OAK RIDGE National Laboratory

PROSPECT

Machine Learning Applications for Reactor Antineutrino Detection at PROSPECT

Andrea Delgado

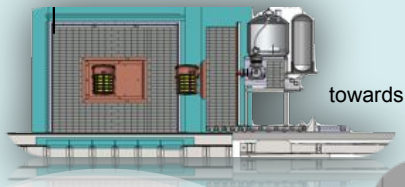
On behalf of the PROSPECT collaboration

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

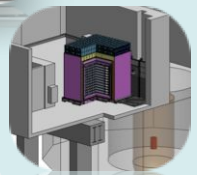
U.S. DEPARTMENT OF ENERGY

ORNL Neutrino Program

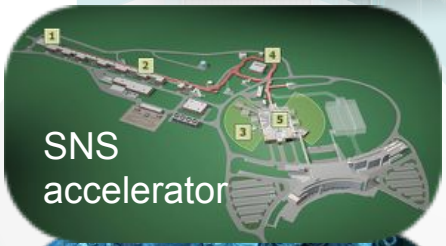
Experimental Neutrino Program

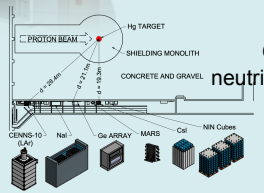


LEGEND-
towards 1 tonne ^{76}Ge experiment



PROSPECT-
A Precision Reactor Neutrino Oscillation and Spectrum Experiment at the 85MW HFIR



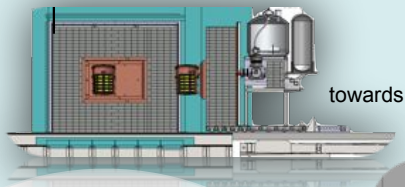


COHERENT-
Coherent elastic neutrino-nucleus scattering at SNS

Dark matter-
detectors technology

ORNL Neutrino Program

Experimental Neutrino Program



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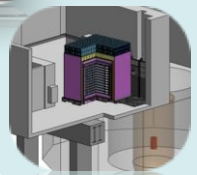

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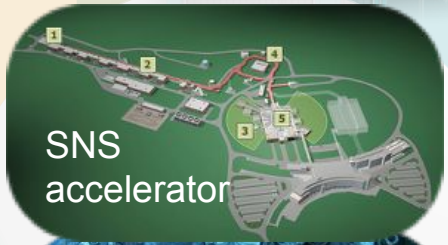

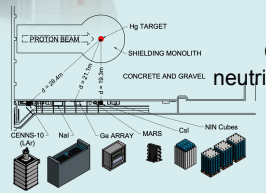

COHERENT-
Coherent elastic neutrino-nucleus scattering at SNS

Dark matter-
detectors technology

AI/ML

Machine Learning Applications-
Physics object reconstruction, classification.

Quantum Information Science-
Quantum Machine Learning

Computational Resources
Through Oak Ridge Leadership Computing Facility:
High-performance computing resources like Summit, access to quantum computing processors through D-Wave and IBM. Data resources like the HPSS archival system and the Spider II center-wide parallel file system.

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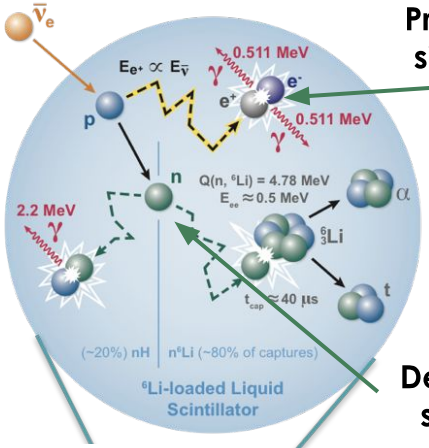
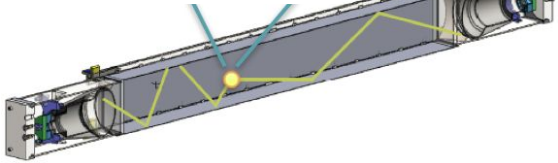
Antineutrino Event Reconstruction

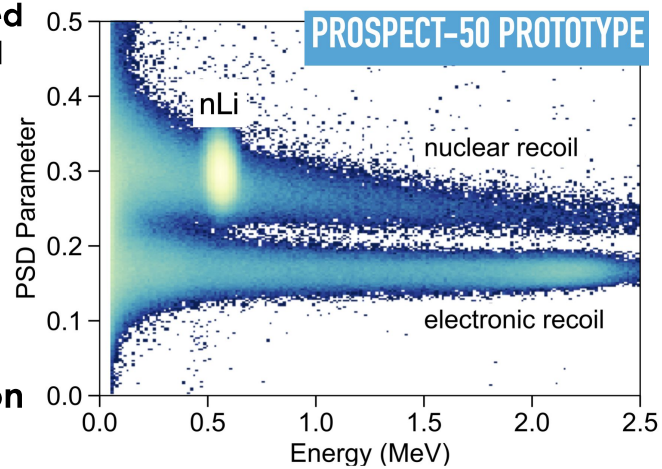


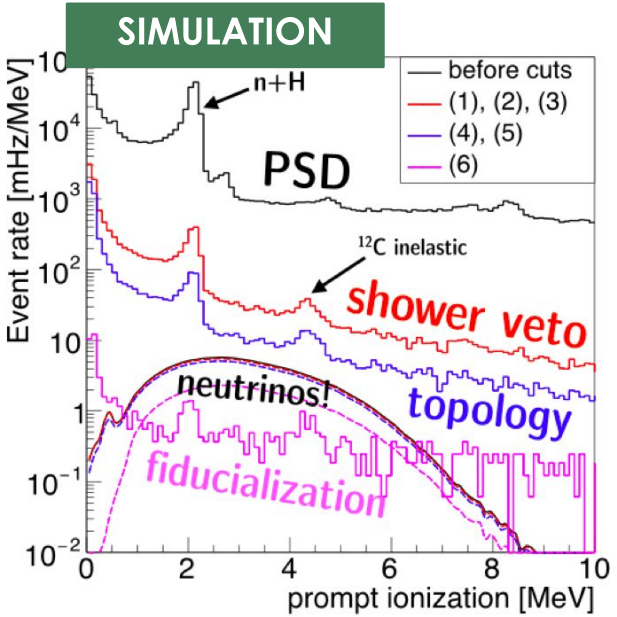
$$\bar{\nu}_e + p^+ \rightarrow n + e^+$$



Antineutrinos detected through Inverse Beta Decay (IBD) interaction

Background suppression through set of cuts based on IBD topology, PSD, cosmic shower veto, etc...





Particle ID classification in 6Li-doped liquid scintillator allows to differentiate ionization/nuclear recoil/quenched n-Li

Prompt signal: ~1-10 MeV positron energy
Delayed signal: ~ 0.5 MeV neutron capture

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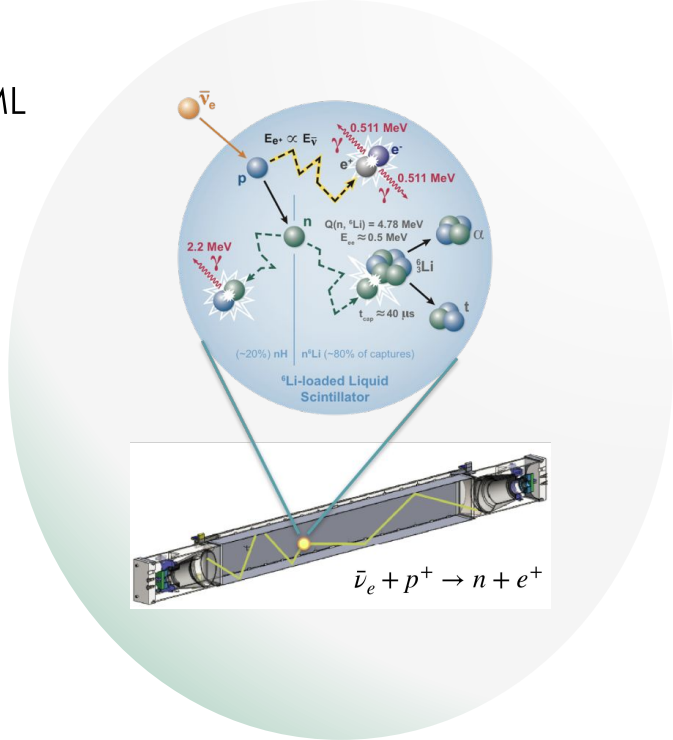
Machine Learning Applications at PROSPECT

Goal: Improving antineutrino event reconstruction by using ML techniques.



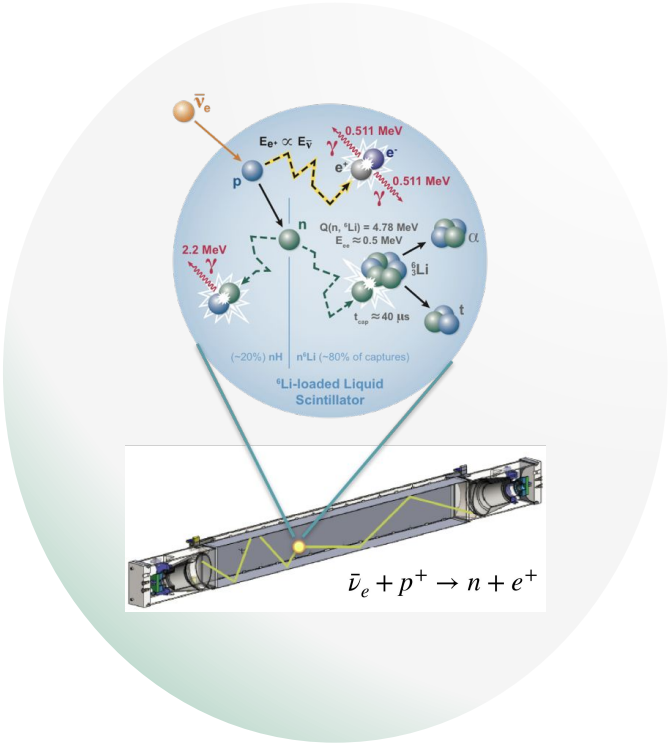
Efficient pulse matching

Improved particle identification

Enhanced background rejection

The Plan

Goal: Improving antineutrino event reconstruction by using ML techniques.



The focus of this talk

Identify potential areas of application → **Find and/or develop a model that matches these needs.** → **Benchmark against classical techniques**

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MVA Analysis for Background Suppression

Used in addition to set of rectangular selection cuts to optimize IBD selection efficiency.

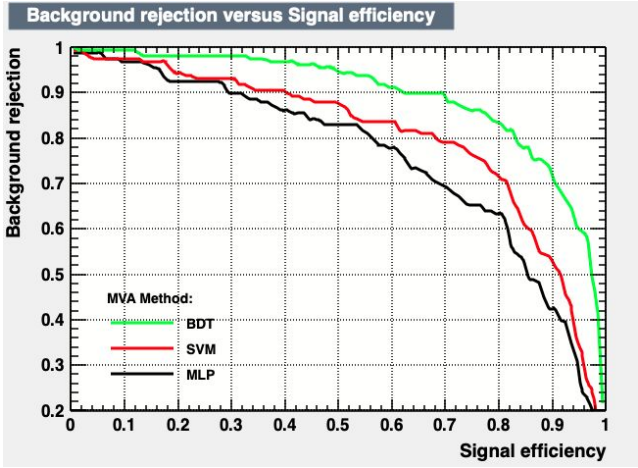
- Keep signal rate, but reduce background contamination.
- Use spatial and temporal correlations of prompt and delayed signals.
- Use ROOT's TMVA package for simplicity + easy to add to existing analysis framework.

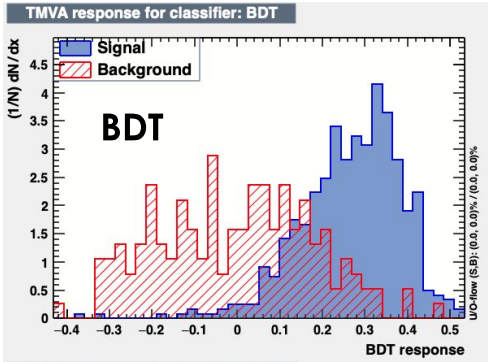
MVA Classifiers

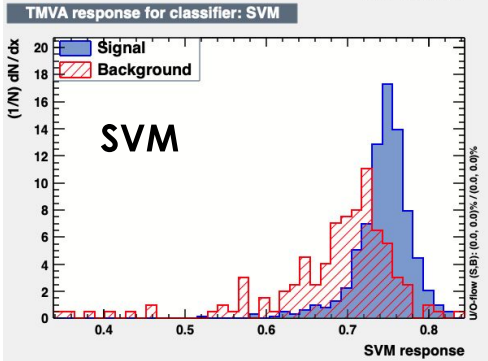
- *Multi-Layer Perceptron (MLP)*
- *Boosted Decision Tree (BDT).*
- *Support Vector Machine (SVM).*

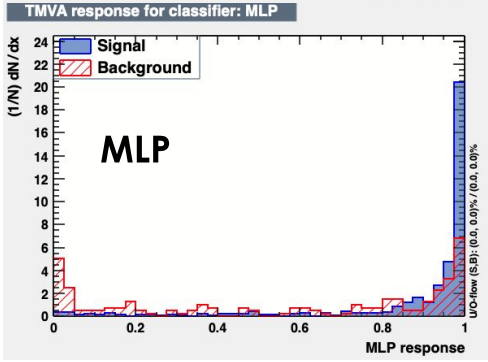
Training/test datasets

- *IBD simulation from PG4 for signal*
- *Reactor-off dataset for background*









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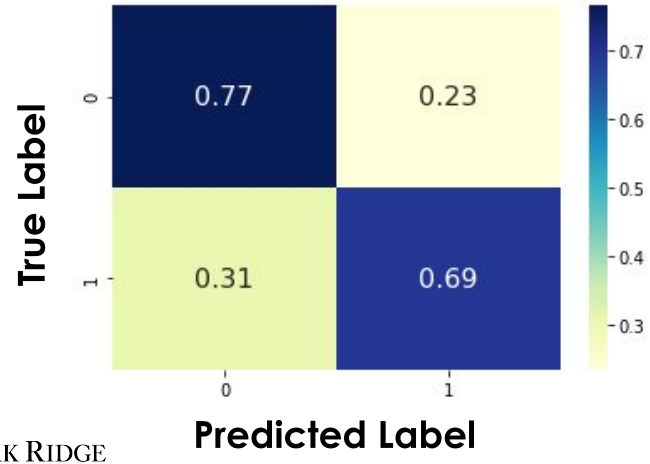
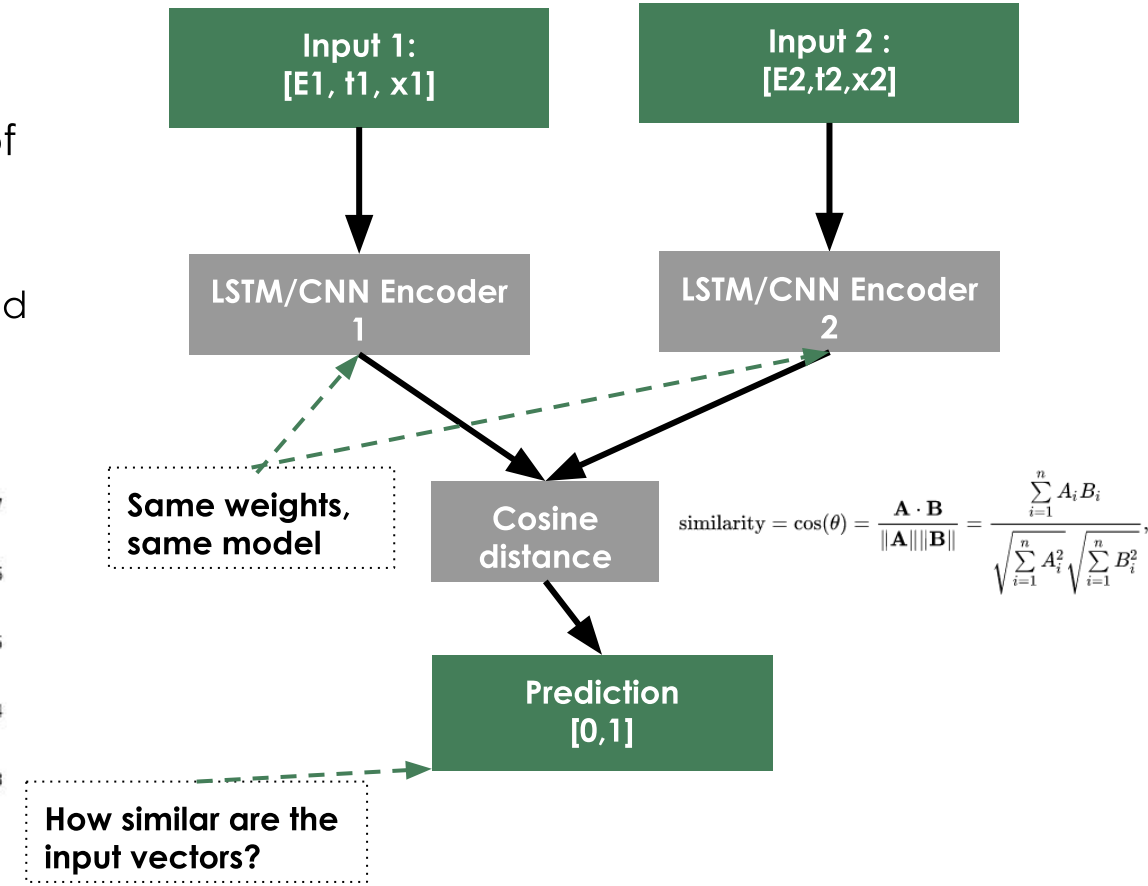
Siamese CNN/LSTM for Pulse Matching

- Cast pulse matching to a "**similarity**" problem.
- Keras-based implementation of **Siamese neural network**.
  - Two identical subnetwork, parameter updating is mirrored across both subnetworks
  - Accuracy of **~73%**.





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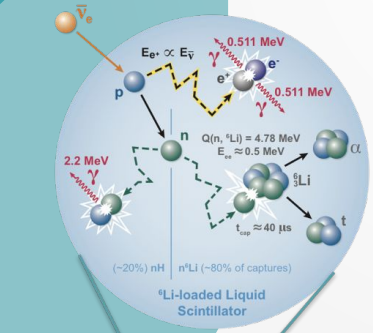
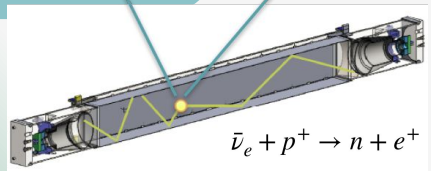
Machine Learning Applications at PROSPECT

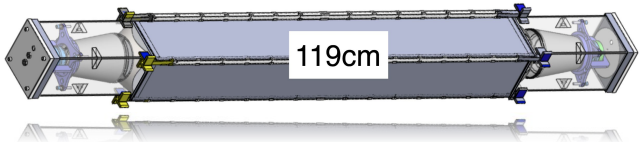
Single PMT Event Reconstruction

- **ML techniques** to maintain/improve **particle-ID** performance regardless of evolving detector conditions (single/double ended PMT readout).
- **Supervised ML** model trained on simulation and validated on experimental data.
- Improvement on cosmogenic background reduction.





See **Xiaobin (Jeremy's) Lu's** talk on **Sunday** @ **10:42** at Session **SN: Instrumentation: Calibration and Electronics II** on ***"Machine learning application to event reconstruction from single-ended PMT readout"***



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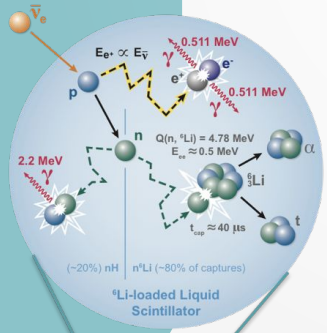
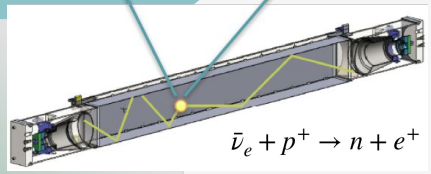
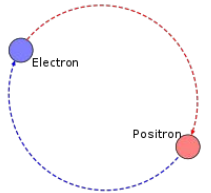




Positron ID through ortho-positronium tagging

- Attempting to perform **Particle-ID** at waveform level.
- **NN** to learn distortion in timing distribution of pulses caused by **o-Ps formation**.
- Great impact on background suppression!



See **Blaine Heffron and Diego Venegas-Vargas'** talk on **Saturday** @ **11:54** at Session **LK: Mini-Symposium: Novel detector technologies, from detectos to data analysis** on ***"Machine learning applications for Ortho-Positronium tagging in liquid scintillator for the PROSPECT experiment"***

Machine Learning Applications at PROSPECT

Single PMT Event Reconstruction

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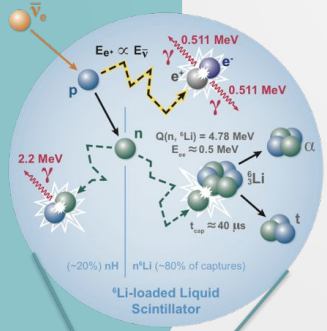
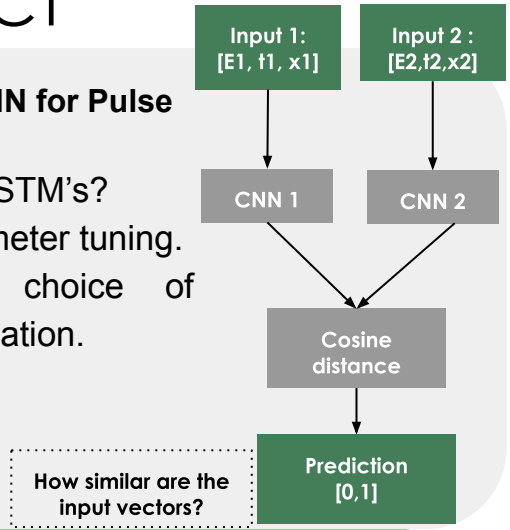


Siamese LSTM/CNN for Pulse Matching

- CNN's vs LSTM's?
- Hyperparameter tuning.
- Optimizing choice of input information.



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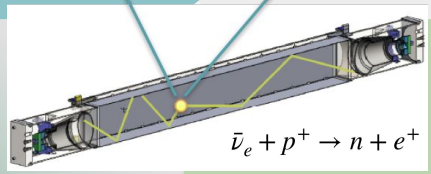
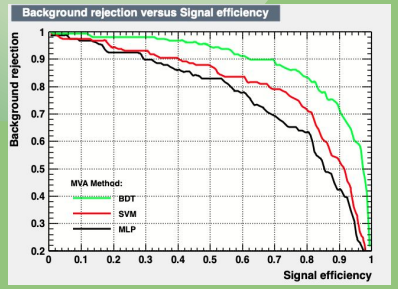


MVA Analysis for Background Suppression

- Train model in MC only.
- Study impact of using discriminant on energy spectrum.



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Summary

- Overview of **ML applications** to ***reactor antineutrino data analysis*** were presented today.
  - Focused on improving event reconstruction methods and background suppression.
  - Currently exploring several models and programming languages.
    - Defining what models are best suited for our needs.
  - For the future, we would like to benchmark these models and applications with current methods.

ML applications in PROSPECT can help enhance PSD and P-ID power and improve reactor antineutrino event reconstruction.

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Thank you!

Questions?

Andrea Delgado
Corey Gilbert
Blaine Heffron
Xiaobin (Jeremy) Lu
Diego Venegas-Vargas
Rosa Luz Zamora-Peinado
Alfredo Galindo-Uribarri

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