Study of muon neutrino interactions in MicroBooNE

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MicroBooNE experiment

Liquid Argon Time Projection Chamber

Located on
- Booster Neutrino Beam line -> neutrinos
- ground level -> cosmics

470 m from target

BNB line
MicroBooNE experiment

Neutrino detection:
• ionization current → 3 wire planes
• scintillation light → 32 PMTs
MicroBooNE goals

Resolve low energy excess observed by MiniBooNE

Perform precise measurement of neutrino cross sections in Argon
Event rates in MicroBooNE

Interaction channel:

- Quasi elastic \(~45\%~
- Resonant pion production \(~25\%~
- Deep inelastic scattering \(~9\%~
- Coherent pion production \(~1\%~
- Meson exchange current \(~20\%~

Neutral Current or Charged Current
Event rates in MicroBooNE

Neutral Current or Charged Current

Interaction channel:

- Quasi elastic ~45%
- Resonant pion production ~25%
- Deep inelastic scattering ~9%
- Coherent pion production ~1%
- Meson exchange current ~20%
Event rates in MicroBooNE
Event rates in MicroBooNE

From now on: focus on $\nu_\mu$ CC interactions inside the Fiducial Volume
Selection paths

FLASH REQUIREMENT:
- signal* efficiency 95.8%
- cosmic rejection 99.0%

Goal:
search for optimization of this requirement

*SIGNAL:
uu mu CC interaction inside Fiducial Volume
Two methods

**Flashes**
- summed OpHits from grouped PMTs

**OpHits**
- pure information from PMTs
- In each time tick (15.625 µs) for each PMT:
  - deposited light (number of PE) is stored as an OpHit

Binning and threshold PE can be tuned

*as used by the MicroBooNE Deep Learning group*
OpFlashes vs OpHits

**BINNING:**

- **6 ticks per bin:**
  gives better efficiency than flashes, but also lower bg rejection

- **9 ticks per bin:**
  is able to give the same bg rejection as flashes, but better efficiency

**CHOICE:** 9 ticks per bin
OpFlashes vs OpHits

PE THRESHOLD:

OpHits: higher efficiency than Flashes to keep current rejection
- OpHits ≥ 50 PE
to increase efficiency
- OpHits ≥ 40 PE

CHOICE: 40 PE
OpFlashes vs OpHits

PE THRESHOLD:

OpHits: higher efficiency than Flashes to keep current rejection

- OpHits ≥ 50 PE
- OpHits ≥ 40 PE

CHOICE: 40 PE
Cuts comparison

4854 signal events

- 4649 events with ≥1 flash ≥ 50 PE
  \[ \varepsilon = 95.8\% \]

- 4634 events with both:
  \[ \geq 1 \text{ flash} \geq 50 \text{ PE} \]
  and \[ \geq 40 \text{ PE per (9-ticks) bin} \]
  \[ \varepsilon = 98.6\% \]

- 4787 events with ≥ 40 PE per (9-ticks) bin

15 events lost
153 new events
Overall gain: 138 events
Cuts comparison

\[ \varepsilon = 95.8\% \]

4649 events with \( \geq 1 \) flash \( \geq 50 \) PE

4854 SIGNAL EVENTS

4634 events with both:
\( \geq 1 \) flash \( \geq 50 \) PE
and \( \geq 40 \) PE per (9-ticks) bin

\[ \varepsilon = 98.6\% \]

4787 events with \( \geq 40 \) PE per (9-ticks) bin

Why?

15 events lost
153 new events
Overall gain: 138 events
event 1_5836_291764
Passed 50PE flash
but not 40PE OpHit

Optical Hits

Optical Flashes

event 1_8063_403128
Passed 50PE flash
and 40PE OpHit
event 1_5836_291764

Passed 50PE flash but not 40PE OpHit

pattern of optical activity in the end of beam spill window (close to 4.8µs) and in range 600-1000 cm along z direction observed in 12 out of 15 events

event 1_8063_403128

Passed 50PE flash and 40PE OpHit
Having the PMT precut...

we have used the time information to exclude 98.8% of background events

but that was just the first step

neutrino interacts once per every ~1000 events, we need to identify these interactions

\[
\text{Flashes} \xrightarrow{\text{matching}} \text{objects detected in TPC}
\]

Beest match = highest flash matching score

\[
\text{SCORE} = 1 / (-\ln L(x_{\text{best}}))
\]

\[
-\ln L(x) = -\sum_{i=0}^{N} \ln \left( \frac{H_i(x)}{O_i} e^{-H_i(x)} \right)
\]

- \( H_i(x) \) = PE hypothesis for PMT \( i \)
- \( O_i \) = PE measurement for PMT \( i \)
To look for neutrino candidates I focus only on objects with *neutrino* or *mixed* origin. Only those objects are included in the following slides.
signal ($\nu_\mu$ CC FV, starting with 6208 events)
background (cosmics)

no cuts applied
5002 events $\epsilon = 81\%$

passing current flash requirement
4716 events $\epsilon = 76\%$

flash matching $\delta x = x_{\text{best}} - x_{\text{flash}}$ (cm)
flash matching $\delta z = z_{\text{hypo}} - z_{\text{flash}}$ (cm)
angle between tracks (rad)
Applied cuts:
- min track quality
- delta z < 100 cm
- delta x < 20 cm
- angle between tracks (0.05; 2.9) rad

$\mathcal{E} = 63\%$
$P = 31\%$

Possible region of high purity signal events:
Cut on flash matching score: 0.6 – 1.2

Efficiency: 23%
Purity: 78%
To sum up

My intern in numbers

- Oxford & Fermilab: 2 places
- Working on MicrBooNE: 3 months
- Updating event rates from MCC 6
- Tuning OpHit cut with 9 tick bins and threshold of 40 PE
- as an alternative to 50 PE flash

Numbers:
- 2
- 3
- 6
- 9
- 40
- 50

To sum up My intern in numbers...
Thank you!

- Roxanne Guenette
- Marco Del Tutto
- Corey Adams, Roberto Soleti & Pandora LEE Group
- Anne Schukraft & Cross Section Group
- Luigi Marchese, Ian Shipsey & Oxford PP Division

and the whole Summer Students Team!
# Event rates in MicroBooNE

### MCC6 (docdb 4331-v9)

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<td>1407</td>
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<td><strong>CC - DIS</strong></td>
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### MCC8.1

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<td>91</td>
<td>65</td>
<td>0</td>
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</table>
Flash requirement

\[
\text{Eff} = \frac{\# \text{ numu CC in FV with PE} > \text{threshold}}{\# \text{ numu CC in FV}}
\]

\[
\text{BgRej} = 1 - \frac{\# \text{ events with PE} > \text{threshold}}{\# \text{ all events}}
\]

Efficiency:
- prodgenie_bnb_nu_cosmic_uboone: 95.8%
- prodcosmics_corsika_cmc_uboone: 99.1%

Background rejection:
- prodgenie_bnb_nu_cosmic_uboone: 99.1%
Define signal from OpHits

- take region of time interest here: beam spill window 3.2 – 4.8 μs
- set new bins: \( n \) time ticks per bin
- set threshold PE

**if** nu mu CC interaction in FV \&\& PE in bin \( \geq \) threshold PE:
- **SIGNAL**

vary \( n \) and **threshold PE** for optimization
Note! DL signal: 1L1P ($E_{lep} > 35\text{MeV}, E_p > 60$ MeV)
My signal: $\nu \mu$ CC in FV

PMT Maximum Fraction not included in this study!
Efficiency & cosmic rejection

Efficiency

\[ \text{Eff} = \frac{\# \text{numu CC in FV with PE > threshold}}{\# \text{numu CC in FV}} \]

Background rejection

\[ \text{BgRej} = 1 - \frac{\# \text{events with PE > threshold}}{\# \text{all events}} \]

Graphs showing efficiency and background rejection for different PE thresholds and tick per bin configurations.

- prodgenie_bnb_nu_cosmic_uboone
- prodcosmicsCorsikaCmcUboone
Choice of binning and threshold PE
Choice of binning and threshold PE

**PE THRESHOLD:**

- **OpHits**: higher efficiency than Flashes to keep current rejection
  - **OpHits ≥ 50 PE**
  - **OpHits ≥ 40 PE**

**CHOICE:** 40 PE

- Compare with DL choice:
  - **OpHits ≥ 20 PE**

<table>
<thead>
<tr>
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<th>Efficiency</th>
<th>Cosmic rejection</th>
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<tbody>
<tr>
<td>Flash ≥ 50 PE</td>
<td>95.8 %</td>
<td>99.0 %</td>
</tr>
<tr>
<td>Flash ≥ 40 PE</td>
<td>96.4 %</td>
<td>98.9 %</td>
</tr>
<tr>
<td>OpHit (9-tick) ≥ 50 PE</td>
<td>97.9 %</td>
<td>98.9%</td>
</tr>
<tr>
<td>OpHit (9-tick) ≥ 40 PE</td>
<td>98.6 %</td>
<td>98.8 %</td>
</tr>
</tbody>
</table>

Efficiency Cosmic rejection

- **Flash ≥ 50 PE**: 95.8 % 99.0 %
- **Flash ≥ 40 PE**: 96.4 % 98.9 %
- **OpHit (9-tick) ≥ 50 PE**: 97.9 % 98.9%
- **OpHit (9-tick) ≥ 40 PE**: 98.6 % 98.8 %

September 28th, 2017

KAROLINA ROZWADOWSKA
Cuts comparison

4854 SIGNAL EVENTS

4649 events with ≥1 flash ≥ 50 PE

4613 events with both:
≥1 flash ≥ 50 PE
and ≥ 40 PE per (9-ticks) bin

ε = 95.8%

4754 events with ≥ 50 PE per (9-ticks) bin

ε = 97.9%

36 events lost
141 new events
Overall gain: 105 events

September 28th, 2017
KAROLINA ROZWADOWSKA
Cuts comparison

4854 SIGNAL EVENTS

4671 events with ≥1 flash ≥ 40 PE

4645 events with both: ≥1 flash ≥ 50 PE and ≥ 40 PE per (9-ticks) bin

ε = 96.2%

4787 events with ≥ 40 PE per (9-ticks) bin

ε = 98.6%

26 events lost
142 new events
Overall gain: 116 events
TPC Objects

- all the reconstructed objects from the light deposited in TPCs

- TPC Objects can originate from:
  - neutrino $\rightarrow$ object: neutrino-induced muon track
  - cosmic $\rightarrow$ object: cosmic track with it’s delta rays
  - mixed (both neutrino and cosmic)

In each event we want to select possible neutrino candidates, so we focus on objects with neutrino or mixed origin
Flash to TPC Object matching

Measured photoelectrons (PE) in each PMT are matched with hypothesis of PE in PMTs from simulation

Best match is chosen with

\[-\ln L = -\sum_{i=0}^{32} \ln \left( \frac{H_i(x))^o_l e^{-H_i(x)}}{O_i!} \right)\]

minimization of \(-\ln L\) gives \(x_{best}\)

Flash matching score = \(\frac{1}{-\ln L(x_{best})}\)
No cuts applied

Efficiency 81%

Overall 6208 signal events
-1170 (flash matching failed)
-36 (no TPCObjects)
\[ \sum 5002 \text{ events} \]

Purity 30%

Signal purity:
how many events that passed the selection are signal events?
Only flash requirement applied

**Efficiency** 76%

**4716** signal events kept

**Signal purity**:
how many events that passed the selection are signal events?
Purity 30%
Applied cuts:
- min track quality 4644
- delta x <20 cm 4260
- delta z <100cm 4205

Efficiency 68%
Purity 31%
Vertex angle check

Eff = 36%

signal

background

Eff = 68%
P = 31%

Applied cuts:
- min track quality 4644
- delta x <20 cm 4260
- delta z <100cm 4205