Gradient Tree Boosting for the Identification of Tau Neutrino Interactions

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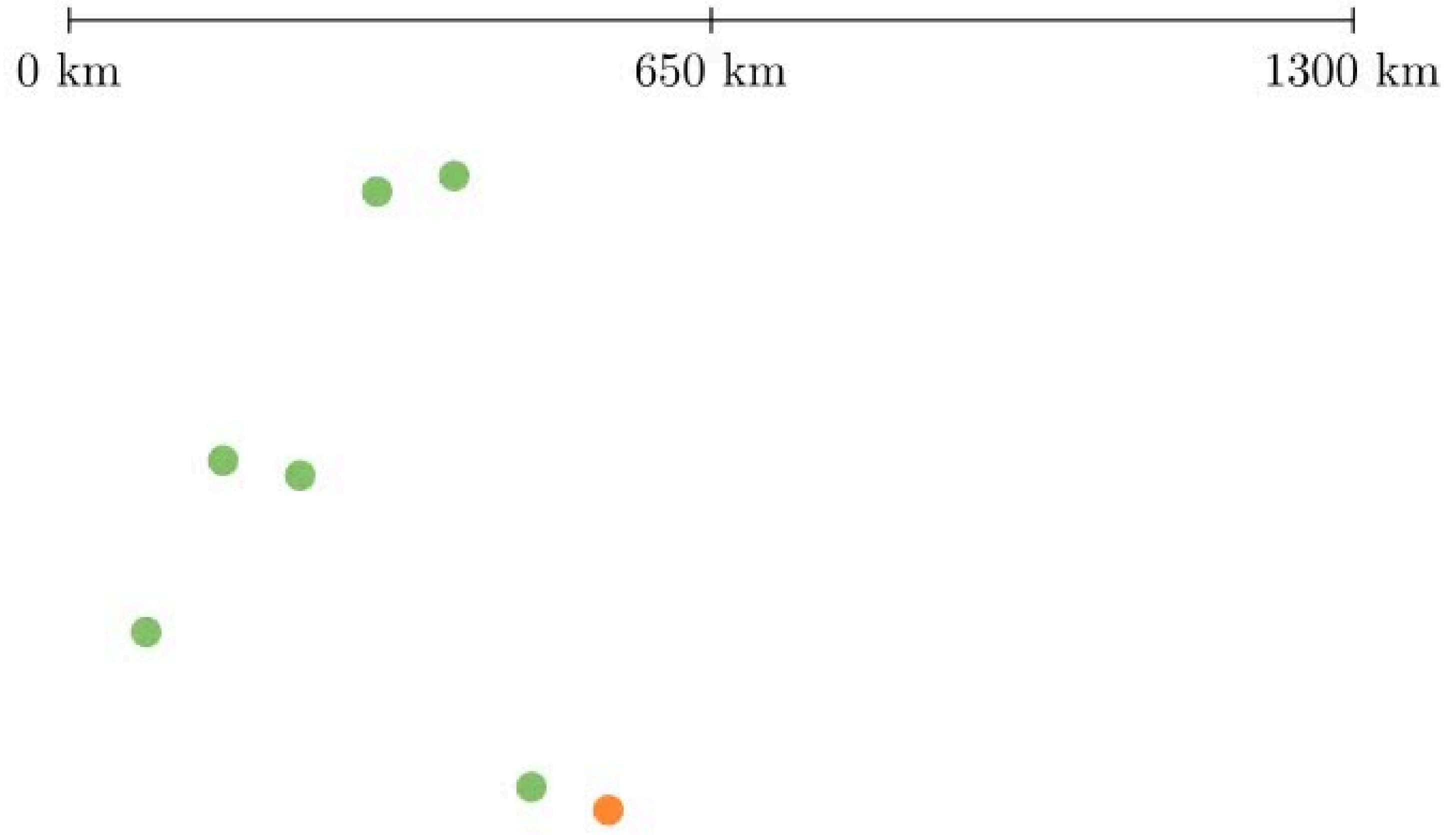
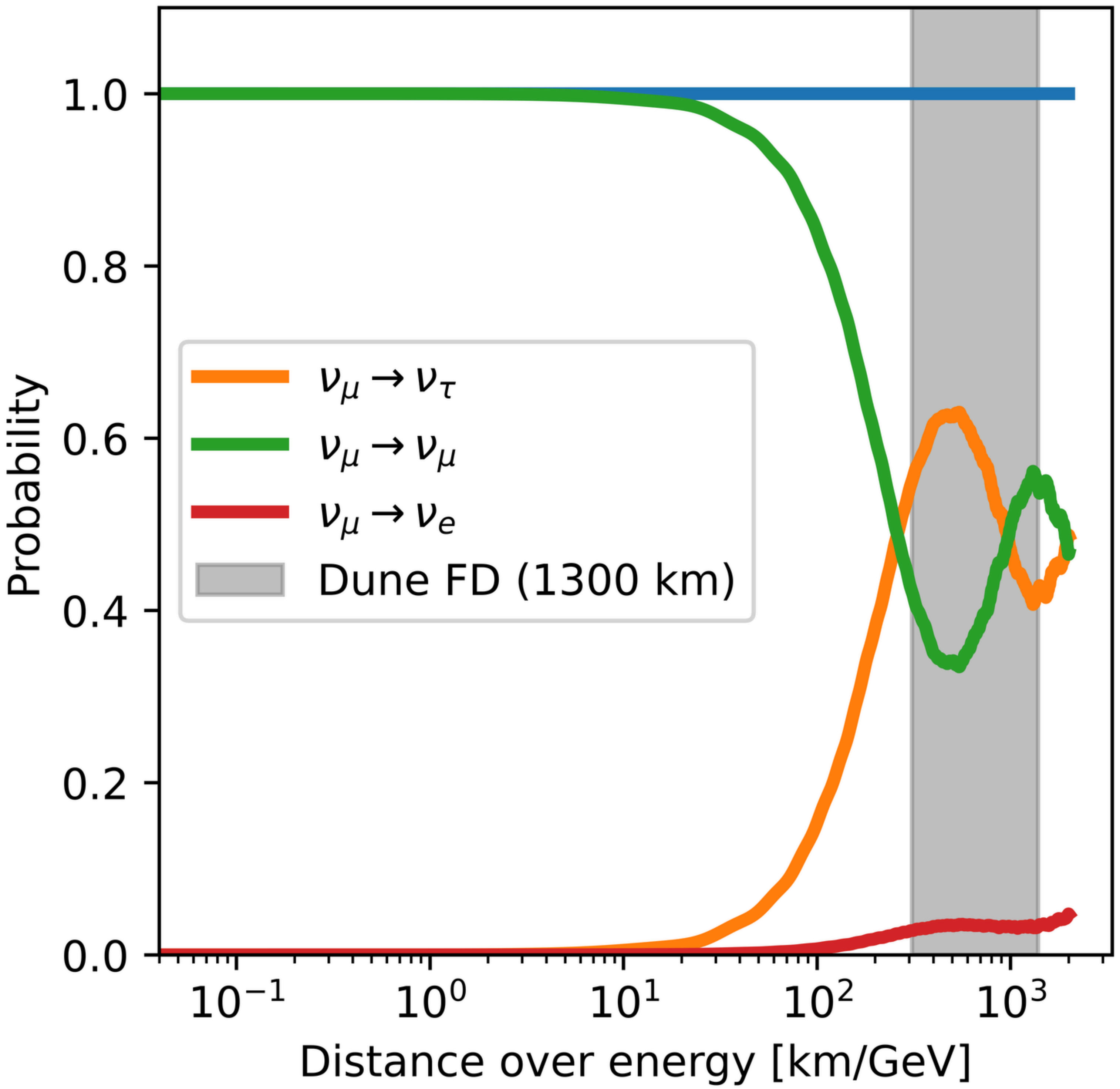
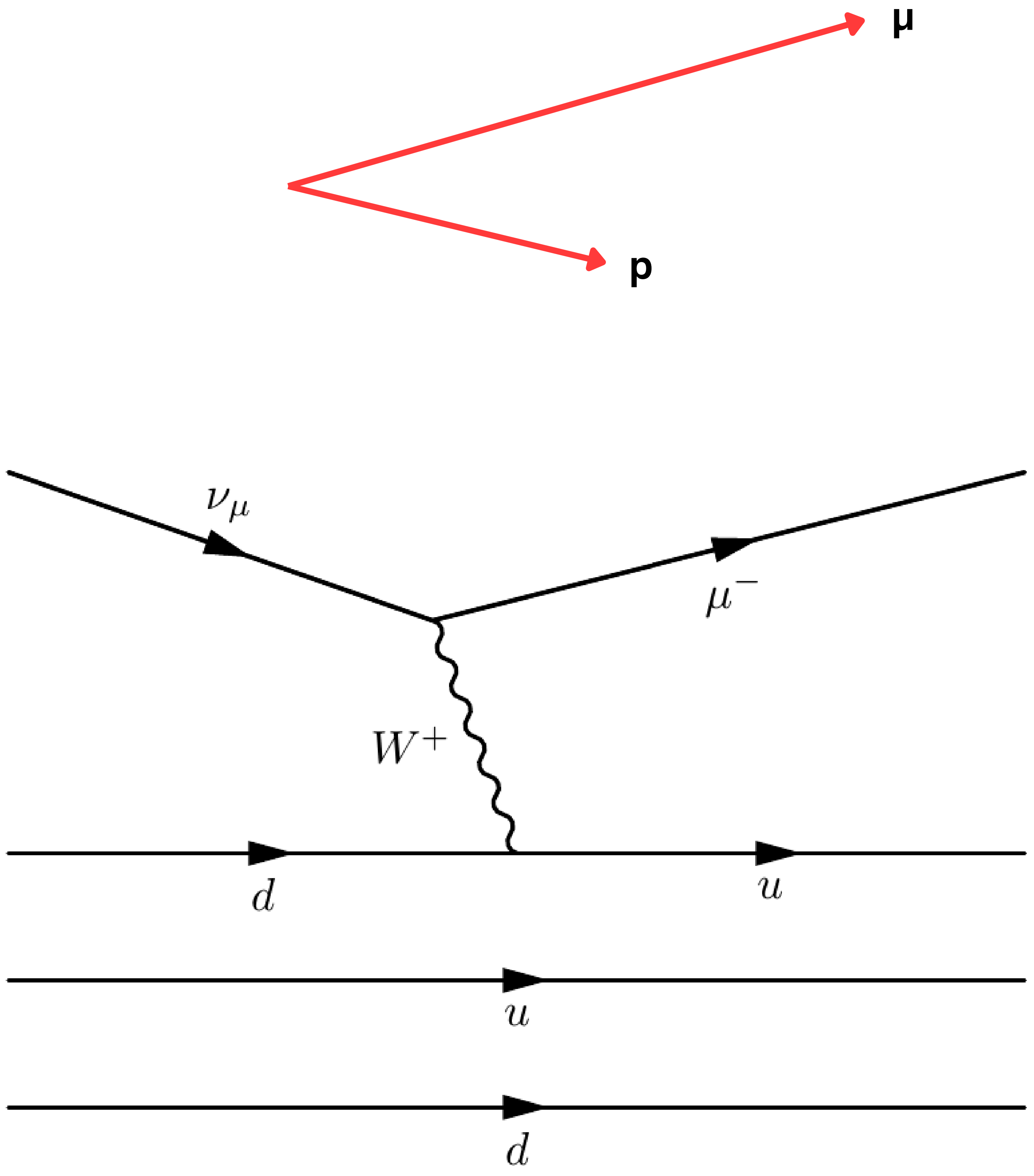
Neutrino Oscillation

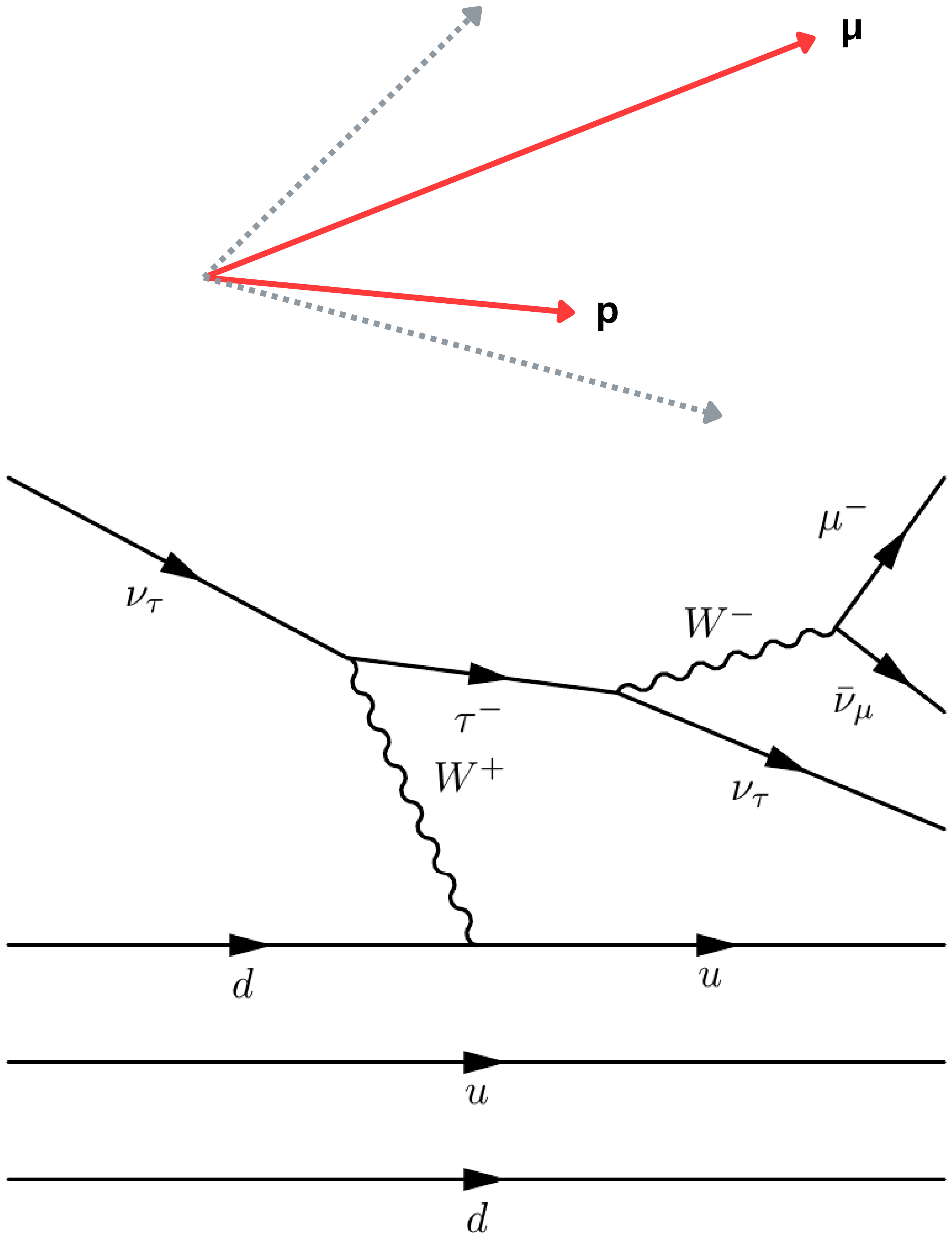
$$P_{\nu_\alpha \longrightarrow \nu_\beta} = \delta_{\alpha\beta} - 4\sum_{j>k} \mathfrak{Re}(U^*_{\alpha j} U_{\beta j} U_{\alpha k} U^*_{\beta k}) \sin^2\left(\frac{\Delta_{jk}m^2 L}{4E}\right)$$
$$+2\sum_{j>k} \mathfrak{Im}(U^*_{\alpha j} U_{\beta j} U_{\alpha k} U^*_{\beta k}) \sin\left(\frac{\Delta_{jk}m^2 L}{4E}\right)$$





Tau and Mu Neutrino Interaction





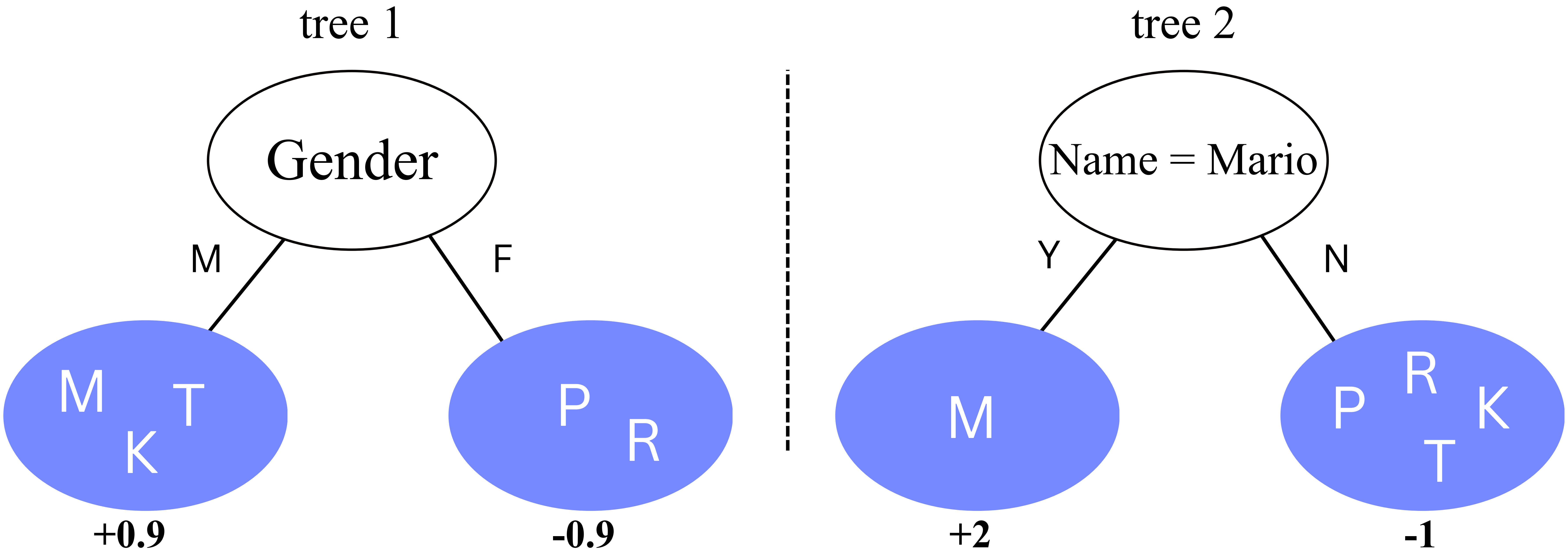
Gradient Tree Boosting Example

Some arbitrary tabular data

Name	Gender	Height	Glasses
Kush	M	180	Y
Paulina	F	183	Y
Rosa	F	190	N
Thomas	M	178	Y
Mario	M	179	N

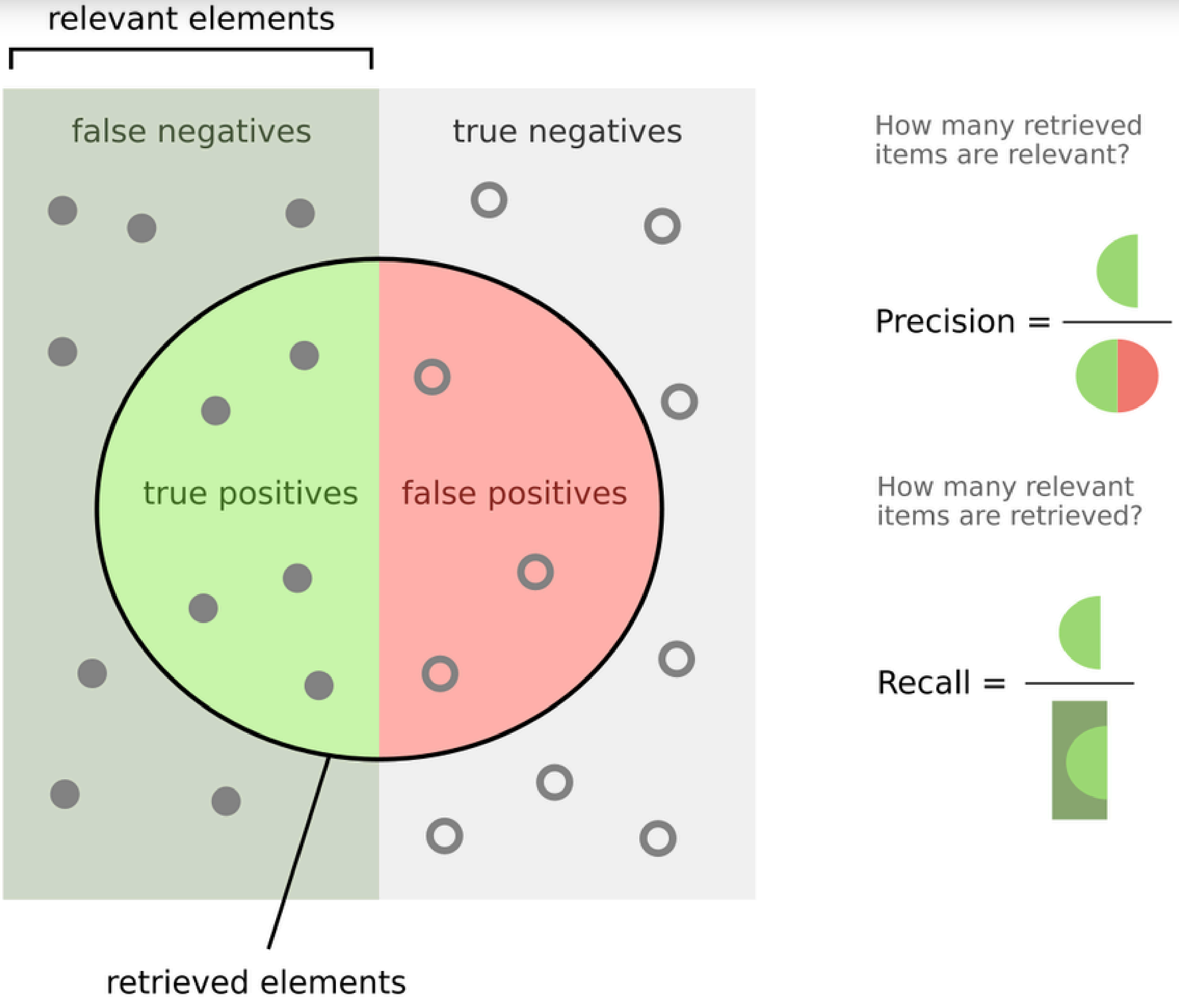
Gradient Tree Boosting Example

Who grabs a second sandwich during lunch?

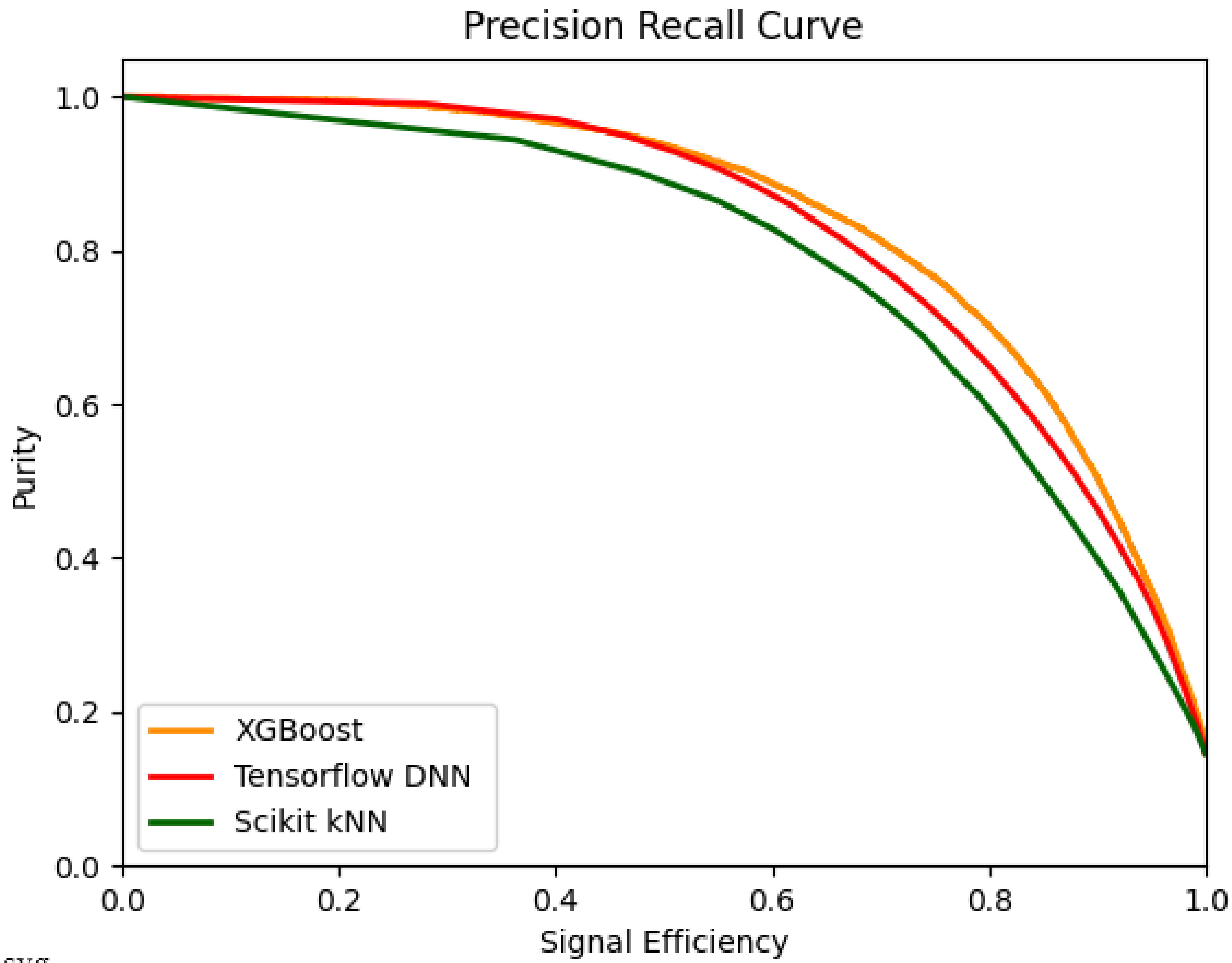


f (M) = +0.9 +2 = 2.9

Performance on simulated neutrino data



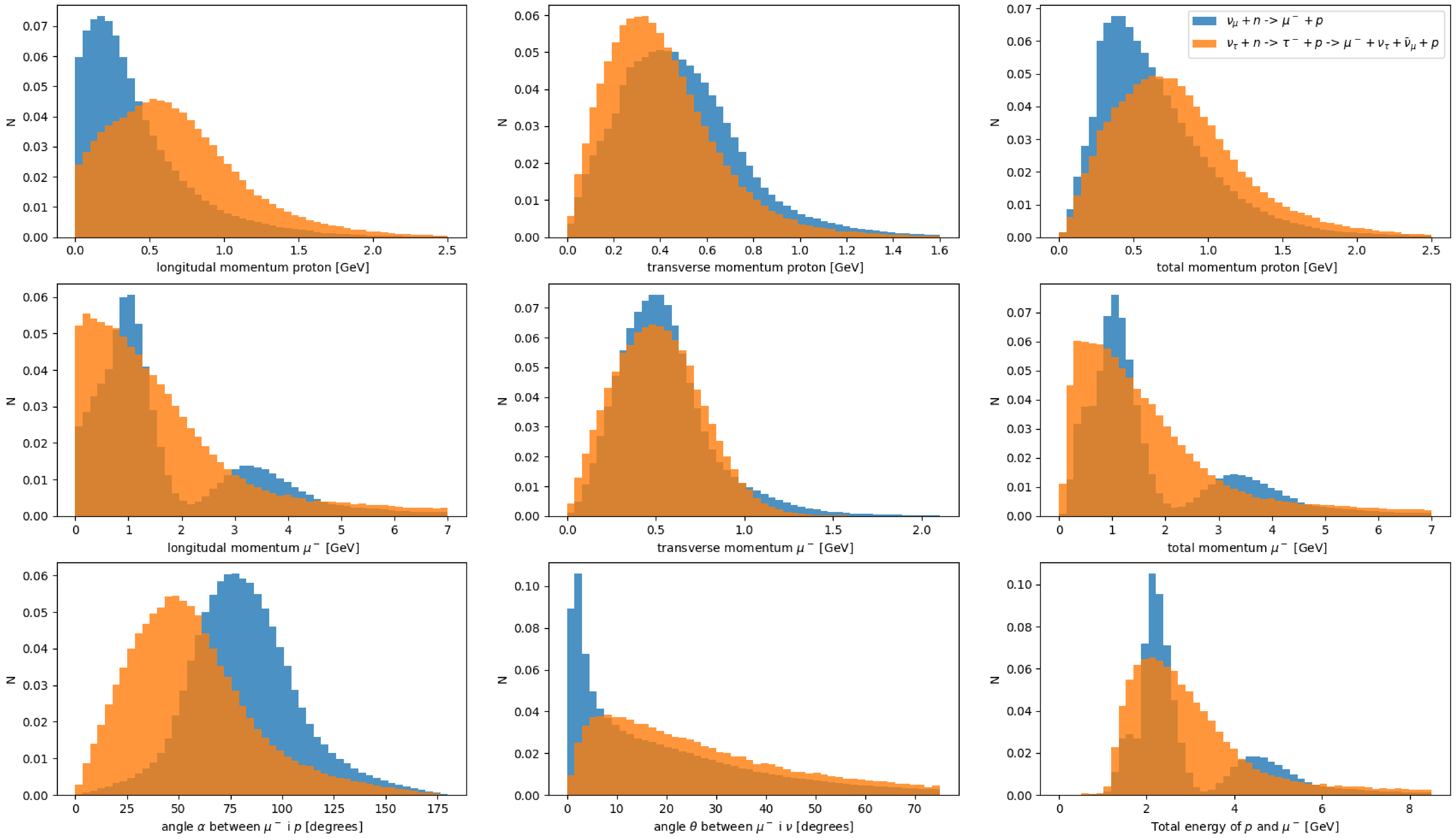
Precision and recall visualization[1]



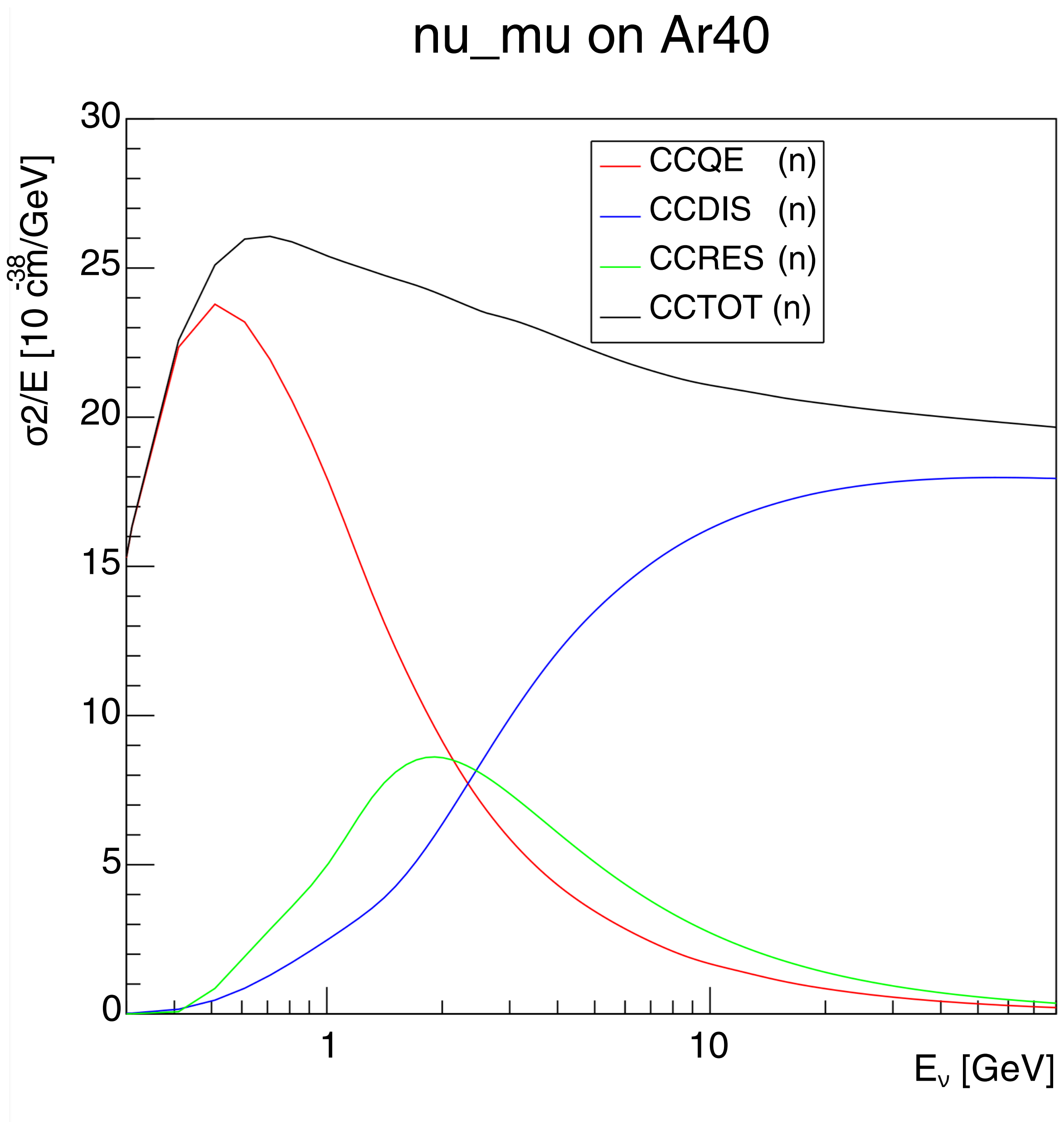
[1] https://commons.wikimedia.org/wiki/File:Precisionrecall.svg

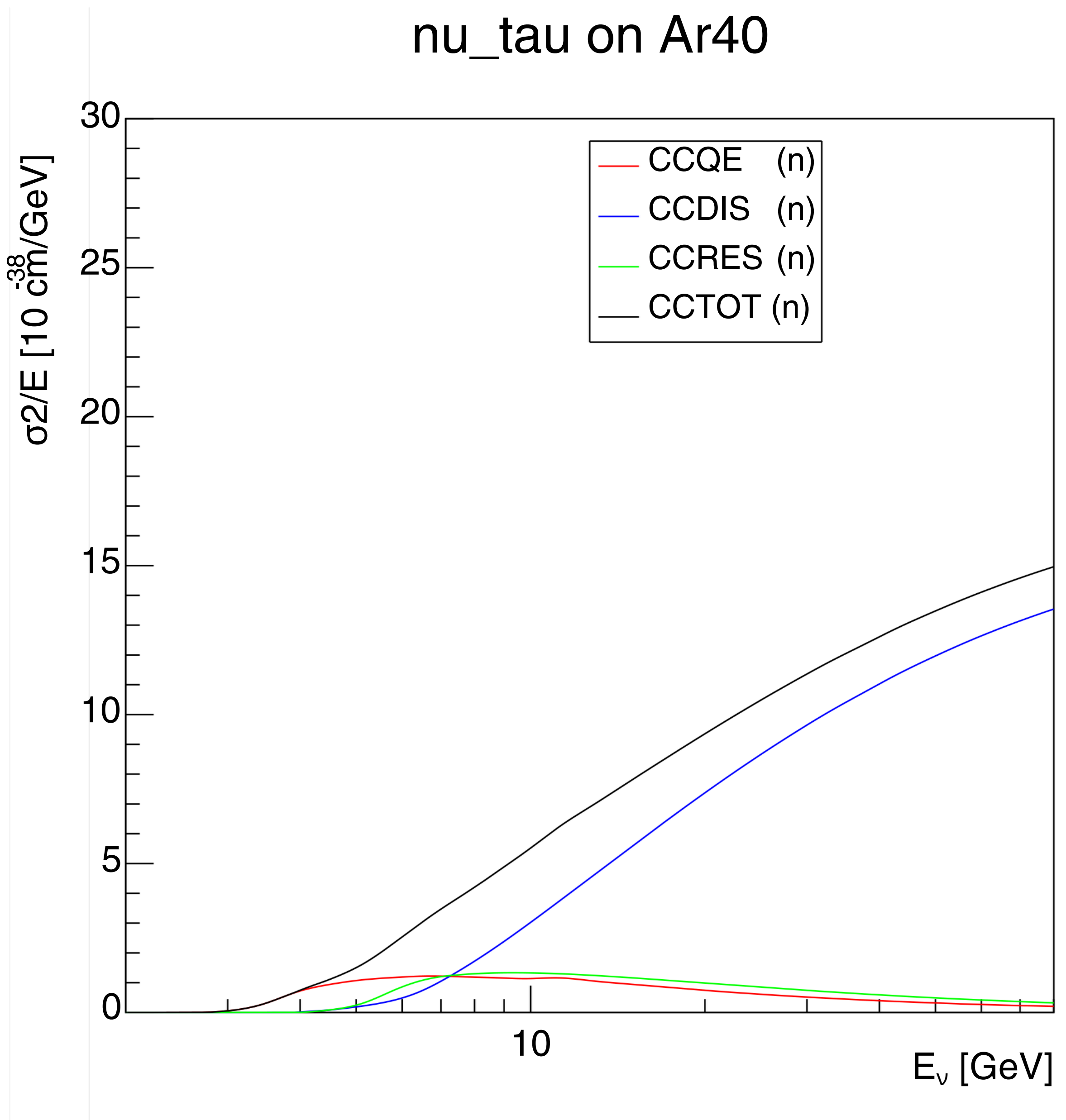
Thank you for your attention

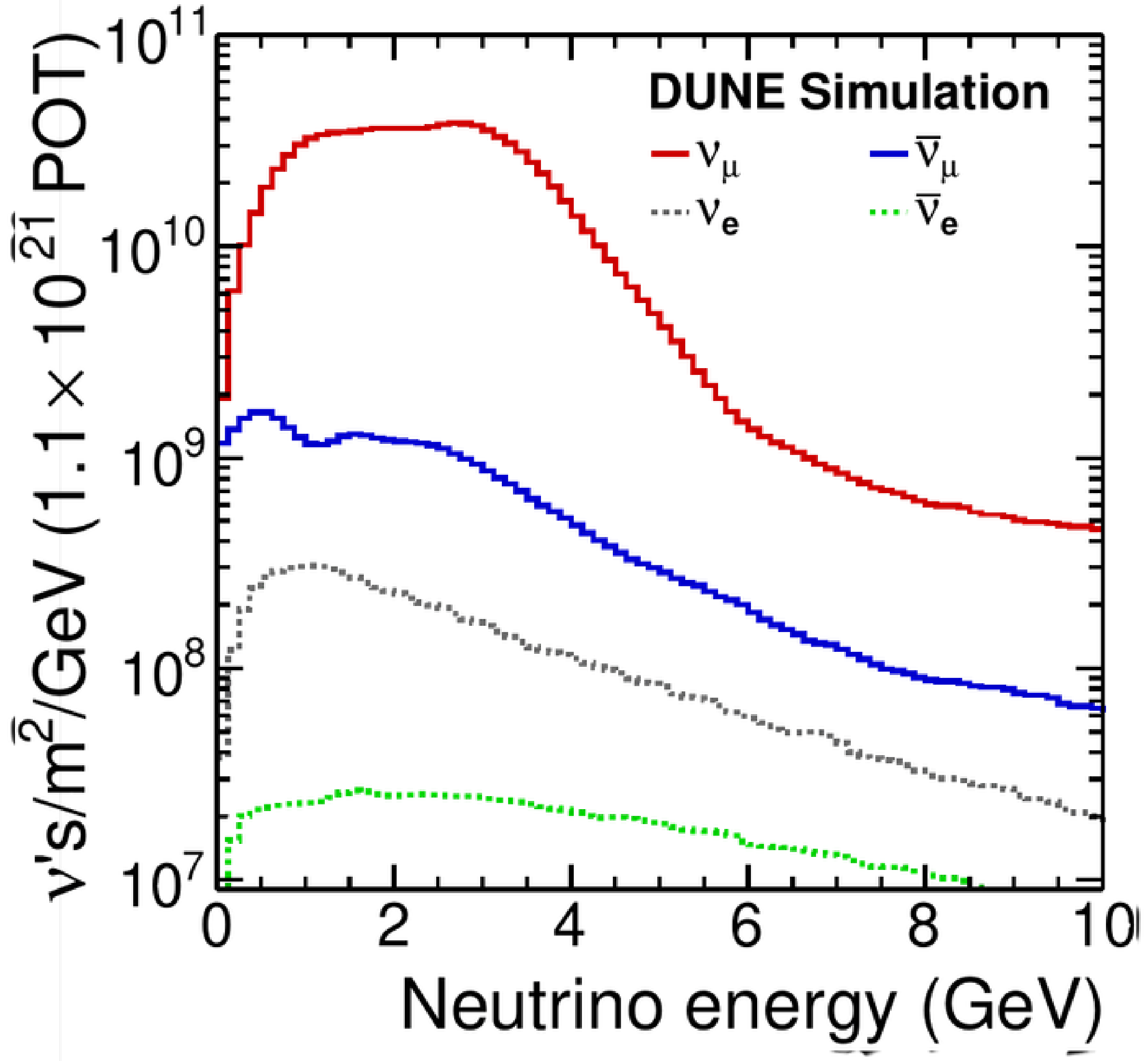
Feature distribution



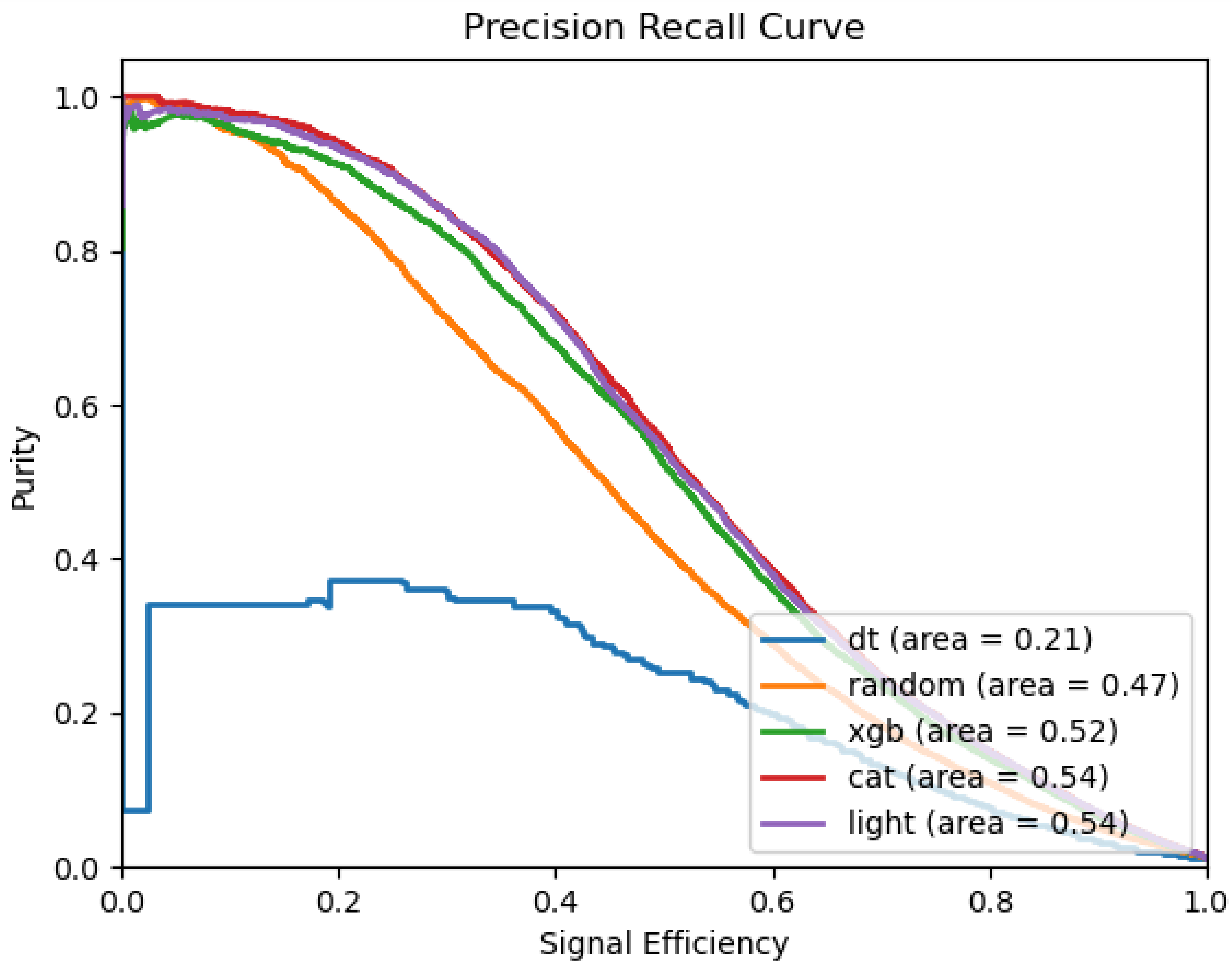
Cross-sections and energy distribution







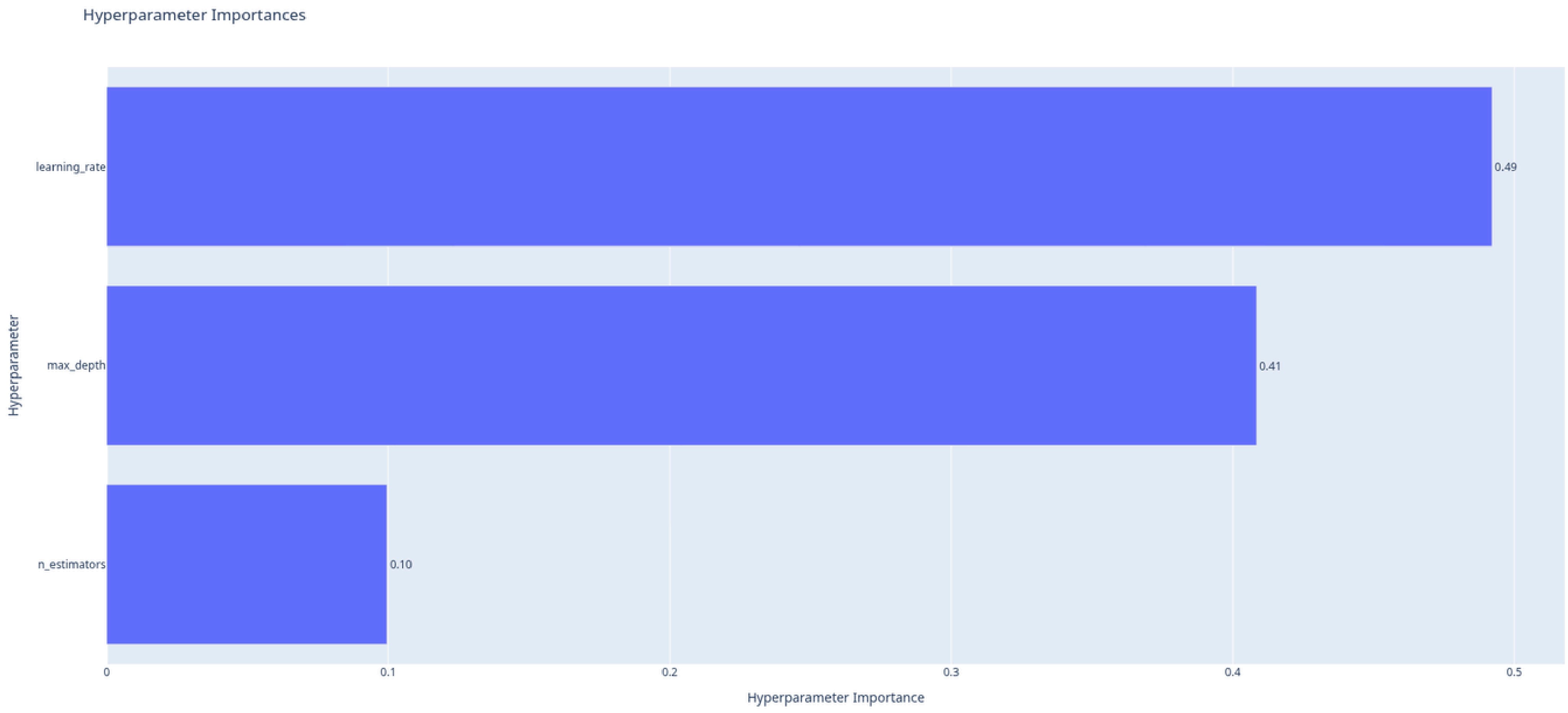
Comparison of GBTs



Gradient tree boosting hyperparameters

Gradient boosted trees have several adjustable parameters (hyperparameters):

- n_estimators - the maximum number of trees allowed in the model
- max_depth - the maximum depth of individual trees allowed (the deeper the tree, the tree becomes very complex and is prone to overfit on the training data)
- learning_rate - how much each individual tree influences the entire model. Usually less than 1 in order to suppress the influence of an individual tree to avoid overfitting



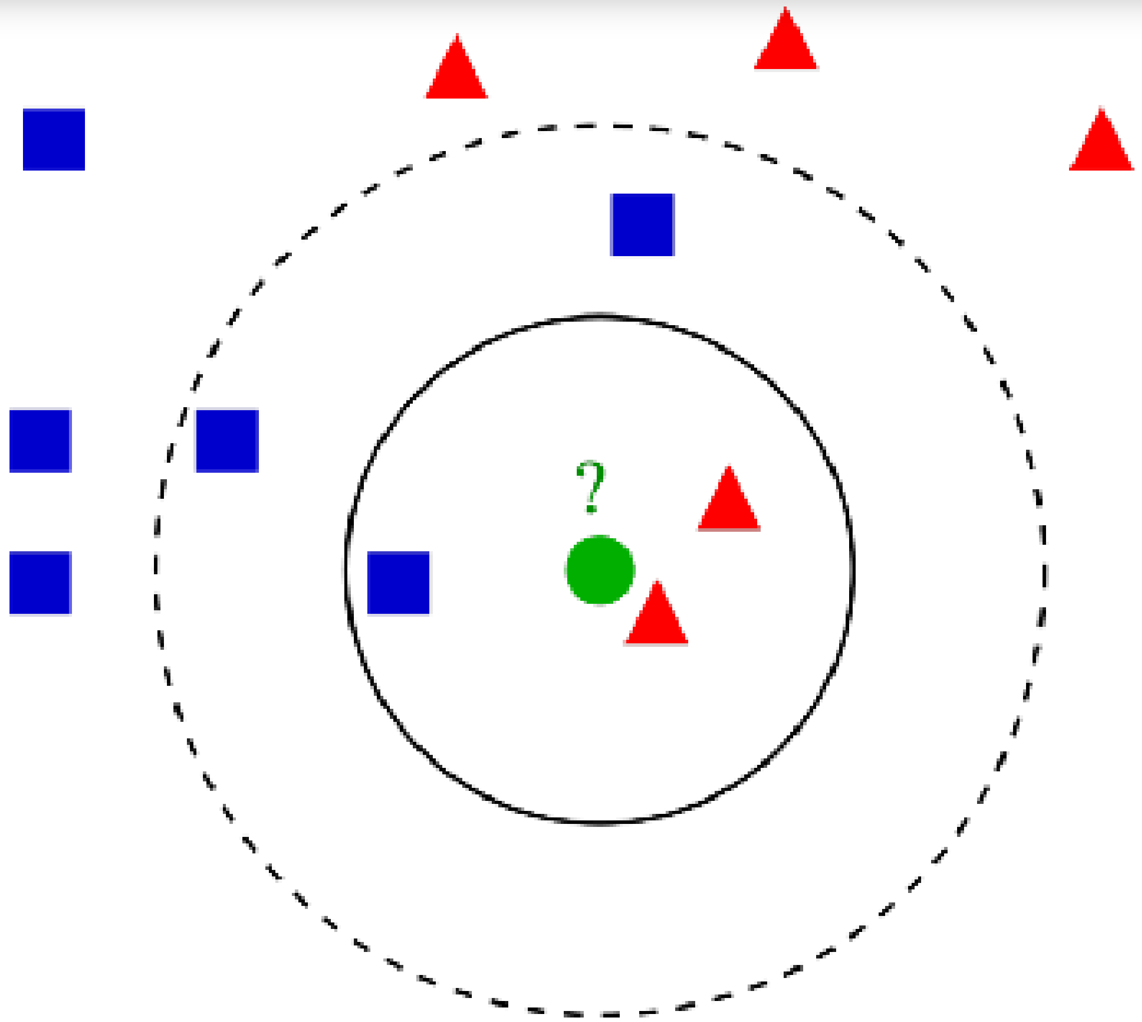
General Gradient Boosting Algorithm

ALGORITHM 1 (Gradient_Boost).

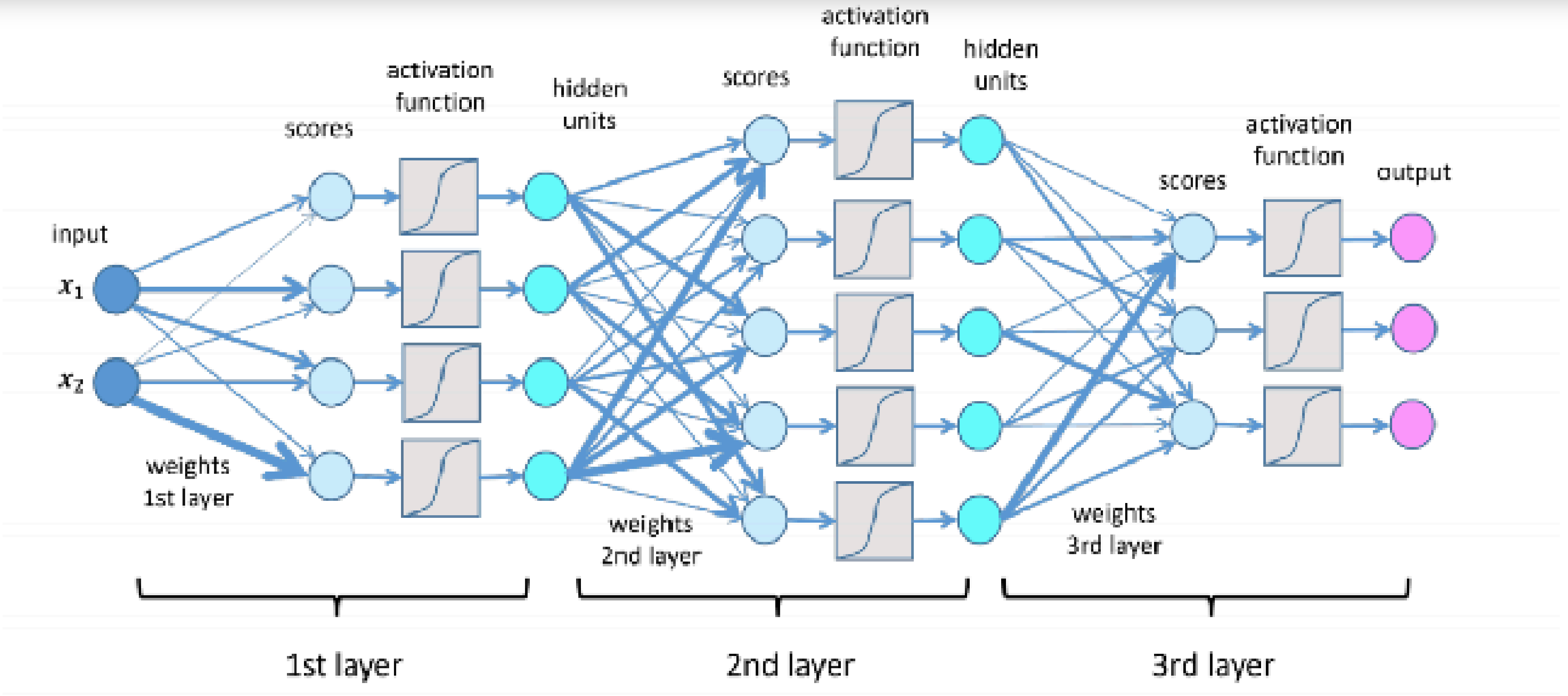
1. $F_0(\mathbf{x}) = \arg\min_\rho \sum_{i=1}^N L(y_i, \rho)$
2. For $m = 1$ to M do:
3. $\tilde{y}_i = -\left[\frac{\partial L(y_i, F(\mathbf{x}_i))}{\partial F(\mathbf{x}_i)}\right]_{F(\mathbf{x})=F_{m-1}(\mathbf{x})}, \quad i = 1, N$
4. $\mathbf{a}_m = \arg\min_{\mathbf{a}, \beta} \sum_{i=1}^N [\tilde{y}_i - \beta h(\mathbf{x}_i; \mathbf{a})]^2$
5. $\rho_m = \arg\min_\rho \sum_{i=1}^N L(y_i, F_{m-1}(\mathbf{x}_i) + \rho h(\mathbf{x}_i; \mathbf{a}_m))$
6. $F_m(\mathbf{x}) = F_{m-1}(\mathbf{x}) + \rho_m h(\mathbf{x}; \mathbf{a}_m)$

Greedy Function Approximation: A Gradient Boosting Machine, Jerome H. Friedman

kNN and DNN



Visualization of k Nearest Neighbor method[1]



Deep neural network visualization [2]

[1] https://commons.wikimedia.org/wiki/File:KnnClassification.svg

[2] https://lamarr-institute.org/blog/deep-neural-networks/

Decay Branches of Tau Lepton

τ^- DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Modes with one charged particle				
particle$^-$ ≥ 0 neutrals $\geq 0K^0\nu_\tau$ ("1-prong")		(85.24 ± 0.06) %		–
particle$^-$ ≥ 0 neutrals $\geq 0K^0_L\nu_\tau$		(84.58 ± 0.06) %		–
$\mu^-\overline{\nu}_\mu\nu_\tau$	[g]	(17.37 ± 0.04) %		885
$\mu^-\overline{\nu}_\mu\nu_\tau\gamma$	[e]	$(3.67 \pm 0.08) \times 10^{-3}$		885
$e^-\overline{\nu}_e\nu_\tau$	[g]	(17.85 ± 0.04) %		888
$e^-\overline{\nu}_e\nu_\tau\gamma$	[e]	(1.83 ± 0.05) %		888
$h^- \geq 0K^0_L\ \nu_\tau$		(12.03 ± 0.05) %		883
$h^-\nu_\tau$		(11.51 ± 0.05) %		883
$\pi^-\nu_\tau$	[g]	(10.82 ± 0.05) %		883
$K^-\nu_\tau$	[g]	$(6.97 \pm 0.10) \times 10^{-3}$		820
$h^- \geq 1$ neutralsν_τ		(37.00 ± 0.09) %		–
$h^- \geq 1\pi^0\nu_\tau$(ex.K^0)		(36.50 ± 0.09) %		–
$h^-\pi^0\nu_\tau$		(25.93 ± 0.09) %		878
$\pi^-\pi^0\nu_\tau$	[g]	(25.49 ± 0.09) %		878
$\pi^-\pi^0$non-$\rho(770)\nu_\tau$		$(3.0 \pm 3.2) \times 10^{-3}$		878
$K^-\pi^0\nu_\tau$	[g]	$(4.33 \pm 0.15) \times 10^{-3}$		814
$h^- \geq 2\pi^0\nu_\tau$		(10.81 ± 0.09) %		–
$h^-2\pi^0\nu_\tau$		(9.48 ± 0.10) %		862
$h^-2\pi^0\nu_\tau$(ex.K^0)		(9.32 ± 0.10) %		862

https://pdg.lbl.gov/2026/tables/contents_tables.html

Derivation of Oscillation

https://www.overleaf.com/9324896741vgtcnhnjwkvn#3409e6