Nuclear Weak Responses by Neutrino & Electron Probes

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I. Neutrinos and nuclear weak responses.

- **Neutrinos are windows for new particle and astronuclear physics.**
- **ν : Majorana/Dirac particle, ν mass, ν helicity, ν oscillation, flavor mixings, mass difference, ν interactions in the sun, sn, stars.**

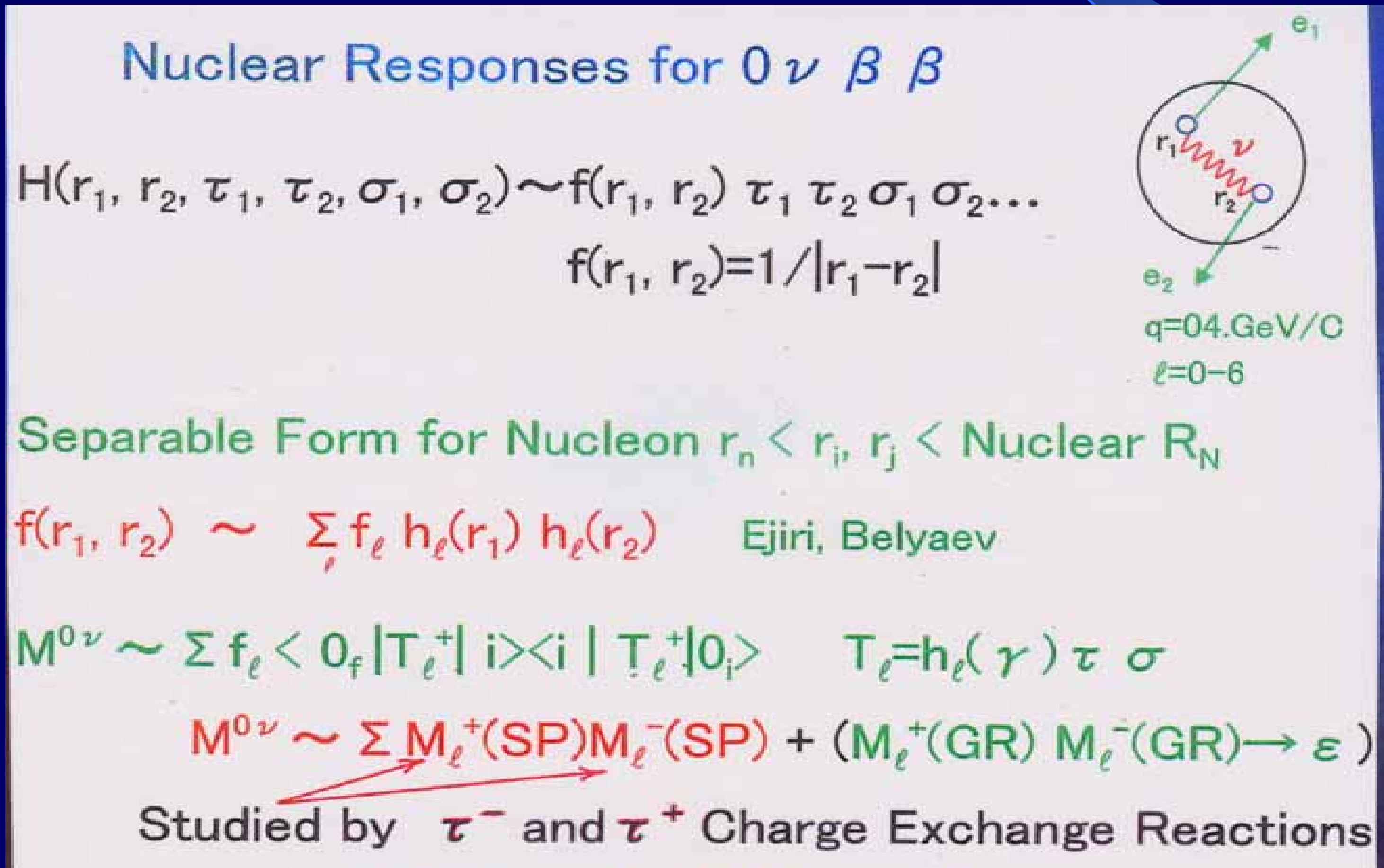
- **Fundamental properties of ν's and week forces and ν astrophysics are studied in nuclei as micro-laboratories .**
- **Nuclear are chosen to select weak processes of interest**

- **Nuclear Responses for ν's are crucial.**

Charged (τ_+,τ_-) , neutral (τ_3) ,vector (σ^S S=0) , axial v (σ^S S=1). Nuclear σ τ responses $G(\alpha)\,\tau\,[\sigma^S Y_L]_J$

$\beta\beta$, ν mass and nuclear responses for ν

- $T^{0\nu} = G^{0\nu} M^{0\nu}(\tau\sigma\tau\sigma rp)(<m_\nu>)^2$
- **Majorana ν, absolute mass in <m> ~0.03 eV.**



Nuclear Responses ($M^{0\nu}$) for $\beta\beta$

- **Hadron probes**
- **Single (^{3}He,t, t,^{3}He), double charge exchange (^{11}B, ^{11}Li)**

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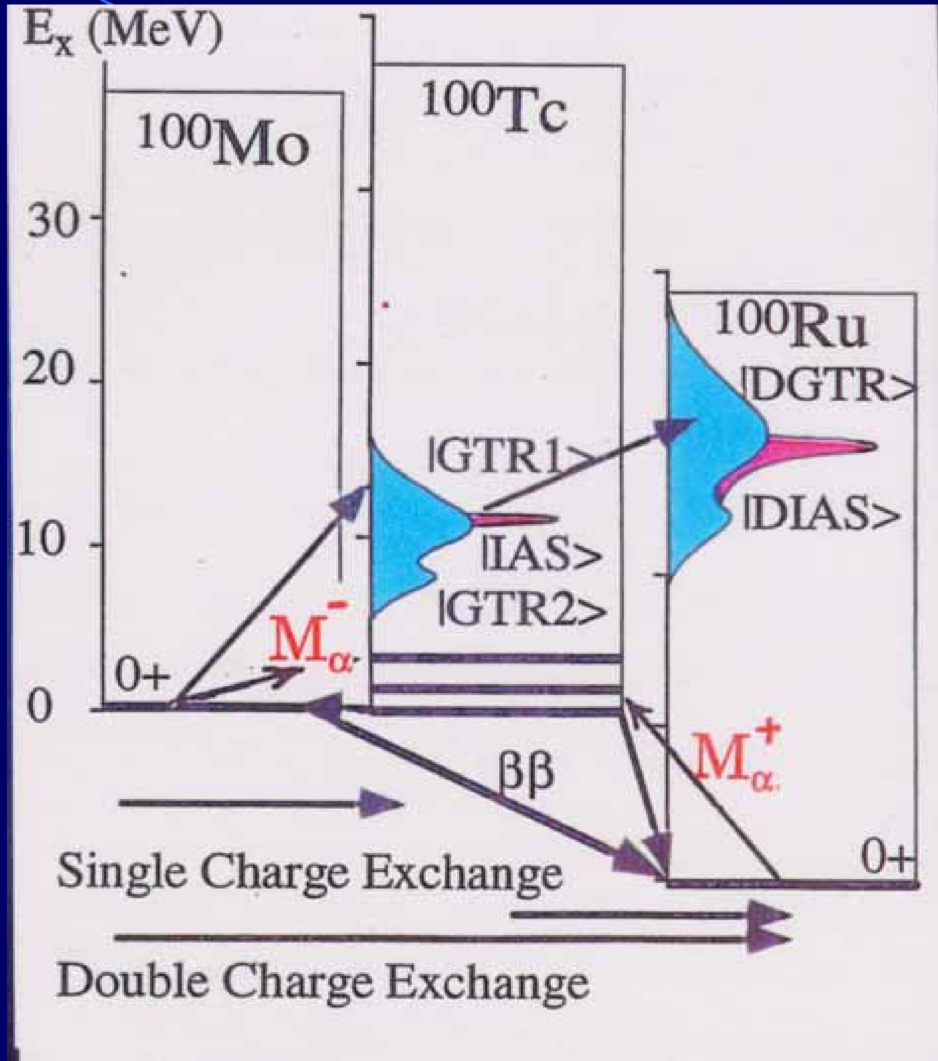
- **Weak e-ν probes**
- **(e,ν γ), (ν,e γ) , (e+, anti-νγ) (Anti-ν,e+ γ)**



Solar ν responses

- 1. Solar-ν rates: Low-E light ions at underground lab.
- 2. Nuclear detector responses for charged and neutral currents
- 3. d, ^{71}Ga, ^{100}Mo, ^{127}I, etc
- up to 15 MeV with a few % δ.
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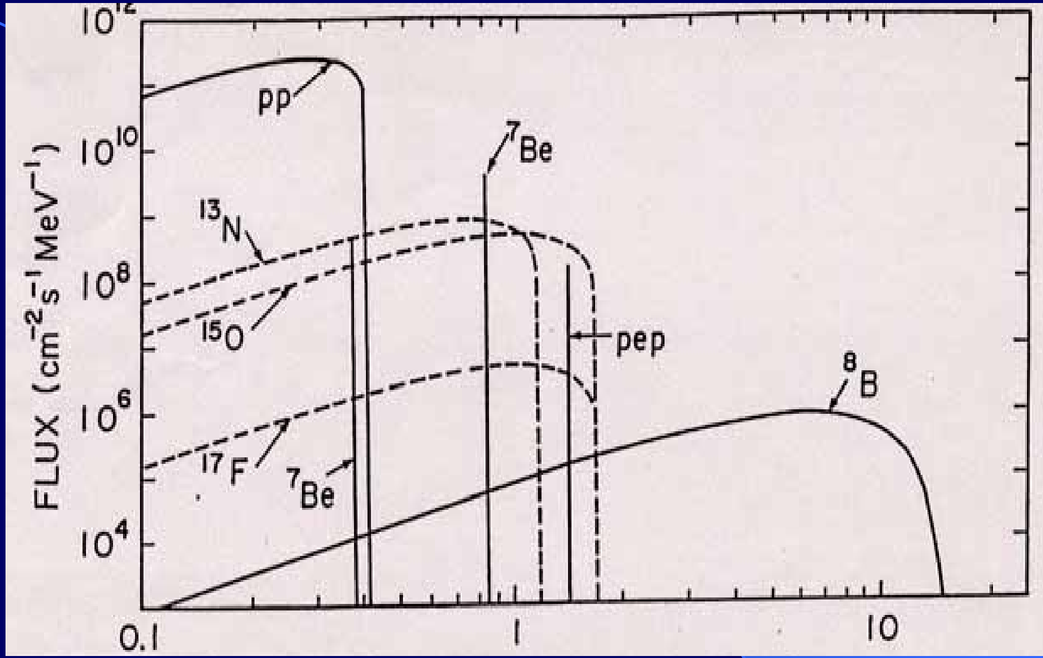
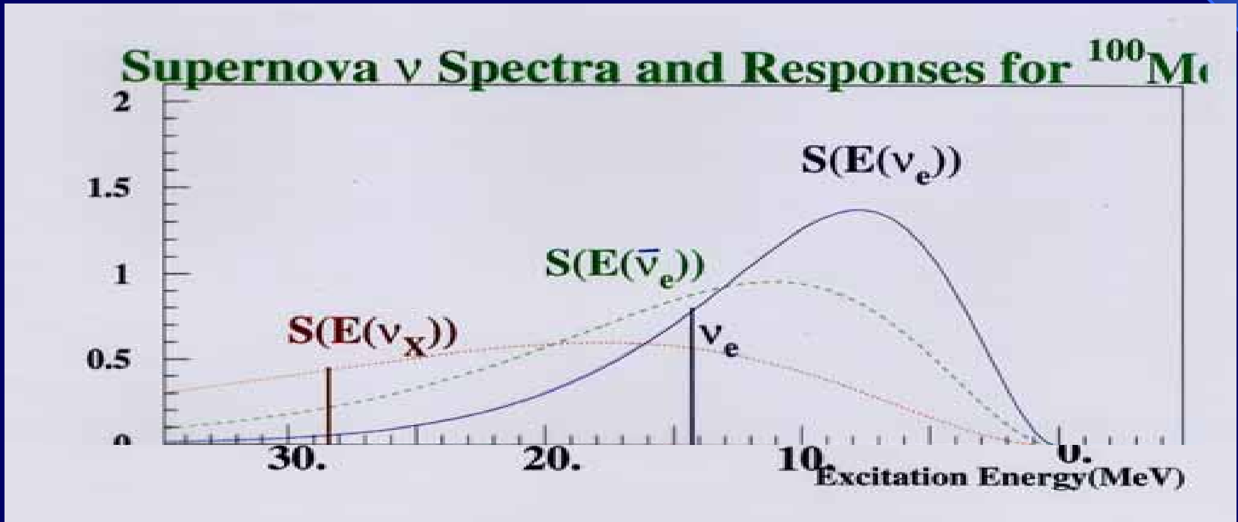


Nucleus	-Q(MeV)	pp	7Be	13N	pep	15O	8B	Tota
^{2}H[a]	1.442	0	0	0	0	-	6	6
^{37}Cl[a]	0.814	0	1.1	0.1	0.2	0.3	6.1	7.9
^{40}Ar[b]	>1.505	0	0	0	0	0	7.2	7.2
^{71}Ge[c]	0.236	70.8	35	3.7	2.9	5.8	12.9	132
^{100}Mo[d]	0.168	639	206	22	13	32	27	965

Supernova ν by inverse β

- Supernova type II   Gravitational collapse.

- ν_e T~3.5 MeV,   <E> ~ 11 MeV.
- Anti ν_e T ~ 5 MeV,   <E> ~ 16 MeV.
- ν_x T ~ 8 MeV,   <E> ~ 25 MeV.



ν spectrum flux : supernova mechanism, spectrum distortion : ν oscillation. ν time : ν mass in 30-50 eV region

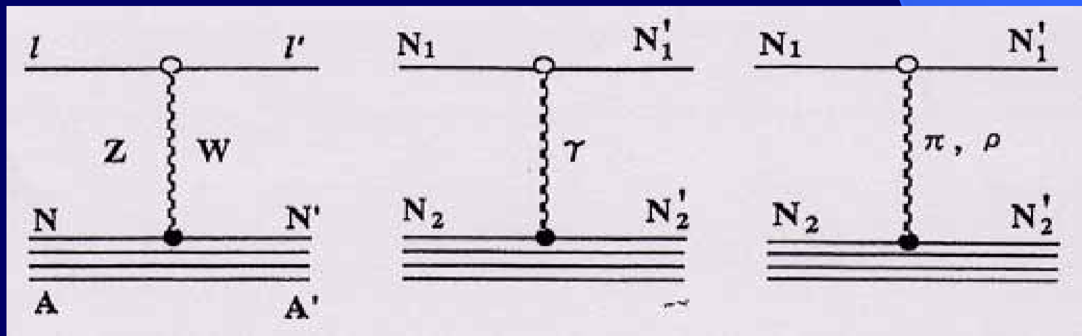
- ν nuclear interaction ν detection in nuclei, ν nuclear responses.

II. Nuclear probes for ν weak responses.

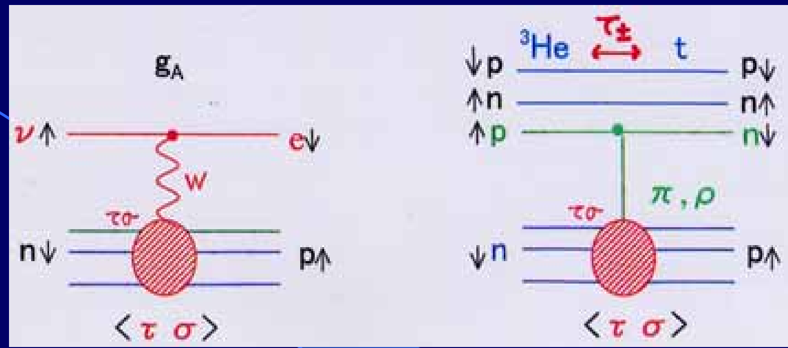
- Charged (τ_+, τ_-) and neutral (τ_3)
- Vector $(\sigma^S \quad S=0)$ and axial vector $(\sigma^S \quad S=1)$
- Isospin $\langle \tau Y_L \rangle$ and spin isospin $\langle \tau \sigma Y_L \rangle_J$

- $0\nu\beta\beta$ L=0,1,2,3,4,5, E < 50 MeV
- $2\nu\beta\beta$ L = 0,1. E < 20 MeV
- Solar ν L = 0,1. E < 13 MeV
- Supernova ν L = 0,1. E < 50 MeV v

- Weak probes ν,e,μ
- EM probes e, γ
- Strong probes p,n



Hadron and EM probes



- **Hodrons with strong interaction**
- **Charge exchange spin flip**
- **(p,n), (d,^{2}He), (^{3}He,t), (^{7}Li.^{7}Be).**
- **Double c exchange (^{11}B, ^{11}Li)**
- **E/A ~ 0.2 GeV with large $V_{ts,}$ and small distortion,**
- **RCNP,MSU, and others.**
- **Non-central interactions, distortions, multi step and others.**

- **EM probes : e, γ at SPring-8, and high Z Coulomb excitation**
- **Neutral current and includes T = 0,1, and**
- **magnetic σ and l contributions**
- **Stretched transitions with J = J'+L,J'-L.**

III. Weak probes/processes

- β decays, limited to charged current responses for
- ground states of daughter nuclei.
-
- ν proe (ν,e γ), direct but need intense ν beams(10^{15}/sec) and large detectors (10 tons) because of $\sigma \sim 10^{-41-42}$ cm^2
- SNS/ORLaND with 1 GeV p and J-PARC with 3 GeV p

- μ probe (μ,ν_μ) captures for T^+ responses up to 100 MeV.
- with very large cross sections (J. Suhonen)

- e probe by (e,ν γ β) with e- beam of I_e ~1mA, N ~ 10g, T~ 0.I y, $\sigma \sim 10^{-40} cm^2$ Y ~ 10^4, e+ beam ~ μA Y ~ 10.

Nuclear responses for ν's

σ for given multi polarity in $10^{-41}cm^2$ and energ

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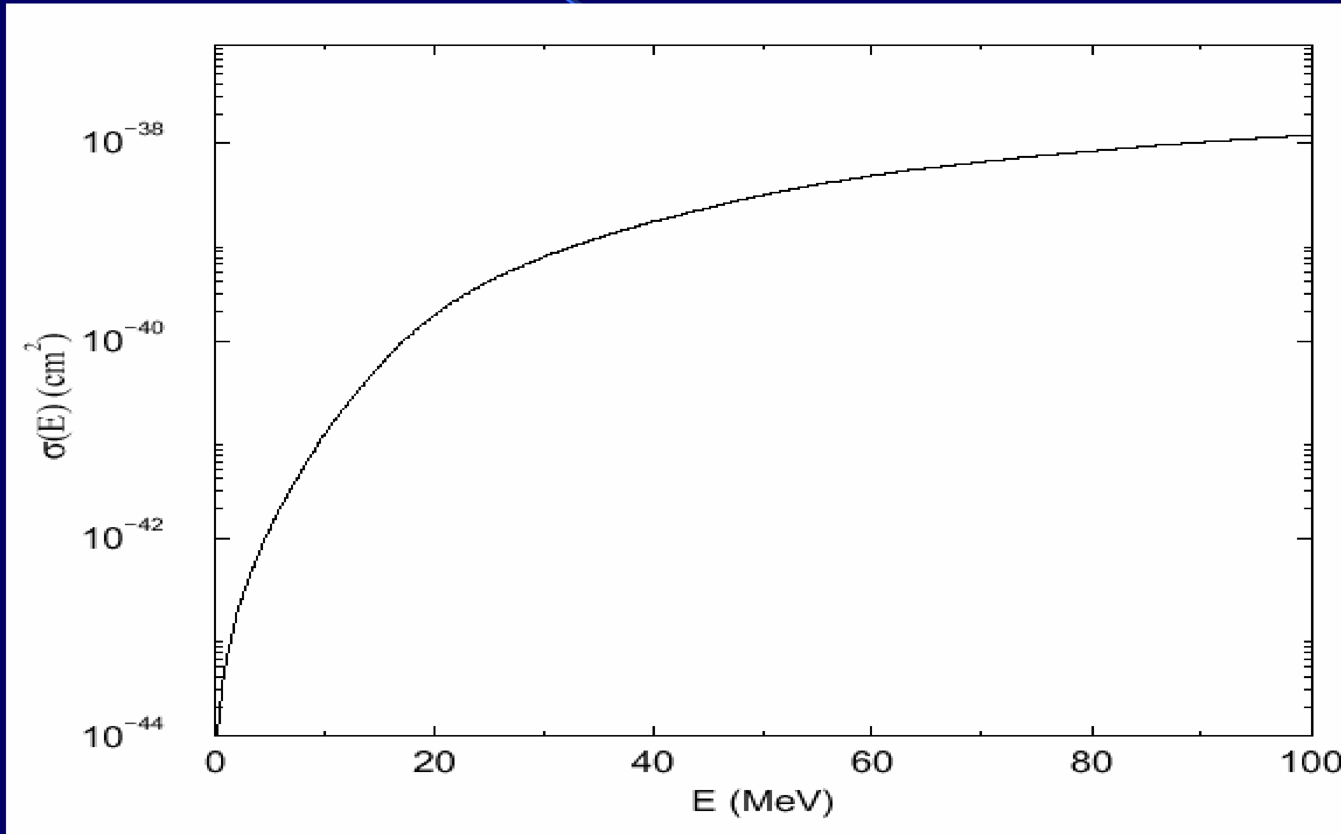
	ν_e	ν_{ex}
0^+	0.65	8.94
0^-	0.02	0.59
1^+	4.62	32.34
1^-	0.14	11.86
2^+	0.04	4.62
2^-	0.34	14.00
3^+	0.03	3.78
3^-	—	1.00
4^+	—	0.23
4^-	—	0.79
total	5.84	78.16



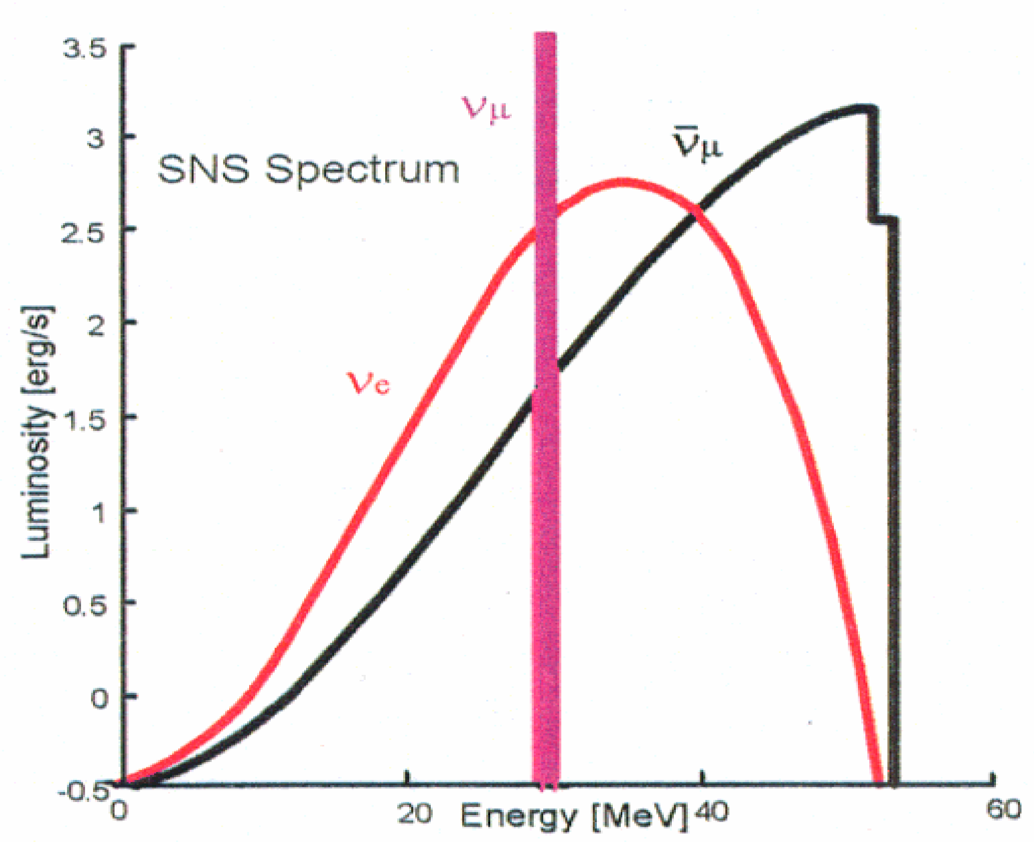
Neutrinos from stopped p^+

$$p + Hg \rightarrow n\,\pi^+$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \underline{\nu}_\mu$$

Neutrino spectra



Source	E GeV	N_p	N_ν	Detector
SNS	1	$6\ 10^{15}$	$7\ 10^{14}$	ORLaND
JHF	3	$1.2\ \ 10^{15}$	$3\ 10^{14}$	(MOON

Electron probes for weak responses

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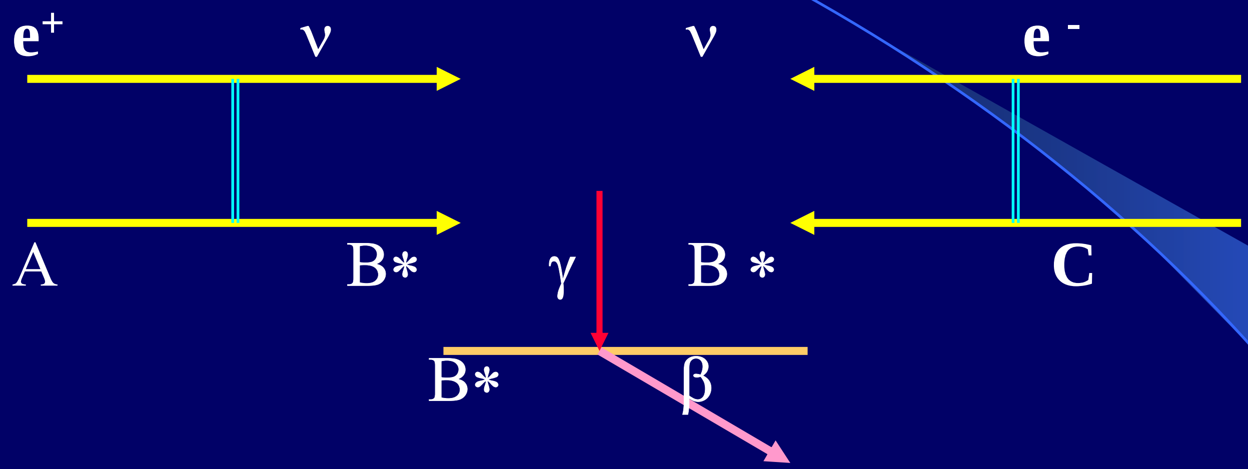

$\beta\beta$ $\mathbf{A} = \mathbf{B^*} + \beta^{-} + \nu$ $\quad B^* + \nu = \mathbf{C} + \beta^{-}$

Solar ν $\quad \nu + \mathbf{A} = \mathbf{e} + \mathbf{B}$

Electron and positron probes

Probe	E MeV	I	σ cm^2	Reaction	T- Mo	Yield /y
Electron	20	1 mA	10^{-40}	(e,νγ)	10 gr/cm^2	1.1 10^5
Positron	20	10^{12}/s	10^{-40}	(e,νγ)	10 gr/cm^2	1.8 10^2

* 20 MeV electron range 12 gr/cm^2

- Experiments

  Real time measurements with highly segmented detectors to reduce accidental coincidence from EM processes.

  Off-beam β activity to get total strength.

- ^{76}Ge ββ to ^{76}Se

  ^{76}Ge (e+, ν γ) ^{76}As ^{76}Ge 7.6 % ^{76}As 2.63 hr β- Q = 2.986 MeV

  ^{76}Se (e-, ν γ) ^{76}As ^{76}Se 9%

  ^{78}Se (e-, e- p n γ) ^{76}As   e- energy below the threshold energy

IV.Concluding remarks

- 1. Nuclear physics of ν's are new windows for physics beyond the SM and astrophysics.
- Nuclear isospin spin responses of τY_λ and $\tau\sigma Y_\lambda$ for ν's are crucial for ν studies in nuclei.
- 2. Hadrons with strong interactions (RCNP) for charged axial currents and photons and electrons with EM interactions (SPring-8) for neutral currents have large cross sections, but other processes and contributions.
- 3. Weak ν e probes direct but extremely small σ's
- Now ν probes are realistic with J-ParC
- Weak e probes can be realistic with new e- facilities.

References

Nuclear responses for neutrinos

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Thank you for attention