AI for Supernova Neutrinos:
Implementation of Neutrino Flavor Conversions in Core-Collapse Supernova Simulations

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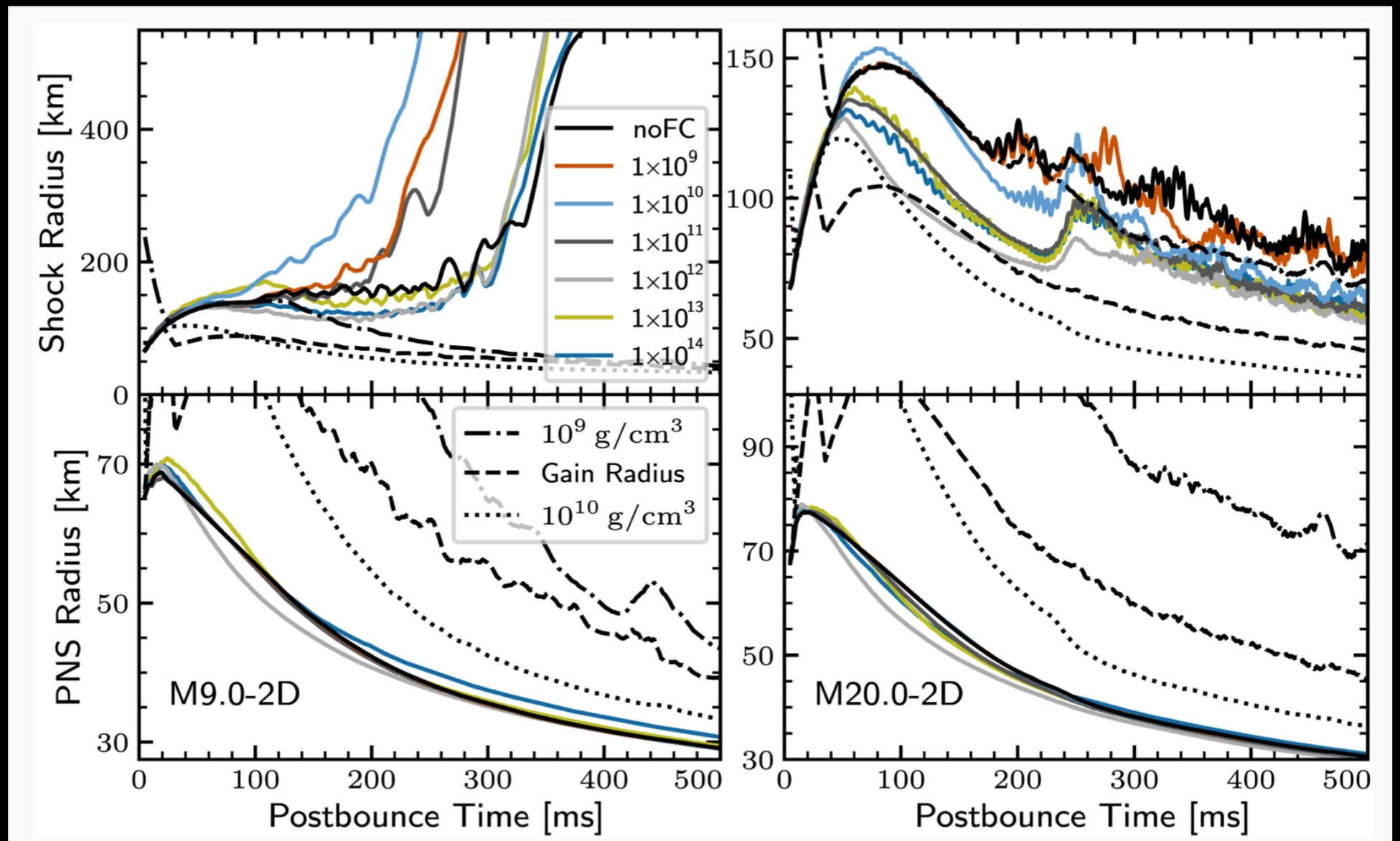
SFB 1258 | Neutrinos Dark Matter Messengers

Including Neutrino Flavor Conversions in CCSNe

- We performed the first SN simulations including neutrino flavor conversions for 2D models, in a parametric way

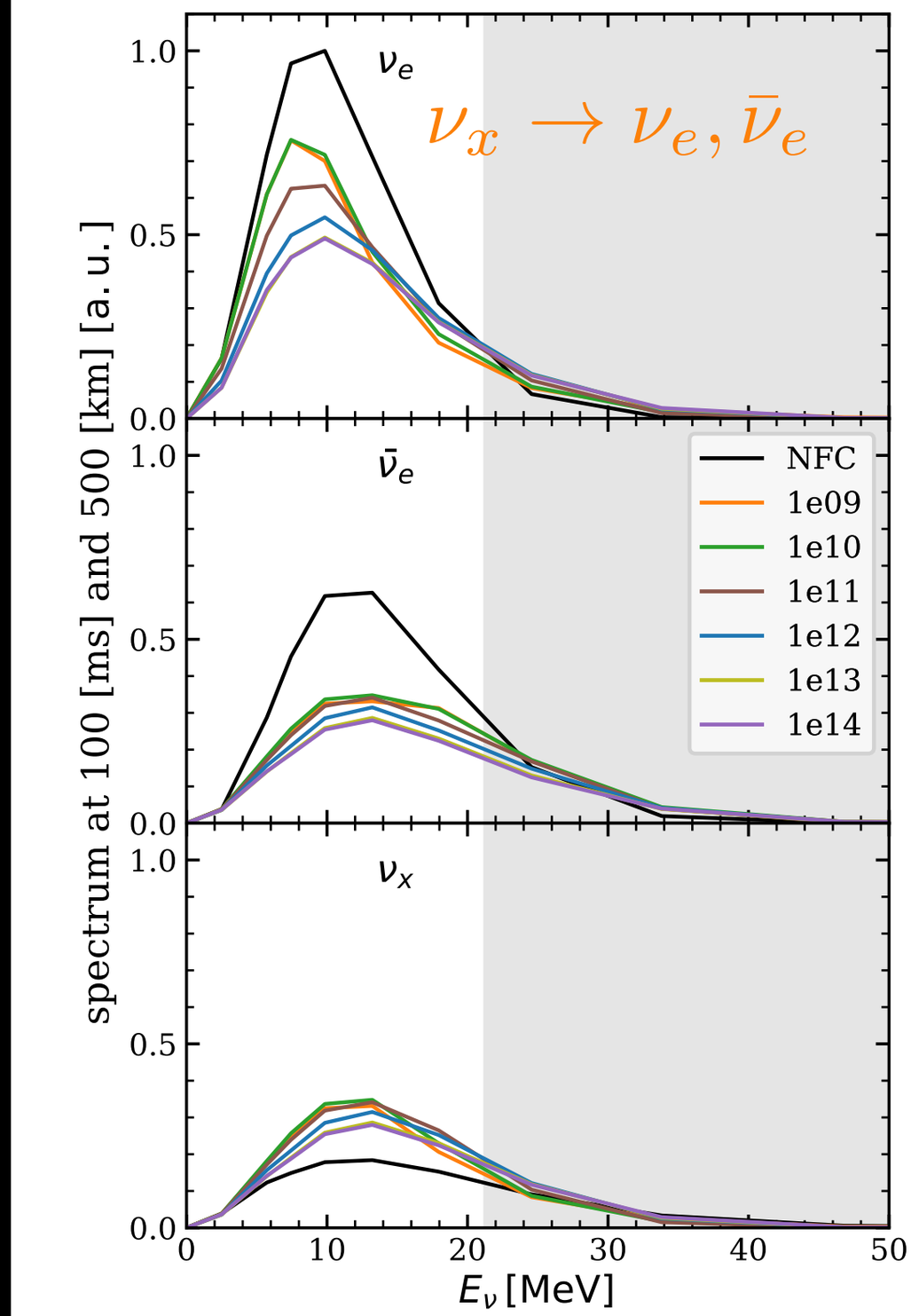
Ehring+2023



Including Neutrino Flavor Conversions in CCSNe

Ehring+(2023)

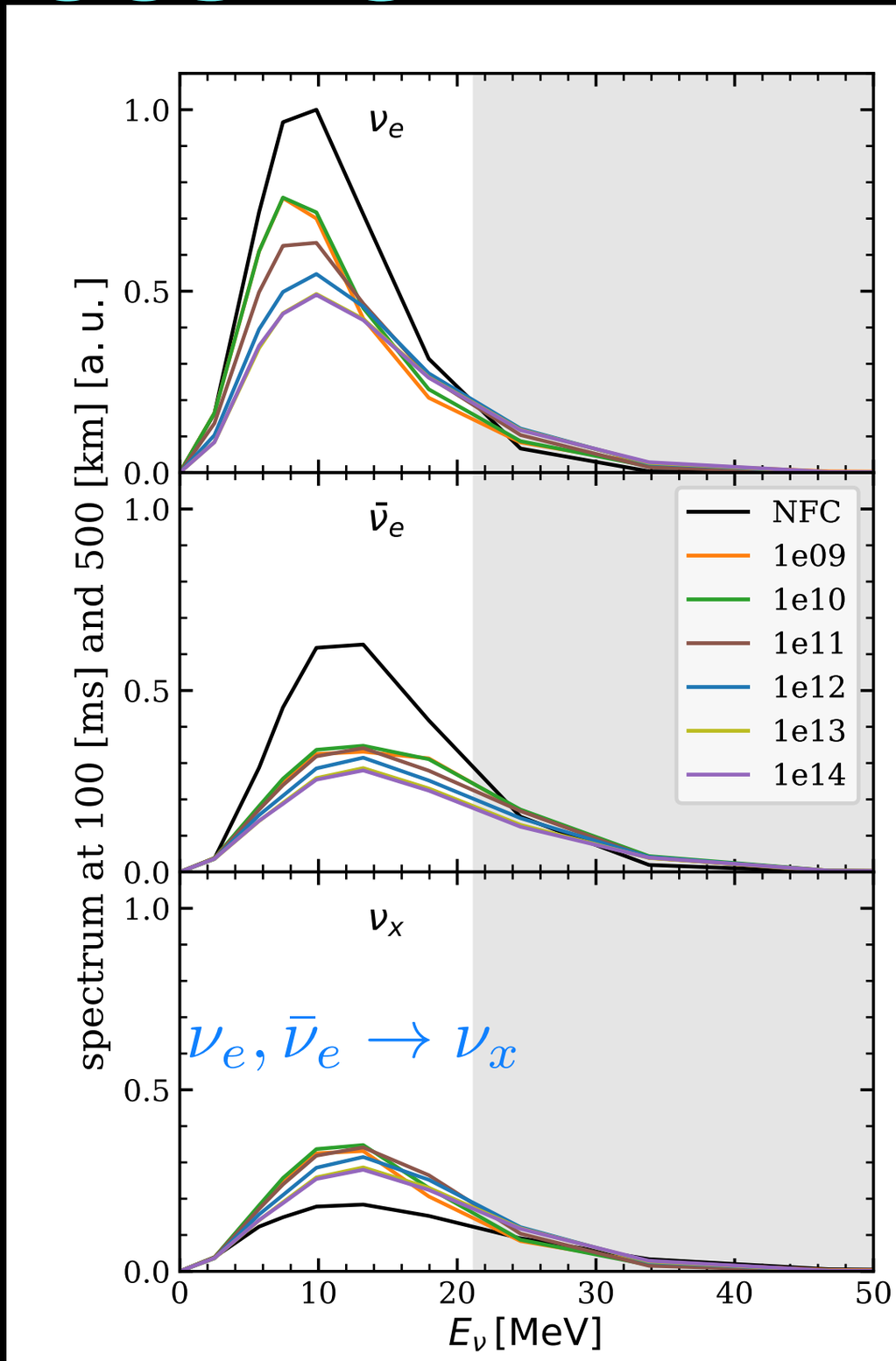
- Two competing effects here
  - $\nu_x \rightarrow \nu_e, \bar{\nu}_e$ at the tail increases heating



Including Neutrino Flavor Conversions in CCSNe

Ehring+(2023)

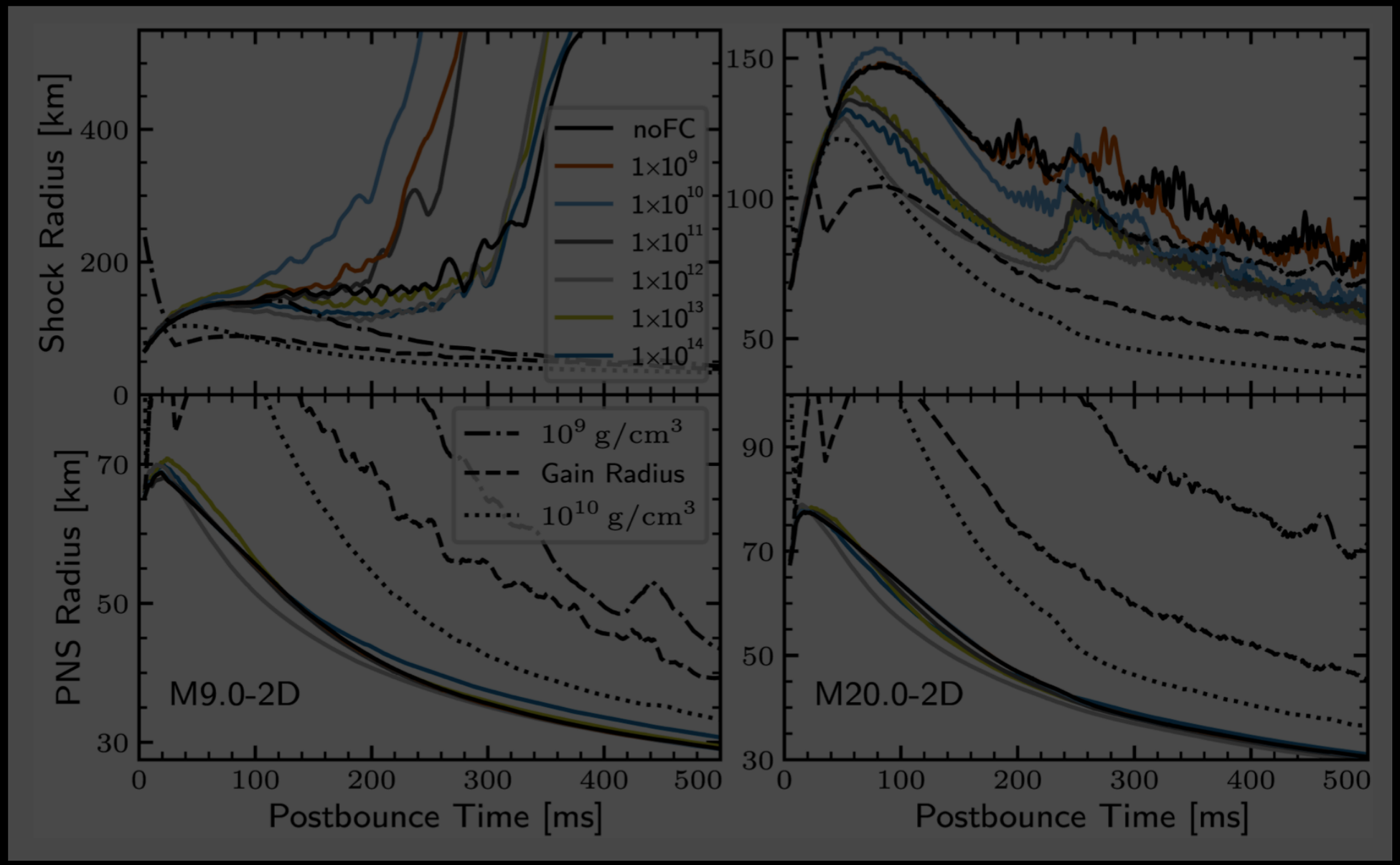
- Two competing effects here
  - $\nu_x \rightarrow \nu_e, \bar{\nu}_e$ at the tail increases heating
  - $\nu_e, \bar{\nu}_e \rightarrow \nu_x$ at the peak increases total neutrino luminosity



Including Neutrino Flavor Conversions in CCSNe

- Neutrino FC cannot be ignored blindly in CCSN simulations!

Ehring+2023



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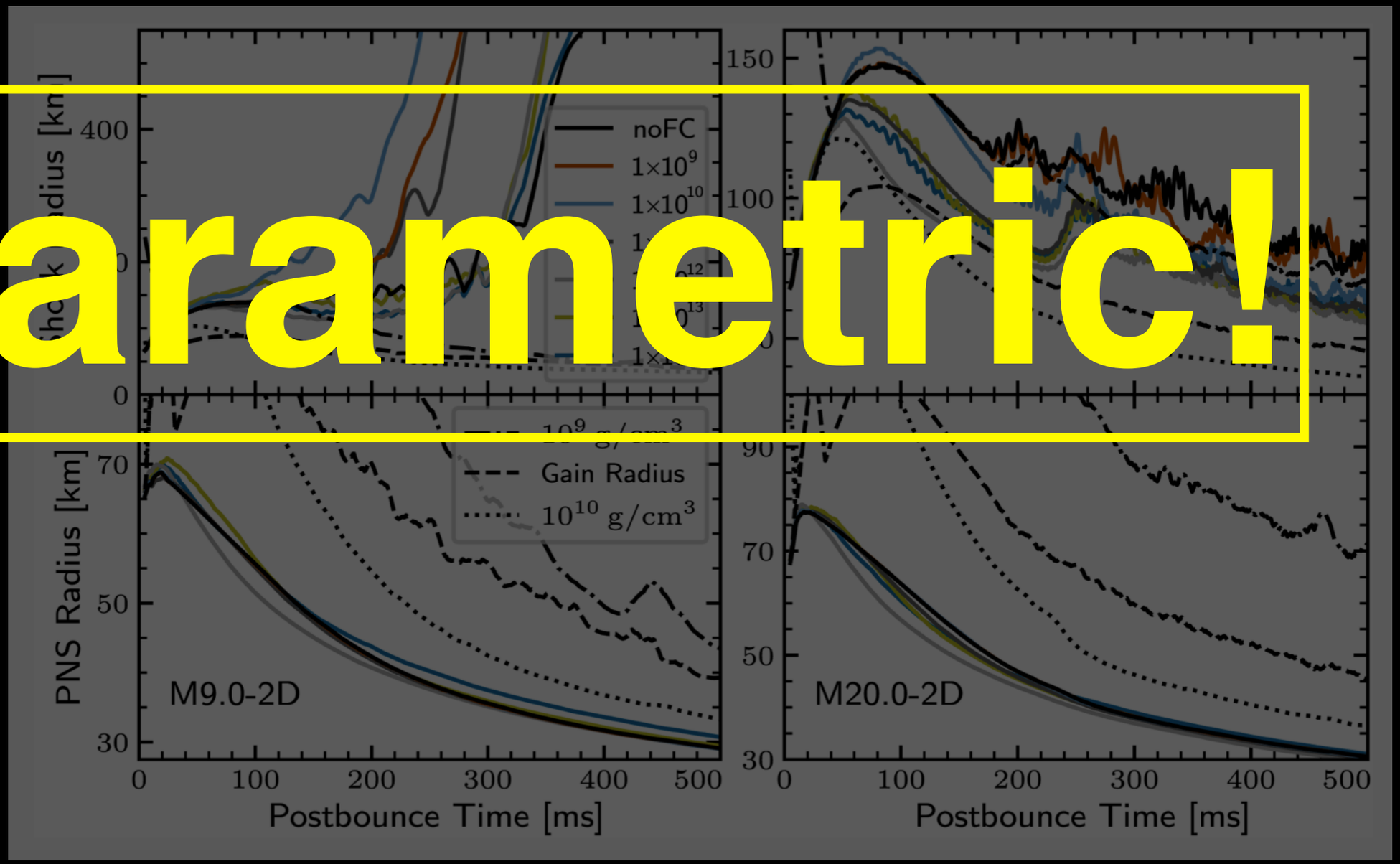


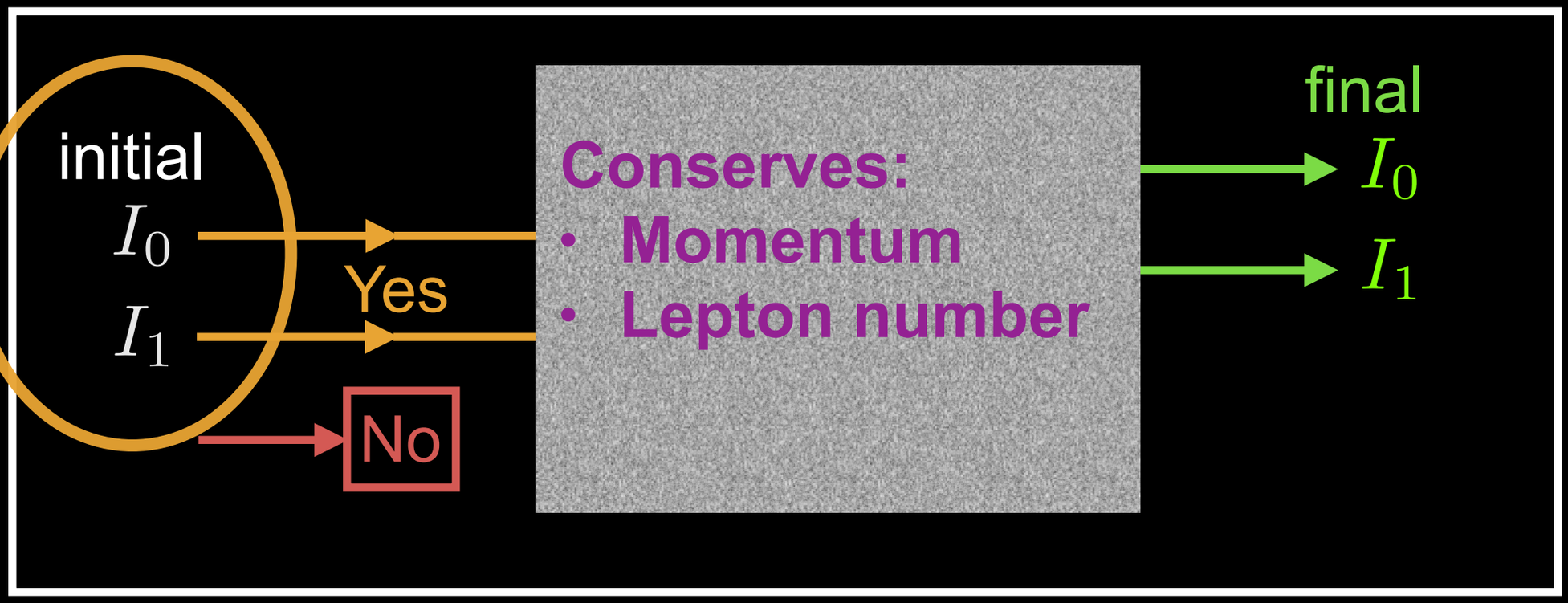
Parametric!

Including Neutrino Flavor Conversions in CCSNe

- We didn’t check the criteria for the occurrence of FCs

- Assuming instantaneous flavor equilibrium (FFCs), the equilibrium state was chosen to maximize the impact of FC

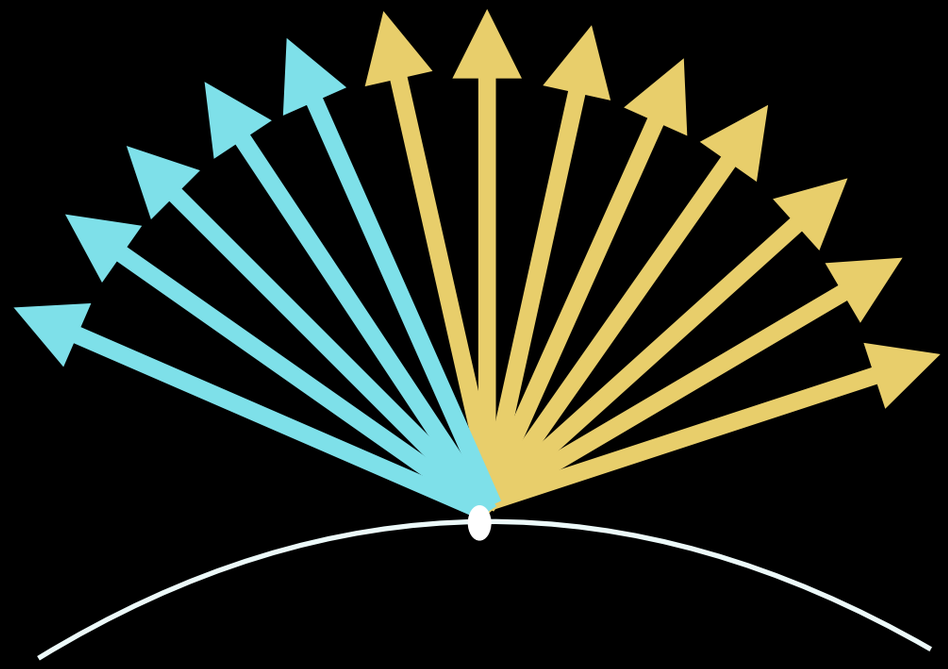
AI for Neutrino Flavor Conversions



- Checking criteria for the occurrence of FCs
- Finding equilibrium state for given initial quantities

Criteria for FFCs

- FFC could occur when there is crossing in $f_{\nu_e}(\theta)$ -$f_{\bar{\nu}_e}(\theta)$



- Scales on which flavor conversion can occur is now proportional to n_ν and could be < 10 cm

Criteria for FFCs

- The angular distributions are not available, instead we have only access to their moments

$$I_n = \int \mathrm{d}\cos\theta_\nu \;\; \cos^n\theta_\nu \;\; f_\nu(\cos\theta_\nu)$$

- In M1 closure scheme only the evolution of zeroth and first moments are followed directly

- AI can detect FFCs based on I_0 and I_1 on the fly
  - A classification problem!
  - We have four feature here: I_0 and I_1 for neutrinos and antineutrinos

Criteria for FFCs

- The error is the same as the error in the noisy labels

Parametric distributions

Logistic Regression (93%)			
	precision	recall	F_1-score
no crossing	83%	93%	88%
crossing	97%	93%	95%
KNN (n=3) (95%)			
	precision	recall	F_1-score
no crossing	90%	90%	90%
crossing	96%	96%	96%
SVM (95%)			
	precision	recall	F_1-score
no crossing	92%	90%	91%
crossing	96%	97%	97%
Decision tree (94%)			
	precision	recall	F_1-score
no crossing	89%	88%	89%
crossing	96%	96%	96%

Abbar2022

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Realistic data

LR (n = 2) (94%)			
	precision	recall	F_1-score
no crossing	96%	95%	95%
crossing	91%	93%	92%
KNN (n=3) (98%)			
	precision	recall	F_1-score
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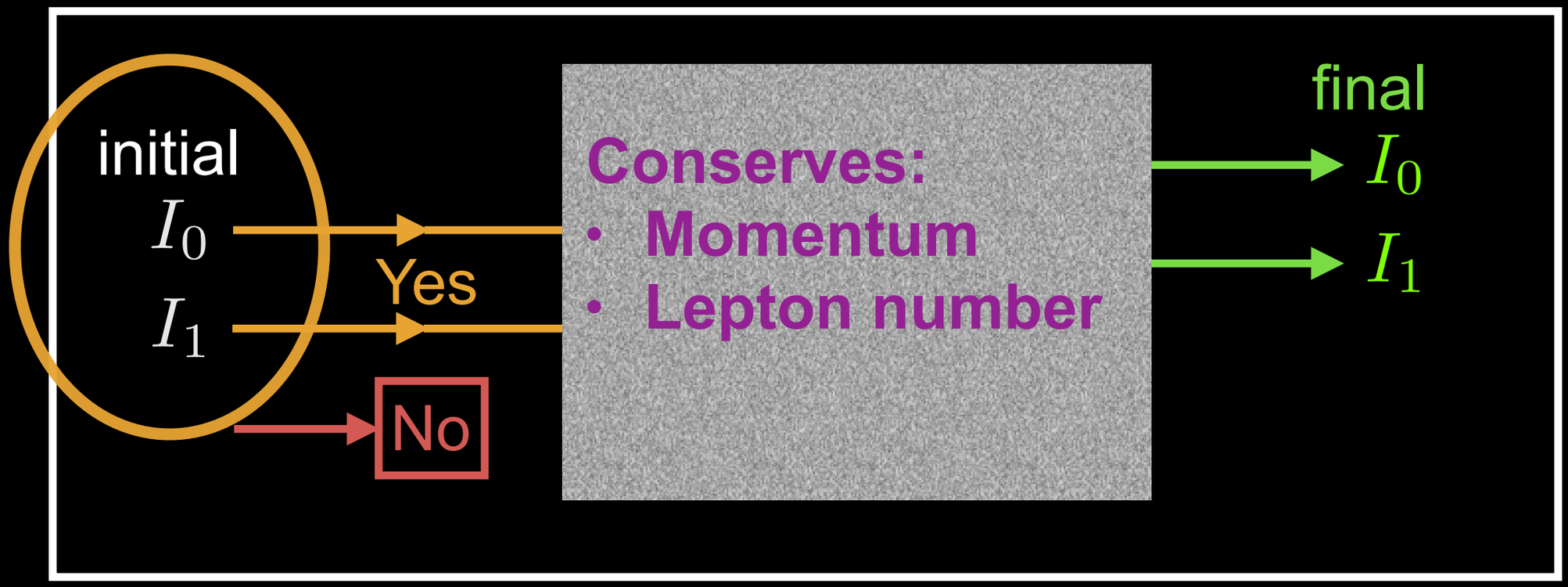
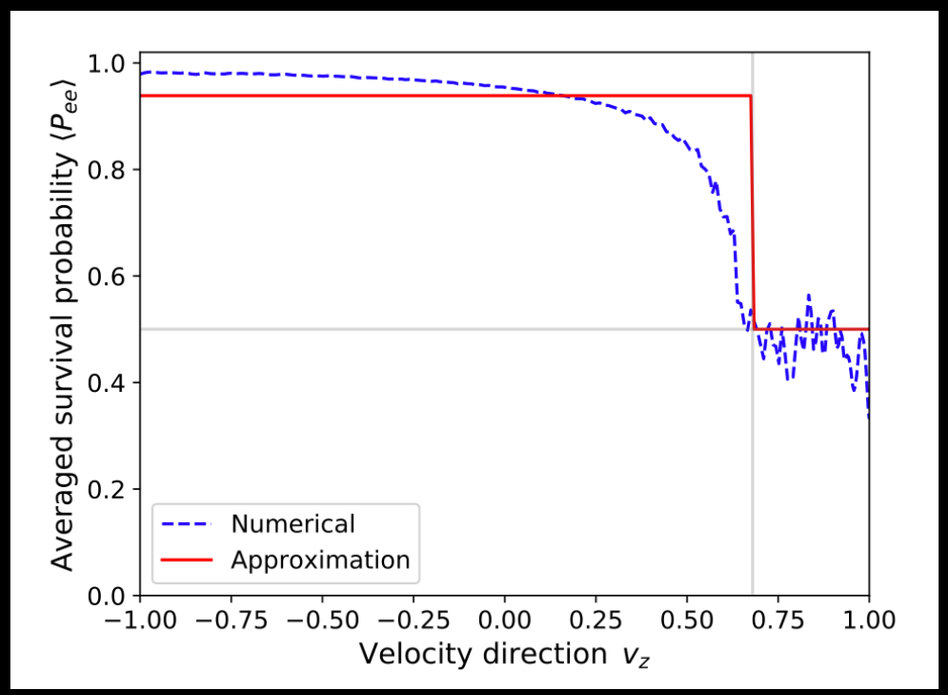
Abbar&Nagakura2023

FFC equilibrium state

- Assuming instantaneous equilibration



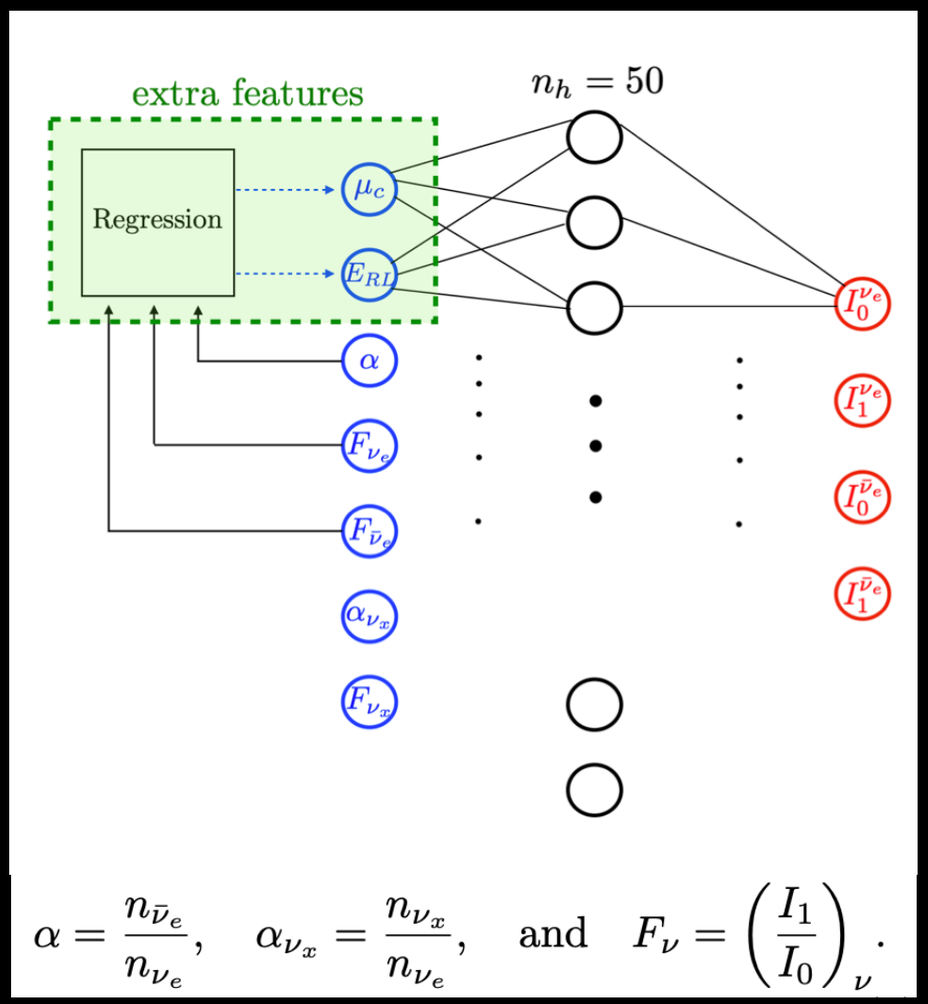


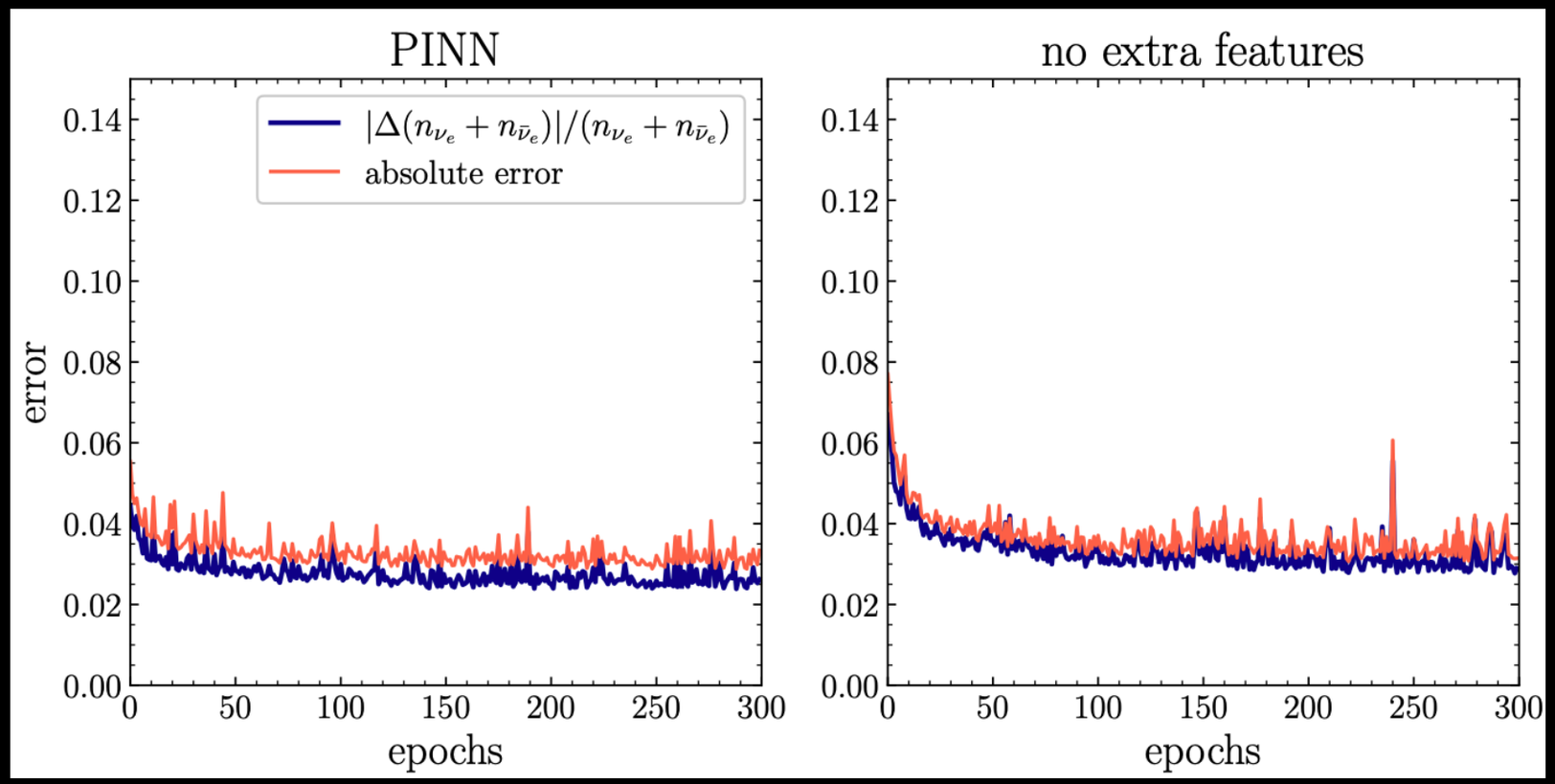
- Assuming the periodic box solution, the survival probability can be found analytically

Nagakura+,Wu+(2022)

FFC equilibrium state

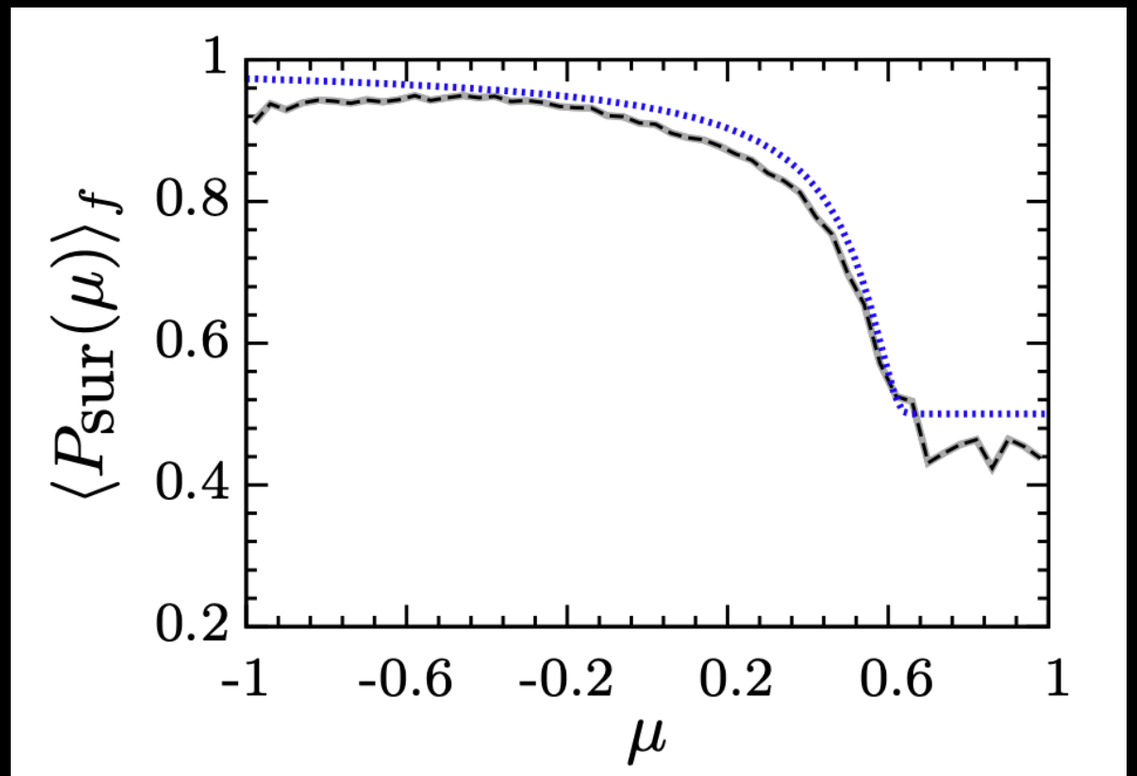
- For a single-energy neutrino gas, NN can predict the outcome of FFCs
- Introducing novel features could help a bit





FFC equilibrium state

- For a multi-energy neutrino gas, all the energy bins follow the same survival probability (if FFC is really fast!)



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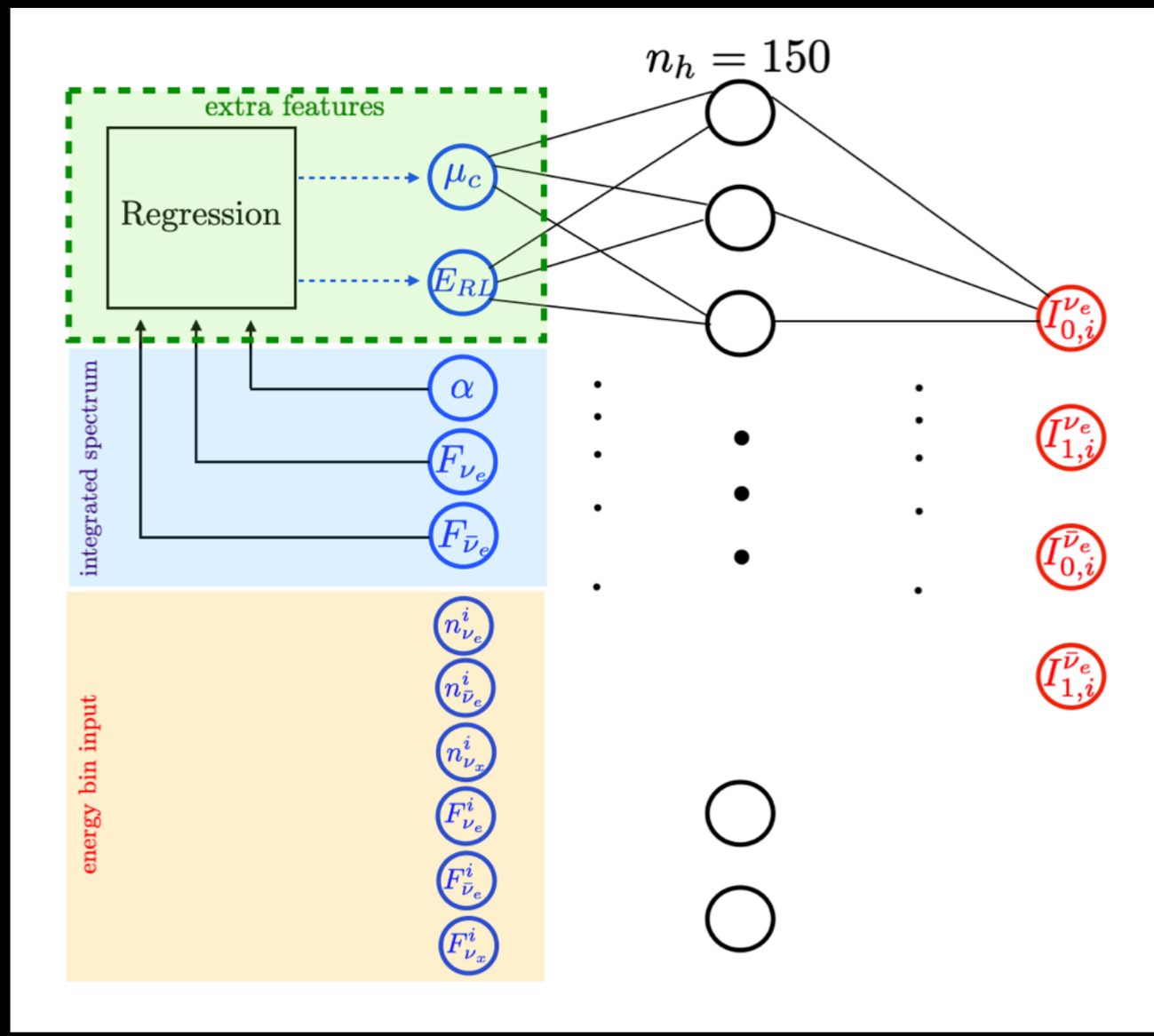

FFC equilibrium state

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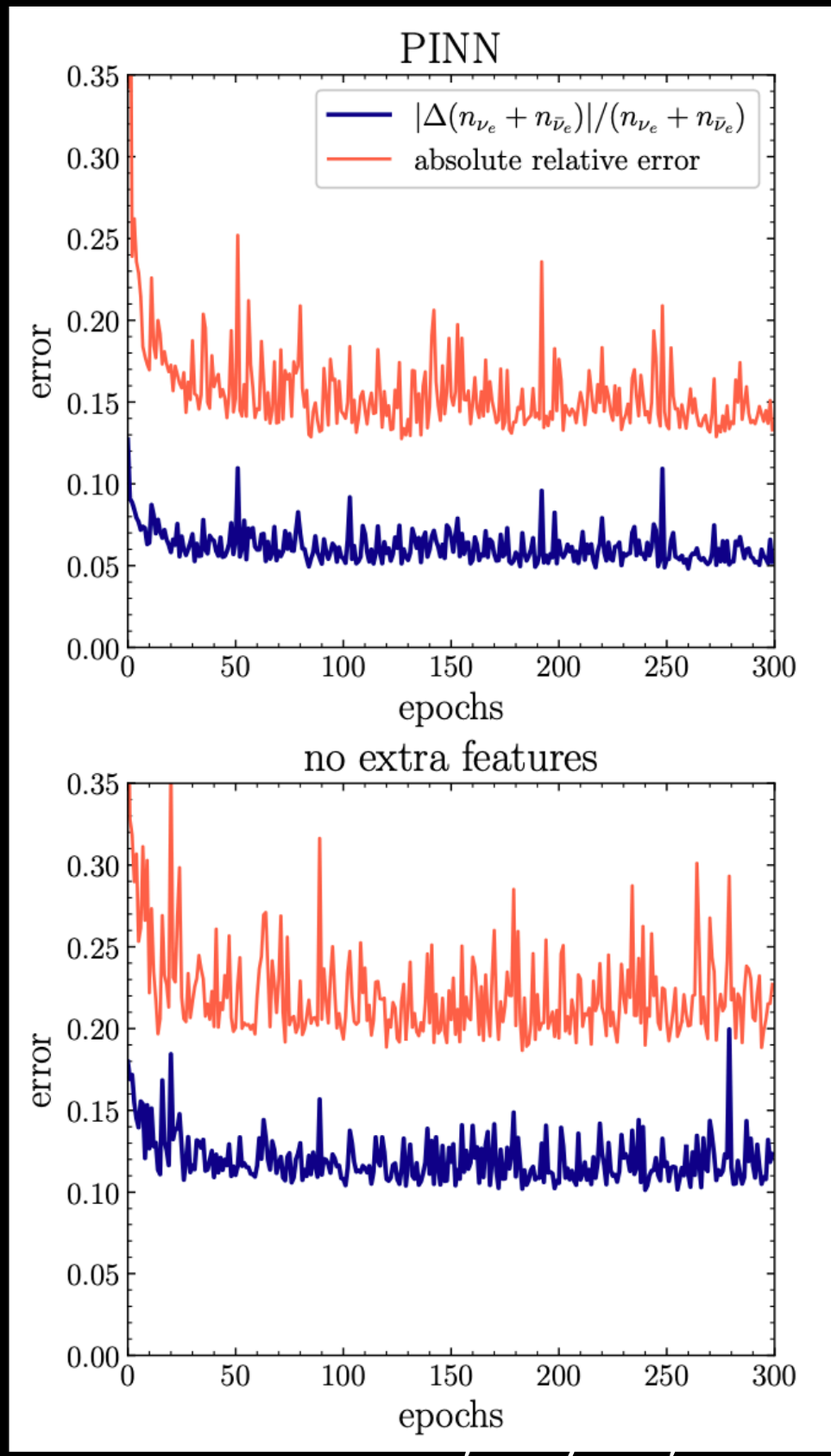
- The error is lager for the multi-energy case
- Feature engineering is important



Summary

- Neutrino Flavor Conversions cannot be ignored blindly in CCSN simulations
- AI can help with this but still lots of issues must be addressed