UNIVERSITY OF TEXAS ARLINGTON

Young ICARUS Flash Talk

ICARUS COLLABORATION MEETING

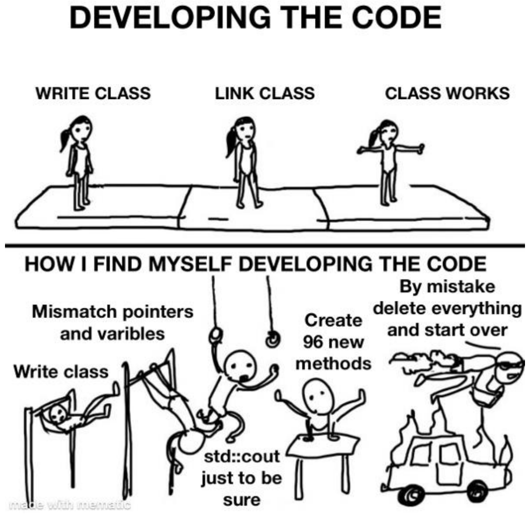
About me

Background:

- BSc @ KCL with Dr. Katori's supervision for my 3rd year Project
  - "Neural Binary Classifier for High Energetic Muon Events"
- Currently working with Dr. Castillo @ UTA on "ν Flux Uncertainties Mitigation"

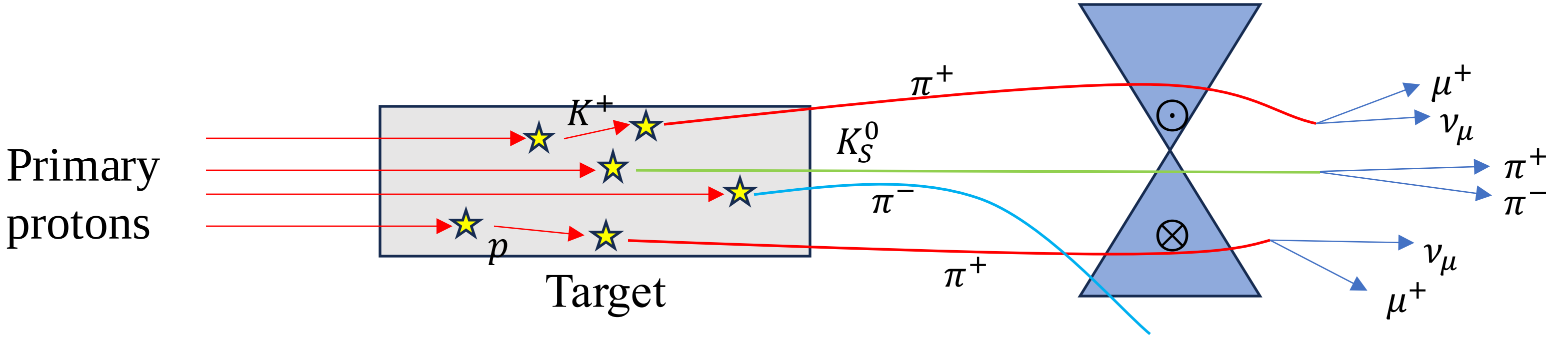
Interests:

- I love sports and motorsports in general
  - I played rugby and football for years and currently rock climb
- I quite enjoy coding [swinging between imposter syndrome and god complex]
  - I'm working on ML implementations and C++ code development
- I also make memes [not professionally, unfortunately]



Hadron Production I

- Some neutrino oscillation experiments uses accelerator particle beams to generate dense fluxes of neutrino via hadronic production
- Neutrinos are produced by the in-flight decay of hadrons created by high (low) energy proton beams for long (short) baseline experiments

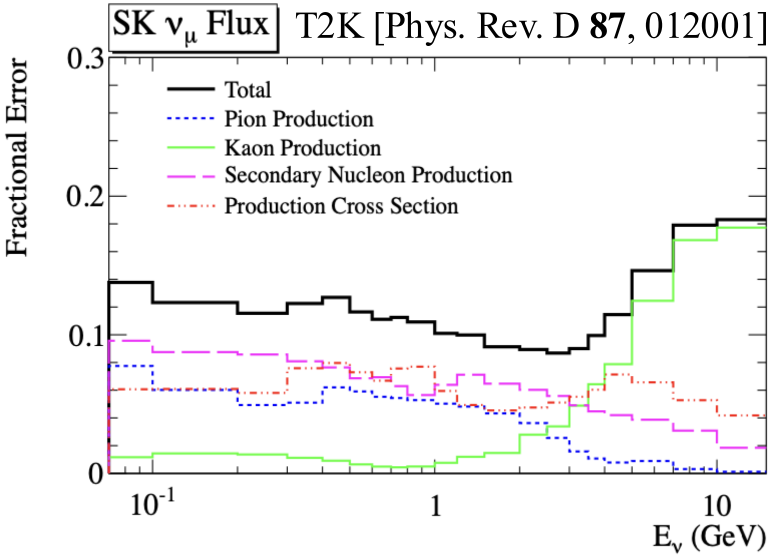


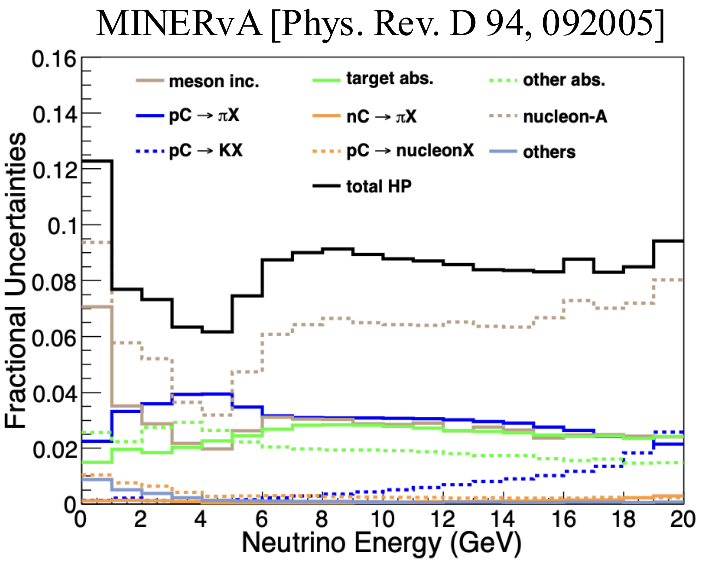
- Hadronic production theory is yet to be complete, hence measurement are key to better understand it:
  - Primary interactions in the target $p + C/Be \rightarrow \pi^{\pm}$ and $K^{\pm}$ → Primary contribution to the flux
  - Secondary interactions with beamline materials
  - Secondary interaction of $\pi^{\pm}$ and $K^{\pm}$ in the target itself → Important contribution to the uncertainties

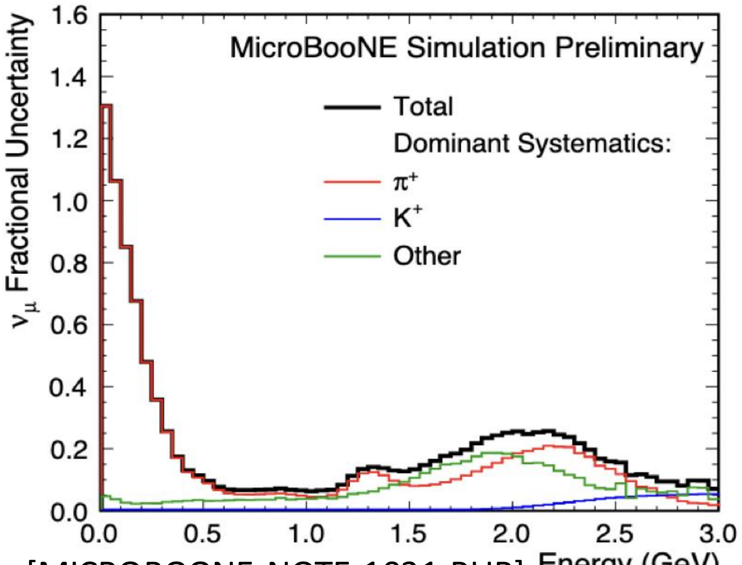
Flux Uncertainties I

- Flux uncertainties for accelerator neutrino measurements are at the level of 10%
  - Leading systematic uncertainty in neutrino measurements
  - Dominant uncertainties come from secondary interactions in materials (target, horn, etc.) at low energies

- Flux is a limiting systematic for all neutrino cross section measurements by current experiments







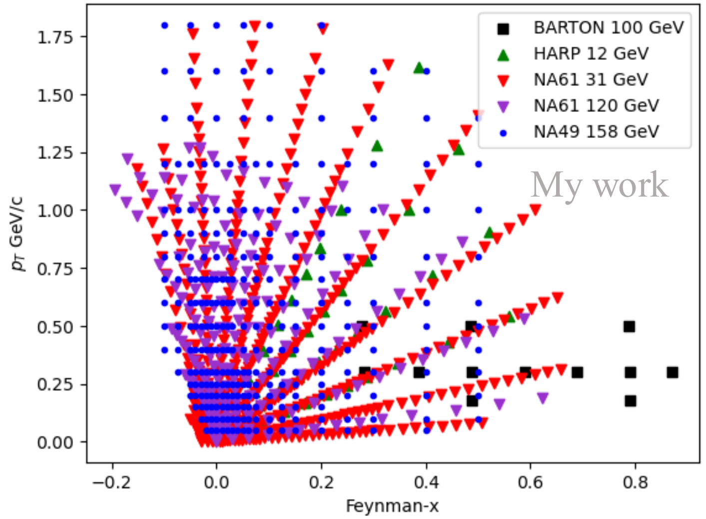
[MICROBOONE-NOTE-1031-PUB]

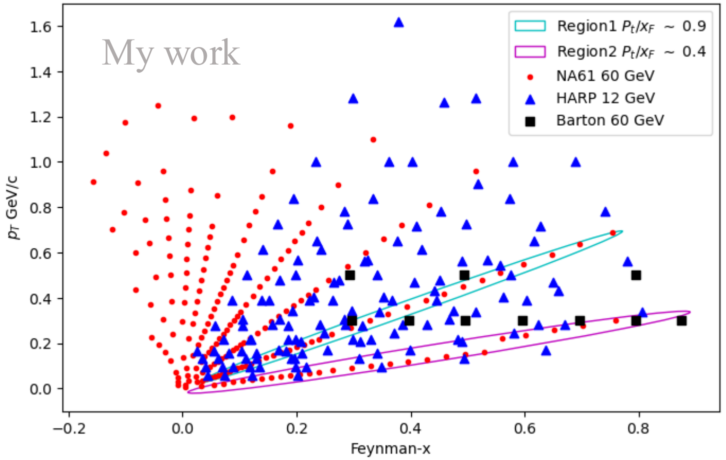
Carbon target, fully constrained

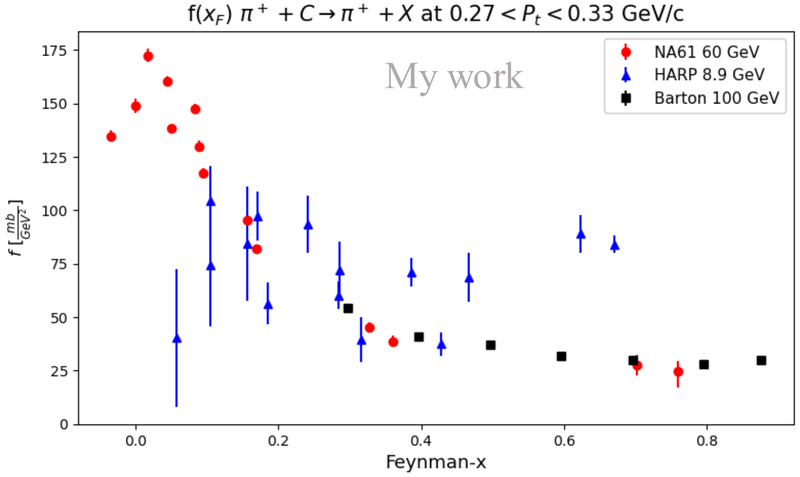
Beryllium target, partially constrained

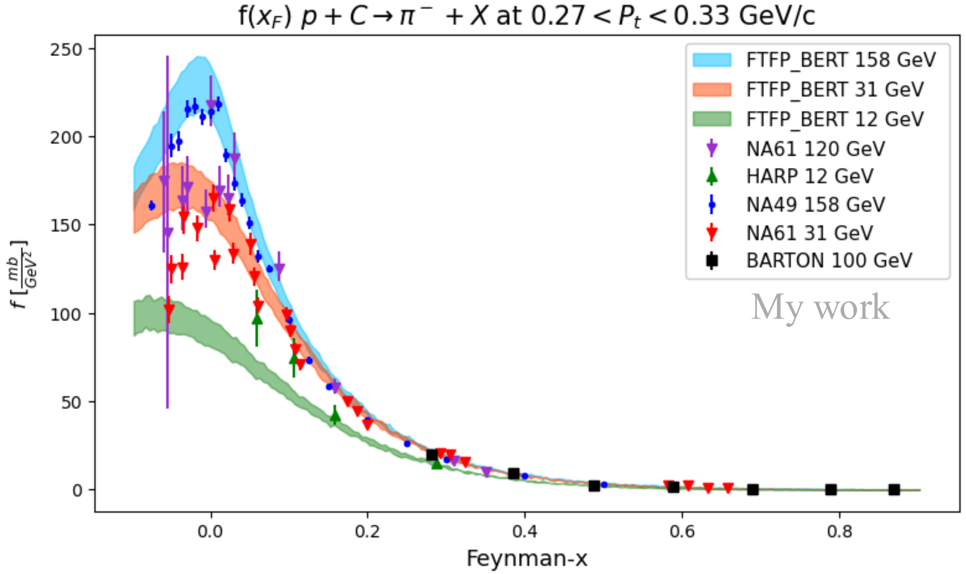
Hadron Production II

- Various experiments have taken data of hadronic cross sections, but newer and older show tensions
- Cross sections can be expressed as invariants wrt beam energy, and plotted as function of transverse momentum and Feynman-x
- The coverage of the phase space {xf,pt} is limited by the available data, and further exploration is needed to reduce the flux uncertainties:
    - EMPHATIC has the potential to explore low energy regions, crucial for SBN









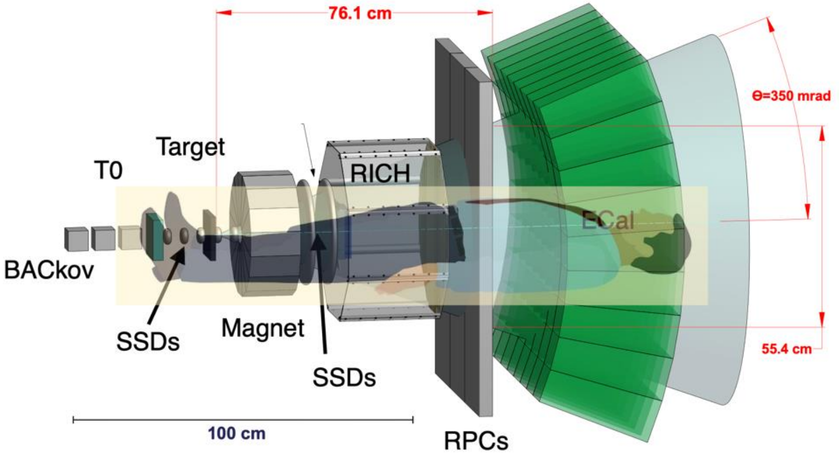
EMPHATIC

- **E**xperiment to **M**easure the **P**roduction of **H**adrons **A**t a **T**est beam **I**n **C**hicagoland

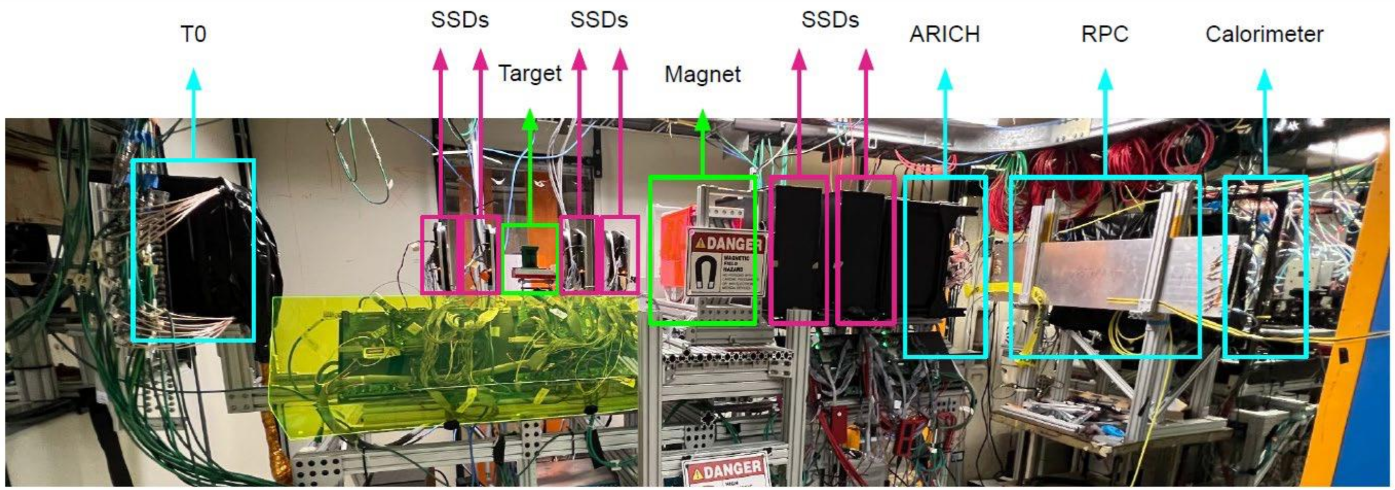
- Table-top size experiment, focused on hadron production measurements with p_{beam}< 15 GeV/c, but will also make measurements with beam from 20-120 GeV/c

- Present at FNAL Test Beam Facility(FTBF), utilizes secondary proton beam, composed of different particles

- It will measure cross sections of hadron production in many materials, for neutrino fluxes:
  - Primaries (proton on target)
  - Secondaries (hadrons on target)

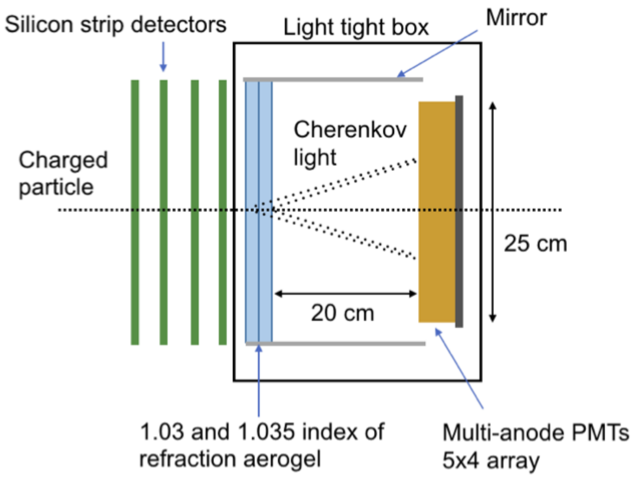


Experimental set up [human for scale][1]

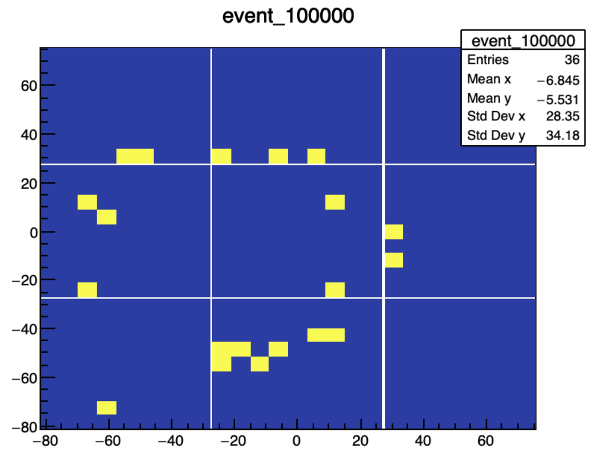


ARICH

[paper]



- I have been working on the ARICH, **A**erogel **R**ing-**I**maging **Ch**erenkov detector
- ARICH utilizes 2 aerogel to focus the Cherenkov radiation, used for identification of forward particles with momenta above ~ 2 GeV/c.
- The first aerogel has n = 1.026 while the second has n = 1.03, focusing the ring onto the detective plane
- At first the ARICH detector used 3x3 array multi-anode PMTs (Hamamatsu R12700)
    - 576 channels
- Each channel typically detects 1 or 0 energy deposits units which are then used to reconstruct and analyze the event
- I have been working on simulation and digitization art modules

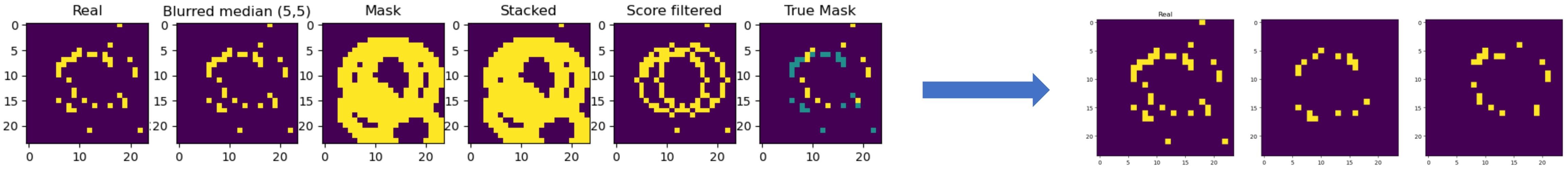


Pion @ 6 Gev/c

ARICH Reconstruction

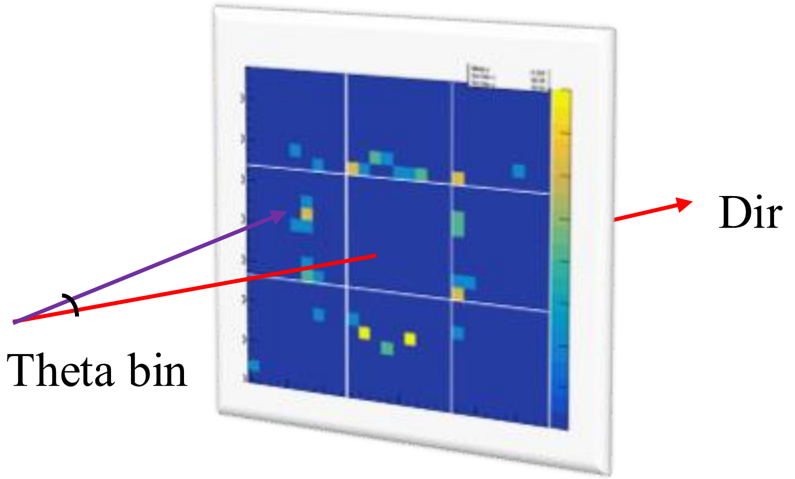
The Reconstructed variables are: Single Rings, PID [best Hypothesis] and Cherenkov angle [median extraction]

- Single Rings: using Hough Circle Transformation is possible to fit multiple circles to an "image", using these circles as intensity masks it's possible to select the best fitting and therefore split overlapping rings into single ones



- PID calculated per particle hypothesis that has the lowest LogLikelihood based on
  - Momentum (track bending, SSDs)
  - Pos-Dir of the charged particle (SSDs)
  - ARICH hits distribution

- Cherenkov angle is reconstructed as the mode of the vector of the aperture angle between particle dir and single bin direction



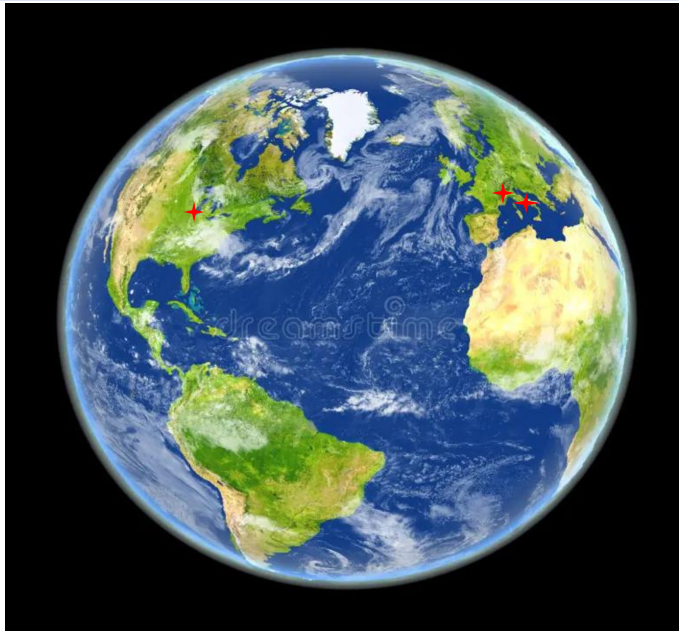
- Machine Learning methods for PID/Cherenkov angle are being studied

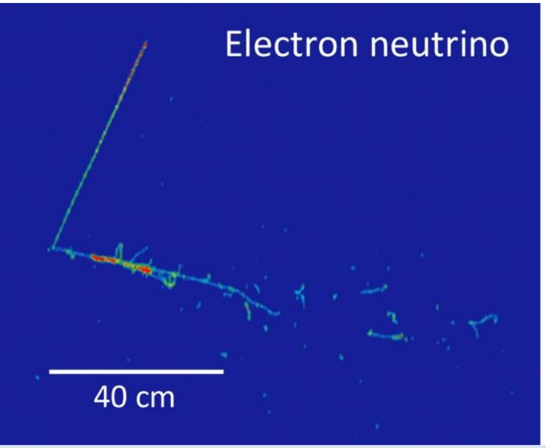
ICARUS Imaging Cosmic And Rare Underground Signals

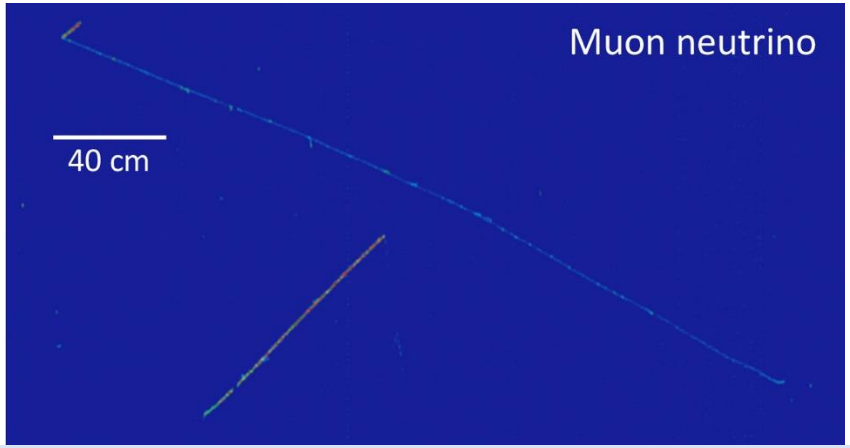
ICARUS, the furthest of the SBN program's detectors, contains multiple LArTPCs in 2 independent cryostats

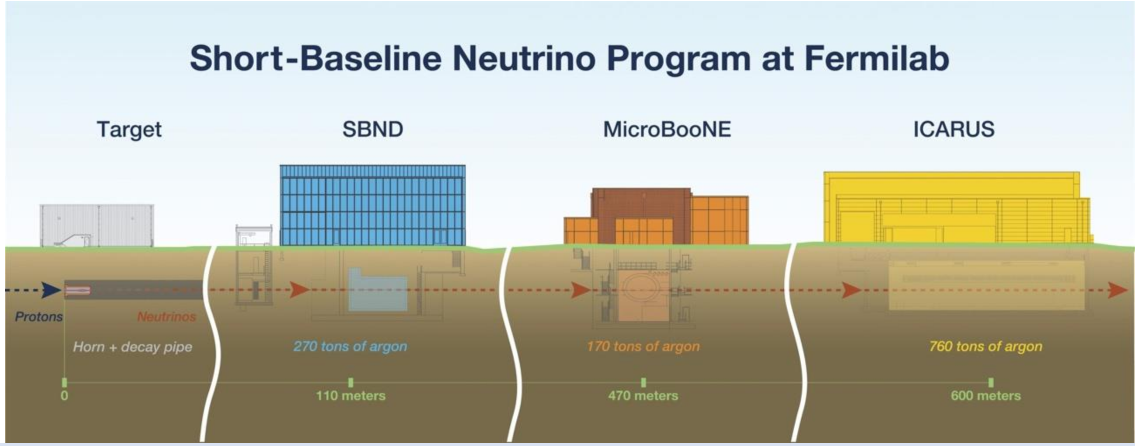
Its position allows it to be able to observe events from both NuMI and BNB, the Fermilab beams, exploring angular dependence for oscillation fits

My current and future work will focus on inclusive ν events, select ν_μ and ν_e events simultaneously to explore deeply the ν_e appearance using background control sample which does not overlap to each other.







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Back ups

Calculations

- The original article by R. Feynman, "Very high-energy collisions of hadrons", published on Phys. Rev. Lett. 23, 1415
- In this article, the existence of an invariant quantity called Feymann-X has been defined

$$x_f = \frac{2p_z^*}{E^*}$$

where * has been used to identify the CoM frame

$$x_f = \frac{2\gamma(p_z^L - \beta E^L)}{E^*}$$

where L represents the Lab frame

- Differential cross sections can be easily mapped into invariant cross sections cross-pointed wrt x_f and the transverse momentum P_T

- $f = E\frac{d^3\sigma}{d^3p}$ invariant cross section, obtainable from measured diff cross sections

Re: Calculations

- Double diff cross section

$$< f(x_f, P_T) > = \frac{\Delta P \Delta \Omega\ k}{D}$$

where ΔP = size momentum bin, $\Delta\Omega = 2\pi(\cos\theta_{min} - \cos\theta_{max})$, k = measured $\frac{d^2\sigma}{d\Omega dP}$ and D = $\int_{bin}\int_0^{2\pi}\frac{p^2}{E}\sin\theta\ \ dp d\theta d\phi$

- Diff cross section

$$< f(x_f, P_T) > = \frac{\Delta P\ g}{D}$$

where g = measured $\frac{d\sigma}{dp}$

- Multiplicity

$$< f(x_f, P_T) > = \frac{\Delta P \Delta \Theta\ \sigma_{prod}\ m}{D}$$

where m = measured multiplicity, $\Delta\Theta$ = size angle bin, σ_{prod} = production cross section

Error Propagation

- The data have been extrapolated from the articles and root files, and moved to a more convenient format → pandas DataFrame

- Then, using NA61 data as example, the Multiplicity column [Multi] has been used to calculate the invariant cross section [Inv_cross] via the formulae in the previous slides

- The paper provides the error on that **quantity**, to propagate it to the invariant cross, new "virtual" data points have been created by adding/subtracting the corresponding value and then mapped into inv_cross sections

- These **new points** have been considered the higher and lower limit of the inv cross sec

	E_B[GeV]	P_{max}	P_{min}	θ_{max}	θ_{min}	Multi	Error_low	Error_up	P_{Zc}[GeV]	θ_c[mrad]	P_T[GeV]	X_f	Inv_cross	Inv_cross_up	Inv_cross_low
1	60	3.0	1.5	0.01	0.0	0.128	0.113	0.037	2.25	0.005	0.011	0.033	304.020	390.694	37.249
2	60	4.0	3.0	0.01	0.0	0.168	0.059	0.034	3.50	0.005	0.017	0.055	255.185	306.531	164.986
3	60	5.0	4.0	0.01	0.0	0.176	0.035	0.050	4.50	0.005	0.022	0.072	208.150	267.072	167.069
4	60	6.0	5.0	0.01	0.0	0.193	0.036	0.044	5.50	0.005	0.027	0.089	186.717	228.783	151.677
5	60	7.0	6.0	0.01	0.0	0.206	0.033	0.032	6.50	0.005	0.032	0.106	168.258	194.154	141.337

ARICH Reco – Single track PID

The training set has 22k single track events spread over 3 particle species and over momentum between 4-12 GeV/c

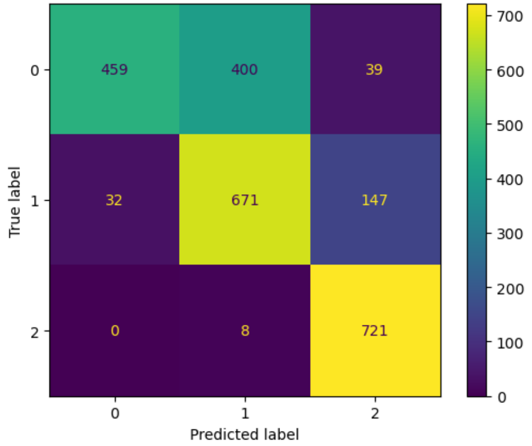
It trained for 10 epochs (1 min), LR 0.001 using a combination of losses to match the minimization of each single output (MSE angle and SCCE for the last)

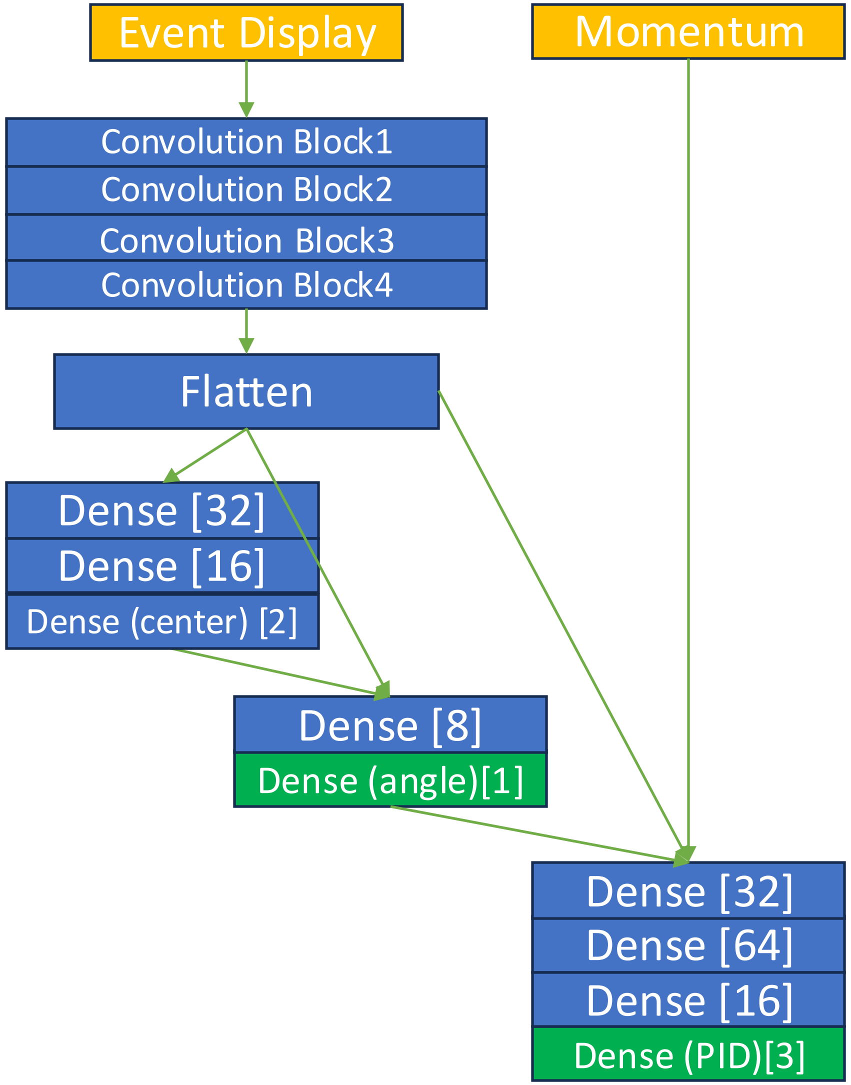
The **test** set contains 2500 events:

- ✓ prediction time ~ 0.38 sec
- ✓ accuracy ~ 74.7%
- ✓ predicts PID & Cerenkov angle

The labels are:

- 0 = pion
- 1 = kaon
- 2 = proton





ARICH Reco – Hough Transform: Gradient Method

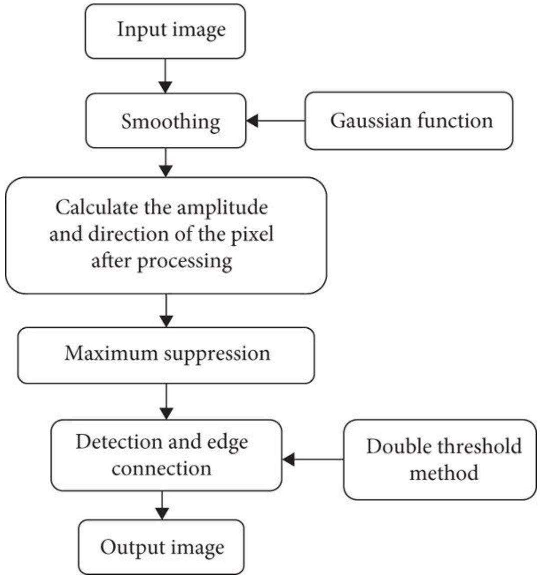
Hough Gradient Method :

1. **Edge Detection**: Using Canny algorithm
   - **Gaussian Blurring**: Smooth the image to reduce noise + gray scale
   - **Gradient Calculation**: Compute the intensity gradients of the image.
   - **Non-Maximum Suppression**: Thin out the edges to get rid of spurious responses.
   - **Double Thresholding**: Determine potential edges.
   - **Edge Tracking by Hysteresis**: Finalize the edges by suppressing weak edges not connected to strong edges.
2. **Sobel Operator:** Convolution using kernels Gx and Gy, highlighting the X, Y edges
3. **Plausible Center Estimation**: For each edge pixel, increase the accumulator's cells that lie in both directions of the gradient, picking the maxima as plausible center
4. **Accumulator for Radii**: Finds most likely radius

This method works better with images than arrays: images usually can have easily 300x300 pixels while arrays are smaller (ours is 24x24) .

This can be fixed using an UpSampling2D, where each pixel becomes of the shape of the upsampling kernel, the next results have been scaled up by a factor of 9, using np.ones(9,9)

Canny Algorithm



-1	0	+1
-2	0	+2
-1	0	+1

Gx

+1	+2	+1
0	0	0
-1	-2	-1

Gy