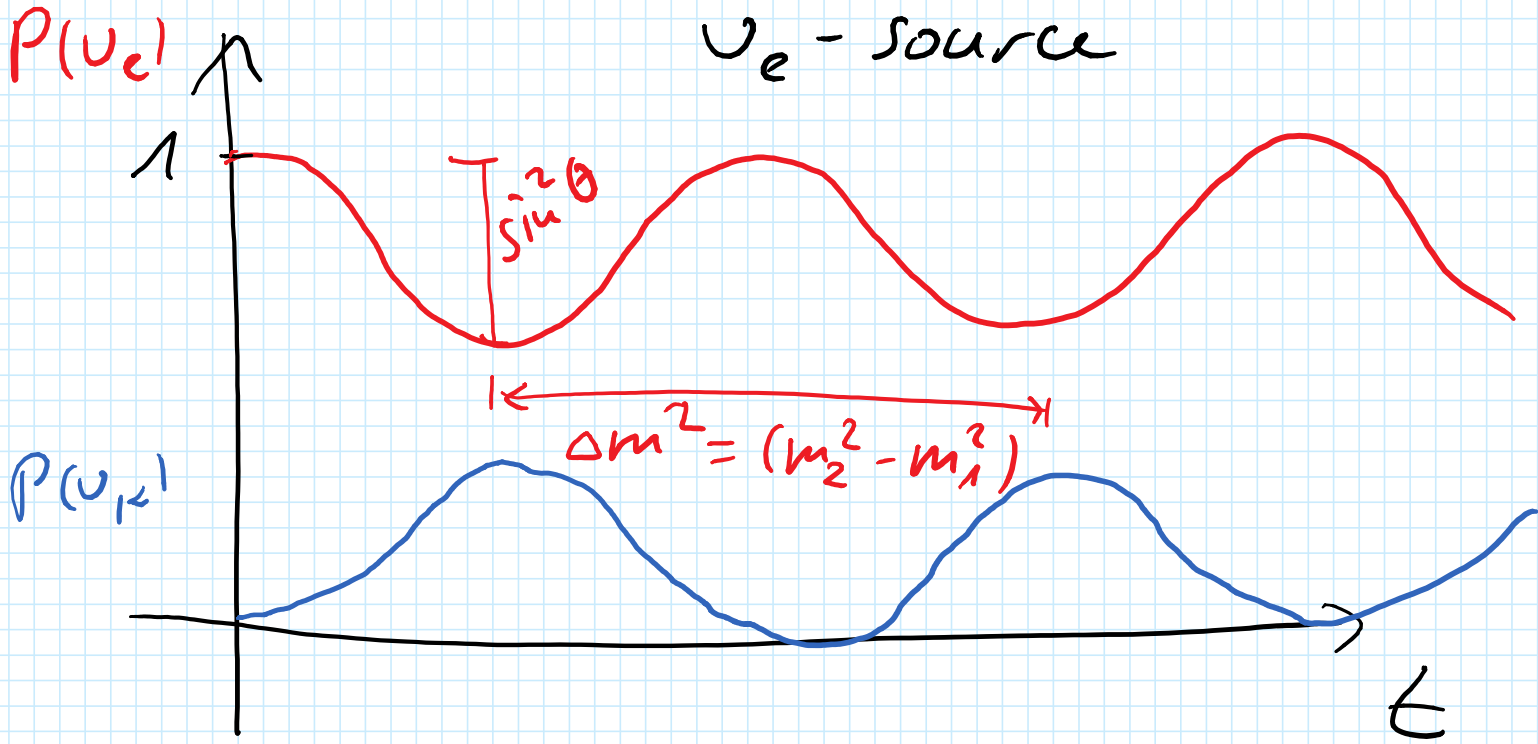
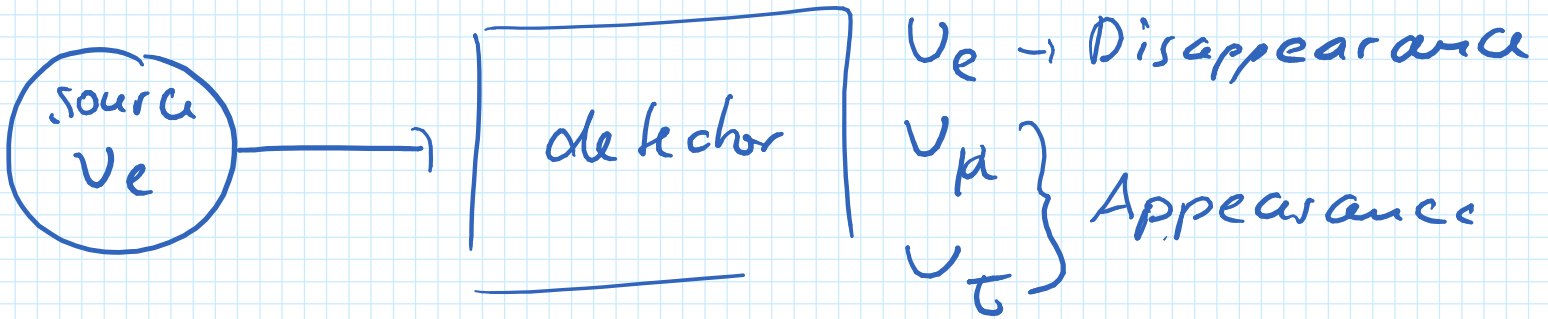


Neutrino Oscillations

Donnerstag, 4. Oktober 2018 09:51





$$\nu_{\tau} + n \rightarrow \tau^{-} + p^{+}$$

$$\xrightarrow{\nu_{\tau}} \otimes (m_N, 0, 0, 0)$$

$$(E_{\nu}, 0, 0, E_{\nu})$$

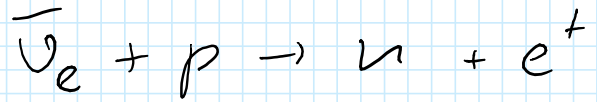
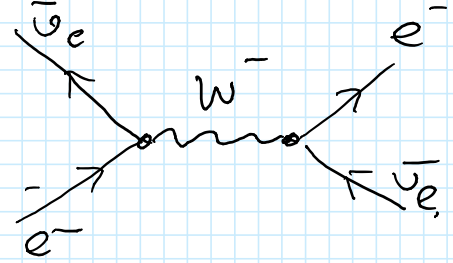
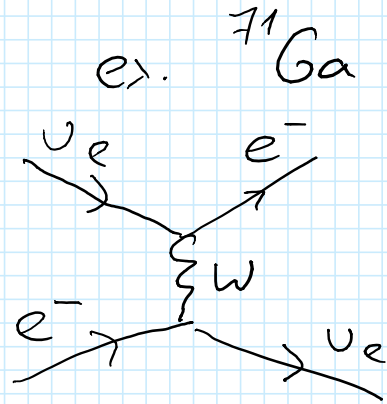
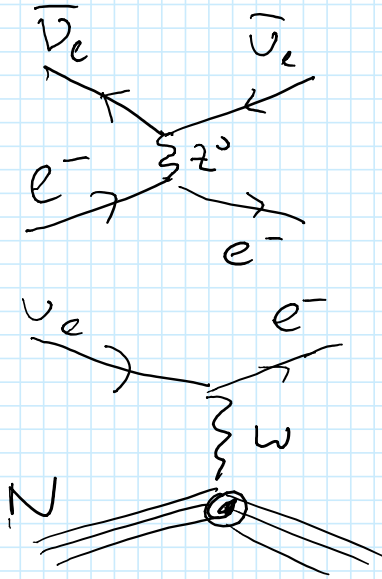
$$s = (E_{\nu} + m_N)^2 - E_{\nu}^2 = \underset{\vec{p}}{2E_{\nu}m_N} + \cancel{m_N^2} > (m_{\tau} + m_n)^2$$

$$E_{\nu} > \frac{1}{2} \left(\frac{m_{\tau}^2}{m_N^2} + 2 \frac{m_{\tau}}{m_N} \right) \cdot m_N \approx 3.4 m_N = m_{\tau}^2 + \cancel{m_n^2} + 2m_{\tau}m_N$$

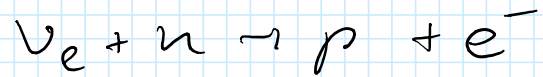
1.4 Neutrino Interactions

Donnerstag, 4. Oktober 2018 07:28

radiodromical



Inverse β -decay IBD

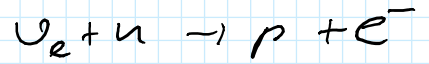
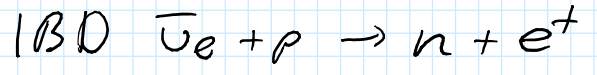


Nuclear

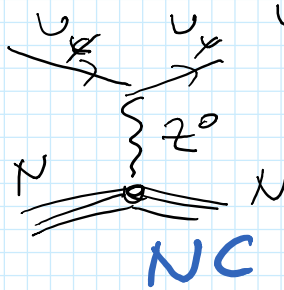
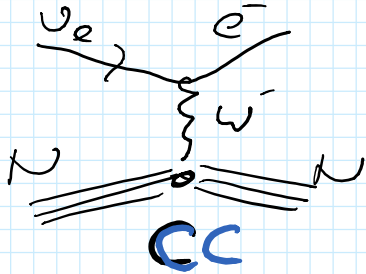
radiodichemical



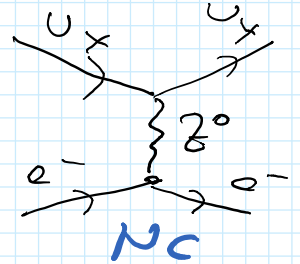
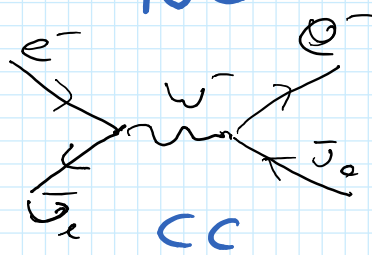
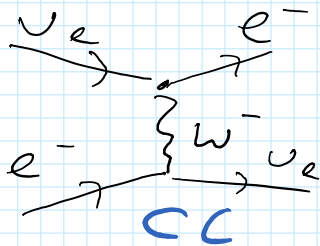
free nucleus



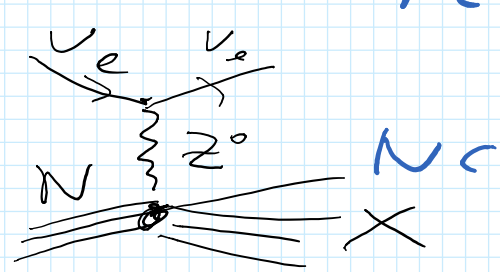
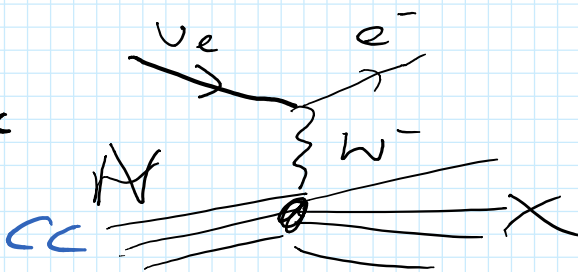
(quasi)elastic scattering



E_ν

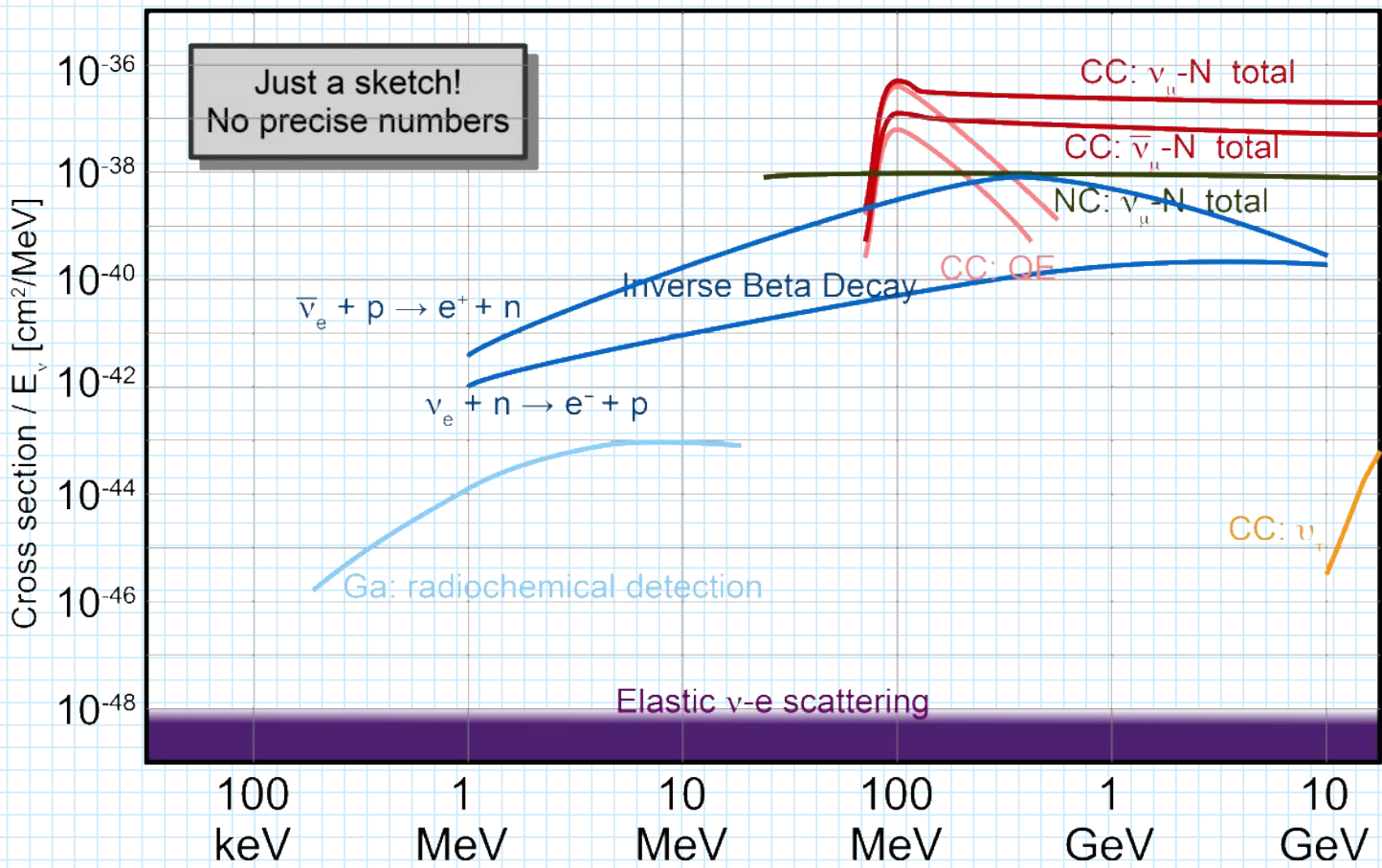


deep inelastic



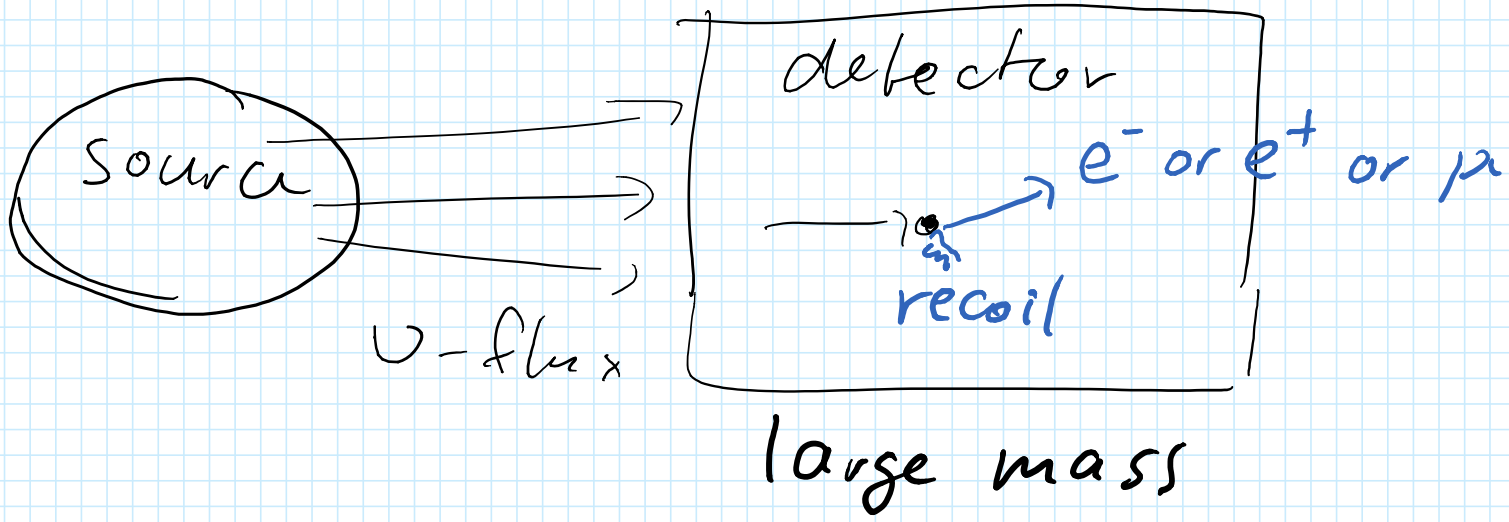
Cross section

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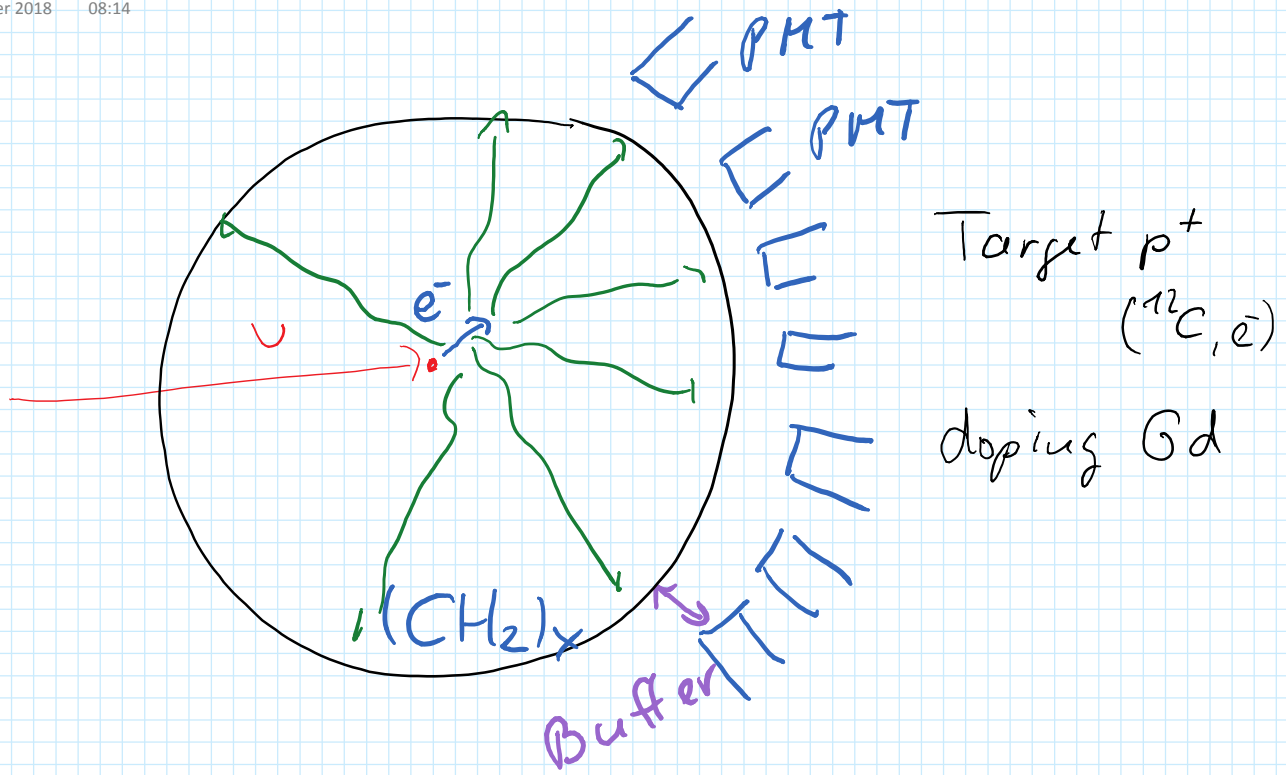
1.5 Detector Technologies

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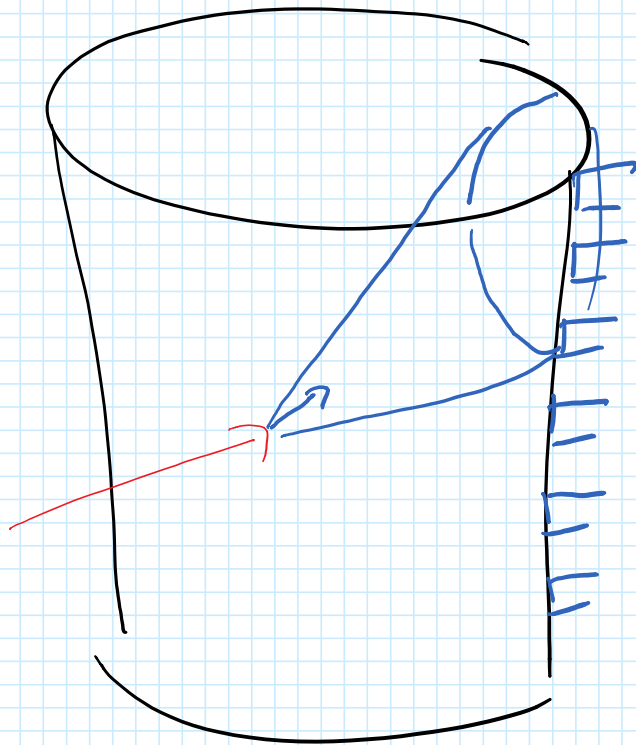
Liquid Scintillator

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Water Cerenkov Detectors

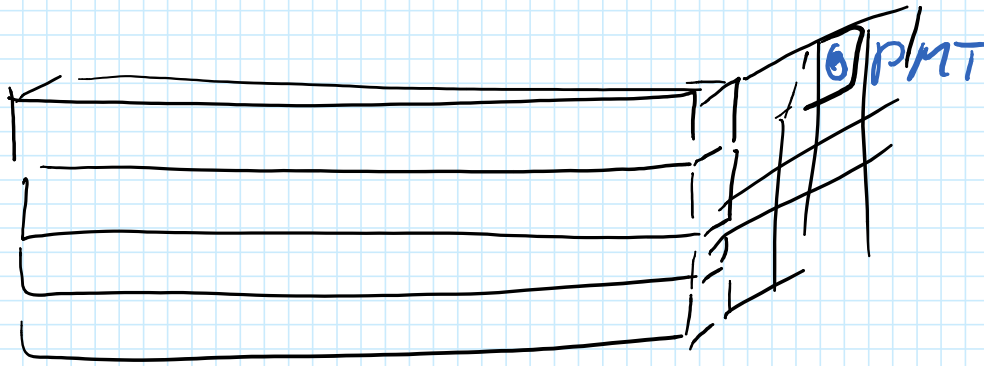
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Cerenkov - threshold

Totally Active Scintillator Detector

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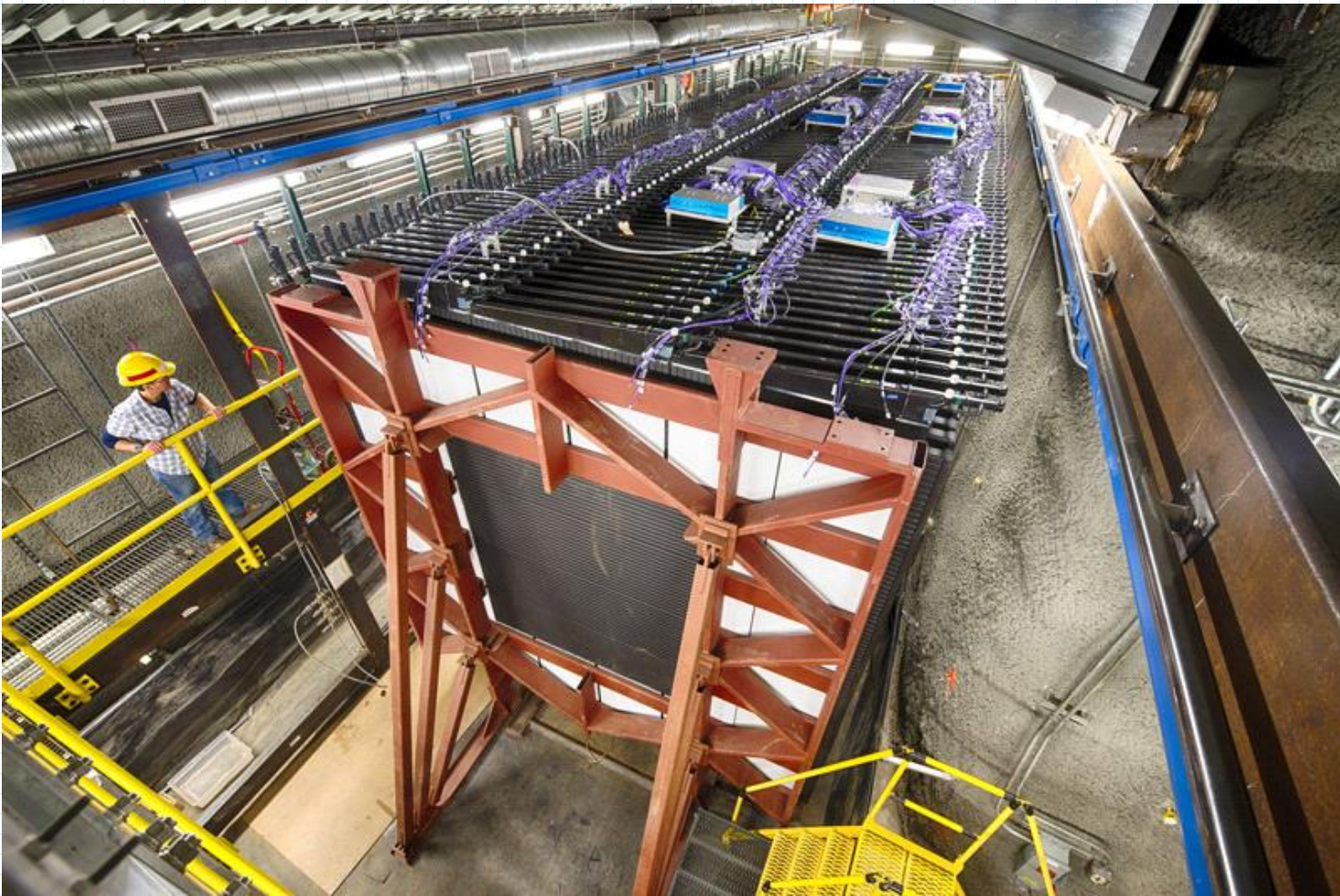


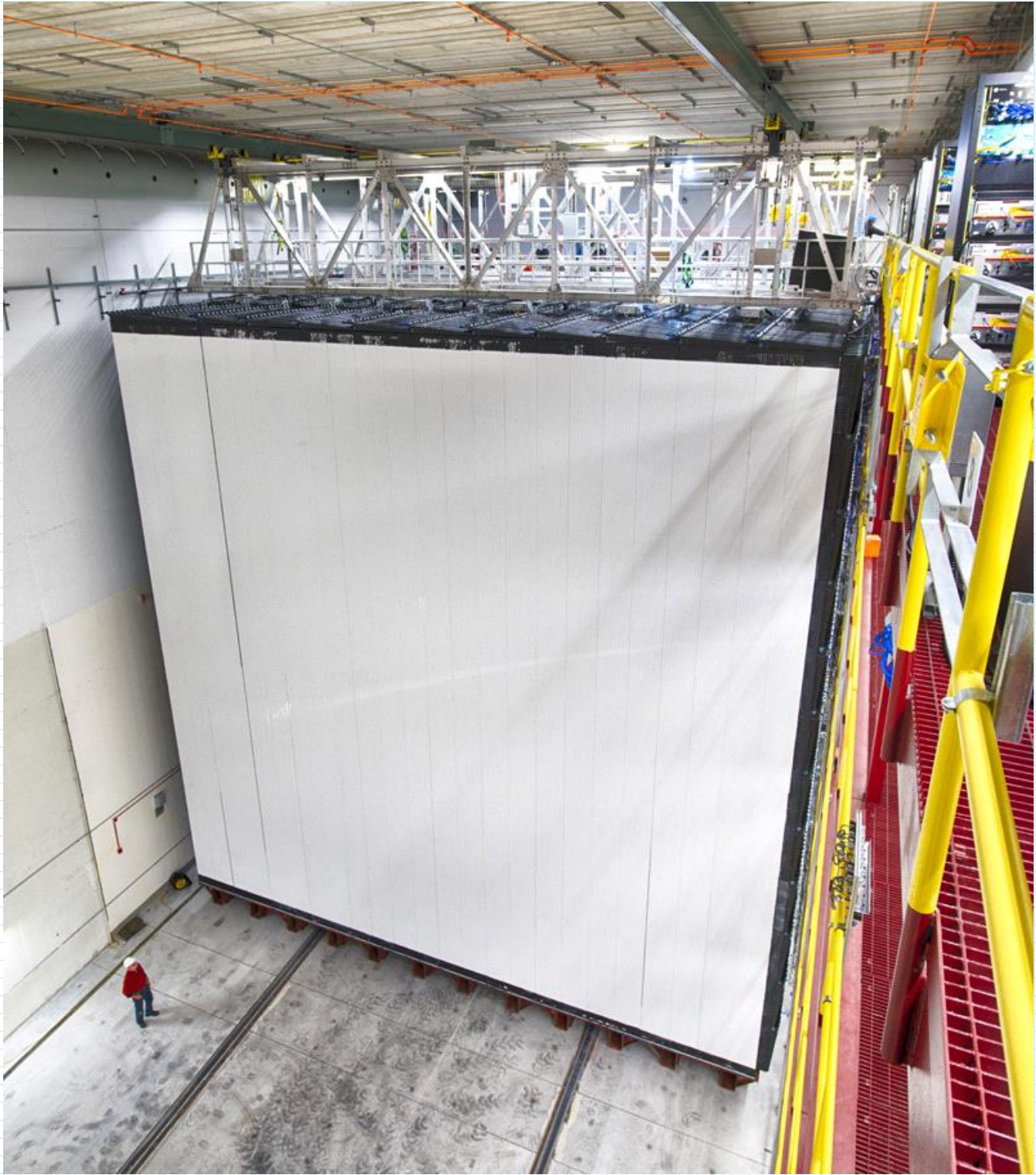
also fibers
+ SiPMs

plastic scintillator bars

Nova Near Detector

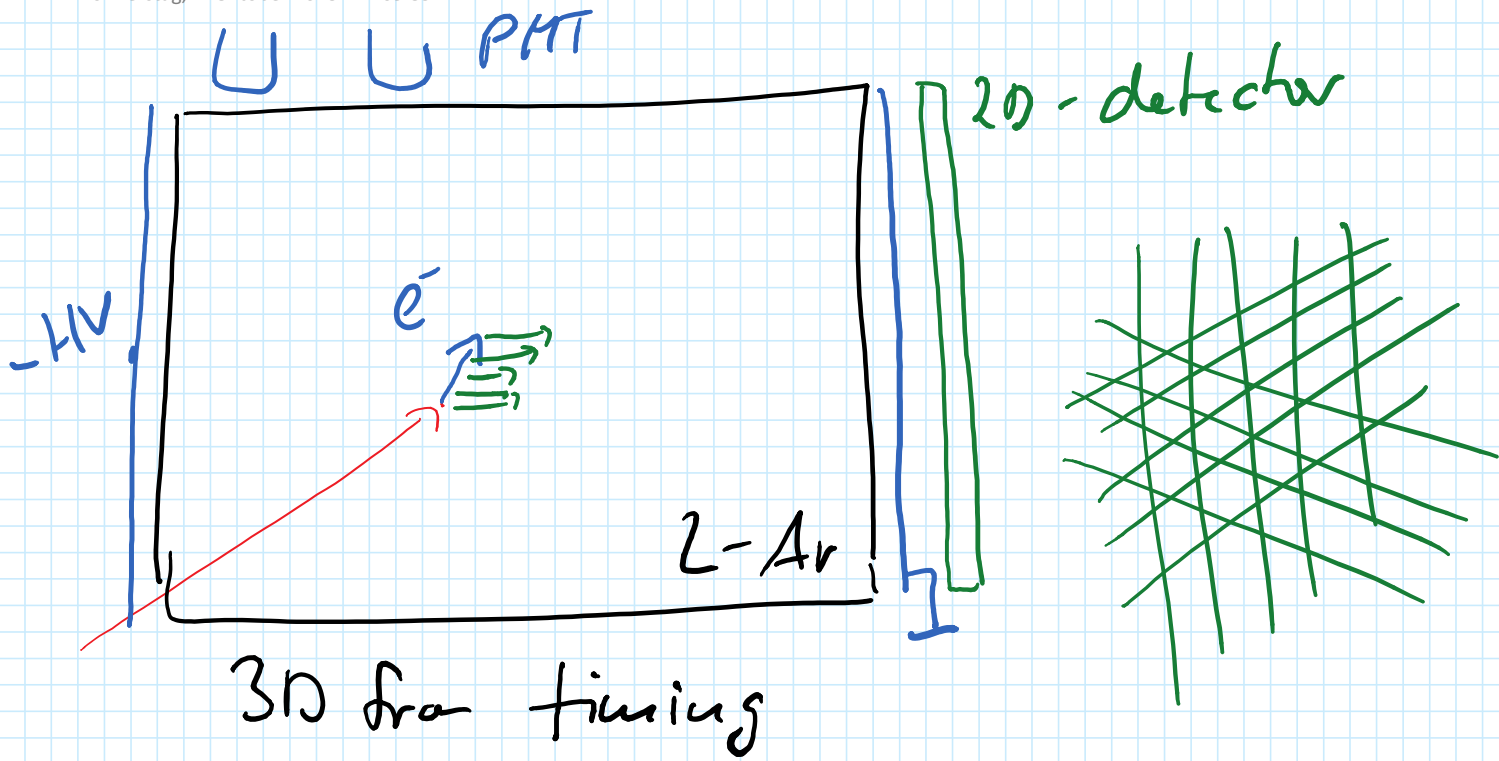
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Liquid Argon TPCs

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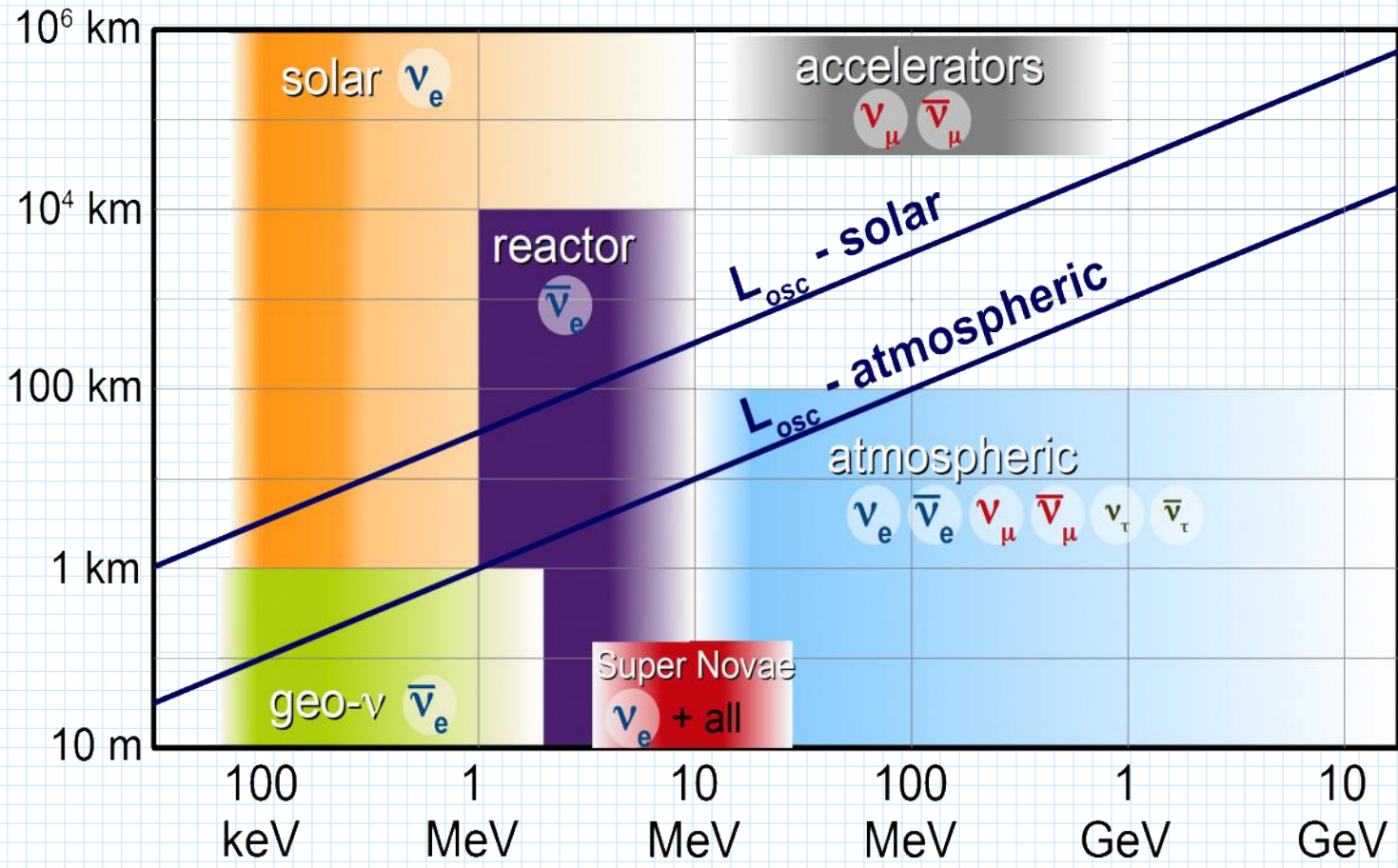
1.6 Neutrino Sources

Donnerstag, 4. Oktober 2018 09:50

- Sun
- accelerators
- reactor- ν
- cosmic rays atmospheric ν
- astrophysics AGN, supernovae
- radioactive sources

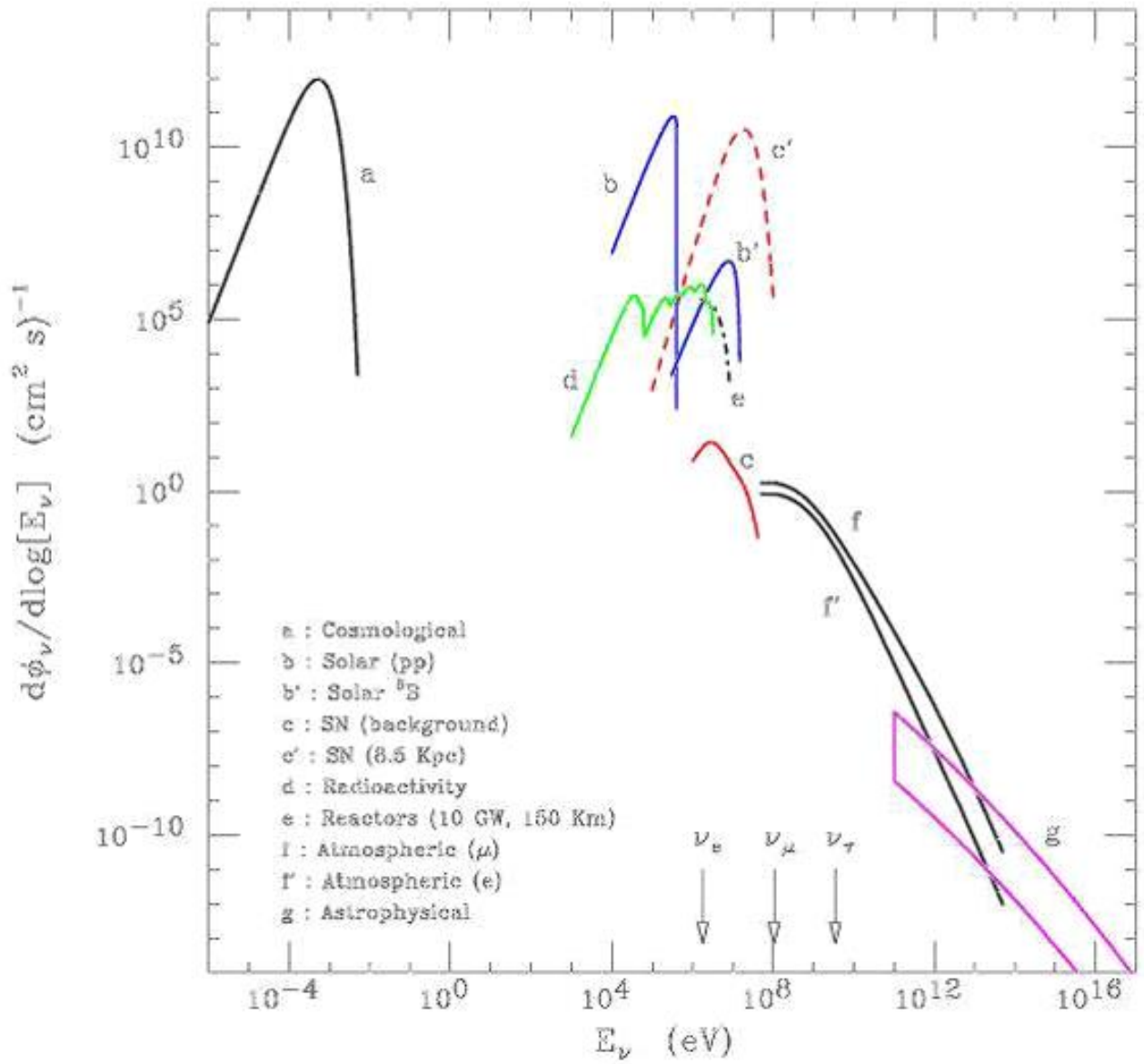
Sources and Baselines

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Fluxes

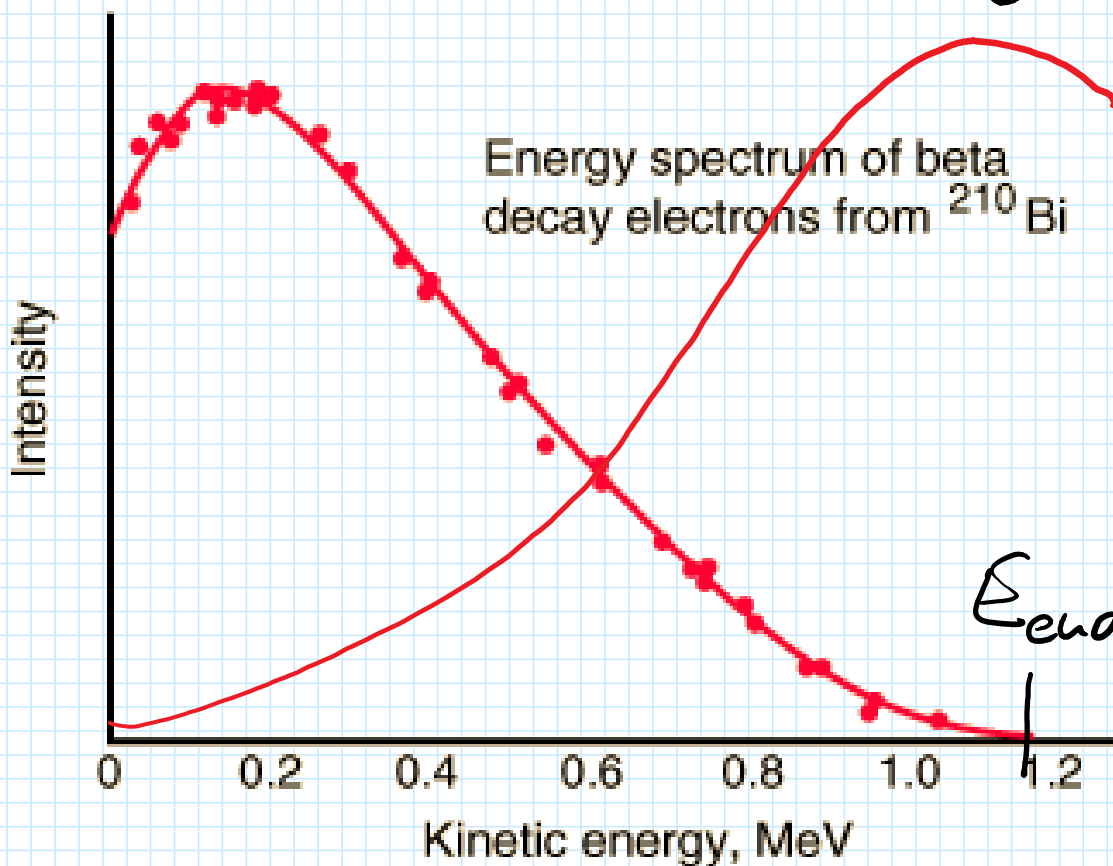
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3.1 Reactor Neutrino Spectrum

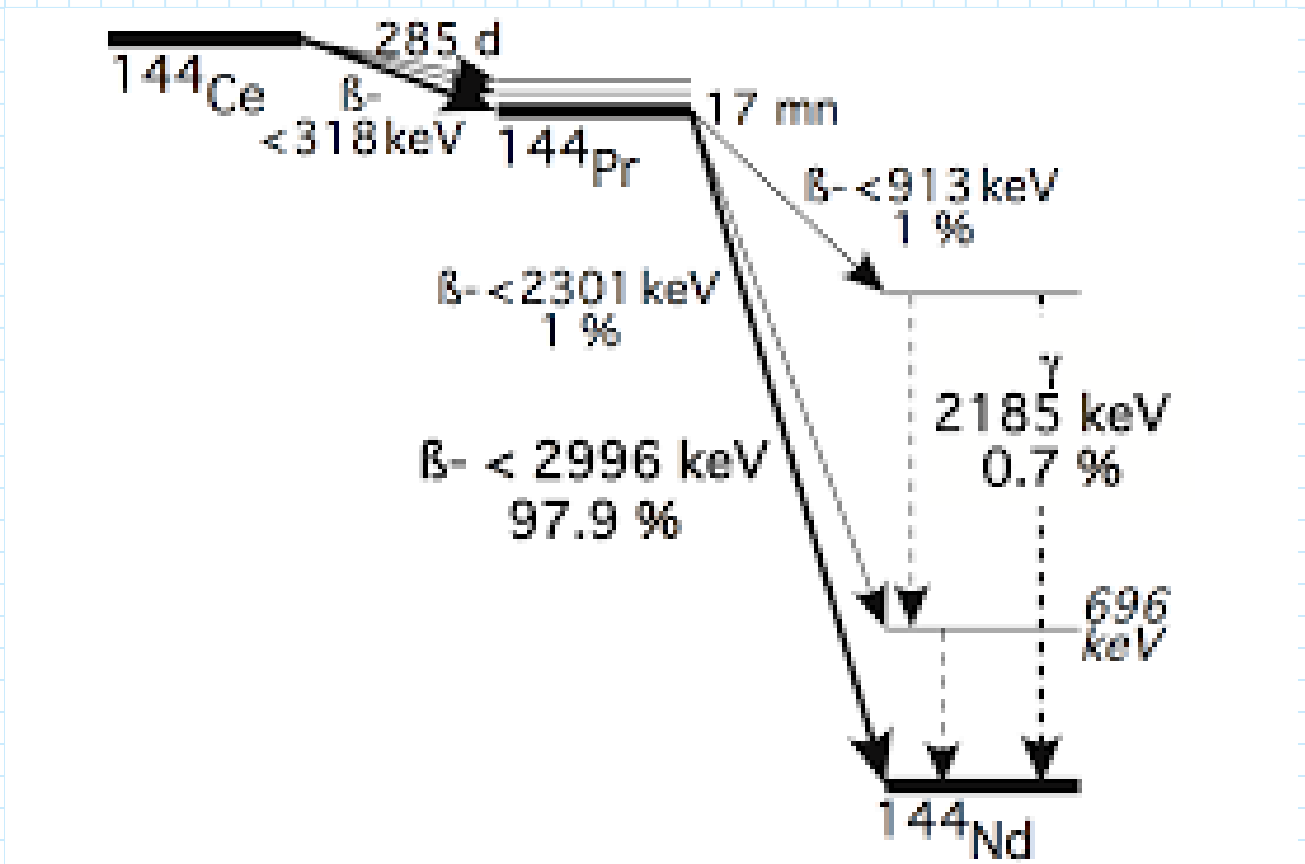
Donnerstag, 4. Oktober 2018 10:28

$$E_e + E_{\bar{\nu}_e} = Q$$



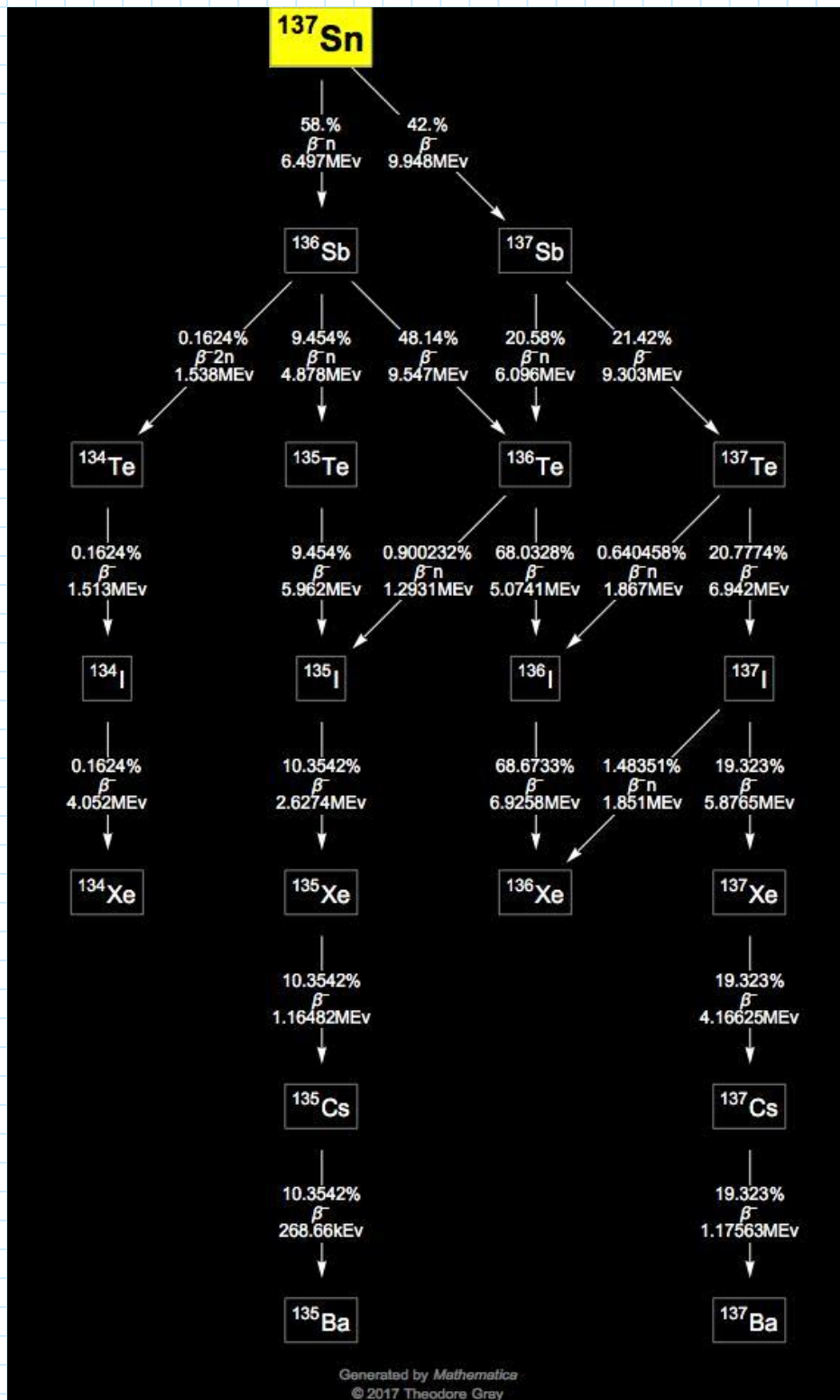
Isotopes

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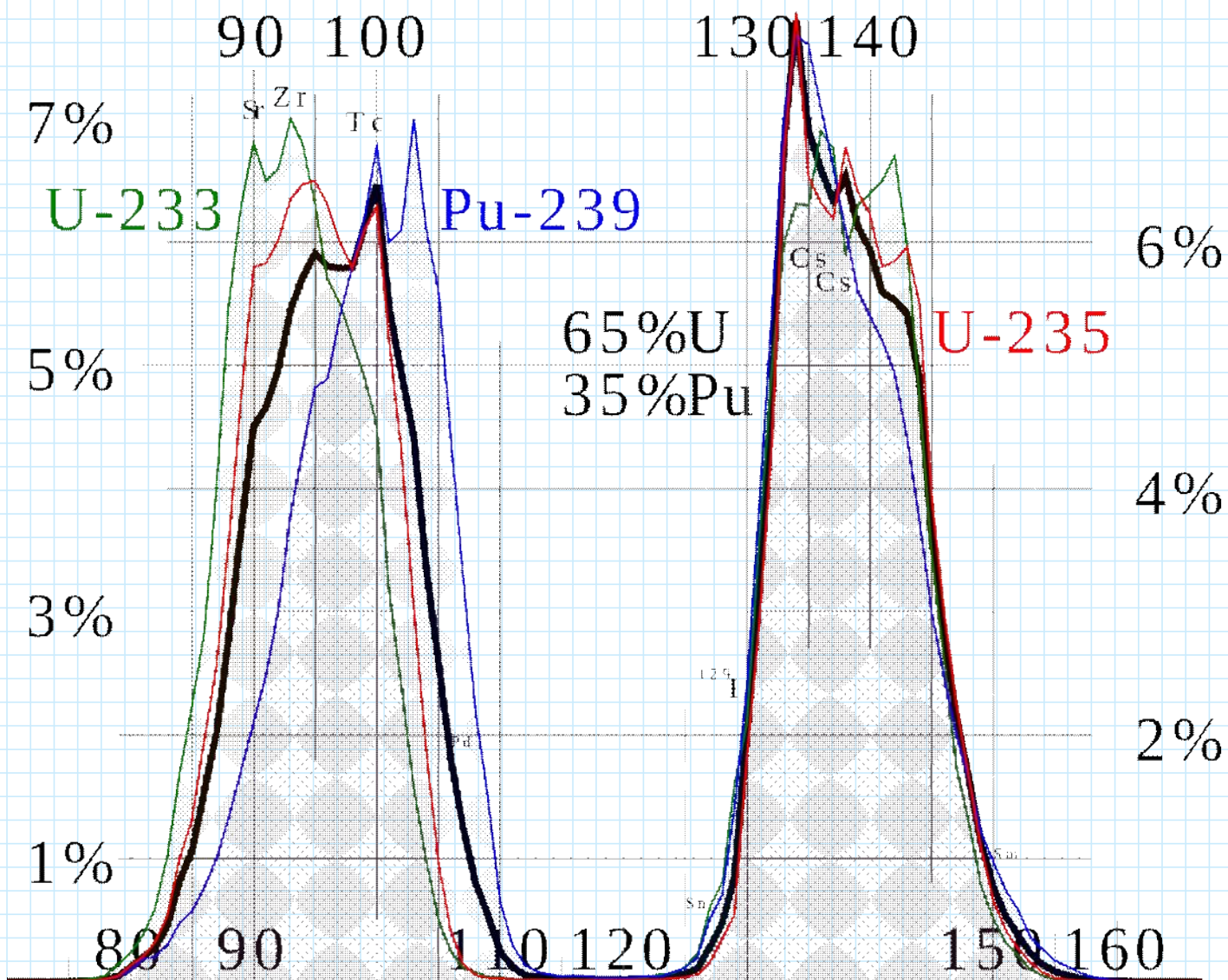
Decay Chains

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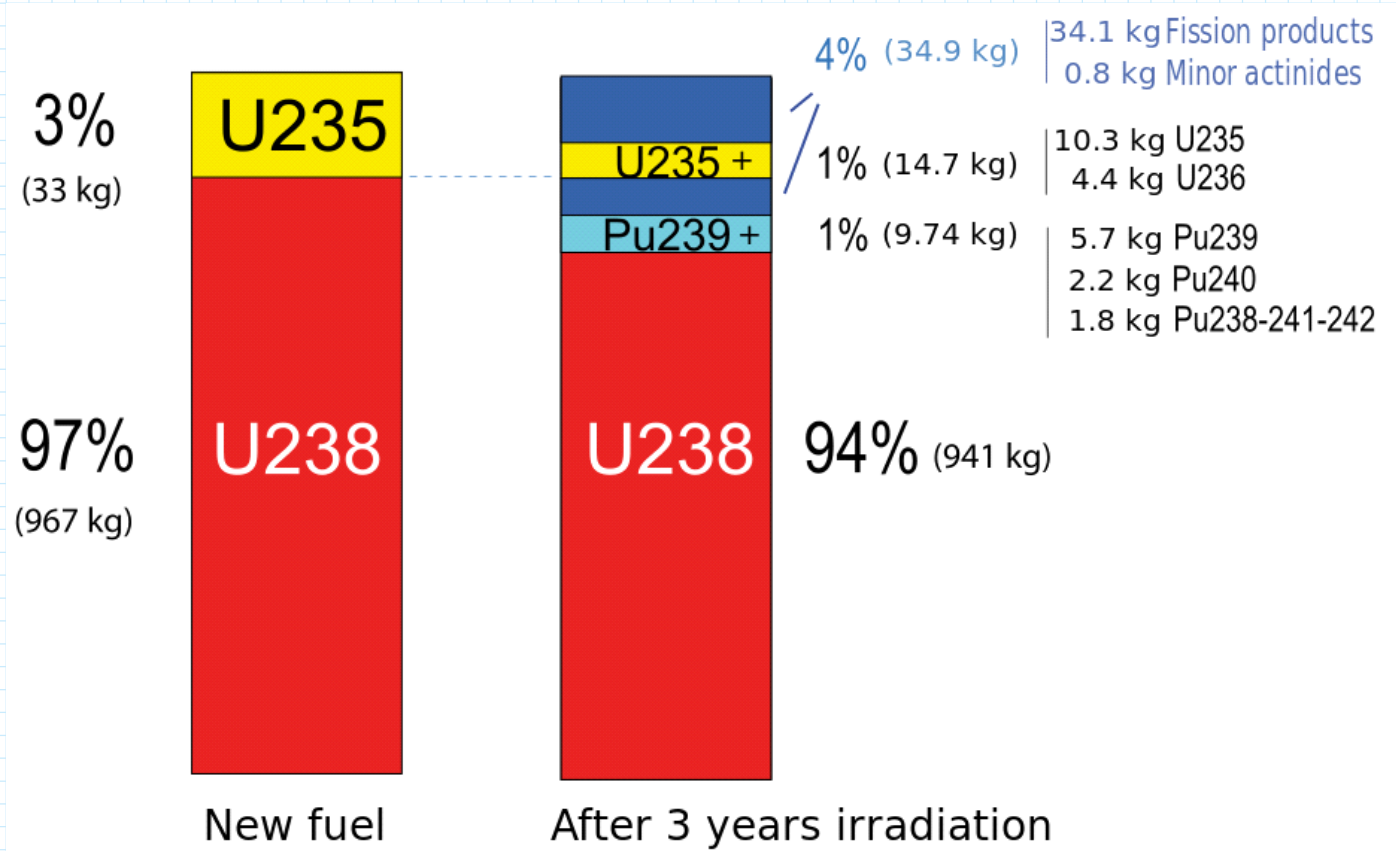
Fission Products

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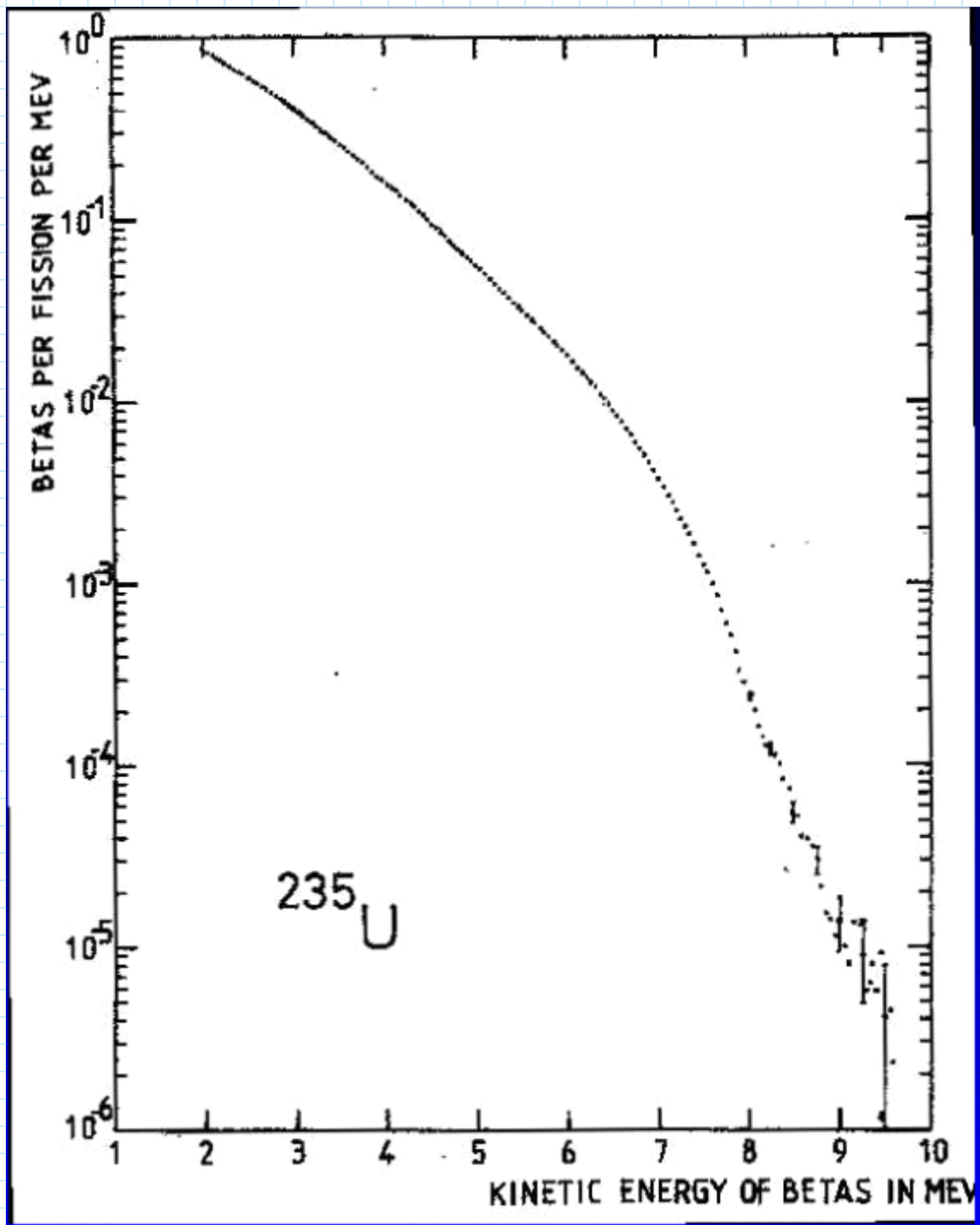
Reactor Fuel

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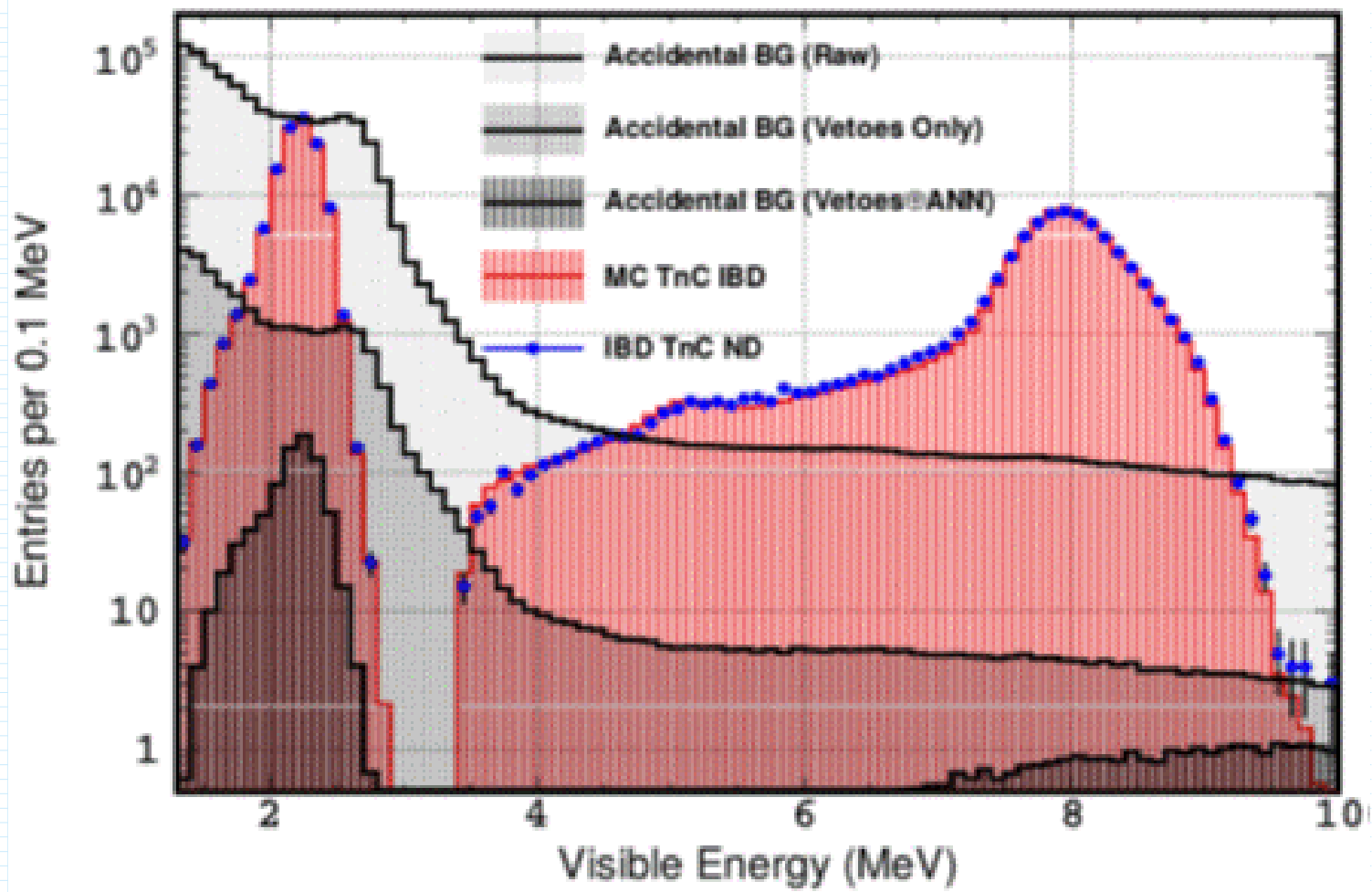
Measurement

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3.3 Inverse Beta-Decay

Donnerstag, 4. Oktober 2018 14:31



3.4 Background

Donnerstag, 4. Oktober 2018 14:48

Background Classes

Donnerstag, 4. Oktober 2018 14:49

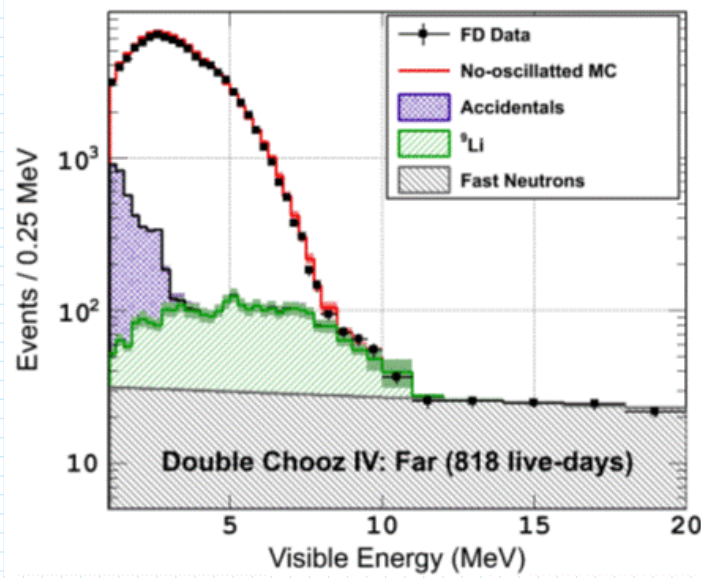
Accidental Background

Donnerstag, 4. Oktober 2018 14:50

Fast Neutrons

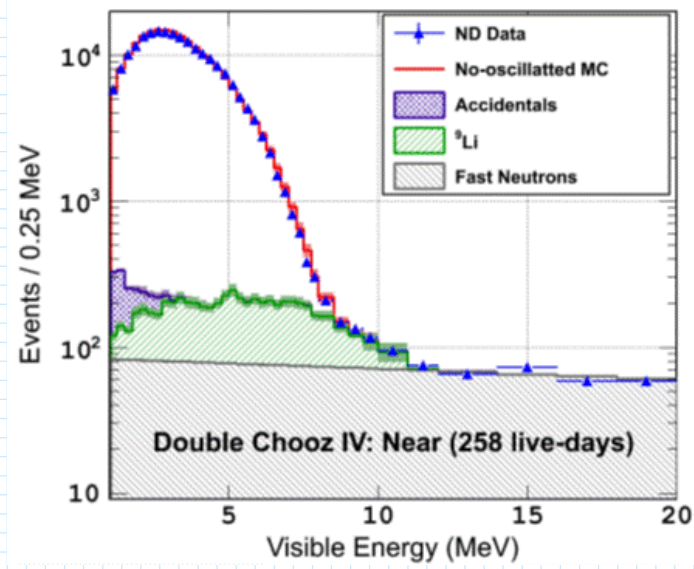
Donnerstag, 4. Oktober 2018 15:04

FAR



Total	1120/d
Accidental	4.130/d
Li	2.620/d
Fast-n	2.500/d

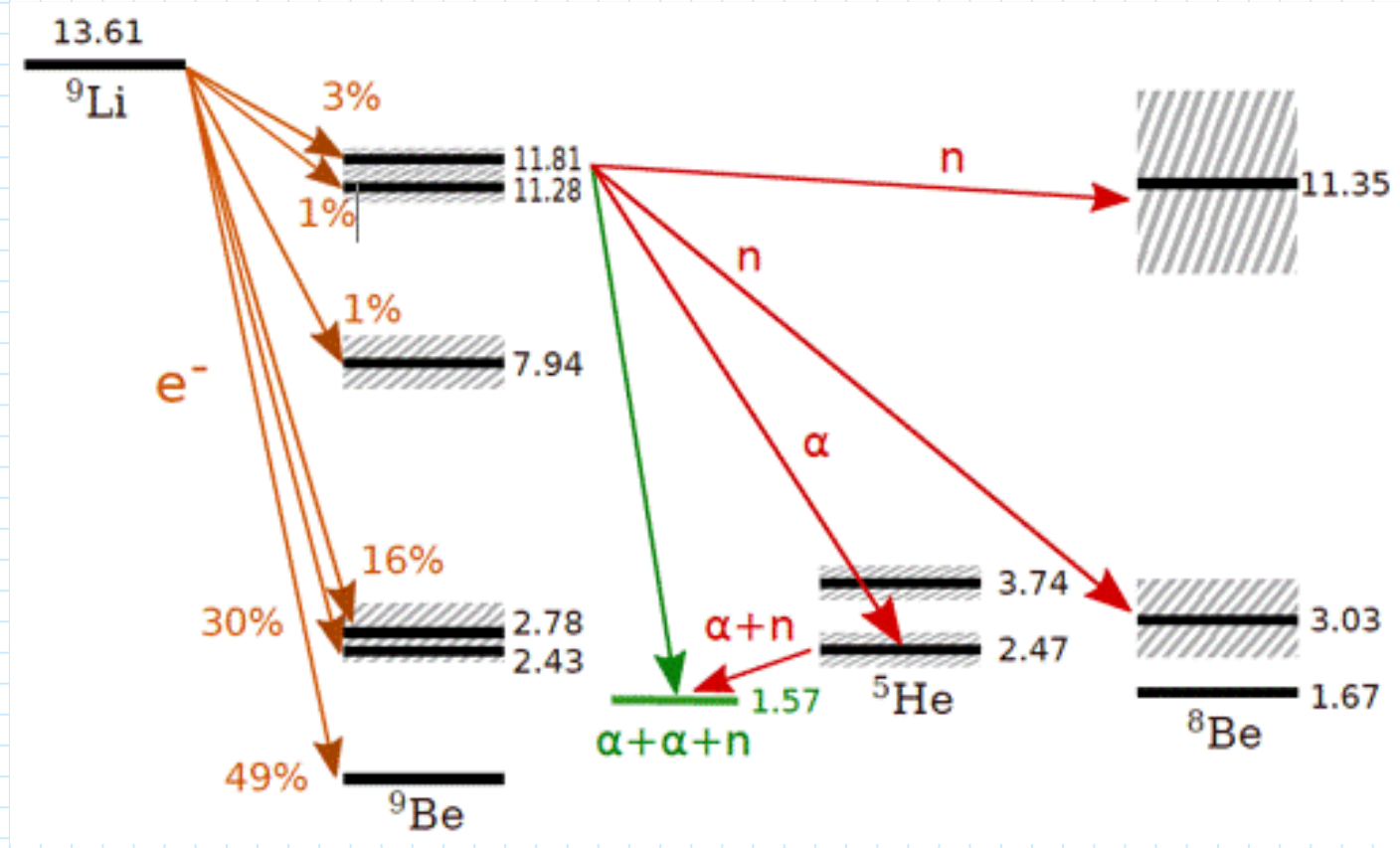
NEAR

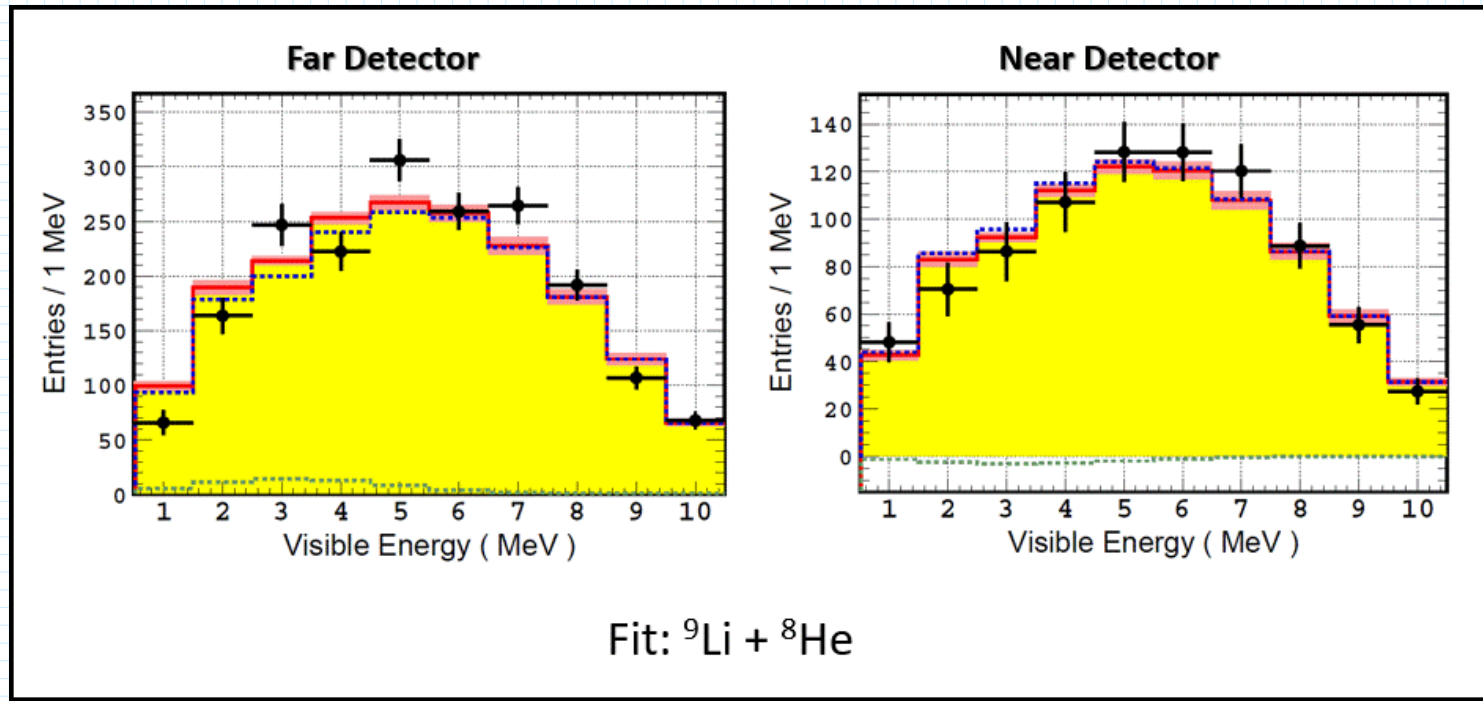


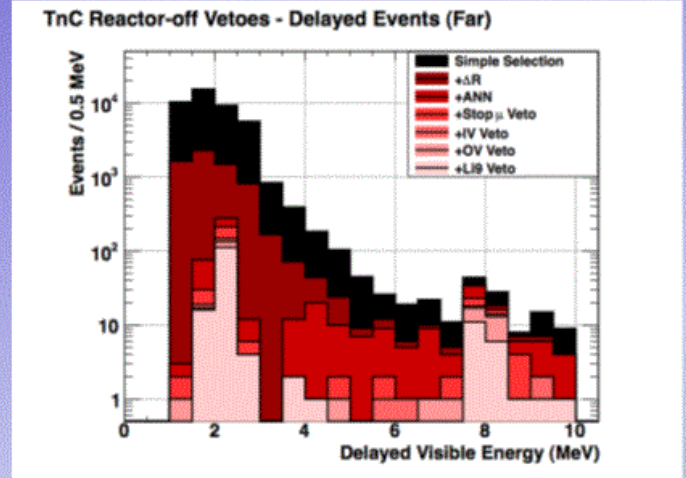
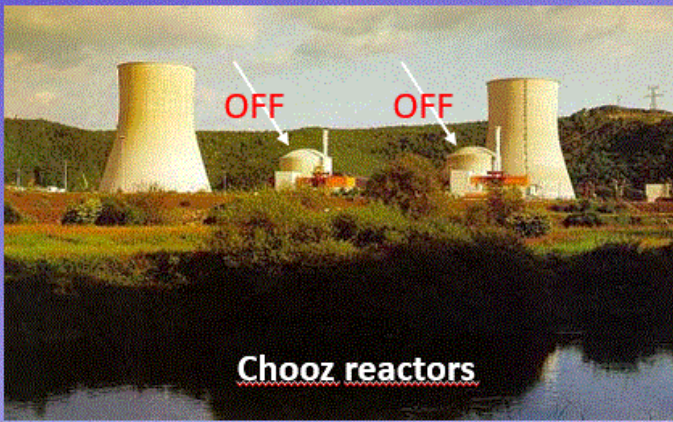
Total	8160/d
Accidental	3.100/d
Li	14.520/d
Fast-n	20.850/d

Cosmogenic

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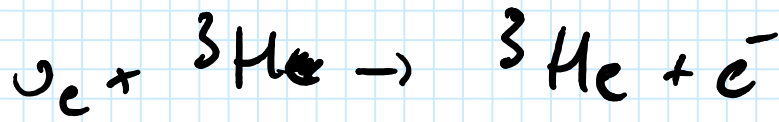


		<u>Near Detector</u> ev./day	<u>Far Detector</u> ev./day
OFF-OFF 2012	8 days	---	8.9 ± 1.2
OFF-OFF 2017	17 days	39.6 ± 2.5	9.8 ± 0.9
<u>Prediction from Fit</u>		38.5 ± 1.5	9.3 ± 0.3

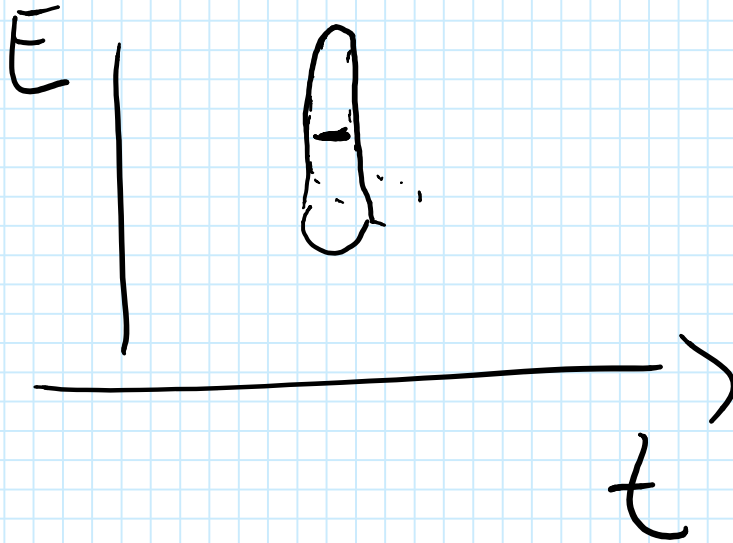
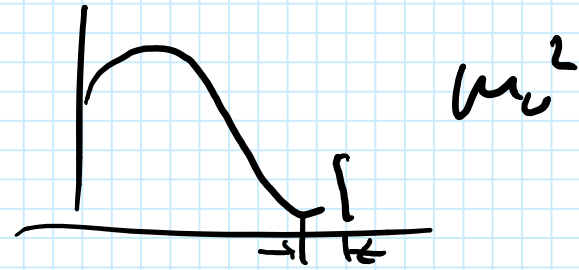
Mass Effects

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endpoint of β -decays $\frac{m_\nu^2}{Q^2}$

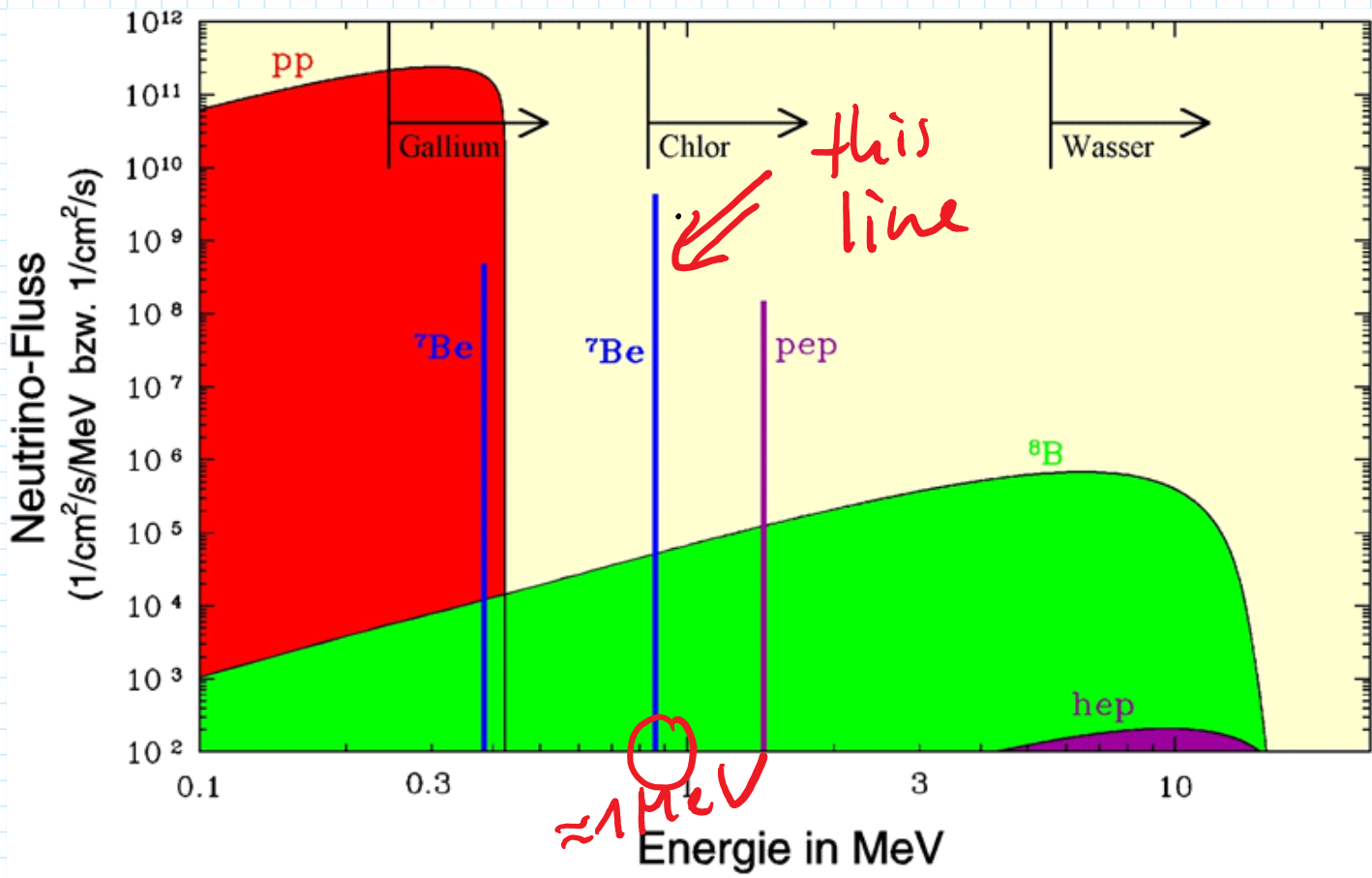


thermal spec. of
cosmogenic ν m_ν



Line Shift

Donnerstag, 4. Oktober 2018 15:30



gravitational field strength

outside sun $G \cdot \frac{M_{\odot}}{r^2}$ $R_{\odot} 700.000 \text{ km}$

inside sun $G \cdot \frac{r}{R_{\odot}^3} \cdot M_{\odot}$ $M_{\odot} 2 \cdot 10^{30} \text{ kg}$
 $G 6.7 \cdot 10^{-11} \frac{\text{m}^3}{\text{kg s}^2}$

$W_G: 3.6 \cdot 10^{-6} \text{ eV}$

5. Status

Freitag, 5. Oktober 2018 08:48

Solar ν : disappearance of ν_e

Homestake, GALLEX, SuperK, SNO, KamLAND, K2K

Borexino

$$\Delta m_{12}^2 \approx 7.5 \cdot 10^{-5} \text{ eV}^2 \quad \theta_{12} \approx 35^\circ$$

Atmospheric ν : disappearance of $\nu_\mu / \bar{\nu}_\mu$

SuperK, MACRO, T2K, MINOS, Nova, OPERA, IceCube, Antares

$$|\Delta m_{23}^2| = 2.5 \cdot 10^{-3} \text{ eV}^2 \quad \theta_{23} = 45^\circ$$

(ν_e -appearance)

reactor ν : disappearance of $\bar{\nu}_e$

Double Chooz, RENO, Daya Bay

$$|\Delta m_{13}^2| \approx 2.5 \cdot 10^{-3} \text{ eV}^2$$

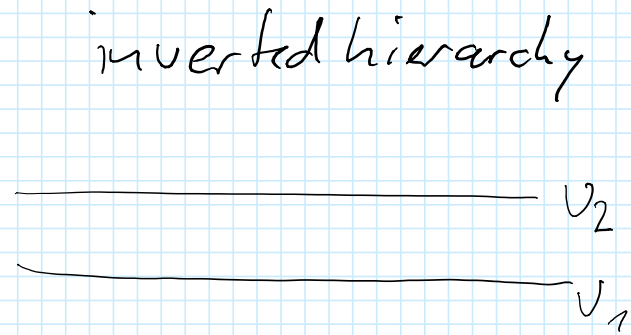
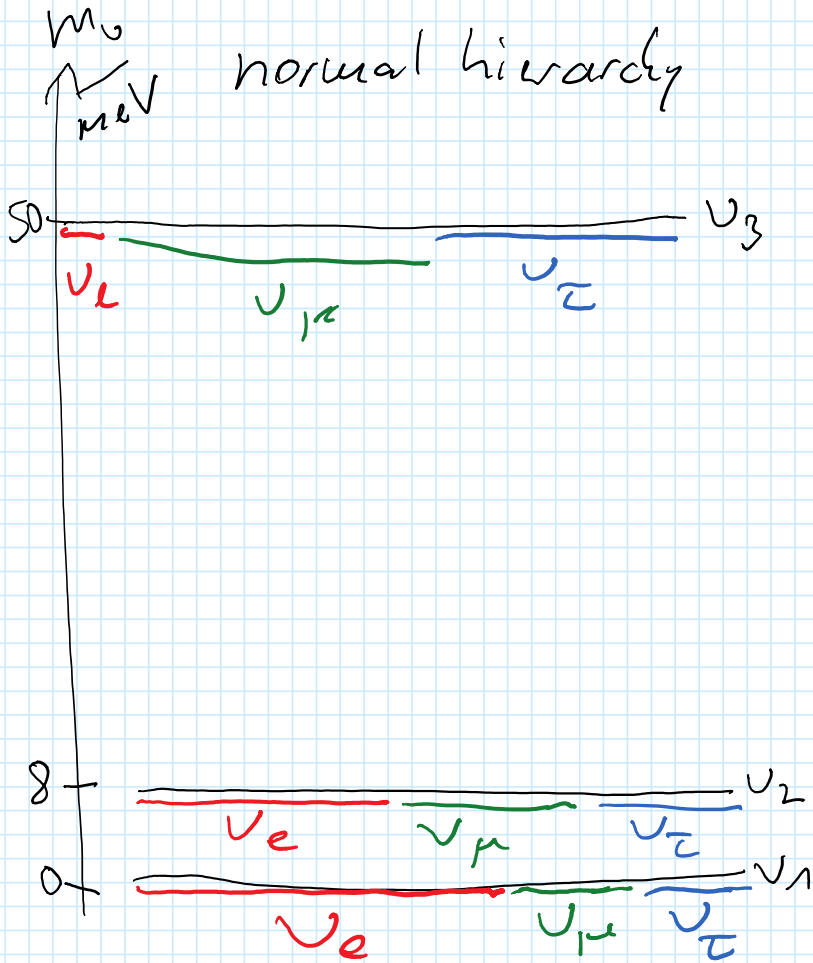
appearance of $\bar{\nu}_e$ from $\bar{\nu}_\mu$

T2K, MINOS, Nova

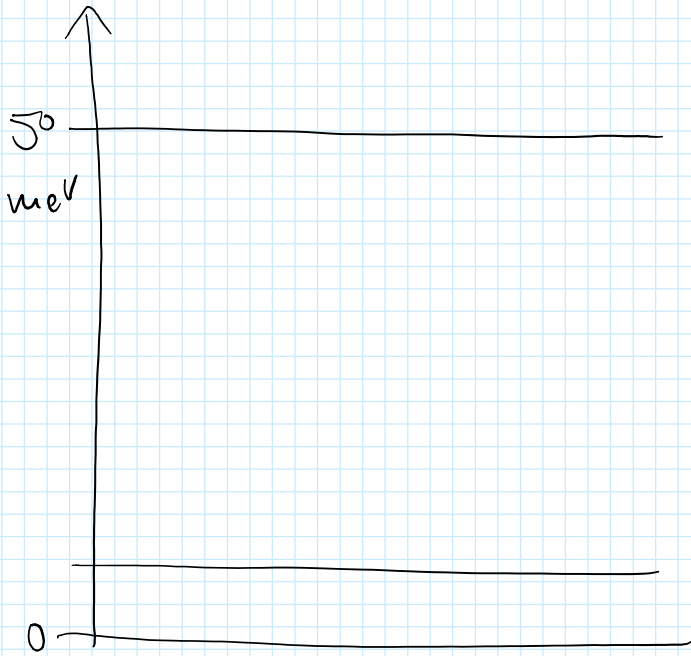
$$\theta_{13} \approx 9^\circ$$

Mass Spectrum

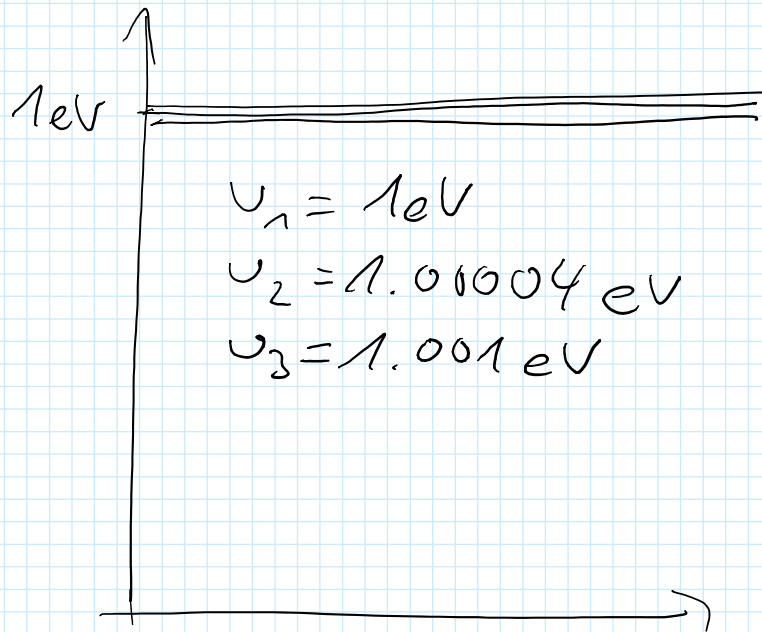
Freitag, 5. Oktober 2018 09:06



hierarchisch



democratic



Open Questions

Freitag, 5. Oktober 2018 09:08

- absolute mass? \rightarrow KATRIN + ?
- normal or inverted? \rightarrow DUNE, T2HK, ORCA, PINGU, JUNE
- sterile ν 's? \rightarrow many?
- Majorana or Dirac? \rightarrow $0 \nu 2\beta$
- CP-violation? \rightarrow DUNE, T2HK, T2K
- θ_{23} maximal? \rightarrow Nova, ...