The LHCb Data Acquisition during LHC Run 1

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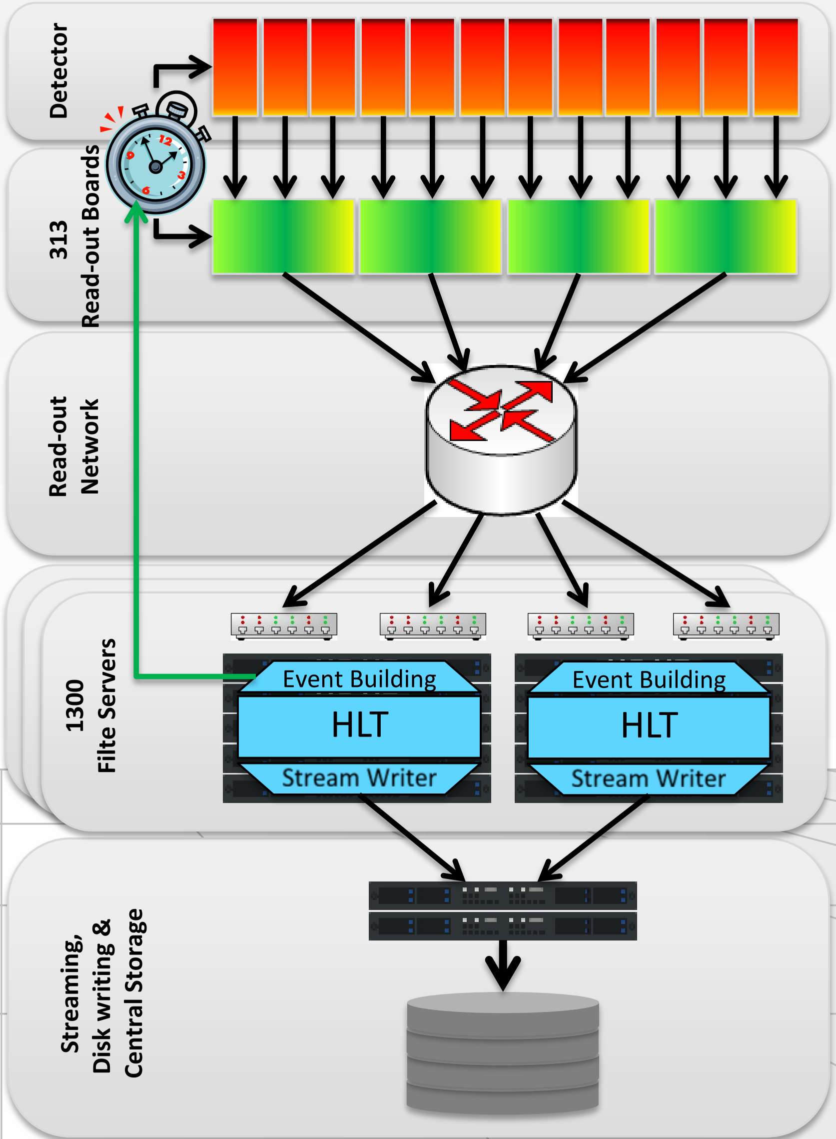
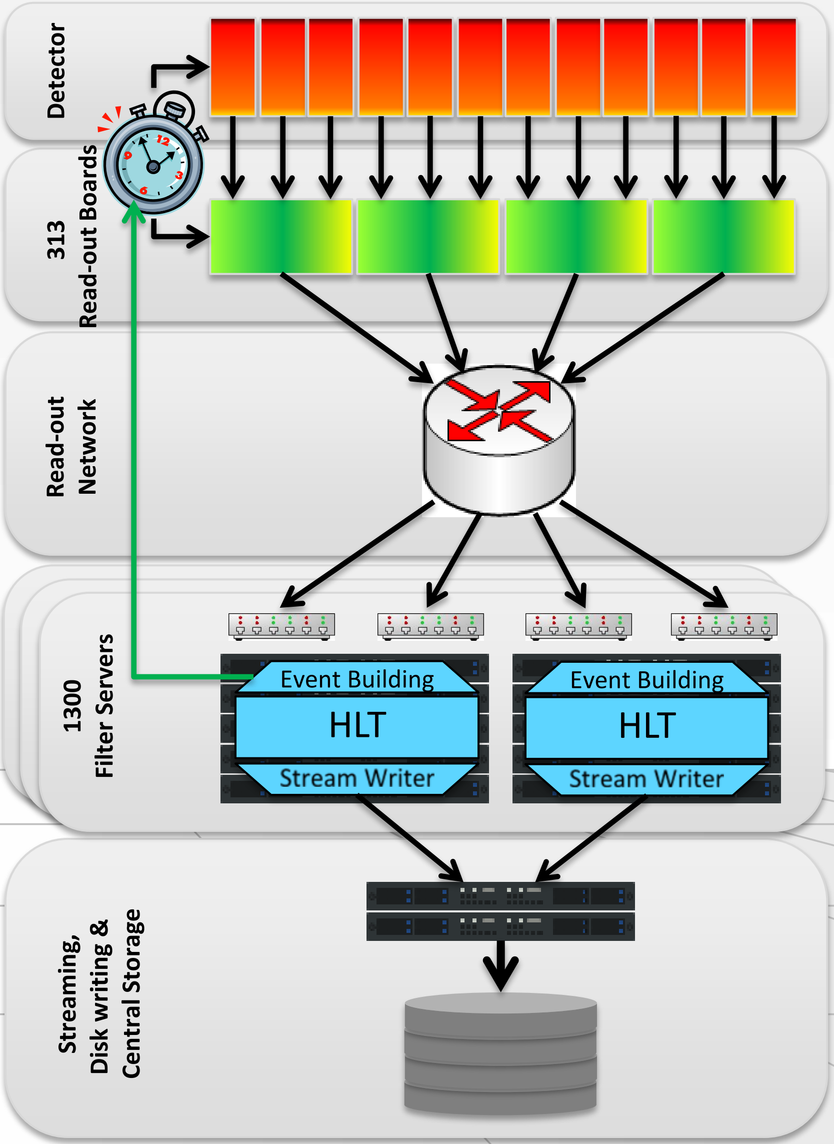
From Front-End to Hard Disk

- $O(10^6)$ Front-end channels
- 300 Read-out Boards with 4 x 1 Gbit/s network links
- 1 Gbit/s based Read-out network
- 1500 Farm PCs
- >5000 UTP Cat 6 links
- 1 MHz read-out rate
- Data is pushed to the Event Building layer. There is no re-send in case of loss
- Credit based load balancing and throttling



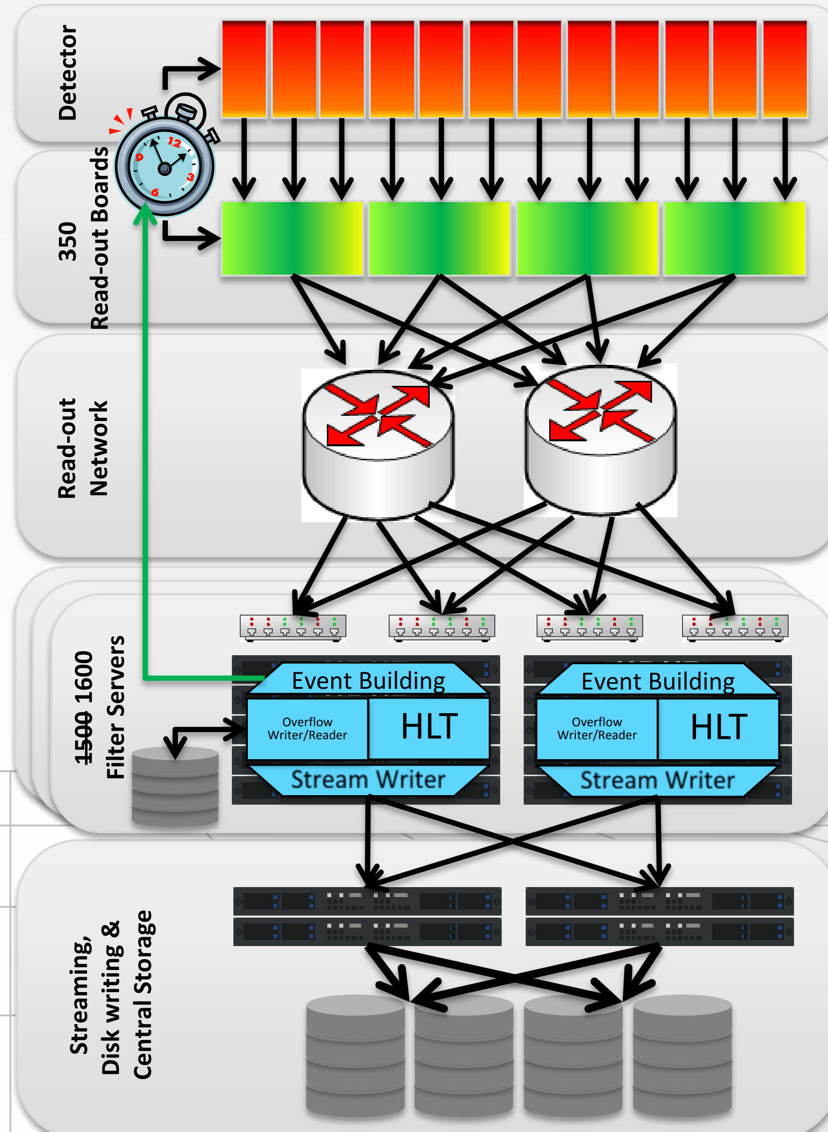
A bit of history

- Original DAQ Specs
  - Readout rate: 1 MHz
  - Up to 16 consecutive triggers
  - Total event size: 35 kB
  - HLT output rate: 2000 Hz
  - HLT output bandwidth: 80 MB/s
- Original DAQ architecture
  - More or less what's on the right
  - Single Core router
  - Data that can't be accepted by the HLT is throttled away.
- Original Storage Back-end
  - Controls software is served from central NFS/Samba servers
  - Trigger software is served from central NFS servers (Diskless Farm)
  - Monolithic Disk array
  - Good redundancy in data writers
  - Weak redundancy in File Systems and NFS/Samba servers



Where are we now?

- Current DAQ Specs
  - Readout rate: 1 MHz
  - Up to 16 consecutive triggers (sort of)
  - Total event size: ~~35~~ 50+ kB
  - HLT output rate: ~~2000~~ 5000 Hz
  - HLT output bandwidth: ~~80~~ 250 MB/s
  - 1000+ MB/s for special calibration runs
- Current DAQ architecture
  - ~~Single~~ Dual Core routers
  - Data that can't be accepted by the HLT is temporarily stored on HLT node for later processing
- Current Storage Back-end
  - Controls software is served from central NFS/Samba servers
  - Trigger software is served from central servers, but cached locally on farm node
  - Monolithic Disk array → internal separation between DAQ data and Software
  - Good redundancy in data writers
  - Self made NAS with OSS based High Availability NFS and Samba servers



Physical Installation (Core Router)

How did we get there (I)

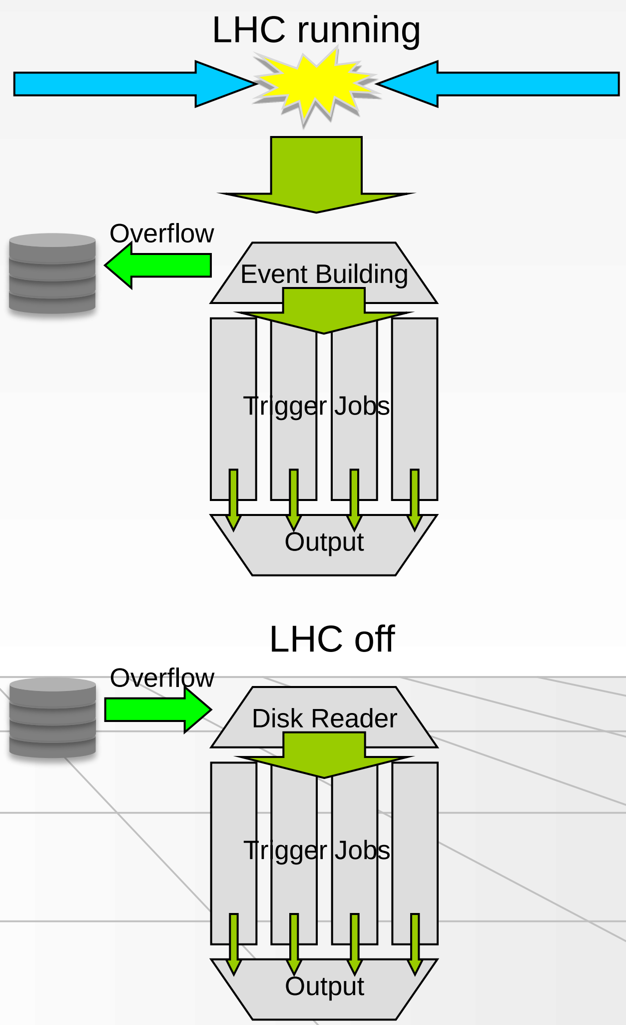
- Increase in Event Size:
  - Luminosity increase. Detector is running at twice its original design specs.
  - Design: $2x10^{32}$, Running at: $4x10^{32}$
  - Higher μ due to 50 ns bunch spacing → Higher detector occupancy → accepted events are bigger
- Output rate increase due to extension of physics program
- Calibration runs use up valuable beam time
  - The more throughput we have, the less beam time we lose
  - Can maintain more than 20 kHz of output with more than 1 GB/s of data rate for several hours
- VDM scans and SMOG runs for beam profile and luminosity measurements demand high throughputs
- Luminosity leveling
  - LHCb does not run at full LHC instantaneous luminosity
  - By continuously adjusting beams we do not suffer beam depletion over time
  - We have to store more data than anticipated per fill → More disks mean more throughput!

How did we get there (II)

- Moore's law helped a lot
  - Original estimates for computing power were very conservative
  - In fact we dropped another level of hardware triggers for software based triggering even before the experiment went online
  - Both trigger stages are run in software now
- Buy computing time through disk space
  - LHC duty cycle is not 100%
  - Process only a fraction of the incoming data immediately
  - Process the other fraction during inter fill gaps and technical stops

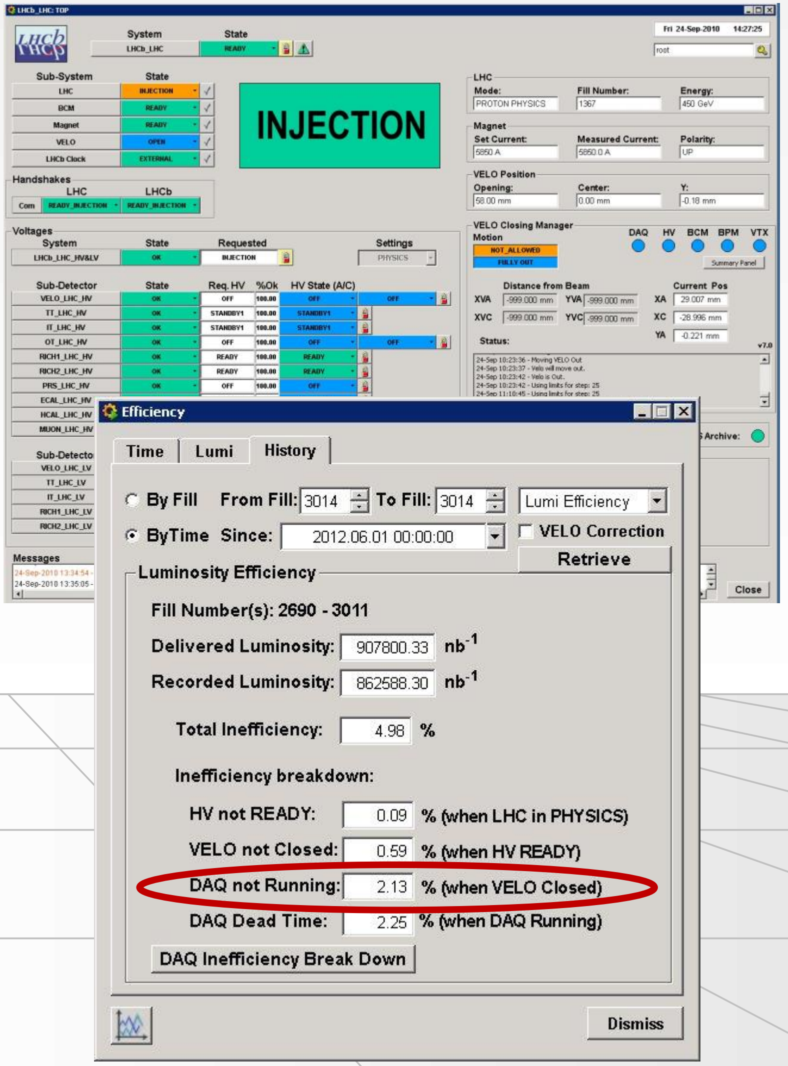
Deferred Trigger

- Procedure:
  - Equipped 1000 machines in our farm with 1-2 TB disks each
  - Over commit Farm by typically 30% while LHC is running
  - Data that can not be processed by the HLT node is written to the local disk
  - Once beams are dumped we start processing the data that has been temporarily stored on the disk
  - Make sure you don't process the same event twice!
- Side effects:
  - Data is not contiguous any more
  - Events of several runs can be in the system simultaneously
  - Disks like to fail, especially if there are many
  - It can sometimes take days before a fill has been completely worked off
  - Had to severely altered the design of the data flow and book keeping
  - The DAQ is constantly pumping out data
  - Less and smaller maintenance windows
- On the bright side:
  - Every failed farm node meant a reduction in DAQ performance
  - Now: other nodes just write a little more to disk



Automation

- Significant amount of efficiency is lost due to human latency
- Big Brother
  - Acts on state changes and communicates with the LHC
  - Automates common task sequences
    - Ramping of HV systems
    - Opening/Closing of the Vertex Detector
    - Calibration runs at EoF
  - Generally asks before acting
- Auto Pilot
  - Starts the system and keeps it running
  - Automatic recovery of common failures
    - Front-End recovery
    - Recovery of failed trigger jobs
    - Recovery of failed farm nodes
- Human intervention still necessary for unknown problems
- Speech synthesis program notifies operator in case of trouble
- → 98% DAQ efficiency since adoption



What went wrong?

Things that did not work quite as expected – Software Rollout

- HLT software roll-out on farm
  - Event Filter Farm is based on diskless nodes
  - Operating system and all software comes via NFS servers
- Software is very modular and organized in small, shared object libraries
  - Libraries are distributed over a large directory tree
  - Several versions of those libraries exist and the correct version is chosen by adding its directory to LD_LIBRARY_PATH of a job
  - LD_LIBRARY_PATH contains O(100) entries
- Launching an HLT job causes several thousand cache misses while searching for a particular .so file
  - No multi-threading → Multiple jobs per farm node
  - Cache misses are propagated to the NFS server
  - 17.000 Jobs are starting at the same time

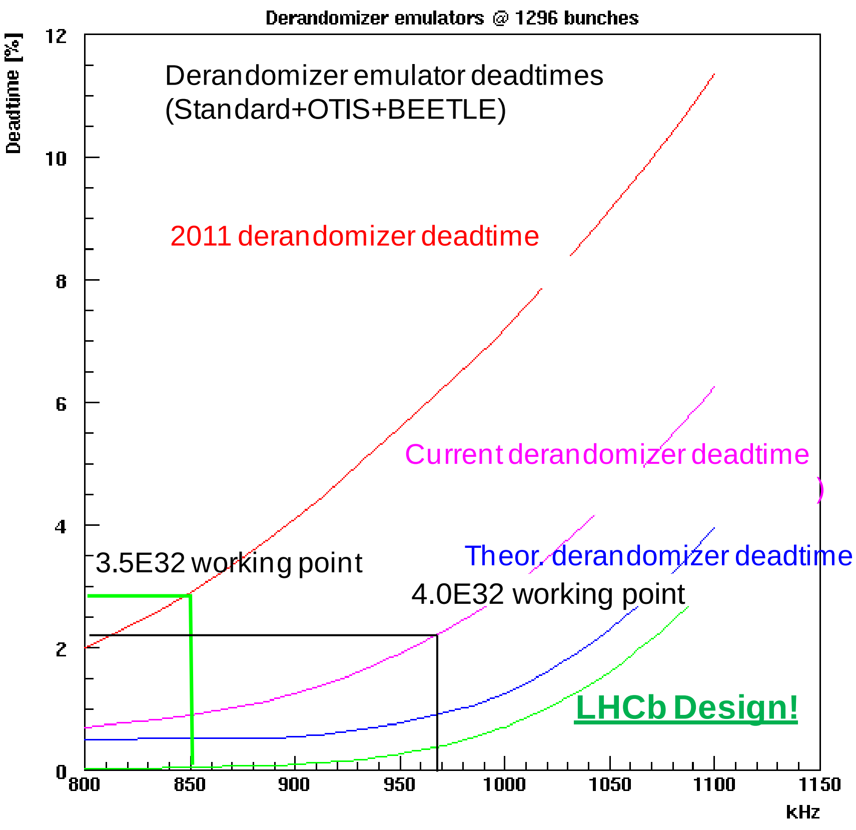
– Even with several very powerful NFS servers it would have eventually taken an hour to successfully launch all jobs

Things that did not work quite as expected – Software Rollout

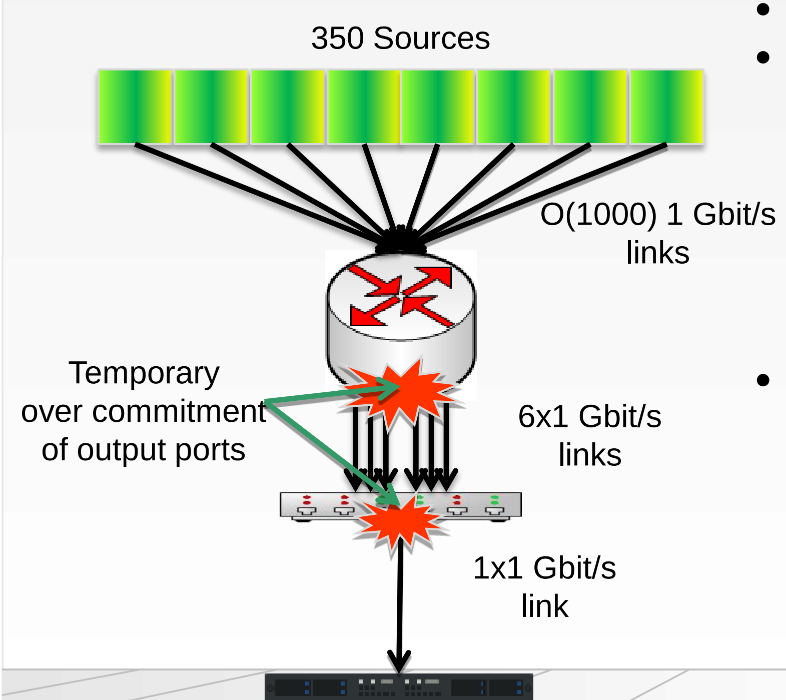
- First solution: Custom, Union-FS like Fuse File System
  - Copies all necessary files into local ram-disk on first application launch
  - Memorizes cache misses locally
  - Successive launches are served from ram-disk and internal DEntry cache
  - Slight disadvantage: Read only! Changes of directory structure are not allowed after directory has been seen for the first time
  - → Startup time: 5-6 mins
- Second step: Launch less jobs
  - Each machine starts only 1 job and clones are *fork()*ed once job has been fully configured and is running
  - Additional benefit: Reduces memory consumption by sharing static pages
  - → Startup time: 2 mins
- Last step:
  - Create memory checkpoint image of running job and store it as monolithic file
  - File is distributed to farm nodes via Bit Torrent protocol
  - Launch single job and fork clones once fully configured
  - → Startup time: O(seconds)

Things that did not work quite as expected – Dead time less read-out

- TDR Specs:
  - 1 MHz L0 rate
  - 16 consecutive triggers
- Front-ends (mostly) fulfill the specs
- What happens after the 16 consecutive triggers?
  - Some FEs need more time to recover from trigger trains due to organization of internal buffers
  - Some FEs have problems with certain trigger patterns
- VHDL code of FEs integrated into Read-out Supervisor FPGA
  - Internally emulates Front-end
  - Determines when buffers would overflow
- While we can't fix the problems in the FEs, we can mitigate the damage
- Dead time reduction: 6% → 2%



Things that did not work quite as expected – Push based Event Building

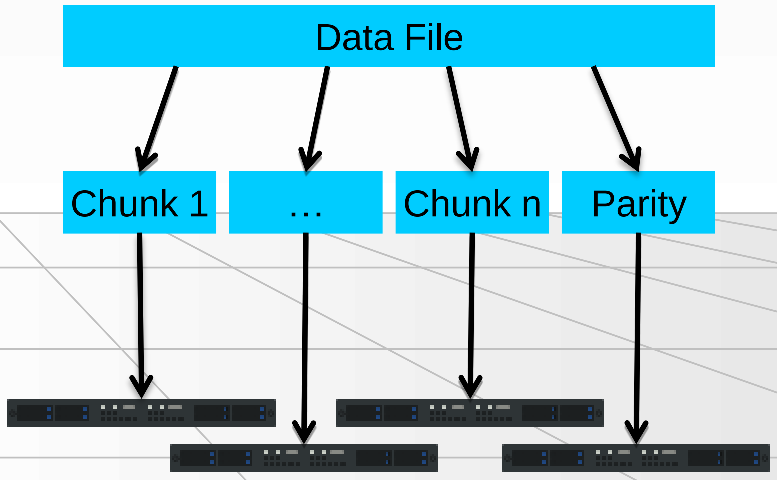


Situation for single event to single farm node

- More of an "expected, but not at this magnitude" thing
- Ingredients:
  - Read-out boards are based on FPGAs
  - Aggregate O(10) event fragments and just drop them onto the wire
  - No resend, no explicit flow control
  - Rely on network hardware with large buffers to handle traffic flow pattern
  - Run at > 90% link load
- Result:
  - Link aggregation load balancing is not 100% fair nor standardized
  - Head of line blocking within sub-farms
  - 1 Gbit/s != 1 Gbit/s → There is a small +- which can cause trouble at very high link loads
  - Output buffers are sufficient on average but are shared between ports
  - **"Time structure analysis of the LHCb DAQ network"** → Today, 15:00 - Poster Session
- Managed to get drop rate down to order of once per hour
- Lot of work and effort
- →Commercial will most of the time not work off the shelf
- After LS2:
  - Computer based ROBs
  - Reliable Event Building network protocol

Things that did not work quite as expected – Deferred Trigger + Unprotected Disks

- Deferred trigger data is transient and stays on disk only for a relatively short time
- Disks are usually not completely full
- We accept, that if a disk breaks, we lose the data on it
- Node level disk redundancy is hard to justify
  - Not enough disk slots for Raid 5+
  - Raid 1 seems a bit of a waste considering the volatility of the data
- Disk hard failure rate is actually very low
- However: Soft failures rate is quite high
  - File System goes to read-only mode
  - In order to not process the same event twice, files are *open()*ed and immediately *unlink()*ed
  - File stays in limbo until the trigger job calls *close()*
  - →Does not work if FS is read-only!
- Cluster File Systems?
  - Either replication (Raid 1) or assume that disk back-end is already protected
  - Too wasteful
- Future: Write our own distributed DAQ file system
  - **"ECFS: A decentralized, distributed and fault-tolerant FUSE file system for the LHCb online farm"** → Unfortunately right now



LS1, Run 2 and beyond

Operational Changes – Virtual Machines

- Modern Servers are too powerful for controls purposes
  - People like to confine different sub-sections of the control system by using different servers
  - A lot of potential CPU power is wasted because the granularity of a single machine is quite large
- Virtual Machines are a way out of this
  - Still strong borders between sub-systems
  - Less physical servers
  - Higher availability through live migration
- Challenges
  - Control system machines eventually have to connect to real hardware
    - Use hardware interfaces that are Ethernet based
    - Limited amount of small machines that act as Hardware ⇔ Ethernet bridges
  - Upside: Good motivation to get rid of most of the Windows machines in our system
  - Less physical servers, but infrastructure becomes more complicated
- **"Performance evaluation and capacity planning for a scalable and highly available virtualization infrastructure for the LHCb experiment",**
  → Today, 15:00 - Poster Session

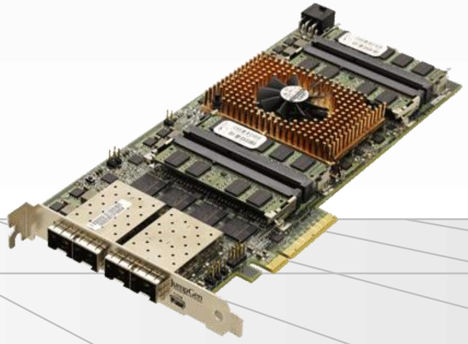
More Operational Changes

- Offline processing on Online Farm during shutdown
  - Online Farm represents a significant computing site
  - Turned farm into a target for our Offline job scheduling system
  - Currently running simulation jobs
- More deferred triggering
  - Currently storing a lot of data that is thrown away by the trigger process later
  - Instead: run a fast selection before storing data and run more detailed processing later/in parallel
  - Allows better usage of the available disk space because data rate has been reduced
  - **“Deferred High Level Trigger in LHCb: A Boost to CPU Resource Utilization”**
    → Tue, 15:45 – This Track

LS2 and beyond

- Trigger free read-out
  - Currently the Online Farm is located close to the detector
  - Need to move upstairs due to power and cooling constraints
  - How do we transport 32 Tbit/s of data over 300 m without going bankrupt?
  - How do we solve the Event Building Problem at these data rates?
  - “**DAQ Architecture for the LHCb Upgrade**”
    → Today, 15:00 – This Track

- Move the Read-out Boards closer into the realm of COTS
  - PCIe based ROB
  - Can be mounted inside a computer
  - The future of networks is hard to predict
  - Gives more options for adopting future network technologies
  - Allows more intelligent Event Building protocols
  - **“A PCIe Gen3 based readout for the LHCb upgrade”**
    → Tue, 14:10 – This Track



- Alternative computing architectures
  - GPUs: “**A GPU offloading mechanism for LHCb** “
    → Today, 15:00 - Poster Session
  - ARM: “**Measurements of the LHCb software stack on the ARM architecture**”
    → Tue, 16:10 – Software Engineering, Parallelism & Multi-Core

Conclusion

- The LHCb Data Acquisition has outperformed its original design specs by more than a factor two, more in certain areas
- Made possible by
  - using our available computing resources to their fullest
  - adopting automation and high availability techniques
  - a lot of hard work by everybody involved
- It was not always smooth sailing
- We learned many lessons from our current system
- We will employ those lessons for future improvements of the DAQ

Thank you for your attention

- Advertisements
  - **"ECFS: A decentralized, distributed and fault-tolerant FUSE file system for the LHCb online farm"**
  - **"DAQ Architecture for the LHCb Upgrade"**
    → Today, 15:00 – This Track
  - **"Time structure analysis of the LHCb Online network"**
    → Today, 15:00 - Poster Session
  - **"Performance evaluation and capacity planning for a scalable and highly available virtualization infrastructure for the LHCb experiment",**
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  - **"A GPU offloading mechanism for LHCb "**
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  - **"Phronesis, a diagnosis and recovery tool for system administrators"**
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