Future Solar Neutrino Experiments

GOAL:

-Determination of neutrino oszillation parameters
-quantitative determination of solar fusion processes

NEEDED:

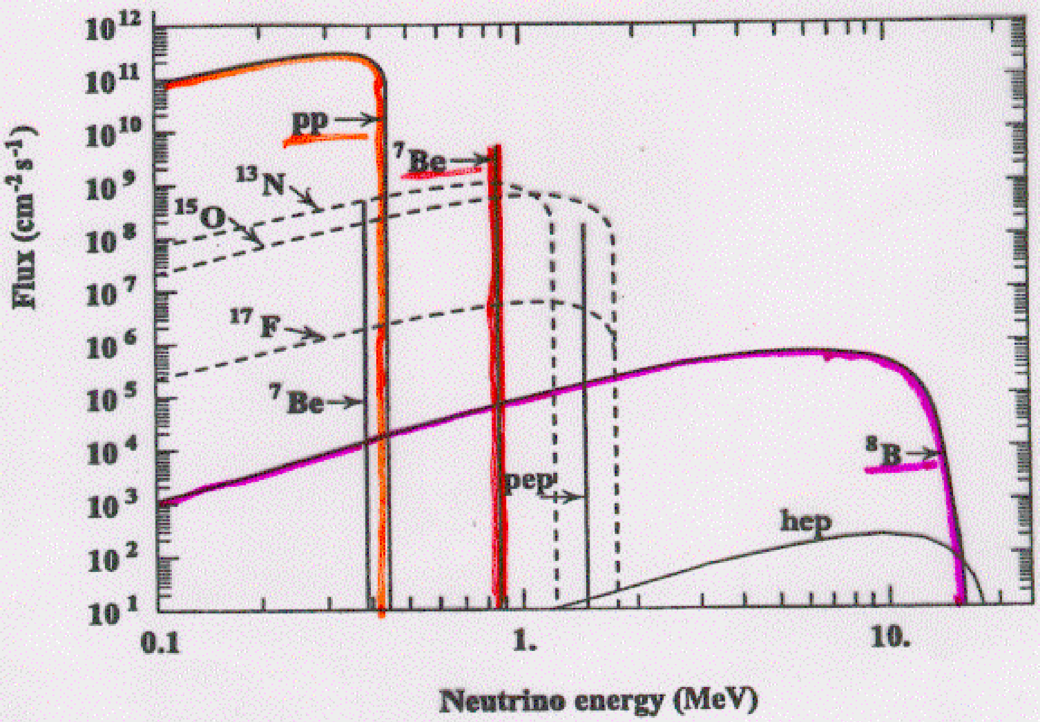
experimental determination of the solar neutrino spektrum in

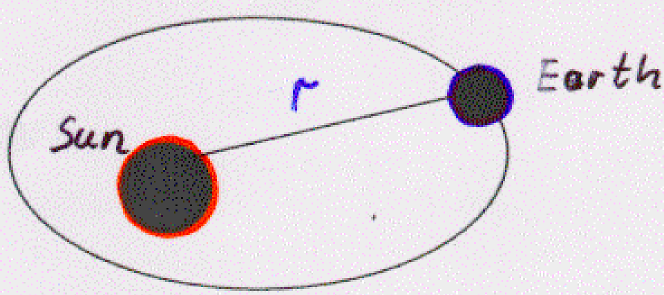
-CC(+ NC)- reaction: ν (e)

-NC - reaction: ν (μ) , ν (τ)

solar ν - spectrum from pp-fusion

$$4\,p \rightarrow 4\,He + 2\,\nu(e) + 27\text{ MeV}$$





$$\Delta r = r(\max) - r(\min) \approx 5 \text{ mio Km}$$

$$r = r(t)$$

Status:

-„High" energy part : 8B spectral information !

--NC + CC from ν, e - scattering SK,SNO

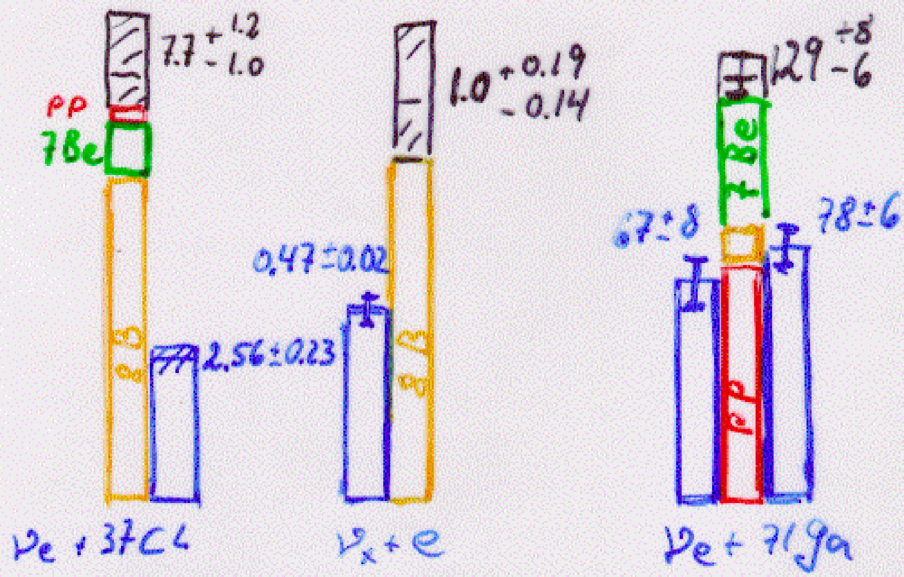
-„Low" energy part:

--CC inverse β decay on 71 Ga $E(\nu) \geq 233keV$

37 Cl $E(\nu) \geq 814$ keV

for pure CC interaction is no energy despersive information avalable up to now

experimental Results



can be explained by ν- oscillations

$$\nu(x) = \sum U(\alpha,i)\,\nu(i)$$

ν(x) Flavour Eigenstates   ν(i) Mass Eigenstates

Interference → oscillation

oscillation length :

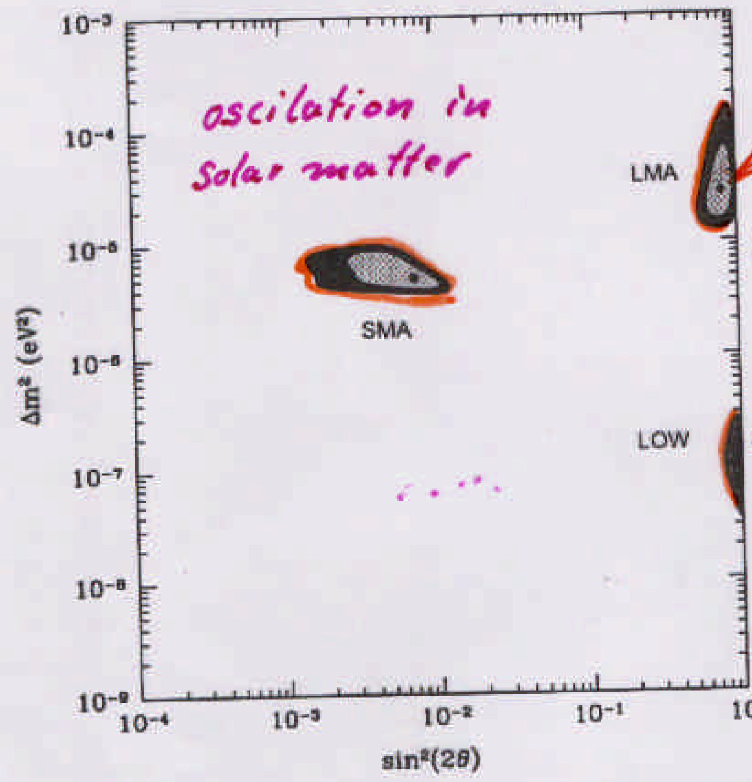
$$L(i,j)\,[m] \approx 2.5\;E\,[MeV] / \Delta m^2(i,j)\,[eV^2]$$

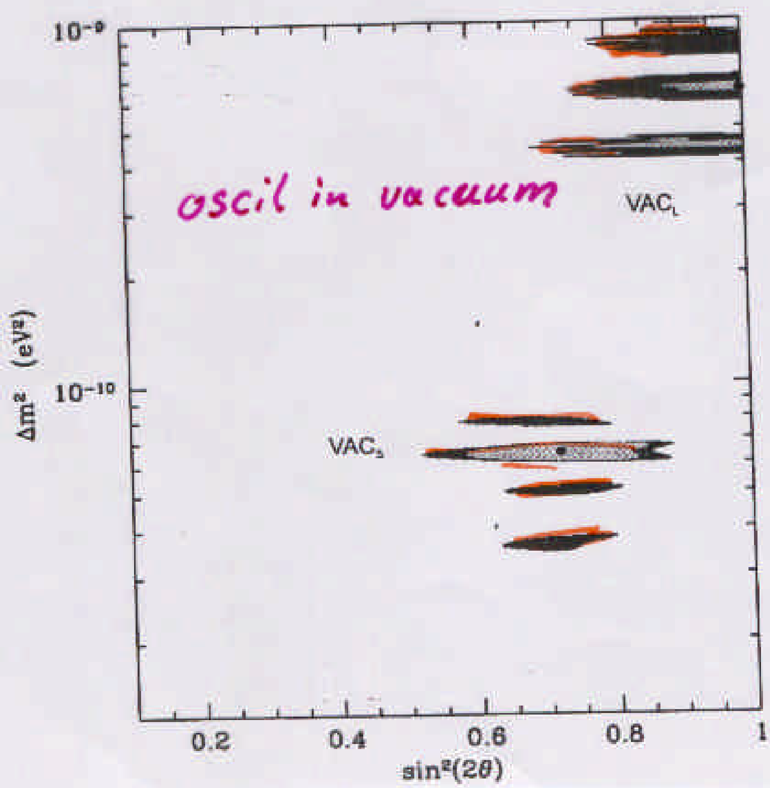
interaction in matter → m (ν) → m (ν) effective

matter induced oszillation

ν mass and mixing parameters

consistent with experimental data



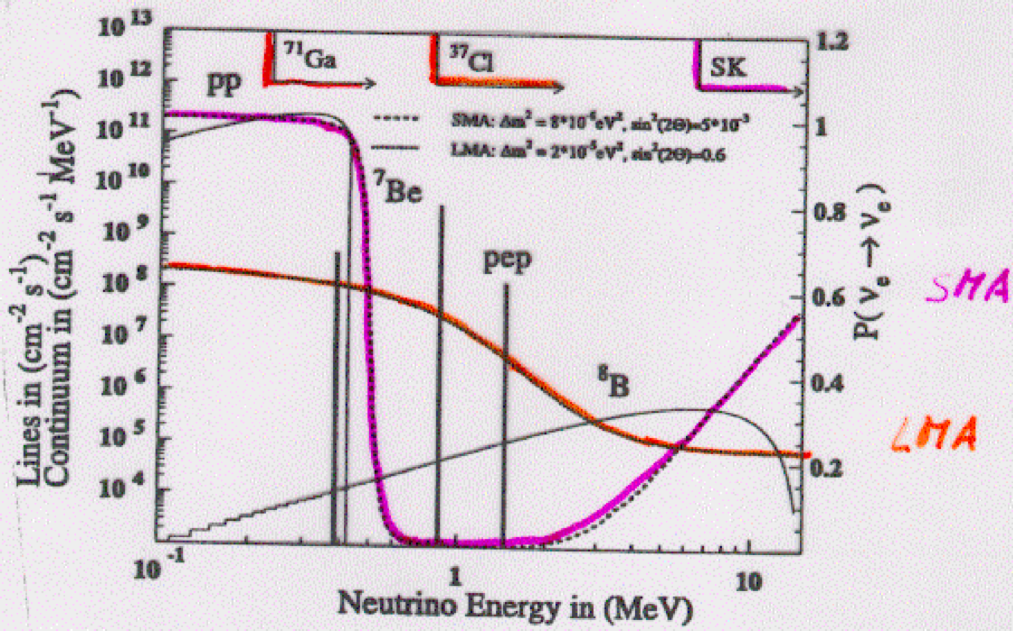


$N(\nu) = N_{(\nu)}(t)$

t ~ season

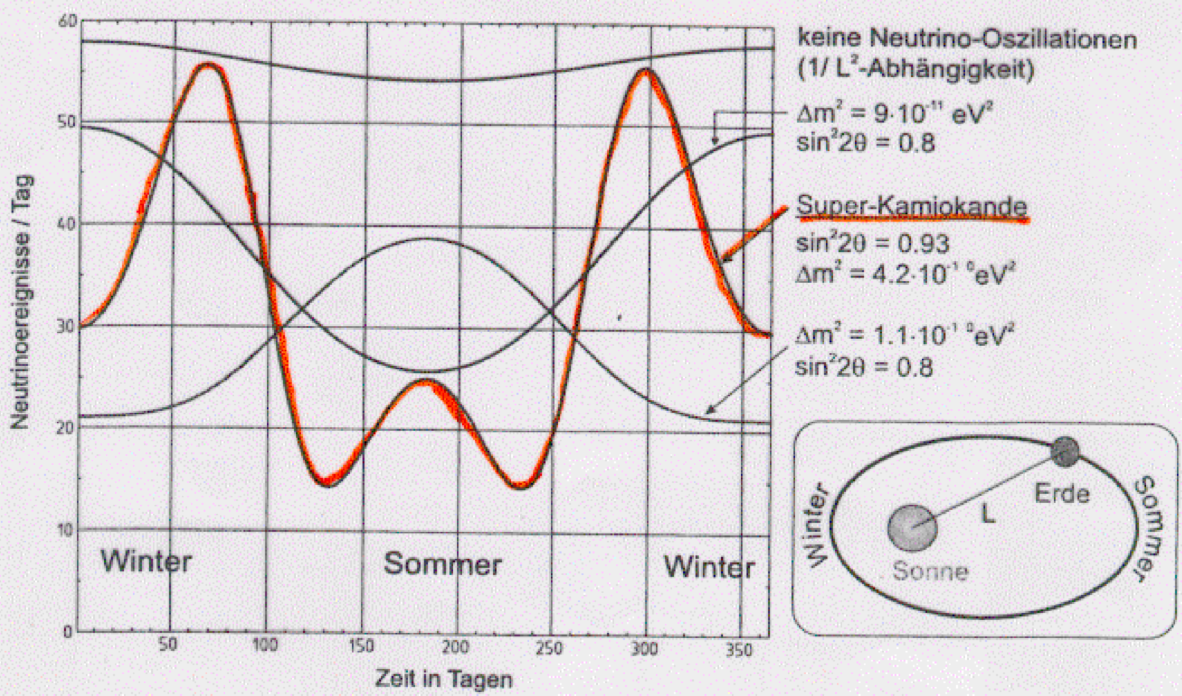
vonFei~ - 06

spectral deformation by ν - oszillation in matter



ν oszillation in vacuum

(rate of 860 KeV ν as a funktion of time)



Future Experiments

CC- ν_e detection

Low energy threshold : pp + 7Be, + ...

GNO (upgrade), SAGE

$\nu_e + {}^{71}Ga \rightarrow {}^{71}Ge + e \qquad E_{\nu_e} > 233\ keV$

timeresolution : ~ 1 month,

LENSE realtime, energy dispersiv

$\nu_e + {}^{176}Yb \rightarrow {}^{176}Lu + e \qquad E_{\nu_e} > 301\ keV$

$\nu_e + {}^{100}Mo \rightarrow {}^{100}Tc + e \qquad E_{\nu_e} > 168\ keV$

GSO $Ga_2SiO_5(Ce)$ szintillating crystal

7Be + 8B

$\nu_e + {}^{127}J \rightarrow {}^{127}Xe + e \qquad E_{\nu_e} > 789\ keV$

kombination: radiochemical
+ scintillation
(energy dispersiv)

? $\nu_e + {}^{115}In$

$E_{\nu_e} \gtrsim 115\ keV$

LENS: Low Energy Neutrino Spectroscopy

Goal:
- direct measurements of solar ν_e from pp, Be7, pep, CNO, B8
- energy-resolved
- real time
- ν_e – flavour specific

Method:
- charged current transition (inverse β-decay) to excited level
- low-energy threshold
- ν_e – tag to discriminate against background

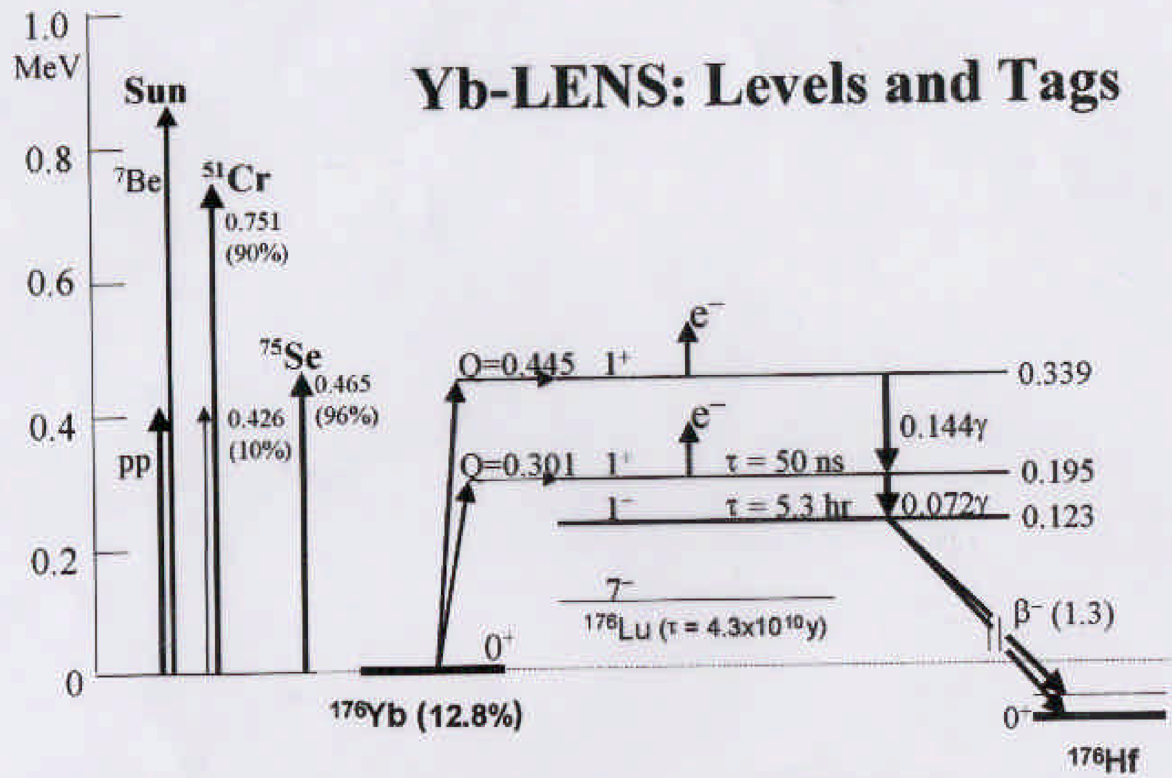
$$E_e = E_{\nu e} - E_{thr}$$

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

delay

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

Yb-LENS: Levels and Tags

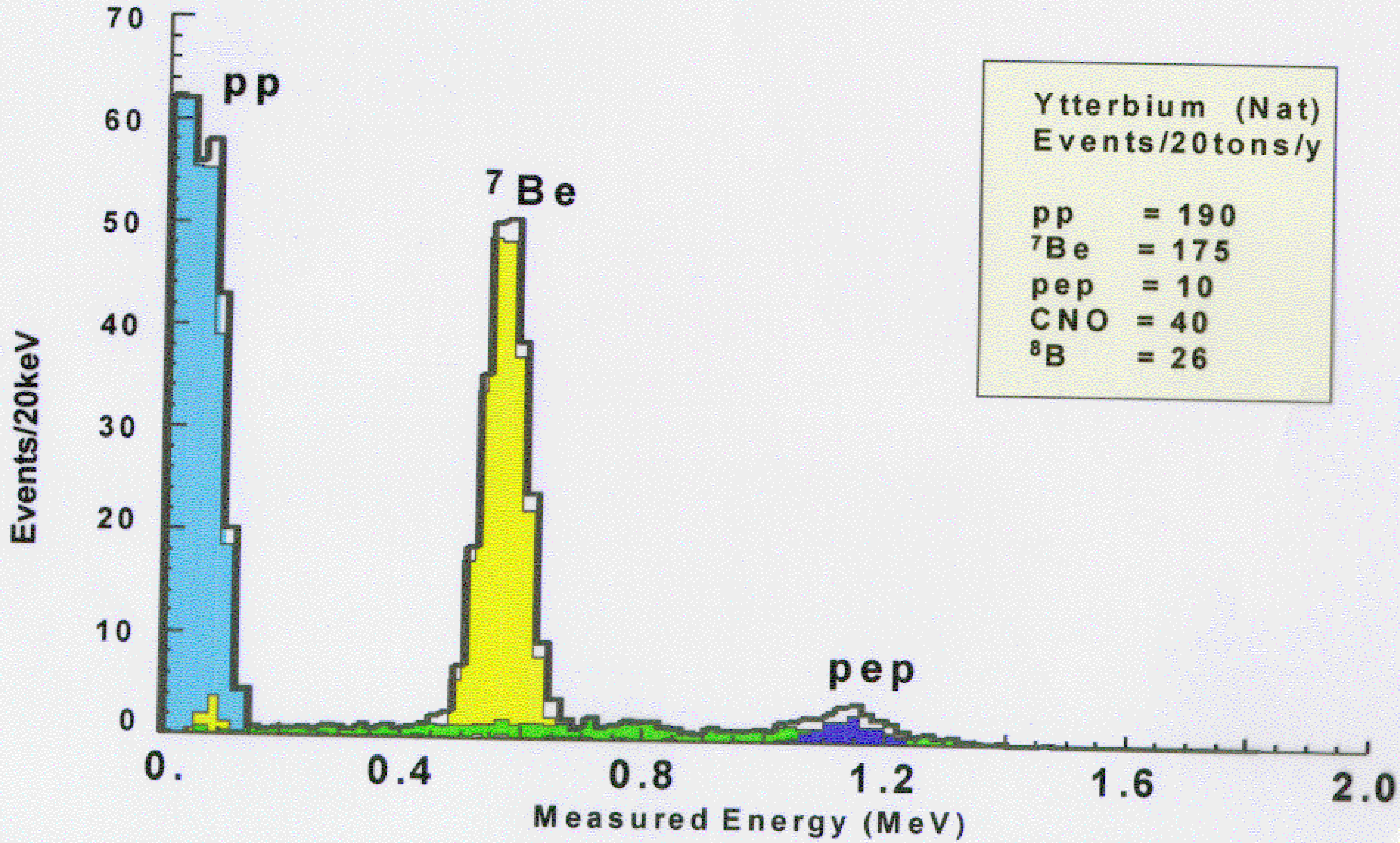


	Yb Level (keV)	B(GT)
1	194.5	0.20(4)
2	338.9	0.11(2)
3	3070	0.62(8)

Ref. M. Fujiwara

Gamov-Teller resonance energies and strengths from ^{176}Yb(^{3}He,t)^{176}Lu; Q_ν=E(level)+106.2 keV

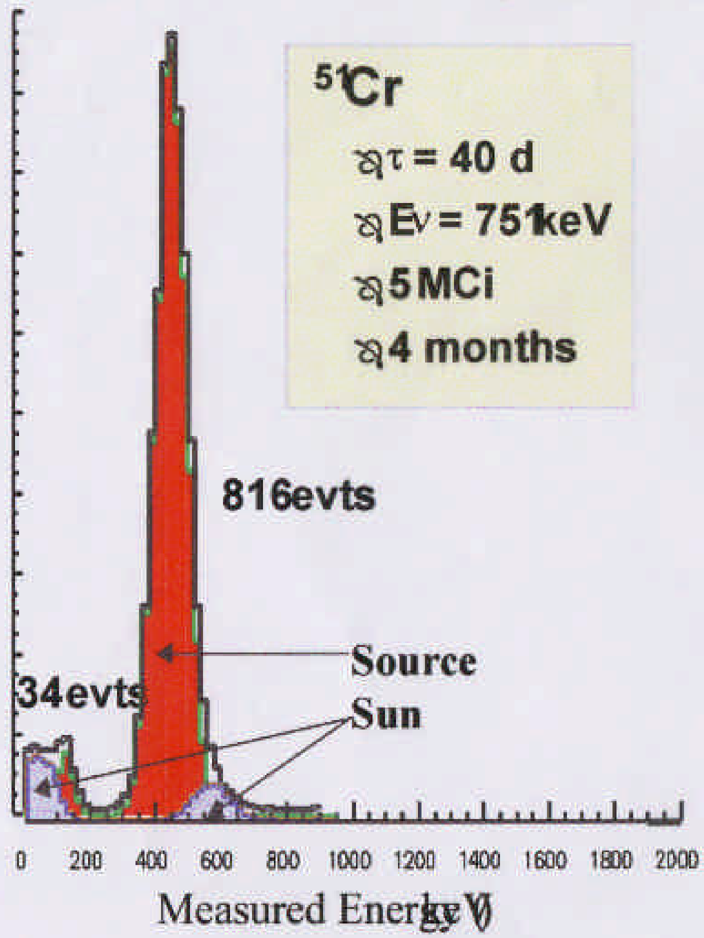
Solar Neutrino Spectrum in Yb-LENS (SSM BP98)

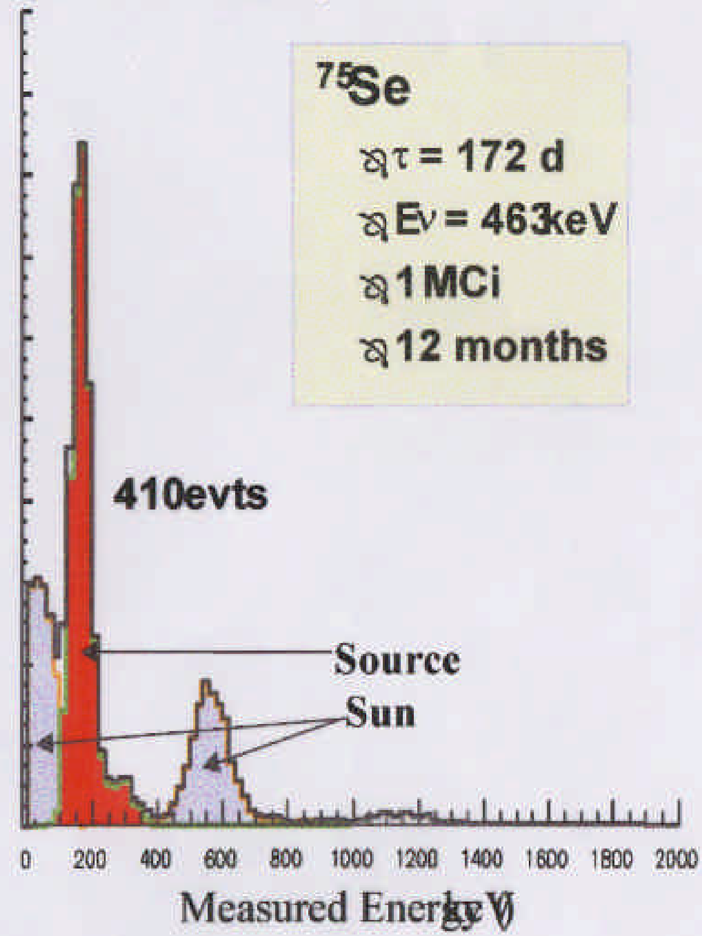


vonFei- - 10

Calibration of ν_e-Capture Cross-Sections

- Response of Yb-LENS to Mega-Curie ν_e-Sources
- Separate calibration of Be-7 and pp-ν_e





- Irradiation tests of GALLEX Cr-50 material in Russian reactor ongoing
- New isotopical enrichment and irradiation of Se-74 under study

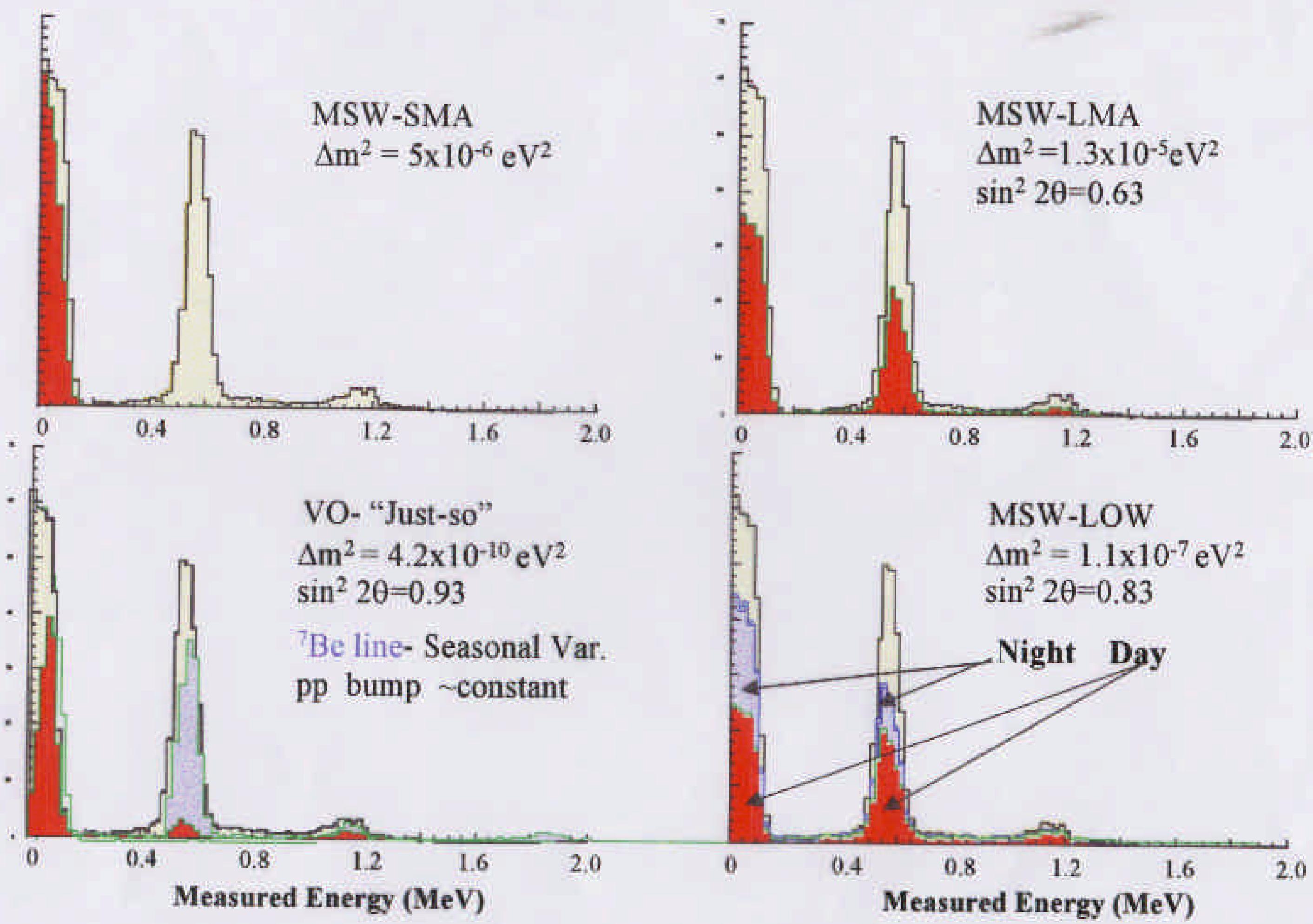
Ongoing and Future Research Activities

preliminary listing

Scintillator development: Bell Labs, Heidelberg, INR, Rhodia, Saclay, ...
Rare earth purification: INR, Rhodia, ...
Ultra-Trace Analysis: Heidelberg, LNGS, Brookhaven ...
Muon induced Bgd: Heidelberg, München ...
Nuclear Cross Sections: Bell Labs, Osaka, Indiana ...
Neutrino Source: Heidelberg, Russia, Saclay, ...
Detector architecture: Heidelberg, Los Alamos, Saclay, ...
Electronics: College de France, Los Alamos ...
Prototyping (CELL @ GS): Heidelberg, LNGS, Los Alamos, Saclay,....

Status: Letter of Intent (1999)
Pilot phase 2000/2001: milestones with prototype detector
Proposal end of 2001

Response of Yb-LENS to Neutrino Flavour Conversion Scenarios



100Mo - solar ν detector

H. Ejiri et al.

Inverse β- decay : ν(e) spectroskopy at low energies
$E(\nu) \geq 168$ keV

sensitive to pp and 7 Be ν

solar- ν absorption rates / 10 T 100 Mo :

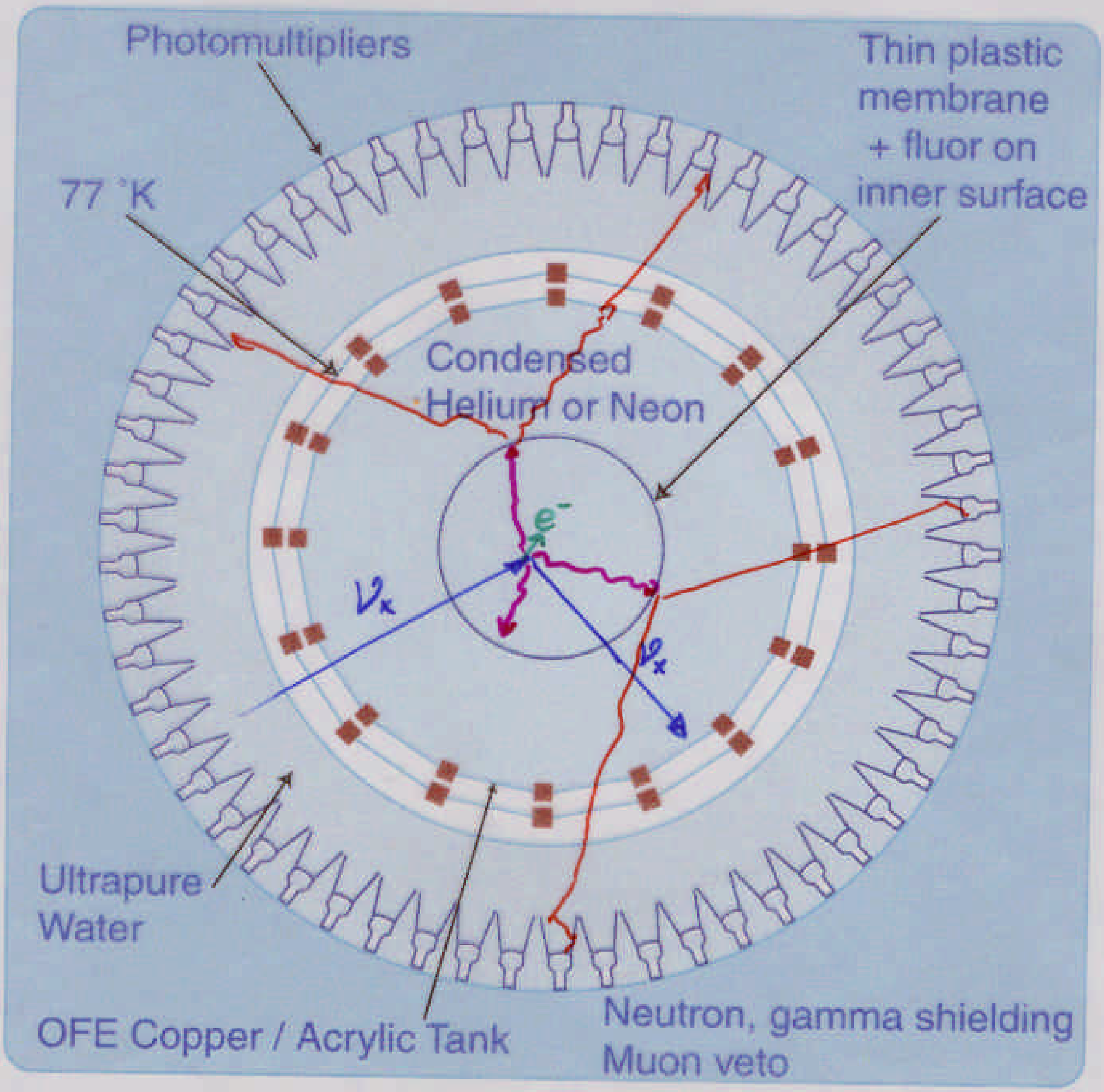
source	rates / SNU	rates per 10T,d
pp	639	3.3
7 Be	206	1.1
8 B	27	0.1

for purities better than 10(-13) g/g U, Th

main background from 2νββ - decay

suppression by delayed coincidence and high granularity (position sensitivity)

CLEAN Experimental Method



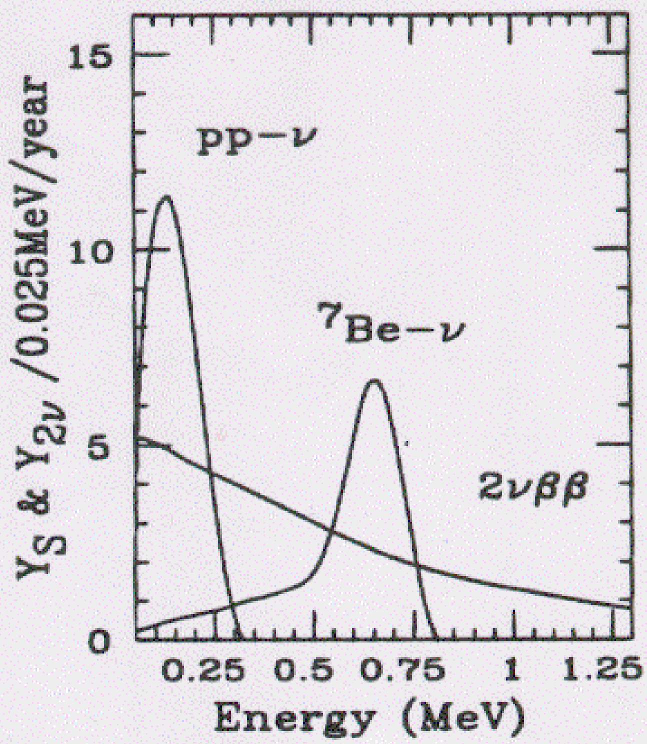
Cryogenic region about 7 m diameter (for neon version)

e,ß- delayed coincidence

reduction in space : $(\Delta x/x)^3 \approx 10(-9)$
time : $\Delta T/T \approx 10(-5)$

$2\nu\beta\beta$- decay rate: ≈ 3.6 10(9) / 10 T a

expected solar neutrino spectrum
with 100Mo 10 T detector
for standard solar model



Gallium ν Observatory

GNO

measurement of low energy CC

ν from $pp + {}^7Be + {}^8B + CNO$

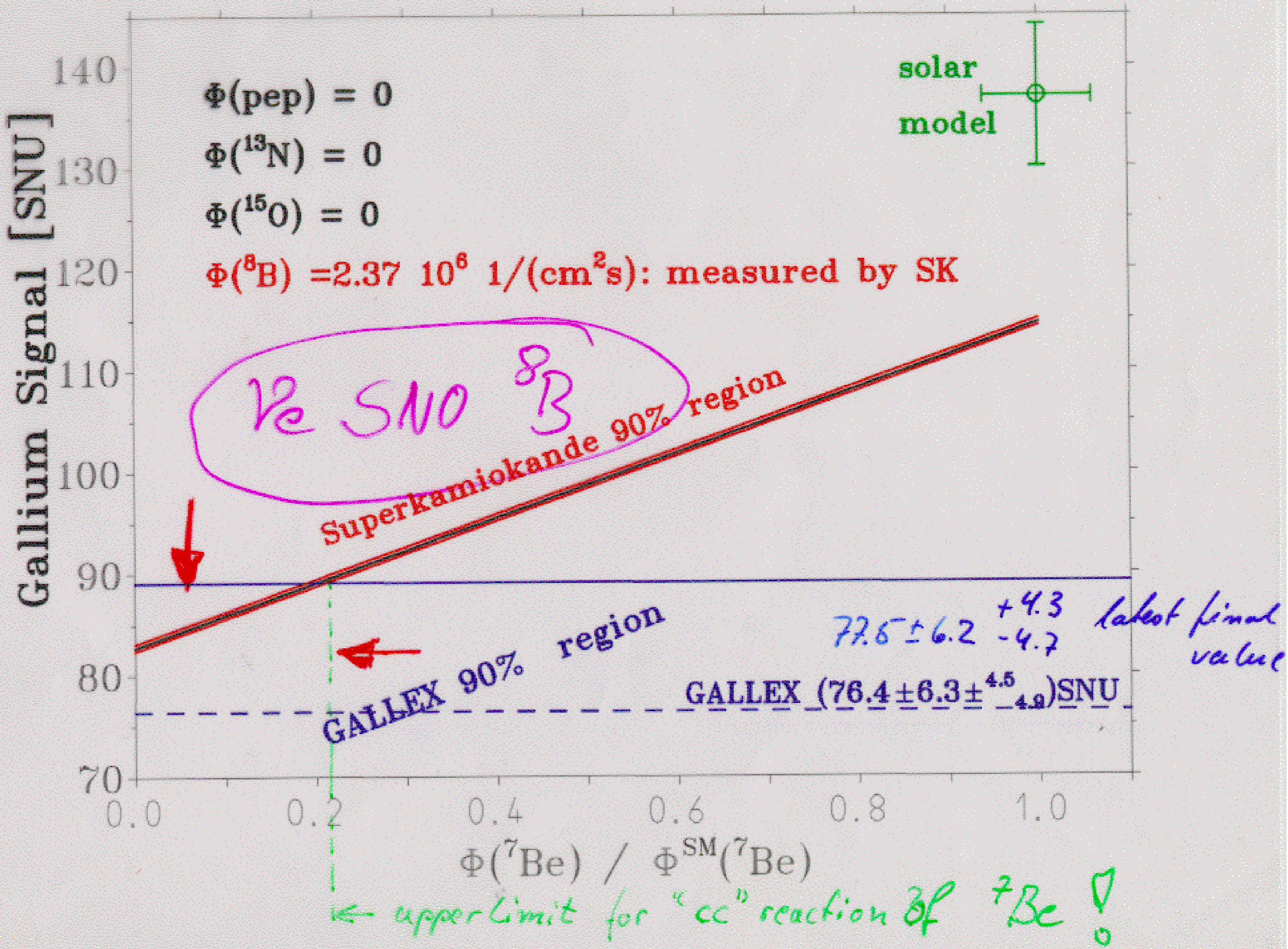
anticipatet

$\Delta n(\nu) / n(\nu) < 5\%$

$$n(\nu_e)({}^7Be) \leq n(\nu_e)\,GNO - n(\nu_e)(SNO) - n_\nu(CNO)$$

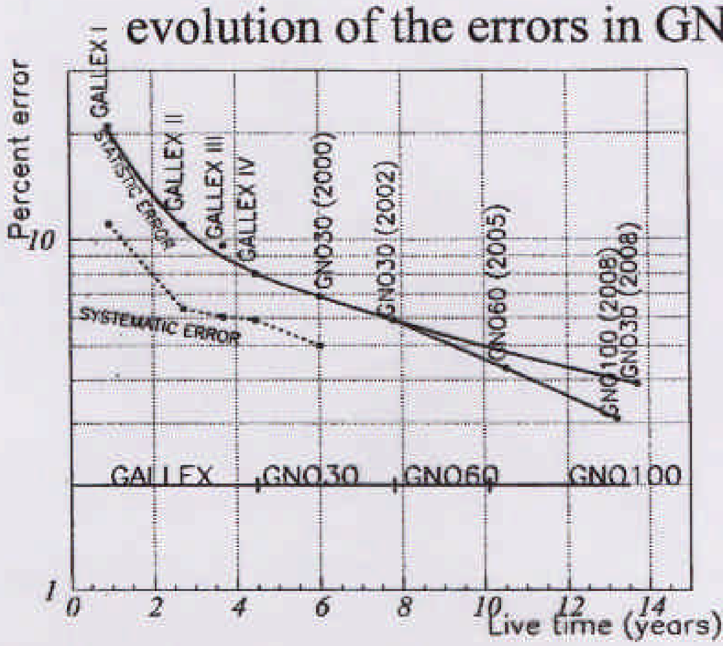
! now possible !

$$n(\nu_e)(pp) = n(\nu_e)\,GNO - \underbrace{n(\nu_e)}_{LENS}\,{}^7Be - \underbrace{n(\nu_e)}_{SNO}\,{}^8B$$



Gallium Signal [SNU]
140
130
120
110
100
90
80
70
0.0
0.2
0.4
0.6
0.8
1.0
Φ(⁷Be) / Φ^SM(⁷Be)
Φ(pep) = 0
Φ(¹³N) = 0
Φ(¹⁵O) = 0
Φ(⁸B) =2.37 10⁶ 1/(cm²s): measured by SK
solar
model
Superkamiokande 90% region
νe SNO ⁸B
GALLEX 90% region
GALLEX (76.4±6.3±4.5 4.9)SNU
77.6 ± 6.2 +4.3 -4.7 latest final value
← upper limit for "cc" reaction of ⁷Be !

evolution of the errors in GNO



plans for new counters:

main systematic uncertainties stem
from counting of ec in 71 GE

new development of heigh accuracy
proportional counters (heigher uniformity)

new development of cryogenic calorimeters

improvement of

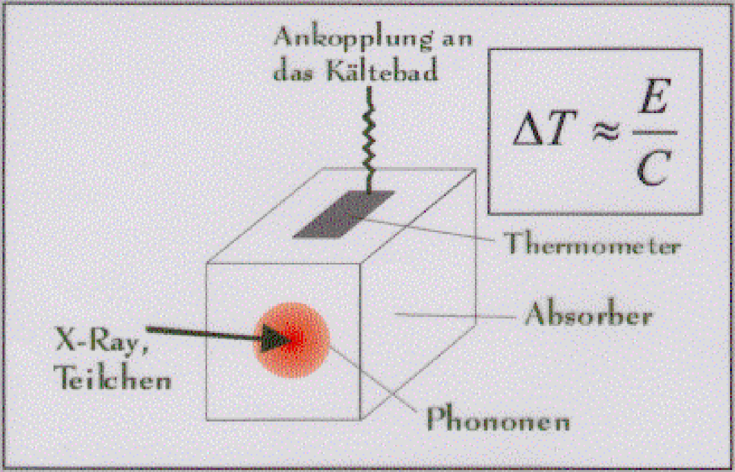
$\varepsilon \approx 70\% \rightarrow \varepsilon \approx 95\%$

high energy resolution and low threshold detection high precission ge-detection in GNO

Kryodetektoren für GNO

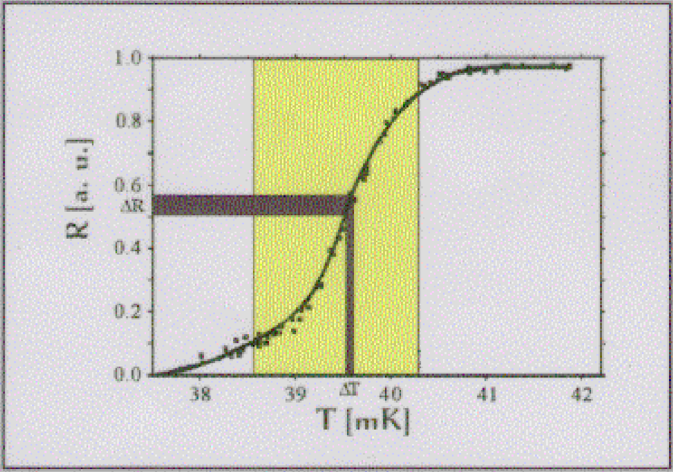
Technische Universität München

Tieftemperatur-Kalorimeter



Energiedeposition
↓
Phononen
↓
Temperaturerhöhung im Thermometer
↓
Signal

Supraleitende Phasenübergangsthermometer



Dünne Ir/Au Schichten

Arbeitspunkt im Übergang Supraleiter-Normalleiter

T_c zwischen 20 - 100 mK einstellbar (proximity effect)

Temperaturerhöhung von <1μK meßbar, Auslese mit SQUIDs

detection of Ge - e⁻ capture 4π
efficiecy > 95 %

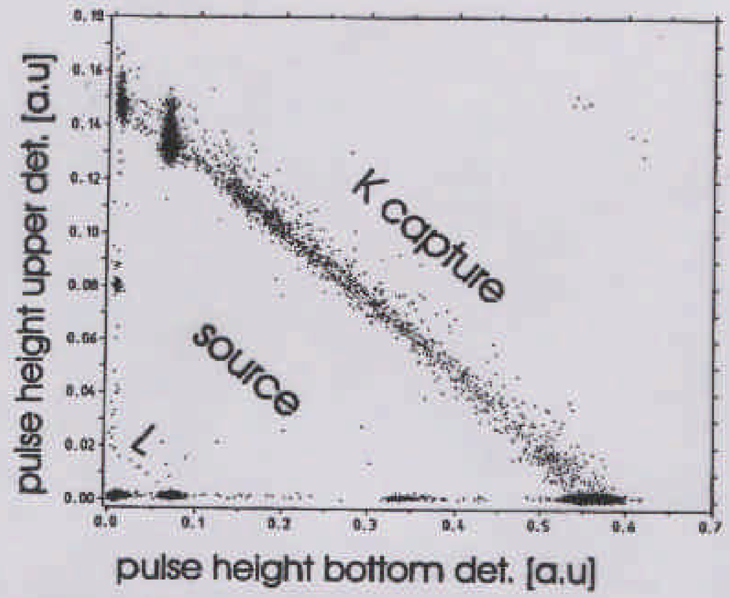


Figure 6.8: *Scatter plot of the pulse height of the upper detector versus pulse height of the bottom detector for the 4π efficient set-up. The different regions corresponding to K, L capture or calibration source are marked. The distribution of the events can be understood considering the different processes in the* ^{71}*Ge decay. Detailed explication can be found in the text.*

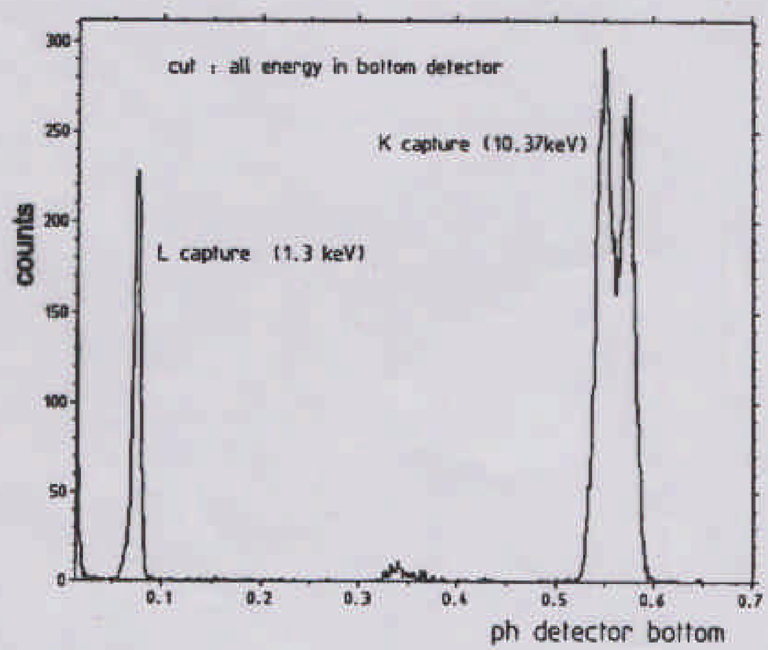
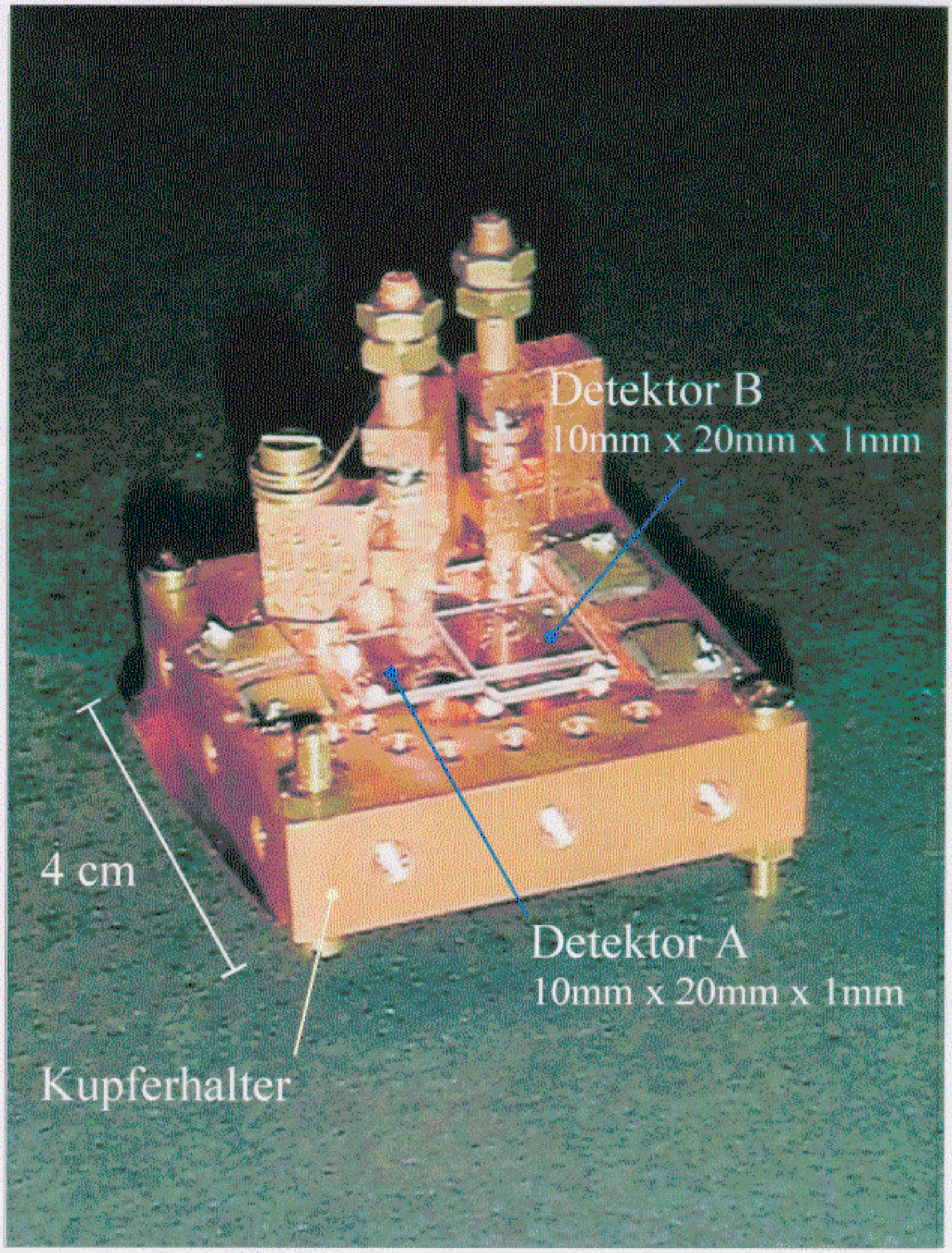


Figure 6.9: *Pulse height spectrum for the lower detector applying the cut, that the full energy is deposited in this detector. The double structure remains unchanged which indicates that it is not due to escape effects.*

4π-Detektor


Detektor B
10mm x 20mm x 1mm
4 cm
Detektor A
10mm x 20mm x 1mm
Kupferhalter

SNO Measurements

Charged Current Reaction (D_2O):

CC — $\nu_e + d \rightarrow p + p + e^-$ $E_{thres} = 1.4$ MeV   (only ν_e)

- High counting rate
- ν_e energy spectrum (distortion MSW effect)
- Some directional sensitivity ($1 - 1/3 \cos\theta_e$)

Neutral Current Reaction (D_2O):

NC — $\nu_x + d \rightarrow \nu_x + p + n$ $E_{thres} = 2.2$ MeV   (ALL ν types)

- Lower counting rate
- Total solar ^8B neutrino flux
- Stellar collapse $\rightarrow \nu_e, \nu_\mu, \nu_\tau$ (arrival times sensitive to mass)

$$\text{Ratio} = \frac{CC}{NC} = \frac{(\nu_e)\ \text{flux}}{(\nu_e + \nu_\mu + \nu_\tau)\ \text{flux}}$$

Elastic Scattering Reaction (D_2O,H_2O):

ES — $\nu_x + e^- \rightarrow \nu_x + e^-$ $E_{thres} = 0$ MeV   (mostly ν_e)

- Low counting rate
- Directional sensitivity (very forward peaked)

SNO Detector Status

SNO Milestones:

- **April 1999-** complete heavy water fill
- **May 1999-** detector “turn-on”
- **Nov 1999-** detector parameters frozen

Running Conditions:

SNO is very quiet!

- Average channel thresholds < 0.5 p.e.
- PMT noise rates ~500 Hz; typical noise PMT / event ~2
- Overall trigger rate (all trigger types) ~ 15 Hz

Trigger Type	Hardware Threshold	Rate (Hz)
Pulsed trigger	zero bias	5
100 ns coincidence	17 PMTs	3-5
20 ns coincidence	15 PMTs	2-3
Energy Sum	~200 p.e.	<1
Prescaled (1:10000)	12 PMTs	<1

>98.5% of all PMT channels fully operational and taking data

water already looks clean:

→ *H_2O radioactivity levels within factor of 3 of goal (incl. Rn)*

→ *D_2O radioactivity levels within factor of 3 of goal (incl Rn)*

Rate of “flasher” PMTs lower by factor ~5 compared to air fill

SNO Physics Goals

Main Physics Goals:

- **Search for Flavour Change (ν oscillations):**
  → ratio of number of charged current (CC) to neutral current (NC) events

- **Distortion of the ^{8}B Neutrino Energy Spectrum (ν oscillations):**
  → CC electron energy spectrum

- **Total ^{8}B Neutrino Flux (standard solar models):**
  → NC measurement of all neutrino flavours

- **Time Dependent Solar Neutrino Flux (ν oscillations):**
  → regeneration in the Earth (MSW)
  → 7% orbital eccentricity (MSW,vacuum)
  → solar magnetic field effects

- **Search for Supernova Neutrinos**
  → sensitivity to all neutrinos provides good test of models

- **Cosmic Ray Muons**

- **Atmospheric Neutrinos**

- **Search for Non-Electron Type Neutrinos from the Sun**
  → unique signature: anti-$\nu_e + d \rightarrow n + n + e^+$

Future Experiments

nc ν_x detection

SNO $\nu_x + d \rightarrow \nu_x + p + n$ $E_{\nu_x} > 2.2$ MeV

NC + CC

$\nu_x + e \rightarrow \nu_x + e$ $CC/NC \approx 6$

CERENCOV detectors

SNO, S-Kamiokande
(1000T) (50000 T)

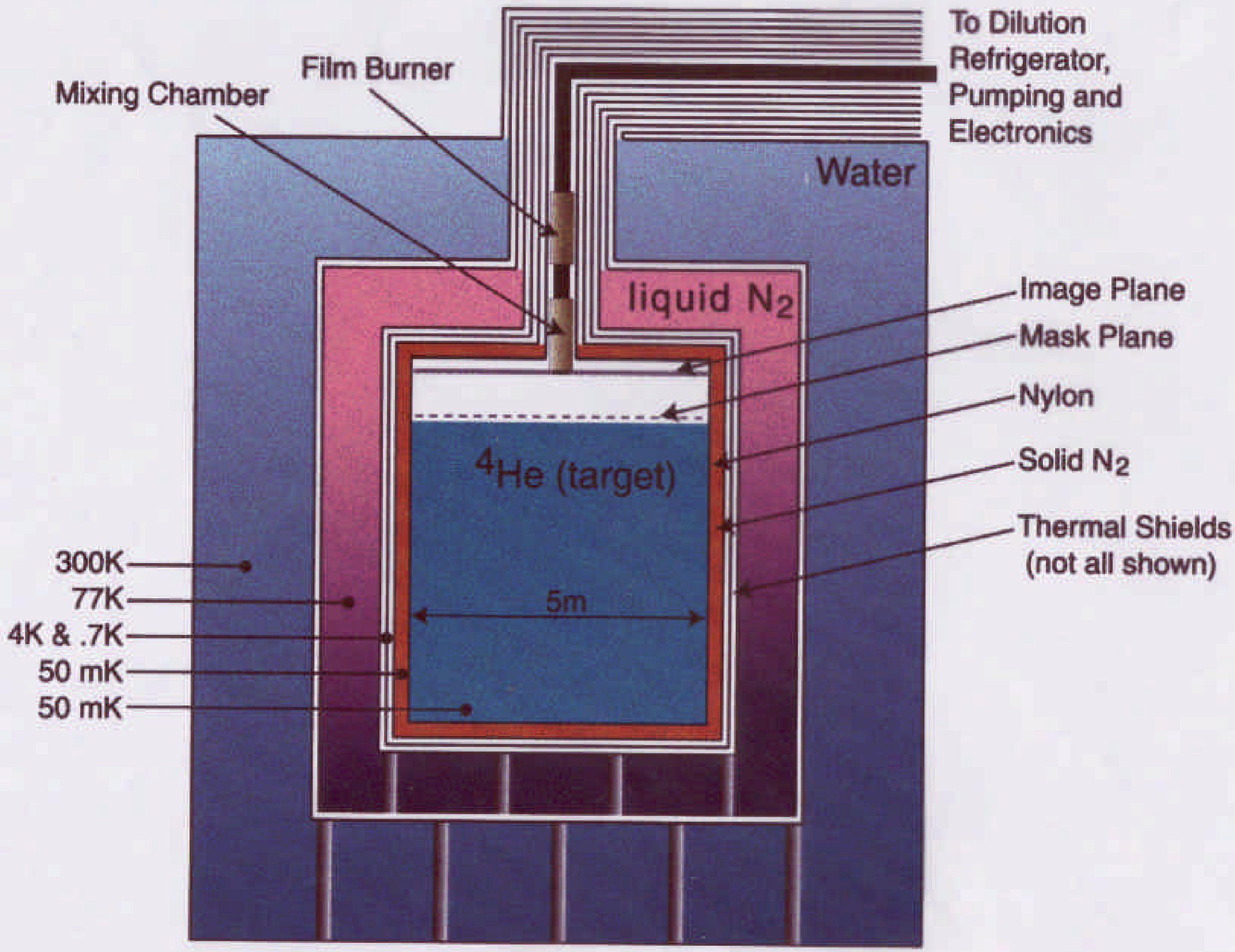
Szintillators

BOREXINO 300T
KAMLAND 1000T } in construktion

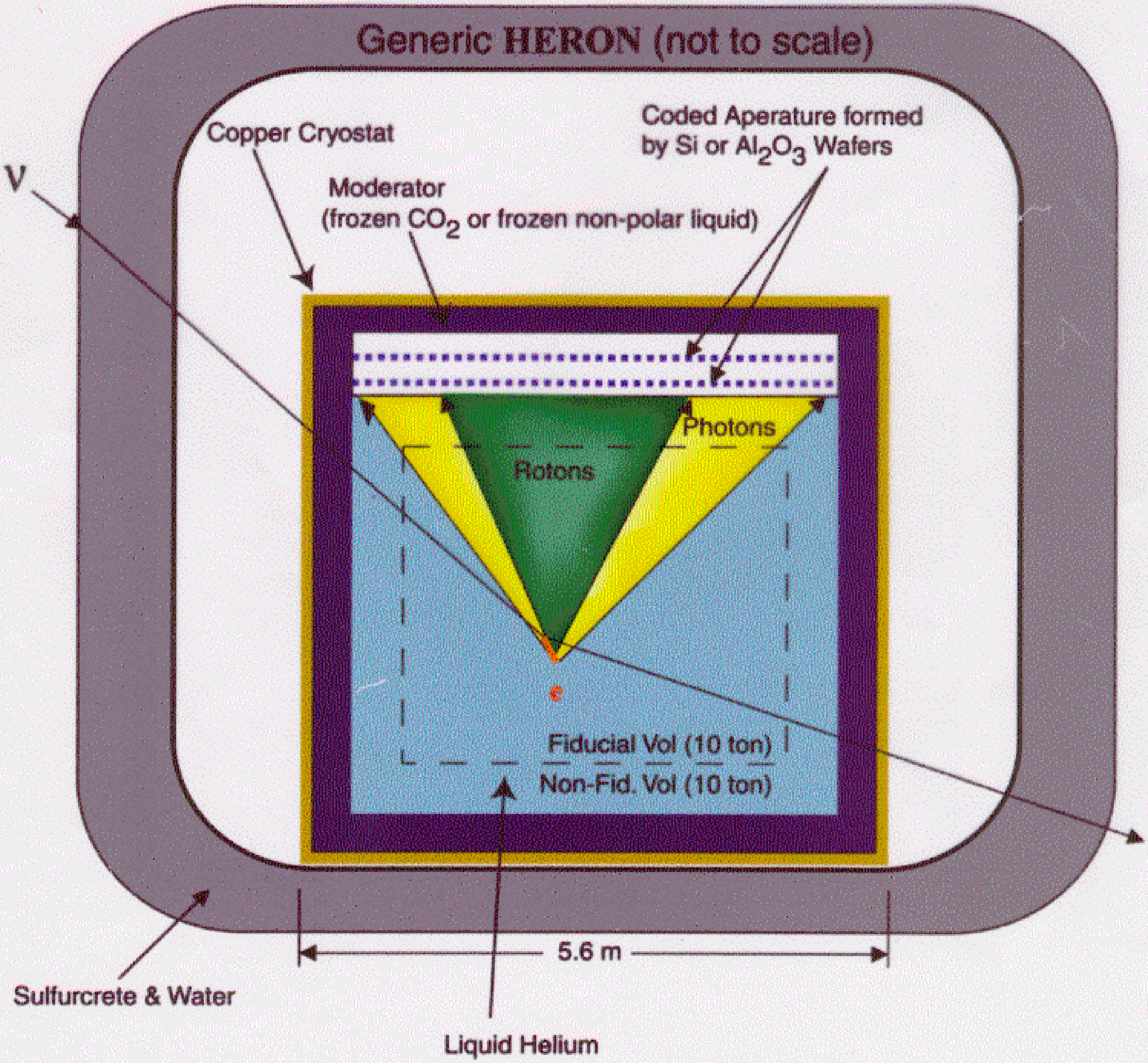
HERON (He(l); Xe(l); Ne (l); (s)); gs0

Drift chambers

Hellas, ^{100}Mo


To Dilution Refrigerator, Pumping and Electronics
Film Burner
Mixing Chamber
Water
liquid N_2
Image Plane
Mask Plane
Nylon
Solid N_2
Thermal Shields (not all shown)
^{4}He (target)
5m
300K
77K
4K & .7K
50 mK
50 mK

HERON


Generic HERON (not to scale)
Copper Cryostat
Coded Aperature formed by Si or Al_2O_3 Wafers
Moderator (frozen CO_2 or frozen non-polar liquid)
ν
Photons
Rotons
e
Fiducial Vol (10 ton)
Non-Fid. Vol (10 ton)
5.6 m
Sulfurcrete & Water
Liquid Helium

BOREXINO

Low energy solar neutrino detection by neutrino- electron scattering

sensitive to NC and CC interaction
determination of 7 Be neutrino flux in real time

target : 100 T scintillator →
ca 43 c/day for standard solar model

high sensitivity to time variations

high sensitivity to neutrino oszillations in vacuum for the monoenergetic 860 keV 7 Be neutrinos

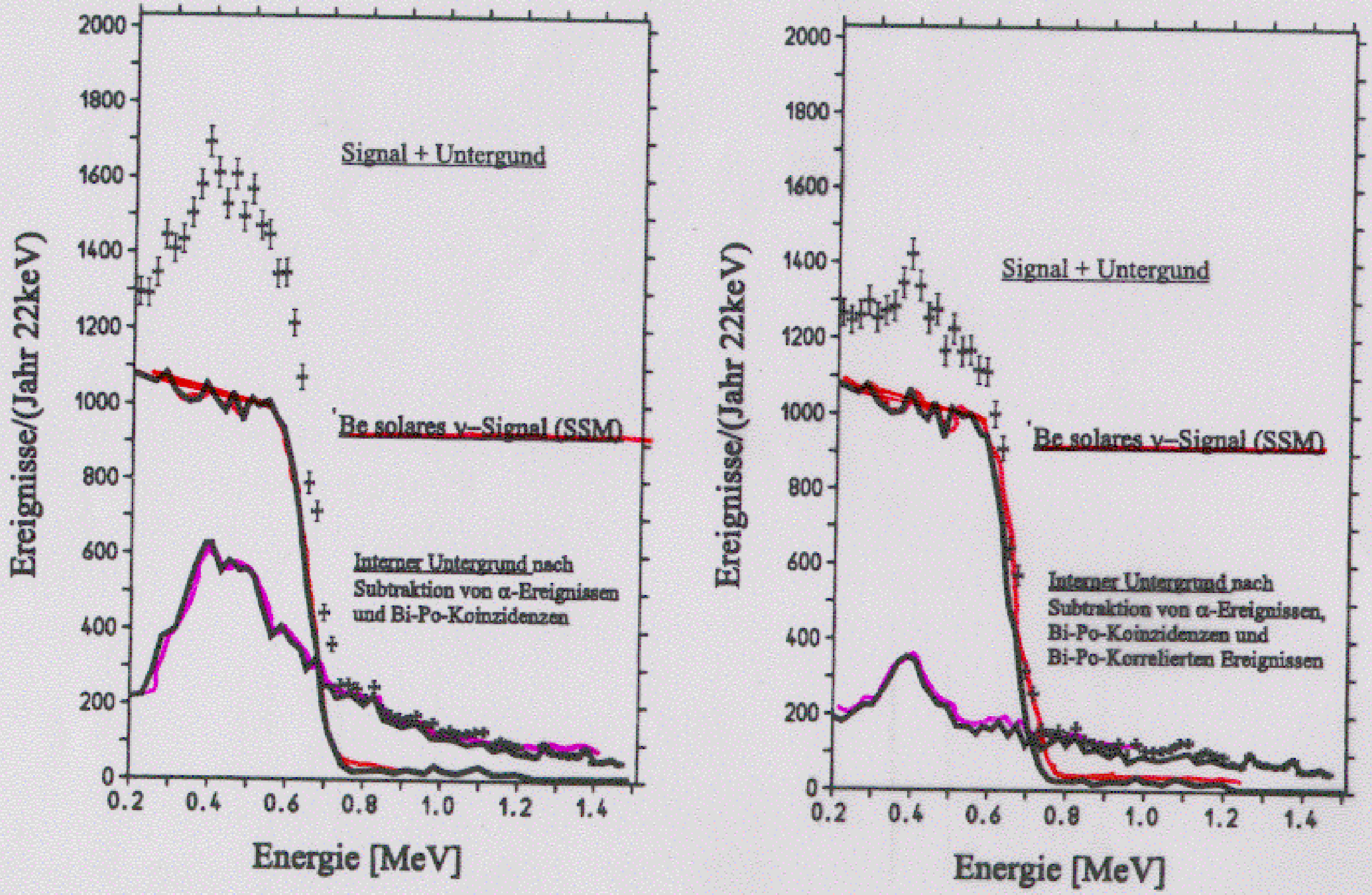
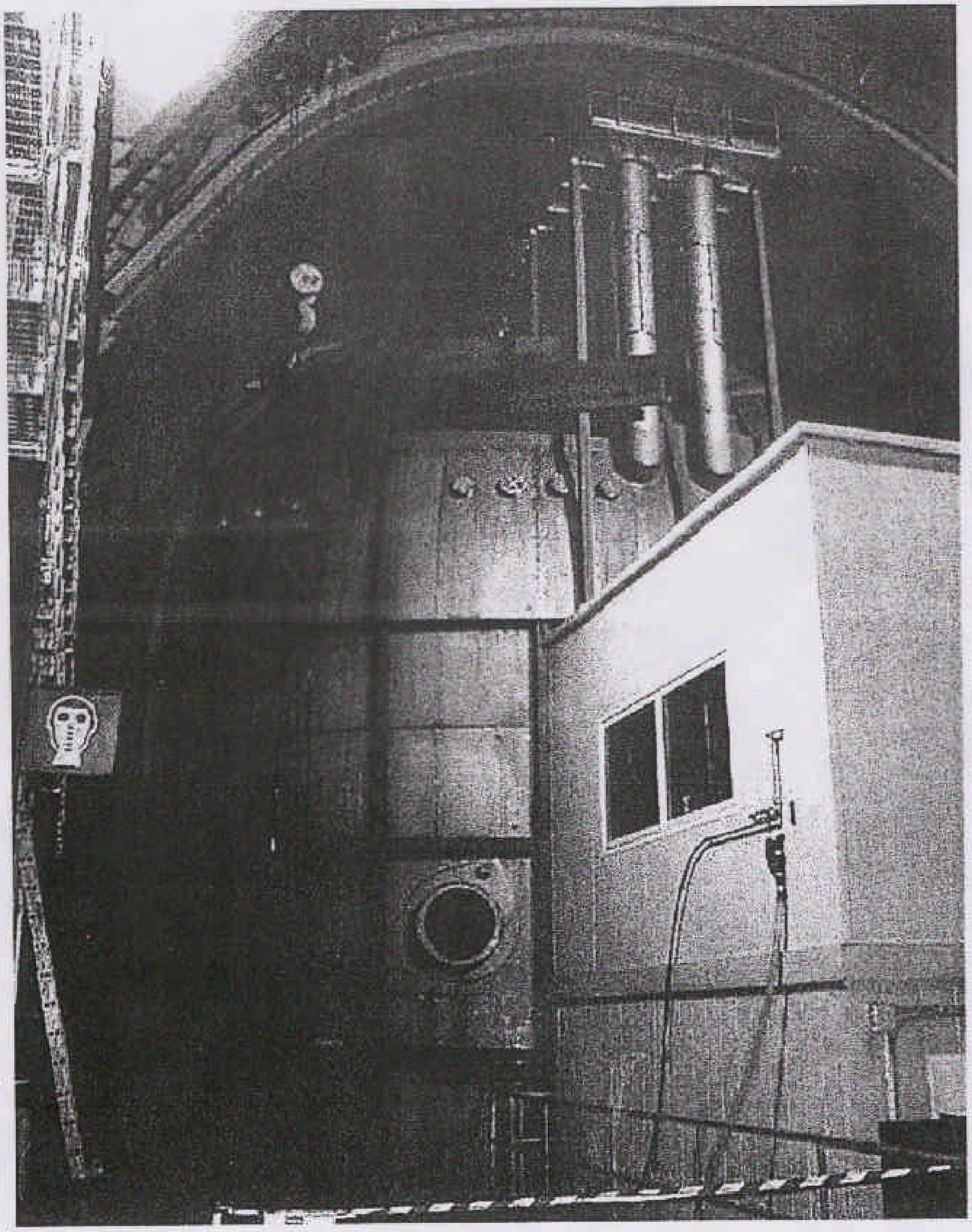
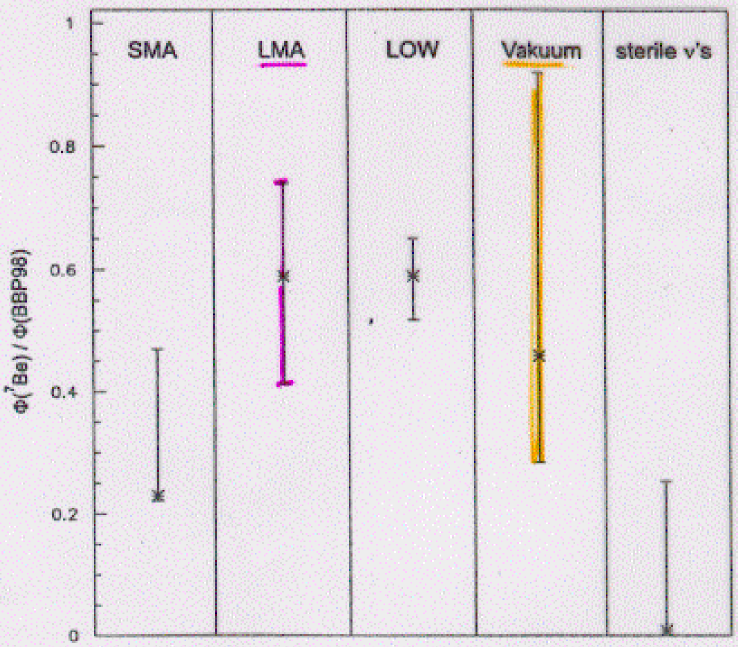


Abbildung 2.4: *Berechneter interner Untergrund und Neutrinosignal des BOREXINO-Detektors. Dabei wurde eine Konzentration für Uran und Thorium von 10^{-16} und für Kalium von 10^{-14} zugrundegelegt [Nef96].*



expected rates for possible oszillation parameters
99 % cl



LMA solution may be identified by reactor ν experiment
(long base line) Kamland, Borexino

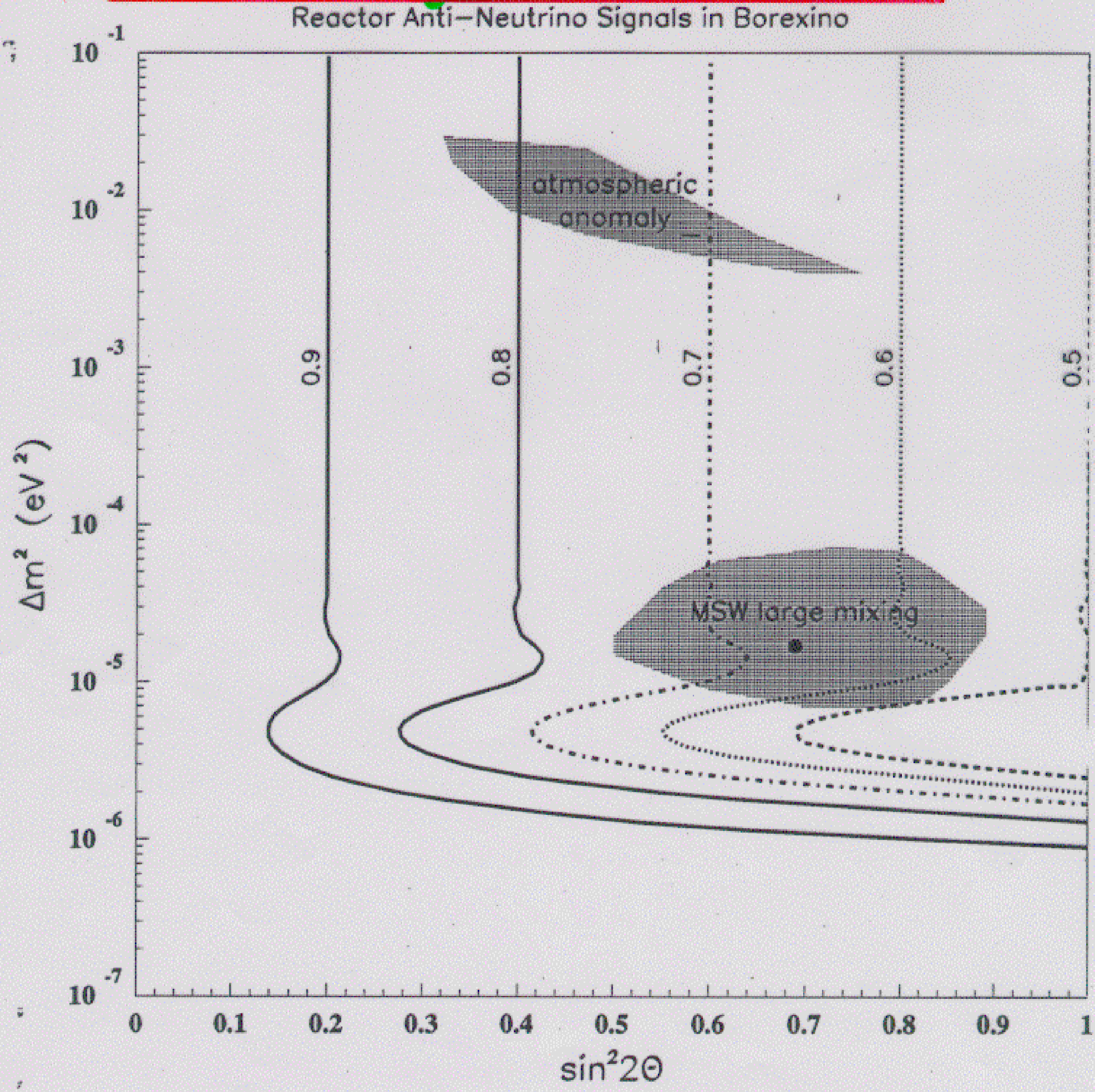
Vacuum Osc. is identified by time variation

BOREXINO may identify the oscillation parameters
(Or KAMLAND ?)

KAMLAND

BOREXINO

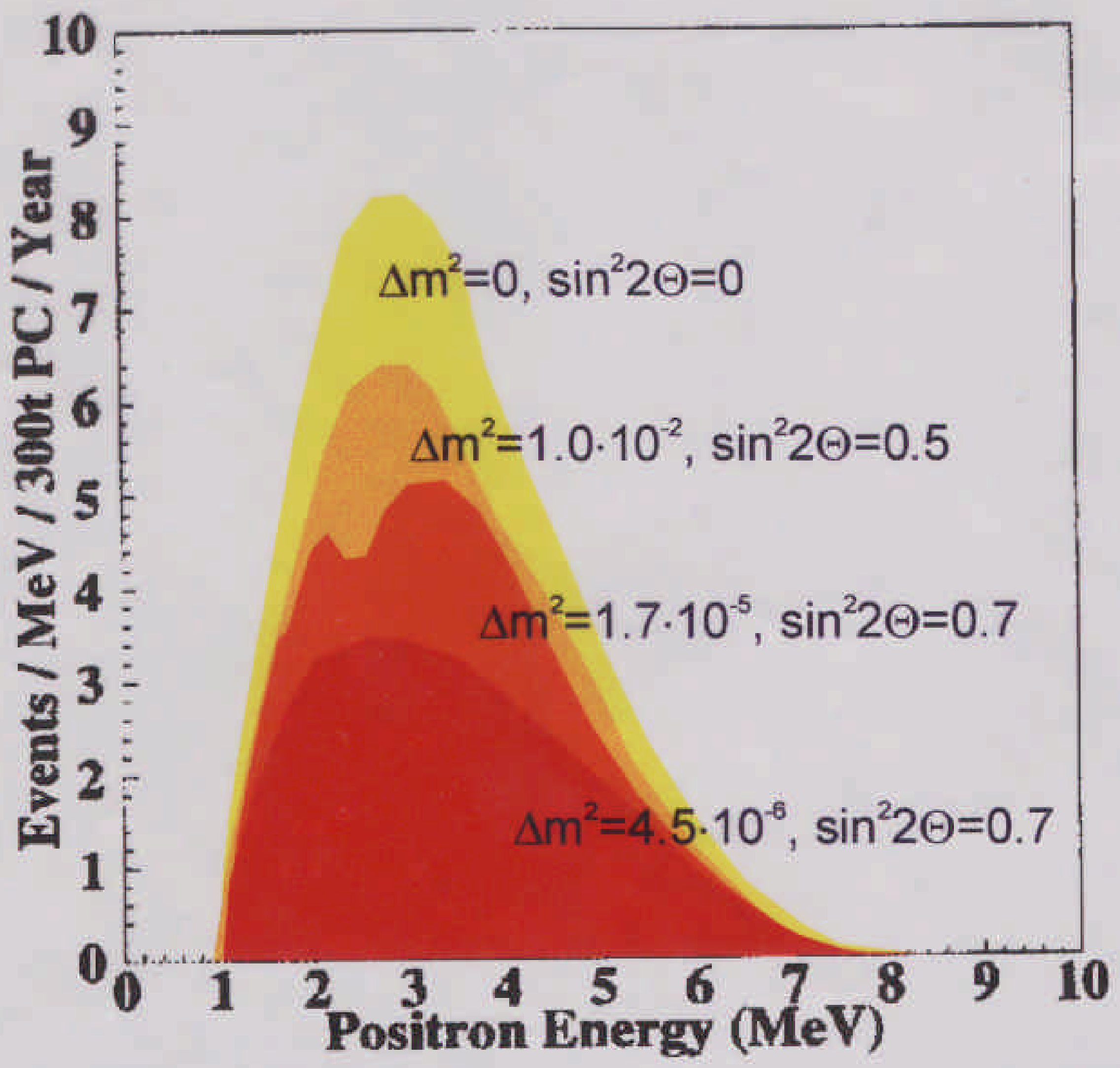
$\bar{\nu}_e$ long baseline



$0{,}25 \lesssim$ Suppression $\lesssim 0.5$

positron energy spectrum of the reaction $\nu_e p \rightarrow e^+ n$ (incl. e^+e^- annihilation) for several Δm^2 - $\sin^2 2\Theta$ combinations.

$\Delta m^2 = 1.7 \cdot 10^{-5}$ eV^2, $\sin^2 2\Theta = 0.7$ corresponds to the solar MSW large mixing angle solution.



CONCLUSION

The future solar neutrino experiments will provide

the solar neutrino spectrum measured in CC and NC

for this we need the present experiments

SK, SNO, GNO + SAGE

and the new experiments

KAMLAND
BOREXINO
GNO (upgrade)
LENS

may be new ideas show better ways

the data from these experiments will determine the

ν - neutrino oscillation parameters

and the solar fusion processes

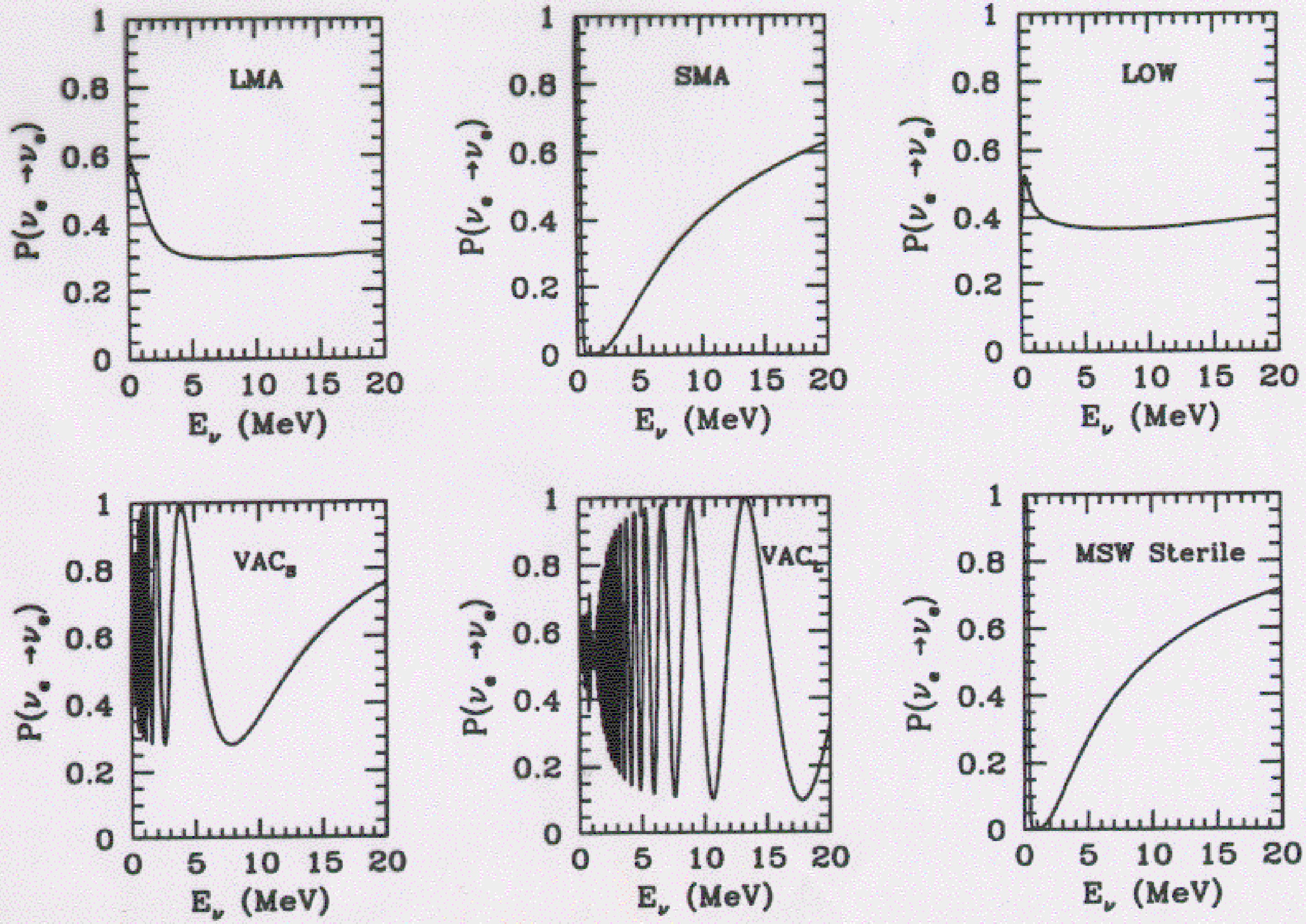


Abbildung 3.4: *Darstellung der Wahrscheinlichkeit $P_{\nu_e \to \nu_e}$ in Abhängigkeit von der solaren Neutrinoenergie für die 6 verschiedenen Neutrino-Oszillations-Szenarien der LMA, SMA, LOW, VAC_S und VAC_L Lösung sowie für sterile Neutrinos [Bah00].*