Spatial reconstruction of neutrino interactions based on a neural network in the JUNO experiment using the 3 inch PMT system

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Jiangmen Underground Neutrino Observatory

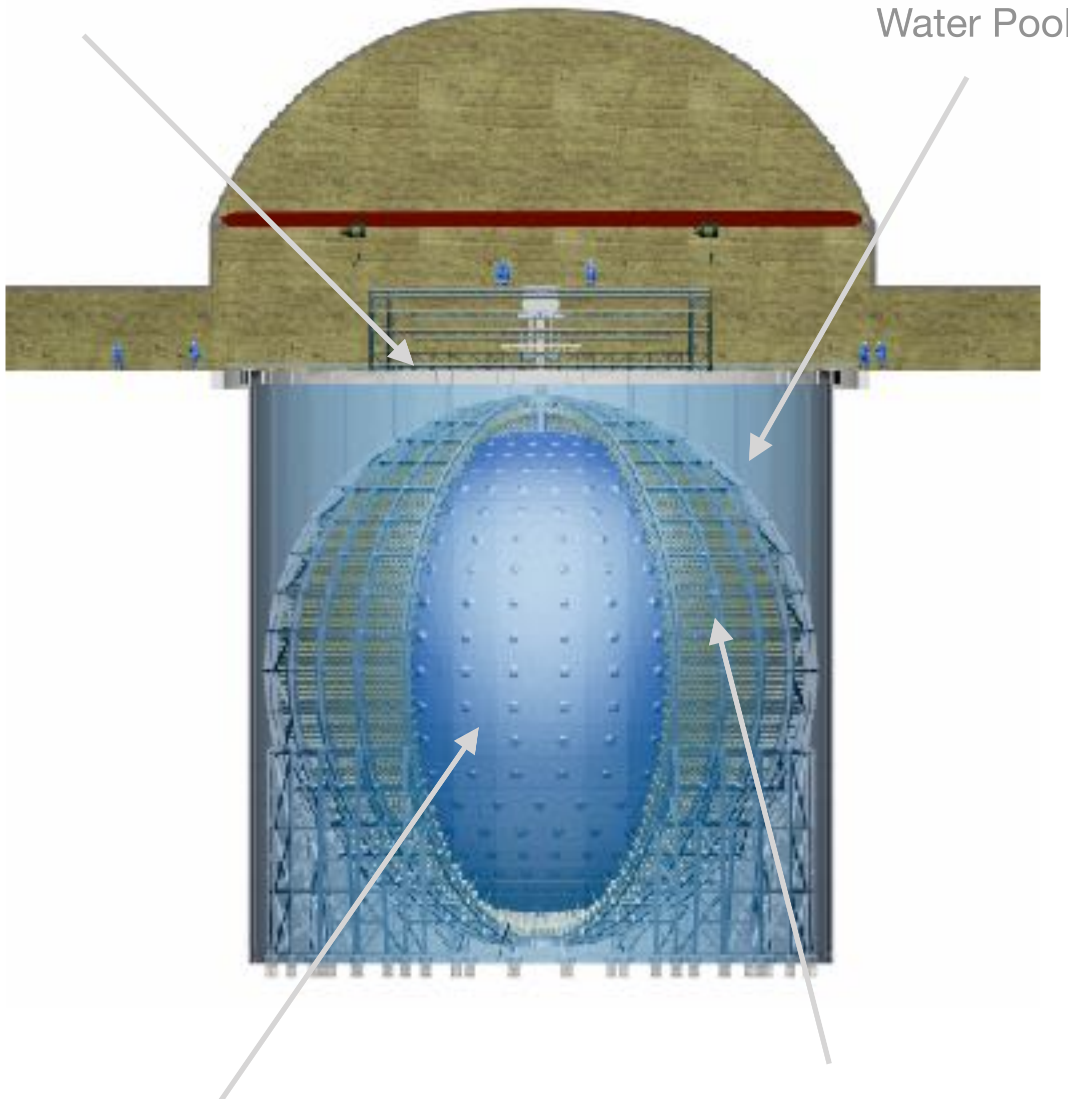
JUNO

- Underground neutrino detector located in China
  - ~52 km from two nuclear plants

- Use a 20 kton **Liquid Scintillator (LS)**
  - **Contained in an acrylic sphere of 17,7m radius**

- Goals:
  - **Neutrino mass ordering**
  - **Precise measurement of oscillation parameters**
  - And other …

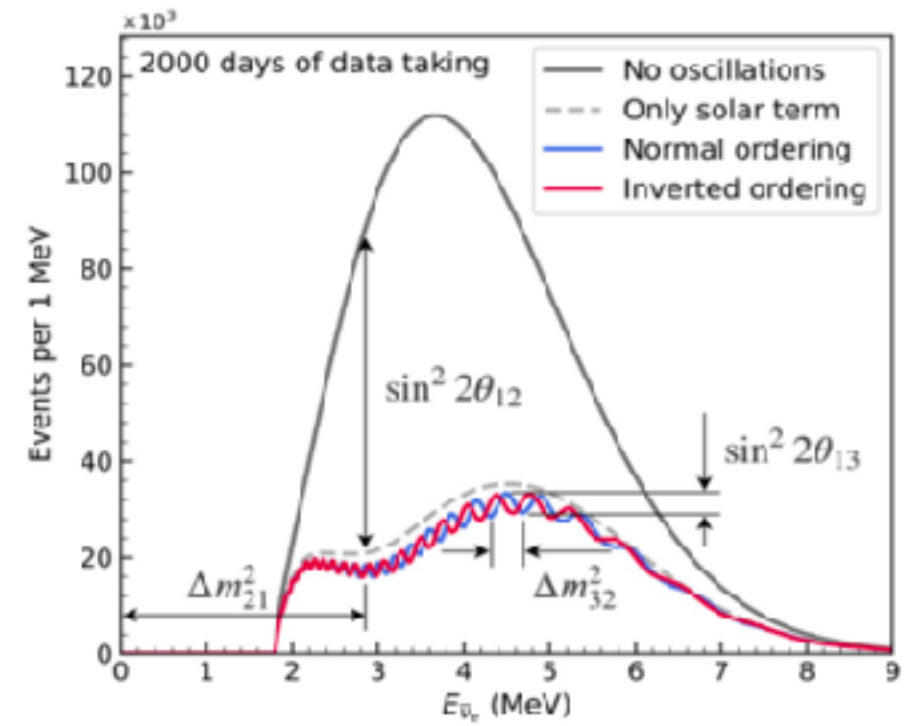
- Neutrino sources:
  - **Nuclear reactors**
  - Atmospheric neutrinos
  - Supernovas
  - Solar neutrinos
  - Geoneutrinos



Mass ordering and oscillation parameters

- JUNO use $\bar{\nu}_e$ coming from reactors to measure the mass ordering & oscillation parameters

- Survival probability of electronics antineutrinos depends on:
  - Distance traveled L
  - Energy E
  - Difference between mass eigenstate's masses Δm^2_{ij}
  - Oscillation parameters θ_{12}, θ_{13}



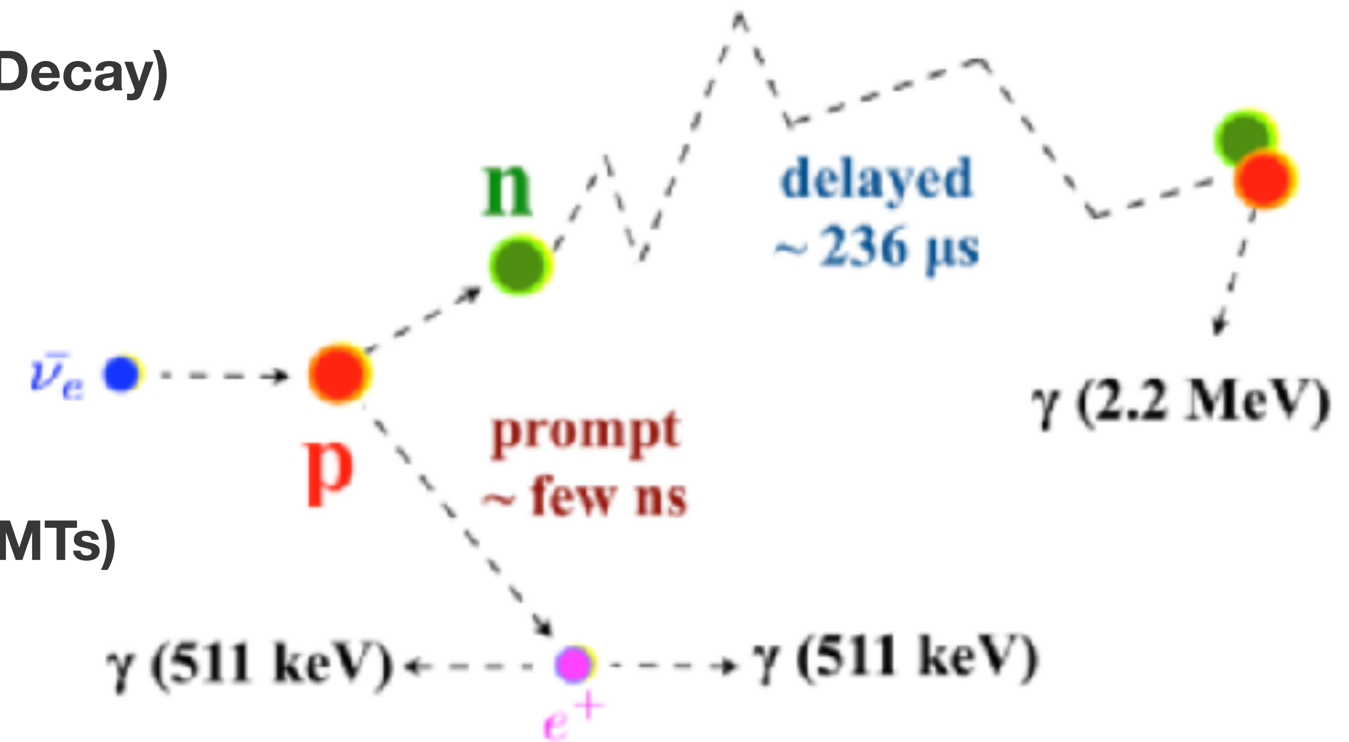
Expected $\bar{\nu}_e$ spectrum from reactors

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e; L) = 1 - \sin^2 2\theta_{12} c_{13}^4 \sin^2 \frac{\Delta m^2_{21} L}{4E} - \sin^2 2\theta_{13} \left[c_{12}^2 \sin^2 \frac{\Delta m^2_{31} L}{4E} + s_{12}^2 \sin^2 \frac{\Delta m^2_{32} L}{4E} \right]$$

Detection principle

- $\bar{\nu}_e$ interacts with **LS** through **IBD (Inverse Beta Decay)**

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



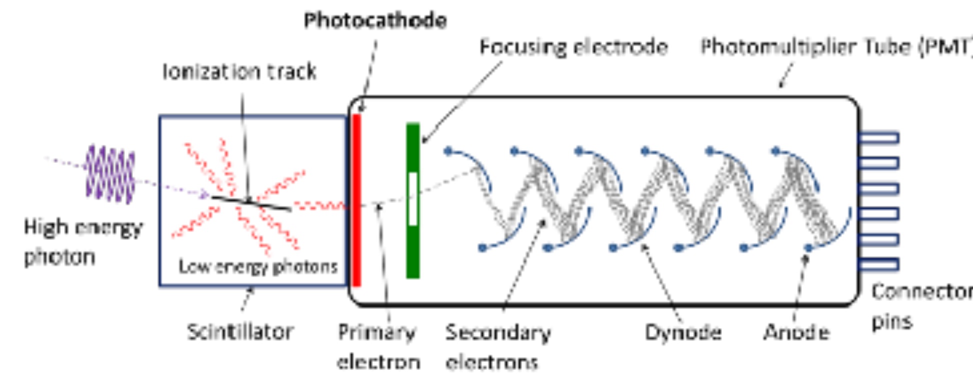
- e^+ and n deposit their energy in the LS
  → LS produces **photons**
  → **Photons** are collected by photomultipliers **(PMTs)**

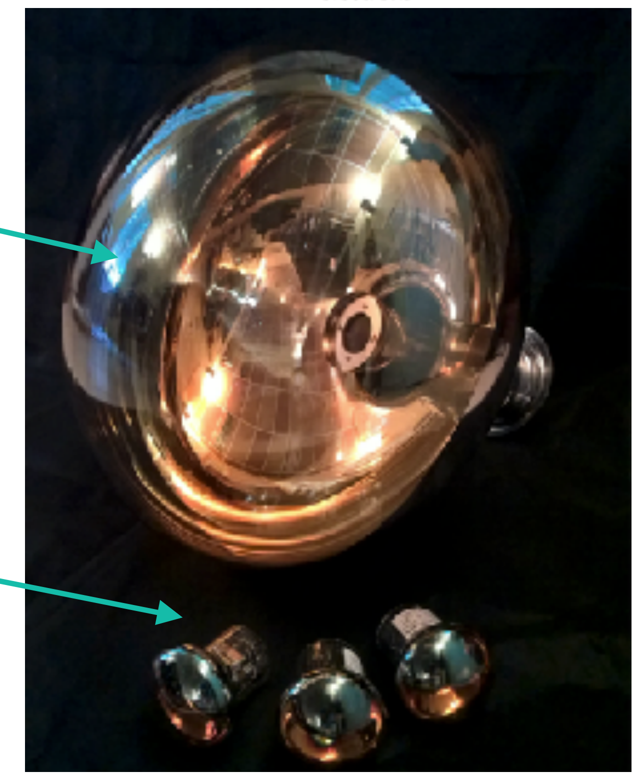
- e^+: **prompt signal**
  - Electronic elastic recoils
  - Annihilation with e^- of the LS → 2 γ (511 keV)
  - γ interact with LS by compton + photoelectric

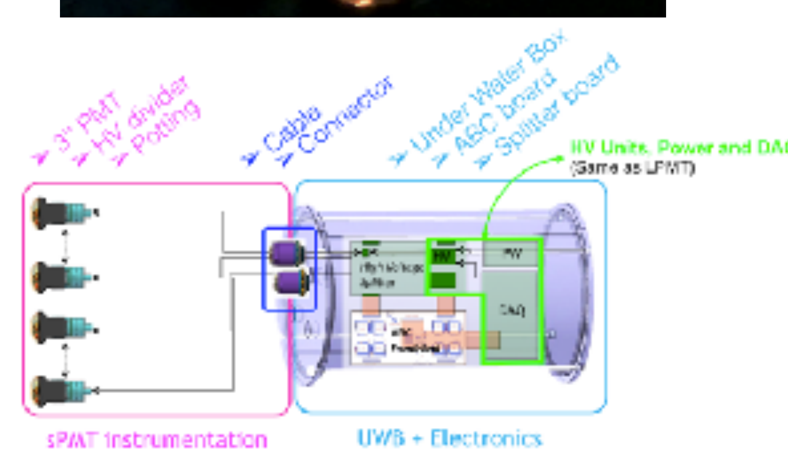
- n: delayed signal
  - Proton and neutron recoils
  - Captured by an hydrogen → γ (2.2 MeV)

Photodetection system

- Scintillation photons read by PMTs
- 2 types: Large PMTs, **Small PMTs**
- LPMTs: 20 inch diameter
  - Large photo-coverage
  - 17,612 used for the detector
- **SPMTs**: 3 inch diameter
  - Collects 1 photon most of the time
  - 25,600 of them in the detector
- Both have their signal digitized by their respective front-end electronics
- Independent and complementary





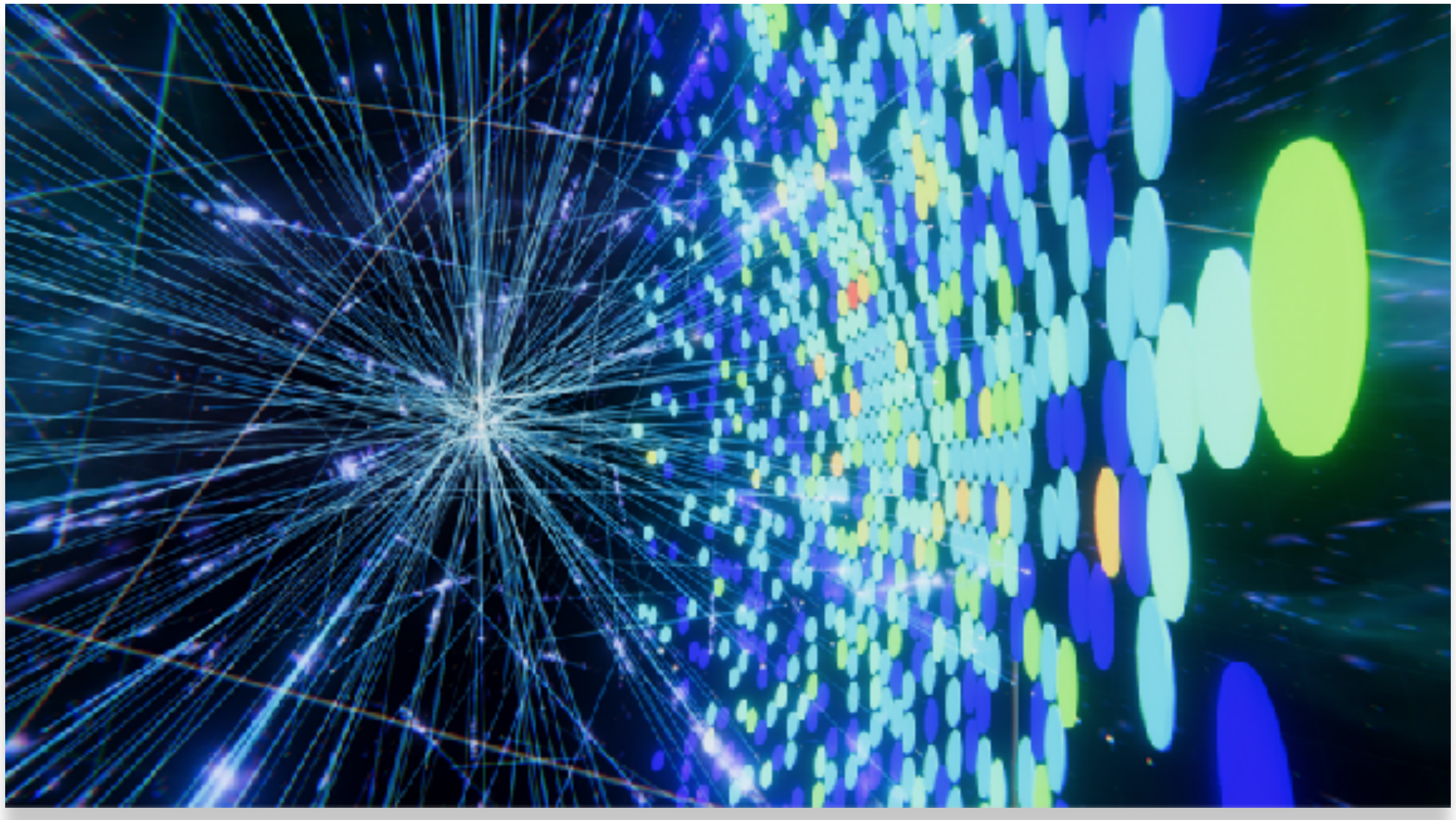


Event reconstruction in the LS

- Two main informations needed

- **Event's interaction vertex**
  - Prompt & Delay spatial coincidence
  - Correction for energy reconstruction
  - Background rejection

- Event's Energy
  - Original neutrino energy



Motivations for using a Neural Network

- Measurement of θ_{12} and Δm^2_{21} possible with only SPMTs
  → Need an event reconstruction with only SPMTs

  - Interaction vertex reconstruction already made with classical methods by Victor Lebrin but have some limitations

  - CNN could overcome those limitations and maybe outp classical methods

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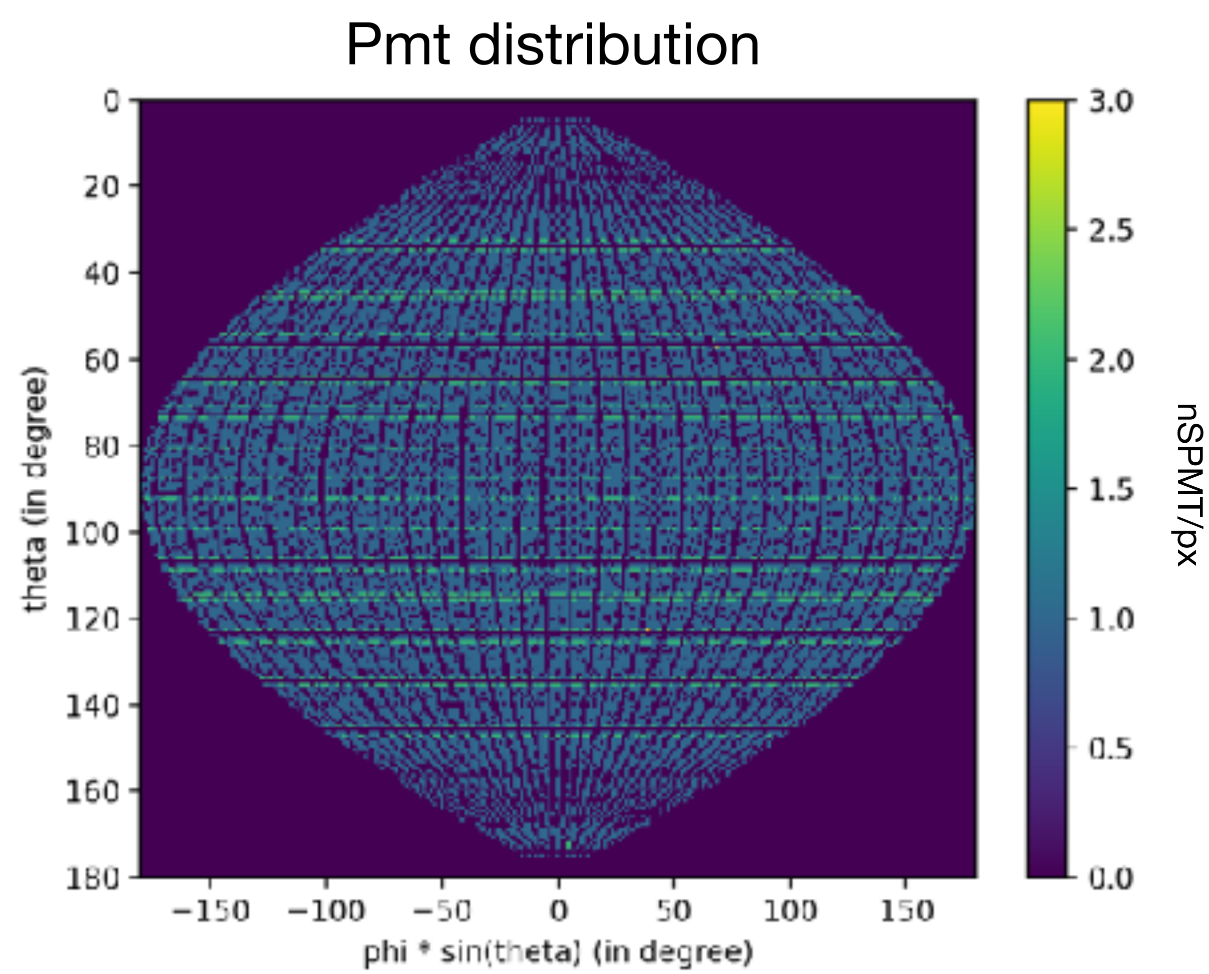
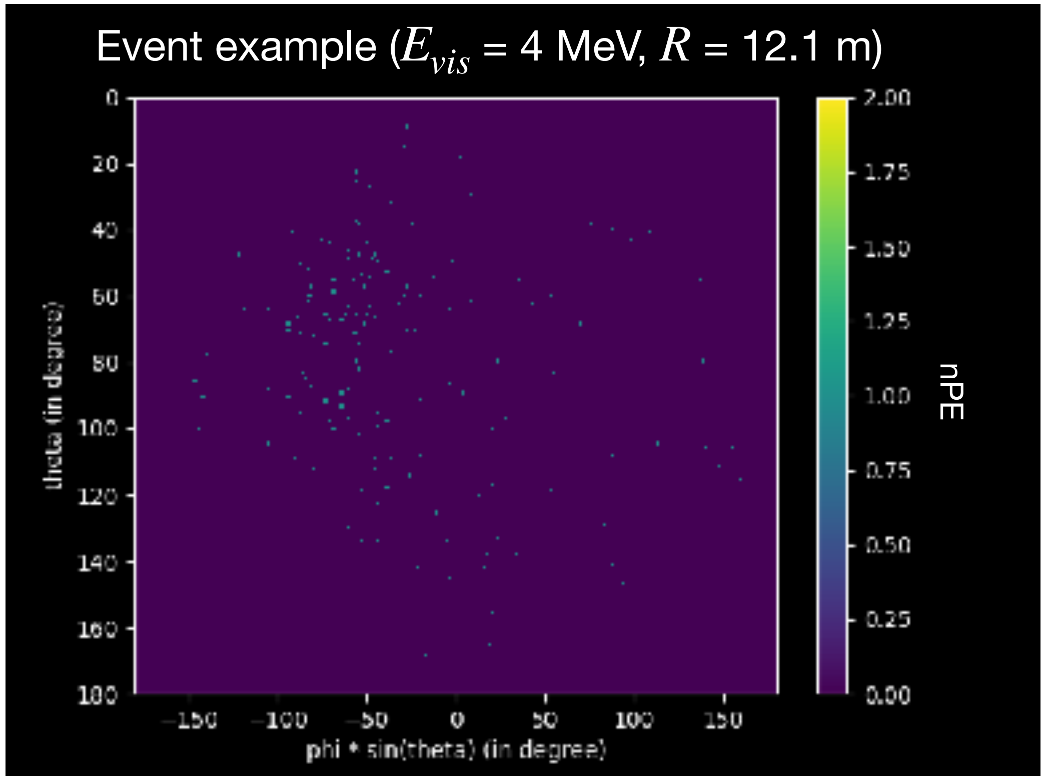
Neural networks

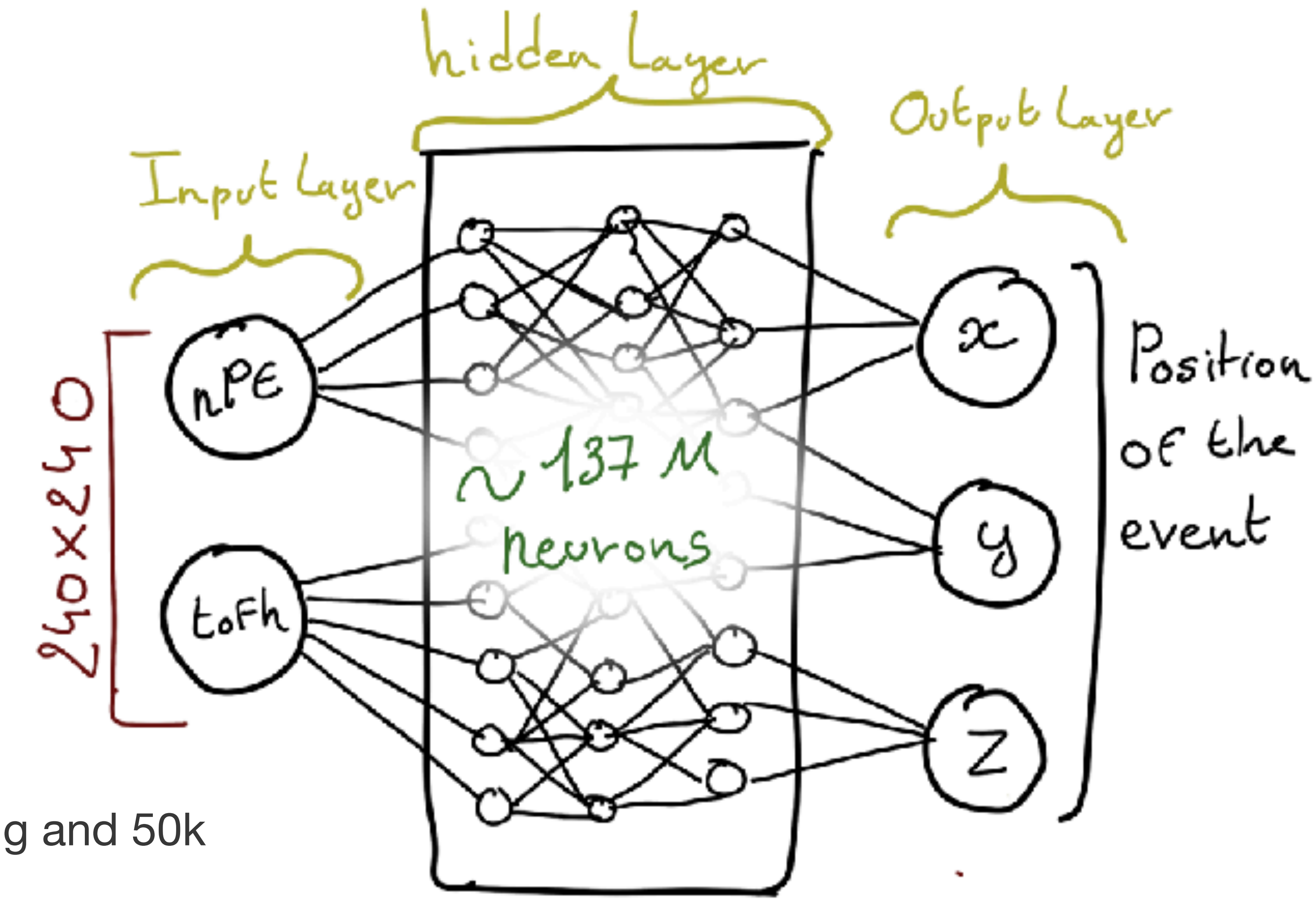
- Neural network is an AI technology based on learning
- Fed with training data
  - It learn how to get a correct result
- Only use the prompt signal
- Inputs: nPE, Tofh, SPMT position
  - nPE: number of photons collected by a SPMT
  - Tofh: Time of hit of the first collected photon
    1 Hit = 1 Photon collected
- Outputs: x, y, z (spatial position of the event)
- Representing inputs as images
  - SPMT position become pixel position
  - Challenging because SPMTs on a sphere





Neural networks training

- The neural network process the training events
- It adjusts its hidden layer accordingly
- At the end of the training, it is challenged with new data
- 980k simulated events for training and 50k used for the results



Preliminary results

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Prelin … ICSU

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Brent Rambo

Conclusion

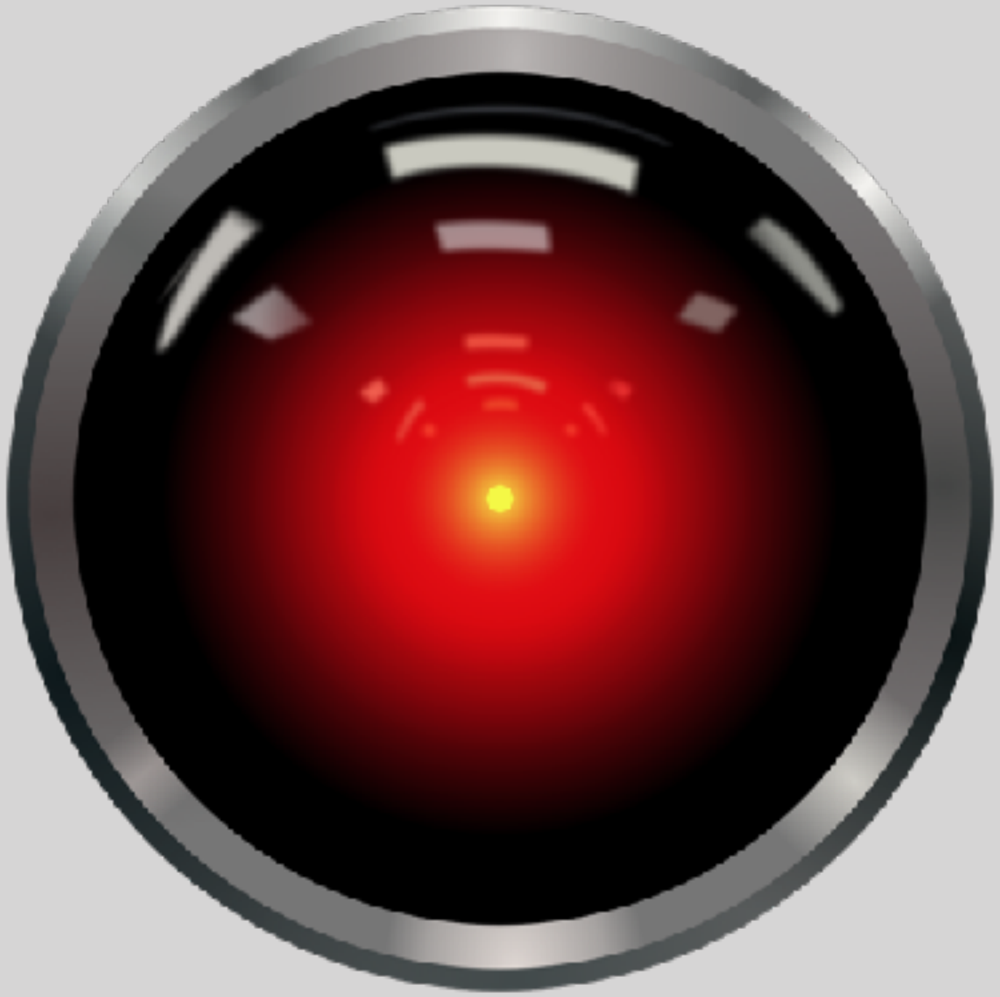
- Neural networks can overcome limitations of man made models

- Future work will maybe be able to outperform classical methods

- But neural networks are black box. It’s important to try to understand how they operate and it will be big part of in my works.

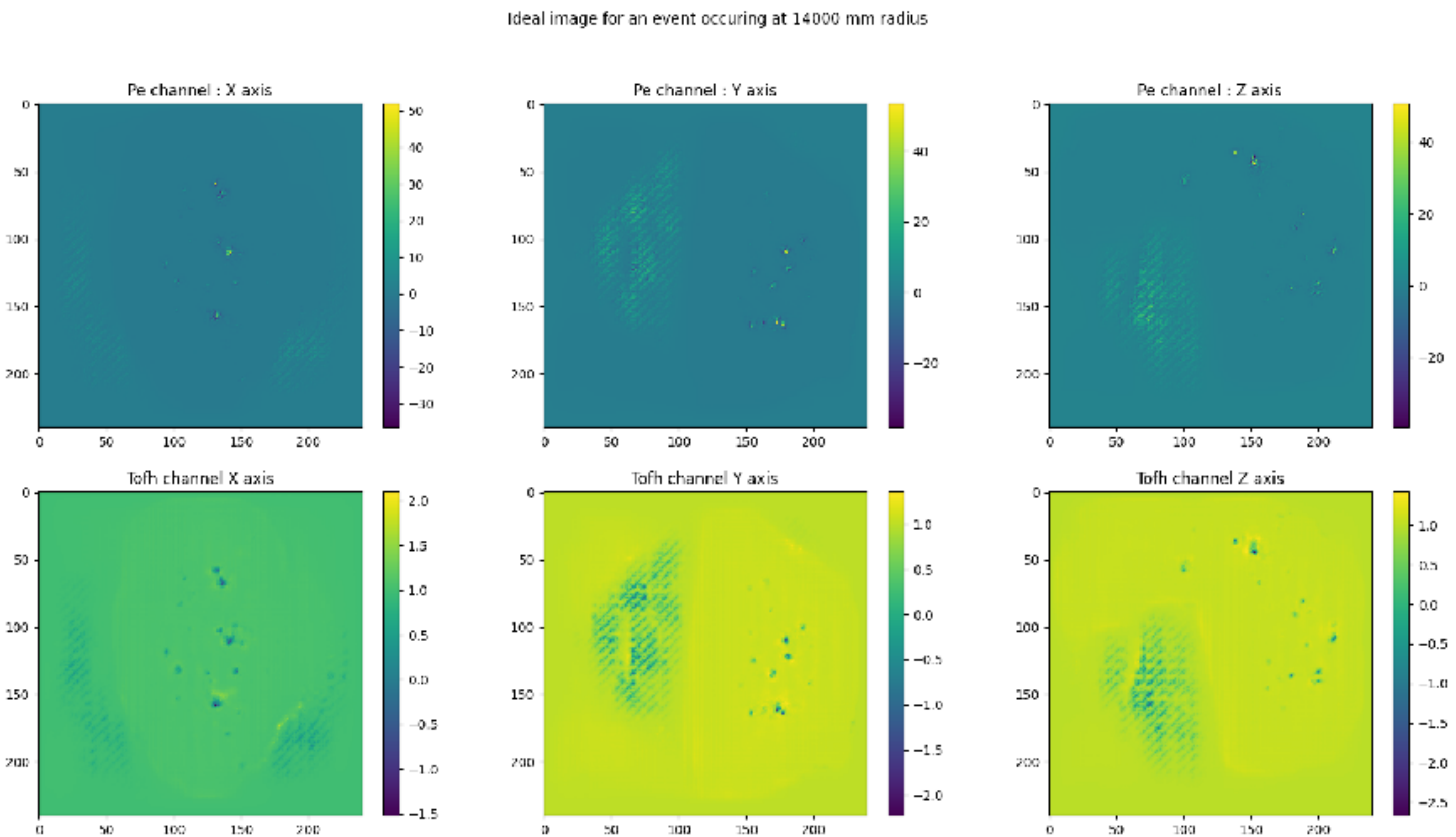
-We will also need to reconstruct the energy and event selection.

Thanks for your attention



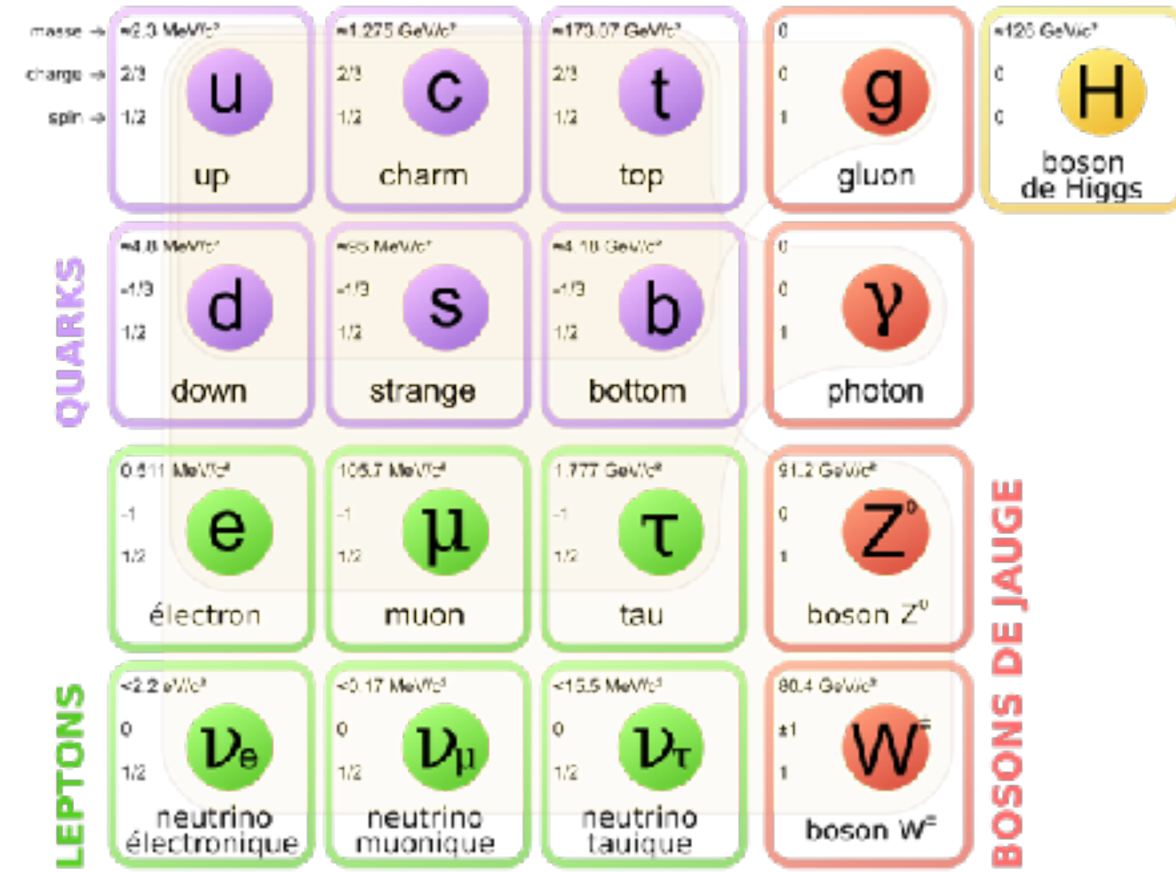
BACKUP

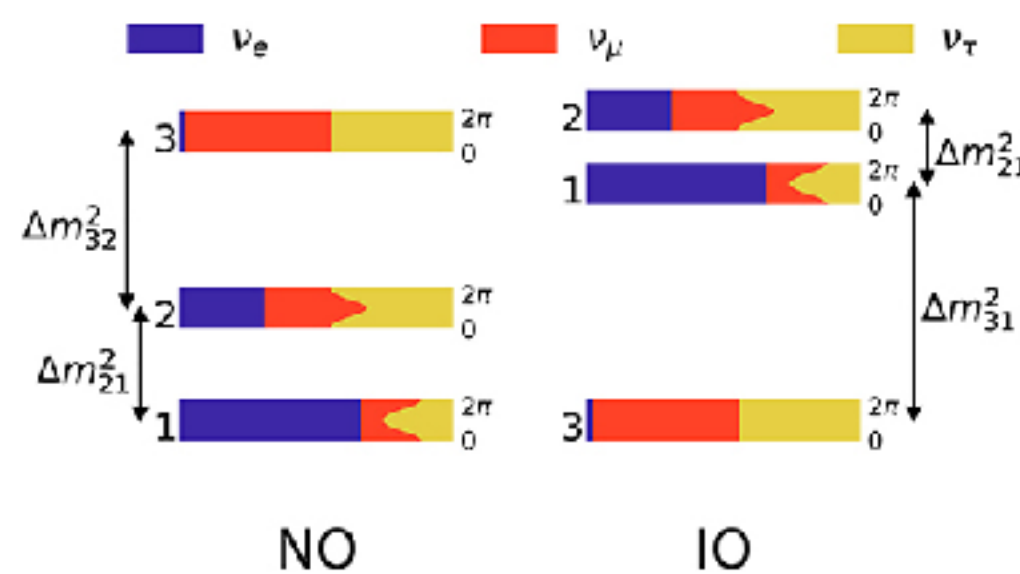
Do NN dream f electric sheep



Neutrinos basics

- Elementary particles
- Very small masses (< eV)
- Leptons → have a flavour
  - Electronic
  - Muonic
  - Tauic
- Interact only through weak interaction
- **Oscillate** between flavours
  - Flavours are mixin of the same 3 mass eigenstates
- **Mass ordering** still unknown



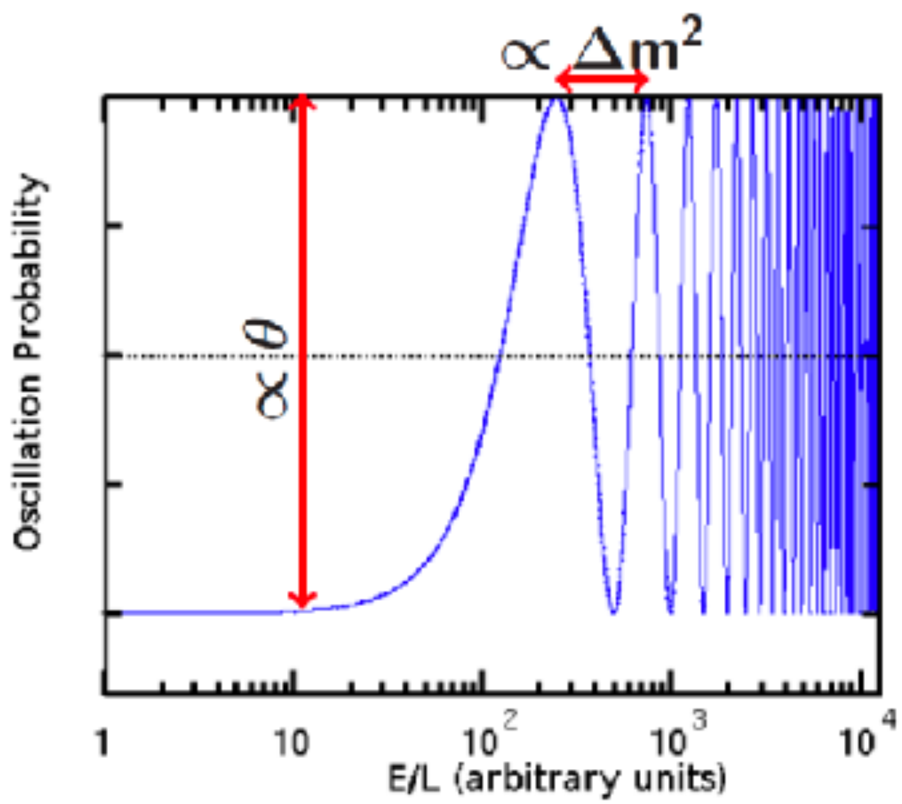


Neutrinos oscillation

- Oscillation described by the Pontecrovo-Maki-Nakagawa-Sakata (PMNS) matrix U

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

- U expressed with θ_{23}, θ_{12}, θ_{13} and a phase factor δ

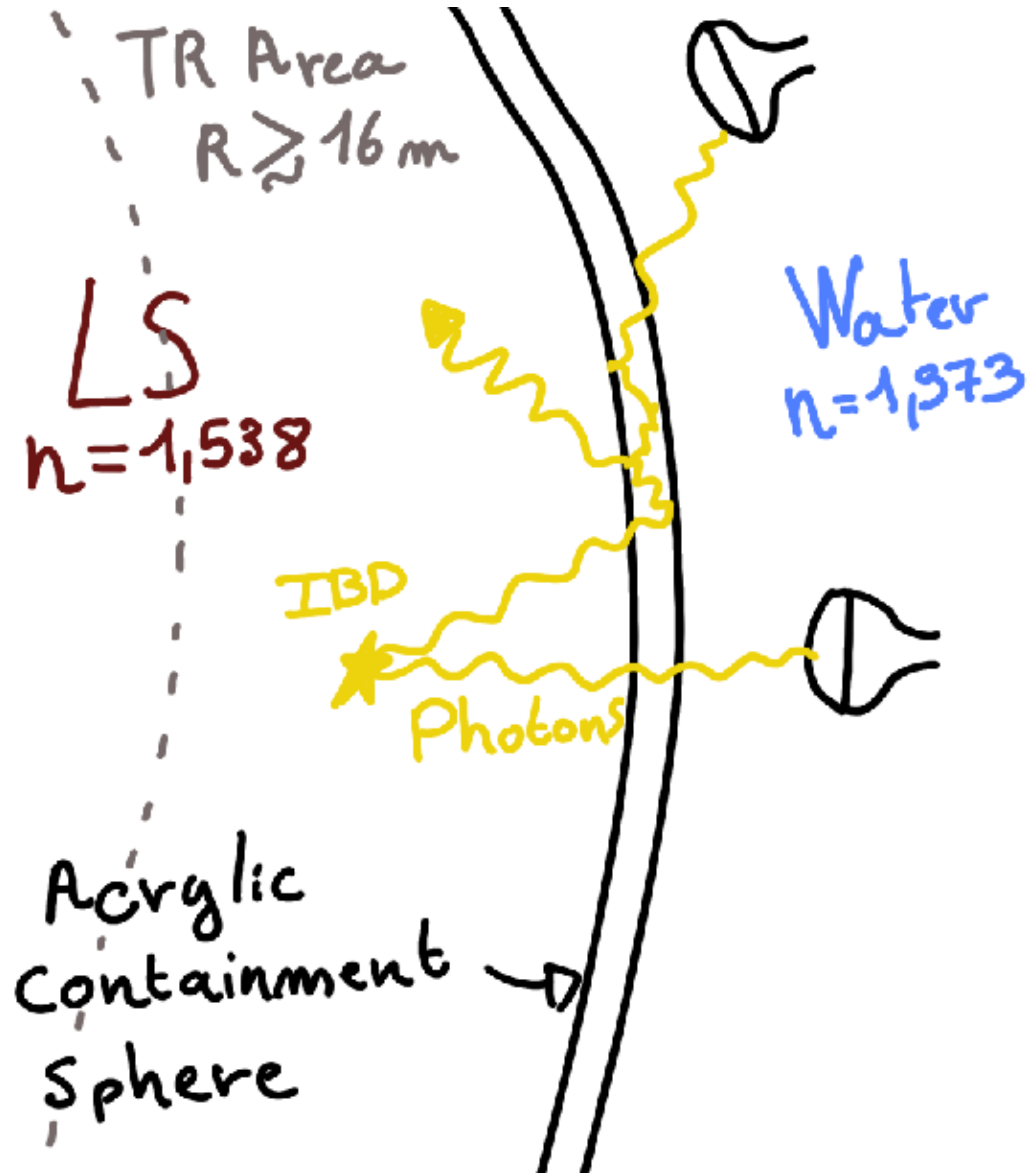


$$U = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\Delta m_{ij}^2 = m_i^2 - m_j^2$$

TR Area

- Area where photons can be reflected at the acrylic/water interface



Resolution vs R^3

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