Technische Universität
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Measurements towards the total antineutrino-spectrum from fission of U-238

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A6 – Double Chooz

10.07.09

SFB meeting @ MPIK Heidelberg

Outline

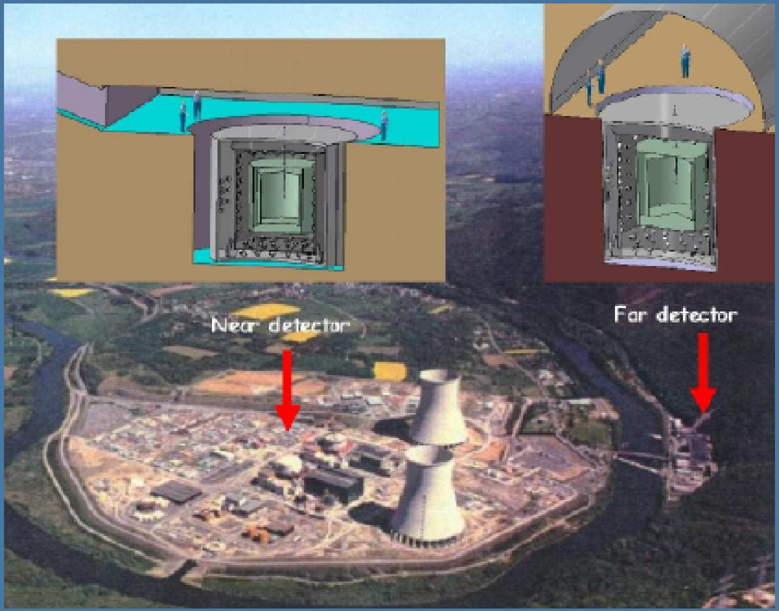
- Motivation (Double Chooz):
  - Reactor neutrinos
- Concept of measuring the U-238 beta spectrum
- Detector setup
- Measurements
  - Detector characteristics
  - Gamma spectroscopy
- Summary

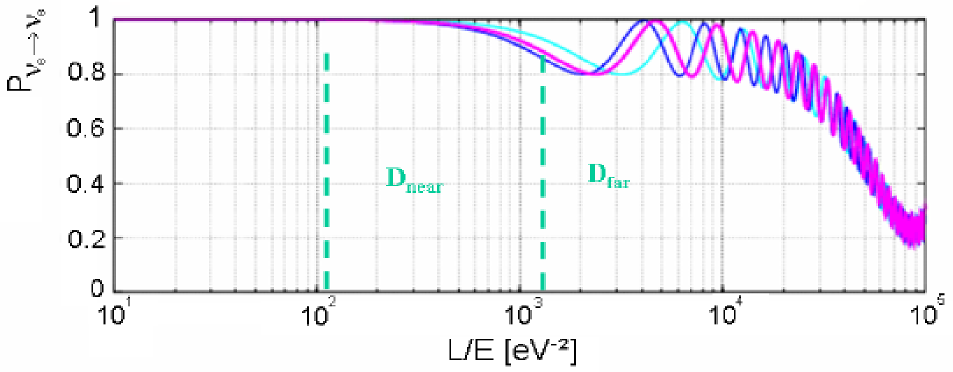
ν - oscillation & Double Chooz

- Parameters yet determined ->
- But for θ_{13} only upper limits exists

- Double Chooz aims at a lower limit
- DC = Reactor electron-antineutrino disappearence experiment

Oscillation parameter	value (90% C.L.)	known from
$\sin^2(2\vartheta_{12})$	$0.86^{+0.03}_{-0.04}$	solar neutrinos, KamLAND
$\sin^2(2\vartheta_{23})$	> 0.92	K2K, atmospheric neutrinos
Δm^2_{21}	$(8.0 \pm 0.3) \cdot 10^{-5}\, eV^2$	KamLAND, solar neutrinos
Δm^2_{32}	$(1.9 \text{ to } 3.0) \cdot 10^{-3}\, eV^2$	Super-Kamiokande, MINOS
$\sin^2(2\vartheta_{13})$	< 0.19	CHOOZ

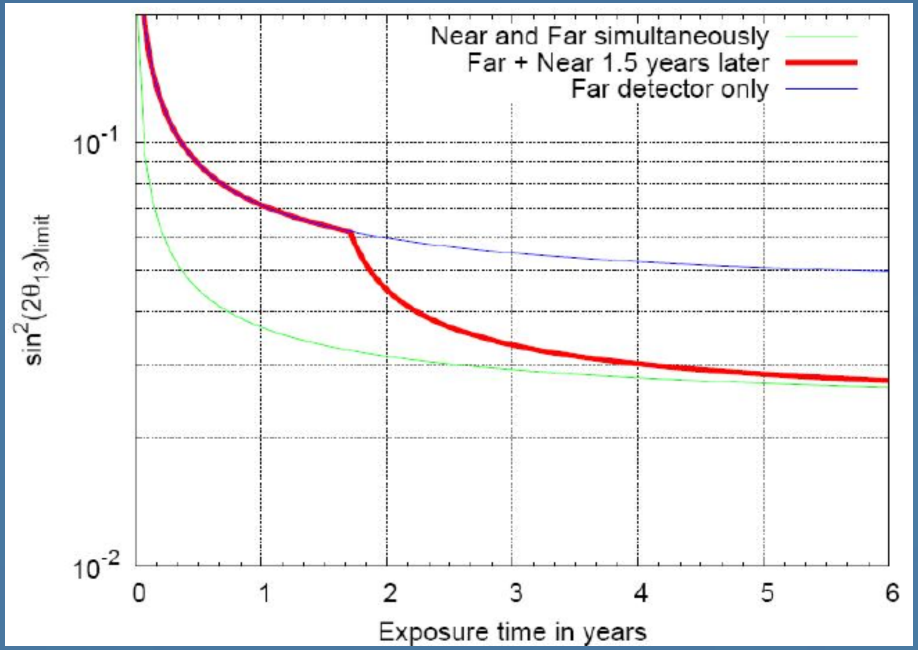


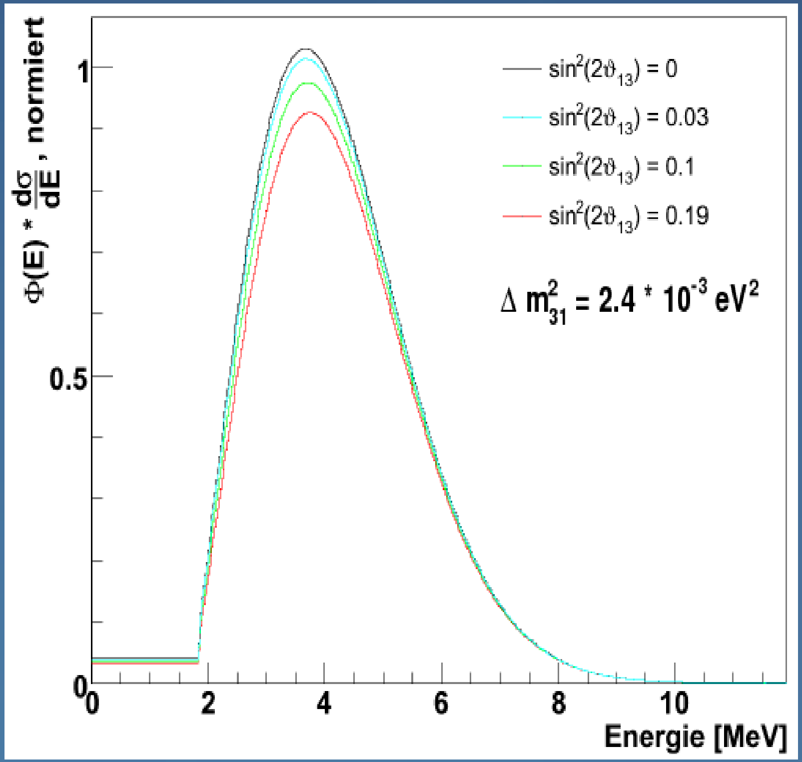


Neutrino oscillation in Double Chooz

- theoretical ν-spectrum folded with σ(inverse beta):

- In Phase 1 knowledge of reactor start spectrum is most important



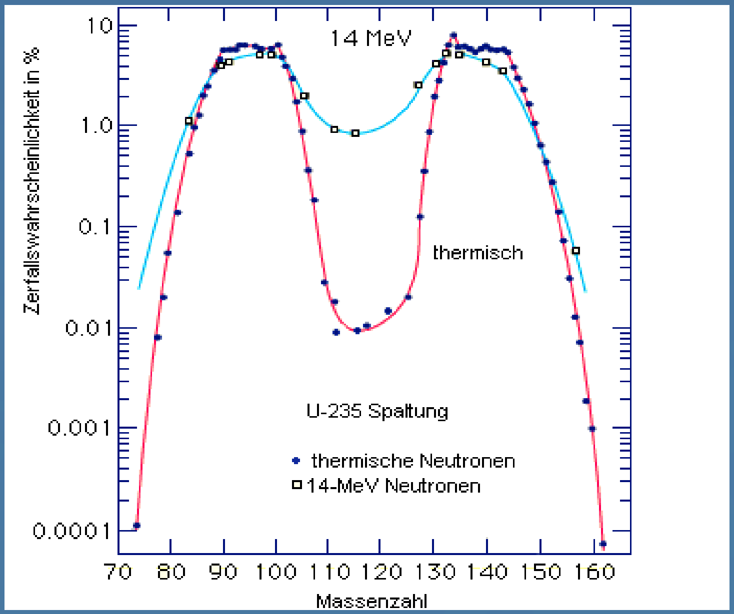


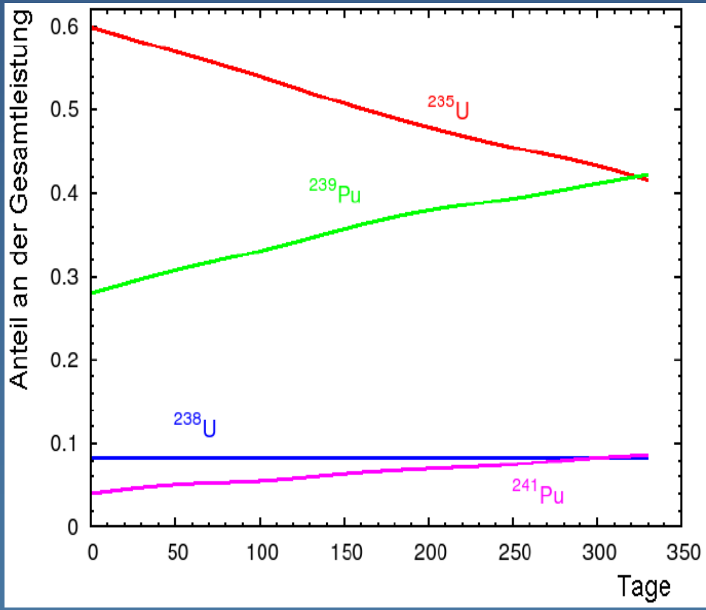
Prediction of spectrum needed until near detector finished !

The reactor antineutrinos

- Antineutrinos stem from beta decays of all fission products of participating fuel isotopes:

$$N^{\nu}(E,t) = \sum_{\substack{\text{i fissile} \\ \text{isotopes}}} \alpha_i(t) \times N_i^{\nu}(E)$$





Spectra of U235, Pu239, Pu241 already measured

BUT: U238 spectra only calculated

Measuring the sum of the betaspectra of U-238

General idea

- Foil from natural Uranium irradiated with thermal neutrons from FRM II
- Second (identical) target irradiated with fast neutrons in identical setup

- Sum of β - spectra of all fission products is detected with gamma-suppressing electron – telescope

- Calibration: comparing experimental data from U235 measurement with well known data from former experiments [Schreckenbach et. al.]*

  * Phys. Lett. B 160, 325 (1985)

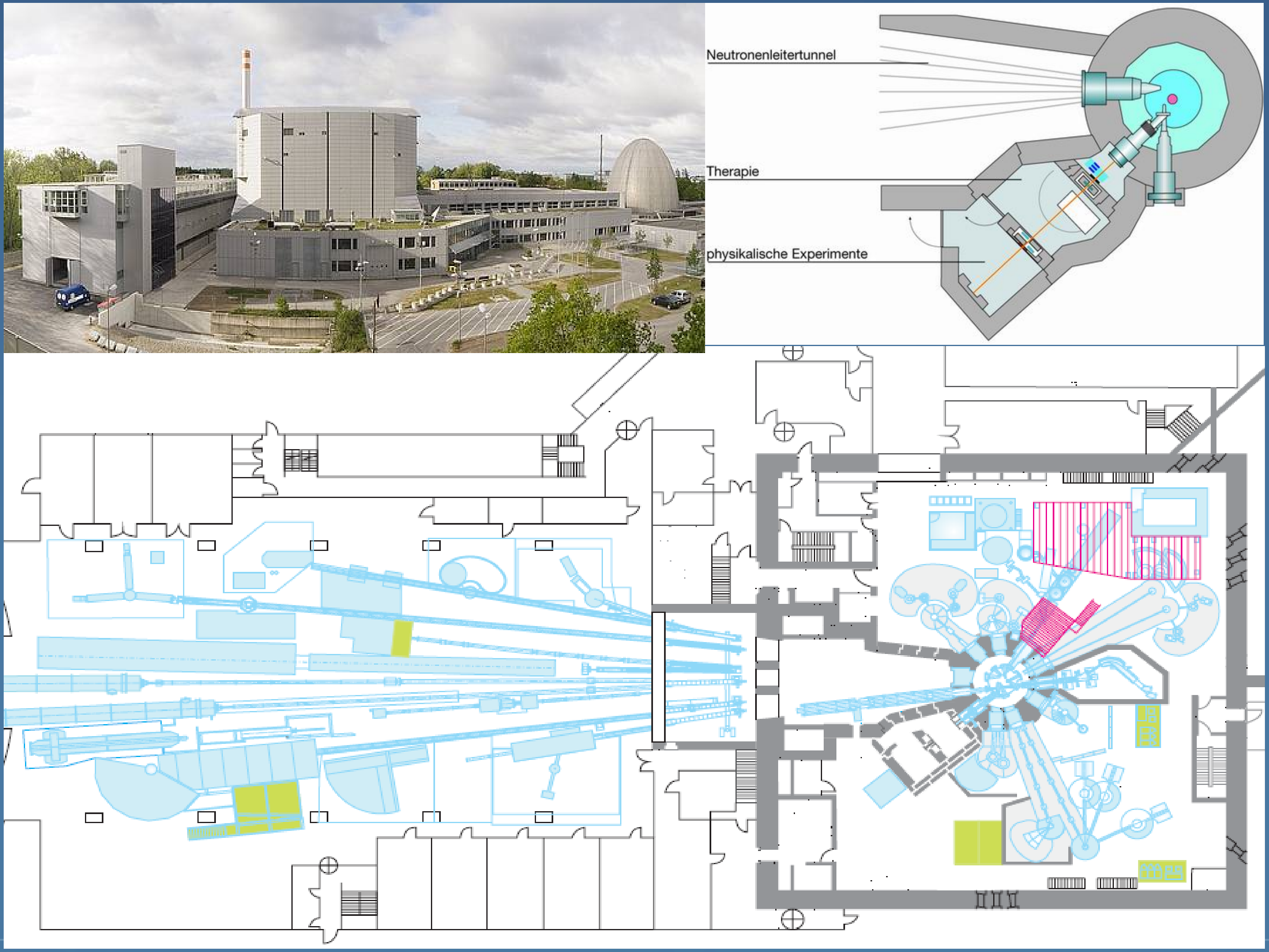
- Measurement of relative gamma - intensities of the same long living fission-products of both isotopes (Ge-Detector)

  -> relative number of fission products determined

- Conversion from β - to antineutrino-spectrum

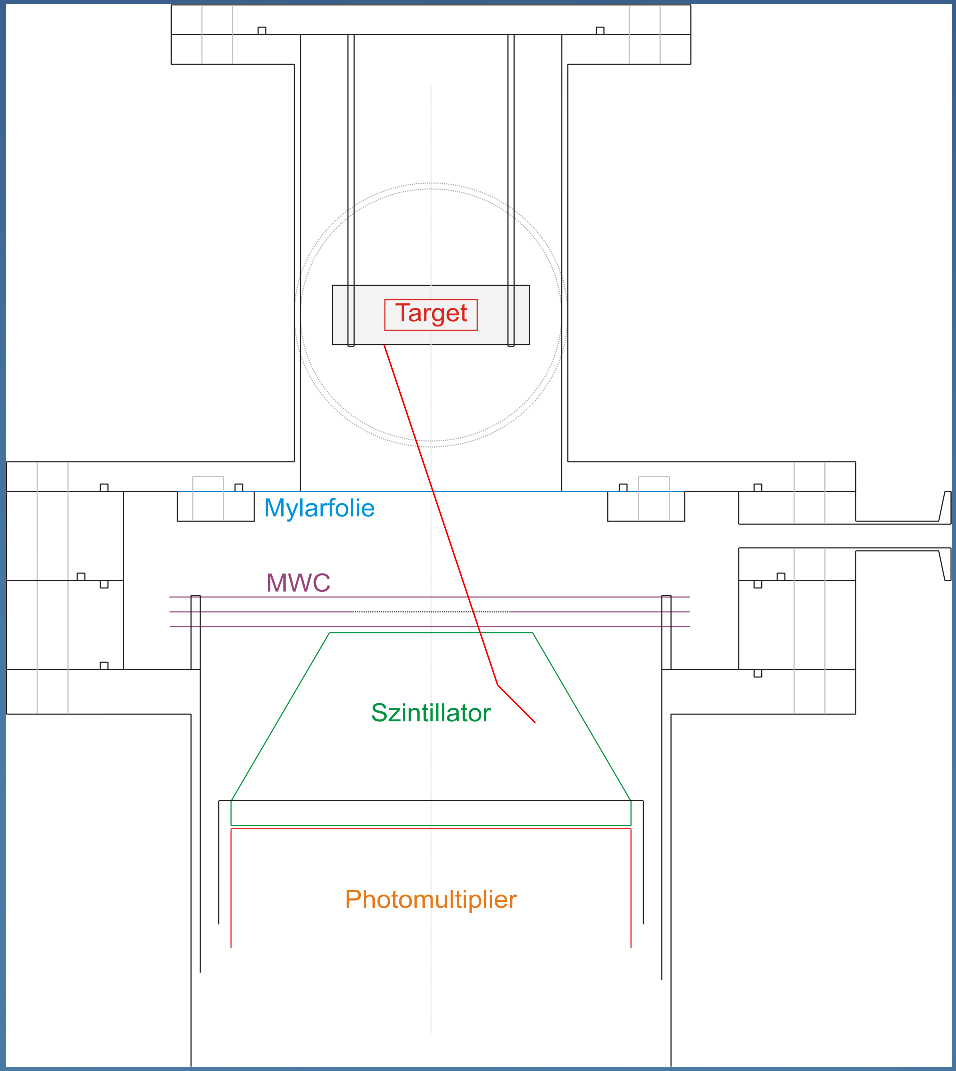
$$\alpha \cdot \frac{N_{238}}{n_{238} - BG} = \frac{N_{235}}{n_{235} - BG}$$

Site – FRM II


Neutronenleitertunnel
Therapie
physikalische Experimente

Experimental Setup

- Line of sight =
  Direction of neutron beam



- Mylarfoil seperating vacuum and MWC-counting gas (CF_4)

- Multiwire Chamber provides signature from charged particles

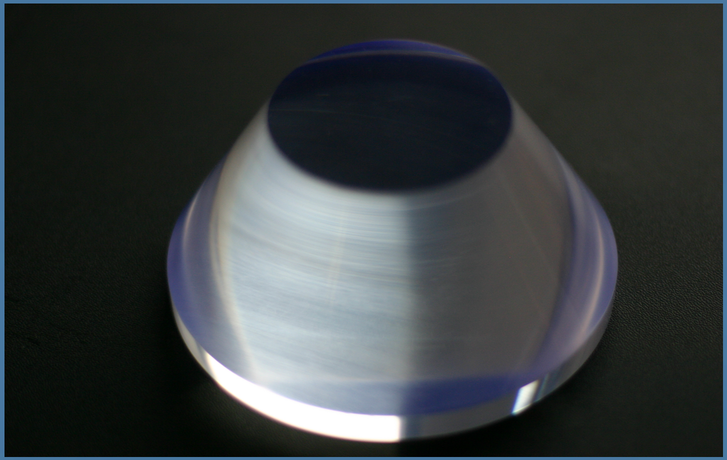
- Plastic scintillator to gain energy information

- Photomultiplier

Coincidence MWC – PM to measure

Detector unit – Scintillator and Photomultiplier

- Truncated cone of 6.5 cm heigth
- Material BC 404: Full energy deposition for electrons up to 10 MeV
- Special shape to provide full absorption for all possible angles of incidence



The MWC

- Tasks:
  - Suppressing gamma-background from target

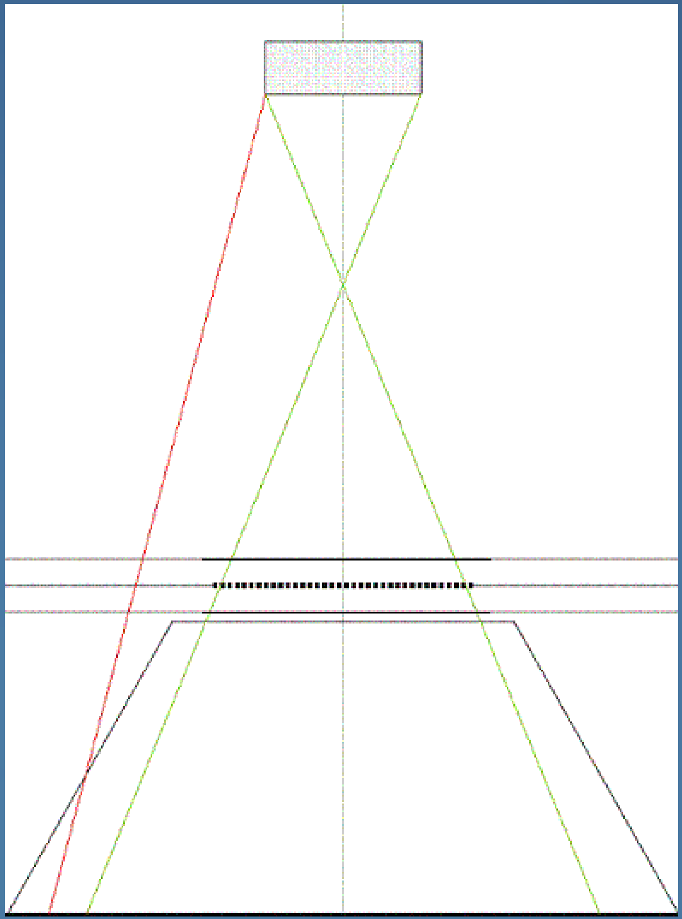
  → Only charged particles seen

  - Defines scintillator surface seen by target (1 % solid angle) in coincidence mode

  → Full energy deposition

- Built from 3 seperate parts:
  - Wire-board
  - 2 cathode-planes

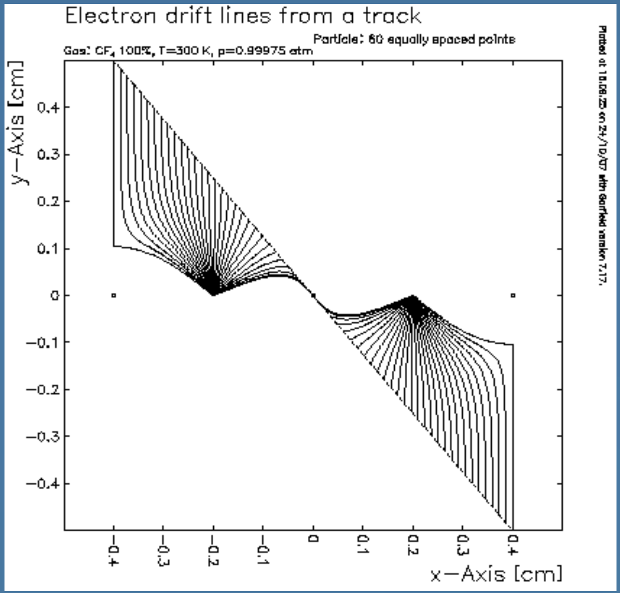
- Gas: CF_4

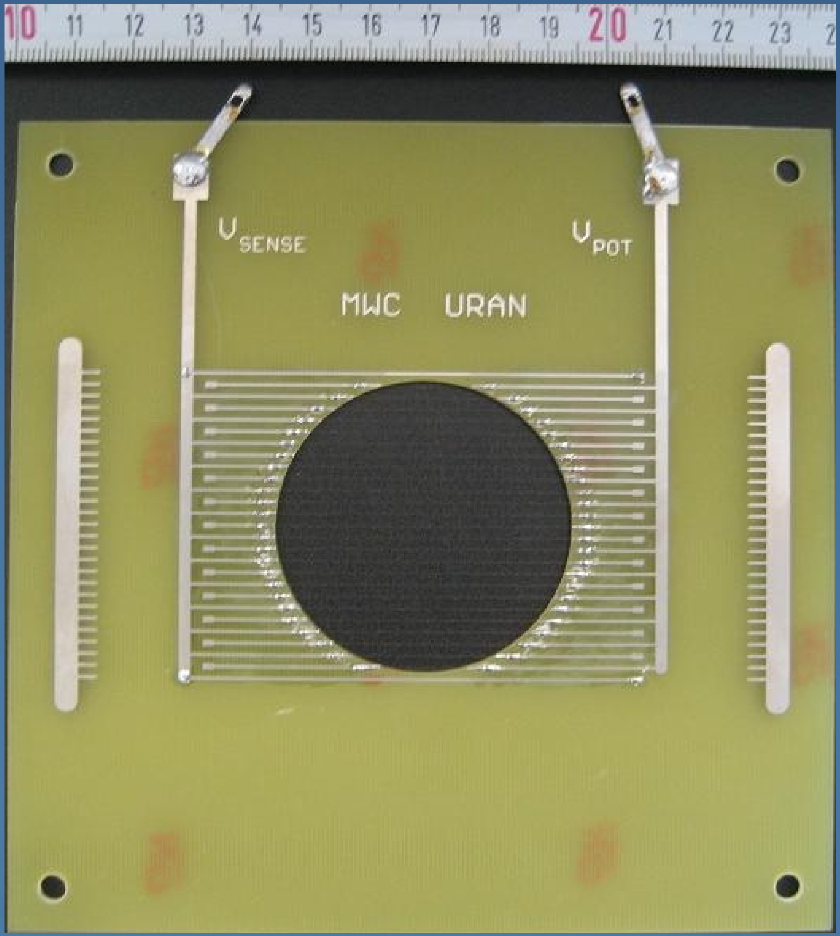


MWC – Wire Plane

- 25 gold-coated tungsten wires
- Wire radius 5 µm

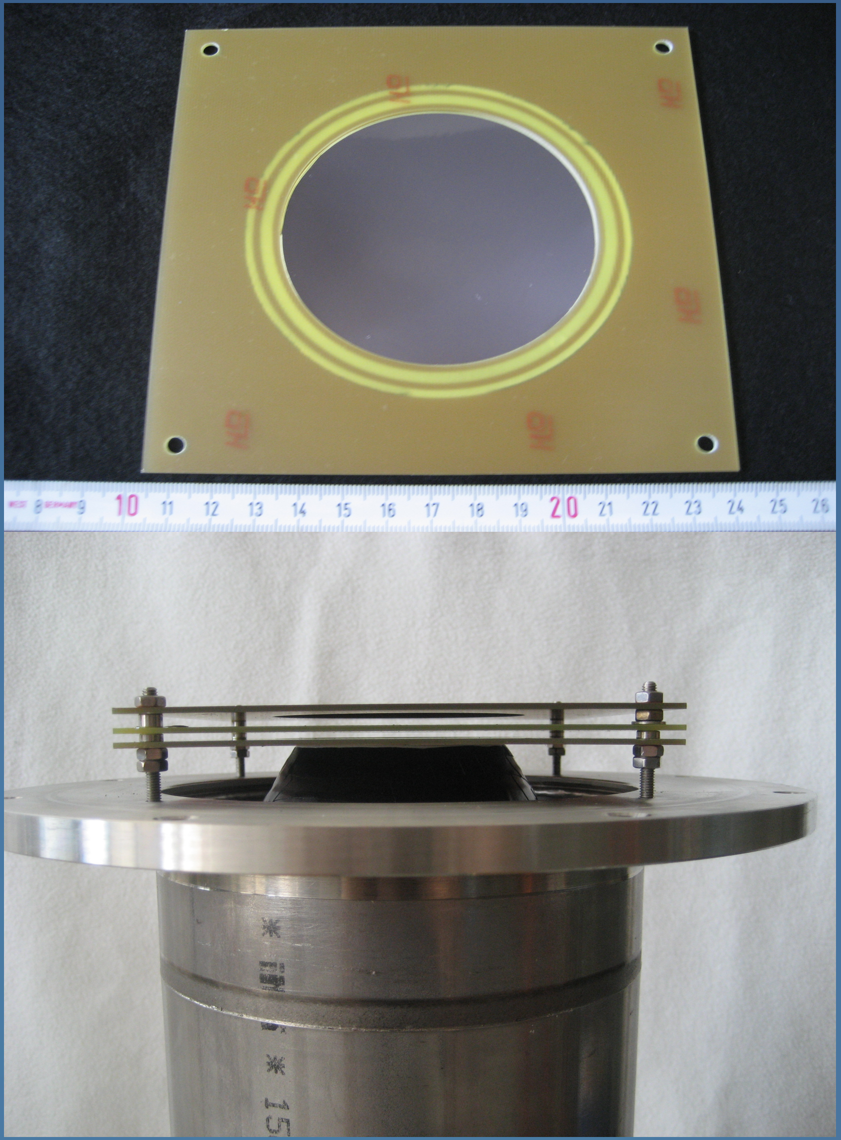
- 12 sense wires @ ca. 2.5 kV
- 13 field wires @ ca. 660 V





MWC – mounting

- Cathodes: 6µm mylar foil
- Total height of MWC: 10 mm
- Distance to Scintillator: 1mm
- Not gastight



Targets

- Same target composition for both measurements (natural uranium)
  - ^{238}U: 99.3 %
  - ^{235}U: 0.7 %
- 25 x 25 mm² metallic foil (240 mg) between Ni
- Around 4 kBq (online) without coinc.
  - Coincident: 200 Hz in detector

The Setup

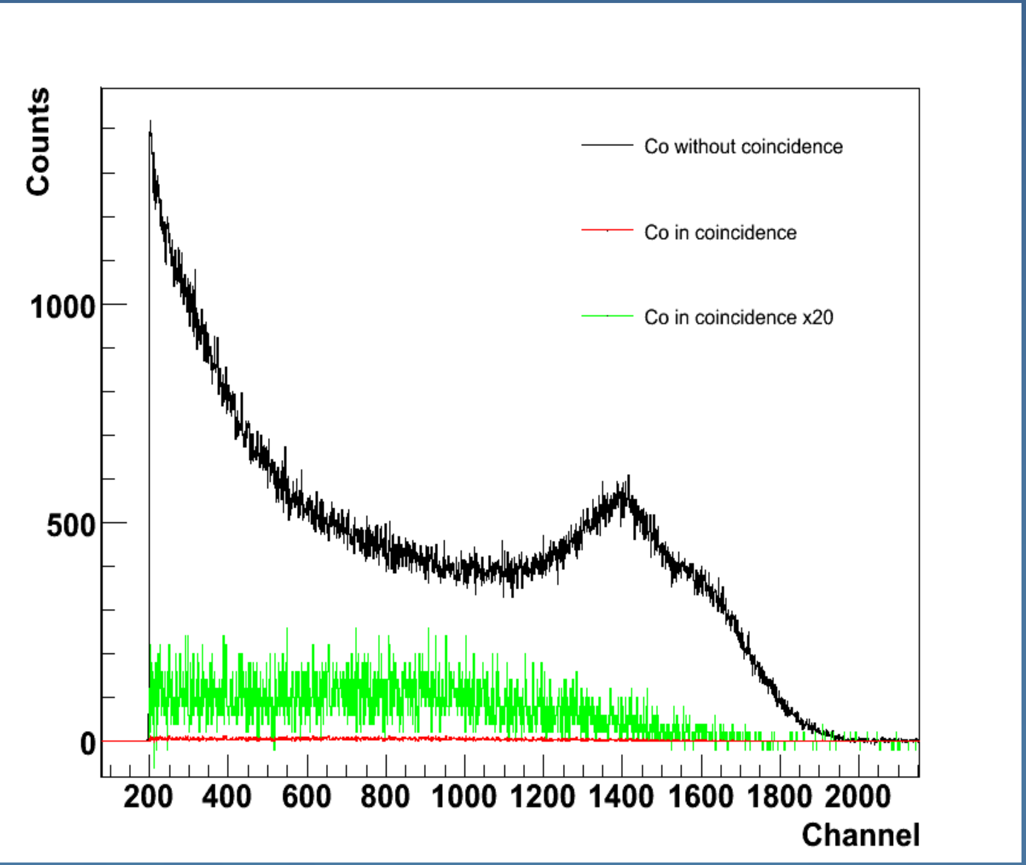
Measurements

MWC- Gamma-discrimination

- Measurement of ^{60}Co
  (Gammas @ 1173 and 1333 keV)

- black: without coincidence
- red: with coincidence

- Gamma-suppression
  better than 99.4 %



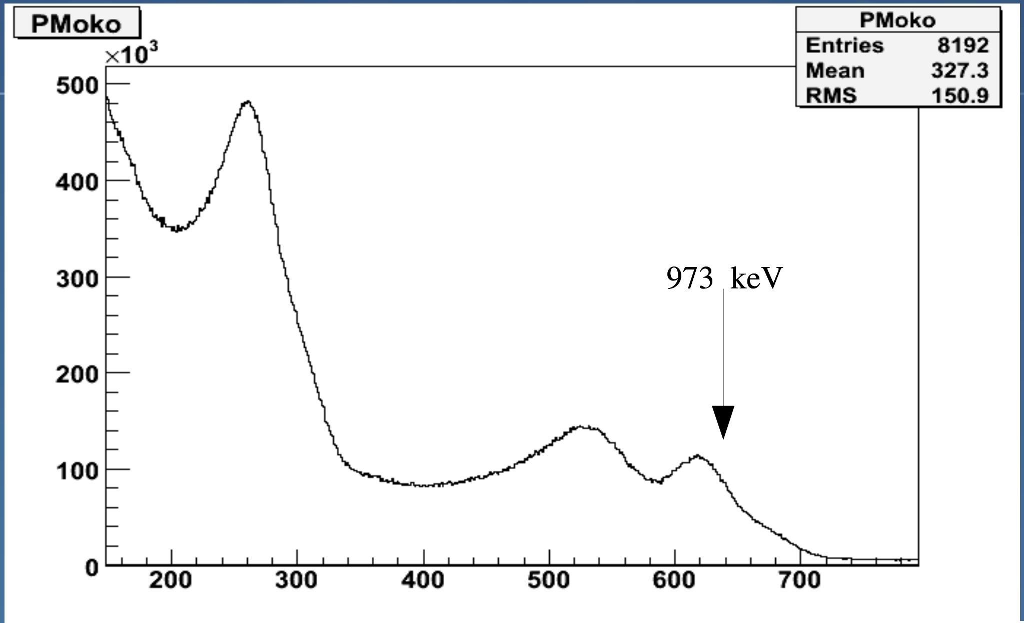
Detector-response-function and energy calibration

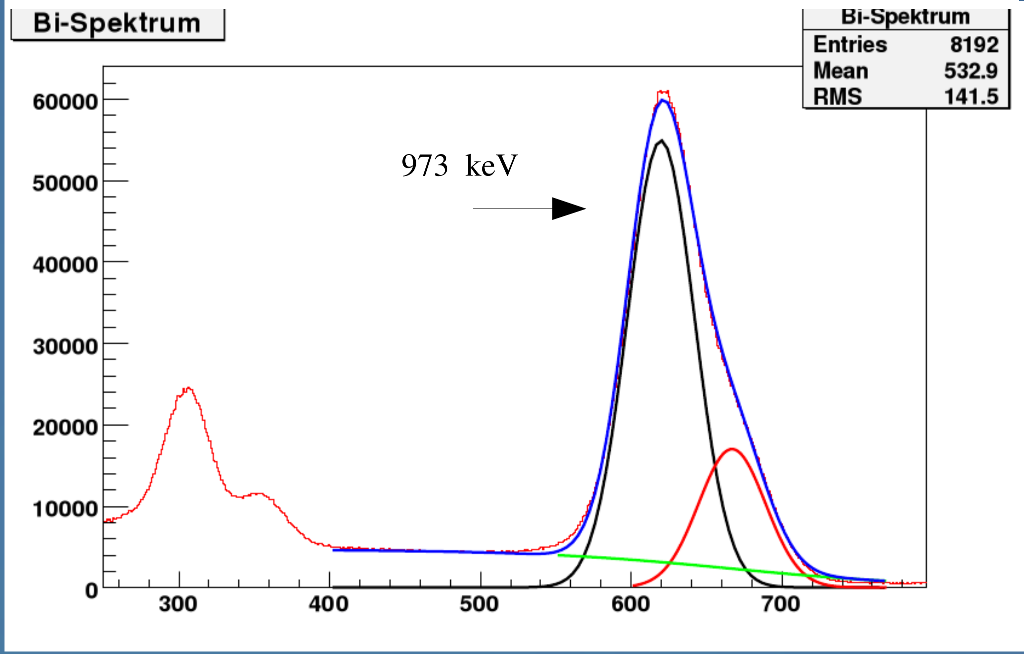
- Spectrum of ^{207}Bi
  Gammas @ 570 & 1064 keV lead to conversion electrons

- Plateau due to
  - Bremsstrahlung
  - Backscattering
  - Electron-escape

- FWHM: ~ 8 %
  @ 1 MeV

- Low energy regime:
  separation between
  K- and L- conversion



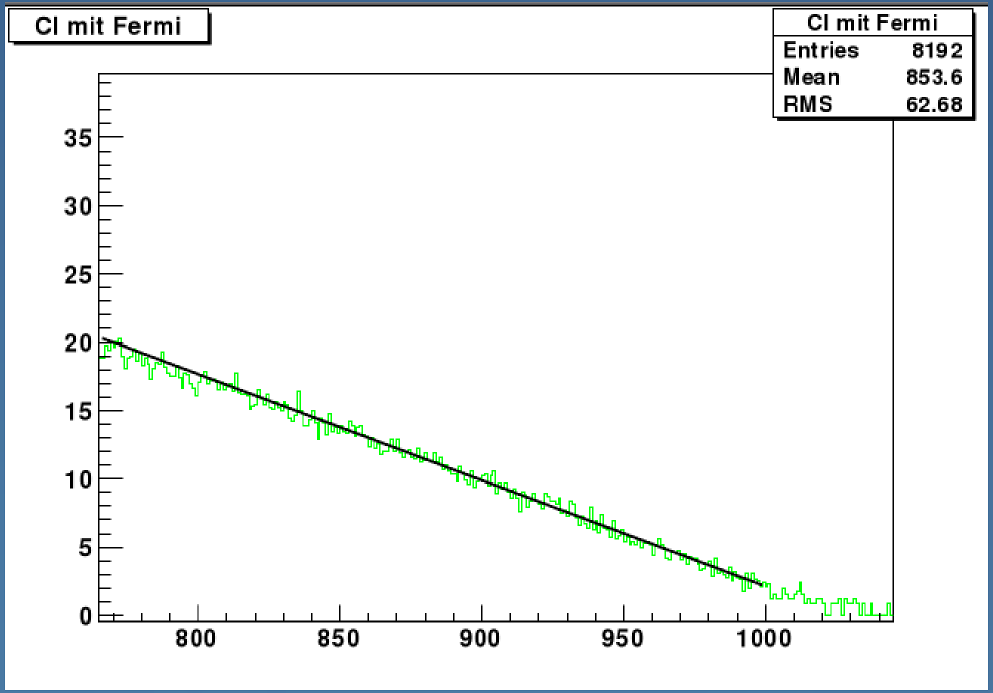


Energy calibration II

- Irradiate In and PVDC-foils with thermal n

- Kurie-plot from
  - ^{116}In (3274 keV)
  - ^{38}Cl (4916 keV)

- Accuracy of fits about 2 %

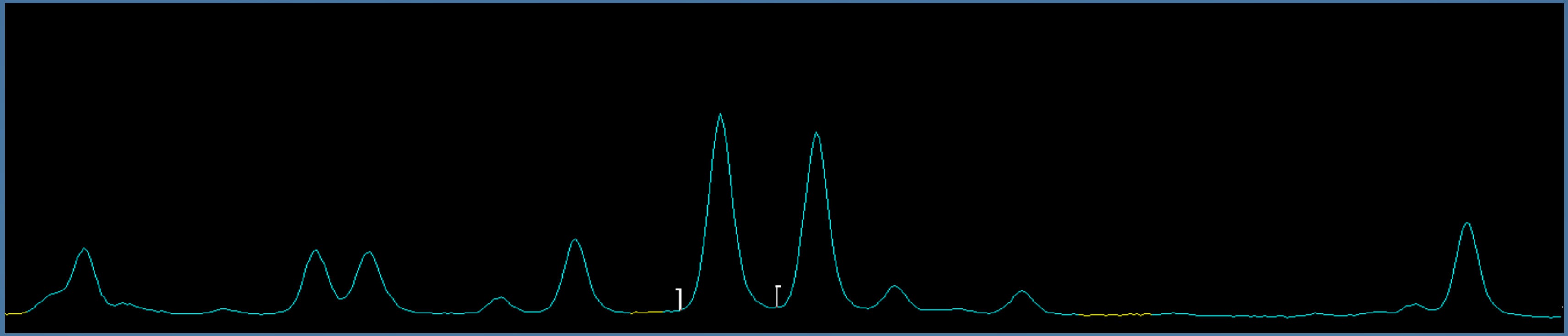


→ Calibration at three different energies (~ 1, 3, 5 MeV)

Gamma spectroscopy

$$\alpha \cdot \frac{N_{238}}{n_{238} - BG} = \frac{N_{235}}{n_{235} - BG}$$

- Determination of production rate of various daughter nuclides via gamma spectroscopy
- Measure the gamma intensities (peak area PA) of decaying daughter isotopes:



- And corellate the PA to the # of fissions

$$PA(\gamma) = \frac{\int_{t_1}^{t_2} \lambda N \, dt}{p(\gamma)\epsilon_{Ge}}$$

Gamma spectroscopy

- Put in the solution of the differential equations:

$$\dot{N}_1 = p - \lambda_1 N_1$$
$$\dot{N}_2 = \lambda_1 N_1 - \lambda_2 N_2$$

- This can be solved analytically and gives a value for the normalisation factor α (~p(th)/p(fast))

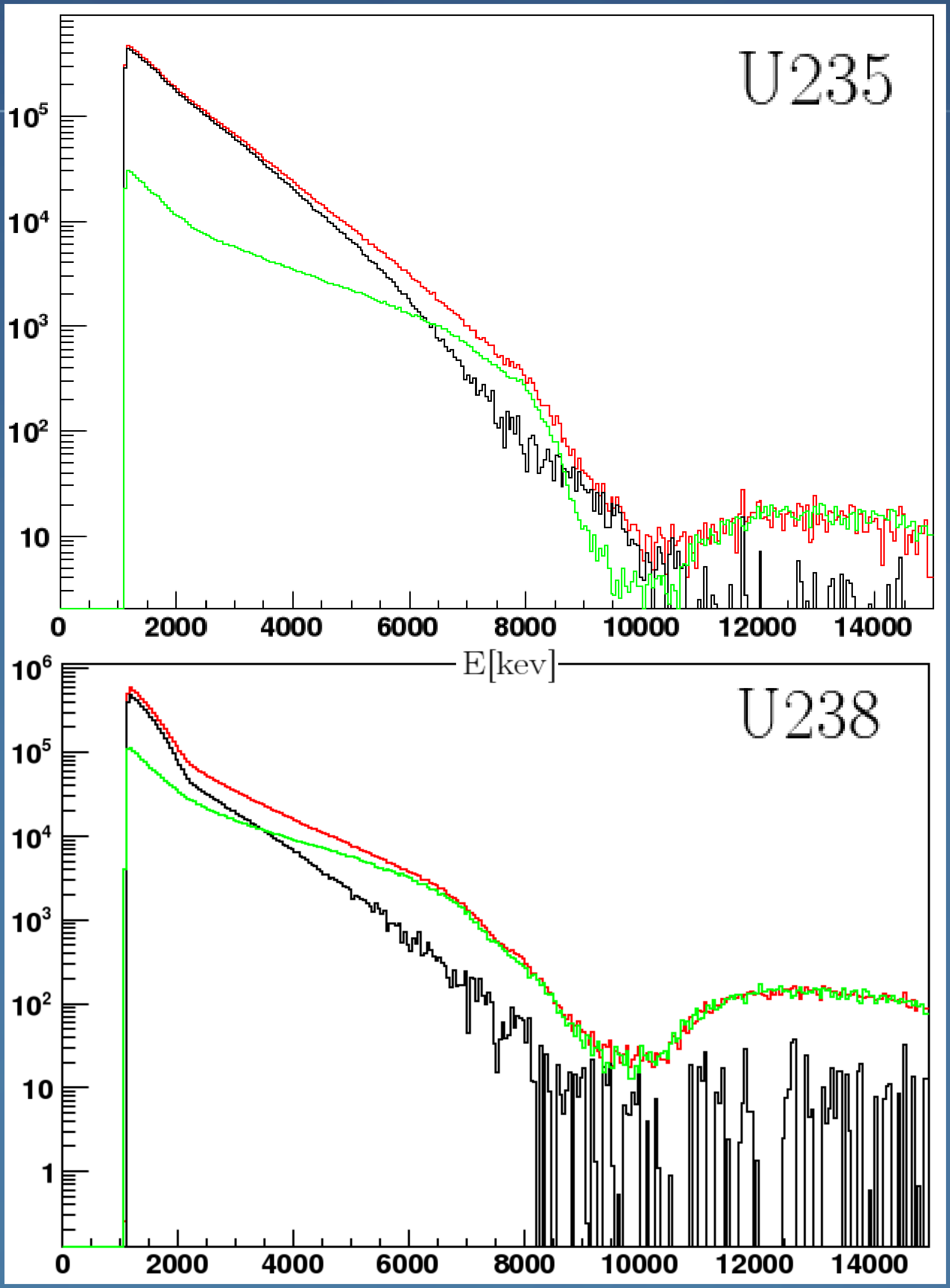
- Using gamma lines from isotopes with different fission yields in thermal and fast fission, one may be able to determine the „pollution“ of U-235 betas in the fast U-238 spectrum

	^{132}Te	^{140}Ba
$^{235}U_{therm}$	4.25 %	6.22 %
$^{238}U_{fast}$	5.15 %	5.82 %

Preliminary Results

- First U238 spectrum
- Until now, no accurate BG subtraction (measured with Pb-dummy)
- No normalisation yet

But ability to get spectra is evident



Summary

- Detector assembly developed and tested to measure the sum of beta spectra of the daughter isotopes of U238

- Measurements for characterisation of detector performed

- Ability to gain U238-spectra proven

- **Status:** **Second beam time finished and analysis ongoing (BG-handling, conversion into nu's)**

- **Next Steps:** **MC simulations of reactor burn-up evolution (MURE - code)**

$$N^{\nu}(E,t) = \sum_{\substack{\text{i fissile} \\ \text{isotopes}}} \alpha_i(t) \times N_i^{\nu}(E)$$

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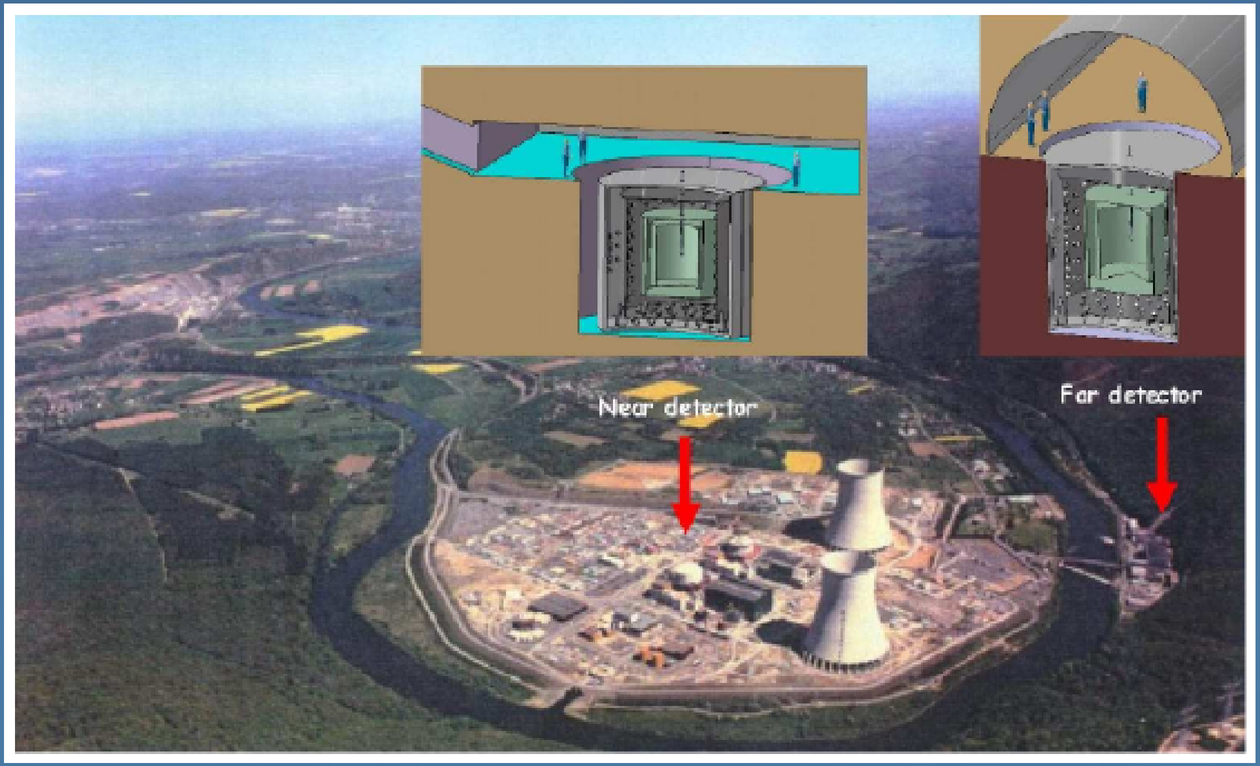
Backup slides : Double Chooz

Double Chooz

- Reactor electron-antineutrino disappearence experiment to measure Θ_{13}
- Located in Chooz (France/Belgium)



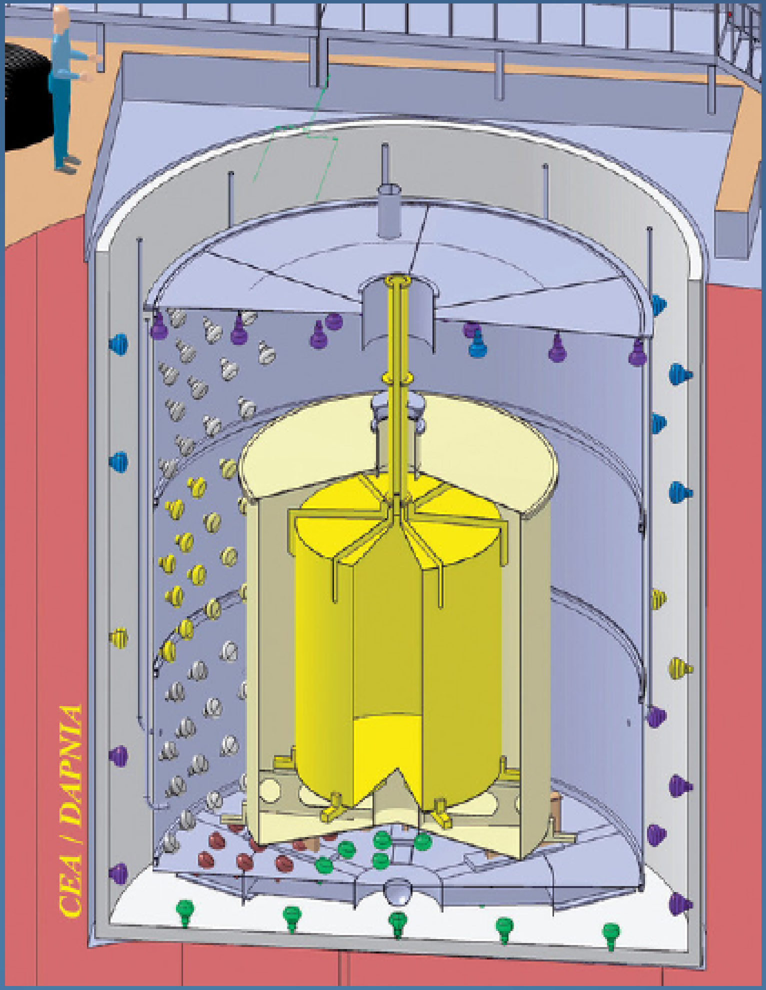
Double Chooz concept

- Target: liquid scintillator doped with Gd
- prompt event: $p + \bar{\nu}_e \rightarrow n + e^+$ E_{thr} = 1.8 MeV
  - minimal energy for neutrino event: 2 x 511 keV from positron annihilation
- Delayed event: $Gd + n \rightarrow Gd^{\star} \rightarrow Gd + \sum \gamma$ E_{gamma} = 8 MeV
  - about 30 µs delay and 3-4 cm distance to vertex
- Energy reconstruction:

$$E_{\bar{\nu}_e} = E_{e+,vis} - 511\,keV + (m_n - m_p) + O\left(\frac{E_{\bar{\nu}_e}}{m_n}\right)$$

Double Chooz detector design

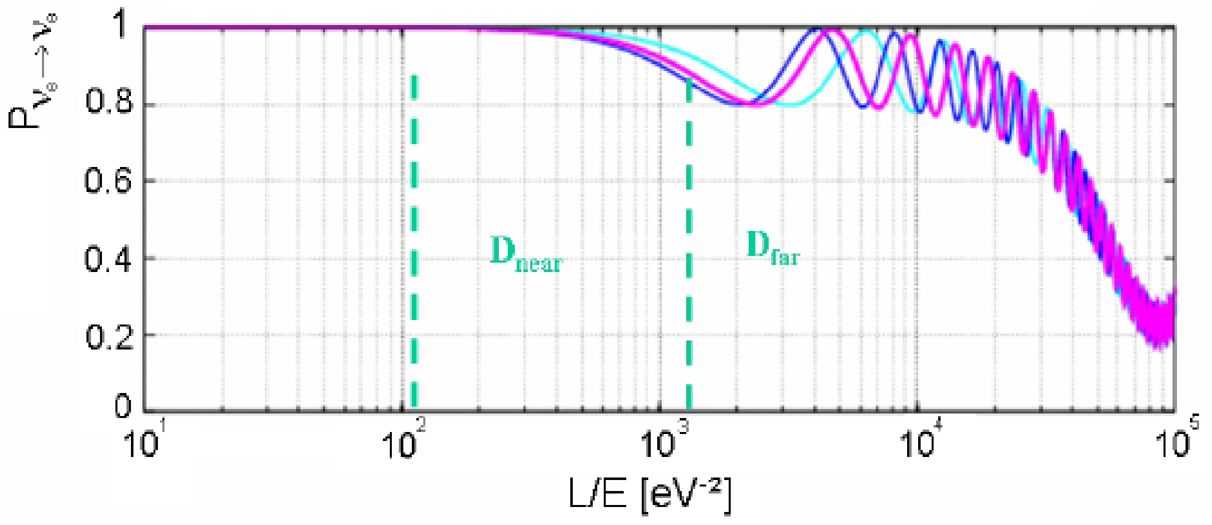
- From center outwards:
  - Acrylic *target* vessel containing 12.7 m^3 of Gd - doped liquid scintillator
  - Acrylic vessel containing a *gamma catcher* from undoped scintillator
  - Steel tank with the PM tubes mounted and the *buffer* liquid (not scintillating)
  - *Inner muon veto* (liquid scintillator)
  - On top: *Outer muon veto* (plastic scintillator)



Neutrino oscillation in Double Chooz

- Neutrino oscillation can be described (approximately) by 2 flavors

$$P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - sin^2(2\vartheta_{13})\, sin^2\left(1.27\, \frac{\Delta m^2_{31}\,[eV^2] \cdot L\,[m]}{E_{\bar{\nu}_e}\,[MeV]}\right)$$



different colors due to different Δm^2

Double Chooz limits

- Best limit $\sin^2(2\Theta_{13}) = 0.19$ from the Chooz experiment
- Double Chooz approach: $\sin^2(2\Theta_{13}) = 0.03$