ProtoDUNE-VD PDS Results and Updates

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on behalf of the NP02 PDS team

INFN Milano Bicocca

Meeting Annuale DUNE-Italia
Frascati, Italy
10/11/2025

Overview

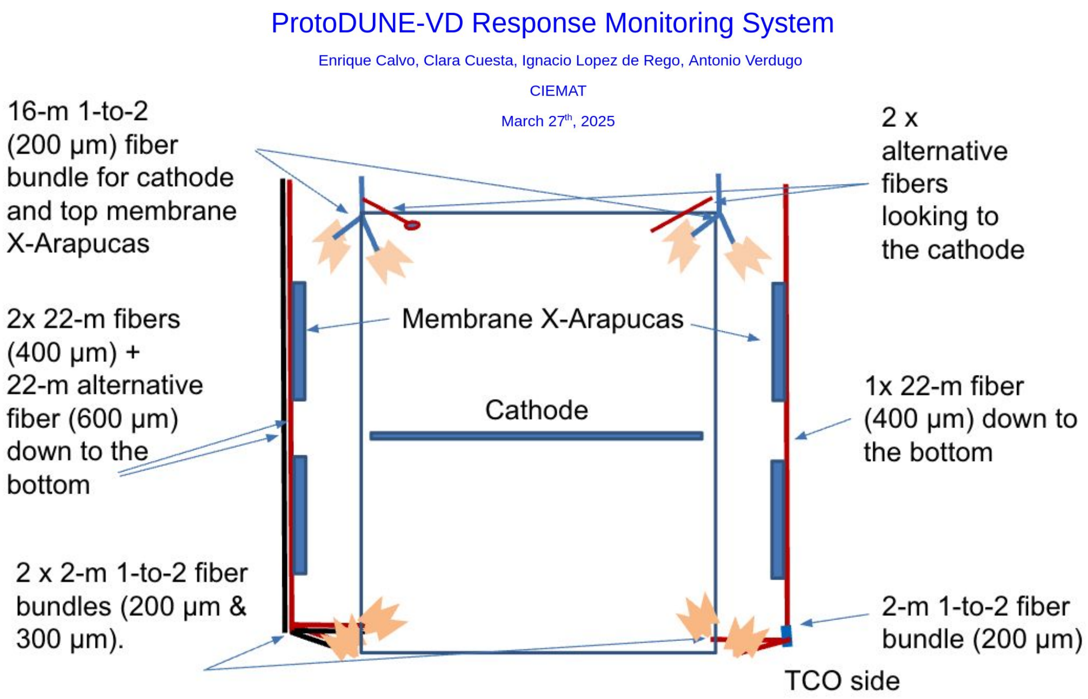
- **PDS Calibration:** definition of the optimal PDS configuration:
  - LED mask and intensity for SPE identification
  - Attenuator
  - Offset
  - Trim
- **NP02 Beam**:
  - Fast analysis developed during acquisition
  - Preliminary results

PDS Calibration

Calibration overview

- In order to calibrate the PDS properly:
  - **Find proper fiber and LED intensity** combination to produce good quality ‘finger plots’ for calibration.
  - **Find breakdown voltage of SiPMs** in the membrane and **set the to proper over-voltage.**
  - **Define DAPHNE attenuation** to establish good SNR (compromised by desired low single photoelectron (PE) amplitude)
  - **Define DAPHNE offset** to maximize dynamic range

Calibration: fibers and LED



- 6 different 'masks' available for calibration
  - During commissioning, only 4
- Scans over intensity and masks were done trying to find appropriate amount of light.
- 3 Masks selected:
  - Top beam – non TCO (Base) for C1-C5
  - Top beam – TCO (Base) for M5-M8
  - Top beam – TCO (Alt.) for M3-M4, C6-C8
- With around 14 runs (~ 50 min) we could calibrate all modules

Calibration masks	Intensities	
Mask 8	[1900, 1750, 1600, 2250, 3250]	Membrane
Mask 16	[1900, 1700, 1600, 1550]	Both
Mask 1	[3100, 3950, 2100, 3500, 2800]	Cathode

Calibration: over-voltage

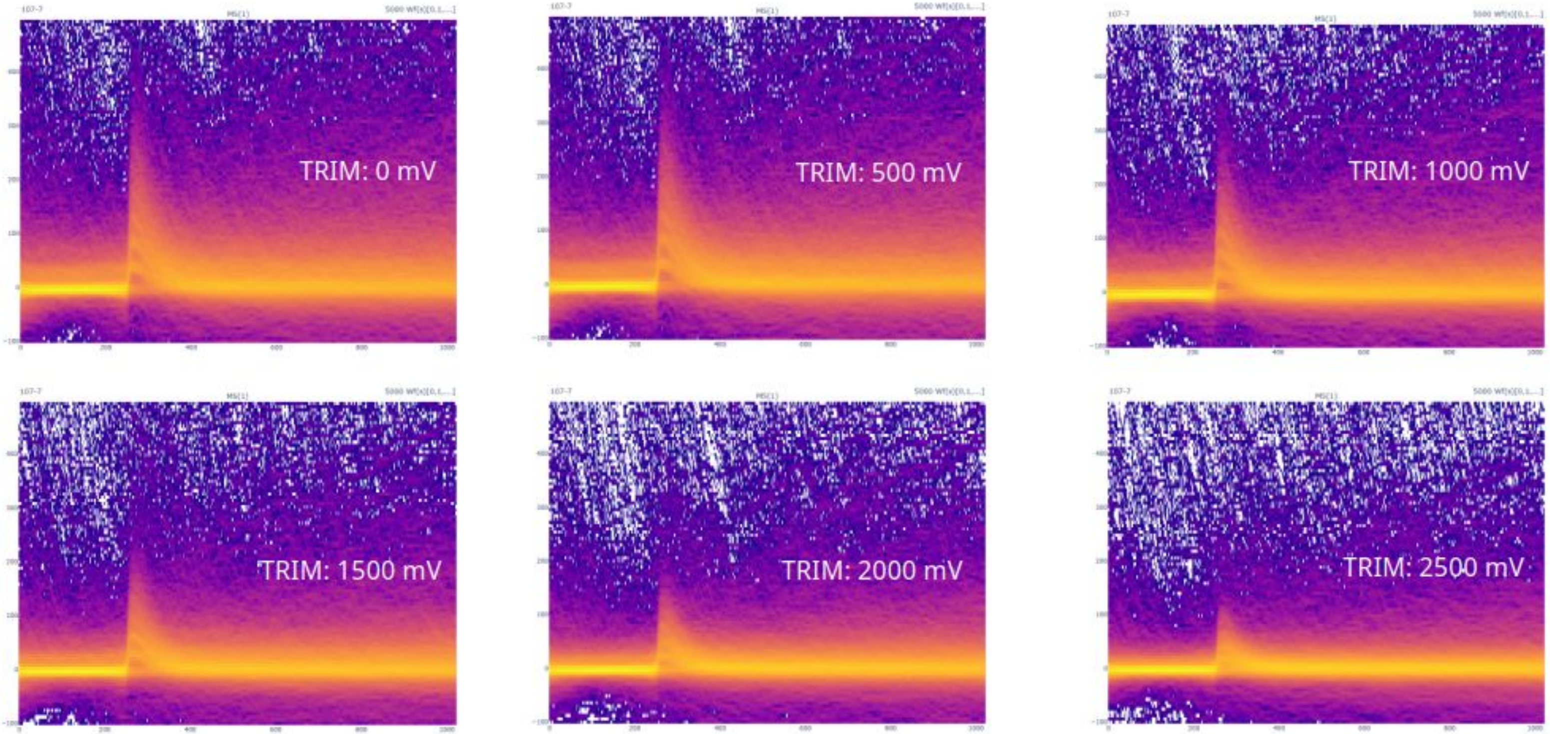
- **Trim scan** can changed the applied voltage over a range of 4 V with 12 bit
- **Goal** of operate membrane modules with specific overvoltage:
  FBK: +4.5 V, HPK +5.0 V
- Several steps:
  - **Attenuator and offset adjustment** to maximize range of trim scan
  - **Multi-gaussian fit** for proper evaluation of ‘gain’
  - **Linear fit**:
    - Retrieve breakdown voltage and uncertainty by confidence level (from Federico Galizzi analysis)
  - **After establishing target trim, necessary to redo attenuator and offset scan**

Why:

- The breakdown voltage information was missing (I-V curve not possible after DAPHNE modifications).
- Moreover, DAPHNE self-measurement of applied voltage can have an offset, so we need to establish a method to set all SiPMs to the same overvoltage.

Calibration: over-voltage

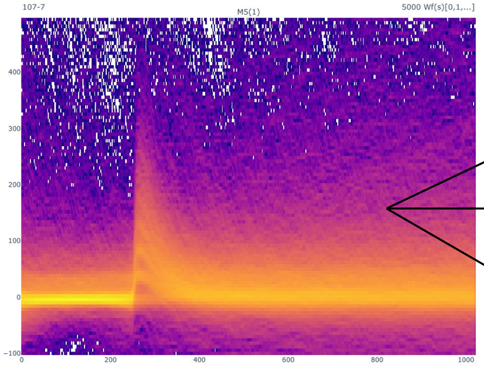
Increasing the TRIM we decrease the voltage applied to the SiPMs with precision of ~1 mV

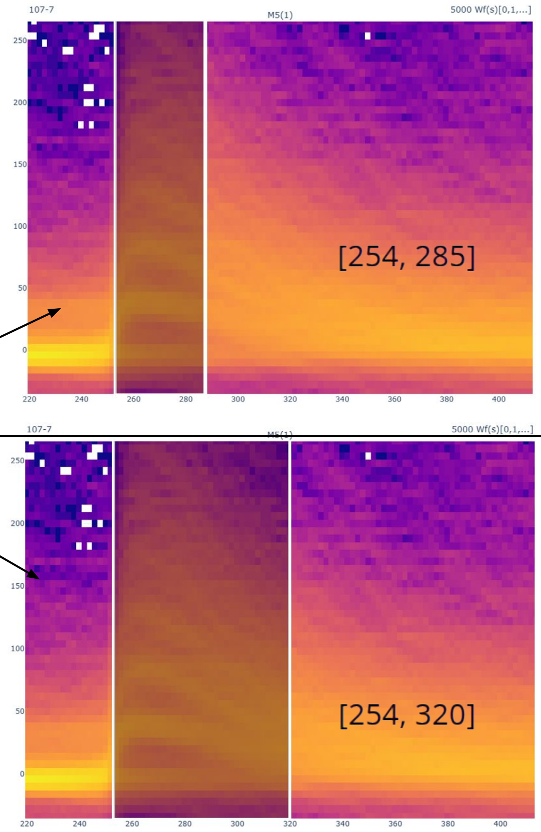


https://indico.fnal.gov/event/71018/contributions/322956/attachments/190987/264059/Trim_Scan.pdf

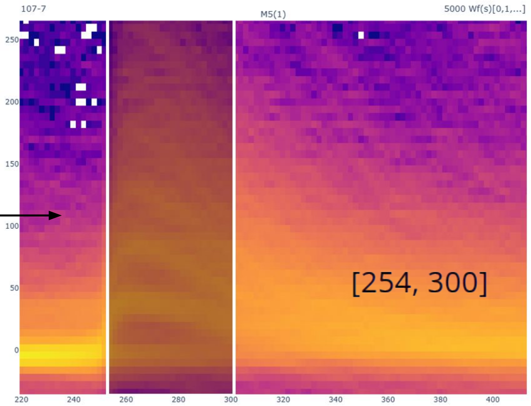
Calibration: over-voltage

We choose 3 different integration windows:





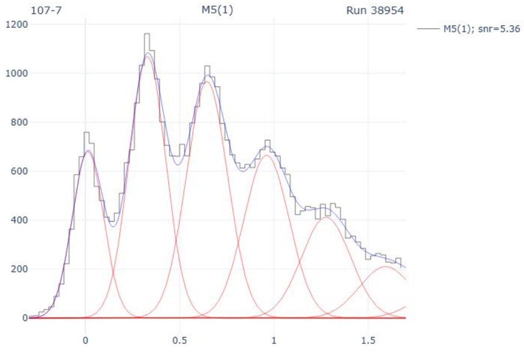
The breakdown voltage does not depend on the integration window

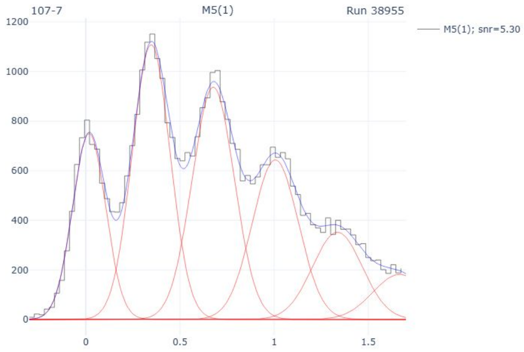


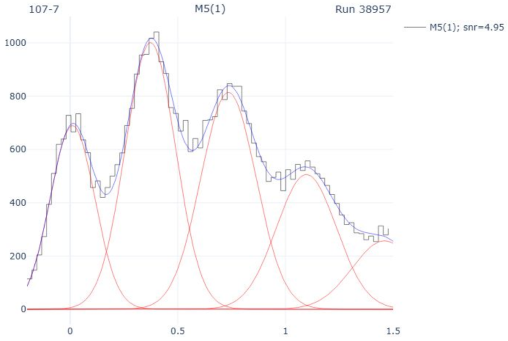
https://indico.fnal.gov/event/71018/contributions/322956/attachments/190987/264059/Trim_Scan.pdf

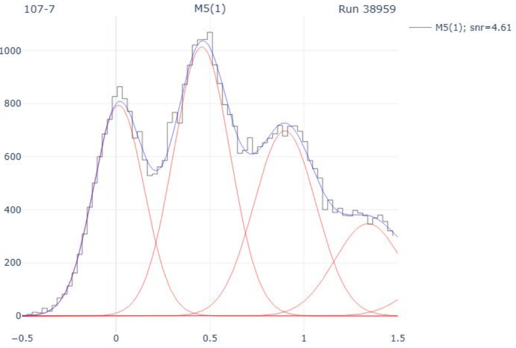
Calibration: over-voltage

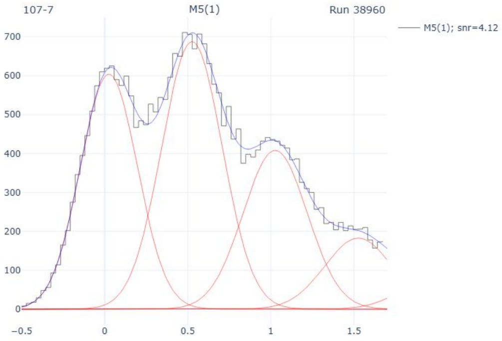
Plot for M5(1) with an integration window: [254, 300] changing trim









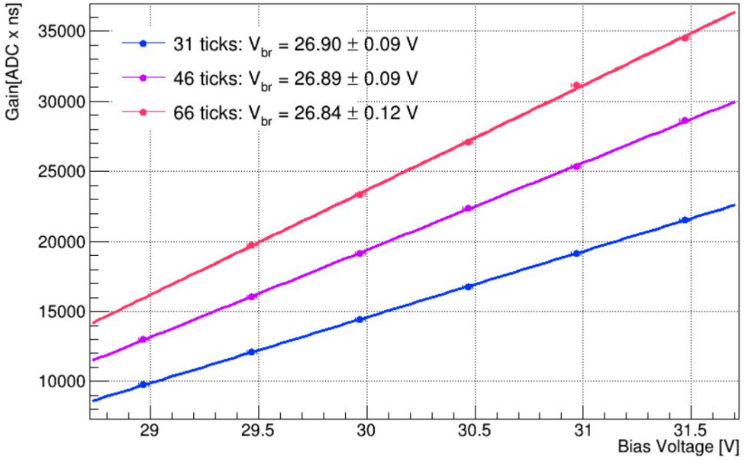


https://indico.fnal.gov/event/71018/contributions/322956/attachments/190987/264059/Trim_Scan.pdf

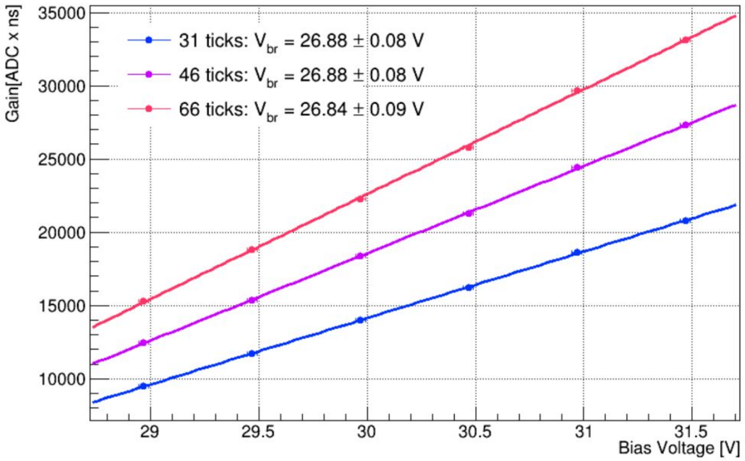
Calibration: over-voltage

- **Trim scan** with the goal of operate membrane modules with specific overvoltage: FBK: +4.5 V, HPK +5.0 V

M5 – channel 1



M5 – channel 2



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Calibration: PDS Calibration

- The calibration was "validated" on-site, values of SNR, gain, offset and others are reported here
- **All codes** and analysis **parameters** are committed in waffles

  Francesca's talk
- The measured values of gain and PE amplitude can be refined, however, they are already available in waffles to be used in analysis

AFTER TRIM SCAN														
Endpoint	**Channel**	**Module**	**AFE**	**Mask**	**LED**	**Attenuator**	**PE**	**RUN**	**SNR**	**Gain**	**Bsl std**	**SPE std**	**SPE integ**	**Offset**
107	47	M1 (1)	AFE4	16										2674
	45	M1 (2)												2516
	40	M2 (1)		16										2842
	42	M2 (2)												2760
	46	M3 (1)		16	1600		16	39215	3.66	3147.79	860.69	967.21	3.36	2888
	44	M3 (2)					16	39215	3.63	3278.53	902.04	989.75	3.65	2657
	43	M4 (1)		16	1600		16	39215	2.93	1380.77	470.54	502.81	3.25	2752
	41	M4 (2)					16	39215	3.78	2205.66	582.84	711.01	3.16	3112
	7	M5 (1)	AFE0	8	1900	2450	10	39210	3.41	4364.88	1281.31	1416.65	3.71	1640
	0	M5 (2)			1750		10	39211	5.01	4221.51	841.74	1186.27	2.24	1248
	27	M6 (1)	AFE2	8	1600	2700	10	39212	3.82	3058.11	801.08	1011.57	3.68	3516
	20	M6 (2)					10	39212	4.22	3009.3	712.66	904.18	3.11	3235
	37	M7 (1)	AFE3	8	2550	2650	10	39223	4.38	2634.38	600.46	682.02	2.21	3328
	30	M7 (2)					10	39223	4.60	2557.6	555.25	636.23	2.21	3393
	17	M8 (1)	AFE1	8	3250	2550	10	39213	3.67	3771.75	1028.13	1139.98	2.88	2267
	10	M8 (2)					10	39213	3.83	3723.89	971.99	1121.94	2.83	2275
106	32	C1 (1)	AFE3	1	3100	2150	20	38695	4.67	3482.9	745.67	892.81	2.52	2811
	33	C1 (2)					8		3.78	1893.97	501.06	559.63	2.81	2882
	30	C2 (1)		1	3950		10	38696	4.14	2148.87	519.10	593.77	2.95	2271
	31	C2 (2)					15		4.89	4332.16	885.20	1103.55	2.9	3257
	34	C3 (1)		1	2100		10	38697	3.12	2063.53	661.40	680.12	3.84	2446
	35	C3 (2)					12							2672
	36	C4 (1)		1	3500		12	38699	3.95	2257.92	570.79	672.06	2.98	2816
	37	C4 (2)					12		3.83	2530.51	661.85	749.55	2.89	2519
	0	C5 (1)	AFE0	1	2800	1995	18	38690	5.13	5225.09	1017.39	1353.22	2.62	4327
	2	C5 (2)					20		5.08	5185.5	1020.88	1082.48	2.75	5322
	1	C6 (1)		16	1900		12.5	38712	3.18	2426.86	762.20	1218.78	4.95	1771
	3	C6 (2)			1700		12	38715	4.30	2685.4	624.57	894.86	4.64	1844
	5	C7 (1)		16	1600		20	38716	4.39	3831.38	871.88	1324.10	2.57	1919
	7	C7 (2)					18		4.14	3567.7	863.19	1139.28	2.76	1949
	4	C8 (1)		16	1500		10	38718	3.30	1526.98	462.65	619.26	3.54	2077
	6	C8 (2)					8		2.44	1258.39	515.79	676.90	5.26	1670

Calibration: PDS Calibration

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Francesca's talk

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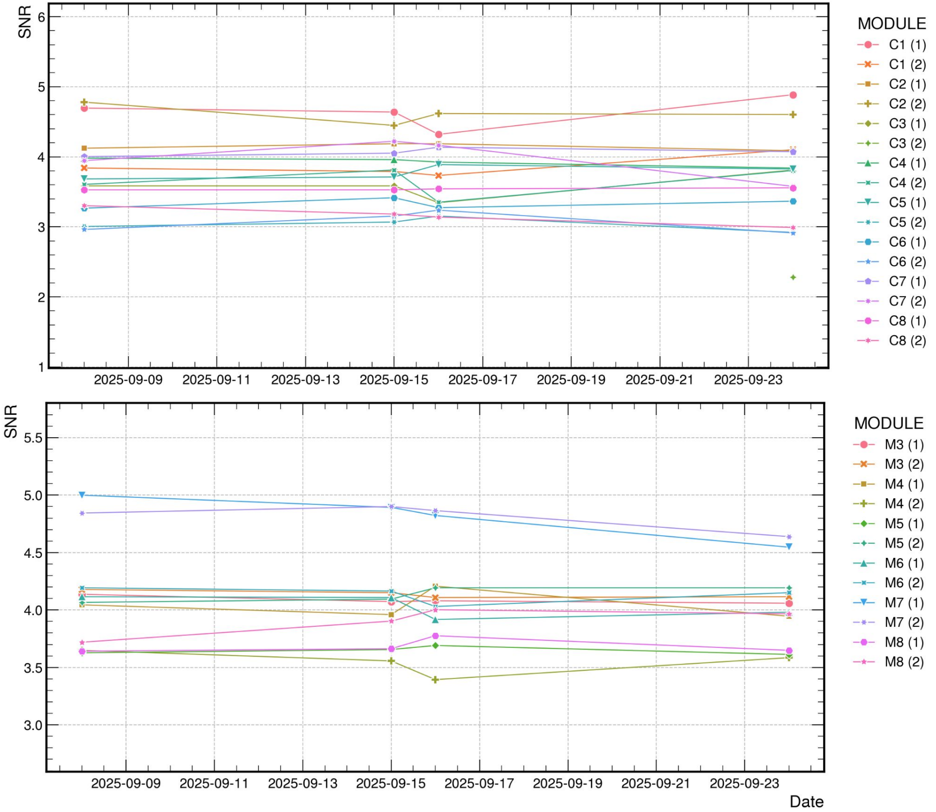


NP02 Beam

Beam: runs acquired

- Operation of beam with different configurations:
  - **PDS only**: DAQ time window of 100 us
  - **PDS + TPC**: DAQ time window of 5 - 7.5 ms

Check Francesca's talk for complete table

PD(only)-DAQ

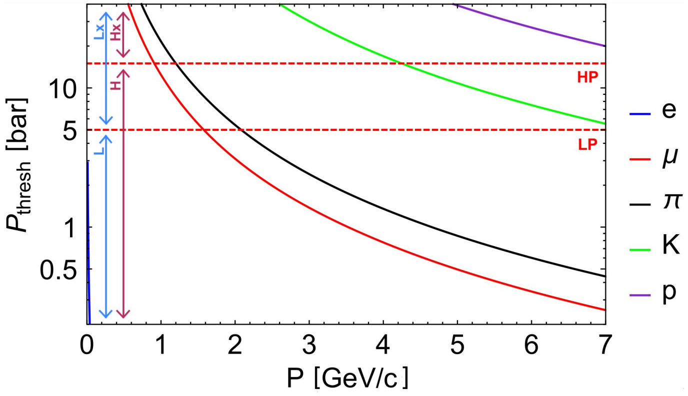
Date	Run n.	Mom GeV/c	Charge	H2-VLE Target	Tot. N.of Beam Triggers
2025-08-25 19:02	39110	0.2	+	Cu	307,530
2025-08-26 21:16	39132	0.3	+	Cu	455,733
2025-08-23 16:16	39046	0.5	+	Cu	13,747
2025-08-27 16:17	39137	0.7	+	Cu	88,128
2025-08-20 20:13	38930	1	+	W	118,530
2025-08-23 16:56	39047	1.5	+	W	406,166
2025-08-23 12:39	39030	2	+	W	46,057
2025-08-24 23:08	39105	2.5	+	W	324,709
2025-08-21 20:25	39007	3	+	W	562,073
2025-08-22 21:22	39029	3	–	W	340,118
2025-08-25 10:16	39106	4	+	Cu	251,800
2025-08-25 15:18	39108	5	+	Cu	278,200
2025-08-22 18:49	39027	6	+	Cu	193,940
2025-08-28 16:43	39183	8	+	W	965,862
					4,352,593

[PD+TPC]-DAQ

Date	Run Type/N.	Mom GeV/c	Charge	H2-VLE Target	Tot. N.of Beam Triggers
	TPC+PD	0.5	+	W	62000
2025-09-09 13:48	39350				
	TPC+PD	1	+	W	
2025-08-31 16:12	39275				
2025-09-02 11:07	39276				
2025-09-04 15:24	39303				
2025-09-05 16:38	39324				1.6 M
	TPC+PD	1.5	+	W	
2025-09-02 15:38	39277				
2025-09-02 17:36	39278				
2025-09-02 18:01	39279				
2025-09-03 21:36	39300				
2025-09-04 16:13	39305	2	+	W	422000
	TPC+PD	3	+	W	
2025-08-30 11:46	39273				
	TPC+PD	4	+	Cu	
2025-09-08 14:16	39344				
	TPC+PD	5	+	Cu	
2025-08-29 12:28	39255				
	TPC+PD	8	+	W	
2025-09-01 17:36	39252				
2025-8-29 8:47	39253				
					>~5M

- Different pressure in Cherenkov detectors allow for tagging of different particles depending on the energy
- Time of Flight information also available offline (LArSoft)

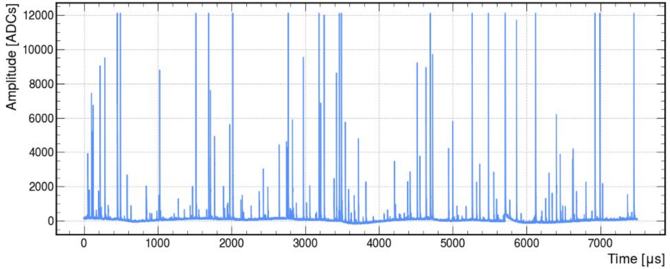
DOI: 10.1103/PhysRevAccelBeams.22.061003

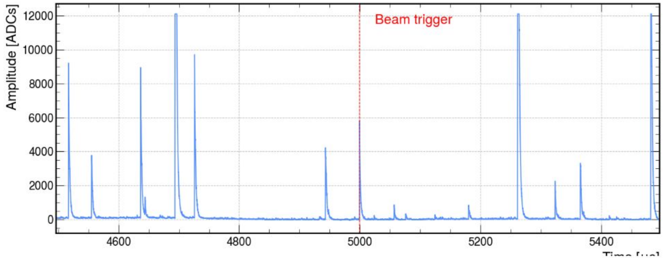


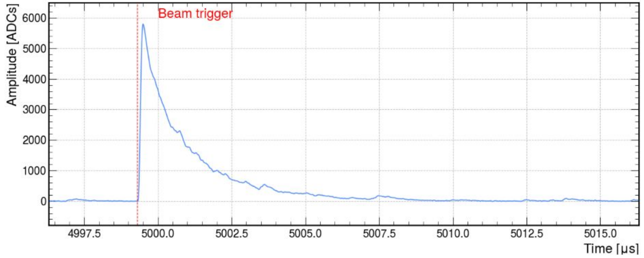
Beam: fast analysis

During operation, we developed fast analysis to (1) give feedback to DAQ, TPC and Beam Instrumentation teams and (2) make a preliminary evaluation of PDS performance:

- Waveforms were selected offline around the beam trigger
- Integration over ~500 ticks (8 us)
- Usage of previous calibration to estimate number of PE
- Evaluate mean PE for each module and for entire detector.





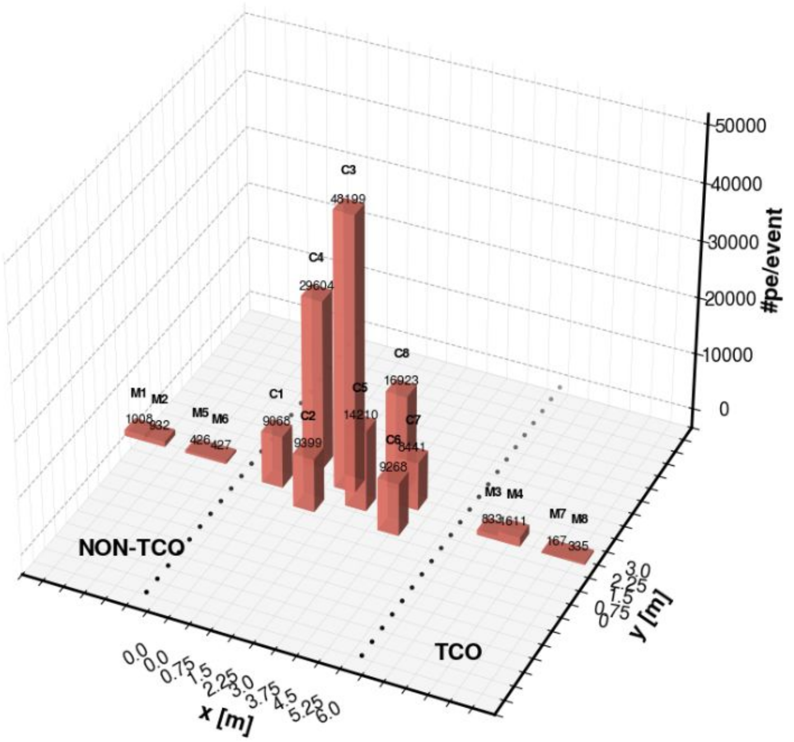


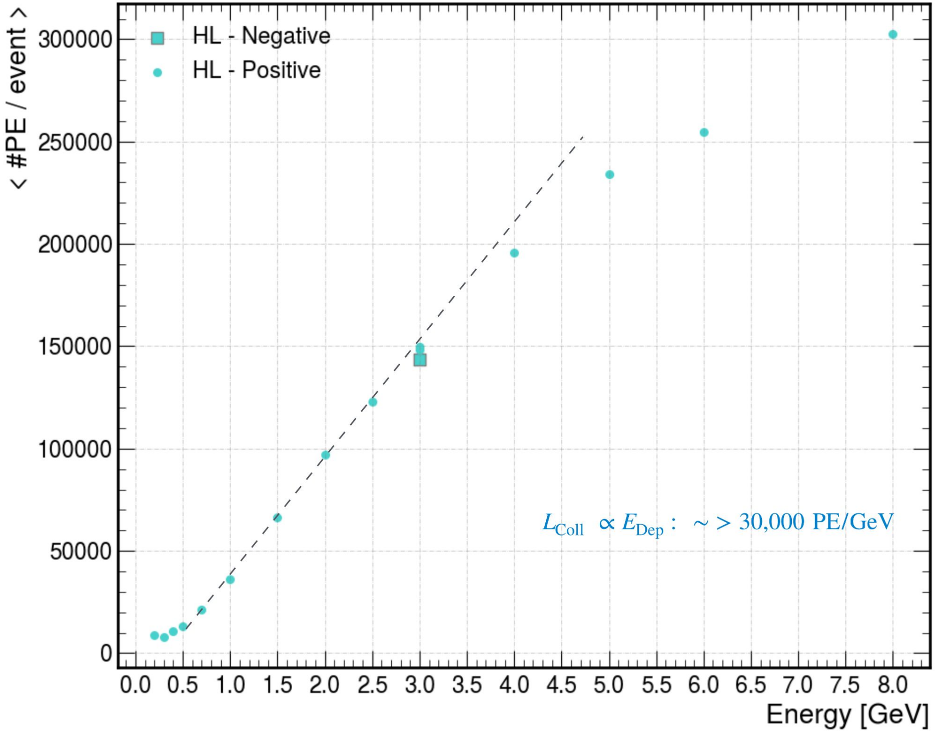
Henrique Souza

Beam runs: fast analysis

- Data visualization and **preliminary** results of PDS shows linear response versus energy

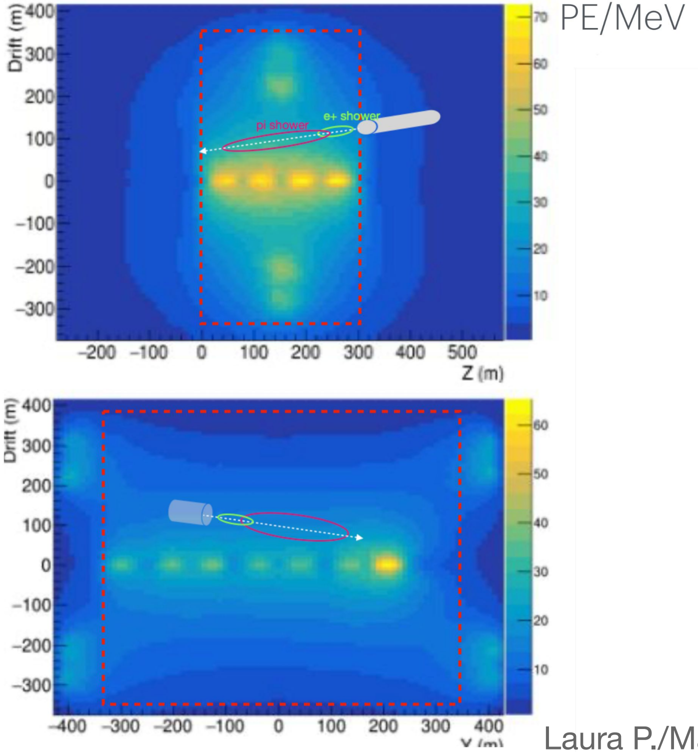
Run 39107, 3 GeV, HLx trigger



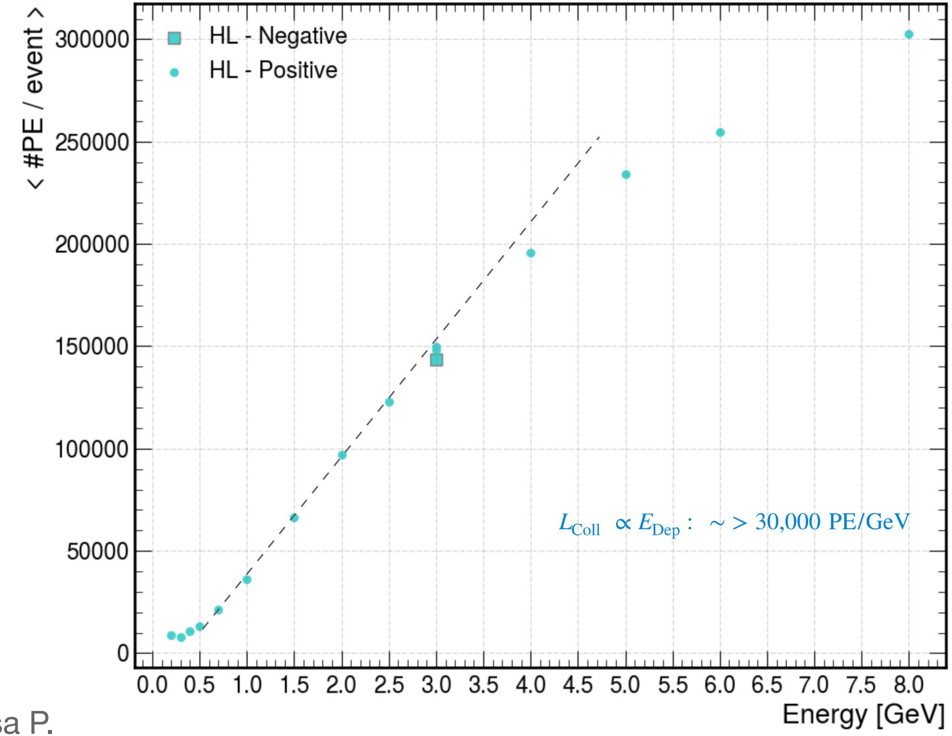


Beam runs: fast analysis

- Data visualization and **preliminary** results of PDS shows linear response versus energy



Laura P./Maressa P.



Conclusions

Stolen from Francesca Alemanno

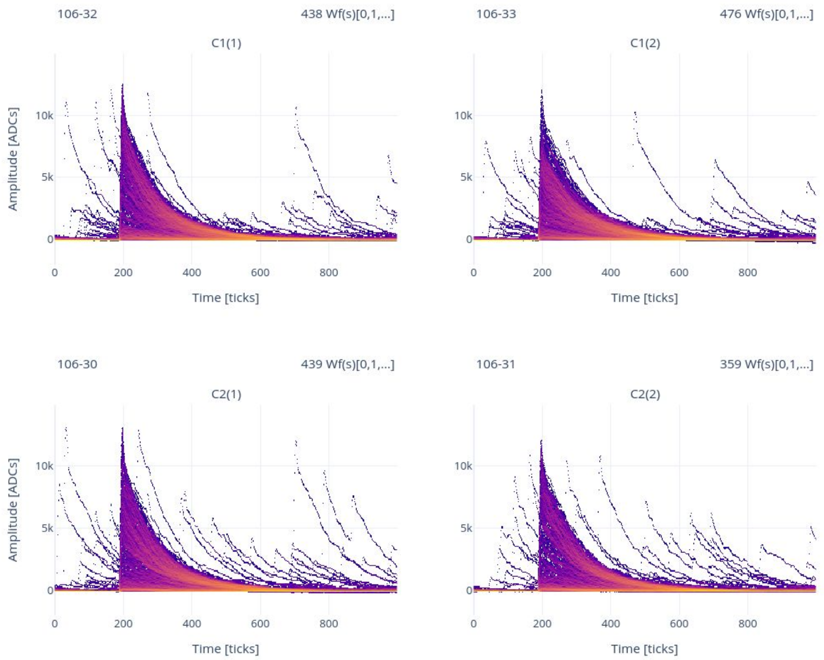
- The protoDUNE-VD operations successfully restarted after the safety pause
- Hardware implementations and software developments
- Huge effort for **PDS calibration**:
  - Definition of optimized configuration for the beam data taking
  - More than 800 runs processed
- PDS **successful data taking over three beam periods**
  - Several PDS-only data collected
  - Full detector (PDS + TPC) integration from the end of August
- First results from preliminary analyses
- More data taking ongoing and to be done in the next months
- Plenty of data to analyze

Thanks to Flavio, Manuel, Valeria, Esteban, Biswaranjan, Jaime, Halit, Gloria, Vlada, Alex, Jacob, Vojtech, Wei, Laura I., Gemma, Sabrina, Nilay, Francesco T., Anselmo, Andrea, Marco R. and the DAQ and NP02 team

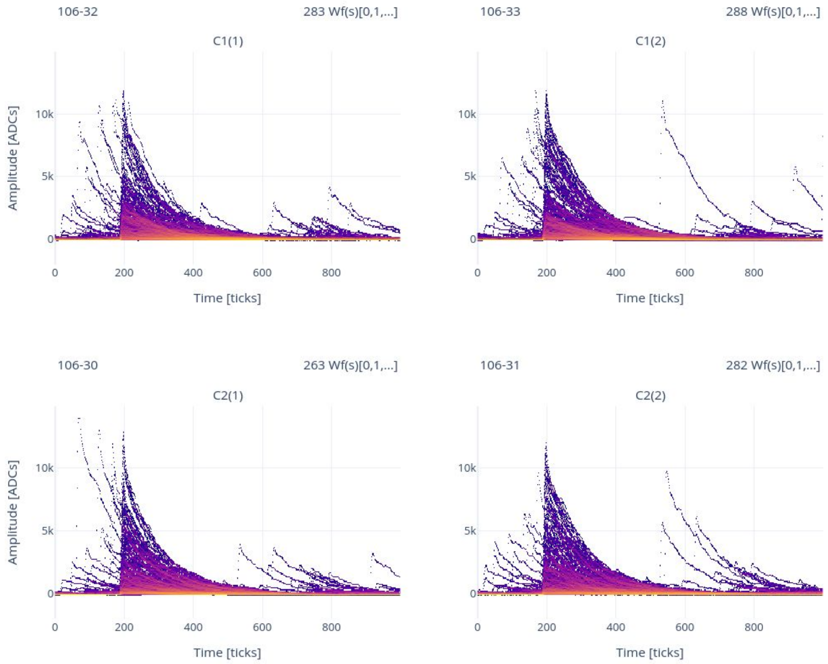
PDS in beam/TPC commissioning

- On-site feedback on beam instrumentation and matching events with TPC

+3 GeV (K, proton)

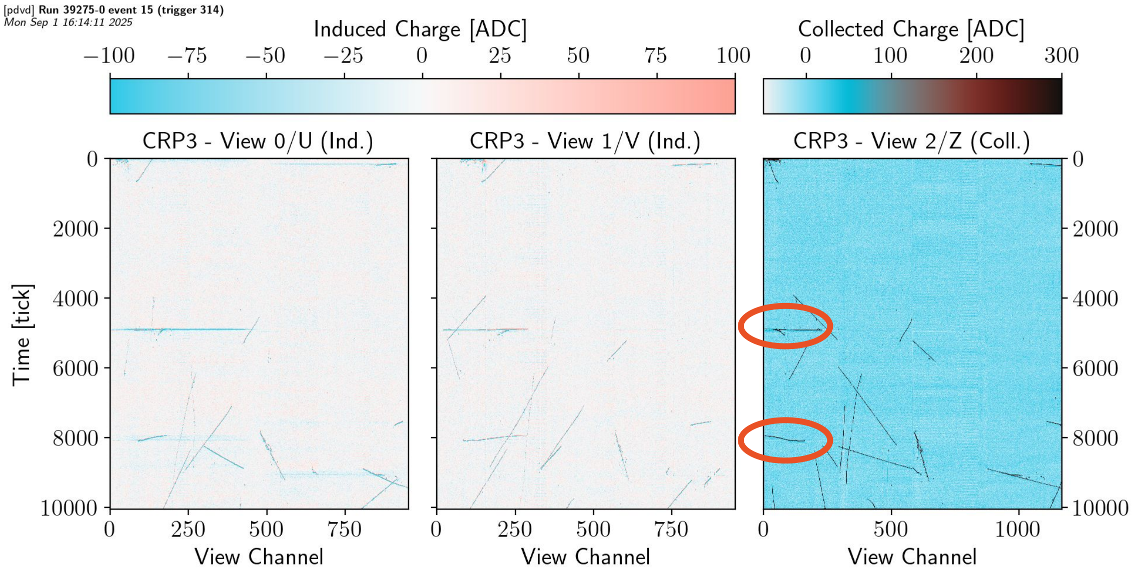


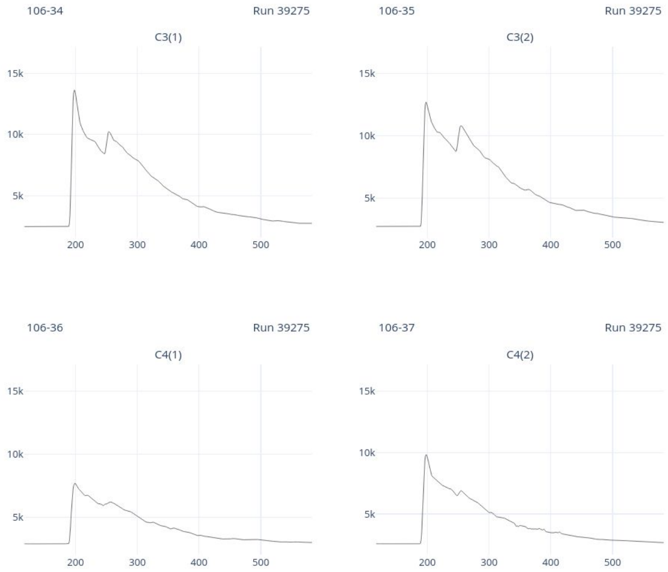
-3 GeV (K)



PDS in beam/TPC commissioning

- On-site feedback on beam instrumentation and matching events with TPC:
  - PDS gave feedback to TPC analyses to search for pion signals @ 1 GeV





Laura Zambelli

Git repo., configurations and more

Git repository to launch runs and establish configurations: https://github.com/DUNE/PDS

Configurations were tagged:

np02-config-beam-v4.0.0	3 hours ago · 92d613b · zip · tar.gz	3rd beam run, after trim setting (membrane at proper OV)
np02-config-beam-v3.0.0	3 weeks ago · 62d1c4e · zip · tar.gz	3rd beam run, first optimization of attenuators and offset
np02-config-beam-v2.0.1	last month · 366d86b · zip · tar.gz	2nd beam run, 2 runs were taken with cathode as self-trigger
np02-config-beam-v2.0.0	on Aug 8 · 6807b62 · zip · tar.gz	2nd beam run, no digital compensators
np02-config-beam-v1.0.0	on Aug 5 · e77119f · zip · tar.gz	1st beam run, with digital compensators on

Git repo., configurations and more

Git repository to launch runs and establish configurations: https://github.com/DUNE/PDS

New implementations allow for:

- LED intensity and mask scans
- Attenuator scans
- Offset scans
- Trim scans
- Threshold scans
- Daily calibration runs
- Cosmic
- Noise

```
─ Options ─────────────────────────────────────────────
* --mode  -m      [cosmics|noise|ledrun|calibrun]
* --conf  -c      PATH
  --help
```

```
─ Commands ────────────────────────────────────────────
run           Launch a PDS data-acquisition run.
thr-scan      Iterate over correlation_threshold values defined in *conf* and take one run per setting.
att-scan      Iterate over attenuators values defined in *conf* and take one run per setting.
offset-scan   Iterate over offset values defined in *conf* and take one run per setting.
trim-scan     Iterate over offset values defined in *conf* and take one run per setting.
seed          Generate configuration files from details.
set           Apply configuration settings to hardware.
```

Git repo., configurations and more

More than 800 runs processed (cathode and membrane)
Location: */eos/experiment/neutplatform/protodune/experiments/ProtoDUNE-VD/commissioning/*

```
commissioning/
├── plots
│   ├── run036995_membrane
│   │   ├── nTCO.html
│   │   └── TCO.html
│   └── run037022_cathode
│       ├── nTCO.html
│       └── TCO.html
├── processed
│   ├── run036995_cathode
│   ├── run036995_membrane
│   │   └── processed_merged_run036995_structured_membrane.hdf5
│   ├── run037022_cathode
│   │   └── processed_merged_run037022_structured_cathode.hdf5
│   └── run037022_membrane
├── raw
│   ├── run036995
│   │   └── np02vd_raw_run036995_0000_df-s04-d0_dw_0_20250702T082435.hdf5
│   └── run037022
│       ├── np02vd_raw_run037022_0000_df-s04-d0_dw_0_20250703T125259.hdf5.copied
│       ├── np02vd_raw_run037022_0001_df-s04-d0_dw_0_20250703T125436.hdf5.copied
│       ├── np02vd_raw_run037022_0002_df-s04-d0_dw_0_20250703T125513.hdf5.copied
│       ├── np02vd_raw_run037022_0003_df-s04-d0_dw_0_20250703T125552.hdf5.copied
│       └── np02vd_raw_run037022_0004_df-s04-d0_dw_0_20250703T125631.hdf5.copied
└── raw_lists
    ├── 036995.txt
    └── 037022.txt
```

We are also able to process data for PMTs

If a run is not processed, or one needs more files processed, please ask

By definition:

$$G = aV_0 + b$$

and for G=0 $V_b = -\frac{b}{a}$

If we now consider a different integration window we expect a different value for the gain, G’, so that

$$G' = a'V_0 + b'$$

and $V_b = -\frac{b'}{a'} = -\frac{b}{a}$

Now $a' = b'\frac{a}{b}$

and $G' = b'\frac{a}{b}V_0 + b'$

$$G' = \frac{b'}{b}(aV_0 + b)$$

$$\frac{G'}{G} = \frac{b'}{b}$$

The bias voltage is evaluated as

AFE *n*: Bias = DAC x (*a* +/- err_a) [mV/DAC] + (*b* +/- err_b) [mV] - trim

And the target trim as $T = V_0 - V_{target}$

where V_0 is the bias voltage at trim = 0 and V_{target} the bias at the correct OV.

Since both V_0 and V_{target} depend on the coefficient *a* and *b* even if the DAC–Bias conversion is not correct the target trim value does not change.