Signal analysis for automated diagnostic applied to LHC cryogenics at CERN

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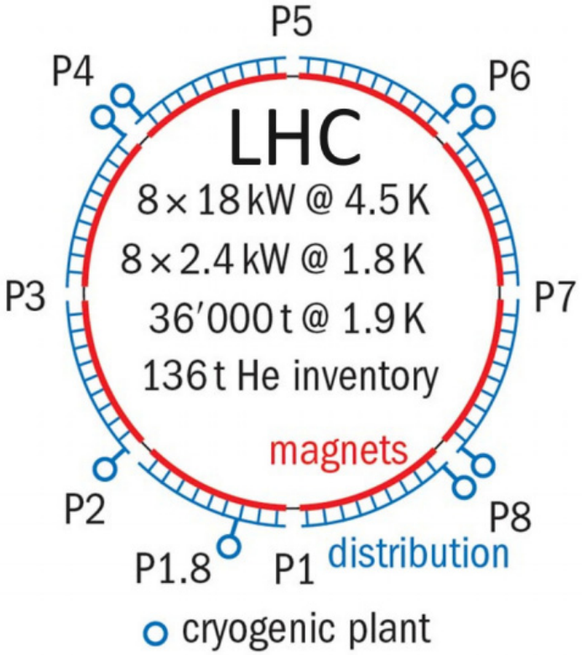
Context

- LHC is 27km long & has the worlds largest cryogenic system.
- 1 cryogenic plant per sector, neighboring plant as backup.
- Cryogenic system acts as a time amplifier in case of failure.
- 172h LHC downtime caused by the cryogenic system in 2018 (97% uptime).
- 60’000 I/O signals and 4’000 PID loops.
- 20’000 analog signals to be monitored by operators daily.

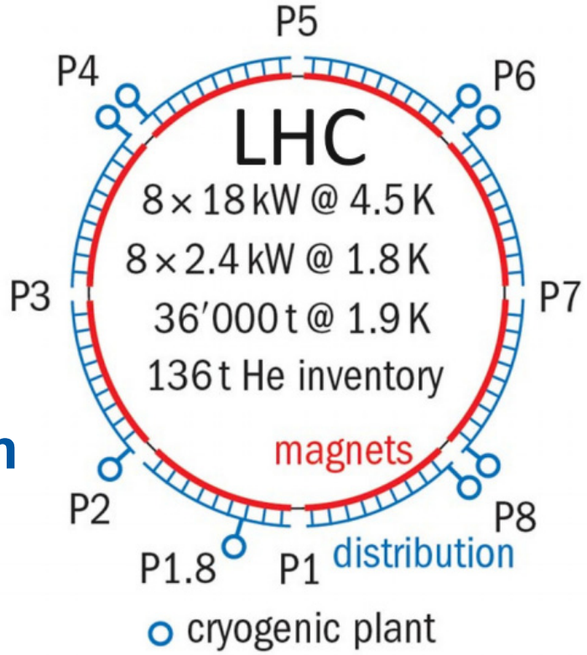


Motivations

- *Why perform daily signal analysis on LHC cryogenics ?*

  - Narrow down information to process for operators.
  - Have a coherent check across similar installations.
  - Detect problems not seen by conventional alarms.
  - Detect unoptimized processes and malfunctioning sensors.
  - Prolong the life span of equipment.

➢ **Improve the availability and performance of the cryogenic system**



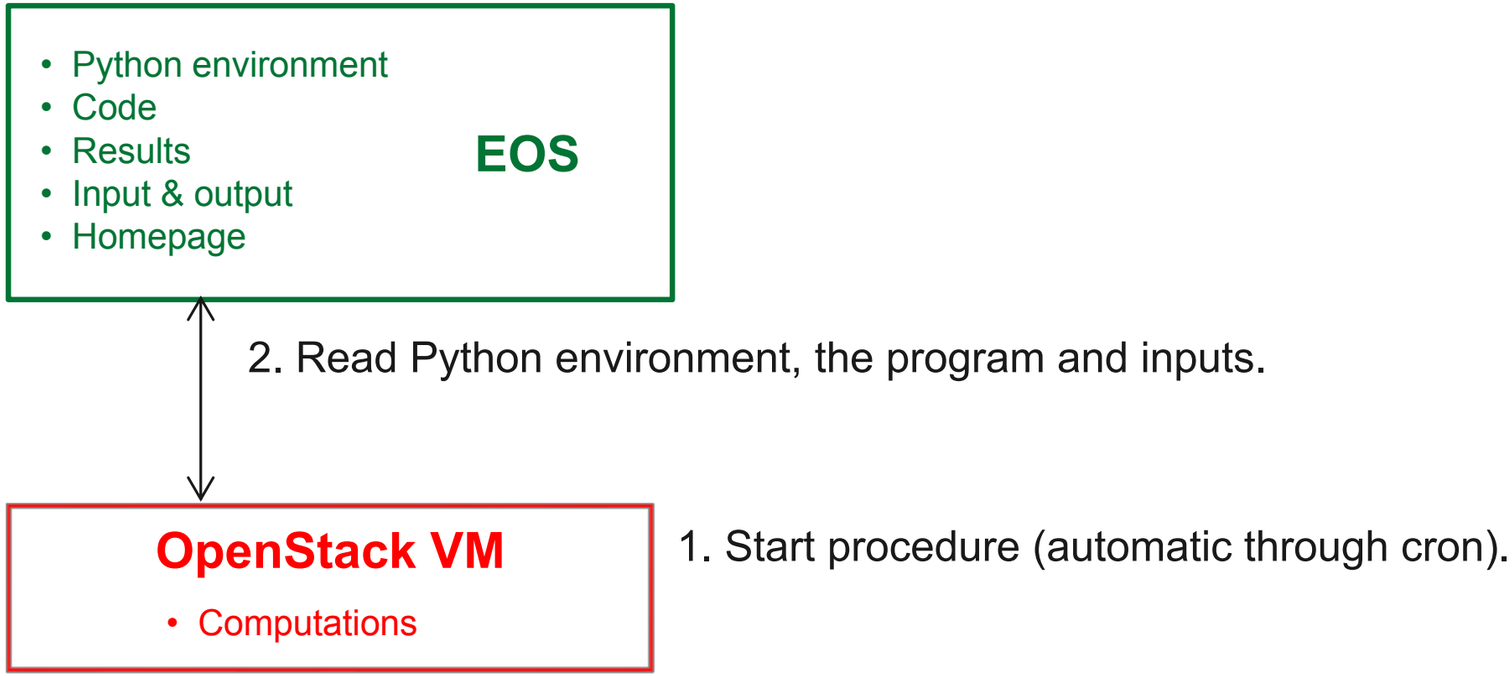
Infrastructure

OpenStack VM

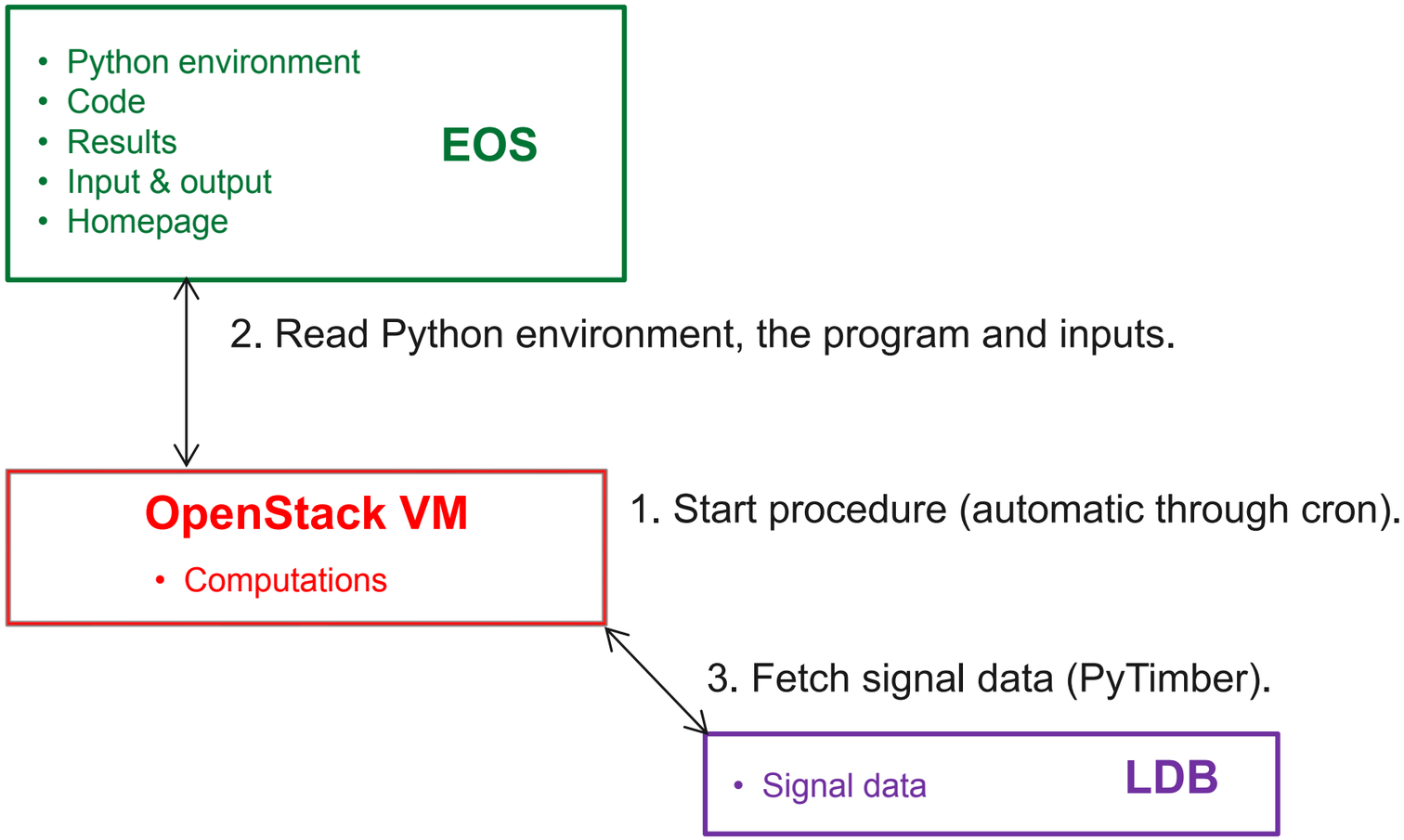
- Computations

1. Start procedure (automatic through cron).

Infrastructure



Infrastructure



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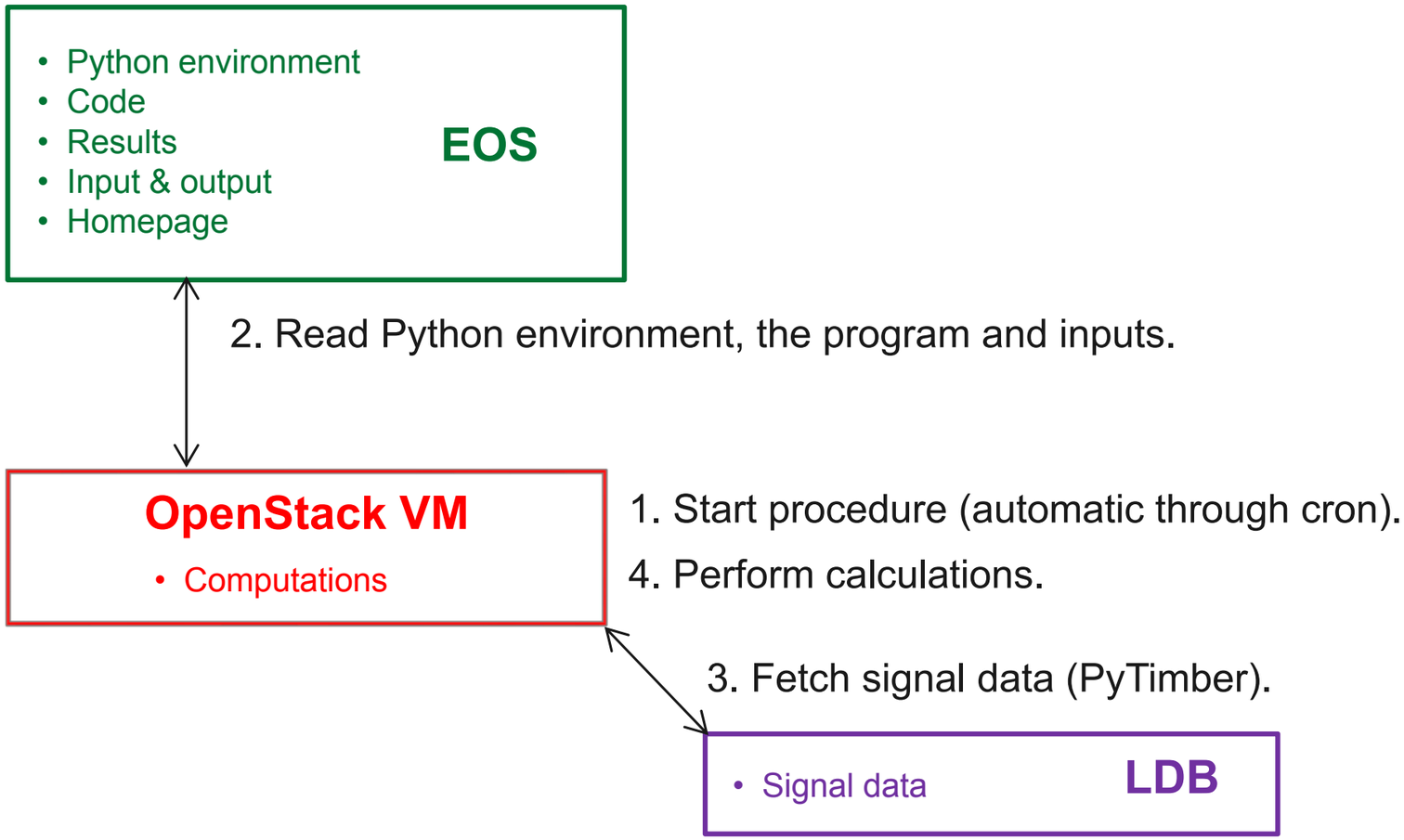

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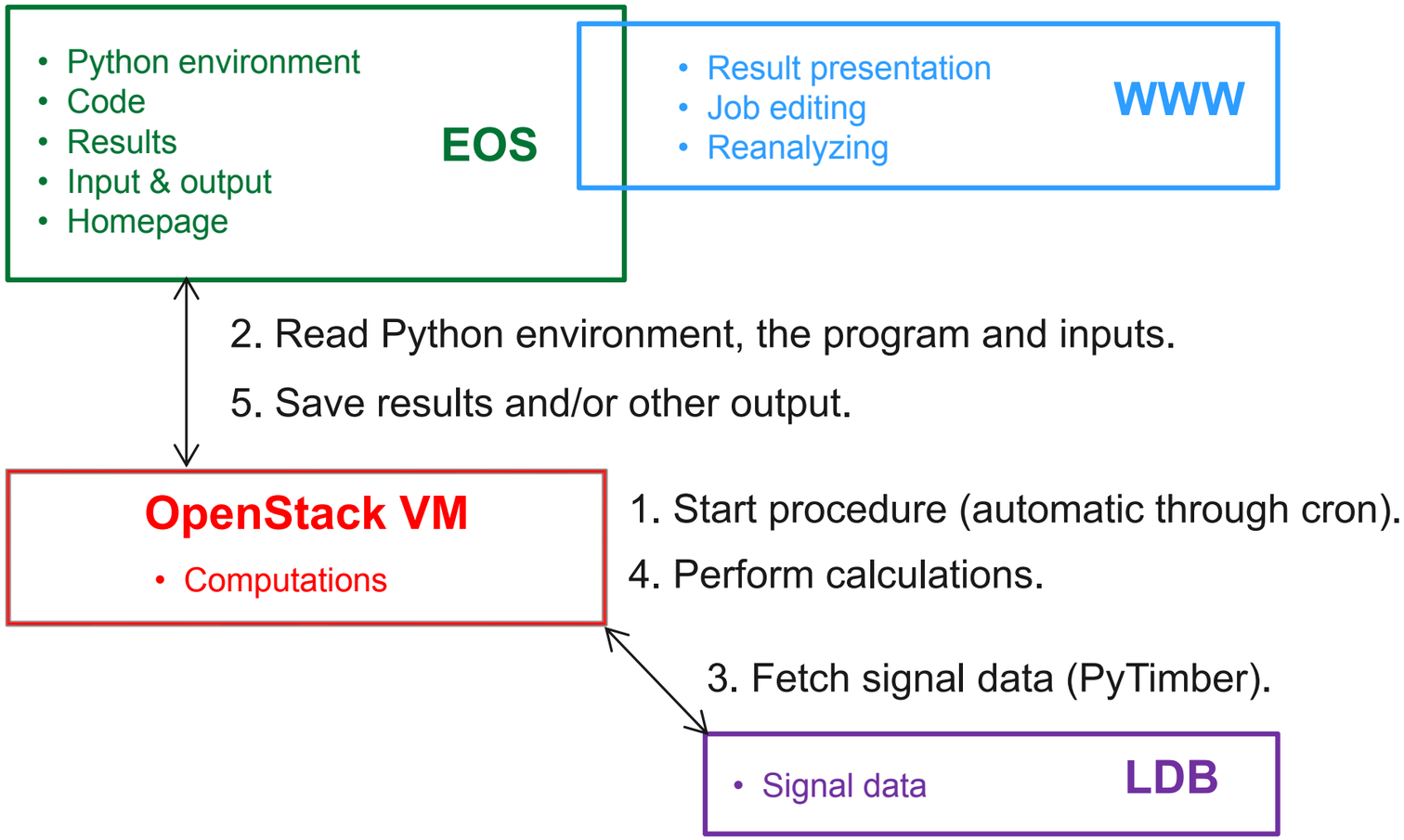

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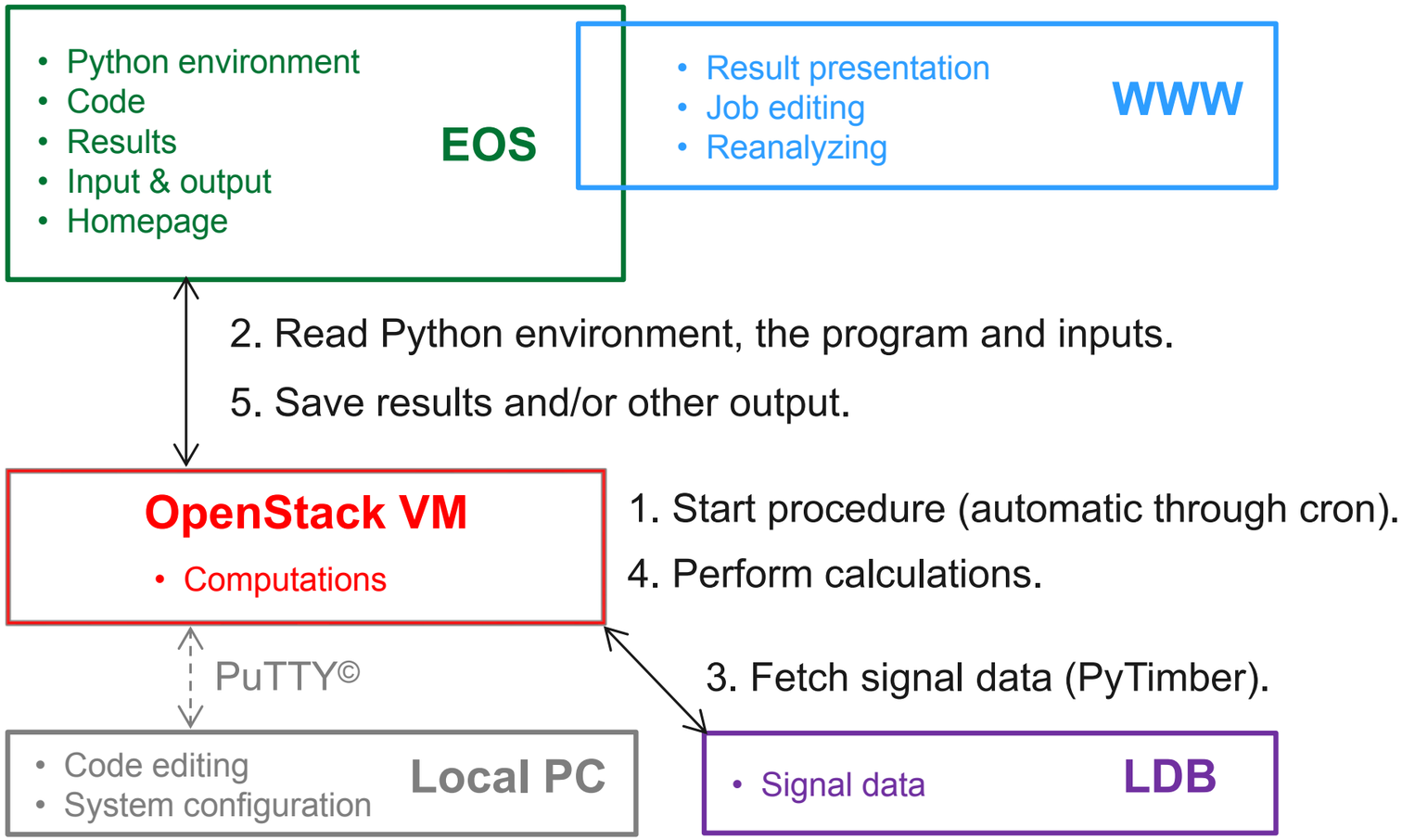


Algorithms

Individual analysis

Average
Checks if the average of a signal is above or below given limits.

Count
Checks if the number of value switches for a Boolean signal is above a given limit.

Slow deviation
Checks if a signal has an accumulating deviation.

Integral
Checks if a signal is significantly above or below its most frequent value.

Relational analysis

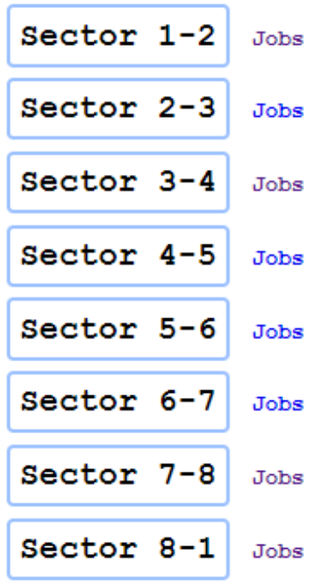
Amplitude comparison
Checks if average (opt. median) amplitude of a signal is significantly larger than others in a group.

Span comparison
Checks if the span of a signal is significantly larger than the average span of other signals in a group.

PID performance
Checks if PID loop is properly tuned
(by looking at setpoint, output and measured values).

Offset
Checks if a signal is significantly distanced from other signals in a group.

Analysis setup



Analysis setup

Sector 1-2 Jobs
Sector 2-3 Jobs
Sector 3-4 Jobs
Sector 4-5 Jobs
Sector 5-6 Jobs
Sector 6-7 Jobs
Sector 7-8 Jobs
Sector 8-1 Jobs

Jobs for sector 12

Algorith explanations | Download jobs | New category

Refrigerator x

#	Job name	Signal(s)	Signal(s) to exclude	Algorithm	Time window [days]	Sampling time [s]	Parameters	
1	filter dP evolution QSCB	QSCB_18_1PTD6%.POSST		slowDeviation	30	18000	weight=1, compSigs=QSCB_18_1ITM.POSST	Edit Delete
2	filter dP evolution QSCB	QSCB_18_2PTD6%.POSST		slowDeviation	30	18000	compSigs=QSCB_18_2ITM.POSST	Edit Delete
3	filter dP evolution QSCB	QSCB_18_3PTD6%.POSST		slowDeviation	30	18000	compSigs=QSCB_18_3ITM.POSST	Edit Delete
4	filter dP evolution QSCB	QSCB_18_6PTD6%.POSST		slowDeviation	30	18000	compSigs=QSCB_18_6ITM.POSST	Edit Delete
5	filter dP evolution QSCB	QSCB_18_7PTD6%.POSST		slowDeviation	30	18000	compSigs=QSCB_18_7ITM.POSST	Edit Delete
6	filter dP evolution QUI	QUIB_18_%DPT794.POSST		slowDeviation	30	18000		Edit Delete
7	filter dP evolution QURCA, B	QURCB_18_PTD240.POSST		slowDeviation	30	18000		Edit Delete
8	Turbine filter dP evolution	QSRB_18%PTD21%.POSST		slowDeviation	30	18000		Edit Delete
9	Supercritical helium pressure	QSRB_18%_PT260.POSST		Oscillation	1	10	absLim=0.1	Edit Delete
10	vacuum daily average	QSRB_18%PT34%.POSST, QSRB_18%PTVac%.POSST, QURCB_18%PT34%.POSST, QUIB_18_VacQPLB.POSST, QUIB_18_VacQULC.POSST, QUIB_18_PT34%.POSST		dailyAverage	2	600		Edit Delete
11	vacuum evolution	QSRB_18%PT34%.POSST, QSRB_18%PTVac%.POSST, QURCB_18%PT34%.POSST, QUIB_18_VacQPLB.POSST, QUIB_18_VacQULC.POSST, QUIB_18_PT34%.POSST		slowDeviation	28	18000		Edit Delete
12	PID evaluation	QS%_B_18%TC%.MV, QU%_B_18%TC%.MV		PID	1	60	window=5, tloop=30	Edit Delete
13	PID evaluation	QS%_B_18%FC%.MV, QU%_B_18%FC%.MV		PID	1	10	window=1, tloop=2	Edit Delete
14	PID evaluation	QS%_B_18%LC%.MV, QU%_B_18%LC%.MV		PID	1	10	window=1, tloop=2	Edit Delete
15	PID evaluation	QS%_B_18%PC%.MV, QU%_B_18%PC%.MV		PID	1	10	window=1, tloop=3	Edit Delete
	Job name	Signals	Signals to ecxlude	Algorithm	tw	ts	Parameters	Submit

Add job(s) as plain text | Submit

QRL x

#	Job name	Signal(s)	Signal(s) to exclude	Algorithm	Time window [days]	Sampling time [s]	Parameters	
1	line C pressure offset	QRL%R1_PT961.POSST, QRL%L2_PT961.POSST		Offset	1	600	offsLim=0.5	Edit Delete
2	line D pressure offset	QRL%R1_PT991.POSST, QRL%L2_PT991.POSST		Offset	1	600	offsLim=0.5	Edit Delete

Results presentation

Results presentation

Sector 1-2 Jobs
Sector 2-3 Jobs
Sector 3-4 Jobs
Sector 4-5 Jobs
Sector 5-6 Jobs
Sector 6-7 Jobs
Sector 7-8 Jobs
Sector 8-1 Jobs

Cryo Data Analytics

Ronde results by date for sector 1-2:

2018-12-31	Recalculate
2018-12-30	Recalculate
2018-12-29	Recalculate
2018-12-28	Recalculate
2018-12-27	Dequeue 1
2018-12-26	Dequeue 2
2018-12-25	Recalculate
2018-12-24	Recalculate
2018-12-23	Recalculate
2018-12-22	Recalculate
2018-12-21	Recalculate
2018-12-20	Recalculate
2018-12-19	Recalculate
2018-12-18	Recalculate
2018-12-17	Recalculate
2018-12-16	Recalculate
2018-12-15	Recalculate
2018-12-14	Recalculate
2018-12-13	Recalculate
2018-12-12	Recalculate
2018-12-11	Recalculate

Cryo Data Analytics

Results for sector 1-2 by category (2018-12-16).

Category	New Warnings	Warnings	Finished	Time Required [s]	
QRL	3	9	21:31:16 - 25/08/19	53.5	Recalculate
DFB-Current leads	2	19	21:57:46 - 25/08/19	763.5	Recalculate
Refrigerator	1	5	21:30:20 - 25/08/19	650.2	Recalculate
Arc cells	0	26	21:37:01 - 25/08/19	340.1	Recalculate
LSS cells	0	4	21:37:39 - 25/08/19	36.8	Recalculate
PS He guard	0	1	21:59:25 - 25/08/19	84.5	Recalculate
Cryostart+maintain	0	0	21:59:30 - 25/08/19	5.2	Recalculate
Thermal shields	0	0	21:58:00 - 25/08/19	13.8	Recalculate
DFB	0	0	21:45:00 - 25/08/19	440.9	Recalculate

Sum of Times

Part	[s]	[%]
Fetching data:	1474.2	61.72
Analysis:	631.2	26.43
Plotting:	283.3	11.86
Total:	2388.5	100

Jobs executed

Results presentation

Cryo Data Analytics

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Cryo Data Analytics

Warnings for Refrigerator in sector 1-2 on 2018-12-16

Analysis finished at 21:30:20 - 25/08/19

#	Urgency [weight*value/limit]	Description	Algorithm	Signal(s)	Time window [days]	Sampling time [s]	Parameters	Plot	# of occurrences last 28 days	
1	3.6666666666666665	PID evaluation	PID	QSRB_18_6PC215_6PT210	1	10	weight=1,window=1,tloop=3,N=3,PI_lim=0.4,stdout_lim=1	Show	25	Exclude Hide
	Nov18 Nov19 Nov20 Nov21 Nov22 Nov23 Nov24 Nov25 Nov26 Nov27 Nov28 Nov29 Nov30 Dec01 Dec02 Dec03 Dec04 Dec05 Dec06 Dec07 Dec08 Dec09 Dec10 Dec11 Dec12 Dec13 Dec14 Dec15									
2	2.0	PID evaluation	PID	QSCB_18_PC177_PT130	1	10	weight=1,window=1,tloop=3,N=3,PI_lim=0.4,stdout_lim=1	Show	0	Exclude Hide
	Nov18 Nov19 Nov20 Nov21 Nov22 Nov23 Nov24 Nov25 Nov26 Nov27 Nov28 Nov29 Nov30 Dec01 Dec02 Dec03 Dec04 Dec05 Dec06 Dec07 Dec08 Dec09 Dec10 Dec11 Dec12 Dec13 Dec14 Dec15									
3	1.6666666666666667	PID evaluation	PID	QSCB_18_PC176_PT100	1	10	weight=1,window=1,tloop=3,N=3,PI_lim=0.4,stdout_lim=1	Show	3	Exclude Hide
	Nov18 Nov19 Nov20 Nov21 Nov22 Nov23 Nov24 Nov25 Nov26 Nov27 Nov28 Nov29 Nov30 Dec01 Dec02 Dec03 Dec04 Dec05 Dec06 Dec07 Dec08 Dec09 Dec10 Dec11 Dec12 Dec13 Dec14 Dec15									
4	1.6666666666666667	PID evaluation	PID	QSCB_18_PC180_PT199	1	10	weight=1,window=1,tloop=3,N=3,PI_lim=0.4,stdout_lim=1	Show	10	Exclude Hide
	Nov18 Nov19 Nov20 Nov21 Nov22 Nov23 Nov24 Nov25 Nov26 Nov27 Nov28 Nov29 Nov30 Dec01 Dec02 Dec03 Dec04 Dec05 Dec06 Dec07 Dec08 Dec09 Dec10 Dec11 Dec12 Dec13 Dec14 Dec15									
5	1.6666666666666667	PID evaluation	PID	QSRB_18_PC230_PT230	1	10	weight=1,window=1,tloop=3,N=3,PI_lim=0.4,stdout_lim=1	Show	11	Exclude Hide
	Nov18 Nov19 Nov20 Nov21 Nov22 Nov23 Nov24 Nov25 Nov26 Nov27 Nov28 Nov29 Nov30 Dec01 Dec02 Dec03 Dec04 Dec05 Dec06 Dec07 Dec08 Dec09 Dec10 Dec11 Dec12 Dec13 Dec14 Dec15									

Recalculate

Time Required

Part	[s]	[%]
Fetching data:	192.7	29.64
Analysis:	454.6	69.92
Plotting:	3.0	0.46
Total:	650.2	100

Results presentation

Cryo Data Analytics

Results for sector 1-2 by category (2018-12-16).

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	Nov18 Nov19 Nov20 Nov21 Nov22 Nov23 Nov24 Nov25 Nov26 Nov27 Nov28 Nov29 Nov30 Dec01 Dec02 Dec03 Dec04 Dec05 Dec06 Dec07 Dec08 Dec09 Dec10 Dec11 Dec12 Dec13 Dec14 Dec15									
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	Nov18 Nov19 Nov20 Nov21 Nov22 Nov23 Nov24 Nov25 Nov26 Nov27 Nov28 Nov29 Nov30 Dec01 Dec02 Dec03 Dec04 Dec05 Dec06 Dec07 Dec08 Dec09 Dec10 Dec11 Dec12 Dec13 Dec14 Dec15									

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Time Required

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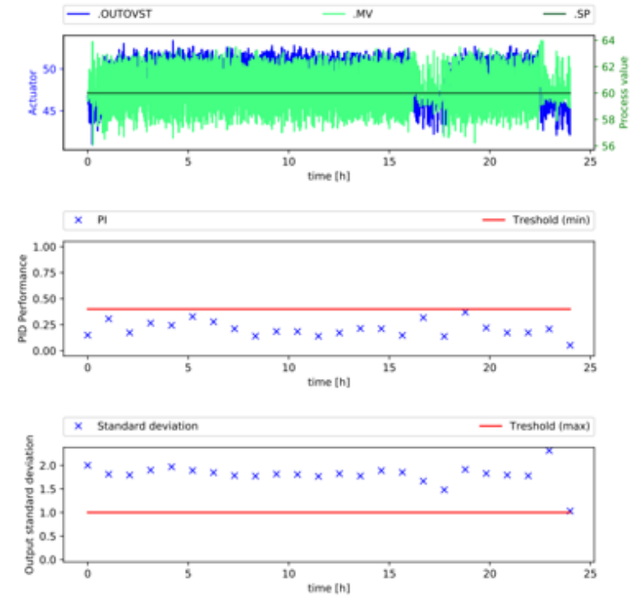
Total:	650.2	100

Found issues

PID performance

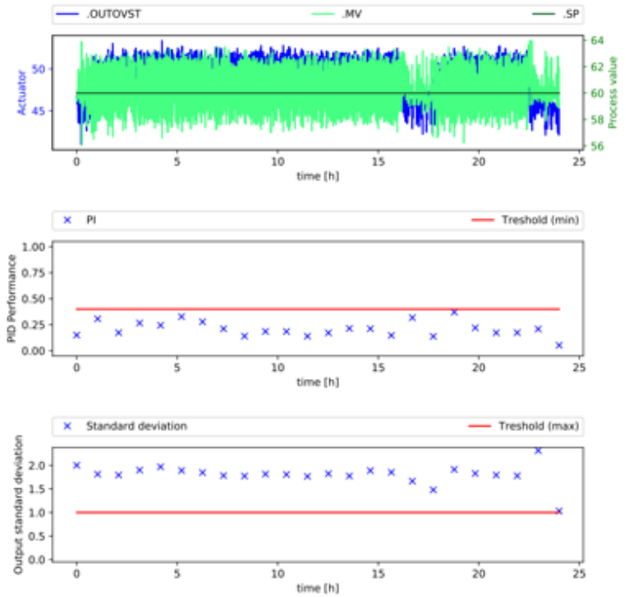


$lim_n = 3$ ⇨ $R_{11} = \frac{24}{3} = 8$

Poorly tuned liquid helium level controller

Found issues

PID performance



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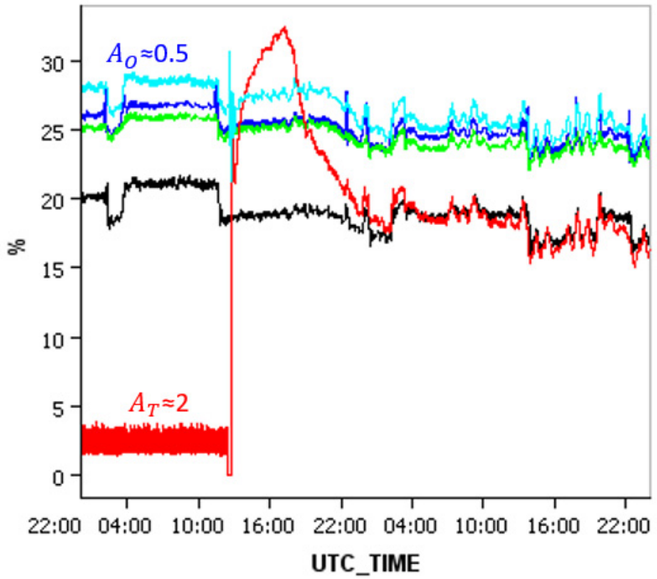
Poorly tuned liquid helium level controller

Amplitude comparison

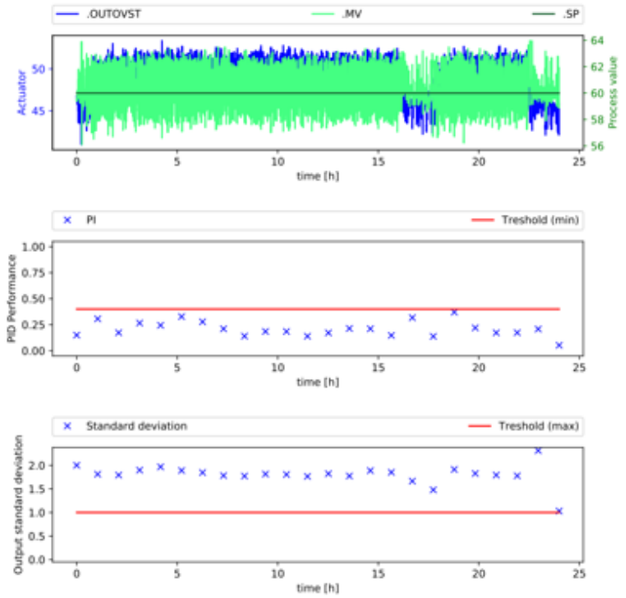


$lim_{diff} = 0.6$, $median = False$ ⇨ $R_2 \approx \frac{2}{0.5*(1+0.6)} = 2.5$

Broken valve electronics

Found issues

PID performance



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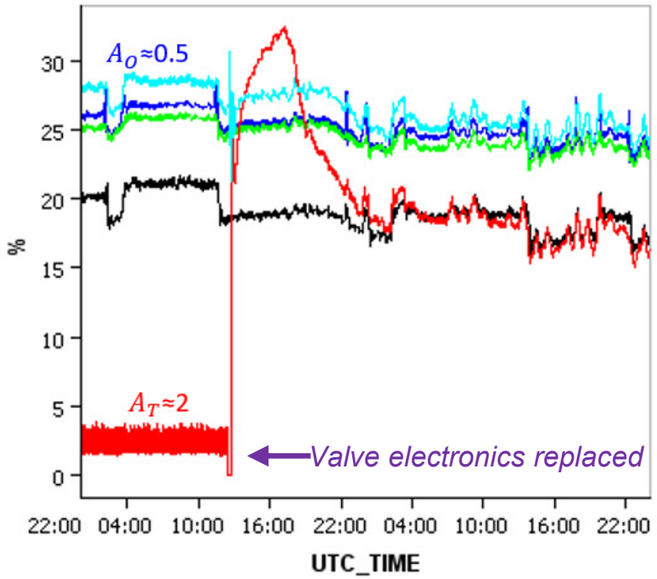

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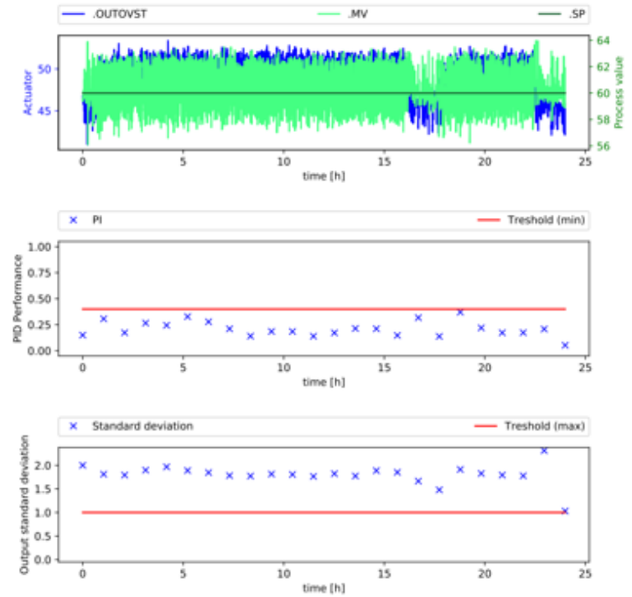

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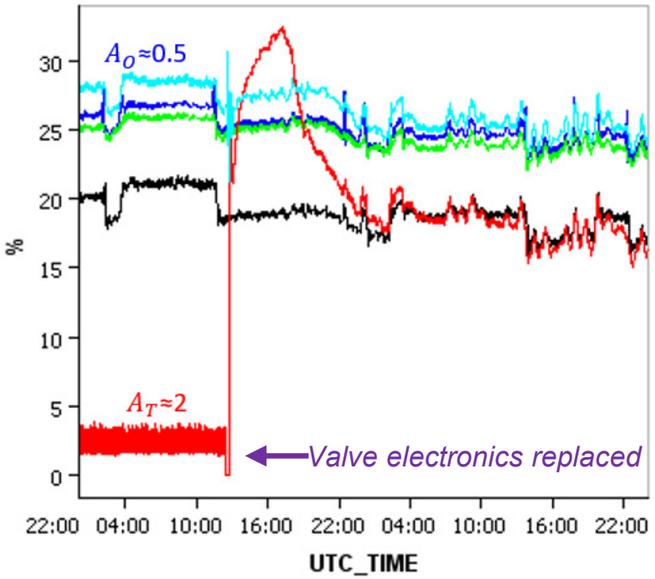
Poorly tuned liquid helium level controller

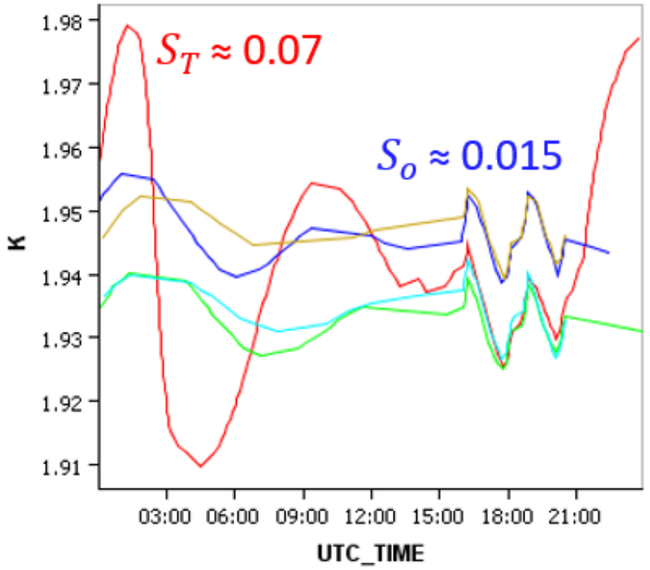
Amplitude comparison



$lim_{diff} = 0.6$, *median = False* ⇨ $R_2 \approx \frac{2}{0.5*(1+0.6)} = 2.5$

Broken valve electronics

Span comparison

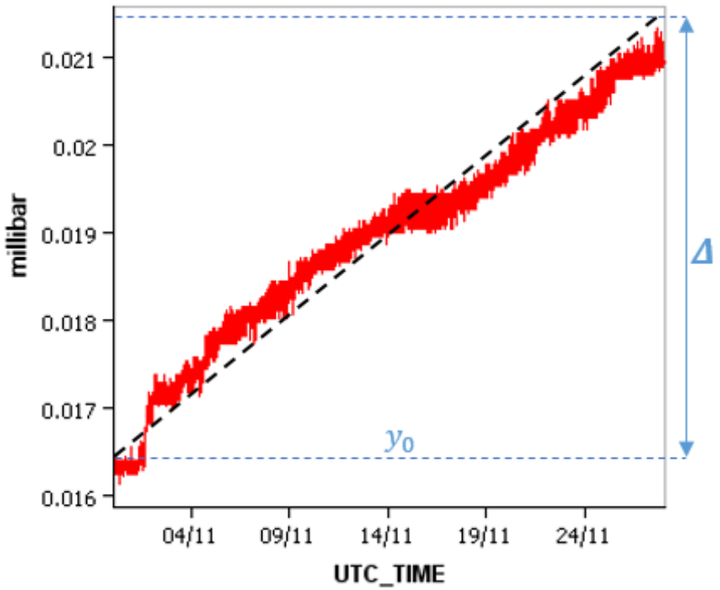


$lim_{diff} = 0.5$ ⇨ $R_4 \approx \frac{0.07}{0.015*(1+0.5)} \approx 3.1$

Extra heat load during ion run

Found issues

Slow deviation



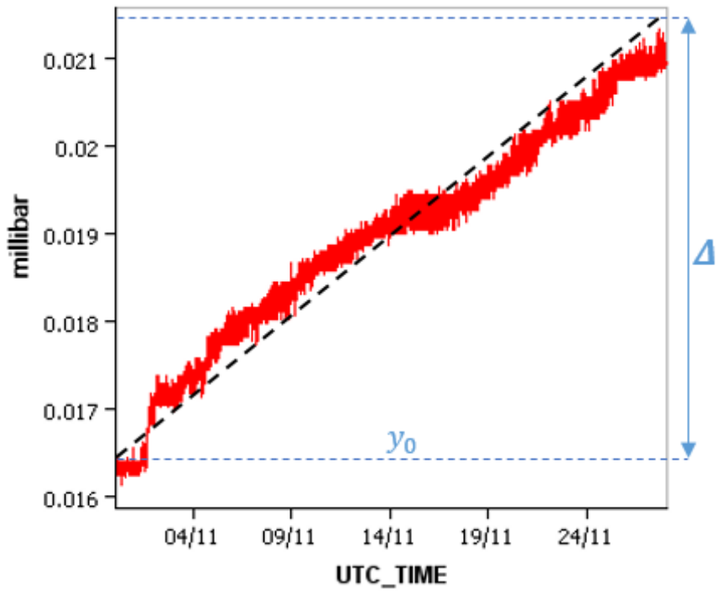
$$\delta = \frac{\Delta}{y_0} \approx \frac{|0.0214 - 0.0165|}{0.0165} \approx 0.3 \quad \Rightarrow \quad R_5 \approx \frac{0.3}{0.1} = 3$$

$$lim_\delta = 0.1$$

Degradation of insulation vacuum

Found issues

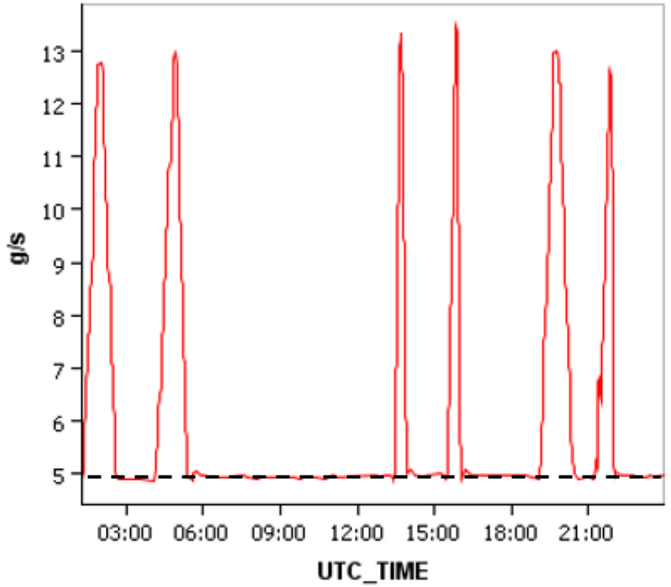
Slow deviation



$$\delta = \frac{\Delta}{y_0} \approx \frac{|0.0214 - 0.0165|}{0.0165} \approx 0.3 \quad lim_\delta = 0.1 \quad \Rightarrow \quad R_5 \approx \frac{0.3}{0.1} = 3$$

Degradation of insulation vacuum

Integral



$$|I| \approx 83{,}000 \quad lim_I = 7{,}000 \quad \Rightarrow \quad R_6 \approx \frac{83{,}000}{7{,}000} \approx 11.9$$

Leak in magnets liquid helium bath

Conclusions

- Ready for LHC run 3 (starts in 2021).
- About 10 available algorithms applied on 8 000 signals.
- 1 sector & 1 day:
  - ~48 minutes analysis (63% for fetching of data).
  - ~40 warnings (3 new)
- Reduction of false triggers is prioritized.
- Further tuning as more data is generated.
- New version prepared for CERN's new logging service.


CERN