Booster Neutrino Beamline Flux Prediction

Z. Pavlovic

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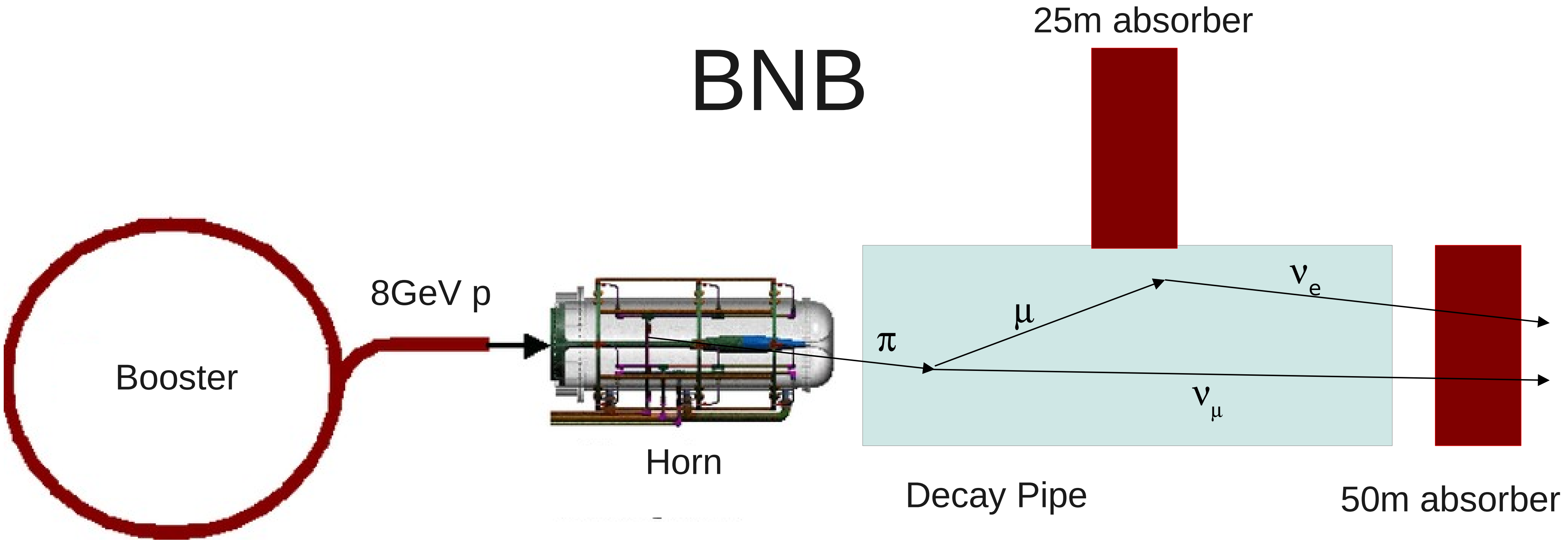
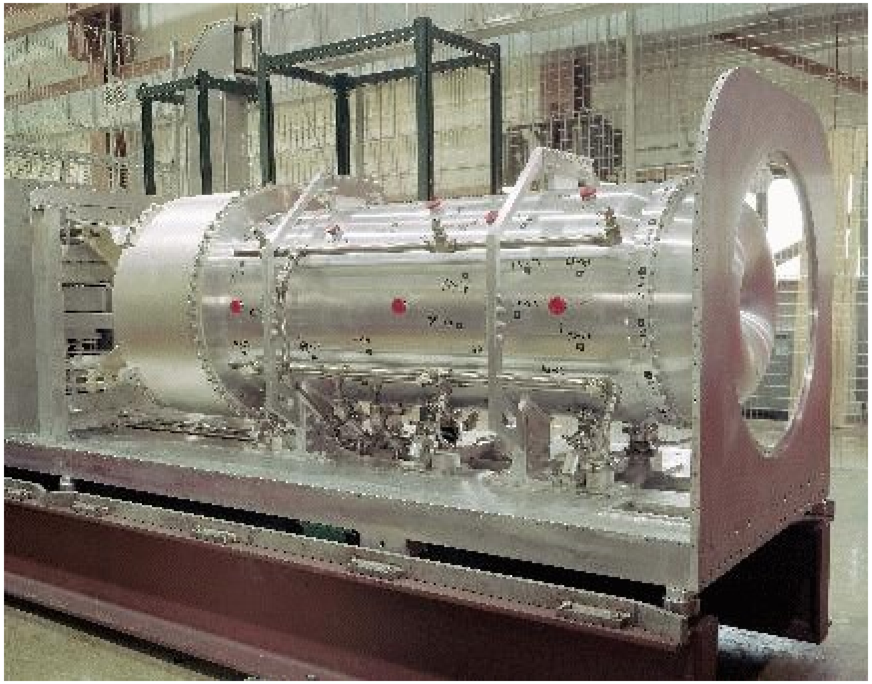
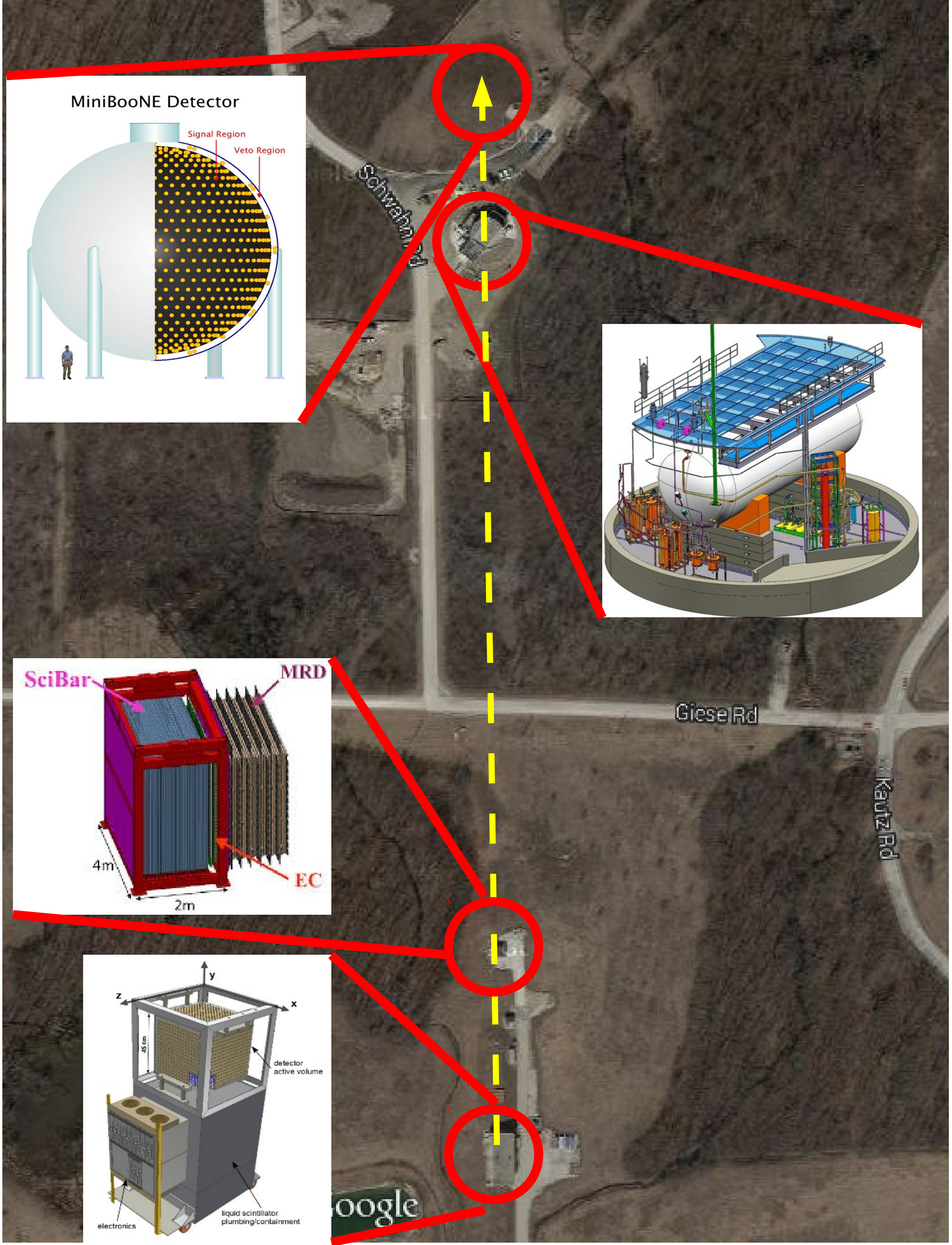
BNB



- Proton delivery:
  - 8 GeV protons from Booster
  - Average rate up to 5Hz
  - 4.2e12 PPP
- Horn:
  - Neutrino mode +170kA
  - Antineutrino mode -170kA



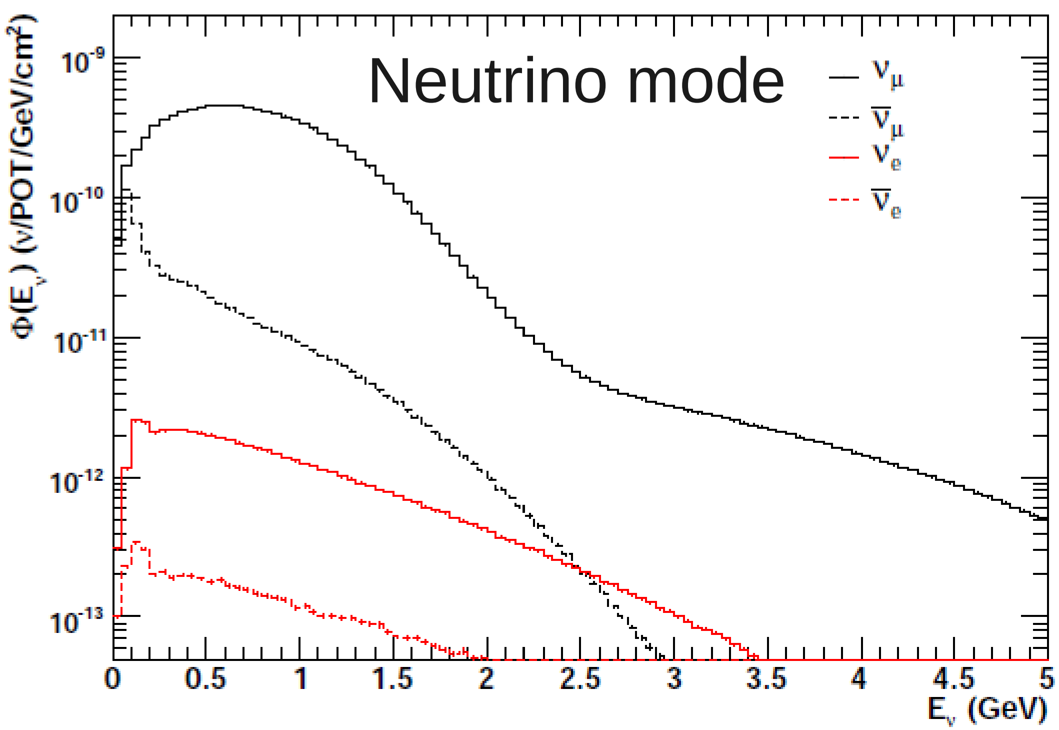


Experiments

- Past/Current
  - MiniBooNE
  - MicroBooNE
  - SciBooNE
  - SciBath
- Future:
  - LAr1ND
  - ICARUS
  - CENNS/Captain
  - ...

Neutrino flux prediction

- Geant4 based MC used to predict the flux
- Hadron production cross sections tuned to external data

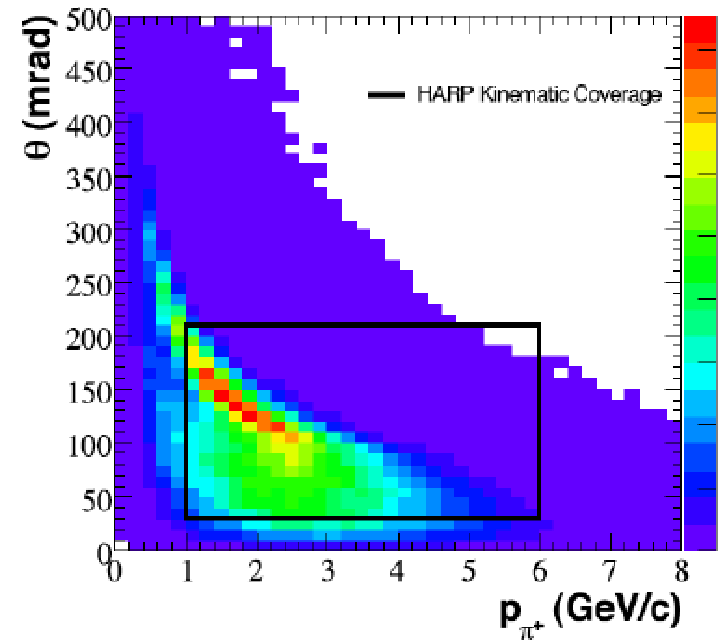


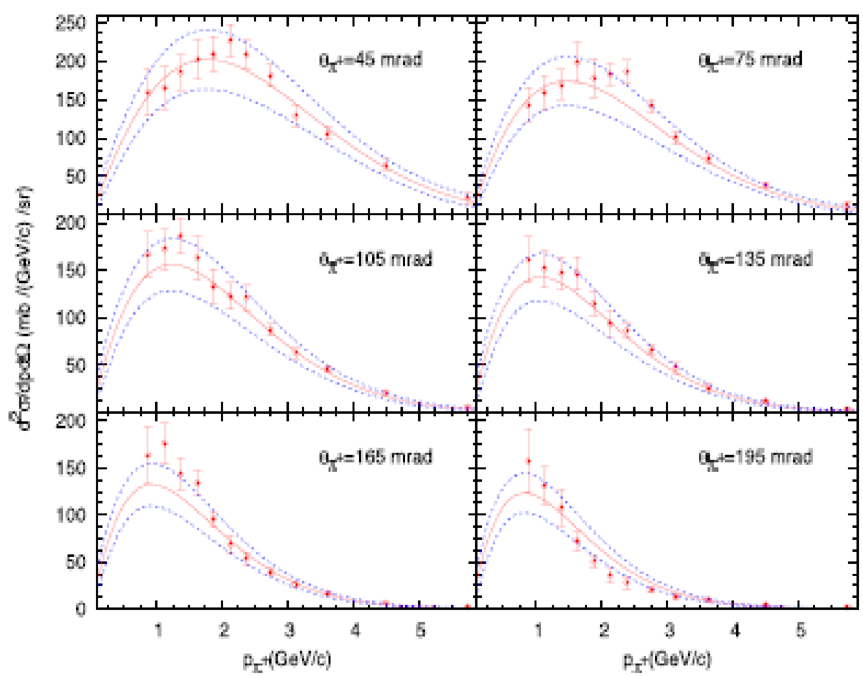
	ν_μ		$\overline{\nu}_\mu$	
Flux (ν/ cm^2/POT)		5.19×10^{-10}		3.26×10^{-11}
Frac. of Total		93.6%		5.86%
Composition	π^+:	96.72%	π^-:	89.74%
	K^+:	2.65%	$\pi^+ \to \mu^+$:	4.54%
	$K^+ \to \pi^+$:	0.26%	K^-:	0.51%
	$K^0 \to \pi^+$:	0.04%	K^0:	0.44%
	K^0:	0.03%	$K^0 \to \pi^-$:	0.24%
	$\pi^- \to \mu^-$:	0.01%	$K^+ \to \mu^+$:	0.06%
	Other:	0.30%	$K^- \to \pi^-$:	0.03%
			Other:	4.43%

	ν_e		$\overline{\nu}_e$	
Flux (ν/ cm^2/POT)		2.87×10^{-12}		3.00×10^{-13}
Frac. of Total		0.52%		0.05%
Composition	$\pi^+ \to \mu^+$:	51.64%	K^0_L:	70.65%
	K^+:	37.28%	$\pi^- \to \mu^-$	19.33%
	K^0_L:	7.39%	K^-:	4.07%
	π^+:	2.16%	π^-:	1.26%
	$K^+ \to \mu^+$:	0.69%	$K^- \to \mu^-$:	0.07%
	Other:	0.84%	Other:	4.62%

Pion production

- Sanford-Wang fits:
  - HARP (thin target)
    - 8.89GeV p on Be target
    - P = 0.75 – 6.5 GeV/c,
      θ = 30 – 210 mrad
  - E910
    - 6.4, 12.3, 17.5 GeV/c
    - P=0.4 – 5.6 GeV/C,
      θ = 18 – 400 mrad
- Fits done both for pi+ and pi-

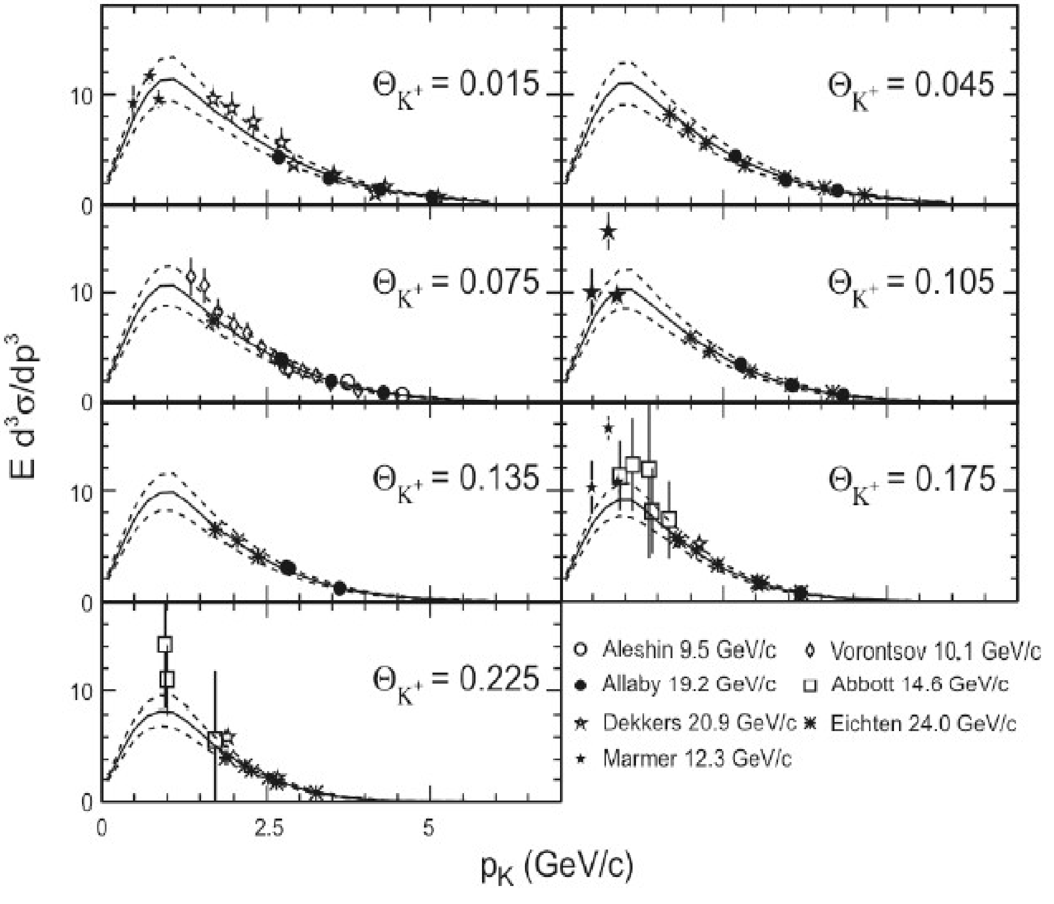




Phys. Rev. D79, 072002 (2009)

Kaon production

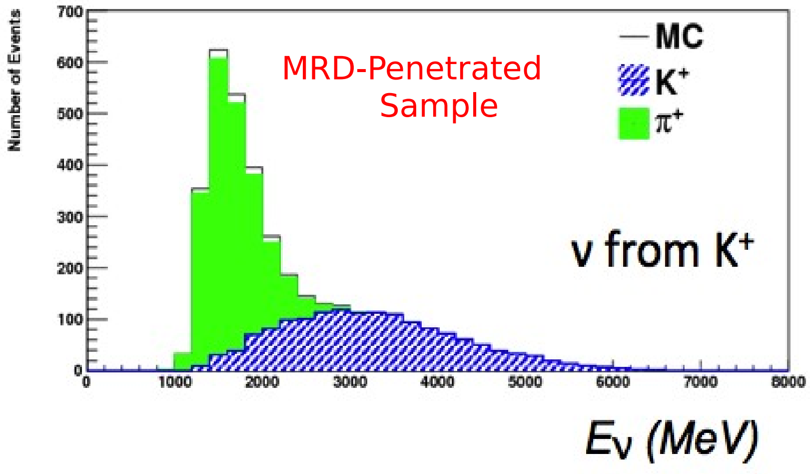
- Feynman scaling based parameterisation used to fit world K+ production data
- Sanford-Wang fits to K0s production data from BNL E910 and KEK Abe et al.

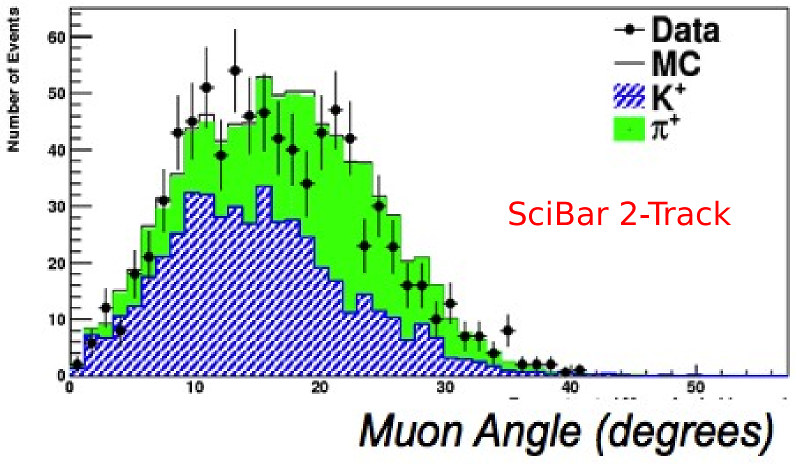


Kaons in BNB

- Kaon production further constrained by SciBooNE measurements
- Found production to be 0.85+-0.12 relative to the global fit to kaons (with 30% error)

Phys.Rev.D84,012009 (2011)

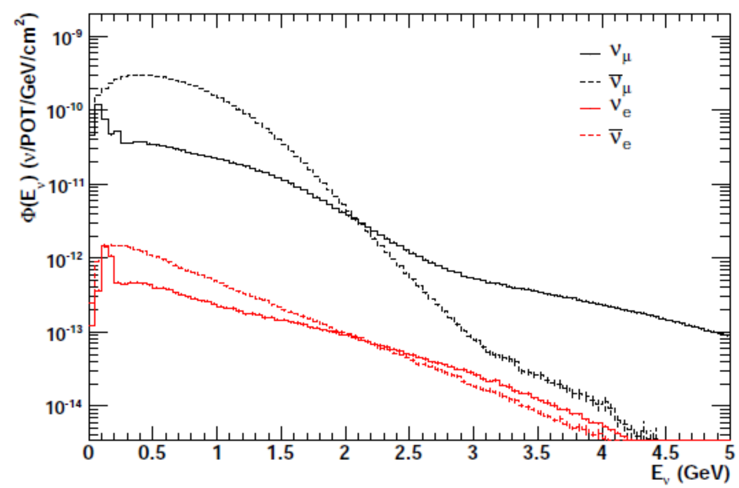


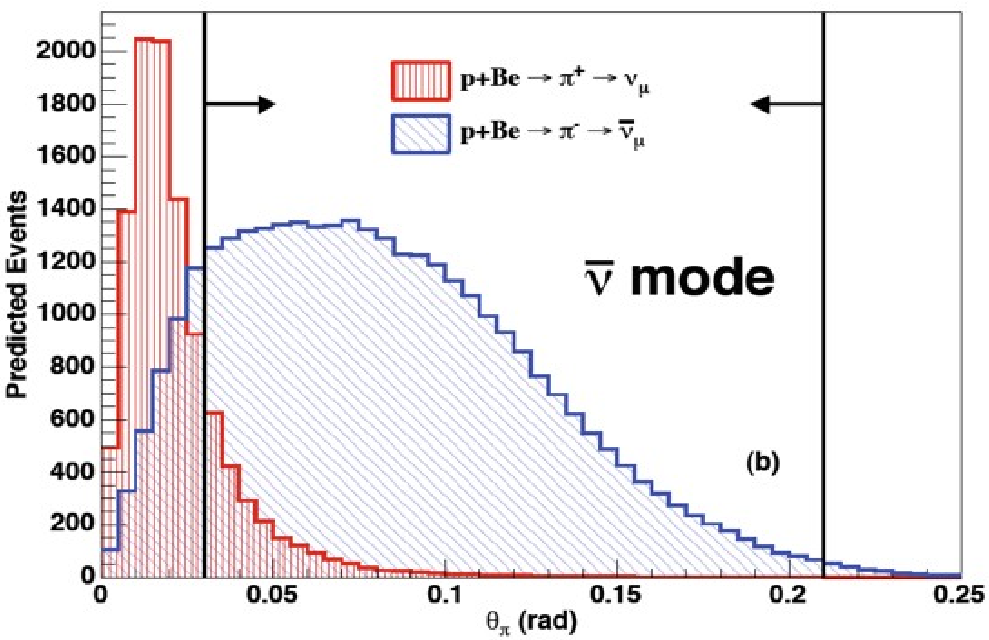


Wrong signs

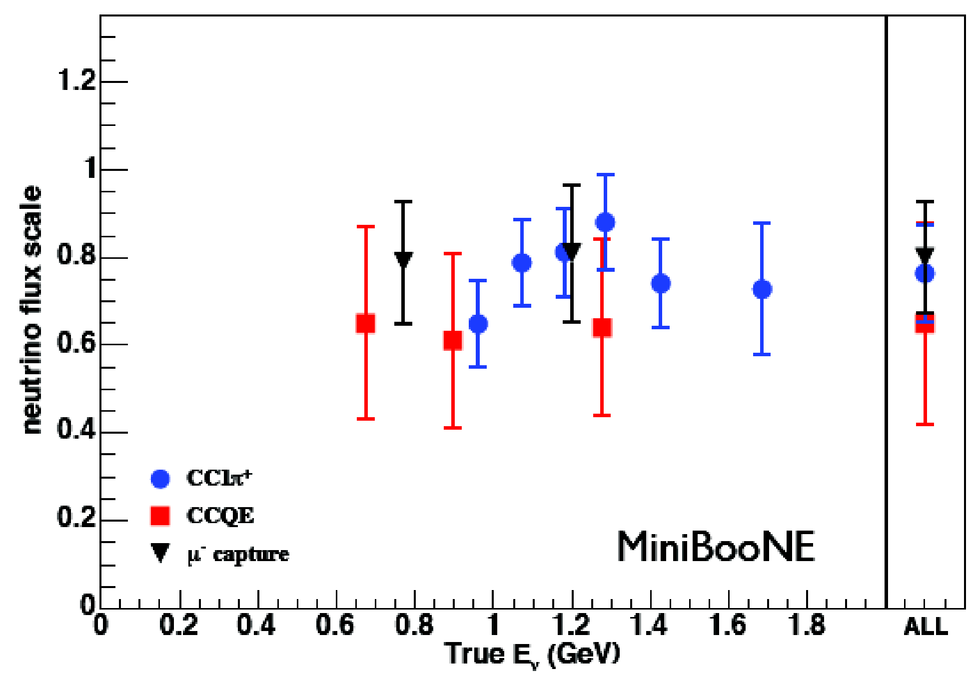
- Significant numu component in antineutrino mode (~16%)
- Not constrained well by HARP/E910
- In-situ measurement in MiniBooNE
  - Numu CCQE angular fit
  - $CC\pi^+$ rate
  - μ^- capture

Antineutrino mode flux





Phys.Rev.D84,072005 (2011)

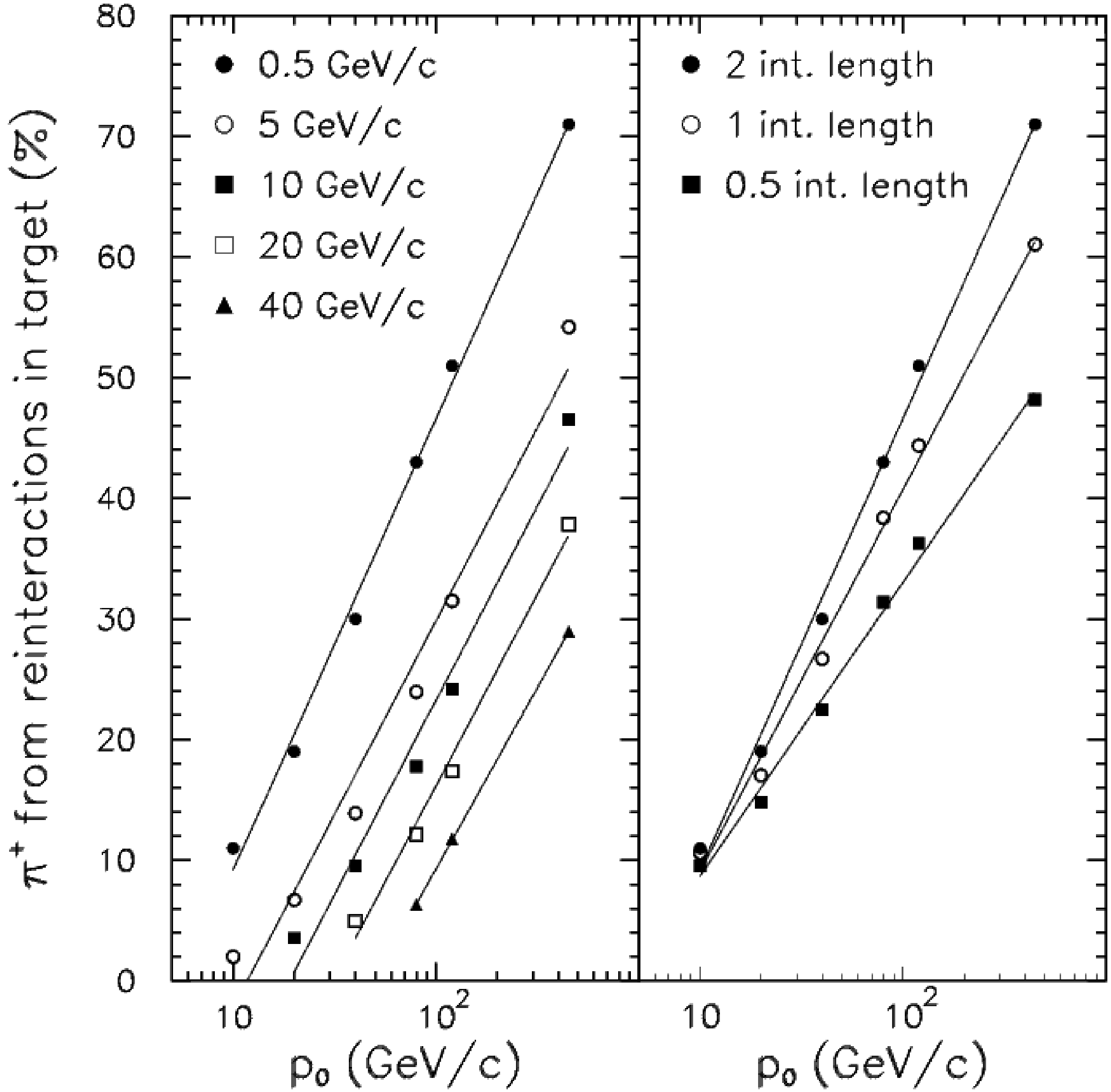


Flux uncertainty

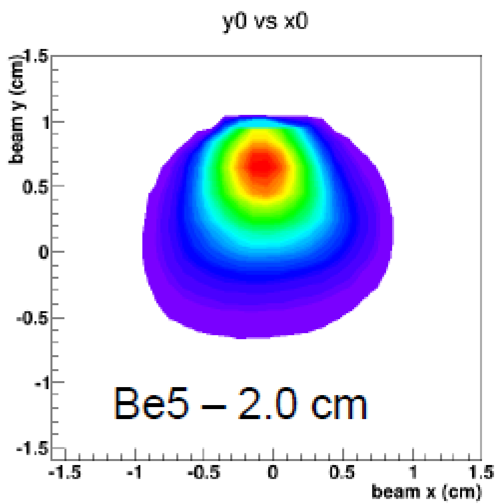
- Propagate uncertainties using many MC worlds to build error matrices that capture correlations between bins of neutrino observables
  - spline fits through HARP data
  - kaon fits
  - Hadron cross sections on Be and Al
  - Horn focusing
  - POT counting
- For numu/numubar CCQE measurement resulting flux uncertainty was at 9-10% level

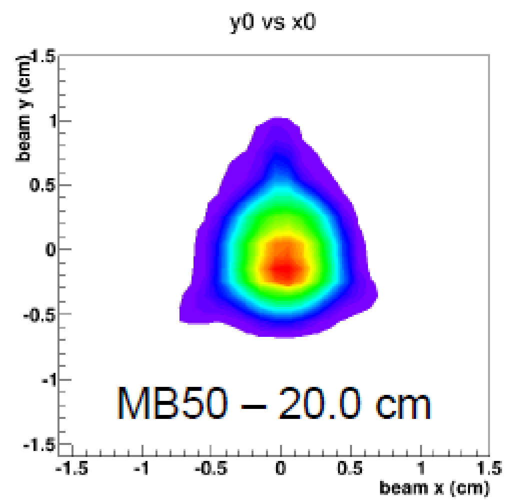
Reinteractions in BNB

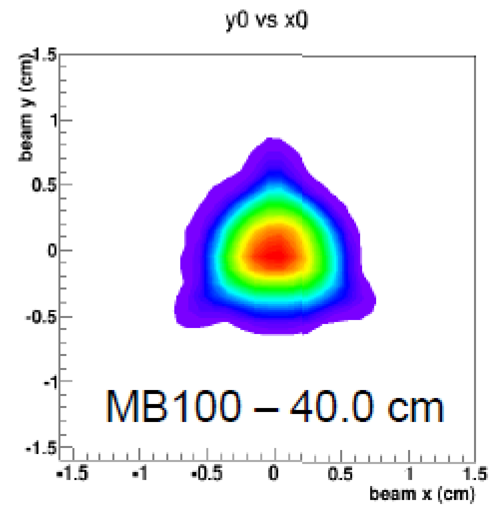
- At Booster energies ~90% of pions contributing to neutrino flux from primary p+Be interactions



HARP thick target analysis



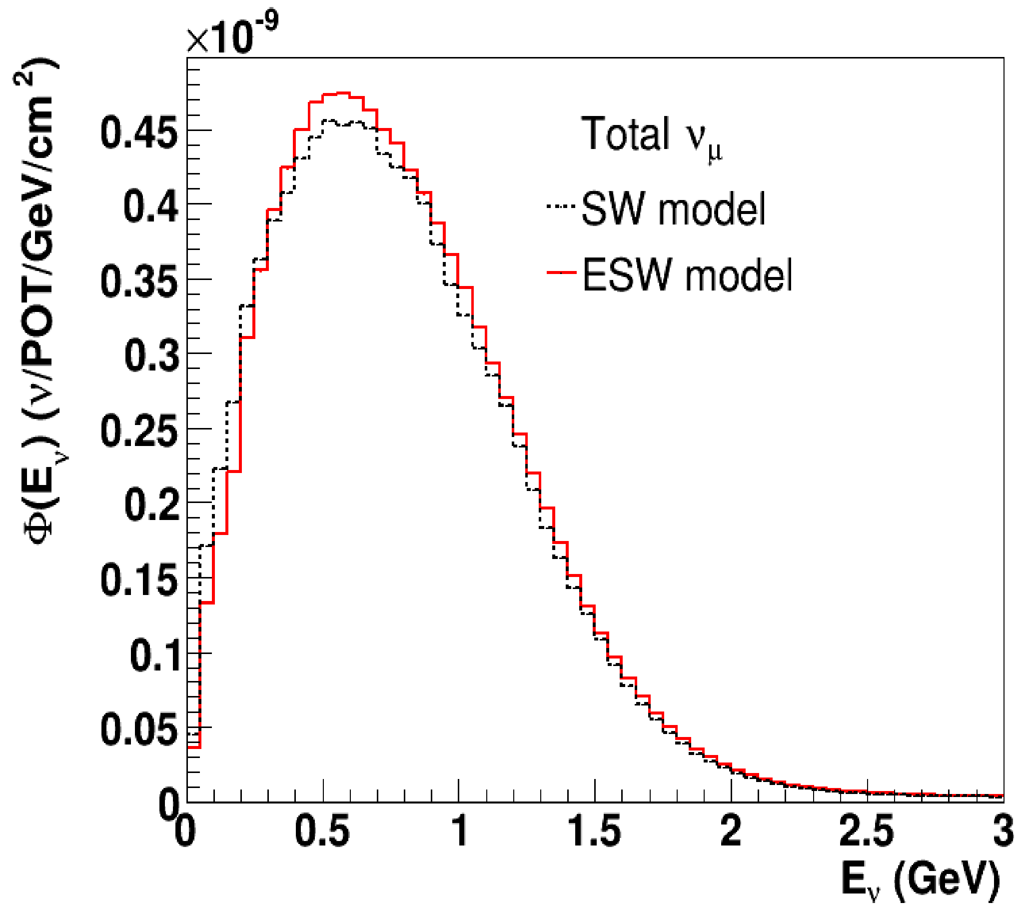




DATA	Beam radius cut (reduce the edge effect)	P.O.T
MB100	0.4 cm	622791
MB50	0.4 cm	814749
Empty	0.4 cm	475776
Be5	1.0 cm	13070000
Empty	1.0 cm	1990000

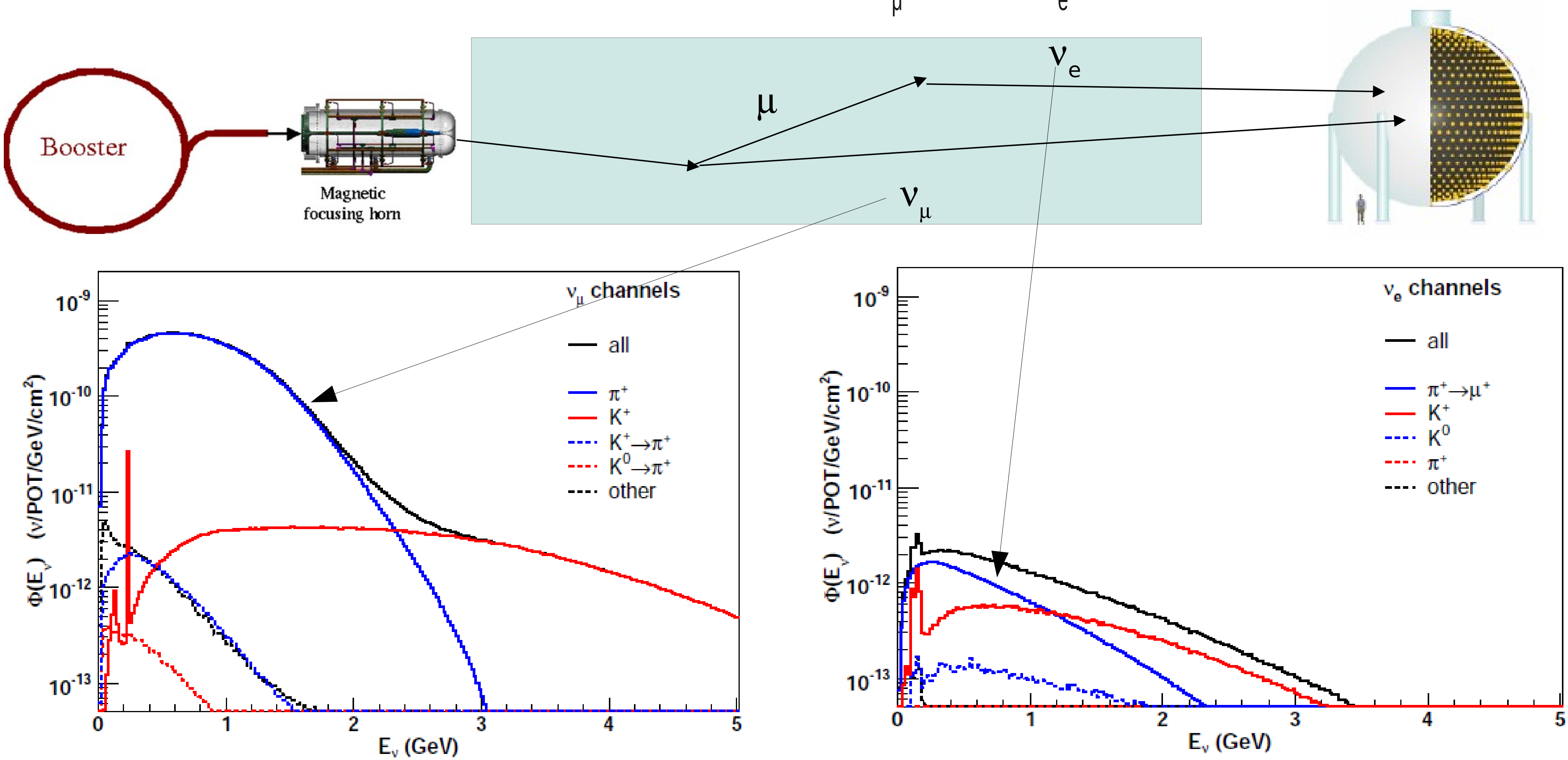
Revisiting HARP

- BNB MC correctly models reinteractions – see talk by A. Wickremasinghe at flux workshop (09/22)
  - Extrapolation to thick target agrees at 1% level
- Analysis using alternative (Extended Sanford Wang) parametrisation fitted to HARP only data results in 2% change in neutrino flux
  - Within the expected systematic error



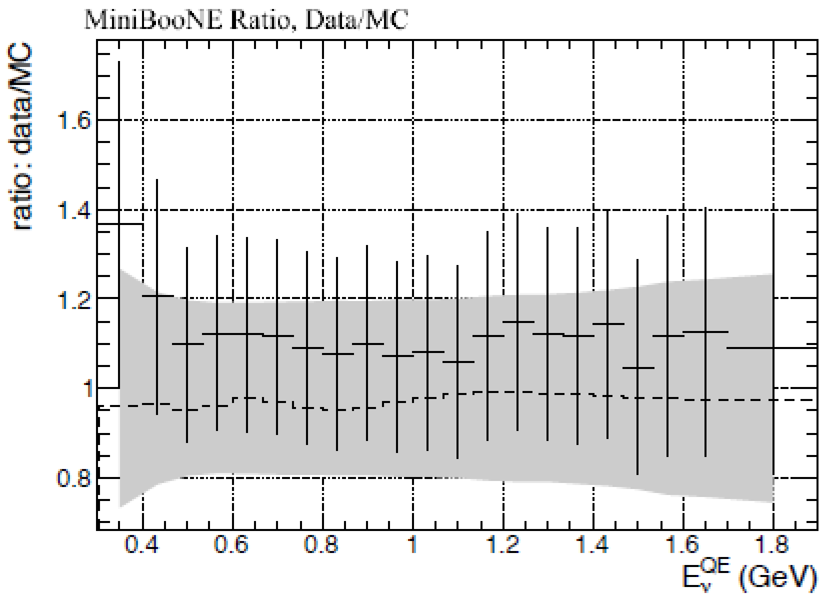
Single detector

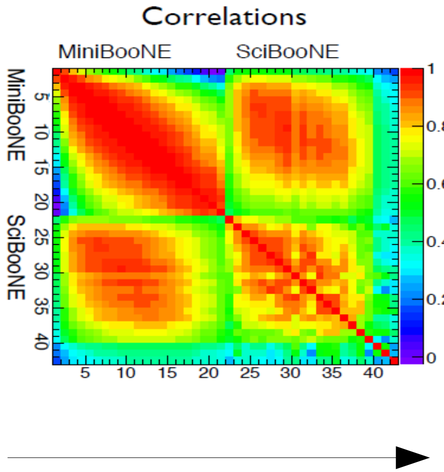
- MiniBooNE ν_e appearance analysis further constrains flux by simultaneously fitting ν_μ and ν_e

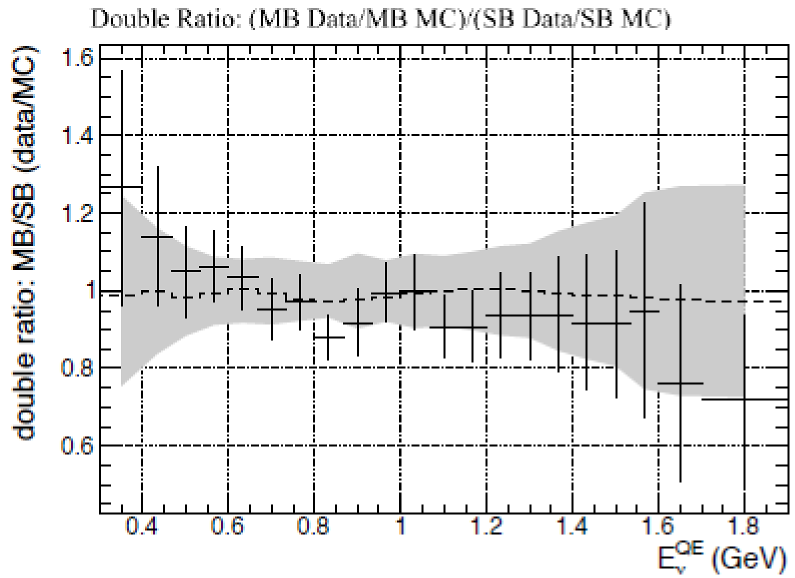


Multiple detectors

- SciBooNE/MiniBooNE muon (anti)neutrino disappearance analysis
- Flux/cross-section uncertainties cancel, detector do not

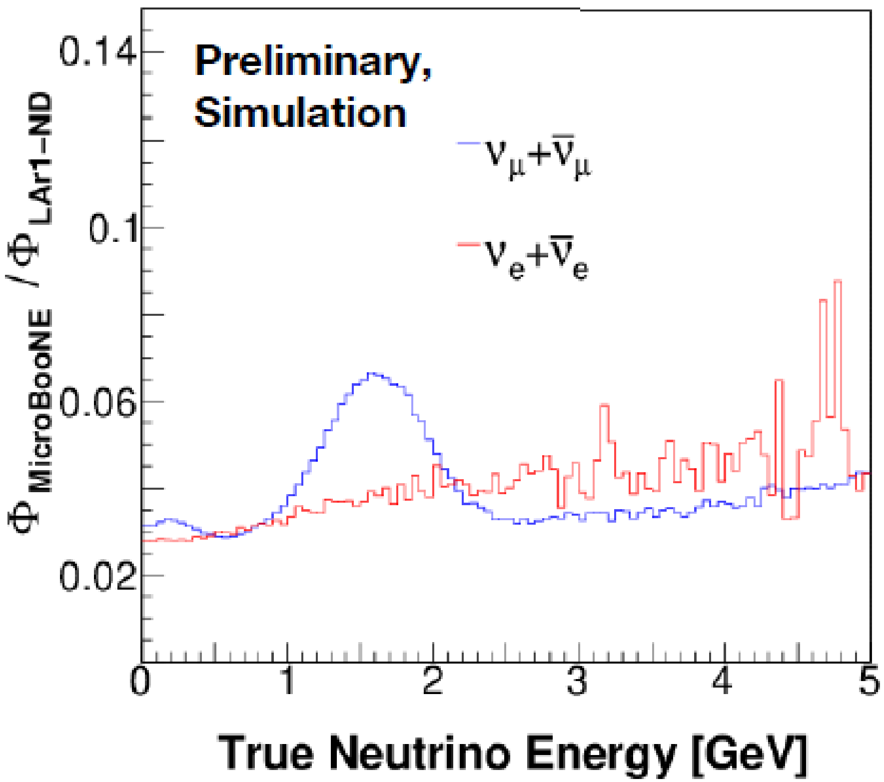




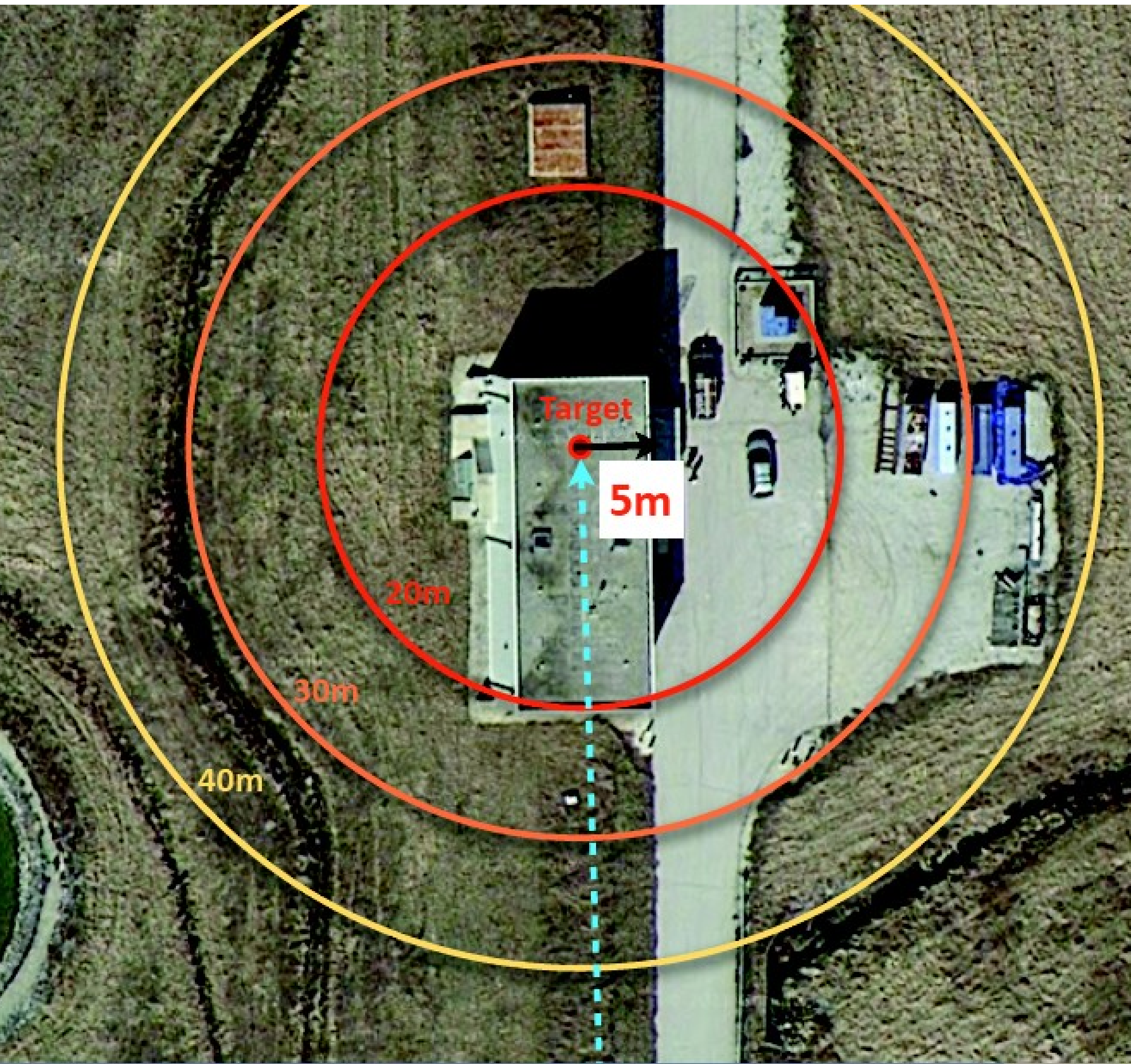


Multiple detectors

- LAr1ND will serve as a near detector for MicroBooNE and any future Far Detector experiment
- Compared to Sci/MiniBooNE expect better cancellation of detector systematics

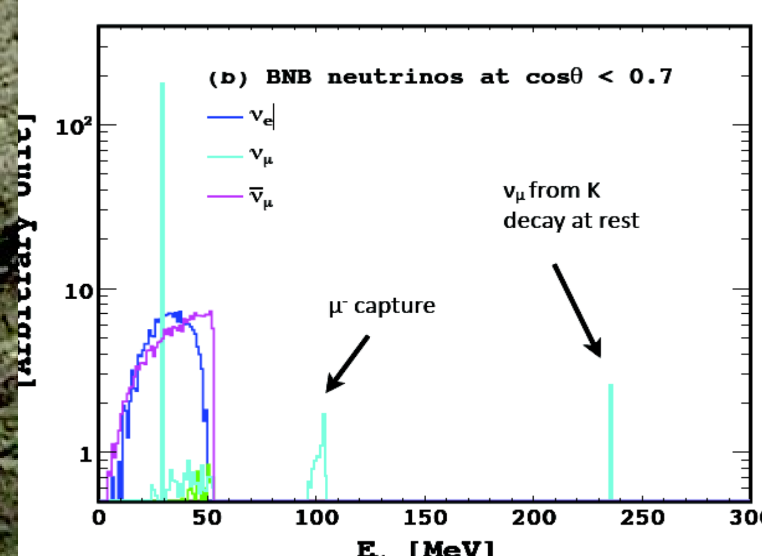


Low energy neutrinos at BNB



- Looking at neutrinos near target hall

From Booster Beam MC

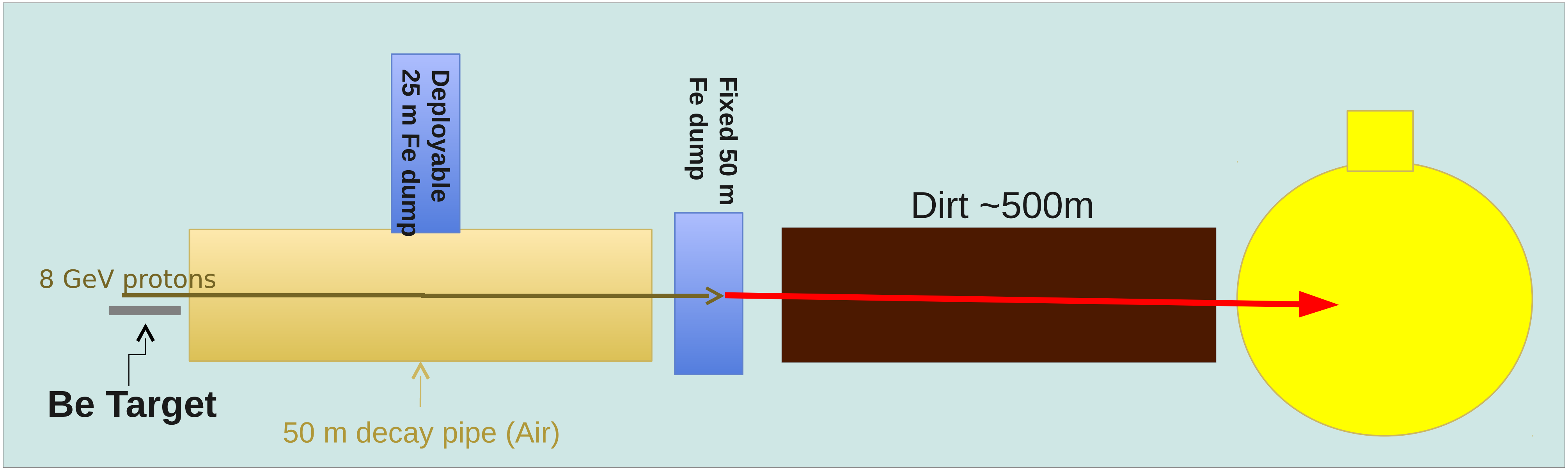


Low energy neutrino physics

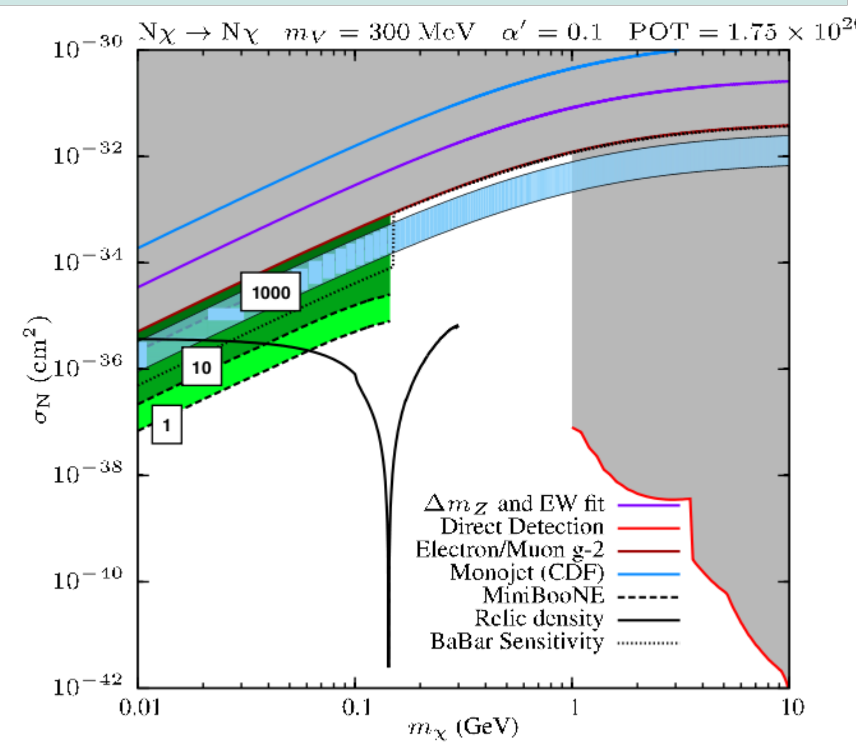
- Core collapse supernova physics
  - Only a couple of ν-N cross sections are measured in SN energy range
  - Important for SN neutrino detection
  - Understanding the supernova explosion process
- Coherent Elastic Neutrino Nucleus Scattering (CENNS)
  - Has not been observed yet
  - Background for dark matter searches
  - Neutron form factor
  - Neutrino magnetic moment
  - Test week mixing angle
  - Non Standard Model Interactions
- Sterile neutrinos and neutrino oscillations
  - L/E with lower energy -> observe oscillation in detector

Slide courtesy J. Yoo

Multipurpose beamline



- Search for Dark Matter in beam off-target mode
- Reduce neutrino flux by ~50 times (background for DM search)
- Collected 1.9e20 POT



Summary

- 12 years of experience running with BNB
- Well understood neutrino flux
  - Constrained using external hadron production measurements
  - Years of running experiments
- Many experiments using the BNB facility
- Exciting future experimental program ahead

Backup

Stable running

- 2 target/horn assemblies
  - 96 million pulses with 1st horn
  - 367 million pulses with 2nd horn
- Neutrino flux remained extremly stable over 12 years of running
- No degradation in flux or energy spectrum