

Fermilab's Neutrino Beamlines (short history & current status)

Craig Moore

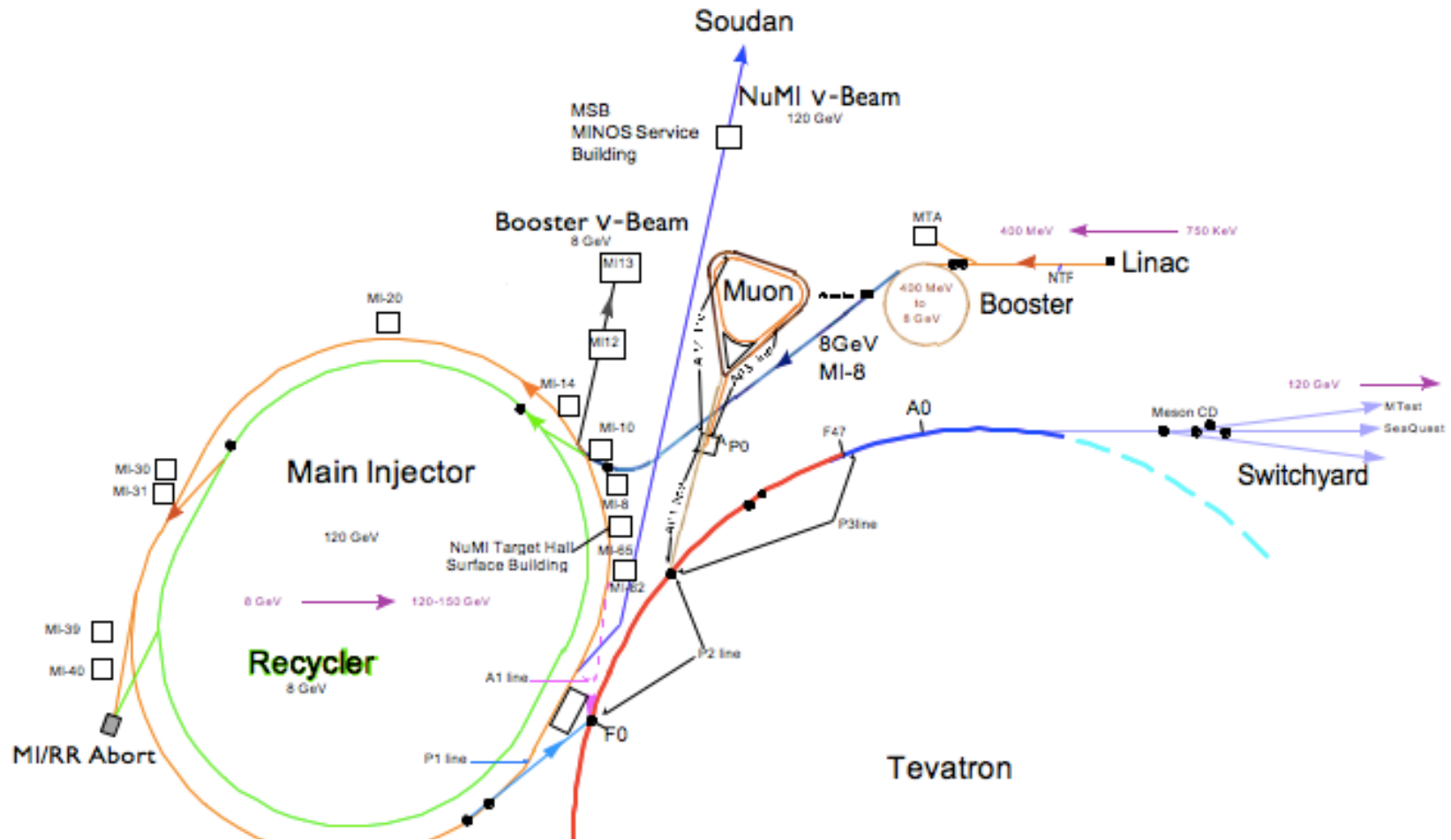
13/8/2015

NuFact15

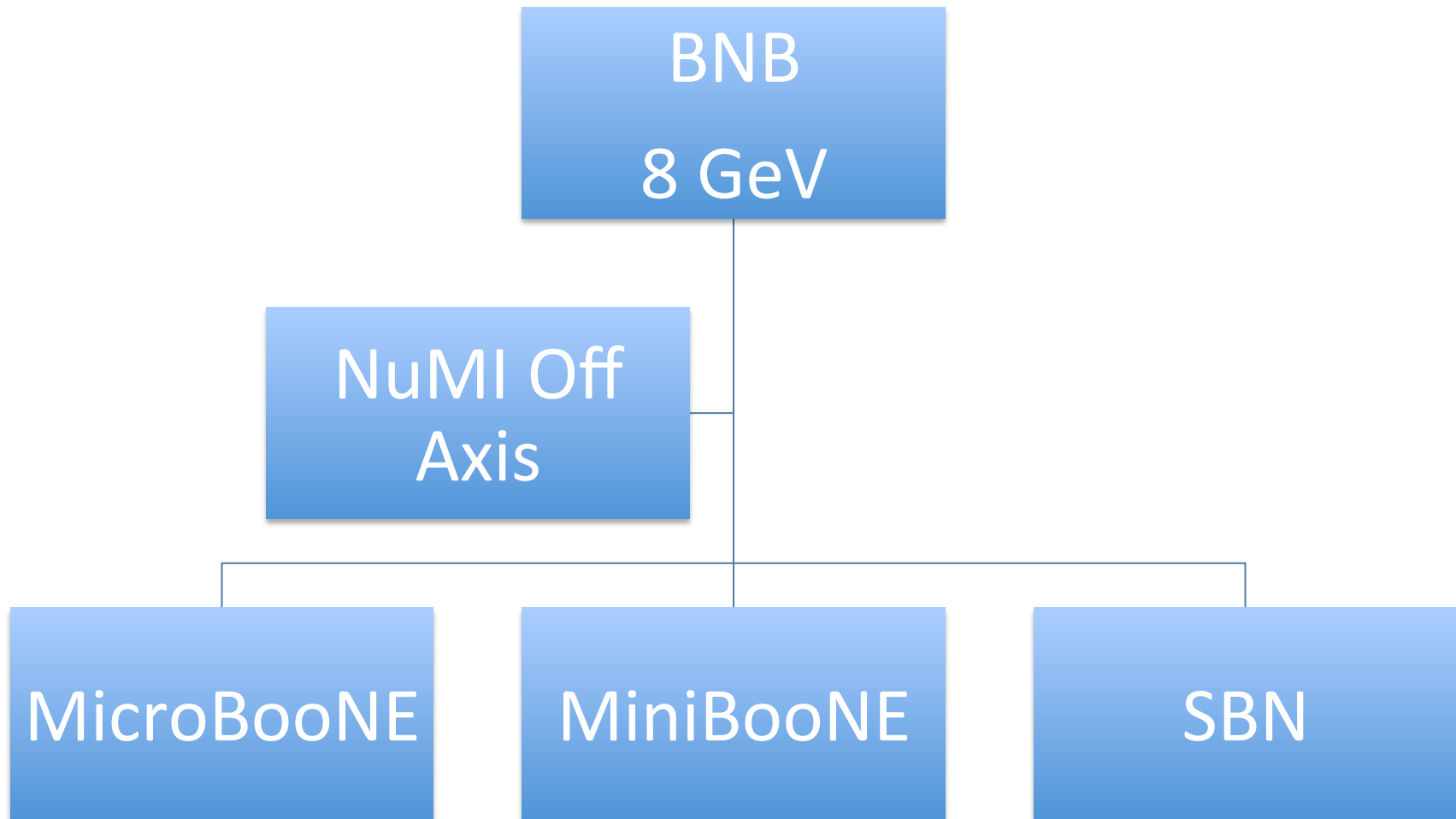
Necessary & Sufficient

- Neutrino experiments need high intensity
- Much concern about targets and horns
- Not so much concern for LBNF Primary Beam
- Reason is the success of present NuMI Beam and we will discuss how the BNB lead the way for the operation of the NuMI Beamline
- Efficient transfer: Large aperture, Beam Permit System, Autotune

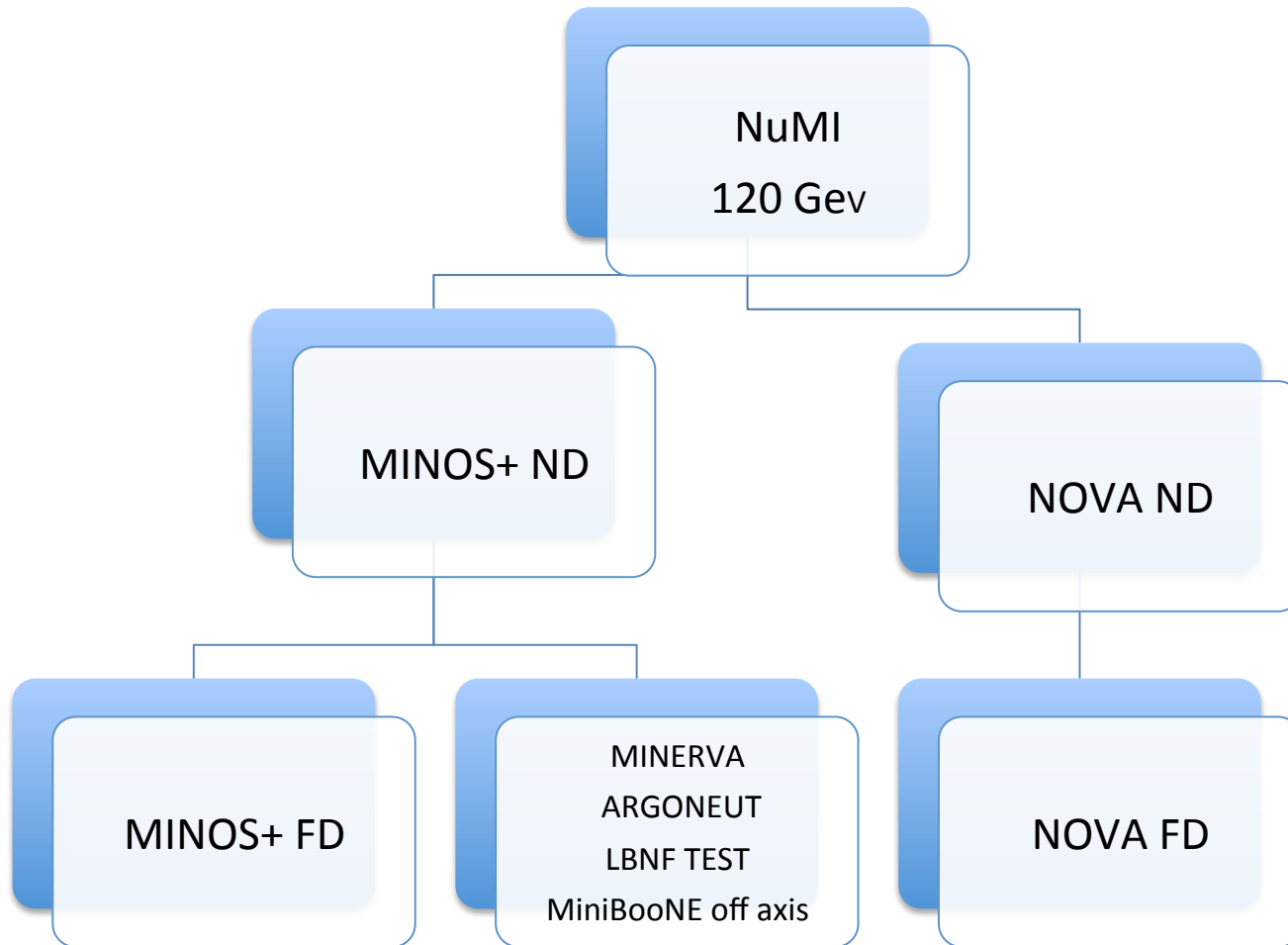
Fermilab Accelerator Complex



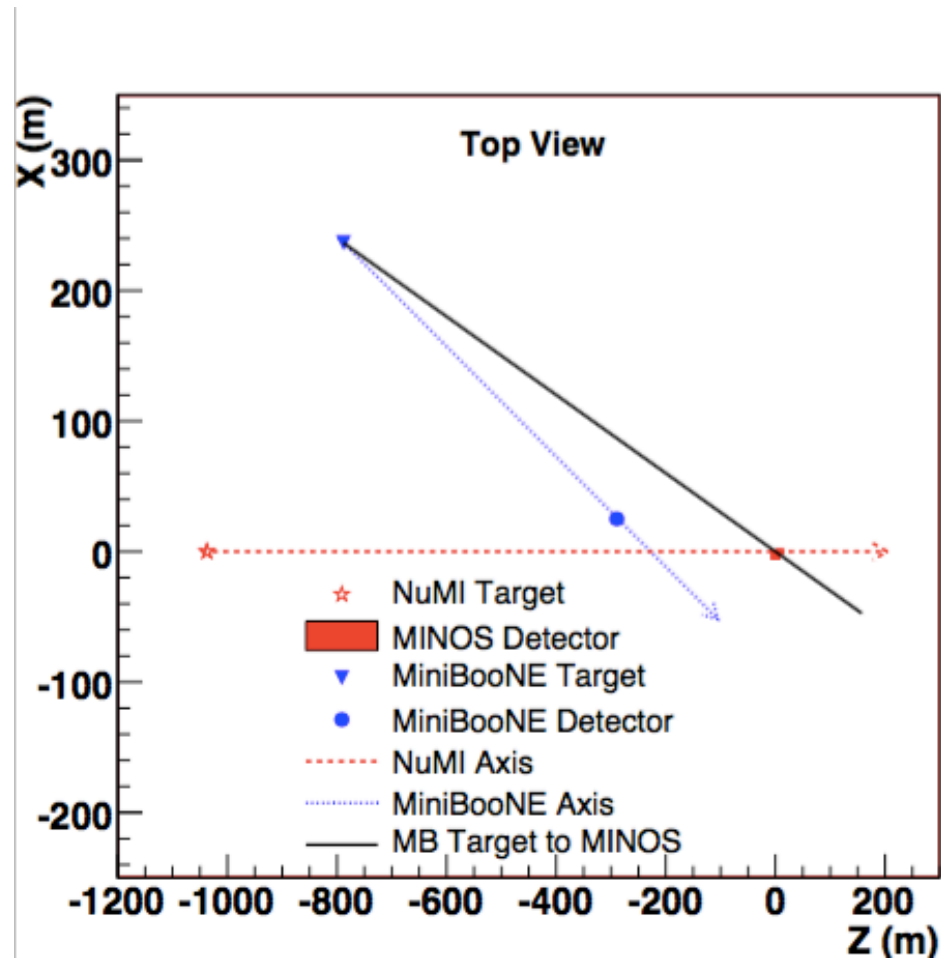
SHORT BASELINE



LONG BASELINE +



Both Detectors see off axis neutrinos



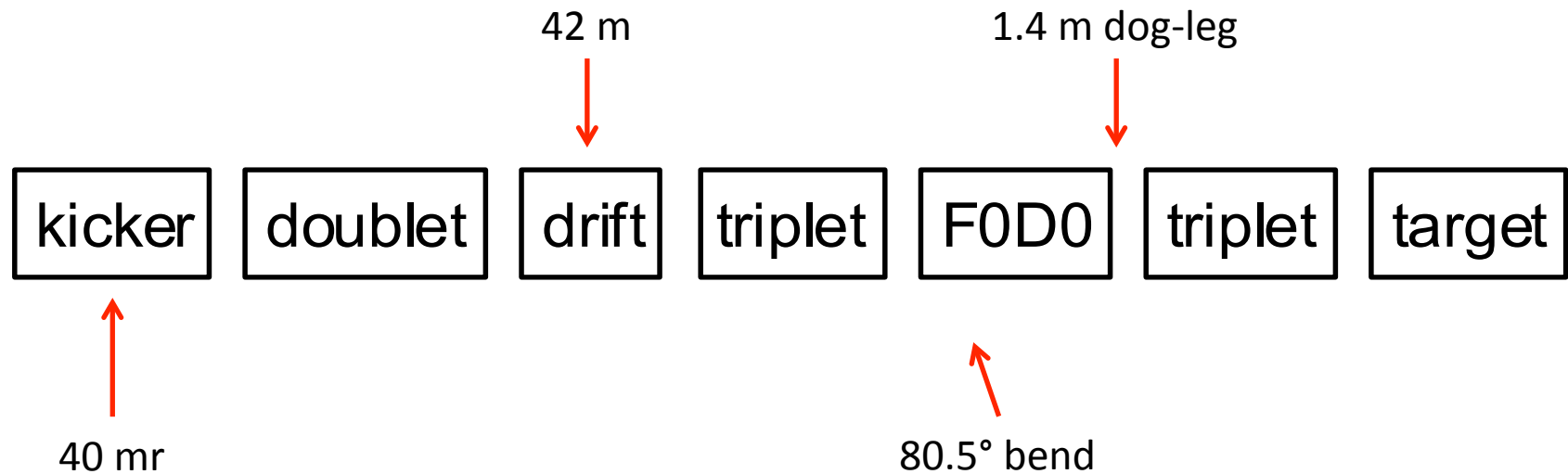
Booster Neutrino Beam

- MiniBooNE took more intensity in a year than was delivered during the 17 years of Fixed Target Running.
- The experiment can run at 18000 pulses/hour at $5E12$ protons per pulse.

Three Necessary Elements

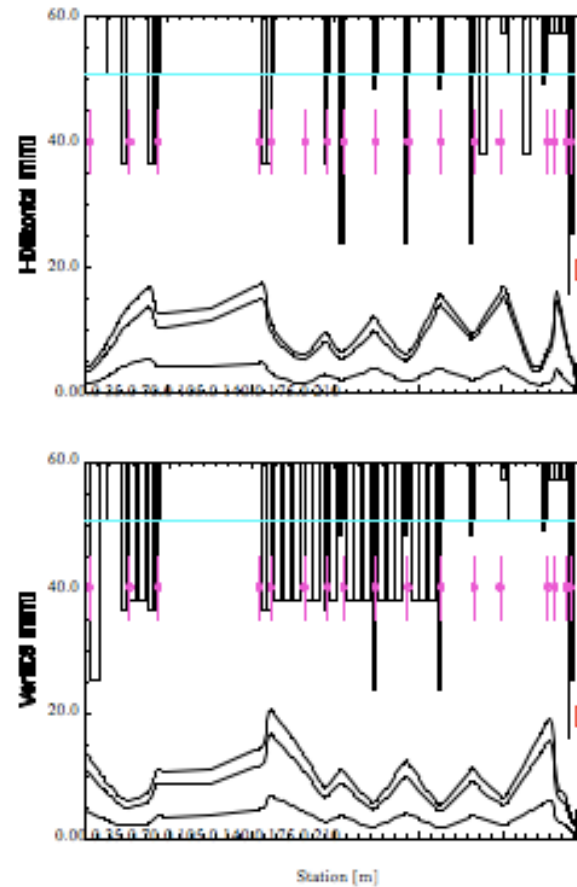
- The design of the beamline ensures sufficient clearance between the beam and apertures.
- A MiniBooNE Beam Permit System has been installed that is able to check various digital and analogue information against nominal values on a pulse by pulse basis.
 - . An automated correction system (Autotune) finds and corrects minor beam wandering.

Beamline – Block Diagram

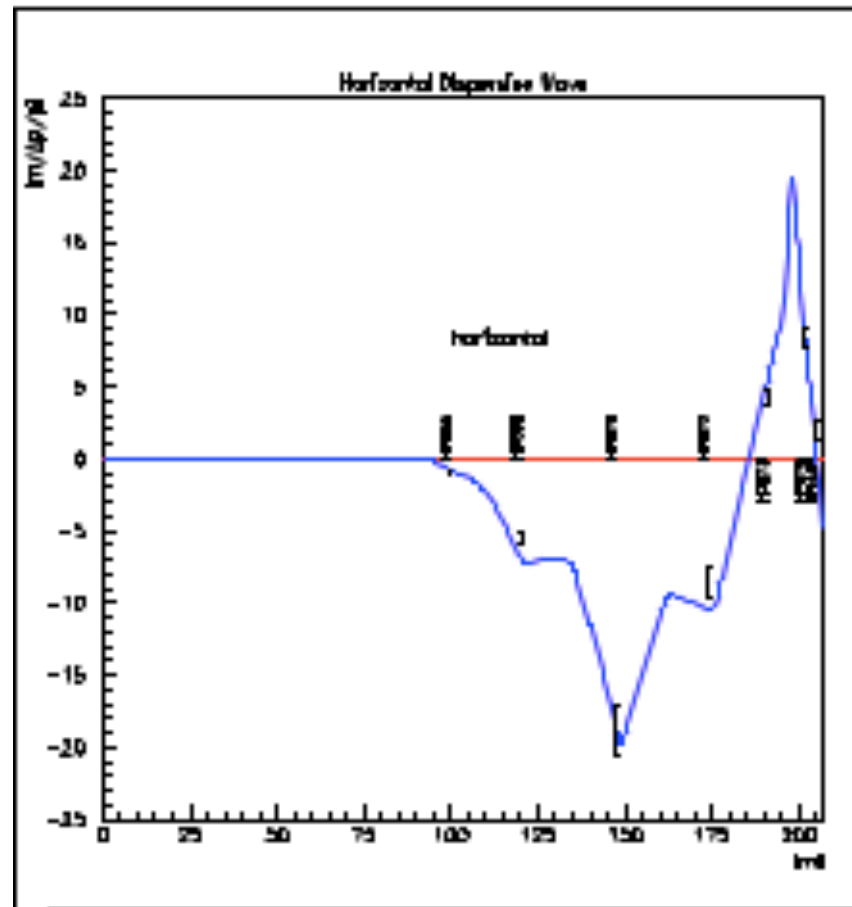


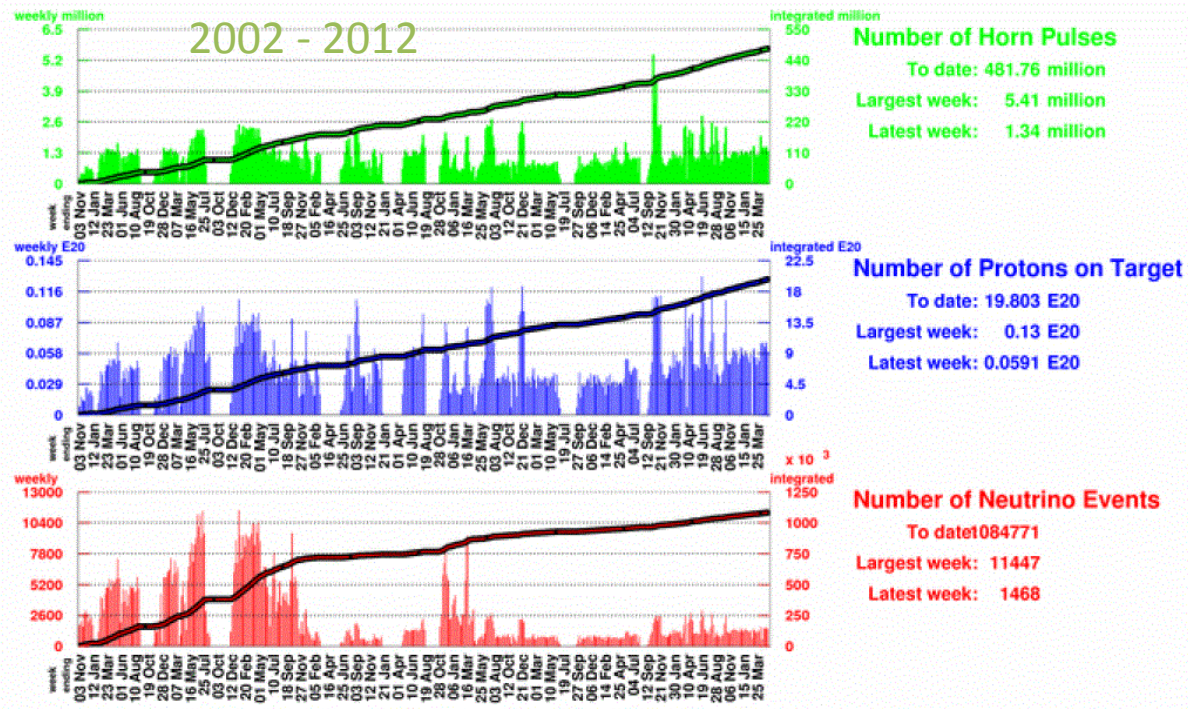
The Booster Neutrino Beamline was designed by Al Russel

Beam envelope and apertures



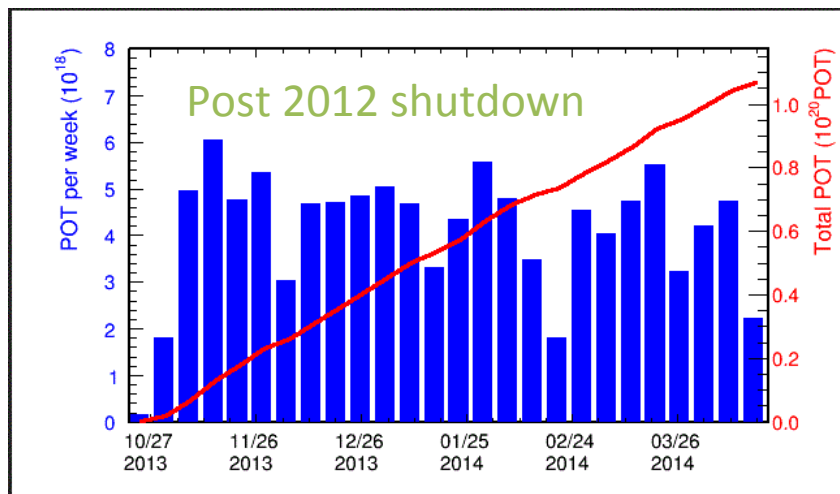
To measure the dispersion, three foils of different thicknesses were inserted into the beam, one at a time, at the same location. For a given foil thickness, the energy loss, and hence the momentum change caused by the foil, is known.





Since turning on,
BNB has
transported 2.1E21
protons.

The horns have
pulsed
half-a-billion
times.



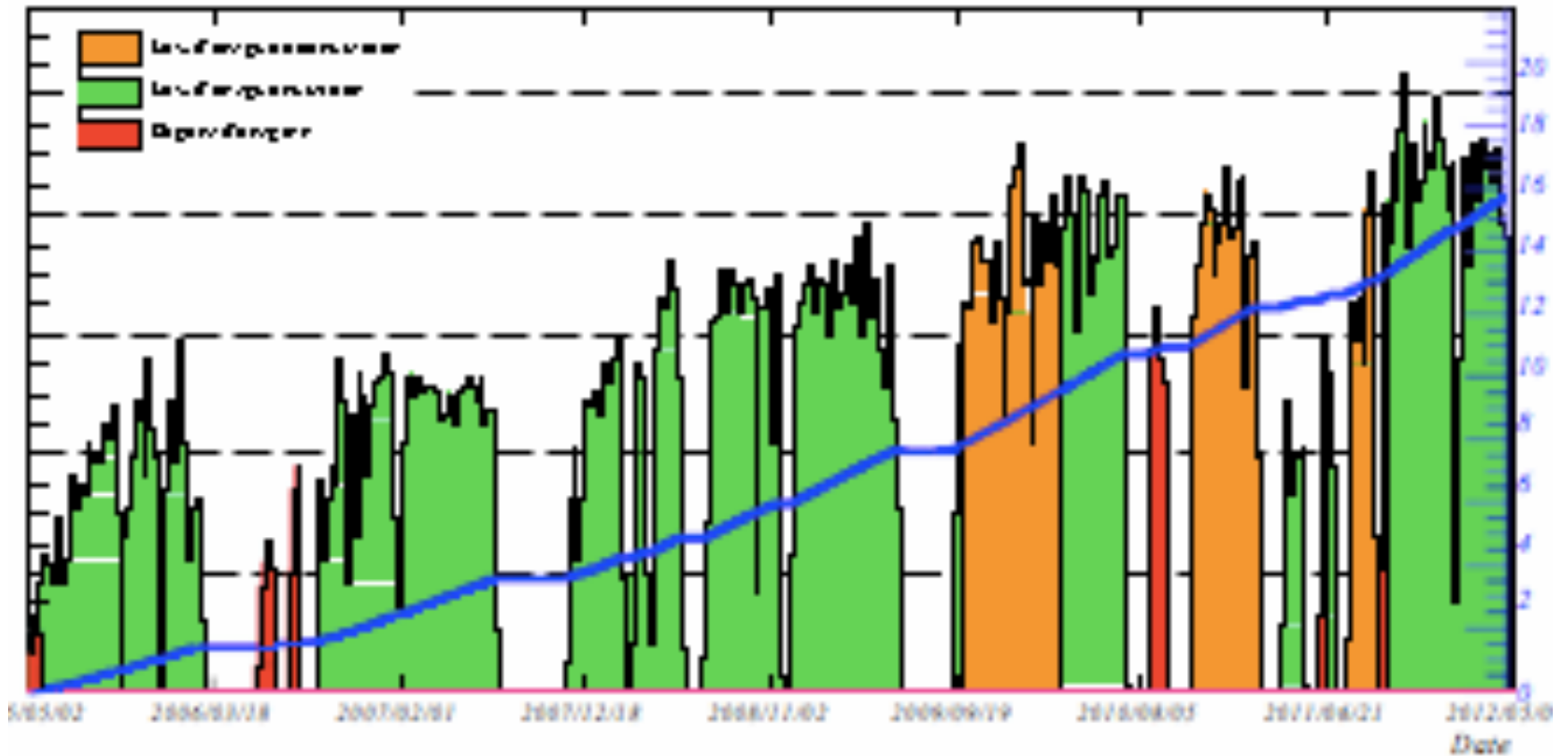
NuMI Beam Issues

- Because of ground water issues NuMI losses were more of a concern than BNB.
- A brute force solution was adopted in that the beam line was designed (by John Johnstone) with a larger acceptance than the largest beam emittance that could be accelerated in the Main Injector.
- Also accuracy and stability of targeting
- NuMI BPS checked ~250 items

Typical Operational Values

- Fractional beam loss prior to the target profile monitor of $3E-7$.
- Angular stability of ± 15 microradians
- Positional stability of ± 100 microns
- Autotune for NuMI was more sophisticated than for BNB

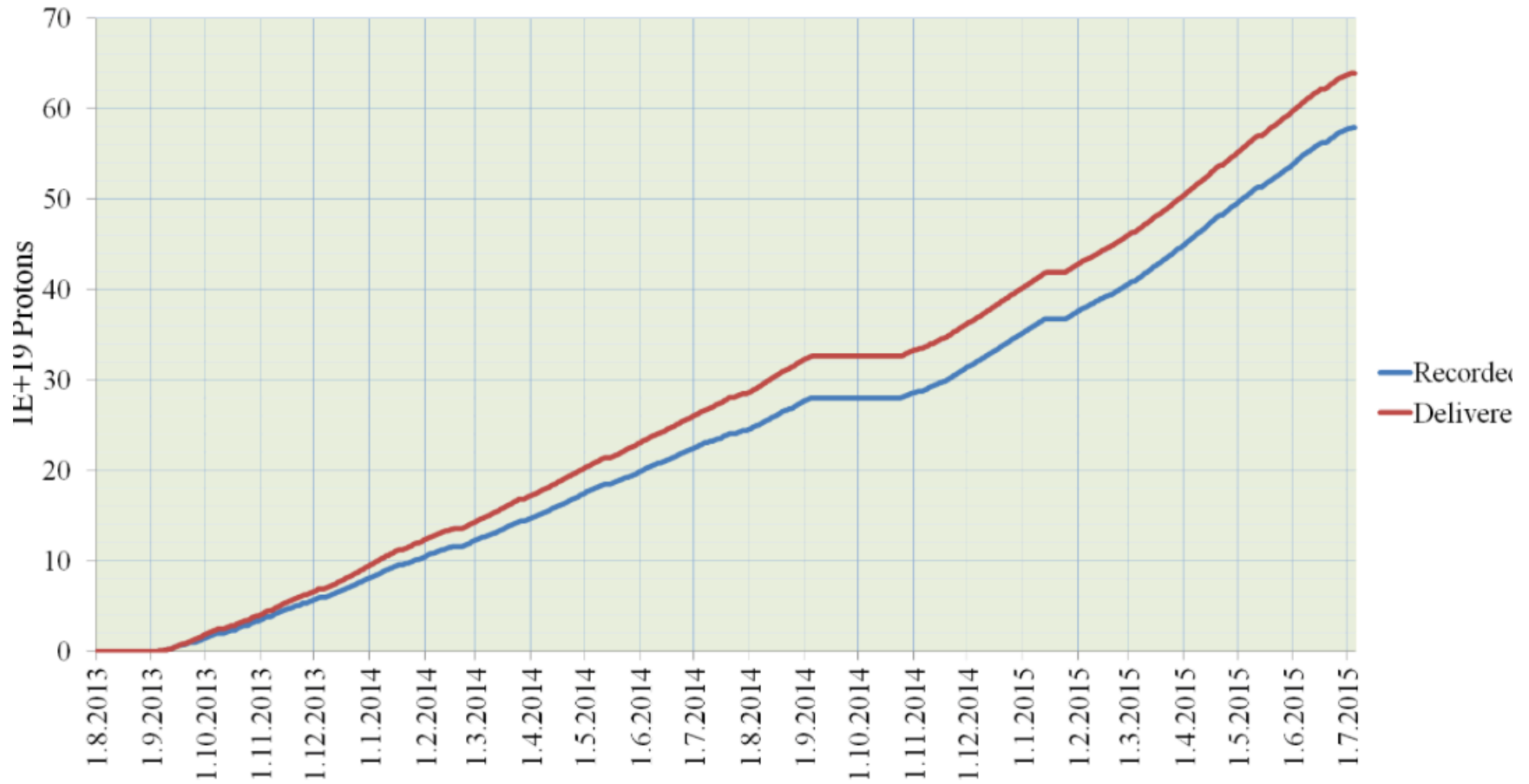
The cumulative POT on the NuMI Target over the MINOS run. The total POT was 1.56×10^{21} in various beam configurations. Green is neutrino, orange is antineutrino and red is special runs (e.g. horn off)



NoVA Medium Energy Run

- Horn 2 moved to 19.2 meters from Horn 1
- Beam spot size increased to 1.3 mm RMS in both directions to keep stress on target ok
- New baffle with 13 mm diameter
- New and more robust target

NoVA POT



Current NuMI and BNB Status

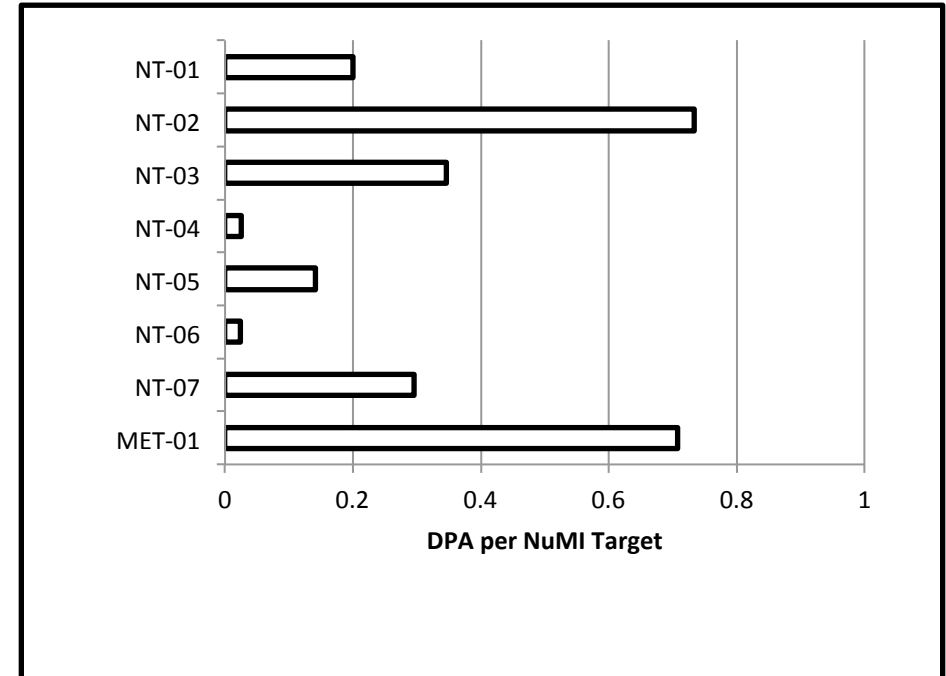
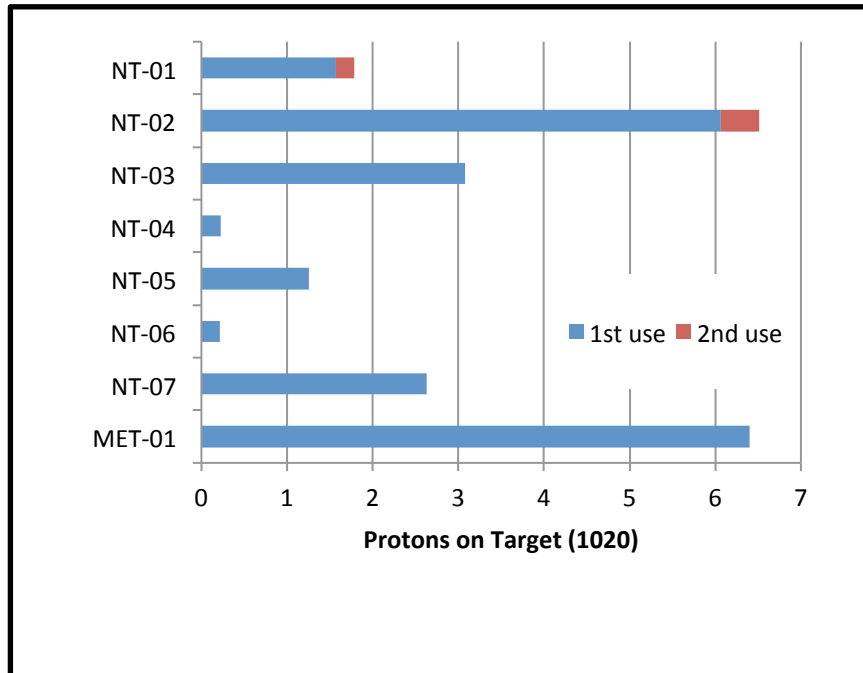
- Recent Horn 1 failures on both NuMI and BNB
- No BNB target failures
- Several old style NuMI target failures
- So far no problems with present NuMI target

700kW Medium Energy Target Status

Target	Status	Location
MET-01	Operation	Beamline 6.4E20 POT
MET-02	Ready Spare, 3 Be Fins	MI-8
MET-03	98% Complete	MI-8
MET-04	40% Complete Finish FY2016	MI-8
MET-05	40% Complete Finish FY2016	MI-8
MET-06	Started Procurement	MI-8
MET-07	Started Procurement	MI-8

Medium Energy Spare Target Situation Sufficient for Ongoing 700kW Beamline Operation

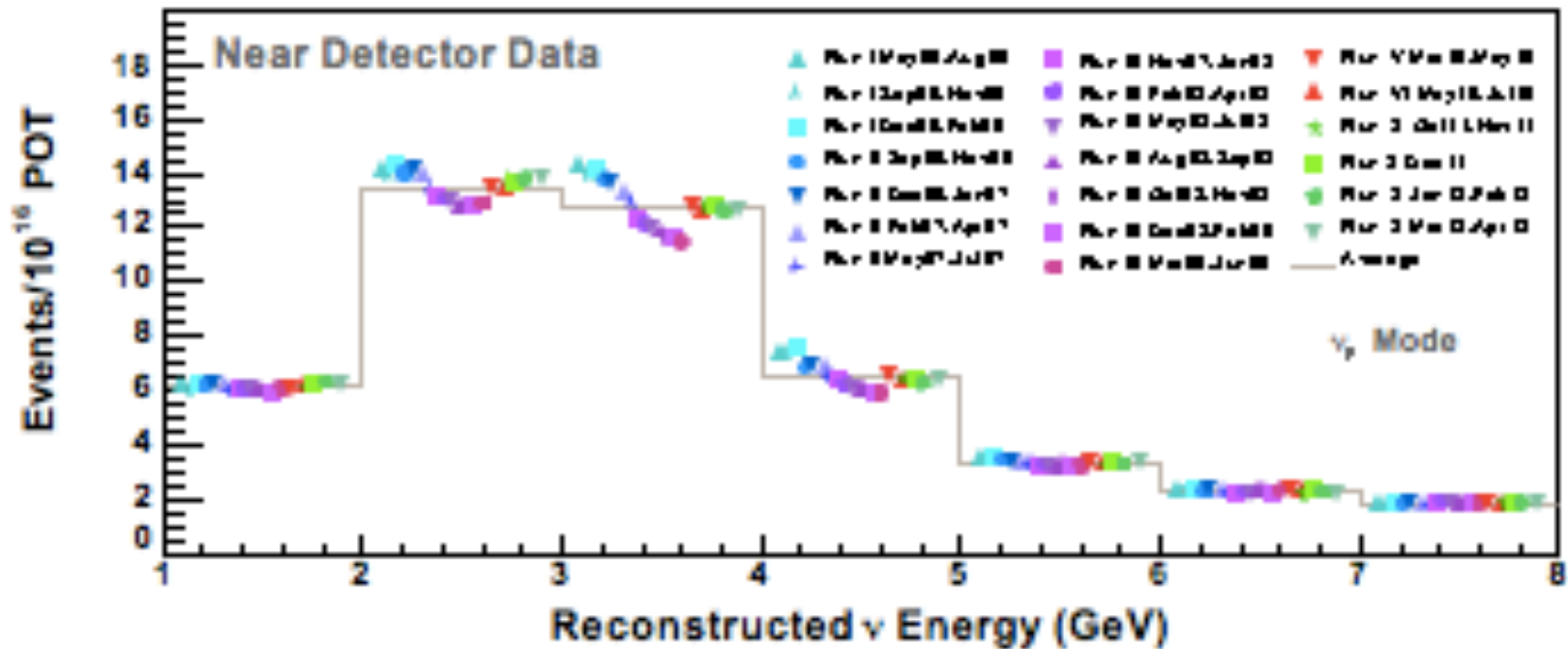
POT Plots*



- MET-01 Exhibits No Sign of Neutrino Yield Degradation
- For Graphite Significant Material Properties Change With DPA > 1

* Courtesy Jim Hylan

All time MINOS LE reconstructed Neutrino Spectrum. The solid line is the POT weighted average spectrum over the whole data taking period while the points represent the data for specific runs. The significant drop in the 2nd, 3rd, and 4th bins is due to NT02 target degradation.



NuMI Horn 1 Status

<u>Horns</u>	<u>Status</u>	<u># Pulses</u>	<u>Location</u>	<u>Comments</u>
PH1-01	Very Used, Water Leak	24.2M	C0 Bay	9 R/hr @ 1 ft. on 5/12/14
PH1-02	Used, Still Operational 400kW "Spare"	45.9M	C0 Bay	35 R/hr @ 1 ft. on 9/10/14
PH1-03	400kW Spare, Upgraded Cooling for higher beam power	0	MI-8	
PH1-04	700 kW Horn Stripline Fracture	27M	NuMI Target Pile	Must be replaced Very Radioactive
PH1-05	'Ready" 700 kW Spare; Same stripline as PH1-04	0	MI-8	Undergone stripline vibration measurements
PH1-06	In process, Complete FY 2017			<u>Need to CNC TIG Weld IC, Much Work Remains</u>
PH1-07	Just started procurement			IC Parts on Order Much work remains

NuMI Horn 2 Status

<u>Horns</u>	<u>Status</u>	<u># Pulses</u>	<u>Location</u>	<u>Comments</u>
PH2-01	Used, Stripline Fracture	28.1M	C0 Bay	Intend to ship off-site FY16
PH2-02	In operation	65.1M Pulses 4/13/2015	NuMI TH Beamline	
PH2-03	Ready 700kW Spare	Test Stand Qualified	MI-8	
PH2-04	Ready for MI-8 Test Stand	0	MI-8	Expect completion FY16
PH2-05	Completion late FY2017			<u>Need to CNC TIG IC, Much Work Remains</u>

Statement Regarding Desired Horn Lifetime

- First 700kW horn 1 (PH1-04) ran for 27M pulses before stripline fracture failure
- Upcoming run plan calls for $6E20$ POT / yr. at an intensity of $4.9E13$ Protons/pulse \ggg 12.2M pulses / yr.
- Or 13.2M pulses with 1.33 sec cycle time at 56% duty factor with possibility of increased duty factor
- A reasonable design specification balancing device cost and complexity is to specify a horn lifetime of ~ 4 years considering 2 to 2-1/2 year production cycle
- **Specify a 700kW horn lifetime of $\sim 50M$ cycles with safety factor**

Spares Situation- Reiteration of Previous Plot

- PH1-05: NOvA Design **READY SPARE**
 - Shares stripline design with PH1-04; might expect similar lifetime of ~30M cycles
 - Strong preference to modify before installation
- PH1-03: MINOS Design **READY SPARE**
 - Initially designed for 400 kW
 - Stripline design unlikely to have same weakness as PH1-04
 - Some modification can be rapidly implemented to increase allowable power above 400 kW
- PH1-02: Used 400kW MINOS Design **EMERGENCY SPARE**
 - Ran for 46 millions pulses, never failed
 - Still quite hot – slated for disposal in 2020
 - Cannot be modified
- PH1-06: NOvA Design **IN FABRICATION**
 - More than one year to be ready
 - Will want stripline design changes
- PH1-07: NOvA Design **PROPOSED**
 - Now will be needed as spare

Schematic Plan

I. Ongoing investigation of failure mechanisms

- PH1-05 and PH1-03 vibration testing @ MI-8 test stand and ANSYS simulation
- More in-depth visual investigation of PH1-04 in workcell
- Ang Lee and Zhijing Tang from PPD to conduct ANSYS work
- Contract in place to utilize David Larson of S&V Solutions for vibration measurements

II. Modify PH1-03 for higher beam power and install this shutdown

- Tight schedule, but can be effected without lost beam time
- Enhanced downstream water cooling to reduce stripline flag and contact terminal temperatures along with using an air diverter to supply more air cooling to stripline flags
- Install Be cross-hair for higher beam intensity (Done)
- PH1-03 vibration measurements and final outfitting needs to be done by week 8 of shutdown (8/24)
- Conduct detailed ANSYS modeling to help determine fatigue safety factor vs. beam intensity (intent is to have this well understood by time of beam startup)
- Operate PH1-03 at some specified power limit until PH1-05 stripline redesign is ready, then remove limits

III. Modify PH1-05 stripline to enhance fatigue lifetime

- Will need several months (~ 8 to 10 months) to devise and implement solution

IV. Advance construction of PH1-06, PH1-07, and BNB-4 in parallel with above efforts (however TSD has some manpower limitations given the volume of work required)

NuMI Running Plan

- Utilize an approach for no beam time loss coming out of the summer shutdown
- Install PH1-03 with some possible power limit
 - ***May be able to avoid power limit altogether if enhanced air cooling efforts and FEA results indicate adequate safety factor for 700kW operation***
 - Run FY16 with PH1-03
 - Remove power limit (if applicable) when PH1-05 with stripline retrofit is ready
- Possible, preventative horn replacement in FY16 shutdown (TBD)
- Produce spares to keep up with consumption

BNB-2 to BNB-3 Changeout

- Decision was made on January 12, 2015 to change out horn BNB-2 due to 400M+ pulses, plugged water spray nozzles, and 2 leaking water supply manifolds that were previously valved out
- ***Many challenges: Required 23 weeks of intense effort to qualify a ready spare BNB-3, mitigate potential for Be⁷ contamination, generate procedure and hardware to remove “stuck” BNB-2, remove old non-functional horn positioning platform into newly designed cask, design and fabricate new rad-hard positioning platform, and reinstall new horn with upgraded RAW skid and pre-target instrumentation***
- In the best scenario a horn requires 2 to 2-1/2 years to construct, pulse test, field map, and final outfit & QA (similar for BNB and NuMI)

BNB-2 to BNB-3 Changeout Highlights



New Horn Adjustment Platform



BNB-3 & New Platform @ MI-8



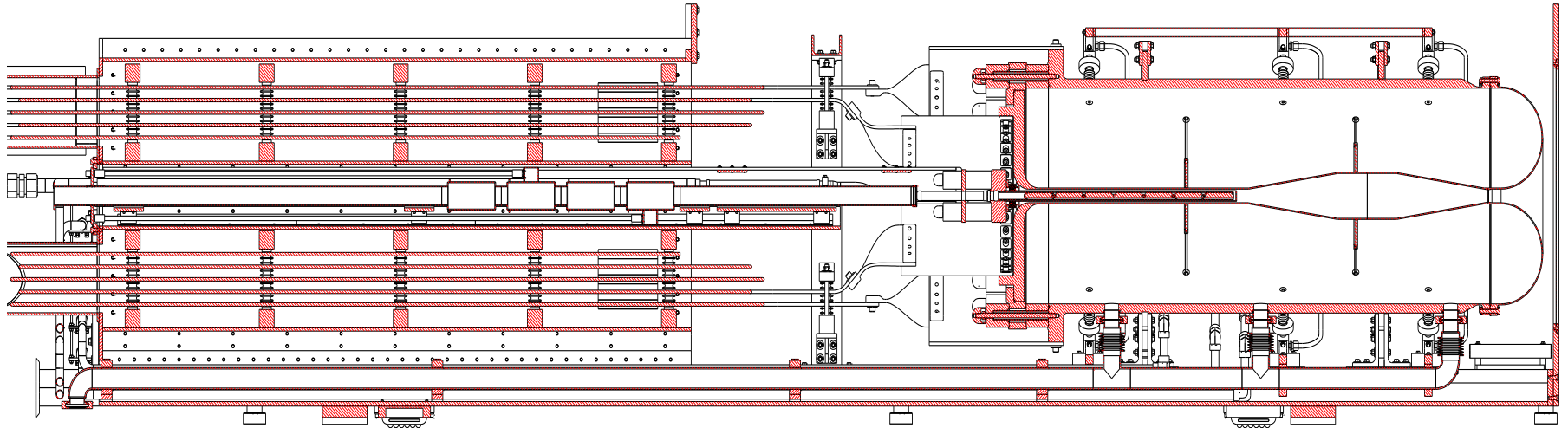
BNB-3 Installation into Target Cave

Target and Horn

Designed by Larry Bartoszek

Built by AD Mechanical Support Target Group

Present engineer is Vladimir Sidorov



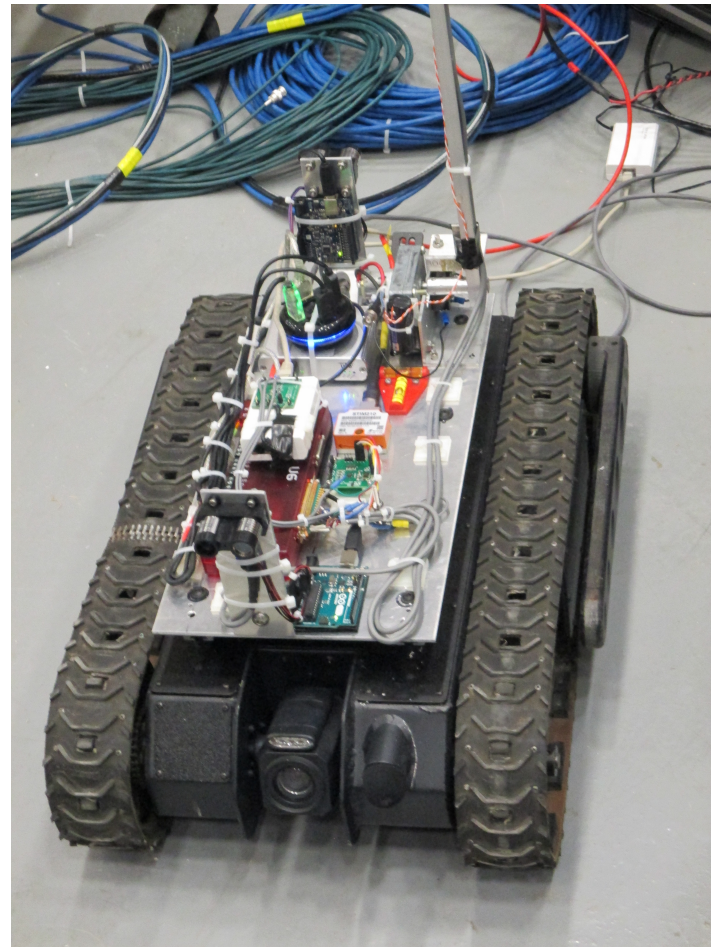
Target and horn are built and installed as a single unit, although it is possible to change only the target.

BNB-4 Spare Horn Status

- Currently BNB does not have a spare horn
- We expect completion of BNB-4 spare horn to be a very high priority in TSD in FY16 and will require a large fraction of an engineer and at least 2 technicians
- ~90% of all hardware has been procured for BNB-4
- Expect to complete construction of BNB-4 in latter part of FY16
- Will start to consider window of opportunity to pulse test horn at MI-12 (requires power supply stripline reconfiguration to pulse test on top of access hatch cover block)

Decay Pipe Inspection- 4/18/2015

- Interest in inspecting decay pipe for general structural integrity
- Interest in magnetic field measurements down the 50m length of the BNB decay pipe



Current BNB Status for next Run

- Horn and target in place, horn power tested
- New horn positioning module will make future changes easier.
- New pre target instrumentation package
- MicroBooNE, MiniBooNE ready for beam
- 3 small experiments: DCTPC,ANNIE,SCIBATH
- Ongoing upgrade studies along with detailed laser scan of the enclosures.