MH and δ_{CP} using existing facilities (in the next decade)

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The Existing Facilities

- Super-K : a previous talk
- IceCube-PINGU : another talk
- NOVA : next talk
- T2K : a previous talk
- Additional NuMi Beam Exploitation : this talk!
  - 3 options to be described
  - Intermediate step towards LBNE
  - Prototyping with physics

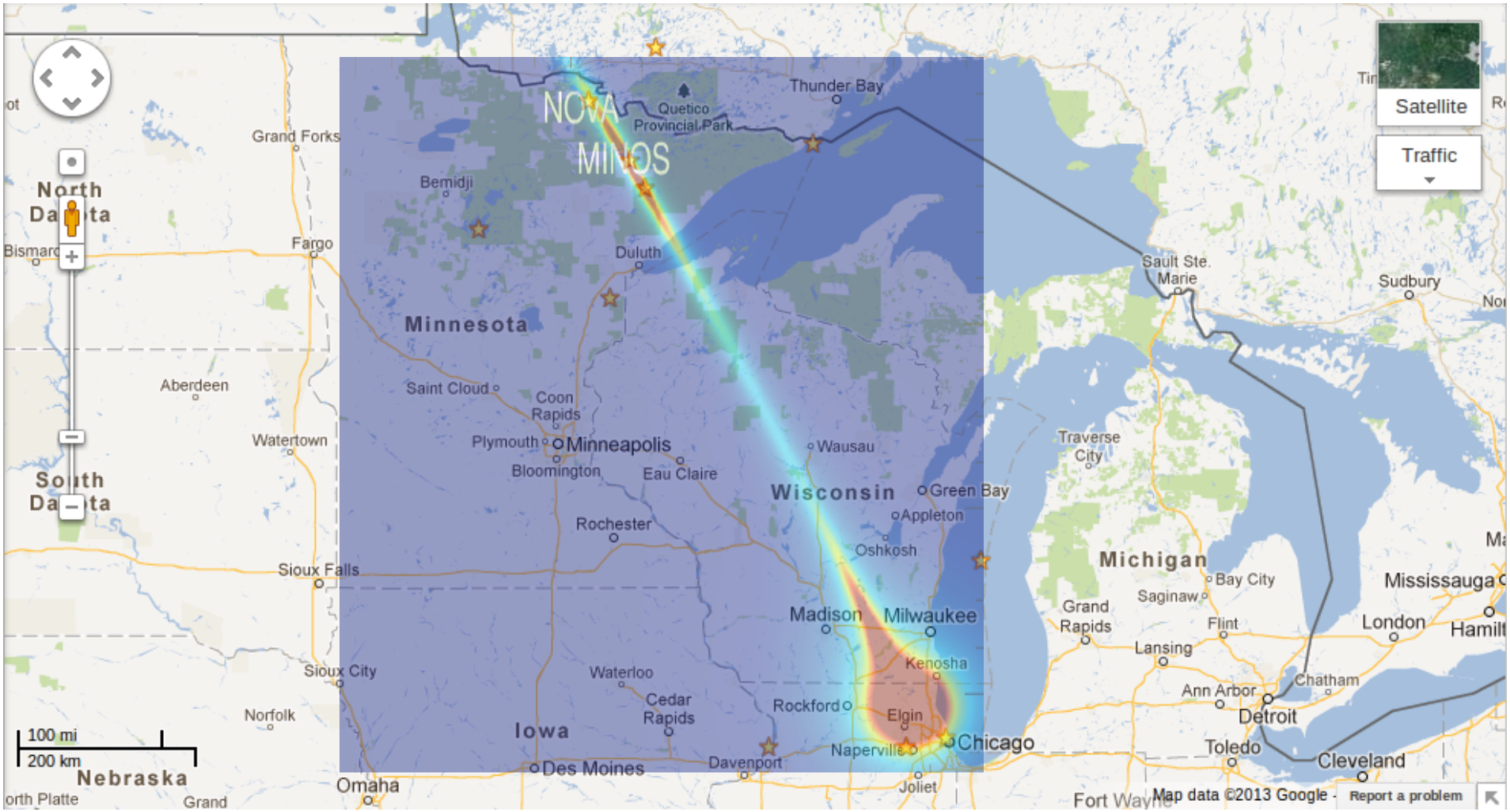
NuMI further exploitation

- NuMI will be the worlds most intense long baseline neutrino beam
  - This summer will see an upgrade towards 6e20pot/year
  - Plan is to run for at least 6 years, probably 8 or 10
  - LBNE will then take on the heavy lifting
- Given time scales for all construction projects (US and Europe but not Asia!) as well as long data collection times for LB neutrinos, we need
  - Intermediate physics opportunities
  - Development of Mt detectors for LBNE and beyond
    - Beams cannot deliver 1-2 orders of magnitude more flux in the forseeable future
    - Only way forward is detector mass
    - Precision studies possibly will be the future direction

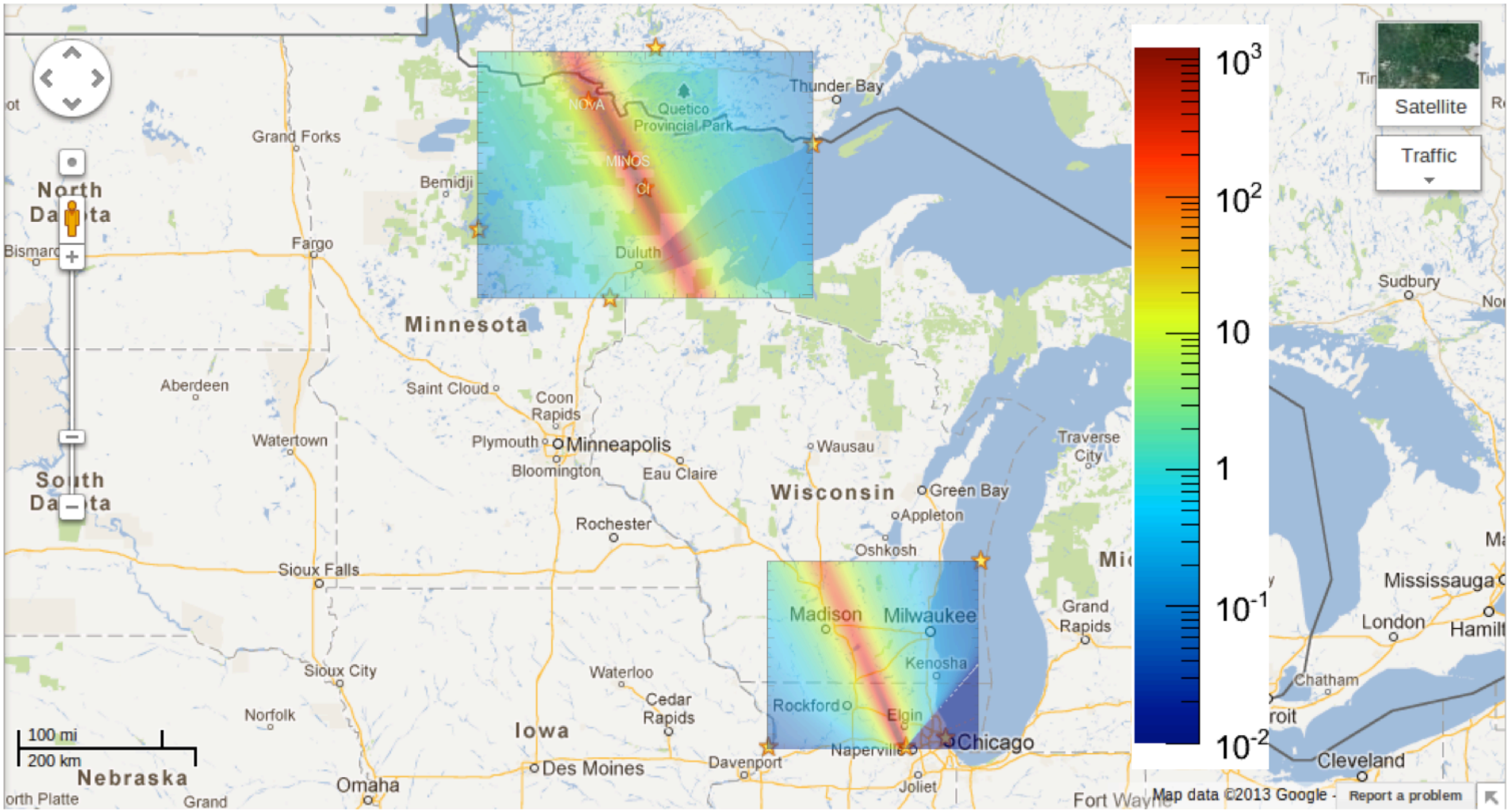
E(xploitation of)-NuMI

- 80-strong group formed to look at the options
- Three significantly different approaches
  - More NOVA
    - Complete 18kt of the detector
  - GLADE @ Ash River
    - 5kt of Lar
    - Test bed for large LAr detector construction
  - CHIPS @ Wentworth Pit
    - Prototype for very very large water detectors

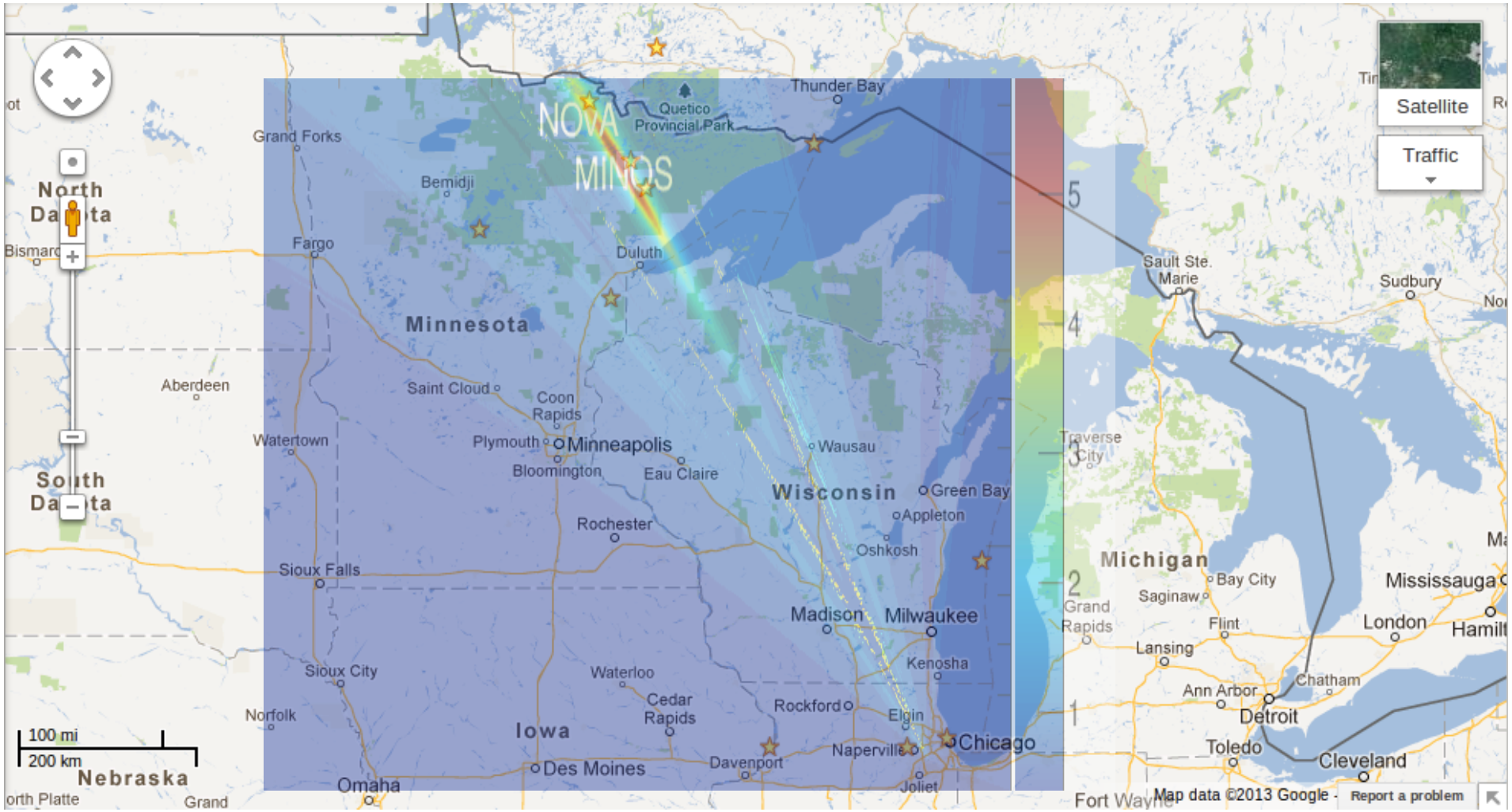
Looking At the NuMI Beam : Flux



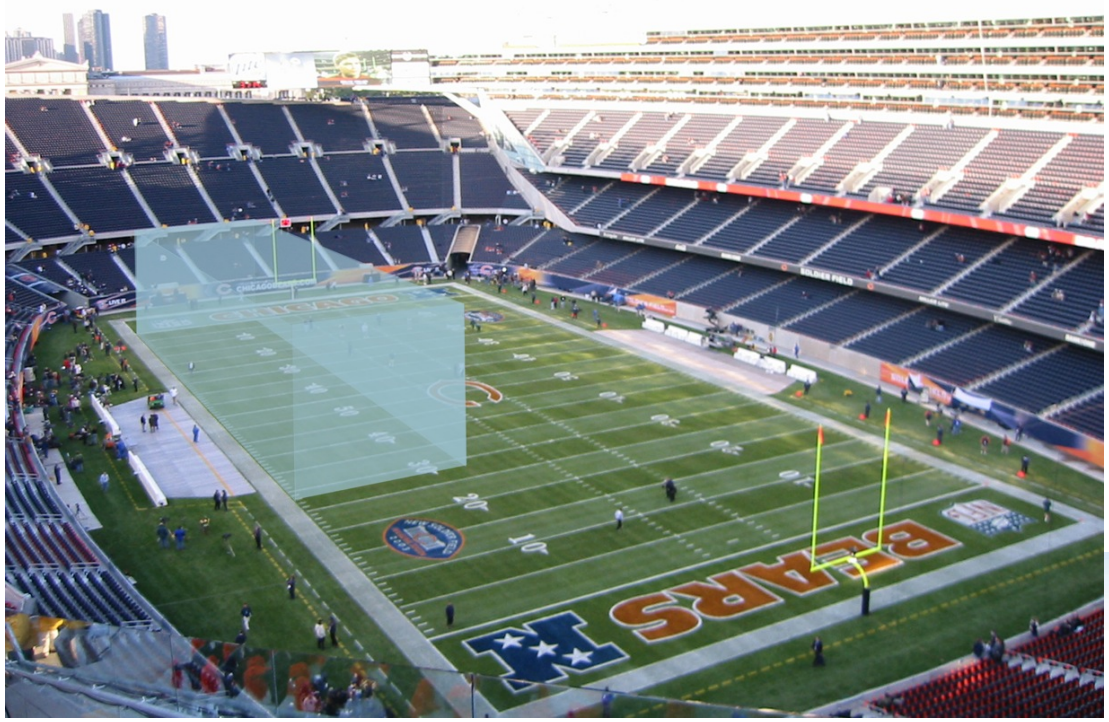
Looking At the NuMI Beam (#events kt-y)



Looking At the NuMI Beam (Peak Energy)



The Ash River Options



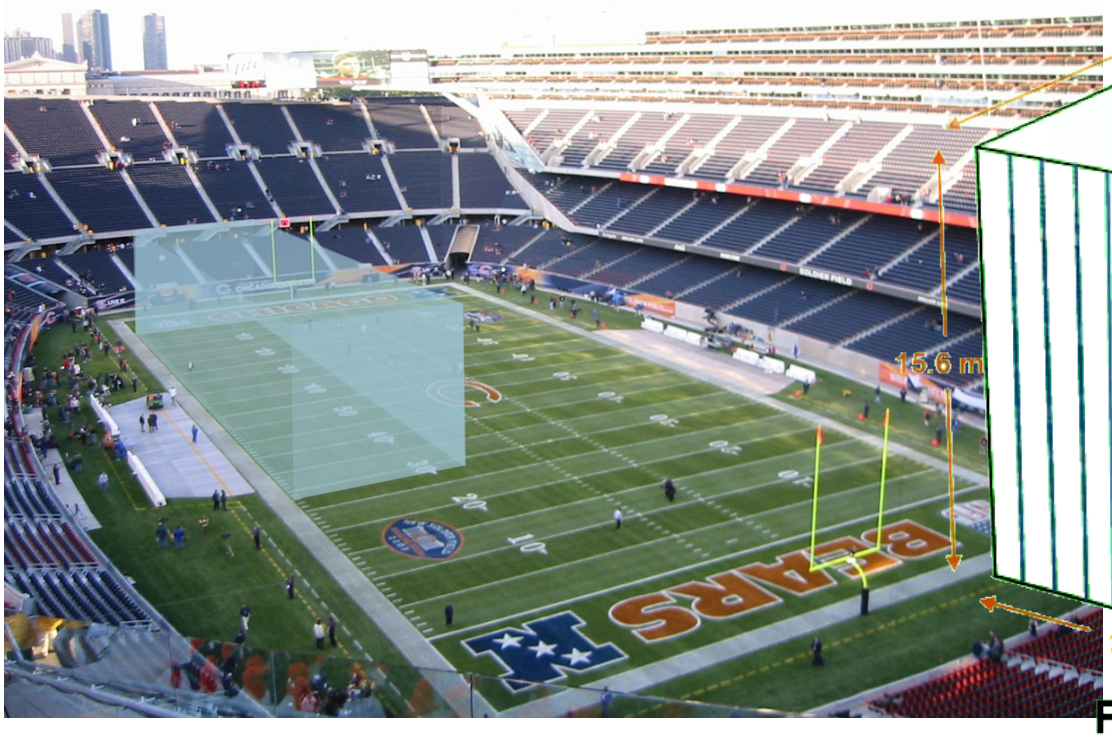
- Both options add to effective detector mass at Ash River

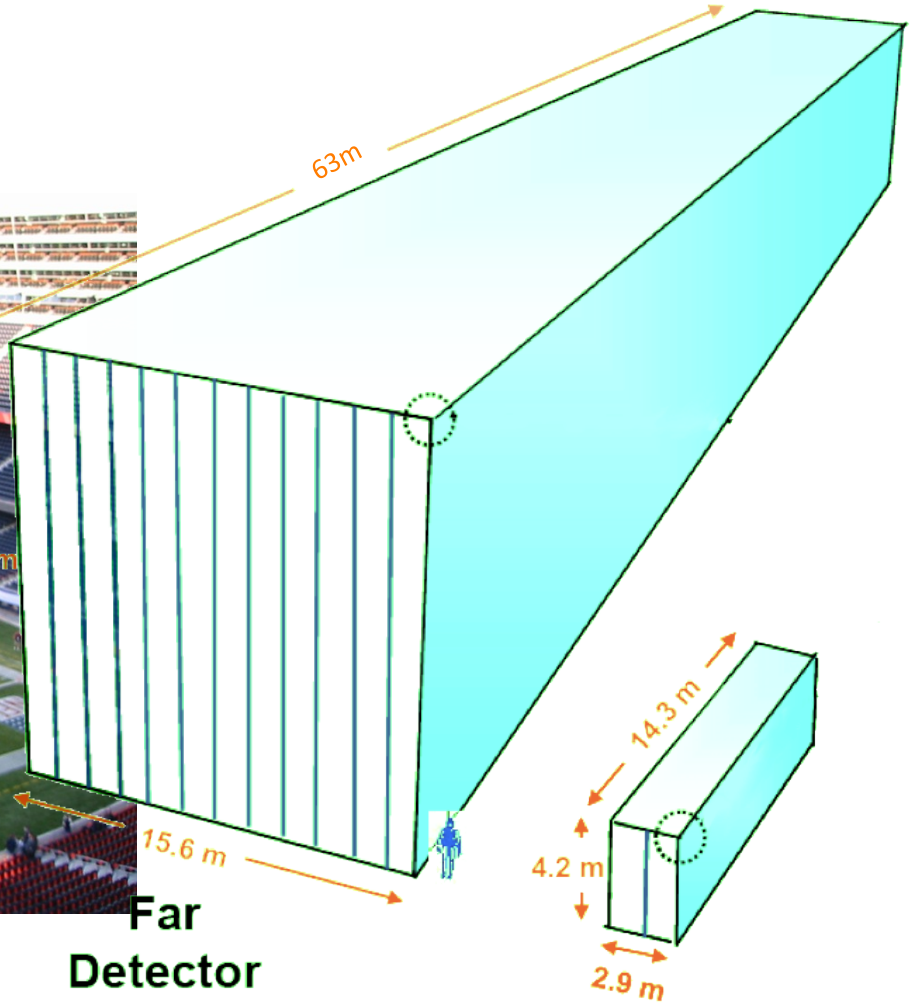
- 4 extra kt of NOνA
- 5kt of LAr

GLADE

Global Liquid Argon Detector Experiment

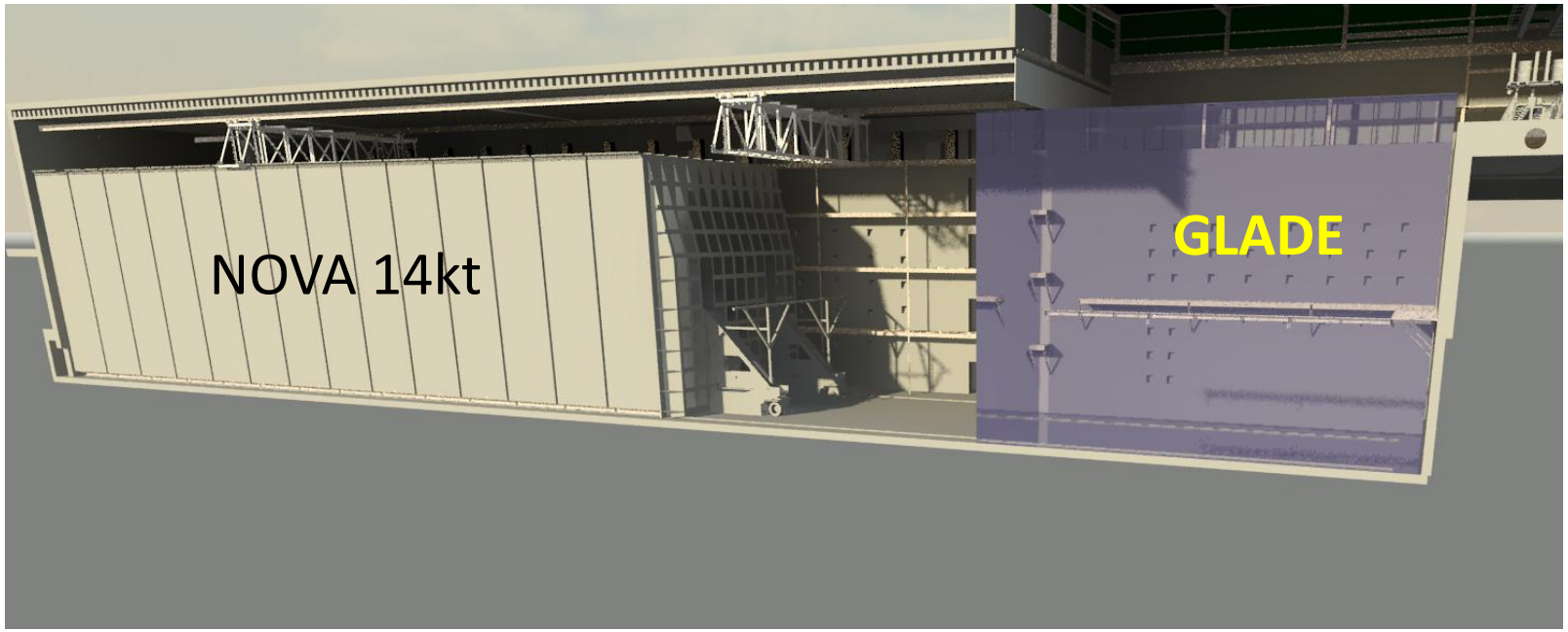
More NOνA





- Massive, Low-Z, 65% active Far Detector
  - 14 kton, 810 km from source
- Functionally equivalent Near Detector to mitigate systematic uncertainties
  - 220 ton Near Detector, 1 km from source

GLADE at Ash River : MH



- Maximum active volume is 16mx16mx18m = 4608m^3 (3600=5kt)
- Ash River building has space for 18kt of NOνA and 5kt LAr
- Emphasis on recyclability for LBNE
  - Valuable experience to be gained for LBNE
- Effectively like doubling NOνA volume for cost of about $160M
- European involvement???

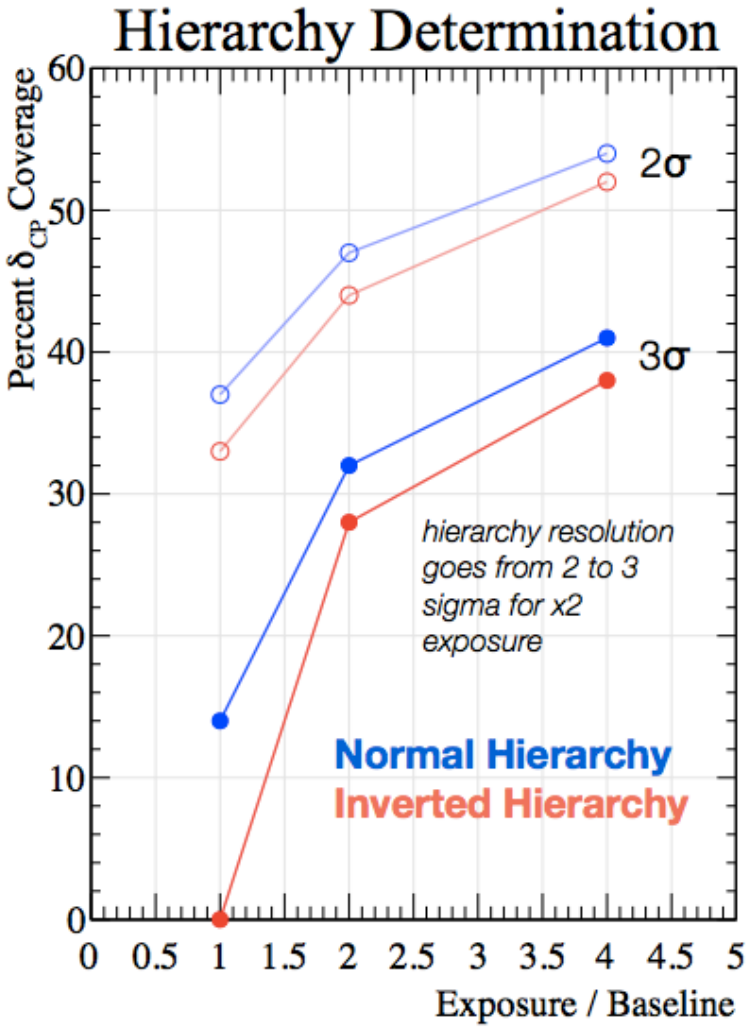
The Ash River Options

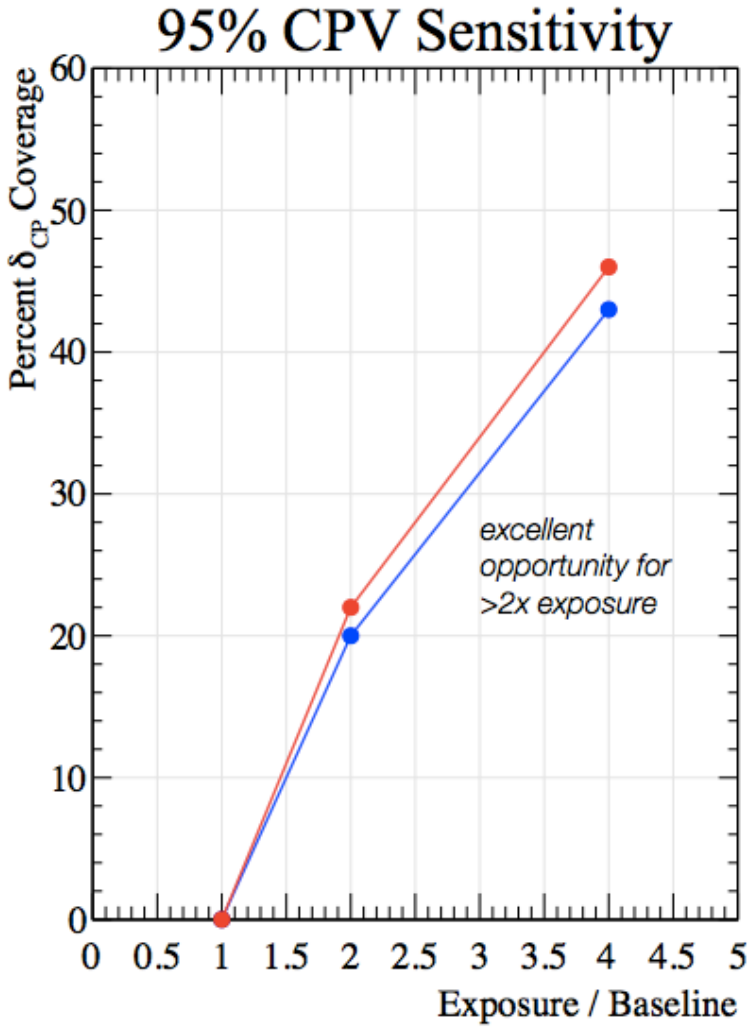
Pathways to higher exposure

[A] 6 years x 700 kW x 14 kt = baseline exposure
[B] 10 years x 700 kW x 18 kt = 2.1x
[C] 10 years x 700 kW x 29 kt = 3.5x

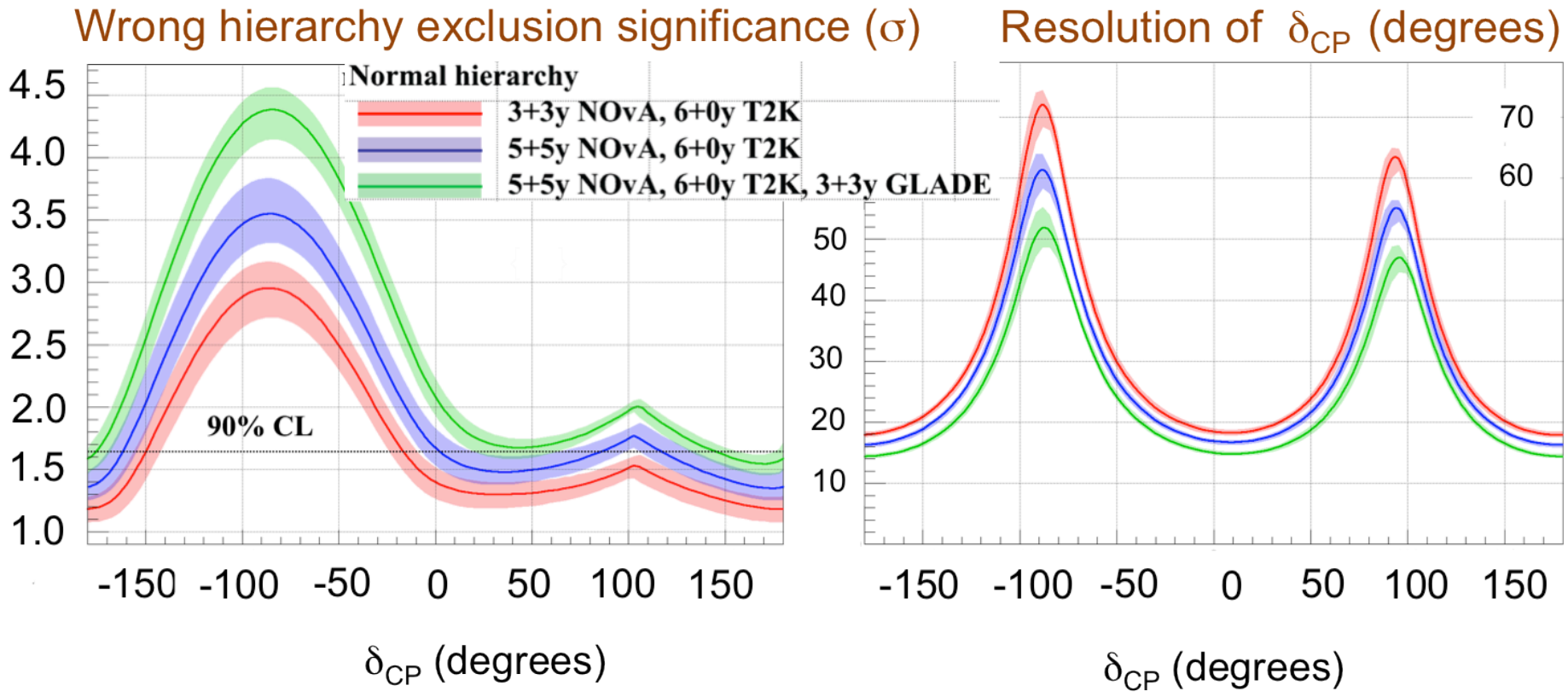
- The extension from 6 years to 10 recognizes the reality of a staged LBNE program.
- Extension of mass from 14 to 18 is relatively low risk based on construction of additional NOvA blocks at $(6-9)M/kt = $24-36M. $6M/kt is if NOvA production does not stop, $9M is upper limit if we have to restart production lines.
- Extension of mass from 14 to "29" imagines adding 5 kt of LqAr to a 14 kt NOvA. 5 kt of LqAr is thought to be equivalent to 15 kt of NOvA.

The Ash River Options





NOVA+T2K+GLADE



- This combination can resolve mass hierarchy at 3σ for 35% of δ_{CP}
- NOVA+T2K (baseline) at 2σ for 35% of δ_{CP}
- δ_{CP} coverage at 2σ for 45%, T2K+NOνA (basline) at 2σ for 25%

CHIPS : δ_{CP}
Water Cherenkov Detector

δ_{CP} : CHIPS on and off axis

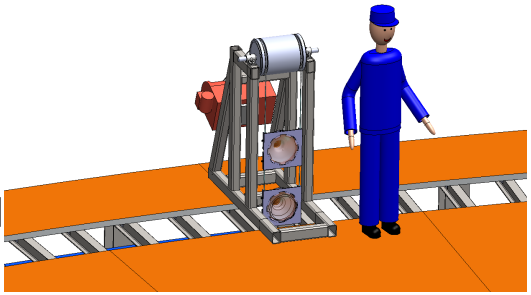
- Water Cherenkov innovations
  - We have to think about bigger detectors to allow results to be collected within the lifetime of the experiment proponents
  - Water is one (the only?) way to get to 1Mt affordably
  - Use natural water as support: deploy underwater in a flooded mine pit (range of off-axis angles), below the freeze zone
  - Minnesota is the Land O' Lakes

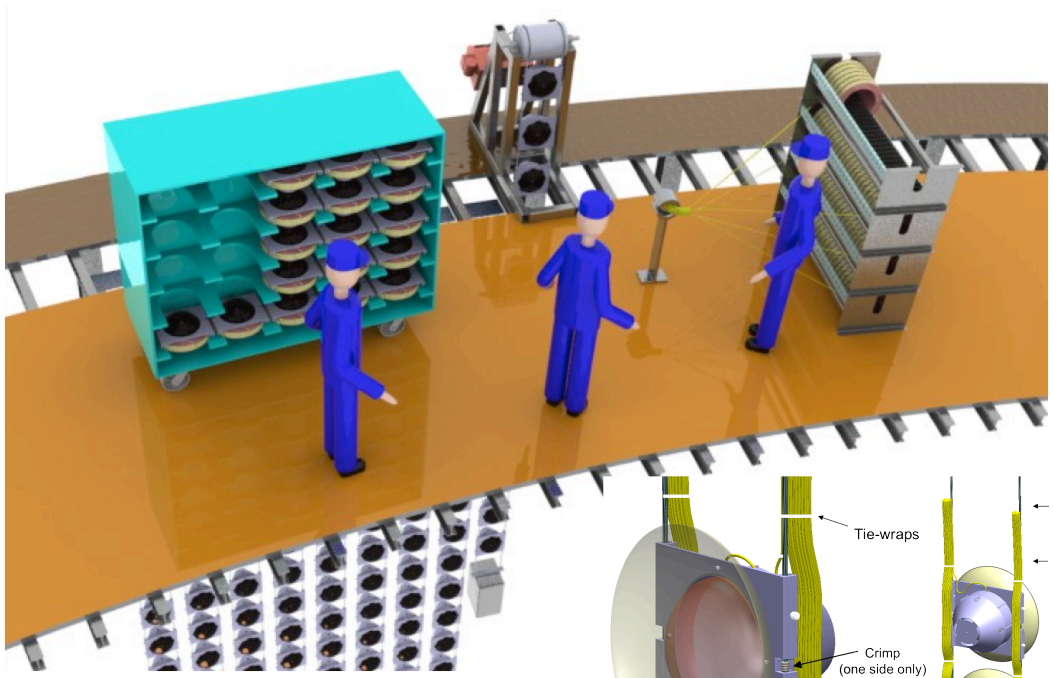
δ_{CP} : CHIPS concept

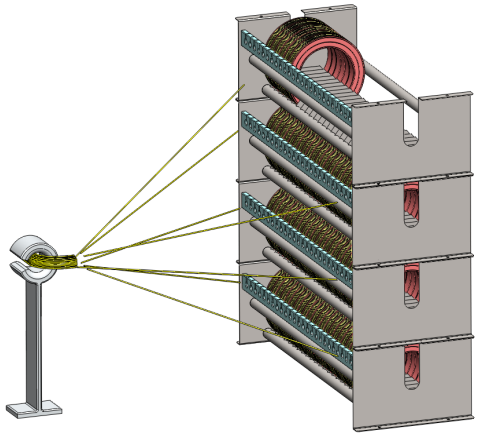
- Deploy from floating platform using industrial products from the fisheries industry
- Replace nets with PVC + KEE roofing membranes rated for continuous underwater use including aggressive oil spill environments, low permeability and light tight
- Fill with pure water for neutrino target
- Pit water acts as mechanical support
- Ice build up easily prevented by water circulation pumps
- Idea developed by Madison group

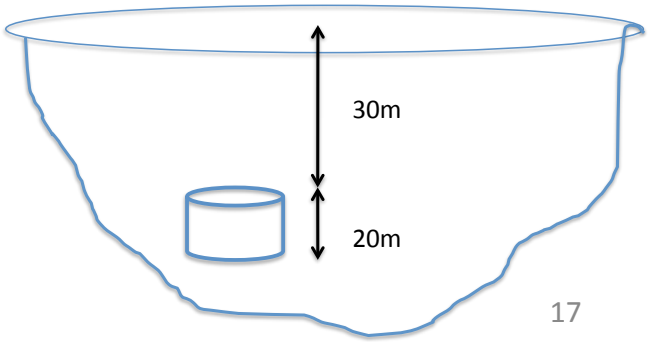
CHIPS design

- Focus on recyclability, what goes down must come up
- Concept for floating deployment developed for LBNE WC
- Use technology based on Ice Cube
  - 10% HQE PMT coverage, PMTS encased in pressure spheres and deployed on wires
- Suspended at ~40-60m under water level



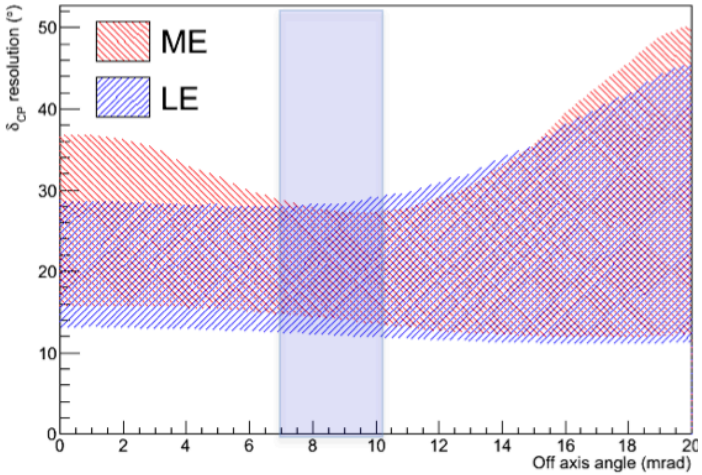


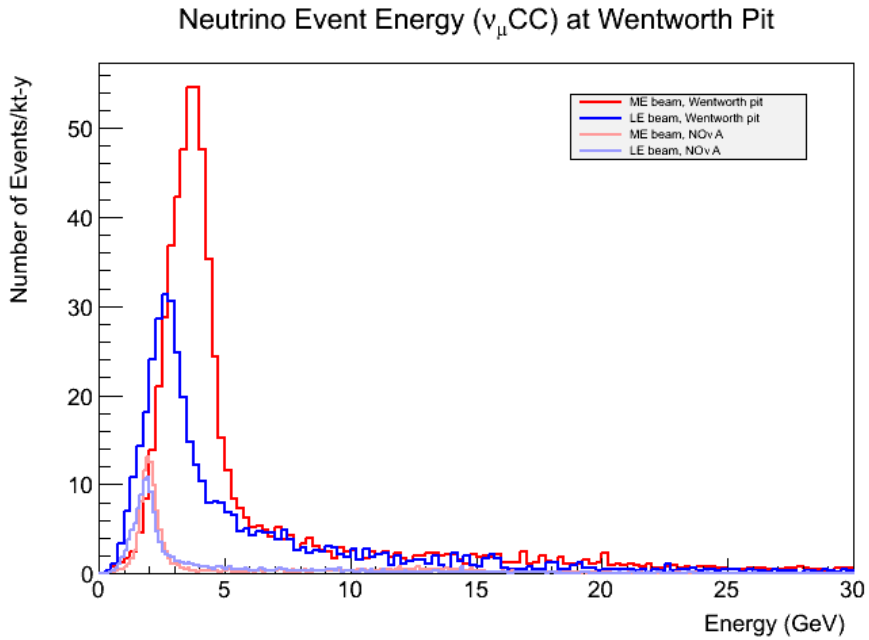


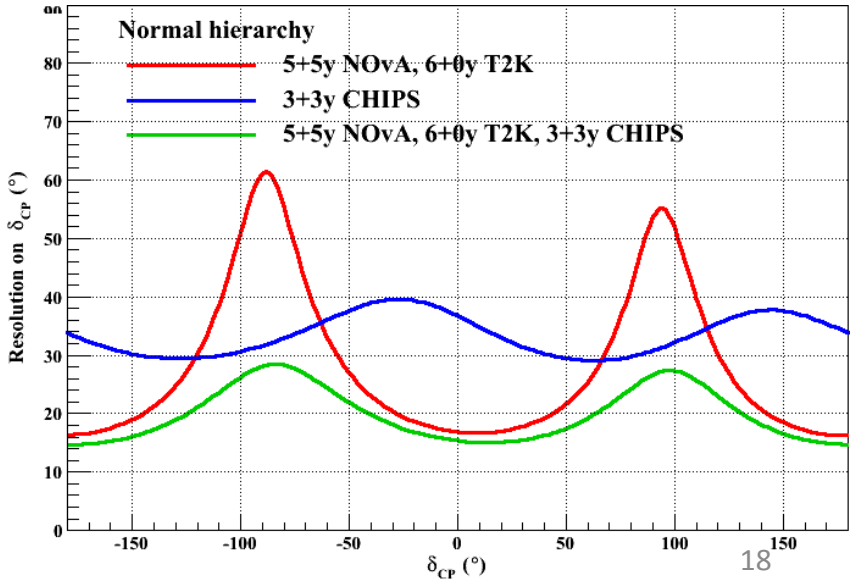


Physics Reach

- Choice of angle between 7-10mr gives best reach in δ_{cp}
- More on-axis increases background, more off-axis reduces rate
- CHIPS will provide **complementary** information on δ_{CP} to NOνA (broader beam spectrum)
- Need to run in both ME and LE beam
- By end of decade, should push $\Delta\delta_{CP}$<(15-28°), not systematics limited
- Will make use of > 50% QE and resonance ν events between 1-3 GeV

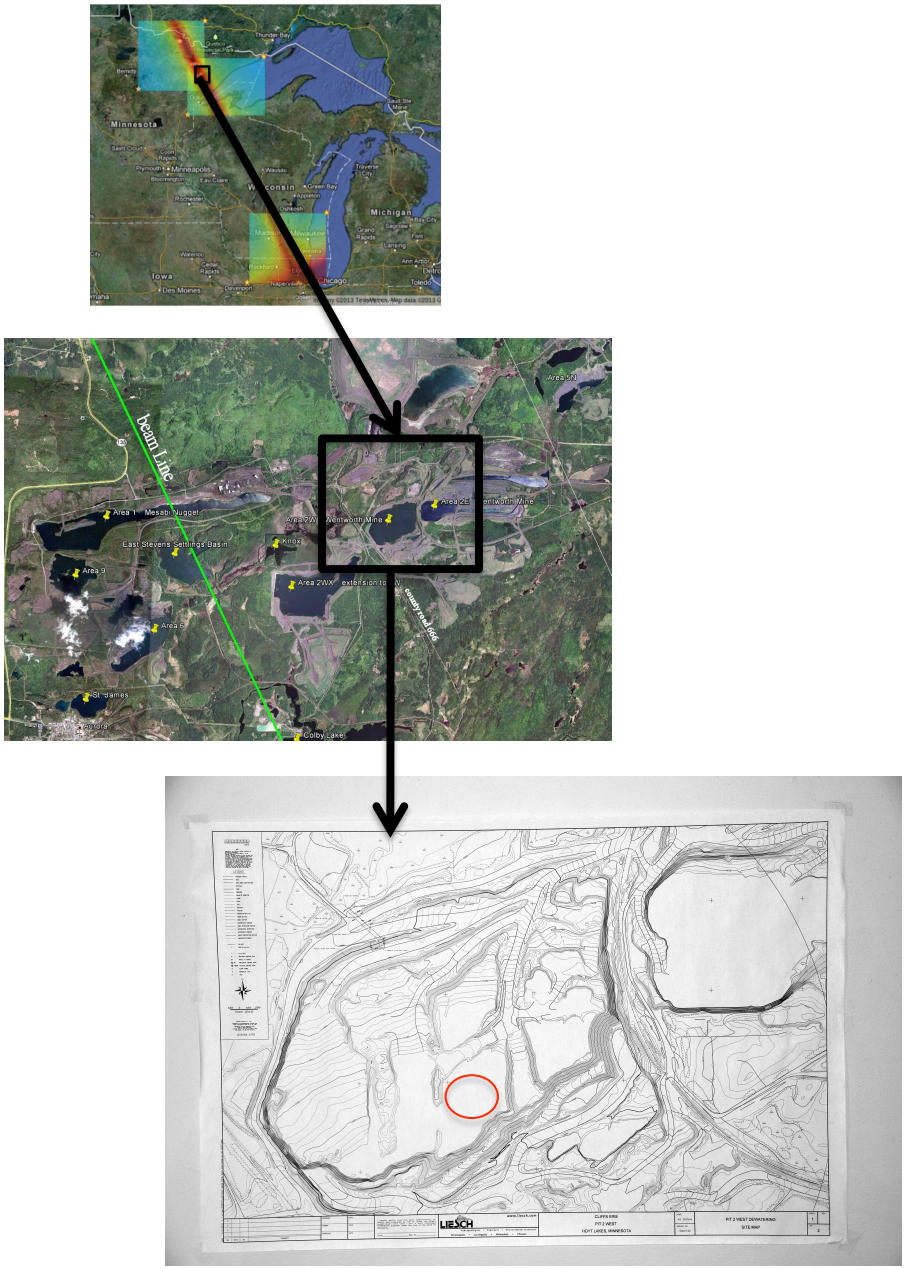






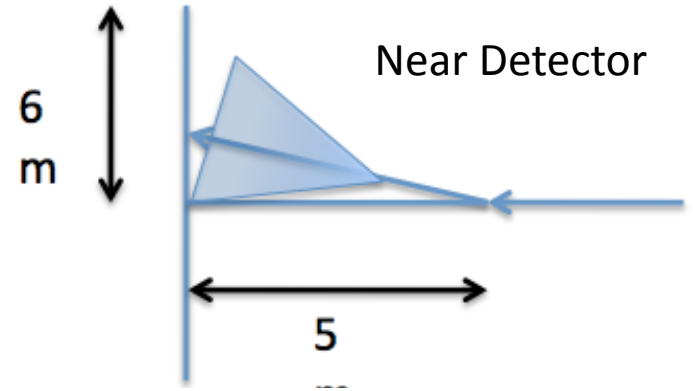
CHIPS : Wentworth Pit

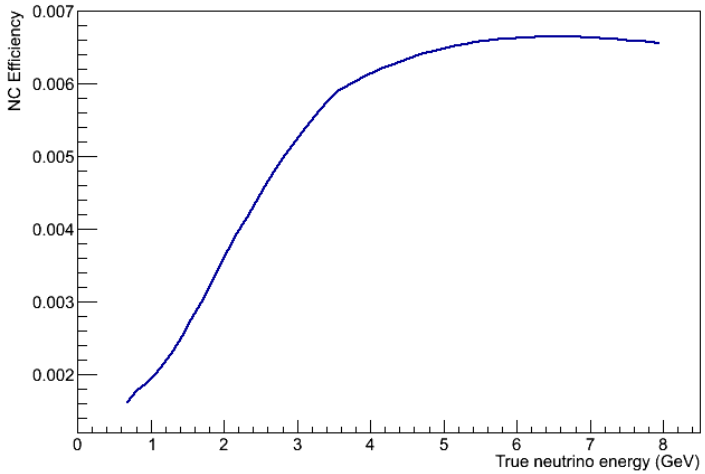
- The water CHerenkov detector In mine PitS, has 100kt target volume
- The Wentworth mine pit is 7mr off axis of the NuMI beam and > 60m deep
  - Deeper region shown
- Veto region needed, 1-100kHz background leads to about <=5% dead-time
- Leasing arrangement already under discussion



CHIPS design

- Near detector <=100t, designed to benchmark MC simulation and enable cross section cancellation for disappearance
- Overlap events at 30% level : also low intensity running available
- Use MINOS ND for muon catcher
- Geant4 simulation provided for LBNE will be used to define ND
  - Small model of FD
  - Small slide of full scale FD
- Rudimentary reconstruction ready for further development
- Same parametrization for GLOBES calculations as for LBNE studies based on Super-K efficiencies



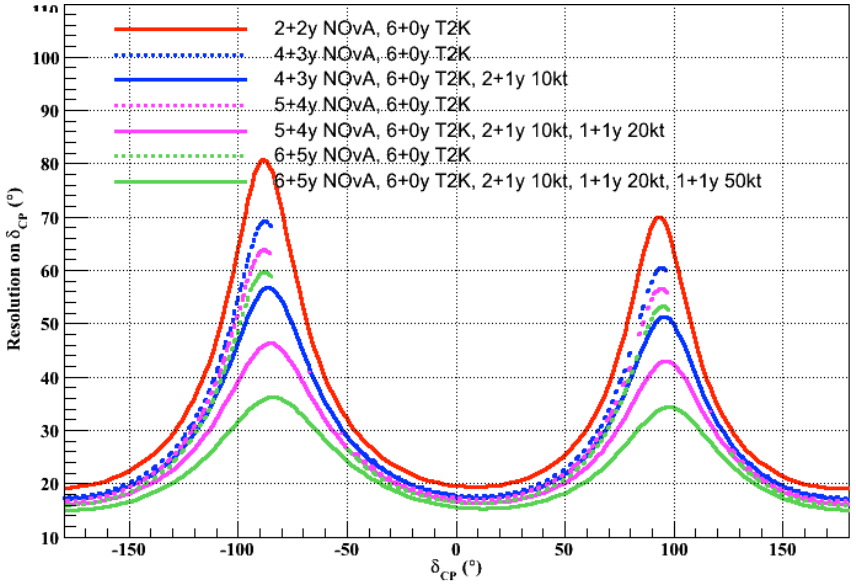


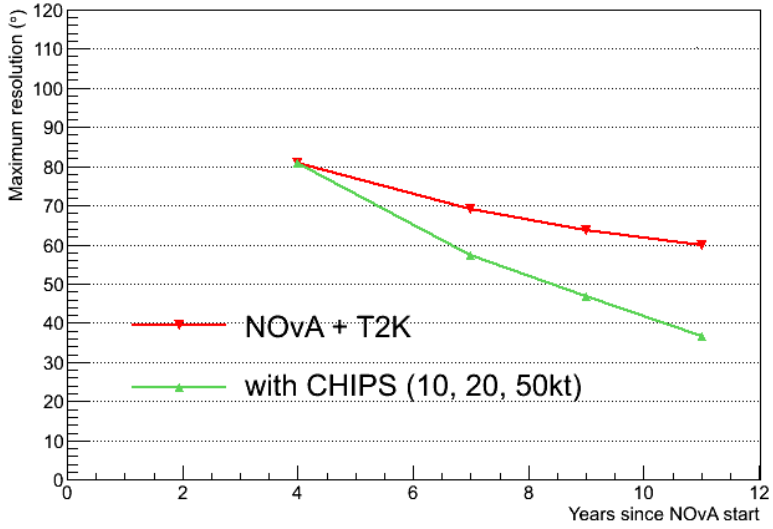
Costs, schedules etc

- For 100kt detector, cost estimate is about $120M
- Cost is dominated by individual PMT+OM cost ($5k)
  - Well understood from Ice Cube
- Fishing infrastructure seems inexpensive (TPD)
  - Liner experts are out there
  - Light tightness will need some attention
- LoI to be submitted to FNAL by summer for short R&D program….
- Hopefully some deployment could happen in Summer 2014
  - Key is to understand limitations/realities as soon as possible
  - Hope to overcome issues and keep building
  - There is physics on the way….

Getting started fast

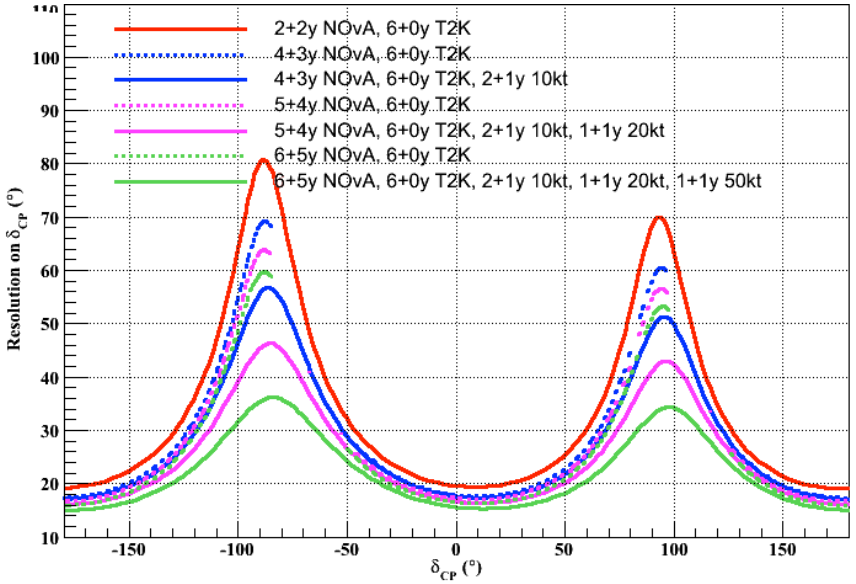
- Starting small can still yield important results
- Imagine starting with 10kt after 4 years of NOVA running
  - 3 years with 10kt then 2 years with 20kt, finally 2 years at 50kt
  - 10kt is about $10M over next three years

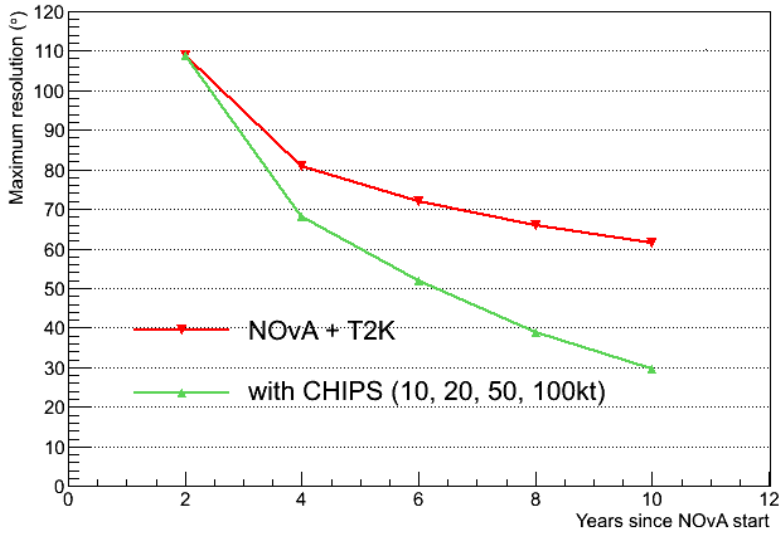




Getting started fast

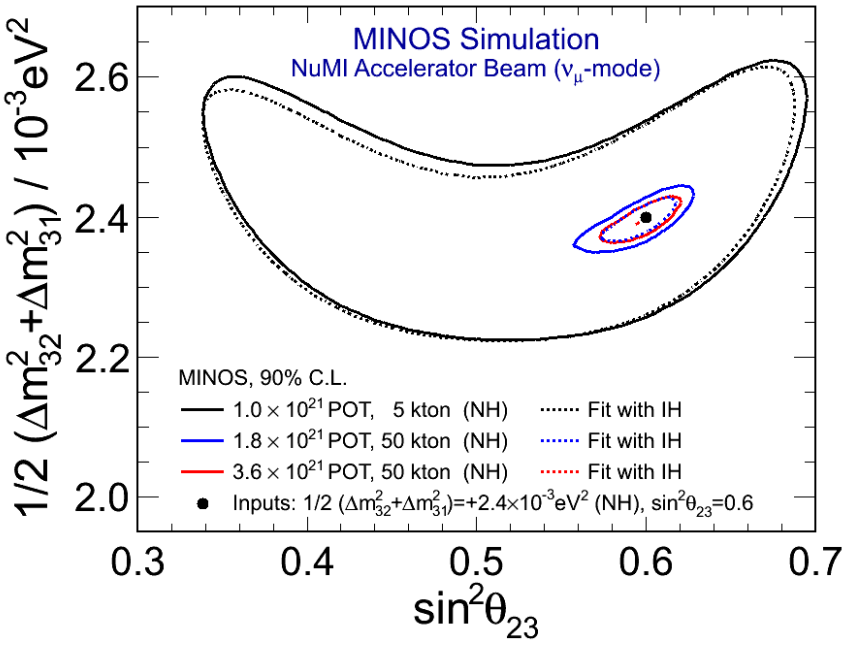
- A faster schedule would be to start with 10kt after 2 years of NOVA running
  - 2 years with 10kt then 2 years with 20kt, 2 years at 50kt then 2 at 100kt
- Has advantage of understanding real costs and schedules
- Slow but continuous detector growth could be possible allowing low and constant funding level ($10-15M/yr)
- Real costs and processes can be fully understood avoiding huge contingencies

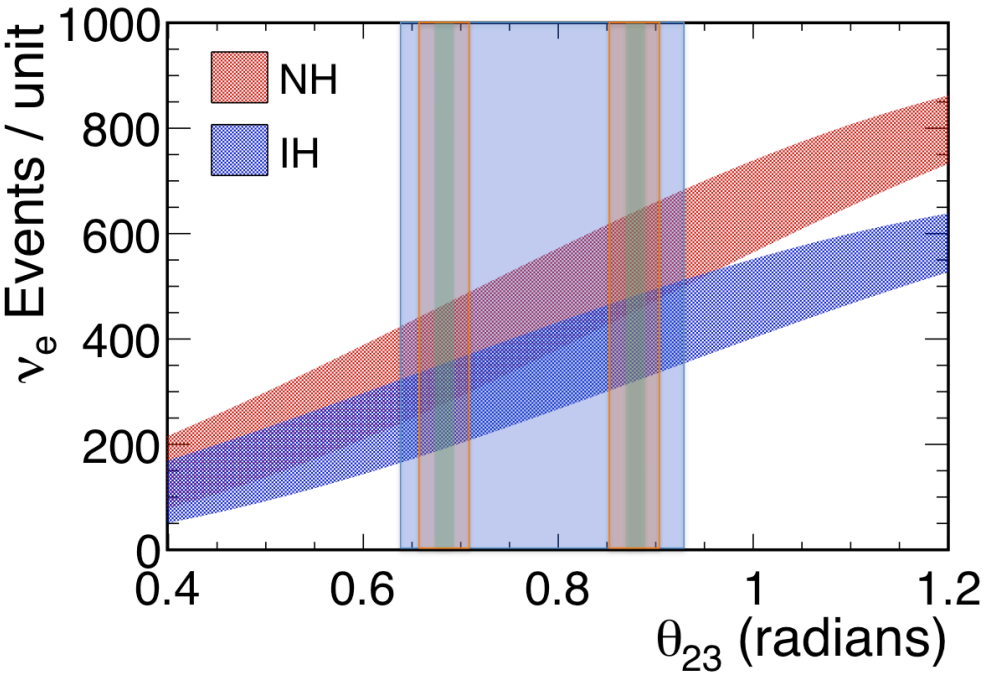




$\sin^2\theta_{23}$

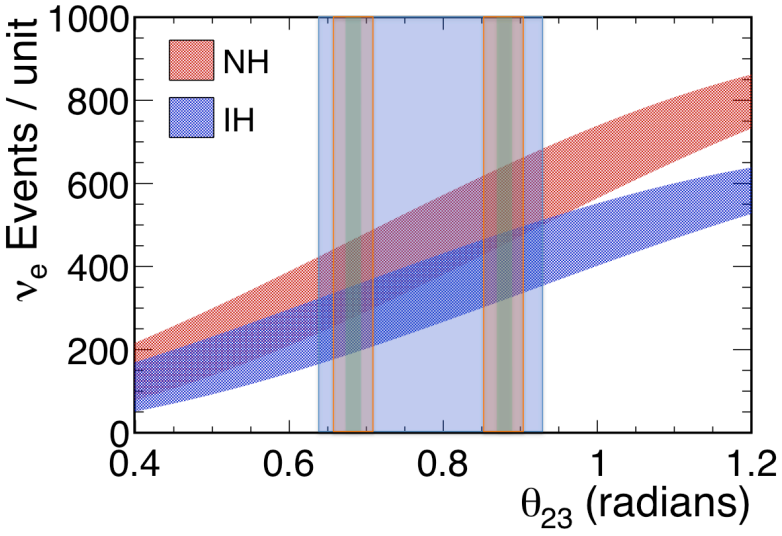
- Very conservative estimate of $\sin^2\theta_{23}$ using MINOS efficiencies
- If θ_{23} not maximal, and in upper octant, reach is enhanced, and MH could be ascertained
- Bands denote totally unknown δ_{CP}

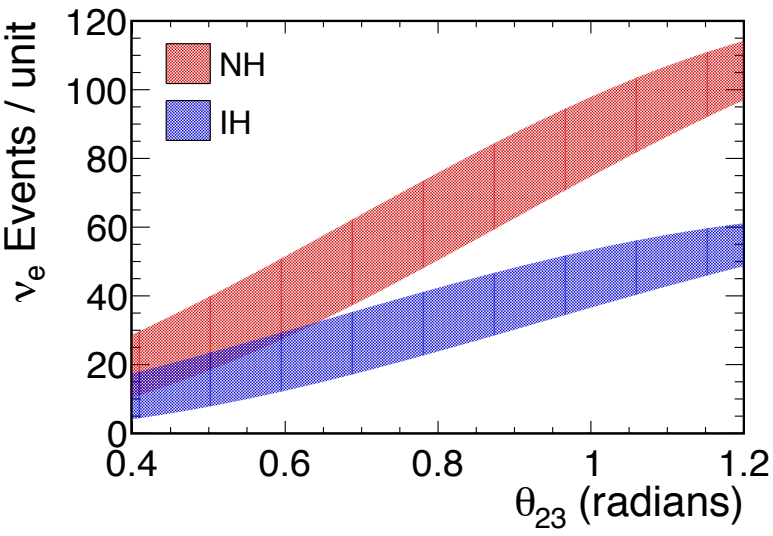




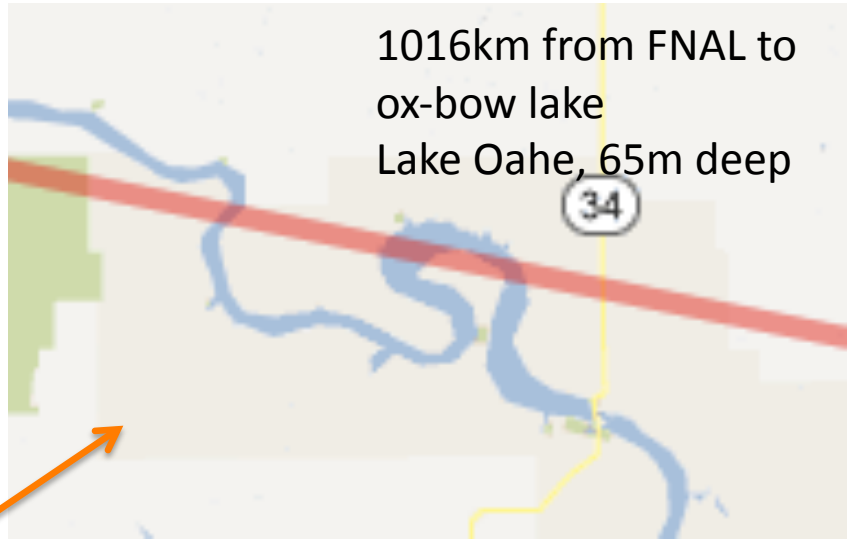
NuMI to LBNE : θ_{23}

- LBNE has better L/E and will take over the heavy lifting at some point in the future
- Redeploy the CHIPS detector somewhere close to the LBNE beam
- A 100kt CHIPS in LBNE beam would provide results much faster than 5+5 years presently foreseen
- With developments in hybrid PMTs (cheaper) the cost can be brought down to maybe $0.5M/kt, for further expansion in the future





CHIPS@LBNE



- There is (at least) one deep reservoir in the beam line
- Proof of principle for Mt scale detectors at a cost of ~ $1M/kt
- Presently cost of NOνA is ~ $10M/kt
- Possible upgrade/ augmentation path for LBNE

Summary

- The future of LB neutrino physics calls for HUGE detectors
  - beams cannot reach 1-2 orders of magnitude higher flux
- Exploitation of the NuMI beam gives an attractive stage 1 to LBNE, for prototyping as well as physics measurements
- More NOνA or GLADE at Ash River for MH reach
- CHIPS for δ_{CP} reach
- Encouragement to think of new ideas for our long term, long baseline future!!
- For 1Mt experiments, we need $100k/kt !
- One vision…..

A vision of LBNE