Data-driven risk matrices for CERN accelerators

A. Apollonio, G. Blarasin, T. Cartier-Michaud, J. Uythoven

Outline

1) Risk Matrix: what, why, how?
2) History of Risk Matrix at CERN
3) #Data-driven approach
4) Continuous Risk Curve
5) Extracting and cleaning the data
6) Risk Matrices and CRC for CERN accelerators

Risk Matrix: what, why, how? (1/2)

wikipedia: risk matrix

- Decision tool summarizing the occurrence (measured as probability or likelihood) vs the severity (measured in CHF, integrated luminosity, …) of an event in order to best allocate resources to mitigate design flaws

- Filled by carefully studying a (design of a) system, listing the failure modes

- Comparison of different events: risk = probability * severity

	Negligible	Marginal	Critical	Catastrophic
Certain	Moderate	High	Extreme	Extreme
Possible	Low	Moderate	High	Extreme
Rare	Low	Low	Moderate	High

Risk Matrix: what, why, how? (2/2)

wikipedia: risk matrix

- Study of complex systems by many experts for many types of risks
- ==> high probability * low severity =?= low probability * high severity
- ==> conversion of “reputation” in “luminosity”? In “injuries” ‘
- ==> exhaustive lists?
- Many events could be in the same box
- ==> need for higher resolution to avoid ties

	Negligible	Marginal	Critical	Catastrophic
Certain	Moderate	High	Extreme	Extreme
Possible	Low	Moderate	High	Extreme
Rare	Low	Low	Moderate	High

History of CERN's risk matrices (1/2)

Original risk matrix from the Machine Protection Design, most recent = 2013
M. Kwiaktowski (link to PhD), B. Todd, R. Schmidt

Event				
Frequency	**Consequences**			
	Minor	Severe	Major	Catastrophic
Frequent	2	3	4	4
Probable	1	2	3	4
Occasional	1	1	2	3
Remote	1	1	1	2

Table 4.1: Risk matrix used for the LHC MPS design.

Frequent = once per 0 - 100 days
Probable = once per 100 - 1000 days
Occasional = once per 1000 - 10000 d.
Remote = not expected in 10000 days

Catastrophic = more than 200 days of repair or more than 50 MCHF
Major = 20 - 200 d. or 1 - 50 MCHF
Severe = 2 - 20 d. or 0.1 - 1 MCHF
Minor = 0 - 2 d. or 0 - 0.1 MCHF

History of CERN's risk matrices (2/2)

2019 Reliability Requirement and Initial Risk Evaluation (RIRE)

M. Blumenschein (link to paper), J Spasic, J. Steckert, J. Uythoven

==> higher resolution (especially toward short / low impact faults)
==> based on (expert estimates of) LHC experience

LHC risk matrix filled with quench detection system End Effect (consequence of a given failure mode)

LHC risk matrix		Recovery						
		∞	year	month	week	day	hours	minutes
Frequency	1 / hour							
	1 / day							
	1 / week							
	1 / month							
	1 / year						EE1,EE3, EE4	
	1 / 10 years					EE5		
	1 / 100 years			EE2, EE6				
	1 / 1000 years							

Directions of development

2020 Data-Driven risk matrices and continuous risk curves

A. Apollonio, G. Blarasin, T. Cartier-Michaud

- How to better define the acceptable / unacceptable limit?
  ==> “unique solution” or “unique shape” of the matrix?

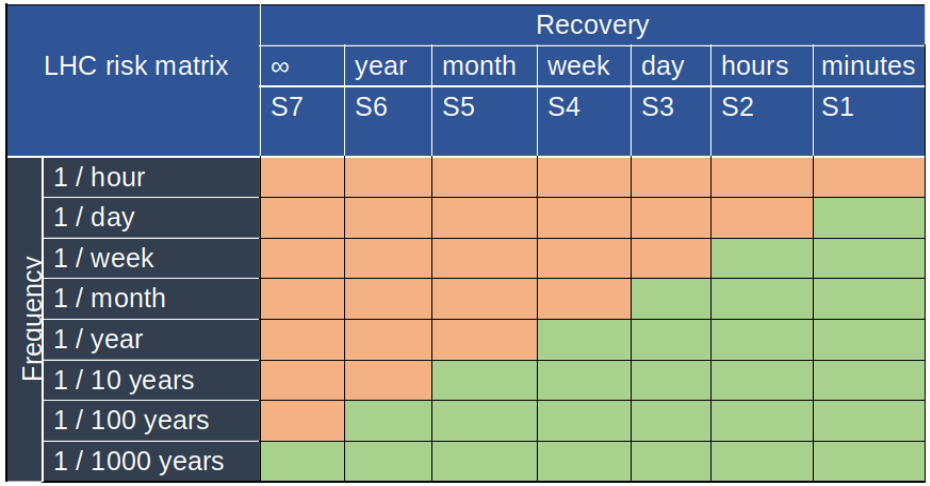
- How to better define the discretisation in both dimension?
  ==> quantification of the loss of information?

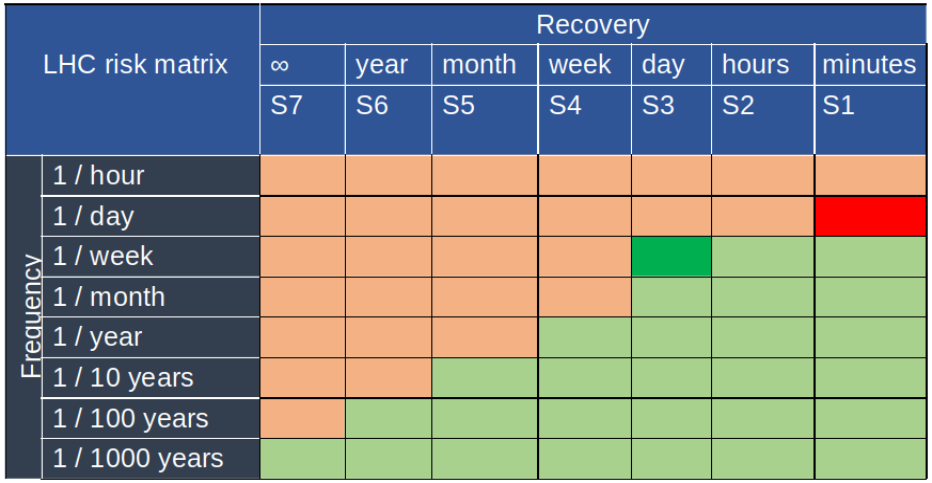
=> use of AFT to populate the risk matrix **#Data-Driven ;-)**

=> introduction of “Continuous Risk Curve” to access the whole knowledge to define the binning and acceptable / unacceptable criterion

#Data-driven shapes

- How to better define the acceptable / unacceptable?
  ==> “unique solution” or “unique shape” of the matrix?
- Several shapes can lead to the same recovery time / cost
- Are we (more or less) pleased with the way injectors operate already?
- ==> definition of the shape by using AFT data + processing of data





Hedi Trabelsi
2 weeks intern

	≤ 45D	≤ 14D	≤ 24H	≤ 5H	≤ 15M
1/H	0	0	0	0	0
1/D	0	0	0	1	1
1/W	0	0	1	1	1
1/M	0	0	1	1	1
1/Y	0	1	1	1	1
1/10Y	0	1	1	1	1
1/100Y	0	1	1	1	1

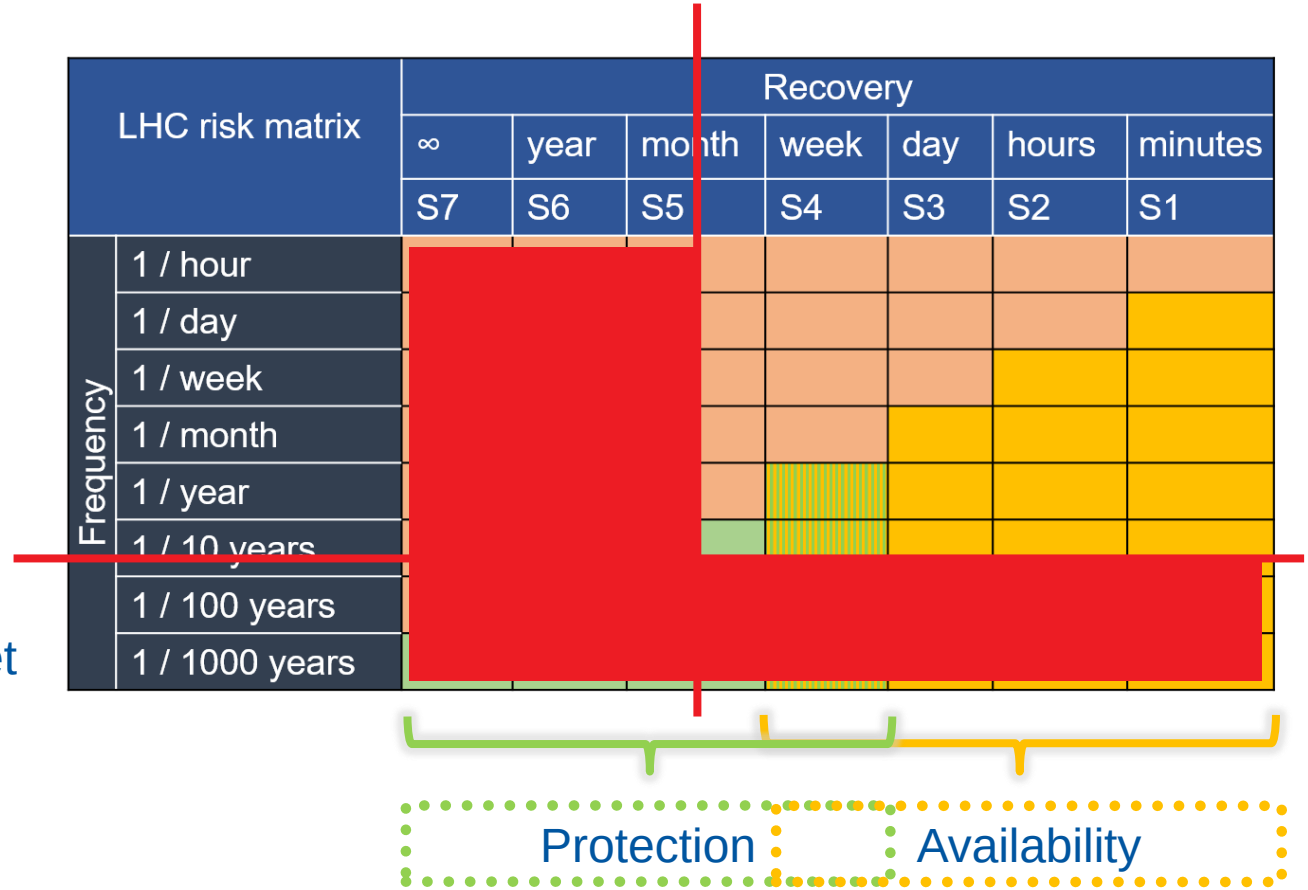
Protection and Availability

Availability range:
Frequency ~< 1/month

- Available statistics
- Possible predictions (AvailSim)

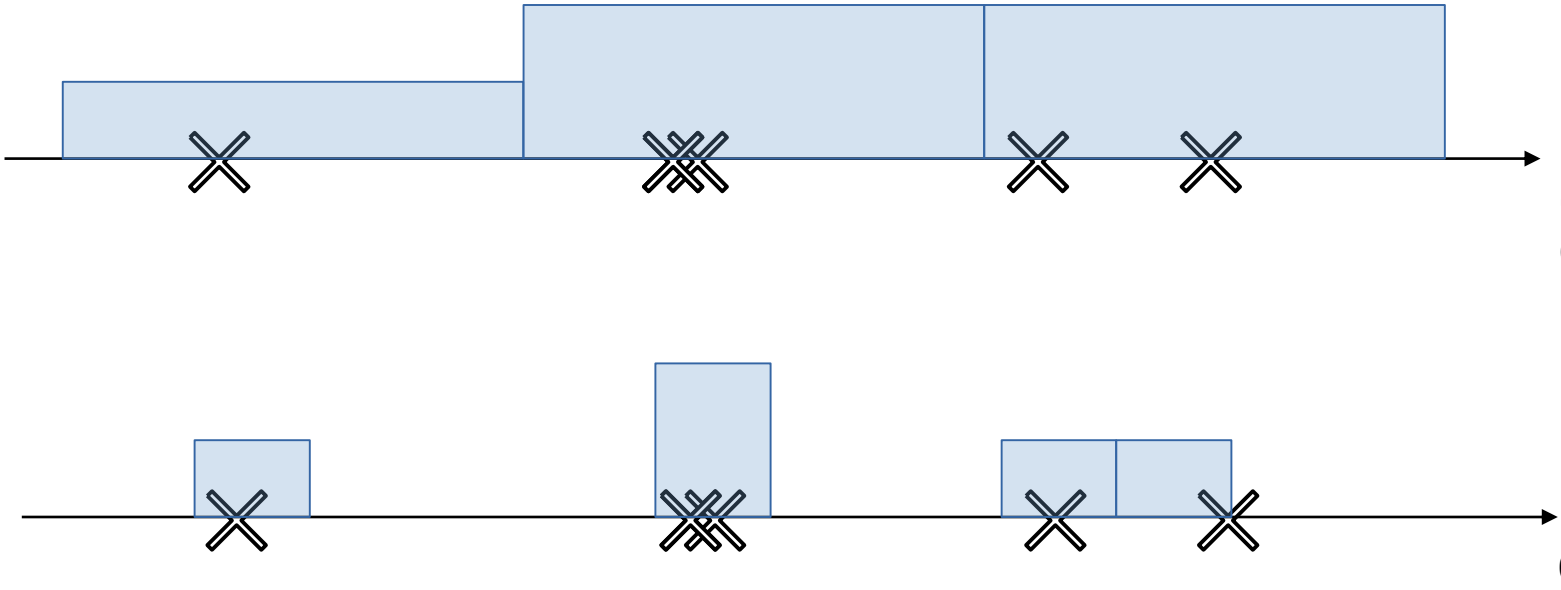
Protection range:
Frequency >~ 1/year

- Not so much statistics yet
- Difficult to predict



Higher resolution: Continuous Risk Curve (1/3)

- Increasing the number of bins of a histogram
- => “artificially” decrease the number of events in each bin



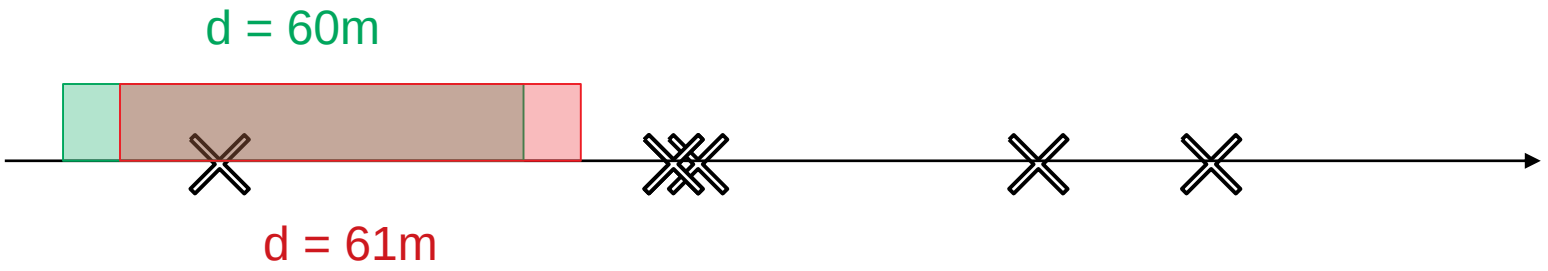
Higher resolution: Continuous Risk Curve (2/3)

- Back to the definition of each column:
  number of events of the order of a duration d
- ==> use of an extra parameter: alpha
- ==> continuous parameter

==> convolution product with rectangle window [d / alpha , d * alpha]

numberOfOccurrences_alpha (d) =

sum_{list of faults f} 1_{d / alpha < f_duration <= d * alpha}



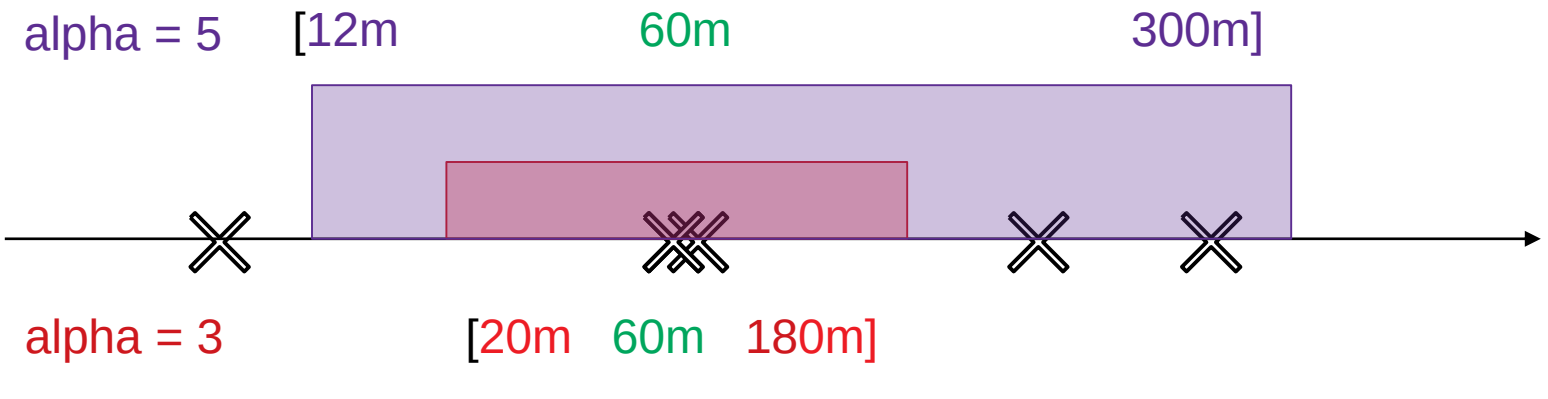
Higher resolution: Continuous Risk Curve (3/3)

- Back to the definition of each column:
  number of events of the order of a duration d
- ==> use of an extra parameter: alpha
- ==> continuous parameter

==> convolution product with rectangle window [d / alpha , d * alpha]

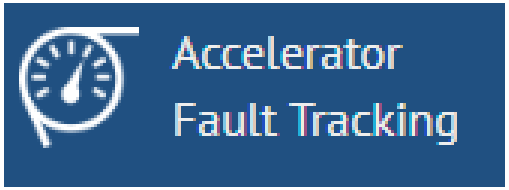
numberOfOccurrences_alpha (d) =

sum_{list of faults f} 1_{d / alpha < f_duration <= d * alpha}



Extracting the data

- Data-sources

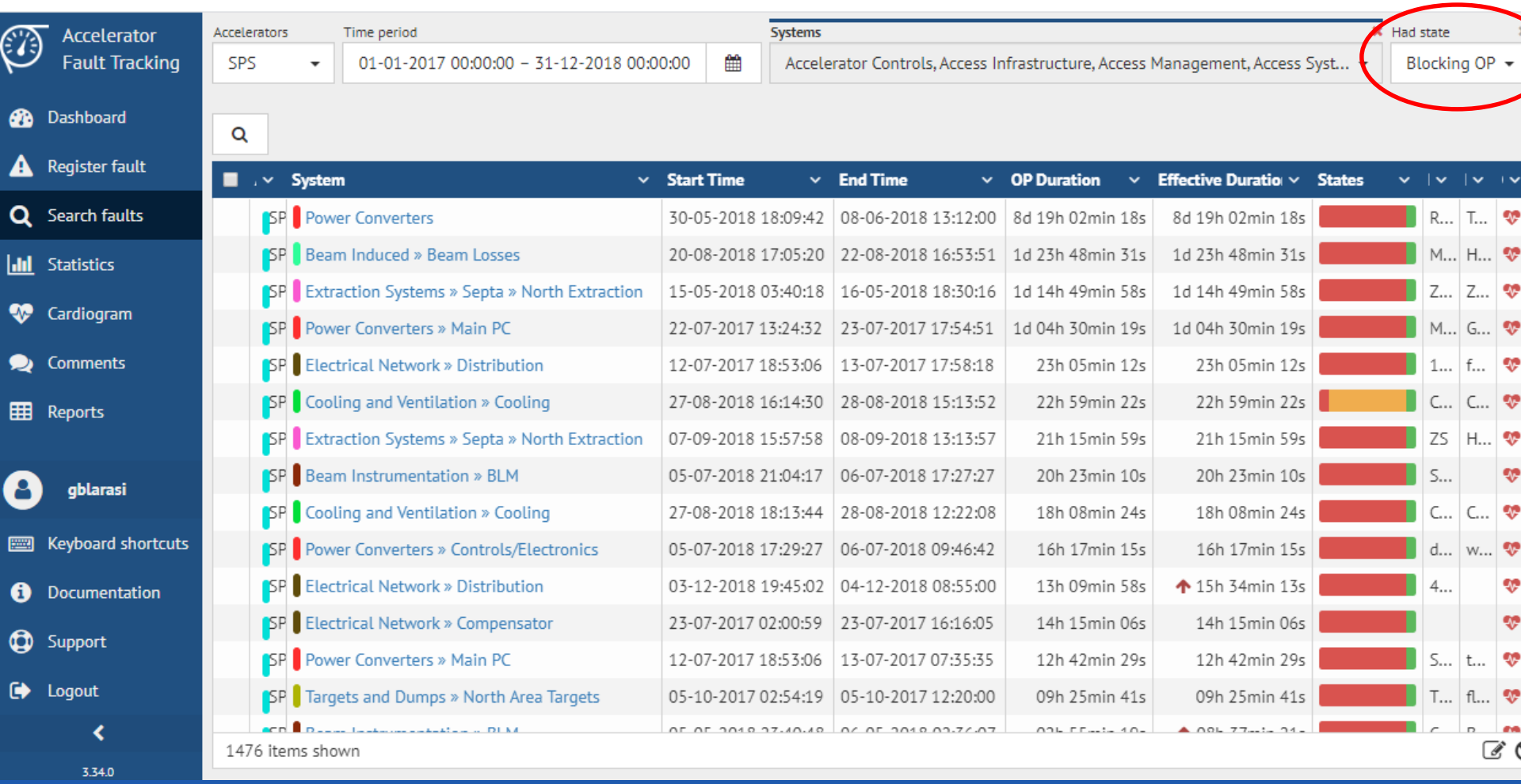


- Since the study is data-driven, choosing and pre-processing databases is an important task

Post Mortem

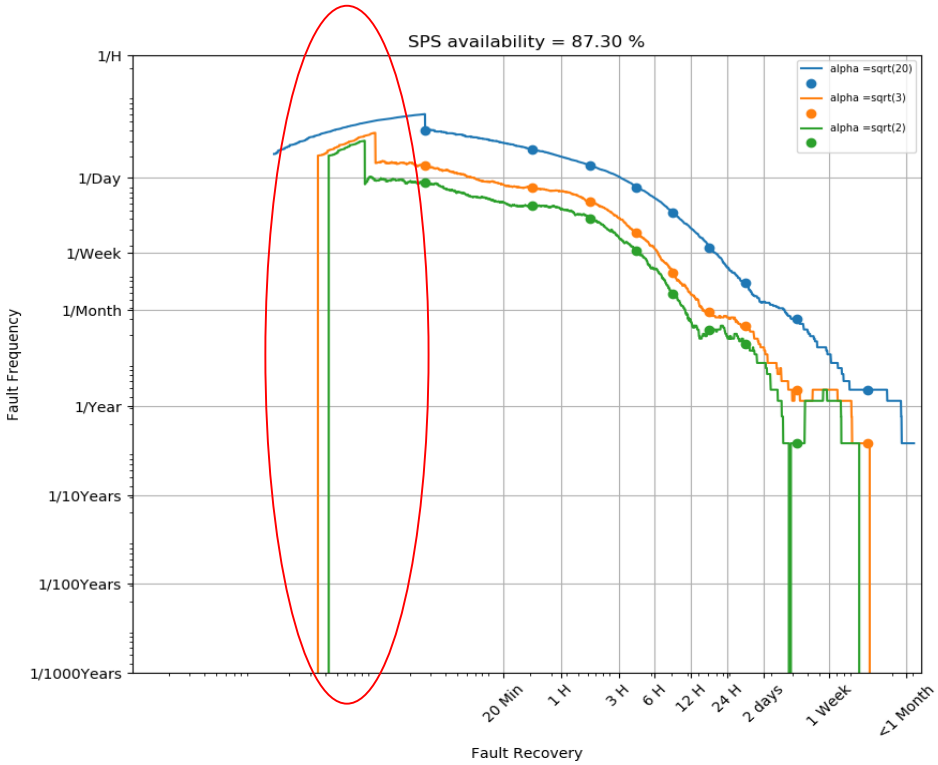
E-Logbook

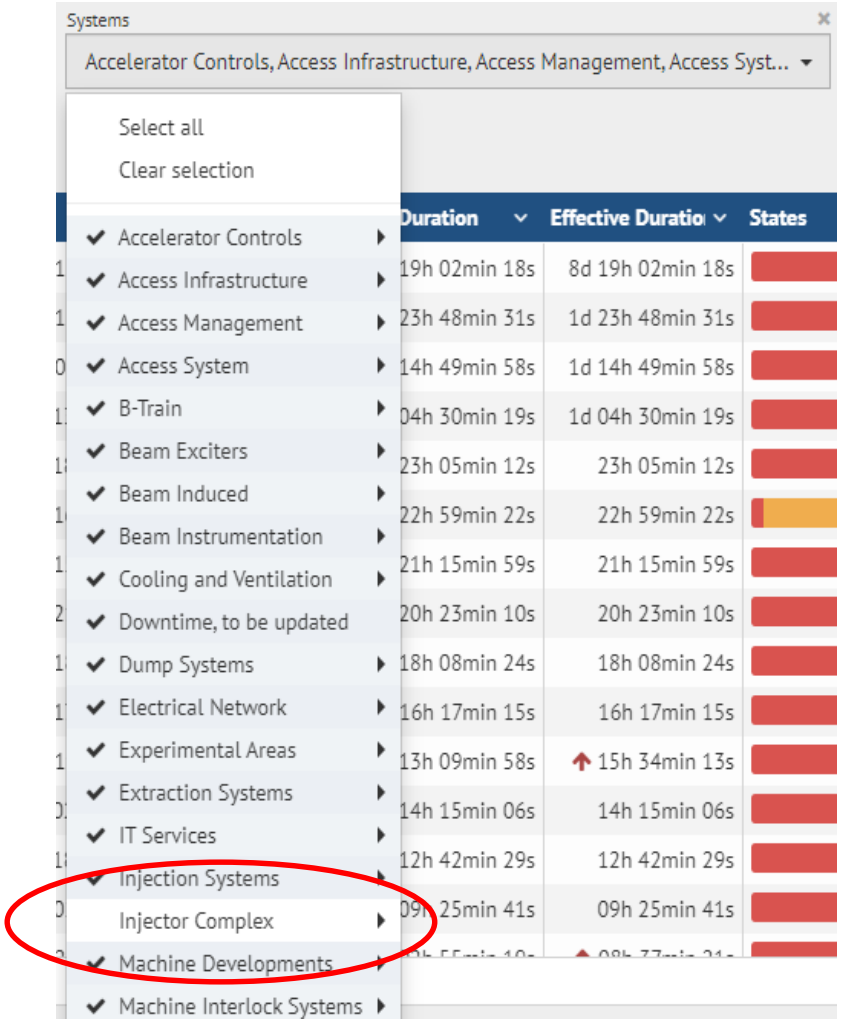
Extracting the data - Filters



Extracting the data - Filters

- Whenever beam is not available for a given machine due to faults of its injectors a fault is assigned to

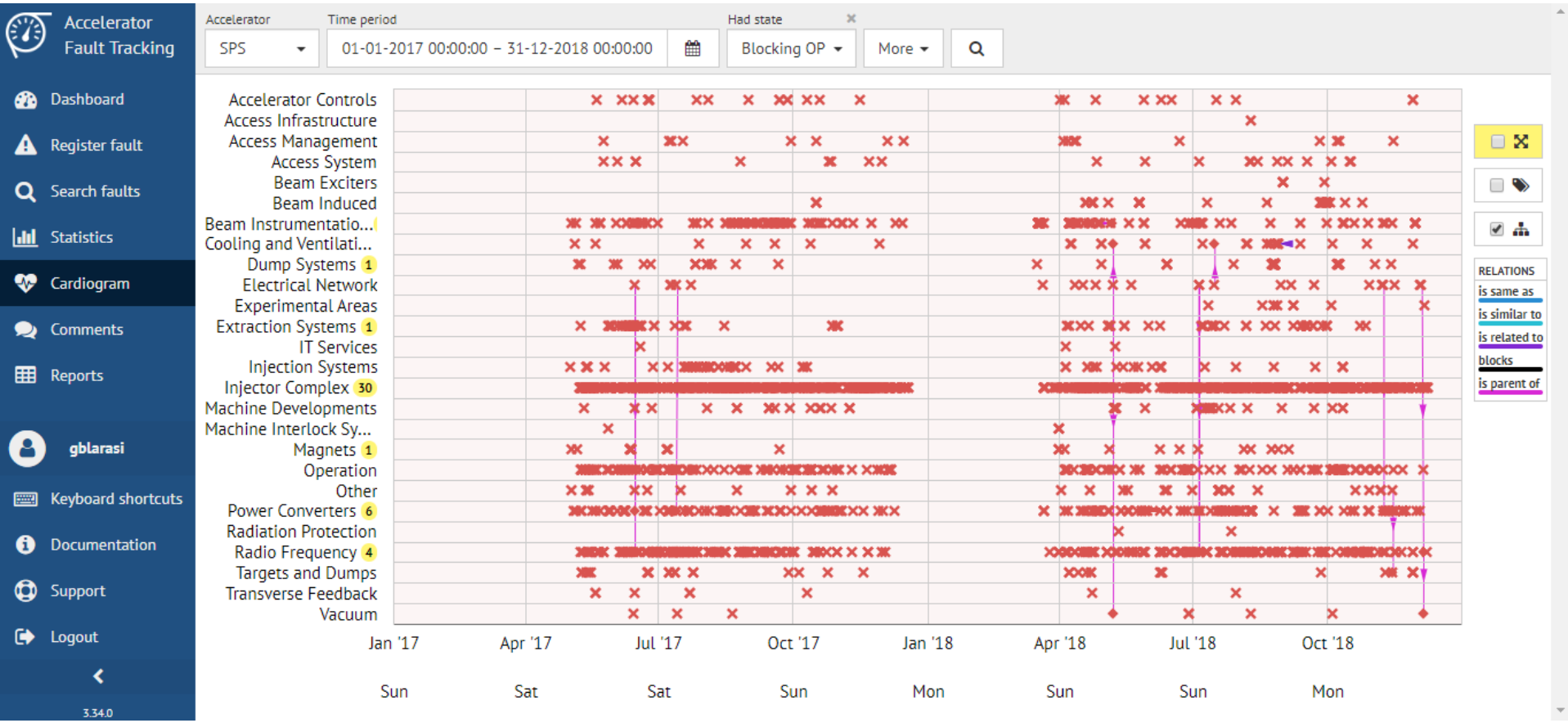




Extracting the data - Scope

- Injectors: [2017 - 2018]
- LHC: [2015 – 2018]
- => AFT has been in use in injectors since 2017, only considering 2 years to have the same accuracy
- => Operational Years. Double check with E-Logbook

Scope - Cardiogram



Scope - Cardiogram

2017

Scope – E-Logbook

- Once we check that is the first (or last) fault, we can define the data extraction interval

SPS ▾ Consignes Phones Vistars Others search

SPS [Monday 01-May-2017 Morning]

FILTERS: EVT SOURCES ▾ Piquets ▾ Expert ▾ INFO

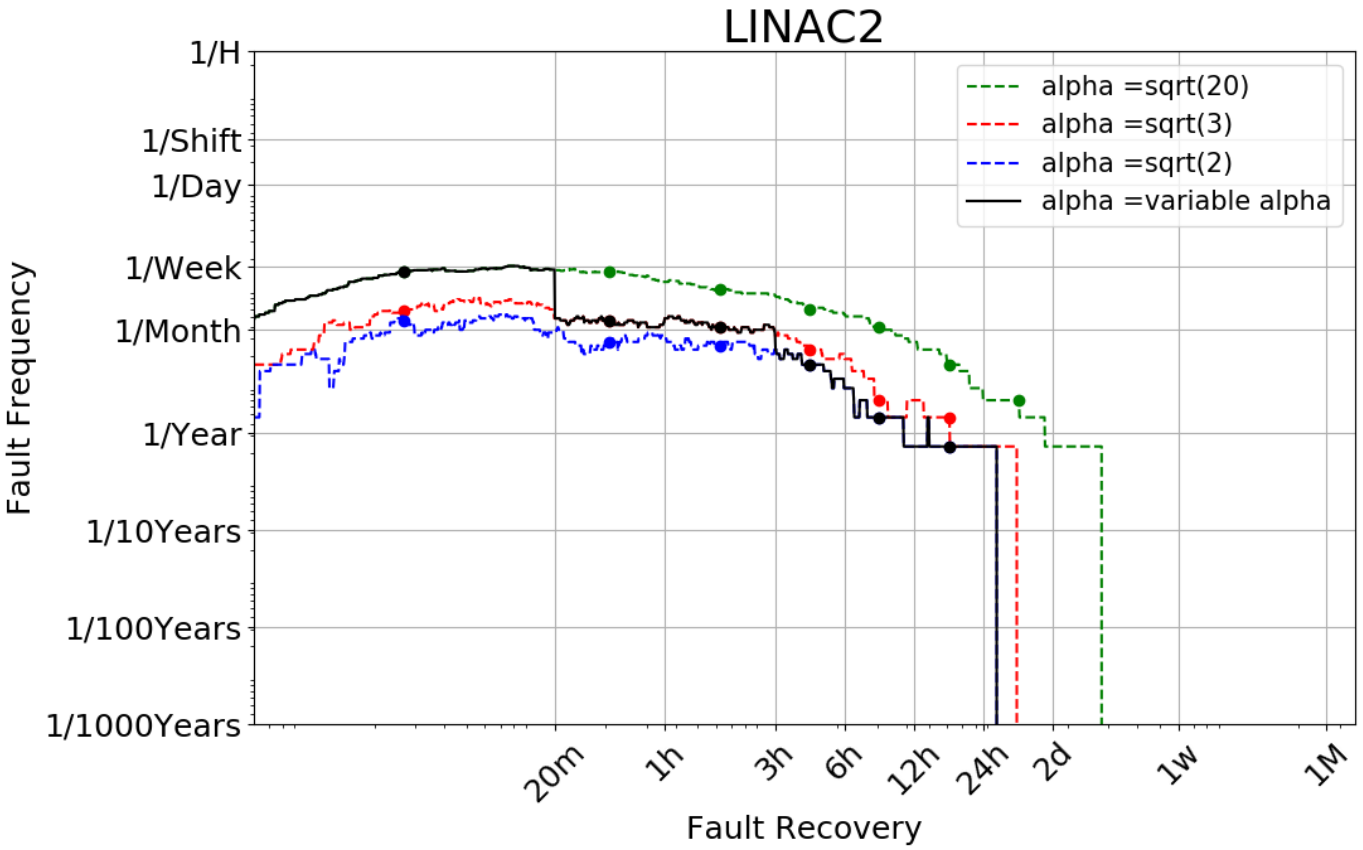
▾ Clear

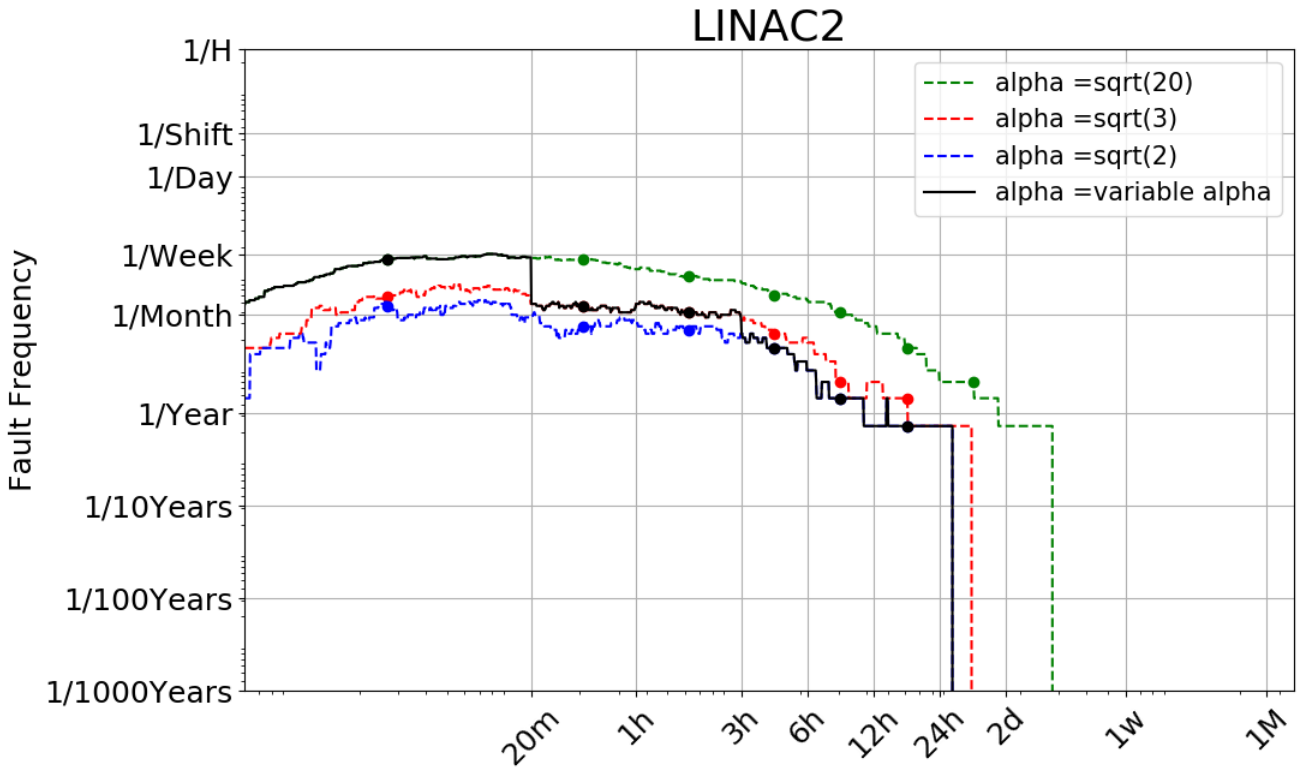
#	Time	LHCPILOT	Comment
1	07:00	LMS	Stephane and Serge created by spsop on CWO-CCC-A7LC
2	08:01	1	**Kicker > Called** Piquet ABT Generator 2 not pulsing  20170501080605.png  20170501080621.png created by spsop on CWO-CCC-A6LC
			Cavity 3 tripped

Examples of continuous curves

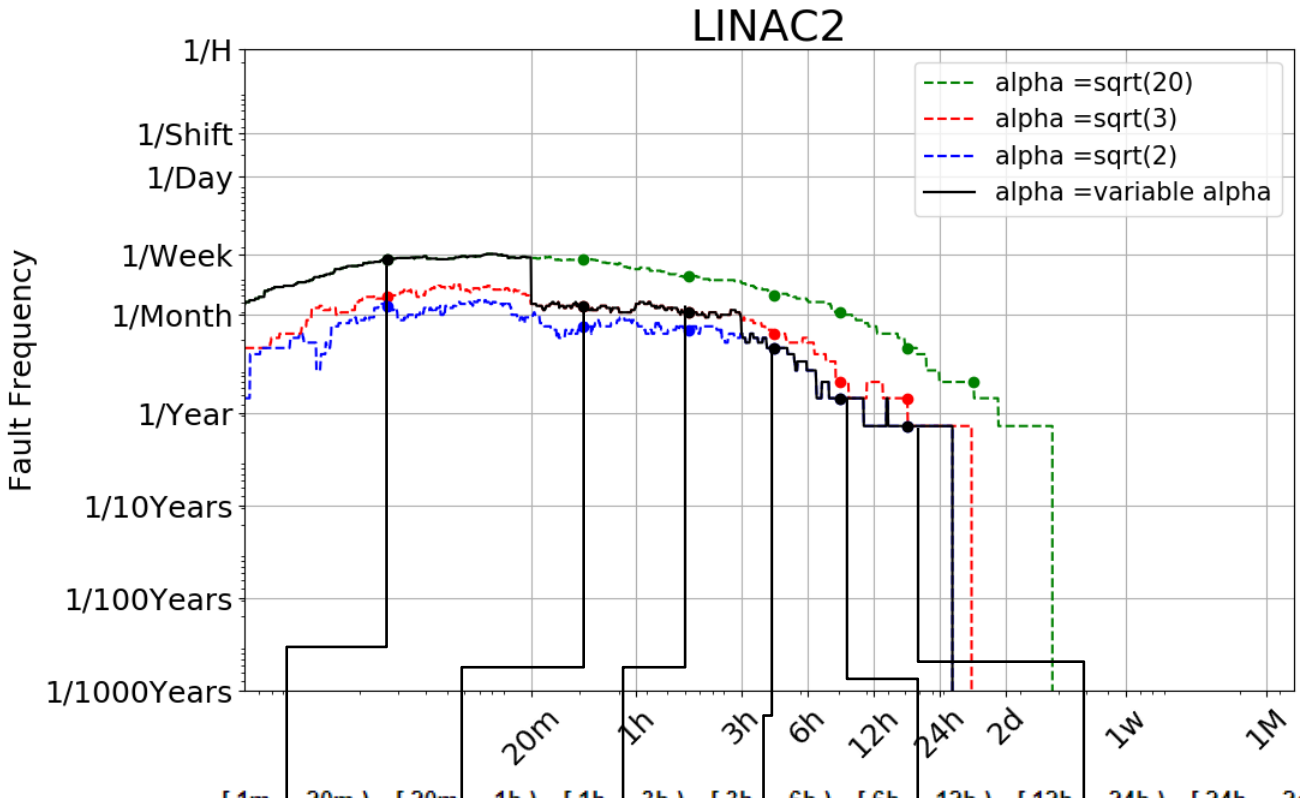
alpha = sqrt(3) :: [35m 60m 105m] :: 105/35 = 3

- Loss of information?
- ➔ The discretisation of the matrix should follow the main variation (non variation) of the curve
- ➔
- Acceptable vs unacceptable?
- ➔ A failure mode is unacceptable if it does not lay in the shadow of the other failure modes





	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1/Shift	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1/Day	0.13	0.04	0.03	0.01	0.00	0.00	0.00	0.00	0.00
1/Week	0.89	0.28	0.24	0.10	0.03	0.01	0.00	0.00	0.00
1/Month	3.86	1.22	1.04	0.43	0.12	0.06	0.00	0.00	0.00
1/Year	46.21	14.67	12.47	5.13	1.47	0.73	0.00	0.00	0.00
1/10Years	462.06	146.69	124.68	51.34	14.67	7.33	0.00	0.00	0.00
1/100Years	4620.63	1466.87	1246.84	513.40	146.69	73.34	0.00	0.00	0.00
1/1000Years	46206.33	14668.67	12468.37	5134.04	1466.87	733.43	0.00	0.00	0.00



	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1/Shift	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1/Day	0.13	0.04	0.03	0.01	0.00	0.00	0.00	0.00	0.00
1/Week	0.89	0.28	0.24	0.10	0.03	0.01	0.00	0.00	0.00
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1/1000Years	46206.33	14668.67	12468.37	5134.04	1466.87	733.43	0.00	0.00	0.00

Computation of Availability

- Availability = (operation time – **down time**) / operation time (or **recovery time**)
- Raw availability: **sum duration of fa**
- Optimistic Risk Matrix Availability: **frequency * lowest bin of each bo**
- Pessimistic Risk Matrix Availability: **frequency * highest bin of each box**
- Geometric Risk Matrix Availability: **frequency * “geometric center” of eacl**
- Continuous Risk C **integral of the cu**

	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)
1/H	0.01	0.00	0.00	0.00	0.00	0.00
1/Shift	0.04	0.01	0.01	0.00	0.00	0.00
1/Day	0.13	0.04	0.03	0.01	0.00	0.00
1/Week	0.89	0.28	0.24	0.10	0.03	0.01
1/Month	3.86	1.22	1.04	0.43	0.12	0.06
1/Year	46.21	14.67	12.47	5.13	1.47	0.73
1/10Years	462.06	146.69	124.68	51.34	14.67	7.33
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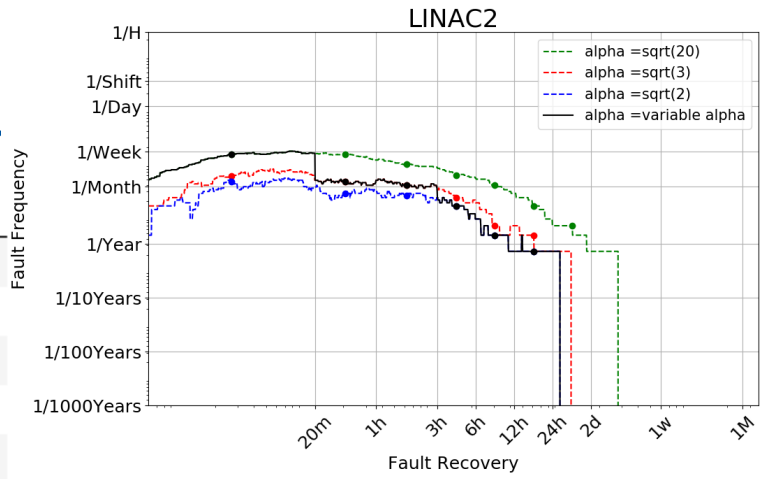
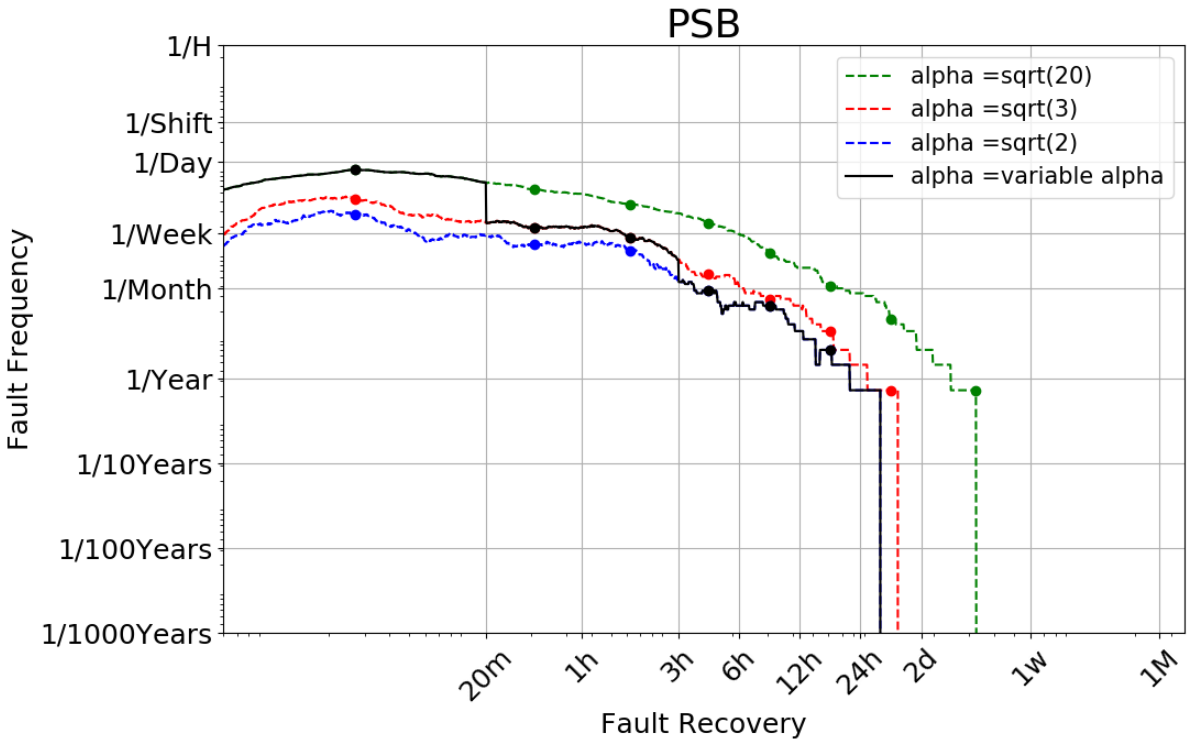
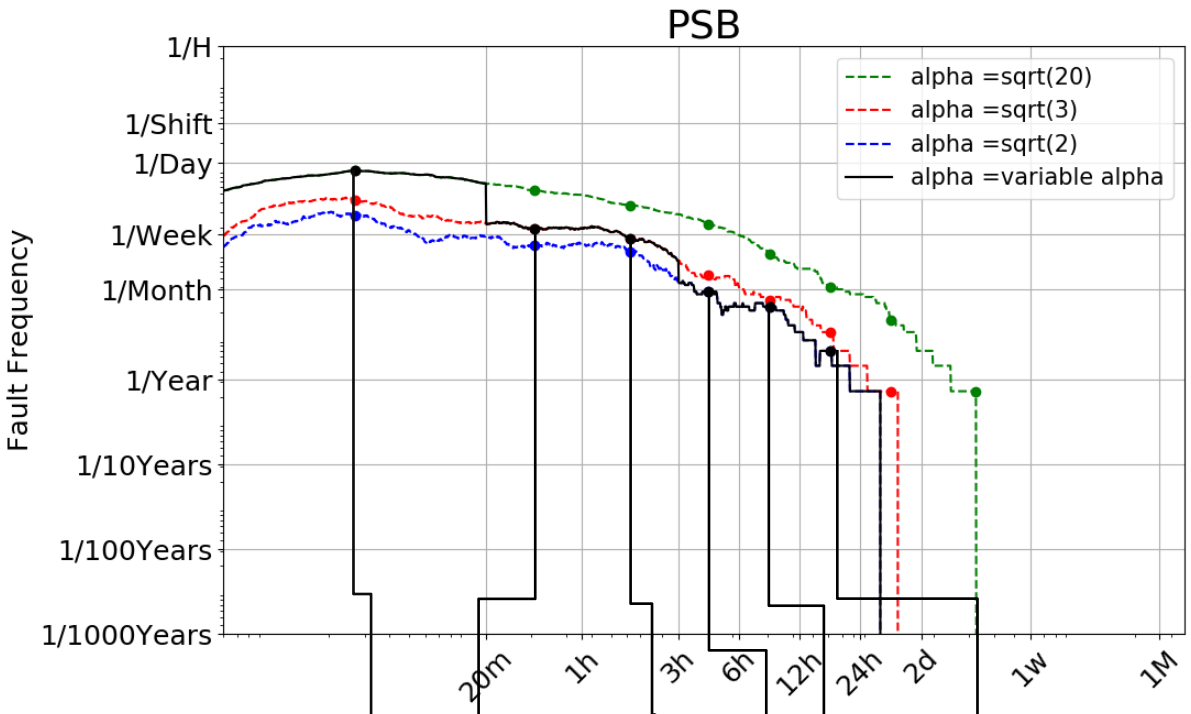
1/1000Years	46206.33	14668.67	12468.37	5134.04	1466.87	733.43

Type of Availability	Availabilty (Intrinsec)
Pessimistic Matrix Availability	98.48 %
Curve Availability	99.02 %
Geometric Matrix Availability	99.09 %
Raw Availability	99.00 %
Optimistic Matrix Availability	99.42 %

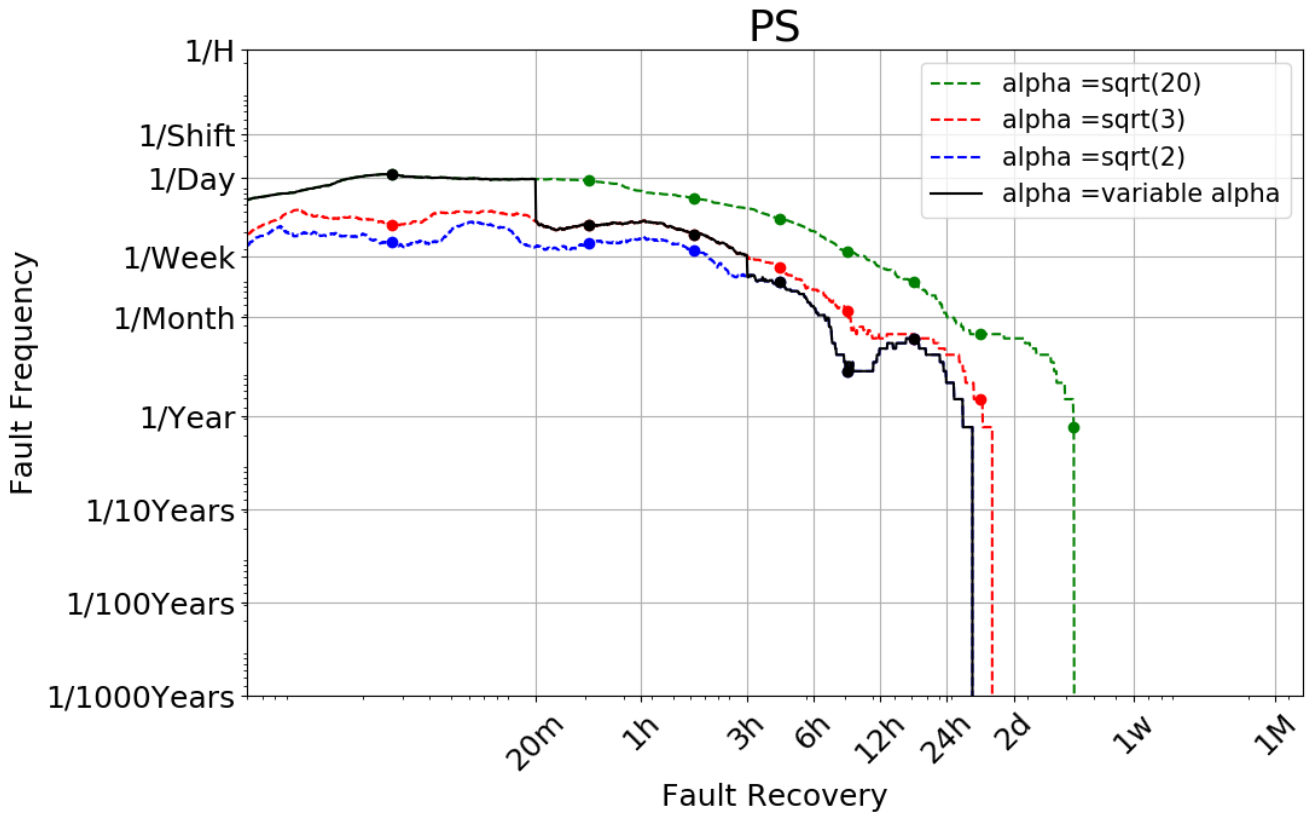




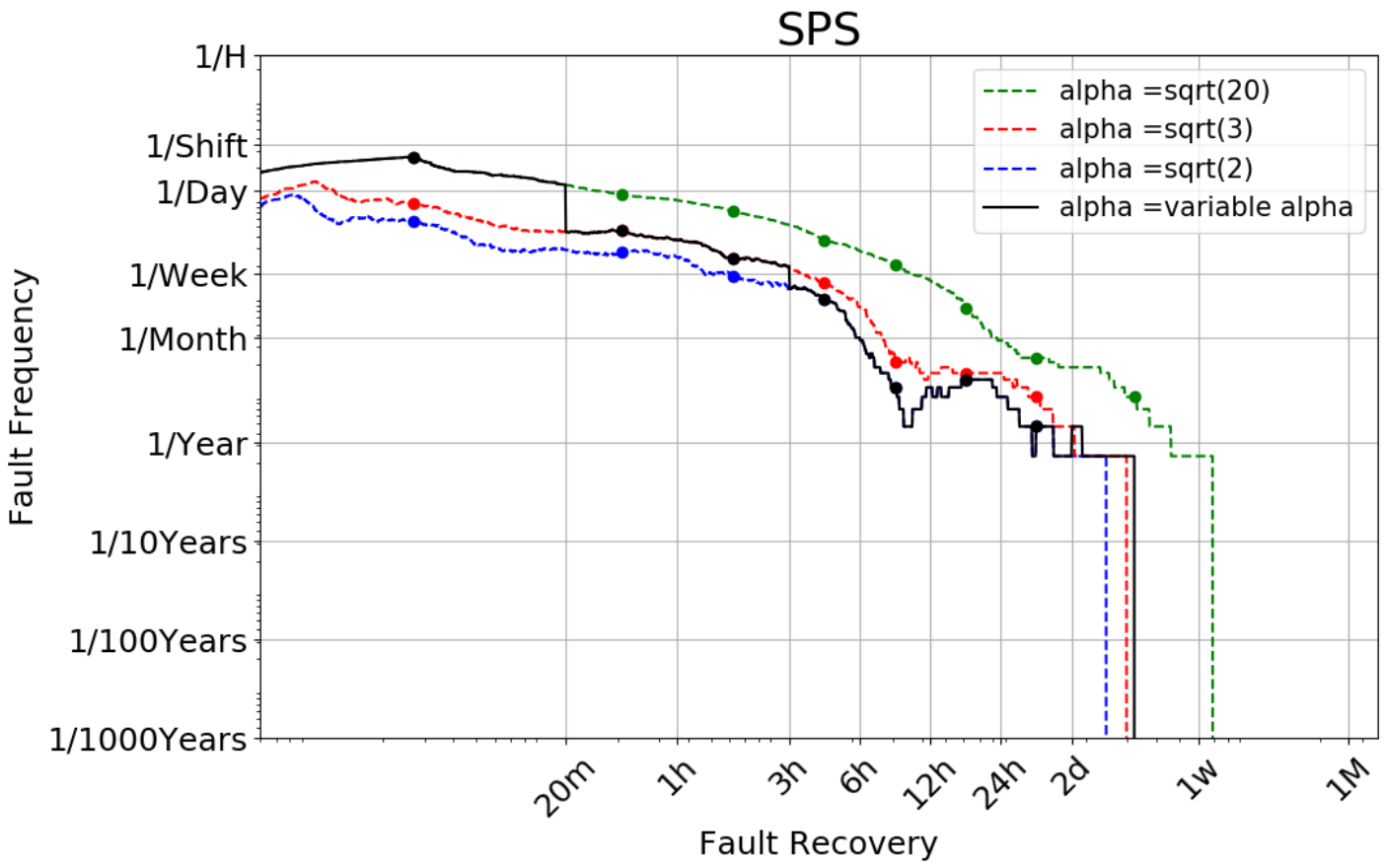
	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1/Shift	0.27	0.06	0.04	0.01	0.01	0.00	0.00	0.00	0.00
1/Day	0.82	0.17	0.13	0.03	0.02	0.01	0.00	0.00	0.00
1/Week	5.72	1.19	0.90	0.21	0.14	0.04	0.00	0.00	0.00
1/Month	24.90	5.17	3.94	0.92	0.61	0.18	0.00	0.00	0.00
1/Year	298.24	61.86	47.13	11.05	7.36	2.21	0.00	0.00	0.00
1/10Years	2982.38	618.57	471.29	110.46	73.64	22.09	0.00	0.00	0.00
1/100Years	29823.84	6185.69	4712.90	1104.59	736.39	220.92	0.00	0.00	0.00
1/1000Years	298238.41	61856.85	47129.03	11045.87	7363.91	2209.17	0.00	0.00	0.00



	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1/Shift	0.27	0.06	0.04	0.01	0.01	0.00	0.00	0.00	0.00
1/Day	0.82	0.17	0.13	0.03	0.02	0.01	0.00	0.00	0.00
1/Week	5.72	1.19	0.90	0.21	0.14	0.04	0.00	0.00	0.00
1/Month	24.90	5.17	3.94	0.92	0.61	0.18	0.00	0.00	0.00
1/Year	298.24	61.86	47.13	11.05	7.36	2.21	0.00	0.00	0.00
1/10Years	2982.38	618.57	471.29	110.46	73.64	22.09	0.00	0.00	0.00
1/100Years	29823.84	6185.69	4712.90	1104.59	736.39	220.92	0.00	0.00	0.00
1/1000Years	298238.41	61856.85	47129.03	11045.87	7363.91	2209.17	0.00	0.00	0.00



	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1/Shift	0.38	0.10	0.08	0.03	0.00	0.01	0.00	0.00	0.00
1/Day	1.13	0.31	0.25	0.08	0.01	0.02	0.00	0.00	0.00
1/Week	7.89	2.19	1.76	0.53	0.06	0.13	0.00	0.00	0.00
1/Month	34.36	9.52	7.66	2.32	0.26	0.58	0.00	0.00	0.00
1/Year	411.48	114.04	91.70	27.74	3.08	6.94	0.00	0.00	0.00
1/10Years	4114.84	1140.44	916.98	277.41	30.82	69.35	0.00	0.00	0.00
1/100Years	41148.42	11404.43	9169.78	2774.05	308.23	693.51	0.00	0.00	0.00
1/1000Years	411484.18	114044.30	91697.78	27740.51	3082.28	6935.13	0.00	0.00	0.00



	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.09	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1/Shift	0.75	0.13	0.07	0.03	0.00	0.00	0.00	0.00	0.00
1/Day	2.24	0.40	0.21	0.08	0.01	0.01	0.00	0.00	0.00
1/Week	15.65	2.77	1.44	0.55	0.07	0.08	0.03	0.00	0.00
1/Month	68.19	12.05	6.27	2.40	0.31	0.37	0.12	0.00	0.00
1/Year	816.66	144.33	75.11	28.72	3.68	4.42	1.47	0.00	0.00
1/10Years	8166.58	1443.33	751.12	287.19	36.82	44.18	14.73	0.00	0.00
1/100Years	81665.78	14433.27	7511.19	2871.93	368.20	441.83	147.28	0.00	0.00
1/1000Years	816657.76	144332.66	75111.90	28719.25	3681.96	4418.35	1472.78	0.00	0.00

Availability estimates

- LINAC2

	Type of Availability	Availabilty (Intrinsec)
0	Pessimistic Matrix Availability	98.48 %
1	Curve Availability	99.02 %
2	Geometric Matrix Availability	99.09 %
3	Raw Availability	99.00 %
4	Optimistic Matrix Availability	99.42 %

- PSB

	Type of Availability	Availabilty (Intrinsec)
0	Pessimistic Matrix Availability	94.18 %
1	Curve Availability	96.51 %
2	Geometric Matrix Availability	96.73 %
3	Raw Availability	96.85 %
4	Optimistic Matrix Availability	97.99 %

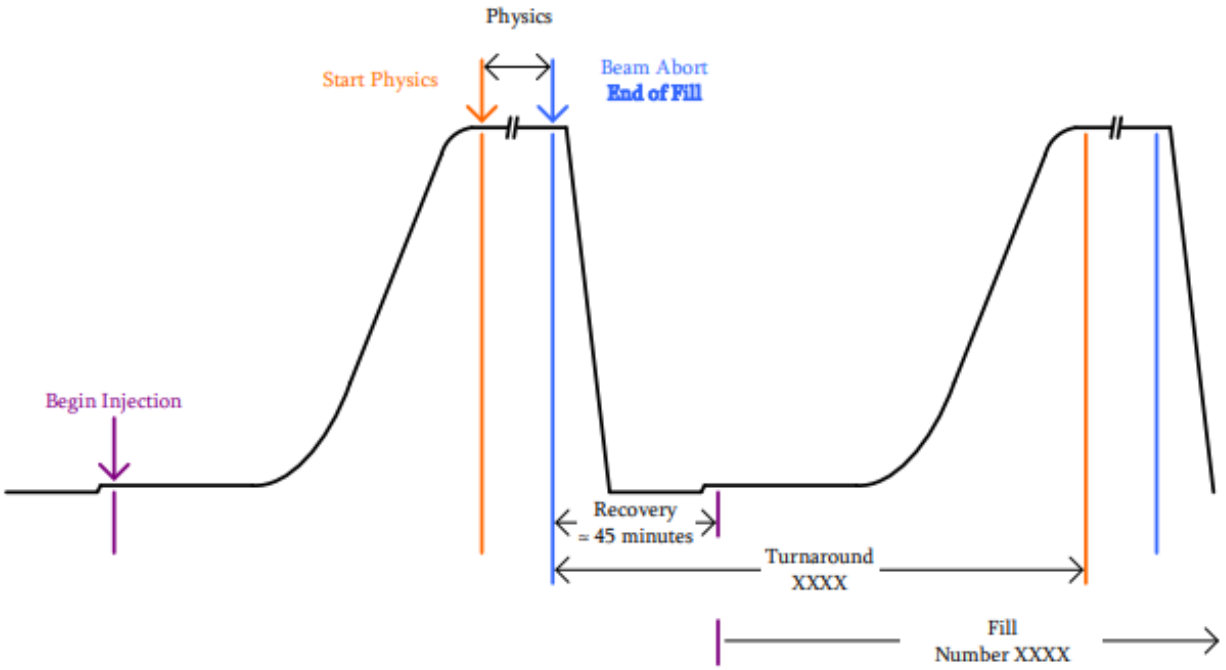
- PS

	Type of Availability	Availabilty (Intrinsec)
0	Pessimistic Matrix Availability	89.78 %
1	Curve Availability	93.81 %
2	Geometric Matrix Availability	94.10 %
3	Raw Availability	94.10 %
4	Optimistic Matrix Availability	96.33 %

- SPS

	Type of Availability	Availabilty (Intrinsec)
0	Pessimistic Matrix Availability	88.19 %
1	Curve Availability	92.66 %
2	Geometric Matrix Availability	93.70 %
3	Raw Availability	93.66 %
4	Optimistic Matrix Availability	96.20 %

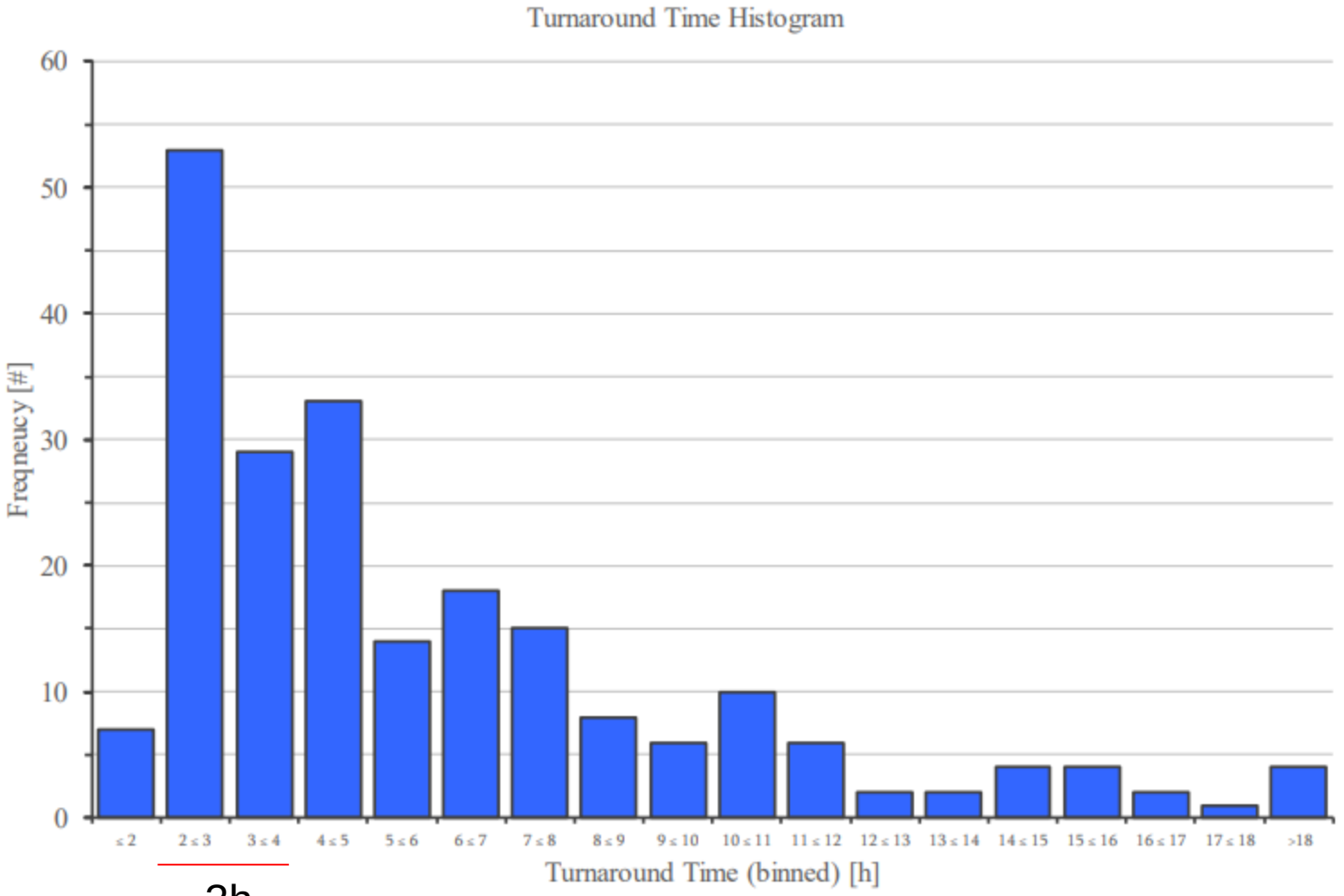
Top Energy Penalties



Turnaround ≈ 3h

- https://cds.cern.ch/record/2650574/files/awg_p+_acc_note_2018_0081.pdf

Turnaround Estimation ≈ 3h



≈ 3h

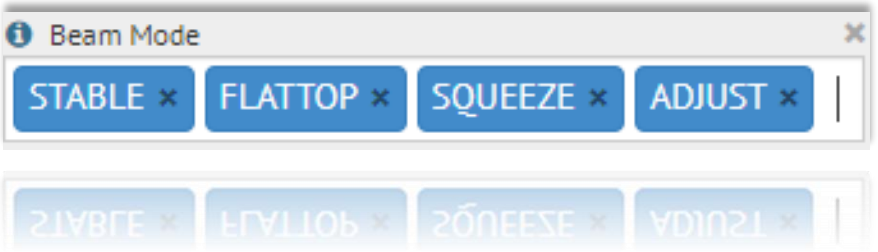
Top Energy Penalties

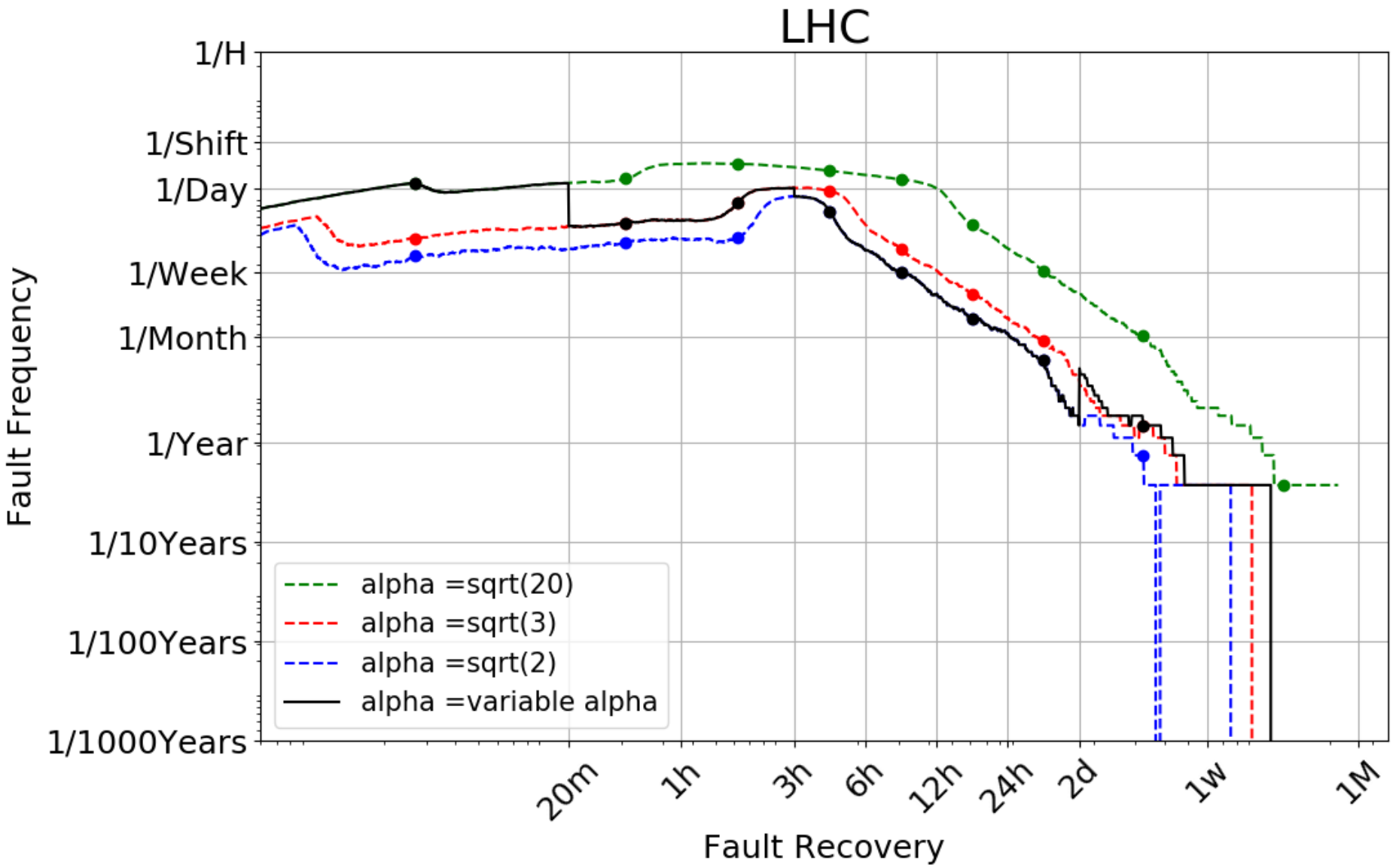
- First Approach:
- Using Pandas
- PM → Protection Dump → Top Energy → Search matches in AFT → Apply penalties

Event Timestamp	Event Category	Beam Mode	Beam Energy [MeV]
28-JUN-2017 10.12.26.564739	PROGRAMMED_DUMP	INJECTION PHYSICS BEAM	450000
28-JUN-2017 14.00.55.120649	PROTECTION_DUMP	STABLE BEAMS	6499320
28-JUN-2017 17.47.59.417364	PROGRAMMED_DUMP	INJECTION PHYSICS BEAM	450000
28-JUN-2017 18.03.54.215489	PROGRAMMED_DUMP	INJECTION PHYSICS BEAM	449880
29-JUN-2017 05.29.45.697000	PROTECTION_DUMP	STABLE BEAMS	6499320
29-JUN-2017 13.51.41.118703	PROTECTION_DUMP	STABLE BEAMS	6499440

Top Energy Penalties

- A new release of AFT was available and allowed filtering by beam mode
- Validated AFT with PM approach: same results :-)
- In comparison with PM crosschecking: Easier to handle




LHC
1/H
1/Shift
1/Day
1/Week
1/Month
1/Year
1/10Years
1/100Years
1/1000Years
Fault Frequency
alpha =sqrt(20)
alpha =sqrt(3)
alpha =sqrt(2)
alpha =variable alpha
20m
1h
3h
6h
12h
24h
2d
1w
1M
Fault Recovery

LHC – With/Without Penalties

Without penalties

	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.065470	0.022426	0.025783	0.010933	0.003874	0.001722	0.000603	0.000172	0.000000
1/Shift	0.523760	0.179408	0.206267	0.087466	0.030992	0.013774	0.004821	0.001377	0.000000
1/Day	1.571281	0.538223	0.618802	0.262397	0.092975	0.041322	0.014463	0.004132	0.000000
1/Week	10.998967	3.767562	4.331612	1.836777	0.650826	0.289256	0.101240	0.028926	0.000000
1/Month	47.924070	16.415806	18.873450	8.003099	2.835744	1.260331	0.441116	0.126033	0.000000
1/Year	573.910382	196.586002	226.017304	95.840393	33.959194	15.092975	5.282541	1.509298	0.000000
1/10Years	5739.103822	1965.860021	2260.173037	958.403926	339.591942	150.929752	52.825413	15.092975	0.000000
1/100Years	57391.038223	19658.600207	22601.730372	9584.039256	3395.919421	1509.297521	528.254132	150.929752	0.000000
1/1000Years	573910.382231	196586.002066	226017.303719	95840.392562	33959.194215	15092.975207	5282.541322	1509.297521	0.000000

With penalties

	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.05	0.02	0.03	0.02	0.01	0.00	0.00	0.00	0.00
1/Shift	0.38	0.15	0.24	0.20	0.05	0.02	0.01	0.00	0.00
1/Day	1.15	0.46	0.73	0.59	0.14	0.05	0.02	0.00	0.00
1/Week	8.08	3.20	5.11	4.12	1.00	0.34	0.13	0.03	0.00
1/Month	35.19	13.93	22.28	17.96	4.35	1.48	0.57	0.13	0.00
1/Year	421.47	166.78	266.77	215.07	52.07	17.73	6.79	1.51	0.00
1/10Years	4214.71	1667.77	2667.68	2150.75	520.71	177.34	67.92	15.09	0.00
1/100Years	42147.13	16677.74	26676.83	21507.49	5207.08	1773.42	679.18	150.93	0.00
1/1000Years	421471.33	166777.38	266768.34	215074.90	52070.76	17734.25	6791.84	1509.30	0.00

LHC – Penalty Effect

- RM_Pen - RM_No_Pen =

	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	-0.017390	-0.003400	0.004649	0.013602	0.002066	0.000301	0.000172	0.000000	0.000000
1/Shift	-0.139118	-0.027204	0.037190	0.108815	0.016529	0.002410	0.001377	0.000000	0.000000
1/Day	-0.417355	-0.081612	0.111570	0.326446	0.049587	0.007231	0.004132	0.000000	0.000000
1/Week	-2.921488	-0.571281	0.780992	2.285124	0.347107	0.050620	0.028926	0.000000	0.000000
1/Month	-12.729339	-2.489153	3.402893	9.956612	1.512397	0.220558	0.126033	0.000000	0.000000
1/Year	-152.439050	-29.808626	40.751033	119.234504	18.111570	2.641271	1.509298	0.000000	0.000000
1/10Years	-1524.390496	-298.086260	407.510331	1192.345041	181.115702	26.412707	15.092975	0.000000	0.000000
1/100Years	-15243.904959	-2980.862603	4075.103306	11923.450413	1811.157025	264.127066	150.929752	0.000000	0.000000
1/1000Years	-152439.049587	-29808.626033	40751.033058	119234.504132	18111.570248	2641.270661	1509.297521	0.000000	0.000000

- As expected, penalties increase the frequency of “medium/long” duration.

LHC – Penalty Effect

- Without Penalty

	Type of Availability	Availabilty (Intrinsec)
0	Pessimistic Matrix Availability	66.71 %
1	Geometric Matrix Availability	79.31 %
2	Raw Availability	79.42 %
3	Optimistic Matrix Availability	86.62 %

- With Penalty

	Type of Availability	Availabilty (Intrinsec)
0	Pessimistic Matrix Availability	54.05 %
1	Curve Availability	73.89 %
2	Geometric Matrix Availability	70.21 %
3	Raw Availability	70.51 %
4	Optimistic Matrix Availability	80.20 %

- penalties cause a decrease in availability about -9 points

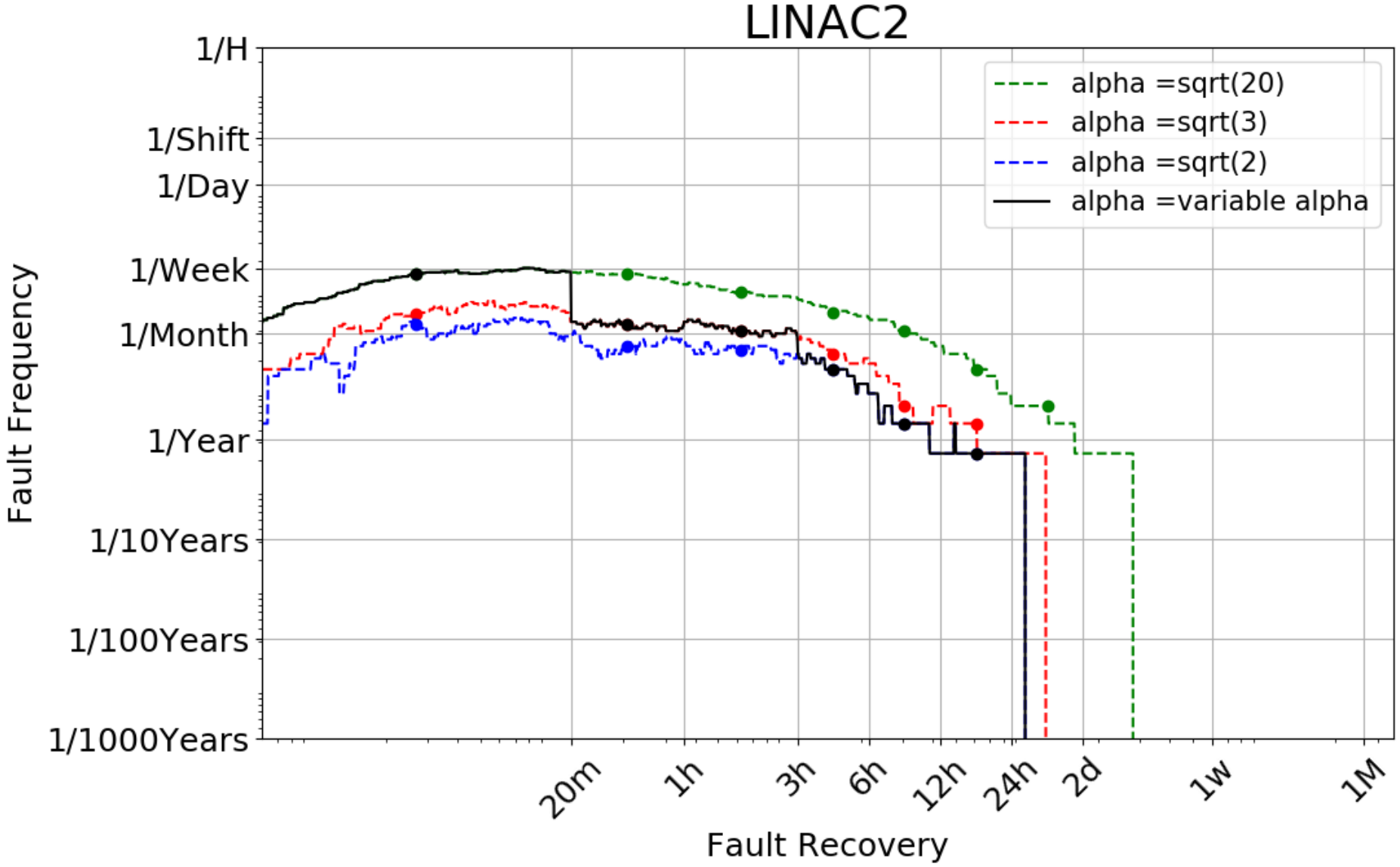
Conclusions

- Risk matrices are a widely used tool for risk analysis
- Their use at CERN goes back to the LHC design phase, where failure probabilities and consequences were estimated by experts
- A new data-driven approach was proposed for a better definition of acceptable and unacceptable failure modes, thanks to the gained experience with the machine:
  - Continuous risk curves
  - New risk matrix discretisation
- The approach was for the first time extended to all CERN machines
- Data-driven risk matrices will improve the definition of reliability requirements for new systems designs (e.g. BIS and SMP 2.0, D1 and D2 protection, R2E project goals, etc.)

Outlook

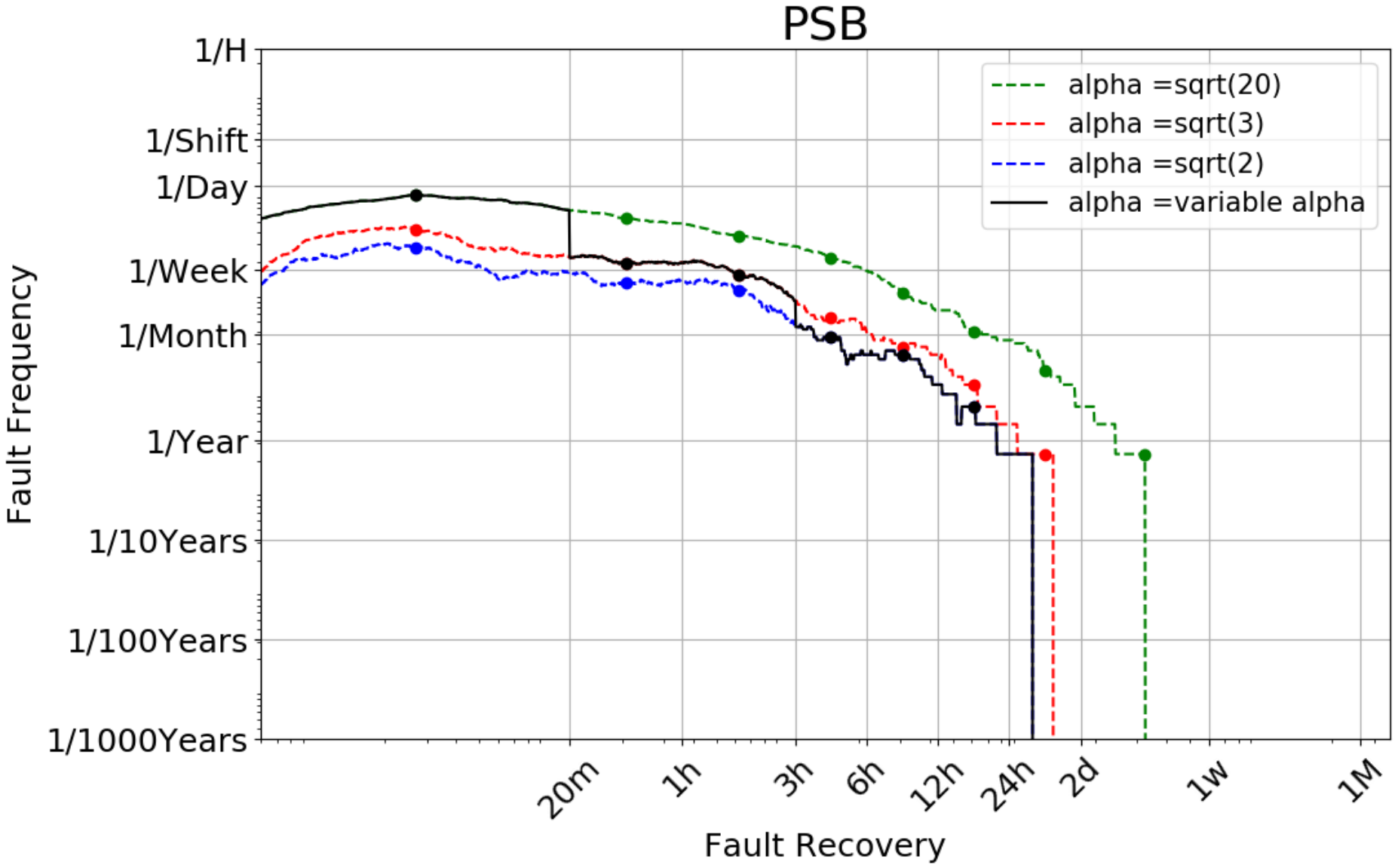
- WIP: extension of the acceptable / unacceptable range to “high impact – low frequency” faults
- The new approach will be discussed in the Machine Availability and Reliability Panel
- A note is under preparation to summarize the outcomes of the analysis (with a detailed description of the process and maths behind)
- If approved, we are going to propose an implementation of the data-driven approach directly in AFT (all developed code is available for sharing in SWAN notebooks)
  - The matrices will be updated online and be self-maintained

Thank you :-)


LINAC2
1/H
1/Shift
1/Day
1/Week
1/Month
1/Year
1/10Years
1/100Years
1/1000Years
Fault Frequency
20m
1h
3h
6h
12h
24h
2d
1w
1M
Fault Recovery
alpha =sqrt(20)
alpha =sqrt(3)
alpha =sqrt(2)
alpha =variable alpha

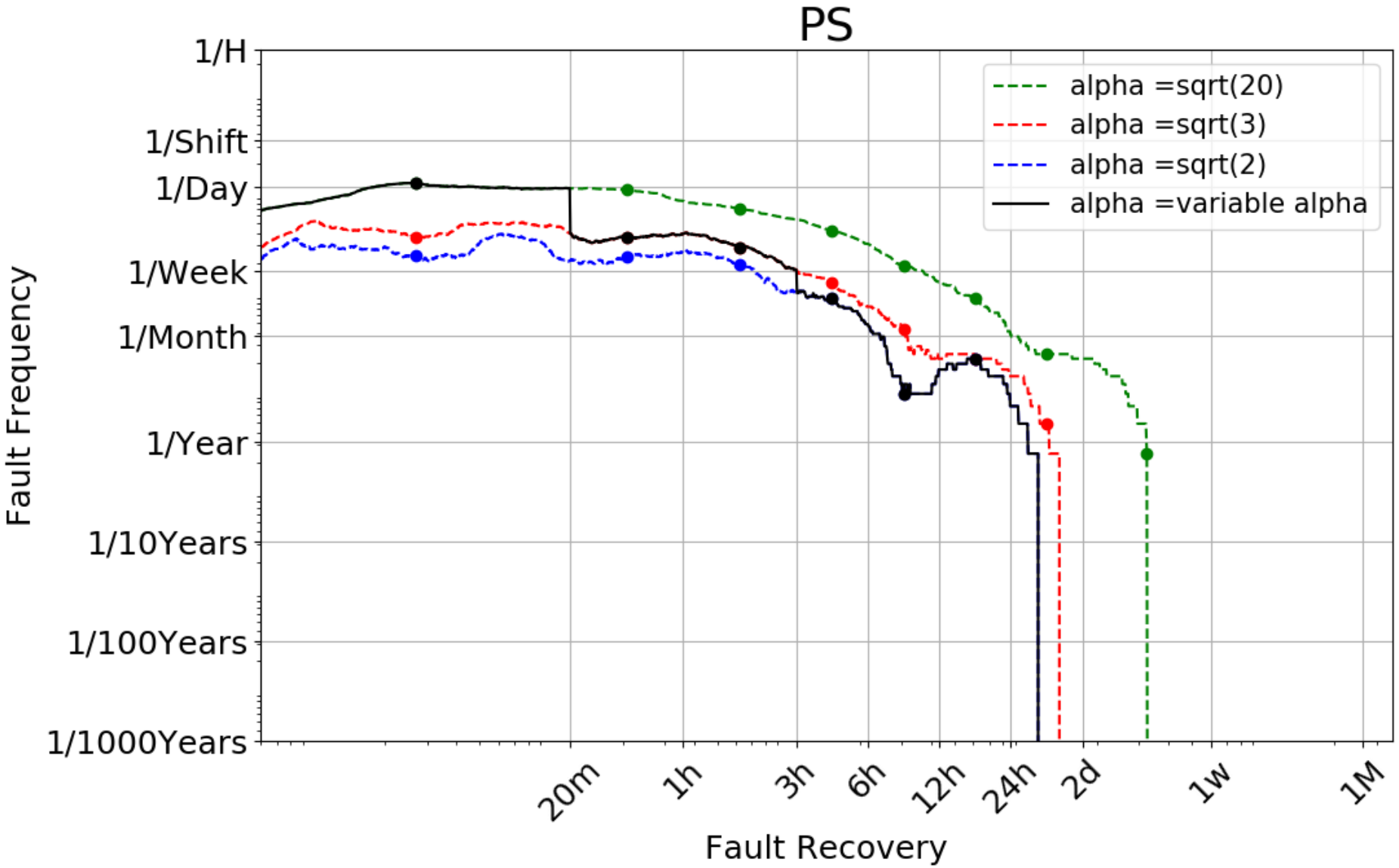
LINAC2

	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1/Shift	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1/Day	0.13	0.04	0.03	0.01	0.00	0.00	0.00	0.00	0.00
1/Week	0.89	0.28	0.24	0.10	0.03	0.01	0.00	0.00	0.00
1/Month	3.86	1.22	1.04	0.43	0.12	0.06	0.00	0.00	0.00
1/Year	46.21	14.67	12.47	5.13	1.47	0.73	0.00	0.00	0.00
1/10Years	462.06	146.69	124.68	51.34	14.67	7.33	0.00	0.00	0.00
1/100Years	4620.63	1466.87	1246.84	513.40	146.69	73.34	0.00	0.00	0.00
1/1000Years	46206.33	14668.67	12468.37	5134.04	1466.87	733.43	0.00	0.00	0.00


PSB
1/H
1/Shift
1/Day
1/Week
1/Month
1/Year
1/10Years
1/100Years
1/1000Years
Fault Frequency
alpha =sqrt(20)
alpha =sqrt(3)
alpha =sqrt(2)
alpha =variable alpha
20m
1h
3h
6h
12h
24h
2d
1w
1M
Fault Recovery

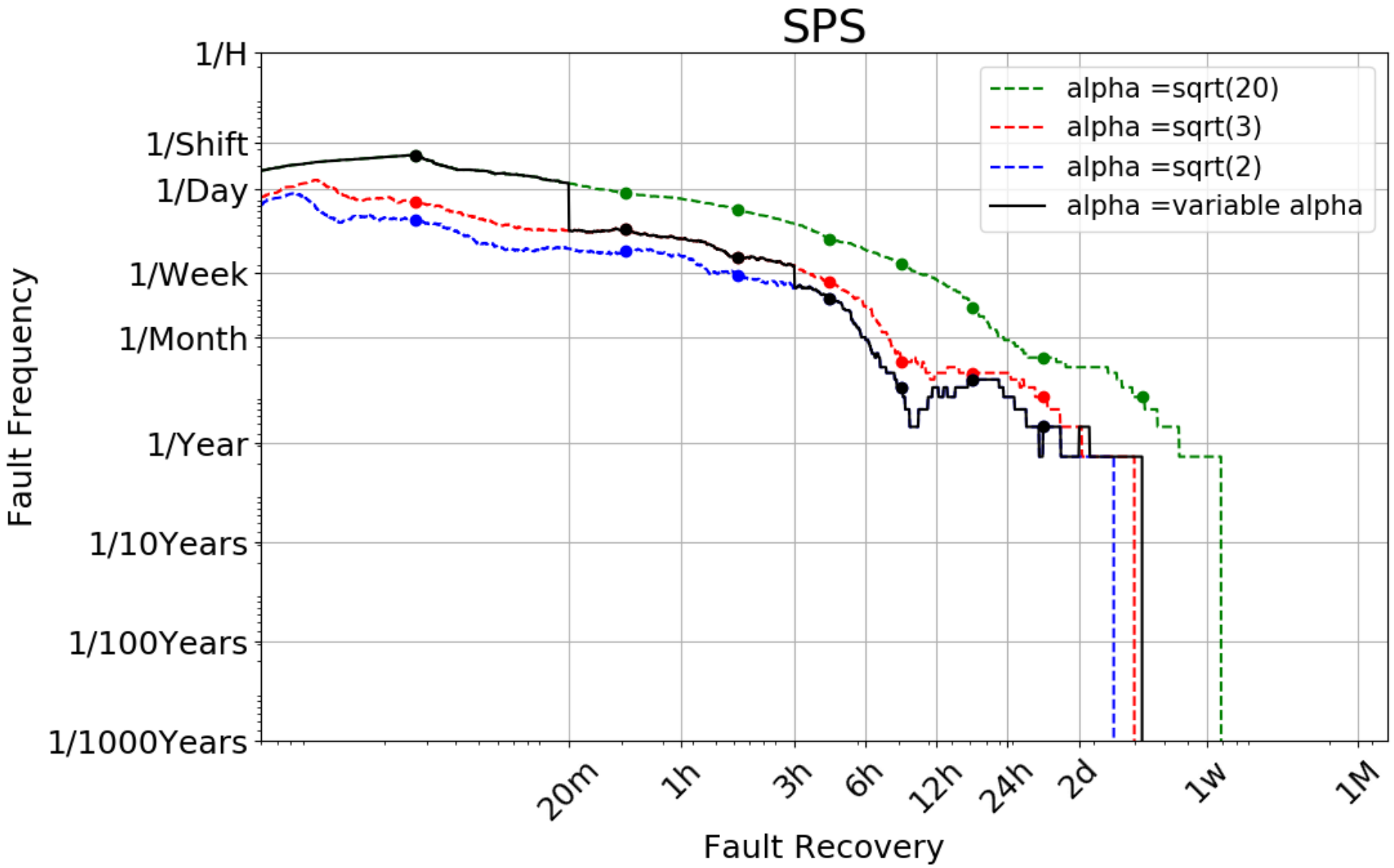
PSB

	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1/Shift	0.27	0.06	0.04	0.01	0.01	0.00	0.00	0.00	0.00
1/Day	0.82	0.17	0.13	0.03	0.02	0.01	0.00	0.00	0.00
1/Week	5.72	1.19	0.90	0.21	0.14	0.04	0.00	0.00	0.00
1/Month	24.90	5.17	3.94	0.92	0.61	0.18	0.00	0.00	0.00
1/Year	298.24	61.86	47.13	11.05	7.36	2.21	0.00	0.00	0.00
1/10Years	2982.38	618.57	471.29	110.46	73.64	22.09	0.00	0.00	0.00
1/100Years	29823.84	6185.69	4712.90	1104.59	736.39	220.92	0.00	0.00	0.00
1/1000Years	298238.41	61856.85	47129.03	11045.87	7363.91	2209.17	0.00	0.00	0.00


PS
1/H
1/Shift
1/Day
1/Week
1/Month
1/Year
1/10Years
1/100Years
1/1000Years
Fault Frequency
alpha =sqrt(20)
alpha =sqrt(3)
alpha =sqrt(2)
alpha =variable alpha
20m
1h
3h
6h
12h
24h
2d
1w
1M
Fault Recovery

PS

	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1/Shift	0.38	0.10	0.08	0.03	0.00	0.01	0.00	0.00	0.00
1/Day	1.13	0.31	0.25	0.08	0.01	0.02	0.00	0.00	0.00
1/Week	7.89	2.19	1.76	0.53	0.06	0.13	0.00	0.00	0.00
1/Month	34.36	9.52	7.66	2.32	0.26	0.58	0.00	0.00	0.00
1/Year	411.48	114.04	91.70	27.74	3.08	6.94	0.00	0.00	0.00
1/10Years	4114.84	1140.44	916.98	277.41	30.82	69.35	0.00	0.00	0.00
1/100Years	41148.42	11404.43	9169.78	2774.05	308.23	693.51	0.00	0.00	0.00
1/1000Years	411484.18	114044.30	91697.78	27740.51	3082.28	6935.13	0.00	0.00	0.00


SPS
1/H
1/Shift
1/Day
1/Week
1/Month
1/Year
1/10Years
1/100Years
1/1000Years
Fault Frequency
alpha =sqrt(20)
alpha =sqrt(3)
alpha =sqrt(2)
alpha =variable alpha
20m
1h
3h
6h
12h
24h
2d
1w
1M
Fault Recovery

SPS

	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.09	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1/Shift	0.75	0.13	0.07	0.03	0.00	0.00	0.00	0.00	0.00
1/Day	2.24	0.40	0.21	0.08	0.01	0.01	0.00	0.00	0.00
1/Week	15.65	2.77	1.44	0.55	0.07	0.08	0.03	0.00	0.00
1/Month	68.19	12.05	6.27	2.40	0.31	0.37	0.12	0.00	0.00
1/Year	816.66	144.33	75.11	28.72	3.68	4.42	1.47	0.00	0.00
1/10Years	8166.58	1443.33	751.12	287.19	36.82	44.18	14.73	0.00	0.00
1/100Years	81665.78	14433.27	7511.19	2871.93	368.20	441.83	147.28	0.00	0.00
1/1000Years	816657.76	144332.66	75111.90	28719.25	3681.96	4418.35	1472.78	0.00	0.00