MiniBooNE
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- Oscillation Analysis
- Issues of the Past Year
  - Normalization
  - Optical Model
  - $\pi^0$ MisIDs
- Summary
- Future
MiniBooNE Goal

- Search for $\nu_e$ appearance in a $\nu_\mu$ beam at the ~0.3% level
  - $L=540$ m ~10x LSND
  - $E\sim500$ MeV ~10x LSND
Particle ID

- Identify electrons (and thus candidate $\nu_e$ events) from characteristic hit topology
- Non-neutrino background easily removed

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Particle ID

- To achieve good sensitivity the Particle ID must
  - Eliminate ~99.9% of all $\nu_\mu$ CC interactions
  - Eliminate ~99% of all NC $\pi^0$ producing interactions
  - Maintain good (~30-60%) efficiency for $\nu_e$ interactions

- It achieves these goals

- Exploring parallel, complementary approaches
  - “Simple” cuts: easy to understand
  - Boosted decision trees: maximize sensitivity
Backgrounds

• Makeup of the backgrounds is different for the two particle ID approaches
  - Different balance between intrinsic $\nu_e$ and misIDed $\nu_\mu$
  - Important check that backgrounds are understood
• Backgrounds are determined from our own data using
  - $\nu_\mu$ CCQE events for intrinsic $\nu_e$ from $\mu^+$
  - Single $\pi^0$ events for $\pi^0$ misID
  - High energy $\nu_e$ events for intrinsic $\nu_e$ from $K^+$
Determining Backgrounds with MiniBooNE Data

- Example oscillation signal
  - $\Delta m^2 = 1 \, \text{eV}^2$
  - $\sin^2 2\theta = 0.004$
- Fit for excess as a function of reconstructed $\nu_e$ energy

Full data sample $\sim 5.3 \times 10^{20}$ POT
Determining Backgrounds with MiniBooNE Data

MisID $\nu_\mu$
- of these......
- $\sim 83\% \pi^0$
  - Only $\sim 1\%$ of $\pi^0$s are misIDed
  - Determined by clean $\pi^0$ measurement
- $\sim 7\% \Delta \gamma$ decay
  - Use clean $\pi^0$ measurement to estimate $\Delta$ production
- $\sim 10\%$ other
  - Use $\nu_\mu$ CCQE rate to normalize and MC for shape

Full data sample $\sim 5.3 \times 10^{20}$ POT
Determining Backgrounds with MiniBooNE Data

Full data sample $\sim 5.3 \times 10^{20}$ POT

$\nu_e$ from $\mu^+$

- Measured with $\nu_\mu$ CCQE sample
  - Same parent $\pi^+$ kinematics
- Most important background
- Very highly constrained (a few percent)
Determining Backgrounds with MiniBooNE Data

Full data sample ~$5.3 \times 10^{20}$ POT

- Use high energy $\nu_e$ and $\nu_\mu$ to normalize
- Use kaon production data for shape
- Need to subtract off misIDs
Determining Backgrounds with MiniBooNE Data

Full data sample \( \sim 5.3 \times 10^{20} \) POT

High energy \( \nu_e \) data
- Events below \( \sim 1.5 \) GeV still in closed box (blind analysis)
Issues Of the Past Year

• Most of the analysis effort over the last year has gone into
  - Normalization
  - Optical Model
  - $\pi^0$ MisIDs

• Each is a significant hurdle that has been overcome
Issues of the Past Year: Normalization

- The MiniBooNE Run Plan reported we were seeing \( \sim 1.5 \) times as many events as the Monte Carlo predicted
  - For an inclusive \( \nu \) event sample
- This normalization difference is now \( \sim 1.2 \)
- Major changes in rate prediction since Run Plan (not complete list) ...
  - 3.5% from better \( \nu \) cross-section modeling
  - +17.5% from better modeling of incoming proton beam
  - +5.2% from CCQE cross-section tuning (\( M_A \) extraction)
  - -6.0% from better modeling of secondary beam interactions
  - +16.2% from HARP \( \pi^+ \) measurement + horn current + better modeling of primary proton interactions
- After a huge amount of cross-checking the agreement between data and \( MC \) \( \nu \) rates is now far less of an issue
Issues of the Past Year: Optical Model

- Two Key features of MiniBooNE
  - Trying to do very precise particle ID to identify a possible ∼0.3% signal
  - Several calibration sources, but none with the perfect properties (e.g. no 1 GeV electron gun)
- The approach must therefore be...
  - Use the available calibration sources (Michel electrons, laser, etc)
  - Have a very well tuned MC to extrapolate from what the calibration sources look like to what the signal and background look like
- Therefore...
  - Need an “optical model” that matches data very well
  - Optical Model = model for how light is created, propagated, and detected in MiniBooNE
Issues of the Past Year: Optical Model

- Stepwise approach to tuning the optical model

- External measurements & laser calibration
  - First calibration with michels
  - Calibration of scintillation light with NC events
  - Final calibration with michels
  - Validation with cosmic muons, $\nu_\mu$ events, and NuMI $\nu_e$ events
Issues of the Past Year: Optical Model

- Many variables are potentially useful in analyses
- Optical Model improvement measured by data/MC agreement in these variables
- Huge gains in data/MC agreement
Issues of the Past Year: $\pi^0$ MisIDs

- About 83% of all MisID background comes from single $\pi^0$ events
- Use cleanly identified $\pi^0$s to measure the $\pi^0$ rate as a function of $\pi^0$ momentum

Need to get to high $\pi^0$ momentum to enable measurement of high energy $\nu_e$ background from $K^+$

Old $\pi^0$ reconstruction could not do this

Have developed a new $\pi^0$ fitter that can go to high momentum and has better $\pi^0$ efficiency and purity
Issues of the Past Year: $\pi^0$ MisIDs

New $\pi^0$ fitter can make $\pi^0$ yield measurements up to the ~1.5 GeV level needed to get at the $\nu_e$s from $K^+$

This is an ongoing analysis - not yet complete
Summary

• Over the past year the major hurdles have been crossed
  - Much more accurate prediction of rate - data/MC ~1.2
  - Optical Model probably now good enough (more checks needed)
  - Analysis for $\pi^0$ misID measurement largely in place

• Still a lot of work to do - but the way forward is clear
• On track for a result as soon as this summer
The Future

• Ran in anti-neutrino mode January 2006 to shutdown
  • Will continue in anti-neutrino mode after shutdown
    – First ever anti-neutrino measurements in this energy region

• SciBooNE experiment, at a near location in the beamline, will start in late 2006 (see SciBooNE talk)

• Possibility to build additional detectors closer or farther away (BooNE)
  – MiniBooNE clone or new technology (e.g. LAr)
  – MiniBooNE result will guide location
    • ~2km detector for low $\Delta m^2$
    • ~0.2km detector for high $\Delta m^2$
Backups
Neutrino Candidates

- DAQ triggered on beam from Booster
- $\nu$ pulse through detector lasts 1.6 $\mu$s
- By requiring tank activity and no veto activity the non-neutrino backgrounds become negligible
proton->Be collisions at 8.9 GeV/c

piplus cross section with full statistical plus systematic errors shown (except the 4% normalization error)

$0.75 < p_\pi < 6.5$ GeV/c

$30 < \theta_\pi < 210$ mrad

Momentum and angular distribution of pions decaying to a neutrino that passes through the MB detector.
Low $Q^2$ & MiniBooNE QE Model

- perform shape fit to MiniBooNE QE $dN/dQ^2$ (~60,000 QE events after cuts)

- fit for:
  - Fermi Gas model pars ($E_B, p_F$)
  - axial mass, $M_A$
  - and background fraction, $B_F$

- best shape fit yields “effective parameters”:
  - $M_A = 1.24$ GeV
  - $E_B = 34$ MeV
  - $p_F = 246$ MeV
  - $B_F = 0.7$ (J. Monroe)
Past $\nu$ Data

- not clear that past QE neutrino data necessarily rules out a larger value for $M_A$

- example: BNL bubble chamber data and $d\sigma/dQ^2$ predictions with different $M_A$ assumptions
Checking Particle ID with NuMI Events

• Because of the off-axis angle, the beam at MiniBooNE from NuMI is significantly enhanced in $\nu_e$s from $K^+$
• Enables a powerful check on the Particle ID
And in the future...

MiniBoonE \( \nu \) results

- continued MB running:
  - BNB-line data
  - NuMI-line data

SciBooNE information

Improved MB signal:
oscillation or decay?

Follow-up Experiments

- BooNE (FNAL):
  - LS and LAr detectors under consideration
- SNS (see APS Neutrino Study)
- JPARC (now under study)

MiniBoonE \( \bar{\nu} \) running (requires \( \sim 3+ \) years for CP Violation)

- positive \( \nu \) result
- negative \( \nu \) result

signal in \( \bar{\nu} \)?

CP violation in...
oscillation?
decay?
... or something else?

Follow-ups under consideration