Determination of the gravitational constant

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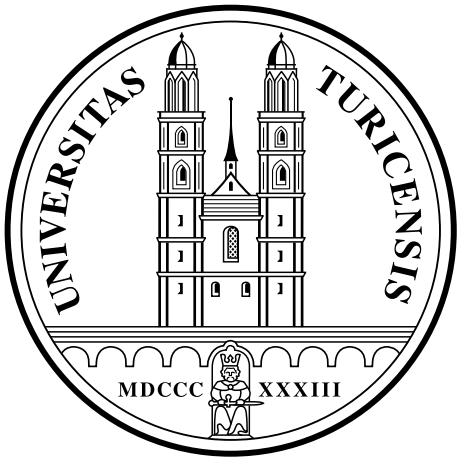
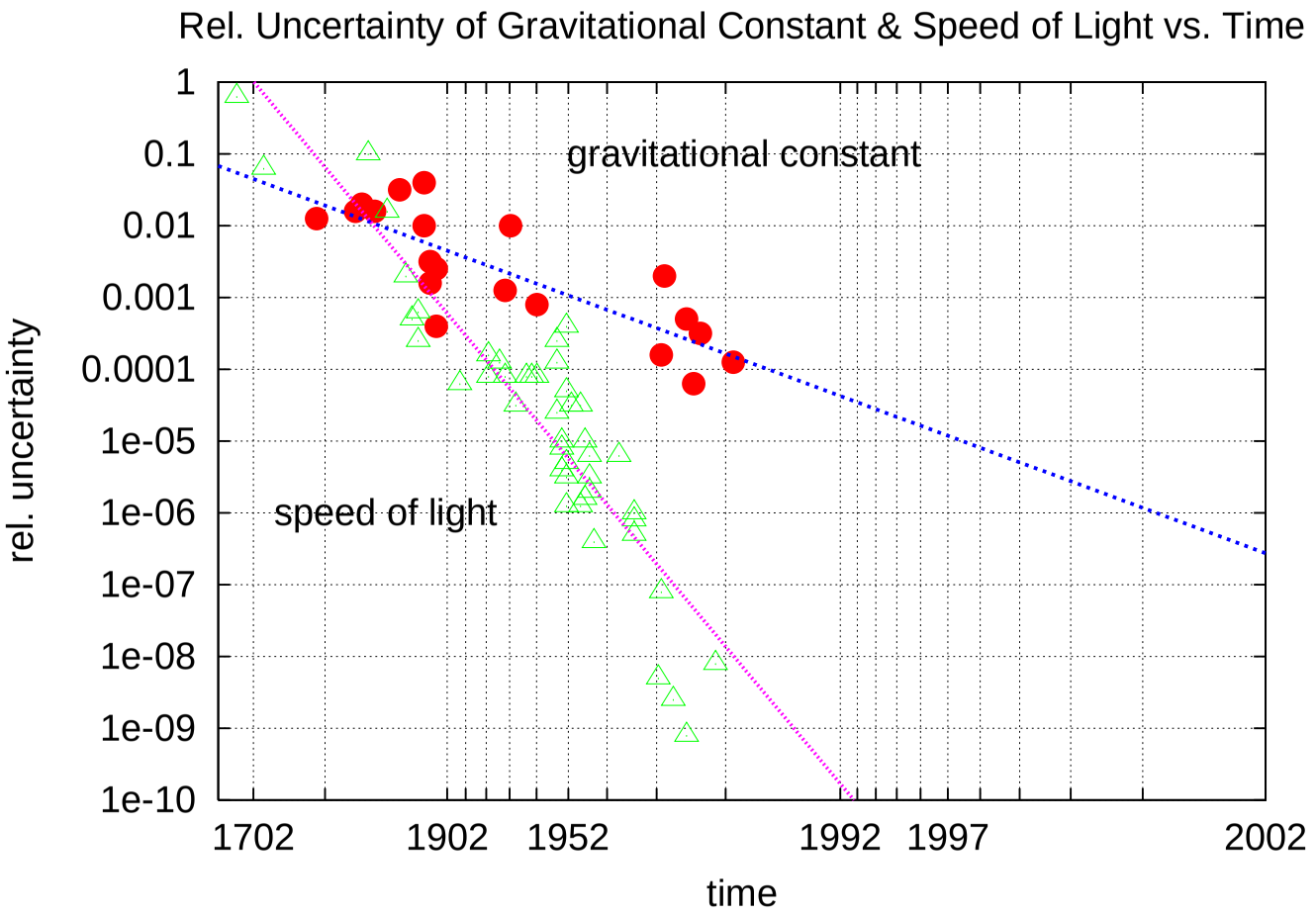


Motivation -I-



Motivation -II-

CODATA Recommended Values of the Fundamental Physical Constants: 1998

Peter J. Mohr and Barry N. Taylor

National Institute of standards and Technology, Gaithersburg

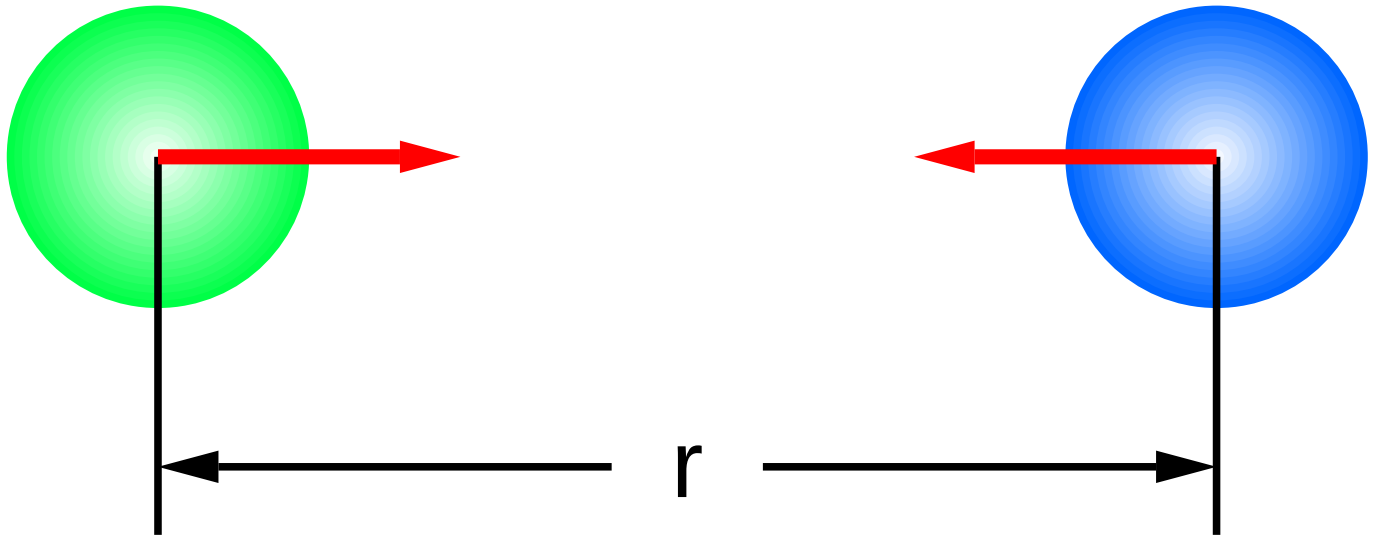
Rev. Mod. Phys. **72**, 351 (2000).

$$G = 6.673(10) \times 10^{-11}\ \mathrm{m^3 kg^{-1} s^{-2}}$$

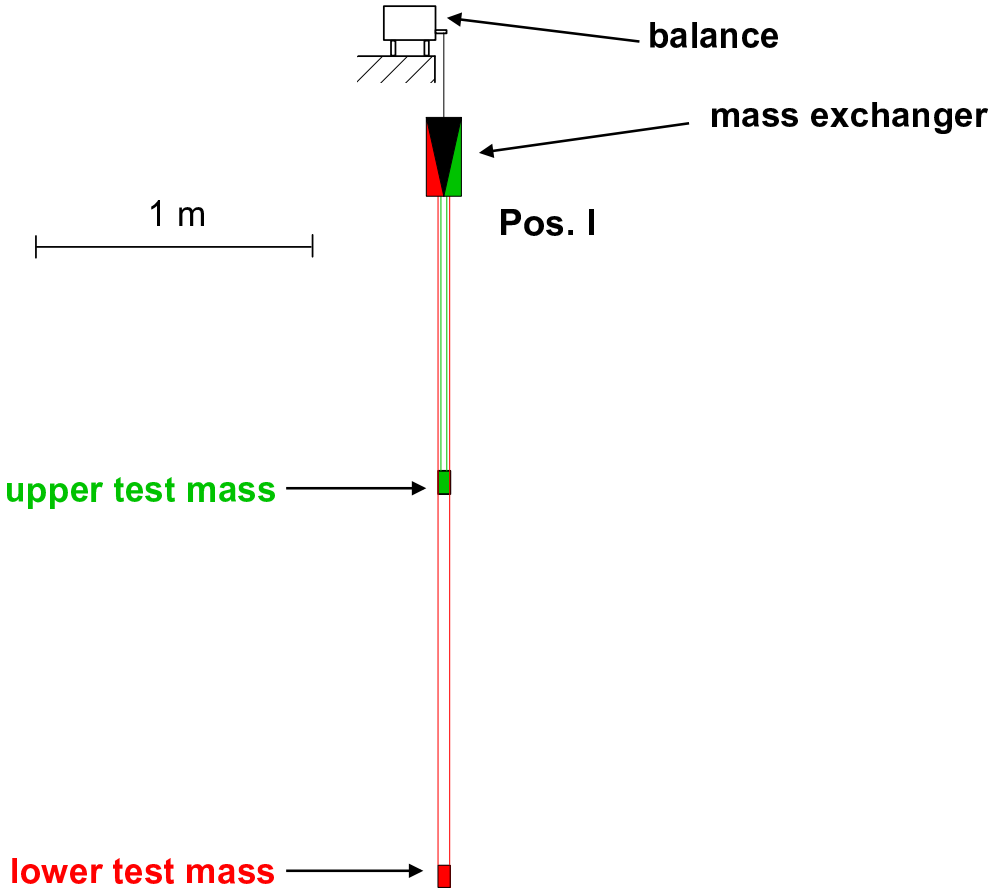
rel. uncertainty $= 1.5 \times 10^{-3}$

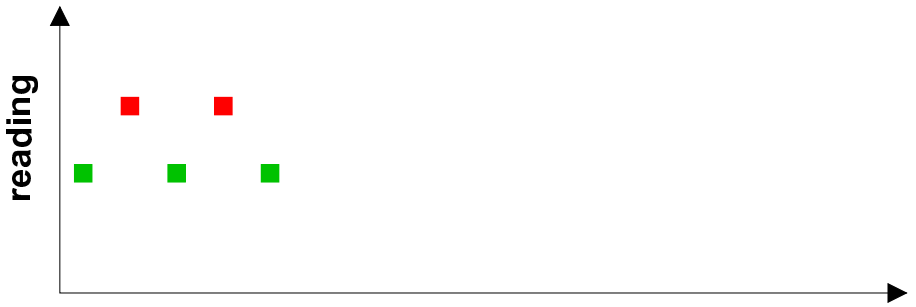
Subject of the Talk

$$F = G \frac{m_1 m_2}{r^2}$$

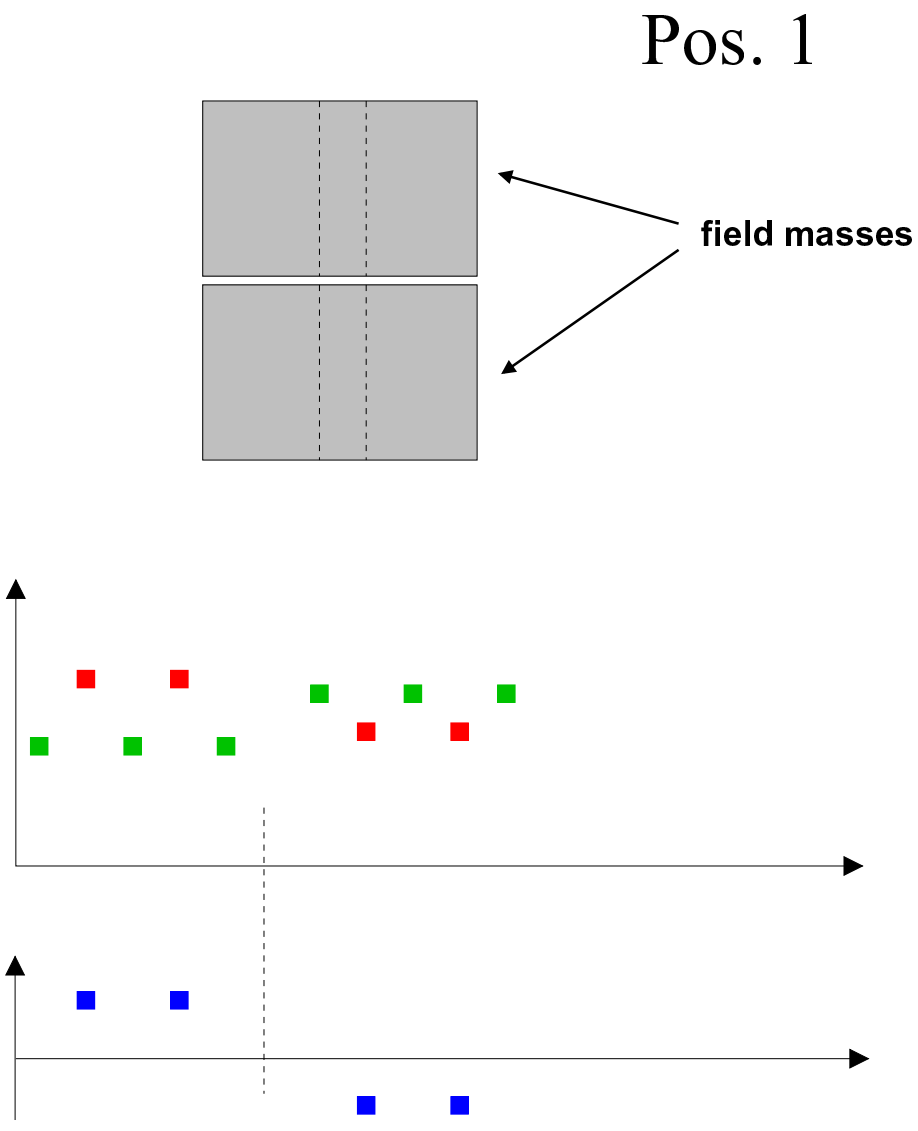


The Principle of our Experiment

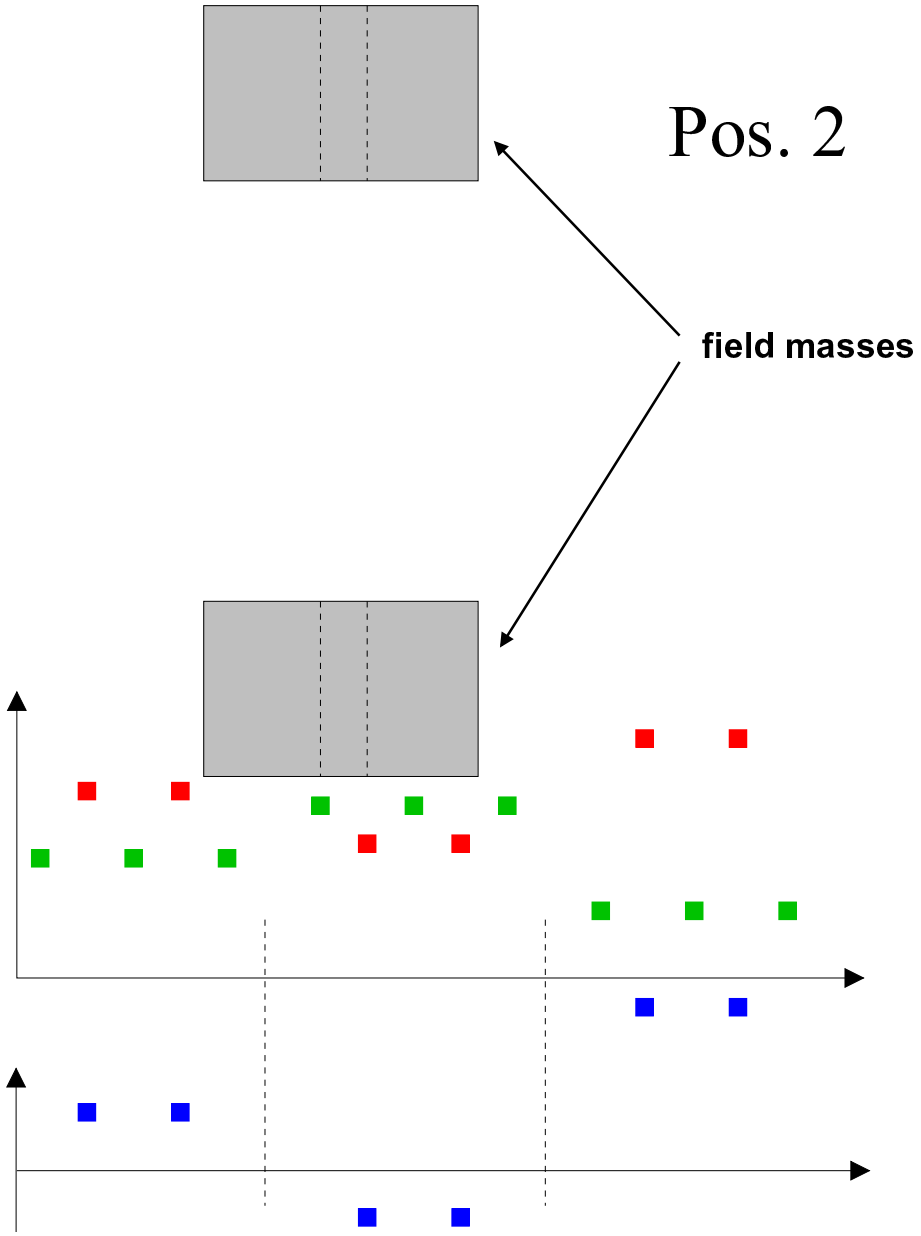




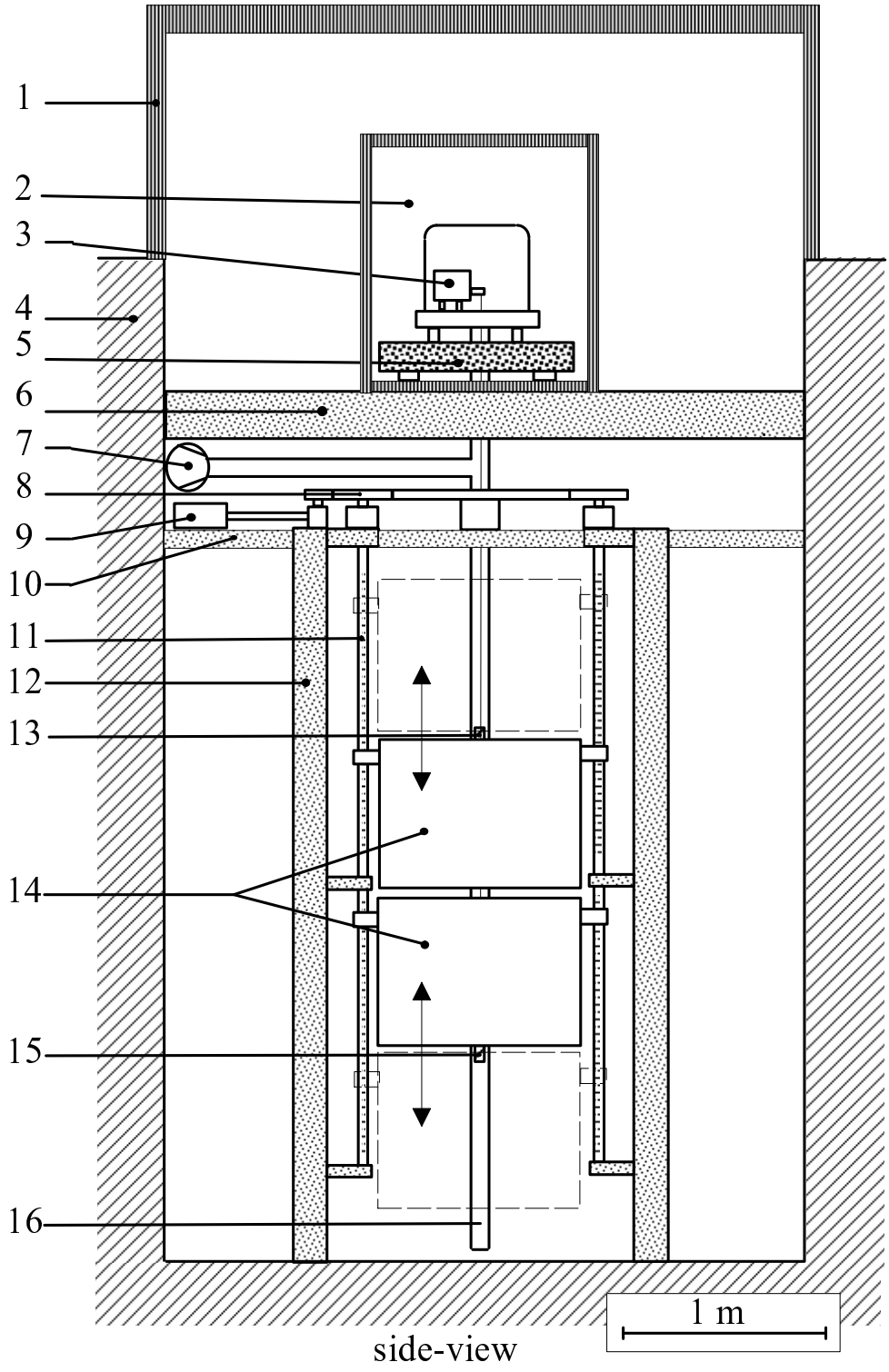
The Principle of our Experiment



The Principle of our Experiment

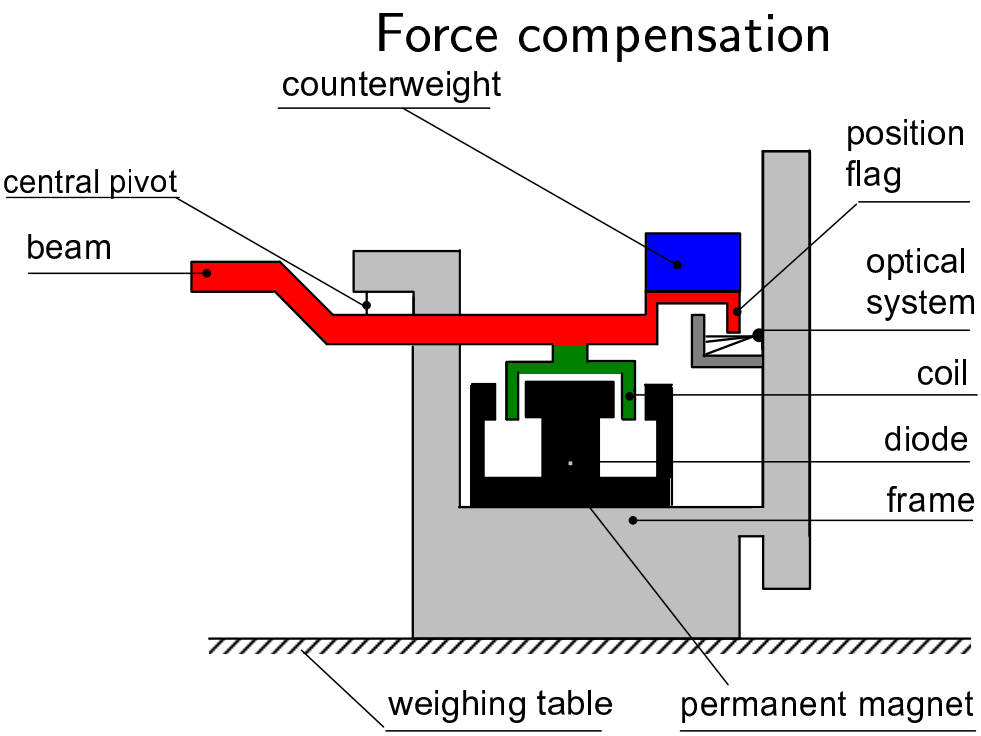


Side View of the complete Apparatus

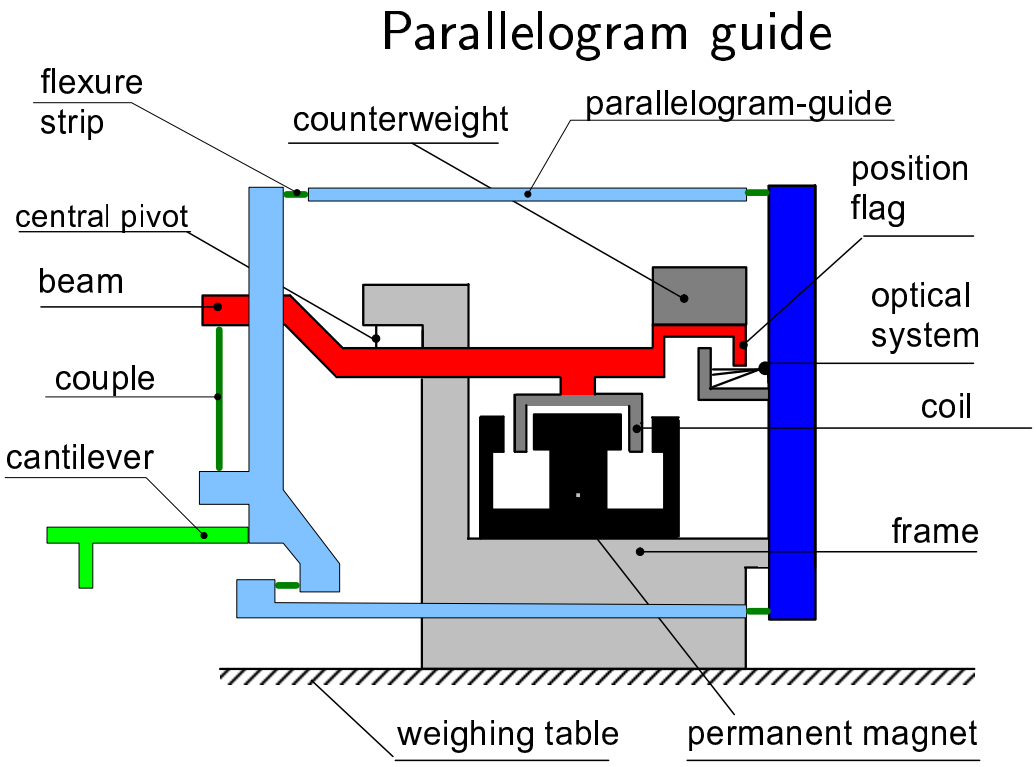


The Balance -I-

Modified AT 1006 Comparator of Mettler Toledo



The Balance -II-



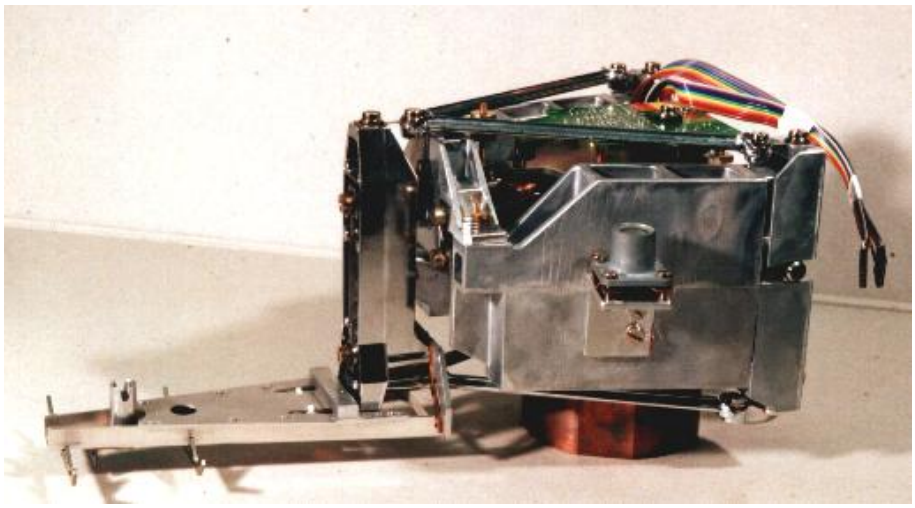
The Balance -III-

(modified Mettler Toledo AT 1006)

- Technical Datas:

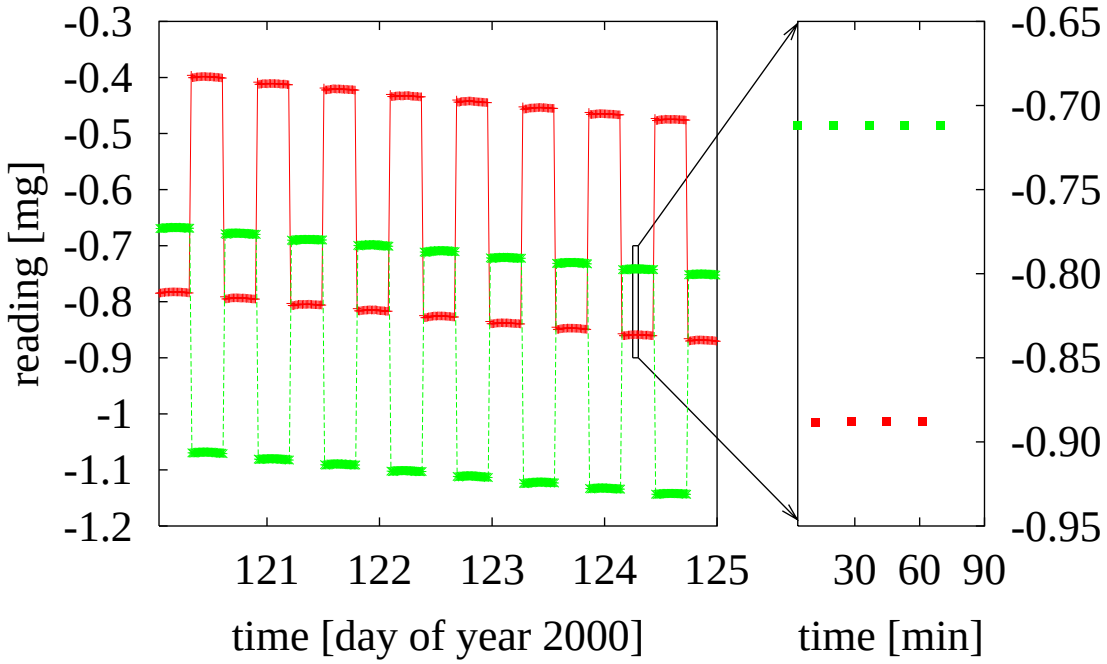
Measuring Range	1000 g to 1004 g
Resolution	12.5 ng
Reproducibility	200 ng

- Advantages to use a balance:
  - Precise force sensor, (not torque)
  - Easy calibration
  - Beam remains at the same position

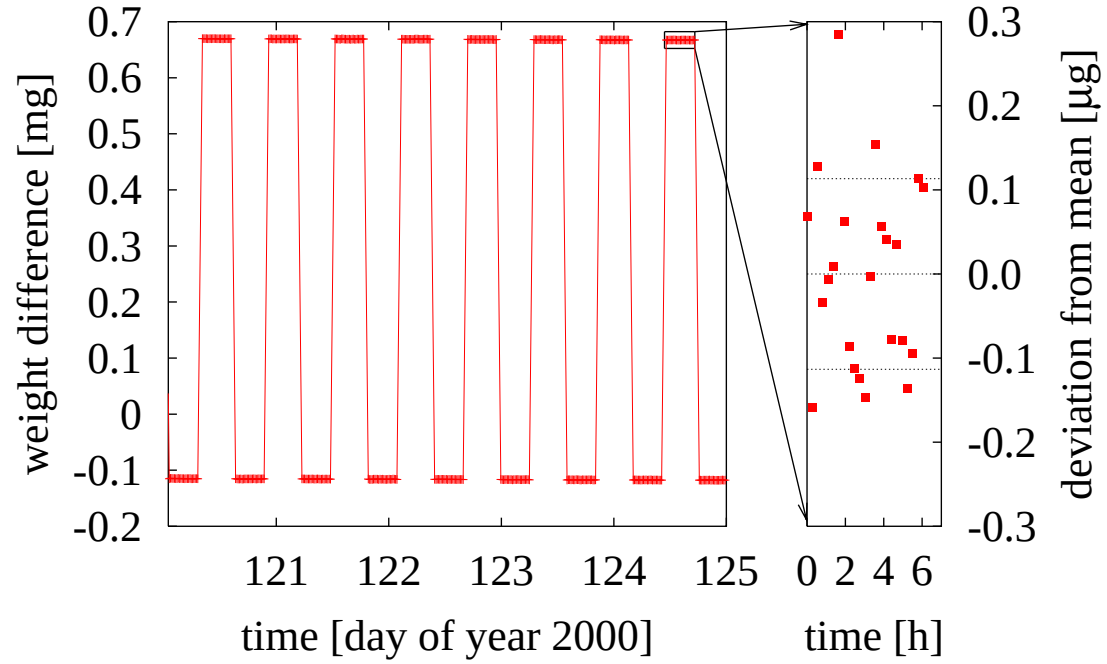


Measurements

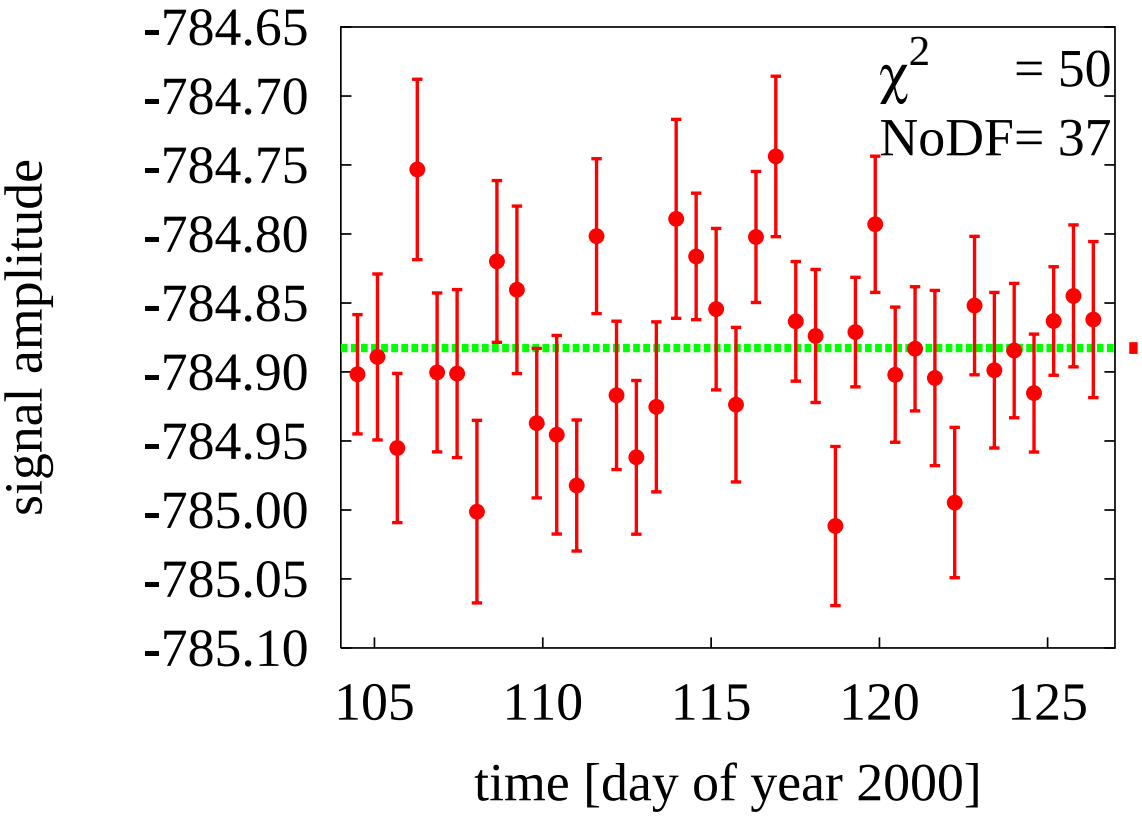
Reading of the Balance



First Difference =: Signal



Amplitude of the Signal



Error of the Mean: $8.9\,\text{ng}$ $(= 11\,\text{ppm})$

Resulate

water	$(6.6754$	$\pm$	0.0005	$\pm$	$0.0014)$	$\times 10^{-11} \frac{m^3}{kgs^2}$
mercury	$(6.6749$	$\pm$		$\pm$	$0.0014)$	$\times 10^{-11} \frac{m^3}{kgs^2}$

Systematic Uncertainties

Source of Uncertainty		Water $\Delta G/G$ [ppm]	Mercury $\Delta G/G$ [ppm]
test masses	position	11	10
	dimension	2.7	2.0
	density inhomogeneity	≤ 1	≤ 2.2
	mass	0.27	0.27
tanks	joints and spindel drive	16	2.2
	shape and volume	14	2
	dimensions	11	1.6
	density inhomogeneity	$\leq$ 5	$\leq$ 0.06
	masses	4	0.5
	air displacement	7	2
liquid	density of the liquid	15	18
	mass of the liquid	8	0.7
others	nonlinearity of the balance	$\leq$ 200	$\leq$ 200
	systematic variation	-	80
	sorption effect	45	6.4
	integration	$\leq$ 13	$\leq$ 5
	tilt effect	$\leq$ 18	$\leq$ 4
	calibration	5	8
	local gravity	0.06	0.06
total		209	217

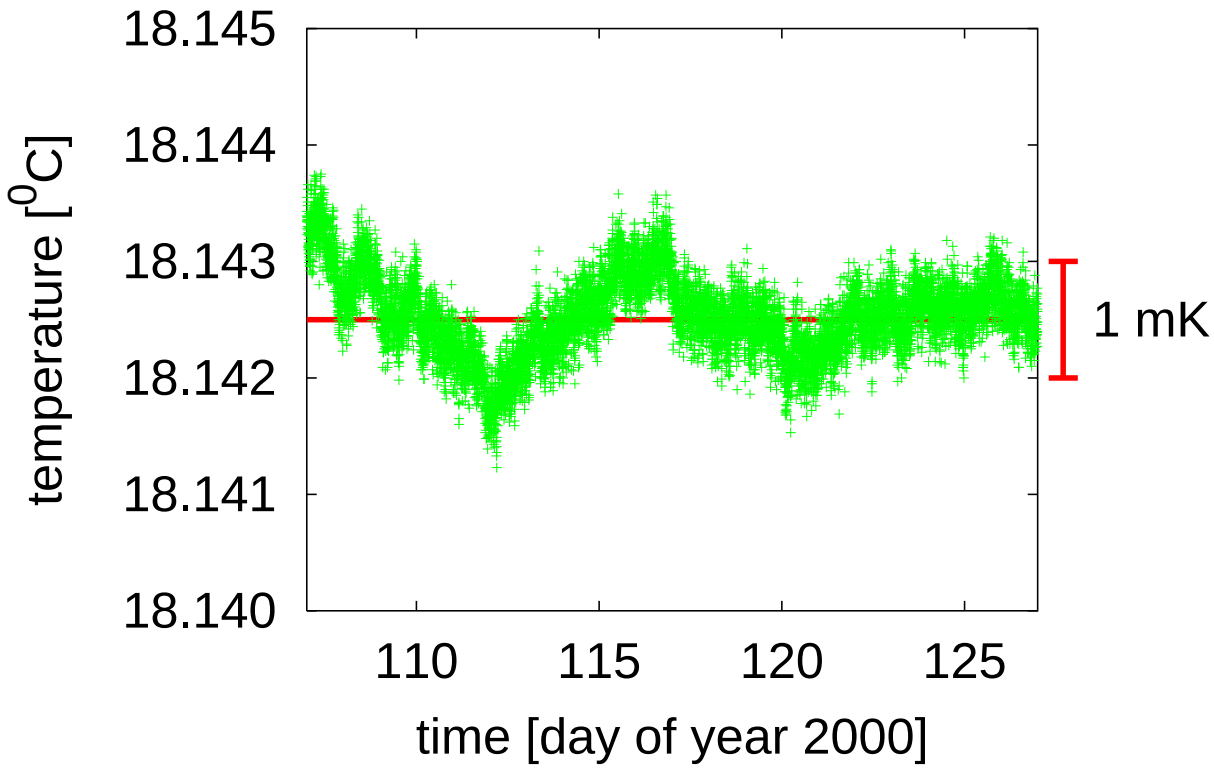
Improvements -I-

- Modification of the balance

Measuring range	:	1.7 g
Resolution	:	12.5 ng
Reproducibility	:	200 ng (old)

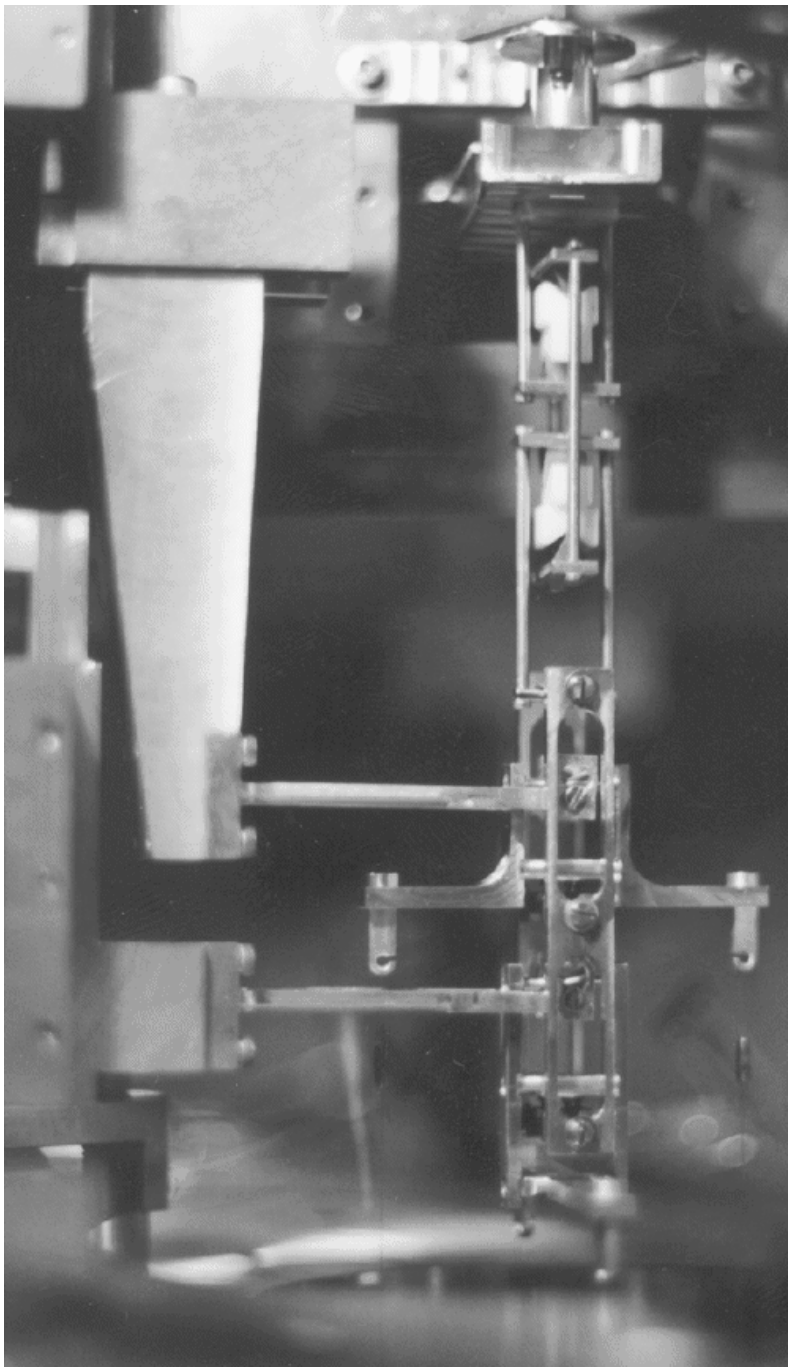
- Improved test mass suspension

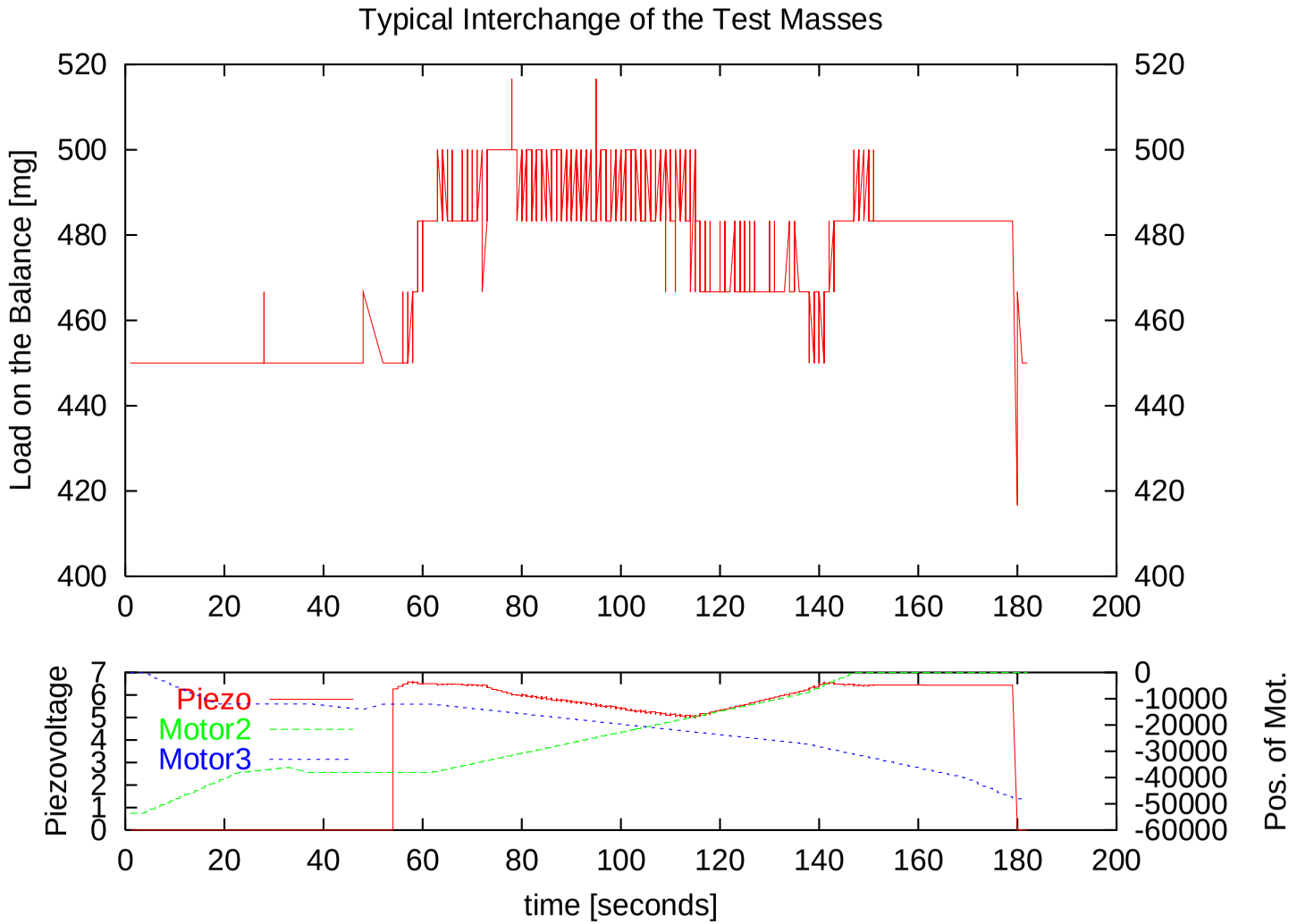
- Active temperature stabilization



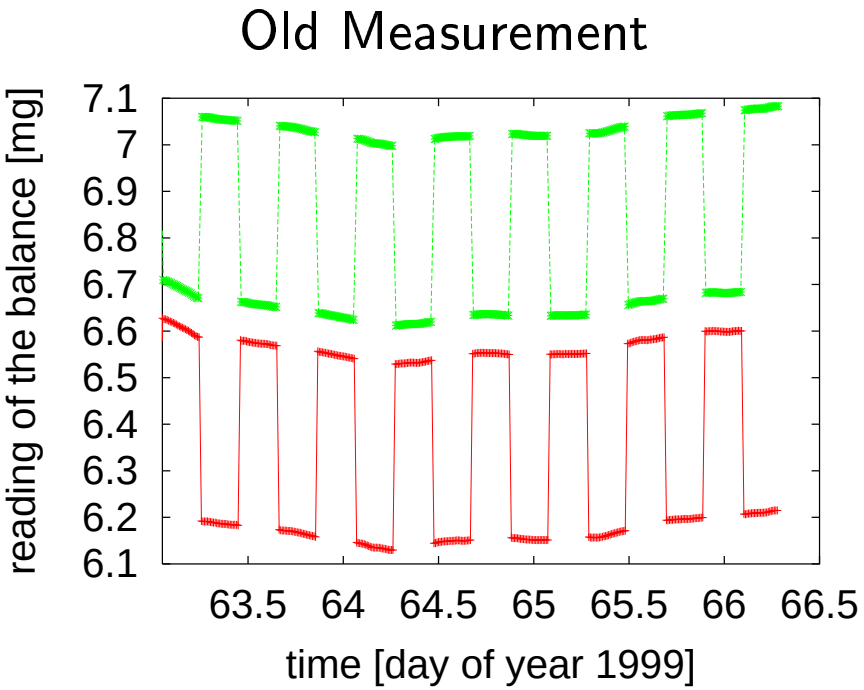
Improvements -II-

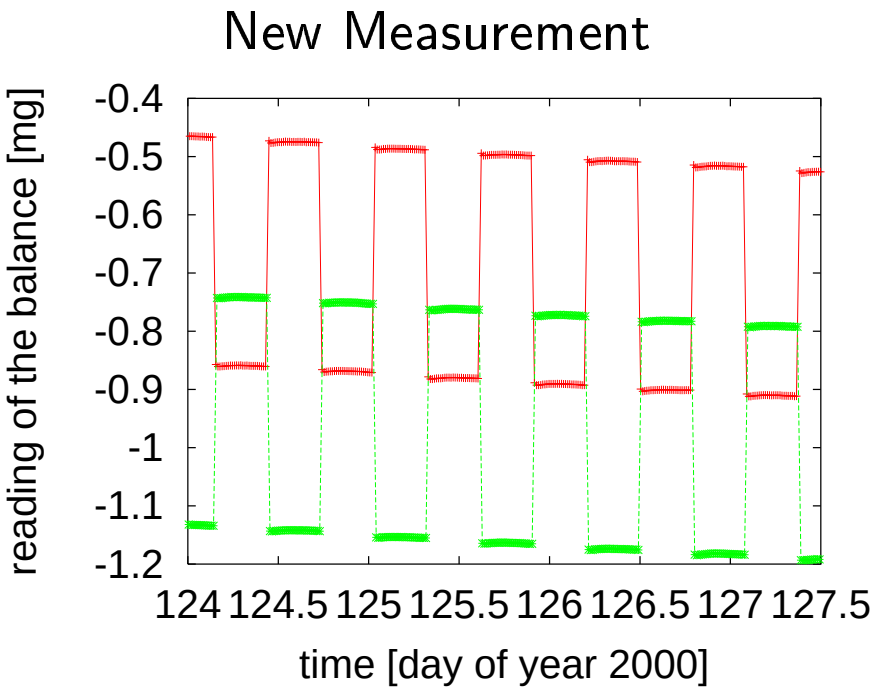
- Improved test mass suspension



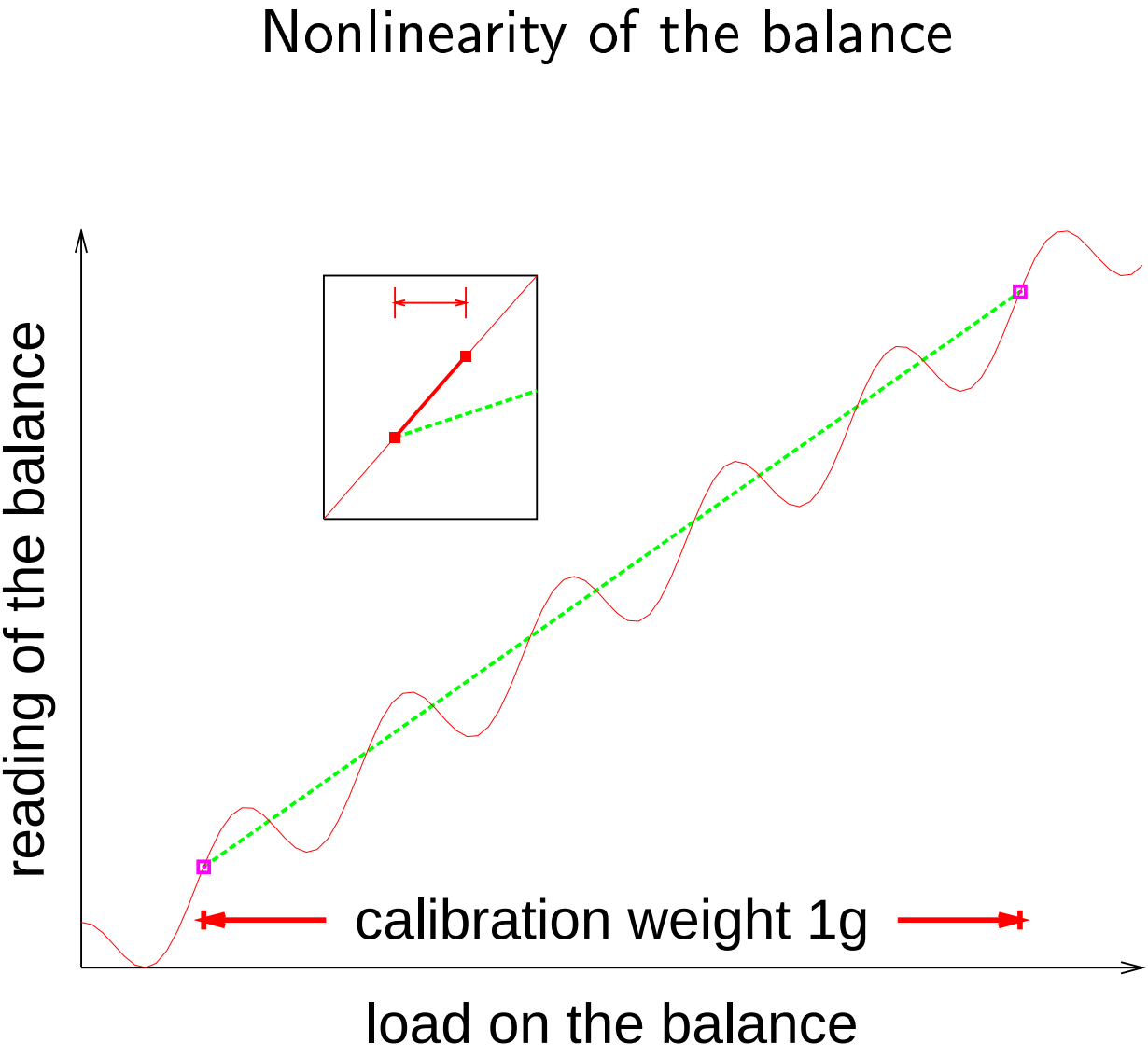

Typical Interchange of the Test Masses
Load on the Balance [mg]
520
500
480
460
440
420
400
0
20
40
60
80
100
120
140
160
180
200
Piezovoltage
Pos. of Mot.
Piezo
Motor2
Motor3
0
-10000
-20000
-30000
-40000
-50000
-60000
time [seconds]

Old Measurement vs New Measurement



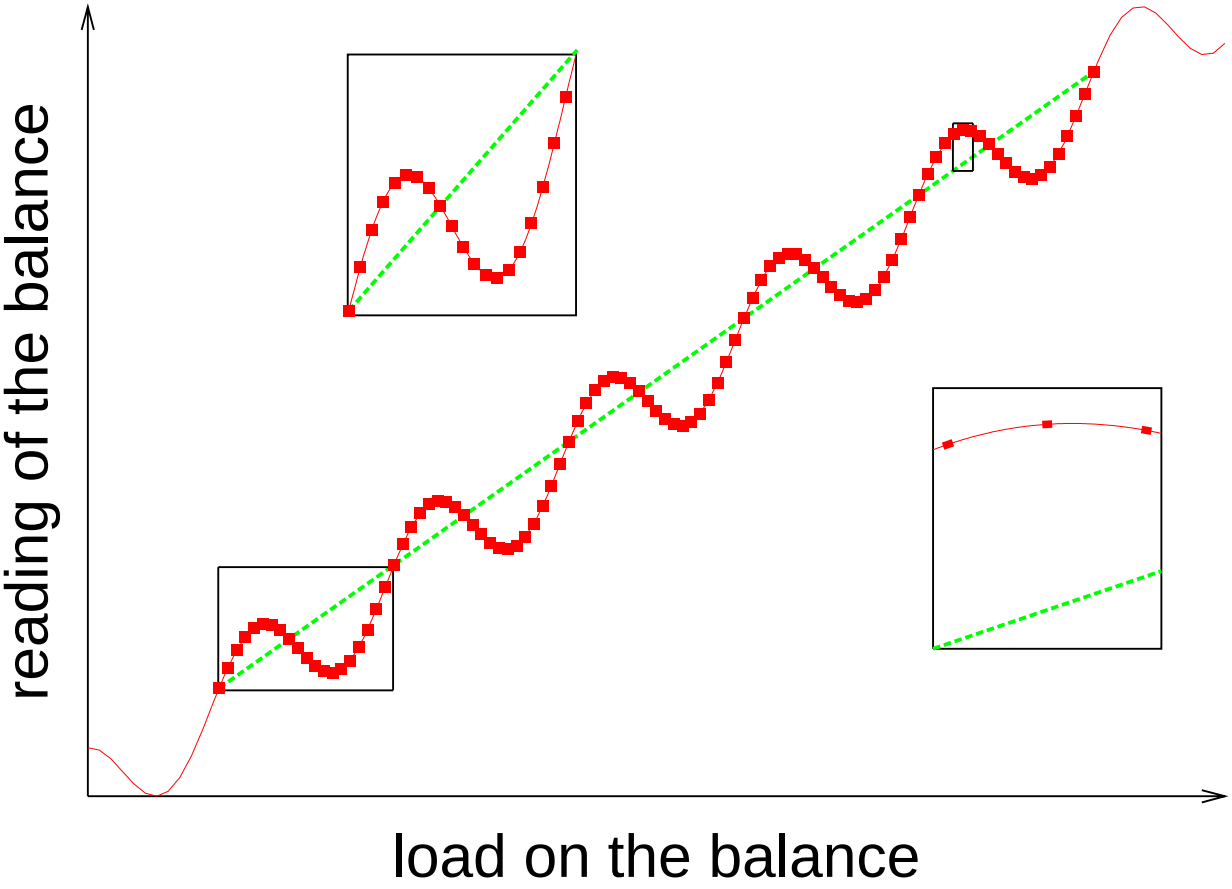


Nonlinearity - Scheme of the Problem

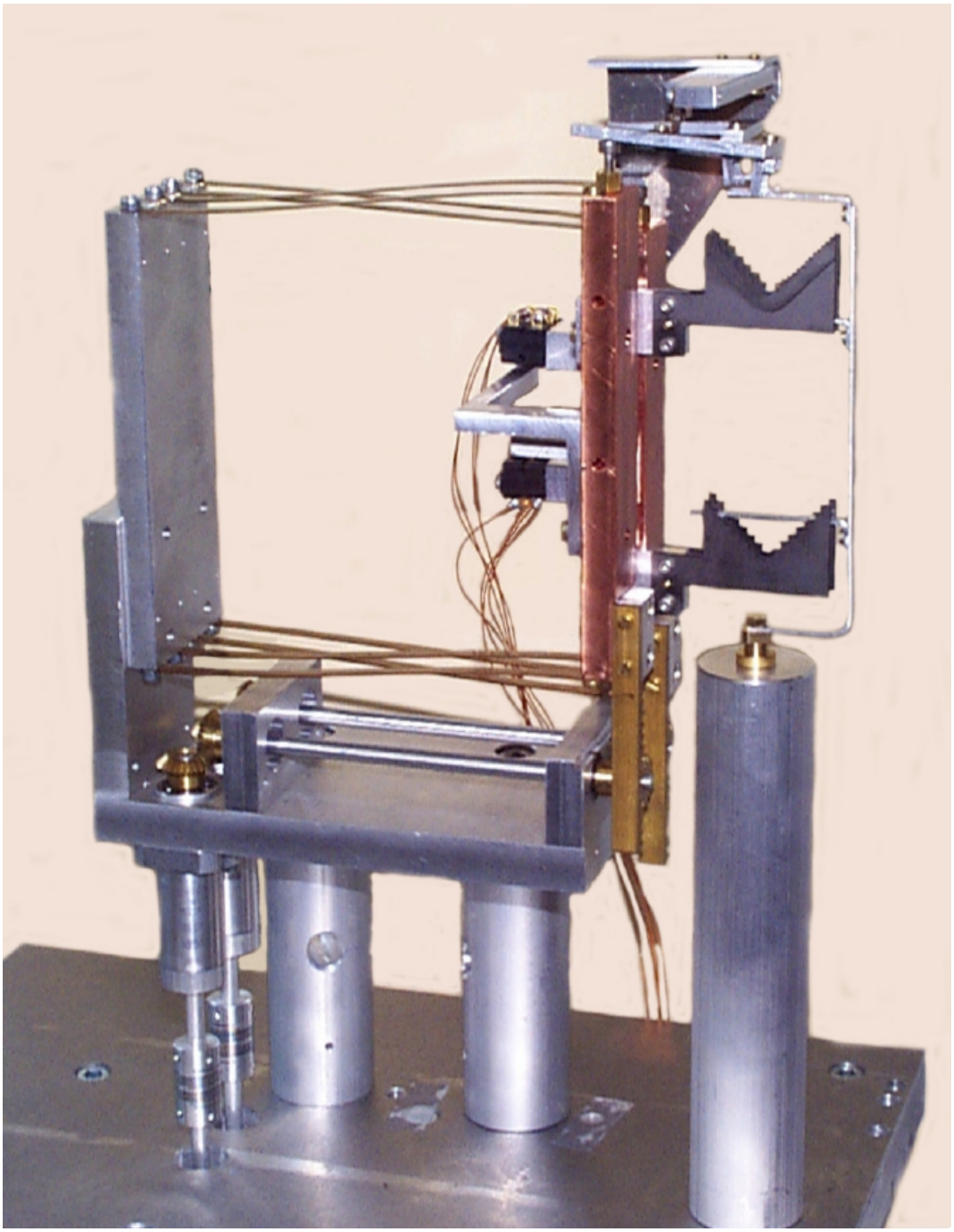


Nonlinearity - Scheme of the Solution

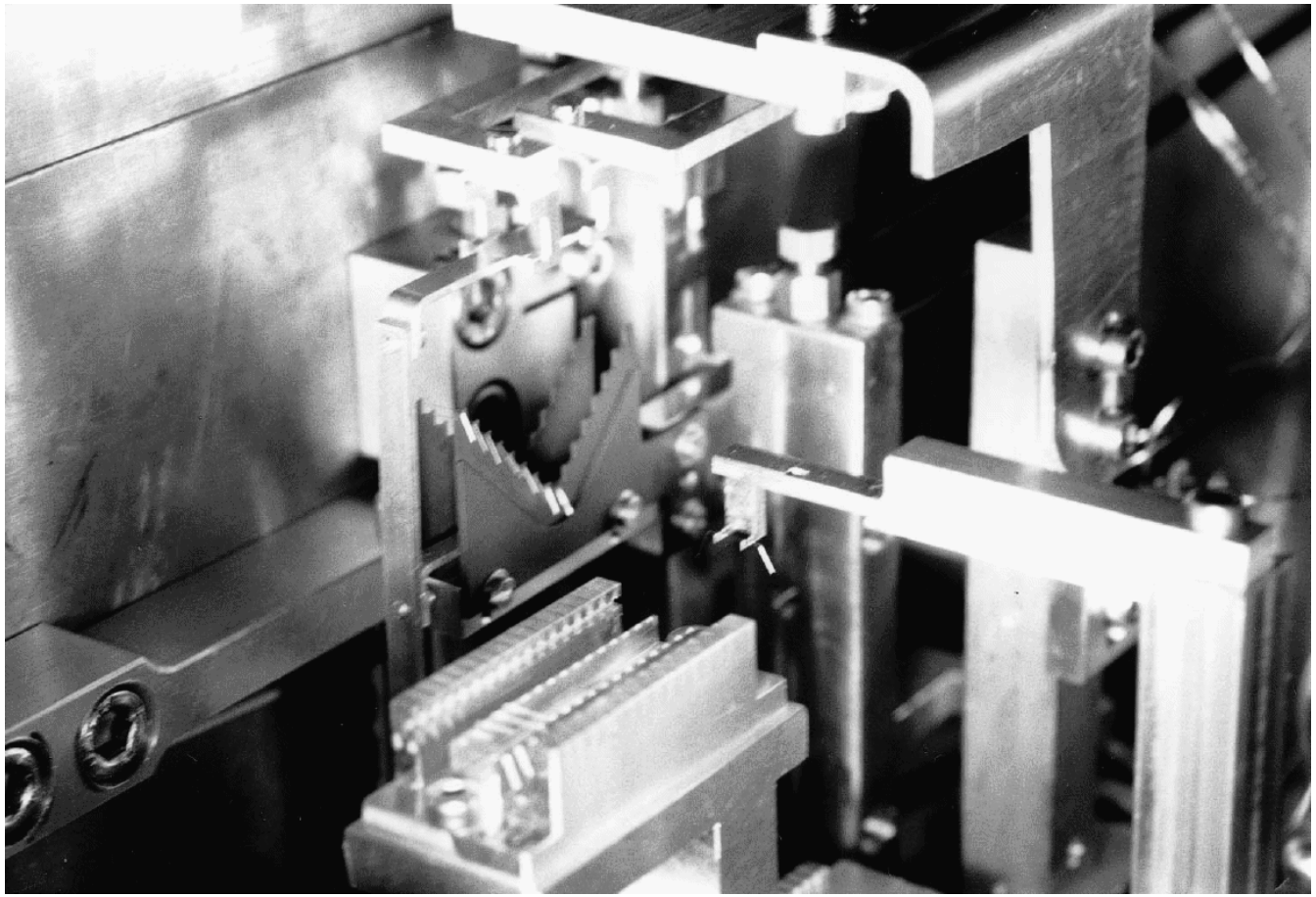
Solution



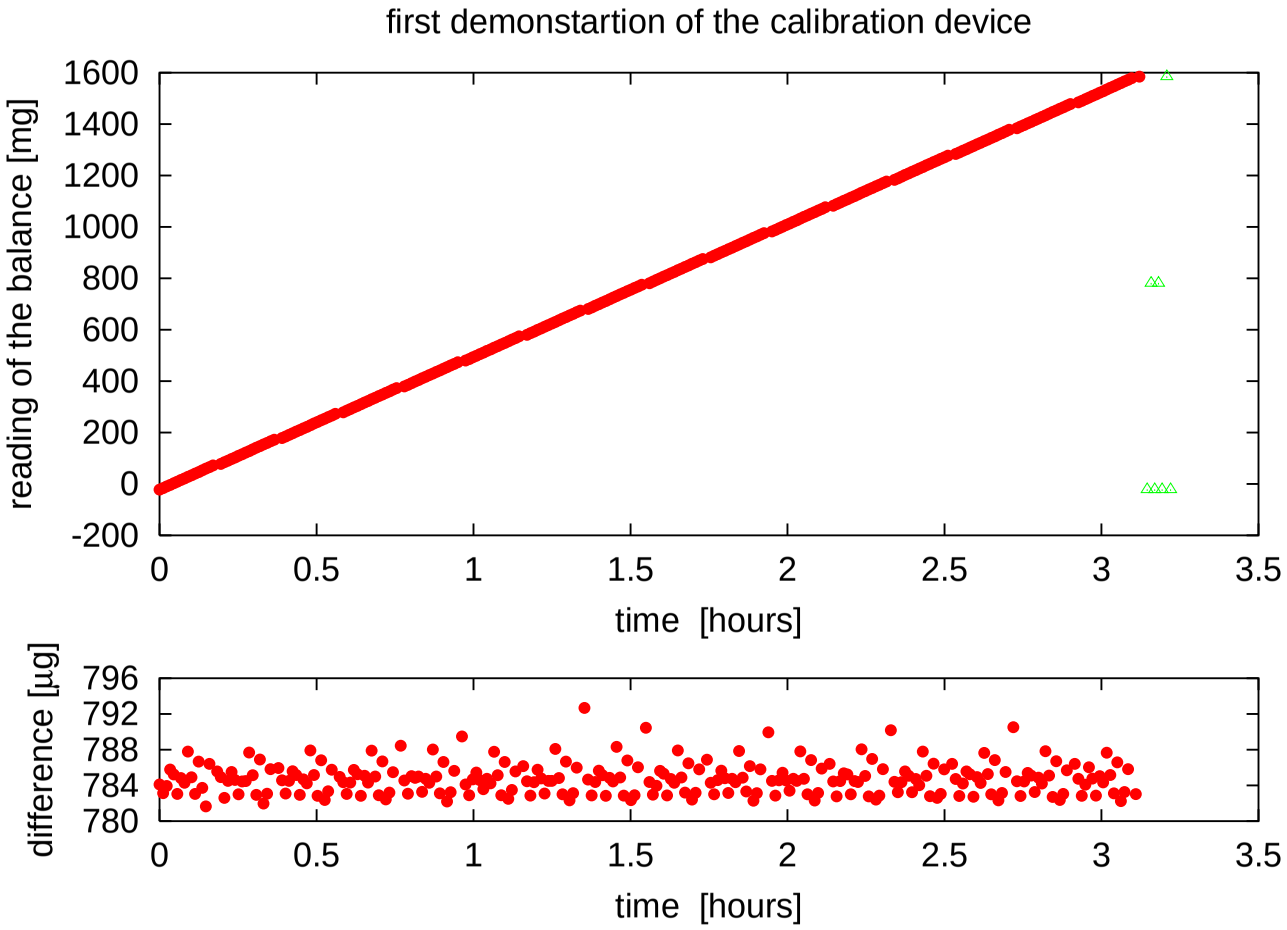
Setup of Calibration Device



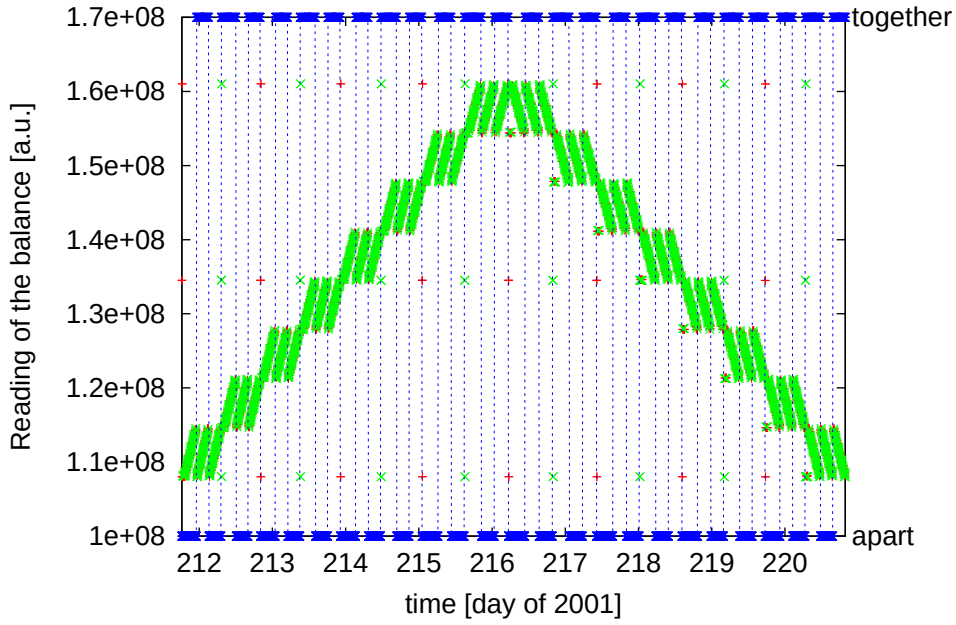
Another Impression of the Cal. Dev.

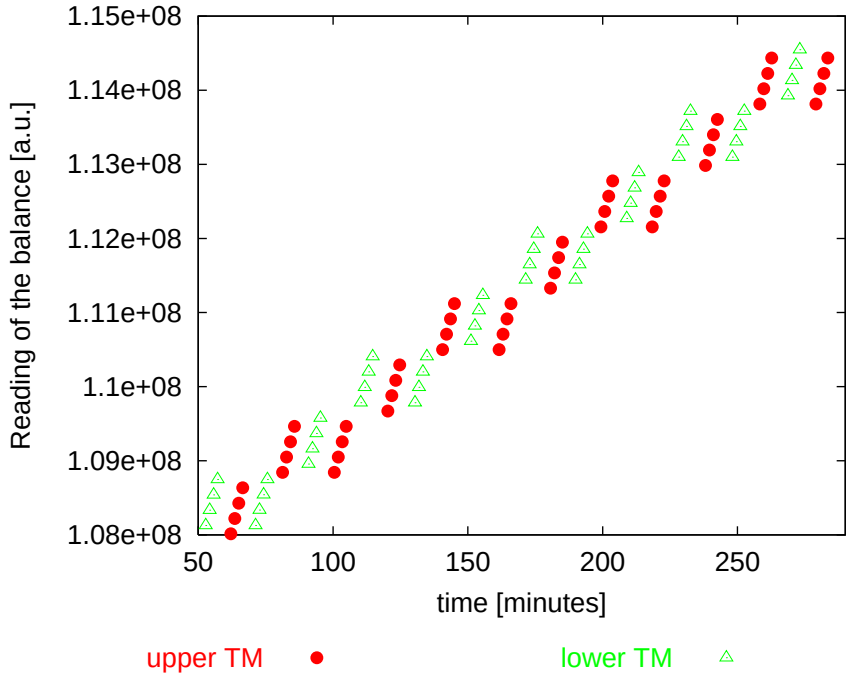


Weight of the Auxillary Masses

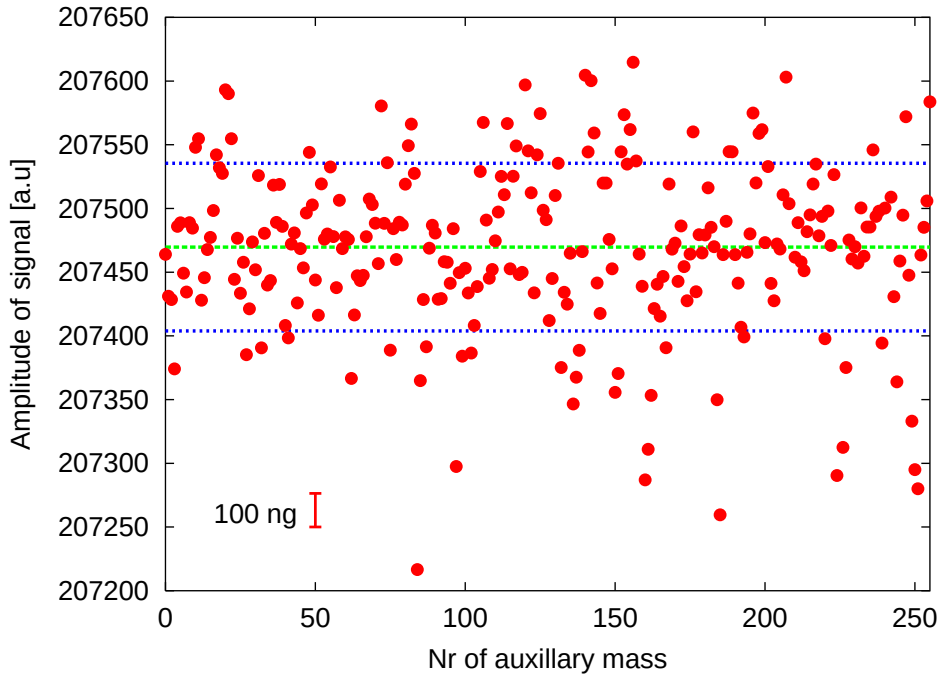


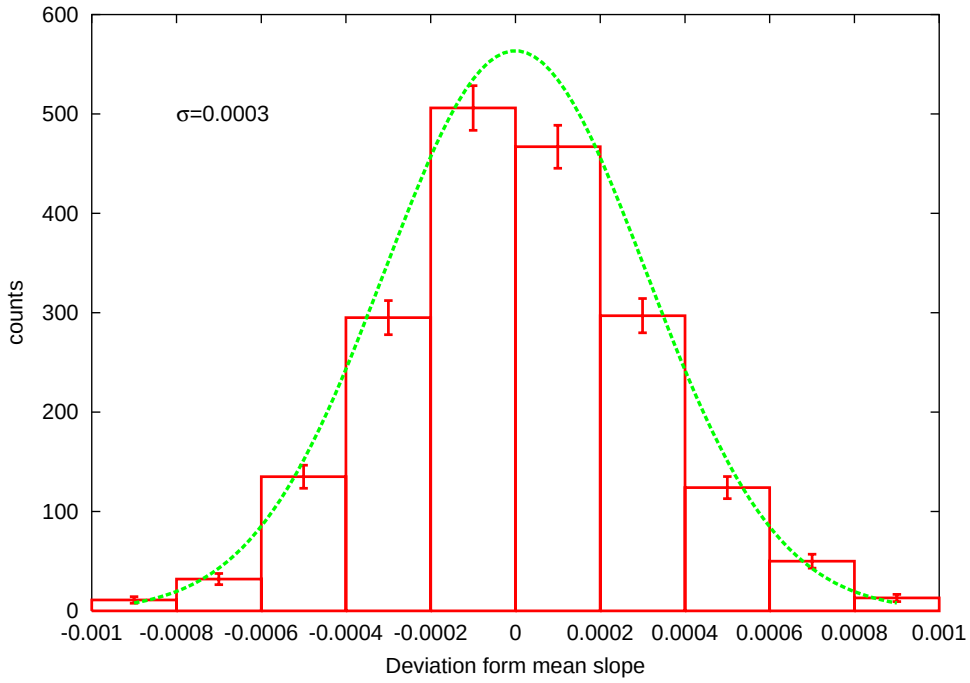
New Measurement Schmeme



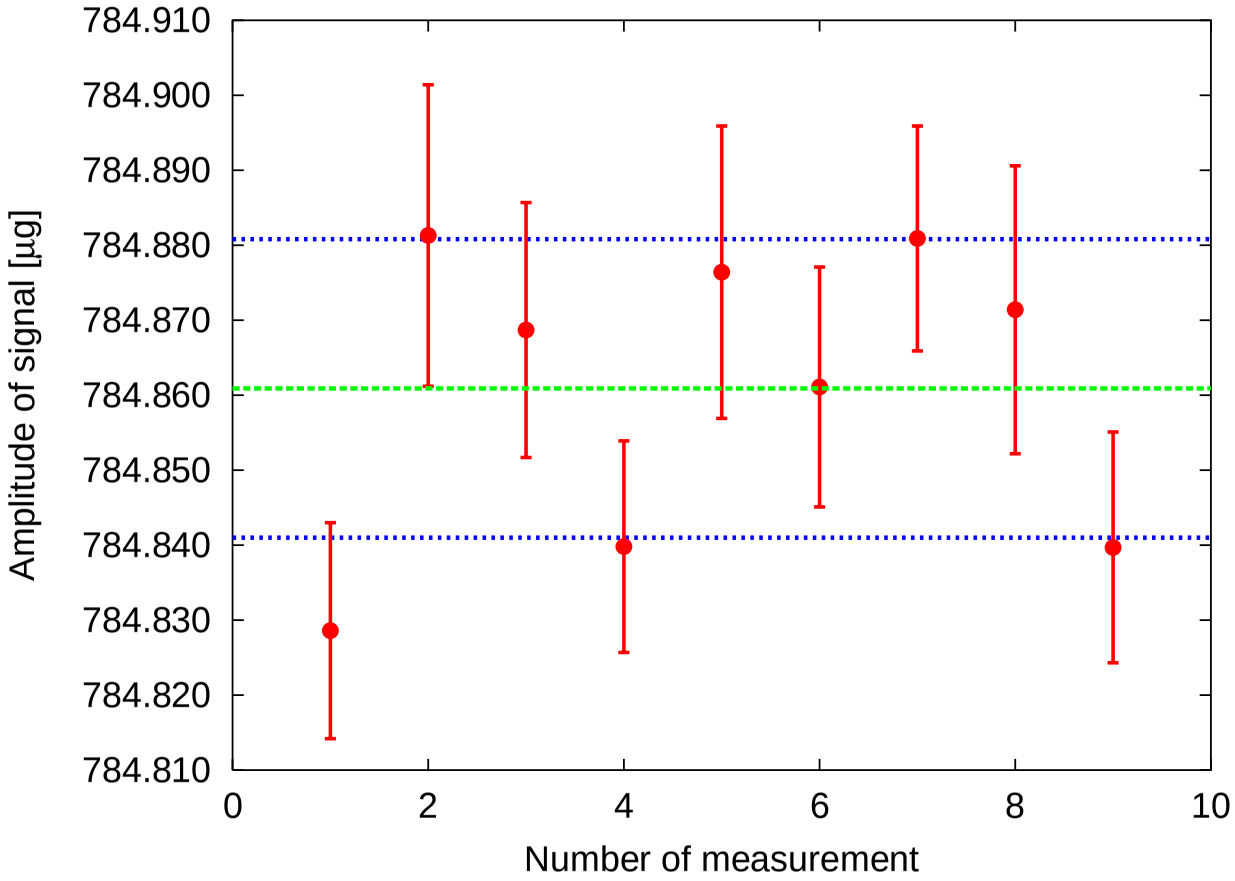


First Measurements





Measurements until now



To Do - Current Situation

- evaluate collected data
- check for systematics (temperature,-gradients, inclination)
- consitency check with a different set of test masses (Tantalum)
- improve mass integration