# Challenges for Multi-Megawatt Neutrino Beamlines

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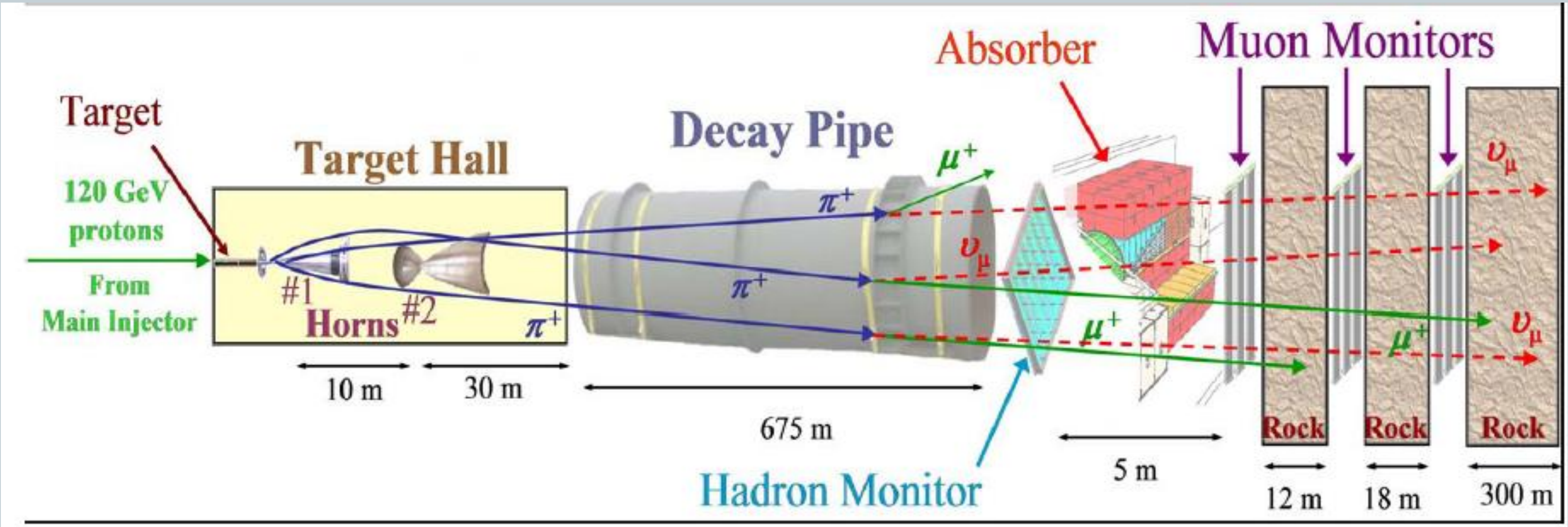
FERMILAB
APS DPF JULY 27, 2009

# Conventional Neutrino Beamline: $\pi^+ \rightarrow \mu^+ + \nu_\mu$




- Neutrino Energy Spectrum
- Lots of ν's
  - Lots of protons
  - Horns to focus pions
- Neutrino Beam Purity

Examples:

CNGS / CERN

NuMI / Fermilab

T2K / JPARC

# Evolution of Beam Power

300 kW → 750 kW → 2-4 MW

| Lab | Operational | Next Step | Future |
|---|---|---|---|
| FNAL<br>120 GeV Protons | 320 kW<br>(NuMI/MINOS) | 700 kW<br>(NuMI/NO$\nu$A) | 2.1 MW Project X<br>(LBNE/DUSEL) |
| CERN<br>400 GeV Protons | 300 kW<br>(CNGS/OPERA) | 750 kW<br>(CNGS) | 4 MW SPL<br>to new $\nu$-beam |
| J-PARC<br>30 GeV Protons | 100 kW in 2010<br>(T2K) | 750 kW in 2011<br>(T2K) | Roadmap to 1.7 MW |

Other neutrino sources (not part of this talk):

- Neutrino Factories
- Beta-beams
- Reactor Sources

INTERESTING TALKS AT NUFACT09
HTTP://NUFACT09.IIT.EDU/

# NuMI

2005 beam started for MINOS

230 kW when running steady

320 kW max without Collider Ops.

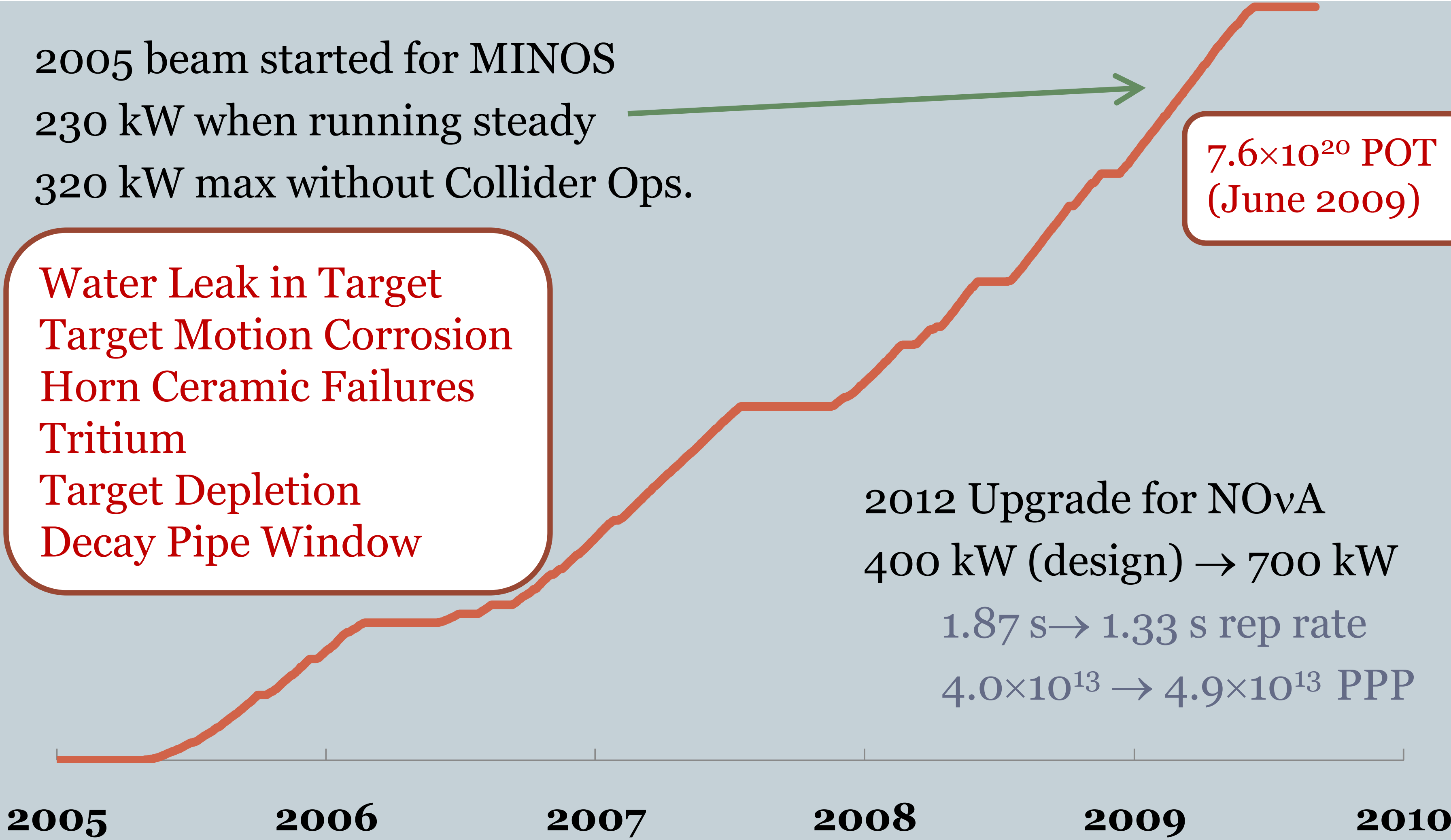
Water Leak in Target
Target Motion Corrosion
Horn Ceramic Failures
Tritium
Target Depletion
Decay Pipe Window

$7.6\times10^{20}$ POT
(June 2009)

2012 Upgrade for NOνA

400 kW (design) → 700 kW

- 1.87 s→ 1.33 s rep rate
- $4.0\times10^{13} \rightarrow 4.9\times10^{13}$ PPP

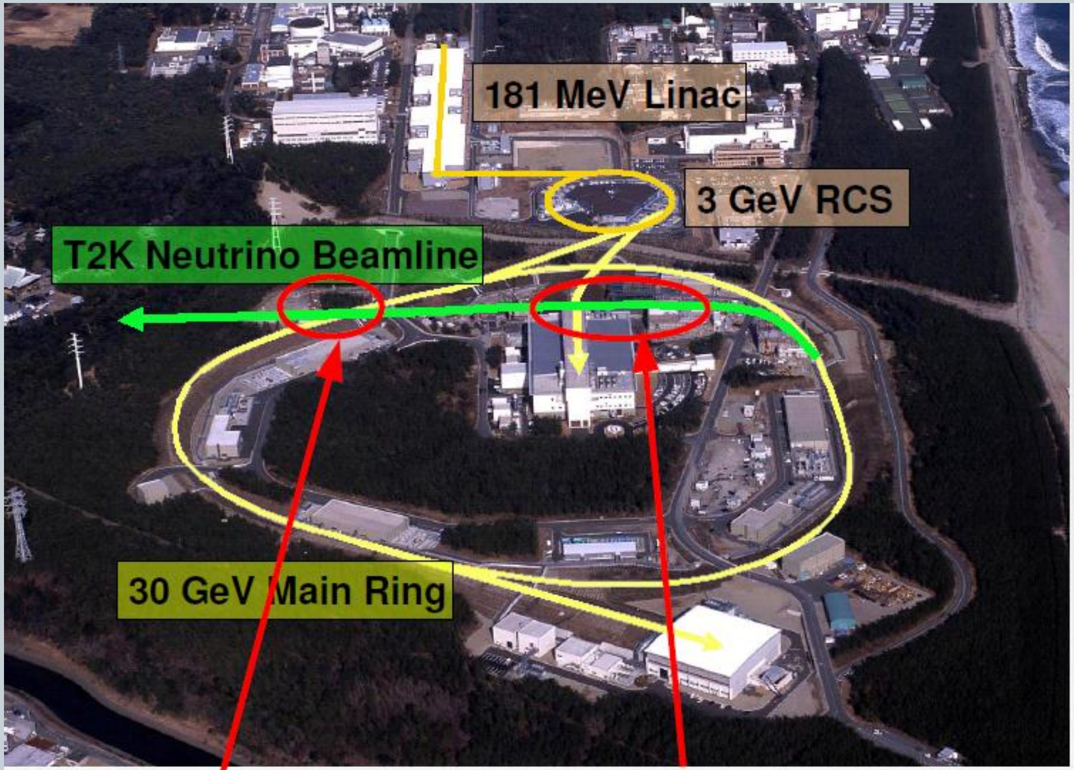


# CNGS

- First operated in 2006
- 2008 Run
  - $1.78 \times 10^{19}$ protons on target.
  - Intensity per pulse reached 2×1c
- The CNGS-1 beam configura
  - $1.2 \times 10^{20}$ pot/yr at 400 GeV/c; power of 512 kW
  - without substantial increases of the SPS performance.


Horn Ceramic Failures
Radiation Shielding
Stripline cable
Earths Magnetic Field

# JPARC




280 m on-axis and off-axis neutrino detectors

Neutrino target hall, decay volume, muon detector

<u>T2K Neutrino Beamline</u>

Design Goal:

- 750 kW
- 30 GeV beam

Initial Commissioning:

- Spring 2009

Physics Running:

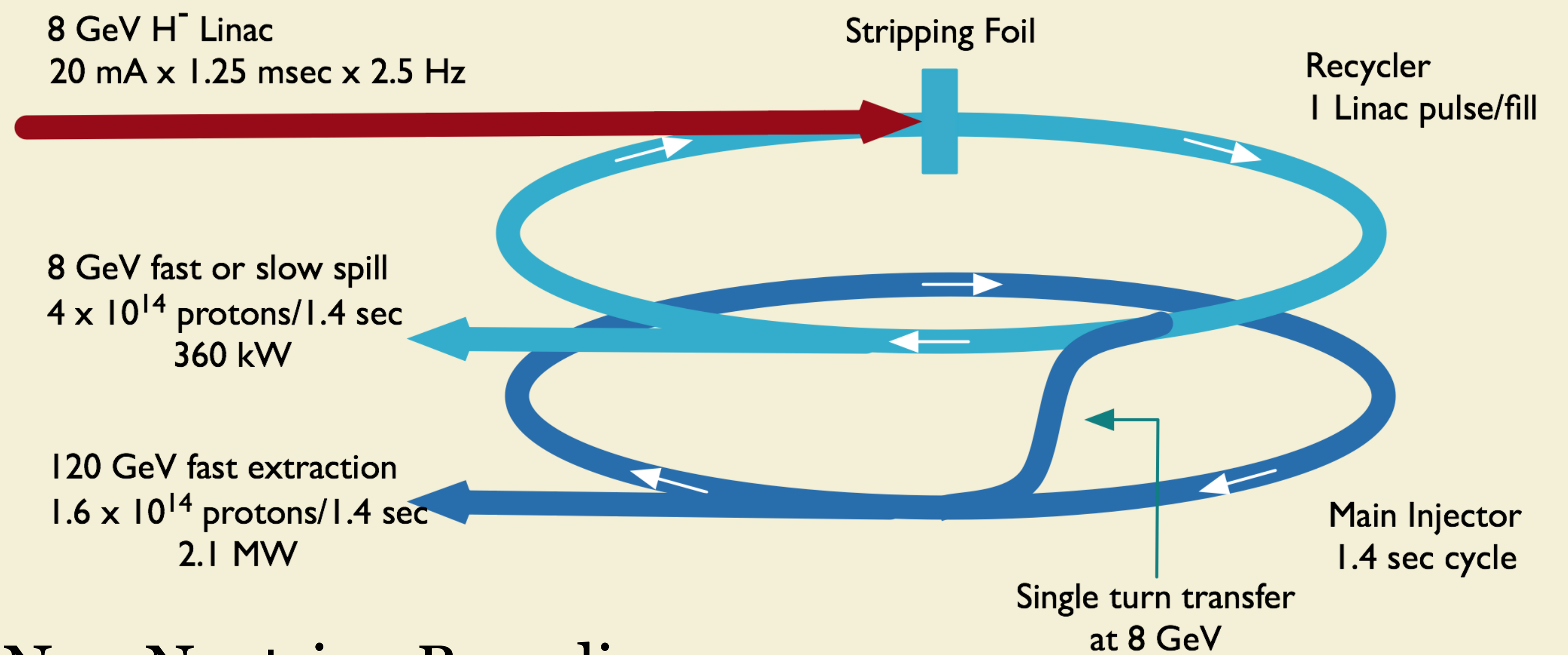
- December 2009

Start at 100 kW ramp up to 750 kW

# Fermilab: Project-X

8 GeV Linac front end to existing Recycler and Main Injector

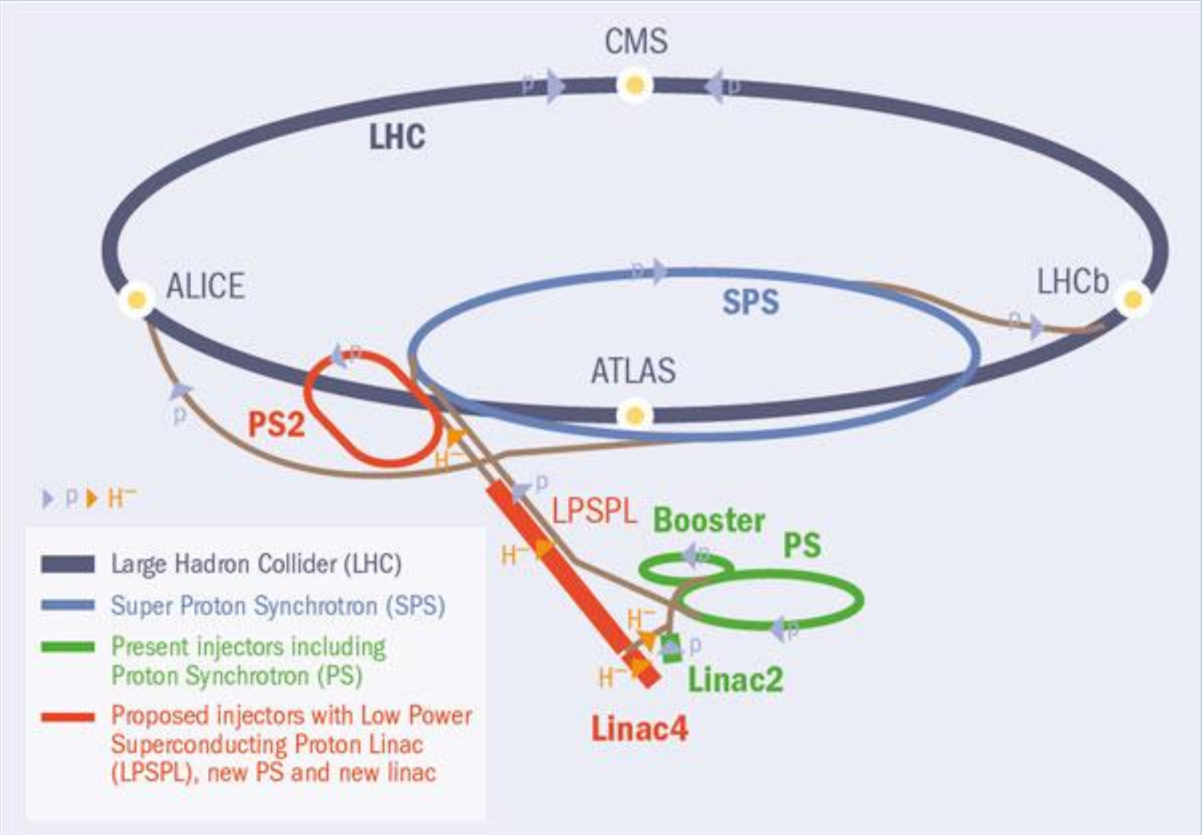
Provide 2 MW between 60 to 120 GeV




New Neutrino Beamline

Fermilab to Homestake

# CERN path to superbeam



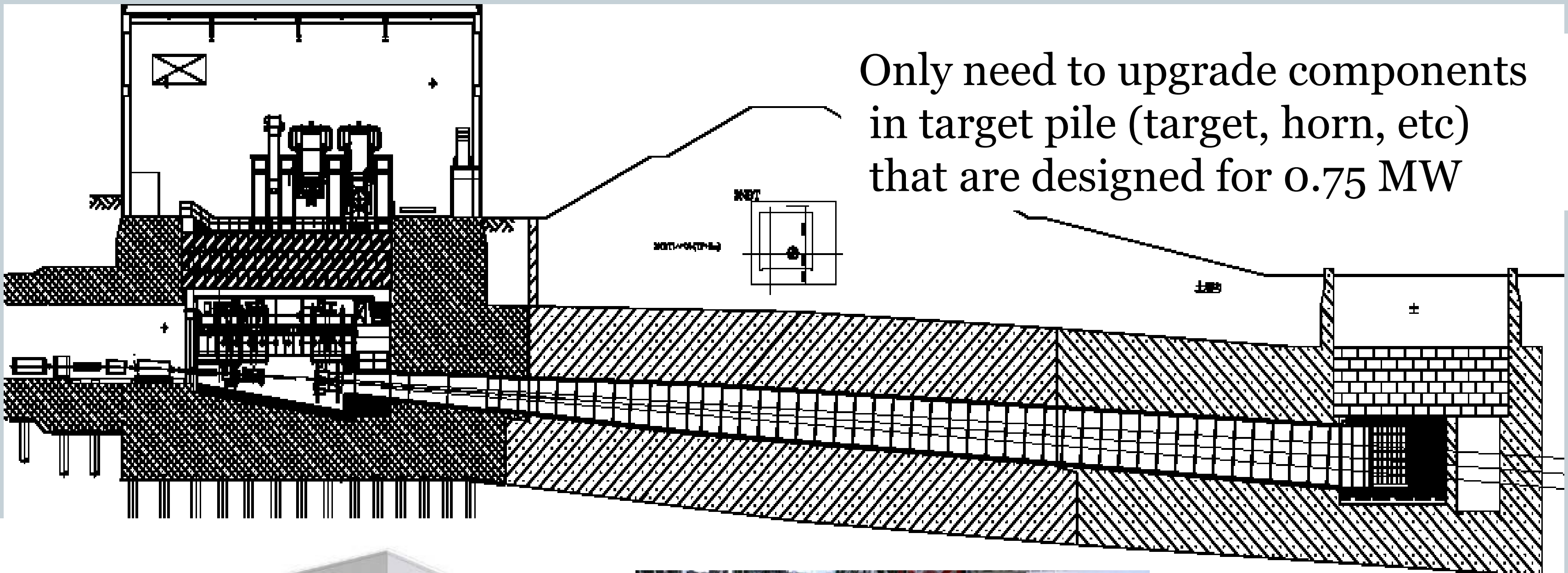

<u>New injectors</u>

- Linac4 (2013)
  - → 160 MeV
- LPSPL (2017)
  - → 4 GeV
- PS2 (2017)
  - → 50 GeV

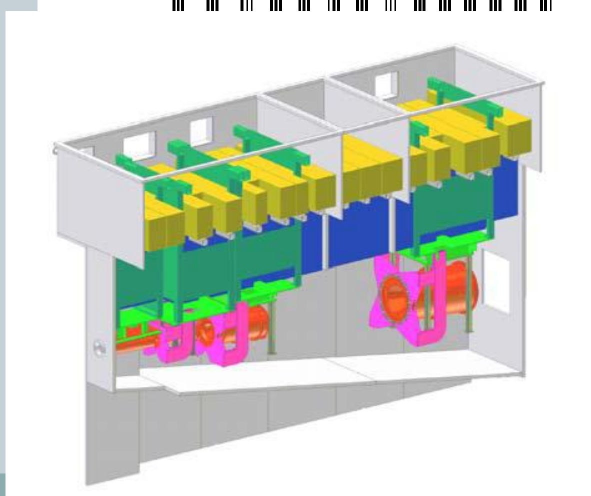
Then upgrade LPSPL to

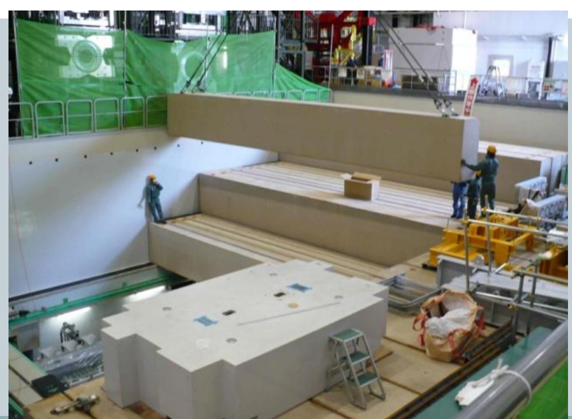
4 MW SC Proton Linac (SPL)

# Target pile, Decay pipe, Absorber at T2K already built for 4 MW Superbeam !



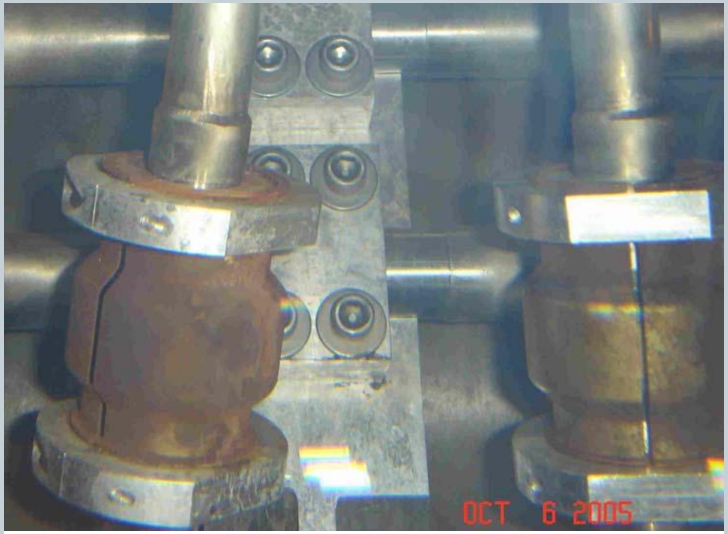
Only need to upgrade components in target pile (target, horn, etc) that are designed for 0.75 MW



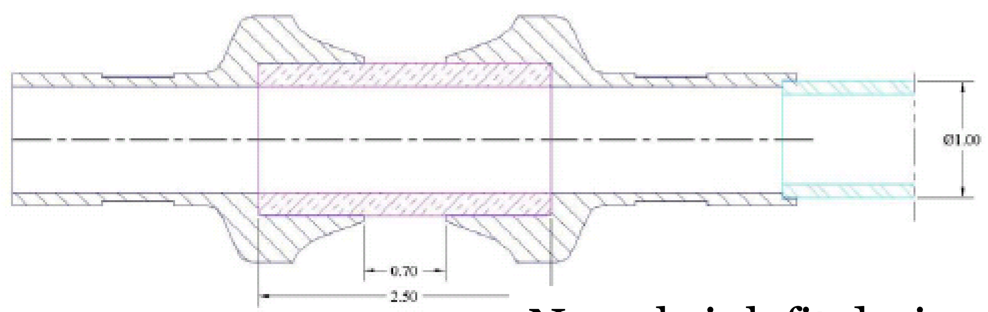


# NuMI Horn Experience (Water)

- Three water line ceramic assembly failures
  - First two were replaced on a hot component
  - Last failure resulted in Horn 1 replacement (too hot) replacement




Leaking Isolator Assembly
Upstream End of Horn 1




New shrink fit design

<u>Plan for repairs at design stage.</u>
NuMI originally planned for complete replacement. Were able to repair twice.

CNGS 2006 run end due to overstress of the ceramic insulator of outlet connectors

# Corrosive Environment

- Chains holding up the Mini-Boone intermediate absorber failed
  - Design strength safety factor of four on the chain.
  - Chain was not in the beam path

- Radiation in humid air creates nitric acid (and Ozone …)
- High strength steel does not like hydrogen (embrittlement)

# Corrosive Environment

Missing high strength washers

NuMI problems with radiation induced accelerated corrosion:

Stripline Clamp Failure

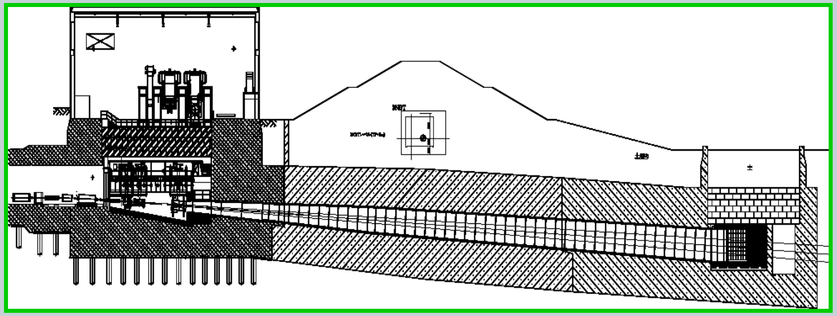
Decay Pipe Window Corrosion

More resources should be applied to general studies of air + radiation, etc

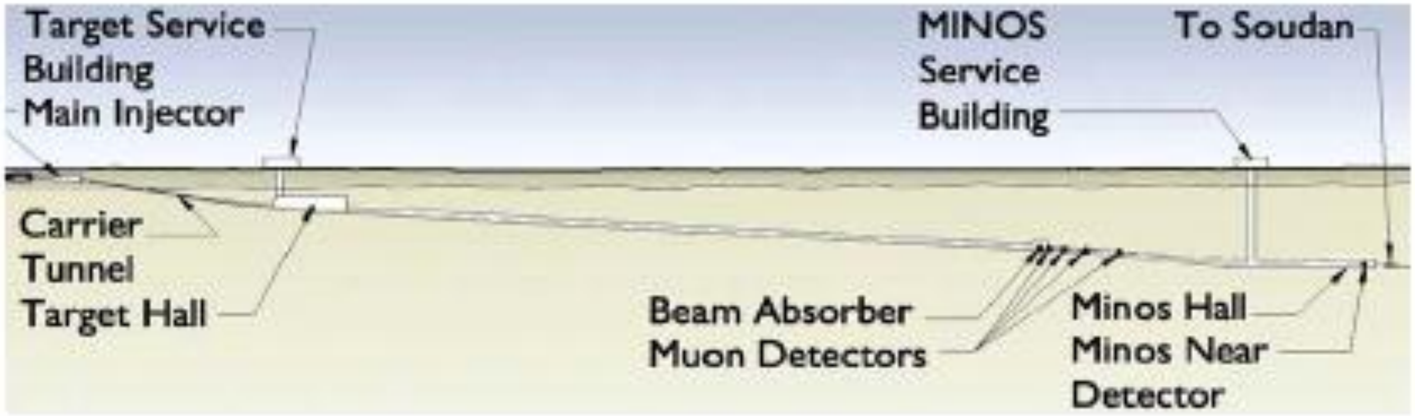
-- we are in rather unusual environmental conditions !

# Decay Pipes

- NuMI was under vacuum
  - Switched to helium gas near atmospheric pressure.
- CNGS under vacuum
- T2K has both target hall and decay region filled with helium



# NuMI Radiological Issues

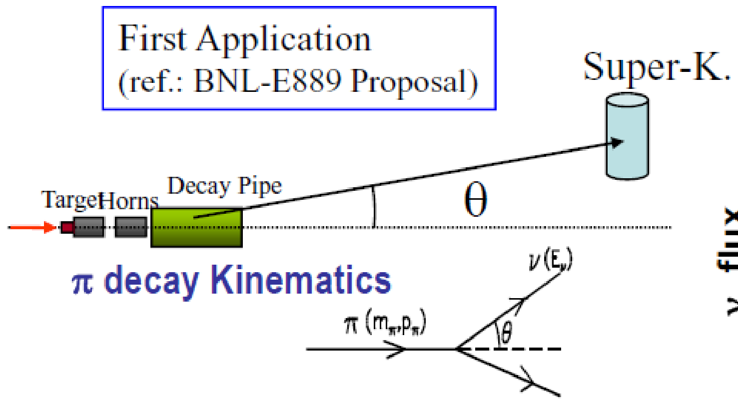


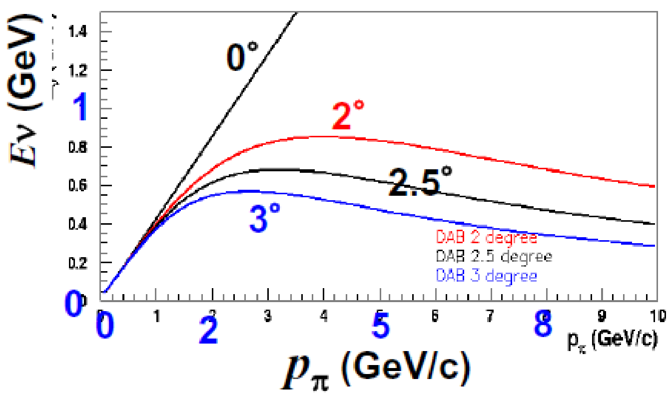

- Tritium Levels
  - Very low compared to regulatory limits, but important to keep them low
  - Source traced to production in the target shielding then carried into the tunnel region by humidity
  - Remedied through dehumidification of target hall
- T2K target hall operates in helium.

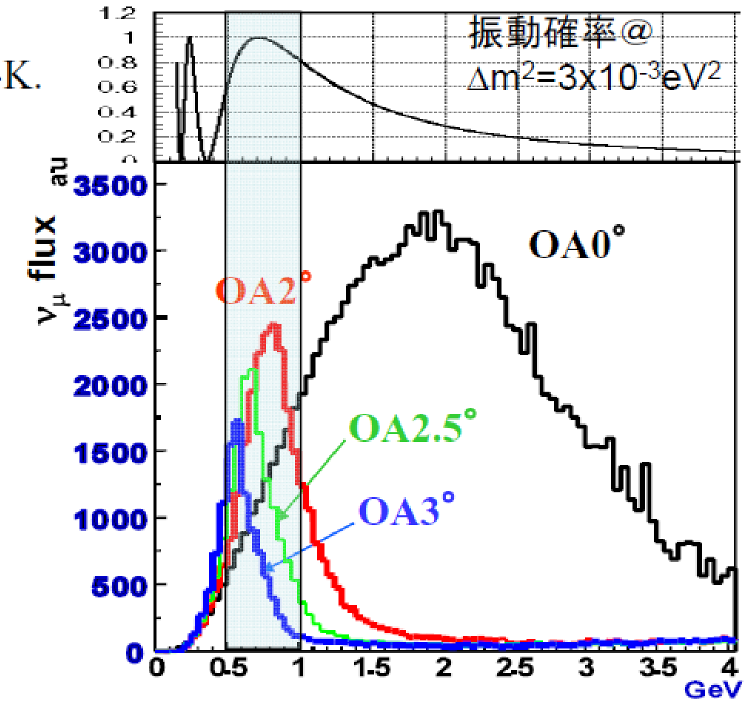
# Neutrino spectrum

- In general, desire neutrino flux at oscillation maximum, so want $E_\nu$ = 2 GeV L/1000 km
- What base-line is desired ? 250 to 1700 km (LBNE longer L to see matter effects)
- Narrow band beam (reduce backgrounds from ν outside oscillation max.) or wide band (see both 1st and 2nd oscillation peaks to resolve ambiguities) ?
- Can detector do event sign selection, or does beam need to switch between ν and ν ?
- Balance between higher ν statistics and background reduction ?

# T2K off-axis beam




- Quasi Monochromatic Beam
- x 2~3 intense than NBB
- Tuned at oscillation maximum

T.Kobayashi (KEK)

**Statistics at SK**

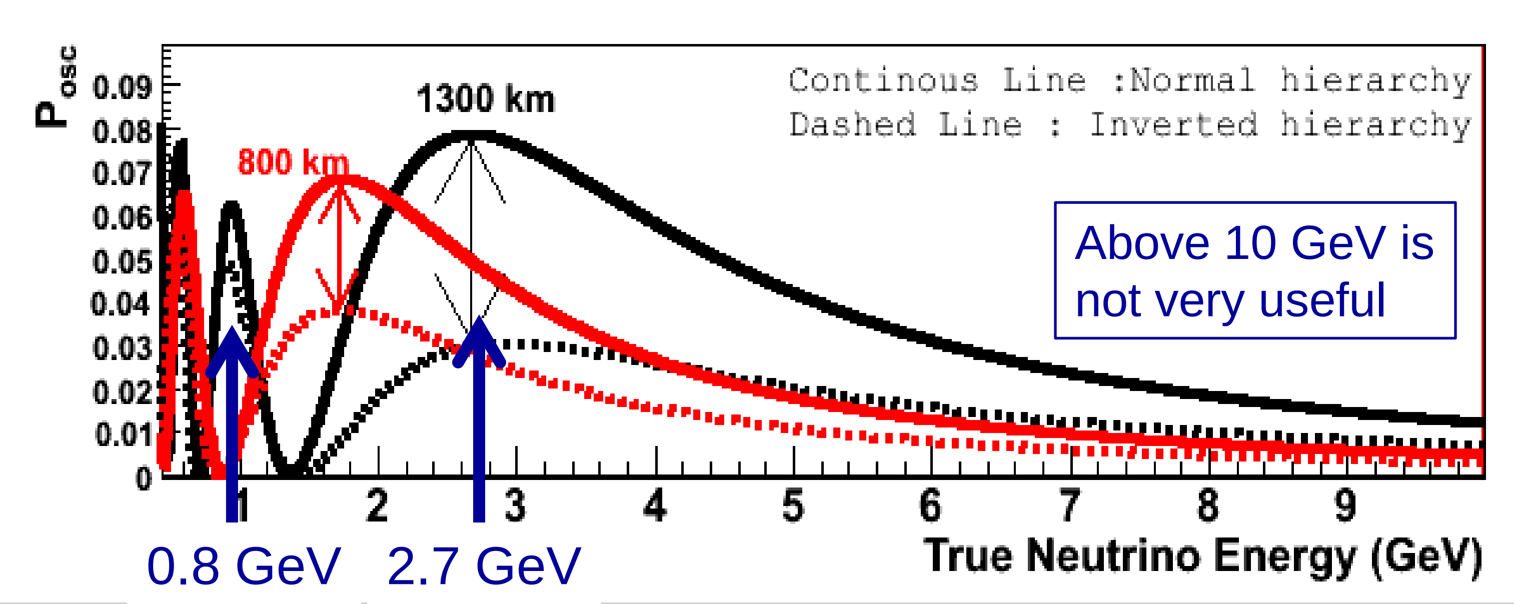
**(OAB 2.5 deg, 1 yr, 22.5 kt)**

**~ 2200 $\nu_\mu$ tot**

**~ 1600 $\nu_\mu$ CC**

**$\nu_e$ ~0.4% at $\nu_\mu$ peak**

# LBNE (FNAL to DUSEL)



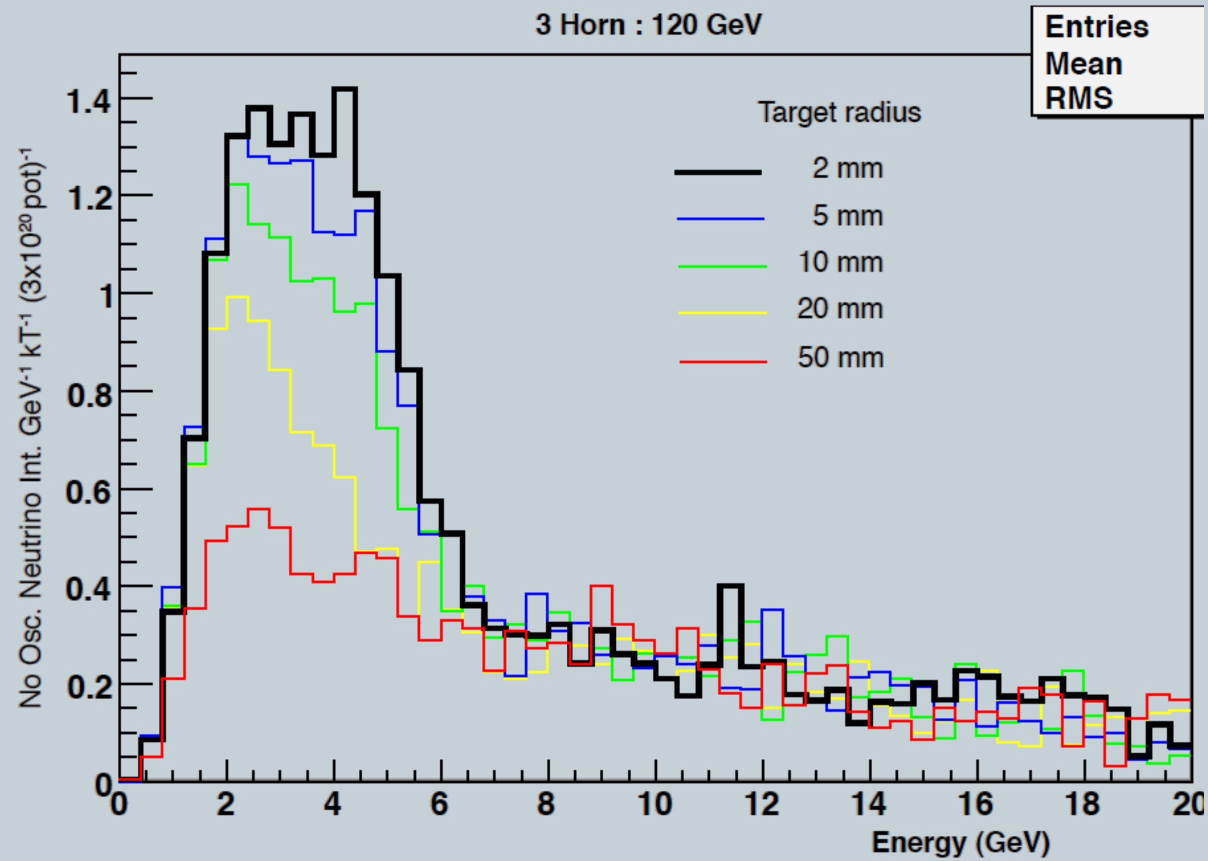

Cover the 1st and 2nd oscillation maximum

Want a wide band beam

Probably an on-axis horn focusing beam,

with target shoved into the first horn (π angle from target ~ 0.1 GeV / $E_\nu$)

# LBNE Example




3 horn (T2K style) focusing but on-axis, horn radius changing with target radius

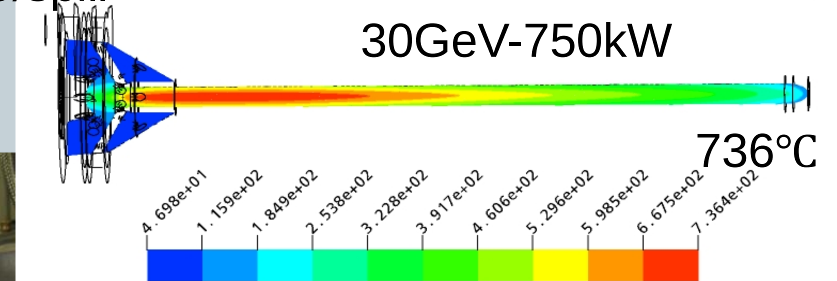
Similar conclusion:

$R_{target}$ < ~10 mm for LBNE

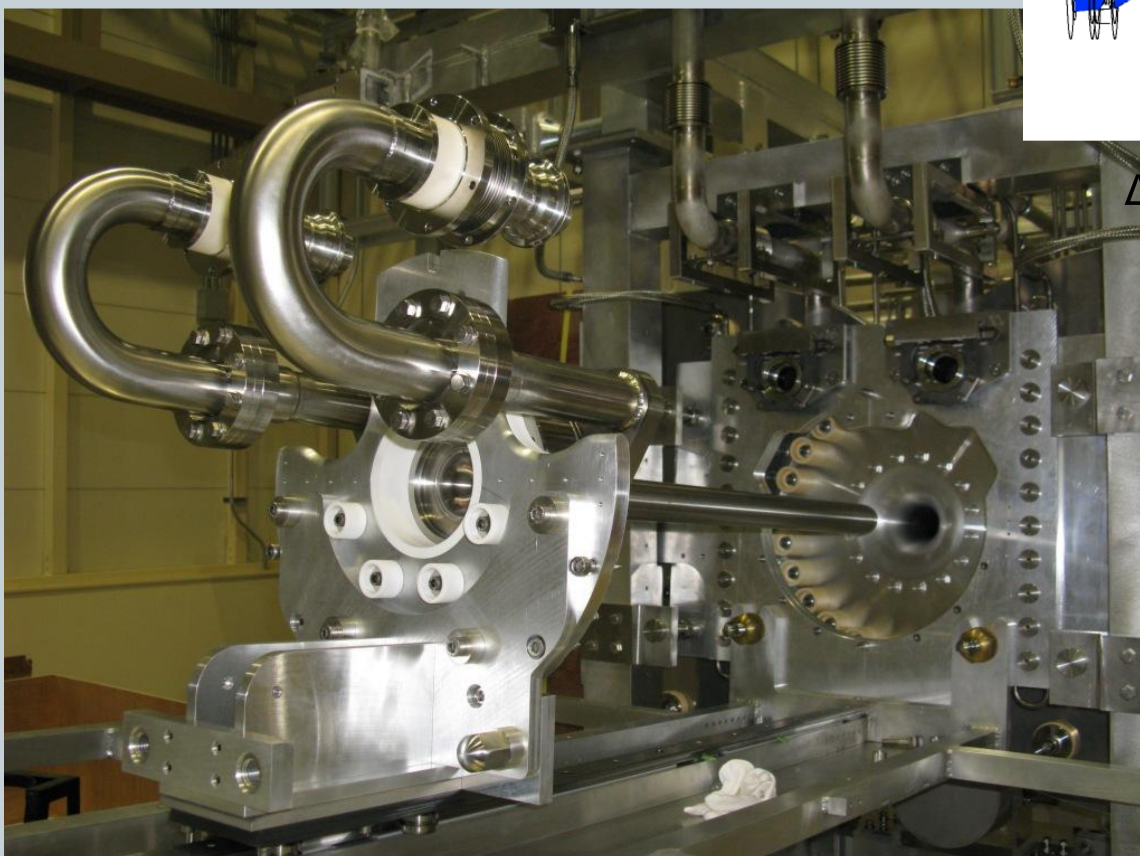
Less impact at lower $E_{\nu}$

# T2K Target for 0.75 MW

58kJ/spill




ΔT~200K ~7MPa(Tensile 27MPa)



Helium-Cooled Graphite Target in the 1st Horn

# IHEP NOVA-Project X 2MW target

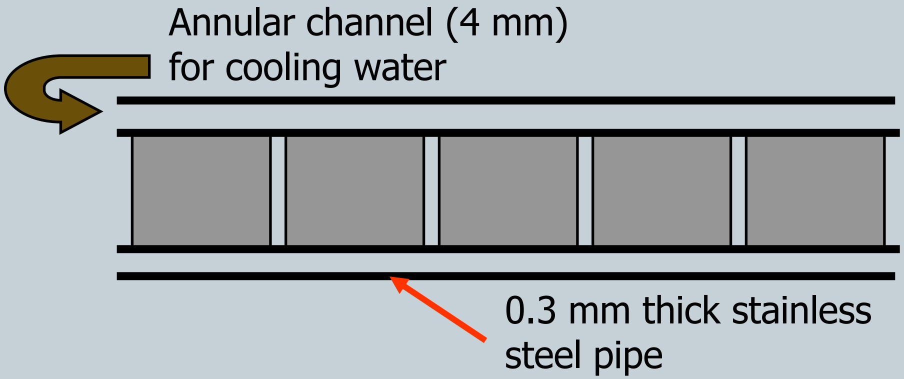
From 2005 study of graphite encapsulated in Al or steel sheath, with water cooling, graphite target stress and temperature were OK for 1.5e14 PPP 2 MW beam.

Remaining issues were:

• Hydraulic shock in cooling water (150 atm.) *(suggested using heat pipe to solve)*

• Radiation damage lifetime *(est. at 1 year but not well known)*

• Windows




***NUMI Target for 2 MW upgrades (IHEP, Protvino)***

# NuMI target experience

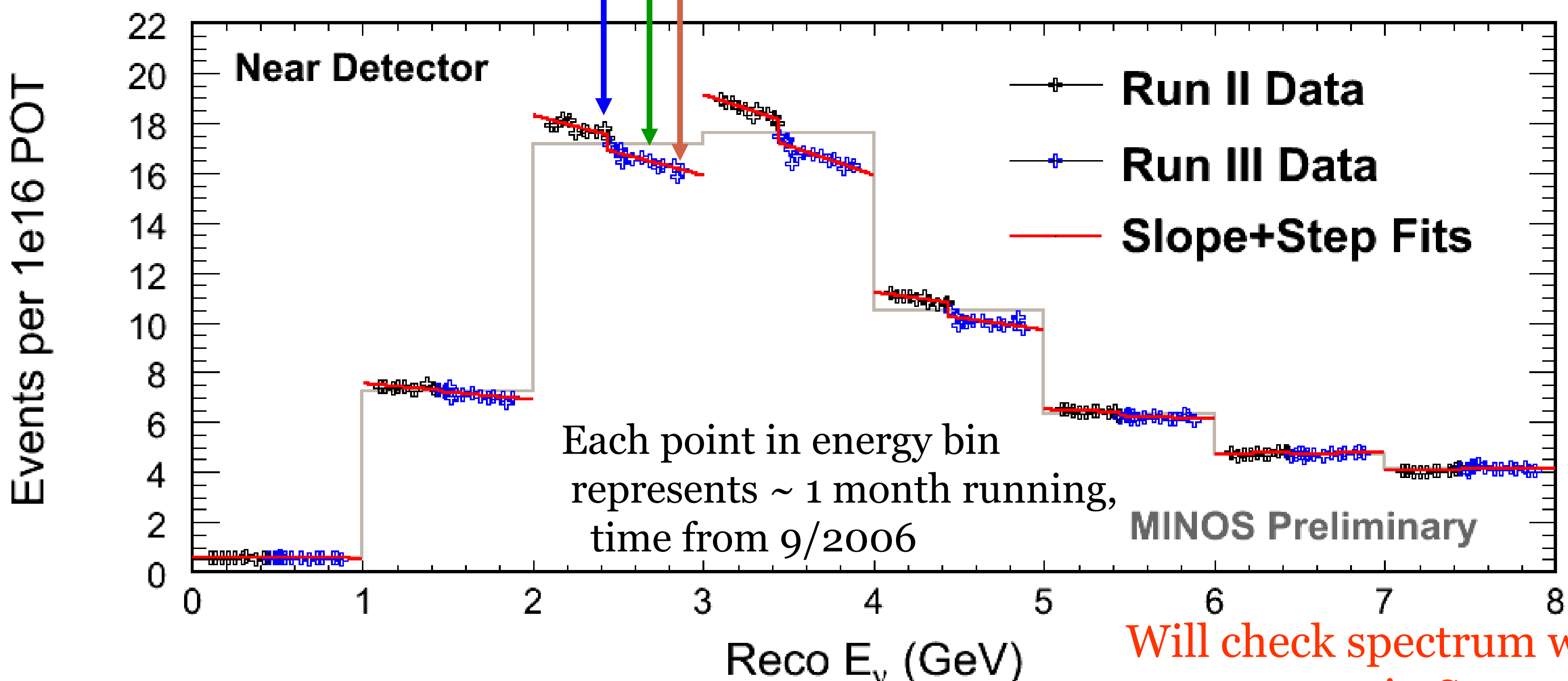
( ZXF-5Q amorphous graphite )

Gradual decrease in neutrino rate attributed to target radiation damage

Decrease as expected when decay pipe changed from vacuum to helium fill

No change when horn 1 was replaced

No change when horn 2 was replaced

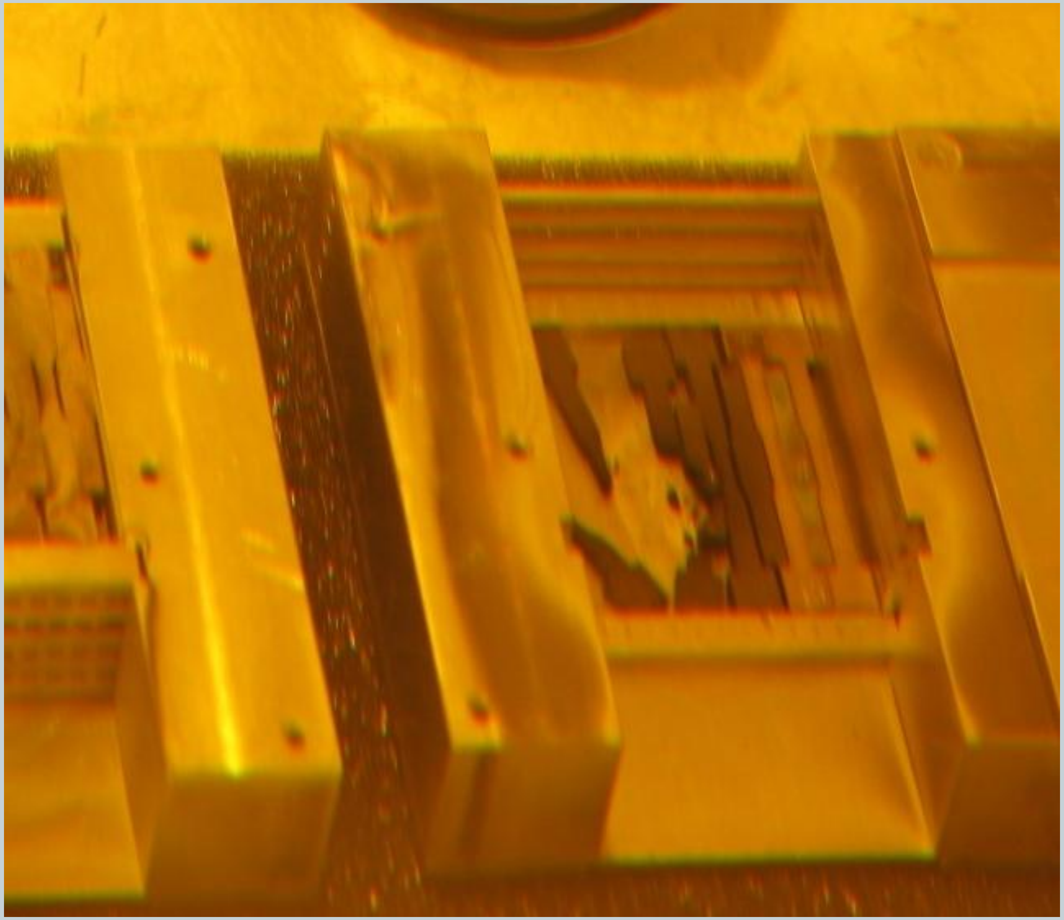



Each point in energy bin represents ~ 1 month running, time from 9/2006

Will check spectrum with new target in Sept.

# Radiation Damage test in IG43 Graphite

*- data from Nick Simos, BNL*



200 MeV proton fluence

~10^21 p/cm$^2$

Scary, this is about how many p/cm$^2$ NuMI gets in a couple months

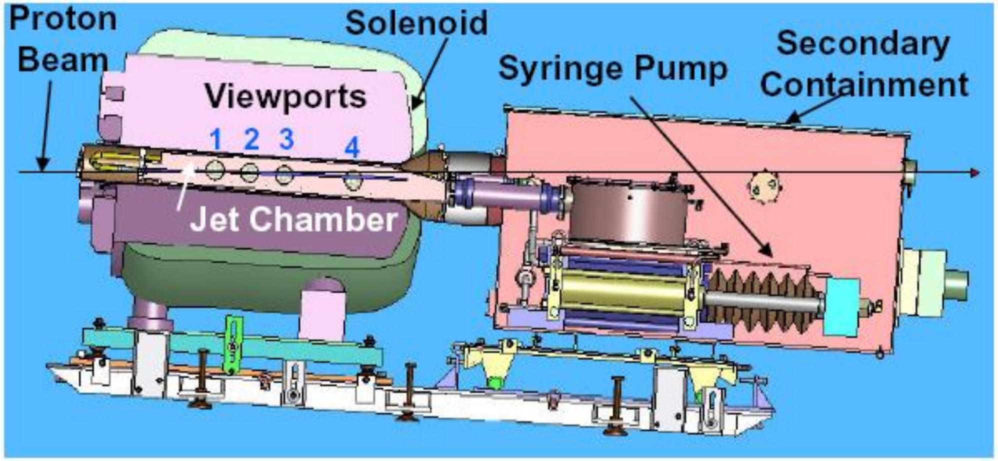
Note it falls apart even without high beam-induced stress

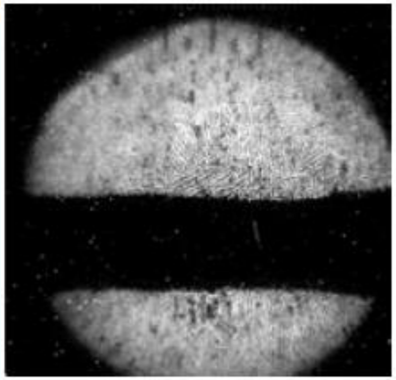
**Latest from Nick:**

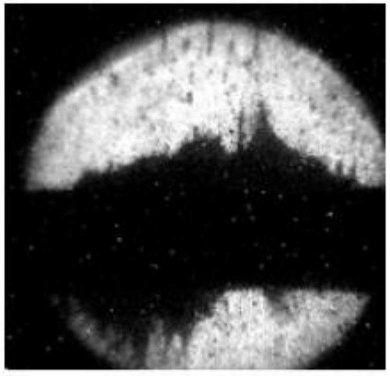
IG430 may be better !

Important to continue testing with variety of graphites in different conditions !

# MERIT Experiment





- MERIT experimental results (See NUFACT09)
- Proton beam induced Hg jet disruption confined to jet/beam overlap region
- 20 m/s operations allows for 70Hz operations
- 115kJ pulse containment demonstrated
- 8 MW operations demonstrated
- Hg jet disruption mitigated by magnetic field
- Hg ejection velocities reduced by magnetic field
- Pion production remains viable up to 350μs after previous beam impact
- 170kHz operations possible for sub-disruption threshold beam intensities

# In Closing

- Planning for Mega-watt proton sources for superbeams is underway
- *superbeams could exist in about a decade*
- What each superbeam looks like depends on the physics one wants to do
- *Once built, will have limited flexibility (unless pre-designed and paid for)*
- The target is the component where materials properties are on the edge
- *For JPARC and FNAL beams, by scaling from current targets,*
- *conventional solid targets appear plausible,*
- *detailed design and engineering remains to be done*
- For T2K, the target hall / decay pipe / absorber for superbeam already exist
- ***For others, significant design choices still remain***