

Search for neutron's invisible decays with JUNO



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On behalf of JUNO collaboration

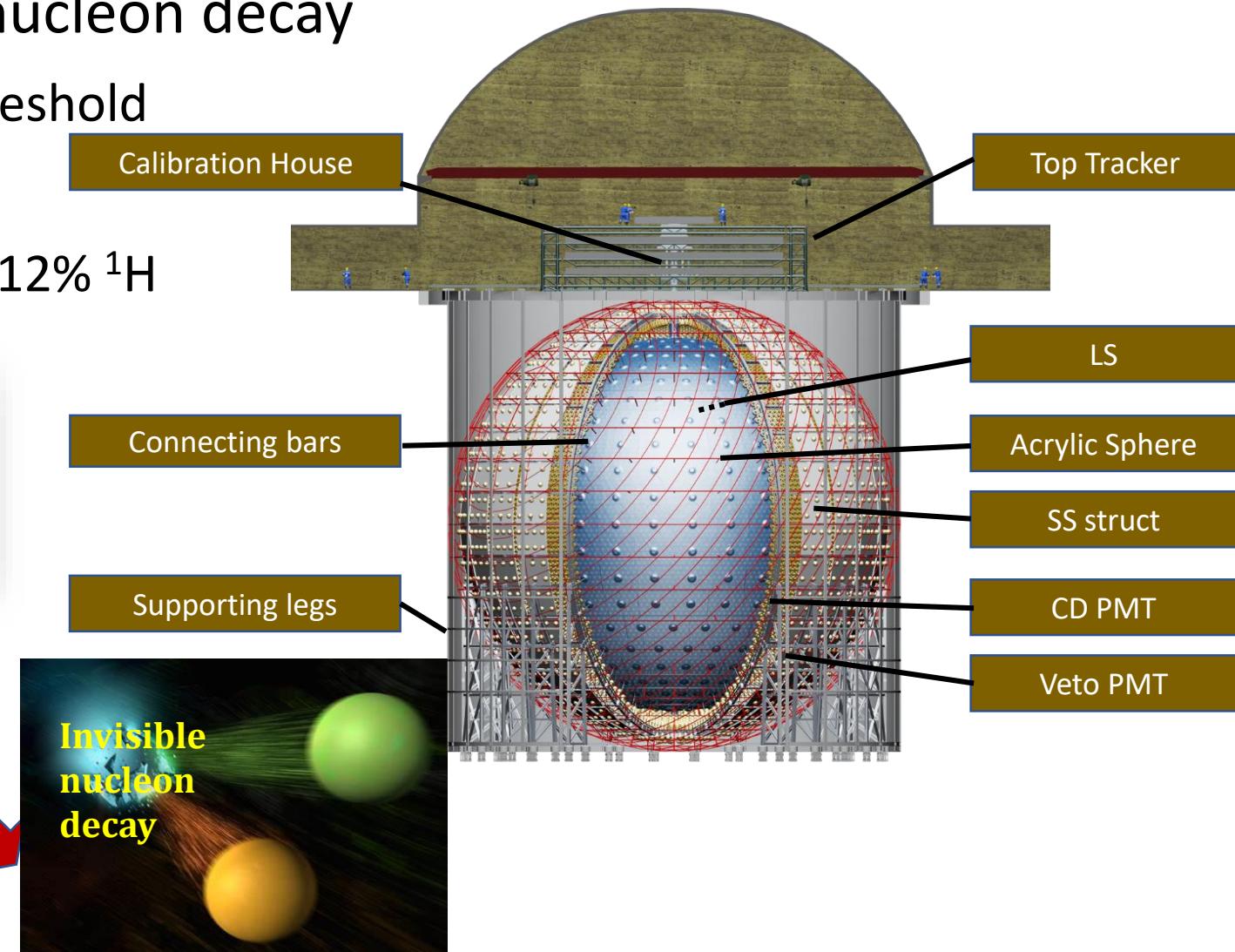
XX International Workshop on Neutrino Telescopes

26th October 2023

JUNO experiment

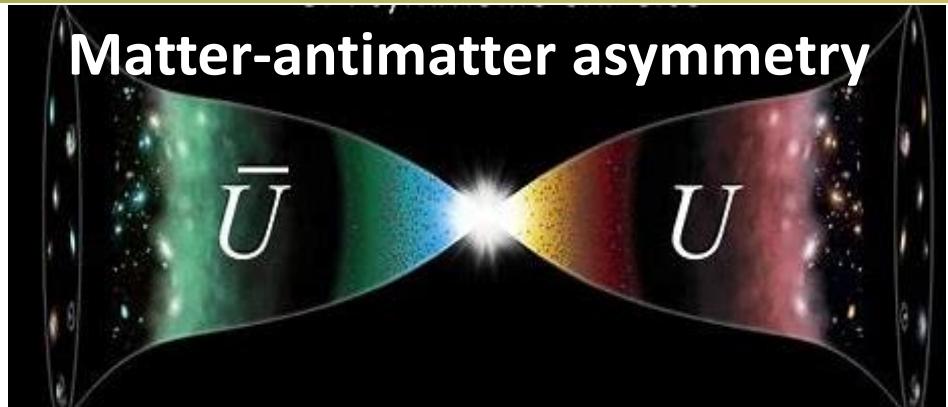
- A multi-purpose experiment
- Great potential to detect invisible nucleon decay

- 20 kton LS, low backgrounds, low threshold
- Energy resolution: 3%@1 MeV
- LS Component: 88% C (99% ^{12}C) and 12% ^1H

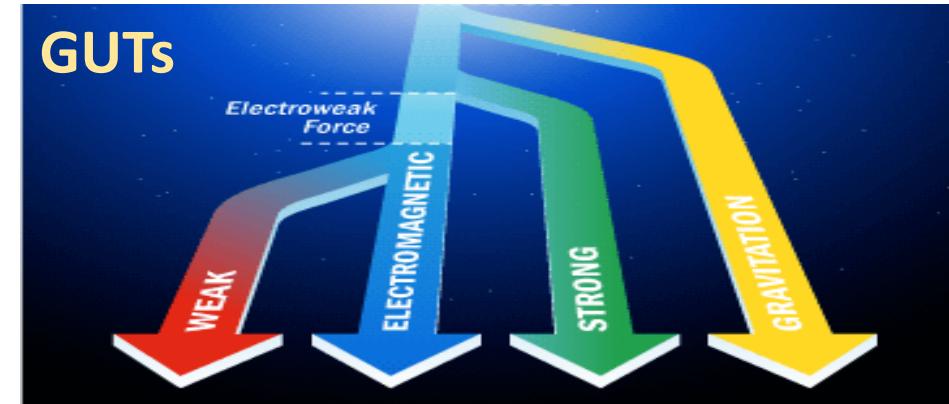


Physical motivation

Matter-antimatter asymmetry



GUTs



Invisible nucleon decays

$$n \rightarrow \nu' s \quad nn \rightarrow \nu' s$$

Basic ingredients

Baryon number violation

Predicted by

But no experimental observations so far !!!

Experiment	$\tau(n \rightarrow inv)$ 90% C. L.	$\tau(nn \rightarrow inv)$ 90% C. L.	reference
Borexino	-	$> 4.9 \times 10^{25} y$	<i>Nucl.Phys.B.Proc.Suppl.</i> 118(2003) 499-499
SNO+	$> 9.0 \times 10^{29} y$	$> 1.5 \times 10^{28} y$	<i>Phys.Rev.D</i> 105 (2022) 11, 112012
KamLAND	$> 5.8 \times 10^{29} y$	$> 1.4 \times 10^{30} y$	<i>PRL</i> 96, 101802 (2006)

Signals signature

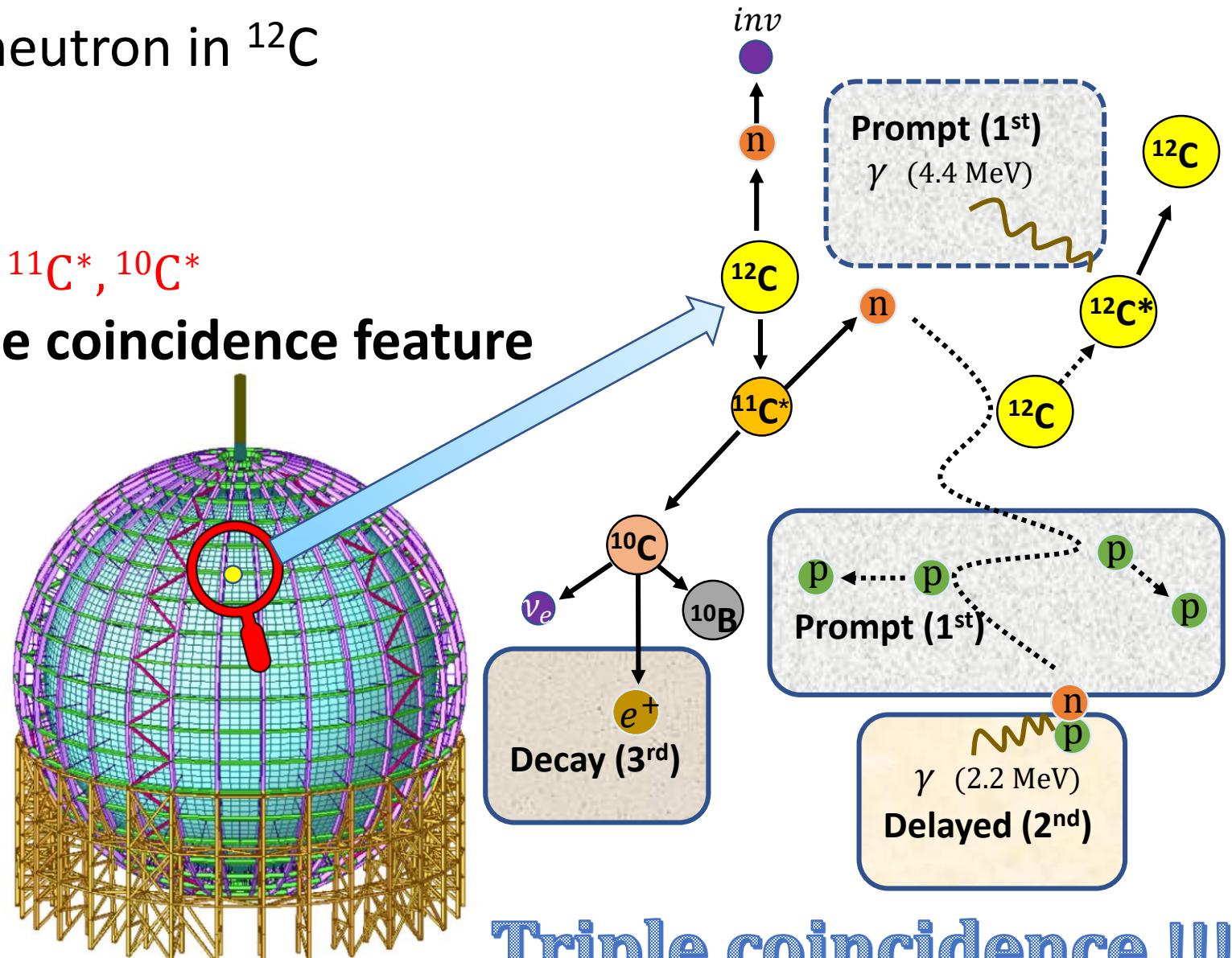
■ Two Invisible decay modes of neutron in ^{12}C

- $n \rightarrow i\nu$ ($^{12}\text{C} \rightarrow ^{11}\text{C}^*$)
- $nn \rightarrow i\nu$ ($^{12}\text{C} \rightarrow ^{10}\text{C}^*$)
- Detect de-excitation products of $^{11}\text{C}^*$, $^{10}\text{C}^*$

■ De-excitation modes have **triple coincidence feature**

$^{11}\text{C}^* \rightarrow n +$	^{10}C	$(Br_{n1} = 3.0\%)$
$^{11}\text{C}^* \rightarrow n + \gamma + ^{10}\text{C}$		$(Br_{n2} = 2.8\%)$
$^{10}\text{C}^* \rightarrow n +$	^9C	$(Br_{nn1} = 6.2\%)$
$^{10}\text{C}^* \rightarrow n + p +$	^8B	$(Br_{nn2} = 6.0\%)$

Yuri Kamyshkov, Edwin Kolbe PRD 67, 076007 (2003)



Triple coincidence !!!

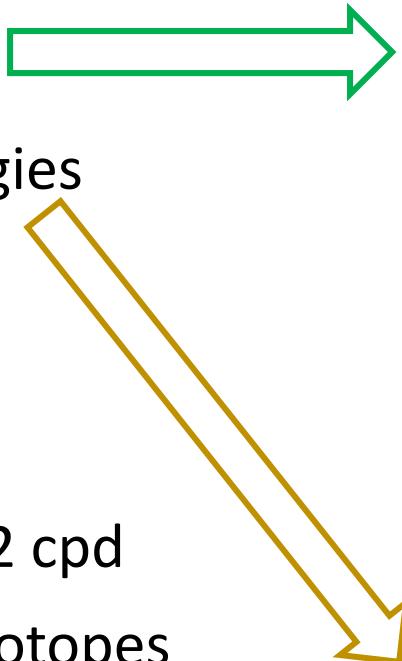
Signals vs backgrounds

■ Signal

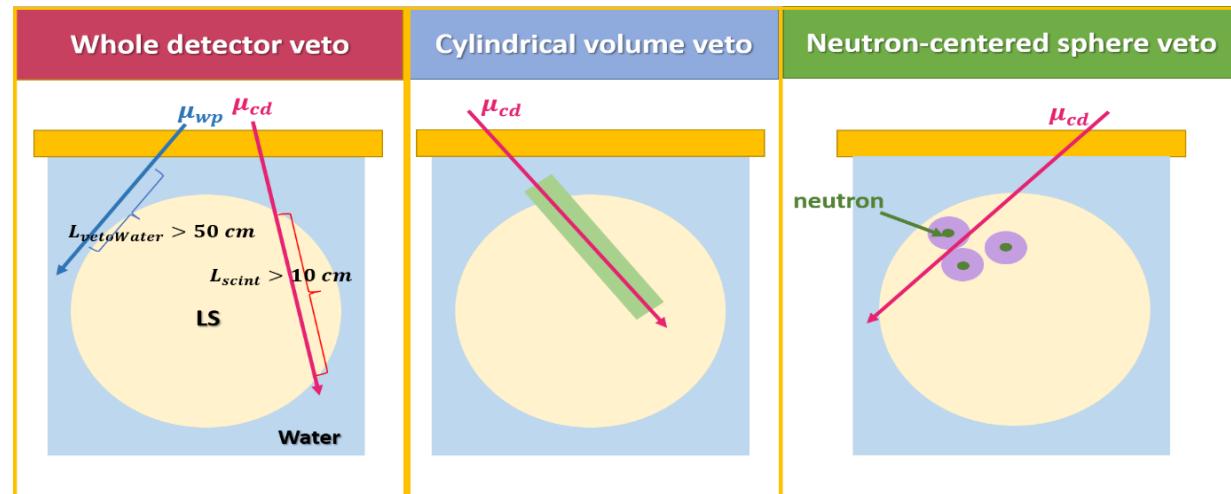
- Basic event selection
- Designed Muon veto strategies
 - Muon rate 28 Hz
 - Reduce isotopes

■ Backgrounds sources

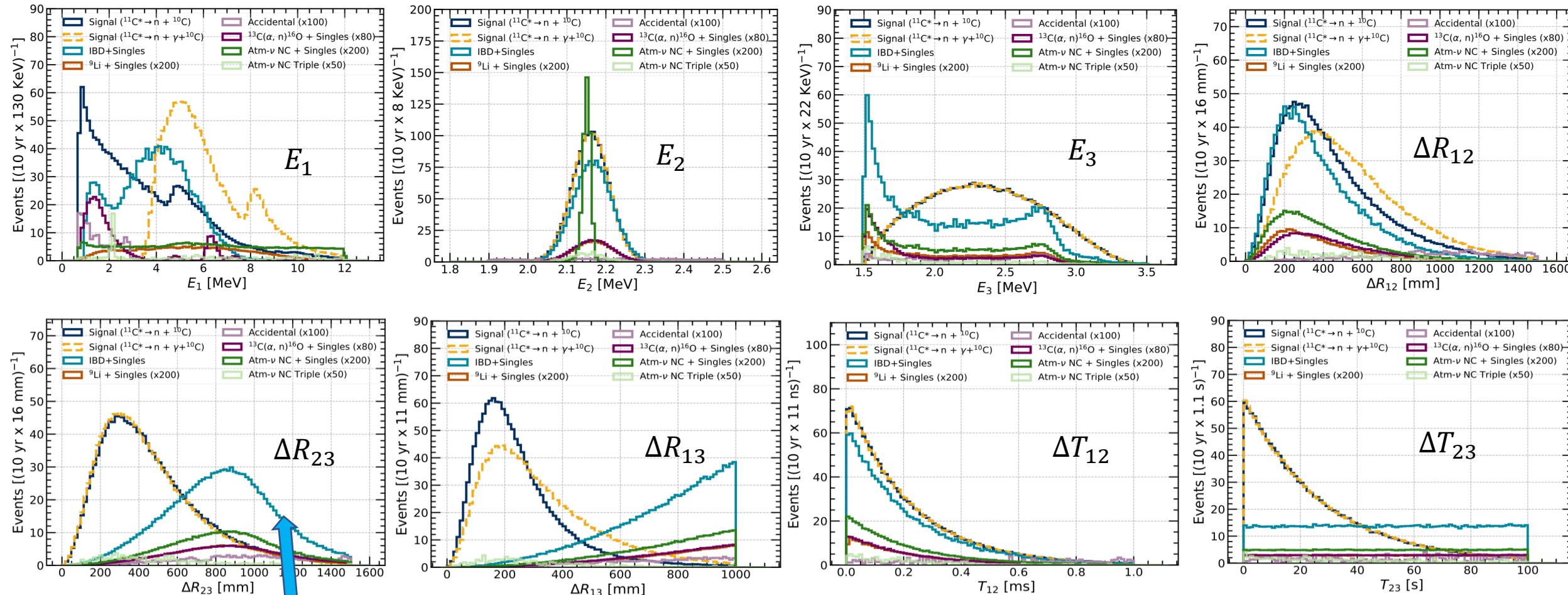
- IBD(Inverse Beta decay) ~ 52 cpd
- Muon induced Long-lived isotopes
- Radioactivity
- Atm – ν NC
- Fast neutron



	$n \rightarrow i\nu$	$nn \rightarrow i\nu$
Fiducial volume	$r < 16.7$ m	$r < 16.7$ m
Selection criteria	$\Delta T_{12} < 1$ ms $\Delta T_{23} \in [0.002, 100]$ s $\Delta R_{12} < 1.5$ m $\Delta R_{23} < 1.5$ m $\Delta R_{13} < 1.0$ m $E_1 \in [0.7, 12]$ MeV $E_2 \in [1.9, 2.5]$ MeV $E_3 \in [1.5, 3.5]$ MeV	$\Delta T_{12} < 1$ ms $\Delta T_{23} \in [0.002, 3.0]$ s $\Delta R_{12} < 1.5$ m $\Delta R_{23} < 1.5$ m $\Delta R_{13} < 1.0$ m $E_1 \in [0.7, 30]$ MeV $E_2 \in [1.9, 2.5]$ MeV $E_3 \in [3.0, 16]$ MeV



Signal ($n \rightarrow \text{inv}$) vs backgrounds



■ Dominant backgrounds

➤ IBD + Singles (Radioactivity, isotope)

Total efficiency (%)

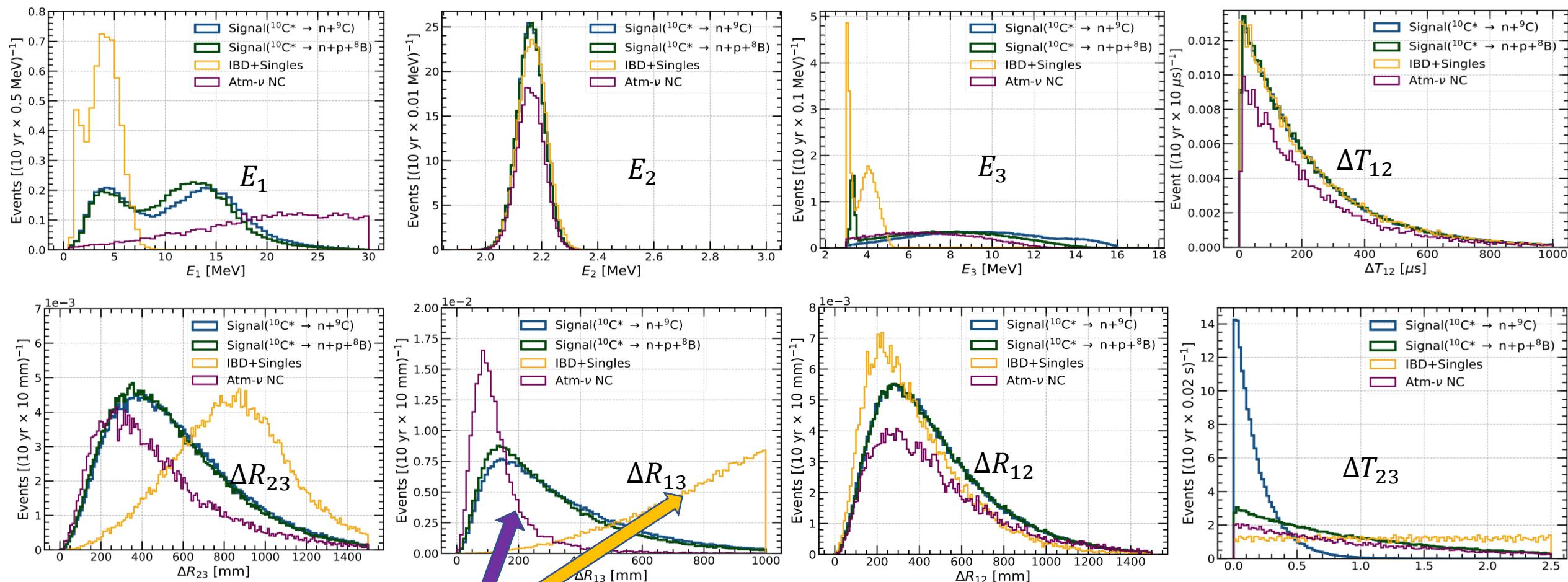
$^{11}\text{C}^* \rightarrow n + {}^{10}\text{C}$

38.8 ± 0.2

$^{11}\text{C}^* \rightarrow n + \gamma + {}^{10}\text{C}$

45.6 ± 0.2

Signal ($nn \rightarrow inv$) vs backgrounds



Dominant backgrounds

- IBD + Singles (Radioactivity, isotope)
- Atm- ν NC

Total efficiency (%)	$^{10}\text{C}^* \rightarrow n + ^9\text{C}$	$^{10}\text{C}^* \rightarrow n + p + ^8\text{B}$
	59.7 ± 0.3	54.3 ± 0.2

Backgrounds suppression

■ PSD(Pulse Shape Discrimination)

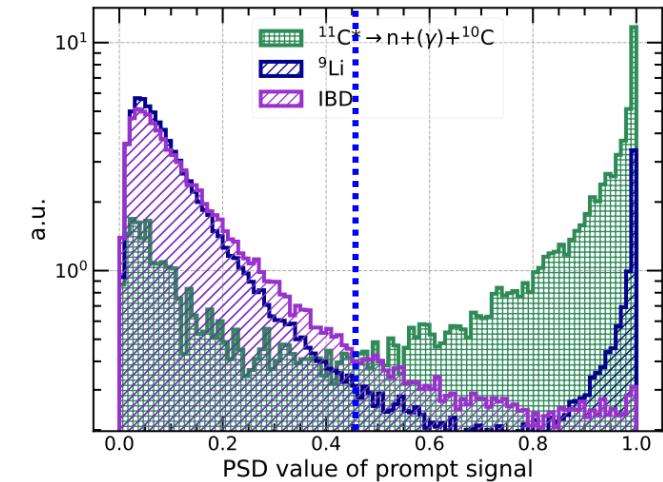
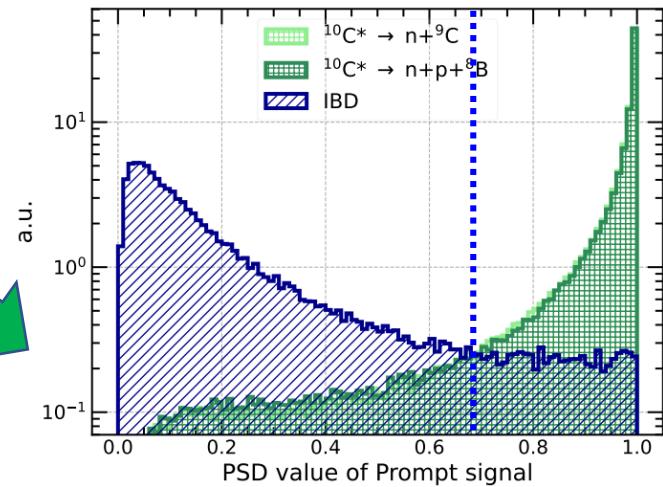
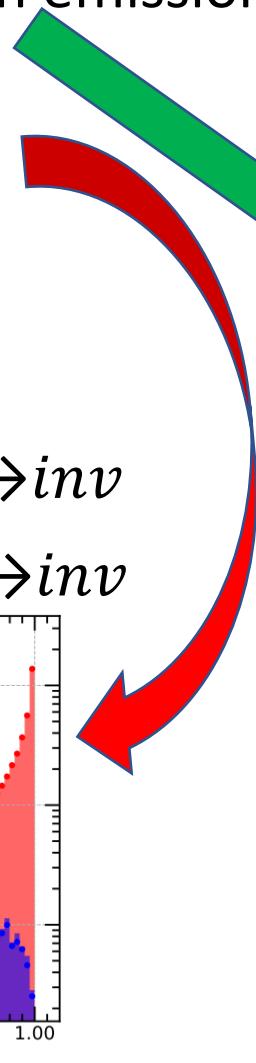
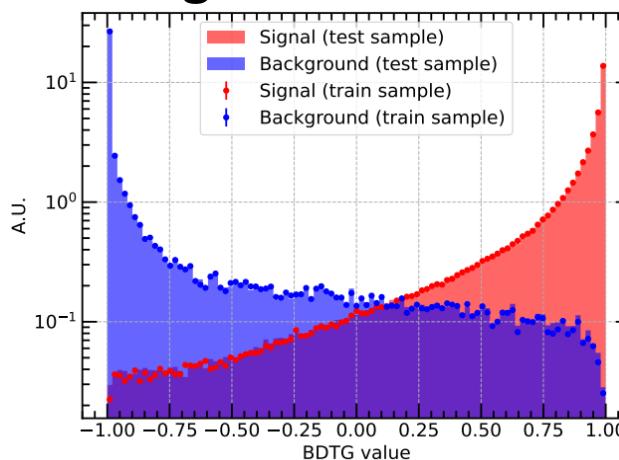
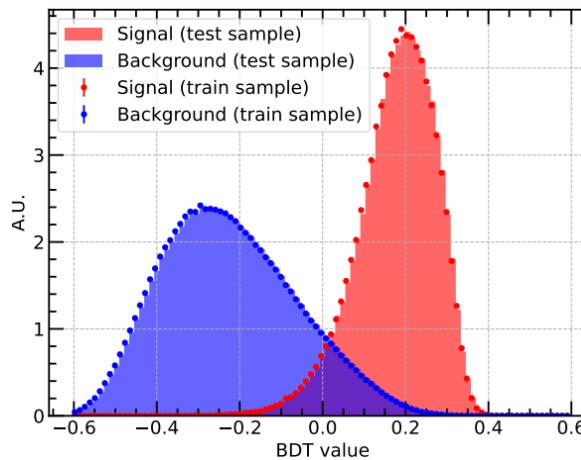
- Different particles give rise to different photon emission time profiles
- Choose a PSD value (blue dash line)

■ MVA(Multi-Variate-Analysis)-BDT/BDTG

- Combine multidimensional features

■ Combine PSD + MVA

- factor of **100** reduction for backgrounds of $n \rightarrow inv$
- factor of **10** reduction for backgrounds of $nn \rightarrow inv$



Summary and outlook

- More target neutron number/pairs
- Signal efficiencies are **acceptable**
- Lower backgrounds than SNO+, comparable backgrounds with KamLAND
- Introduce ML to suppress backgrounds

➤ Before ML, $\frac{\epsilon_{sig}}{\sqrt{bkg_{tot}}}$

- $\sim 0.01 (n \rightarrow inv), \sim 0.2 (nn \rightarrow inv)$

➤ After ML, $\frac{\epsilon_{sig}}{\sqrt{bkg_{tot}}}$

- $\sim 0.06 (n \rightarrow inv), \sim 0.6 (nn \rightarrow inv)$

		SNO+	KamLAND	JUNO		
Life time limit		$\tau (n \rightarrow inv) > 9.0 \times 10^{29} y$	$\tau (nn \rightarrow inv) > 1.4 \times 10^{30} y$	$n \rightarrow inv$		
Fiducial volume cut		--	< 5.5 m	< 16.7 m		
Target mass		$\sim 0.9 \text{ kt H}_2\text{O}$	$\sim 0.5 \text{ kt LS}$	16.8 kt LS		
Target neutron number/pairs		1.2×10^{32}	2.3×10^{31}	1.5×10^{33}	7.4×10^{32}	
Br. ϵ_n	Br1. ϵ_{nn1} Br2. ϵ_{nn2}	~ 0.26	~ 0.04	~ 0.023	~ 0.03	
			~ 0.04		~ 0.03	
Expected backgrounds ($\text{yr}^{-1} \text{kton}^{-1}$)		~ 200	~ 0.02	~ 7.4	~ 0.03	
$N \cdot \text{Br. } \epsilon_{sig} / \sqrt{bkg}$		2.3×10^{30}	1.8×10^{31}	3.1×10^{30}	6.3×10^{31}	
Dominant background combination		${}^8\text{B}$ solar ν Atmospheric ν	IBD + singles ${}^9\text{Li}$ + singles ...	IBD + singles ${}^9\text{Li}$ + singles ...	IBD + singles ${}^9\text{Li}$ + singles ...	

JUNO has a great potential to search for neutron's invisible decays !!!

Thanks for your attention !