Geodetic and Alignment Concepts for the Long-Baseline Neutrino Experiment

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The Long-Baseline Neutrino Experiment

- The neutrino research program is part of the Intensity Frontier research priorities at Fermilab
- LBNE is a newly proposed neutrino experiment
- ***Physics Goals***: determine the mass hierarchy and look for CP violation, precision measurement of other oscillation parameters, test the validity of the three-neutrino mixing model

- Recently the LBNE project went through a reconfiguration and a phased approach to meet the DOE funding profile and still achieve the science goals
- The LBNE project scope includes Technical Components and Conventional Facilities for :
  - A high energy primary proton beam extracted from the Main Injector:
    - with the flexibility to operate at energy range from 60 to 120 GeV
    - beam power: start with a 700 kW beam upgradeable > 2.3 MW with Project X
  - The world's highest-intensity (muon) neutrino beam
  - Massive neutrino far detector located at 1300 km distance and at the Sanford Underground Research Facility (SURF) in the Homestake mine in Lead, South Dakota:
    - 10 kton LAr TPC particle detector on or close the surface (with additional funding support it could be placed ≈1500 m underground => enable proton decay + supernova neutrino physics)

- Subsequent phases would include:
  - Build a highly capable near neutrino detector (=> reduce systematic errors of oscillation measurements + enable a broad program of short-baseline neutrino physics)
  - Increase in far detector mass from 10 to 35 kton placed underground at the 4850 ft (≈1500 m) level

LBNE Beamline
From Fermilab to SURF, South Dakota

Massive LAr TPC detector at SURF/Homestake built on surface and/or 1.5 km underground

Intense neutrino and anti-neutrino beams from Fermilab

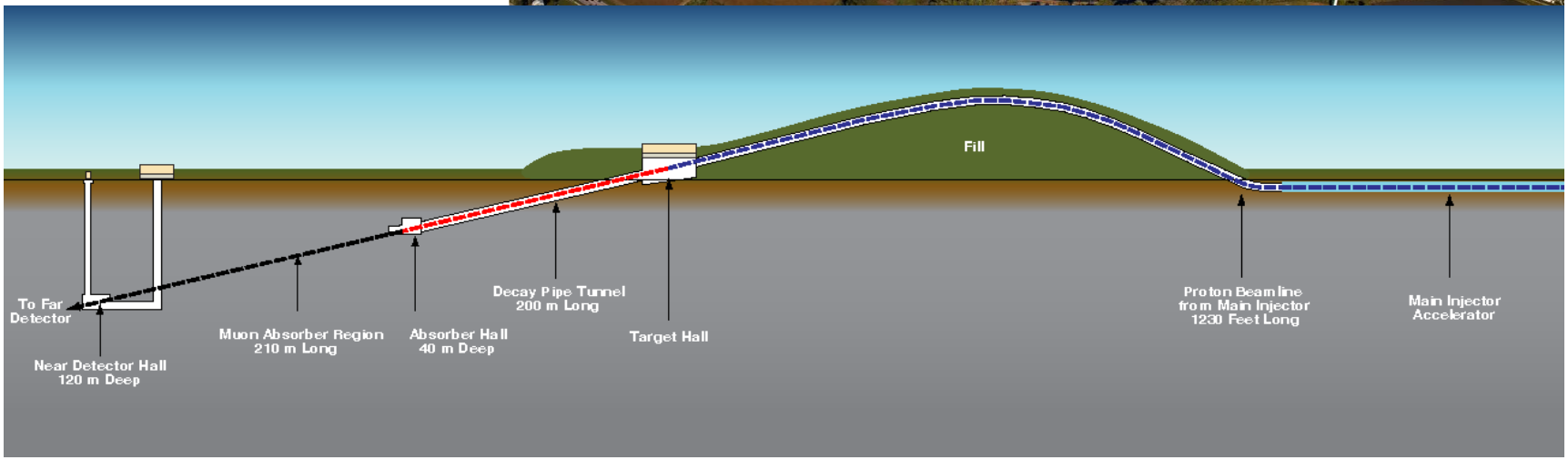
The LBNE Beam Facility at Fermilab

- Primary beam extracted from the Main Injector – MI-10

The LBNE Beam Facility at Fermilab

Tunnels and Halls

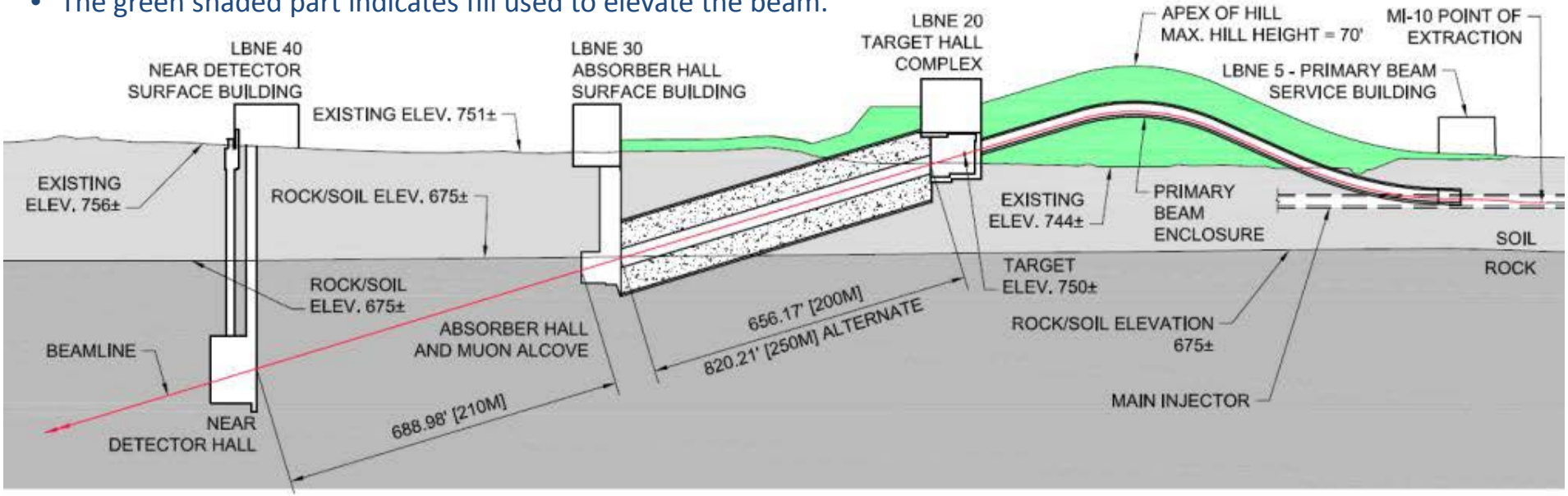
- "Shallow" beam extracted at MI-10:
  - Avoids beam crossings
  - Allows for a simpler extraction enclosure
  - Enables a cost-effective facility design of the entire extraction region
  - Interferes minimally with existing beam systems in this region
  - Provides some shielding separation from accelerator tunnel



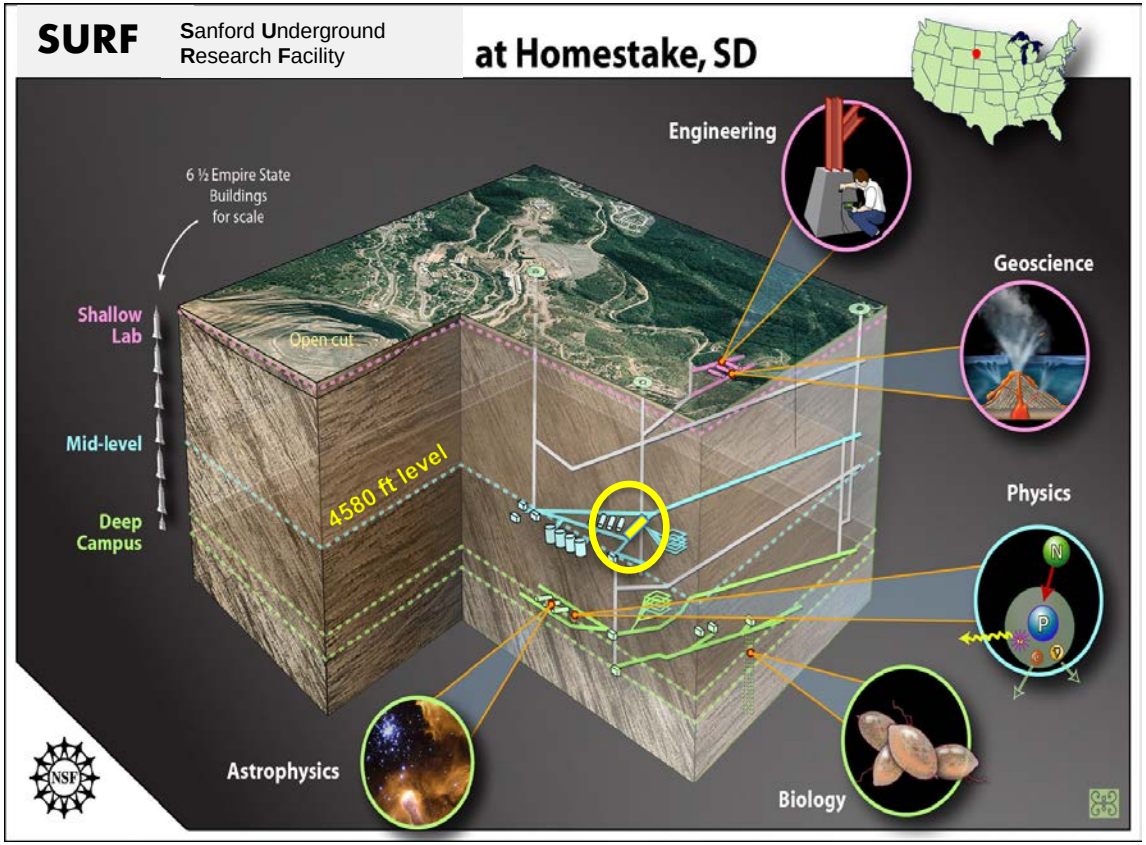
The LBNE Beam Facility at Fermilab

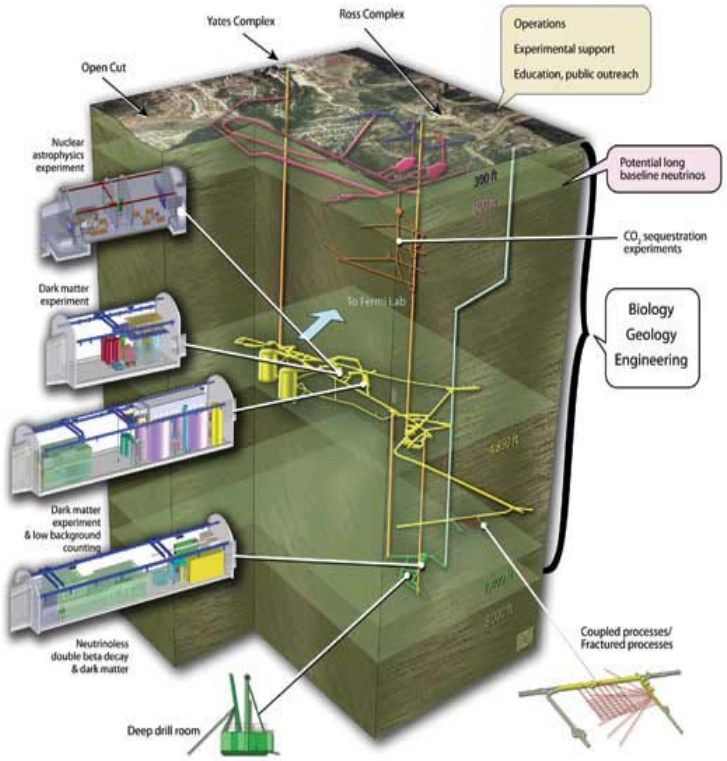
Tunnels and Halls – elevation view

- Showing the concept of elevating the beamline through construction of an earthen embankment (hill):
  - minimizes expensive underground construction
  - enhances significantly capability for ground-water radiological protection
- **The primary beam enclosure will be founded to bedrock**
- The embankment will need to be approximately 280 m long and 18 m high above grade at its peak
- The primary beam will be above grade for about 168 m
- The downward pitch angle is 5.79^0 (101 mrad)
- The green shaded part indicates fill used to elevate the beam.



The Sanford Underground Research Facility
at Homestake, SD

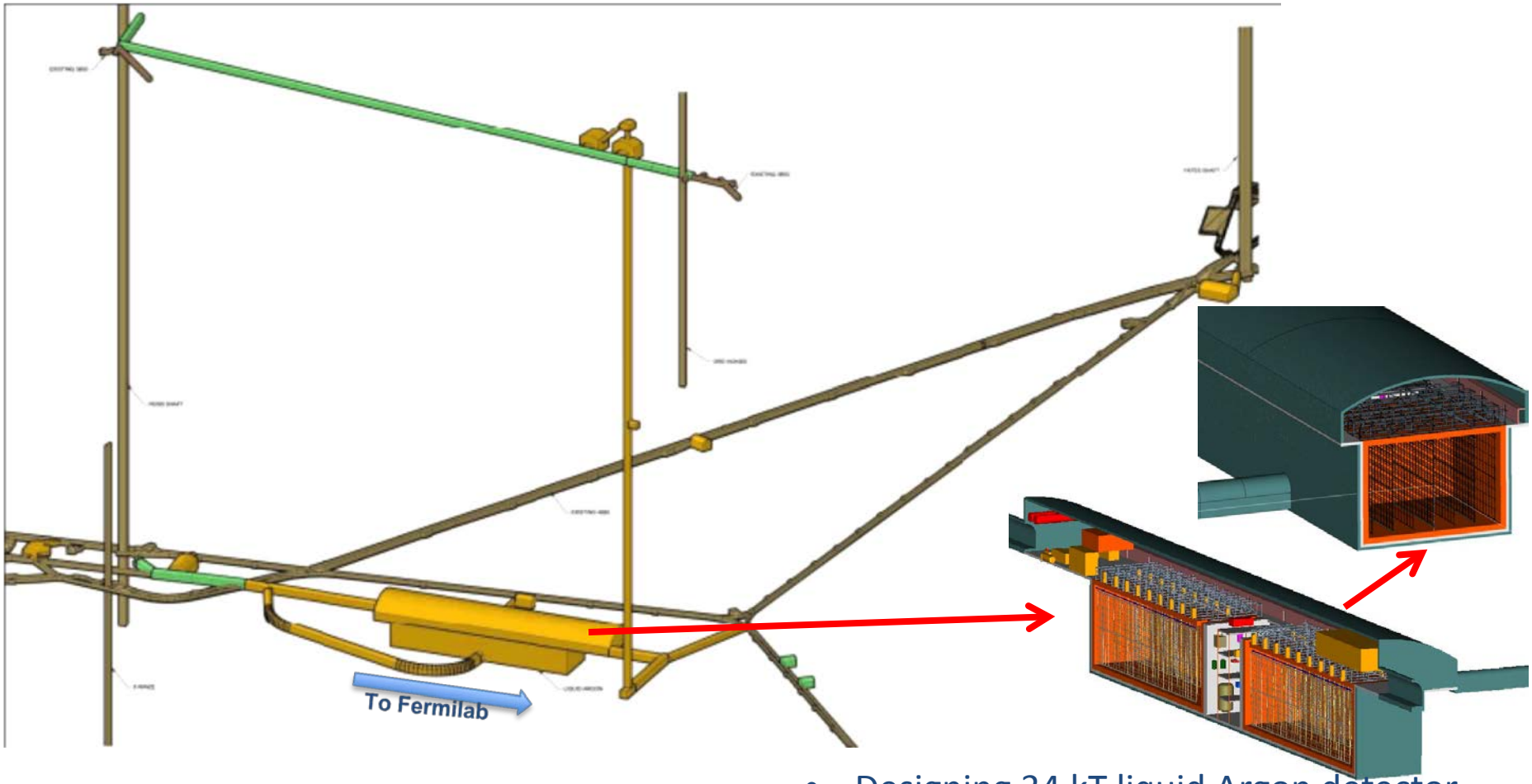




- Homestake is the deepest mine in North America with rooms at 8000 ft (2438 m)
- Major scientific fields solicited experiments: particle and nuclear physics, geology, hydrology, geo-engineering, biology, and biochemistry.
- Proposed physics experiments in five research categories: supernovae, dark matter, proton decay, neutrino mass hierarchy and neutrinoless double beta decay.
- Proposed LBNE far detector at 4850 ft (approximate depth 1500 m)

LBNE Far Detectors
Conceptual layout

- At the proposed SURF laboratory in Lead, South Dakota, the caverns for the Homestake Neutrino Detector would be located 1500 m underground.



- Designing 34 kT liquid Argon detector

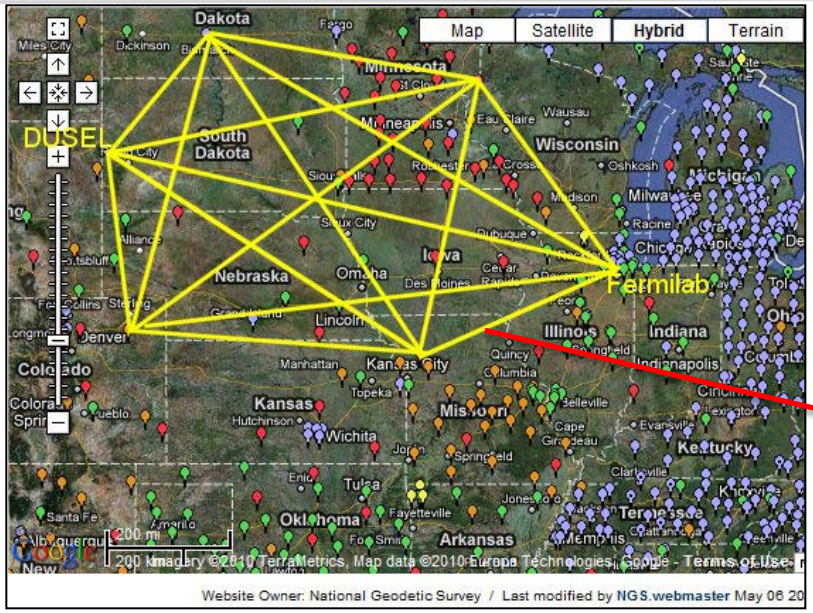
Alignment Requirements

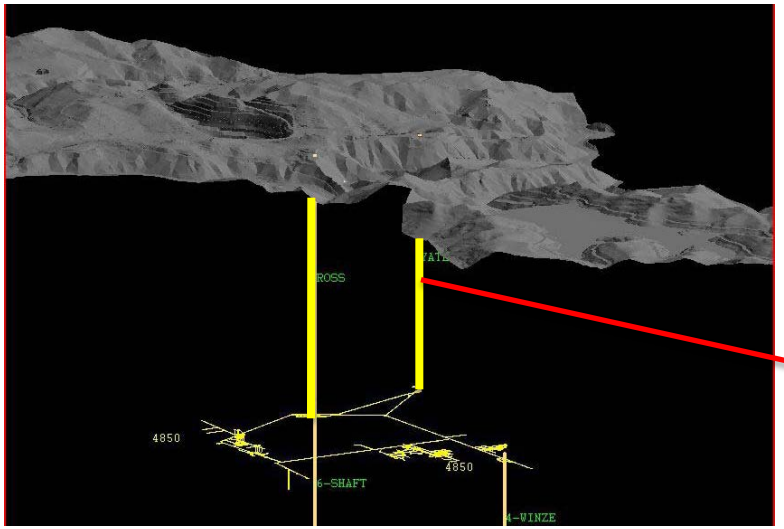
- Absolute and relative alignment tolerances for LBNE were assimilated from NuMI (absolute tolerances calculated proportionally to SURF, South Dakota)
- Absolute tolerances - at global level:
  - Primary proton beam centered ± 21 m at the far detector (± 0.016 mrad)
  - Neutrino beam centered ± 133 m at the far detector ± 0.102 mrad)
- Relative tolerances - between components:

Beam position at target	**± 0.45 mm**
Beam angle at target	**± 0.7 mrad**
Target position - each end	**± 0.5 mm**
Horn 1 position - each end	**± 0.5 mm**
Horn 2 position - each end	**± 0.5 mm**
Decay pipe position	**± 20 mm**
Downstream Hadron monior	**± 25 mm**
Muon Monitors	**± 25 mm**
Near Detector	**± 21 mm**
Far Detector	**± 133 m**

- LBNE is mainly sensitive to final primary beam trajectory : primary beamline components, Target and Horn alignment => relative positions ±0.35 mm (1σ)

Geodetic determination of global positions



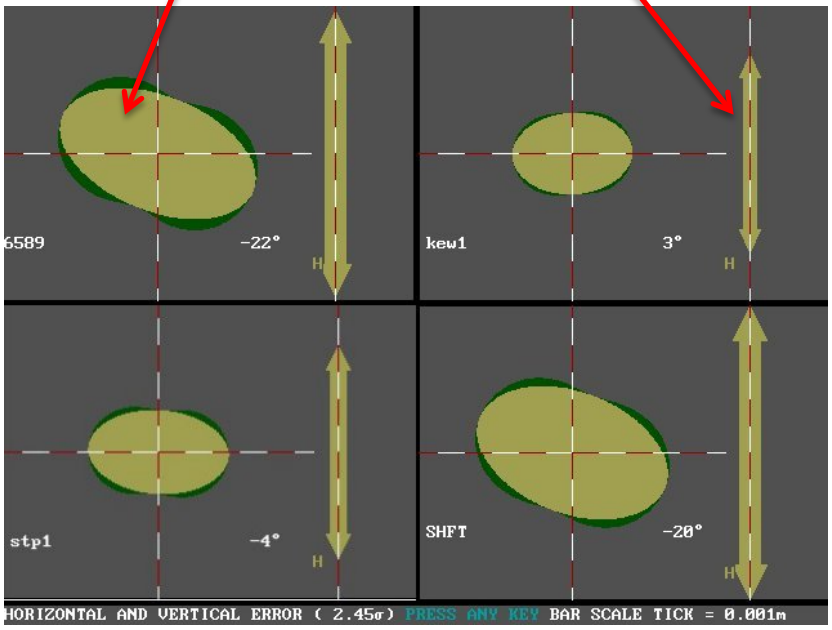


- The correct aiming of the beam is of great importance for the experiment
- Requires a rather exact knowledge of the geodetic orientation parameters of the beam => absolute & relative positions of the target (Fermilab) and the far detector (SURF) at the global level
- Two steps procedure:
  1. FNAL/SURF long GPS baseline measurements tie the surface control to the National Geodetic Survey's Continuously Operating Reference Station (CORS) precision GPS geodetic network
     - vector known to better than 1 cm horizontally and vertically
     - solution in International Terrestrial Reference Frame of 2000 (ITRF00) reference system => then transformed in the national North American Datum of 1983 (NAD 83) system
     - NGS will provide an independent solution (for NuMI we had excellent agreement within1 cm)
  2. Precision inertial system survey through Yates and Ross shafts ties the 4850 level of the mine (depth ~ 1500 m) to surface geodetic control

Geodetic determination of global positions
Expected accuracy results

Ellipses of Error in x, y plane

Errors in Height

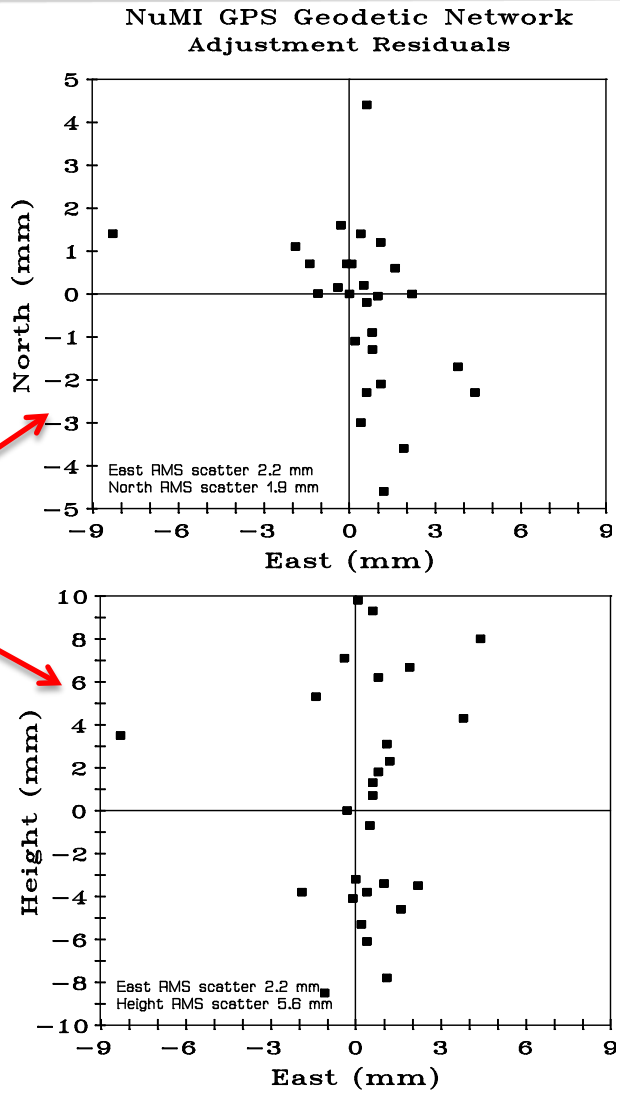


Ellipses of Error @ 95% confidence level
(bar scale tick = 1 mm)

Rms of residuals @
95% confidence level

Long/Lat = 2 mm

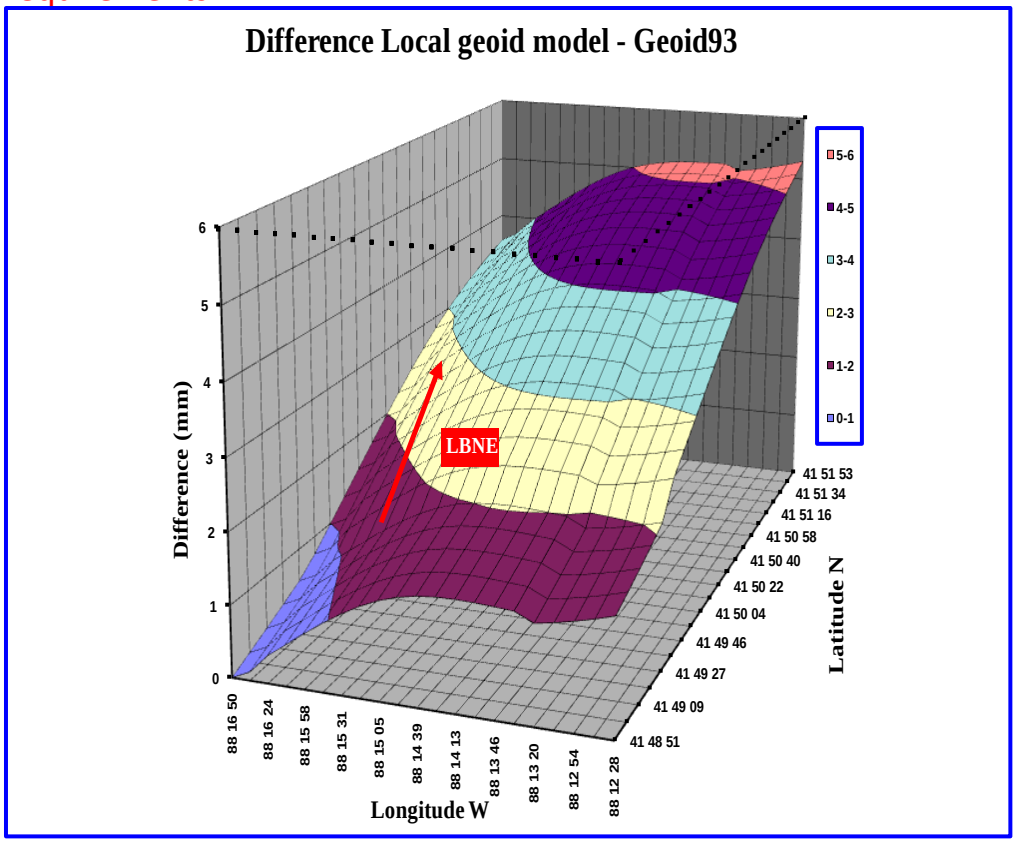
Height = 6 mm

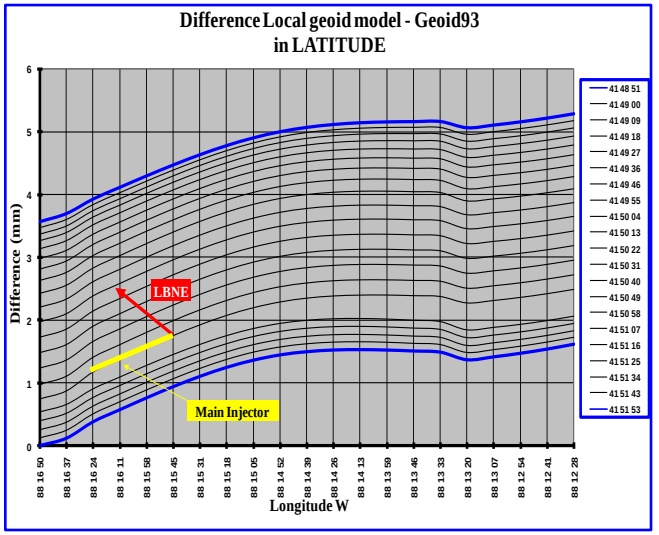


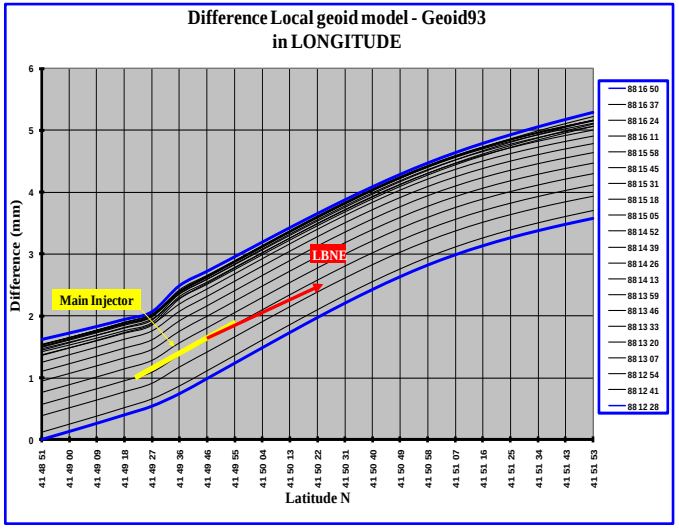
- NuMI global position accuracy is shown
- LBNE results are expected to be similar

Geodetic determination of global positions
Geoid consideration

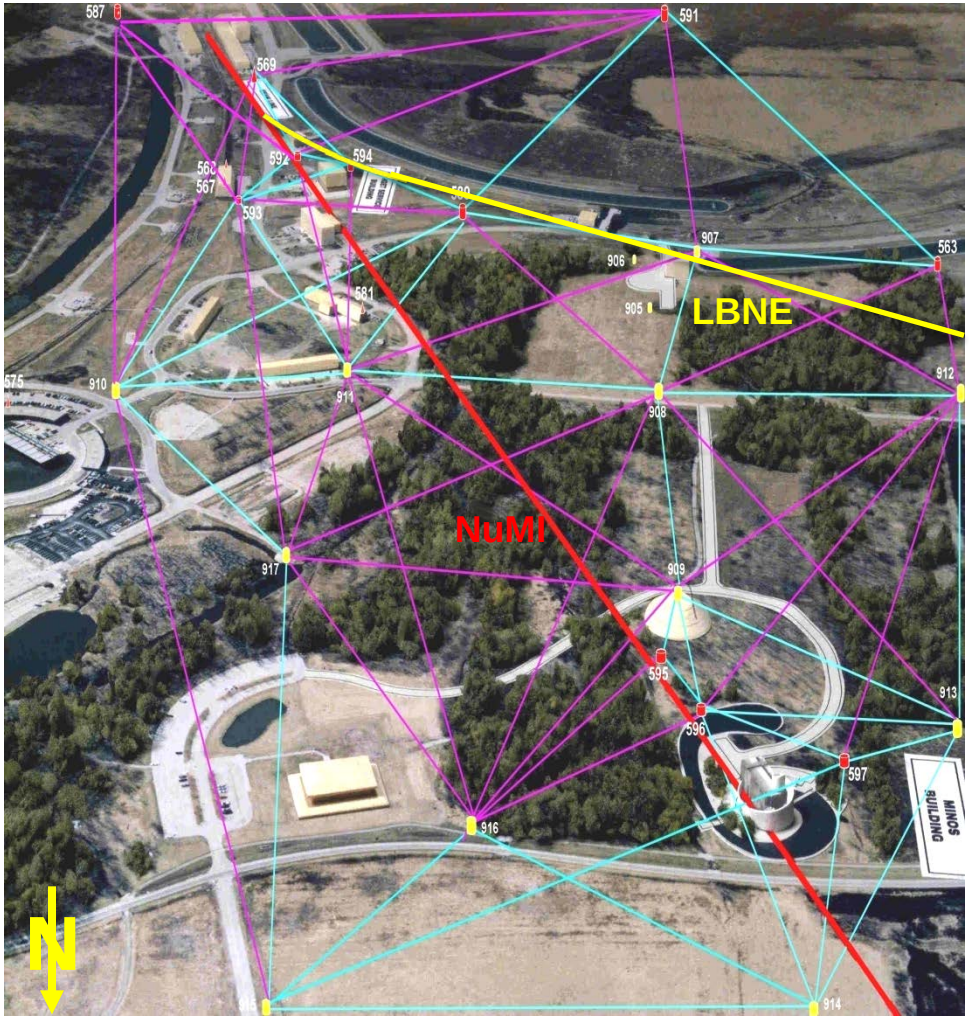
- Needed knowledge of the gravity vector at the origin (Fermilab)
- Previous study comparing a Local Geoid Model and NGS Geoid93 model
- Differences up to 5 mm (consistent with expected values)
- LBNE beam within 1.5 mm range of differences
- Geoid93 model (presently used) - sufficient to cover tolerance requirements







Primary surface geodetic network



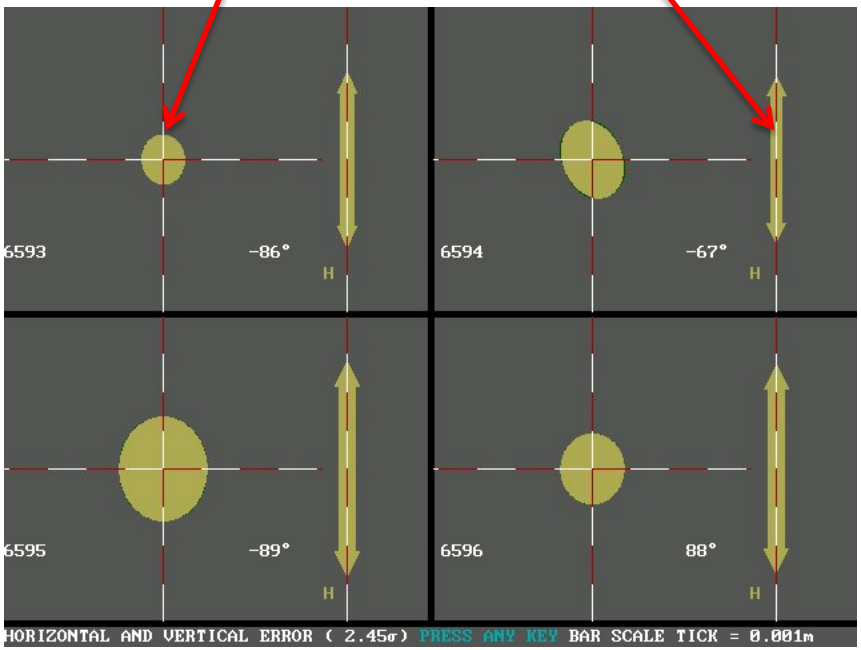
- Provides the basis for construction surveys and for the precision underground control networks
- existing Fermilab control network (accuracy < 2 mm @ 95% confidence level)
  - horizontal geodetic datum = North American Datum of 1983 (NAD 83) based on the reference ellipsoid Geodetic Reference System 1980 (GRS-80)
  - vertical datum = North American Vertical Datum of 1988 (NAVD 88)
  - geoid model = NGS model Geoid93
- includes 3 monuments tied through CORS to SURF
- add 6 new geodetic monuments (densification around access shafts)
- ~400 GPS, terrestrial and astronomic observations
- expected error ellipses in millimeter range (@ 95% confidence level)

- NuMI surface geodetic network is shown
- LBNE surface network will have similar density and configuration

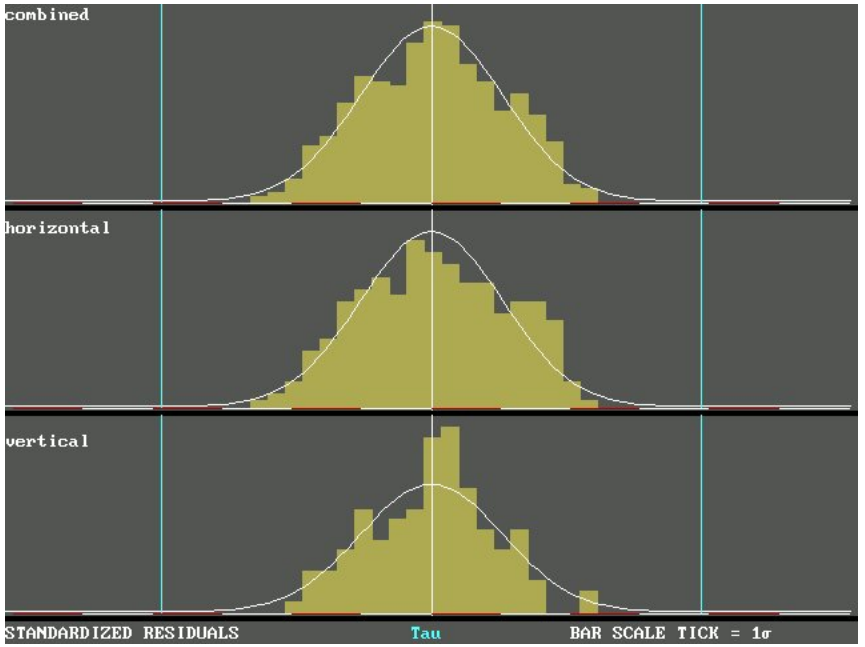
Primary surface geodetic network at Fermilab
Expected accuracy results

Ellipses of Error in x, y plane

Errors in Height



Ellipses of Error @ 95% confidence level
(bar scale tick = 1 mm)

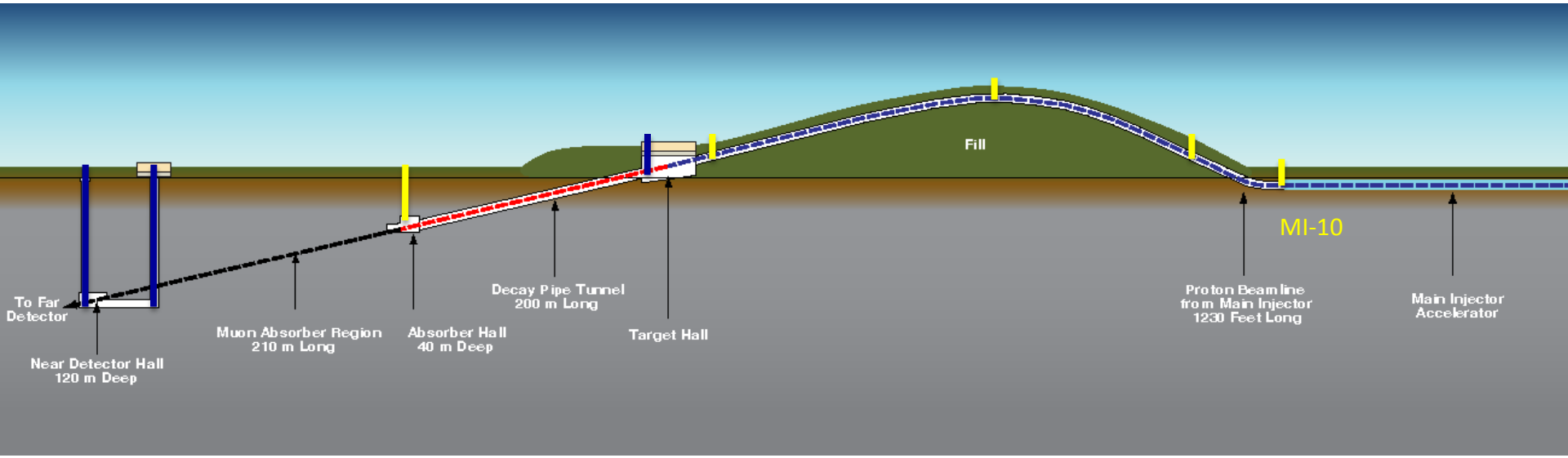


Histogram of standardized residuals
(bar scale tick = 1 σ)

- NuMI surface geodetic network accuracy is shown
- LBNE results are expected to be similar

Precision underground control networks

- Provided vertical sight risers for transferring coordinates from the surface to the underground (better and more efficient for controlling error propagation in a weak geometry tunnel network)
- Network simulations => 8 locations for transferring coordinates from the surface (5 vertical sight risers, 3 tunnel Access Shafts)
- Due to the increased depth of the tunnel, designed adequate procedure for precision transfer of surface coordinates underground

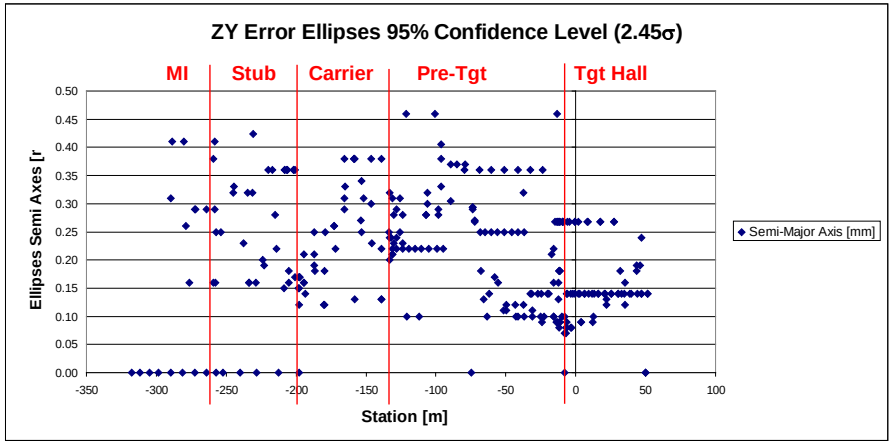


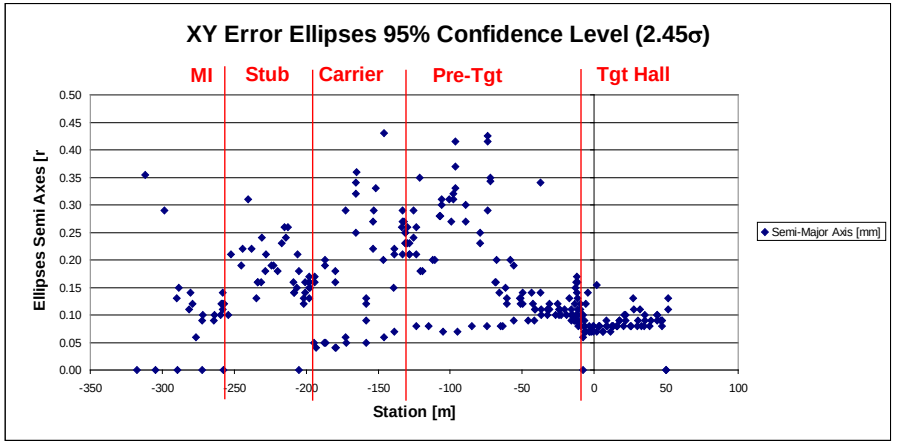
Precision underground control network
For the Primary Beam

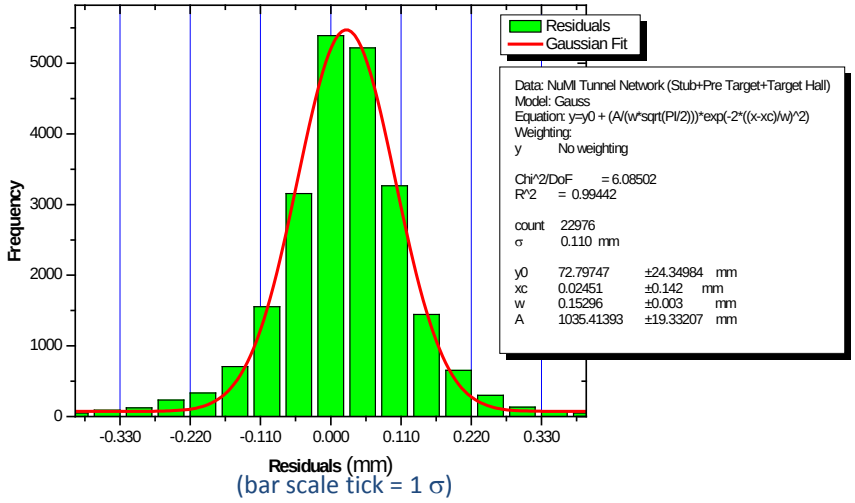
- Built to support the alignment of Primary Beam components and the Target and focusing Horns
- Components alignment scope are very similar to NuMI:
  - Primary beam magnets and instrumentation aligned to ±0.25 mm
  - Target station components aligned to ±0.5 mm
- Error budget network requirements ±0.50 mm at 95% confidence level
- Network: from MI-10 to the downstream end of the Target Hall
- Constraints at underground transfer points: MI-10, sight risers and access shafts
- Network type: Laser Tracker processed as trilateration
- Additional measurements to study and control network behaviour
- Azimuth confirmed by first order Astronomical Azimuth between final primary beam trajectory surface transfer points (for NuMI we had excellent agreement at 0.004 mrad with σ=±0.001 mrad)

Precision underground control network
Expected accuracy results

- Errors Ellipses ±0.45 mm and histogram of residuals σ=±0.110 mm at 95% confidence level







- NuMI underground network accuracy is shown
- LBNE results are expected to be similar

Summary

- From the Alignment perspective, the LBNE project is very similar with NuMI
- The distance to and the depth of the far detector have doubled from NuMI
- Presents a challenge with respect to the detail and complexity of the geodetic aspects
- Past experience from NuMI:
  - The absolute global tolerances have been achieved successfully
  - The relative alignment tolerances of beamline components have been also achieved successfully
- Similar geodetic and alignment concepts are proposed for LBNE

- LBNE current status:
  - Critical Decision 0 (CD-0) - the formal conceptualization of the proposed LBNE project has been approved in January 2010
  - Critical Decision 1 (CD-1) – the preparation phase to develop a conceptual design and cost estimate for a new LBNE neutrino beam and far detector complex in progress => review at end of October 2012

LBNE Project Time Line

- CD-0 (Approve Mission Need) Jan-2010
- CD-1 (Conceptual design, preliminary cost and schedule range) Jan-2013
- CD-2 (project baseline) depending on funding Mar-2016
- CD-3 (start construction) depending on funding Apr-2017
- CD-4 (start operations) Jun-2023