FASER Liverpool :
May Update (2nd May 2025)

Sinead Eley

ALPtrino : Recap

- Using ABCD approach to estimate background due to geometric muons in signal region
- Consider each energy bin in each region independently
  - I.e. Each bin becomes the signal region in its own ABCD
- Need to account for the number of neutrinos in each bin
  - Correct for this using neutrino MC
- Apply correction factor
  - Need as this uses an inverse timing cut relative to ALPtrino
- Apply both statistical errors and systematic errors to the results
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Systematics

- Different generators used in production of neutrino MC samples
  - EPOS-LHC is the nominal for light hadrons
  - POWHEG+Pythia is the nominal for charm hadrons
- Each generator differs in their theoretical modelling
  - Have other samples from:
    - SIBYL, QGSJET, Pythia-forward & different POWHEG tunes
- Uncertainty given by the spread of the event generator predictions
  - E.g. Do the same calculations on nominal and uncertainty samples
    - Take the difference between the nominal result and each of the systematic results
    - Find the largest difference
      - That's your uncertainty
    - This is done for both light and charm, respectively
    - Combine light and charm in quadrature to get overall systematic uncertainty

Correction Factor

- As inverted timing cut is applied need to correct for this
- Using a correction factor ‘f’, can apply this to data to get an overall prediction
  - f = ratio of events that pass a cut of timing > 20 pC, to those that are < 20 pC
  - $f = \frac{N_{>20pC}}{N_{<20pC}}$
- Factor is calculated for each year of data independently and applied before combining all years to get a total prediction

Timing Correction Factor [2022 Data]

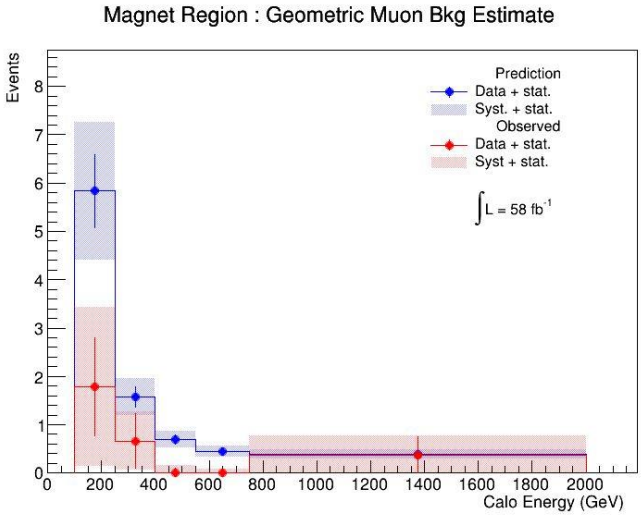
Timing Cut	Events Passing Cut	Timing Correction Factor	Stat. Err
Over 20 pC	41530425	–	–
Under 20 pC	109643233	–	–
Timing Factor	–	0.379	$6.902e^{-05}$

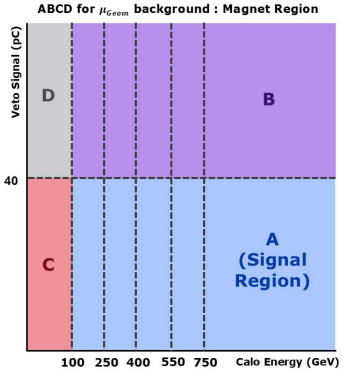
Timing Correction Factor [2023 Data]

Timing Cut	Events Passing Cut	Timing Correction Factor	Stat. Err
Over 20 pC	48522011	–	–
Under 20 pC	129812028	–	–
Timing Factor	–	0.374	$6.289e^{-05}$

Magnet Region

- Magnet Region Cuts:
  - PS1 nMIP >10
  - PS ratio < 1.5
- Prediction is a lot larger than observed in bin 1
  - Perhaps another background that needs to be taken into account
- Higher energy bins
  - <1 event predicted and 0 events observed
- Final bin prediction and observed agree very nicely





Geometric Muon ABCD - Magnet Region [2022&2023 Data]

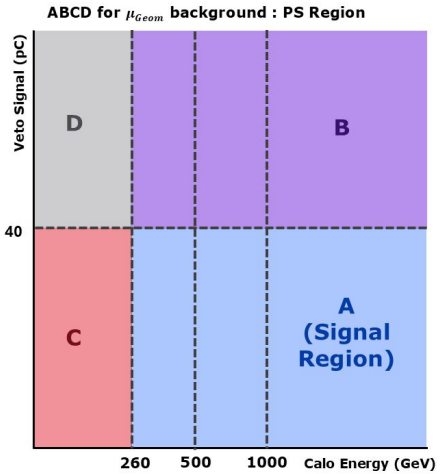
ABCD Region	Calo Energy (GeV)	Data	ν_{MC}	Data - ν_{MC}	Prediction	Stat. Err	ν Syst. Err [Upper]	ν Syst. Err [Lower]	Observed	Stat. Err	ν Syst. Err [Upper]	ν Syst. Err [Lower]
A_0	100	–	–	–	5.837	0.757	0.476	1.114	1.787	1.013	0.407	1.222
A_1	250	–	–	–	1.576	0.205	0.128	0.301	0.662	0.563	0.143	0.141
A_2	400	–	–	–	0.699	0.092	0.057	0.133	0	0.099	0.058	0.111
A_3	550	–	–	–	0.448	0.059	0.037	0.085	0	0.050	0	0.059
A_4	750	–	–	–	0.392	0.052	0.032	0.075	0.377	0.381	0.004	0.060
B_0	100	19000	5.380	18994.620	–	–	–	–	–	–	–	–
B_1	250	5130	1.346	5128.654	–	–	–	–	–	–	–	–
B_2	400	2274	0.528	2273.472	–	–	–	–	–	–	–	–
B_3	550	1458	0.298	1457.702	–	–	–	–	–	–	–	–
B_4	750	1277	0.238	1276.762	–	–	–	–	–	–	–	–
C	25	78	6.840	71.160	–	–	–	–	–	–	–	–
D	25	87122	15.068	87106.932	–	–	–	–	–	–	–	–

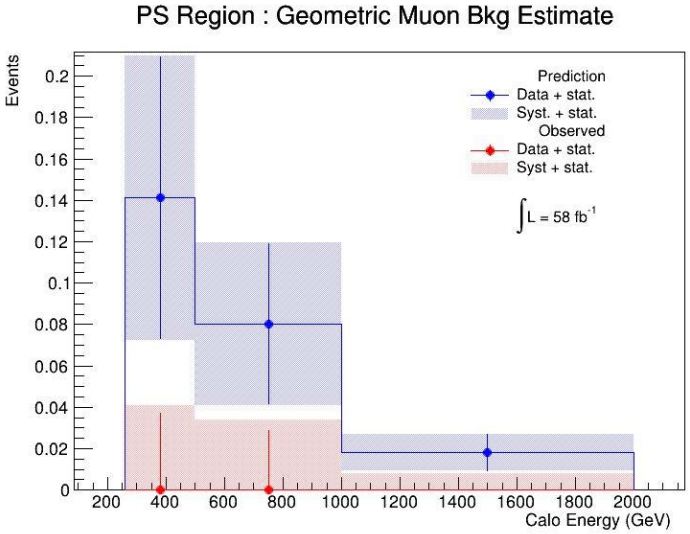
Note: Prediction and Observed values have been multiplied by a correction factor f

$$f^{2022} = 0.379,\ f^{2023} = 0.374,$$

PS Region

- PS Region Cuts:
  - PS1 nMIP >10
  - PS ratio > 4.5
- Less than 1 event predicted in PS region
  - 0 events observed





Geometric Muon ABCD - PS Region [2022&2023 Data]

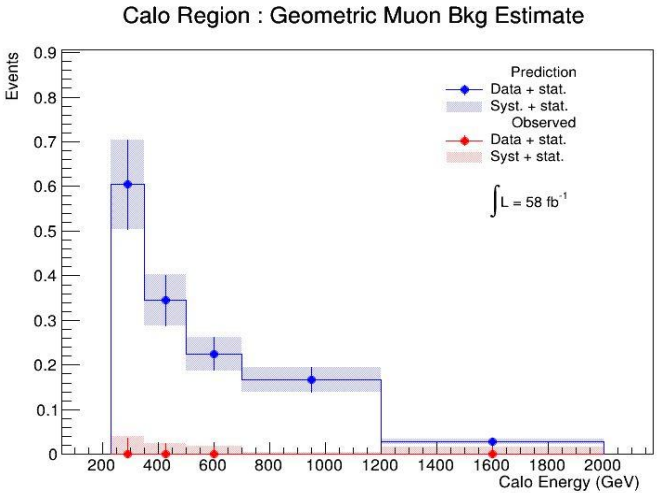
ABCD Region	Calo Energy (GeV)	Data	ν_{MC}	Data - ν_{MC}	Prediction	Stat. Err	ν Syst. Err [Upper]	ν Syst. Err [Lower]	Observed	Stat. Err	ν Syst. Err [Upper]	ν Syst. Err [Lower]
A_0	260	–	–	–	0.141	0.068	0.010	0.006	0	0.037	0.008	0.015
A_1	500	–	–	–	0.080	0.039	0.005	0.003	0	0.029	0.006	0.017
A_2	1000	–	–	–	0.018	0.009	0.001	0.001	0	0	0	0.008
B_0	260	1188	0.130	1187.870	–	–	–	–	–	–	–	–
B_1	500	675	0.050	674.950	–	–	–	–	–	–	–	–
B_2	1000	153	0.017	152.983	–	–	–	–	–	–	–	–
C	25	5	0.234	4.766	–	–	–	–	–	–	–	–
D	25	15071	2.455	15068.545	–	–	–	–	–	–	–	–

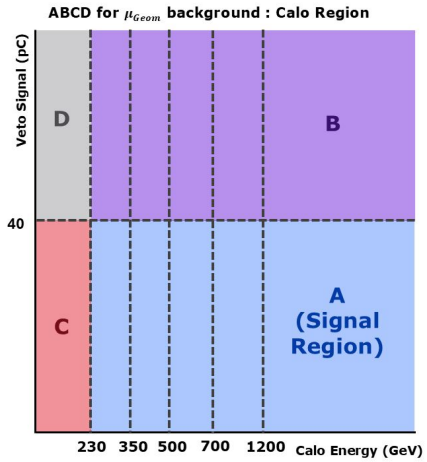
Note: Prediction and Observed values have been multiplied by a correction factor f

$$f^{2022} = 0.379,\ f^{2023} = 0.374,$$

Calo Region

- Calo region cuts:
  - PS1 nMIP < 10
- Less than 1 event predicted in all bins
  - 0 events observed in all bins





Geometric Muon ABCD - Calo Region [2022&2023 Data]

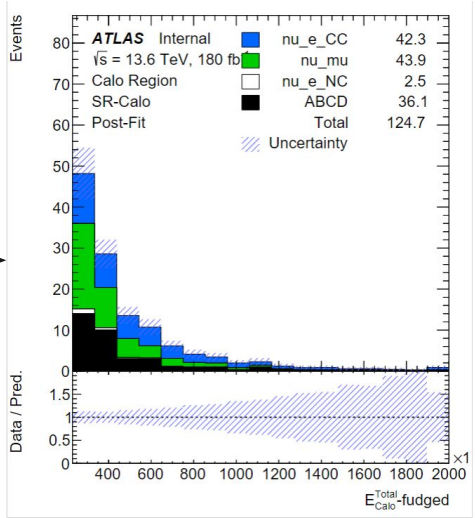
ABCD Region	Calo Energy (GeV)	Data	ν_{MC}	Data - ν_{MC}	Prediction	Stat. Err	ν Syst. Err [Upper]	ν Syst. Err [Lower]	Observed	Stat. Err	ν Syst. Err [Upper]	ν Syst. Err [Lower]
A_0	230	–	–	–	0.604	0.100	0.007	0.005	0	0.037	0.012	0.008
A_1	350	–	–	–	0.345	0.057	0.004	0.003	0	0.023	0.008	0.004
A_2	500	–	–	–	0.225	0.037	0.003	0.002	0	0.017	0.004	0.009
A_3	700	–	–	–	0.167	0.028	0.002	0.001	0	0	0	0.004
A_4	1200	–	–	–	0.028	0.005	0.000	0.000	0	0.017	0.004	0
B_0	230	5858	0.058	5857.942	–	–	–	–	–	–	–	–
B_1	350	3340	0.021	3339.979	–	–	–	–	–	–	–	–
B_2	500	2184	0.012	2183.988	–	–	–	–	–	–	–	–
B_3	700	1623	0	1623	–	–	–	–	–	–	–	–
B_4	1200	275	0	275	–	–	–	–	–	–	–	–
C	25	38	0.396	37.604	–	–	–	–	–	–	–	–
D	25	136909	3.631	136905.369	–	–	–	–	–	–	–	–

Note: Prediction and Observed values have been multiplied by a correction factor f

$$f^{2022} = 0.379,\ f^{2023} = 0.374,$$

TREx Fitter

- Learning how to use TREx fitter to get significance and include elec nu CC signal (with elec NC and muon nu as background)
  - Can also add geom muon ABCD as a background
- Got this working for me locally
  - Can now plot a significance for all regions
  - There is an ability to add an ABCD estimate for background too
    - Will add the correct binning for this to the fitter
      - As well as ABCD data
    - Potentially will add a tree write out with the needs of TREx in mind to the RDF

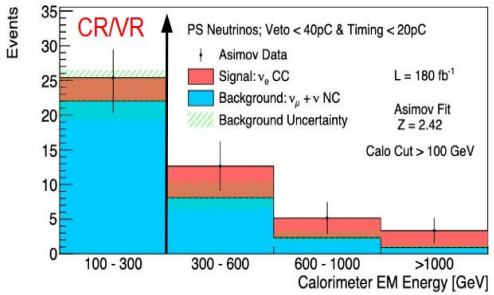


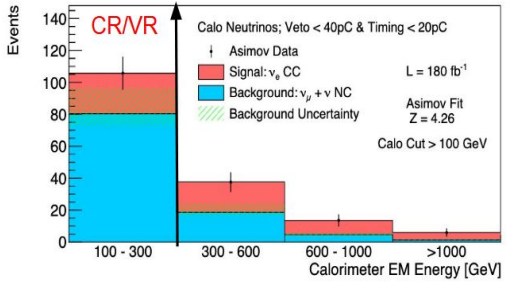
Muon Neutrino Background

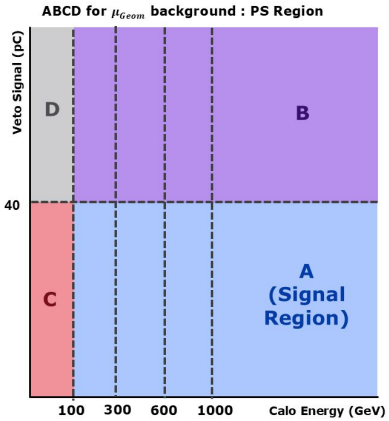
- After the Physics meeting a few weeks ago, the ALPtrino team have been coming up with a plan of attack for using a data driven method to account for muon neutrino background
- With the plan we have decided to use:

$$\Phi_{data}\left(\frac{q}{p},\eta\right) = \Phi_{MC}\left(\frac{q}{p},\eta\right) \cdot \text{CORRECTION}\left(\frac{q}{p}\right)$$

  - Use electronic neutrino result as flux measurement
  - Need a data to MC ratio (i.e. repeat plot from electronic neutrino analysis with 24' data)
  - Binning matching electronic neutrino analysis
    - Would have to recalculate geom. Muon neutrinos for this binning
    - Use 100-300 bin as a CR
  -







Summary

- ABCD method seems to work well
  - Will likely need adjusting once control regions and signal regions are decided on
    - These will be necessary for a data driven muon neutrino background estimate
  - Can adjust regions in ABCD accordingly
- Can run TREx Fitter now to get significance for combination of regions
  - Using John's extra script to extra ABCD background can also get the significance taking into account the ABCD for a region