Digitization of the PANDA EMC

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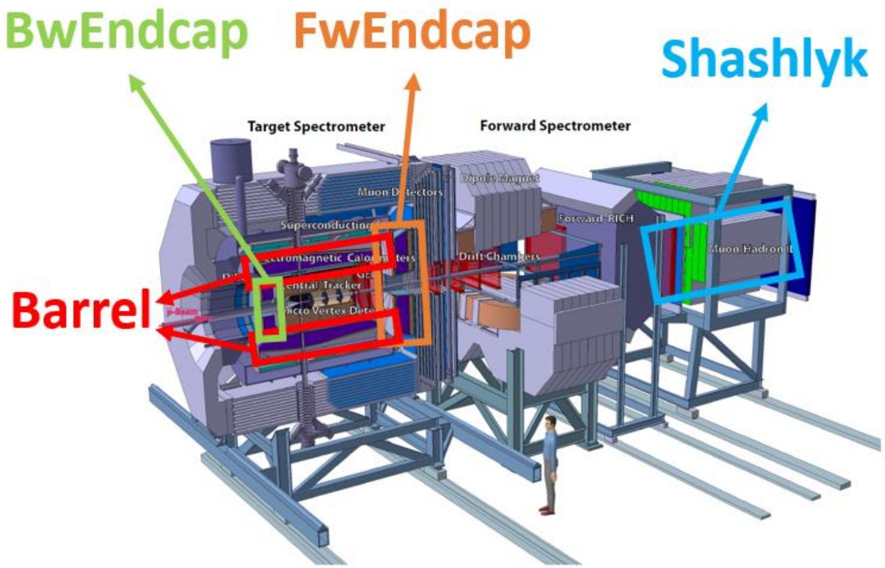
Outline

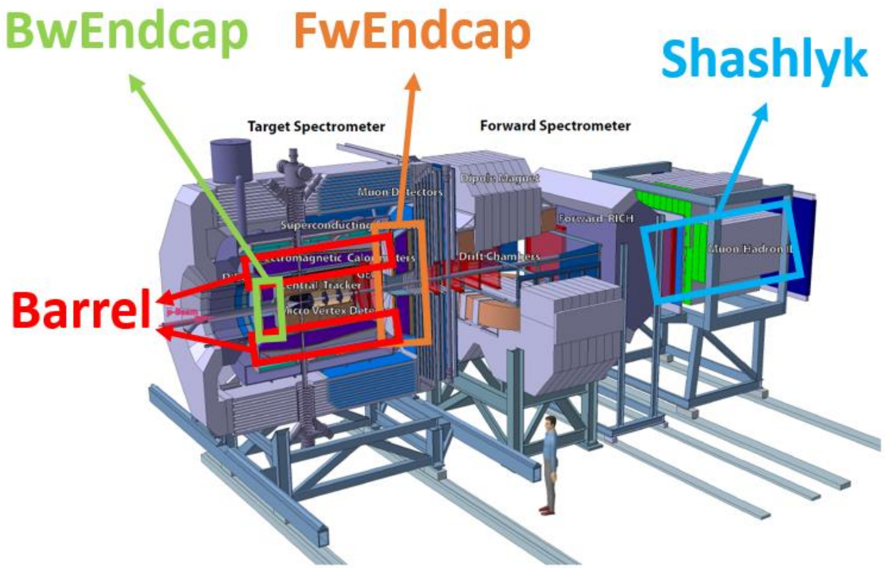
- **Introduction**
- **Digitization**
  - Backward endcap EMC
  - Shashlyk EMC
  - Code design
- **Summary**

The PANDA EMC



- ✓ **Target detector: barrel/bwec/fwec**
  - ✓ **PWO-II crystals**
    - ✓ Fast scintillator material (high count rates)
    - ✓ Short X_0 & $R_{moliere}$ (compact)
    - ✓ Work in -25C environment (x3-4 light yields)
  - ✓ **Photodetectors**
    - ✓ APD
    - ✓ VPTT (better for high rate, fwec)
  - ✓ **Preamplifiers**
    - ✓ APFEL-ASIC
    - ✓ Basel-LNP

The PANDA EMC



- ✓ **Forward detector: shashlyk**
  - ✓ **Shashlyk cells**
    - ✓ Scintillator + lead
    - ✓ Wavelength-shifting fiber (read out light)
  - ✓ **Photodetectors**
    - ✓ PMT
      - ✓ Higher gain, no preamplifier (absence of magnetic field)

The PANDA EMC requirements

Table 4.1: Requirements on the EMC detectors in PANDA. Data taken from [23, 48].

Property	Required values			
	Backward endcap	Barrel	Forward endcap	Shashlyk
Relative energy resolution σ_E/E	$\leq 1\% \oplus \frac{2\%}{\sqrt{E/\mathrm{GeV}}}$	$\leq 1\% \oplus \frac{2\%}{\sqrt{E/\mathrm{GeV}}}$	$\leq 1\% \oplus \frac{2\%}{\sqrt{E/\mathrm{GeV}}}$	$\leq 1\% \oplus \frac{(2-3)\%}{\sqrt{E/\mathrm{GeV}}}$
Photon-energy threshold [MeV]	10	10	10	10
Single-detector threshold [MeV]	3	3	3	3
Energy-equivalent noise [MeV]	1	1	1	1
Maximum detectable energy [MeV]	700	7300	14600	15000
Polar-angle coverage (lab frame) [°]	≥ 140	≥ 22	≥ 5	≥ 0
Solid-angle coverage (lab frame) [% 4π]	5.5	84.7	3.2	0.74
Hit rate per detector* [MHz]	0.06	0.06	0.5	~ 1
Radiation hardness [Gy y^{-1}]	10	10	125	1000

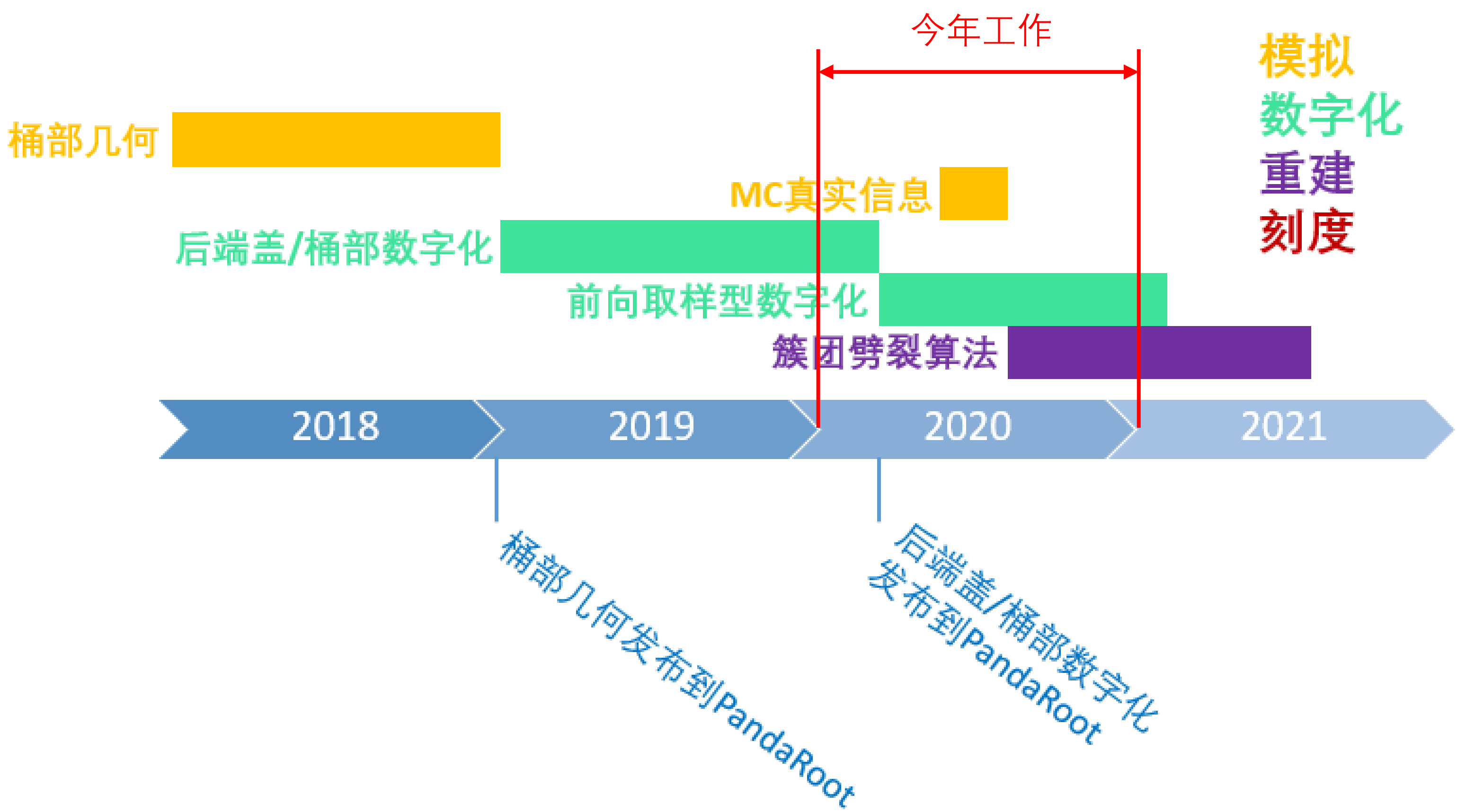
* Hit rate per individual crystal or cell.

Remarks:

- Energy resolution ~2-3% @ 1GeV
- Small detection threshold: 10 MeV for a photon

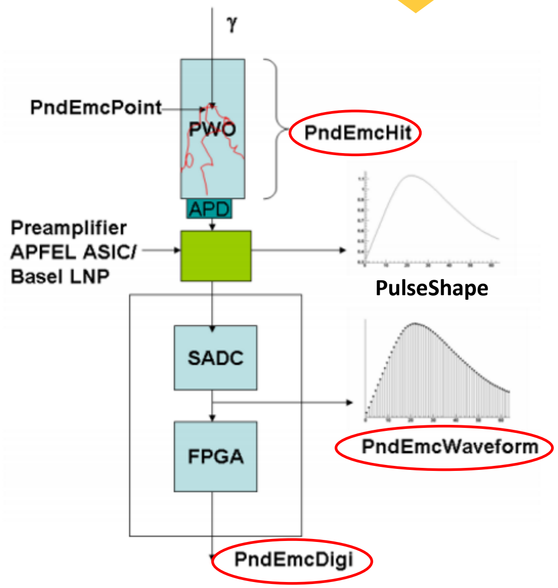
Require simulation in great details to meet the requirements

Road Map


今年工作
模拟
数字化
重建
刻度
桶部几何
MC真实信息
后端盖/桶部数字化
前向取样型数字化
簇团劈裂算法
2018
2019
2020
2021
桶部几何发布到PandaRoot
后端盖/桶部数字化
发布到PandaRoot

Digitization in PandaRoot

Event Generation	Detector Simulation	Digitization	Reconstruction	Rootification
EVTGEN	HITS	DIGITS	SHOWERS	TTree/THist



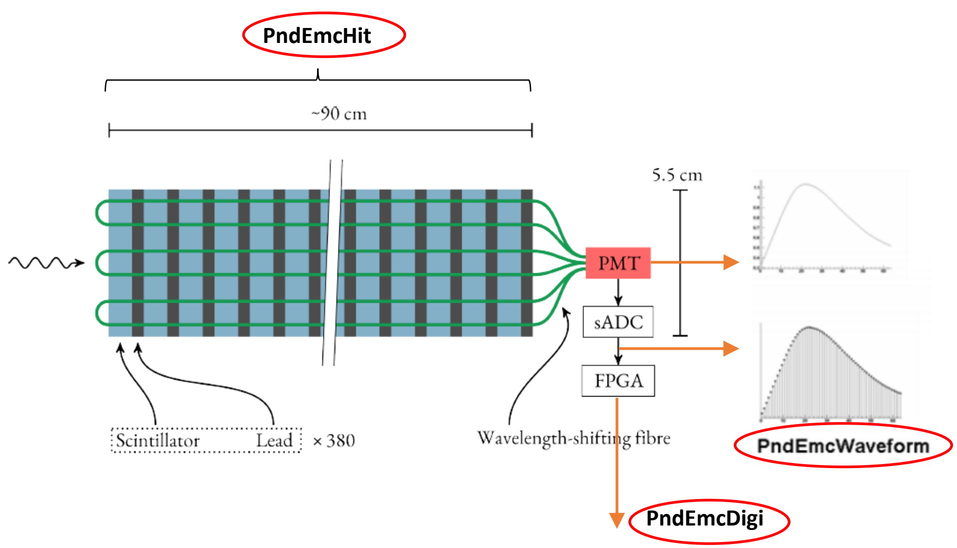
Signal Generator (SG)
- Analog waveforms creation
- Noises generation
- Digitization
- Pile-up waveforms creation

Feature Extraction (FE)
- Hit detection
- Amplitude/time extraction
- Pile-up recovery

Time-based simulation

Digitization in PandaRoot (II)

Event Generation	Detector Simulation	Digitization	Reconstruction	Rootification
EVTGEN	HITS	DIGITS	SHOWERS	TTree/THist



Signal Generator (SG)
- Analog waveforms creation
- Noises generation
- Digitization
- Pile-up waveforms creation

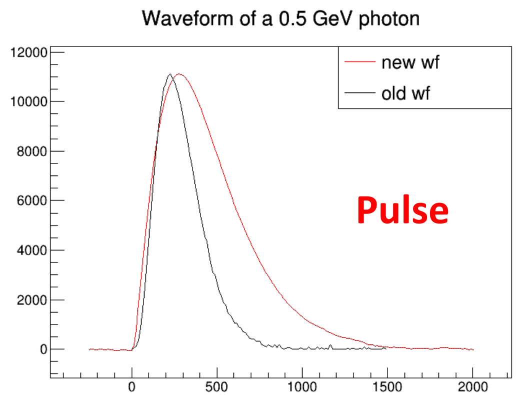
Feature Extraction (FE)
- Hit detection
- Amplitude/time extraction
- Pile-up recovery

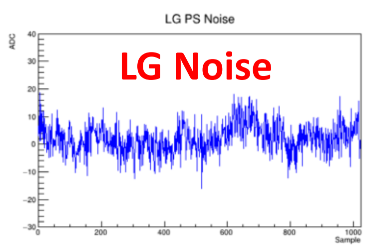
Time-based simulation

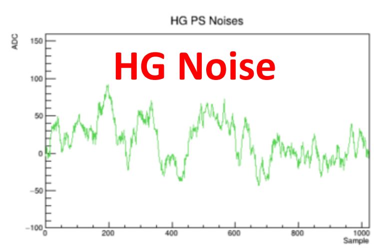
Backward endcap/barrel EMC digitization

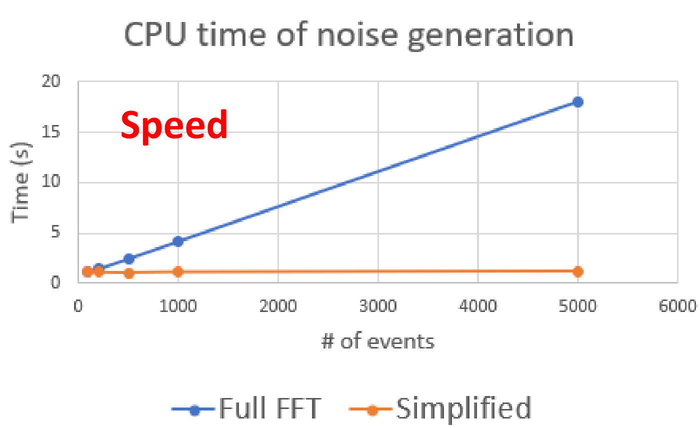
- **In collaboration with Oliver Noll from Institute Mainz**

Signal Generator







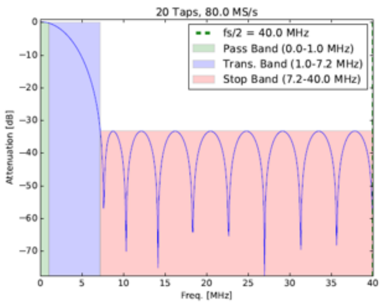


- **APFEL ASIC pulse**
  - APD gain = 200
  - APFEL amplifier: 2 gains
    - HG/LG = 10.5
  - Full pulse width: ~1700 ns
  - Rising time: ~300 ns
  - Sampling rate: 80 MHz

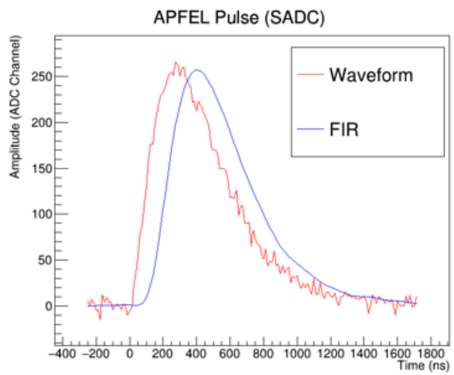
- **Electronics Noises**
  - Generate FFT analyzed noises
    - Pre-amplifier
    - ADC
    - Transmission
  - Good agreement with data
  - Performance optimization
    - FFT is extremely slow
    - Optimize the model with a much faster speed

Feature extraction

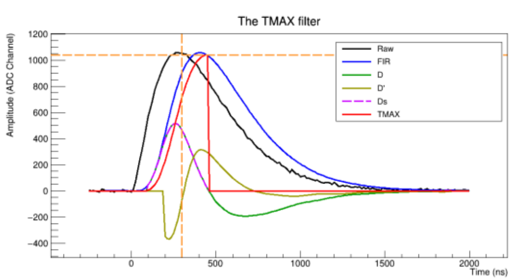
Smoothing



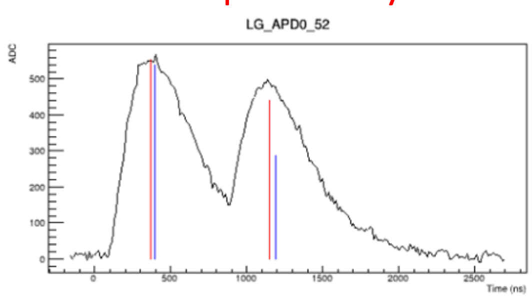
Low pass filter to smooth the waveform
(20 coefficients, ~10 cycle clocks latency)



Time/amplitude extraction



Pile-up recovery



Feature Extraction

- Smoothing with an FIR filter
- Time/energy extraction
  - TMAX algorithm in FPGA
- Pile-up recovery

PandaRoot development

Merged Opened 10 months ago by **Guang Zhao** Edit

Backward endcap EMC digitization

Overview 1 Commits 9 Pipelines 5 Changes 31

A new package for the backward endcap EMC digitization, including

- Signal generator task
- Feature extraction task
- Digitization parameters

To use the new package

- Run macros in /macro/detectors/emc/BwEndCap2020

The code has been published in the PandaRoot repository

Shashlyk EMC digitization

- **In collaboration with Markus Preston from Stockholm University**

Signal generator

Photon statistics

PndEmcHit
(Energy & Time)

Scaled by *Energy* & *Q.E.*

$N_{p.e.}$

Photon statistics in PMT:

Importing the photon statistics by smearing the energy*:

$$\frac{\sigma_E}{E} = \frac{1}{\sqrt{E}} \times \sqrt{\frac{F}{N_{p.e.}}}$$

(*Q.E.* = 0.15, *F* = 1.3)

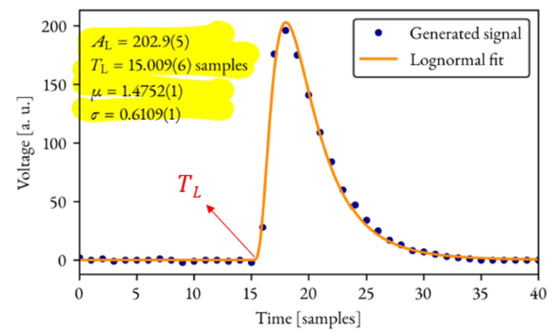
* EMC TDR

PndEmcWaveform

Idea pulse

Idea pulse generation by sampling:

$$f_L(t) = \begin{cases} \frac{A_L \exp(\mu - 0.5\sigma^2)}{t - T_L} \exp\left[\frac{[\log(t-T_L)-\mu]^2}{2\sigma^2}\right], & \text{if } t > T_L \\ 0, & \text{otherwise,} \end{cases}$$



PndEmcHit
(Energy & Time)

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($Q.E.$ = 0.15, F = 1.3)

* EMC TDR

Real pulse

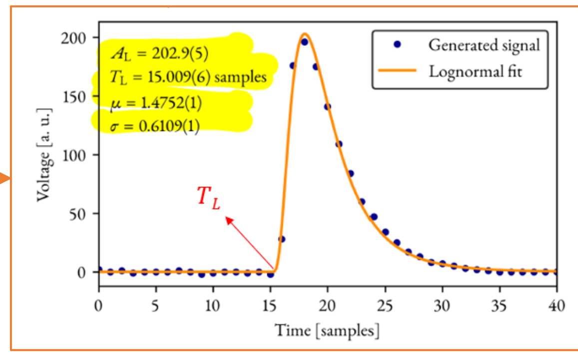
Idea pulse generation by sampling:

$$f_L(t) = \begin{cases} \frac{A_L \exp(\mu - 0.5\sigma^2)}{t - T_L} \exp\left[\frac{[\log(t - T_L) - \mu]^2}{2\sigma^2} \right], & \text{if } t > T_L \\ 0, & \text{otherwise,} \end{cases}$$

ADC pulse generation:

- Adding electronics noise: 1 ADC
- Digitizing: 125 MHz

PndEmcHit
(Energy & Time)



PndEmcWaveform

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$N_{p.e.}$

* EMC TDR

Pulses in simulation

Idea pulse generation by sampling:

$$f_{\mathrm{L}}(t) = \begin{cases} \frac{A_{\mathrm{L}} \exp(\mu - 0.5\sigma^2)}{t - T_{\mathrm{L}}} \exp\left[\frac{[\log(t - T_{\mathrm{L}}) - \mu]^2}{2\sigma^2}\right], & \text{if } t > T_{\mathrm{L}} \\ 0, & \text{otherwise,} \end{cases}$$

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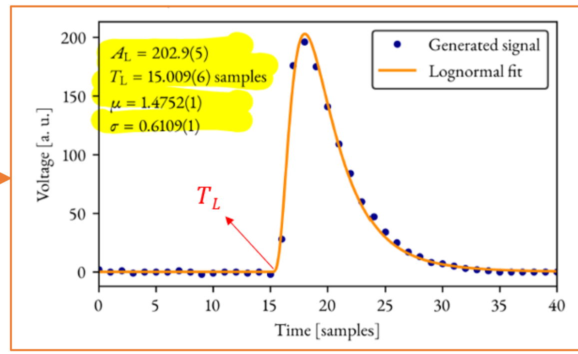
PndEmcHit (Energy & Time)



PndEmcWaveform

Scaled by *Energy* & *Q.E.*

$N_{p.e.}$

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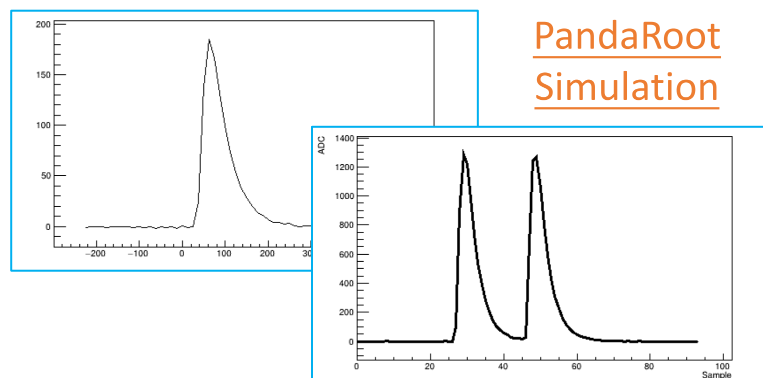
* EMC TDR

PandaRoot Simulation



Feature Extraction

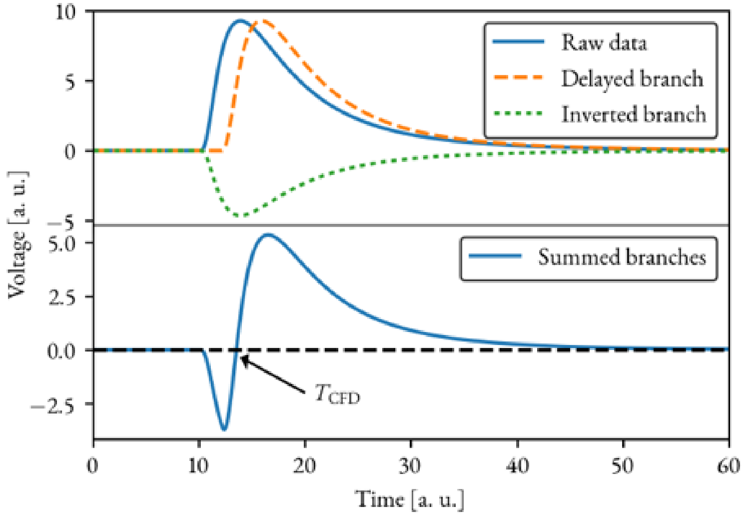
Feature Extraction

PndEmcWaveform ⇢ PndEmcDigi

Time determination: CFD

PndEmcWaveform $\xrightarrow{\text{CFD}}$ T0

PndEmcDigi



Constant Fraction Discriminator (CFD)

- Extract time at a fixed fraction of the maximum height
- To reduce the time-walk

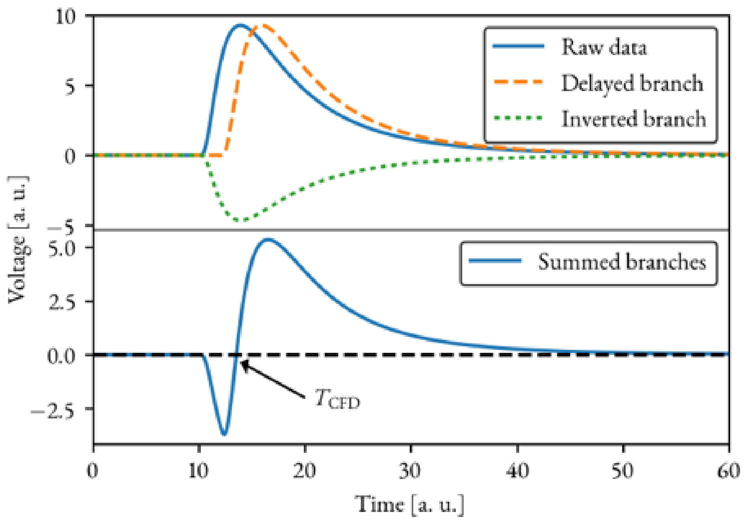
$$V_{\mathrm{CFD}}(t) = (V(t-t_d) - V_0(t-t_d)) - f(V(t) - V_0(t))$$

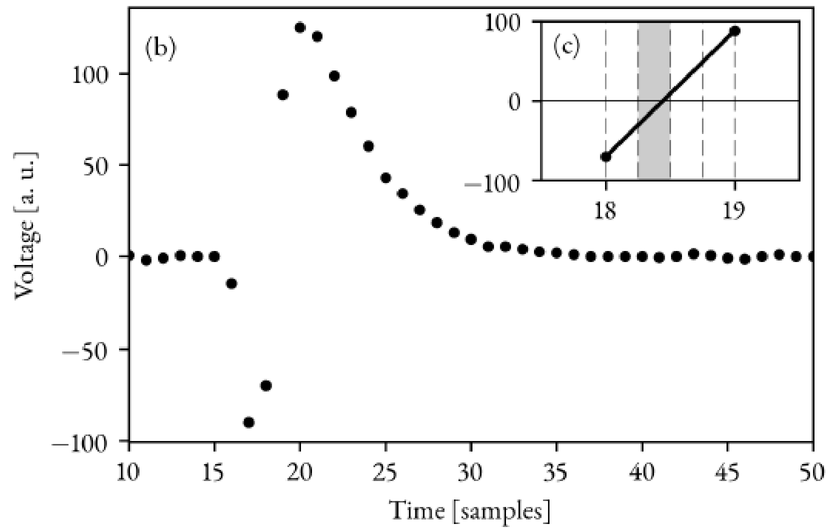
CFD parameters: $t_d = 2$, $f = 0.5$

Time determination: Binary-CFD

PndEmcWaveform —CFD→ T0

PndEmcDigi





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CFD parameters: $t_d = 2$, $f = 0.5$

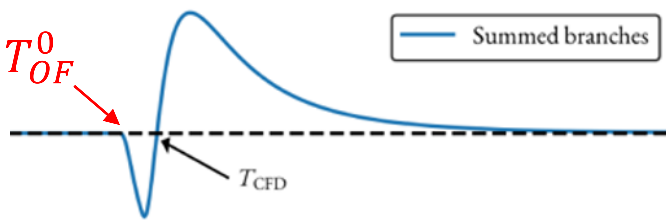
Binary-Search CFD

- Binary search the zero-crossing quarter-sample wide window
- $T_{B\text{-}CFD}$: Center of the window
- Arithmetic:
  - One-bit shift: (V(1) – V(0))/2
  - Much faster than division

Time determination: Correction

PndEmcWaveform $\xrightarrow{\text{CFD}}$ T0   PndEmcDigi

Time correction: Correction from the zero-crossing to the actual waveform start time



$$T^0_{\mathrm{OF},\,i} = T_{\mathrm{B\text{-}CFD},\,i} - \langle T_{\mathrm{B\text{-}CFD}} - T_{\mathrm{L}} \rangle.$$

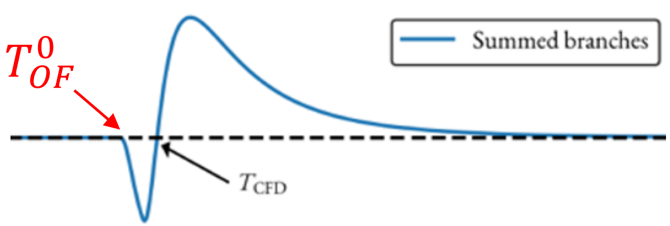
B-CFD window	$\langle T_{\mathrm{B\text{-}CFD}} - T_{\mathrm{L}} \rangle$ [samples]
1	3.454
2	3.460
3	3.417
4	3.413

Time determination: Simulation

PndEmcWaveform $\xrightarrow{\text{CFD}}$ T0

PndEmcDigi

Time correction: Correction from the zero-crossing to the actual waveform start time



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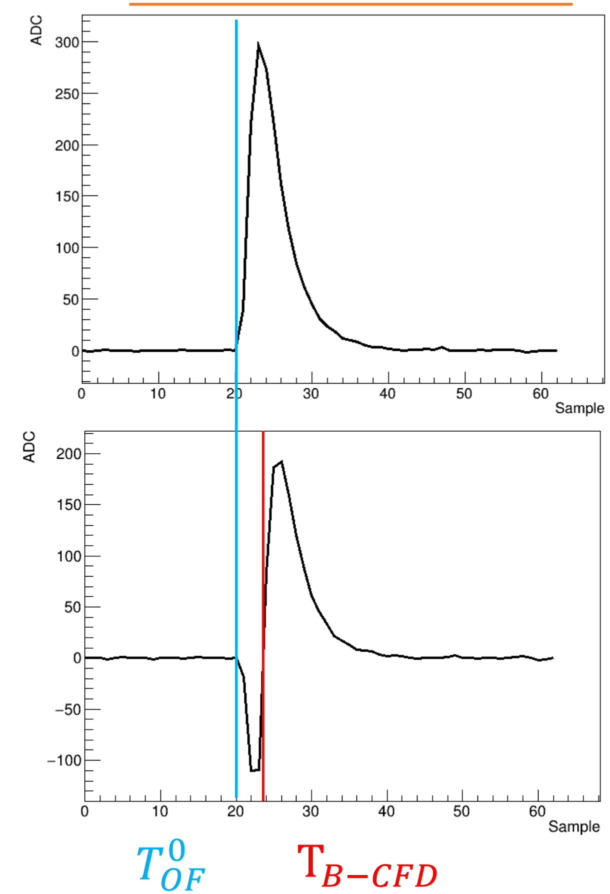
PandaRoot Simulation



Optimal Filter: Fine time/amplitude determination

PndEmcWaveform $\xrightarrow{\text{CFD}}$ T0 $\xrightarrow{\text{OF}}$ T/A $\longrightarrow$ PndEmcDigi

Optimal Filter (OF)

- The process of OF is equivalent to fitting the incoming data with a linearized version of the known pulse shape in a χ^2 fit

$$\chi^2 = \sum_{i=1}^{M}\sum_{j=1}^{M}(S_i - Ag(t_i-\tau)V_{ij}(S_j - Ag(t_j-\tau))$$

g(t): Pulse function
A: Amplitude
τ: Time difference to T^0_{OF}
S: Waveform content

- By solving this linear problem, the ***A*** and ***Aτ*** can be written in the following form, which are two FIR filters:

$$\alpha_1 \equiv A = \sum_{i=1}^{M} a_i S_i$$

$$\alpha_2 \equiv A\tau = \sum_{i=1}^{M} b_i S_i$$

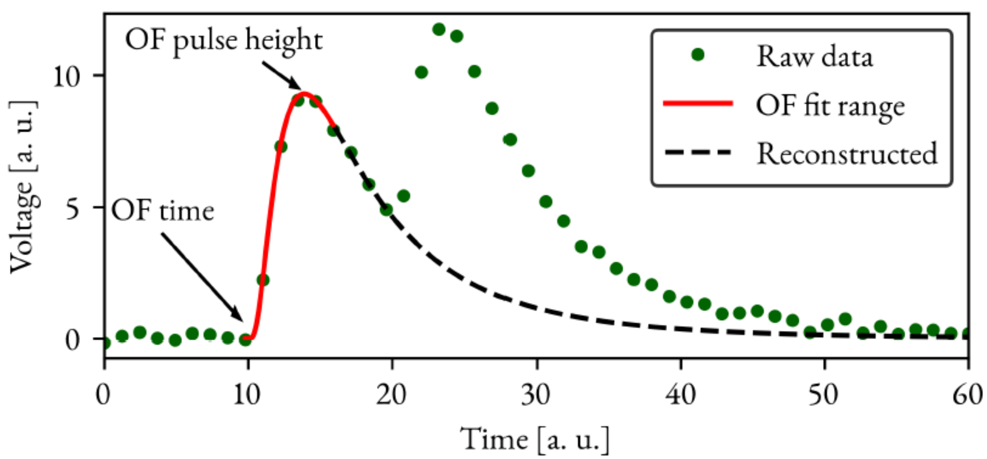
- The coefficients a and b can be analytically solved, which gives the ***A*** and ***τ***
- The OF can provide an amplitude and a more accurate time as it used more information of the waveform

Optimal Filter: Pile-up recovery

PndEmcWaveform $\xrightarrow{\text{CFD}}$ T0 $\xrightarrow{\text{OF}}$ T/A $\rightarrow$ PndEmcDigi

Pileup recovery:

- To reduce the contamination from upcoming pile-up waveforms, a truncated pulse shape are used in the OF (B0, B0+M)
- The previous detected pulse are subtracted as the baseline
- Perform the CFD + OF for the remaining waveform

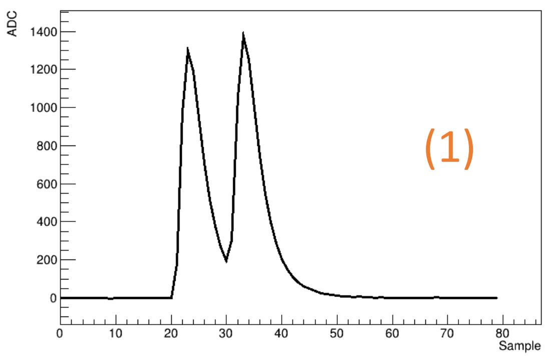


B0 = -3
M = 4

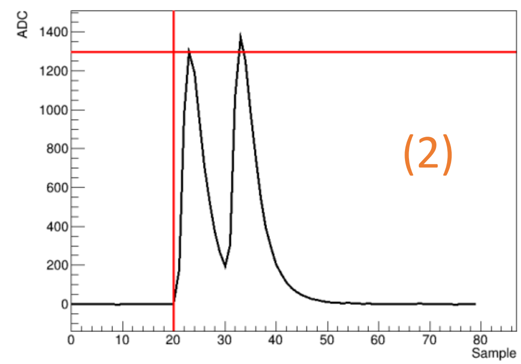
PandaRoot simulation

PndEmcWaveform —CFD→ T0 —OF→ T/A → PndEmcDigi

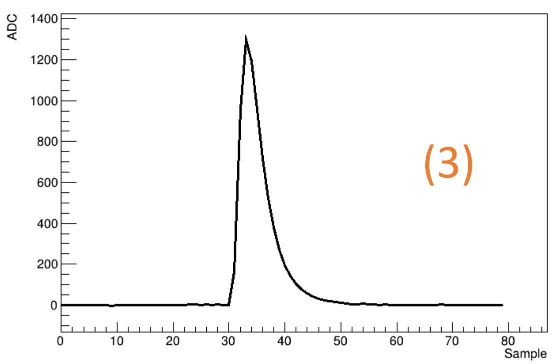
PandaRoot Simulation



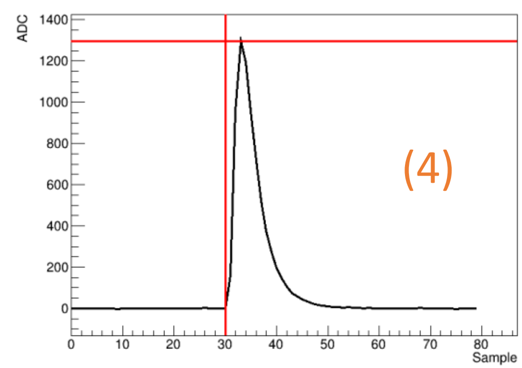
(1) A pile-up waveform



(2) First waveform detected

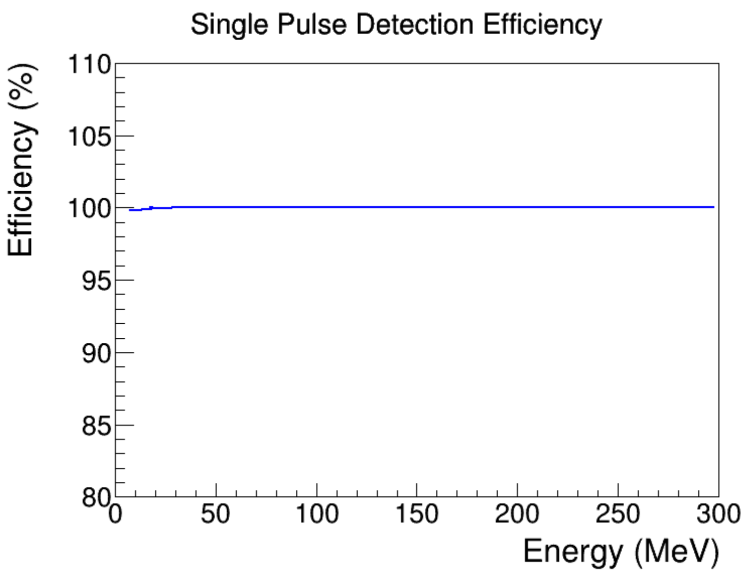


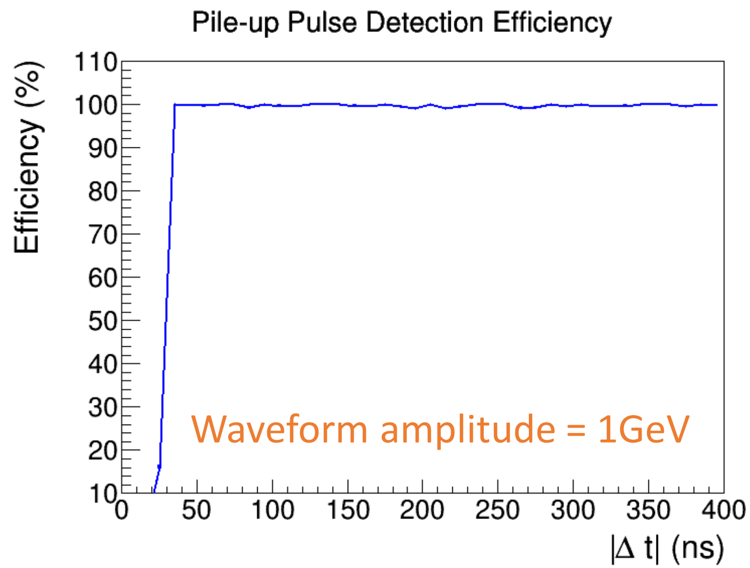
(3) Baseline subtracted



(4) Second waveform detected

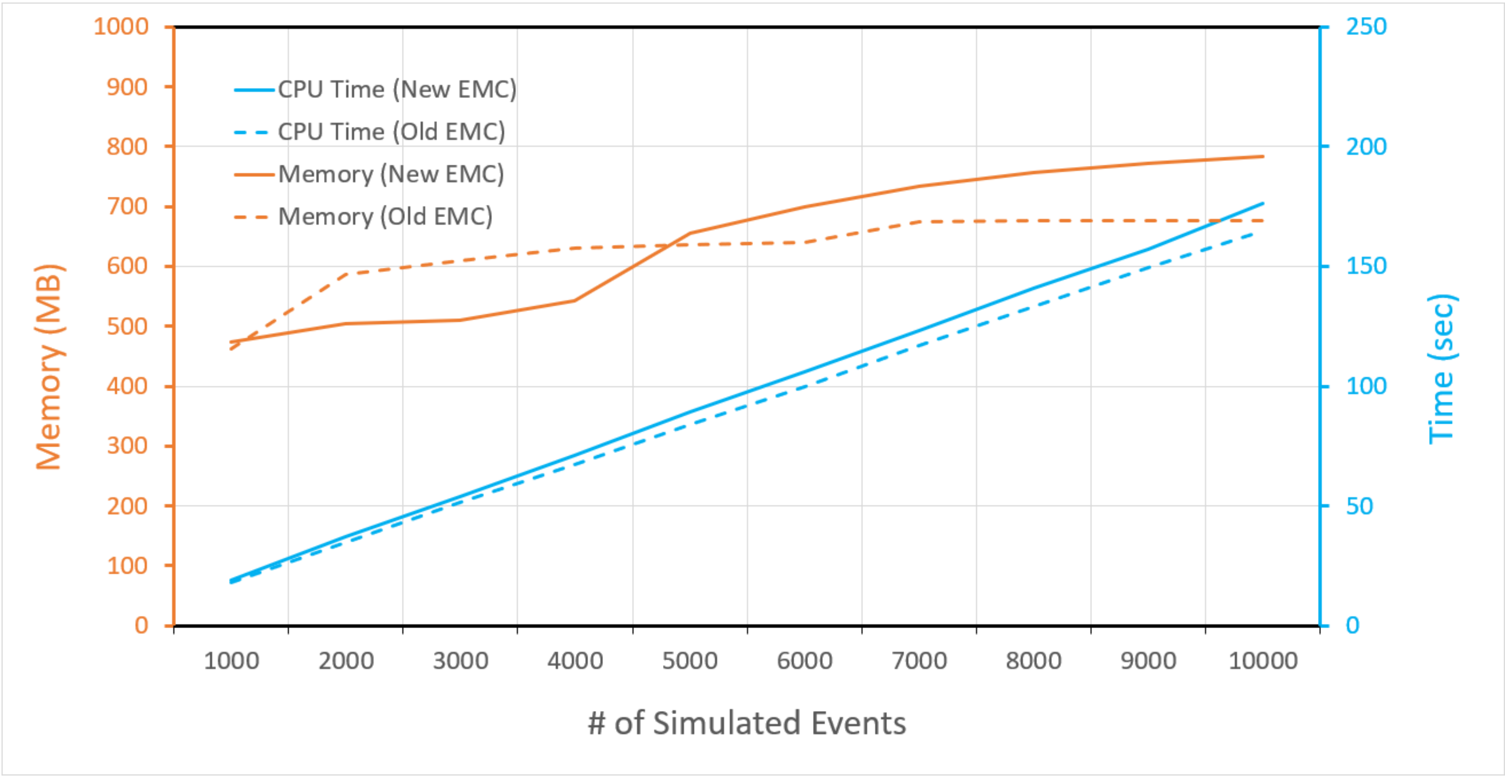
Waveform detection efficiency in simulation





Reasonable pulse detection efficiencies

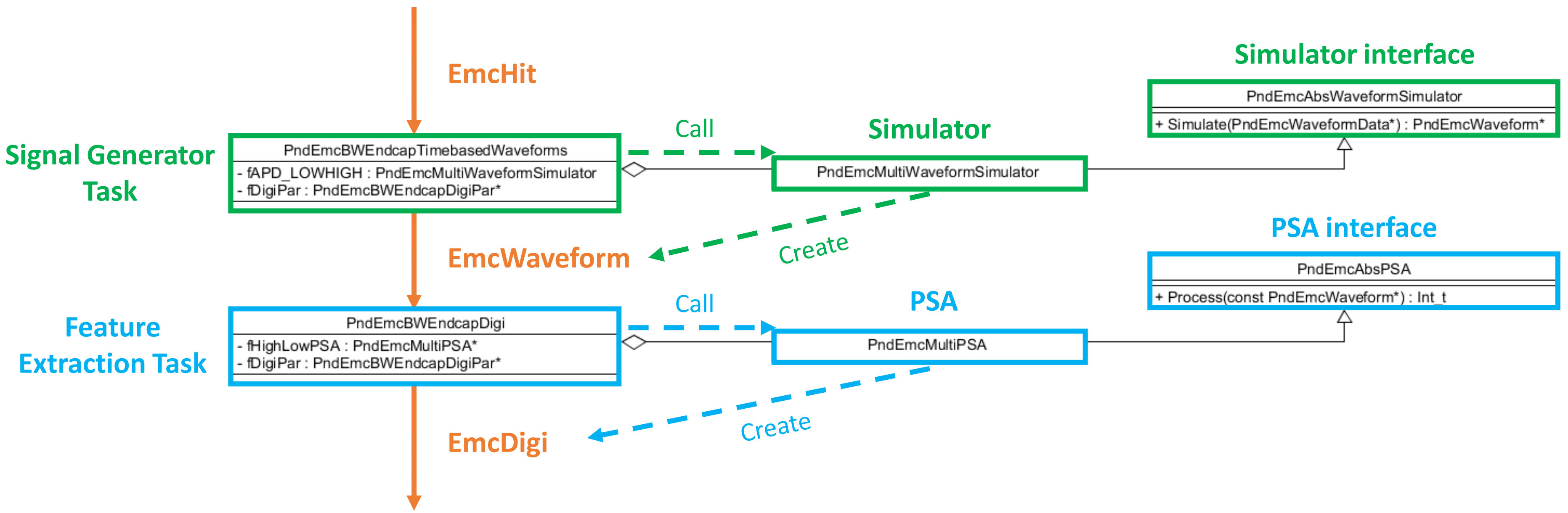
Performance Test



We can obtain quite similar computing performance compared to the old PandaRoot algorithm

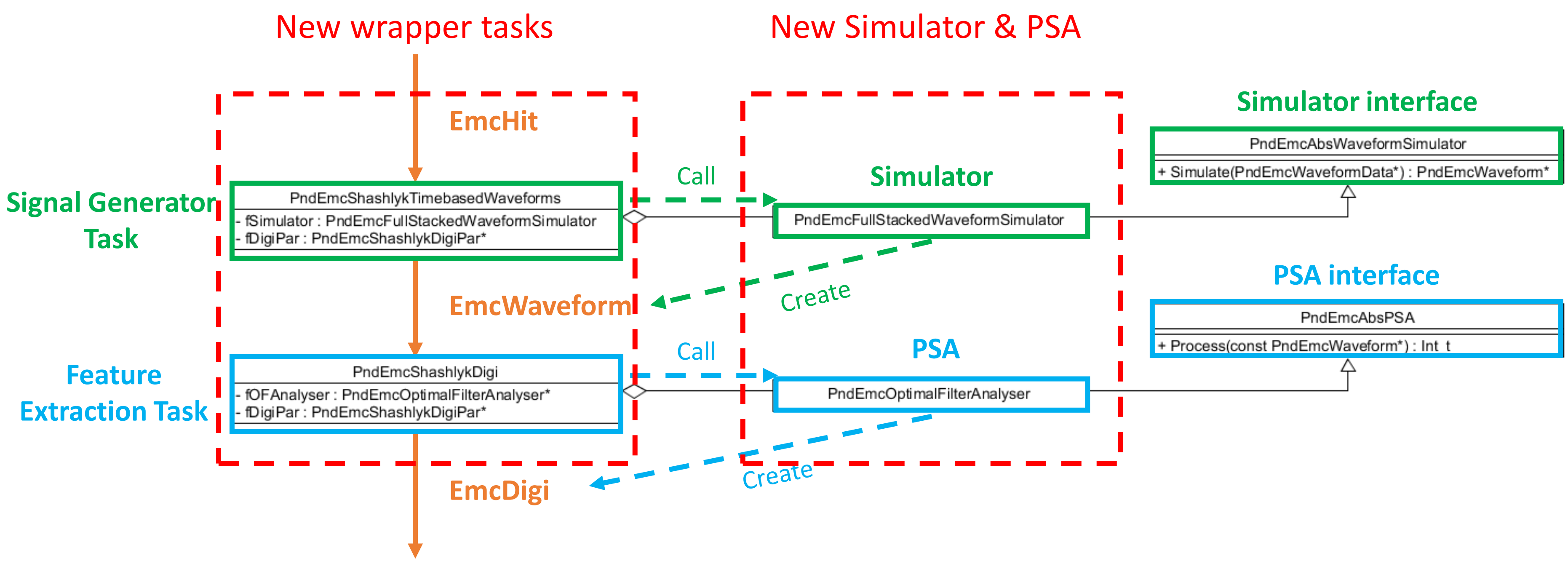
Code design

Code Structure (BWEC)



- Two tasks for signal generator and feature extraction respectively
- Simulator and Pulse Shape Analyzer (PSA) as the “algorithms”
- The algorithms inherit from the “interfaces”

Code Structure (Shashlyk)



- Easy to modify from the bwec package by plugging in two new “algorithms”
- An entirely new Simulator and PSA are implemented for the shashlyk EMC (core algorithms)
- New wrapper tasks (only simple modifications)

Summary

- **Digitization for the backward endcap/barrel EMC is finished**
  - Code has been released in the PandaRoot repository
- **Digitization for the shashlyk EMC is almost done**
  - Have implemented Markus' work in PandaRoot, including
    - Pulse generation using a shape template
    - Feature extraction using CFD+OF filters
  - Code is most ready. Need some final checks before checking in
- **Code design**
  - Unified OO framework for the digitization
  - Key functionalities are modularized. Can be easy for migration

Summary (II)

- **The digitization work has been reported in the collaboration meetings**
  - 19/2: *Backward endcap EMC Digitization* in Computing session
  - 19/3: *Backward endcap EMC Digitization* in Computing session
  - 20/3: *Shashlyk EMC Digitization* in Computing & EMC session

- **Plan**
  - More tests with the beam test data (obtained from Markus)
  - To finish the code of shashlyk EMC digitization
  - Will be focusing on the reconstruction
    - Guide Qing to study the cluster splitting algorithm

Thank you!