A Combined BNL and FNAL Long Baseline Experiment

Brett Viren

bv@bnl.gov

Physics Department

Brookhaven National Lab

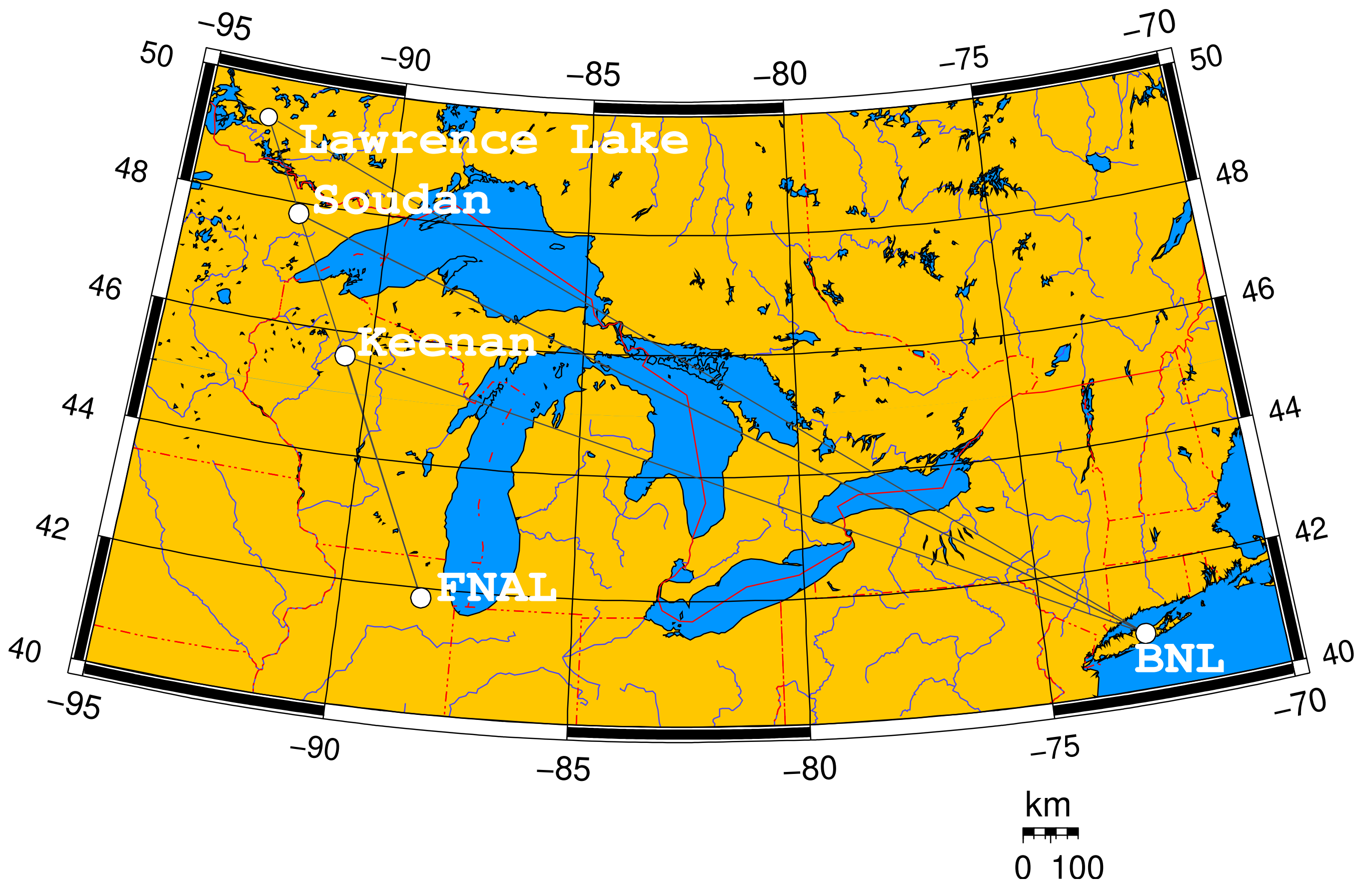
Outline:

- Baselines Considered.
- NuMI and AGS Beams.
- Detector and Run Time Assumptions.
- Oscillation Probabilities and,
- Expected Event Rate Distributions.
- Conclusions and Future Work.

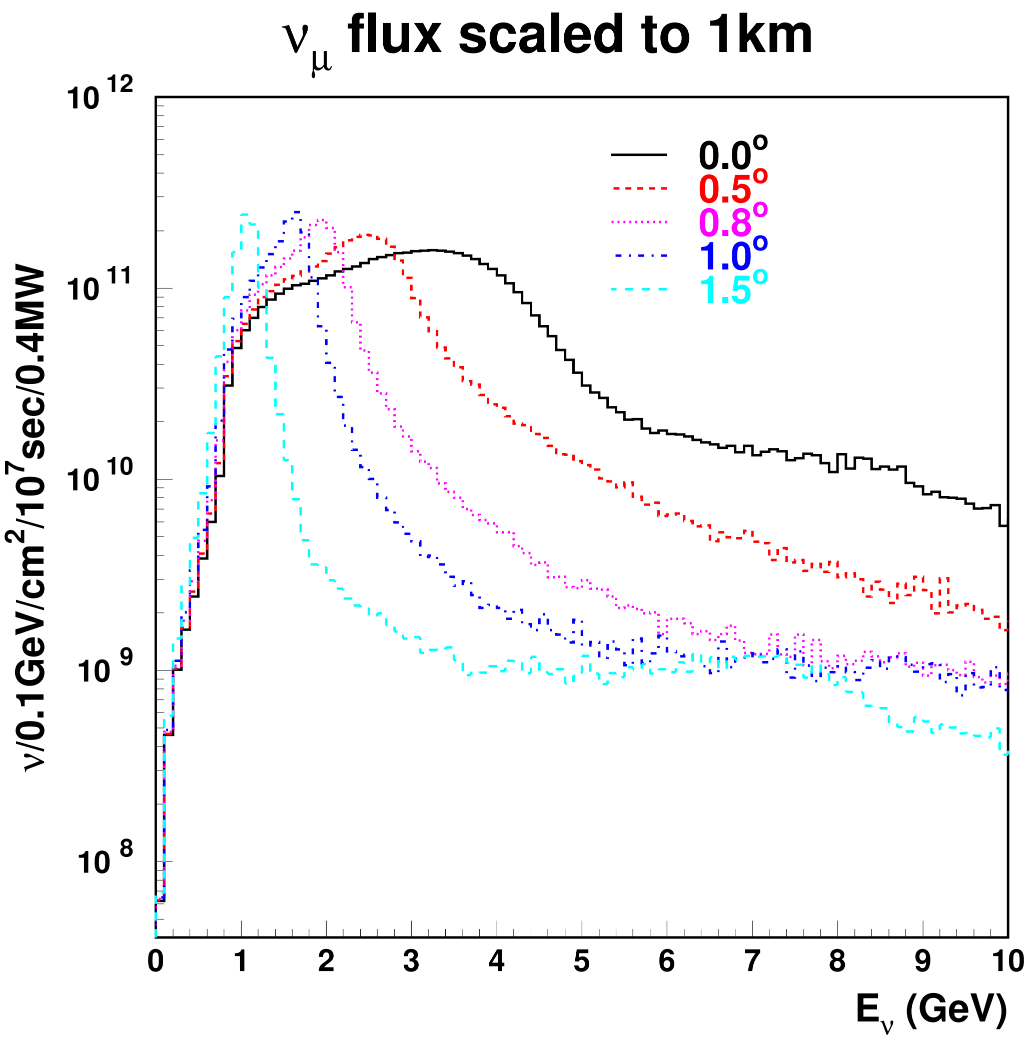
Baselines

BROOKHAVEN NATIONAL LABORATORY

	Keenan, WI	Soudan, MN	Lawrence Lake, ON
FNAL	458 km	735 km	911 km
BNL	1522 km	1711 km	1840 km



FNAL NuMI Beam



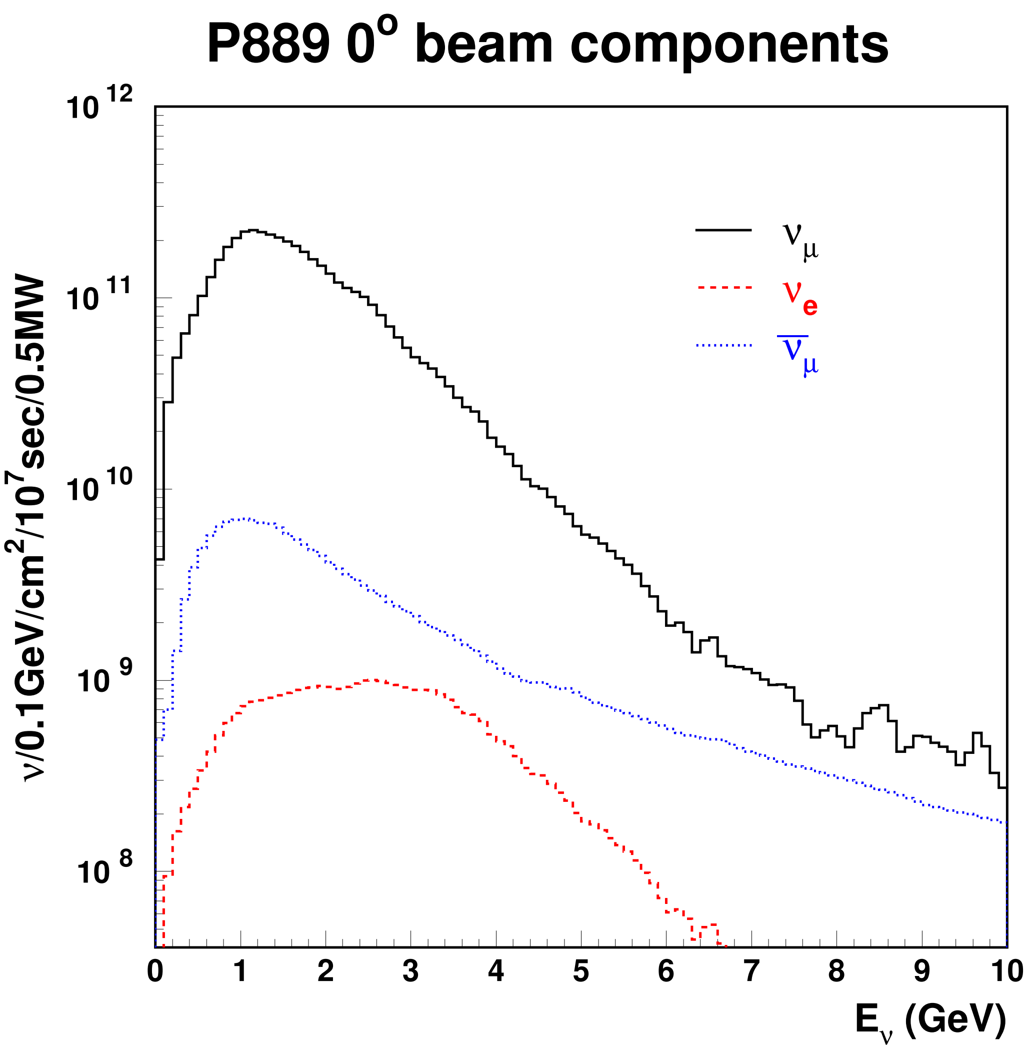
- 0.4 MW, 120 GeV protons
- GNUMI simulation
- Must target Δm^2:

@ $\Delta m^2_{atm} = 2.5 \times 10^{-3}$

Angle (deg)	E_{peak} (GeV)	L_{osc} (km)	Location
0.0	3.0	1500	
0.5	2.5	1250	
0.8	2.0	1000	(L. Lake)
1.0	1.5	750	(Soudan)
1.5	1.0	500	(Keenan)
2.0	0.7	350	

BNL AGS Beam

BROOKHAVEN NATIONAL LABORATORY



- On-axis P889 beam
- Wide $\Rightarrow$ covers range of Δm^2
- Harder spectrum, low tail.
- These spectra: 0.5 MW, 28 GeV protons
- Upgrade AGS to **1.5 MW** $\longrightarrow$

AGS Upgrade to 0.5 and 1.3 MW

BROOKHAVEN
NATIONAL LABORATORY

AGS upgrade costs, (Bill Weng, BNL. Letter of Intent to BNL, 2002.)

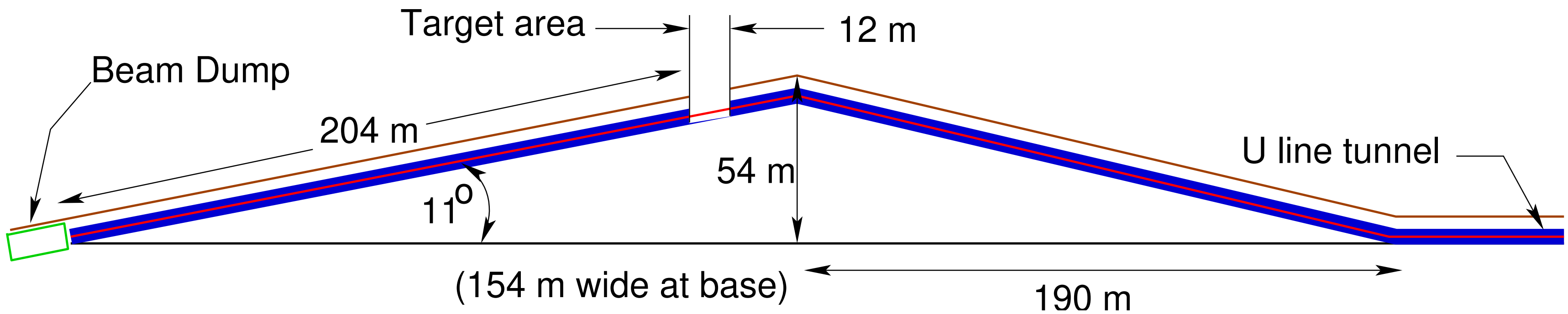
Phase I (AGS at **1 Hz**) 538 kW $\Rightarrow 1.2 \times 10^{21}$ ppp.	$\$10^6$
300 MeV SRF (116 MeV to 400 MeV)	35
2.5 GeV AGS accumulator ring	25
AGS Injection at 2.5 GeV	5
Total for Phase I	**65**

Phase-II (AGS at **2.5 Hz**), 1344 kW $\Rightarrow 2.9 \times 10^{21}$ ppp.	
AGS power supply	32
AGS RF upgrade	8.6
Booster Power Supply	5.5
AGS Collimation and Shielding	8.0
Total for Phase-II	**54.1**

- **1.5 MW** assumed for this study.

The BNL Hill (Mt. Palmer)

Use BNL-Homestake hill as *eg.*:



Numbers are for BNL-HS hill and ν-beamline. Cheaper for lower dip angle.

Item	Basis	200 m ($\$10^6$)	150 m ($\$10^6$)
Proton transport	RHIC injector	11.85	11.85
Target/horn	E889	3.0	3.0
Installation/Beam Dump	New	2.67	2.67
Decay Tunnel	E889	0.45	0.45
Conventional const. (hill)	New	8.0	5.0
Conventional const. (other)	E889	9.1	9.1
Total		35.19	32.19

(Dana Beavis, BNL. Letter of Intent to BNL, 2002.)

Detector and Run Time Assumptions

BROOKHAVEN NATIONAL LABORATORY

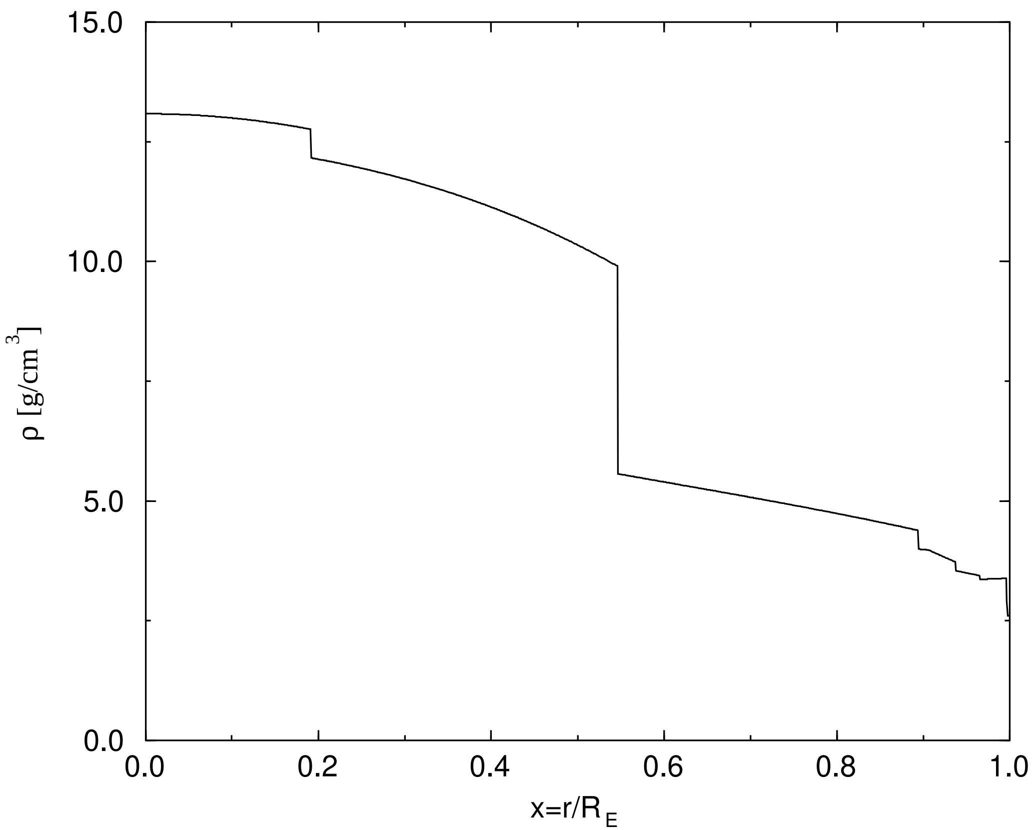
Assuming:

- 100 kTon (fiducial) water Cerenkov detector.
- SuperK-like reconstruction efficiencies and resolutions estimated from SK ν_{atm}-MC:
  - $\varepsilon_{\mu,sr,cc,qe} = 80\%$. Not corrected for larger detector.
  - $\varepsilon_{e,sr,cc,qe} = 40\%$. Lower than typical due to tighter SR requirements.
  - 10% energy resolution. Correct at 1 GeV, overestimate at > 1 GeV.
  - NC background to ν_e CC QE: generate matrix: $[E_{\nu_{e,reco}} \bigotimes E_{\nu_\mu,mc}]$, relating number of ν_μ CC QE interactions with $E_{\nu_\mu,mc}$ to the number of ν_μ interactions in that same energy bin which look like S.R. e-like events and reconstruct to $E_{\nu_{e,reco}}$. This makes use of the known ν direction.
- Running time: 5 years, 1 year = 10^7 seconds.

Oscillation probability calculation

BROOKHAVEN NATIONAL LABORATORY

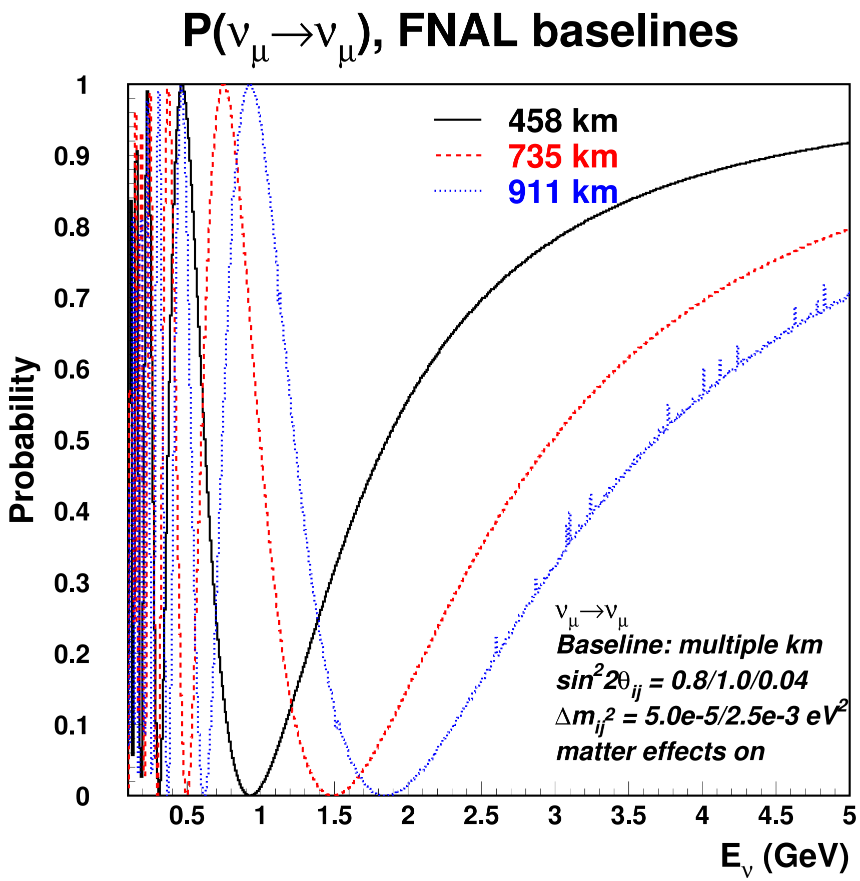
Exact, numerical 3-ν, 2-Δm^2-scale, matter effects with PREM earth density profile.

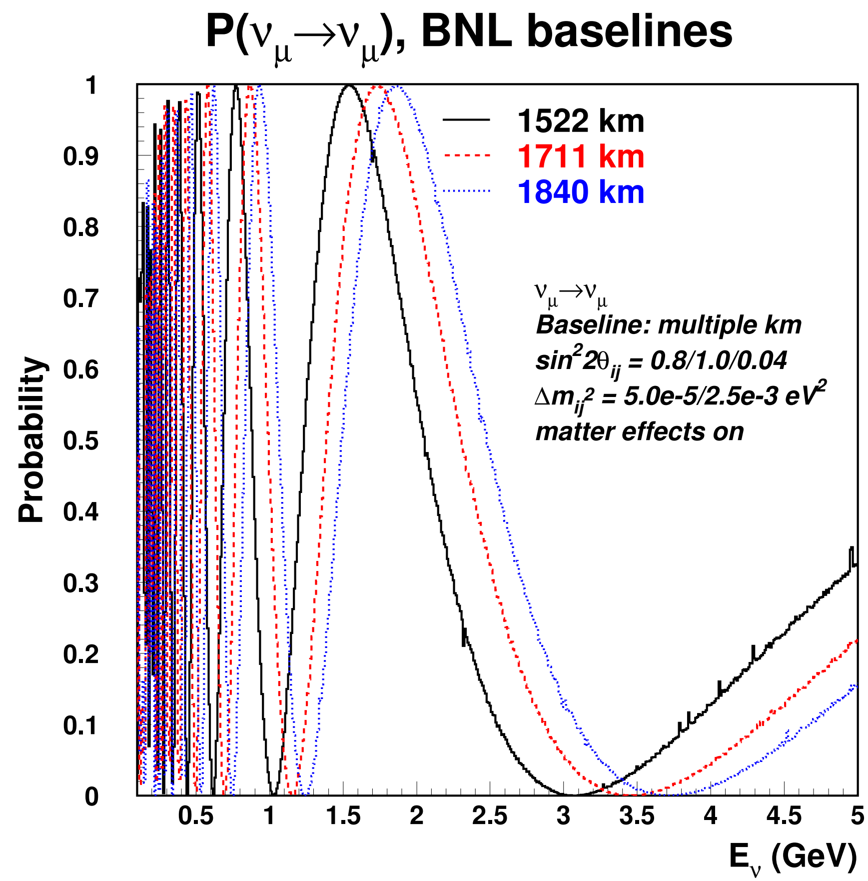


Test point:
LMA, max mix atm, medium θ_{13}:

- $\sin^2 2\theta_{12} = 0.8$
- $\sin^2 2\theta_{23} = 1.0$
- $\sin^2 2\theta_{13} = 0.04$
- $\phi_{cp} = 0$
- $\Delta m^2_{sol} = 5.0 \times 10^{-5} e\text{V}^2$
- $\Delta m^2_{atm} = 2.5 \times 10^{-3} e\text{V}^2$

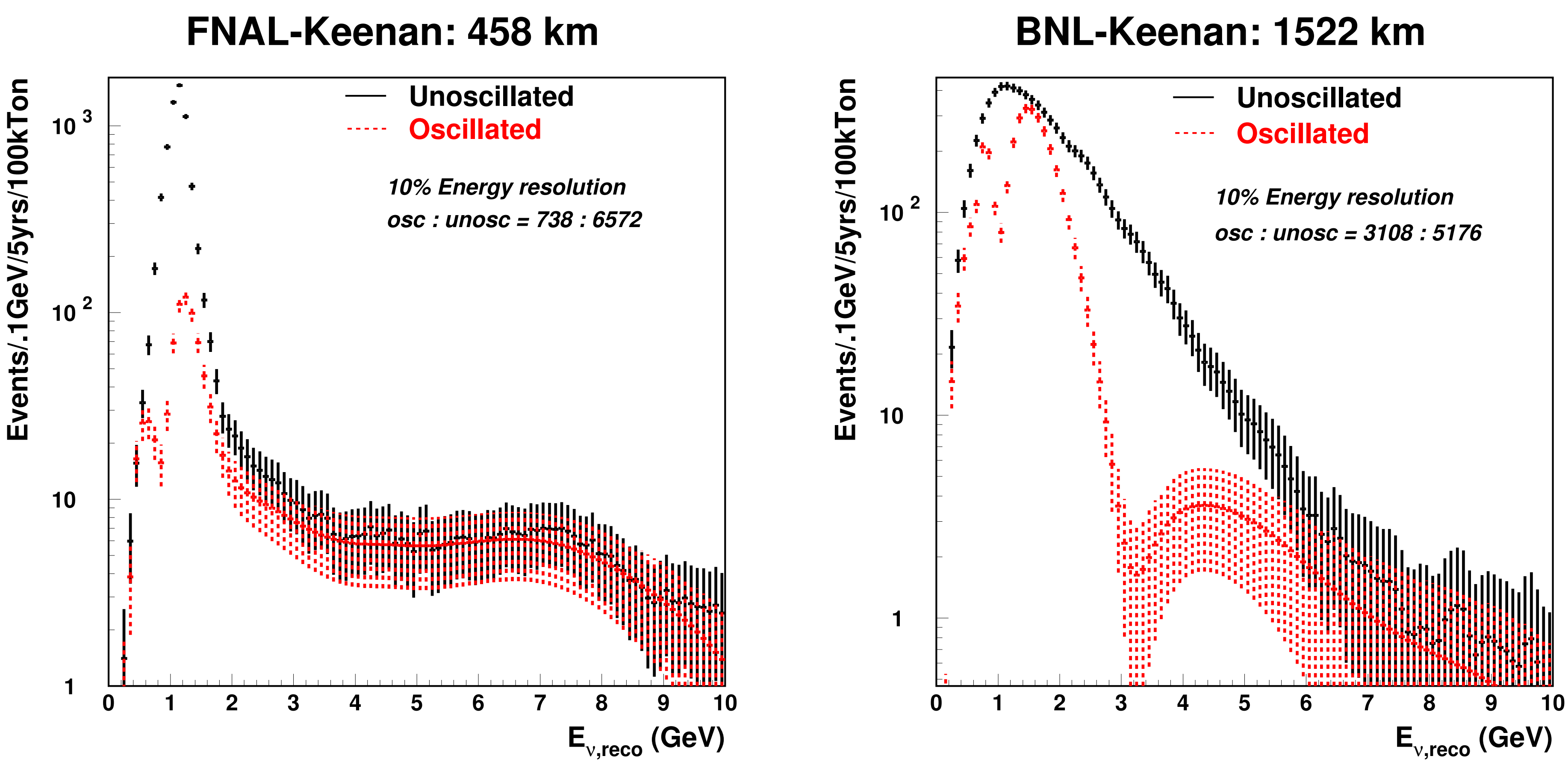
$\mathbf{P}(\nu_\mu \to \nu_\mu)$



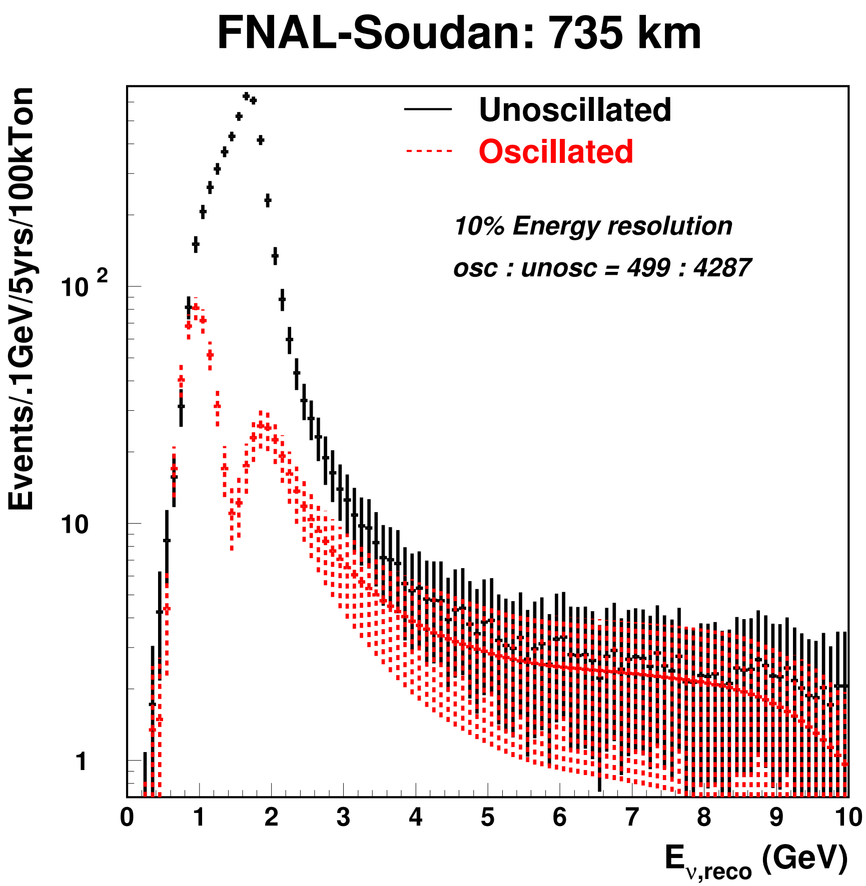


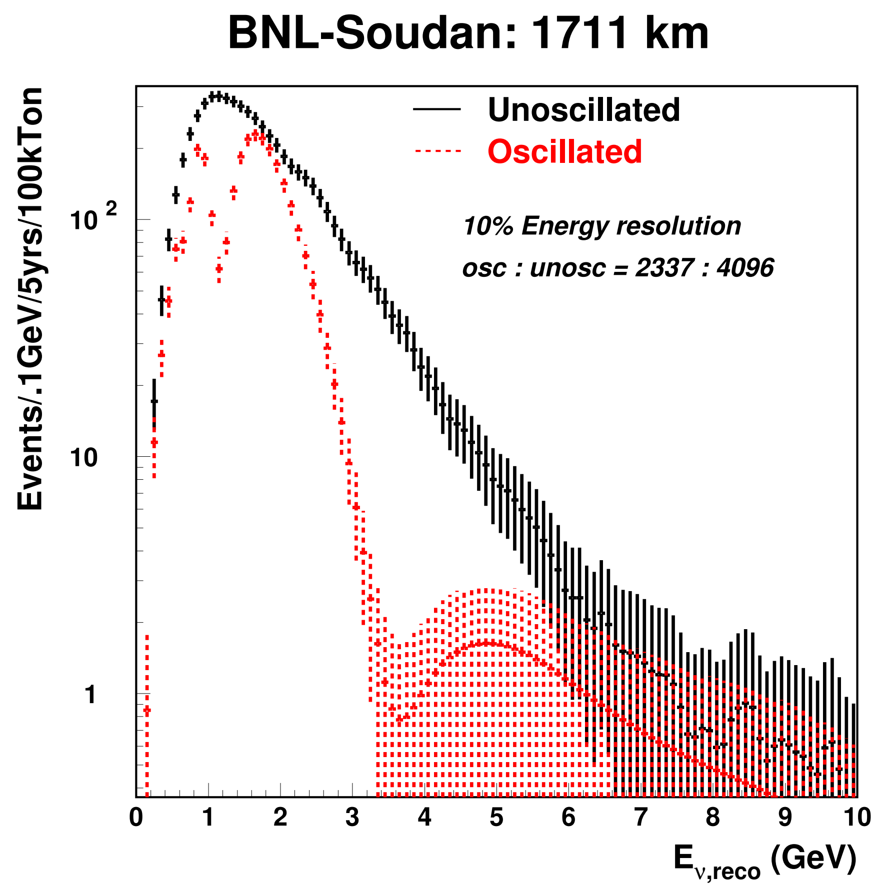
- FNAL beam targets Δm^2 (to be *a priori* well known) and sees 1^{st} osc. node.
- BNL beam covers 2^{nd}, part of 1^{st}, just gets a little of the 3^{rd} osc. node and covers a range of Δm^2s.

Keenan event rates - $\nu_\mu \to \nu_\mu$ Disappearance



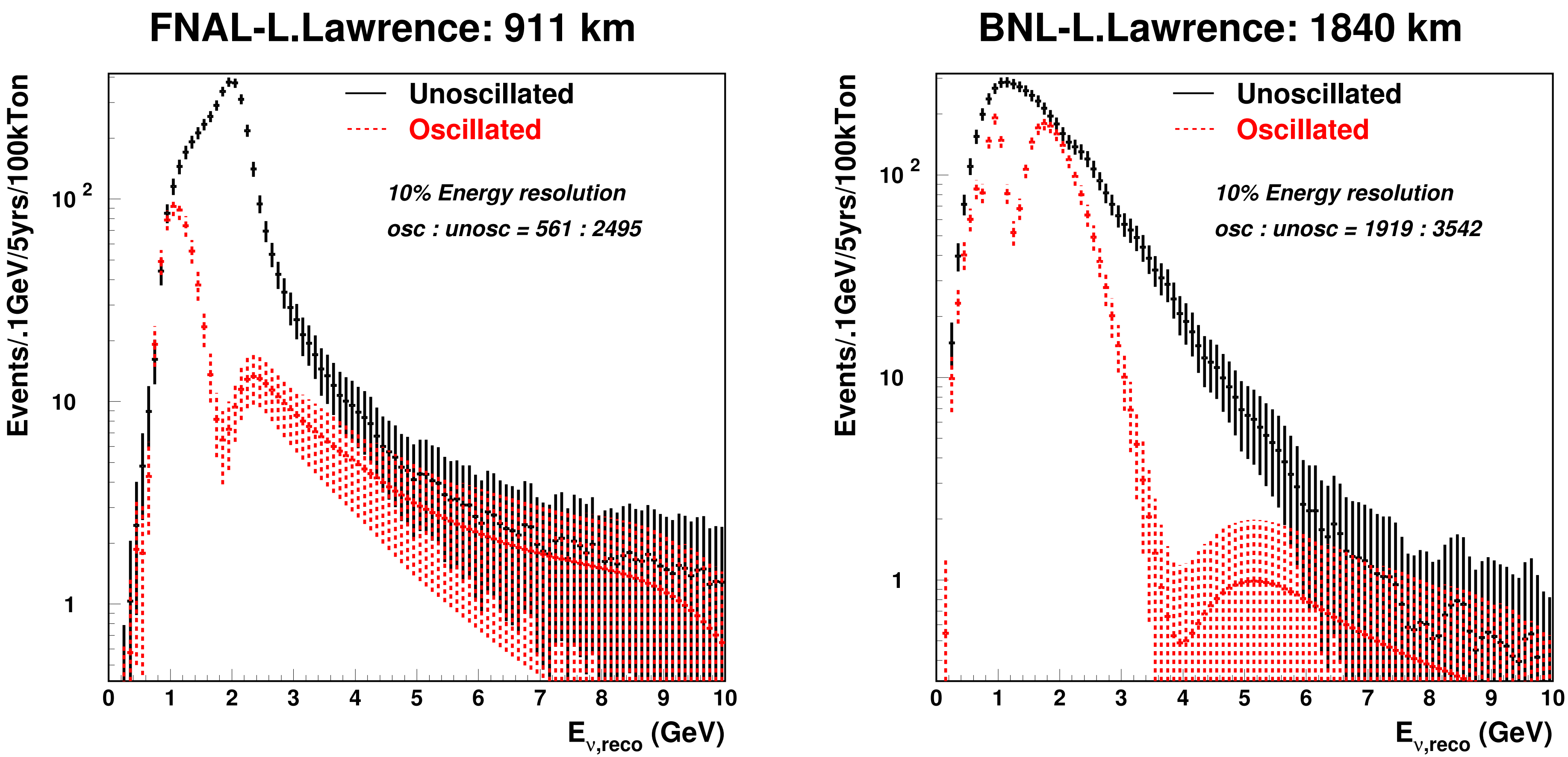
Soudan event rates - $\nu_\mu \to \nu_\mu$ Disappearance



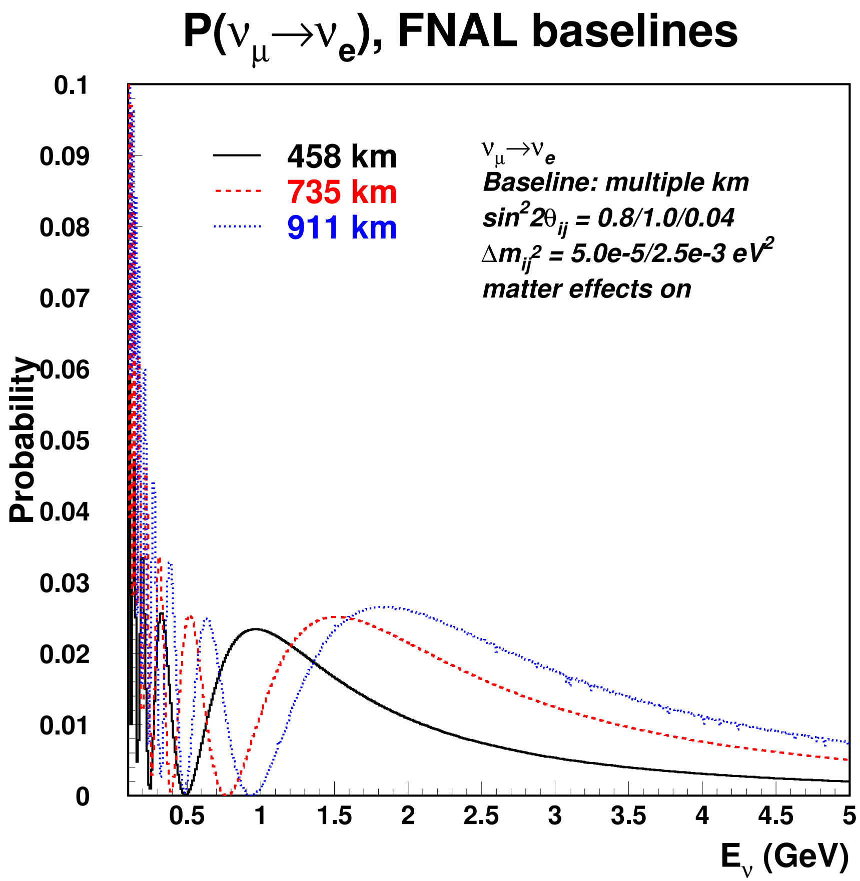


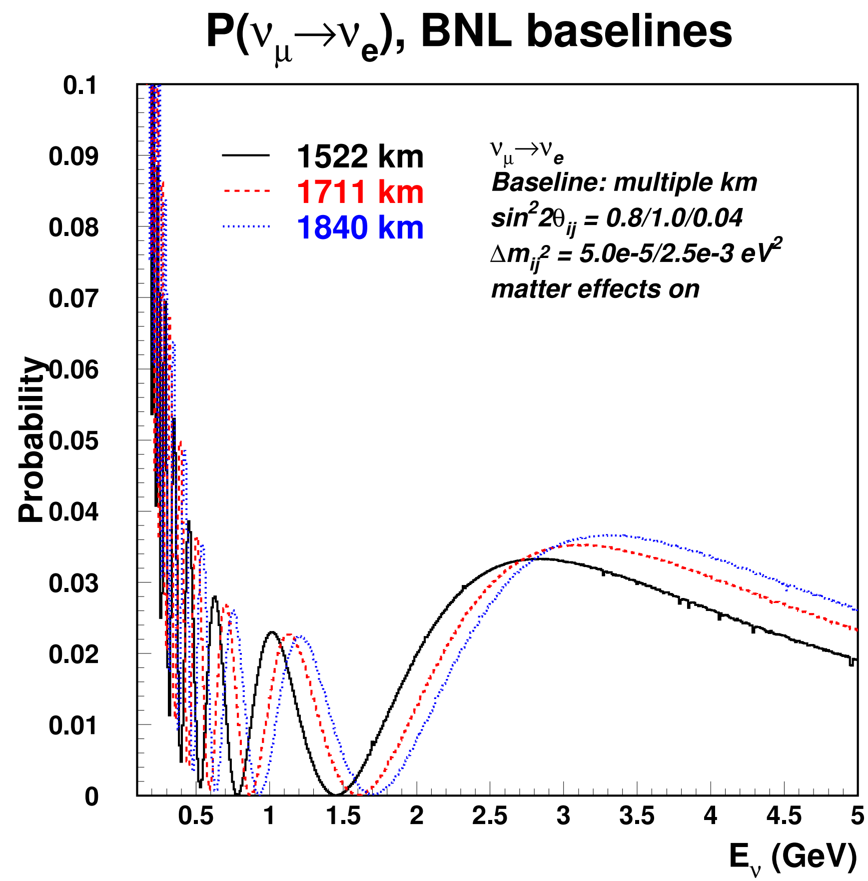
L.Lawrence event rates - $\nu_\mu \rightarrow \nu_\mu$ Disappearance

BROOKHAVEN NATIONAL LABORATORY



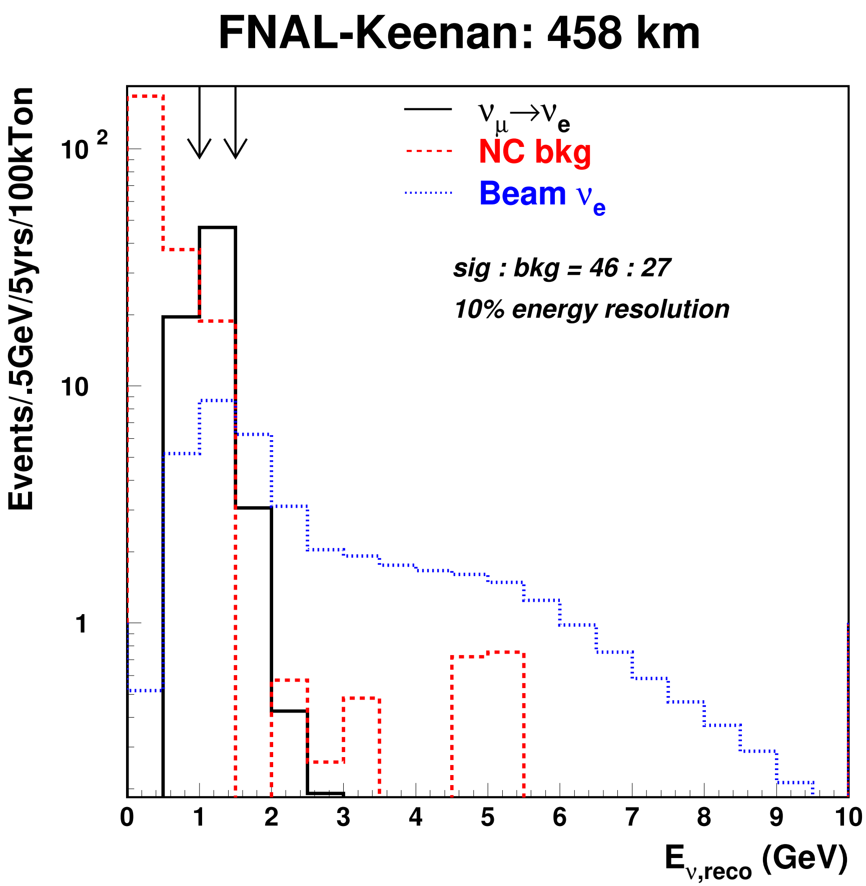
$\mathbf{P}(\nu_\mu \rightarrow \nu_e)$

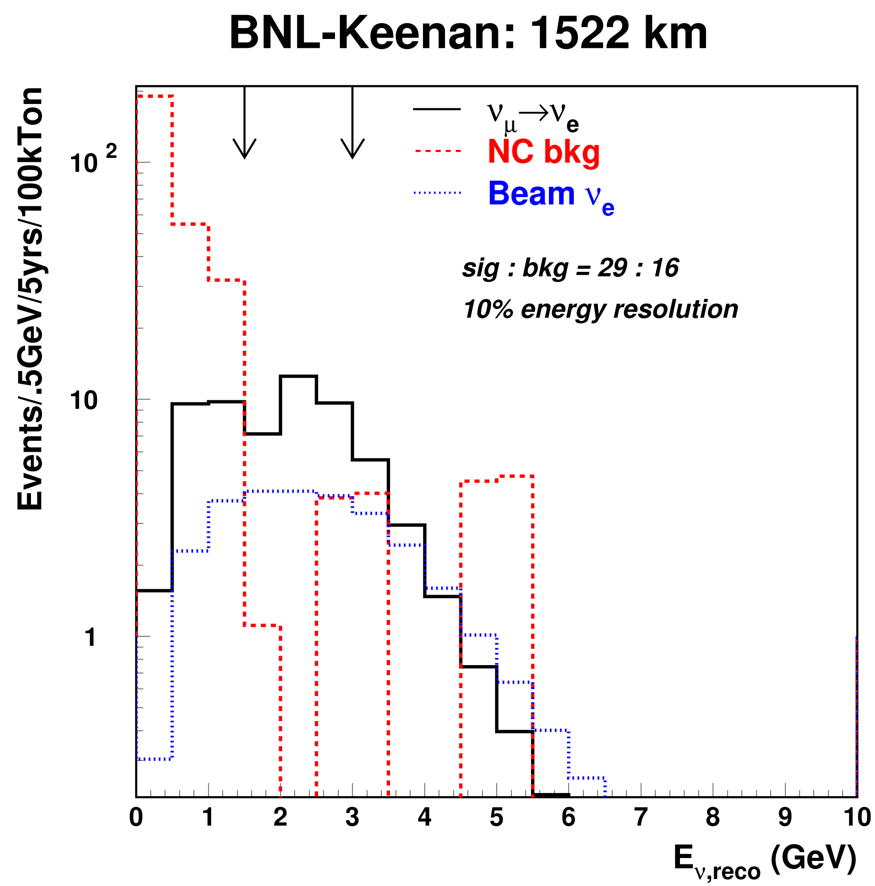




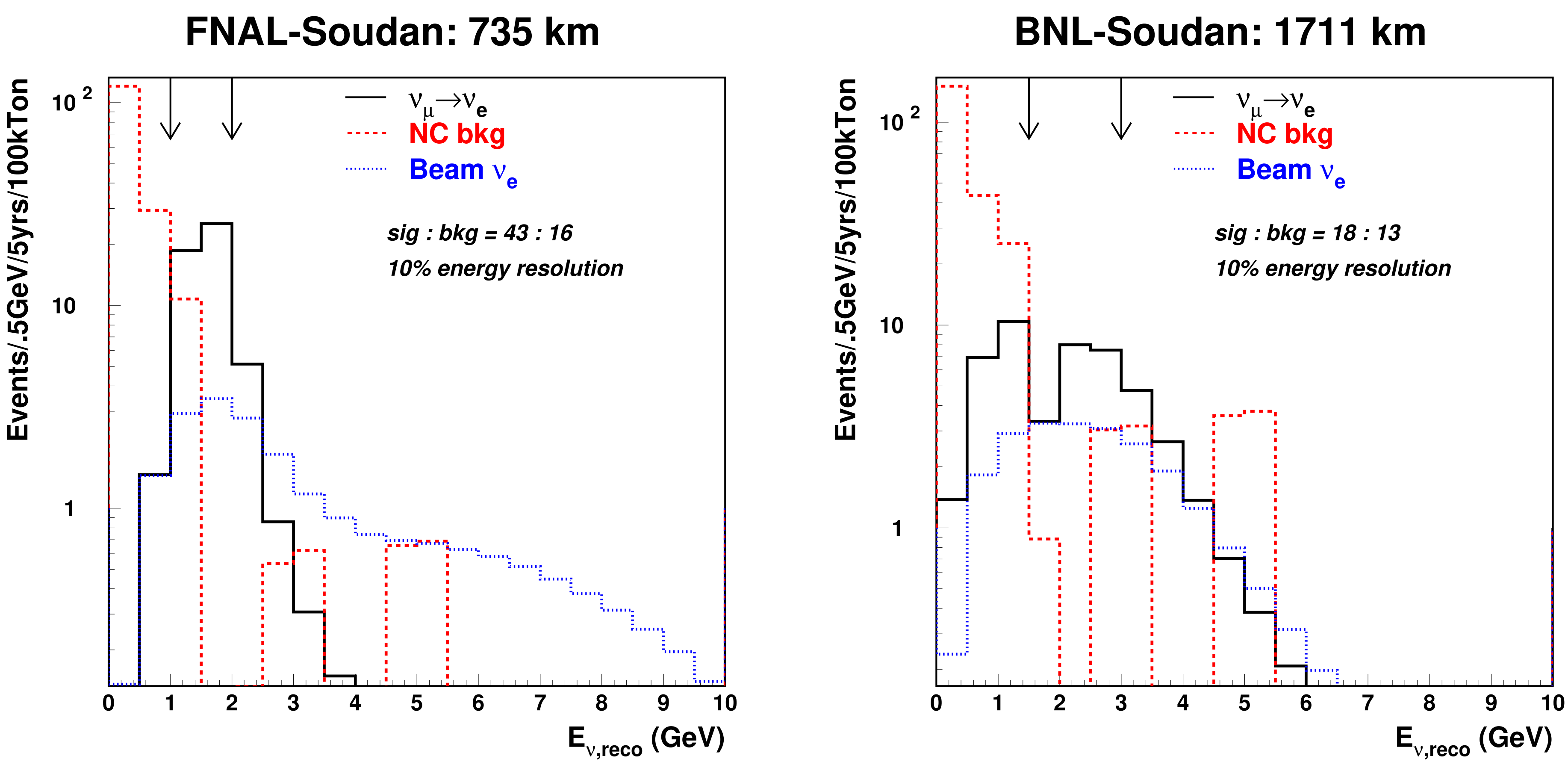
- FNAL sees 1^{st} oscillation, BNL 2^{nd} and part of 1^{st}.
- Matter enhancement accessible at BNL and not at FNAL distances.

Keenan event rates - $\nu_\mu \to \nu_e$ Appearance

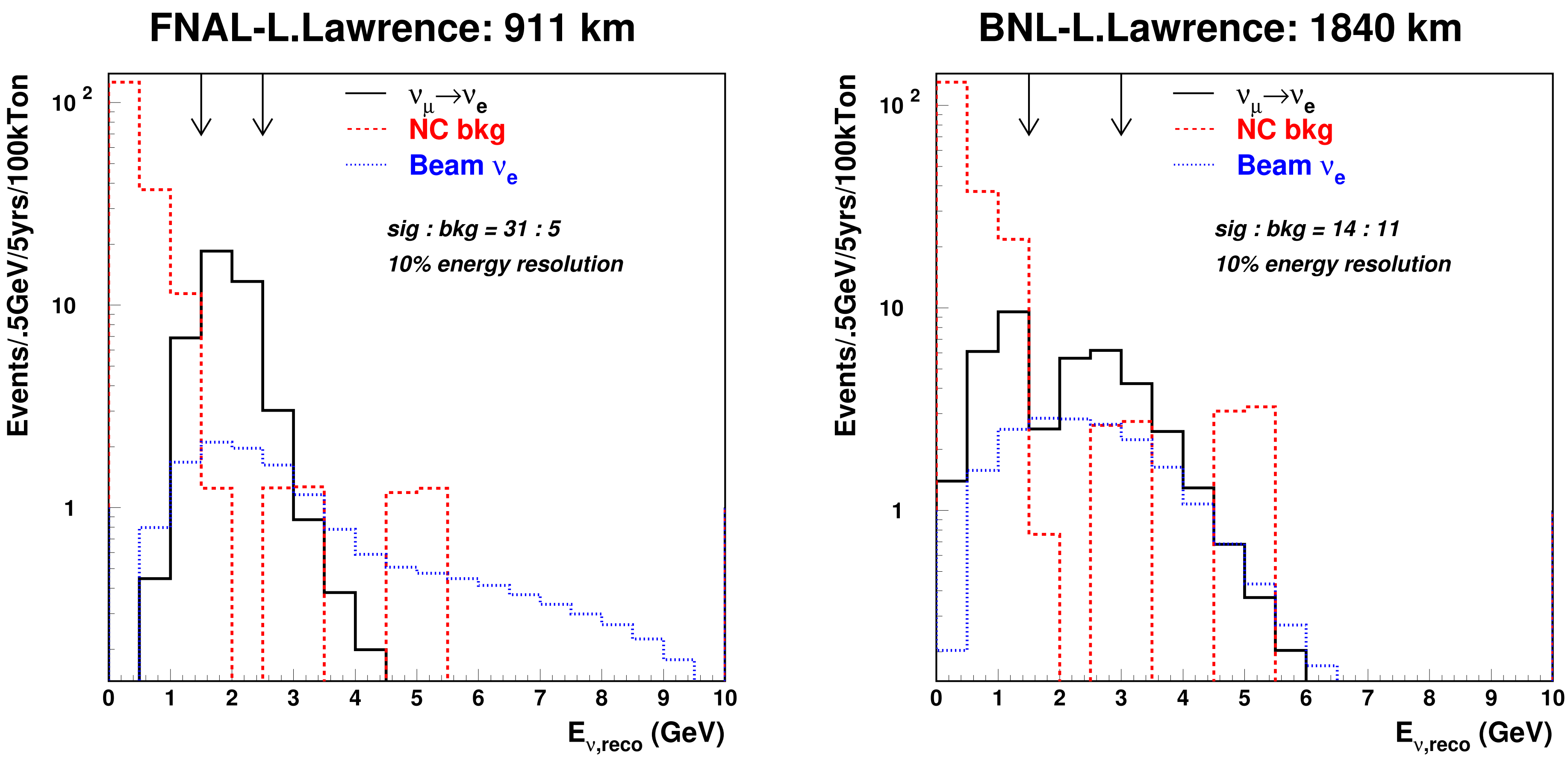




Soudan event rates - $\nu_\mu \rightarrow \nu_e$ Appearance



L.Lawrence event rates - $\nu_\mu \to \nu_e$ Appearance



Summary event rates - $\nu_\mu \to \nu_e$ Appearance

Baseline	$\nu_\mu \to \nu_e$ Signal	Beam ν_e oscillated	NC in cuts	Tot bkg	% tot bkg / ν_μCCQE	$S/\sqrt{B}$
FNAL-Keenan	46.7	8.7	18.8	27.5	0.42%	8.91
FNAL-Soudan	44.0	6.4	10.3	16.7	0.39%	10.75
FNAL-L.Lawrence	31.6	4.1	1.0	5.1	0.30%	14.03
BNL-Keenan	29.3	12.1	4.7	16.8	0.32%	7.16
BNL-Soudan	18.8	9.6	3.7	13.3	0.32%	5.16
BNL-L.Lawrence	14.3	8.3	3.2	11.5	0.32%	4.22

Note:

- Total background remaining in cuts is 0.2%-0.4% of total ν_μ CC QE
- Total NC background is consistent with E889 studies.
- Actual distribution of NC events is less certain:
  - Estimated with reconstructed SuperK atm-ν MC
  - Spectra reweighted, but low statistics for $E_{\nu,atm} >\sim 3$GeV.
  - FNAL on edge or under NC wall, BNL partially under.

Conclusions

- AGS upgrade to 1.5 MW possible, relatively affordable.
- BNL and FNAL beams are complimentary.
  - Δm^2: FNAL closer, higher rate; BNL further, sees multiple oscillations.
  - θ_{13}: FNAL has higher rate; BNL has low NC and access to matter effects.
- Understanding NC background distribution is crucial for both.

Future Work

BROOKHAVEN NATIONAL LABORATORY

Short term:

- Use NUANCE + SuperK detector simulation and reconstruction chain to nail down NC and intrinsic ν_e backgrounds for these beams in an SK-like detector.
- Optimize BNL beam to lower beam ν_e and harden spectrum to better access matter enhancement effect.

Longer term:

- Is it possible to optimize reconstruction chain to knock down the NC wall?
- What changes are needed to “port” an SK-type detector to a 100+ kTon fiducial mass detector?
- Look at other detectors?