### 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"

6/4/2020

- ==> 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 <u>PhD</u>), 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 <u>paper</u>), 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
	1 / hour							
	1 / day							
	1 / week							
sncy	1 / month							
Frequency	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?

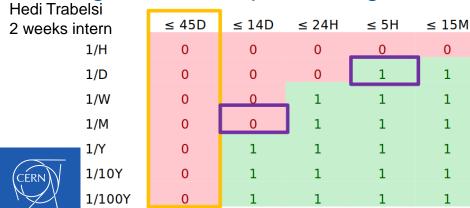
=> use of AFT to populate the risk matrix #Data-Driven ;-)

=> 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



					Recove	ry		
	LHC risk matrix	∞	year	month	week	day	hours	minutes
			S6	S5	S4	S3	S2	S1
	1 / hour							
	1 / day							
2	1 / week							
Frequency	1 / month							
edt	1 / year							
ũ	1 / 10 years							
	1 / 100 years							
	1 / 1000 years							

					Recove	ry		
	LHC risk matrix	Ø	year	month	week	day	hours	minutes
		S7	S6	S5	S4	S3	S2	S1
	1 / hour							
	1 / day							
2	1 / week							
Frequency	1 / month							
edi	1 / year							
цŢ	1 / 10 years							
	1 / 100 years							
	1 / 1000 years							

# **Protection and Availability**

Availability range: Frequency ~< 1/month

- Available statistics
- Possible predictions (AvailSim)

Protection range: Frequency >~ 1/year

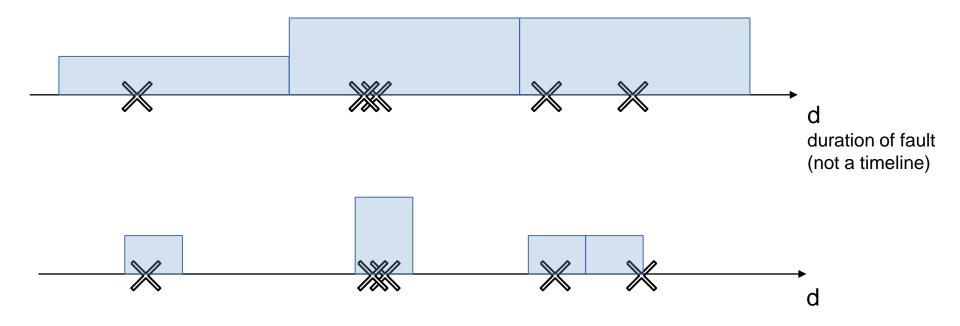
- Not so much statistics yet
- Difficult to predict

					Recovery					
	LHC risk matrix	∞	year	mo	nth	week	day	hours	minutes	
		S7	S6	S5		S4	S3	S2	S1	
	1 / hour		ĺ							
	1 / day									
ÿ	1 / week									
lenc	1 / month									
Frequency	1 / year									
ш́.	1 / 10 years									
	1 / 100 years									
	1 / 1000 years									
					_				·	
		• • • • • • • • •	Prot	ect	ion	• • •	Ava	ailabilit	V	



### Higher resolution: Continuous Risk Curve (1/3)

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

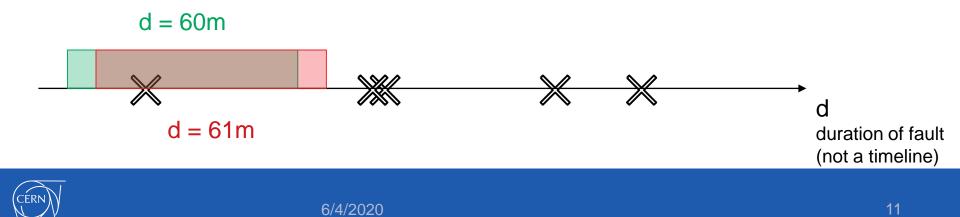




### Higher resolution: Continuous Risk Curve (2/3)

- 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) =

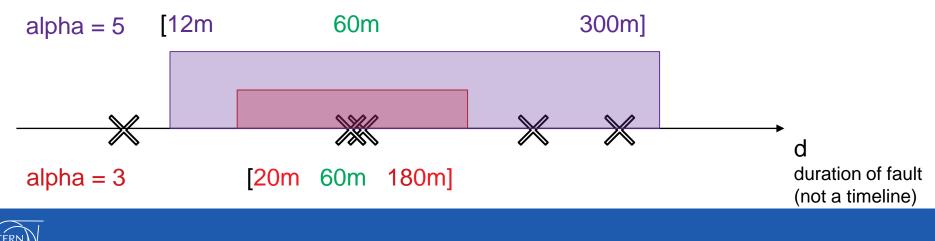
sum\_{list of faults f} 1\_{d / alpha < f\_duration <= d \* alpha}</pre>



### 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}</pre>



## Extracting the data

Data-sources



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

Post Mortem

E-Logbook



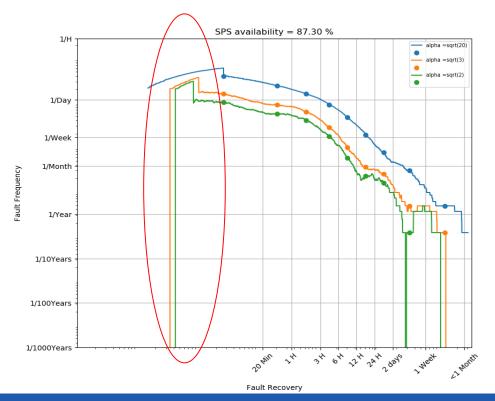
### Extracting the data - Filters

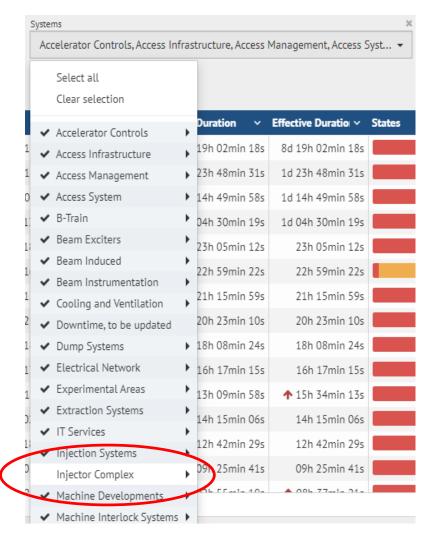
$\overline{\mathbb{C}}$	Accelerator	Accelerators Time period		Systems				- (	Had state	e	
e	Fault Tracking	SPS • 01-01-2017 00:00:00 - 31-12-2018 00:0	0:00	Accelerator Controls, Access Infrastructure, Access Management, Access Syst					Blocking OP 🗸		
	Dashboard	Q								_	
	Register fault	■ , ~ System ~	Start Time	~	End Time v	OP Duration V	Effective Duratio 🗸	States	✓ ↓	·   •	•
Q	Search faults	SP Power Converters	30-05-2018 1	.8:09:42	08-06-2018 13:12:00	8d 19h 02min 18s	8d 19h 02min 18s		<b>R</b> .	т	-
lulul - 1	Statistics	SP Beam Induced » Beam Losses	20-08-2018 1	7:05:20	22-08-2018 16:53:51	1d 23h 48min 31s	1d 23h 48min 31s		M	н	. 💎
		SP Extraction Systems » Septa » North Extraction	15-05-2018 0	3:40:18	16-05-2018 18:30:16	1d 14h 49min 58s	1d 14h 49min 58s		Z.	Z	. 💖
<b>~</b>	Cardiogram	SP Power Converters » Main PC	22-07-2017 1	3:24:32	23-07-2017 17:54:51	1d 04h 30min 19s	1d 04h 30min 19s		M	G	. 💎
2	Comments	SP Electrical Network » Distribution	12-07-2017 1	8:53:06	13-07-2017 17:58:18	23h 05min 12s	23h 05min 12s		1.	f	V
	Reports	SP Cooling and Ventilation » Cooling	27-08-2018 1	6:14:30	28-08-2018 15:13:52	22h 59min 22s	22h 59min 22s		C.	C	. 💎
		SP Extraction Systems » Septa » North Extraction	07-09-2018 1	5:57:58	08-09-2018 13:13:57	21h 15min 59s	21h 15min 59s		Z	5 Н.,	. 💖
A	qblarasi	SP Beam Instrumentation » BLM	05-07-2018 2	1:04:17	06-07-2018 17:27:27	20h 23min 10s	20h 23min 10s		S.		V
U		SP Cooling and Ventilation » Cooling	27-08-2018 1	8:13:44	28-08-2018 12:22:08	18h 08min 24s	18h 08min 24s		C.	C	. 💖
	Keyboard shortcuts	SP Power Converters » Controls/Electronics	05-07-2018 1	7:29:27	06-07-2018 09:46:42	16h 17min 15s	16h 17min 15s		d.	w	. 🕫
i	Documentation	SP Electrical Network » Distribution	03-12-2018 1	9:45:02	04-12-2018 08:55:00	13h 09min 58s	🛧 15h 34min 13s		4.		v
		SP Electrical Network » Compensator	23-07-2017 0	2:00:59	23-07-2017 16:16:05	14h 15min 06s	14h 15min 06s				V
0	Support	SP Power Converters » Main PC	12-07-2017 1	8:53:06	13-07-2017 07:35:35	12h 42min 29s	12h 42min 29s		S.	t	v
	_ogout	SP Targets and Dumps » North Area Targets	05-10-2017 0	2:54:19	05-10-2017 12:20:00	09h 25min 41s	09h 25min 41s		Т.	fl	. 🕫
	<		OF OF 2019 1	7.40.40	0/ 05 2019 02-7/-07	005 5510-	▲ 005 77:- 01-		c I	0	
	3.34.0	1476 items shown								l	<u>I</u> (



## 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

	Apr		t Stable sams		onswith ounches May					June			
Wk	14	15	16	17	18	19	20	21	22	23	24	25	26
Мо	Easter 2	9	16	Scrubbing 23	30	7	14	Whitsun 21	28	4	11	18	25
Tu			¥		1st May							ты	
We			Inter	eaved								- 154 -	
Th	Recommi with t		commis	sioning &		Ascension					- MD1 -		
Fr			intenaty	ramp up									_β*=90 m_ run
Sa					Y							VdM	
Su												program	



# Scope - Cardiogram

ET?	Accelerator	Accelerator Time period		Had state 🗙		
Ý	Fault Tracking	SPS - 01-01-2017 00:00:	00 - 31-12-2018 00:00:00	Blocking OP ▼ More ▼	Q	
- 🚱	Dashboard	Accelerator Controls	× ×× ×	×× × × × ×	ж × × × × >	(X X
		Access Infrastructure				×
A	Register fault	Access Management		x xx xx	× 2000	× × × 📃 🔀
	-	Access System	×××	X X XX	× × ×	<b>x</b> x x x x
0	Search faults	Beam Exciters				× × 🔍
$\sim$	Scarennades	Beam Induced		×	<b>ж x x</b> x	X 3KXX
1 nd	Ctatistics	Beam Instrumentatio(	SIC SIC SIC SIC		38: 38080636 × >< >088 3	×× × × × × × × × ×
	Statistics	Cooling and Ventilati	××	× × × × ×	X X4 X X4	× x x × × × × ×
		Dump Systems 1	ж ж ж	XXX X X	× × ×	X X X X RELATIONS
~~	Cardiogram	Electrical Network	× ×	k X	× × × × × × ×	IS same as
		Experimental Areas			×	× × × × is similar to
2	Comments	Extraction Systems 1	× 301000K× >	ok X XK		IX X XX X0000K XX is related to
		IT Services	× .		× *	historia
m	Reports	Injection Systems	×××× ××	XIII XXX XXX XXXXXXXXXXXXXXXXXXXXXXXXX	× 38K (XXXX) XX	
		Injector Complex 30			SCHOOLENDER CHARGE SHERE	is parent of
		Machine Developments	× *×	× × ж× ж× х	· · · · · · · · · · · · · · · · · · ·	xx x x x xx y
		Machine Interlock Sy	×		×	
	gblarasi	Magnets 1	× × ×	×	* * * *	XX XXX
		Operation		BERICK OC MEDICALES ENGINE MEDIC/COCHECT		x 300000 300388 38830000 200 x
(5000)	Keyboard shortcuts	Other	× <b>x</b> × ×	× × × × ×		oc x xxxx
	,,	Power Converters 6	BC< 30+30001K/38C		>C XK XHEEDC>OOHHHOC XHKHKXH	INTERVIEW SCARE SCARE SCARE × SEALAR
i	Documentation	Radiation Protection			×	×
•	Documentation	Radio Frequency 4	Sabe Same			
•	_	Targets and Dumps		(X XX XX X	30 X00K	× XK ×
<b>Q</b>	Support	Transverse Feedback	× ×	× ×	×	×
		Vacuum	× 3	x x	• ×	× × +
	Logout	Jan '17	Apr '17 Jul '13	7 Oct '17 Jan '1	18 Apr '18 Jul '18	Oct '18
	<		-		·	
		Sun	Sat Sat	Sun Mor	n Sun Sun	Mon
	3.34.0					Ψ.



# Scope - Cardiogram

ET:	Accelerator	Accelerator Time period			Had state 🗙				<u>^</u>		
$\mathbf{e}$	Fault Tracking	SPS - 01-01-201	7 00:00:00 - 31-12-2	018 00:00:00 🛗	Blocking OP - More	- Q					
									_		
- 220	Dashboard	Accelerator Controls		× ×× <b>×</b> ×>	<pre></pre>	× ×		×	_		
		Access Infrastructure		× ××	× × × ×		× ×	× × ×			
A	Register fault	Access Management Access System		XXX AA	x x xx	<b>~</b> ,		(xx x x x x			
		Beam Exciters		~~~~	· · · · · · · · · · · · · · · · · · ·			XX			
Q	Search faults	Beam Induced			×		x x x	X XXX			
1 - 1		Beam Instrumentatio		ж ж хананск жа		36 2000	NEWE X X XXXXXX XXXXXXXXXXXXXXXXXXXXXXXX	× × × × × × × ×	✓ ♣		
	Statistics	Cooling and Ventilati		x x X	x x x x	X	X4 X X4 X	₩ <b>6</b> <× × × ×			
		Dump Systems 1		ж ж ж хх	K X X		x x x	X X XX	RELATIONS		
<b>~</b>	Cardiogram	Electrical Network		<b>X X</b> X		X XX	××× ××	XX X XXX X	is same as		
-		Experimental Areas						×xx × ×	is similar to		
2	Comments	Extraction Systems 1		× 300000 × ××	× <b>ж</b>		XXXX XXX	XX XBBOR XK	is related to		
		IT Services Injection Systems	(1		DOIBCX XX XX	×	кжжжа к	× × ×	blocks		
<b>=</b>	Reports	Injector Complex 30	U						is parent of		
		Machine Developments		x xx x	X XXX XXX X		X X X X X X X X X X X X X X X X X X X	X X XX Y			
		Machine Interlock Sy		×		×	Y				
	gblarasi	Magnets 1		<b>x x</b> x	×	*	× ××× ×	XXX IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII			
		Operation				36(30	CHEX XK 30C380 XXX 30X	XXX XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX			
(FEER)	Keyboard shortcuts	Other		×x x× ×	× ×××	× ×					
	,,	Power Converters 6				× × ×					
i	Documentation	Radiation Protection							_		
<b>•</b>		Radio Frequency 4				>00000000 >00000			_		
ര	Support	Transverse Feedback		× × ×	X	X		<u> </u>	_		
•	Sapport	Vacuum		X X	X	<b>^</b>	• x x	× •			
	Logout	Jan '1	7 Apr '17	Jul '17		n '18 Apr '18	Jul '18	Oct '18			
	2		/ Api 1/	Jul 17	ULL 1/ Ja	110 Api 10	Jul 10	001 10			
	<	Sun	C-+	C-+	Sun	lon Cur	Sup	Man			
	3.34.0	Sun	Sat	Sat	Sun	1on Sun	Sun	Mon	-		
	5.54.0				047						
	2017										



# Scope – E-Logbook

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

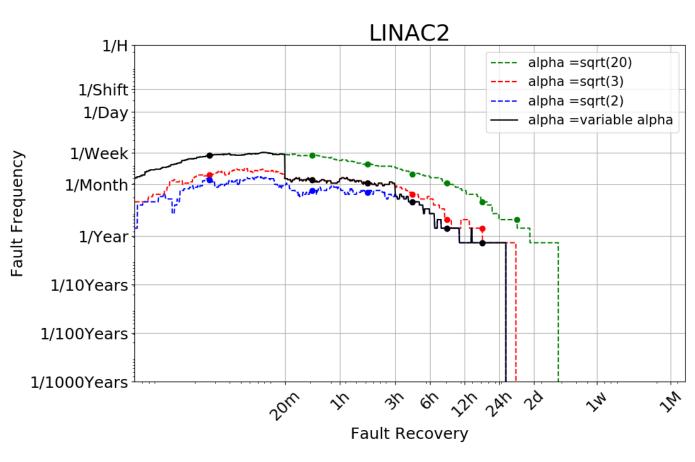
S	PS		۲	Consign	nes Phones Vi	stars O	thers			-		search
						SPS	[Monday	01-May-201	7 Morning]			
							<b>4</b>	۲	<b>&gt;</b>	-		۱
FI	LTERS:	EV	T SOURCES	lear		<ul> <li>Piquet:</li> </ul>	3		▼ Expert		▼ INFO	
	Time	L O T						Comment				
1	07:00	LMS	Stephane and S	lerge							created by spsop on	CWO-CCC-A7LC
	08:01		Kicker > Calle Piquet ABT Generator 2 nc			3:0         3:0 <td></td> <td></td> <td></td> <td></td> <td>created by spsop on</td> <td>080-000-2610</td>					created by spsop on	080-000-2610
H			Cavity 3 tripr	ed							created by spsop on	CWO-CCC-A6LC
	$\frown$											



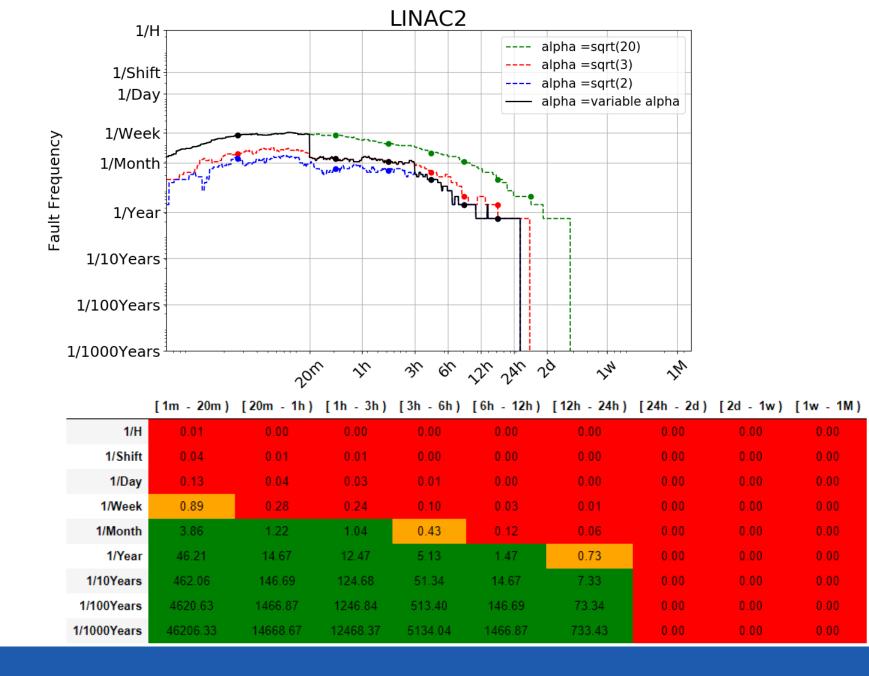
## Examples of continuous curves

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

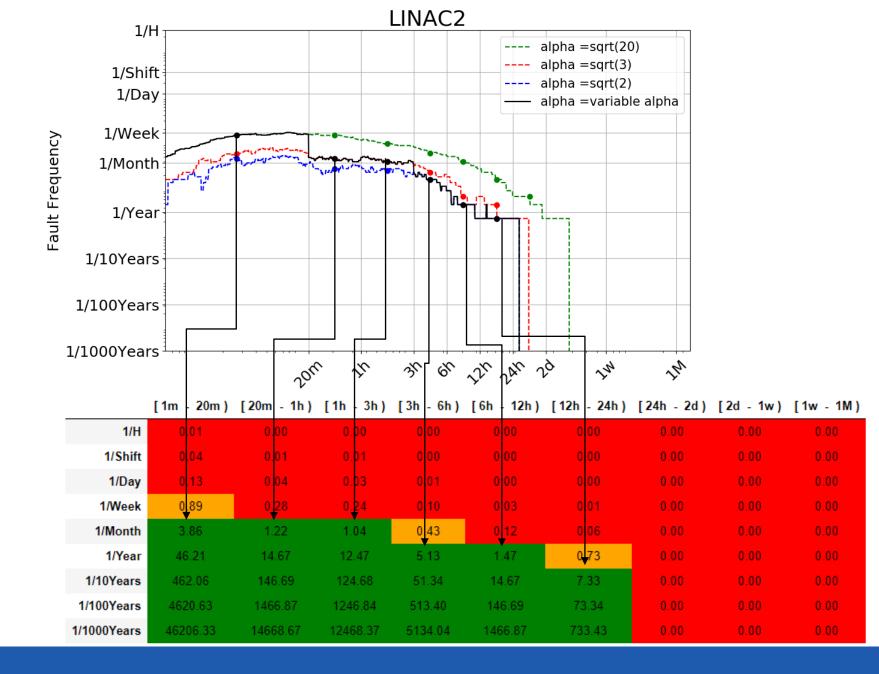
- Loss of information?
- → The discretisation of the matrix should follow the main variation (non variation) of the curve
- →
- Acceptable vs
   unacceptable?
- A failure mode is unacceptable if it does not lay in the shadow of the other failure modes











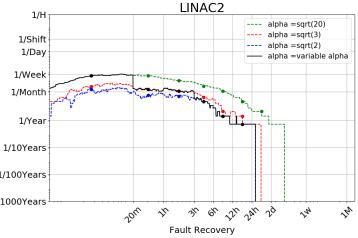


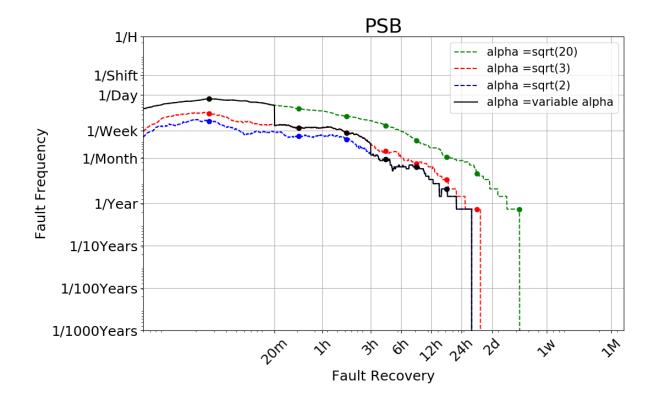
# **Computation of Availability**

- 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
   1
- Pessimistic Risk Matrix Availability: 1000
   frequency \* highest bin of each box
- Geometric Risk Matrix Availability: frequency \* "geometric center" of eacl 2

	Type of Availability	Availabilty (Intrinsec)	requ
	Pessimistic Matrix Availability	98.48 %	ault F
<u>Continuous Risk C</u>	Curve Availability	99.02 %	1
toursl of the eu	Geometric Matrix Availability	99.09 %	1/:
ntegral of the cu	Raw Availability	99.00 %	1/10
	Optimistic Matrix Availability	99.42 %	

	[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
100Years	4620.63	1466.87	1246.84	513.40	146.69	73.34
000Years	46206.33	14668.67	12468.37	5134.04	1466.87	733.43

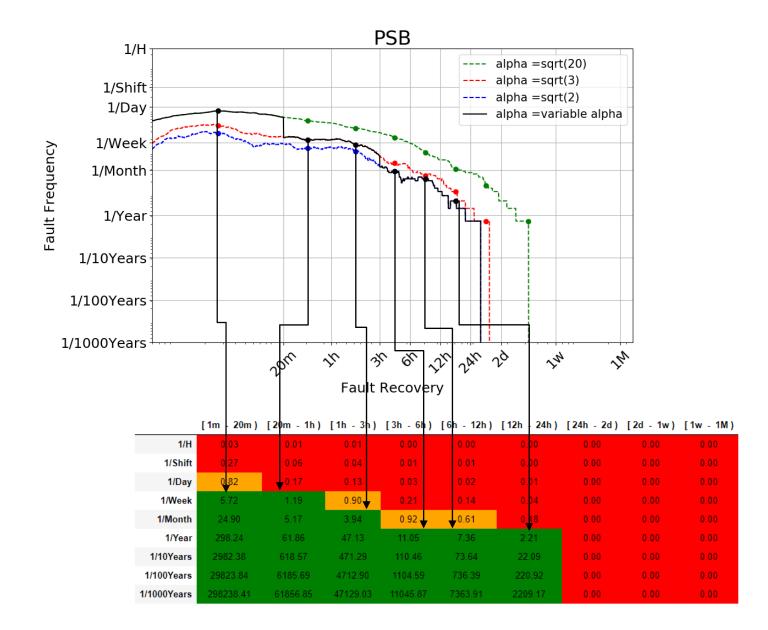




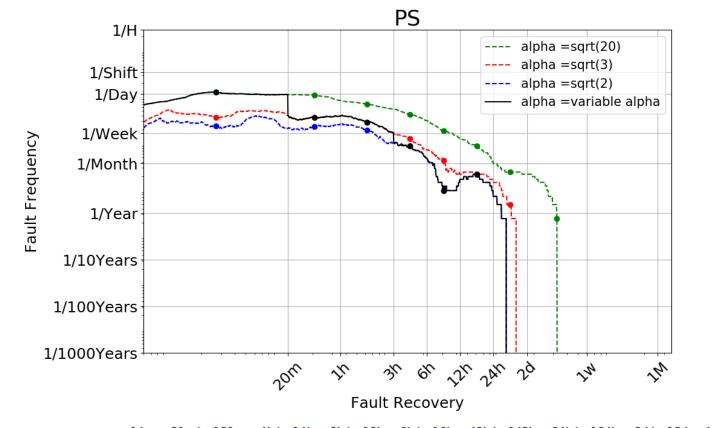
	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1/Shift	0.27	0.06	0.04	0.01	0.01	0.00	0.00	0.00	0.00
1/Day	0.82	0.17	0.13	0.03	0.02	0.01	0.00	0.00	0.00
1/Week	5.72	1.19	0.90	0.21	0.14	0.04	0.00	0.00	0.00
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



6/4/2020

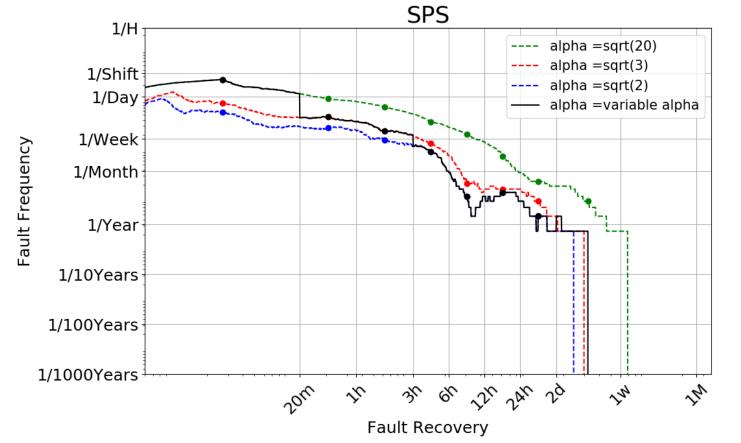






	[1m - 20m)	[20m - 1h)	[1h - 3h)	[3h - 6h)	[6h - 12h)	[12h - 24h)	[24h - 2d)	[2d - 1w)	[1w - 1M)
1/H	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1/Shift	0.38	0.10	0.08	0.03	0.00	0.01	0.00	0.00	0.00
1/Day	1.13	0.31	0.25	0.08	0.01	0.02	0.00	0.00	0.00
1/Week	7.89	2.19	1.76	0.53	0.06	0.13	0.00	0.00	0.00
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 %

#### • **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 %

#### • PSB

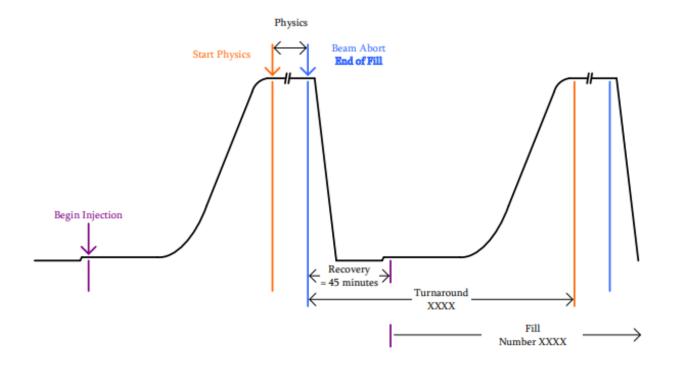
	Type of Availability	Availabilty (Intrinsec)
0	Pessimistic Matrix Availability	94.18 %
1	Curve Availability	96.51 %
2	Geometric Matrix Availability	96.73 %
3	Raw Availability	96.85 %
4	Optimistic Matrix Availability	97.99 %

• 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**

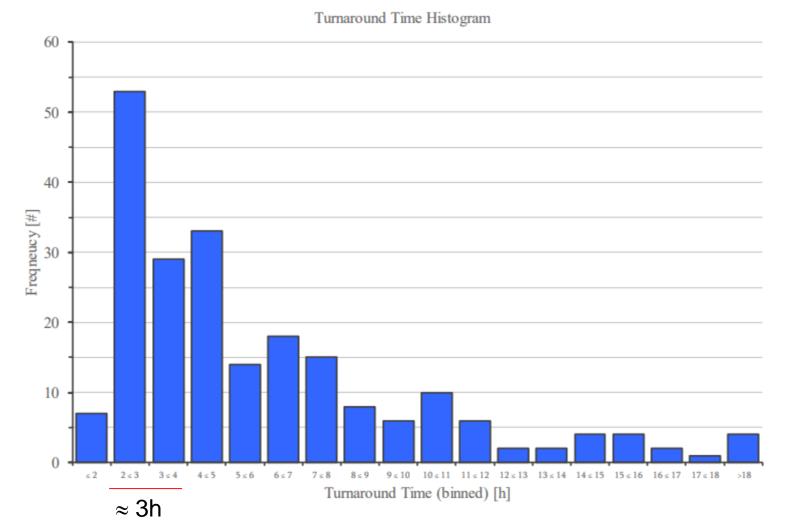


#### Turnaround $\approx$ 3h

• https://cds.cern.ch/record/2650574/files/awg\_p+\_acc\_note\_2018\_0081.pdf



## Turnaround Estimation $\approx$ 3h



CERN

# **Top Energy Penalties**

6/4/2020

• 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 10.12.26.5 64739	PROGRAMMED_DUMP	INJECTION PHYSICS BEAM	450000		
28-JUN- 2017 14.00.55.1 20649	PROTECTION_DUMP	STABLE BEAMS	6499320		
28-JUN- 2017 17.47.59.4 17364	PROGRAMMED_DUMP	INJECTION PHYSICS BEAM	450000		
28-JUN- 2017 18.03.54.2 15489	PROGRAMMED_DUMP	INJECTION PHYSICS BEAM	449880		
29-JUN- 2017 05.29.45.6 97000	PROTECTION_DUMP	STABLE BEAMS	6499320		
29-JUN- 2017 13.51.41.1 18703	PROTECTION_DUMP	STABLE BEAMS	6499440 31		

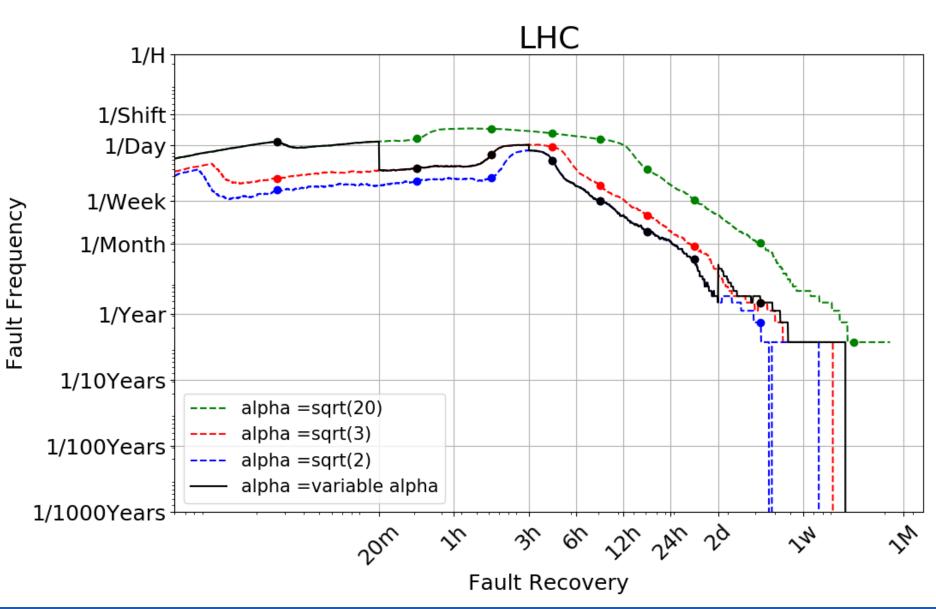


# **Top Energy Penalties**

- 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: <u>Easier to</u> <u>handle</u>









# LHC – With/Without Penalties

		[1	m - 20m)	[20m - 1h)	[1h - 3h]	) [3h - 6	h) [6h-	12h )	[12h -	24h )	[24h - 2d	) [2d	l - 1w)	[1w - 1M)
$\leq$	1/H		0.065470	0.022426	0.025783	0.0109	0.0	03874	0.0	01722	0.00060	30	.000172	0.000000
Without	1/Shift		0.523760	0.179408	0.206267	0.0874	66 0.0	30992	0.0	13774	0.00482	1 0	.001377	0.000000
no	1/Day		1.571281	0.538223	0.618802	0.2623	97 0.0	92975	0.0	41322	0.01446	3 0	.004132	0.000000
t p	1/Week		10.998967	3.767562	4.331612	1.8367	0.6	50826	0.2	89256	0.10124	0 0	.028926	0.000000
en	1/Month		47.924070	16.415806	18.873450	8.0030	99 2.8	35744	35744 1.26		0.44111	<mark>6</mark> 0	.126033	0.000000
alti	1/Year	5	73.910382	196.586002	226.017304	95.8403	93 33.9	59194	15.0	92975	5.28254	1 1	.509298	0.000000
	/10Years	57	39.103822	1965.860021	2260.173037	958.4039	26 339.5	91942	150.9	29752	52.82541	3 15	.092975	0.000000
• •	100Years	573	91.038223	19658.600207	22601.730372	9584.0392	256 3395.9	19421	1509.2	97521	528.25413	2 150	.929752	0.000000
1/10	)00Years	5739	10.382231	196586.002066	226017.303719	95840.3925	62 33959.1	94215	15092.9	75207	5282.54132	2 1509	.297521	0.000000
			[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	0.0	0 (	00.00	0.0	C
With	1/5	Shift	0.38	0.15	0.24	0.20	0.05	0	.02	0.0	1 (	00.00	0.0	)
	1/	Day	1.15	0.46	0.73	0.59	0.14	0	.05	0.0	2 (	00.00	0.0	C
penalti	1/W	eek	8.08	3.20	5.11	4.12	1.00	0	.34	0.1	3 (	0.03	0.0	C
alt	1/Mo	onth	35.19	13.93	22.28	17.96	4.35	1	.48	0.5	7 (	).13	0.0	C
ies	1/)	/ear	421.47	166.78	266.77	215.07	52.07	17	7.73	6.7	9 1	.51	0.0	D
0,	1/10Ye	ears	4214.71	1667.77	2667.68	2150.75	520.71	17	7.34	67.9	92 1	5.09	0.0	D
	1/100Ye	ears	42147.13	16677.74	26676.83	21507.49	5207.08	177	73.42	679.	18 15	50.93	0.0	)
	1/1000Ye	ears	421471.33	166777.38	266768.34	215074.90	52070.76	177	34.25	6791	.84 15	09.30	0.0	C



# 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

#### • With 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 %

	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 <u>estimated by experts</u>
- A new data-driven approach was proposed for a better definition of acceptable and unacceptable failure modes, thanks to the gained <u>experience with the machine</u>:
  - Continuous risk curves
  - New risk matrix discretisation
- The approach was for the first time extended to <u>all CERN machines</u>
- 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

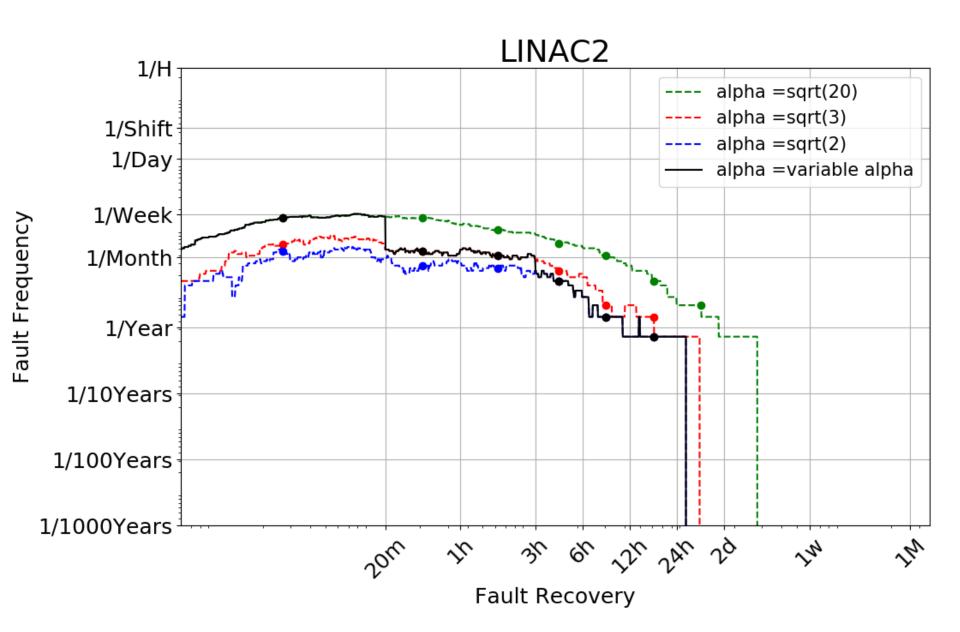
- WIP: extension of the acceptable / unacceptable range to "high impact – low frequency" faults
- The new approach will be discussed in the Machine Availability and Reliability Panel
- A note is under preparation to summarize the outcomes of the analysis (with a detailed description of the process and maths behind)
- If approved, we are going to propose an implementation of the datadriven 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 :-)





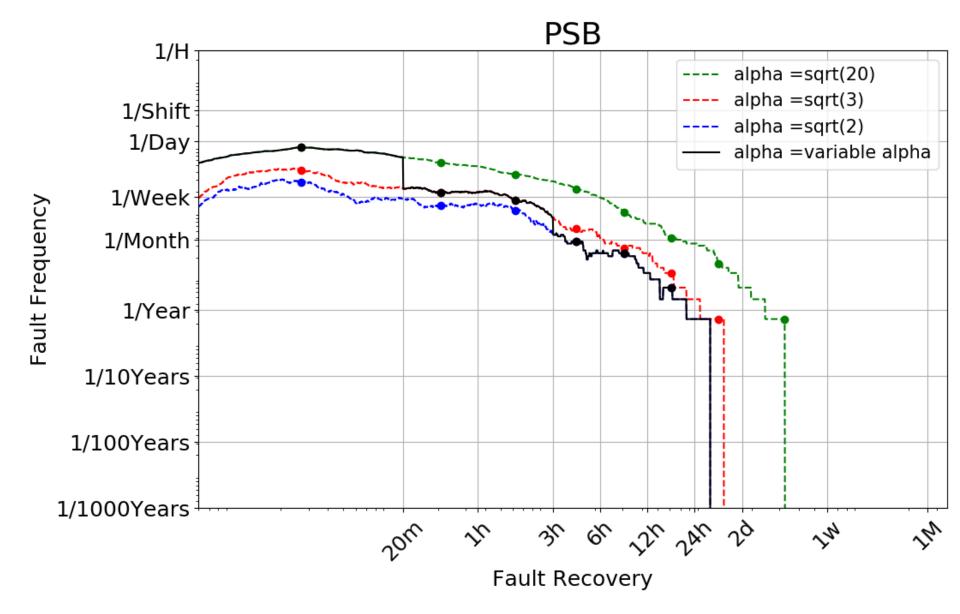




### LINAC2

	[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



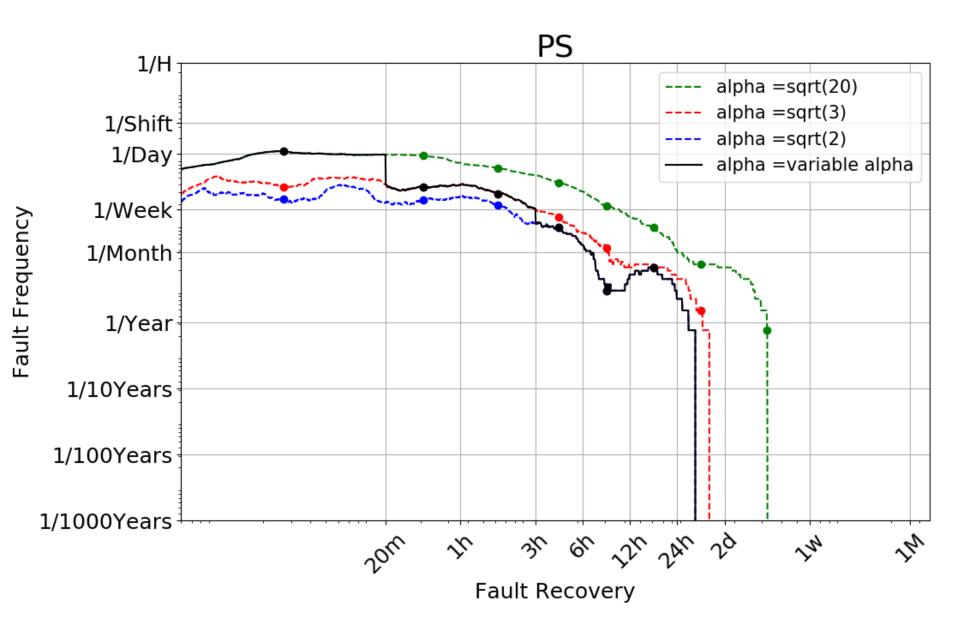




### PSB

	[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



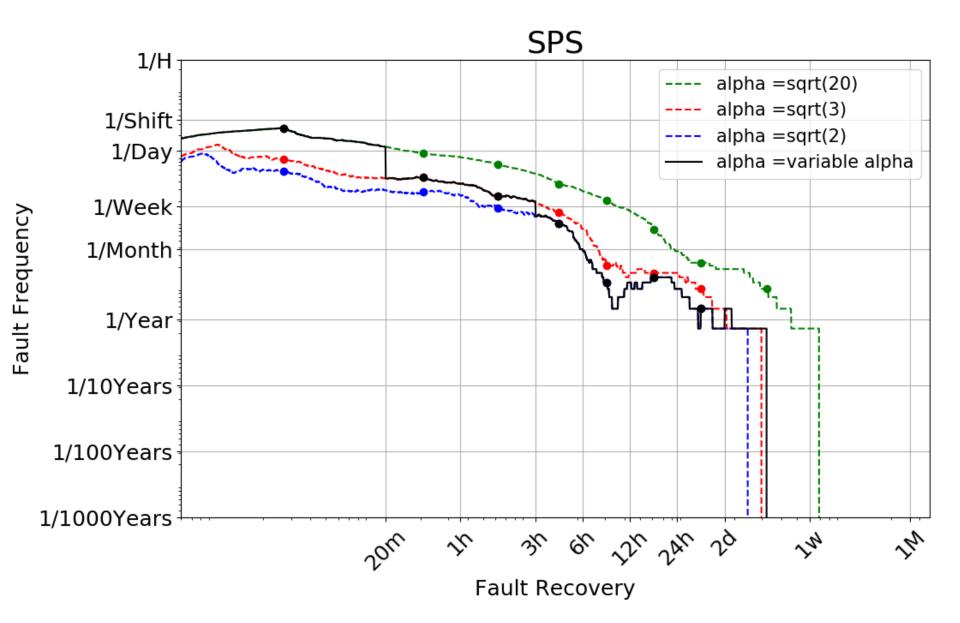




PS

	[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

	[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

