

MovingKnowledge17  
International Neutrino Summer School



# Study of muon neutrino interactions in MicroBooNE

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Karolina Rozwadowska

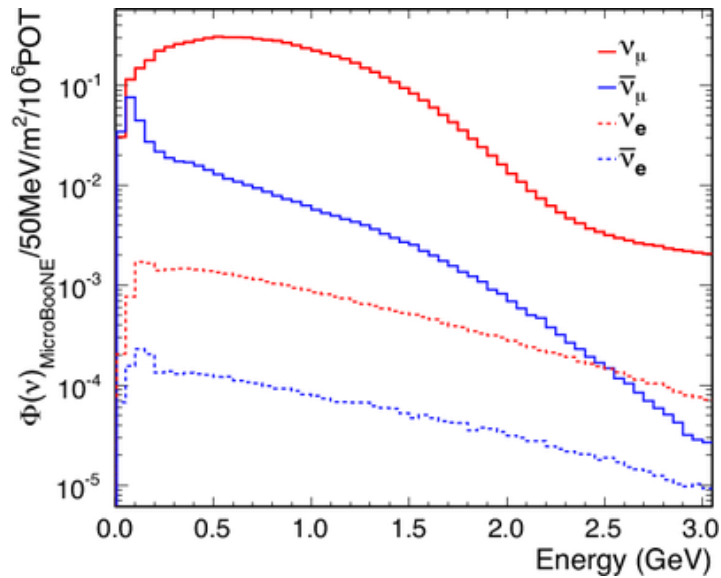
supervised by Roxanne Guenette and Marco Del Tutto



September 27th, 2017

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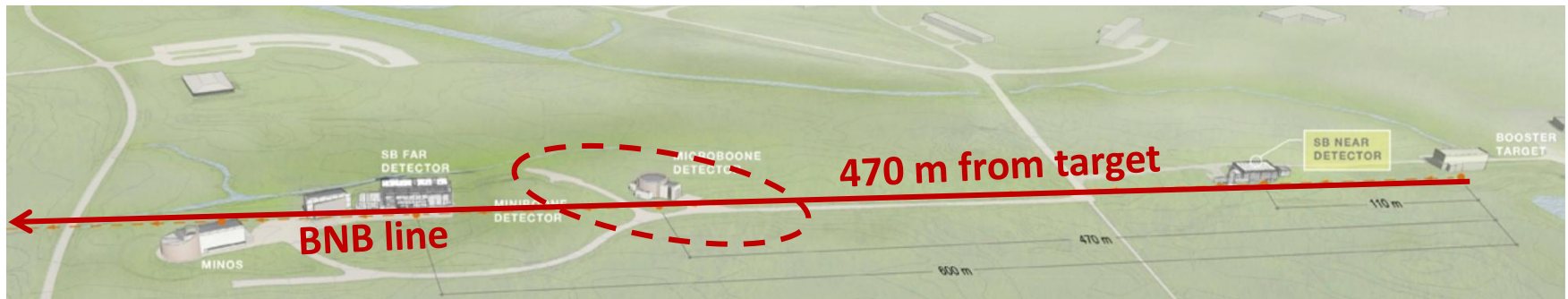
# MicroBooNE experiment



Liquid Argon Time Projection Chamber

Located on

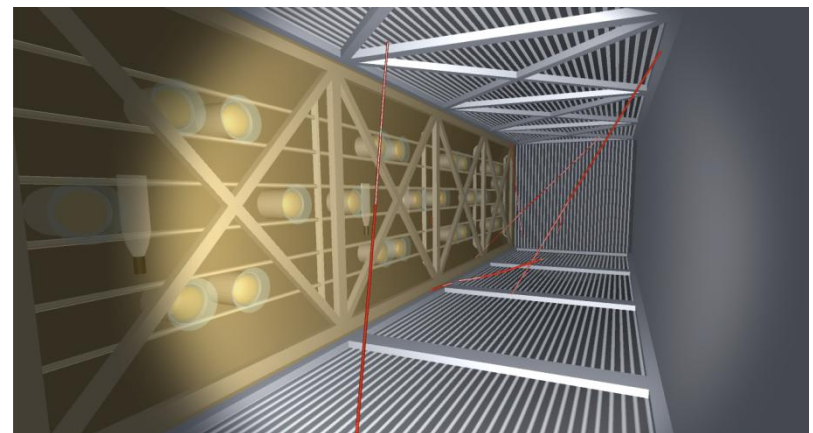
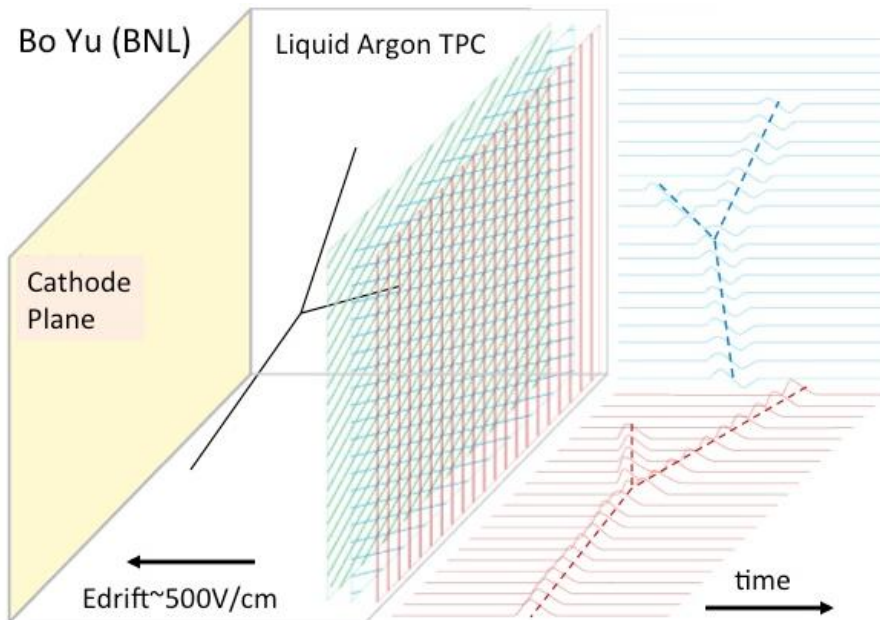
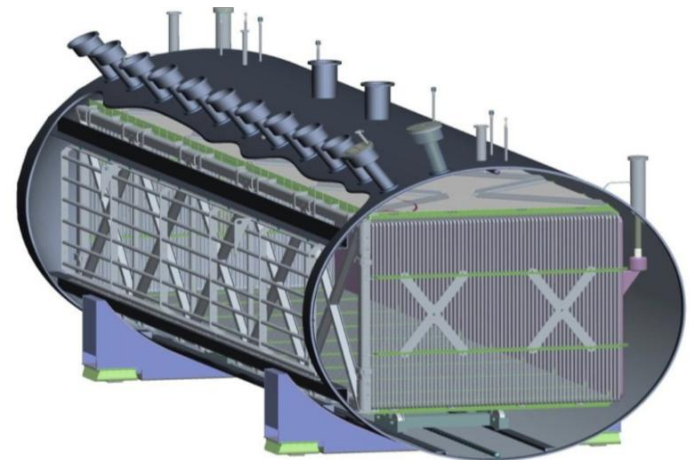
- Booster Neutrino Beam line → neutrinos
- ground level → cosmics



# MicroBooNE experiment

Neutrino detection:

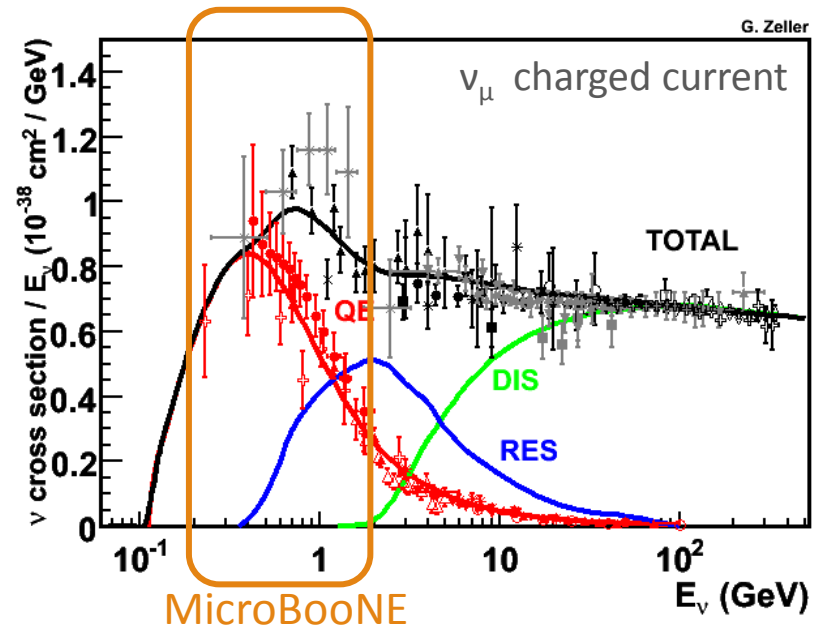
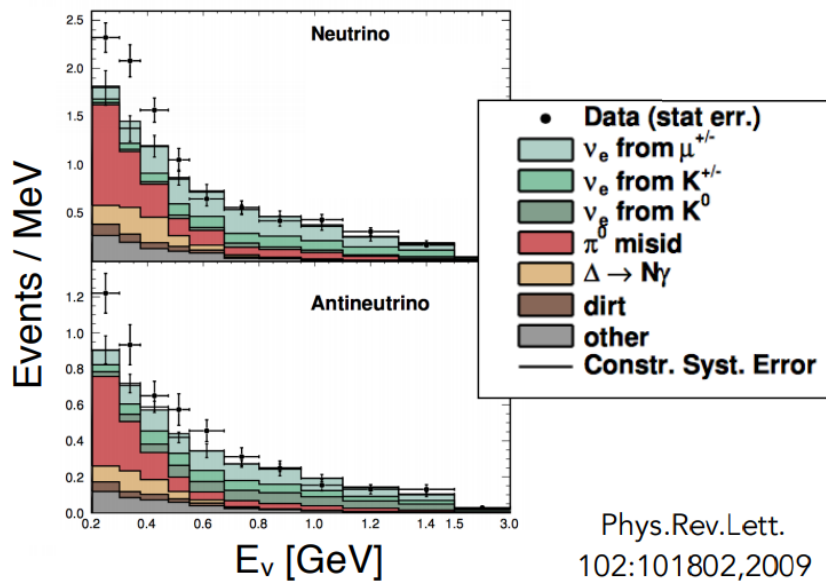
- ionization current  $\longrightarrow$  3 wire planes
- scintillation light  $\longrightarrow$  32 PMTs



# MicroBooNE goals

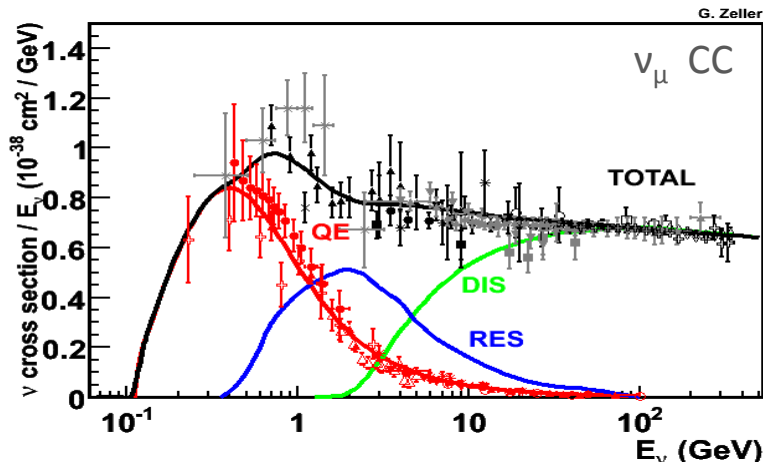
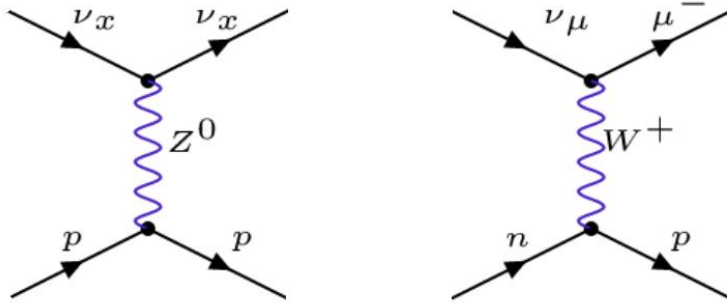
Resolve low energy excess  
observed by MiniBooNE

Perform precise measurement of  
neutrino cross sections in Argon



# Event rates in MicroBooNE

Neutral Current or Charged Current

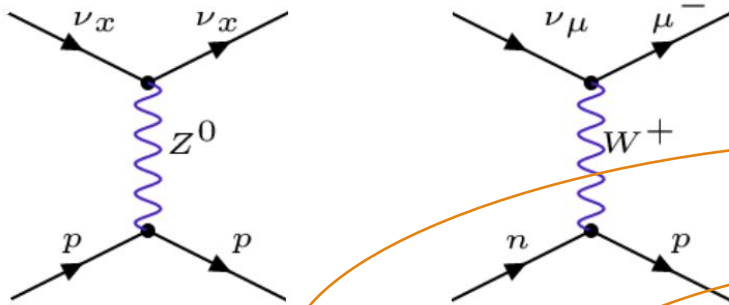


Interaction channel:

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

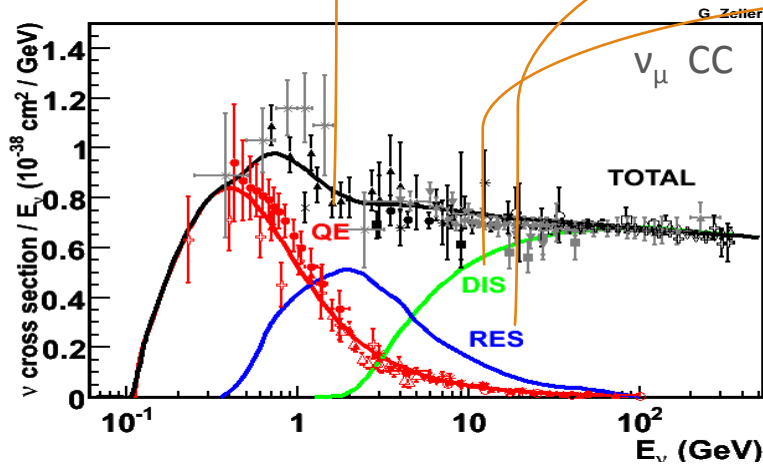
# Event rates in MicroBooNE

Neutral Current or Charged Current

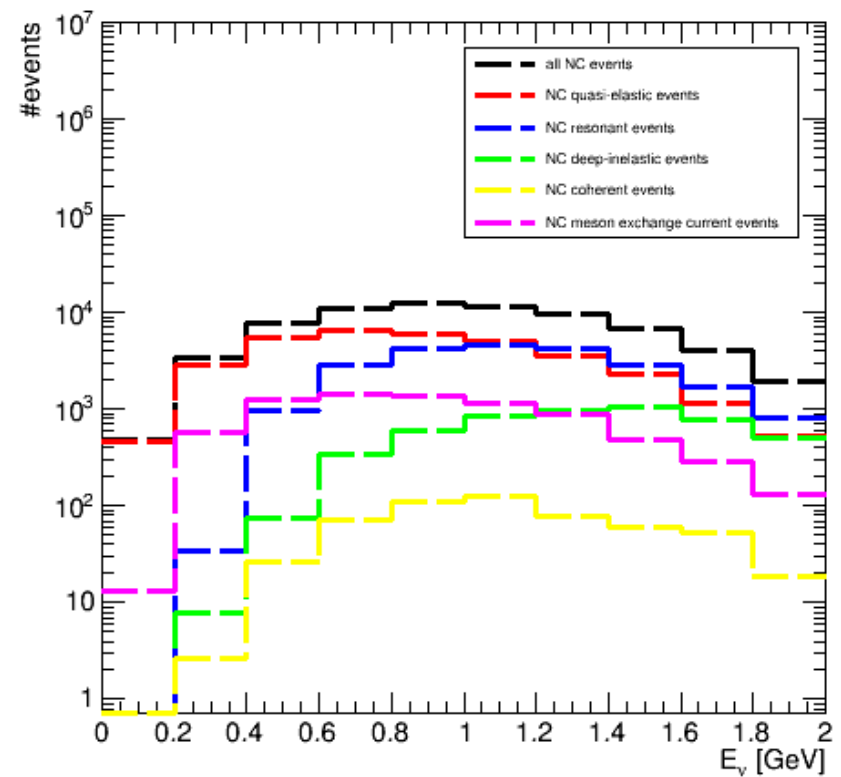
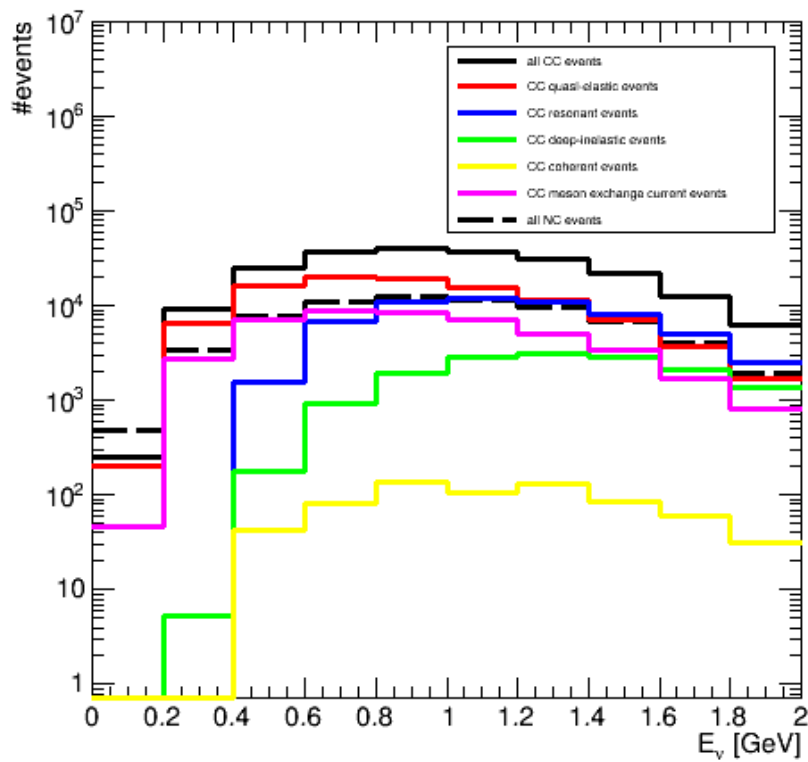


Interaction channel:

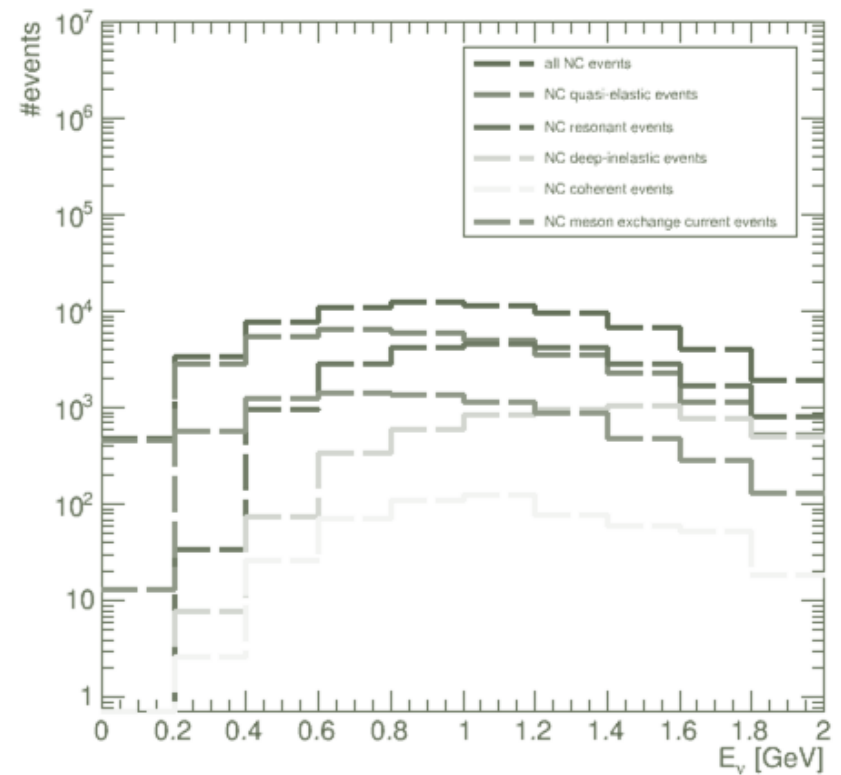
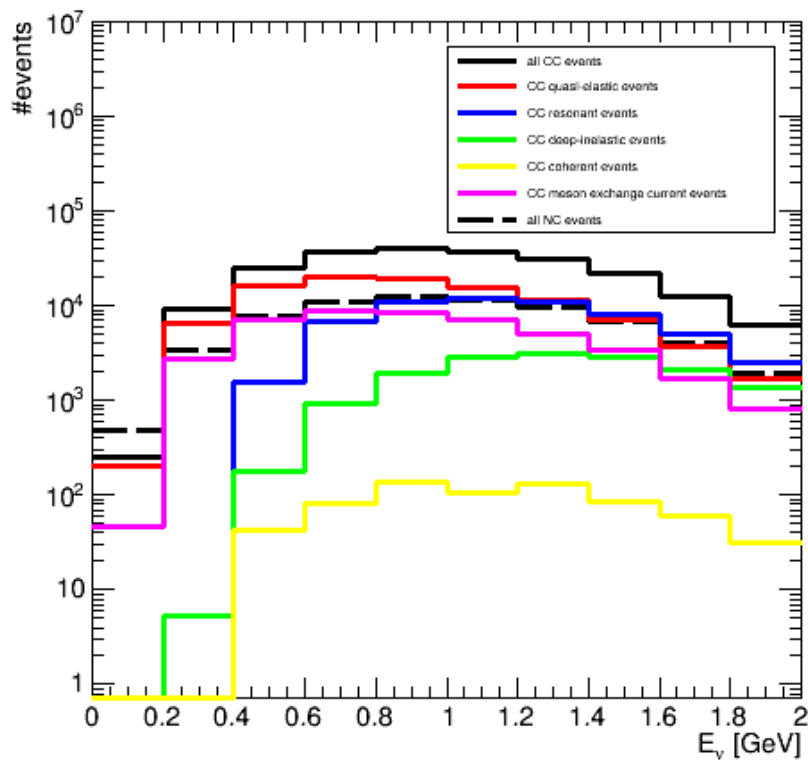
- Quasi elastic ~45%
- Resonant pion production ~25%
- Deep inelastic scattering ~9%
- Coherent pion production ~1%
- Meson exchange current ~20%



# Event rates in MicroBooNE



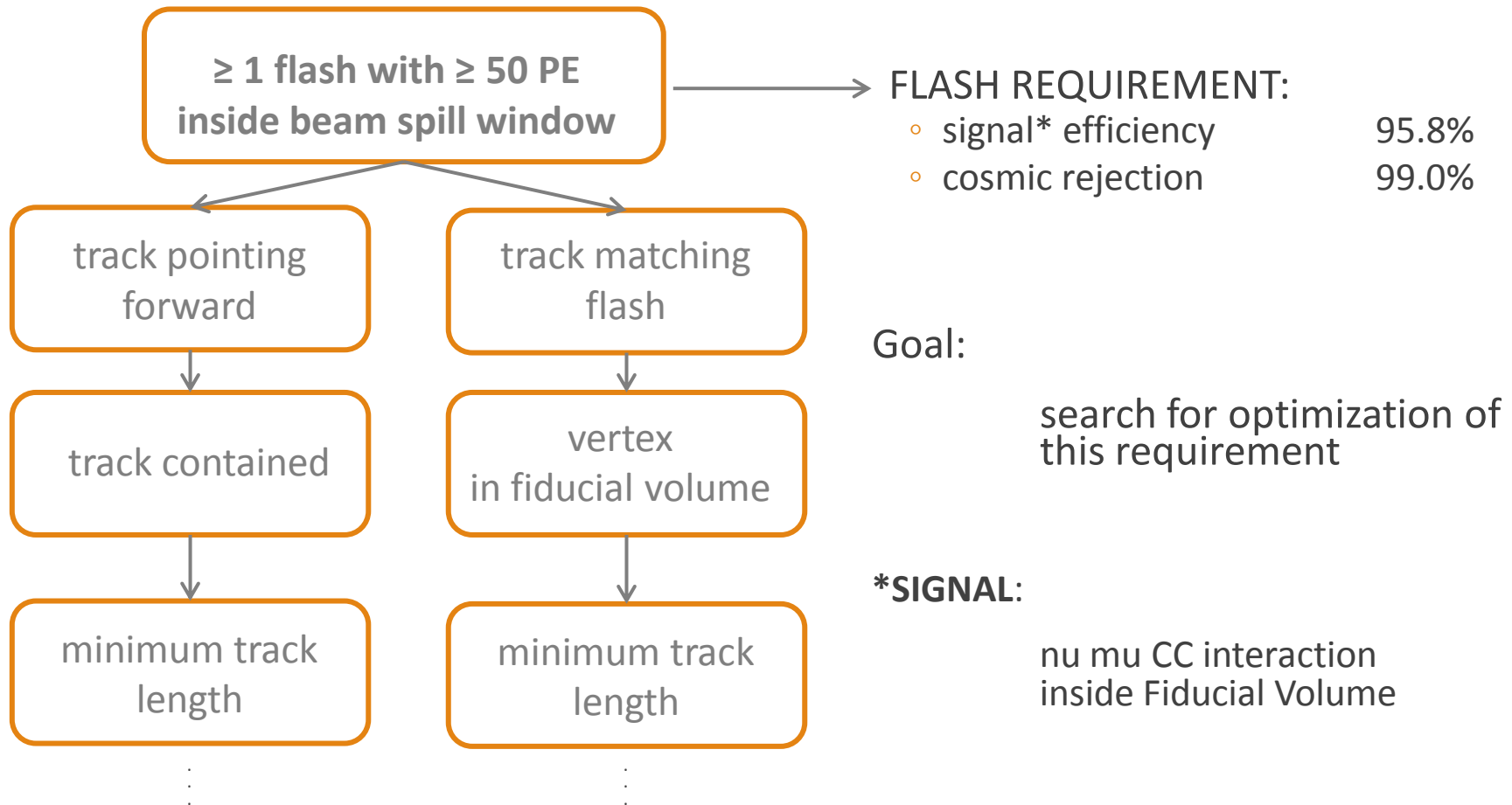
# Event rates in MicroBooNE



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



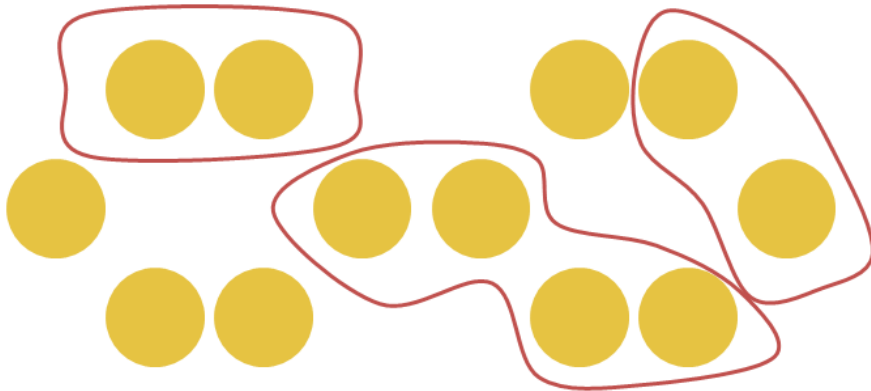
# Selection paths



# Two methods

## Flashes

summed OpHits from grouped PMTs



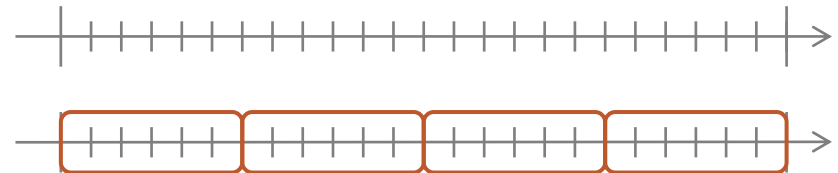
current requirement: 50 PE  
Threshold PE can be tuned

## OpHits

pure information from PMTs

In each time tick (15.625  $\mu$ s ) for each PMT:

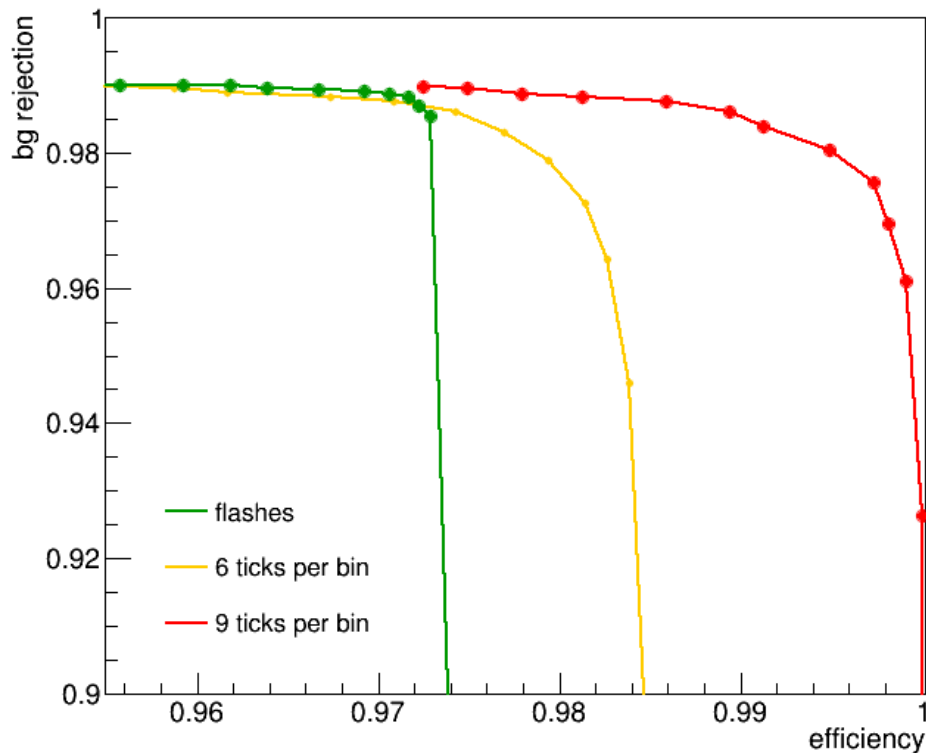
deposited light (number of PE) is stored as an OpHit



Binning and threshold PE can be tuned

*as used by the MicroBooNE Deep Learning group*

# OpFlashes vs OpHits



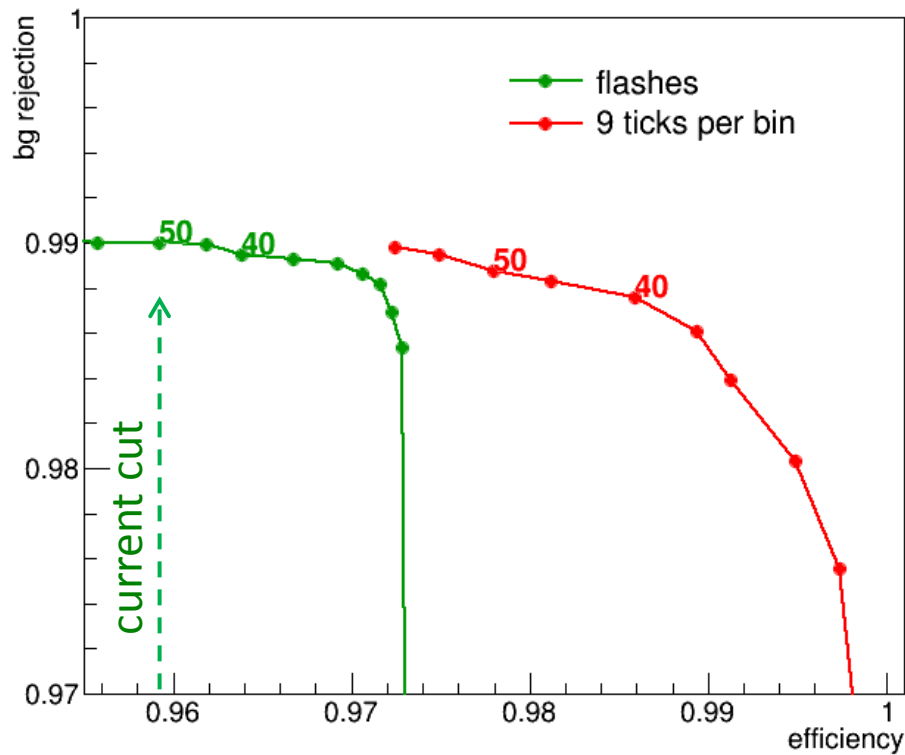
## BINNING:

**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

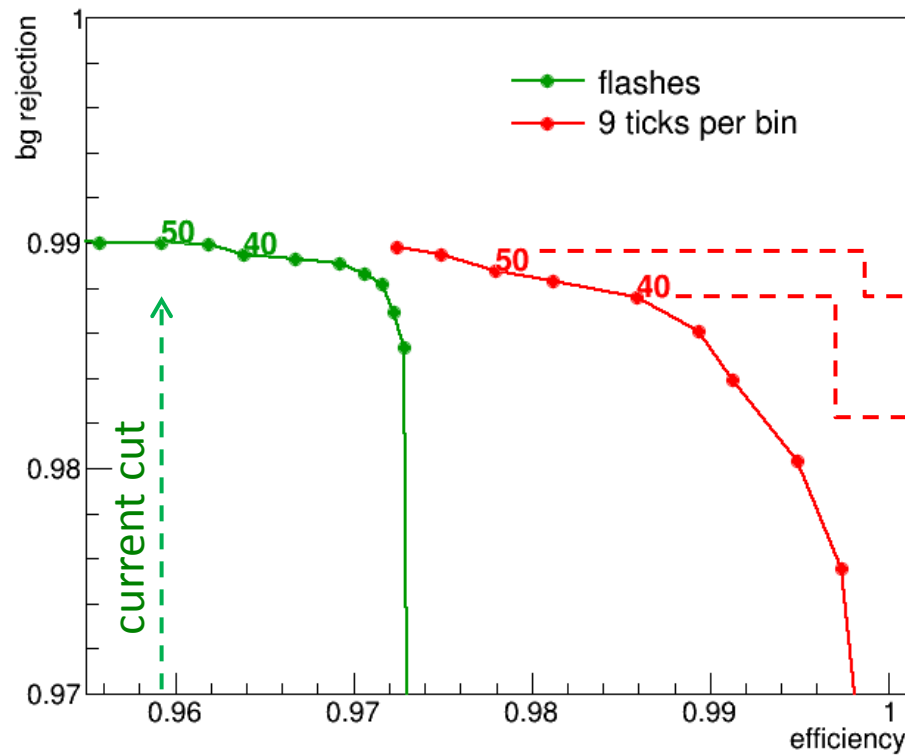
OpHits  $\geq$  50 PE

to increase efficiency

OpHits  $\geq$  40 PE

CHOICE: 40 PE

# OpFlashes vs OpHits



PE THRESHOLD:

OpHits: higher efficiency than Flashes  
to keep current rejection

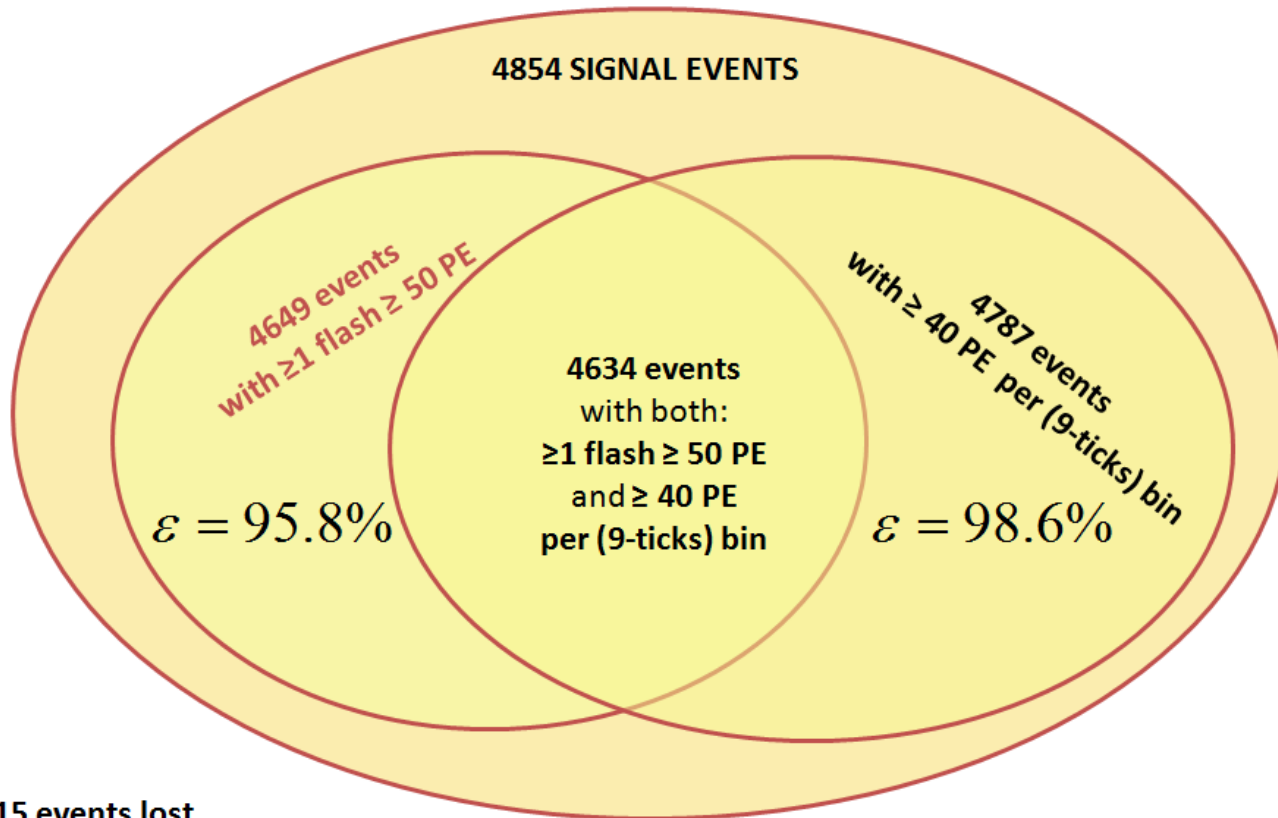
→ OpHits  $\geq$  50 PE

to increase efficiency

→ OpHits  $\geq$  40 PE

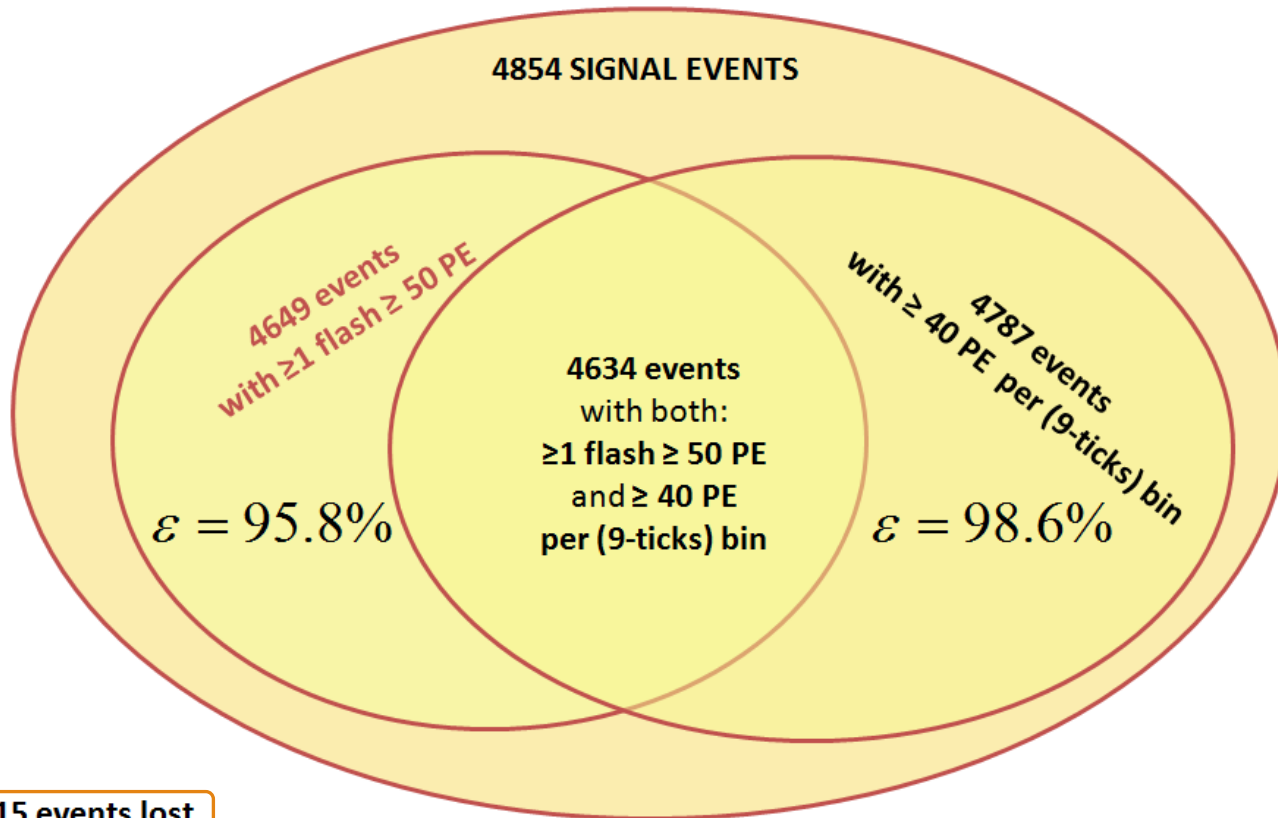
CHOICE: 40 PE

# Cuts comparison



15 events lost  
153 new events  
Overall gain: 138 events

# Cuts comparison



Why?

15 events lost

153 new events

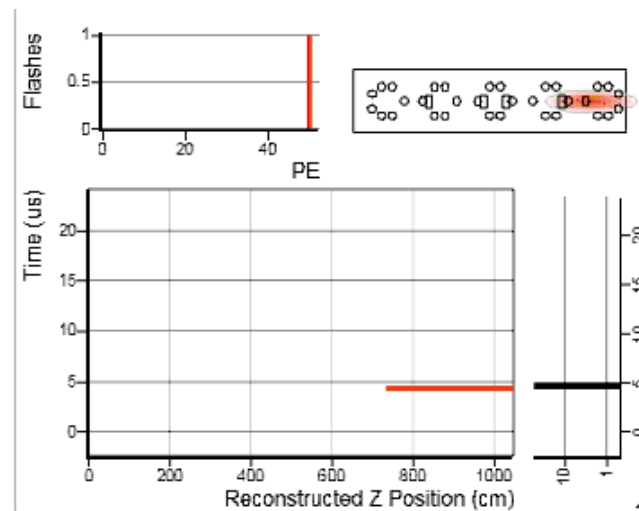
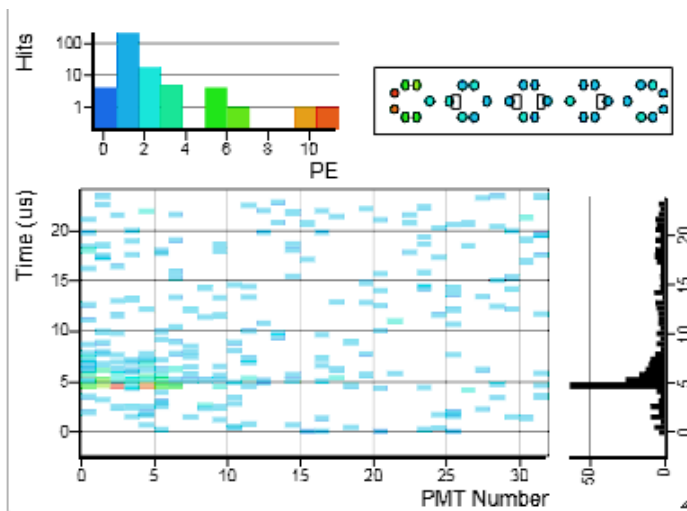
Overall gain: 138 events

### Optical Hits

### Optical Flashes

event 1\_5836\_291764

Passed 50PE flash  
but not 40PE OpHit

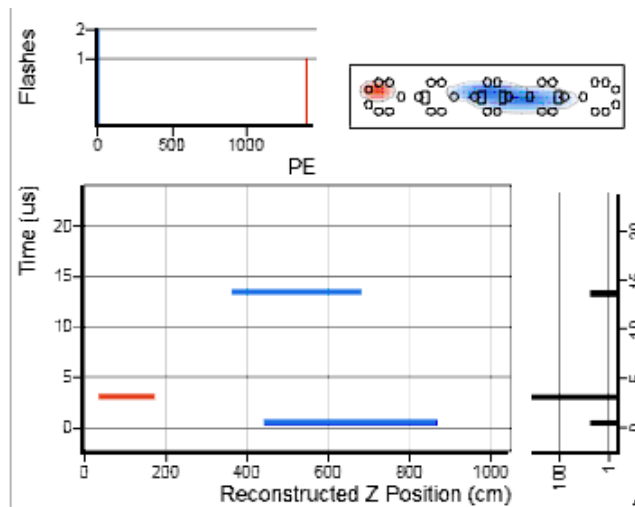
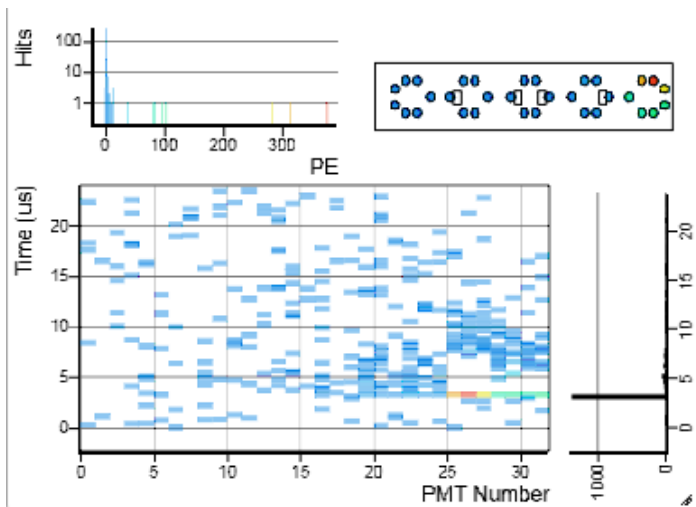


### Optical Hits

### Optical Flashes

event 1\_8063\_403128

Passed 50PE flash  
and 40PE OpHit



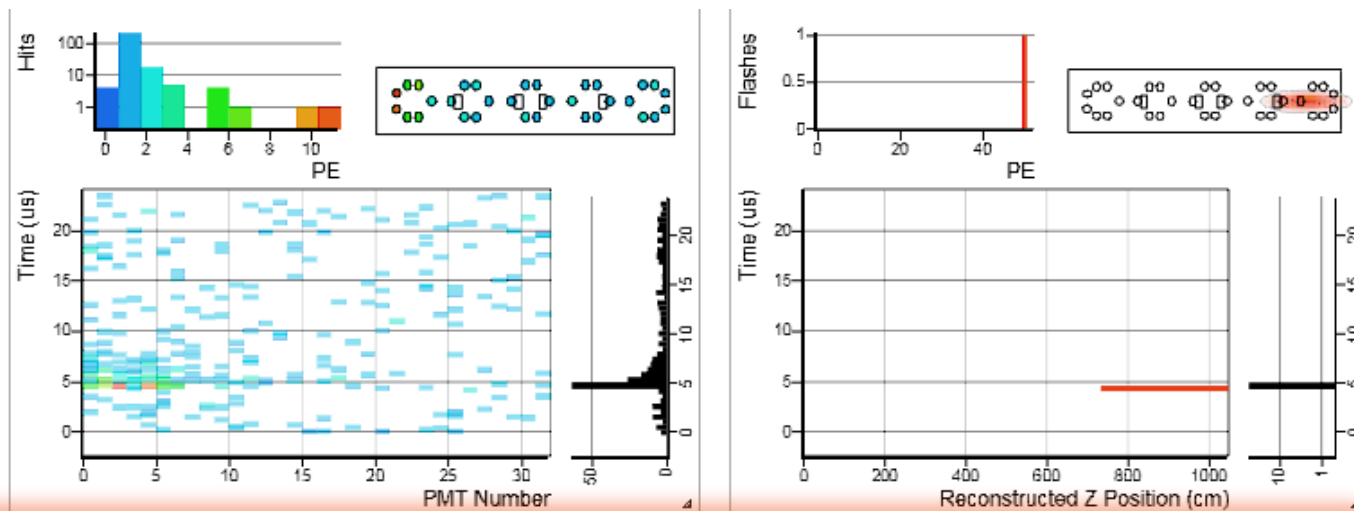


### Optical Hits

### Optical Flashes

event 1\_5836\_291764

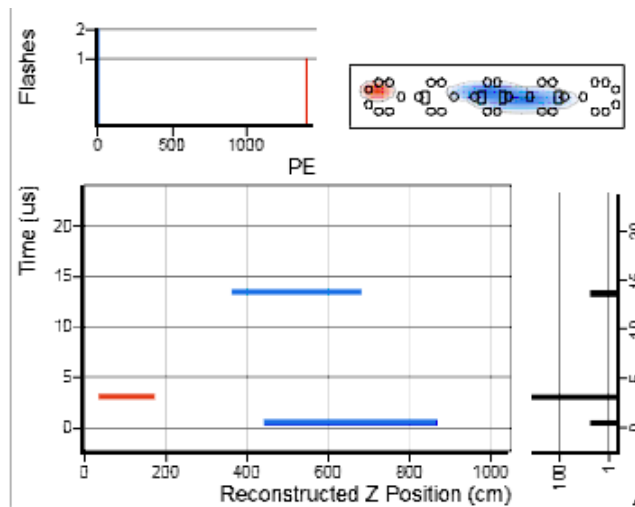
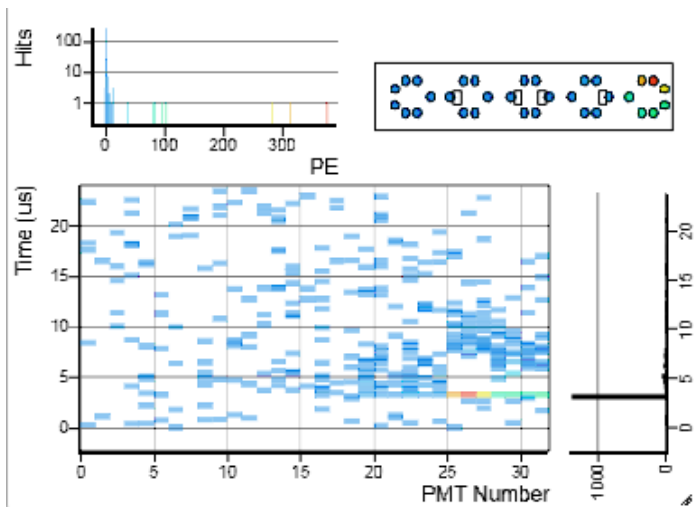
Passed 50PE flash  
but not 40PE OpHit



pattern of optical activity in the end of beam spill window (close to  $4.8\mu\text{s}$ ) and in range 600-1000 cm along z direction observed in 12 out of 15 events

### Optical Hits

### Optical Flashes



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

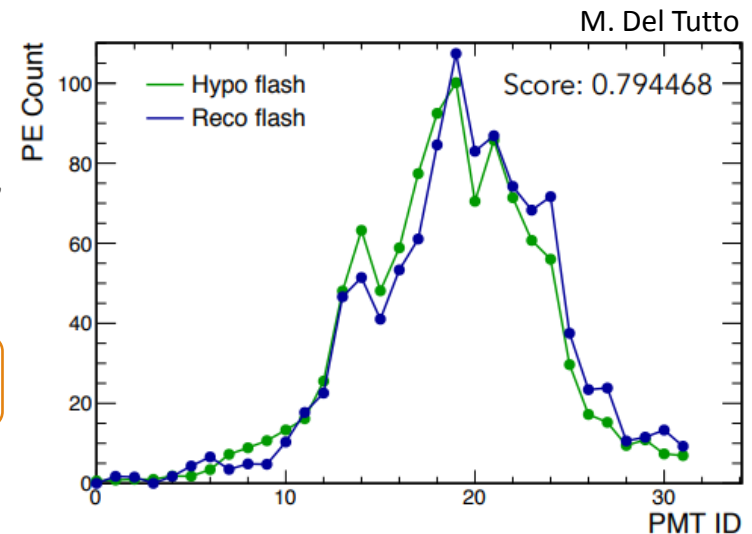
but that was just the first step

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



Best match = highest flash matching score

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



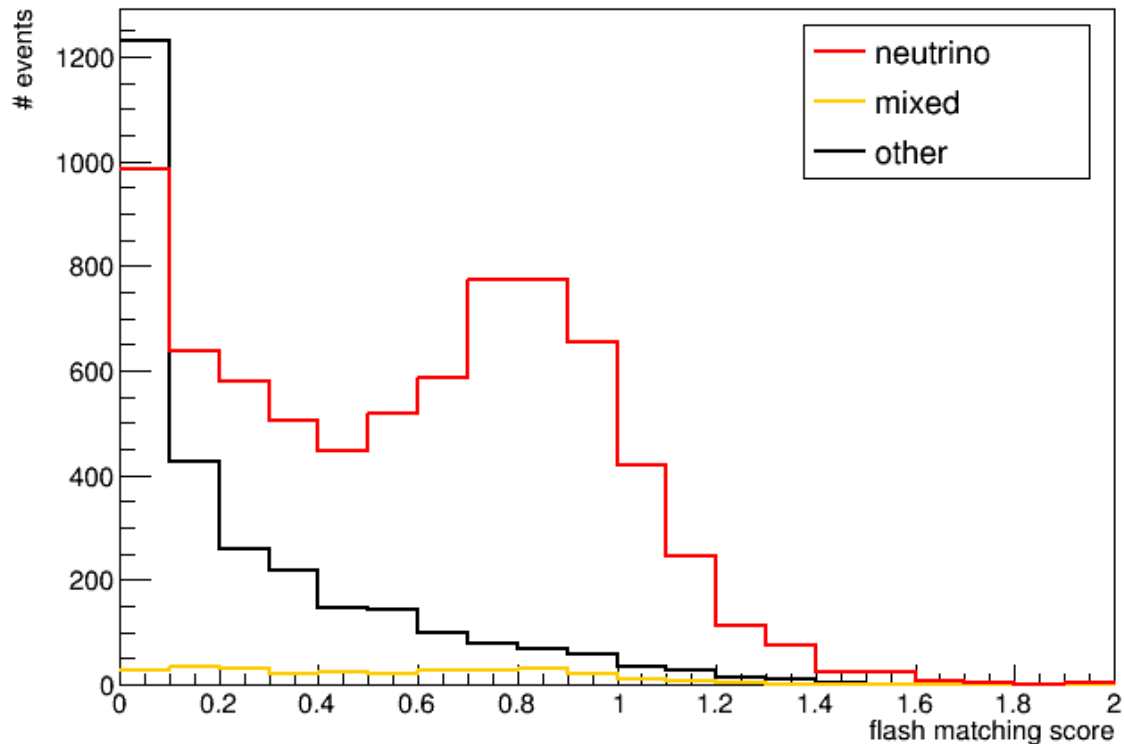
$$-\ln L(x) = -\sum_{i=0}^N \ln \frac{(H_i(x))^{O_i} e^{-H_i(x)}}{O_i!}$$

$H_i(x)$  = PE hypothesis for PMT  $i$

$O_i$  = PE measurement for PMT  $i$

# Flash matching score

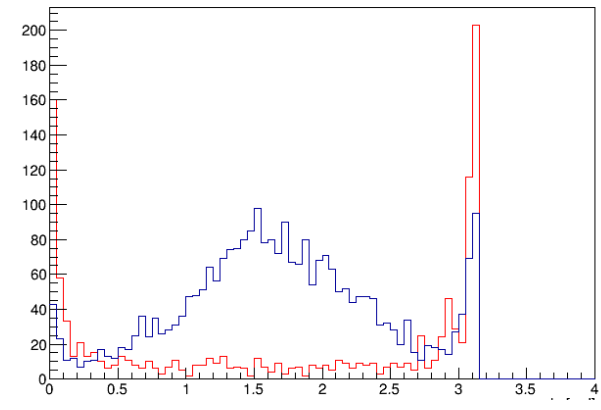
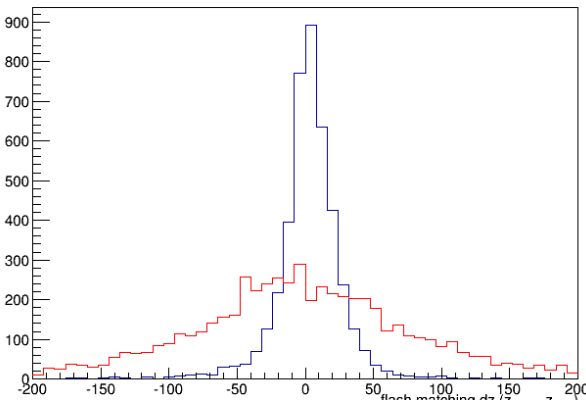
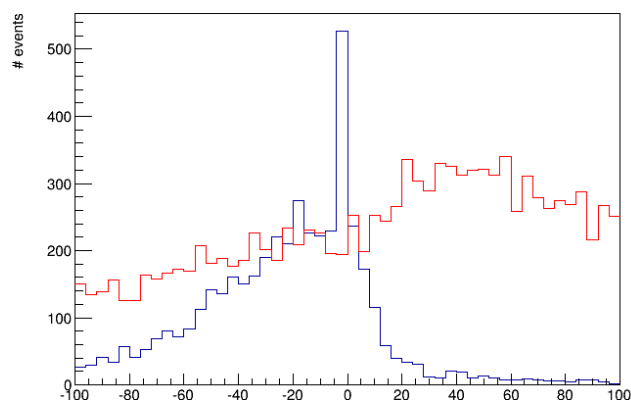
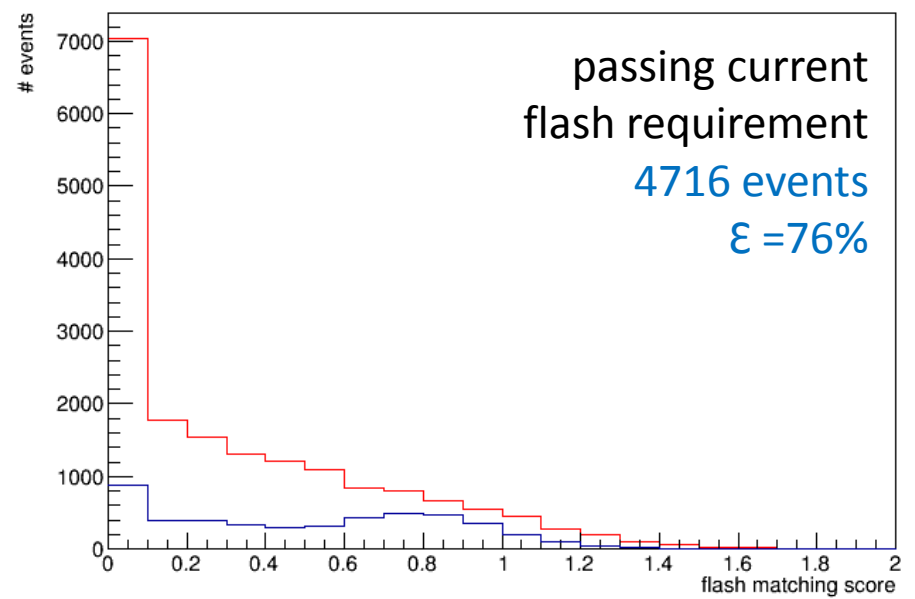
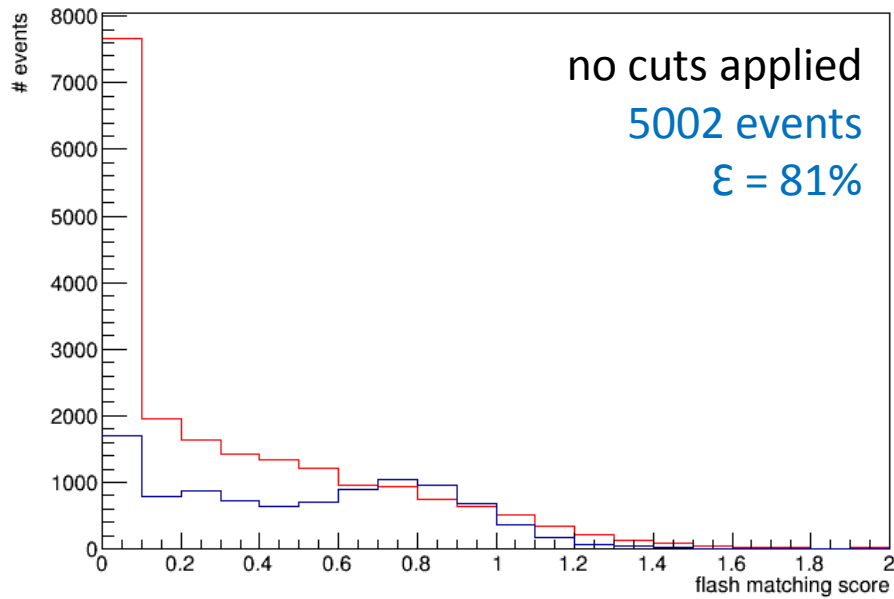
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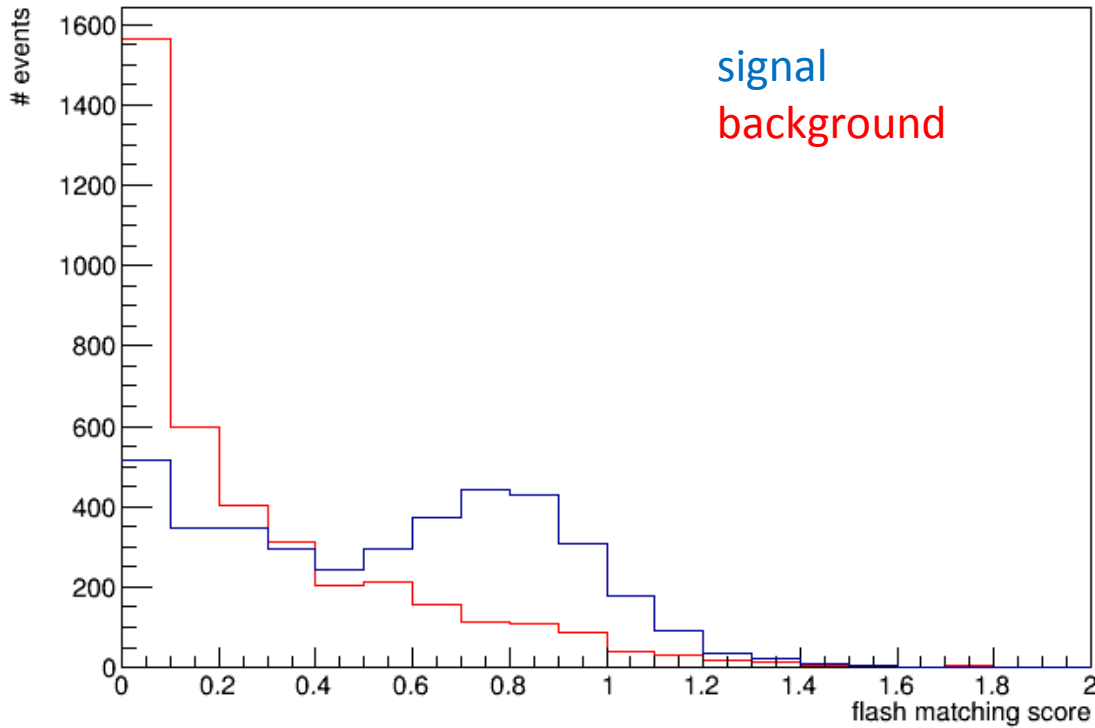
To look for neutrino candidates I focus only on objects with **neutrino** or **mixed** origin. Only those object are included in the following slides.

signal ( $\nu_\mu$  CC FV, starting with 6208 events)

background (cosmics)



flash mathing  $\delta x = x_{\text{best}} - x_{\text{flash}}$  (cm) flash mathing  $\delta z = z_{\text{hypo}} - z_{\text{flash}}$  (cm) angle between tracks (rad)

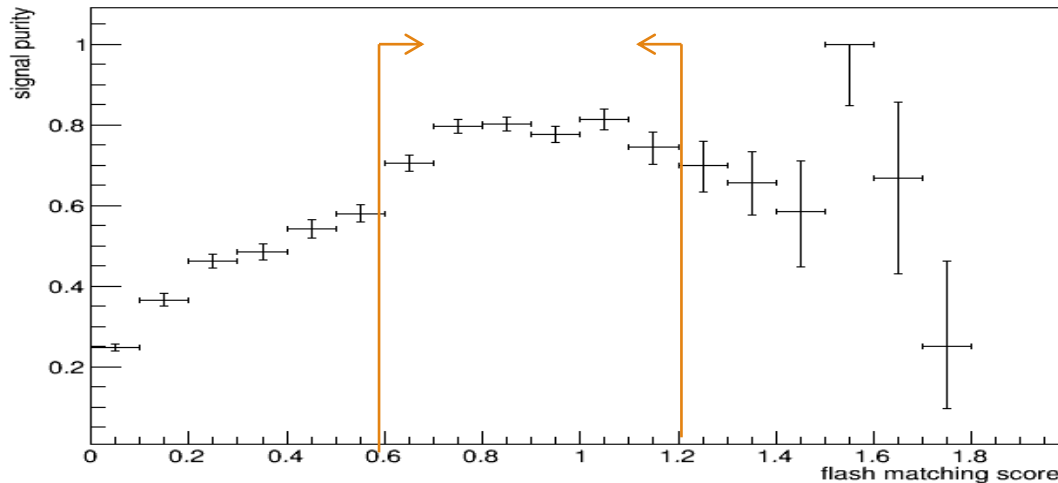


6208

- Applied cuts:
- min track quality ..... 4644
  - delta z <100cm 4260
  - delta x <20 cm 4205
  - angle between tracks (0.05; 2.9) rad 3953

$\mathcal{E} = 63\%$

$P = 31\%$



Possible region of high purity signal events:

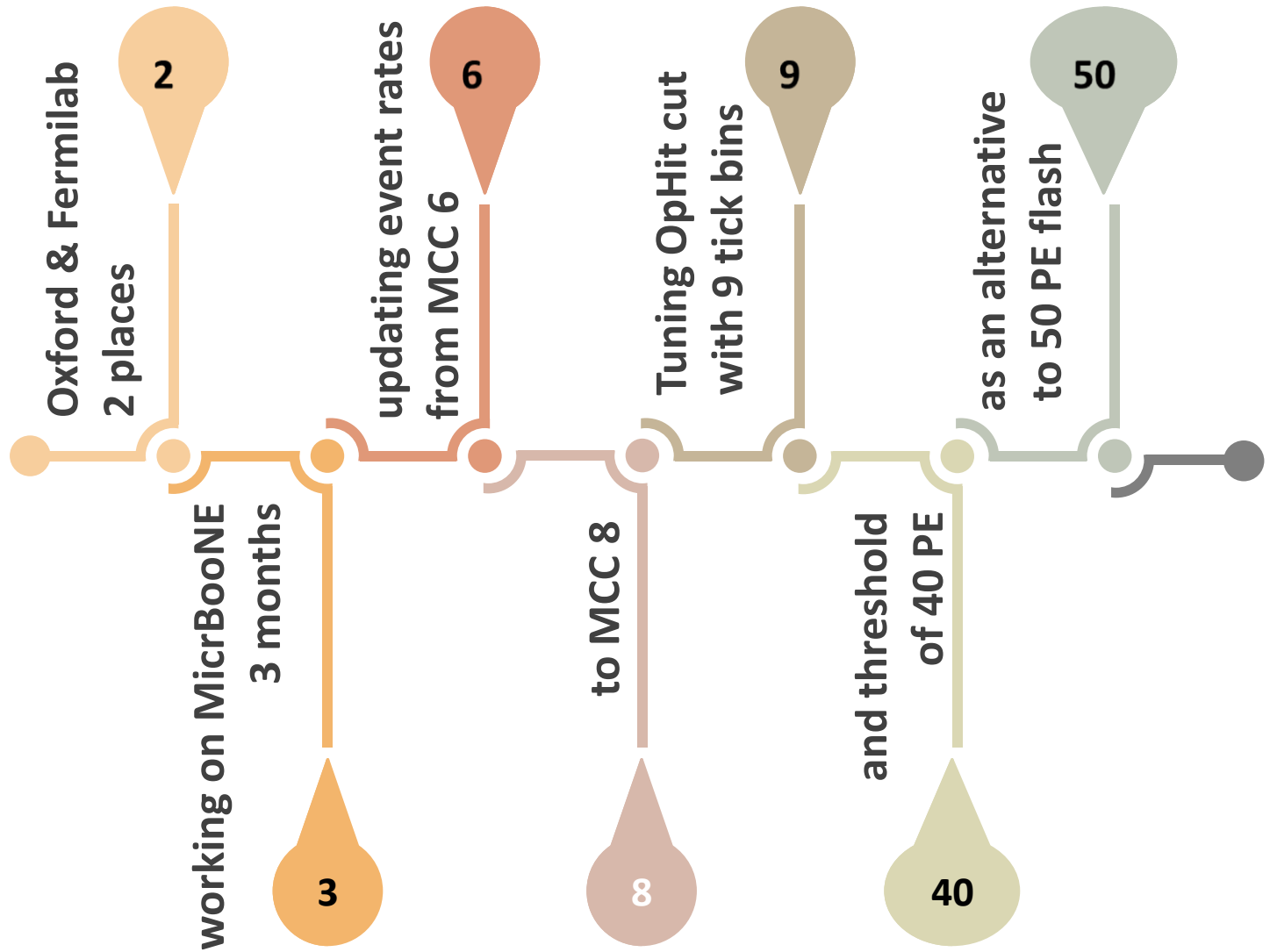
Cut on flash matching score:  
0.6 – 1.2

*Efficiency: 23%*

*Purity: 78%*

# My intern in numbers

## To sum up



# Thank you!

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- 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!

# BACKUP SLIDES

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# Event rates in MicroBooNE

MCC6 (docdb 4331-v9)

	numu	numubar	nue	nuebar
<b>CC Total</b>	173302	1407	1469	36
CC - QE	95296	773	729	17
CC - RES	75657	604	702	18
CC - DIS	1607	1.3	29	0.5
CC - COH	740	29	8.5	0.7
<b>NC Total</b>	64661	1002	502	17
NC - QE	35951	633	254	7.0
NC - RES	27665	358	236	9.4
NC - DIS	519	1.3	8.8	0.2
NC - COH	525	10	3.2	0.6

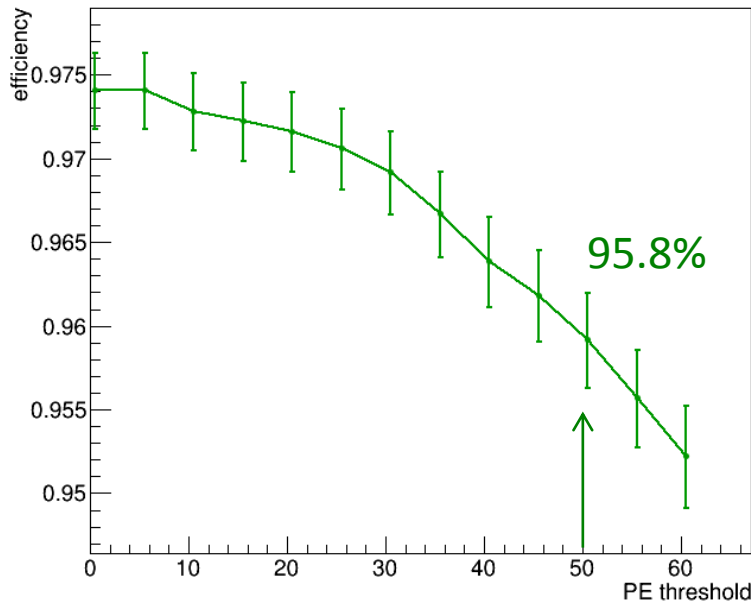
MCC8.1

	numu	numubar	nue	nuebar
<b>CC Total</b>	234941	1958	1997	47
CC - QE	104235	984	762	10
CC - RES	62741	439	614	26
CC - DIS	20484	120	251	5
CC - COH	749	16	10	0
<b>CC - MEC</b>	46732	399	360	5
<b>NC Total</b>	73449	1073	546	24
NC - QE	34622	590	251	16
NC - RES	23727	285	162	3
NC - DIS	6823	89	63	5
NC - COH	590	18	5	0
<b>NC - MEC</b>	7661	91	65	0

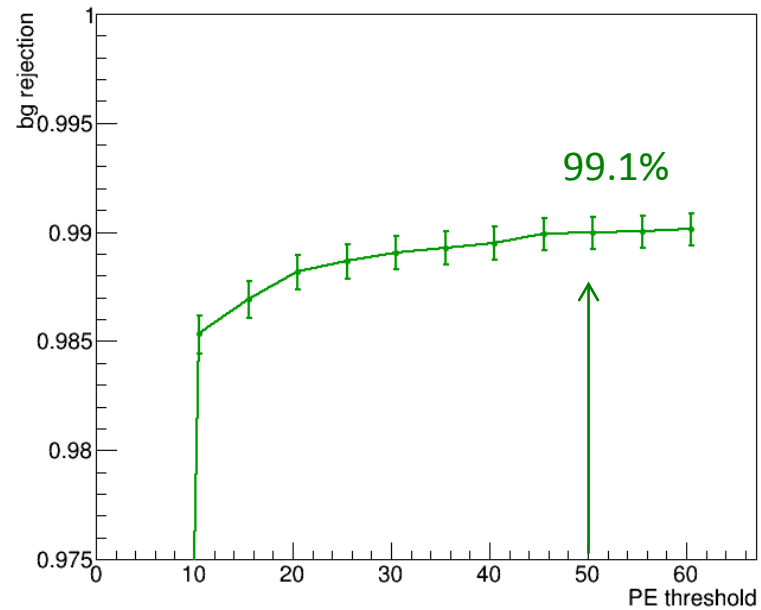
# Flash requirement

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

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



prodgenie\_bnb\_nu\_cosmic\_uboone



prodcosmics\_corsika\_cmc\_uboone

# Define signal from OpHits

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take region of time interest  
here: beam spill window 3.2 – 4.8  $\mu$ s

set new bins: **n** time ticks per bin

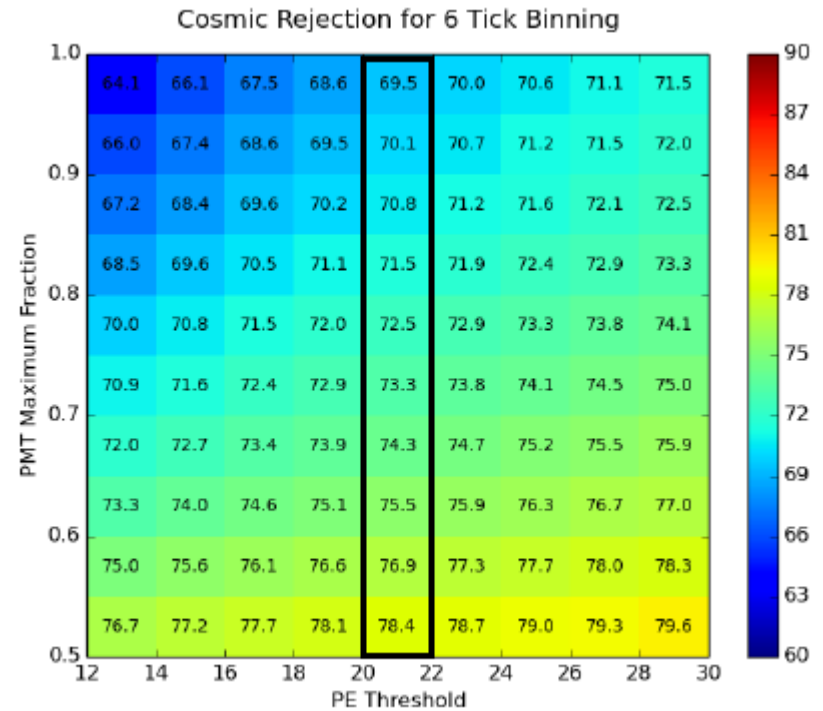
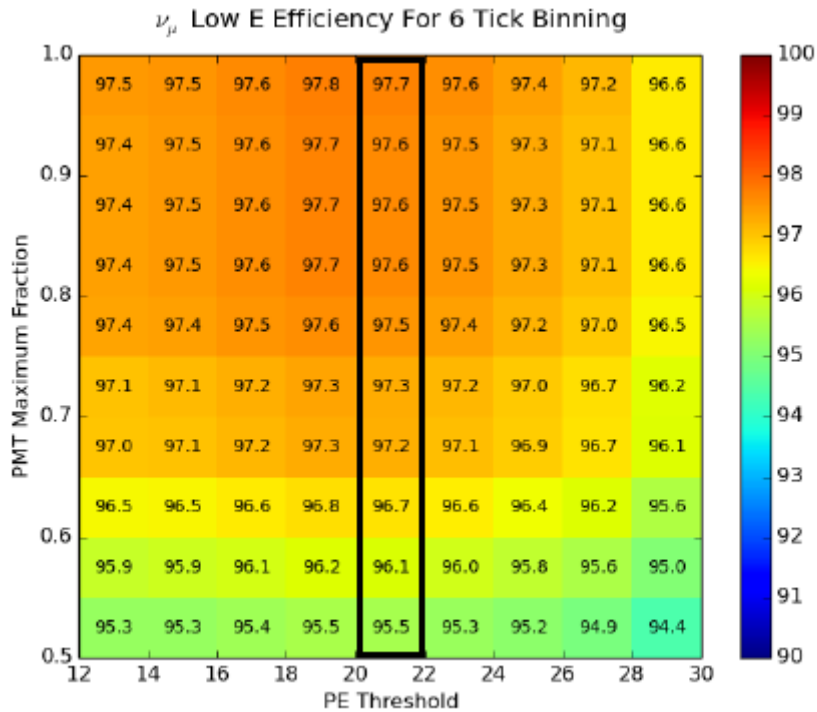
set **threshold PE**

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

vary **n** and **threshold PE** for optimization

# DL choice

6 Tick Binning  
20 PE Threshold

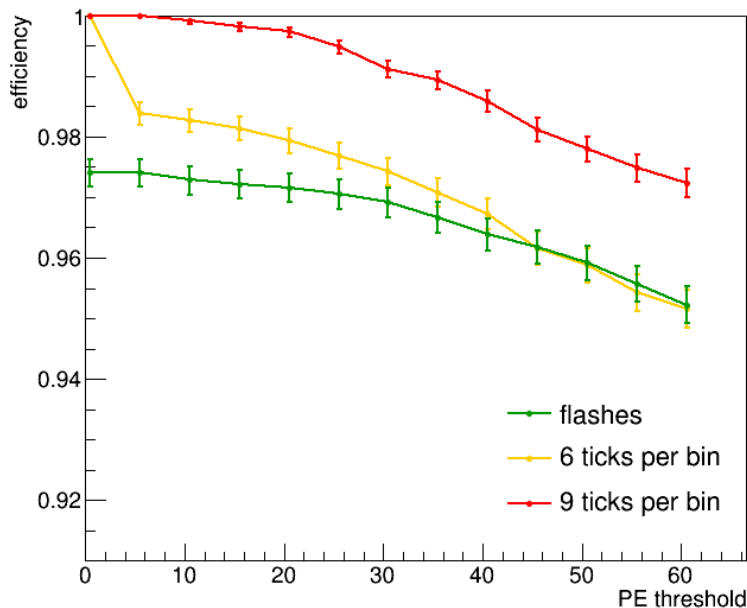


Note! DL signal: 1L1P ( $E_{lep} > 35 \text{ MeV}$ ,  $E_p > 60 \text{ MeV}$ )  
My signal:  $\nu_\mu$  CC in FV

PMT Maximum Fraction not included in this study!

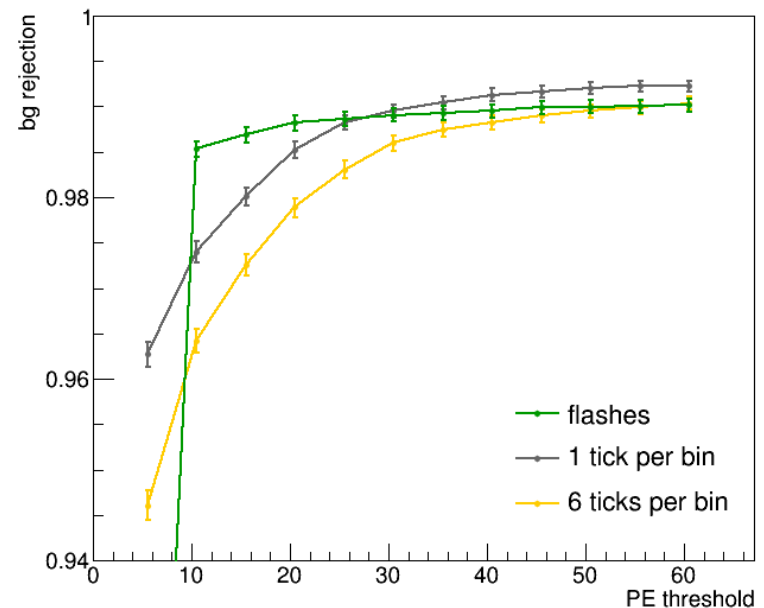
# Efficiency & cosmic rejection

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



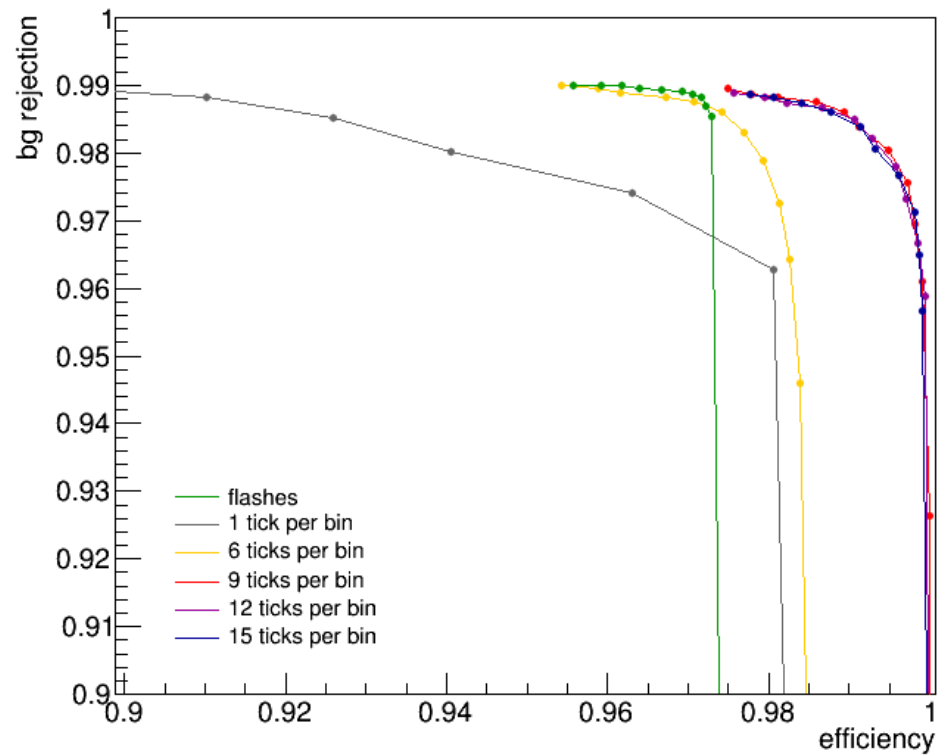
prodgenie\_bnb\_nu\_cosmic\_uboone

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



prodcosmics\_corsika\_cmc\_uboone

# Choice of binning and threshold PE



# Choice of binning and threshold PE

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	Efficiency	Cosmic rejection
--	------------	------------------

Flash $\geq$ 50 PE	95.8 %	99.0 %
Flash $\geq$ 40 PE	96.4%	98.9 %
OpHit (9-tick) $\geq$ 50 PE	97.9 %	98.9%
OpHit (9-tick) $\geq$ 40 PE	98.6 %	98.8 %

PE THRESHOLD:

OpHits: higher efficiency than Flashes to keep current rejection

OpHits  $\geq$  **50 PE**

to increase efficiency

OpHits  $\geq$  **40 PE**

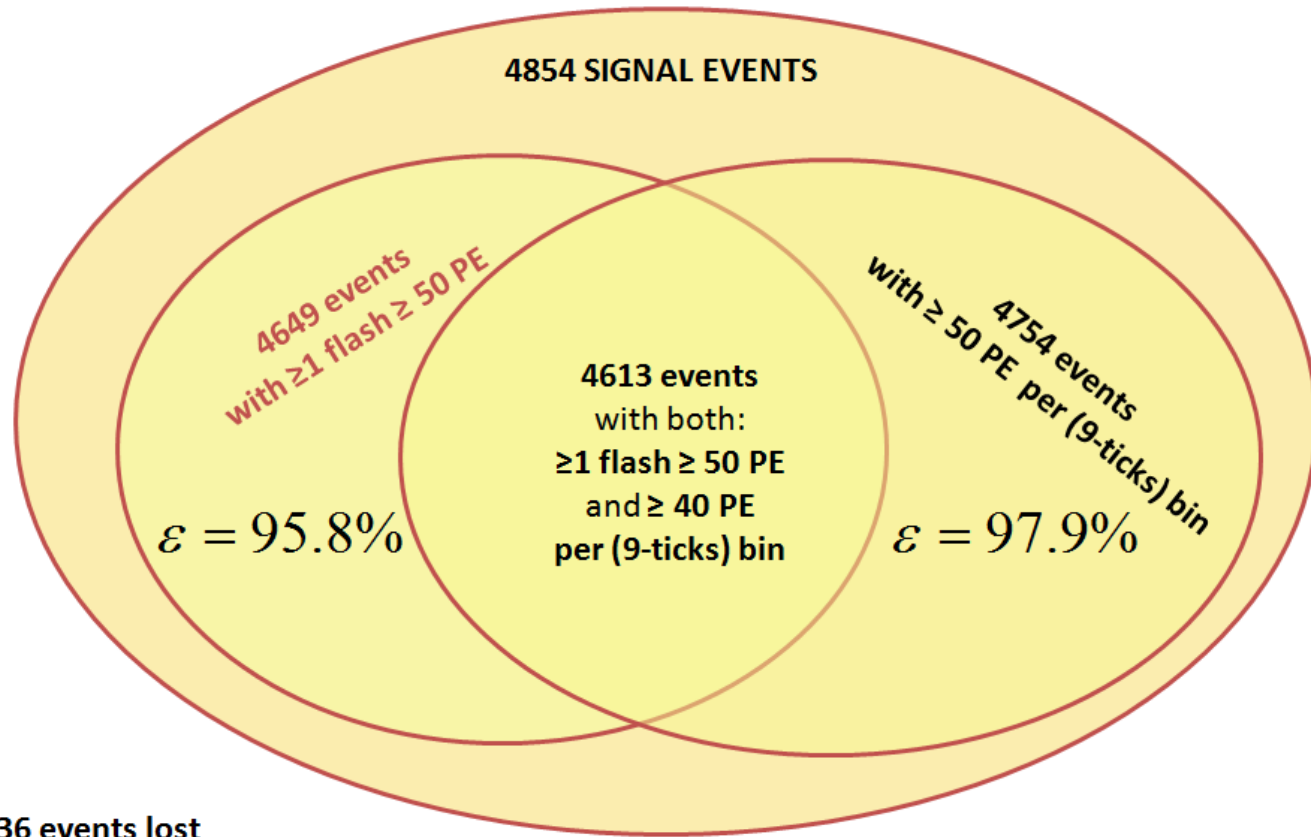
CHOICE: **40 PE**

compare with DL choice:

OpHits  $\geq$  **20 PE**

# Cuts comparison

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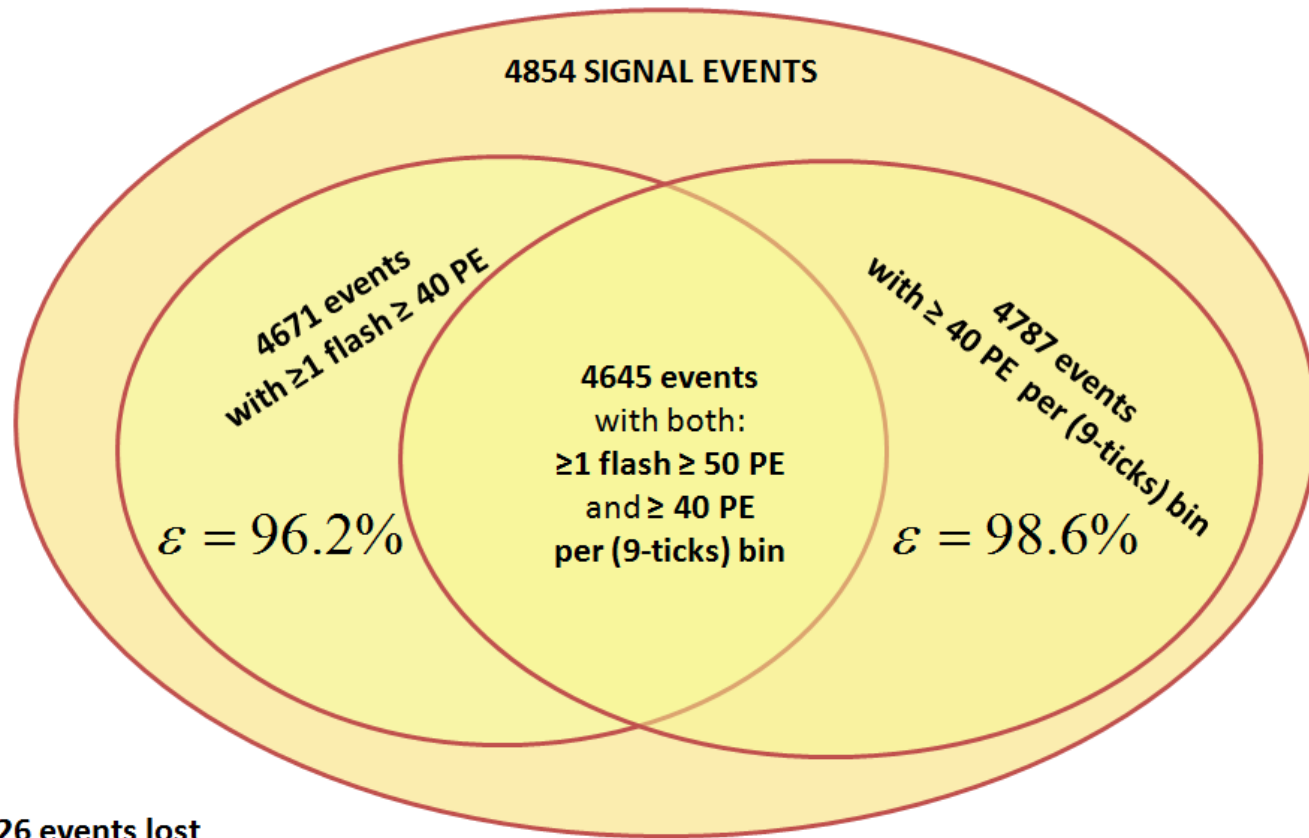


36 events lost  
141 new events  
Overall gain: 105 events



# Cuts comparison

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26 events lost  
142 new events  
Overall gain: 116 events

# TPC Objects

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- all the reconstructed objects from the light deposited in TPCs
- TPC Objects can originate from:
  - neutrino → object: neutrino-induced muon track
  - cosmic → object: cosmic track with its 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

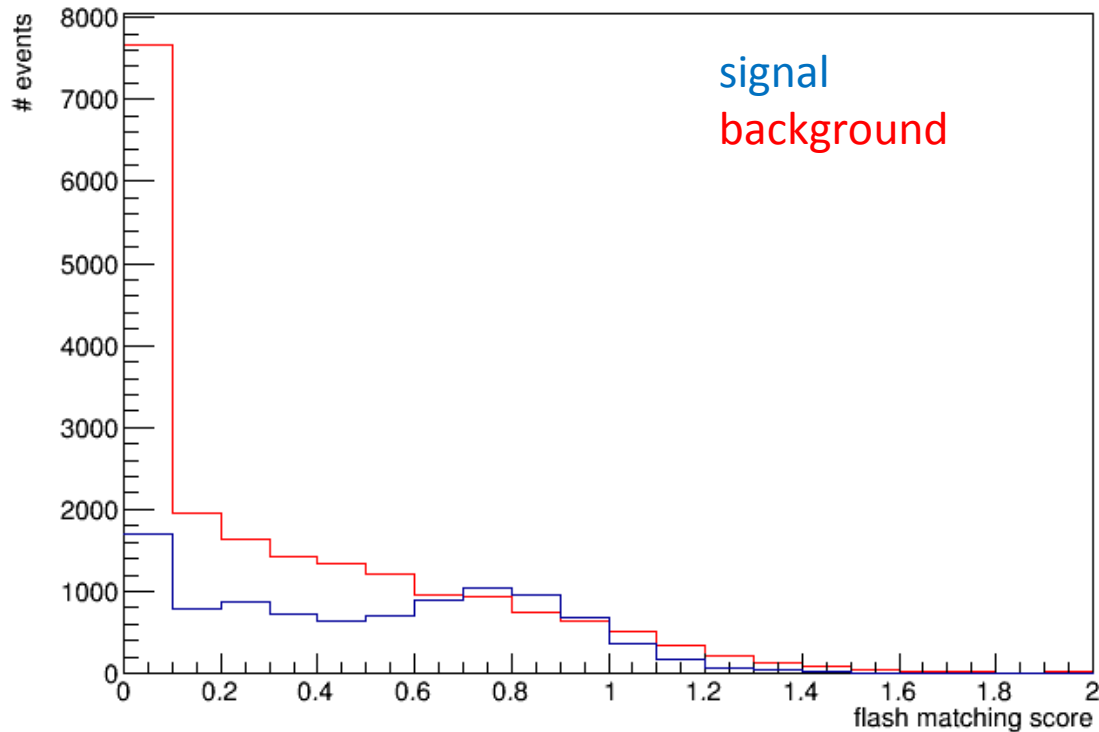
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Measured photoelectrons (PE) in each PMT are matched with hypothesis of PE in PMTs from simulation

Best match is chosen with 
$$-\ln L = -\sum_{i=0}^{32} \ln \frac{(H_i(x))^{O_i} e^{-H_i(x)}}{O_i!}$$

minimization of  $-\ln L$  gives  $x_{best}$

Flash matching score = 
$$\frac{1}{-\ln L(x_{best})}$$



No cuts applied

Efficiency 81%

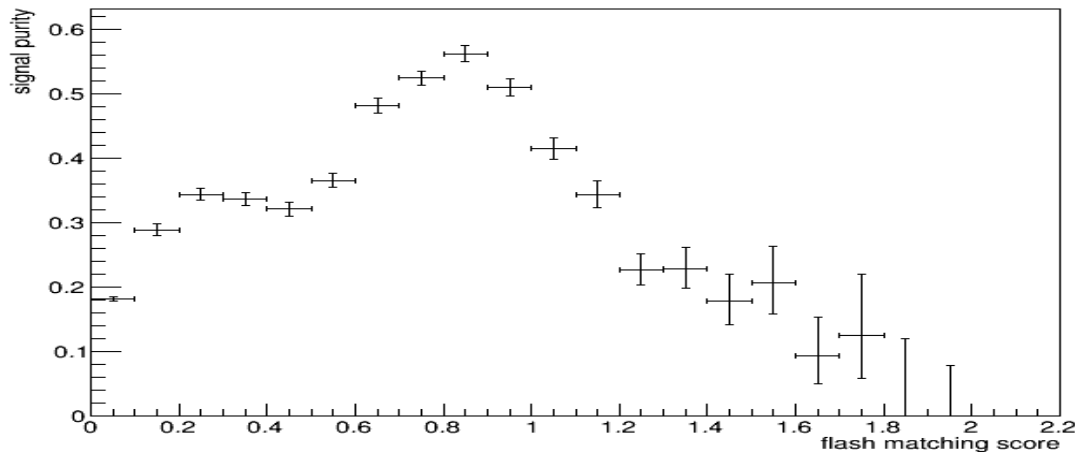
Overall **6208** signal events

-**1170**(flash matching failed)

-**36** (no TPCObjects)

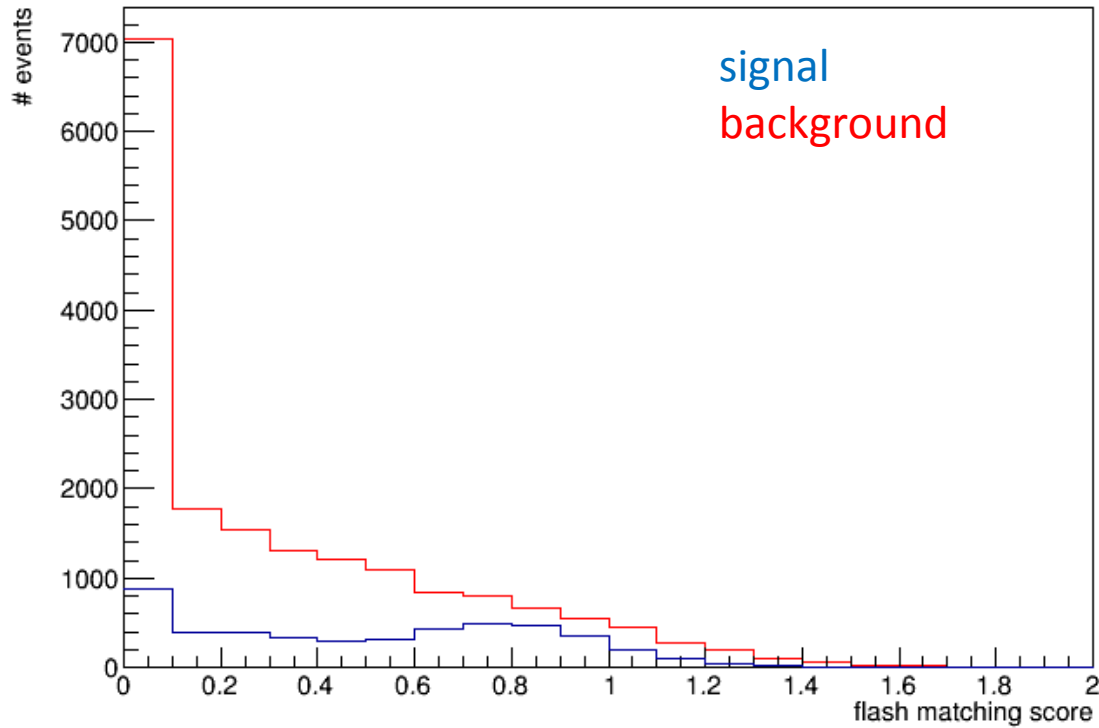
$\Sigma$  **5002**events

Purity 30%



**Signal purity :**

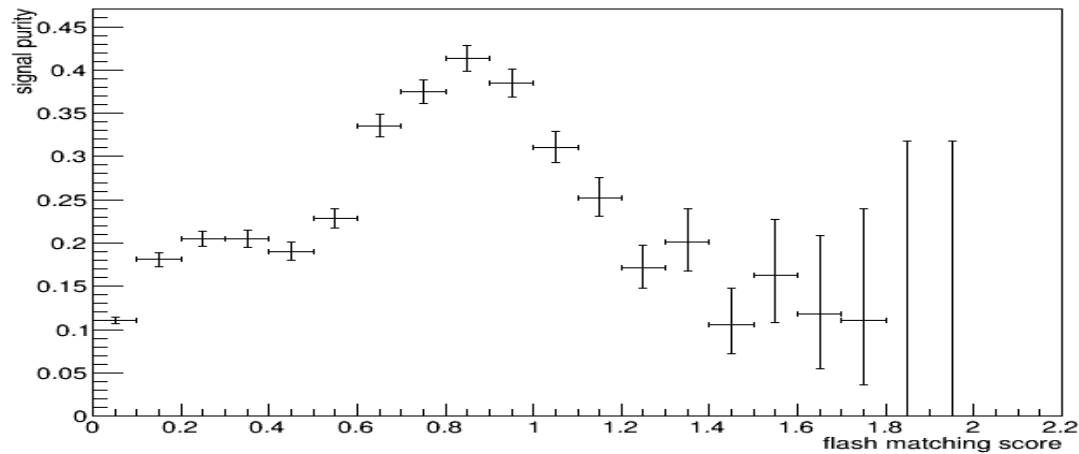
how many events that passed the selection are signal events?



Only flash requirement applied

Efficiency 76%

**4716** signal events kept



**Signal purity :**

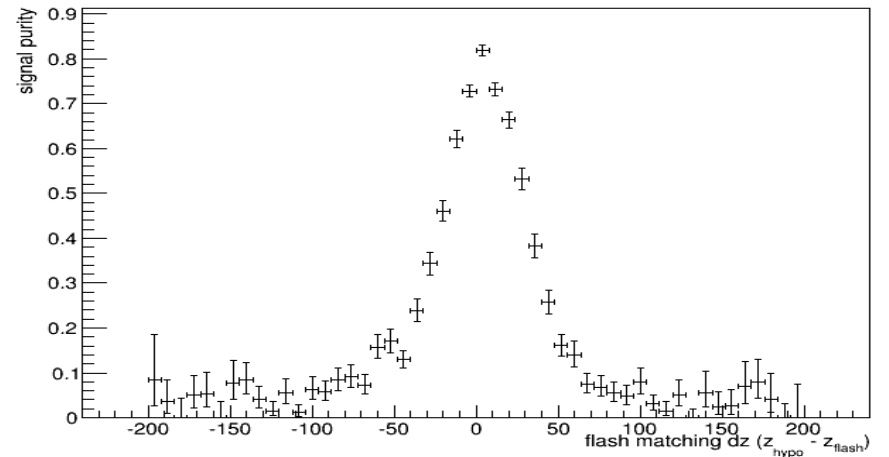
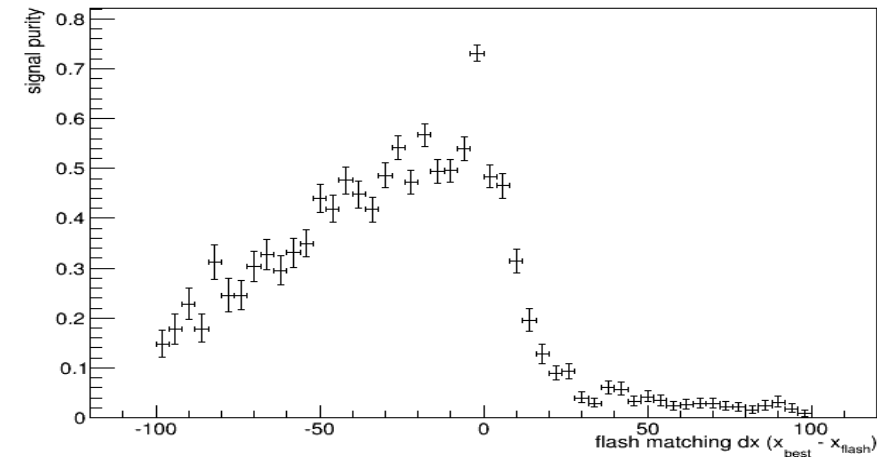
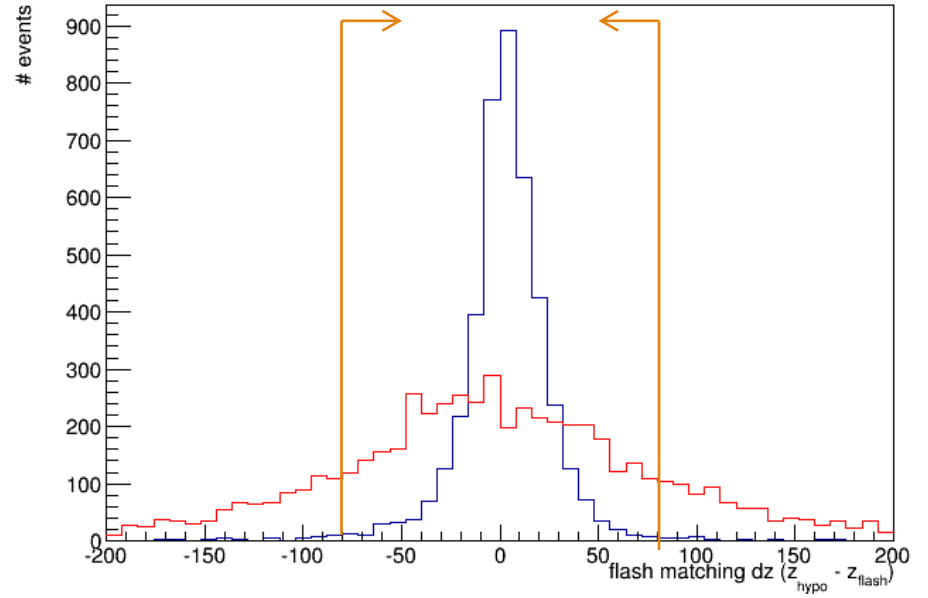
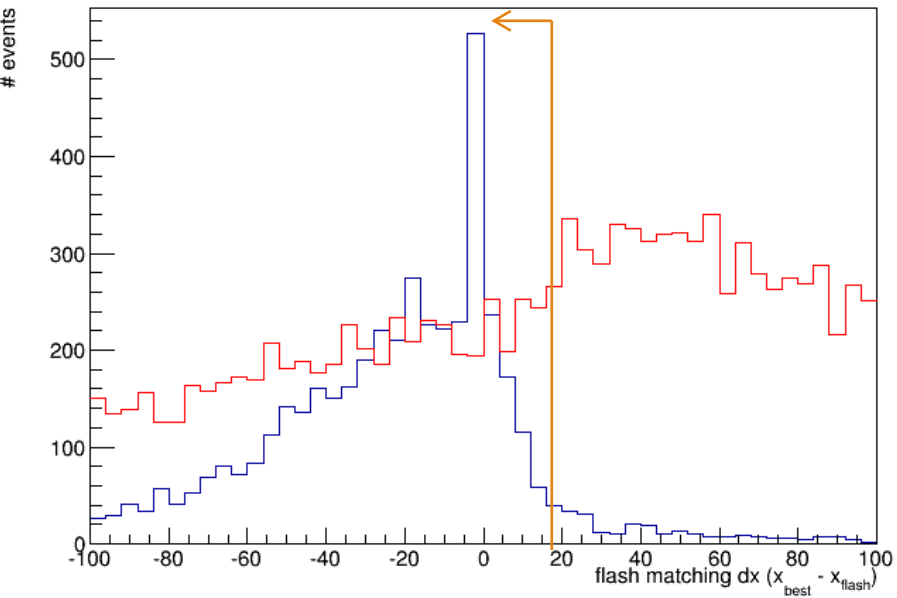
how many events that passed the selection are signal events?

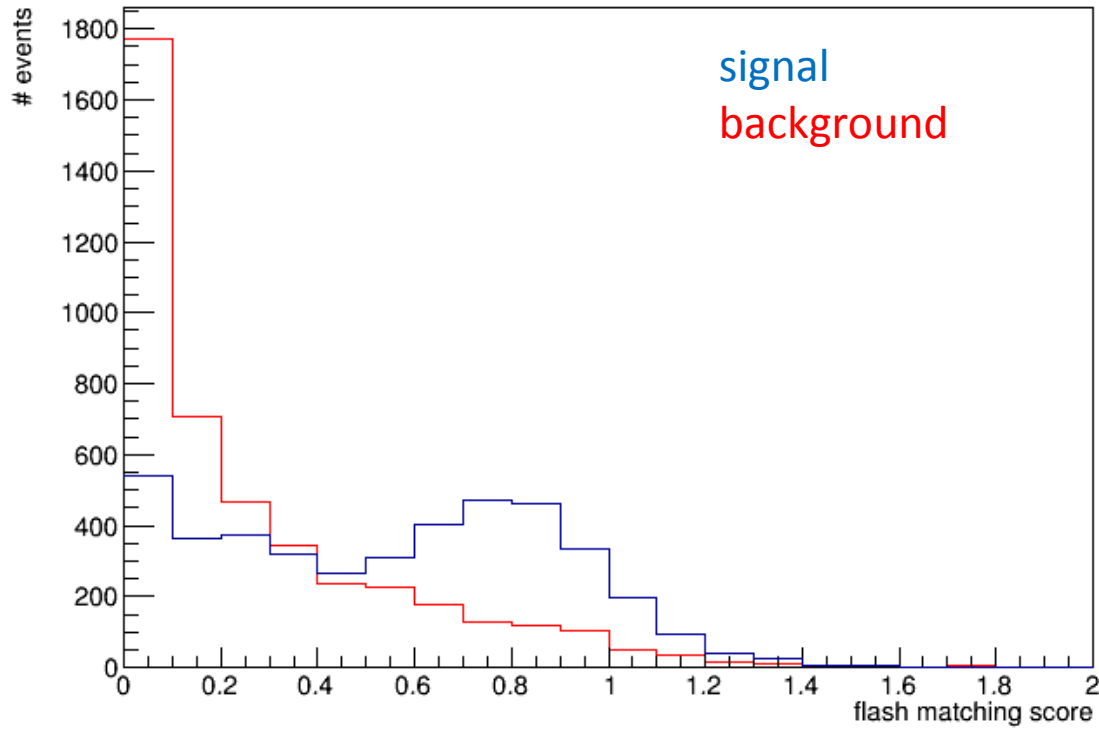
Purity 30%

delta x

signal  
background

delta z

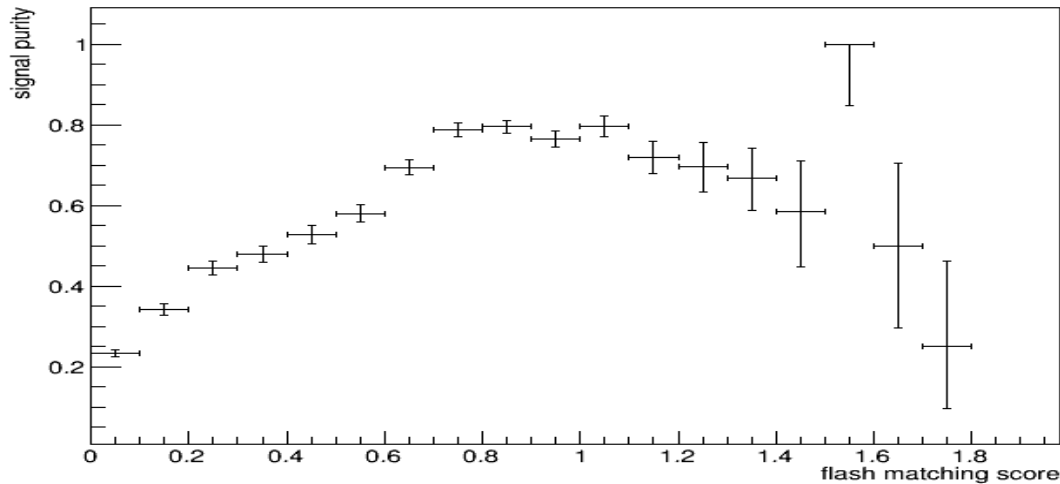


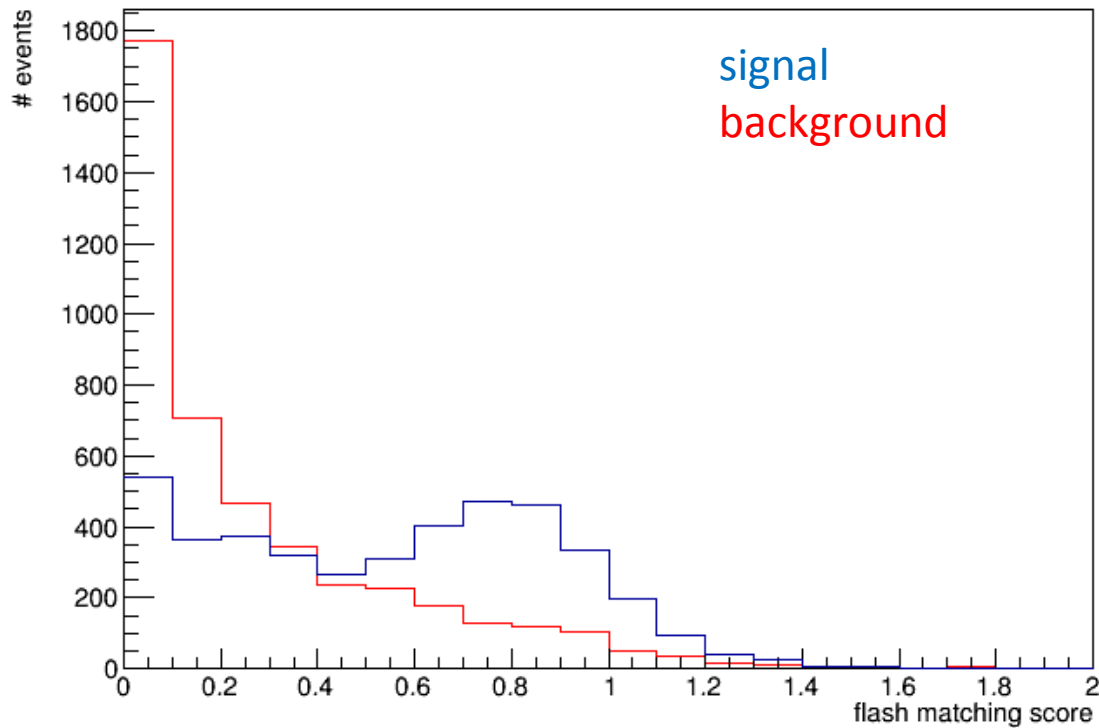


Applied cuts:

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

*Efficiency 68%*  
*Purity 31%*





Applied cuts:

- min track quality 4644
- $\Delta x < 20$  cm 4260
- $\Delta z < 100$  cm 4205

