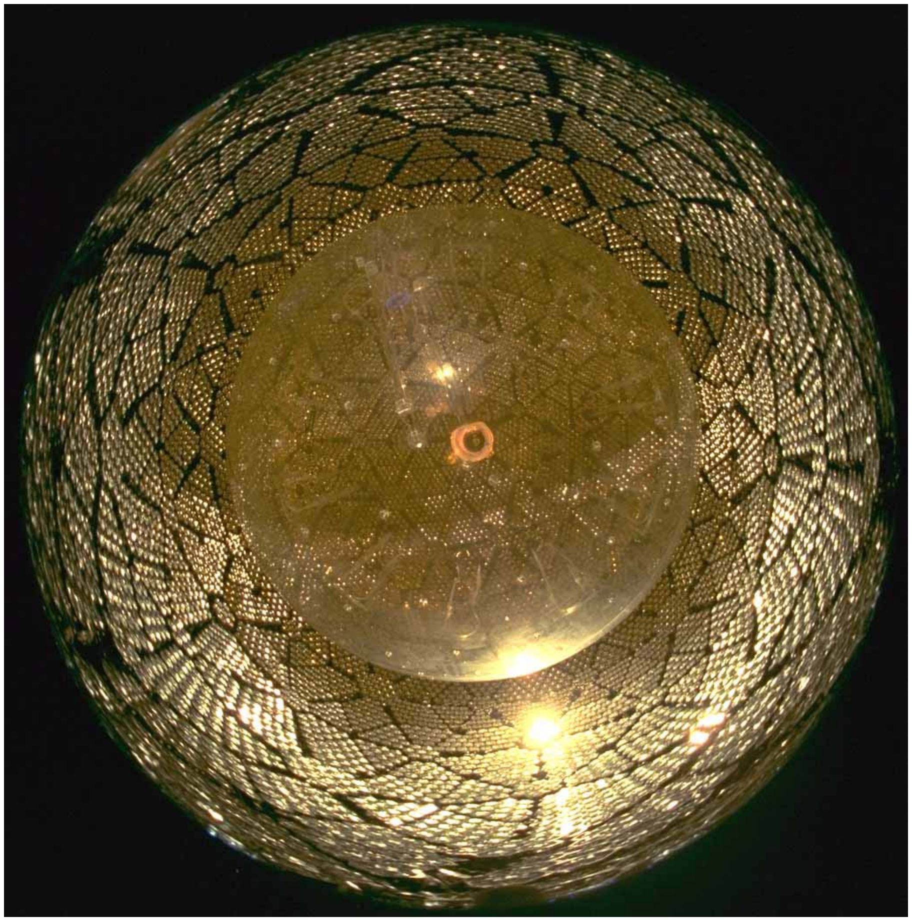


Future Solar Neutrino Experiments

WIN'03

Lake Geneva, WI

Mark Chen

Queen's University &
The Canadian Institute for Advanced Research

Future Solar Neutrino Experiments

- what can they measure?
  - solar physics
  - neutrino physics
- what should they measure?
- very brief survey of future experiments

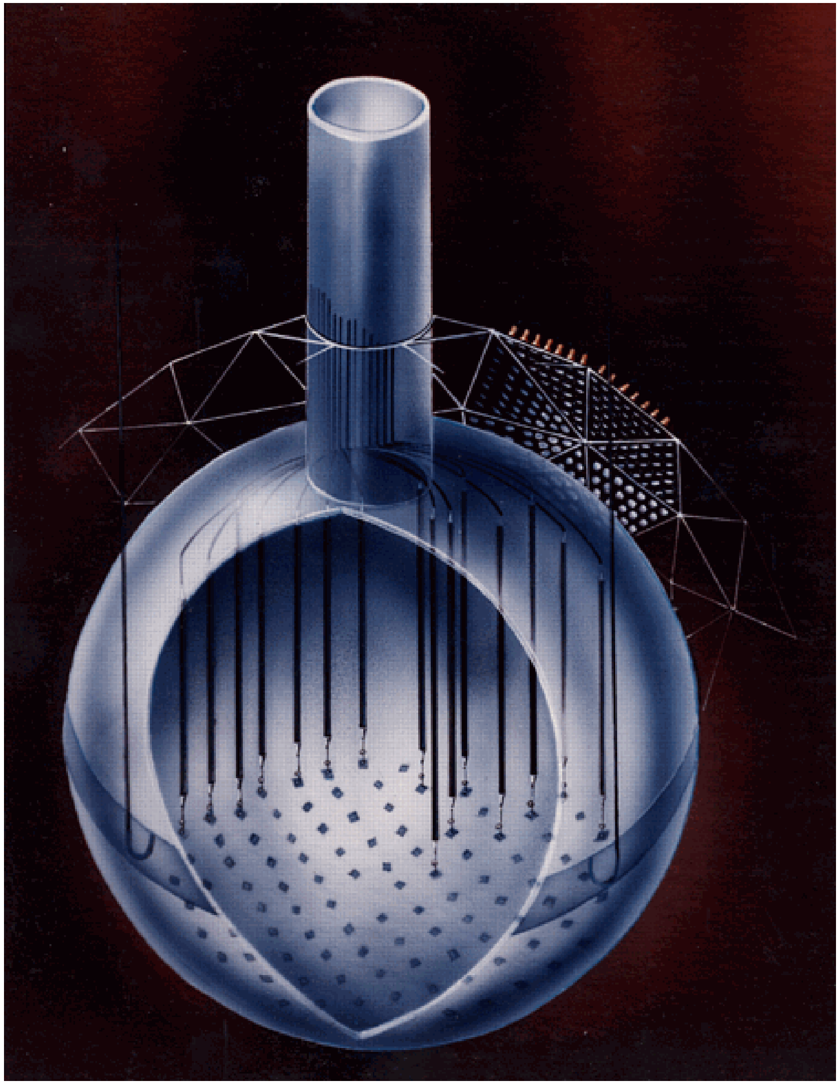
- any new experiment can yield a surprise
  - *Q: why make a measurement?*
  - *A: because you should take a look if you can!*

SNO Neutral Current Detectors

☆desalination polishing mode

☆NCD pre-deployment welding, preparations taking place

☆NCD deployment: Winter 2004



- NCD's act as a neutron "poison" → allowing cleaner look at low-energy CC spectral distortions
- event-by-event CC-NC separation eliminates statistical correlations

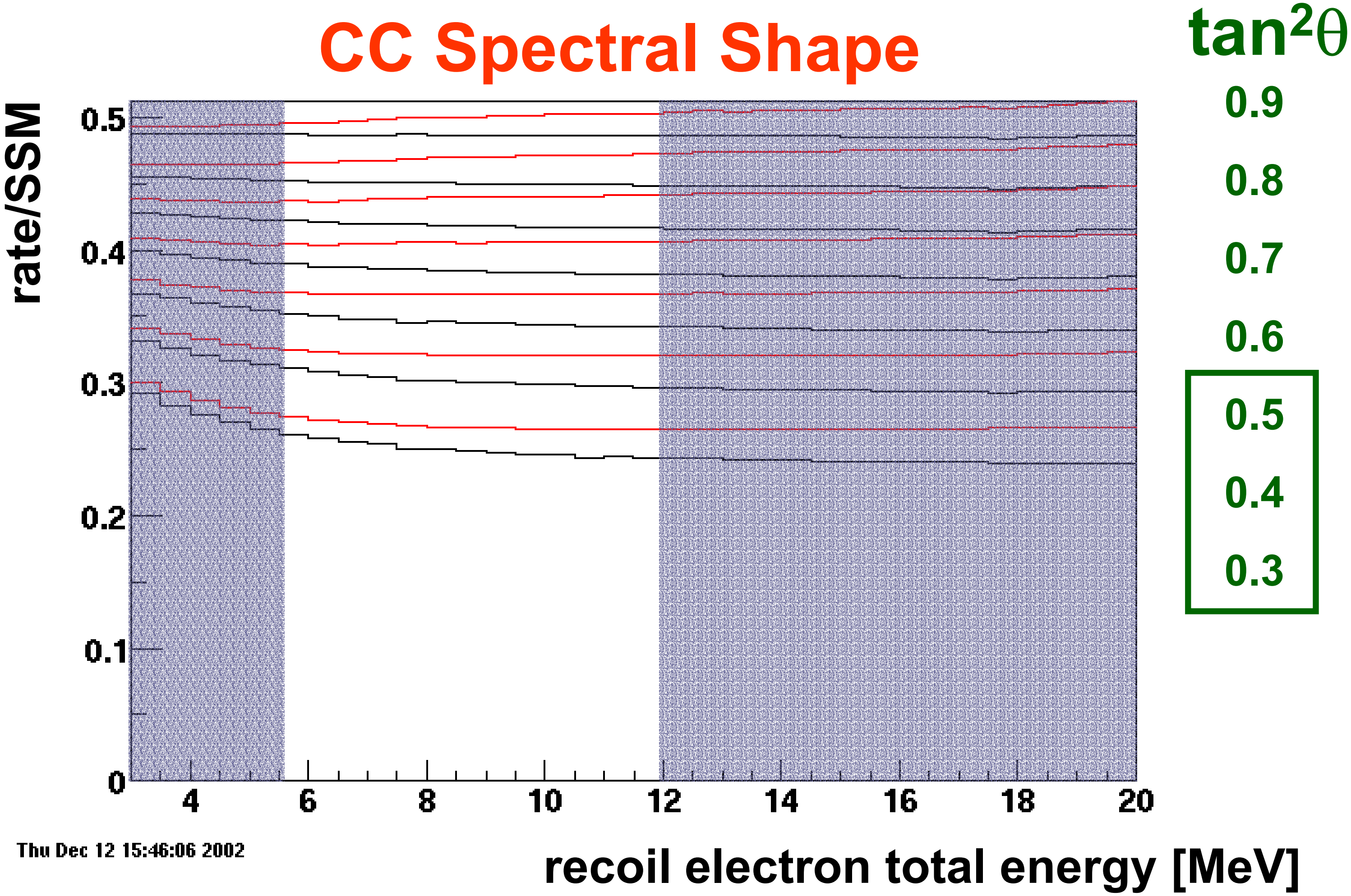
SNO LMA Observables

what will new SNO data tell us?

- spectral shape distortion
- CC/NC ratio → **direct measure survival probability**
- day/night asymmetry

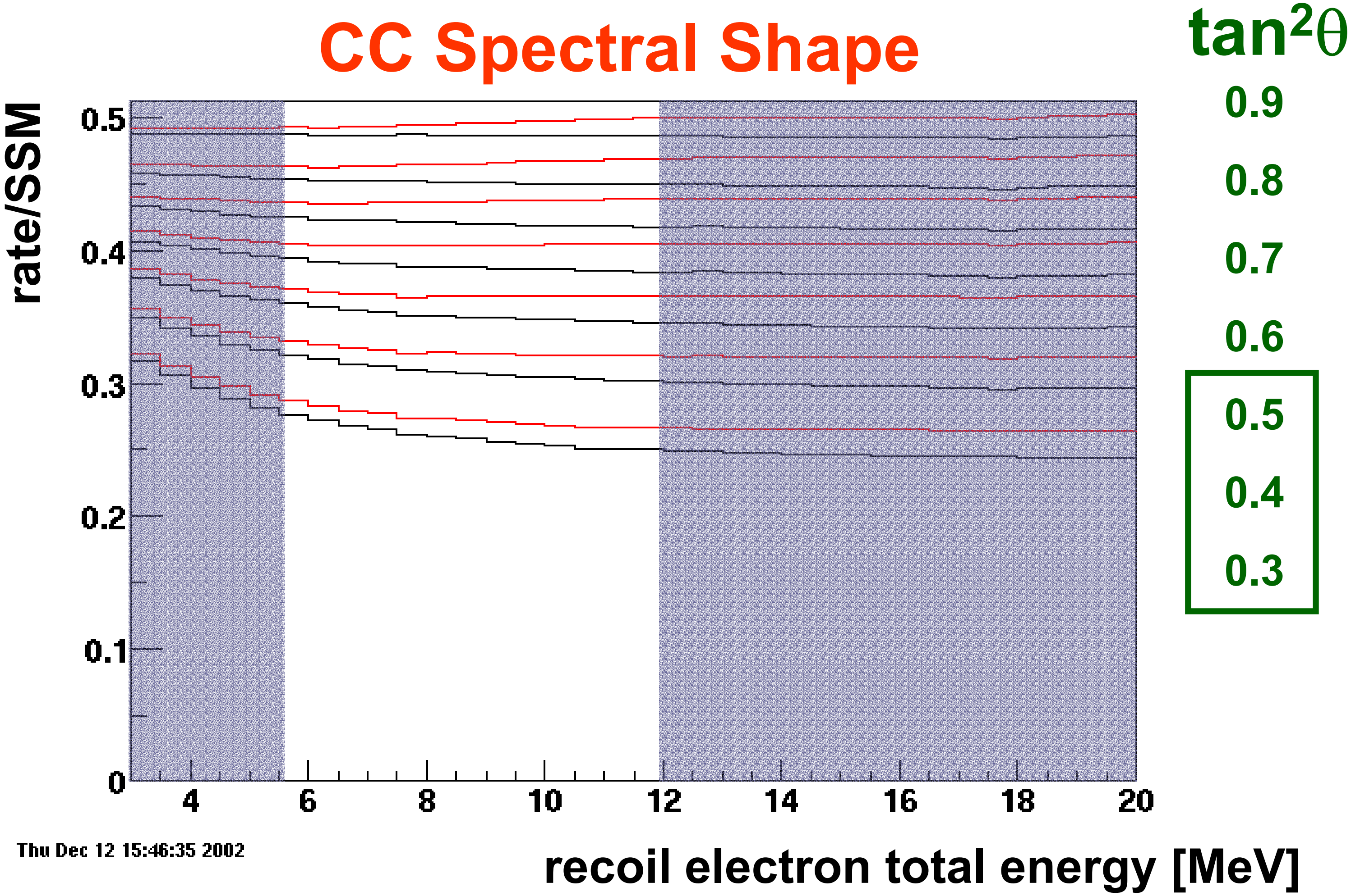
- CC-only theoretical, recoil electron spectrum (w/detector resolution)

SNO LMA Observables



$\Delta m^2 = 5 \times 10^{-5}\ eV^2$

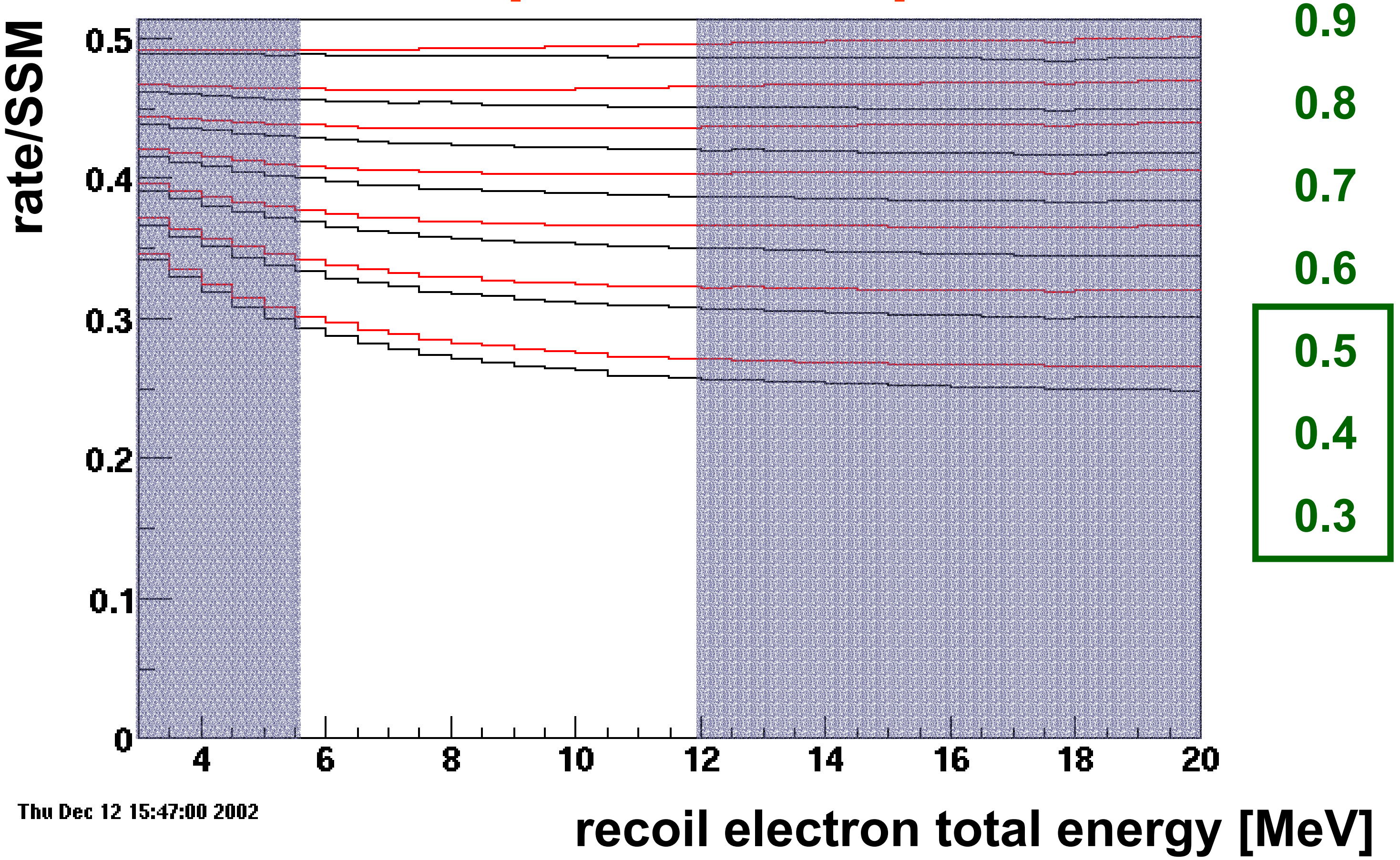
SNO LMA Observables



$\Delta m^2 = 6 \times 10^{-5}\ eV^2$

SNO LMA Observables

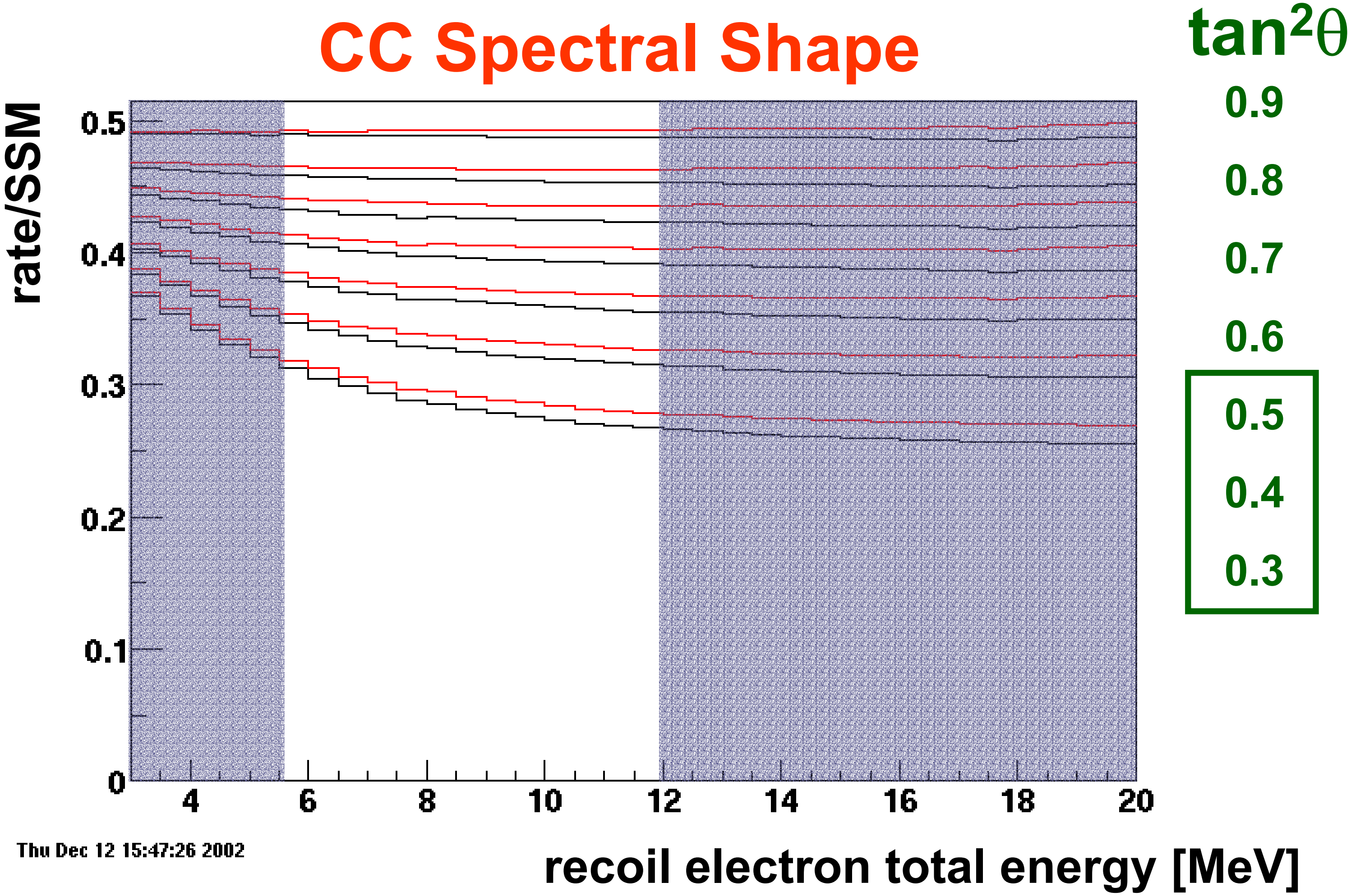
CC Spectral Shape



$\Delta m^2 = 7 \times 10^{-5}\ \mathrm{eV}^2$

SNO LMA Observables

CC Spectral Shape



$\Delta m^2 = 8 \times 10^{-5}\ eV^2$

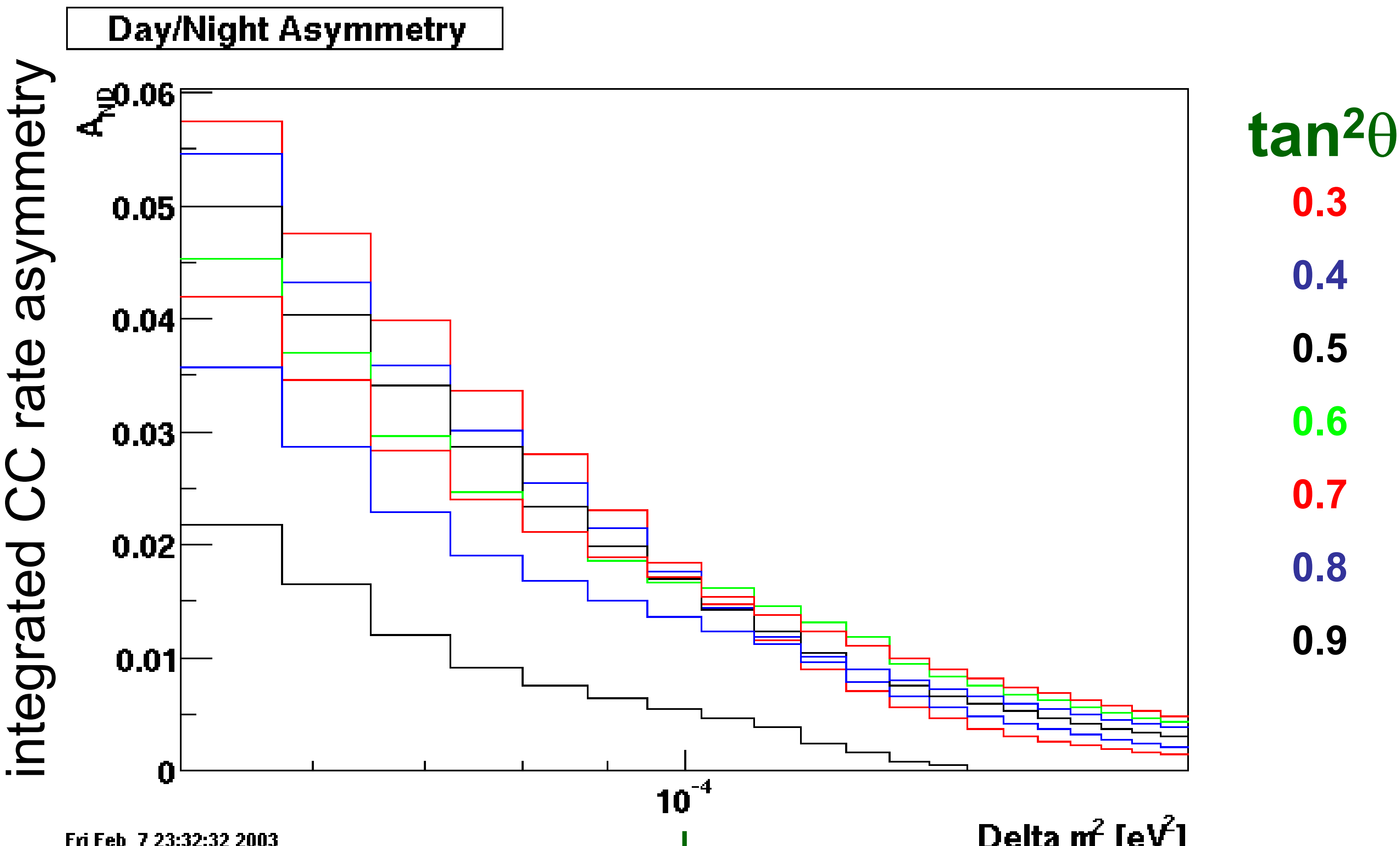
SNO LMA Observables

what will new SNO data tell us?

- spectral shape distortion
- CC/NC ratio $\longrightarrow$ **direct measure survival probability**
- day/night asymmetry

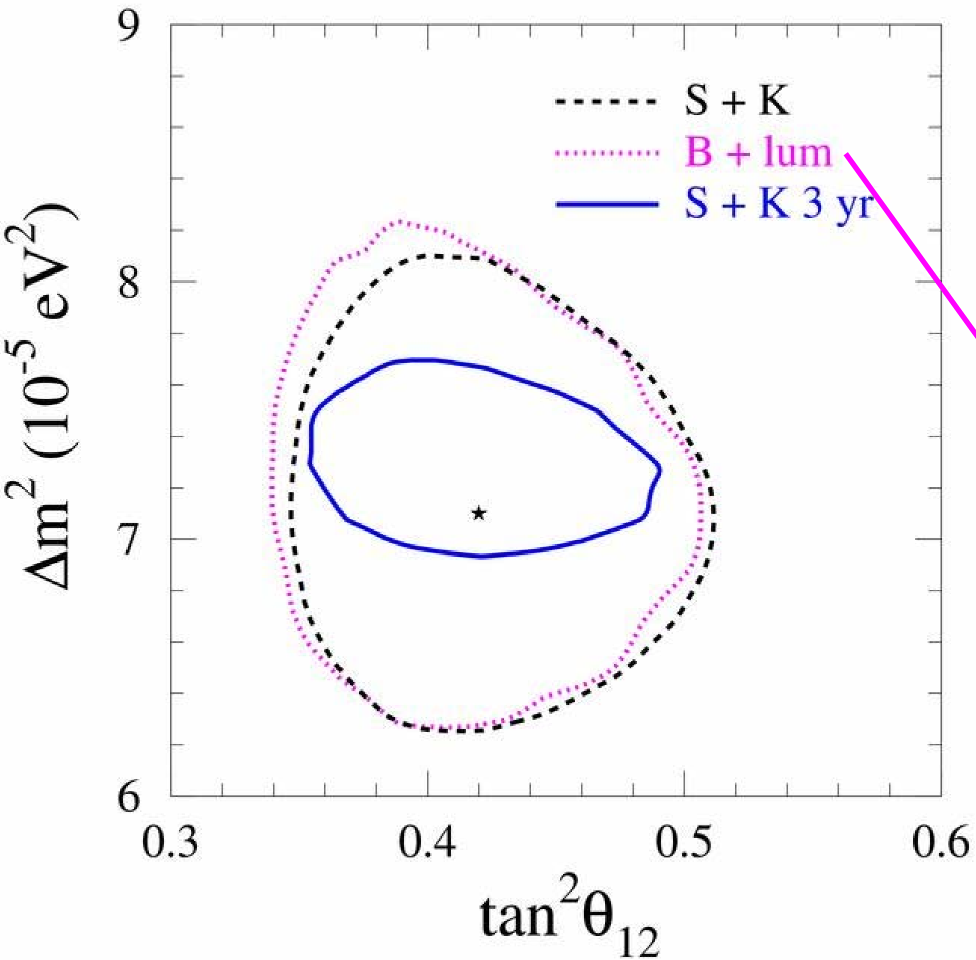
- day/night asymmetry would be evidence for MSW ν_e regeneration
- A_{ND} helps to specify Δm^2
- SNO pure D_2O result: $A_e = 7.0 \pm 5.1\%$

SNO LMA Observables



$3.3^{+5.7}_{-1.6}$ % | $0.6^{+1.1}_{-0.4}$ % ← Bahcall, Gonzalez-Garcia, Peña-Garay, hep-ph/0212147

Solar + KamLAND (3 yr)



1σ contours

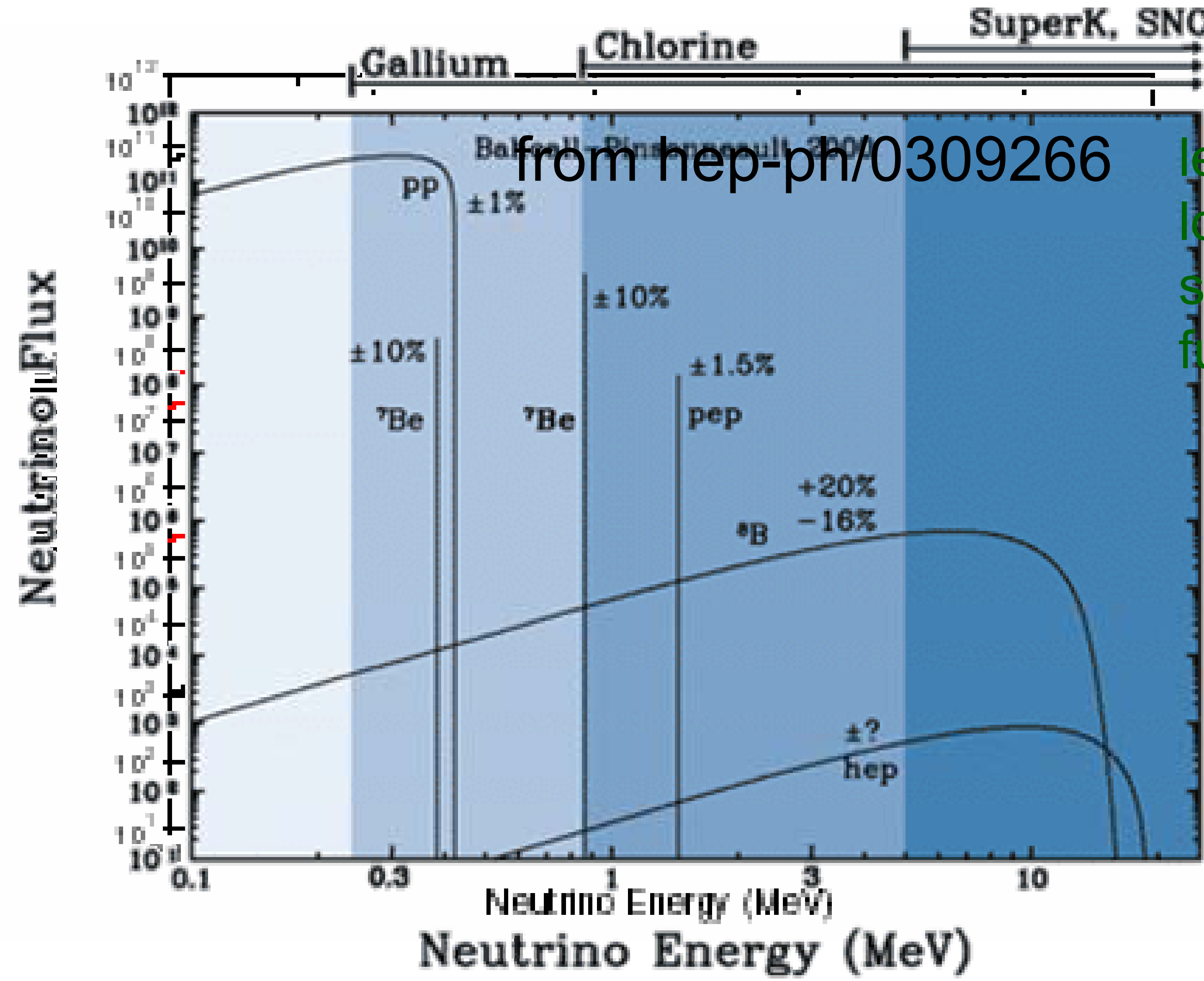
includes new SNO salt results

all ν fluxes free, subject to luminosity constraint

future KamLAND data will improve Δm^2 constraints; mixing angle from future SNO data…

from Bahcall and Peña-Garay, updated from hep-ph/0305159

Solar Neutrino Energy Spectrum



let's examine low-energy solar neutrinos further…

Future Solar ν Experiments

- low-energy *pp*, ^{7}Be (pep? CNO?)

CC	ES	
	Borexino	almost built
	KamLAND	upgrading for solar
LENS	CLEAN	
MOON	HERON	
	Solar TPC	
	XMASS	

proposed, being developed

My Random Thoughts

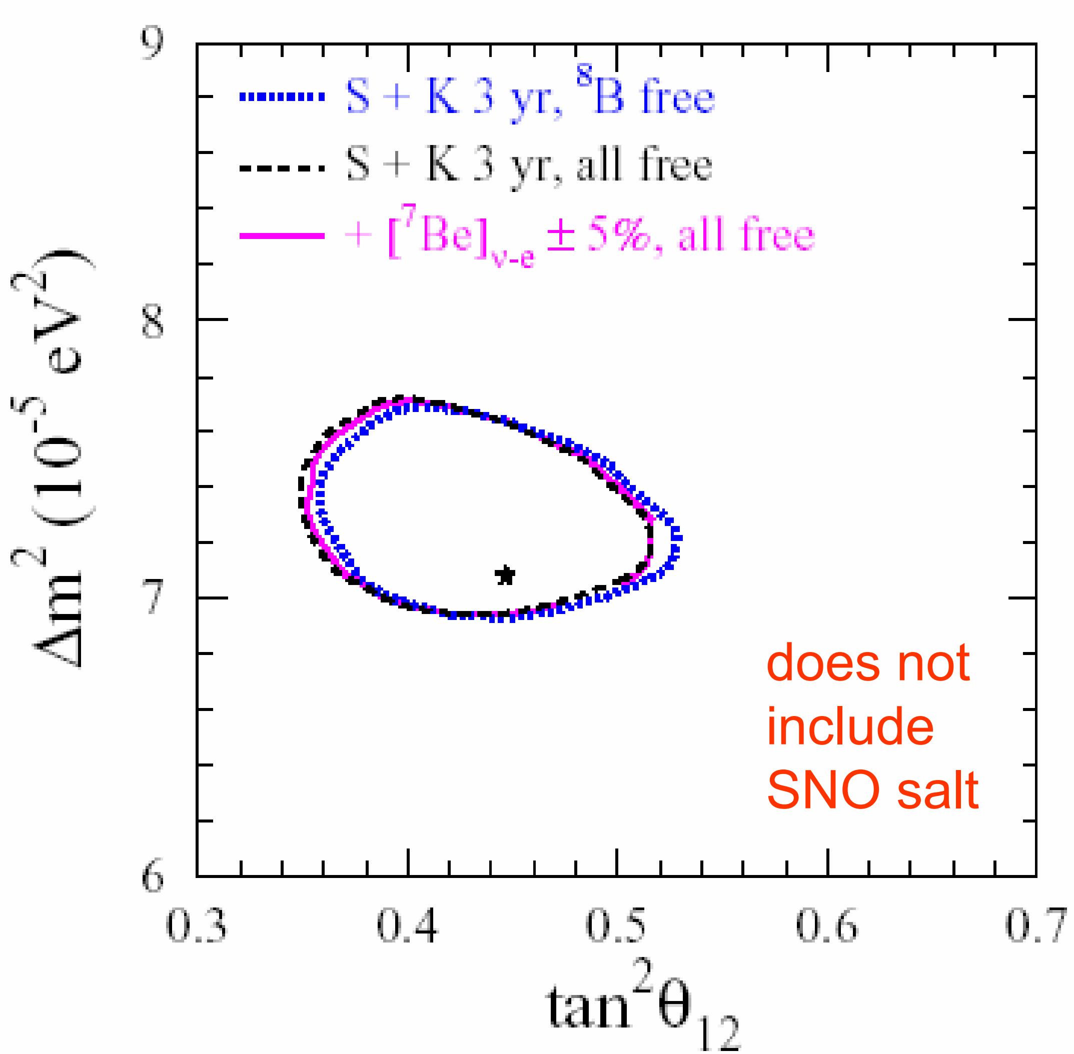
- *pp* CC: infer from Ga experiments… especially if you know the ^{7}Be ν_e contribution
- *pp* ES: 1% source and known cross section $\rightarrow$ helps to constrains θ_{12} and sub-dominant
- ^{7}Be CC: useful to combine with ^{7}Be ES
- ^{7}Be ES: useful to combine with ^{7}Be CC
  - otherwise, it's astrophysics
- CNO: interesting astrophysics

} for neutrino physics

More Random Thoughts

- for ^{7}Be CC and ES give total flux and survival probability
- for *pp* you can rely on the SSM flux prediction…CC or ES alone is sufficient
- ^{7}Be ES by itself (Borexino) does not improve knowledge of oscillation parameters much beyond present
- value of Borexino (nominal ^{7}Be) helps to constrain *pp* CC
- value of LENS (nominal *pp* CC) is actually to offer ^{7}Be CC as a companion for ^{7}Be ES

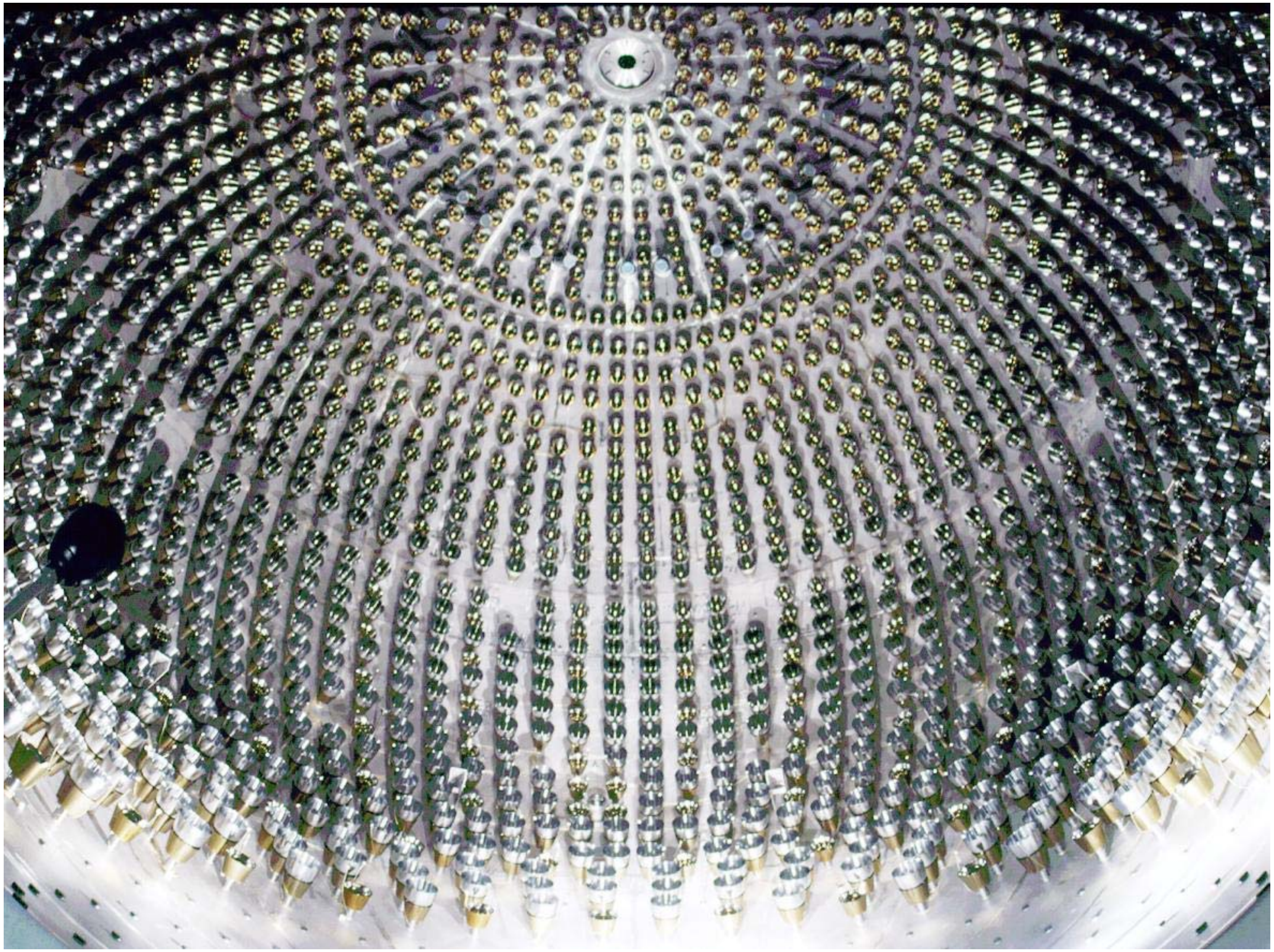
Simulating 5% ^{7}Be Measurement



- ^{7}Be ES ±10% measurement will shrink ^{7}Be flux uncertainty factor of four
- ^{7}Be ES ±5% measurement will shrink *pp* experimental flux determination to 0.5% error!

from Bahcall and Peña-Garay, hep-ph/0305159

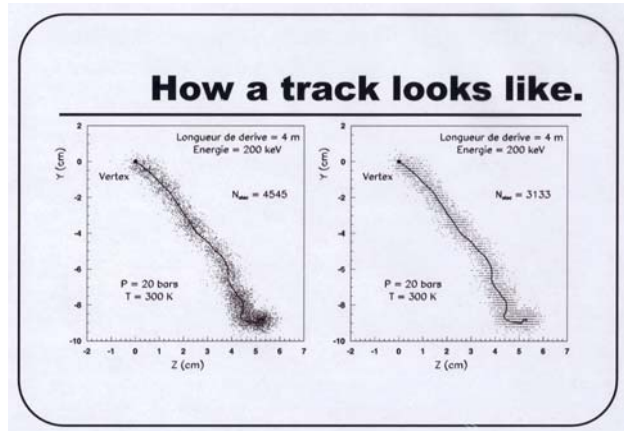
Borexino Detector

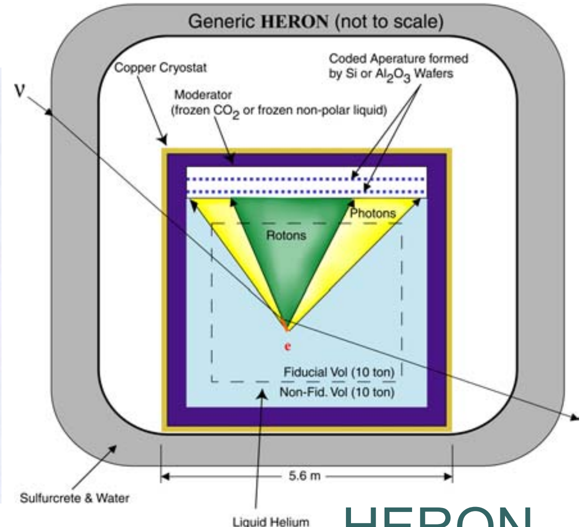


inside the inner detector stainless steel sphere

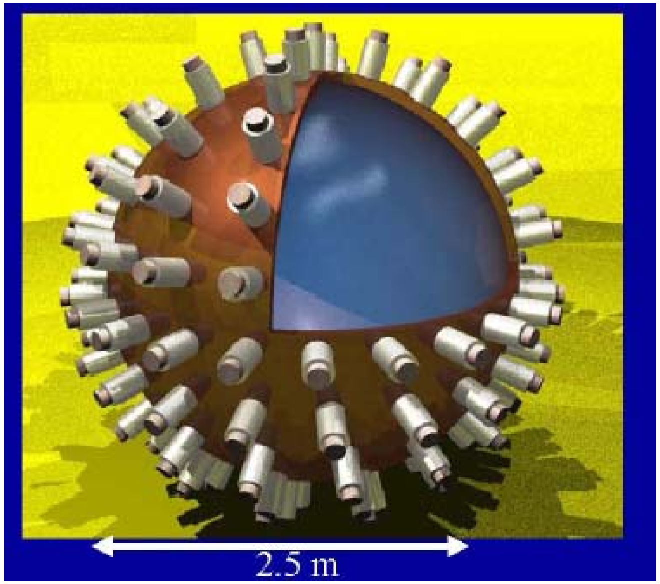
New Low-Energy Solar ν Detectors

HELLAZ





HERON

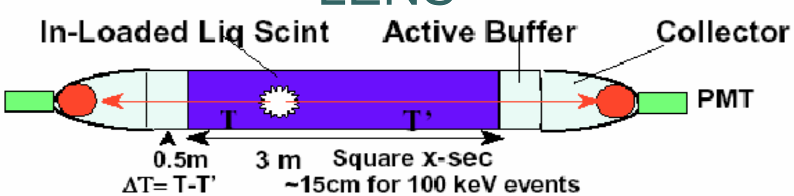


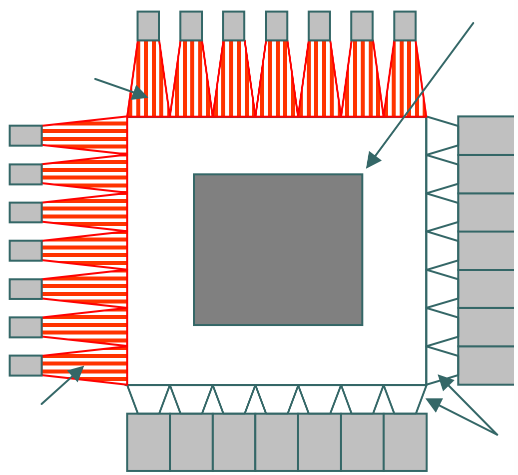
XMASS

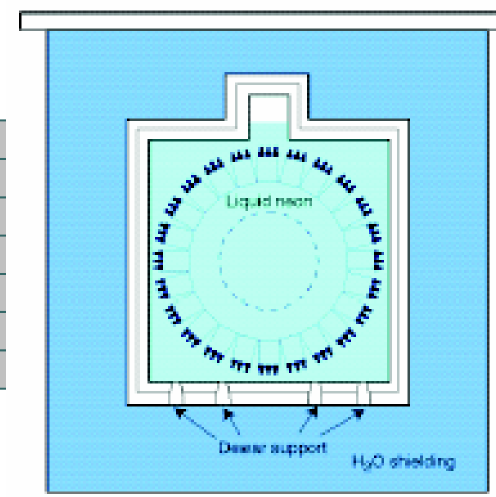
MOON

CLEAN

LENS

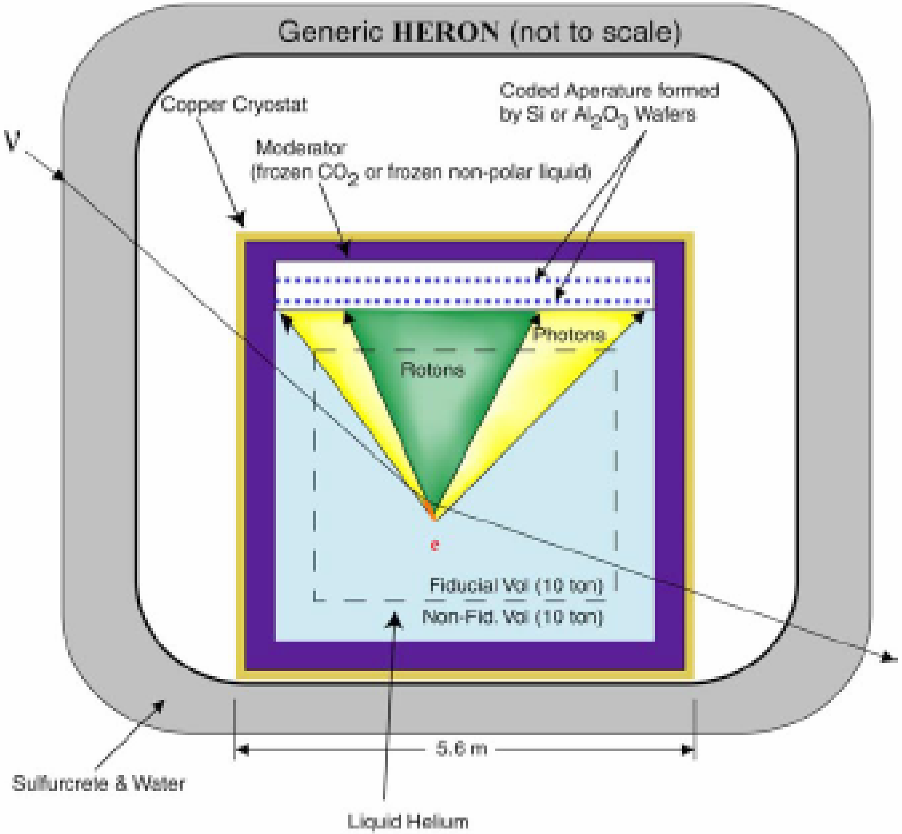






pp ES Experiments

- HERON
- CLEAN
- XMASS
- Solar TPC (HELLAZ)

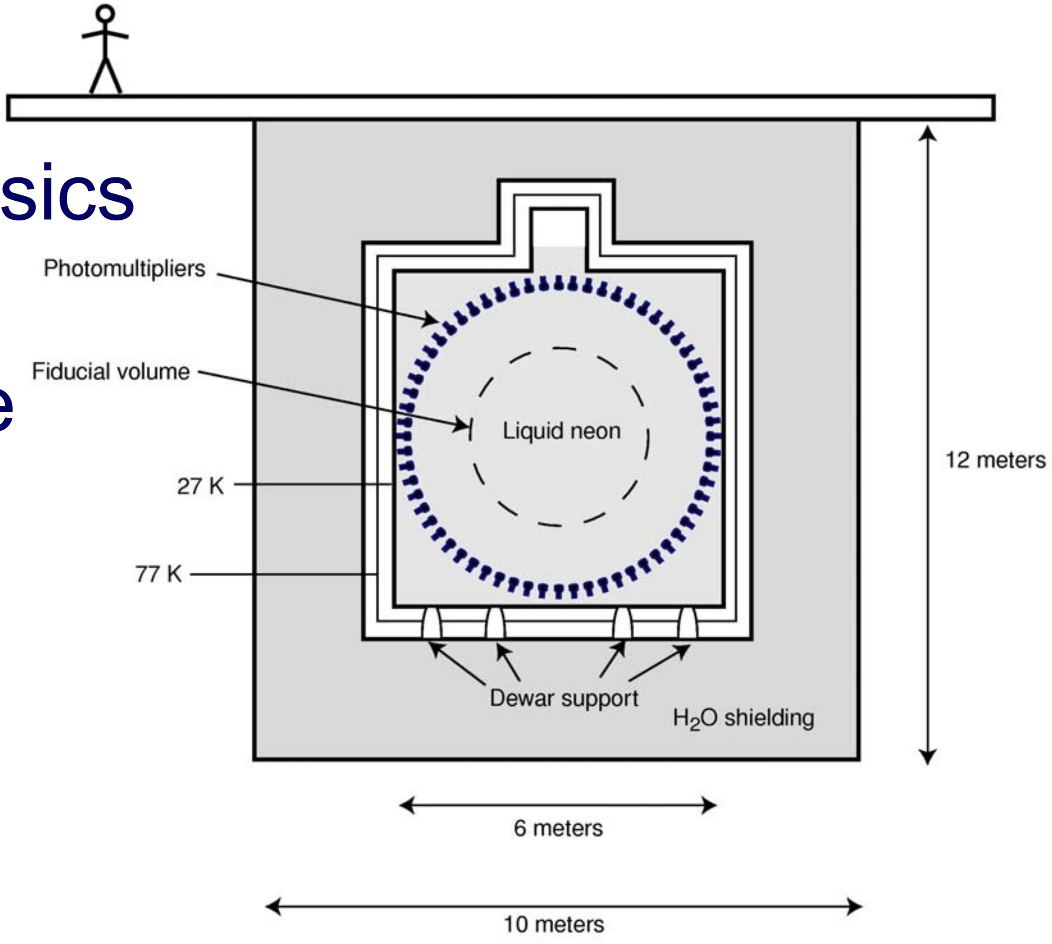


General Properties

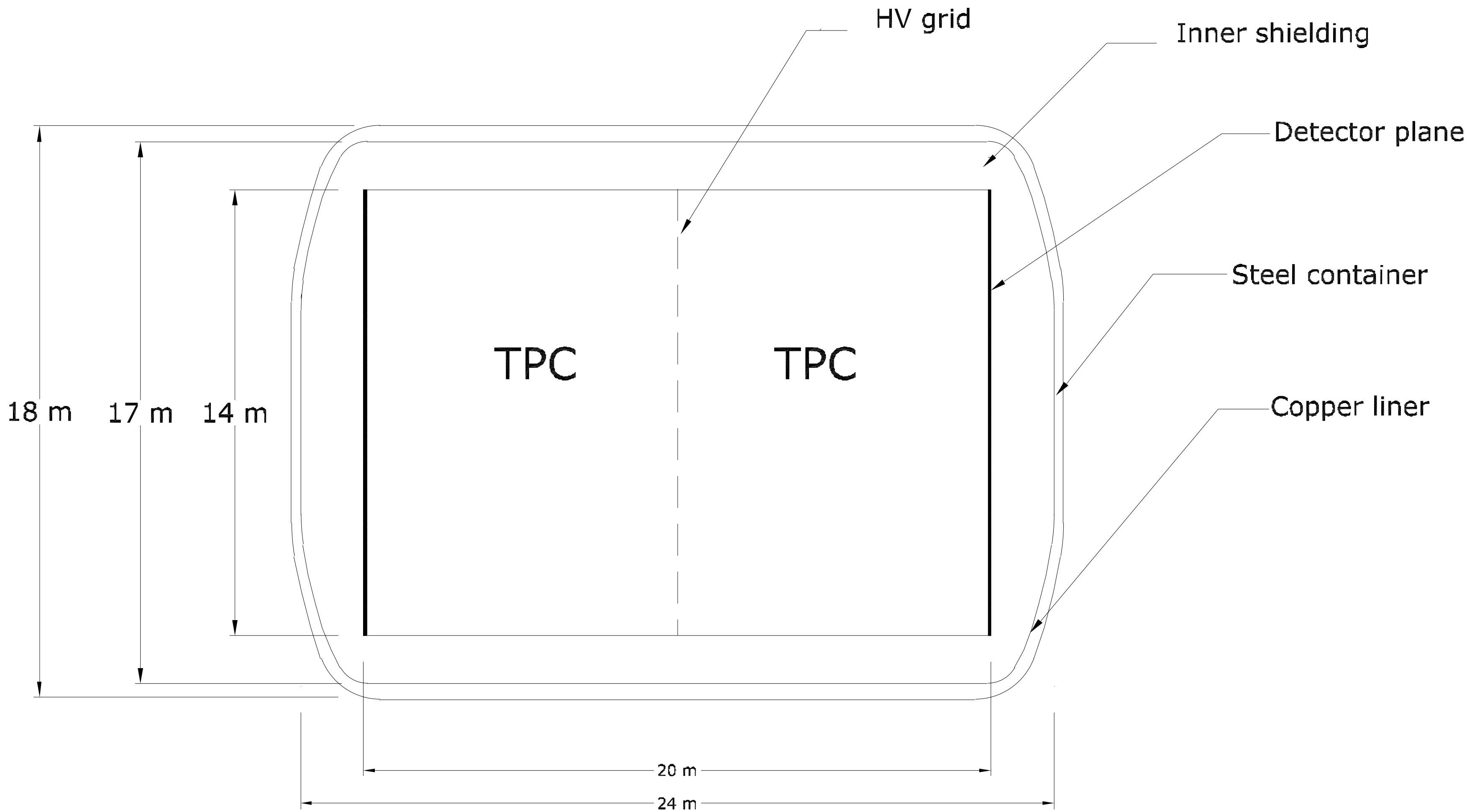
- Total Helium mass 20 (28) tonnes at 50mK.
- Detection: wafer calorimeters above liquid.
- Scintillation: 35% of E_e into 16 eV UV ($\lambda_{Rayl.} > 200$ meter).
- Scintillation/rotons or Scintillation/e-bubbles. (complement & redundancy)
- Event location: coded aperture array; few cm.).
- Fiducial volume variable: 1.25 evts/(day-tonne) SSM $E_{recoil} > 50$ keV .
- No internal backgnd (superfluid self-cleaning).
- No radon diffusion at low temperature.
- Helium immune to muon spallation/capture.
- External backgrounds from Gammas :
  - Deep site & Shielding
  - Material
  - Event signature (coded aperture)
  - Fiducial cuts

CLEAN

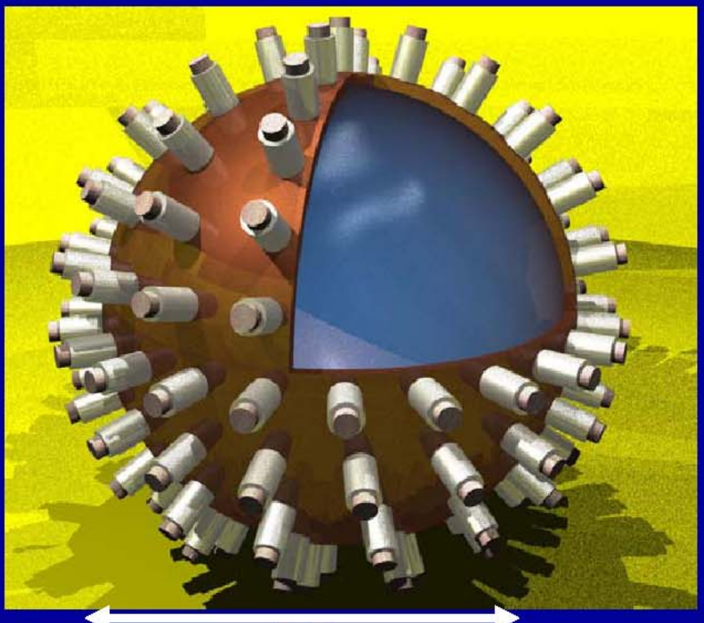
- Cryogenic Low Energy Astrophysics with Neon
- scintillating noble liquid detector
- very low intrinsic radioactivity



Solar TPC (4000 m^3, 7 tons of He)

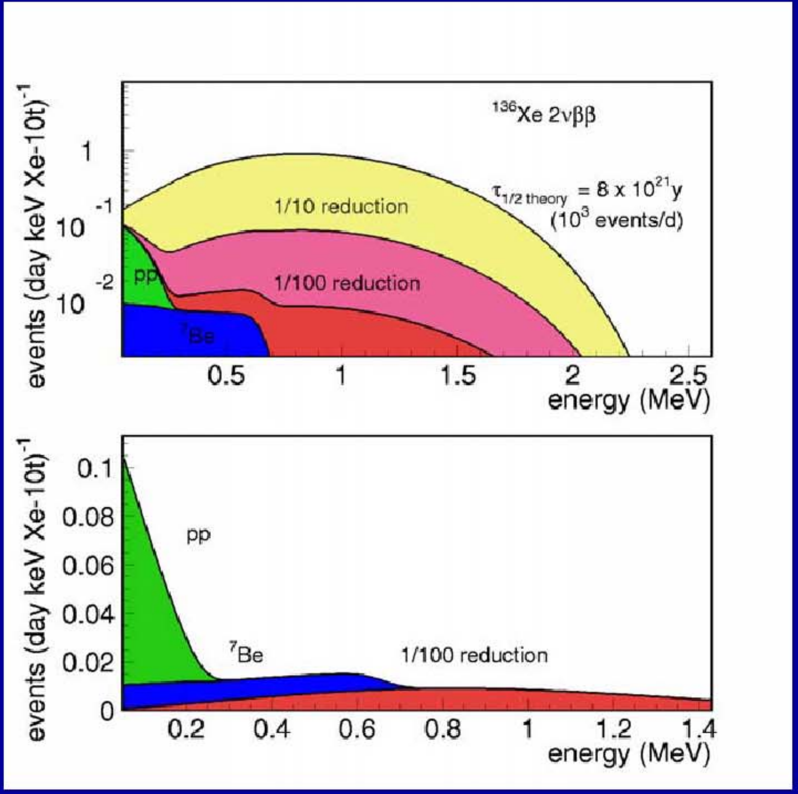


XMASS – liquid xenon scintillation detector for solar-ν, DBD & DM

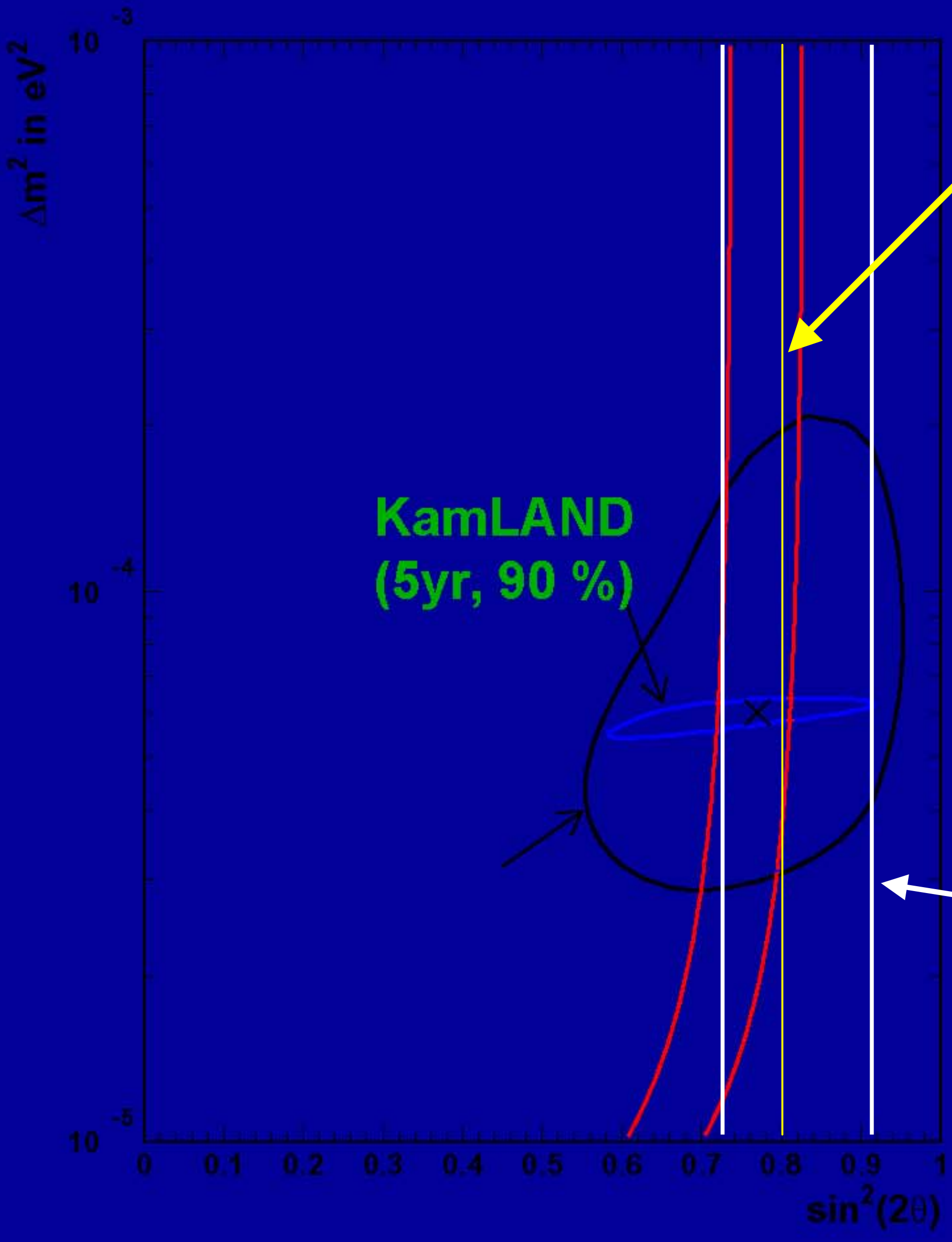


- Detection reaction: ES ($\nu + e^- \rightarrow \nu + e^-$)
- 23 t (10 t fid.) detector
- 30cm self-shield (ρ=3.06 g/cm³)
- 1350 3´´ PMTs
- 42,000 scintillation photons/MeV
- No inactive buffer (23t volume active)

XMASS: expected ν-signal and
2ν-ββ background of Xe-136



XMASS: Θ_{sol} – sensitivity



Bahcall and Peña-Garay,
hep-ph/0305159
3% measurement, 1σ

pp neutrino flux measurement (90 % C.L.) by :

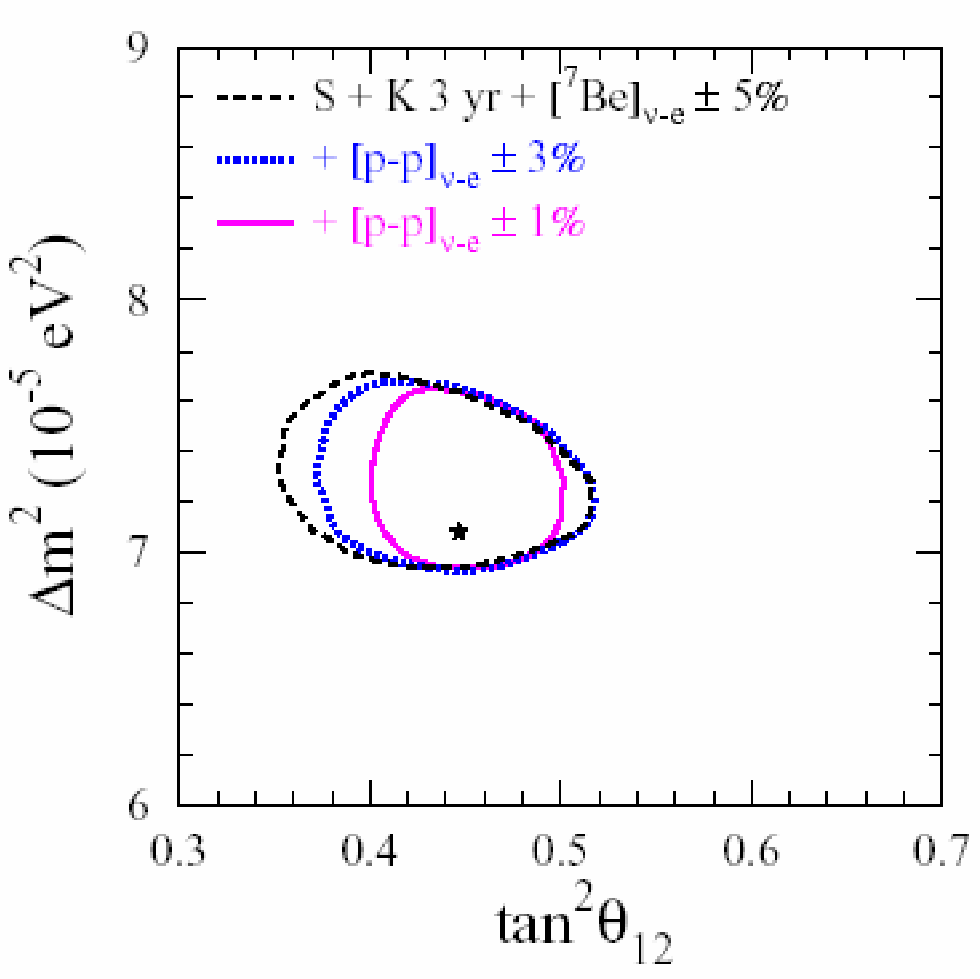
- ES, 10 ton detector
- 5 years data
- (Statistical error + SSM flux uncertainty(1%))

Accuracy of mixing angle :
$\sin^2 2\Theta = 0.77 \pm 0.03$ (stat.+SSM)

SNO Salt 90% CL angle range

Nakahata, LowNu 2002
additional bounds added

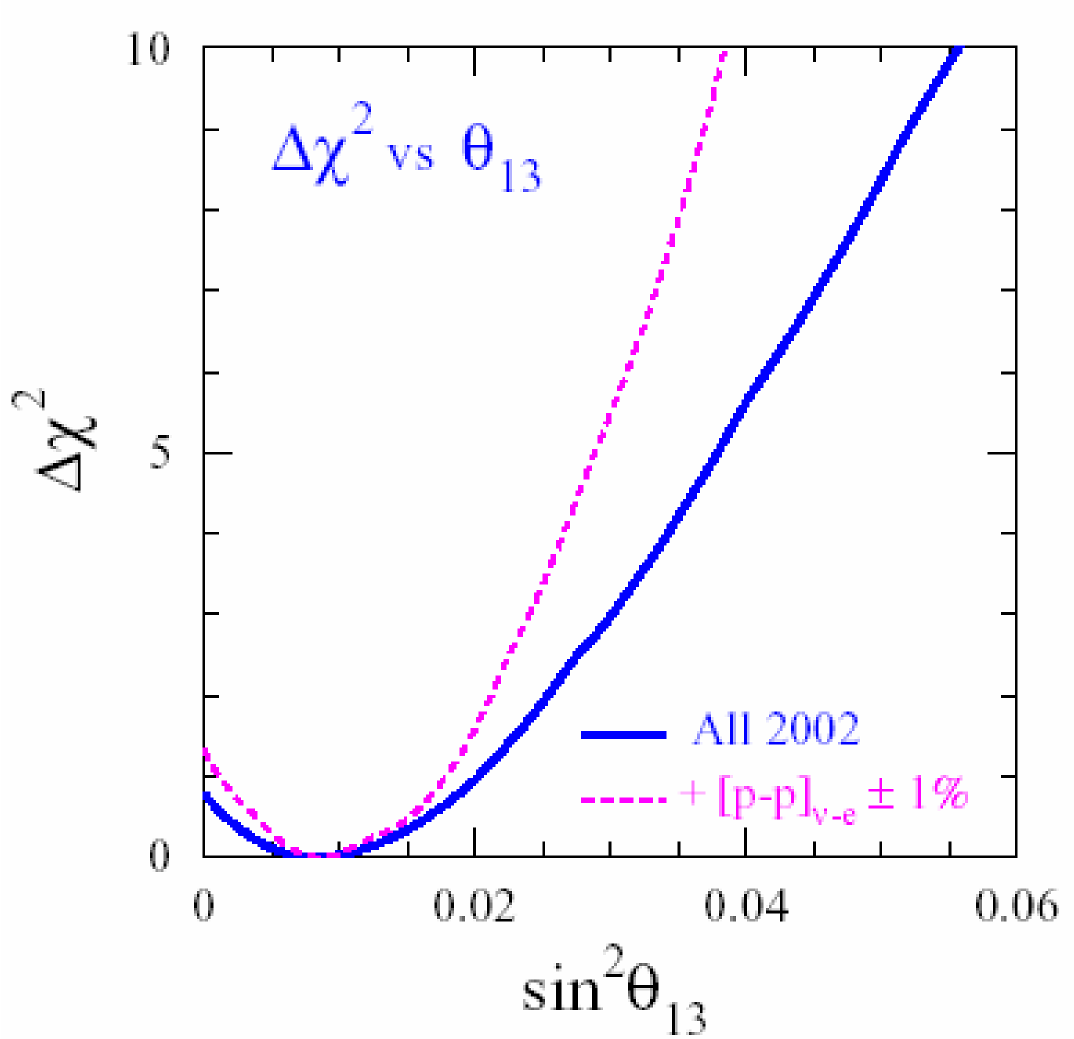
Simulating 3% *pp* Measurement



- must achieve 3% or better measurement to start constraining the oscillation analysis
- ES superior to CC since CC will have cross section uncertainty at least 1%, likely much higher

from Bahcall and Peña-Garay, hep-ph/0305159

pp θ_{13} Sensitivity



- marginal improvement in θ_{13} limit
- 3σ limit goes from current $\sin^2\theta_{13} < 0.05$ down to $\sin^2\theta_{13} < 0.036$

from Bahcall and Peña-Garay, hep-ph/0305159

pp (^{7}Be) CC Experiments

- LENS
- MOON

LENS: Low Energy Neutrino Spectroscopy

Method

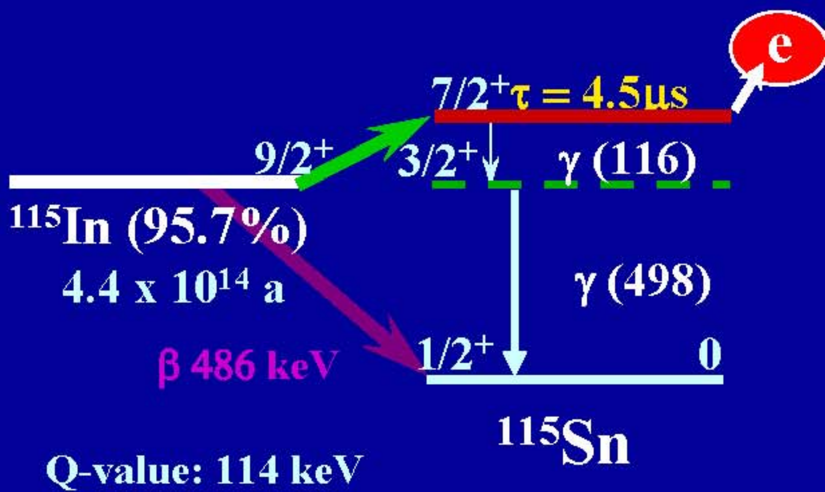
•charged current **(CC)** transition (inverse EC) to excited level (ν_e – only!)

$$E_e = E_{\nu e} - E_{thr}$$

$$\nu_e + (A,Z) \Rightarrow e^- + (A,Z+1)^*$$

delay

$$(A,Z+1) + \gamma$$



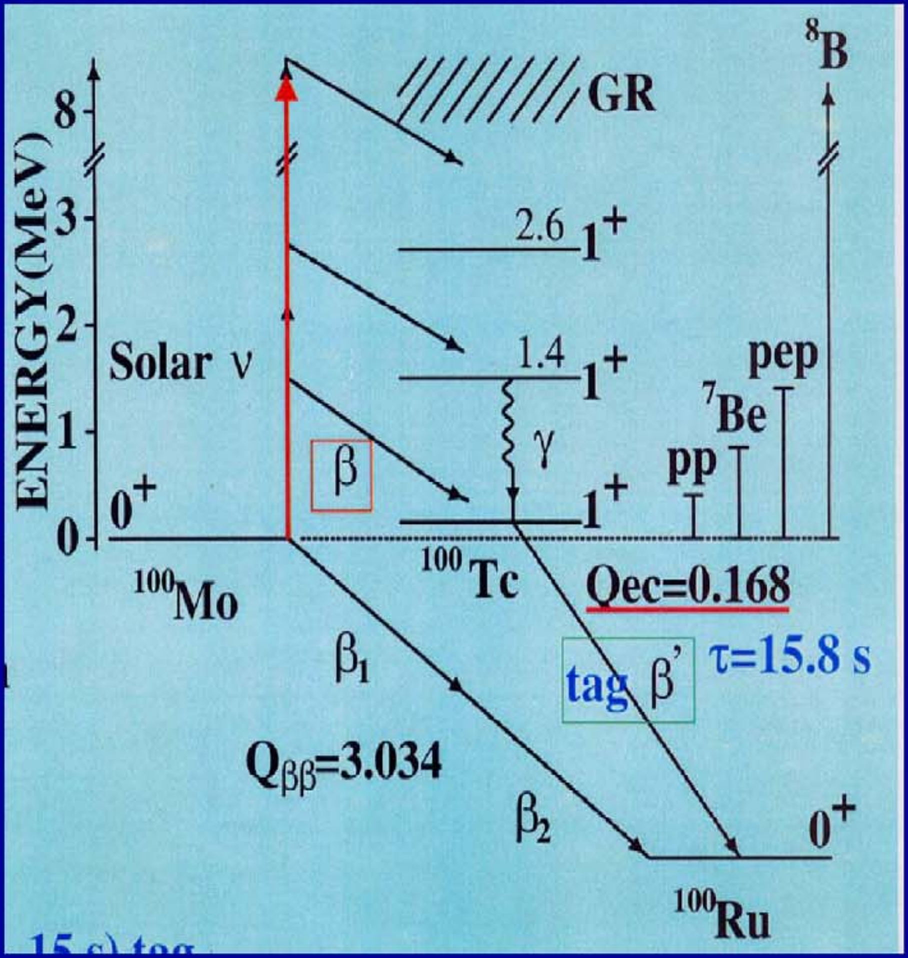
⇒Complement to BOREXINO/XMASS **(ES)**

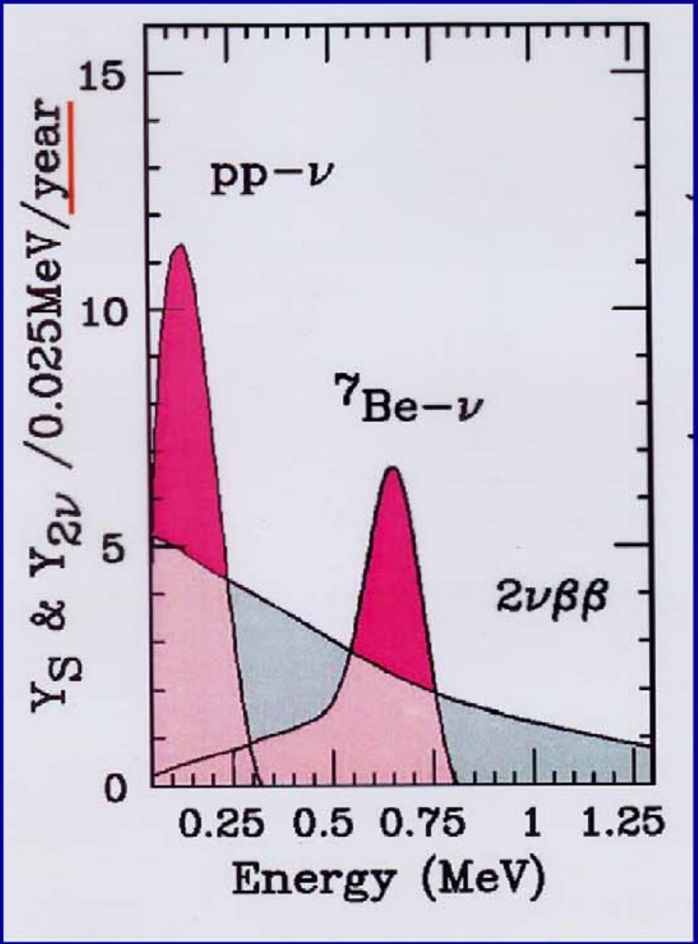
•low-energy threshold: **pp-, Be-7,...**

•ν_e – tag to discriminate against background

•ν_e –target (=Yb, In) loaded into liquid scintillator

MOON - ^{100}Mo CC detection for solar-ν, DBD

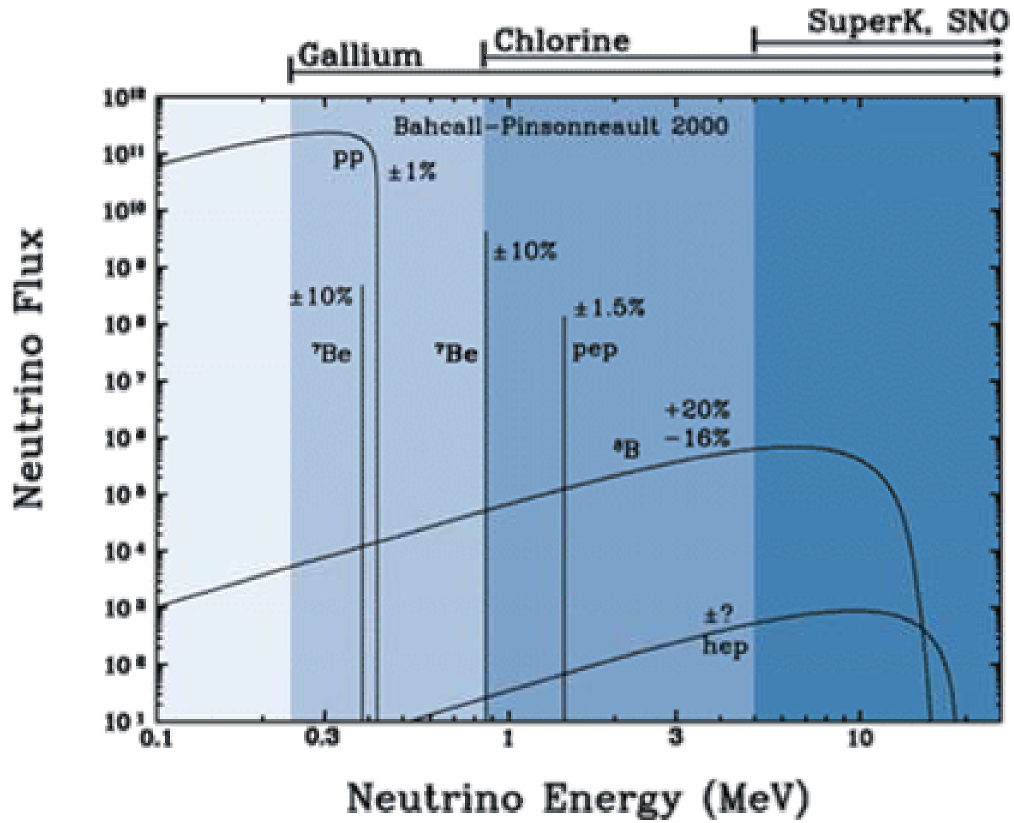




Challenge: detector granularity ~ 1/10^9 required

pep Solar Neutrinos

- solar model flux uncertainty is ±1.5%
- ν–e⁻ scattering cross section (no uncertainty)
- rate measurement at the O(%) level possible
- ~3000 events per year in 600 fiducial tons (LMA oscillated)

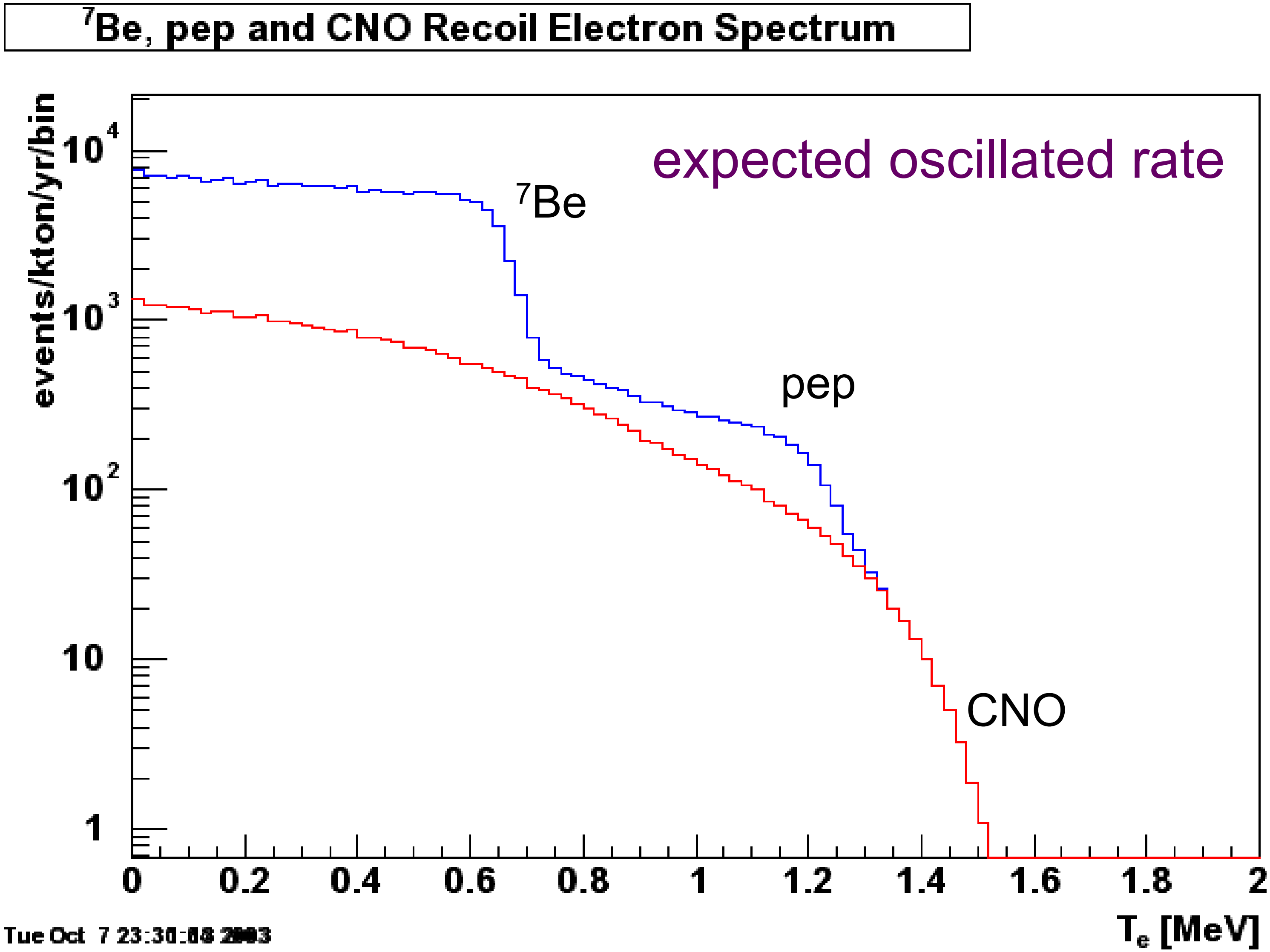


pp and *pep* solar neutrinos are standard candles

Solar *pep* Experiment

- fill SNO with a liquid scintillator after we're done with the heavy water
- observe *pep* neutrino-electron scattering recoil edge
- Borexino (and KamLAND) liquid scintillator purification techniques combined with SNO low-background experience

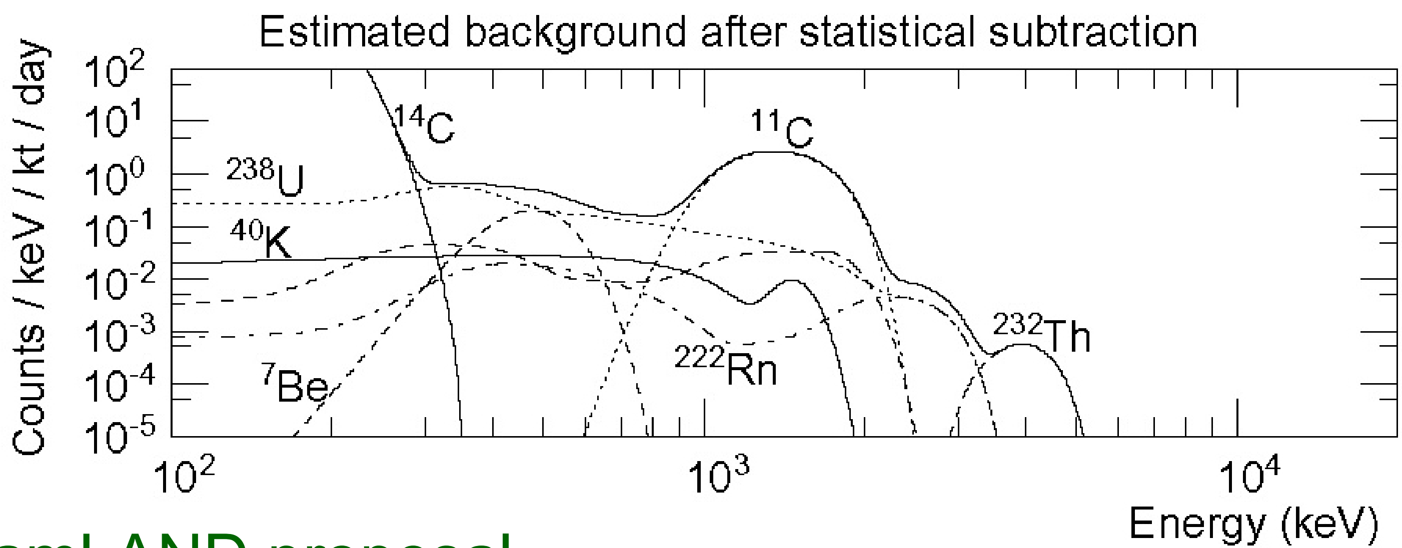
pep Recoil Electron Spectrum



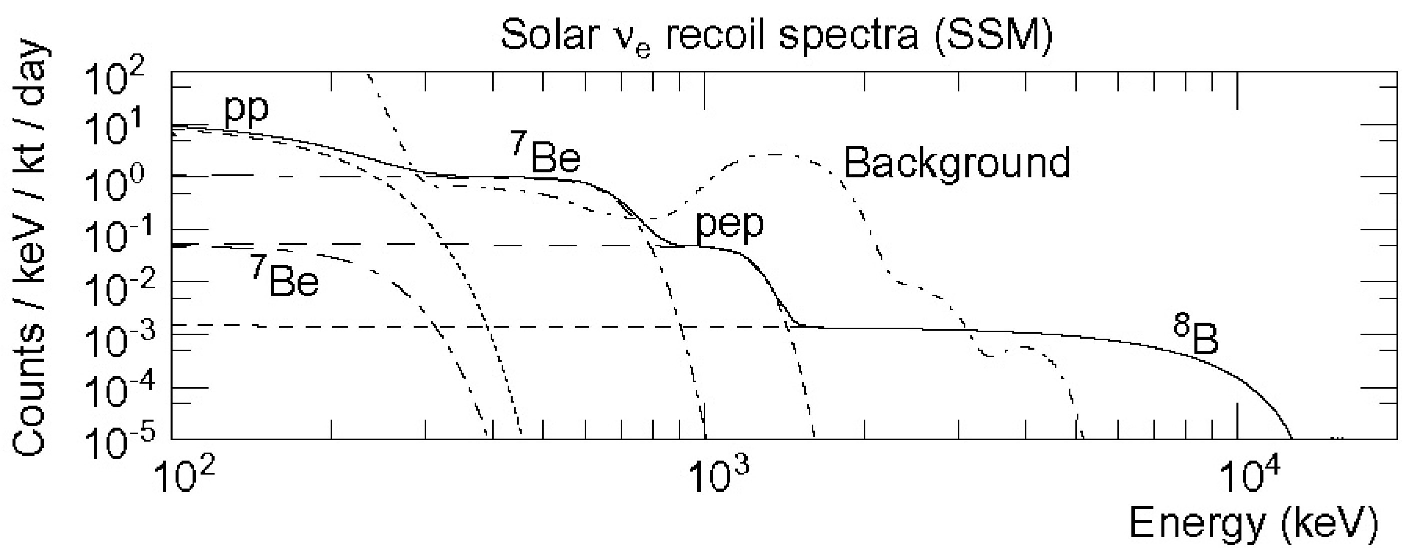
pep Solar Neutrino Backgrounds

- KamLAND (and to a lesser extent Borexino) cannot detect *pep* solar neutrinos due to underground ^{11}C cosmogenic production
  - 20 minute half-life of ^{11}C cannot be vetoed
  - positron decay guarantees 1 MeV energy deposited, right in the *pep* $\nu - e^-$ recoil window
- CNO neutrinos are a background
  - good energy resolution desired to see clear "recoil edge" for monoenergetic *pep* ν
- radiopurity requirements likely to be challenging
  - U, Th, K, ^{210}Bi (Rn daughter) Q_β = 1.2 MeV
  - ^{85}Kr, ^{210}Po (plaguing KamLAND) not a problem

^{11}C Cosmogenic Background



from KamLAND proposal



Precision θ_{12} in SNOLAND? SNOrexino?

- 70 muons per day thru SNO versus 10,000 muons per day thru Borexino at Gran Sasso! (and more through KamLAND)
- larger detector (than Borexino) helps to detect smaller *pep* solar neutrino flux
- takes advantage of SNOLAB's deep site; possible conversion of the existing SNO detector for a future, new measurement

Concluding Question

- how well do we need to measure θ_{12} and Δm^2_{12}?