# The DarkLight experiment

Jan C. Bernauer

APEX collaboration meeting, April 2015

Massachusetts Institute of Technology

# DARKLIGHT Collaboration

R. Alarcon, D. Blyth, R. Dipert, L. Ice, G. Randall

**Arizona State University, Phoenix, AZ**

B. Dongwi, N. Kalantarians, M. Kohl, A. Liyanage, J. Nazeer

**Hampton University, Hampton, VA**

S. Benson, J. Boyce, D. Douglas, P. Evtushenko, C. Hernandez-Garcia, C. Keith, C. Tennant, S. Zhang

**Thomas Jefferson National Accelerator Facility, Newport News, VA**

J. Balewski, J. Bernauer, J. Bessuille, R. Corliss, R. Cowan, C. Epstein, P. Fisher*, D. Hasell, E. Ihloff, Y. Kahn, J. Kelsey, R. Milner*, S. Steadman, J. Thaler, C. Tschalär, C. Vidal

**MIT, Cambridge, MA**

M. Garçon

**CEA Saclay , Gif-sur-Yvette, France**

R. Cervantes, K. Dehmelt, A. Deshpande, N. Feege

**Stony Brook University, Stony Brook, NY**

B. Surrow

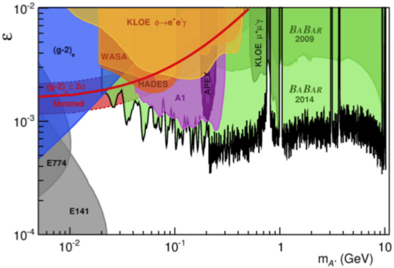
**Temple University, Philadelphia, PA**

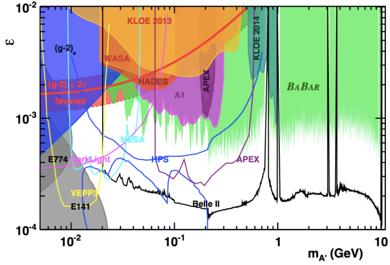
To come: Johannes Gutenberg University, Mainz, Germany

# Current and future exclusion limits

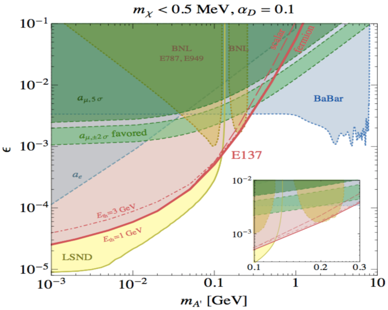
current | future

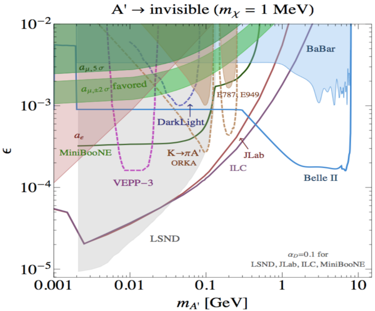
visible




invisible



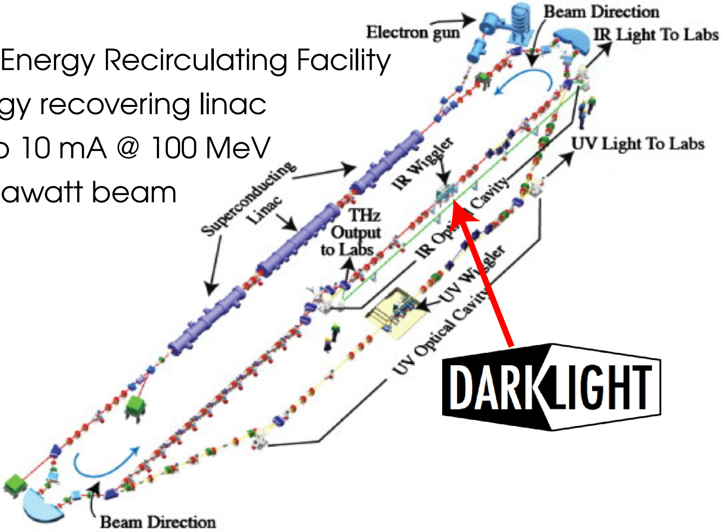



# Design goals

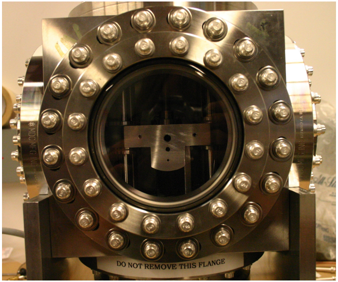
- Measure $e^- + p \longrightarrow e^- + p + A' \longrightarrow e^- + p + (e^+ + e^-)$
- 100 MeV beam $\Longrightarrow$ below pion threshold, simple final state
- *Complete* reconstruction of final state: $e^+e^-$pair from decay, scattered electron, recoil proton
  $\Longrightarrow$ large acceptance
  $\Longrightarrow$ proton only has 1-5 MeV $\Longrightarrow$ gas target
- Resolution of reconstructed $A'$ of 1-3 MeV
- Final state leptons 10-100 MeV $\Longrightarrow$ multiple scattering dominant $\Longrightarrow$ minimize material
- 0.5 Tesla solenoidal magnet for momentum measurement and to bottle up Møller electrons
- Definitive measurement in about 1 month: high luminosity: 10 mA @ $10^{19}$ Atoms/cm$^2$
  $\Longrightarrow$ JLAB LERF world's only such accelerator

# JLab LERF

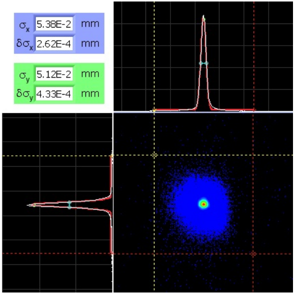
- Low Energy Recirculating Facility
- Energy recovering linac
- up to 10 mA @ 100 MeV
- Megawatt beam



# Successful beam test July 2012




Target system designed and constructed at MIT-Bates R&E center




- 4.3 mA, 100 MeV (430 kWatt beam power) transmitted through 2 mm hole, 127 mm long
- Maximum loss of 3 ppm in 7 hours
- ERL has required stability

Phys. Rev. Lett. 111, 165801 (2013)
Nucl. Instr. Meth A729, 233 (2013)
Nucl. Instr. Meth. A729, 69 (2013)

# Phased approach

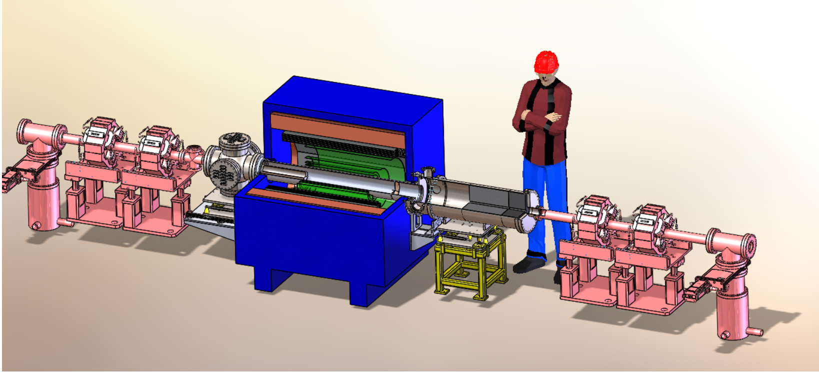
**Phase 1**

- Accelerator studies
- Measure SM physics / detector test
- Pilot DM search

**Phase 2**

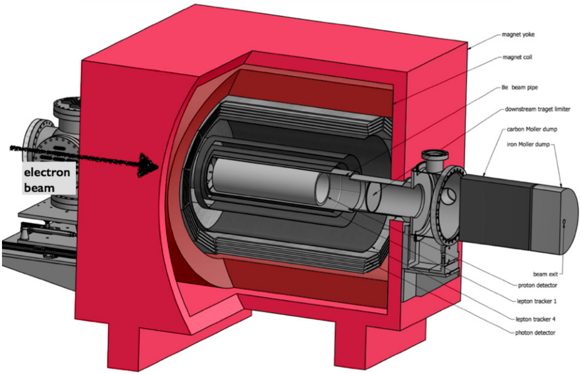
- Full DM search
- Invisible search
- Full streaming readout

DARKLIGHT



J. Balewski et al., arXiv:1412.4717 (physics.ins-det)

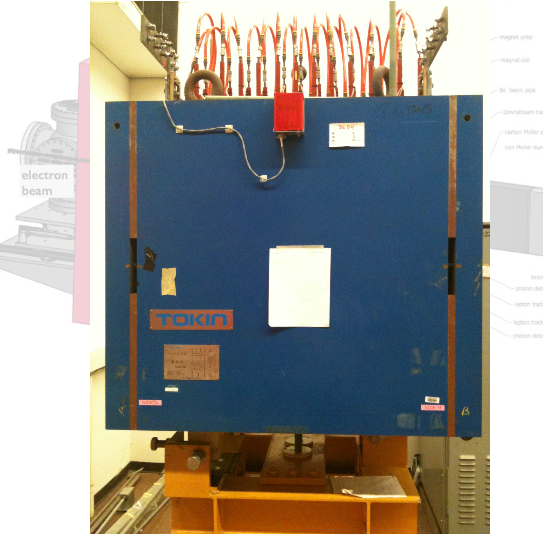
# Detector setup




- Solenoid magnet

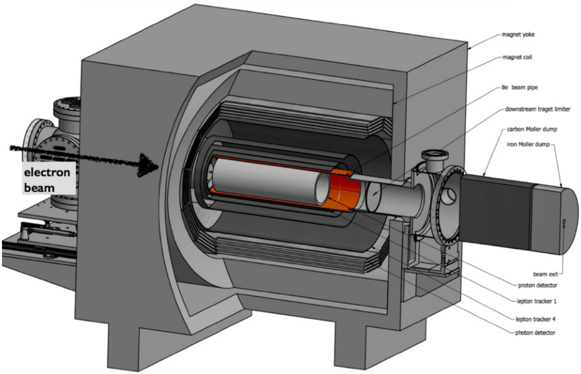
# Detector setup

- Solenoid magnet



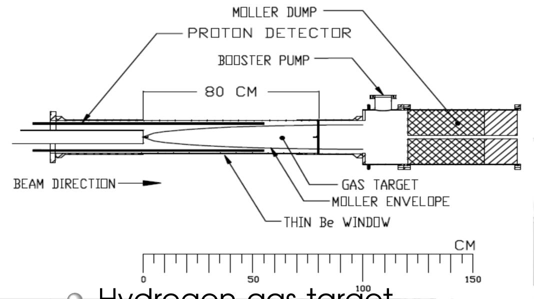

- Procured existing magnet
- 0.5 Tesla max field
- Inner diameter 712mm
- Now at MIT-Bates

# Detector setup




- Solenoid magnet
- Target

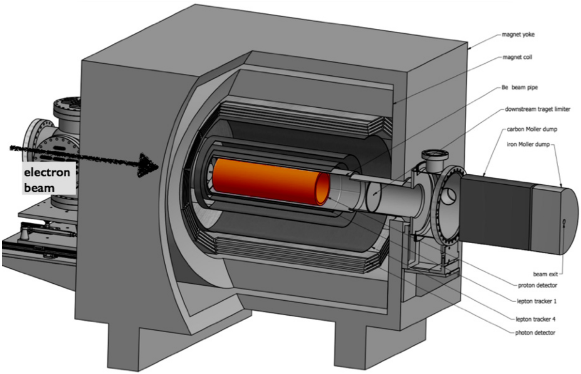
# Detector setup




- Hydrogen gas target
- Thickness: $10^{19}$ $Atoms/cm^2$
- 2mm apertures to limit flow
- Multiple stages of pumping
- 1mm thin berrylium pipe
- Investigating jet target

- Solenoid magnet
- Target

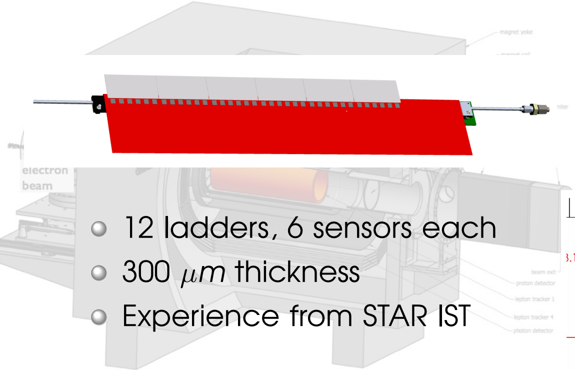
# Detector setup



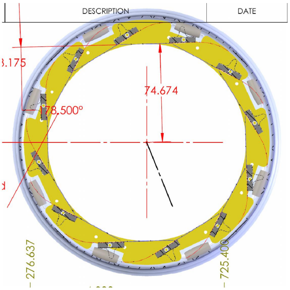

- Solenoid magnet
- Target
- Proton silicon detector

# Detector setup

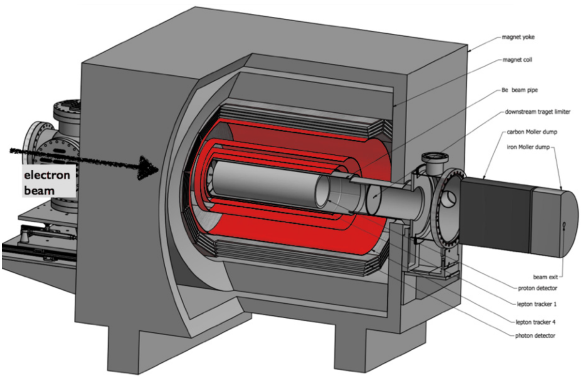
- Solenoid magnet
- Target
- Proton silicon detector




- 12 ladders, 6 sensors each
- 300 $\mu m$ thickness
- Experience from STAR IST

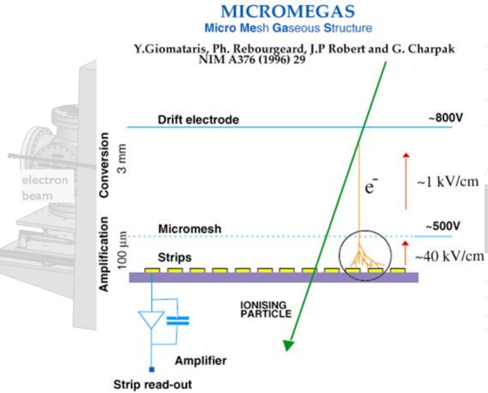


# Detector setup



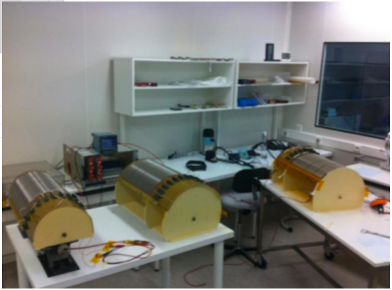

- Solenoid magnet
- Target
- Proton silicon detector
- Lepton tracker
  4 layers MicroMegas

# Detector setup

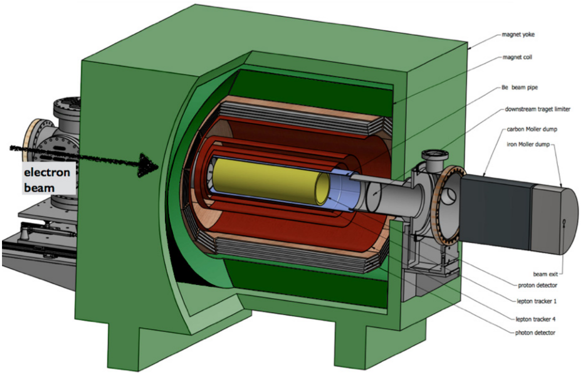



- Thin, high rate capable
- Cylindrical detectors possible

- Solenoid magnet
- Target
- Proton silicon detector
- Lepton tracker
  4 layers MicroMegas

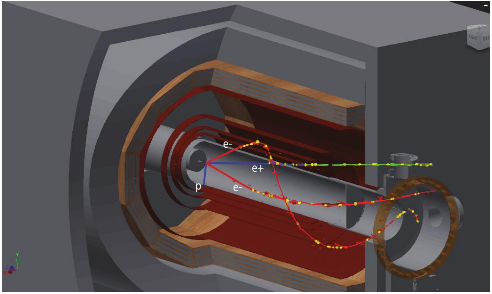


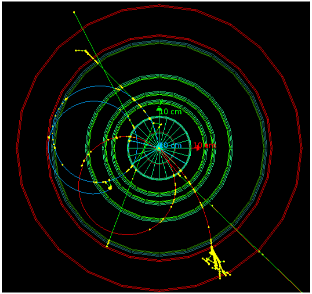
# Detector setup




- Solenoid magnet
- Target
- Proton silicon detector
- Lepton tracker
  4 layers MicroMegas
- Design is still in flux!

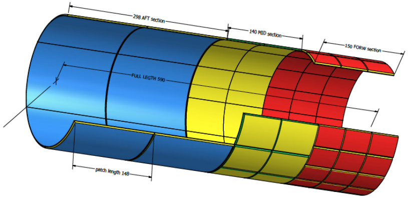
# Kinematics



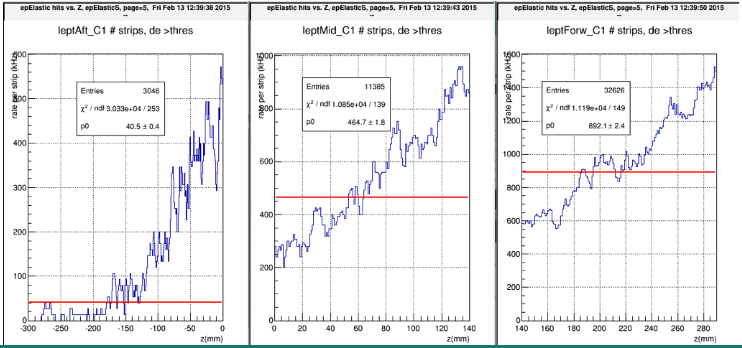




- ☺ Can detect full final state
- ☺ Large acceptance
- ☹ How to trigger?
  - Signal tracks do not reach beyond lepton tracker
  - Can not identify reaction on trigger level
  - Can not trigger on "3 particles": background to high

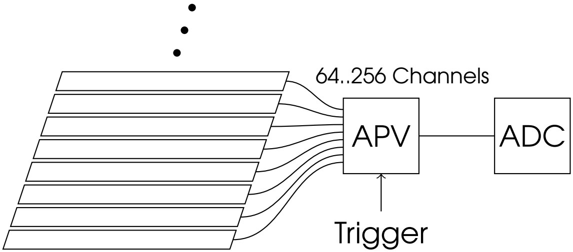
# Background rates: Elastic scattering




- 90 patches
- independent 2D strip readout
- >20 tracks every 25 ns frame

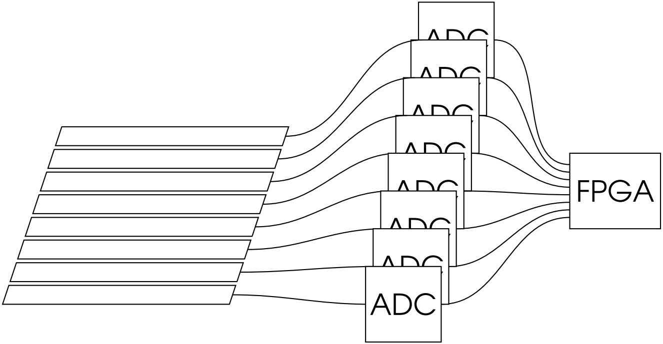


# Normal electronics




- APV/DREAM/... multiplex $N$ channels to 1 ADC
- Theoretical maximum readout rate: $1/N$ of ADC clock

# Streaming front end electronics: NSA Scale




- Continuous readout
  80k ch, 40 MSps @ 12 bit $\Longrightarrow$ 4.8 Terabyte/s
  $\sim$ 80 M ch, 40 KSps
  $\Longrightarrow$Listening to every German citizen in CD quality.
- Zero suppression: 250 Gigabyte/s

# Streaming back end electronics

- Transport data from FEE to CPU farm
- Solve transposition problem ("Event building")
  - Data aggregated per channel
  - Must be processed by time slice

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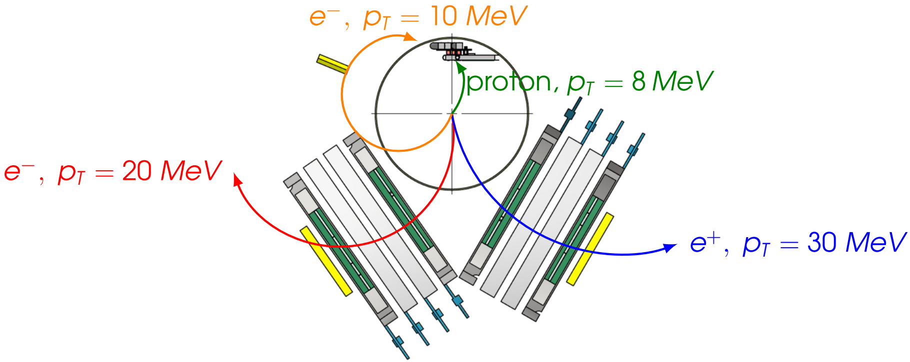
**Common problem at intensity frontier**

- Solve once and reuse
- Open design
  - wire protocol
  - hardware
- Use standard hardware
  - cheaper
  - easier to extend

# Phase 1

- Beryllium $\longrightarrow$ Aluminum pipe
- Cylindrical MicroMegas $\longrightarrow$ planar GEMs
- Only one proton detector ladder
- Only partial streaming readout

# Phase 1 current design




- Tripple coincidence to select QED background / $A'$ candidate events at reasonable rates
- Investigate if we can run double coincidence
- Run APV in quasi-streaming mode - free running trigger, mutiple frames

# Summary

- Phase 1:
  - Proof of target concept
  - SM processes: Møller, elastic scattering
  - DM search mock up
  - Prototyping of streaming readout
  - Will run 2016
- Phase 2:
  - Full acceptance with full streaming readout
  - Visible and invisible search

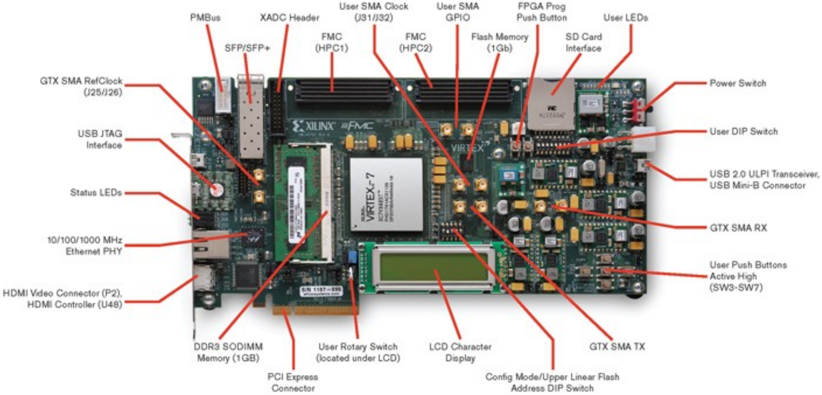
**Low energy, intense beam physics**

Intense Electron Beams Workshop
Cornell University, June 17-19, 2015
http://www.classe.cornell.edu/NewsAndEvents/IEBWorkshop

# Backup slides

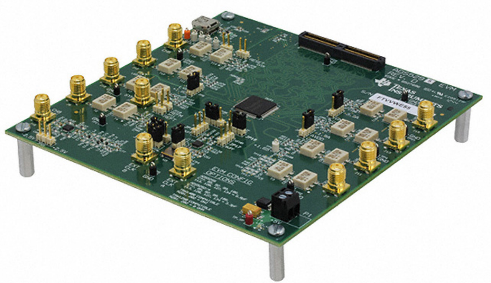
# Current status: Hardware

- Xilinx Virtex-7 development board: VC 707
  - XC7VX485T-2FFG1761
  - Gigabit Ethernet + SFP/SFP+
  - FMC connectors



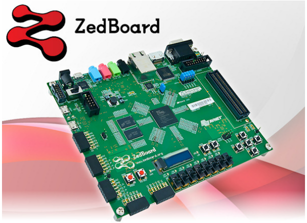
# Current status: Hardware

- Xilinx Virtex-7 development board: VC 707
  - XC7VX485T-2FFG1761
  - Gigabit Ethernet + SFP/SFP+
  - FMC connectors
- TI ADS5295 evaluation module + adapter board
  - 8 channels
  - 80 MSPS / 12 bit



# Current status: Hardware

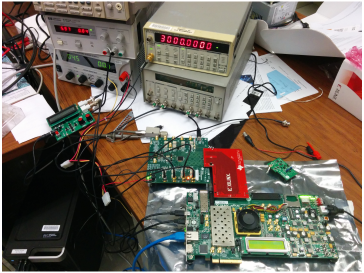
- Xilinx Virtex-7 development board: VC 707
    - XC7VX485T-2FFG1761
    - Gigabit Ethernet + SFP/SFP+
    - FMC connectors
- TI ADS5295 evaluation module + adapter board
    - 8 channels
    - 80 MSPS / 12 bit
- Signed up for Xilinx university program
    - XUP donated hardware & software



# Current status: FPGA firmware

Milestones:

- Setup
- Ethernet send/receive
    - OSI layer 2



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Milestones:

- Setup
- Ethernet send/receive
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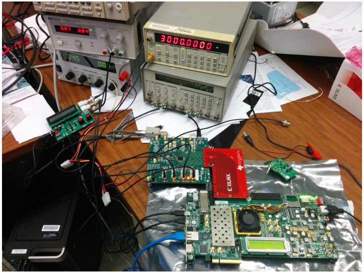
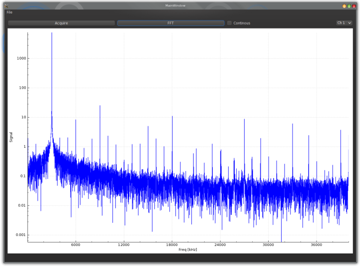
- Readout of ADC:
  - Full data of 1 ch.
  - 8 ch. with zero suppression





# Current status: FPGA firmware

Milestones:

- Setup
- Ethernet send/receive
  - OSI layer 2
- Readout of ADC:
  - Full data of 1 ch.
  - 8 ch. with zero suppression
- Planned:
  - Partial streaming readout for DL phase 1
  - Full streaming readout for DL phase 2