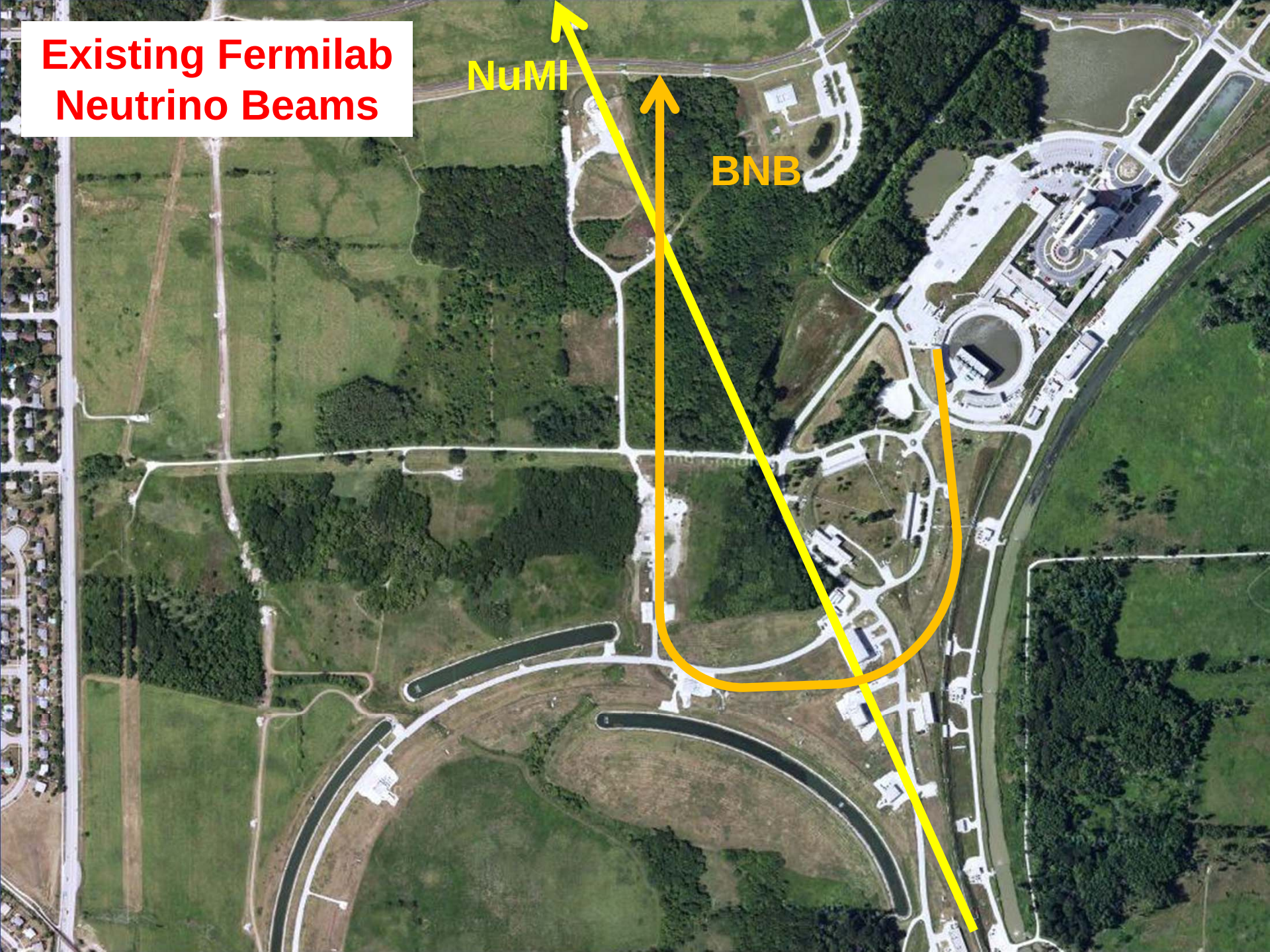
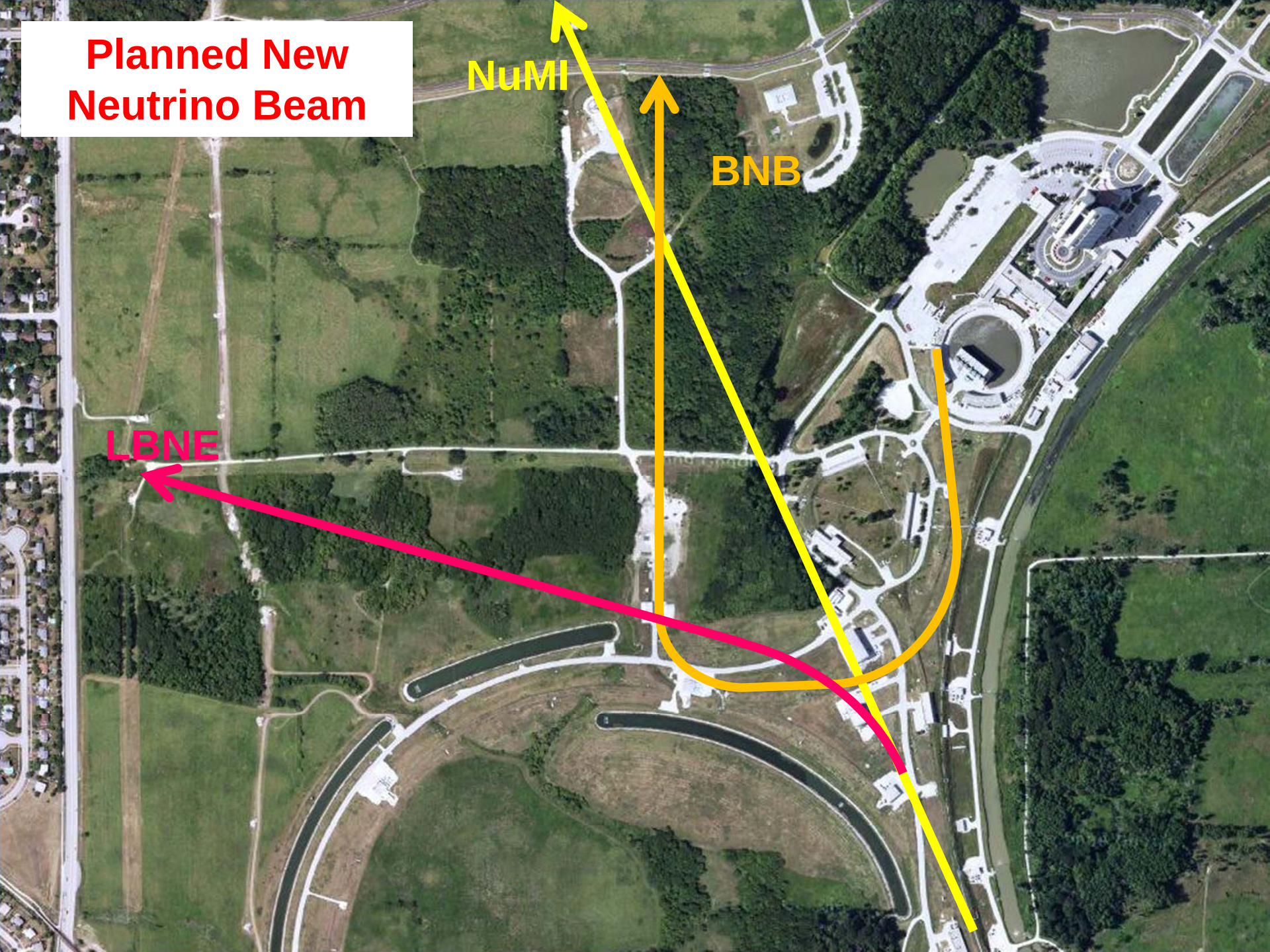
Long-Baseline Neutrino Beams at Fermilab

Jim Strait, Fermilab
NuFact ’11
2 August 2011

U.S. DEPARTMENT OF ENERGY

Fermilab


Existing Fermilab
Neutrino Beams
NuMI
BNB


Planned New
Neutrino Beam
NuMI
BNB
LBNE

Beams of several baselines

- Long Baselines (oscillation physics)
  - NuMI to MINOS: L/E ≅ 735 km / 3 GeV ≅ 250 km/GeV
  - NuMI to NOvA: L/E ≅ 810 km / 2 GeV ≅ 400 km/GeV
  - LBNE L/E ≅ 1300 km / 2.5 GeV ≅ 430 km/GeV
- Short Baseline (oscillation physics)
  - BNB to MiniBoone: L/E ≅ 0.6 km / 0.6 GeV ≅ 1 km/GeV
- Shorter Baseline (experiments assume no oscillation effects)
  - NuMI to MINERvA: L/E ≅ 1 km / 3 GeV ≅ 0.3 km/GeV
  - BNB to SciBooNE: L/E ≅ 0.1 km / 0.6 GeV ≅ 0.15 km/GeV

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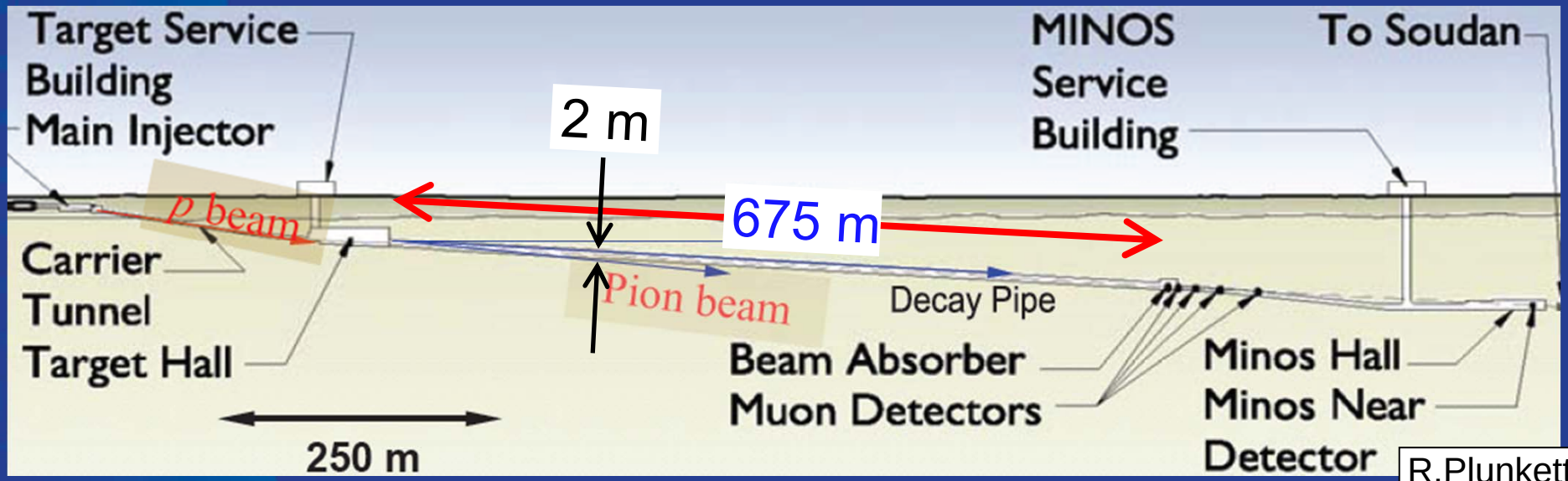
NuMI Beam

See also talks by Jeff Hartnell, Phil Adamson, Mathew Meuther

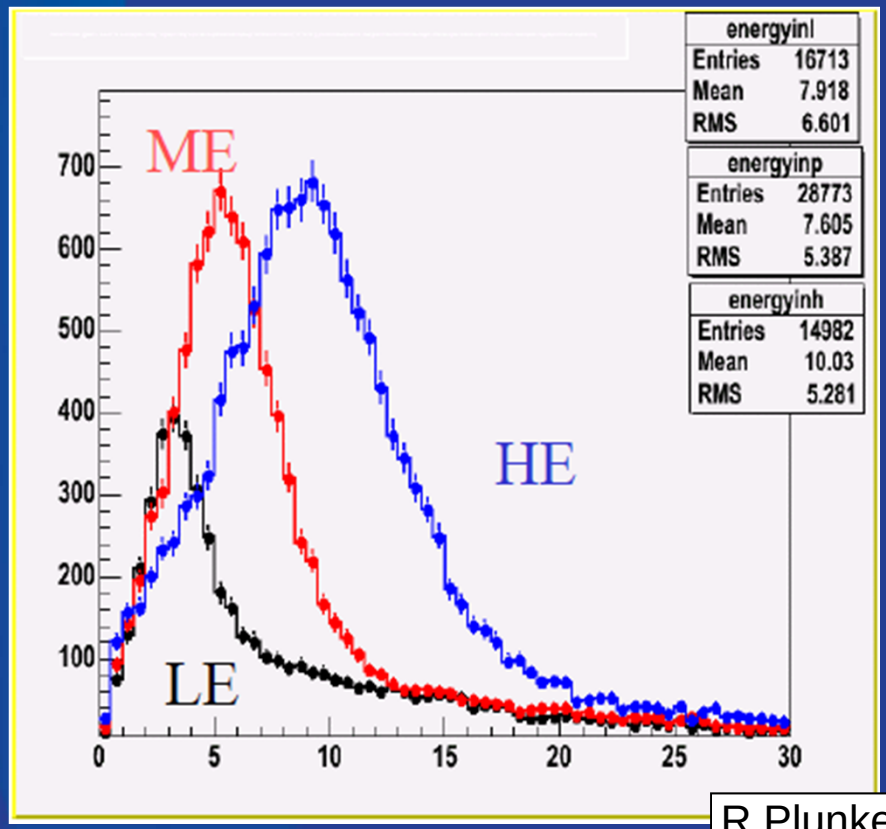
Beam Layout



- Optimized for high energy and tuneability (designed before oscillation parameters were known)

NuMI Beam – Tuneability of on-axis spectrum

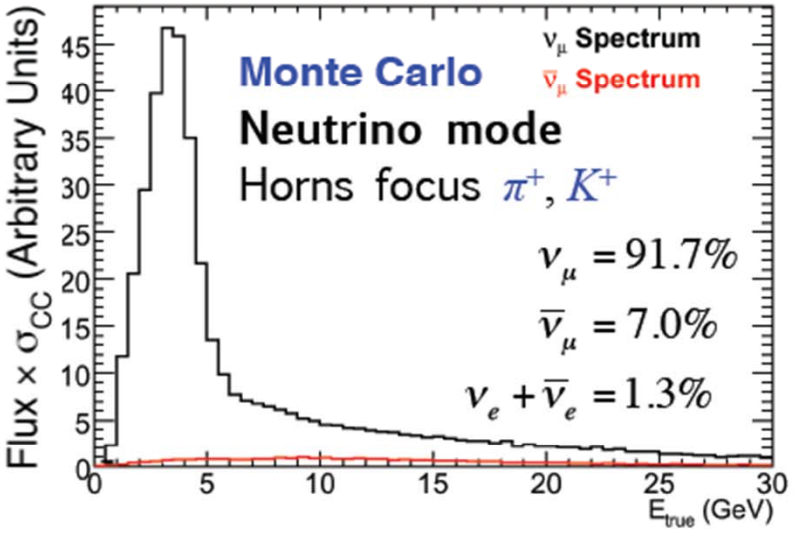
- Beam energy can be change by moving the target in (low energy) and out (high energy) of first horn.

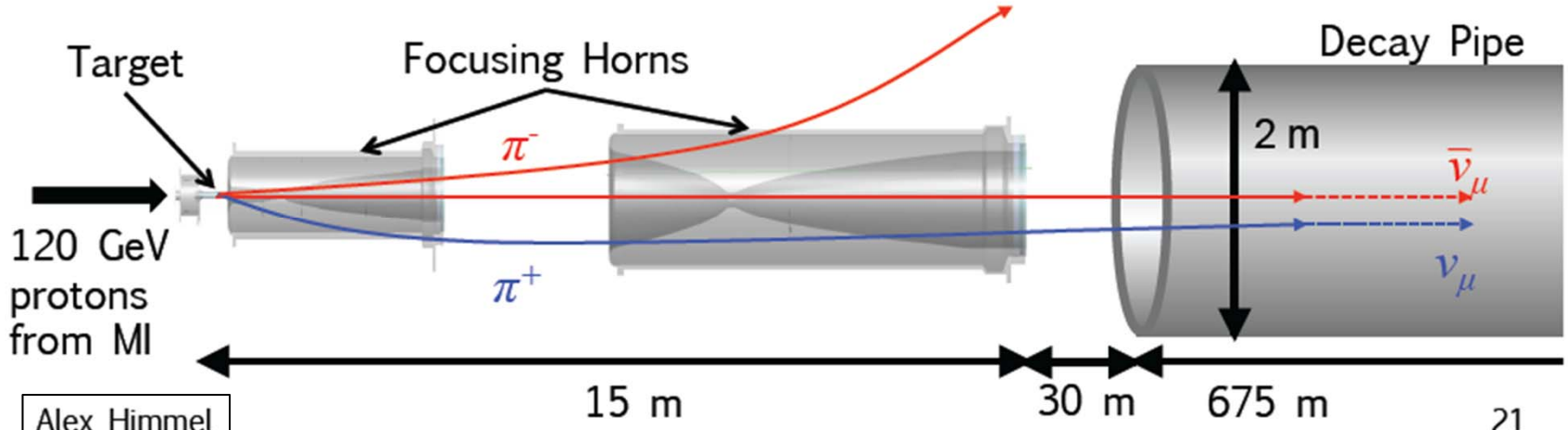


R.Plunkett

- MINOS running has mainly been in the LE tune.

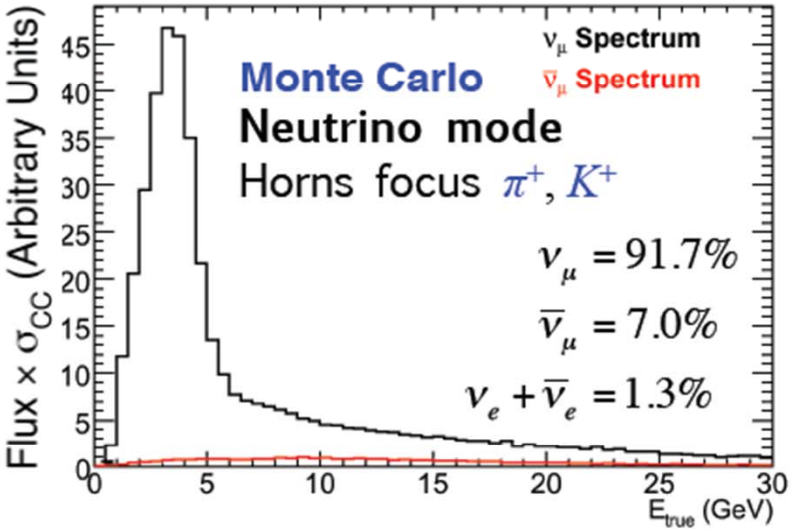
Neutrino Mode

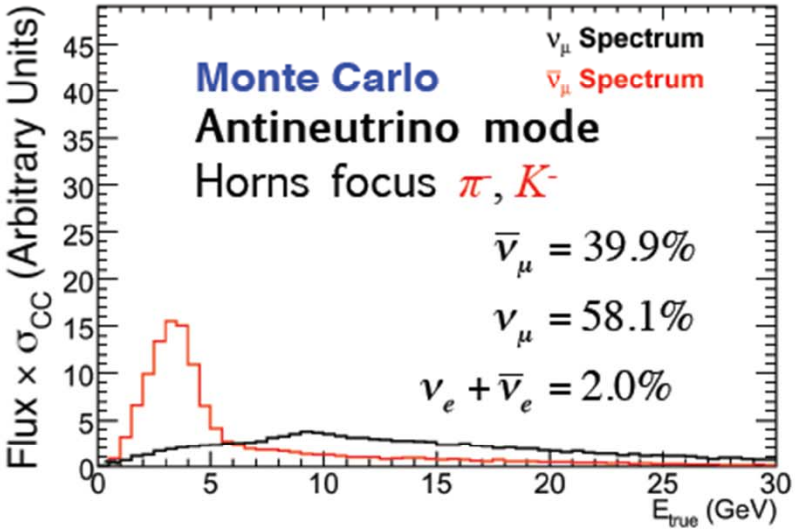


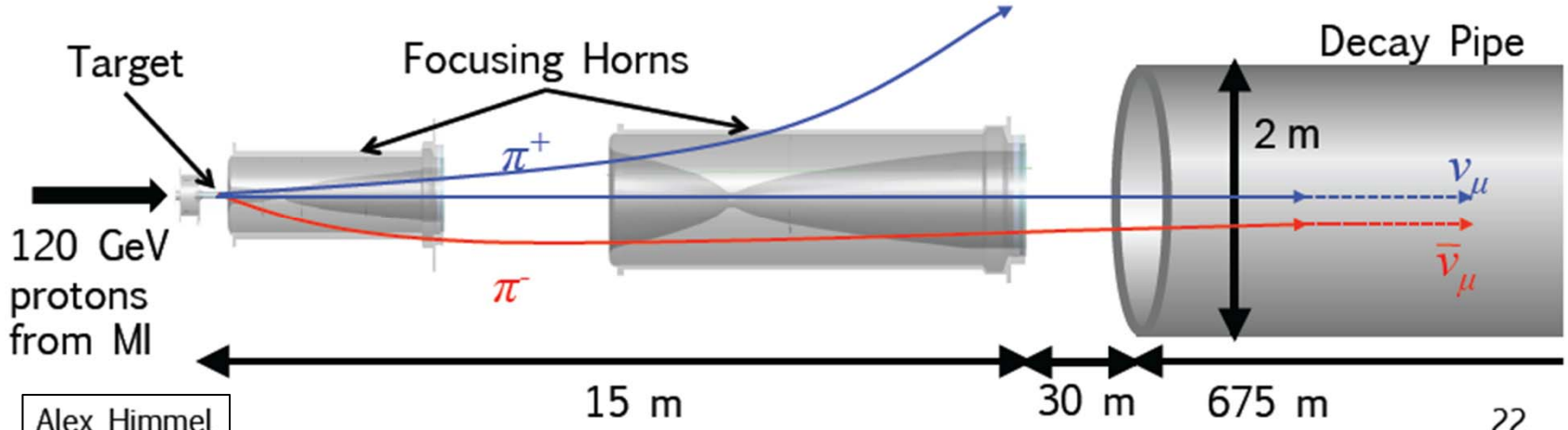


Alex Himmel

Antineutrino Mode



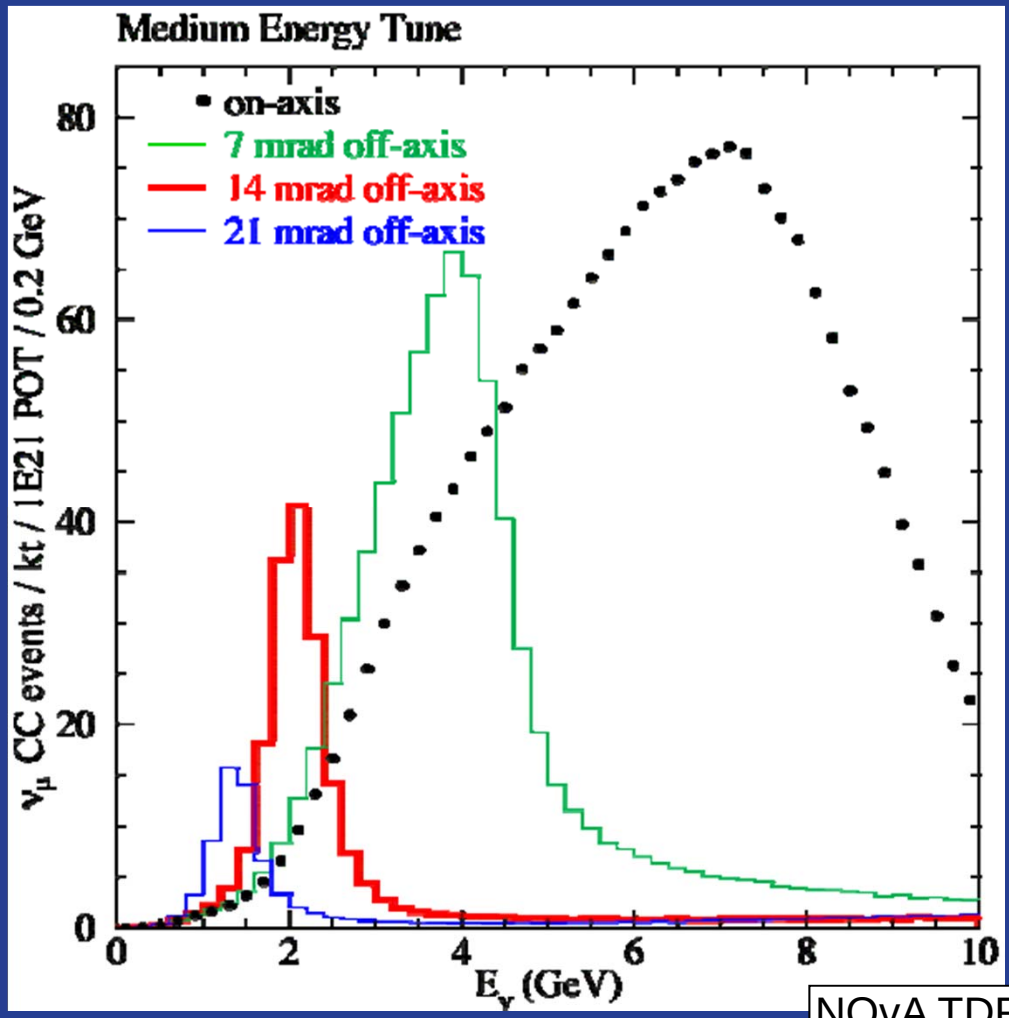




Alex Himmel

NuMI Off-Axis Beam for NOvA

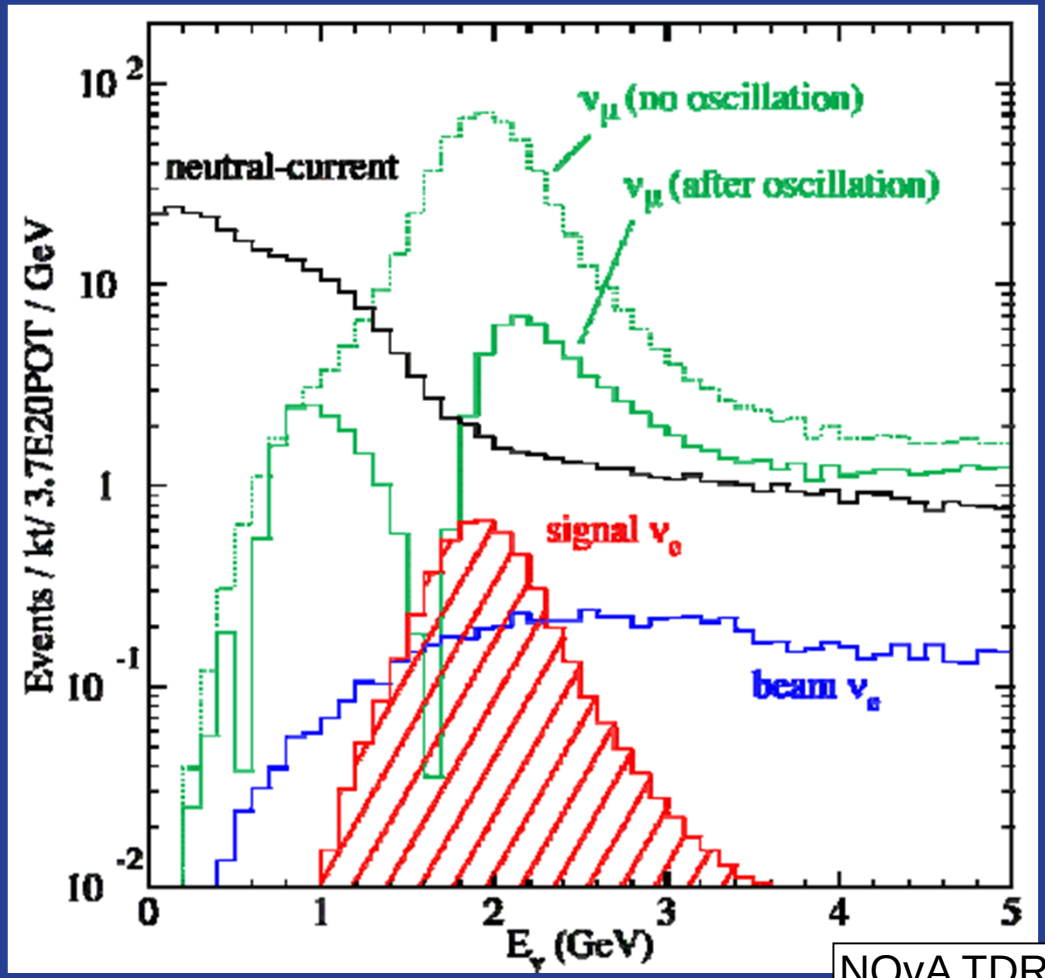
- NOvA will operate with ME tune, 14 mrad off-axis => 2 GeV narrow band beam.



NOvA TDR

NuMI Off-Axis Beam for NOvA

- NOvA beam has excellent purity in terms of ν_e background in oscillation region.



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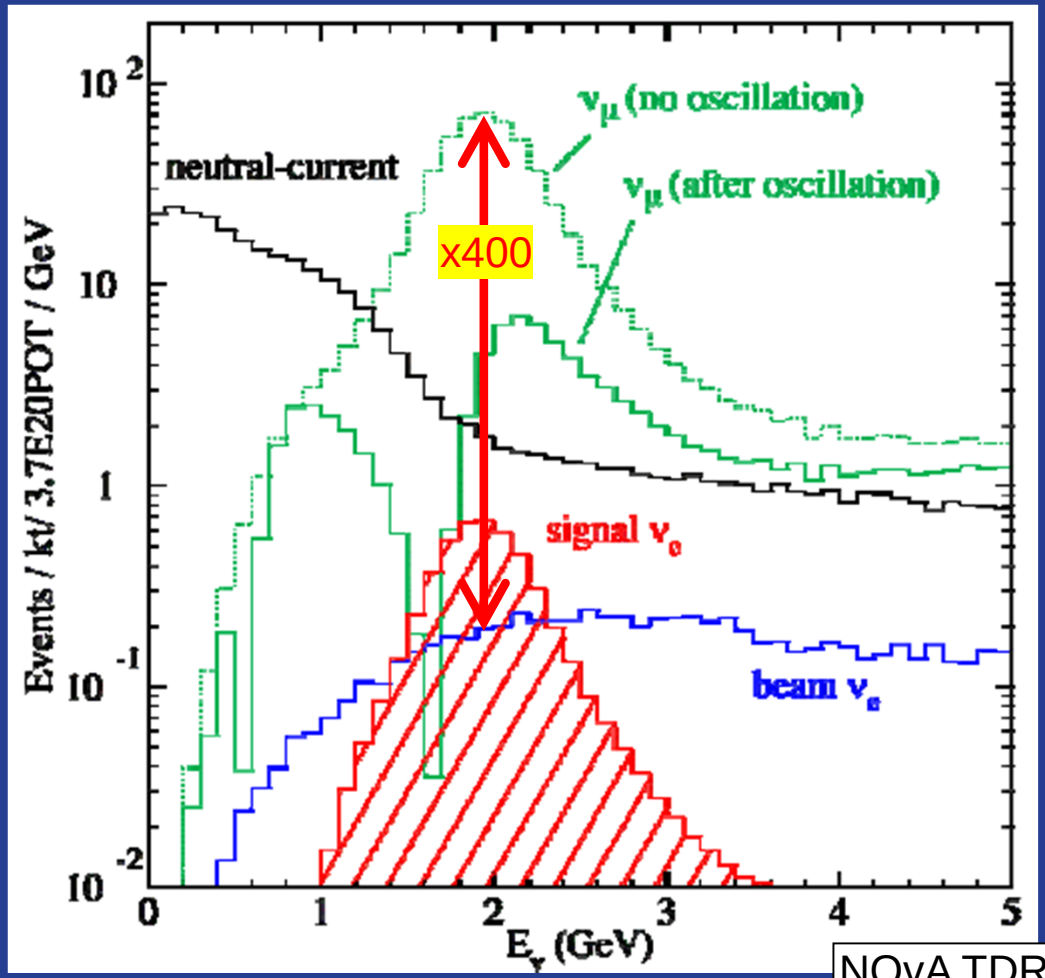
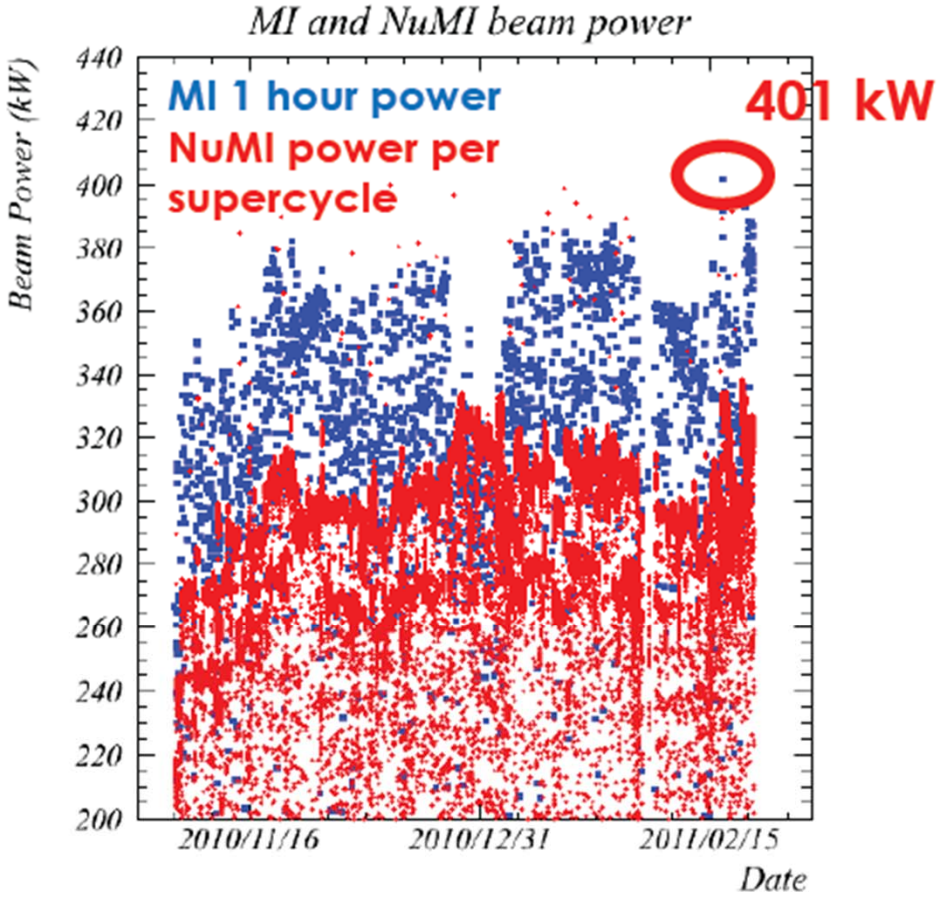


NOvA TDR

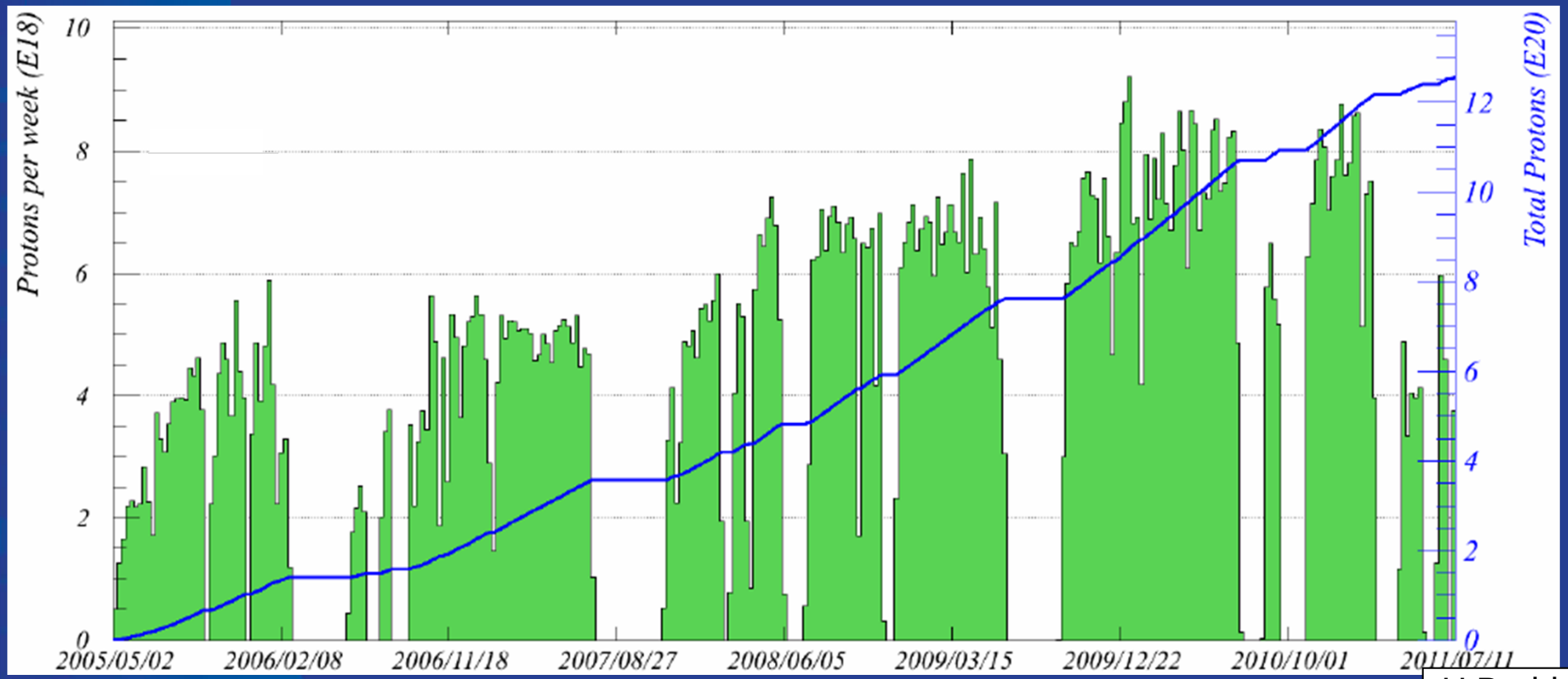
NuMI Beam Power – Maximum achieved for 1 hour

- Beam power shows increasing trend over last few months
- Exceeded 400 kW in MI for 1 hour in "normal" running
- Will push again when target is installed



P.Adamson

NuMI Beam Power – Weekly Average



H.Budd

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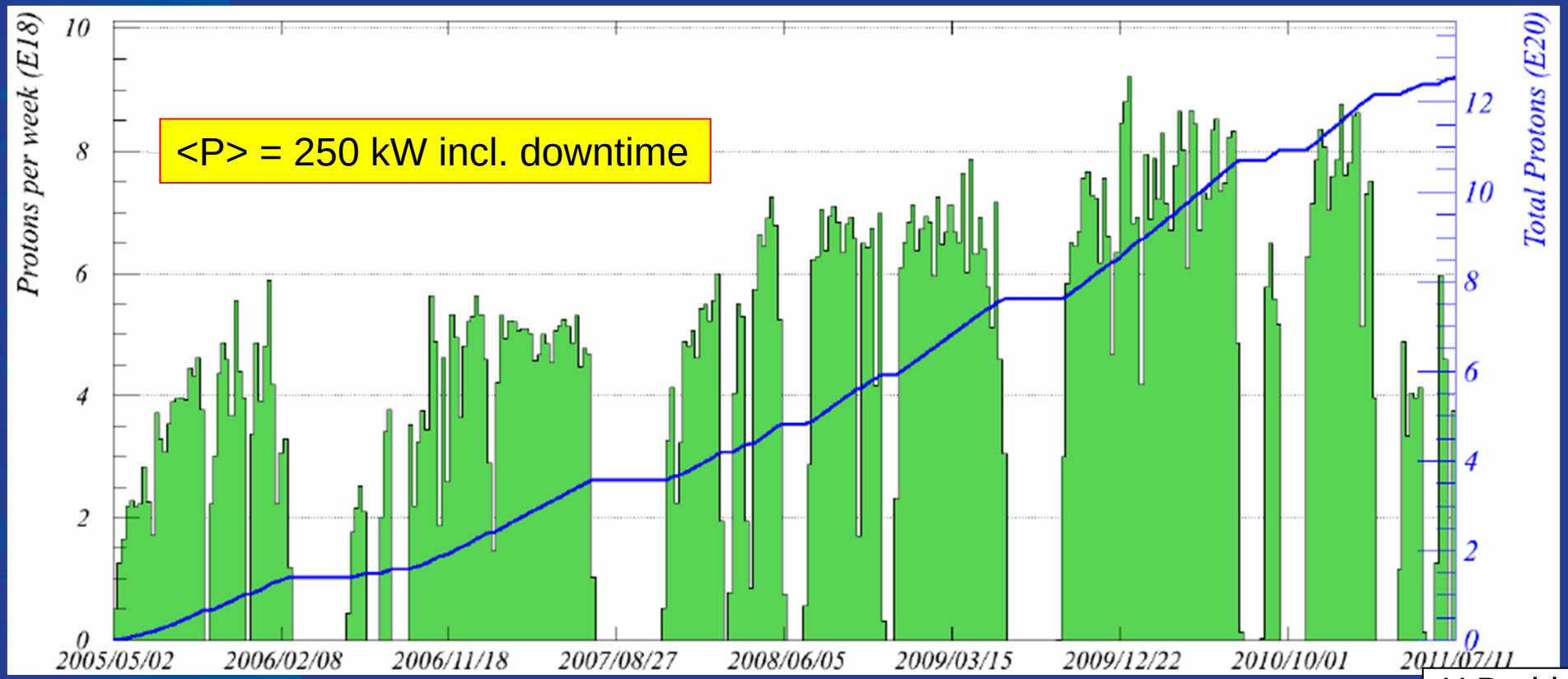

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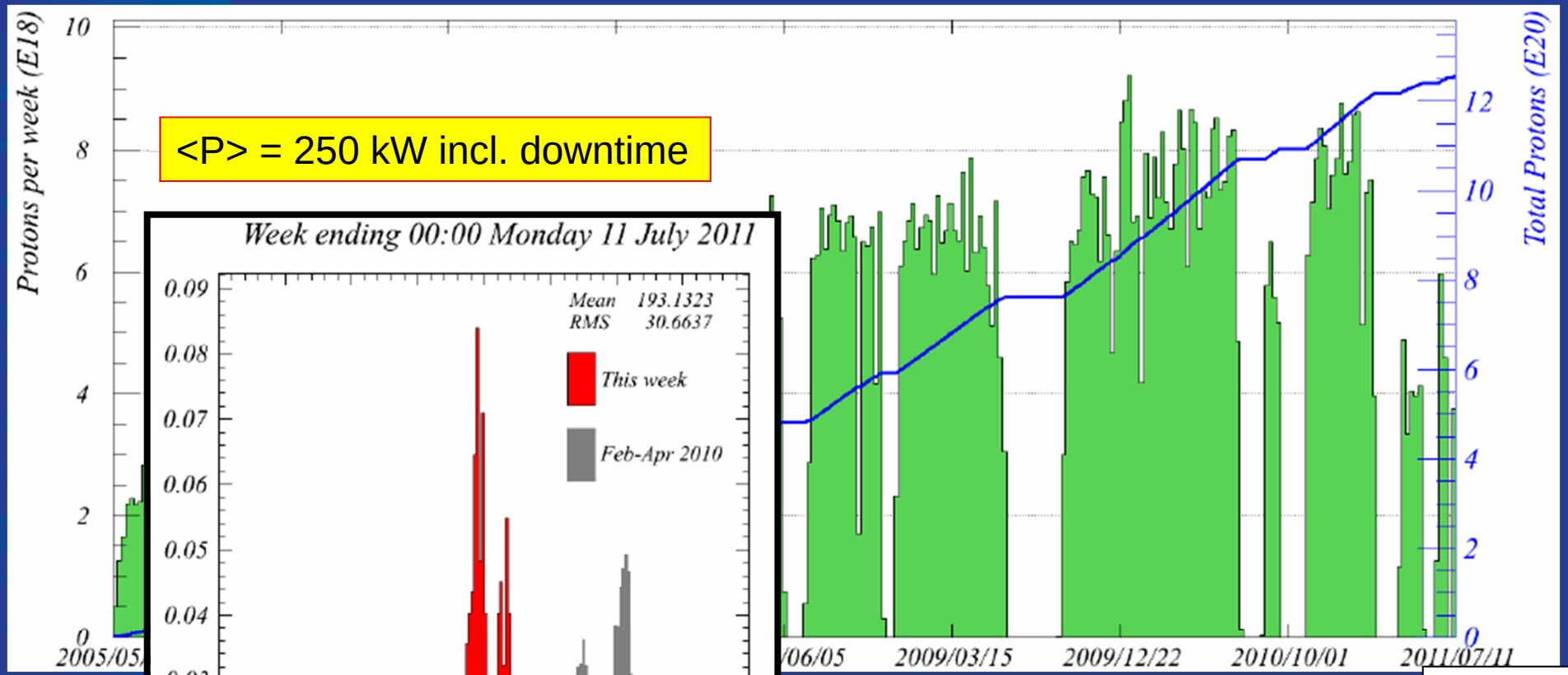

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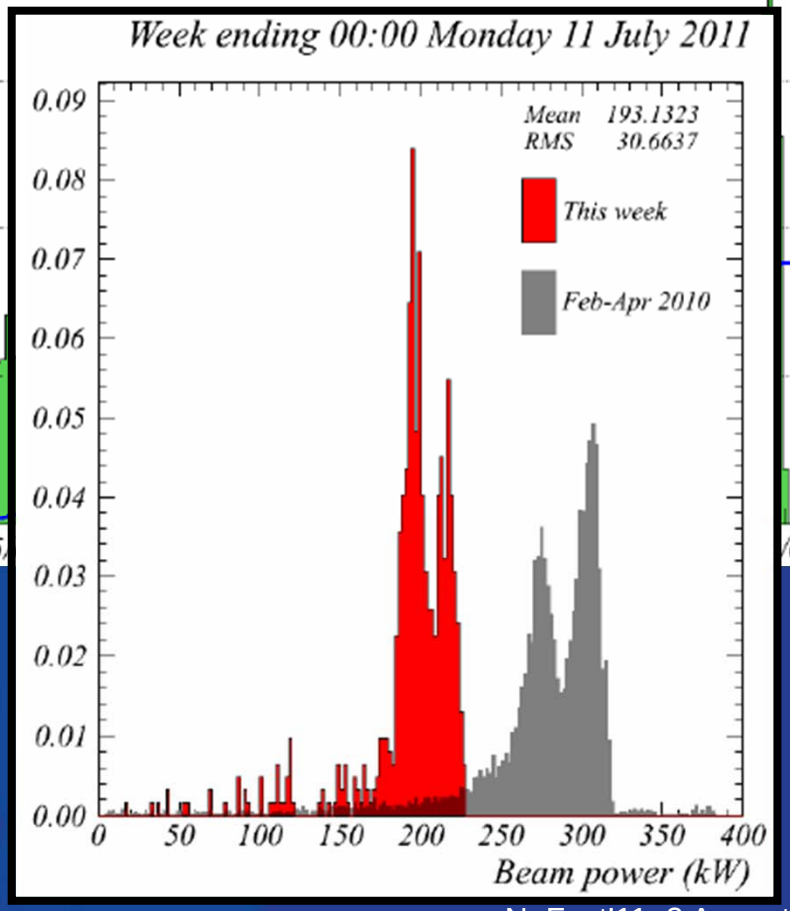
NuMI Beam Power – Weekly Average

2.4 MW x 10^7 sec

<P> = 250 kW incl. downtime



H.Budd

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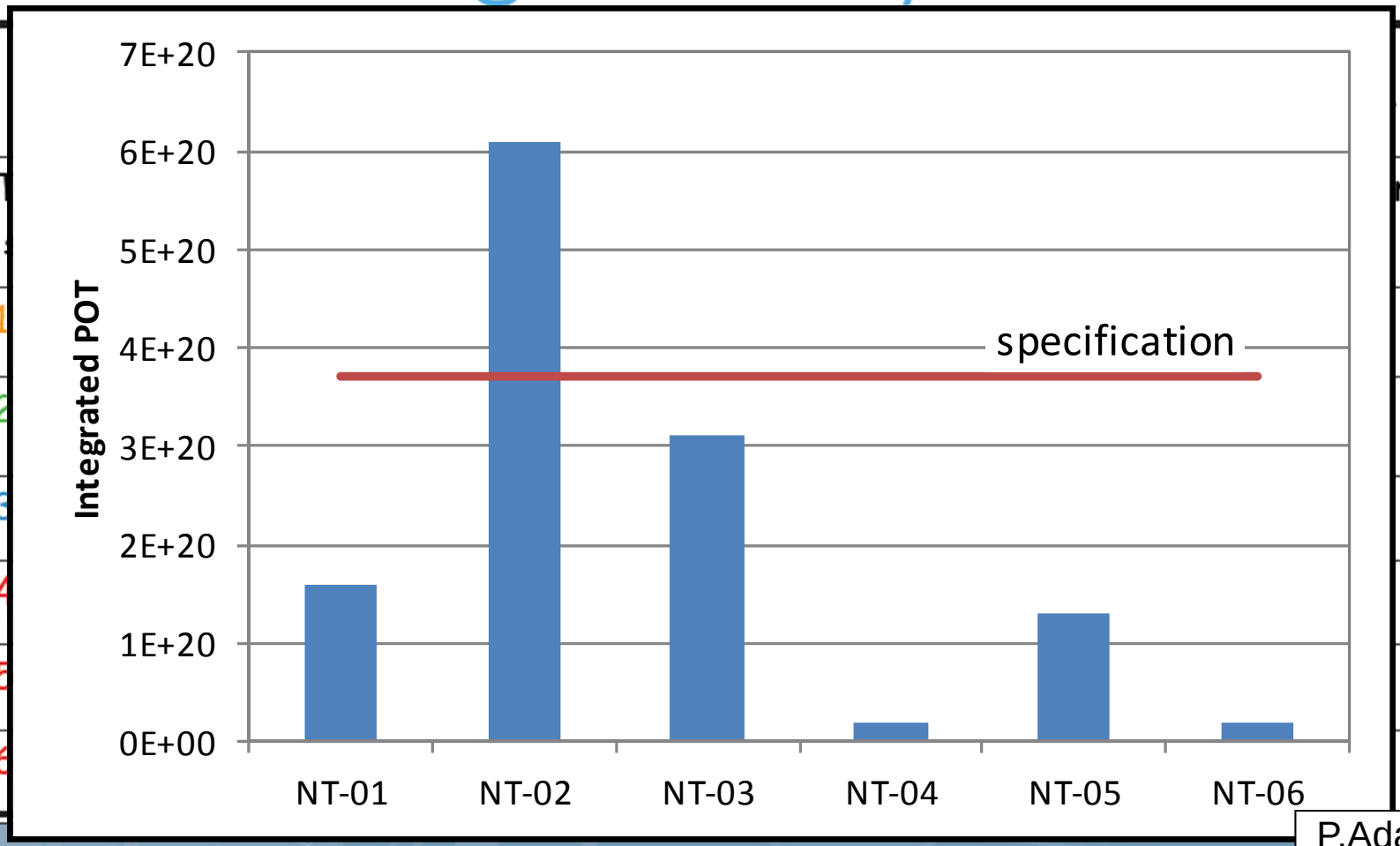
NuMI Target History

	Max. Proton/pulse	Max. Beam Power	Integrated Protons on Target
Target Design specification	4.0e13 p.p.p. *at 120 GeV*	400 kW	3.7 e20 p.o.t. or 1yr minimum lifetime
1st target	3.0 e13 p.p.p.	270 kW	1.6 e20 p.o.t.
2nd target	4.0 e13 p.p.p.	340 kW	6.1 e20 p.o.t.
3rd target	4.4 e13 p.p.p.	375 kW	3.1 e20 p.o.t.
4th target	4.3 e13 p.p.p.	375 kW	0.2 e20 p.o.t.
5th target	4.0 e13 p.p.p.	337 kW	1.3 e20 p.o.t.
6th target	3.5 e13 p.p.p.	305 kW	0.2 e20 p.o.t.

P.Adamson

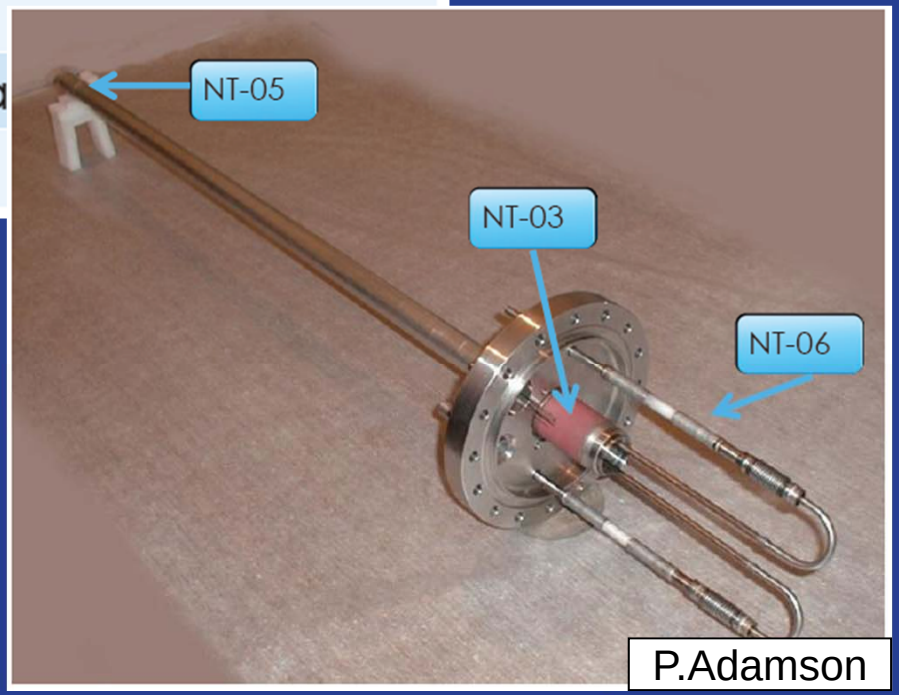
NuMI Target History



P.Adamson

Target Summary

Target	Fate
NT-01	Zombie target – now running
NT-02	~15% Radiation damage to graphite
NT-03	Failure in ceramic at upstream end of can
NT-04	Unknown water leak, Be windows destroyed
NT-05	Water leak at DS turna
NT-06	Water leak upstream



P.Adamson

NuMI Beam Power Upgrades for NOvA

- Injection and Slip Stacking in Recycler Ring
  - Cut $^{2}/_{3}$ second for injection from cycle
  - 12 batches from Booster instead of 11
- Single turn transfer to MI
- Ramp to 120 GeV
  - Faster ramp: 1.333 second
  - All 12 to NOvA target: ~4.9e13 706 kW
- 1.333 second cycle
  - 9 Hz demand on Booster
  - 12 consecutive pulses
  - 1.4e17/hour
- Target Station:
  - New target design
  - New Horn configuration

P.Derwent

LBNE Beam

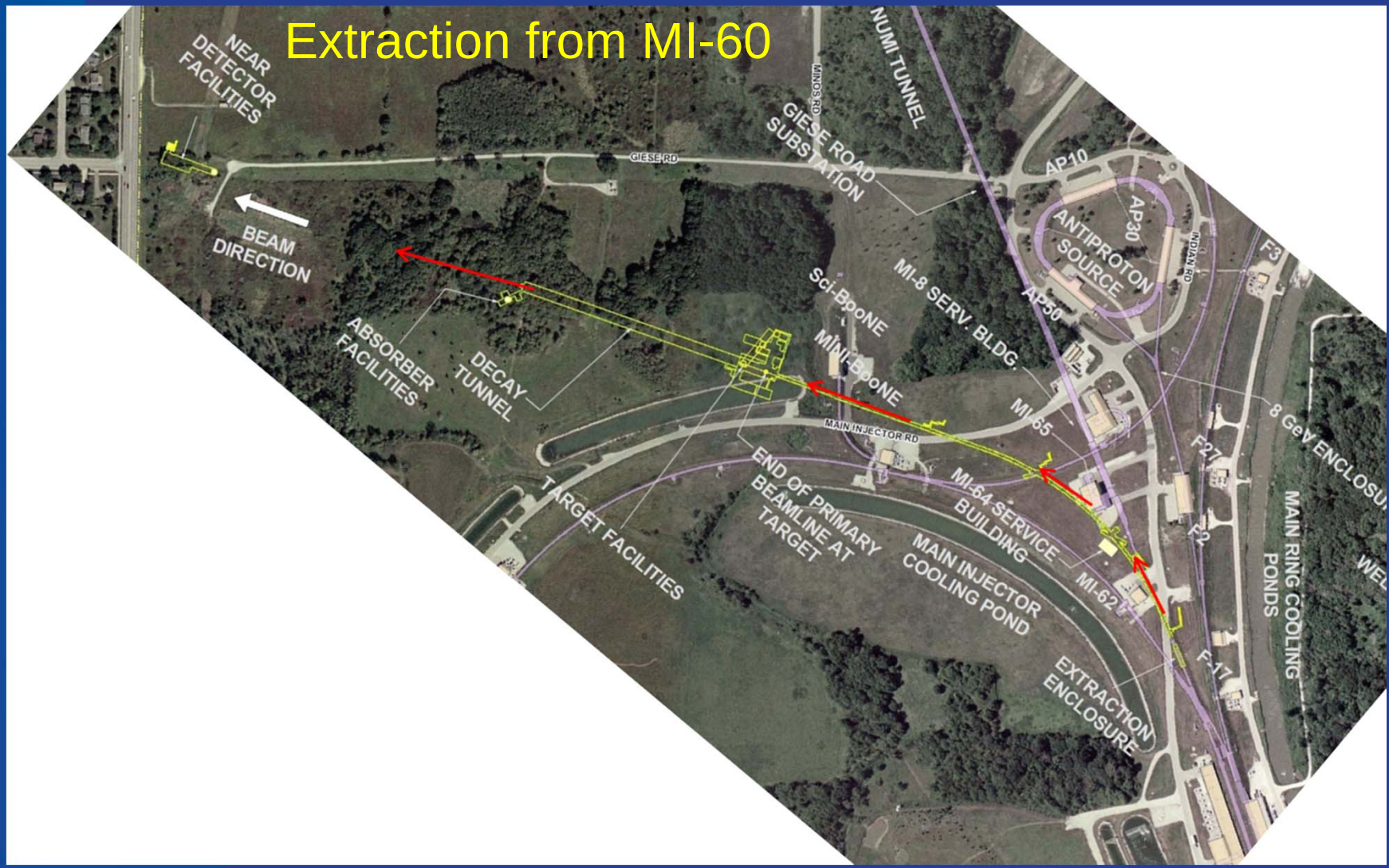
See also talk by Vaia Papadimitriou

- We need a new beamline for LBNE:
  - Need longer baseline (see my WG1 talk earlier today)
    Longest baseline along NuMI direction ~ 1000 km (where beam axis is ~15 km above ground)
  - Need to plan for higher-power Project X beam
    Power limitation of NuMI line is certainly << 2 MW
  - Need beam optimized for lower energy and smaller ν_e component => shorter, wider decay pipe.
  - Need beam pointed to Homestake / Sanford Lab

LBNE Beam – High-Level Requirements

- Beam pointed to Homestake => 1300 km baseline
- Broad-band beam, covering 1st and 2nd maxima (2.5 and 0.8 GeV)
- Minimize high energy tail above ~5 GeV
- Minimize ν_e and "wrong-sign" ν_μ
- Tunable => proton beam 60 < E < 120 GeV
- Design for initial power = 700 kW, upgradeable to >2 MW
- Beam and Near Detector on Fermilab site
- Stringent radiation safety requirements
- Minimize cost!

LBNE Beamline Major Alternatives



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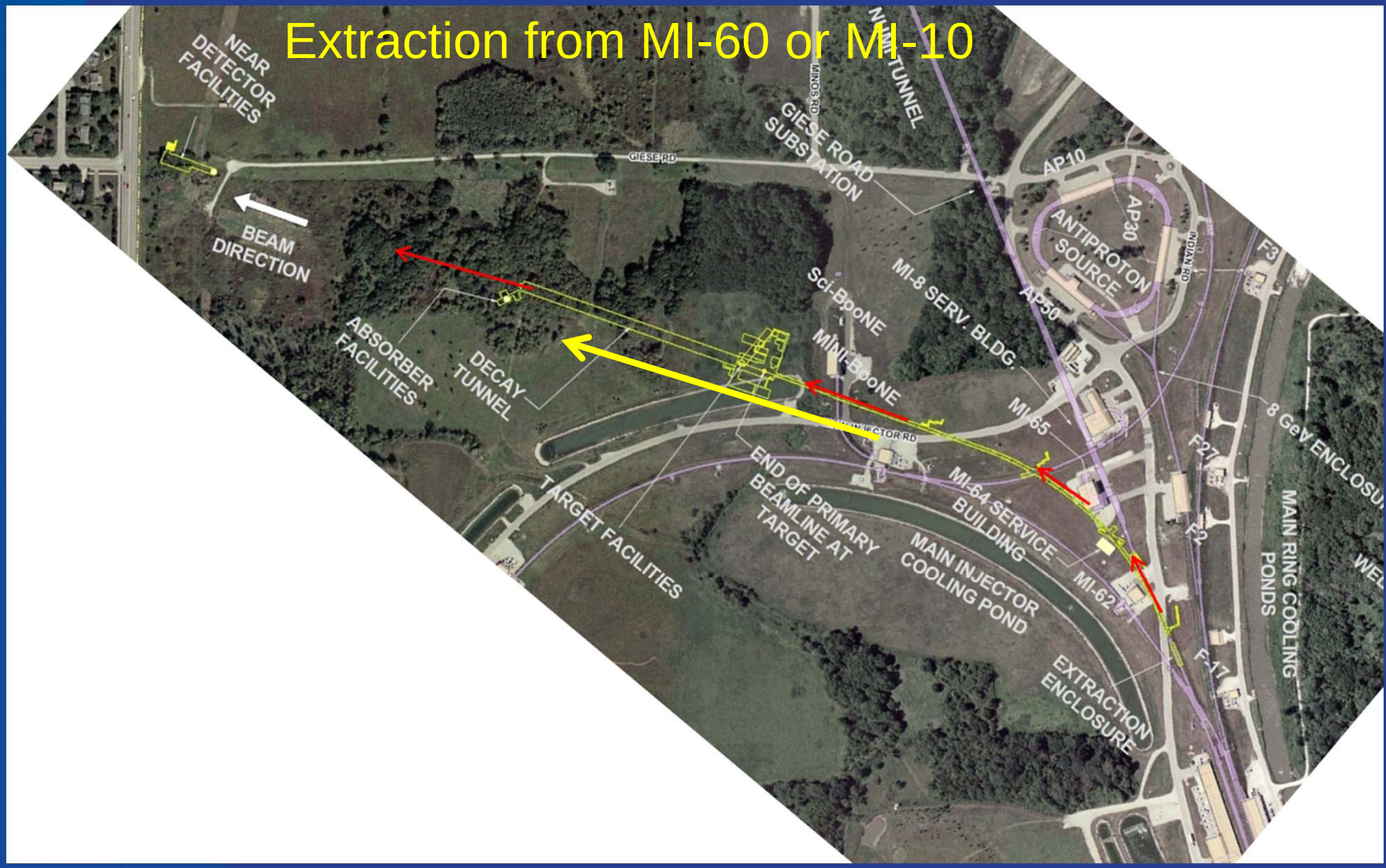

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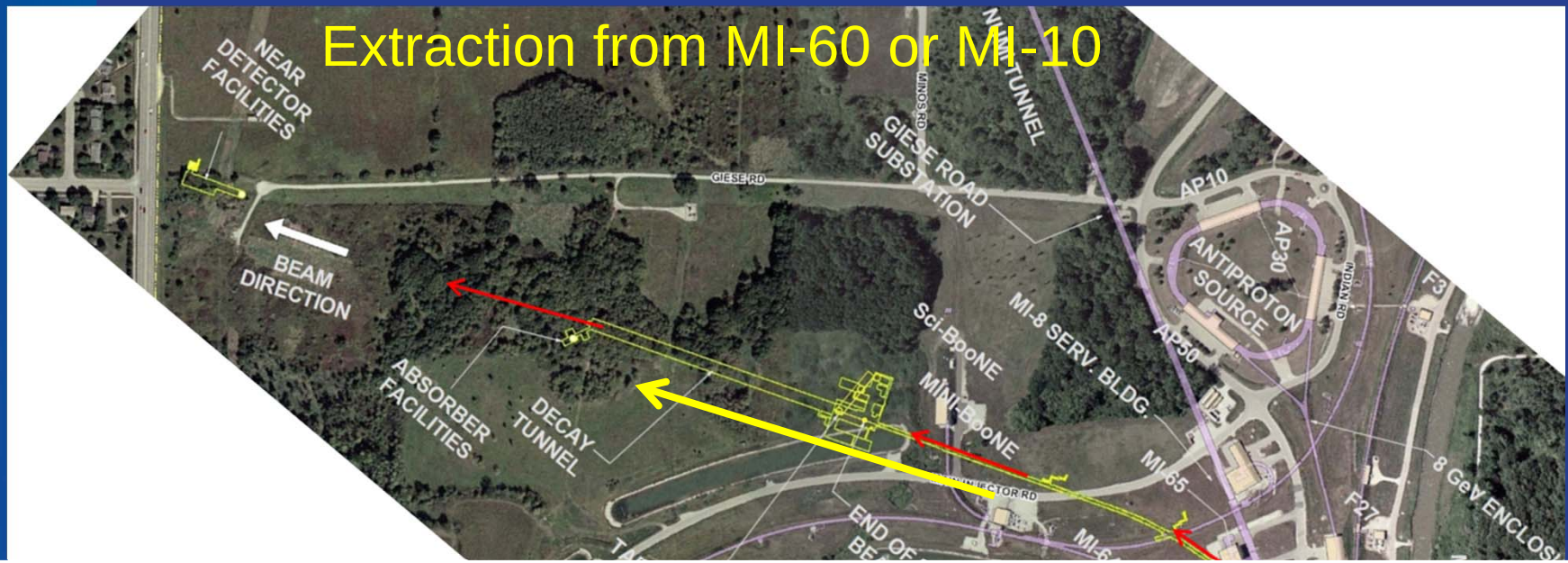
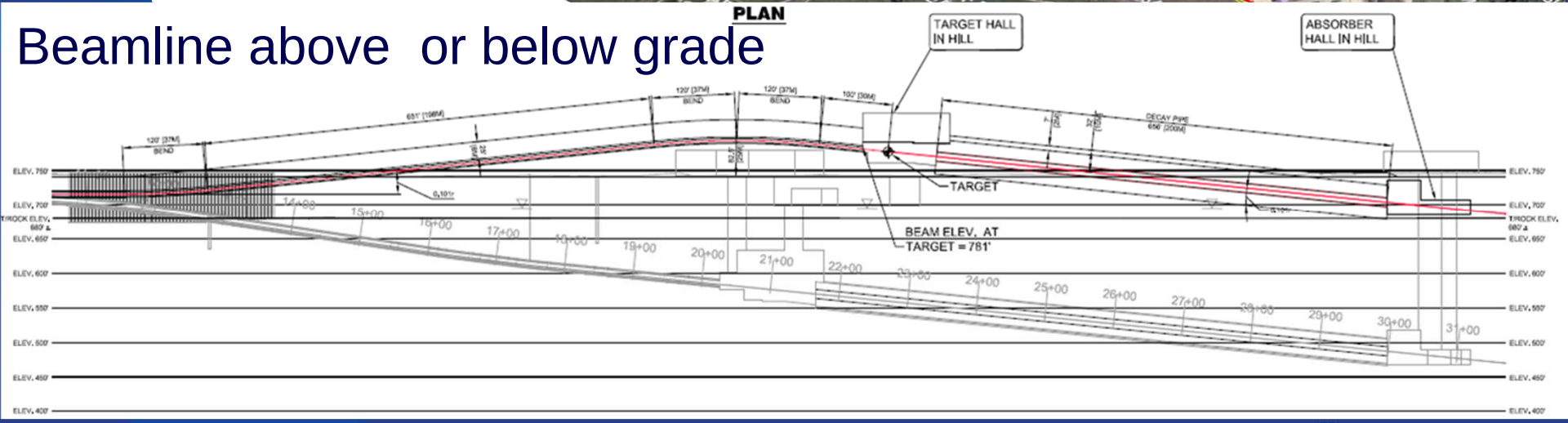


Beamline above or below grade



LBNE Expected Beam Spectrum

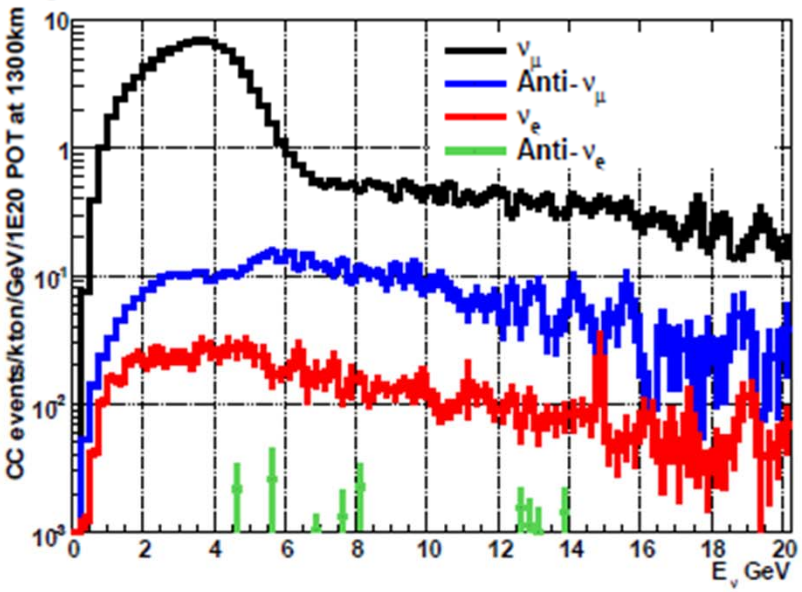
The LBNE design selected for physics studies maximizes the ν_e appearance signal at 1300km.

Target: Carbon target, r=0.6cm, l=80cm, $\rho = 2.1$ g/cm^3. Located -30cm from Horn1.

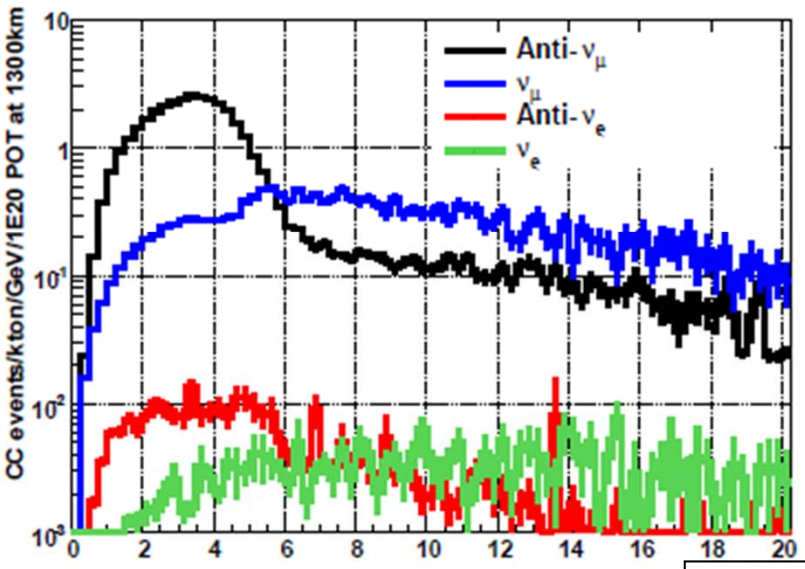
Horns: 2 Al NuMI Horns, 6m apart, 250 kA.

Decay Pipe: r=2m, l=280m, He filled/evacuated.

Aug 2010 Neutrino Beam



Aug 2010 Anti-Neutrino Beam



M.Bishai

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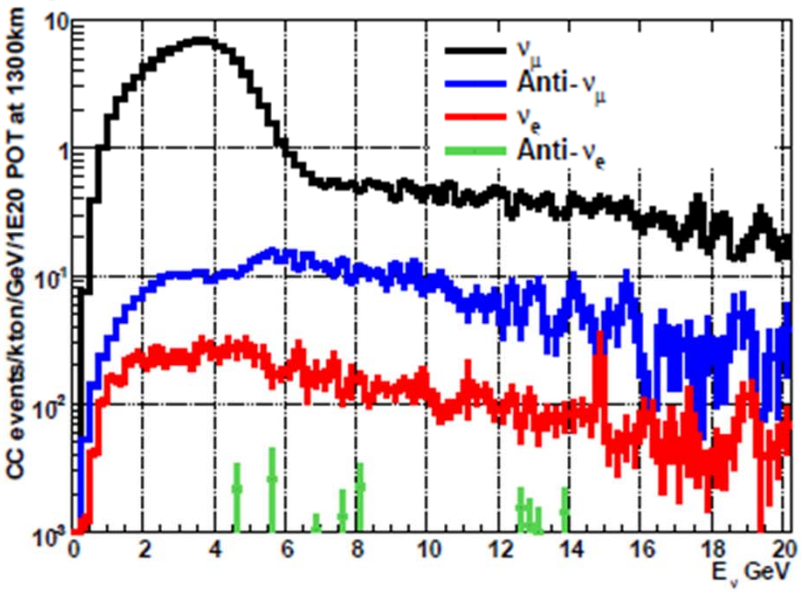
Decay Pipe: r=2m, l=280m, He filled/evacuated.

Maybe a little more optimistic that what we will be able to afford.

Aug 2010 Neutrino Beam



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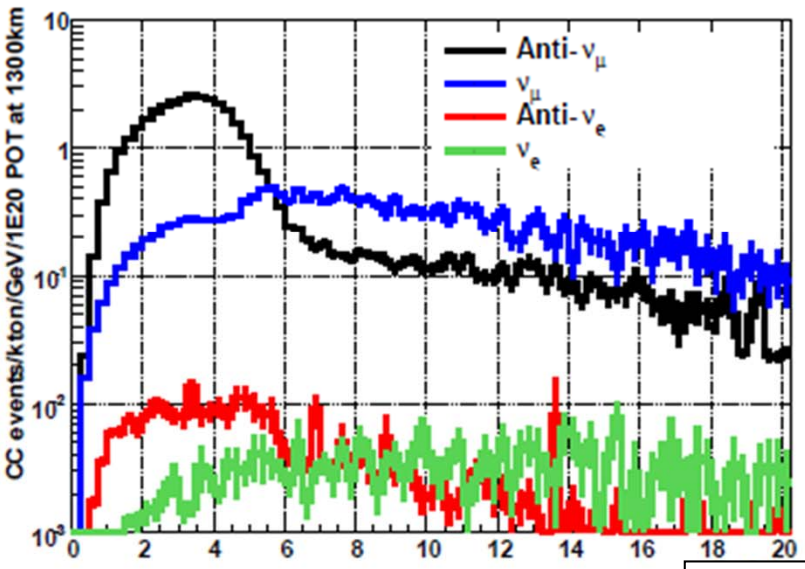


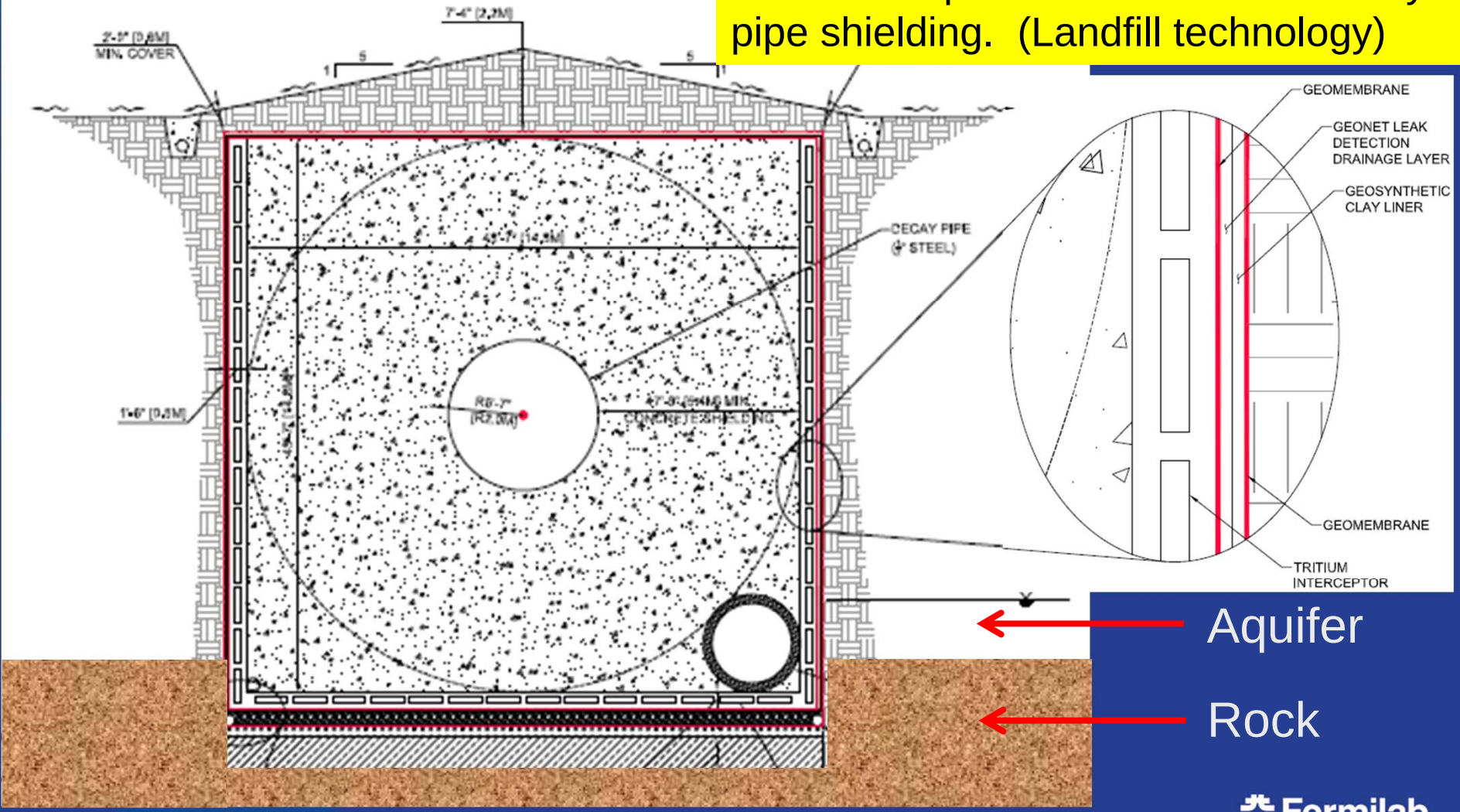
M.Bishai

LBNE Beamline Design Issues

- Radiation safety with above grade beam
  - Prompt radiation at site boundary
  - Tritium isolation with decay pipe and absorber partially in the aquifer.
- Decay pipe length and diameter
  (cost vs. performance, space relative to site boundary)
- Target lifetime – assume that this will be solved by NOvA for 700 kW beam, but work is required towards 2 MW
- Difficult to obtain substantial flux at 800 MeV = 2nd oscillation max
  - Lower beam energy helps
  - Innovative target designs?

Radiation / Tritium Safety with Shallow Beam

Robust geomembrane system required to isolate aquifer from Tritium in decay pipe shielding. (Landfill technology)



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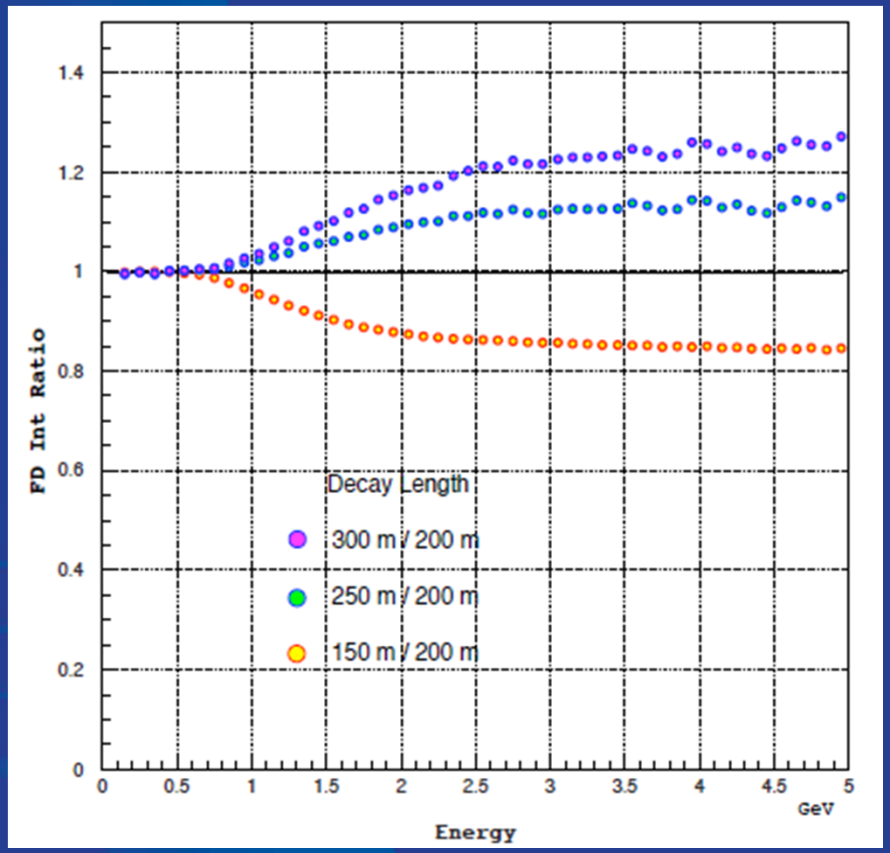
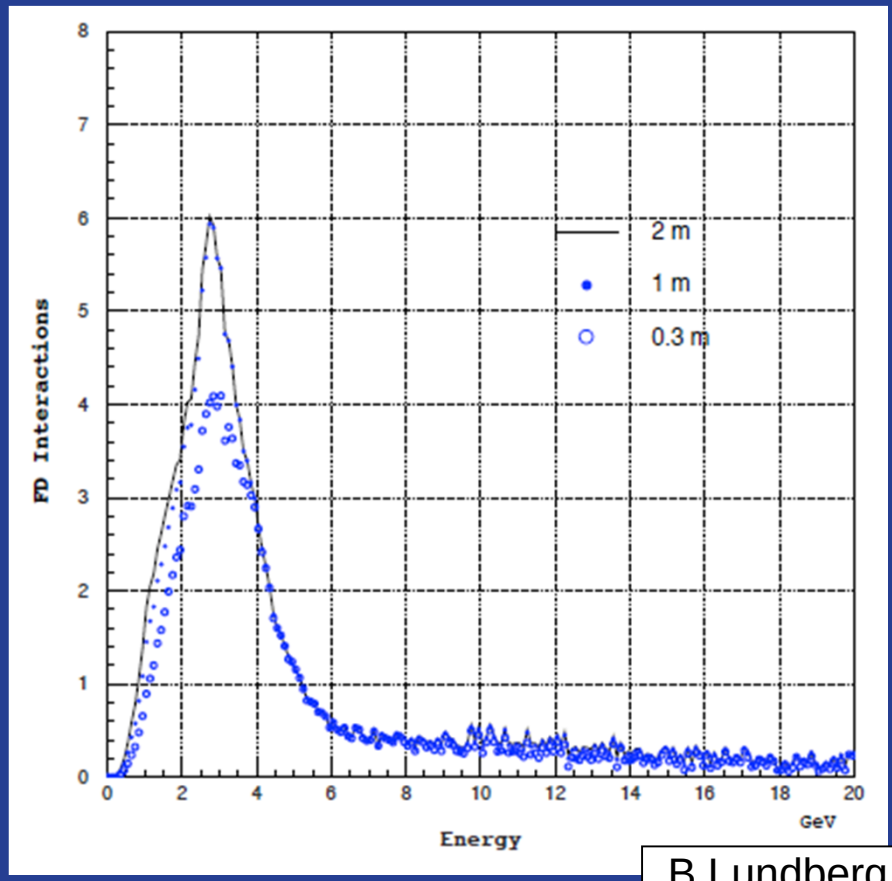
LBNE Beam – Vary decay pipe dimensions

Decay pipe length

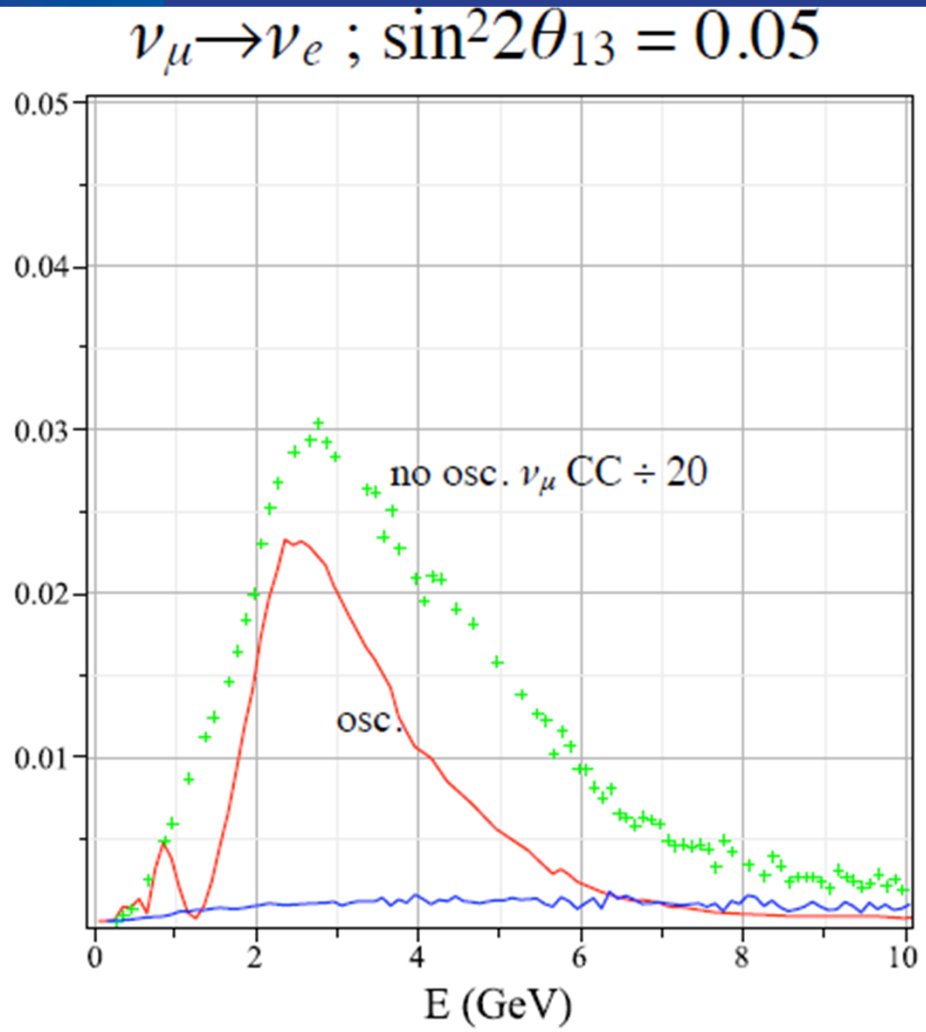


Decay pipe diameter



B.Lundberg

LBNE Beam – Flux at 2nd Oscillation Maximum



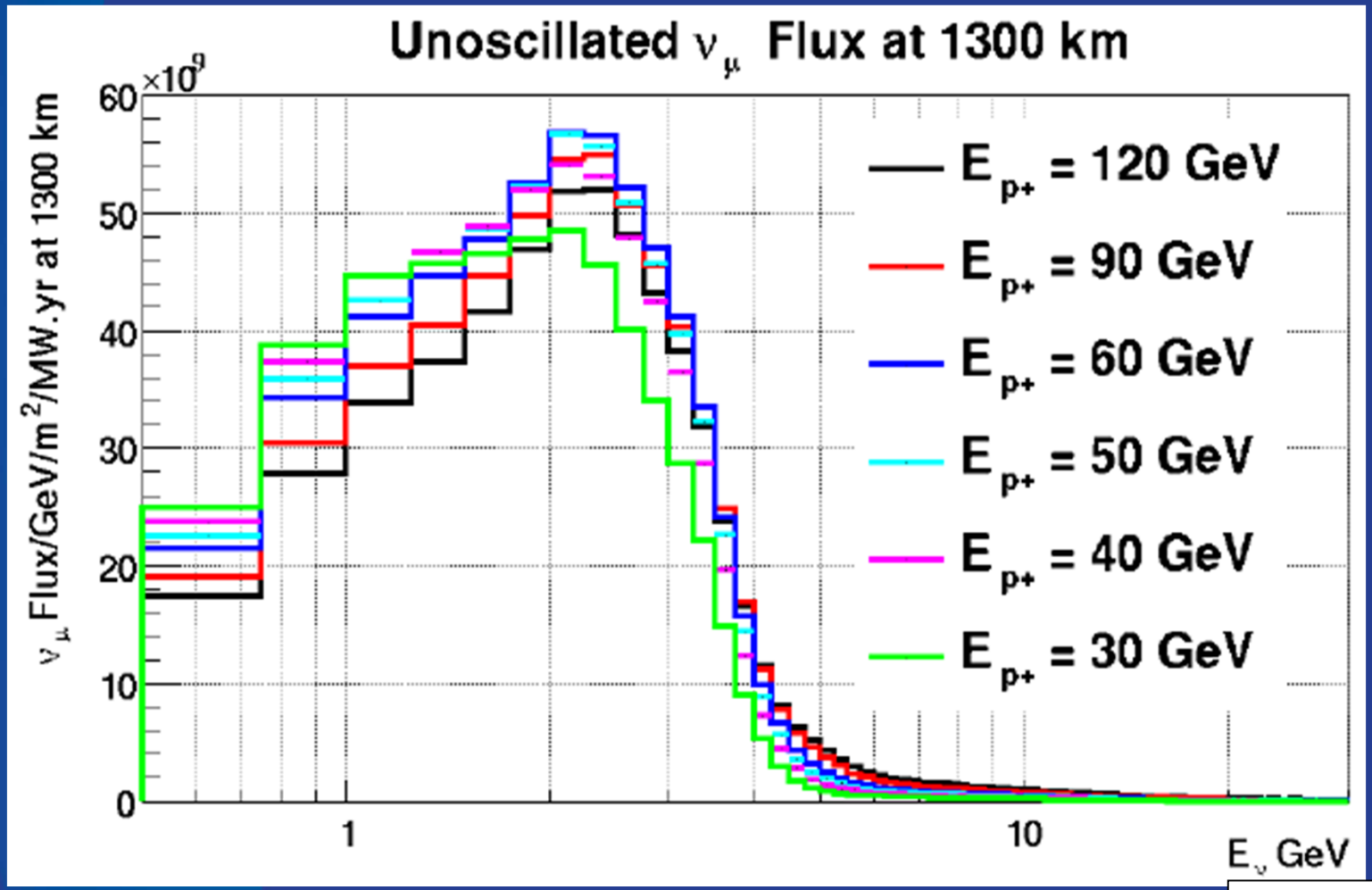
-Reminder about rates-
per 100kt per year at 700kW (over bkg):

E <1.2 GeV → 11 events

1.2<E<6 → 360 events

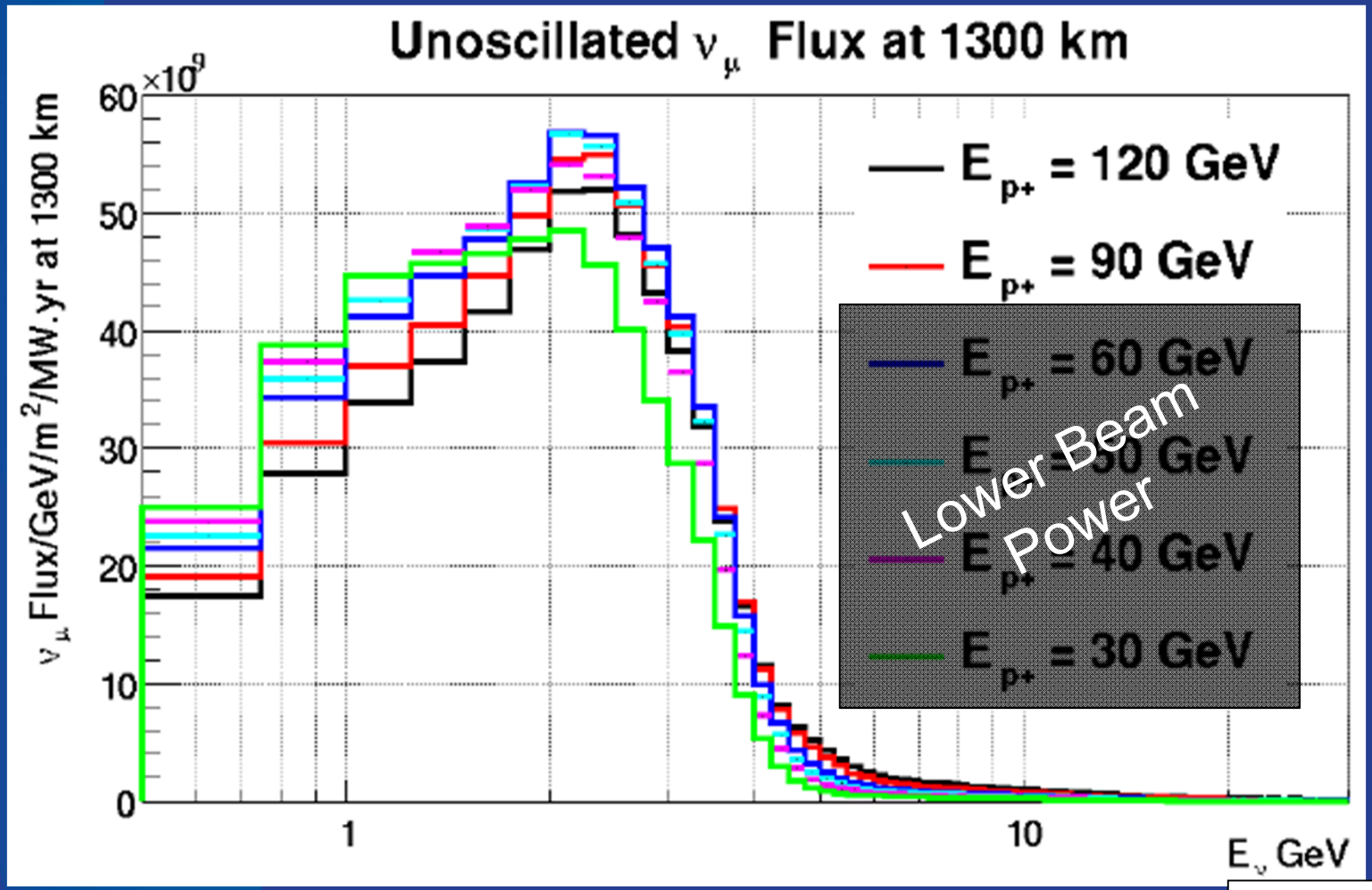
B.Lundberg

Flux at 2nd Max – Effect of Proton Energy



M.Bishai

Flux at 2nd Max – Effect of Proton Energy

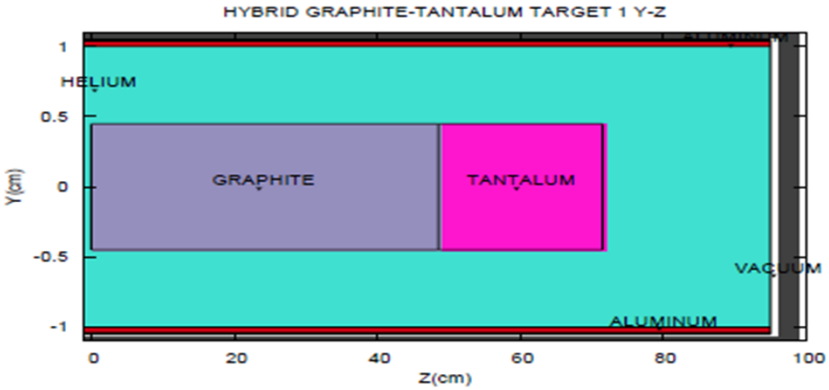


M.Bishai

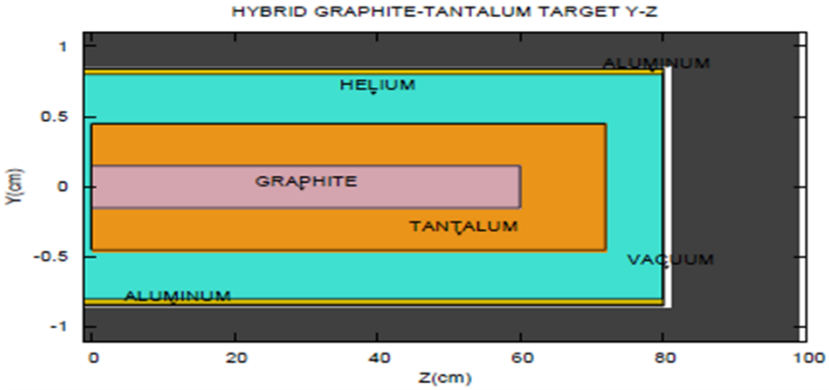
Flux at 2nd Max – Innovative Targets?

Hybrid target design: NEW

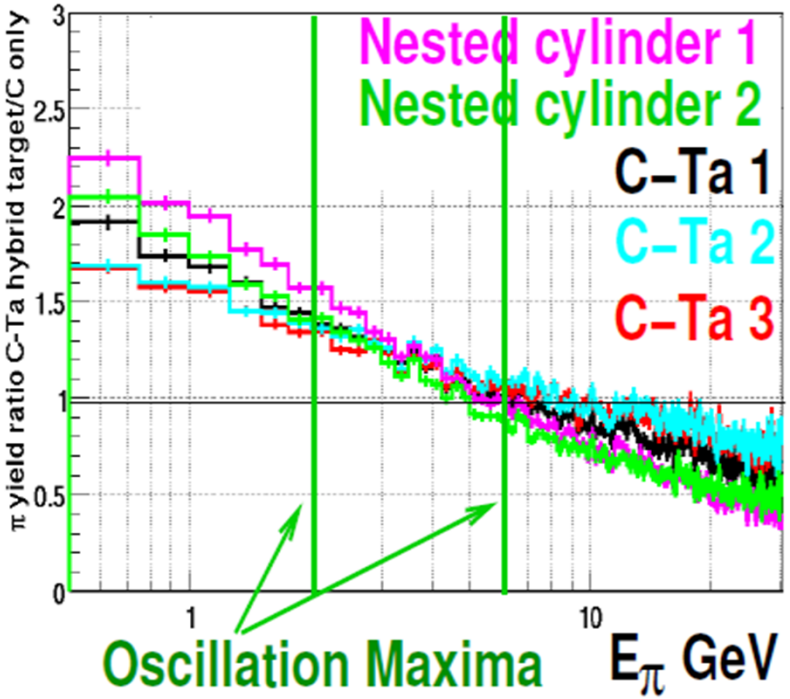
C-Ta Design



Nested-cylinder Design



Pion yields from a hybrid C-Ta target at 120 GeV



Increases π flux at 2nd maximum by $\sim$ 50%

Decreases π flux $>$ 20 GeV ($E_\nu > 8$ GeV) by 50%

M.Bishai

Flux at 2nd Max – Innovative Targets?

Hybrid target design: NEW

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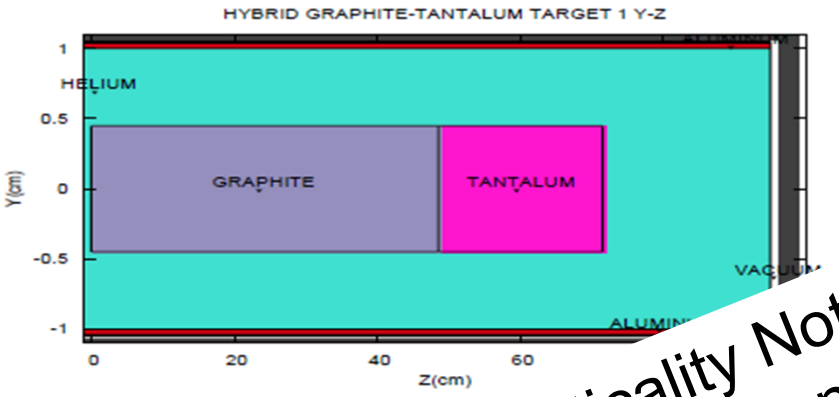
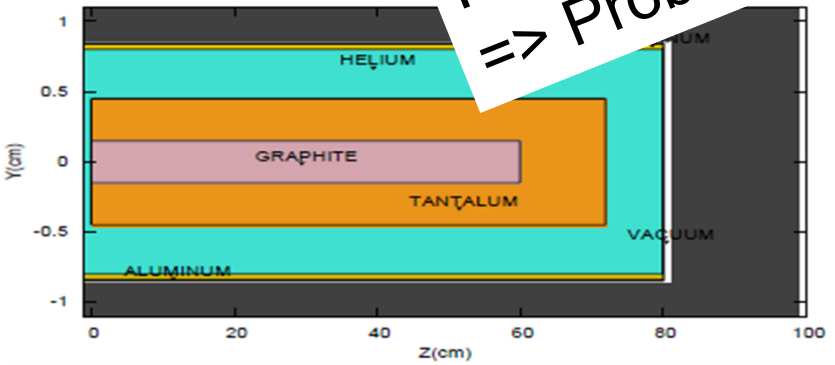
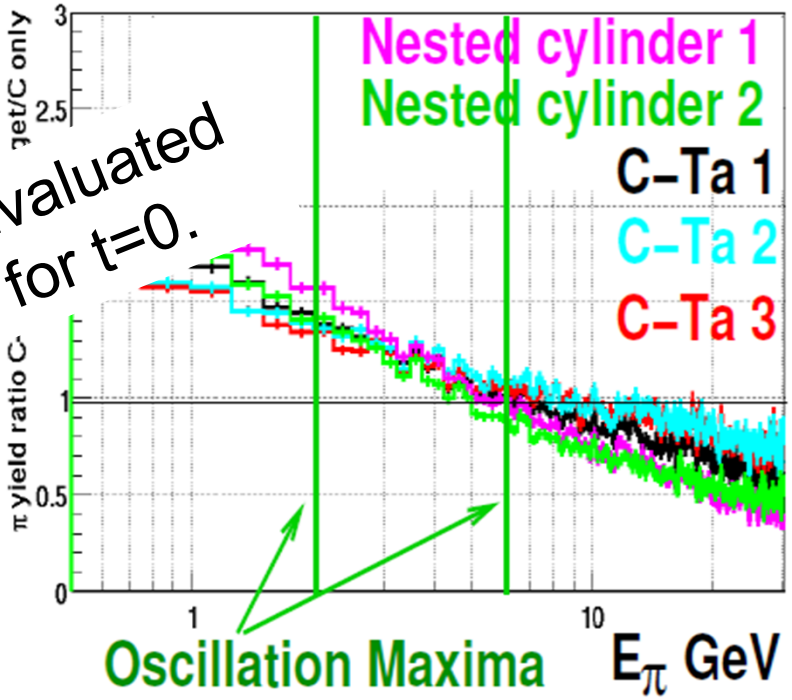


Nested-cylin



Practicality Not Evaluated
=> Probably not for t=0.

Pion yields from a hybrid C-Ta target at 120 GeV



Increases π flux at 2nd maximum by $\sim$ 50%

Decreases π flux $>$ 20 GeV ($E_\nu > 8$ GeV) by 50%

M.Bishai

Summary

- NuMI Beam is operating at a typical weekly average power of 250 kW, including downtime
  Peak hourly average power = 400 kW.
- NOvA upgrades will increase beam power to 700 kW
- LBNE beam is under design.
  - Higher power capability to > 2 MW
  - Optimizing spectrum for 1300 km baseline
  - Studying shallow options and different decay pipe dimensions for cost reduction.

  More details in Vaia Papadimitriou's talk in WG3 earlier today.

Many thanks to those who helped me prepare this talk and from whom I took slides