Testmessungen für das Triggersystem des Double Chooz Experiments
• Introduction to $\theta_{13}$
• Double Chooz Experiment
• Triggersystem
• Calibration of the Discriminators
• Increase FIFO Size
• Afterpulses of PMTs
• Conclusion
Double Chooz is a so-called disappearance experiment.

Simple oscillation formula valid at small distances ($L$).

$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) \approx 1 - \sin^2 2\theta_{13} \sin^2 \left(\frac{\Delta m_{31}^2 L}{4E}\right) + O(10^{-3})$

$P(\bar{\nu}_e \rightarrow \bar{\nu}_e)$ is a function of $\Delta m_{31}^2$ (well known) and $\sin^2 2\theta_{13}$ (goal).

Independent of $\delta_{\text{CP}}$.

Negligible matter effects.

Clean and direct measurement of $\theta_{13}$.
Double Chooz

main goals:
- high precision
- small systematic errors

\[
\sin^2 2\theta_{13} = 0.1 \\
\Delta m^2_{31} = 2.5 \times 10^{-3} \text{eV}^2
\]

Chooz Reactors
4.27GW\text{th} x 2 cores

Near Detector
\( \langle L \rangle \) 400m
120m.w.e.
Early 2013

Far Detector
\( \langle L \rangle \) 1050m
300m.w.e.
April 2011
$\bar{\nu}_e$ detection principle

**delayed coincidence scheme:**

→ Prompt: $e^+$ annihilation

→ Delayed: $n$ capture on Gd

→ time correlation $\sim 30$ μs (thermalization of the $n$)

→ allows to suppress backgrounds

**Inverse beta decay**

$$\bar{\nu}_e + p \rightarrow e^+ + n$$
glove box
preparation of calibration sources in controlled atmosphere

outer veto (plastic scintillator strips)
tagging “near-by” μs

shielding (250 tons of steel, 15 cm thick)
reduce γ background from surrounding rock

inner veto (steel vessel, 90 m³ scint. + 78 PMTs)
detection of cosmic μs, fast neutrons, γs etc.

inner detector (three layers)

buffer (110 m³ mineral oil + 390 PMTs)
→ reduction of γs from PMTs and outside and fast neutrons

gamma catcher (acrylic vessel, 22.3 m³ scint.)
→ conversion of γs leaving the target

target (acrylic vessel, 10.3 m³ scint. + 1 g/l Gd)
→ ν-target, fiducial volume
detector photo

inner veto

buffer

gamma catcher

target
DAQ and electronics

- **ID**: 390 PMTs (R7081MOD)
- **IV**: 78 PMTs (R1408)

**ν-DAQ**
- Custom trigger system
  - "energy trigger + multiplicity"
  - (RWTH Aachen)
- ν-FADC VX1721
  - 500 MHz
  - (CAEN & APC)
- HV supply
  - (SY1527LC&A1535P)
- Custom splitter
  - (CIEMAT)
- Custom Frontend Electronics
  - (Drexel U. & LLNL)

**v-DAQ**
- Controlled by MVME3100
  - (Emerson)
- Implemented in ADA

**TB**
- Custom trigger system
  - “energy trigger + multiplicity”
  - (RWTH Aachen)

**TMB**
- Trigger, common clock, event number & event pre-classification

+ Outer veto DAQ (independent but synchronized to vDAQ by trigger clock)

11.09.2012
Manuel Schumann
calibration of the discriminators
• 18 analog inputs for the triggerboard
  – > each has 2 discriminators
• 12 Bit (4096) for -1.2 V to +1.2 V
  \[0 \approx -1.2 \text{ V} \quad 2048 \approx 0.0 \text{ V} \quad 4096 \approx +1.2 \text{V}\]

• 1 sum signal
  – > four discriminators
  – 12 Bit resolution for event pre-categorisation
Voltage: -1.0 to -0.1 V
Steps: 100 mV
Shape: rectangle
frequency: 501 Hz
duration: 100 ns

set threshold (DAC)

count pulses in certain time (IRC)
Triggerboard 1 channel 1A voltage -0.6 mV

\[ f(DAC) = \frac{1}{2} \left( 1 + \text{erf} \left( \frac{DAC - \mu}{\sqrt{2}\sigma} \right) \right) \]
Triggerboard 1 channel 1A voltage -0.6 mV

$$DAC = \text{Slope} \times \text{Voltage} + \text{Base}$$
Voltage: -1.0 to -0.1 V
Steps: 100mV
Shape: rectangle
frequenz: 501 Hz
duration: 100ns

set threshold

count pulses in certain time
Triggerboard 1
channel SUM_A

\[ \chi^2 / \text{ndf} = 0.7839 / 8 \]
Slope: \( 0.08923 \pm 0.0004394 \)
Base: \( 2048 \pm 0.8788 \)
## Calibration

<table>
<thead>
<tr>
<th>Kanal</th>
<th>Slope A in DAC/mV</th>
<th>Base A in DAC</th>
<th>Slope B in DAC/mV</th>
<th>Base B in DAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,643 ± 0,010</td>
<td>2060 ± 3</td>
<td>1,645 ± 0,010</td>
<td>2043 ± 3</td>
</tr>
<tr>
<td>2</td>
<td>1,639 ± 0,010</td>
<td>2059 ± 3</td>
<td>1,641 ± 0,010</td>
<td>2054 ± 3</td>
</tr>
<tr>
<td>3</td>
<td>1,634 ± 0,010</td>
<td>2060 ± 3</td>
<td>1,641 ± 0,010</td>
<td>2048 ± 3</td>
</tr>
<tr>
<td>4</td>
<td>1,649 ± 0,010</td>
<td>2047 ± 3</td>
<td>1,651 ± 0,010</td>
<td>2045 ± 3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kanal</th>
<th>Slope in DAC/mV</th>
<th>Base in DAC</th>
<th>dynamischer Bereich in V</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUM_A</td>
<td>0,0892 ± 0,0004</td>
<td>2048 ± 1</td>
<td>−22,9 ± 0,1</td>
</tr>
<tr>
<td>SUM_B</td>
<td>0,0597 ± 0,0003</td>
<td>2048 ± 1</td>
<td>−34,3 ± 0,2</td>
</tr>
<tr>
<td>SUM_C</td>
<td>0,1815 ± 0,0009</td>
<td>2053 ± 2</td>
<td>−11,3 ± 0,1</td>
</tr>
<tr>
<td>SUM_D</td>
<td>0,1219 ± 0,0006</td>
<td>2052 ± 1</td>
<td>−16,8 ± 0,1</td>
</tr>
</tbody>
</table>
increase FIFO size
increase FIFO size

motivation:

- comparing eventnumber from FADC and Triggerboard
- FIFO in TB/TMB can store up to 128 events
- if more than 128 trigger in 6ms => “ROP4 crash/error”
- 2 “ROP4 crash/error” per day => loosing data
- with new firmware 256 Events

method:

- rough read out speed: 150 Hz => 6,7 ms
- count number of triggers in 6,7 ms
- estimate rate above 128 events
quality check

look for trigger within 6ms after each trigger
Trigger in 6,7 ms

Look for trigger in 6,7 ms slices

\[
f(x) = \exp(c_1 + s_1 \times x) + \exp(c_2 + s_2 \times x)
\]

\[
P(n > 128) = \frac{1}{N_{128}} \int_{128}^{\infty} f(x)dx
\]
more runs + sum of all

sum of all runs ≈ 25 days
more runs + sum of all

1.4 error/day

6.4 error/day

sum of all runs ≈ 25 days

0.9 error/day

1.3 error/day
more runs + sum of all

1.4 error/day

6.4 error/day

old FIFO: 2 errors/day

new FIFO: 0.047 error/day

=> 1 error in 21 days

0.9 error/day

1.3 error/day
Afterpulses from the Double Chooz Photomultiplier
Hamamatsu R7081MOD
afterpulses

ionization of remnant gas:

- ion accelerates back to cathode
- produces more electrons
- these electrons give additional pulses

- proportional to number of primary photo-electrons
goal: verification of afterpulse measurements performed during PMT calibration in Heidelberg

original hardware from the experiment

2 methods:
- SPE signals from LED
- dark noise signals
LED intensity 10%: every 10\textsuperscript{th} trigger leads to a signal => single photo-electron (SPE) signals
time stability

first pulse after trigger signal
- signal > noise
- resolution

software triggered

1. PMT signal
2. PMT signal
3. PMT signal
x PMT signal

time

histogram

$\text{t}_0$
first pulse after trigger signal

- signal > noise ✔
- resolution $\sigma_t \approx 32 \text{ ns}$ ✔
- intensity below 10% ✔

software trigger
1. PMT signal
2. PMT signal
3. PMT signal $\times$ PMT signal

$t_0$ $t$ histogram
LED afterpulse

1. PMT signal
2. PMT signal
3. PMT signal
x PMT signal

trigger

1. PMT signal
2. PMT signal
3. PMT signal
x PMT signal

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LED afterpulse

afterpulse

1. PMT signal
2. PMT signal
3. PMT signal
x PMT signal

trigger

!=432-624ns
to

time

histogram

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PMT calibration at Heidelberg: average over 400 PMTs
→ Measurements consistent!

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dark noise afterpulse
dark noise

expectation:
random poisson process
=> exponential decay
+ afterpulses
dark noise

- expectation poisson dark noise
- afterpulse created by dark noise
- additional, non poissonian, correlated noise
- same distribution measured at Heidelberg
• calibration for Triggerboard 1,5,6 is done for installation and commissioning of the near-detektor

• increase of FIFO size will help significantly

• Afterpulse measurements from Aachen and measurements from Heidelberg consistent
• dark noise measurements show:
  1) same time pattern of afterpulses
  2) additional correlated noise
thanks for your attention
triggermasterboard