

Optical Simulation of the Taishan LAr CE ν NS Experiment

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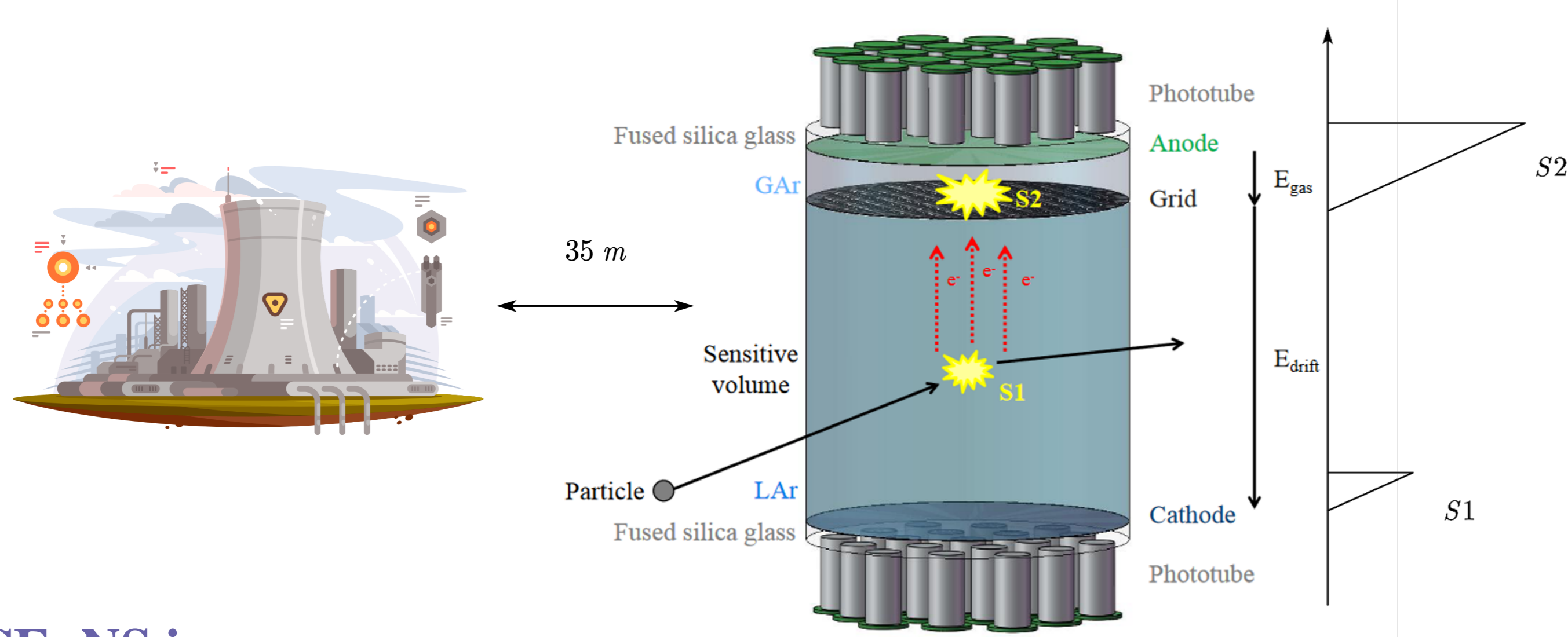
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Introduction

Coherent elastic neutrino-nucleus scattering (CE ν NS) is an important resort of testing Standard Model in low energy weak interaction. Considering the CE ν NS signal of reactor neutrino has not been observed yet, we propose an experiment utilizing dual-phase Ar Time Projection Chamber (TPC) technology and a 4.6 GW_{th} nuclear power plant (NPP) located in Taishan, Guangdong to search CE ν NS signals from reactor neutrinos. The distance between the detector and the NPP considered to be 35 m. Muons and neutrons from cosmic rays, however, will lead to complex backgrounds in the TPC. In order to evaluate a precise discovery sensitivity, it's necessary to estimate the dead-time effect and the pile-up with accurate optical simulation.

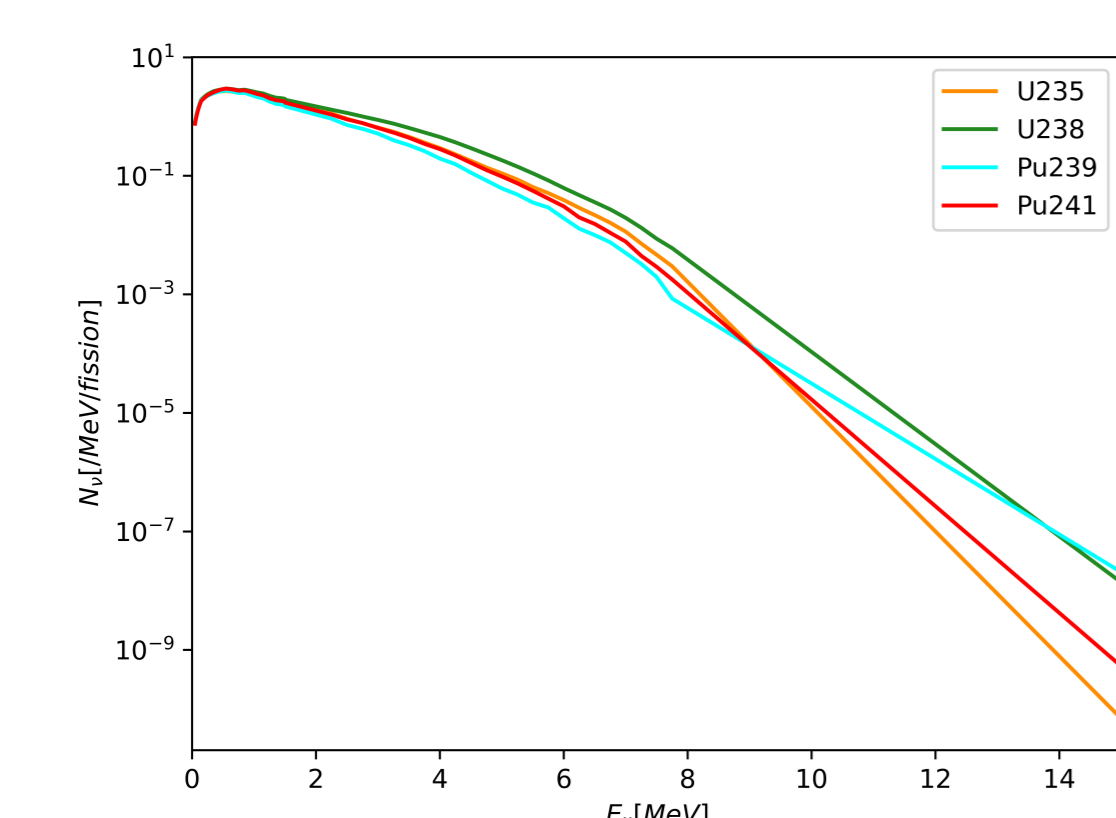
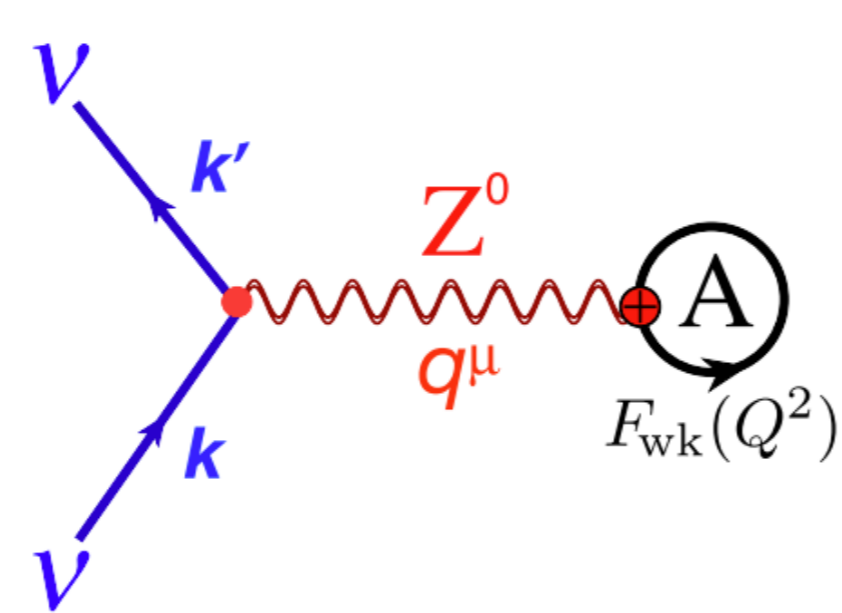


CE ν NS in argon

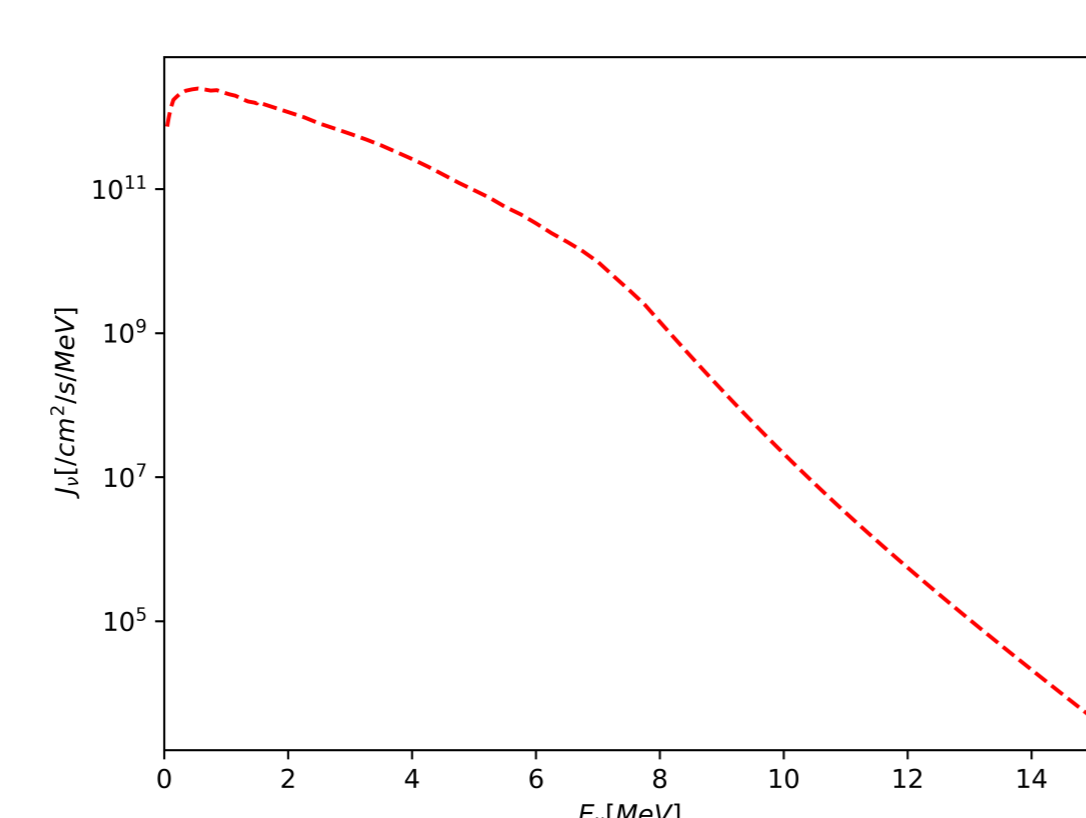
For low energy neutrino-nucleus interaction, because of $\vec{q} \cdot \vec{R} \ll 1$, the total scattering amplitude is approximate to the identical summation of the individual neutrino-nucleon scattering amplitude. This will lead to a cross section amplification which is roughly proportional to the square number of neutrons in the nucleus. The differential cross section of CE ν NS is given by [1]:

$$\frac{d\sigma}{dT} = \frac{G_f^2 M}{2\pi} Q_w^2 \left[1 + \left(1 - \frac{T}{E_\nu} \right)^2 - \frac{MT}{E_\nu^2} \right] F_w^2(Q^2) \quad (1)$$

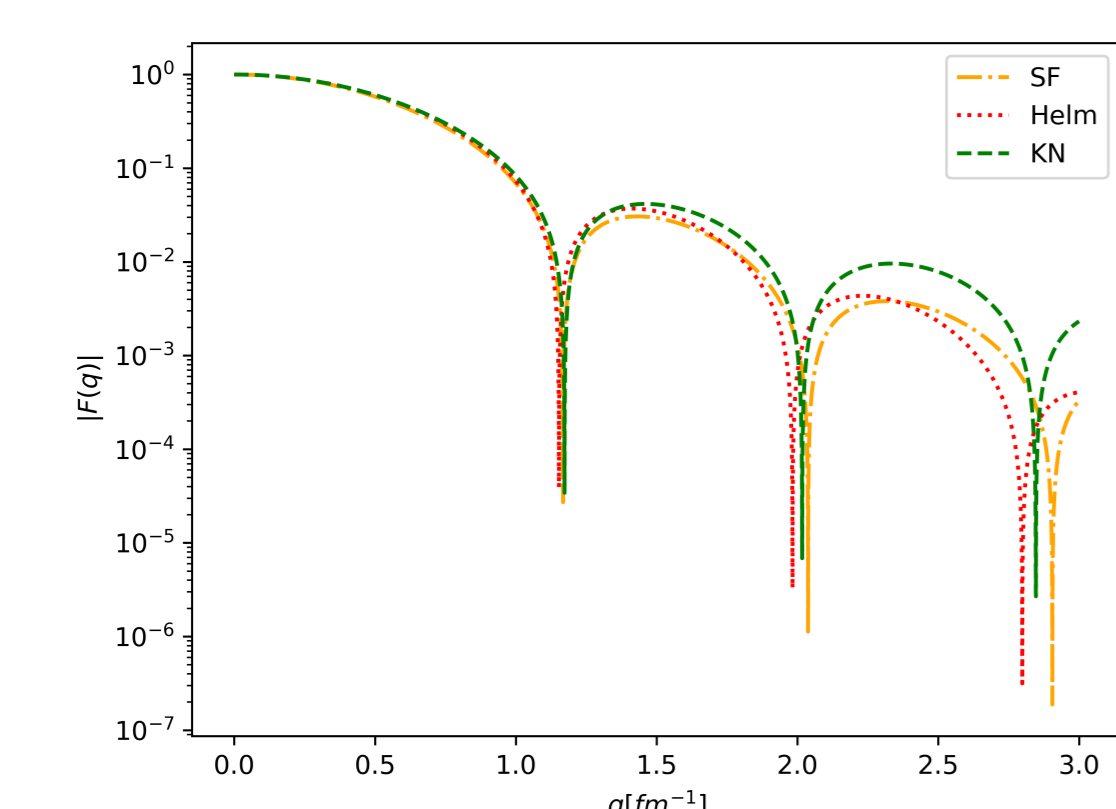
We use Hubber-Mueller and Fallot spectrum to calculate the total neutrino flux, then use eq.(1) generating nucleus recoil energy spectrum that used in MC generator.



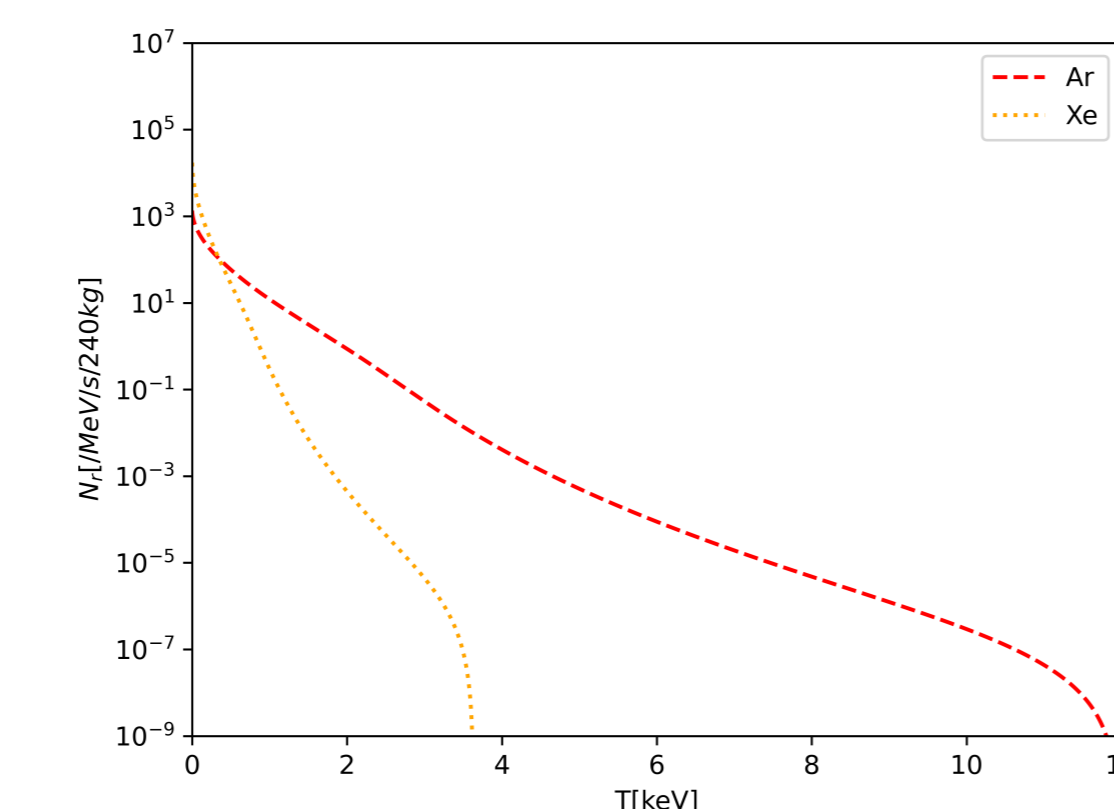
(a) Fission spectrum, for $E_\nu > 1.5 \text{ MeV}$ Hubber-Mueller spectrum is applied, while $E_\nu < 1.5 \text{ MeV}$ Fallot spectrum used.



(b) Neutrino flux spectrum calculated from fission spectrum @ 35 m from the NPP.



(c) Different $|F(q)|$ functions used in eq.(1).

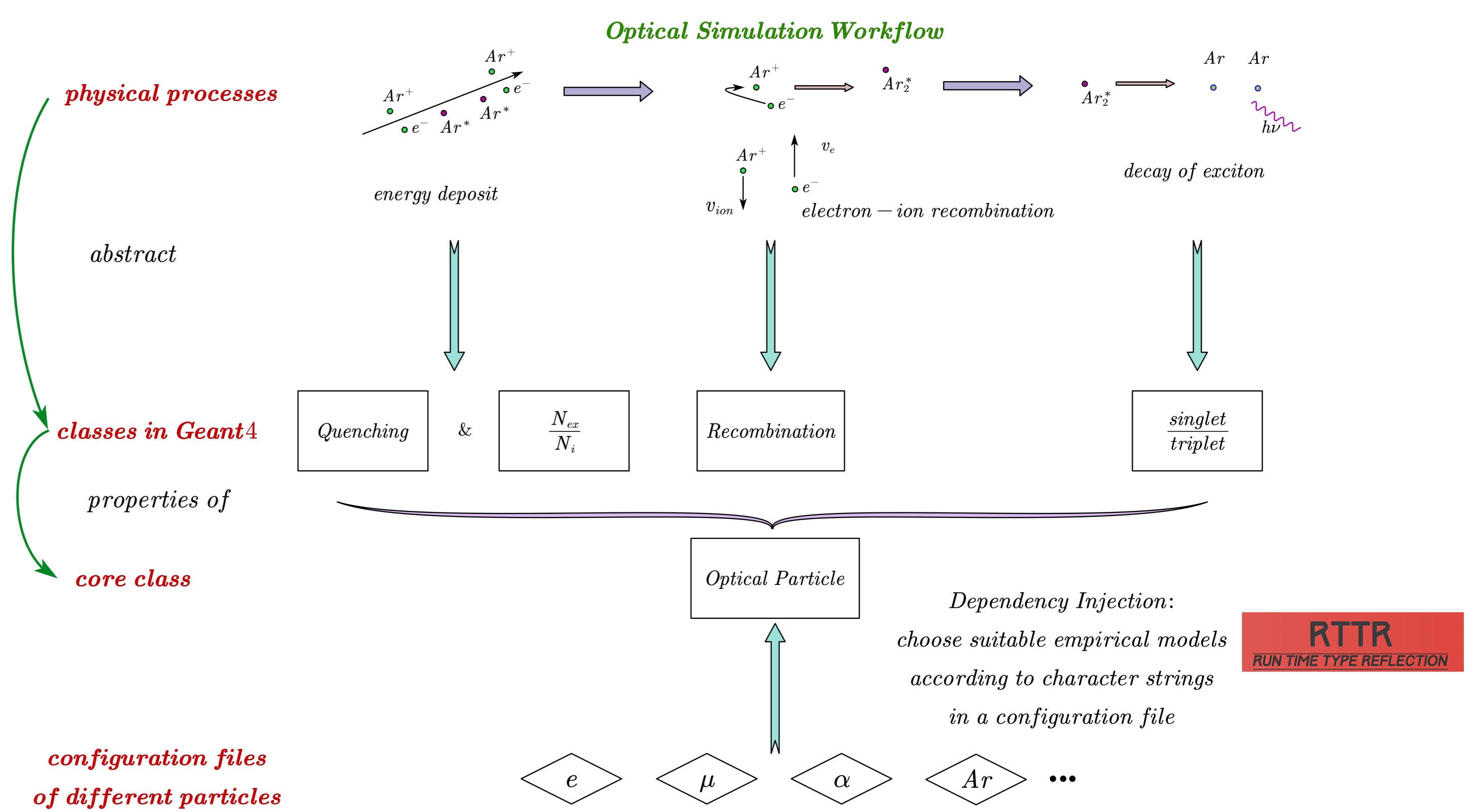


(d) The calculated recoil energy spectrum (Xenon as a comparison).

Optical Simulation

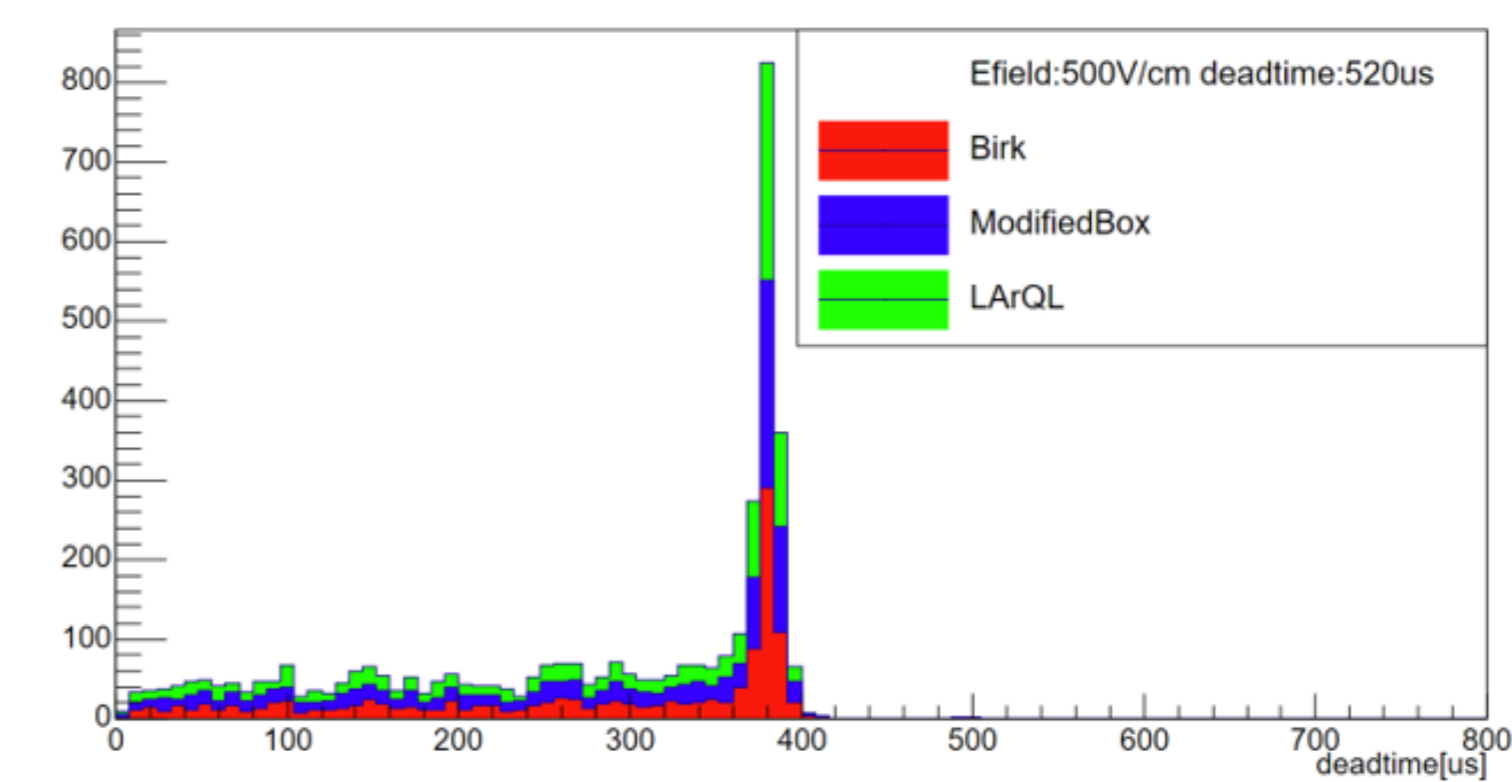
Muons and neutrons from cosmic rays will generate intricate high-energy-backgrounds in the TPC. In the meanwhile, CE ν NS events are low energy nuclear recoil (NR) events. Different models have to be implemented for different particle

types and different energy ranges. Therefore, an extensible and compatible programming framework is needed. We design a Geant4 simulation program as the logic shown in this picture, based on G4DS [2]:



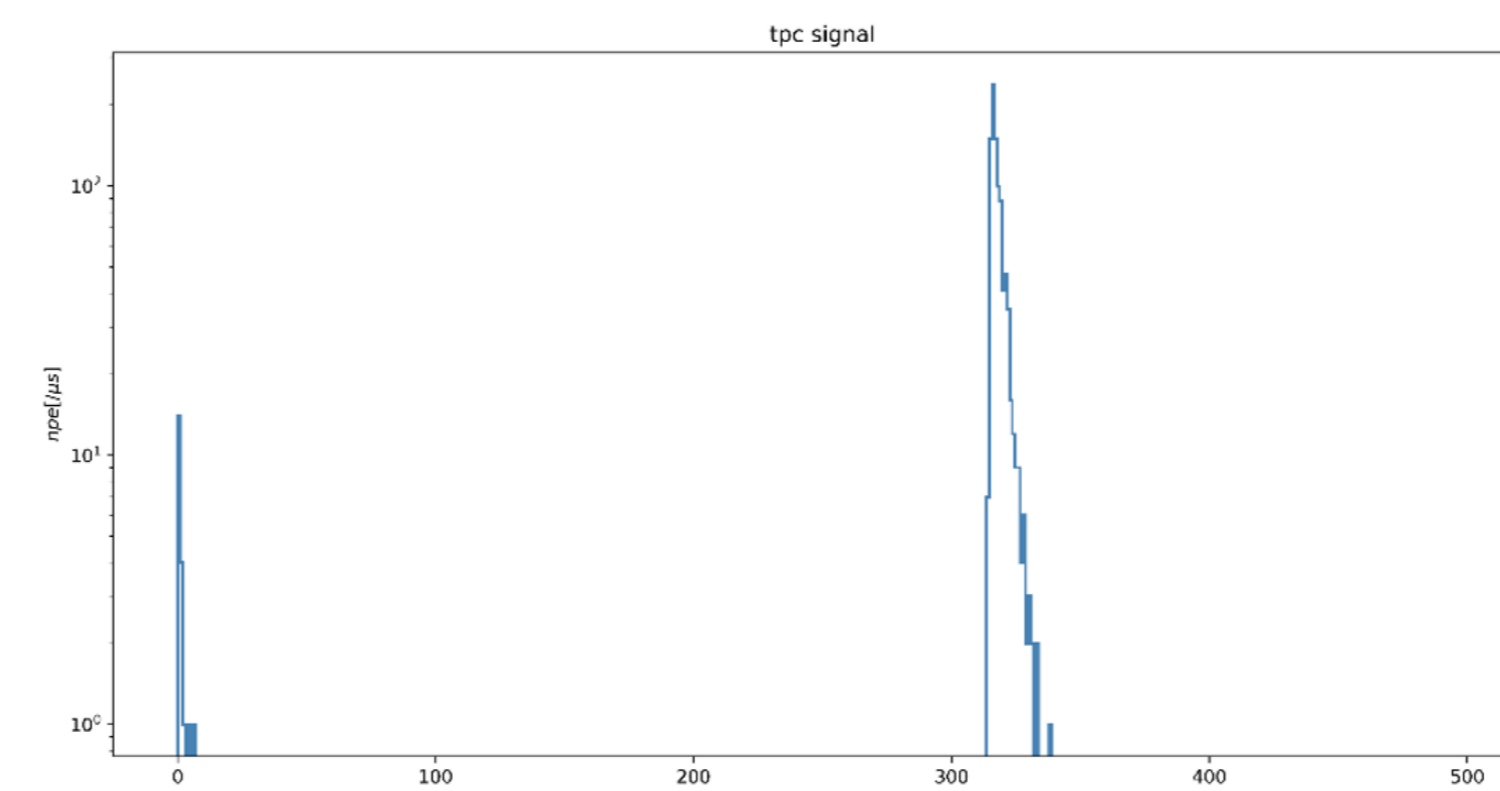
Estimation of dead-time and pile-up rate

With this developed program, we generate both CE ν NS signals and background signals in the detector. Regarding the dead-time, we adjust the TPC electrical drift field according to the dead-time caused by cosmic μ (the major background). The most optimized electrical field is considered to be 500 V/cm while the dead-time can be squeezed to 520 us/event.

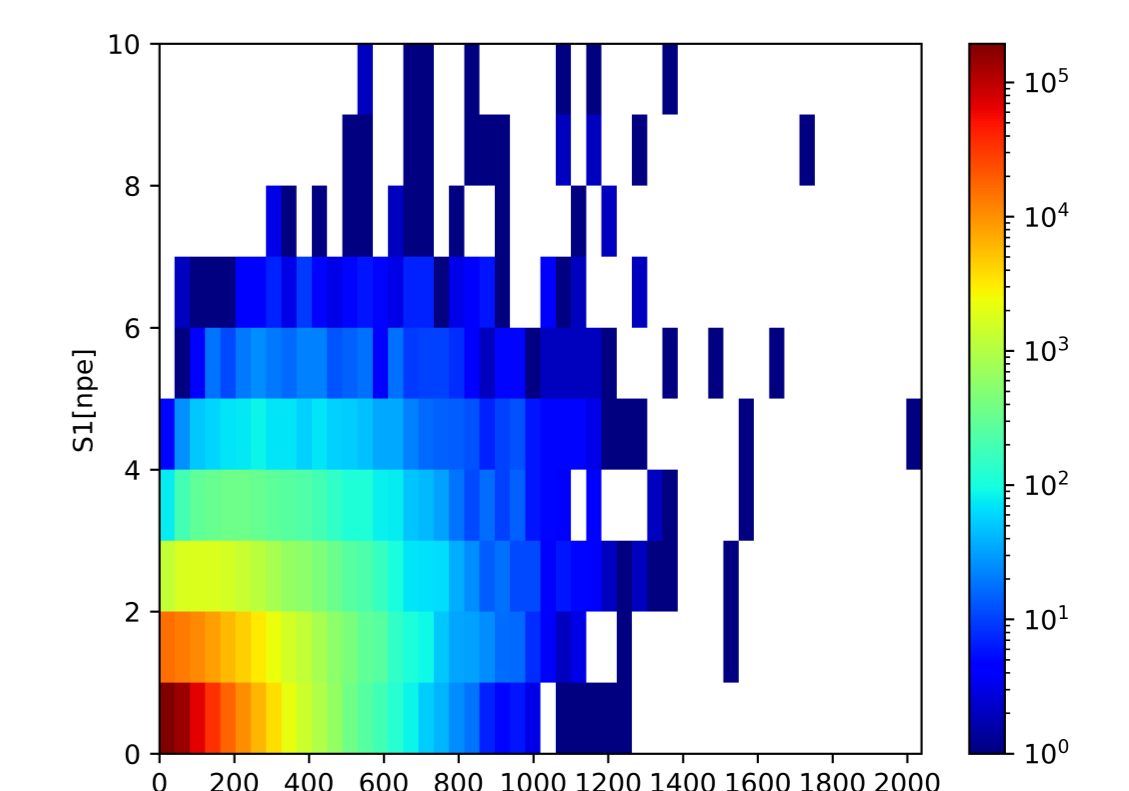


(e) Dead-time distribution of cosmic μ in the TPC from different recombination models.

Signals from CE ν NS and signals from backgrounds (generated separately from the optical model) have been mixed to evaluate the pile-up rate. If a CE ν NS signal is overlapping a background signal in time axis, this CE ν NS signal is tagged as a pile-up event. And we find the overall pile-up rate between CE ν NS signals and background signals ≈ 0.003 . If the DAQ system is set to be triggerless mode and the event cluster algorithm is efficient enough. The pile-up effect won't significantly reduce the number of CE ν NS signals that can be selected.



(f) A TPC signal sample used in pile-up calculation.



(g) CE ν NS signal number of pe spectrum.

Conclusions

- A dual-phase Ar TPC is proposed for reactor CE ν NS searches.
- A program package based on G4DS is developed to simulate CE ν NS signals and background signals.
- The pile-up rate between CE ν NS signals and background signals has been calculated. We consider it won't be critical for the CE ν NS signal selection.
- The next step of this work is to calculate the discovery sensitivity of this experiment.

[1] F. Palumbo. Coherent effects of a weak neutral axial current on nuclei with spin-isospin order. *Phys. Rev. C*, 23:2785–2787, Jun 1981.

[2] P. Agnes et al. Simulation of argon response and light detection in the darkside-50 dual phase tpc. *Journal of Instrumentation*, 12(10):P10015, oct 2017.

[3] P. Agnes et al. Calibration of the liquid argon ionization response to low energy electronic and nuclear recoils with darkside-50. *Phys. Rev. D*, 104:082005, Oct 2021.