An Update on the DarkLight status

Jan C. Bernauer

MAGIX Workshop
February, 2017

Massachusetts Institute of Technology

New physics? Beyond Standard Model search

DarkLight origin story

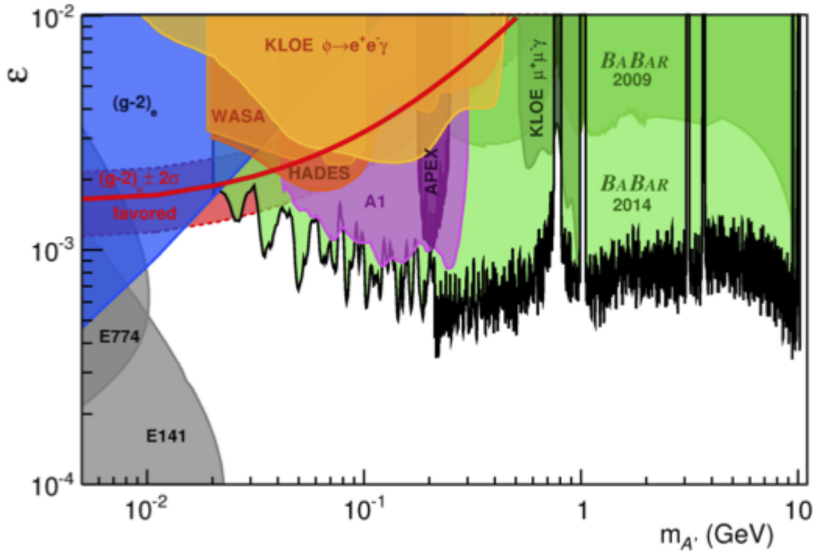
- A' is a proposed new, light force carrier
- couples to SM only weakly
- motivated by $g_\mu - 2$ discrepancy
- might also explain the proton radius puzzle
    - needs some fine-tuning

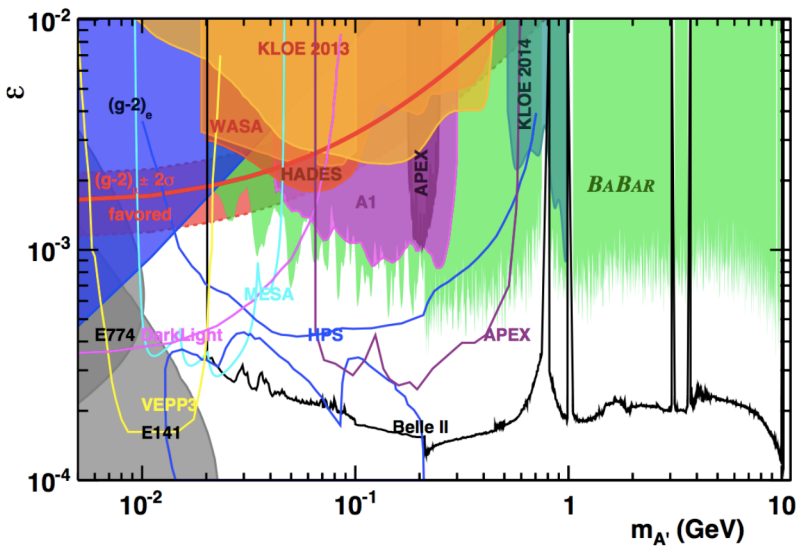
Current and future exclusion limits

current

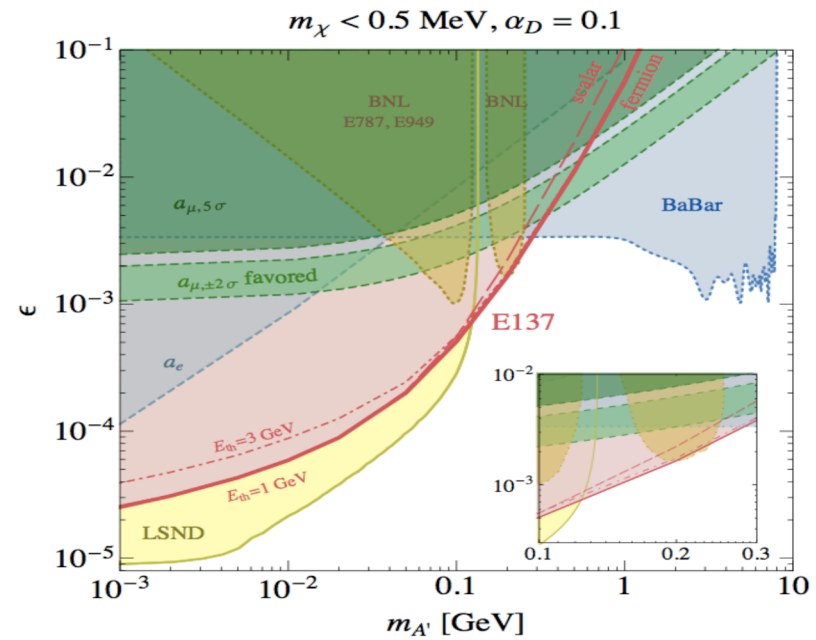
future

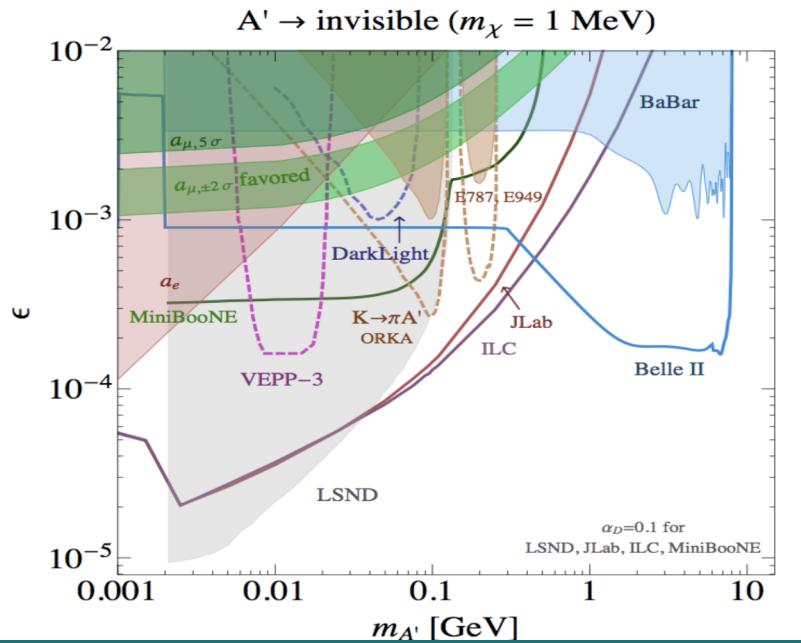
visible





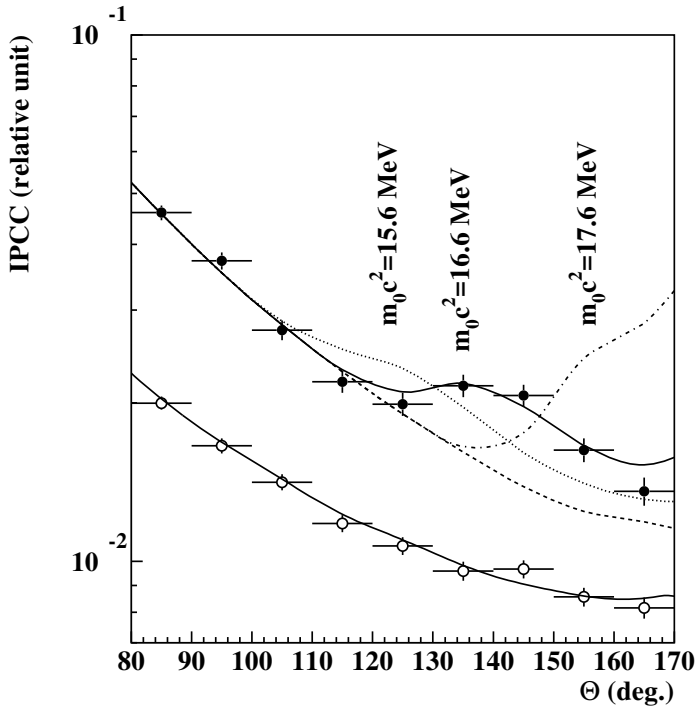
invisible





The models evolve...

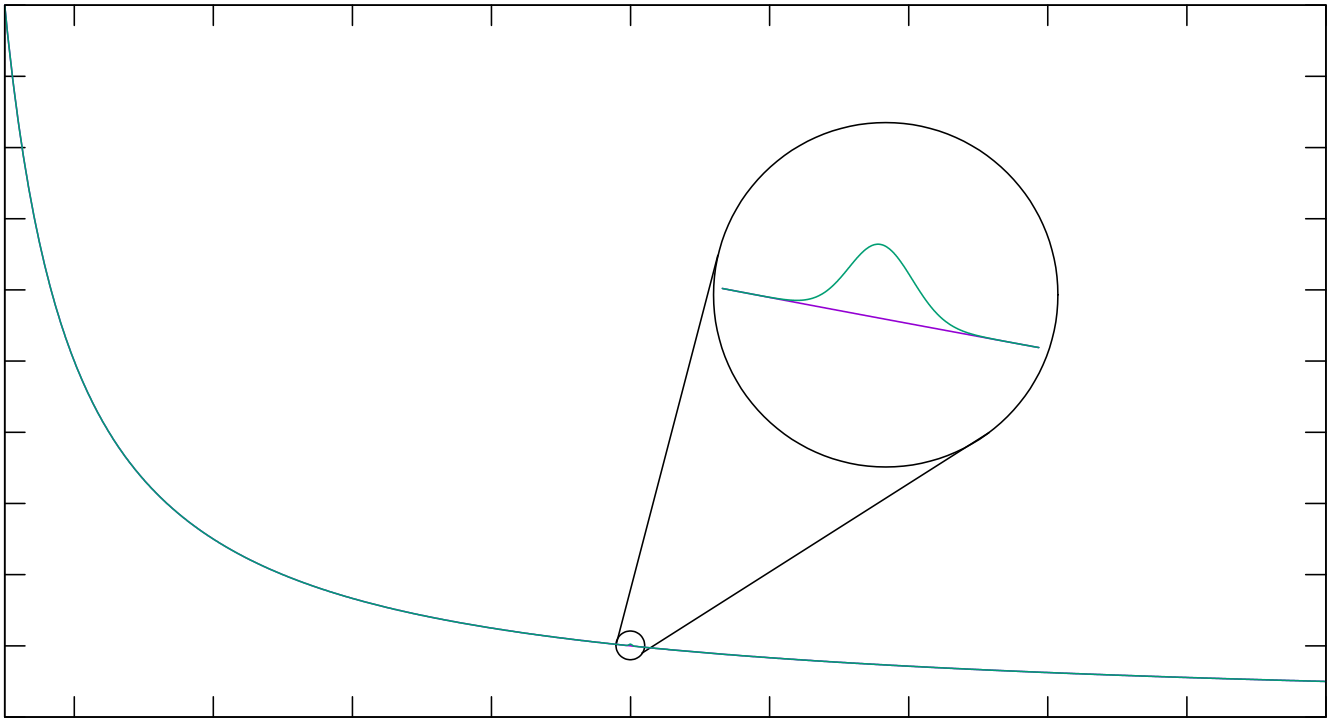
- Can evade many limits with tuned couplings
- For example: Protophobic fifth force as an explanation for $^8Be^*$ decay anomaly
- Not that strange: Z^0 coupling to p/n like 0.074/1

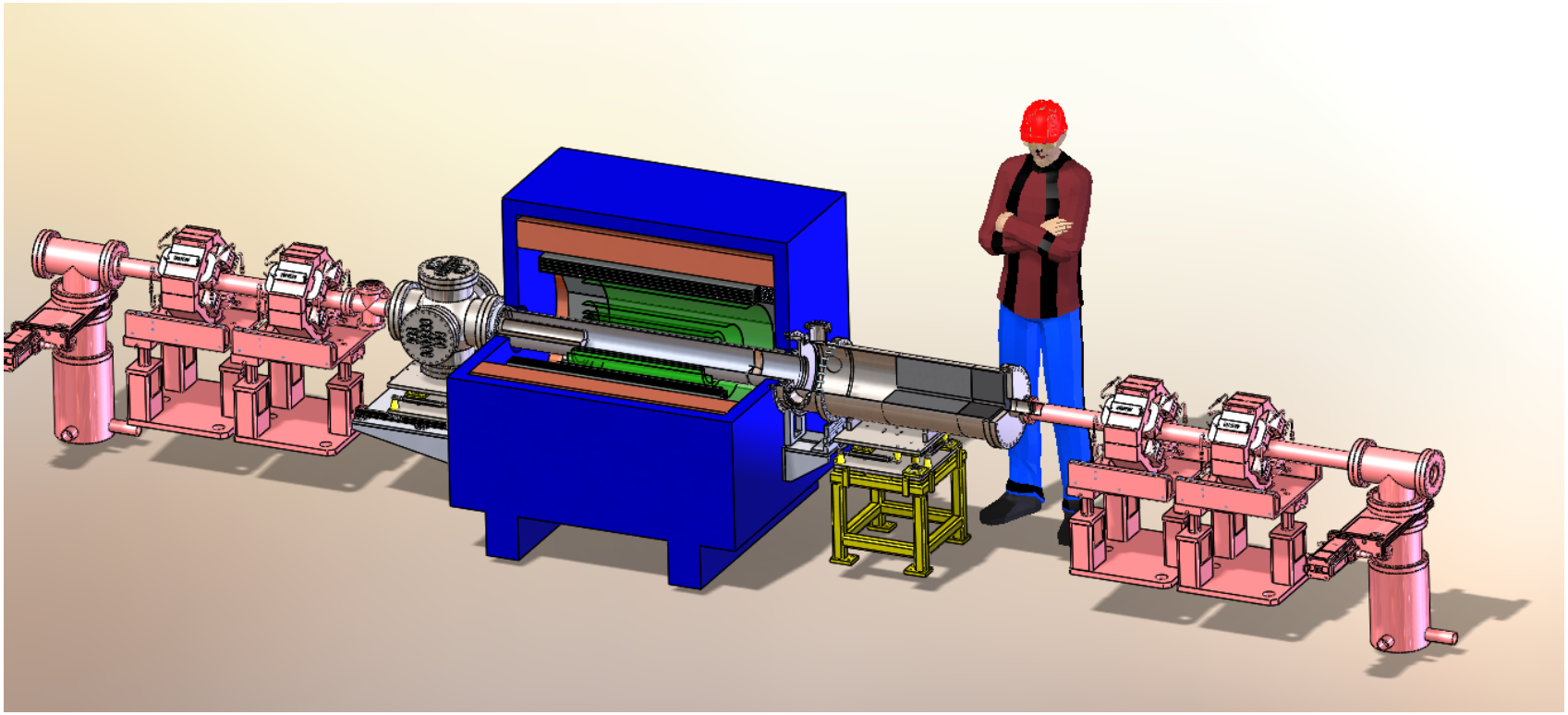


From: Krasznahorkay, A. J. et al., PRL 116 042501 (2016)

Precision frontier is Intensity frontier

- Bump hunt
  - Intensity frontier: Measure tiny effect
  - Precision frontier: Measure tiny effect on top of large background



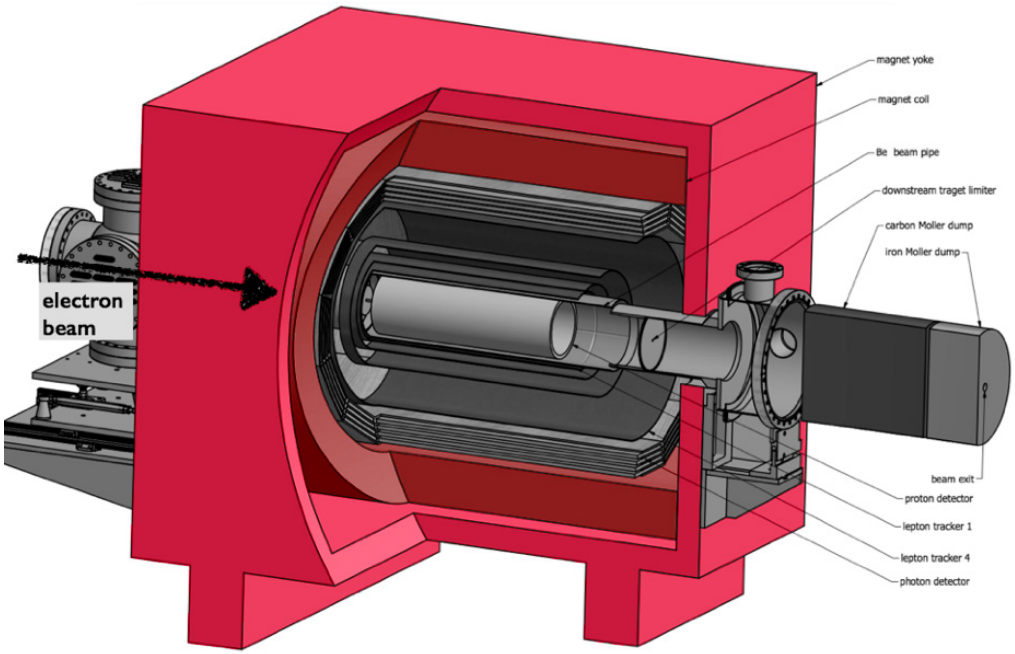


- @JLab LERF (Low Energy Recirculating Facility, fka FEL)
  - 5-10 mA, 100 MeV beam, 1 attobarn^{-1}/month
- Measure $e^- + p \longrightarrow e^- + p + A' \longrightarrow e^- + p + (e^+ + e^-)$

J. Balewski et al., arXiv:1412.4717 [physics.ins-det]

Detector setup: phase 2 concept

- Solenoid magnet



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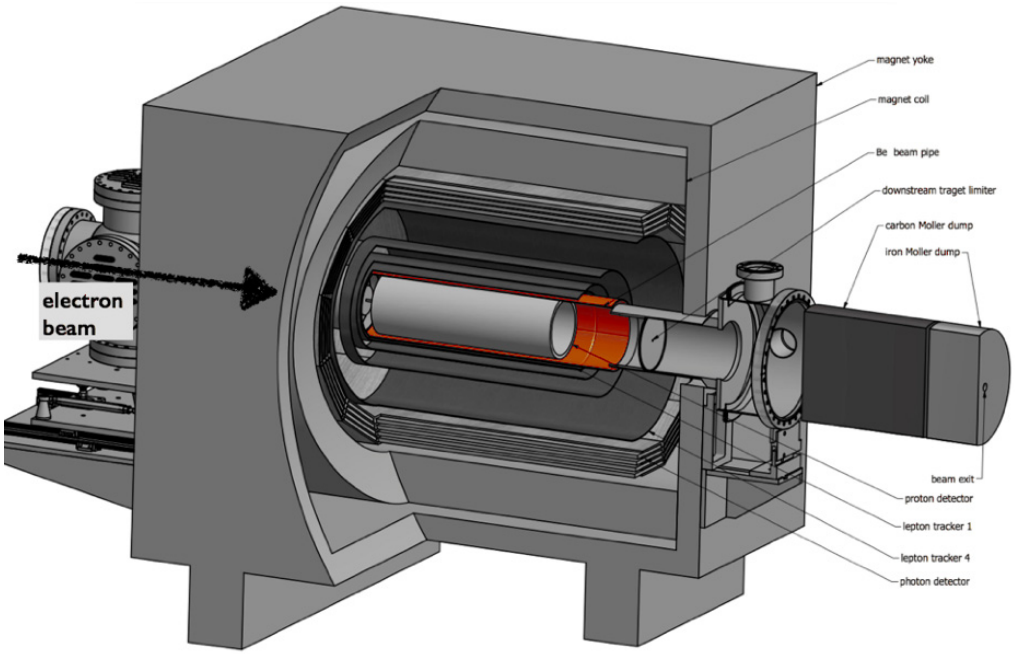
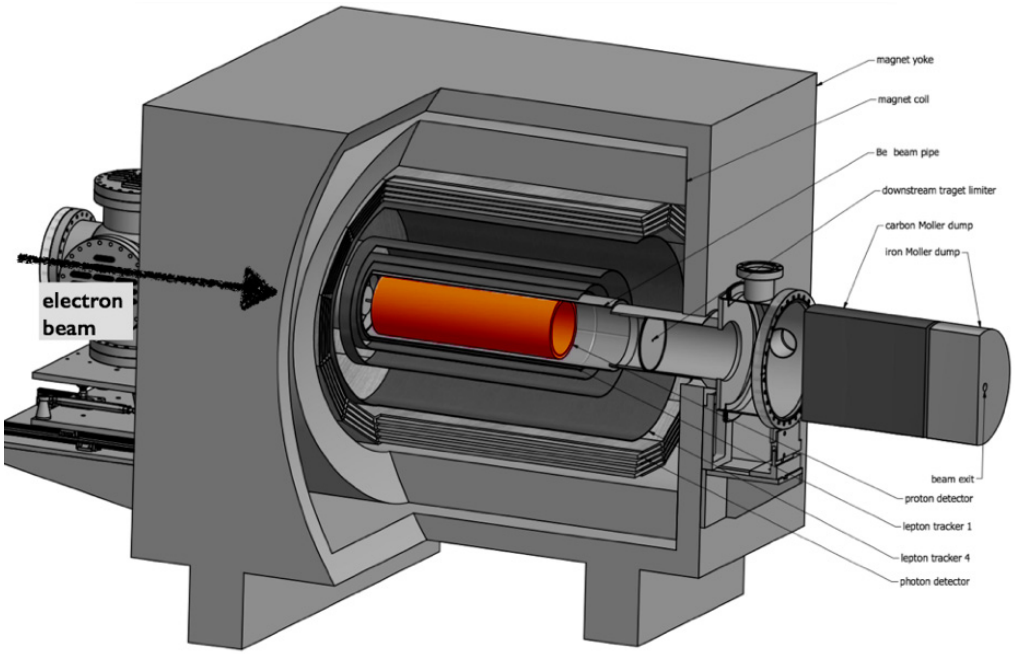


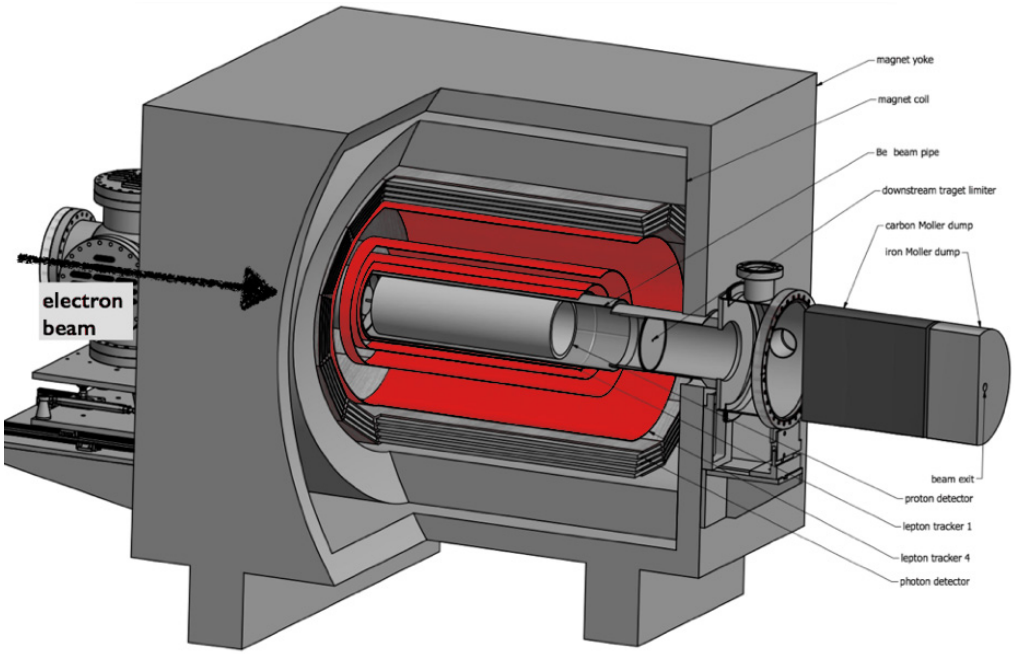
- Solenoid magnet
- Beryllium beam pipe

Detector setup: phase 2 concept



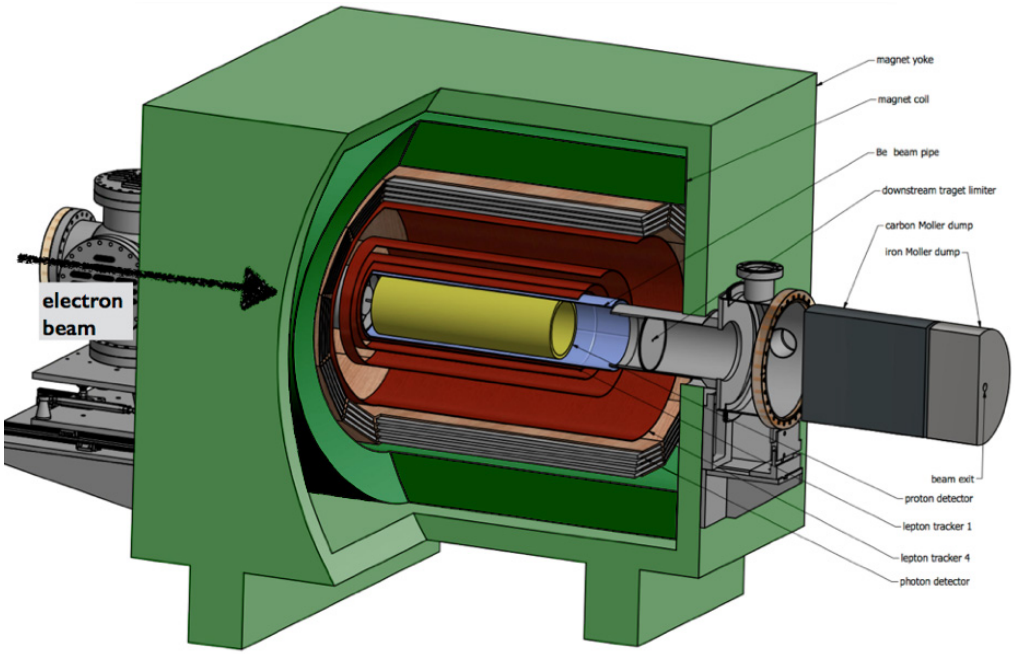
- Solenoid magnet
- Beryllium beam pipe
- Proton detector
  Silicon strip

Detector setup: phase 2 concept



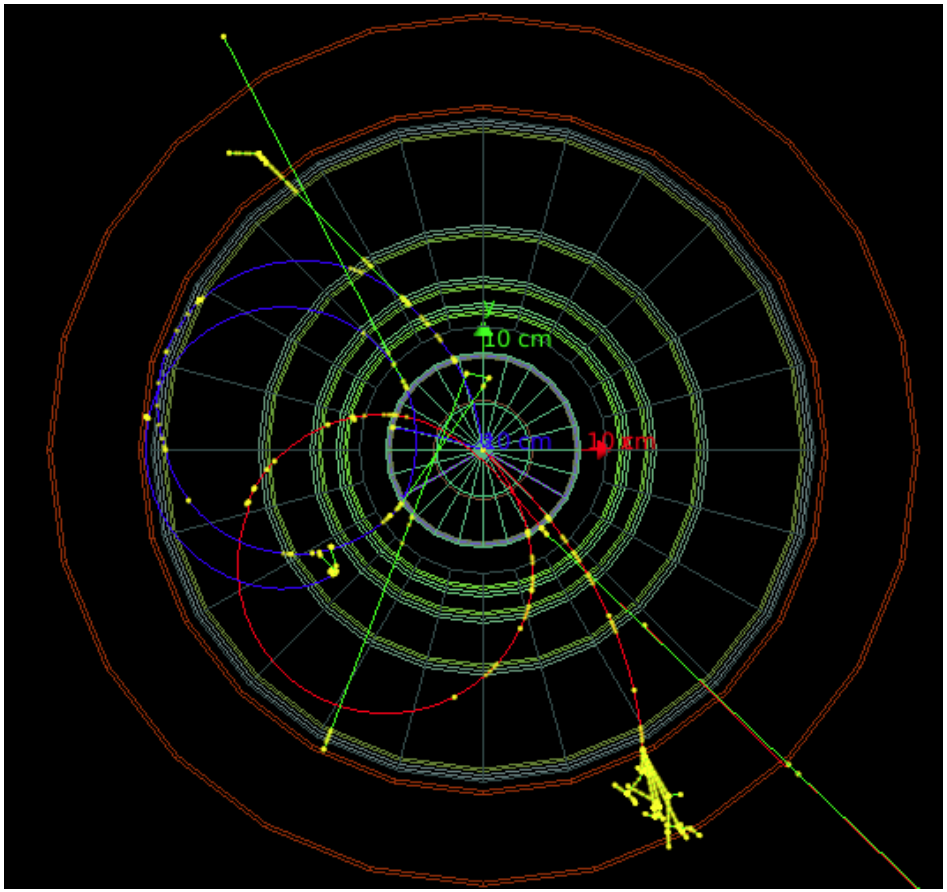
- Solenoid magnet
- Beryllium beam pipe
- Proton detector
  Silicon strip
- Lepton tracker
  4 layers
  GEM/MicroMegas
  >60000 channels

Detector setup: phase 2 concept



- Solenoid magnet
- Beryllium beam pipe
- Proton detector
  Silicon strip
- Lepton tracker
  4 layers
  GEM/MicroMegas
  >60000 channels
- Design is still in flux!

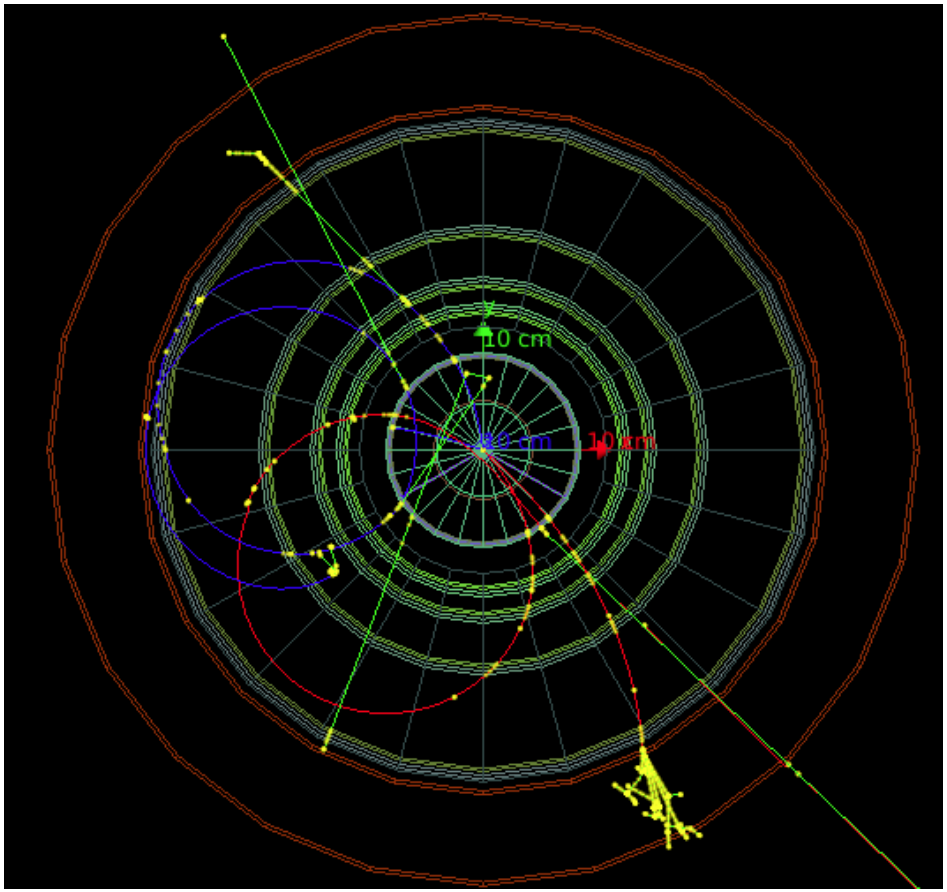
Trigger?



Trigger detectors?

- Not outside: Not reached by interesting events
- Not inside: Material destroys resolution

Trigger?



Trigger detectors?

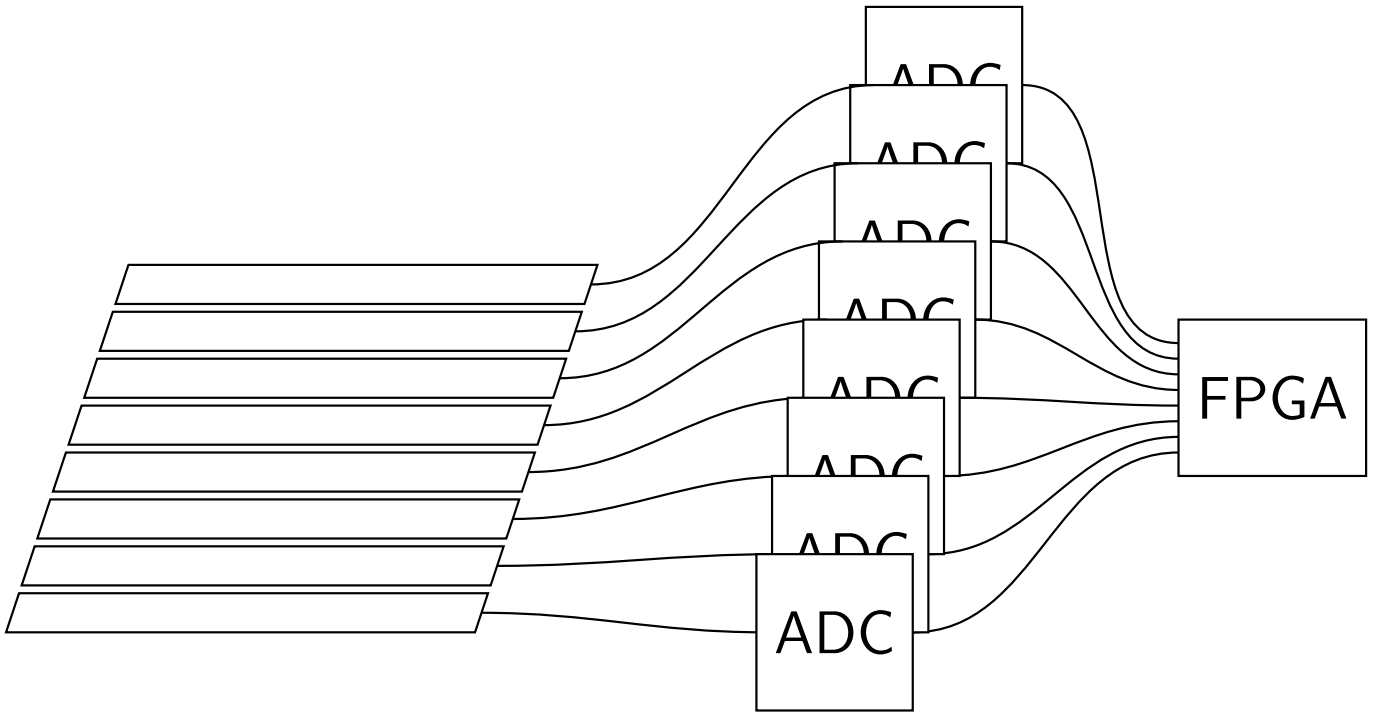
- Not outside: Not reached by interesting events
- Not inside: Material destroys resolution

Trigger off Lepton tracker?

- GEMs/MicroMegas: Does not work reliably
- Rate too high

CANNOT discriminate in hardware trigger.
Full online tracking!

Streaming front end electronics



- Continuous readout: 4 Terabyte/s
- Zero suppression: 200 Gigabyte/s

Streaming readout

- Solve transposition problem ("Event building")
  - Data aggregated per channel
  - Must be processed by time slice

Streaming readout

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  - Data aggregated per channel
  - Must be processed by time slice

Common problem at intensity frontier

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

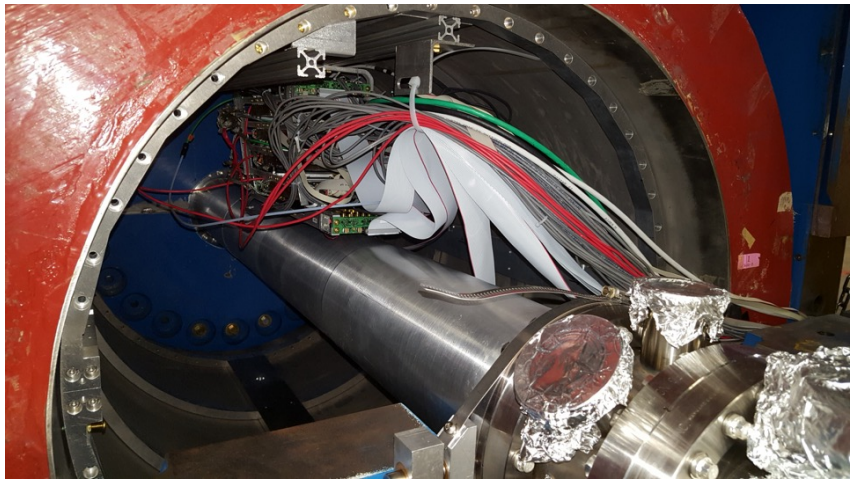
- Ongoing workshop series for EIC, but of interest for MAGIX?

DarkLight phase 1

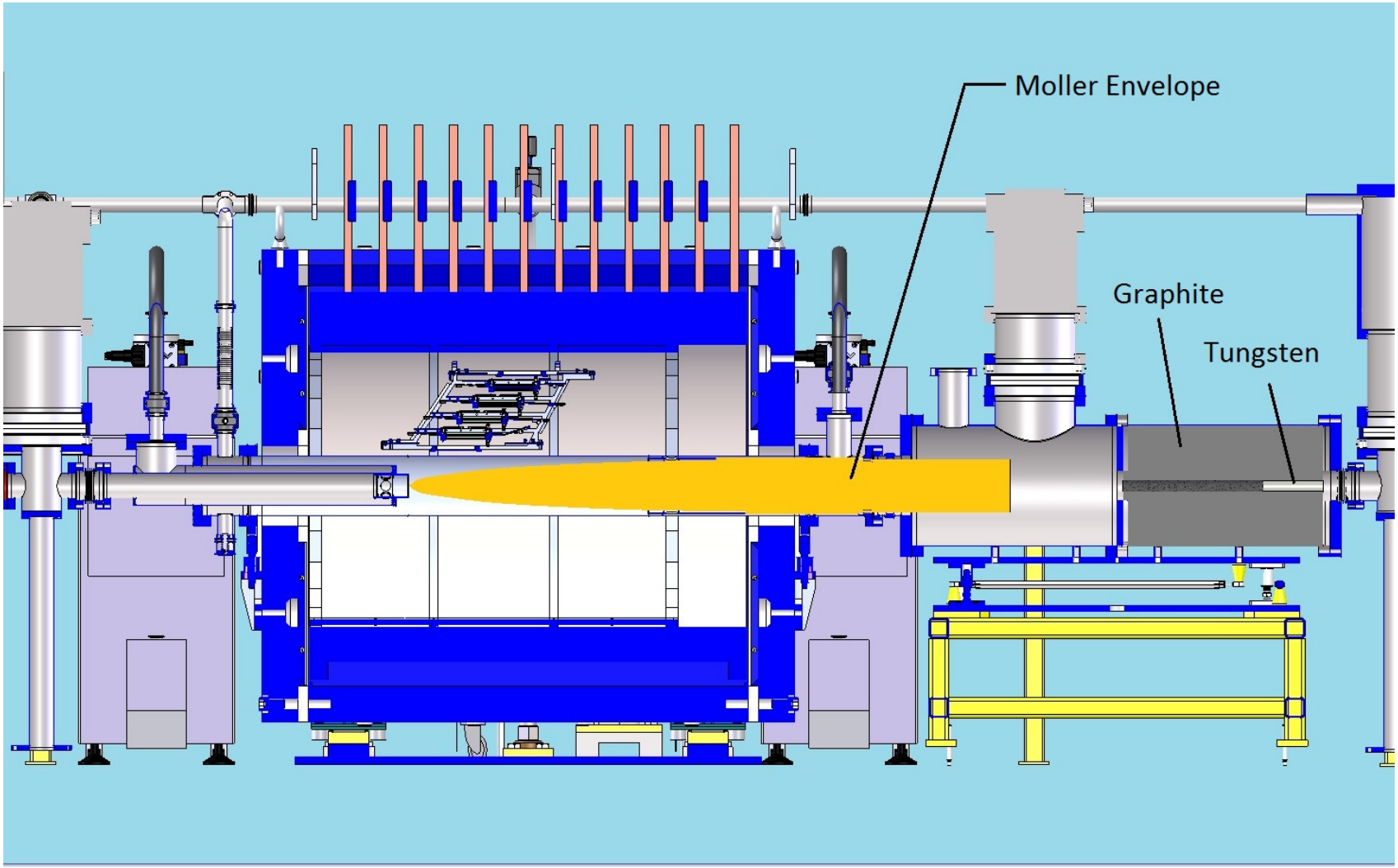
- 1A: Proof of target system and accelerator integration
- 1B: Measurement of Møller scattering at low energies
- 1C: Hunt for protophobic fifth force around 17 MeV (timeline: 1-2 years)

Phase 1A

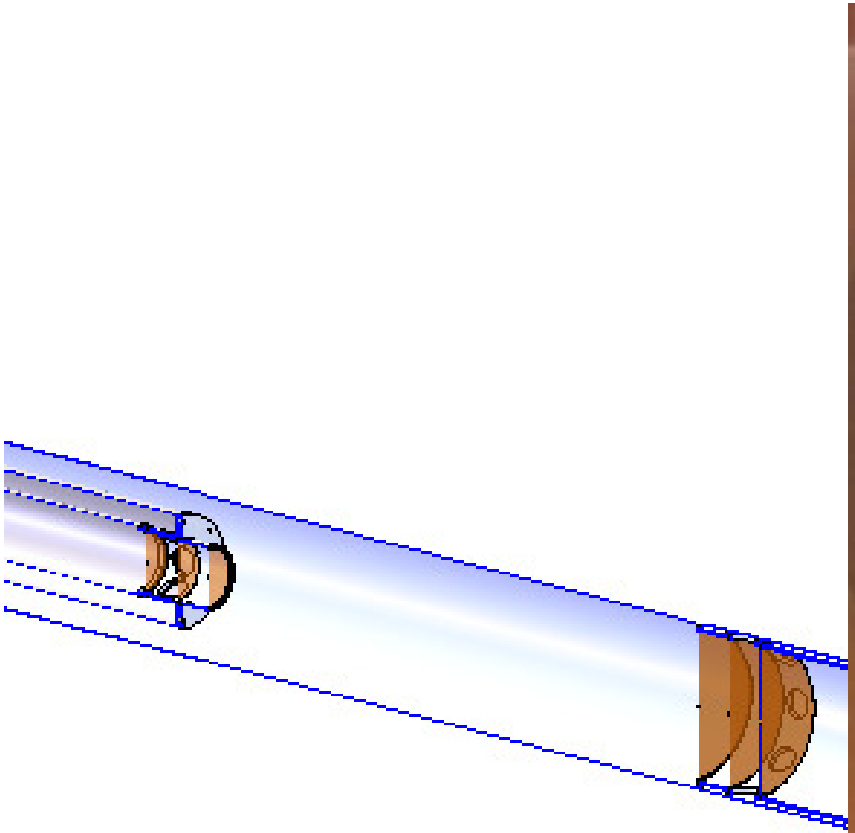
- Initial commissioning run for magnet + target
- Parasitic "engineering run" for detector development

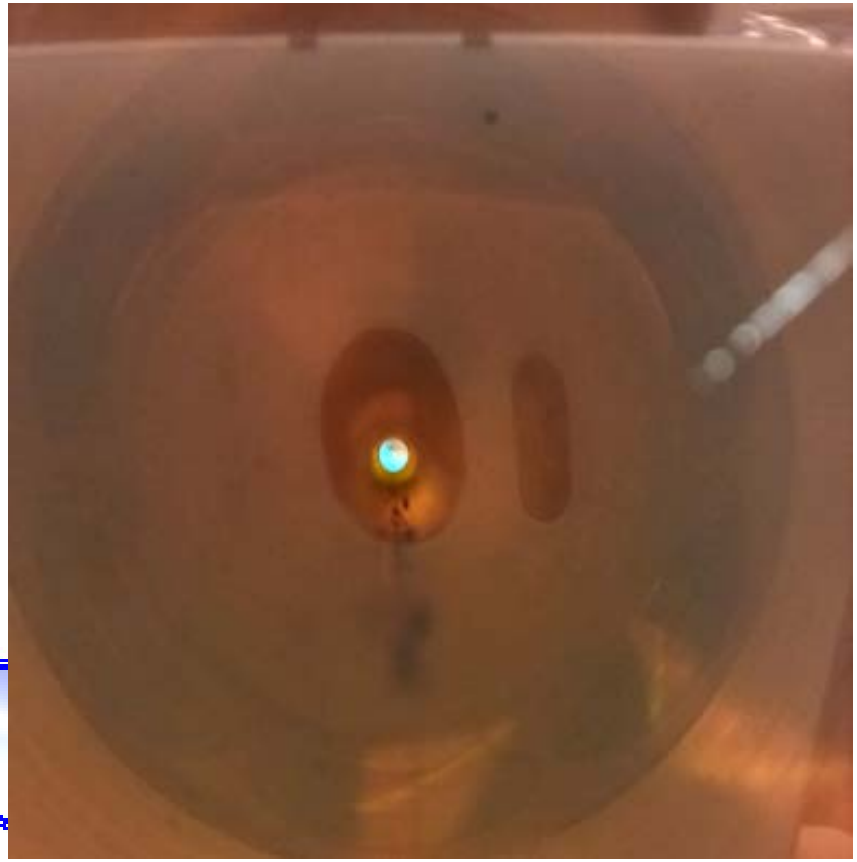


Target system



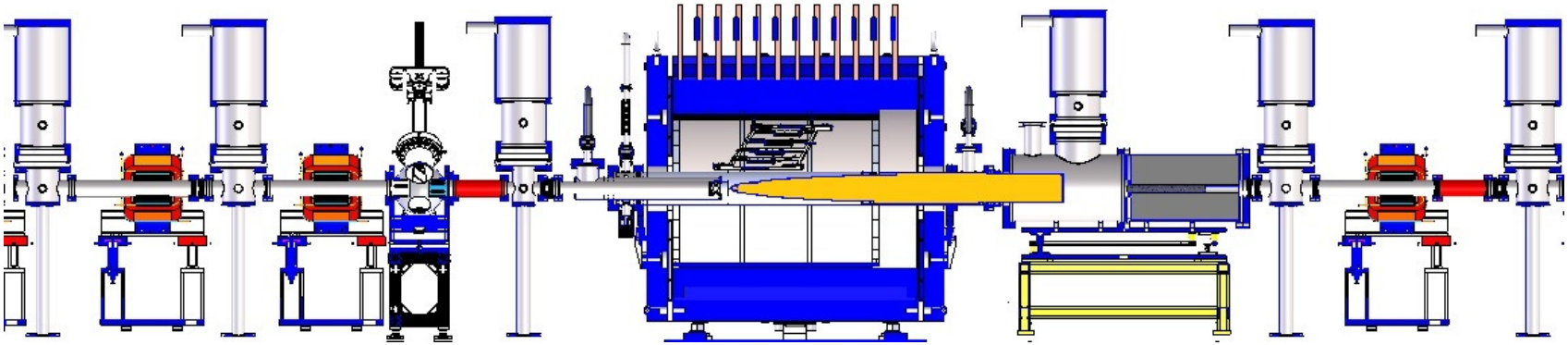
Baffles

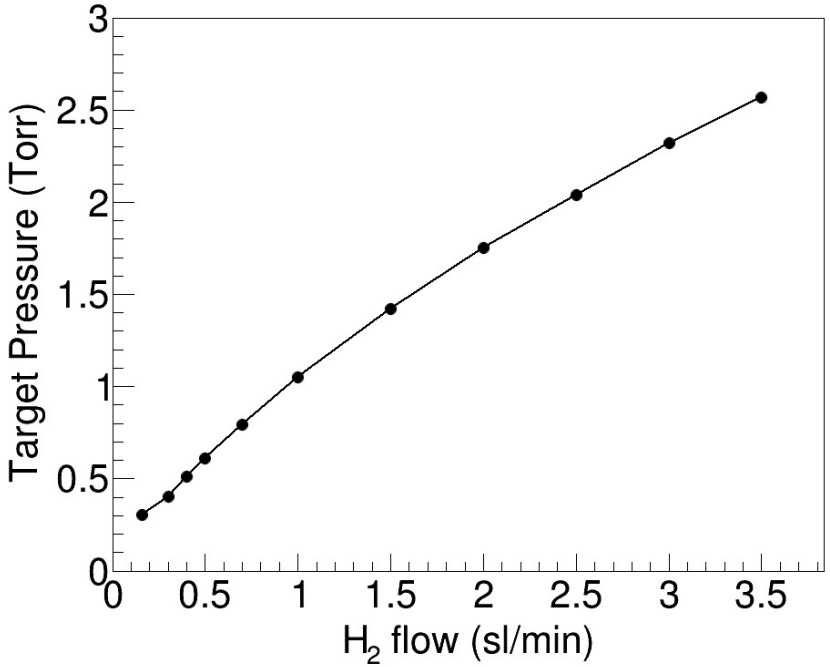


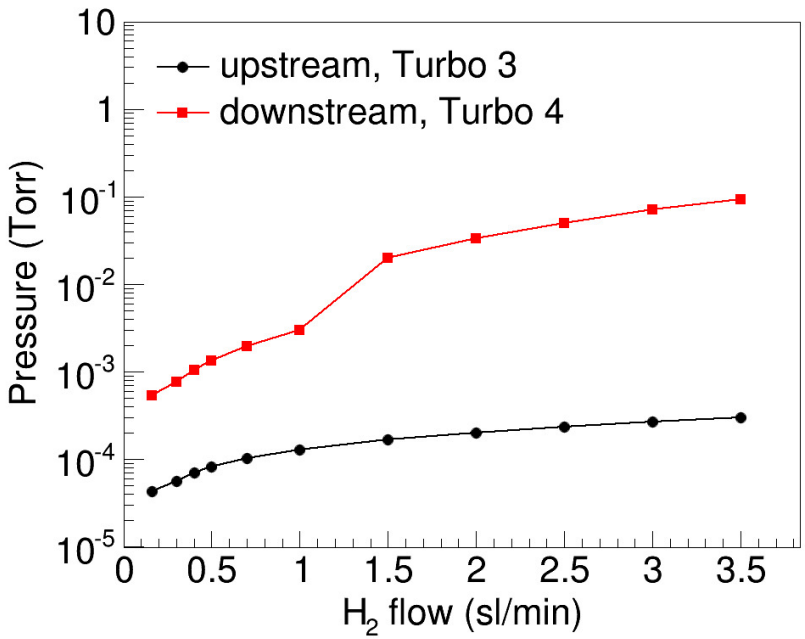


- Kapton baffles with 3mm apertures centered on beam axis

Vacuum system / Target performance

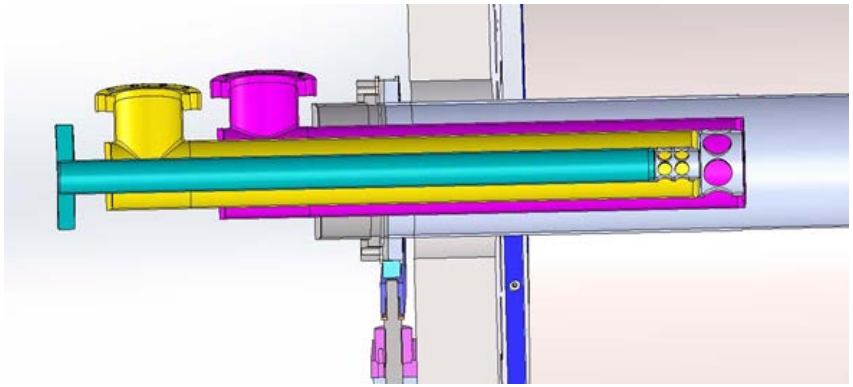


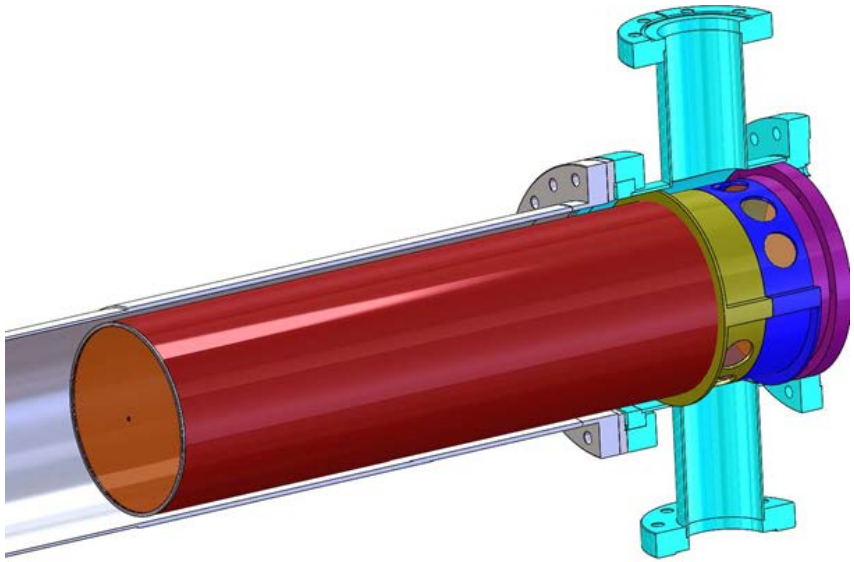




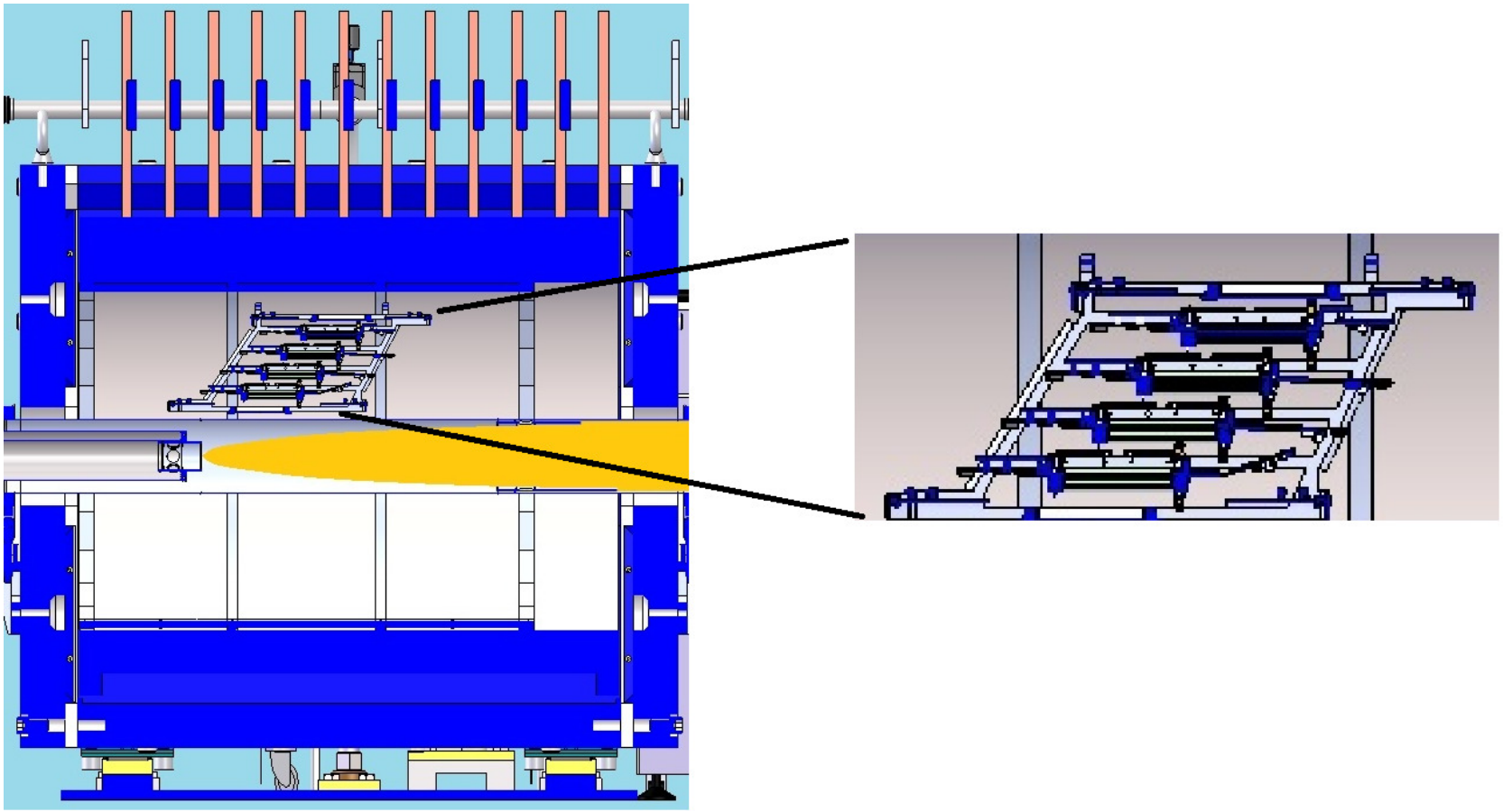
Status/ Upgrades

- Achieved 1/3 of target pressure
- Limit: Turbo 3 pressure / pressure in accelerator
- Upgrades to baffle system, multi stage pumping in baffles



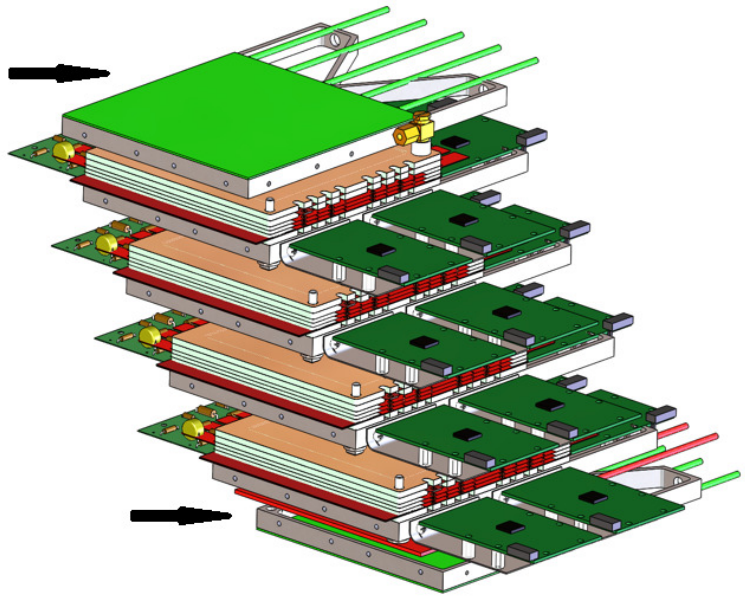


Prototype detector system I



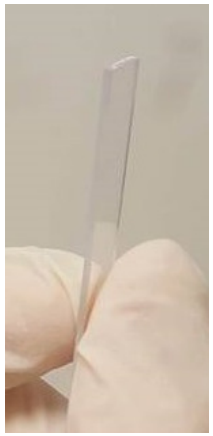
Prototype detector system II

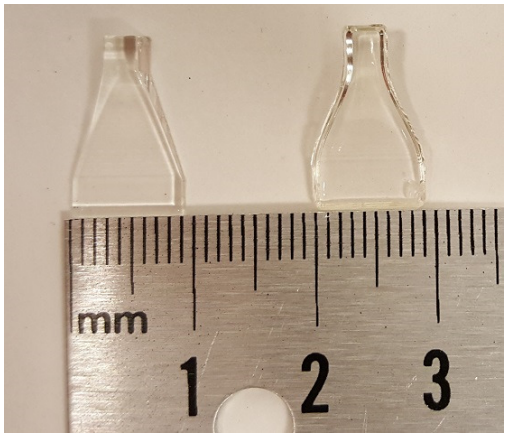
- 4x T-GEM detectors
- APV readout, need trigger
- Two trigger planes
  - highly segmented
  - thin
  - fast

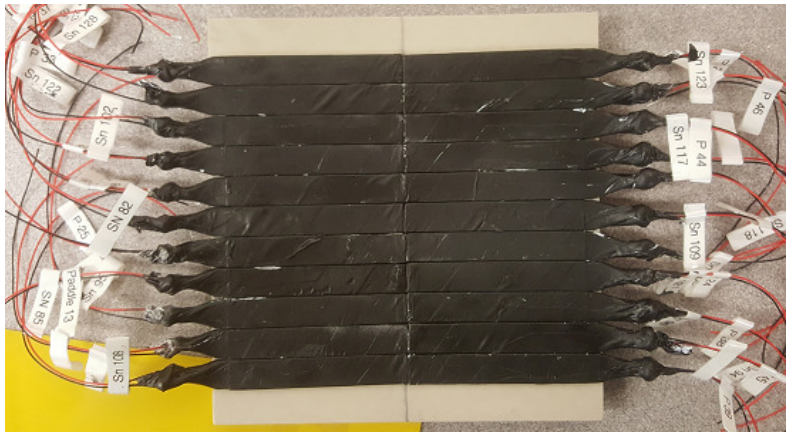


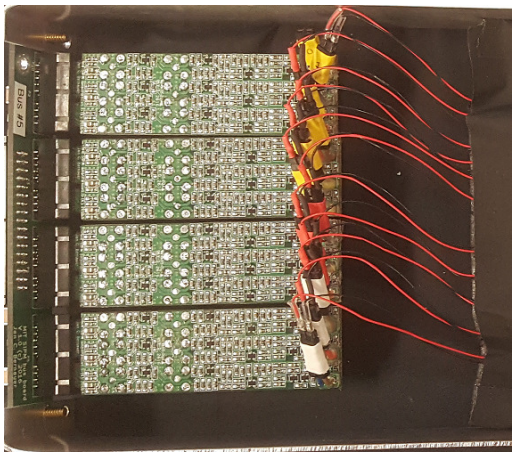
Trigger paddles

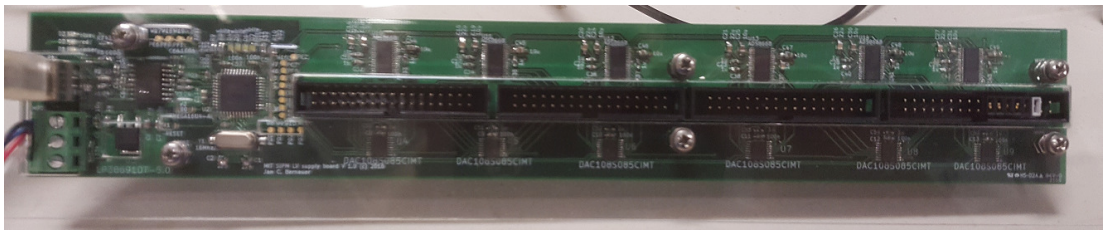
- 50mm × 9mm × 1mm scintillator
- 3D printed lightguides
- SiPM readout
- Custom amplifier and voltage controller











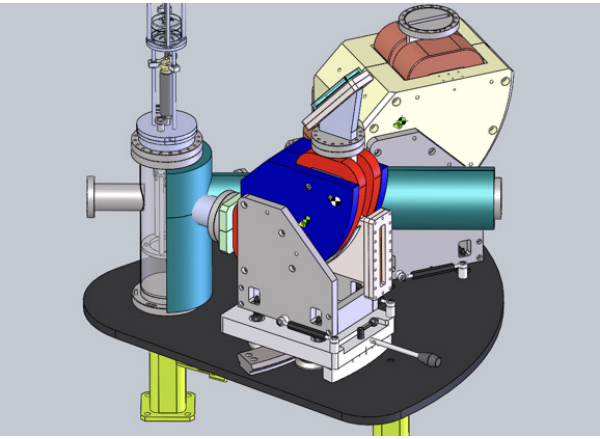
Phase 1A wrap up

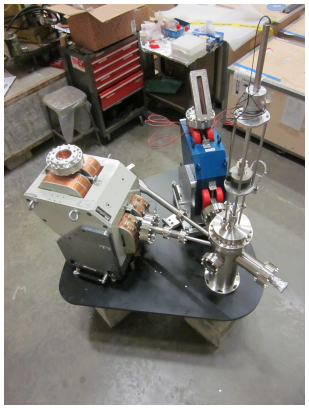
- Baffles misaligned, no clean transmission
- Collected "splash" data
- GEM data looks promissing, in analysis
- Target behaved well, but needs upgrades
- Trigger-detectors performed well, but need further tests with beam.

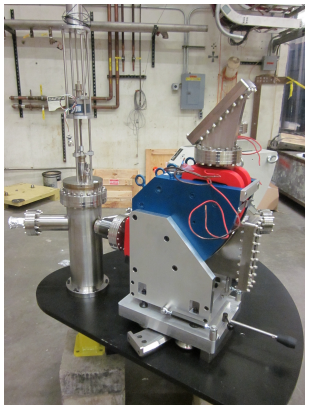
Phase 1B

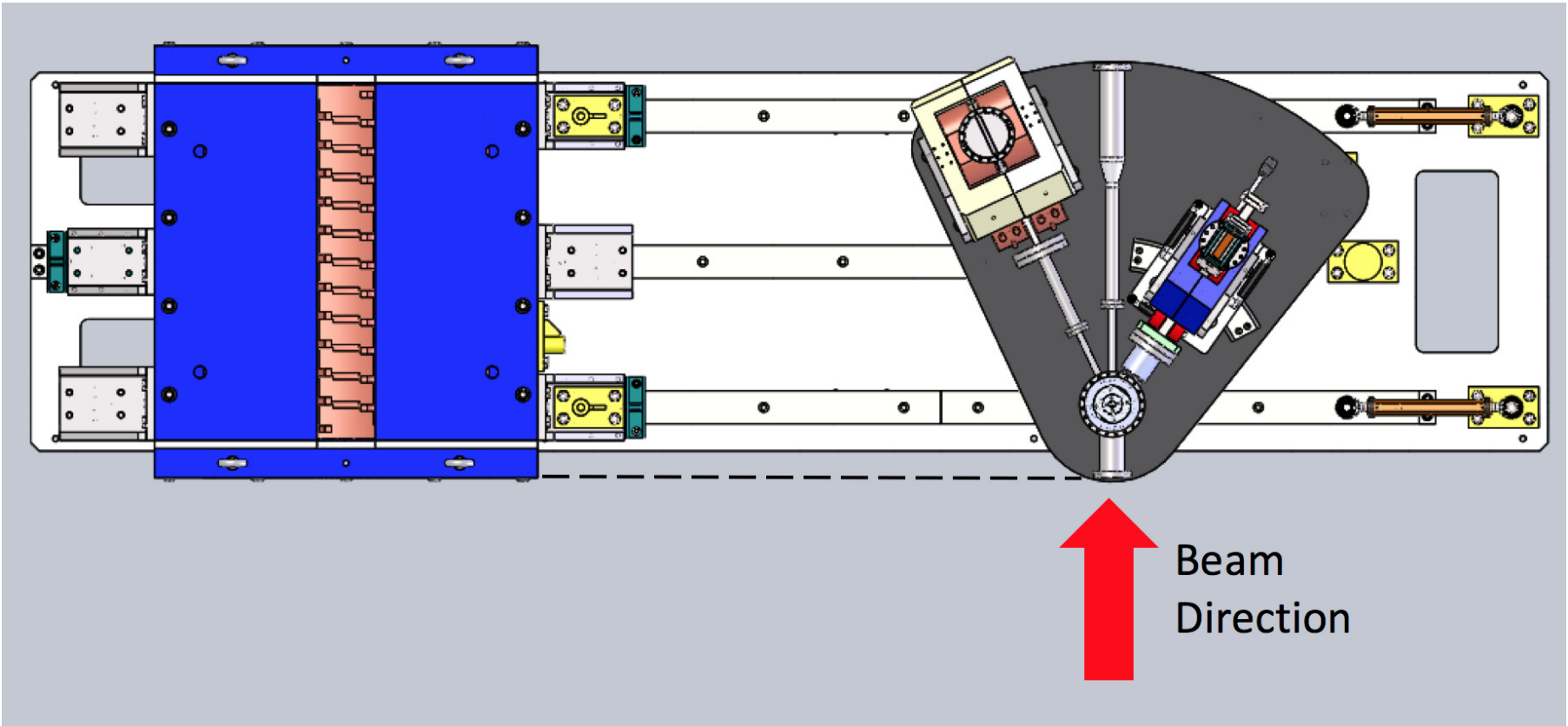
- Goal: Measure radiative Møller scattering in regime where electron mass can not be neglected.
- Validation for theory and event generators
- Design:
  - 2 spectrometers, one for cross section, one for luminosity
  - Diamond foil target

Phase 1B current status

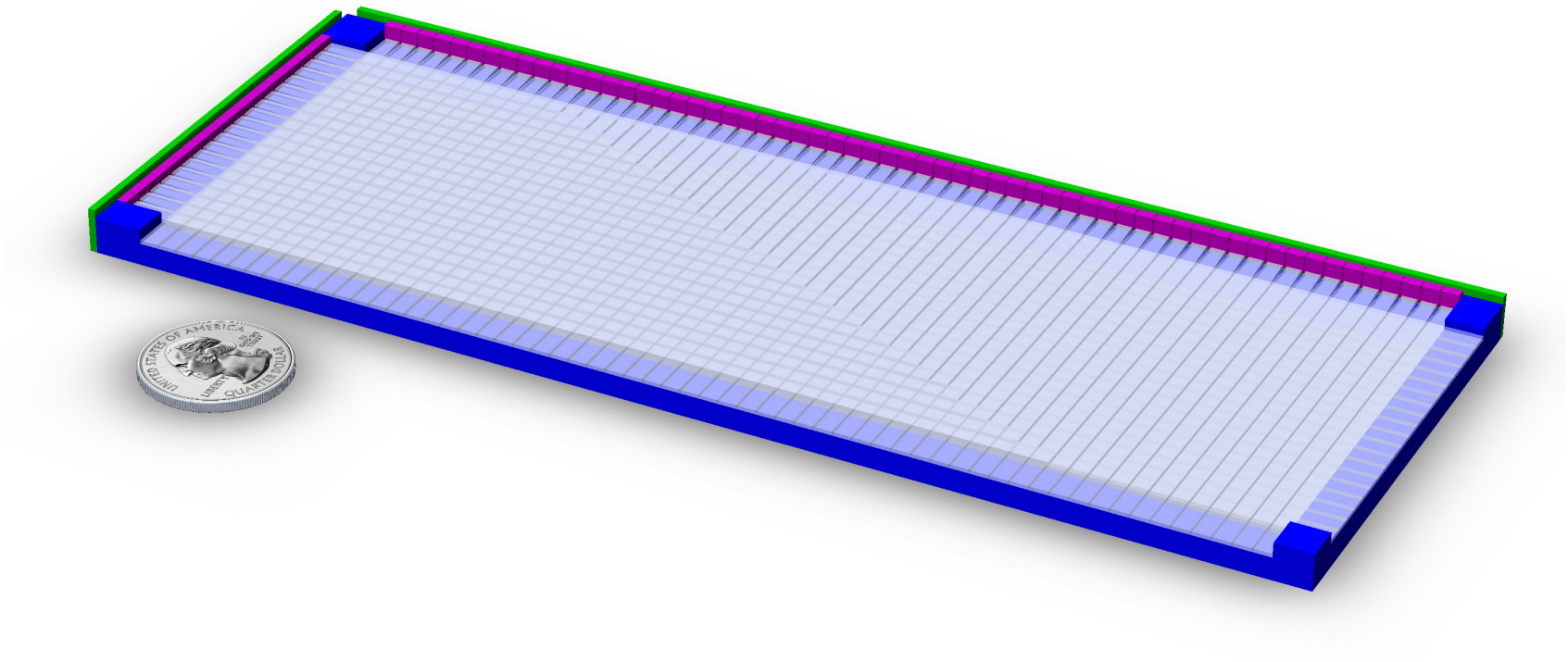








1B detectors



- Need to detect few MeV electrons!
- Two layers of scintillator
- Active area: 150mm $\times$ 50mm, with strips, 2.5mm $\times$ 0.5mm
- SiPM readout
- Currently designing FEE. Can be used in streaming mode.

Phase 1C

- Originally R&D for phase 2
- Pivot to test of 17 MeV fifth force carrier
- 2 spectrometer detecting e^+e^- pairs
- 50 MeV, 10 degrees
- Detectors similar to 1B, or GEMs, or combination
- Foil target, or external beam?

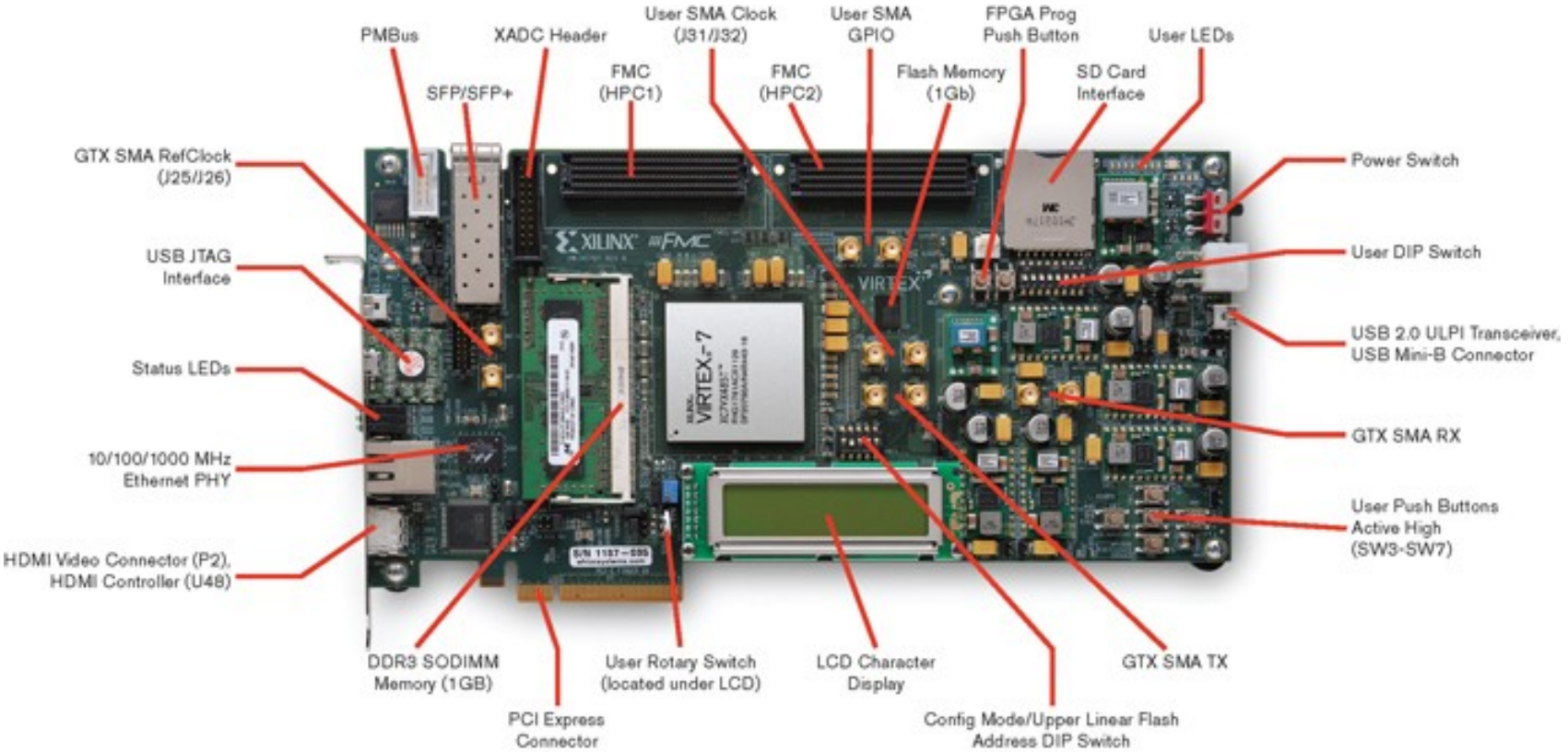
Summary

- Phase 1A: target design promising, have to redo beam
- Phase 1B: measurements imminent, test bed for streaming readout (this year)
- Phase 1C: Physics output: test of 17 MeV fifth force carrier (this or next year)

- Phase 2: Full measurement

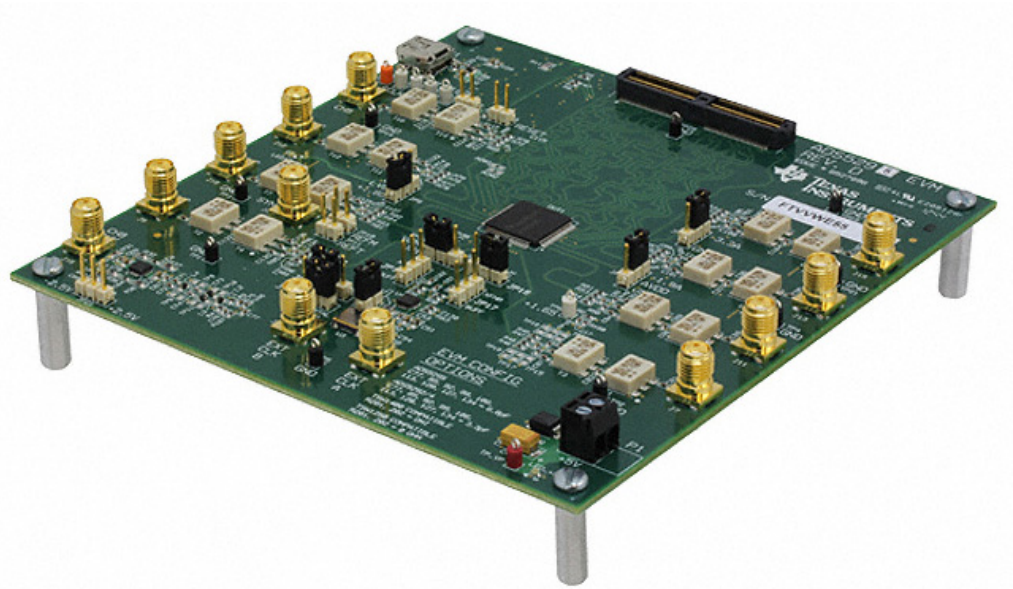
Prototype design: Hardware

- Xilinx Virtex-7 development board: VC 707



Prototype design: Hardware

- Xilinx Virtex-7 development board: VC 707
- TI ADS5295 evaluation module + adapter board
  - 8 channels @ 80 MSPS / 12 bit



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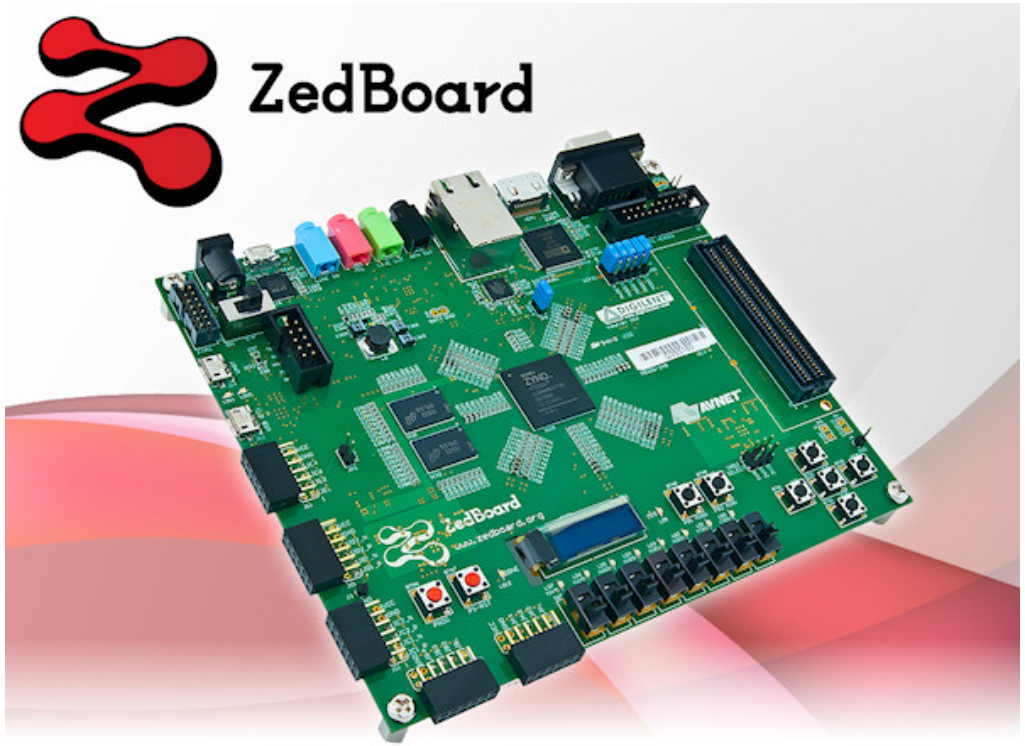
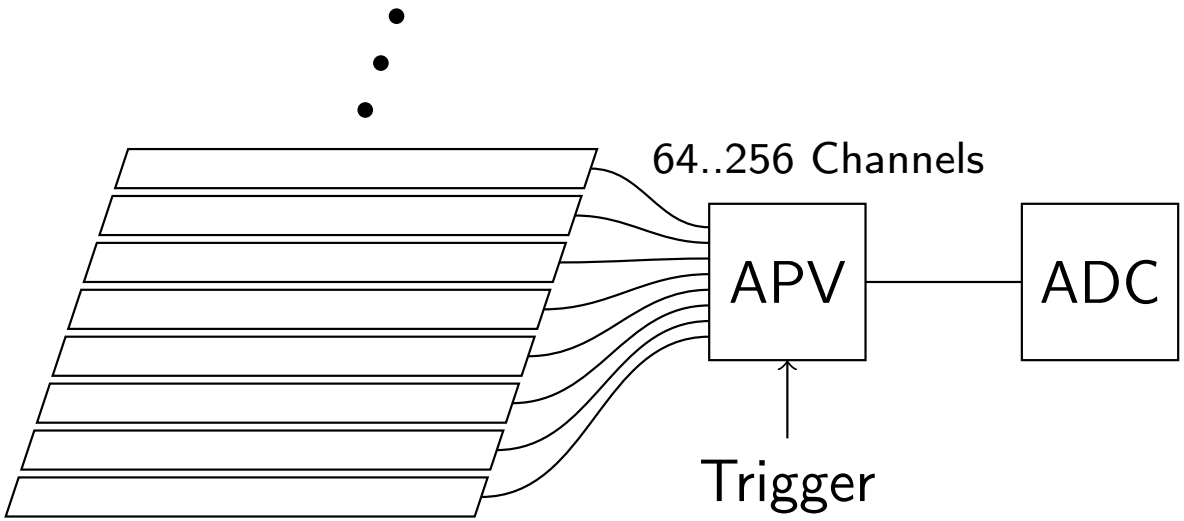
- Signed up for Xilinx university program
  - XUP donated hardware & software



Prototype design: Hardware

- Xilinx Virtex-7 development board: VC 707
- TI ADS5295 evaluation module + adapter board
  - 8 channels @ 80 MSPS / 12 bit
- Signed up for Xilinx university program
  - XUP donated hardware & software
- Additionally:
  - Investigate modification of Stanford electronic group's HPS electronics for our purpose.
  - Work with industry: In contact with AlphaCore, development of high channel count AFE+ADC chip

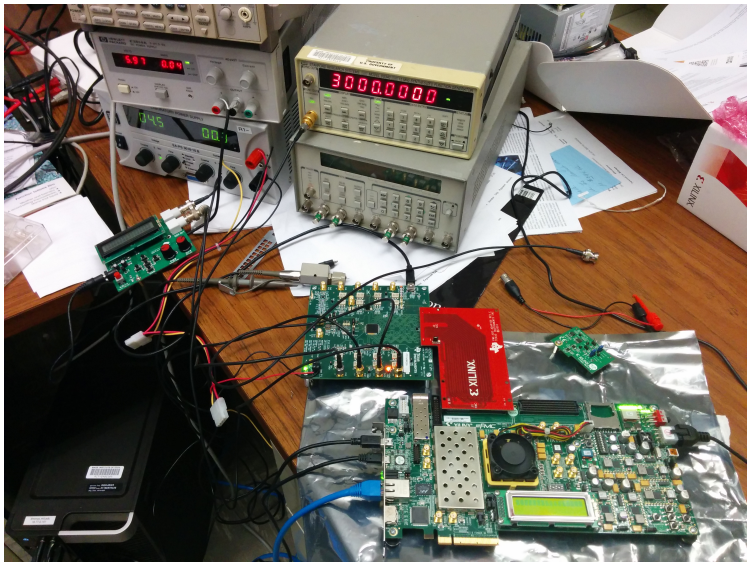
Normal electronics



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

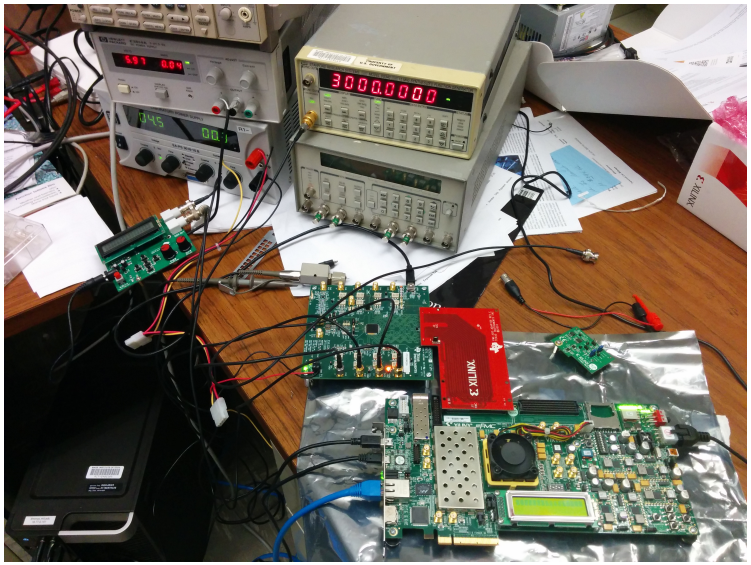
Milestones

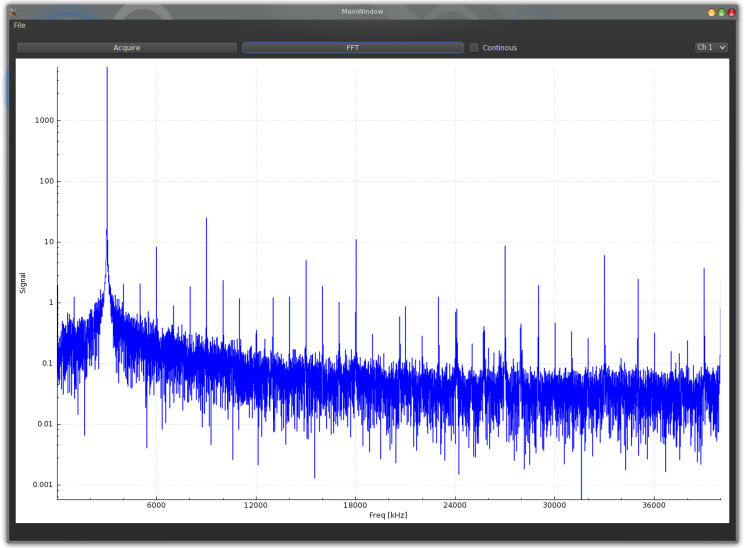
- Setup
- Ethernet send/receive



Milestones

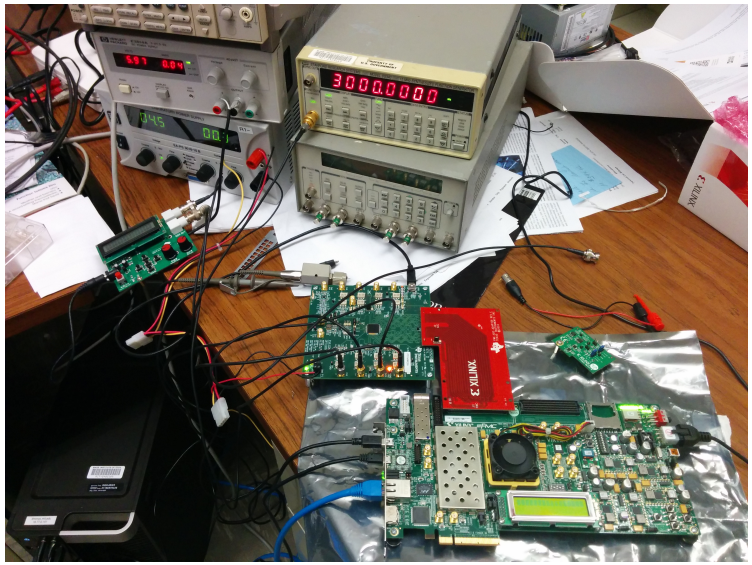
- Setup
- Ethernet send/receive
- Readout of ADC:
  - Full data of 1 ch.
  - 8 ch. with zero suppression

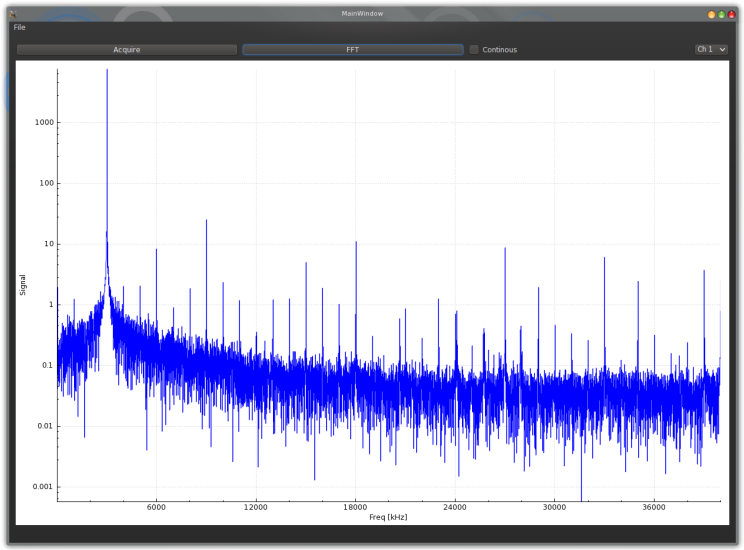




Milestones

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





A typical experiment....

... works like a red light camera trap:

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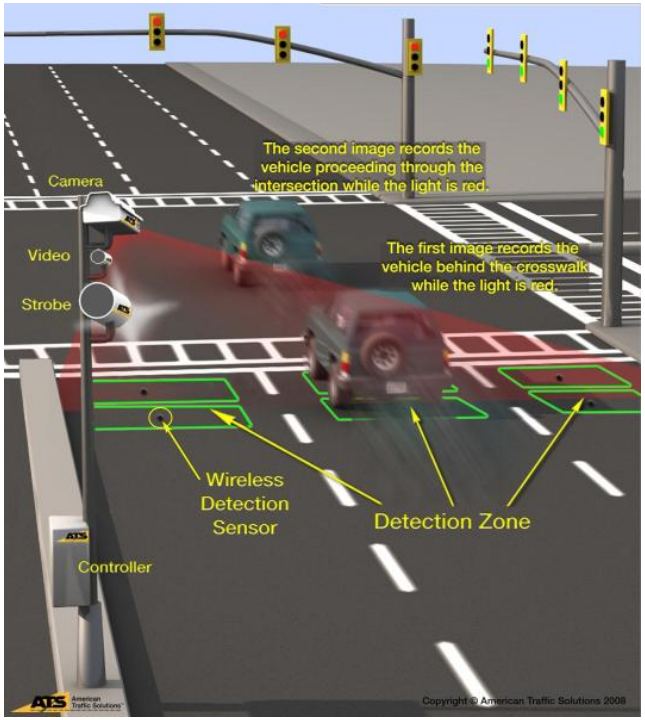


- Trigger: Maybe something interesting happened.
  - Something went over the line when the light was red.

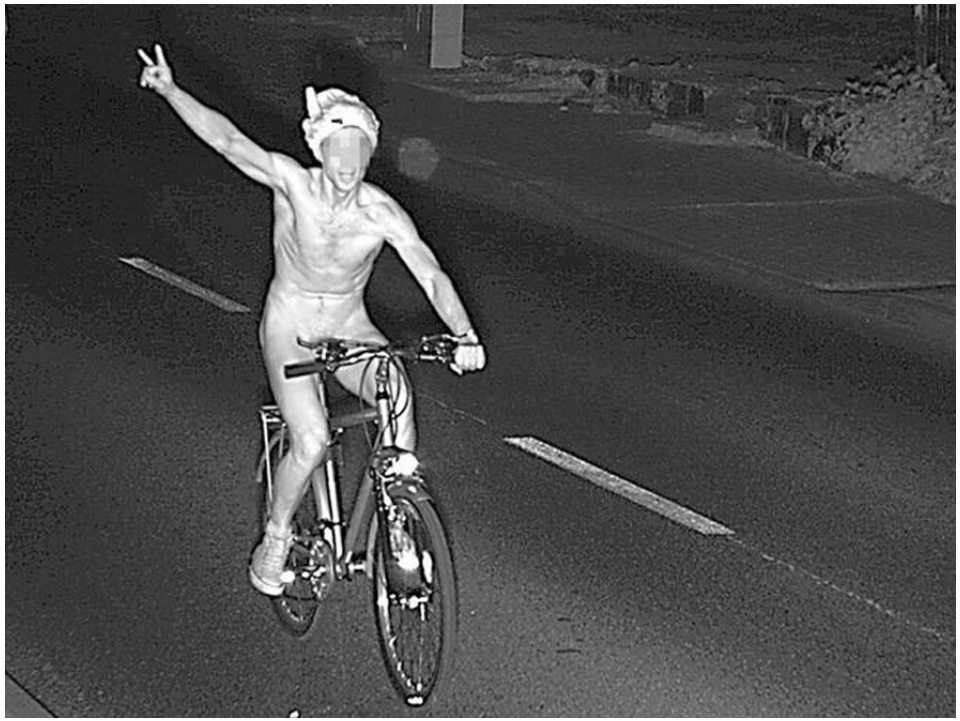
A typical experiment....

... works like a red light camera trap:

- Data readout: We make a snapshot of everything.
  - But we might miss a second car because the camera isn't ready again.

A typical experiment....

... works like a red light camera trap:



- Analysis: Sort out the (few) bad cases. Send tickets.
  - Ambulances and fire trucks

Looking for the black swan

EIC will have high luminosity:

- High rates for common events
- Detect rare events

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- Cannot save everything
  $\Longrightarrow$(proto) analyse data on the fly and save:
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Fast readout system

- continuous, trigger-less, high-rate capable
- scaling from small to large channel counts, data rates
- (close to) deadtime free
- solve *transposition problem*

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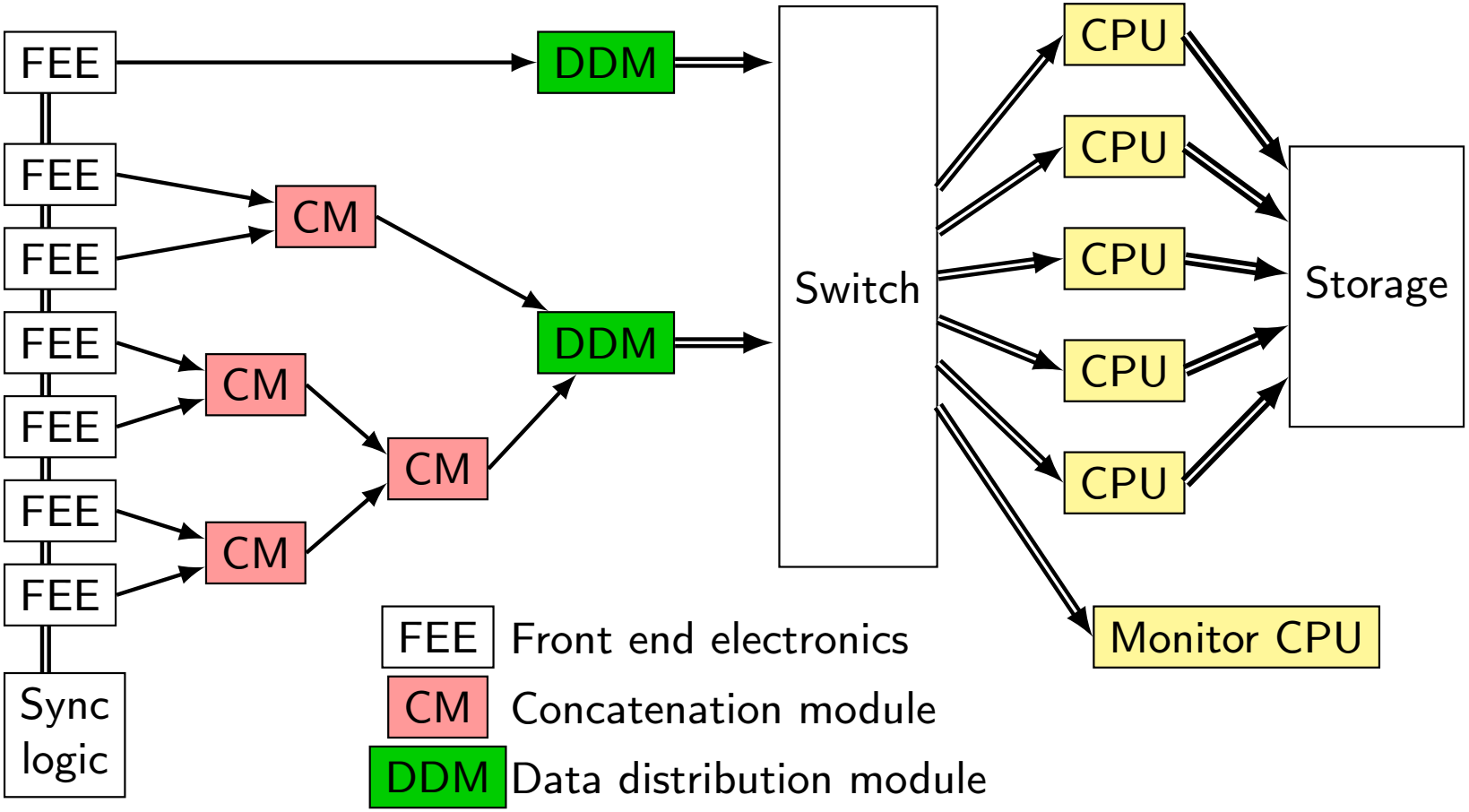
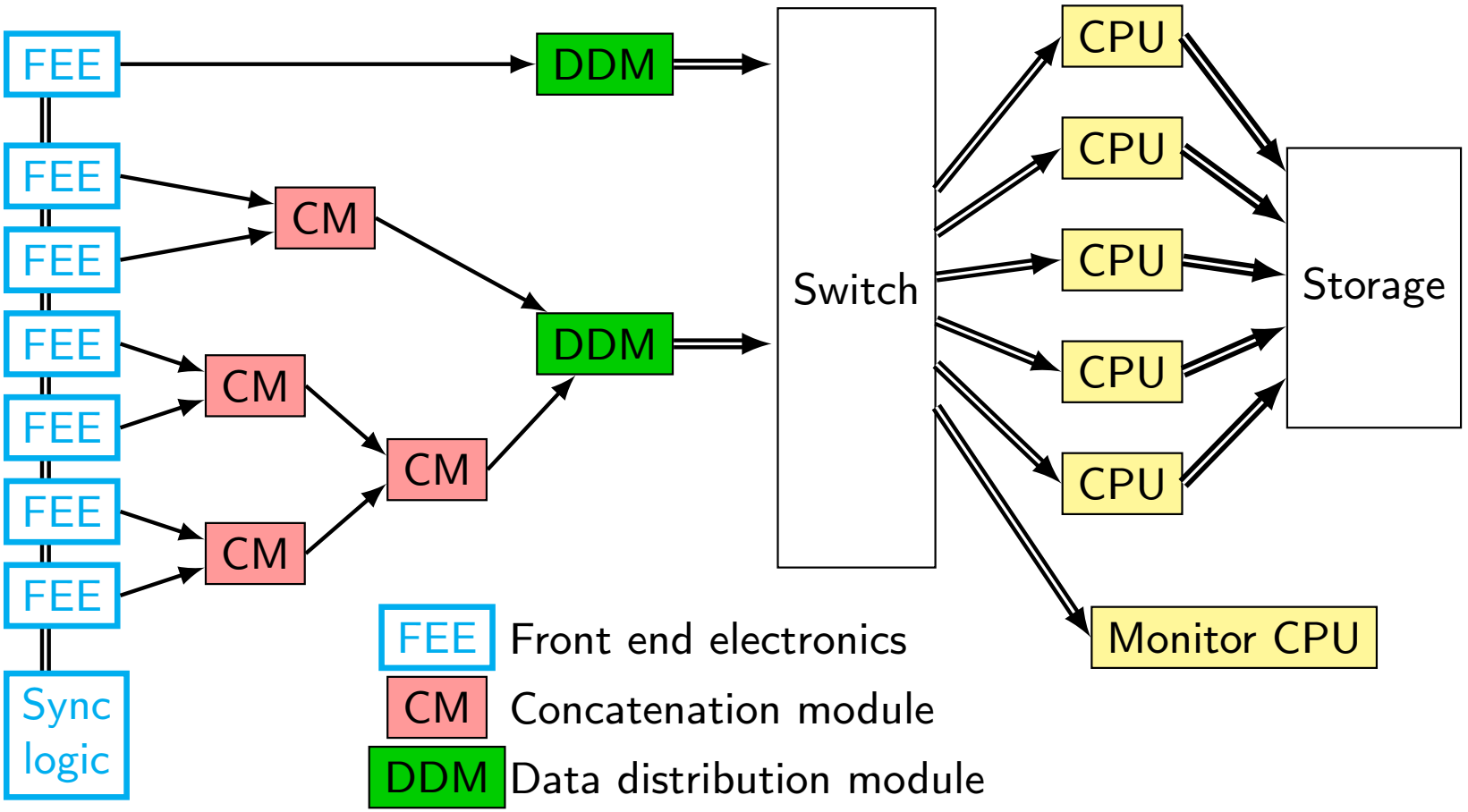
Why not distribute in DAQ itself?

Overview

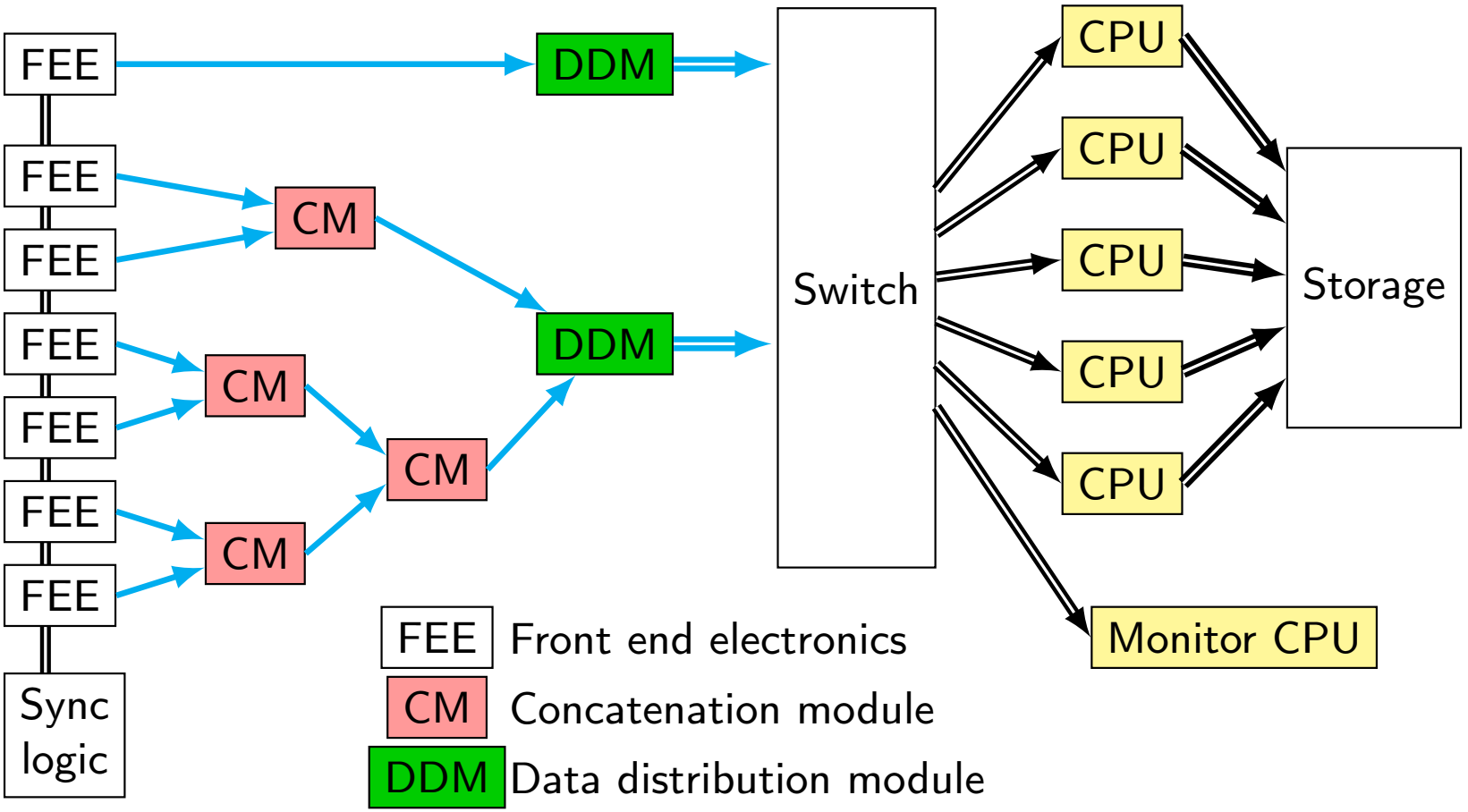

FEE
FEE
FEE
FEE
FEE
FEE
FEE
Sync logic
CM
CM
CM
CM
DDM
DDM
Switch
CPU
CPU
CPU
CPU
CPU
Storage
Monitor CPU
FEE Front end electronics
CM Concatenation module
DDM Data distribution module

Overview



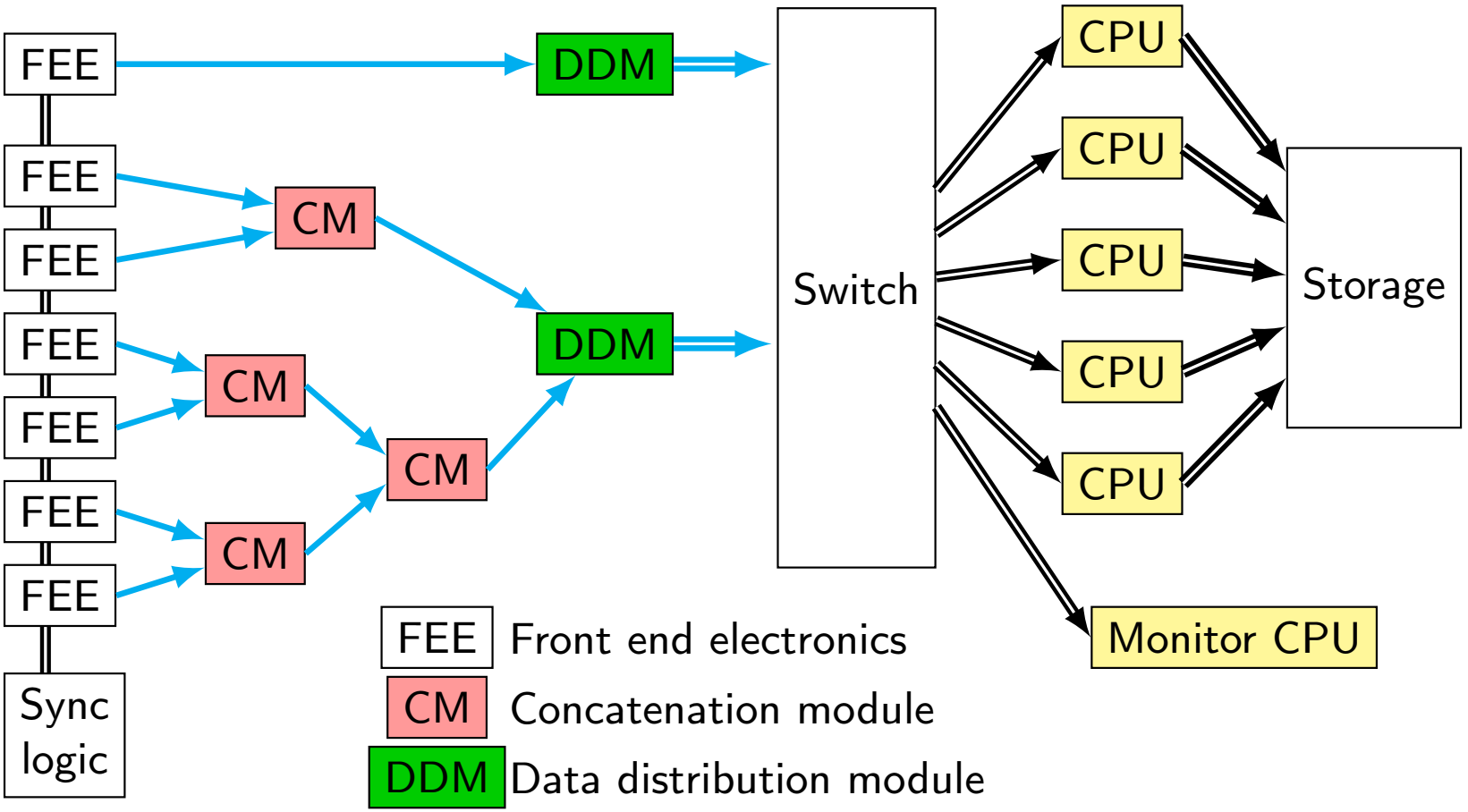
- Only front end electronics is detector specific

Overview



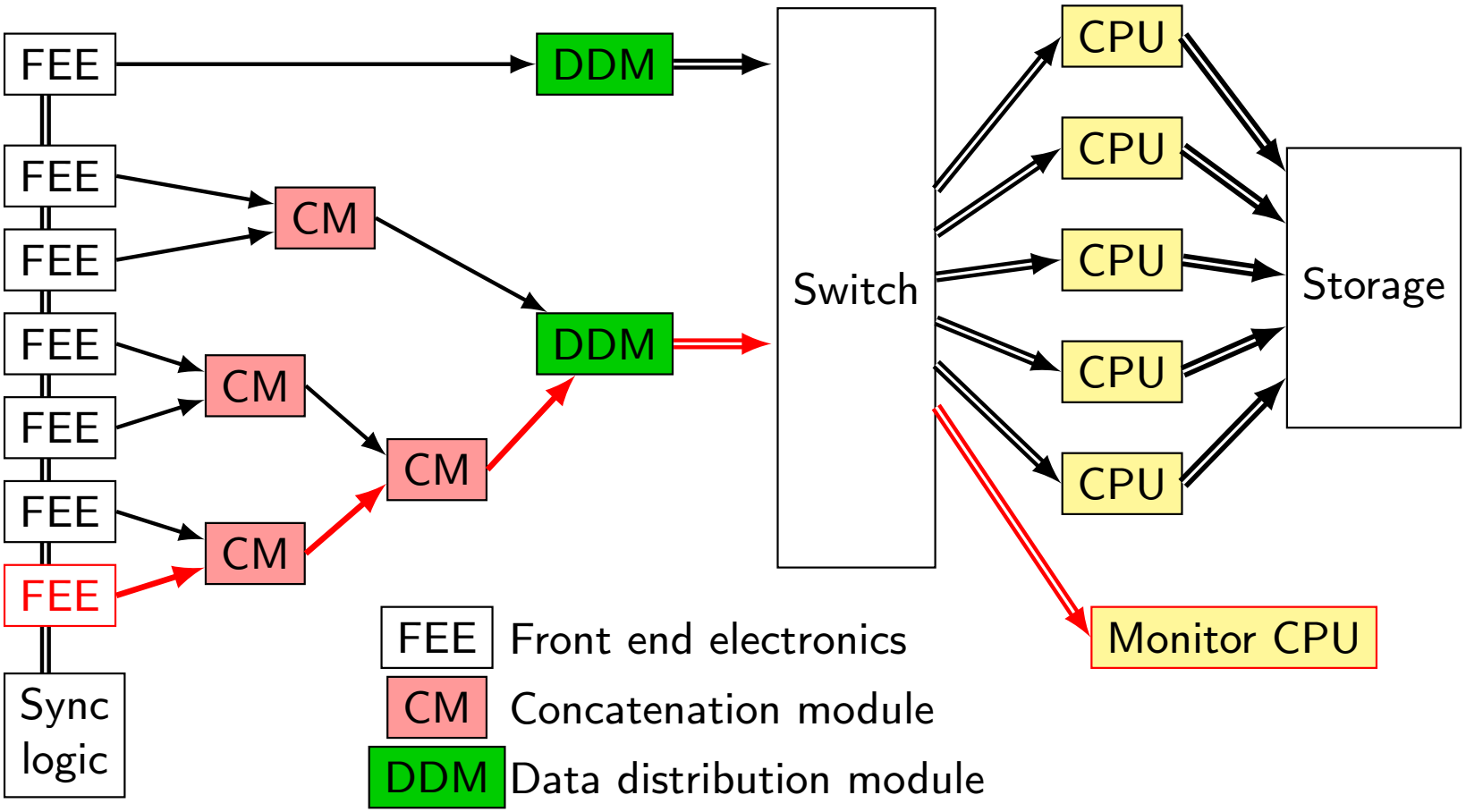
- Only front end electronics is detector specific
- Protocol is agnostic!

Overview



- Protocol must:
  - have low overhead

Overview



- Protocol must:
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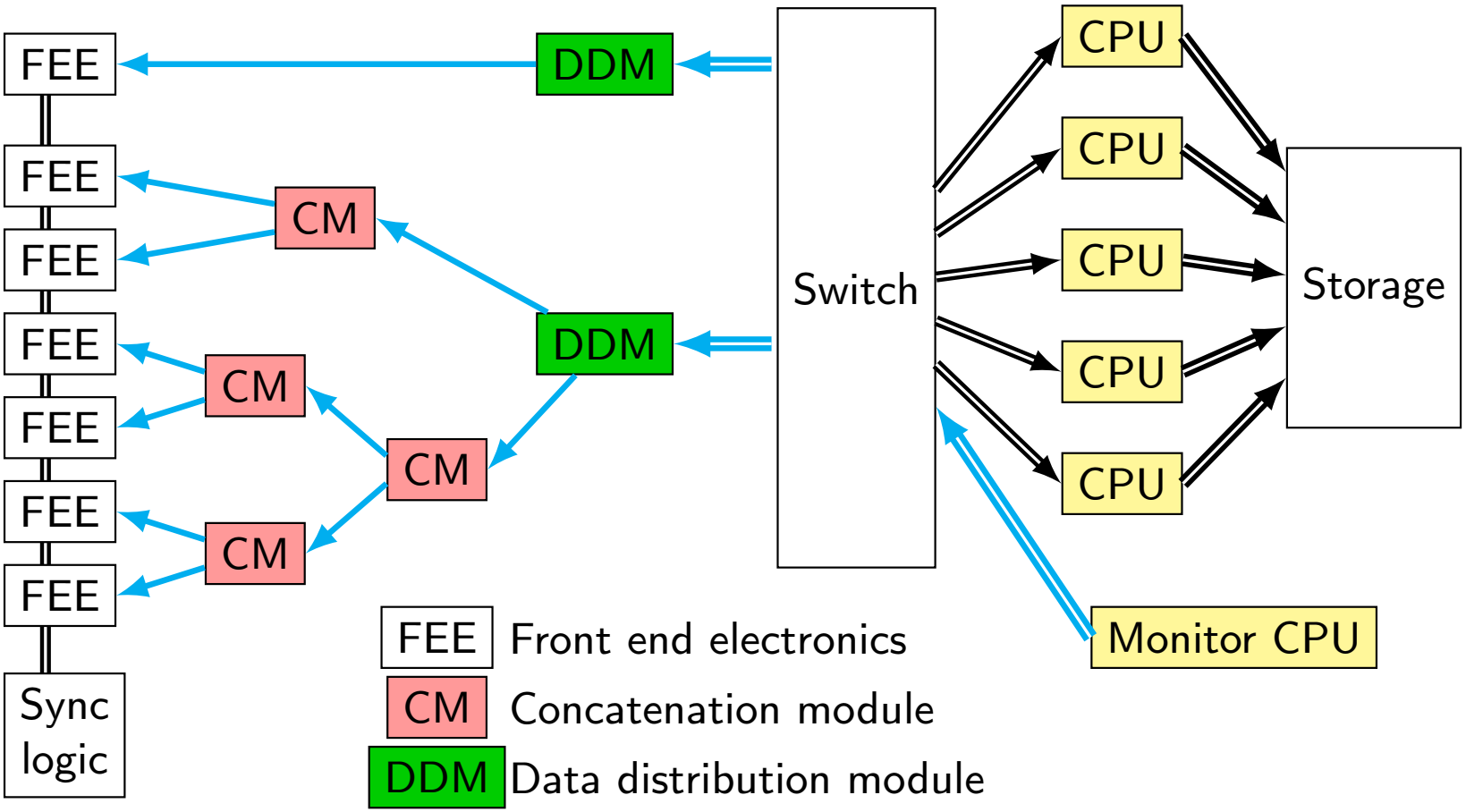
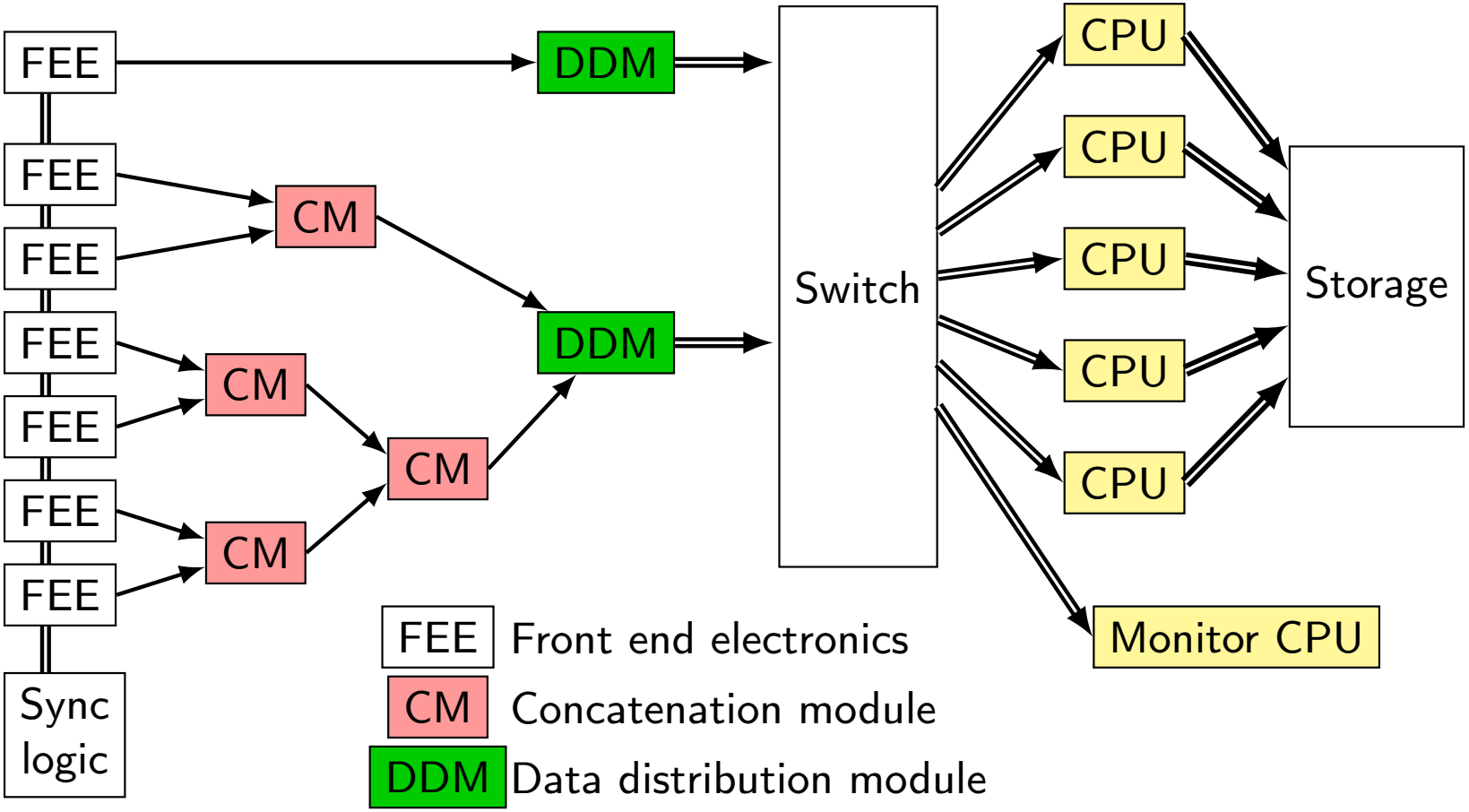
  - allow for out-of-band data (calibration, ...)

Overview



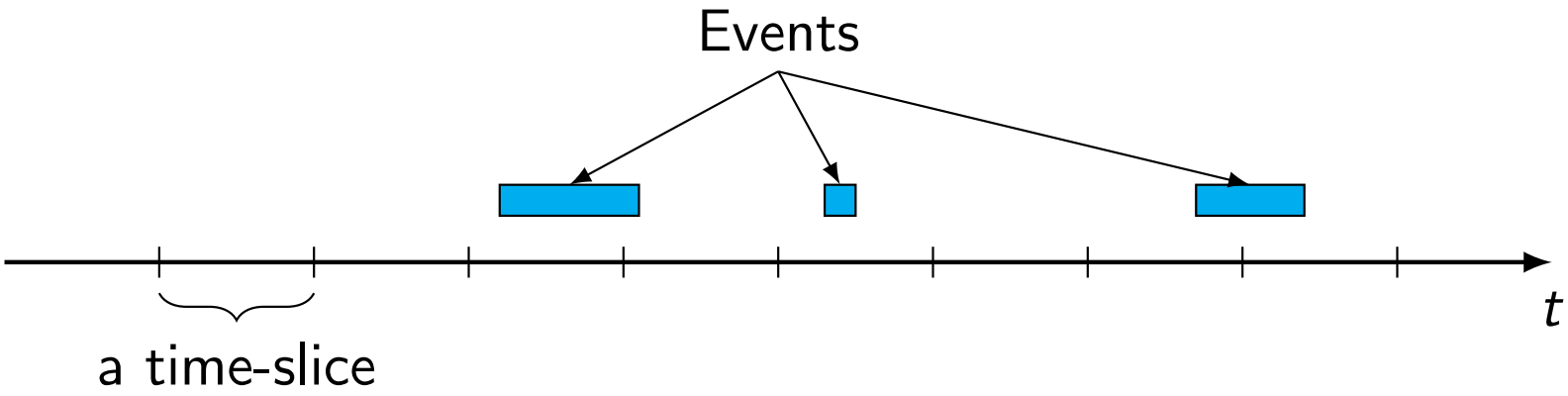
- Protocol must:
  - have low overhead
  - allow for out-of-band data (calibration, ...)
  - have a back channel (setup, calibration, ...)

Overview



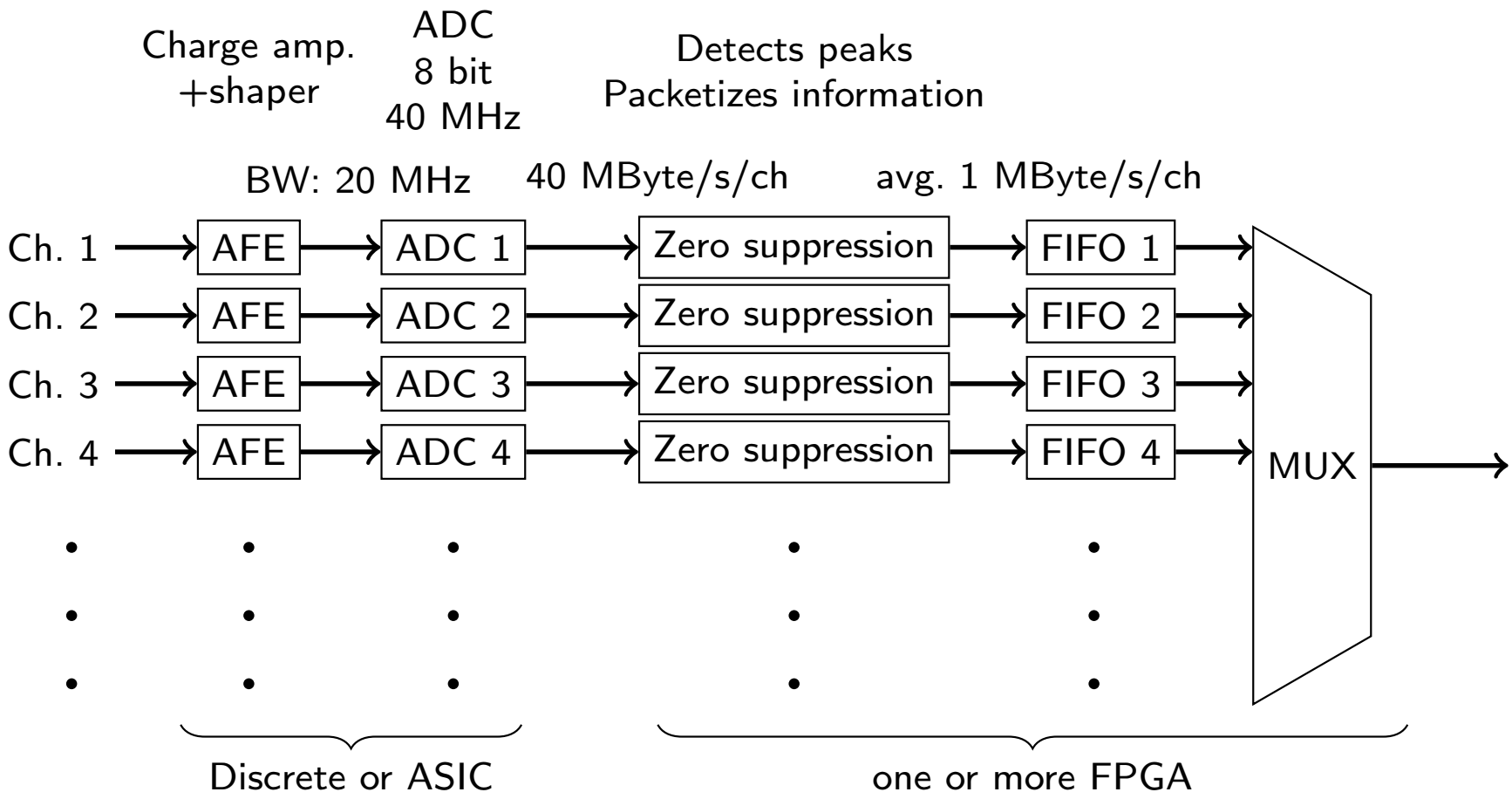
Need external input for further protocol requirements
$\Longrightarrow$Collaborate with detector groups, iterate design.

Time-slice



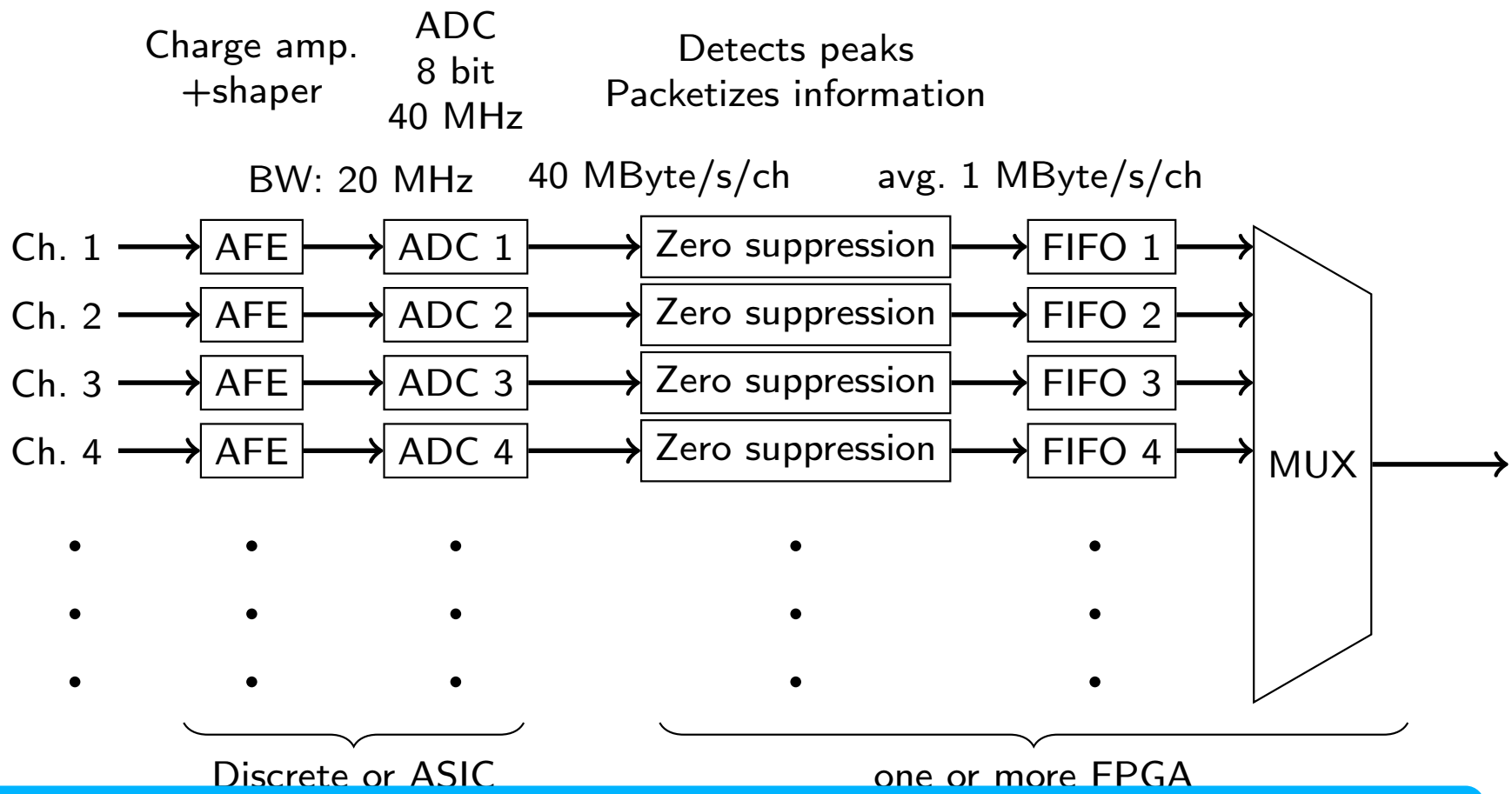
- A constant clock defines time-slices.
- Period is slightly larger than maximal event duration in detector.
- Each event can overlap two time-slices at most.

Front end electronics



- Highly detector dependent$\Longrightarrow$mock up with data generator modules, build baseline design (collaboration!)
- Can be more complex, e.g. CPU based

Front end electronics



Detector design $\Longleftrightarrow$ readout design

- No trigger detector needed
- Readout must handle detector specifics