High-speed Decision Making on Live Petabyte Data Streams

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Future(s)

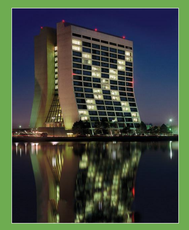
Traditional Separation of Hardware & Software

The *NUMI Off-Axis Neutrino Appearance* experiment will search for muon-neutrino to electron-neutrino oscillations, determine the ordering of neutrino masses, and search for CP violation.

The NOvA online system must
- Continuously stream data from 380,000 channels in 5 ms slices
- Save parts of slices which are in time with NUMI beam pulses
- Identify other slices of interest based on detector data contents

The *Muon g-2* experiment will achieve a fourfold improvement in the uncertainty of the muon anomalous magnetic moment (g-2) measurement. This will sharply discriminate among extensions to the Standard Model.

The Muon g-2 online system characteristics are:
- 600 µs events taken at 18 Hz
- 35 segments per calorimeter array and 24 arrays
- Waveforms collected at 500 MHz sampling rate
- GPGPUs proposed for waveform analysis



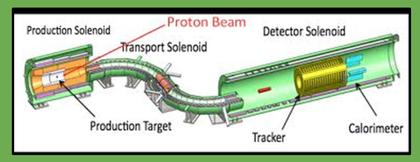
Metric	NOvA	Muon g-2
Aggregate input rate	2 GB/s	2-5 GB/s
Number of cores	180*16=2880	24 GPGPUs
Rate	0.7 MB/s/core	100-200 MB/s/GPGPU
Time budget per event	0.9 s	0.05 s

Analysis Predominantly in Software

DarkSide-50 will search for weakly interacting massive particles using a liquid argon detector with high sensitivity for direct detection of WIMPs. The DarkSide-50 experiment predicted sensitivity goes down to 1e-47 cm^2 in WIMP-Nucleon cross section.
The DarkSide-50 online system characteristics are:
- 300 µs events taken at 100 Hz
- 38 channels digitized at 250 MHz
- Standard HEP Intensity Frontier data filtering and reconstruction framework
- Mu2e will measure the ratio of the rate of the neutrinoless conversion of muons into electrons in the field of a nucleus, relative to the rate of ordinary muon capture on the nucleus. This conversion process is an example of charged lepton flavor violation, a process that has never been observed experimentally.

The Mu2e online system characteristics are:
- 275 front-end data sources
- 30 GB/s of waveform data sampled at 100 MHz

Filtering software must reduce this rate to 30 MB/s

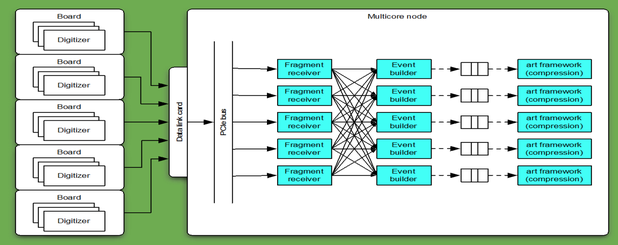


Mu2e Solenoids & Detectors

Metric	DarkSide-50	Mu2e
Aggregate input rate	900 MB/s	20-30 GB/s
Number of cores	5*32 = 160	48*32 = 1536
Rate	6 MB/s/core	13-20 MB/s/core
Time budget per event	0.01 s	1.7 µs

Data Filtering Completely in Software

All of the future experiments demand moving software closer to the data source. Software R&D is underway and is focused on performing all digital signal processing, filtering functions, and analysis steps using all digitizer samples. High Performance Computer computing resources, networking, and software libraries are being utilized.

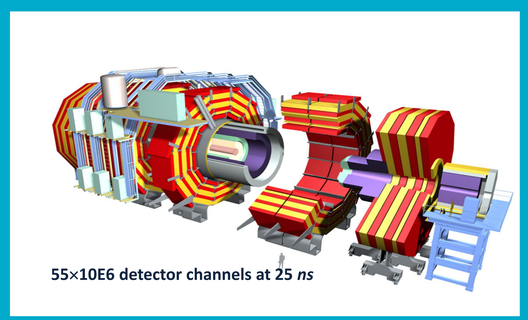


A typical streaming DAQ software architecture for future experiments.

Program	Data Driver Sensitivity Metric	Detector Flow Volume	Annual Data to Steward	Program Era
LBNE neutrino & underground science	Full galactic scan for Super-Novae	3-30 GB/s	1-10 PB	2019-2030
Muon Campus program: Mu2e → Project-X	Probing the rarest lepton decays: 1 part in 10^{17}-10^{19}	30-300 GB/s	1-10 PB	2015-2030
DarkSide-NG	Direct search for dark matter candidates (WIMP)	30-300 GB/s	0.5-1 PB	2020-2025
Rare kaon decay program: ORKA → Project-X	Probing the rarest quark decays: 1 part in 10^{13}-10^{15}	100-1000 GB/s	1-10 PB	2017-2030

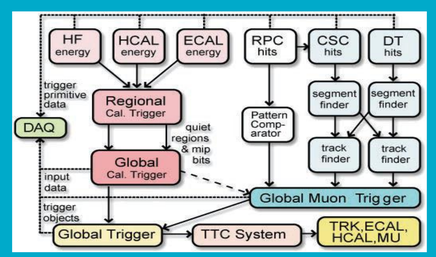
Now

CMS Experiment at the LHC

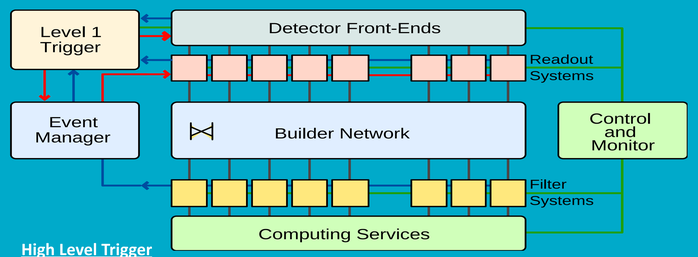


55×10E6 detector channels at 25 *ns*

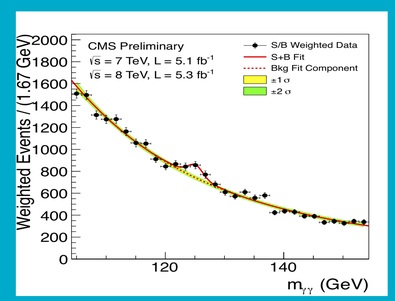
Multiple exabytes per second



Level 1 Trigger
Massively parallel custom FPGAs, ASICs, pipelines performing pattern recognition and event selection
100 kHz output, 1-2 MB events



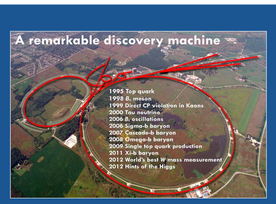
High Level Trigger
High speed network with thousands of commercial processors
400 Hz event record output
10's of TB per day into the trigger farm, output is 1 to 4 TB per day.



Discovery of a Higgs Boson!

Past

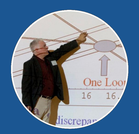
Tevatron Run II Experiments



Accelerator Innovations
- First major SC synchrotron
- Industrial production of SC cable (MRI)
- Electron cooling
- New RF manipulation techniques

Detector innovations
- Silicon vertex detectors in hadron environment
- LAr-U238 hadron calorimetry
- Advanced triggering

Analysis Innovations
- Data mining from Petabytes of data
- Use of neural networks, boosted decision trees
- Major impact on LHC planning and developing
- GRID pioneers



Major discoveries
- Top quark
- B_s mixing
- Precision W and Top mass → Higgs mass prediction
- Direct Higgs searches
- Ruled out many exotica

The next generation
- Fantastic training ground for next generation
- More than 500 Ph.D.s
- Produced critical personnel for the next steps, especially LHC