Study Solar Neutrinos at Jinping

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Jun. 5, 2015 at Jinping neutrino workshop

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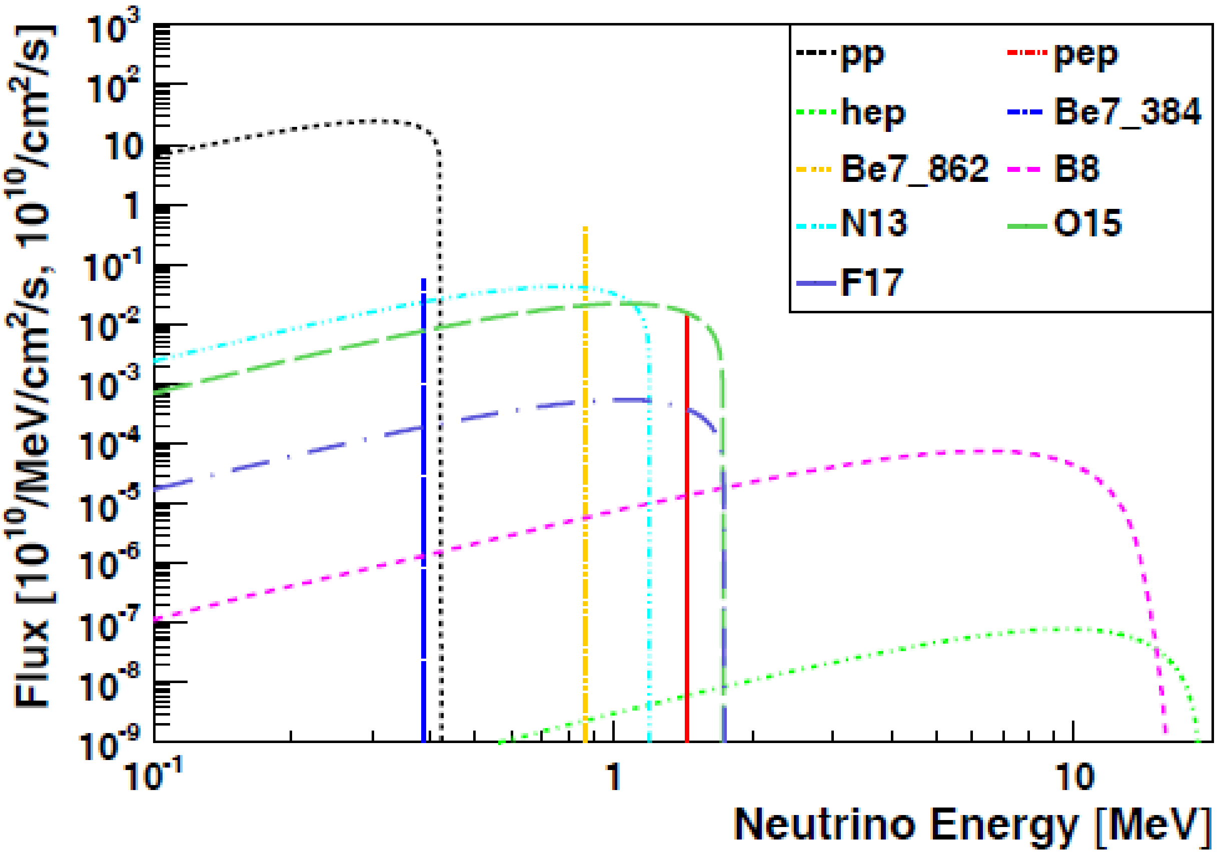
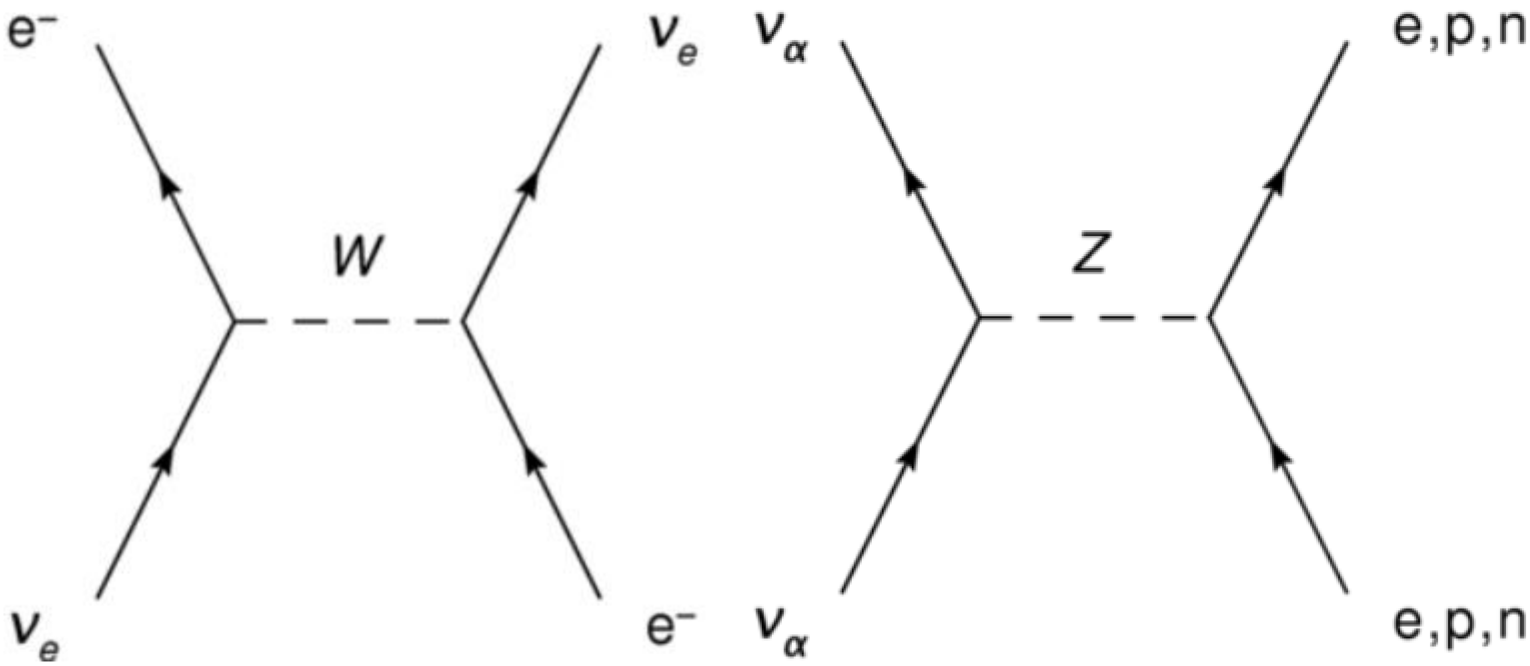
Current solar neutrino study situation

Standard Solar Model



Standard input from J. Bahcall

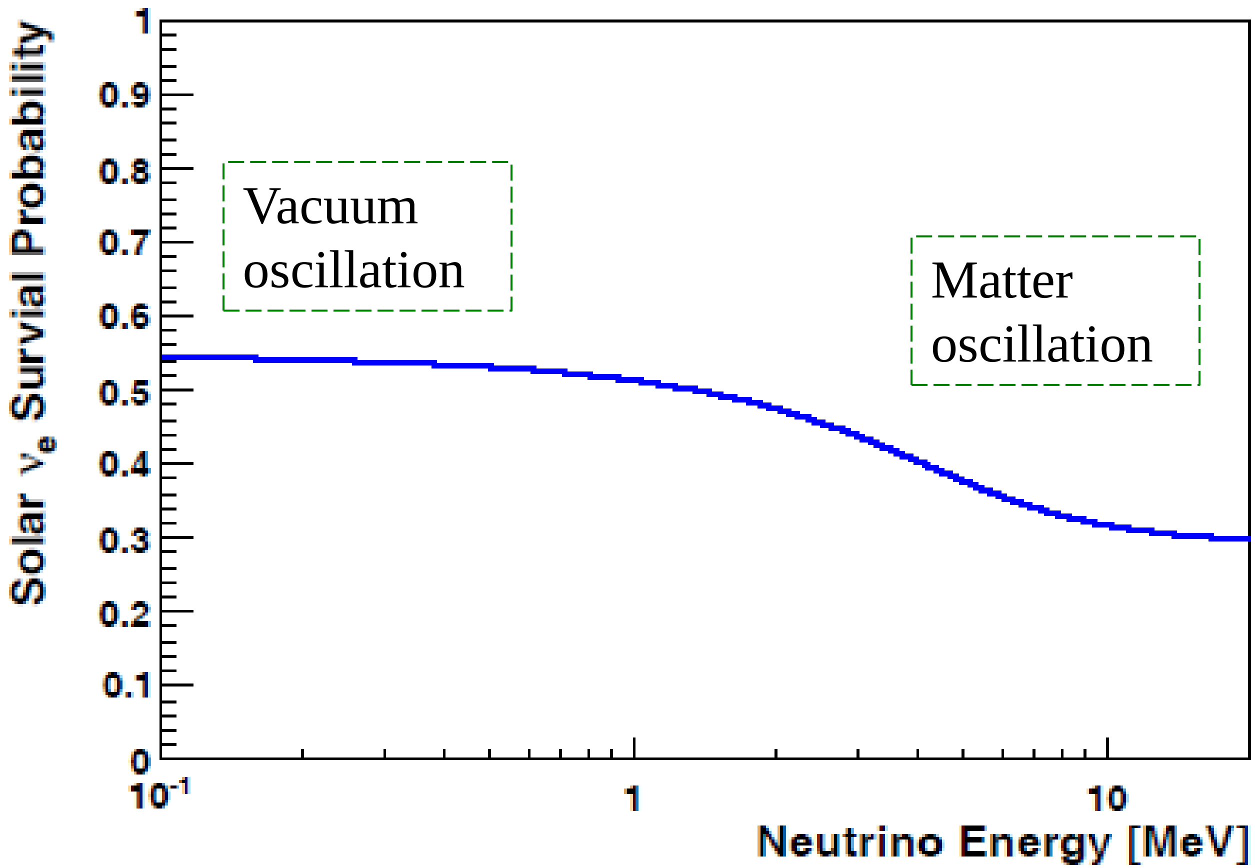
Neutrino propagation in matter (MSW)



Asymmetry between ν_e and $\nu_{\mu\tau}$

Oscillation probability density dependent

The matter-vacuum transition

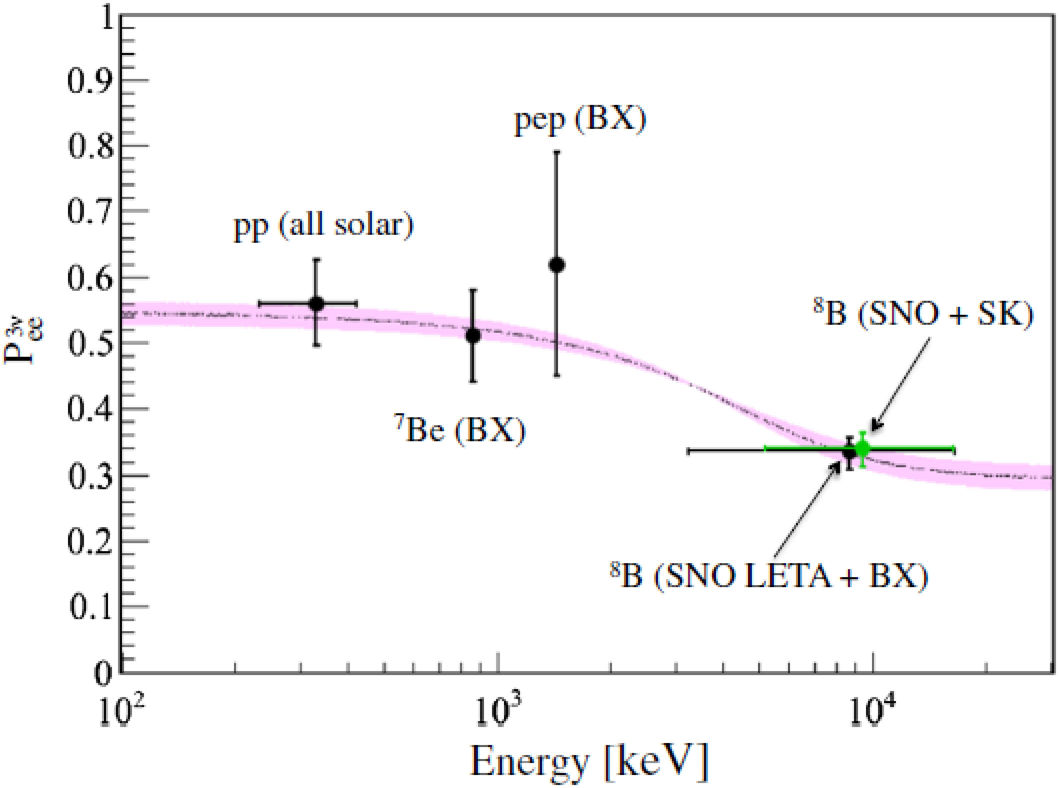


Current best solar measurements

- Low energy (<3 MeV) From Borexino and chemical experiments
- High energy (>3 MeV) From Super Kaminokande and SNO

Measured flux

Non-oscillation Prediction

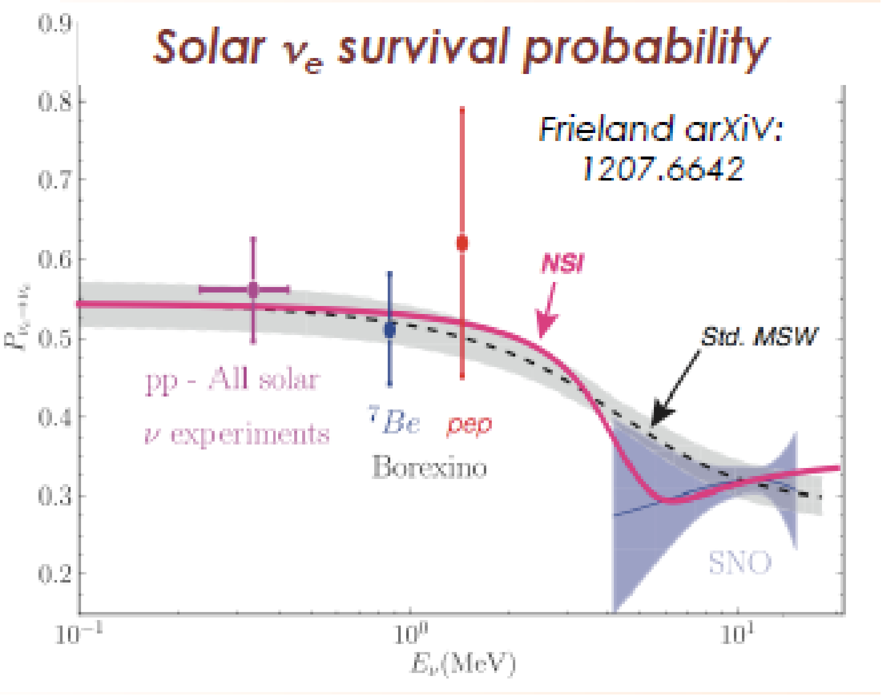


PHYSICAL REVIEW D 89, 112007 (2014)

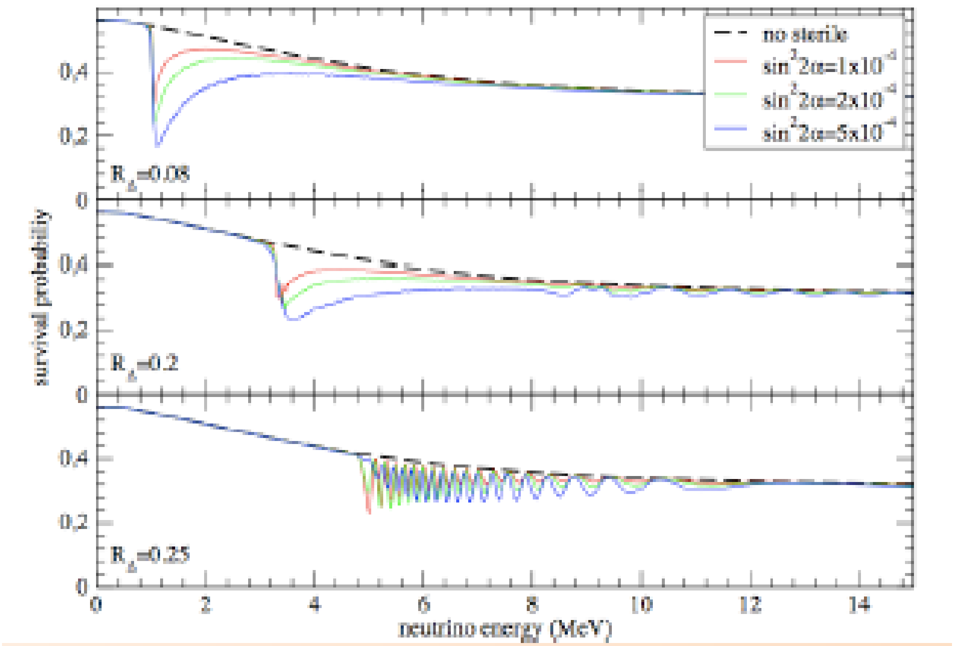
Missing latest BX pp flux: (6.6 +/- 0.7) × 10^{-10}cm^{-2} s^{-1}

New physics

1. **Constrain on new physics is loose**

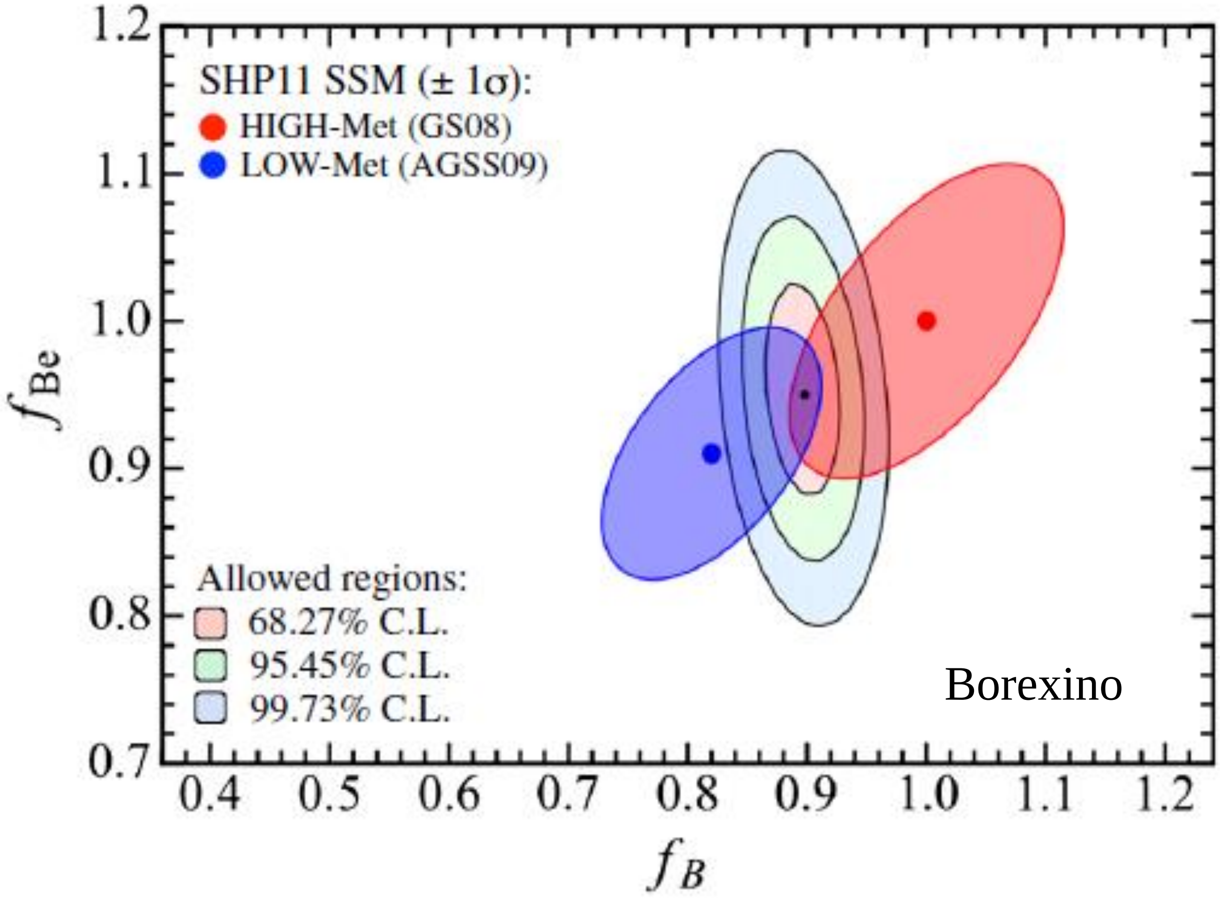


^8B –ν upturn, P. De Jolanda PRD 83 (2011)



Sterile neutrino, NSI, etc.

Metallicity problem – High or Low?



Questions for solar neutrino physics

✓ **Solar Model**

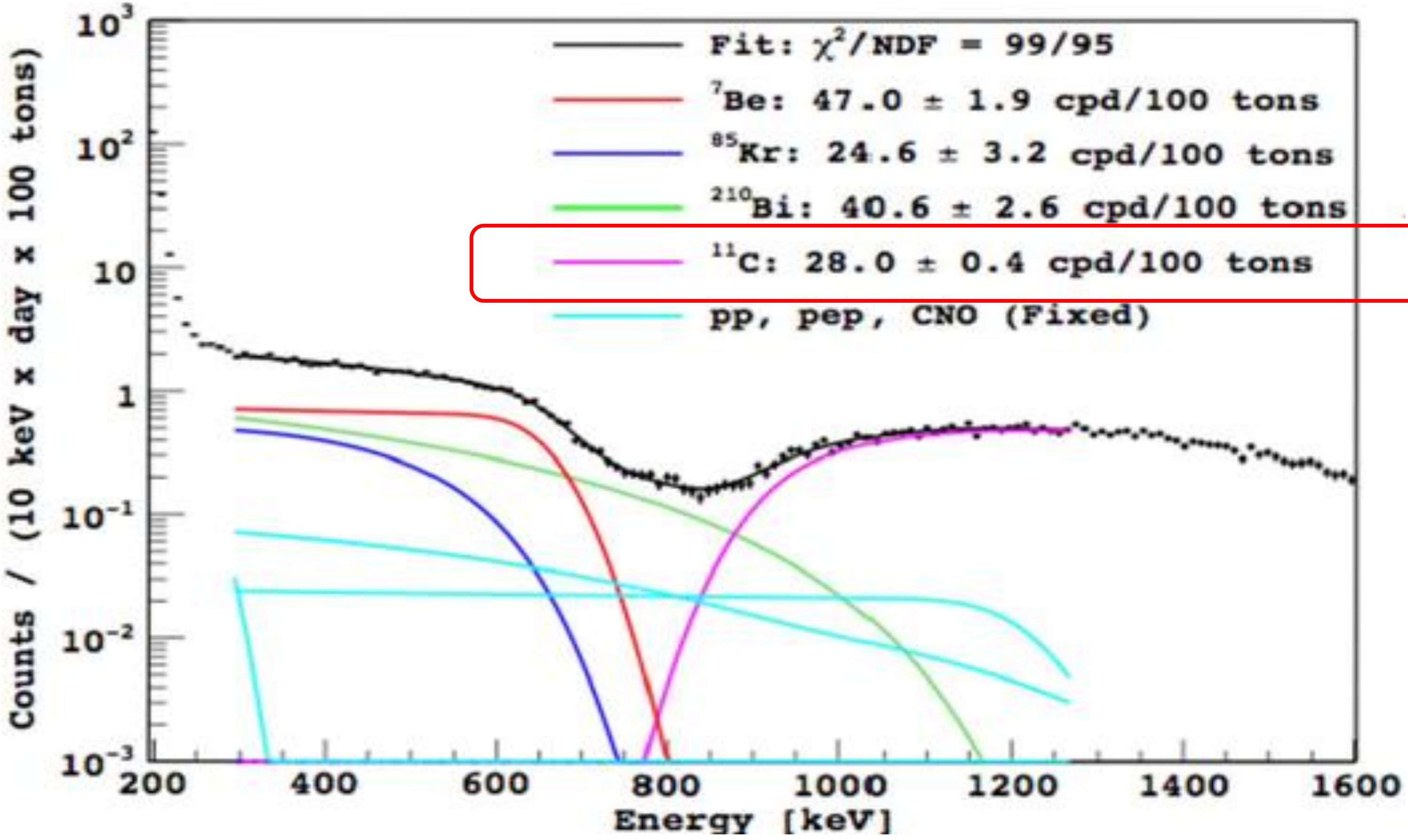
1. **CNO neutrino not discovered (High temperature stars)**
2. **Metallicity problem**
3. **hep neutrino not discovered**
4. **pp neutrino precision**

✓ **MSW effect**

1. **Oscillation transition from matter to vacuum**
2. **Constrain on new physics**
3. **Matter effect on the Earth**

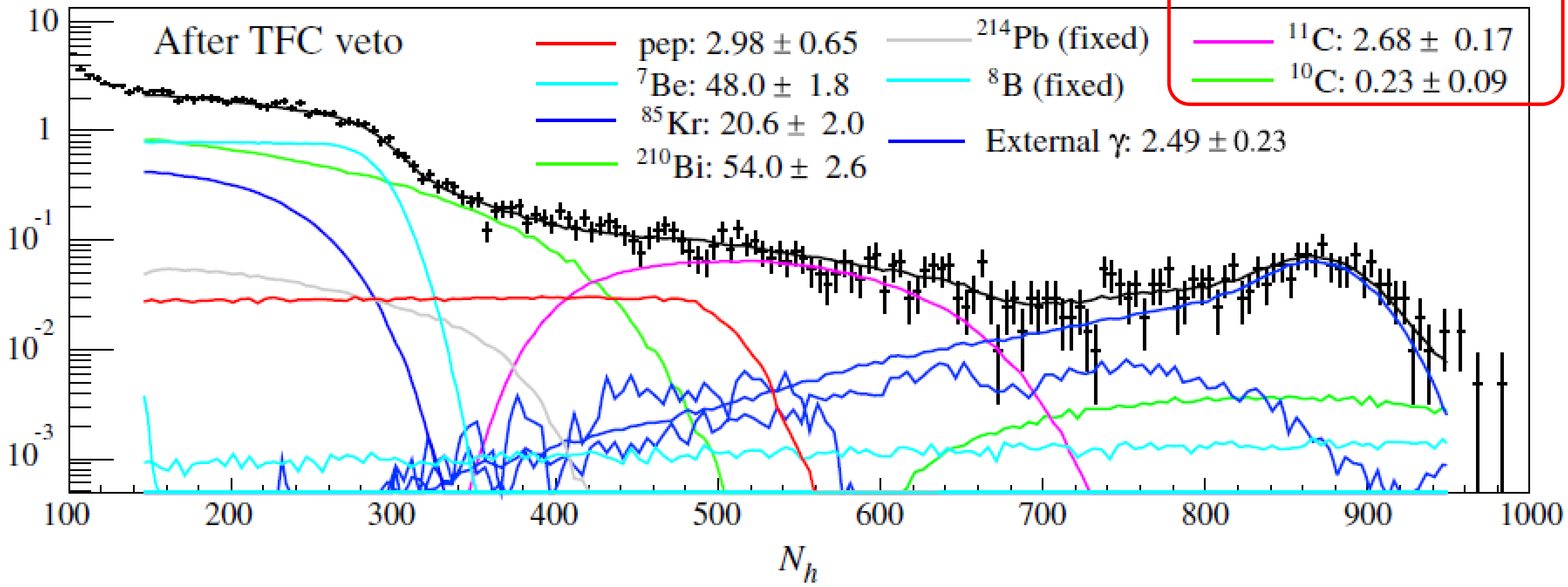
Main issue of Borexino

Bx Be7 measurement



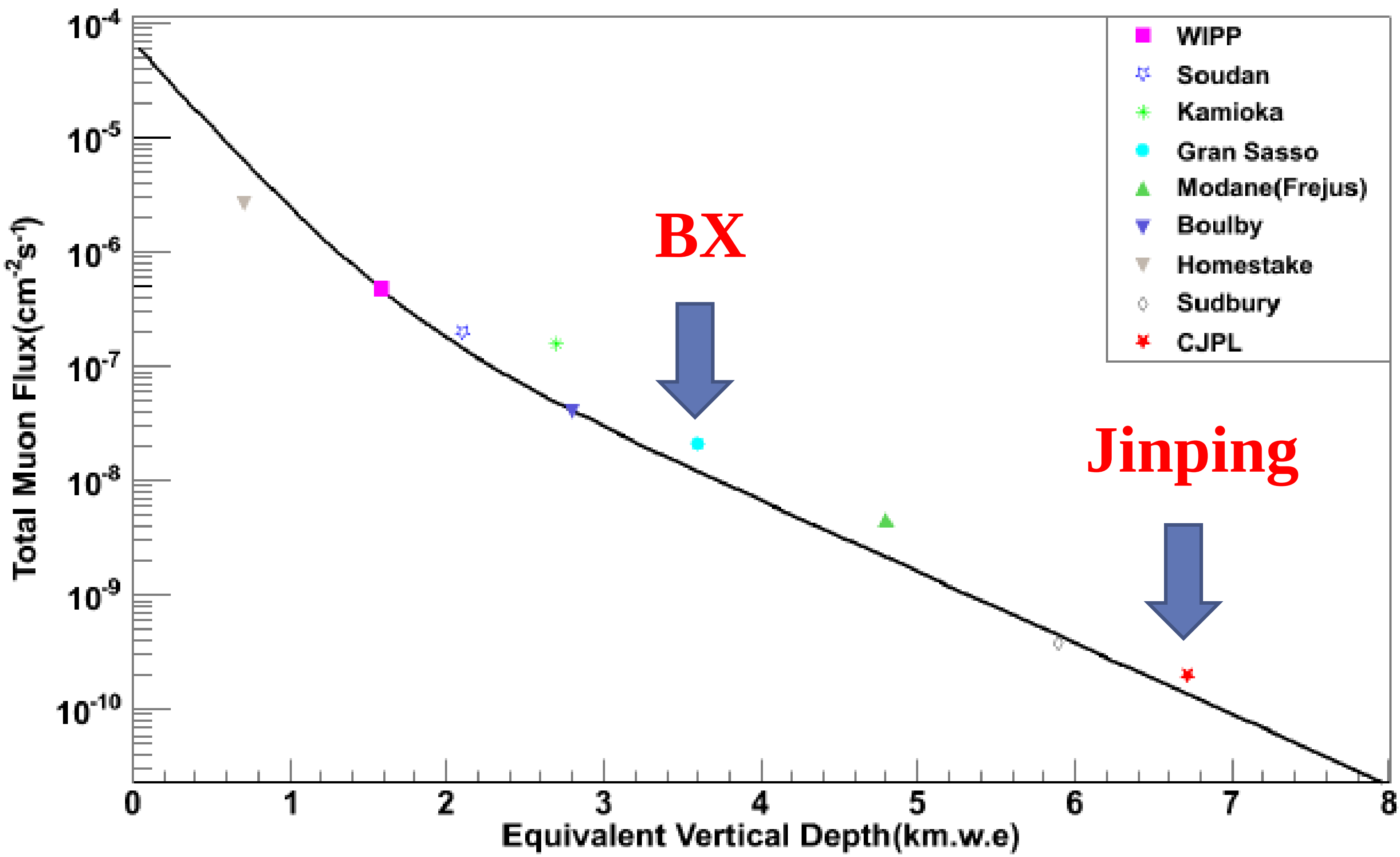
Cosmic genic C10 and C11 are the main background.

BX pep measurement



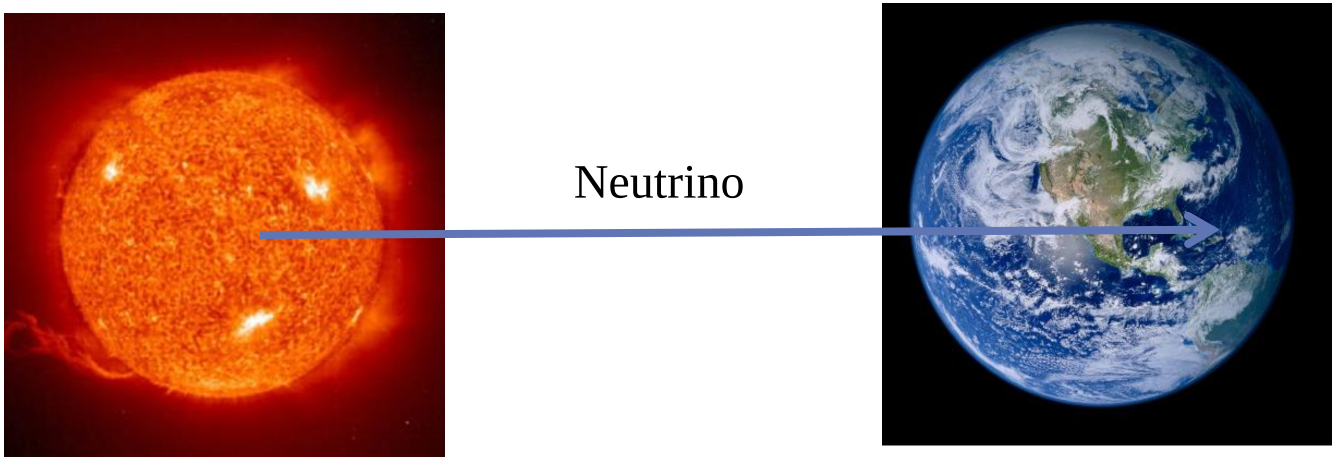
Cosmic genic C10 and C11 are the main background.
External gamma is also a problem.

Muon rate of Jinping is 1/200 of BX



Sensitivity of Jinping for solar neutrino physics

Neutrinos' journey from the Sun to the Earth



Generated in fusion in any place.

Reach solar surface.

Reach the Earth surface. Detected

May go through. Detected.

High density

vacuum

Low density

Neutrino flux on the Earth

Total flux

Solar neutrino spectrum

Detection Cross seciton for ν_e

Solar ν_e survival Prob.

Total target electrons

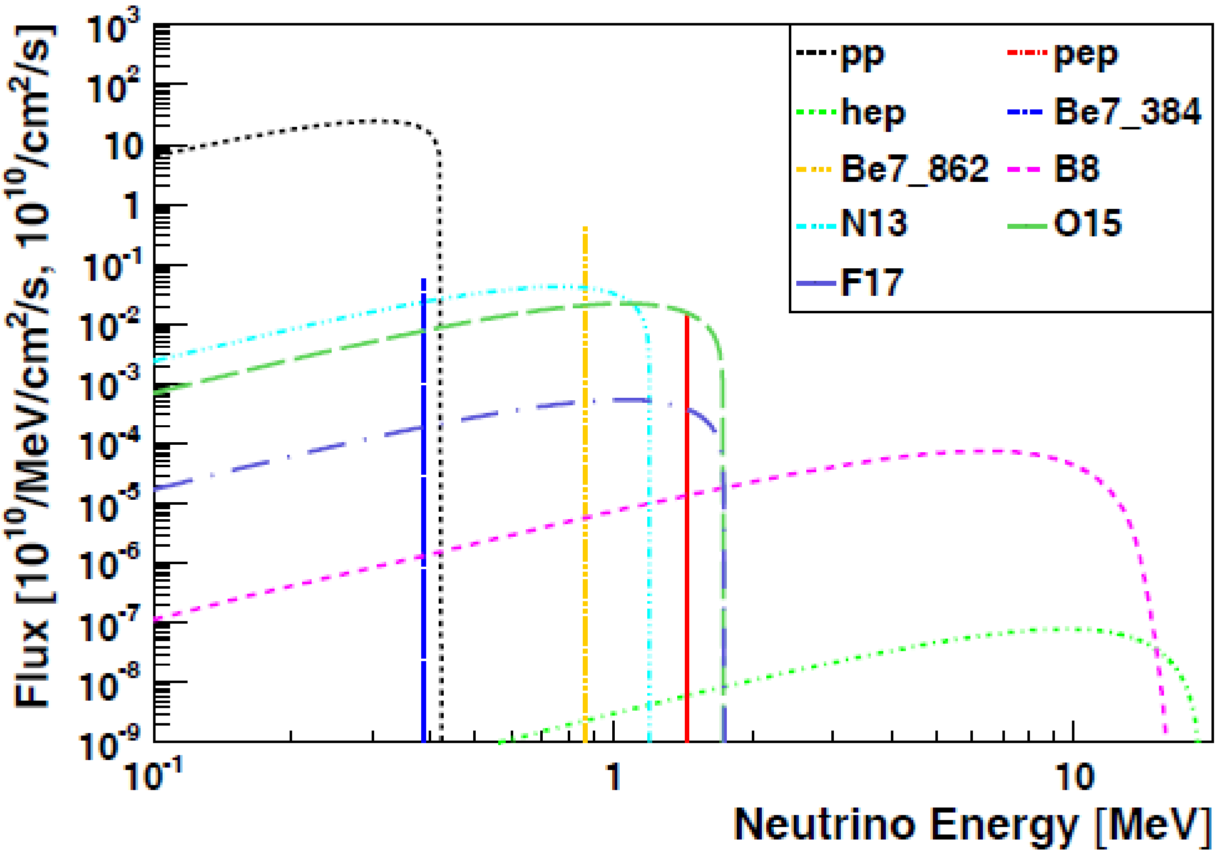
$$R_\nu = N_e \Phi_\nu \int dE_\nu \frac{d\lambda}{dE_\nu} \int \left\{ \frac{d\sigma_e(E_\nu, T)}{dT} P_{ee}(E_\nu) + \frac{d\sigma_\mu(E_\nu, T)}{dT} [1 - P_{ee}(E_\nu)] \right\} dT,$$

Detection Cross seciton for $\nu_{\mu\tau}$

ν_e goes to other flavors

Kinetic energy of scattered electron

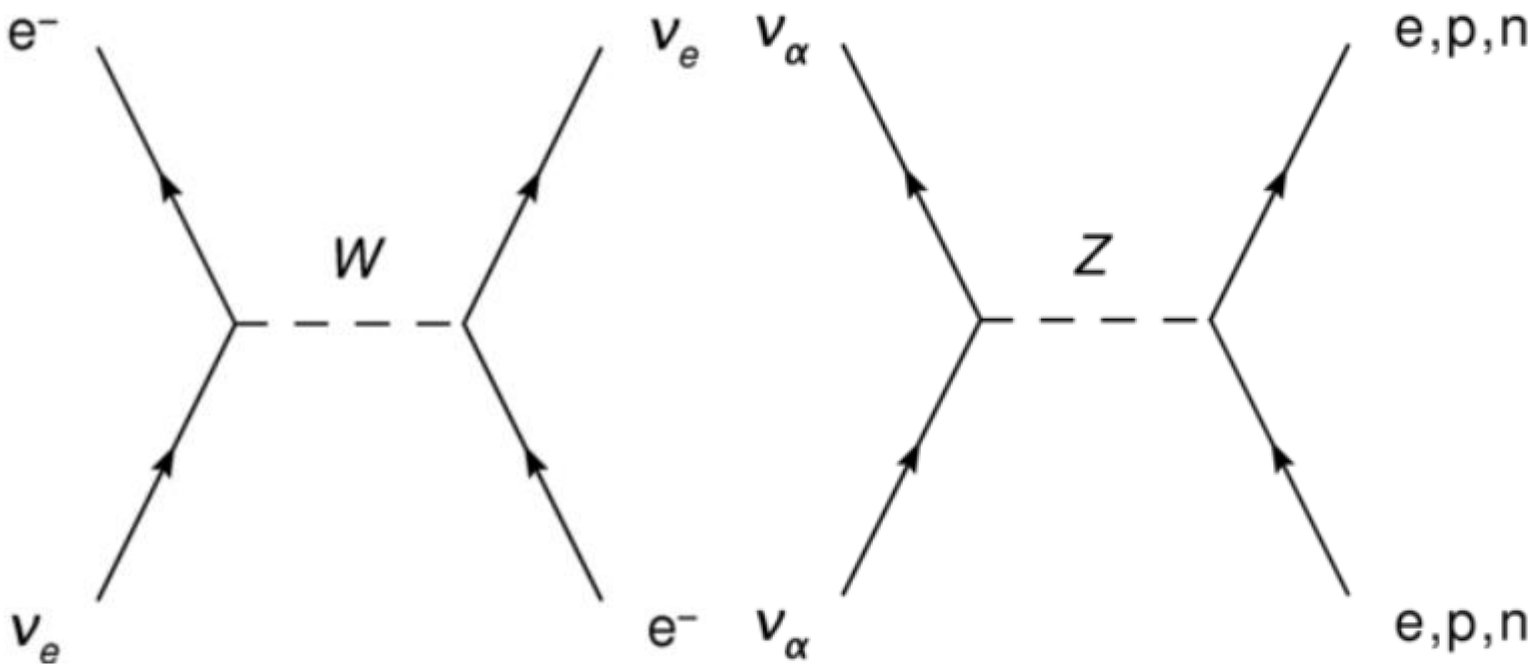
Standard Solar Model



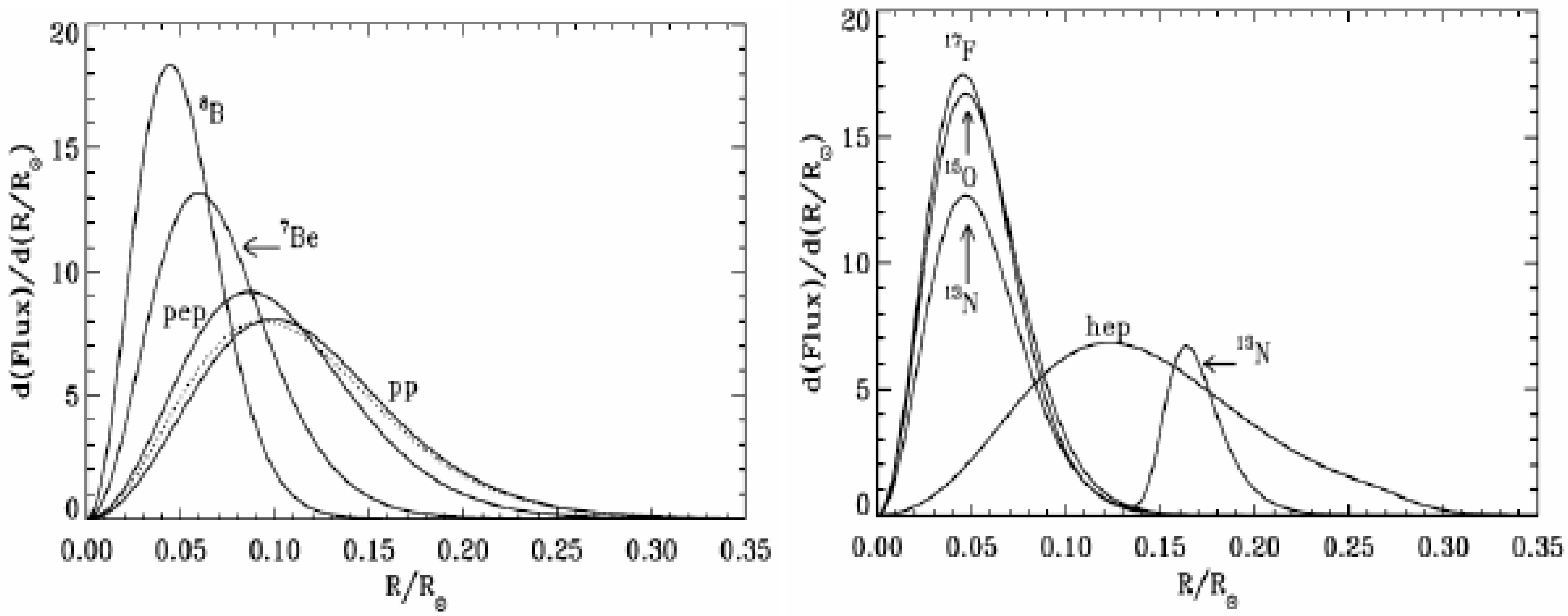
Standard input from J. Bahcall

Neutrino detection

- Focus on neutrino-electron scattering



Generation region is skipped here



Not useful for current study

Flux with high or low matellicity

	E_{Max} or E_{Line} [MeV]	Flux (GS98) high metallicity [$\times 10^{10} s^{-1} cm^{-2}$]	Flux (AGS09) low metallicity [$\times 10^{10} s^{-1} cm^{-2}$]
pp	0.42 MeV	$5.98(1 \pm 0.006)$	$6.03(1 \pm 0.006)$
^{7}Be	0.38 MeV	$0.053(1 \pm 0.07)$	$0.048(1 \pm 0.07)$
	0.86 MeV	$0.447(1 \pm 0.07)$	$0.408(1 \pm 0.07)$
pep	1.45 MeV	$0.0144(1 \pm 0.012)$	$0.0147(1 \pm 0.012)$
^{13}N	1.19 MeV	$0.0296(1 \pm 0.14)$	$0.0217(1 \pm 0.14)$
^{15}O	1.73 MeV	$0.0223(1 \pm 0.15)$	$0.0156(1 \pm 0.15)$
^{17}F	1.74 MeV	$5.52 \times 10^{-4}(1 \pm 0.17)$	$3.40 \times 10^{-4}(1 \pm 0.17)$
^{8}B	15.8 MeV	$5.58 \times 10^{-4}(1 \pm 0.14)$	$4.59 \times 10^{-4}(1 \pm 0.14)$
hep	18.5 MeV	$8.04 \times 10^{-7}(1 \pm 0.30)$	$8.31 \times 10^{-7}(1 \pm 0.30)$

Astrophys. J. **743**, 24 (2011); Astrophys. J. Lett. **705**, L123 (2009).

Oscillation probability

$$P_{ee}^{\odot} = \cos^4\theta_{13}\left(\frac{1}{2} + \frac{1}{2}\cos 2\theta_{12}^M \cos 2\theta_{12}\right)$$

Solar ν_e survival Probability

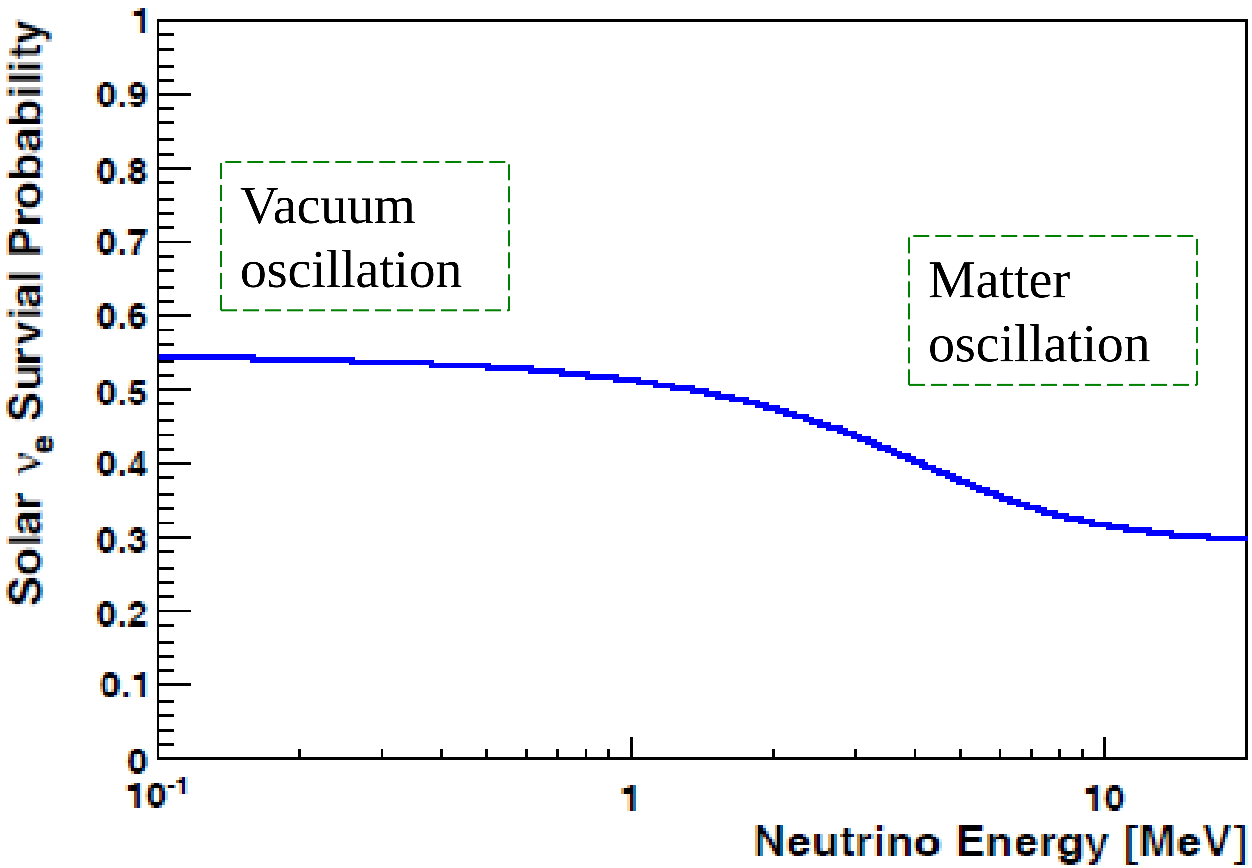
$$\cos 2\theta_{12}^M = \frac{\cos 2\theta_{12} - \beta}{\sqrt{(\cos 2\theta_{12} - \beta)^2 + \sin^2 2\theta_{12}}}$$

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

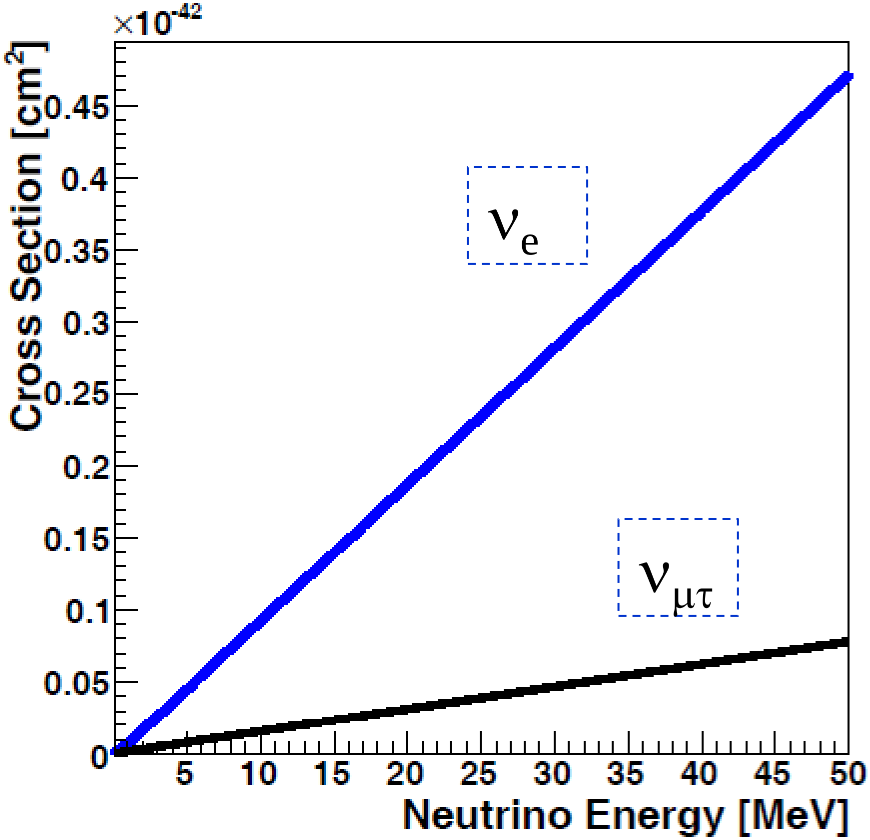
Electron density

Adiabatic assumption

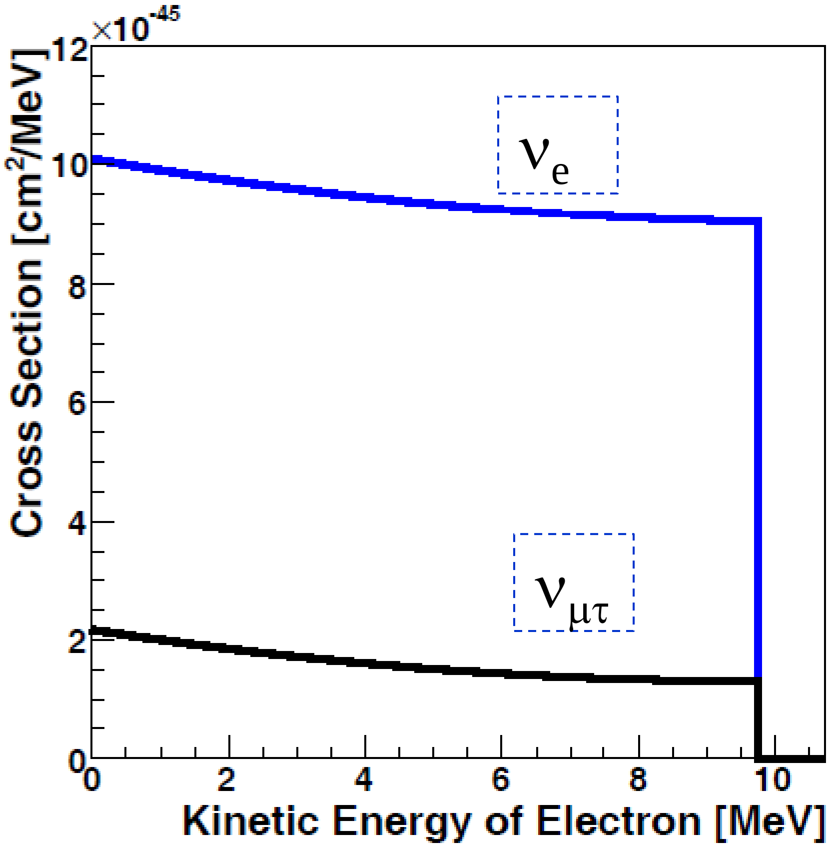
The matter-vacuum transition



Neutrino-electron scattering

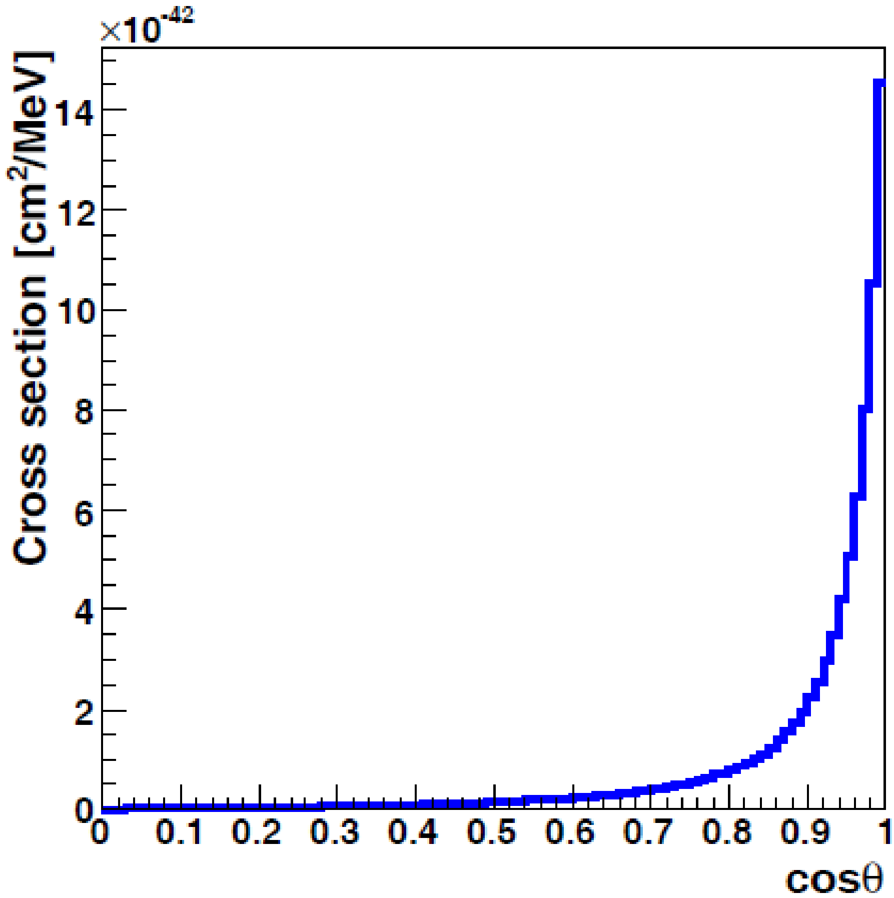


Total cross-section



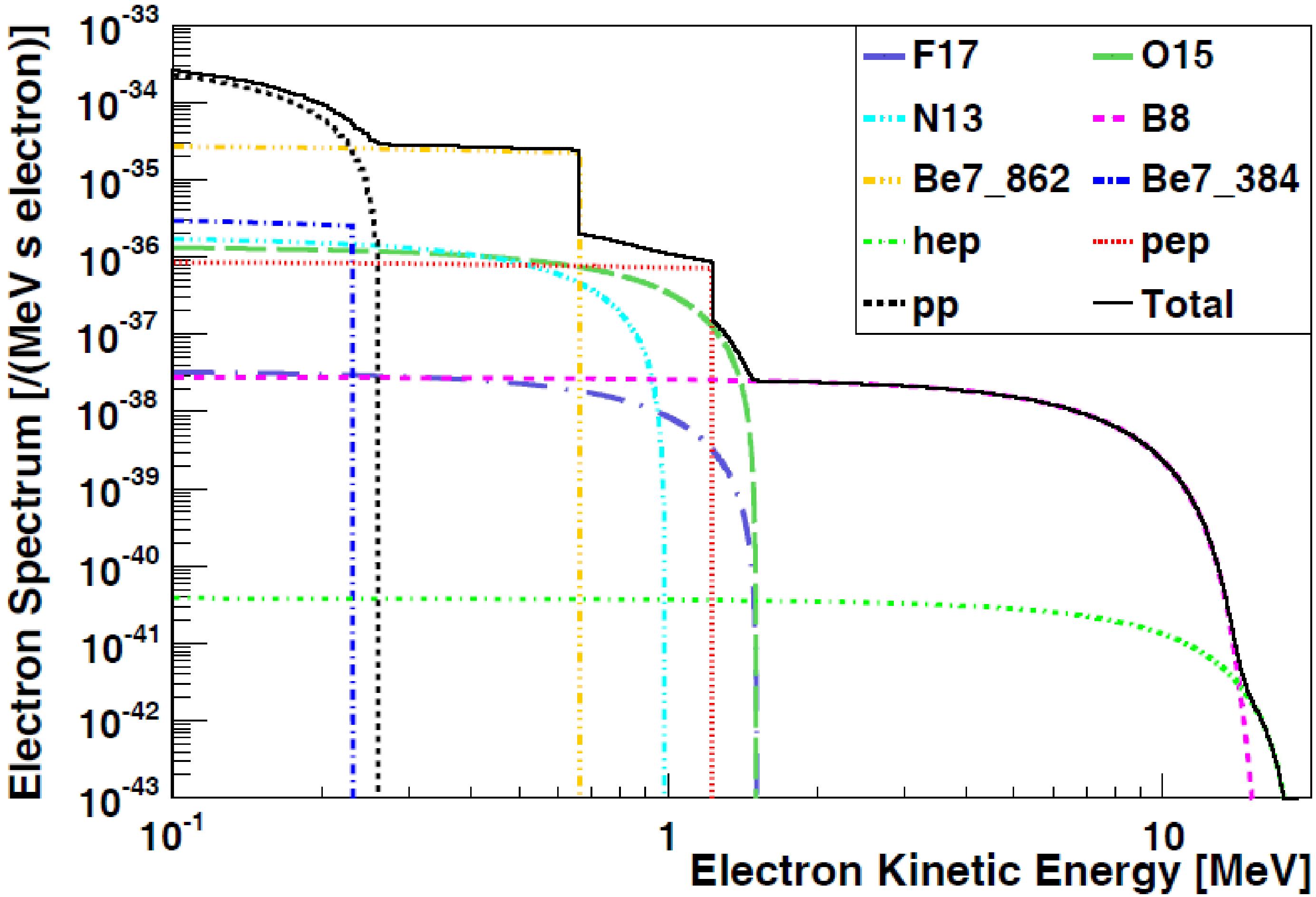
Differential cross-section for 10 MeV ν

Forward peaking feature



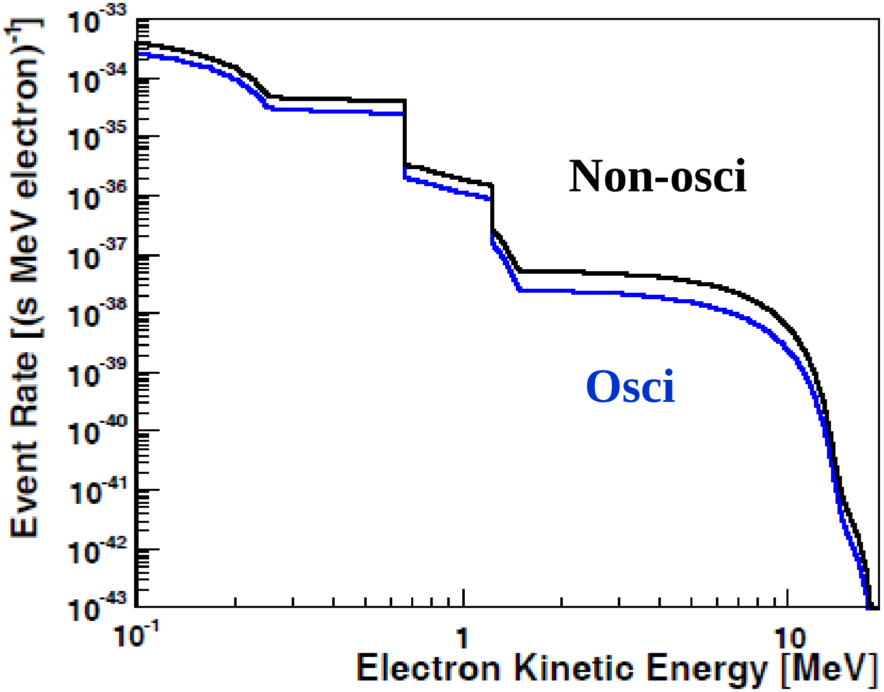
Scattered electrons like to go forward (10 MeV ν)

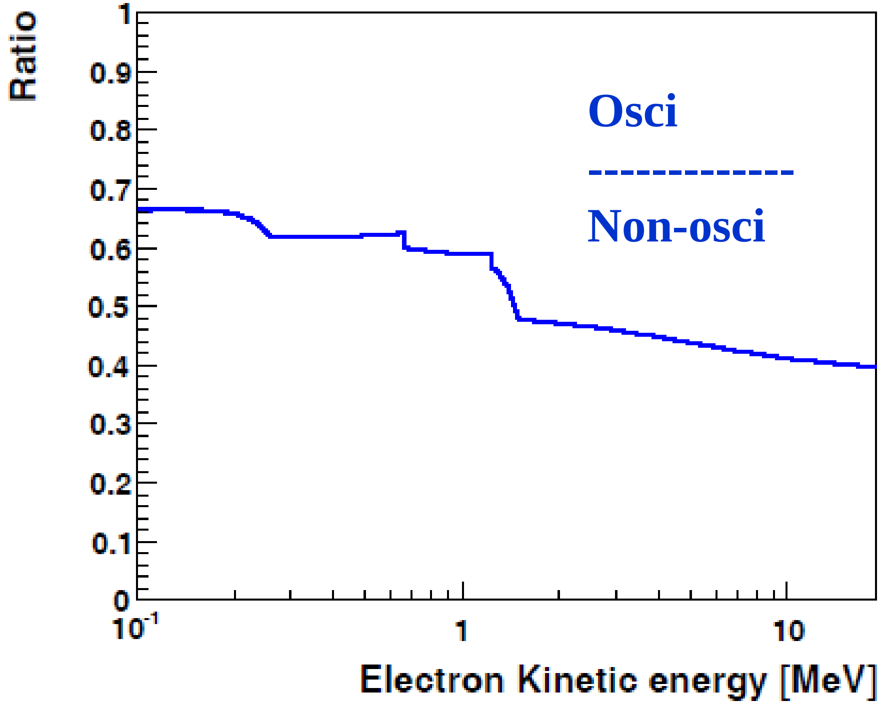
Detectable spectra of electron kinetic energy



With cross-section and oscillation considered.

Upturn in electron kinetic energy

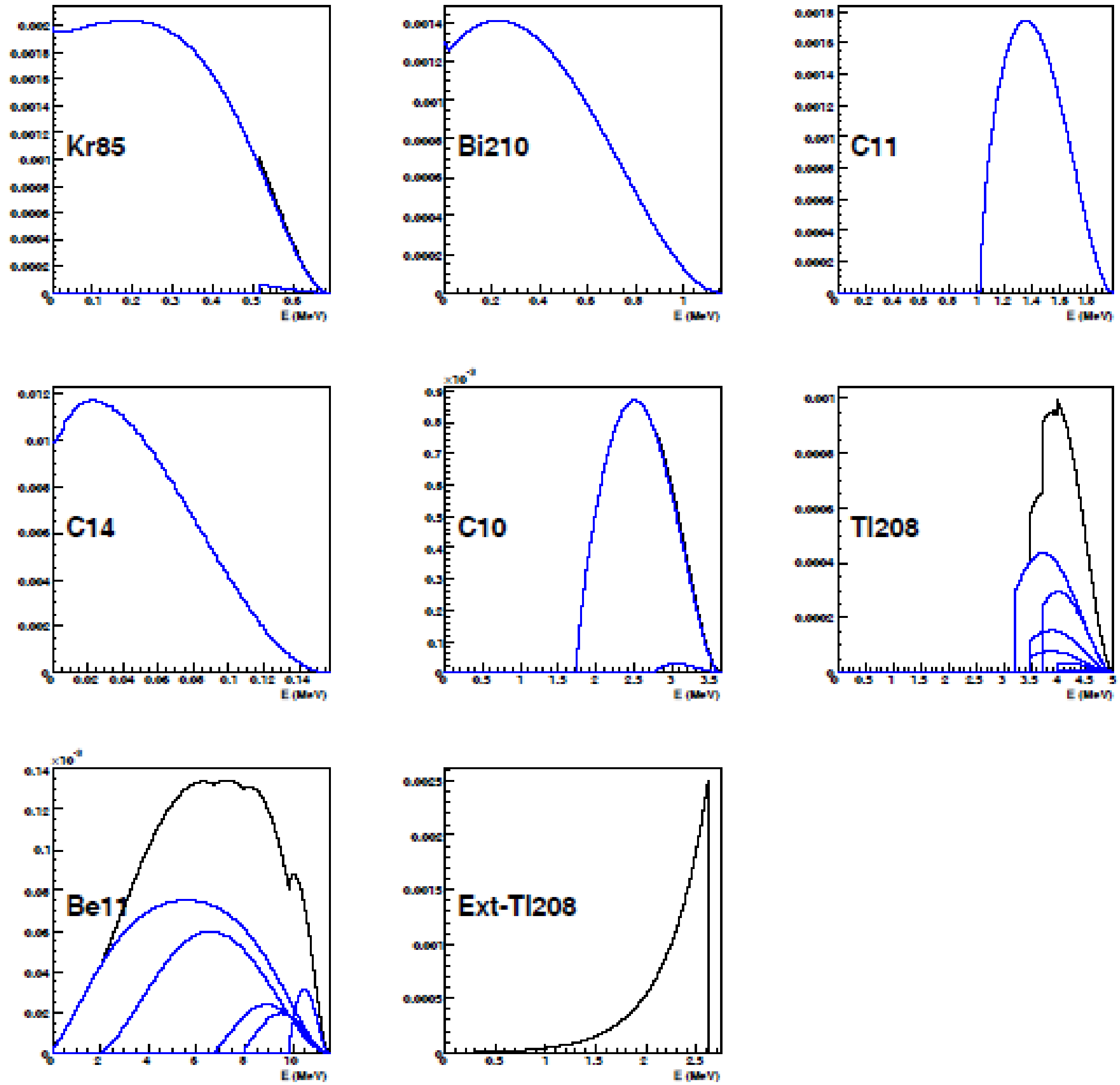




Backgrounds

- Internal
  1. Kr85, Bi210, C14, Tl208
  2. Same level as Borexino
- External
  1. Tl208
  2. Same level as Borexino
- Cosmo-genic
  1. C11, C10, Be11
  2. divided by 200

Background spectra



Target mass

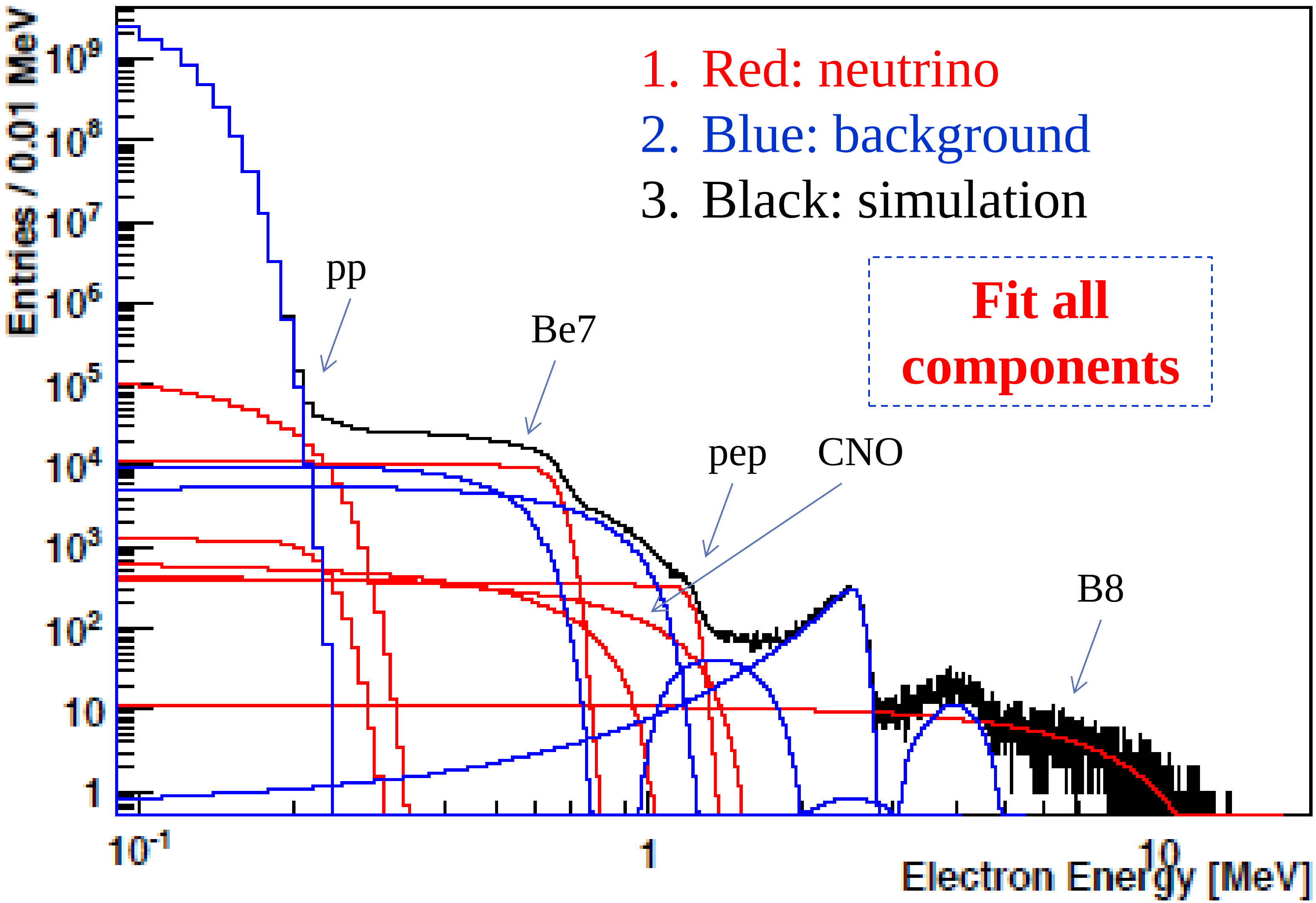
- Expect a detector larger than SNO
- 1 kton tried first

1 kton is fiducial mass. It needs a buffer of ~4 m on each side.

Detector resolution

Resolution	Material
200 PE/MeV	Water-like
500 PE/MeV	WbLS-like
1000 PE/MeV	High light yield LS

After resolution smearing



Systematic uncertainty

1. First step: precise flux measurement. Need a precise target mass value.

2. Fiducial target mass: Depend on vertex calibration precision. Assume 1%. (1 cm bias on 3 meter is not significant)

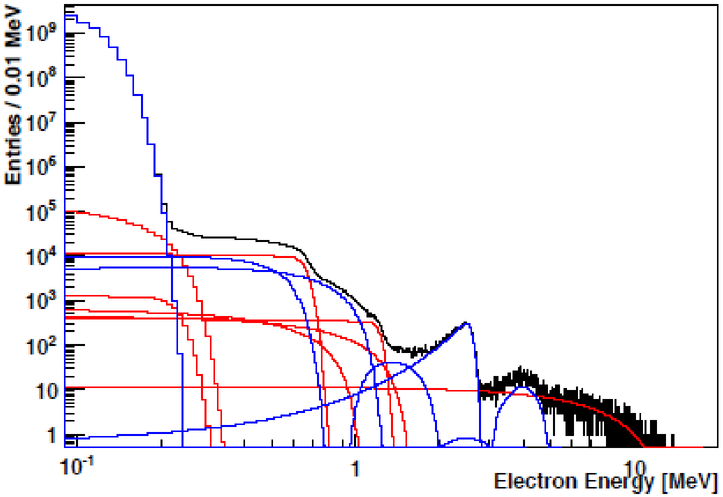
3. Non-linear energy response. Assume 1% based on Daya Bay experience

4. Total 1.5%

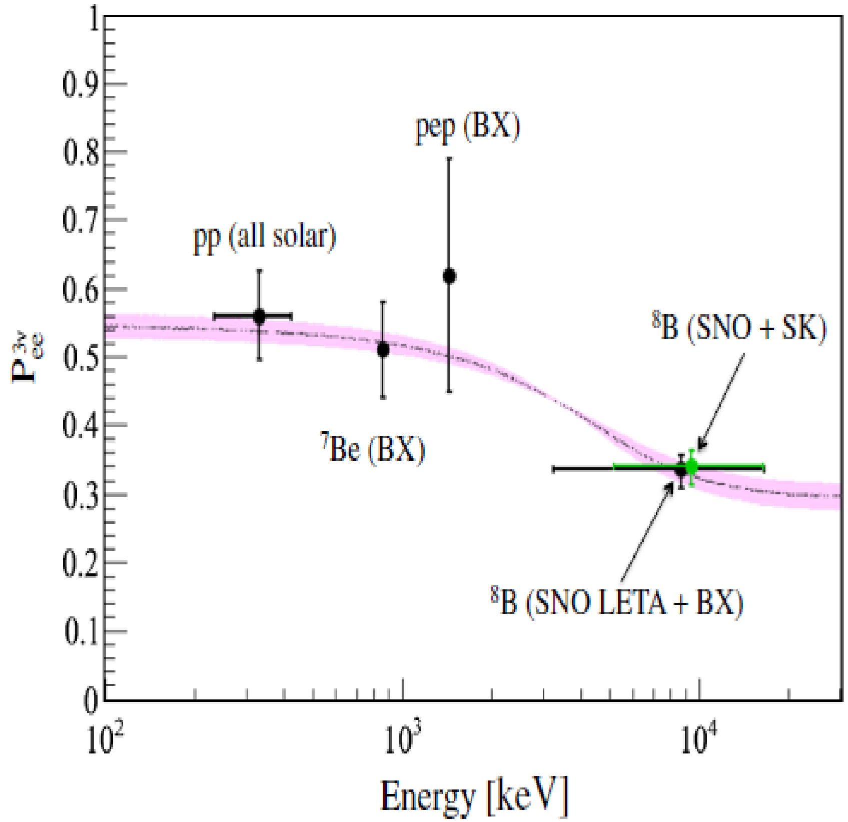
Discover CNO, improve all precisions

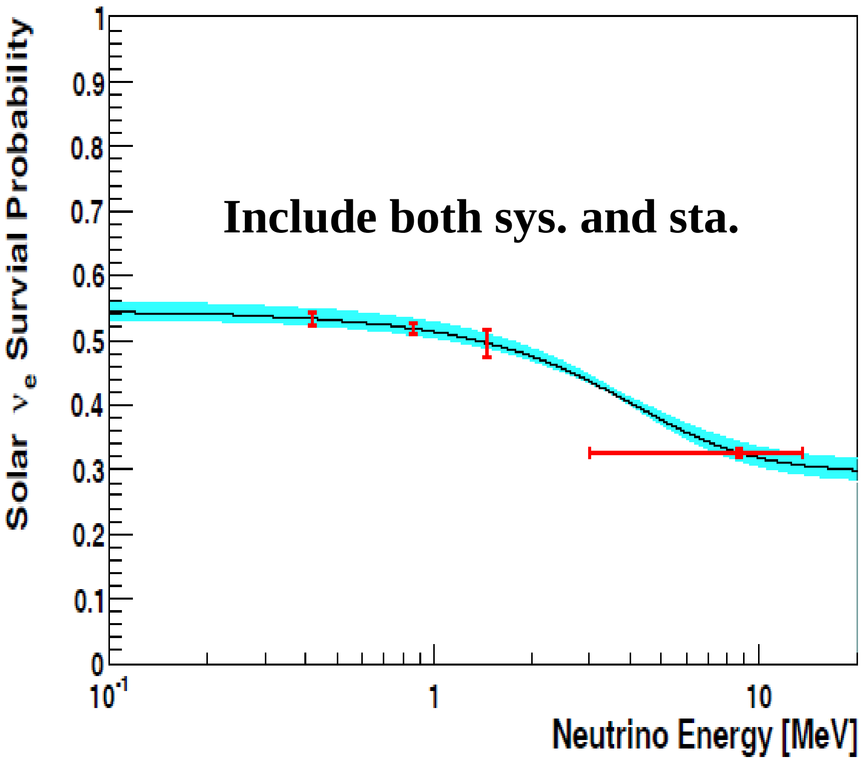
Relative error	Statistical			Systematic
	200 PE/MeV	500 PE/MeV	1000 PE/MeV	
pp	0.02	0.008	0.006	0.015
^{7}Be (0.86 MeV)	0.008	0.006	0.006	0.015
pep	0.06	0.04	0.04	0.015
^{13}N	NA (NA)	0.5 (NA)	0.2 (0.4)	0.015
^{15}O	0.3 (0.4)	0.2 (0.3)	0.1 (0.2)	0.015
^{8}B	0.02	0.02	0.02	0.015

1. pp window is narrow. Need good resolution. Expect stat. unc. <1%
2. Be7， pep stat. unc. <1%. Insensitive to resolution
3. To discover CNO, need good resolution to differentiate all shapes
4. B8 is limited to target mass



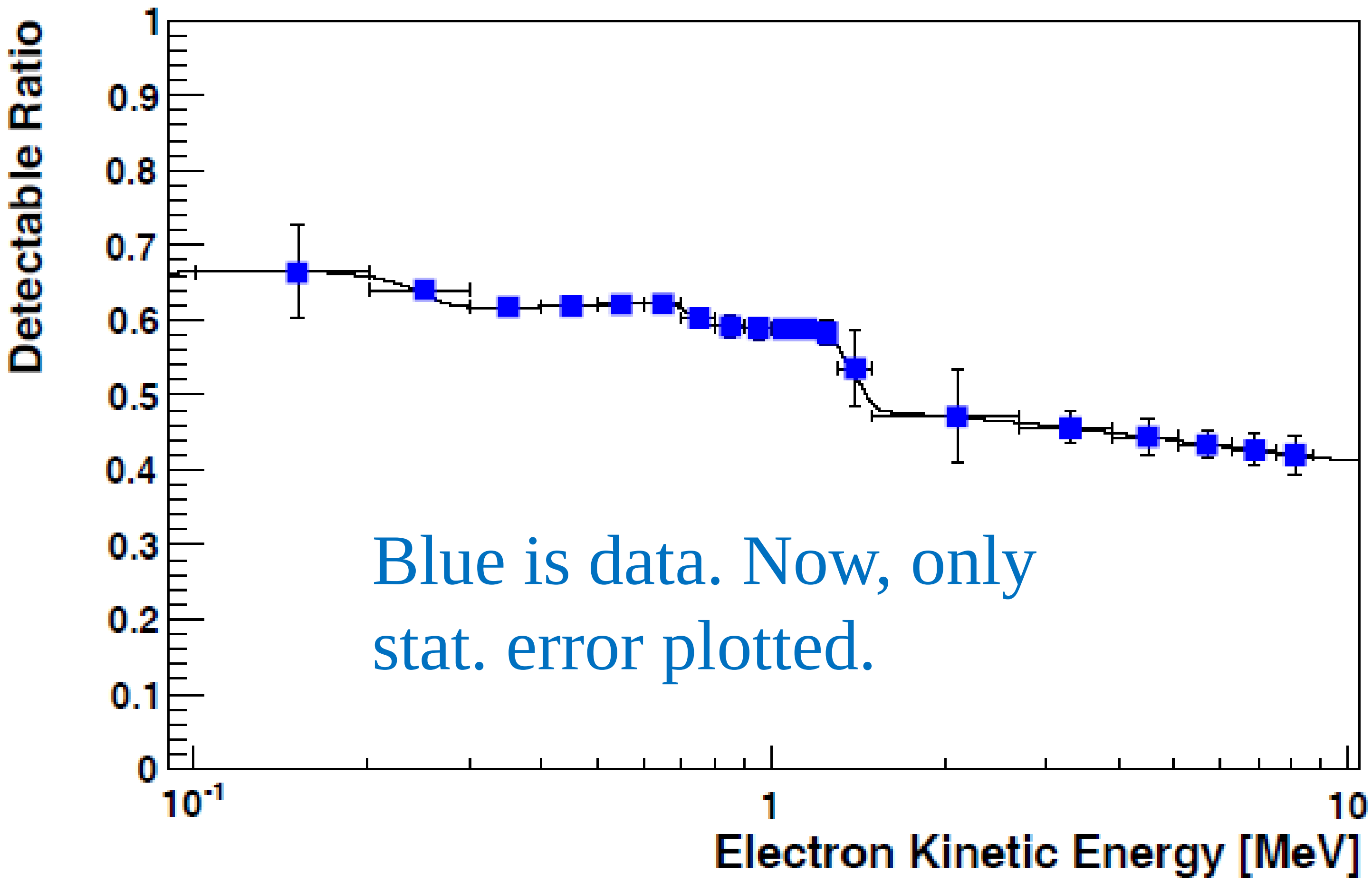
Upturn





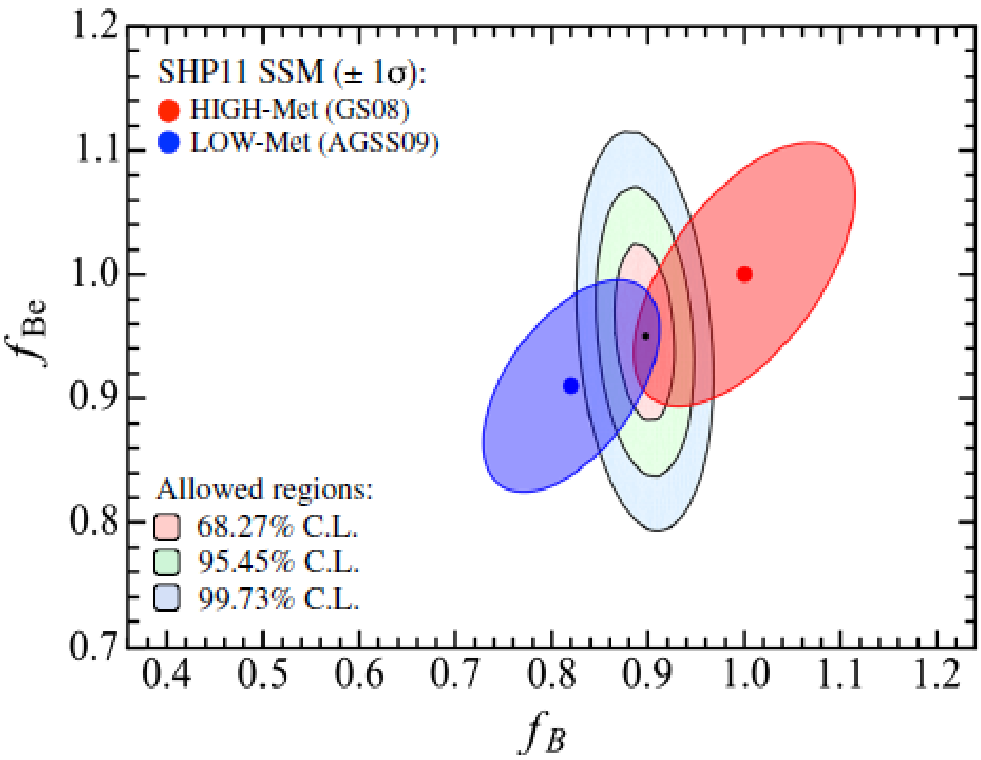
Borexino,etc. → Jinping

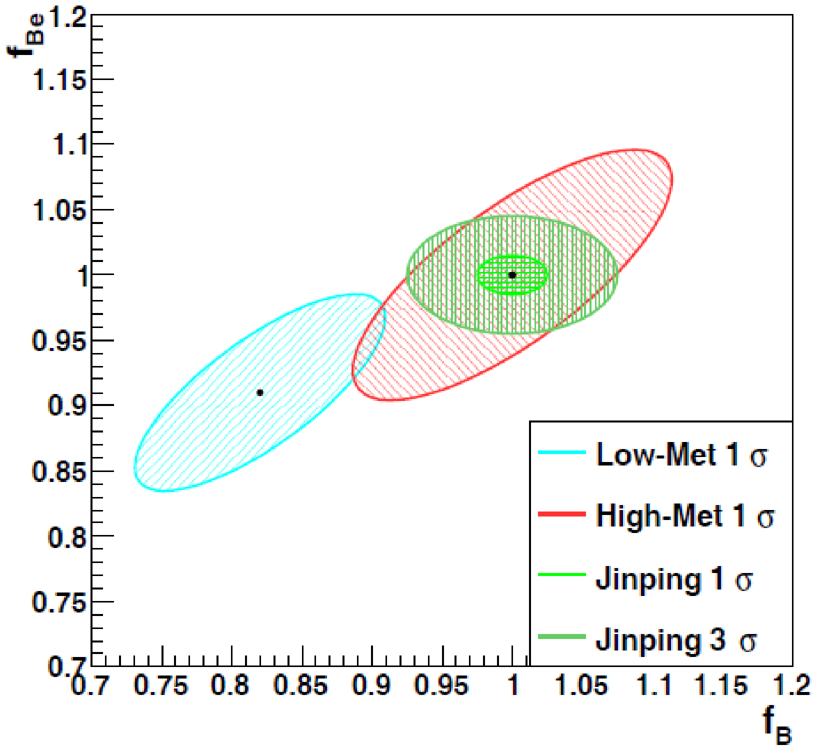
Upturn in electron kinetic energy



Metallicity

- With good stat. error of Be7, pep, and B8
- Dominated by systematic





Borexino,etc. → Jinping

Day-night asymmetry

- When solar neutrinos go though the Earth, ν_e is regenerated.

- Theoretical day-night asymmetry mainly for is <3%
- But Jinping B8 flux precision is only 2%

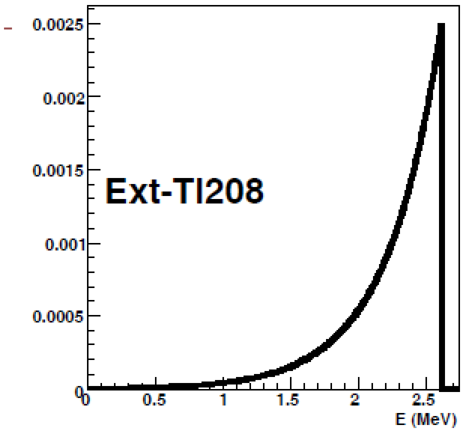
- Target mass limits the precision.

Other studies not done

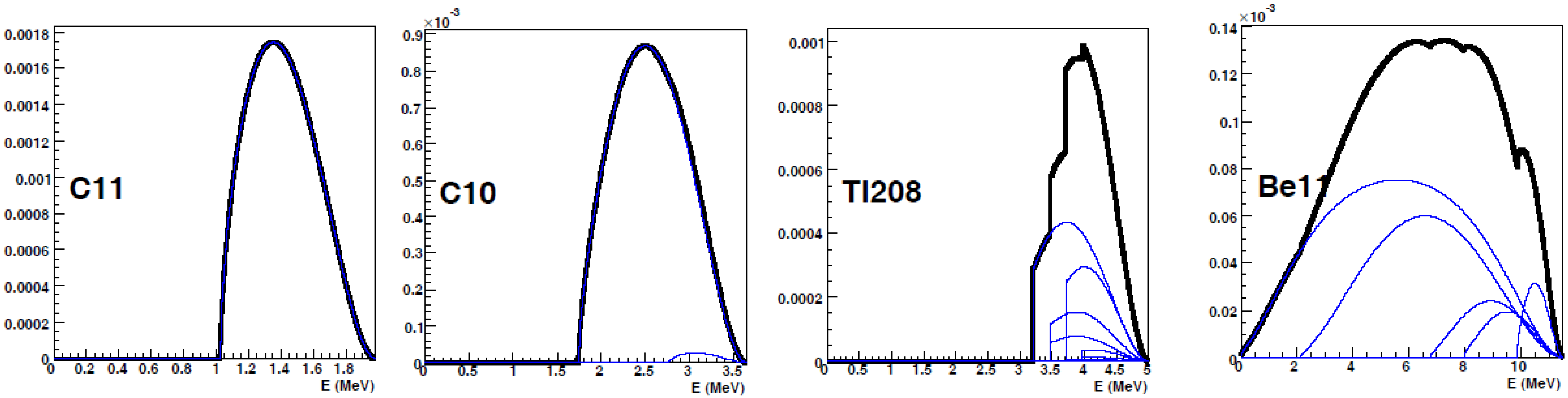
- Improvement on solar mixing angle
- Rejection or discovery power for new physics

In progress…

Outlook with WbLS



- Cherenkov and scintillation separation
  1. Gamma and electron separation
     External gamma background
     Internal C10, C11, Tl208 involve gammas



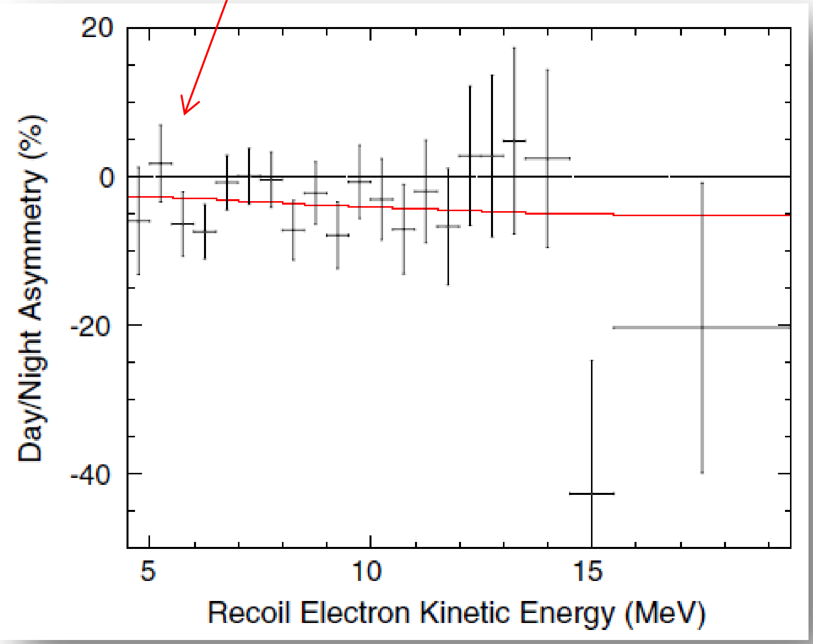
  2. Electron direction reconstruction
     Correlation with solar angle
- Further improve S/N by 2 or more

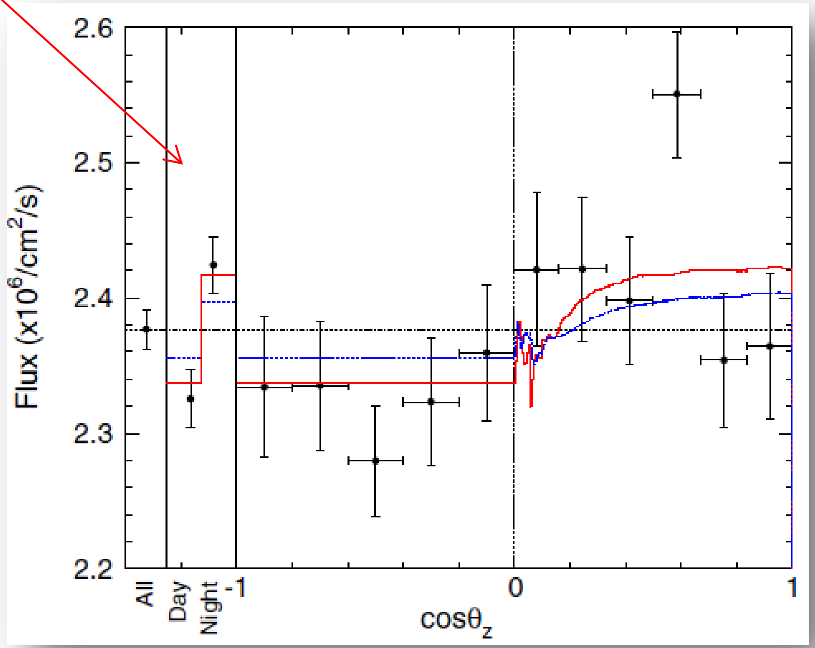
Slow … scintillator

Compare with other detectors

Super Kaminokande and Hyper Kaminokande

- The huge target mass =>
- precise B8 flux measurement
- day-night asymmetry
- Upturn around 3 MeV





JUNO

- 20 kton (Assume low bkg rate as Borexino)
- Good statistical sensitivities of Be7 and B8: σ_{stat}<<1%
  1. Similar or much better than Jinping 1 kton
- Key is systematic for a useful flux measurement: σ_{syst}<1% which requires
  1. Energy response nonlinearity
  2. Position reconstruction precision and calibration

Be7 and B8 precision is hindered by systematic,
to have large target mass is not the 1st priority.

Large LAr TPC

- LBNE/DUNE 30 kton
- Large target mass and tracking capability
- Shortcoming:
  1. High energy threshold >10 MeV
  2. Overburden
- So far B8 neutrinos only

Recommendations for Jinping

- Liquid scintillator or WbLS
- Large detector is not urgent
  1. Kilo-ton : Easy to handle (purification and calibration)
- Fine calibration: nonlinearity and position

	mass	Material	Threshold	Be7	B8	Other components	Need
Jinping	1 kton	LS or WbLS	~200 keV	s_{stat}<<1%	s_{stat}~2%	Y	Calib.
JUNO	20 kton	LS	~200 keV	s_{stat}<<1%	s_{stat}<<1%	N	Calib
SuperK (HyperK)	> 50 kton	water	~3 MeV	-	s_{stat}<<1%	N	Calib
LBNE/ DUNE	> 30 kton	LAr TPC	~10 MeV	-	s_{stat}<<1%	N	Calib

Summary

1. Jinping is ideal for solar neutrino physics study
2. Kilo-ton scale detector will work!
3. LS or WbLS for the best
4. In physics:
   1. Discover CNO neutrino
   2. Precision measurement of other components
   3. Conclusive constraint of matter-vacuum transition
   4. Resolve metallicity puzzle (relying systematic)
   5. Weak in attacking day-night asymmetry
   6. Improvement on mixing angles and constraint on new physics will be studied

Thank you！

e⁻, gamma, e⁺ comparison