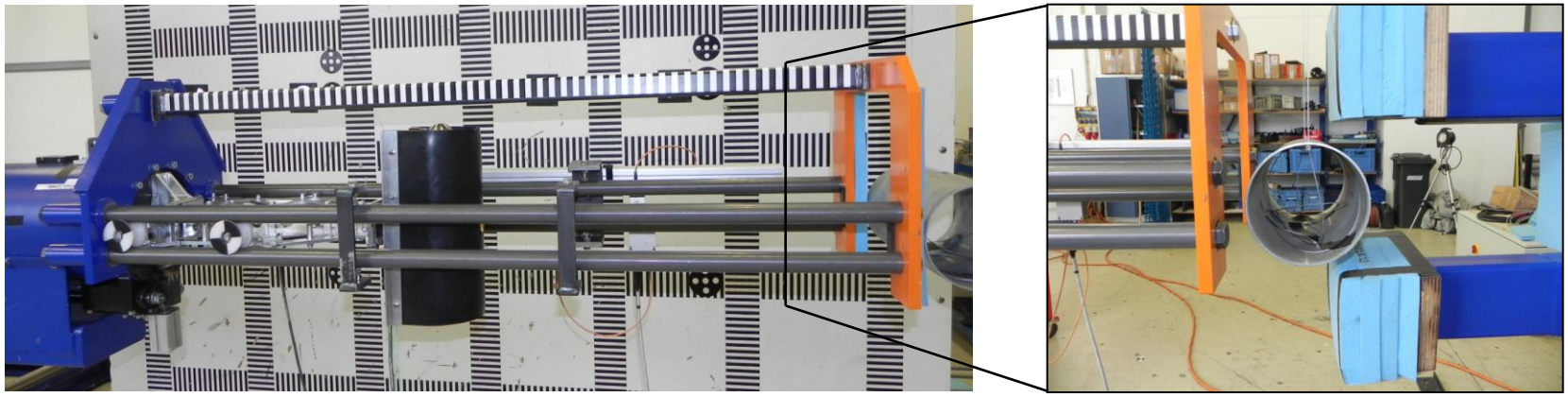
Upper-Leg Energy-Equivalence-Study for ACEA

G.Pauer, 10.04.2013

○ Test setup



Setup as in ULF-certification procedure:

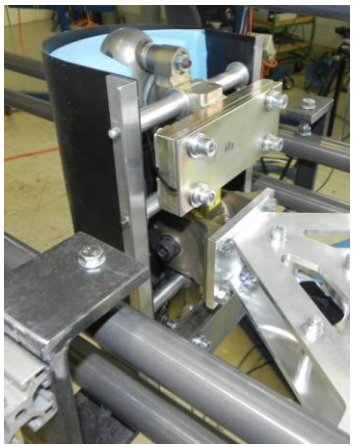
impact angle = 0° (horizontal)
certification tube length = 275 mm
tube diameter = 150 mm
tube mass = 3.0 kg
impact location at center of ULF and tube

- Impactors

Toyota-ULF

Min. Toyota ULF-mass = 3.808 kg
(incl. foam, screws,..)

Concept (TRL)-ULF



Min. ULF-mass = 5.664 kg
(incl. foam, screws,..)

Mass of linear guiding system = 3.476 kg

Min. tot. mass with Toyota ULF= 7.284 kg

Min. tot. mass ULF = 9.500 kg

○ Boundary conditions / Test configurations

Rem.1: the total mass of ULF + guiding system could not be reduced to this value!

Table-1: Impactor-Initial Velocity [km/h]

Mass [kg]:	Energy [J]: 100	200	300	400	450	500	600	700
5.00	22.77	32.20	39.44	45.54	48.30	50.91	55.77	
~~6.50~~	~~19.97~~	~~28.24~~	~~34.59~~	~~39.94~~	~~42.36~~	44.65	48.91	
7.284 ~~7.50~~	18.59	26.29	32.20	37.18	39.44	41.57	45.52	
9.50	16.52	23.36	28.61	33.04	35.04	36.94	40.46	43.70
11.00	15.35	21.71	26.59	30.70	32.56	34.32	37.60	40.61
12.00	14.70	20.78	25.46	29.39	31.18	32.86	35.99	38.88
15.00	13.15	18.59	22.77	26.29	27.89	29.39	32.20	34.77

Rem.: [ ] ...conditions of an Upper Leg - certification

Tests with Toyota-ULF

Tests with Concept/TRL-ULF

Rem.2: the lowest total mass of ULF + guiding system has been used!

Rem.3: the 450 J condition has been included for the lowest mass! → 4 data points for each energy

○ Correlating Toyota-ULF and “normal”-ULF

Background:
The aim of this study is to find scaling factors for signal maxima obtained with the “normal” ULF-impactor, to extrapolate maximum signal values that would be obtained with a much lighter impactor for different kinetic energies

→ **Problem:**
The lighter (Toyota) impactor is made from different materials (titanium), leading to different mass distribution within the impactor (in front of / behind the load cells) and different bending stiffness (as can be seen in DMS-signals)

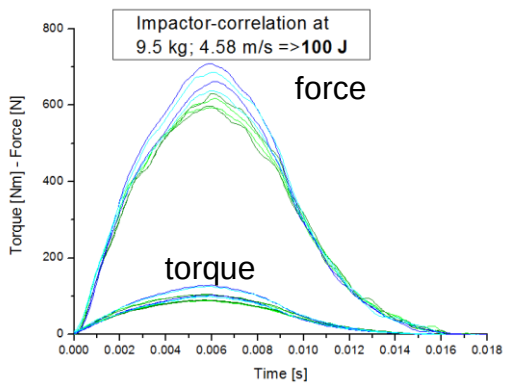
→ **Solution:**
Correlation of signal-maxima between both impactor types for 100, 300 and 450 Joule and for different weights

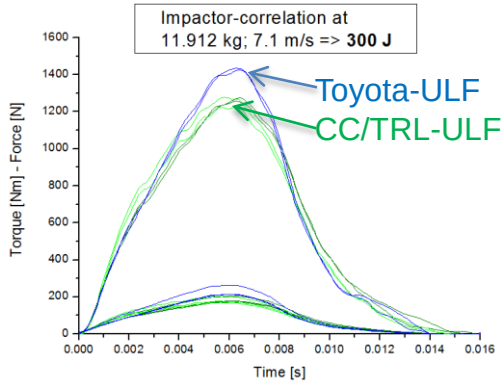
→ **Results of correlation tests:**
Correction factors for the signal-maxima-heights obtained with the Toyota-ULF, to allow a direct comparison with the standard (TRL) ULF signal maxima

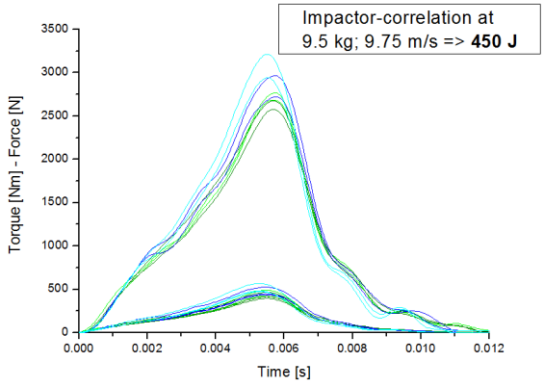
Rem.:
- The central DMS torque signal scales differently than the upper and lower ones!
→ Different scale factors have been considered for signal correlation of M_c and $M_{u/l}$!

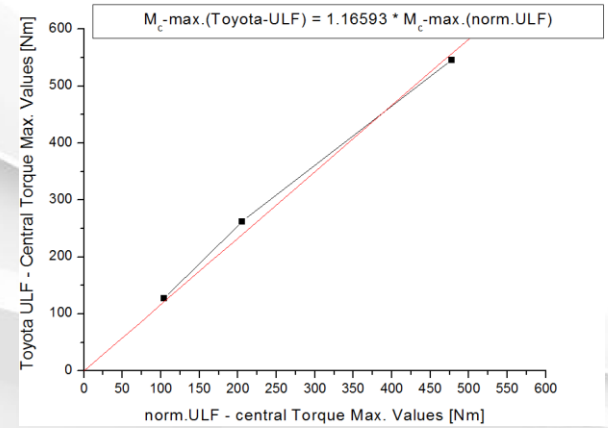
- Due to a different mass distribution, the load cells of the Toyota ULF give higher values, even if the total weight is matched with the normal ULF!

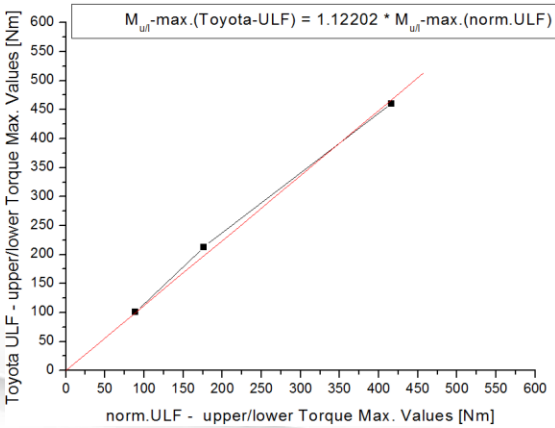
- Correlating Toyota-ULF and Concept/TRL-ULF

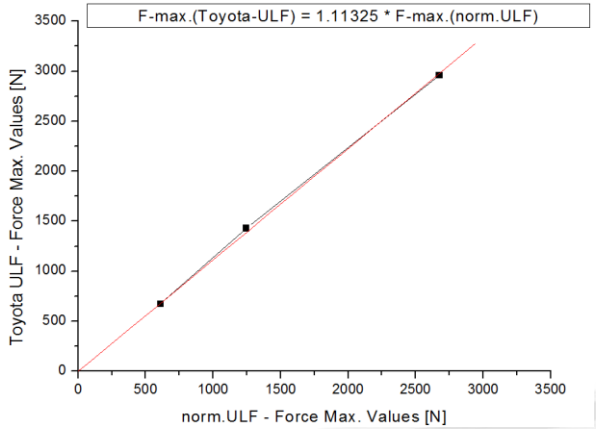




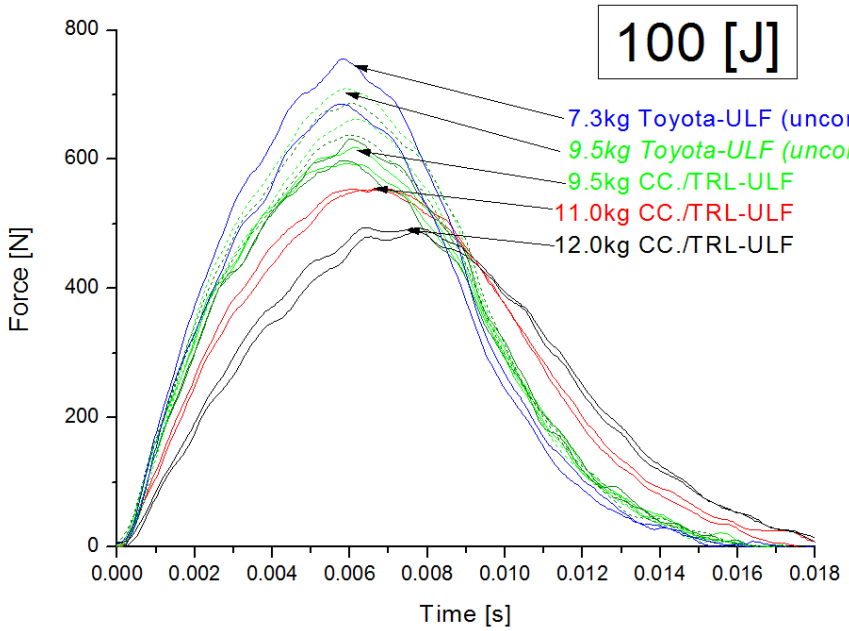


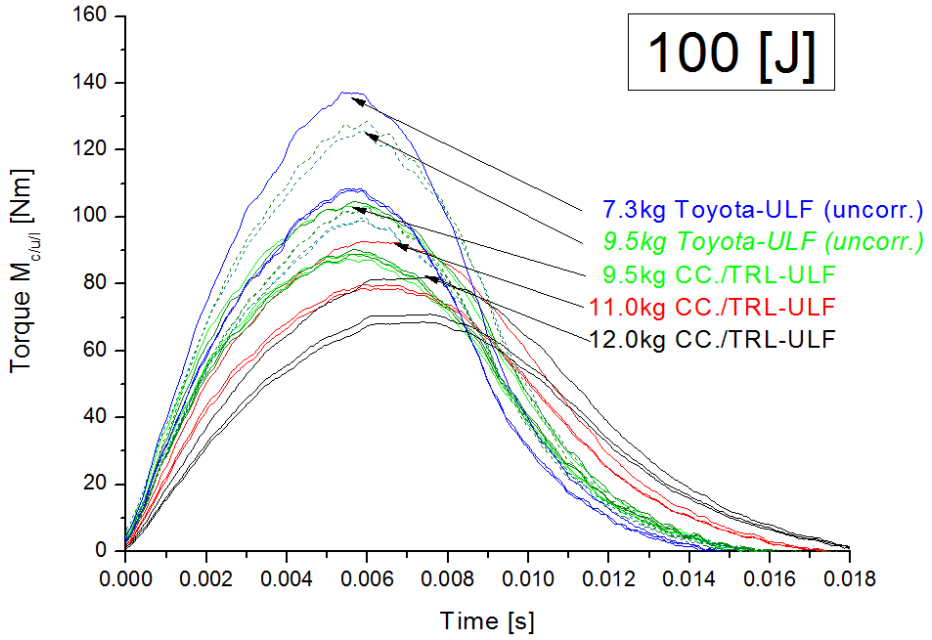




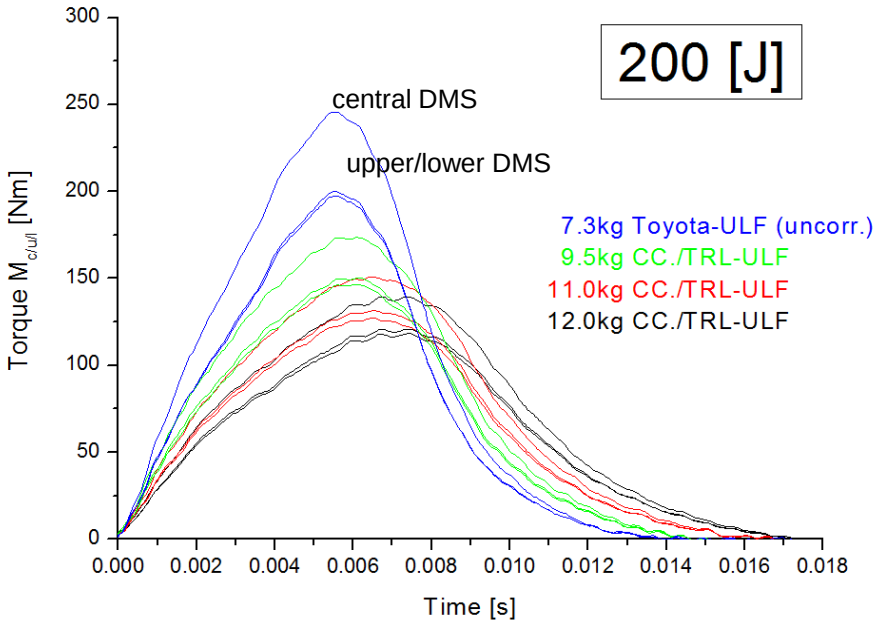


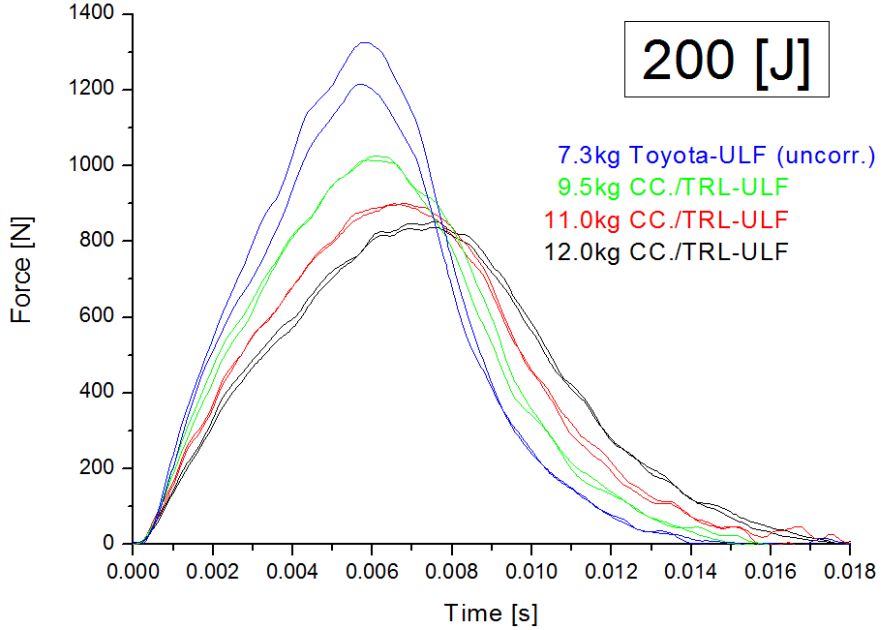
○ Results – signals @ 100 Joule



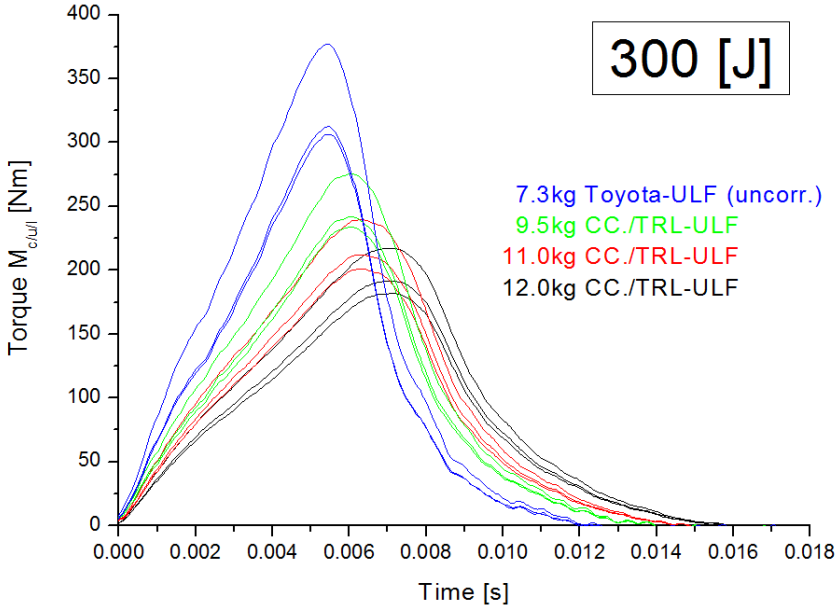


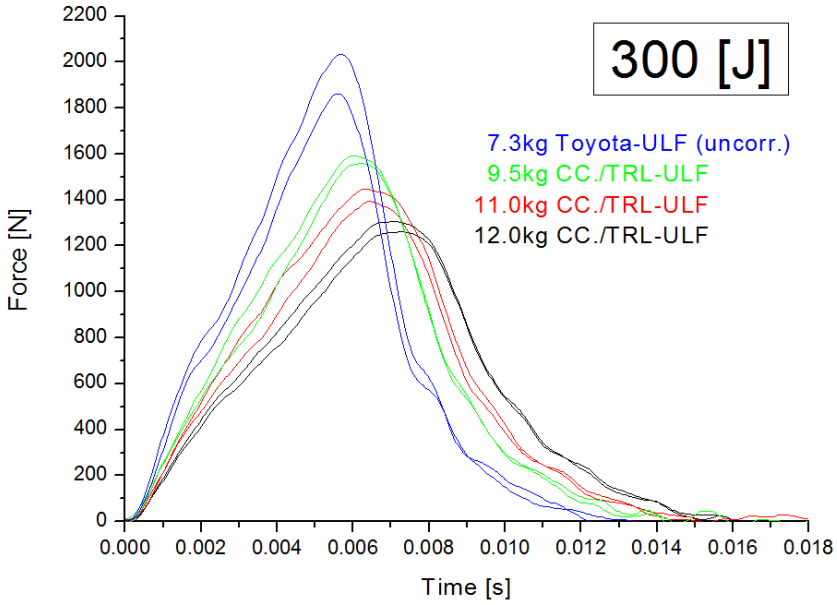
○ Results – signals @ 200 Joule



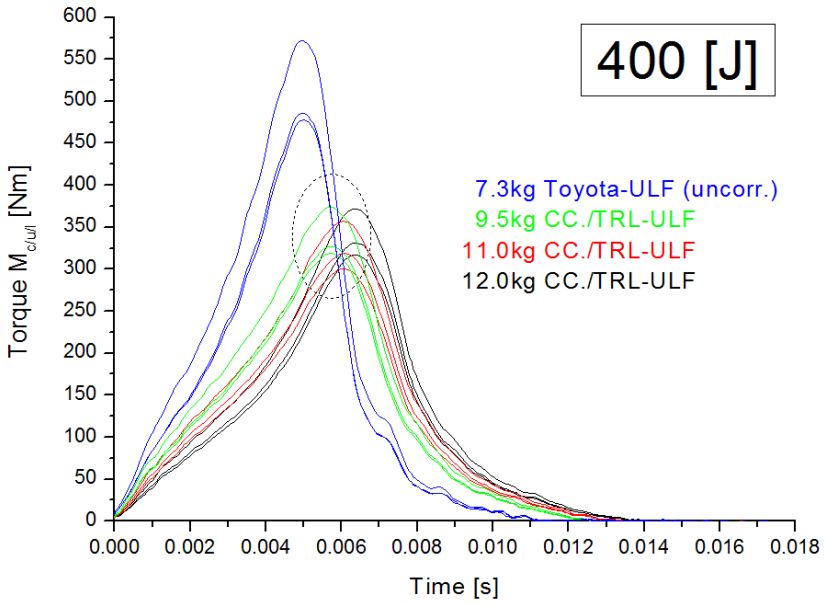


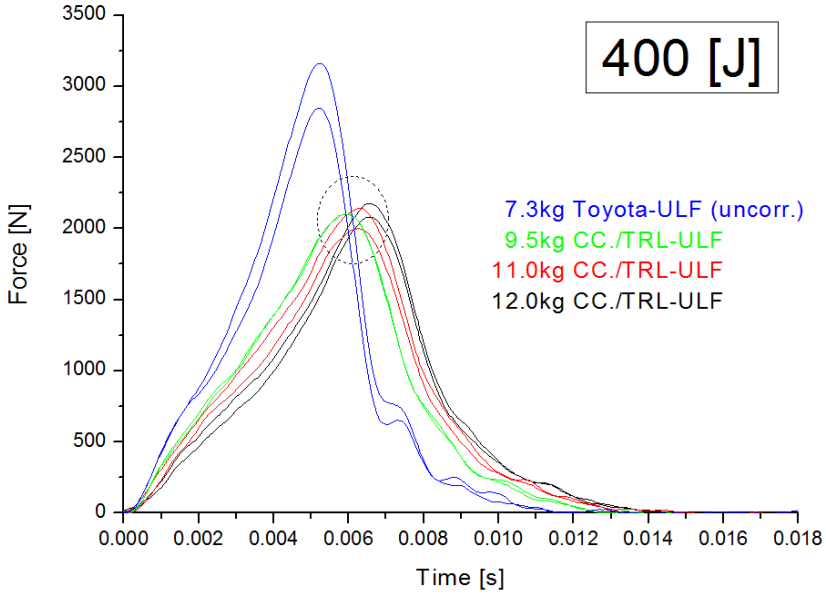
○ Results – signals @ 300 Joule





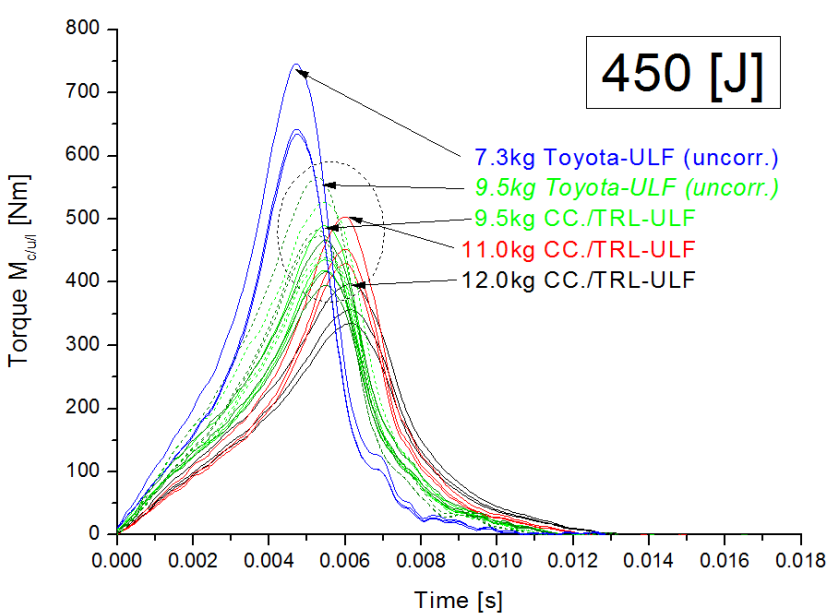
○ Results – signals @ 400 Joule

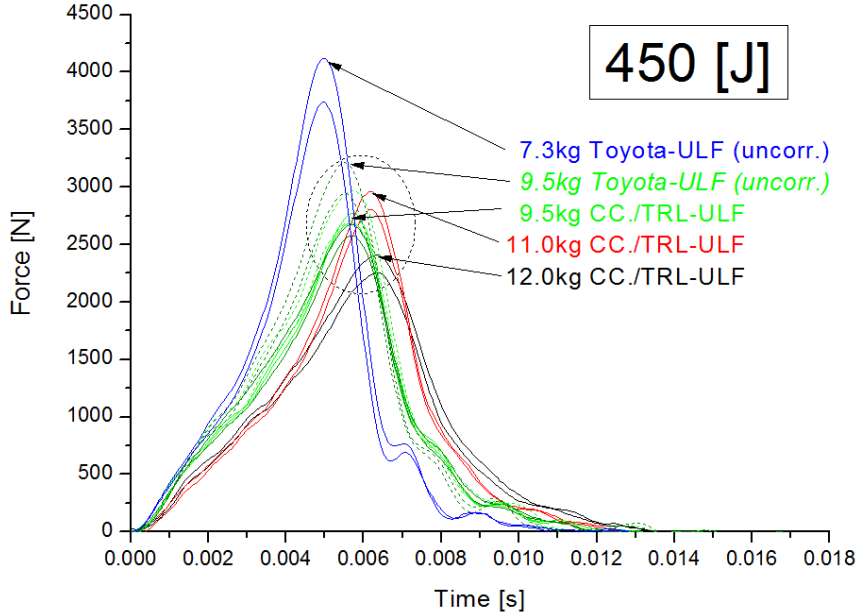




Rem.: At 400 Joule, the continuous increase of the signals, towards higher impact-velocities, or lower ULF-masses, seems to be interrupted (see dashed circles)!

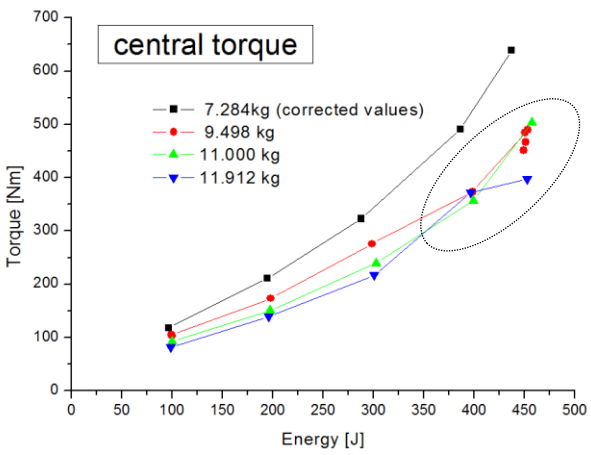
○ Results – signals @ 450 Joule

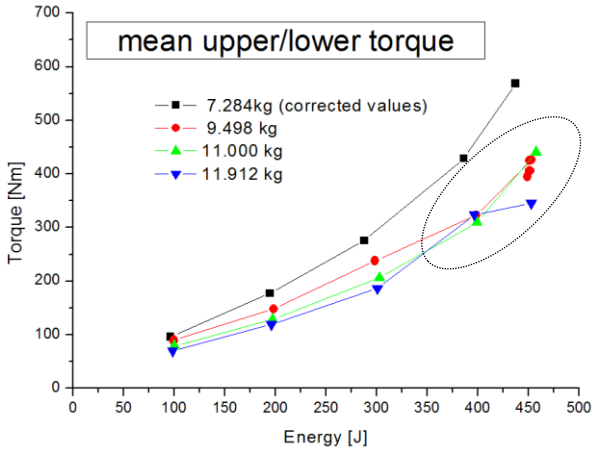


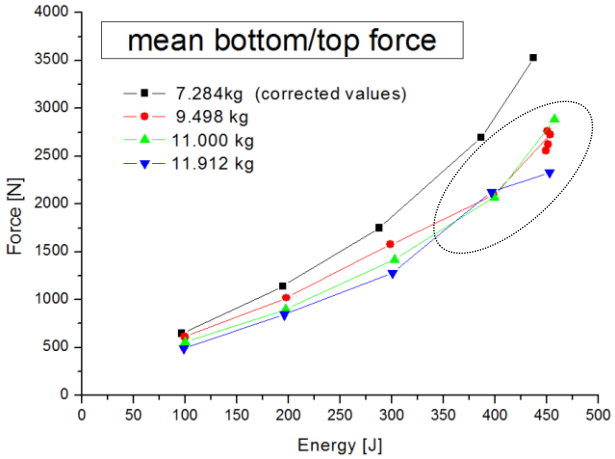


Rem.: At energies >=400 Joule, the continuous increase of the signals, towards higher impact-velocities, or lower ULF-masses, seems to be interrupted (see dashed circles)!

- Results – signal-max. vs. energy (mass=const.)

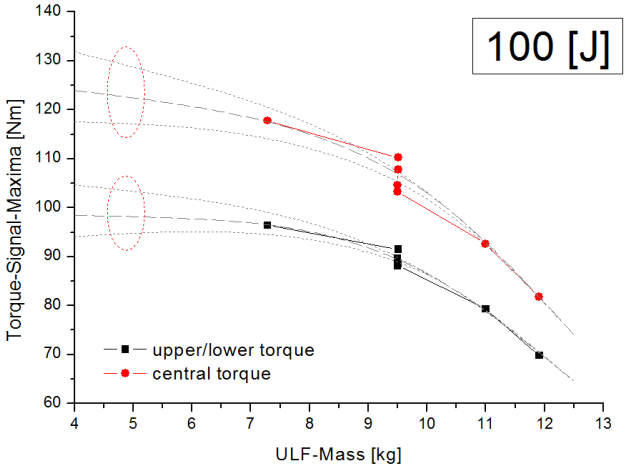


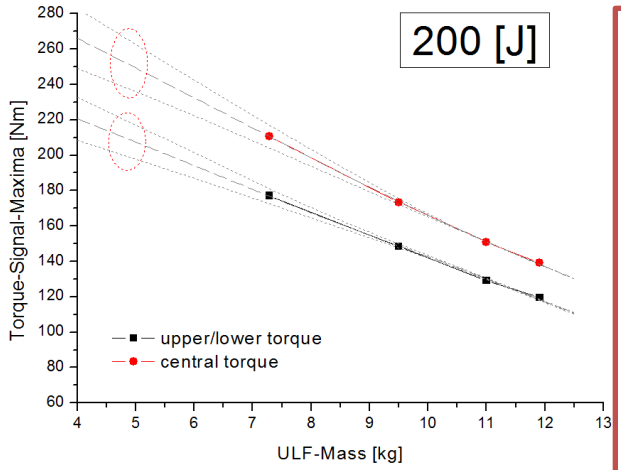


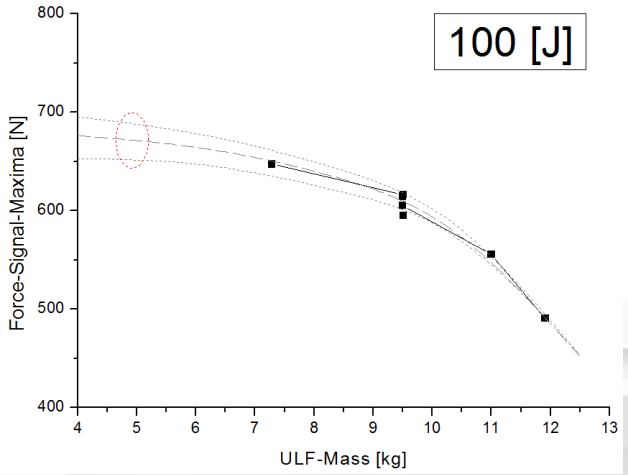


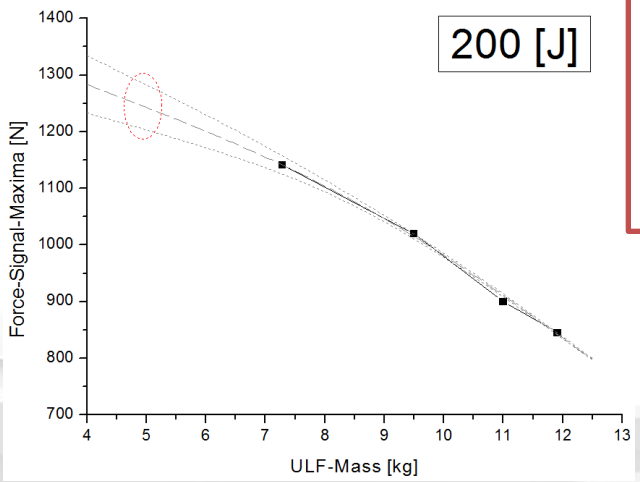
Rem.: At energies >=400 Joule, the continuous increase of the signals, towards higher impact-velocities, or lower ULF-masses, seems to be interrupted (see dashed circles)!

○ Results – signal-max. vs. mass (energy=const.)





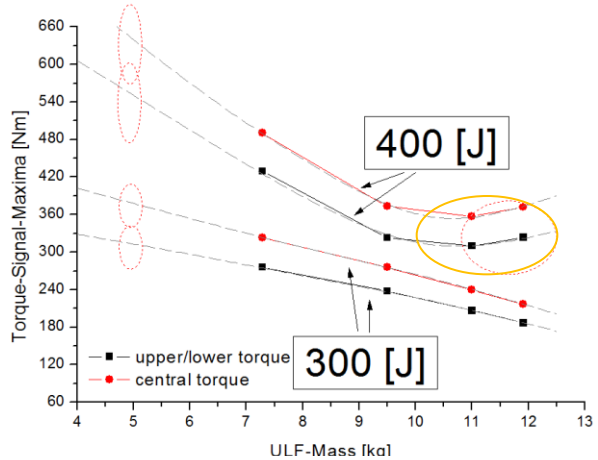


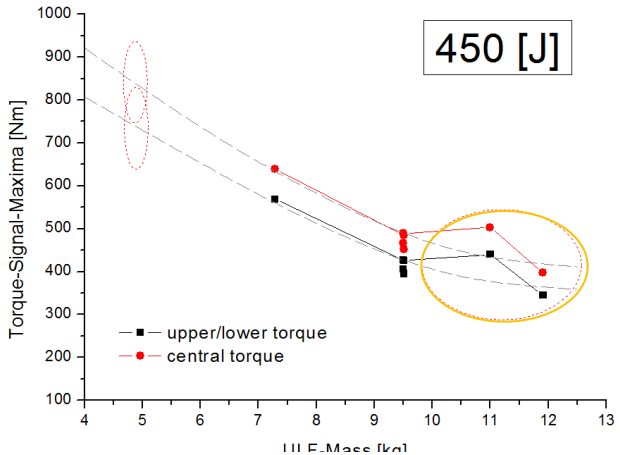


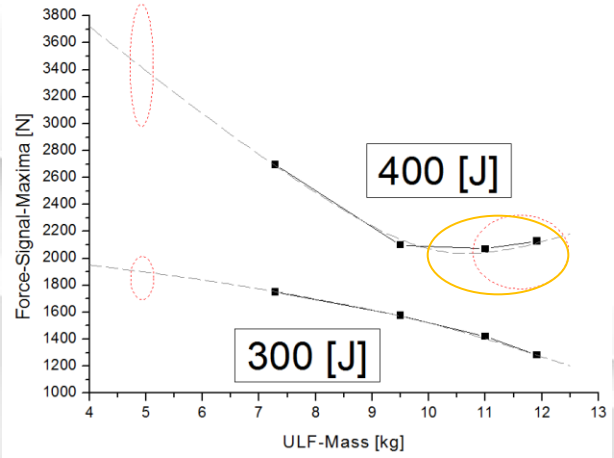
Rem.: The correlation between the signal maxima and impactor-mass is
(i) nonlinear and
(ii) shows different characteristics at different energies!

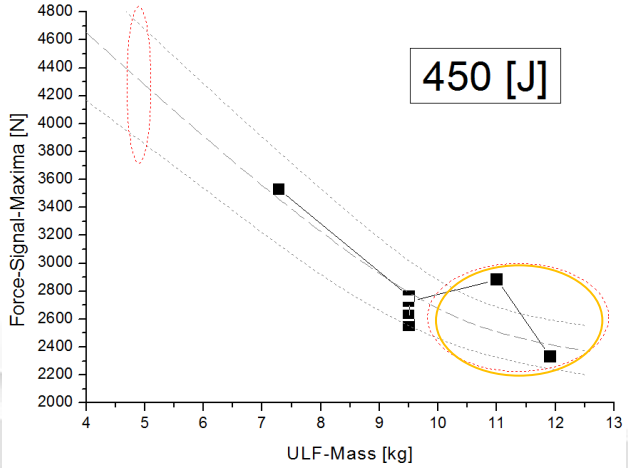
→ Due to the observed nonlinearity and the small number of data, an extrapolation of the signal values for lower ULF-masses implies large errors!

○ Results – signal-max. vs. mass (energy=const.)









→ Due to the observed nonlinearity and the small number of data, an extrapolation of the signal values for lower ULF-masses implies large errors!

→ For energies >400 Joule, an additional deviation occurs for higher masses (orange circles)!

Conclusion - I

- It has been observed, that the **force/torque-signal-maxima show a nonlinear characteristics as function of energy and impactor mass.**

- The **limited number of tests** did not allow to determine the reasons for the observed deviations at higher impactor masses and energies (>11 kg, >400 Joule).

- Due to the different materials used in the Toyota-ULF, the signals can not be compared directly. The correlation procedure is based on very few data, leading to rather large uncertainties in the corrected Toyota-ULF signal heights.

Conclusion - II

- As can be seen in the figures on the previous slides, **the conversion of signal heights** from one configuration to another, **can not be done by linear extrapolation, e.g. by simple conversion factors** and therefore is afflicted with large errors.

- **One possible solution would be to determine a nonlinear 2D-best-fit surface for each sensor-signal (central torque, upper/lower torque, bottom/top force), but this should be based on more experimental data** (see Appendix-III)! Nevertheless an extrapolation to impactor weights as low as 5 kg would still be only rough approximations.

- Another approach would be to perform FE-simulations of the present experimental setup. In this case, the minimum weight of the linear guiding system would not restrict the possible test configurations and the 5.0 kg signals could be determined virtually. The current set of data could be used as basis for a validation of the FE-impactor model.

○ Appendix – I

"Test-Data-Overview"

Test	Impactor-Type	Tot.-Mass ± 0,1 [kg]	Mass of lin.-guide [kg]	Mass of Impactor (foam, screws,..) [kg]	added mass [kg]	TOTAL MASS [kg]	Energy [J]	test vel. ± 0,1 [m/s]	test vel. [km/h]	actual velocity [m/s]	actual velocity [km/h]	Temperature [°C]	rel. humidity [%]
SA_1200_0710_03	SAIC	12.00	3.476	5.664	2.772	11.912	300	7.10	25.56	7.13	25.662	19.7	26.7
SA_1200_0710_05	SAIC	12.00	3.476	5.664	2.772	11.912	300	7.10	25.56	7.08	25.479	21.3	29.4
TE_1200_0710_01	Toyota	12.00	3.476	3.834	4.692	12.002	300	7.10	25.56	7.05	25.368	20.1	33.2
SA_1200_100_01	CC/TRL-ULF	12.00	3.476	5.664	2.772	11.912	100	4.08	14.70	4.04	14.546	21.6	23.1
SA_1200_200_01	CC/TRL-ULF	12.00	3.476	5.664	2.772	11.912	200	5.77	20.78	5.74	20.663	22.1	22.4
SA_1200_300_01	CC/TRL-ULF	12.00	3.476	5.664	2.772	11.912	300	7.07	25.46	7.11	25.613	21.9	22.3
SA_1200_400_01	CC/TRL-ULF	12.00	3.476	5.664	2.772	11.912	400	8.16	29.39	8.16	29.369	21.8	21.6
SA_1200_450_01	CC/TRL-ULF	12.00	3.476	5.664	2.772	11.912	450	8.66	31.18	8.72	31.376	21.8	20.3
SA_1100_100_01	CC/TRL-ULF	11.00	3.476	5.664	1.860	11.000	100	4.26	15.35	4.27	15.385	21.6	21.3
SA_1100_200_01	CC/TRL-ULF	11.00	3.476	5.664	1.860	11.000	200	6.03	21.71	5.99	21.577	21.7	21.3
SA_1100_300_01	CC/TRL-ULF	11.00	3.476	5.664	1.860	11.000	300	7.39	26.59	7.42	26.706	21.0	21.9
SA_1100_400_01	CC/TRL-ULF	11.00	3.476	5.664	1.860	11.000	400	8.53	30.70	8.52	30.672	21.7	22.3
SA_1100_450_01	CC/TRL-ULF	11.00	3.476	5.664	1.860	11.000	450	9.04	32.56	9.12	32.835	21.8	22.3
SA_0950_100_01	CC/TRL-ULF	9.50	3.476	5.664	0.358	9.498	100	4.59	16.52	4.59	16.506	20.9	28.0
SA_0950_200_01	CC/TRL-ULF	9.50	3.476	5.664	0.358	9.498	200	6.49	23.36	6.46	23.266	21.0	28.1
SA_0950_300_01	CC/TRL-ULF	9.50	3.476	5.664	0.358	9.498	300	7.95	28.61	7.93	28.563	21.1	28.1
SA_0950_400_01	CC/TRL-ULF	9.50	3.476	5.664	0.358	9.498	400	9.18	33.04	9.16	32.983	21.1	28.8
SA_0950_450_01	CC/TRL-ULF	9.50	3.476	5.664	0.358	9.498	450	9.73	35.04	9.77	35.183	21.1	29.4
COMPARE_SA_0950_100_01	CC/TRL-ULF	9.50	3.476	5.664	0.358	9.498	100	4.59	16.52	4.58	16.503	20.7	30.3
COMPARE_SA_0950_450_01	CC/TRL-ULF	9.50	3.476	5.664	0.358	9.498	450	9.73	35.04	9.75	35.088	20.9	30.0
COMPARE_TE_0950_100_01	Toyota	9.50	3.476	5.318	0.714	9.508	100	4.59	16.52	4.58	16.484	20.7	28.7
COMPARE_TE_0950_100_02	Toyota	9.50	3.476	5.318	0.714	9.508	100	4.59	16.52	4.57	16.442	20.8	28.8
COMPARE_TE_0950_450_01	Toyota	9.50	3.476	5.318	0.714	9.508	450	9.73	35.04	9.72	34.983	20.8	28.4
COMPARE_TE_0950_450_02	Toyota	9.50	3.476	5.318	0.714	9.508	450	9.73	35.04	9.74	35.074	20.8	28.5
TE_0750_100_01	Toyota	7.30	3.476	3.808	0.00	7.284	100	5.16	18.59	5.15	18.550	21.2	27.8
TE_0750_200_01	Toyota	7.30	3.476	3.808	0.00	7.284	200	7.30	26.29	7.31	26.298	21.1	28.8
TE_0750_300_01	Toyota	7.30	3.476	3.808	0.00	7.284	300	8.94	32.20	8.89	32.016	21.4	28.6
TE_0750_400_01	Toyota	7.30	3.476	3.808	0.00	7.284	400	10.33	37.18	10.30	37.074	21.4	27.6
TE_0750_450_01	Toyota	7.30	3.476	3.808	0.00	7.284	450	10.96	39.44	10.96	39.458	21.5	26.6

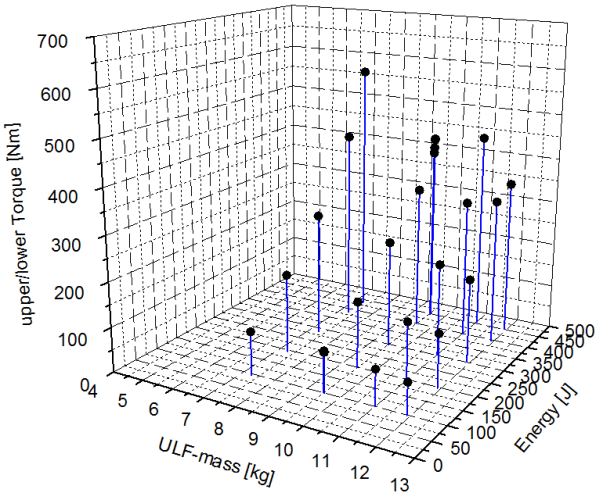
○ Appendix – II

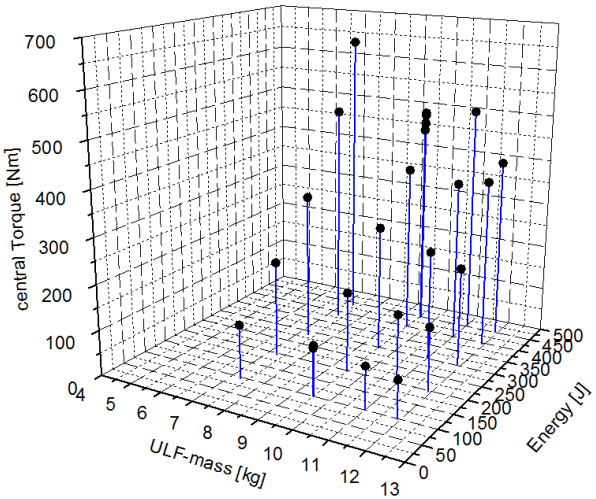
"Overview of corrected signal maxima"

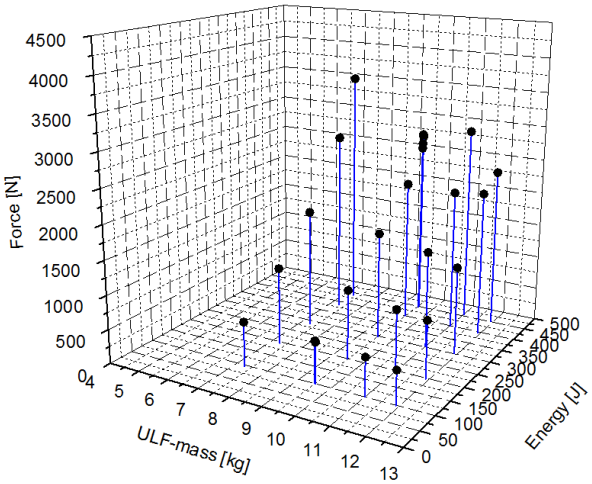
Test	Mass [kg]	Vel [m/s]	Energy [J]	Mu [Nm]	Mc [Nm]	Ml [Nm]	Fb [N]	Ft [N]	<M-ul> [Nm]	<M-c> [Nm]	<F-bt> [N]	Mul-scale	Mc-scale	F-scale
SA_1200_100_01	11.912	4.070	98.661	70.955	81.815	68.610	494.090	487.175	69.78	81.82	490.63	1	1	1
SA_1100_100_01	11.000	4.270	100.281	79.907	92.620	78.654	553.879	557.099	79.28	92.62	555.49	1	1	1
SA_0950_100_01	9.498	4.590	100.052	88.877	103.266	87.444	593.166	617.650	88.16	103.27	605.41	1	1	1
COMPARE_SA_0950_100_01	9.498	4.580	99.617	90.292	104.624	89.032	598.268	630.719	89.66	104.62	614.49	1	1	1
COMPARE_TE_0950_100_01	9.508	4.580	99.722	98.953	125.655	99.678	686.680	638.212	88.51	107.77	595.06	1.12202	1.16593	1.11325
COMPARE_TE_0950_100_02	9.508	4.570	99.287	102.613	128.577	102.741	709.679	662.143	91.51	110.28	616.13	1.12202	1.16593	1.11325
TE_0750_100_01	7.284	5.150	96.595	107.856	137.325	108.515	755.451	685.838	96.42	117.78	647.33	1.12202	1.16593	1.11325
SA_1200_200_01	11.912	5.740	196.236	120.777	139.385	118.182	837.557	852.464	119.48	139.39	845.01	1	1	1
SA_1100_200_01	11.000	5.990	197.341	131.397	150.896	126.940	900.827	899.165	129.17	150.90	900.00	1	1	1
SA_0950_200_01	9.498	6.460	198.183	150.243	173.450	146.423	1025.571	1014.326	148.33	173.45	1019.95	1	1	1
TE_0750_200_01	7.284	7.310	194.614	197.323	245.738	200.147	1324.861	1214.980	177.12	210.77	1140.73	1.12202	1.16593	1.11325
SA_1200_300_01	11.912	7.110	301.088	191.596	217.019	181.940	1304.953	1260.787	186.77	217.02	1282.87	1	1	1
SA_1100_300_01	11.000	7.420	302.810	212.190	239.653	201.098	1446.975	1393.956	206.64	239.65	1420.47	1	1	1
SA_0950_300_01	9.498	7.930	298.640	241.856	275.598	234.089	1593.172	1559.086	237.97	275.60	1576.13	1	1	1
TE_0750_300_01	7.284	8.890	287.835	306.511	376.651	312.524	2033.745	1862.859	275.86	323.05	1750.10	1.12202	1.16593	1.11325
SA_1200_400_01	11.912	8.160	396.584	330.941	371.818	316.458	2174.166	2081.535	323.70	371.82	2127.85	1	1	1
SA_1100_400_01	11.000	8.520	399.247	318.723	356.980	300.432	2141.952	1999.104	309.58	356.98	2070.53	1	1	1
SA_0950_400_01	9.498	9.160	398.468	327.186	373.475	318.679	2098.276	2099.386	322.93	373.48	2098.83	1	1	1
TE_0750_400_01	7.284	10.300	386.380	477.586	571.862	485.434	3157.125	2845.530	429.15	490.48	2696.00	1.12202	1.16593	1.11325
SA_1200_450_01	11.912	8.720	452.885	356.242	397.332	334.713	2406.375	2253.404	345.48	397.33	2329.89	1	1	1
SA_1100_450_01	11.000	9.120	457.459	451.860	503.410	429.319	2960.060	2805.173	440.59	503.41	2882.62	1	1	1
SA_0950_450_01	9.498	9.770	453.306	435.090	489.340	418.467	2769.638	2686.067	426.78	489.34	2727.85	1	1	1
COMPARE_SA_0950_450_01	9.498	9.750	451.452	416.393	466.172	395.163	2673.477	2574.802	405.78	466.17	2624.14	1	1	1
COMPARE_TE_0950_450_01	9.508	9.720	449.150	439.216	526.466	447.322	2966.854	2723.895	395.06	451.54	2555.92	1.12202	1.16593	1.11325
COMPARE_TE_0950_450_02	9.508	9.740	451.001	473.062	565.524	481.955	3212.171	2940.382	425.58	485.04	2763.33	1.12202	1.16593	1.11325
TE_0750_450_01	7.284	10.960	437.483	634.902	745.301	641.629	4118.545	3737.649	568.85	639.23	3528.49	1.12202	1.16593	1.11325

○ Appendix – III

"signal maxima 3D-plots"







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