Future Outlook: Experiment

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Preface

- My talk is **neither** a summary talk **nor** general view in future.
- This is a quite **biased and personal view** of a direction of the ***future*** large scale neutrino experiments

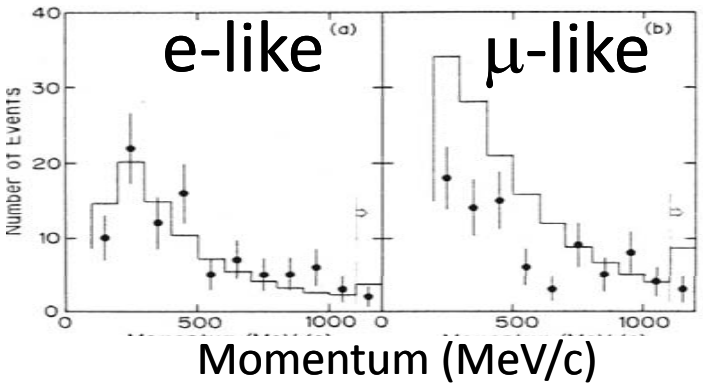
  ➔ **'Ultimate' Experiments beyond the next generation experiments:**
  - more than 20 years from now (or more)
- Please relax and have a dream together

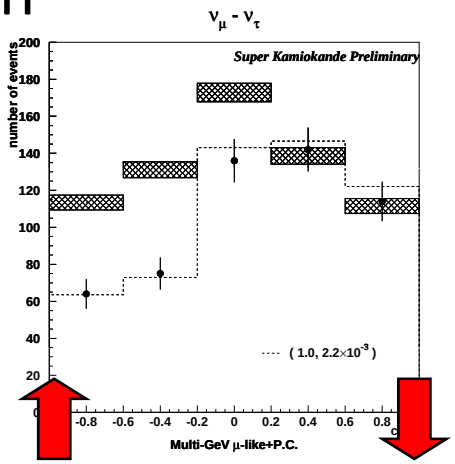
Note for the audience

This talk may contain hazardous opinion and may spoil you (PG40).
It is your own responsibility to listen me.

10^{th} anniversary of the Discovery of the Neutrino Oscillation

- It started as ***an Atmospheric Neutrino Anomaly*** (ν_μ deficits in 1988, by Kamiokande)
  - Background of the Proton Decay Search





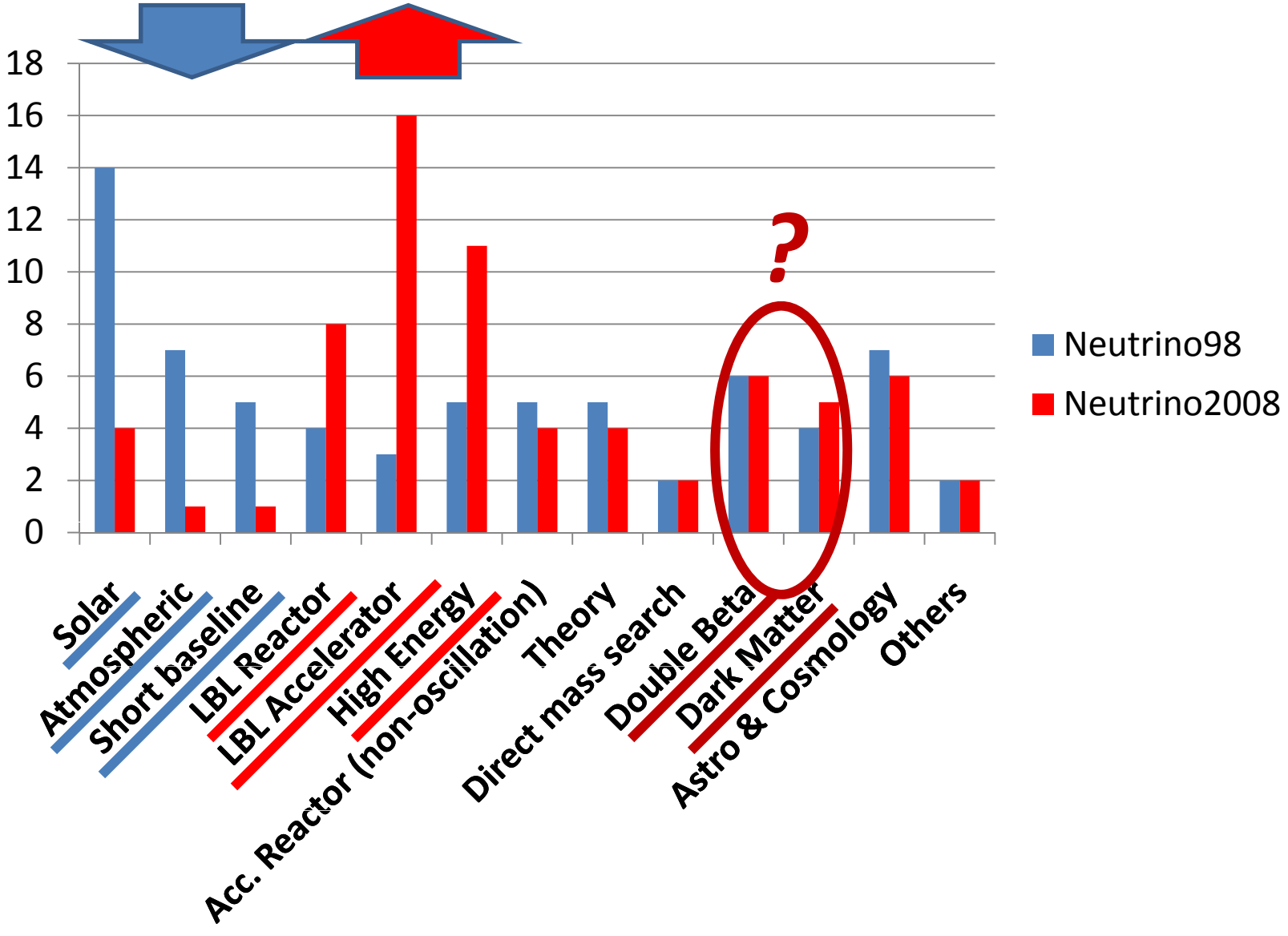
- It took 10 years to establish as an **Real** Effect
  - Convincing Evidence came from Super-K (1998)
    - **High Statistical Measurement**
    - **Independent of the Flux calculation**

More than 30 years

- Solar neutrino problem:
  - Started in late 60
  - Solved in 2001 (SNO +SK)
    - **High statistical experiments**
    - **Flux independent evidence (SNO+SK, SNO NC+CC)**

➔ Discovery of Neutrino Oscillation has really changed the world

Number of Talks @N98 & N08



After the establishment of the neutrino oscillation

- We now have well motivated 'standard' menu to do.
  - Physics parameters to be measured!
  - Questions to be answered ?
    - θ_{13} !
    - CPV ?, CP phase !
    - Majorana or Dirac ?, Majorana mass !
    - Mass hierarchy ?
    - Absolute mass !
    - ……
- Though the above list are significant and important, there are no big **puzzles or problems** like solar neutrino problem or atmospheric anomaly.
- In any way we are guided to the fruitful and promising future !??????

Ultimate experiment after the next

Since we will build a huge detector and spend big amount of money with large number of scientists

1) Cover the **standard list** as much as possible
2) Include **other** scientific possibility, or **new opportunity** as much as possible

   θ13 may not be determined positively!

   DB decay may not be accessible!
3) Need **bread and butter** science

   need 'measurements' as well as searches

➔ ***Build GOOD Versatile detectors***

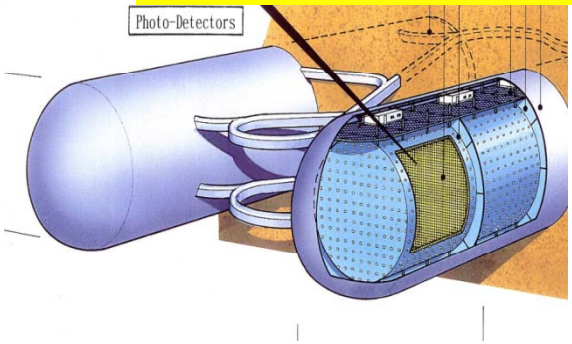
Limit myself to discuss two example, because of the limitation of the time

1) Neutrino Oscillation Experiments, and
2) Double Beta Decay Experiments

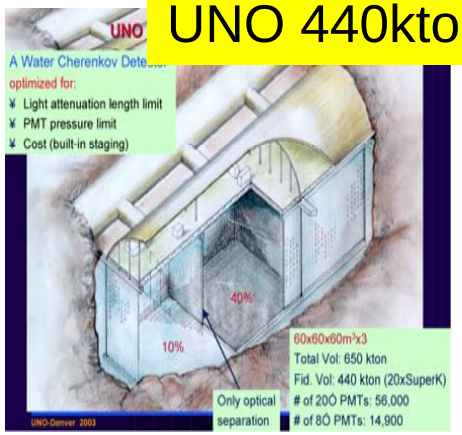
‘Standard’ Next Neutrino Oscillation Experiments

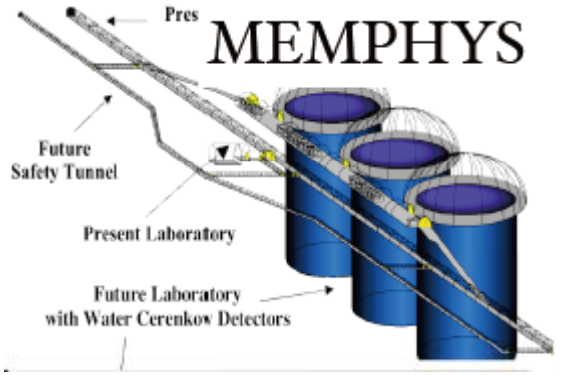
- Aim to study CPV, Mass hierarchy
- Megaton Scale Detector + Upgraded Accelerator
- Typical ➔ Detector 0.5 Mton (fiducial Volume)

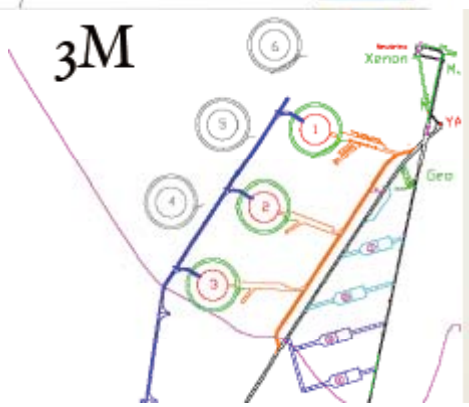
Hyper-K 540kton



UNO 440kton







- Other Subjects
  - Proton Decay (10^{35} years for $e\pi^0$)
  - SN neutrinos

Is the Proton Decay sensitivity of 10^{35} years for $e\pi^0$ (10 years of running) strong enough?

What is the best goal for the proton decay search

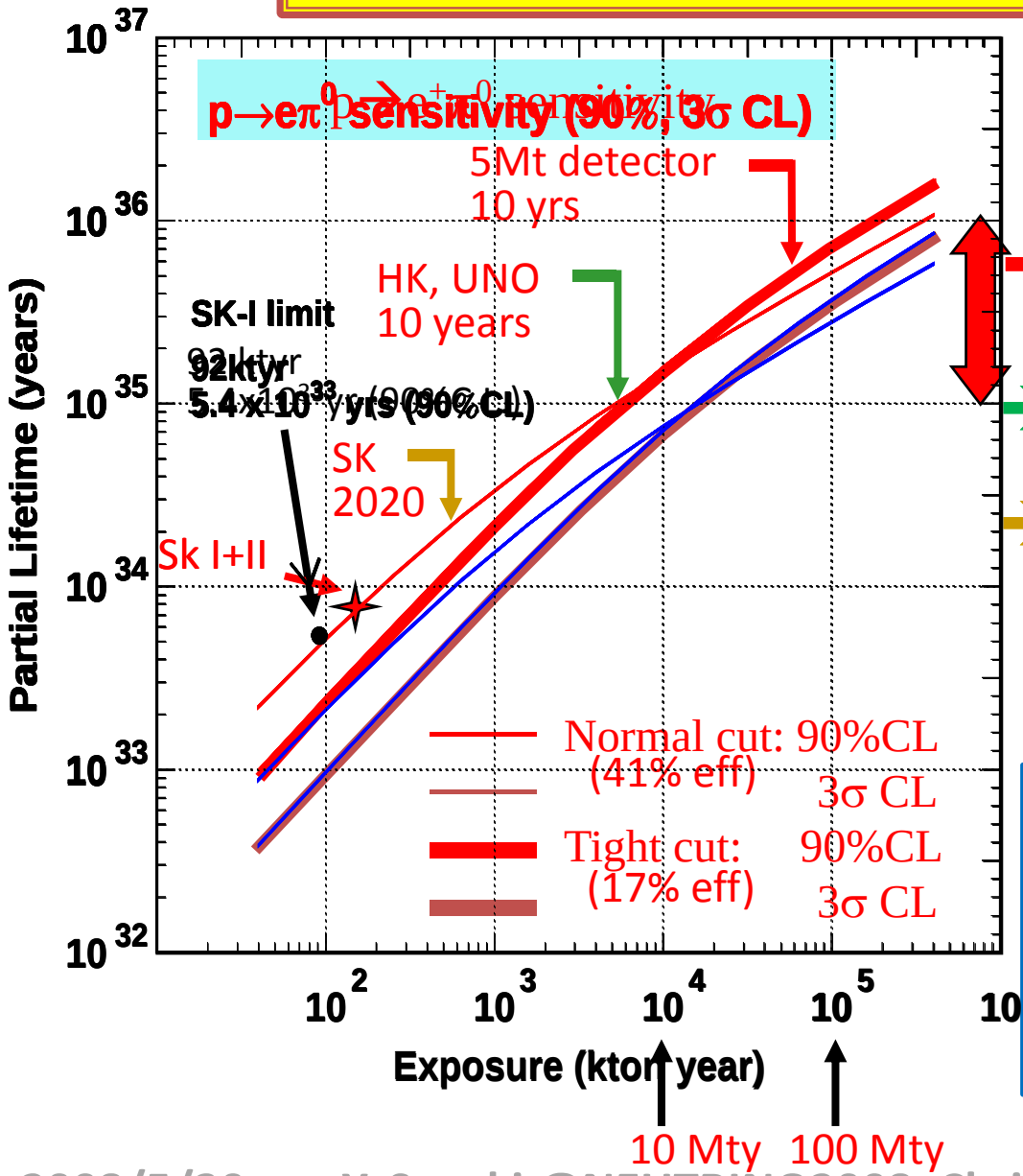
- ***νK, μK*** : strong model dependence
- Prediction of Dimension 6 in SUSY GUT
  - Less model dependent
  - Reasonable range: ***10^{35} ~10^{36} yr for $e\pi^0$***

← From coupling unification

→ Search up to ~10^{36} yr is quite important and add significant value to the neutrino oscillation exp.

→ Sensitivity for $e\pi^0$ will guide the size of the experiment

Sensitivity for $p \rightarrow e^+ \pi^0$



5 Mt detector
10 yrs operation

→ ~7x10^{35} yrs

→ ~1x10^{35} yrs

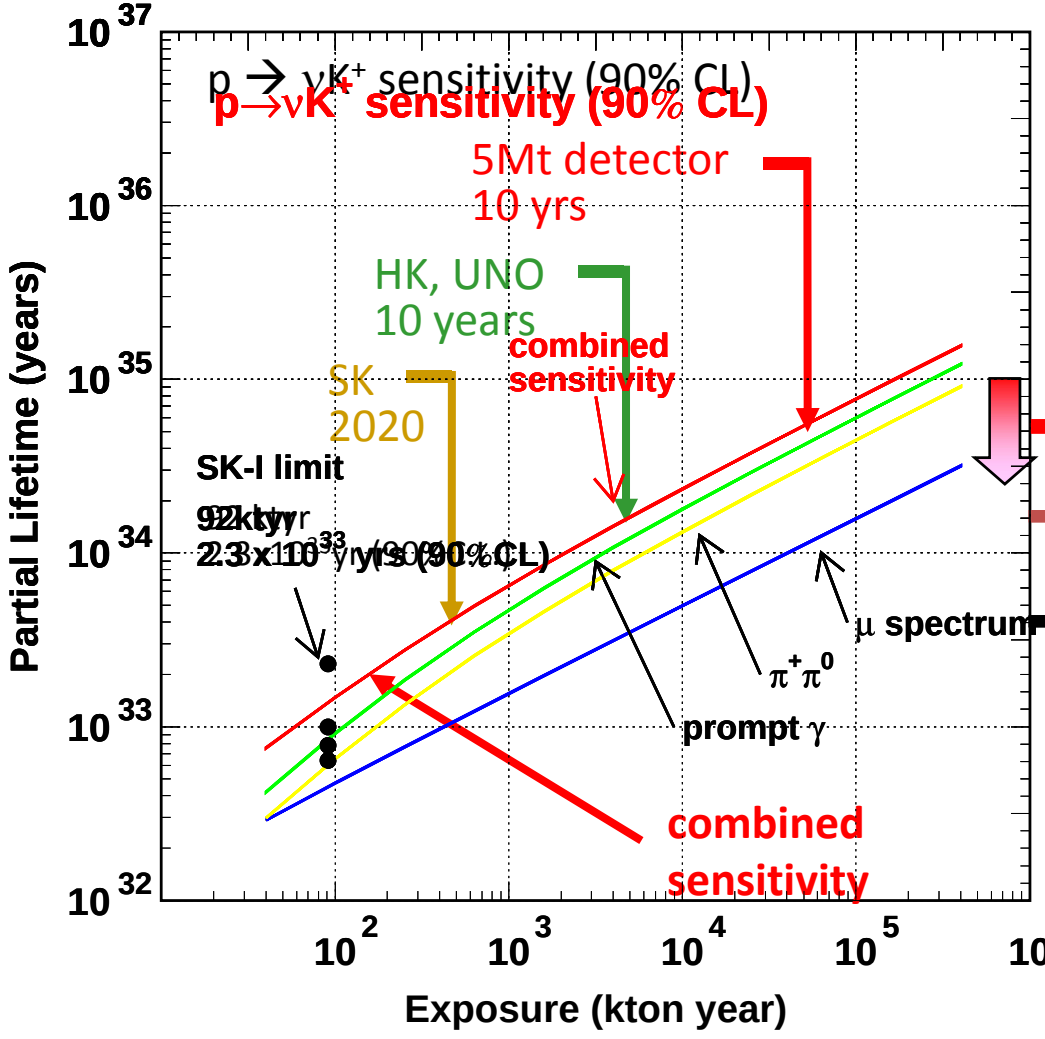
0.5Mt detector
10 yrs operation

→ ~3x10^{34} yrs

SK (22.5 kt)
25 yrs operation (2020)
effective: close to 0.5Mty exposure

To reach 10^{36} years, need 200Mty exposure--10Mt 20years, but 5Mt 10years reaches to ~7x10^{35}yr. If detector is expandable, then we can start with 5Mt or less

Sensitivity for $p \rightarrow \nu K^+$



Once you find the proton decay by $e\pi^0$ mode, then νK will constrain models.

5 Mt detector
10 yrs operation

→ ~7×10^{34} yrs

→ ~2×10^{34} yrs

0.5 Mt
10yrs opereration

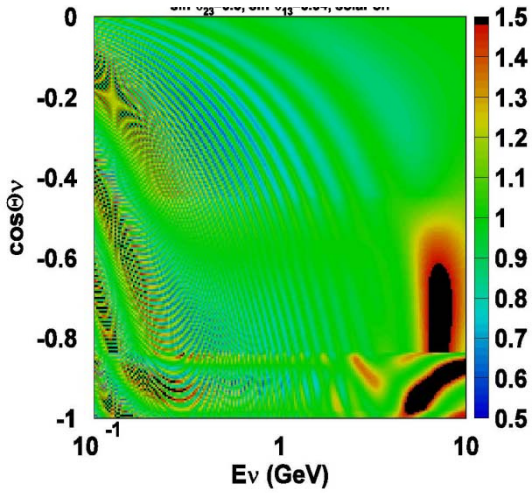
→ ~4×10^{33} yrs

SK (22.5 kt)
25 yrs operation (2020)

If the detector is expandable, you can continue to study the sensitive regions.

Bread and Butter

- Do you have a bread and butter science for 5Mt detector.
  - Obviously Atmospheric ν
    - ➔ A.Smirnov said 'Oscillograms' ➔



- Do you have other than Atm ν?

  Answer: Yes!

  We can detect neutrino bursts from supernovae from 5Mpc distance

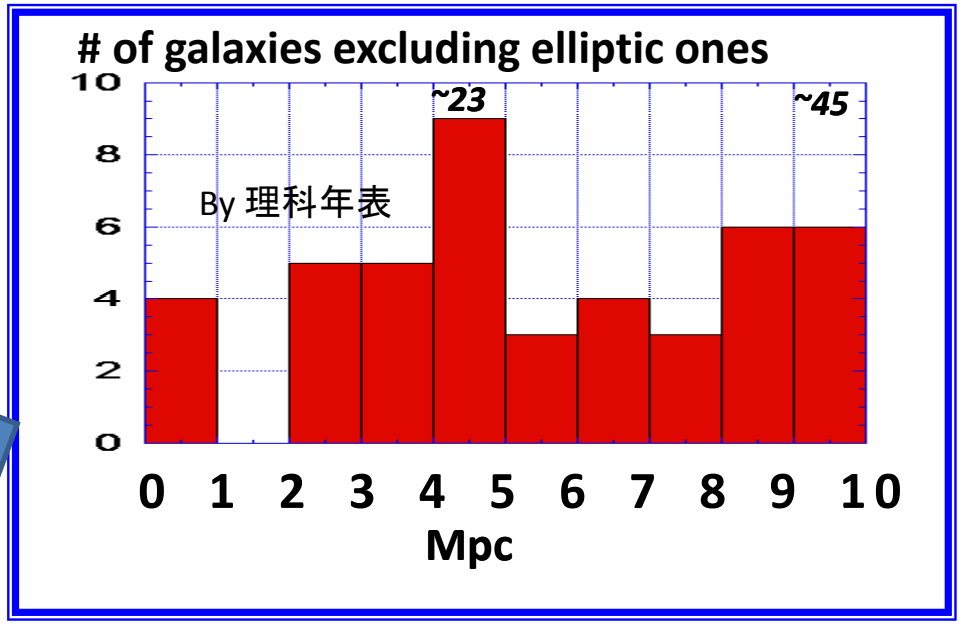
  ➔ gives you one SN neutrino burst detected every year !!!

Supernova Rate

- **Galactic SN rate**
  - **Every 30 ~50 years in our Galaxy**
    - ← SN rate external Gal., Galactic ^{26}Al abundance, Historical Gal. SN, ……..,
- **Number of Galaxies**
  - **23 within 5 Mpc**
  - **45 within 10 Mpc**

➔ 1 SN every 1~2 years (5~10Mpc)

- **There are Galaxies beyond 2 Mpc where SNe have frequently happened**



- **NGC6946 (5.9 Mpc) *10 in 90yr***

1917A, 1939C, 1948B, 1968D, 1969P, 1980K, 2002hh, 2004et

- **M83 (4.3Mpc) *6 in 60yr***

1923A, 1945B, 1950B, 1957D, 1968L, 1983N

- **NGC2403 (3.3Mpc) *3 in 50yr***

1954J, 2002kg, 2004dj

➔ 1 SN every year (within 5 Mpc) is not bad estimate

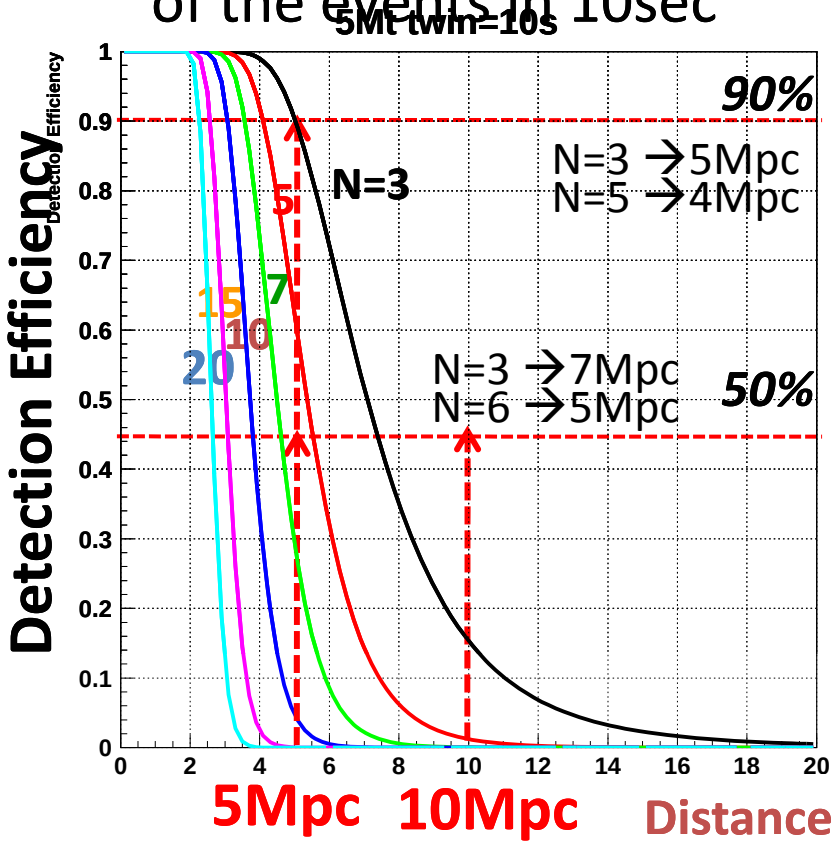
Is it possible to detect SN neutrinos from the distance of 5Mpc

- Yes!
- SN1987A(50kpc): Extrapolation to 5Mpc & 5Mt
  - ➔ Kamiokande: 2.7 events
  - ➔ IMB: 6.0 events
- Typical Simulation 5.2 events

Expect ~5 events for 5Mt and 5Mpc distance

Trigger sensitivity to distant SNe

N: required multiplicity of the events in 10sec



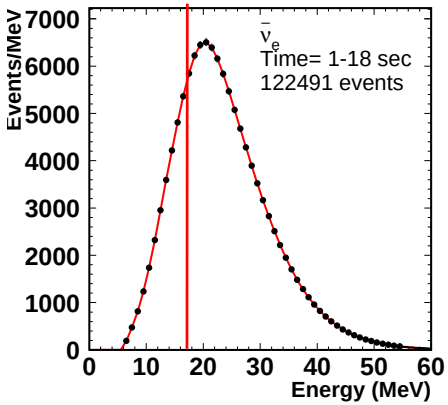
Background:

Most BG from single spallation ev.

➔ accidental coincidence

Select Eth > 18 MeV to remove spallation events

BG free measurement



signal loss:
~20% at most

No significance influence

Could detect SN almost every year

Galactic SN (10kpc)	***1.3M events***
Neutronization B	***2500 events***

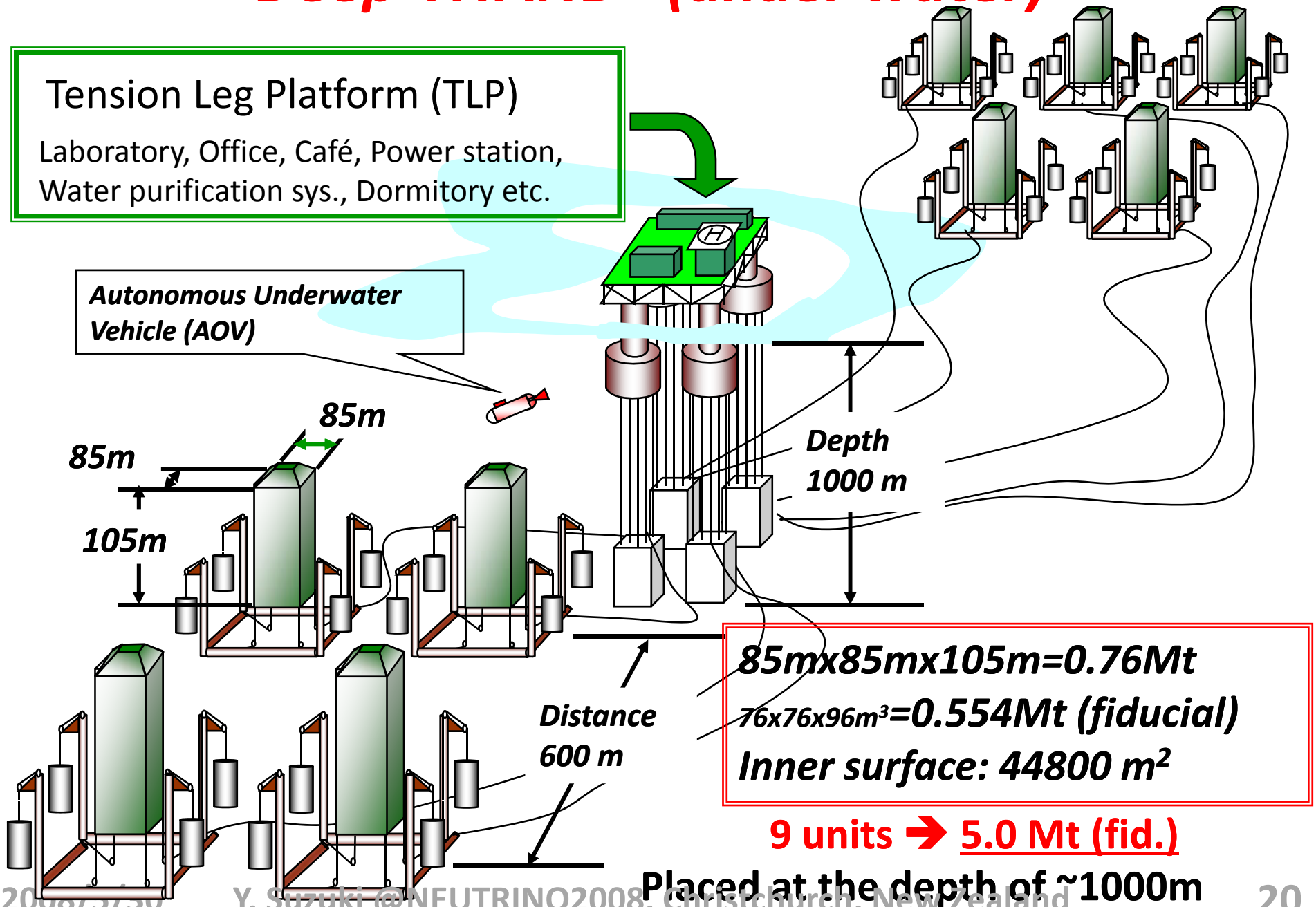
How does the 5Mt detector look like?

Requirements for the detector

1) Scalability: May start with 5 Mt (or maybe 1Mt)
2) Better to place > 700m depth (w.e.)
3) Low cost
4) Short construction time

- Underground?
  - OK Up to some level
    - Expansion may become difficult

Deep-TITAND (under water)



5 Mt Neutrino Oscillation Detector

- *Proton decay search ~10^{36}yr*
- *SN neutrino detection: ~1 every year*
  - *Reaches 5Mpc w/ ~5 events*

➔ *PD and SN really add the value to the experiment*

- *Precise atmospheric neutrino measurements*
- *Flexible location of the detector for a long baseline neutrino oscillation experiment*
- *Effective investment: accelerator or detector*
  - *More on detector*

➔ *possibility to find unexpected*

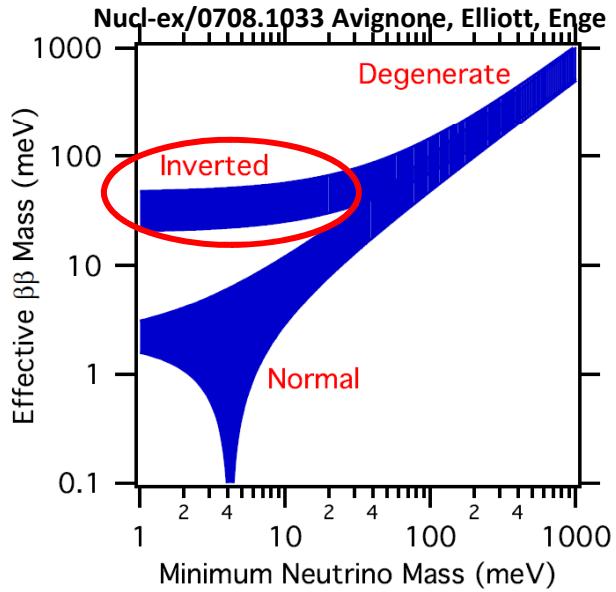
- *Many technical challenges*

➔ *Need to start R&D now for a detector of more than 20 year from now*

Double Beta Decay (DB) Experiments

The next 'Standard' neutrino-less double beta decay experiments

- Double beta decay is much important than Proton Decay (T. Yanagida)
- Aim to search for **30meV～50meV**
  - Cover the region for inverted mass hierarchy

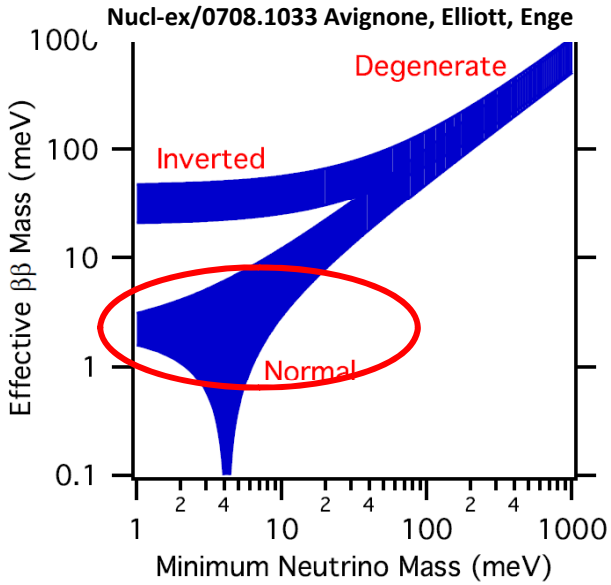


'Next' DB experiments

Experi-ments	Nucleus	Det.mass (kg)	Sensitivity (meV)	start (yr)
GERDA	^{76}Ge	15~100	780~30	2008~
SuperNEMO	^{82}Se	100	130~40	2012~
	^{150}Nd	100	70	2012~
CUORE	130Te	220	120~20	2012~
EXO-200	^{136}Xe	160	550~90	2007~
others				

An 'ultimate' experiment beyond the next

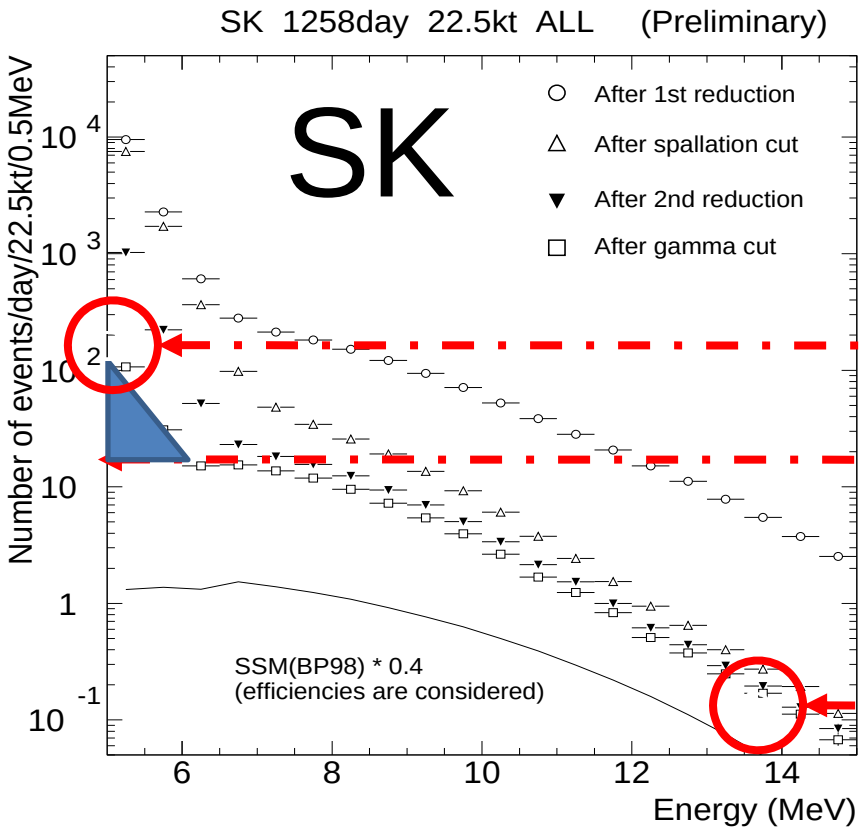
- Cover substantial region predicted for the normal mass hierarchy ➔ sensitivity < a few meV
  ~ a few x 10^{29} yr
  - **4 orders of magnitudes improvement !!! from the next gen. experiments**
- Larger mass (> x100):
  100kg ➔ **>10 ton**
- Lower BG (< x1/100)
  - Gerda, NEMO, Cuore : 10^{-3}/kg/keV/yr (3×10^{-6} /kg/keV/day (dru))



➔ **$<10^{-5}$/kg/keV/yr (10^{-9}~10^{-8} /kg/keV/day (dru))**

internal BG: U/Th < 10^{-16}g/g

Is it possible to achieve 10^{-9}~10^{-8} dru ?



~ 10^{-8} ev /day/keV/kg
(5 MeV)

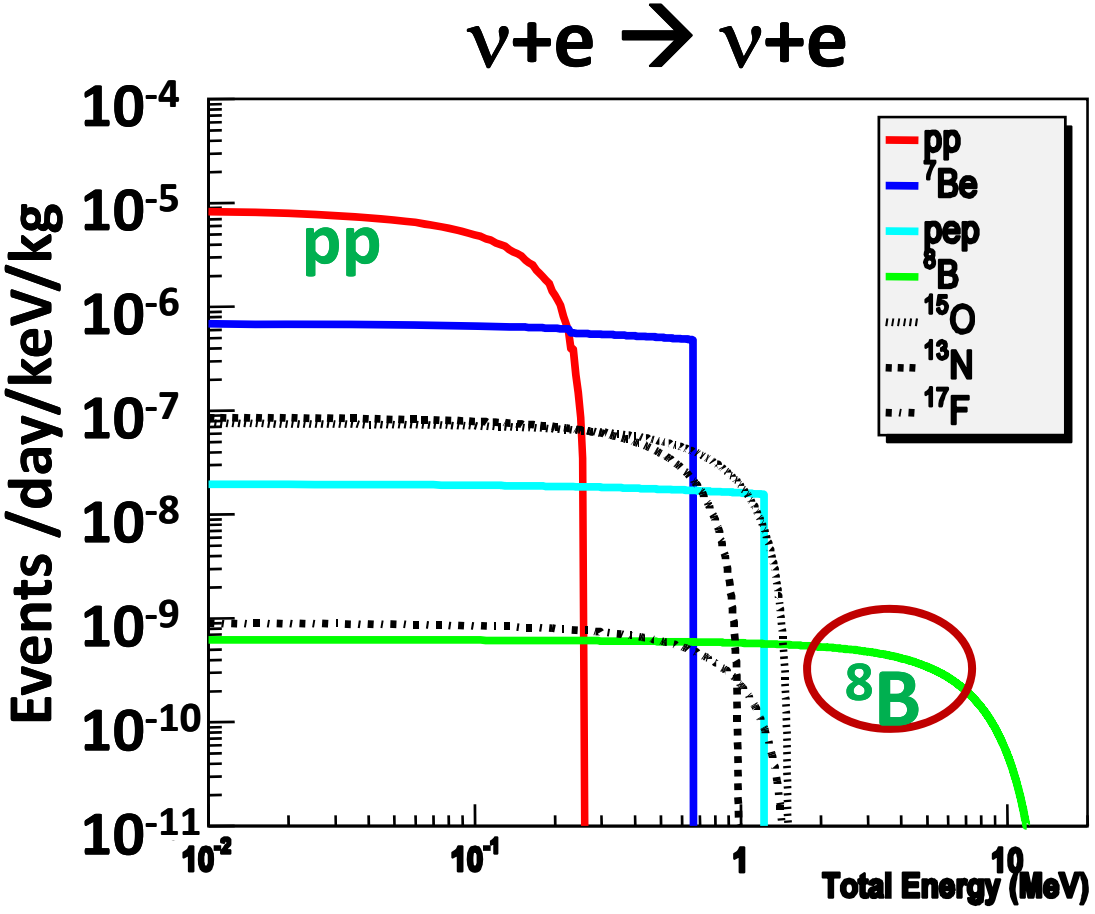
Remove Rn (214Bi tail)

➔ ~ 10^{-9} dru

~ 10^{-11} ev /day/keV/kg
(14 MeV)

10^{-9}: remaining BG ➔ spallation(CG), High energy gamma.
This is W.Ch. (w/poor resolution) and not DB experiment
➔ but tell you that 10^{-8}~10^{-9} dru is not completely crazy!!

Ultimate BG



1) 8B solar neutrinos:
➔ a few x10^{-10} dru
(@ a few MeV region)

2) 8B solar neutrinos are the ultimate BG. and you need to separate single and double electron events if you go beyond this point.

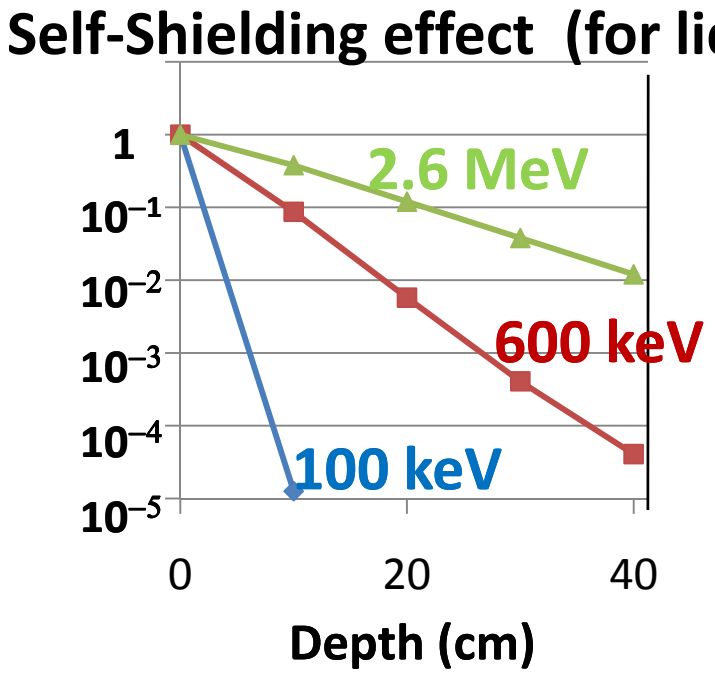
3) Enrichment is MUST to enhance the signal

In addition to those requirements, the 'ultimate' experiment (as my definition) must include other subjects

+ Dark Matter ➔ Possible discovery or precise study
+ Low Energy Solar Neutrinos (as a bread and butter subject)

- Many people have thought about this combination and partly done for the past years though the sensitivity was not high.
  – Good DB experiments → have given results on DM
- **This time: It is MUST, or you never get funded!**

Low energy is easier than DB region in the following sense



Double beta decay region

only 2 orders reduction

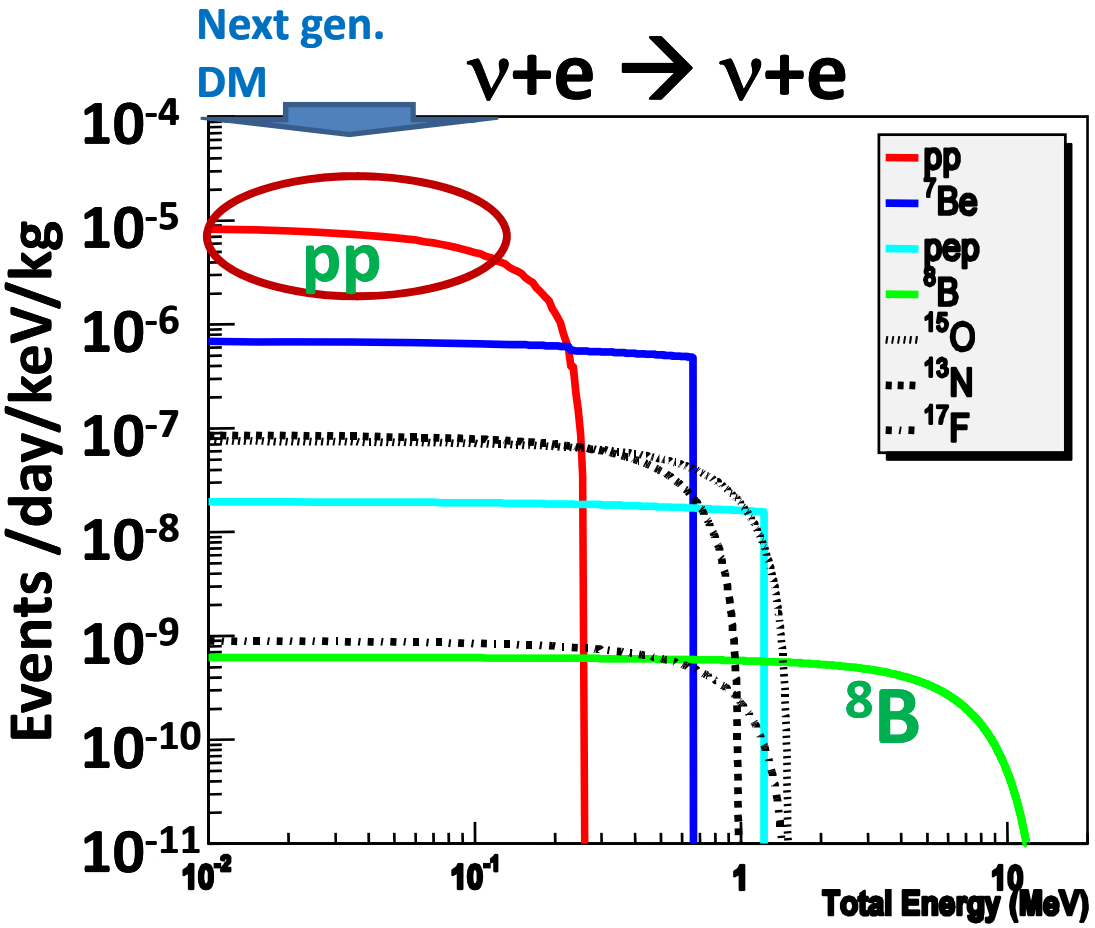
w/ 40cm depth

Low energy region (DM+pp)

>5 orders reduction

possible

Signals



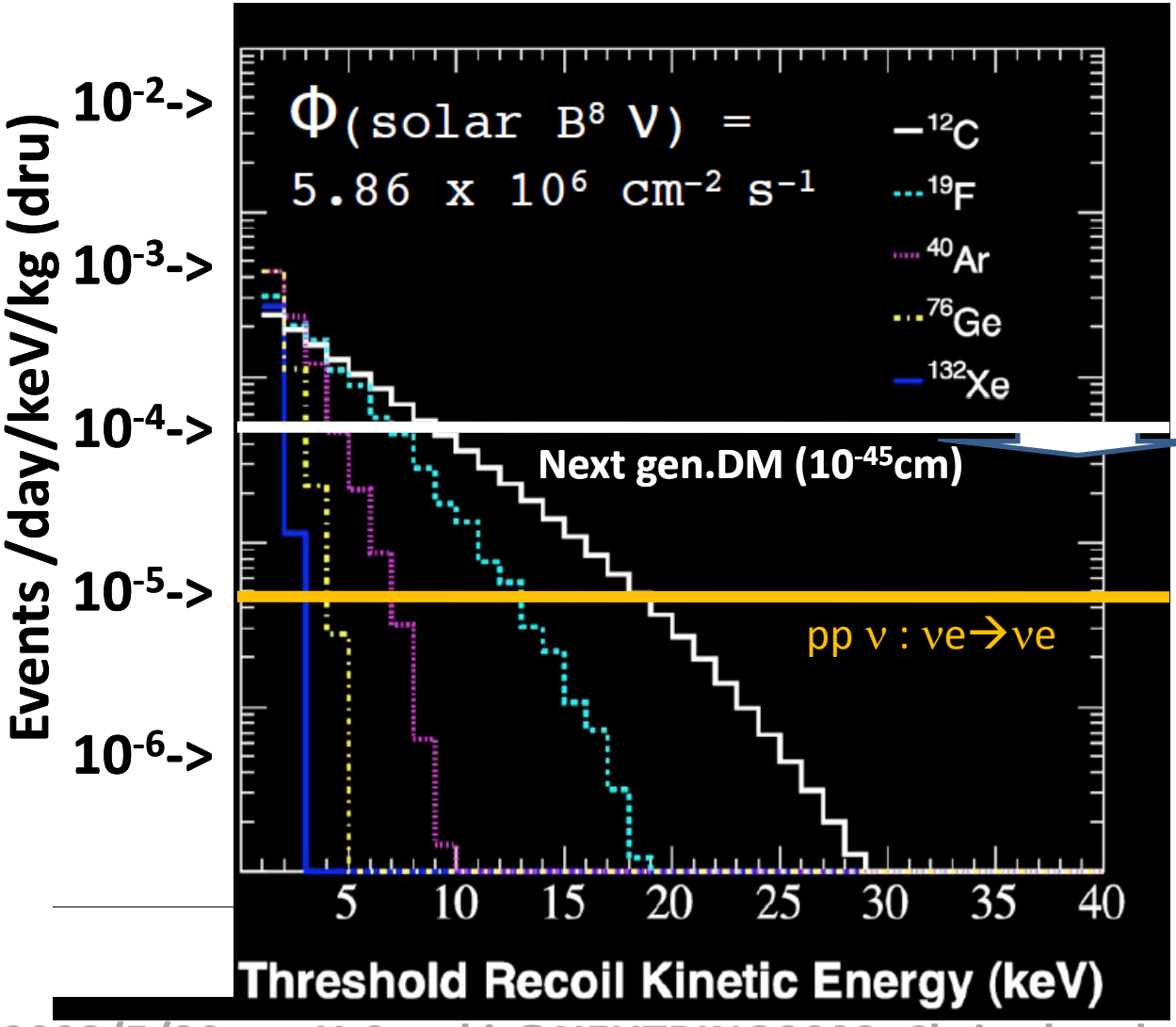
- pp-solar neutrinos:
  → ~10^{-5} dru @ <100keV

To see pp neutrinos
→ BG should be lower than
< 10^{-5} dru level

- We will be in <10^{-4} dru region for the next DM experiments:
  10^{-4} dru ←→ 10^{-45}cm^2 SI

We will be seeing solar pp-neutrinos relatively soon !!

Coherent scattering of ^{8}B solar neutrinos (J. Monroe)



1) Integrated histogram
2) high A ➔ sharp in lowe
   ex. Xe <2keV @10^{-4} dru
   Ge <3keV
   Ar <5keV

- high A may be OK
  ? Resolution ??
- Careful for gas chamber
  using 'C' or 'F'

BG in low energy

Requirement for BG is modest

External → self-shields work, water for neutron

Internal → 10^{-16}g/g (U/Th) (same as DB requirements)

Watch: Cosmo-genic, neutron BG from Detector, and so on.

But, mutual obstructive among the signals:

1) DM ←→ pp neutrinos (νe→νe)

- Electron/NR separation

[watch coherent scattering of 8B neutrinos: irreducible]

2) pp neutrinos ←→2νDB

if 2νDB is shorter than some level,

- Single and double electron discrimination
- depletion of DB isotope

→ two different detector configurations may be a choice(DB & DM/pp)

‘In Reality’

Low BG PMT development

- We have achieved two order of magnitude improvement for the last **5 years**:

  (Primarily for DM search (Lq.Xenon))

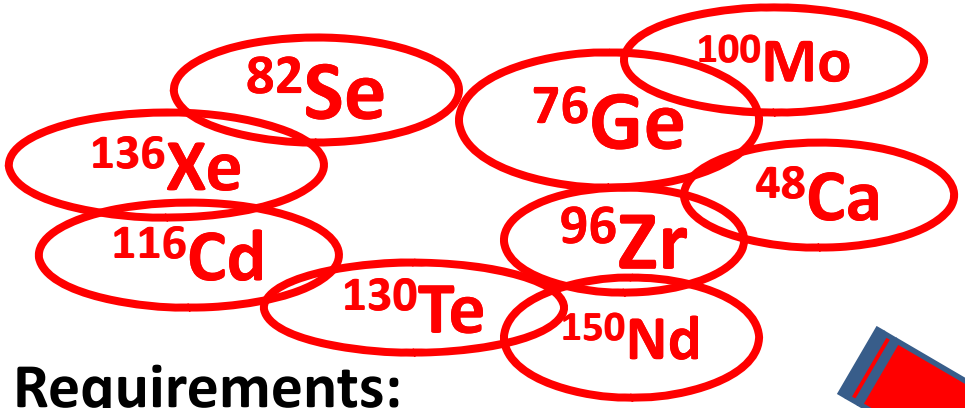
  – U=180mBq, Th=69mBq

  ➔ ~1mBq (including the base)

With 30 cm self-shield (70% photo-coverage)
➔ 10^{-5}~10^{-4} dru @2. 47 MeV
<10^{-5} dru @ < 100keV
[close to : pp-ν rquirement (10^{-6} dru)]
But PMT cannot be used as a major device as it is for ‘Ultimte’ DB experiments (10^{-8} dru)
(Typical next DB: 100kg 10^{-6}~10^{-5})

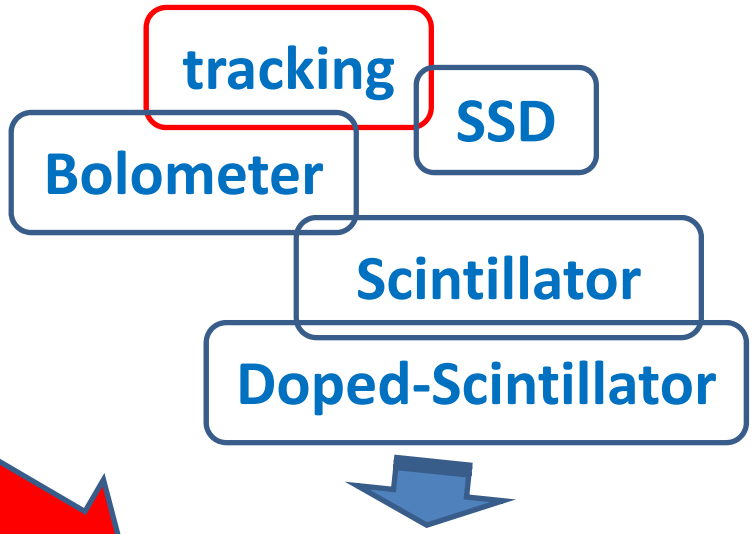
Further improvement is very challenging !

Choice of material and technology



Requirements:

Good energy resolution, Enrichment, Reduce BG (U/Th, γ, neutrons), Particle Id (e, 2e, γ, α, NR), Reduce Cosmogenic BG, Good Vertex Reconstruction, Material purification, less PMTs, Inexpensive, Availability



10ton
10^{-9}~$^{-8}$ dru
@ a few MeV

+

10^{-6} dru
@ <500keV

What is your choice?

First, I thought I would say my preference, but I have decided not to mention that.

Many Many technical challenges !
Get R&D started now

Summary: Situation and What to do

- ‘Ultimate Detectors’ (Multi-Mt and DB) beyond the next generation detectors will be the ‘only one’ experiment in the world, and must have various other opportunities for including bread and butter subjects
  - Size of the detector
  - Many technical challenges
  - Problems of the world economy
    - Increasing material price
    - sub-prime problem
  - Head wind
    - Public Society wants innovation, not basic science

➔ It cannot be supported by a single country

MUST be an International Collaboration

➔ Start R&D right away

How we can establish the world wide efforts for the 'only one' experiment

➔ Please do not make a political framework first

➔ Start R&D from bottom up

1) Exchange of information

2) Exchange of technology

3) Exchange of people

(ex. Exchange Program: Kamioka-SNO)

→ trust each other

→ can naturally form an international working group

Dream is power of progress

Prepare for the future

Thank you for your attention