Report on levelling and GNSS results for stations on the MPQ campus in Garching

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Preface

This technical report describes the levelling and GNSS (Global Navigation Satellite System) results for stations on the MPQ (Max-Planck-Institut für Quantenoptik) campus in Garching, aiming at the derivation of relativistic redshift corrections for novel clock comparison experiments. The underlying observations were carried out mainly in the year 2016, but supplementary information and data were also considered until the end of 2018. The (relative) accuracy of the levelled heights within the internal network on the MPQ campus is estimated to be better than 1 – 2 mm, which is based on the raw double-run levelling discrepancies and loop misclosures involving also stations on rooftops of buildings. The accuracy of the GNSS (ellipsoidal) heights is estimated to be better than 1 cm. The consistency between the levelled and GNSS heights was evaluated internally by approximating the quasigeoid by a horizontal plane as well as externally by comparing with a gravimetric quasigeoid model, yielding maximum residuals of only 2 – 3 mm.

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Levelling results

In order to perform clock comparisons between the Max-Planck-Institut für Quantenoptik (MPQ) in Garching and other sites, precise height information is required to derive the necessary relativistic redshift corrections. For this purpose, levelling benchmarks were installed in several laboratories inside the MPQ main building, and in addition some benchmarks were also installed outside of the building (e.g., near the entrances). The main purpose of the inside points is to allow an easy height transfer from the benchmarks to the clocks (e.g., by a simple spirit level used for building construction), while the outside points serve as securing points and for separating the inside and outside levelling operations. After installing the markers and allowing some time for settlement, the heights of the markers were determined for the most part in June 2016, while some supplementary observations were also carried out in September 2018 to include the PTB clock container (parked on the MPQ campus) and a new GNSS antenna on the rooftop of the MPQ main building. The geometric levelling technique was used primarily, but for some rooftop stations also vertical distances were measured with steel tapes or electronic distance meters. All heights were determined in connection to existing benchmarks of the German national levelling network denoted as DHHN92 (Deutsches Haupthöhennetz 1992); the heights within this system are normal heights (height status 160), referring to the level of the Normaal Amsterdams Peil (NAP) tide gauge.

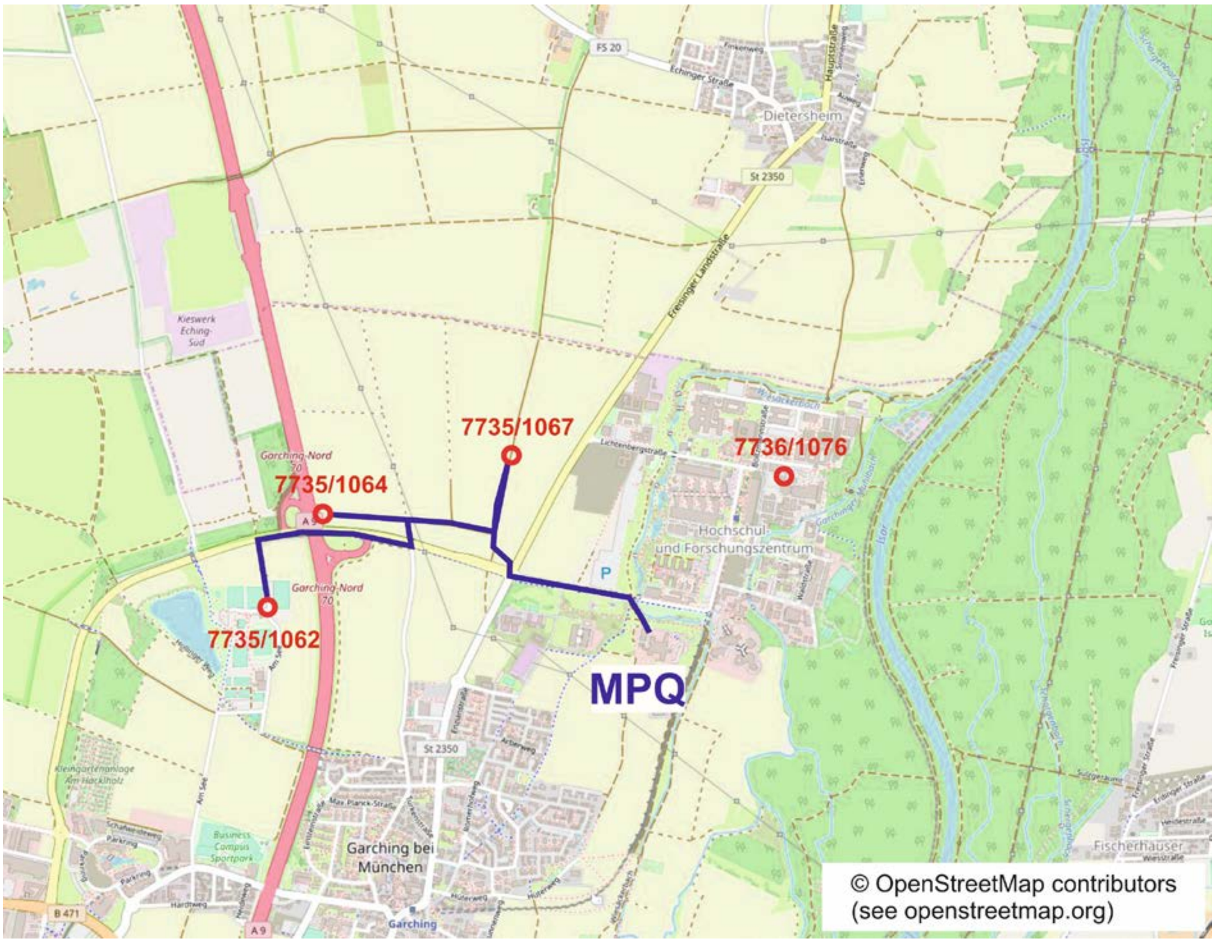

Fig. 1: Levelling benchmarks (red dots) and levelling lines (in blue) observed around the MPQ campus in Garching (map basis: © OpenStreetMap contributors, see openstreetmap.org)

Around the MPQ campus, several national levelling benchmarks were available (see Fig. 1). Two nearby benchmarks were used as connection points for the levelling measurements, namely stations 7735/1062 and 7735/1067, while two other nearby benchmarks (7735/1064 and 7736/1076) were destroyed or not found. The normal heights (height status 160) of the aforementioned points are given in Table 1 and the locations are shown in Fig. 1.

For the levelling observations, a digital automatic level Leica NA3003 with bar-code fiberglass staffs was employed; the accuracy of the entire system as specified by the manufacturer is 1.2 mm for 1 km double-run levelling with fiberglass staffs and 0.4 mm with invar staffs, respectively. Furthermore, the instrument includes an automatic data control and storage system. All observed levelling lines are depicted in Fig. 1.

Most of the levelling observations were done in June 2016. The main levelling loop started and ended at MPQ and included the national benchmarks 7735/1062, 7735/1064 and 7735/1067, but benchmark 7735/1064 was tilted and partly destroyed and hence could not be used. The heights of the other two benchmarks (7735/1062 and 7735/1067) agreed with the levelling observations within 1.0 mm. The supplementary levelling observations in September 2018 were connected to the existing benchmarks on the MPQ campus, and no differences were found in comparison to the heights determined in 2016. Furthermore, all observations were carried out as double-run levelling, and consequently all national benchmarks as well as the newly installed benchmarks on the MPQ campus are connected by at least two independent observations, ensuring a sufficient redundancy and error control. All levelling discrepancies found were less than 1 mm.

The stations on the MPQ campus are depicted in Fig. 2. A special situation exists for the GNSS antenna (stations 4003A and 4003B) on the rooftop of the MPQ main building, as it could not be reached directly by geometric levelling. In this case, vertical distances were also measured with steel tapes and laser distance meters at two places (namely in the staircase and on the outside of the building), but even under these somewhat difficult circumstances, the loop misclosure was less than 1 mm.

The final normal heights of all points are listed in Table 2; the heights refer to the German national levelling network denoted as DHHN92 – Deutsches Haupthöhennetz 1992 (height status 160). The (relative) height accuracy within the internal network on and around the MPQ campus is estimated to be better than 1 – 2 mm, which is based on the raw double-run levelling discrepancies of less than 1 mm, involving also stations on rooftops and inside buildings. Finally, station data sheets with photographs and further information are given in the appendix for all relevant sites.

Table 1: Normal heights (height status 160) of existing national levelling benchmarks around the MPQ campus.

Station	Description	Normal Height (H160) [m]
7735/1062	PB – Pfeilerbolzen (Am See, Sport- und Erholungszentrum)	477.936
7735/1067	PB – Pfeilerbolzen (Am Weg zw. Garching und Zettelhof)	475.876
7735/1064	SB – Stehbolzen (Autobahnabfahrt Garching-Nord) – destroyed	477.312
7736/1076	LB – Landeshöhenbolzen (Reaktorgelände, Kesselhaus) – not found, destroyed	474.472

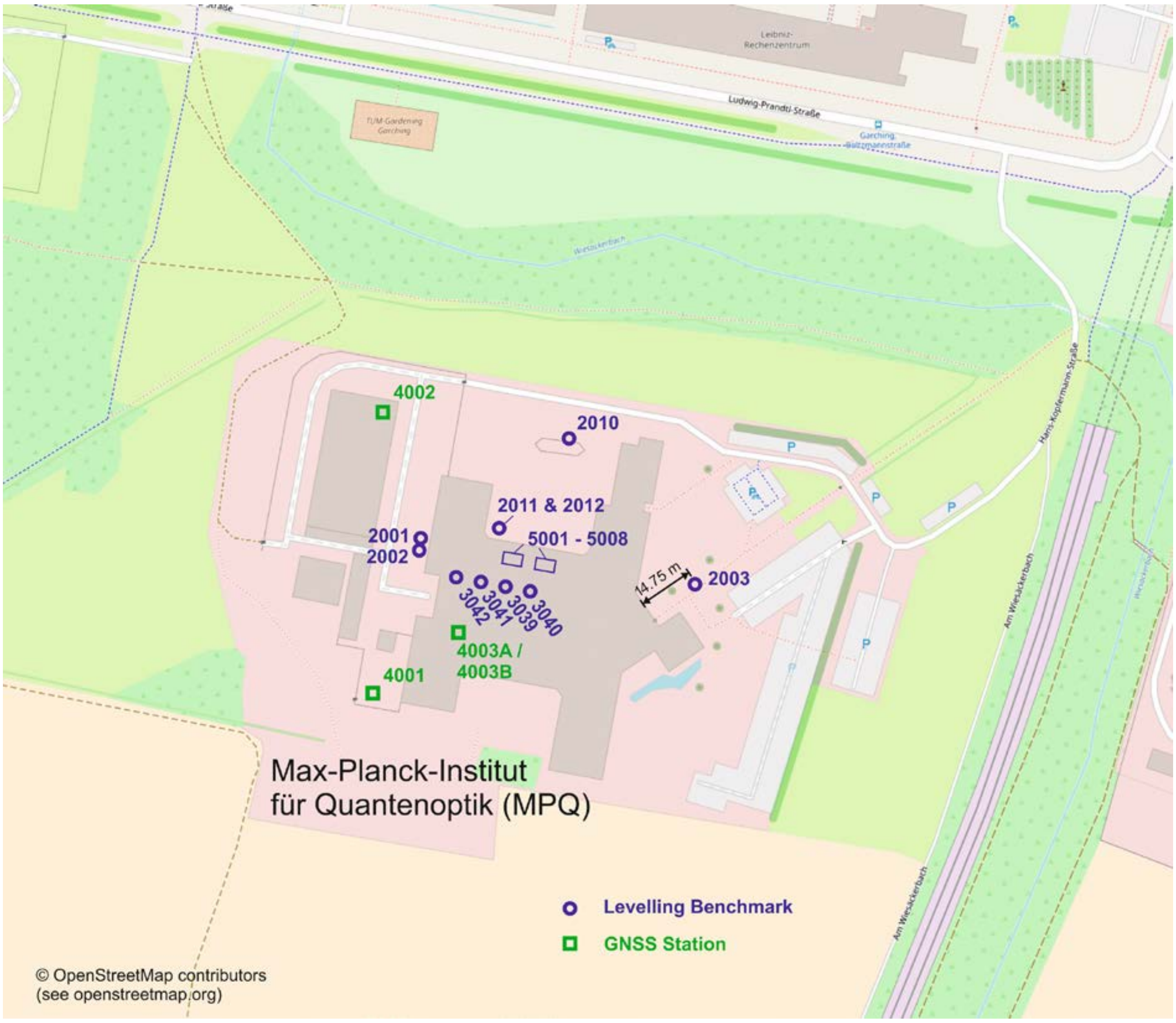

Fig. 2: Levelling benchmarks and GNSS stations on the MPQ campus in Garching (map basis: © OpenStreetMap contributors, see openstreetmap.org)

In addition, geopotential numbers, i.e., potential differences with respect to the zero-level surface of the DHHN92 system, were computed; the results are also provided in Table 2 in the unit $m^2 s^{-2}$. The basis for the computations is the definition equation for the normal heights

$$H^{N(i)} = \frac{C_{P(i)}}{\overline{\gamma}} = \frac{W_{0(i)} - W_P}{\overline{\gamma}}, \qquad \overline{\gamma} = \frac{1}{H^{N(i)}} \int_0^{H^{N(i)}} \gamma \, dH^{N(i)} \, , \tag{1}$$

where W_P is the gravity potential for a given point P, $W_{0(i)}$ is the gravity potential for the zero-level surface of the DHHN92 system, and $\overline{\gamma}$ is the mean normal gravity value along the normal plumb line (computed from ellipsoidal height zero up to $H^{N(i)}$). By rearranging the above equation, the geopotential numbers $C_{P(i)}$ can be derived easily from the corresponding normal heights $H^{N(i)}$, where $\overline{\gamma}$ can be computed without any hypotheses, e.g., according to formulas given in Denker (2013). Further details on heights as well as geometric levelling and the associated error theories can be found in standard textbooks on geodesy (e.g., Torge 2001) and surveying (for instance, Kavanagh and Mastin 2014, or Anderson and Mikhail 2012).

The relativistic redshift correction for a clock at rest on the Earth's surface is directly related to the gravity potential and the geopotential numbers, giving a fractional frequency shift of

$$\frac{\Delta f}{f_P} = \frac{f_P - f_0}{f_P} = \frac{W_P - W_0}{c^2} + O(c^{-4}) \ , \tag{2}$$

where f_P and f_0 are the proper frequencies at points P at the Earth's surface and P_0 on the zero-level surface. Furthermore, in the context of international timescales, the zero-potential value W_0 = 62,636,856.00 $m^2 s^{-2}$ should be employed to be consistent with the international recommendations for the definition of Terrestrial Time (TT), for further details see Denker et al. (2018). In addition, depending on the accuracy requirements for the envisaged clock comparisons, it may also be necessary to consider time variable parts of the gravity potential, especially due to solid Earth and ocean tides, as outlined in Voigt et al. (2016).

Table 2: Compilation of levelling results for the MPQ height network. Status: end of 2018

Station	Measurement Epoch	Internal Station Number	Normal Height $H^{N(i)}$ (DHHN92) [m]	Geopotential Number $C_{P(i)} = W_{0(i)} - W_P$ (DHHN92) [$m^2 s^{-2}$]
MPQ-4001	01 June 2016	4001	476.181	4670.58
MPQ-4002	01 June 2016	4002	482.796	4735.46
MPQ-4003A	02 June 2016	4003A	490.496	4810.97
MPQ-4003B	25 Aug. 2018	4003B	490.510	4811.11
MPQ-2001	01 June 2016	2001	476.578	4674.47
MPQ-2002	01 June 2016	2002	477.022	4678.83
MPQ-2003	01 June 2016	2003	476.345	4672.19
MPQ-2010	01 June 2016	2010	476.699	4675.66
MPQ-2011	25 Aug. 2018	2011	476.861	4677.25
MPQ-2012	25 Aug. 2018	2012	476.545	4674.15
MPQ-3039	02 June 2016	3039	477.490	4683.42
MPQ-3040	02 June 2016	3040	477.501	4683.52
MPQ-3041	02 June 2016	3041	477.499	4683.50
MPQ-3042	02 June 2016	3042	477.492	4683.44
MPQ-5001	25 Aug. 2018	5001	485.991	4766.79
MPQ-5002	25 Aug. 2018	5002	485.992	4766.80
MPQ-5003	25 Aug. 2018	5003	485.996	4766.84
MPQ-5004	25 Aug. 2018	5004	485.998	4766.86
MPQ-5005	25 Aug. 2018	5005	486.000	4766.88
MPQ-5006	25 Aug. 2018	5006	485.996	4766.84
MPQ-5007	25 Aug. 2018	5007	486.005	4766.93
MPQ-5008	25 Aug. 2018	5008	486.001	4766.89

GNSS results

A GNSS campaign was carried out over 14 full-day sessions in the period from 29 May – 11 June 2016. The campaign included three stations on the MPQ campus (4001, 4002, and 4003A; see Fig. 2). One of these stations is the permanent GNSS station on the rooftop of the MPQ main building, which is associated with the station names 4003A and 4003B, where point 4003A is the antenna reference point (ARP) as found in June 2016, while point 4003B is the corresponding ARP levelled in September 2018, after a new permanent GNSS receiver and antenna were installed in August 2016 (Th. Udem, personal communication, 11 Aug. 2016). The levelling results showed that station 4003B (Sept. 2018) is 1.4 cm higher than 4003A (June 2016). Furthermore, regarding the MPQ permanent GNSS station on the rooftop, it should be noted that it is mounted on a steel construction (see photos in the appendix), but unfortunately the steel construction is not firmly attached to the building, and hence the antenna position may change over time with respect to the building. Accordingly, the GNSS and levelling observations were done more or less simultaneously in May/June 2016.

Besides the MPQ permanent GNSS station, two additional temporary stations were established. All three stations were also connected to the local levelling network to allow a cross-check between the GNSS and levelling heights (see next section). Different GNSS receivers were employed in the GNSS campaign in 2016, namely a Javad receiver on station 4001 on the ground, a Leica receiver on station 4002 on the rooftop of the workshop, and a Septentrio PolaRx2e receiver on the permanent station 4003A on the rooftop of the main building. More details on the instrumentation and antenna heights used during the GNSS survey are given in Table 3.

The observations were processed with the Bernese 5.2 software using precise satellite orbits and clock information derived by the CODE analysis centre (Dach et al. 2018) as well as antenna phase centre corrections (phase centre offsets PCO plus phase centre variations PCV). The station coordinates were computed as L3/L0 (ionosphere-free) solutions using an elevation cut-off angle of 3°. Tropospheric parameters were estimated for each hour using the Vienna mapping function (Böhm et al., 2006). The GNSS data were analysed together with the data of the nearby IGS reference stations GRAS, GRAZ, MARS, OBE4, POTS PTBB, SBG2, WSRT, WTZR ZIM2, and ZIMM. Apart from stations MPQ-4003A, PTBB, WSRT, and ZIMM, where only GPS observations were available, GPS and GLONASS observations were used in the analysis for all other stations. All GNSS data were processed at the epoch of the observations in the IGb08 reference frame (as recommended in Boucher and Altamimi 2011); the 24 h sessions were analysed independently and then averaged, such that the computed coordinates refer to the epoch 2016.4271. The accuracy of the ellipsoidal heights is estimated to be better than 10 mm.

In this context, no distinction is made between the IGS reference frame IGb08 (solely based on GNSS) and the corresponding ITRF2008 frame (based on a combination of different techniques); for further details see Rebischung et al. (2012). Furthermore, to make it easier to compare the results with other sites, all coordinates were finally transformed to the epoch 2005.0, which is the standard reference

Table 3: GNSS instruments and antenna heights used during the GNSS survey

Station	Receiver Type	Antenna Type	Radome Code	Antenna Height [m]
MPQ-4003A	Septentrio PolarX2	ASH701945E_M	SNOW	0.0000
MPQ-4001	JAVAD TRE_G3T DELTA	LEIAR25.R3	NONE	1.4468
MPQ-4002	LEICA GR25	LEIAR10	NONE	1.2142

epoch associated with the ITRF2008 (see Altamimi et al. 2011). The necessary velocities were taken from the neighbouring IGS station Oberpfaffenhoffen (OBER – OBE4) given in the ITRF2008. All results are given as Cartesian coordinates and velocities as well as ellipsoidal coordinates and velocities in Tables 3 and 4, respectively, with all quantities referring to the ITRF2008 reference frame at the epoch 2005.0. Furthermore, corresponding results referring to the European Terrestrial Reference Frame 2000 (ETRF2000(R08)) at epoch 2005.0 are given in Tables 5 and 6, respectively; the transformation from ITRF2008 to ETRF2000(R08) was carried out according to Boucher and Altamimi (2011). The ETRF2000(R08) is a realization of the ETRS89 reference system, which is generally preferred in Europe and is also recommended by the EU; the ETRS89 is attached to the stable part of the Eurasian plate and coincident with the ITRS at the epoch 1989.0, resulting in much smaller station velocities for European sites (see Tables 3 to 6).

Evaluation of the GNSS and levelling results

In order to check the consistency between the GNSS and levelling heights, quasigeoid heights were computed as $\zeta_{GNSS} = h - H^N$, where h is the ellipsoidal height from GNSS (ITRF2008, epoch 2005.0; see Table 4) and H^N is the normal height (see Table 2); the results are given in Table 7. As the maximum distance between the GNSS stations is less than 100 m, the quasigeoid on the MPQ campus can be approximated in the first instance as a horizontal plane; the remaining residuals are listed in column five of Table 7, attaining a maximum value of 3 mm (RMS 1.8 mm). Besides this simple internal evaluation, a comparison with the independent gravimetric quasigeoid model EGG2015 (European Gravimetric (Quasi)Geoid 2015; see Denker et al. 2018) is performed, which is considered as an external evaluation. Table 7 shows the EGG2015 quasigeoid heights ζ_{EGG2015}, the (raw) differences $\zeta_{GNSS} - \zeta_{\mathrm{EGG2015}}$ and the residuals about the mean difference (columns 6 to 8, respectively). Of most interest are the residuals about the mean difference, which in this case attain a maximum value of only 2 mm (RMS 1.5 mm), which proves the excellent consistency of both the GNSS and levelling results; the mean difference of +9.0 cm is of little relevance, as it is related to the level of the zero height reference surface of the DHHN92 system and neglected tidal system corrections. Regarding the latter point, it should be noted that the ellipsoidal heights in Tables 4 and 6 refer to the non-tidal system, which is standard in most GNSS processing software and the ITRS with its associated reference frames. On the other hand, the EGG2015 is based on the zero-tide system in agreement with recommendations of the International Association of Geodesy (IAG), while the levelling heights usually do not take into account any tidal corrections and hence correspond to the mean tide system. Within the present small network on the MPQ campus, the different tidal systems show up as constant shifts and hence are not very relevant in this context. However, depending on the application, the different tidal systems have to be considered. Further details on this topic can be found for instance in Denker (2013).

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Table 3: Cartesian coordinates (X, Y, Z) and velocities (v_X, v_Y, v_Z) referring to the ITRF2008 reference frame at epoch 2005.0.

Station	X [m]	Y [m]	Z [m]	v_X [m/year]	v_Y [m/year]	v_Z [m/year]
MPQ-4003A	4166673.200	860343.346	4736552.069	-0.0155	0.0177	0.0107
MPQ-4001	4166699.481	860305.301	4736516.790	-0.0155	0.0177	0.0107
MPQ-4002	4166629.137	860296.704	4736588.668	-0.0155	0.0177	0.0107

Table 4: Ellipsoidal coordinates (latitude, longitude, height; φ, λ, h) and velocities (north, east, height; v_n, v_e, v_h) referring to the ITRF2008 reference frame at epoch 2005.0 and the GRS80 ellipsoid.

Station	φ			λ			h	v_n	v_e	v_h
	[°]	[']	["]	[°]	[']	["]	[m]	[m/year]	[m/year]	[m/year]
MPQ-4003A	48	15	35.02523	11	39	59.74055	535.986	0.0158	0.0205	0.0003
MPQ-4001	48	15	33.82899	11	39	57.67654	521.675	0.0158	0.0205	0.0003
MPQ-4002	48	15	37.08423	11	39	57.95797	528.287	0.0158	0.0205	0.0003

Table 5: Cartesian coordinates (X, Y, Z) and velocities (v_X, v_Y, v_Z) referring to the ETRF2000(R08) reference frame at epoch 2005.0.

Station	X [m]	Y [m]	Z [m]	v_X [m/year]	v_Y [m/year]	v_Z [m/year]
MPQ-4003A	4166673.493	860343.112	4736551.857	-0.0005	0.0000	-0.0003
MPQ-4001	4166699.774	860305.066	4736516.578	-0.0005	0.0000	-0.0003
MPQ-4002	4166629.430	860296.470	4736588.456	-0.0005	0.0000	-0.0003

Table 6: Ellipsoidal coordinates (latitude, longitude, height; φ, λ, h) and velocities (north, east, height; v_n, v_e, v_h) referring to the ETRF2000(R08) reference frame at epoch 2005.0 and the GRS80 ellipsoid.

Station	φ			λ			h	v_n	v_e	v_h
	[°]	[']	["]	[°]	[']	["]	[m]	[m/year]	[m/year]	[m/year]
MPQ-4003A	48	15	35.01488	11	39	59.72655	535.987	0.0002	0.0001	-0.0005
MPQ-4001	48	15	33.81864	11	39	57.66254	521.676	0.0002	0.0001	-0.0005
MPQ-4002	48	15	37.07387	11	39	57.94397	528.288	0.0002	0.0001	-0.0005

Table 7: Evaluation of ellipsoidal heights (ITRF2008, epoch 2005.0) and normal heights (DHHN92) internally and externally by comparisons with the European gravimetric geoid EGG2015.

Station	h [m]	H^N [m]	$\zeta_{GNSS} = h - H^N$ [m]	$\zeta_{GNSS} - Mean$ [m]	ζ_{EGG2015} [m]	$\zeta_{GNSS} - \zeta_{\mathrm{EGG2015}}$ [m]	Residual [m]
MPQ-4003A	535.986	490.496	45.490	0.002	45.401	0.089	0.001
MPQ-4001	521.675	476.181	45.494	-0.003	45.402	0.092	-0.002
MPQ-4002	528.287	482.796	45.491	0.001	45.402	0.089	0.001

Appendix (station descriptions)

MPQ-2001	West entrance, wall marker (bolt)
MPQ-2002	West entrance, floor marker (dome)
MPQ-2003	Main entrance, wall marker (bolt)
MPQ-2010	Transformer station, no marker
MPQ-2011	Basement entrance, top of railing, no marker
MPQ-2012	Basement entrance, top of concrete, no marker
MPQ-3039	Lab D0.39, wall marker (bolt)
MPQ-3040	Lab C0.40, wall marker (bolt)
MPQ-3041	Lab D0.41, wall marker (bolt)
MPQ-3042	Lab D0.42, wall marker (bolt)
MPQ-4001	GNSS station in lawn, temporary marker
MPQ-4002	GNSS station on roof of workshop, top of screw
MPQ-4003A	GNSS station on roof of main building, top of steel tripod, old antenna
MPQ-4003B	GNSS station on roof of main building, top of steel tripod, new antenna
MPQ-5001 – MPQ-5004	T-beam base frame #1 on roof of main building, no marker
MPQ-5005 – MPQ-5008	T-beam base frame #2 on roof of main building, no marker

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Benchmarks (MPQ)

Location: Max-Planck-Institut für Quantenoptik (MPQ), Garching

Point No.: **2001**	West Entrance	H= 476.578 m (DHHN92)

Lat = 48° 15' 35.5"
Lon = 11° 39' 58.6"
(ETRS89)

NOTE: Levelling rod cannot be setup vertically on point 2001 due to the railing mounted above. Better use point 2002!

2001: Wall marker (bolt)

Point No.: **2002**	West Entrance	H= 477.022 m (DHHN92)

Lat = 48° 15' 35.5"
Lon = 11° 39' 58.6"
(ETRS89)

2002: Floor marker (dome)

Date / Author: 2016-06-02, Heiner Denker

Benchmarks (MPQ)

Location: Max-Planck-Institut für Quantenoptik (MPQ), Garching

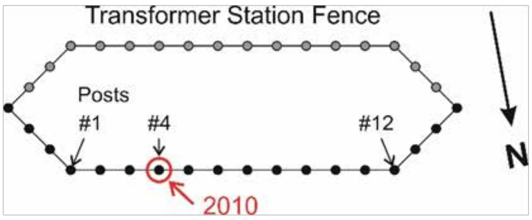
Point No.: **2003**	Main Entrance	H= 476.345 m (DHHN92)

Lat = 48° 15' 35.1"
Lon = 11° 40' 03.4"
(ETRS89)

2003: Wall marker (bolt)
(Distance to entrance: 14.75 m)

Point No.: **2010**	Transformer Station	H= 476.699 m (DHHN92)

Lat = 48° 15' 36.7"
Lon = 11° 40' 01.1"
(ETRS89)



2010: Top of wall covering in front of post (no marker)

Date / Author: 2016-06-02, Heiner Denker

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Benchmarks (MPQ)

Location: Max-Planck-Institut für Quantenoptik (MPQ), Garching

Point No.: **2011** | Basement Entrance | H= 476.861 m (DHHN92)

Lat = 48° 15' 35.8"
Lon = 11° 40' 00.1"
(ETRS89)

2011: Top of railing
(no marker)

Point No.: **2012** | Basement Entrance | H= 476.545 m (DHHN92)

Lat = 48° 15' 35.8"
Lon = 11° 40' 00.1"
(ETRS89)

2012: Top of concrete
in front of post (no marker)

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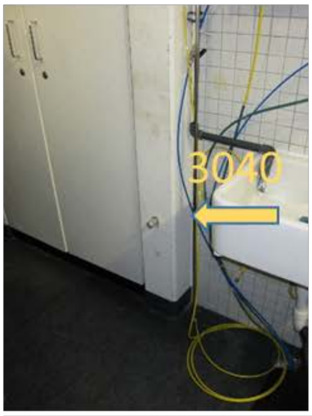
Benchmarks (MPQ)

Location: Max-Planck-Institut für Quantenoptik (MPQ), Garching

Point No.: **3039**	Lab D0.39	H= 477.490 m (DHHN92)
		Lat = 48° 15' 35.0" Lon = 11° 40' 00.5" (ETRS89)

3039: Wall marker (bolt)
(Lab D0.39)

Point No.: **3040**	Lab C0.40	H= 477.501 m (DHHN92)
		Lat = 48° 15' 34.9" Lon = 11° 40' 01.0" (ETRS89)



3040: Wall marker (bolt)
(Lab C0.40)

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Benchmarks (MPQ)

Location: Max-Planck-Institut für Quantenoptik (MPQ), Garching

Point No.: **3041**	Lab D0.41	H= 477.499 m (DHHN92)
		Lat = 48° 15' 35.0" Lon = 11° 40' 00.0" (ETRS89)

3041: Wall marker (bolt)
(Lab D0.41)

Point No.: **3042**	Lab D0.42	H= 477.492 m (DHHN92)
		Lat = 48° 15' 35.1" Lon = 11° 39' 59.5" (ETRS89)

3042: Wall marker (bolt)
(Lab D0.42)

Date / Author: 2016-06-02, Heiner Denker

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Benchmarks (MPQ)

Location: Max-Planck-Institut für Quantenoptik (MPQ), Garching

Point No.: **4001**	GNSS, Lawn	H= 476.181 m (DHHN92)

Lat = 48° 15' 33.8"
Lon = 11° 39' 57.7"
(ETRS89)

4001: GNSS point in lawn
(temporary marker, top of cover on steel pipe)

Point No.: **4002**	GNSS, Roof, Workshop	H= 482.796 m (DHHN92)

Lat = 48° 15' 37.1"
Lon = 11° 39' 58.0"
(ETRS89)

4002: GNSS point on roof of workshop
(top of screw on mounting bracket)

Date / Author: 2016-06-02, Heiner Denker

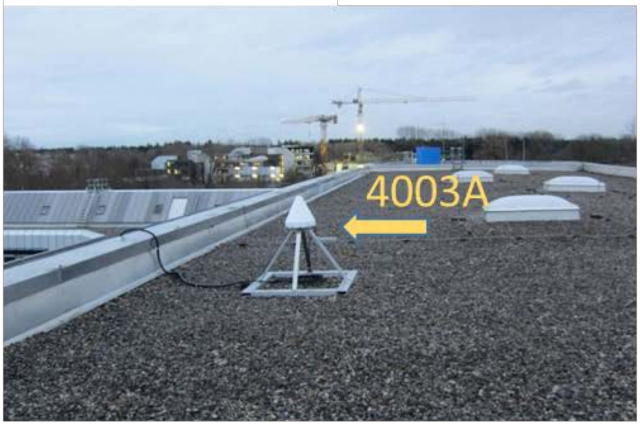
Benchmarks (MPQ)

Location: Max-Planck-Institut für Quantenoptik (MPQ), Garching

Point No.: **4003A**	GNSS, Roof, Main Building	H= 490.496 m (DHHN92)

Status: 2016-06-02

Lat = 48° 15' 35.0"
Lon = 11° 39' 59.7"
(ETRS89)



4003A: GNSS point on roof of main building (top of steel tripod)

Point No.: **4003B**	GNSS, Roof, Main Building	H= 490.510 m (DHHN92)

Status: 2018-09-25 (with new GNSS equipment)

Lat = 48° 15' 35.0"
Lon = 11° 39' 59.7"
(ETRS89)

4003B: GNSS point on roof of main building (top of steel tripod)

Date / Author: 2016-06-02 & 2018-09-25, Heiner Denker

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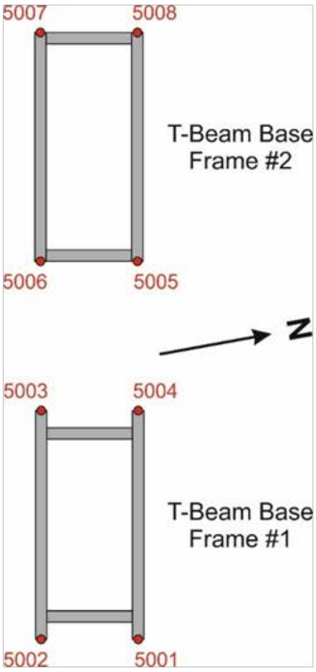
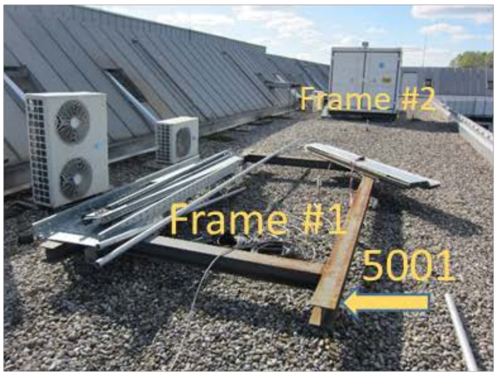
Benchmarks (MPQ)

Location: Max-Planck-Institut für Quantenoptik (MPQ), Garching

Point No.: **5001**	Roof, Main Building	H= 485.991 m (DHHN92)

Lat = 48° 15' 35.4"
Lon = 11° 40' 01.0"
(ETRS89)

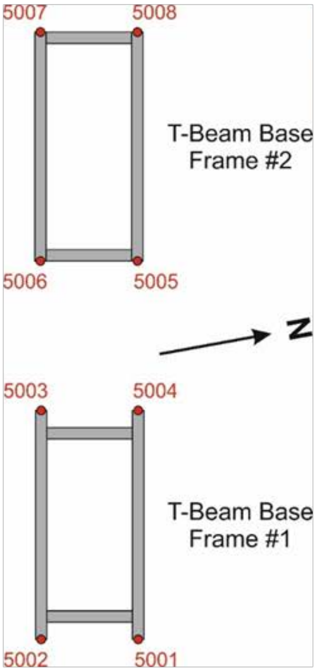




5001: T-Beam Base Frame #1
(top of steel T-beam frame at corner, see sketch)

Point No.: **5002**	Roof, Main Building	H= 485.992 m (DHHN92)

Lat = 48° 15' 35.4"
Lon = 11° 40' 01.0"
(ETRS89)



5002: T-Beam Base Frame #1
(top of steel T-beam frame at corner, see sketch)

Date / Author: 2018-09-25, Heiner Denker

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Benchmarks (MPQ)

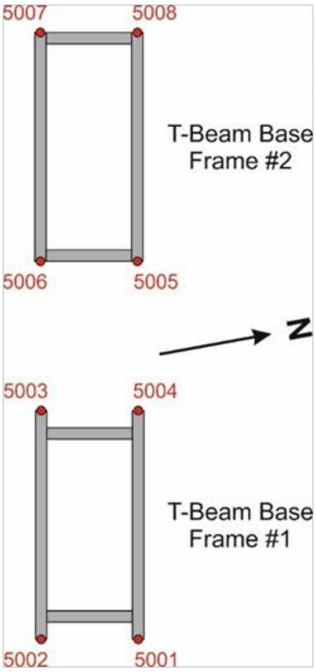
Location: Max-Planck-Institut für Quantenoptik (MPQ), Garching

Point No.: **5003**

Roof, Main Building

H= 485.996 m (DHHN92)

Lat = 48° 15' 35.4"
Lon = 11° 40' 01.0"
(ETRS89)



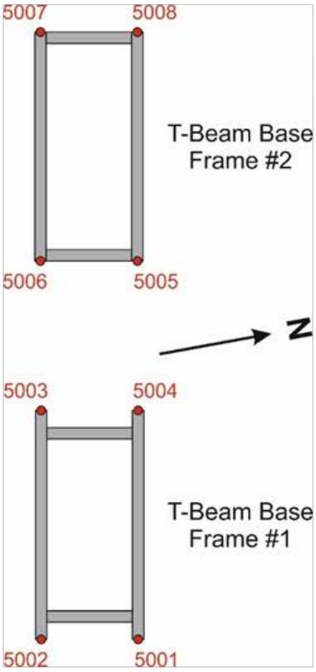
5003: T-Beam Base Frame #1
(top of steel T-beam frame at corner, see sketch)

Point No.: **5004**

Roof, Main Building

H= 485.998 m (DHHN92)

Lat = 48° 15' 35.4"
Lon = 11° 40' 01.0"
(ETRS89)



5004: T-Beam Base Frame #1
(top of steel T-beam frame at corner, see sketch)

Date / Author: 2018-09-25, Heiner Denker

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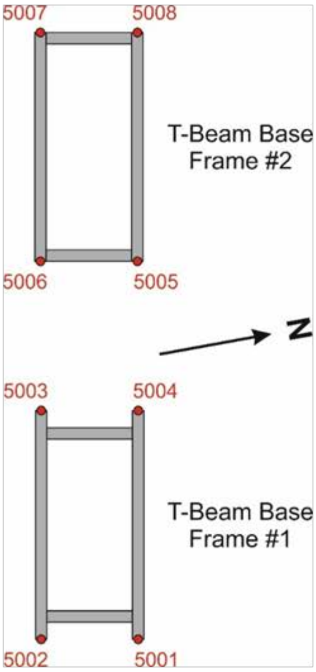
Benchmarks (MPQ)

Location: Max-Planck-Institut für Quantenoptik (MPQ), Garching

Point No.: **5005**	Roof, Main Building	H= 486.000 m (DHHN92)

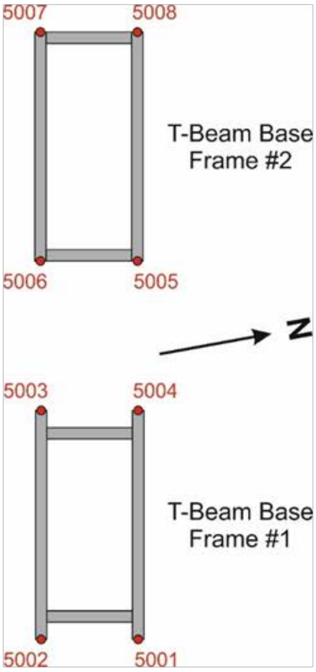
Lat = 48° 15' 35.5"
Lon = 11° 40' 00.3"
(ETRS89)



5005: T-Beam Base Frame #2
(top of steel T-beam frame at corner, see sketch)

Point No.: **5006**	Roof, Main Building	H= 485.996 m (DHHN92)

Lat = 48° 15' 35.5"
Lon = 11° 40' 00.3"
(ETRS89)



5006: T-Beam Base Frame #2
(top of steel T-beam frame at corner, see sketch)

Date / Author: 2018-09-25, Heiner Denker

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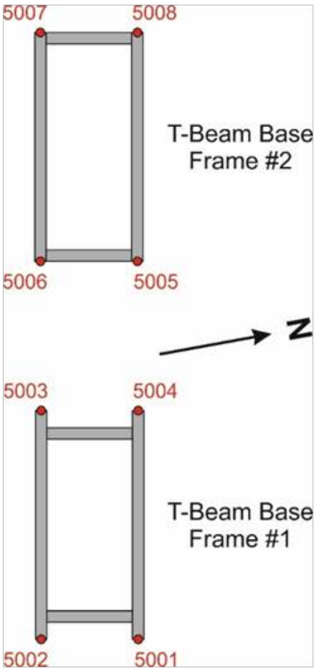
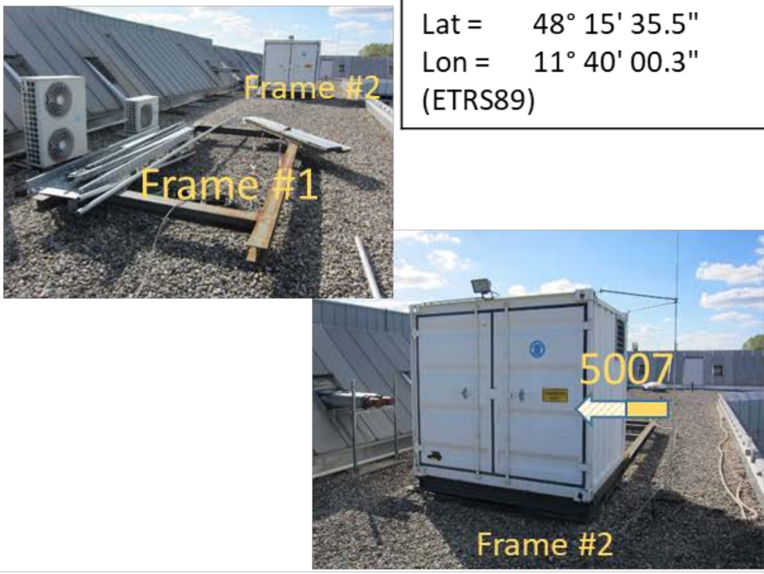
Benchmarks (MPQ)

Location: Max-Planck-Institut für Quantenoptik (MPQ), Garching

Point No.: **5007**	Roof, Main Building	H= 486.005 m (DHHN92)

Lat = 48° 15' 35.5"
Lon = 11° 40' 00.3"
(ETRS89)

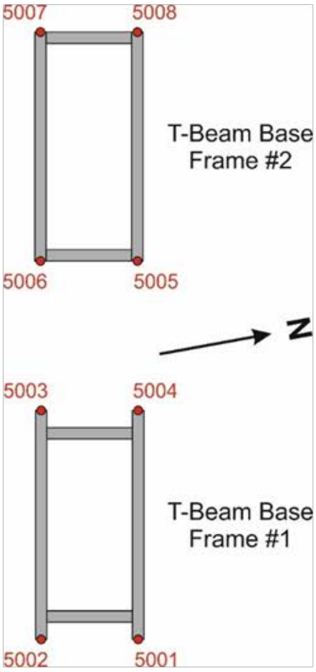


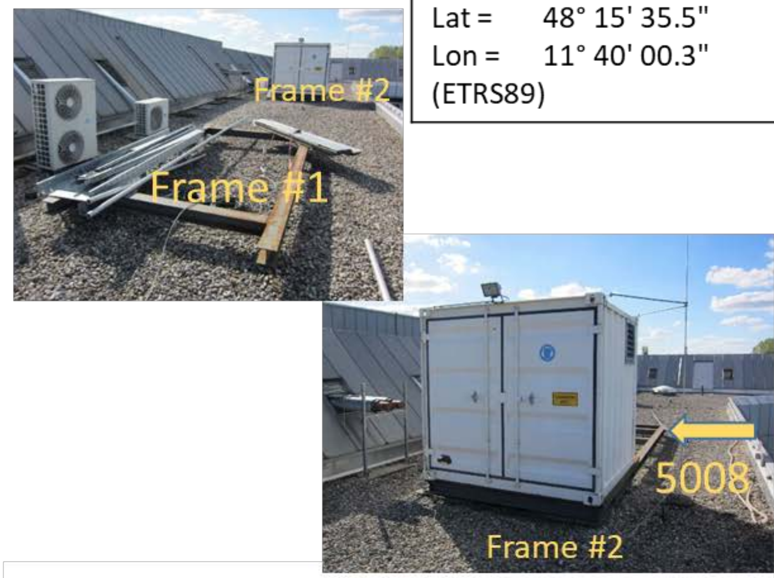


5007: T-Beam Base Frame #2
(top of steel T-beam frame at corner, see sketch)

Point No.: **5008**	Roof, Main Building	H= 486.001 m (DHHN92)

Lat = 48° 15' 35.5"
Lon = 11° 40' 00.3"
(ETRS89)





5008: T-Beam Base Frame #2
(top of steel T-beam frame at corner, see sketch)

Date / Author: 2018-09-25, Heiner Denker

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