Overview of recent data-quality checks for the Underground Muon Detector

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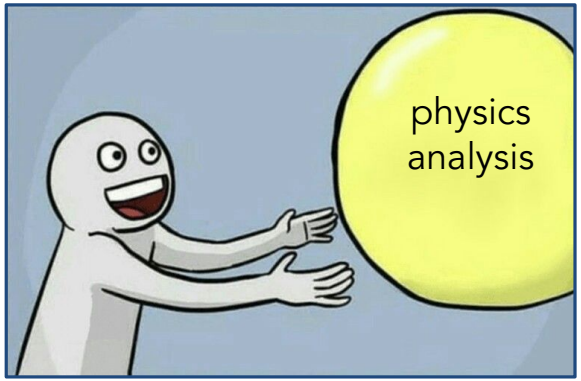
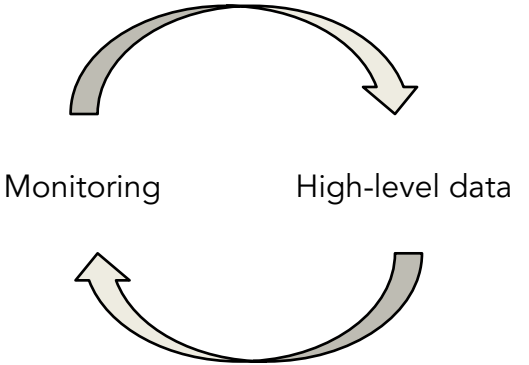
Nov 13, 2025

Annual Meeting of DDAp/DDEIT and HIRSAP

Motivation





Go back and forth between monitoring observables and data aiming to:

1. Improving monitoring if possible
2. Understanding our data a bit better
3. Taking action when needed/possible

Brief review of previous works

GAP2018-056 → First steps (intensity & dilution)

GAP2022-043 → Early UMD shift concept (latch bin position & others)

GAP2023-039 → Rate-based bad periods (similar to SD bad periods)

PoS(ICRC2023) → long-term monitoring & performance

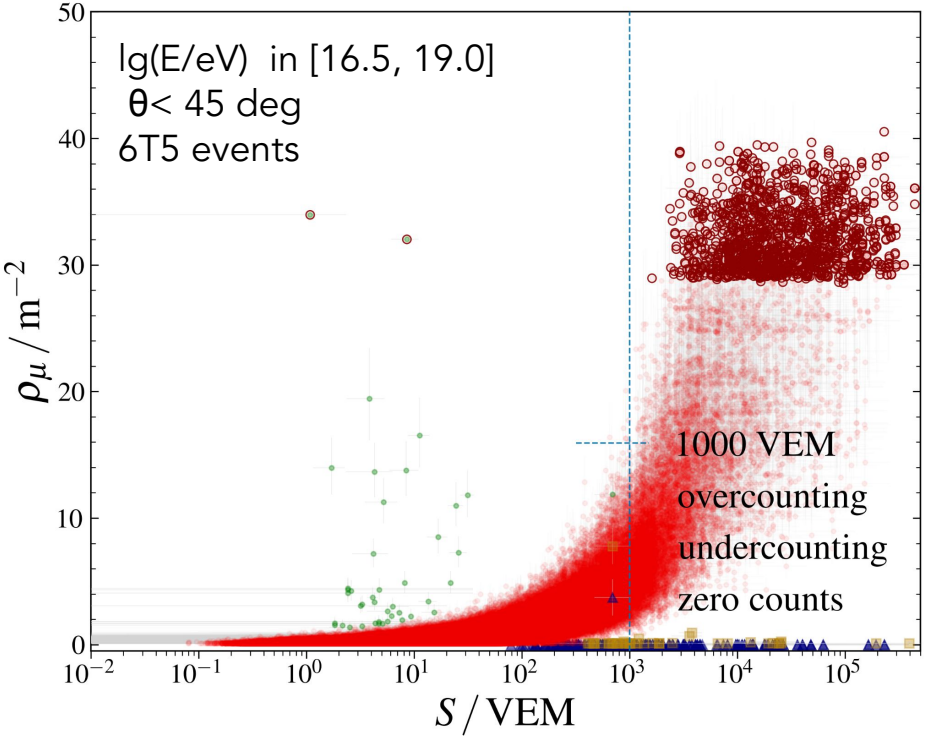
GAP2024-038 → UMD shift consolidation (behind the scenes)

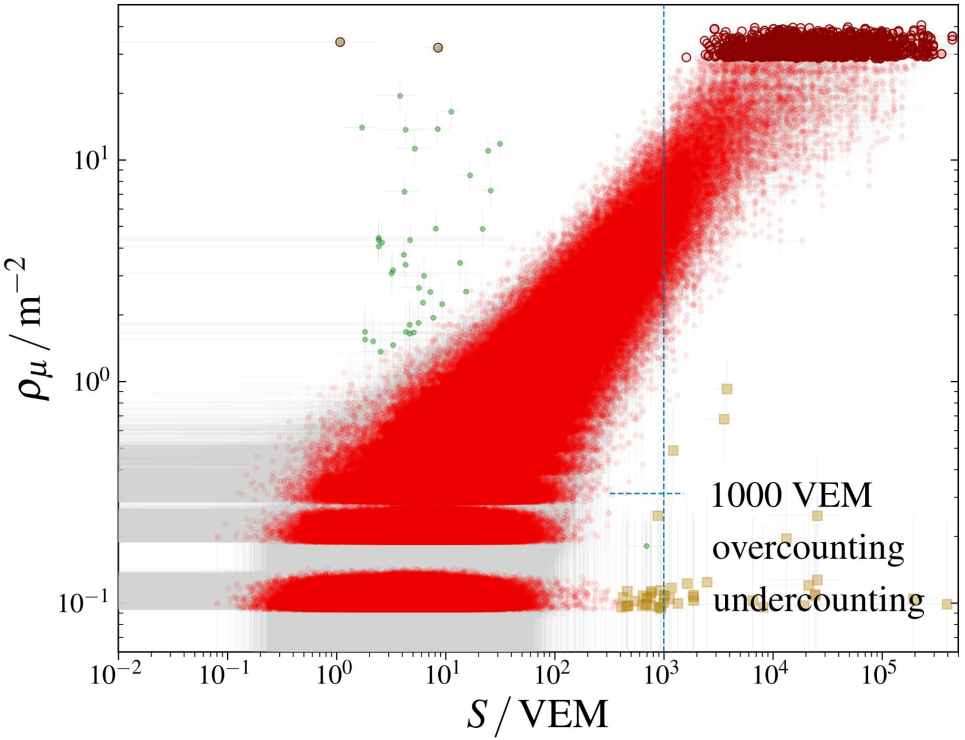
From GAP2024-038

> Another unexplored aspect is the connection between the variables and data quality in high-level analysis. In this regard, since the mean trace length is directly related to the structures of the binary traces, it is important to explore its correlation with the physical observables, such as ρ_μ. This could be extremely useful, potentially allowing for the identification of bad periods on a daily basis without relying on data reconstruction. Conversely, it may also lead to adjustments in the test limits.

We are looking at percent-level effects

ALL modules from SD-433 and SD-750 events in Phase I.

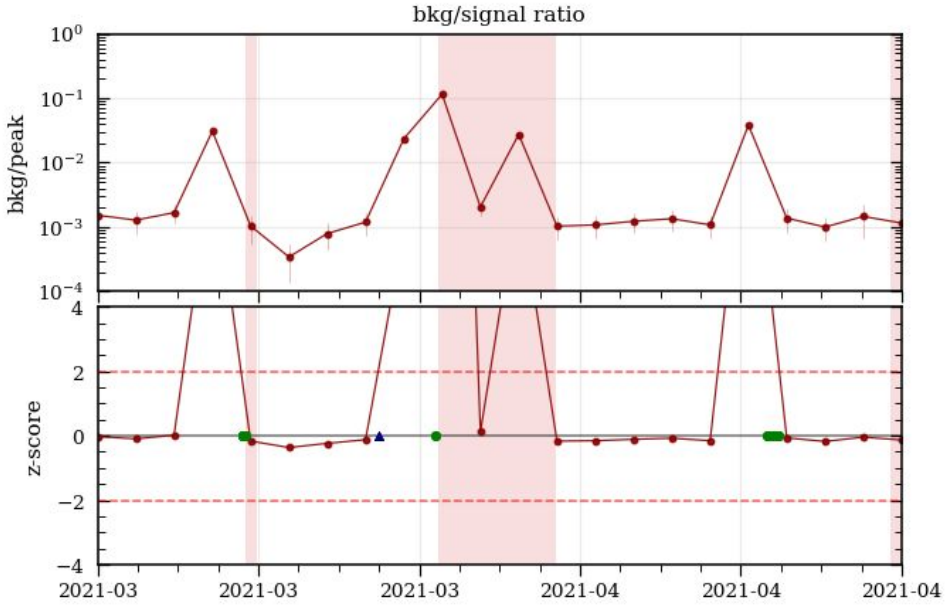


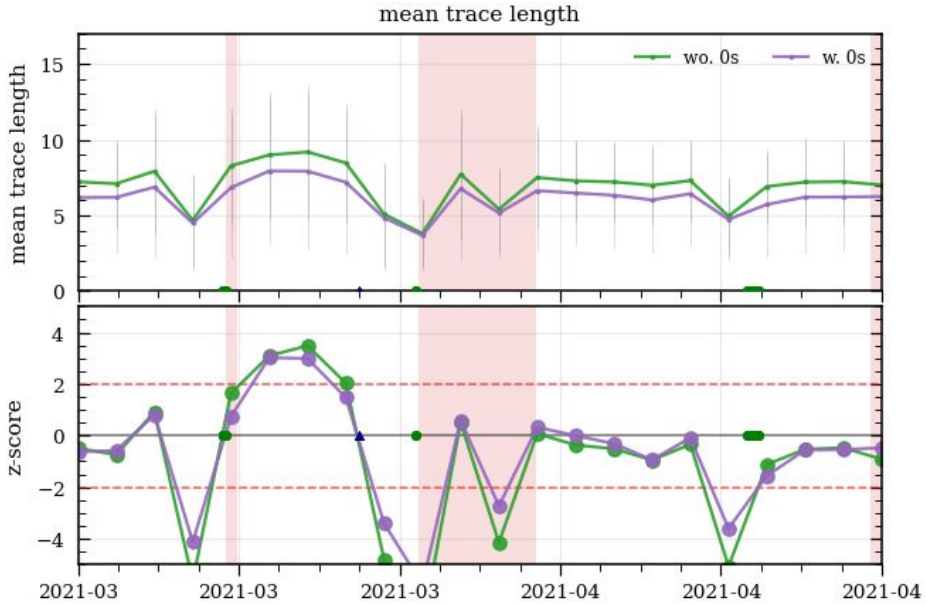


Spotting deviations from expected behavior

Overcounting
1769-m102

Green circles at z-score=0 mark the timing of overcounting labelled events.

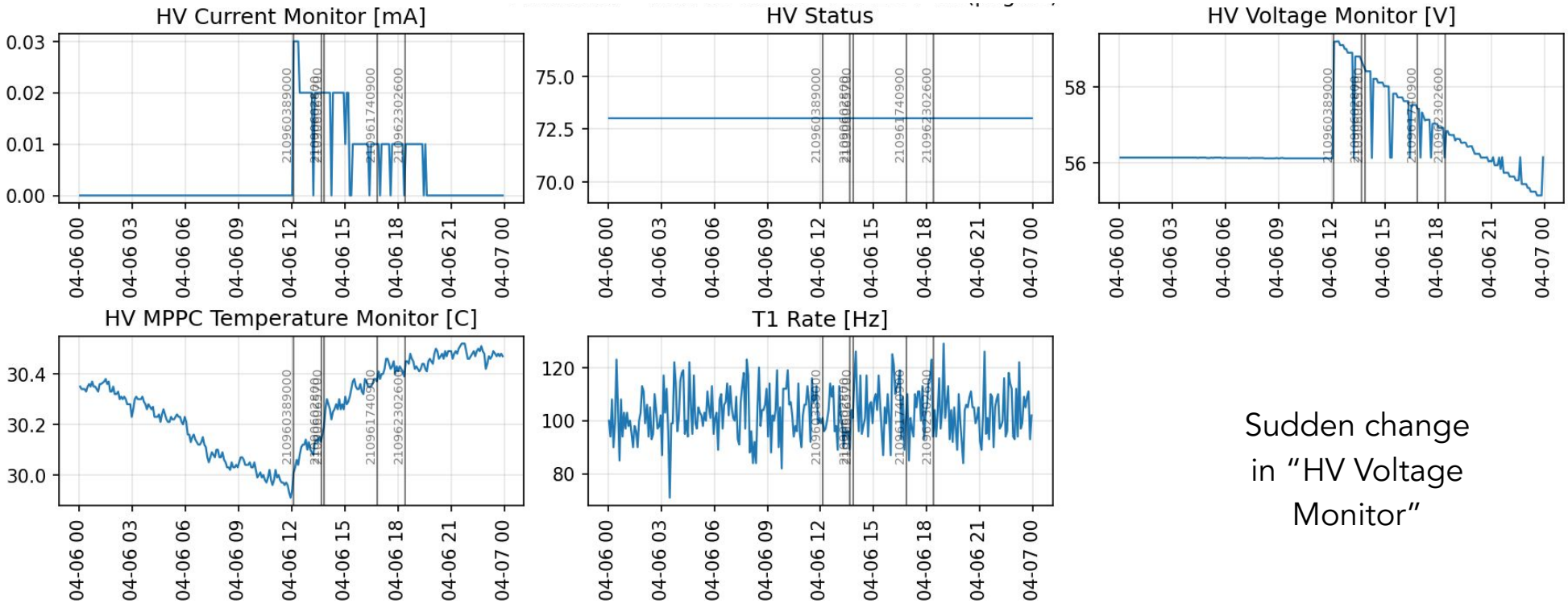




Extreme z-scores for the mean trace length and bkg/signal ratio show coincidence with the overcounting.

Deviations caused by hardware sudden changes

2021-04-06
1769-m102



Sudden change in "HV Voltage Monitor"

Insights from studying “overcounting” modules

1. Some suspicious measurements look like fluctuations and valid physical measurements.
2. Some are out-of-time stations from other events.
3. Some are bad measurements, most confirmed as hardware related issues.

What should we do?

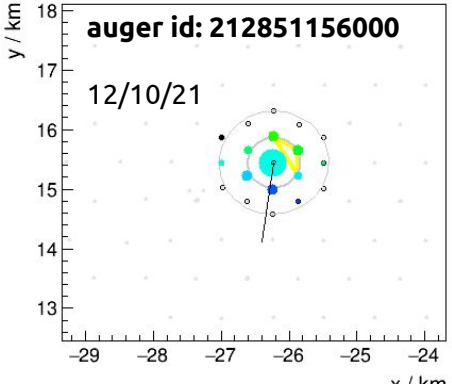
1. Nothing.
2. Reject based on SD’s out-of-time criteria.
3. Include bad modules with known hardware issues per day in the UMD bad periods.

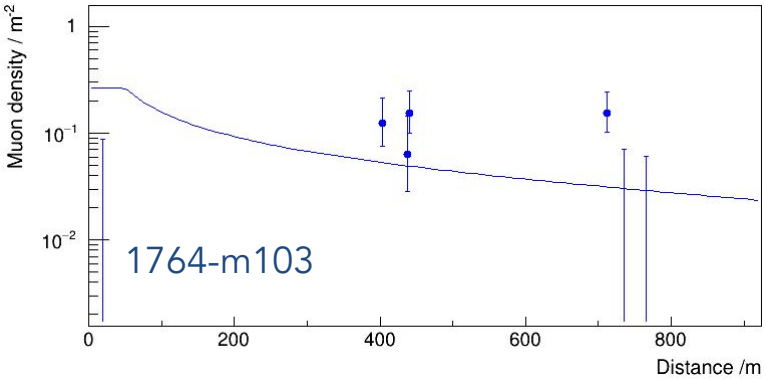
Undercounting

We have buried “Pinocchios”.

The term comes from
GAP 2019-049 (Ioana C. Maris)

Example from the last MOLTP call.





Modules from station 1764 show zero counts

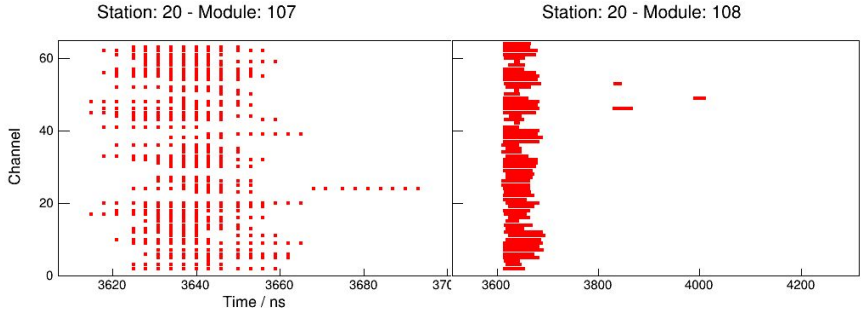
no trace data

no trace data

no trace data

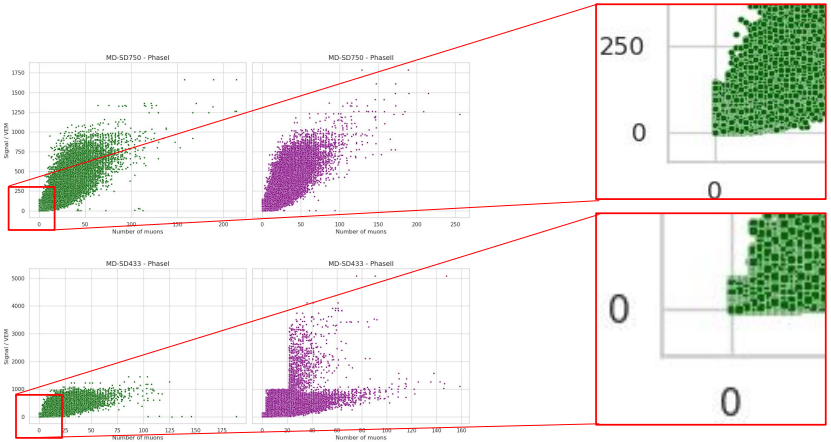
Modules originally from 1764 and connected to doublet station 20 are happy to see some muons

no trace data

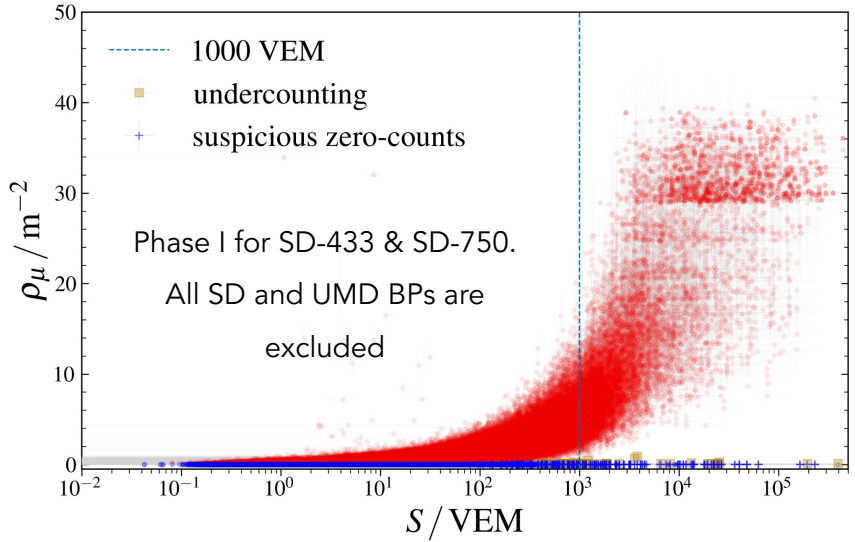


What we know about buried Pinocchios

- Before we had hard cuts on the ratio of the SD signal and muon density → we didn't see them
- Doesn't seem to be a hardware problem → we checked high- and low-level monitoring observables
- Raw traces in md files already show no muons → not a merging problem
- Seems like a problem between the WCD and the UMD counter → all modules are affected
- Appear both in Phase I and Phase II, but more frequently for SD-433 stations starting 2021

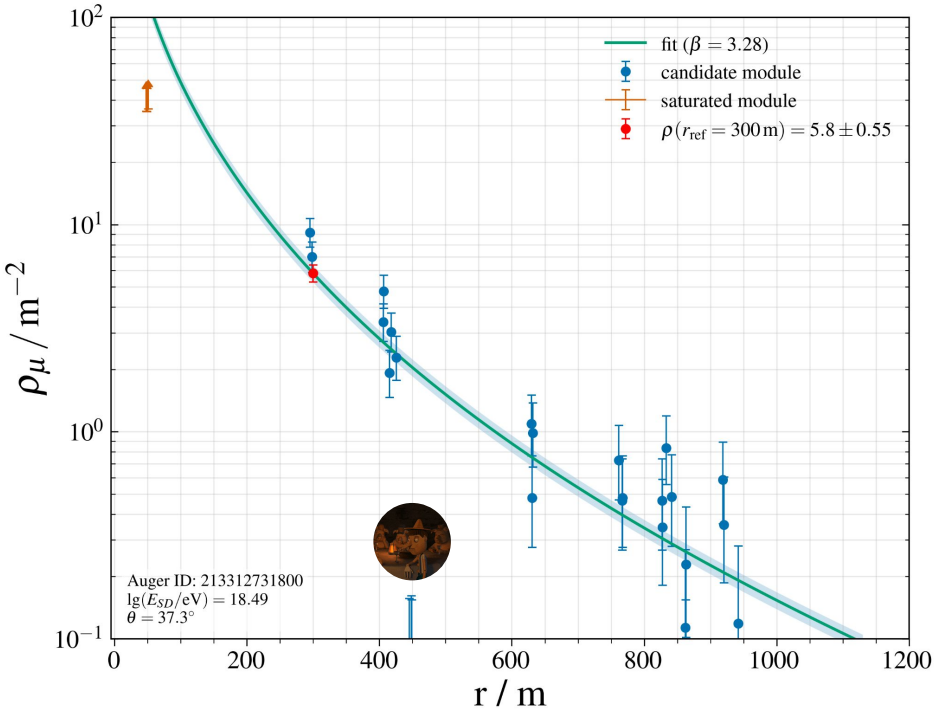


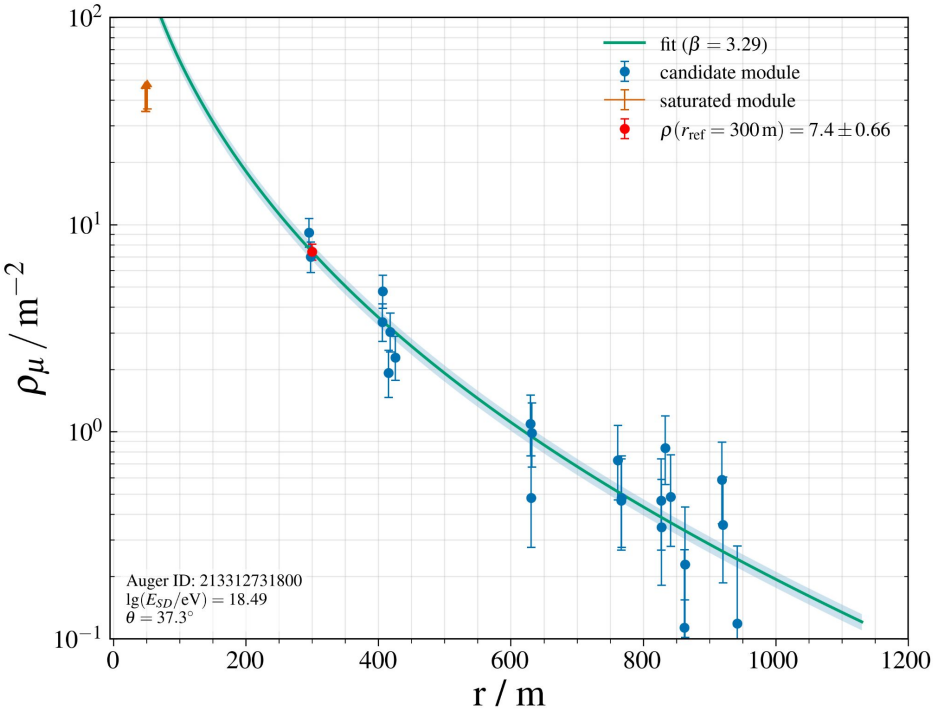
From ICRC25 Data Production Report - Belén Andrada



Simple explanation

We let the shape of the MLDF decide if a module is a Pinocchio or not.

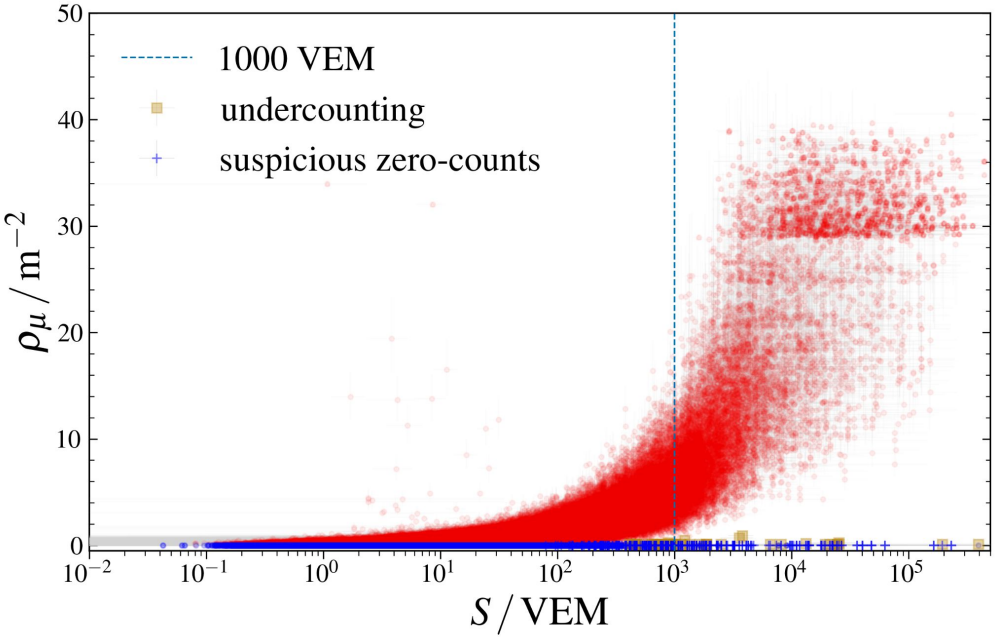


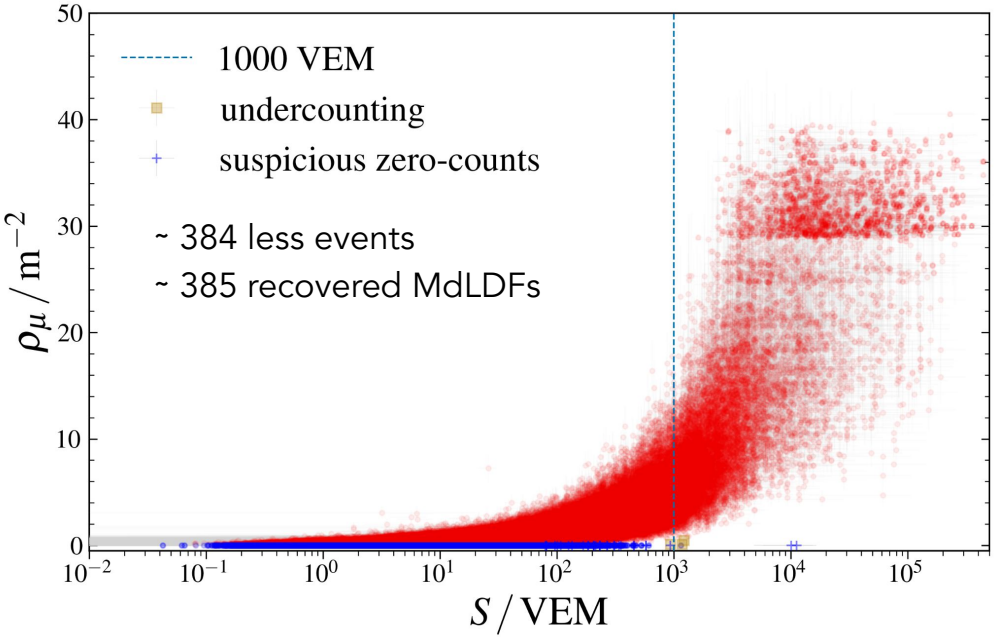


Even if the fits look similar, the difference in ρ_μ(ref) is noticeable.

Applying the method in a test production

Most of overcounting and undercounting is gone. There's still room for improvement.





The implementation in Offline is quite mature.

Summary

- Computed monitoring observables for the UMD (SD-433/SD-750).
- Cross-checked with reconstructed densities. We identified:
  - *Overcounting modules* (mostly hardware or OOT stations, removed when possible)
  - *Undercounting modules* ("buried Pinocchios" at counter-level)
- Implemented MLDF-based strategy to detect and discard Pinocchios.
- UMD Phase I data in good shape for physics analysis (after merge).
- More details at the Collaboration Meeting.

All is well!

Backup

Approach

Reproduce monitoring observables for Phase I (excluding rate-based observables)

from md files (before even merging into xad files)

and compare values with suspicious measurements (both from SD-433 and SD-750)

using recomputed reference thresholds from the UMD shift (excluding bad periods)

1. bkg. rate
2. mean trace length
3. latch bin position
4. bkg/peak ratio

Also check at specific examples for intraday hints of malfunctioning and inspect the events to assess "validity" of measurements

Motivation

at least 450 in a dataset of ~2M measurements (lower bound ~0.02%)

Zero counts >= 366

counter_id	module_id	suspicious	
1764.0	103.0	1	26
	104.0	1	25
12.0	103.0	1	24
	102.0	1	23
	101.0	1	22
97.0	101.0	1	22
	102.0	1	18
	103.0	1	16
30.0	101.0	1	15
	103.0	1	14
	102.0	1	10
93.0	101.0	1	9
	102.0	1	8
1570.0	101.0	1	8
1773.0	101.0	1	8
1765.0	102.0	1	7
688.0	101.0	1	7
1570.0	103.0	1	7
	102.0	1	7
1765.0	101.0	1	6
688.0	102.0	1	6
1574.0	101.0	1	5
	102.0	1	5
1622.0	106.0	1	5
...			
	102.0	1	1
1769.0	101.0	1	1
688.0	103.0	1	1
1773.0	103.0	1	1

Undercounting ~ 46

counter_id	module_id	suspicious	
1764.0	104.0	1	5
12.0	102.0	1	4
	101.0	1	2
97.0	102.0	1	2
1764.0	103.0	1	2
	108.0	1	2
97.0	103.0	1	2
1622.0	106.0	1	2
93.0	102.0	1	2
30.0	103.0	1	2
	102.0	1	2
12.0	103.0	1	2
1769.0	101.0	1	1
1761.0	103.0	1	1
1765.0	103.0	1	1
	102.0	1	1
	101.0	1	1
1767.0	102.0	1	1
1574.0	101.0	1	1
1760.0	103.0	1	1
1622.0	105.0	1	1
	101.0	1	1
734.0	102.0	1	1
	101.0	1	1
...			
	102.0	1	1
669.0	102.0	1	1
97.0	101.0	1	1
1773.0	101.0	1	1

Overcounting ~ 42

counter_id	module_id	suspicious	
1769.0	102.0	1	12
93.0	102.0	1	4
688.0	103.0	1	3
93.0	101.0	1	3
1764.0	103.0	1	2
1574.0	101.0	1	2
30.0	101.0	1	1
1574.0	102.0	1	1
1764.0	104.0	1	1
1762.0	103.0	1	1
1761.0	103.0	1	1
	102.0	1	1
1760.0	101.0	1	1
1570.0	102.0	1	1
734.0	103.0	1	1
	102.0	1	1
	101.0	1	1
688.0	102.0	1	1
669.0	103.0	1	1
	102.0	1	1
	101.0	1	1
1773.0	101.0	1	1

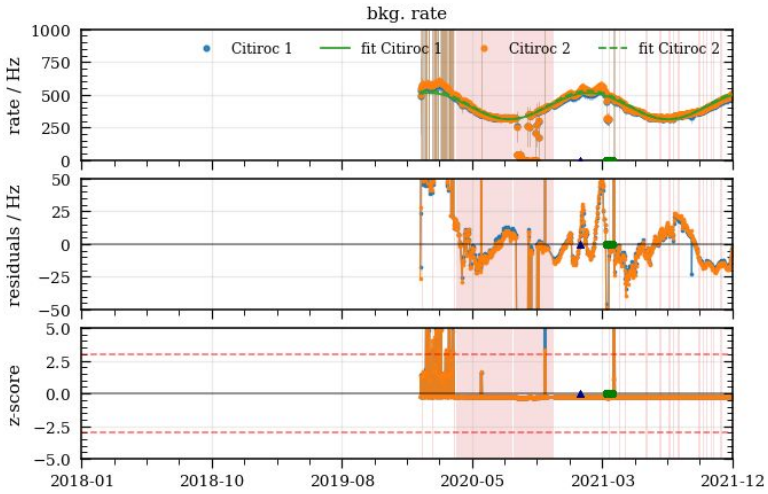
suspicious zero counts and undercounting modules are notably more common in the SD-433

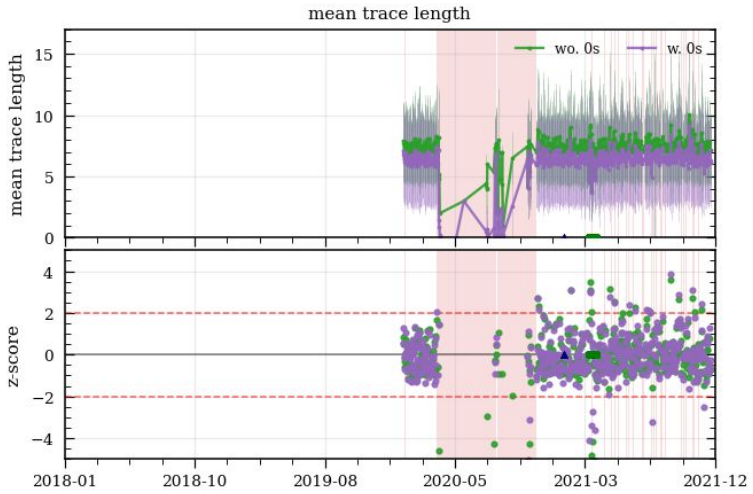
Overcounting 1769-m102

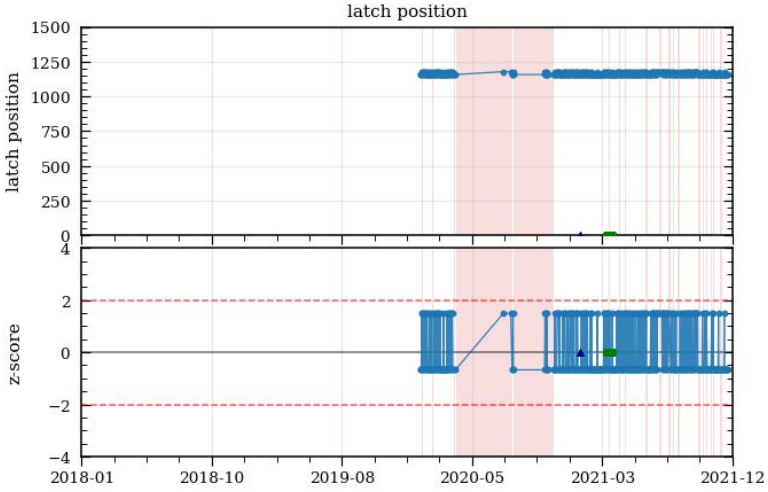
Complete Phase I used to compute reference values.

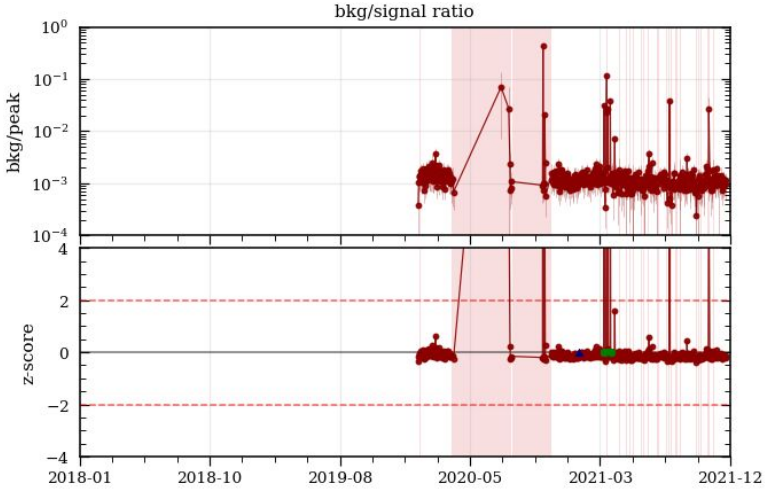
Shaded in red are the rated-based bad periods. Data falling here are not employed to compute references.

z-scores to check for deviations of normal behaviour.





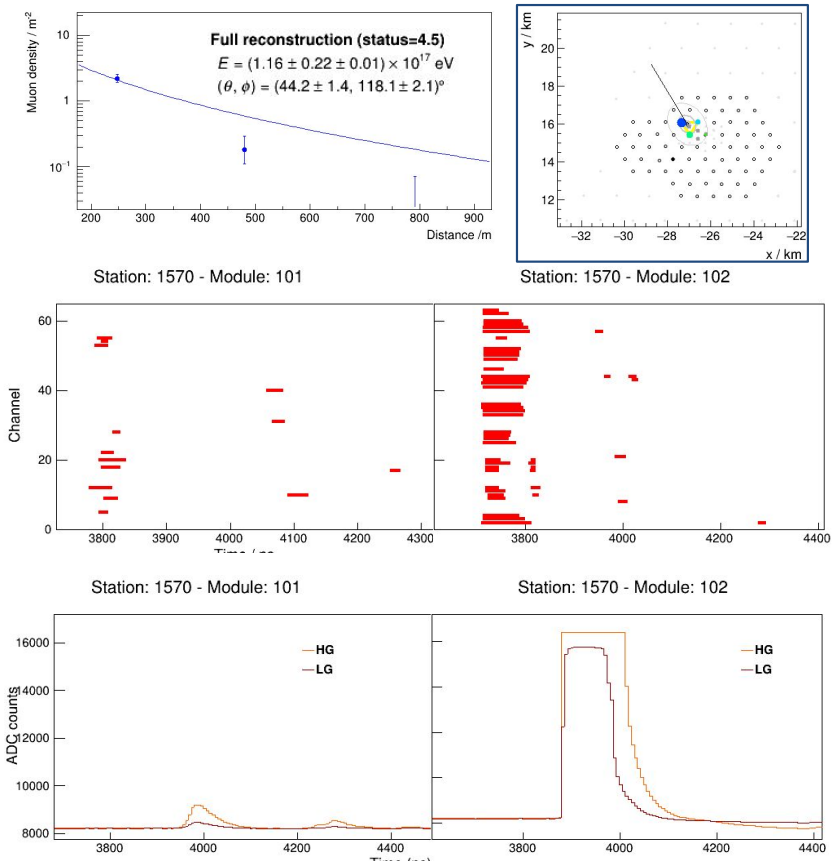




Simple cases of overcounting - some examples

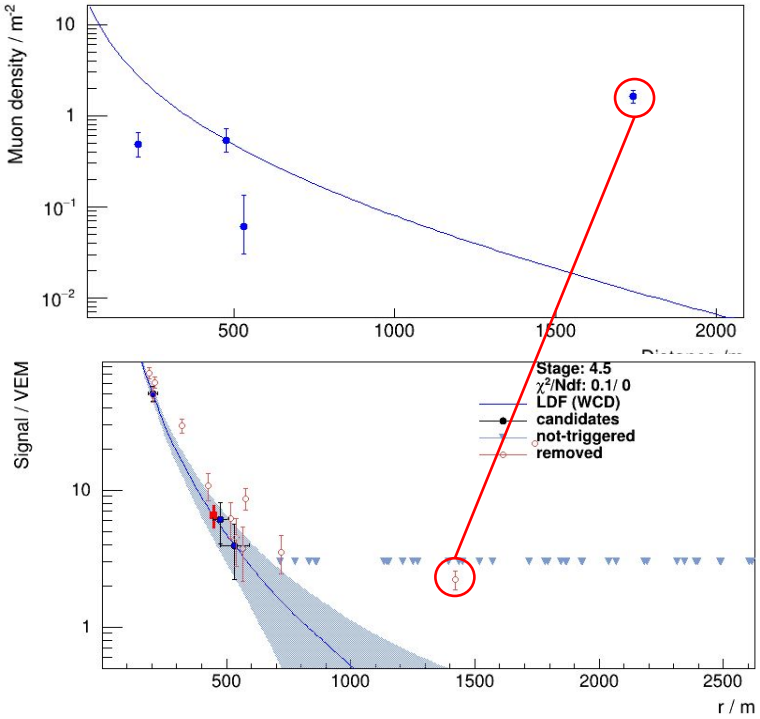
auger id: 192510592600
1570-m102 at 240m

Inclined event. **Nothing to do!**
VALID MEASUREMENT!?



auger id: 212256651500
1762-m103 at 1700m

VALID MEASUREMENT!!! NOT part of the event.
We should reject by SD Out-of-Time!
Easy to do. Machinery already implemented.

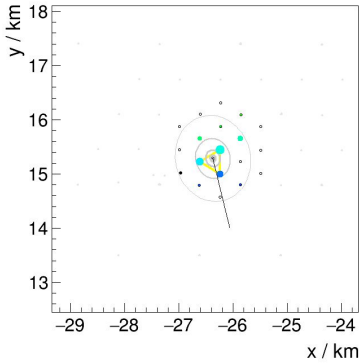


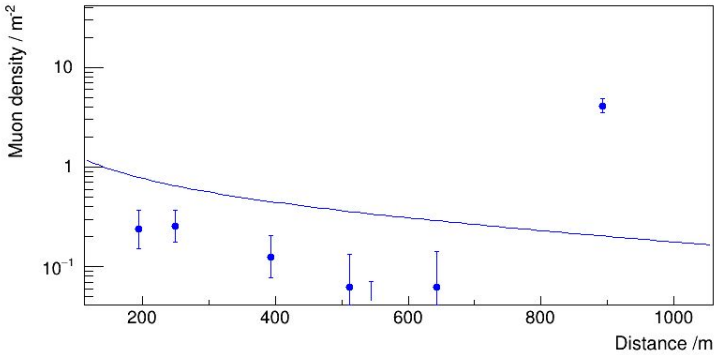
Overcounting 1769-m102

auger id: 210960602800

06/04/21

other examples in the backup slides

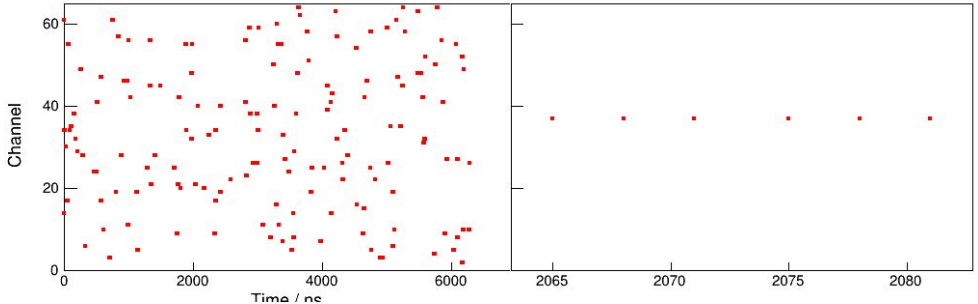




Station: 1769 - Module: 102

Station: 1769 - Module: 103

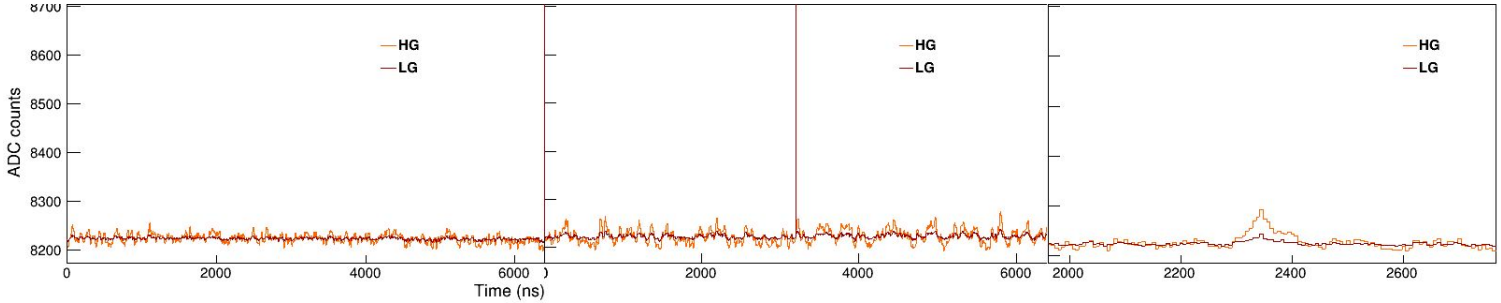
no trace data



Station: 1769 - Module: 101

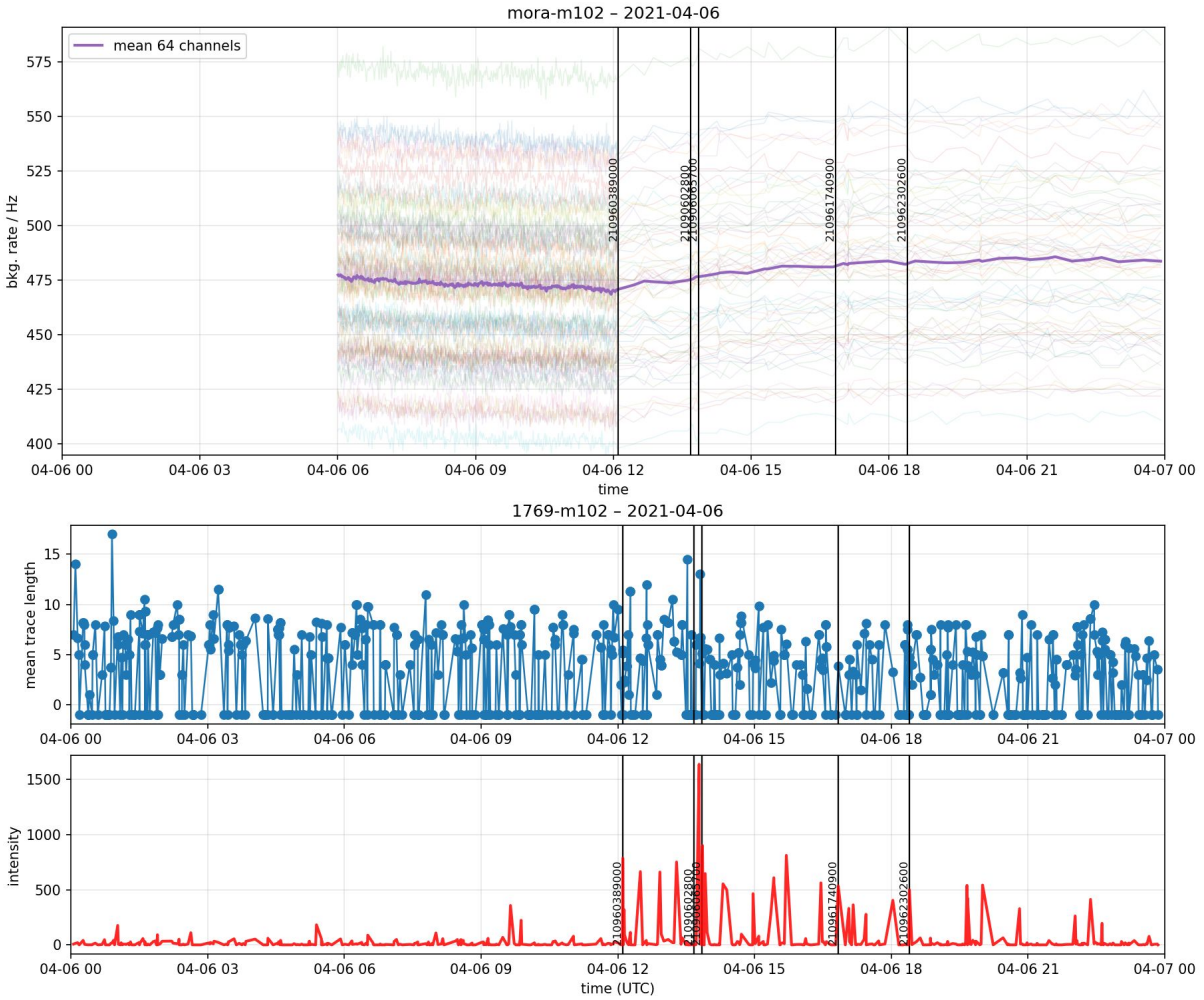
Station: 1769 - Module: 102

Station: 1769 - Module: 103



Intraday checks

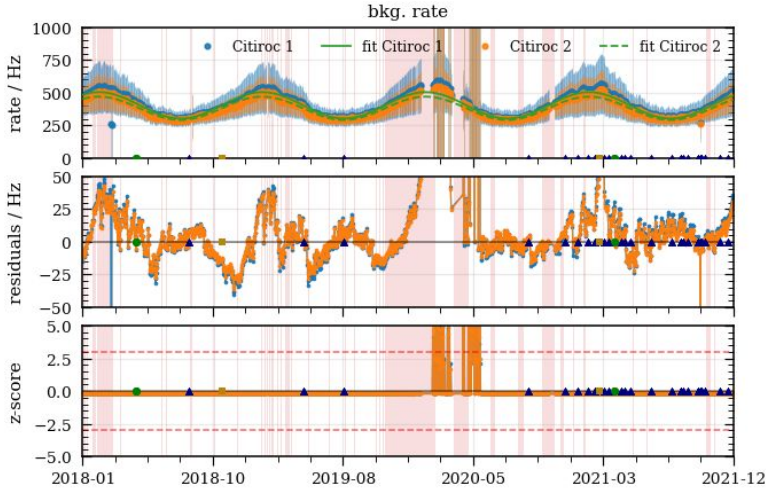
2021-04-06
1769-m102

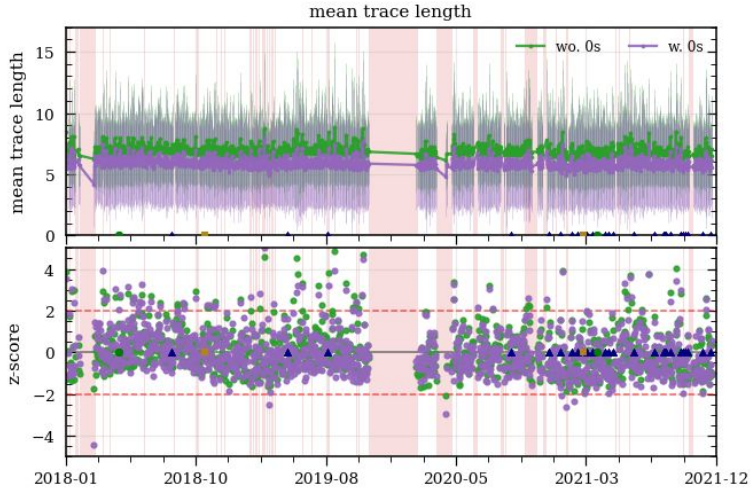


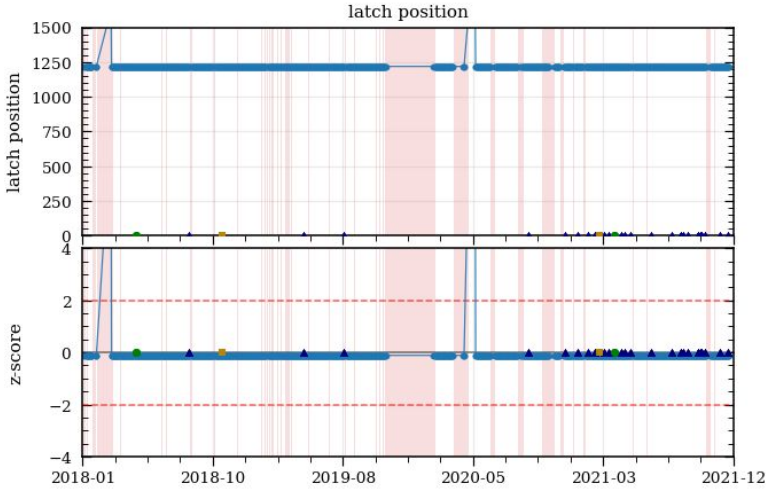
1764-m103
suspicious zero counts

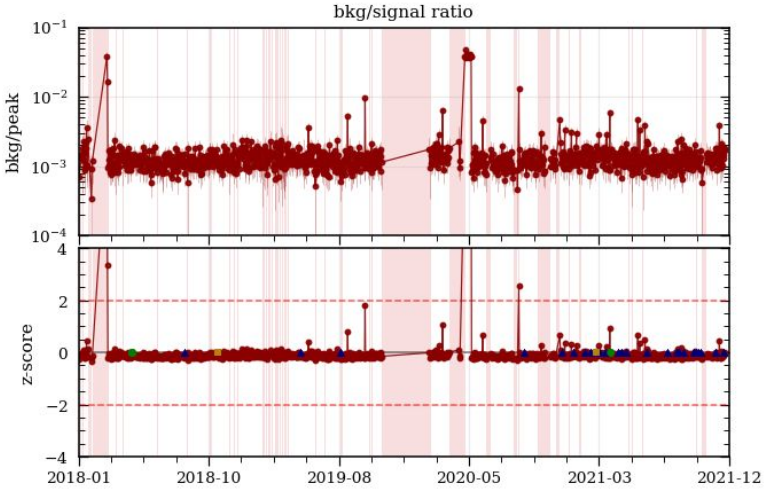
Appear frequently starting 2021

No clear correlation with monitoring observables









Some hints

Suspicious “zero counts” intensify for SD-433 starting 2021

No clear hints of malfunction from hardware checks

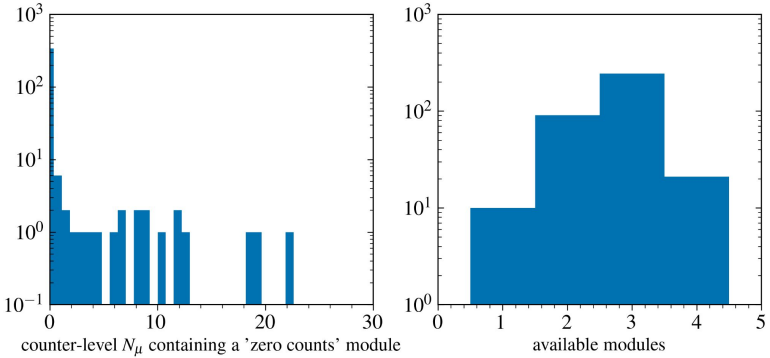
45/46 modules suspected of undercounting are paired with a suspicious zero count modules

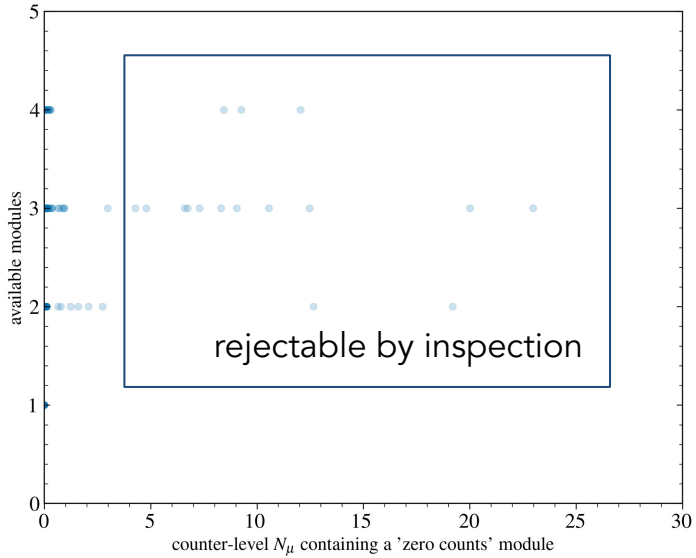
Counter-level zero muon predictions are common

indication of problem at counter-level???

Very few instances where it seems a module-level problem

Looking into this at the moment…



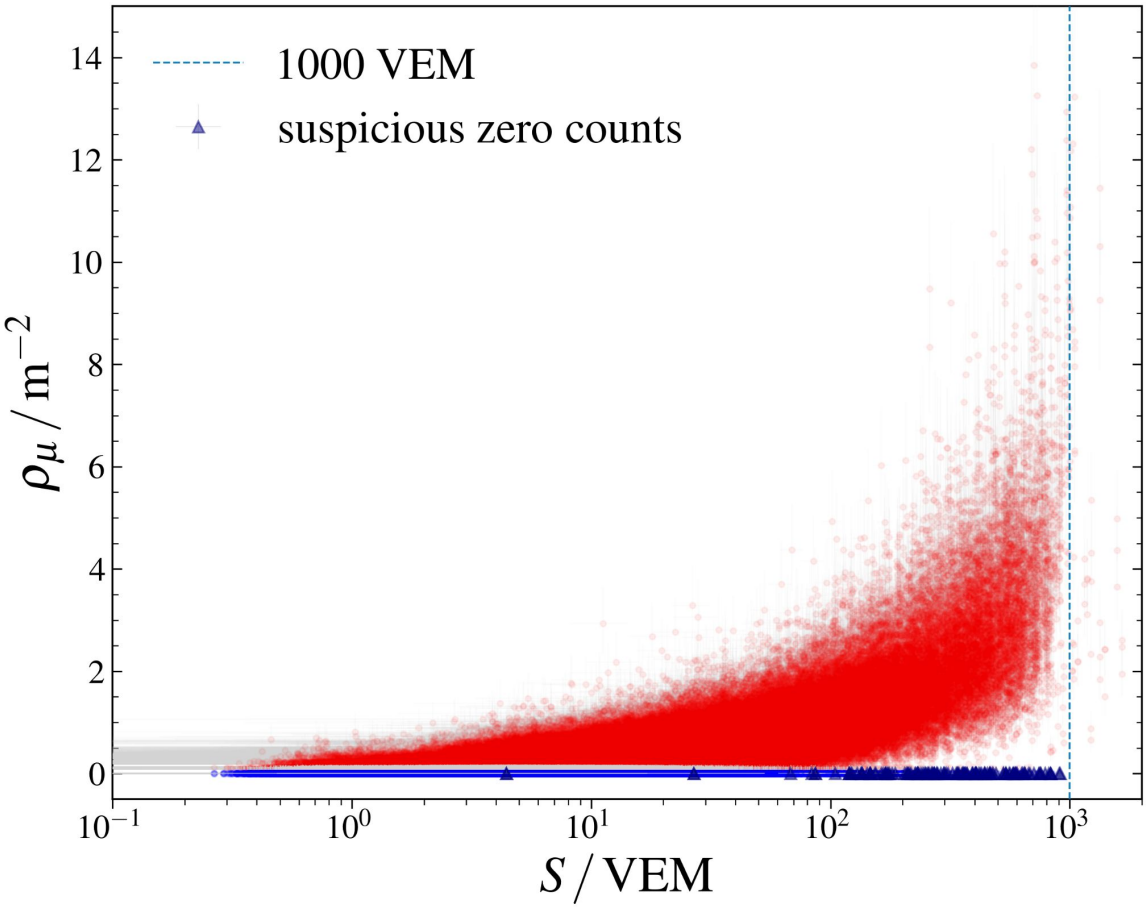


Quick check for Phase II from yesterday

SD-433 from 2023 to 2024.

No rejection by SD bad periods.

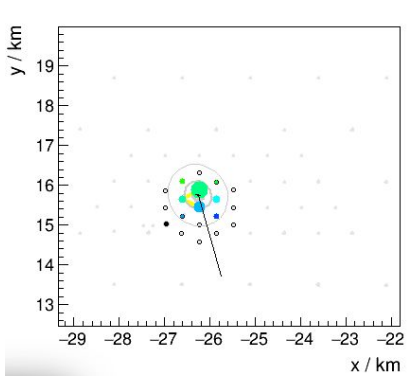
Looks like we also have some here.

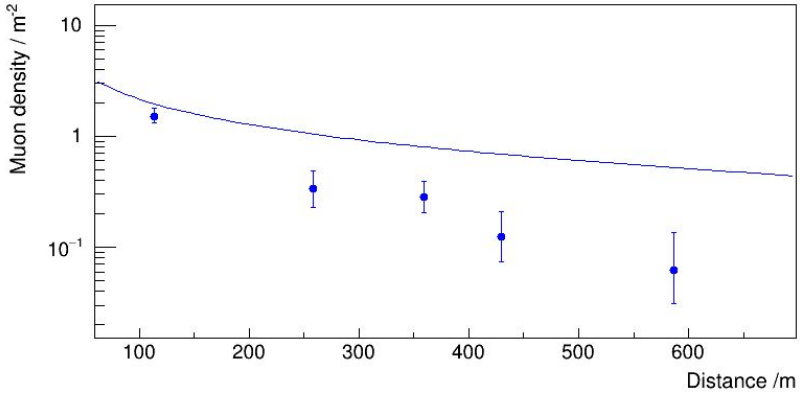


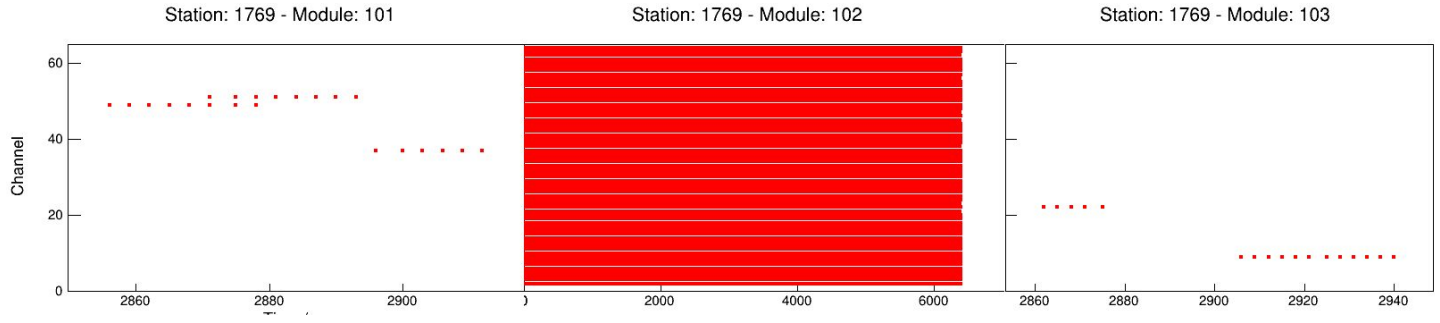
Overcounting
1769-m102

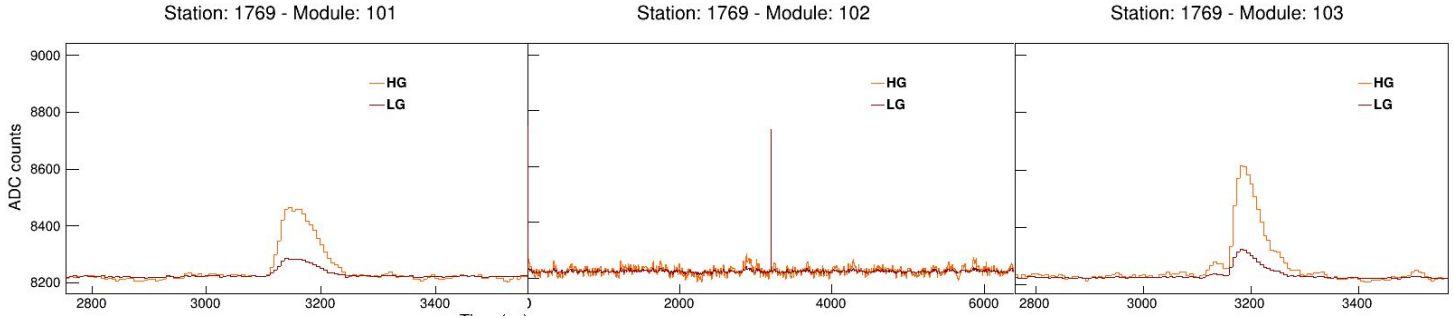
auger id: 210822560100

23/03/21





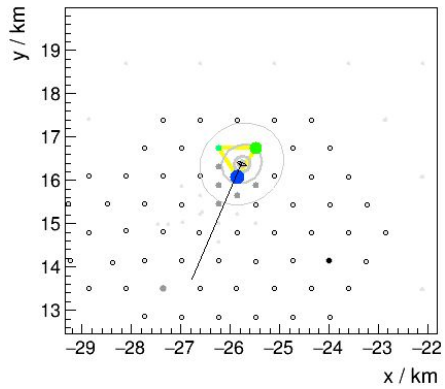


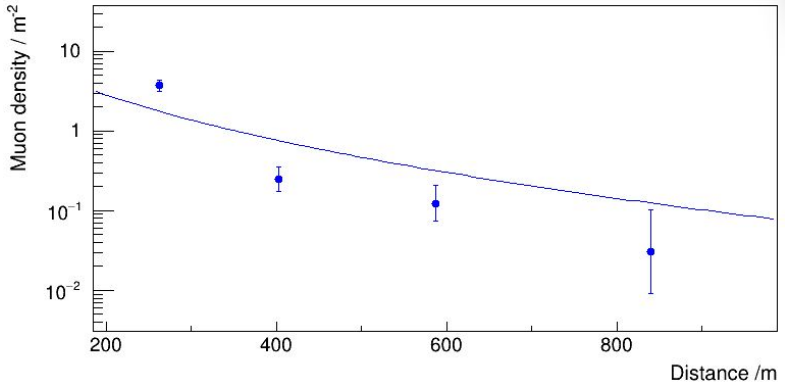


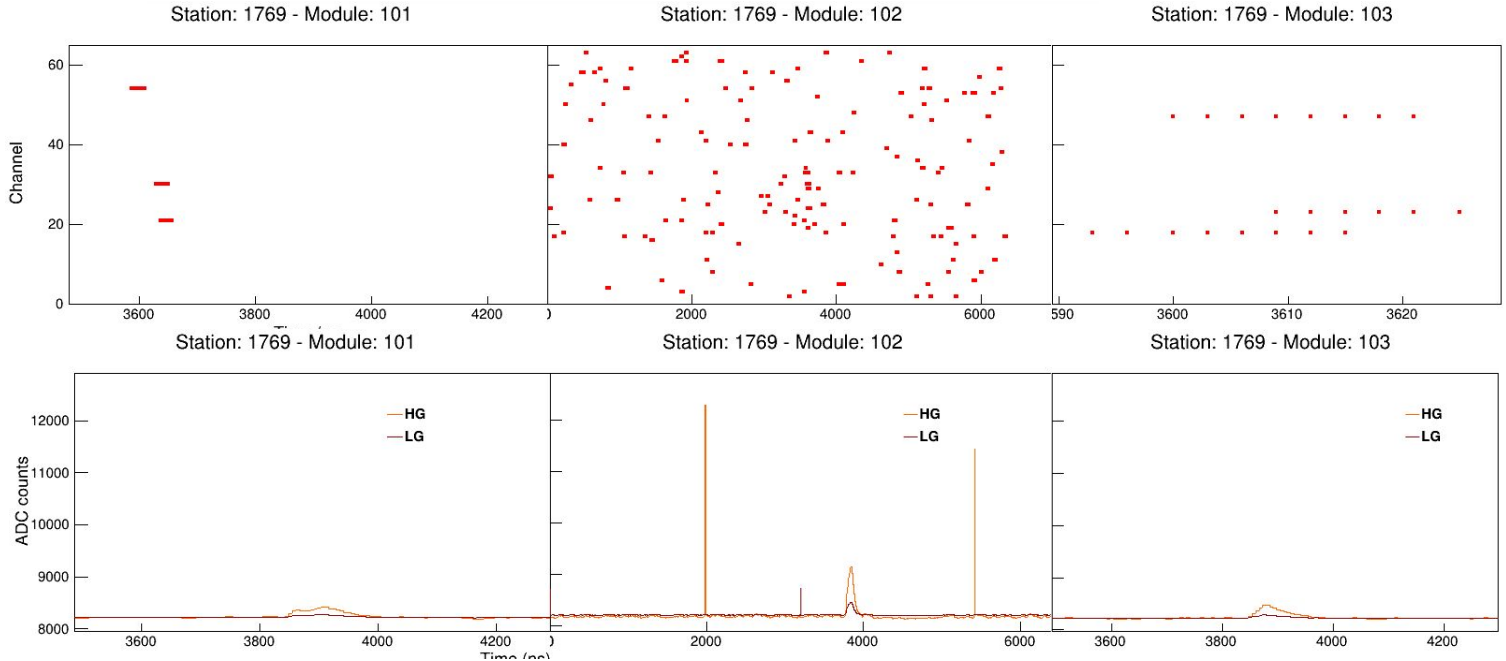
Overcounting
1769-m102

auger id: 210872833100

28/03/21

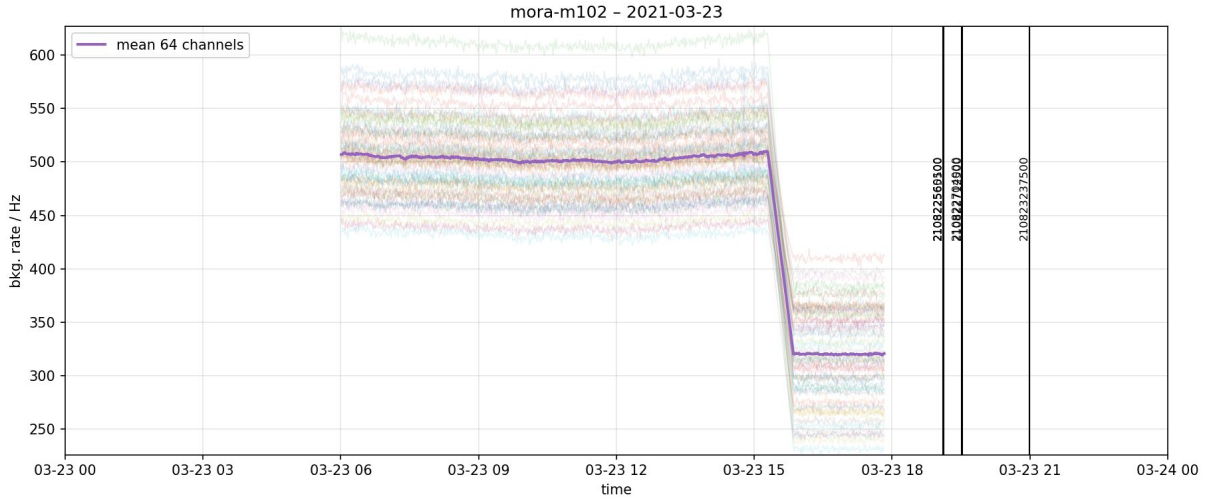


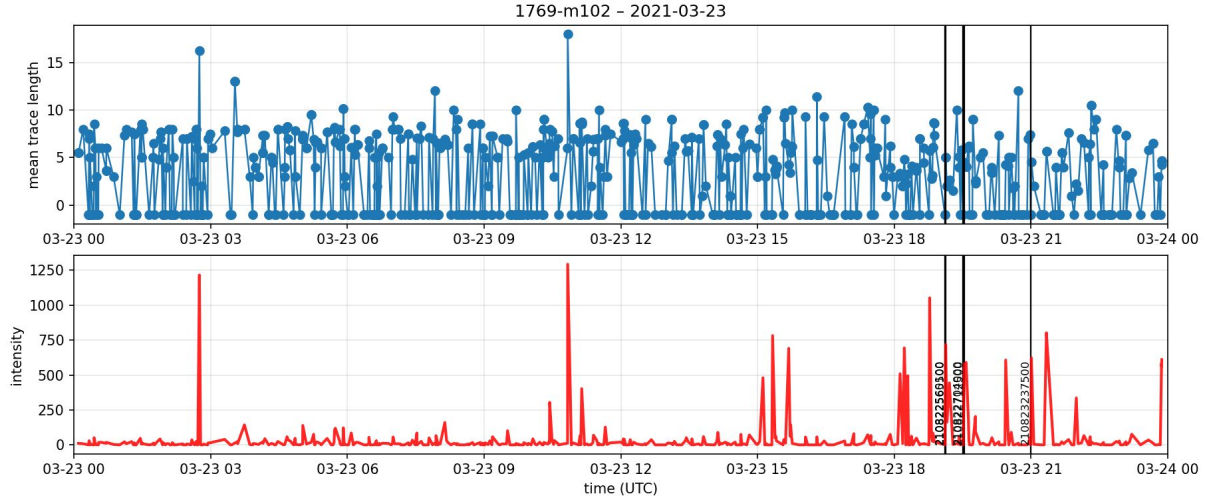




Intra-day checks

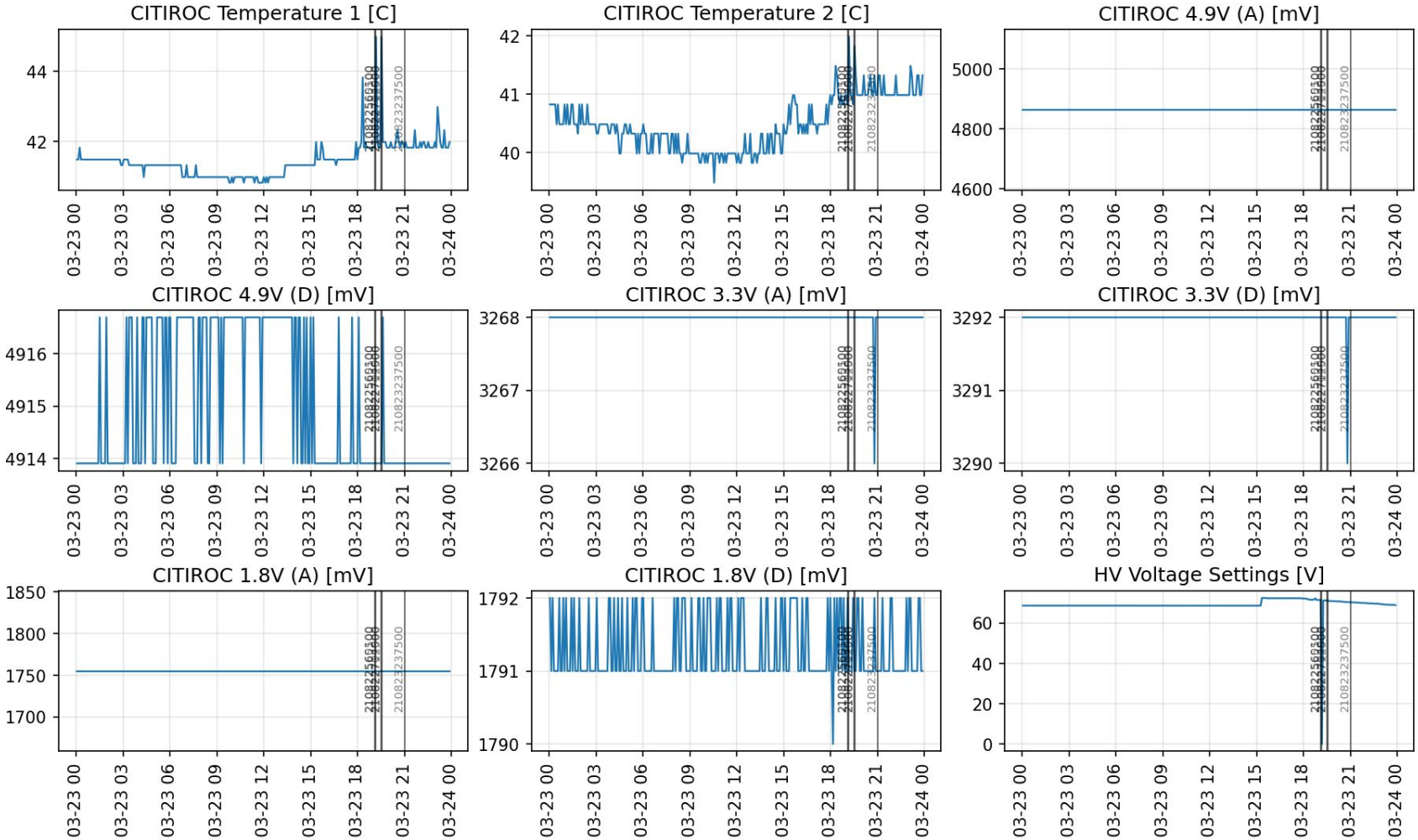
2021-03-23
1769-m102





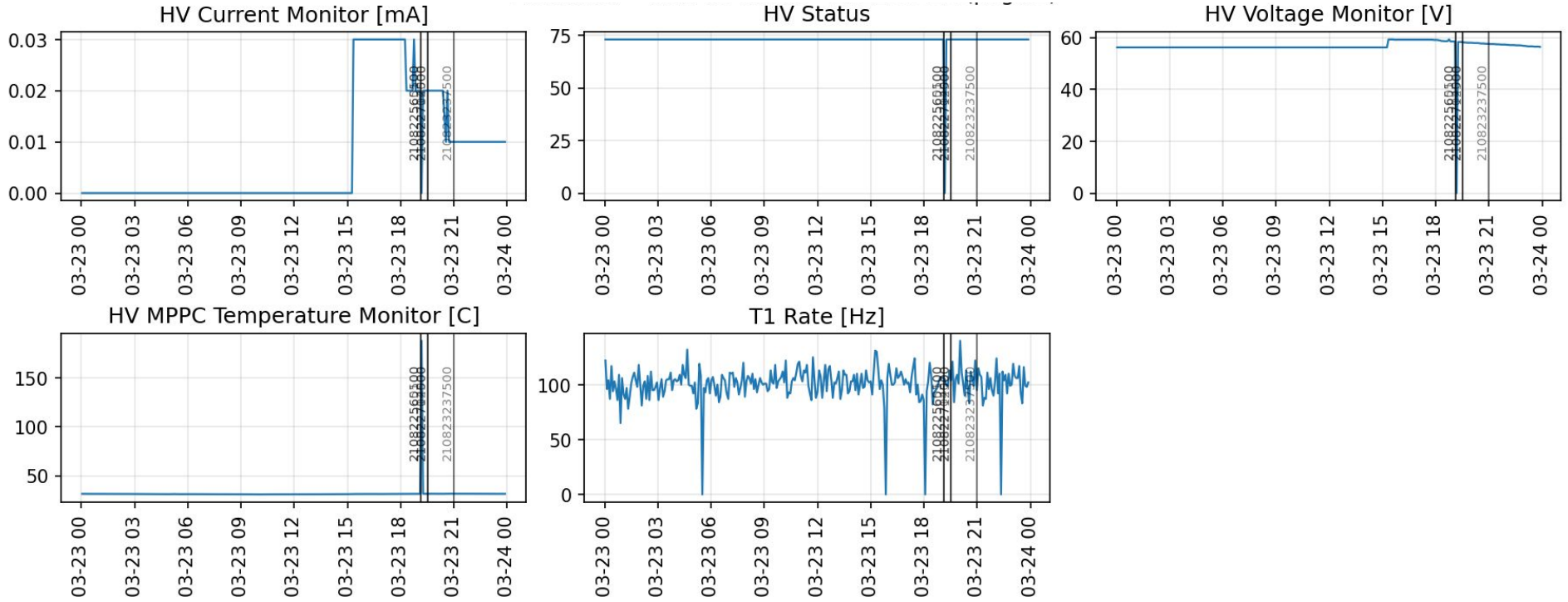
MonitSlow

2021-03-23
1769-m102



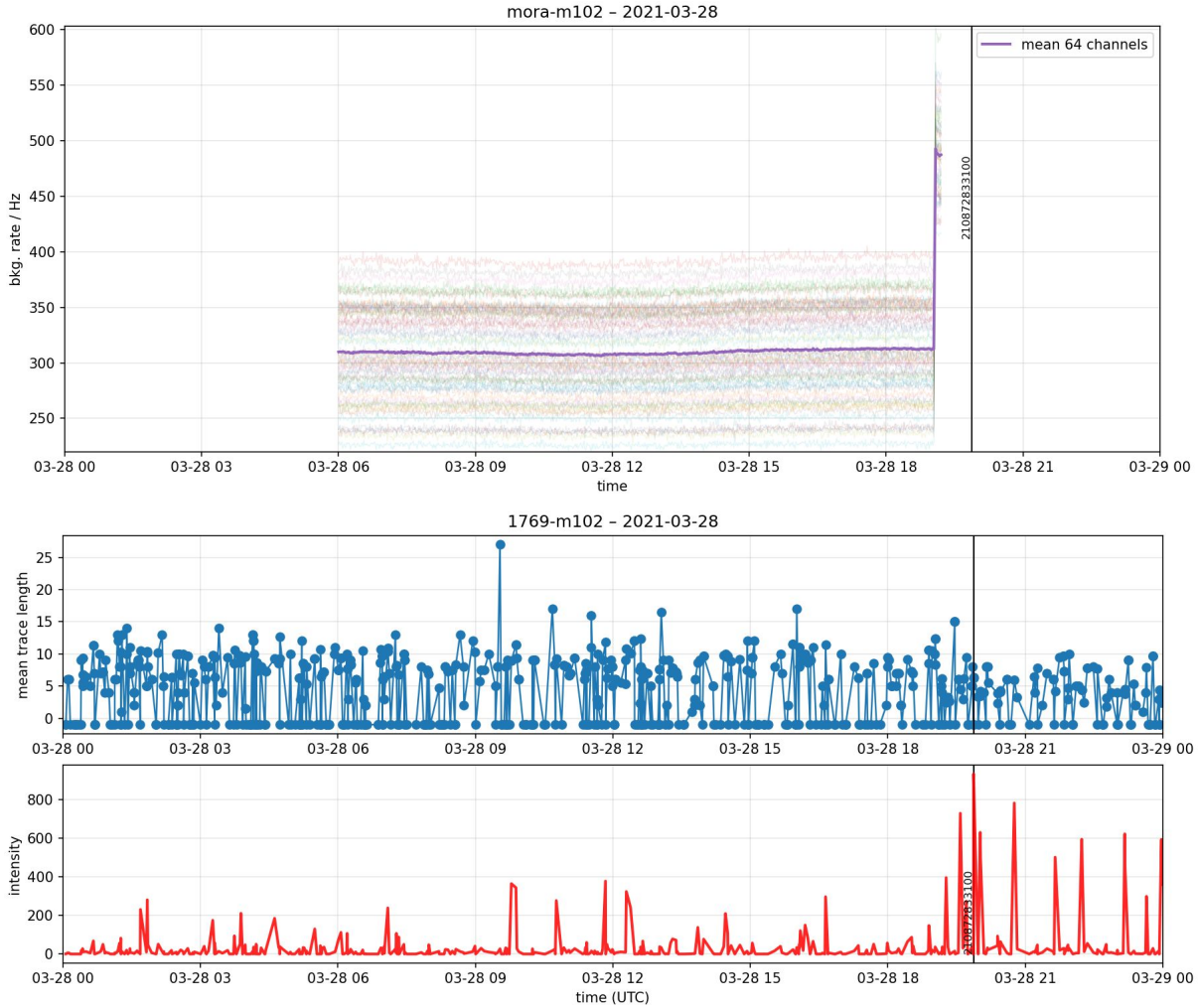
MonitSlow

2021-03-23
1769-m102



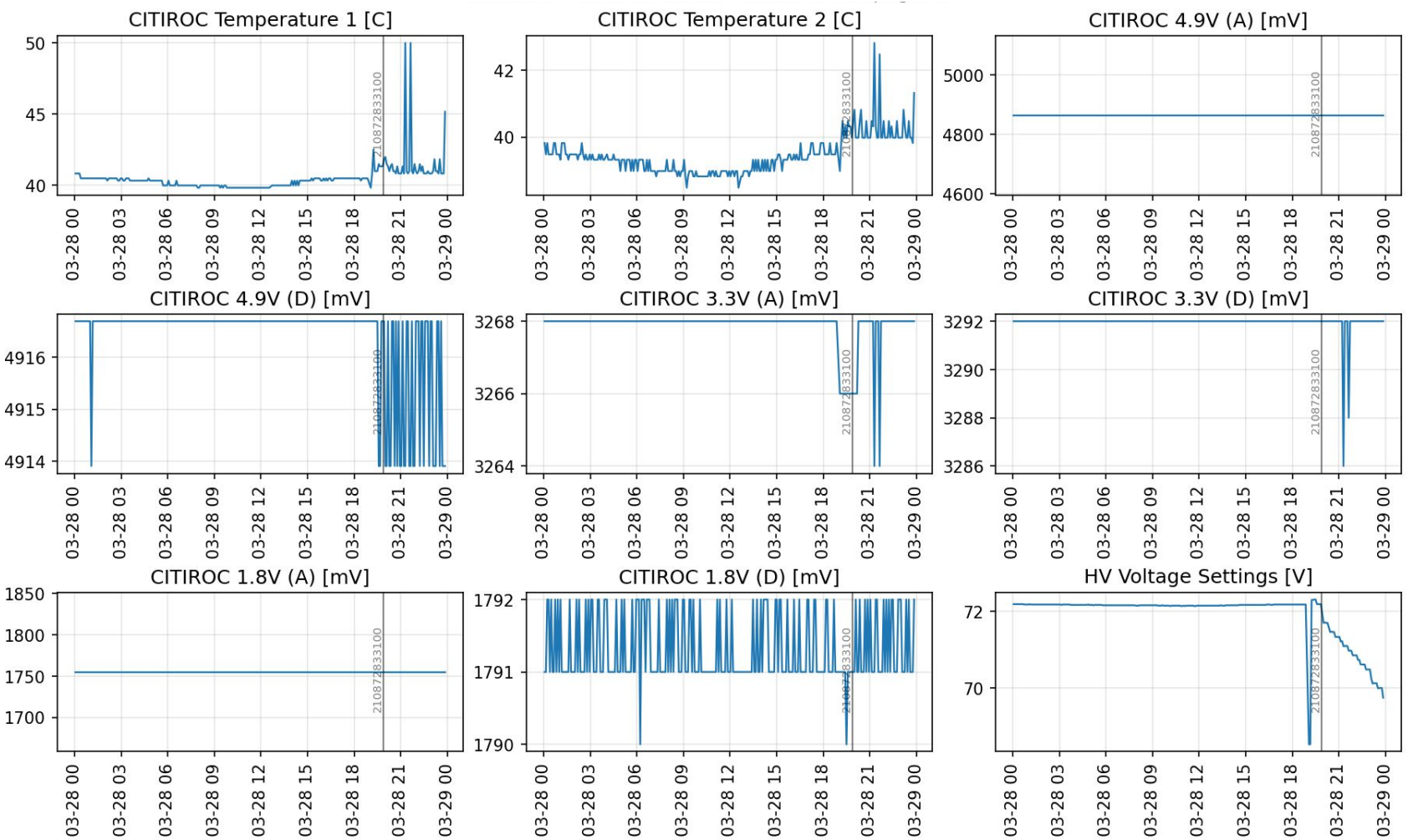
Intra-day checks

2021-03-28
1769-m102



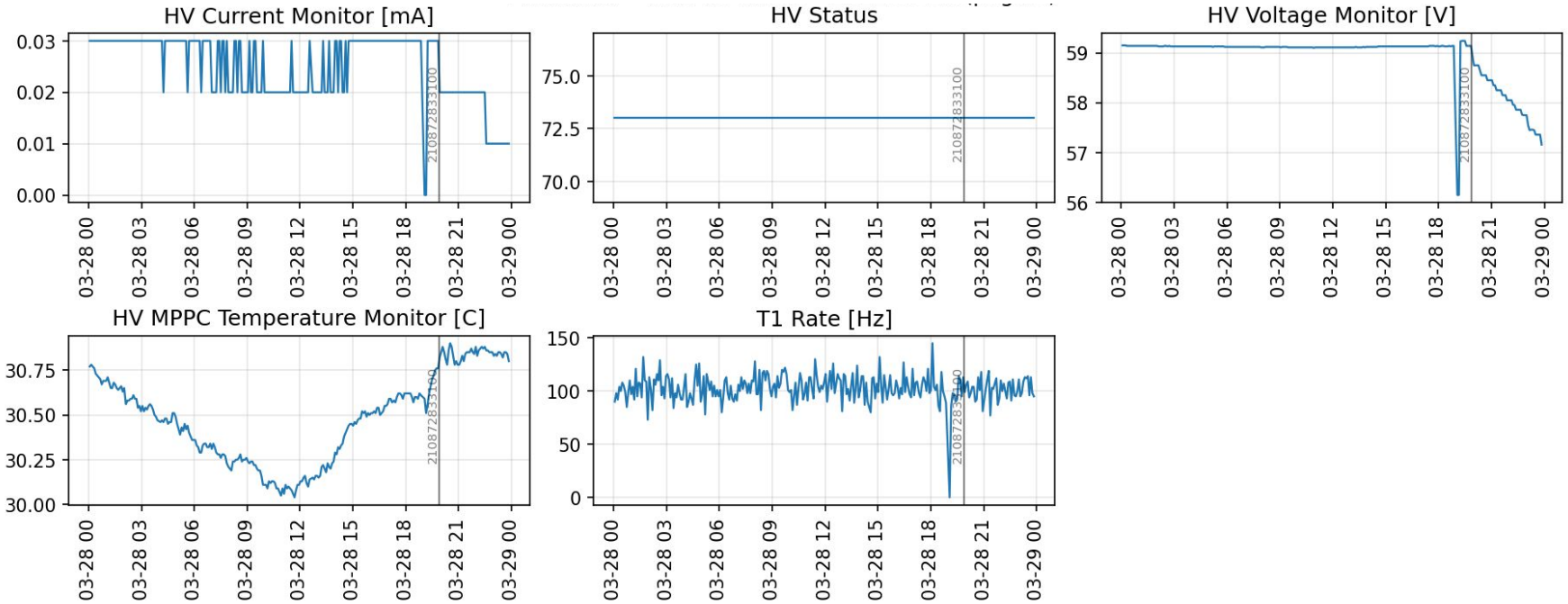
MonitSlow

2021-03-28
1769-m102



MonitSlow

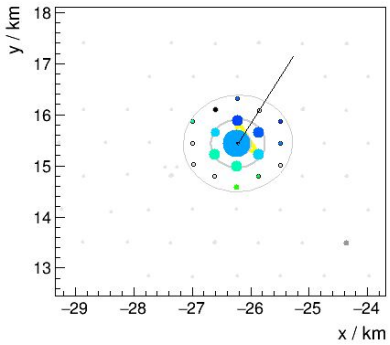
2021-03-28
1769-m102

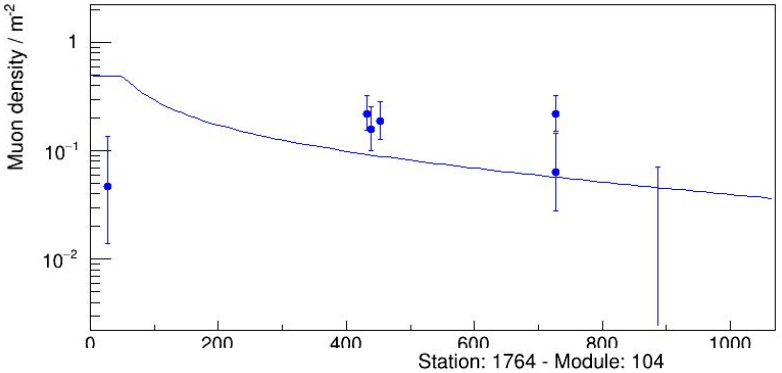


1764-m104 undercounting

auger id: 212940013200

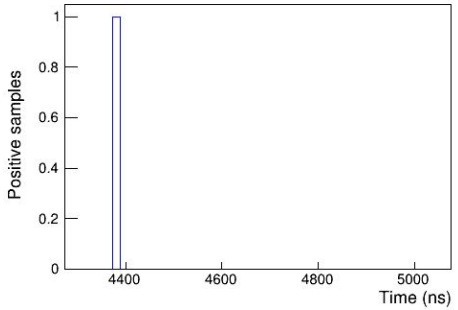
21/10/21



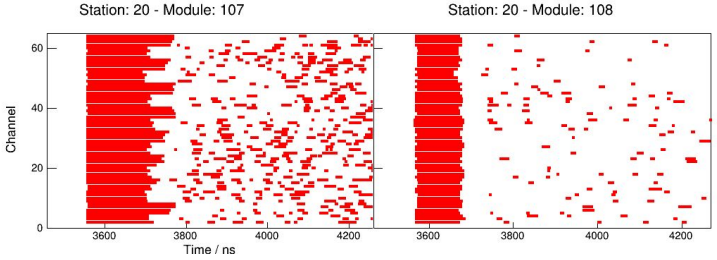


no trace data

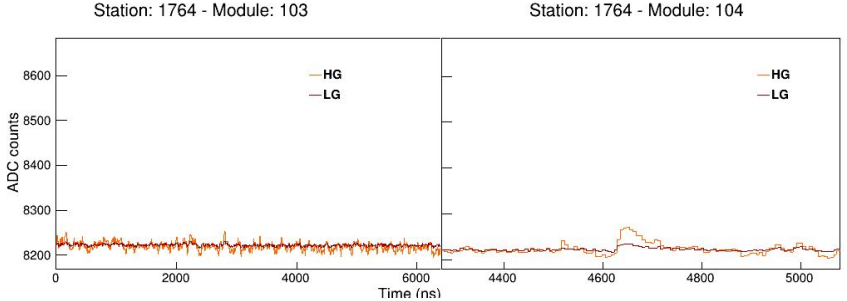
no trace data



Counter 20 at less than 20 mts from 1764 was on fire D:



no trace data



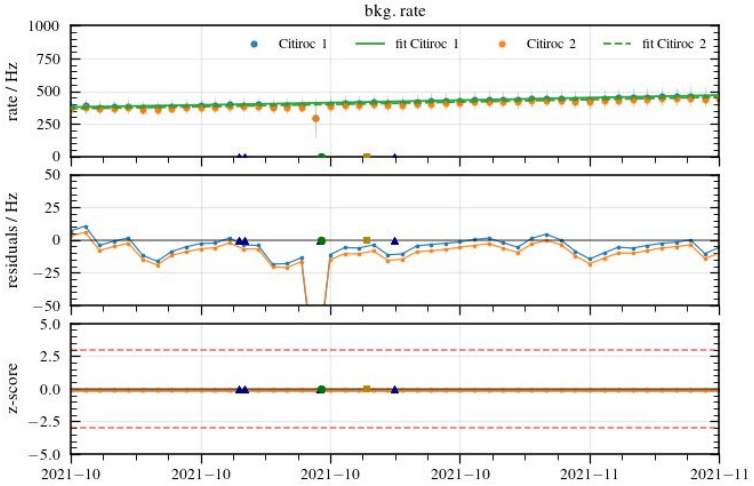
1764-m103 undercounting

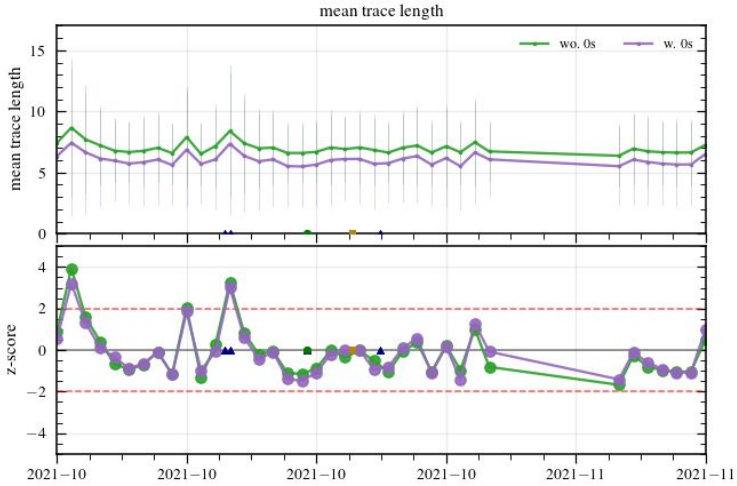
auger id: 212940013200

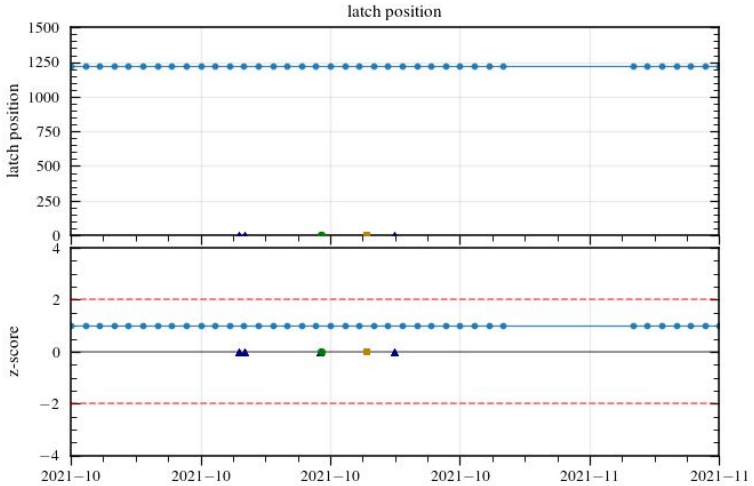
21/10/21

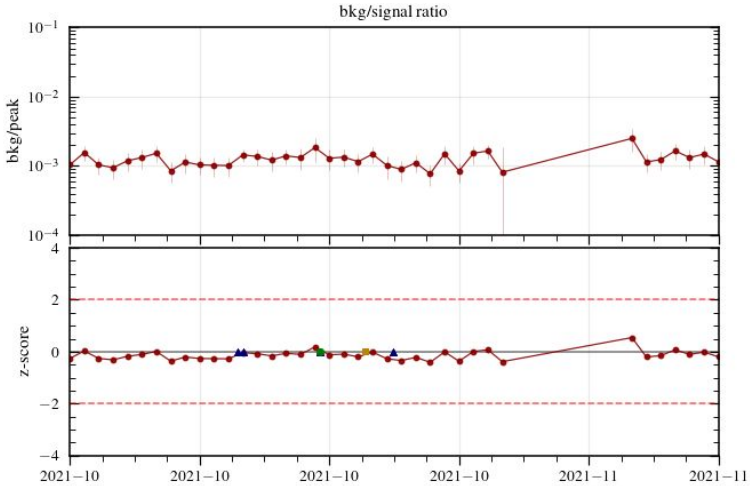
Where are the bad periods at module-level?

1764-m104 is a production module.





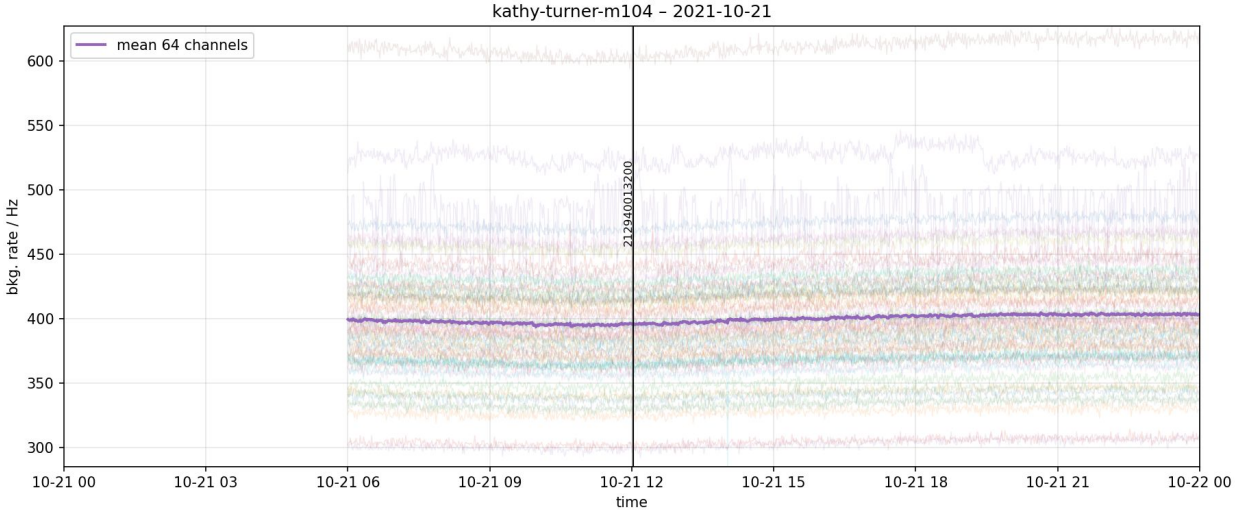


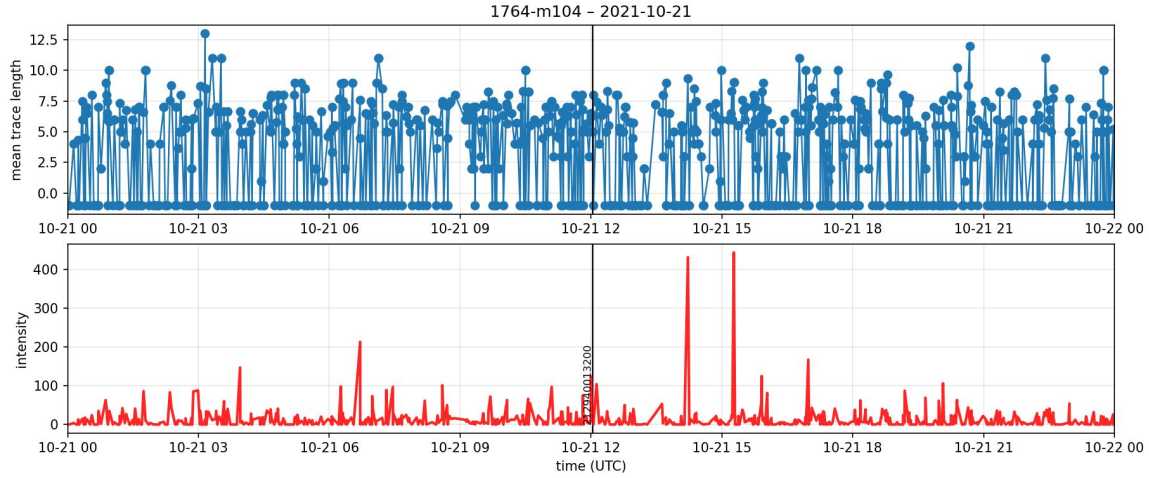


1764-m103 undercounting

auger id: 212940013200

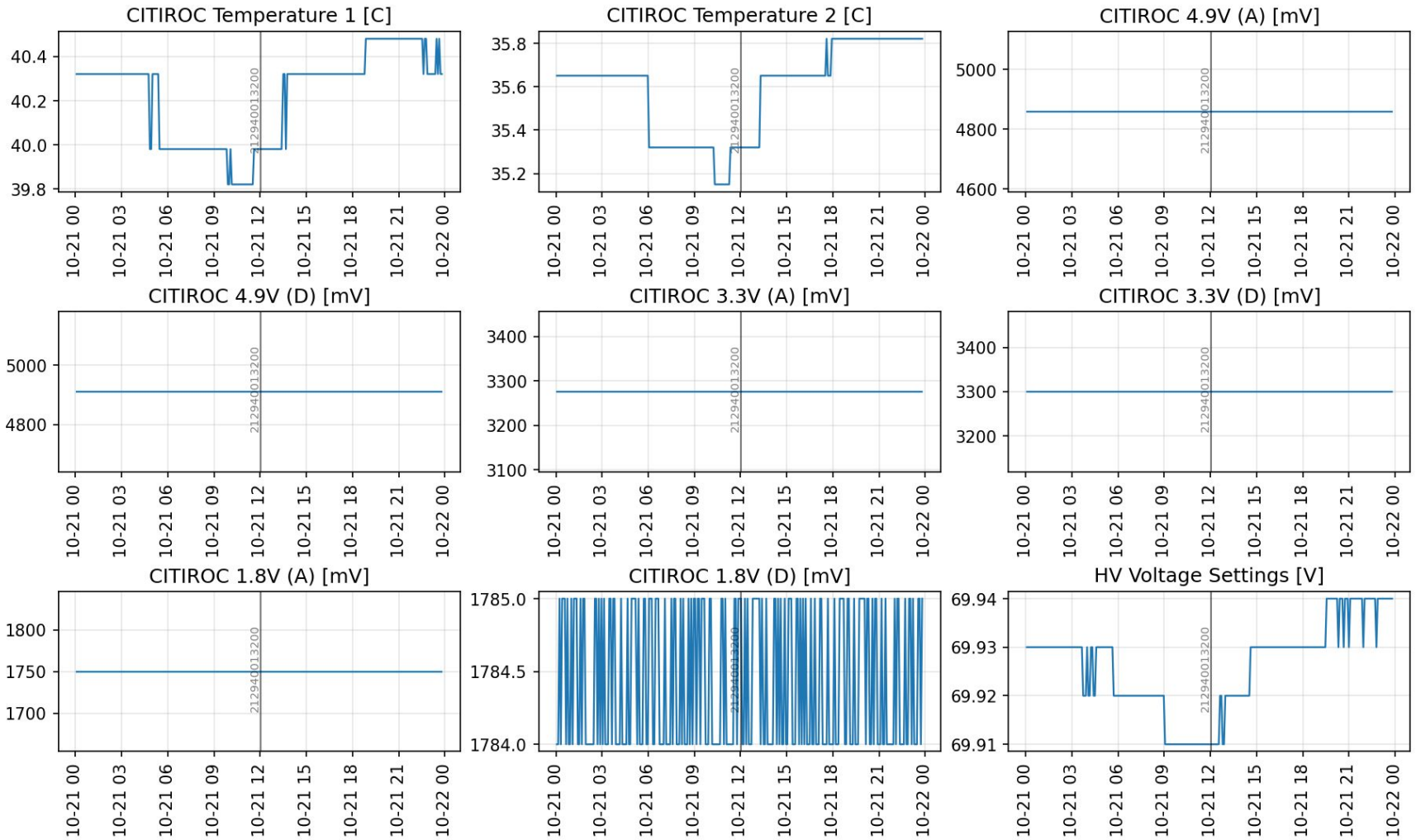
21/10/21





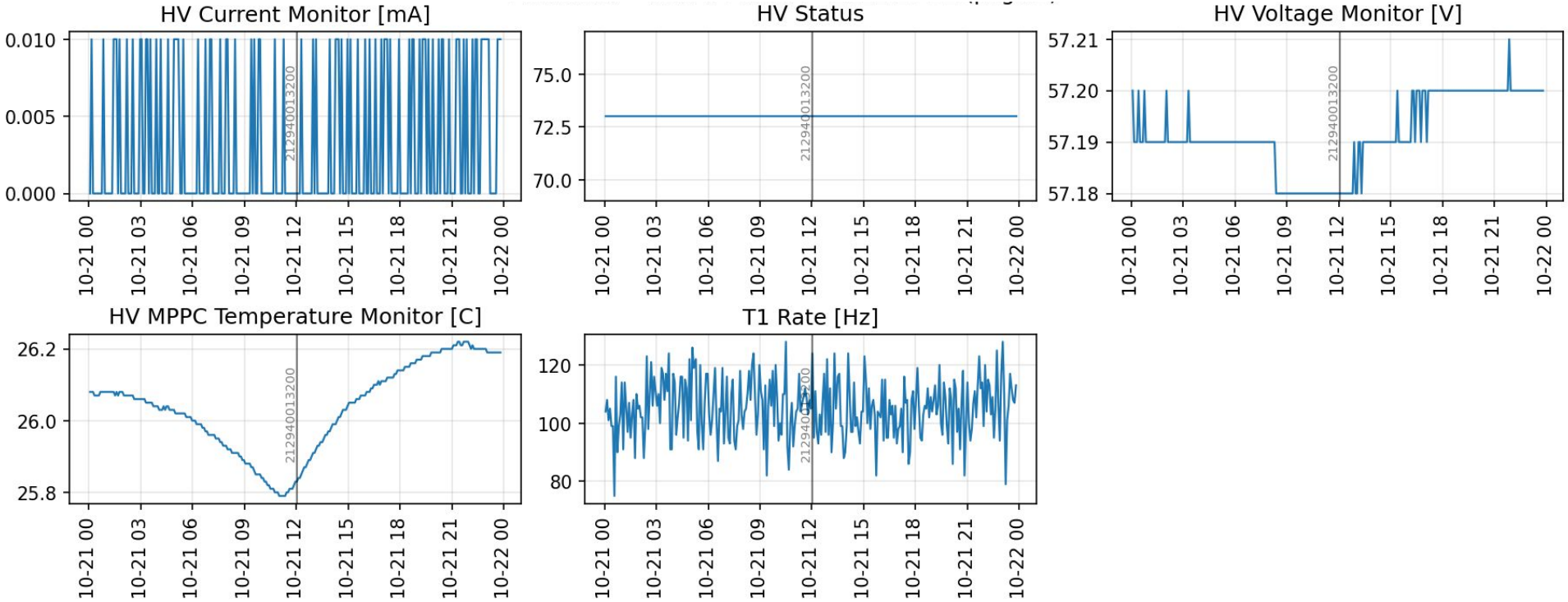
MonitSlow

2021-10-21
1764-m104



MonitSlow

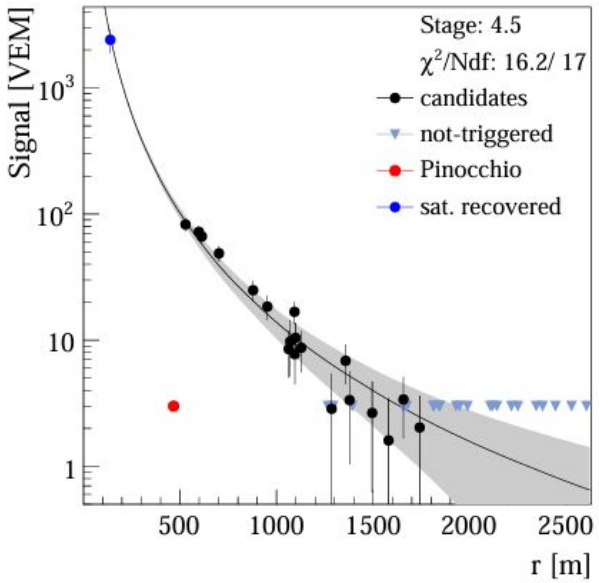
2021-10-21
1764-m104

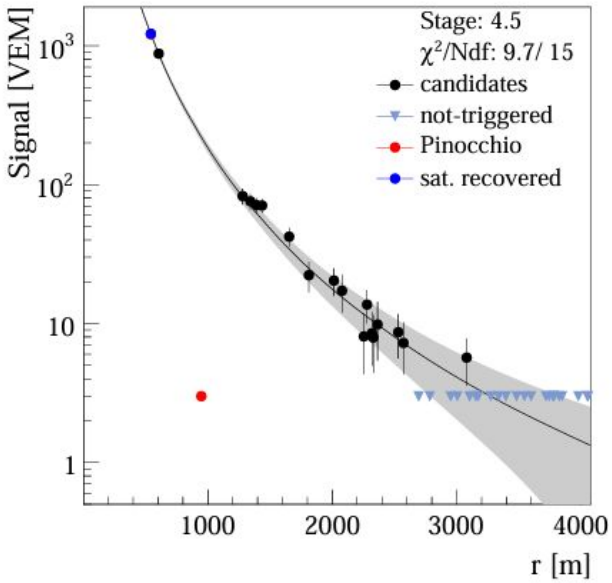


What are Pinocchios?

[GAP 2019-049]

Ioana C. Maris

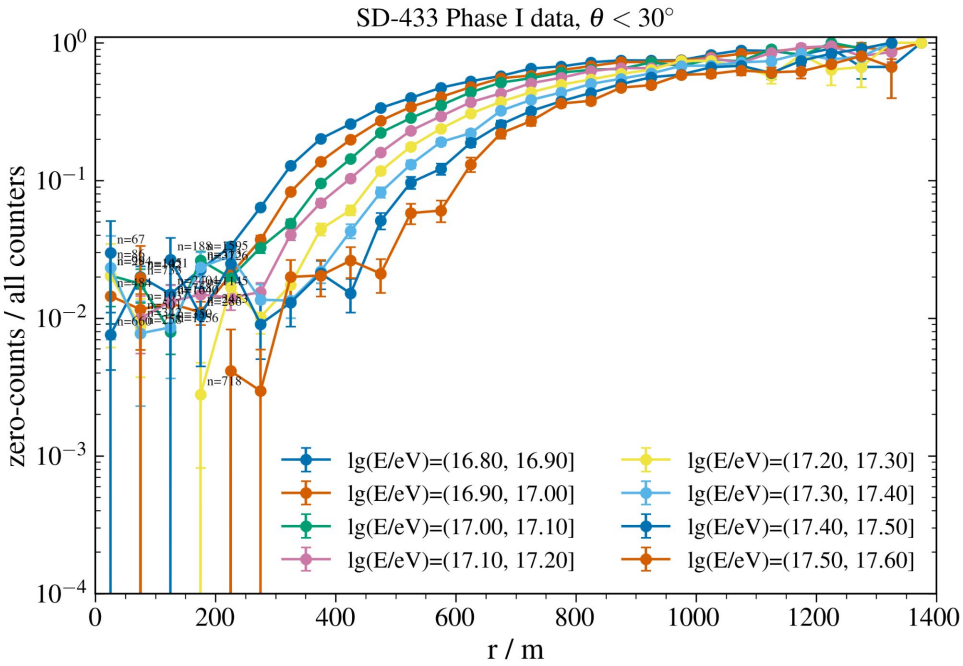


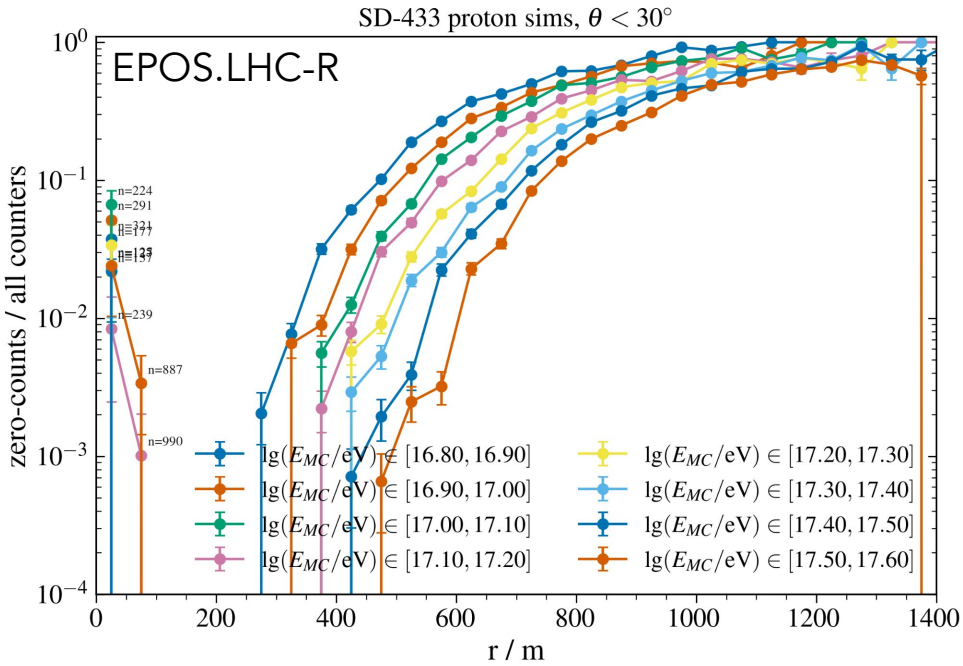


For the SD: Non-triggered stations in SD-750 events denoted as “bad silents”.

Where are the Pinocchios?

No clear lower bound in simulations. Ratio seems to fall faster.

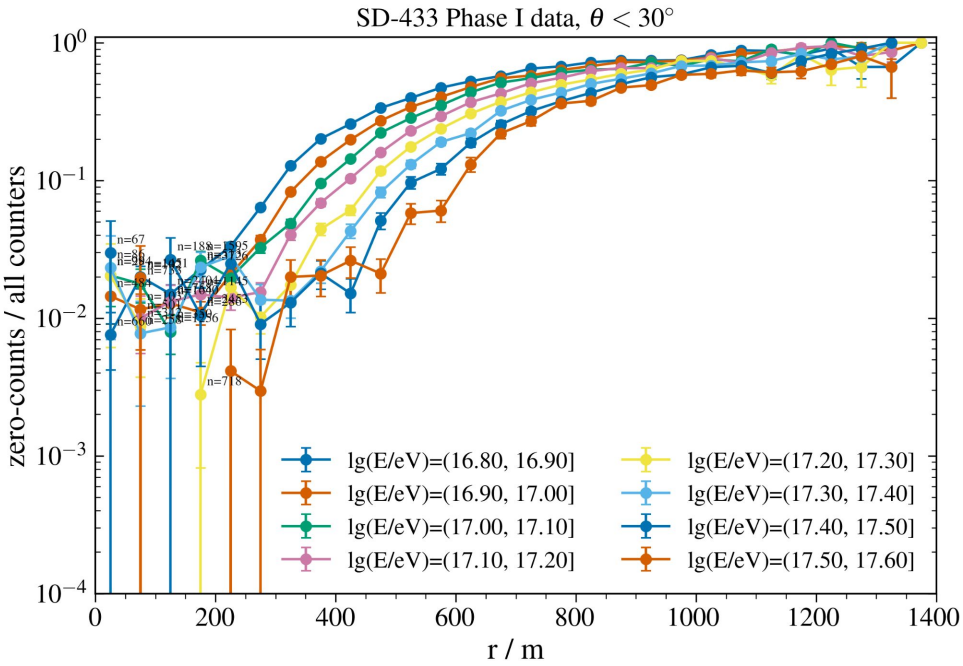


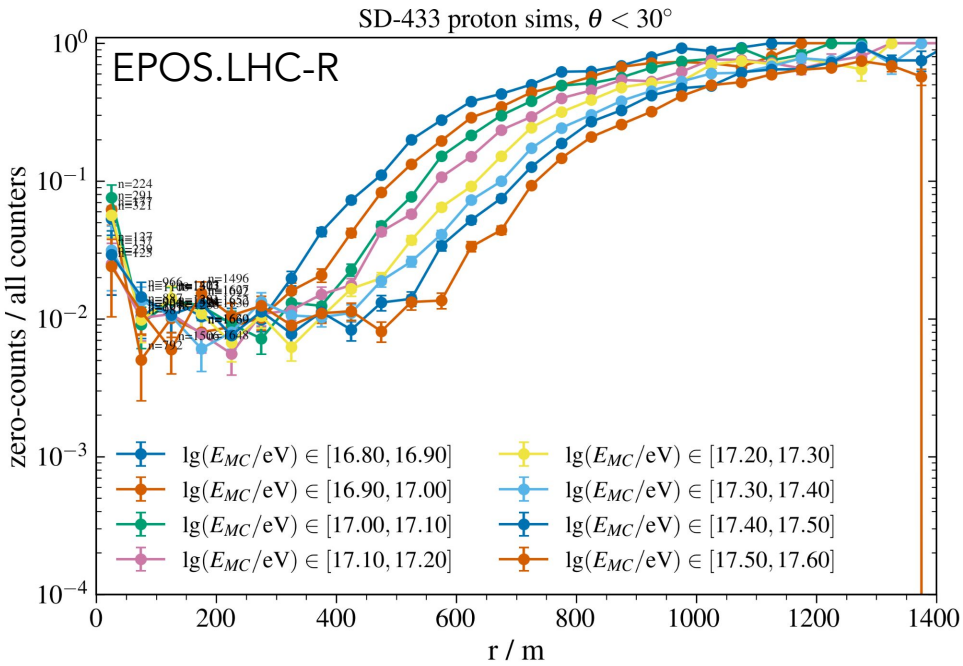


Roughly 1 over 100 counters seem affected.

Where are the Pinocchios?

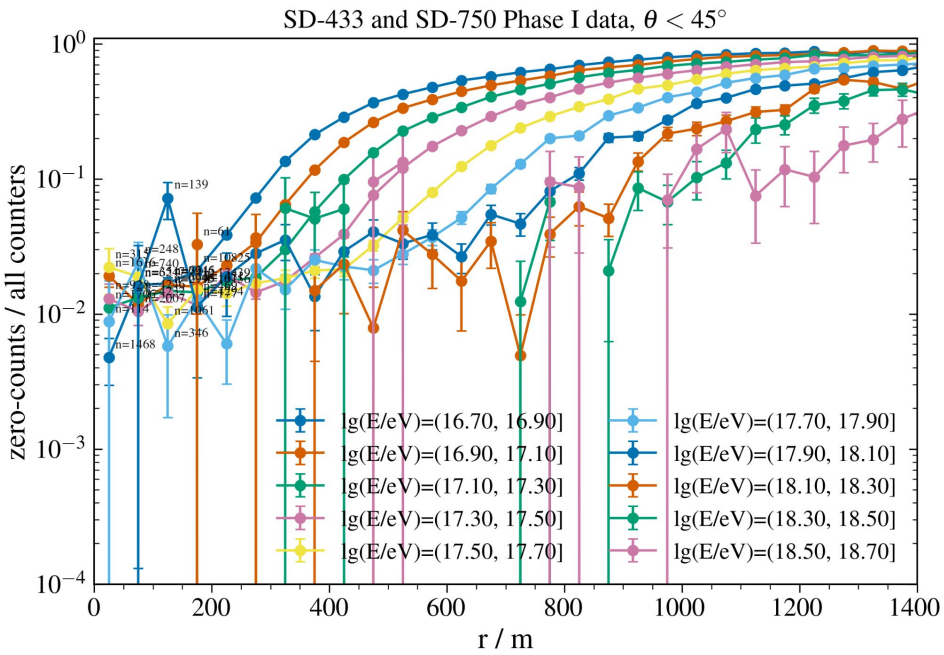
Now we randomly assign zeroes to all counters with a 0.01 rate.





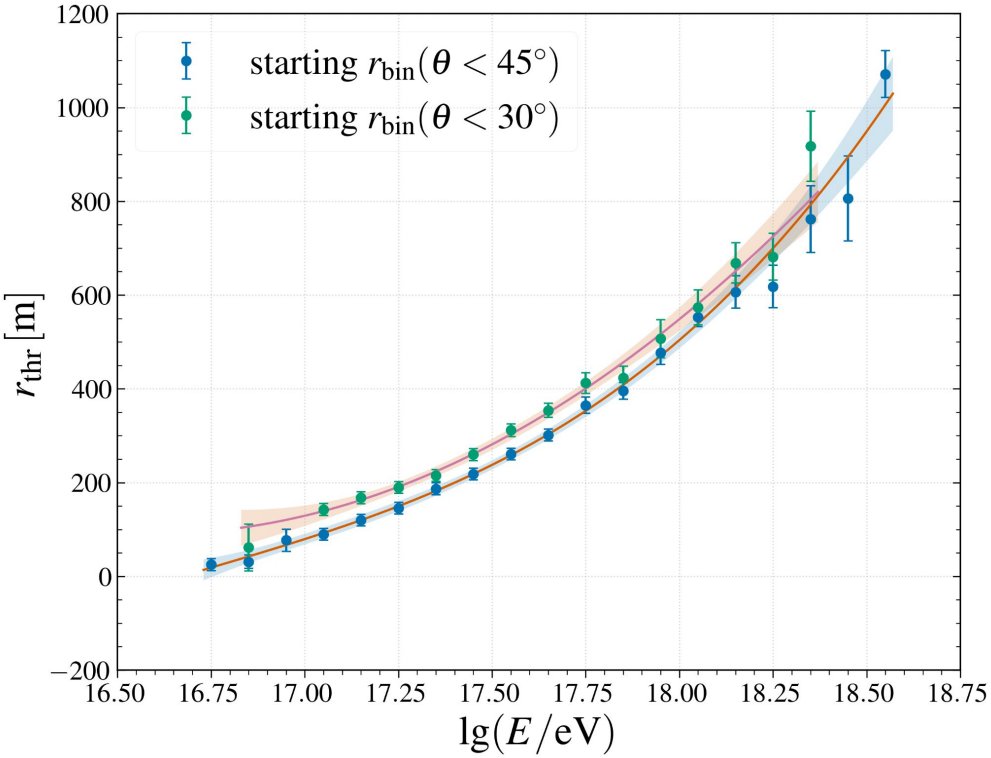
If this is the case, Pinocchios are everywhere and sometimes compatible with “physical” zero-count fluctuations.

Flagging suspicious modules



As a function of energy, at which r-bin can I fit an exponential increase in the zero rate?

For both SD-433 and SD-750 modules.
Rule of thumb, it is not meant to be precise.



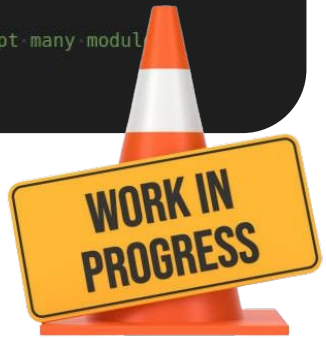
Digging up Pinocchios with the MLDF (preliminary implementation)

Changes in the MdLDFFinder. The preliminary implementation code is in a draft MR.

Fit A → Fit B → Fit C

- Fit A is the original fit.
- Before Fit B we flag suspicious modules
- Fit B is without potential Pinocchios
- We reject modules incompatible with MdLDF
- Fit C is the final one (no Pinocchios left)

```
<zeroRejection>
  <enabled>1</enabled>
  <!-- r_cut [m] = sum_k coeffs[k] * (lgE - polyLogEShift)^k -->
  <polyLogEShift> 17.3 </polyLogEShift>
  <coeffs>164.44912464 331.6148489 170.1803702 78.12098809</coeffs>
  <!-- Tag a module as 'zero-like' if n_mu_hat <= threshold -->
  <moduleZeroLikeThreshold>2.3</moduleZeroLikeThreshold>
  <!-- Per-module one-sided tail compatibility (3 sigma is sim 0.0013) -->
  <pvalueThreshold>0.0013</pvalueThreshold>
  <!-- Max number of modules to reject -->
  <maxRejectCount>4</maxRejectCount>
  <!-- Soft band around the cut (meters) to accept many modul
       The restrictive cut is the p-value-->
  <epsilonNearCut unit="m">50</epsilonNearCut>
</zeroRejection>
```



Currently tuning the code/configuration.

The MdLDF Reconstruction Stage

Inspired by the LDF reconstruction stage from the SD. For the UMD is an integer.

```
// needed for the recStage
enum class AStatus  : int { NotRun=0, Ok=1, InvalidMin=2, InvalidCov=3 };
enum class ZRStatus : int { Off=0, OnNoSuspects=1, SuspectsButFitBNotViable=2, SuspectsFitBAttempted=3, OnButFitAFailed=4 };
enum class BResult  : int { NA=0, SuccessAllCompat=1, SuccessButFitCNotViable=2, SuccessAllIncompat=3, SuccessMixed=4, Failed=5 };
enum class CResult  : int { NA=0, Failed=1, Success=2 };
enum class FinalSrc : int { None=0, A=1, C=2 };
```

Log example of no detection of Pinocchio suspects

[INFO] Modules/MdReconstruction/MdLDFFinderAG/MdLDFFinder.cc:744: Run: Final MdLDF reconstruction stage code = 10011 (0x10011), dec=65553.
Summary: FitA:Ok | ZeroesRejection:OnNoSuspects | FitB:NA | FitC:NA | FinalMdLDFFrom:FitA

Log example of detected and removed Pinocchios

[INFO] Modules/MdReconstruction/MdLDFFinderAG/MdLDFFinder.cc:744: Run: Final MdLDF reconstruction stage code = 22331 (0x22331), dec=140081.
Summary: FitA:Ok | ZeroesRejection:SuspectsFitBAttempted | FitB:SuccessAllSuspectsIncompatible | FitC:Success | FinalMdLDFFrom:FitC

Test productions for SD-750 & SD-433: MdLDF Reconstruction Stage

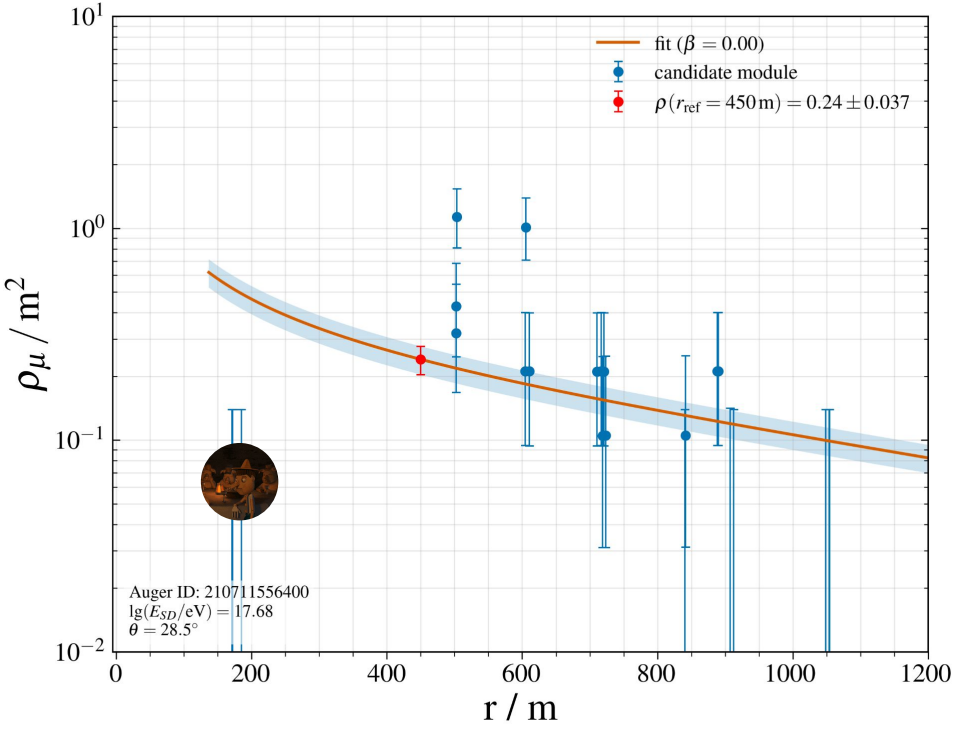
md_LDF_rec_stage	count	hex	percent	summary
65553	350524	0x10011	99.78	FitA:Ok | ZeroesRejection:OnNoSuspects | FitB:NA | FitC:NA | FinalMdLDFFrom:FitA
140081	385	0x22331	0.11	FitA:Ok | ZeroesRejection:SuspectsFitBAttempted | FitB:SuccessAllSuspectsIncompatible | FitC:Success | FinalMdLDFFrom:FitC
65841	216	0x10131	0.06	FitA:Ok | ZeroesRejection:SuspectsFitBAttempted | FitB:SuccessAllSuspectsCompatible | FitC:NA | FinalMdLDFFrom:FitA
0	152	0x0	0.04	FitA:NotRun | ZeroesRejection:Off | FitB:NA | FitC:NA | FinalMdLDFFrom:None
140337	16	0x22431	0.00	FitA:Ok | ZeroesRejection:SuspectsFitBAttempted | FitB:SuccessMixedSuspectsOutcome | FitC:Success | FinalMdLDFFrom:FitC

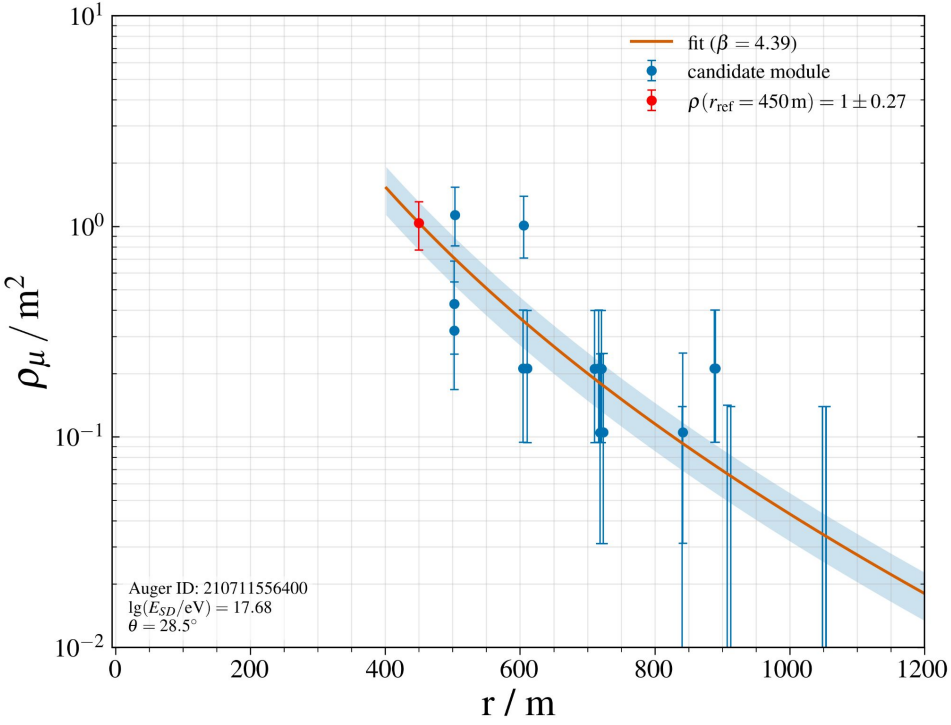
- Events with suspects represent less than 1%

  Does it matter then? It depends…
- MdLDFRecStage ∈ {140337,65841} → review p-value cut and events
- MdLDFRecStage=0 → should not happen, revision needed!
- MdLDFRecStage=140081 → 😀
- MdLDFRecStage=65553 → same as before

Test production - Successful cases

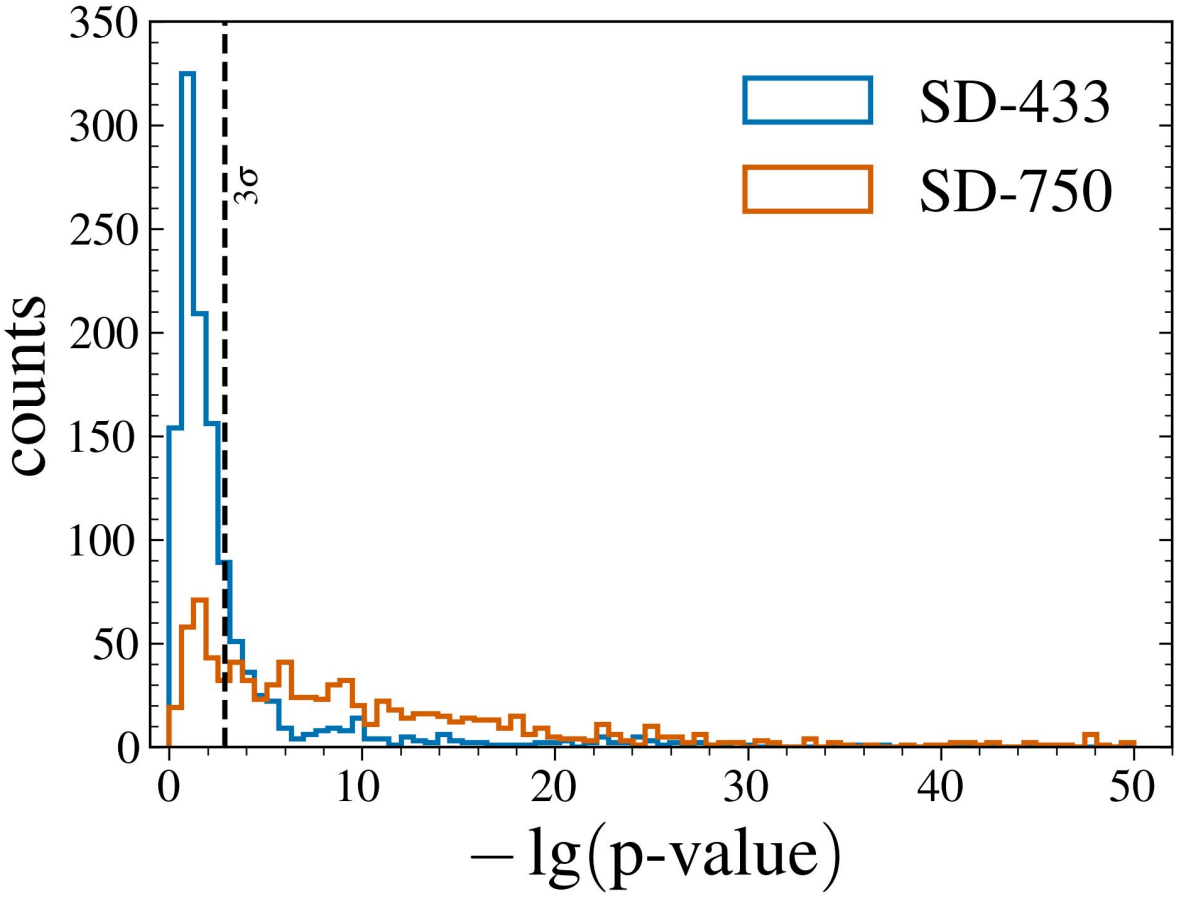
Low-energy example from the SD-750 test production.





It won't make it through strict ADST cuts, but at least we can discard it now.

p-values of potential Pinocchios



Change in rho_{ref}

Not enough statistics to have a clear picture.