Session 7: Availability, efficiency and equipment reliability

LHC inner triplet fault

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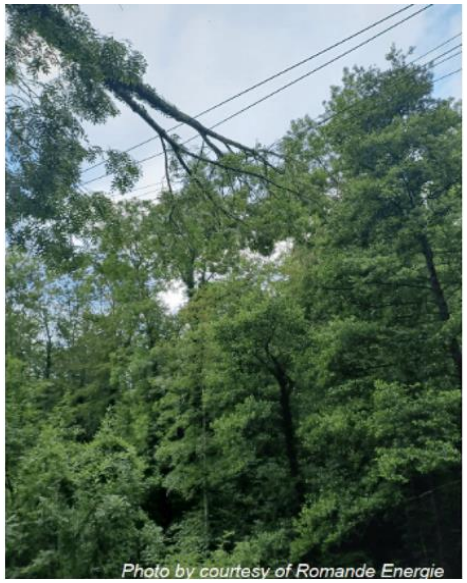
Joint Accelerator Performance Workshop 2023

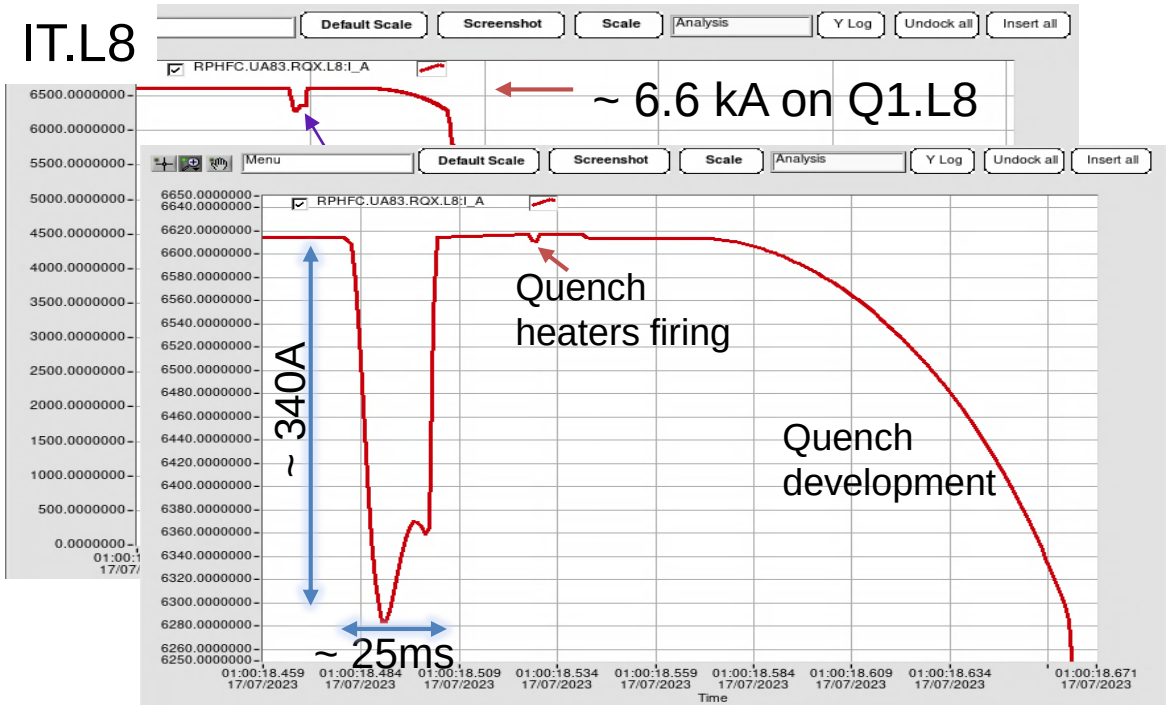
17th July event : Electrical glitch

1 am : At stable beam in the LHC since 9 min, an electrical glitch occurred on the RF and magnet circuits, dumping the beam and triggering the protection system of a few LHC circuits, which IT.L8.



Monday, 17 July, 1 a.m.: ROOT CAUSE

The reason for the electrical glitch that caused the safety systems in the LHC to dump the beam and several magnets to quench was found: a tree on the Swiss side (about 55 km from CERN in the Canton of Vaud) fell on the power lines and disrupted the power system.



Signals measured by the quench detection system (QDS) are similar for a large current variation or a symmetrical quench (quench development in two adjacent coils). For the magnet protection, the quench heaters are triggered.

Similar event occurred in Aug 22, without damage.

17th July event : After the electrical glitch

30s after the quench, a significant leak appears in the vacuum vessels of IT.L8 assembly.

8 hours after the quench, the pressure in the vacuum vessels is at 1bar and the average temperature of the cold masses is 150K

Cryogenic scenarios

As the leak is in the IT cold mass volume, it possible to isolate it from the QRL.

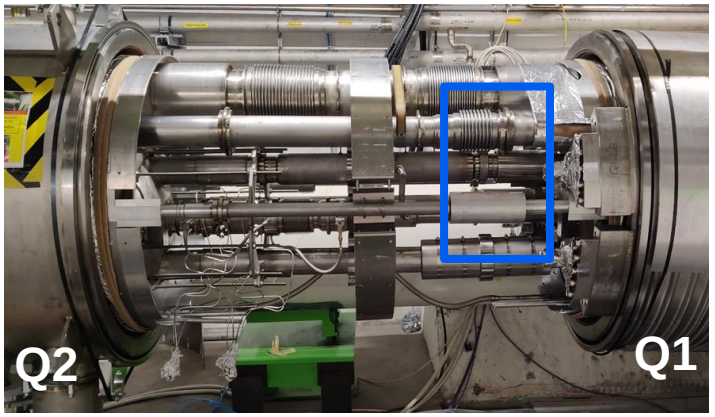
#	Opening what ?	How long ? *(from 24/07)*	Cryo status and consequences	Risks *(if no sector warm-up)*
A	W bellow only	< 3 days	ARC @ 20 K➔30 K QRL @ 20 K➔ 100 K	Helium circuit pollution + IT/QRL vac barrier condensation
B	IT cold mass interconnect bellows	< 10 days *(ARC cooldown before 20 days)*	ARC @ 20 K ➔ 60 K QRL @ 20 K ➔ 250 K ➔ Reconditioning of the IT + D1 needed (without QRL)	+ QRL mechanical damage during unexpected transients (bellows) **Retained scenario**
C	IT cold mass interconnect bellows	> 10 days *(ARC cooldown after +20 days)*	ARC TTmax > 80 K QRL > 250 K ➔ Reconditioning of the IT + D1 needed (without QRL)	+ Magnet interconnect mechanical damage due to thermal dilation (PIMS, bellows, shields, etc.). ➔ **Risky situation, sector warmup* highly recommended**
D	QRL lines or magnet removal	People safety and magnet integrity cannot be guaranteed ➔ **Sector warm-up* mandatory** (baseline)		

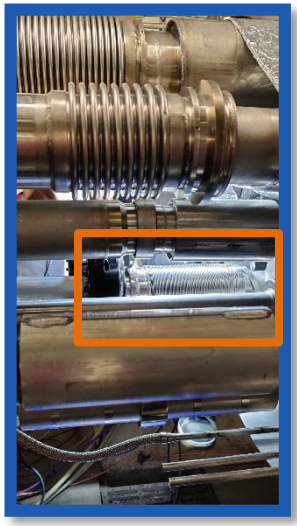
**Sector warm-up = 4 weeks , Sector cool-down = 5 weeks*

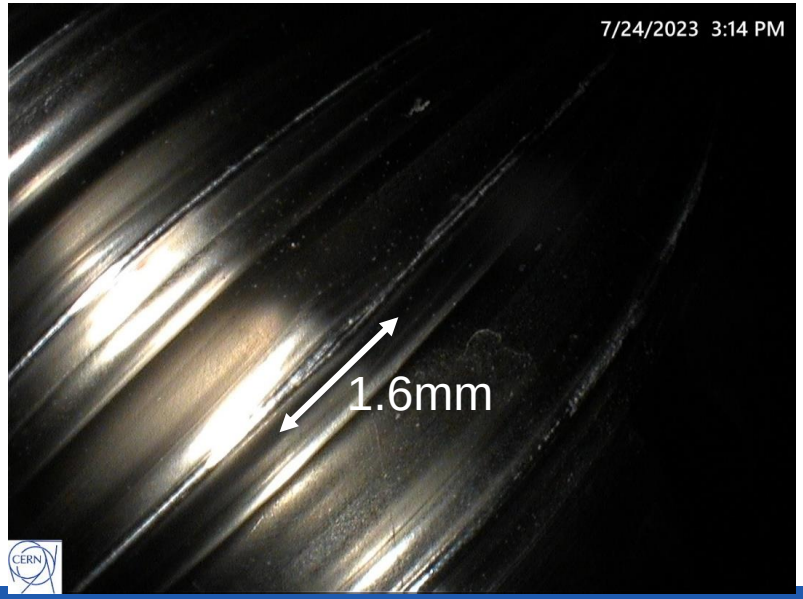
24th – 28th July, Exchange of the faulty bellow

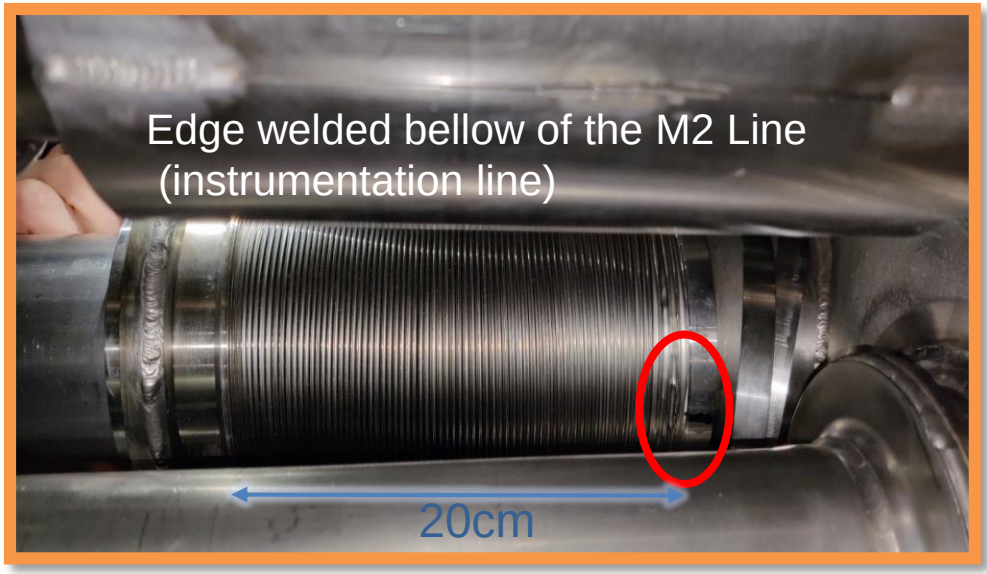
After the depressurisation of all cryogenics lines and injection of dry air into the vacuum vessels, the interconnection Q1-Q2 is open.

The leak is found on an edge welded bellow of the instrumentation line (M2)





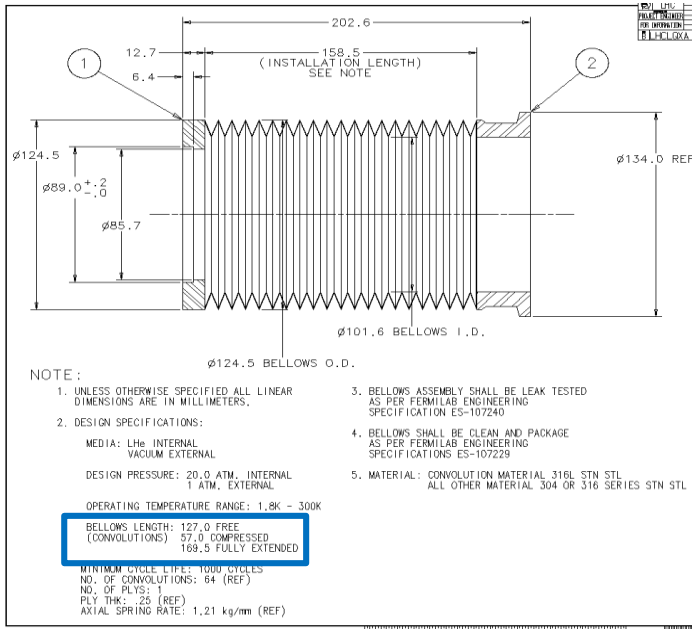




Details of the repair: LMC on 2/08/12 : indico 1309715

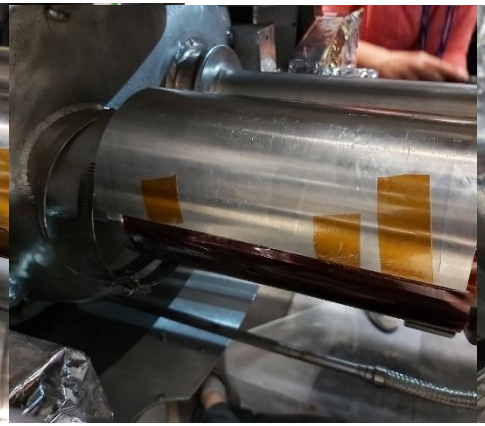
What was observed?

The bellow is extended over the specification length



Protection shells of the bellow in place (buckling prevention)

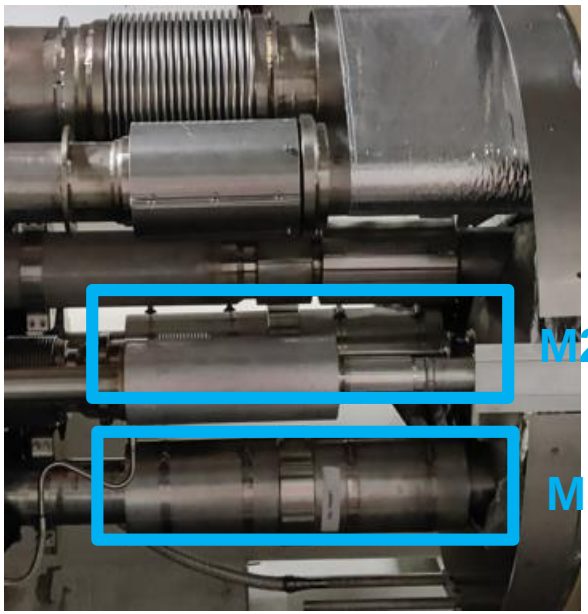
Guiding shells position at room temperature. At cold, the bellow is extended by 8-12 mm.



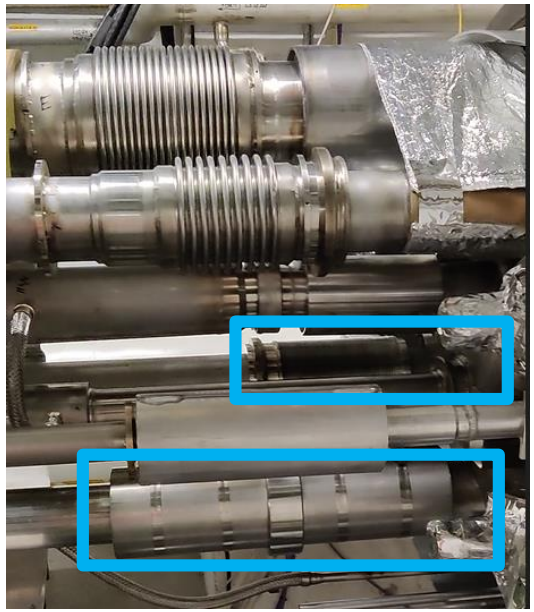
Kapton layer to reduce bellow friction. The Kapton is pinched at the top of the bellow convolutions.

Edge welded bellows in IT interconnection

Q3



Q2

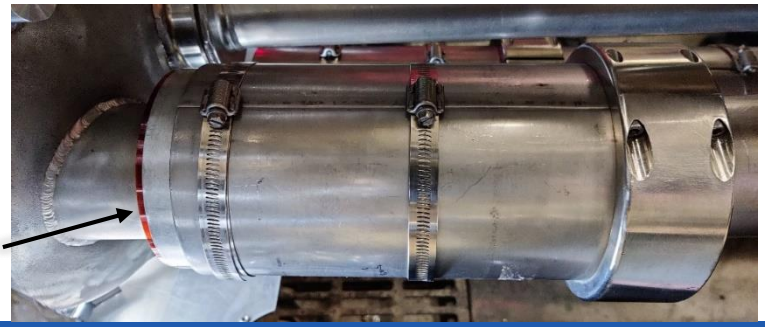


Q1

Localised on M1 (busbar line) and M2 (instrumentation line), the edge welded bellows are installed in pairs. Only M2 line in Q1-Q2 interconnection contains a single bellow.

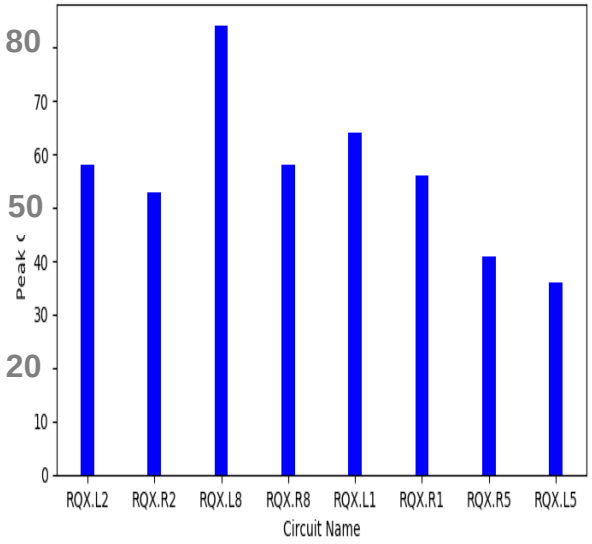
Protection and guiding shells are correctly adapted for bellows in pairs, but they are at the limit for the single one.

Longer guiding shells installed in IT.L8



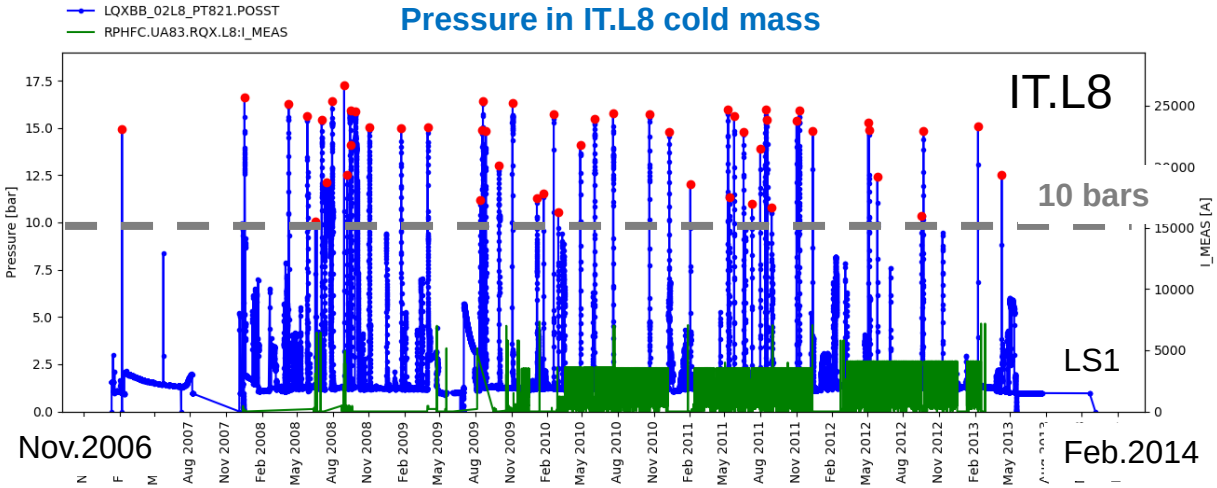
IT cold mass pressurisation

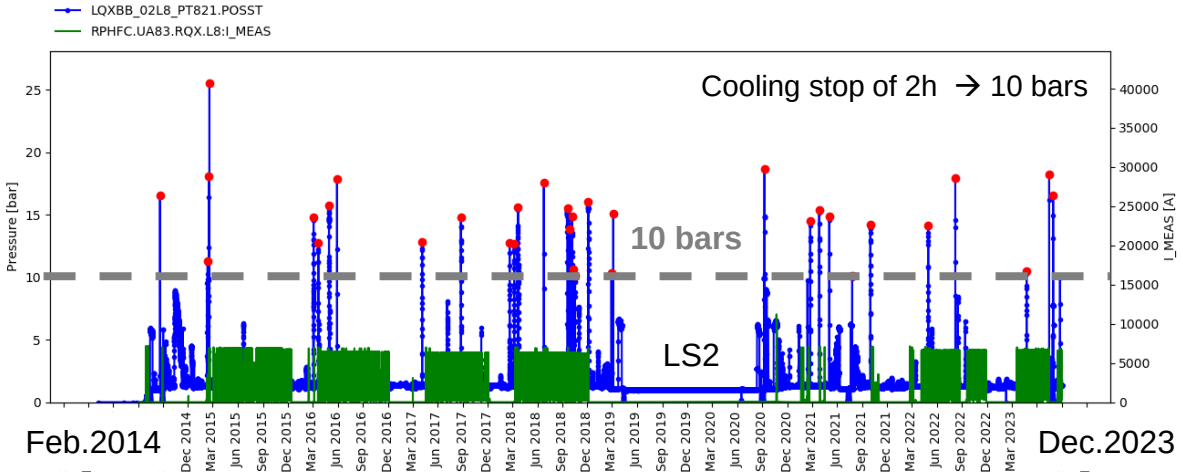
Even if the guiding shells are at the limit of the bellow flange (M2 line –Q1-Q2 IC), the IT.L8 experienced many pressuri-sations since its installation (84 cycles above 10 bars).



Number of pressurisation cycles above 10 bars in IT

Pressure in IT.L8 cold mass





Present status

- Equivalent risk of failure on others IT
  - Similar bellow extension
  - MME report on IT.L8 bellow (EDMS 2922194)
    - Microcrack initiations independent of the position on the bellow
    - Ductility reduction at low temperature due to the presence of δ-ferrite on edge welds.
  - All triplets experienced multiple pressurisations since their installation without failure and all reached 16 bars after LS2.

- Mitigation measures
  - No mechanical intervention planned (IT maintained at cold)
  - Avoid fast event like quench heater firing at nominal current (16 bars in 30s) .
    - IT training is done since 2021
    - Large current variation versus quench development detection → new QDS cards in production (TE-MPE)
  - Prepared for an eventual repair
    - Spare bellows (12)
    - Components for a bellow exchange in preparation
    - Procedure for bellow exchange known
  - A consolidation study is recommended for a possible intervention in LS3

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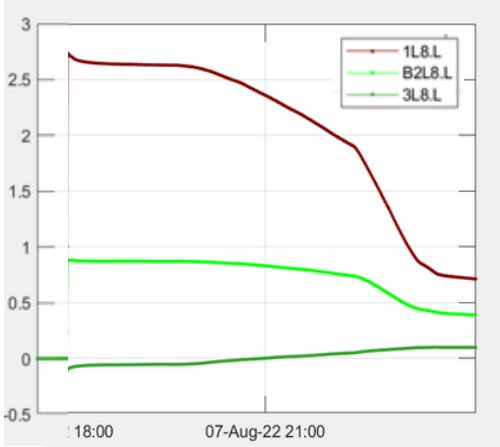
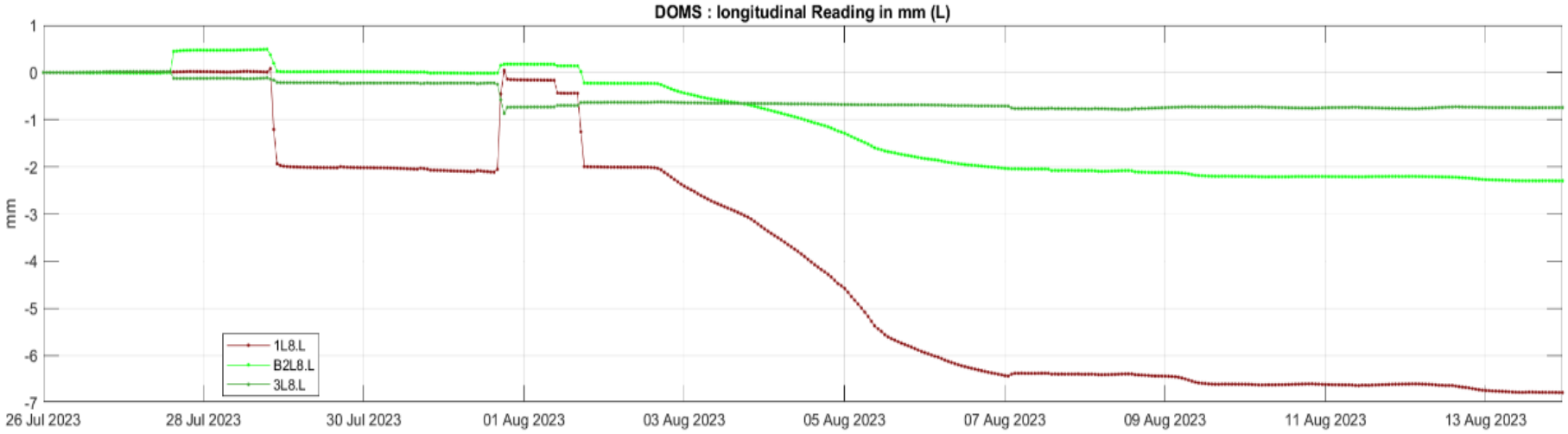
Q1-Q2 movement

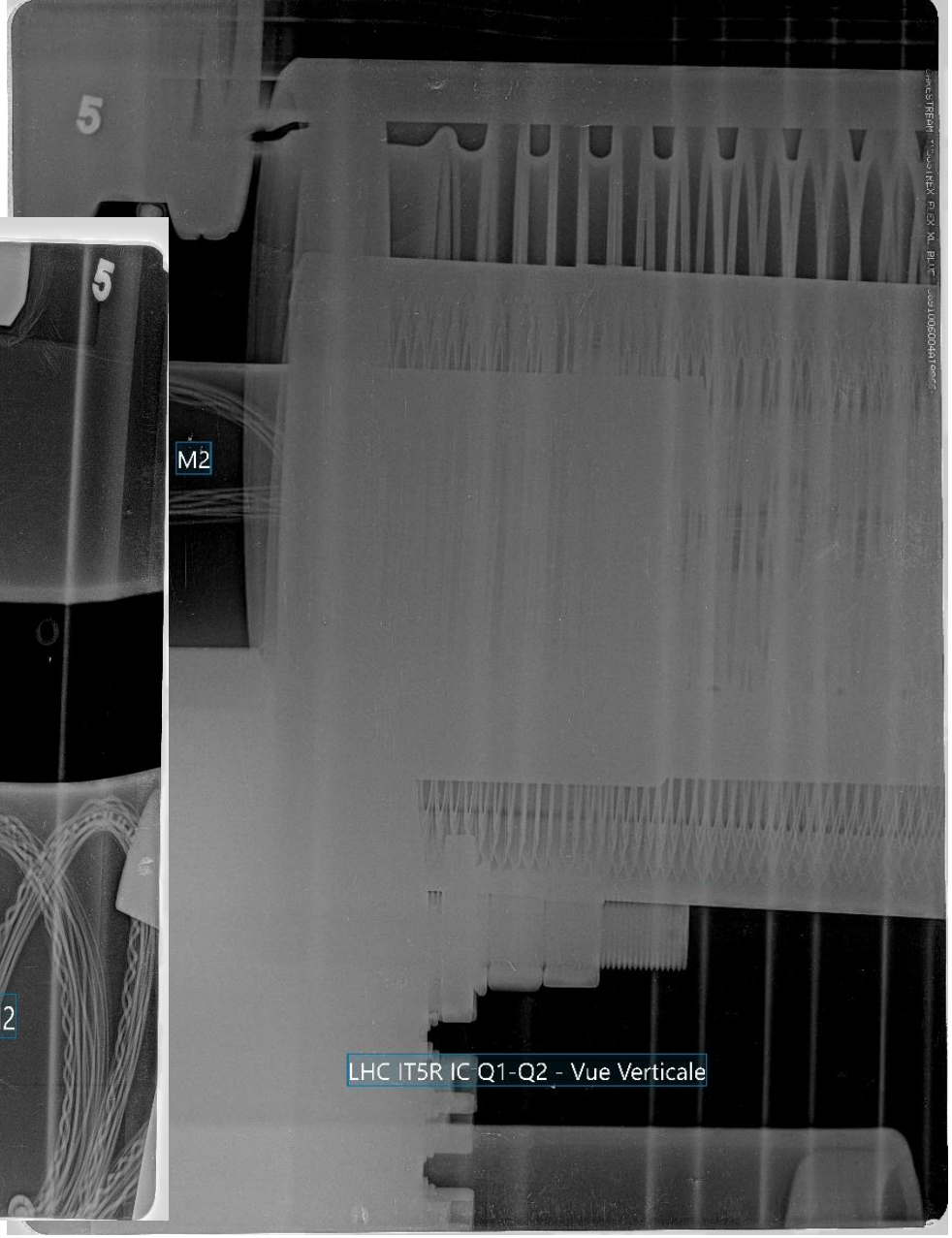
During QH firing at nominal current



During vacuum pumping (30Jul) and cool down (from 1 Aug)



M2 line in IT point5



Other investigation before opening : X-ray

All radiographies are available in
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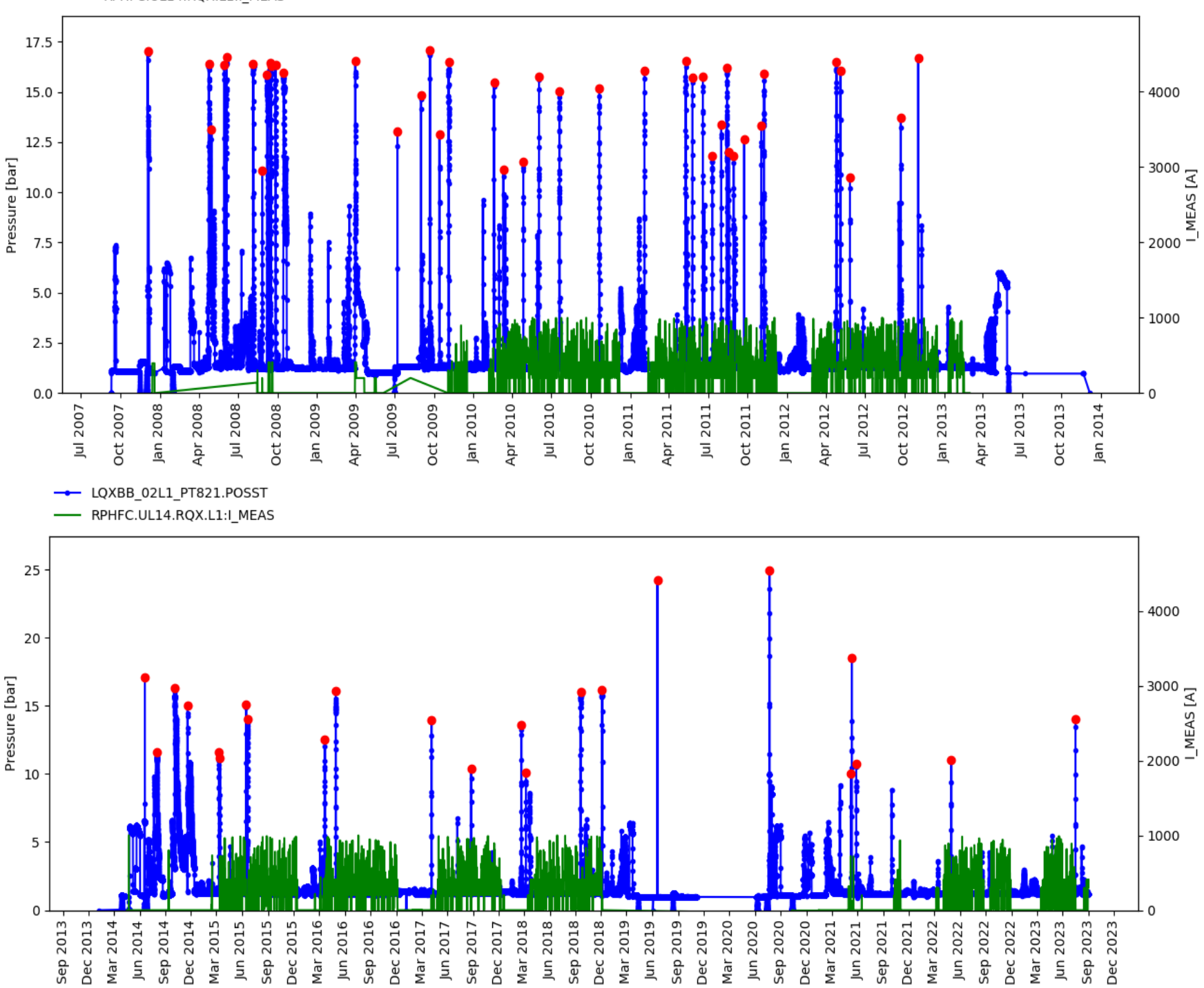
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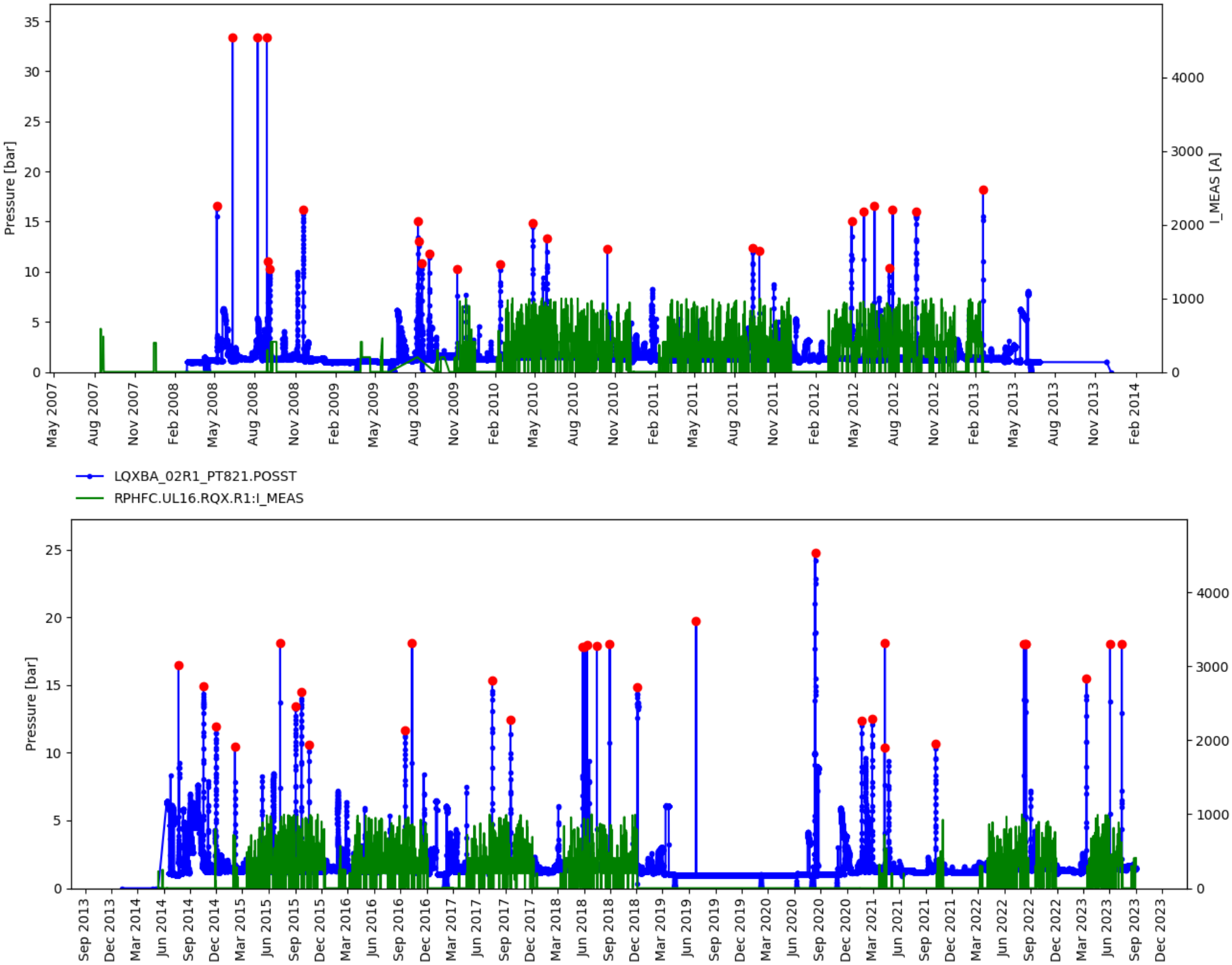
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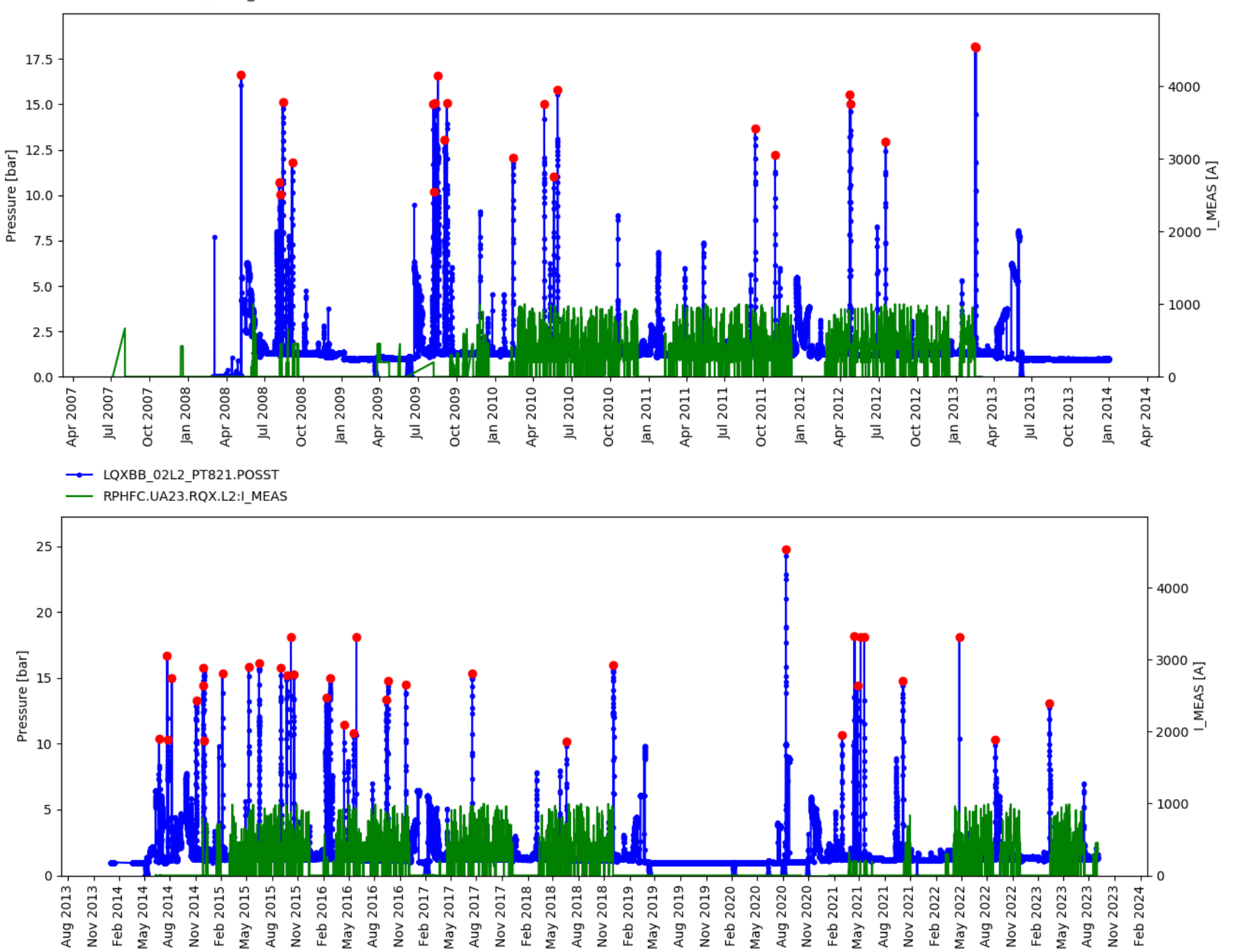
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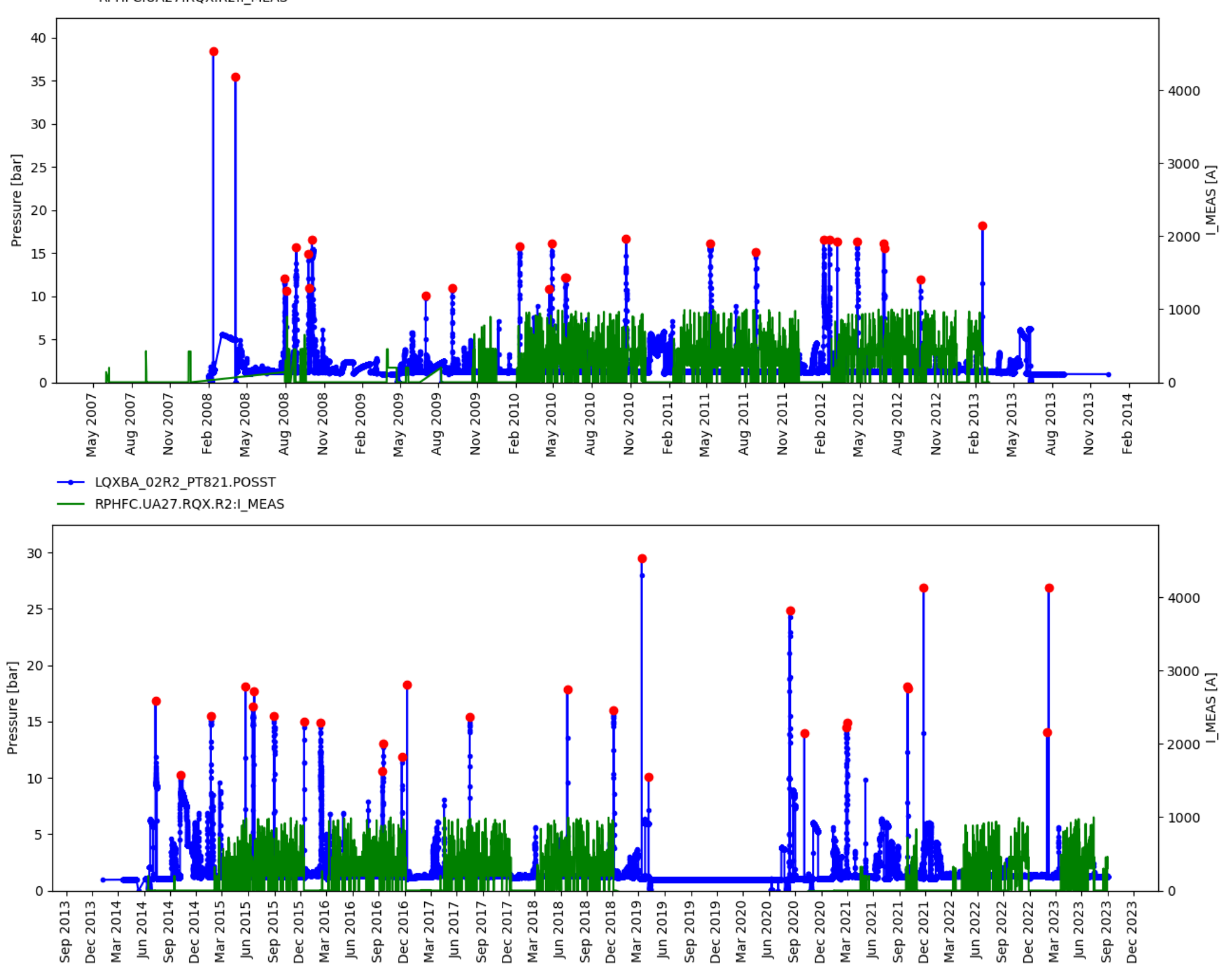
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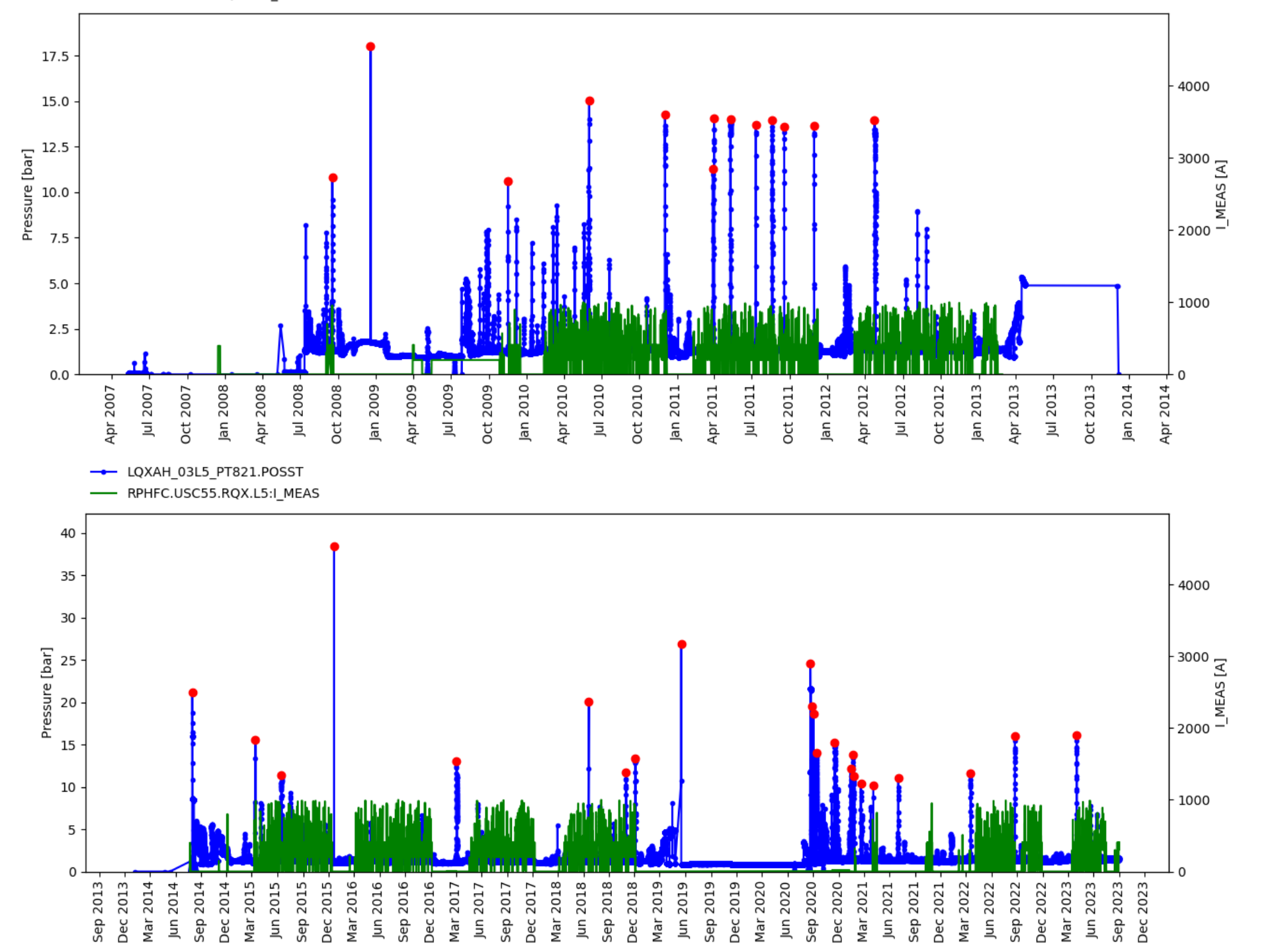
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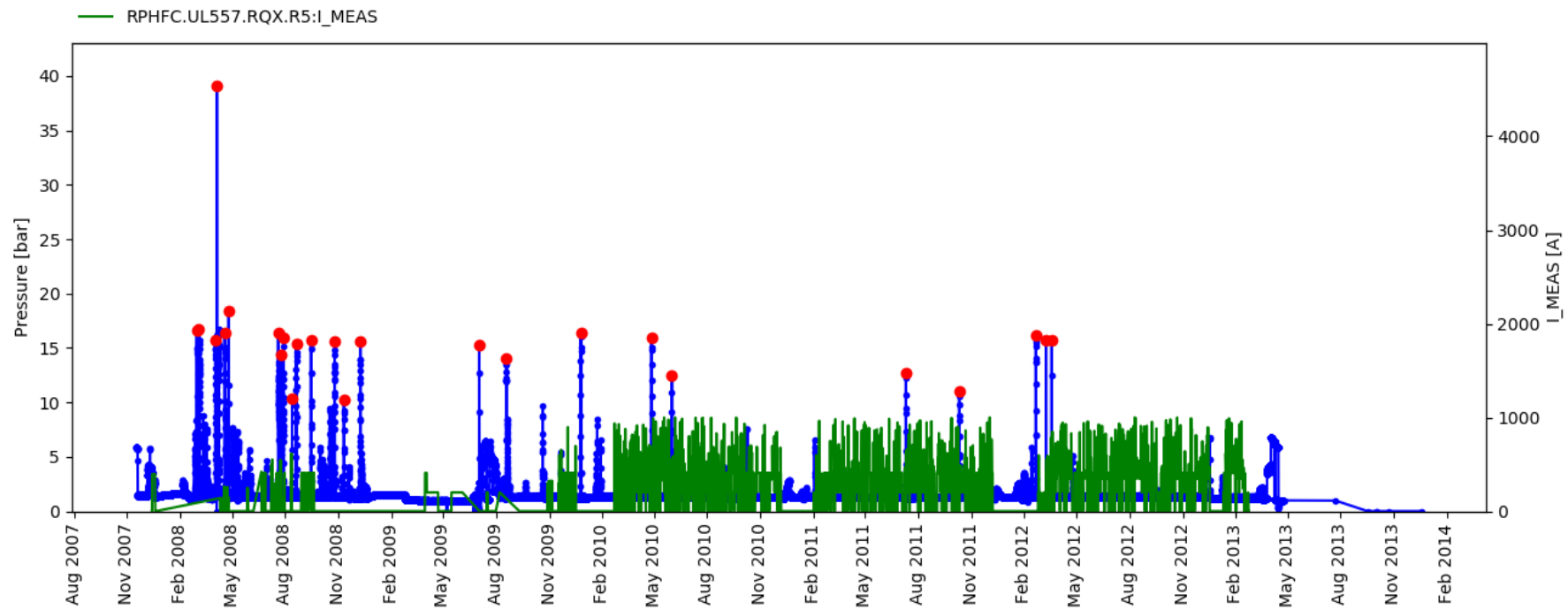
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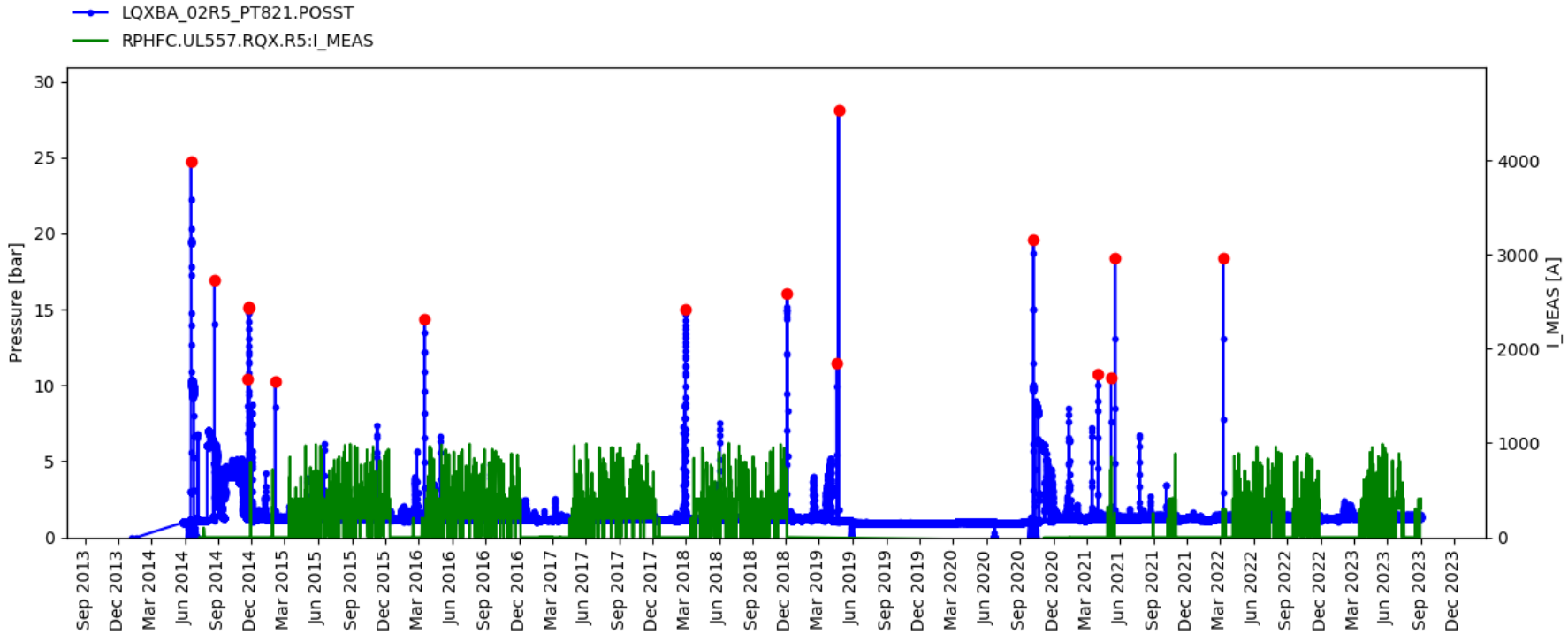
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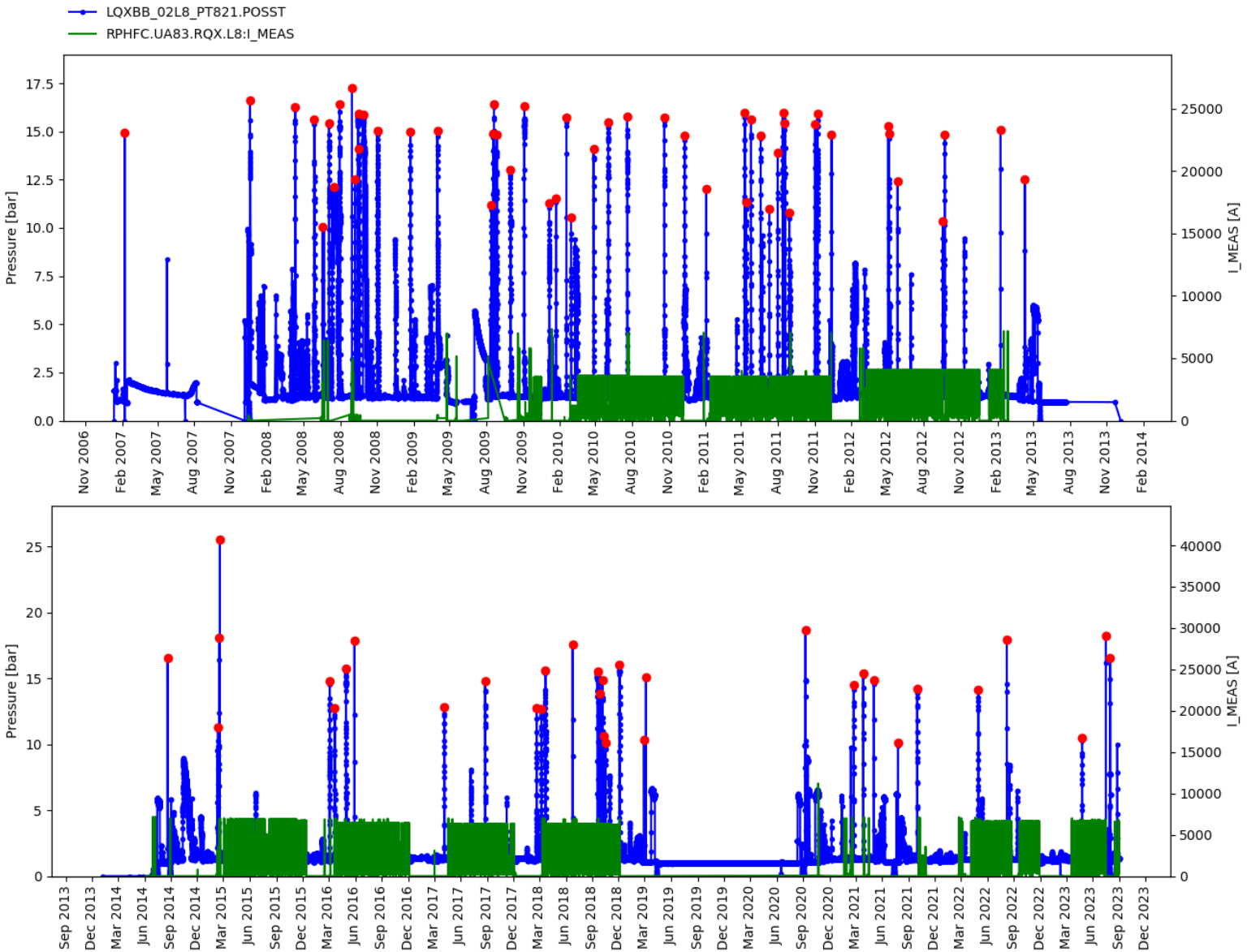
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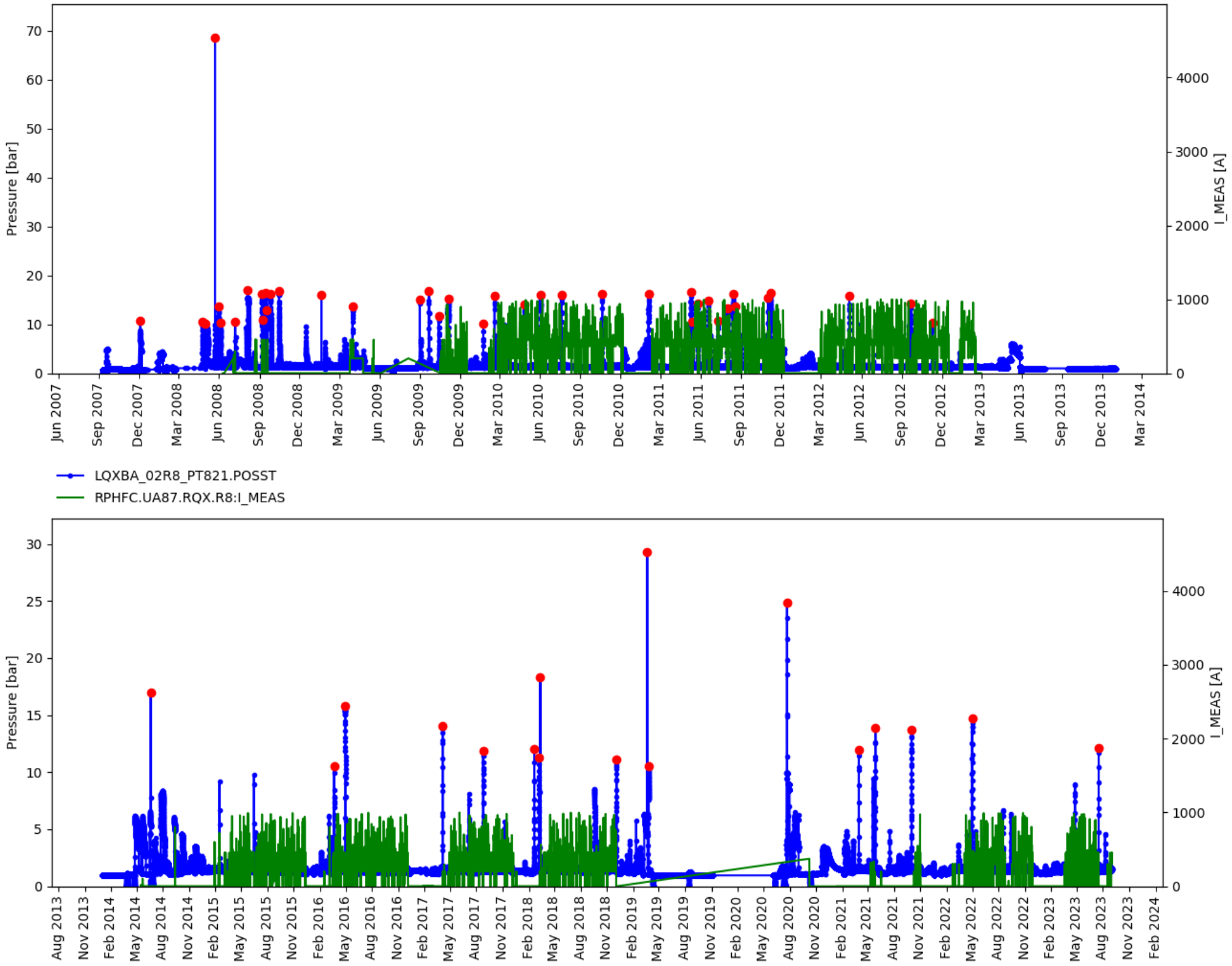
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