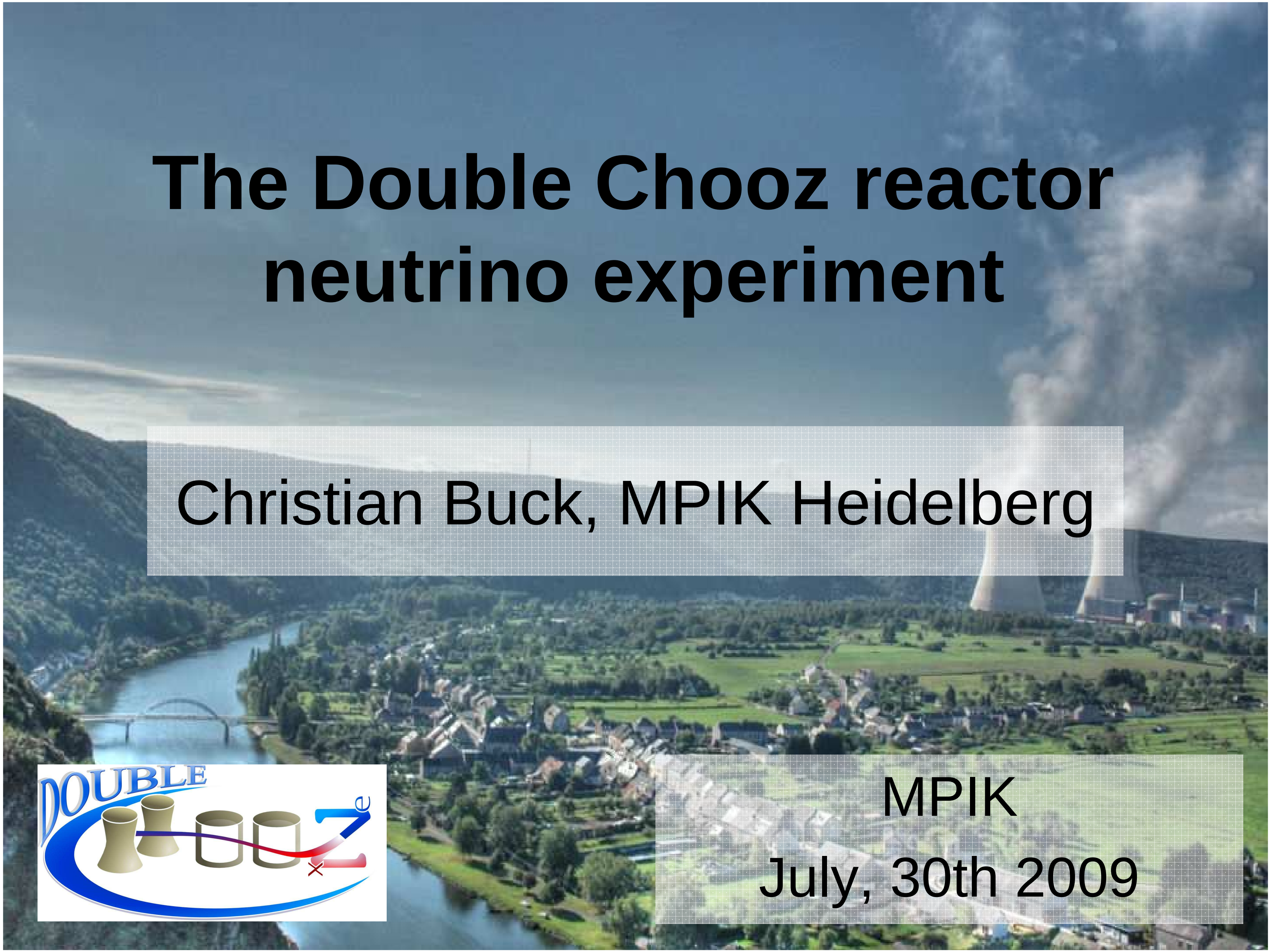
The Double Chooz reactor neutrino experiment



Christian Buck, MPIK Heidelberg

MPIK

July, 30th 2009

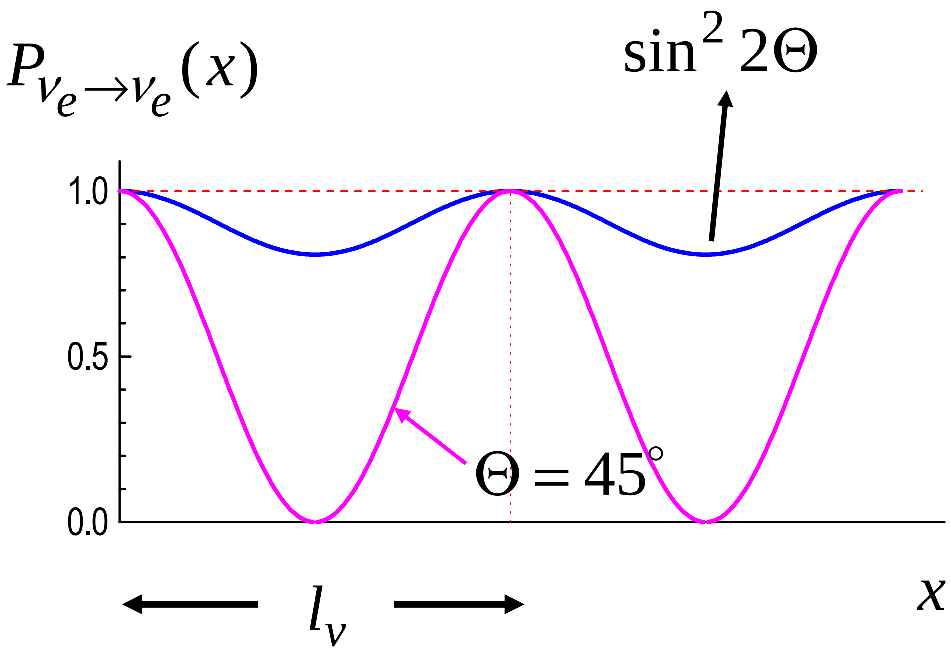
Overview

- Motivation
- Double Chooz concept and design
- Status of experiment
- MPIK activities
- Summary

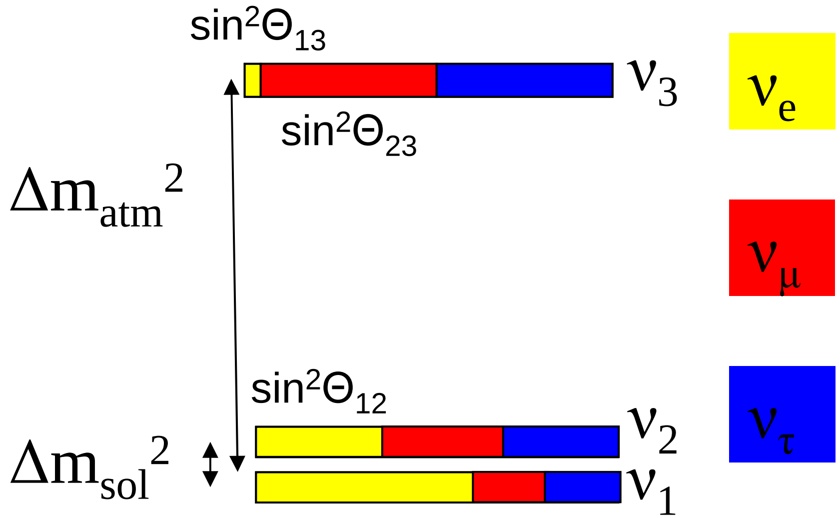
Neutrino oscillations

$$\nu_e = \nu_1 \cos\Theta + \nu_2 \sin\Theta$$
$$\nu_\mu = -\nu_1 \sin\Theta + \nu_2 \cos\Theta$$

$$P_{\nu_e \to \nu_e}(x) = 1 - \sin^2 2\Theta \, \sin^2\left(\pi \frac{x}{l_\nu}\right)$$



$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

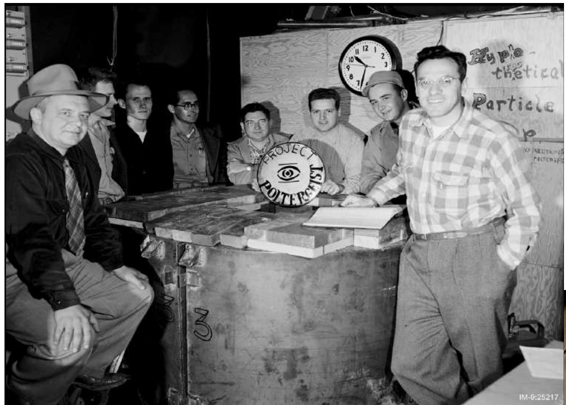


$\Delta m_{sol}^2 \sim 7.7 \cdot 10^{-5}$ eV^2, $\sin^2(2\Theta_{12}) \sim 0.85$
$\Delta m_{atm}^2 \sim 2.4 \cdot 10^{-3}$ eV^2, $\sin^2(2\Theta_{23}) \sim 1$

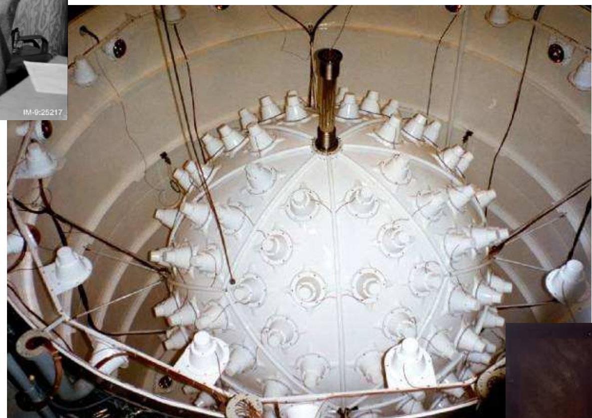
Why Double Chooz?

- Improved knowledge of mixing matrix
- Key experiment to unveil leptonic CP violation
- Discovery potential: Θ_{13} in models often close to experimental bound
- Complementarity to beam experiments
  - Degeneracies + parameter correlations
  - Optimize future accelerator experiments
- Discrimination power of $0\nu\beta\beta$
- Safeguard applications,…

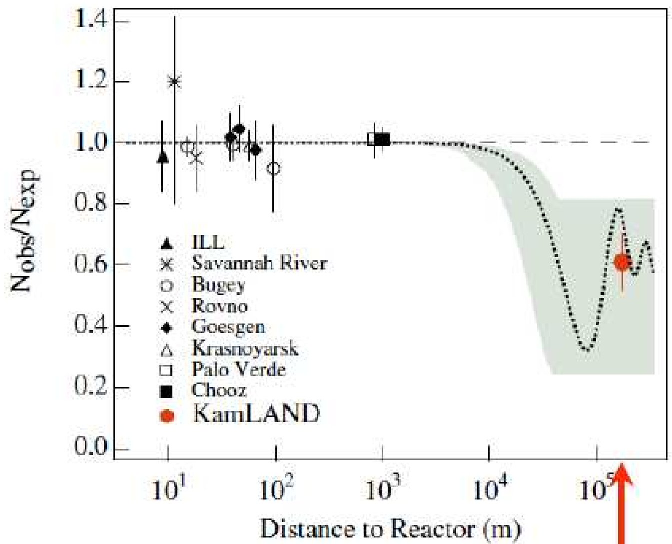
Reactor neutrino experiments



1956: First observation (Nobel Prize 1995)



1990s: Chooz, Palo Verde ($\sin^2 2\Theta_{13} < 0.2$)



180 km

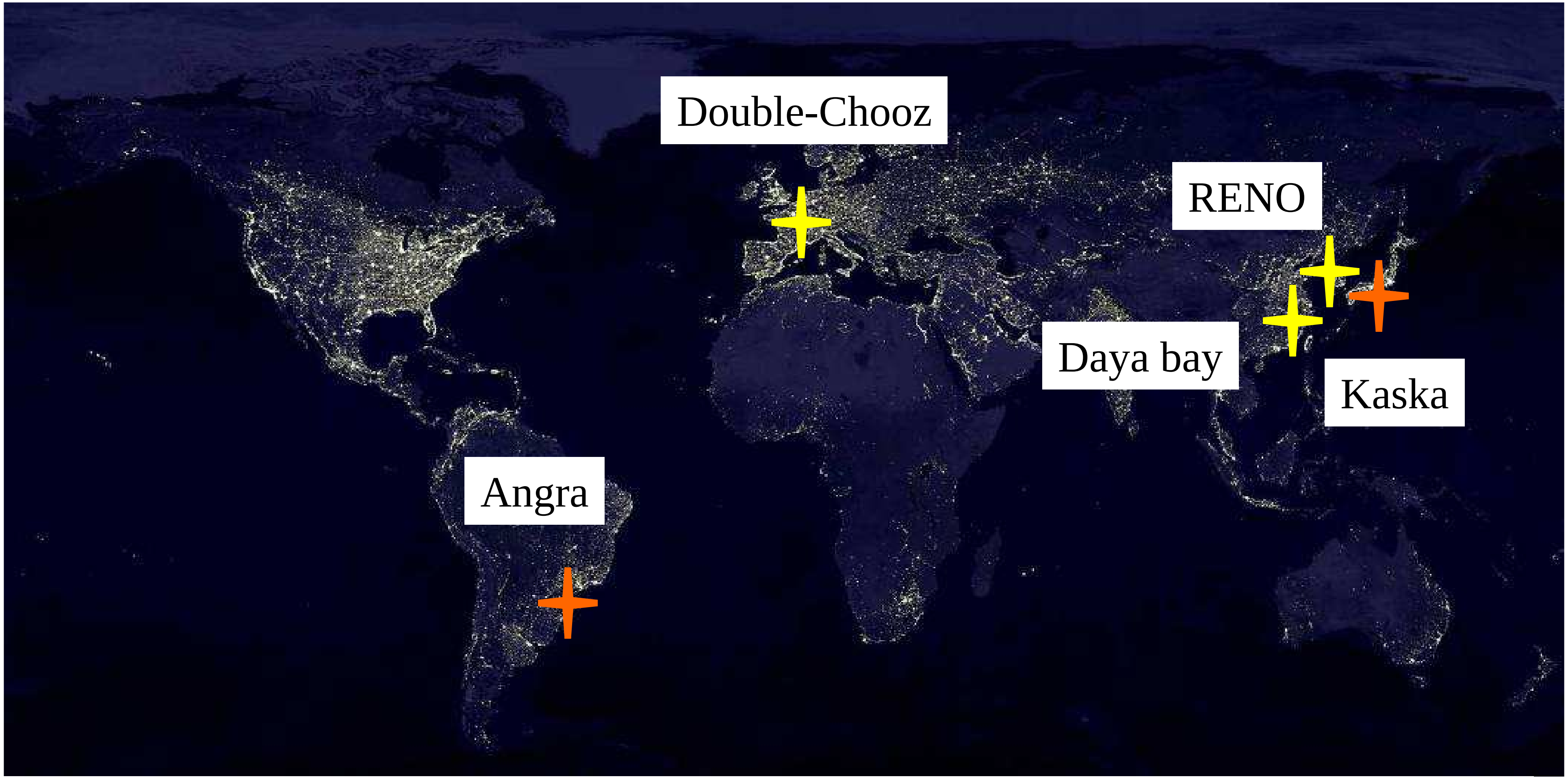
2002: KamLand

Δm_{12}, Θ_{12}

Reactor neutrinos:

- Pure antineutrino beam
- Intense flux (~2% precision)
- Detection: inverse β-decay
- Energy: few MeV

Current proposals

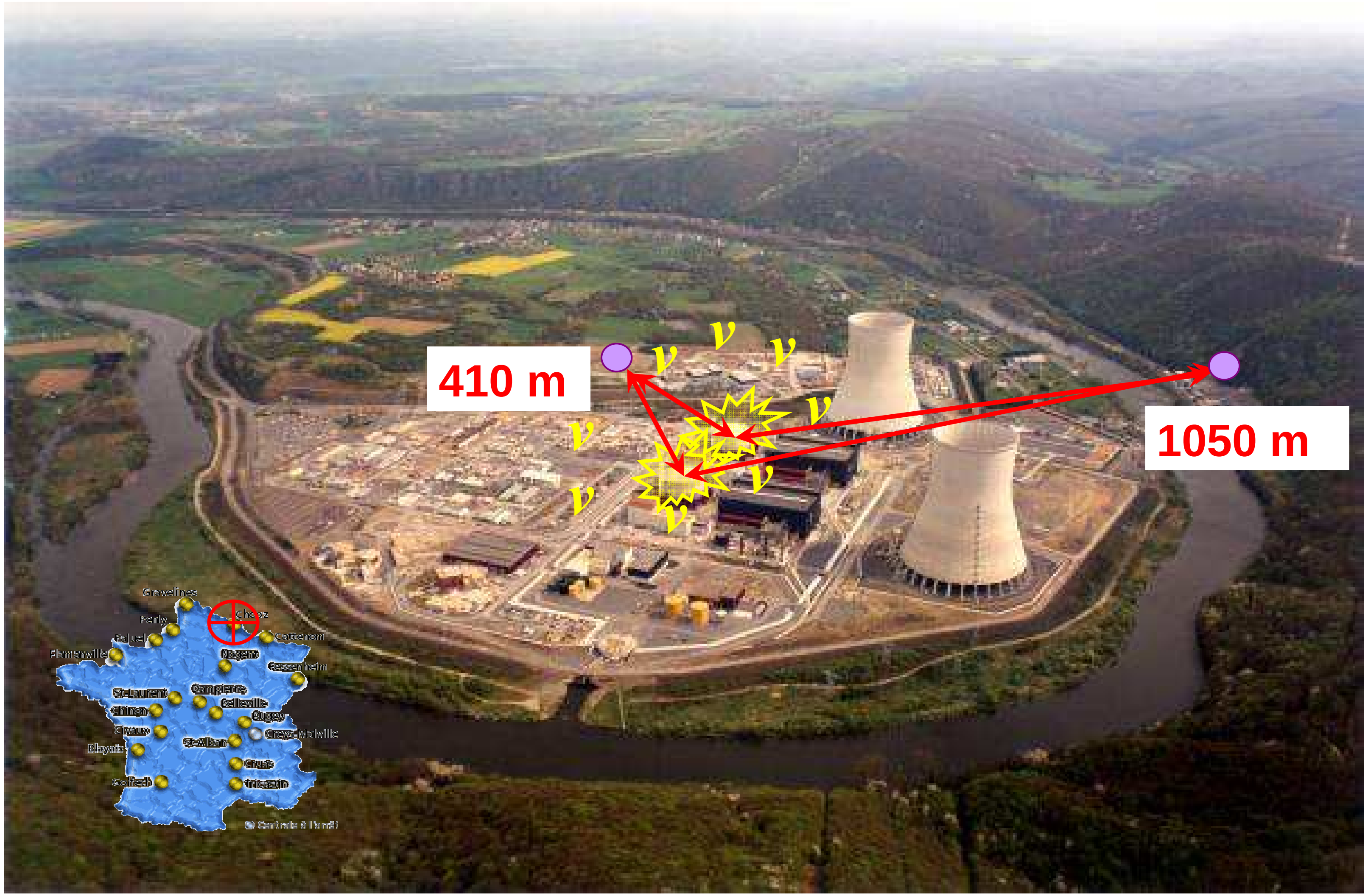


- **December 2002:** 1st European meeting, MPIK
- **April 2003 – February 2005:** 4 int. workshops in U.S., Germany, Japan and Brazil
- **1st Double Chooz Meeting:** Nov 2003

Double Chooz collaboration

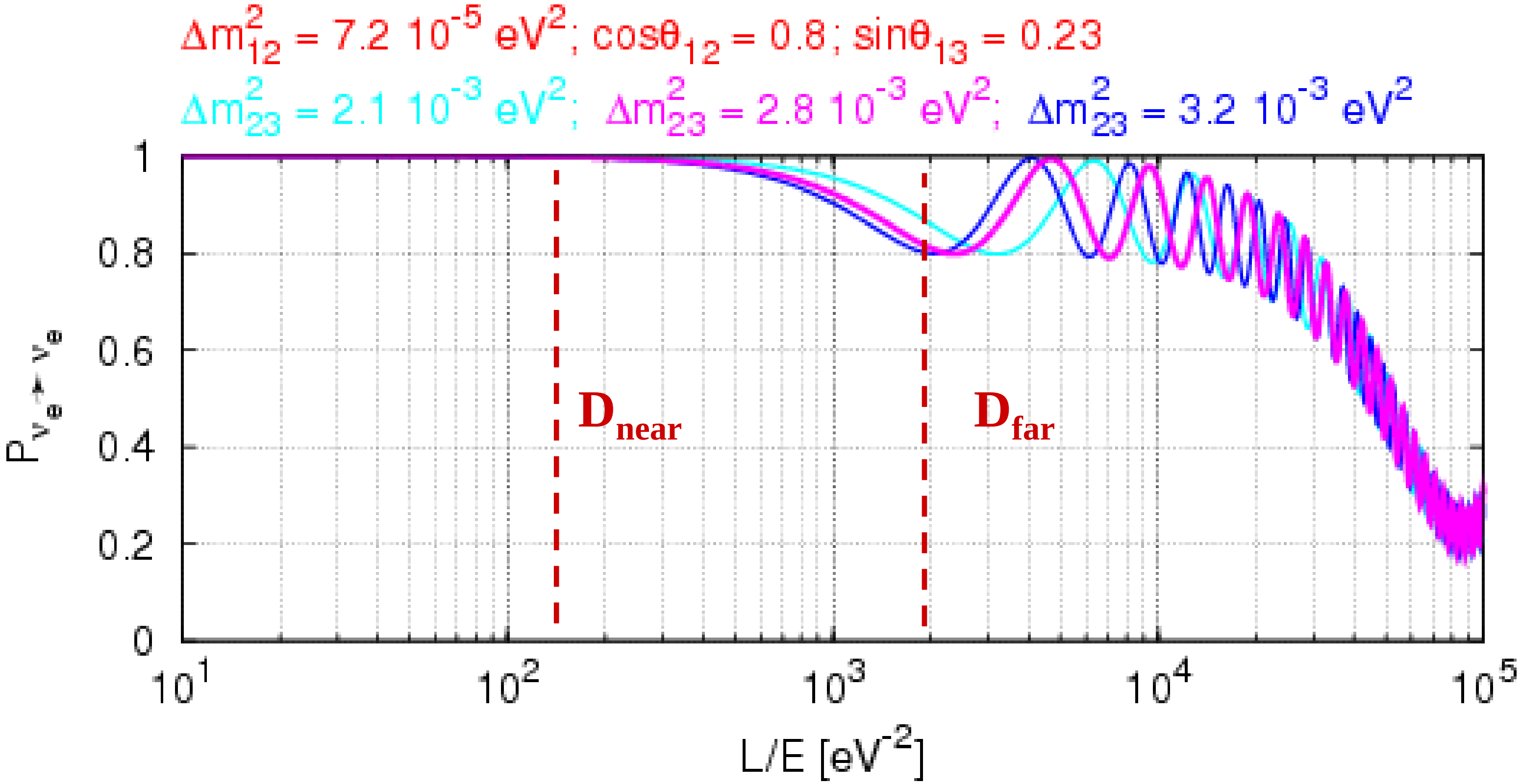
- **Spokesman: H. de Kerret (APC)**
- France: CEA Saclay, APC Paris, Subatech Nantes, IPHC Strasbourg
- Germany: MPIK Heidelberg, TU München, EKU Tübingen, Universität Hamburg, RWTH Aachen
- USA: Univ. of Alabama, Argonne Nat. Lab., Chicago, Drexel, Kansas State, LLNL, Notre Dame, Tennessee, Columbia Univ., Davis, MIT, Sandia
- Spain: CIEMAT Madrid
- Japan: Tohoku University, Kobe University, Tokyo Inst. of Tech., Niigata University, Tokyo Metropolitan University, Hiroshima Inst. of Tech.
- England: University of Sussex
- Russia: RAS Moskau, Kurchatov Institute
- Brasil: CBPF Rio de Janeiro, UNICAMP

The Double Chooz principle



Survival probability

Survival probability assuming $\sin^2(2\Theta_{13}) = 0.2$ for different Δm_{13}

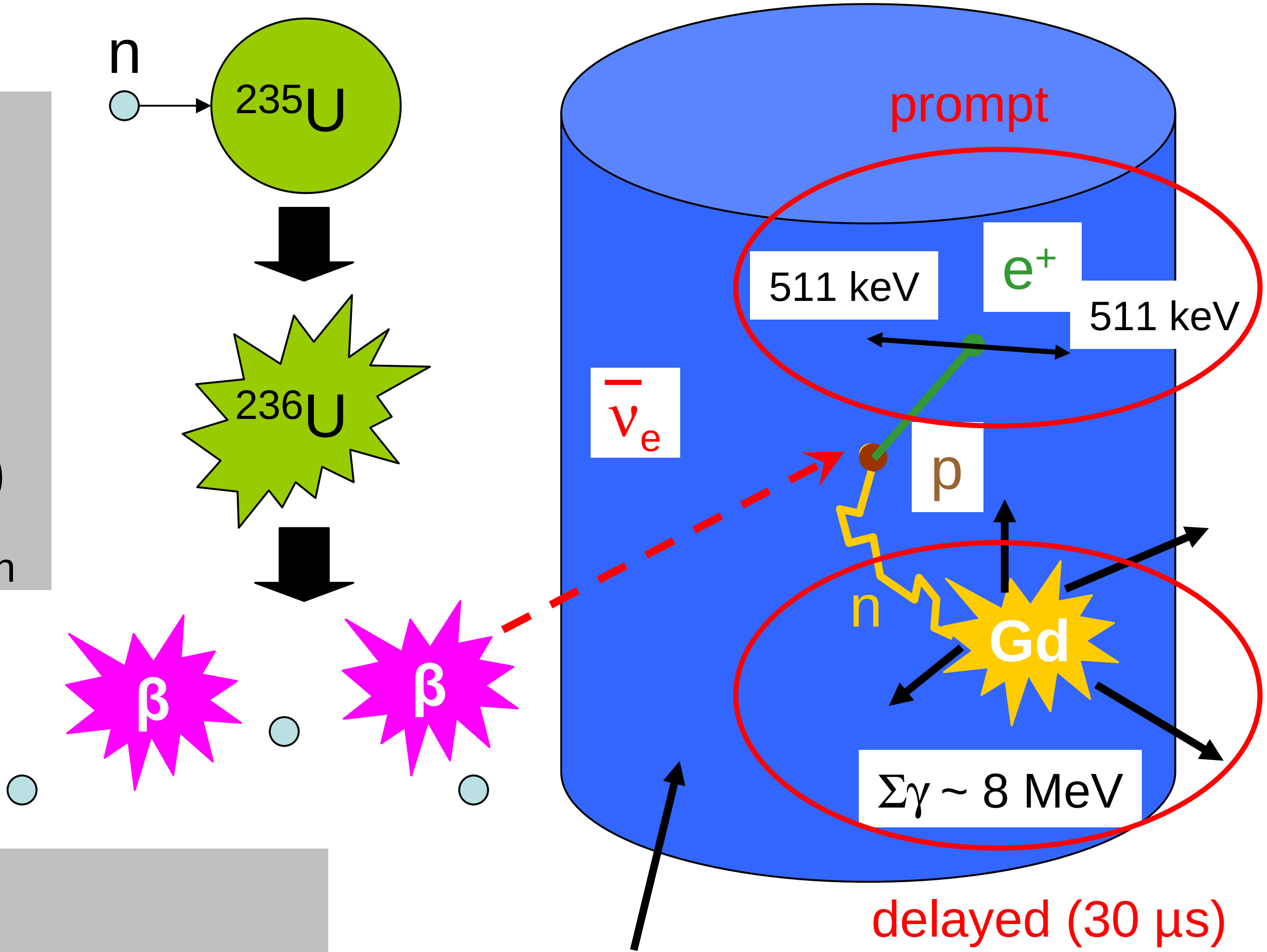


$$P_{ee} \approx 1 - \sin^2 2\Theta_{13} \sin^2\left(\frac{\Delta m_{13}{}^2 L}{4E_\nu}\right) - \cos^4\Theta_{13}\sin^2 2\Theta_{12}\sin^2\left(\frac{\Delta m_{12}{}^2 L}{4E_\nu}\right)$$

Neutrino signal

- pure $\overline{\nu}_e$ source
- E_ν ~ MeV
- E_{min} ~ 1.8 MeV
- > 10^{20} ν/(s·GW)

Chooz: ~ 7.4 GW_{th}

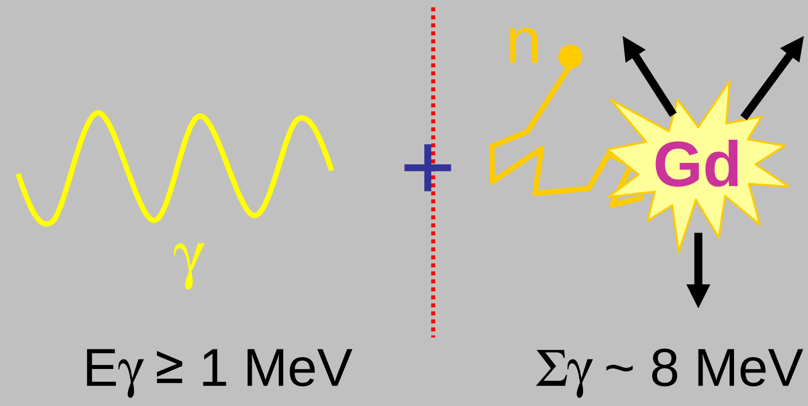


Target: Gadolinium loaded liquid scintillator (MPIK!)

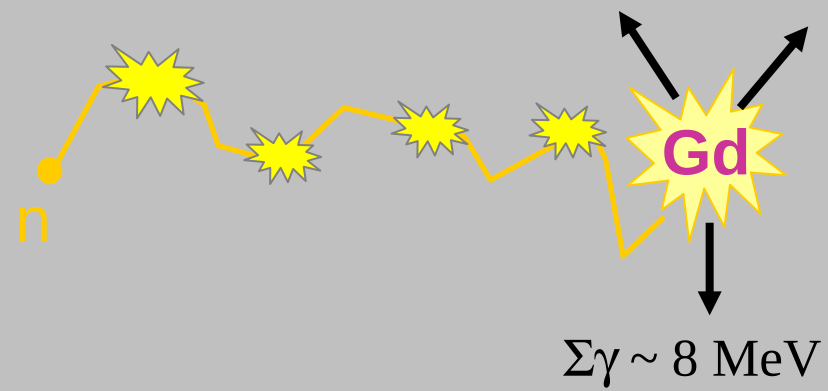
Neutrino rates:
- far: ~50/day
- near: ~300/day

Background

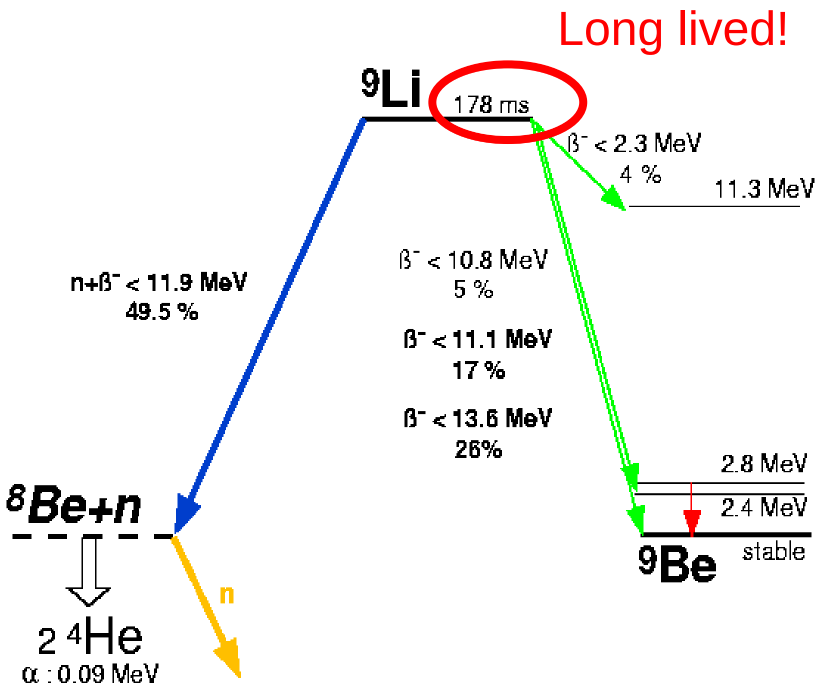
Accidentals



fast neutrons



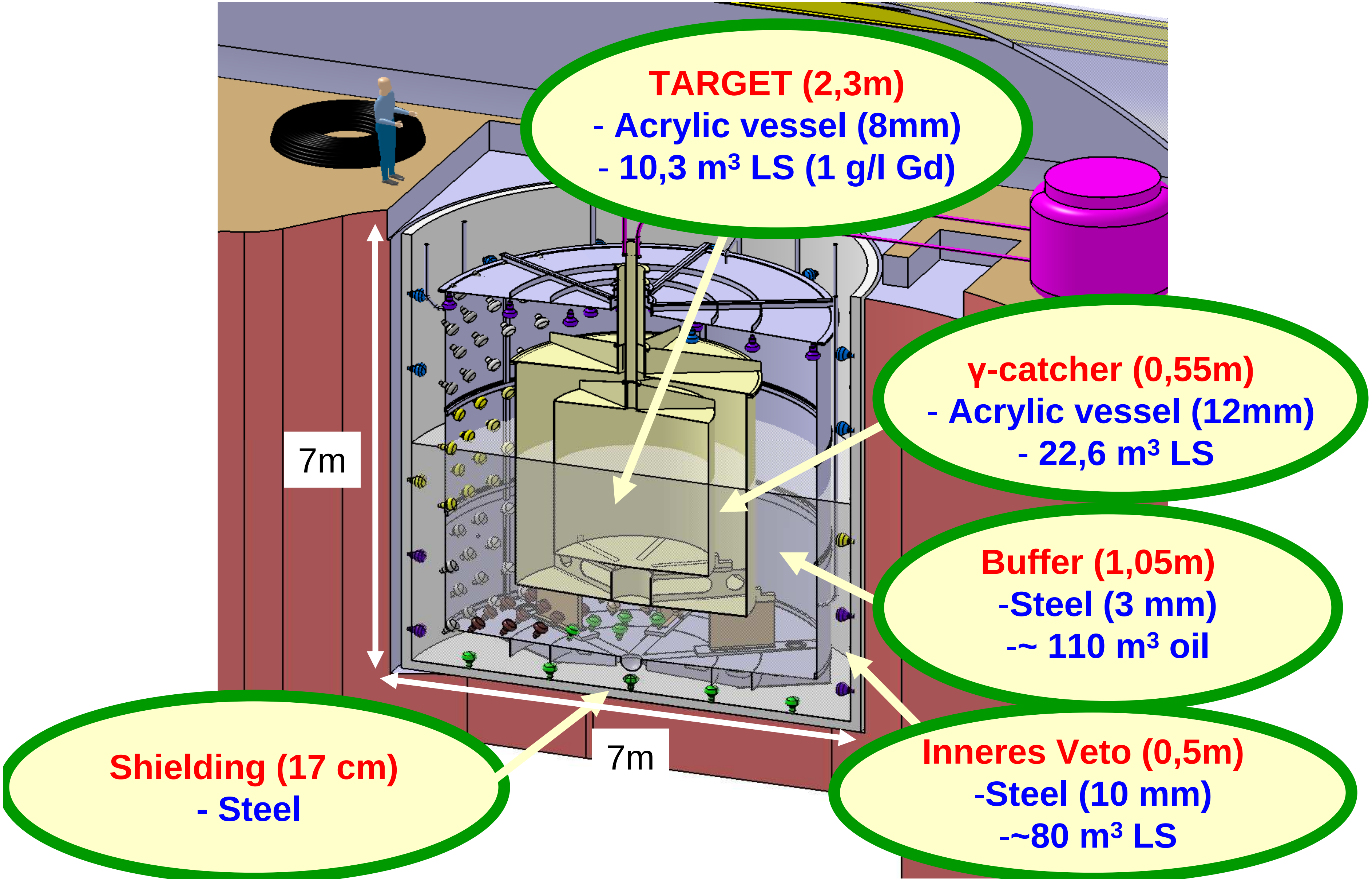
β-n-cascades: ^{9}Li,^{8}He



Chooz data:

far detector: ca. 1.4/day

Detector Design



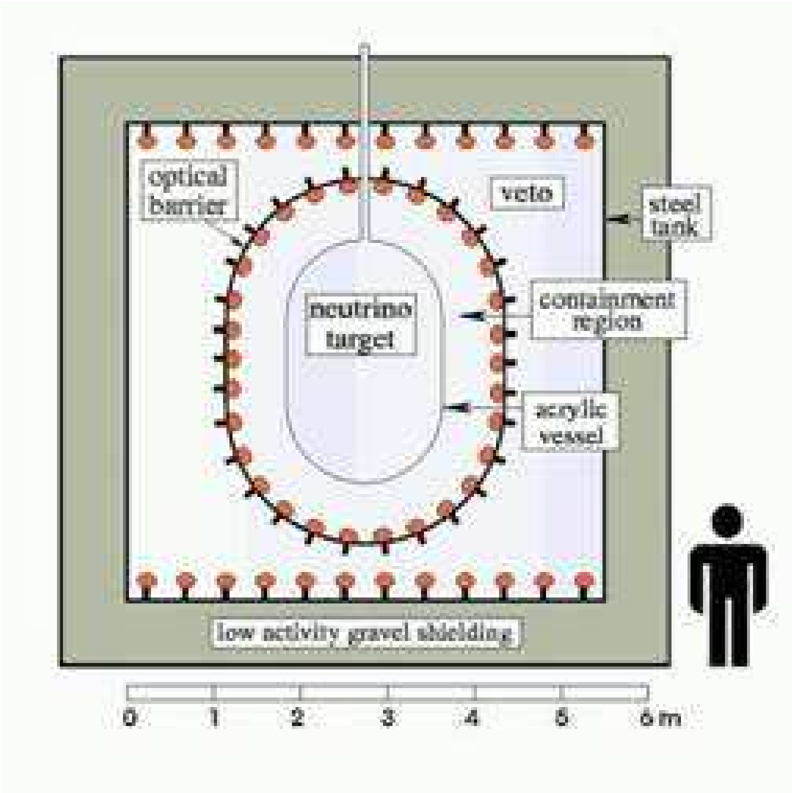
Comparison with Chooz

Best limit: CHOOZ

$\sin^2(2\theta_{13}) < 0.15$ (90% CL)

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

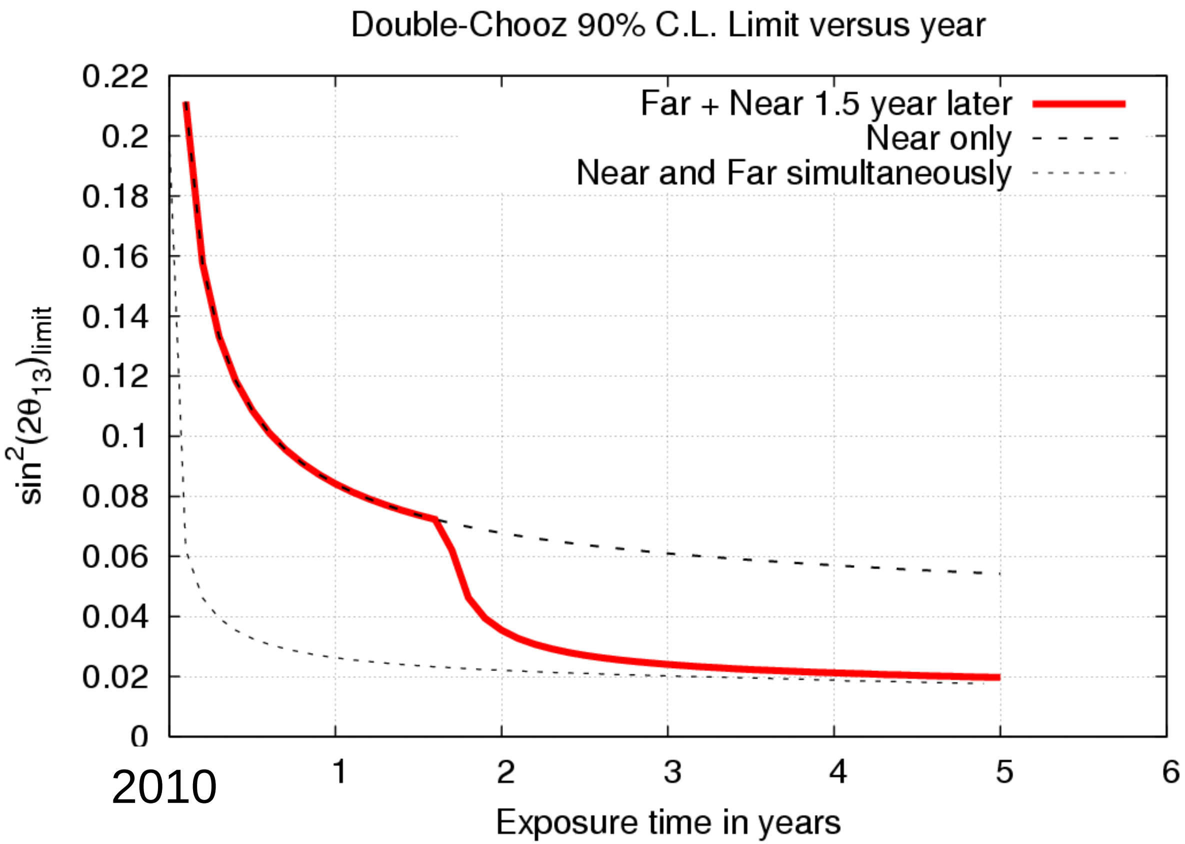
$R = 1.01 \pm 2.8\%(stat) \pm 2.7\%(syst)$



	Fehler	Chooz	DC
	Statistical	**2.8%**	**0.4%**
Reactor	Flux, σ	1.9 %	<0.1 %
Reactor	E/fission	0.6 %	<0.1 %
Reactor	power	0.7 %	<0.1 %
Detector	# protons	0.8 %	0.2 %
Detector	Det.eff.	1.5 %	0.3 %
	Σ System.	**2.7 %**	**~ 0.6%**

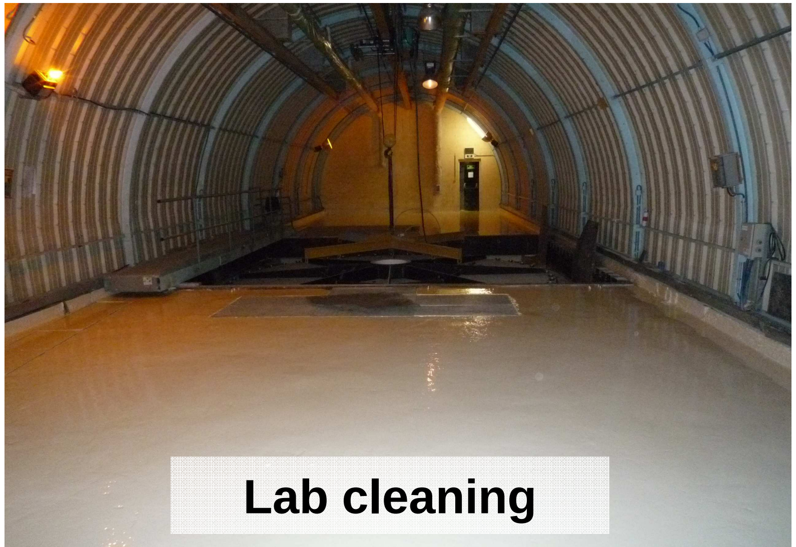
Sensitivity

Sensitivity 2010 – 2015 (near detector starts < 2 y after far)
for $\Delta m^2_{atm} = 2.8 \cdot 10^{-3}\ eV^2$



Far detector filled beginning 2010!

Status far detector

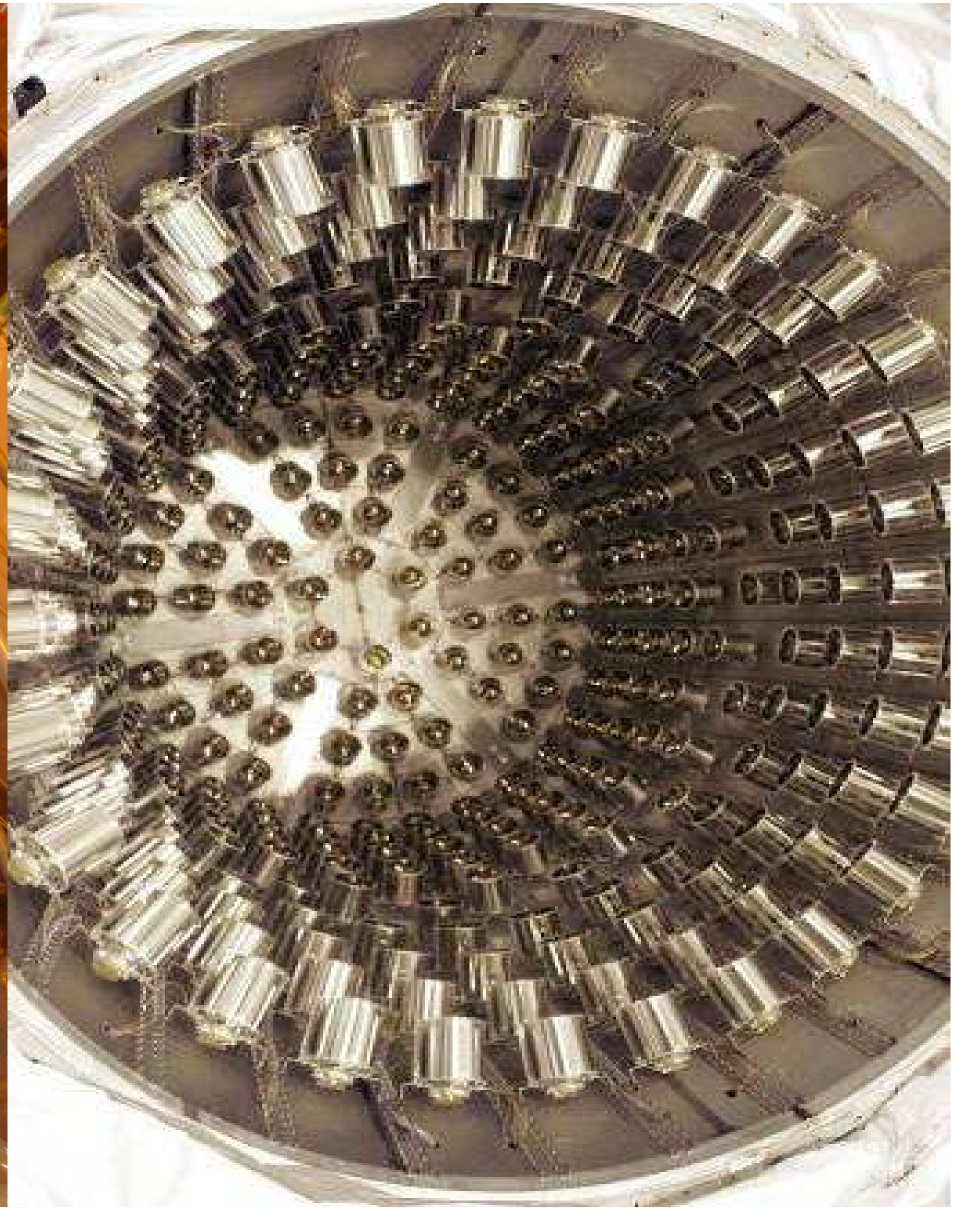


Lab cleaning

Installation Veto and Veto-PMTs

Installation Buffertank

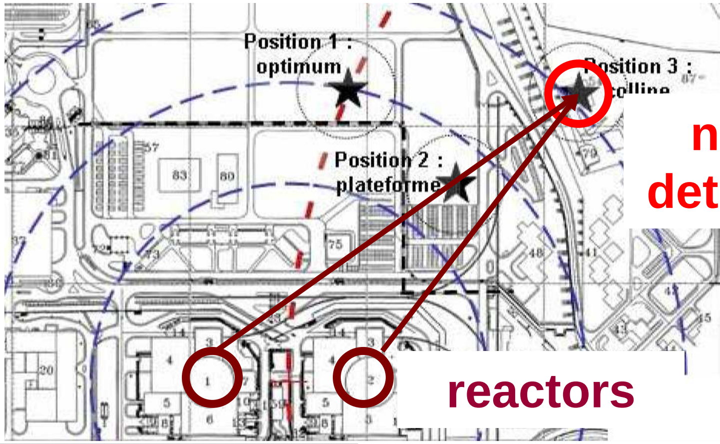
PMT installation

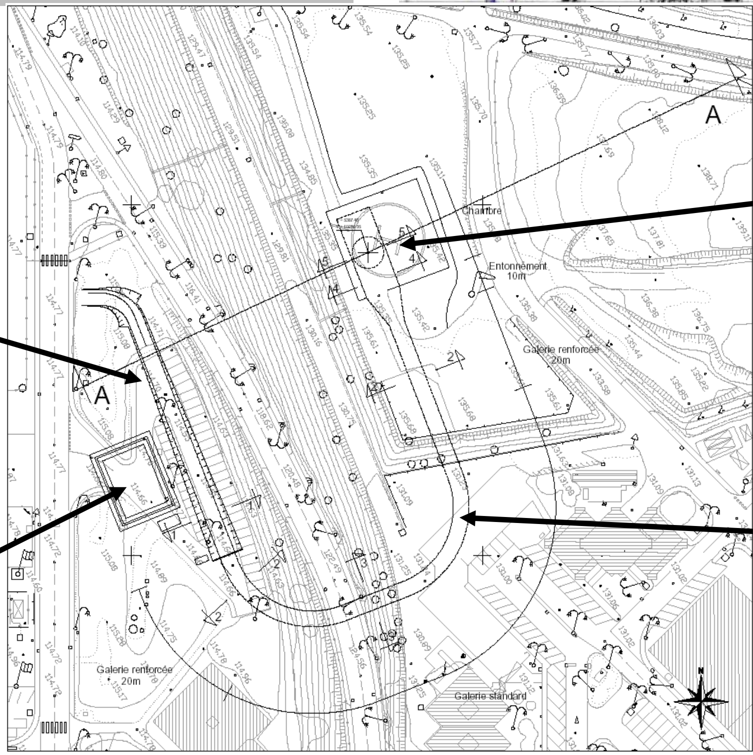


Acrylic vessel installation

Status near detector

- Distance: 415 m
- Shielding: 115 m w.e.
- Myons (Veto): 250 Hz
- Data taking: 2011





Scintillator development (MPIK)

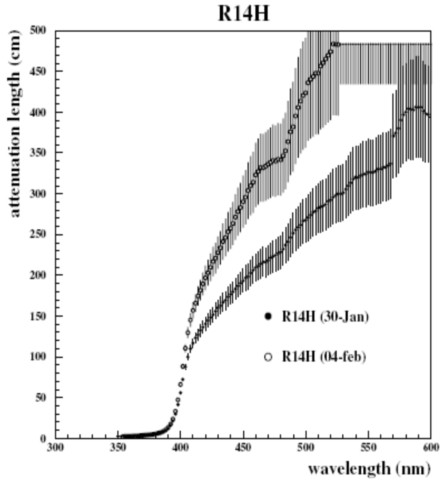
Requirements:

- ➢ Gd-solubility > 1 g/l
- ➢ Stability (> 5 years!)
- ➢ Transparency
- ➢ Material compatibility
- ➢ Radiopurity
- ➢ Target – Gamma catcher matching (optics + density)
- ➢ Large scale (multi tons)

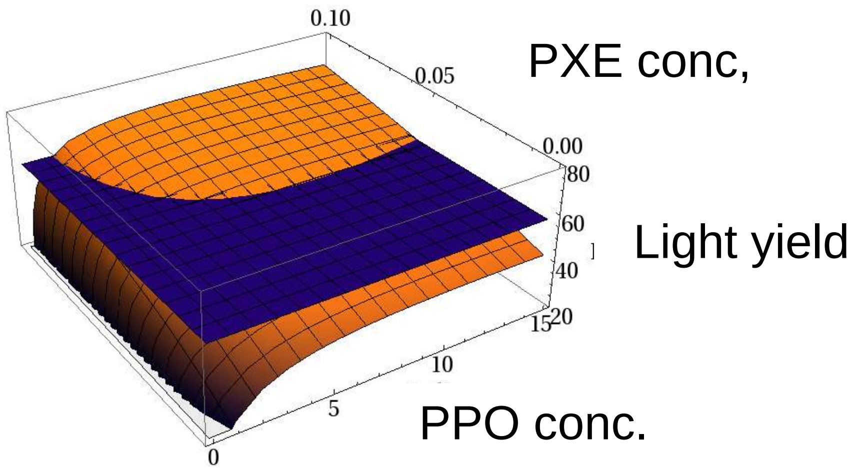
Chooz stability:

$Gd(NO_3)_3$

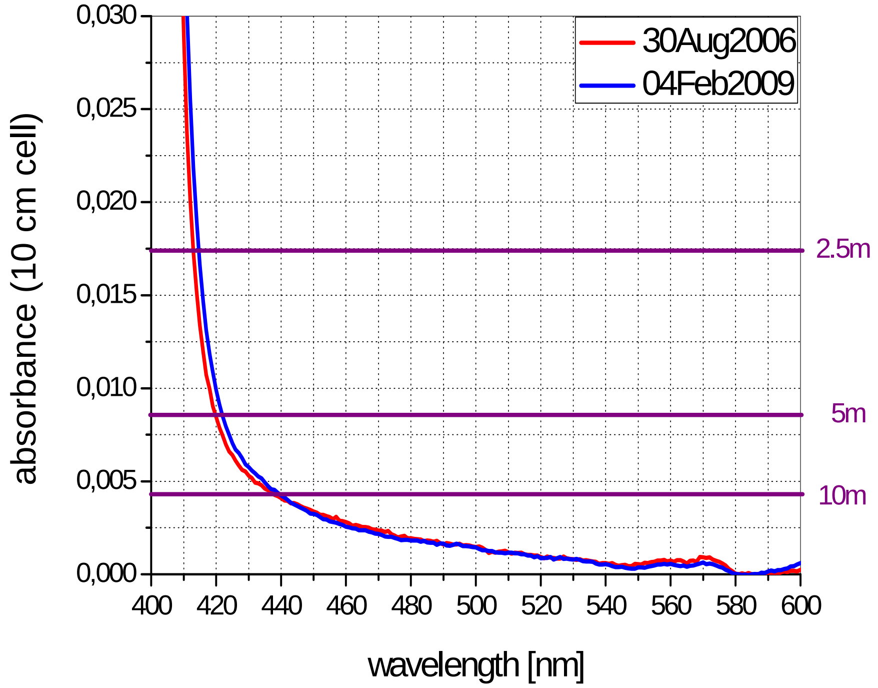
τ ~ 240 days



Chooz Coll.; Eur.Phys.C27, 331-374 (2003)

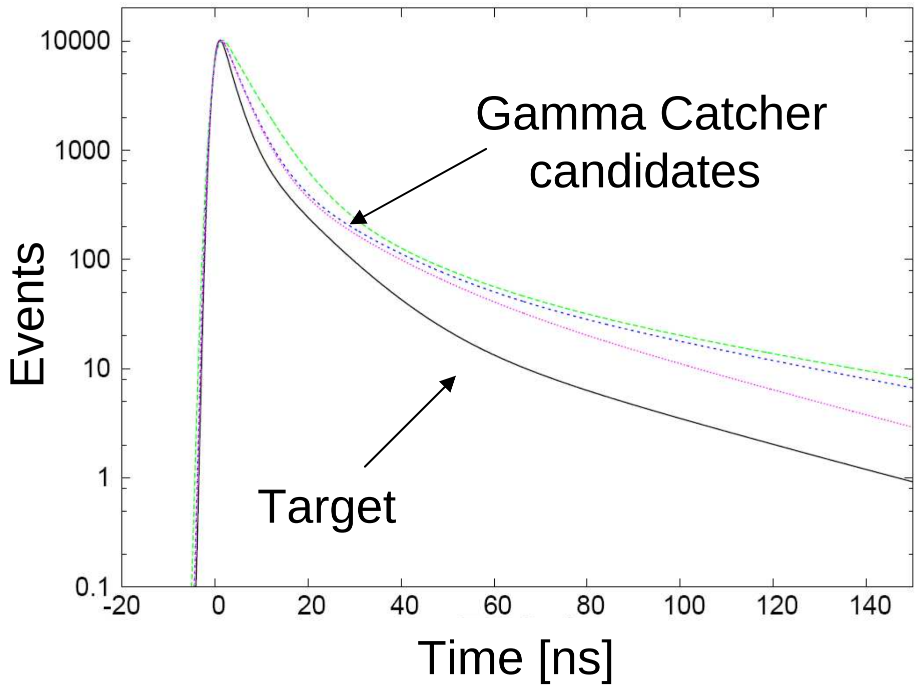


Scintillator properties



Transparency in ROI stable in 10 m range!

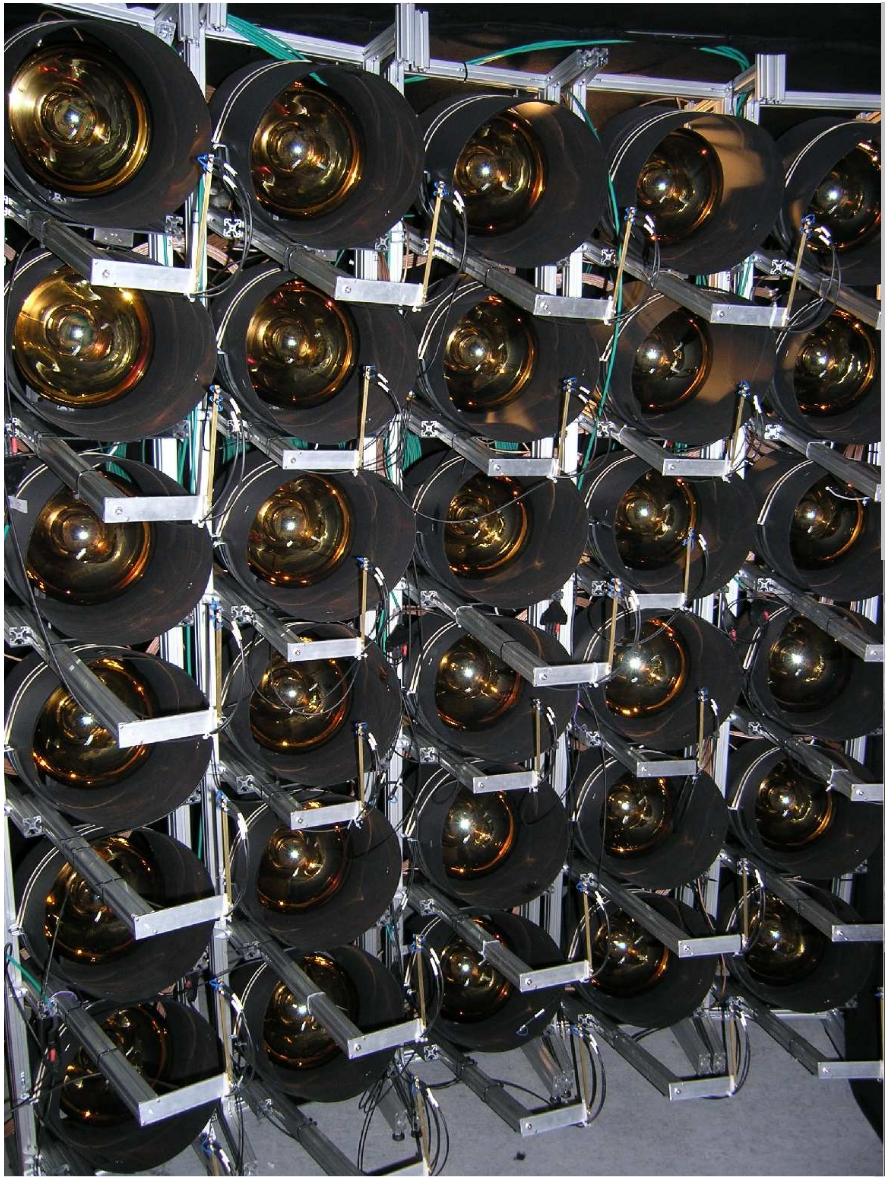
Event localization by pulse shape analysis



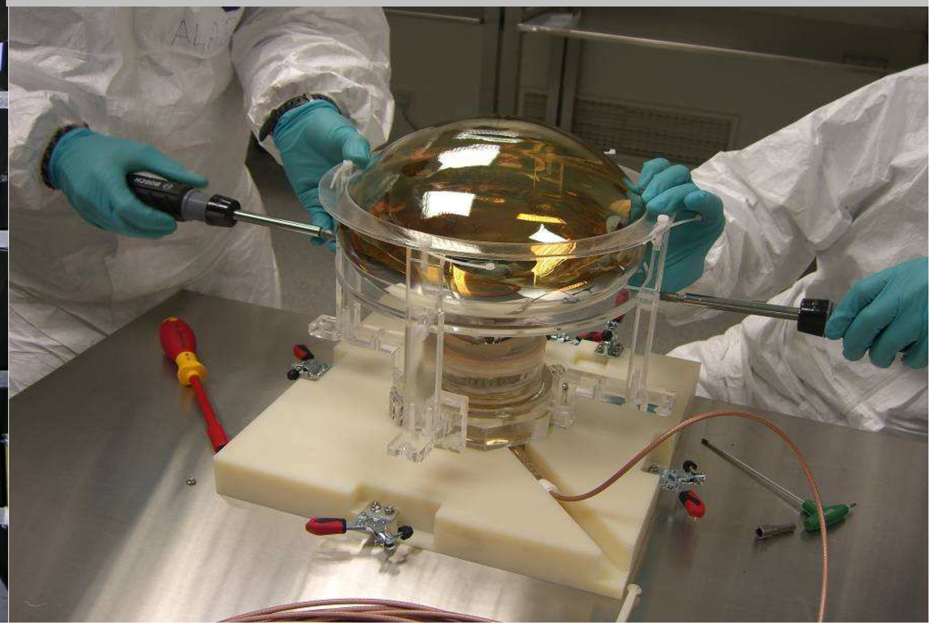
Large scale production

- All components (40 tons) delivered to MPIK
- current activities: final purification, prepare for mixing
- Scintillator production and transport to Chooz end of 2009

PMT activities at MPIK



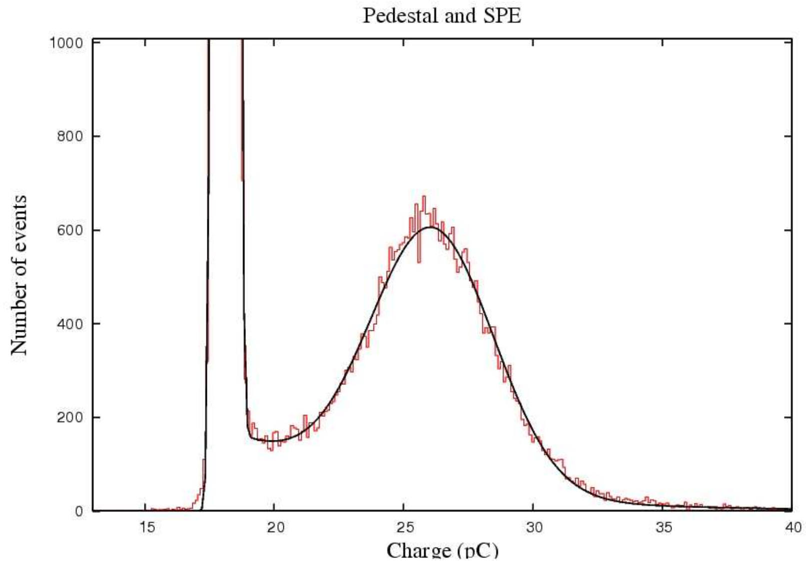
- Testing
- Assembly / Installation
- Implementation of data in Double Chooz software
- Future upgrade: full detector segment

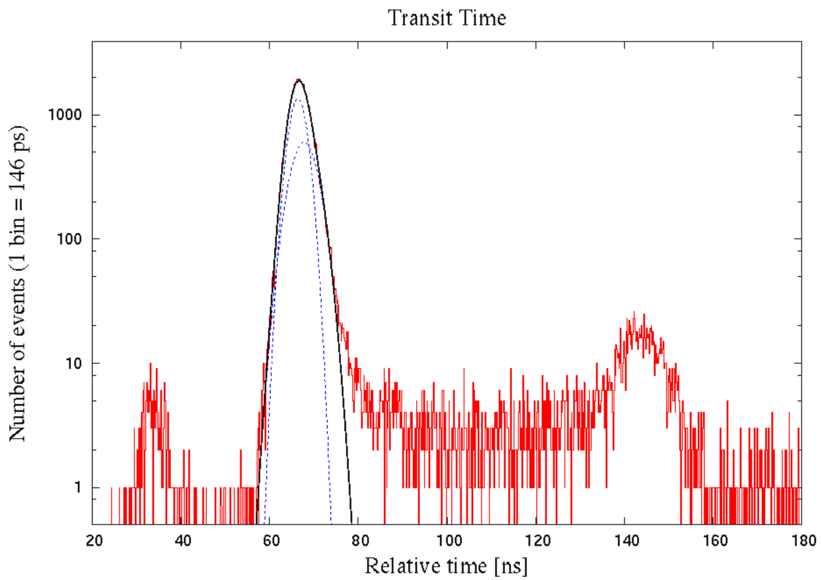


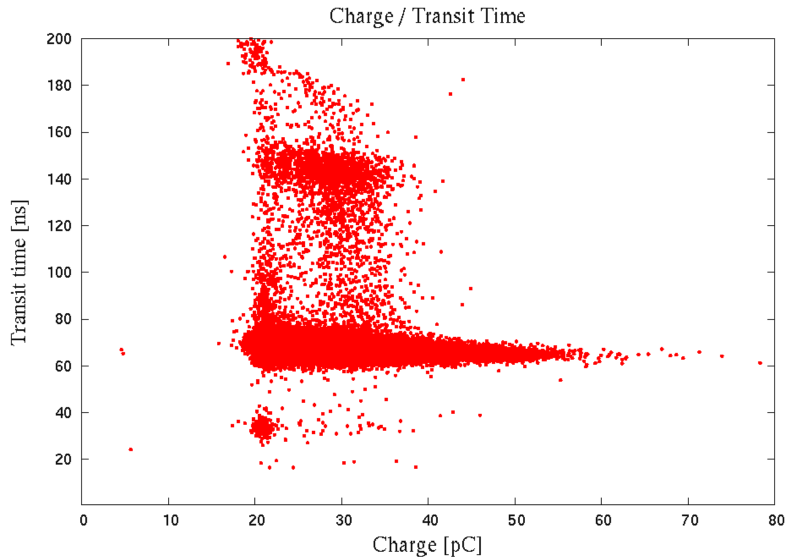
PMT calibration

Calibration program:

- HV scans
- Single photon electron (P/V)
- Transit time
- Dark rate
- Quantum efficiency







Summary

- Goal of Double Chooz reactor neutrino experiment: Determination of mixing angle Θ_{13} ($\sin^2(2\theta_{13}) \sim 0.03$)
- 2-detector concept to reduce systematical error
- Detection via inverse β-decay in Gadolinium loaded liquid scintillator
- Schedule:
  - Data taking far detector: beginning of 2010
  - Near detector: end of 2011
- MPIK: scintillators, PMTs, Analysis