Annual Modulation of the Muon Flux in the GERDA Experiment

A. Schütz, K. Freund, P. Grabmayr, J. Jochum, C. Schmitt

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Annual Modulation of the Muon Flux

The μ-flux shows a 3-4% summer-winter modulation.

artificial:
CNGS beam
- 2% effect
- high intensity ν_μ - beam
- $\nu_\mu + u \rightarrow \mu^- + d$
- in upstream rock

natural:
ΔT of the atmosphere
- 1.5% effect
- change in mean free path of primaries
- change in secondary spectrum

But: no effect on germanium data.

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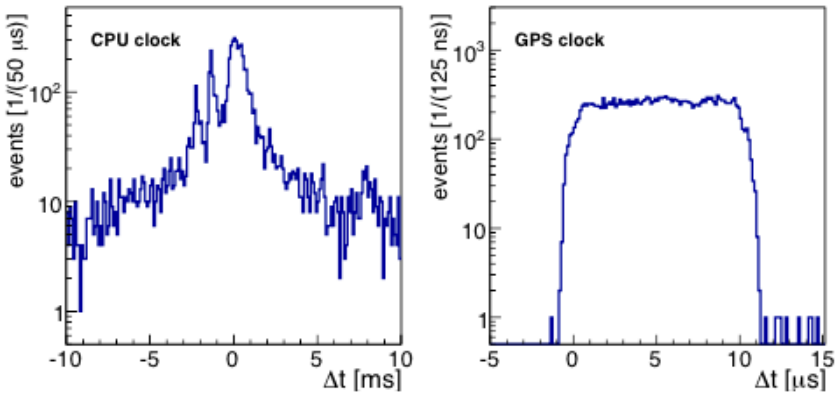
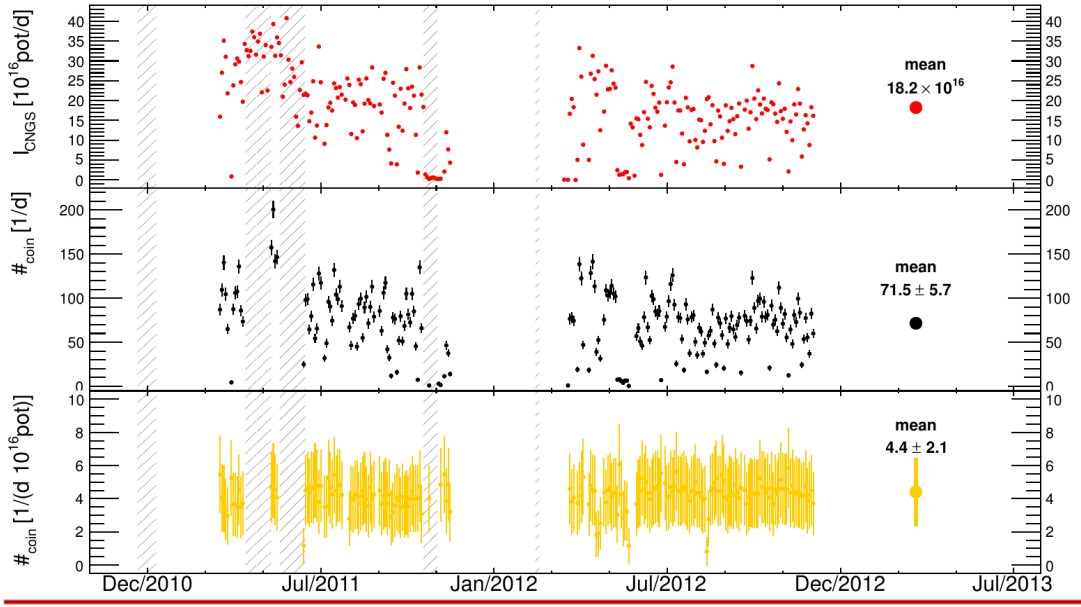
CNGS Events over Time

- two bunch extr., 50 ms apart
- 10.5 µs width/bunch
- 6 s repetition
- 2.4 µs TOF to LNGS
- r_{cngs} = (0.114 ± 0.006)/s
- clock update Nov. 2011 (internal CPU → GPS clk)
- jumps in CPU clk @ -1.2 s





- 2011 most “luminous“ year
- large changes in beam intensity
- coin. events follow same pattern
- ratio is flat: correlation
- grey hatched areas: DAQ-pauses
- correct for CNGS events

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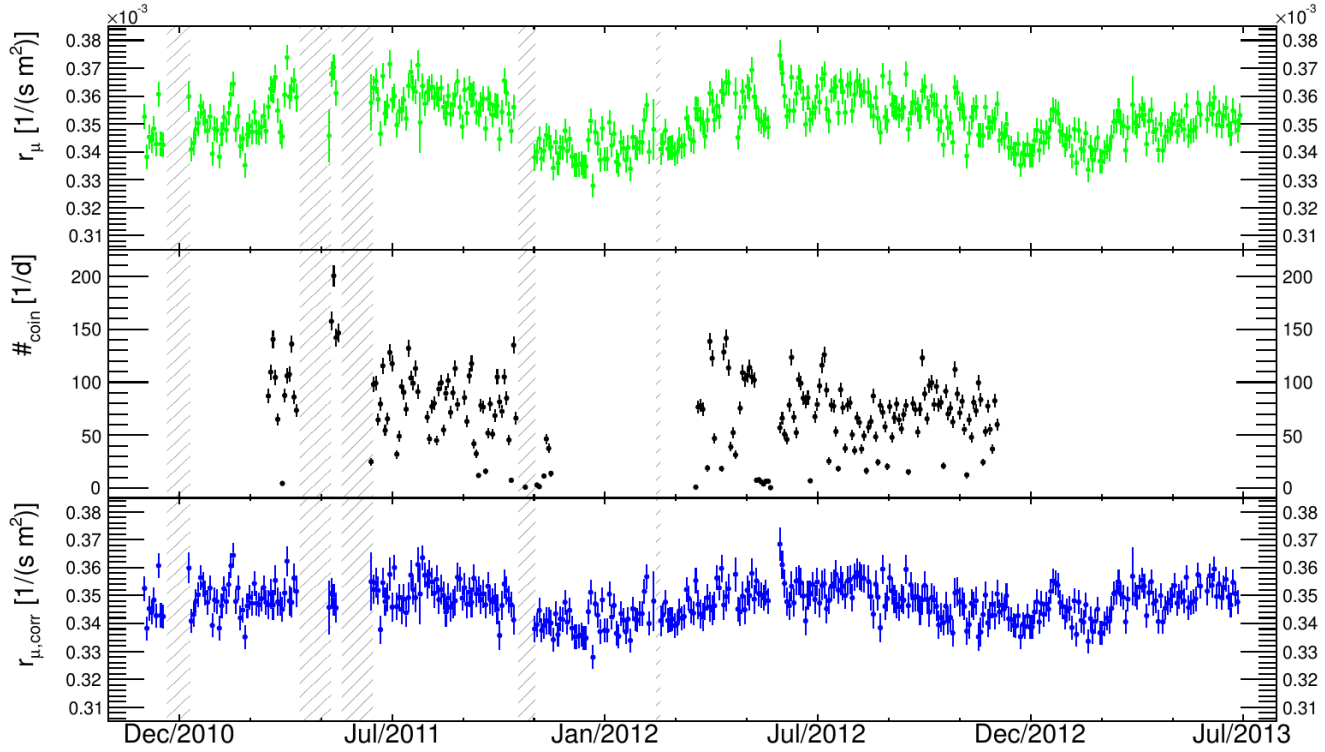
CNGS Event Correction

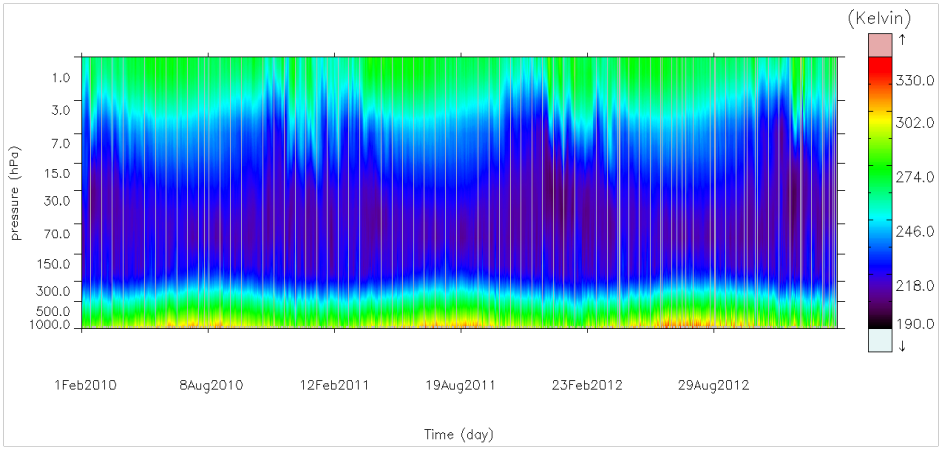


- $r_{\mu,d} \approx 3100/d$, $r_{\mu,s} \approx 3.6 \cdot 10^{-2}/s$
- most used: $r_{\mu} \approx 3.48 \cdot 10^{-4}/(s\ m^2)$
- norm. on effective detector area

- correction evens out rate
- pure natural modulation remains
- consistent with other exp. @ LNGS

Atmospheric Effect on the Muon Flux

- $p + p \rightarrow K, \pi \rightarrow \mu$
- E_μ depends on temperature T
- $\langle E_\mu \rangle \sim \langle E_{K,\pi} \rangle \sim \langle \ell_{K,\pi} \rangle \sim \langle T \rangle = T_{eff}$
- rock overburden acts as E_{thr}
- cutoff for shifting spectrum
- climate data from ECMWF & NASA AIRS



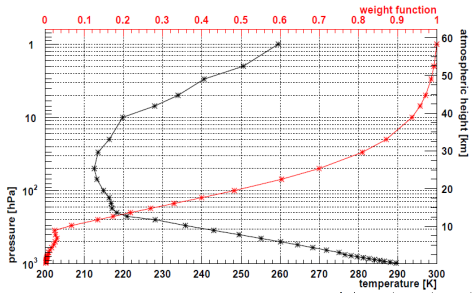
flux approximation: $I_\mu(t) = I_\mu^0 + \Delta I_\mu \cos(2\pi/T \cdot (t-t_0))$

weight function W gives relative muon production per atmospheric level P

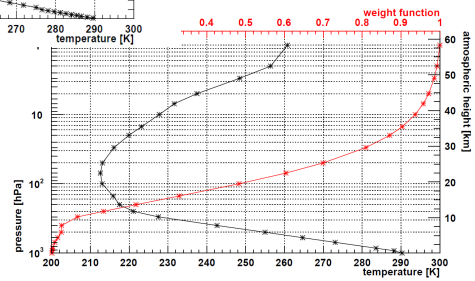
define:

$$T_{\text{eff}} = \frac{\int_0^\infty \Delta P T(P) W(P)}{\int_0^\infty \Delta P W(P)}$$

weight W(P) ~ E_{thr}, $\cos\theta$, $\Lambda_{n,K,\pi}$, $r_{K/\pi}$, [...]

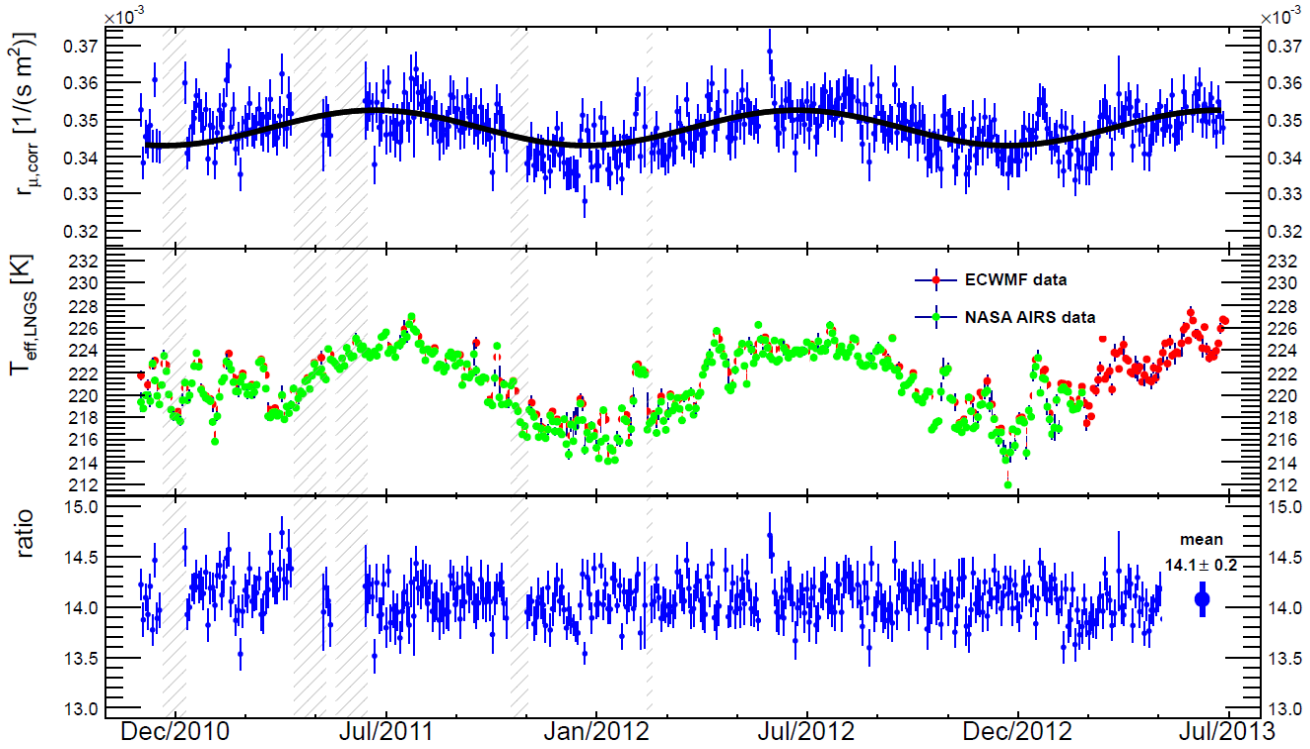


ECMWF



NASA AIRS

Muon Rate and T_{eff}

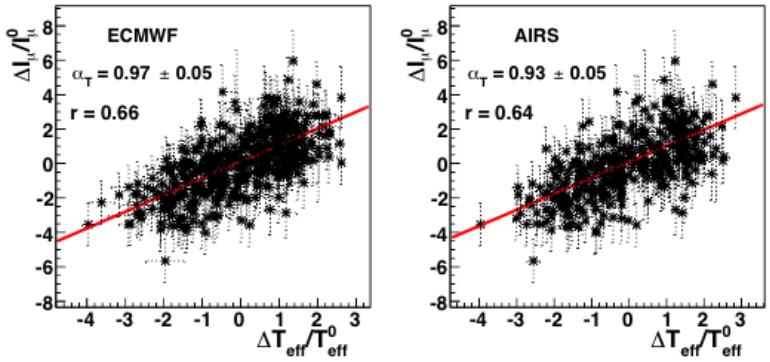


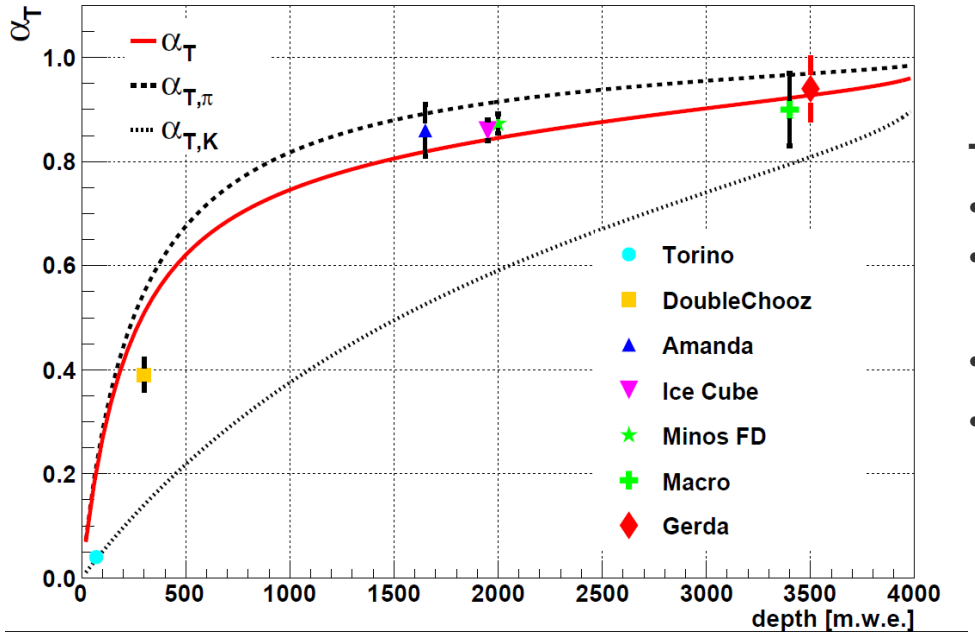
- fit to the muon rate:
- $I_\mu^0 = (3.48 \pm 0.06) \times 10^{-4}/(m^2\ s)$
- $\Delta I_\mu = (1.4 \pm 0.1)$ %
- $t_0 = (10^{th} \pm 4)$ July, T =1 yr
- flat ratio: good correlation
- DAMA maximum in June

Correlation between Muon Rate and T_{eff}

Correlation of ΔI_μ and ΔT_{eff}

- $\Delta I_\mu / I_\mu^0 = \alpha_T \cdot \Delta T_{eff} / T_{eff}^0$
- correlation coeff. r = 0.66, 0.64
- strong positive correlation





Test of model:

- change laboratory, i.e. [m.w.e.]
- assume purely pionic/ kaonic μ production processes
- mix with lit. value $r_{K/\pi}$ = 0.149
- α_T model in good T_{eff} agreement with all other experiments

Correlation between Muon Rate and T_{eff}

experiment	LVD	MACRO	BOREXINO	GERDA
site	LNGS-A	LNGS-B	LNGS-C	LNGS-A
duty cycle [y]	8	7	4	2.5
active years	2001-08	1991-97	2007-11	2010-13
E_{thr} [TeV]	1.833 / 3.4	1.833 / 3.4	1.833 / 3.4	1.833 / 3.4
rate [μ/(s m^2)]	3.31 ± 0.03	3.22 ± 0.08	3.41 ± 0.01	3.47 ± 0.06
period [d]	367 ± 15	–	366 ± 3	–
phase [d]	185 ± 15	–	179 ± 6	191 ± 4
temp. data	Aer.Mil.	Aer.Mil.	ECWMF	ECWMF/AIRS
T_{eff} model	π	π	π+K	π+K
correlation	0.53	0.91	0.62	0.62/0.65
α_T	–	0.91 ± 0.07	0.93 ± 0.04	0.97 ± 0.05
($\alpha_{T,\mathrm{LNGS}} = 0.92$)				0.93 ± 0.05

Conclusion and Outlook

- there are two causes for the modulation of the muon rate:
  - CNGS beam
  - atmospheric temperature change
- with a CNGS data set, this influence was corrected
- the temperature effect was measured with high precision
- the muon veto works well enough to disentangle these two effect with a total contribution of 3-4%
- consistent with other experiments @ LNGS

- present status: the muon veto is working

Sources

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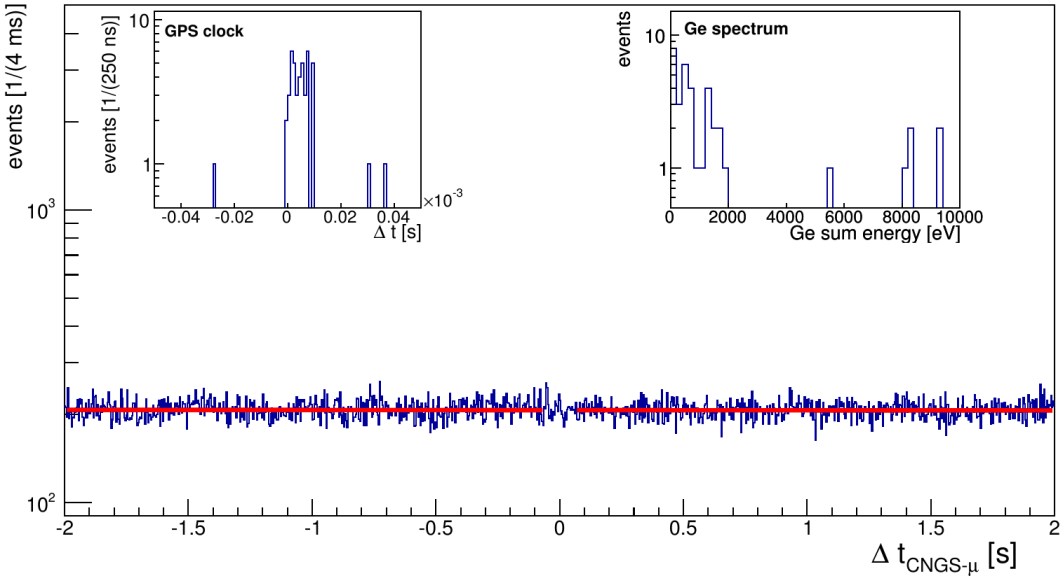
CNGS Muons @ GERDA ^{enr}Ge

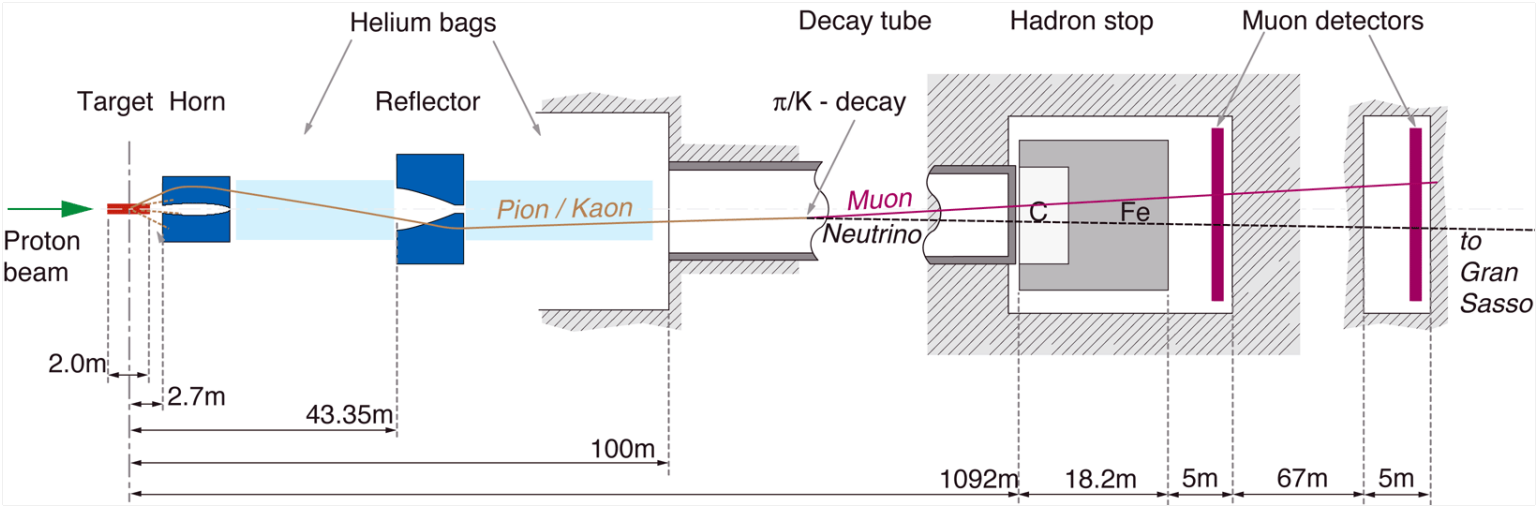


@ GERDA Ge-DAQ

- no structure: small target
- flat random background
- good time res. allows tagging

- 45 events in 100 μs window
- 6 without veto, rand. events: (4.9 ± 2.2)
- 3 events outside peak are random coin.
- ROI event @ 1943 keV in one det. (vetoed)

CNGS @ CERN



404 days of common operation with μ-DATQ

operation parameters:

- operation 2008-2009
- April - December
- ≈ 4 x 10^{19} POT/yr
- earth's curvature: 3.5° beam incl.
- 5.85 x 10^{-17}CC ev./(POT kt)
- ≈ 1.2 μ/(d m^2) expected