Experimental fundamentals II

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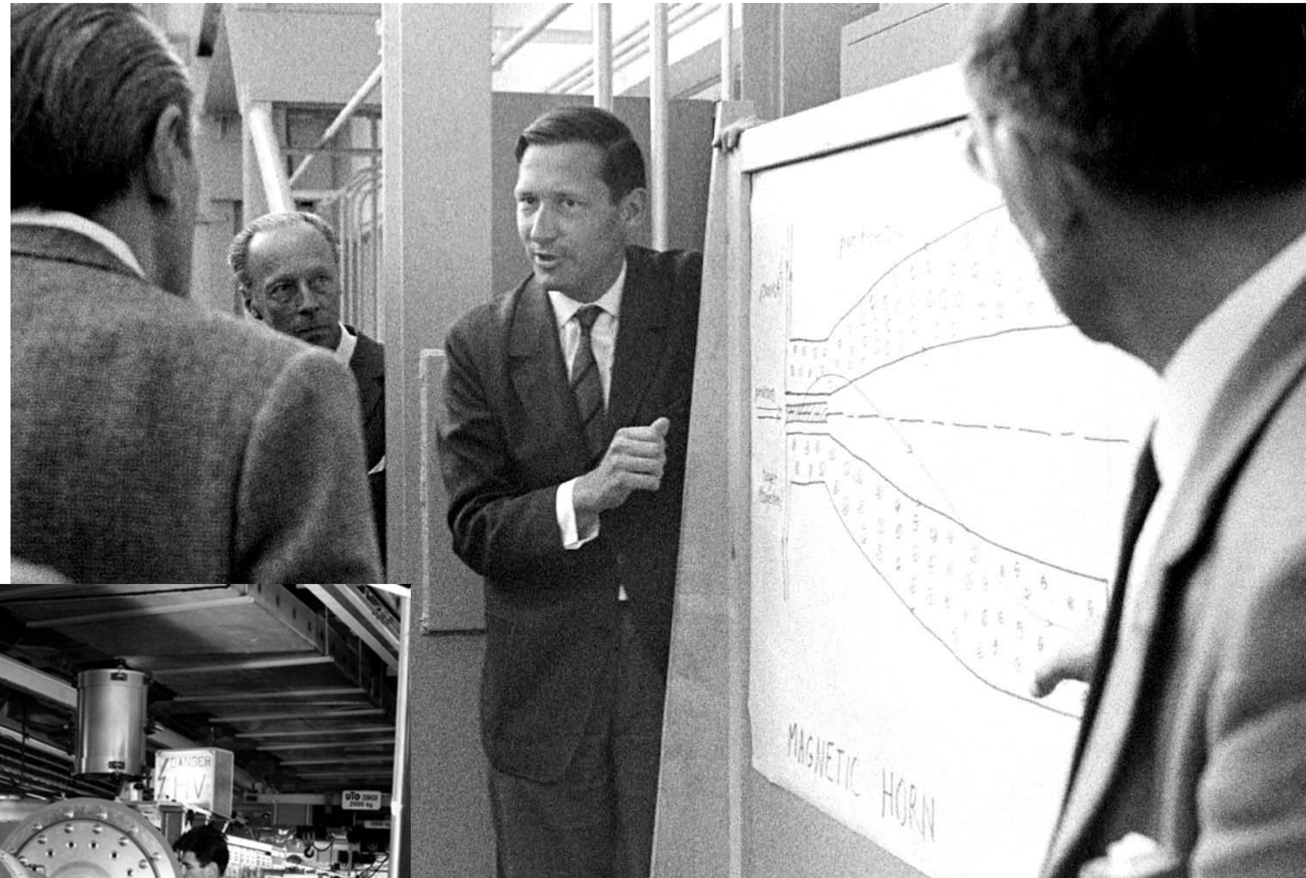
1. Historical introduction
2. Neutrino interactions

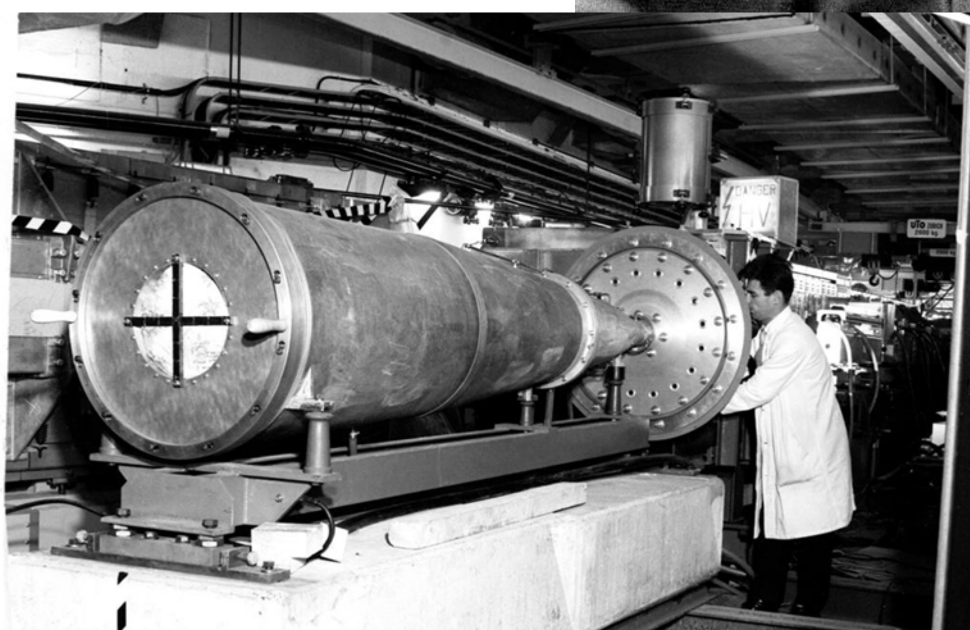
3. Astrophysical neutrinos

4. **Neutrinos from accelerators**
5. Neutrino detectors at accelerators

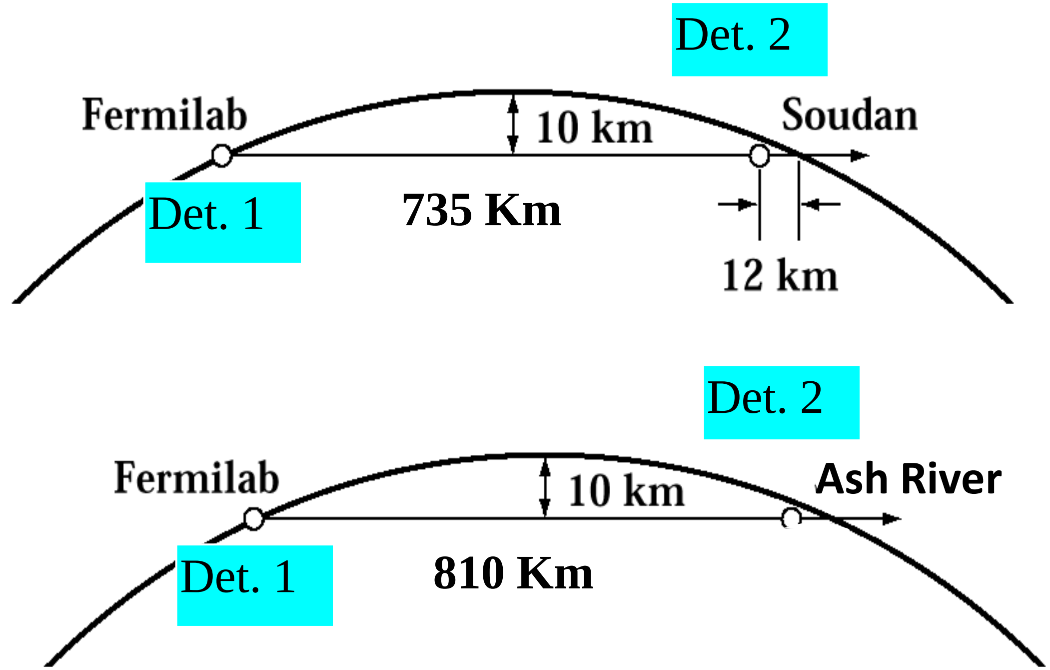
6. Beta decay and reactor neutrinos

Neutrinos from accelerators



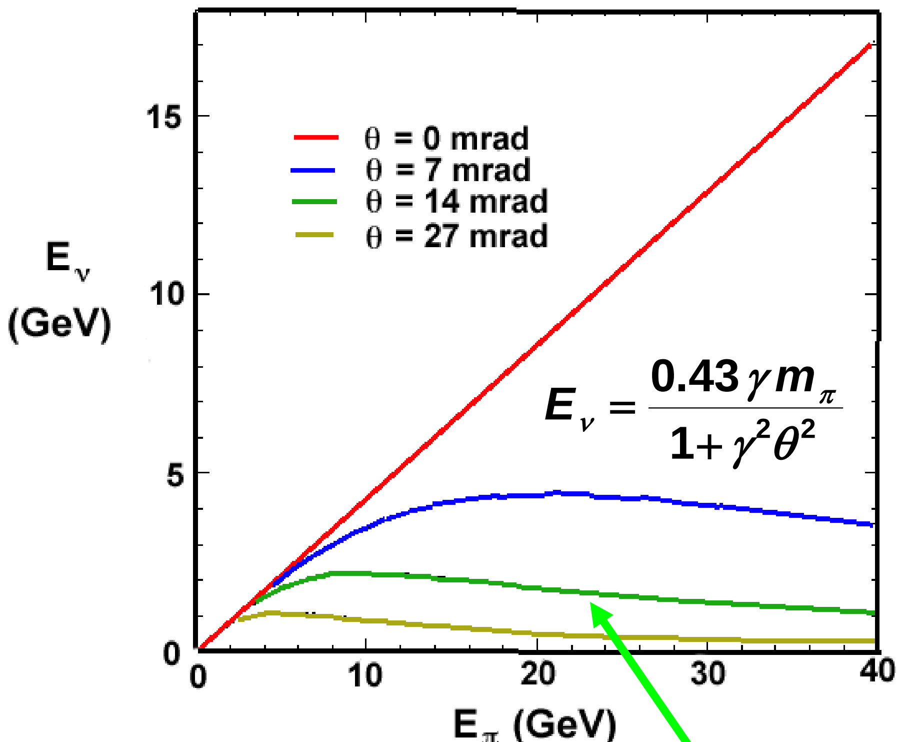


NuMI: ν's at the Main Injector

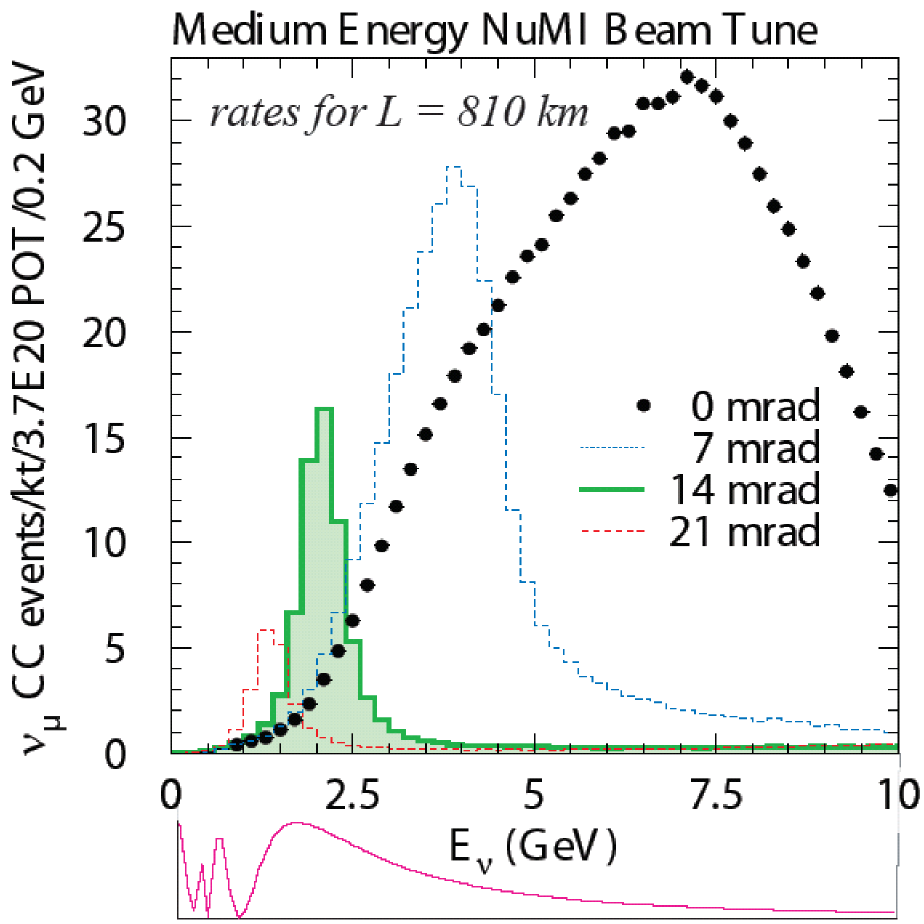


- **a neutrino beam from Fermilab to northern Minnesota**
  - over 735 km to Soudan mine (MINOS far detector)
  - over 810 km to NOvA

NuMI as an Off-Axis beam

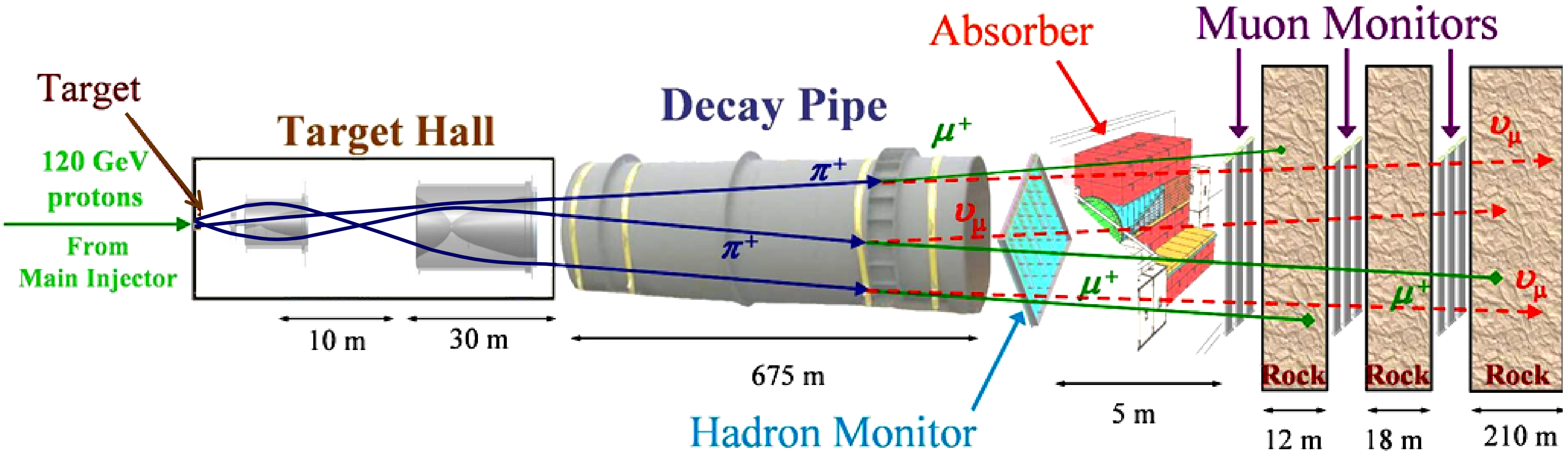


Off-axis beam from ME configuration



For a given θ≠0, a large range of pion energies contributes to a small range of neutrino energies

The NuMI beamline



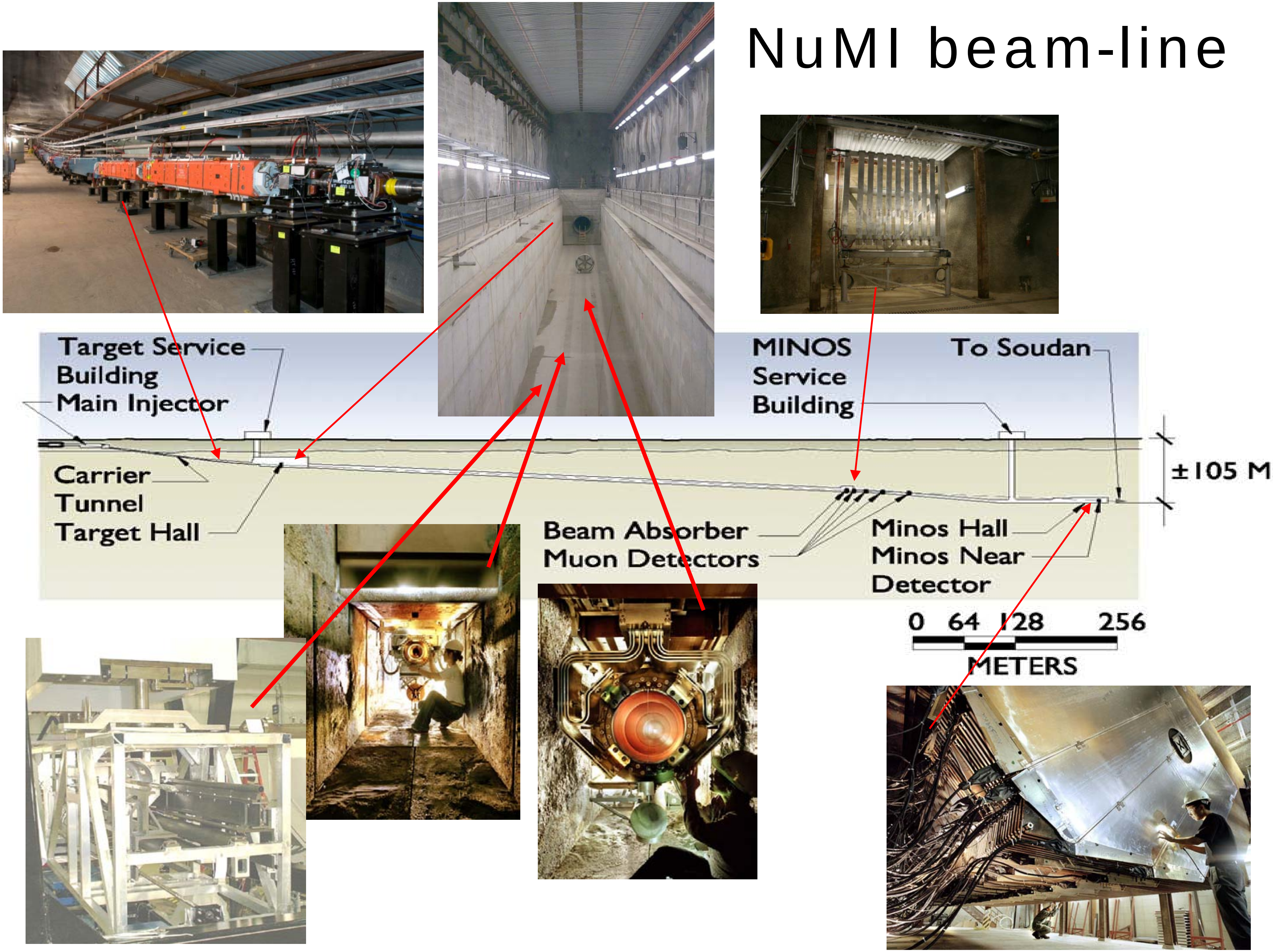
Water-cooled segmented graphite target

- 47 2.0 cm segments; total length of 95.4 cm

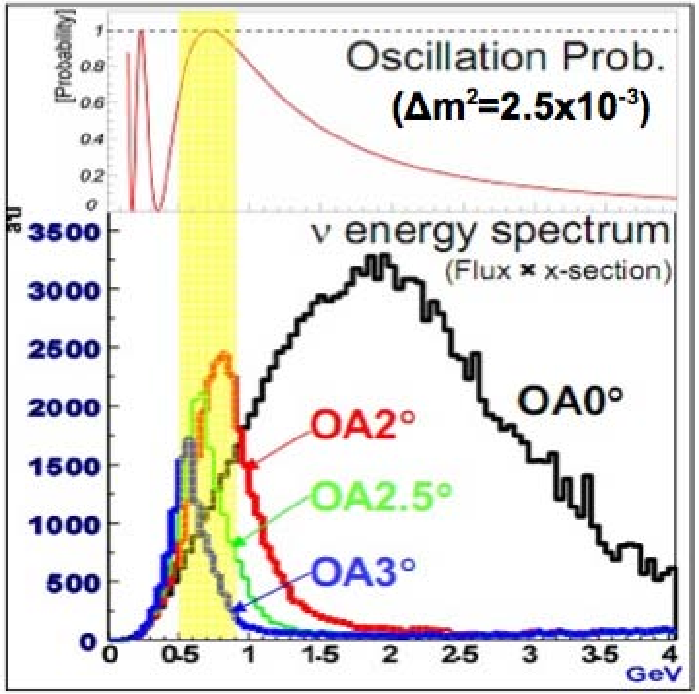
2 parabolic horns carrying

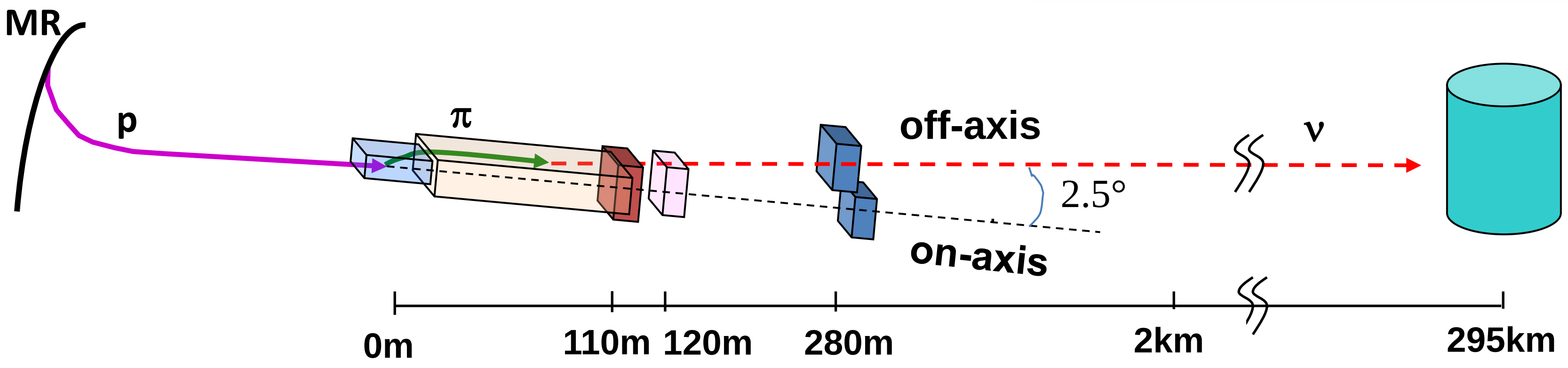
- Up to 200 kA current provides up to 3T fields
- Target can be remotely positioned up to 2.5m upstream of the first horn to change beam energy

NuMI beam-line

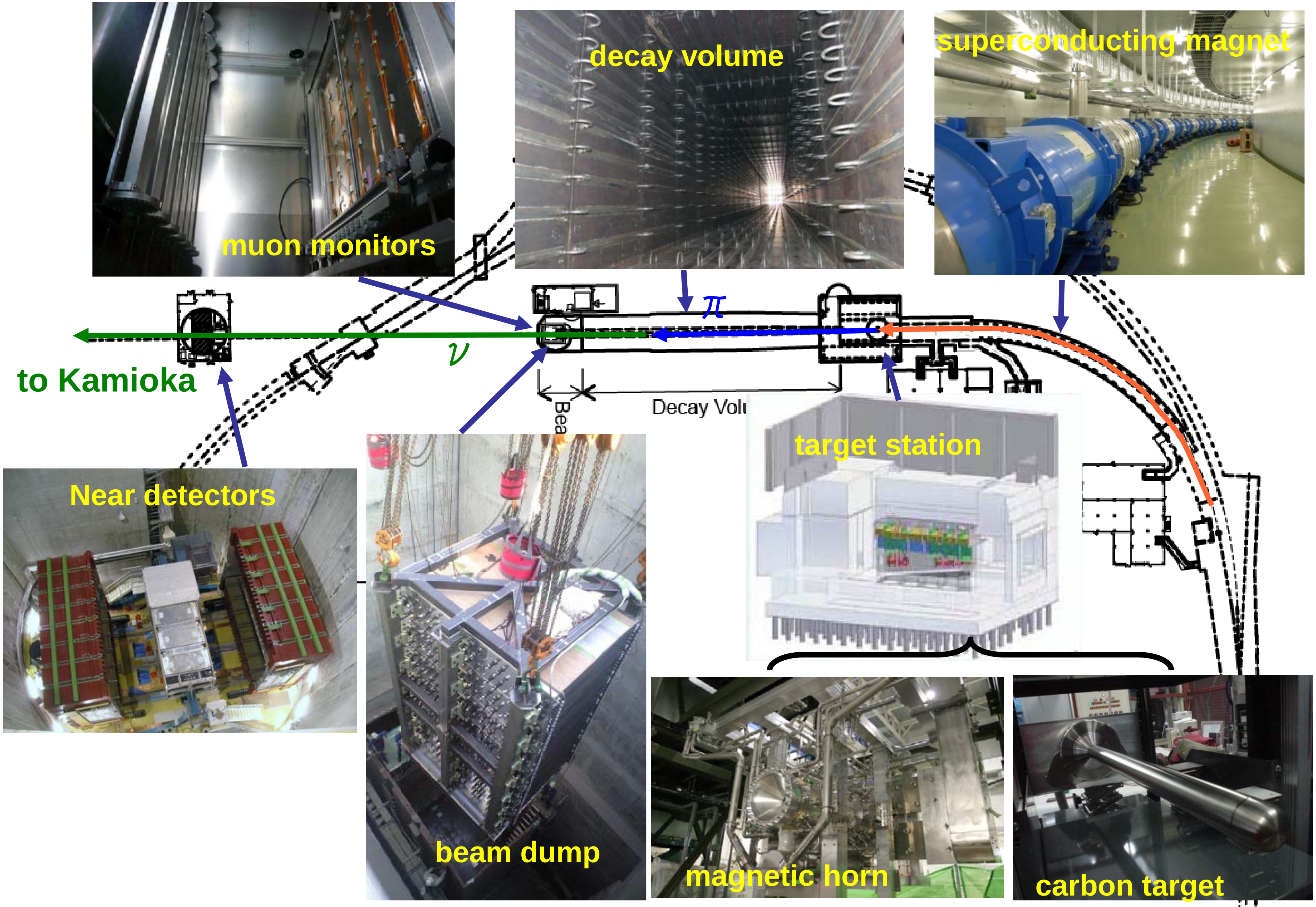


T2K: Tokai to Kamioka

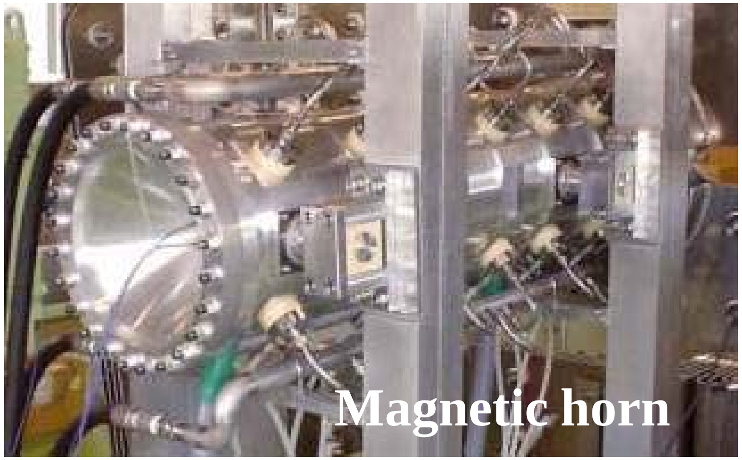


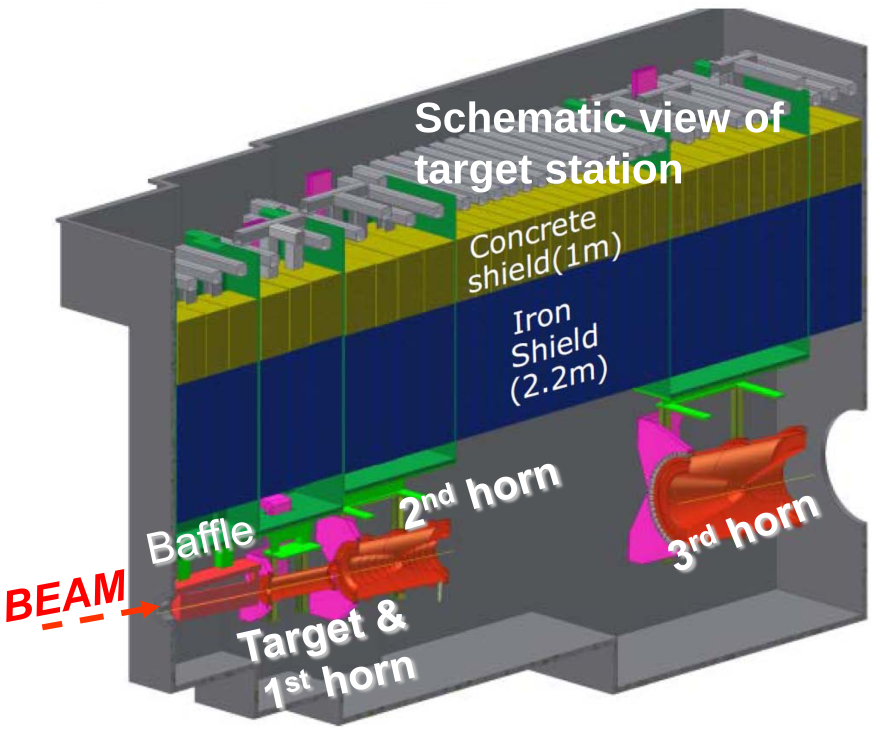


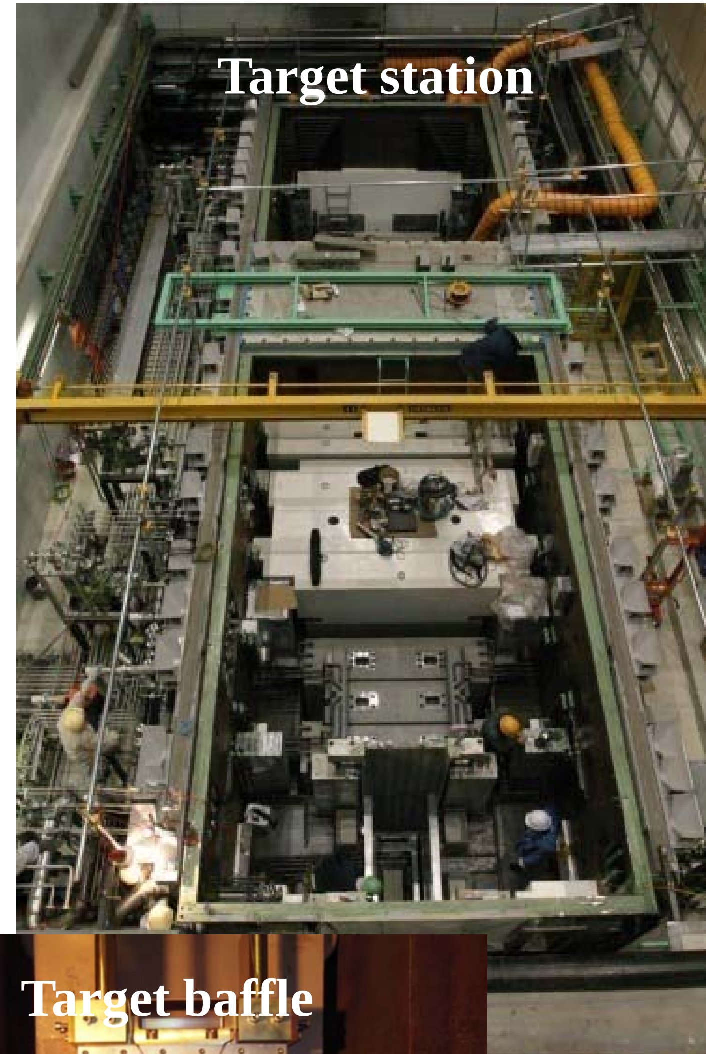
T2K ν beamline

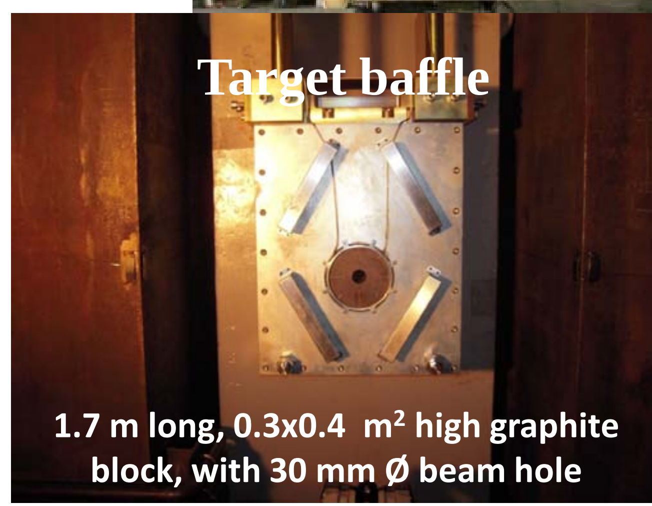


T2K target station

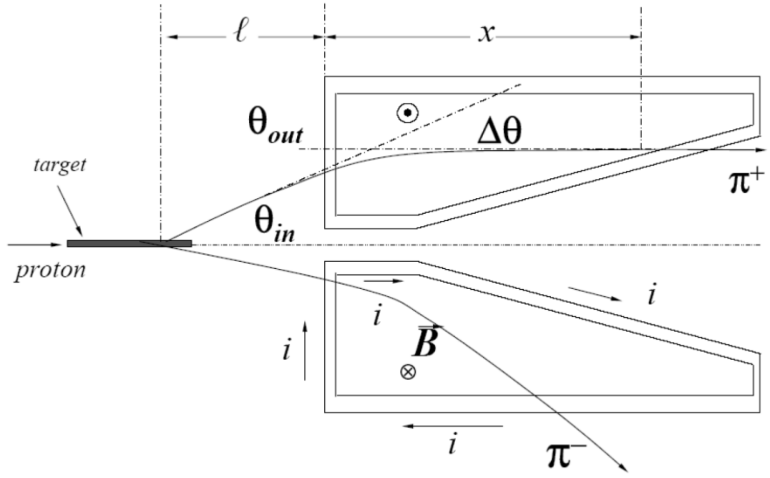




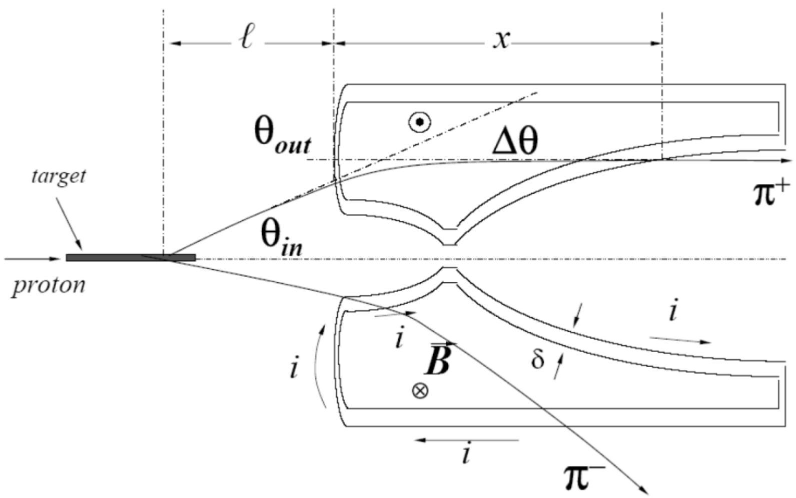




Focusing devices (Horns)

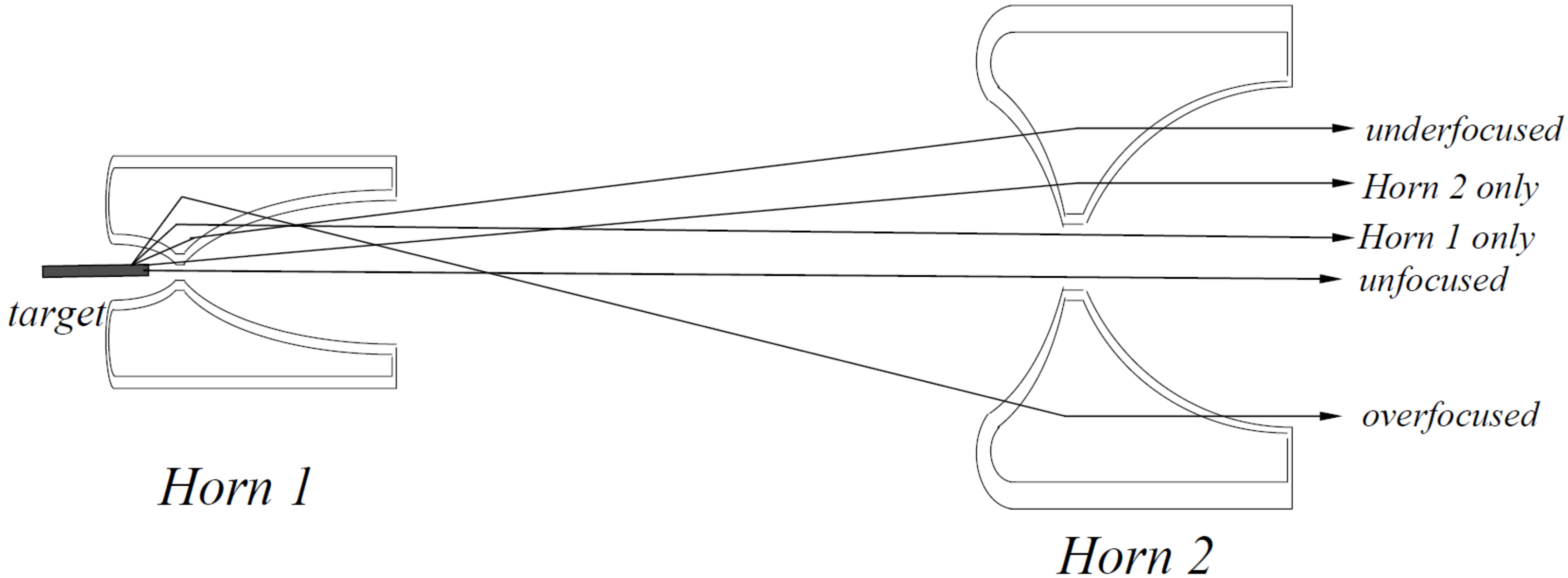


Focuses all momenta for a given angle of pion into the horn. It produces a broad band beam.

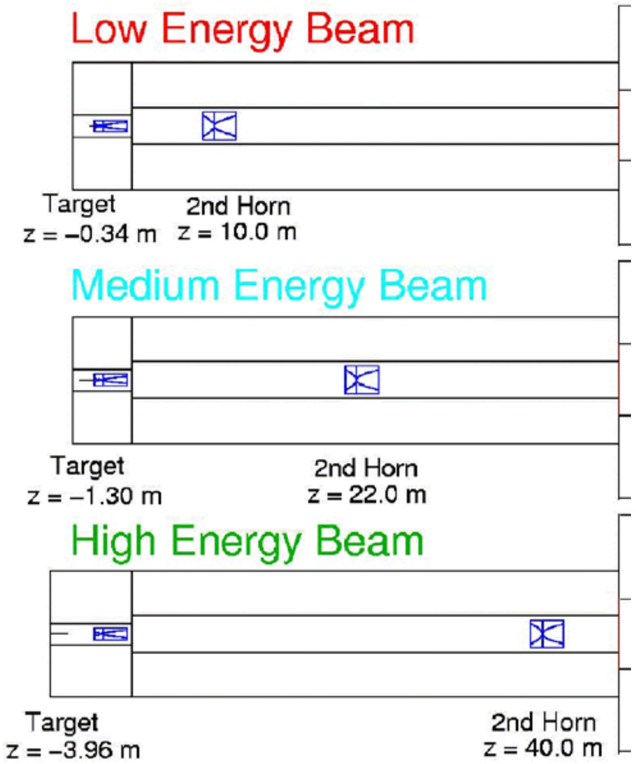


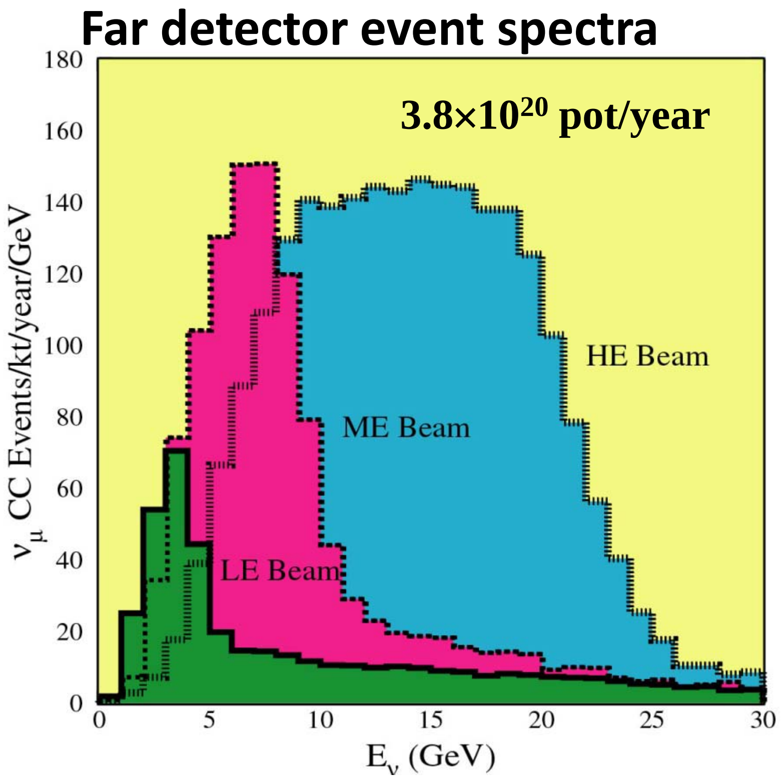
With a parabolic shaped horn inner conductor, the horn behaves like a lens (p_t kick proportional to the distance from the axis), with a focal length proportional to the momentum

Multi-horn systems



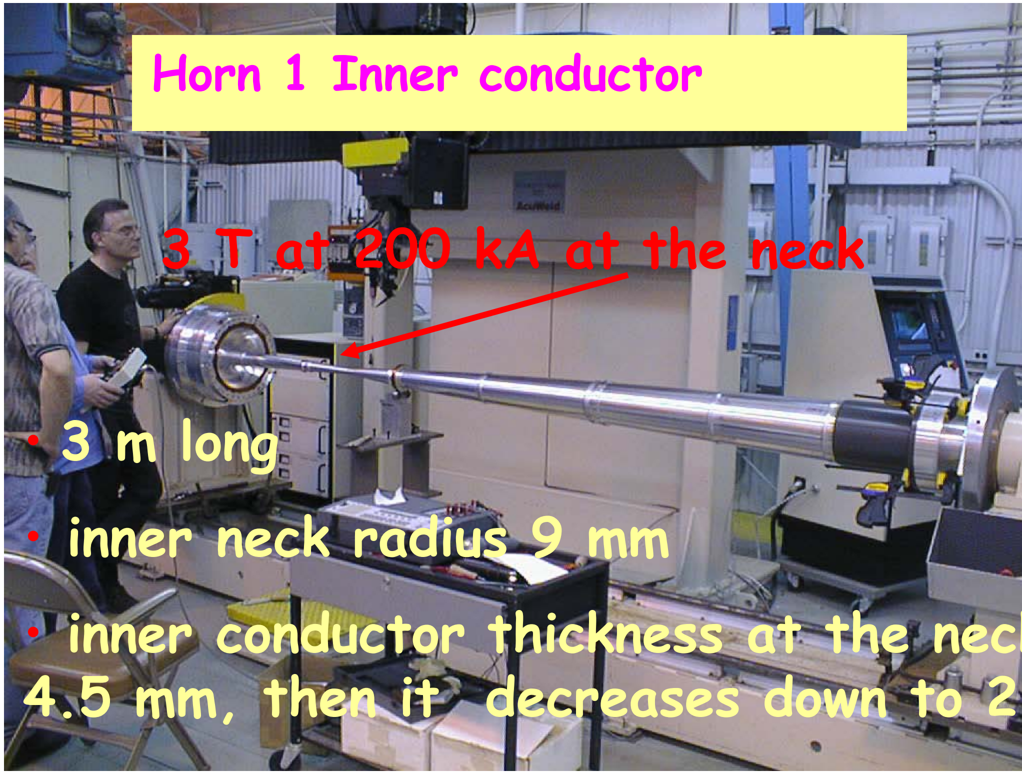
Multi-horn system: the NuMI case

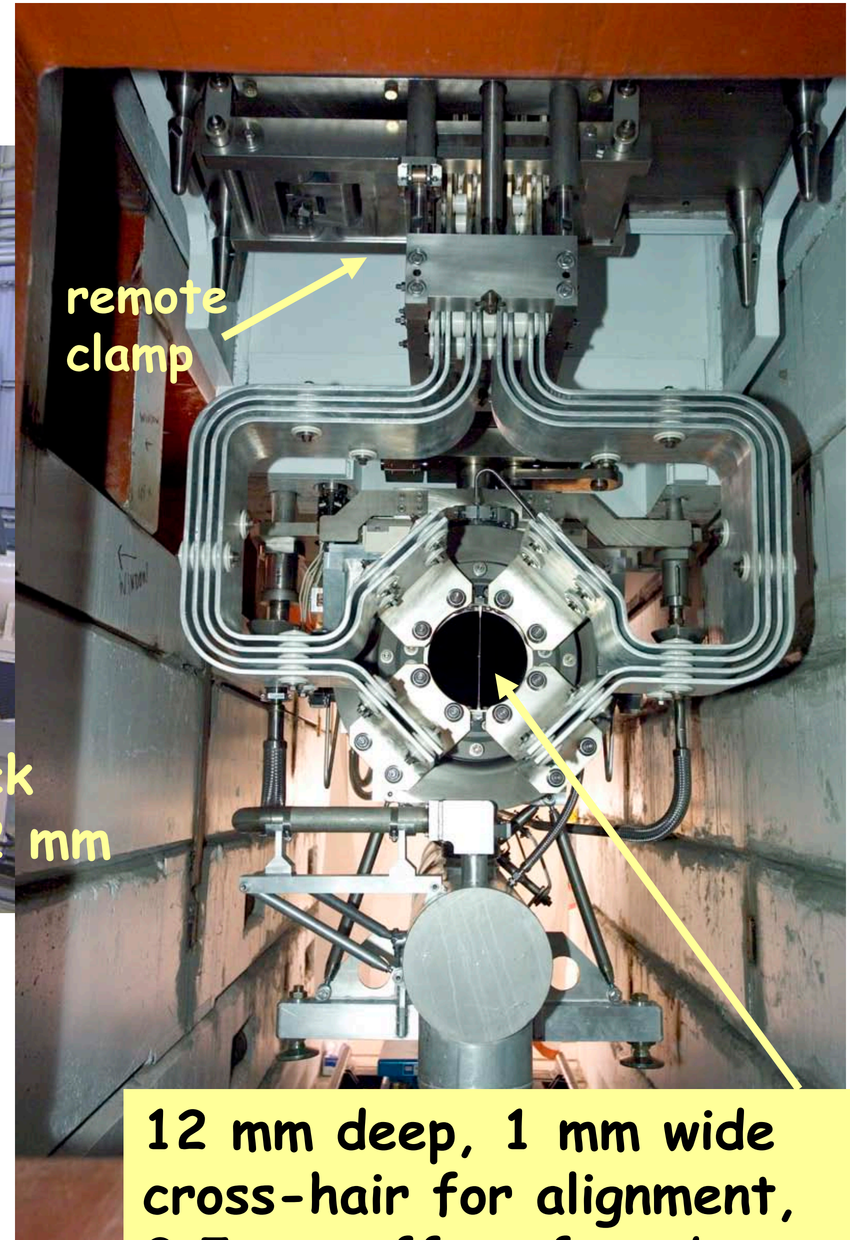




- Fully optimized spectra for each energy are obtained by moving the target and the 2nd horn, but most of the effect is due to the position of the target
- in LE configuration, 2/3 of the target length is positioned inside the 1st horn

NuMI Horn 1





- Made of Aluminum 6061
- Outer conductor anodized (corrosion, insulation)
- Inner conductor nickel plated (corrosion, fatigue)

12 mm deep, 1 mm wide cross-hair for alignment, 2.5 mm offset from beam center

Targets

NuMI target, 95.4 cm long

47 graphite segment, 20 mm long, spaced by 0.3 mm, $6.4 \times 15\ mm^2$ cross section, water cooled

T2K target

- Isotropic Graphite $1.8 g/cm^3$
- 26mm(Ø)x900mm(L), 1.9 λ_I
- Thermal shock stress ($\Delta T \sim 200K$) ~ 7MPa (< tensile strength 37MPa)
- Forced flow Helium gas cooling in Ti-alloy(Ti-6 A1-4V) container

Decay pipe and Hadron Absorber

T2K

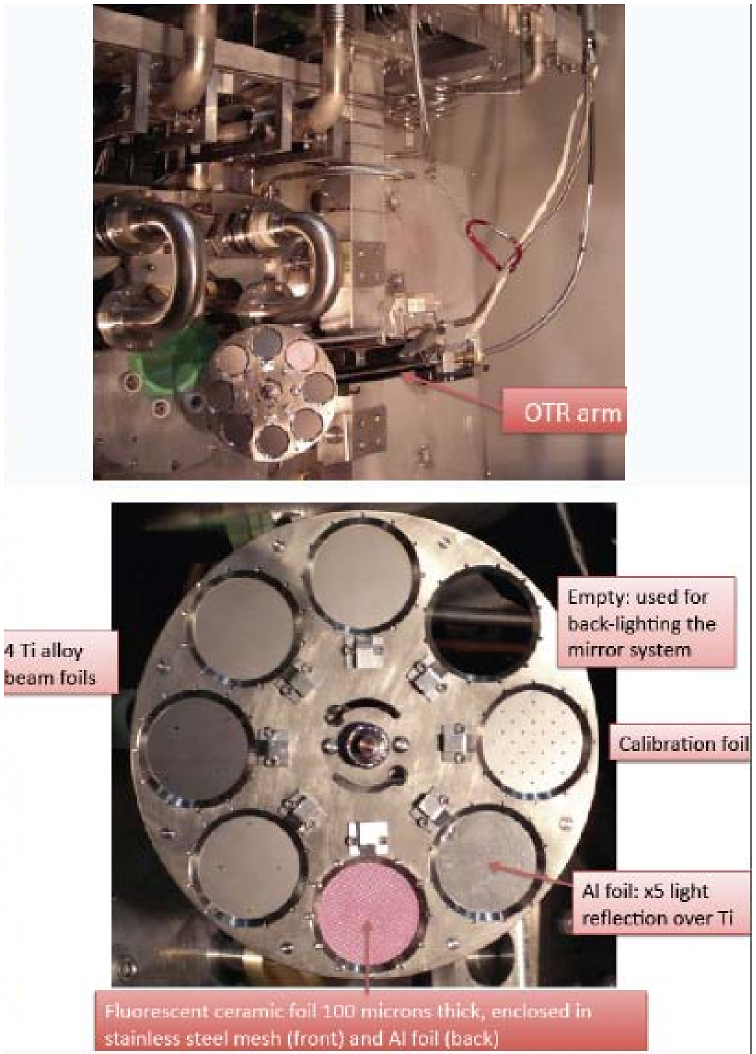
- 96 m long steel tunnel
- $1.4x1.7\ m^2$ at the upstream end
- $3.0x5.0\ m^2$ at the downstream end

Beam dump

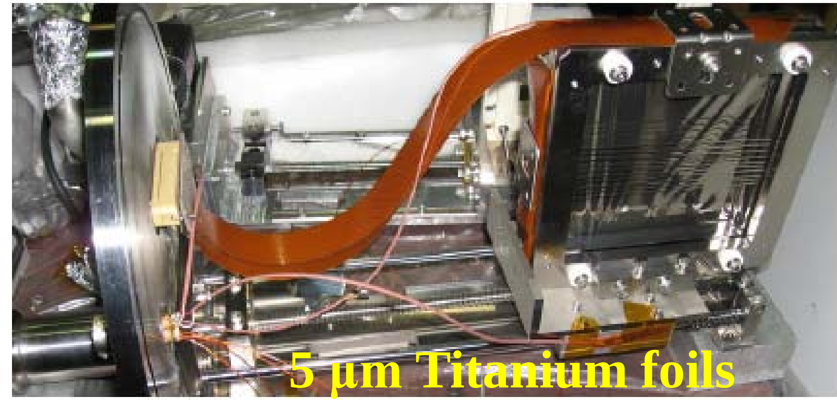
- Graphite blocks
- Water-pipe casted Al block attached to both side
- Up to 3 MW beam

Proton beam monitors

OTR, T2K

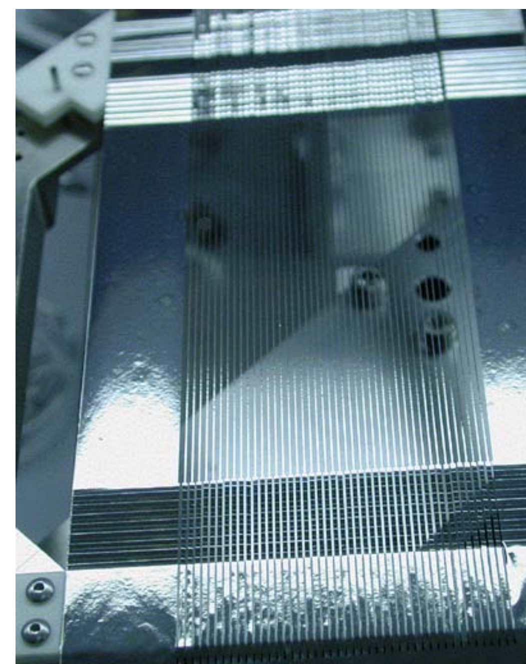


Profile monitor, T2K



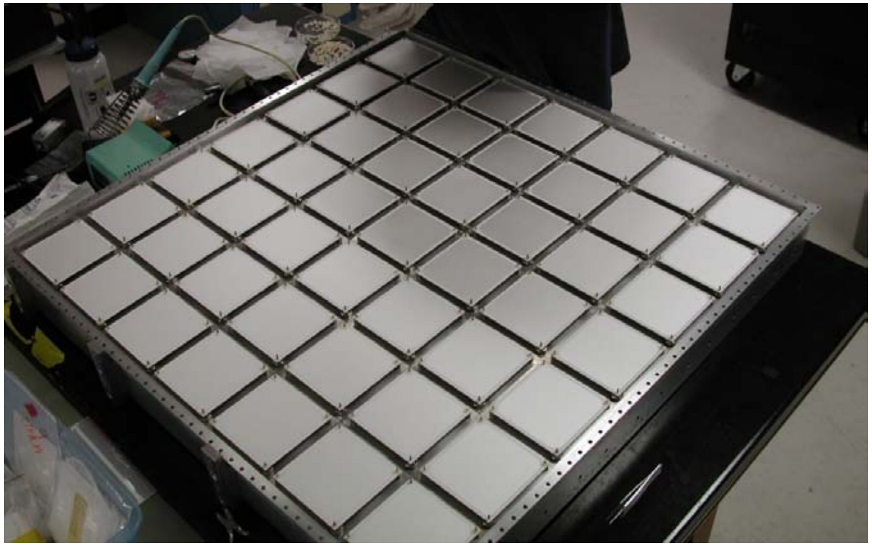
Profile monitor, NuMI

- 5 µm Titanium foils
- Pitch 1 mm (8 units) or 0.5 mm (2 units)



Hadron/Muon Monitors

NuMI Hadron Monitor
@ end of decay pipe
Max flux ~ 10^9 part./cm^2/spill



4”×4” He parallel plate ion chambers
ceramic wafers with Ag-Pt electrodes

T2K Muon Monitor
sensor array covering 150 x 150 cm^2

Ionization chamber array
49 sensors 75 x 75 mm^2
ceramic parallel plate chambers
He with 1% N_2

Silicon PIN
photodiode array
49 sensors 10 x 10 mm^2
>0.1% resolution in intensity