# ATLAS muon detector upgrade TDAQ and Electronics R&D ideas

UMassAmherst

**Thiago Costa de Paiva**

**US Higgs Factory Planning Meeting**

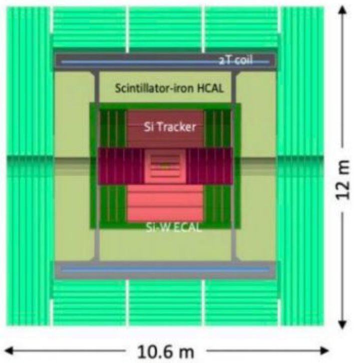
December 19th, 2024

# Detector Concepts for FCC-ee

Link with more details

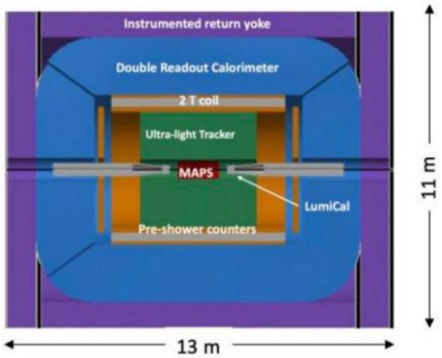
CDR

## CLD



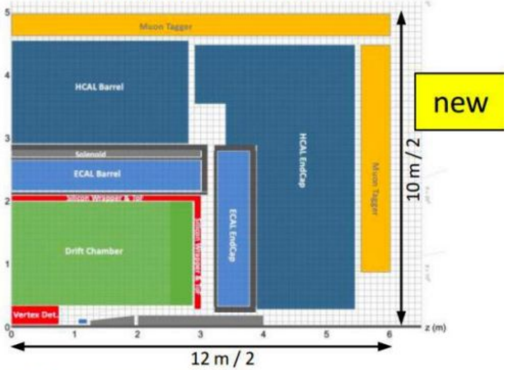

- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker;
- CALICE-like calorimetry;
- Large coil, muon system **RPC**
- Engineering still needed for operation with continuous beam (no power pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector optimizations
  - $\sigma_p/p$, $\sigma_E/E$
  - PID ($\mathcal{O}$(10 ps) timing and/or RICH)?
  - …

## IDEA




- A bit less established design
  - But still ~15y history
- Si vtx detector; ultra light drift chamber w powerful PID; compact, light coil;
- Monolithic dual readout calorimeter;
  - Possibly augmented by crystal ECAL
- Muon system **μ-RWELL**
- Very active community
  - Prototype designs, test beam campaigns, …

## ALLEGRO
## Noble Liquid ECAL based

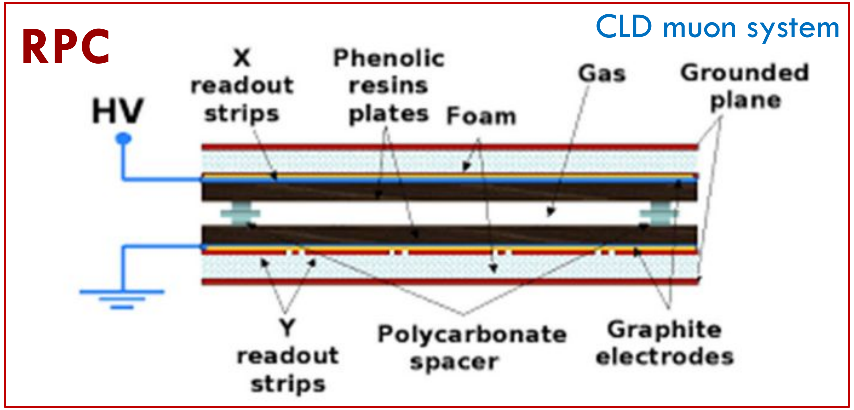



- A design in its infancy
- Si vtx det., ultra light drift chamber (or Si)
- High granularity Noble Liquid ECAL as core
  - Pb/W+LAr (or denser W+LKr)
- CALICE-like or TileCal-like HCAL;
- Coil inside same cryostat as LAr, outside ECAL
- Muon system. **Open technology choice**
- Very active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies

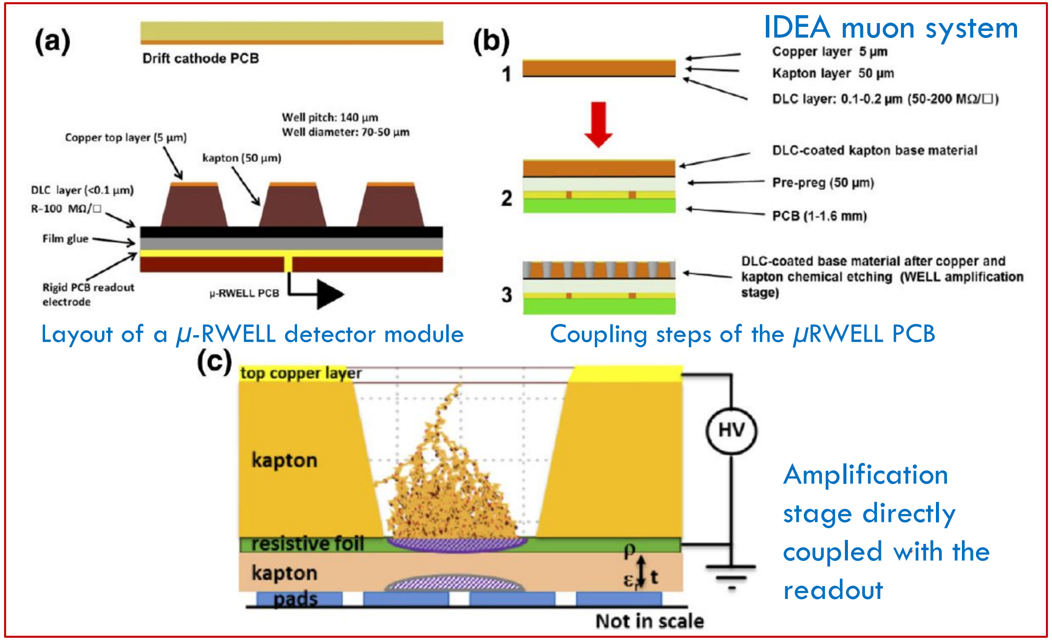
FCC-ee CDR: https://link.springer.com/article/10.1140/epjst/e2019-900045-4

# Proposed Detectors

## μ-RWELL




- Large RPC detectors are used in LHC experiments
  - Fast timing (a few ns) trigger detector
  - Provide 2nd - coordinator with precision (a few cm)
  - Limited rate capability (at an order of ~102 Hz/cm2)
- Challenges
  - Use Eco-friendly gas
  - Need good angular resolution to match ID muon tracks
  - Limited spatial resolution for detection of LLP
  - Reliable operations, efficiency, rate capabilities

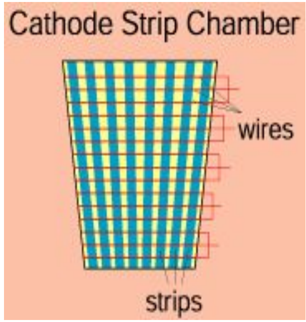



- Challenges
  - Not yet used in experiments; Needs intensive R&D
  - Large number of channels – 5 Million for the IDEA proposal
  - Limited spatial resolution -- < 400 mm for the IDEA proposal

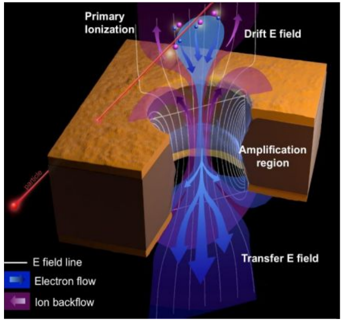
# US Muon Expertise - CMS



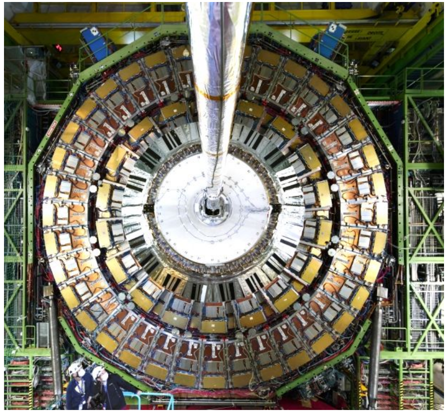
CMS precision endcap muon detectors: **Cathode Strip** & **Triple-GEM** Chambers




GEM

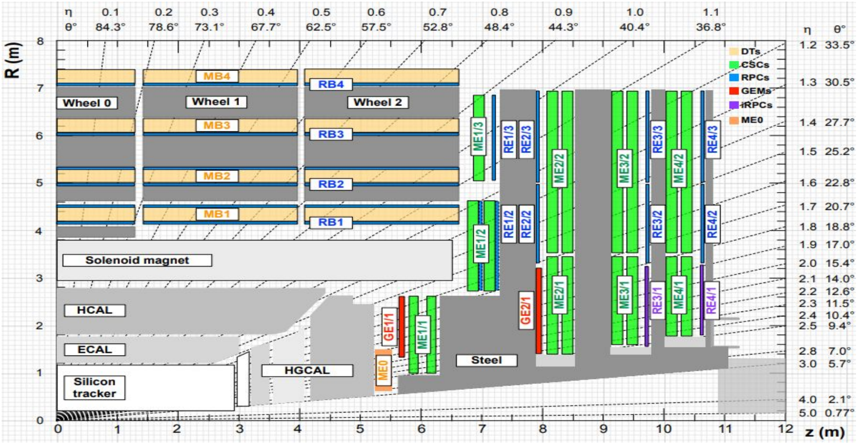



GE2/1 GEM Installation



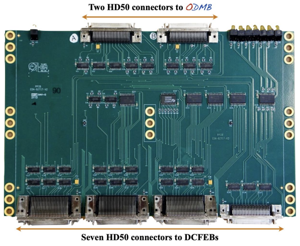
Endcap CSC disk Built by US

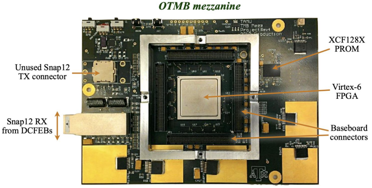
| Muon subsystem | Cathode strip chamber (CSC) | Gas electron multiplier (GEM) |
|---|---|---|
| $\|\eta\|$ range | 0.9–2.4 | 1.55–2.18 |
| Number of chambers | 540 | 72 |
| Number of layers/chamber | 6 | 2 |
| Surface area of all layers | 7000 $m^2$ | 60 $m^2$ |
| Number of channels | 266 112 (strips) 210 816 (wire groups) | 442 368 |
| Spatial resolution | 50–140 $\mu$m | 100 $\mu$m |
| Time resolution | 3 ns | <10 ns |

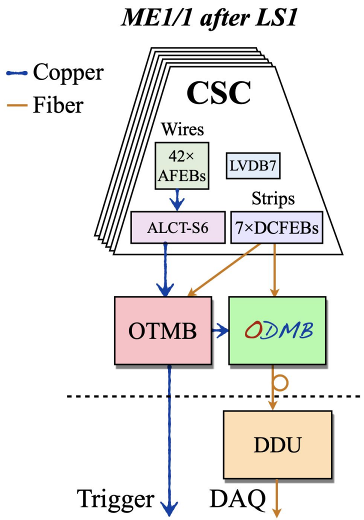


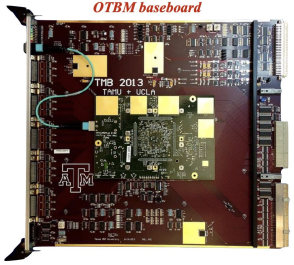
# US Muon Electronics - CMS

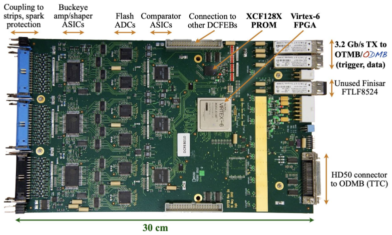
## CSC

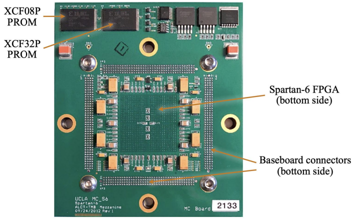


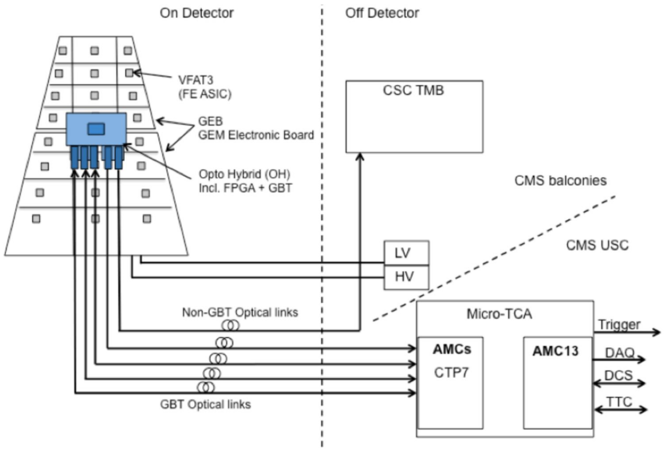



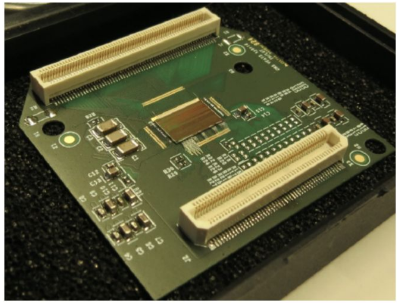




## GEM



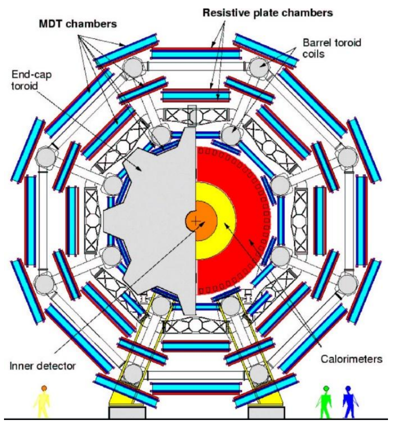



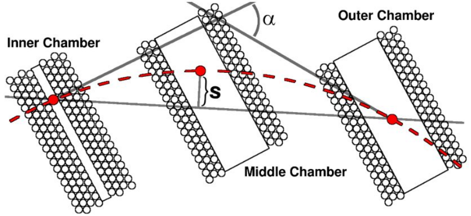
# US Muon Expertise - ATLAS



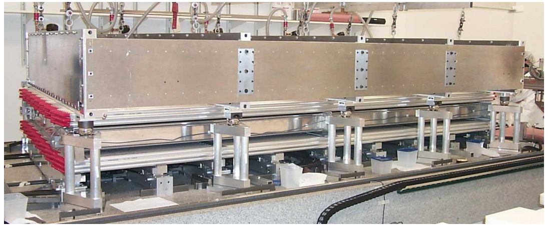
ATLAS precision muon detector: Monitored Drift Tube (MDT) chambers

Drift gas: Ar:CO2 (93:7), p=3 bar,  max drift time 750 ns

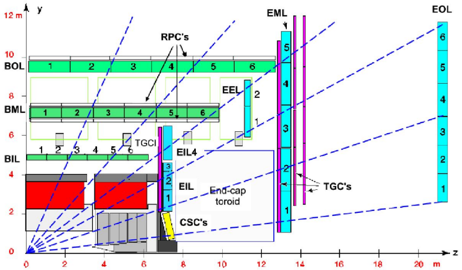


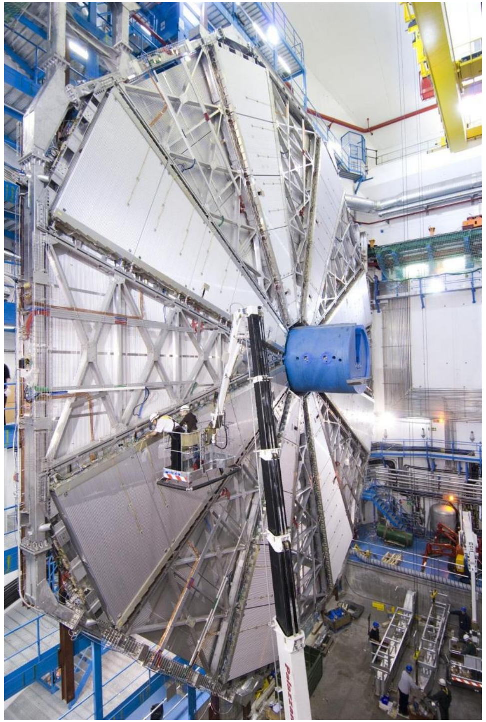

Muon MDT chamber, tube d=3 cm, 80μm/wire



MDT chamber construction at UM



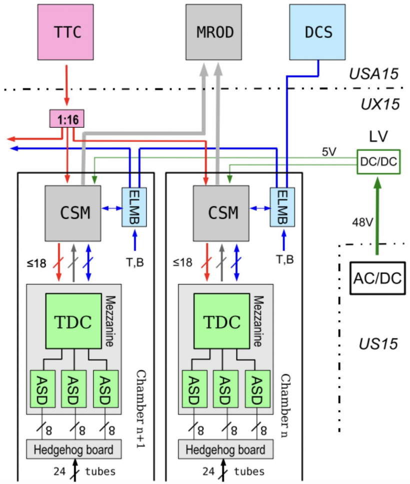

Magnet: Solenoid (inner) + Toroid (outer)

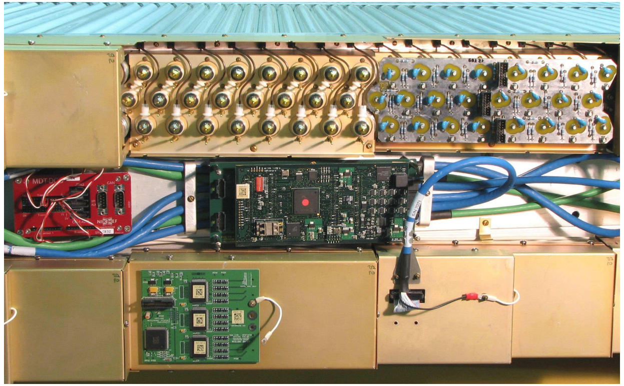


Big Wheel (endcap) built in the US, installation in ATLAS

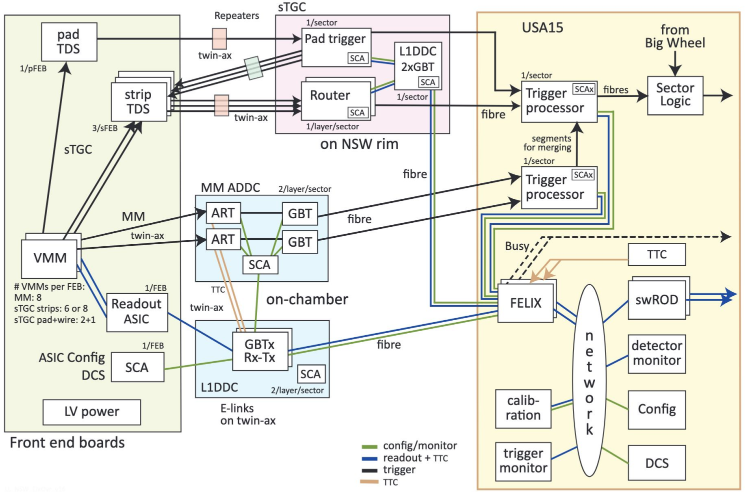
# US Muon Electronics - ATLAS

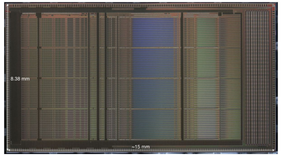
## MDTs

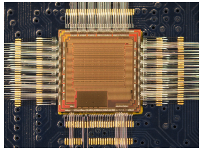


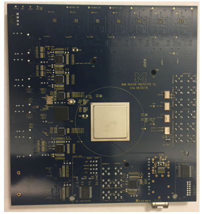



## MM and sTGC for the NSW



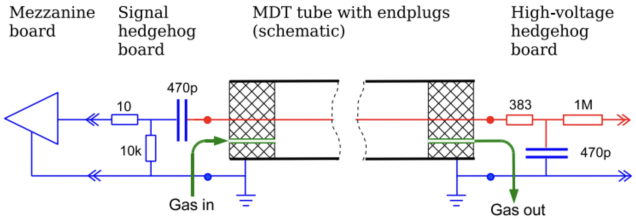


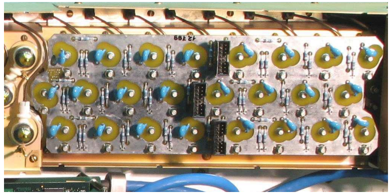


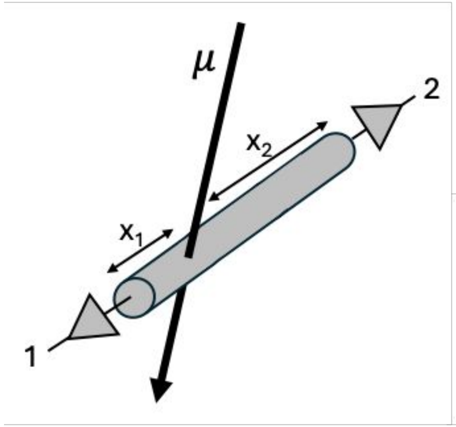
# Drift Tube Electronics

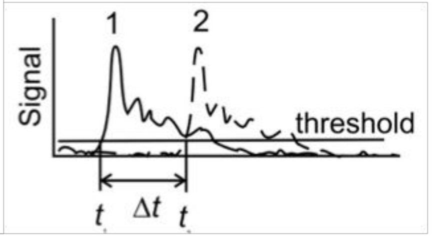
- Proposal for muon detector including drift tubes for tracking & trigger
  - Simple, robust, and inexpensive suitable for large scale construction
  - Capable of achieving < 200 mm single wire resolution for all muon incident angles
- Goals for electronics – requires R&D
  - Capable of 3D tracking achieving < 200 mm single wire resolution and few cm in 2nd coord (along tube)
  - Capable of trigger: determining $t_0$ with few ns time resolution, determine BCID
- Detector R&D to accompanied by additional electronics R&D including
  - Choice of chamber drift gas
  - Alternative geometries such as a squared drift tube detector

# Drift Tube Electronics R&D



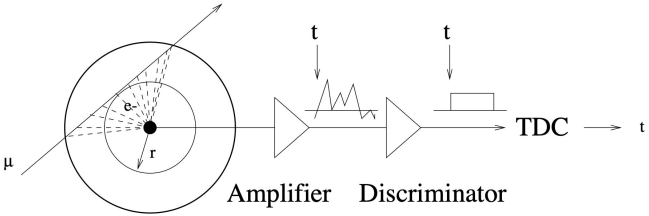



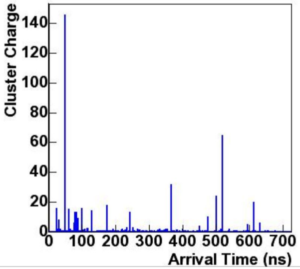


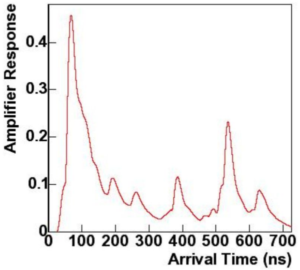



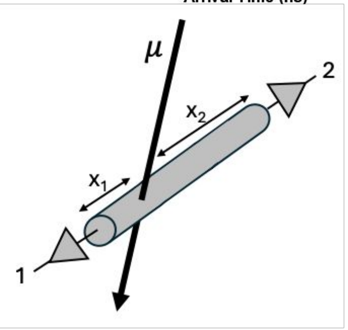

- Study extensions of current drift tubes
  - 3D tracking, including the non-precision 2nd coordinate (along the tube direction)
  - Trigger timing requirements
- Investigate how to read out signal from both ends (currently only one is used) and extract position from time difference
  - Study signals including in simulation
  - Design and build prototype new electronics hedgehog card

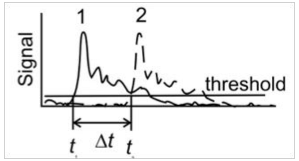
# Drift Tube Electronics R&D



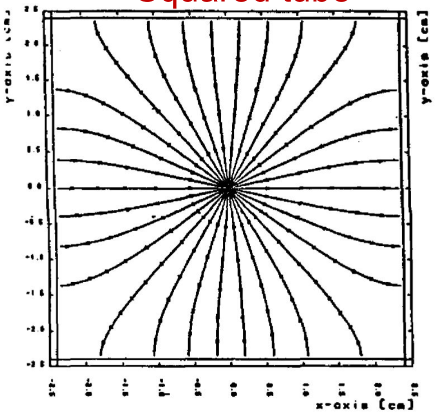




- Investigate new low-power front-end electronics with precise timing resolution
  - Interesting to explore low-power digital TDC designs with sub-200ps measurement resolution
  - Improved position and timing resolution for tracking and triggering
    - Propagation in tube about 0.78 x speed of light
    - Current MDT TDC resolution 0.78ns corresponds to about 18cm precision
    - **Sub-200ps is key to achieving few cm precision**
- Synergistic with broader interest in electronics for gaseous detectors
  - DRD1 and DRD7

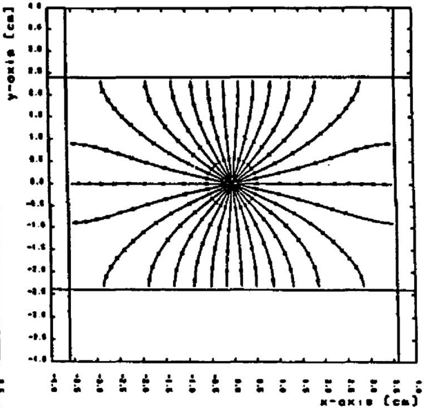
# Electronics for Square Drift Tubes

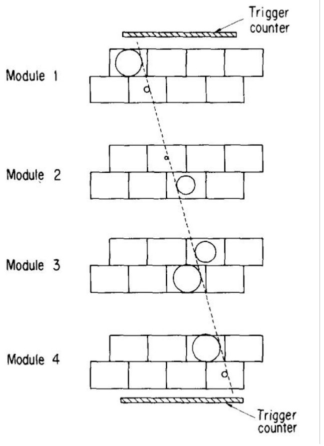
- Study signals from alternative geometries (e.g. square tube) and investigate changes in the electronics requirements using simulations
- Also study signals from alternative drift gases

Squared tube



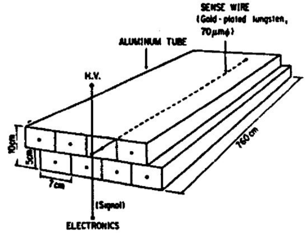

rectangular tube




Y. Asano et al NIM A259 (1987) 430

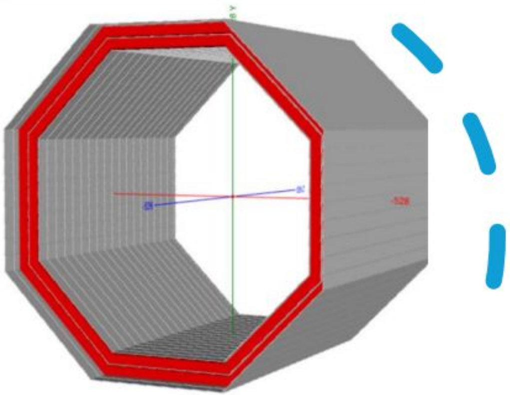
Cosmic ray tests of 7.6 m drift-tube counters and the readout electronics system of the VENUS muon detector

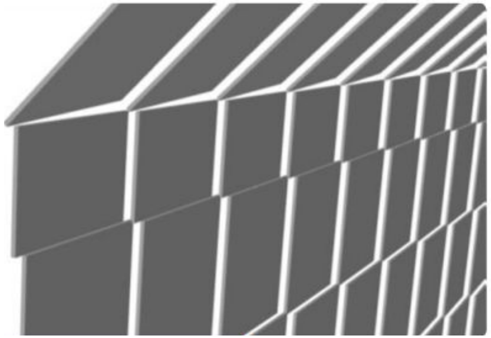



# µ-RWELL Electronics R&D

- A modern micro-pattern gas detector (MPGD) with single amplification stage
  - Currently proposed by IDEA experiment for muon system
- Several R&D topics in the US
  - Chamber production capabilities in the US
  - Studies of gas mixtures
- Electronics essential for success of R&D
  - Interesting to explore needs and interest in US
  - Overlaps with past experience

IDEA Muon system

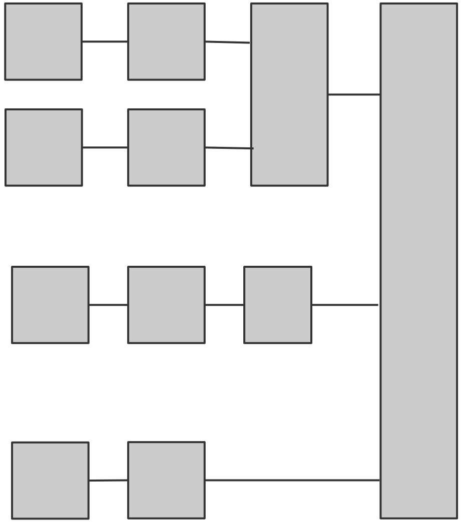




50cm x 50cm µRWELL modules

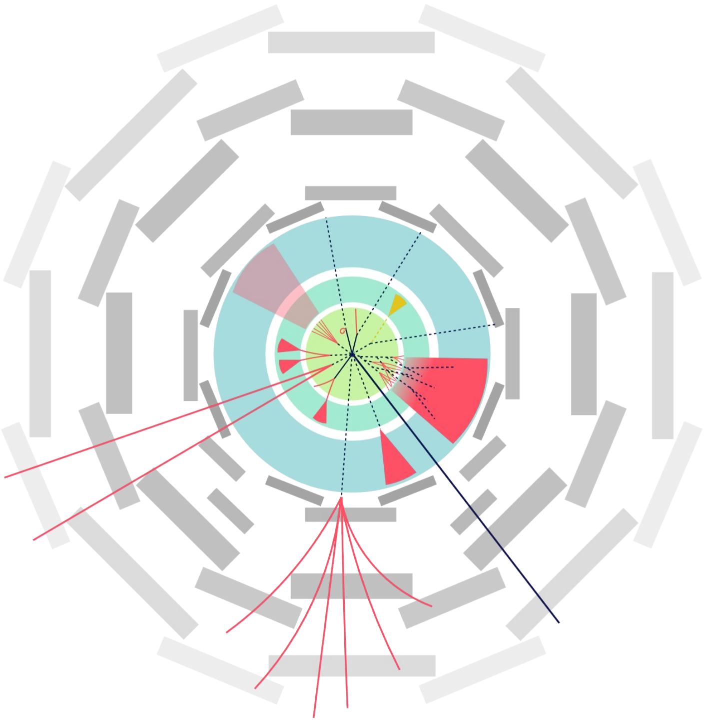
# Connection to TDAQ R&D

- Traditional multi-layered  triggered architecture
  - Efficient data reduction, may involve multiple subsystems, synchronized data processing, progressive filtering, centralized decision
- Self-trigger capabilities
  - multi-layer detection, trajectory reconstruction, flexible, adaptable, reduced latency, less complex infrastructure, data reduction at source
- Triggerless "streaming" mode
  - Simpler infrastructure, comprehensive data, sophisticated offline algorithms,  no hardware latency
- Other remarks
  - Real time decision, scalable, versatile, comprehensive
  - New technologies? Machine Learning, adaptive algorithms, etc



# Expanding Possible Signatures

- New detector opens up possibilities for exotic signatures which can be difficult to trigger on and reconstruction
  - Long-lived particle decays with non-pointing signatures
  - Slow moving or highly-ionizing particles with different timing
  - High muon multiplicity signals
- New electronics could help improve sensitivity, for example
  - Charge measurements in addition to time
  - Multi-thresholds to distinguish pileup
  - Flexible design



from H. Russell

# Conclusions

- Electronics are a crucial part of the design of the muon detectors to achieve goals of high resolution and fast measurements for tracking and trigger
- Focusing initial Muon Electronics R&D in a few areas
  - Simulations to characterize the signals and the electronics to accompany the detector R&D
    - Different geometries
    - Alternative drift gas choices
  - Design and prototype for dual-sided readout of drift tubes
  - Study possibilities for low-power high precision timing
  - Investigate trigger and DAQ architectures possible with front-end design
- Building up the R&D collaborations, and contribute to the detector concept design
  - Harvard, U Michigan, and UMass Amherst in the US, together with MPI
  - Discussing with other groups about joining effort U. Wisconsin