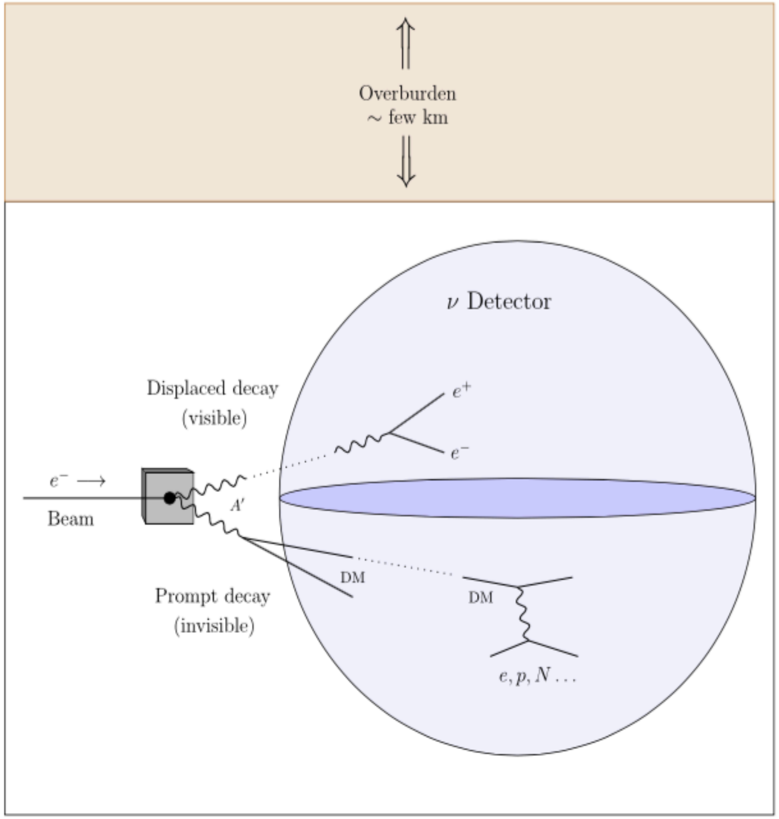
keV-MeV scale dark matter deep underground – Izaguirre et al. PRD92, 095014 (2015)

Motivated by a proposal by Pospelov's group.

- 100MeV 1MW electron accelerator coupled to large detector for dark photon search.
- What about going to a little lower version of this proposal ?

We should identify needs for new underground laboratory at Handuk for future experiments.

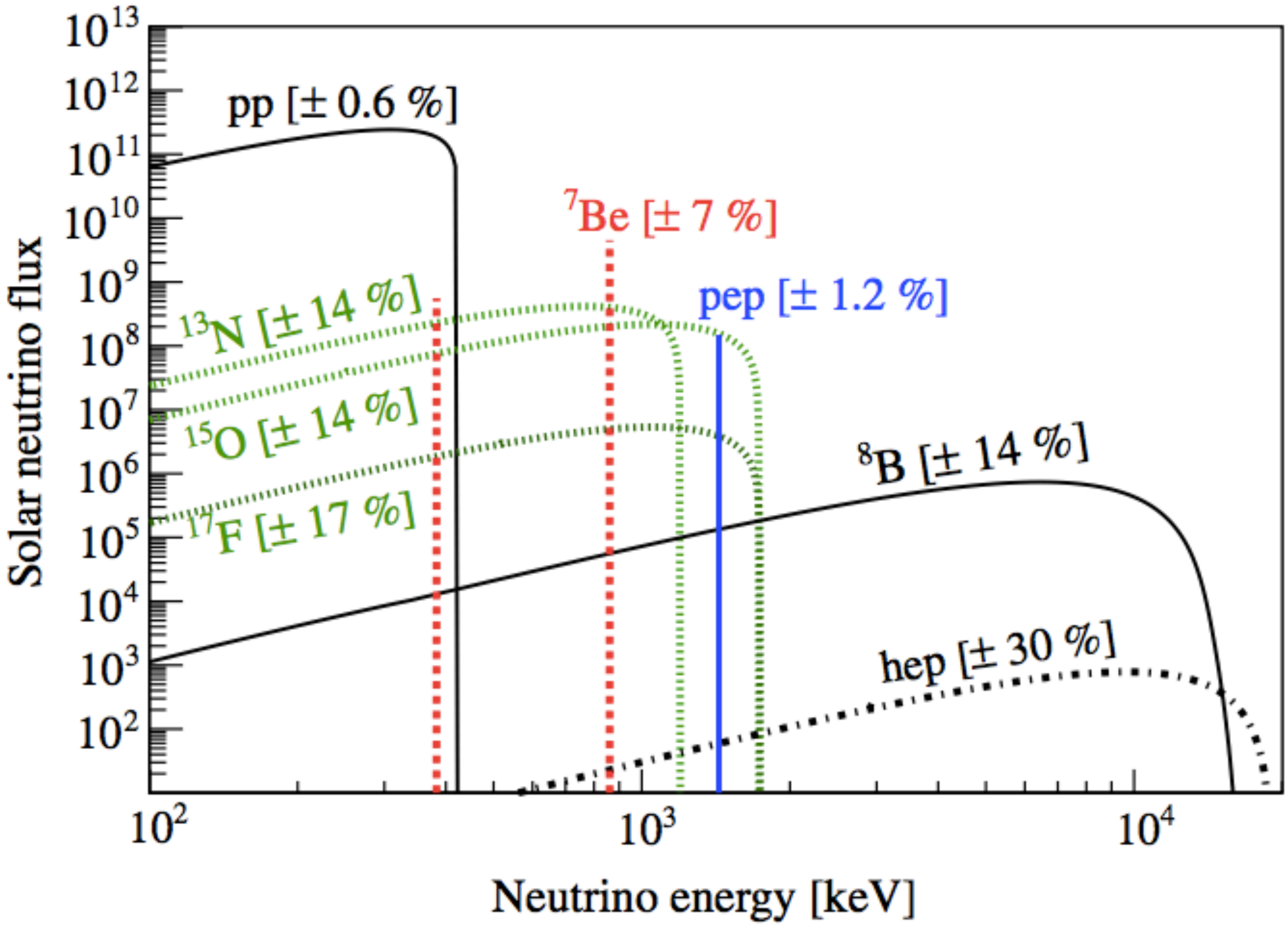


Multi-purpose Large (~kT) Liquid Scintillator

1. Dark Photon Search
2. Precision PP neutrino detection
3. Double beta decay

Precision pp neutrino detection

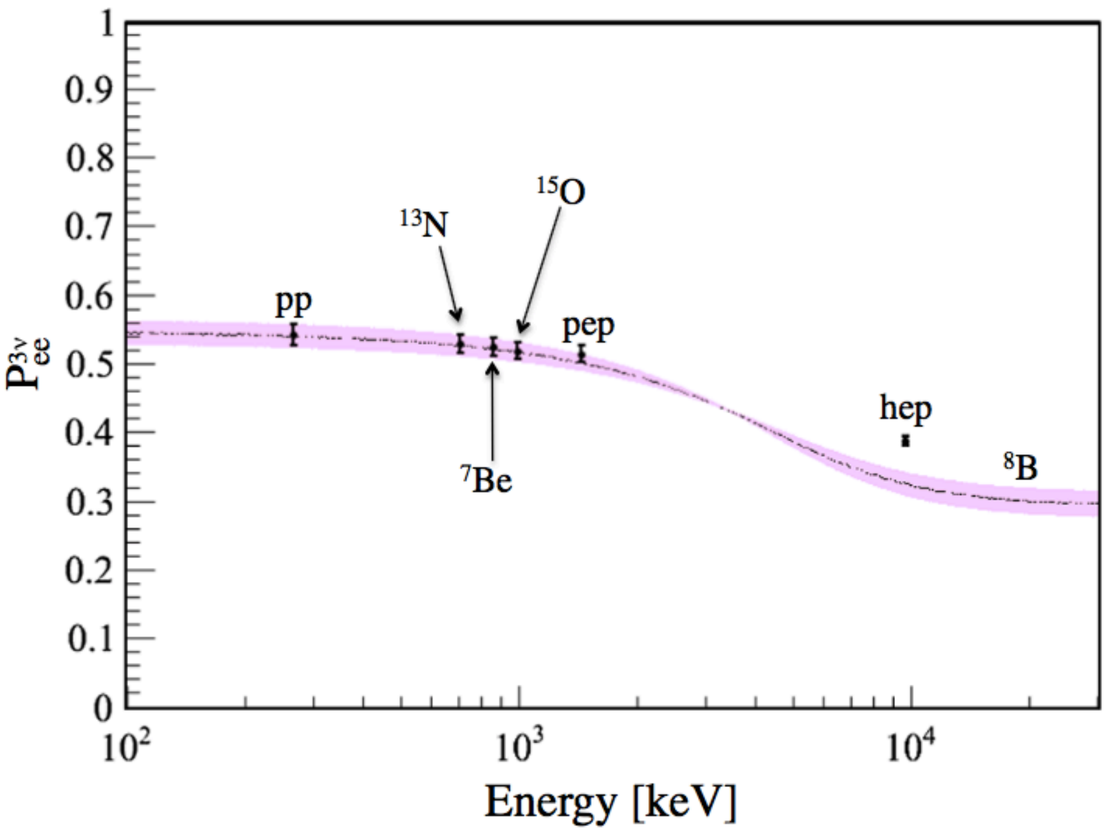
Bellini et al., PRD89, 112007 (2014)



MSW effect

$$P_{ee}^{3\nu} = \frac{1}{2}cos^4\theta_{13}(1 + cos2\theta_{12}^M cos2\theta_{12}) \qquad cos2\theta_{12}^M = \frac{cos2\theta_{12} - \beta}{\sqrt{(cos2\theta_{12} - \beta)^2 + sin^2 2\theta_{12}}}$$

$$\beta = \frac{2\sqrt{2}G_F cos^2\theta_{13} n_e E_\nu}{\Delta m_{12}^2}$$



Neutrinos from different reactions are produced in the Sun at different radii and the electron density in the Sun decreases with increasing radius. This means that P for a given neutrino energy is expected to depend on the neutrino species under consideration.

Borexino detector

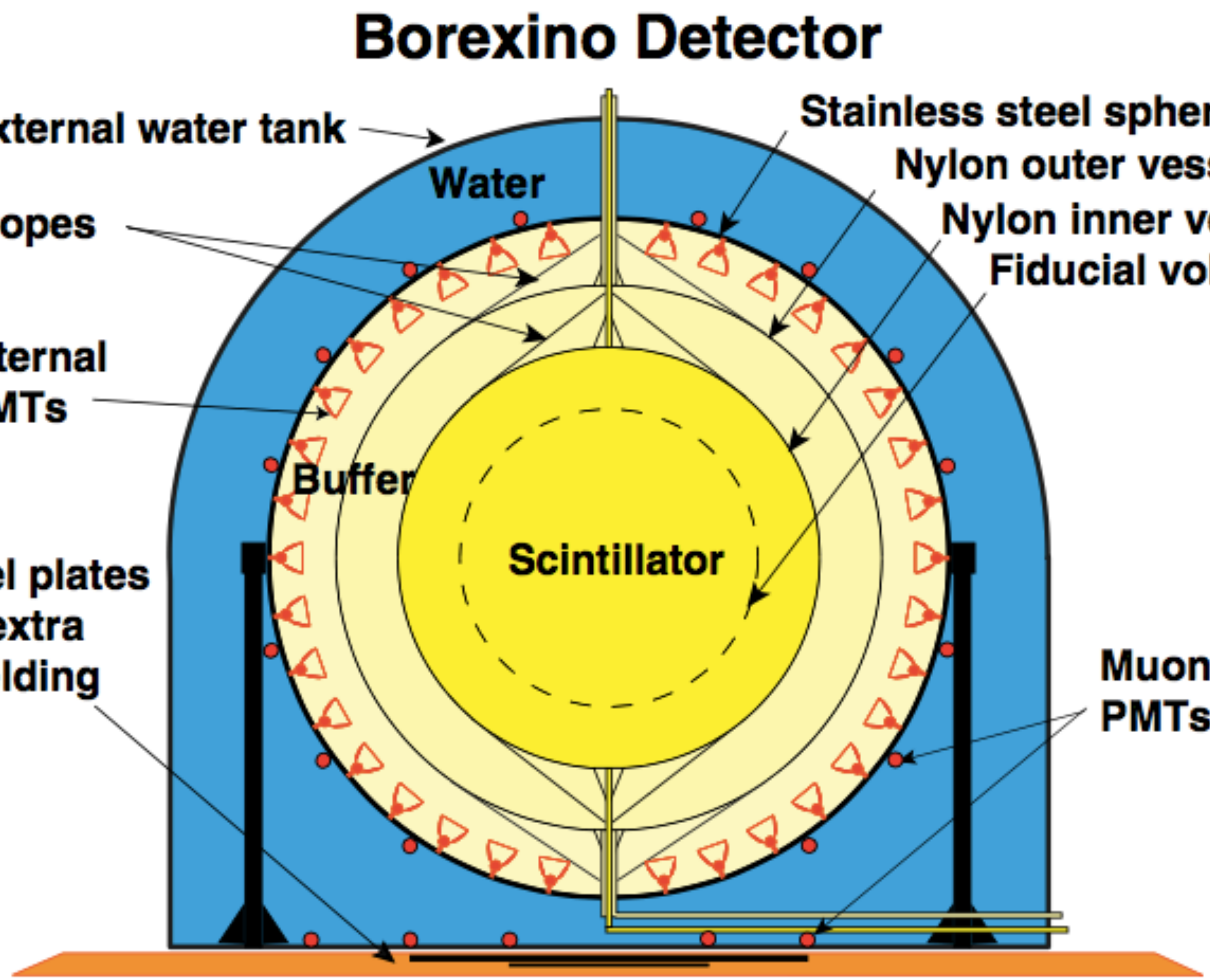
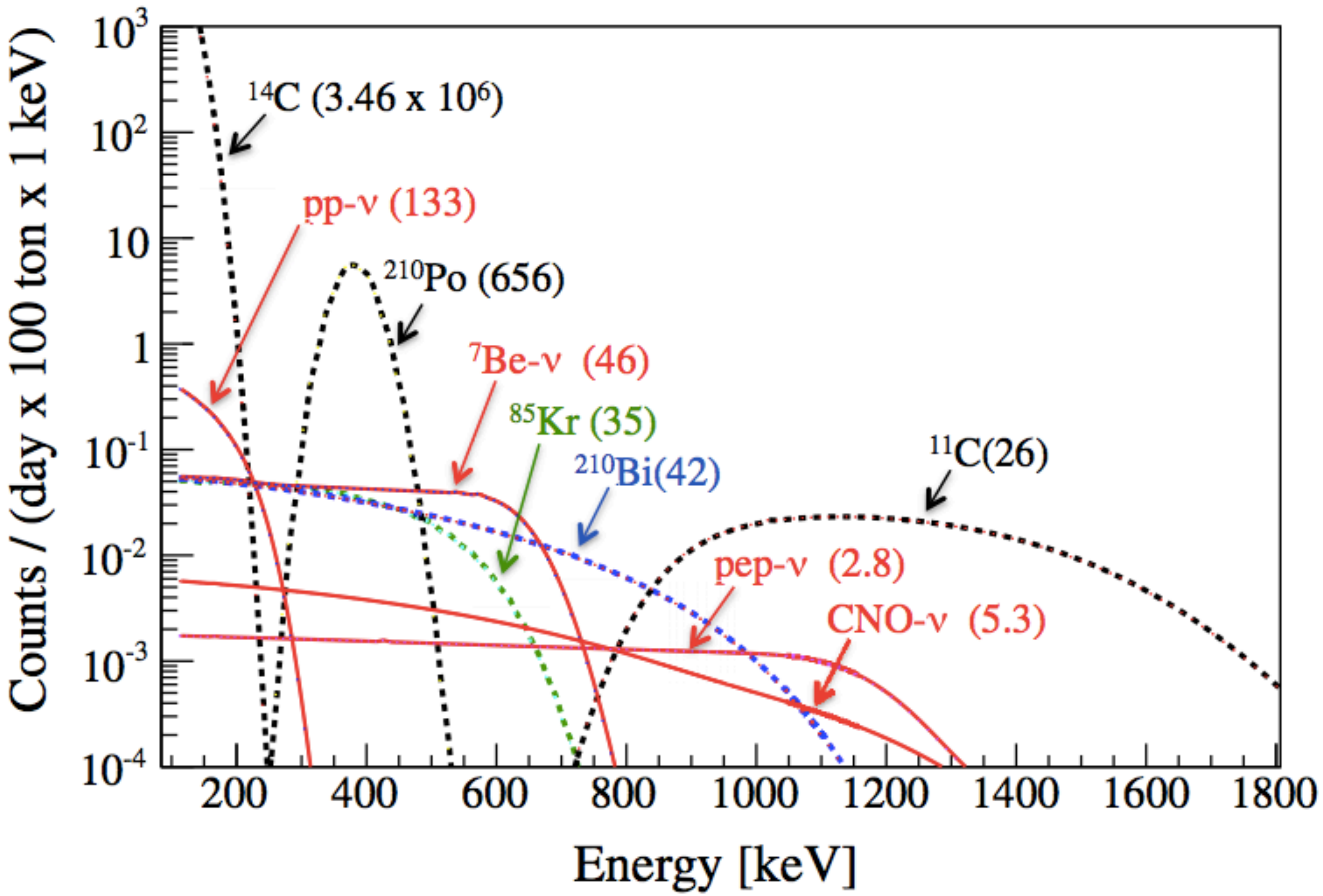


FIG. 2 (color online). The schematic view of the Borexino detector.

Solar neutrinos and backgrounds

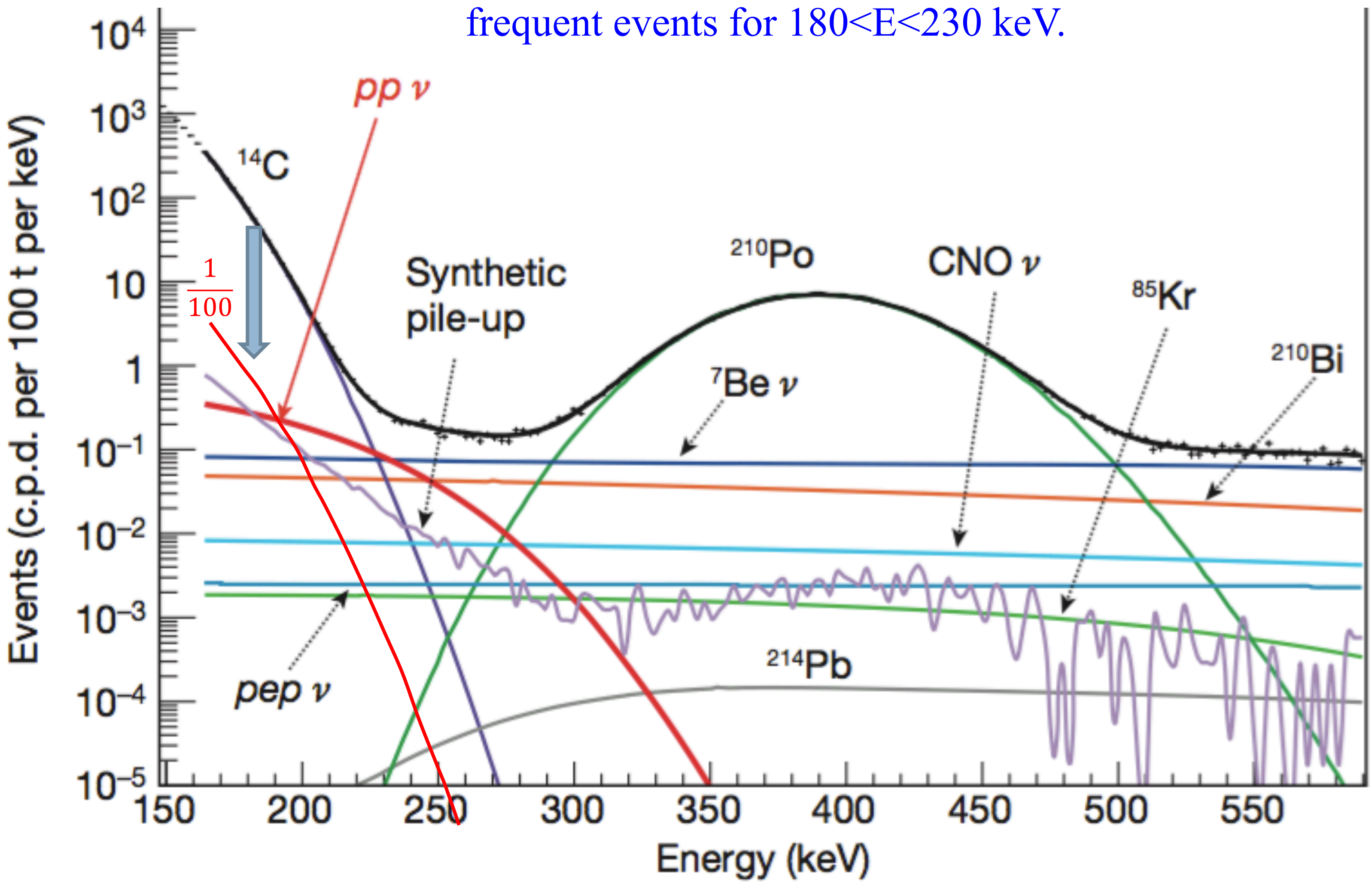
At low energy (E<200 keV), ^{14}C completely dominates over solar neutrinos.



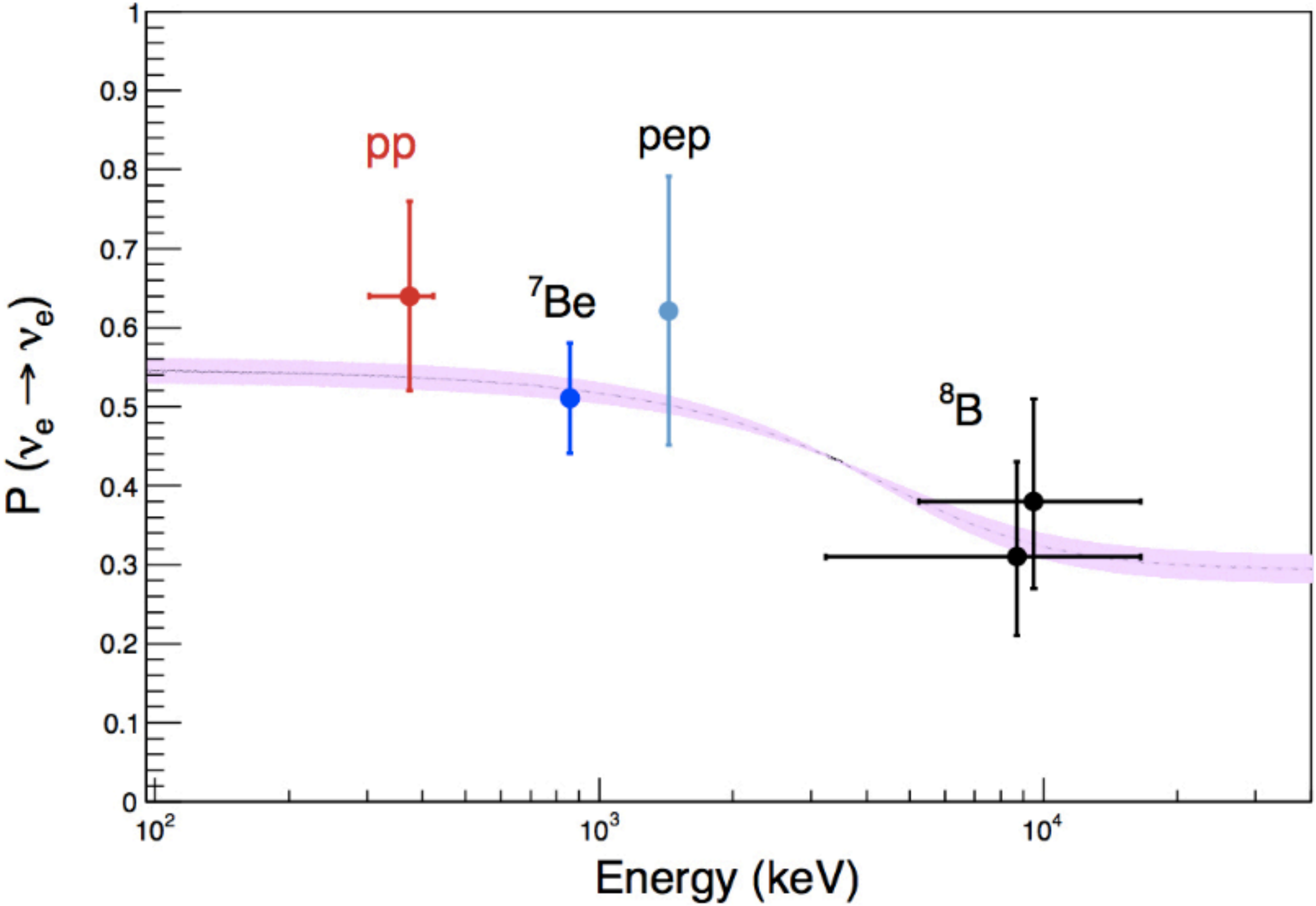
Borexino pp neutrino measurement

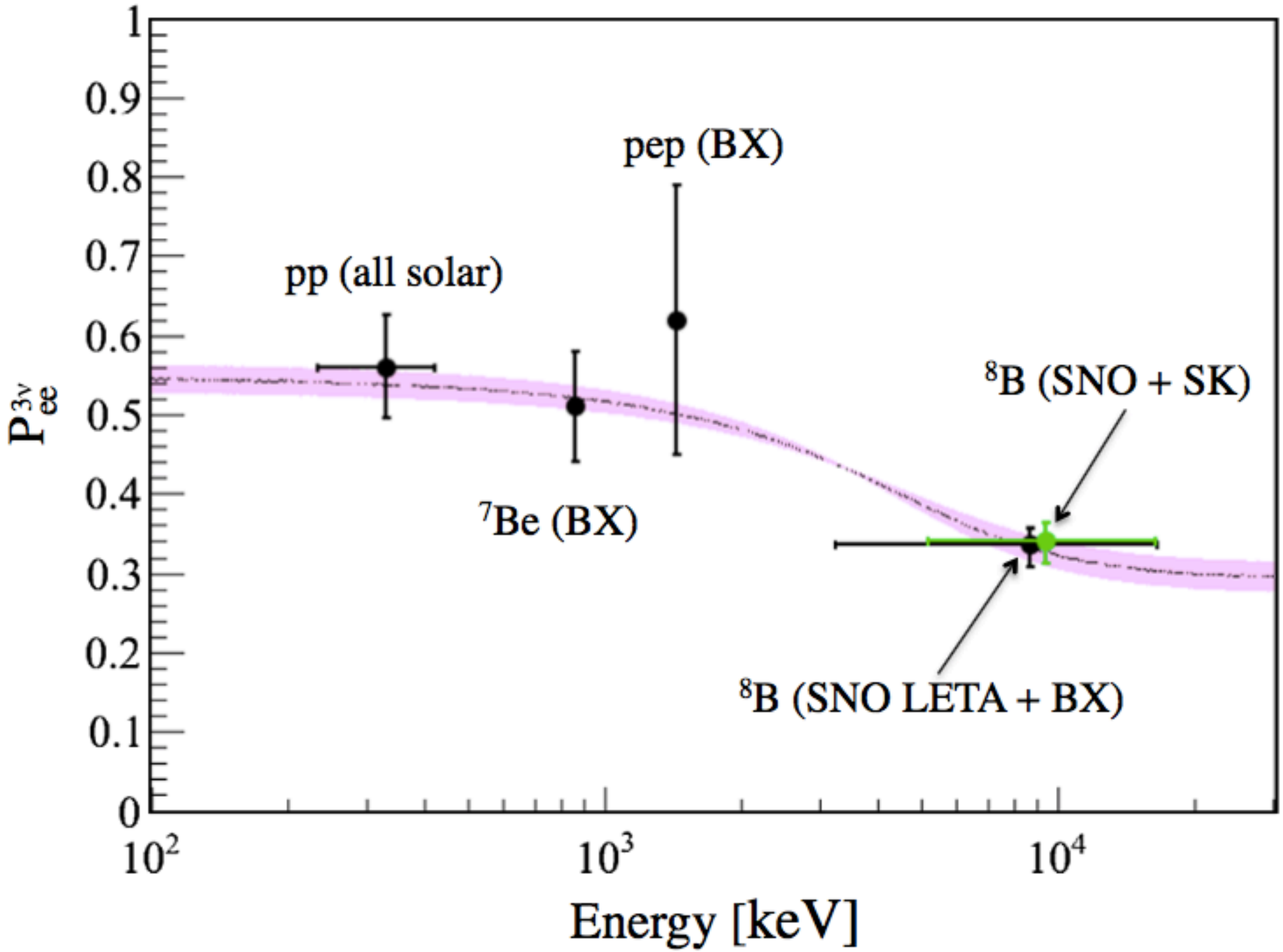
The solar *pp* neutrino interaction rate measured by Borexino is 144 ± 13 (stat.) ± 10 (syst.) c.p.d. per 100 t. The stability and robustness of the

If ^{14}C is reduced by a factor of 100, pp neutrino is most frequent events for 180<E<230 keV.



All Borexino measurements




pep (BX)
pp (all solar)
7Be (BX)
8B (SNO + SK)
8B (SNO LETA + BX)
$P_{ee}^{3\nu}$
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
10^2
10^3
10^4
Energy [keV]

Can we reduce ^{14}C ?

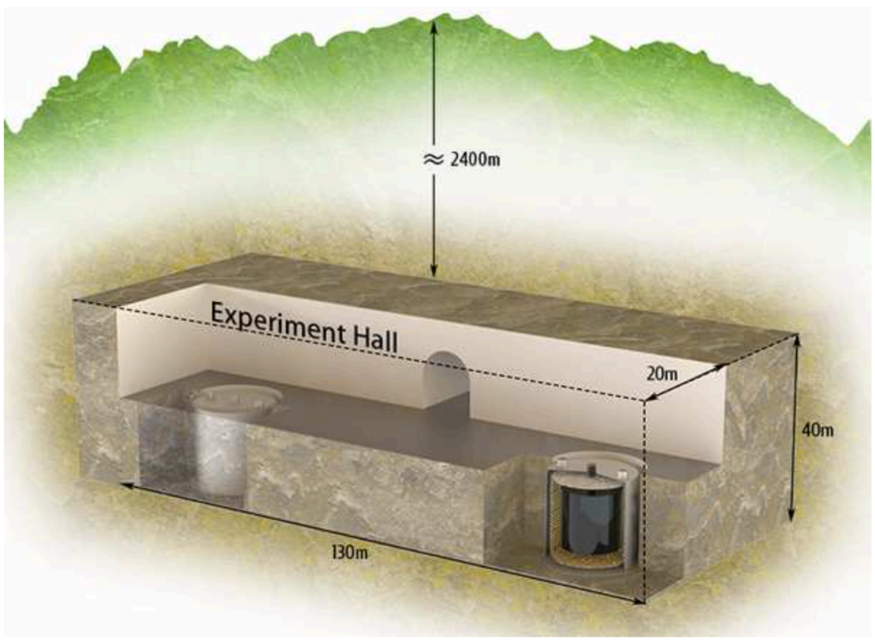
For pp neutrinos with a few % measurement, we need to reduce ^{14}C.

For dark photon measurement at underground less than 200 keV, need to reduce ^{14}C.

Letter of Intent:

Jinping Neutrino Experiment

John F. Beacom[1], Shaomin Chen[*2], Jianping Cheng[2], Sayed N. Doustimotlagh[2], Yuanning Gao[2], Guanghua Gong[2], Hui Gong[2], Lei Guo[2], Ran Han[3] , Hong-Jian He[2], Xingtao Huang[4] , Jianmin Li[2], Jin Li[2], Mohan Li[2], Xueqian Li[5] , Wei Liao[6] , Guey-Lin Lin[7] , Zuowei Liu[2], William McDonough[8] , Jian Tang[10], Linyan Wan[2], Yuanqing Wang[9] , Zhe Wang[†2], Zongyi Wang[9] , Hanyu Wei[2], Yufei Xi[11], Ye Xu[12], Xun-Jie Xu[2], Zhenwei Yang[2], Chunfa Yao[13], Minfang Yeh[14], Qian Yue[2], Liming Zhang[2], Yang Zhang[2], Zhihong Zhao[9] , Yangheng Zheng[15], Xiang Zhou[16], Xianglei Zhu[2], and Kai Zuber[17]



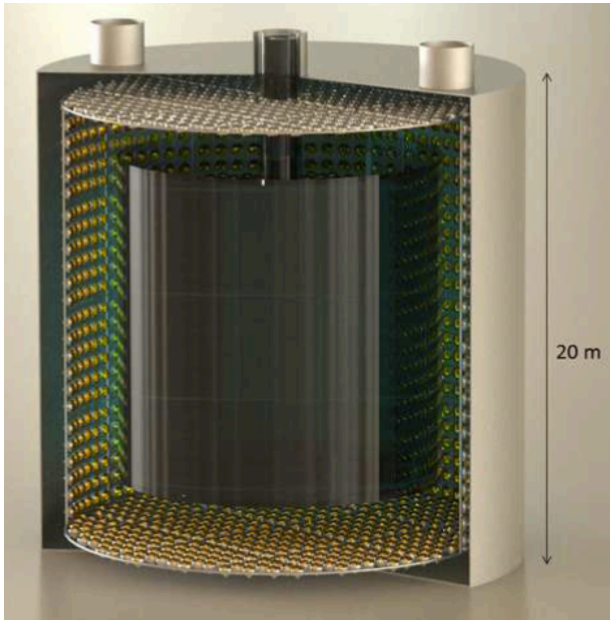
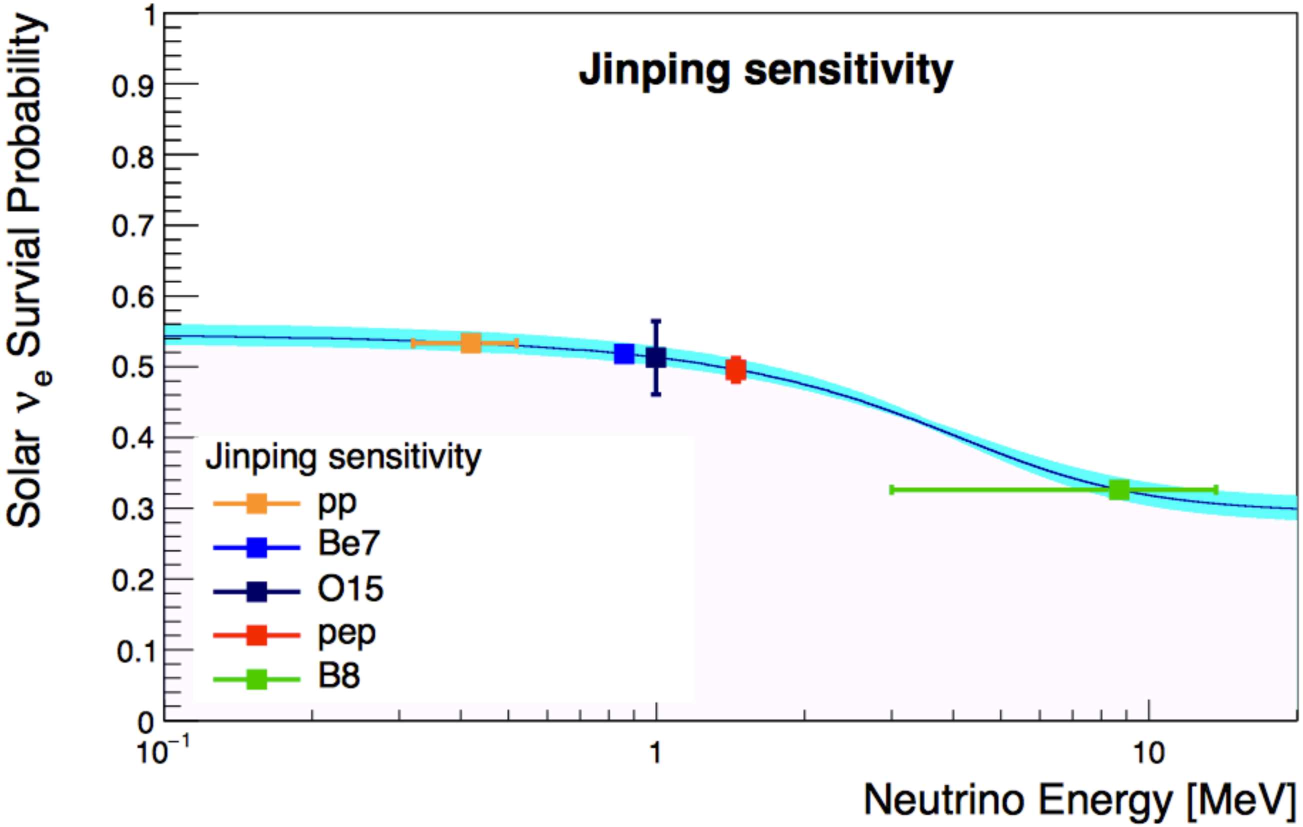


Figure 2.1: (Color online) Experimental hall layout.


Jinping sensitivity
Solar ν_e Survial Probability
Neutrino Energy [MeV]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10^{-1}
1
10
Jinping sensitivity
pp
Be7
O15
pep
B8

1. Germanium	^{76}Ge
2. Low temperature crystal	^{100}Mo, ^{130}Te
3. Liquid scintillator doped	^{136}Xe, ^{130}Te
4. Tracking	^{82}Se
5. Liquid TPC	^{136}Xe
6. High Pressure Gas TPC	^{136}Xe

KAMLand- Xen

- 13ton Xe-LS, D=3.08m, 25micrometer thick nylon film.
- Xe-LS, 82% decane, 18% pseudocumene, 2.7g/liter PPO+2.52% xenon
- Light output of Xe-LS is 3% lower than LS.
- 1kton OD, D=13m
- 3.2kton water cherenkov veto.

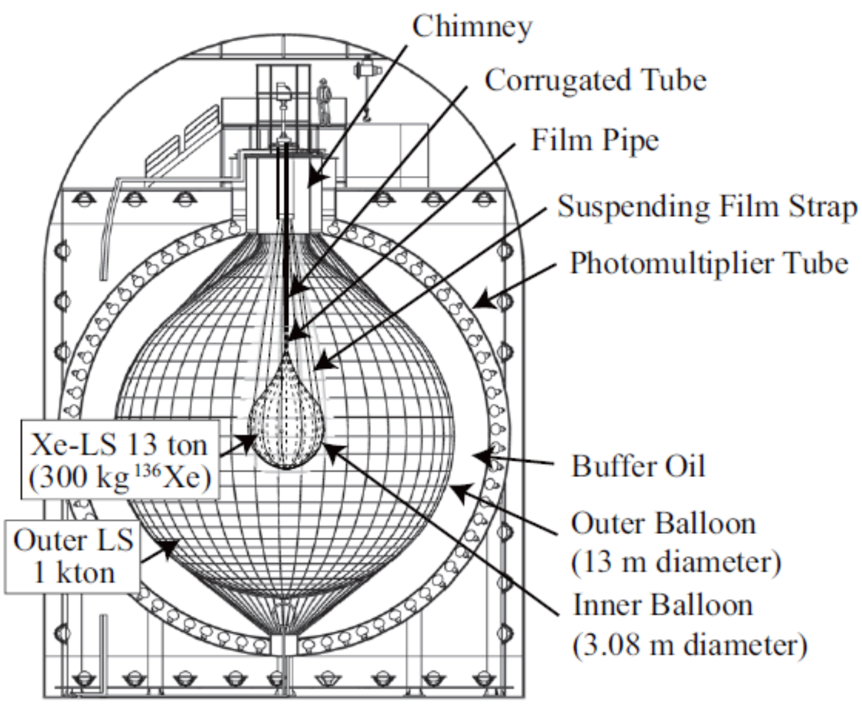
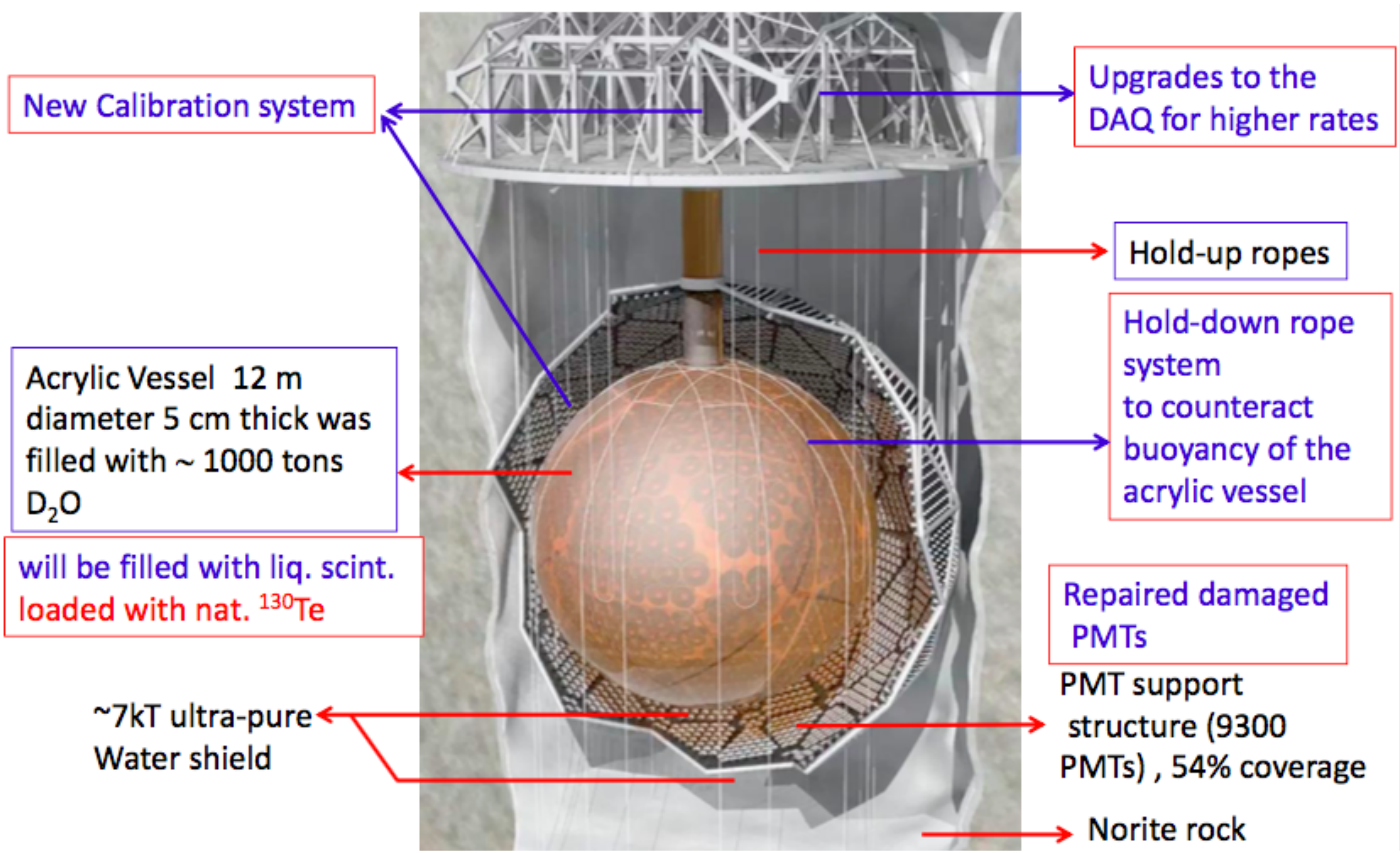


FIG. 1: Schematic diagram of the KamLAND-Zen detector.

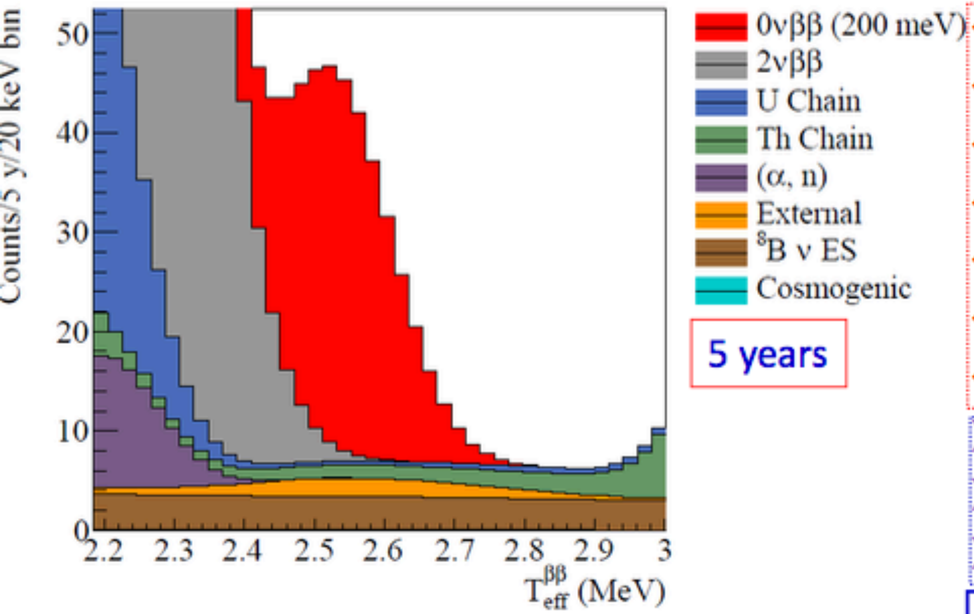
- Vertex resolution 15cm/sqrt(E(MeV))
- 6.6%/sqrt(E(MeV)) @2.6MeV
- 4.21% @ 2.458MeV

- 77.6 days, 129kg of ^{136}Xe
- T(0nu)>5.7x10^{24} w/ 90% CL
- Background rate
  = 10 events/50keV/129kg/77.6days
  =0.0073 /keV/kg/year

SNO→SNO+

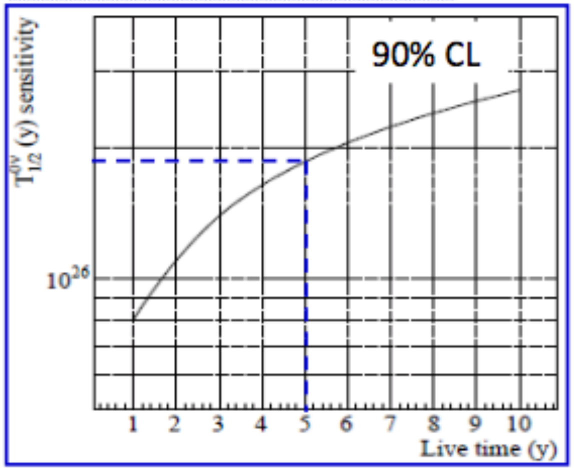

New Calibration system
Upgrades to the DAQ for higher rates
Hold-up ropes
Hold-down rope system to counteract buoyancy of the acrylic vessel
Acrylic Vessel 12 m diameter 5 cm thick was filled with ~ 1000 tons D_2O
will be filled with liq. scint. loaded with nat. ^{130}Te
Repaired damaged PMTs
PMT support structure (9300 PMTs) , 54% coverage
~7kT ultra-pure Water shield
Norite rock

SNO+ 0νββ Spectrum



- LAB+PPO(2g/L) +bisMSB(15mg/L)
- 1300 kg ^{130}Te (0.5% by mass)
- 3.5 m (20%) FV cut
- 390 Nhits/ MeV (~4% ΔE)
- > 99.9% efficient ^{214}BiPo tag
- > 98% efficient of ^{212}BiPo tag
- Negligible cosmogenic isotopes

- NME = 4.03 (IBM-2)
- gA = 1.269
- G = 3.69 × 10^{-14} yr^{-1}



	1 year	5 years
$T_{1/2}$ [10^{26} yr]	0.80	1.94
mbb [meV]	75.2	38-92*

*NME range : 2.06 (ISM) – 4.98 (EDF)

Improvements

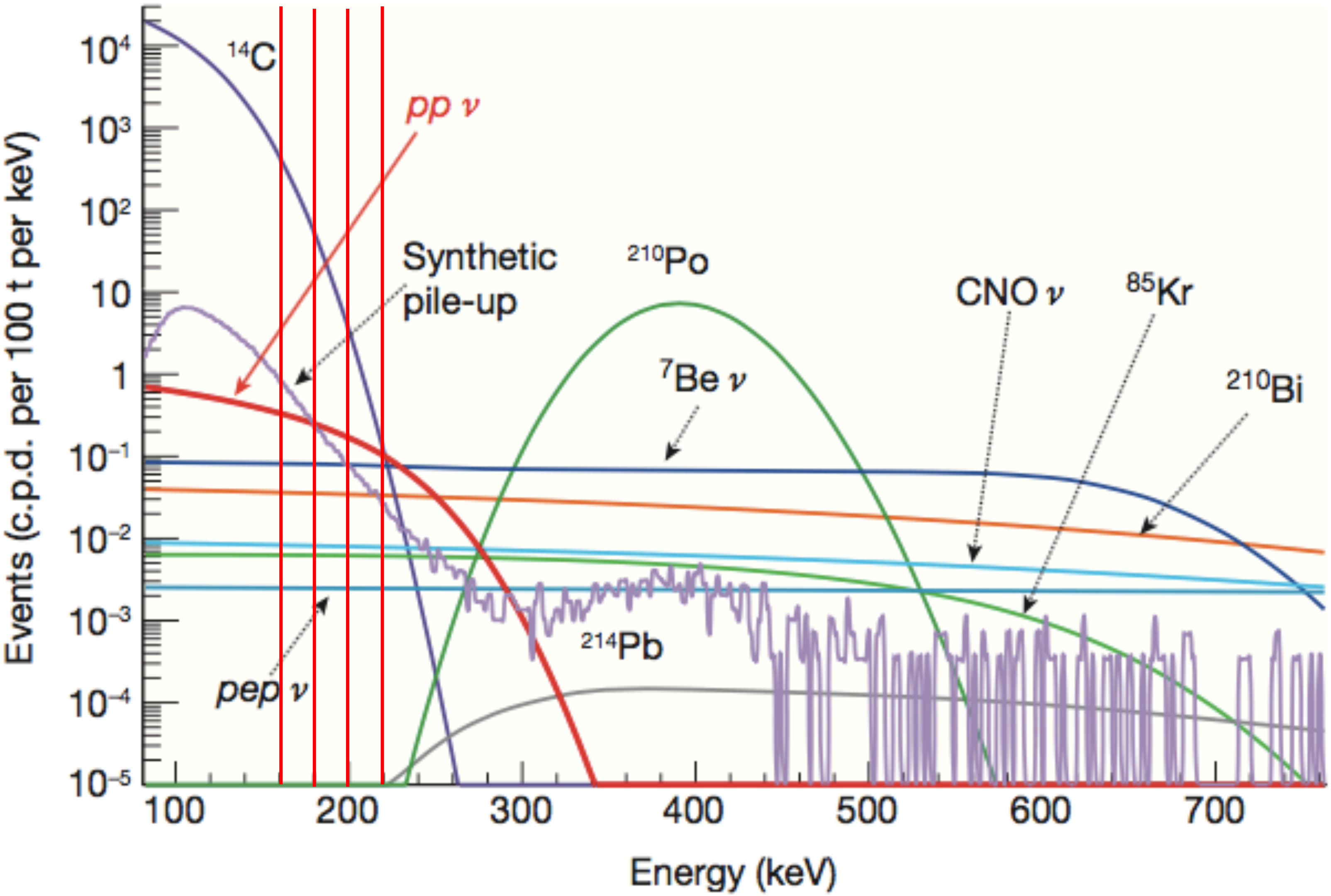
1. Backgrounds : Need to estimate realistic
2. Resolution : could reach 4 % FWHM
3. Multi ton of isotopes : 5 ton ^{130}Te possible ?

Summary

- Size :
  1. Dark Photon — Larger is better
  2. Solar neutrino — ~ 1 kton
  3. Double beta : — ~ 1 kton

- Resolution :
  1. Dark photon — E>50 keV
  2. Solar neutrino — E>150 keV
  3. Double beta — 4% FWHM possible

- Double beta : Multi ton of isotopes : 5 ton ^{130}Te possible ?



^{14}C
pp ν
Synthetic
pile-up
^{210}Po
CNO ν
^{85}Kr
^{7}Be ν
^{210}Bi
^{214}Pb
pep ν
Events (c.p.d. per 100 t per keV)
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
100
200
300
400
500
600
700
Energy (keV)

C-14 backgrounds for LS

For Borexino, the data throughput is dominated by ^{14}C, the largest source of trigger rate; a concentration of about 3×10^{-18}g/g corresponds to 250Bq in the active volume.

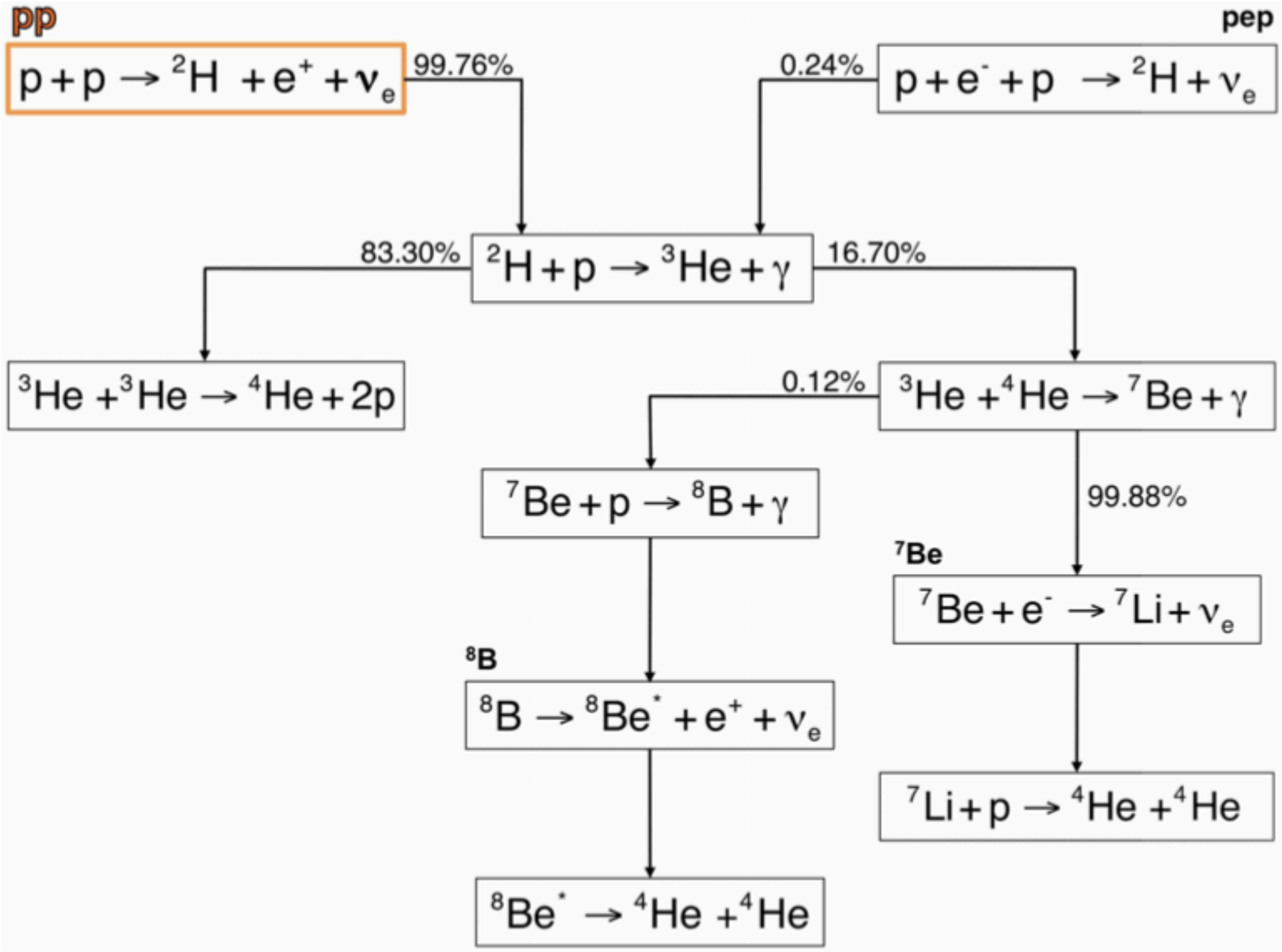
- (1×10^{15}g/kg)/14*6e23*0.693/(5730*365days)=6*0.693/5730/365e8/kg/day=199/kg/day =2.3Hz/ton
- Q=156.5 keV
- For JUNO, 200*20e6/86400=4.6e4/sec

1. $^{17}O(n,a)^{14}C$, 0.038%
2. $^{14}N(n,p)^{14}C$
3. $^{13}C(n,g)^{14}C$, 1.11%
4. $^{11}B(a,n)^{14}C$

TABLE II. The solar neutrino fluxes Φ_ν calculated with the high-metallicity standard solar model (GS98) [2], the ones obtained with the low-metallicity model (AGSS09) [19], and the corresponding expected ν-interaction rates R_ν in Borexino. The fluxes are given in units of 10^{10}(*pp*), 10^9 (^{7}Be), 10^8 (*pep*, ^{13}N, ^{15}O), and 10^6 (^{8}B, ^{17}F). The CNO flux is the sum of the ^{13}N, ^{15}O, and ^{17}F fluxes. The rate calculations are based on Eq. (3). The last column lists some of the relevant background components in the energy region of interest of a given ν species; see Sec. XI C for a discussion about them.

Solar-ν	Φ_ν(GS98) high metallicity [cm^{-2} s^{-1}]	Φ_ν(AGSS09) low metallicity [cm^{-2} s^{-1}]	R_ν(GS98) high metallicity [cpd/100 ton]	R_ν(AGSS09)low metallicity [cpd/100 ton]	Main background
pp	$5.98\ (1 \pm 0.006)$	$6.03\ (1 \pm 0.006)$	130.8 ± 2.4	131.9 ± 2.4	^{14}C
^{7}Be* (384 keV)	$0.53\ (1 \pm 0.07)$	$0.48\ (1 \pm 0.07)$	1.90 ± 0.14	1.73 ± 0.12	^{85}Kr, ^{210}Bi
^{7}Be* (862 keV)	$4.47\ (1 \pm 0.07)$	$4.08\ (1 \pm 0.07)$	46.48 ± 3.35	42.39 ± 3.05	^{85}Kr, ^{210}Bi
pep	$1.44\ (1 \pm 0.012)$	$1.47\ (1 \pm 0.012)$	2.73 ± 0.05	2.79 ± 0.06	^{11}C, ^{210}Bi
^{13}N	$2.96\ (1 \pm 0.14)$	$2.17\ (1 \pm 0.14)$	2.42 ± 0.34	1.78 ± 0.23	
^{15}O	$2.23\ (1 \pm 0.15)$	$1.56\ (1 \pm 0.15)$	2.75 ± 0.42	1.92 ± 0.29	
^{17}F	$5.52\ (1 \pm 0.17)$	$3.40\ (1 \pm 0.16)$	0.068 ± 0.012	0.042 ± 0.007	
CNO	$5.24\ (1 \pm 0.21)$	$3.76\ (1 \pm 0.21)$	5.24 ± 0.54	3.74 ± 0.37	^{11}C, ^{210}Bi
^{8}B	$5.58\ (1 \pm 0.14)$	$4.59\ (1 \pm 0.14)$	0.44 ± 0.07	0.37 ± 0.05	^{208}Tl, ext γ

*The production branching ratios of the 384 and 862 keV ^{7}Be-ν lines are 0.1052 and 0.8948, respectively. The respective ratio of interaction rates in Borexino is 3.9:96.1.

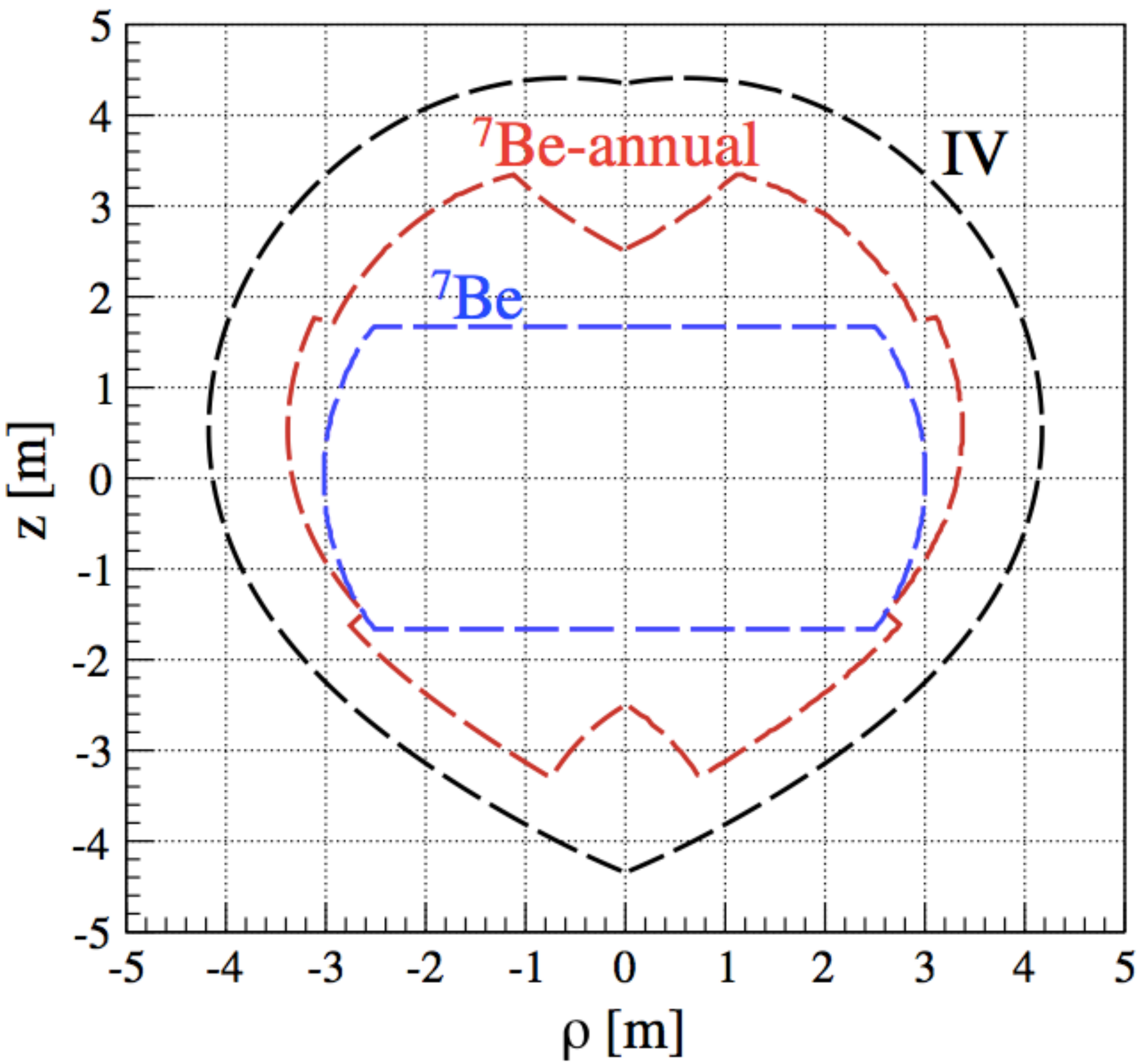


pp
$p + p \rightarrow {}^2H + e^+ + \nu_e$
99.76%
pep
0.24%
$p + e^- + p \rightarrow {}^2H + \nu_e$
83.30%
${}^2H + p \rightarrow {}^3He + \gamma$
16.70%
${}^3He + {}^3He \rightarrow {}^4He + 2p$
0.12%
${}^3He + {}^4He \rightarrow {}^7Be + \gamma$
${}^7Be + p \rightarrow {}^8B + \gamma$
99.88%
7Be
${}^7Be + e^- \rightarrow {}^7Li + \nu_e$
8B
${}^8B \rightarrow {}^8Be^* + e^+ + \nu_e$
${}^7Li + p \rightarrow {}^4He + {}^4He$
${}^8Be^* \rightarrow {}^4He + {}^4He$

TABLE VIII. Decay rate of the main internal radioactive backgrounds considered in this work; if the rate has changed in time the minimum and maximum values are quoted. For ^{85}Kr contamination, both the results of delayed coincidence method *(a)* and spectral fit analysis *(b)* are reported.

Isotope	Decay Rate [cpd/100 ton]	Reference
^{14}C	$(3.46 \pm 0.09) \times 10^6$	Sec. XI C 1
^{85}Kr	$(30.4 \pm 5.3 \pm 1.5)^{(a)}$	Sec. XI C 2
	$(31.2 \pm 1.7 \pm 4.7)^{(b)}$	Sec. XXII
^{40}K	< 0.42 (95% C.L.)	Sec. XI C 3
^{39}Ar	~0.4	Sec. XI C 4
^{238}U	(0.57 ± 0.05)	Sec. XI C 5
^{222}Rn	(1.72 ± 0.06)	Sec. XI C 5
^{210}Bi	$(41.0 \pm 1.5 \pm 2.3)$	Sec. XI C 7
^{210}Po	5×10^2–8×10^3	Sec. XI C 8
^{232}Th	(0.13 ± 0.03)	Sec. XI C 9

Fiducial Volume



IV 278 ton
7Be rate measurement : 75 ton
7Be annual : 142 ton