DRS4 – a convenient electronics not only for high energy physics experiments

Piotr Podlaski

University of Warsaw
Faculty of Physics

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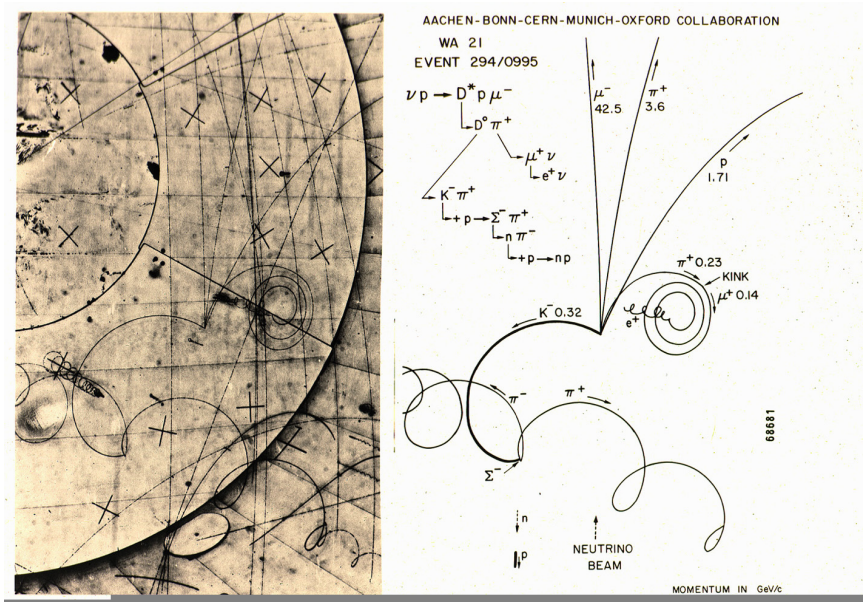
Outline

Electronics in high energy physics

Past:



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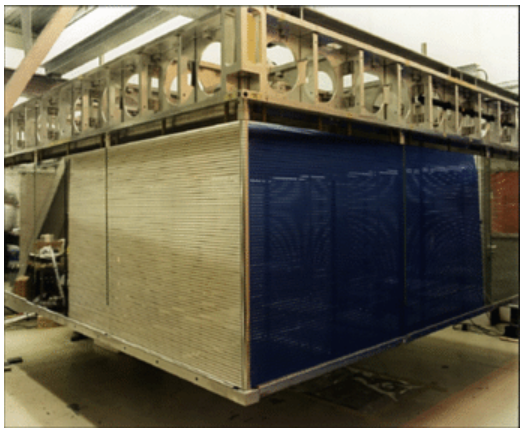
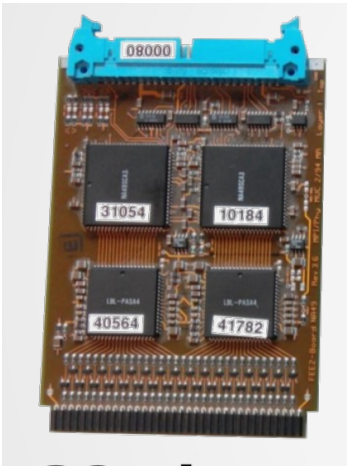
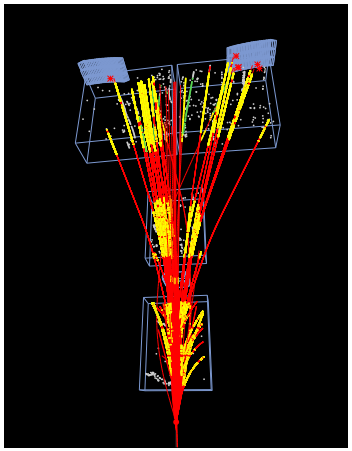






Electronics in high energy physics

Challenges to be faced by modern readout electronics:

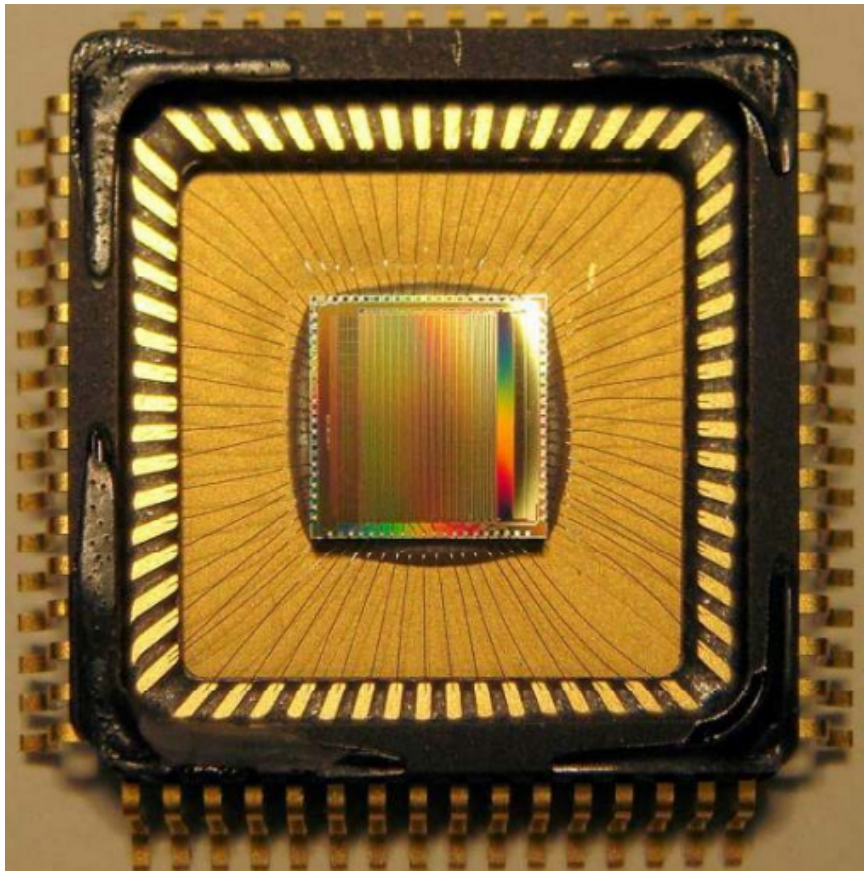
- Large number of channels - up to several hundred thousands
- Dynamic range to deal with used detectors
- Timing resolution at level of single ps or better
- Small or none dead time - high event rates
- Scalability
- Ease of integration
- Price per channel
- Available off-the-shelf solutions - big advantage for smaller experiments
- Big experiments often design custom electronics strictly for their purpose
- Physicists and engineers from Paul Scherrer Institute in Switzerland decided to make something more general...

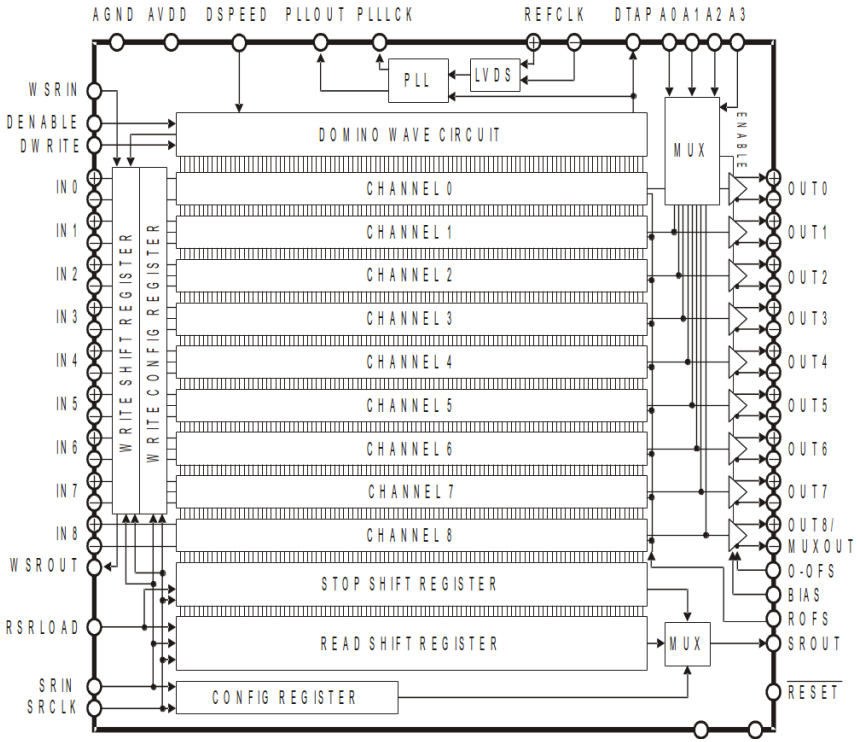
DRS4 electronics

DRS4

DRS4 (Domino Ring Sampling) is a chip developed in PSI, Switzerland, it features:

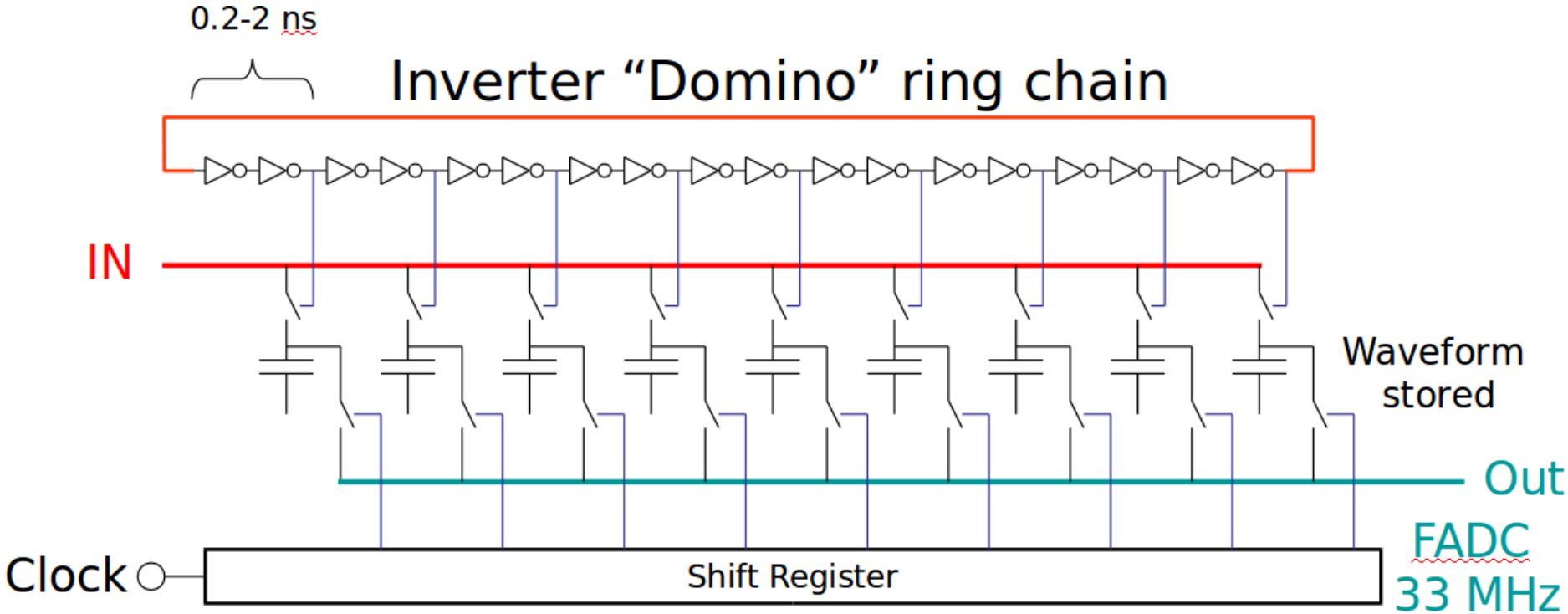
- **A**pplication-**S**pecific **I**ntegrated **C**ircuit (ASIC)
- **S**witched **C**apacitor **A**rray (SCA) - fast analog buffer
- Analog sample rate up to 5 GS/s
- Analog bandwidth of 950 MHz
- 8+1 channels per chip
- Memory depth of 1024 cells per channel
- Time window of 200 ns at full sampling speed





Switched Capacitor Array

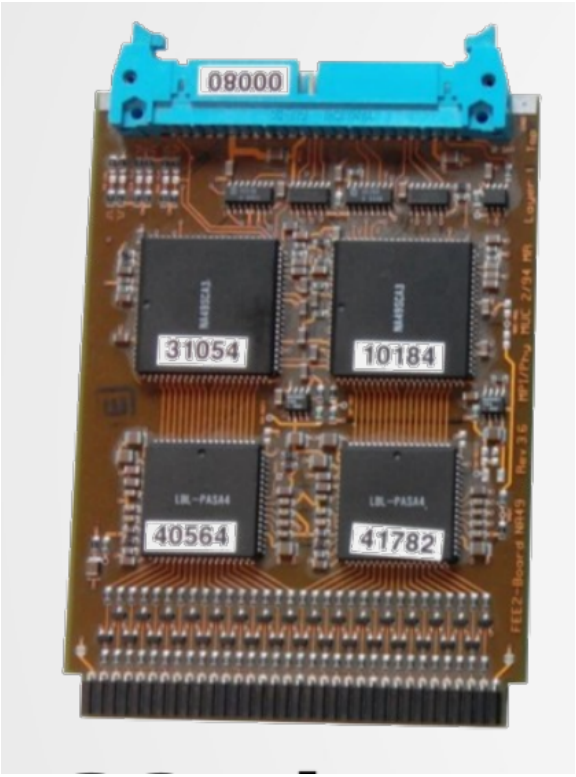
- Analog signal is sampled with rate up to 5 GHz and stored in an array of capacitors
- Sampling is controlled by Domino Wave circuit
- When trigger occurs sampling is stopped and readout process is started
- Capacitors are read out with much slower rates - typically around 30 MHz
- Analog memory has topology of circular buffer



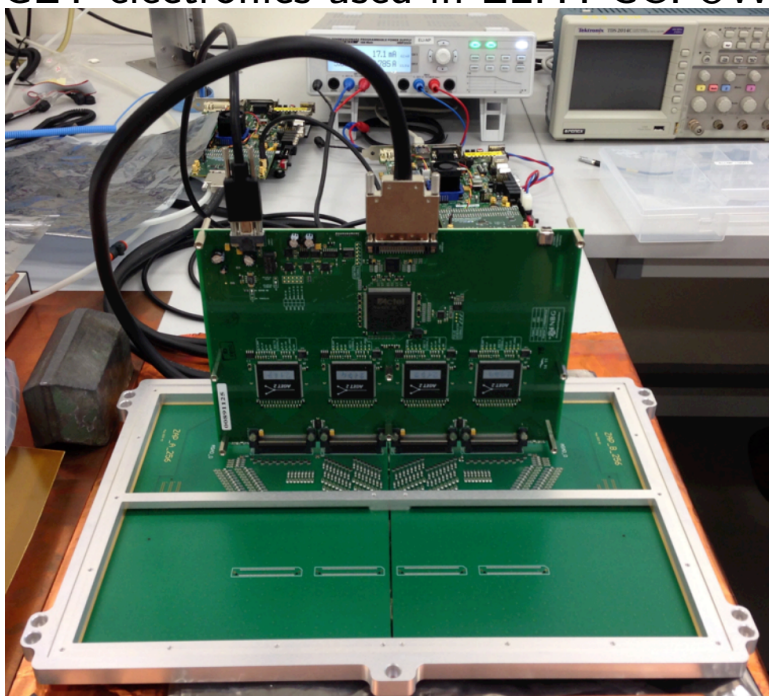
Switched Capacitor Array - applications

- Switch Capacitor Array technology is widely used in front-end electronics for high energy physics
- SCA stretches time - it combines fast sampling rates with slow digitization
- Analog memory capabilities allow reading out multiple channels with single ADC which lowers cost significantly

NA61/SHINE TPC FEE

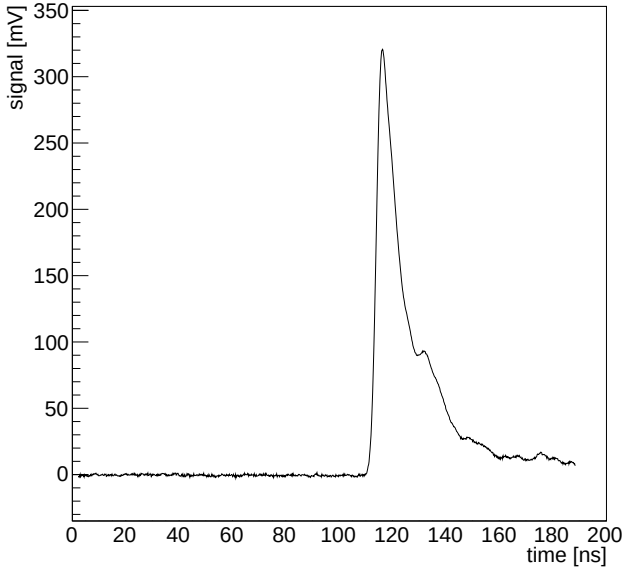


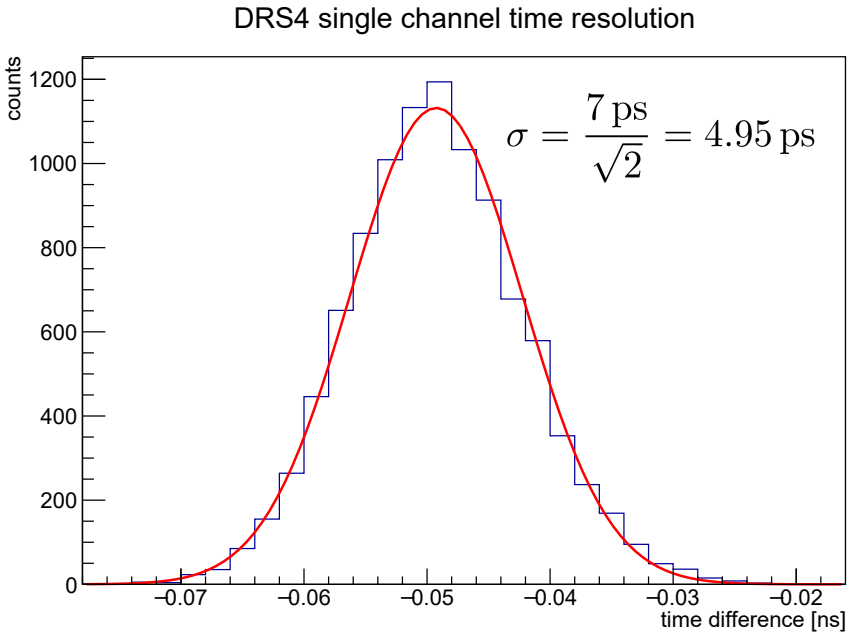
GET electronics used in ELITPC@FUW

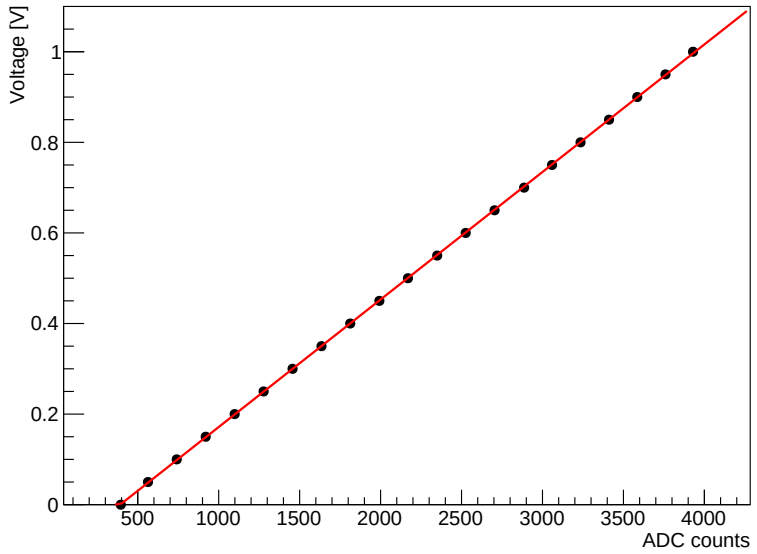


DRS4 performance

- DRS4 offers excellent single channel timing resolution at the level of 5 ps
- Advanced time calibration methods allow to obtain sub-picosecond time resolution
- Linear voltage response
- SNR for voltage measurement at level of 11.5 bits

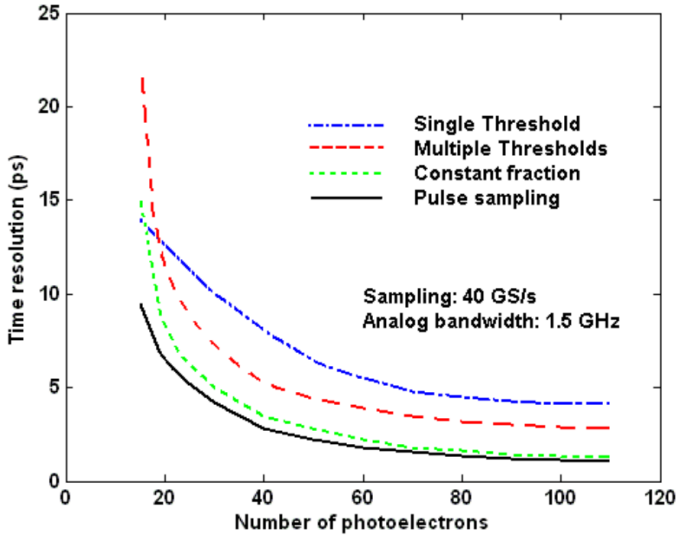




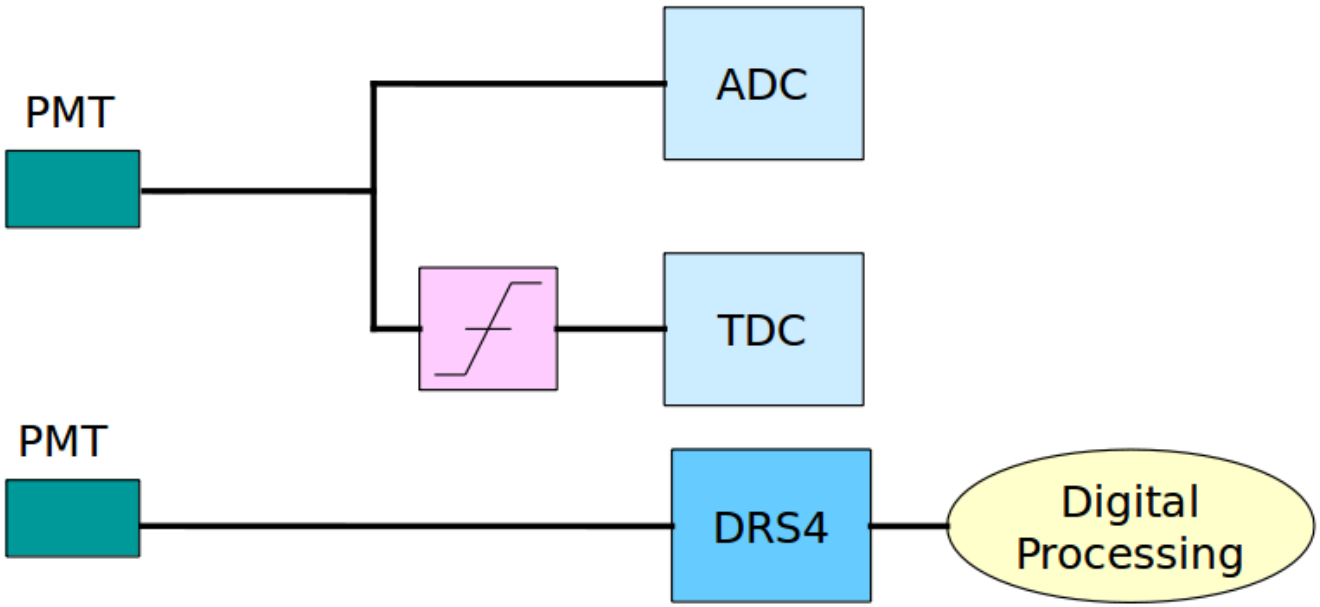


Advantages of waveform digitization

- In many cases it is essential to measure precise timing and amplitude (charge) of the signal
- It is usually done with TDC and ADC, we end up with two numbers: charge and time
- Fast signal sampling and waveform digitization allows for digital processing of the signal, opening new analysis paths
- It is possible to implement more advanced algorithms for timing and amplitude estimation, together with quality cuts removing pile-up



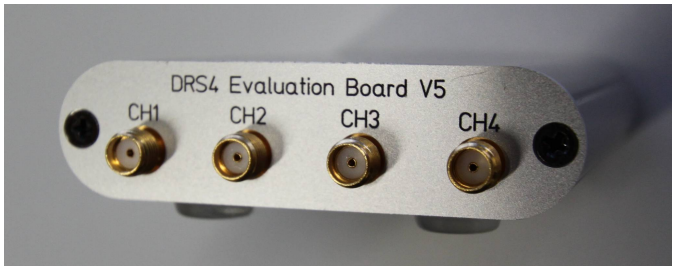
J.-F. Genat et al., arXiv:0810.5590 (2008)

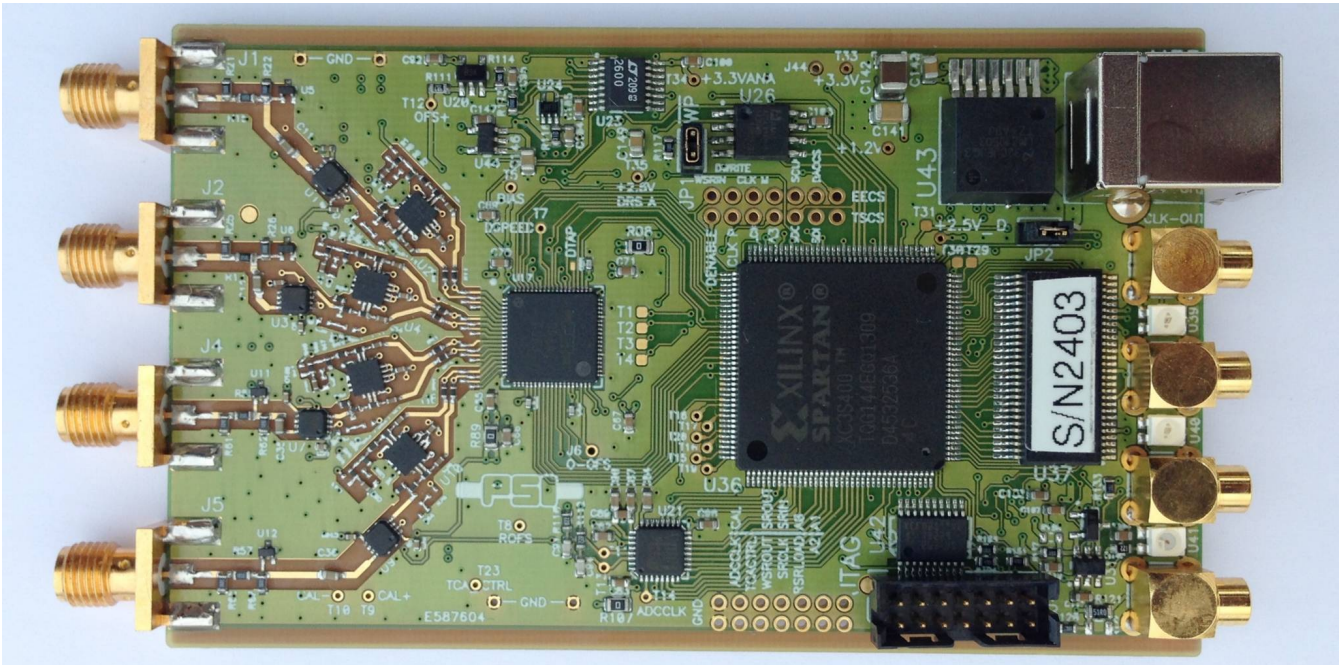


Available DRS-based electronics

DRS4 evaluation board

- 4 channels, USB powered, Plug and Play
- 750 MHz analog bandwidth
- Up to 5 GS/s sampling rate
- 14 bit ADC
- On-board DAC and oscillator for time and voltage calibration
- Possible to synchronize multiple boards (master/slave mode)
- Cost: around 1200 EUR - order of magnitude lower that scope with similar specs





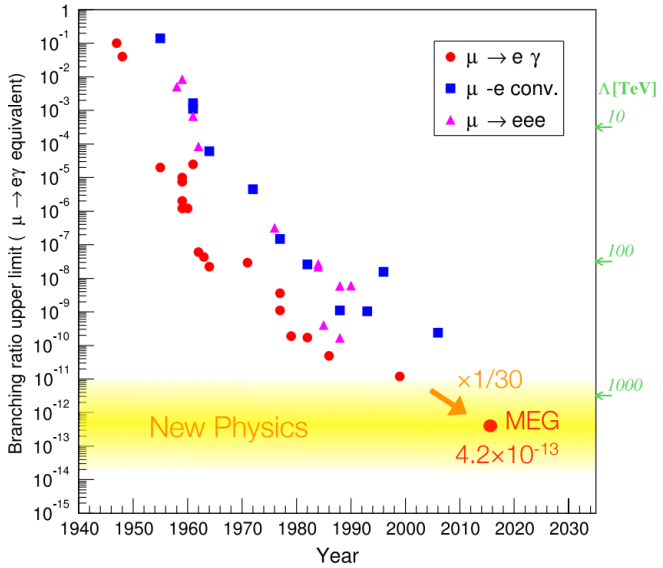
CAEN DRS based digitizers

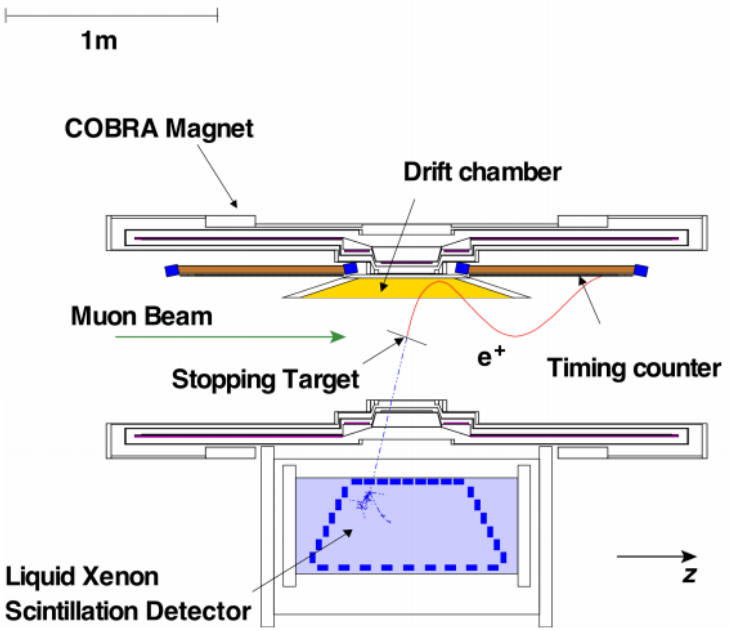
- 16-32 channels per module
- VME, NIM and desktop versions
- USB, CAEN CONET (optical link) and VME64/VME64X readout
- 0.75-5 GS/s sampling rate
- 12 bit ADC
- Memory buffer for 128 or 1024 events
- Multi board synchronization available for VME modules
- Pricing starts at 6000 EUR for smallest memory option

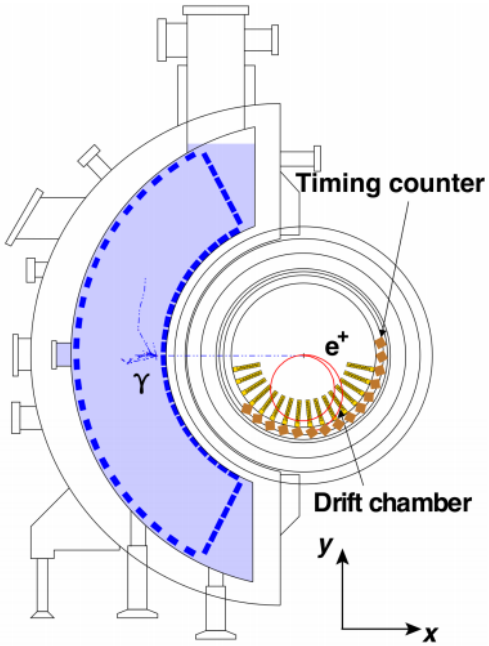
DRS in high energy physics experiments

MEG experiment

- Mu to E Gamma
- Search for the Lepton Flavor Violating Decay $\mu^+ \to e^+\gamma$
- Located at PSI, Switzerland
- Operated in 2009-2013
- Main result was strongest so far constraint for branching ratio of this process
- $BR(\mu^+ \to e^+\gamma) < 4.2 \cdot 10^{-13}$

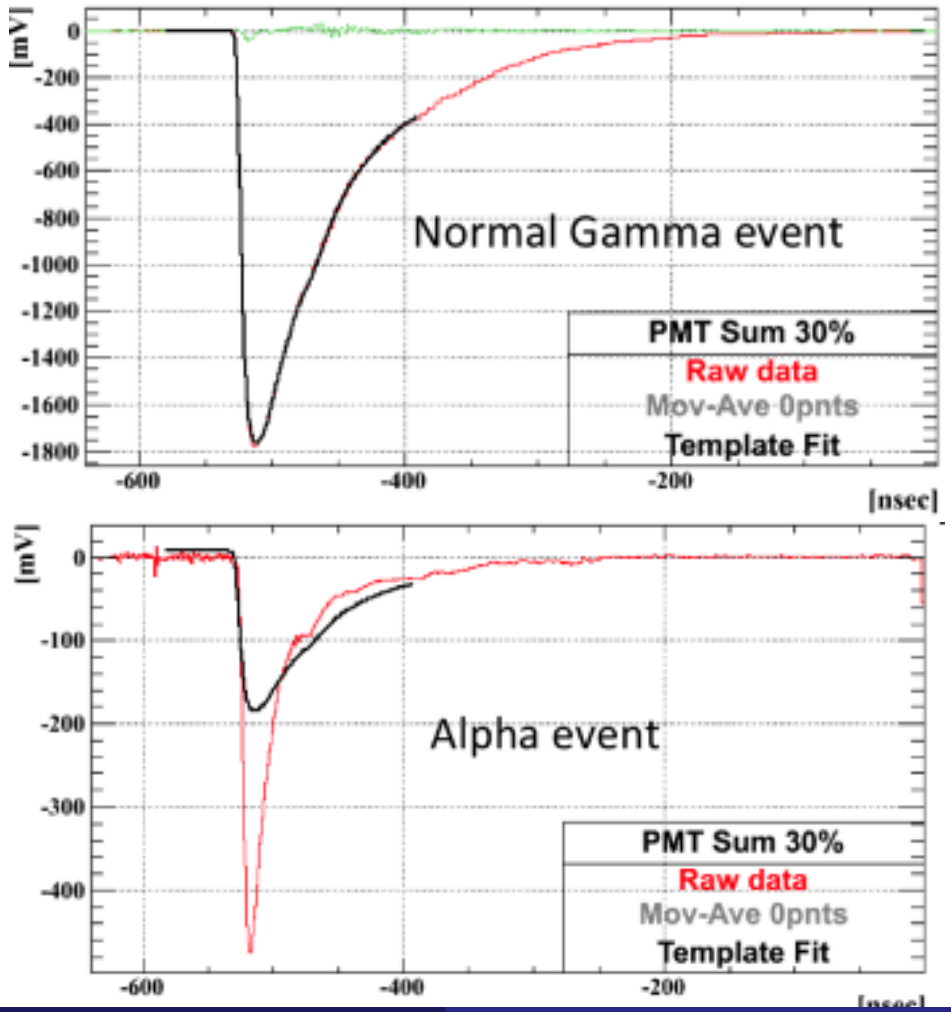


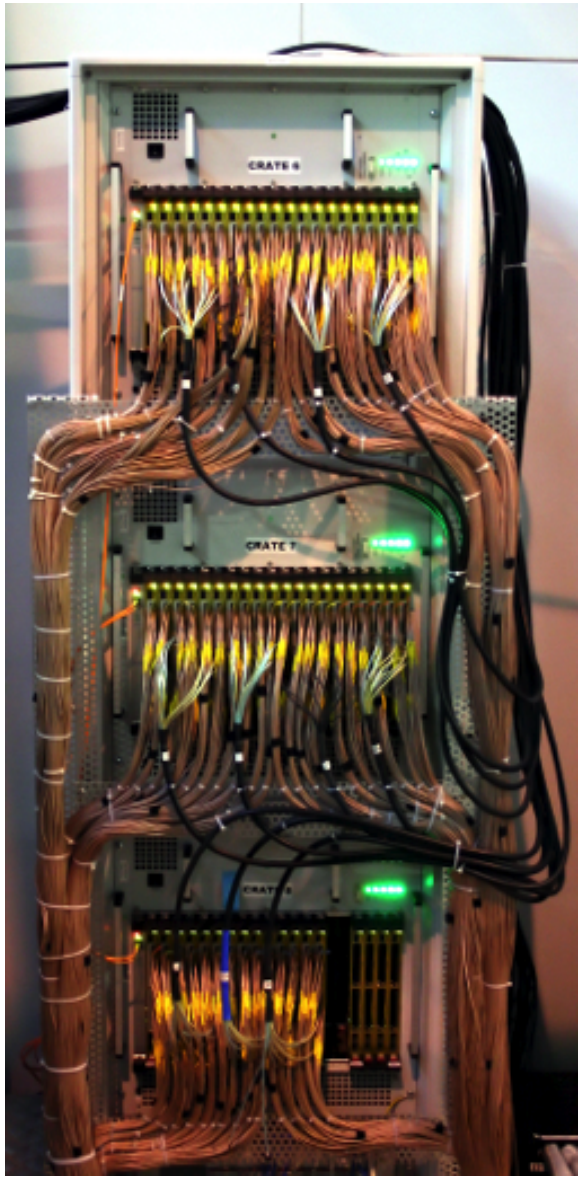




MEG experiment - readout

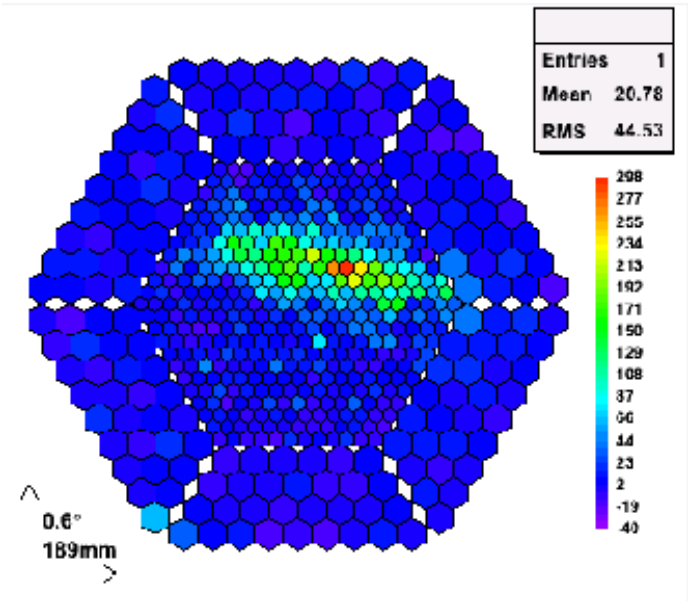
- DRS4 based readout for all PMTs and drift chamber
- 3000 channels in total
- Pulse shape is used to distinguish α form γ
- Data analysis takes full advantage from waveform digitization

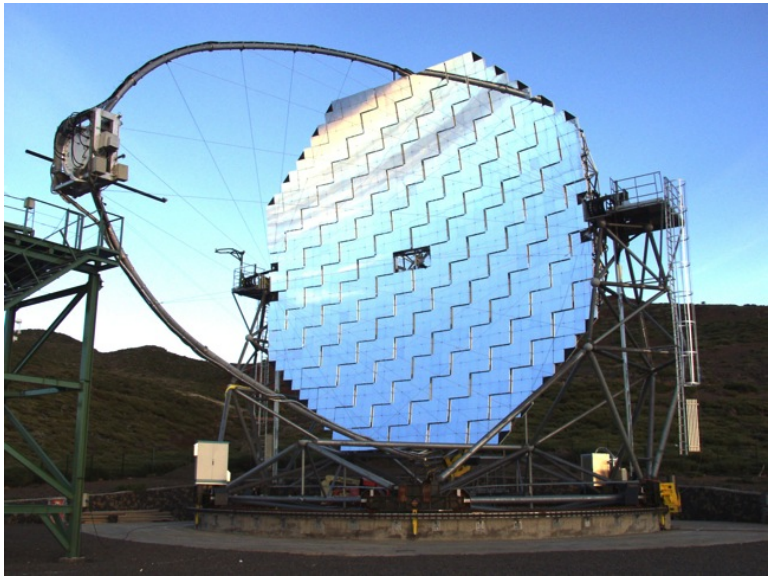


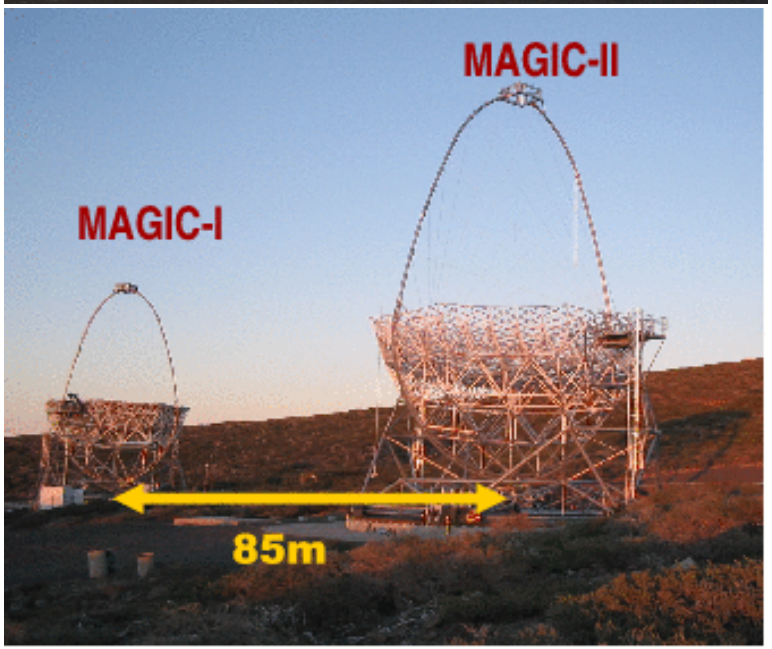


MAGIC telescopes

- Major Atmospheric Gamma Imaging Cherenkov Telescopes
- A system of two Imaging Atmospheric Cherenkov telescopes
- Located in Roque de los Muchachos Observatory, Canary Islands
- Data taking since 2004 (MAGIC) and 2009 (MAGIC II)
- Sensitive to γ energies in range 25 GeV - 30 TeV







MAGIC telescopes - readout

Old system:

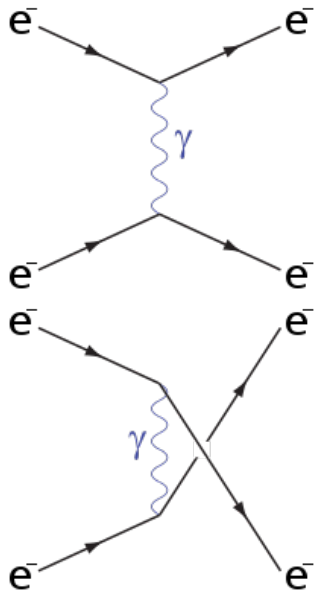
- 2 GHz flash ADC (multiplexed)
- 512 channels
- Total of five racks
- Around 20 kW power consumption

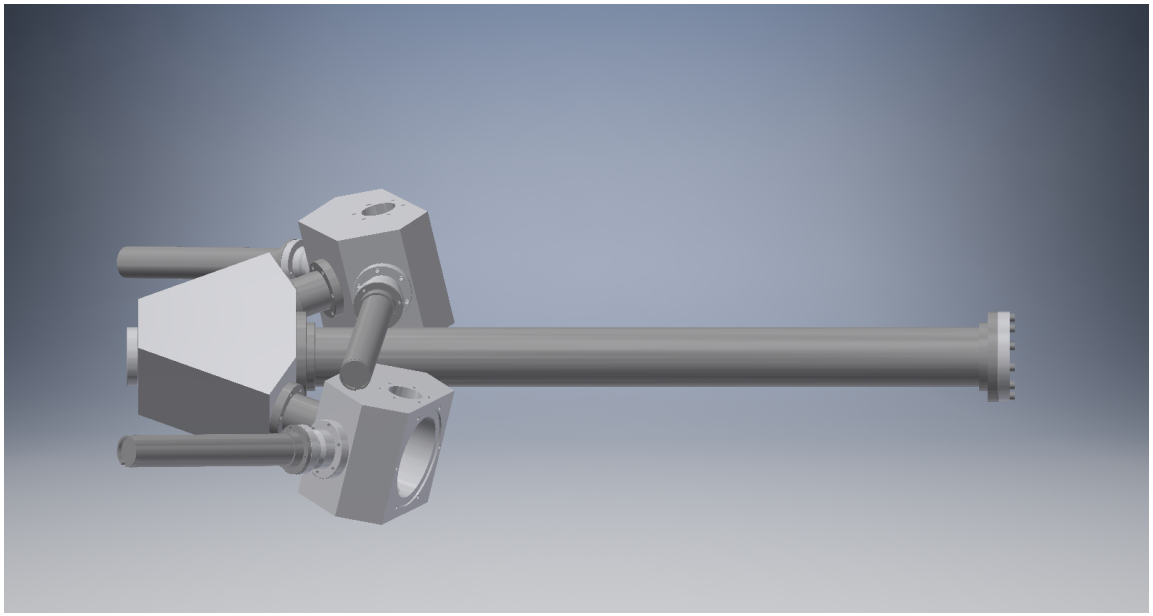
New system:

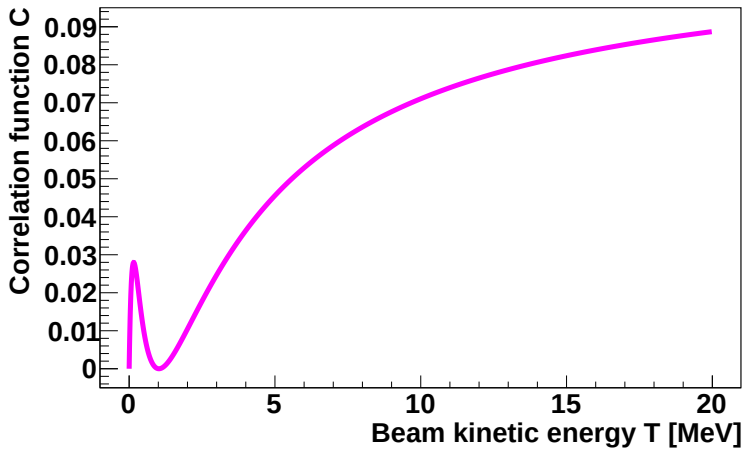
- 2 GHz SCA (DRS4 based)
- 2000 channels
- 4 VME crates
- Channel density 10x higher

2Pol experiment designed at FUW

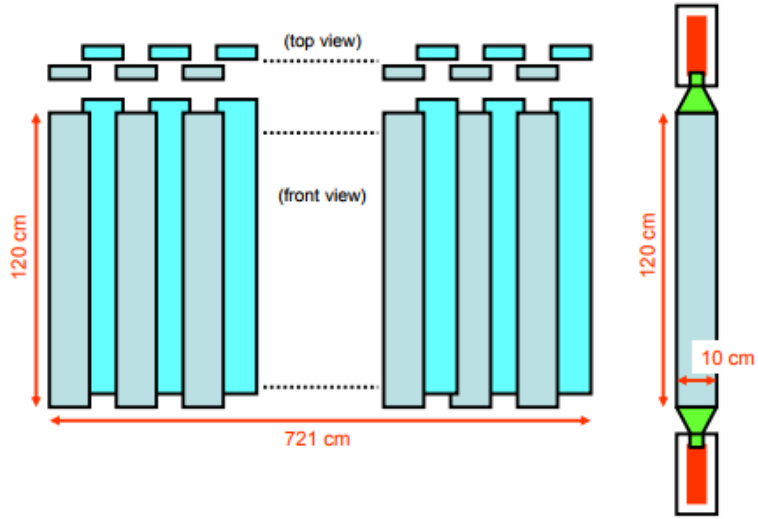
- Pioneering measurement of correlation function for massive relativistic particles
- First measurements to verify theoretical predictions of relativistic QM
- Møller scattering as a source of entangled electrons
- Double Mott polarimeter to measure spin projection of both electrons - 4 channels in total
- Planned readout - DRS4 evaluation board
- 3 MeV polarised electron beam

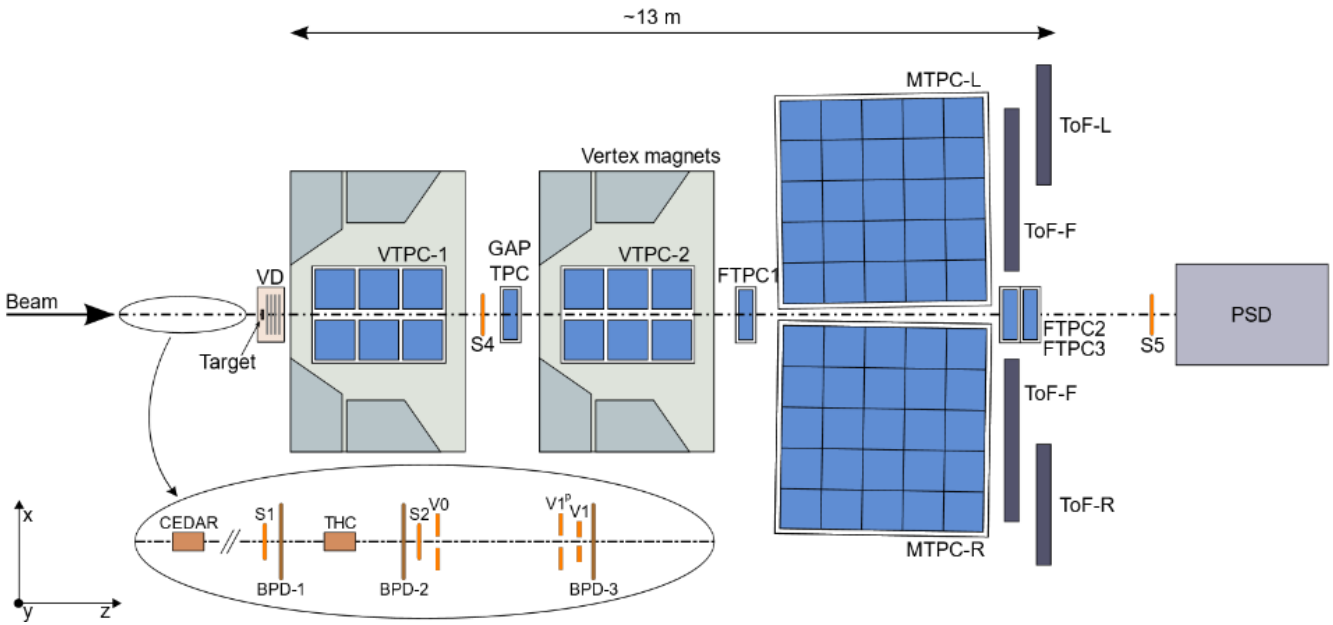






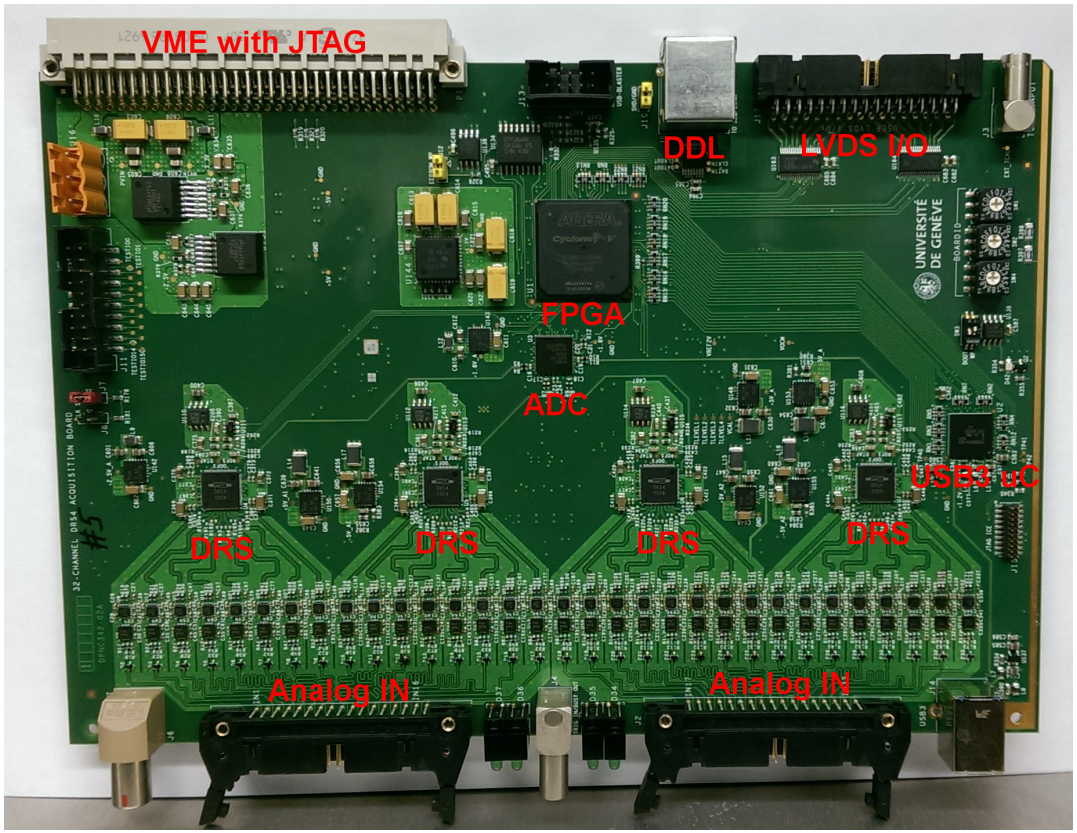
- NA61 SPS Heavy Ion and Neutrino Experiment
- Fixed target experiment located at CERN SPS
- Multi purpose hadron spectrometer
- Broad physics program covering strong interactions, neutrino physics and cosmic rays
- DRS4 readout of TOF-F detector implemented last year

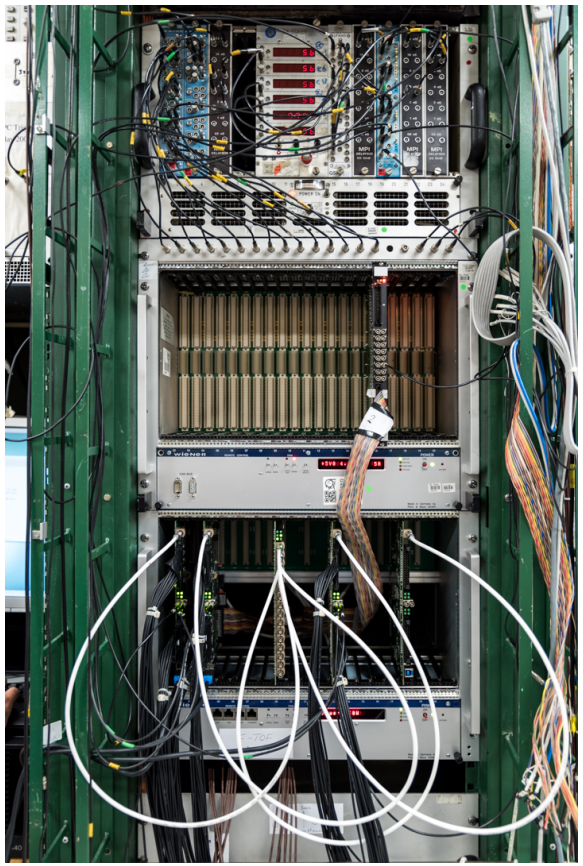




NA61/SHINE - TOF-F readout

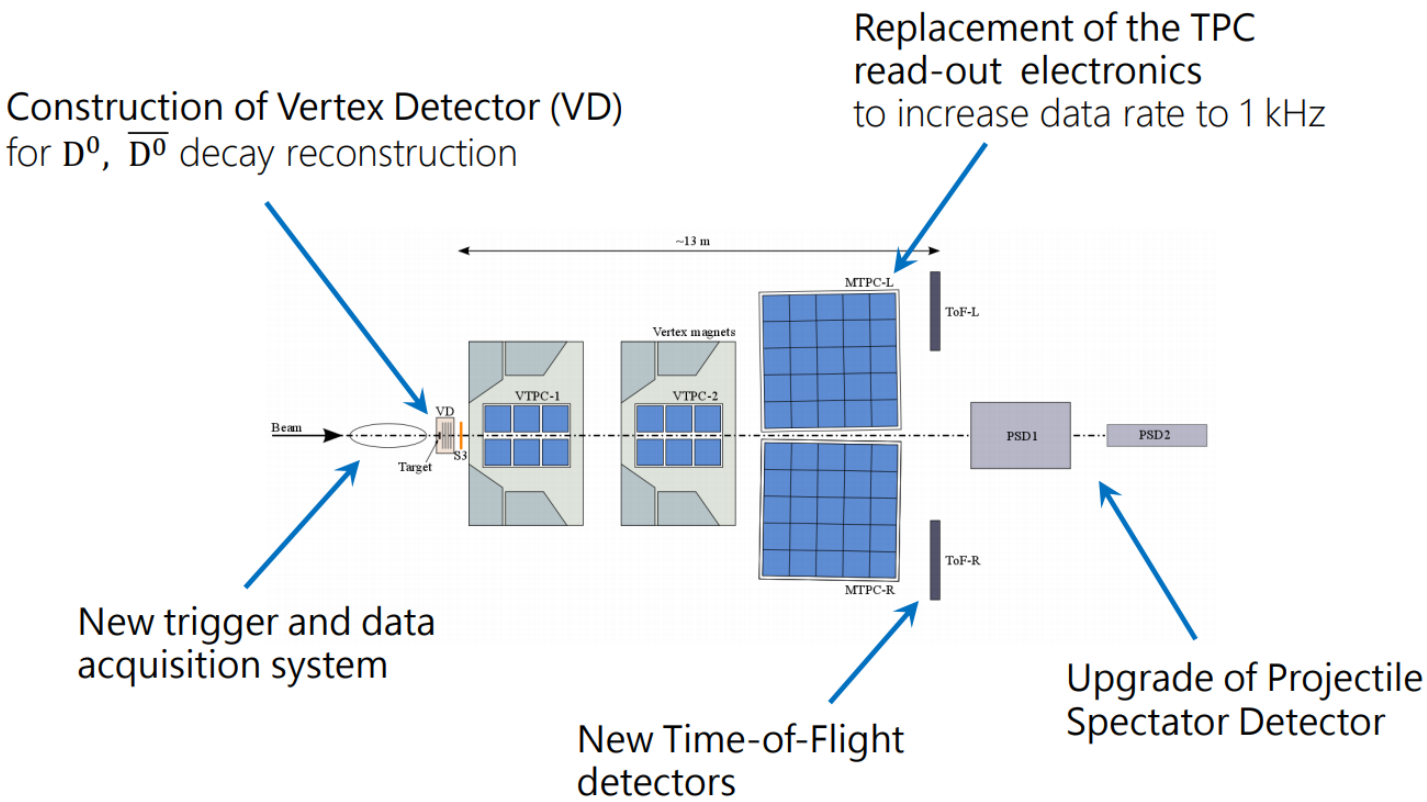
- During summer 2017 DRS4 readout of TOF-F detector was implemented
- TOF-F consists of 32 scintillator tiles, 2 PMTs each
- Custom DRS4 boards developed at University of Geneva were used
- Each board features 4 DRS chips, 32 analog channels in total
- 12 bit ADC is used





DRS4 in NA61/SHINE after 2020

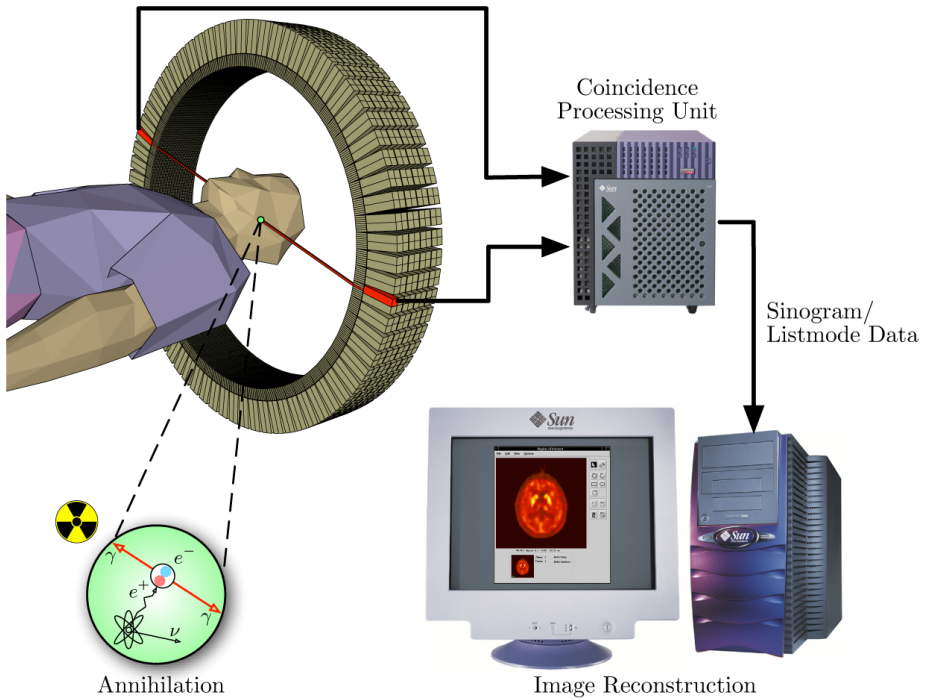
- Major hardware upgrades of NA61/SHINE detector are planned during LS2
- Increase rate of recorded events from around 80 Hz up to 1 kHz
- Introduce new, Large Acceptance Vertex Detector
- Use DRS4 to read out big part of the detector: TOF, beam detectors and PSD
- Around 3000 DRS4 channels, development ongoing
- Several racks with old NIM and CAMAC electronics will be replaced by few VME crates

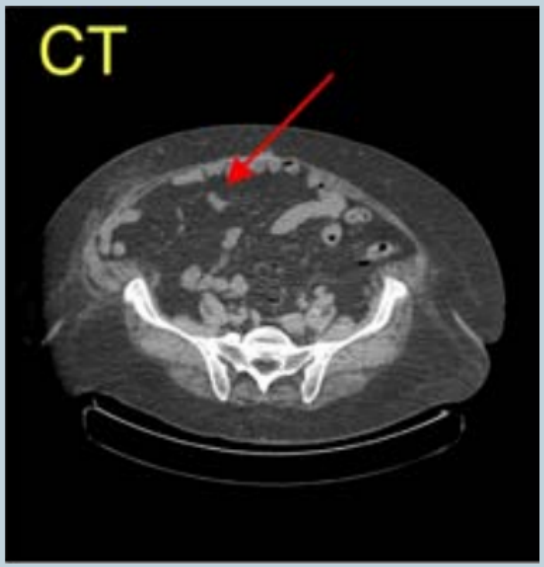


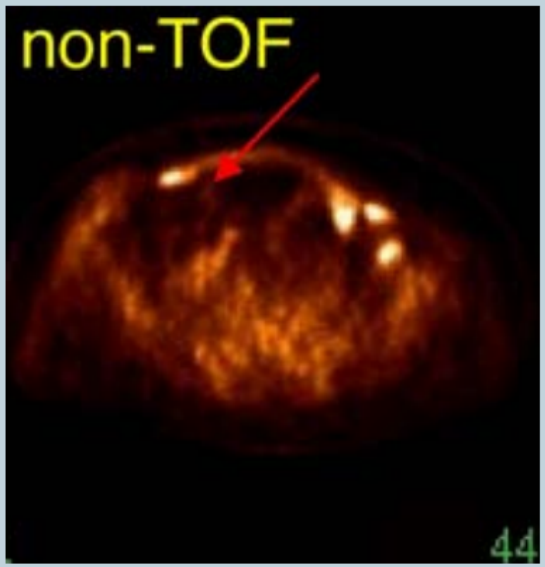
Possible DRS applications beyond physics

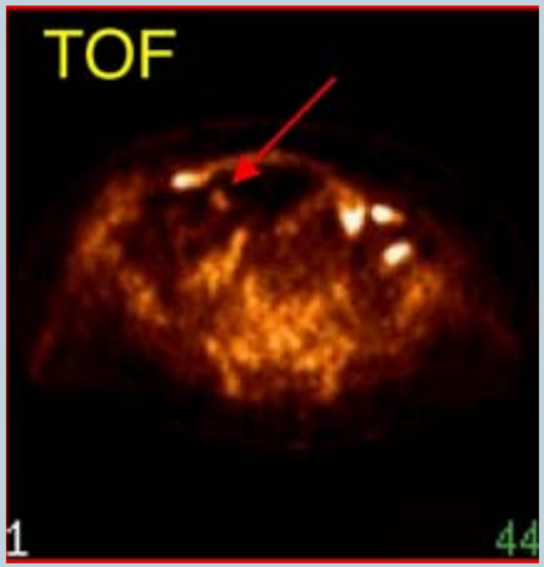
Beyond physics - Positron Emission Tomography

- PET is a imaging technique used in medical sciences
- It is based on detection of γ pairs coming from positron - electron annihilation
- Precise timing measurement at level of 100 ps allows for vast improvement of imaging resolution



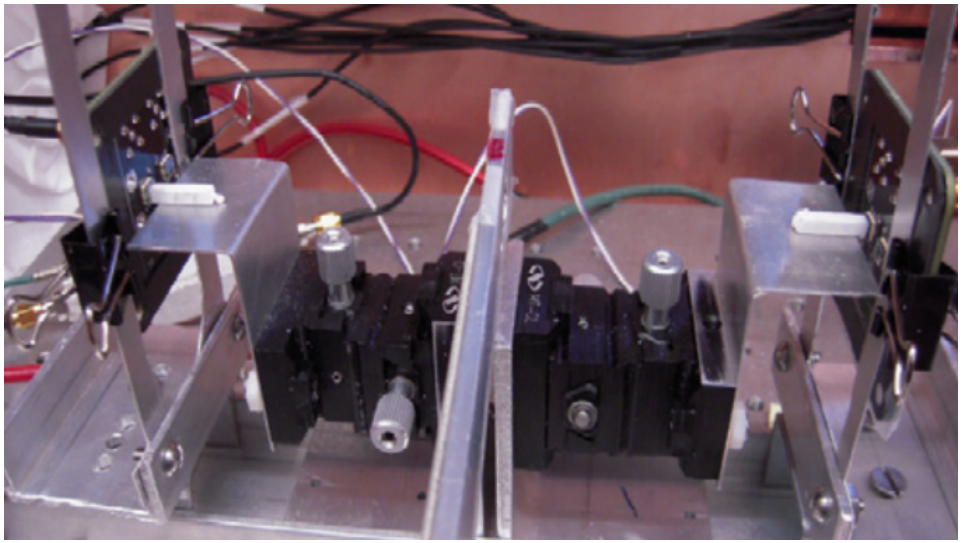


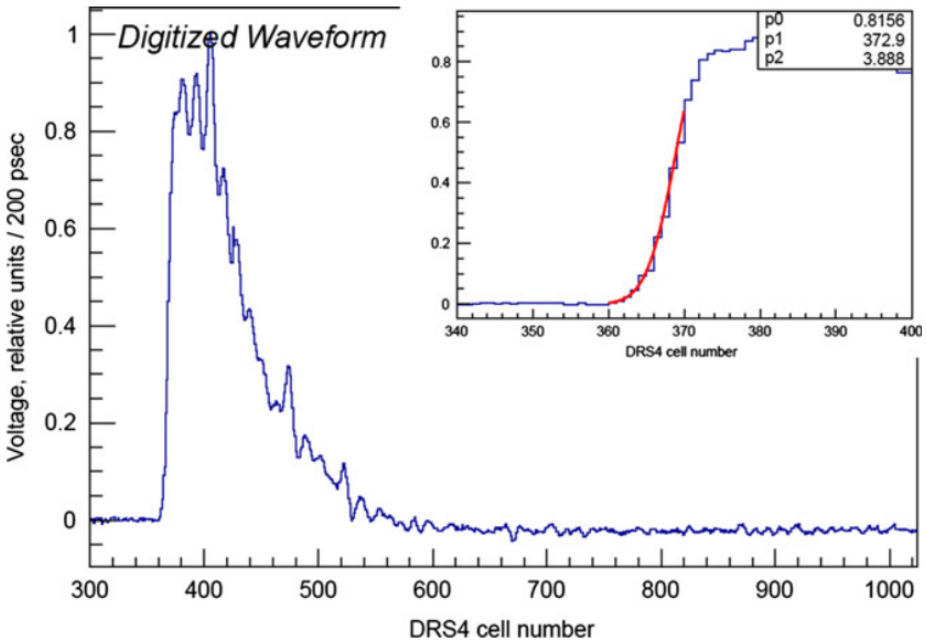


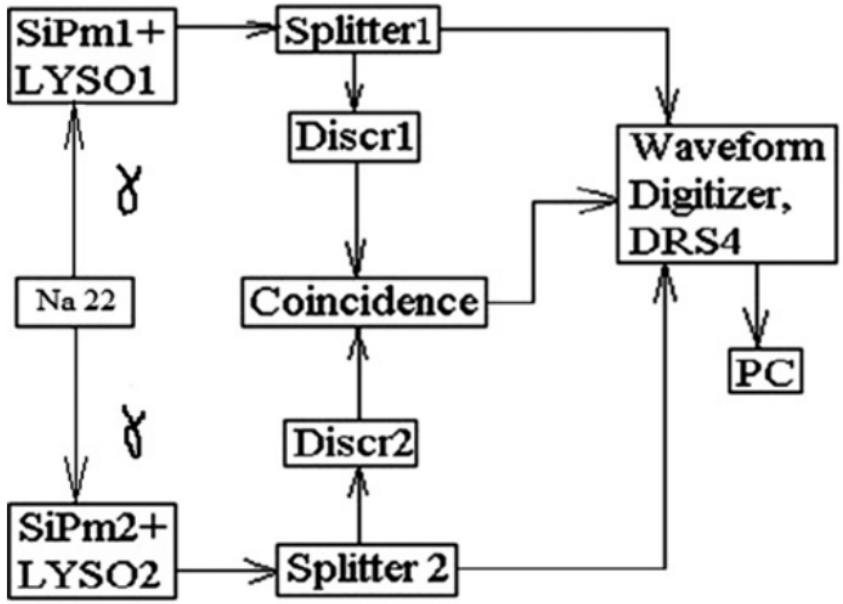


TOF PET with DRS4

- In 2013 A. Ronzhin et.al. designed DRS4 based TOF PET model detector
- Setup was tested with ^{22}Na source
- They achieved 180ps time resolution
- Further improvements are possible (time calibration, scintillators, SiPMs)
- DRS4 is an affordable candidate for TOF PET imaging



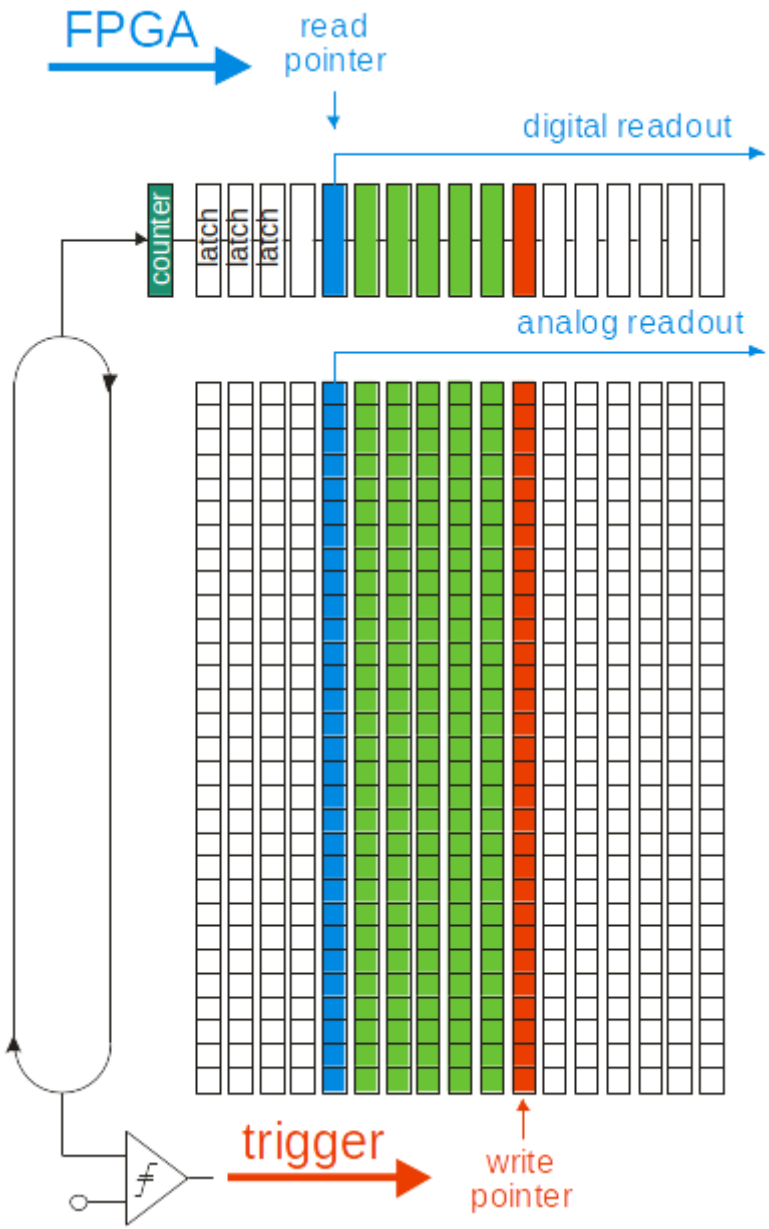




Future - DRS5

DRS5

- 10 GS/s sampling rate
- 5 GHz analog bandwidth
- Two stage sampling: fast 32 cell SCA plus slow buffer
- Self-trigger writing of 128 short 32-bin segments (4096 bins total)
- Storage of 128 events:
  - Accommodate long trigger latencies
  - Quasi dead time-free up to a few MHz
  - Possibility to skip segments $\rightarrow$ second level trigger
- Attractive replacement for CFD+TDC



Summary

- DRS4 is an affordable and powerful candidate for front end electronics in physics experiments
- It offers excellent timing resolution allowing for readout of time of flight detectors
- Waveform digitization opens new paths for data analysis
- DRS4 is flexible and can be used for many different detector types - unification of readout even in complex experiments
- DRS4 based electronics was successfully used in High Energy Physics experiments
- Existing experiments, such as NA61/SHINE, plan to use DRS4 in hardware upgrades
- SCA technology is a promising candidate for applications beyond physics such as PET
- DRS5 is on the horizon - more bandwidth, higher sampling rate and improved dead time

Thank you

Backup slides

DRS daisy chain

- DRS allows for channel daisy-chaining
- it extends time window by reducing number of channels
- DRS4 can be partitioned in: 8x1024, 4x2048, 2x4096, 1x8192 cells
- chip daisy-chaining is also possible - as long analog buffer as needed