# DS-20K DAQ&Trigger

Warsaw, Jan 2019

Marco Rescigno/INFN Roma1

# DS20K Trigger & Daq Tasks

- Two detectors (TPC and Neutron Veto)
  - Possibility for an expansion with on outer muon veto
- Digitization of the the 8280 PDM analog signals for the TPC
  - possibly reduced number if channel sum is implemented
  - Include on-board hit discrimination algorithm (filter) and preliminary S1/S2 discrimination
- Digitization of the ~3000 channel for neutron veto…
- Development of a software trigger farm able to digest the raw data rate produced by the TPC and Veto
  - Online reconstruction and selection of events
  - Online monitoring
  - Data logging
- Development of an online software framework for DAQ/Run Control/ Slow Control
- Eventually development and installation of a counting room to host digitizer/trigger farm/power supplies etc.

- Regular meeting time: Thursday 6 pm LNGS time
  - https://fnal.zoom.us/j/7707626441

# Rate Estimates

- Three sources considered: $^{39}$Ar decays; surface background due to radiogenic background; SiPM noise rate:
  - ➢ $^{39}$Ar activity in AAr is 1 Bq/Kg, UAr depletion is assumed to be 1400 as in DS50, scaling with mass (40 active Ton vs 50 Kg)
    - ✧ Expect 30 Hz from $^{39}$Ar (notice no Kr contamination is expected after Aria purification)
  - ➢ Scaling the residual Bkg rate with the ratio of DS20K to DS50 surfaces (>60), overly conservative:
    - ✧ Low background design adopted, impact of radioactivity in materials closer to the Uar target should be tiny…
  - ➢ Negligible trigger rate from noise from simulation
- Assume 50 Hz as typical trigger rate in the following
- Pile-up expected in >10 % of the triggers

# Simulation/S1 and S2

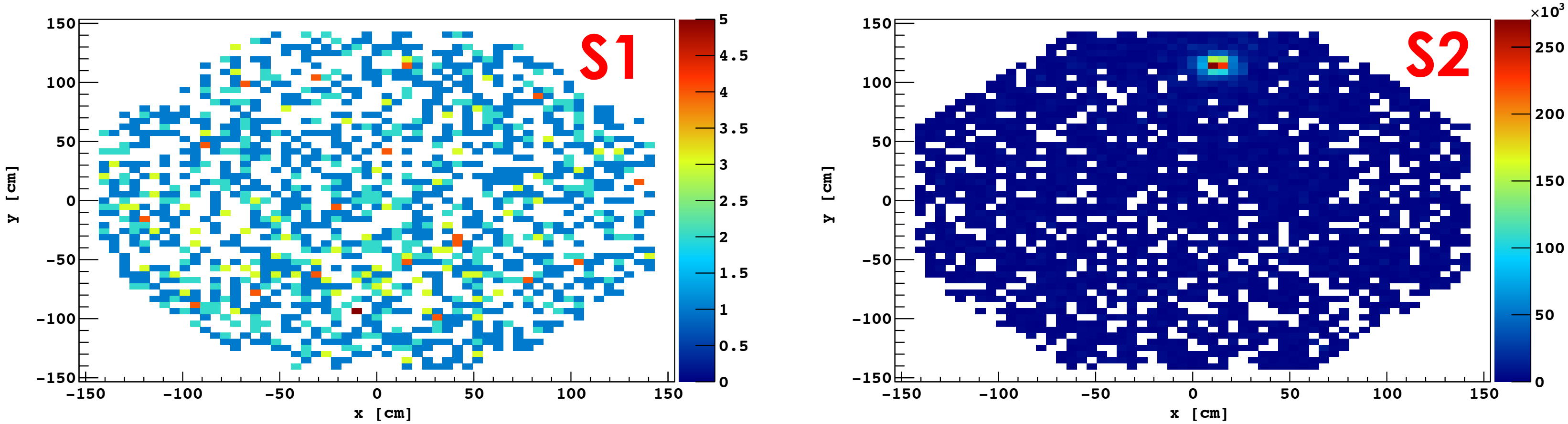



FIG. 82. Hit Maps for the bottom plane of a typical S1 signal **(Left)** and for the top plane of the S2 signal **(Right)**.

- In the DM region of interest S1 signal inducess less than 1 pe per readout channel (PDM) distributed flat in space
- S2 signal nicely localized in few channels, simplified photon counting algorithm provide sub-cm xy resolution, PDM signal saturate at around 50 pe pileup, special attention shall be devoted to study/mitigate saturation effects

# Simulation/S1 & S2 (YB)

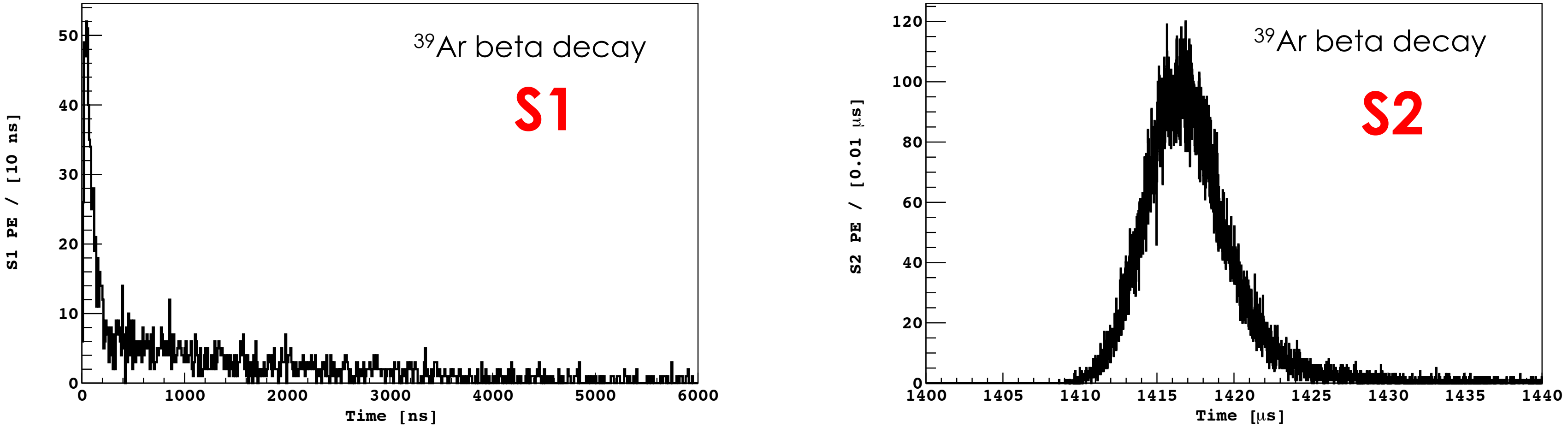
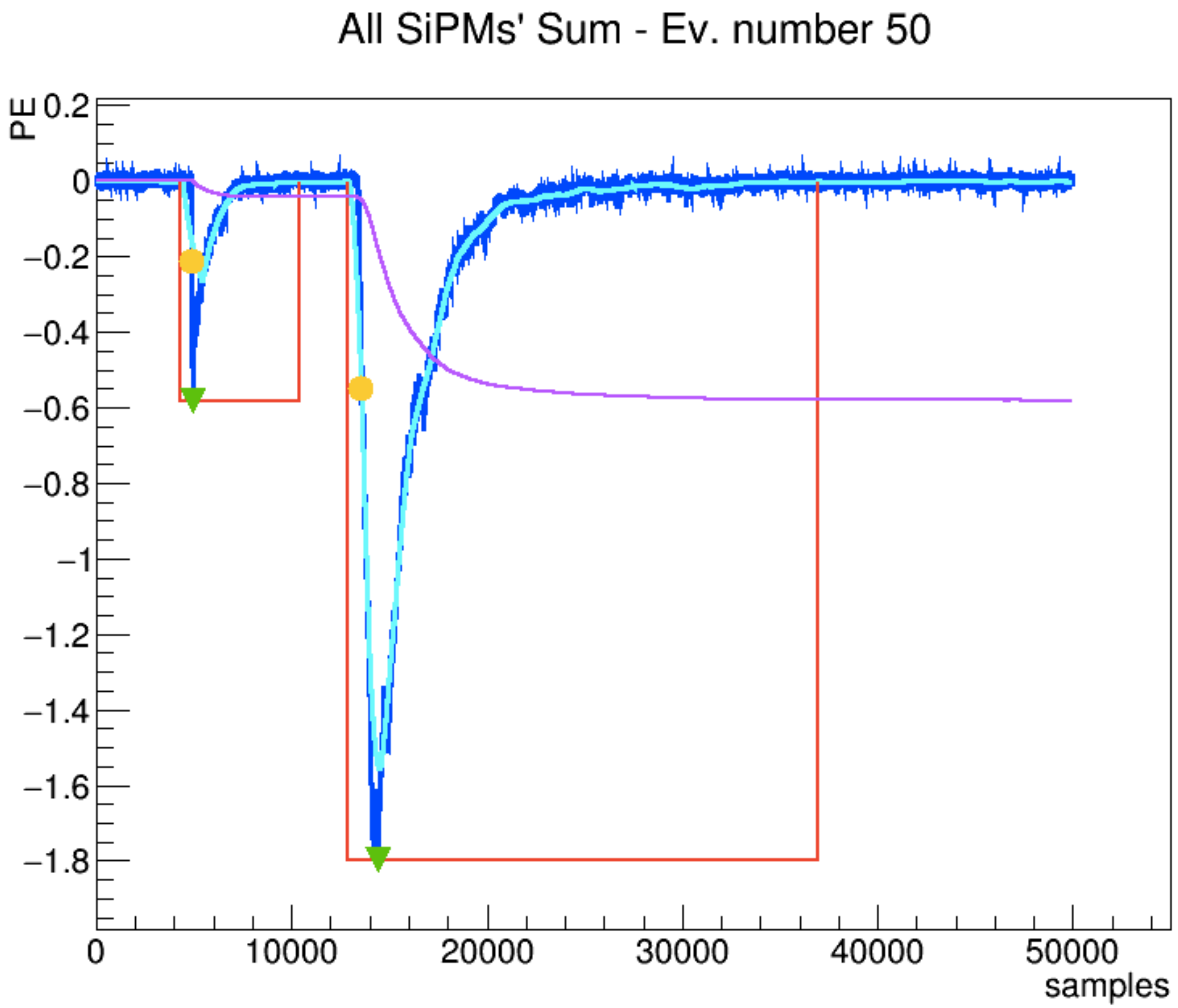


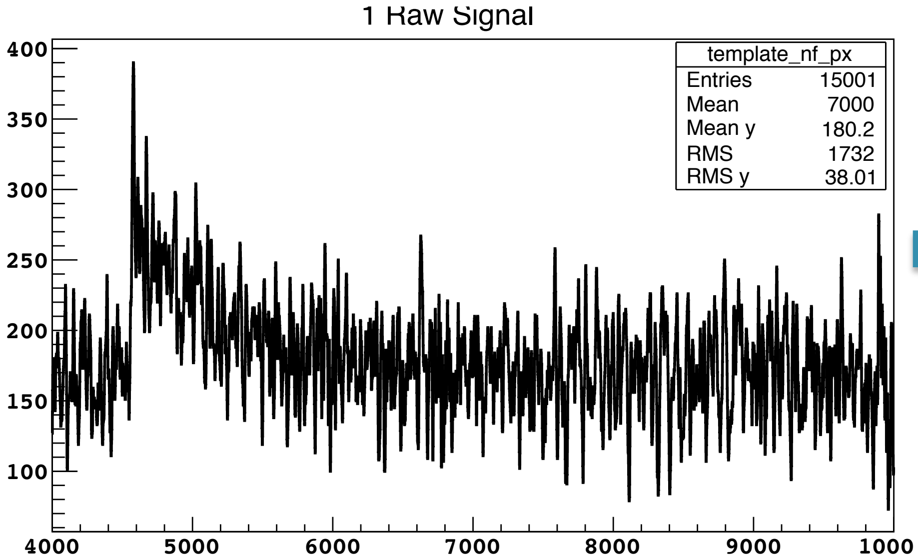

FIG. 81. Arrival time of S1 **(Left)** and S2 **(Right)** in DarkSide-20k, resulting from a complete simulation of the detector, electronics, and DAQ.

- First simulations completed for the YB publication. Included early implementation of electronic noise noise (DCR, cross talk and after pulses) and readout electronics (to be updated with latest numbers and more realism).
  - S1 signal collected in 5-6 us, probability of multiple hit on a single tile very low, with the exception of events near cathode or anode
- S2 signal much slower (~20 us )
  - The proposed design will be able to acquire an S2 waveform upon identification of a long pulse in a single tile: improve double hit resolution and S1/S2 discrimination

# A real example (from ReD)

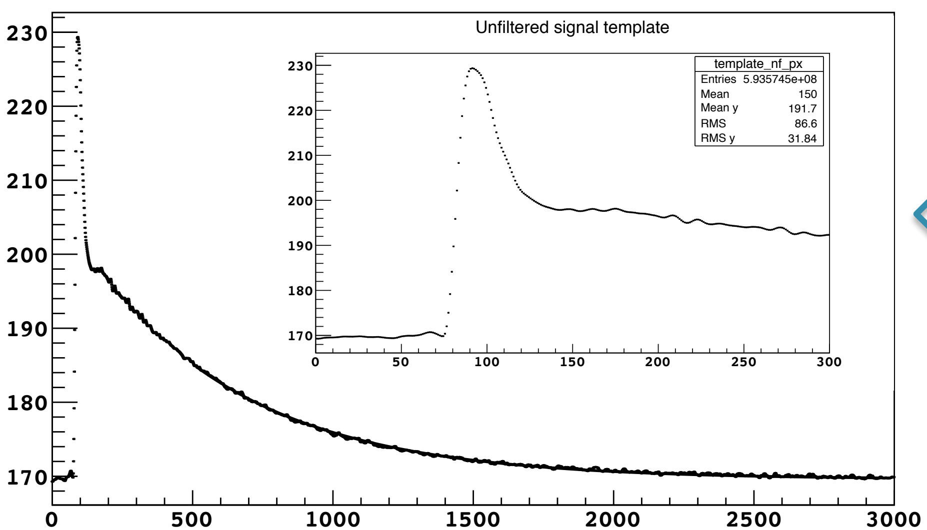


# Signal from PDM




S/N ~3 (raw)
Time constant ~500 ns (currently, may change)
Fast pulse <1/20 of overall signal
10-15 mV with current FEB
<50 MHz BW
~100 dynamic range

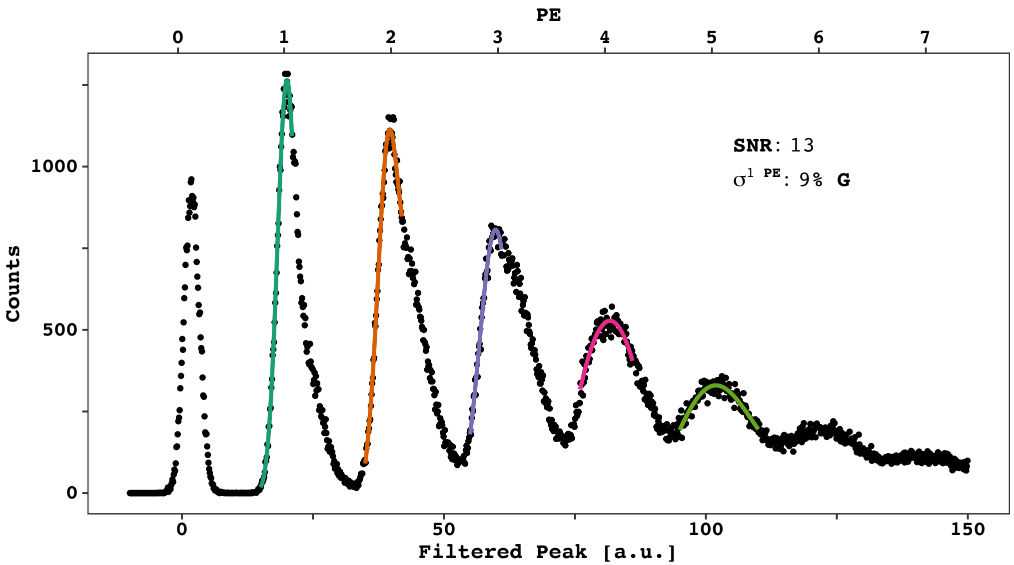
**1PE Template**

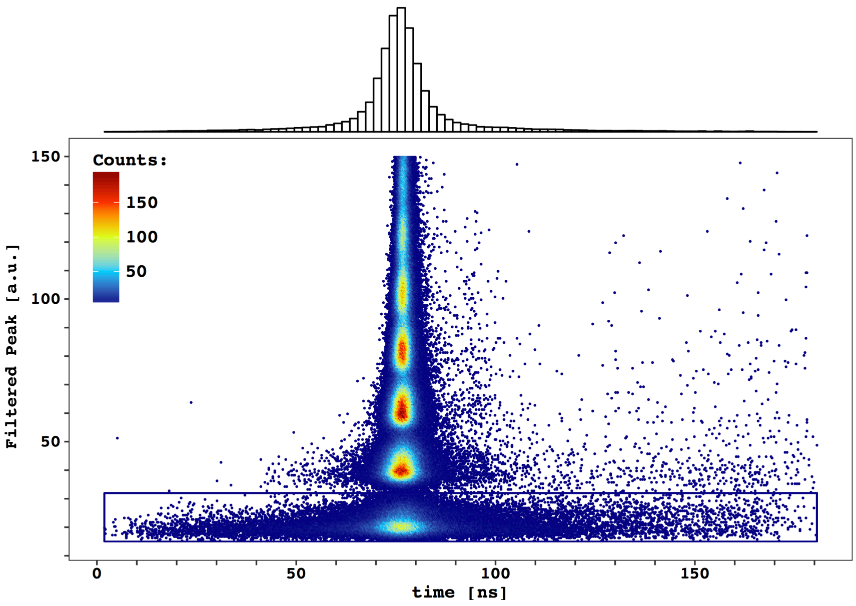



SPE signal averaged over thousands traces (Template for DSP)

# Pulse Height Spectra After DSP

arxiv:1706.04220



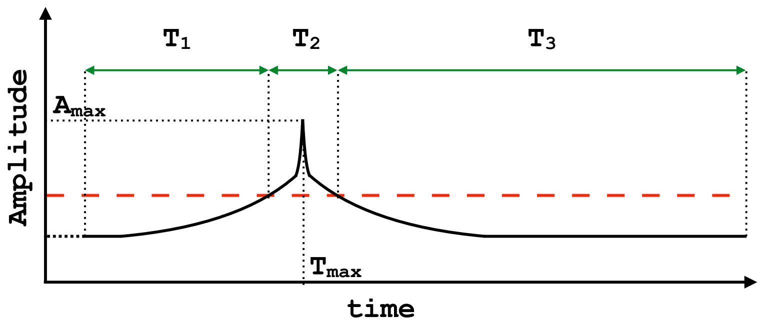

**16 ns resolution (RMS) for 1PE peak**

**Signal acquired with a fast digitizer and processed offline with a cross correlation filter with $\tau$ of 400 ns**

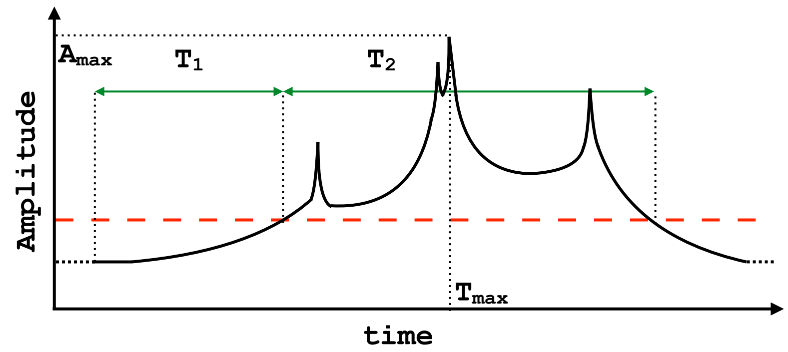
To obtain the needed S/N and time resolution on single PE for online trigger purposes a DSP need to be foreseen at the digitizer board level

# S1/S2 digitization

Filtered signal




From C. Savarese Phd thesis

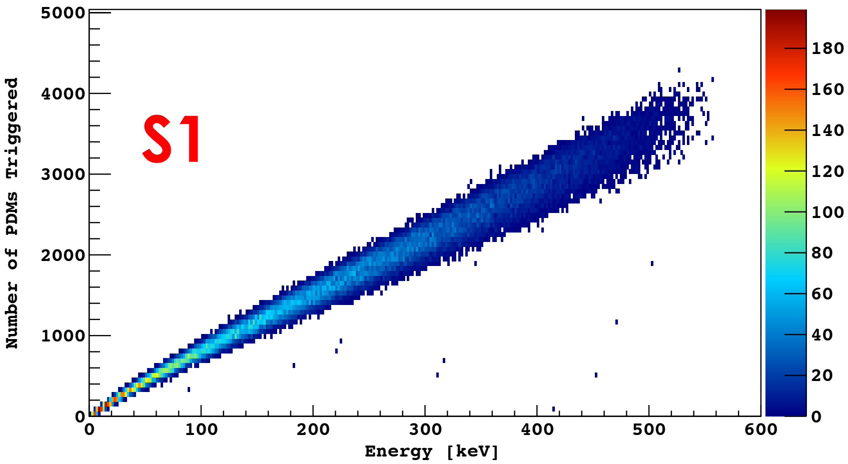


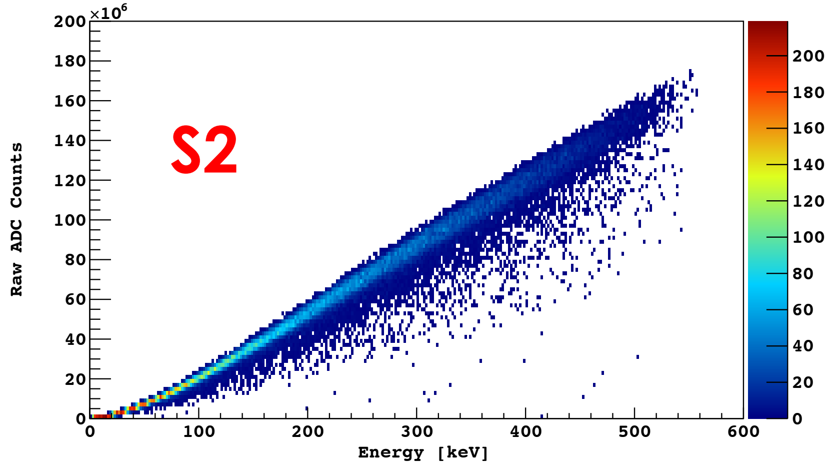

- On-board algorithm to distinguish S1 from S2-like algorithm
- Possibly based based on Time over Threshold (e.g. S1<5 μs, S2>5 μs)
- Allow raw waveform to be digitized for single PE hits and a reduced sampling rate digitization for S2-like signals
- Should time the single-PE hit with O(10 ns) resolution to allow low threhold
- A matched FIR filter is adequate

# Work on Simulation

- New, more accurate simulation will allow to be tested against ReD (and then prototype) signals
- Relevant studies for DAQ/Trigger that are needed
  - Study accuracy of matched filter algorithms on realistic events
  - Study accuracy of other filter strategies more gentle on the FPGA resources
  - Study special cases to optimize data reduction strategies
  - Study S2 decimation strategies to optimize energy/position determination

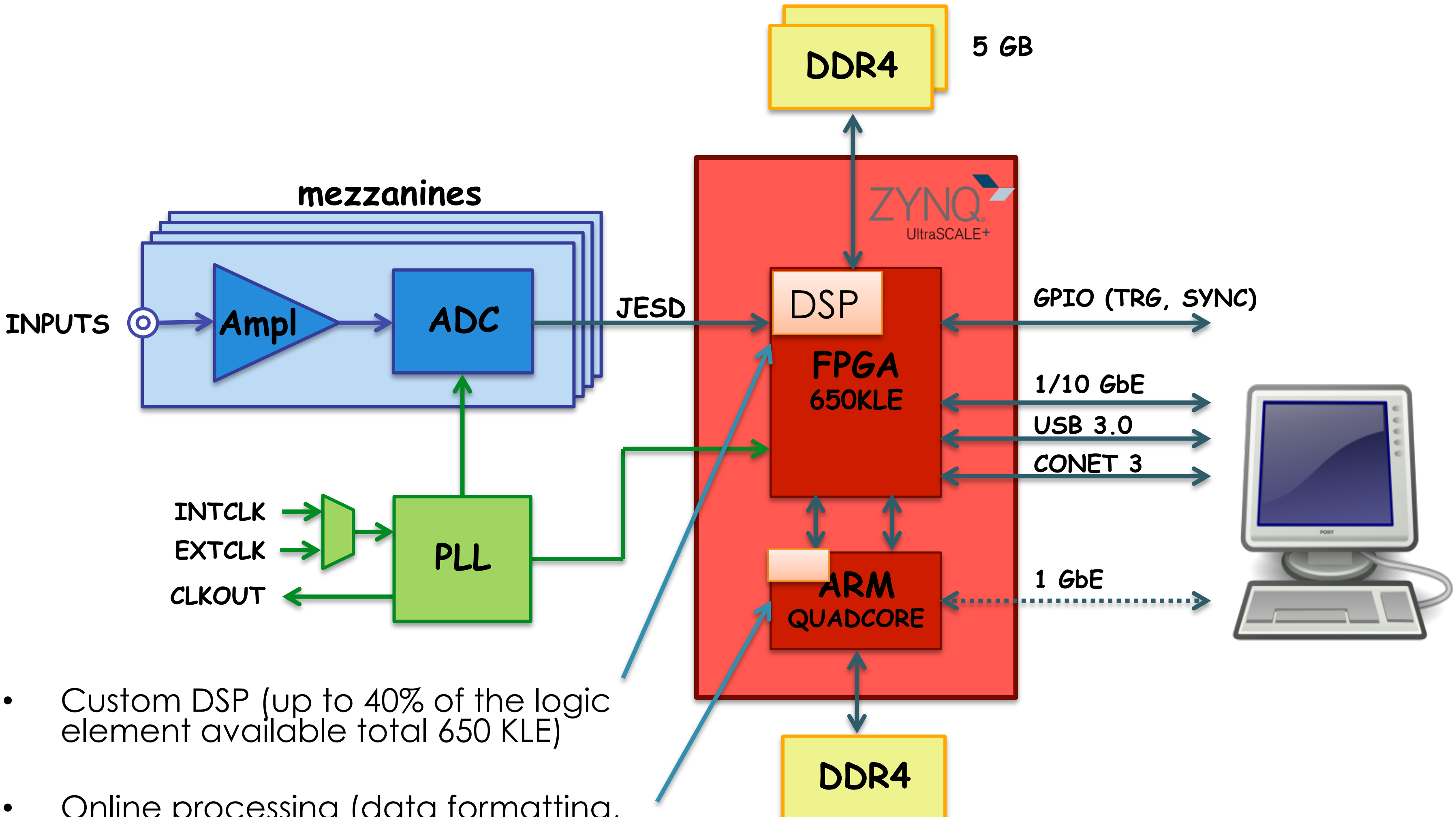
# Simulation/S1 and S2 reco




- Good linearity and reasonable resolution with
  - 5-10% by counting PDMs above threshold (S1) (Single photon counting)
  - 20% by integrating charge with 12 bit/100 MHz and a dynamic range of 64 (S2)
- Improvement in linearity, resolution etc. need to be studied in the context of a "realistic" data acquisition

# CAEN board architecture



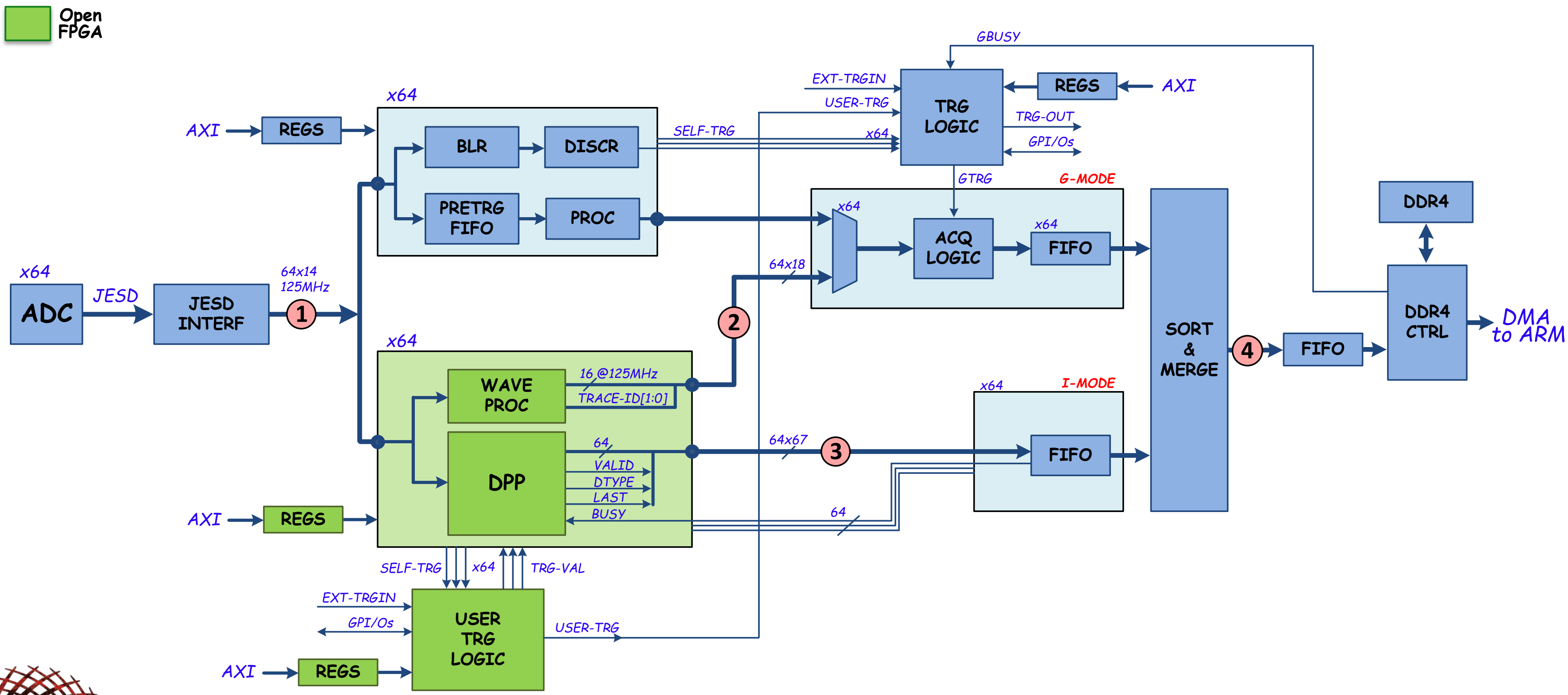

- Custom DSP (up to 40% of the logic element available total 650 KLE)
- Online processing (data formatting, monitoring, compression) also available on the Linux cores

# Tech Specs

- **Form Factor**: VME 6U (1U wide)
- **ADC**: 125 MSps, 14 bit
- **Analog Inputs**: 64 differential, 2 Vpp, 100 ohm, no programmable DC offset
- **Input Connector**: ???
- **Clock+Sync**: two 4 pin connectors (IN and OUT) with retention clip. Daisy-chainable sync bus
- **TRGIN-OUT**: two LEMO connectors (NIM or TTL)
- **GPI/GPO**: two LEMO connectors (NIM or TTL). Start/Stop, Busy, Veto, Tstamp reset, etc…
- **LVDS I/Os**: 16 differential, 2.54 mm header. Trg Pattern, Coincidences, Ctrl signals, etc…
- **DAC out**: 2 Vpp, 125 MSps. Signal inspector, majority, buffer occupancy, etc…
- **FPGA**: Zync US+, Mod. XCZU11EG-L2FFVC1760E; 653K LE, 50 Mbit RAM, Embedded Quad ARM
- **Interfaces**: 1 GbE, 10 GbE, VME, USB 3.0, CONET
- **Memory**: DDR4 (2.5 + 2.5 GB) for PL, DDR4 (2 GB) for PS

# Detailed Block Diagram

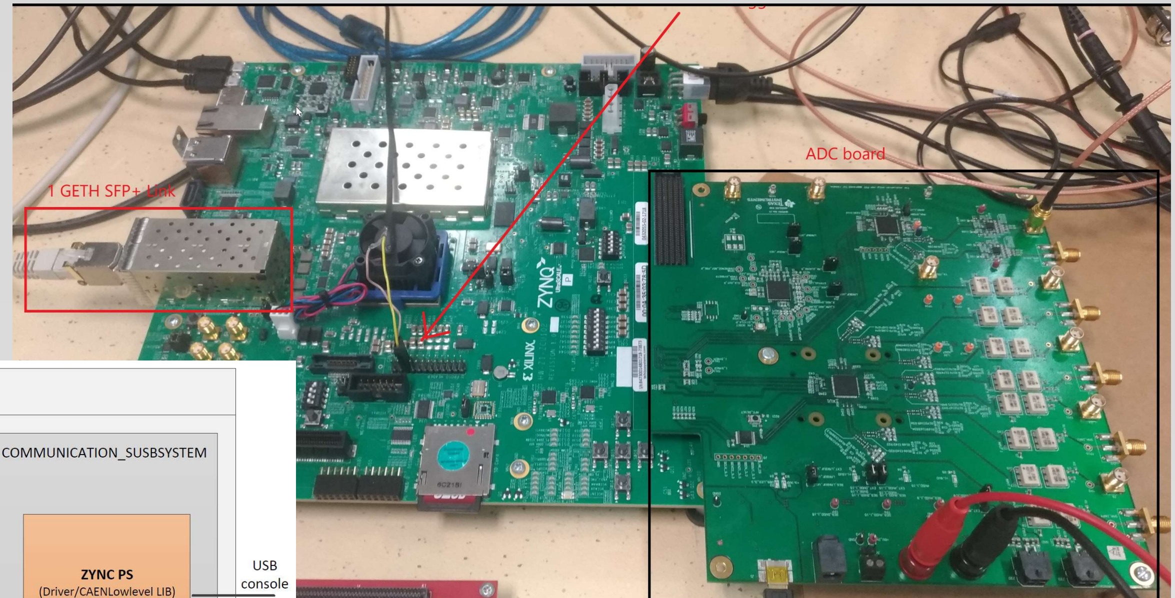
## Detailed FPGA Block Diagram

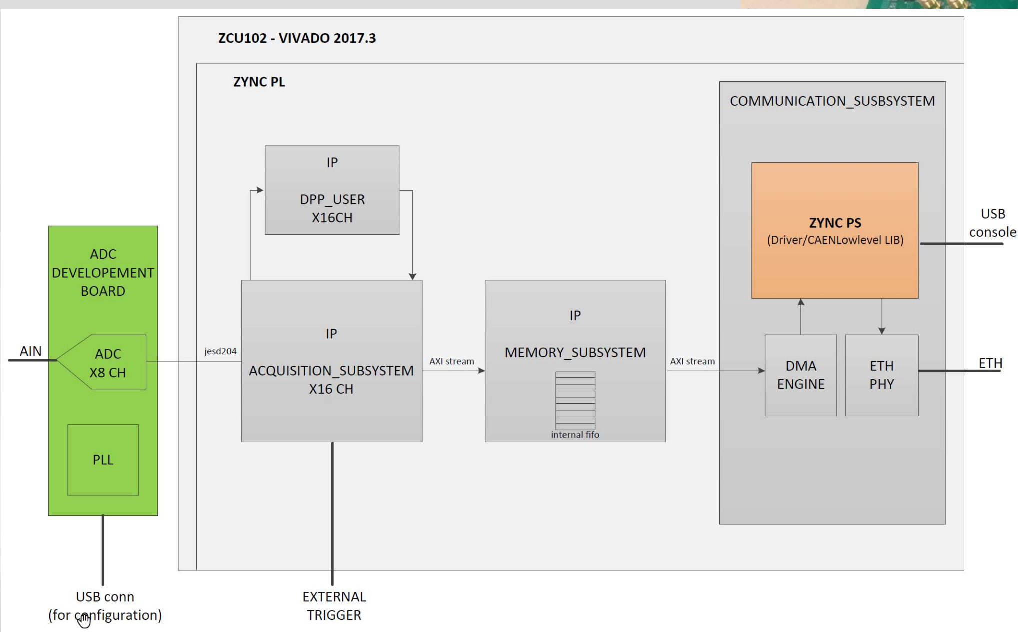


# Existing Evaluation Board

***Proto-II DAQ***

***CAEN Hardware***




Two full channels

Fittingt proposed FIR filter within FPGA may prove difficult

- Bigger FPGA under evaluation
- Restructuring of CAEN firmware and using DDR memory directly

# DSP to do

- Need to revise algorithm to fit into predefined memory and space available in the FPGA → evaluate performance first offline
- May use differently the foreseen h/w
- Need to implement/tune S2-like algorithm
- Need to test using realistically simulated pulses and study performances
  - What happen for photons falling on the same tile within O(1 us) ?
  - How to tune the algorithm, what is the window of the digitized wf to be saved
  - How to set threshold ? What parameters should be set
- Trigger logic for a given board can be foreseen, useful?

# MIDAS DAQ s/w

TRIUMF

## *DEAP Midas DAQ*

Status | Messages | ELog | Programs | History | Sequencer | Chat

Stop FEs | (Re)Start FEs

Run Log | Expert page | CurrentDTMTrigger | MPOD_HV | VME | AARFs | Notifications | Plots | SHUT DOWN HV | Start or Stop Run | Logout

### Run Status

Run 23942 Running

Start: Sat Oct 27 17:29:16 2018 | Running time: 20h01m36s

Alarms: On | Restart: No | Data dir: /deap/dug1/data/MidasFiles

| | |
|---|---|
| **HV on?:** | 1 |
| **Run comment:** | AmBe source deployed in CalB at equator. Physics trigger at 1000ADC in 8 bin, beta prescale factor 100, SQT filtering, VETO self-trigger, LAr fill complete. |
| **Run started by:** | Krzysztof Pelczar |
| **Run type:** | 505 |
| **Data quality link:** | Click here to edit DQ info for this run |

17:41:14 [febuilder,INFO] The EB ring buffer for fragment BUF40 (ID=5) is more than 70per full (70.019901 full). Probably indicates either spurious events or that the mlogger cannot write data to disk quickly enough.

### Equipment

| | Equipment + | Status | Events | Events[/s] | Data[MB/s] |
|---|---|---|---|---|---|
| Physics | EBuilder | Started run | 245.747M | 3210.7 | 44.809 |
| | DTM | Started run | 246.201M | 3468.0 | 0.305 |
| | FEV1720MTI00 | Started run | 43.694M | 690.9 | 15.388 |
| | FEV1720MTI01 | Started run | 43.694M | 95.6 | 1.935 |
| | FEV1720MTI02 | Started run | 43.695M | 644.7 | 13.567 |
| | FEV1720MTI03 | Started run | 43.692M | 123.5 | 2.436 |
| | FEV1740MT | Started run | 6.129M | 102.8 | 6.835 |
| | FEVETO | Started run | 2.494M | 41.9 | 0.059 |
| | FECALIB | Started run | 43.742M | 777.4 | 1.835 |
| Slow Control | deapScb | Acq On: 28/28 | 7181 | 0.0 | 0.000 |
| | deapmpod | Ok | 0 | 0.0 | 0.000 |
| | deapcdu | Ok | 0 | 0.0 | 0.000 |
| | deapups | Ok | 0 | 0.0 | 0.000 |
| | deapwater | H2O Pw[W]: 2205/ 810/ 392 | 7171 | 0.0 | 0.000 |
| | NutUps01 | Status: OL, 100%, 4.8min | 0 | 0.0 | 0.000 |
| | NutUps02 | Status: OL, 100%, 4.5min | 0 | 0.0 | 0.000 |
| | NutUps03 | Status: OL, 100%, 4.7min | 0 | 0.0 | 0.000 |
| | deapvme01 | Ok | 0 | 0.0 | 0.000 |
| | deapvme02 | Ok | 0 | 0.0 | 0.000 |
| | deapvme03 | Ok | 0 | 0.0 | 0.000 |
| | Hydrophone | Ok | 11 | 0.0 | 0.000 |

### Logging Channels

| | Channel | Events | MB written | Compr. | Disk level |
|---|---|---|---|---|---|
| Data Logger | #0: .deap_00023942_0737.mid.gz | 245708559 | 1431653.589 | 50.5% | 89.4 % |

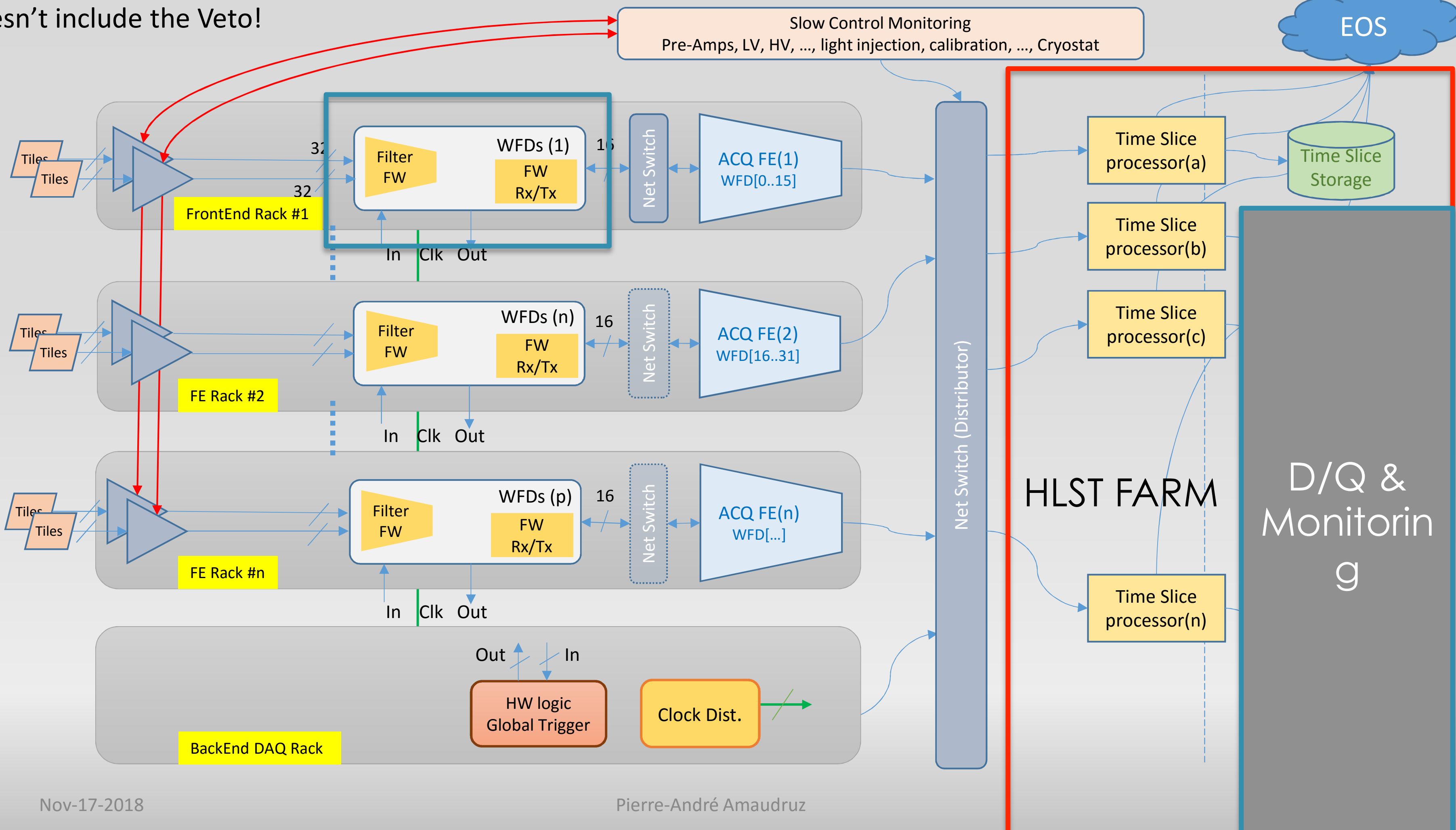
### Clients

Applications

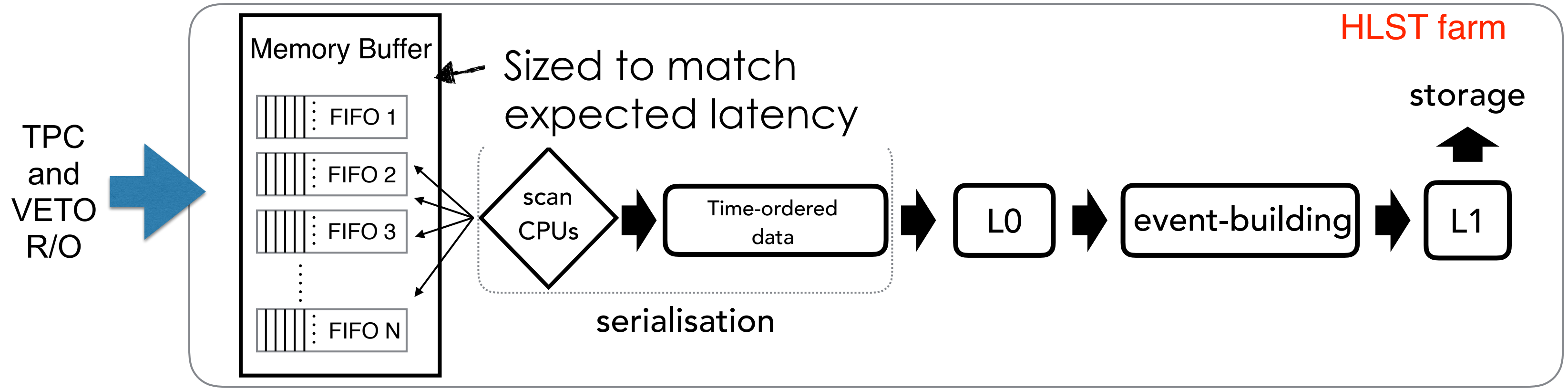
| | | |
|---|---|---|
| mhttpd [deap00] | fedeapvme03 [deap00] | mserver [deap00] |
| fedeapvme01 [deap00] | deapcdu [deap00] | fedeapmpod [deap00] |
| Logger [deap00] | feWater [deap00] | deapups [deap00] |
| MultipleChannelTrips [deap00] | RunStoppedTooLong [deap00] | NoNewEvents [deap00] |
| fenutups01 [deap00] | fenutups02 [deap00] | fenutups03 [deap00] |
| fedeapvme02 [deap00] | fedeapScb [deap00] | DaqMonitor [deap00] |
| online_ana_webserv [deapana] | feHydrophone [deapana] | feDTM [lxdeap01] |
| feov1720MTI00 [deap01a] | feov1720MTI01 [deap02b] | feov1720MTI02 [deap03c] |
| feov1720MTI03 [deap04d] | feov1740MT [deap05e] | feCALIB [deap05e] |
| feVETO [deap05e] | febuilder [deap00] | deapdisplay [deapcalib] |

# DAQ scheme

DAQ Architecture proposal for DS-20K
!Doesn't include the Veto!



# HLST overview




- **serialisation:** parallel data-fragments from digitisers are time-orderd and stored in one or more serial buffers
- **Level-0 (L0):** simple selections are applied on data packets:
  - example: S1-trigger: ≥N S1 hits above a given threshold in a given time window independently from S2 and/or veto
  - possible to run several selections in parallel (final decision OR of different selections): S1-trigger, S2-trigger (suited for leptophillic WIMPs), Veto-trigger, …)
- **event-building:** data packets from TPC and Veto in the time window selected by the L0 algorithms assembled in physics events and stored in buffers for L1 processing
- **Level-1 (L1):** offline-quality reconstruction performing data compression (compression of the waveforms replacing them with parametric representations), selection requirements to purify the samples, sub-divide the events in specific analysis/monitoring streams, and eventually to produce the offline root based data-structure that will be saved in the permanent storage.

Estimated that a farm with 250-300 cores of present day CPU would allow to process 200 ev/s, extrapolating current DS50 full offline reconstruction
Proposed budget based on INFN typical computing cost (as of 2016)

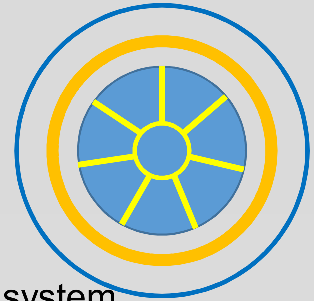
Note about the new design:
System design and cost need to updated with respect to possible new veto design

# Evolution scheme

- Need to adapt MIDAS frontend to include an acquisition front-end handling a connection from one/more boards
- Need to include and connect within a MIDAS a smarter Event Builder and then an Event reconstruction/filtering process
- This has strong ties with software framework for Event reconstruction !
  - In principle we want to have prompt online reconstruction for monitoring/event classification/logging using the same algorithm as in the offline
  - Will also greatly reduce the resource needed for offline

# DS-20k readout rack

## *DS-20K DAQ scheme* *Ver 0.1*

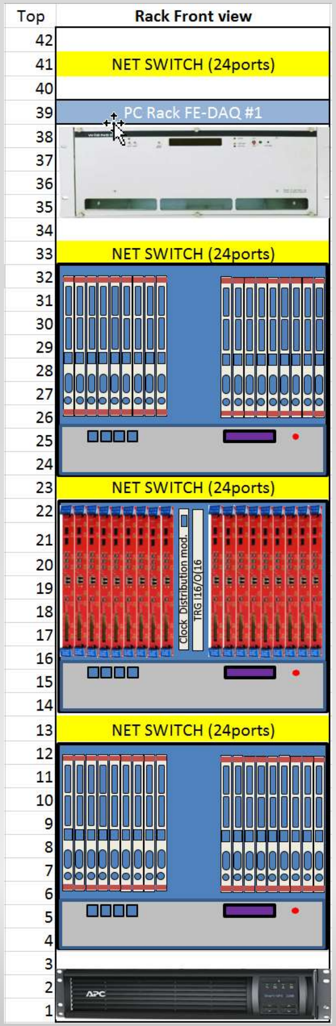


- Vertical slice Bot+Top sectors per rack

- Triggerless and Triggered Data acquisition system
- Data Flow simulation studies

- Online data monitoring
- Semi-offline, offline, data storage infrastructure
- Slow control aspect
  - PDM control/monitoring
  - Light injection, calibration
  - Vessel monitoring

- DAQ Timeline and Deliverables
  - To be defined by Q3'19
    - Modular Rack system see fig.

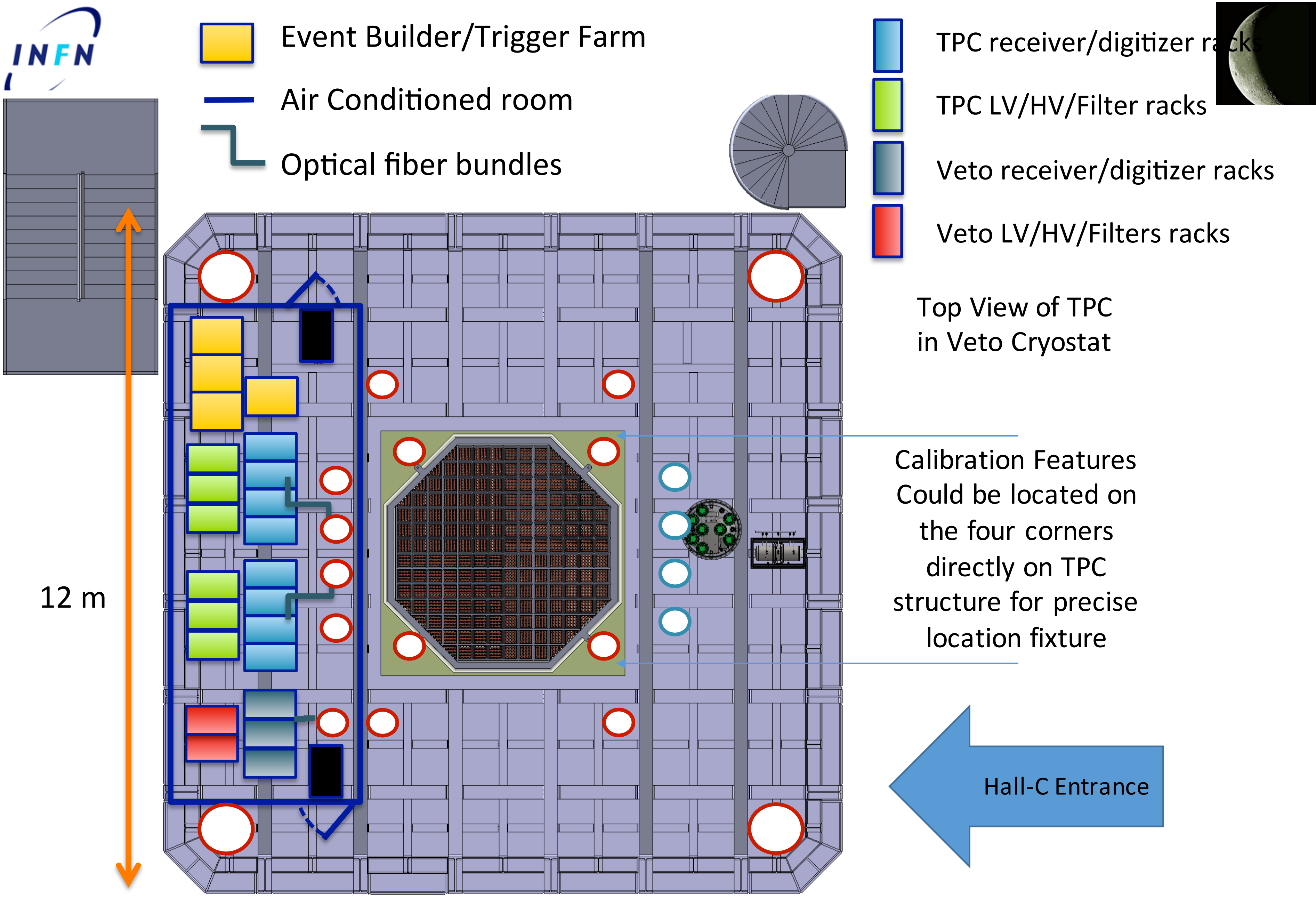



***Frontend rack***

16 WFD64 slots (1024ch.)
32 OptRec slots (1024ch.)
1 Clock Dist. Slots (1->24)
1 Trigger I/O (2x16)
Low Voltage PS (OptReceiver)
4 Net switches (24ports)
3 VME crates (networked)
1 UPS (Switches, PC)
1 CDU (nice for restart)
1 Rack power management

8..10 FE Racks (10Kchannels)
1 Global DAQ racks
1..2 Rack Backend PCs

Nov-17-2018 Pierre-André Amaudruz 12


INFN
Event Builder/Trigger Farm
Air Conditioned room
Optical fiber bundles
TPC receiver/digitizer racks
TPC LV/HV/Filter racks
Veto receiver/digitizer racks
Veto LV/HV/Filters racks
Top View of TPC in Veto Cryostat
12 m
Calibration Features Could be located on the four corners directly on TPC structure for precise location fixture
Hall-C Entrance

# Prototype

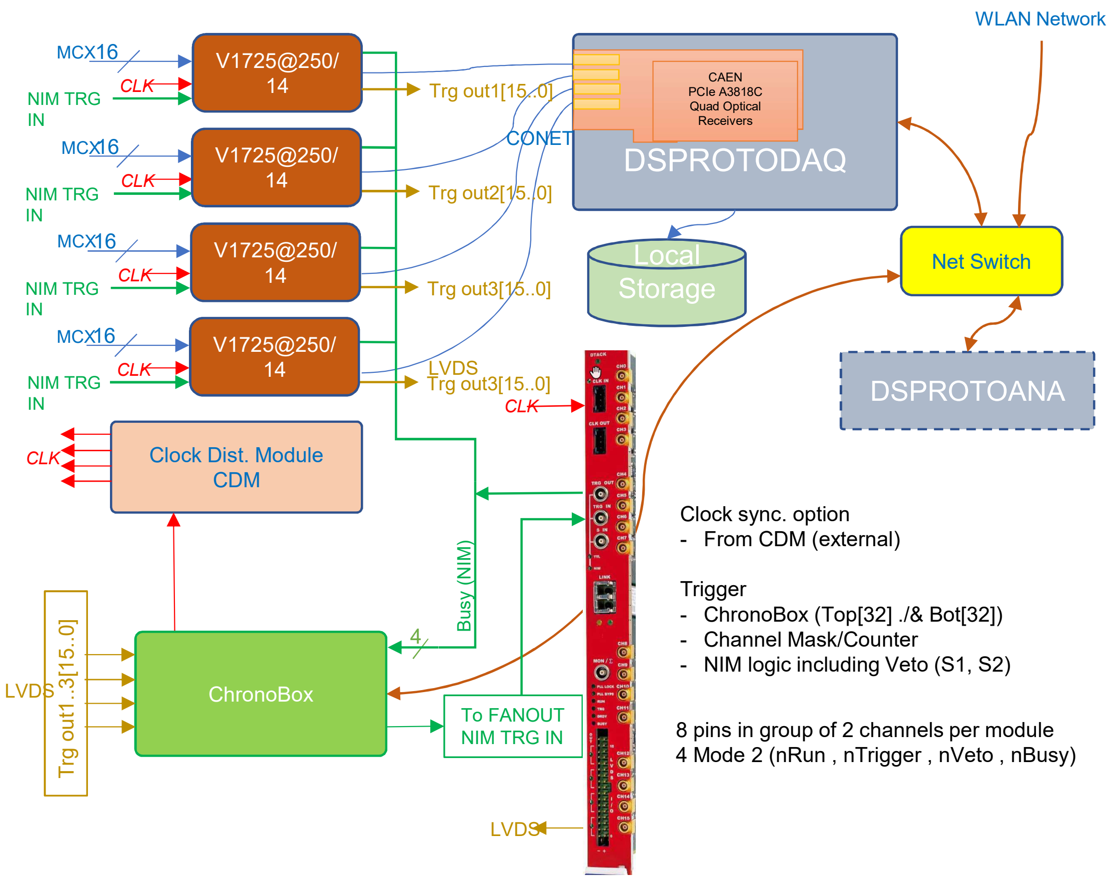
# 2019/2010 Milestone

- In spring 2019 we want to read-out 50 (?) PDMs in DS-proto → MIDAS/DEAP like daq from TRIUMF group
- Later (summer 2019) we need a revamp of MIDAS software to use new digitizer board from CAEN
- Later in the year/spring 2010 a system running on the 400 channel DS-proto with the new board integrated

# Proto-0 Readout

TRIUMF

## Hardware Architecture




Applications running on DSPROTODAQ

Midas frontend: V1725 readout
Midas data server (mserver)
Midas web server (mhttpd)
Midas data logger (mlogger)
Midas data monitor (mdsproto, root based)

Applications running on DSPROTOANA

Root
Online/Offline data analyzer (root based)
Custom package

Clock sync. option
- From CDM (external)

Trigger
- ChronoBox (Top[32] ./& Bot[32])
- Channel Mask/Counter
- NIM logic including Veto (S1, S2)

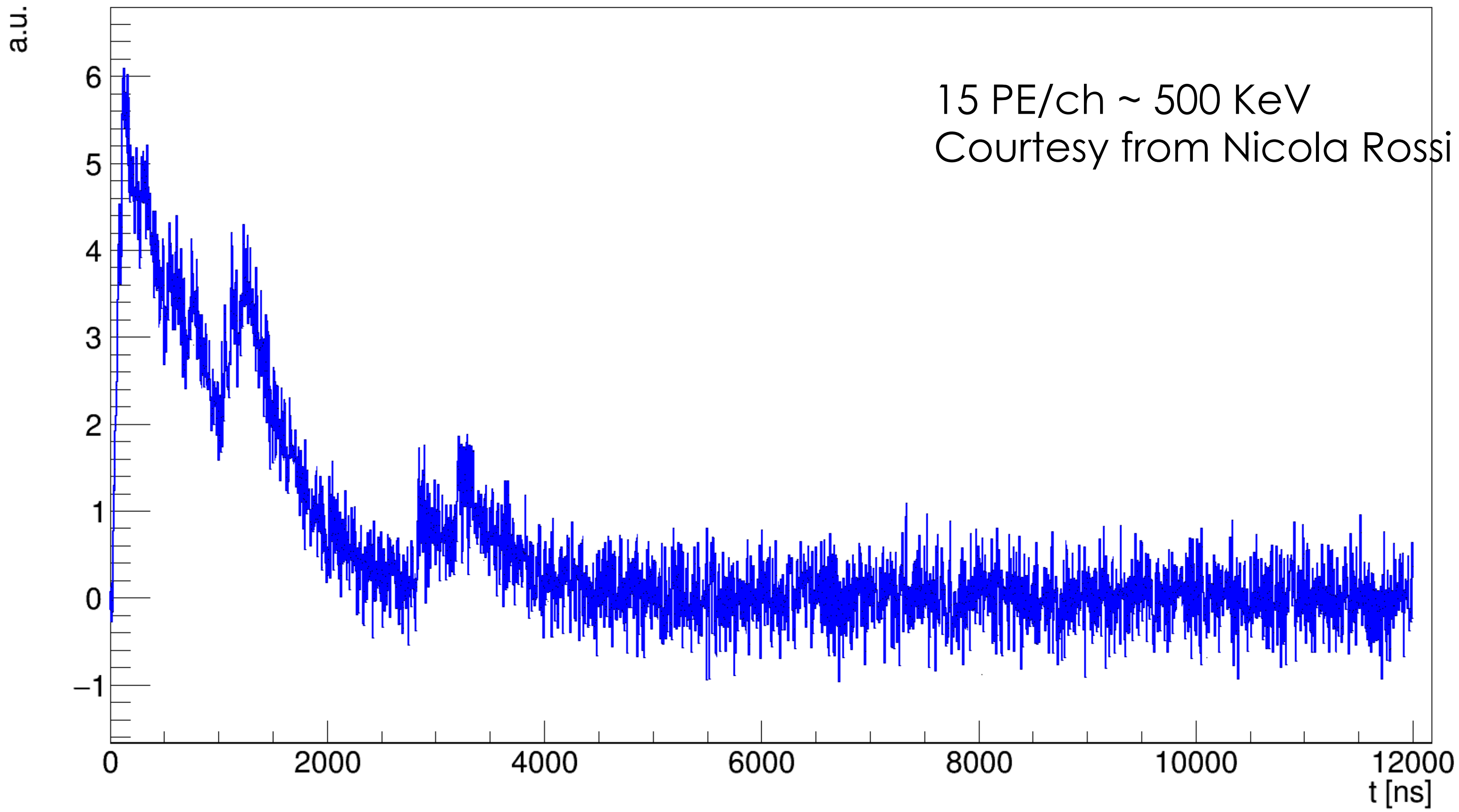
8 pins in group of 2 channels per module
4 Mode 2 (nRun , nTrigger , nVeto , nBusy)

System:
- Running Mode : Event-by-Event
- Up to 64 inputs
- Midas event composed of data collected after global trigger generation.
- Each event composed of 4 Midas banks (one per module) AND one ChronoBox bank.

- Each V1725 bank is composed of N samples for each channels in ZLE format.
- ChronoBox bank composed of Global trigger timestamp AND trigger primitive mask, counters.

- HW clock Synchronized across all 4 V1725 + ChronoBox
- Timestamps across banks are checked

# “Typical” S1 waveform




DS-Proto readout cannot really be similar to DS-20k
Worse case scenario for current setup, after pulses?
Will need to readout

# DSP for Proto

- Unclear the foreseen DSP would work for DS-proto
- S1/S2 discrimination ?
- Should use simple waveform recording firmware?
- Data compression must be realized in a prototype Trigger farm that should be operational with the time scale of DS-Proto

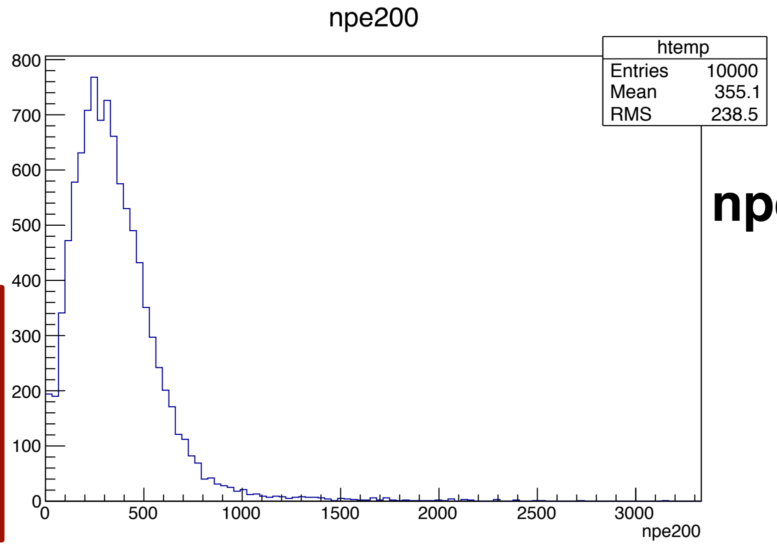
# VETO INTEGRATION

# Veto DAQ ?

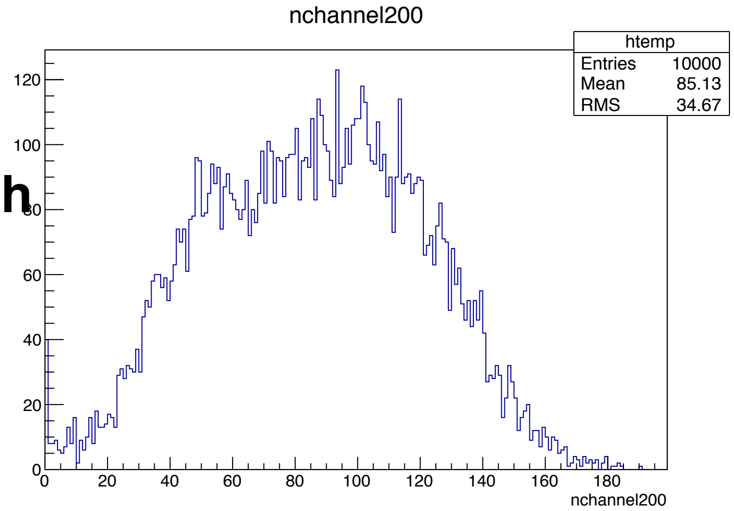
- Evolving project not yet fully finalized
- Will have different requirement as the TPC
- Important to have a special focus from now on, as the system wide implications & cost can be very relevant

# Veto DAQ

inside+ outside




**npe/nch ~4**




From Madrid CM: now out-dated

- 90 Ton AAr and ~3000 PDM +single channel threshold >=1 PE threshold, imply a total aggregate bandwidth for the VETO of 100 Gbps using current scheme!
- Considering two options including integrated electronics:
- Analog output: many possible way out: threshold >=2 (?), downsampling of acquired waveform, charge and time measurement in firmware, integrated electronic with digital readout… need to consider further
  - Specialized f/w development
- Fully digital output: will need to integrate a new digital data link into the architecture

# SPARE

# Expected Rates

PhysRevD.93.081101

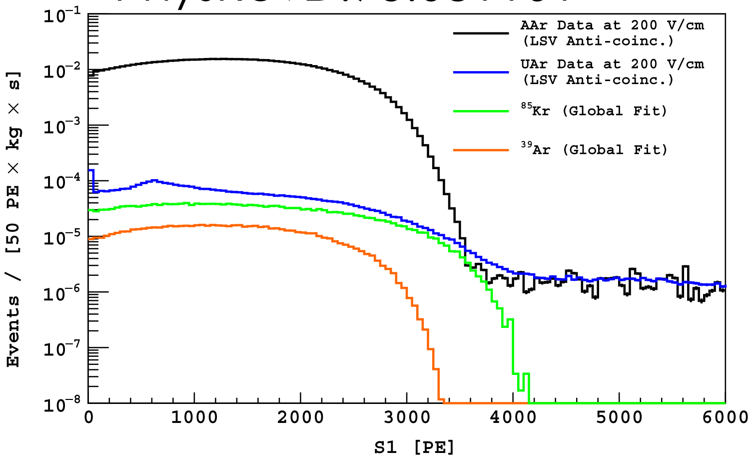



FIG. 1. Live-time normalized S1 pulse integral spectra from single-scatter events in AAr (black) and UAr (blue) taken with 200 V/cm drift field. Also shown are the $^{85}$Kr (green) and $^{39}$Ar (orange) levels as inferred from a MC fit. Note the peak in the lowest bin of the UAr spectrum, which is due to $^{37}$Ar from cosmic-ray activation. The peak at ~600 PE is due to $\gamma$-ray Compton backscatters.

Arxiv:1804..

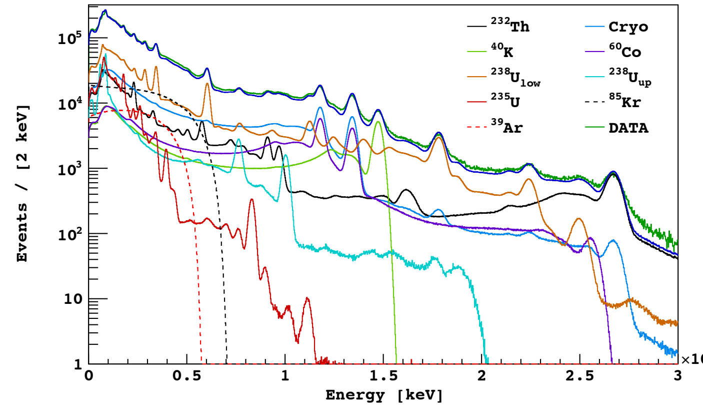



FIG. 2. Measured $\gamma$-ray spectrum in TPC (dark green) with total from fit (dark blue) including cryostat activity (light blue) fixed to assayed values and fitted PMT activities (see legend). The energy scale is the combined S1-S2 ER energy scale (see text).

- In Ds50 background rates fully accounted for by known sources
- Ds50 Trigger rate ~1.5 Hz
  - Residual 39Ar in Uar target <0.7 mBq/Kg
  - 2/3 of rate from PMT

TABLE I. TPC component activities, estimated by fitting $^{232}\mathrm{Th}_{\mathrm{PMT}}$, $^{238}\mathrm{U}^{\mathrm{lower}}_{\mathrm{PMT}}$, $^{40}\mathrm{K}_{\mathrm{PMT}}$, and $^{60}\mathrm{Co}_{\mathrm{PMT}}$ in sequence, followed by $^{235}\mathrm{U}_{\mathrm{PMT}}$, $^{238}\mathrm{U}^{\mathrm{upper}}_{\mathrm{PMT}}$ while $^{85}$Kr and $^{39}$Ar are fixed at their measured rates as reported in [15]. Cryostat activities ($_{\mathrm{c}}$) are summed across all cryostat locations, and fixed at their respective measured rates from assays. PMT activities ($_{\mathrm{p}}$) are summed across all PMT locations, and across all 38 tubes.

| Source | Activity [Bq] | Source | Activity [Bq] |
|---|---|---|---|
| $^{232}\mathrm{Th}_{\mathrm{p}}$ | 0.277±0.005 | $^{232}\mathrm{Th}_{\mathrm{c}}$ | 0.19±0.04 |
| $^{40}\mathrm{K}_{\mathrm{p}}$ | 2.74±0.06 | $^{40}\mathrm{K}_{\mathrm{c}}$ | $0.16^{+0.02}_{-0.05}$ |
| $^{60}\mathrm{Co}_{\mathrm{p}}$ | 0.15±0.02 | $^{60}\mathrm{Co}_{\mathrm{c}}$ | 1.4±0.1 |
| $^{238}\mathrm{U}^{\mathrm{low}}_{\mathrm{p}}$ | 0.84±0.03 | $^{238}\mathrm{U}^{\mathrm{low}}_{\mathrm{c}}$ | $0.378^{+0.04}_{-0.1}$ |
| $^{238}\mathrm{U}^{\mathrm{up}}_{\mathrm{p}}$ | 4.2±0.6 | $^{238}\mathrm{U}^{\mathrm{up}}_{\mathrm{c}}$ | $1.3^{+0.2}_{-0.6}$ |
| $^{235}\mathrm{U}_{\mathrm{p}}$ | 0.19±0.02 | $^{235}\mathrm{U}_{\mathrm{c}}$ | $0.045^{+0.007}_{-0.02}$ |
| $^{85}$Kr | 1.9±0.1 mBq/kg | $^{39}$Ar | 0.7±0.1 mBq/kg |

# “Typical Rates including VETO

| | TOTAL AGGREGATE DATA INTO EVENT BUILDER (EB) OR STORAGE (DISK/TAPE) | | | | | EB | DISK | TAPE |
|---|---|---|---|---|---|---|---|---|
| | NOISE HITS | | SIGNAL HITS | | Packet Size | | | |
| | Assumption | Total (kHz) | Typical | Total (kHz) | (B) | (Gbps) | (MB/s) | (TB/day) |
| S1 | 200 Hz x 8280 channels | 1656 | 500 Hits x 50 Hz | 25 | 1756 | 23.61 | 480.1 | 41.48 |
| S2 | N/A | 0 | 4000 Hits x 50 Hz | 200 | 506 | 0.81 | 101.2 | 8.74 |
| VETO | 200 Hz x 3000 channels | 600 | 90 T AAr x 100 hits??? | 9000 | 1756 | 134.9 | 842.9 | 72.82 |
| | | | | | | **159.3** | **1424.2** | **123.0** |

Data reduction at the Event Builder is crucial:

- Could detect physical pulses by analyzing whole TPC (discard DCR related hits in the quiet window between S1 and S2, dominating the actual output rate
- Could/should optimally fileter S1 waveform to extract physics information
- Could compress data
- Could prescale uninteresting events

# Proposed scheme

- Soft Trigger task will oversight the implementation for event building and identification from the hit fragments in time slices provided by the DAQ, the study and implementation of a full event reconstruction and trigger selection and provide a way to monitor online data with key performance parameters based on full reconstruction

Electronics coordinator

DAQ

f/w

s/w

Event Builder

Soft Trigger

Trigger Algorithm

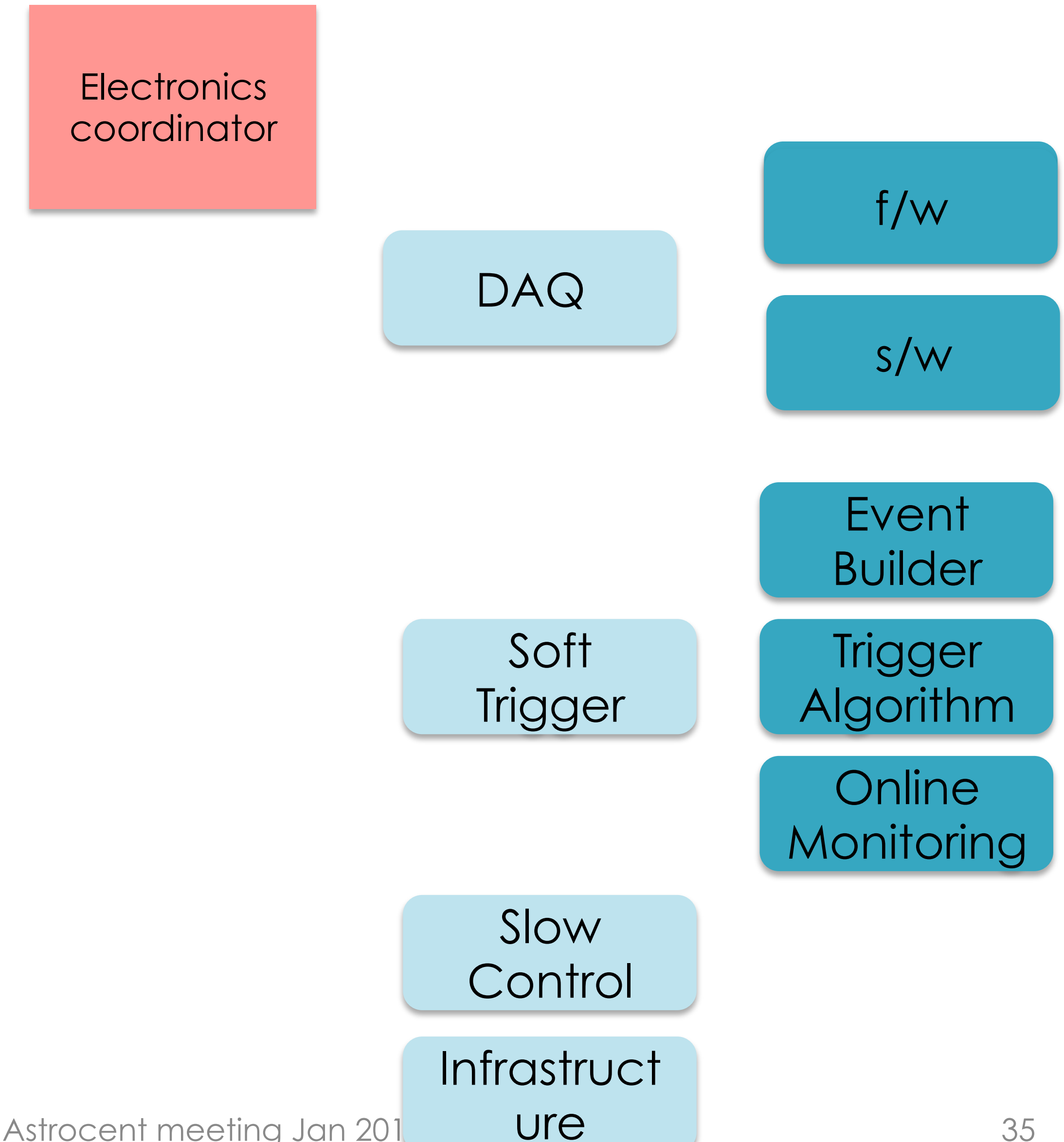
Online Monitoring

Slow Control

Infrastruct ure

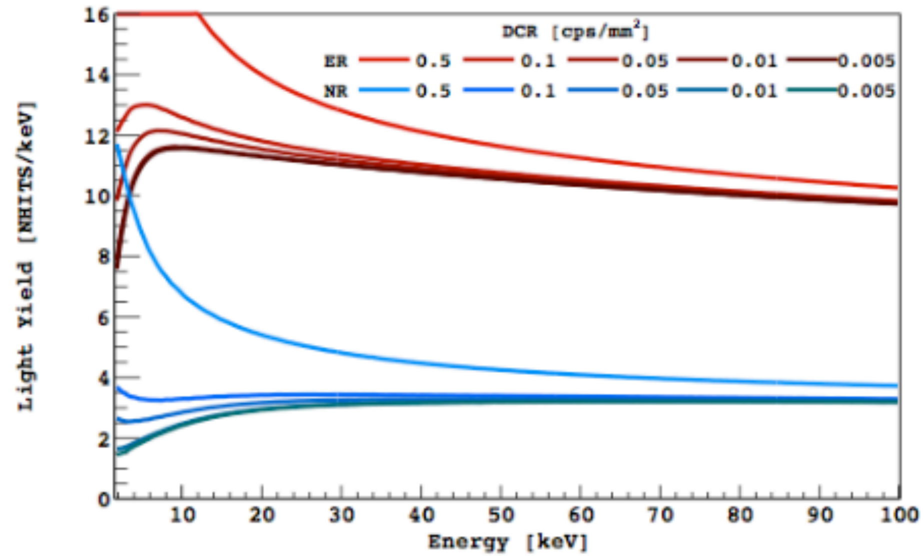
# Proposed scheme

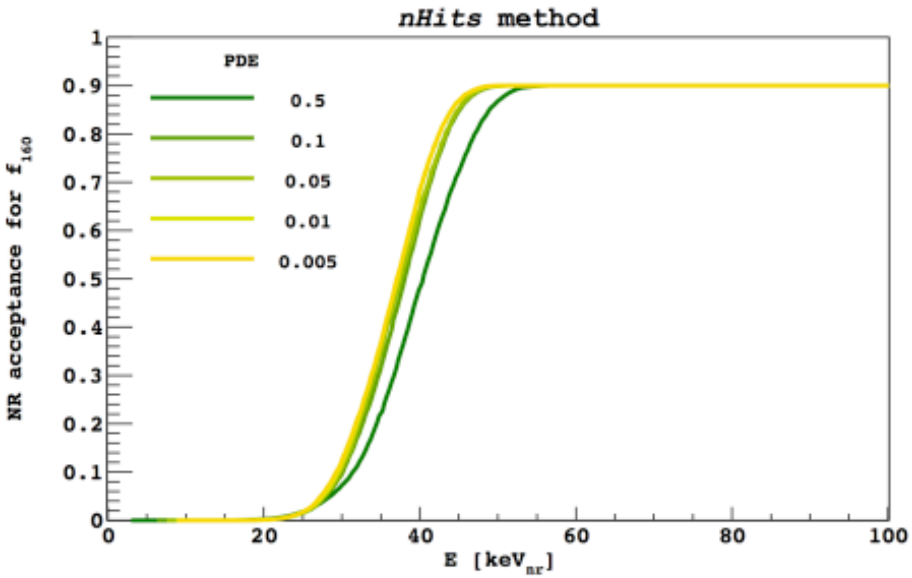
- Slow Control task is responsible to deploy the hardware for cryogenics control and other key control checks and provide monitoring data to MIDAS though e.g. an OPC service interface
- Infrastructure coordination will need to oversight at control room/ electronic room building including all services and need to interface with the main infrasctructure group of DS20k

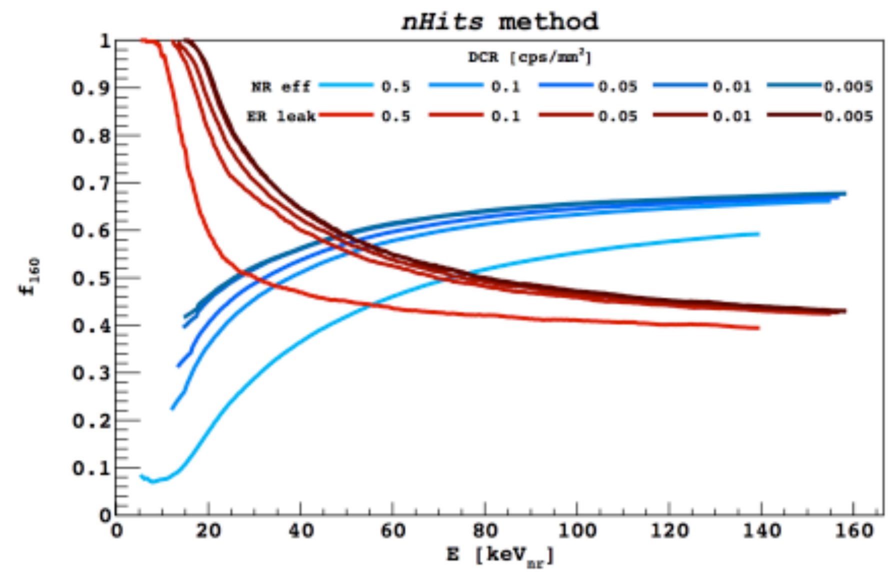


# Primary Noise Rate

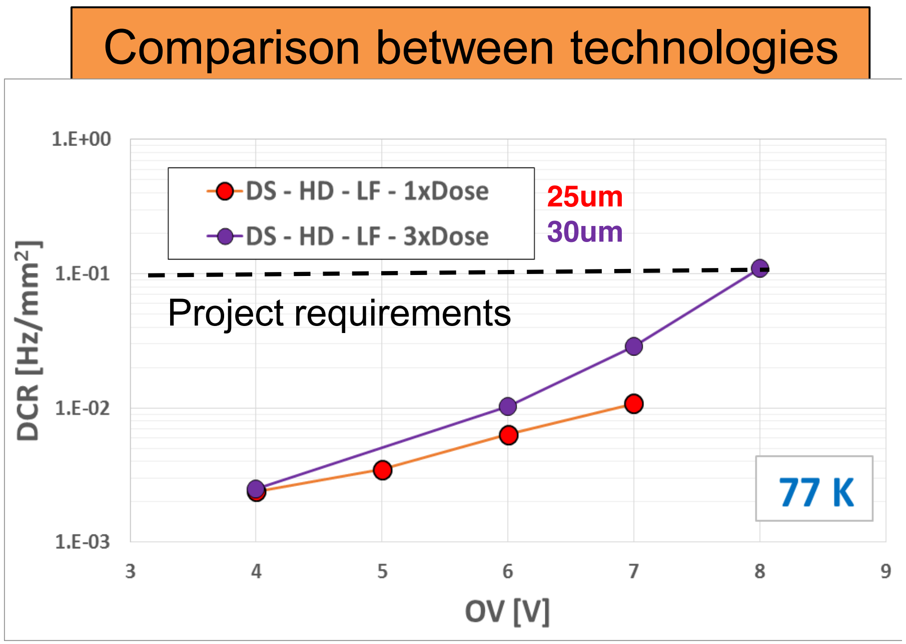
- Primary noise rate creates spurious PE which affect energy reconstruction and PSD.
- Bias of the $f_p$ distributions to low values and reduction of their distance.
- Requirement: < 0.1 cps/mm²

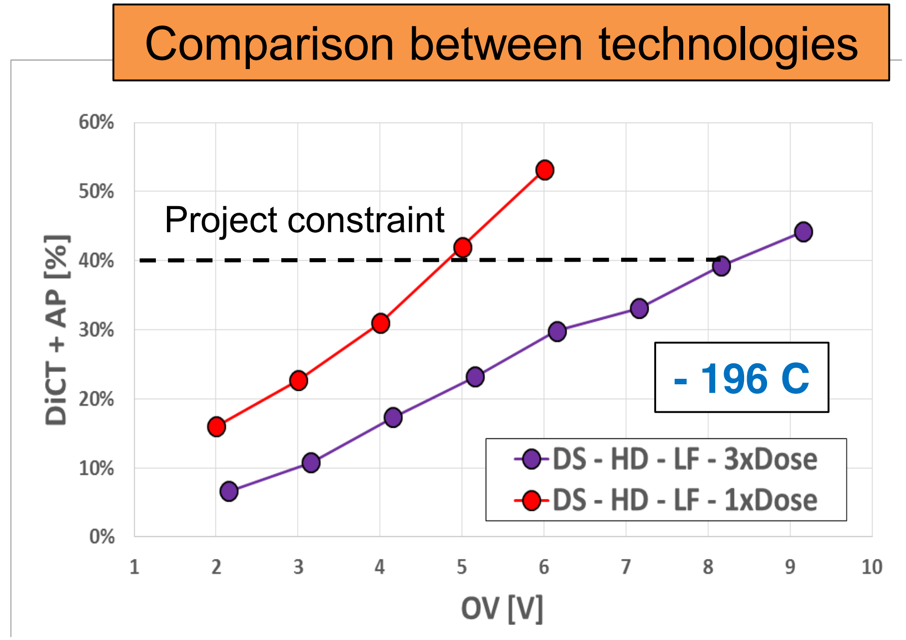


# Even if..




- 3xdose FBK SiPM vs 1xdose NUV-HD-LF

# DS20K DAQ Overview

## PS Veto + S1&S2 Waveform readout