The NuMI Beamline

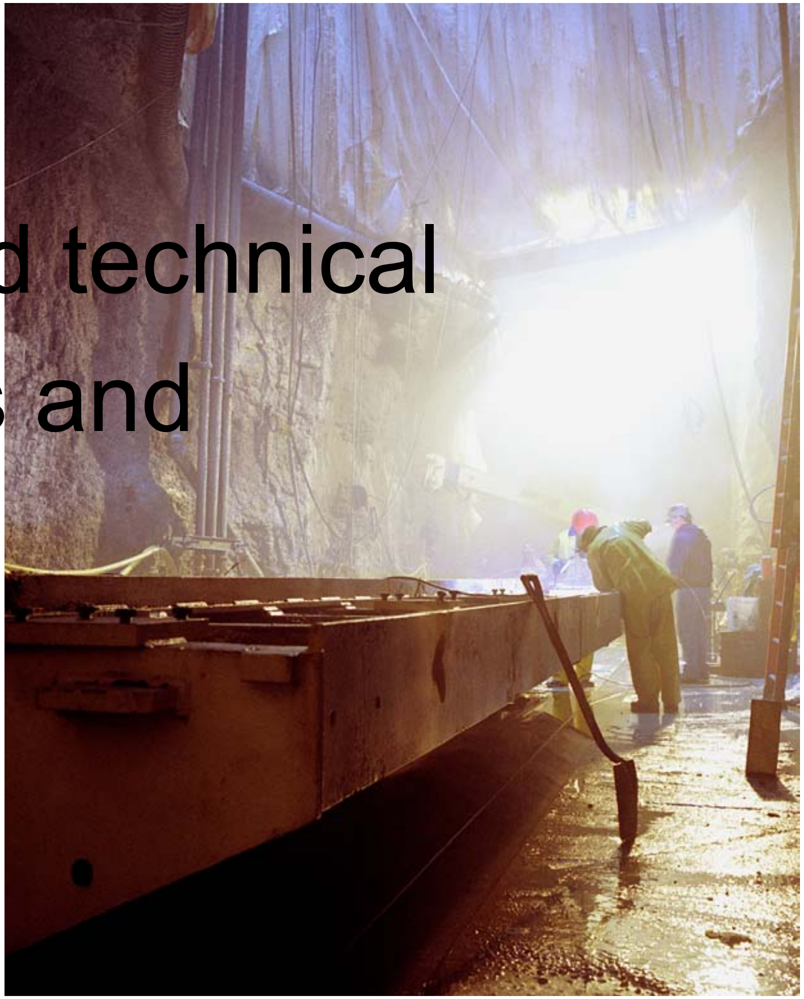
DPF 2004 UC Riverside

Andrew Godley
for the
NuMI/MINOS Collaboration

University of South Carolina
High Energy Physics Group

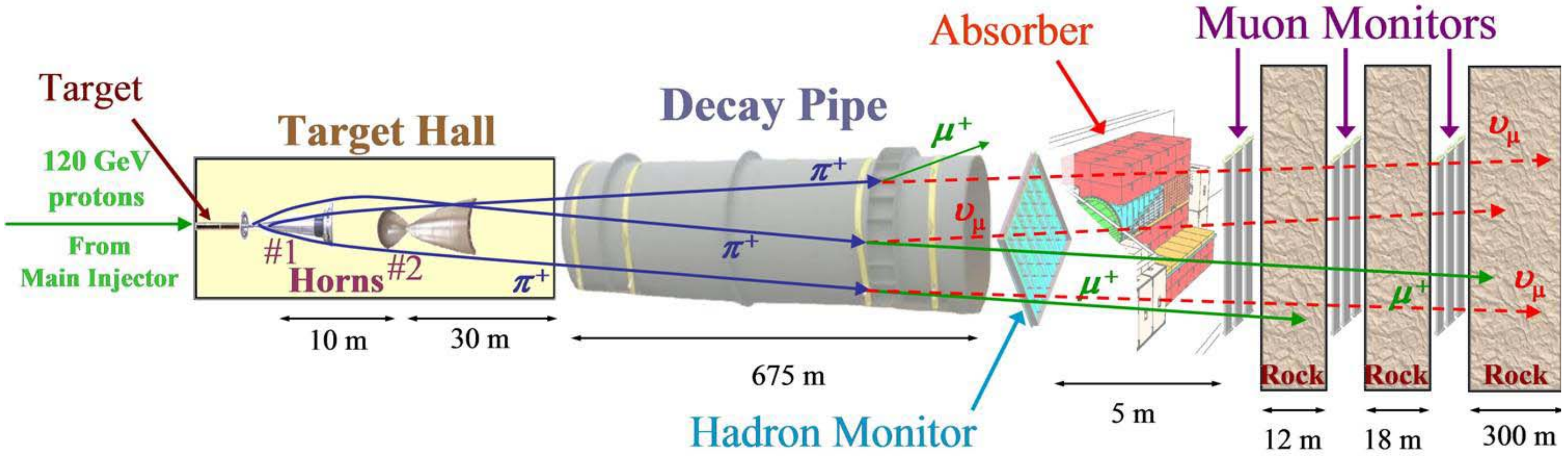
Contents

1. Neutrino beams
2. Construction, civil and technical
3. Accelerator upgrades and instrumentation
4. Beamline monitoring
5. Commissioning
6. Applications



Generating a neutrino beam

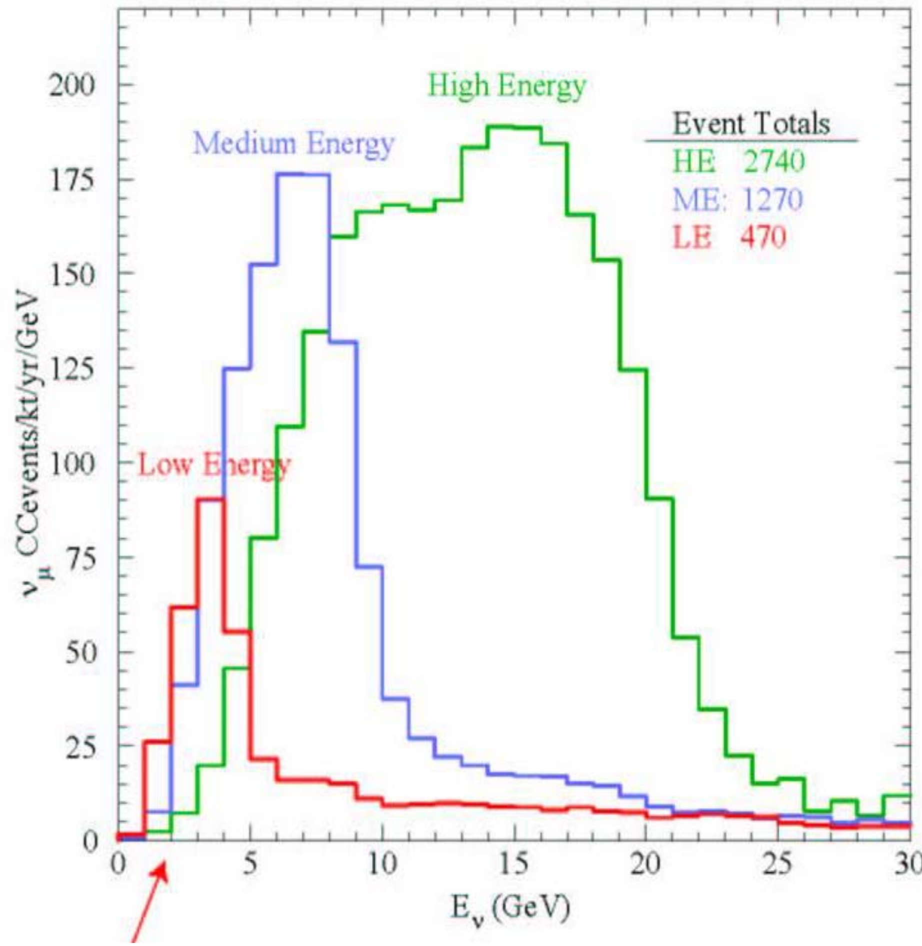
- Atmospheric neutrinos are created by cosmic ray protons colliding with nitrogen and oxygen in the atmosphere, producing pions which decay into neutrinos
- Neutrino oscillations were observed with this source of neutrinos
- It is critical to verify this observation with an artificial beam that is fully quantified (flux and energy)
- An artificial beam also allows for the refinement of the observation to determine the exact oscillation parameters by adjusting the peak energy
- Accelerator neutrino beams begin in a similar way as atmospheric neutrinos:



Capability of NuMI

- 400kW primary beam at 120 GeV, ~10 μs spill
- Multiple beams possible with 3, 6 and 15 GeV peak neutrino energies
- Intense neutrino beam at FermiLab, MINOS near detector rate is ~3.2 events/m/spill for the low energy beam
- Opportunity for precise neutrino physics measurements
- Off axis beams have potential to select neutrino energy
- More on experimental users of the beam later

Event rates and spectra at MINOS far detector assuming 4 10^{20} p/year

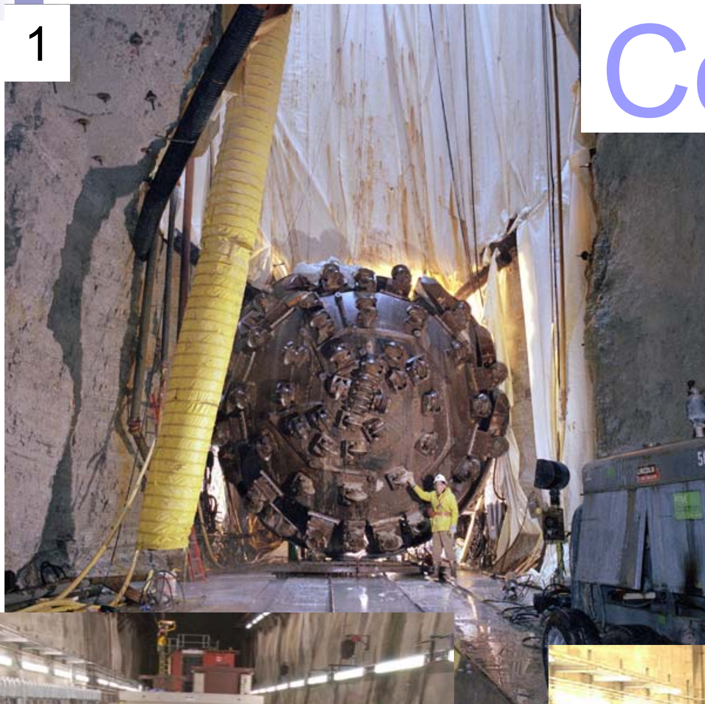


A Godley, U of South Carolina

Construction

1. Tunnel boring machine
2. Decay pipe
3. Decay tunnel
4. Target hall
5. Target hall: shielding installed

1



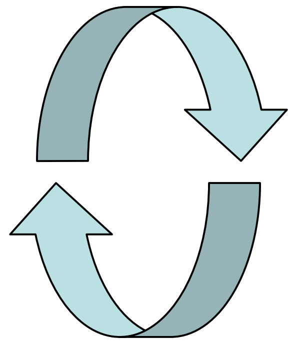
2

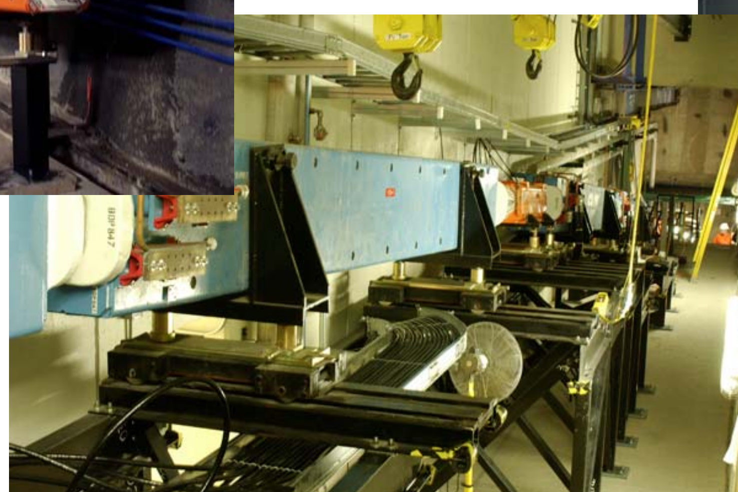
3

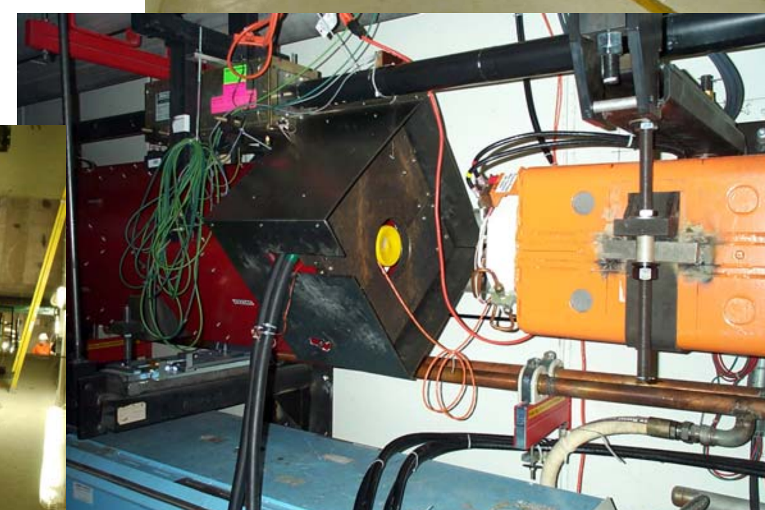
4

5

Extraction line



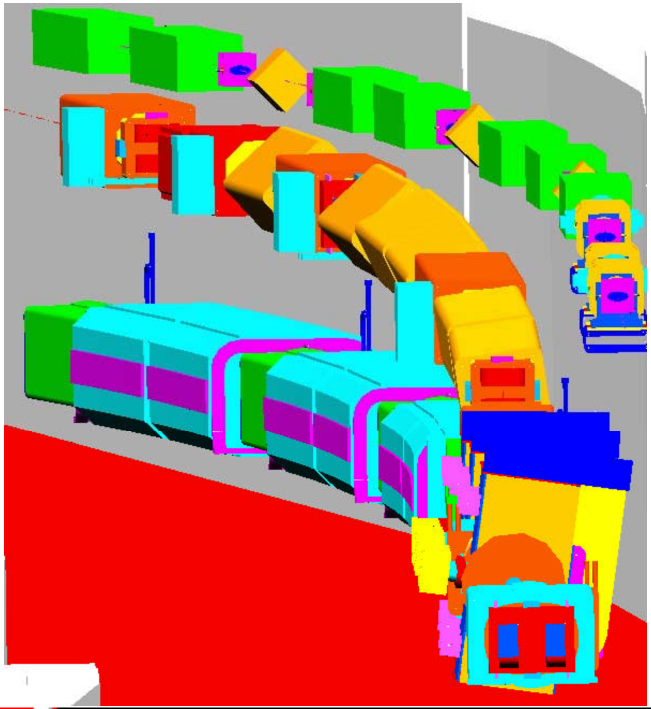




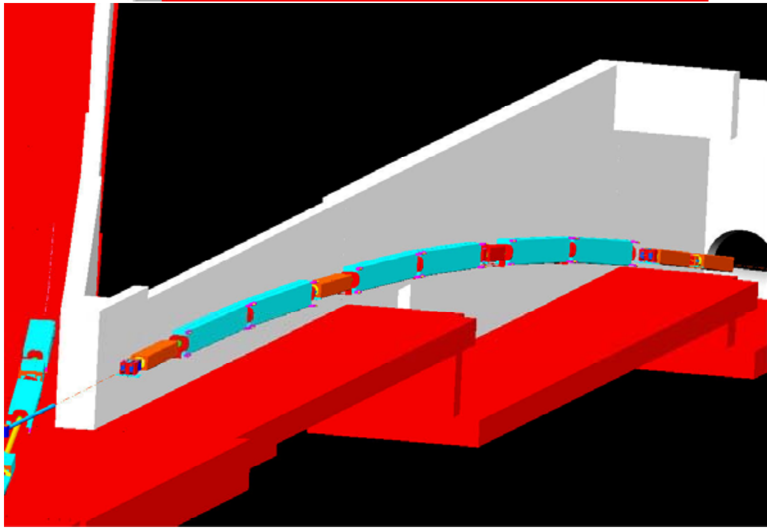
Extraction line - II

- Three kicker magnets knock the Main Injector circulating beam into extraction orbit
- Three Lambertson magnets extract the beam
- External proton beam(EPB) dipoles to bend the proton beam down steeply through to the dolomite rock layer and then a second bend to the -3.3° incline to the Soudan mine just before the target hall

Extraction

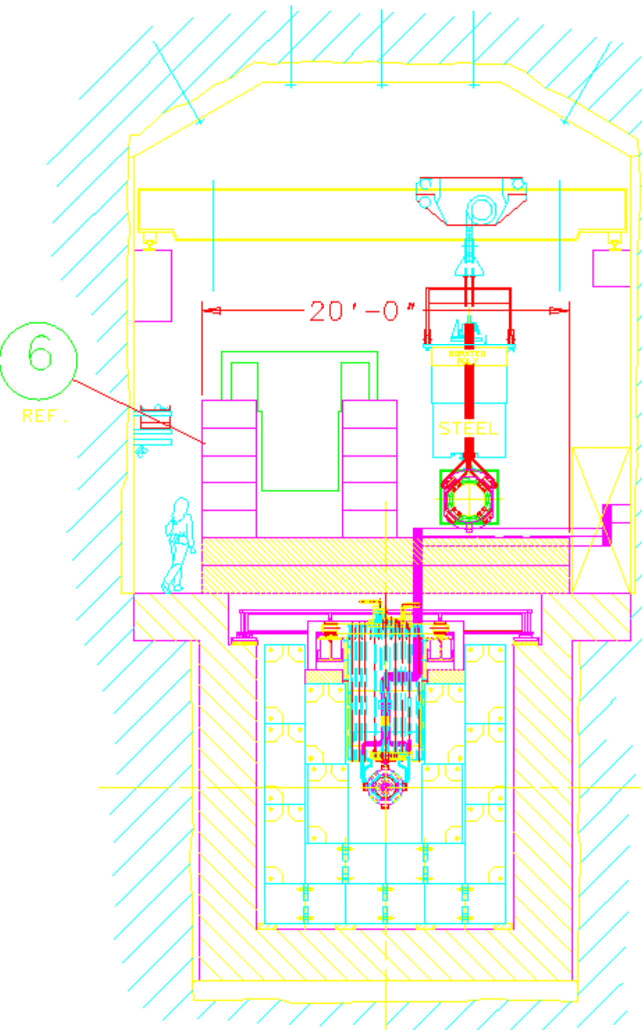


Kicker to be installed during shutdown

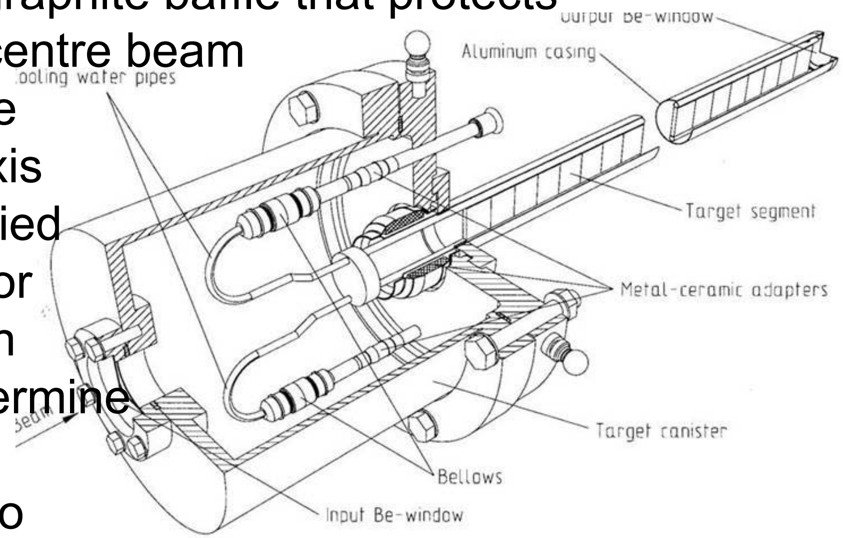


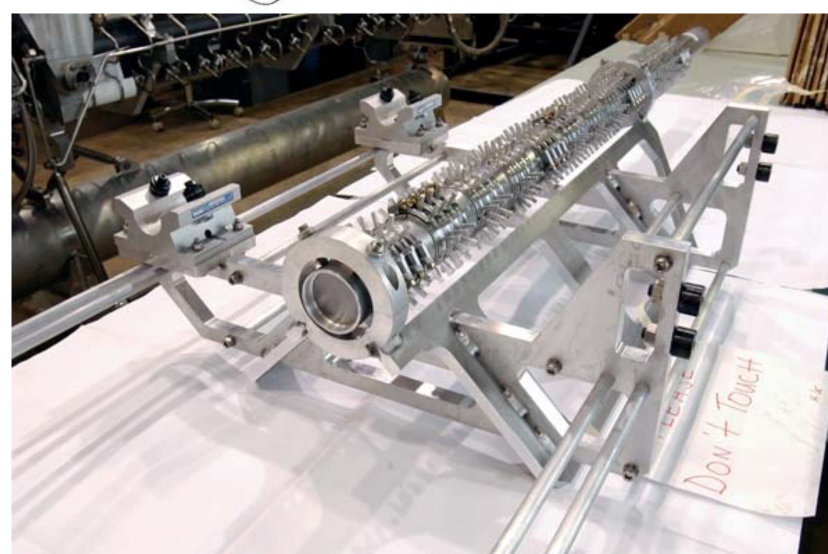
NuMI Stub

Technical Construction - Target



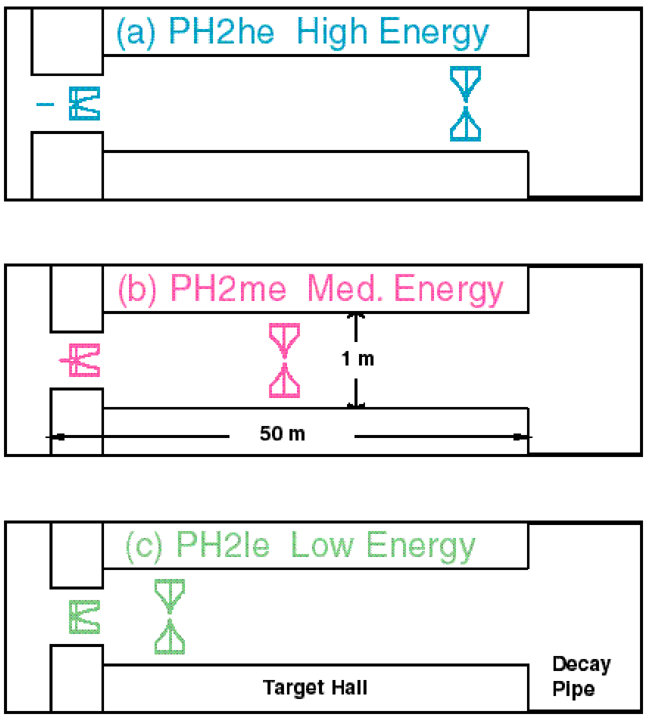
- A meter long, water cooled, plate graphite target is used
- 1 mm beam spot versus 6.4 x 28 mm^2 target profile
- Surrounded by a graphite baffle that protects the horn from off centre beam
- Target is moveable along the beam axis
- Target will be studied by the Main Injector Particle Production experiment to determine pion/kaon yields to improve neutrino flux predictions

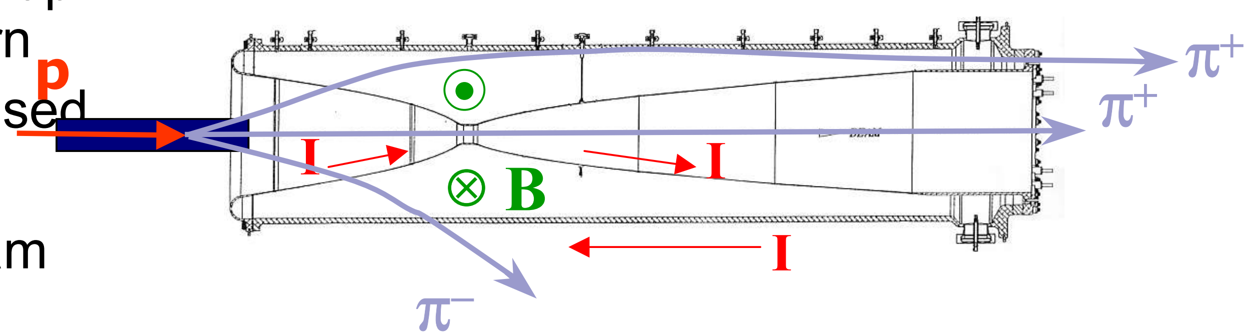




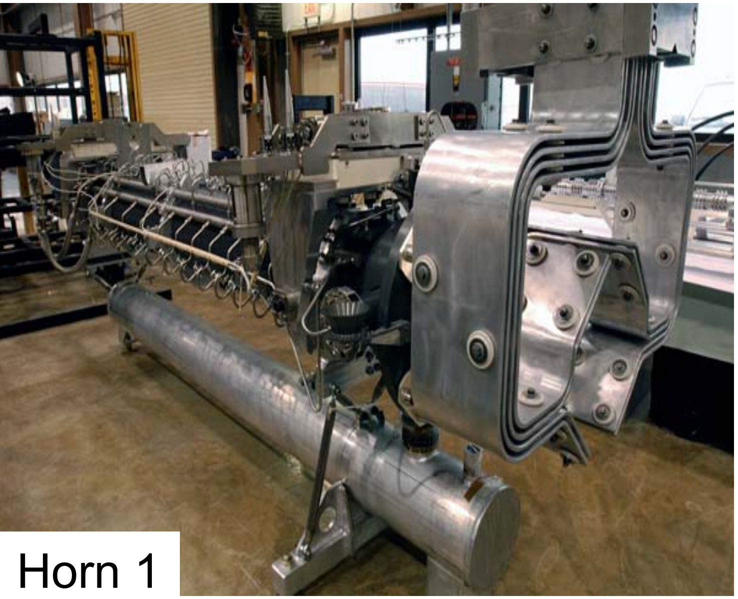
Technical construction – Horns I

- Two water cooled horns will be used, constructed as modules to allow the horns to be moved via remote motors
- Primary task is to focus positive pions towards Sudan
- The position of the horns relative to the target determine the energy spectrum of the neutrino beam
- Pulsed at 200 kA to generate a 3 T field at the neck
- Field monitored by pickup coils, three in each horn
- Cross hairs on horns used to align the horn using the primary proton beam



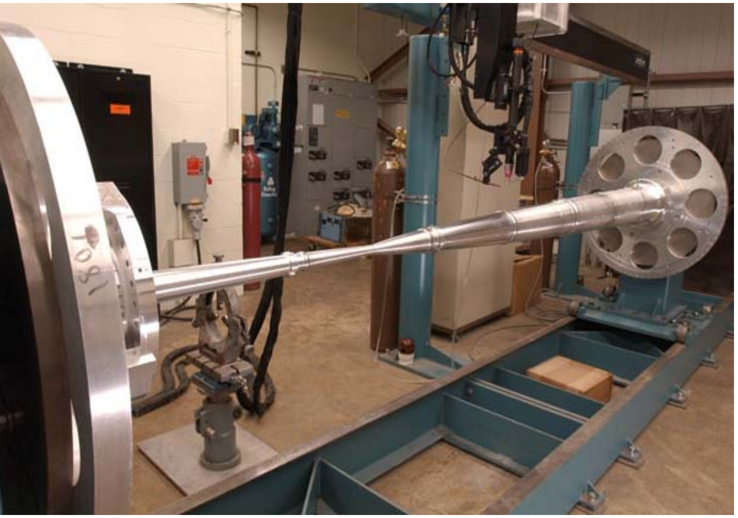


Technical construction – Horns II



Horn 1

Horn 1 inner conductor



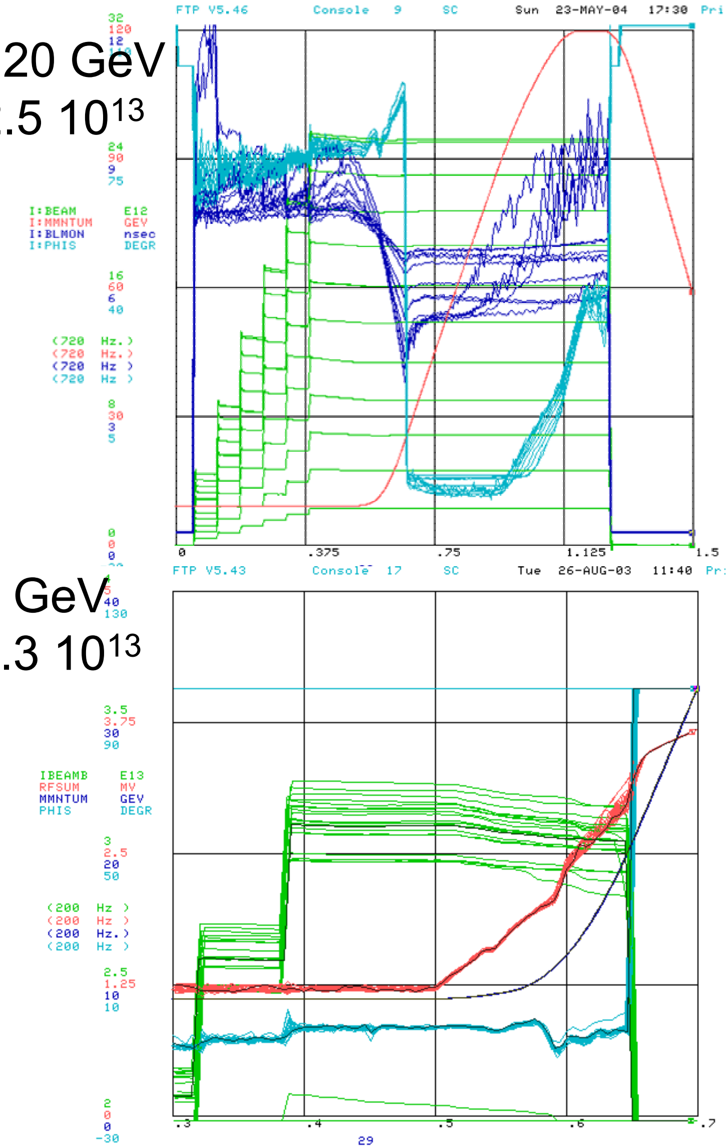
Horn 1 installed front and back

Horn 2 module being installed

MI intensity & multi-batch

120 GeV
2.5 10^{13}

8 GeV
3.3 10^{13}



- The Main Injector currently runs with one batch per cycle to feed the p-bar source, taking 8 GeV protons from the booster and accelerating them to 120 GeV
- NuMI will need the MI to run in multi-batch mode with 6 batches per cycle, 5 going to NuMI and one still to the p-bar source
- The total (6 batch) intensity in the MI has been slowly pushed up to 3.3 10^{13} protons per cycle (1.9s)
- The design intensity for NuMI is 4 10^{13}

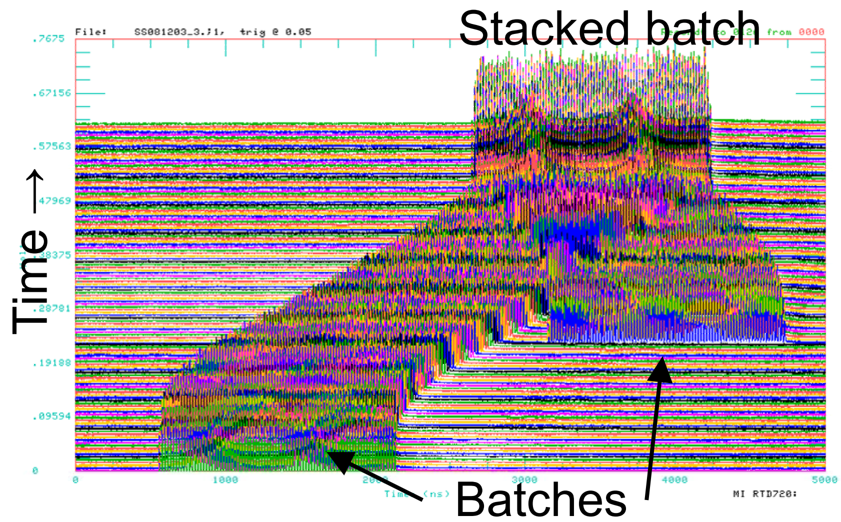
Slip stacking & cogging

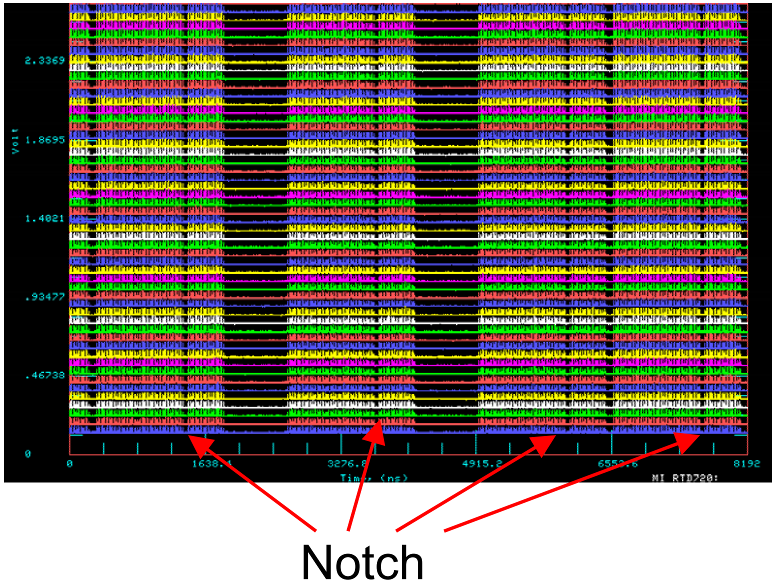
Slip or Barrier RF Stacking:

- Booster losses limits single batch intensity in main injector
- Place two batches in the MI
- A purpose built power supply generates two RF barrier pulses bracketing the two batches
- Shifting these pulses together squeezes two batches into one, potentially doubling the batch intensity but increasing the cycle time

Booster cogging:

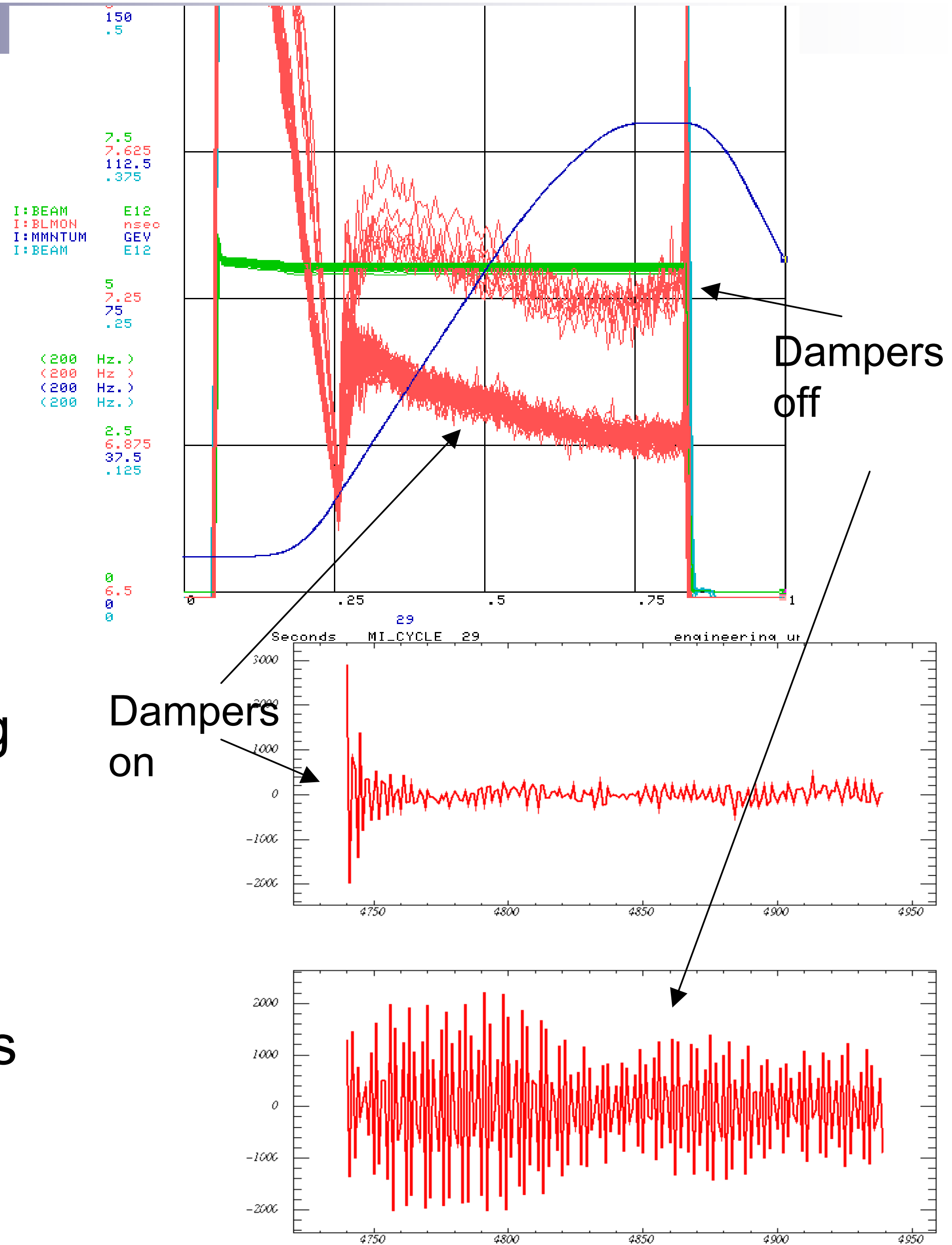
- A notch (empty buckets) is placed in the booster as the kicker risetime is greater than the bucket spacing
- This notch must also be used to ensure extraction from booster to MI is synchronised
- Cogging ensures notch is in the same known position each booster cycle to allow for successful synchronisation





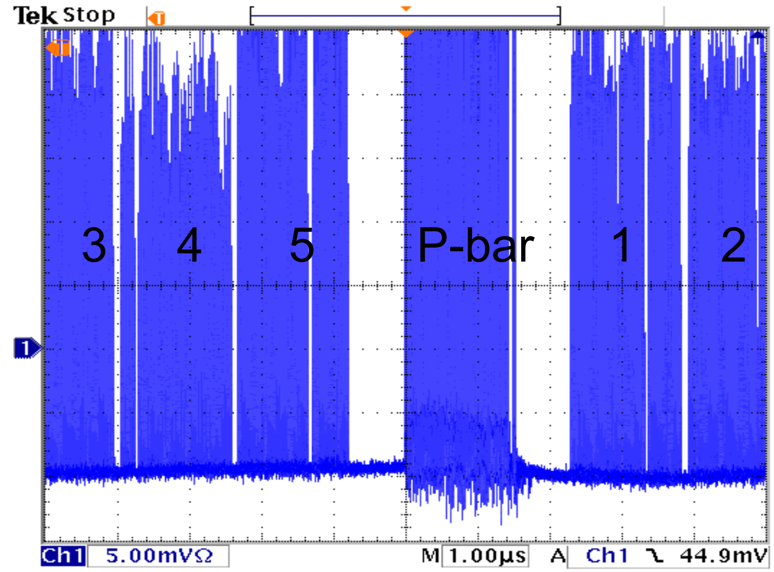
Dampers

- Kicker magnets are connected to beam position feedback circuits to reduce longitudinal and transverse oscillations
- Top plot shows decrease in bunch length with dampers on
- Lower plot shows damping of transverse oscillations (caused by injection)
- These will reduce loses and instabilities, allowing the higher beam intensities required for NuMI



Monitoring in the MI

- Beam Permit System controls beam extraction to NuMI target (based on the BPS of MiniBooNE)
- BPS must not be too lax else there will be excessive radiation, nor too strict else decreased total intensity
- Over 200 inputs including MI loss monitors, power supplies as well as signals from the NuMI line
- Some new systems have been developed for the BPS including a Batch by Batch Intensity monitor
- This device integrates the beam's image current measured in a Resistive Wall Monitor to calculate the intensity of the 6 batches in the main injector



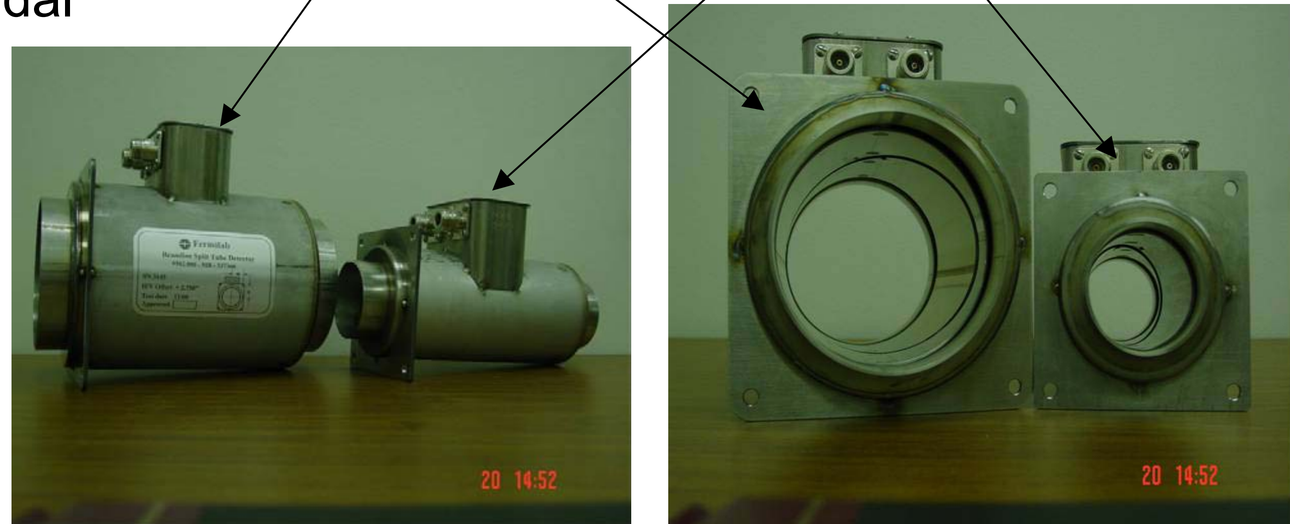
Resistive Wall Monitor Signal
P-bar and 5 NuMI batches

Monitoring the target area and primary beam

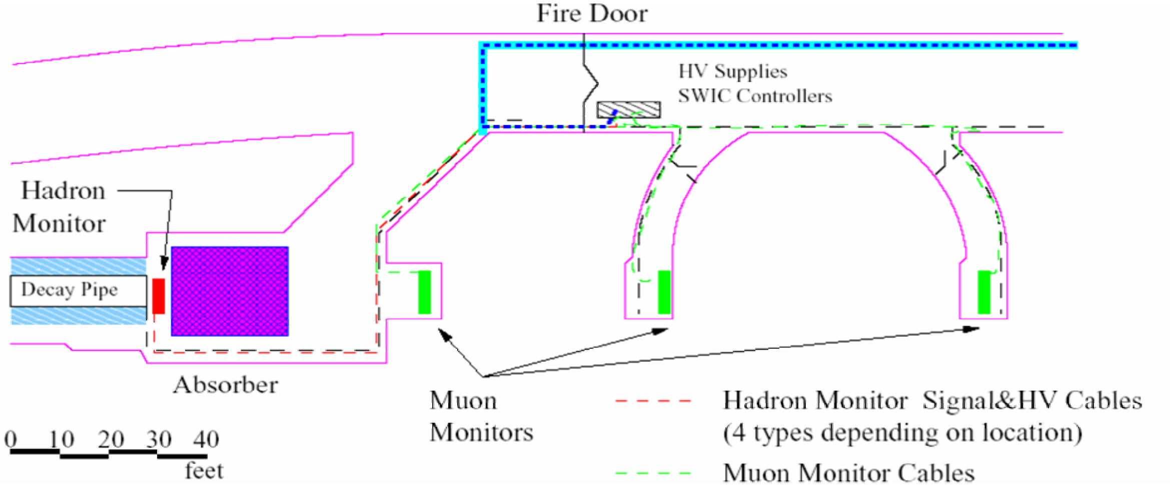
- Torroid intensity monitor
- Beam loss monitors and total loss monitors
- Beam position monitors (cylindrical plate) in the transport and pre-target line
- Multi-wire SEM primary beam profile monitors
- Target is electrically isolated and so is used as a Budal monitor, test position of target with a horizontal scan of the beam

Multi-wire SEM profile monitor

Transport line BPM　　Target BPM



Monitoring secondary beam quality



- Hadron and muon monitors will be used in aligning and commissioning the beamline as well as monitoring the secondary beam rate and detect potential error conditions such as off centre beam or misaligned horns
- The primary task of the hadron monitor (parallel plate ionisation chamber) is to align the proton beam prior to the installation of the target
- The muon monitors (2 x 2 m ion chamber arrays) can infer the profile, intensity and energy distribution of the neutrino beam by measuring the muons produced with the neutrinos in the pion decays

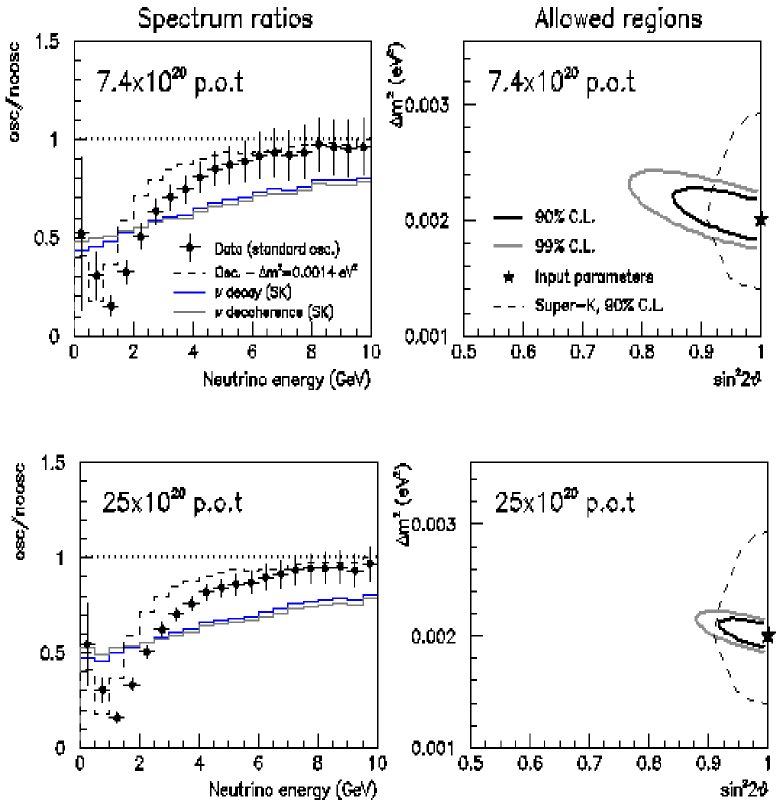
Commissioning – Starting December

Description	Intensity	Target	Day
MI setup (single batch)	$3\ 10^{11}$	Out	0.5
1st beam to NuMI (observe beam profiles)	$3\ 10^{11}$	Out	1.5
Aperture scan	$3\ 10^{11}$	Out	2.5
Horn alignment	$3\ 10^{11}$	Out	7.5
Target/Baffle alignment LE	$3\ 10^{11}$	LE	8.5
Raise intensity	$1\ 10^{12}$	Out	3.5
Calibration & 1st neutrinos	$1\ 10^{12}$	ME	4.5
Tuning of BPS inputs	$1\ 10^{12}$	ME	5.5
Radiation survey	$1\ 10^{12}$	ME	6
Monitor position sensitivity	$1\ 10^{12}$	ME	7
Target/Baffle alignment ME	$3\ 10^{12}$	ME	8
BPS – Set “Baseline Running Conditions”	$1\ 10^{12}$	Out	9
Multi Batch tuning – 2, 3, 4, 5, then 6 batches	$1\ 10^{12}$	LE	14
Reduce cycle time from 60 to 1.9 s	$5\ 10^{12}$	LE	15

MINOS

- Original user of the NuMI beamline
- 735km baseline neutrino oscillation search with a near 908 ton and far 5.4 kton detector
- Observe and precisely measure $\nu_\mu \rightarrow \nu_\tau$ oscillations, test if mixing is maximal, demonstrate that ν_μ disappearance is due to oscillations
- Also opportunity to search for $\nu_\mu \rightarrow \nu_e$ appearance

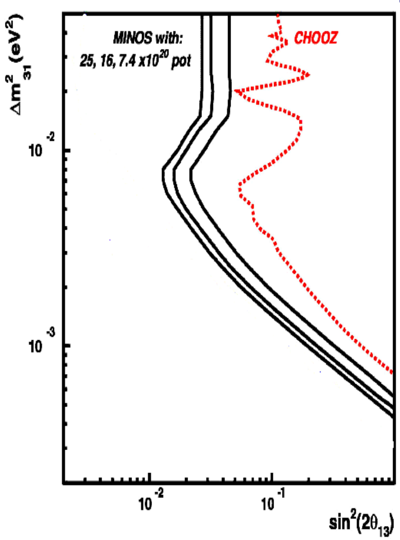
$\nu_\mu \rightarrow \nu_\tau$

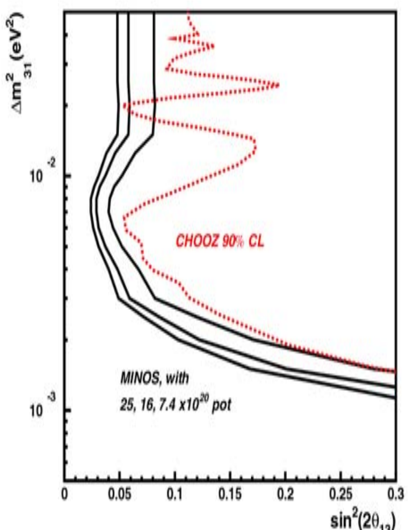


For $\Delta m^2 = 0.0020\ eV^2$, $\sin^2 2\theta_{23} = 1.0$

$\nu_\mu \rightarrow \nu_e$

90% C.L. Exclusion Contours





3 σ Discovery Contours

A Godley, U of South Carolina
DPF 2004 at UC Riverside, August 28th

MINERνA: Fine grain near hall detector

NuMI would generate a million CC interactions a year

Stage 1 Approval

Improve our understanding of low energy ν interactions

Quasielastic

$\sigma(E_\nu)$ and $d\sigma/dQ^2$
$F_A(Q^2)$

Coherent π

σ(E) for NC and CC
Model comparisons
A-dependence

Strange/Charm

exclusive σ(E)
charm at threshold

Nuclear Effects

C,Fe and Pb targets
FSI in nuclear media
NC/CC vs A
(anti)-shadowing/EMC effect

Oscillation Physics

Aid measurement of $\sin^2(2\theta_{23})$, Δm^2_{23} in MINOS
$\sin^2(2\theta_{13})$ measurement

Courtesy of S. Boyd, NuINT04

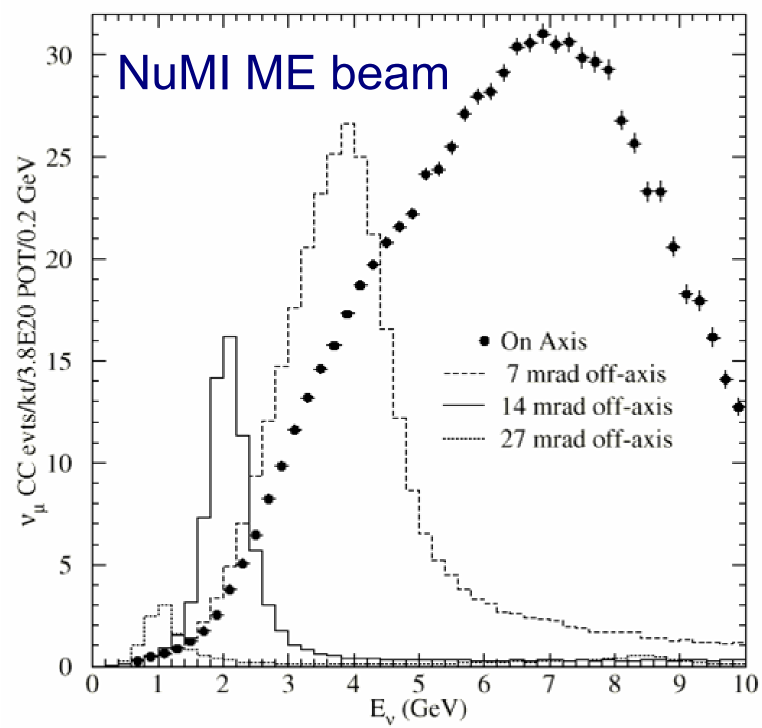
Resonance

$\sigma(E_\nu)$ and $d\sigma/dQ^2$ for individual channels
Duality
Comparison with electro and photoproduction
Nuclear effects in 1-π, 2-π and 3-π channels

Structure Functions

Precision measurement of low energy DIS cross sections
Resonance-DIS region - Duality
High x_{bj} studies

NOνA: Off axis experiment



$\Delta m^2 = 3.0 \times 10^{-3}$ eV^2 $\sin^2 2\theta_{13}=0.1$

NOVA potential with 20 10^{20} total protons

	ν_μ CC	NC	Beam ν_e	Signal ν_e
all	10714	4080	292	302
after cuts	1.8	9.3	11	123

- At the distance of the MINOS far detector the neutrino beam is dispersed over tens of km
- An off-axis detector would see a narrow-band beam energy spectrum due to pion decay kinematics
- This reduces background from neutral current interactions, easier to detect $\nu_\mu \to \nu_e$ appearance
- Also search for CP violation with $P(\nu_\mu \to \nu_e) \neq P(\nu_\mu \to \nu_e)$
- NOVA has been proposed to accomplish these tasks

Summary

Ready: Construction will be completed during current shutdown. Commissioning this December, physics in Jan/Feb

Flexible: NuMI can provide a variable energy (including narrow-band off-axis energies), high intensity, multiple baseline neutrino beam

Matched: It is the precise tool for the current and future goals of neutrino physics (oscillation and non-oscillation)

Numi teas and teasans

Six flavours will be produced by Numi:

1. Morning rise
2. Berry Black
3. Moonlight Spice
4. Rainforest green
5. Ruby Chai
6. Green African Bush

Will they mix?