

**Update on the ongoing  
neutrino factory physics study**

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**Group 2: Detectors & backgrounds**

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**Group 3: Oscillation theory & scenarios**

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**Group 4: Oscillation measurements**

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**Group 5: Non-Oscillation physics**

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## Recap

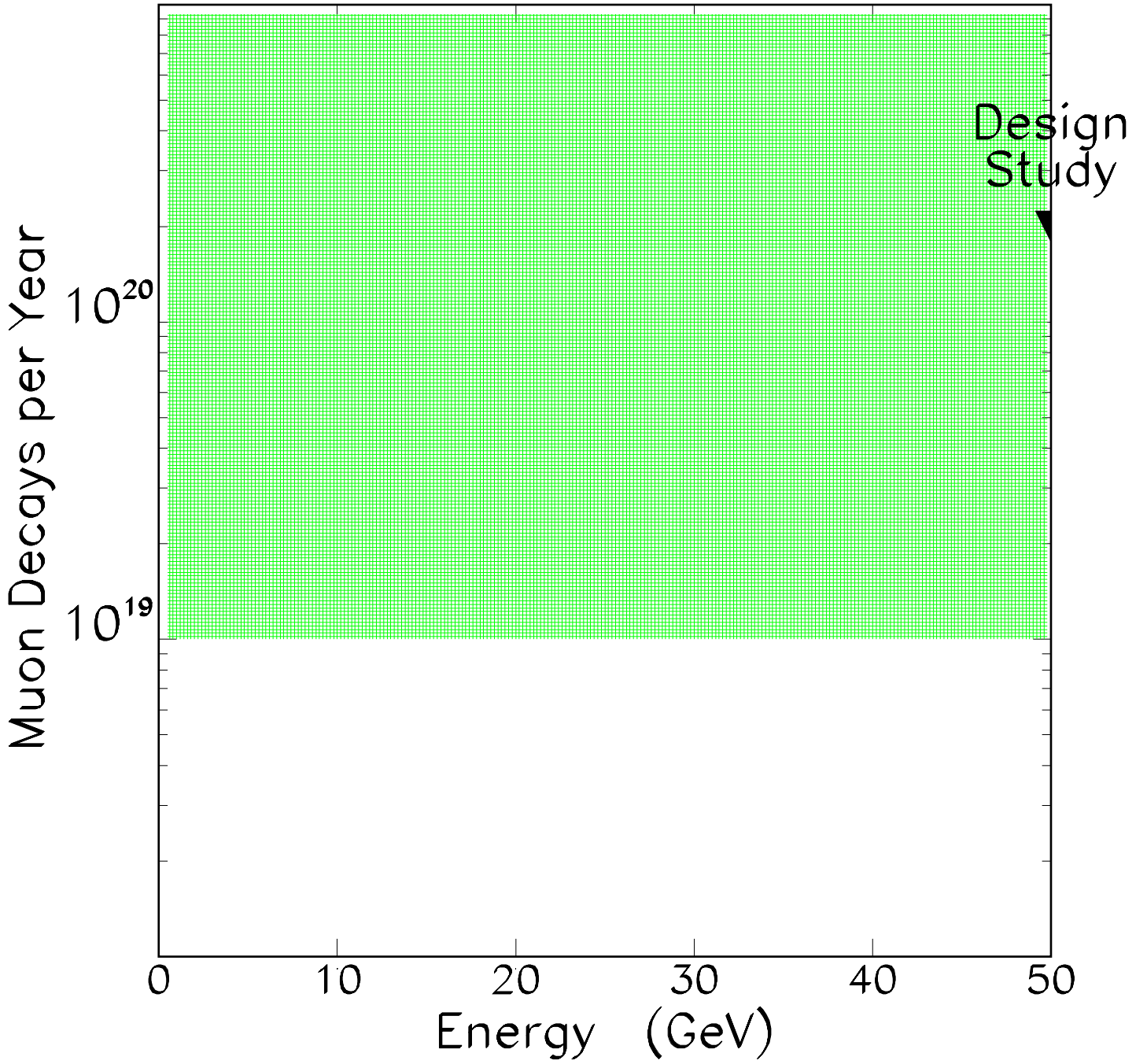
Last time (FARDOG meeting, 10th Nov. 99) talked about organization of the physics study, charge, strategy, & initial encouraging results.

- 1. Organization:** There are 60 people that have subscribed to our study email list. There are 40 people signed up for one of the 5 specific working groups ... most of these are actively involved in the study.
- 2. Charge:** Explore neutrino physics potential versus muon intensity, energy, baseline length, polarization ... report by March 31st.
- 3. Strategy:** (i) Define representative points that span the oscillation parameter space & for each point determine physics potential, (ii) study detector characteristics & limitations, (iii) survey non-oscillation physics possibilities.
- 4. Initial oscillation results:** With  $2 \times 10^{20}$  decays &  $E = 30$  GeV muons can do great things over large region of parameter space  $\rightarrow$  1st observation of  $\nu_e \rightarrow \nu_\mu$ , measure  $\sin^2 2\theta_{13}$  & matter effects & determine who is heavier than who.

## **Six-Month Physics Study**

The charge for the group will be to deliver a concise report by March 31, 2000 that will explicitly include:

- 1. The physics motivation for a neutrino source based on a muon storage ring, operating in the era beyond the current set of neutrino oscillation experiments.**
- 2. The physics program that could be accomplished at a neutrino factory as a function of:
  - (a) The stored muon energy, with the maximum energy taken to be 50 GeV.**
  - (b) The number of muon decays per year in the beam-forming straight section, taken to be in the range from  $10^{19}$  to  $10^{21}$  decays per year.**
  - (c) The presence or absence of muon polarization within the storage ring.**
  - (d) For oscillation experiments, the baseline length including investigations evaluating matter effects.****



## Primary Motivation

## Beam needed

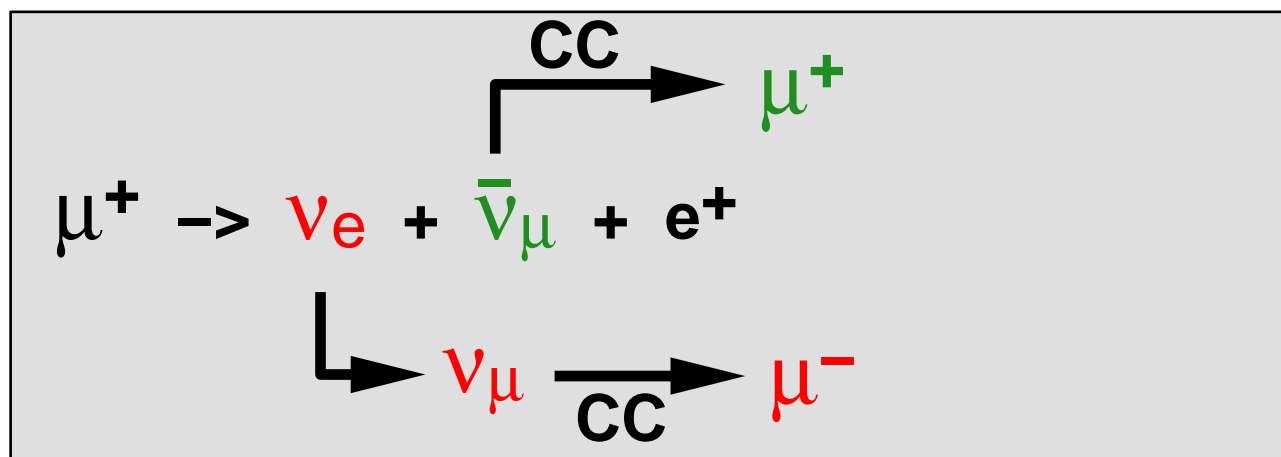
- |  |                      |
|--|----------------------|
| 1. 1st observation of $\nu_e \rightarrow \nu_\mu$<br>or stringent limit on $\sin^2 2\theta_{13}$ | $\nu_e$              |
| 2. 1st observation of matter effects   | $\nu_e, \bar{\nu}_e$ |
| 3. Measurement of sign of $\delta m^2_{32}$  | $\nu_e, \bar{\nu}_e$ |
| 4. Measurement of /limits on $\delta$<br>(CP Violation)  | $\nu_e, \bar{\nu}_e$ |
| 5. Observation / limits on $\nu_e \rightarrow \nu_\tau, \nu_s$                                   | $\nu_e$              |
| 6. Sum of above (1–5) enables test<br>of oscillation scheme consistency                          | $\nu_e, \bar{\nu}_e$ |

## Additional Motivation (B&B)

- |  |                      |
|--|----------------------|
| 1. High precision measurements<br>of (limits on) $\nu_\mu \rightarrow \nu_\tau, \nu_s$   | $\nu_\mu$            |
| 2. Stru. Fus, spin stru. fus, precision<br>$\sin^2 \theta_W$ , charm production, D– $\bar{D}$<br>mixing, B–physics, exotics, ... | $\nu_e$ or $\nu_\mu$ |

If MiniBooNE does not confirm the LSND oscillation result, the world-attention grabbing channel is:

$$\nu_e \rightarrow \nu_\mu$$



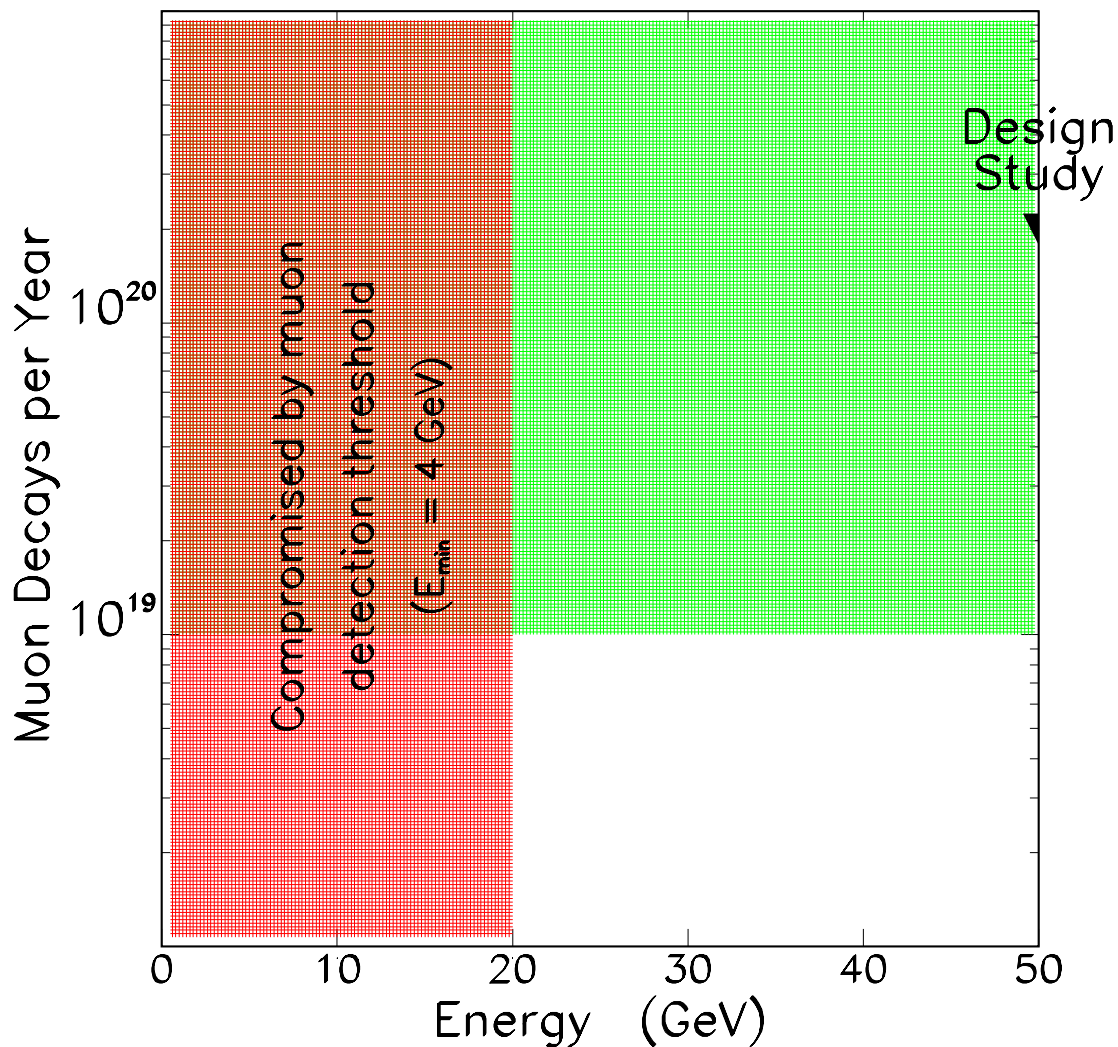
**Wrong-sign muons and long baselines**

If MiniBooNE does confirm the LSND oscillation result, the world-attention grabbing channel is:

$$\nu_e \rightarrow \nu_\tau$$

**$\tau$  appearance and shorter baselines**

- 1. Muon Threshold:** To detect & measure wrong-sign muons (the key signature) need to place a threshold on the detected muon energy of  $\sim 4$  GeV. This puts a limit on the minimum muon storage ring energy of about 20 GeV :

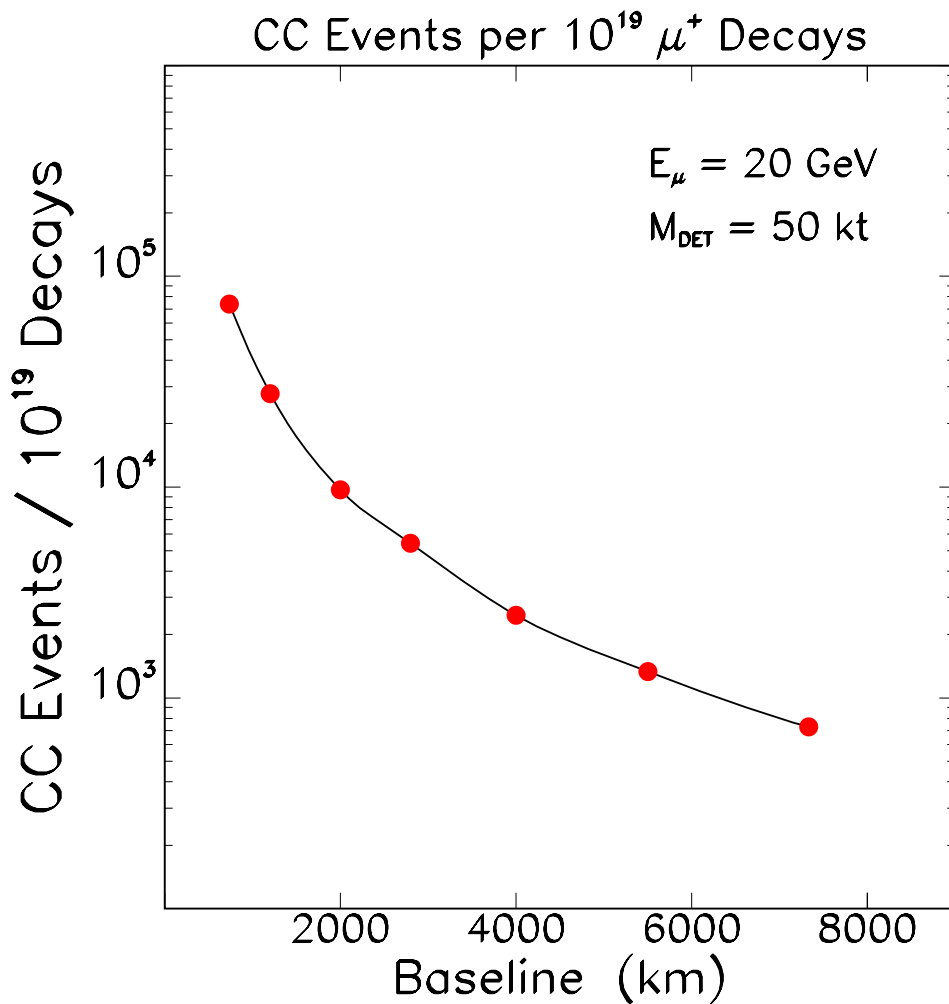


- 2. Detector mass:** Sensitivity  $\sim$  detector mass  $\times$  neutrino flux .... so the larger the detector the smaller the number of muons required in the neutrino factory. The next generation nucleon decay detector under discussion is 500 kt ! The nu-factory detector group is considering **50 kt** ... also chosen by our European friends.
  
- 3. Several 3-flavor oscillation scenarios:** Similar sensitivities to  $\nu_e \rightarrow \nu_\mu$  oscillations for all the solar neutrino solution scenarios (LMA, SMA, LOW) .... in each case a **50 kt** detector with  **$1 \times 10^{20}$  decays / year** & a **20 GeV** storage ring would give great results.

**To make contact with the world-attention grabbing physics will need much less than  $10^{20}$  decays per year !**

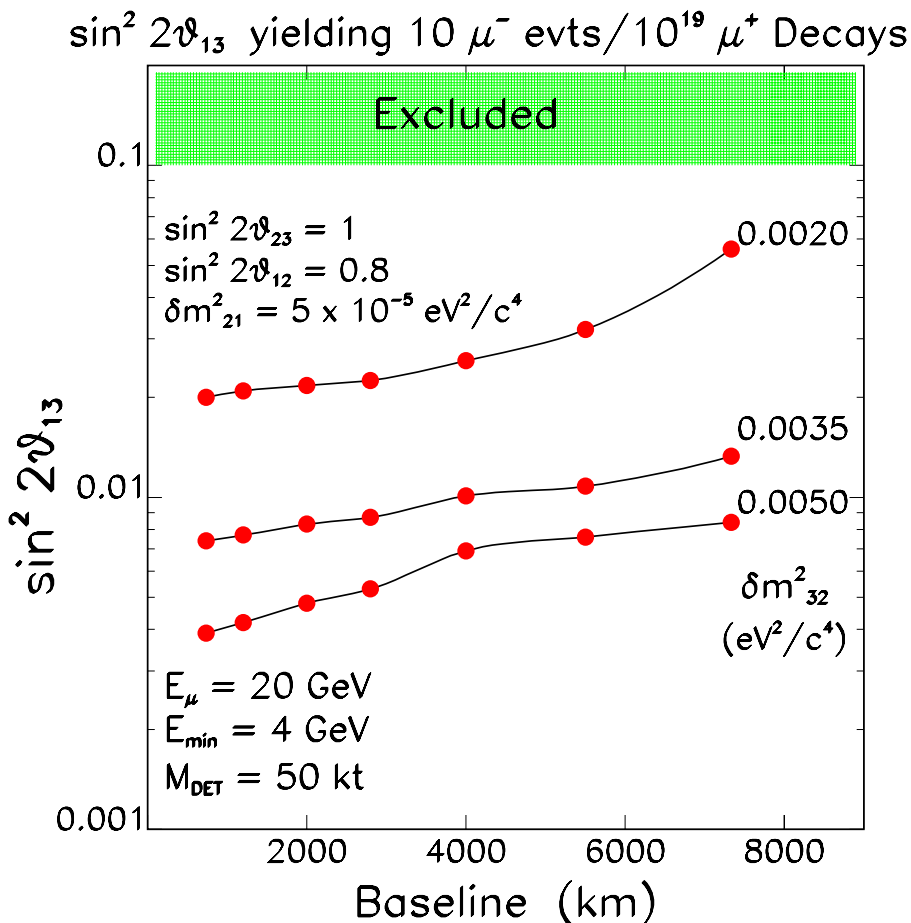
## Whats New ?

- 4. Baseline:** If we want to have small or zero backgrounds, the background rate (with respect to the total CC rate) will result in a minimum baseline length  $L$ . The detector group studies suggest that backgrounds from non-interacting pions could be at the  $10^{-4}$  level (possibly less background at lower storage ring energies)  $\rightarrow$  choose baseline  $> \sim 2000$  km.



**How many muon decays/year are needed to make contact with the world attention grabbing neutrino oscillation physics if the muon energy is 20 GeV ?**

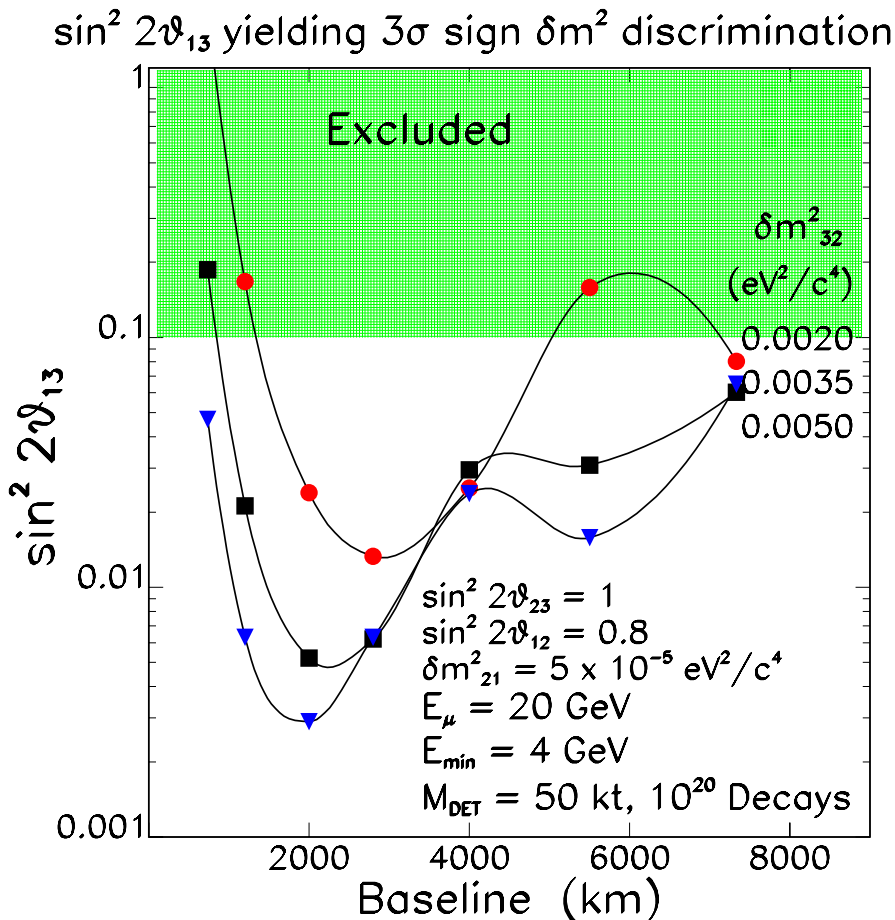
**Suppose the "entry-level" physics goal is to make the first observation of  $\nu_e \rightarrow \nu_\mu$  at the 10 event level and make the first measurement of  $\sin^2 2\theta_{13}$**



**Conclude that  $10^{19}$  decays/yr (factor of 20 less than Norberts study) would enable the "entry level" goals to be met provided  $\sin^2 2\theta_{13}$  is not small than an order of magnitude below the currently excluded region.**

**How many muon decays/year are needed for a "beyond the entry level" neutrino factory if the muon energy is 20 GeV ?**

**Suppose the "upgrade" physics goal is to make the first measurement of matter effects & determine who is heavier than who at  $3\sigma$ .**

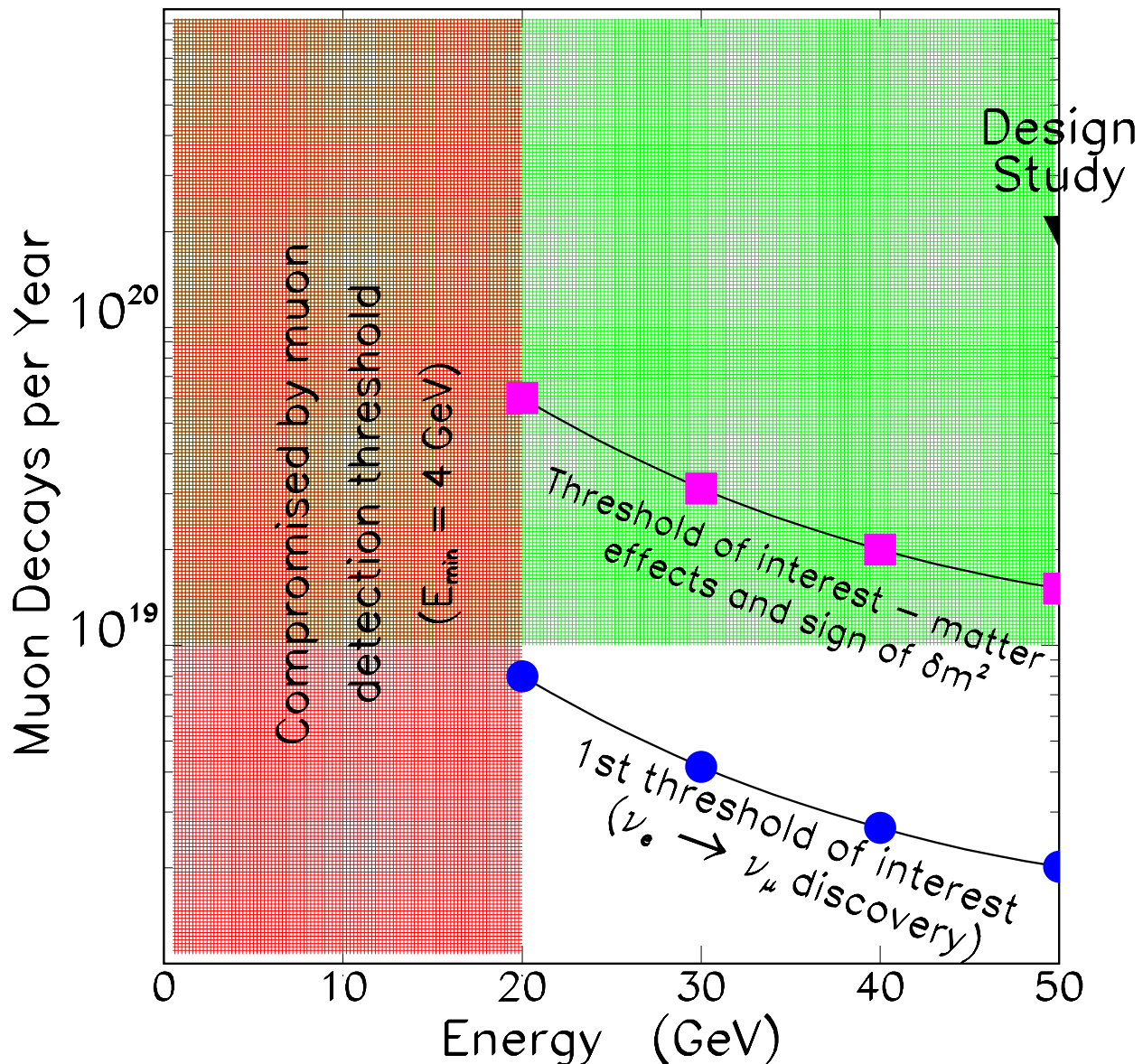


**Conclude that 1020 decays/yr (factor of 2 less than Norberts study) would enable "upgrade level" goals to be met provided  $\sin^2 2\theta_{13}$  is not small than an order of magnitude below the currently excluded region.**

Conclude that there appears to be a staging strategy for neutrino factories

If MiniBooNE does not confirm LSND:

50 kt Detector,  $\delta m^2_{32} = 0.0035 \text{ eV}^2$



If MiniBooNE confirms LSND ... might be even more favorable for nu factories (under study)

To pull things together before writing our report we will have a 2–day meeting in 1 West Feb. 17–18. Lots of interesting presentations:

[http://www.fnal.gov/projects/muon\\_collider/nu/study/two\\_day.html](http://www.fnal.gov/projects/muon_collider/nu/study/two_day.html)

Our charge (wisely) restricted our physics study to the neutrino physics potential of a neutrino factory. We will not address the great physics that can be done with:

- 1. A 1 MW proton driver.**  
Kaon, conventional neutrino, ...
- 2. Intense stopped muon source (no cooling).**  
 $\mu \rightarrow e\gamma$ ,  $\mu \rightarrow e$  conversion, hyperfine splitting, muonium–antimuonium,  $\mu$  decay parameters
- 3. Low energy muon source (some cooling).**  
 $g-2$ ,  $\mu$  EDM, ...

En–route to a neutrino factory there are many physics possibilities.

## Summary

**We have made lots of progress in understanding the physics potential of neutrino factories versus baseline, energy, and intensity for the scenario in which MiniBooNE does not confirm LSND.**

**A 20 GeV ring with  $10^{19}$  decays / year might be a good entry-level nu-factory .... our 2-day meeting will provide an opportunity to discuss this.**

**Scenarios in which MiniBooNE confirms LSND are now under study ... expect some results by the 2 day meeting.**

**The case for polarization is also under study ... not sure how clear an answer we will have.**

**We have a very active local group involved in the study .... good investment for the future.**