Experimentelle Elementarteilchenphysik

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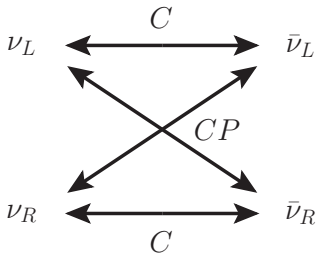
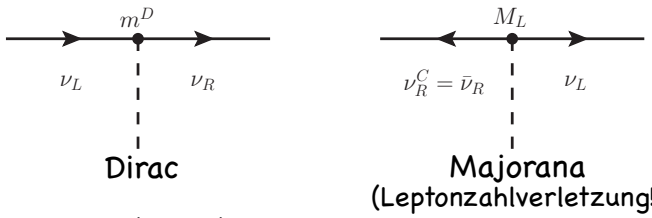
Dirac oder Majorana?

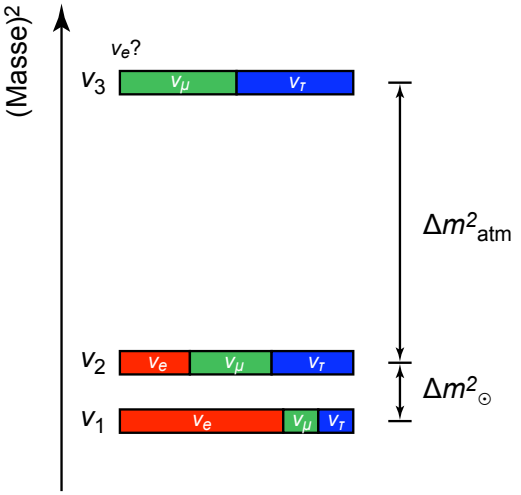
- Ladungskonjugation C und CP-Operation bei Neutrinos:



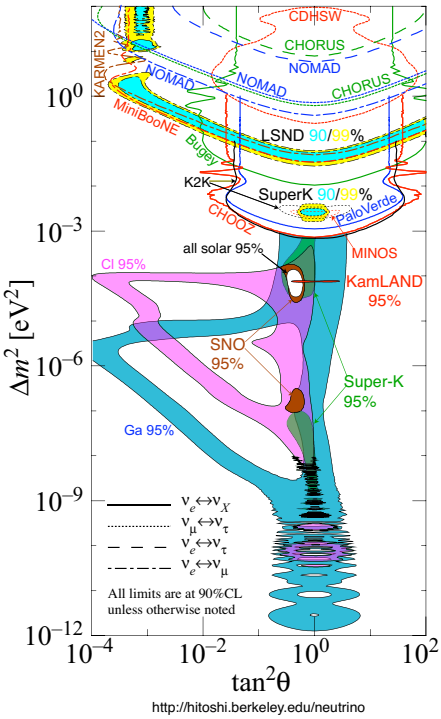
- Majorana-Neutrinos: identifiziere $\nu_L \equiv \nu_R^C, \quad \nu_R \equiv \nu_L^C$
- Dirac- und Majorana-Massen:



Evidenz für Neutrinomassen



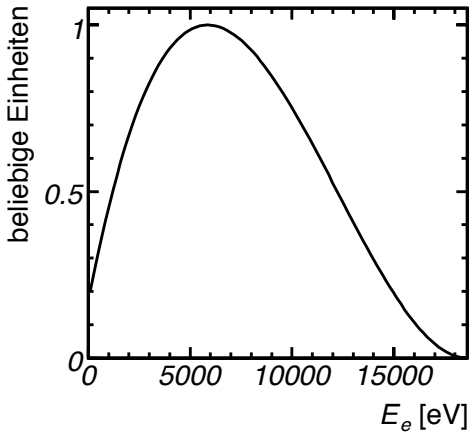
„normale" Massenhierarchie
→ invertiert?



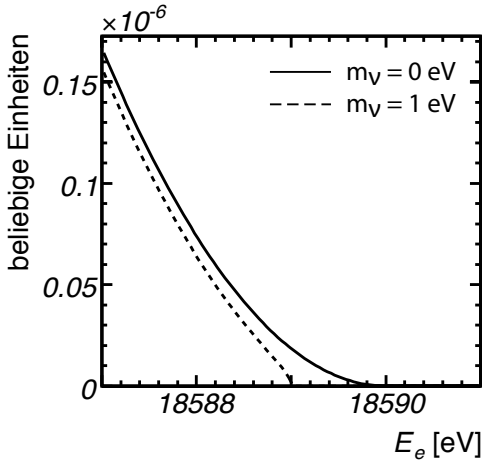
Tritium-Betazerfall

- Energiespektrum der Elektronen:

Gesamtspektrum
(ohne Fermi-Funktion)

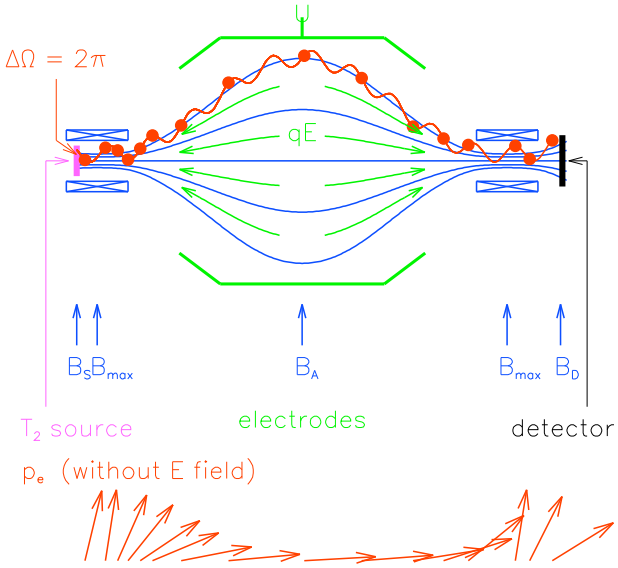


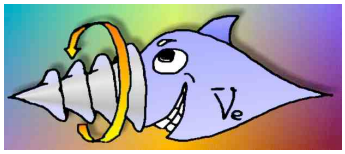
Endpunkt des
Energiespektrums



Tritium-Experimente

- MAC-E-Prinzip: elektrostatischer Filter mit magnetischer adiabatischer Kollimation





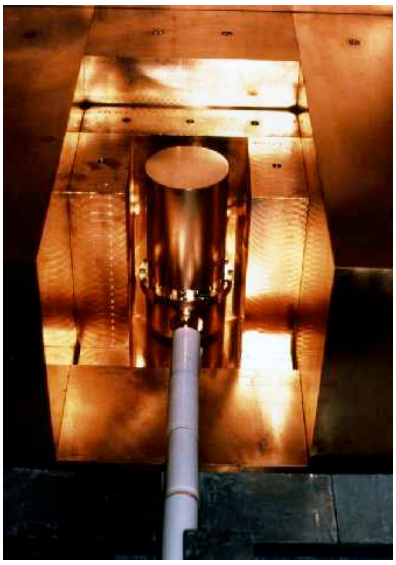
[J. Angrik et al., FZKA Scientific Report 7090]

Ab 2012: KATRIN

[http://www-ik.fzk.de/~katrin/]

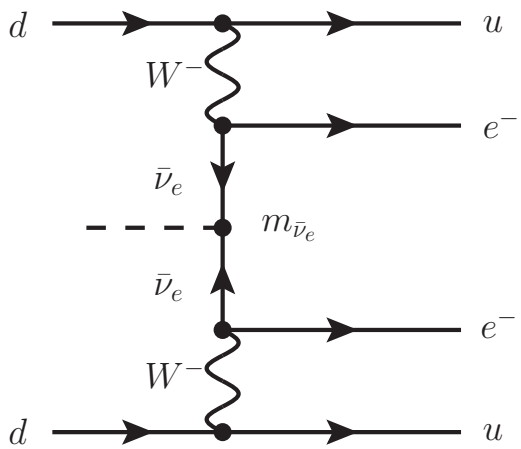
0νββ-Experimente

Germaniumkristall im Heidelberg-Moskau-Experiment



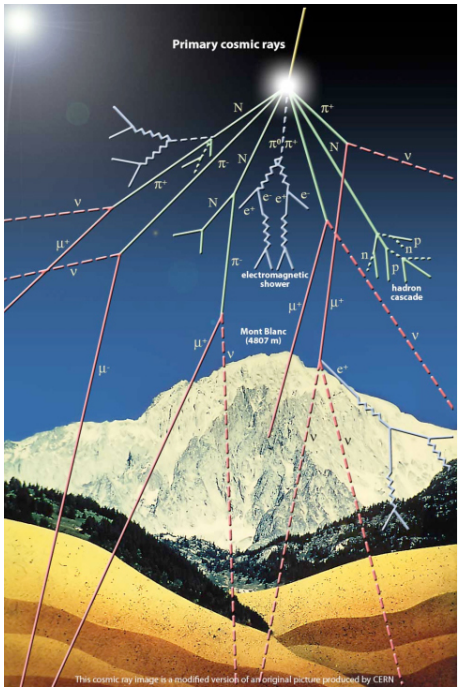
[http://www.klapdor-k.de/]

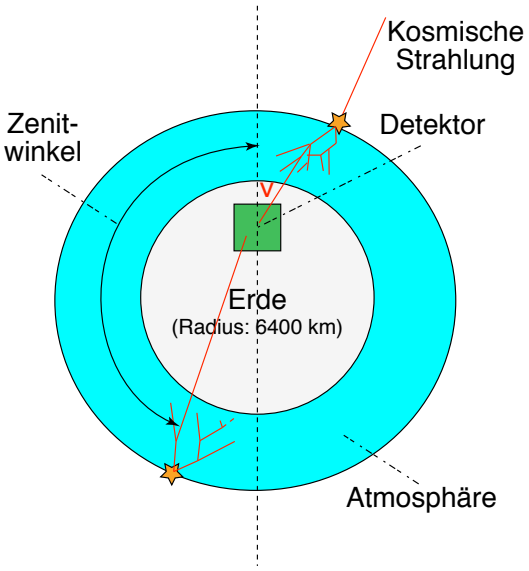
0νββ-Zerfall auf Quarkniveau



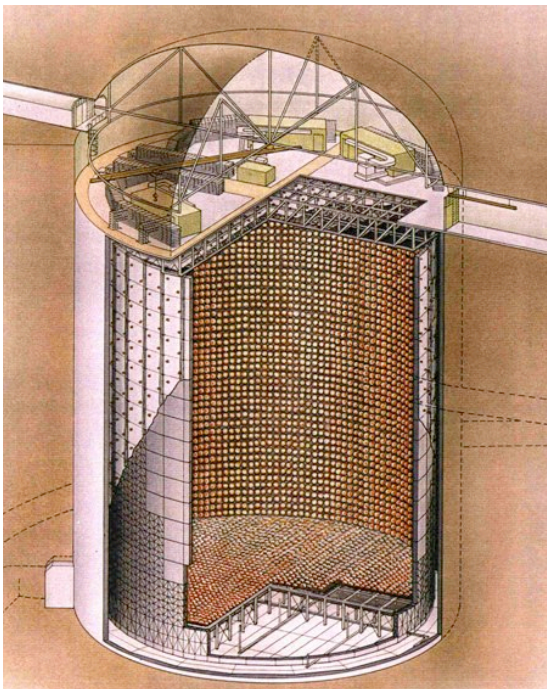
Atmosphärische Neutrinos

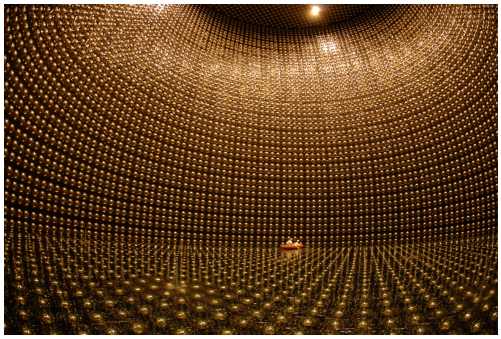
[http://www.expeditions.udel.edu/antarctica/]

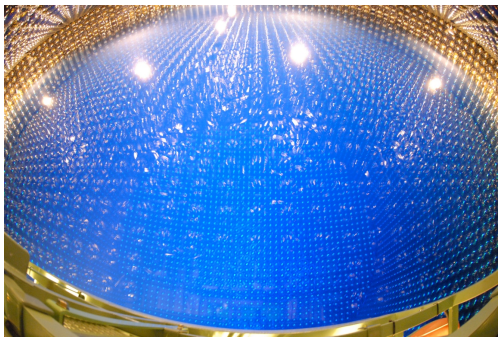




Super-Kamiokande





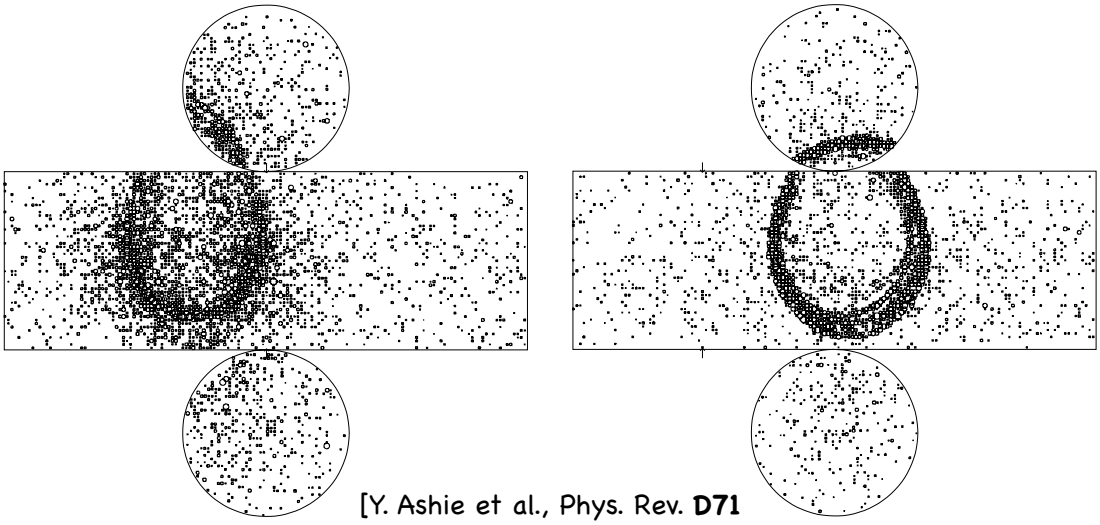


[http://www-sk.icrr.u-tokyo.ac.jp/sk/]

Super-K: e- und μ-Nachweis

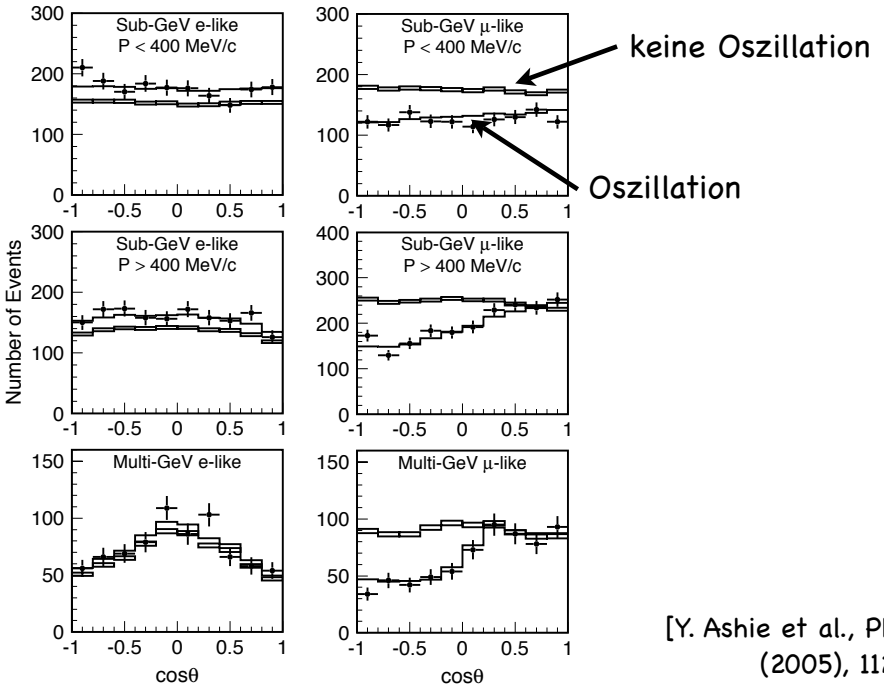
Gestopptes Elektron:
elektromagnetischer Schauer

Gestopptes Myon:
klarer Cherenkov-Ring



[Y. Ashie et al., Phys. Rev. **D71** (2005), 112005]

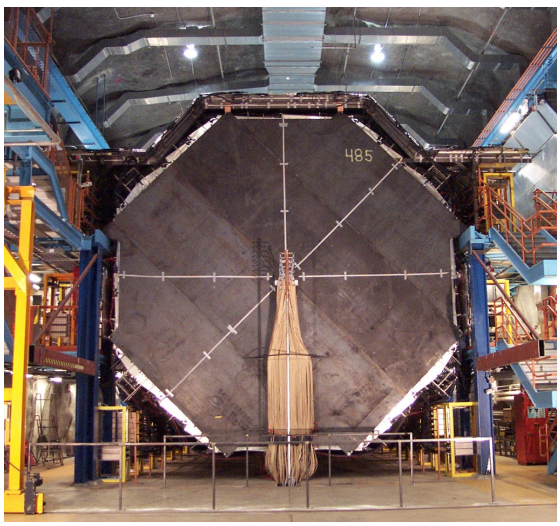
Super-K: Zenitwinkel-Analyse



[Y. Ashie et al., Phys. Rev. **D71** (2005), 112005]

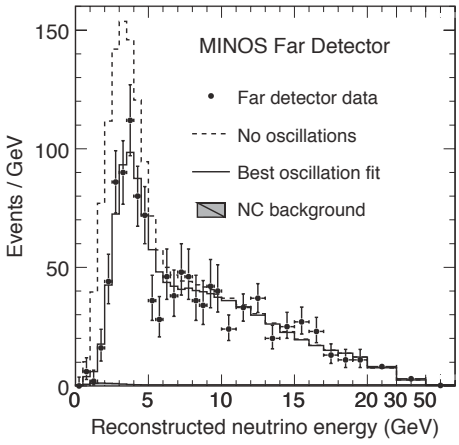
Beschleuniger-ν: MINOS

MINOS Far Detector



[http://www-numi.fnal.gov/]

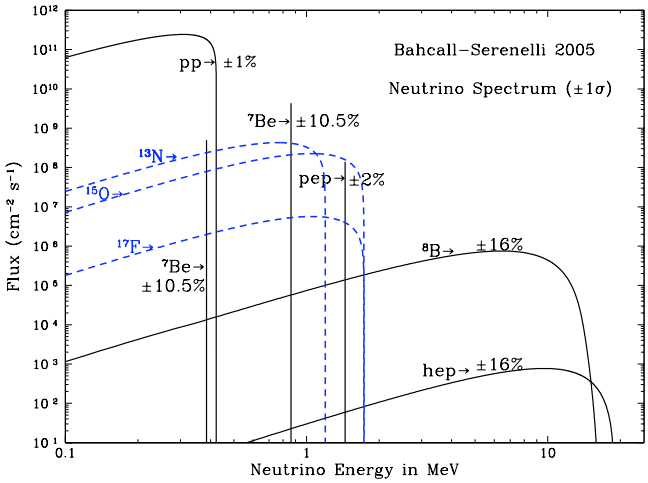
$$\text{CC:} \quad \nu_\mu + \text{Fe} \rightarrow \mu^- + X$$
$$\text{NC:} \quad \nu_\mu + \text{Fe} \rightarrow \nu^\mu + X$$



[P. Adamson et al., Phys. Rev. Lett. **101** (2008)]

Sonnenneutrinos

Neutrinofluss im Standard-Sonnenmodell

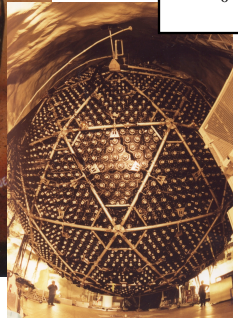


[http://www.sns.ias.edu/~jnb/SNviewgraphs/snviewgraphs.html]

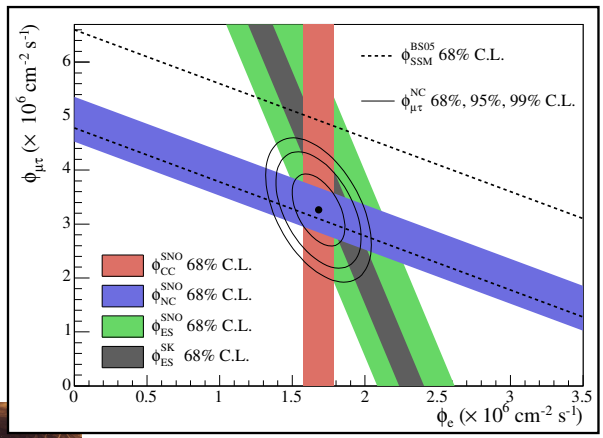
Fusionsreaktionen in der Sonne

Name	Reaktion
Wasserstofffusion	$^1\mathrm{H} + {}^1\mathrm{H} \rightarrow {}^2\mathrm{H} + e^+ + \nu_e$
Deuteriumfusion	$^2\mathrm{H} + {}^1\mathrm{H} \rightarrow {}^3\mathrm{He} + \gamma$
pp-Reaktion I	$^3\mathrm{He} + {}^3\mathrm{He} \rightarrow {}^4\mathrm{He} + {}^1\mathrm{H} + {}^1\mathrm{H}$
pp-Reaktion II	$^3\mathrm{He} + {}^4\mathrm{He} \rightarrow {}^7\mathrm{Be} + \gamma$ $^7\mathrm{Be} + e^- \rightarrow {}^7\mathrm{Li} + \nu_e$ $^7\mathrm{Li} + {}^1\mathrm{H} \rightarrow {}^4\mathrm{He} + {}^4\mathrm{He}$
pp-Reaktion III	$^3\mathrm{He} + {}^4\mathrm{He} \rightarrow {}^7\mathrm{Be} + \gamma$ $^7\mathrm{Be} + {}^1\mathrm{H} \rightarrow {}^8\mathrm{B} + \gamma$ $^8\mathrm{B} \rightarrow {}^8\mathrm{Be} + e^+ + \nu_e$ $^8\mathrm{Be} \rightarrow {}^4\mathrm{He} + {}^4\mathrm{He}$
pep-Reaktion	$^1\mathrm{H} + e^- + {}^1\mathrm{H} \rightarrow {}^2\mathrm{H} + \nu_e$
hep-Reaktion	$^3\mathrm{He} + {}^1\mathrm{H} \rightarrow {}^4\mathrm{He} + e^+ + \nu_e$

Sonnenneutrinos: SNO



[http://www.sno.phy.queensu.ca/]

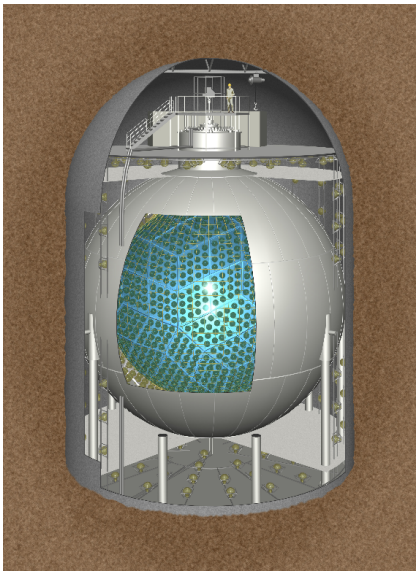


[B. Aharmim et al., Phys. Rev. **C72** (2005), 055502]

$$\begin{aligned} \text{CC:} &\quad \nu_e + d \rightarrow e^- + p + p \\ \text{ES:} &\quad \nu + e^- \rightarrow \nu + e^- \\ \text{NC:} &\quad \nu + d \rightarrow \nu + p + n \end{aligned}$$

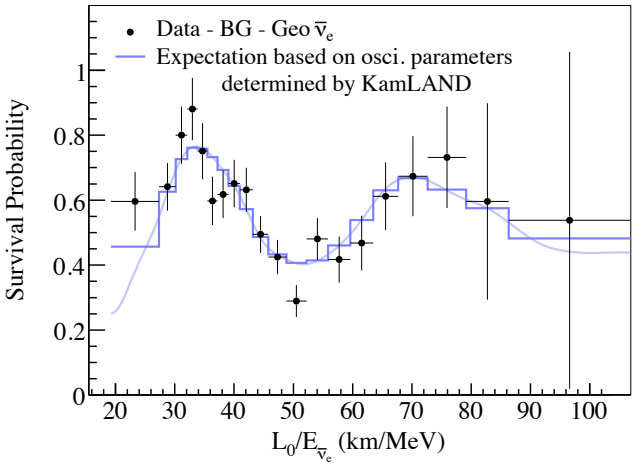
Reaktorneutrinos: KamLAND

KamLAND: Flüssigszintillator



[http://kamland.lbl.gov/]

$$\bar{\nu_e} + p \rightarrow e^+ + n$$



[S. Abe et al., Phys. Rev. Lett. **100** (2008), 221803]

Neutrinophysik: Offene Fragen

- Welche Masse haben Neutrinos?
- Gibt es sterile Neutrinos?
- Sind Neutrinos Majorana-Teilchen?
- Ist der Mischungswinkel θ_{13} ungleich Null?
- Ist die Hierarchie der Neutrinomassen normal oder invertiert?