DarkSide-20k
Data Acquisition System

Maria Adriana Sabia
Sapienza, INFN, TRIUMF
on behalf of the DarkSide-20k Collaboration

Overview

- DarkSide-20k as a Dark Matter Experiment and much more
- Light detection in DS-20k using novel SiPMs
- How to readout the signals from the SiPMs ? DS-20k data acquisition system
  - Overview of the system
  - The Quadrant: a mockup system for DS-20k data acquisition
- Conclusions and next steps

DarkSide-20k experiment

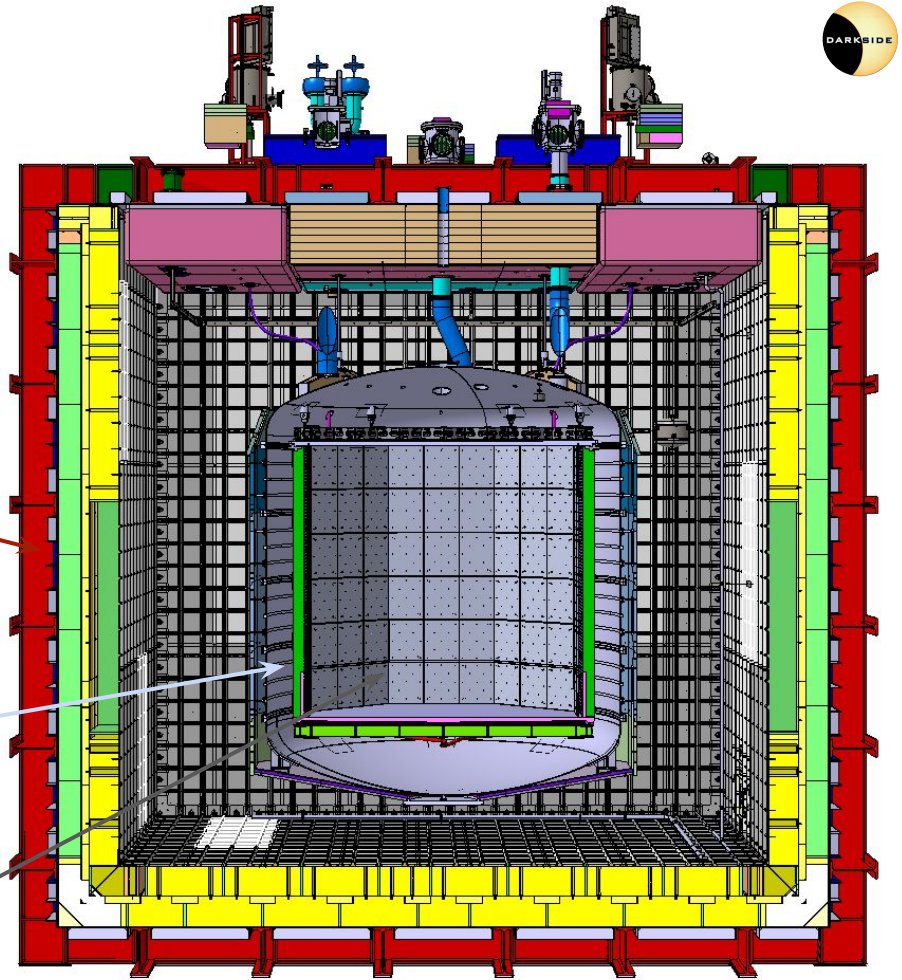
The Detector

Dual phase Liquid Argon Time Projection Chamber currently under construction at Laboratori Nazionali del Gran Sasso (LNGS)

Cryostat filled with 650t of **Atmospheric Argon** (AAr) and instrumented with photodetectors to work as an outer veto

Inner Veto: 36t of Liquid Underground Argon within a stainless steel vessel and surrounding the TPC to work as a **neutron veto**

TPC: 50t of Liquid Underground Argon (20t) fiducial constituting the detector core.



DarkSide-20k experiment

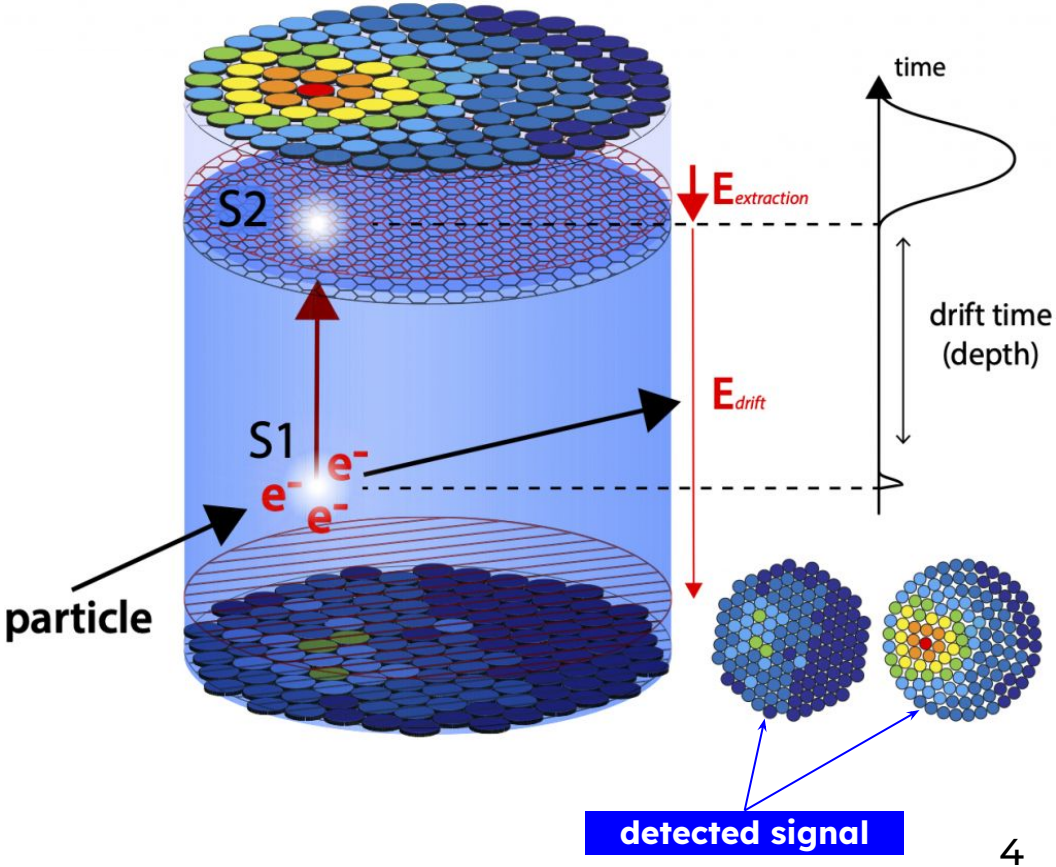
A Dark Matter search experiment..

WIMP – nucleus coherent elastic scattering → single nuclear recoil, ROI: [30, 200] keVnr

Energy deposition in LAr produces scintillation photons and free electrons

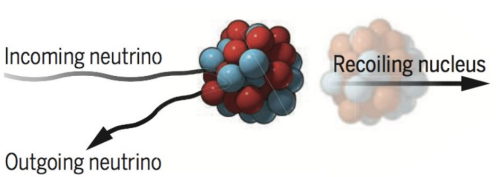
S1: primary scintillation in LAr (energy information and pulse shape discrimination)

S2: secondary scintillation from electroluminescence of electrons in gas pocket (energy information and position reconstruction)

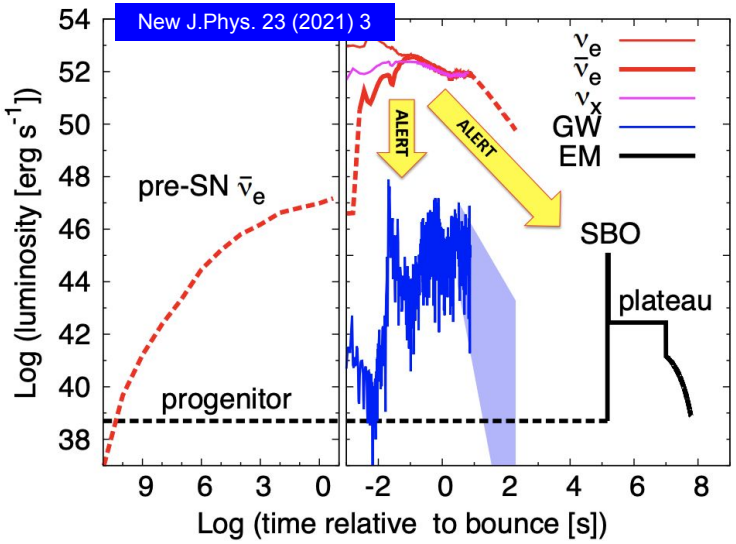


… and much more !

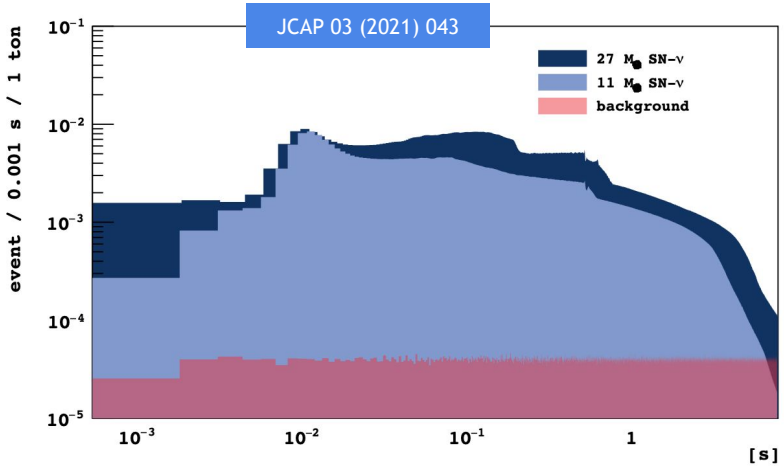
DS-20k as a Supernova detector



DS-20k can be sensitive to CEvNS (sub-keV recoil energy) via S2-only analysis.
Expected contribution to Supernova Early Warning System (SNEWS 2.0)



Neutrinos can serve as a prompt alert in case of a Supernova event via CEvNS, Coherent Elastic Neutrino-Nucleus Scattering → sensitive to all neutrino flavors!

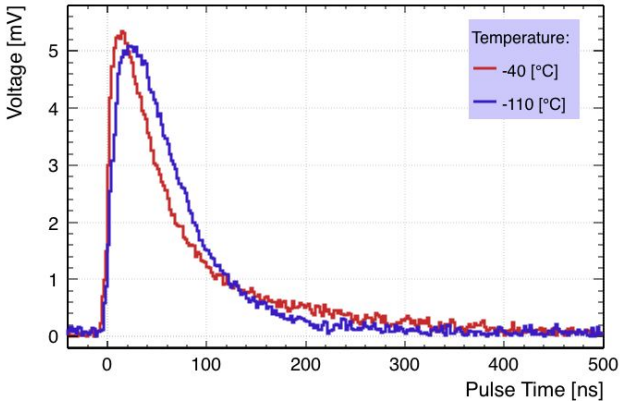


Event time resolution is dominated by the electron drift time (maximum drift time ~ 3.5 ms)

Light detection in DS-20k

Silicon PhotoMultipliers (SiPM

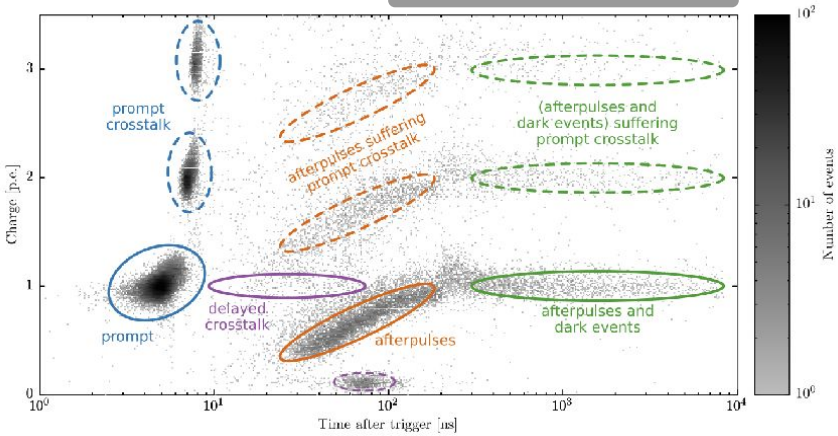
Single Photon Avalanche PhotoDiodes (SPADs) connected in parallel operated in reverse bias mode



Advantages:

- High gain at low bias voltage
- Single photon detection resolution
- High radiopurity
- Suitable at cryogenic temperature
- High Photon Detection Efficiency (PDE)

IEEE Trans.Nucl.Sci. 65 (2018)



Uncorrelated Avalanche Noise

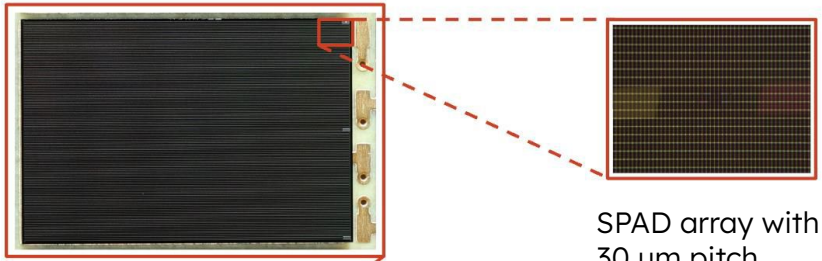
- Dark Count Rate (DCR)

Correlated Avalanche Noise

- Afterpulse (AP)
- Internal Cross talk (CT), Prompt (<< 1 ns) or Delayed (> ns)
- External CT

Light detection in DS-20k

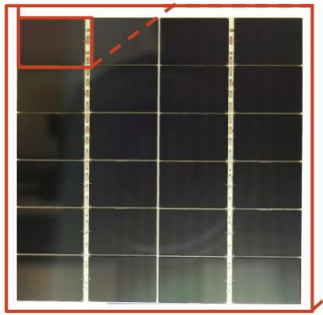
from SiPMs to PDUs



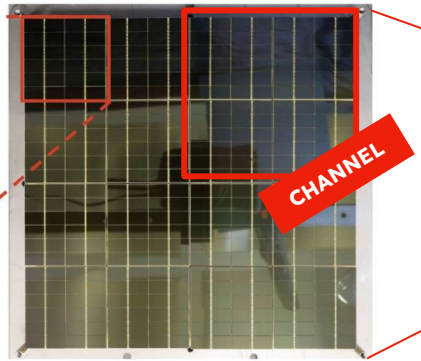
SiPM 11.8 x 7.9 mm^2

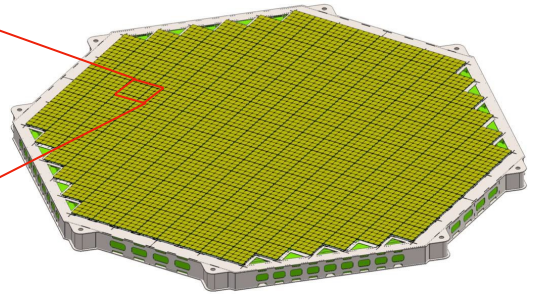
SPAD array with 30 μm pitch

PDU: 16 Tiles, 20 x 20 cm^2



Tile: 24 SiPMs, 4.95 x 4.95 cm^2





21 m^2 optical planes

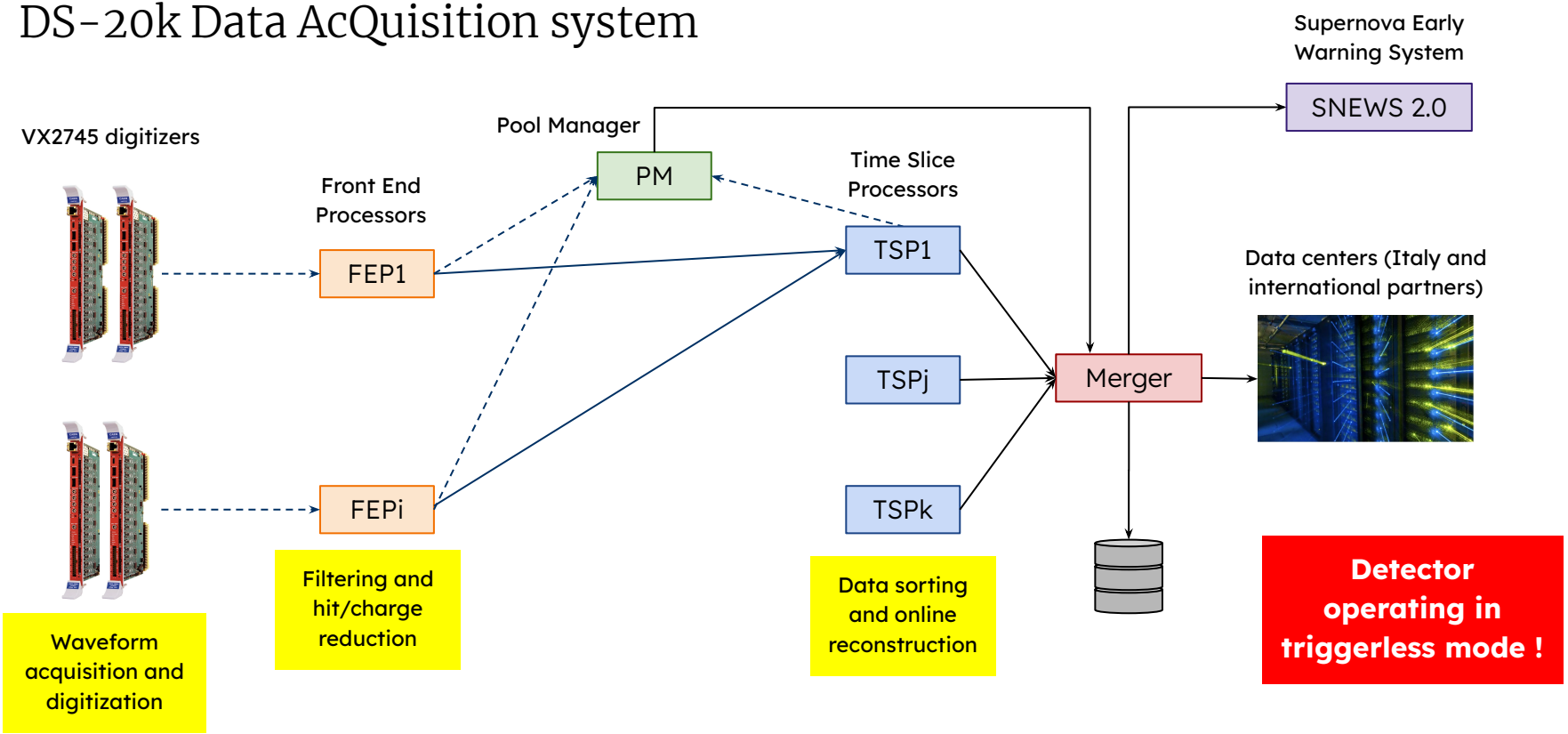
The main detection unit is the Photo Detection Unit (PDU), made up of 16 Tiles, in turn composed of 24 cryogenic, low noise and low background SiPMs.

4 tiles (10 cm^{2}x10 cm^2) constitute a readout channel. Large area implies higher noise.

PDUs assembled in the cleanroom packaging facility Nuova Officina Assergi (NOA) at Laboratori Nazionali del Gran Sasso (LNGS).

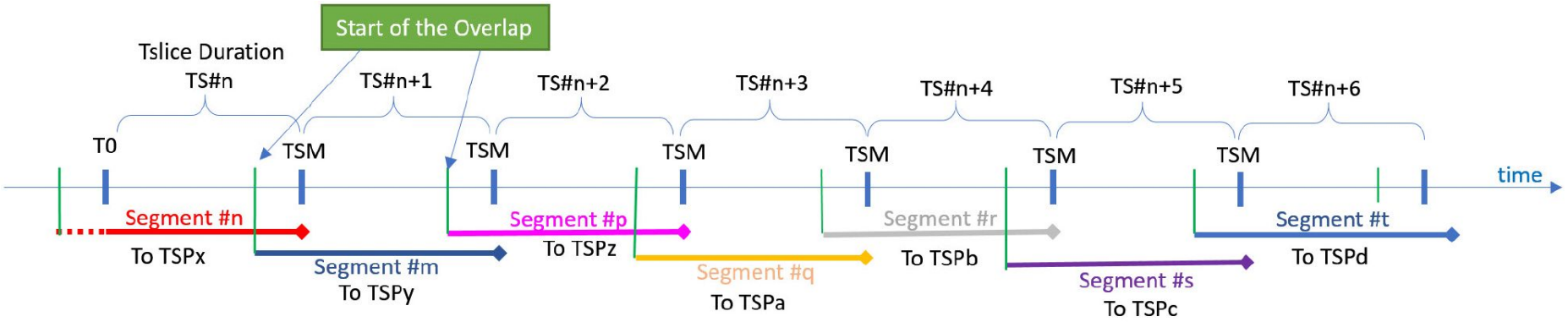
How to readout the signals from the SiPMs

DS-20k Data AcQuisition system

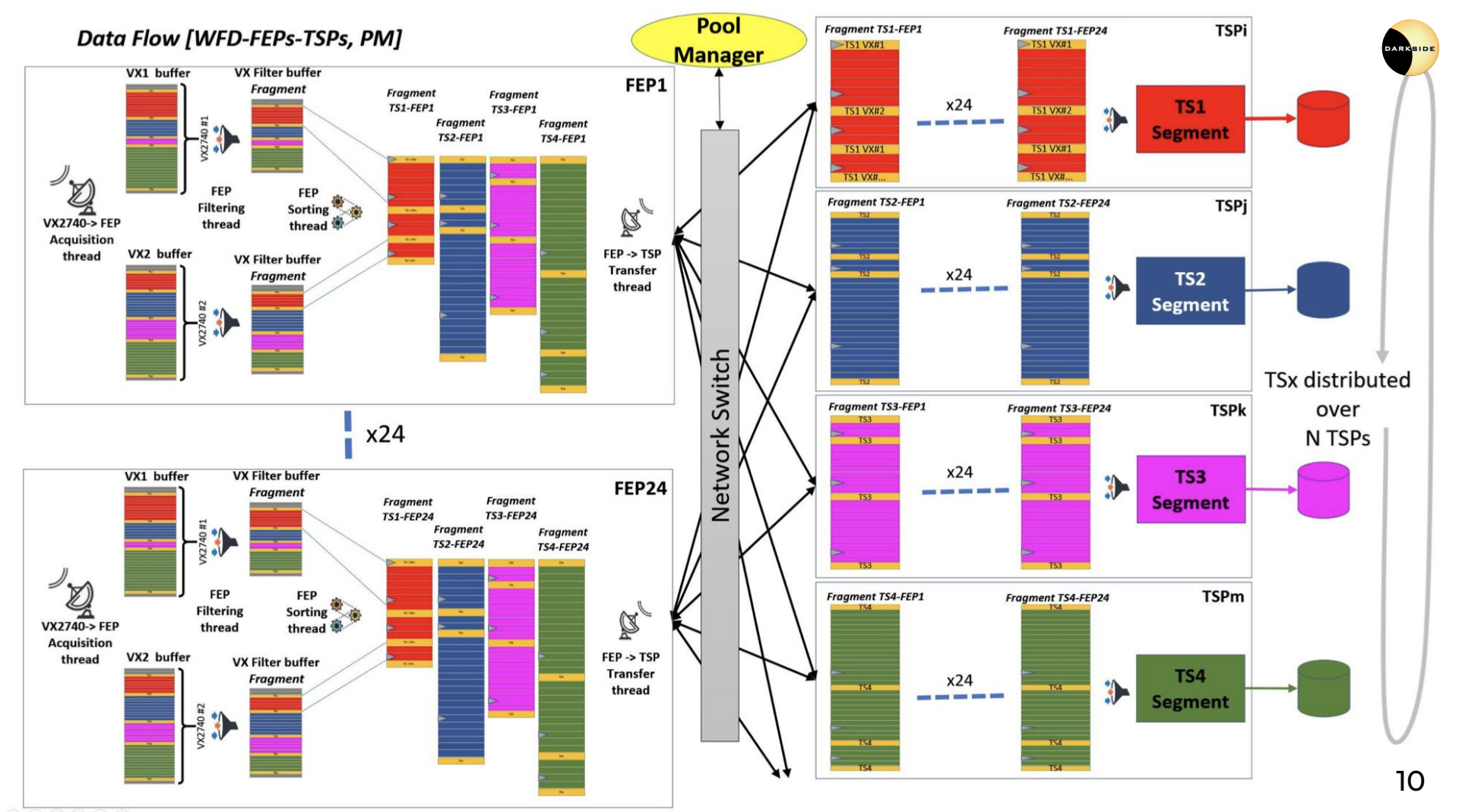


DarkSide-20k data acquisition

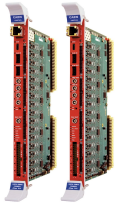
Time Slice concept

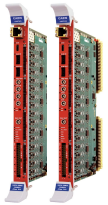


- Data acquisition divided into **time slices**
- A **time slice** is the complete collection of detector data over a fixed amount of time (with overlap with previous slice)
- Time Slices are submitted individually to a dedicated processor, TSP (see later)
- Time Slice Marker (TSM) is injected at the digitizer level

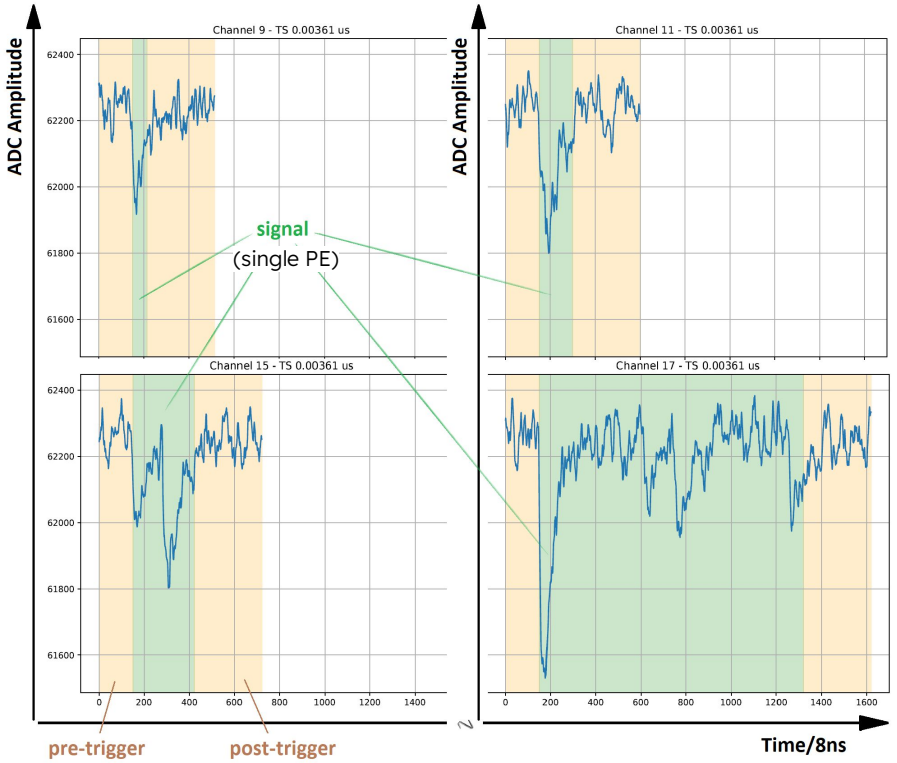

Data Flow [WFD-FEPs-TSPs, PM]
Pool Manager
FEP1
VX1 buffer
VX Filter buffer
Fragment
VX2740 #1
VX2740-> FEP Acquisition thread
FEP Filtering thread
FEP Sorting thread
VX2 buffer
VX2740 #2
Fragment TS1-FEP1
Fragment TS2-FEP1
Fragment TS3-FEP1
Fragment TS4-FEP1
FEP -> TSP Transfer thread
x24
FEP24
Fragment TS1-FEP24
Fragment TS2-FEP24
Fragment TS3-FEP24
Fragment TS4-FEP24
Network Switch
Fragment TS1-FEP1
Fragment TS1-FEP24
TSPi
TS1 VX#1
TS1 VX#2
TS1 VX#...
TS1 Segment
Fragment TS2-FEP1
Fragment TS2-FEP24
TSPj
TS2
TS2 Segment
Fragment TS3-FEP1
Fragment TS3-FEP24
TSPk
TS3
TS3 Segment
Fragment TS4-FEP1
Fragment TS4-FEP24
TSPm
TS4
TS4 Segment
TSx distributed over N TSPs

Waveform digitization



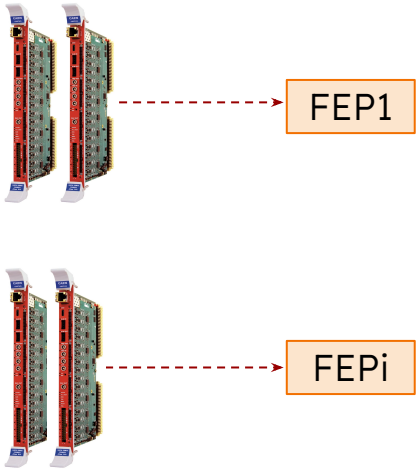


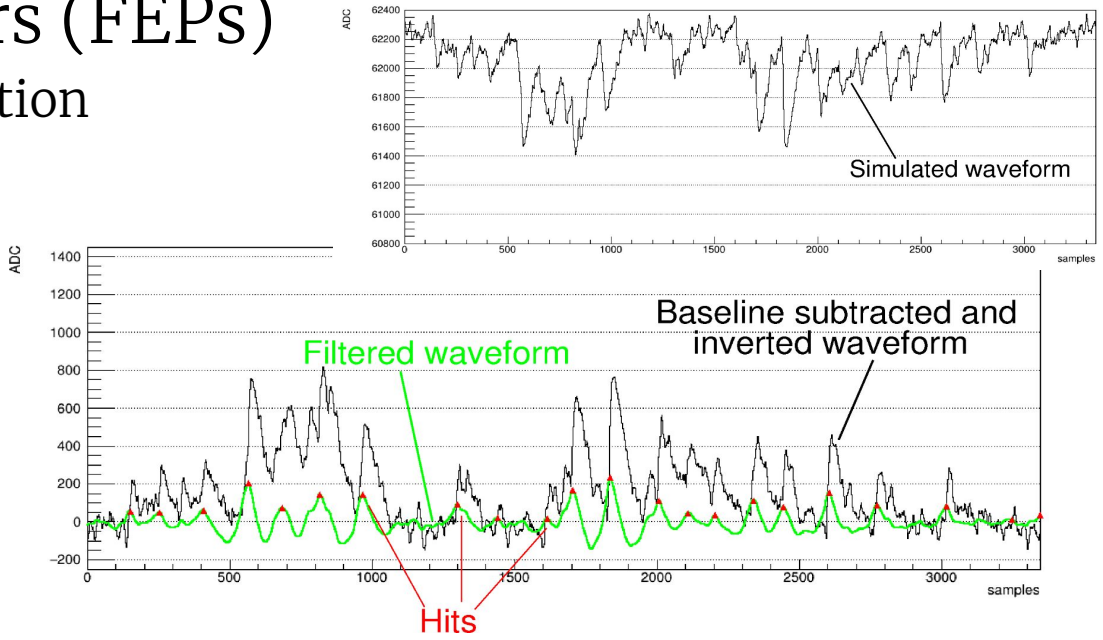
- Waveforms from the photosensors are digitized by **VME VX2745 CAEN** digitizer modules **16 bit, 125MS/s ADC**
- **Custom firmware** developed at TRIUMF laboratory designed to identify only waveform segments containing a signal
- **Dynamic waveform window**: enlarge the gate if the post-trigger contains a new trigger



Front End Processors (FEPs)

The challenge of data reduction

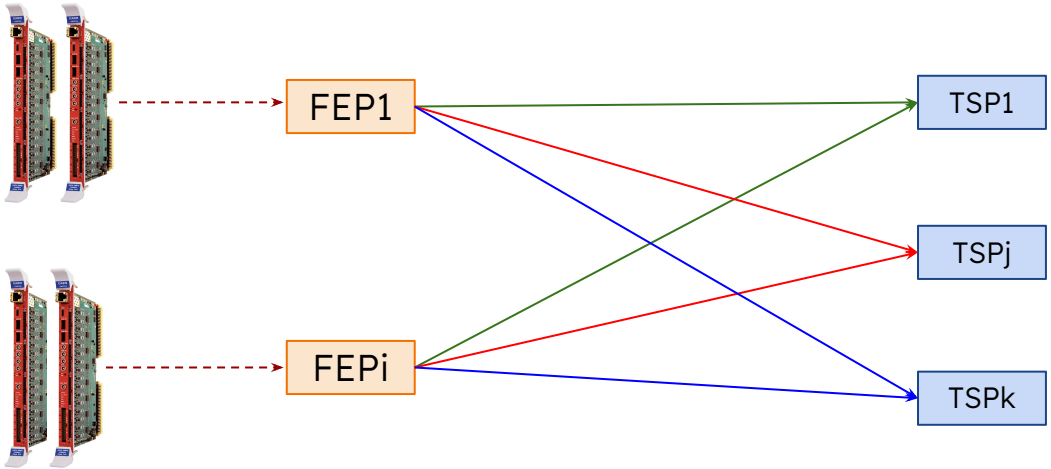




- DS-20k will operate in **triggerless mode,** with an expected event rate of **200 evts/s** → we cannot save all the individual channel waveforms to disk !
- Filtering is necessary to remove noise spikes (ARMA algorithm)
- Waveform **reduction to hit** time/charge (# PEs) is needed in real time (still 2PB/year!)
- Data are sorted into 1 s time slices to be sent to the next acquisition stage

Time Slice Processors (TSPs)

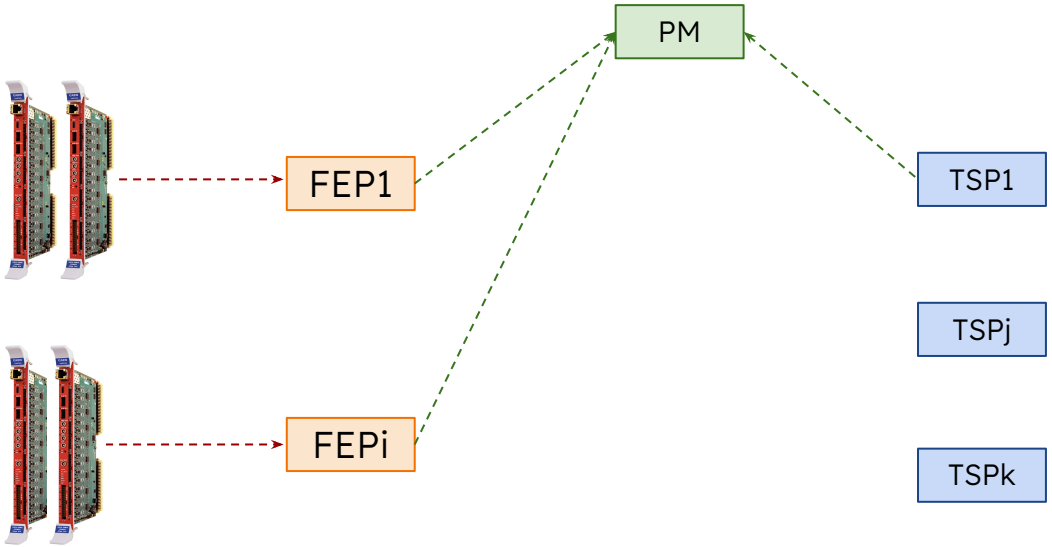
The challenge of data reduction



- Hits sequences belonging to the same 1 s time slice are gathered into the same online computing node
- Time slices are sent via raw TCP/IP sockets
- Perform high level analysis on the TSPs (hit clustering / pulse finding, energy, XY…)
- TSPs responsible for streaming data according to the physics event

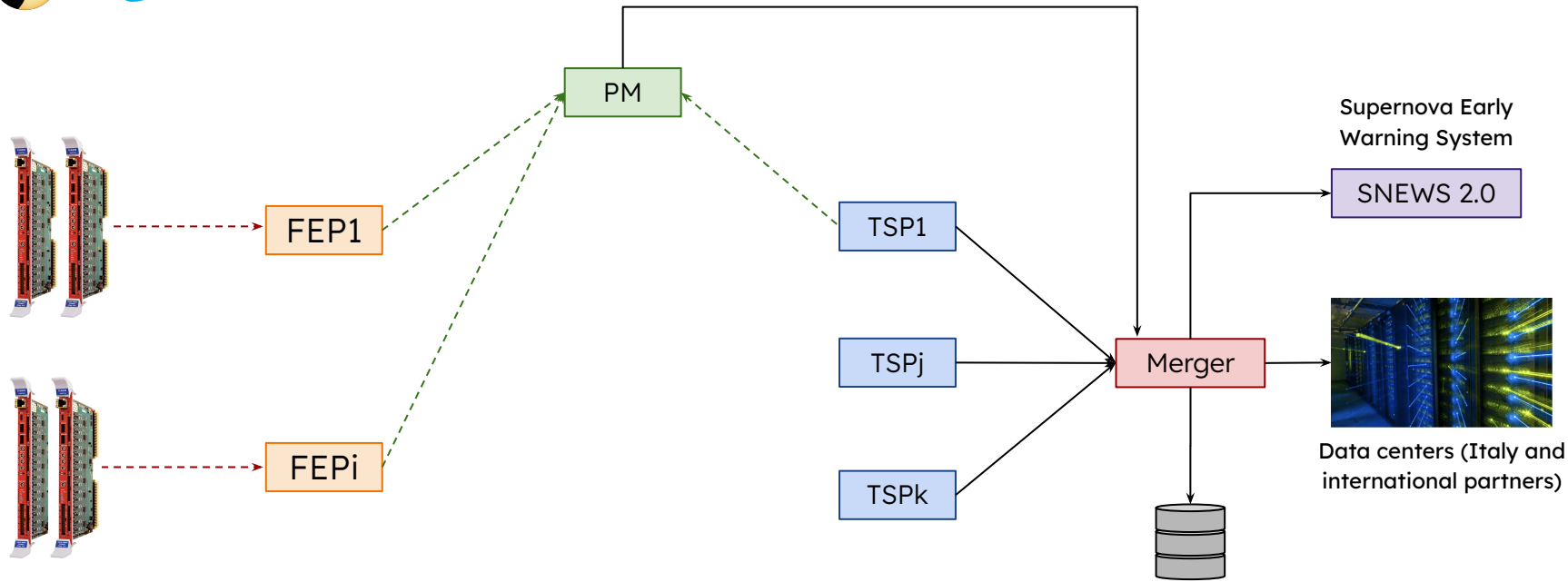
Pool Manager (PM)

Orchestrating the data flow



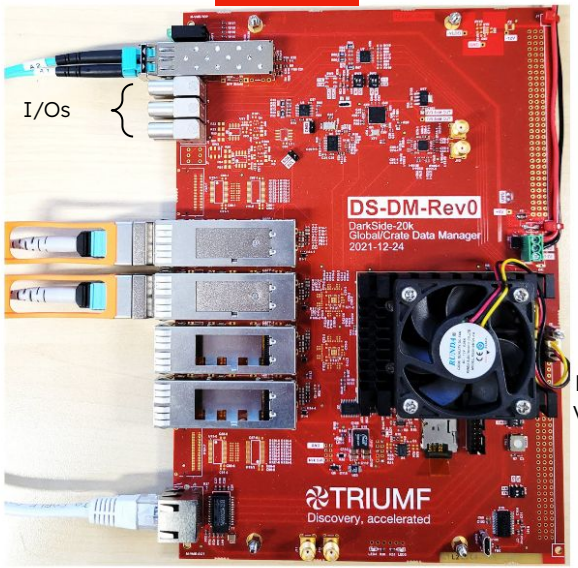
- The Pool Manager (PM) communicates with both the FEPs and TSPs via ZeroMQ message queue: it gets informed by the FEPs about the available time slices and from TSPs about their status
- The PM informs the FEPs of the next available TSPs

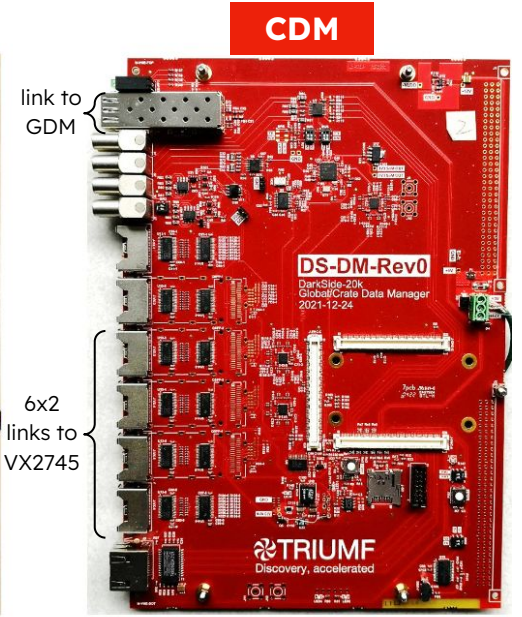
The Merger



- Time slices from different TSPs are collected into the Merger, stored to disk and sent to Data Centers
- The Merger can also perform physics analysis on longer timescales like Supernova identification and send the results to the Supernova Early Warning System (SNEWS 2.0)

Global Data Manager (GDM) and Crate Data Manager (CDM)





CDM

Transmits to 12 VX:

- Common clock
- VX commands

Collects up to 12 VX:

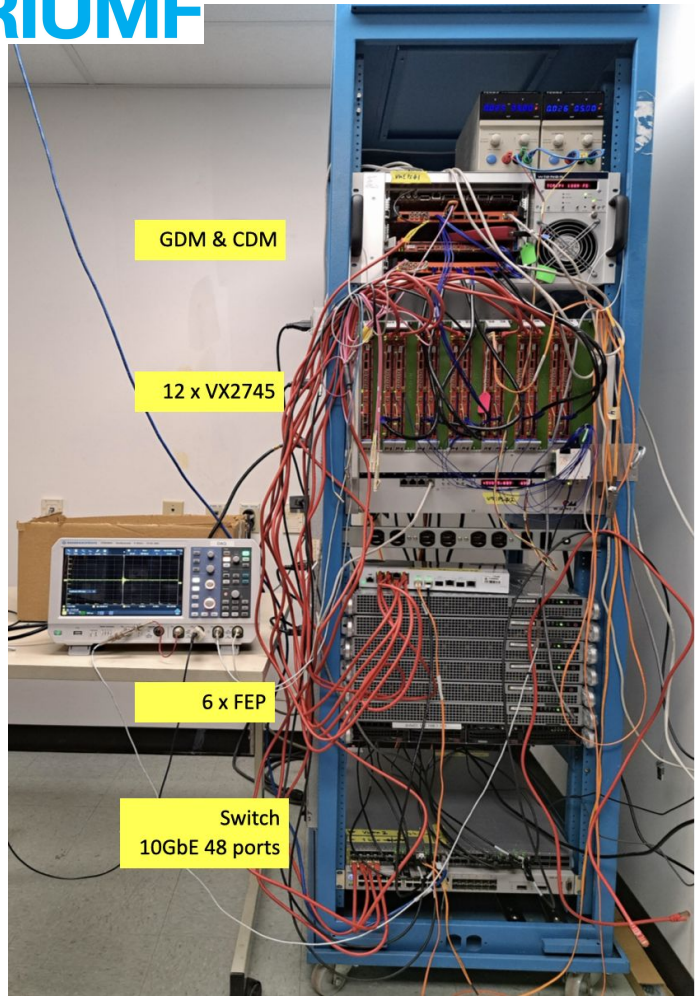
- Module busy bits
- Prompt “self-trigger “ bits

I/Os	Specification	Purpose
1 RJ45 port	1Gbit Ethernet	Configuration
4 QSFP+	2.5Gb/s communication to CDM	Clock Trigger
4 NIM inputs	IRIG-B, 10MHz Ref clock, Ext TrgIN-1, Ext TrgIN-II	GPS, Triggers
4 NIM outputs	1PPS, Ext TrgOUT-1	GPS, Trigger

The Quadrant

A test bench for DS-20k data acquisition

- ¼ of DarkSide-20k data acquisition system up and running at TRIUMF laboratory (Vancouver, Canada)
- System structure:
  - 1 x GDM
  - 1 x CDM
  - 12 x VX2745 digitizers
  - 6 x FEP computers
  - 1 x 48 ports 10 GbE switch
- The system allows for firmware testing, digitizer software and machine-specific softwares performing the online analysis



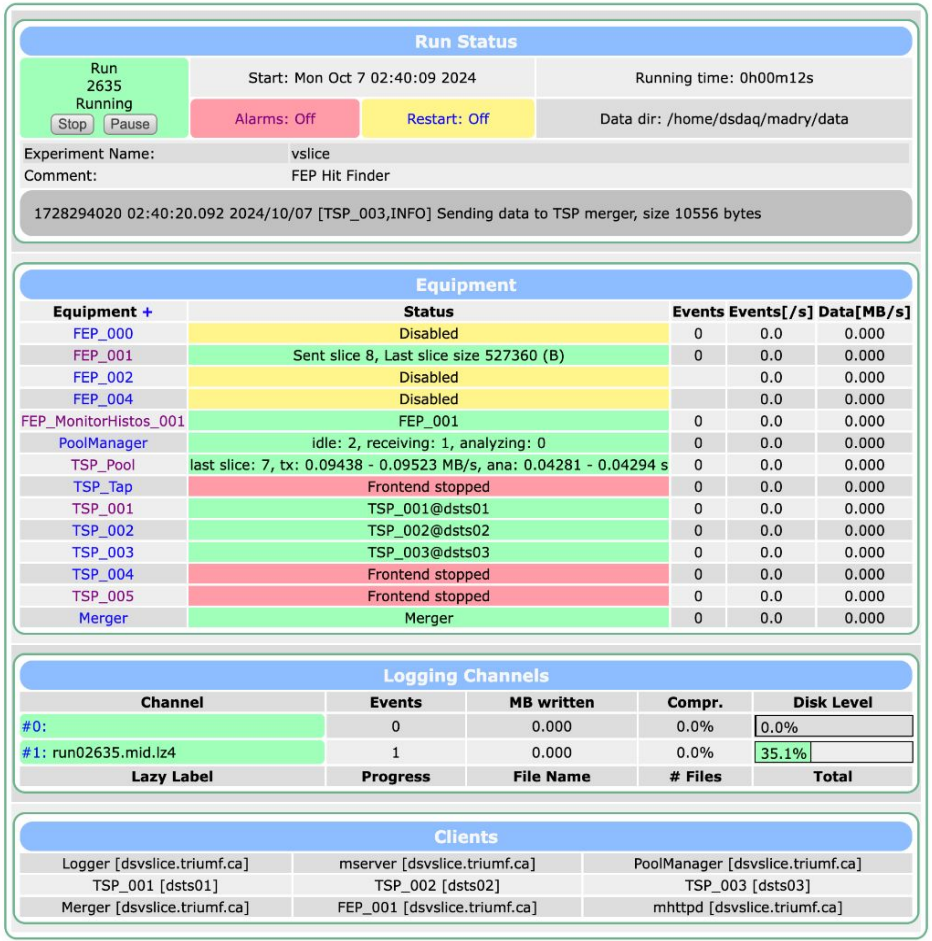
A mockup of DS-20k data flow

A software implementation of the full data flow

Input can be real data from the VX2745 or binary data with simulated waveforms

DAQ infrastructure built in MIDAS (Maximum Integrated Data Acquisition System) software package developed at TRIUMF and PSI

Monitoring system under development: key quantities displayed on a webpage



Run Status

Run 2635 Running [Stop] [Pause]	Start: Mon Oct 7 02:40:09 2024	Running time: 0h00m12s
	Alarms: Off / Restart: Off	Data dir: /home/dsdaq/madry/data

Experiment Name:	vslice
Comment:	FEP Hit Finder

1728294020 02:40:20.092 2024/10/07 [TSP_003,INFO] Sending data to TSP merger, size 10556 bytes

Equipment

Equipment +	Status	Events	Events[/s]	Data[MB/s]
FEP_000	Disabled	0	0.0	0.000
FEP_001	Sent slice 8, Last slice size 527360 (B)	0	0.0	0.000
FEP_002	Disabled		0.0	0.000
FEP_004	Disabled		0.0	0.000
FEP_MonitorHistos_001	FEP_001	0	0.0	0.000
PoolManager	idle: 2, receiving: 1, analyzing: 0	0	0.0	0.000
TSP_Pool	last slice: 7, tx: 0.09438 - 0.09523 MB/s, ana: 0.04281 - 0.04294 s	0	0.0	0.000
TSP_Tap	Frontend stopped	0	0.0	0.000
TSP_001	TSP_001@dsts01	0	0.0	0.000
TSP_002	TSP_002@dsts02	0	0.0	0.000
TSP_003	TSP_003@dsts03	0	0.0	0.000
TSP_004	Frontend stopped	0	0.0	0.000
TSP_005	Frontend stopped	0	0.0	0.000
Merger	Merger	0	0.0	0.000

Logging Channels

Channel	Events	MB written	Compr.	Disk Level
#0:	0	0.000	0.0%	0.0%
#1: run02635.mid.lz4	1	0.000	0.0%	35.1%
Lazy Label	**Progress**	**File Name**	**# Files**	**Total**

Clients

Logger [dsvslice.triumf.ca]	mserver [dsvslice.triumf.ca]	PoolManager [dsvslice.triumf.ca]
TSP_001 [dsts01]	TSP_002 [dsts02]	TSP_003 [dsts03]
Merger [dsvslice.triumf.ca]	FEP_001 [dsvslice.triumf.ca]	mhttpd [dsvslice.triumf.ca]

Conclusion and next steps

A lot of results...

- DAQ quadrant system operational at TRIUMF
- System expected to be shipped to Laboratori Nazionali del Gran Sasso in Feb/March 2025
- Paper on DarkSide-20k DAQ in preparation for publication in late 2025

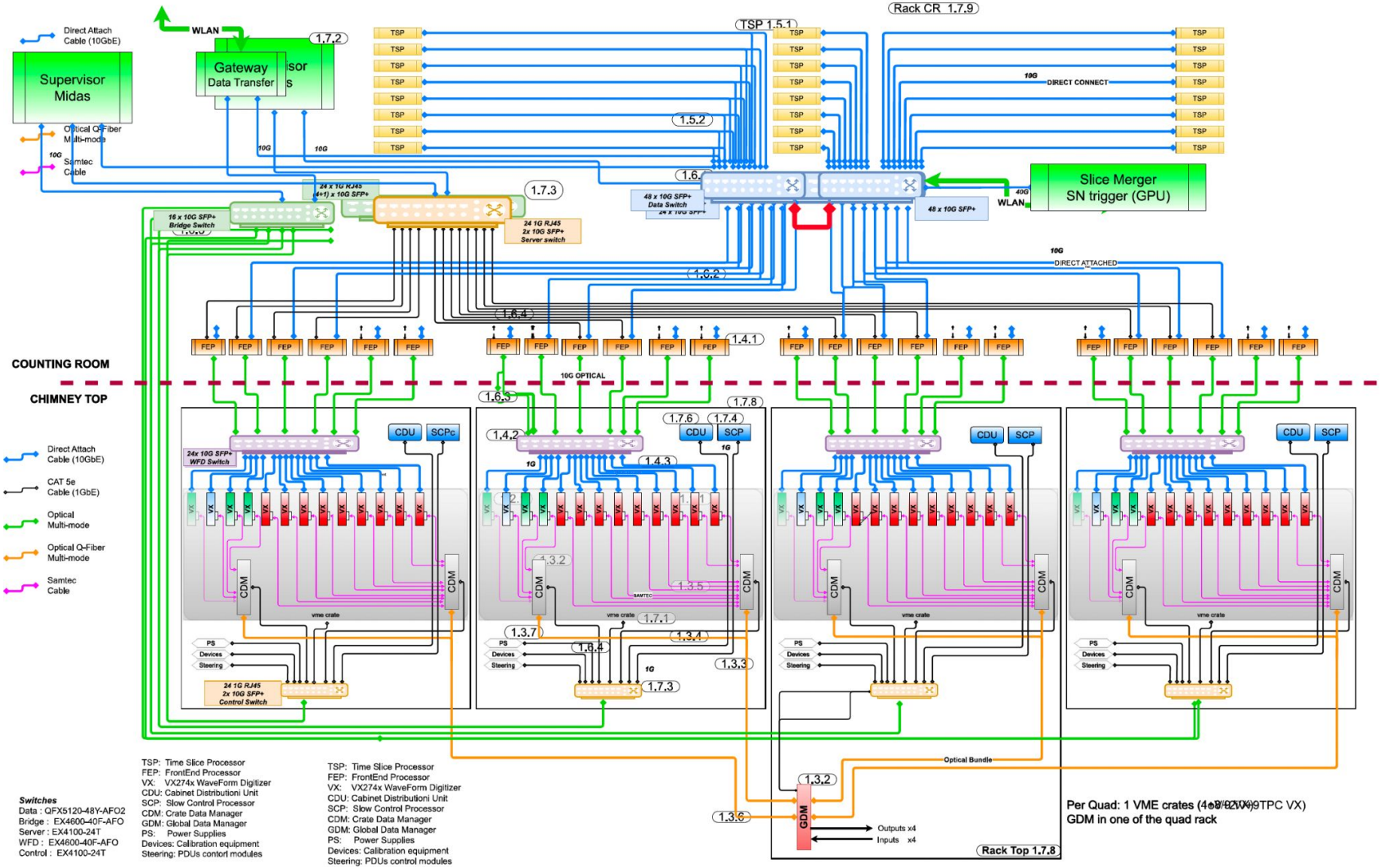
... and a lot more to come!

- Monitoring system to be completed with additional features
- Online analysis to be refined and tested
- Supernova trigger to be implemented
- DAQ chain and online analysis to be tested with data from DS-20k prototype, currently running at Università Federico II, Naples.

THANK YOU FOR YOUR ATTENTION!

Maria Adriana Sabia
mariaadriana.sabia@uniroma1.it

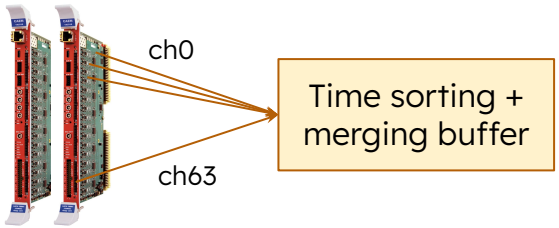
Backup



Direct Attach Cable (10GbE)
Supervisor Midas
Optical Q-Fiber Multi-mode
Samtec Cable
WLAN
Gateway Data Transfer
1.7.2
10G
TSP 1.5.1
Rack CR 1.7.9
TSP
1.5.2
DIRECT CONNECT
Slice Merger SN trigger (GPU)
40G
WLAN
48 x 10G SFP+
24 x 1G RJ45 (4+1) x 10G SFP+
16 x 10G SFP+ Bridge Switch
1.7.3
24 1G RJ45 2x 10G SFP+ Server switch
48 x 10G SFP+ Data Switch
DIRECT ATTACHED
1.6.2
1.6.4
1.4.1
FEP
COUNTING ROOM
CHIMNEY TOP
10G OPTICAL
1.6.3
1.7.8
1.7.6
1.7.4
1.4.2
1.4.3
CDU
SCPc
SCP
1G
24x 10G SFP+ WFD Switch
VX
CDM
vme crate
1.3.2
1.3.5
1.7.1
1.3.7
1.6.4
1.3.4
1.3.3
PS
Devices
Steering
24 1G RJ45 2x 10G SFP+ Control Switch
Direct Attach Cable (10GbE)
CAT 5e Cable (1GbE)
Optical Multi-mode
Optical Q-Fiber Multi-mode
Samtec Cable
Optical Bundle
1.3.2
1.3.6
GDM
Outputs x4
Inputs x4
Rack Top 1.7.8
Per Quad: 1 VME crates (4+8/8/2TPC VX)
GDM in one of the quad rack
Switches
Data : QFX5120-48Y-AFO2
Bridge : EX4600-40F-AFO
Server : EX4100-24T
WFD : EX4600-40F-AFO
Control : EX4100-24T
TSP: Time Slice Processor
FEP: FrontEnd Processor
VX: VX274x WaveForm Digitizer
CDU: Cabinet Distributioni Unit
SCP: Slow Control Processor
CDM: Crate Data Manager
GDM: Global Data Manager
PS: Power Supplies
Devices: Calibration equipment
Steering: PDUs contorl modules
TSP: Time Slice Processor
FEP: FrontEnd Processor
VX: VX274x WaveForm Digitizer
CDU: Cabinet Distributioni Unit
SCP: Slow Control Processor
CDM: Crate Data Manager
GDM: Global Data Manager
PS: Power Supplies
Devices: Calibration equipment
Steering: PDUs control modules

BUSY logic

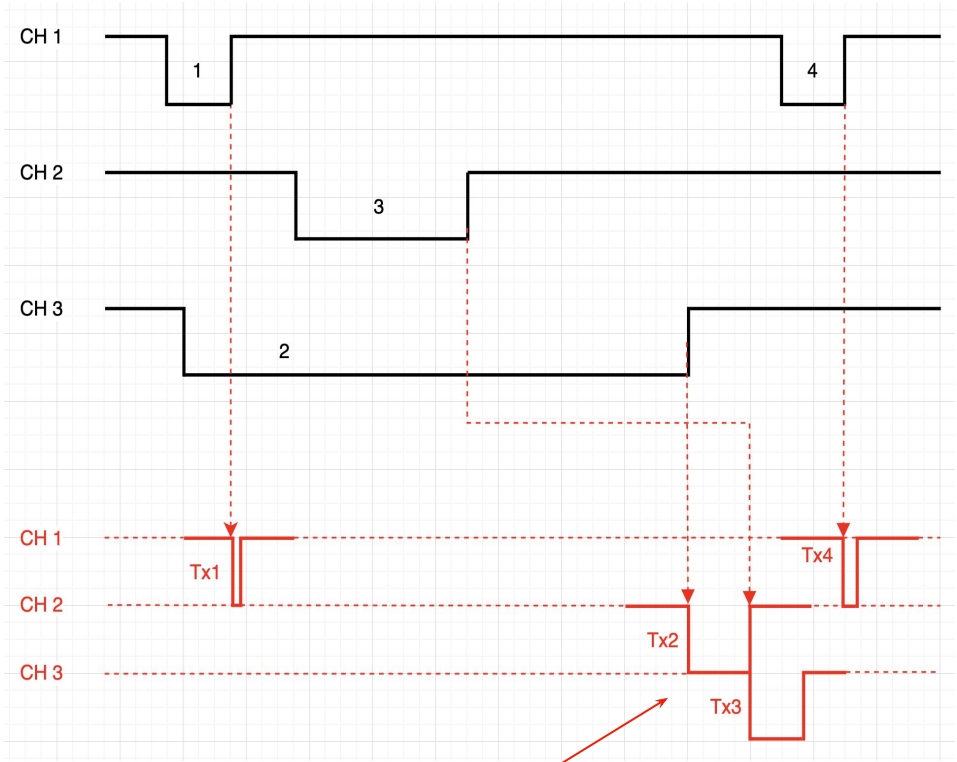
Firmware implementation



64 channels/module merged in the same buffer where they are sorted in time

= Input

= Transmission (Tx) output FIFO to sorting buffer



The readout is **16 bits per 8 ns**

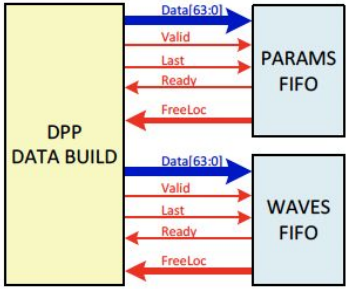
The Tx to the sorting is 64 bits per 4 ns = **8x faster than the readout**

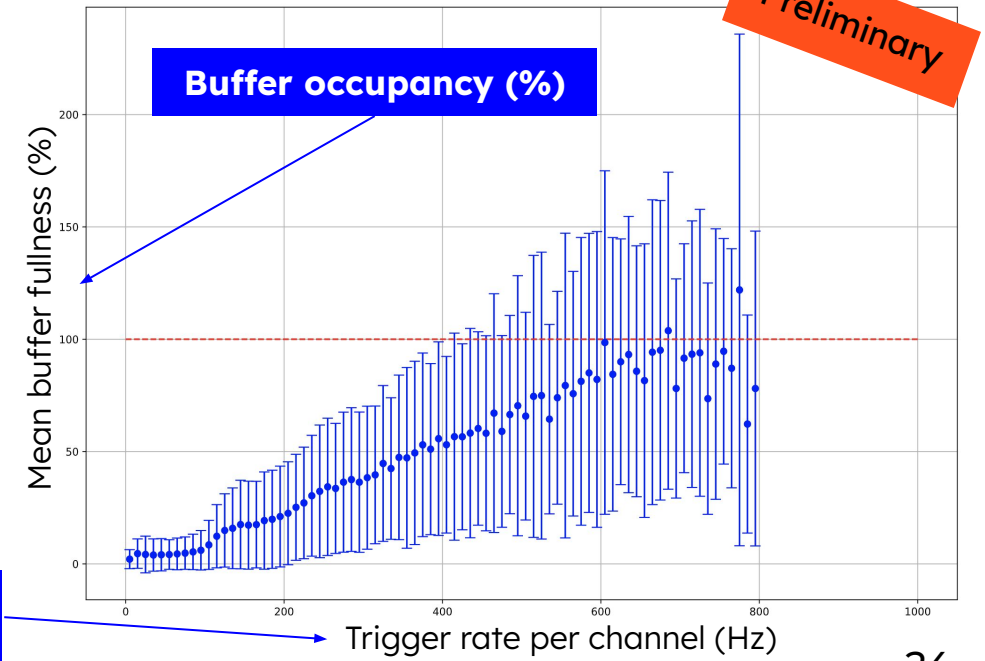
"Ladder" trend expected due to time sorting

Software for the DAQ

BUSY logic simulation: the challenge

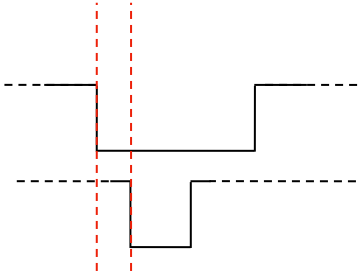
- Triggerless mode for maximum flexibility …
- … but event bursts can introduce dead time (DAQ BUSY)!
  - multiple scattering events from gamma radioactivity
  - large pulses
- Simulation of the digitiser firmware busy logic to evaluate impact on detector exposure

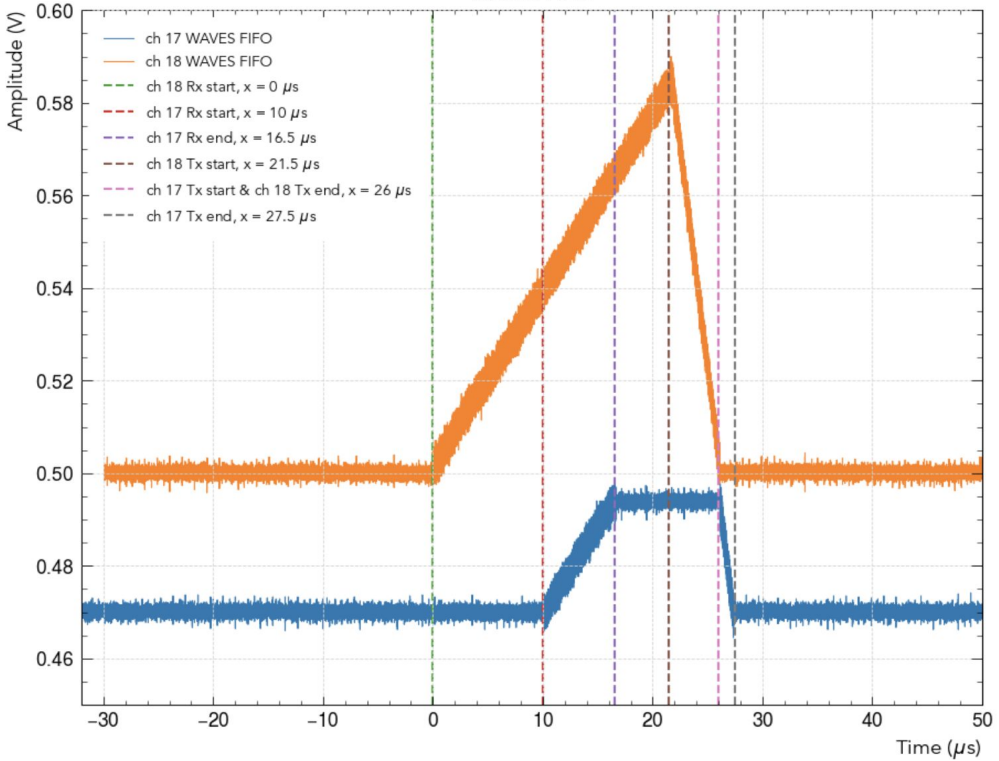




BUSY logic

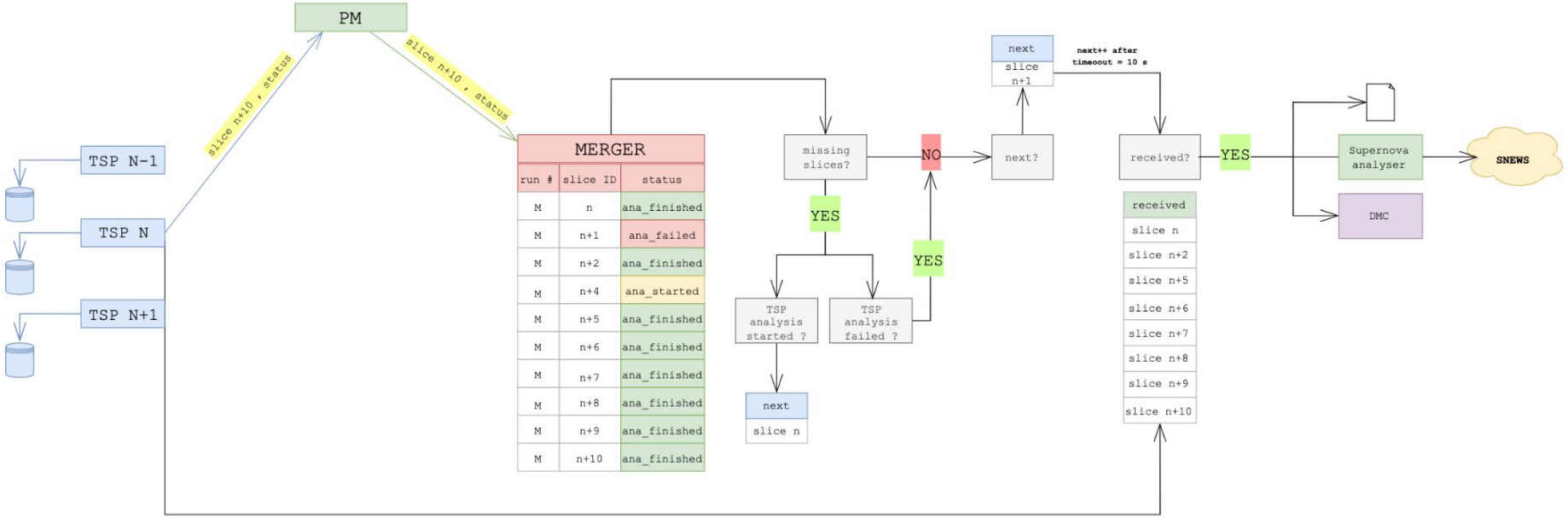
Simulation vs data comparison



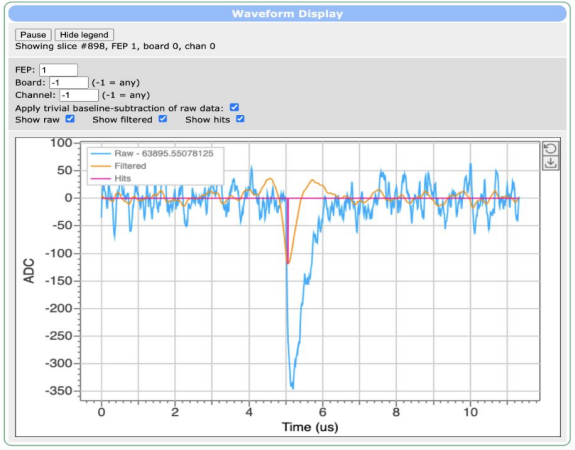
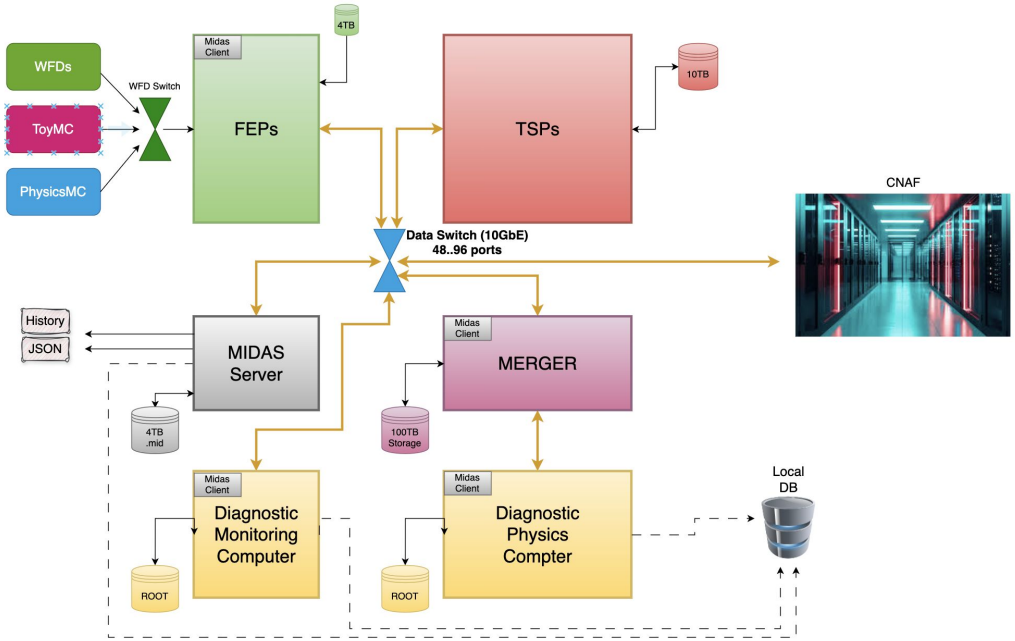


- Same waveform pattern can fed into the digitizers
- Buffer level of each channel can be read out from the front panel and fed into an oscilloscope
- The firmware implementation also allows for the most occupied channel buffer to be retrieved

The merger


PM
slice n+10 , status
slice n+10 , status
TSP N-1
TSP N
TSP N+1
MERGER
run # | slice ID | status
M | n | ana_finished
M | n+1 | ana_failed
M | n+2 | ana_finished
M | n+4 | ana_started
M | n+5 | ana_finished
M | n+6 | ana_finished
M | n+7 | ana_finished
M | n+8 | ana_finished
M | n+9 | ana_finished
M | n+10 | ana_finished
missing slices?
NO
next?
next
slice n+1
next++ after timeoout = 10 s
received?
YES
YES
TSP analysis started ?
TSP analysis failed ?
YES
next
slice n
received
slice n
slice n+2
slice n+5
slice n+6
slice n+7
slice n+8
slice n+9
slice n+10
Supernova analyser
DMC
SNEWS

Monitoring system

3 groups of monitoring quantities:

1. per-channel monitoring: event variables such as fingerplots and hit rates, some expensive computations like noise FFTs, manual studies like individual waveforms visualization
2. detector-level monitoring: S1/S2 identification, energy spectra, pulse-level statistics
3. DAQ monitoring: transmission rates, buffer sizes, CPU usages