Direct Search for Dark Photon at Fermilab: Experimental Highlights

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LANL LDRD ER Review
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How we could improve E906 to accommodate dark photon search

- **New Geant4-based simulation package**
  - ➢ significantly improved performance on minimum-bias simulation
  - ➢ updated sensitivity estimation for prompt/displaced *A'* search
  - ➢ current/future trigger detector R&D

- **Data acquisition (DAQ) system upgrade**

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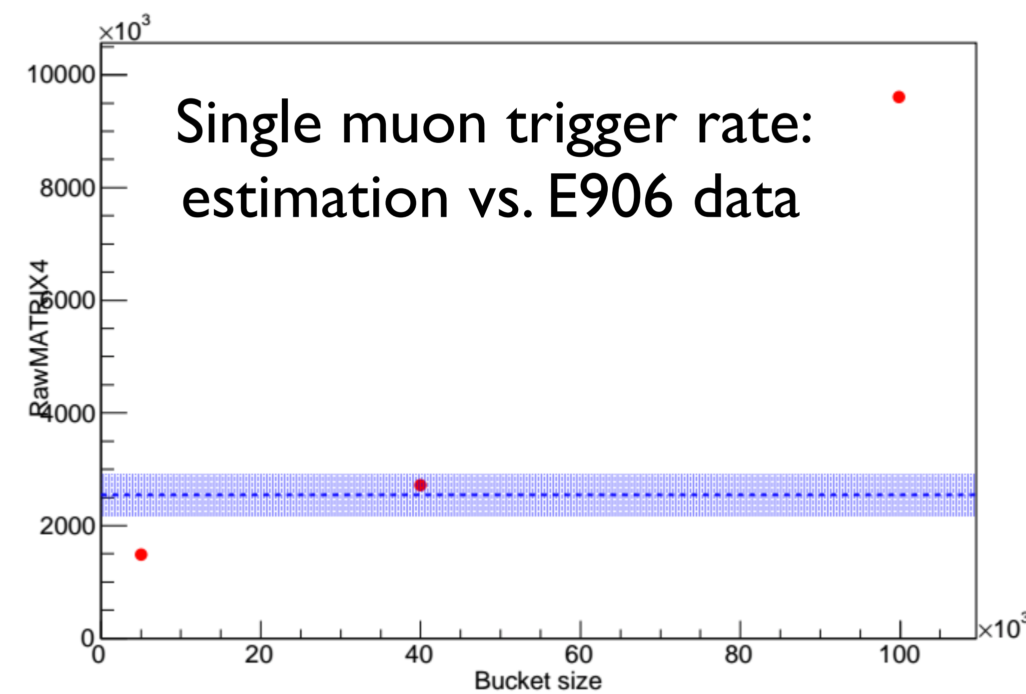
Dark Photon Simulation (DPSim)

- Hosted on github (https://github.com/liukDPSim), and being used by outside collaborators (Argonne, Rutgers, UIUC, etc…)
- Also intended to replace the existing E906/E1039 simulation package
- Main features:
  - ➢ implemented various dark photon/higgs generator models from our theory colleagues and from Pythia8
  - ➢ simple interface to adjust the detector setup for detector/trigger R&D
  - ➢ ultra-fast minimum-bias MC simulation for trigger optimization

Ultra-fast minimum-bias MC simulation

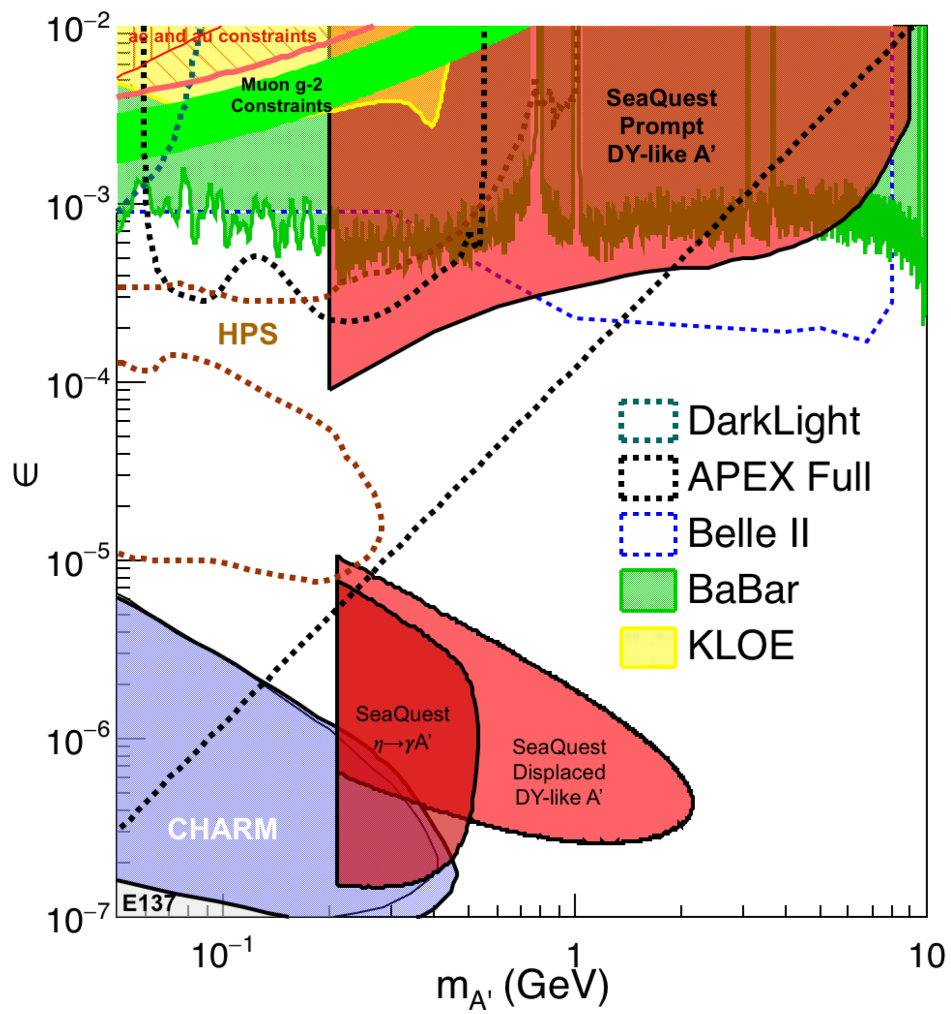
- **A large minimum-biased MC of pp collision is needed:**
  - ➢ study and optimize the trigger performance
  - ➢ understand the beam-rate induced systematic uncertainties
- **At E906, ~1E12 protons are delivered to our spectrometer every second**
- **Current MC package for E906 takes 44M CPU hours to simulate one second worth of data**
  - ➢ it cannot make full use of the grid computing resources, because of the limited I/O bandwidth
  - ➢ current trigger rate estimation has huge uncertainties
  - ➢ detector occupancy/trigger rate estimation is more than one magnitude smaller than data

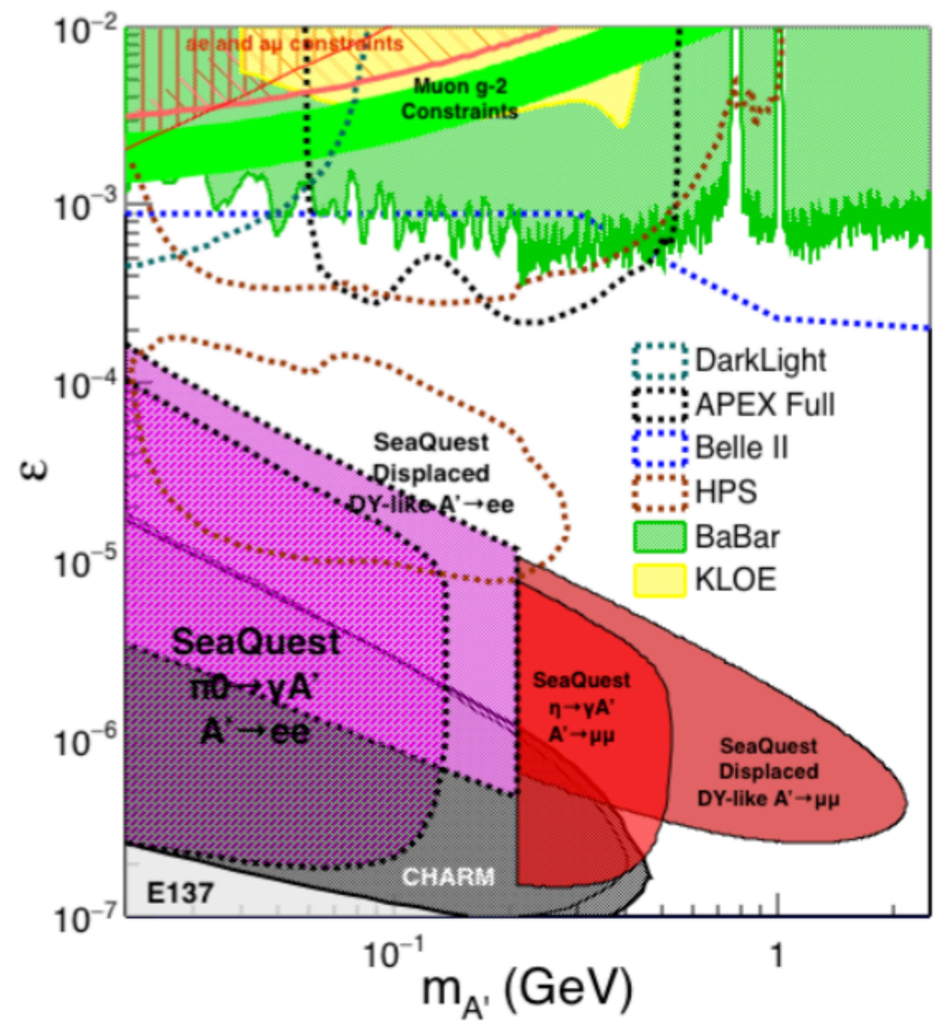
- **In the new MC:**
  - ➢ IO is completely re-written so that it can run on grid (Fermi and Open Science)
  - ➢ introduced a new layer between generation and detector simulation to cut the useless events, single core performance improved by a factor of 350
  - ➢ tuned the physics process to agree with data as much as possible



Application I: updated sensitivity reach

2-yr of running, with and without the additional EMCal

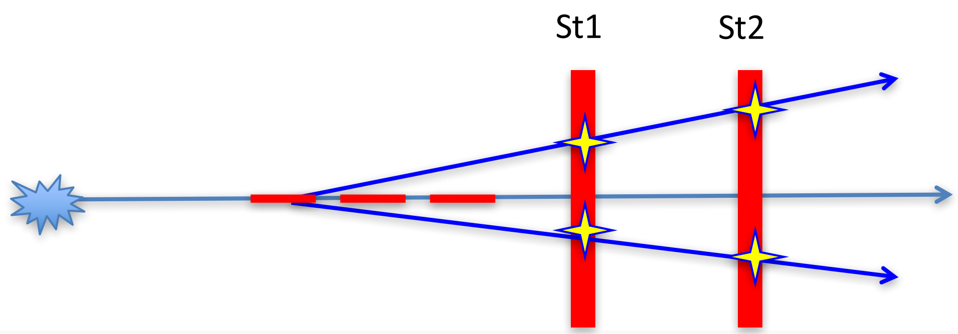


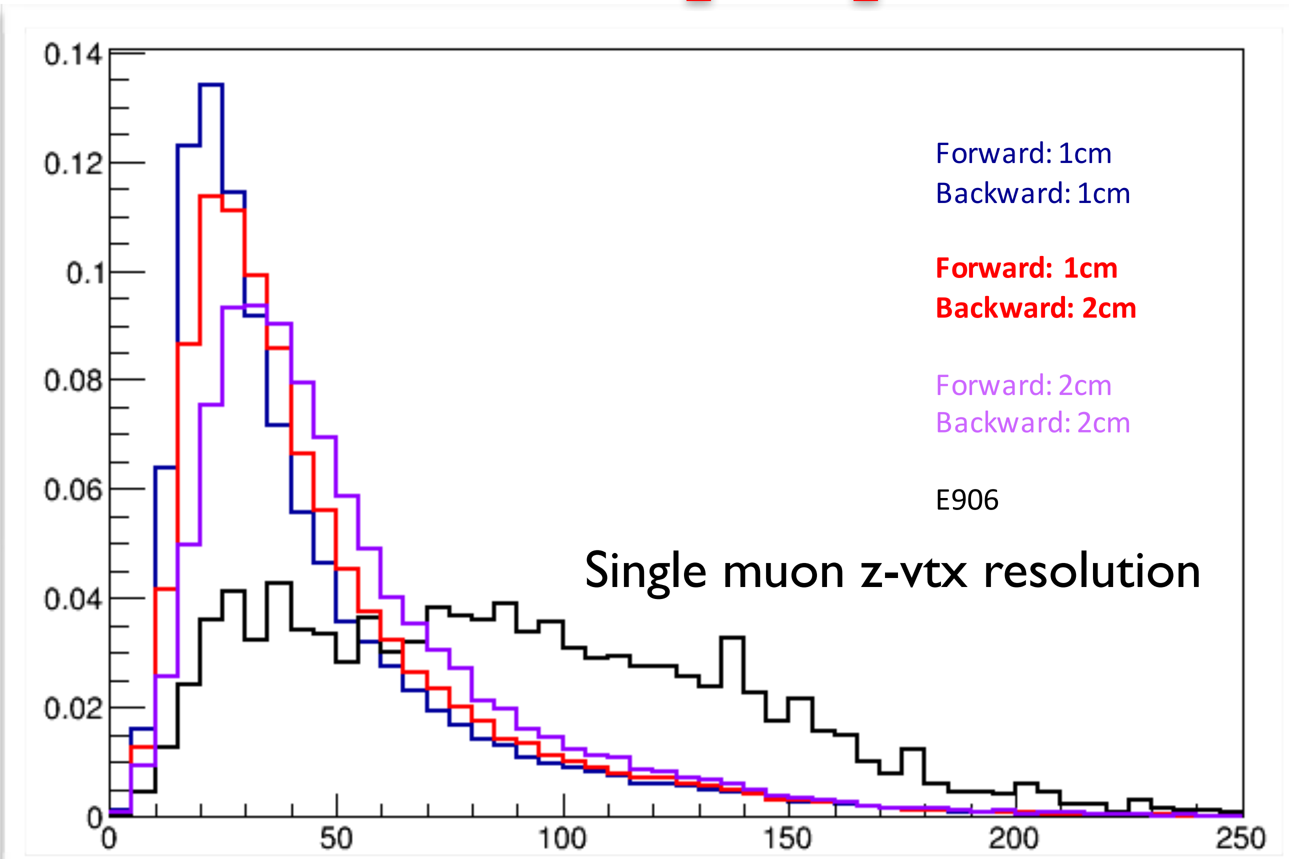


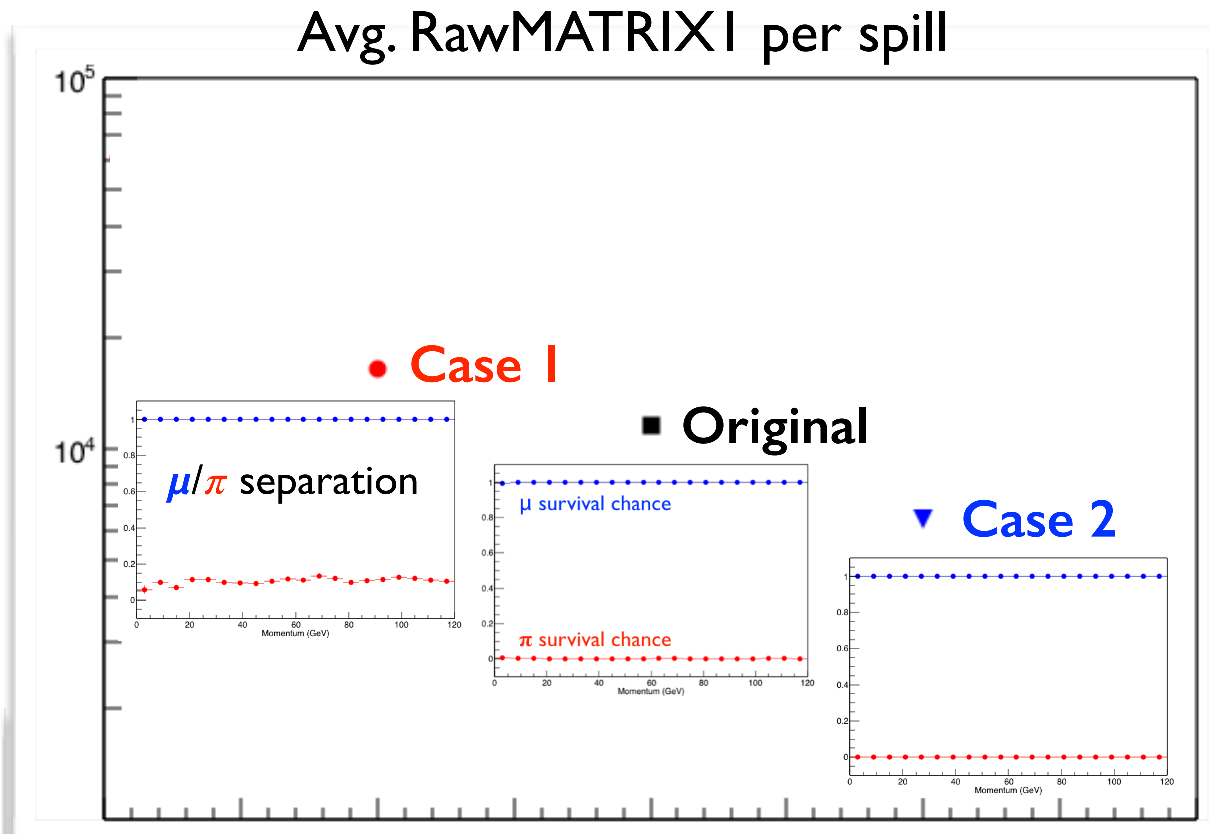
- With full detector simulation and theory model inputs
- Cross-checked with external collaborators
- More "dark signatures" (dark higgs, multiple resonance, "p_T broadening", etc.) beyond the original proposal are being considered and simulated

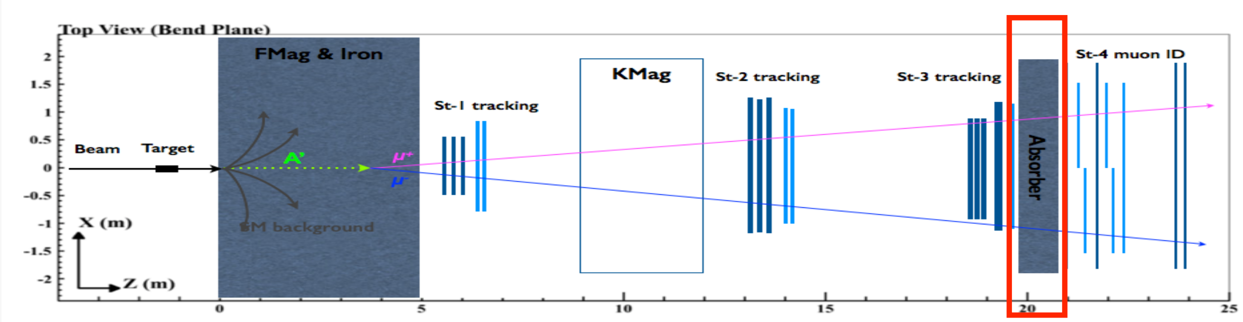
Application II: trigger R&D and optimization

Choice of the forward/backward vertex trigger scintillator size, and how it compares with the current E906 vertex resolution





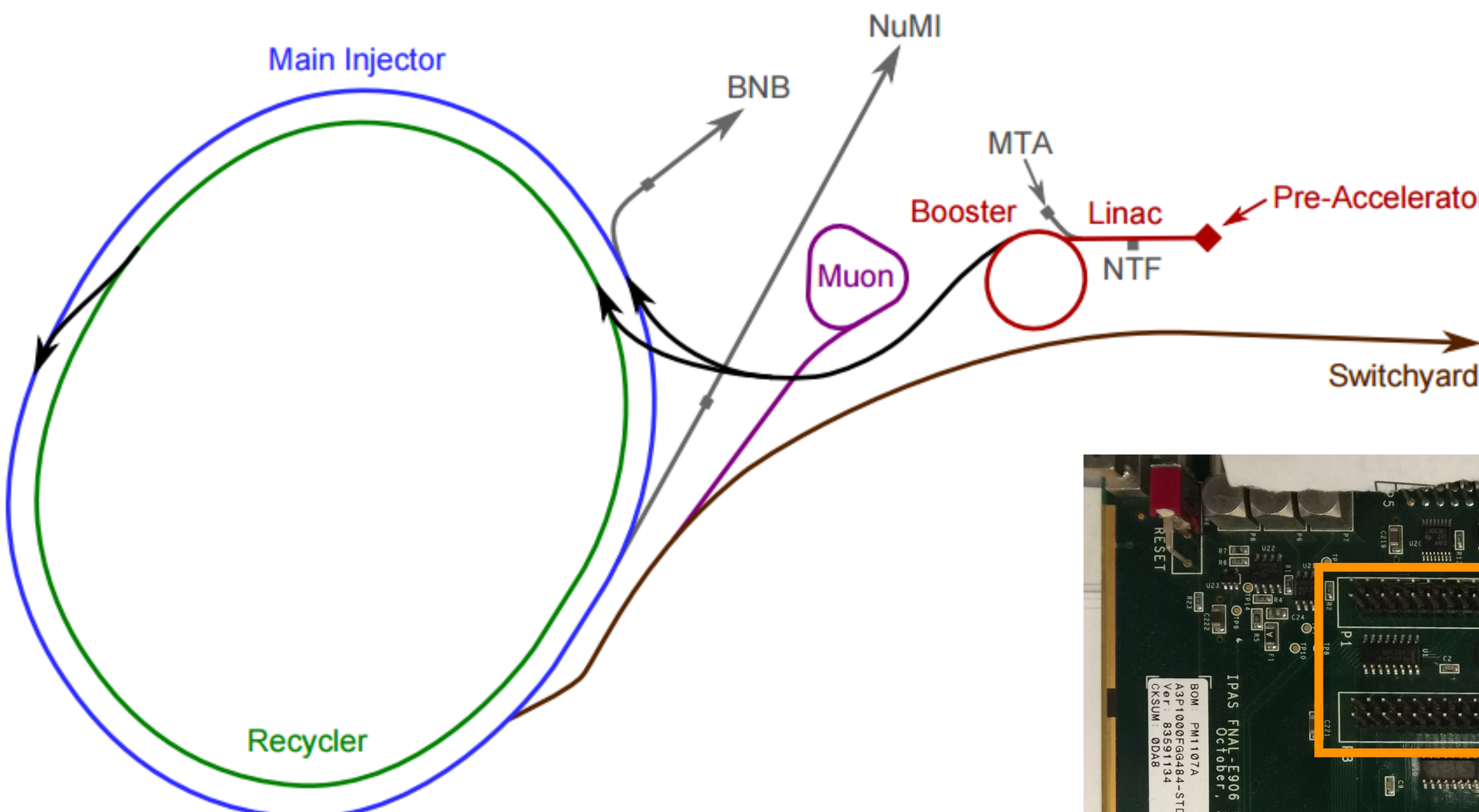




Incorporation options:

Case I: use EMCal to replace the absorber
Case II: insert EMCal between H3 and absorber (will need to slightly adjust station-3 position)

DAQ Upgrade: current status and opportunities



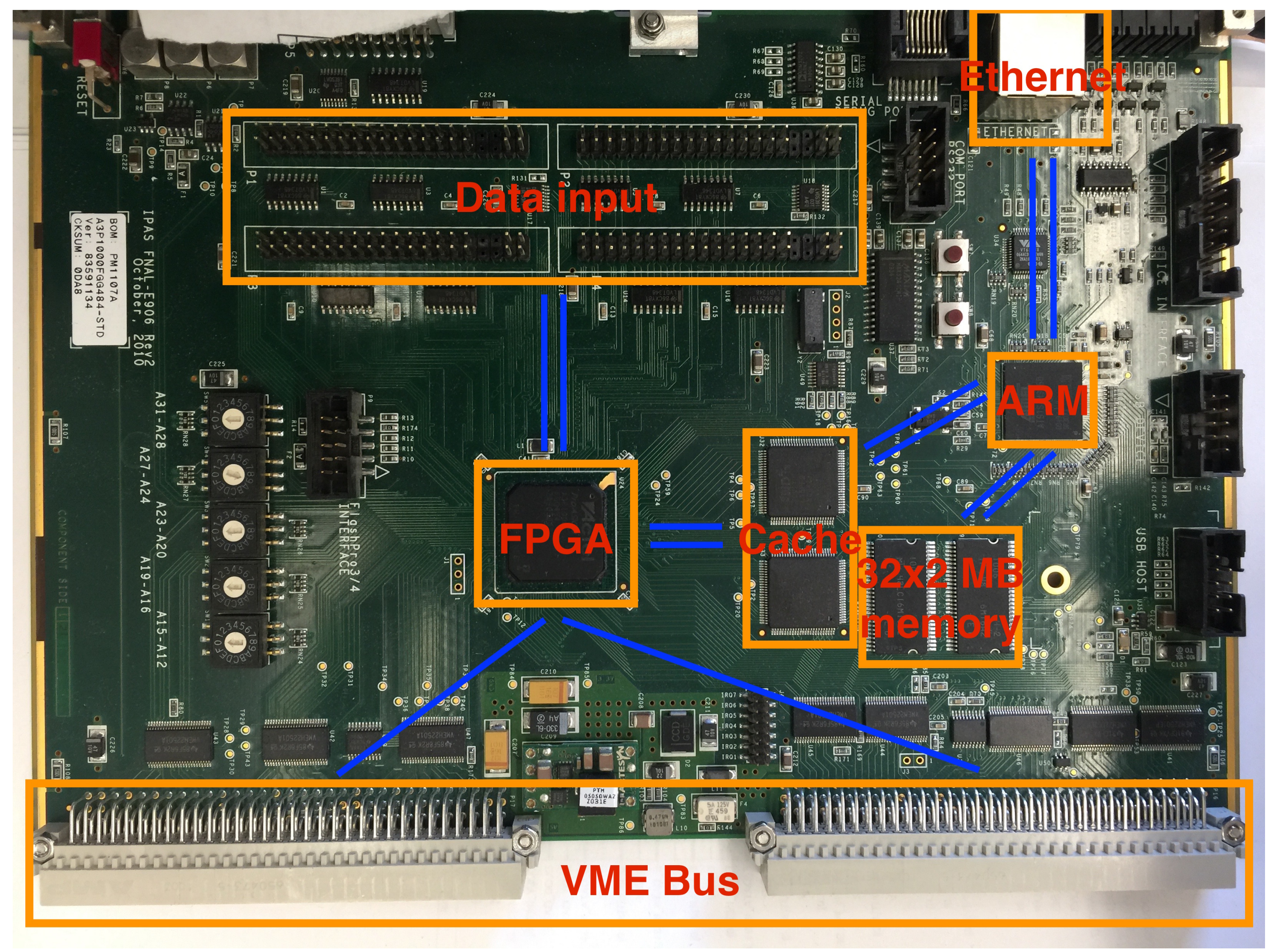
In every minute:

- beam delivered to SeaQuest in the first 4.2s
- for the rest of the minute, beam is directed to neutrino experiments and SeaQuest just sits idle

SeaQuest

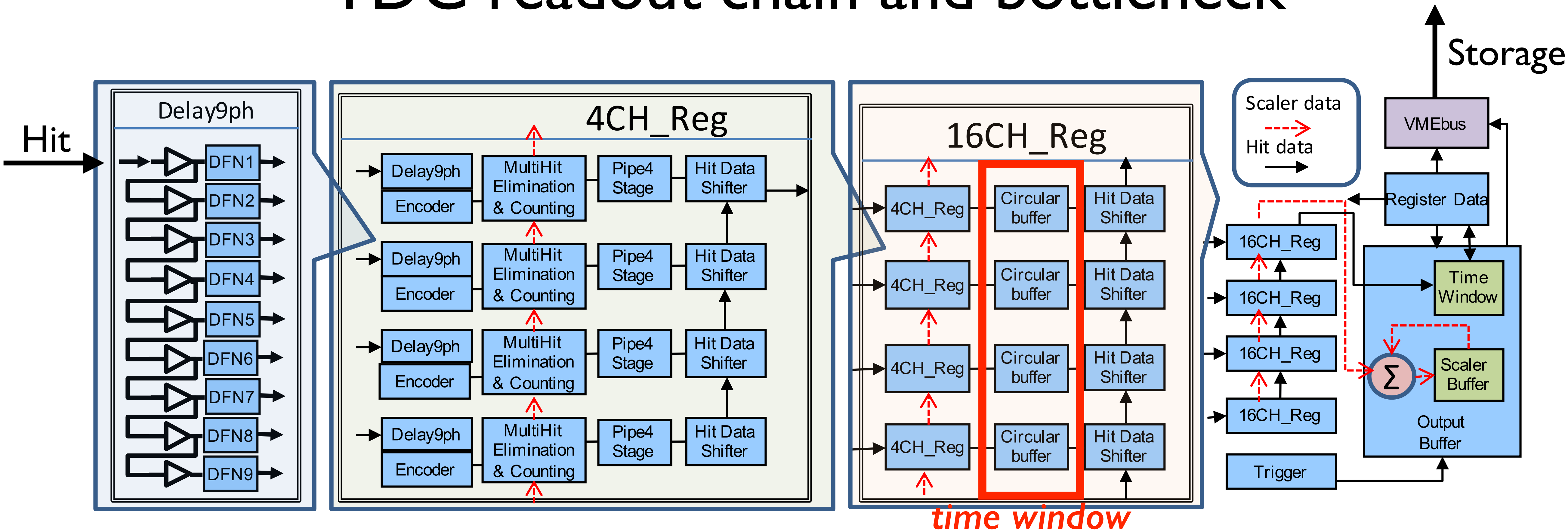
Once a detector channel is fired, its timing is measured by our VME-based Time to Digital Convertor (TDC):

- the board design is equipped with FPGA, ARM, cache and large memory storage
- currently only FPGA is utilized, and data is sent to central event builder through VME back plane (very time-consuming)
- For a typical event, the DAQ dead time is ~**150**μ**s**, which limits the data rate to **1~1.5kHz**



We need at least a factor of 10x DAQ bandwidth run '*parasitically*'

TDC readout chain and bottleneck



- Incoming hit timing is measured by a 9-phase delay line
- Data from a group of 4 channels are temporarily stored in a circular buffer to wait for the trigger
- When trigger arrives, the hits (within pre-defined time window) in the circular buffer are pushed to the event buffer through the 4-by-4 pipeline. This copy process takes a fixed amount of clock cycles proportional to the number of time slots and pipeline stages. (*copy-in-progress* time)
- The event buffer is mapped to the VME address space, which is read out sequentially (~250 ns per hit)

At E906:

- Time window needs to be as large as 2μs: 32 μs CIP time
- A typical event has ~500 hits in the busiest readout crate: ~120 μs VME transfer time
- Everything happens in the 4.2s beam on time

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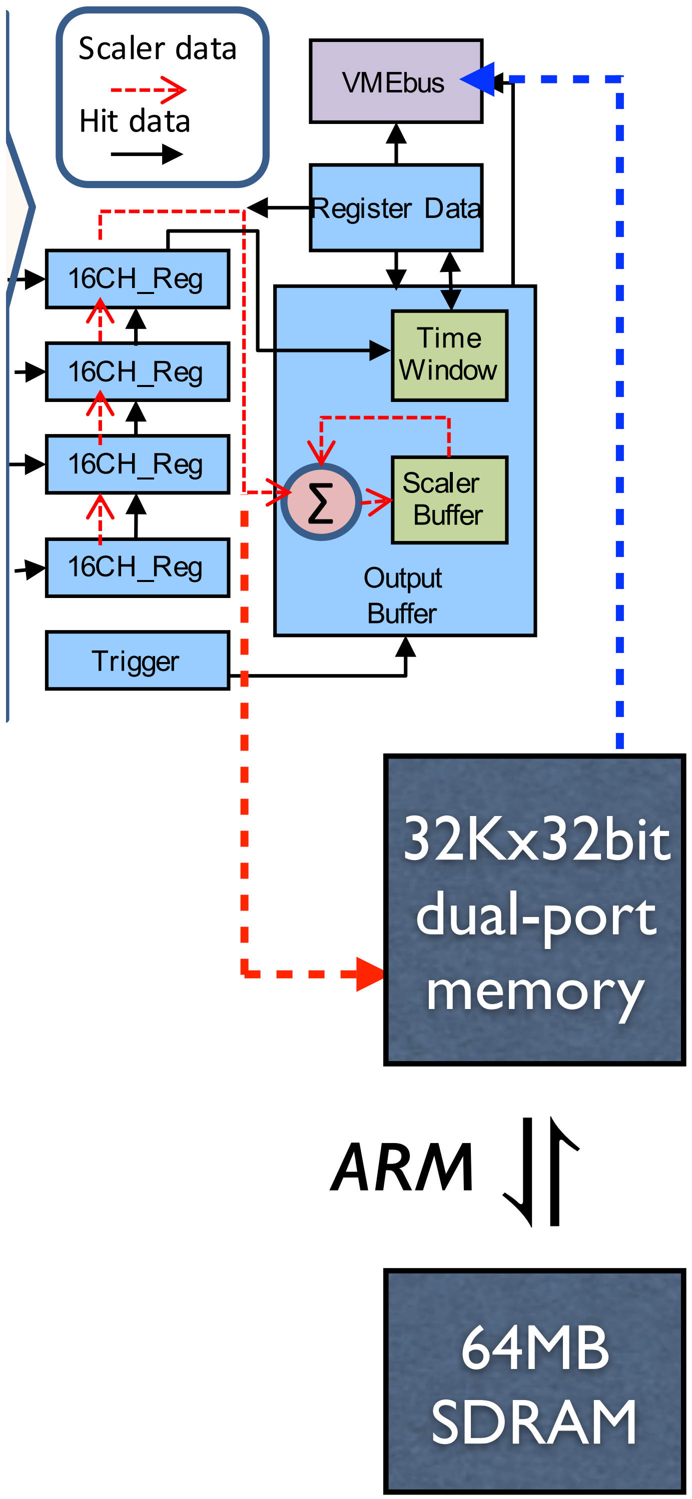
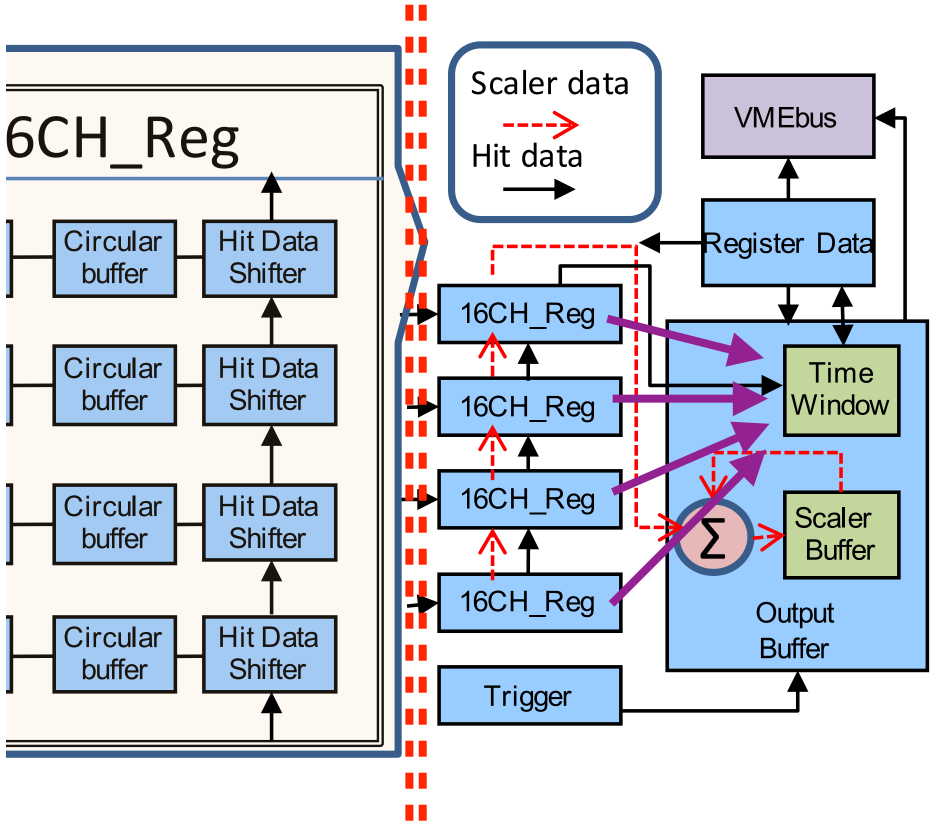
Elimination of the data-transfer time



- The hits in event buffer are duplicated in the onboard dual-port memory
- Instead of reading event buffer through VME bus (250 ns per hit), events in dual-port memory is read by ARM and saved in SDRAM (20+20 ns per hit)
- Dual-port memory is large enough to host 16 events at the same time, so that we don't need to wait for ARM reading.
- Similar to event buffer, the dual-port memory is mapped to VME bus as well, so that we could read the data back (and suppress the zeros) when the beam is off.

This process completely removes the dead time caused by event-by-event VME transfer

Copy-in-progress time reduction



Directly map the 16-channel group to the event buffer

- instead of 4 pipeline push, each 16-channel group directly writes to the event buffer
- the data is re-aligned and zero-suppressed by ARM

Intermediate layer of data packing:

- encode the channel information into compressed bits
- associate the timing information with compressed channel info

CIP time reduced by a factor of 4!

32 μs ⇨ 8 μs

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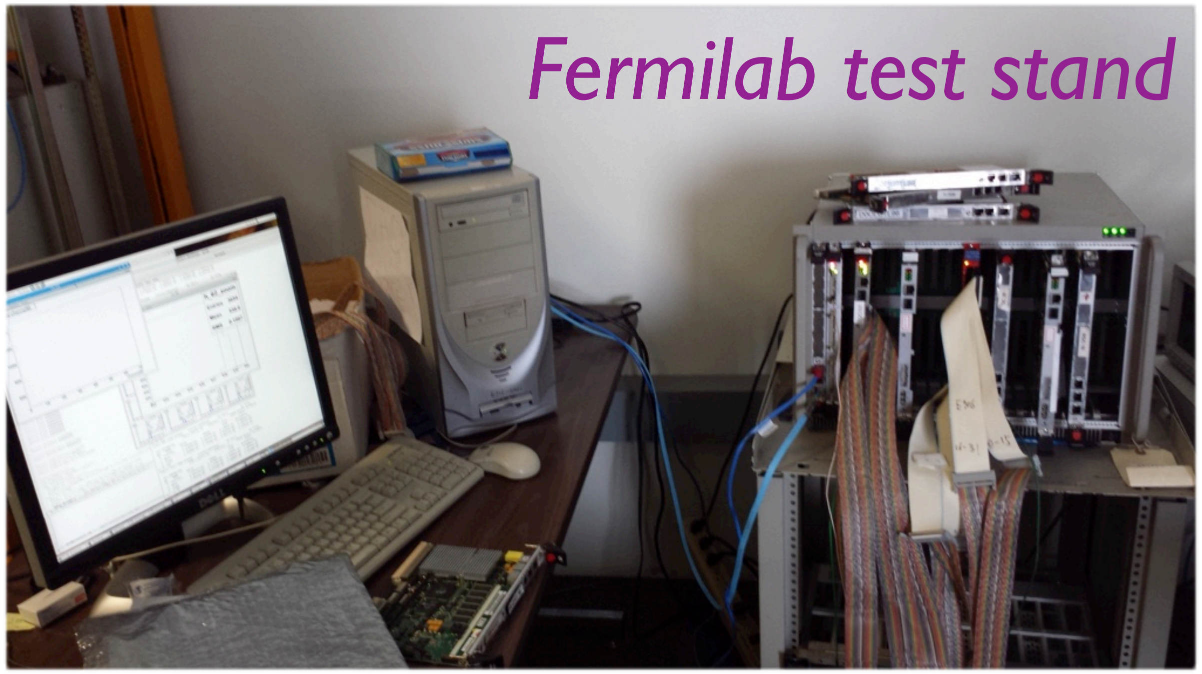
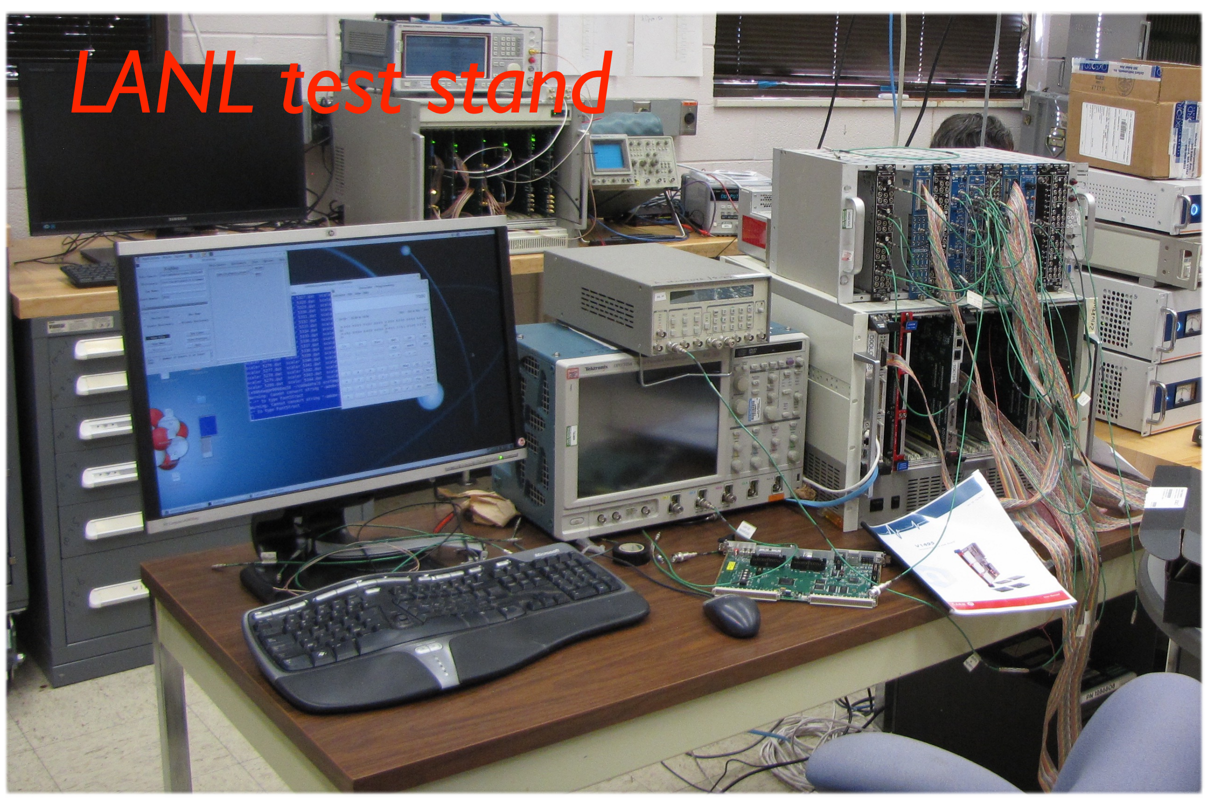
Current progress





- two full-functional DAQ/trigger test stands were set up at Fermilab and LANL, for onsite/local tests
- all the development and stress tests were carried out locally at LANL
- Kun is now at Fermilab for the final integration and real system test
- New system ready before next run (in 2 weeks)
  - ➢ immediately brings 2x DY and 10x J/ψ to E906 and all future physics programs
  - ➢ enable us to run *parasitically* alongside the main physics programs

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Summary

In addition to the newly proposed vertex trigger, we also greatly improved the existing infrastructure to benefit both current and future experiments:

- **a brand new MC simulation program to facilitate:**
  - ➢ detector R&D
  - ➢ trigger optimization
  - ➢ sensitivity estimation of various models as well as understanding of the systematics

- **15x faster DAQ system with only the existing hardware**

Thank you!

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