Triggering and data acquisition in ten years

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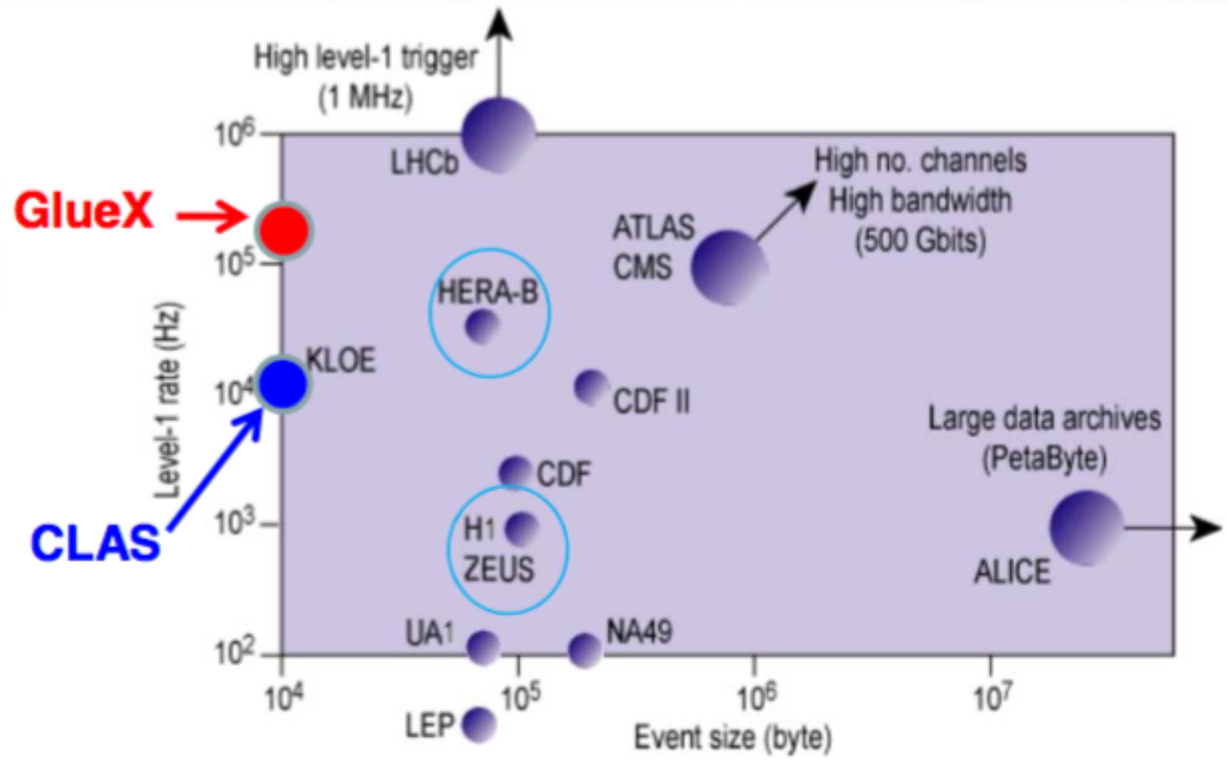
Data acquisition for NP

- Whether the experiment is fixed target or colliding beam a number of different detector types are used to capture the interaction being studied. Signals from the detectors are digitized and read out by the DAQ system.
- The early stages of readout are controlled by trigger electronics which use the output of fast detectors to reject unwanted data and reduce background.
- Typical trigger systems are organized hierarchically with events surviving the fast trigger being subjected to further trigger stages that involve data from more detectors and are progressively slower.
- In many experiments the trigger system is implemented entirely in electronics but in some cases rejection of background events requires some level of processing of the data in software. This is typically done in the late stages of the DAQ when data from all of the detectors is available.
- The trigger rate is influenced by:
  - Interaction rate
  - Speed of detector.
  - Speed of digitizing electronics.
  - Speed of trigger electronics.
- Data rate is event size multiplied by the acceptance rate of the trigger stage.

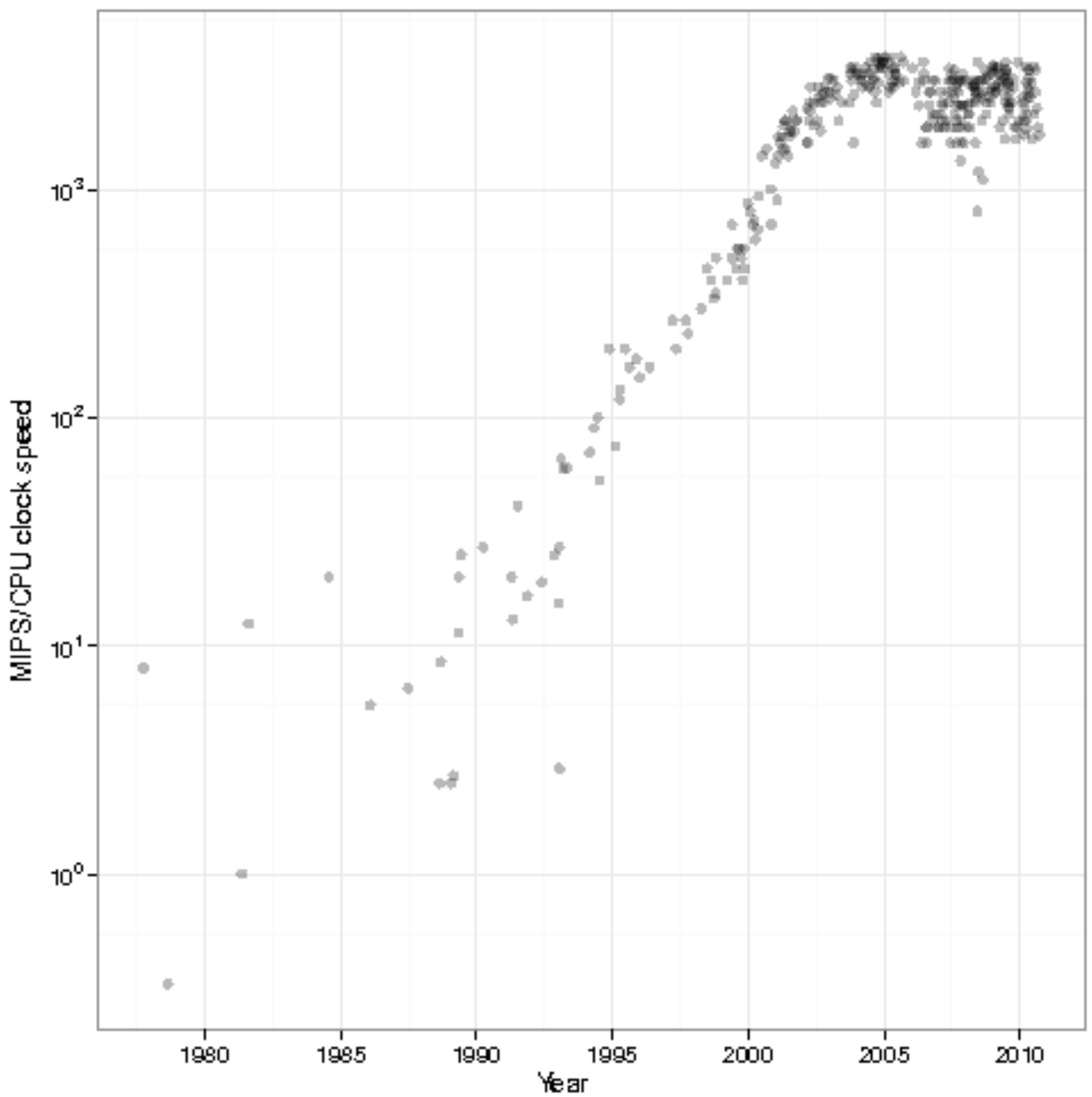
Trends in experiments

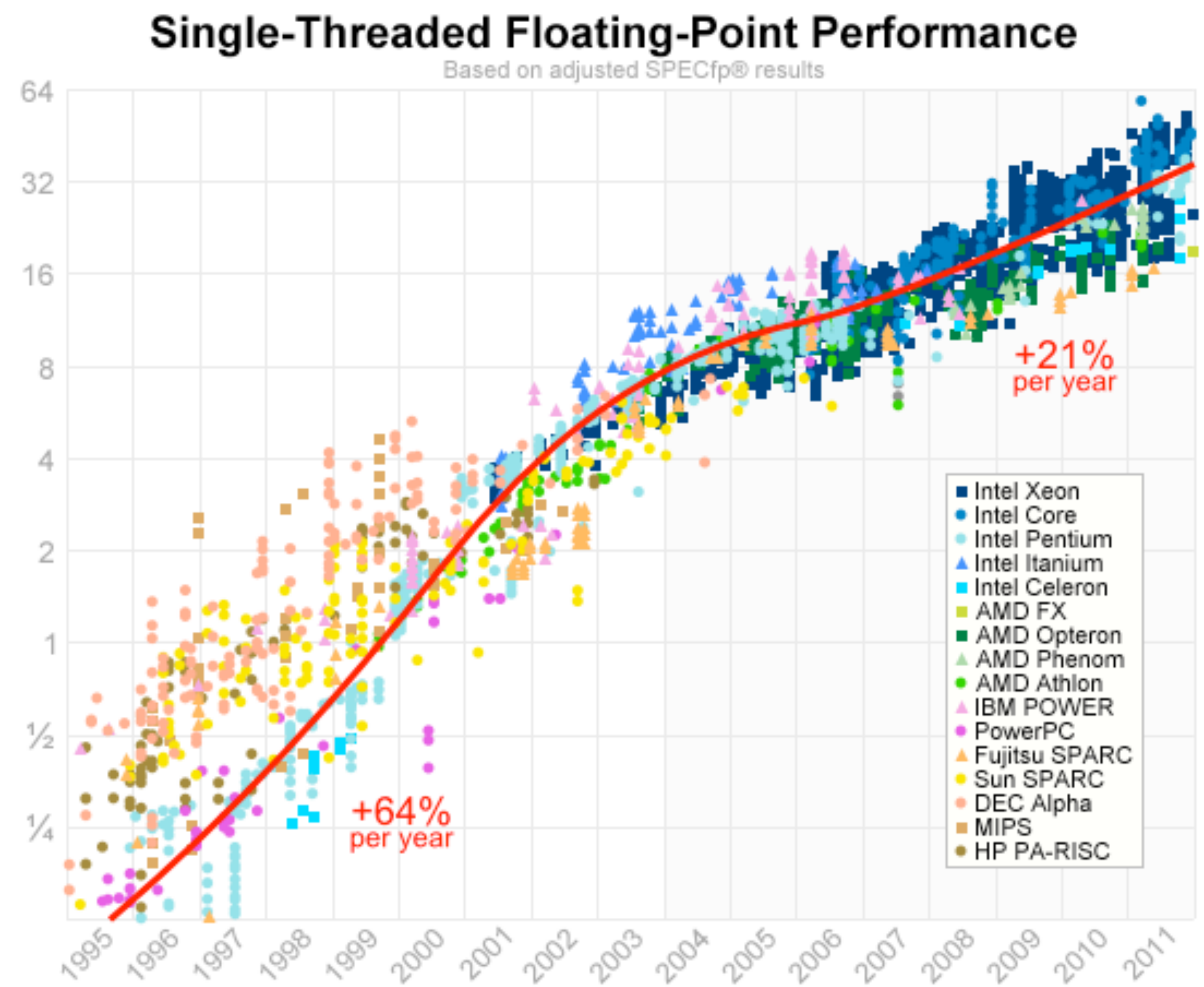
- Look at historical trigger and data rates.
- At JLab
  - mid 1990's CLAS, 2 kHz and 10-15 MB/s
  - mid 2000's - 20 kHz and 50 MB/s
  - mid 2010's
    - HPS, 50 kHz and 100 MB/s
    - GLUEX
      - 100 kHz, 300 MB/s to disk.
      - (Last run 35 kHz 700 MB/s)
- FRIB - odd assortment of experiments with varying rates
  - LZ Dark matter search 1400 MB/s
- RHIC PHENIX 5kHz 600 MB/s
- Looking at the most demanding experiments for trigger or data rate :
  - Highest data rate increases by factor of 10 every 15 years.
  - Highest trigger rate increases by a factor of 10 every 10 years.



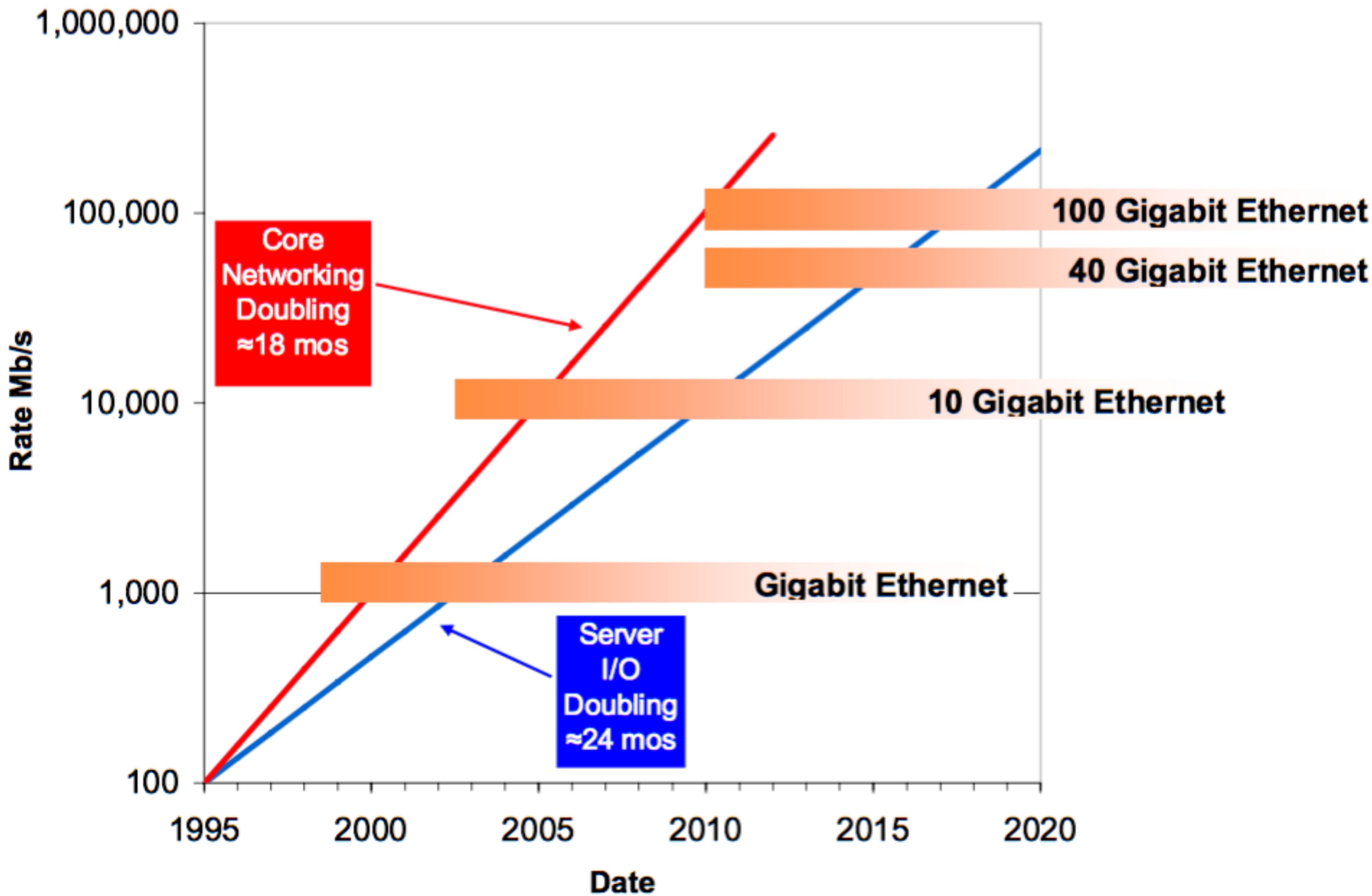
Electronics speed

- Famous Moore's law - transistor count doubles every two years.
- Clock speed plateaued ten years ago!
- Advances purely by squeezing more cores per chip and improved architectures.





Data transport



IEEE 802.3 Higher Speed Study Group - TUTORIAL

Observations

- The precision of the science depends on statistics which leads to :
  - Development of detectors that can handle high rates.
  - Improvements in trigger electronics - faster so can trigger at high rates.
- Beam time is expensive so data mining or taking generic datasets shared between experiments is becoming popular.
  - Loosen triggers to store as much as possible.
- Limiting factor is available technology vs budget. This is a constraint that is shared by all experiments at the various facilities.
  - It is not surprising that trigger and data rates follow an exponential trend given the "Moore's law" type exponential trends that technologies have been following.
  - The exponential growth in speed of electronics is faster than the growth rate for network and I/O speed.
  - **What matters is not when a technology appears but when it becomes affordable**. It takes time for a technology to become affordable and for someone to use it in DAQ.
    - Electronics speed determines limit of trigger rate.
    - Network and I/O speed determines ultimate limit of data rate.

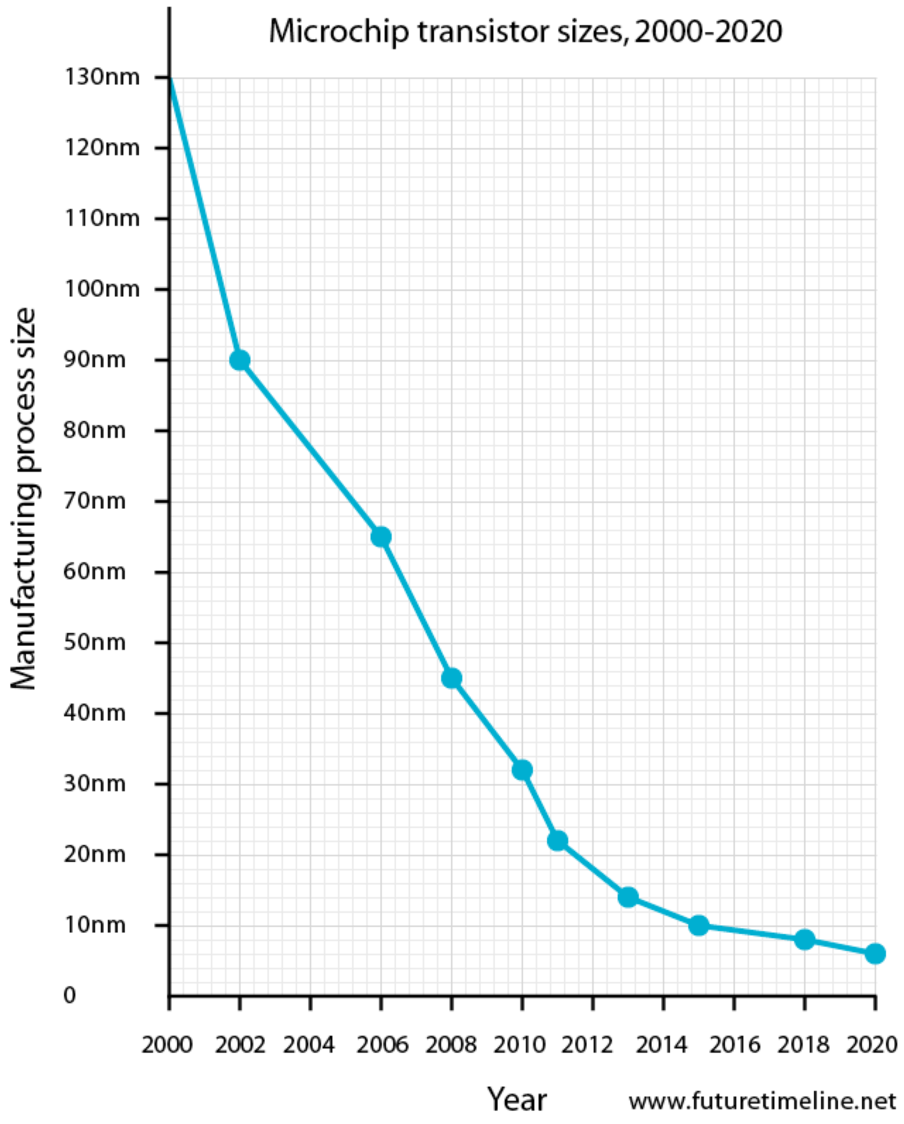
What would we expect in 10 years?

- If we extrapolate current trends:
  - DAQ performance requirement:
    - Factor of 10 higher trigger rate ~ 1 MHz
    - Factor of 6 higher data rate ~ 2 GB/s
  - Technology:
    - Single thread performance factor of 5 higher than today
    - Performance per $ factor of 80 higher - use systems in parallel.
    - Core network speeds factor of 100 higher - maybe factor of 10 affordable.
    - Server I/O bandwidth factor of 30.

- Looking at experiments on the 10 year horizon that have been proposed so far most fall well below the extrapolated trend.
  - It would appear all is well…. or is it?

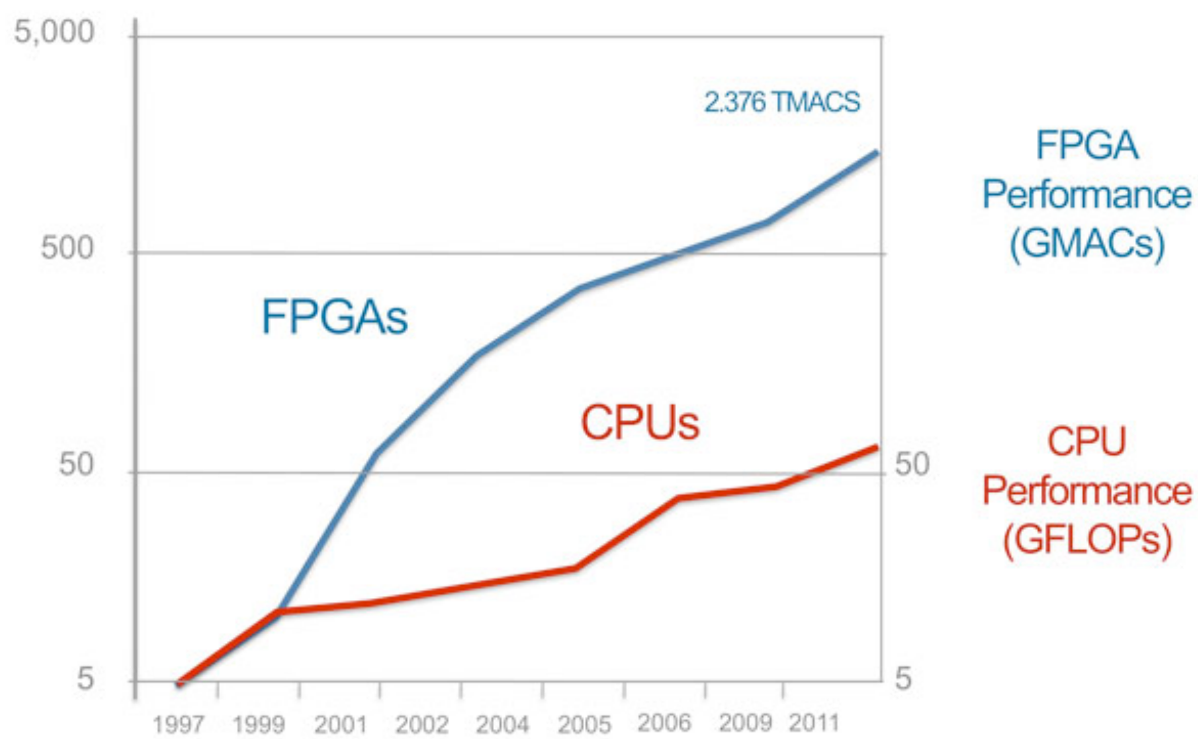
A dose of reality

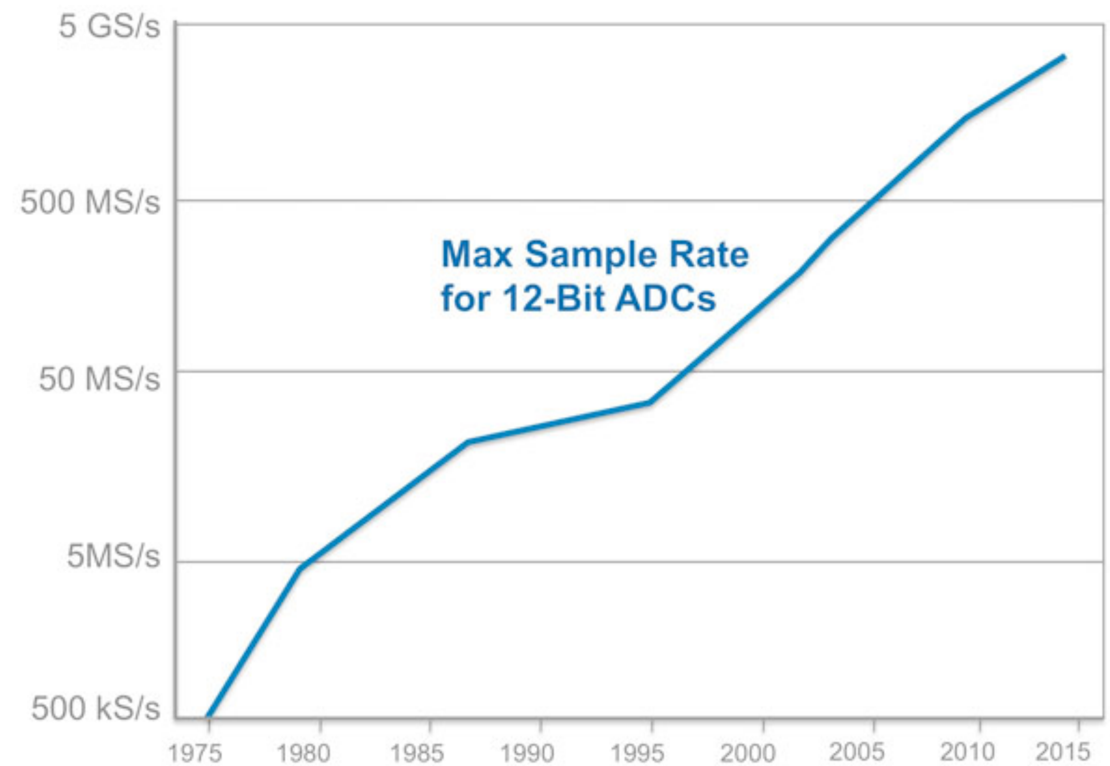
- Manufacturers are struggling shrink transistors.
  - How much further can Moore's law continue?
  - Does this affect the performance of other DAQ electronics?
- Use of mobile devices is driving tech in a direction that may not be helpful to NP DAQ, low power and compact rather than high performance.
- NP hasn't driven electronics innovation for a long time.
  - Are the rates for proposed experiments low because of low expectation?
  - Does the requirement of the experiment expand to take full advantage of the available technology?
  - If we come back in five years from now and look at experiments proposed for five years after that will we see a different picture than the one that we now see looking forward ten years? Probably yes.



Trigger and electronics

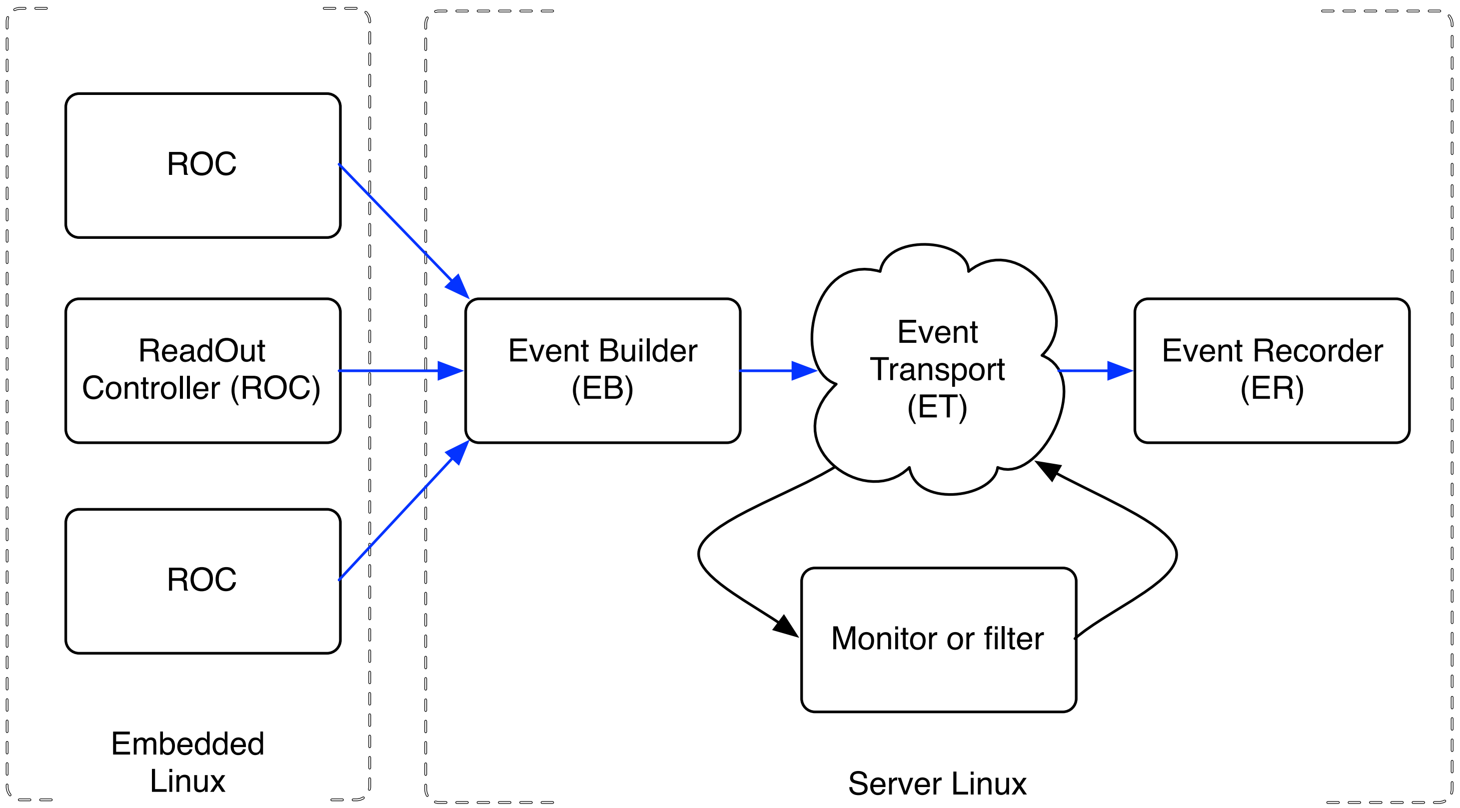
- Another factor of six in data rate is more than VME (and it's variants) can handle.
  - Move to other industry standards like MicroTCA.
- Current trend is to push some functionality currently performed in software running on embedded processors into firmware on custom electronics. This will probably continue:
  - Slow increase in single thread CPU performance.
  - Delay between when technology is developed and when it becomes affordable for use in custom electronics means that there is room for growth over the next ten years.





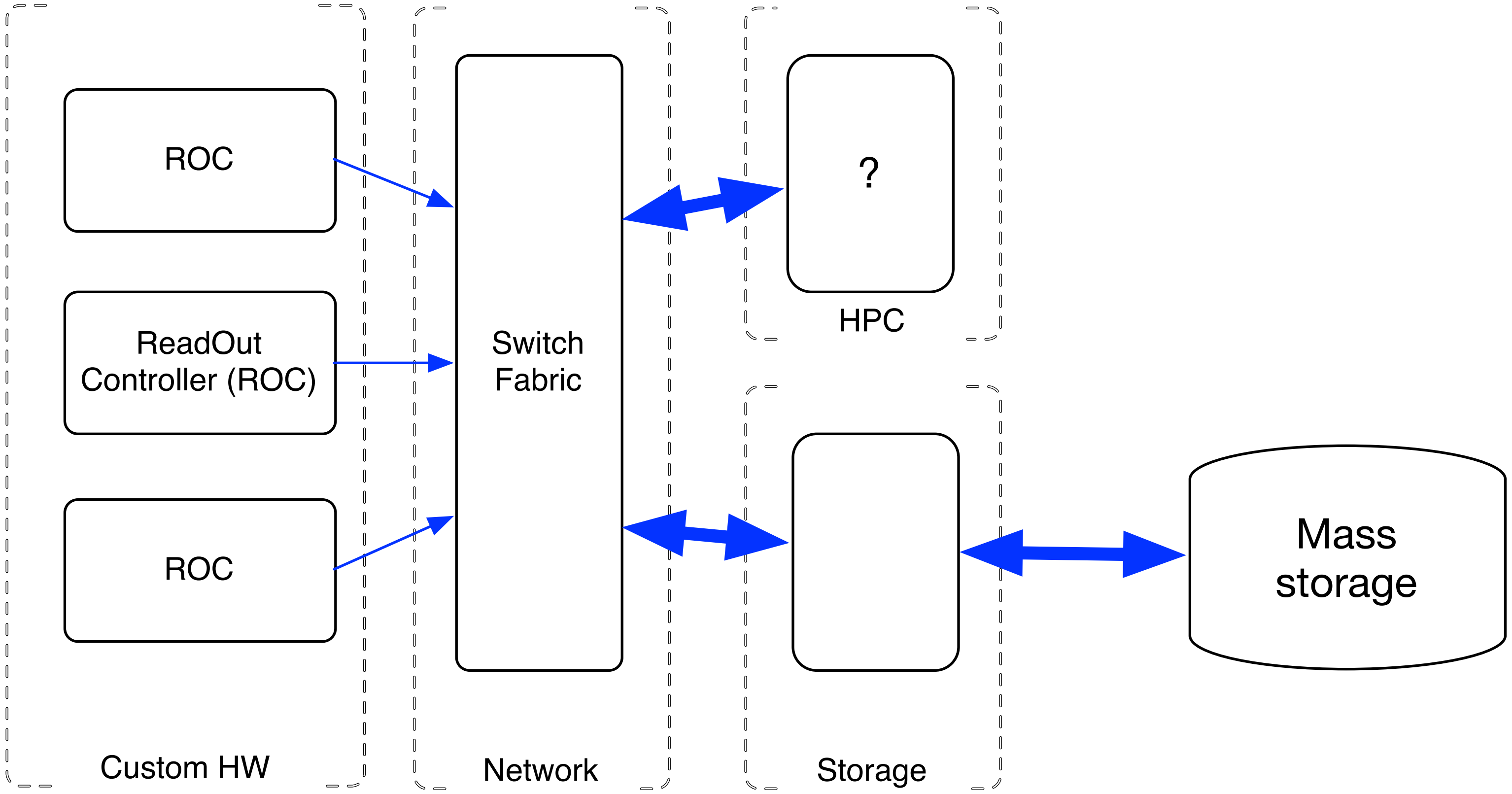
System architecture

- DAQ architectures have not changed much in twenty years.
  - Signals are digitized by electronics in front end crates.
  - Data is transported to an event builder.
  - Built events are distributed for filtering, monitoring, display etc.
  - Event stream is stored to disk.
- Issues :
  - Bottlenecks
  - Scalability
  - Stability



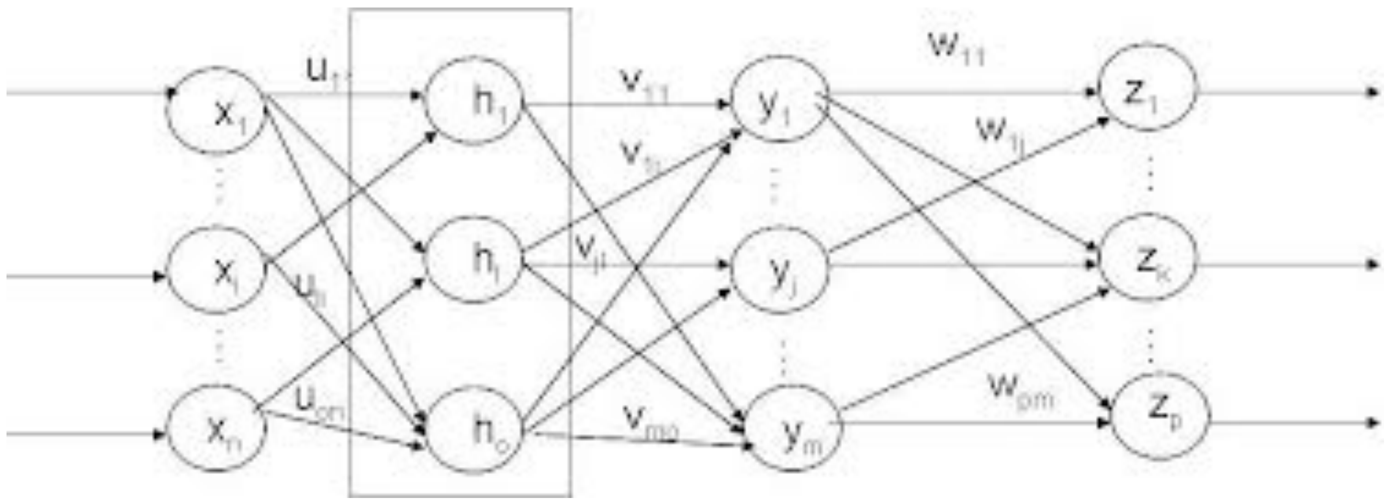
In ten years?

- Can’t escape some sort of crate to put the electronics in - MicroTCA ?
- Pipe the data through a network directly to temporary storage.
- High performance compute system processes the data online.
- Data surviving trigger or output from online processing migrates to long term storage freeing space for raw data.
- Much simpler architecture - more stable DAQ - but needs affordable versions of :
  – Reliable high performance network accessible storage.
  – High bandwidth network.
  – Terra scale computing.



Sidestep Moore’s law

- Get off the Moore’s law curve by doing something radically different.
- Some groups have already studied using neural networks to implement trigger systems for HEP and NP DAQ systems.
- Data is pre-processed then fed into a neural network trained to recognize patterns in the data.
  - Training using MC output fed into front-end boards.
  - Looks for clusters, tracks, rings in Cherenkov detectors etc.
- Traditional “do this then that” algorithms don’t scale well on parallel systems.
- Neural systems are inherently parallel.



Trickle-down advances

- Large projects like Exascale computing invariably lead to standards, software packages and hardware technologies that can be of use in the DAQ environment.
  - Storage - reliable high bandwidth network accessible storage
  - Data transport - secure and reliable high bandwidth inter-process communication for control and data flow.
  - Operating systems - make a cluster behave like a single machine.
  - Stream oriented - hardware and software developed to handle streams of data.
  - Languages - easier to take full advantage of parallelism on these machines.
  - Neural Net - technologies allowing new approaches to old problems.

Summary

- At first glance comparing an extrapolation of current trends of experiment requirements out ten years to a similar extrapolation of technology indicates that DAQ only gets easier with time.
- Caveats :
  - Technology trends in the next ten years show indications that simple extrapolation may be invalid. Good chance of disruptive technologies emerging.
  - Proposed requirements for new experiments may be based on perceptions of what will be possible that are artificially low.
  - Requirements are based on a workflow that may be non-optimal - there are other ways of doing things that are not accessible now but may be in ten years.
- Advances towards Exascale computing and other advanced computing projects will have a considerable impact on how NP DAQ is done.