CEDAR Performance 2018...
...and lessons we learned from it!

Benjamin Moritz Veit

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CERN

Federal Ministry
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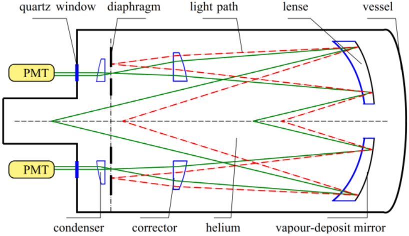
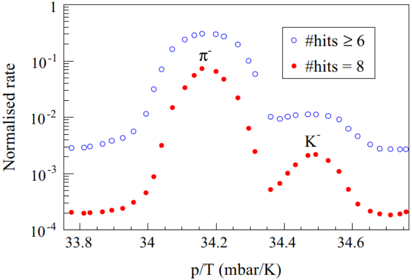
and Research

COMPASS

CEDAR working principle

CEDAR detectors are Cherenkov counter which are used at compass to identify particle species of the incoming beam.





Variation of gas pressure and diaphragm aperture to select particle species.

M2-Beamline parameters (hadron beamfile):
Nominal beam:(190GeV/c): 96.8% π^-, 2.4% K^-, 0.8% $\bar{p}$
Nominal/maximal intensity: 3.7×10^8 / 4.2×10^8 particles per spill

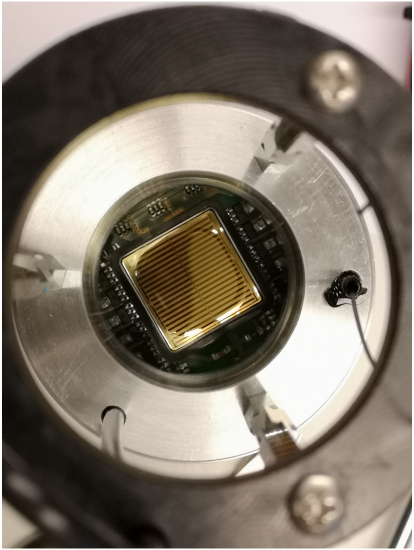
CEDAR Upgrade Project

Goal: Modify CEDARS to withstand higher rate ($\approx 10^8$ particles/s)

- Exchange of photomultipliers / voltage dividers:
  - PMTs exchange against Hamamatsu R11265-203
  - New Base design with amplifier located at PMT
  - Differential signal readout of each photo cathode
- Exchange of readout:
  - exchange Gandalf/F1 TDC readout against iFTDC architecture
    Limits of old readout: 4M/channel in hi-res mode / double-peak-resolution $\approx$ 18 ns

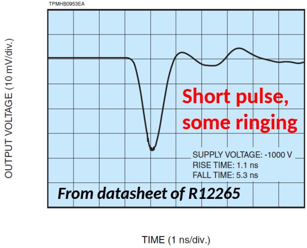
    $\rightarrow$ iFTDCs are able to deal with higher rates and higher double pulse resolution!
- Thermal system to gain p/T stability.
  $\rightarrow$ not scope of this talk!
- Monitoring of PMT gain stability. Under progress ...
  $\rightarrow$ not scope of this talk!

PMTs R11265-203

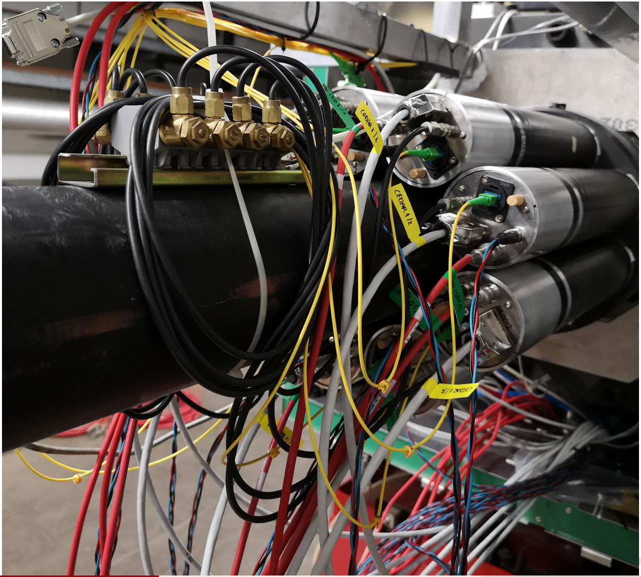


R11265-203 properties:

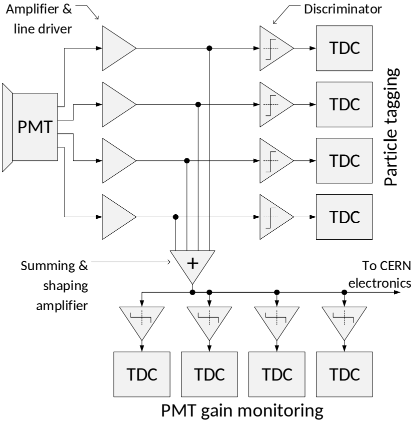
- Small metal channel PMT ($23x23\ mm^2$ active area)
    - Less dark rate
    - Better timing
    - HQE photocathode (4pads)
- $t_{rise} = 390\,\text{ps}$, FWHM $\leq 2\,\text{ns}$
- TTS $= 390\,\text{ps}$(FWHM)



PMT integration

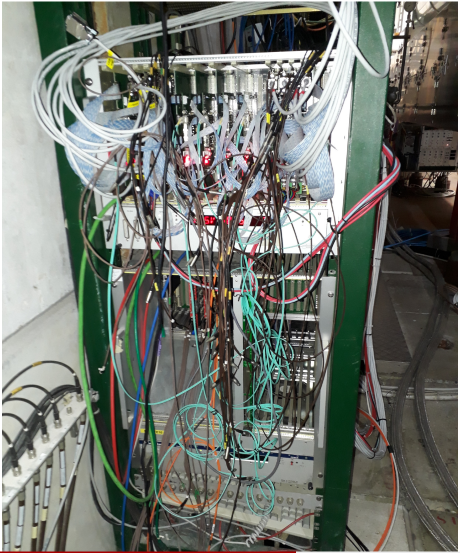


Readout scheme



- Differential signal between PMT base and discriminator
- Analog signal is split and shape for CERN electronics (Sum of PC per PMT [CESAR]) and ToT readout for gain monitoring
- New Discriminator by WUT
  - Differential signal input via DSUB-9 connector
  - Thresholds are set by FastBus protocol
- Signals for CERN electronics are summed and amplified via NIM modules

iFTDC Readout



- Placed next to CEDARs in beam line.
- 6+1 iFTDCs for READOUT.
  - 4x Particle tagging.
  - 2x ToT gain monitoring.
  - 1x T0 reference.
    (in Trigger barracks)
- 2x 8 PMTs x 4 PC = 64 Channel
  - 16 channel per iFTDC for Tagging
  - 32 channel per iFTDC for ToT.
- One multiplexer located next to CEDARs connected via X-switch to main DAQ.
- VME as module format.
  (only for power distribution)

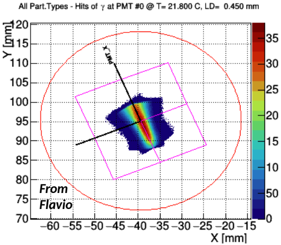
Expected Rates

Estimates rates from the DY proposal were calculated (TB2017.1):

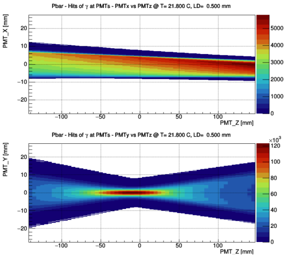
- 10^7 particles/s $\rightarrow$ 3.5 MHz/PMT
- 10^8 particles/s $\rightarrow$ 35.0 MHz/PMT

$\rightarrow$ Estimated worst case: **1 pulse every 29 ns (on average).**

(Rate distribution during spill is close to Gaussian, with spike at the beginning)



Losses expected through border between photocathodes.



Solution: place PMT cathode out of focus to distribute rate

Distributed over the 4 photocathodes $\rightarrow \leq$ **10 MHz/ TDC channel**

First version of iFTDC firmware for CEDARs

Changes of firmware in comparison to NA64 firmware:

- 16 channels instead of 64 to increase hit rate capability
- 1 ns bin size version
  - 10% differential non linearity
  - 8 ns minimum time interval between hits
- 0.5 ns bin size version (never used)
  - 20% differential non linearity
  - 4 ns minimum time interval between hits
- Programmable signal edge hit detection: rising, falling or both

Firmware Limitations:

- 15 MHz per channel maximum hit rate capability
- Maximum 100 hits per event otherwise TDC stops sending data to MUX till next spill
- No built-in monitoring such as hit rate measurement per channel and hit loss monitoring

Problems during the first part of commissioning

Discriminators:

- Broken cables leads to: missing signals / double pulses / crosstalk.
- If threshold very low → No rate at all.
- If threshold to low → we see oscillation of discriminator (≈100 MHz).
- No access to the electronics during Beam
  (check signal/behaviour with scope at full rate.)

Firmware Issues:

- No data from one or more TDCs. → Caused by event size exceeding.
- Wrong hit time → solved by reloading firmware (radiation?).
- Two hits with the same timing. → Error in time encoding.

If the rate is to high no reliability of TDC readout through to hit rate limitations and error rate of the iFTDC firmware

→ **Unexpected behaviour of Threshold-/HV-Scans!**
Problems with data error rate during high intensity beams!

Improved iFTDC Firmware for CEDARs

Main problem is limited hit rate capability due to hit multiplexing!

- Delay of all hits until trigger decision for 3-4 μs.
- No sharing of hits between consecutive events.
- Start hit multiplexing after hits are accepted by trigger.
- Adding a scaler feature per channel which is independent from Trigger and give access to the raw rates per channel during spill. (Independent readout via IPBus)

→ Increased rate stability above 50 MHz/channel (observed)
→ Scaler feature is important during commissioning for debugging and Threshold/High Voltage scans where rate can hit the readout limit of the DAQ.

Made the commissioning of the detector possible!

First real rates!

High intensity pion beam scaler rates per spill (4.8 s eff. duration)

CEDAR 1				
PMT 1	57 173 139	48 892 759	81 431 278	71 218 810
PMT 2	46 476 589	37 640 674	20 095 445	22 984 783
PMT 3	14 202 662	23 098 666	32 456 929	19 456 721
PMT 4	26 464 459	31 591 168	16 889 004	16 792 590
PMT 5	22 698 686	37 698 768	29 852 869	26 653 032
PMT 6	40 413 118	32 237 416	43 977 691	59 685 259
PMT 7	58 584 284	72 809 988	54 195 157	53 511 962
PMT 8	83 594 077	83 069 841	96 658 824	93 303 436

CEDAR 2				
PMT 1	54 253 340	67 626 183	59 623 202	51 713 281
PMT 2	45 638 841	52 931 703	45 670 261	42 801 770
PMT 3	52 361 902	50 100 287	37 258 006	33 852 286
PMT 4	41 859 929	31 603 368	44 527 598	50 201 827
PMT 5	36 428 313	43 524 045	44 959 162	41 989 160
PMT 6	40 377 073	43 012 832	27 352 721	35 148 828
PMT 7	35 952 058	46 422 558	59 895 339	52 999 674
PMT 8	72 896 505	58 320 844	37 314 732	49 841 972

Channels show rates up to $\approx$ 20 MHz per photocathode.

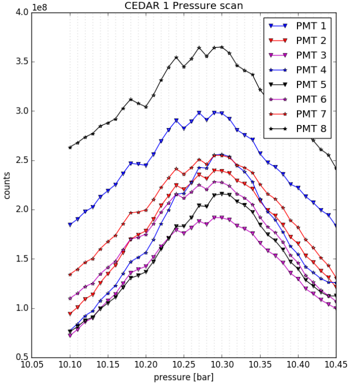
The estimation of the rates was to low from the beginning!

We observed a large background rate from beam halo:
Average $\approx$2 MHz/PMT channel, max. $\geq$ 10 MHz/PMT channel.

Halo signals are large due to Cherenkov radiation in PMT glass (large current at anodes of the PMTs which exced. specs.).

Rates during pressure SCAN

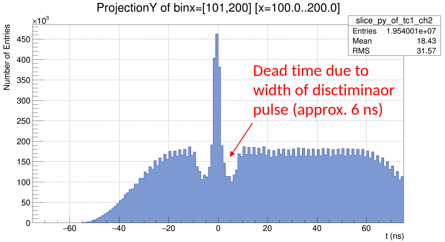
High intensity pion beam scaler rates per spill (4.8 s eff. duration)

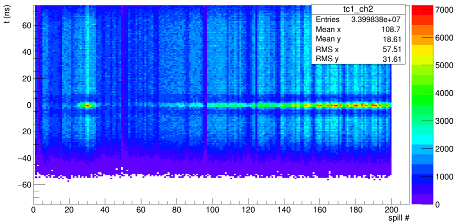


With the new firmware and scaler features we are able to make pressure scans with our readout chain!

TDC readout via DAQ

Also TDC readout at these rates was possible with minimal error rate!





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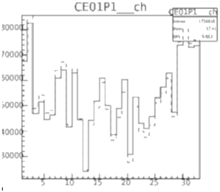
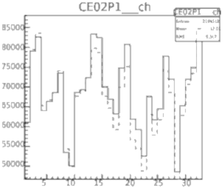
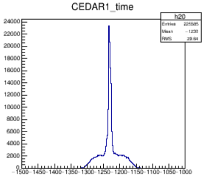
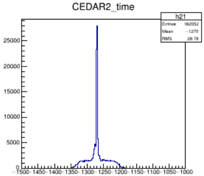








Remaining observation and remarks

- **Radiation Issues** (equipment is placed close to Beamline)
  - Wrong hit time
  - Stuck Multiplexer/iFTDC
    $\rightarrow$ Both are solved by reloading the FPGA firmware
- **Programming and Addressing**
  - MAC&IP addresses fix in source-code $\rightarrow$ makes things unnecessary difficult and add a lot of bitstream compilation time.
    Solution: Generating MAC out of unique FPGA identifier memory (DNA) and implementation of RARP protocol for IP assignment
    $\rightarrow$ **Already done for iFTDCs now!**
  - Bare-bone pc with programmer attached to all FPGA $\rightarrow$ good idea! But assignment between FPGA/Programmer/Firmware was difficult!
  - Store as much parameter as possible (DNA,MAC,IP,FW-Version,config Parameters, config memory type, ...) in a central database (front-end db?) to make documentation and programming easier.

Remaining observation and remarks

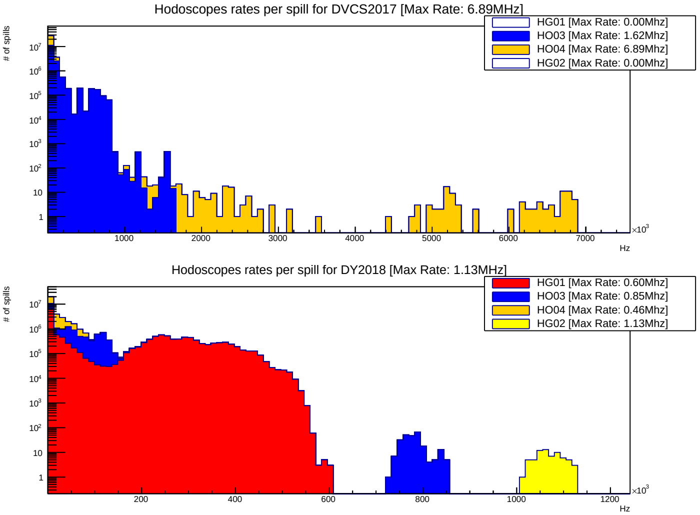
- **Monitoring and management tools:**
  - Independent scaler feature: Important for commissioning of equipment.
  - Need of hit loss monitoring and error rates.
  - Early implementation in existing monitoring and management tools like front-end database and coool are very important.
    More monitoring is always better!
- **Neat features:**
  - Data lines (I2C/SPI) on robinson nugent connector to allow programming of e.g. thresholds of discriminators via IPBus.
  - LED per SFP cage to show link status.
  - Reset button would make power cycling easier.

In the end we were able to get the full readout chain running at full DY beam intensity!

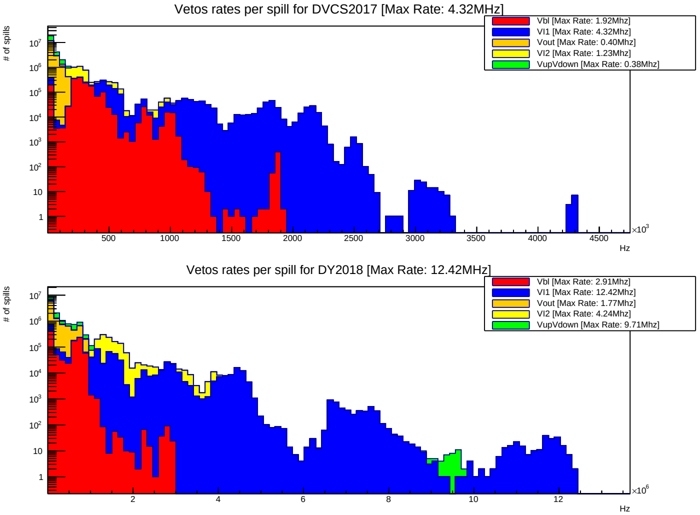
But ...

What rates can we expect for other equipment?

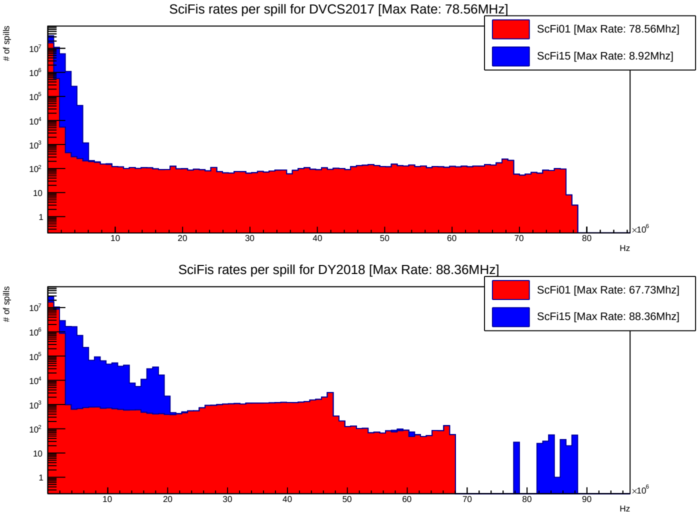
Rate of Hodoscopes



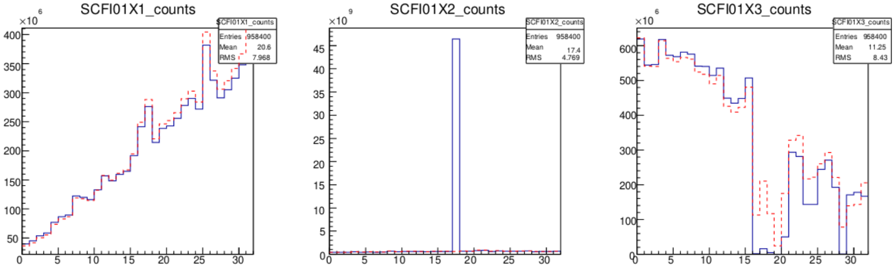
Rate of Vetos



Rate of SciFis



Rate issues



Problems of noisy channels epically in our SciFis

→ Front-ends has to be able to deal with such channels.

Rates Summary

Only a few information until now but these give us some hits:

Det.	max. Rates	driven by	remarks
Hodoscopes	7 Mhz	LAS/Outer	No info of other hodoscopes
Vetos	12.5 Mhz	VI1	Hadron beams much higher
SciFi	90 Mhz	noisy channels	only information SciFi1/15
CEDARs	20 Mhz	beam rate	high halo contribution
...			

Have in mind that these are average rates over the spill. At the beginning of the spill we have an overshoot.

Front-ends has to be robust to deal with noisy/channels and changing rates for the different physics programs.

Question & Remarks ?

Big thanks to:
Marcin Ziembicki, Robert Kurjata, Vincent Andrieux, Flavio Tosello, Igor Konorov, Vladimir Frolov, Johannes Bernhard, Fulvio Tessarotto, Andrzej Rychter, Janusz Marzec, Philippe Carriere, Serge Mathot, Wen-Chen Chang, Caroline Riedl and Vladimir Anosov for help in this project!
(apologies if I missed someone)

Also material used from most of them for this talk.