Workshop on Neutrino Frontier 2016
Nov. 28-30, 2016, Yunokuni-Tensho, Ishikawa

JSNS^2; particle- and astro-physics with J-PARC MeV neutrino beams

Tatsushi Shima
RCNP, Osaka University, for JSNS^2 collaboration

- Sterile neutrino search; current status
- JSNS^2 experiment to search for sterile-ν
- Neutrino-nucleus interaction for supernova physics
- Summary

Sterile neutrino

- introduced to solve anomalies in short baseline ν-oscillation experiments (→ next page)
- singlet fermion of gauge interactions
- beyond SM, beyond simple GUTS like SU(5)
- sensitive to gravity only, but affects ν-oscillations
- possible candidate of cold or warm dark matter

Indications of sterile neutrino

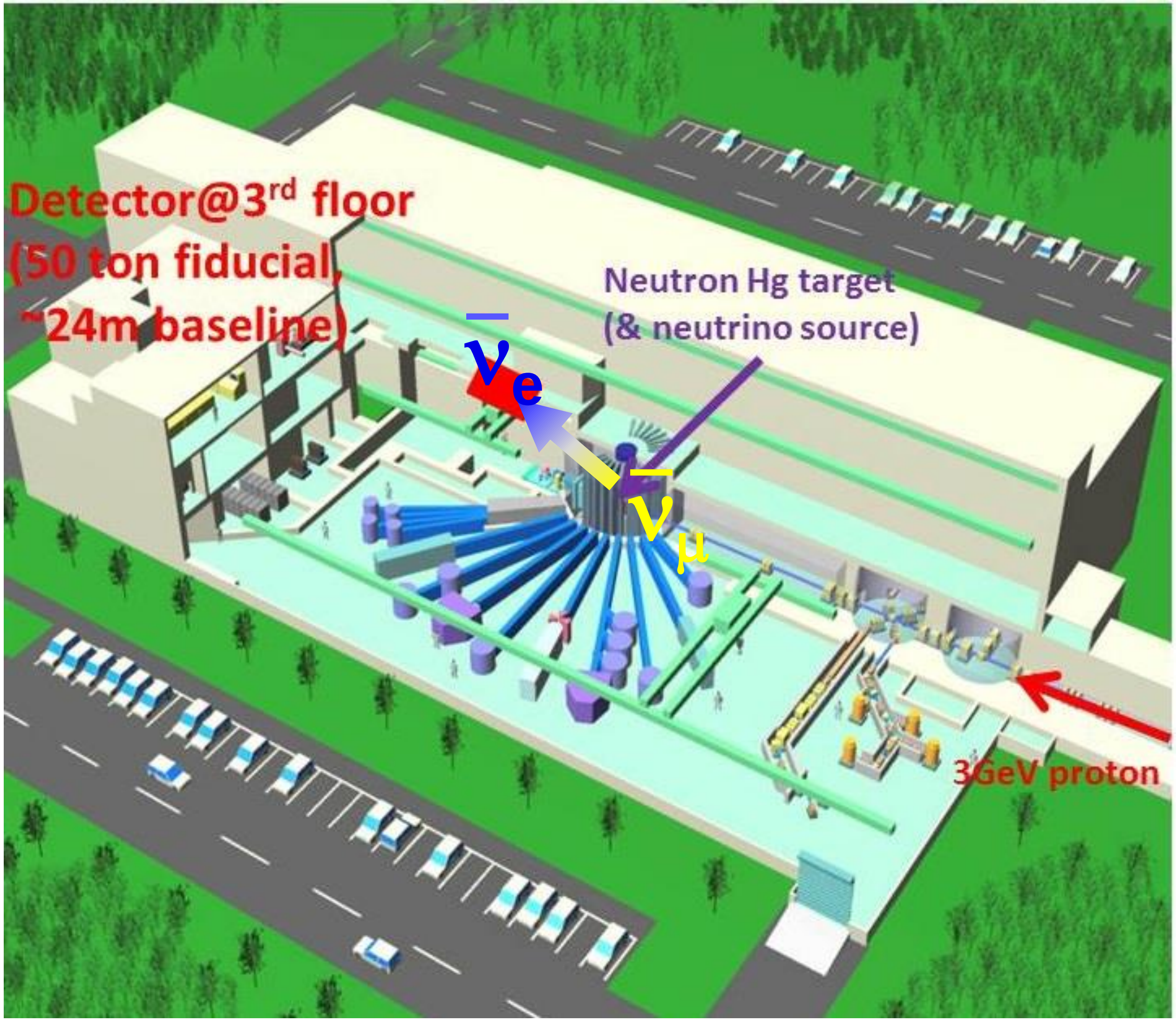
Exp.	ν source	Signal	Significance	E_ν [MeV]	L [m]
LSND	μ Decay-At-Rest	$\bar{\nu}_\mu \to \bar{\nu}_e$	3.8σ	40	30
MiniBooNE	π Decay-In-Flight	$\bar{\nu}_\mu \to \bar{\nu}_e$	3.4σ	800	600
		$\nu_\mu \to \nu_e$	2.8σ		
		Combined	3.8σ		
Ga	e capture	$\bar{\nu}_e \to \bar{\nu}_x$	2.7σ	<3	10
Reactors	Beta decay	$\bar{\nu}_e \to \bar{\nu}_x$	3.0σ	3	10^{1-2}


J-PARC
Linac
3 GeV
Neutrino
Materials and Life
Science Facility
50 GeV
Hadron Exp. Facility

M. Harada *et al*, arXiv:1601.01046 [physics.ins-det]

JSNS^2

J-PARC Sterile Neutrino Search using νs from J-PARC Spallation Neutron Source (E56)



$JSNS^2$ collaboration

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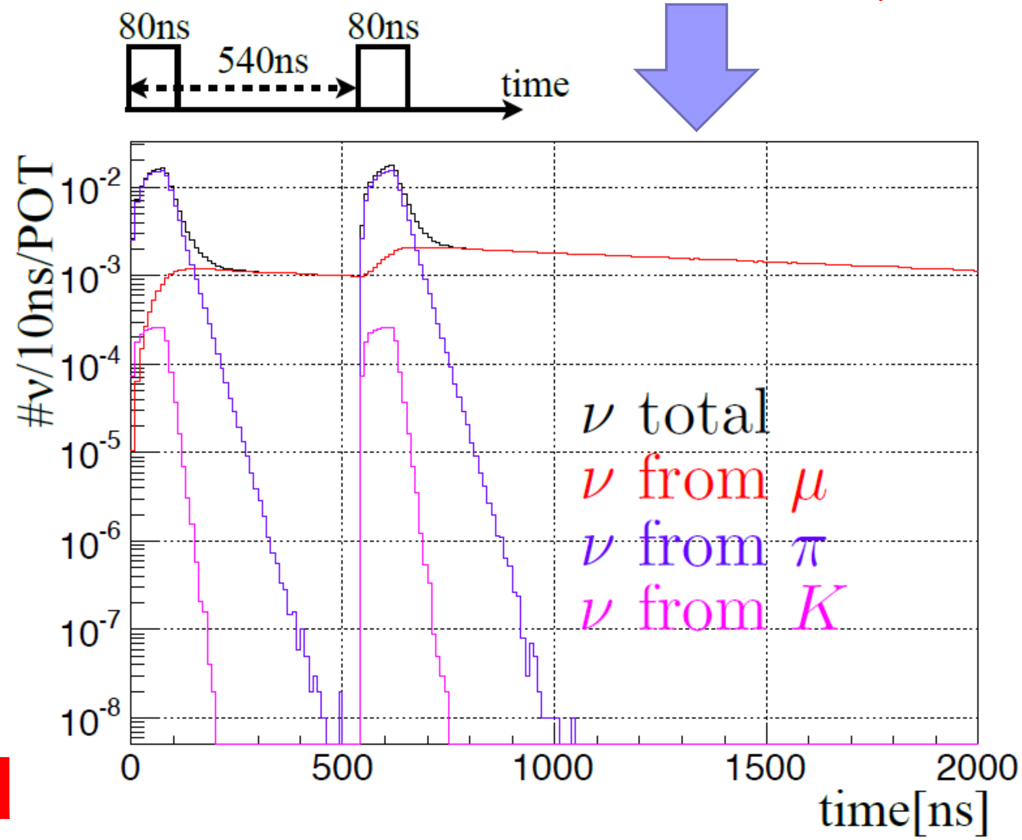
Time profile of neutrino beam

- Pulse width; 80ns ×2 (double pulses, 540ns interval)
- Repetition rate; 25Hz
- ν from decay-at-rest μ ; well separated from beam pulse

→ **low background**

Pure $\nu_e + \overline{\nu_\mu}$!



Detector

Gd-loaded liq. scintillator or/and Cherenkov, 25 ton × 2, detecting

$\overline{\nu}_e + p \rightarrow n + e^+$ (prompt)

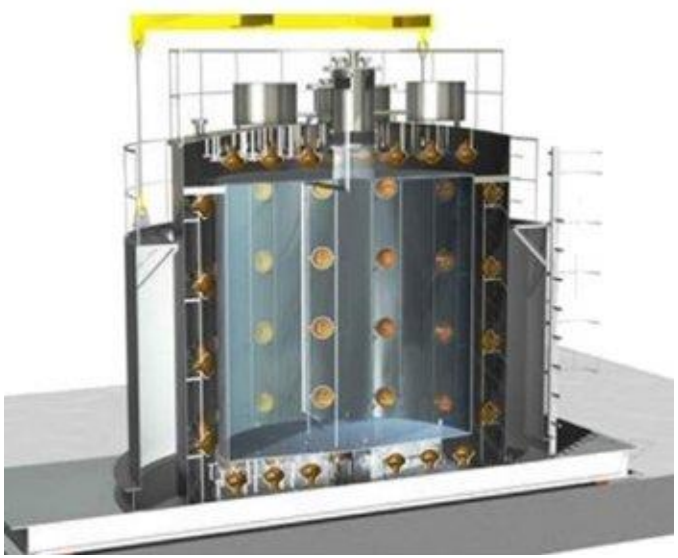
$n + {}^{157}Gd \rightarrow {}^{158}Gd + \gamma$ (delayed; Q~8MeV, τ_{cap}~30μs)

(253000b@thermal)

Prompt; t_e=1~10μs, E_e=20~60MeV

Delayed; t_γ=1~100μs, E_γ=7~12MeV

→ Delayed coincidence



Merits of JSNS^2

- Neutrino beam

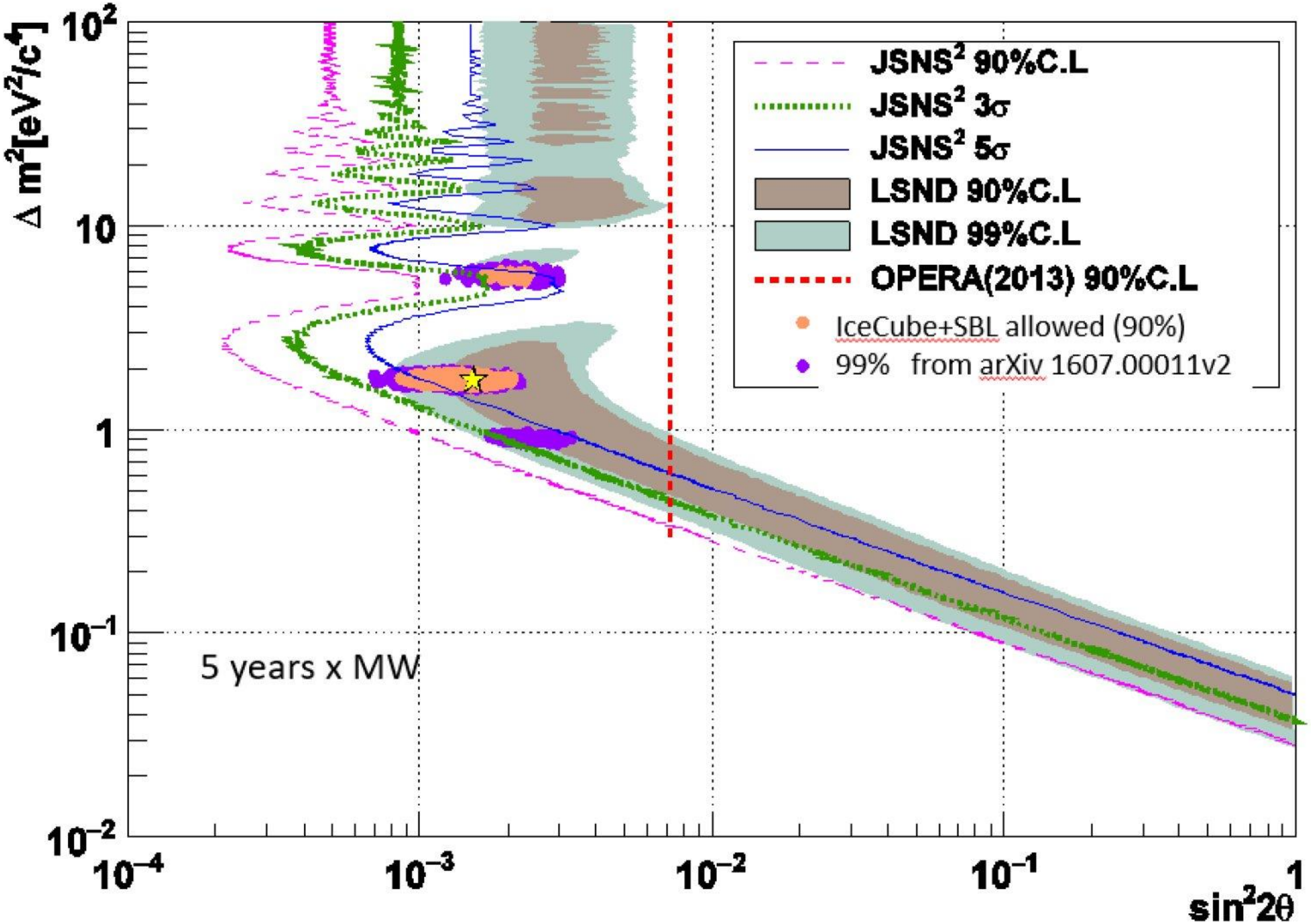
	Facility	Beam Pow. [MW]	Rep. Rate [Hz]	Pulse Width [ns]	Duty Factor
JSNS^2	**J-PARC/MLF**	**1**	**25**	**620**	**1.55e-5**
LSND	LANL/LAMPF	0.8	120	6e+5	0.072
KARMEN	RAL/ISIS	0.16	50	430	2.15e-5

--- Φ_ν ~10×KARMEN S/N > 1000×LSND

- Detector

	Type	Mass [t]	L [m]
JSNS^2	**Gd-LS PSD or/and Cherenkov**	**50**	**24**
LSND	LS	167	30
KARMEN	LS + Gd coating	56	17.7

JSNS^2 sensitivity (5y·MW)



Current Status

Design and R&D are in progress for the followings;

- Tank structure
- PSD capability of LS and PSD-LS+Cherenkov
- PMT selection, calibration procedure
- Veto system
- Electronics (DAQ, HV)
- Software/Simulation

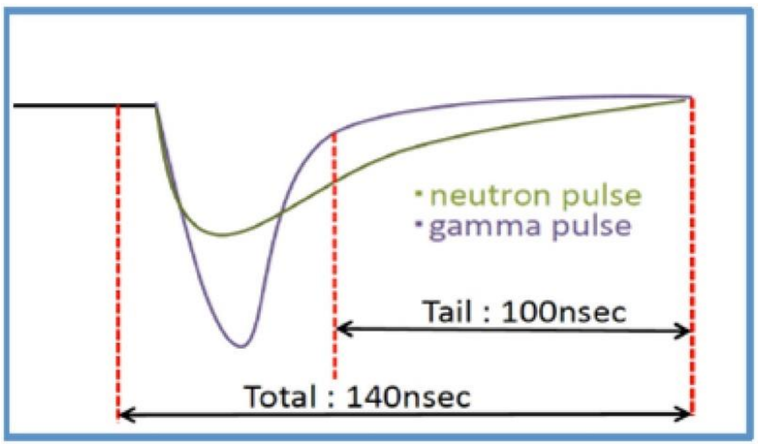
etc.

arXiv:1610.08186 [physics.ins-det]

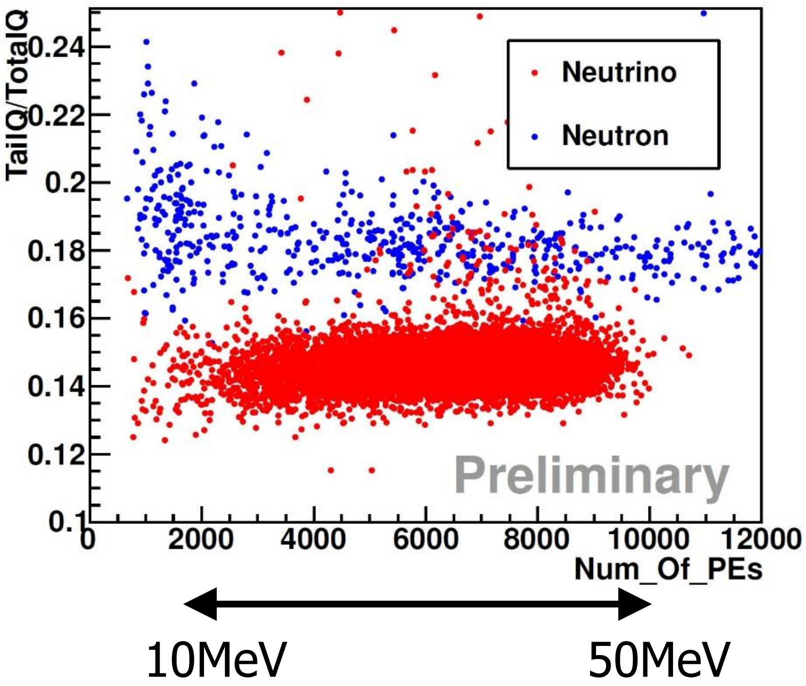
Detector R&D

for good energy resolution and high neutron rejection factor

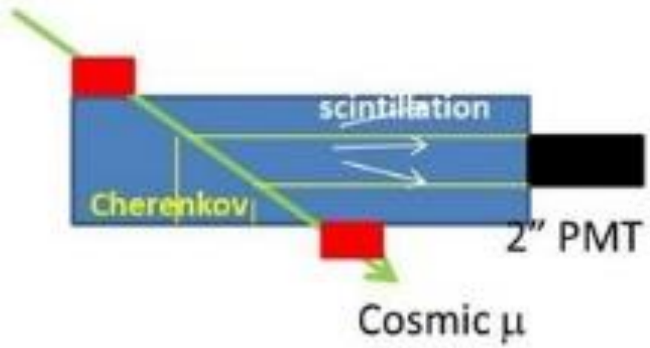
Performance test of n-γ discr. by waveform (Daya Bay type, Gd-loaded LAB-based LS)



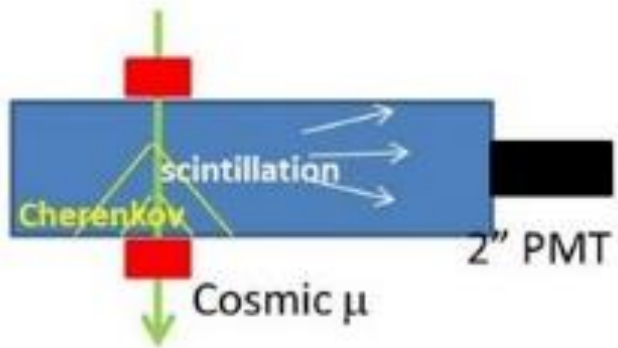
MC for charge ratio in JSNS[2] (based on ^{252}Cf test data)



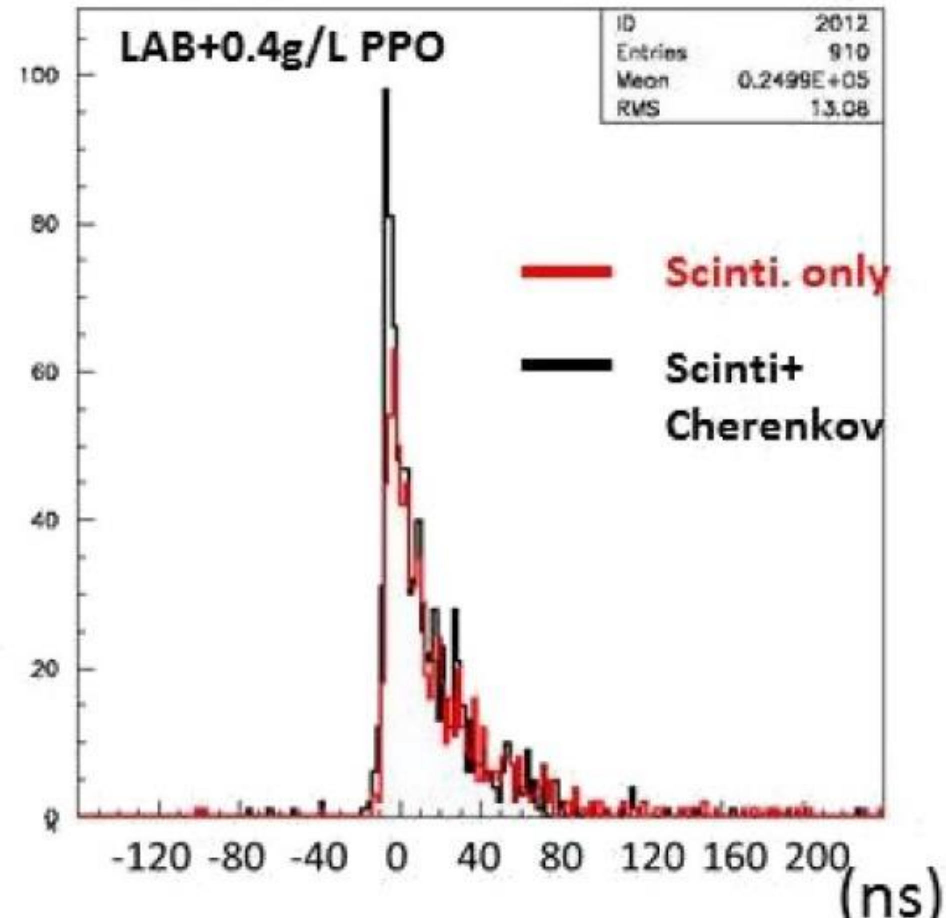
Scintillation + Cherenkov test with cosmic-ray



(A) Cherenkov + Scint.

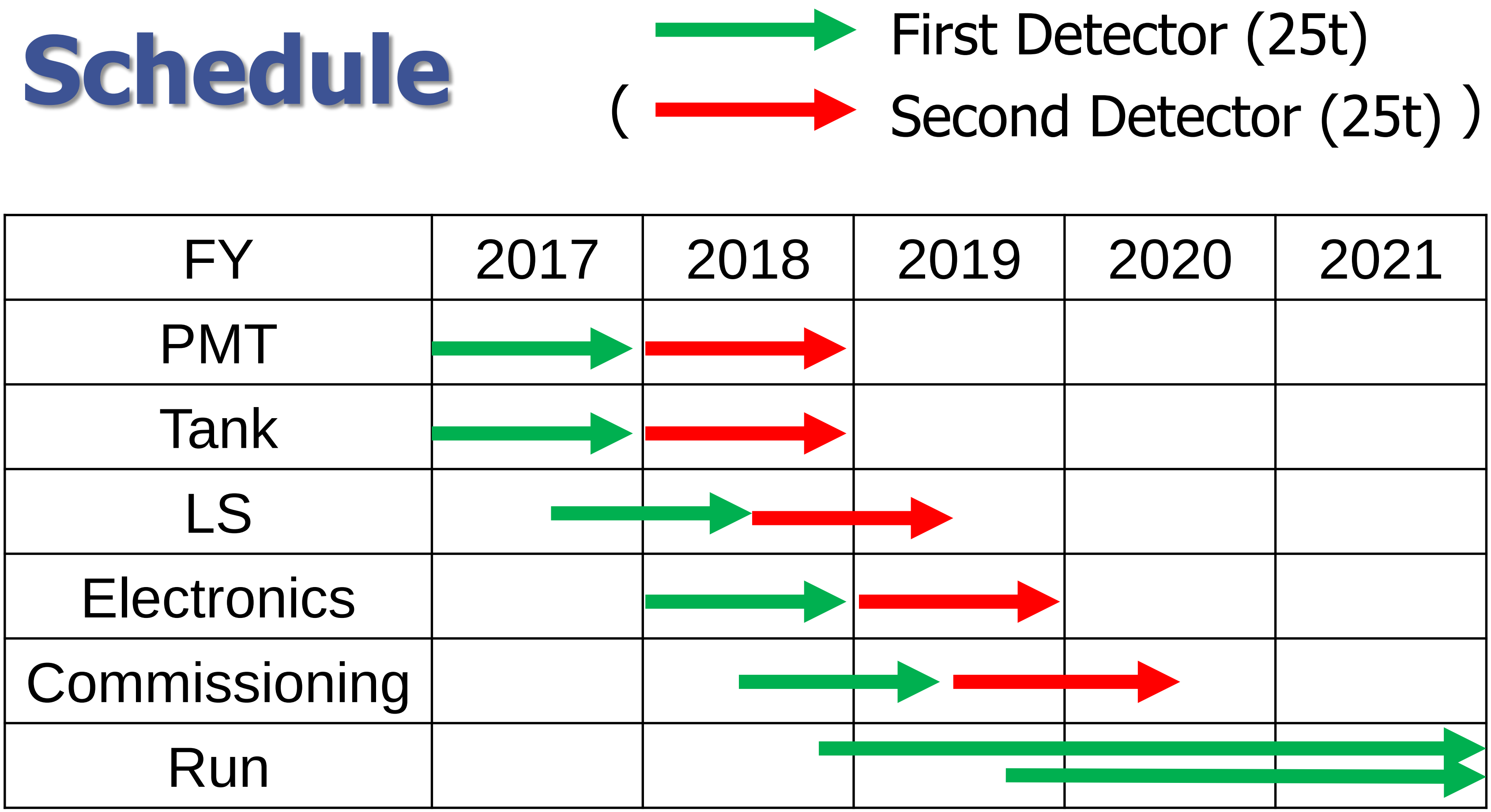


(B) Scint. only



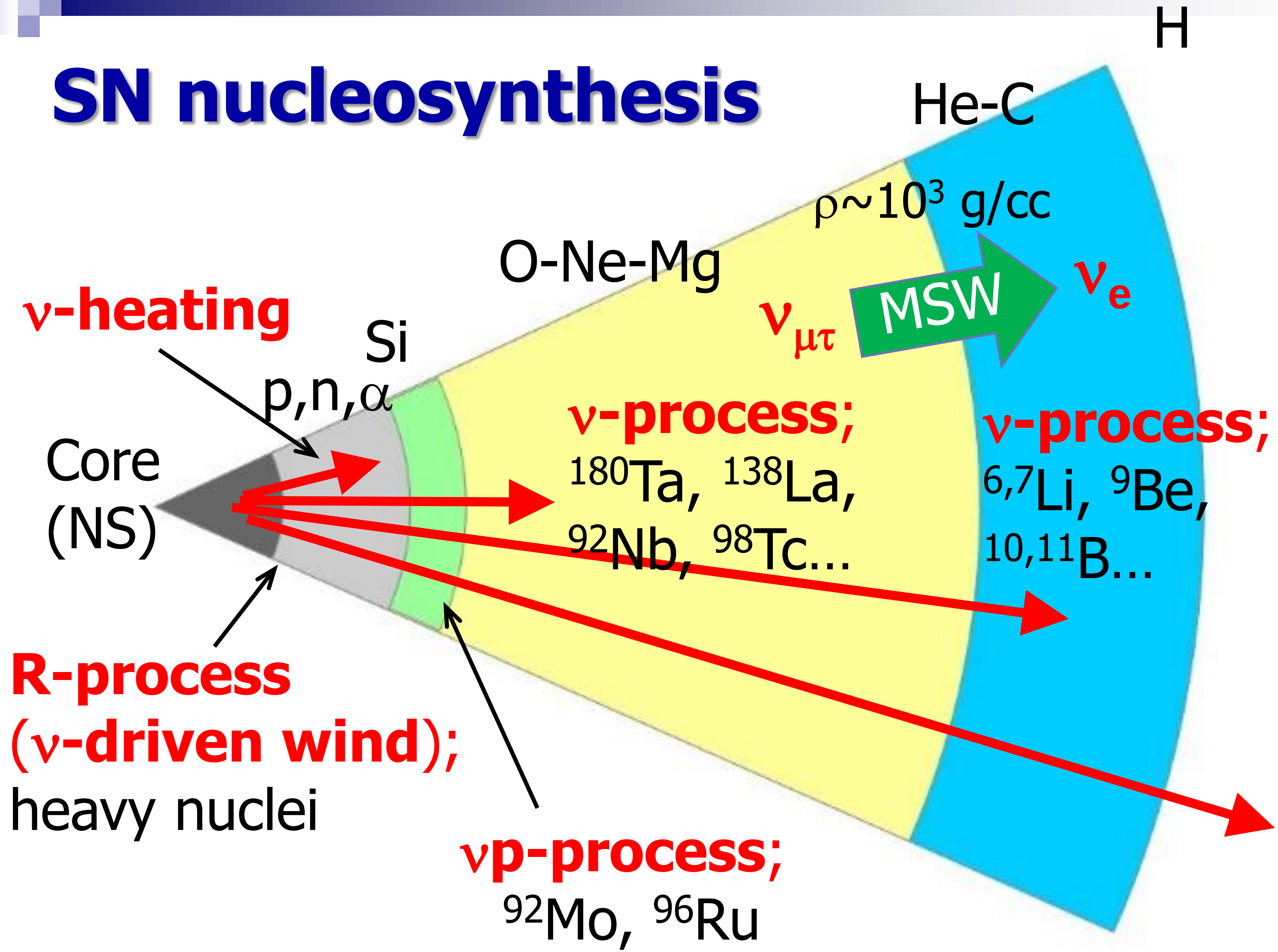
Tests with 300MeV proton/80MeV neutron are planned at RCNP (E477).

Schedule



- Approved as KEK Stage-1 experiment (E56)
- Funded by Grant-in-Aid for Scientific Research (S) for **first detector**

SN nucleosynthesis



Summary of direct measurements

Reaction	Method	Accuracy
$d(\nu_e,e^-)$, $d(\nu,\nu')$	Solar ν, reactor, ^3H-β	~2%
$^{12}C(\nu_e,e^-)$	Real-time meas.	~15%
$^{12}C(\nu_e,\nu_e)$	Real-time meas.	~30%
$^{13}C(\nu_e,e^-)$	Real-time meas.	76%
$^{56}Fe(\nu_e,e^-)$	Real-time meas.	37%
$^{71}Ga(\nu_e,e^-)$	Radiochemical	11%
$^{127}I(\nu_e,e^-)$	Radiochemical	33%

⇔ SN models need accuracy of ~10%

How to determine ν-A reaction rates ?

- Direct method --- secondary beams necessary
  Real neutrino beam experiment
  Beta decay of unstable nuclei (inverse reaction)
  Muon capture (inverse reaction)

- Indirect method --- analogous interaction
  Photobreakup, Coulomb dissociation, (e,e'), (p,p')
  → Neutral current (N.C.)
  Charge-exchange reactions (CEX); (p,n), (^{3}He,t), ...
  → Charged current (C.C.)

Reduced transition probability

Gamow-Teller:
$$B(GT_\pm) = \frac{1}{2J_i + 1} \cdot \left| \left\langle i \left| \sum_k^A \boldsymbol{\sigma}_k \boldsymbol{\tau}_k^\pm \right| f \right\rangle \right|^2$$

CEX cross section:
$$\frac{d\sigma_{CE}}{d\Omega}\left(\theta = 0^\circ\right) \square K \cdot N_{\sigma\tau} \cdot \left| J_{\sigma\tau}\left(\Delta q = 0\right)\right|^2 \cdot B(GT)$$
$$= \hat{\sigma}_{GT}\left(\theta = 0^\circ\right) \cdot B(GT)$$

K ; kinematical factor, $N_{\sigma\tau}$; distortion factor

$J_{\sigma\tau}$; volume integral of effective interaction

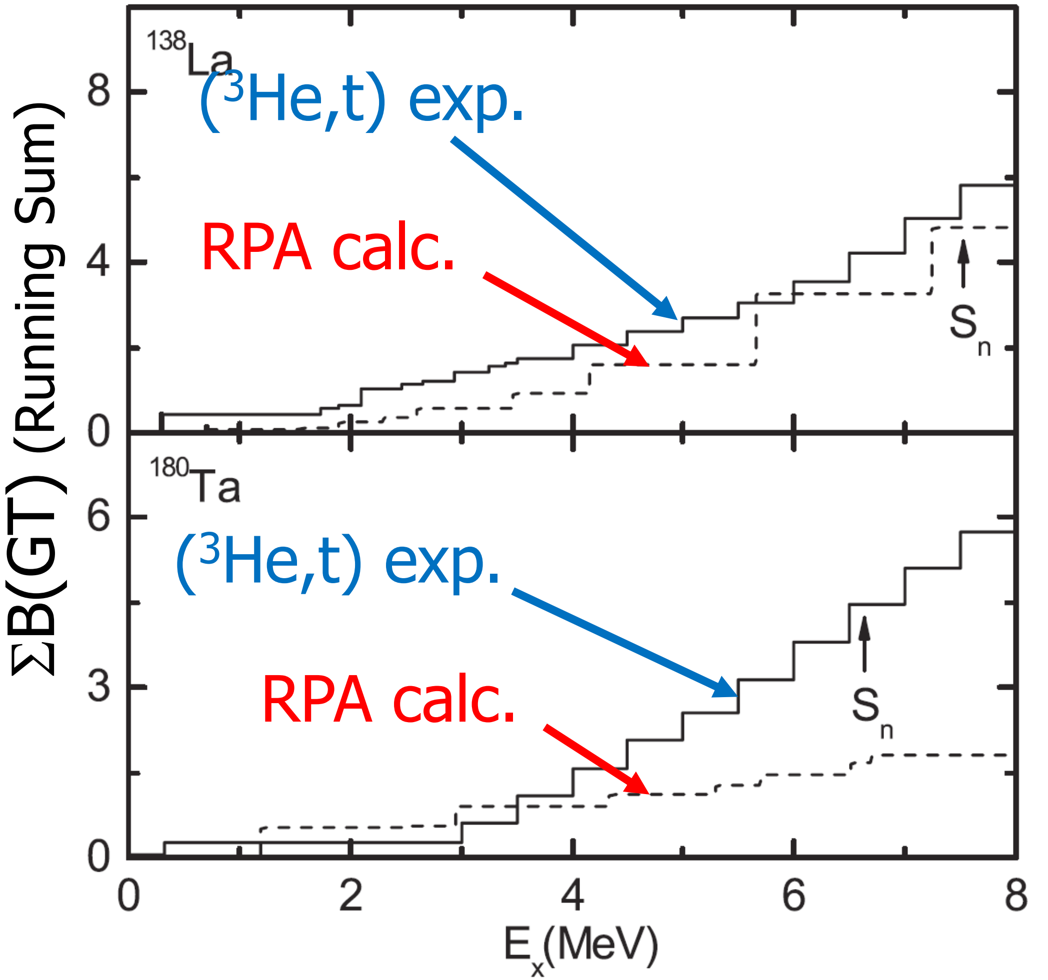
$\hat{\sigma}_{GT}$; "unit cross section"

fixed by using β-decay data, but $E_x < Q_\beta$ ...

Data of absolute σ_{GT} are needed for calibration !

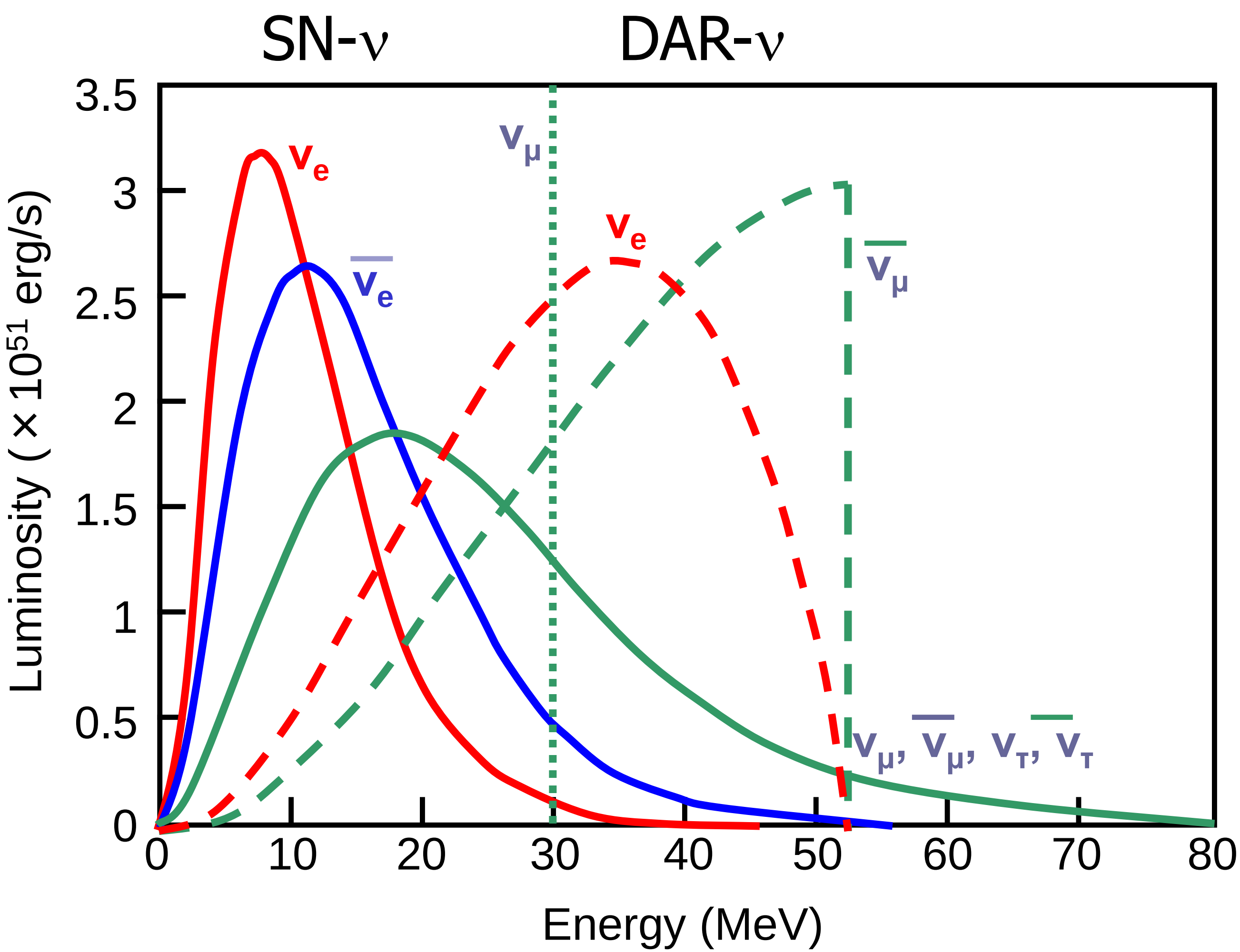
B(GT); (^{3}He,t)@RCNP vs RPA calc.

A. Byelikov et al., PRL98, 082501 (2007)



Data of absolute σ_{GT} are needed for calibration !

Energy Spectra of Decay-At-Rest ν



$^{12}C(\nu_e, e^-)^{12}N_{g.s.}$ signal

$$\nu_e + {}^{12}C \rightarrow e^- + {}^{12}N \quad (Q = -17.3\text{MeV} \rightarrow E_e < 35.5\text{MeV})$$

$$^{12}N \rightarrow {}^{12}C + e^+ + \nu_e \quad (Q = +17.3\text{MeV})$$

$$(T_{1/2} = 11.0\text{ms})$$

Prompt; t_{e-}=1~10μs, E_{e-}=20~40MeV

Delayed; t_{e+}=0.1~47.6ms, E_{e+}=10~18MeV

S/N and statistical accuracy

	$^{12}C(\nu_e,e^-)^{12}N_{g.s.}$	Background
Rate (single) [/y/MW/50t]	1513	2.43×10^5
Efficiency (coincidence)	0.396	---
Prob. of acc. Coin. [/detector]	---	1.15
Effi. with ΔVTX<20cm	0.82	0.0011
Effi. with Lifetime cut	0.91	0.45
Rate (coin.) [/y/MW/50t]	448	138.3
Stat. err. [%]	**6.0 (1y) / 2.7 (5y)** **<<15% (previous) !!**	

Summary

- The experiment J-PARC E56 has been proposed by the JSNS^2 collaboration to search for sterile neutrinos.
- From BG study, JSNS^2 is expected to have a sensitivity to survey the region claimed by previous experiments.
- Approved as KEK Stage-1 exp. and funded for one detector.
- Data of absolute cross sections of neutrino-induced nuclear reactions are indispensable to quantitatively understand mechanism of SNe and SN nucleosynthesis.
- JSNS^2 will be also useful for direct measurement of $^{12}C(\nu_e,e^-)^{12}N$ reaction rate with better accuracy, which will contribute to better modeling of SNe.