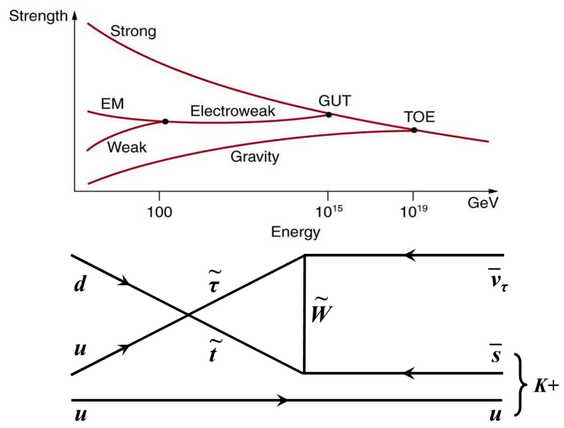
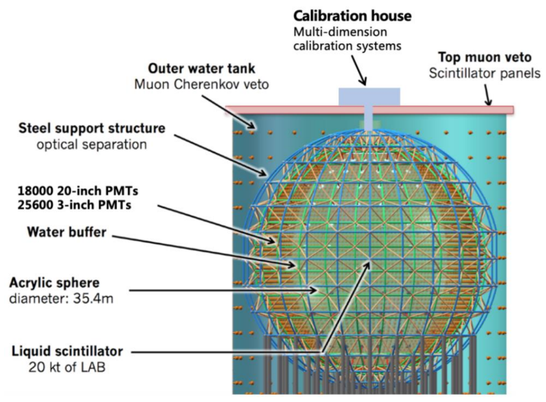
Prospects for Proton Decay Searches in JUNO

Yuhang Guo * , Livia Ludhova, Wanlei Guo, Qingmin Zhang (On Behalf of JUNO Collaboration)
*guoyuhang@stu.xjtu.edu.cn

1. Introduction

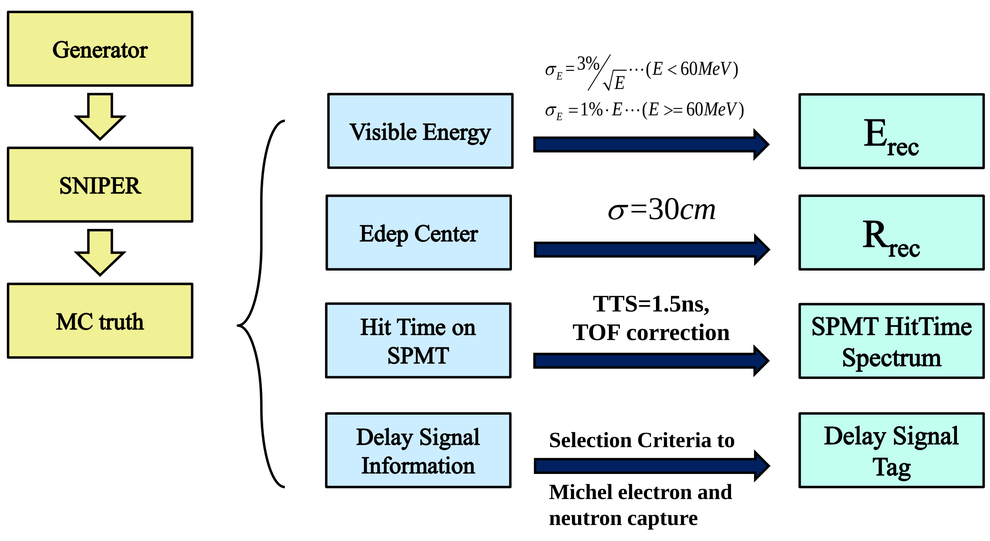




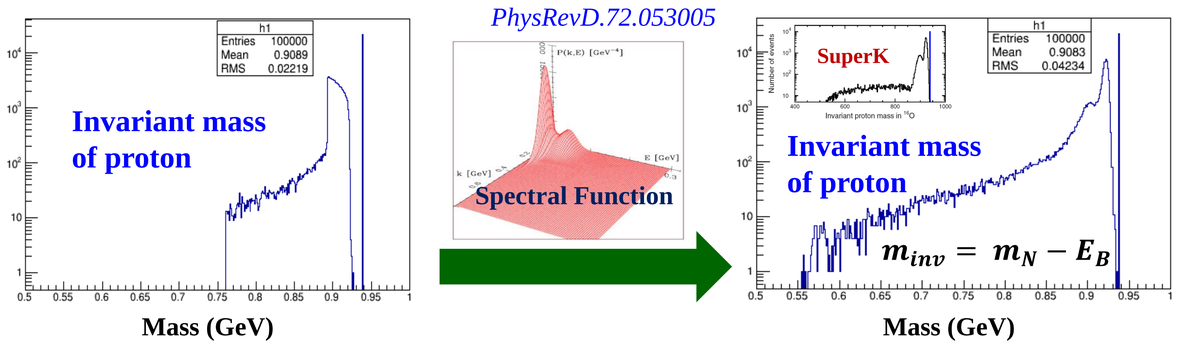
- Proton Decay (PD) is an apparent prediction of Grand Unification Theories (GUTs). The baryon number violation is one of three basic ingredients for an explanation to the asymmetry of Matter and Anti-matter in Universe.
- So many predicted decay modes, among which $p \to \nu K^+$ has large branching ratio in Super Symmetry (SUSY) GUTs.
- Many experiments have been contributed on this mode to explore new physics, including Super-K and KamLAND.
- The Jiangmen Underground Neutrino Observatory (JUNO) , which will be constructed at Jiangmen in South China. It is a 20 kton Liquid Scintillator (LS) detector equipped with ~ 17600 20 inch photomultiplier tubes (PMTs) and ~25000 3 inch PMT.
- The energy resolution is expected to achieve 3%/sqrt(E) (MeV), which is very beneficial to low energy delay signal discrimination.

2. Simulation

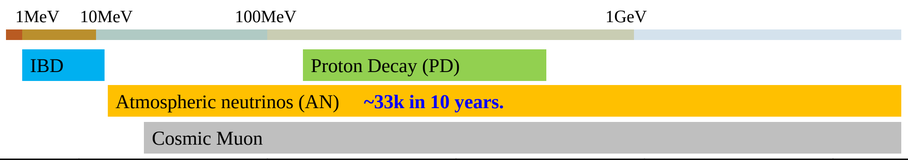
- A MC study is undergoing to estimate JUNO's sensitivity to p2vK. The tool is SNIPER, a Geant4 based MC software developed by JUNO collaboration.



- The generator is produced by GENIE, in which the binding effect, the Fermi motion, the N-N correlations of C12 nucleus and the Final State Interaction (FSI) have been included.
- In order to descript correctly the initial proton and K+ FSI, we have modified the codes based on the Spectral Function.



- The dominant backgrounds are the Atmospheric neutrinos (AN) and Cosmic Muons.



	Kaon Production	Pion Production	Quasi-elastic Scattering	Nucleon Recoil	Total
Neutral current	0.30%	9.74%	---	20.23%	30.27%
Charge current	0.81%	23.75%	45.16%	---	69.73%

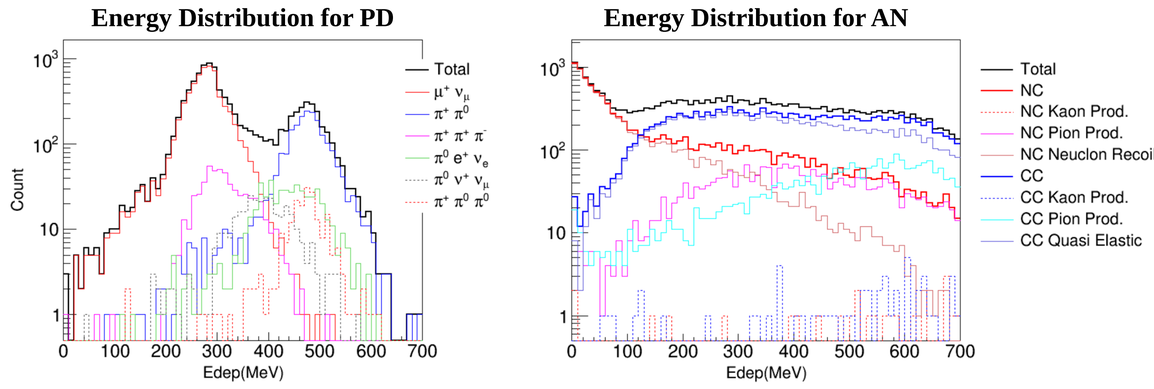
$\nu_\mu + n \to \mu^- + K^+ + \Lambda^0$
$\nu_\mu + n \to \mu^- + K^+ + \Lambda^0 + \pi^0$
$\nu_\mu + p \to \mu^- + \pi^+ + p$
$\pi^+ \xrightarrow{26ns} \mu^+ + \bar{\nu}_\mu$
$\bar{\nu} + p \to n + l^+$
$\bar{\nu} + n \to p + l^-$
$\nu + N \to N' + p + n$

3. Analysis

- We totally simulated 10 k p2vK and 120 k atmos. ν events as candidate sample in SNIPER. The background data volume is equivalent to data volume of 36 years.
- Based on the MC simulation, a set of criteria have been proposed in order to find the rarely seen p2vK from the huge amount of background.
- The criteria can be divided to 3 classes:

1. Primary Selection

- 200 MeV < E_{vis} < 600 MeV
- R<17.5m



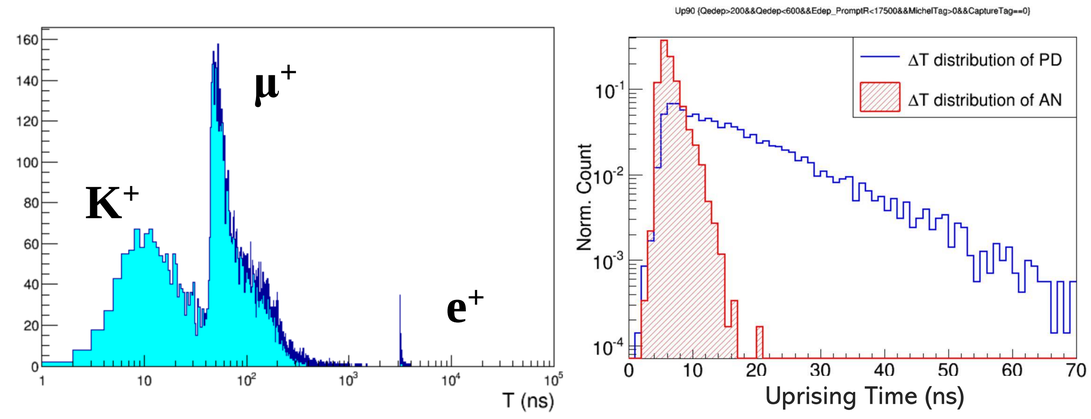
2. Delayed Signal Selection

- Michel Electron $K^\pm \to \pi^\pm, \mu^\pm \xrightarrow{2200ns} e^\pm$
- Neutron Capture $n + H \xrightarrow{200\mu s} \gamma + d$

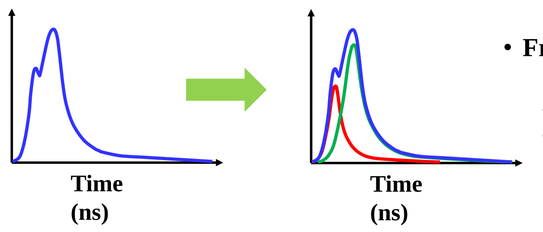
To tag a delayed signal:
1. **Correlated ΔT**
2. **Correlated E_{dep}**
3. **Correlated Position**

γ - 2.2 MeV

3. Time Analysis Selection



- Double pulse pile-up in Time spectrum is a feature of p2vK in LS
- Uprising time is defined the time period from **10% Max to 90% Max.**
- p2vK is expected to have a larger uprising time.
- Reconstruction of the both signals can also help to distinguish



- **From BLUE to RED and GREEN**, we can know:
  1. Tendency to be Double/Single pulse event (χ^2 of fitting);
  2. Correlated ΔT (K+ lifetime);
  3. Correlated Edep (kinetic of K+ and μ+);

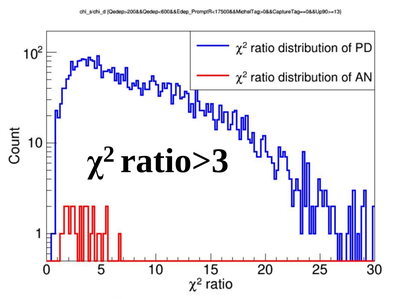
- The hit time spectrum will be fitted with :

$$\phi_Y(x) = \varepsilon_K \cdot f_K(x) + \varepsilon_Y \cdot f_Y(x - \Delta T_Y)$$
$$\phi_B(x) = \varepsilon_B \cdot f_B(x)$$

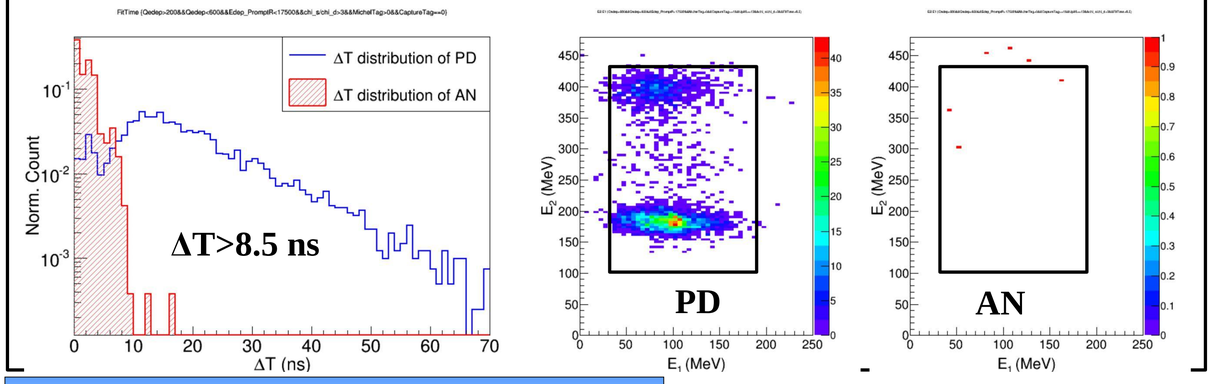
- Energy of each component is: $E_i = \frac{\varepsilon_i \cdot E^i_{ref}}{\sum_i \varepsilon_i \cdot E^i_{ref}} \cdot E_{total}$
- The $\chi 2$ is calculated as:

$$\chi^2_Y = \sum_i \frac{(\phi(x) - \phi_Y(x))^2}{\sigma^2(\phi(x))}$$
$$\chi^2_B = \sum_i \frac{(\phi(x) - \phi_B(x))^2}{\sigma^2(\phi(x))}$$
$$\chi^2_{ratio} = \frac{\chi^2_Y}{\chi^2_B}$$

- $f_K f_Y f_B$: Fitting reference function of K+, decay daughter and AN;
- ΔT : Correlated Time difference;
- $\varepsilon_K \varepsilon_Y \varepsilon_B$: Energy facor of K^+, decay daughter and *AN;*
- E^i_{ref} : Energy of reference function.



- χ^2_{ratio} of PD is required to be >3 for a much stricter selection.
- The reconstructed correlated time difference ΔT and energy deposition of sub pulses (E_1 and E_2) are compared for further selection.



4. Conclusion

- With 36 years data volume, the p2vK detection efficiency is estimated as 32.48% with 3 Atmos.ν remained in 36 years.
- This is a preliminary result and expecting further detailed study and improvement.

40th International Conference on High Energy Physics, Jul. 28 - Aug. 6, 2020, Online