A Roadmap for Fermilab

P5 Fermilab Meeting 4/18/06

Pier Oddone

Fermilab and the Community

- Fermilab will be the only remaining US laboratory solely devoted to particle physics
- It will provide the major facilities, infrastructure and technical support for the field
- The road map has to be a joint enterprise with the national and international physics community

Goals

Overarching Goals:

Enable the most powerful attack on the fundamental science questions of our time for our community

Provide world class facilities for HEP as part of the global network

Develop science and technology for particle physics and cosmology research

Specific Goal: make vital contributions to particle physics in the next decade by:

- *Exploiting the energy frontier with the Tevatron and LHC and developing ILC*
- *A world class neutrino program*
- *Smaller initiatives that add vitality and texture -- and the elimination of which does not help the initiatives above*

Strategic context: U.S. contribution

Domestic accelerator program with no new investment

✓ = leading

X = secondary

	Neutrino Frontier	Flavor frontier	Energy Frontier
2015	X	X	X
2010	X	X	X
2005	✓	✓	✓

Strategic context: U.S. contribution

Domestic accelerator program with new and redirected investment

✓ = leading

X = secondary

	Neutrino Frontier	Flavor frontier	Energy Frontier
2015	✓	X	✓
2010	✓	X	X
2005	✓	✓	✓
			First Priority

Outline for this presentation

- Strategy for the ILC
- Strategy for the neutrino program
- Strategy for the smaller initiatives and R&D program
- Interaction between the elements above in constrained budgets

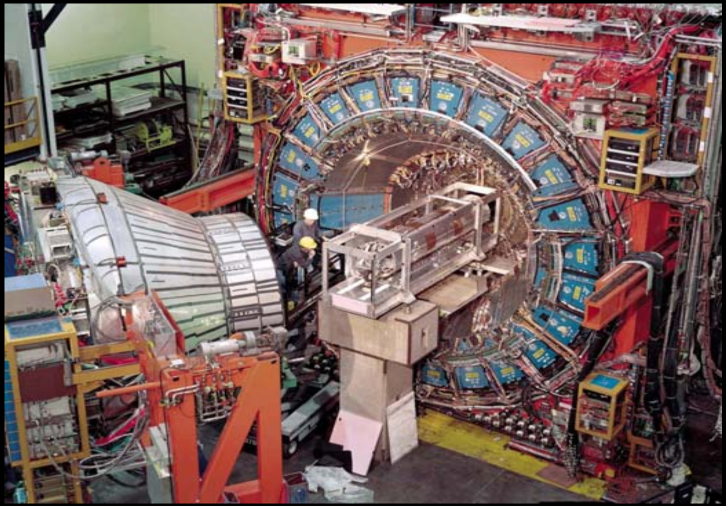
ILC Strategy

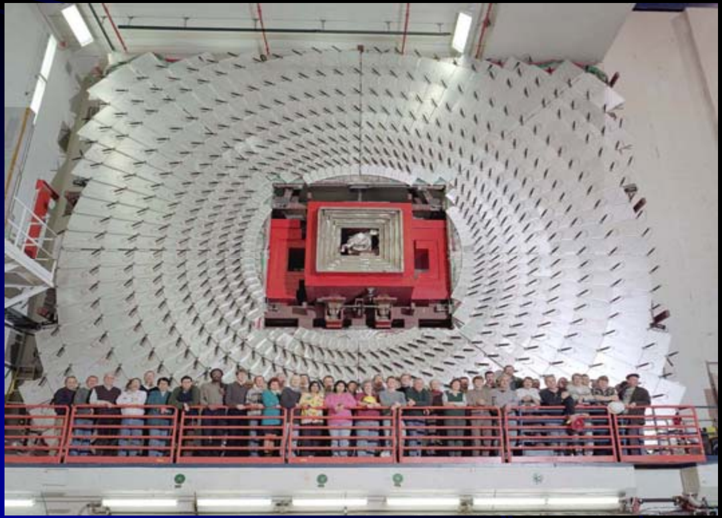
- Deliver on the present program: more than $3B in the next four years (a must).
- Make the LHC a success (a must).
- Make early decision with the agency that ILC path will be supported (RDR).
- Be ready by the end of the decade with site specific design/cost/international arrangements, completed component R&D, industrialization plans.

The first element: deliver on the present program

- We must deliver on our “ships of the line”:
  - The Tevatron Program: Integrated Luminosity, CDF and D0
  - The neutrino program: Minos and MiniBoone
  - LHC and CMS

Tevatron Program





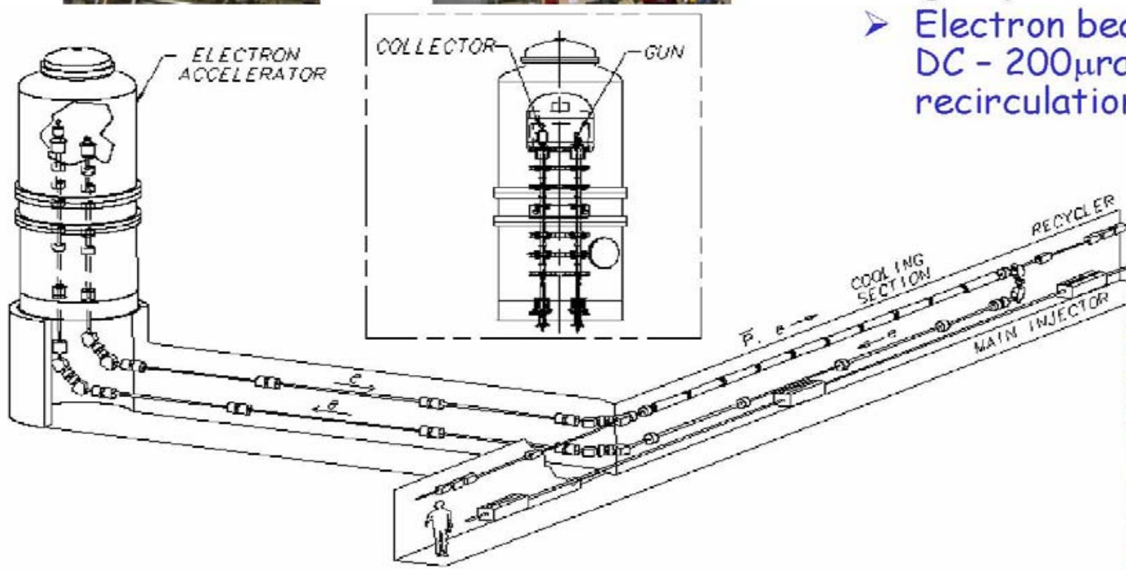
- Greatest window into new phenomena until LHC is on
- 1500 collaborators
  - 600 students + postdocs
- 1.3 fb^{-1} / experiment recorded
- Producing results with ~1fb^{-1}
  - within ~1 month of data taking
- Show only a few highlights

Recent technological success

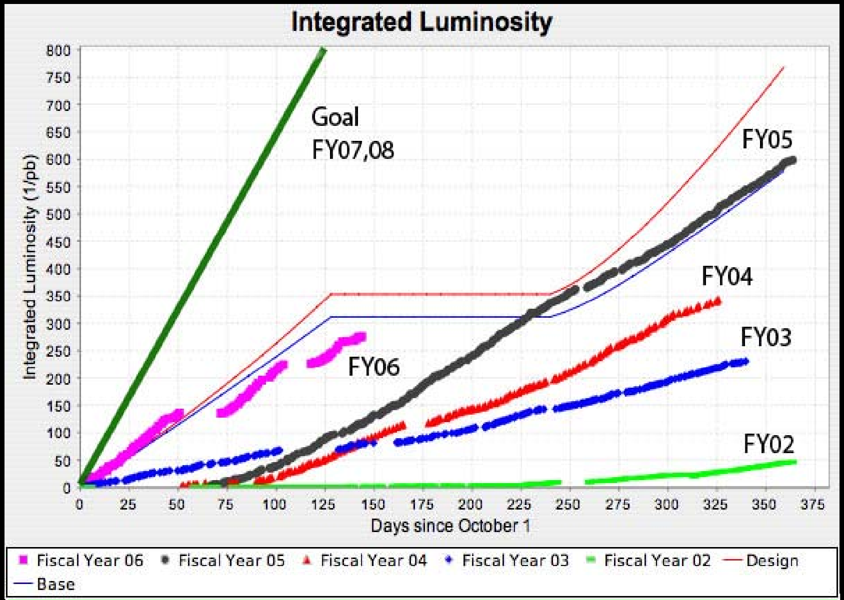
Fermilab
Accelerator Division

Recycler Electron Cooling

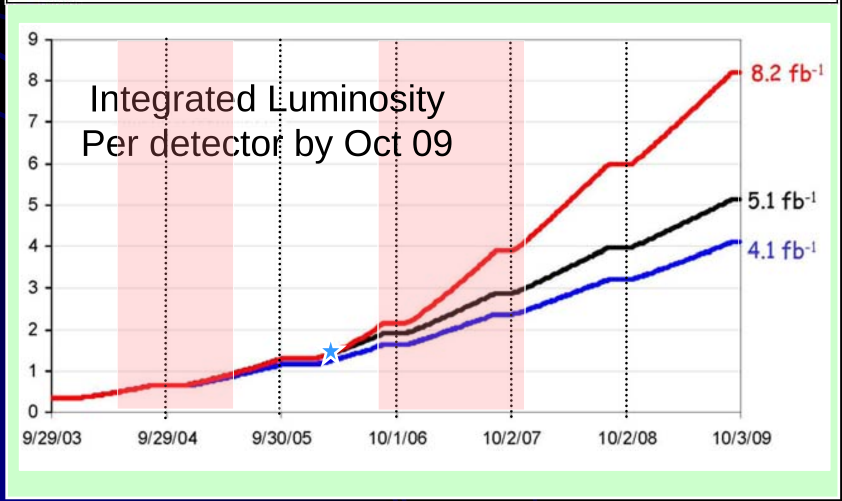
- The maximum antiproton stack size in the Recycler is limited by
  - Stacking Rate in the Debuncher-Accumulator at large stacks
  - Longitudinal cooling in the Recycler
- Longitudinal stochastic cooling of 8 GeV antiprotons in the Recycler is being replaced by Electron Cooling
  - Electron beam: 4.34 MeV – 0.5 Amps DC – 200μrad beam spread – 99% recirculation efficiency



Tevatron: key is luminosity



Luminosity history
for each fiscal year



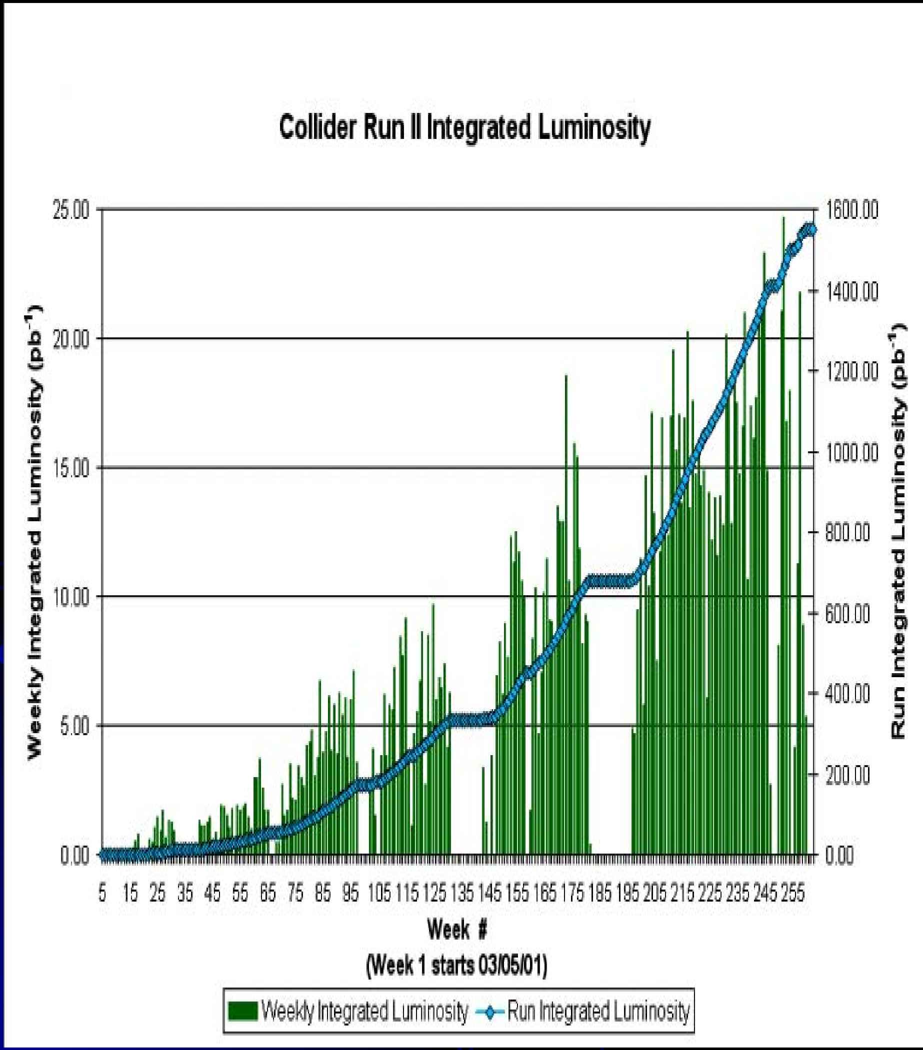
Integrated luminosity
for different assumptions

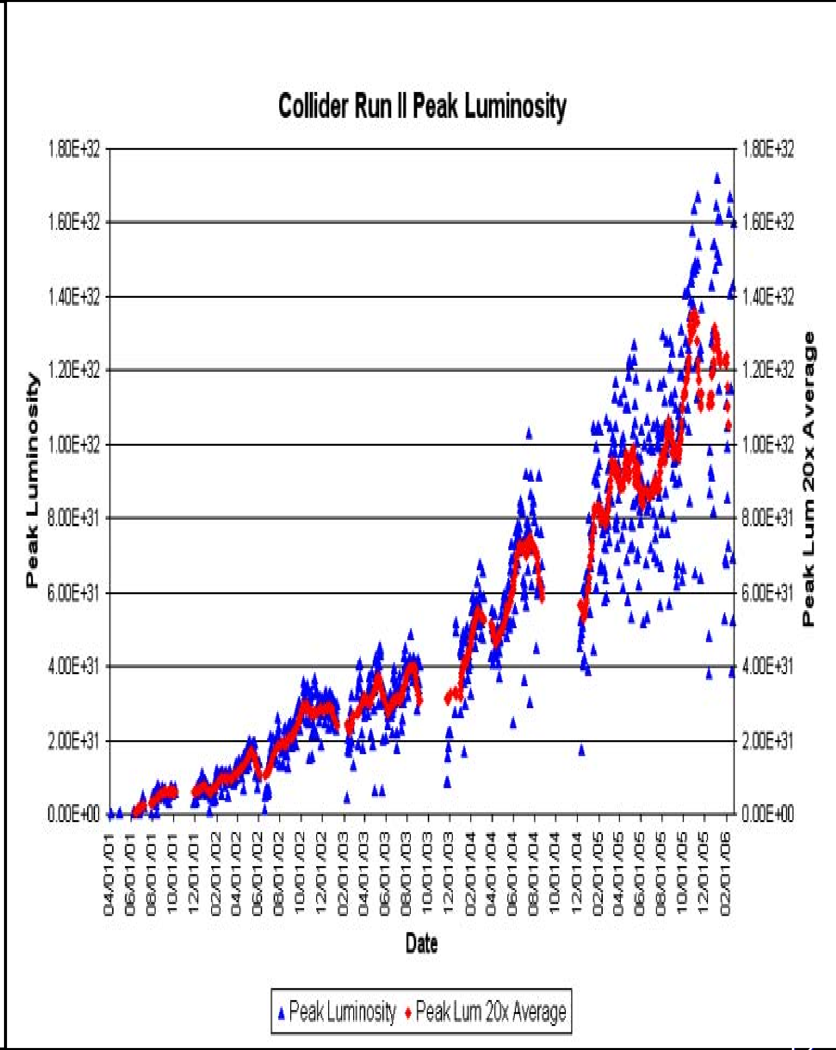
Top Line: all run II upgrades work

Bottom line: none work

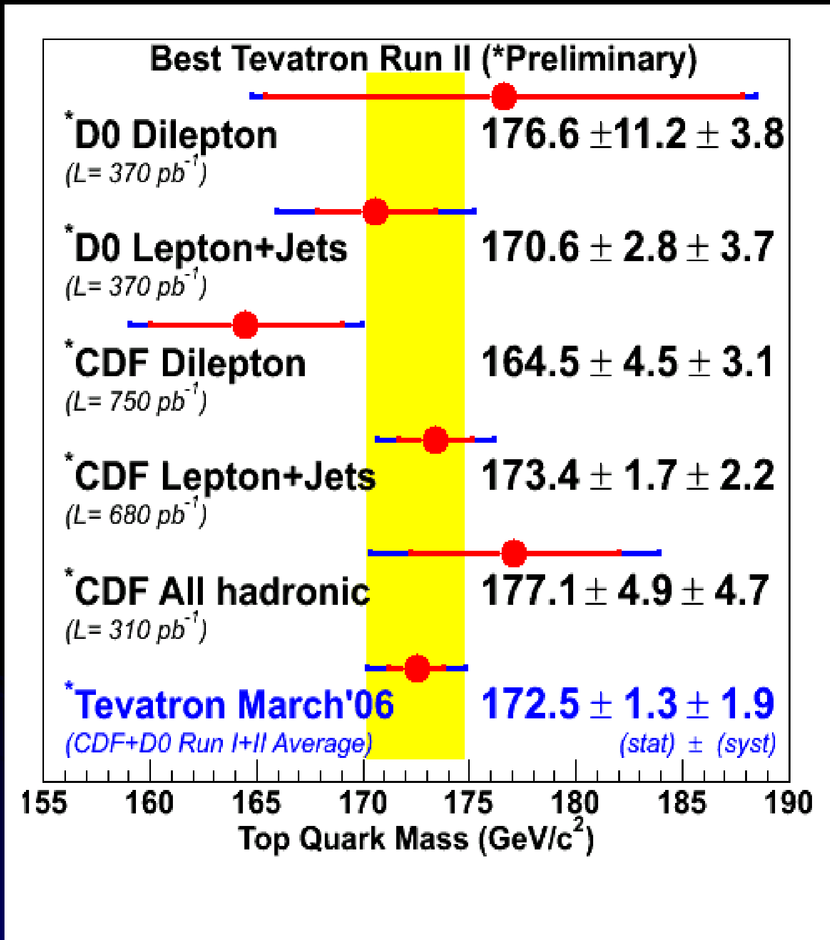
(pink/white bands show the doubling times for the top line)

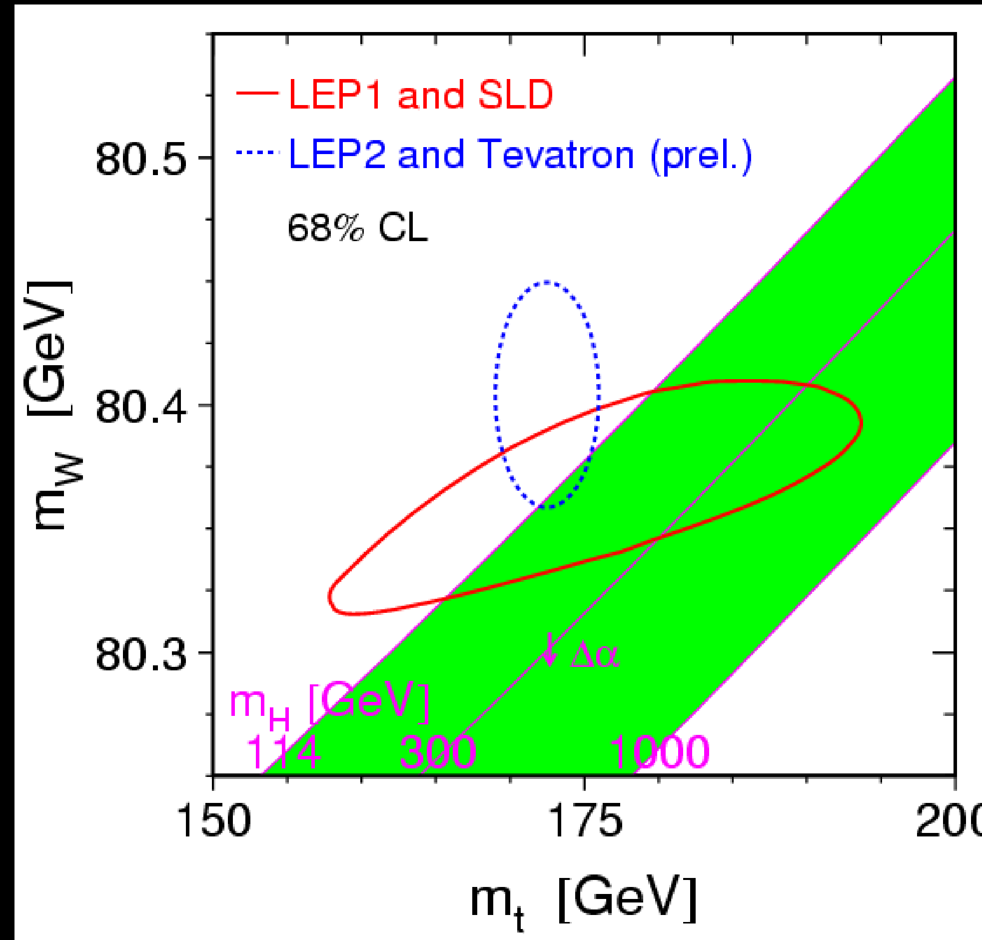
Tevatron Performance





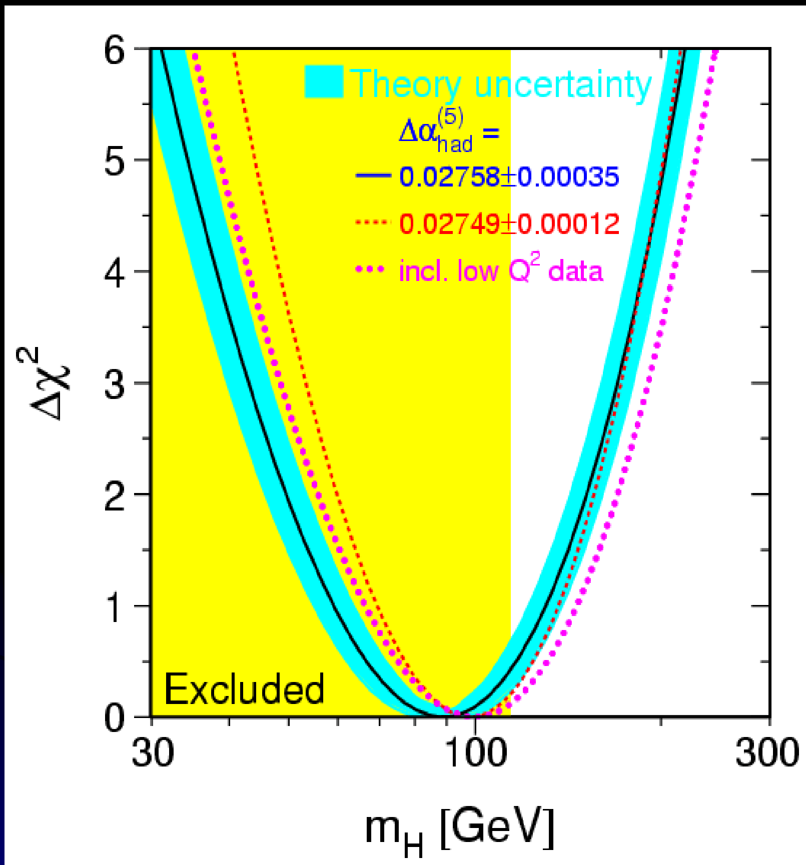
Top Quark Mass Measurements



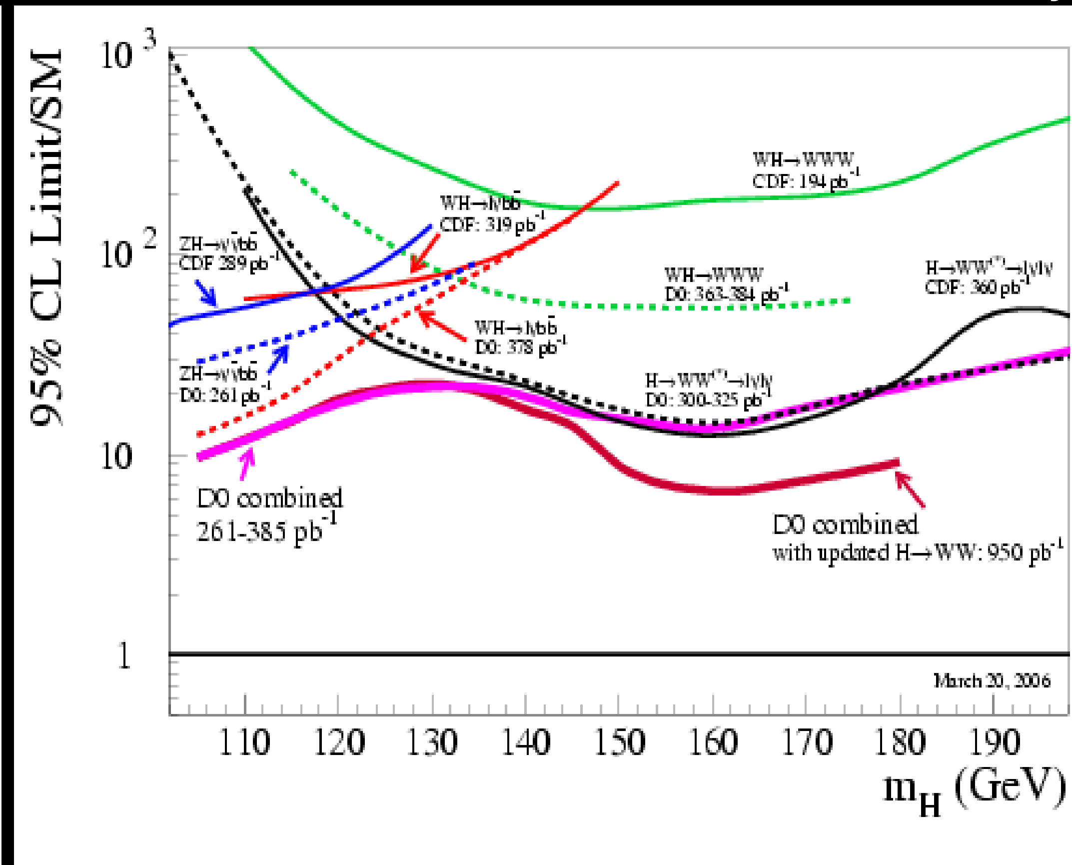


- $\delta M_{top} = 2.3$ GeV
  - x2 better than the Run I result
  - much better than expected - new ideas!
- Another x2 improvement by the end of Run II

Closing in on the the SM Higgs



Tevatron Run II Preliminary

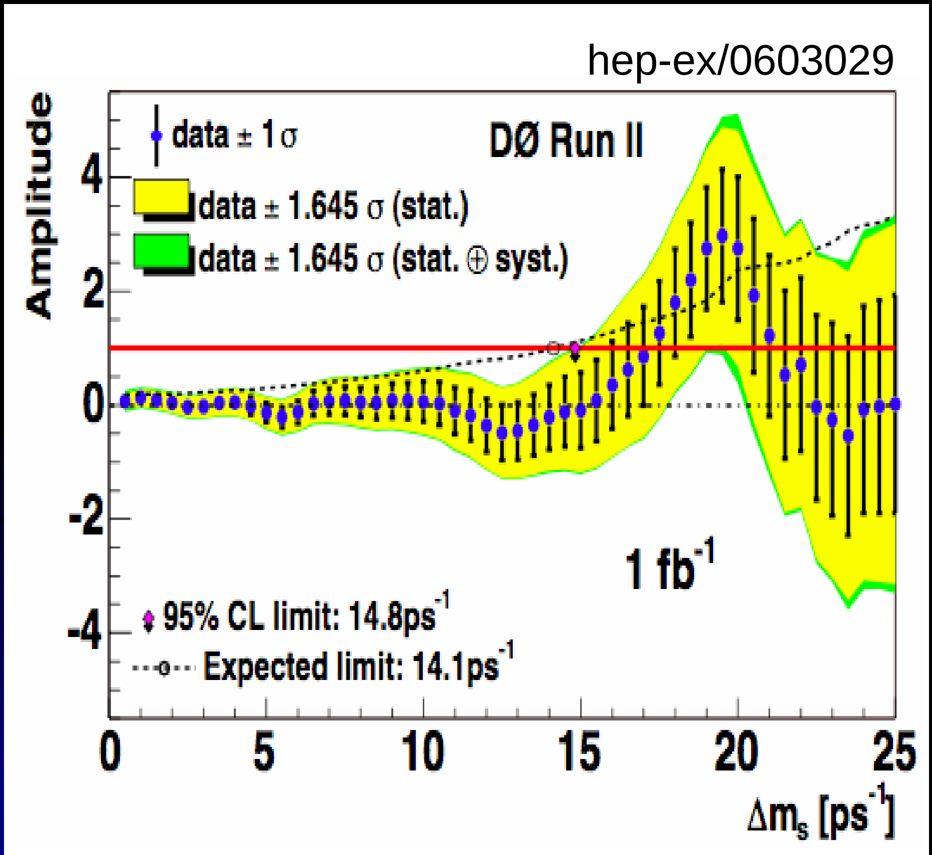


- Sensitivity to low mass Higgs, or
- Severely constrain mass

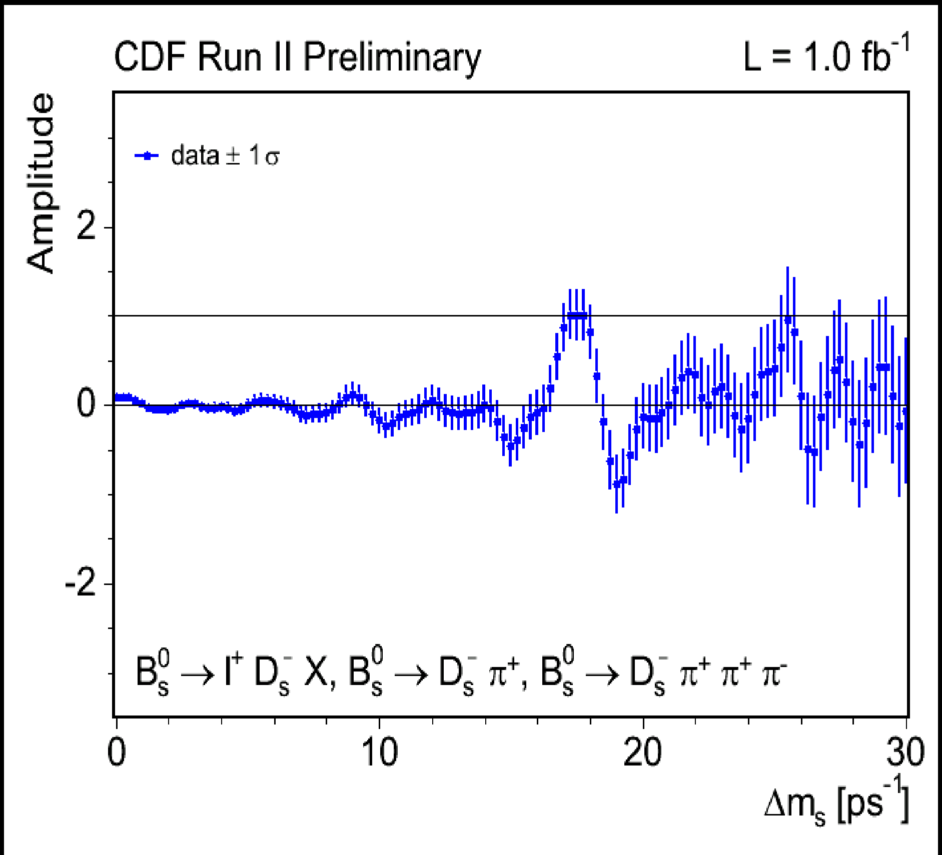
B_s Flavor Oscillation

World average $\Delta m_s < 14.4\ ps^{-1}$ (Summer 2005)

DØ (1 fb^{-1}) March 2006



CDF (1 fb^{-1}) April 2006



$17 < \Delta m_s < 21\ ps^{-1}$ at 90% CL

$\Delta m_s = 17.33\ ^{+0.42}_{-0.21} \pm 0.07\ ps^{-1}$

Windows to New Physics?!

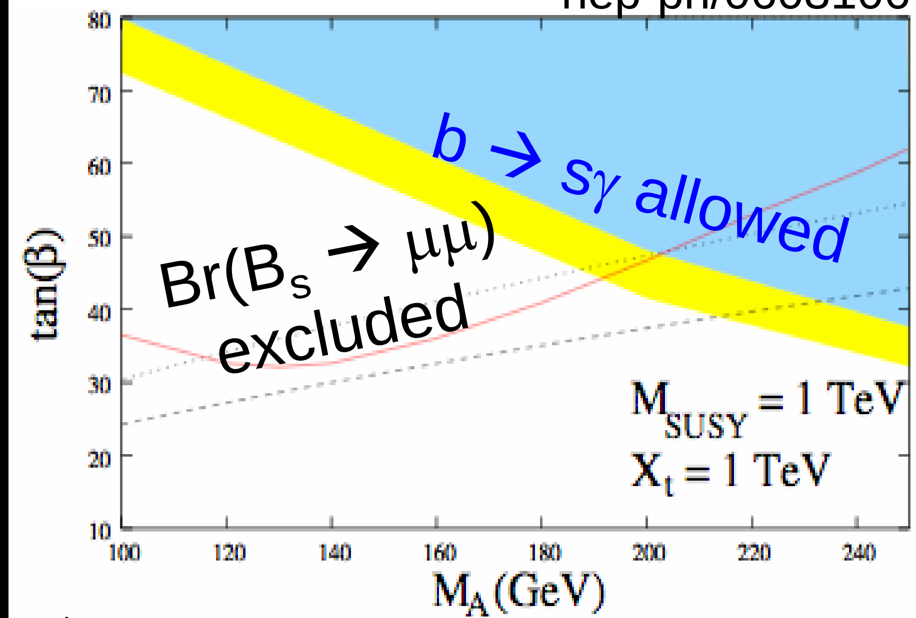
Many SUSY models predict significant flavor-changing effects

in rare decays of B_s mesons
and
in oscillation of B_s mesons

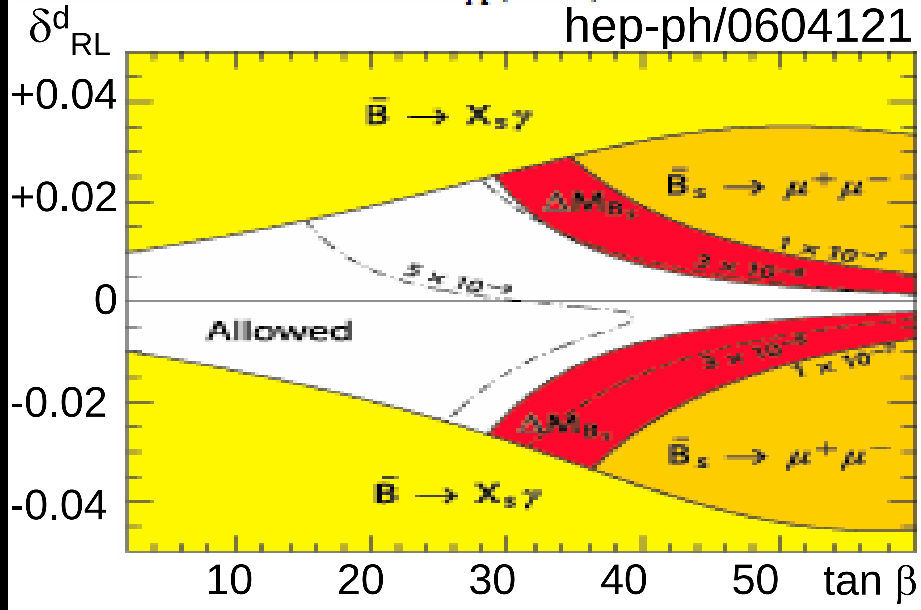
95% CL Branching Ratio Limits

Channel	CDF ($0.8\ fb^{-1}$)	DØ ($0.3\ fb^{-1}$)
$B_d \rightarrow \mu\mu$	3.0×10^{-8}	
$B_s \rightarrow \mu\mu$	1.0×10^{-7}	3.7×10^{-7}
$B_s \rightarrow \mu\mu\phi$		4.1×10^{-6}

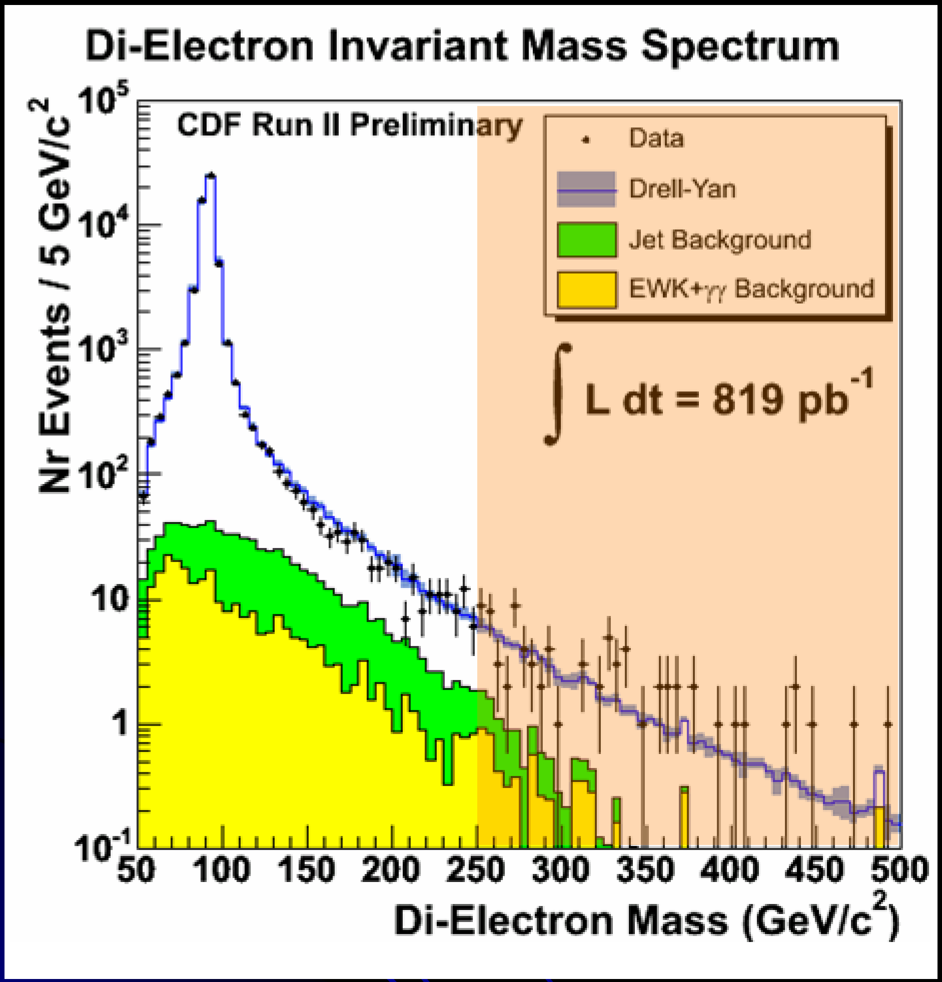
hep-ph/0603106

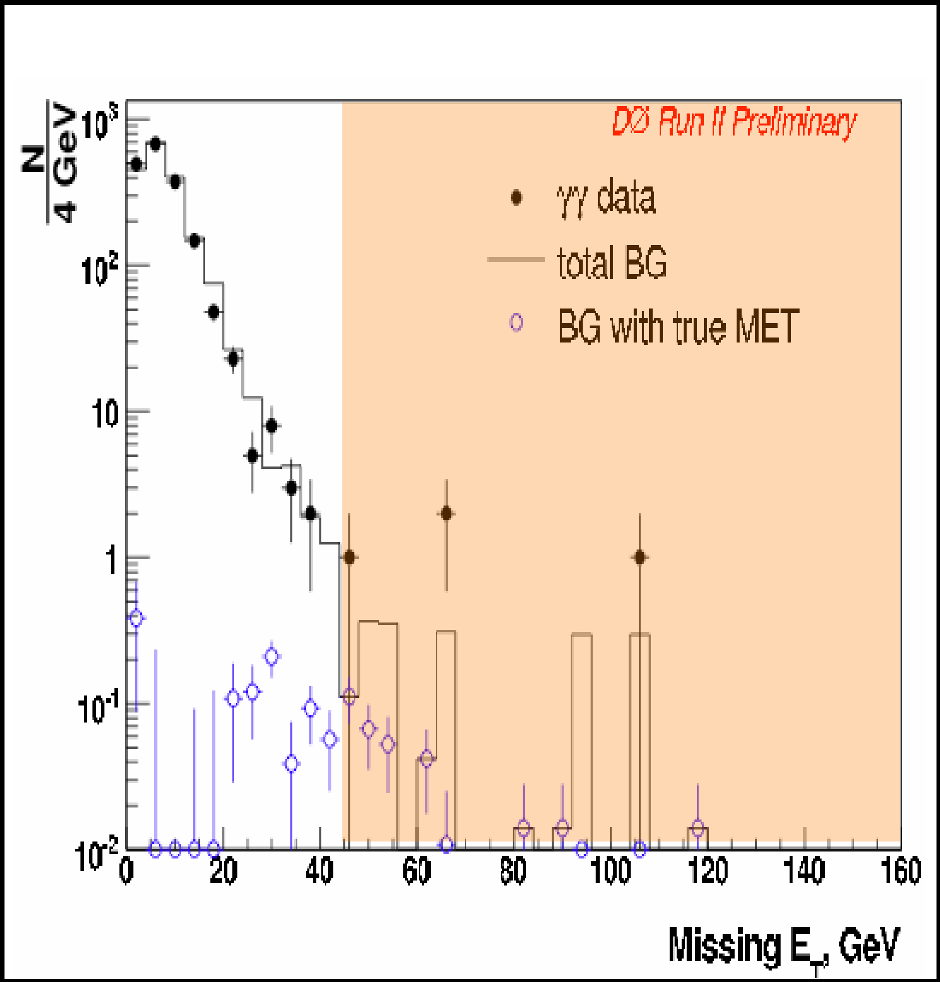


hep-ph/0604121



Z’, LED, SUSY(GMSB), ….



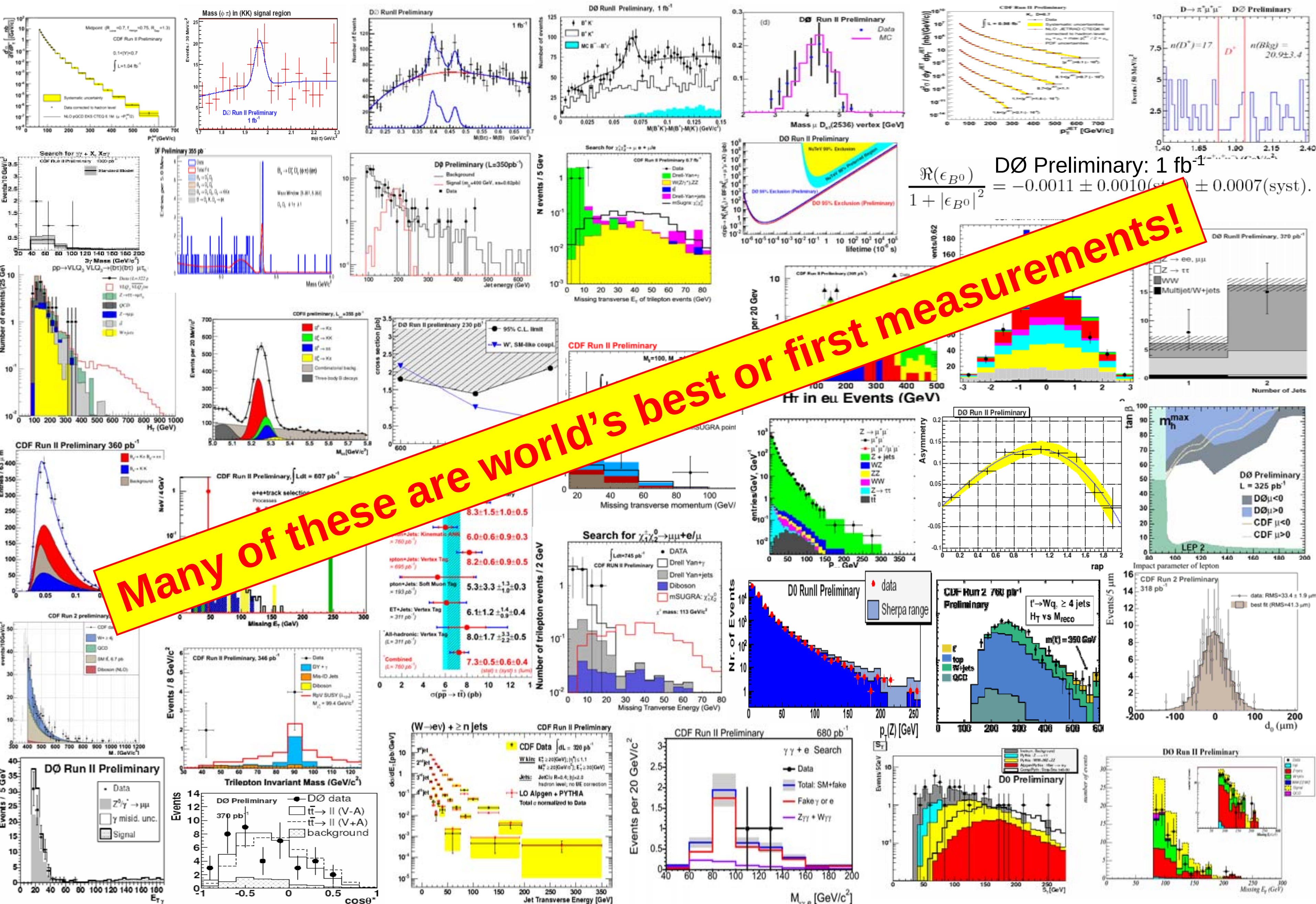


95% CL Excluded:

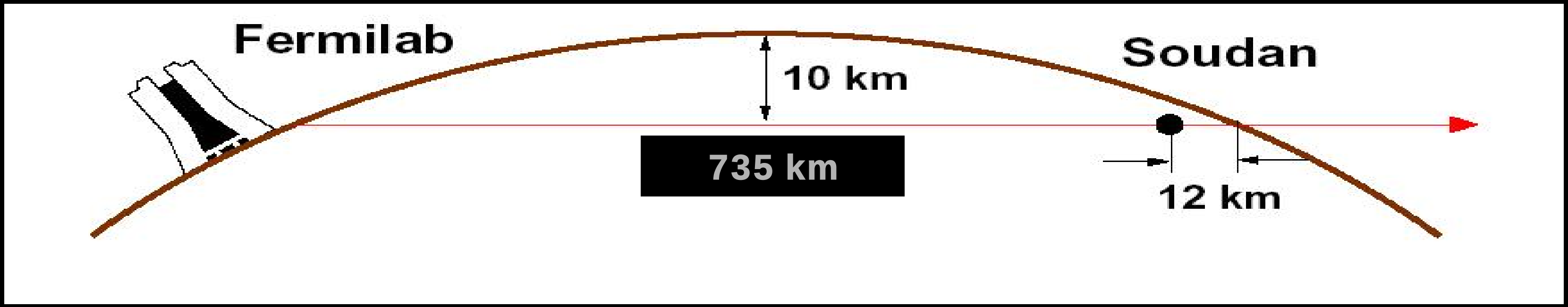
$M_{Z'}$ < 850 GeV (Standard Model like Z’)

$M(\chi_1^0) < 120$ GeV, $M(\chi_1^\pm) < 220$ GeV (Gauge-Mediated SB)

Other Results since September 2005



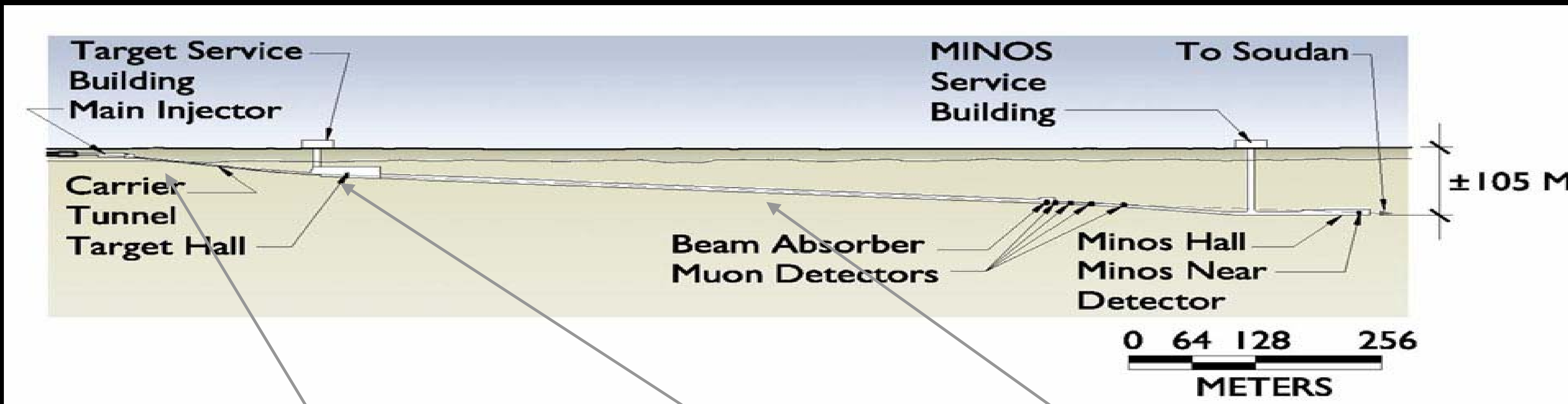
Present Neutrino Program: MINOS



Minos near detector: 1 kton

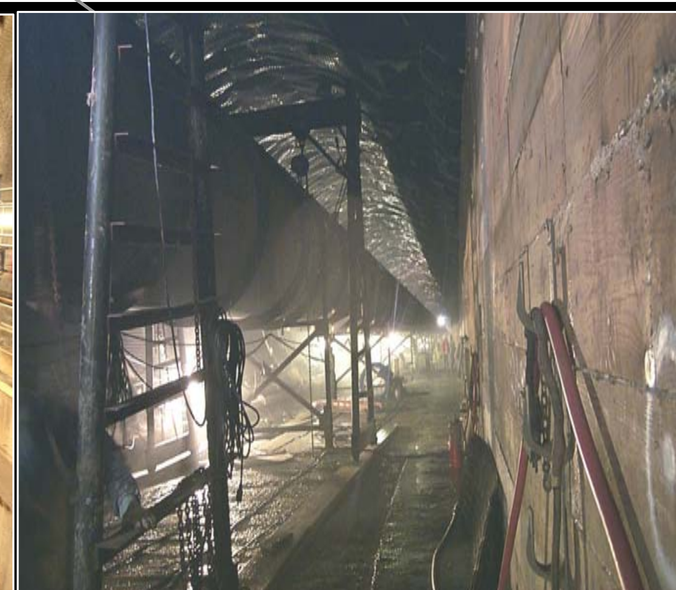
Minos Far detector: 5.4 kton

The NuMI beamline



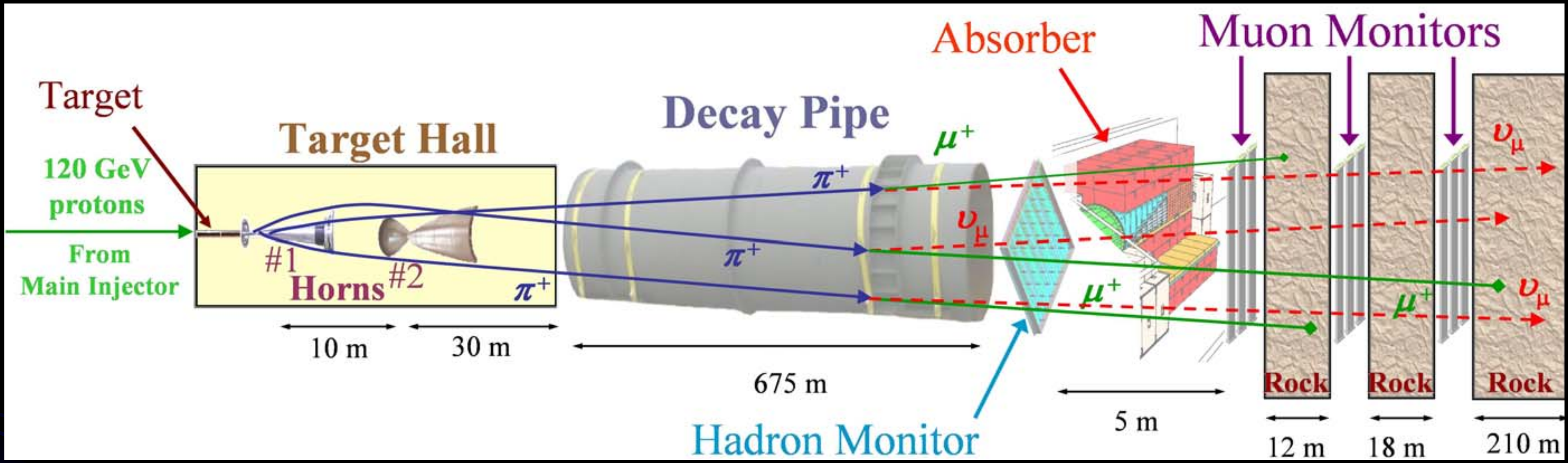
Primary proton line

Target hall



Decay pipe

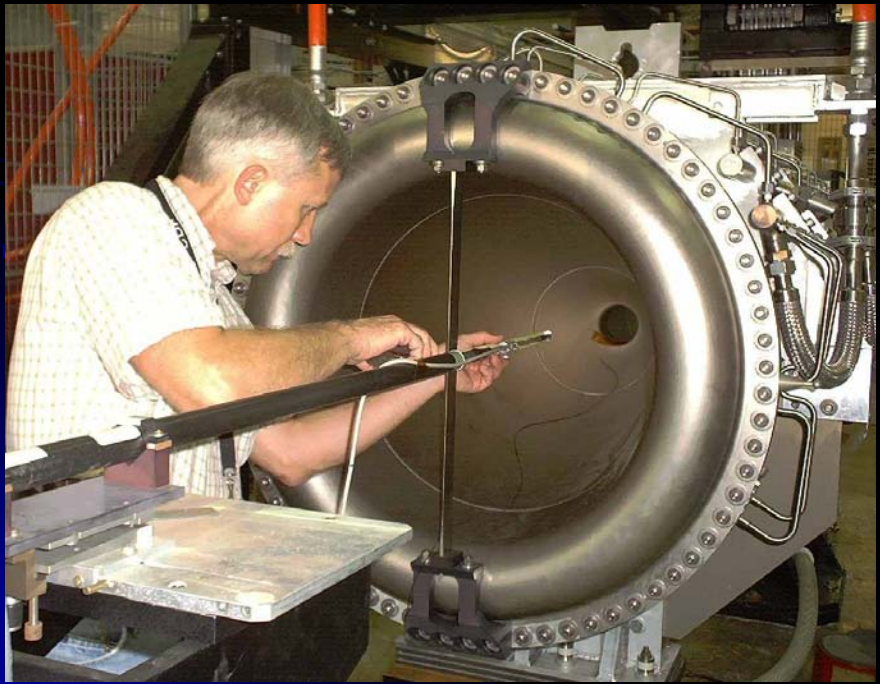
Producing the neutrino beam

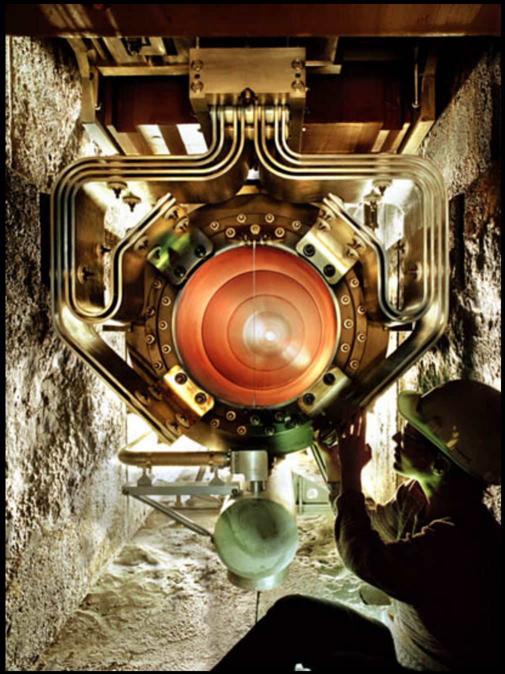


- Moveable target relative to horn 1 – continuously variable neutrino spectrum

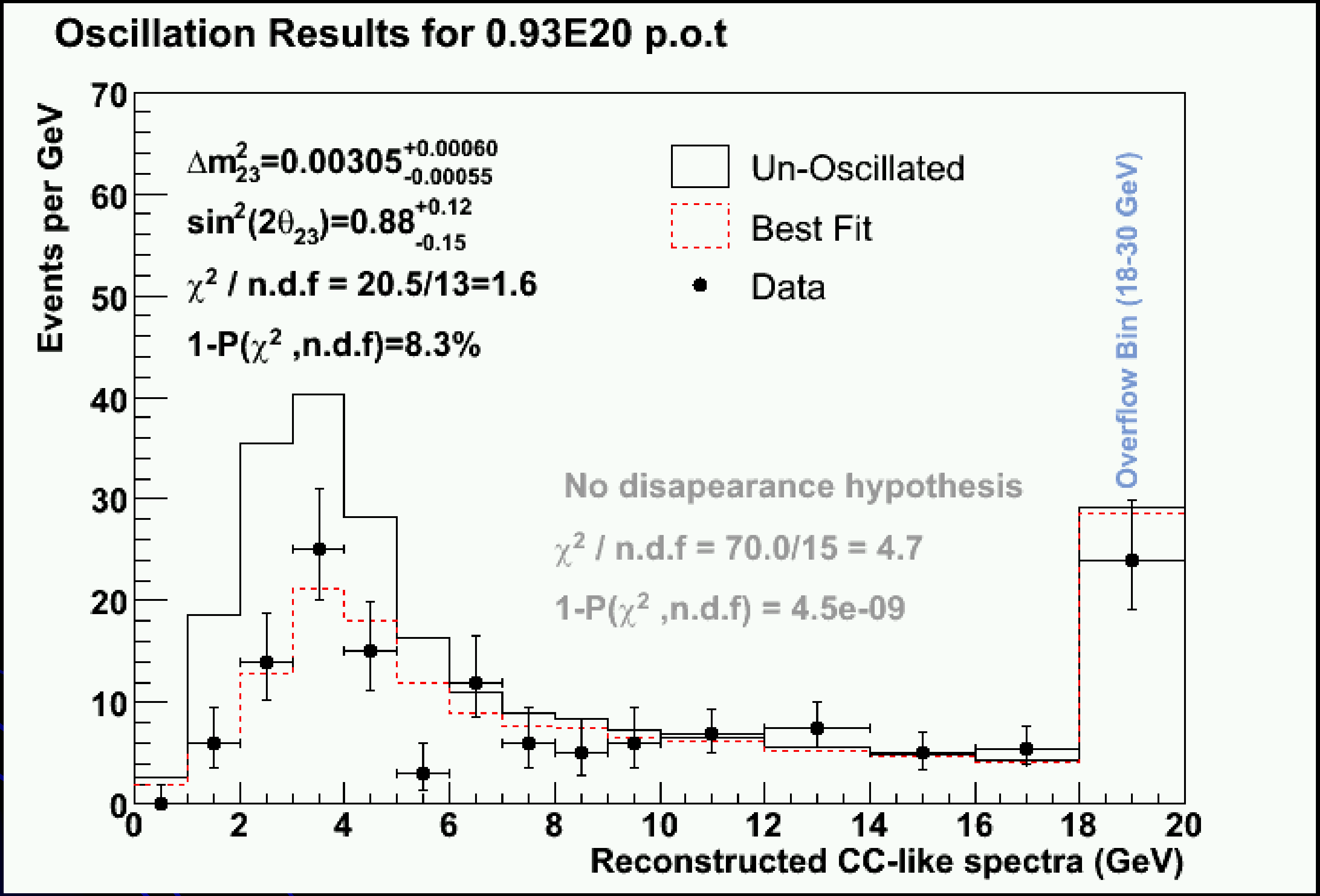
Focussing horns

- Two parabolic focussing horns connected in series.
- Nominal horn current at 200 kA
- Produces 3.0 Tesla peak field



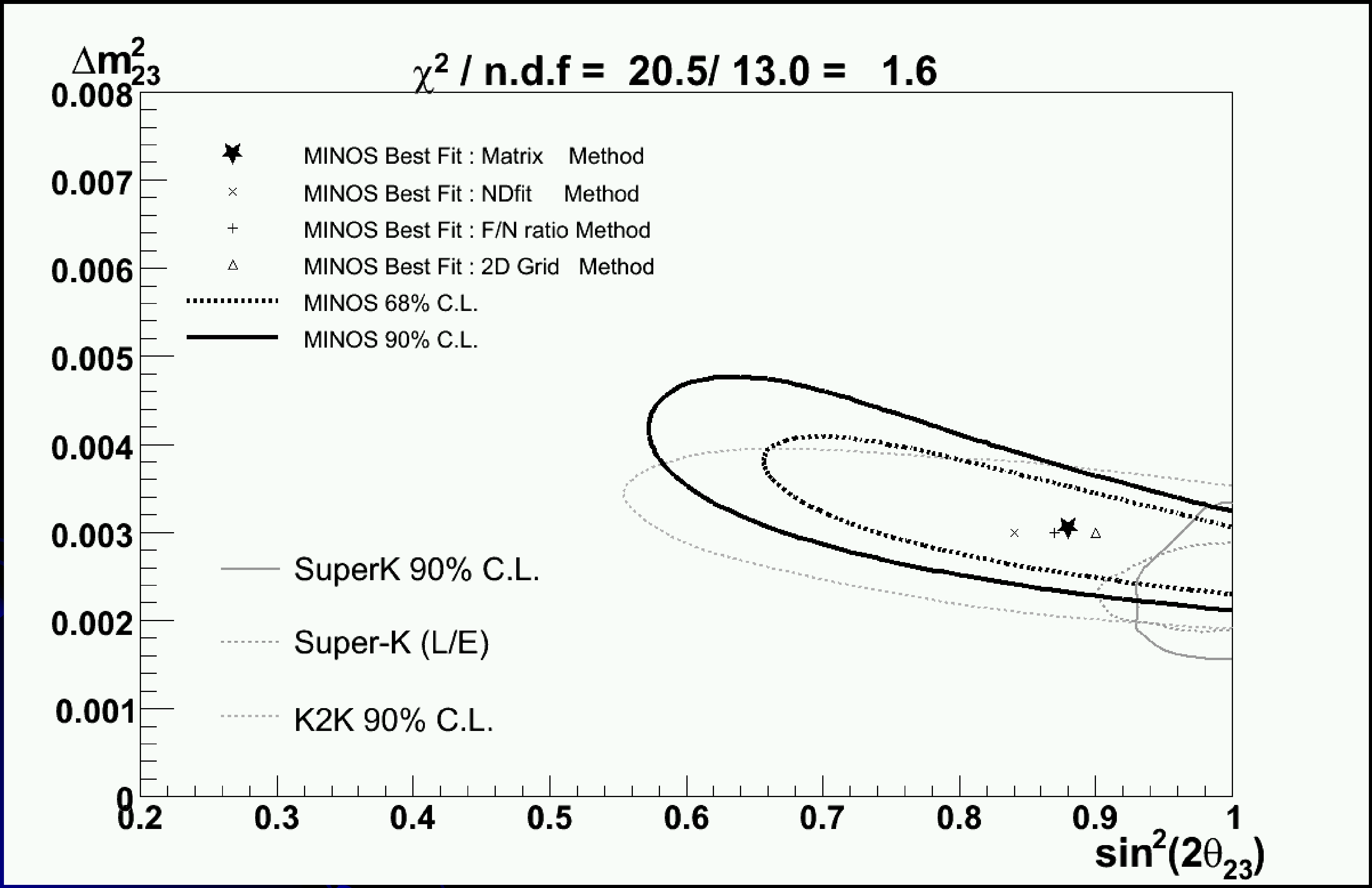


Best-fit spectrum



- Measurement errors are 1 sigma, 1 d.o.f.

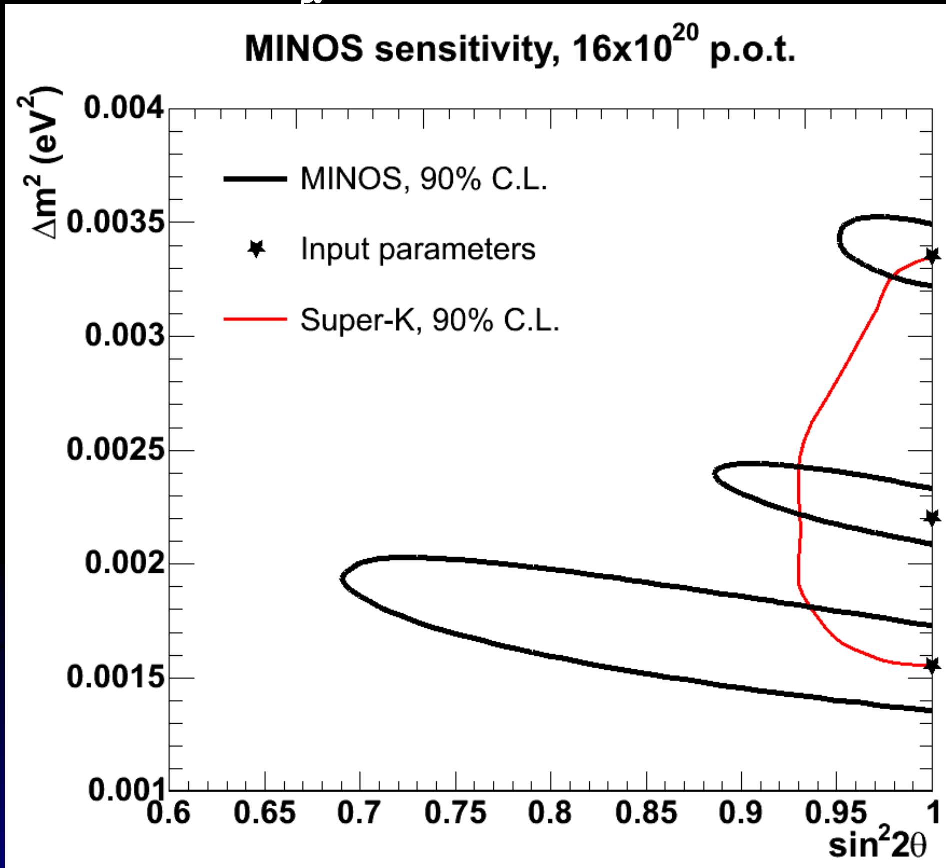
Allowed regions



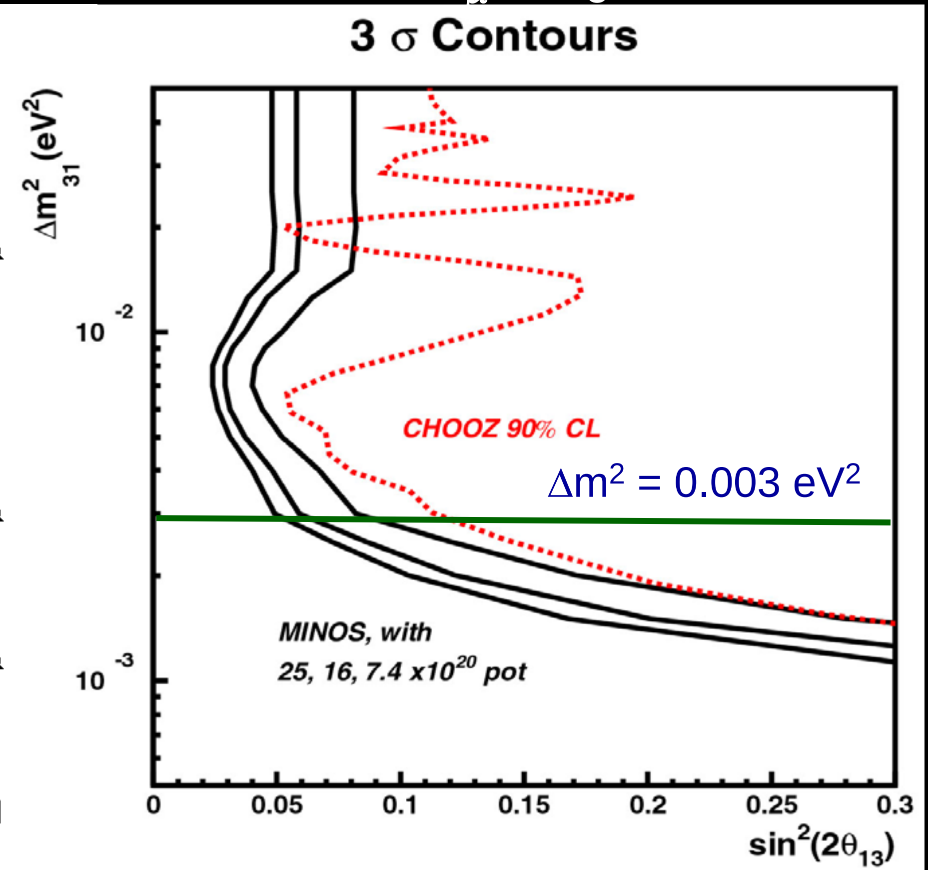
- **The results of the four different extrapolation methods are in excellent agreement with each other.**

Projected sensitivity of MINOS

ν_μ disappearance



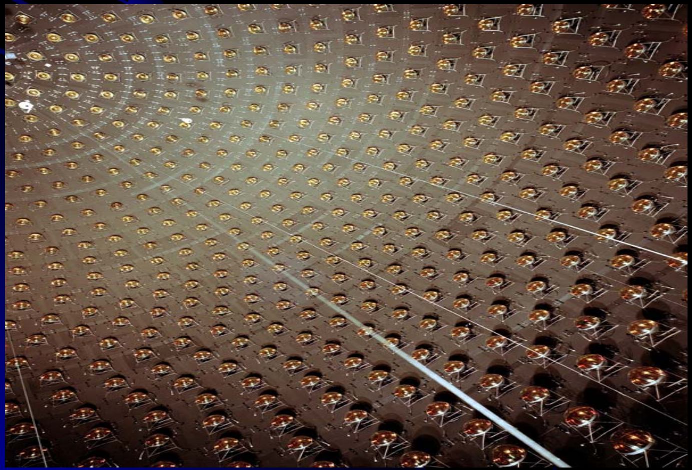
$\nu_\mu \rightarrow \nu_e$



•With increased statistics, we should be able to make a very precise measurement of Δm^2_{23} and also search for sub-dominant $\nu_\mu \rightarrow \nu_e$ oscillations well-below the current exclusion limit

•In addition, by making a precise measurement of the CC spectrum, we should be able to test/rule out alternate models such as neutrino decay.

Present Neutrino Program



- MiniBooNE

  - 1 GeV neutrinos (Booster)

  - 800 ton oil cerenkov

  - Operating since 2003

  - $\nu_\mu \to \nu_e$ appearance

  - Box not open: 60% more events than expected

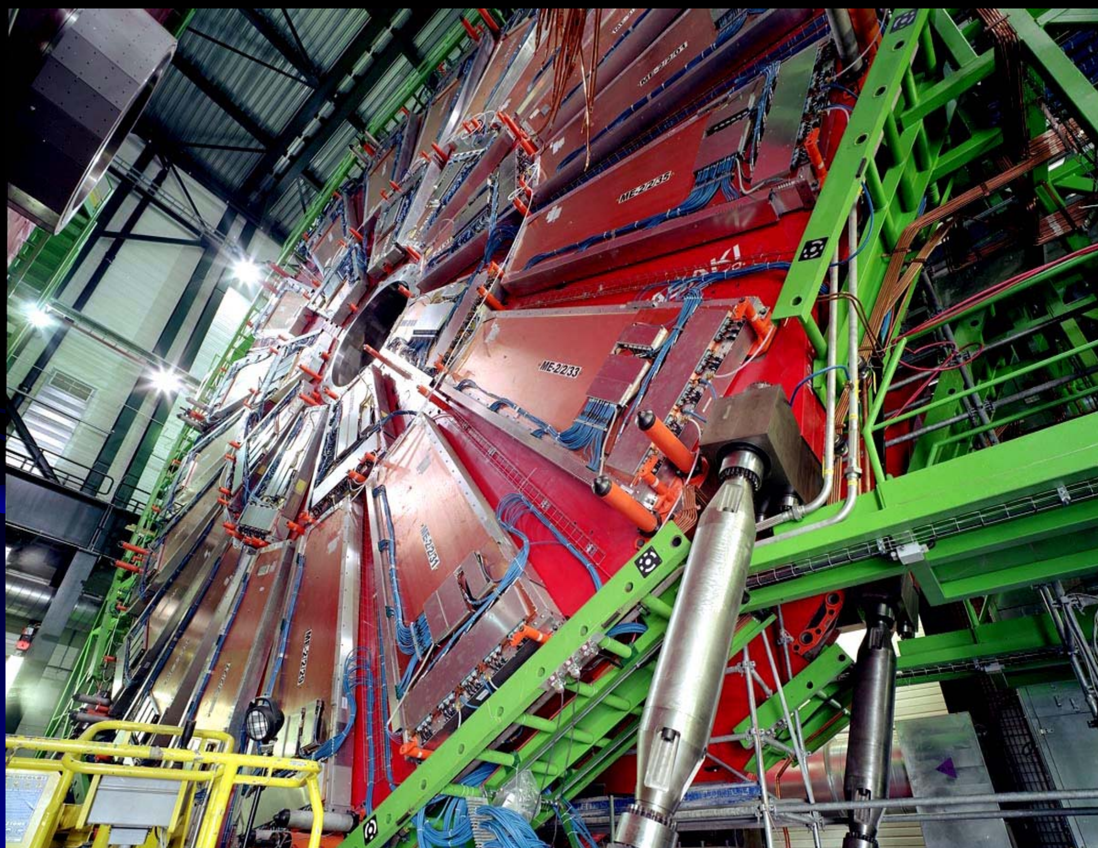
Second element: make LHC successful

LHC: delivering on the promise

- Huge increase in physics reach: 7 times the energy, 100 times the luminosity of the Tevatron
- With increase in energy and luminosity come special challenges (e.g., 300 Megajoules of stored energy in the beam!)
- Fermilab: principal US support for the commissioning

CMS: Compact Muon Detector

- Coming together: aimed at completion by end of 2007



Muon detectors

Magnet cold mass

CMS: Compact Muon Detector

- US collaboration doubled in the last three years

>400 Collaborators

44 Institutions

US CMS: and Fermilab’s role

- Only major US lab associated with CMS: a central support role for the US community in construction, commissioning and physics
- Attention now to huge data and physics discovery challenge: the LHC Physics Center (LPC)

Remote operation center

- In support of accelerator operations and CMS operations, we are creating remote operation center. Shared for CMS and accelerator
- Aim: as good as being there for US institutions!

Third element: Support for RDR

- Secretary Bodman: How much …….?
- The RDR is now key element: it determines whether DOE leadership states intent to bid-to-host and makes necessary investment.

Fermilab's Role in the RDR

- GDE goal = complete the Reference Design Report (RDR) and a cost estimate by the end 2006 → established RDR organization

- Design & Cost Board (coordinates machine design)
  - Responsible for producing the RDR and the cost estimate
  - 9 members (3/region) + Chairman
  - P Garbincius (FNAL) = chair, R. Kephart (FNAL) member

- Change Control Board (ILC baseline configuration control)
  - 9 member board (3/region), N Toge = Chairman
  - S. Mishra (FNAL) is one of 3 U.S. Members

Fermilab's Role in the RDR

- ILC Machine "Area" Leaders (typically 3 Ldrs 1/region)
  - Civil and Site: Vic Kuchler (FNAL) = Americas Ldr
  - Main Linac Design: N. Solyak (FNAL) = 1 of 2 Americas Ldrs
  - Cryomodule: H. Carter (FNAL) = Americas Ldr
  - Cryogenics system: T. Peterson (FNAL) = Americas Ldr
  - Magnet systems: J. Tompkins (FNAL) = Americas Ldr
  - Communications: E. Clements (FNAL) = Americas Ldr
- FNAL is playing a major role in the GDE & ILC machine design

What do we want with the RDR?

- Cost will not be precise: no known time scale, no real engineering design, no detailed site design; R&D not finished; no industrialization; done outside DOE costing rules ……

- So what good is it?
  - Hopefully it allows the DOE to decide we really want to do this and to make the large investment necessary in the next few years to do real design and industrialization.
  - We hope it will allow DOE to initiate international discussions on process for a bid-to-host

Fourth element: ready for decision by the end of the decade

- After the RDR, will need site specific designs
- How many? 0,1,2,3…. All regions will contribute to generic elements of the design but individual regions to their site-specific designs
- Decision at the end of the decade will be based on success of R&D, full site specific design, credible cost estimate.
- No engineering test facility (2-3% of ILC) will be possible outside the project – if we want an early start of the ILC

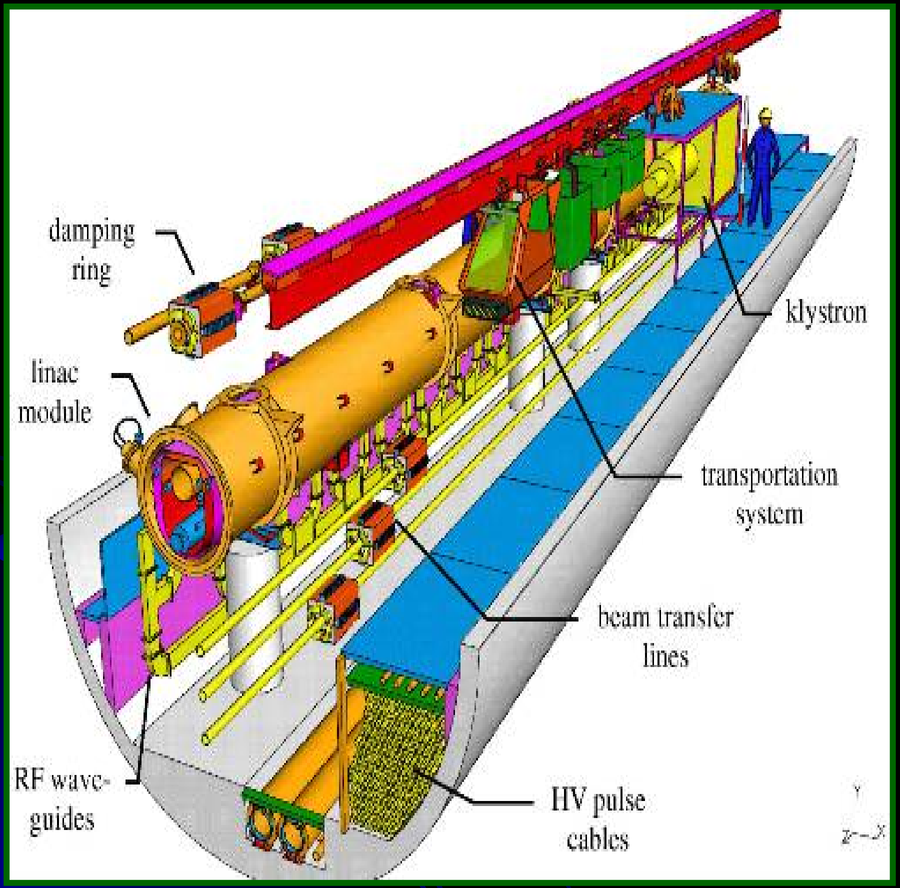
Getting ready for decision

- Fermilab ILC R&D activities:
  - ILC Machine Design
  - Development of SCRF technology & infrastructure
  - Conventional Facility & Site Studies for a US ILC site
  - Industrialization & Cost Reduction
  - ILC Physics, Detector Design, and Detector R&D

- Support activities of and build partnerships with laboratories and universities

- Support GDE and transition to follow-on organization

ILC Machine Design

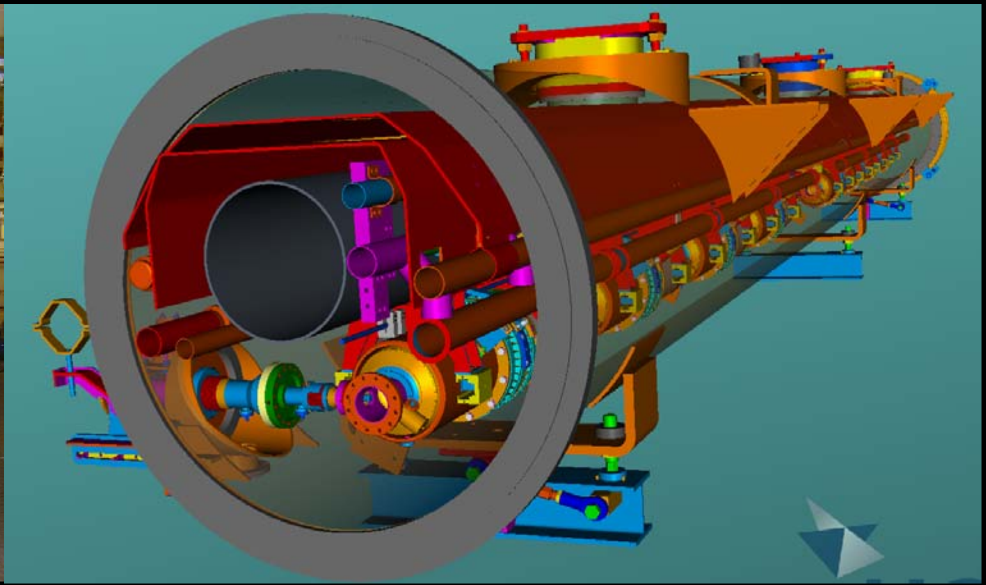


- Fermilab has focused its R&D efforts on the ILC Main Linacs. Broad collaboration.
- Main Linac activities:
  - Accelerator physics design
  - Demonstrate feasibility of all Main Linac technical components
  - Engineering design of ML technical systems
  - Estimates of the ML cost & methods for cost reduction
  - U.S. Industrialization of high volume ML components

ILC 1.3 GHz Cavities @ FNAL

- Industrial fabrication of cavities, some in U.S. Industry
- Two Single/large Crystal cavities under development with TJNL
- BCP and vertical testing at Cornell (25 MV/m)
- EP and vertical testing at TJNL. (35 MV/m)
- Joint BCP/EP facility being developed ANL (2007)
- High Power Horizontal test facilities @ FNAL (2006)
- Vertical test facility @ FNAL (2007)

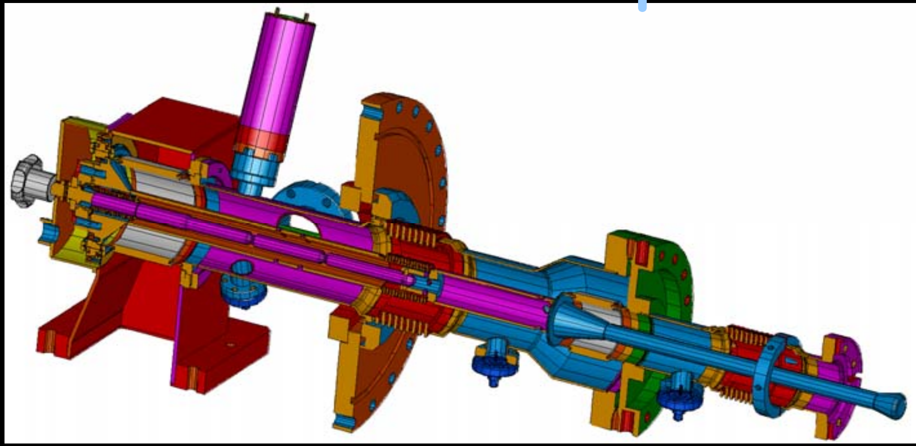
Cryomodule



- ILC cryomodules are complex objects
- TTF cryomodules (type III) need to evolve for ILC
- FNAL is collaborating with DESY, INFN, KEK, CERN, JLAB, SLAC, etc. on the design of the next generation ILC cryomodule (Type IV)

Main Coupler & Tuner R&D

TESLA Main Coupler



1.3 GHz, pulsed operation
Two windows, adjustable
2K (4K) heat load 0.06 (0.5) W

TESLA Blade-Tuner

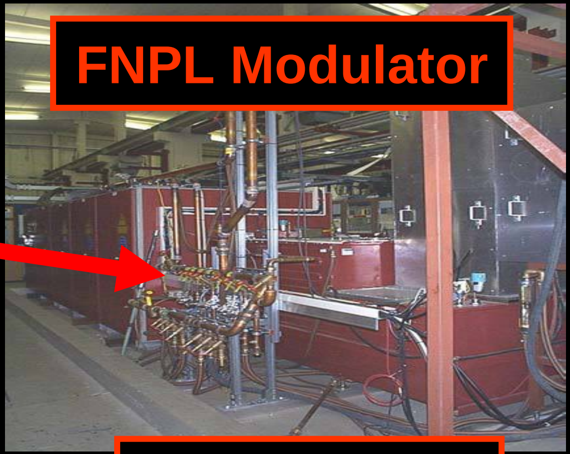
Main Couplers and tuners are complex
FNAL plans R&D aimed at cost reduction

Fermilab plans to build a facility to test couplers

Fermilab is also working on controlling Lorentz detuning via Piezoelectric tuners in a feed-forward system

ILC RF Systems R&D

- Modulator R&D
  - 10 Modulators built based on Fermilab design
  - 3 by FNAL and 7 by industry
  - In operation ~10 yrs @ DESY and FNPL
  - 2 new Modulators will be finished in FY06 in collaboration with SLAC
- Klystrons
  - Plan to order new 10 MW klystron; US/Japan
  - Design improvements are needed to reach reliable long-term operation at 10 MW peak / 150 kW average power. Industry+SLAC?
  - Also need to develop U.S. vendors
- LLRF R&D in collab with Penn, DESY, INFN, etc.



FNAL SCRF Infrastructure

- A Cryomodule Assembly Facility (CAF) is being built in (MP9)
- Vertically tested cavities will be dressed (He vessel, coupler, etc) in smaller clean rooms prior to horizontal test
- Horizontally tested cavities assembled into a string in large clean room before final Cryo-module assembly takes place

Plan = expand CAF into Industrial Center Bldg after LHC quads

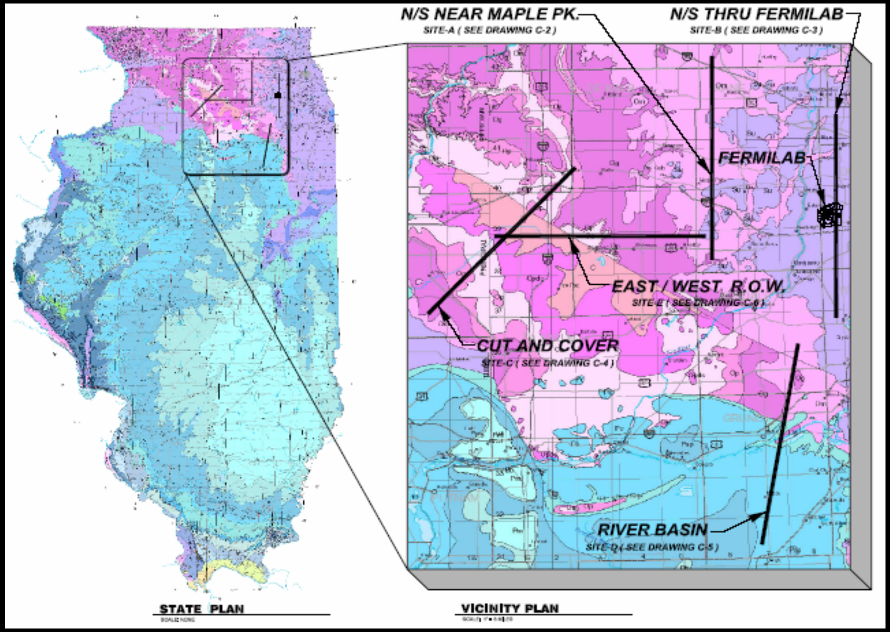
ILC Test Areas (ILCTA)

- SCRF test facilities are needed to carryout the ILC program
- Vertical Test (bare cavities) IB1
  - IB1 has 60 W @ 1.8 K now
- Horizontal Test (dressed cavities)
  - IB1 & Meson Bldg (PD)
  - Meson will have 60 W @ 1.8 K soon
- Cryomodule test facility
  - Cleaning out New Muon Lab
  - Remove CCM install cryogenics
  - Photo injector moves ➔ e beam
  - Power 1st cryomodule in 2007
- RF Power & Cryogenics ➔

These are Big expensive facilities !

Civil and Site Development

"The U.S. Department of Energy has expressed its interest in the possibility of hosting a linear collider, at Fermilab, subject to the machine being affordable and scientifically validated by physics discoveries at the LHC.“

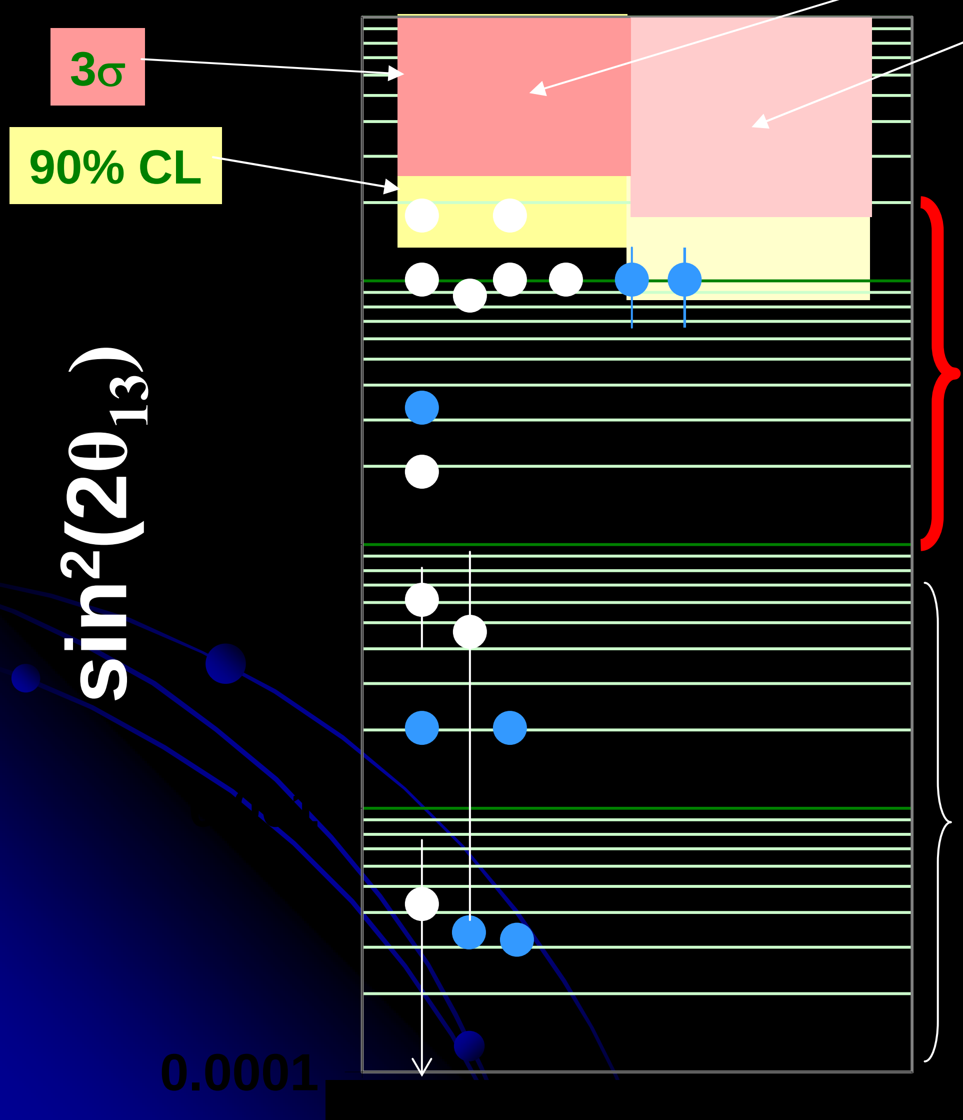


- Our goal is to determine the best possible host site for a prospective ILC bid in northern Illinois
- With the GDE we are developing the ILC Civil Design
  - Tunnel Design
  - Geological and environmental studies

Neutrino strategy

- Understanding the Neutrino matrix:
  - What is $sin^2 2\theta_{13}$
  - What is the Mass Hierarchy
  - What is the CP violation parameter δ
- Fermilab is in the best position to make vital contributions to answer these questions with complementary program to T2K facility in Japan

Theory Model Predictions for $\sin^2(2\theta_{13})$



CHOOZ + ATM + K2K

Global fit
with solar + 2004 KamLAND
(these limits from
Maltoni,Schwetz,Tortola,& Valle
hep-ph/0405172)

About factor of 10 within NOvA/T2K/reactor reach

7 too small for all proposals

● from Albright 2004

● From Minakata hep-ph/0505262

Neutrino Strategy

- Address Tritium issues
- Upgrade existing complex to reach 1 MW beam power (2010 shutdown)
- Build NOvA to
  - Have strongest reach into $\sin^2 2\Theta_{13}$
  - Sensitivity to the Mass Hierarchy (not possible in T2K)
  - Some sensitivity to CP

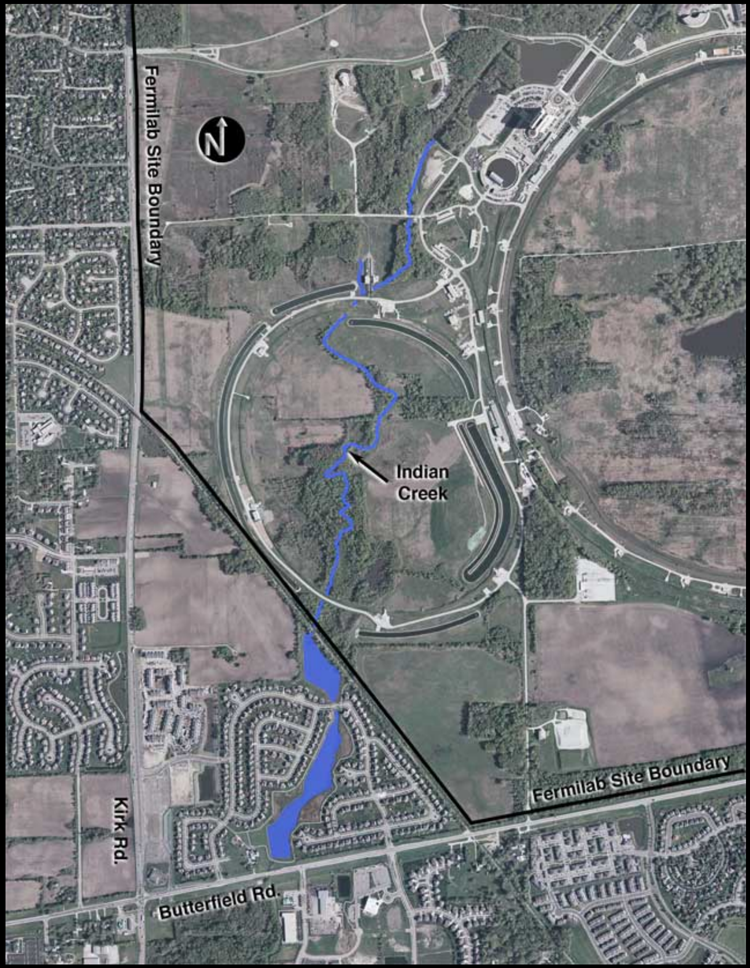
Covered by G. Feldman's Presentation

- Together with other regions, plan roadmap for long term future of neutrino program if further reach is needed beyond NOvA +T2K
- For the long term, carry out R&D on future high intensity proton sources.

Tritium

- Detectable (>1 pCi/ml) levels of tritium observed last November in the Indian Creek discharge
  - Measured 3.3 pCi/ml (site boundary)
    - DOE regulatory limit for surface water is 2000 pCi/ml
    - (20 pCi/ml for drinking water)
  - Currently:
    - Indian Creek below detectable
    - Onsite surface waters at 2-3 pCi/ml
  - Updated Indian Creek levels publicly available at

www.fnal.gov/pub/about/community/chart.html



Tritium

- Primary source is NuMI
  - Currently (during beam operations) pumping roughly 175 gpm @ 13 pCi/ml
    - Note: The pumping of HTO to the surface is per design to protect the aquifer
  - Levels exceed expectations, but well below regulatory limits
    - Modeling prediction is ~0.8 pCi/ml due to activation in the rock surrounding the enclosure
- How is it being produced?
  - Primary mechanism appears to be formation of HTO in the target chase atmosphere, followed by condensation and/or absorption into enclosure walls.
    - Measured concentration in target chase humidity is 70,000 pCi/ml

Tritium

- Remediations
  - Repair of pipe connecting Ponds C-D (immediate source of November discharge)
  - Collecting condensate from target chase chiller (2 gph @ 70,000 pCi/ml)
  - Re-routing of Booster sump discharges
  - Installing target hall dehumidification

- Modeling
  - An extensive set of measurements of concentrations, flows, and neutron fluxes has been, and to continue to be, made.
  - Comparison with models is still not finished, but indicates direct activation in the rock is <u>not</u> the favored explanation
  - Have engaged help from the LBL Earth Sciences Department
  - Model of water movement on Fermilab site under development

Tritium

- Plan under development by the Water Quality Task Force Strategy:
  - Reduce source term as much as possible
  - Utilize evaporation to the atmosphere (CUB) to the extent possible
  - Manage water on the site to maximize dilution and minimize off-site creek discharges
- Prospects
  - We have been extremely careful not to promise either the public or the regulatory agencies that there will never be measurable tritium in the creek discharges. We have said we will always be below regulatory limits.
  - Reasonable goals as we understand now would be:
    - Creek discharges (on average): pCi/ml < 2.5 x P (MW)
    - Ground water: < 1 pCi/ml for all power levels away from tunnel

Proton Development Plan

Goal: 1 MW beam power onto the neutrino production target, utilizing accelerator assets available after Run II.

- Run II era ("Proton Plan"; in process)
  - 5.4×10^{13} ppp @ 120 GeV @ 2.2 sec
    - **1.0×10^{13} to antiproton target; 4.4×10^{13} to NuMI target (380 kW)**
- Post Run II: Utilization of the Recycler for proton accumulation
  - 5.4×10^{13} ppp @ 120 GeV @ 1.5 sec
    - **No antiproton target; 5.4×10^{13} to NuMI target (700 kW);**
- Post Run II: Utilization of the Accumulator for momentum stacking
  - 7.2×10^{14} ppp @ 120 GeV @ 1.3 sec
    - **7.2×10^{14} to NuMI target (1000 kW)**

Proton Development Plan

- Required Upgrades (0.7 MW)
  - Recycler: new injection line, new RF system
- Required Upgrades (1.0 MW)
  - Booster: 15 Hz operation
  - Main Injector: RF and shielding ugrades
  - Accumulator: new injection and extraction lines, new RF system
  - NUMI: cycling of proton line, tritium handling, target chase cooling, new horns, target

Proton Development Plan

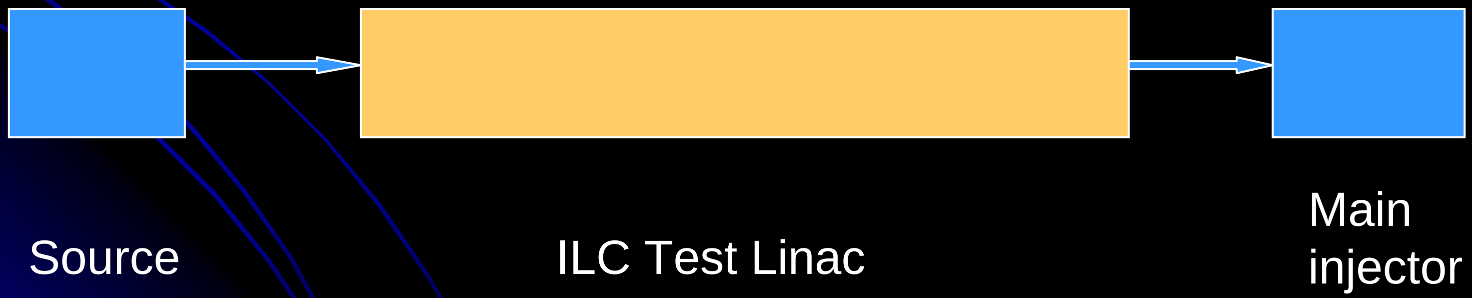
- Proton Evolution ("design" goals)

(Fiscal) Year	Weeks Operations	Initial Power (kW)	Final Power (kW)	Integrated Protons/year
2010	0	Install all upgrades required for 1000 kW		
2011	44	400	700	5.30E+20
2012	38	700	1000	7.30E+20
2013	44	1000	1000	9.90E+21

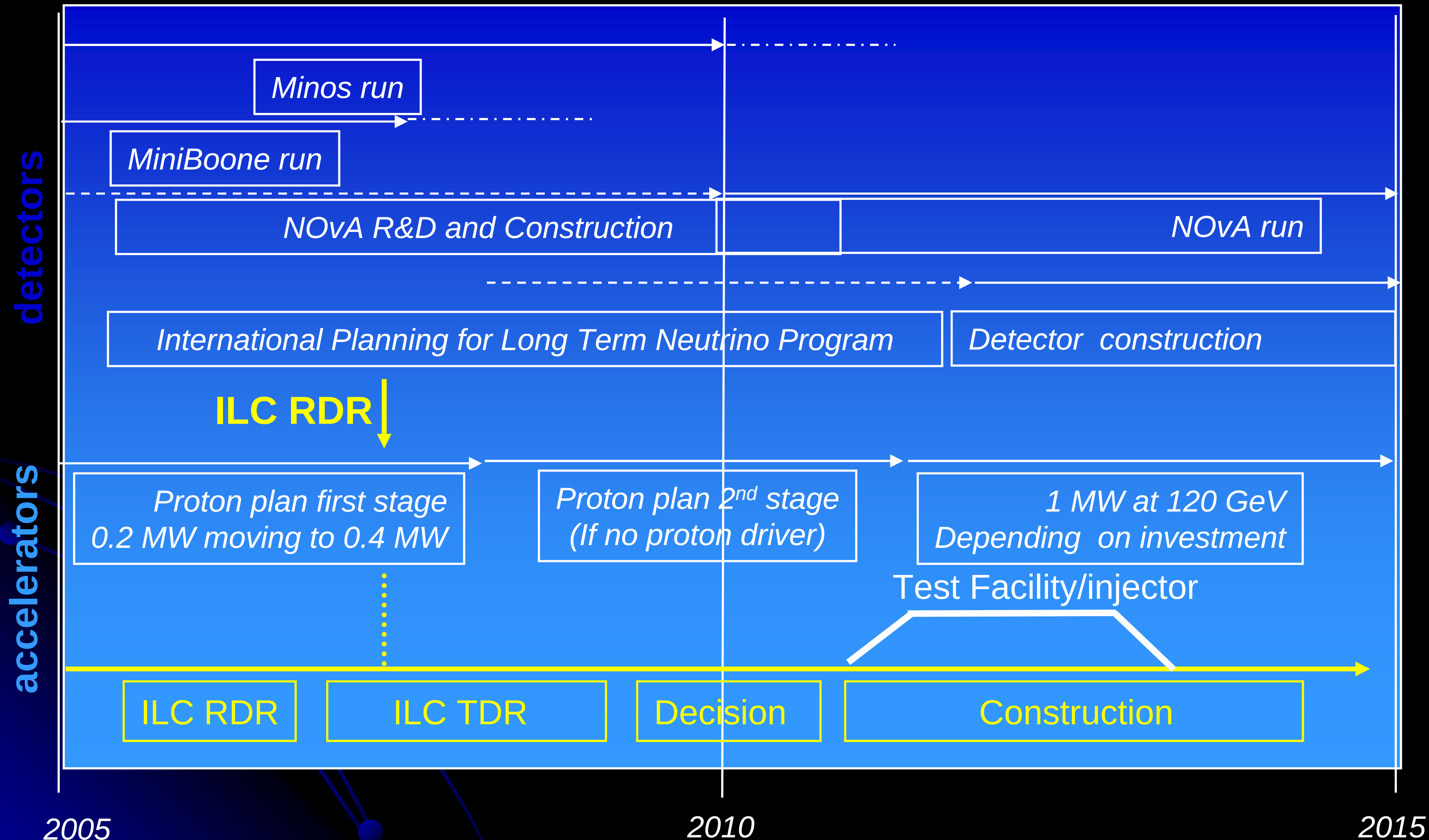
- Cost Estimate:
  - **PRELIMINARY, ($FY06), no contingency, M&S + direct cost only**
  - 700 kW ≈$10M
  - 1000 kW ≈$32M

R&D on neutrino source

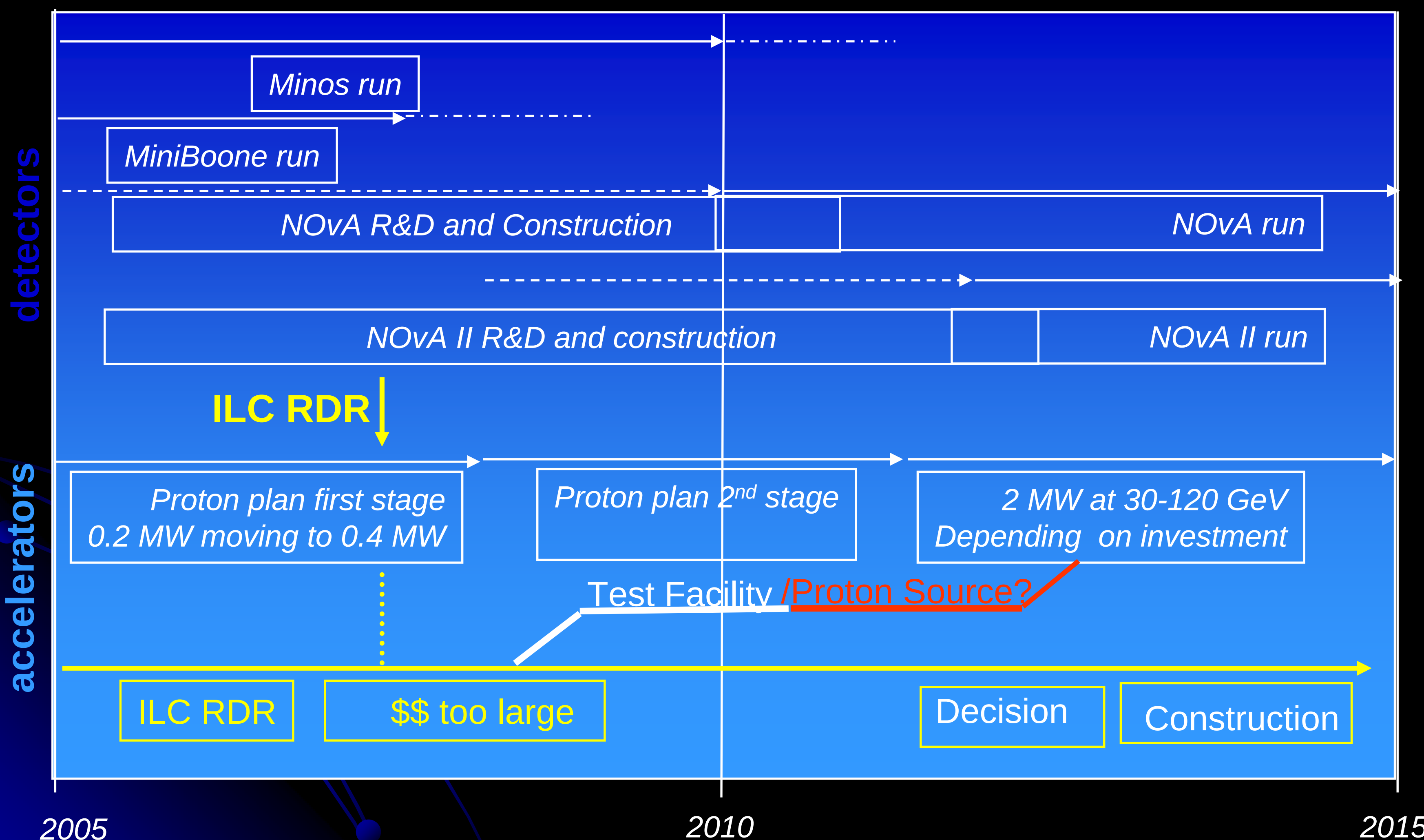
- R&D on SCRF Proton Source: 2MW any energy
  - R&D helps develop base of SC RF technology
  - Extremely flexible operations = much simplified complex
  - Accelerator energy is 2% of ILC
  - Allows evolution of the program under various scenarios: neutrinos, muons



Accelerator Programs



Accelerator Programs



Smaller Projects Strategy

- Keep vitality of the field and yield physics in the medium term
- Fermilab is currently supporting:
  - Pierre Auger
  - Sloan Digital Sky Survey
  - Dark Energy Survey (P5 will hear directly)
  - CDMS (P5 will hear directly)
  - Minerva
- Generally these projects compete nationally for construction/operation dollars

Interlinked Roadmap

- The immediate major decisions are: NOvA, and level of support of ILC R&D.
- Options get looked a year down the line after ILC RDR
- LHC input will determine branch points at the end of the decade
- Smaller projects provide near-term physics