

Statistical Analysis of FLASH-uptime- and downtime-durations

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- 1. Motivation**
- 2. Descriptive Analysis and Results**
- 3. Mathematical Analysis and Results**
- 4. Conclusion and Outlook**



- **Objective judgement of actual FLASH-uptime and downtime-data**
- **Adaquate treatment of reliability and availability**
- **Projection from FLASH on XFEL and ILC**

Logbook-entries

Operation-status:

Beamdelivery
Accelerator-development
Tuning
Offtime
Downtime-total

Downtime-reasons:

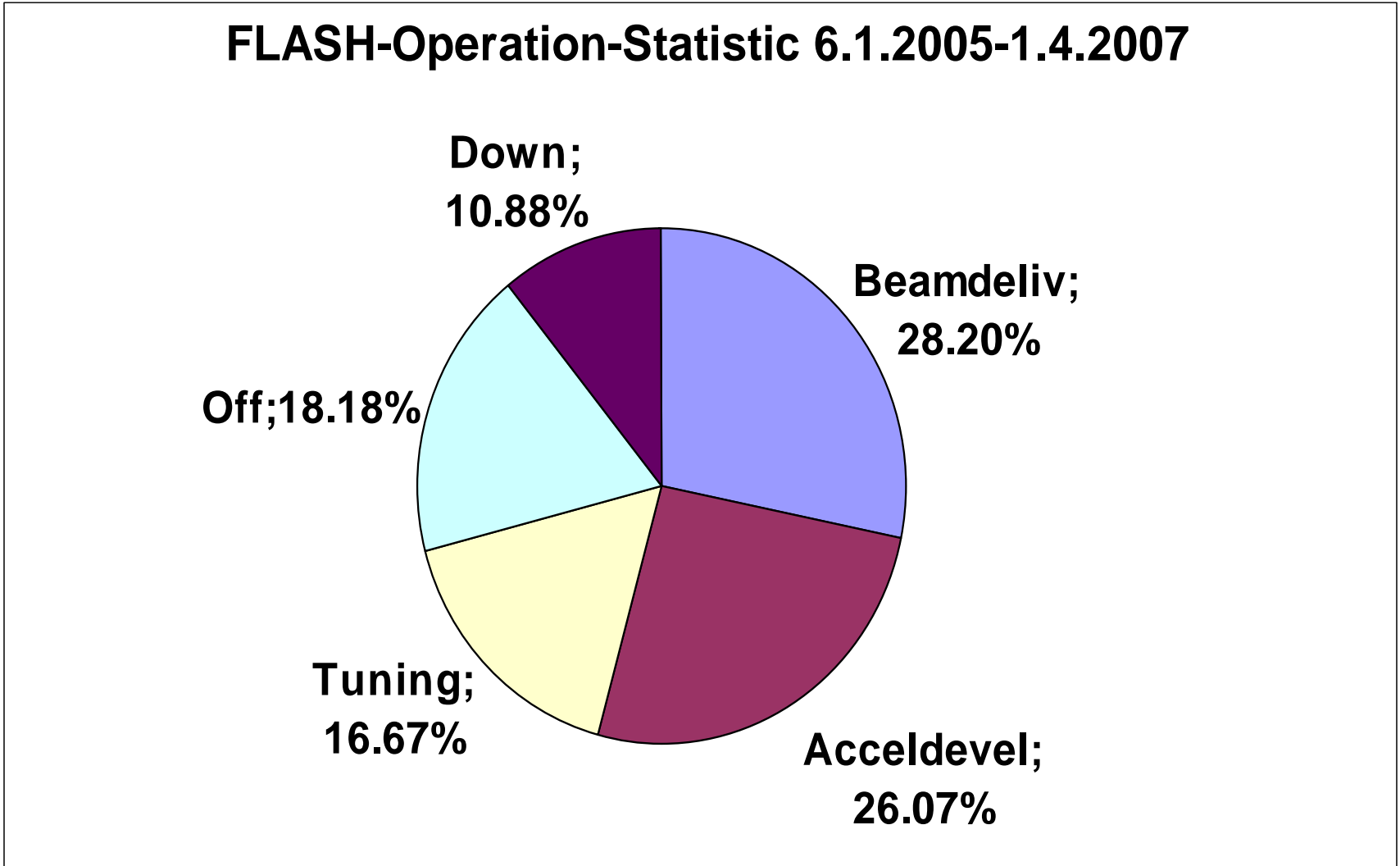
Laser
Kryo
Vacuum
Magnets
Controls
Klystron
LLRF
Diagnosis
Water/Mains
MPS
Photon-Beamline
Operator
Other

Raw data list for FLASH-Operation-status and Downtime-reasons

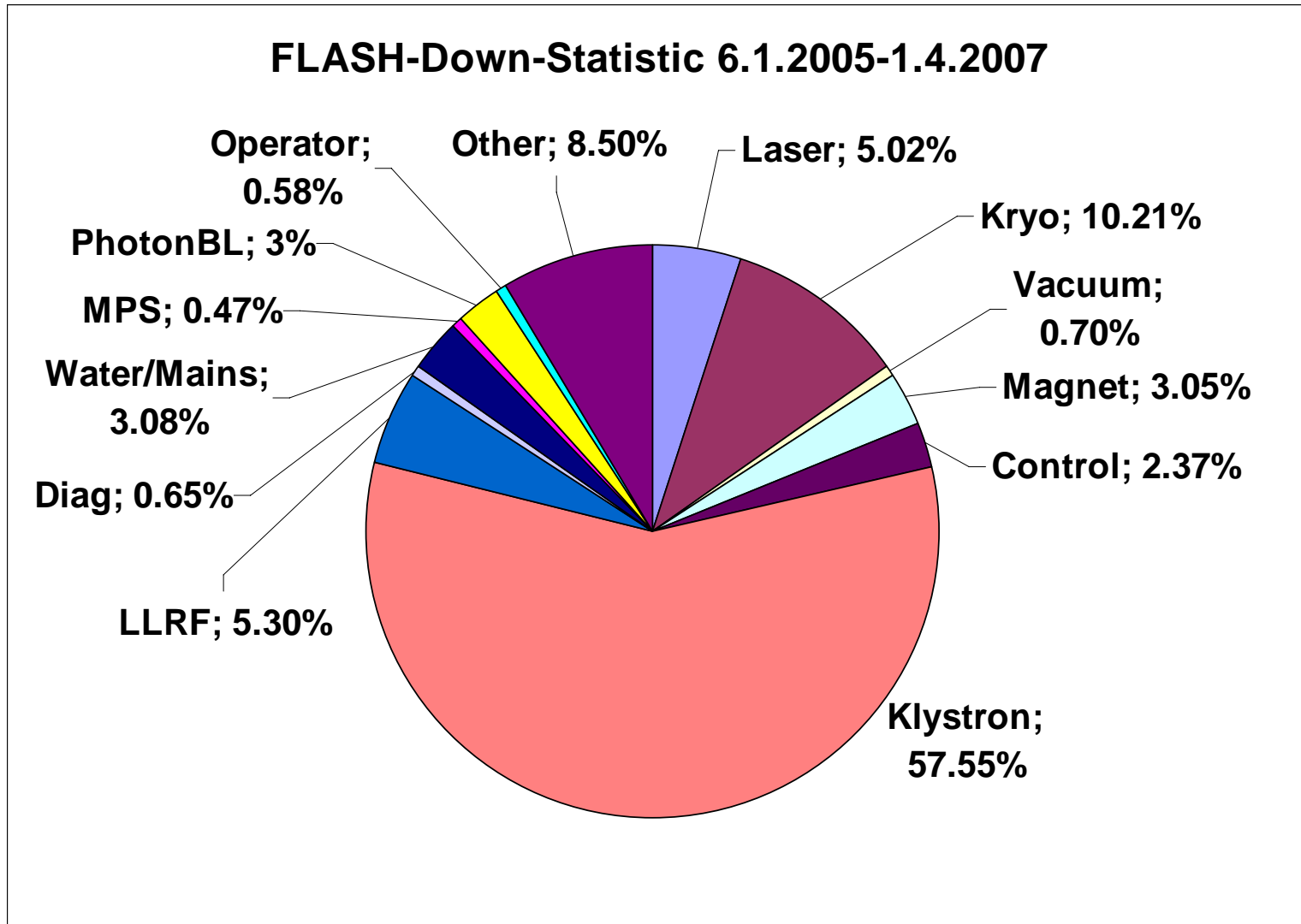
FLASH-Operations-Statistik-Urliste 2005ff aus Logbuch bis 1.4.2007_3

shift-date	beamd	accdev	tuning	offime	downir	laser	kryo	vacuun	magne	control	klystro
06/01/2005	0	0	8	0	0	0	0	0	0	0	0
06/01/2005	0	0	8	0	0	0	0	0	0	0	0
07/01/2005	0	5.5	0	2.5	0	0	0	0	0	0	0
07/01/2005	0	0	0	0	0	0	0	0	0	0	0
07/01/2005	0	0	8	0	0	0	0	0	0	0	0
08/01/2005	0	8	0	0	0	0	0	0	0	0	0
08/01/2005	0	0	8	0	0	0	0	0	0	0	0
08/01/2005	0	0	0	0	0	0	0	0	0	0	0
09/01/2005	0	0	5	0	3	0	0	0	0	0	2
09/01/2005	0	8	0	0	0	0	0	0	0	0	0
09/01/2005	0	3	5	0	0	0	0	0	0	0	0
10/01/2005	0	0	0	0	0	0	0	0	0	0	0
10/01/2005	0	0	8	0	0	0	0	0	0	0	0
10/01/2005	0	0	7.3	0.5	0.2	0	0	0	0	0	0.2
11/01/2005	0	0	0.5	7.5	0	0	0	0	0	0	0
11/01/2005	0	0	0	0	0	0	0	0	0	0	0
11/01/2005	0	8	0	0	0	0	0	0	0	0	0

Pie chart of FLASH-Operation



Pie chart of FLASH-Down



SASE-delivery for Users

1.User-Run:

cw 30 – 31 2005
cw 34 – 35 2005
cw 42 – 45 2005
cw 48 2005
cw 50 – 51 2005
cw 3 - 8 2006

349 shifts

2.User-Run:

cw 19 – 22 2006
cw 26 – 26 2006
cw 28 – 29 2006
cw 36 – 39 2006
cw 45 – 49 2006
cw 5 - 6 2007
cw 9 - 12 2007

462 shifts

FLASH 1.User-RUN raw data list

FLASH-Operations-Statistik-Urliste 1.User-Run

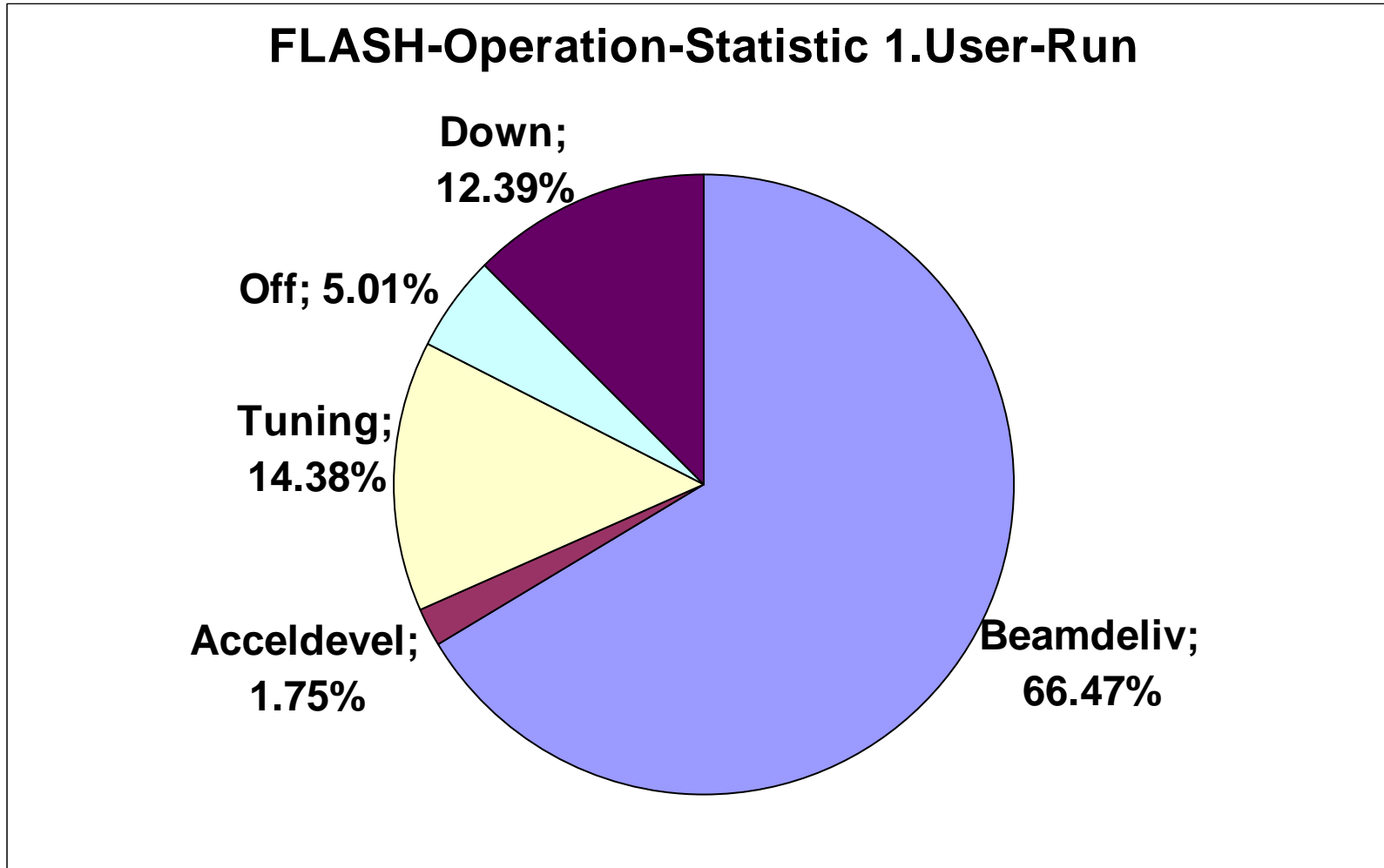
shift ra	beamd	accdev	tuning	offtime	downti	laser	kryo	vacuun	magne	control	klystro
602	7	0	0	0	1	0	0	0	0	0	1
603	6	0	0	0	2	0	0	0	0	0	0
604	0	0	8	0	0	0	0	0	0	0	0
605	0	0	3	5	0	0	0	0	0	0	0
606	0	0	5	0	3	0	0	0	0	0	0
607	7.5	0	0	0	0.5	0	0	0	0	0	0.5
608	2	0	6	0	0	0	0	0	0	0	0
609	7.5	0	0.5	0	0	0	0	0	0	0	0
610	8	0	0	0	0	0	0	0	0	0	0
611	5.2	0	2	0	0.8	0	0	0	0	0	0.8
612	6	0	0.5	0	1.5	0	0	0	0	1	0.5
613	5	0	3	0	0	0	0	0	0	0	0
614	5	0	0.5	0	2.5	0	2	0	0	0	0.5
615	0	3	0	0	5	0	5	0	0	0	0
616	0	0	0	0	8	0	8	0	0	0	0
617	0	0	0	0	8	0	8	0	0	0	0

FLASH 2.User-RUN raw data list

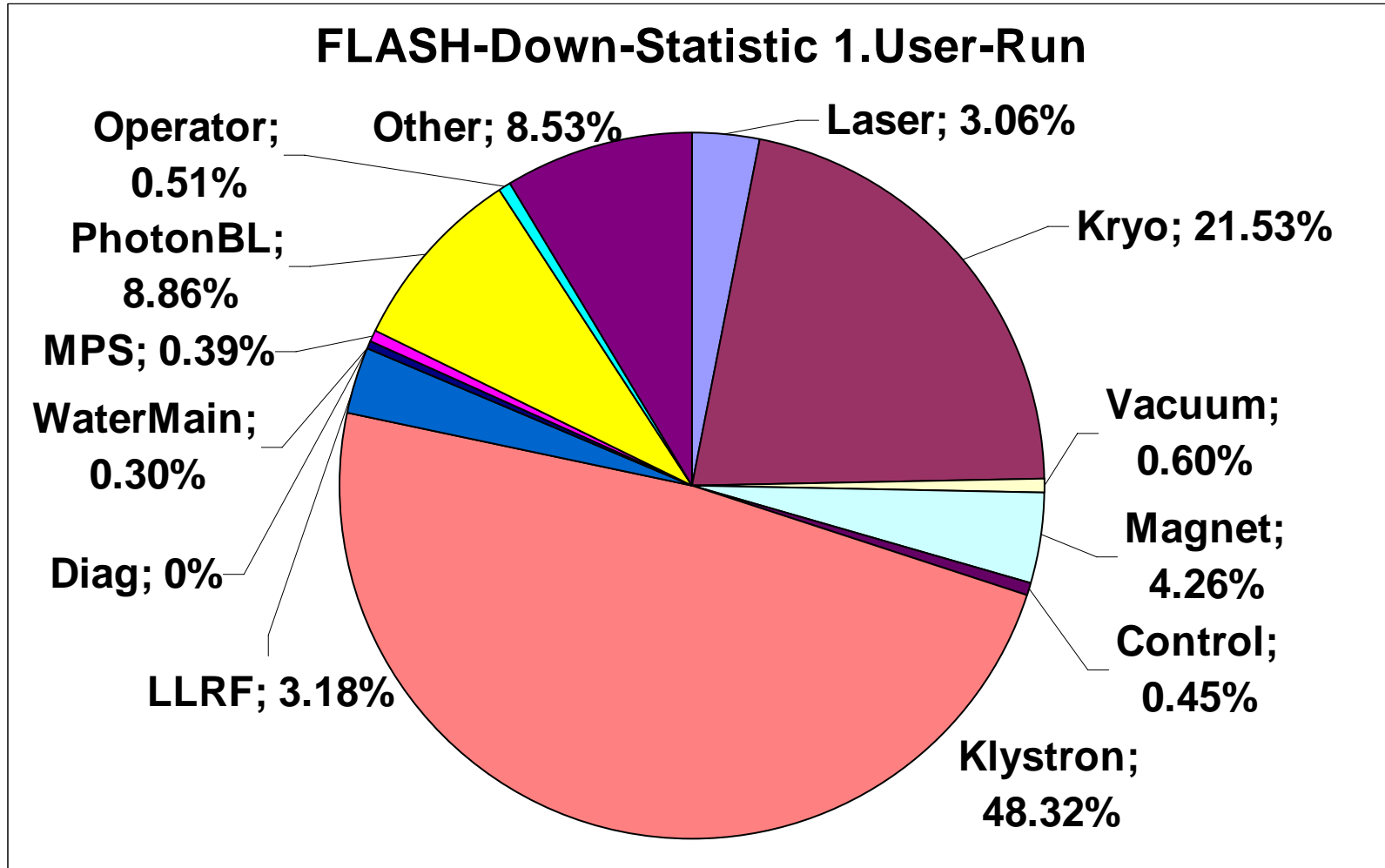
FLASH-Operations-Statistik-Urliste 2.User-Run

shift ra	beamd	accdev	tuning	offtime	downti	laser	kryo	vacuun	magne	control	klystron
1463	7.2	0	0	0	0.8	0	0	0	0	0	0.8
1464	8	0	0	0	0	0	0	0	0	0	0
1465	0	0	5	0	3	0	0	0	0	0	0
1466	0	0	0	0	0	0	0	0	0	0	0
1467	0	0	8	0	0	0	0	0	0	0	0
1468	0	2.5	1	0	4.5	0	0	0	0	3	1.5
1469	7	0	0	0	1	0	0	0	0	0	0
1470	1	0	6	0	1	0	0	0	0	0	0
1471	0	0	6	0	0	0	0	0	0	0	0
1472	8	0	0	0	0	0	0	0	0	0	0
1473	8	0	0	0	0	0	0	0	0	0	0
1474	0	0	0	0	0	0	0	0	0	0	0
1475	8	0	0	0	0	0	0	0	0	0	0
1476	8	0	0	0	0	0	0	0	0	0	0
1477	8	0	0	0	0	0	0	0	0	0	0
1478	8	0	0	0	0	0	0	0	0	0	0

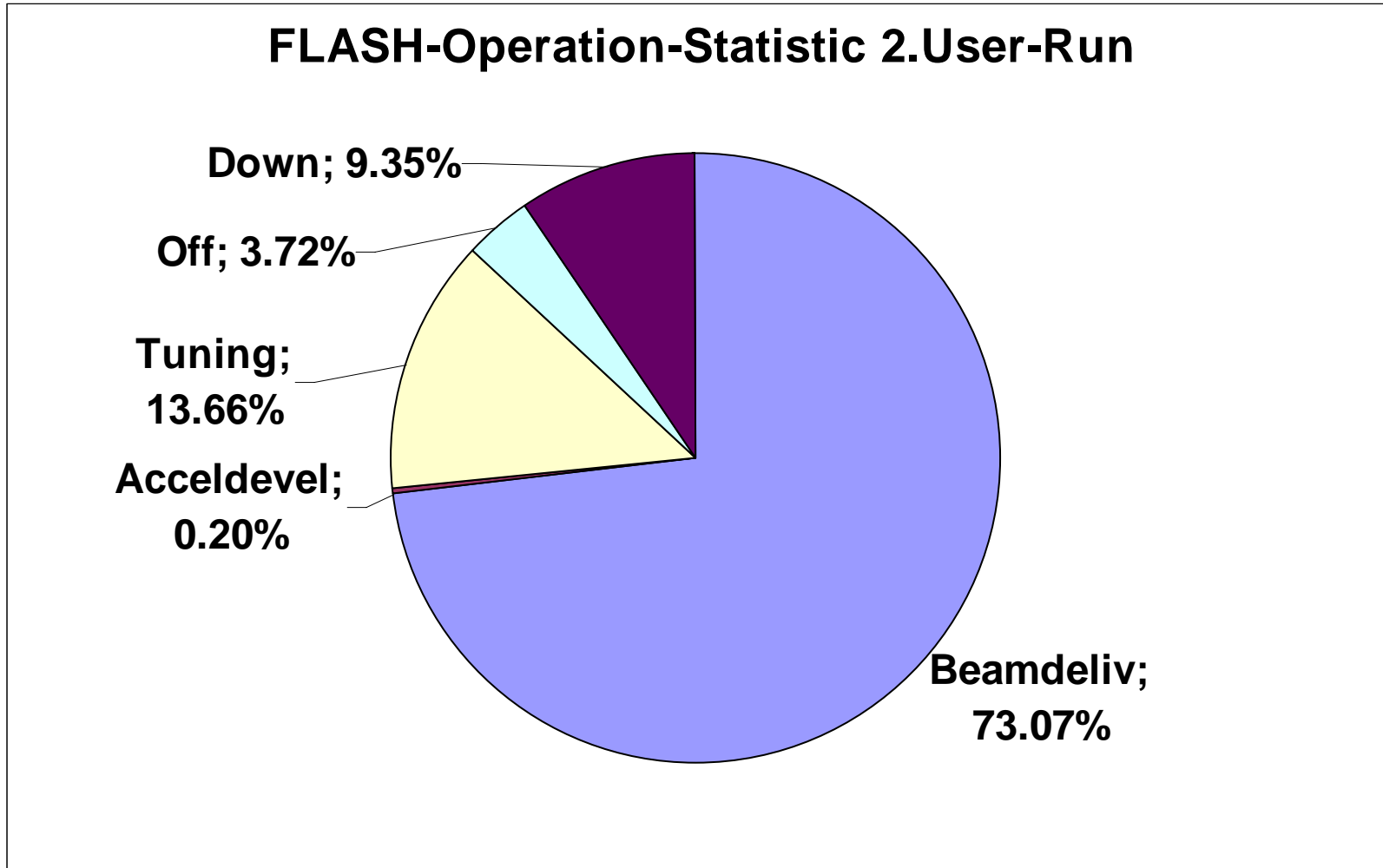
Pie chart of FLASH-Operation 1.User-Run



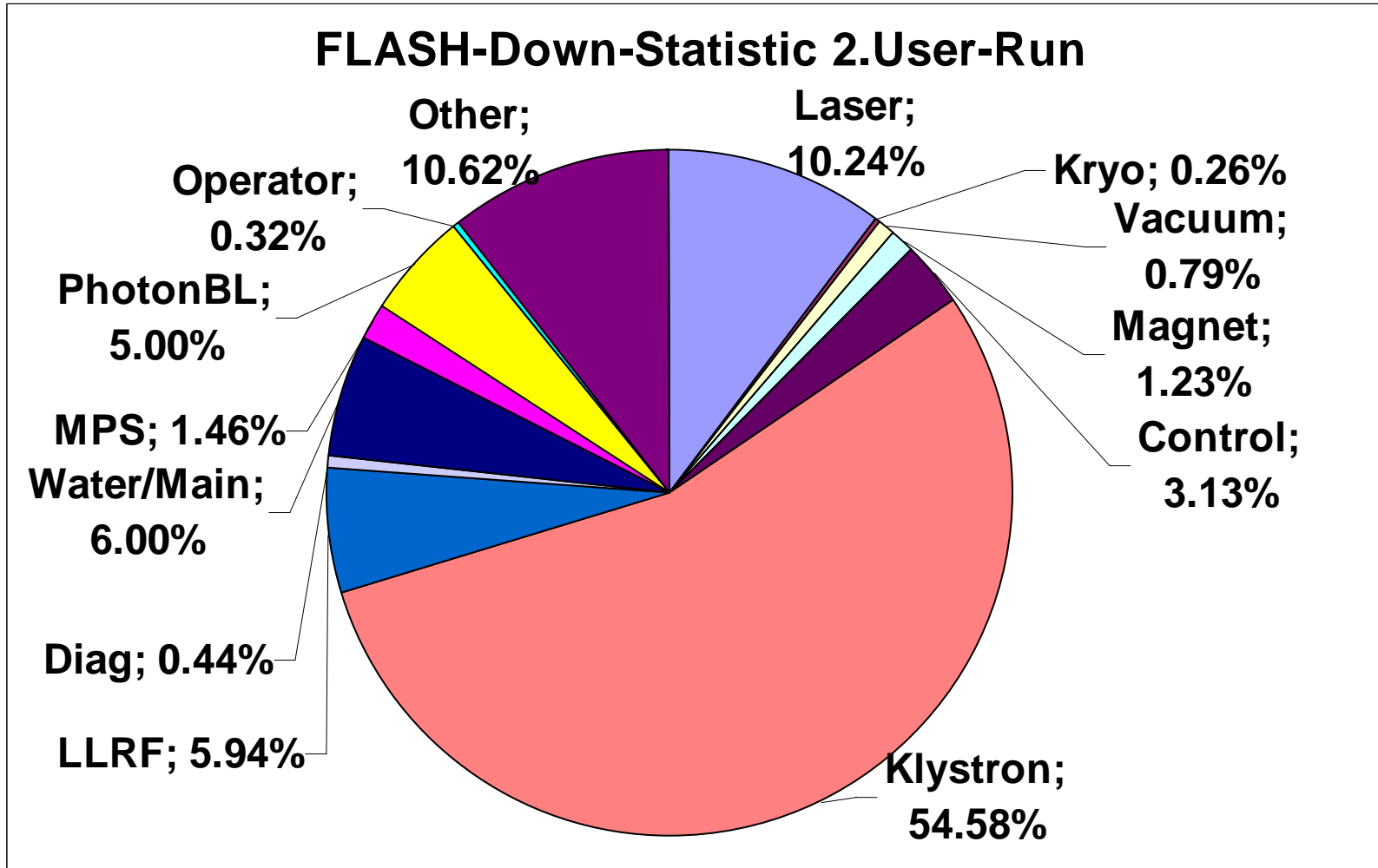
Pie chart of FLASH-Down 1.User-Run



Pie chart of FLASH-Operation 2.User-Run



Pie chart of FLASH-Down 2.User-Run



Weibull-Distribution

$$G(t, T, b, t_0) = 1 - \exp\left[-\left(\frac{t - t_0}{T}\right)^b\right] = \text{failure-probability, event-probability}$$

T = scale-parameter = characteristic time

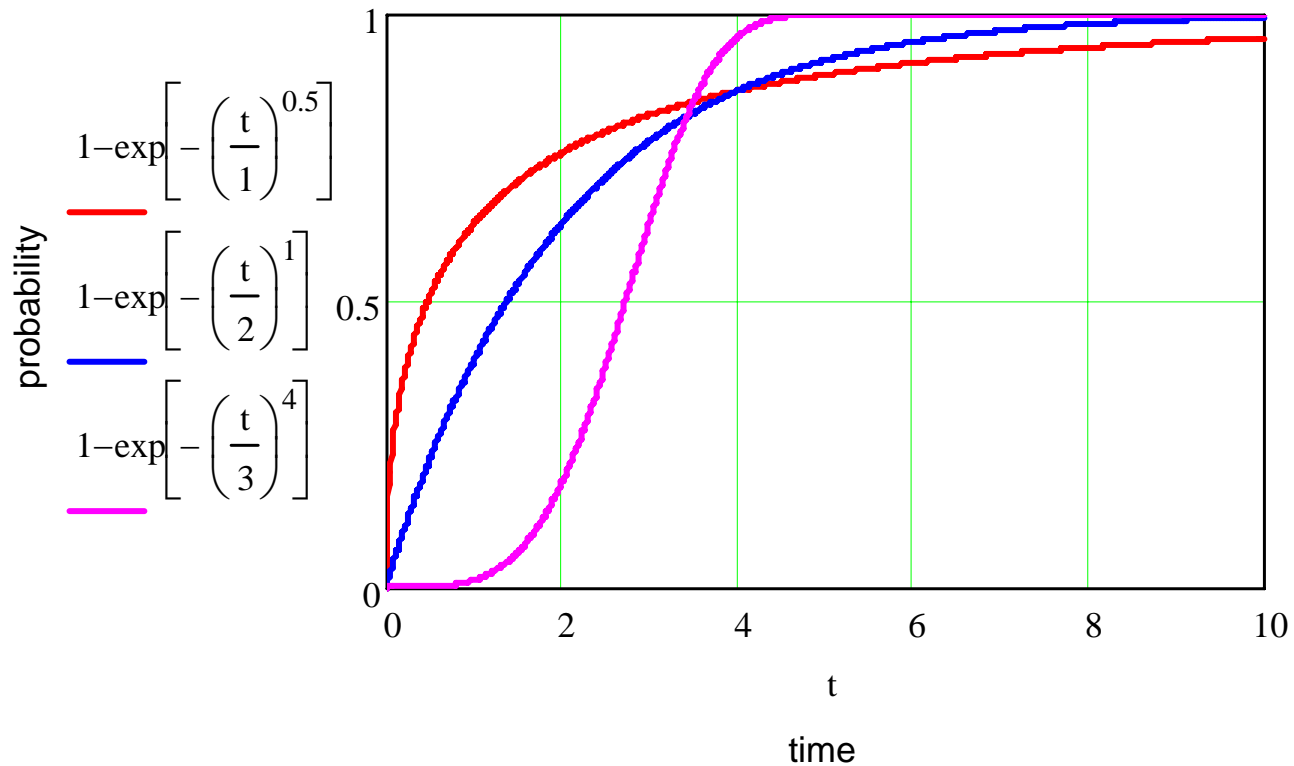
b = shape-parameter = failure-slope

t_0 = location-parameter = failure-free time

$T > 0$, $b > 0$, t_0 arbitrary real; t = continuous random variable, $t > t_0$; $G(t=0) = 0$, $g(t=0) = 0$

Weibull-Distribution (2-parametric)

$$t := 0, 0.01.. 10 \quad G(t, T, b) := 1 - \exp\left[-\left(\frac{t}{T}\right)^b\right]$$

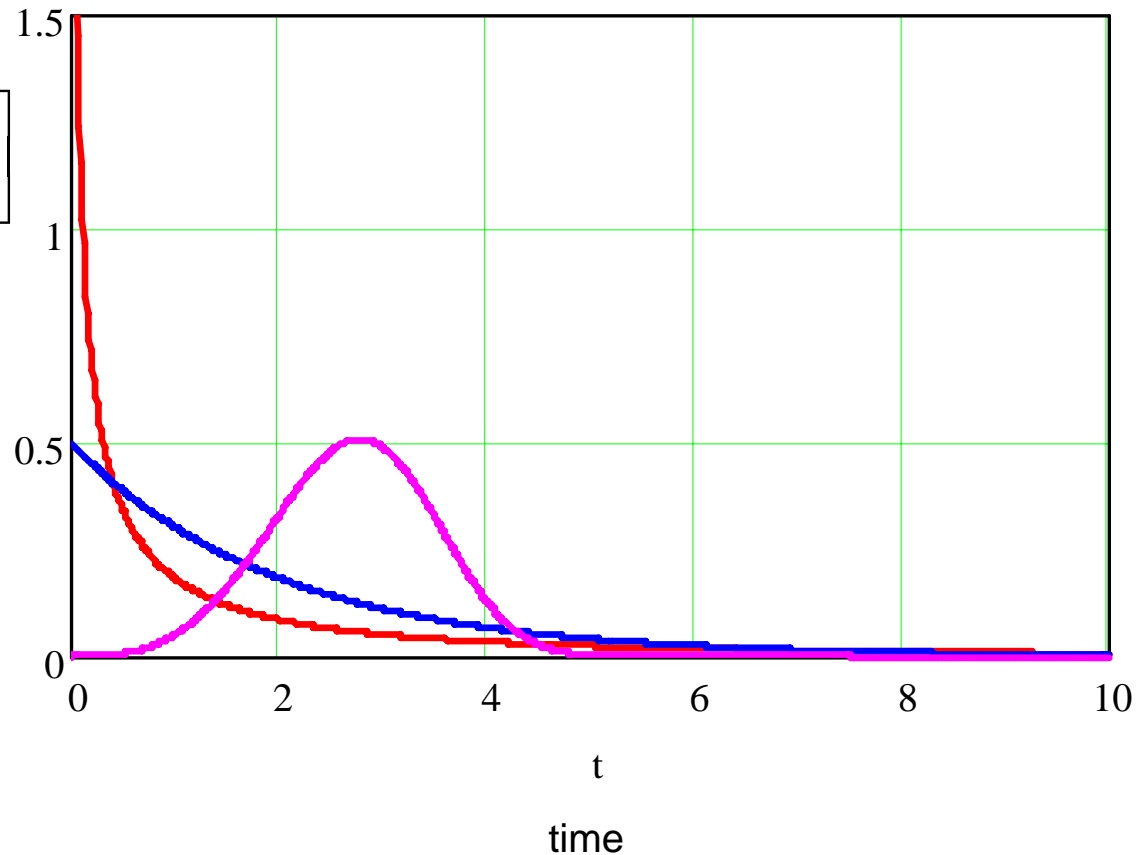


Weibull-Distribution-Density (2-parametric)

$$g(t, T, b) := \left(\frac{t}{T}\right)^{b-1} \cdot \frac{b}{T} \cdot \exp\left[-\left(\frac{t}{T}\right)^b\right]$$

probability/time

$$\frac{\left(\frac{t}{1}\right)^{0.5-1} \cdot \frac{0.5}{1} \cdot \exp\left[-\left(\frac{t}{1}\right)^{0.5}\right]}{\left(\frac{t}{2}\right)^{1-1} \cdot \frac{1}{2} \cdot \exp\left[-\left(\frac{t}{2}\right)^1\right]} \cdot \frac{\left(\frac{t}{3}\right)^{4-1} \cdot \frac{4}{3} \cdot \exp\left[-\left(\frac{t}{3}\right)^4\right]}{\left(\frac{t}{3}\right)^{4-1} \cdot \frac{4}{3} \cdot \exp\left[-\left(\frac{t}{3}\right)^4\right]}$$



Klystron from 1.User-Run-raw-data-list for analysis as example

FLASH-Operations-Statistik-Urliste 1.User-Run												klystron	llrf
shift	ra	beamd	accdev	tuning	offtime	downti	laser	kryo	vacuun	magne	control		
602		7	0	0	0	1	0	0	0	0	0	1	0
603		6	0	0	0	2	0	0	0	0	0	0	2
604		0	0	8	0	0	0	0	0	0	0	0	0
605		0	0	3	5	0	0	0	0	0	0	0	0
606		0	0	5	0	3	0	0	0	0	0	0	0
607		7.5	0	0	0	0.5	0	0	0	0	0	0.5	0
608		2	0	6	0	0	0	0	0	0	0	0	0
609		7.5	0	0.5	0	0	0	0	0	0	0	0	0
610		8	0	0	0	0	0	0	0	0	0	0	0
611		5.2	0	2	0	0.8	0	0	0	0	0	0.8	0
612		6	0	0.5	0	1.5	0	0	0	0	1	0.5	0
613		5	0	3	0	0	0	0	0	0	0	0	0
614		5	0	0.5	0	2.5	0	2	0	0	0	0.5	0
615		0	3	0	0	5	0	5	0	0	0	0	0
616		0	0	0	0	8	0	8	0	0	0	0	0
617		0	0	0	0	8	0	8	0	0	0	0	0

1. User-Run Klystron Result: uptime/downtime-event-list

FLASH-1. User-Run RF-Stations				
no.	uptime(h)	downtime(h)	shiftno.	shiftdate
1	7	1	602	"07/25/2005"
2	39.5	0.5	607	"07/26/2005"
3	31.2	0.8	611	"07/28/2005"
4	7.5	0.5	612	"07/28/2005"
5	15.5	0.5	614	"07/29/2005"
6	76	4	624	"08/01/2005"
7	15.7	0.3	626	"08/02/2005"
...
70	7.8	0.2	1226	"02/18/2006"
71	31.6	0.4	1230	"02/19/2006"
72	23.9	0.1	1233	"02/20/2006"
73	4	4	1234	"02/20/2006"
74	63	1	1243	"02/23/2006"
75	7.5	0.5	1244	"02/24/2006"
76	7.7	0.3	1245	"02/24/2006"

1. User-Run Klystron Result: Maximum-Likelyhood-Estimates (MLEs)

uptime:	characteristic time	TB = 30.551 h
	event-slope	bB = 0.940
	event-free-time	tOB = - 0.018 h

downtime:	characteristic time	TS = 0.952 h
	event-slope	bS = 0.742
	event-free-time	tOS = 0. h

1. User-Run Klystron Result: 95%-confidence-ranges of MLEs (*)

uptime:	characteristic time	TBI = 23.365 h	TBU = 39.693 h
	event-slope	bBI = 0.772	bBU = 1.109
	event-free-time	tOBI = - 0.023 h	tOBU = - 0.013 h
downtime:	characteristic time	TSI = 0.678 h	TSu = 1.327 h
	event-slope	bSI = 0.609	bSu = 0.875
	event-free-time	tOSI = 0. h	tOSu = 0. h

(*) "Inferences on the Parameters of the Weibull Distribution";
 D.R.Thoman, L.J.Bain, C.E.Antle; 1969

1. User-Run Klystron Result: MLE-based up-and downtime-expectation-values, availability, cycle-time and 95%-confidence-ranges

MLE-based expectation-values and their 95%-confidence-ranges for uptime and downtime:

uptime: ETB = 31.423 h
ETBI = 22.487 h
ETBu = 46.188 h

downtime: ETS = 2.144 h
ETSI = 0.725 h
ETSu = 1.958 h

MLE-based availability (A), cycle-time (C) and 95%-confidence-ranges:

A=ETB/(ETB+ETS):

A = 0.94

AI = 0.97 (at C=23.2h)

Au = 0.99 (at C=46.9h)

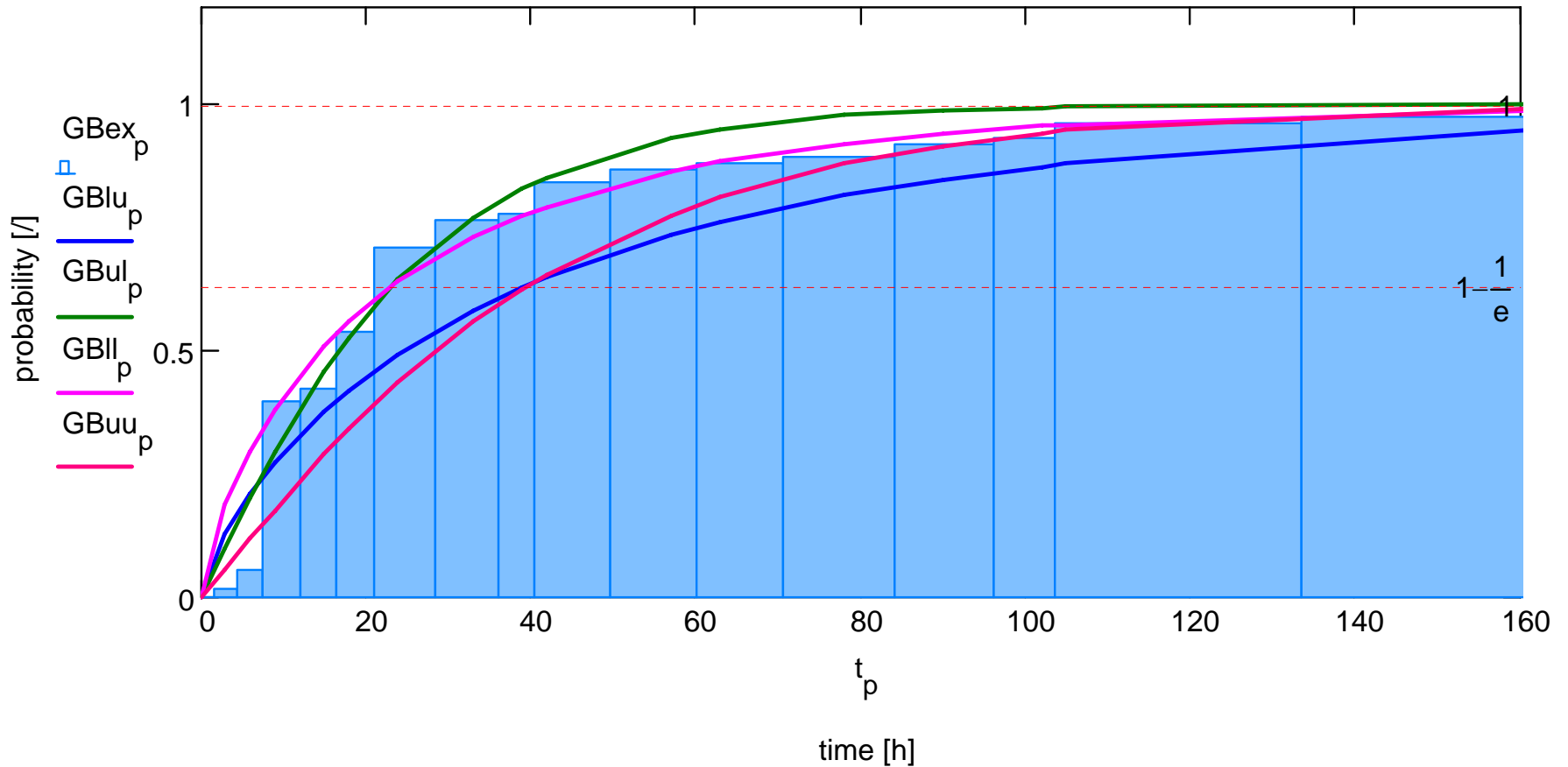
C=ETB+ETS:

C = 33.6 h

CI = 23.2 h (at A=0.97)

Cu = 48.2 h (at A=0.96)

Klystron 1. User-Run failure-probability(G) for end of uptime(B):
GBex = cumulated experimental(ex) data and Weibull-95%-confidence-ranges



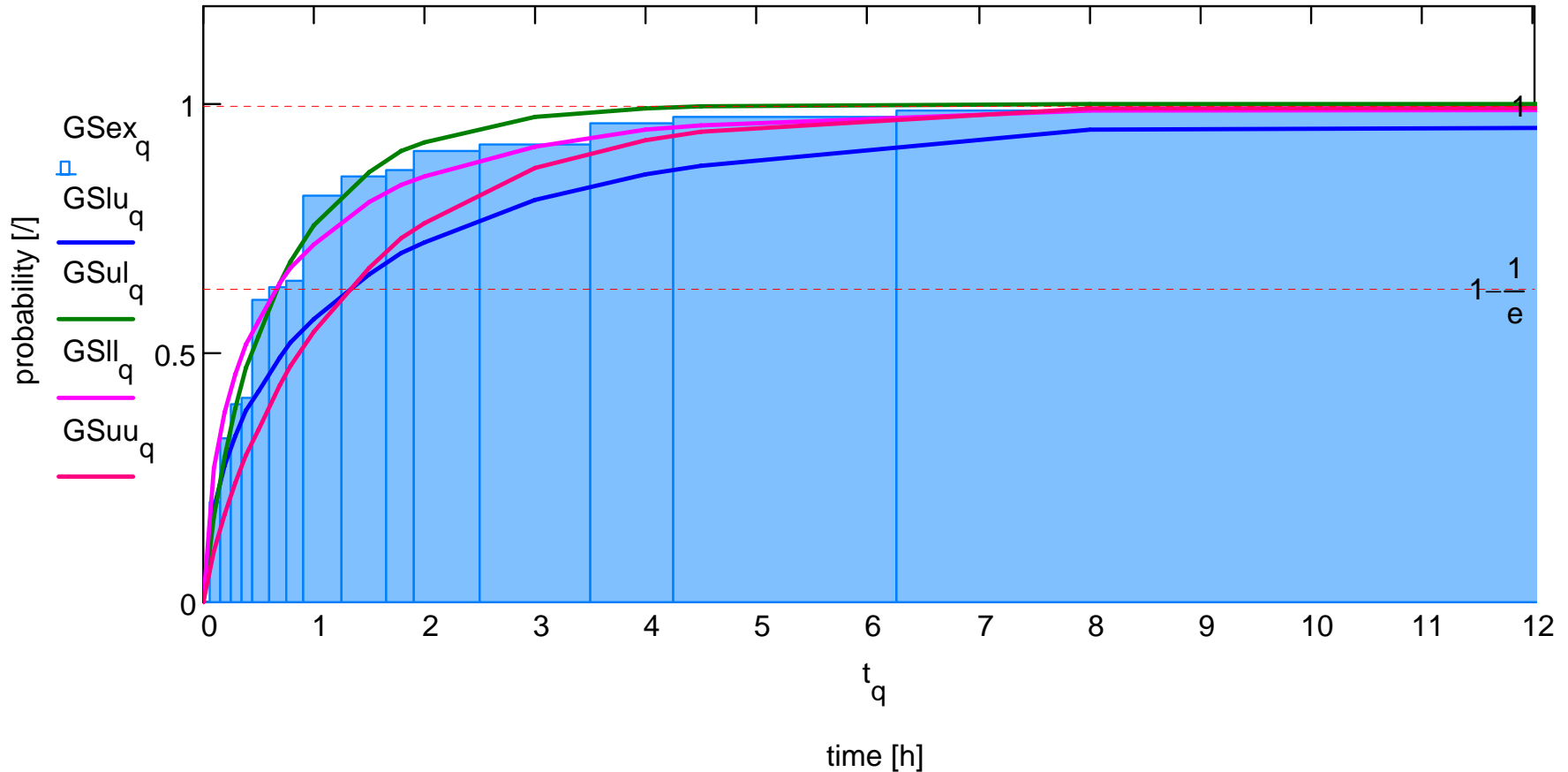
$$GBu(t_p) = 1 - \exp\left[-\left(\frac{t_p}{TBu}\right)^{bBu}\right]$$

$$GBul(t_p) = 1 - \exp\left[-\left(\frac{t_p}{TBI}\right)^{bBu}\right]$$

$$GBll(t_p) = 1 - \exp\left[-\left(\frac{t_p}{TBI}\right)^{bBl}\right]$$

$$GBuu(t_p) = 1 - \exp\left[-\left(\frac{t_p}{TBu}\right)^{bBu}\right]$$

Klystron 1. User-Run failure-probability(G) for end of downtime(S):
GS_{ex} = cumulated experimental(ex) data and Weibull-95%-confidence-ranges



$GSu_q(t_q) = 1 - \exp\left[-\left(\frac{t_q}{TSu}\right)^{bSl}\right]$	$GSul_q(t_q) = 1 - \exp\left[-\left(\frac{t_q}{TSI}\right)^{bSu}\right]$	$GSII_q(t_q) = 1 - \exp\left[-\left(\frac{t_q}{TSI}\right)^{bSl}\right]$	$GSuu_q(t_q) = 1 - \exp\left[-\left(\frac{t_q}{TSu}\right)^{bSu}\right]$
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Results of 1. and 2.User-Run

1.User-Run	n[-]	TB[h]	TBI[h]	Tbu[h]	bB[-]	bBI[-]	bBu[-]	ETB[h]	ETBI[h]	ETBu[h]	TS[h]	TSI[h]	TSu[h]
Laser1	6	234.4	53	1169	0.829	0.298	1.388	259.3	48.37	1.12E+04	1.953	1.282	3.077
Kryo1	7	149.7	33.78	732.7	0.719	0.294	1.157	184.8	32.09	7477	5.657	0.915	39.49
Vacuum1	2	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
Magnet1	11	161.9	75.06	354.9	0.995	0.527	1.463	162.2	67.98	647.8	1.132	0.559	2.329
Control1	2	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
Klystron1	76	30.55	23.36	39.69	0.94	0.772	1.109	31.43	22.49	46.19	0.952	0.678	1.327
LLRF1	11	144.1	58.18	363.9	0.843	0.446	1.239	157.6	54.3	919.7	1.176	0.672	2.081
Diag1	0	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
Water/Main1	1	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
MPS1	3	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
PhotonBL1	9	87.49	30.83	259.1	0.843	0.404	1.284	95.7	28.54	838.9	3.595	1.751	7.6
Operator1	3	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
Other1	20	96.17	55.67	164.9	0.966	0.629	1.303	97.66	51.39	234.1	1.787	1.083	2.928
Downtotal1	129	19.24	16.36	22.11	1.217	1.053	1.381	18.03	14.95	21.66	1.843	1.41	2.276

2.User-Run	n[-]	TB[h]	TBI[h]	Tbu[h]	bB[-]	bBI[-]	bBu[-]	ETB[h]	ETBI[h]	ETBu[h]	TS[h]	TSI[h]	TSu[h]
Laser2	19	133.5	81.99	216.3	1.116	0.717	1.516	128.2	73.93	267.9	1.809	1.078	3.02
Kryo2	2	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"n"	"na"	"na"
Vacuum2	3	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"n"	"na"	"na"
Magnet2	7	157	40.62	664.1	0.792	0.323	1.274	179.2	37.67	4479	0.713	0.487	1.07
Control2	8	267	123.8	604.1	1.25	0.558	1.948	248.6	109.8	1005	1.446	0.662	3.318
Klystron2	109	30.81	25.54	39.75	1.064	0.905	1.223	30.07	23.91	41.69	1.361	1.059	1.913
LLRF2	25	104.7	61.36	177.3	0.869	0.598	1.141	112.4	58.53	268	0.739	0.48	1.129
Diag2	2	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"n"	"na"	"na"
Water/Main2	2	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"n"	"na"	"na"
MPS2	2	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"n"	"na"	"na"
PhotonBL2	9	137.8	31.76	635.3	0.599	0.287	0.912	207.9	33.17	7232	2.099	0.917	4.968
Operator2	3	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"n"	"na"	"na"
Other2	34	56.84	35.49	90.03	0.828	0.607	1.064	62.87	34.64	133.5	1.29	0.987	1.675
Downtotal2	192	19.04	16.83	21.26	1.279	1.138	1.42	17.65	15.3	20.3	1.748	1.485	2.012

n=number of event-shifts

T=scale-parameter=characteristic time

b=form-parameter=event-steepness

B=uptime

S=downtime

C=cycletime

ETB=expectation-value of B

ETS=expectation-value of S

ETC=expectation-value of C

A=availability

l=lower limit

u=upper limit

Results of 1. and 2.User-Run (ctd.1)

bBu[-]	ETB[h]	ETBI[h]	ETBu[h]	TS[h]	TSI[h]	TSu[h]	bS[-]	bSI[-]	bSu[-]	ETS[h]	ETSI[h]	ETSu[h]	A[-]
1.388	259.3	48.37	1.12E+04	1.953	1.282	3.077	2.927	1.051	4.904	1.742	1.176	3.017	0.99
1.157	184.8	32.09	7477	5.657	0.915	39.49	0.588	0.24	0.945	8.749	0.938	1222	0.96
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
1.463	162.2	67.98	647.8	1.132	0.559	2.329	1.083	0.573	1.592	1.098	0.501	3.728	0.99
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
1.109	31.43	22.49	46.19	0.952	0.678	1.327	0.742	0.609	0.875	1.144	0.725	1.958	0.97
1.239	157.6	54.3	919.7	1.176	0.672	2.081	1.368	0.724	2.01	1.076	0.596	2.555	0.99
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
1.284	95.7	28.54	838.9	3.595	1.751	7.6	1.222	0.586	1.862	3.366	1.555	11.81	0.96
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
1.303	97.66	51.39	234.1	1.787	1.083	2.928	1.055	0.687	1.423	1.749	0.985	3.777	0.98
1.381	18.03	14.95	21.66	1.843	1.41	2.276	0.773	0.669	0.877	2.142	1.505	3.015	0.91
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
1.516	128.2	73.93	267.9	1.809	1.078	3.02	1.051	0.675	1.428	1.773	0.98	3.964	0.98
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
1.274	179.2	37.67	4479	0.713	0.487	1.07	2.816	1.15	4.528	0.635	0.445	1.018	0.99
1.948	248.6	109.8	1005	1.446	0.662	3.318	1.23	0.549	1.916	1.352	0.587	5.663	0.99
1.223	30.07	23.91	41.69	1.361	1.059	1.913	0.796	0.677	0.915	1.547	1.105	2.502	0.96
1.141	112.4	58.53	268	0.739	0.48	1.129	1.079	0.743	1.418	0.717	0.437	1.355	0.993
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
0.912	207.9	33.17	7232	2.099	0.917	4.968	1.062	0.509	1.618	2.05	0.822	9.619	0.98
"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"	"na"
1.064	62.87	34.64	133.5	1.29	0.987	1.675	1.458	1.068	1.873	1.169	0.876	1.633	0.97
1.42	17.65	15.3	20.3	1.748	1.485	2.012	0.989	0.88	1.098	1.757	1.434	2.144	0.91

n=number of event-shifts

T=scale-parameter=characteristic time

b=form-parameter=event-steepness

B=uptime

S=downtime

C=cycletime

ETB=expectation-value of B A=availability

ETS=expectation-value of S l=lower limit

ETC=expectation-value of C u=upper limit

Diagram of 95%-confidence-ranges of uptime 1.User-Run

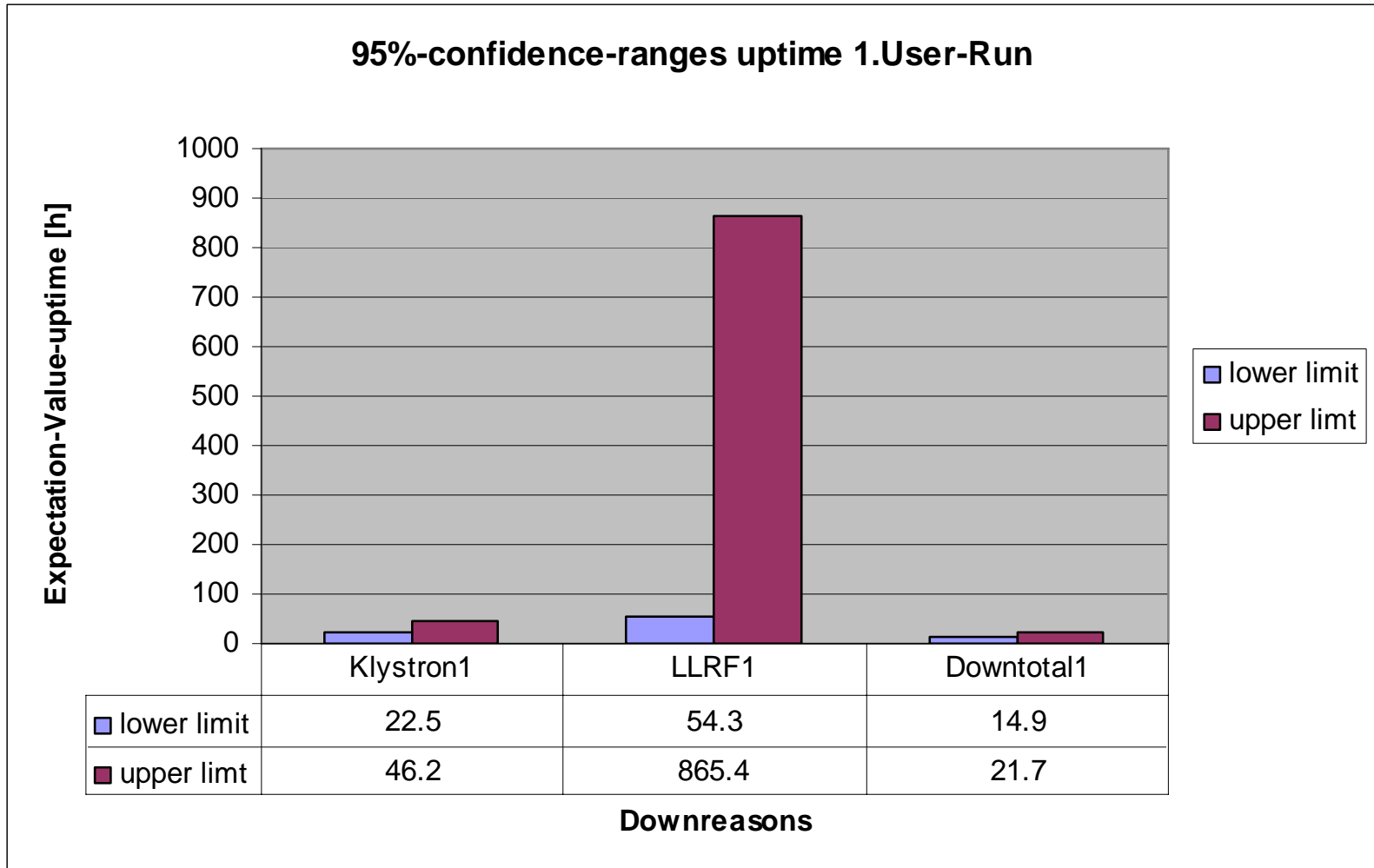


Diagram of 95%-confidence-ranges of downtime 1.User-Run

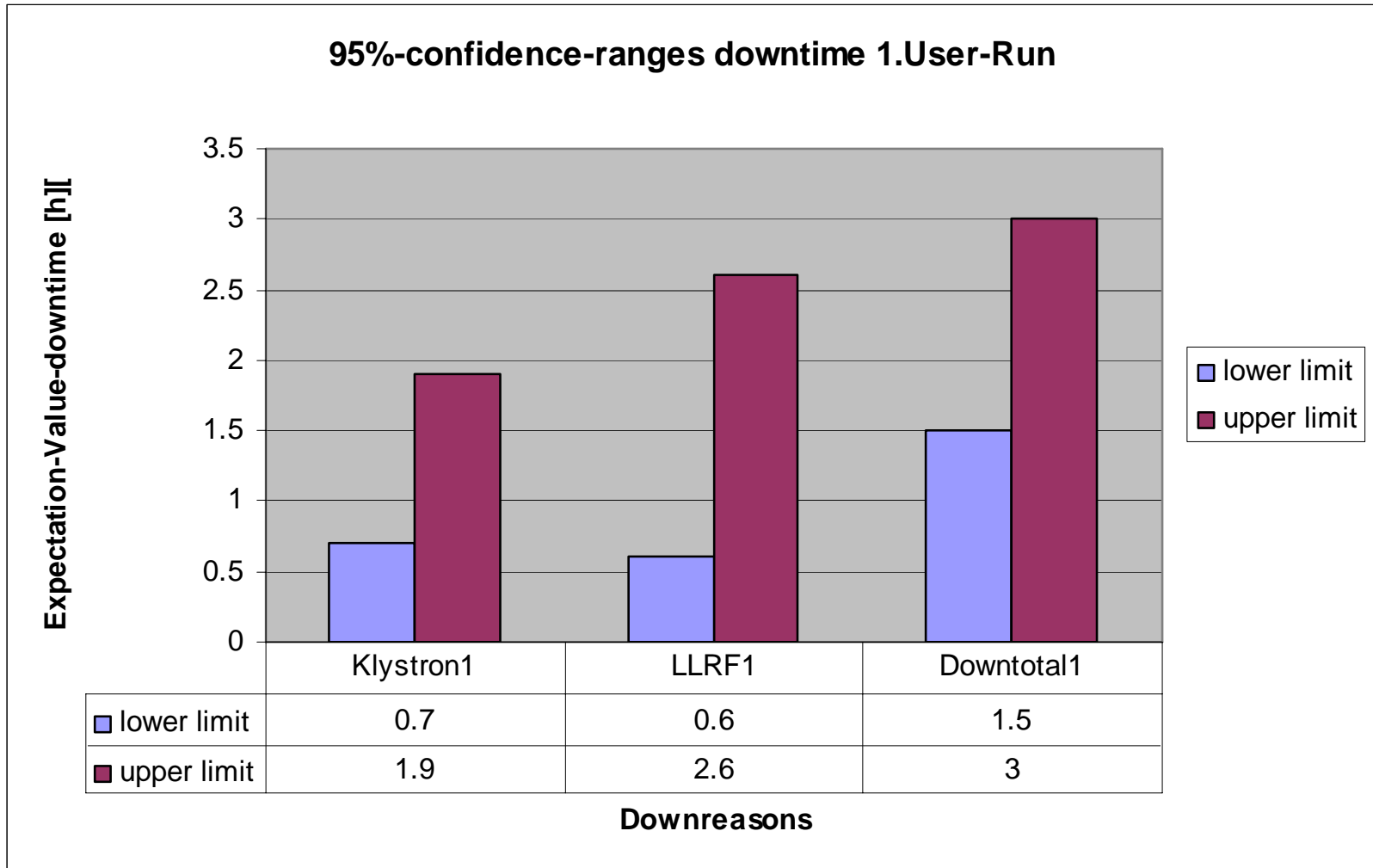


Diagram of 95%-confidence-ranges of cycle-time 1.User-Run

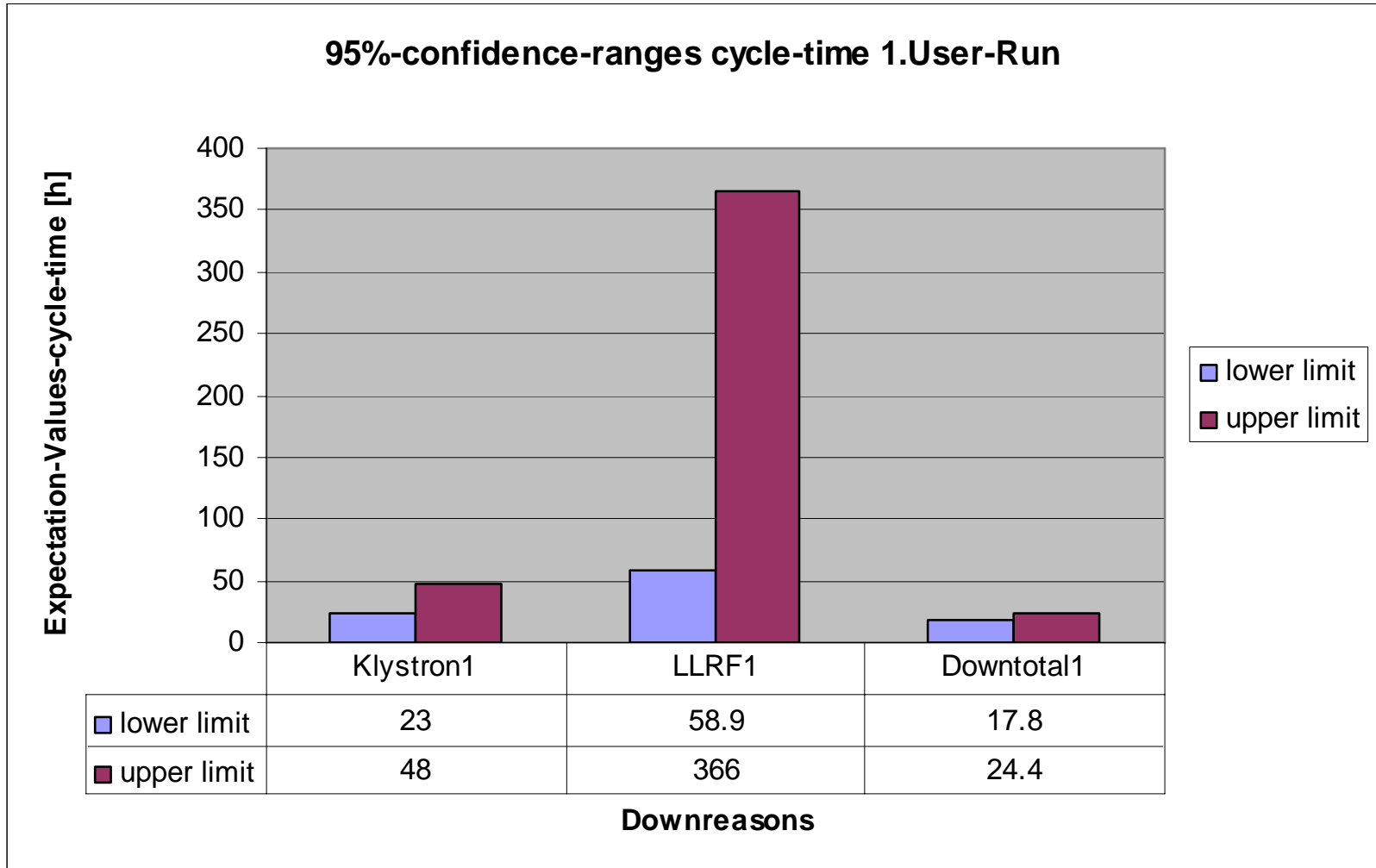


Diagram of 95%-confidence-ranges of uptime 2.User-Run

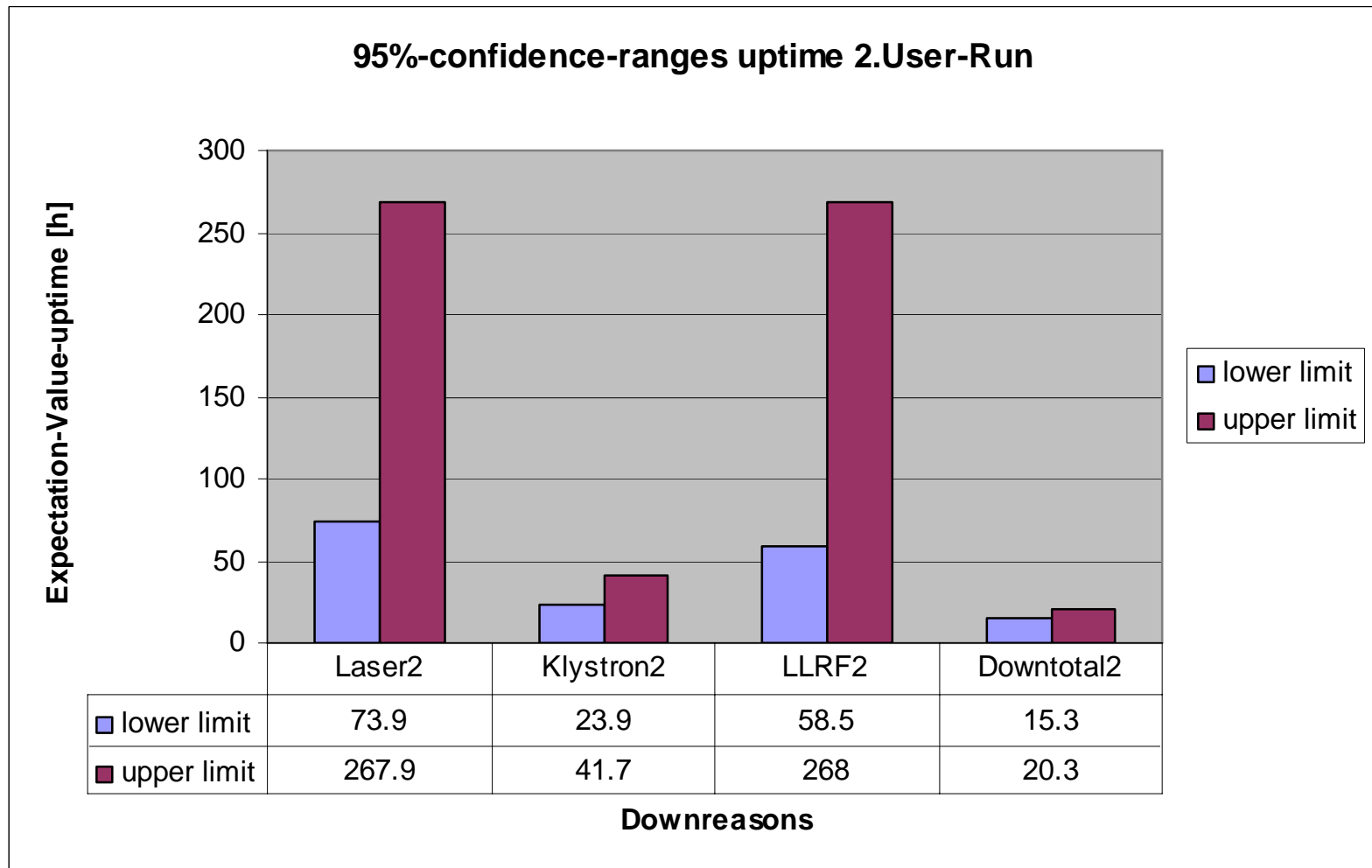


Diagram of 95%-confidence-ranges of downtime 2.User-Run

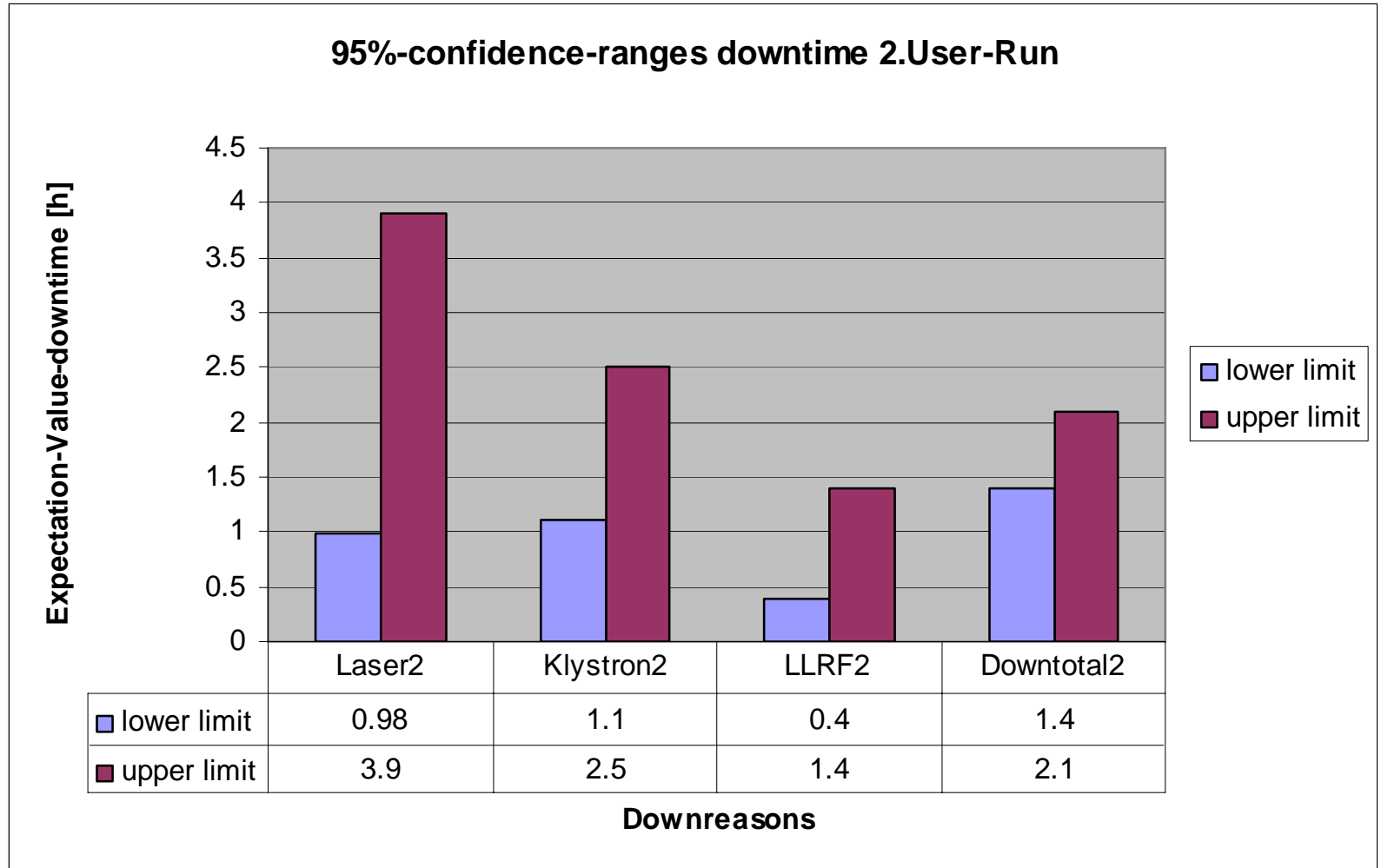
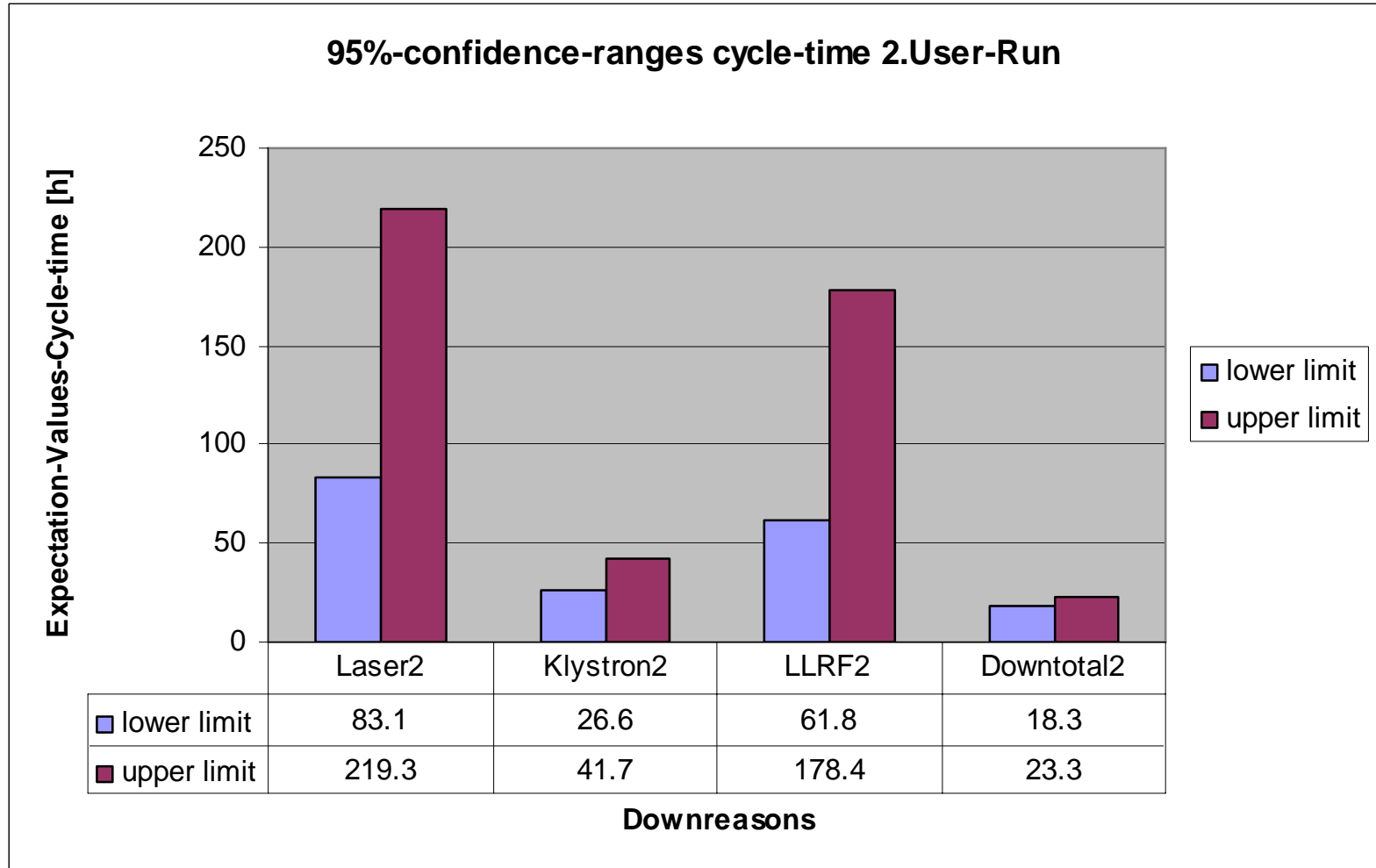


Diagram of 95%-confidence-ranges of cycle-time 2.User-Run



- **Weibull-Statistic-Analysis** appears adequate for FLASH-
reliability
availability
- **Confidence-ranges** for expectation-values are determined
for all FLASH-downreasons with regard to their
uptime
downtime
cycletime
- **FLASH-state-of-the-art** is described by these results
- **Data-collection** to be adapted due to FLASH-findings
and experience
- **Application of FLASH-results** for projection towards
XFEL and ILC need further studies