A Triggerless Readout System for the PANDA Electromagnetic Calorimeter

Outline:
1. Introduction to PANDA
2. The EMC and its readout scheme
3. Simulating the data flow
4. Summary and discussion

M. Tiemens
for the PANDA Collaboration
PANDA - Introduction

PANDA: $\bar{p}$ Annihilations at Darmstadt
PANDA - Introduction
The PANDA Electromagnetic Calorimeter

11,360 crystals (Barrel)

3,856 crystals (Forward Endcap)

528 crystals (Backward Endcap, not shown)
The PANDA Electromagnetic Calorimeter

- PbWO$_4$ (PWO-II): improved light yield:
  - x2 w.r.t. PWO-I
  - + x2 by cooling to -25 °C
EMC Readout Electronics: Challenges

Y(4260): [ref to BES paper]

Example of desired signal:

\[ pp \rightarrow Y(4260) \rightarrow J/\psi \pi^0 \pi^0 \rightarrow e^+ e^- + 4\gamma \]

\[ \sigma_{signal} = small \]

Typical background channels:

\[ pp \rightarrow J/\psi \eta \eta \rightarrow e^+ e^- + 4\gamma \]

\[ pp \rightarrow J/\psi \eta \pi^0 \rightarrow e^+ e^- + 4\gamma \]

\[ pp \rightarrow J/\psi \pi^+ \pi^- \pi^0 \pi^0 \rightarrow e^+ e^- + 4\gamma \]

Low E, lost

\[ \sigma_{bg} = large \]

(many channels with same final state)

Impossible to use conventional triggered readout.
EMC Readout Electronics: Solution

Example of desired signal:

\[ p\bar{p} \rightarrow Y(4260) \rightarrow J/\psi \pi^0 \pi^0 \rightarrow e^+ e^- + 4\gamma \]

Requiring \( M_{\gamma\gamma} \) to have a peak at \( m_{\pi^0} \) for each pair kills \( p\bar{p} \rightarrow J/\psi \eta \pi^0 \) and \( p\bar{p} \rightarrow J/\psi \eta \eta \)

Requiring \( M_{(e^+ e^- + 4\gamma)} \) to have a peak at 4260 MeV kills \( p\bar{p} \rightarrow J/\psi \pi^+ \pi^- \pi^0 \pi^0 \)

Use e.g. invariant mass for “triggering”
EMC Readout Electronics: Overview

Intelligent, self-triggering, dead-time-free readout

- Photo sensor
- Preamplifier
- Digitiser
- Data Concentrator
- Compute Node

Front-end electronics: inside EMC volume
EMC Readout Electronics: Photo-sensors

Hamamatsu

› QE: 70-80%
› Active area: 7x14 mm
› 2 per crystal

Large Area Avalanche Photo Diodes
EMC Readout Electronics: Photo-sensors

Hamamatsu
› QE: ~20%
› Radiation hard
› 1 per crystal

Vacuum Photo Tetrodes
EMC Readout Electronics: Digitisers

[Hardware designed by P. Marciniewski, Uppsala University]

- 64 channels
- Sampling rate: 80 MHz
- Resolution: 14 bits

160 mm

100 mm
EMC Readout Electronics: Digitisers

[Hardware designed by P. Marciniewski, Uppsala University]

Baseline follower
Pulse detection
Pile-up detection
EMC Readout Electronics: Digitisers

[Hardware designed by P. Marciniewski, Uppsala University]
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EMC Readout Electronics: Digitisers

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EMC Readout Electronics: Digitisers

Digitiser summary

› Digitisation of 32 preamps (dual range) @80MHz
› Calibration, pulse detection and feature extraction

Additional properties

› Compact device: 160 x 100 mm
› Debugging: Read baseline, output waveforms
› Fast reboot after configuration damage: ~ms
EMC Readout Electronics: Data Concentration

TRB v3

Crystal

APD

APD

Digitisers

Data Concentrator

0010110011

0010110011
EMC Readout Electronics: Data Concentration

TRB v3

- $E_1$
- $t_1$
- $E_2$
- $t_2$
EMC Readout Electronics: Data Concentration

Pile-up recovery [PhD Thesis G. Tambave, University of Groningen]
[G.Tambave et al., JINST 7, P11001, 2012.]

\[ \frac{I}{A_1} = k(1 + \frac{A_2}{A_1}) \]
EMC Readout Electronics: Data Concentration

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\[
\frac{I}{A_1} = k\left(1 + \frac{A_2}{A_1}\right)
\]
EMC Readout Electronics: Data Concentration

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EMC Readout Electronics: Data Concentration

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\[ I = k(A_1 + A_2) \]

FWHM = 732.5

FWHM = 908.6
EMC Readout Electronics: Data Concentration

- Precision: 20 ps
- Continuous monitoring

Data Concentrators

Digitisers

SODANET Clock source
EMC Readout Electronics: Compute Node


Data Concentrators (40)

5 Gbps lines
EMC Readout Electronics: Compute Node


Example of desired signal:
\[ p\bar{p} \rightarrow Y(4260) \rightarrow J/\psi \pi^0\pi^0 \rightarrow e^+e^- + 4\gamma \]

Typical background channels:
\[ p\bar{p} \rightarrow J/\psi \eta \rightarrow e^+e^- + 4\gamma \]
\[ p\bar{p} \rightarrow J/\psi \eta\pi^0 \rightarrow e^+e^- + 4\gamma \]
\[ p\bar{p} \rightarrow J/\psi \pi^+\pi^- \pi^0\pi^0 \rightarrow e^+e^- + 4\gamma \]

Low E, lost
EMC Readout Electronics: Status

✓ Performance close to requirements:
  › Digitiser design (Firmware, hardware)
  › Data Concentrator design (Firmware)
  › SODANET design (Firmware, hardware)

☐ To do:
  › Implement & test online pile-up recovery
  › Optimize topology of network
The PANDA EMC: Simulation

GEANT simulated data:

However:

\[
\begin{align*}
\text{Event 1} & \quad \text{Time} \\
\text{Event 2} & \quad \text{Time} \\
\text{Event 3} & \quad \text{Time}
\end{align*}
\]

\[
\text{Annihilation rates up to 20 MHz} \\
\text{\( p\bar{p} \rightarrow \text{anything} \)}
\]
The PANDA EMC: Simulation

Timebased simulation:

Event 1

Event 2

Event 3

MC Data
The PANDA EMC: Simulation

Timebased simulation (Forward endcap):

Hit distribution (GeV)

› Next step:
Check efficiency for
\[ pp \rightarrow h_c \rightarrow \eta_c + \gamma \rightarrow \pi^0\pi^0\eta\gamma \rightarrow 7\gamma \]
Summary

Triggerless readout system for the PANDA EMC

- WHY do we need it?
  - Similar topology of final states + high interaction rates → Triggered readout not possible

- HOW will we implement it?
  - Event Generation (MC/real data) → Event Preprocessing → Event Separation → Event Selection
Summary
Backup: Photo-sensor Characteristics

**Hamamatsu**
- Thickness: 0.200 mm
- QE: 70-80%
- Dark current ~30 nA
- Active area: 7x14 mm

**Hamamatsu**
- Diameter: 24.9 mm
- QE: ~20%
- Dark current ~1 nA
- Gain: ~55

**Large Area Avalanche Photo Diodes**

**Vacuum Photo Tetrodes**
Backup: Preamplifiers

**Rise time:**

\(~50\ \text{ns}\)
Backup: Preamplifiers (Forward Endcap)

- Low noise: ~160 keV
- Low power: 45 mW
- Large dynamic range: 2 MeV – 12 GeV

Low Noise, Low Power Preamplifier
Backup: Digitiser Functionality

Feature Extraction:
(developed at KVI)

Stage I:
- Base-line follower
- Pulse detection
- Pile-up detection (output waveforms)
- Time-stamp at maximum

Stage II:
- Precise time
- Precise energy
Backup: Data Concentrator Functionality

Data Concentration (EMC):

- Time-distribution functionality
- Separation of the hit-data and slow-control streams
- Combine information from two photo-sensors, reading out same crystal
- Identification and correction of a nuclear counter effect
- Energy calibration
- Time-ordering of the data
- Pile-up recovery
Backup: Pile-up Recovery
[PhD Thesis G. Tambave, University of Groningen]
[G.Tambave et al., JINST 7, P11001, 2012.]

Simulated single pulses

Simulated pile-up pulses
Backup: Pile-up Recovery
Backup: Readout Chain Overview

Intelligent front-end electronics

EMC volume: -25 °C

- Preamp.
- Photo sensor
- PWO II

Digitiser

- Sampling ADC
- FPGA
  - Online pulse-data processing: Feature Extraction

Synchronisation of Sampling ADC clocks & Slow control

Optical link

Hit-data

Data Concentrator

- Event pre-building
- Pile-up correction
- Data calibration

Time distribution SODANET

Event builder

- CN
- CN
- CN
- CN

Online computing

- CN
- CN
- CN
- CN

Data storage

Particle production:
- 20 MHz
- \(10^7\) events/s
- 300 GB/s

Data reduction:
- Factor 1500
- \(10^4\) events/s
- 200 MB/s

Triggerless readout