neutrinos from a PIon beam Line - **nuPIL**

Fermilab New Perspectives 2016

Ao Liu
on behalf of the nuPIL group

Abstract

nuPIL presents a modification of the current LBNF baseline, it is one step beyond the conventional van der Meer horn + decay pipe.

- nuPIL has a cure
  - for many of the concerns that you must already have for the current baseline.

Our team

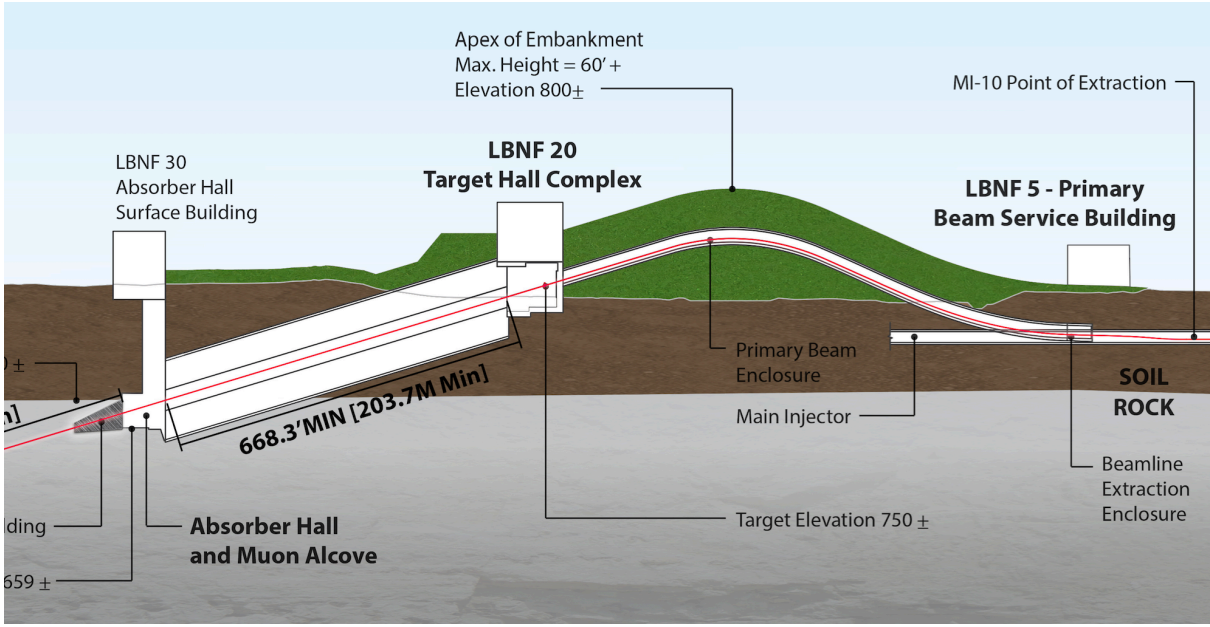
- Alan Bross (FNAL)
- JB Lagrange (Imperial College London), Pilar Coloma (FNAL), Terry Hart (U of Mississippi), Ao Liu (FNAL), David Neuffer (FNAL), Jaroslaw Pasternak (IC London),
- Your Name (Your institution);

Outline

- Introduction
- Beamline design
- Neutrino flux
- Optimization results
- Moving forward

Introduction

- nuPIL is based on a pion beamline that bends pions by 5.8° towards the DUNE detector. With this beamline:
  - We do not need to construct a hill to bend the high energy protons:



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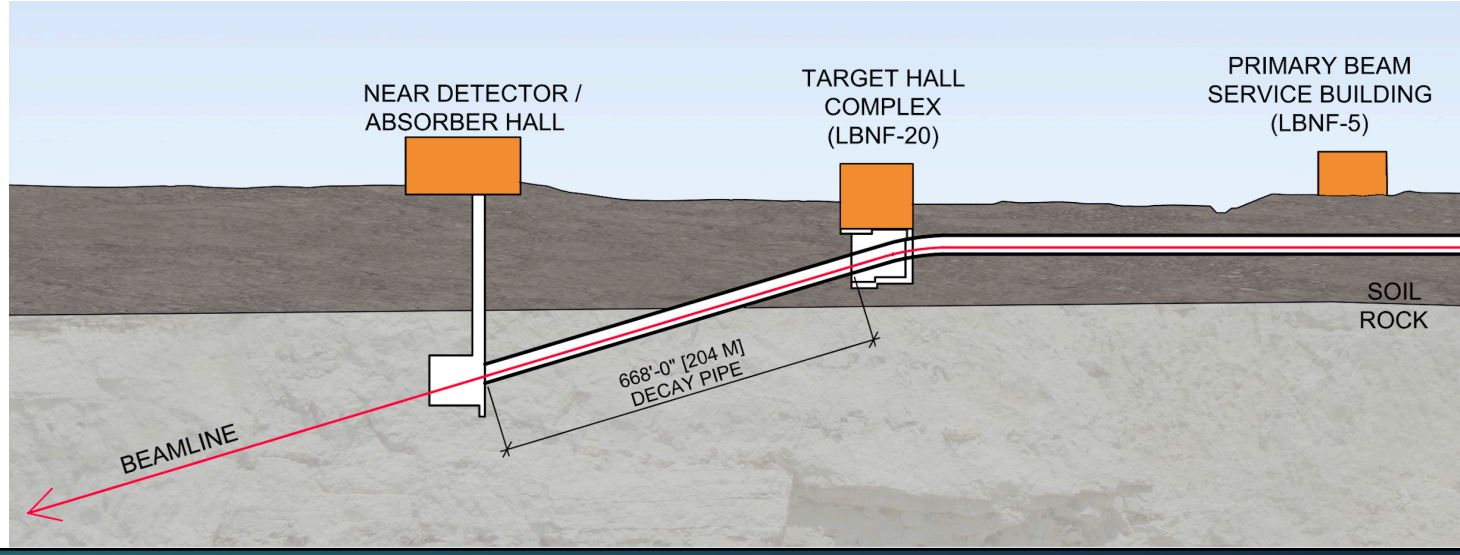


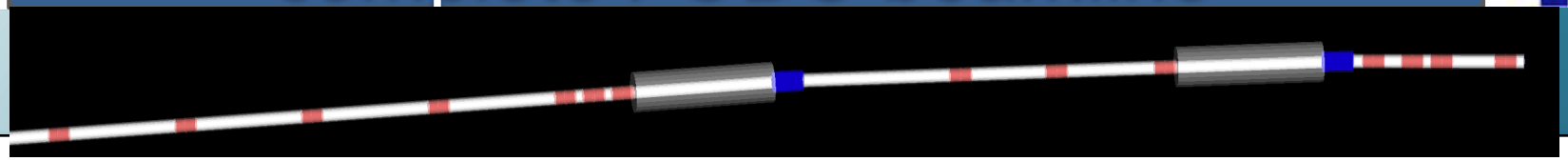
Introduction

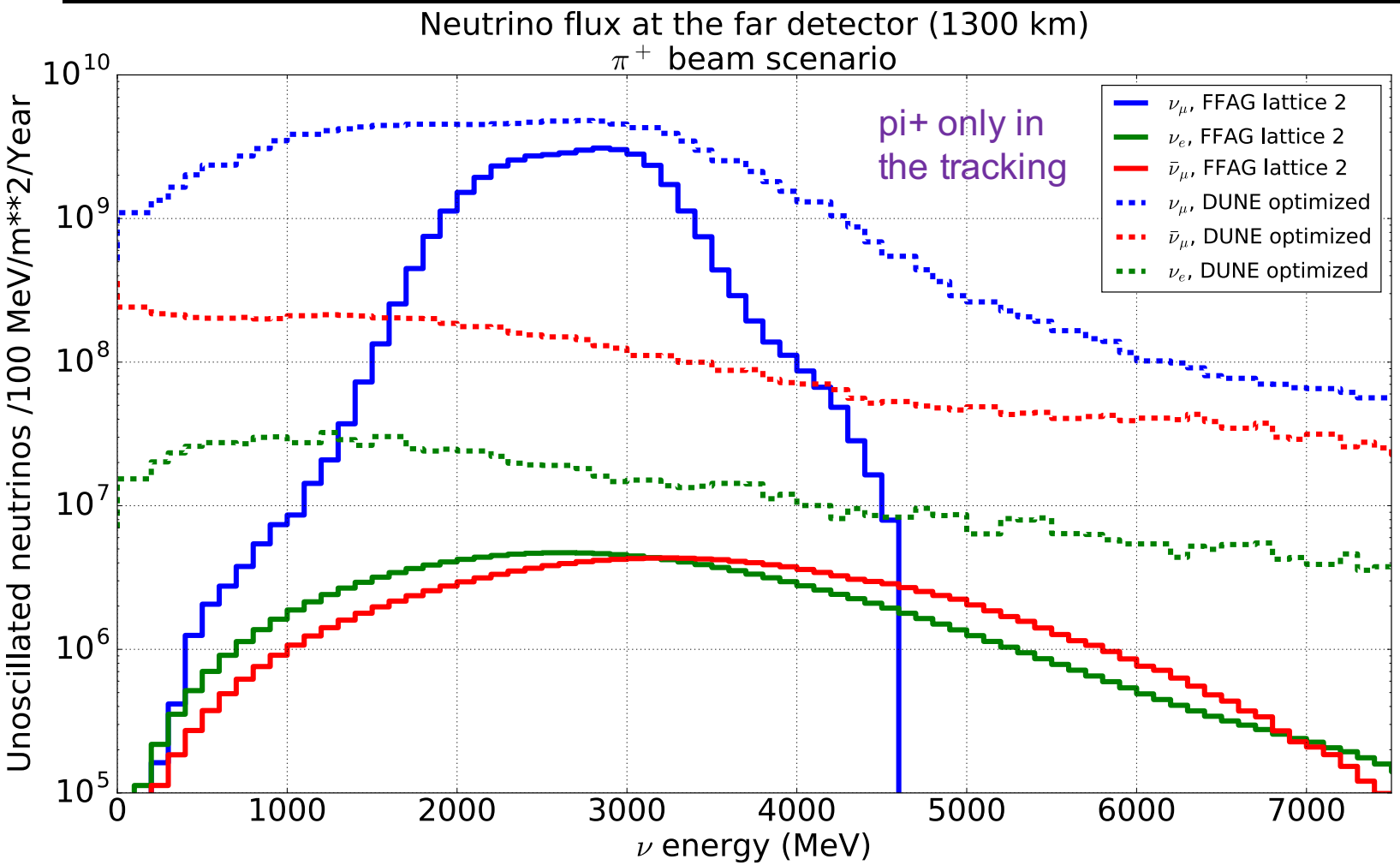
- nuPIL is based on a pion beamline that bends pions by 5.8° towards the DUNE detector. With this beamline:
  - We do not need to construct a hill to bend the high energy protons;
  - Bending structure in the beamline provides sign and momentum selection for the pions
    - Provides a flavor pure neutrino beam;
    - Much less power sent to underground – high energy protons absorbed at MI depth
- Beam systematics:
  - Conventional neutrino facilities: Pion/Kaon production, proton & target interaction stability, horn stability, etc.
  - nuPIL: None of above
    - pion flux + optics measurable and predictable in a magnetic beamline.

Beamline Design - two scenarios

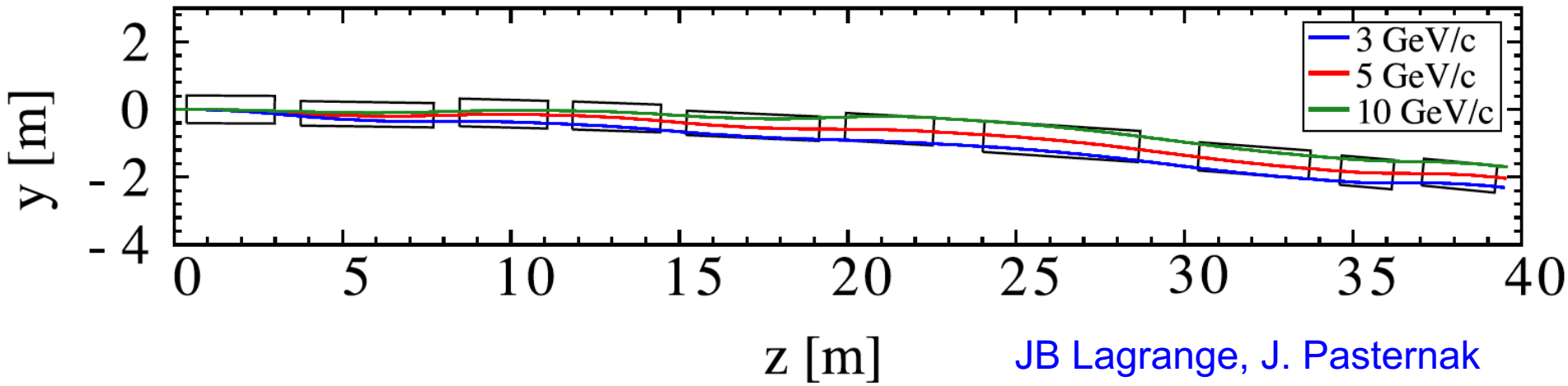
- 1. Use a decay pipe (204 m in length, 2 m in radius) as the production straight
  - Higher flux, but less capability to measure the beam precisely
- 2. Use a magnetic straight beamline (204 m) instead
  - Full diagnostics in the straight to characterize the pion beam: precisely known neutrino flux at the detector, but less flux due to the finite acceptance of a beamline.
- Both of above have steering bend section (the part that steers the pions towards FD);
- Studied more than 13 lattices, including FODO, FFAG and hybrid.
  - Here, the (up-to-now) best designs for the above 2 scenarios are shown (lattice 11 for DP scenario and lattice 2 for BL)

Beamline Design – lattice 2 – A complete FODO beamline

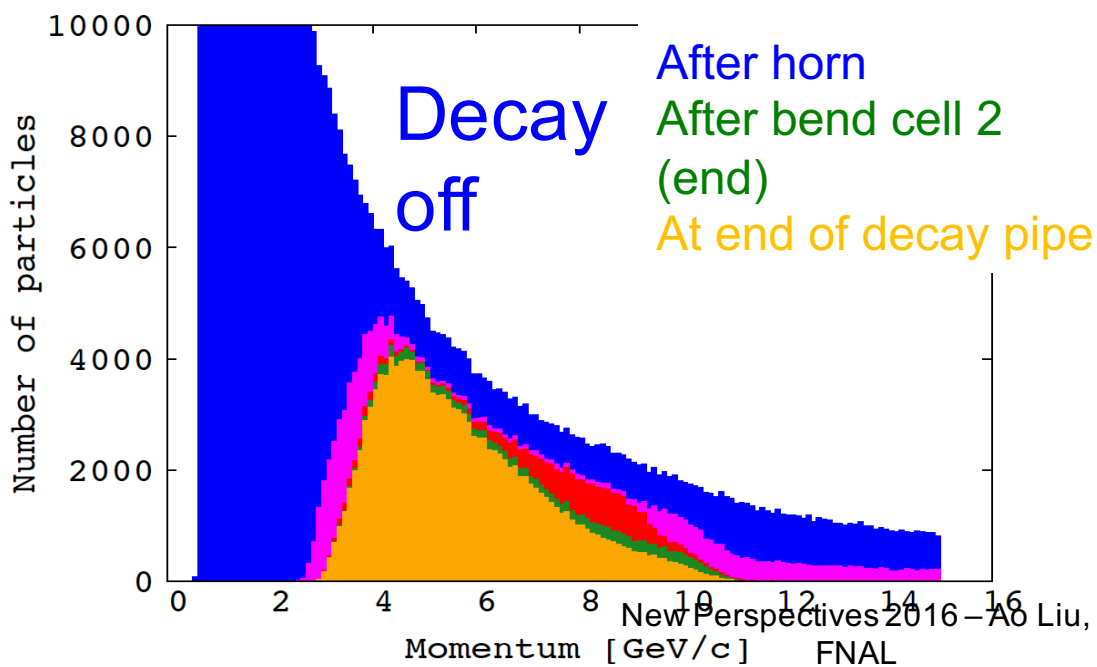




Beamline design – lattice 11 – FFAG bend + DP



JB Lagrange, J. Pasternak

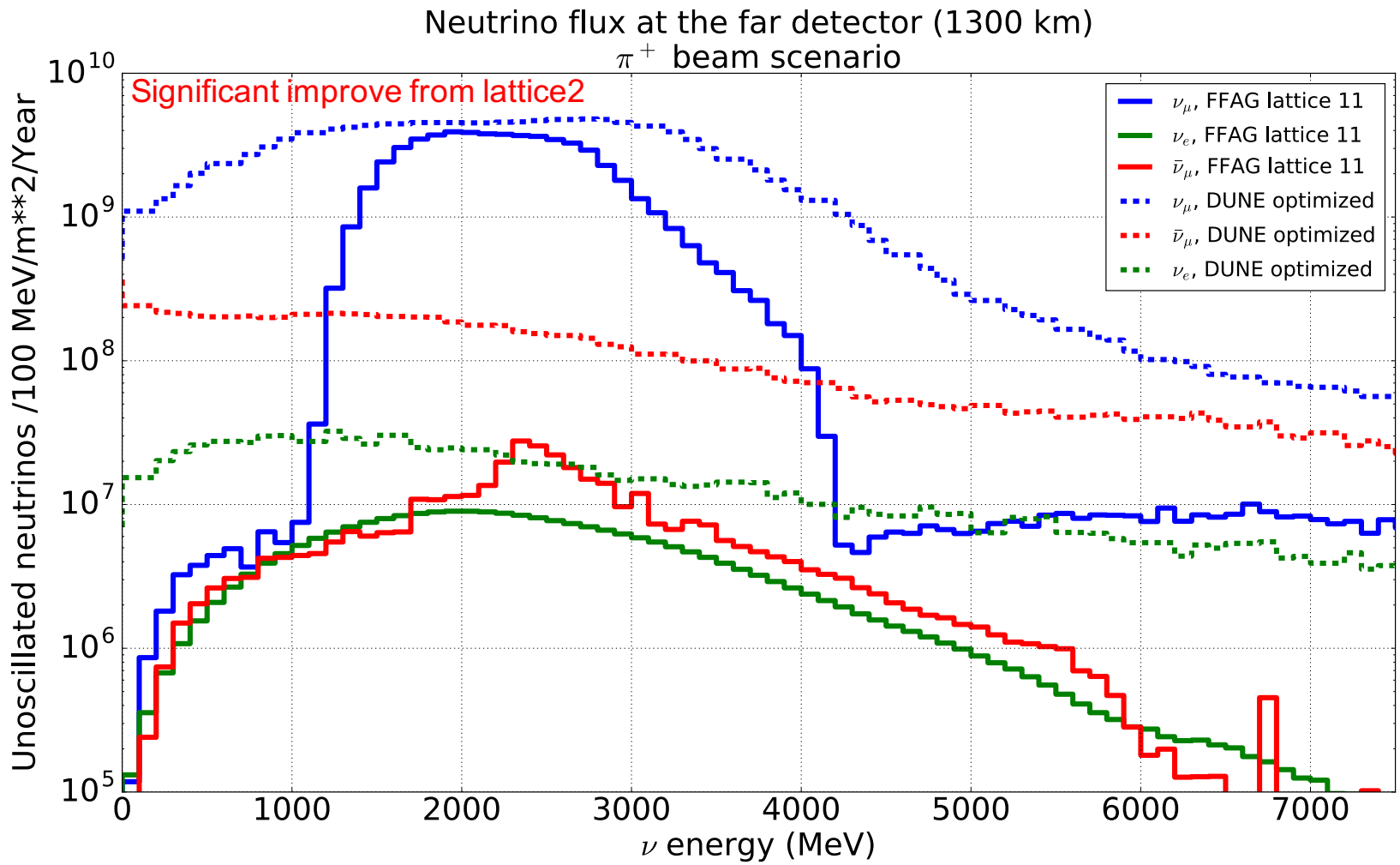


Scaling FFAG section: Dispersion vanishes after the bend

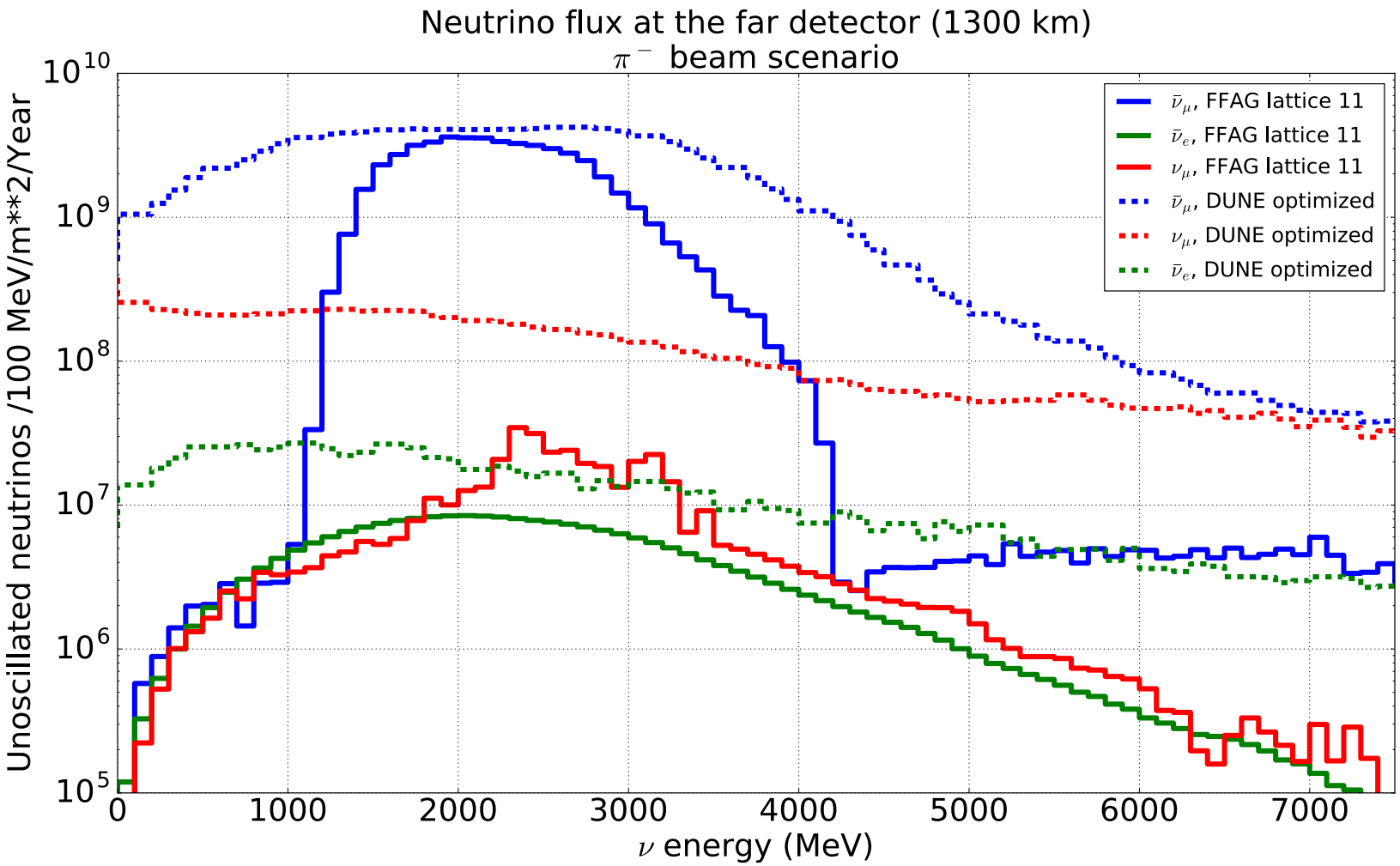
Starts with a single NuMI-like horn (designed for nuSTORM) and a 38 cm Gold target (other robust targets later)

No horn optimization was done at this step.

Beamline performance – nu mode

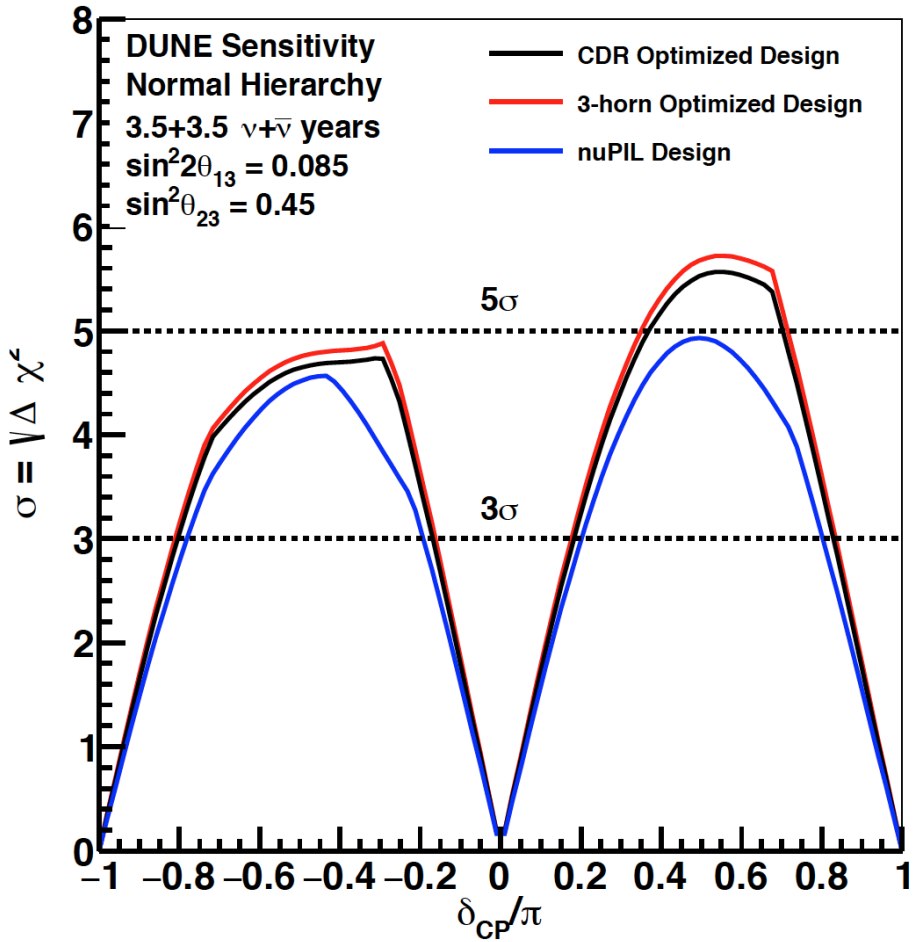


Beamline performance – antinu mode

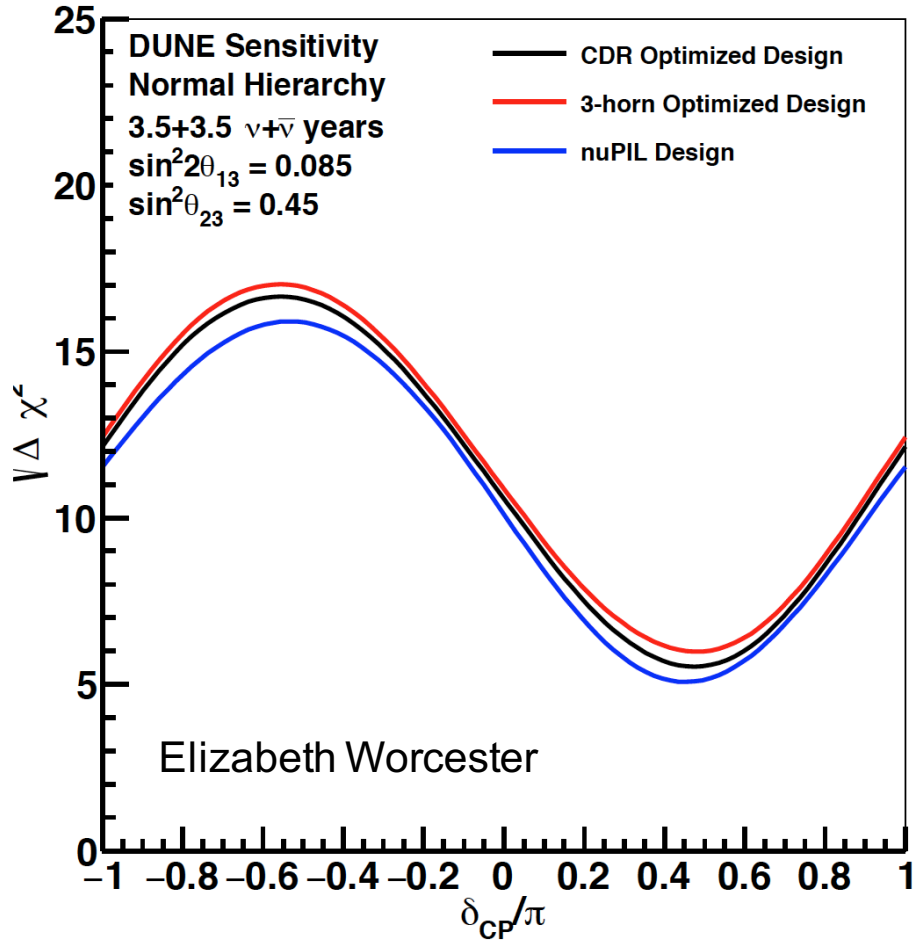


Physics reach

CP Violation Sensitivity

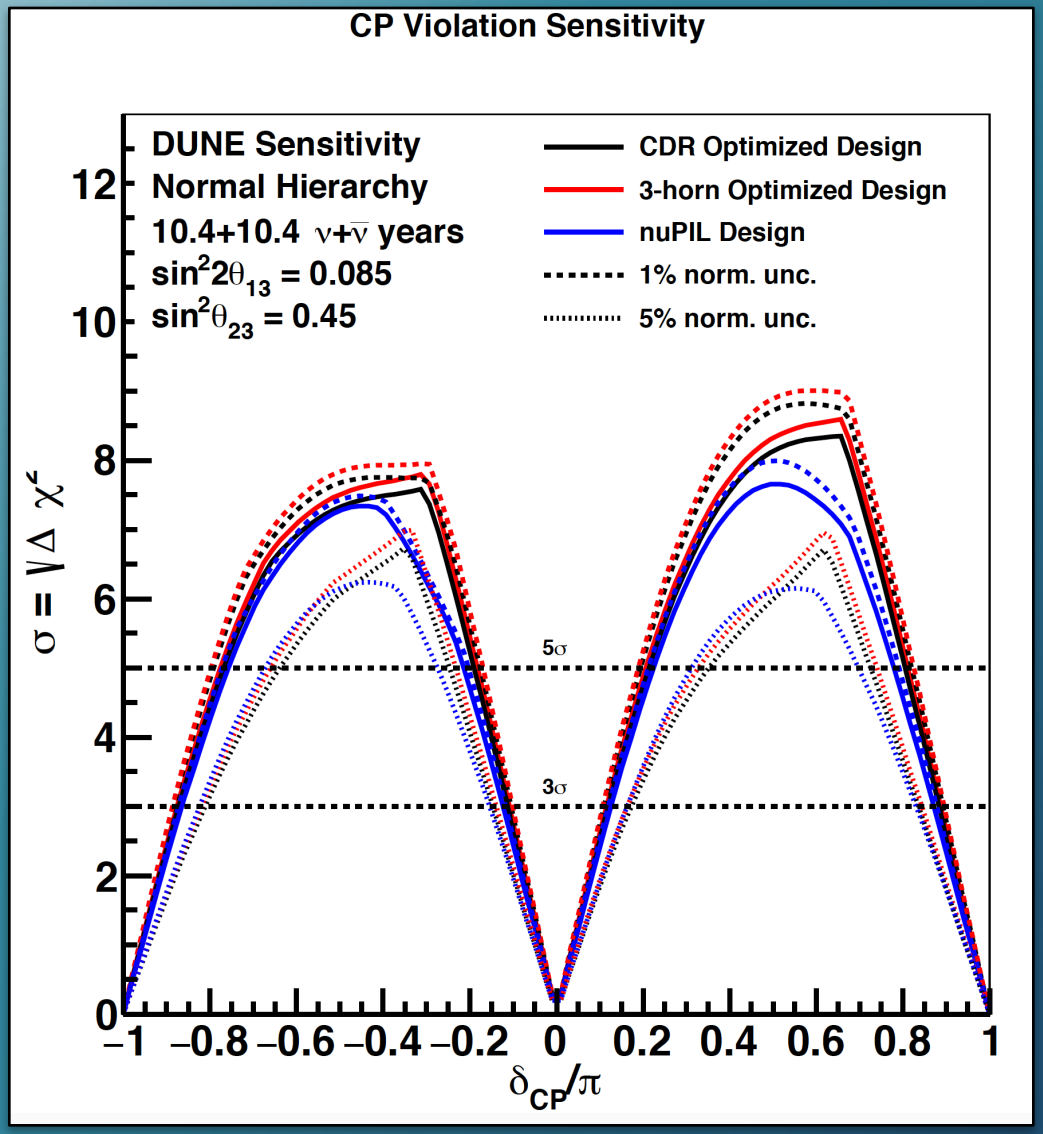


Mass Hierarchy Sensitivity



Elizabeth Worcester

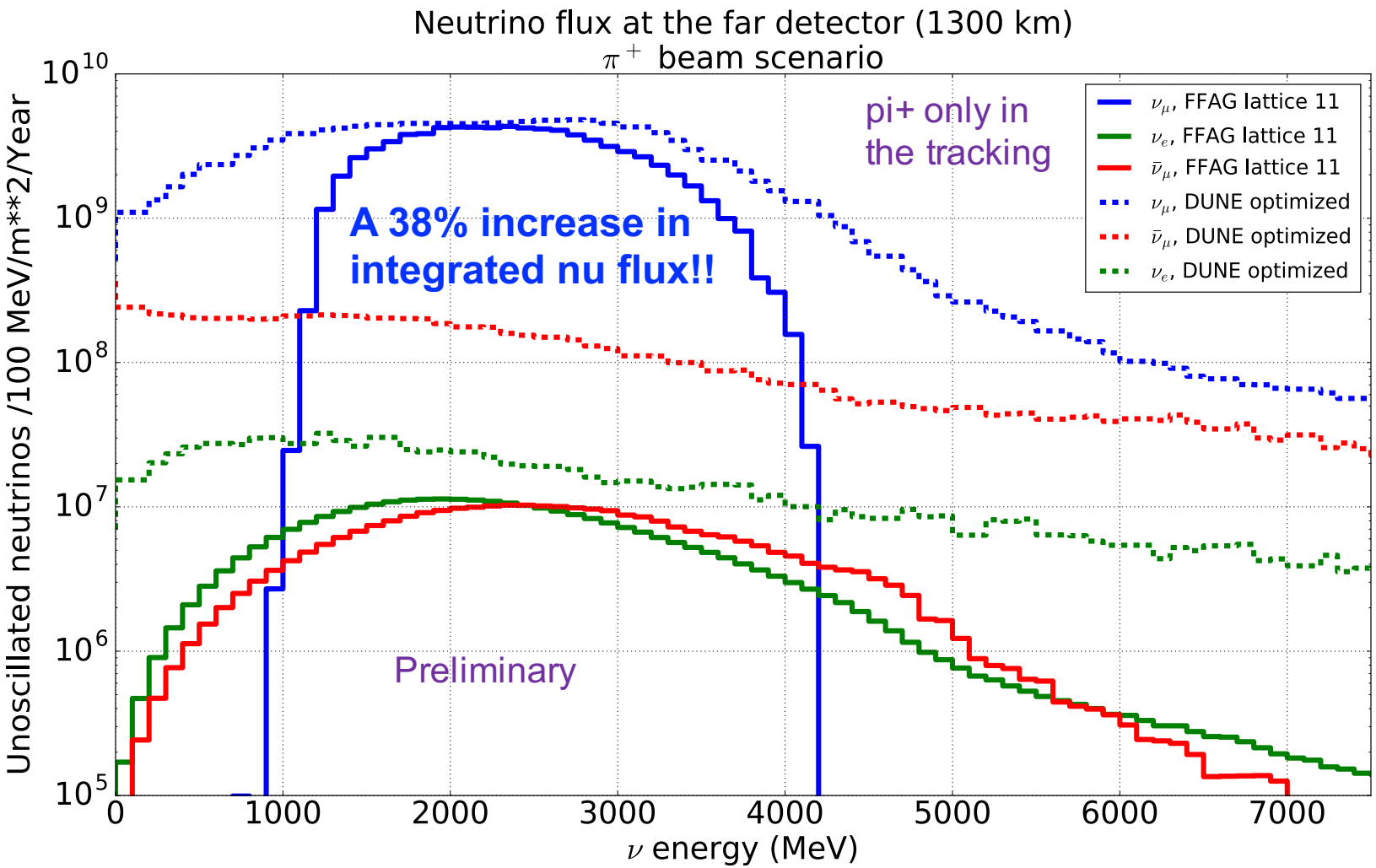
Physics Reach with Uncertainties



Genetic Algorithm Optimization of the horn(s)

- Target and horn used for nuPIL preliminary studies was designed for nuSTORM (with 38 cm Inconel target), and Gold target can not tolerate proton power at 1.1 MW.
- Perform an optimization on the horn with a 4 interaction lengths Carbon target
  - Objective function: pions (selected sign) in the acceptance of lattice 11, which was characterized by the multi-particle tracking in lattice 11.
  - Single horn optimization from nuSTORM experience might yield 20% increase; Two horns TBD.

Single Horn Optimization Result



Physics reach from this beam to be done

Two-horn opt. shows another 10% inc. in accepted pions

Conclusions and future

- nuPIL provides a (almost) flavor-pure neutrino beam through a measurable and manipulable pion beam
  - It has less systematics uncertainties, less radiation hazard, more reliability, a magnetic beamline rather than a hill, needs a much easier hadron absorber (ND can be a Super ND!)
  - **Again, nuPIL has a cure.**
- Concept has already been presented to the DUNE collaboration at the last CM (Rapid City)
  - We welcome:
    - Help on neutrino analysis
    - Help on beamline design and optimizations
    - Help on instrumentation design
  - Are you willing to witness something ν?

Backup slides

THANK YOU FOR YOUR ATTENTION!

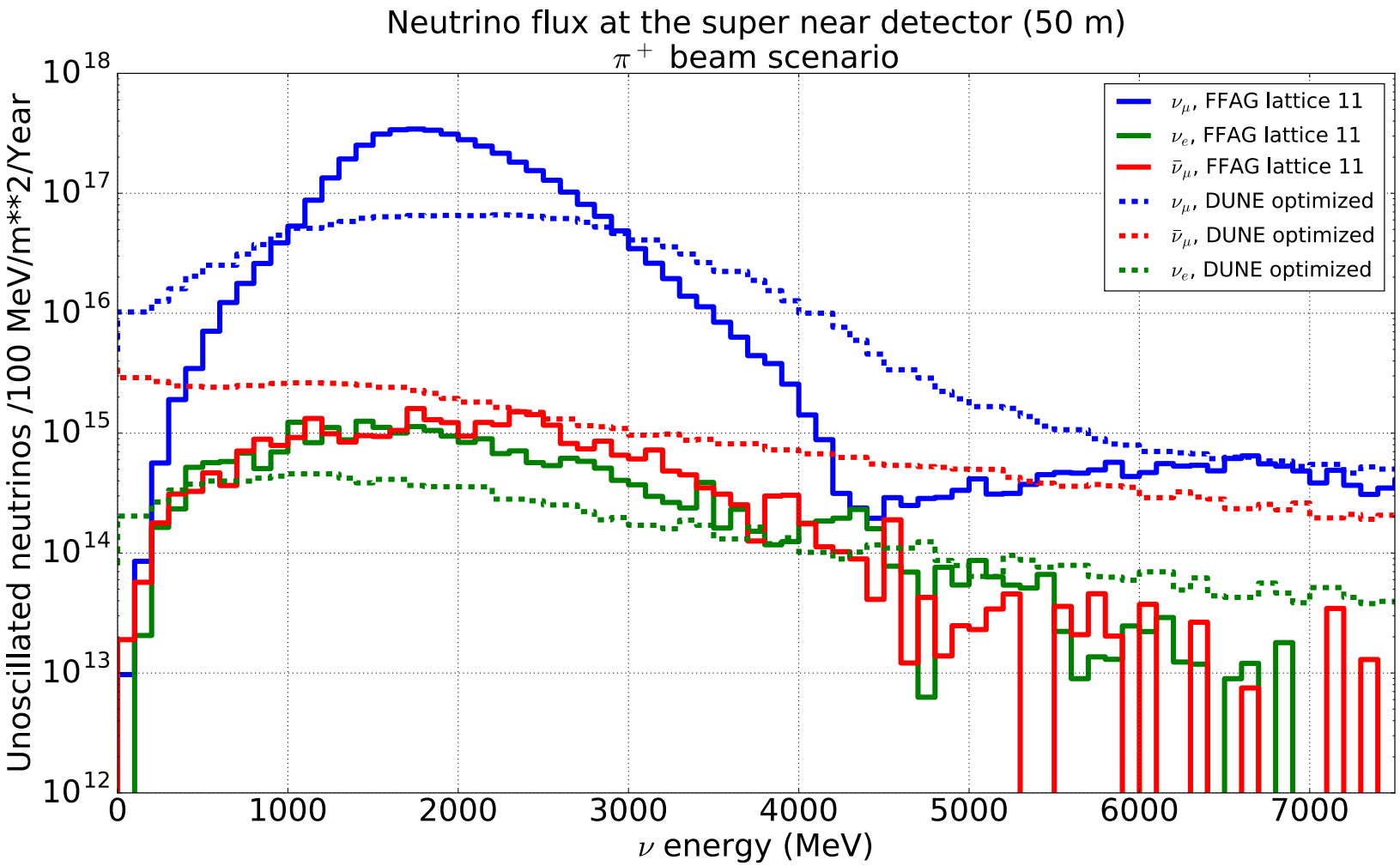
Beam diagnostics

Quantity	Detector(s)	Comments
Beam Intensity	Beam current transformers	<1% resolution obtainable
Beam Position	BPMs	1 cm resolution
Beam profile	Scintillating screens, etc	Destructive
Energy	Polarimeter	<1% resolution
Energy spread	Profile measurement in bend	
Beam loss	Conventional	

Analysis (for the neutrino experts, not for myself)

Pilar Coloma

- GLoBES framework
  - $\theta_{23} = 42°$
  - $\theta_{13} = 9°$
  - $\theta_{12} = 33°$
  - $\Delta m^2_{atmos} = 2.45 \times 10^{-3}$ eV^2
  - $\Delta m^2_{sol} = 7.64 \times 10^{-5}$ eV^2
  - 6 years (3 nu/3 anti-nu), 1.07 MW, 40kT
  - 5⊕2 signal systematic uncertainties

- Intrinsic ν_e and ν_e-bar contamination, with the same efficiency as the signal
- Neutral-current (NC) backgrounds coming from the leading flux component after interacting at the detector. MMs used
  - 99.5% rejection eff. for app.
  - 99% rejection eff. for dis.
- τ contamination implemented
  - 40% rejection eff.
- An overall normalization uncertainty was implemented for all signal and background contributions.

nuPIL SND flux