Prospect for Reactor Neutrino Experiments In Europe

Thierry Lasserre (CEA/Saclay)

NOON03

11/02/2003, Kanasawa, Japan

- ✓ The HLMA project in the light of the first KamLAND results
  - o The Heilbronn site, Germany
  - o The Boulby site, UK
- ✓ $|U_{e3}|^2$ measurement/constraint with a new reactor experiment
  - o In the frame of the HLMA project
  - o At the maximum of oscillation, D~2 km

Neutrino Mass & Mixing

$[\Delta m^2_{21} - \theta_{12}]$ [redacted]

sol

Solar ν's

\+

KamLAND

\+

? HLMA ?

↓

MSW-LMA

$\Delta m^2_{12} \sim O(10^{-5})\ eV^2$

$\sin^2(2\theta_{12}) \sim 0.8$

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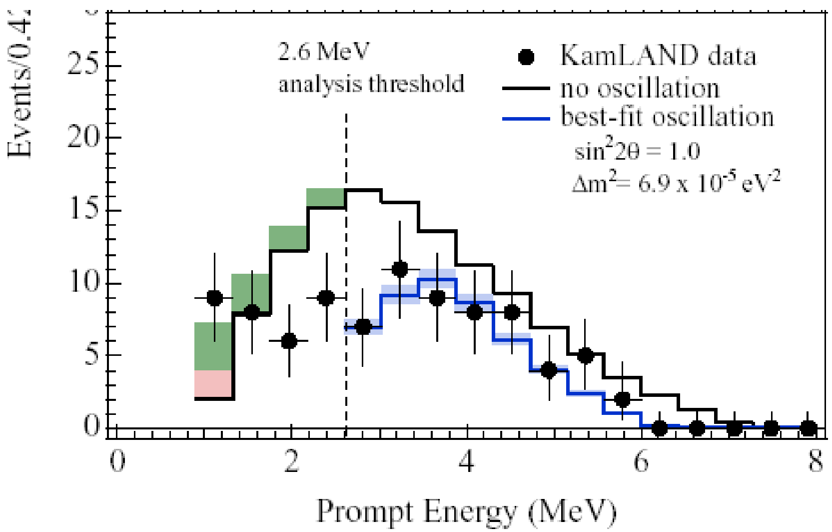
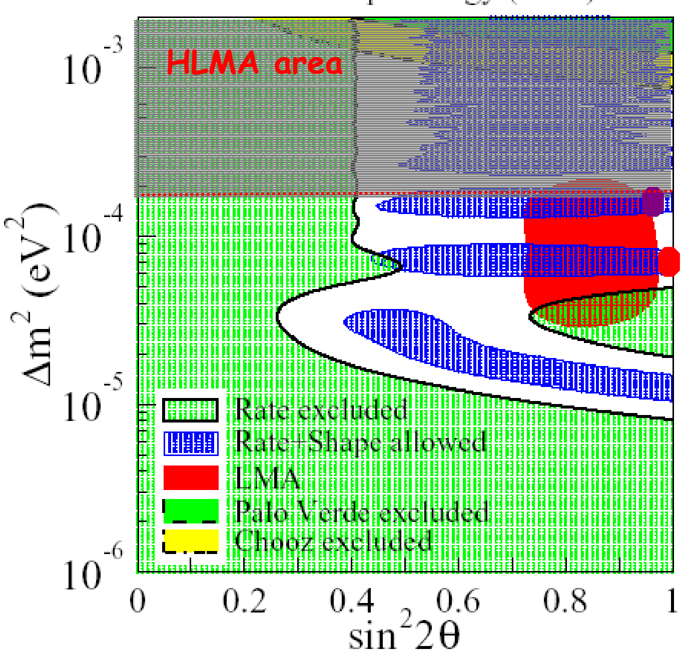
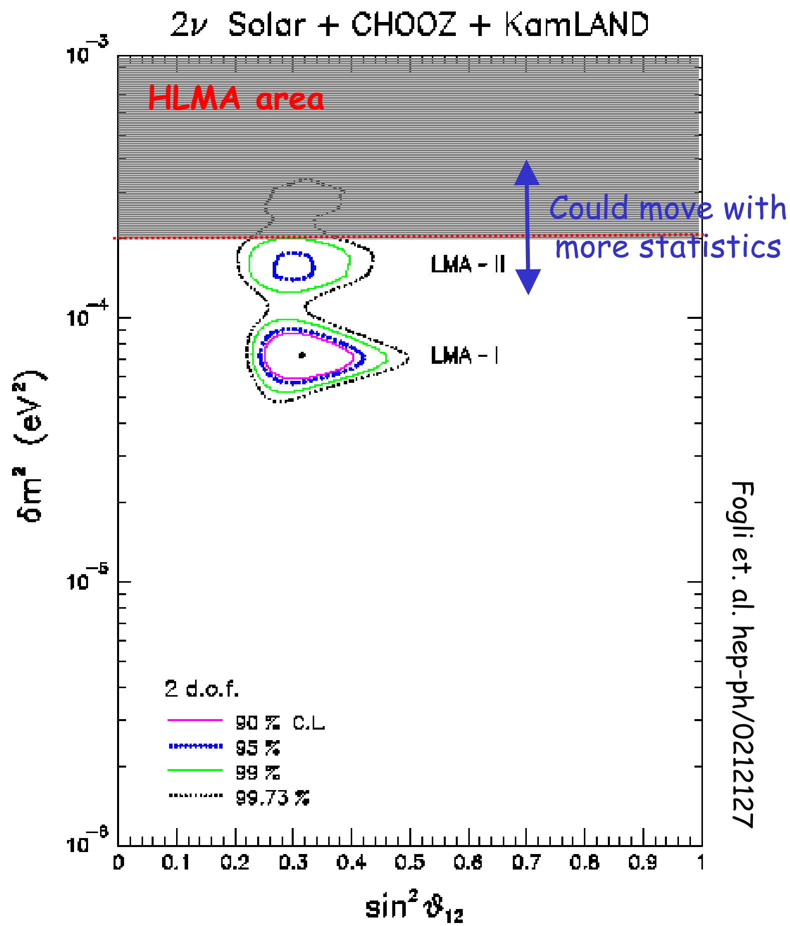
KamLAND first results





KamLAND Coll., K. Eguchi et.al



Fogli et. al. hep-ph/0212127

LMA-II (~HLMA) disfavored, BUT statistically acceptable
➔It should not be neglected a-priori

Can KamLAND disentangle LMA-I & LMA-II if the true solution ~LMA-II ? If yes, which exposure is needed ?

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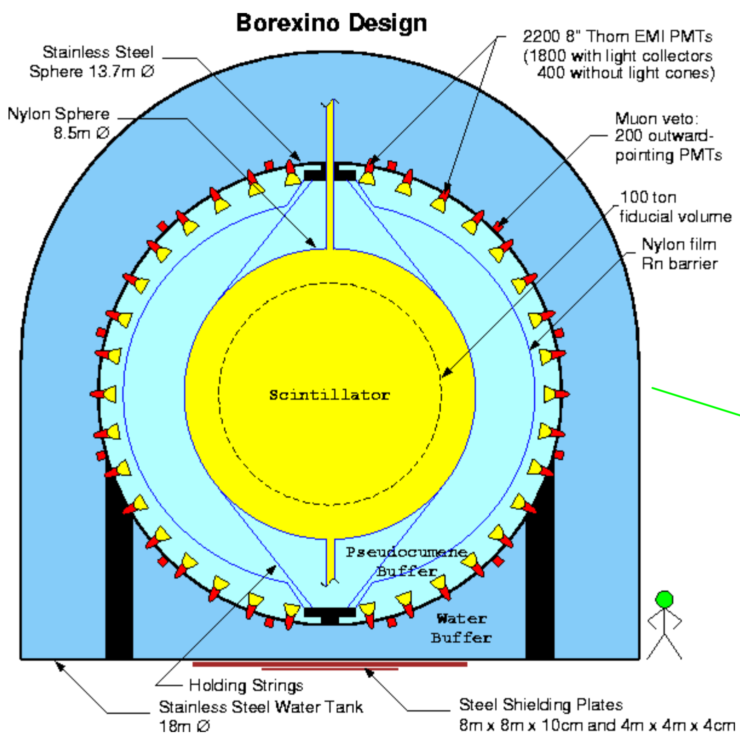
Coming next: BOREXINO



- ✓ Located at the LNGS laboratories
- ✓ Main reactors in France, Switzerland, Germany, <L> ~ 800 km
- ✓ 300 tons of pseudocumene (PC), ~30 interactions/year (22 events above 2.6 MeV)
- ✓ Goals: 1) ^{7}Be solar neutrinos
  2) Test MSW-LMA solution with reactors anti-neutrinos → KamLAND confirmation
- ✓ Optimum: few $10^{-6} < \Delta m^2 < \sim 4\ 10^{-5}$ eV^2
- ✓ Rate analysis only (no shape distorsion expected)

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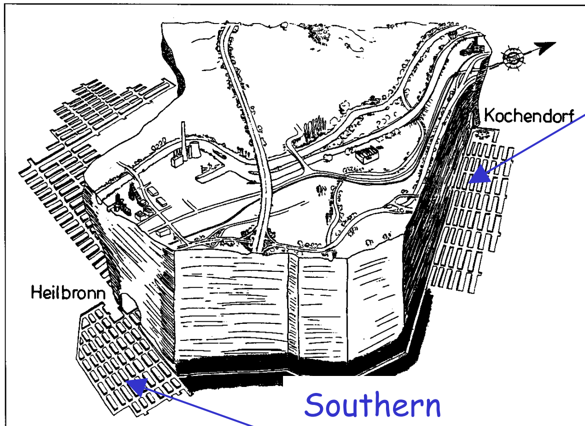
The HLMA Project Heilronn, Germany

New reactor neutrino project to probe the HLMA region $\Delta m^2 > 1.5\ 10^{-4}\ eV^2$

The Heilbronn salt mine



~ 2000 caverns
15 x 10-20 x 100-200m

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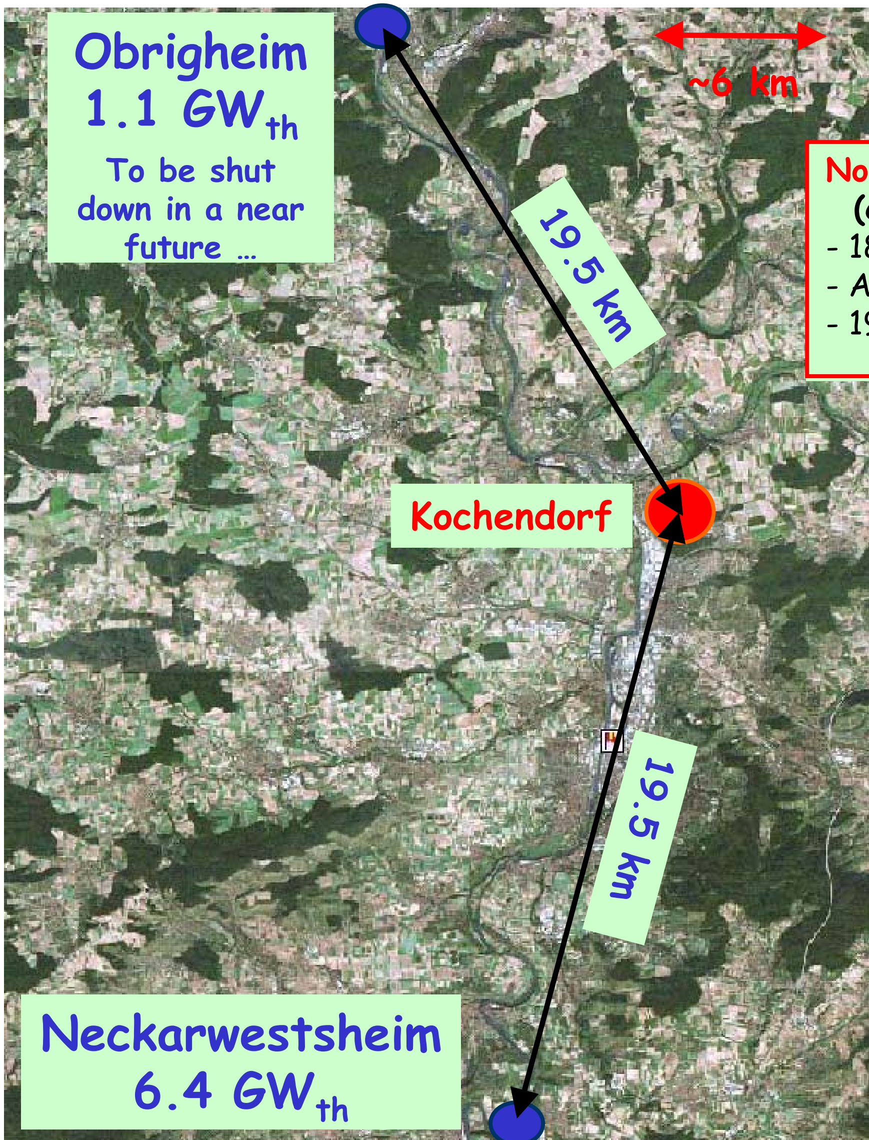
hep-exp/0203013, S. Schönert (MPIK), T. L. (CEA/Saclay), L. Oberauer (INFN,TUM)

Heilbronn detector site: Aerial view



Northern area: Kochendorf
(current best site)
- 180m (480 mwe)
- Accessible via elevator (visitor site)
- 19,5 km from Obrigheim/Neckar.

Southern area: Neubollinger Hof
- 180-240m (480-640 mwe)
- elevator 3mx3mx10m
- Closer to Neckarwestsheim (14 km)

The two sites are connected by a tunnel

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Anti-ν_e interaction rate at Heilbronn

- >300 GW_{th} European power plants included
- Average typical fuel composition (U, Pu)
  $\nu_e + p \rightarrow e^+ + n$
  $\langle\sigma\rangle$/fission = 5.825×10^{-43} cm^2
- For 10^{31} protons, **194 tons PXE** ($C_{16}H_{18}$)
- **Load factor**: 80% to 90%
- **Expected rate** ~ 1150/year (100% eff.)
  ~ 1025/year (Obrigheim OFF)

Reactor	Distance [km]	Power [GW_{th}]	R_L	R_L/R_0
Neckarwestheim	19.5	6.388	754	66%
Obrigheim	19.5	1.057	125	11%
Philipsburg	54	6.842	107	9%
Biblis	80	7.420	52	4%
Grundremmingen	117	7.986	26	2%
Others (Europe)	> 100	~ 293	86	8%

77% @ 20 km

↓

74% @ 20 km
If
Obrigheim is OFF

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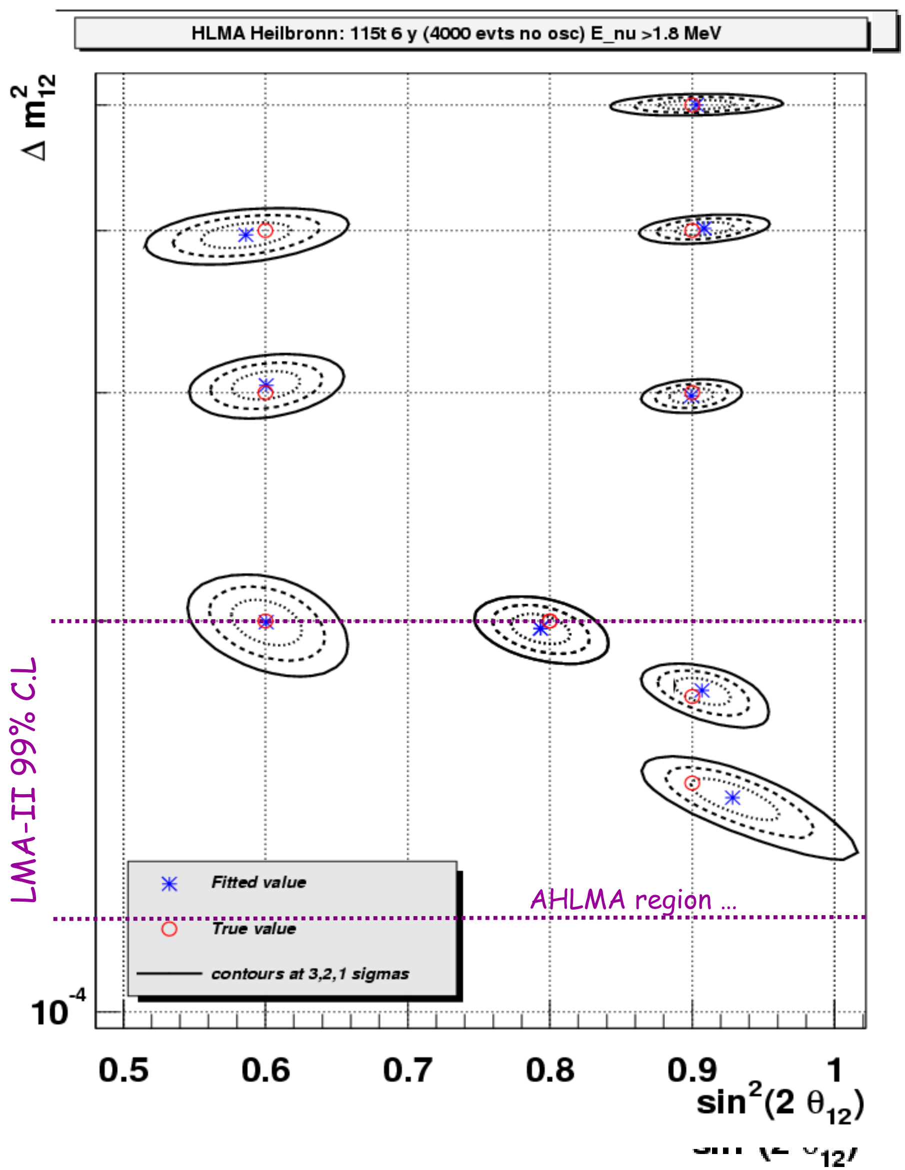
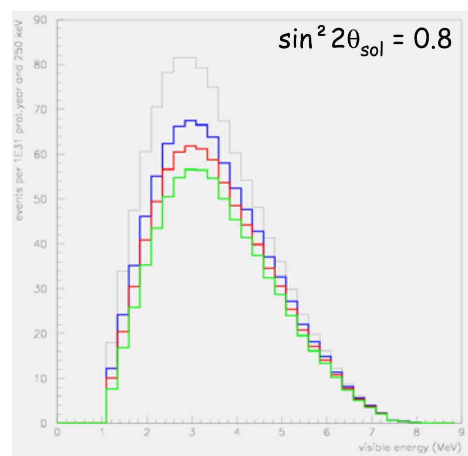
HLMA@Heilbronn : Δm^2_{sol} & $\sin^2 2\theta_{sol}$



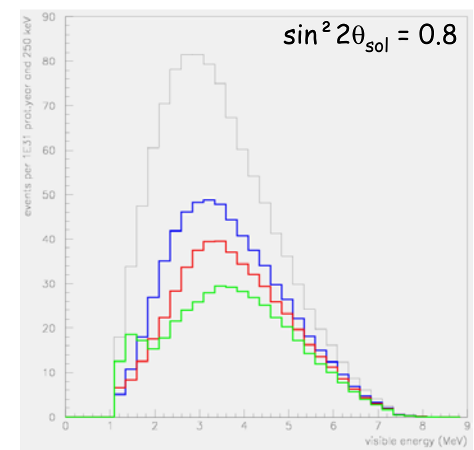
Simulation of HLMA @Heilbronn (kochendorf)

- No background included
- 250 keV bins - 100% efficiency
- **Exposure: 115 tons / 3 years (2000 events)**
- Sensitivity starts at >~1.5 10^{-4} eV^2

Δm^2_{sol} eV^2	$\sin^2 2\theta_{sol}$	$\delta(\Delta m^2_{sol})$ 1σ	$\delta(\sin^2 2\theta_{sol})$ 1σ
$>2\times10^{-4}$	0.8	< 5 %	~5 %



LMA-I
5×10^{-5} eV^2
7×10^{-5} eV^2
9×10^{-5} eV^2



LMA-II
12×10^{-5} eV^2
16×10^{-5} eV^2
20×10^{-5} eV^2

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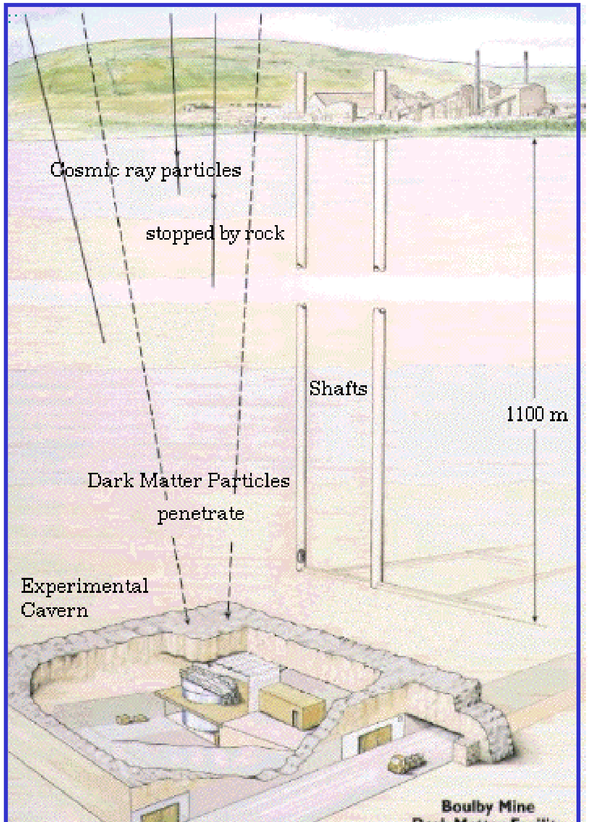
The Boulby site, England



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BOUBLY: a possible site for HLMA ?

✓ **Motivation: LMA-II ➔ Δm^2_{21} ~ 1.2-2.0 10^{-4} eV^2**

- If LMA-II is the solution ➔ precision of KamLAND ?
- HLMA@Heilbronn → sensibility starts at 1.5e-4 eV2

✓ **The Boulby mine location**

- Existing underground laboratory
- 25 km away for the Hartlepool nuclear plant (AGR type, yield~40%,3.2 GW_{th})

✓ **Overburning: 1100 m of rocks.**

- Muon flux attenuated by 10^6

✓ **Statistics ➔ 2000 evts / 500 tons PXE / 3 years**

- Flux(Hartlepool)/Flux(Total) = 81 %
- 90% of the flux from 5 nuclear plants

✓ **Discimination power between LMA-I and LMA-II**

- Sensitivity starts at Δm^2_{21} ~ 1.2 10^{-4} eV^2
- Discrimination power within the LMA-II solution

Reactor	L (km)	P (GW_{th})	F/F_{tot}
Hartlepool	25	3.1	81 %
Heysham	147	5.9	4.5 %
Torness	186	3.1	1.5 %
Graveline	441	17.0	1.5 %
Paluel	526	16.4	1.0 %
Others	-	-	~10 %

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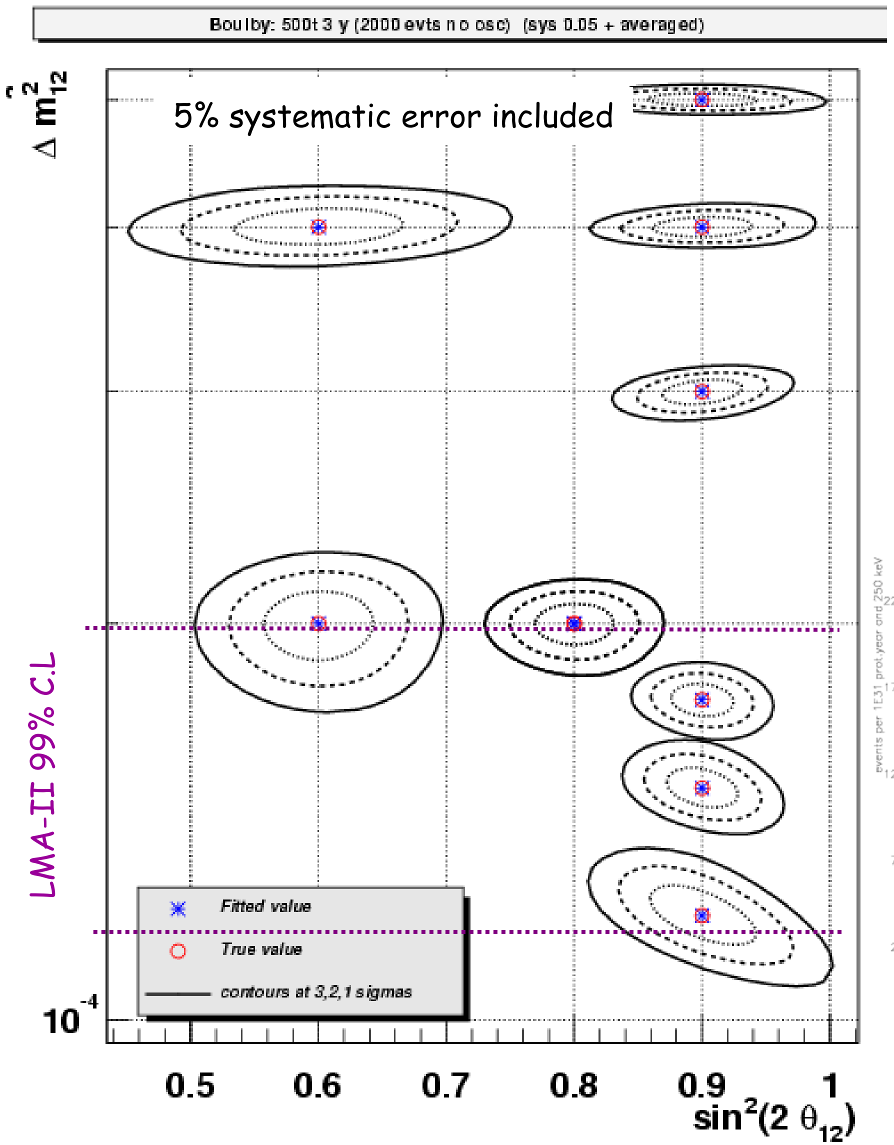
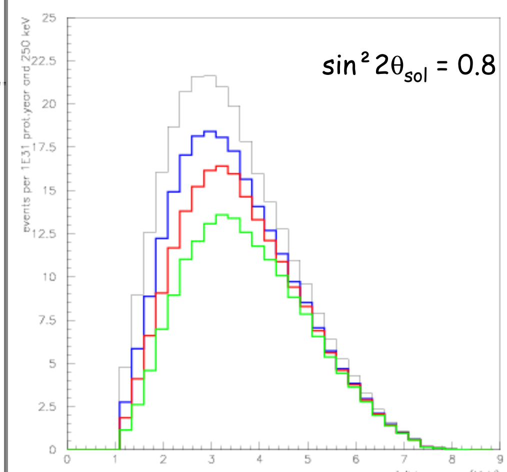
HLMA@Boulby : Δm^2_{sol} & $\sin^2 2\theta_{sol}$



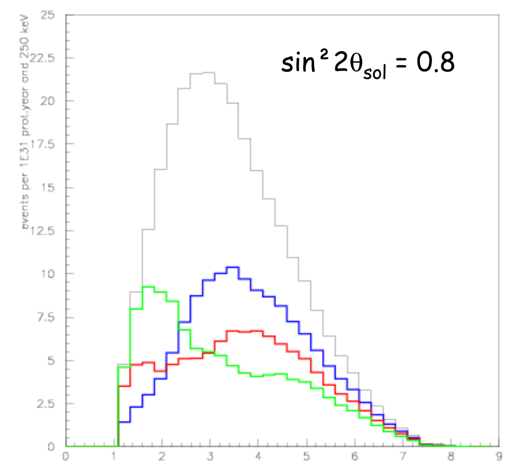
Simulation of HLMA @Boulby

- No background included
- 250 keV bins - 100% efficiency
- **Exposure: 500 tons / 3 years (2000 events)**
- Sensitivity starts at >~1.2 10^{-4} eV^2

Δm^2_{sol} eV^2	$\sin^2 2\theta_{sol}$	$\delta(\Delta m^2_{sol})$ 1σ	$\delta(\sin^2 2\theta_{sol})$ 1σ
>1.5×10^{-4}	0.8	< 5 %	~5 %



LMA-I
5×10^{-5} eV^2
7×10^{-5} eV^2
9×10^{-5} eV^2



LMA-II
12×10^{-5} eV^2
16×10^{-5} eV^2
20×10^{-5} eV^2

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HLMA@Heilbronn: outline of the detector

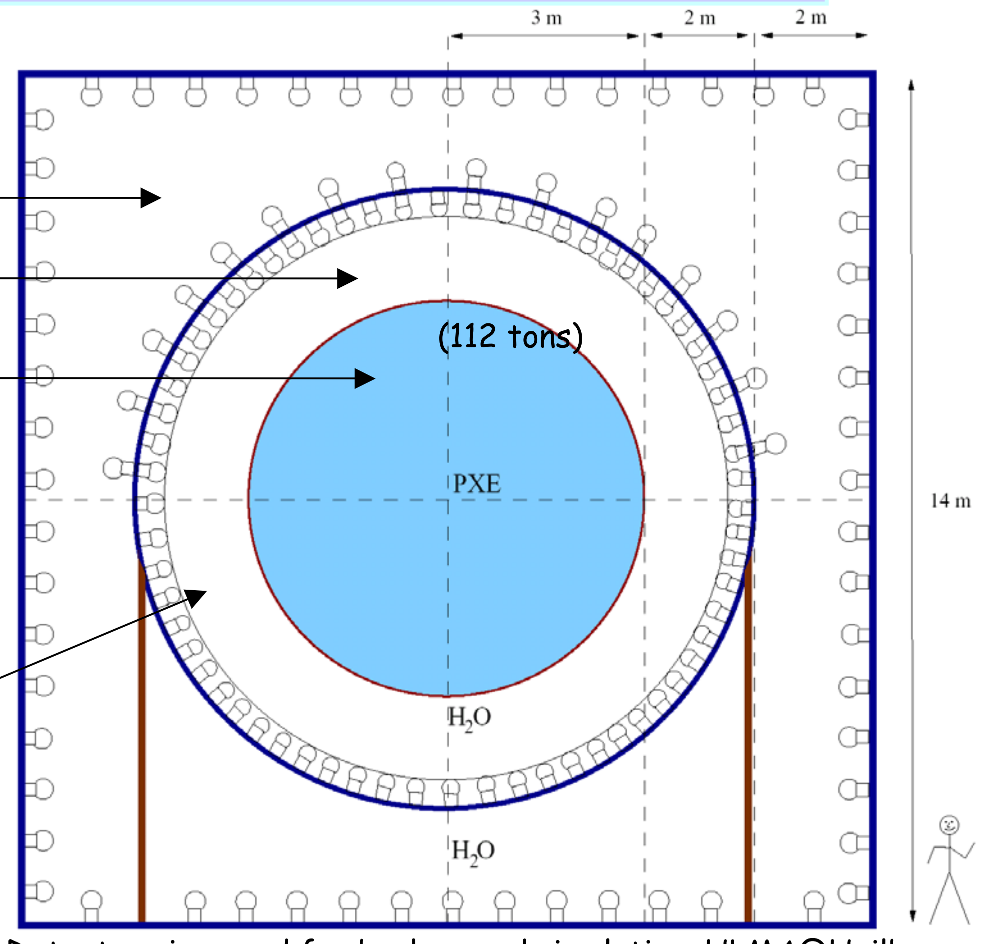
Anti-ν_e tag: $\nu_e + p \rightarrow e^+ + n$, ~1.8 MeV Threshold

- Prompt e+, E_P=1-8 MeV, visible energy
- Delayed neutron capture on H, E_D=2.2 MeV
- Prompt (β/γ) - Delayed(β/γ) ➔ pulse shape discrimination

Time correlation: τ ~ 200µsec

Space correlation: < 1m³

- "CTF" like design
- Muon Veto
- Water Buffer
- Pure PXE scintillator
  - d= 0.99 g/cm³
  - P_{vapor}=1.4 10^{-5} kPa @20°C
  - Flash point = 149 °C
  - High LY (no Gadolinium)
  - Stable
  - Excellent PSD
  - < 10^{-17} gU/g
  - No fiducial volume
- PMTs coverage ~30%
  - 400 pe/MeV



Detector size used for background simulation, HLMA@Heilbronn

$\overline{\nu}_e$ detection free of background

✓ **Geophysical $\overline{\nu}_e$**

- From ^{238}U, ^{232}Th daughters - characteristic spectrum – E_ν < 2.4 MeV
- Rate: 5-33/year/10^{31} protons (<3% reactor rate for HLMA@Heilbronn, <13% for HLMA@Boulby)
- Measurement @ KamLAND & BOREXINO

✓ **Background from radioactivity**: Goal → rate accidental background < 1/year

- **PMTs:** (BOREXINO Scaling), Th-chain: ^{208}Tl line @2.6 MeV
  @BOREXINO: activity (Th activity ➔ 10^3 Bq). R_{PMTs}>5 meters ➔ b_{acc}< 0.1/year
- **Water shield:** (MC simulation): $U \leq 10^{-12}$ g/g , $Th \leq 10^{-12}$ g/g , $K \leq 10^{-10}$ g/g ➔ $Rn \leq \sim 100$ mBq/m³
  CTF ➔ $U \leq 10^{-14}$ g/g , $Th \leq 10^{-14}$ g/g
- **Trace impurities in liquid scintillator:** (MC simulation): $U \leq 10^{-13}$ g/g , $Th \leq 10^{-13}$ g/g , $K \leq 10^{-12}$ g/g
  CTF Values (NNA) ➔ $U \leq 10^{-17}$ g/g , $Th \leq 2\ 10^{-16}$ g/g

✓ **Background induced by cosmic rays** ➔ For HLMA@Heilbronn Only. Deeper = Safer !

- **Calculations at Kochendorf site 480 mwe: <E> ~ 72 GeV , ~756 μ/h/m²**
- **Dominant Trigger Rate ➔ 5.6 μ/s (115 tons)**
- **Background: Production of radioactive nuclei**
  NA54: Isotope production on ^{12}C target @SPS/CERN, μ beam @100/190 GeV
  - ❑ **Single Rate**:, dominated by 11C ,Rate(HLMA)~3500/day ➔ bacc < 1/year
  - ❑ **Correlated events**: β-n cascade, τ~few 100ms, Only ^8He, ^9Li, ^{11}Li,
    Rate(HLMA)~3000/year, μ-n-β-n tag ➔ strong rejection with muon track)
- **Neutrons background induced by μ**
  - ❑ In the water shielding: ~65 n/day/ton → loss < μ track loss <~1/10^6 μ events
  - ❑ In the surrounding rocks: Water shielding to be optimized & PSD optimisation

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Neutrino Mass & Mixing

[redacted] - $sign(\Delta m^2_{32})$ - θ_{13} - δ

LBL
+
ν reacteurs

$\sin^2(2\theta_{13}) < 0.14$ (CHOOZ) → θ_{13} ?

Hierarchie: $sign(\Delta m^2_{32})$?

δ, Violation CP ?

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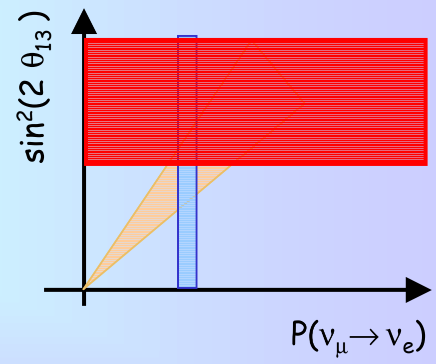
Parameter degeneracy in LBL experiments

LBL ν_μ disappearance gives: $\sin^2(2\theta_{23}) \Rightarrow$ 2 solutions : θ_{23} & $\pi/2-\theta_{23}$
$|\Delta m^2_{13}| \Rightarrow$ 2 solutions $m_1>m_3$ or $m_3>m_1$

LBL appearance probability given by:

$$P(\nu_\mu \to \nu_e) \sim K_1 \sin^2(\theta_{23}) \sin^2(2\,\theta_{13}) + K_2 \sin(2\theta_{23}) \sin(\theta_{13}) \,\mathrm{sign}(\Delta m^2_{31}) \cos(\delta) \pm K_3 \sin(2\theta_{23}) \sin(\theta_{13}) \sin(\delta)$$



- K_1, K_2, K_3: known constants (within experimental error)
- dependence on $\sin(2\theta_{23})$, $\sin(\theta_{23}) \Rightarrow$ 2 solutions
- dependence on $\mathrm{sign}(\Delta m^2_{31}) \Rightarrow$ 2 solutions
- δ-CP phase can run in $[0,2\pi] \Rightarrow$ Interval of solutions in general

$|U_{e3}|^2$ measurement with reactors

- Few MeV $\nu_e \Rightarrow$ **disappearance experiments**
- Few MeV ν_e + very short baseline $\Rightarrow$ **No matter effect contribution** ($O(10^{-4})$ relative effect) $|U_{e3}|^2 \Rightarrow$ measurement independent of $\mathrm{sign}(\Delta m^2_{13})$
- **$|U_{e3}|^2$ measurement independent of the δ-CP phase**

O. Yasuda's talk for details

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Constraint on $|U_{e3}|^2$ & reactor experiment

$$P_{\bar\nu_e\to\bar\nu_e} = 1 - 2|U_{e3}|^2(1-|U_{e3}|^2)\left(1-\cos\frac{\Delta m^2_{31}L}{2E}\right) \qquad (4.1)$$

Atmospheric

$$-\frac{1}{2}(1-|U_{e3}|^2)^2\sin^2 2\Theta_{12}\left(1-\cos\frac{\Delta m^2_{21}L}{2E}\right)$$

Solar

Interference

$$+2|U_{e3}|^2(1-|U_{e3}|^2)\sin^2\Theta_{12}\left(\cos\left(\frac{\Delta m^2_{31}L}{2E}-\frac{\Delta m^2_{21}L}{2E}\right)-\cos\frac{\Delta m^2_{31}L}{2E}\right).$$

In the frame of the HLMA project

- ✓ If $|U_{e3}|^2 \geqslant O(10^{-2})$ & $\Delta m^2_{sol} \lesssim \Delta m^2_{atm}$ and @HLMA baseline ~ 20km
  ➔ **BOTH** atmospheric and solar oscillations develop without being averaged
- ✓ 2 by-products of the HLMA
  constraint on $|U_{e3}|^2$ & ν mass hierarchy ?
- ✓ Exposure of $O(10^{32}$ protons.year) needed …

CLEAN constraint on $|U_{e3}|^2$ & complementarity with long baseline experiments

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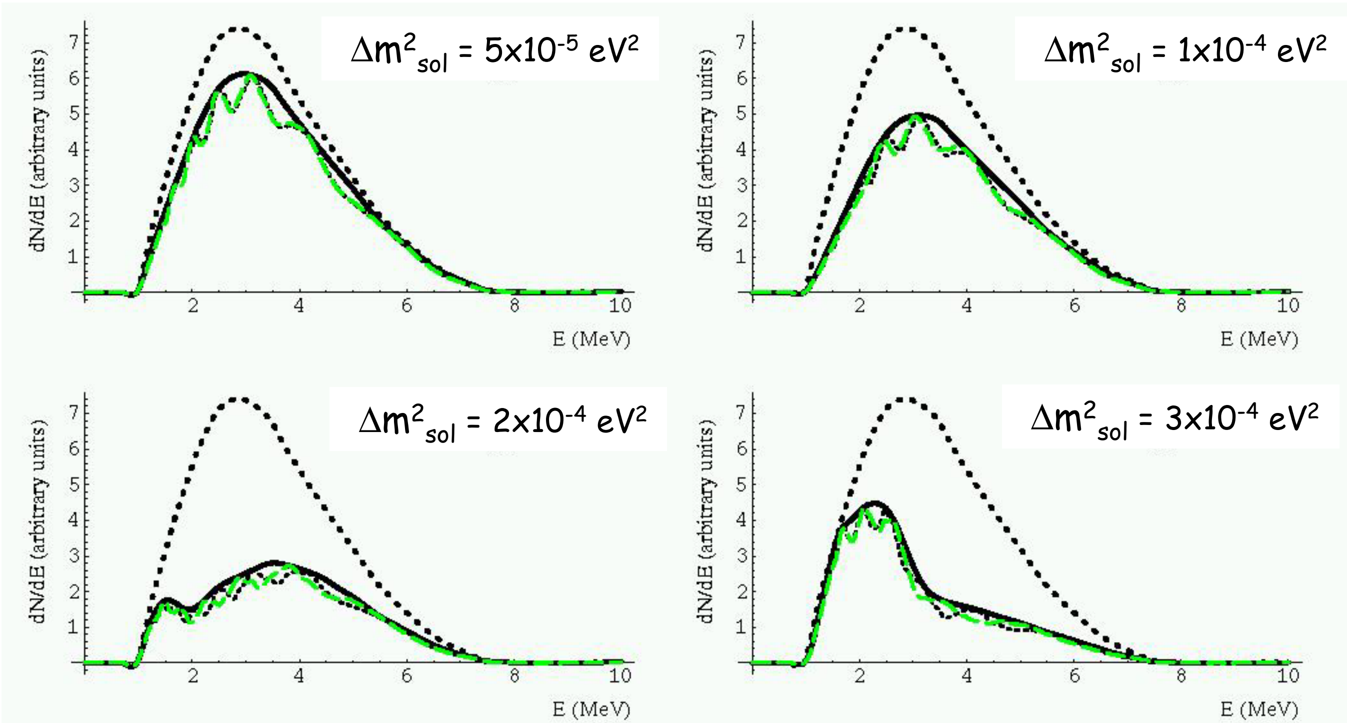
HLMA: constraint on $|U_{e3}|^2$



- .... No-oscillation
- ——— 2ν mixing
- – – – 3ν mixing & NH
- .... 3ν mixing & IH

- HLMA@Heilbronn
- Visible energy,
- unbinned spectra
- No energy resolution
- Δm^2_{atm}=2.5 10^{-3} eV^2
- $\sin^2 2\theta_{sol}$=0.8
- $|U_{e3}|^2$ = 0.04

HLMA: ν mass hierarchy ?

$$+2|U_{e3}|^2(1-|U_{e3}|^2)\ \begin{matrix}\sin^2(\theta_{sol})\\ \cos^2(\theta_{sol})\end{matrix}\ \left(\cos\left(\frac{\Delta m^2_{atm} L}{2E}-\frac{\Delta m^2_{sol} L}{2E}\right)-\cos\frac{\Delta m^2_{atm} L}{2E}\right)$$

Interference term :
- Normal Hierarchy (NH) ➔ $\sin^2(\theta_{sol})$
- Inverted Hierarchy (IH) ➔ $\cos^2(\theta_{sol})$

(Petcov & Piai, hep-ph/0112074)

Sensitivivity to the mass hierarchy: ~2-4 x 10^{-4} eV^2 if $|U_{e3}|^2 \geqslant O(10^{-2})$, for Δm^2_{atm}=2.5 10^{-3} eV^2 (for HLMA@Heilbronn)

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Constraint on $|U_{e3}|^2$ & reactor experiment

$$P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - 2|U_{e3}|^2(1-|U_{e3}|^2)\left(1-\cos\frac{\Delta m^2_{31}L}{2E}\right) \quad (4.1)$$

Atmospheric

$$-\frac{1}{2}(1-|U_{e3}|^2)^2 \sin^2 2\Theta_{12}\left(1-\cos\frac{\Delta m^2_{21}L}{2E}\right)$$

Solar

Interference

$$+2|U_{e3}|^2(1-|U_{e3}|^2)\sin^2\Theta_{12}\left(\cos\left(\frac{\Delta m^2_{31}L}{2E}-\frac{\Delta m^2_{21}L}{2E}\right)-\cos\frac{\Delta m^2_{31}L}{2E}\right).$$

[redacted]

With short (CHOOZ like) baseline

✓ What is the ultimate reactor experiment to constraint $|U_{e3}|^2$?

- Distance optimisation
- Near & Far detectors
- Increase statistics
- Decrease systematics

CLEAN constraint on $|U_{e3}|^2$ & complementarity with long baseline experiments

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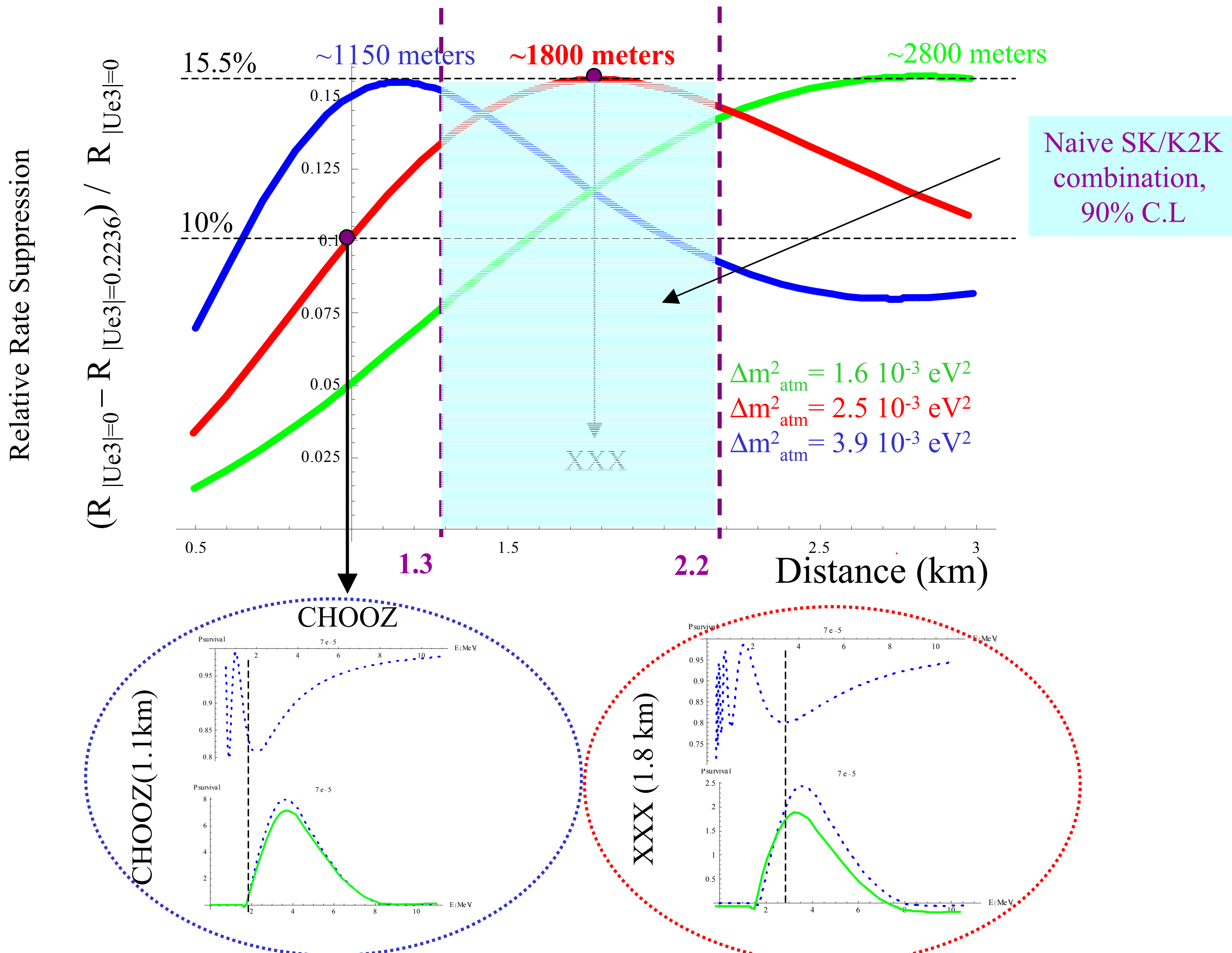
Optimal distance reactor-detector VS Δm^2_{atm}



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General Concepts

- ✓ **Near & Far detector concept to compare the anti-ν spectra at D_1~200-300m & D_2~2 km**
  - Cancellation of uncertainties on the interaction rate (positron spectrum, σ(E), burn-up, power)
- ✓ **2 identical detectors large enough to minimize the statistical error**
  - 40000 events in the far detector ➔ σ_{stat}~0.5 %
  - 20t – 10 GW_{th} – @2km – 70% efficiency ➔ ~8000 events.year
  - Minimize differences of behavior, calibration, efficiencies
  - Possibility to swap the 2 detectors ?
- ✓ **Detectors located underground.**
  - Shielding against muon induced background (minimum 600 mwe)
  - Depth needed ? Will depend on the reactor site → possiblity to do ON/OFF subtraction ?

- ✓ **Nuclear reactor:**
  - As less reactor core(s) as possible ➔ only 1 near detector
  - High thermal power ➔ small detector (especially if one has to dig …)
  - Reactor complex with ON/OFF cycle for efficient background suppression
  - Friendly … to allow us to run an experiment ~300m away from the nuclear core !

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Detector concept & experimental challenge

- ✓ **New (open) working group:**
  - College de France (from CHOOZ), CEA/Saclay, MPI Heidelberg, TU Munchen, Krasnoyarsk Coll.
  - First meeting in December 2002, next coming soon …

- ✓ **Reactor experiment could be *cheap & fast* only if one shows that σ_{sys} can be reduced to 1%**
  - **Exp:** CHOOZ ➔ 2.8%, Bugey ➔ 4.9% to 2.0% with a near detector.
  - **Project goal:** Kr2Det ➔ 0.5 % with a near detector, Kashiwasaki ➔ 0.8 % with a near detector
  - Our goal ➔ 1%, BUT IS IT ACHIVABLE ?

- ✓ **Some identified experimental issues:**
  - Number of protons in target (~1% in CHOOZ) ➔ needs R&D effort ?
  - Energy scale & Detector knowledge ➔ Calibration/Design effort
  - Detector differences !
  - …

- ✓ **Natural detector site:**
  - CHOOZ ?
  - Krasnoyarsk ?
  - Some site candidates …

- ✓ **Analysis:**
  - Rate suppression only ➔ trivial distance optimisation
  - Spectrum distortions analysis. Compensate the distance optimisation with rate only

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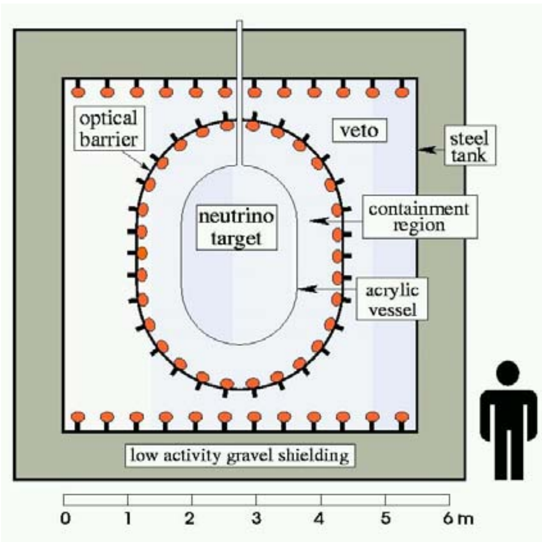
The Chooz experiment



- Site: CHOOZ, Ardennes, France
- Reactor: 2 cores, 2x4.2 GWth
- Depth: 300 mwe
- Target: 5 tons of liquid scintillator (gadolinium loaded)
- <L> = 1100 m
- Best constraint, $|U_{e3}|^2 < 0.036$
- R = 1.01 ± 2.8%(stat) ± 2.7%(syst)

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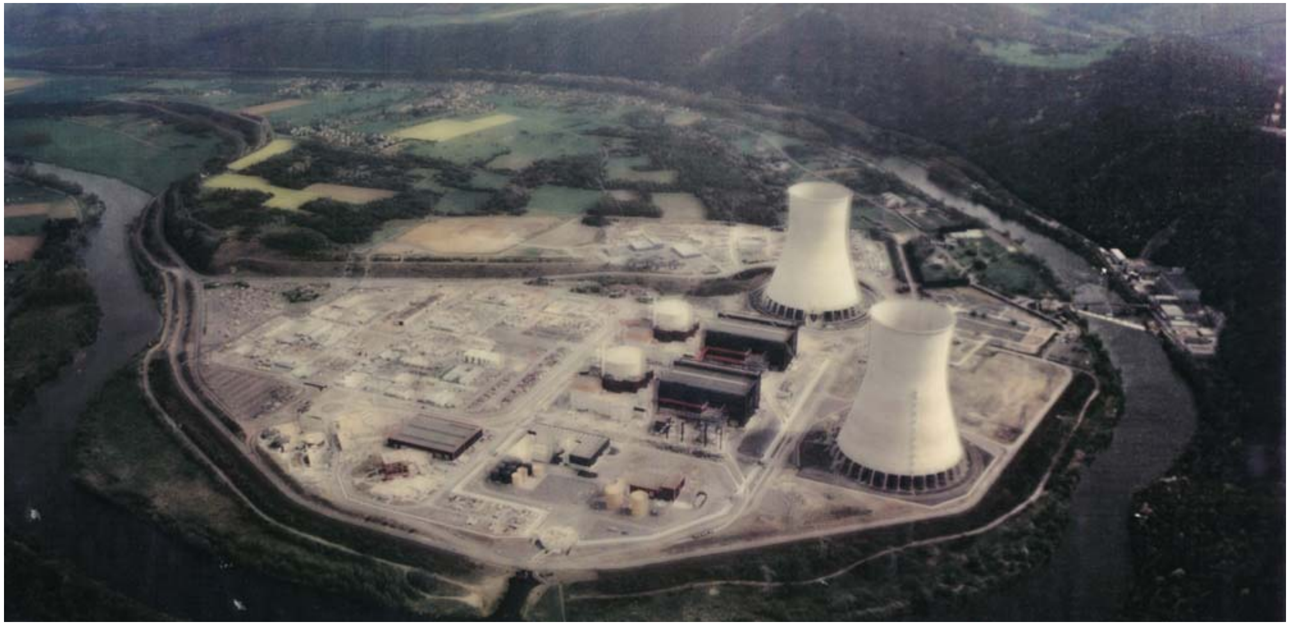
Possibiliy of re-using the CHOOZ site ?

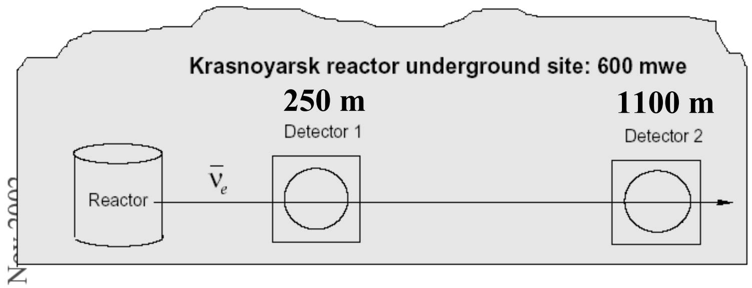


- ✓ Discussion with the reactor site company already started
- ✓Statistics to be increased ➔ **~10-20t target required** ➔ detector site cavity at 1100m would have to be enlarge ➔ it will cost time & money (if it is possible …)
- ✓ There exists an underground railway, with a **cavity at 400-500 meters** (~50-100 meters deep) that could be used for a near detector. But a bit too far: suppression~2.4% for $|Ue3|^2$=0.036
- ✓ Sounds not so promising …

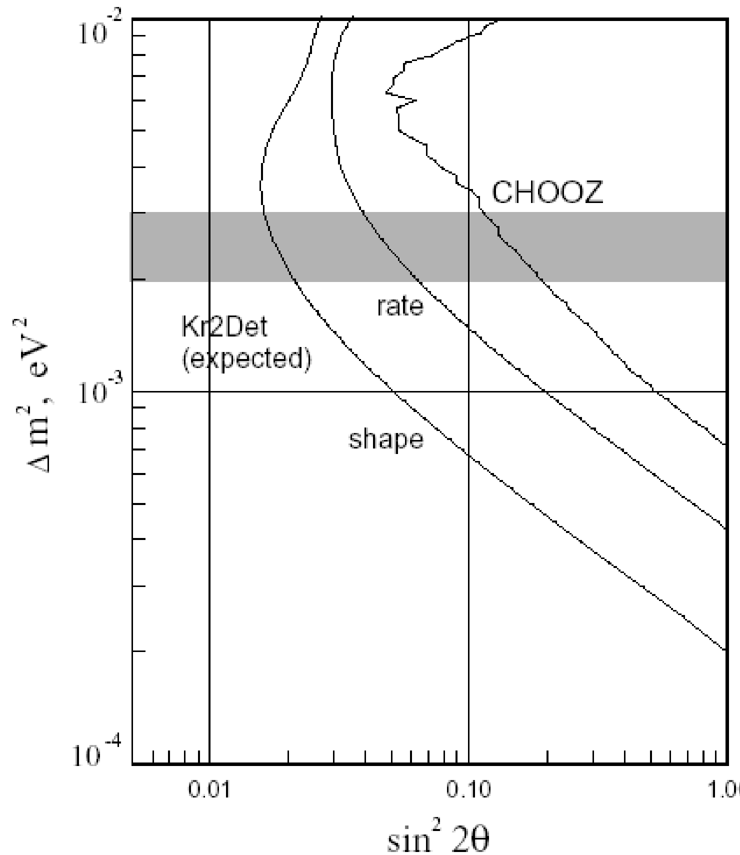
Current best existing site: Krasnoyarsk

V. Martemyanov, L. Mikaelyan, V. Sinev, V. Kopeikin, Y. Kozlov, Russian Research Center “Kurchatov Institute”

Kr2Det



Siberian Taiga (from Europe, 2x5h plane, + 2h drive)



Assuming $\sigma_{sys} = 0.5$ %

@$\Delta m^2_{atm} = 2.5\ 10^{-3}$ eV^2

Rate analysis: $|U_{e3}|^2 < 0.01$ (90% C.L)

Shape analysis: $|U_{e3}|^2 < 0.004$ (90% C.L)

✓Advantages:

- 1 reactor core only
- ON/OFF cycle [50d/ON & 7d/OFF] cycle
- Underground reactor
- Underground cavern (600 mwe) with 2 sites at ~100m and ~1000m
- 2 identical detectors (same overburned)
- Site available now

✓ Weak points:

- Far detector @1000m only ➔ probably not optimal
- Only 1.6 GWth ➔ 50tons detector for 15kevents/year

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Forthcoming $|U_{e3}|^2$ constraints

Experiment	$\sin^2(2\theta_{13})$	$\|U_{e3}\|^2$	θ_{13} (deg)	$\|U_{e3}\|^2$ constraint
CHOOZ (95%C.L.)	<0.14	<0.036	<11	-
MINOS	<0.06	<0.015	<7.1	?
ICARUS 5 years	<0.04	<0.010	<5.8	2011 ?
OPERA 5 years	<0.06	<0.015	<7.1	2011 ?
NUMI-OA 5 years	<0.006	<0.0015	<2.3	2012 ?
JHF2K 5 years	<0.006	<0.0015	<2.3	2011 ?
Kr2Det (Russia)	<0.016	<0.004	<3.6	?
Kashiwasaki (Jp)	**<0.013**	**<0.0033**	**< 3.3**	**?**
XXX ***With a near detector*** (σ_{sys} = 1%)	**<0.02**	**<0.005**	**<4.1**	**2009/2010 ?**

- When the C.L. are not given, upper limits correspond to 90% C.L
- Δm^2_{atm}= 2.5 10^{-3} eV^2 and $\sin^2(2\theta_{atm}) = 1$
- $\sin^2(2\theta_{13}) = 4 \ |U_{e3}|^2 (1 - |U_{e3}|^2)$
- Non exhaustive table …

T. Lasserre

LowNu03

4th International Workshop on Low Energy and Solar Neutrinos

May 19 (afternoon) - May 21 (noon), 2003,

organized by the

"Astroparticule & Cosmologie" Laboratory (APC),
Paris, France

http://cdfinfo.in2p3.fr/LowNu2003

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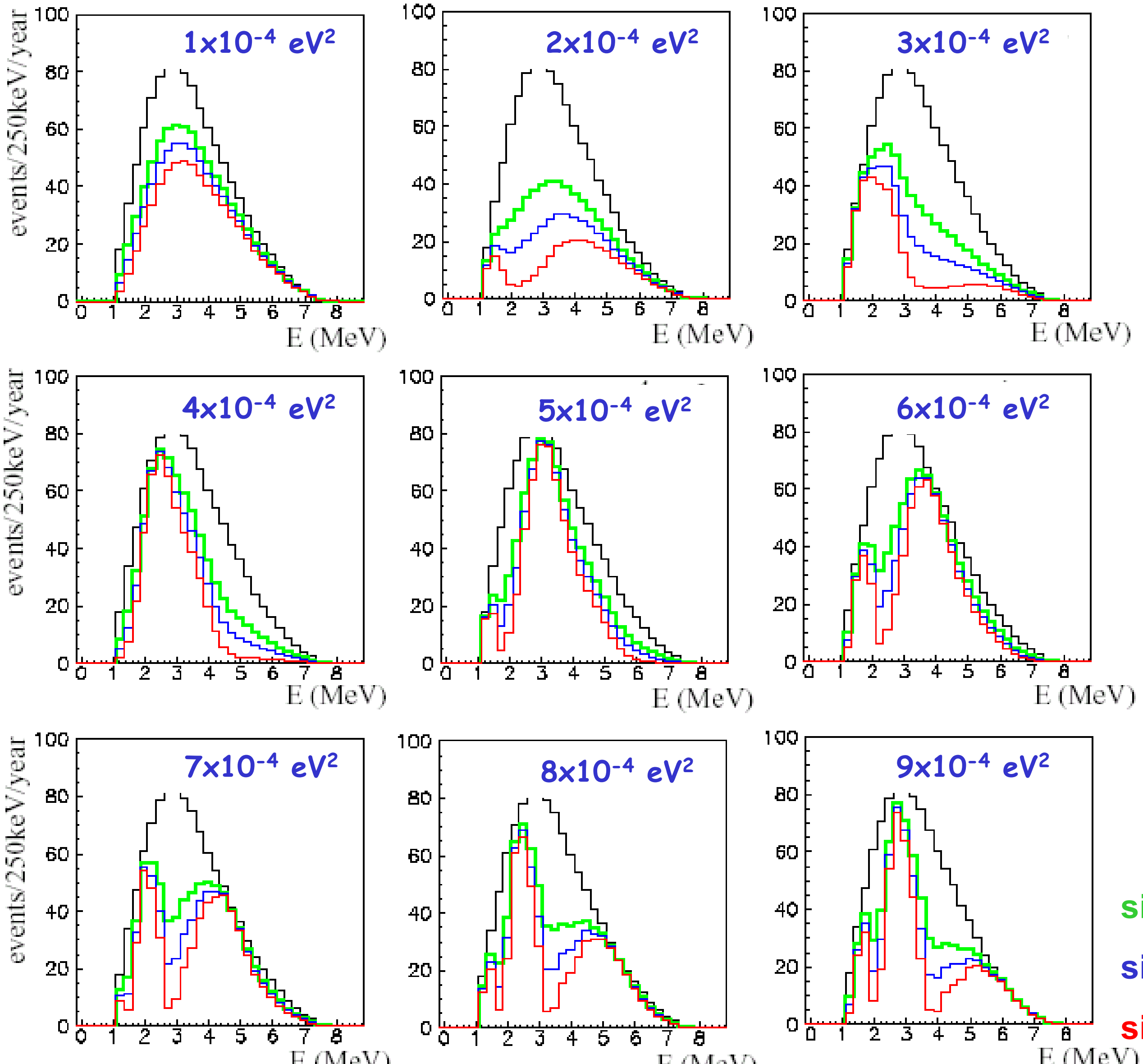
HLMA Focus: Solar mixing parameters



- 2 neutrino mixing
- 10^{31} protons
- No energy resolution
- 250 keV bins
- $\Delta m^2 < 10^4$ eV^2 only rate suppr.
- Optimised for HLMA region
- High sensitivty to Δm^2

$\sin^2 2\theta = 0.6$

$\sin^2 2\theta = 0.8$

$\sin^2 2\theta = 1.0$

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By-product 2: ν mass hierarchy (1)

Normal Hierarchy (NH)

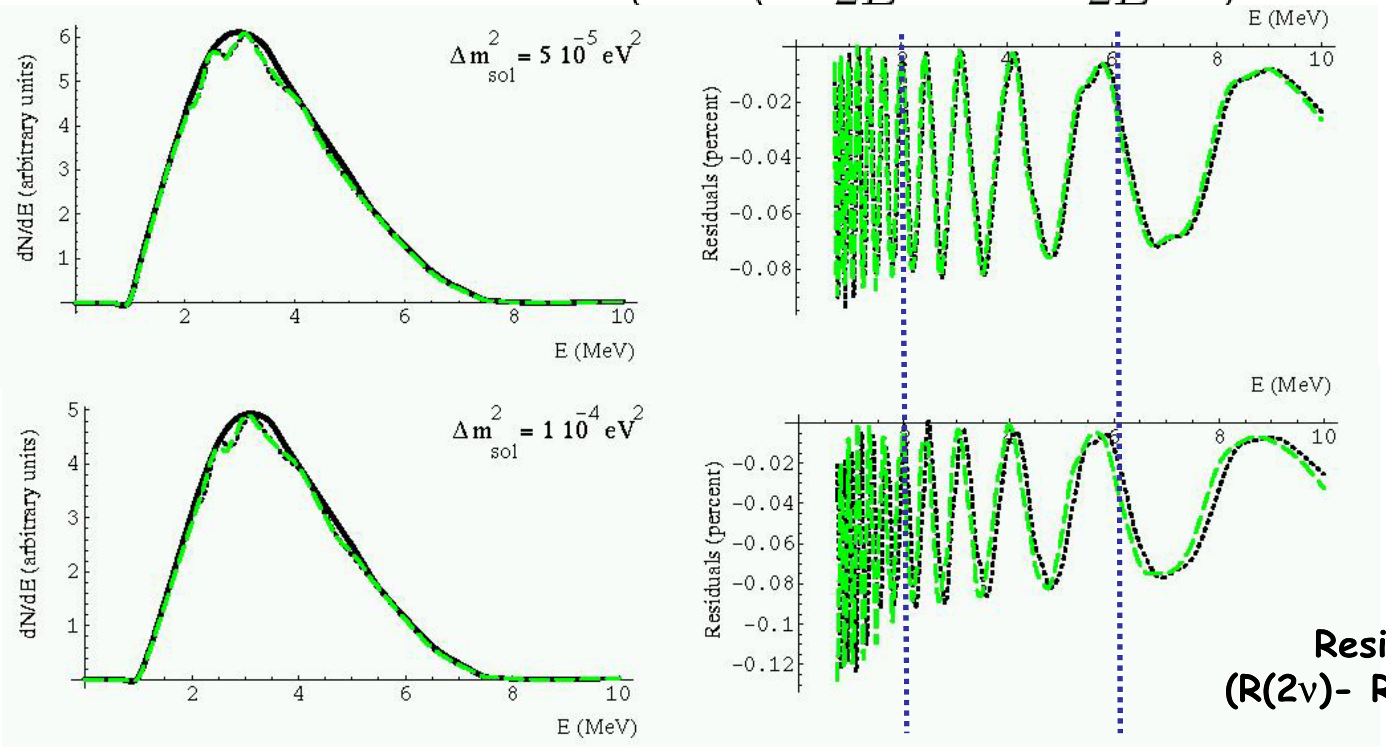
- $m_1 < m_2 < m_3$
- Interference term: $\sin^2(\theta_{sol})$
- constraint on $|U_{e3}|$

Inverted Hierarchy (IH)

- $m_3 < m_1 < m_2$
- Permutation 3→1 , 2→3, 1→2
- Interference term: $\cos^2(\theta_{sol})$
- constraint on $|U_{e1}|$

$$+2|U_{e3}|^2(1-|U_{e3}|^2)\ \begin{matrix}\sin^2(\theta_{sol})\\ \cos^2(\theta_{sol})\end{matrix}\ \left(\cos\left(\frac{\Delta m^2_{atm}L}{2E}-\frac{\Delta m^2_{sol}L}{2E}\right)-\cos\frac{\Delta m^2_{atm}L}{2E}\right)$$

$|U_{e3/1}|^2 = 0.04$



Residuals:
(R(2ν)- R(3ν)) / R(2ν)

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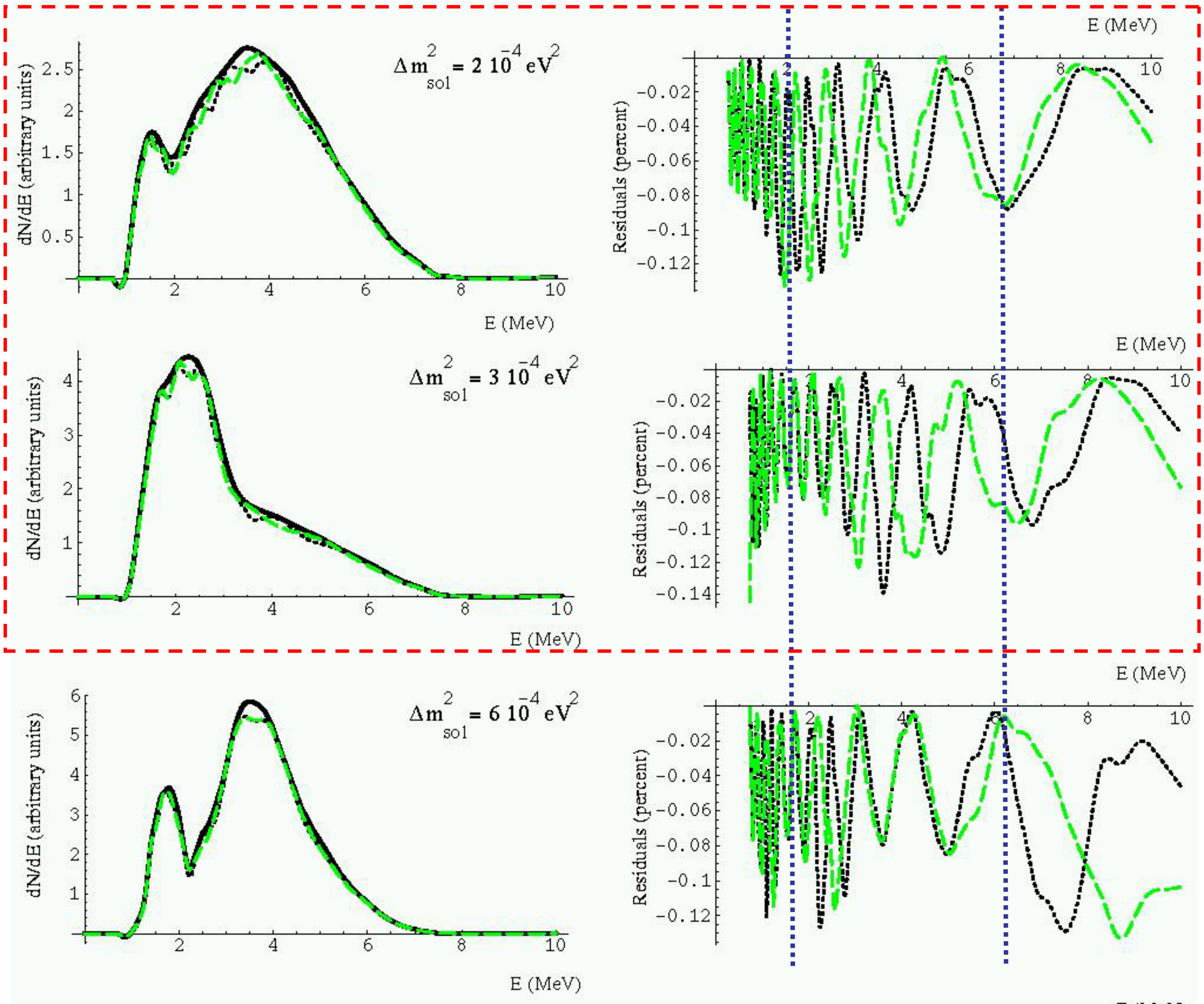
By-product 2: ν mass hierarchy (2)

Sensitive to hierarchy: ~2-4 × 10⁻⁴ eV²



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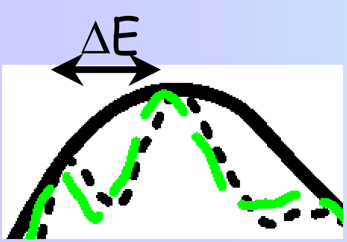
HLMA: Physics goals & Detector design

I) Accurate measurement of the solar mixing parameters

- Target size scale: ~ 5×10^{30} protons-year (~100t PXE)
- $\delta(\Delta m^2) < 5\%$ & $\delta(\sin^2 2\theta) < 5\%$ (2 sigmas)

II) By-product 1: Constraint on $|U_{e3}|$
By-product 2: Sensitivity to ν mass hierarchy ?

- Target size scale: 10^{32} protons-year for $|U_{e3}|^2 \sim 0.01$ (KamLAND scale)
- Resolve Δm^2_{atm} driven oscillations ➔ Energy resolution δE



$$\delta E < \Delta(E) = \left(\frac{a \cdot E^2_{\bar{\nu}_e}[MeV]}{1 - a \cdot E[MeV]} \right)$$

$$2\pi / a = 2.54 \cdot \Delta m^2_{atm}[eV^2] \cdot L[m]$$

@20 km

@3MeV ➔ $\delta E < 0.5$ MeV
@4MeV ➔ $\delta E < 1.0$ MeV
@5MeV ➔ $\delta E < 1.7$ MeV

- Energy Resolution ➔ 400 pe/MeV, ~7% σ (1MeV)

***) Anti-neutrino detection free of background !

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