

NUTRIG First Level Trigger

Pablo Correa

GRAND Collaboration Meeting | 4 June 2025





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Minimum data bandwidth

The NUTRIG Project

Maximum signal selection efficiency

NUTRIG: Develop scalable radio trigger

GRAND requires autonomous radio trigger

Trigger must be scalable to GRAND10k arrays

First level trigger (FLT): this talk

Maximum purity

Minimum cost

Minimum SNR threshold

- Second level trigger (SLT): <u>Jelena's talk</u>
- Air-shower emission model: Lukas's talk @ ARENA





Trigger overview: **Olivier's talk**



GRAND Trigger Scheme





FLT-1 Database: Background

- Take GP80 data (see log)
- CD runs complemented with MD run for low SNR
- Apply offline lowpass FIR filter at 115 MHz
- See backup & source code
- Apply offline FLT-0 with relaxed T1/T2
- Trigger on X or Y (source code)

| FLT-0 parameter | Relaxed (FLT-1 database) | Optimal (<u>Marion</u> & <u>SLT</u>) | | | | |
|--------------------------|-----------------------------|---|--|--|--|--|
| T_1 [ADC] | 45 | 55 | | | | |
| T_2 [ADC] | 35 | 40 | | | | |
| T _{quiet} [ns] | 500 | 500 | | | | |
| T _{period} [ns] | 1000 | 500 | | | | |
| T _{sepmax} [ns] | 200 | 50 | | | | |
| NC _{min} | 2 | 2 | | | | |
| NC _{max} | 10 | 7 | | | | |





| Run | Trigger Mode | Start Date (UTC) | Duration (HH:MM:SS) | | | | |
|-------|-----------------|---------------------|------------------------|--|--|--|--|
| 145 | MD | 2025-02-04 | 02:57:32 | | | | |
| 10083 | CD | 2025-04-26 | 07:46:17 | | | | |
| 10085 | CD | 2025-04-30 | 14:58:37 | | | | |
| 10086 | CD | 2025-05-07 | 06:44:42 | | | | |



FLT-1 Database: Signal

- Take DC2.1rc2 simulations
 - Added noise (AN) from GP80 run 145
 - See /sps/grand/pcorrea/dc2/noise/gp80/README.md
- Apply offline lowpass FIR filter at 115 MH
- Apply offline FLT-0 with relaxed T1/T2
 Trigger on X or Y

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FLT-1 Database: Final Step





- Make a uniform selection in SNR
 - For a one-to-one comparison per SNR bin
 - For now target 1,000 traces per bin
- Lacking statistics for signal
 Need full set of Dc2.1rc2 simulations!
- More details about NUTRIG database:

/sps/grand/pcorrea/nutrig/database/v2/README.md

Olivier wants to call this the PECC database...





Template Library





- Take DC2.1rc2 simulations
 - No jitter/noise (NJ)
 - Select traces with max > 100 ADC
 - Apply offline lowpass FIR filter at 115 MHz
- ► Construct 5 uniform bins in $\omega/\omega_c \in [0,2]$
- Find most representative template per bin
 - Template that yields maximum average cross-correlation with other templates in bin
- Shape dominated by RF response
- Expected for air-shower pulses of ~10 ns
- ► 5 templates are very similar
- Keep 5 templates since no impact online



NEV

Template FLT-1 Method

Step 1: Compute cross correlations

- For input trace V_i at polarization i with each template T_{ij} at polarization i
- For τ in 20 ns window around FLT-0 pulse time

 $\rho_{ij}(\tau) = \int T_{ij}(t) \, V_i(t+\tau) \, \mathrm{d}t$

Step 2: Find best-fit time

 $\hat{\tau}_{ij} = \operatorname*{argmax}_{\tau} |\rho_{ij}(\tau)|$

Step 3: Find correlation of **best-fit template**

$$\rho_i = \max_j |\rho_{ij} (\tau = \hat{\tau}_{ij})|$$

Step 4: Combine polarizations to compute test statistic

 $TS \equiv \rho \equiv \max_{i} \rho_i$







Offline "Results"





- NUTRIG FLT-1 UNIFORM, POL = XY, MODE = ORSNR 3.0-4.0: background SNR 3.0-4.0: signal 12.5 SNR 4.0-5.0: background SNR 4.0-5.0: signal SNR 5.0-6.0: background 10.0 SNR 5.0-6.0: signal SNR 6.0-7.0: background SNR 6.0-7.0: signal PDF 7.5 SNR 7.0-8.0: background SNR 7.0-8.0: signal 5.0 2.5 0.0 0.2 0.4 0.6 0.8 0.0 1.0 ρ
- Input: FLT-1 database uniform in SNR
- FLT-1 logic: X or Y
- Lack of statistics for signal!
- Crude indication of separation power

Offline "Results"

- The money plot we're after!
 - We improved our ARENA results!
 - Need full DC2.1rc2 simulations to show updates at ICRC!



GRND



Case Study: Mine Transformer





- Mine pulses selected by Nathan
- GP80_20250309_235256_RUN10070_CD_20dB_23DUs_ GP43-ChY-X2X-Y2Y-CD-10000-22.root
- Offline FLT-0 on mine pulses
- No FIR filter
- T1/T2 = 80/55 ADC, NC in [2,15]
- Selects 1168/1368 pulses
- No FIR filter for simulations & templates
 T1/T2 = 45/35 ADC, NC in [2,10] as before
- FLT-1 yields good mine discrimination
 Keep information above 115 MHz for FLT?



Case Study: Mine Transformer





Template FLT-1 example of mine event vs air-shower simulation (no FIR filter)



Air shower



Portage to FEB

Template FLT-1 method translated to C++
 See <u>GitHub project</u>

BIG THANKS to

Bohao, Xu Xing, Xishui

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- Successfully integrated in DAQ stream
- Algorithm ported to Petalinux CPU on FEB
- Isolated speed test of template FLT-1
- One test trace evaluated 20,000 times
- For different number of templates
- For 5 templates the FLT-1 can infer >1kHz



NEW



Online Testing: Plan



- FLT-1 results currently stored in binary data file
 - Fields: adc_sampling_frequency OND adc_sampling_resolution
- Controlled testing at LPNHE
- Use AWG to feed FLT-1 database pulses to FEB
- Reproduce offline efficiency plot
- Target: 2nd half of June (to show at ICRC...)
- Testing at GRAND@Nançay
- First test in realistic conditions
- Aim is to ensure stability
- Target: Beginning of July (to show at ICRC...)
- Testing at GRANDProto300
 - The final boss!
 - Target: September



| L1 trigger frequence is 16/s | | | and and a | | in a state of the | | |
|-----------------------------------|---|-----|-----------------------|-----|-------------------|----|----------|
| Template FLT correlation (channel | 1 | - | X) | >>> | rho | ų | 0.664758 |
| Template FLT correlation (channel | 2 | H | Y) | >>> | rho | H | 0.652028 |
| CNN FLT >>> score = 0.169982 | | | | | | | |
| Template FLT correlation (channel | 1 | i i | X) | >>> | rho | | 0.663264 |
| Template FLT correlation (channel | 2 | T | Y) | >>> | rho | - | 0.633543 |
| CNN FLT >>> score = 0.175805 | | | | | | | |
| Template FLT correlation (channel | 1 | п | X) | 555 | rho | 10 | 0.665082 |
| Template FLT correlation (channel | 2 | щ | Y) | >>> | rho | I | 0.633985 |
| CNN FLT >>> score = 0.172288 | | | | | | | |
| Template FLT correlation (channel | 1 | H | X) | >>> | rho | J. | 0.655947 |
| Template FLT correlation (channel | 2 | F | Y) | >>> | rho | = | 0.64601 |
| CNN FLT >>> score = 0.16967 | | | | | | | |
| Template FLT correlation (channel | 1 | Ŀ | X) | >>> | rho | | 0.665581 |
| Template FLT correlation (channel | 2 | H | Y) | >>> | rho | - | 0.637911 |
| CNN FLT >>> score = 0.169329 | | | | | | | |
| Template FLT correlation (channel | 1 | H | X) | >>> | rho | 11 | 0.661174 |
| Template FLT correlation (channel | 2 | п | Y) | >>> | rho | п | 0.631423 |
| CNN FLT >>> score = 0.172199 | | | | | | | |
| | | | and the second second | | | | |

Conclusions and Outlook



Summary

- Updated NUTRIG-FLT database
- Need full set of DC2.r1v2 simulations!
- Offline template-FLT promising
- Preliminary results due to lack of statistics
- Separation bkg-signal per SNR looking good
- Might be very good discriminator for mine
- Online template-FLT implemented
- Ported to DAQ on Petalinux CPU of FEB
- >1kHz throughput possible for 5 templates

Outlook

- Obtain final offline results with all sims!
- Perform online tests of FLT-1 methods
 - Controlled tests at LPNHE test bench
 - Reproduce offline efficiency plot
- Tests in real conditions at GRAND prototypes
- Set the foundations for publication
- ICRC important first step
- Paper draft hopefully this year!



BACKUP



Able to accurately reproduce online lowpass filter GP80.202

Offline Lowpass Filter



GRND

GP80_20250430_171335_RUN10085_CD_20dB-GP65-OC-Y2float-CD-100000-2.root

400

Templates





CNN FLT-1: Summary







CNN FLT-1 Performance @ ARENA2024



FLT-1 ML CPU Performance

- Using old dataset of ICRC2023
 - FLT-0 = double 3σ pre-trigger [Le Coz PoS ICRC2023 224]
- TensorFlow Lite on two Cortex A53 CPUs
- Not integrated in DAQ
- Separation index defined as
 - $I = 1 \sum_{i} B_i S_i$
- Inference rate for $I \approx 0.87$:
- 300 Hz for 3 CNN layers
- 730 Hz for 2 CNN layers

