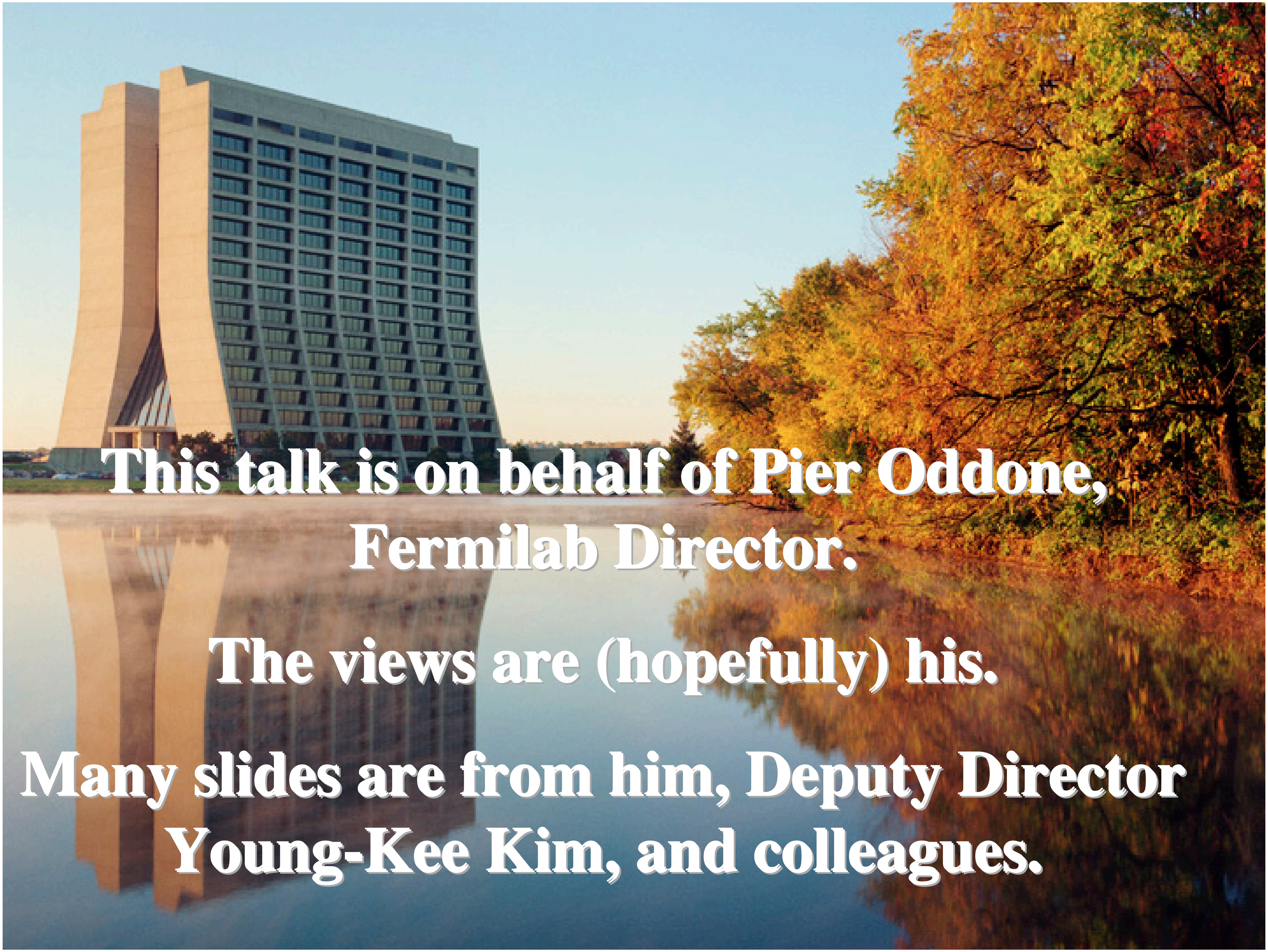
Neutrino Project X @ Fermilab

Stephen Parke
for Pier Oddone
NO-VE, April 18, 2008


This talk is on behalf of Pier Oddone,
Fermilab Director.
The views are (hopefully) his.
Many slides are from him, Deputy Director
Young-Kee Kim, and colleagues.

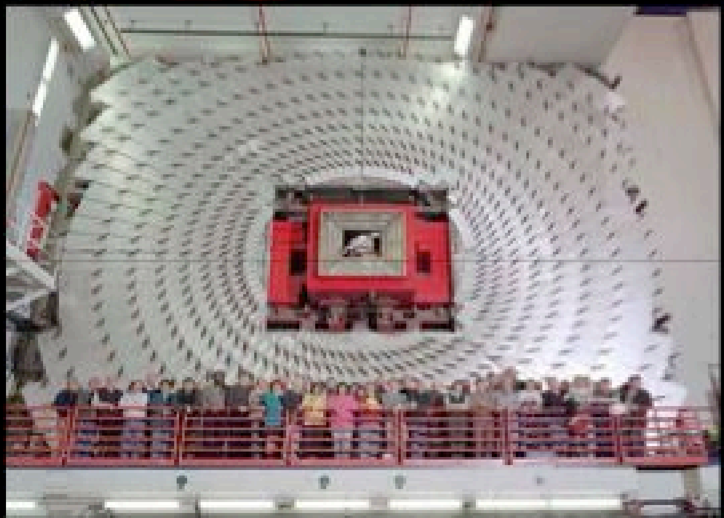
Fermilab Today

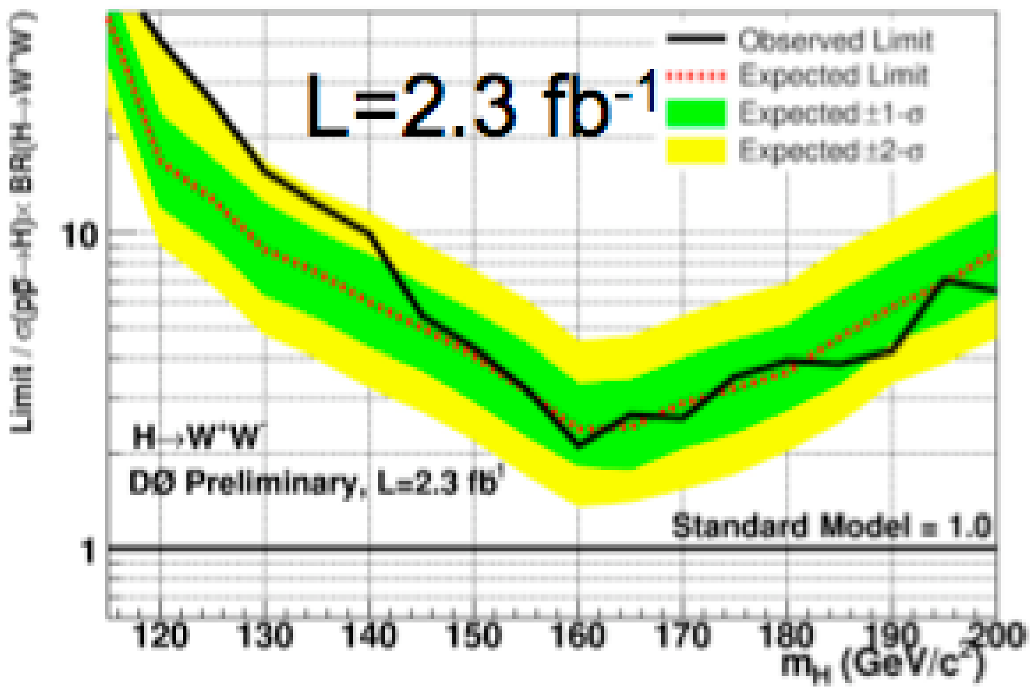
World leader in particle physics along several fronts.

P. Oddone

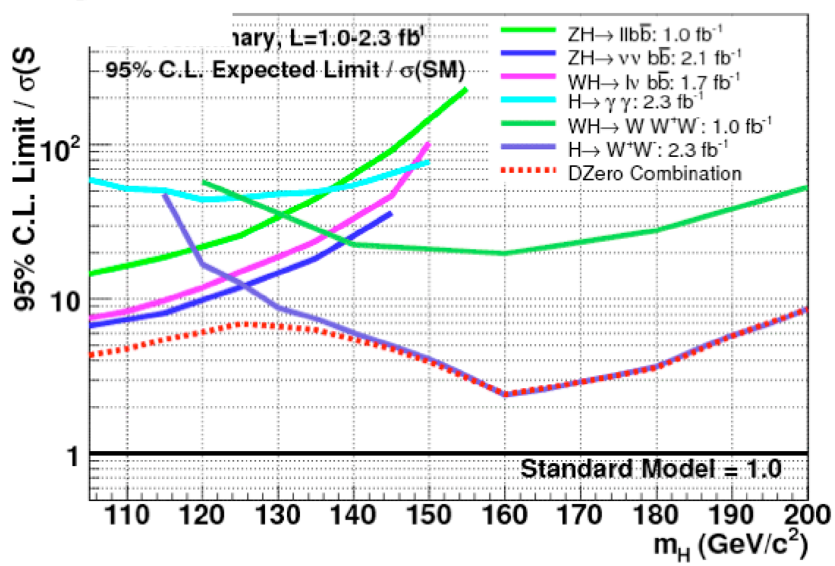
Ongoing program: Tevatron

- Greatest discovery opportunities before LHC
- Strong collaborations; 80 PhDs last year
- Great operations at high luminosity
- Dominates world physics results

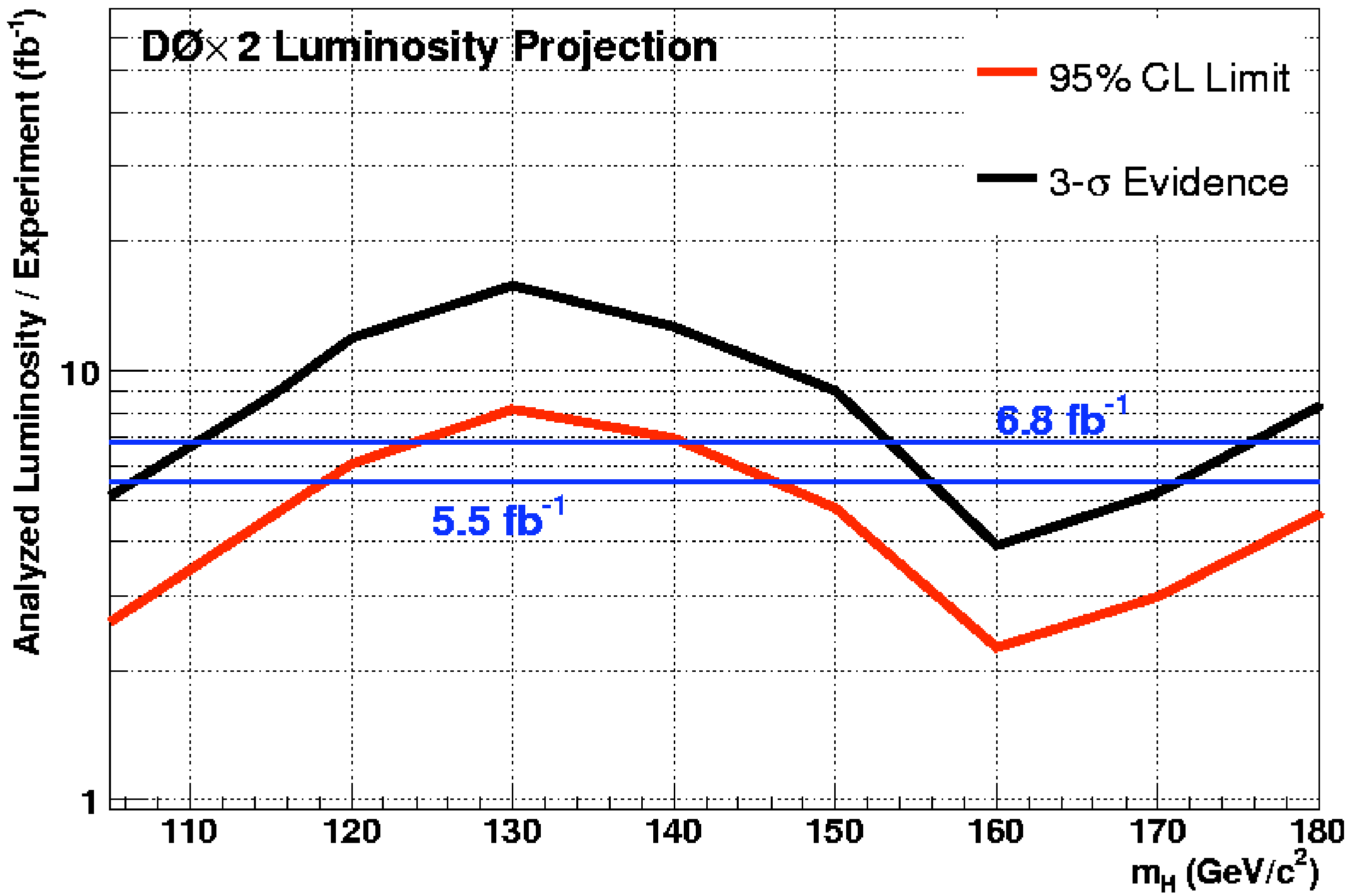




Expected Sensitivities



Possibility of Evidence for the SM Higgs



2010
2009

Assumes two experiments (CDF and D0)

D. Wood/D0

Future Tevatron Running

P. Oddone

Ongoing program: neutrinos

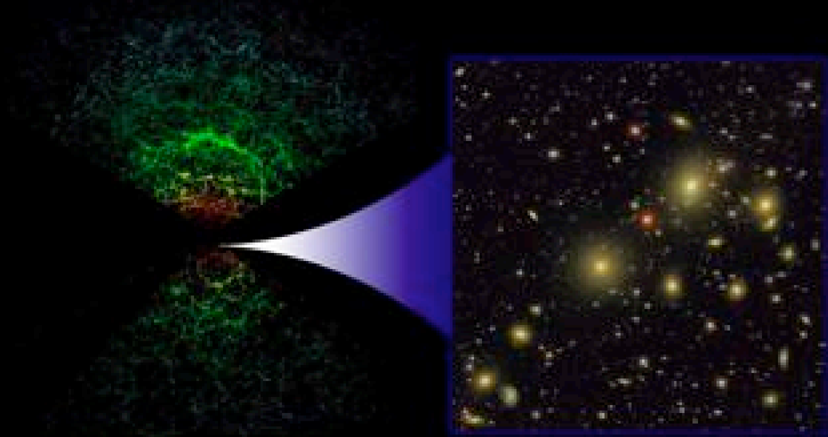
Minos Far detector

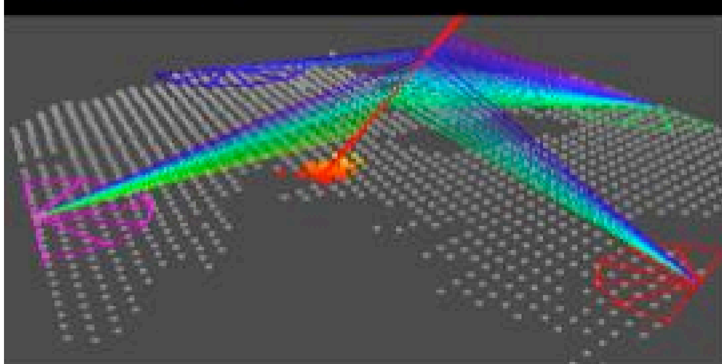
MiniBooNE detector

- MINOS: neutrino oscillations in the atmospheric region; coming electron appearance at CHOOZ limit or below
- MiniBooNE: neutrino oscillations in the LSND region; exploration of low energy anomaly in neutrino interactions
- SciBooNE: neutrino cross sections

P. Oddone

Ongoing program: astrophysics



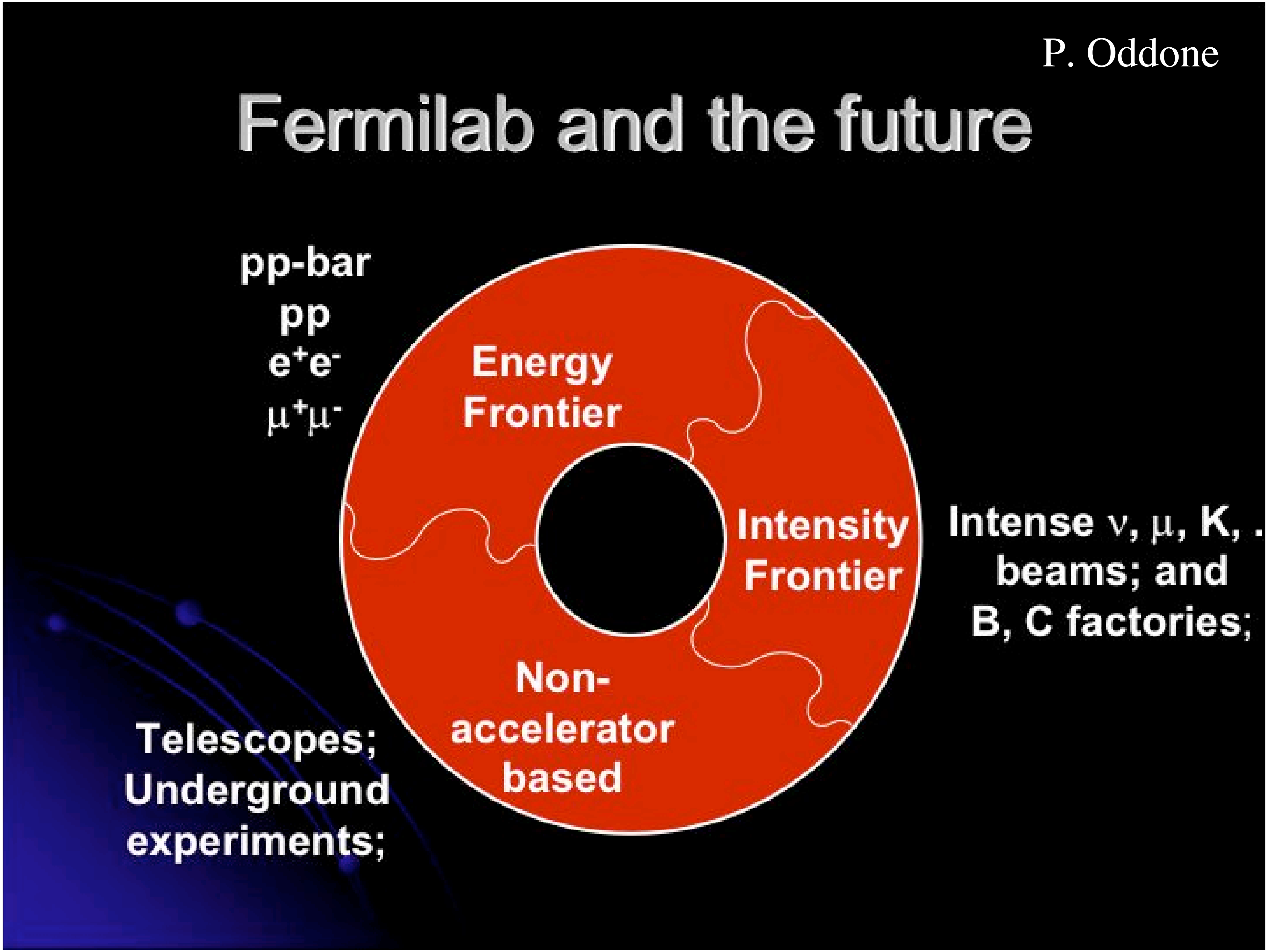


- CDMS – Best dark matter bound above 40 GeV
- SDSS – huge impact survey, baryon acoustic oscillation
- Pierre Auger – GZK, association with active galactic nuclei
- COUPP – competitive results for spin-dependent WIMPS, scalable

P. Oddone

On going program: capabilities

- Powerful theory group, including leading role in phenomenology, lattice gauge
- Computational science, large data sets
- Detector instrumentation, silicon detectors
- Accelerator design, control and operations
- Mechanical (including cryogenic), electronic engineering, magnet design
- World-wide collaborations


P. Oddone
Fermilab and the future
pp-bar
pp
e^+e^-
$\mu^+\mu^-$
Energy Frontier
Intensity Frontier
Non-accelerator based
Intense ν, μ, K, . beams; and
B, C factories;
Telescopes; Underground experiments;

Fermilab's Role

Energy Frontier –

Participation in the LHC program

R&D towards the ILC; eventual bid to host

Intensity Frontier –

Project X

Non-Accelerator Frontier –

Astrophysics-Cosmology

P. Oddone

HEP world: LHC and Fermilab

- The LHC is the single most important physics component of the US program
- Fermilab supports the US CMS effort. Built major components of CMS supporting the universities.
- Now have Tier 1 computing center, LHC Physics Center, Remote Operations Center (ROC), CERN/Fermilab summer schools

P. Oddone

HEP world: LHC and Fermilab

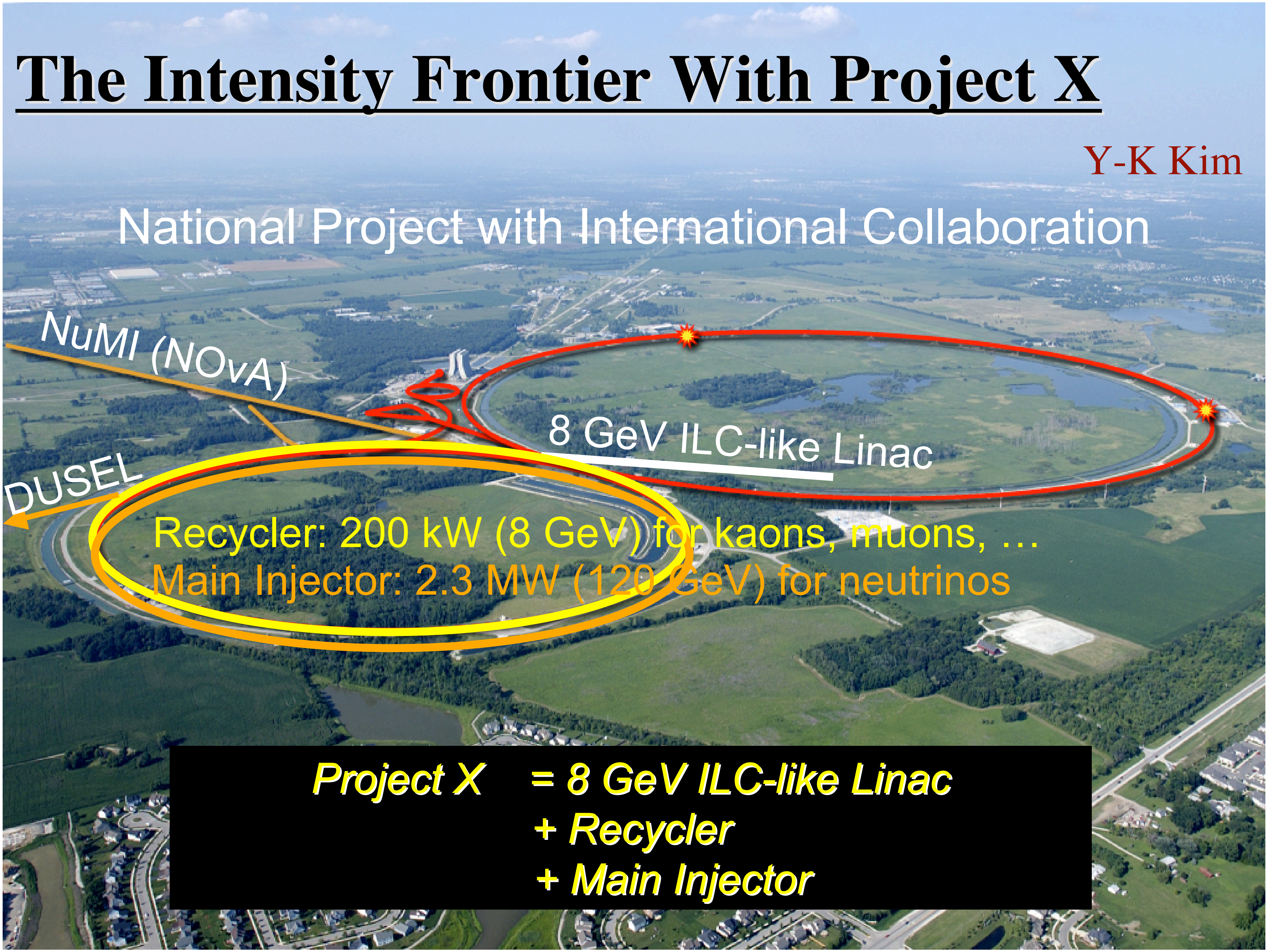
- Major contribution to the accelerator. We are now helping to commission LHC.
- To continue to be welcome, US and Fermilab must contribute to detector and accelerator improvements.
- Aim: critical mass at Fermilab, as good as going to CERN (once detectors completed).

Astrophysics-Cosmology Frontier

- **Dark Energy Survey (DES) construction**
- **Collaboration on SNAP**
- **Support of CDMS – 25 kg**
- **COUPP (Direct DM detection in a bubble chamber)**

The Intensity Frontier With Project X

Y-K Kim



Neutrino Masses

Standard Model is incomplete.

Empirical proofs —

- Neutrino Masses
- Baryon Asymmetry of the Universe
- Dark Matter
- Dark Energy

Neutrino masses are the only new phenomena seen so far in the laboratory.

They point, via the See-Saw, to new physics at a very high mass scale.

Neutrino Physics at the Intensity Frontier

Questions to be answered —

Does neutrino oscillation violate CP?

A positive answer would support *Leptogenesis* as the source of the Baryon Asymmetry of the Universe.

Is the neutrino mass spectrum quark-like, as in Grand Unified Theories, or inverted, pointing to a new leptonic symmetry?

What is the unknown mixing angle θ_{13}?

Answering this suite of questions will require ***intense*** neutrino beams and large detectors.

Neutrino Vision at Fermilab

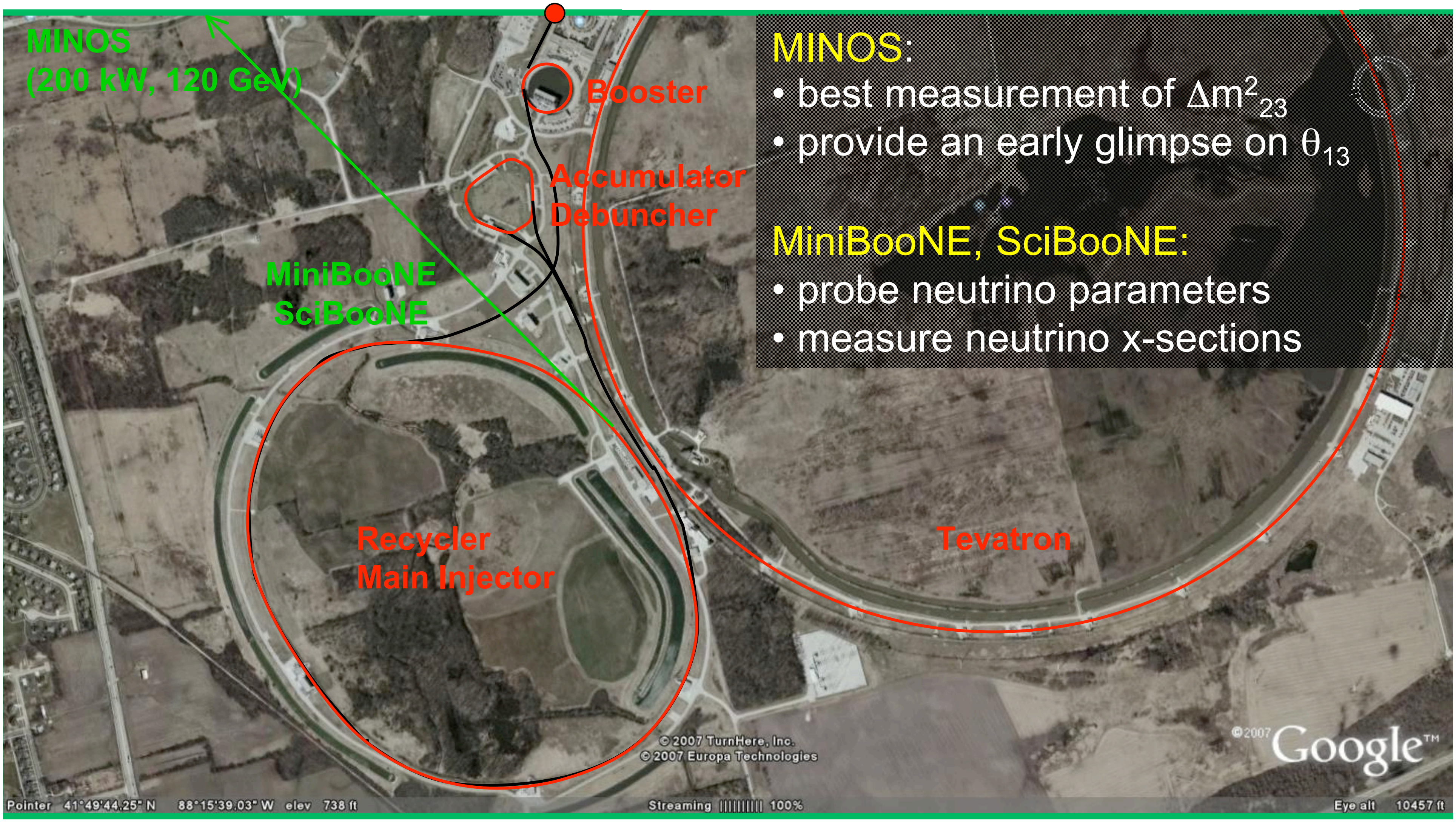
“World-Leading Neutrino Program”

By developing
a phased approach with
ever increasing beam intensities
and ever increasing detector capabilities

Neutrino Mixing, Mass Ordering, CP Violation

Y-K Kim

Present:


MINOS
(200 kW, 120 GeV)
Booster
Accumulator
Debuncher
MiniBooNE
SciBooNE
Recycler
Main Injector
Tevatron
MINOS:
• best measurement of Δm^2_{23}
• provide an early glimpse on θ_{13}
MiniBooNE, SciBooNE:
• probe neutrino parameters
• measure neutrino x-sections
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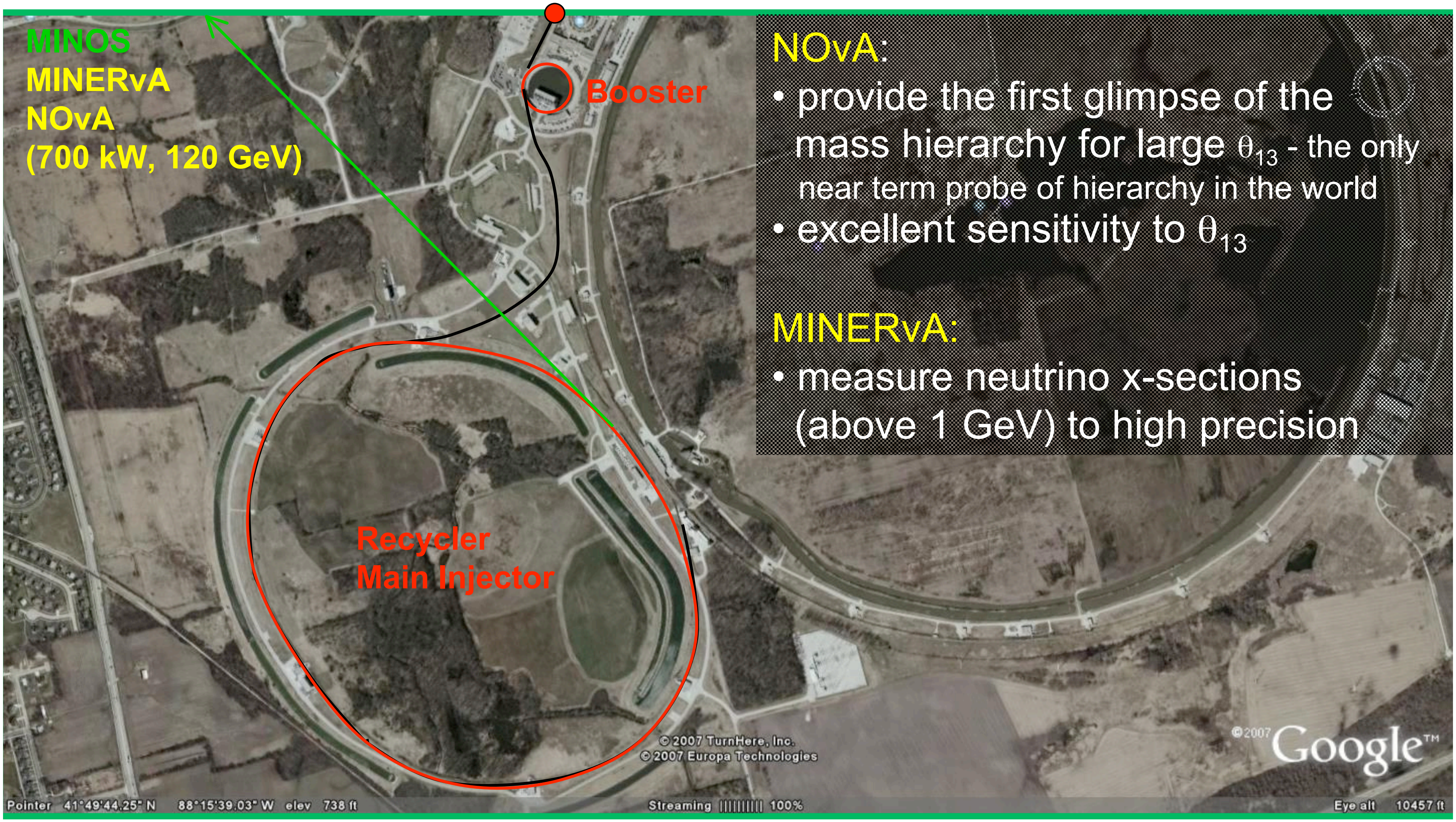
Streaming |||||||||| 100%
Eye alt 10457 ft

Phase 1:



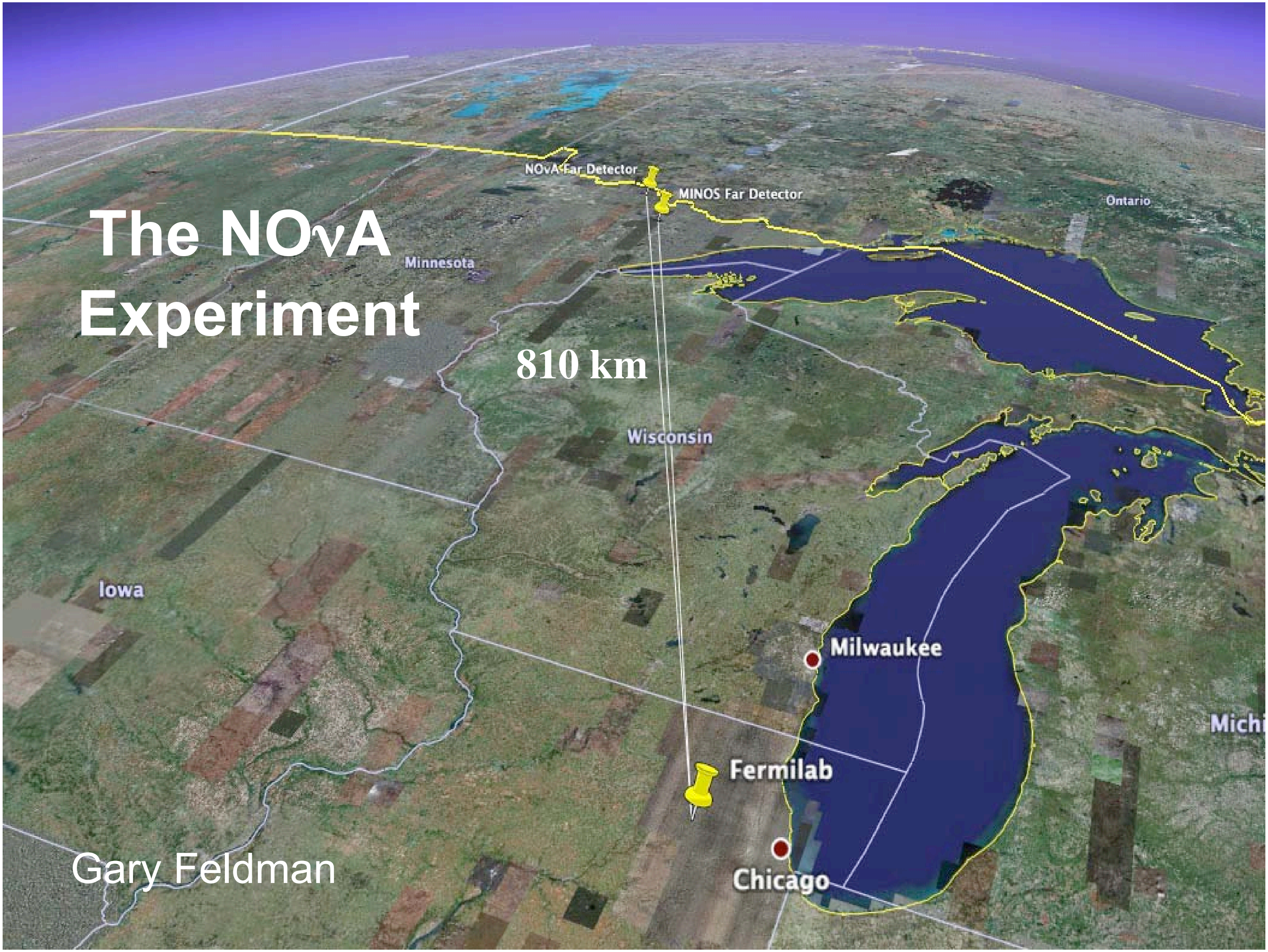
NOvA:

- provide the first glimpse of the mass hierarchy for large θ_{13} - the only near term probe of hierarchy in the world
- excellent sensitivity to θ_{13}

MINERvA:

- measure neutrino x-sections (above 1 GeV) to high precision

The NOνA Experiment

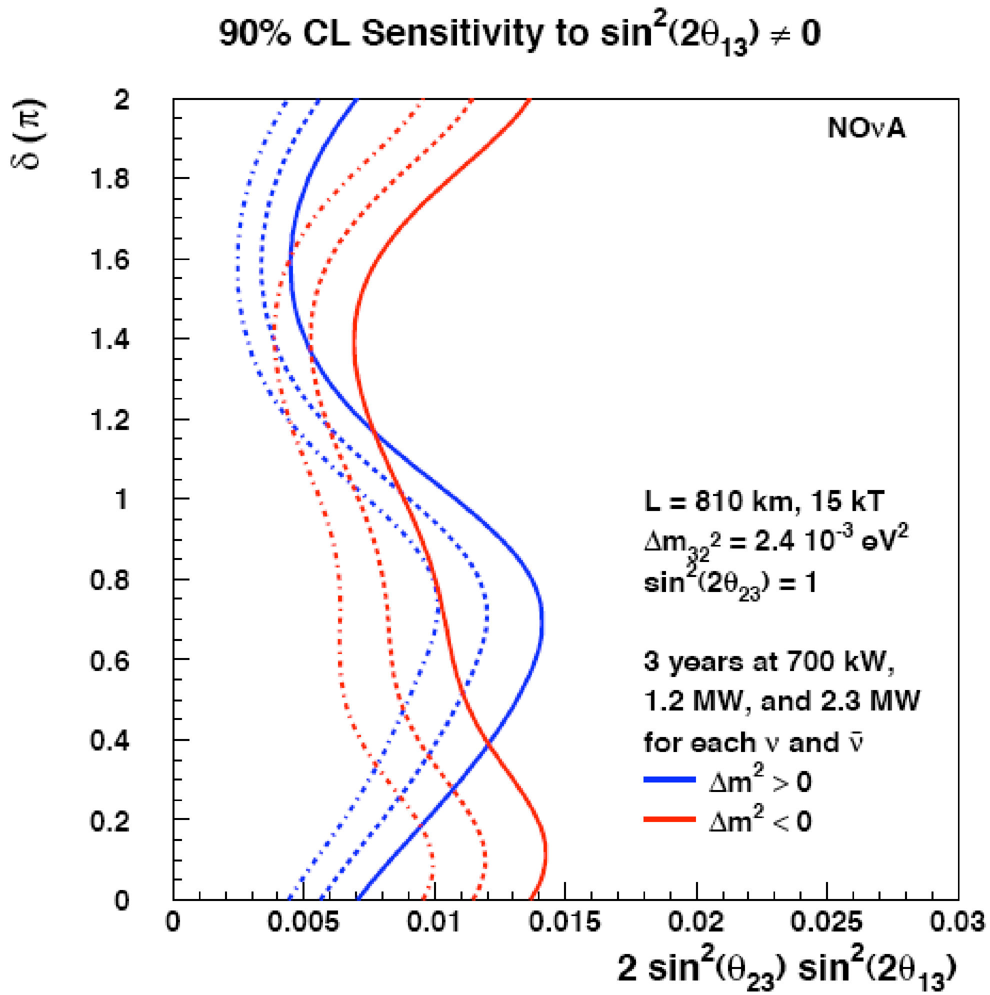


Gary Feldman

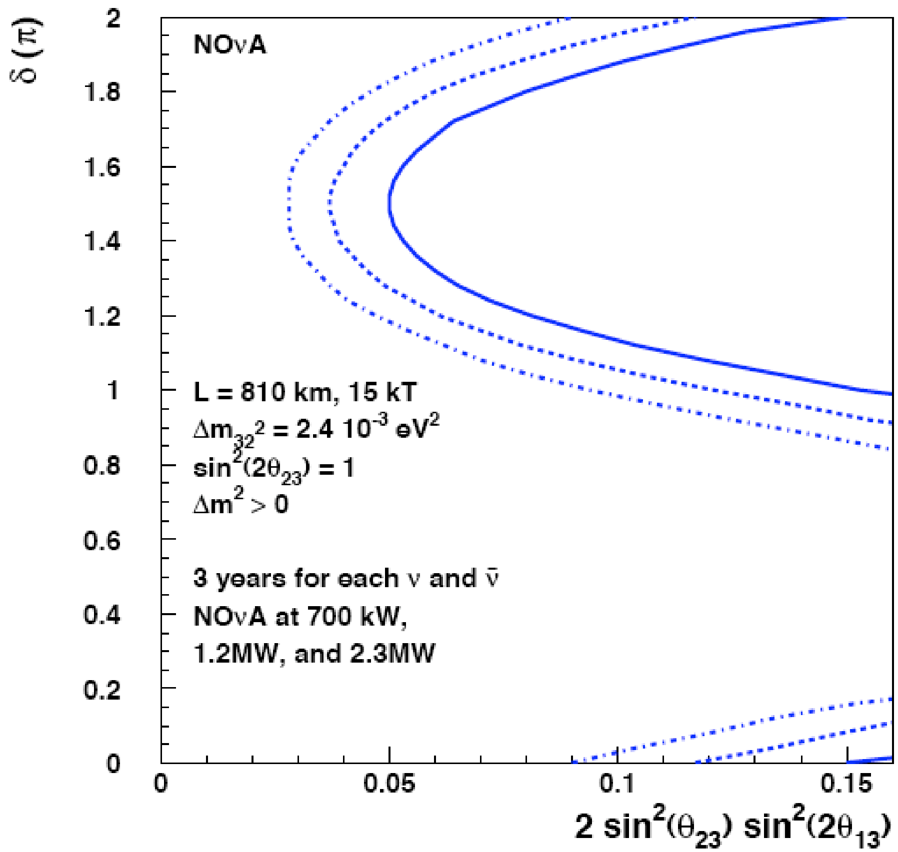
NOνA

- A study of $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
- ~ 15 kton liquid scintillator detector
- Off the axis of Fermilab's NuMI neutrino beamline
- L = 810 km; E ~ 2 GeV
- *Main goal: Try to determine whether the spectrum is* ***Normal*** *or* ***Inverted***

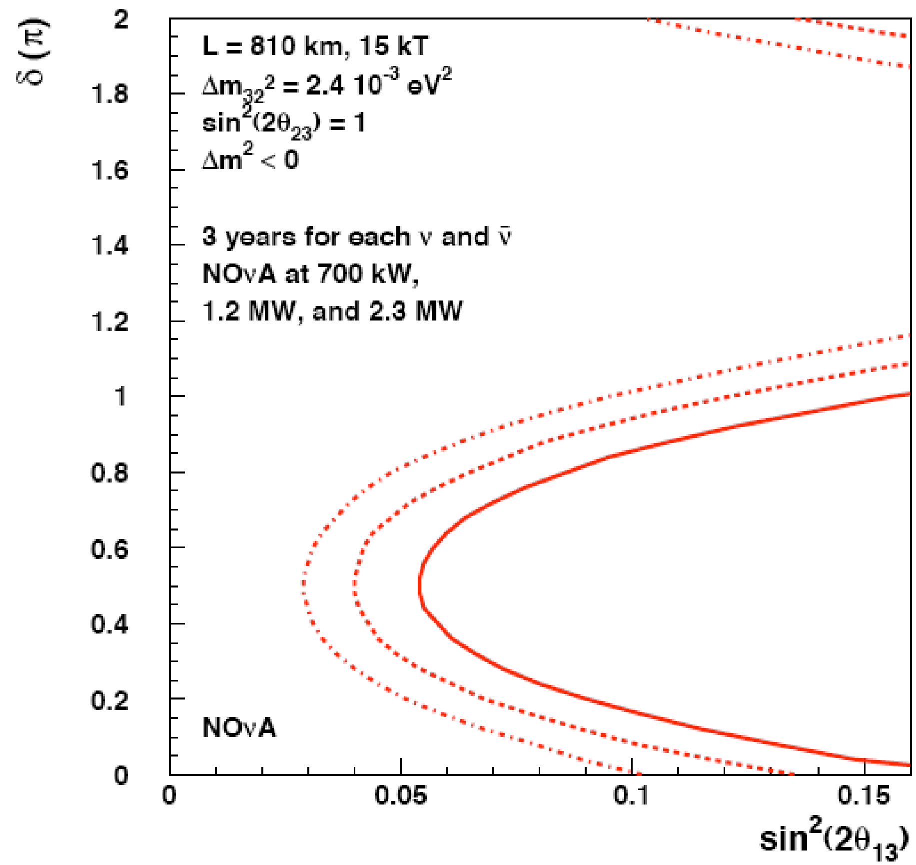
Sensitivity to $\sin^2(2\theta_{13}) \neq 0$



95% CL Resolution of the Mass Ordering NOνA Alone

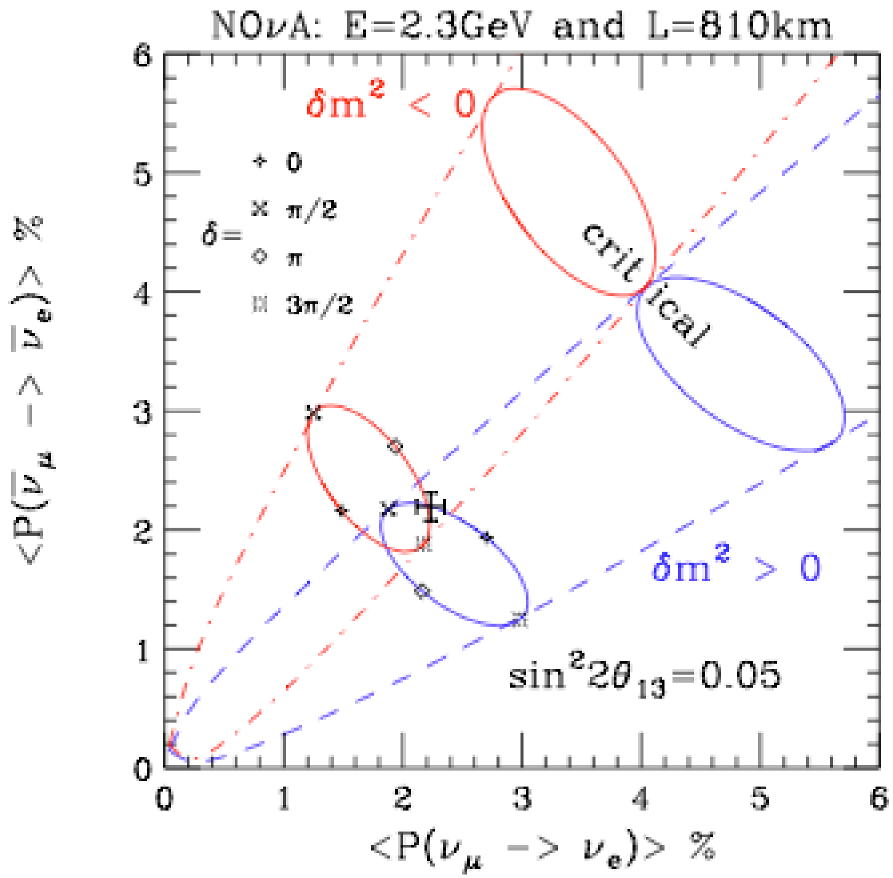


Normal Ordering



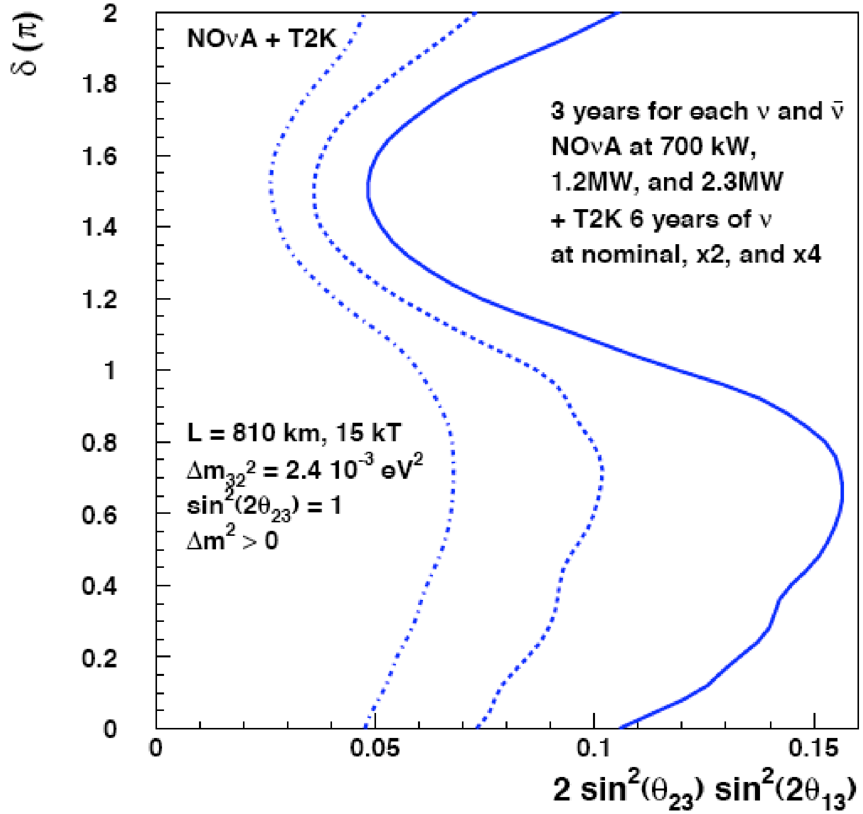
Inverted Ordering

NOvA:

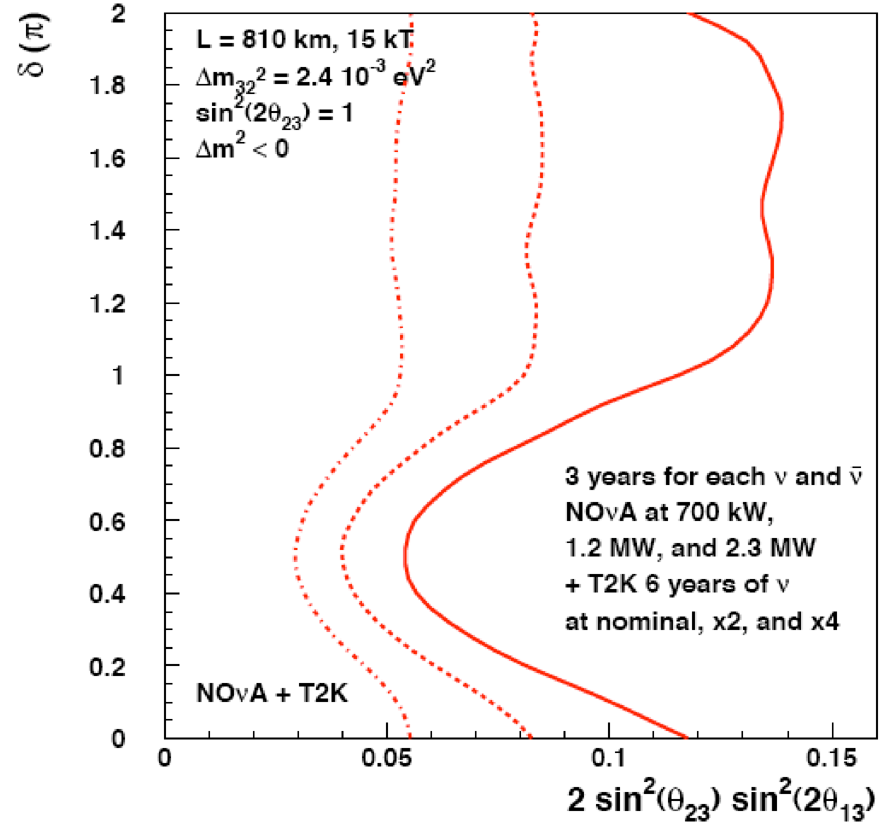


NOνA: E=2.3GeV and L=810km
δm² < 0
δ=
0
π/2
π
3π/2
critical
δm² > 0
sin²2θ₁₃=0.05
<P(ν̄μ -> ν̄e)> %
<P(νμ -> νe)> %

95% CL Resolution of the Mass Ordering NOνA Plus T2K



Normal Ordering

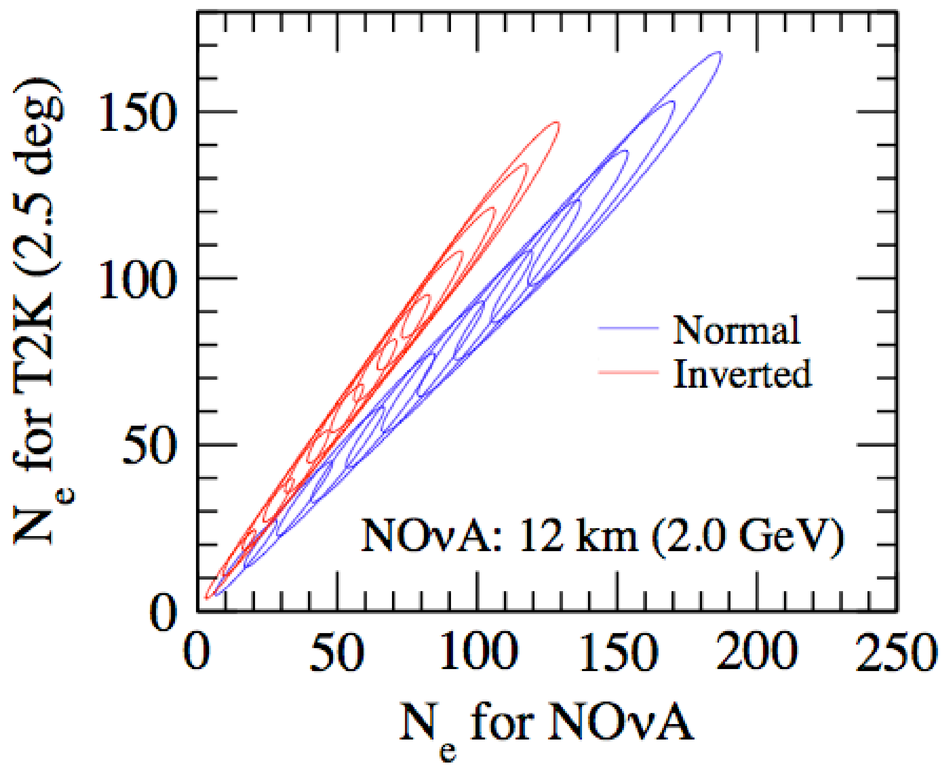


Inverted Ordering

T2K + NOνA, Neutrino Only, $\sin^2 2\theta_{13}$=0.01,0.02,..,0.1

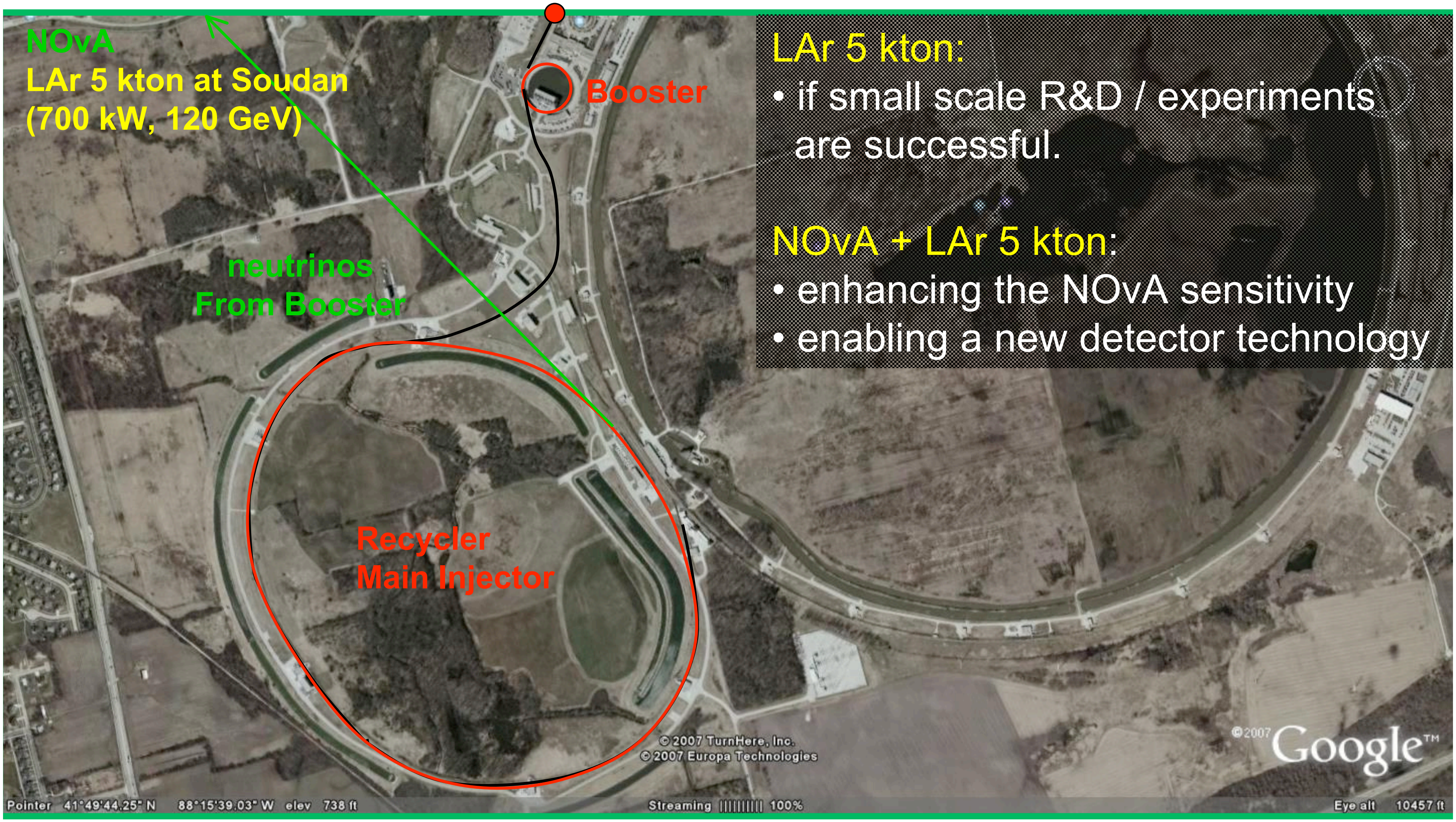
T2K: 0.75 MW, 5 yrs, 22.5 kton

NOνA: 6.5e20 POT/yr, 5 yrs, 30 kton, 24%



Mena, Nunokawa and SP hep-ph/0609011

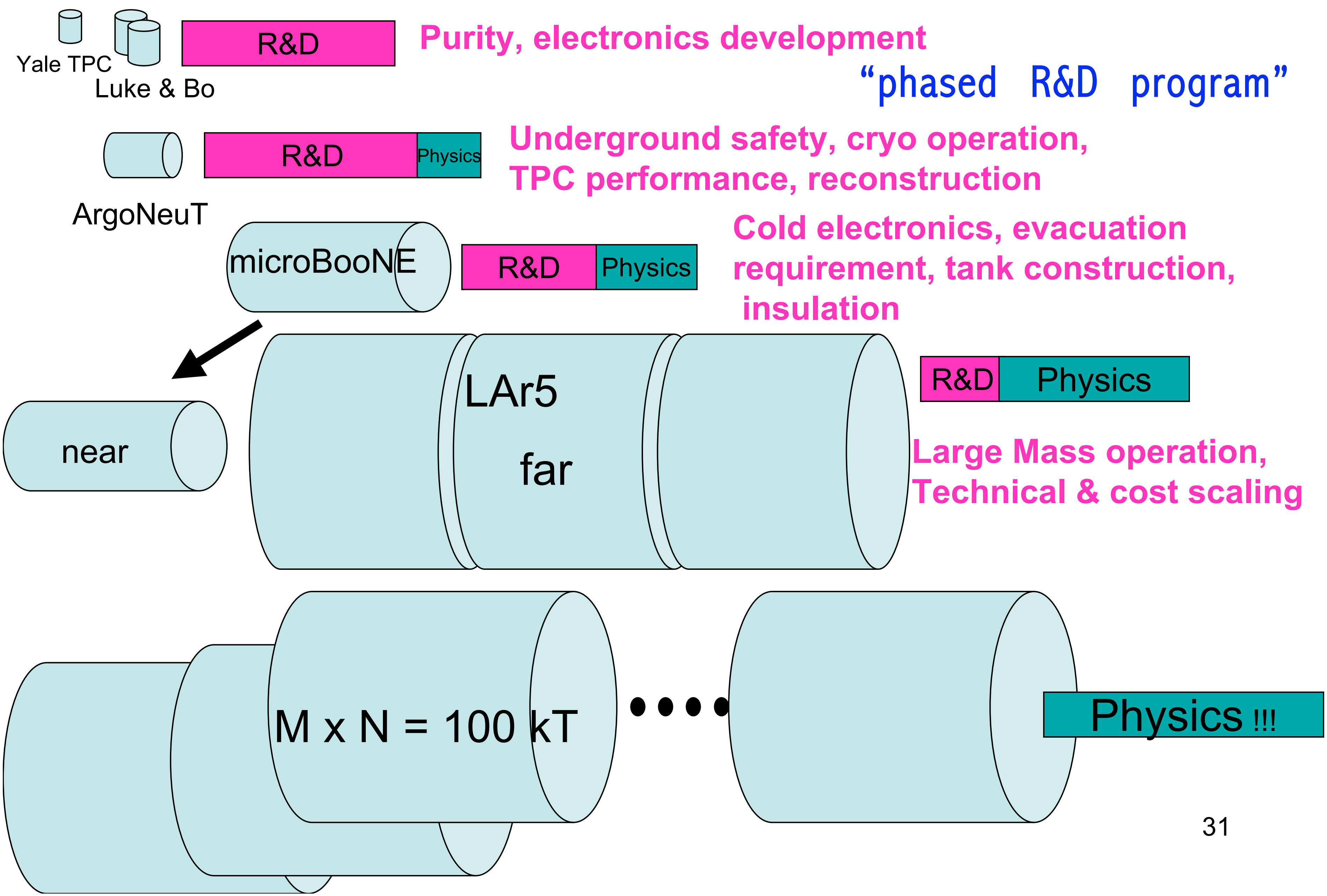
Phase 1.5:



LAr 5 kton:
- if small scale R&D / experiments are successful.

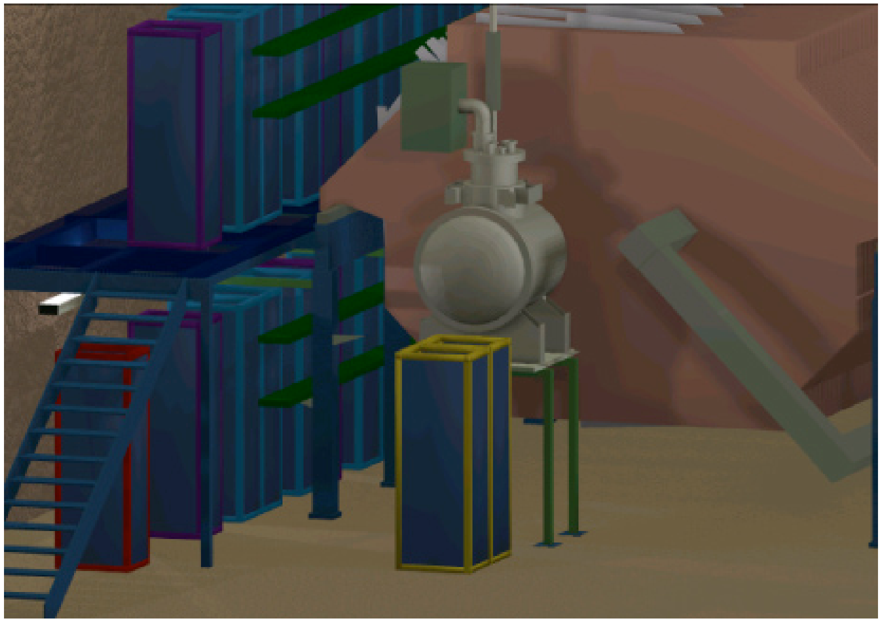
NOvA + LAr 5 kton:
- enhancing the NOvA sensitivity
- enabling a new detector technology

Evolution of the Liquid Argon Physics Program



R&D | Physics

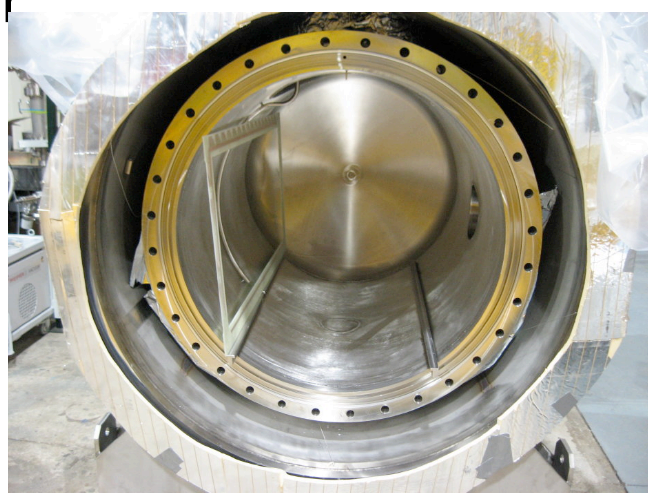
ArgoNeuT (Spring 2008)

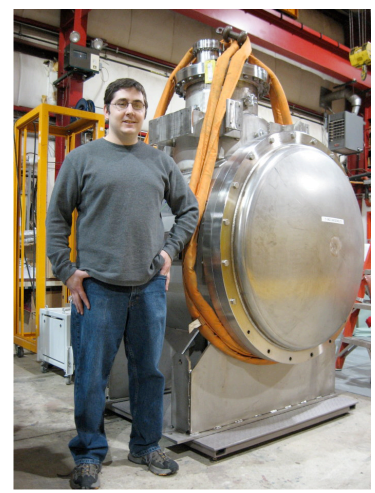


Located in NuMI near hall using MINOS near detector as a muon catcher

0.3 ton active volume
0.5 x 0.5 x 1.0 m^3 TPC; 500 channels

- See neutrino interactions
- (~150 evts/day)
    - Physics Development: Simulation, reconstruction, Verification of efficiencies and purities
- Long term running conditions
- Underground issues

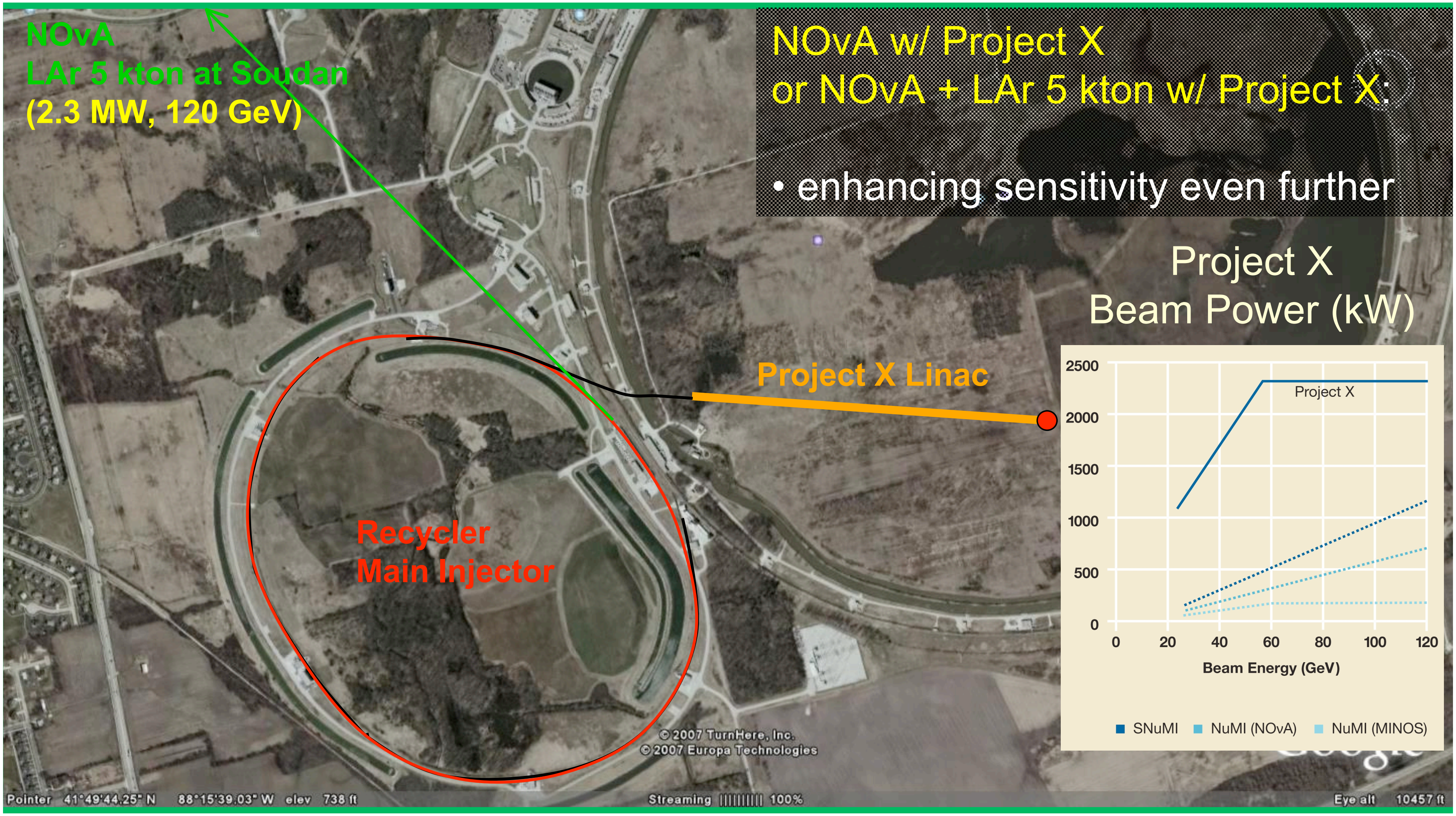




Joint NSF/DOE project

M. Soderberg, Yale

Phase 2:



NOvA
LAr 5 kton at Soudan
(2.3 MW, 120 GeV)
NOvA w/ Project X
or NOvA + LAr 5 kton w/ Project X:
• enhancing sensitivity even further
Project X
Beam Power (kW)
Project X Linac
Recycler
Main Injector
2500
2000
1500
1000
500
0
0 20 40 60 80 100 120
Beam Energy (GeV)
Project X
SNuMI
NuMI (NOvA)
NuMI (MINOS)
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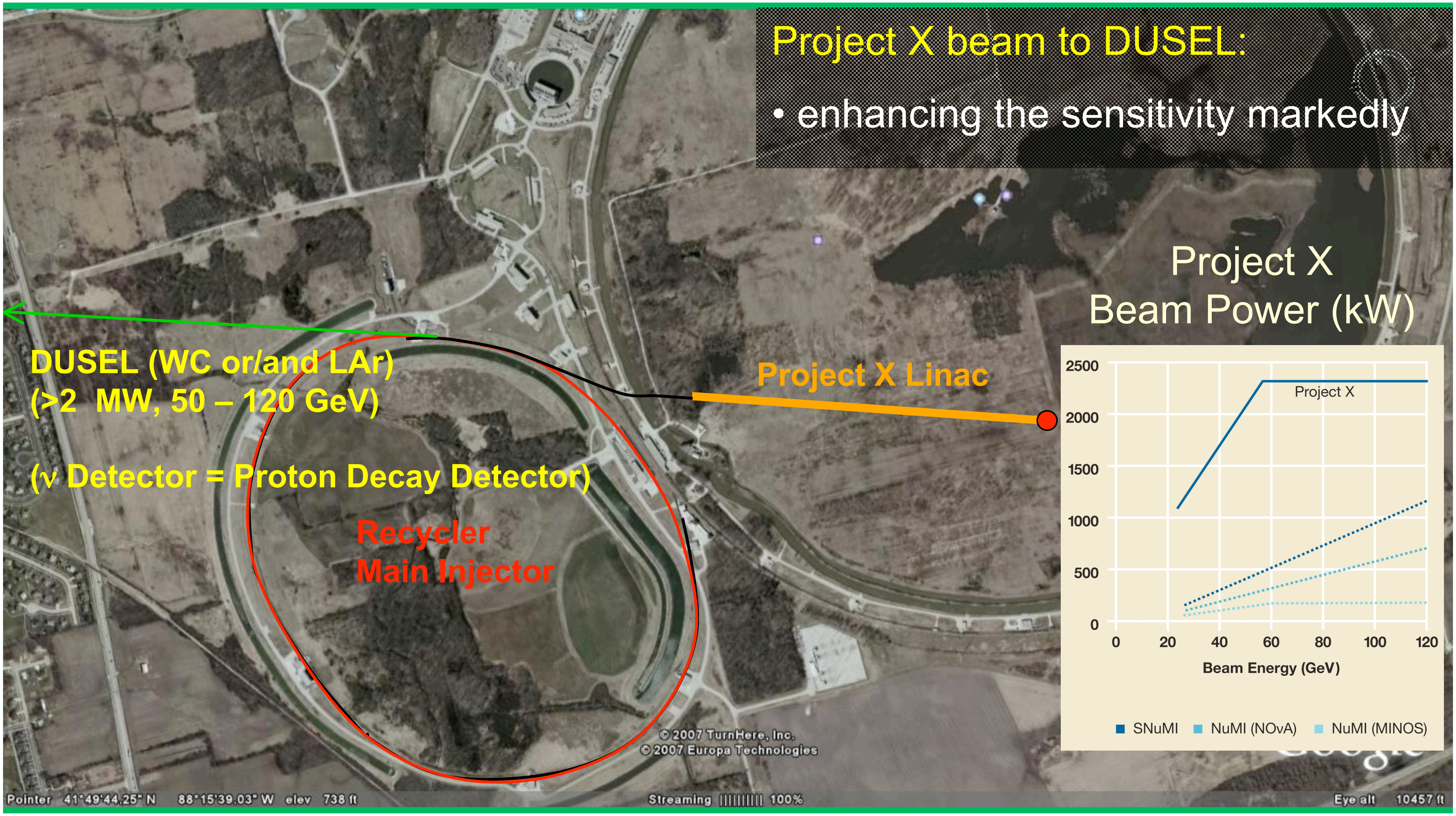
Eye alt 10457 ft

Phase 3



Project X beam to DUSEL:
• enhancing the sensitivity markedly
Project X
Beam Power (kW)
DUSEL (WC or/and LAr)
(>2 MW, 50 – 120 GeV)
(ν Detector = Proton Decay Detector)
Project X Linac
Recycler
Main Injector
2500
2000
1500
1000
500
0
0
20
40
60
80
100
120
Beam Energy (GeV)
Project X
SNuMI
NuMI (NOvA)
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Vacuum LBL: $\nu_\mu \longrightarrow \nu_e$

$$P_{\mu\to e} \approx \left| \sqrt{P_{atm}}\, e^{-i(\Delta_{32} \pm \delta)} + \sqrt{P_{sol}} \right|^2$$

$$\Delta_{ij} = |\delta m^2_{ij}| L / 4E$$

CP violation !!!

where $\sqrt{P_{atm}} = \sin\theta_{23} \sin 2\theta_{13} \ \sin\Delta_{31}$

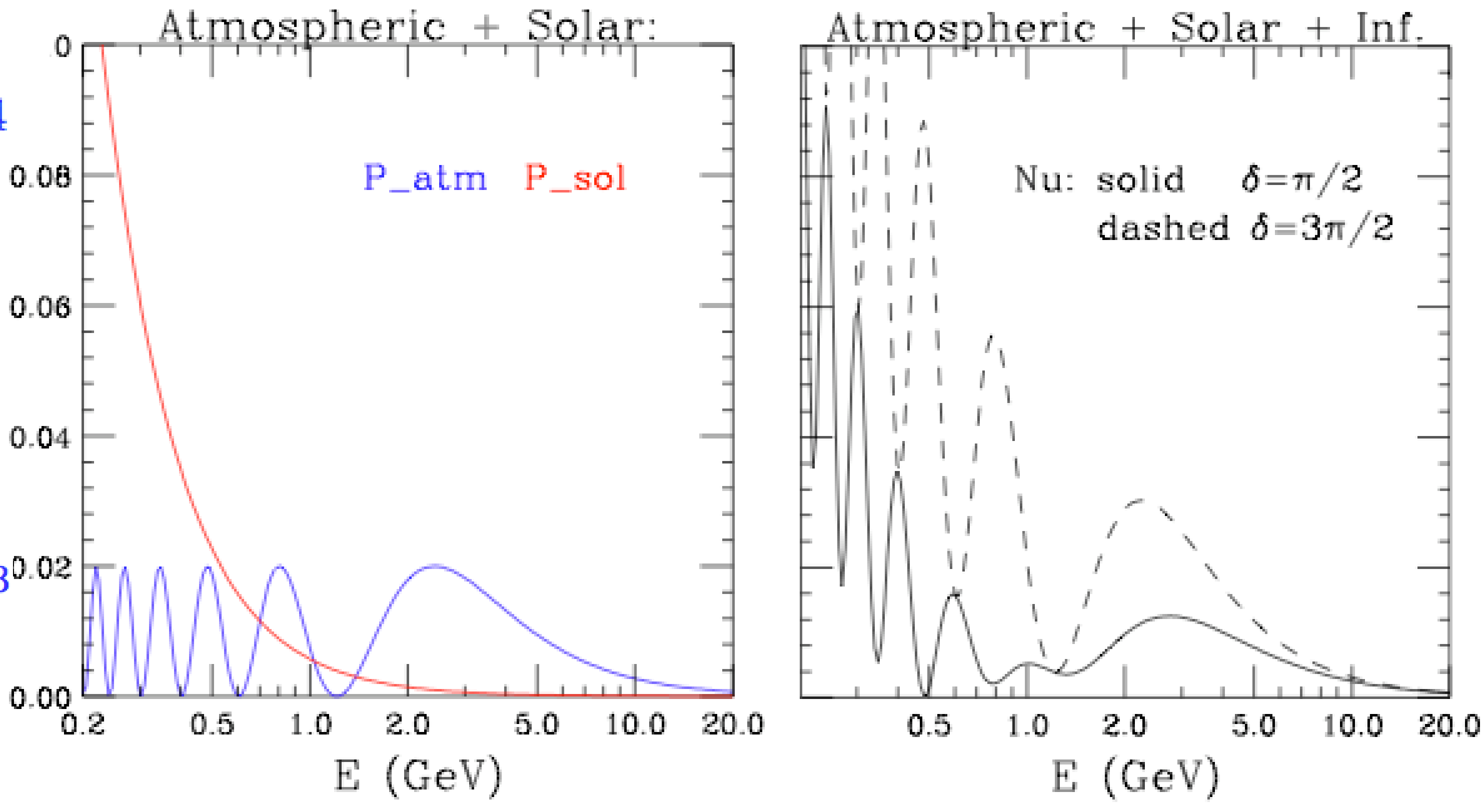
and $\sqrt{P_{sol}} = \cos\theta_{23} \sin 2\theta_{12} \ \sin\Delta_{21}$

$$P \approx P_{atm} + 2\sqrt{P_{atm} P_{sol}} \cos(\Delta_{32} \pm \delta) + P_{sol}$$

$$P(\nu_\mu \to \nu_e) \approx |\sqrt{P_{atm}}e^{-i(\Delta_{32}+\delta)} + \sqrt{P_{sol}}|^2$$

For $L = 1200\ km$
and $\sin^2 2\theta_{13} = 0.04$

$\sin^2\theta_{23}\sin^2 2\theta_{13}$



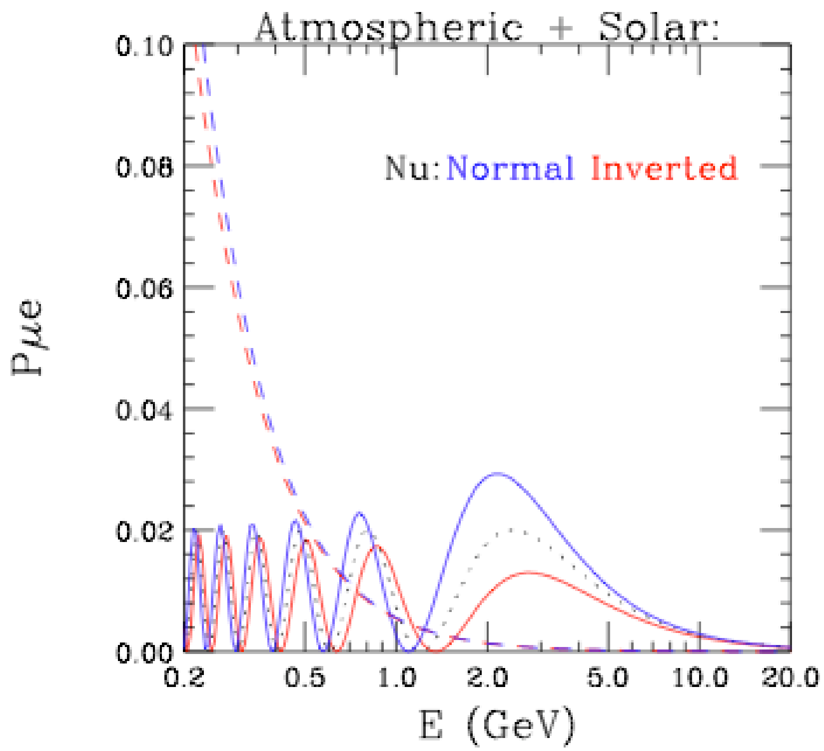
$$P_{atm} \leq P_{sol}$$

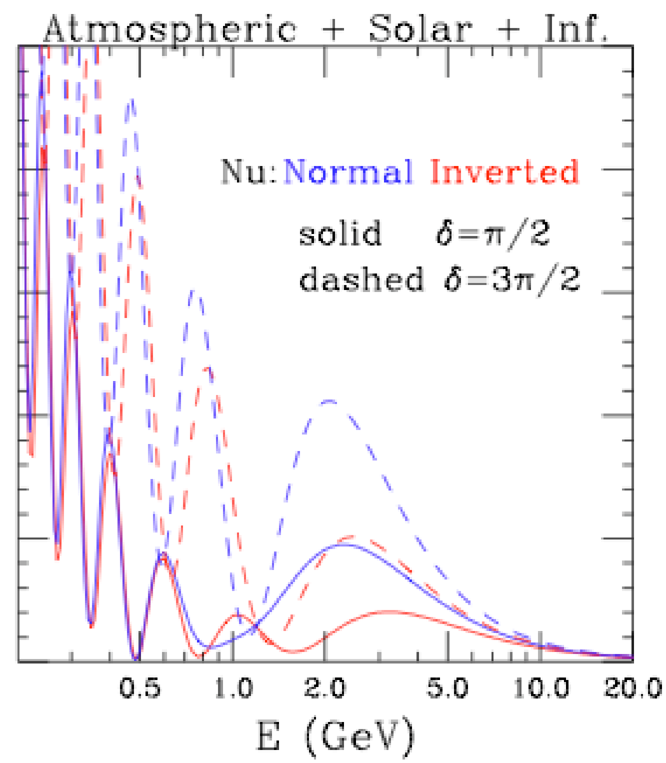
when $\sin^2 2\theta_{13} \leq \frac{\sin^2 2\theta_{12}}{\tan^2\theta_{23}}\left(\frac{\delta m^2_{21}}{\delta m^2_{31}}\right)^2 \approx 0.001$

In Matter:

$$P_{\mu \to e} \approx | \sqrt{P_{atm}} e^{-i(\Delta_{32} \pm \delta)} + \sqrt{P_{sol}} |^2$$

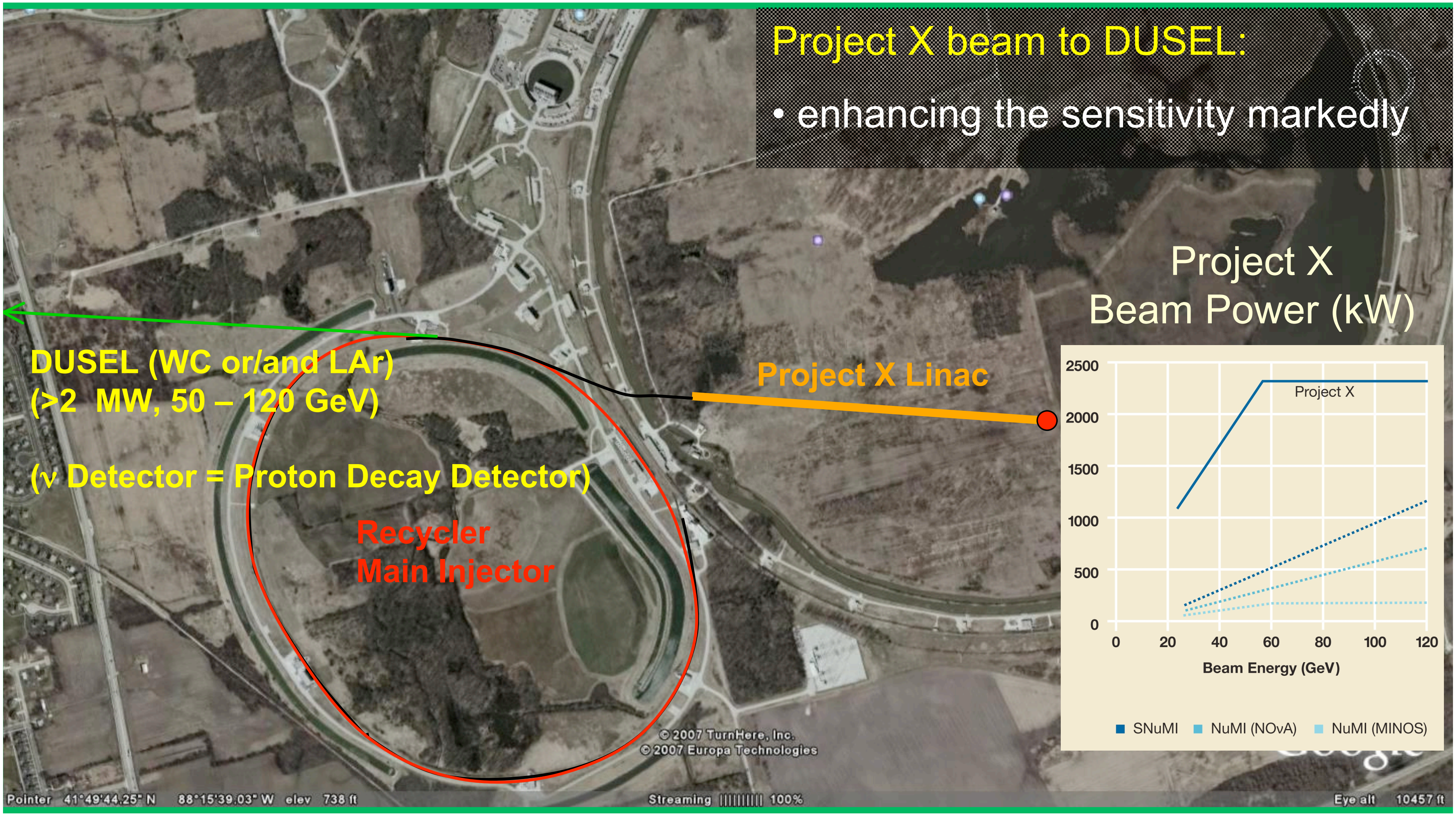
For $L = 1200\ km$
and $\sin^2 2\theta_{13} = 0.04$





Anti-Nu: Normal Inverted
dashes $\delta = \pi/2$
solid $\delta = 3\pi/2$

Phase 3



Project X beam to DUSEL:
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Project X
Beam Power (kW)
DUSEL (WC or/and LAr)
(>2 MW, 50 – 120 GeV)
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Recycler
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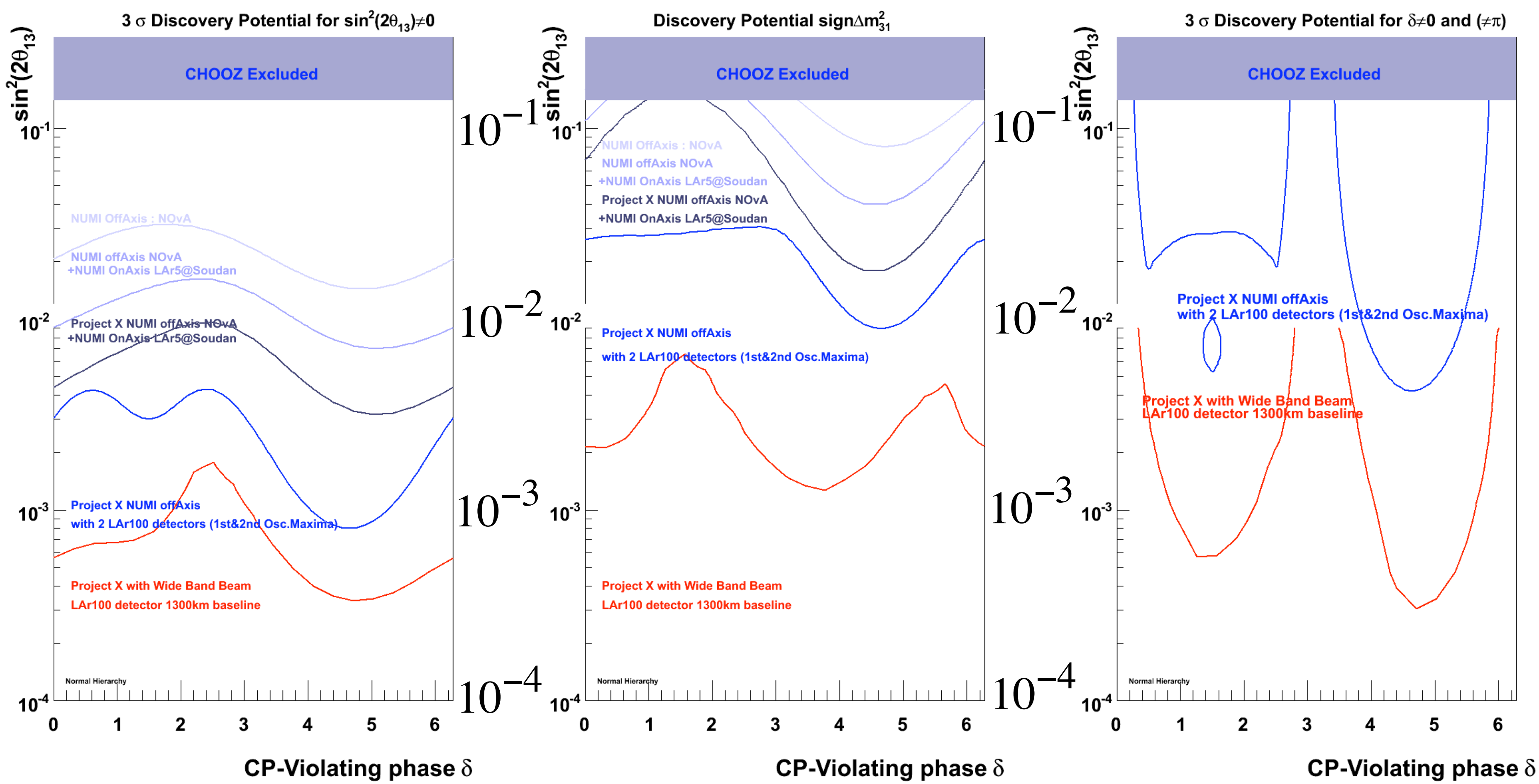
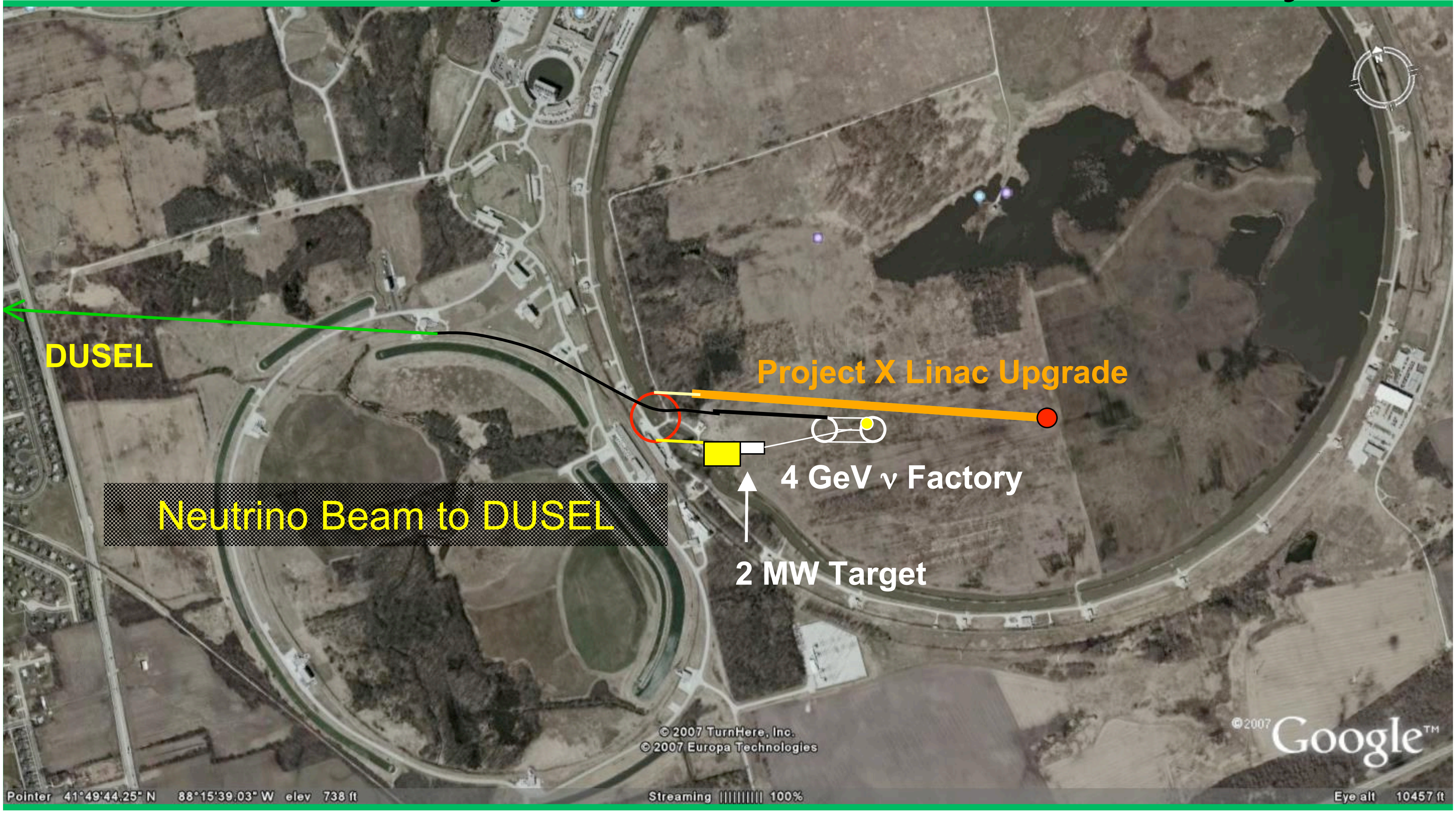
The 3σ Reach of the Successive Phases

$\sin^2 2\theta_{13}$ | Mass Ordering | CP Violation

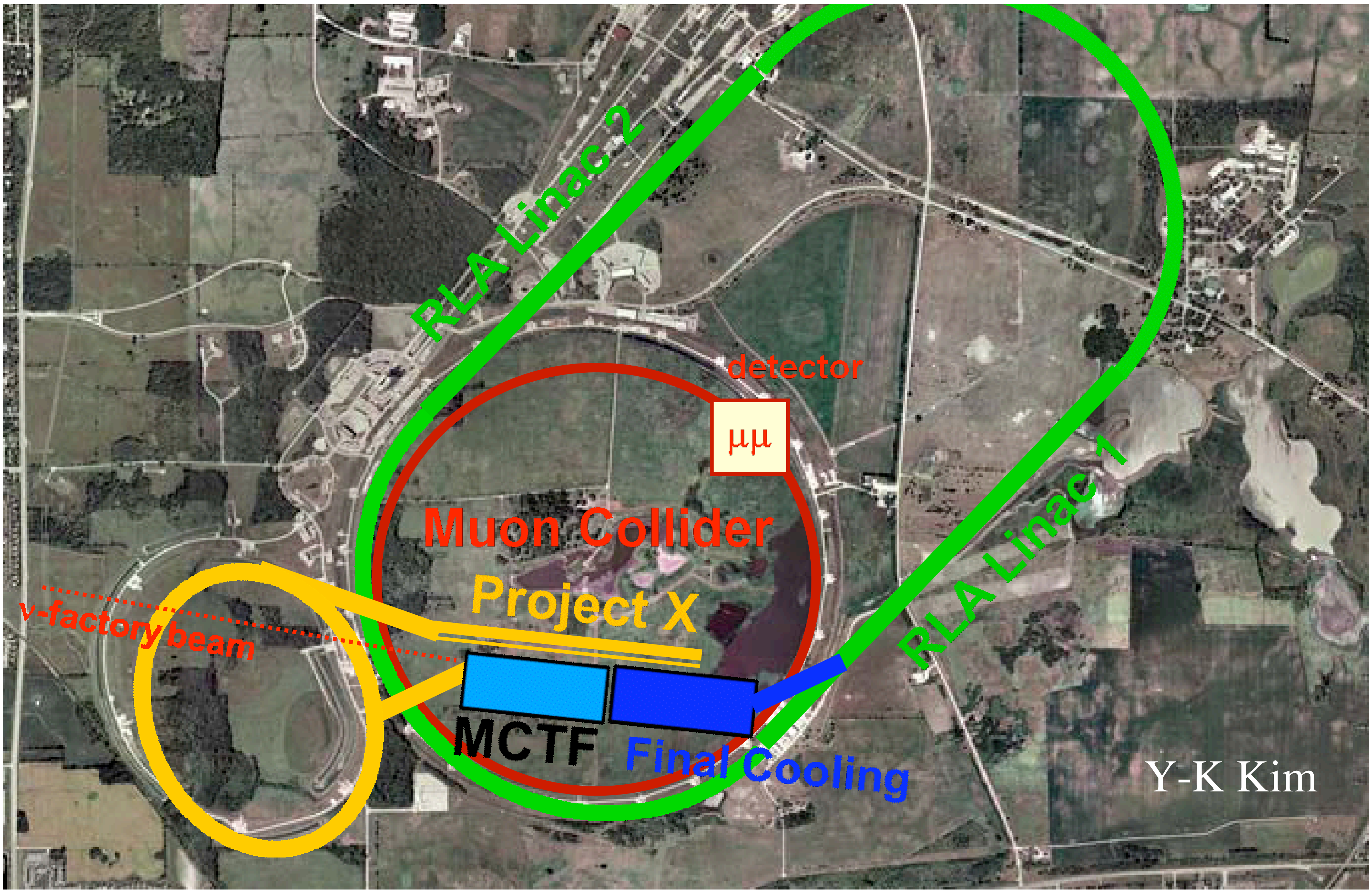


N. Saoulidou

Toward "Proton Intensity Upgrade" Evolutionary Path to a Neutrino Factory



Evolutionary Path to a $\mu^+\mu^-$ Collider



ILC Alignment of Project X

Project X is based on an 8 GeV superconducting H^{-} linac.

- Downstream 7 GeV would use ILC cryomodules and RF distribution systems
- H^{-} ions, but same beam parameters as for ILC

A Possible Timeline

- Tevatron Collider runs through 2010
- NOνA completed 2014
- Muon and Kaon experiments running mid 201Xs
- Project X accelerator completed 2nd half of 201Xs
- Large detector available in DUSEL ~ 2020
- ILC starts taking data mid-202Xs

Diverse Directions

It is also suggested that after Tevatron Collider shutdown, there be a Tevatron fixed-target program including —

- *precision studies of* $\nu_\mu - e$ *scattering*
- *searches for new physics in the charm system*

It is also suggested that Fermilab's intense antiproton source form the basis of a diverse program including —

- *Hyperon CP violation studies*
- *Antihydrogen CPT studies*

Conclusion

Fermilab's Project X provides a world-leading, exciting, diverse program for decades to come.