Trends and Challenges in Modern DAQ Systems

Outline

- Introduction
- Tasks the DAQ has to Fulfill
- A Short History of DAQ Systems
- ASICs/FPGAs
- Solutions for Common Tasks
  - Time to Digital Conversion
  - Discrimination vs. fast ADC
- Networks / Computing
- Conclusion

Trends and Challenges in Modern DAQ Systems
Introductory Remarks

- “Forecasts are very difficult, particularly if they concern the future”
  - Winston Churchill, Niels Bohr, Kurt Tucholsky or any important person in history you like...
- Most forecasts are in the best case wishful thinking and most of the times biased by own interests

- “The best way to predict the future is to invent it”
  - Alan Curtis Kay (American Computer Scientist)
- The “Trends” described here are not neutral and are my opinion
  - Shared with others but not accepted by everyone
  - Statements are not black and white

Introductory Remarks: “Trends” Examples of Predictions in our Field of Science

- Transputers (parallel computers with communication channels): invented 1978, **the** hype of the 1980s
  - Without any doubt: A great idea and a huge potential
  - Failed (1990s) due to the complexity of the software
    - Parallelize algorithms is very hard
  - All points are still valid today and next try is ongoing
    - GPUs, Multicore-CPUs, FPGAs.
- Online Reconfigurable Hardware
  - Save hardware resources and reconfigure hardware on the fly for the current task
  - 15 years ago many people were talking about it
  - Today we still do!
- General Observation
  - Technologists are blinded by the technological potential and ignore the complexity of realization

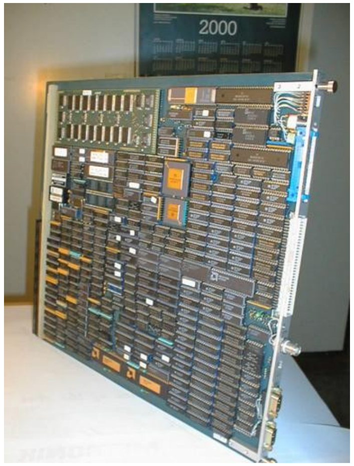
Tasks the DAQ has to Fulfill

- Data Acquisition: What should it do?
  - Front End Electronics (FEE)
    - Convert analog signals to digital ones
  - Transport data and store data
- General tasks did not really change over time
  - The same analog signals have to be converted and transported
  - We are driven by:
    - Number of channels
    - Number of events (time slices) per time interval
    - Size of electronics (e.g. ASICs)
    - Radiation tolerance (close to the detector)
    - Price

"History" of DAQ Systems
Standardization and Commercial Modules

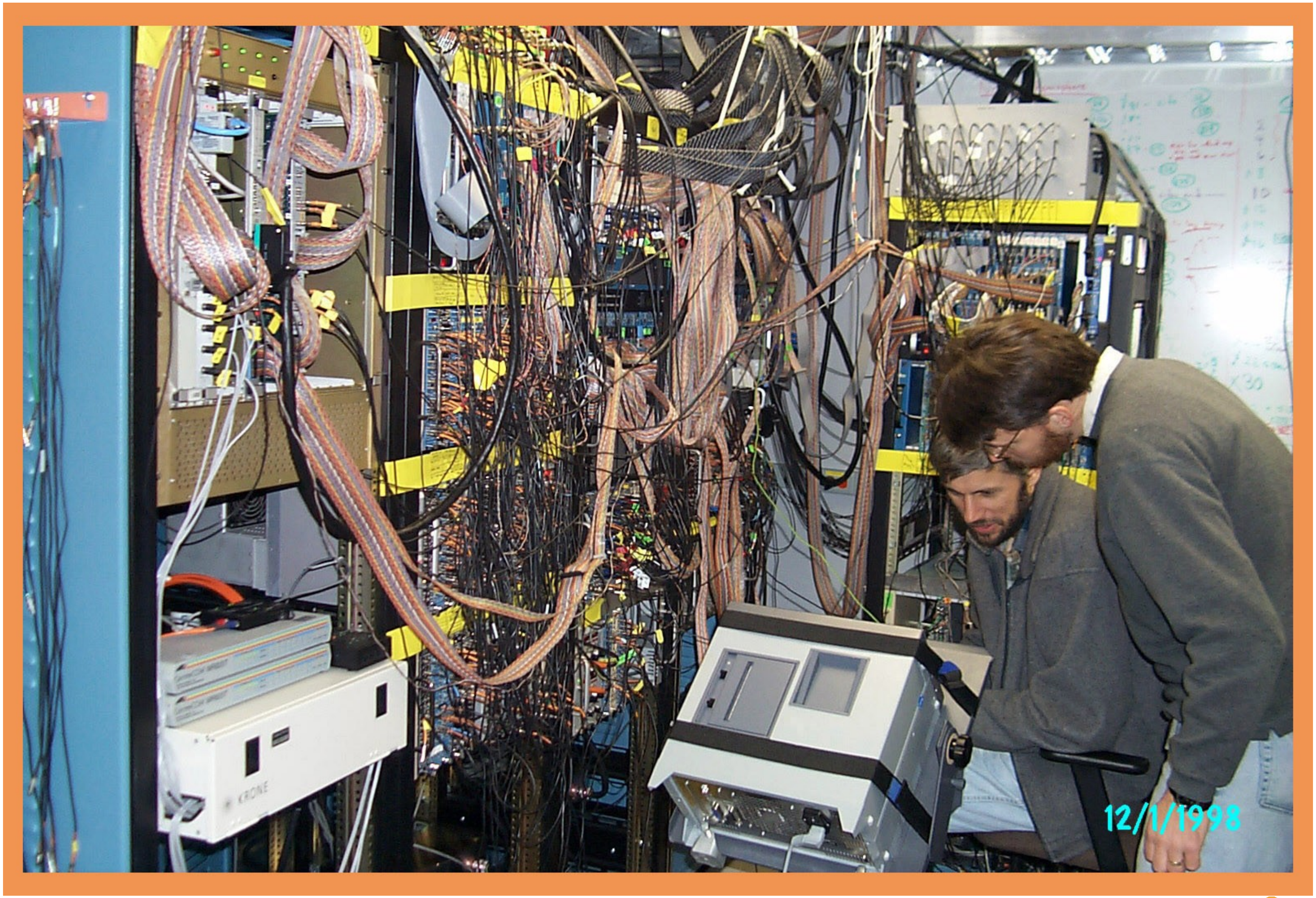
- Common tasks cry for standardized and commercial solutions
  - Crate systems: NIM (1964), CAMAC (1975), FASTBUS(1984), VME(1981), VME64(1994), ATCA (2002)



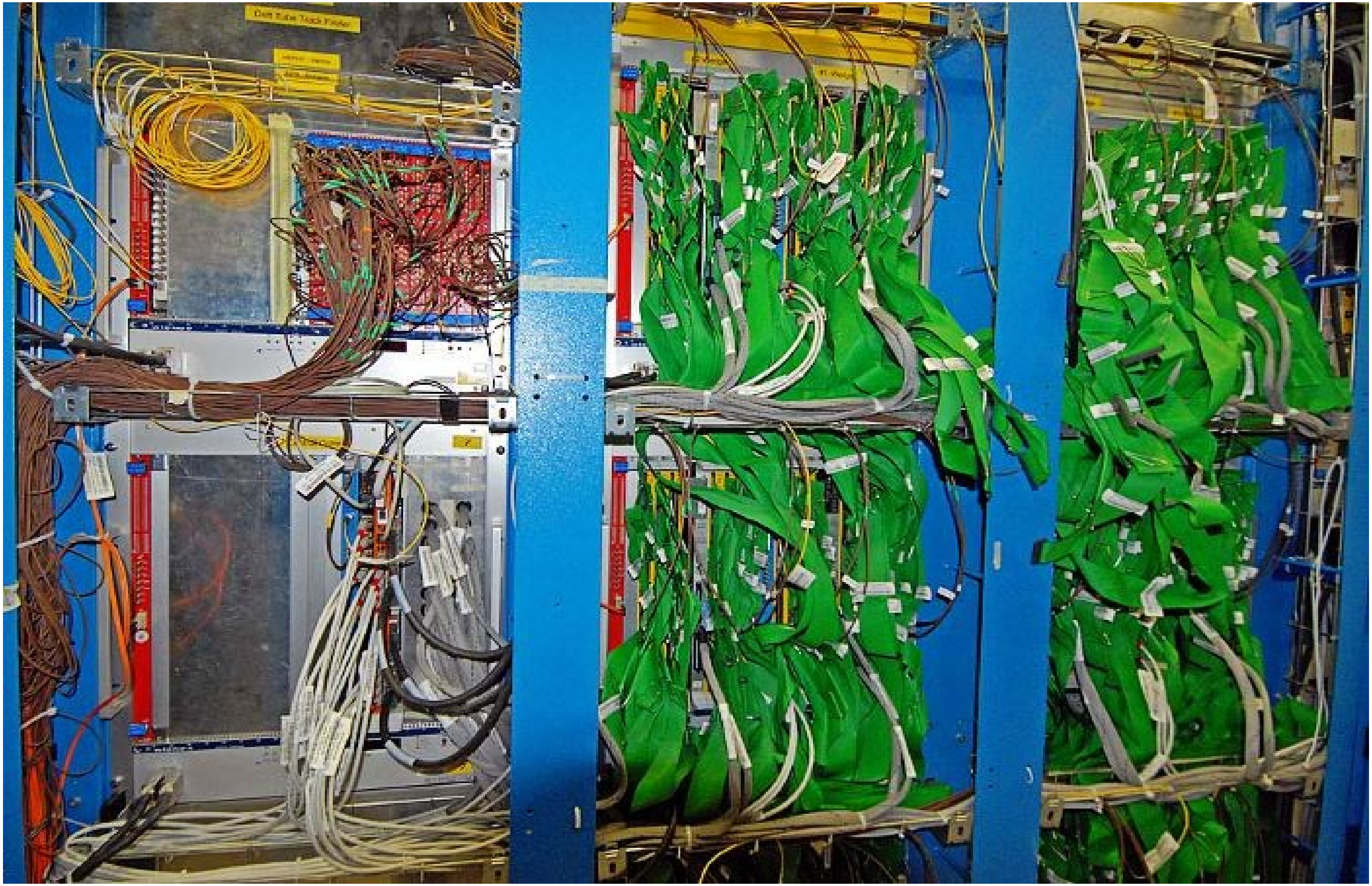


  - Suppliers: LeCroy (out of business), Ortec, CAEN and many others
  - Nuclear Physics was the "trendsetter" and inventing technologies in the beginning
    - there was nothing else and money was "not an issue"
  - Nowadays we can only take what the world wide consumer/telecom industry has already developed
    - But this available technology is amazing!

"History" of DAQ Systems
E.g.: Microball (Washington University)



“History” of DAQ Systems
E.g.: CMS Drift Tube Track Finder: 2010



"History" of DAQ Systems Results and Trends

- Fast to realize DAQ systems with commercial and verified solutions
- "Easy" to use: Physicists can build and maintain a system
- Also from today's point of view still a good way to go
- Not easily scalable: a good solution for ~1000 channels
  - Each channel needs a cable to a counting house with racks and modules → Cable Hell!
  - Price is high

- Modern DAQ-Systems tend to put the FEE to the detector
- "More modern" ones even put the digital part on the detector (where possible)
  - To achieve this one needs very high integrated analog and digital electronics, networking + power-supply techniques

Trends for DAQ Systems: FEE ASICs

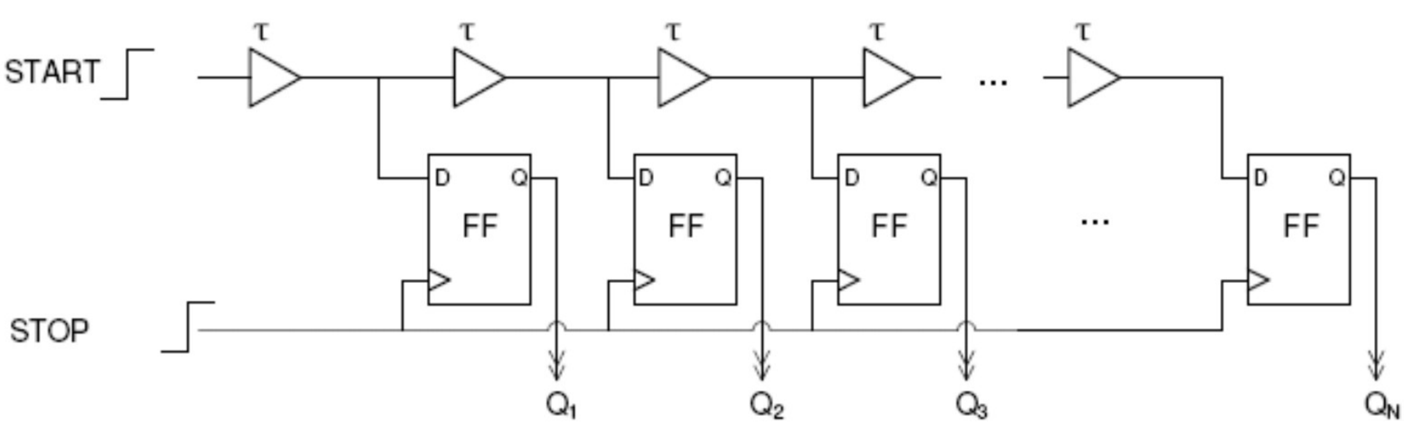
- Application Specific Integrated Circuits (ASICs)
  - Forced by requirements
    - # of channels per unit-length or per area
    - Power dissipation (compact detectors)
    - Radiation environment
    - Price/channel (>100k)
  - Detector and Readout-Electronics are combined
    - Example: MIMOSA (MAPS: Monolithic Active Pixel Sensors for Charged Particle Tracking)
      - Started in 1999, MIMOSA 34 released now, to be continued...
  - Extreme contradiction to standardization (application specific)
  - Downside: Timescales and manpower involved, initial costs
  - Technology far away from the state of the art concerning the digital part
    - 350nm ($100k for masks, Pentium II, replaced by 250nm in 1998) compared to 20nm (~$10 million for the masks), 14nm FinFET

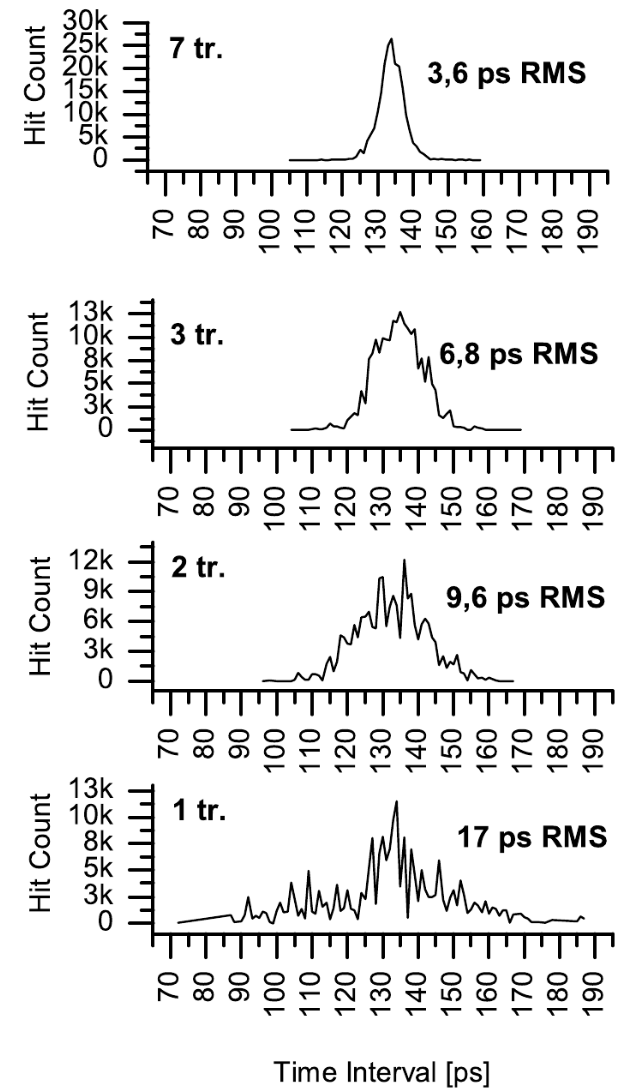
Trends for DAQ Systems: FEE FPGAs

- The happy medium between modules and full custom ASICs
  - Concerning the digital part of the DAQ for systems >1k channels
- Benefit from the world wide effort for highest performance (speed, power dissipation, price) digital electronics
- Application specific solution which is reprogrammable
  - More details about FPGA technology in talk from Grzegorz Korcyl
- “Freely” configurable hardware
  - Unpredictable potential, very exciting
  - Caution: This is not for free!
  - Law of conservation of complexity
    - Less cables, but the same complexity is inside the FPGA
    - Can only be efficiently and reliably programmed by an expert
- FPGAs are no replacement for general purpose computing like CPUs and GPUs

Trends for DAQ Systems: FEE FPGAs: Unpredicted Results

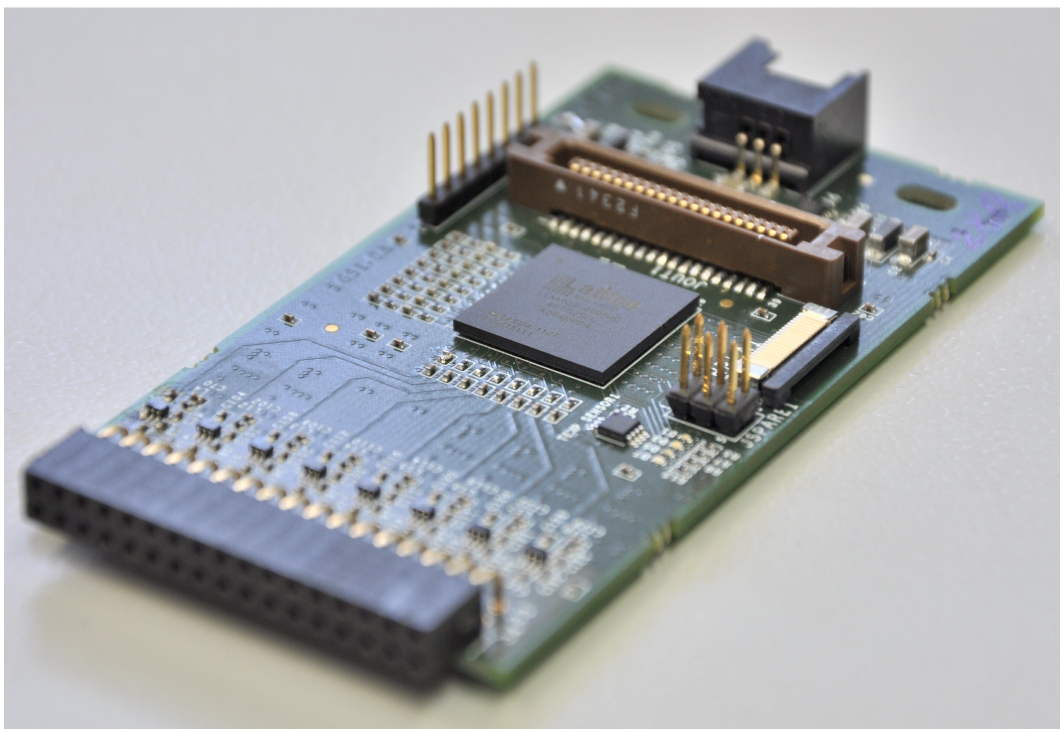
- FPGAs can be misused in the analog world
- Time to Digital Conversion (TDC) is very common task in Physics Experiments
- Only ASICs could be used up to now
- Can be done with an unexpected precision in an FPGA
- More flexible than an ASIC solution
- Digital DAQ part with high performance included





Trends for DAQ Systems: FEE
FPGAs: Come & Kiss

- FPGAs have high quality differential receivers built in
- Misuse an FPGA as discriminator
- In the simplest case (no amplification, e.g. for PMTs) FPGA does everything



- Can be used for time measurements of fast signals
- FPGAs can be used close to the detector as FEE

Trends for DAQ Systems: FEE
Fast Analog to Digital Converter (ADC)

- The best DAQ-system is still a high quality oscilloscope
  – All information of the original signal is recorded
  – Unfortunately only a few channels
- Fast ADCs and online data processing
  – Digital Pulse Processing
- Needed for “unknown” pulse shapes or in case of pileup
- Downside
  – $100-$200 for two channel 250MSPS ADC
  – 300mW/channel
  – Processing resources in FPGA needed
- No affordable solution for 1ns pulses of fast PMTs

Trends for DAQ Systems: DAQ Network and Computing

- You can't compete with industry in networking and computing
  - Just use the great stuff what is available
  - Costs reduce every year, features increase
- Network
  - Convert your data-stream as soon as possible to Ethernet/Infiniband to benefit from the high performance and “cheap” hardware available
- GPU (parallel computing) vs. CPU (multicore)
  - No final statements possible
  - The “new” technology will most likely go along with the existing technology for special tasks
    - There are algorithms which are very well suited for GPUs
  - But again: more care/time has to be put into the programming of GPUs compared to CPUs (still much less than FPGAs)

Conclusion

- FPGAs simplifies the setup of an experiment dramatically
- Complexity is preserved!
- New unforeseen applications of FPGAs possible even in the “analog” world
- FPGAs don't replace general purpose computing
- Development effort is **not** small and needs experts
- ADC vs. Time-Measurements: Both have their valid fields of applications
- Networking is a mission critical single point of failure:
  - Any commercial network has **many** huge advantages compared to a **highly** optimized custom solution
- Don't compete with commercial solutions: Try to assimilate them!

Thank you for your attention!