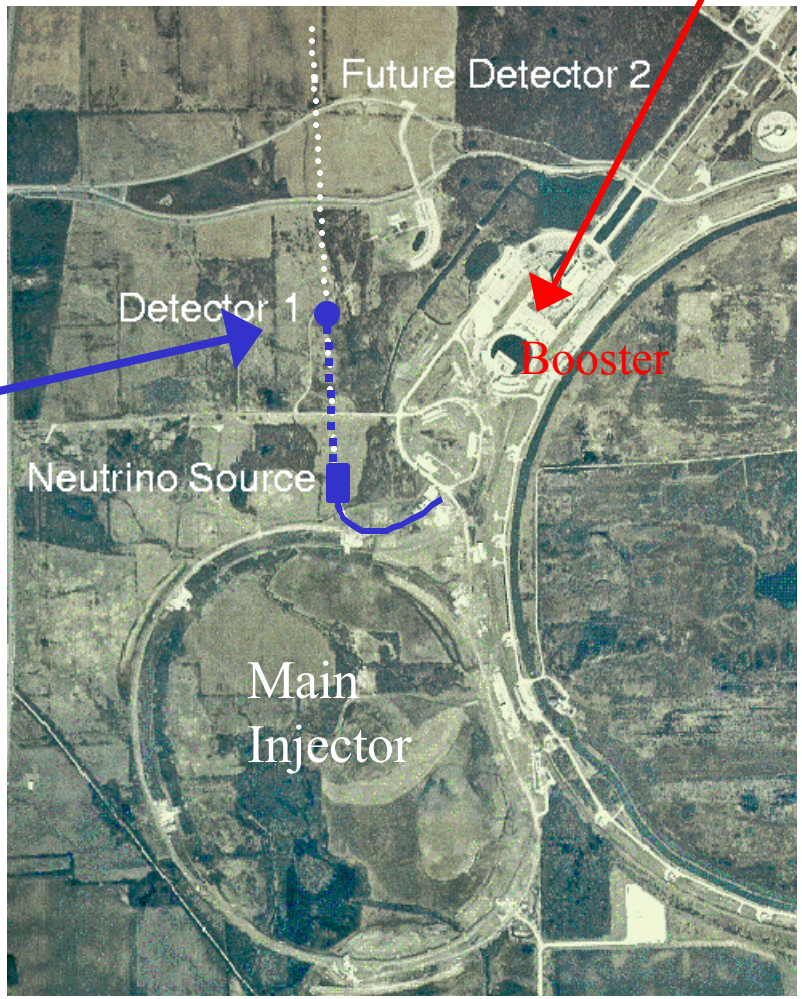
See oscillatory behavior in charged current rate vs E_n



MiniBooNE Experiment

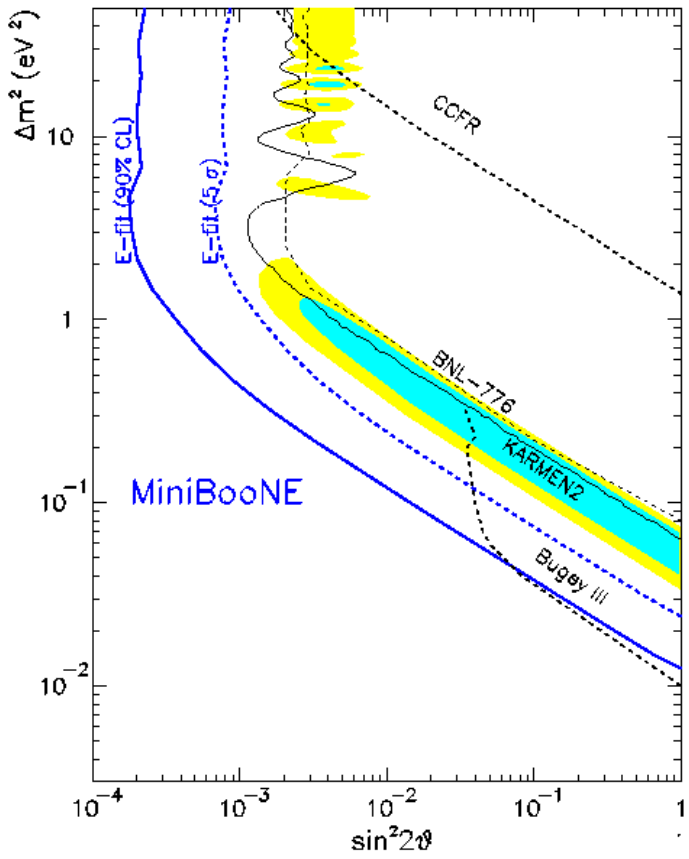
Use protons from the 8 GeV booster
⇒ Neutrino Beam
$<E_\nu>$~ 1 GeV





12m sphere filled with mineral oil and PMTs located 500m from source

MiniBooNE Rates and Sensitivity



- Expected events
  - 500,000 ν_μ CC quasi-elastic
  - **~1000 n_e if LSND correct**
- Decisive investigation of LSND region
  - LSND → >5σ signal in MiniBooNE
  - Osc. signal has different energy than intrinsic ν_e
  - Experimental determinations of all backgrounds.
- If MiniBooNE sees a signal
  ⇒ Very rich ν-osc. phenomenology ($\nu_{sterile}$, ν_τ appearance, CP .....)

- If signal is observed in MiniBooNE, then add second detector at appropriate distance
  Þ **Two detector BooNE experiment**

BooNE can measure:
Δm^2 to ± 0.014 eV^2
$\sin^2 2\theta$ to ± 0.002

MiniBooNE Detector and Beam Status

May 19

- About 50% of Photomultiplier tubes are installed
- Detector ready for commissioning in Dec. 01
- Beam preparations going well

Beginning of data taking - April, 2002

April 25

Quark Flavor Physics Studies at Fermilab

- Expect"New Physics" to show up as anomalous CP Violation

- Best measurements should have well understood, small experimental and theoretical errors.
  - $B_d \rightarrow \psi K_s$, $\rho \pi$
  - $B_s \rightarrow \psi \eta$, $D_s K$
  - $\Delta M_d / \Delta M_s$ in B_d and B_s decays
  - $K \rightarrow \pi \nu \bar{\nu}$

Need to measure all of these processes since "New Physics" may change only one

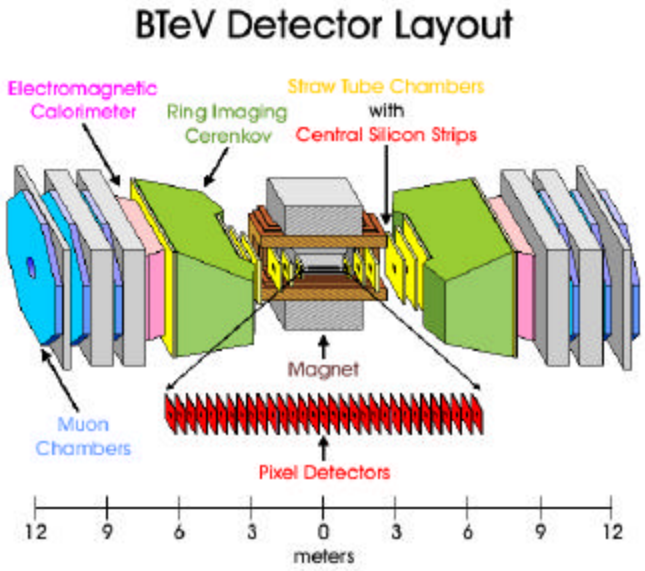
- CDF and D0
  - $B_d \rightarrow \psi K_s$ and $\sin(2\beta)$
  - x_s measurements

- BTeV
  - Wide range of B_s and B_d studies
  - $B_d \rightarrow \psi K_s$, $\rho \pi$; $B_s \rightarrow \psi \eta$, $D_s K$

- Rare Kaon Decays
  - CKM: $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ (SM: ~8 x 10^{-11})
  - KAMI: $K^0 \rightarrow \pi^0 \nu \bar{\nu}$ (SM: ~3 x 10^{-11})

BTeV: State-of-Art Hadronic B Experiment

- Physics
  - Many critical CP studies require the ***large data samples*** and ***both B_d and B_s*** available at hadron colliders
- BTeV Experiment
  - Innovative forward spectrometer PbWO4 EM Calorimeter and RICH
  - Level 1 trigger based on pixels takes full advantage of enormous B cross section



- Status:
  - Given Stage I approval after June, 00 Aspen PAC meeting based on:
    - Compelling physics that could be key in clarifying CP violation.
    - The BTeV detector unparalleled in its capabilities for this physics
- Next Steps and schedule:
  - BTeV doing R&D for Technical Design Report and working towards Stage II approval
  - Plan is for construction with a completion date in 2007

MI Kaon Program

- The rare processes $K \rightarrow \pi \nu \bar{\nu}$ are robust theoretically
  - Cleanliness comparable to the best B-meson time asymmetries
  - $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ measures V_{td} and $K^0 \rightarrow \pi^0 \nu \bar{\nu}$ measures η

- CKM and KAMI collaborations submitted proposals this Spring and Lab decision was made after recommendations from June PAC meeting
  - Key criteria was ability to measure BR at 10% level and credibly establish a discrepancy or agreement with B-physics parameters

- Lab decision:
  - CKM ($K^+ \rightarrow \pi^+ \nu \bar{\nu}$) was given Stage I approval
    - Convincing redundant experimental technique
    - Backgrounds can be understood from data
  - KAMI ($K^0 \rightarrow \pi^0 \nu \bar{\nu}$) was not given approval

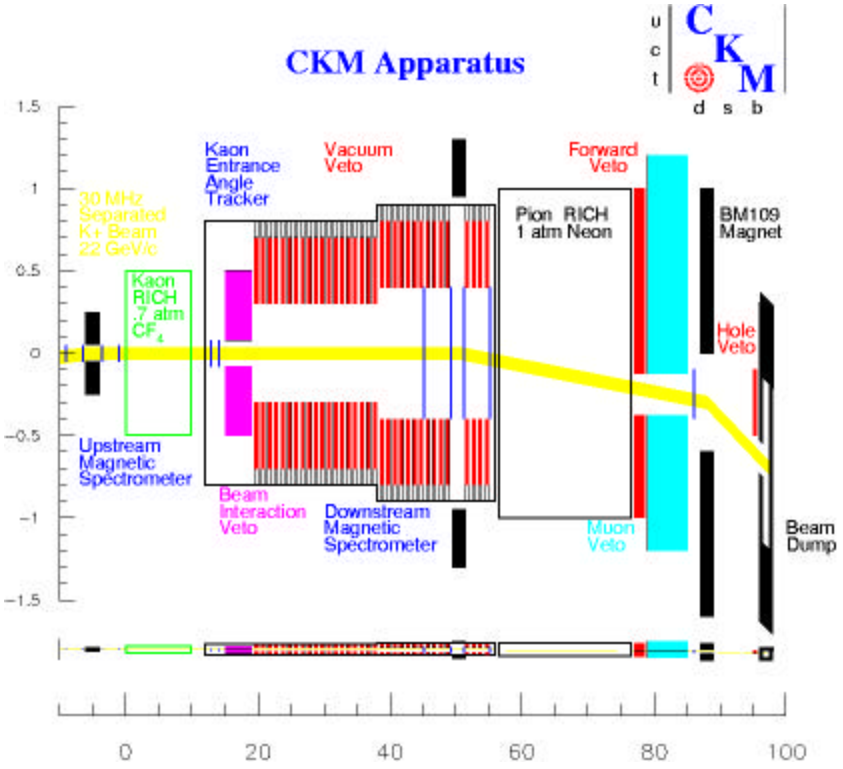
CKM (Charged K^+ Experiment)

- Goal is to collect 100 $K^+ \to \pi^+\nu\nu$ events
  (Expect BR = $8 \pm 3 \times 10^{-11}$)
  $\Rightarrow$ Measure |Vtd| to 10%
  (BNL787 has seen one event)

- Key component is 22 GeV super-conducting RF separated K^+ beam

- Incident K^+ and decay π^+ velocities and momenta are measured with two high-speed redundant spectrometers.

- The two principle backgrounds of $K^+ \to \mu^+\nu$ and $K^+ \to \pi^+\pi^0$ are controlled with ultra-hermetic muon and photon veto systems
  - Bkgnd can be derived from obs. events



The CKM is a joint effort with BNL E-949 (follow-up to BNL E-787)

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