

SEARCH FOR ELECTRON NEUTRINOS AT THE SND@LHC

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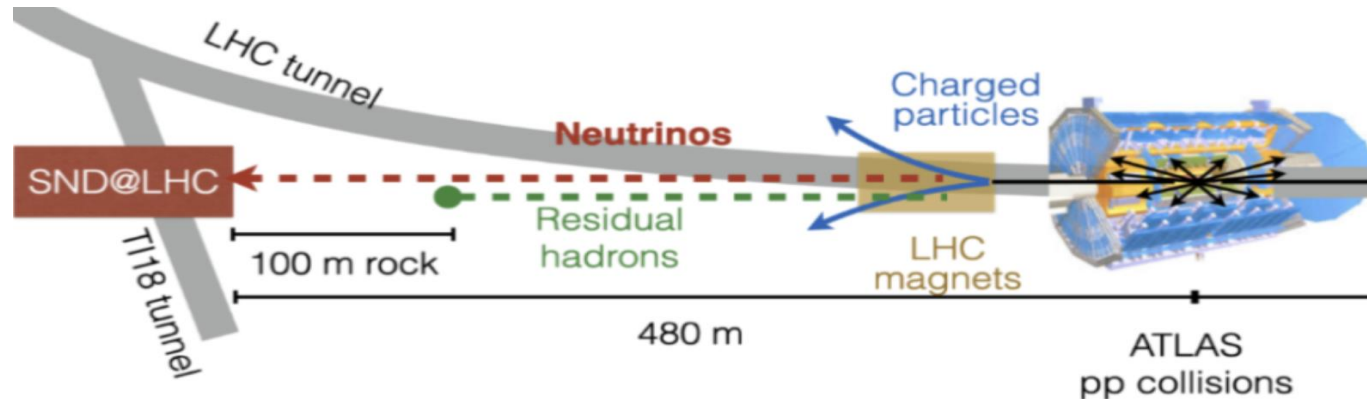
**LIP - Laboratório de Instrumentação
e Física Experimental de Partículas**
Partículas e Tecnologia

Motivation

- Neutrinos are the 2nd most abundant particle in the universe
- Traditionally studied by placing massive detectors near nuclear power plants and underground laboratories
- First observation of neutrinos at colliders achieved recently by FASER and SND@LHC

Standard Model of Elementary Particles

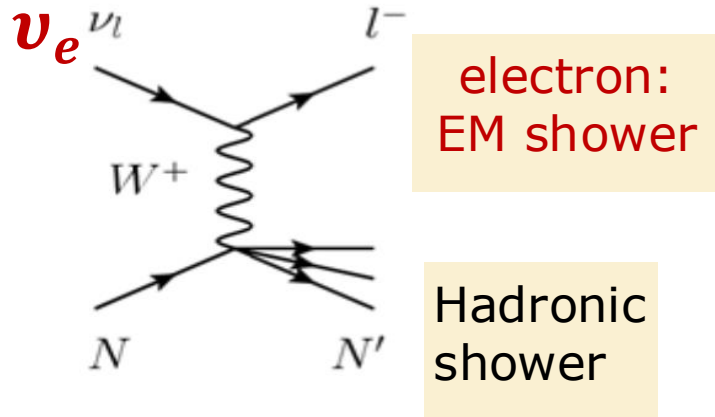
three generations of matter (fermions)						interactions / force carriers (bosons)	
I			II			III	
mass $\approx 2.16 \text{ MeV}/c^2$	$\frac{1}{2}$	$\frac{1}{2}$	$\approx 1.273 \text{ GeV}/c^2$	$\frac{1}{2}$	$\frac{1}{2}$	$\approx 172.57 \text{ GeV}/c^2$	$\frac{1}{2}$
u			c			t	
up			charm			top	
$\approx 4.7 \text{ MeV}/c^2$	$\frac{1}{2}$	$\frac{1}{2}$	$\approx 93.5 \text{ MeV}/c^2$	$\frac{1}{2}$	$\frac{1}{2}$	$\approx 4.183 \text{ GeV}/c^2$	$\frac{1}{2}$
d			s			b	
down			strange			bottom	
$\approx 0.511 \text{ MeV}/c^2$	$\frac{1}{2}$	$\frac{1}{2}$	$\approx 105.66 \text{ MeV}/c^2$	$\frac{1}{2}$	$\frac{1}{2}$	$\approx 1.77693 \text{ GeV}/c^2$	$\frac{1}{2}$
e			μ			τ	
electron			muon			tau	
$< 0.8 \text{ eV}/c^2$	0	0	$< 0.17 \text{ MeV}/c^2$	0	0	$< 18.2 \text{ MeV}/c^2$	0
ν_e			ν_μ			ν_τ	
electron neutrino			muon neutrino			tau neutrino	
						$\approx 125.2 \text{ GeV}/c^2$	$\frac{1}{2}$
						H	
						higgs	
						$\approx 125.2 \text{ GeV}/c^2$	$\frac{1}{2}$
						g	
						gluon	
						$\approx 125.2 \text{ GeV}/c^2$	$\frac{1}{2}$
						γ	
						photon	
						$\approx 125.2 \text{ GeV}/c^2$	$\frac{1}{2}$
						Z	
						Z boson	
						$\approx 125.2 \text{ GeV}/c^2$	$\frac{1}{2}$
						W	
						W boson	



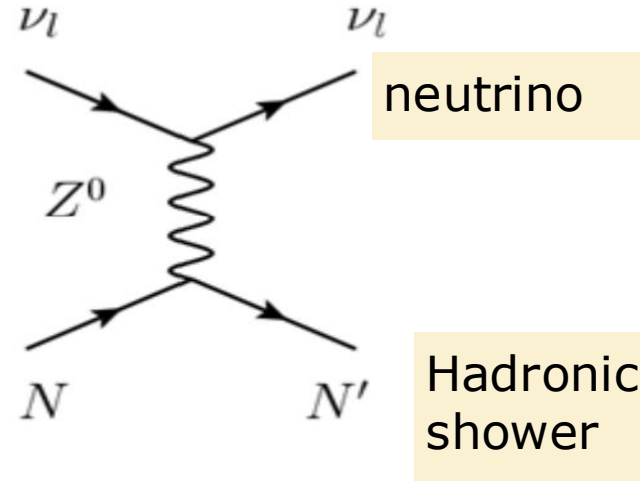
What are neutrinos and how can we identify them?

- Identification using the outgoing lepton – **electron produces an EM shower**
- Separate signal (**charged current**) the background (**neutral current**) interactions using **topological signal selection**

Charged Current (CC)

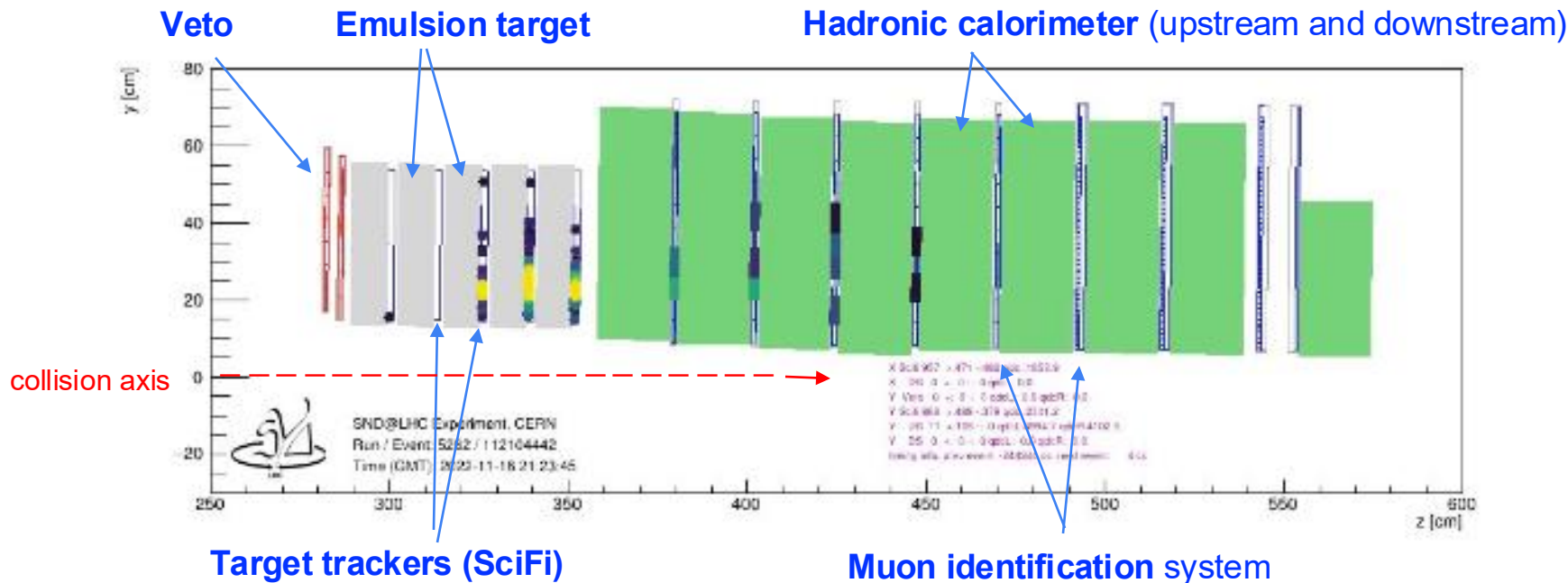
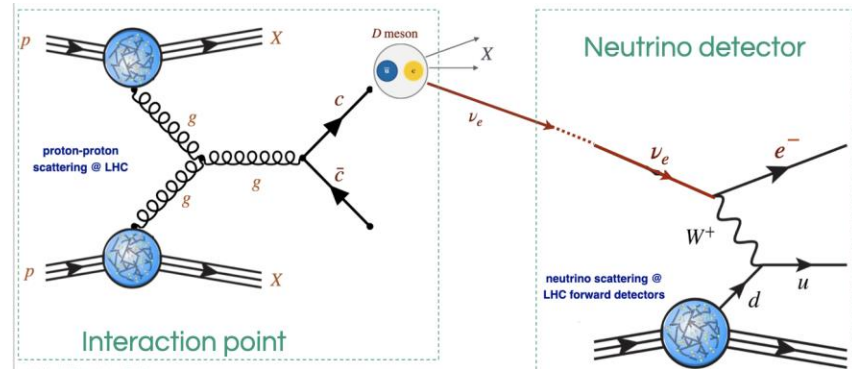


Neutral Current (NC)

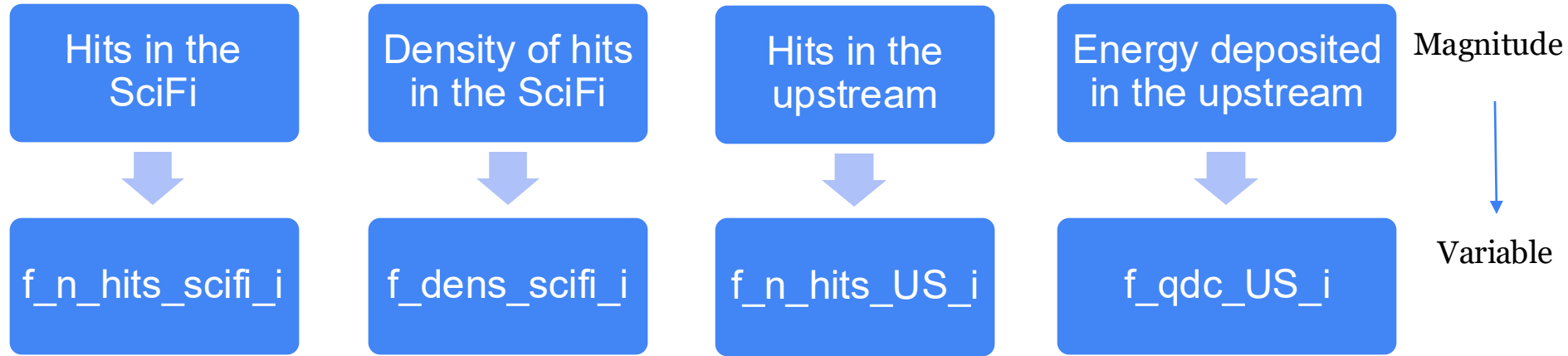


What SND@LHC consists of

- Incoming particles pass through the different detector layers
- Allows to reconstruct the trajectories of the particles



Selection variables



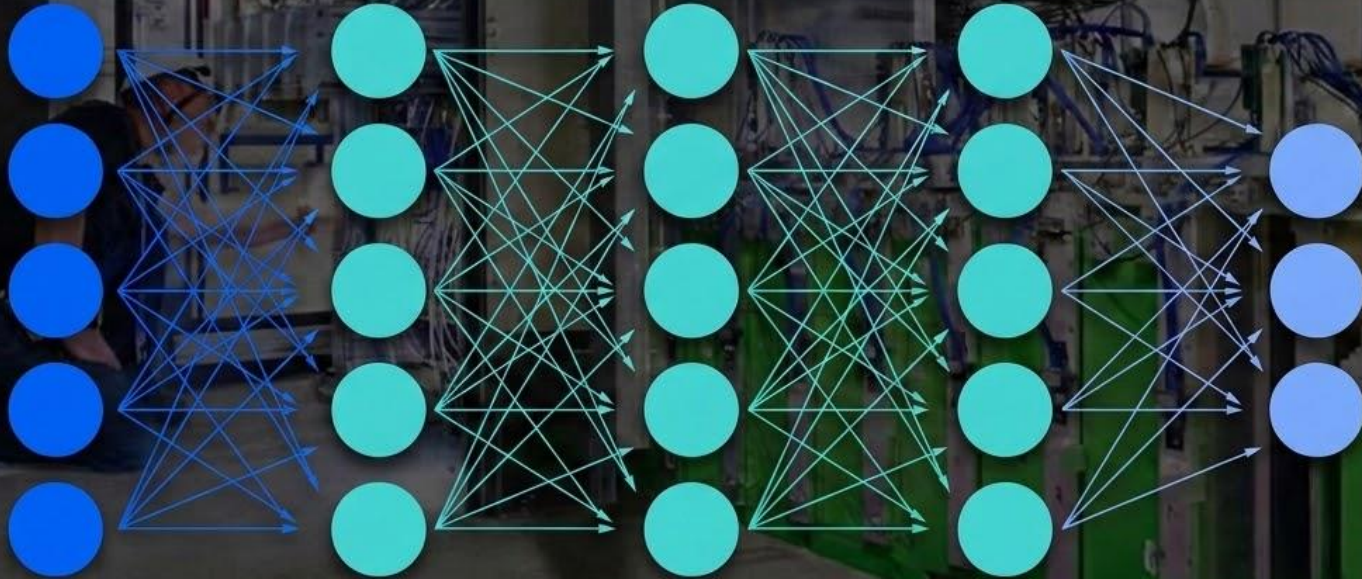
- Studying these variables we can reconstruct the interaction and **identify the incoming particle!**

Idea: Implementation of neural network in an existing model

Input layer

Multiple hidden layer

Output layer



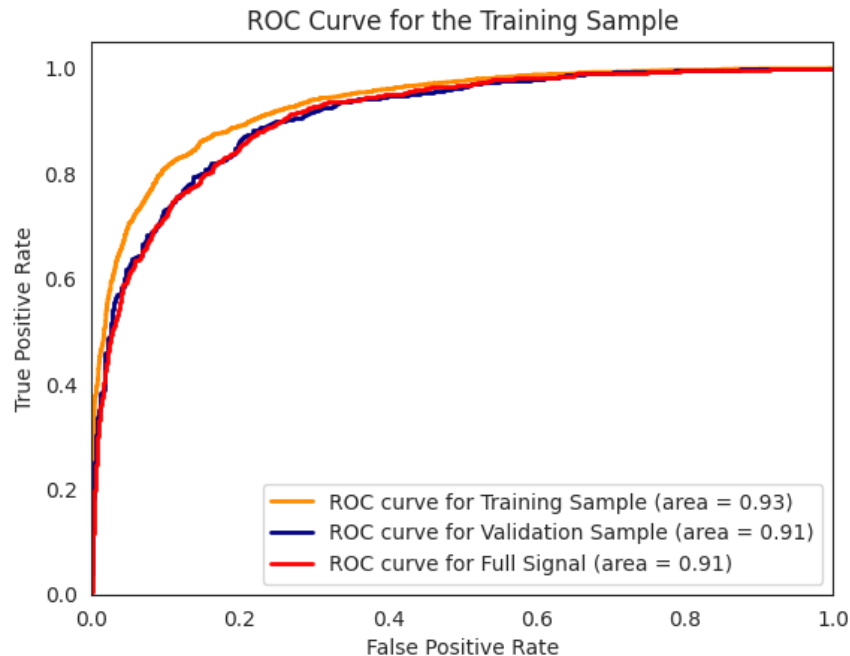
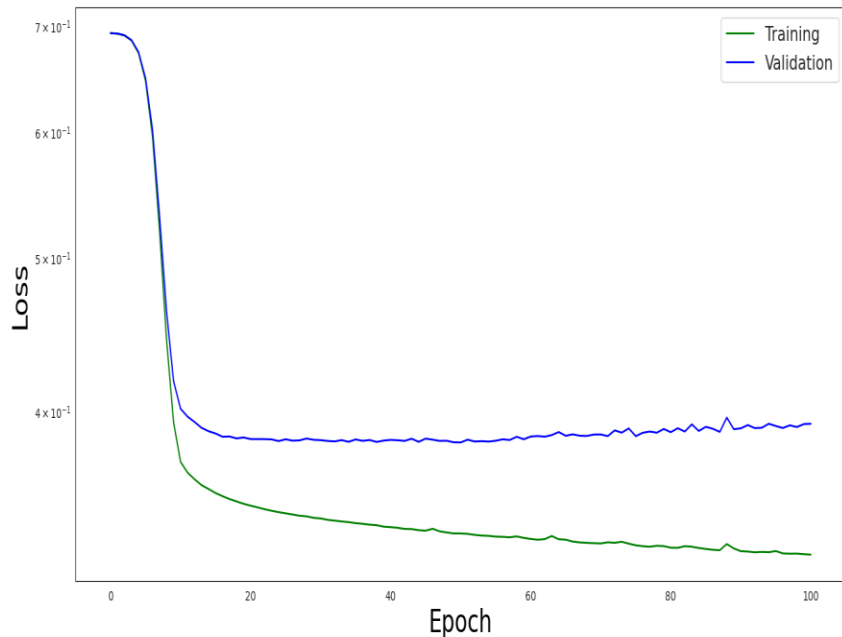
Training options and classifier

Basic structure of the neural network

Binary classifier for signal and background events

- **Input features:** input data coming from MC simulations are standardized before training
- **Activation function:** ReLU $f(x)=\max[0,x]$ in hidden layers
- **Classifier:** sequential dense neural network: 3 hidden layers of depth and a width of 20 units each
- **Output layer:** a single sigmoid neuron returns the event signal probability

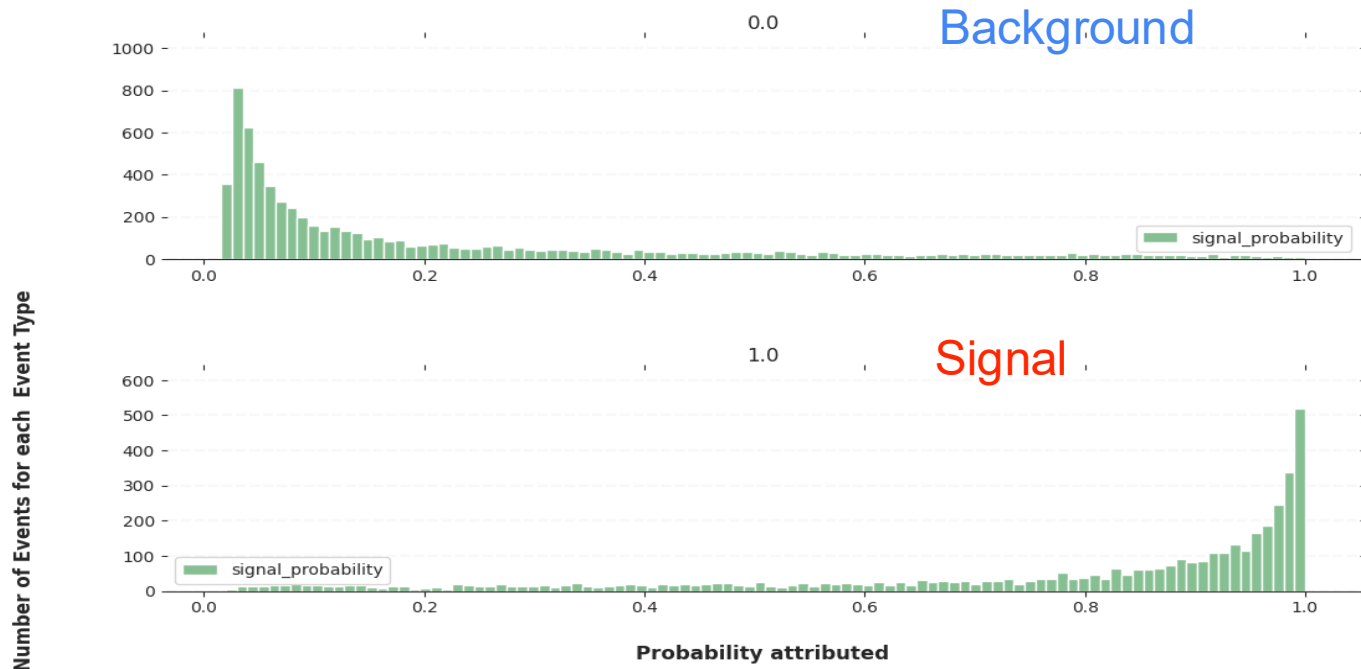
NN Training



Ensemble all the variables and events in a pandas dataframe, from 2022 and 2024.
Split data in 2 sections: training and validation, examine it in 1000 epochs.

NN output

assign a probability of each event from 0 to 1, being 0 background and 1 signal

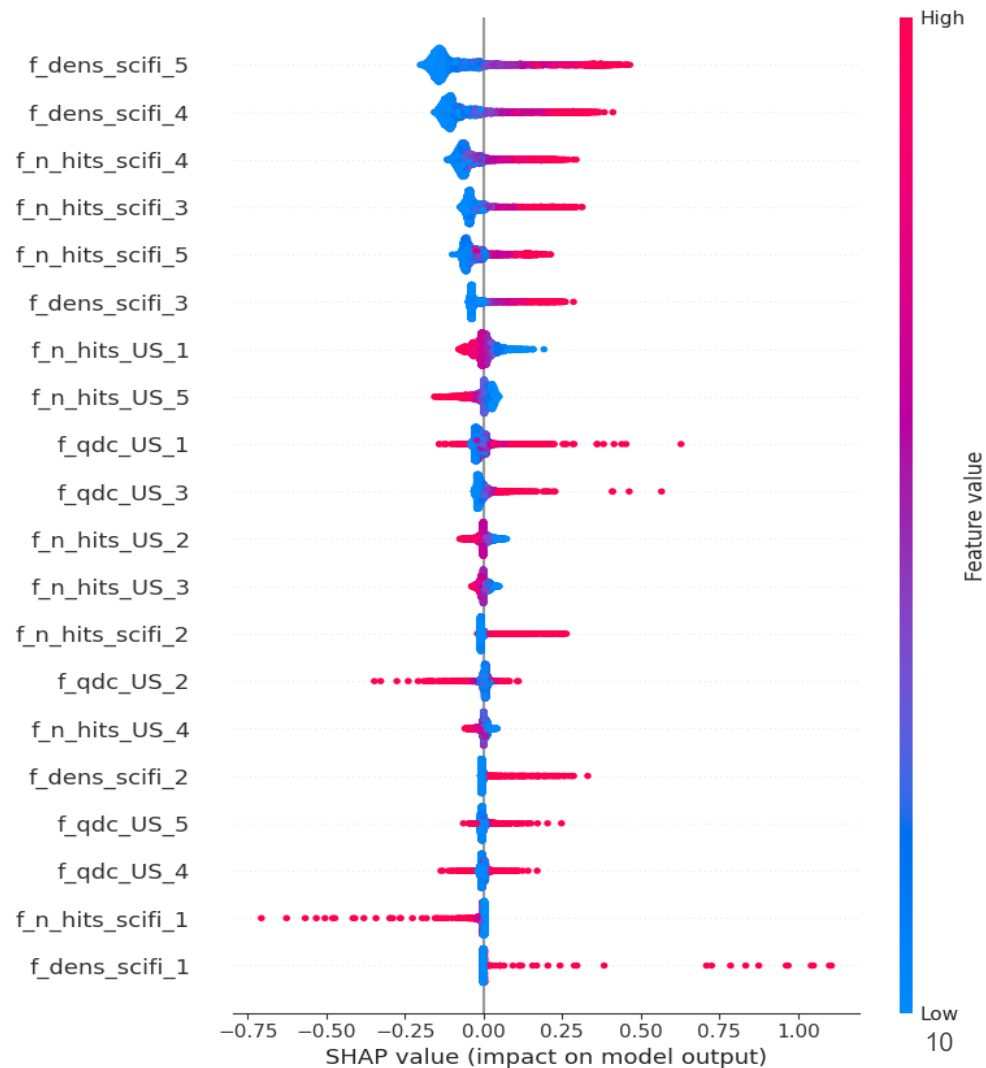


But how does the NN knows what probability assign?

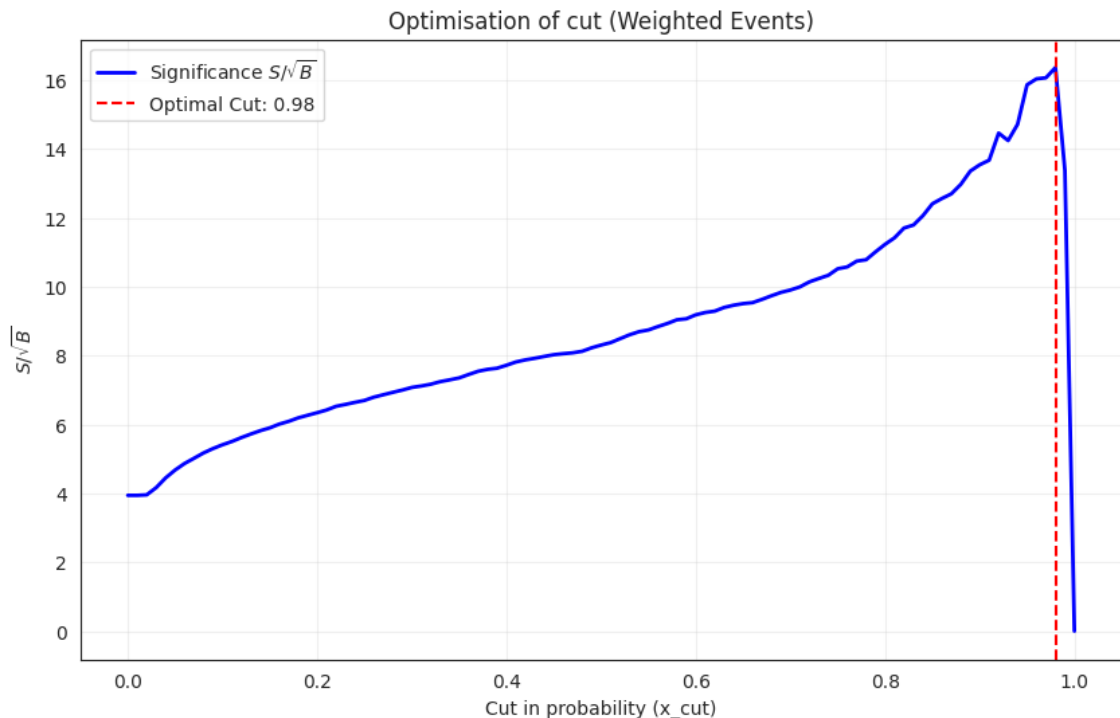
SHAP values:

impact on the model output

- Higher value of the feature: redder; else bluer
- Higher separation from the origin: better discrimination (right as signal and left as background)
- Ordered by importance from higher to lower



To improve the significance of the MC data: establish a cut



The best ratio $S/\sqrt{B}$ is 16.36
obtained with a cut of 0.98

Total retained yield: 5.63 events
(8.64%)

Retained signal: 5.52 events
(22.08%)

Retained background: 0.11 events
(0.28%)

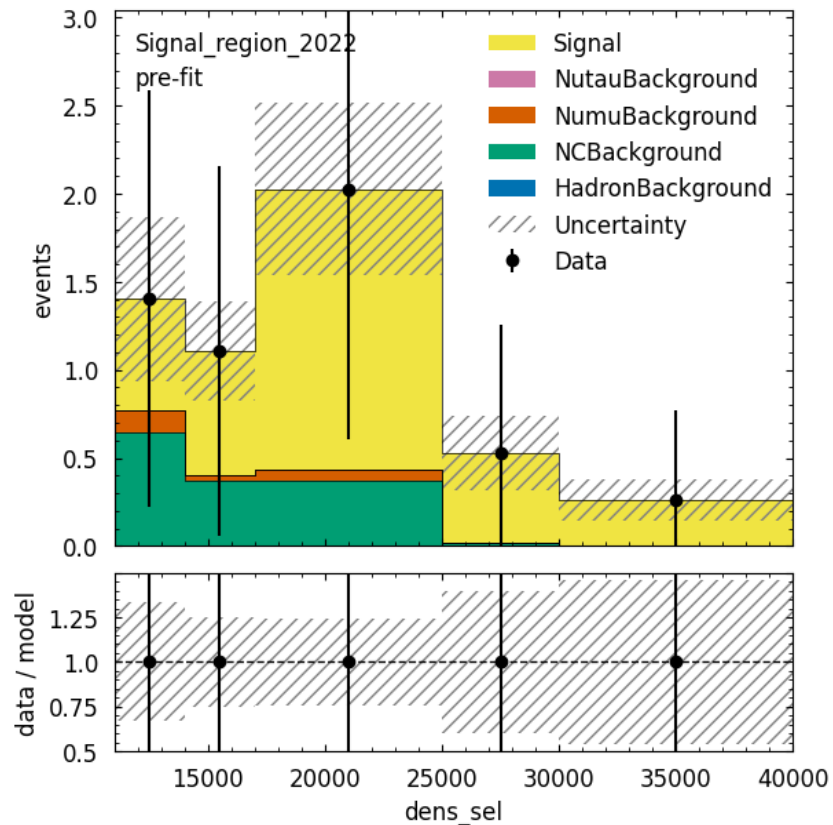
- We will try to find the cut that gives us the best significance without losing a lot of information on how precisely we can measure signal

After analysing several cuts in the probability...

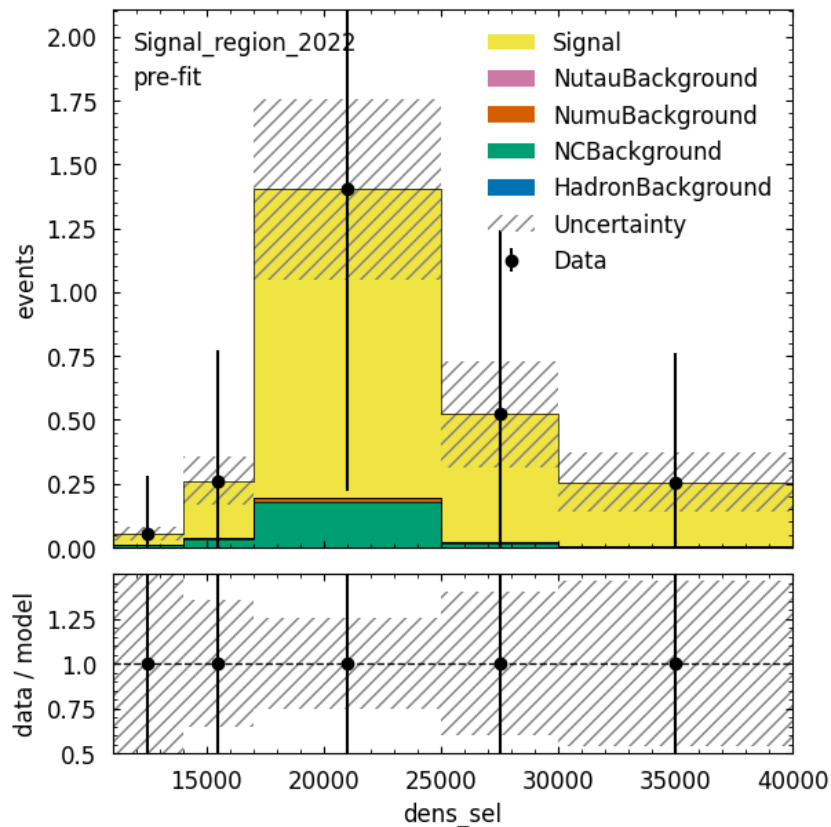
Cut	Exp significance (asimov data)	Signal_norm (asimov data)
0	4.762	1.0000+/-0.4370
0.60	4.709	1.000 +/- 0.435
0.70	4.770	1.000 +/- 0.435
0.75	4.819	1.000 +/- 0.435
0.80	4.862	1.0000 +/- 0.445
0.825	4.838	1.000 +/- 0.446
0.85	4.897	1.0000 +/- 0.453
0.875	4.887	1.0000 +/- 0.468
0.90	4.800	1.0000 +/- 0.484

2022 region: pre-fit (asimov data)

Before NN cut

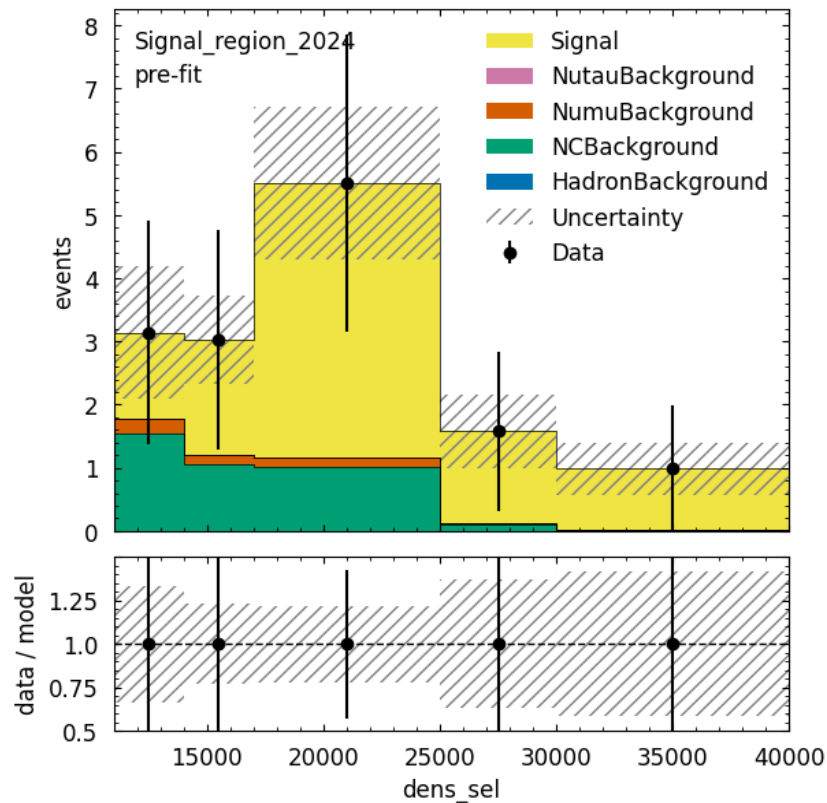


After NN cut (0.85)

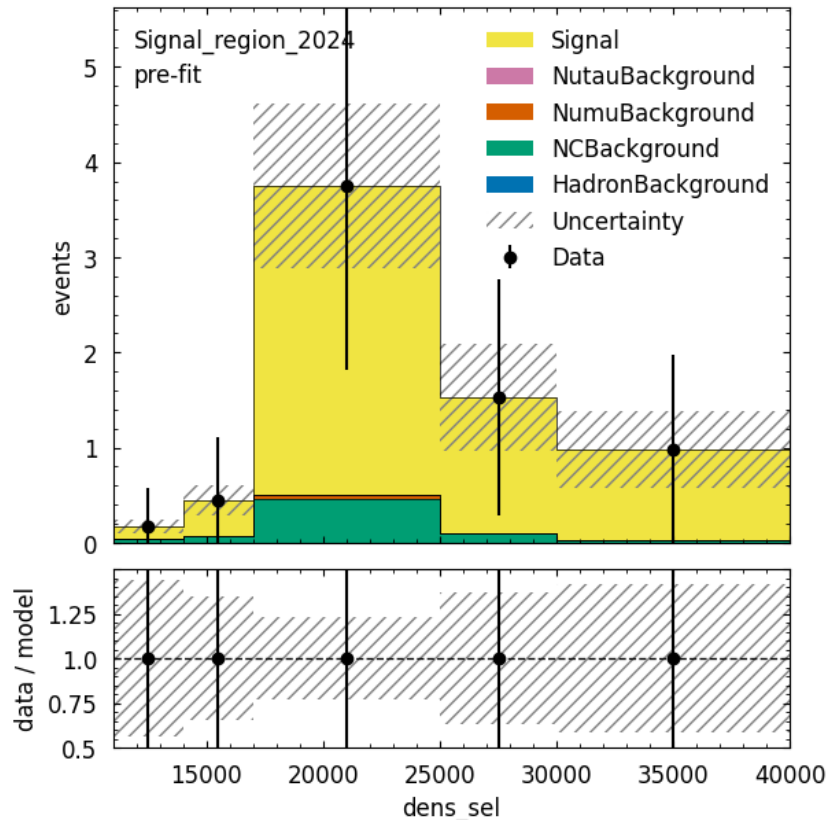


2024 region: pre fit

Before NN cut



After NN cut (0.85)



Conclusions and possible next steps...

- Studied variables for neutrino identification at SND@LHC
- Significance improvement using simulations of electron neutrino
- Look for possible updates in the detector on the best SHAP values
- Evaluate the NN on additional simulated samples and real data

Questions?