Tracker intrinsic resolution, electronics, readout

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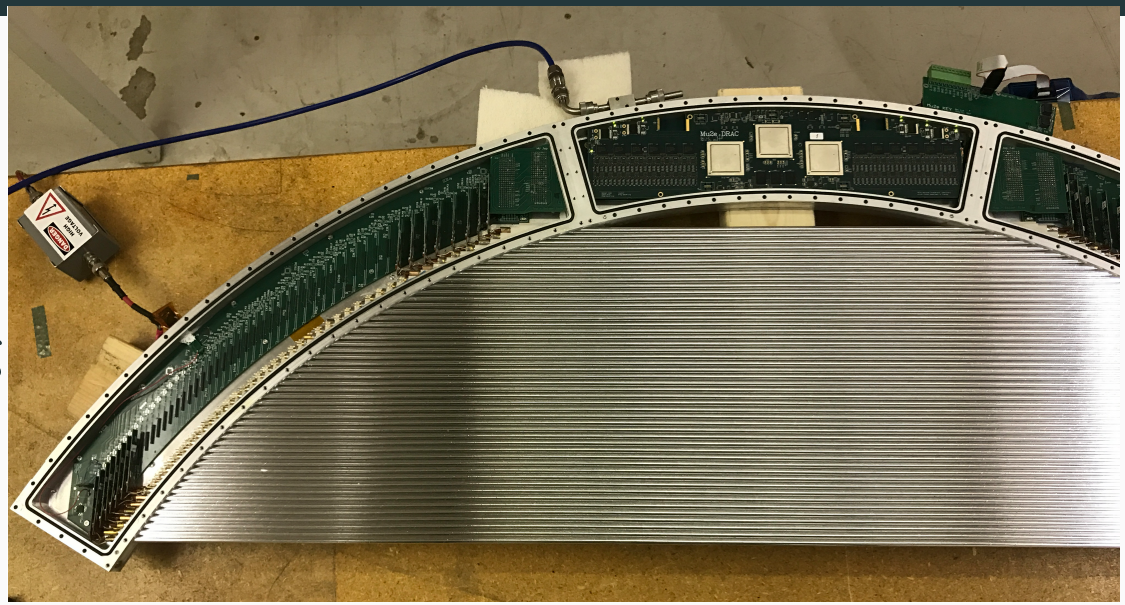
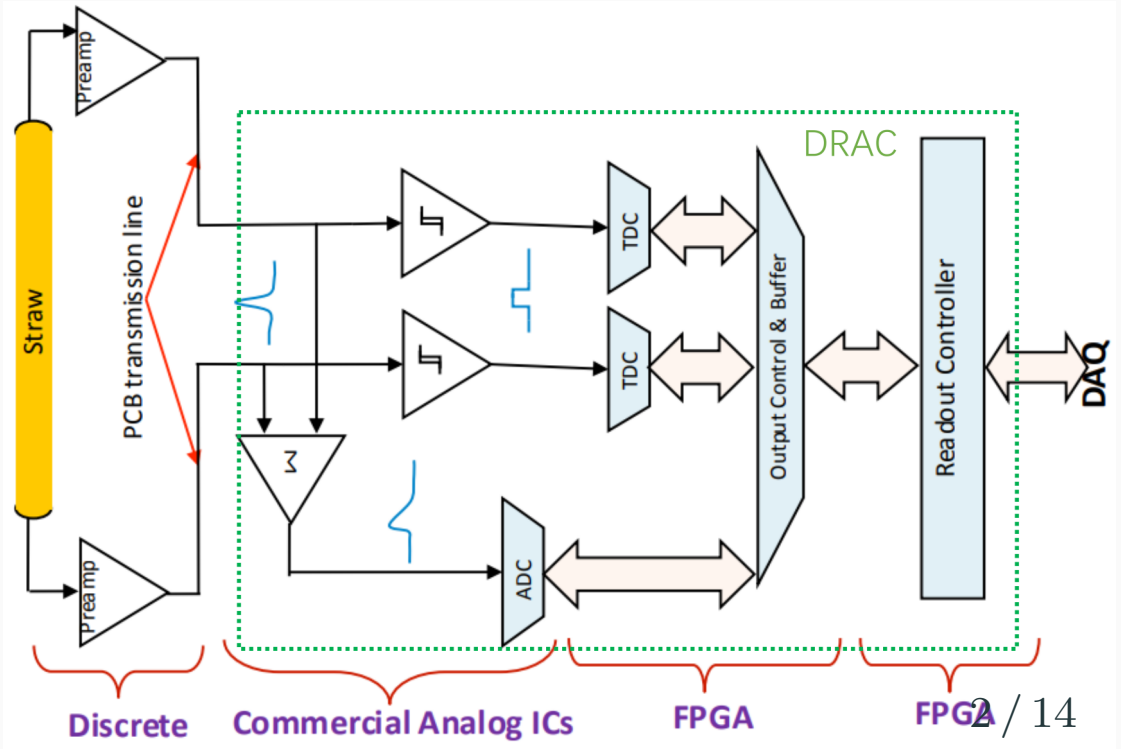
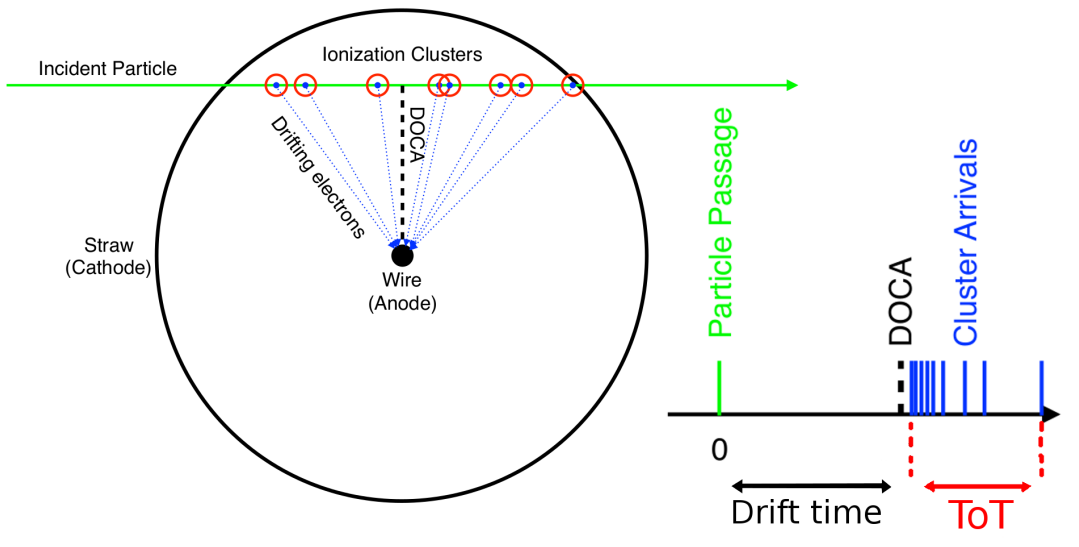
Mu2e setup

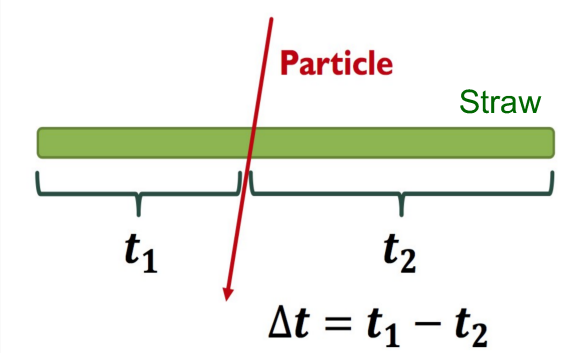
- Preamp at straw end, analog routed to central digitizer
- Comparator for applying threshold for time measurement
- 50 MHz digitizers
- 3x Microsemi PolarFire FPGAs w/ firmware TDC
- VTRx optical transciever





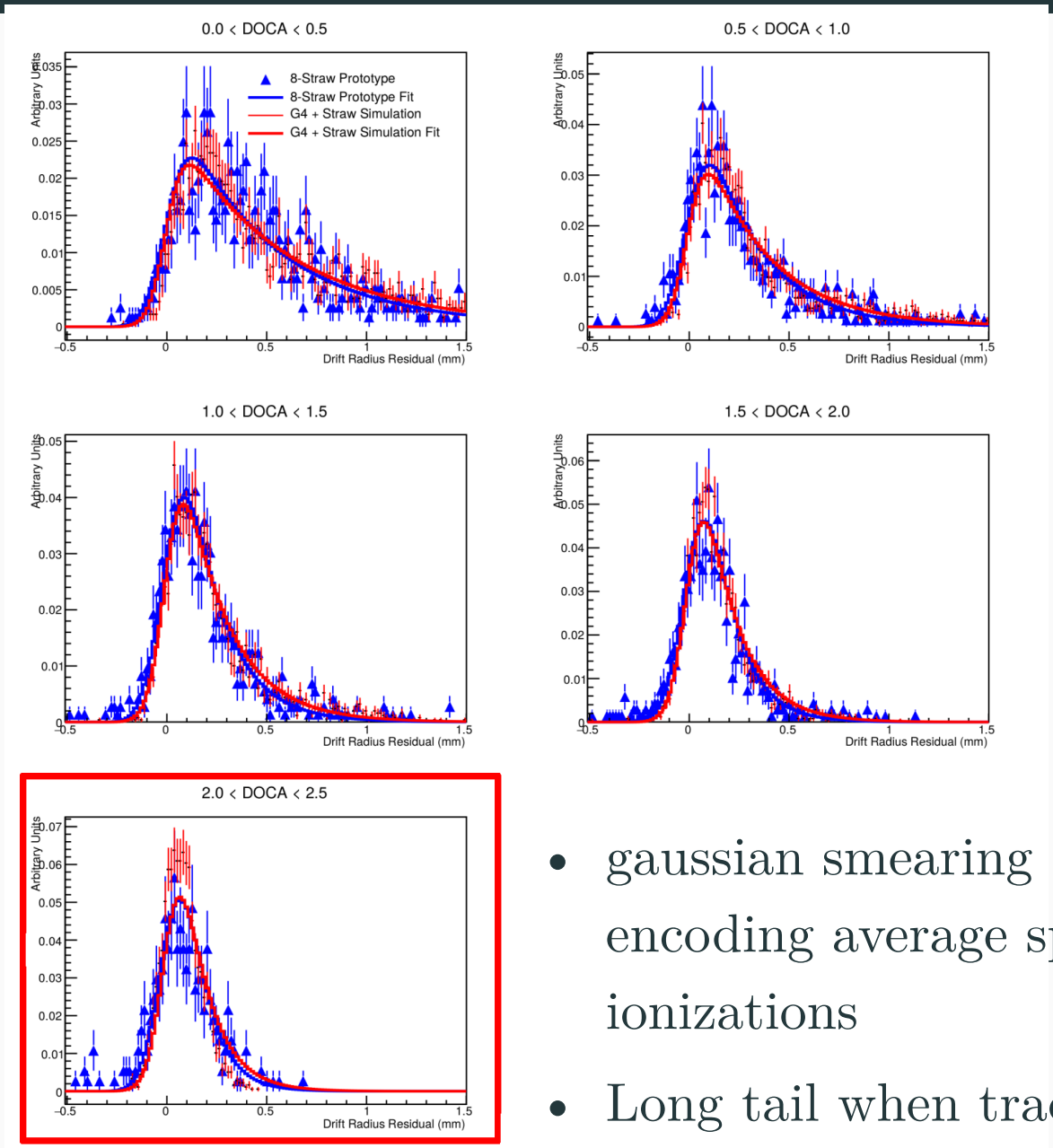
Mu2e measurements from each hit straw

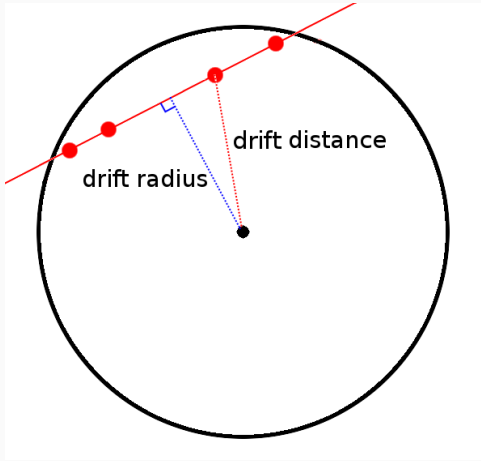




- Drift time $\sim$2.5 ns $\rightarrow$ transverse radius $\sim$150 μm
- Time division $\sim$400 ps $\rightarrow$ longitudinal position $\sim$4 cm
- Time-over-threshold to 4 ns $\rightarrow$ t_0 $\sim$7 ns
- 50 MHz digitized waveform $\rightarrow$ energy deposition $\sim$10%

Drift response in Mu2e





- gaussian smearing × exponential encoding average spacing between ionizations
- Long tail when track near wire

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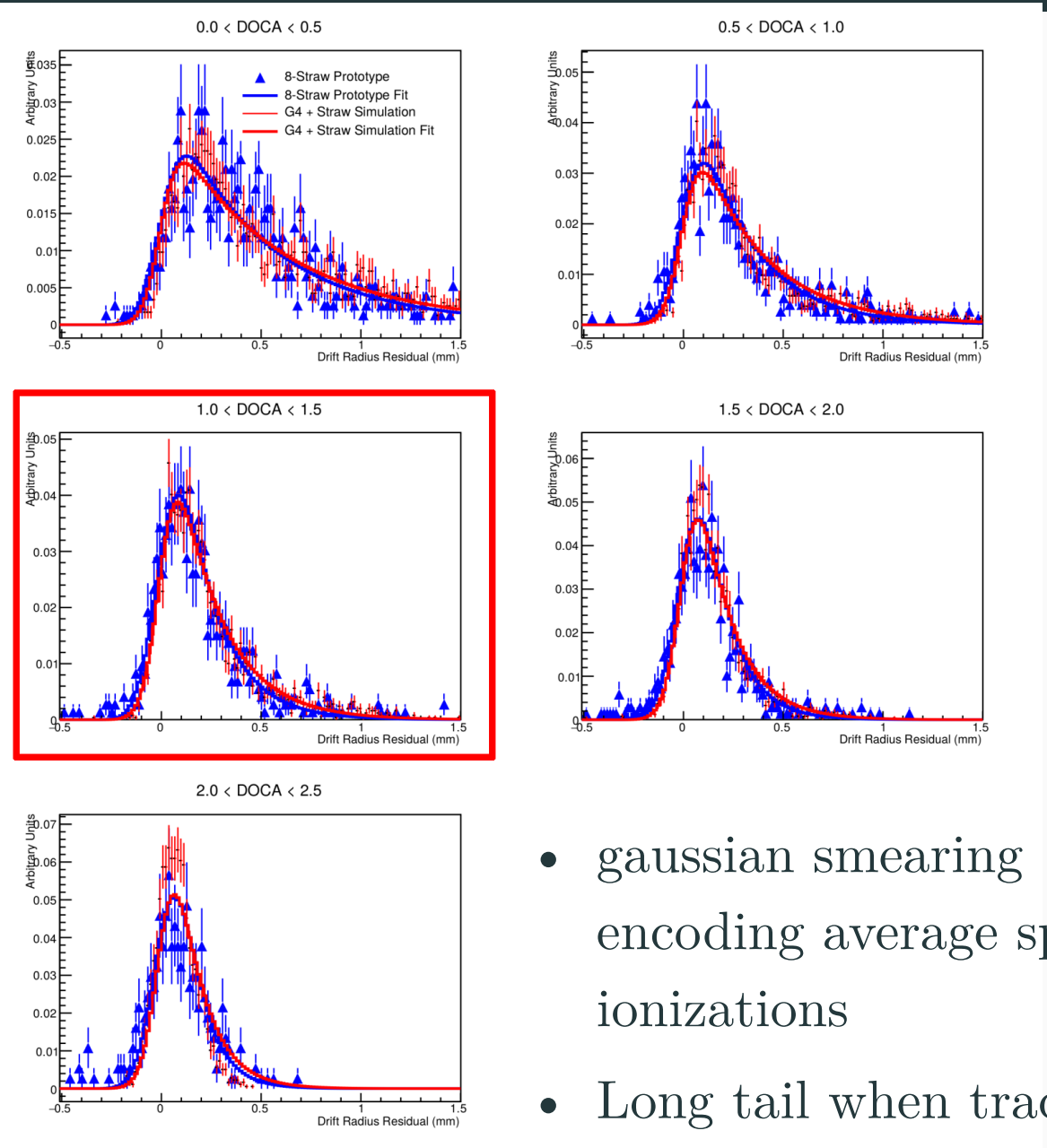

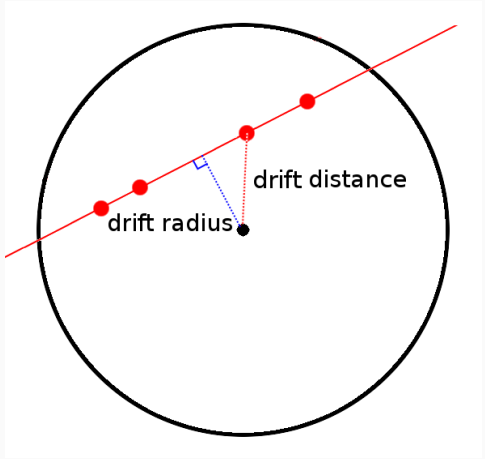

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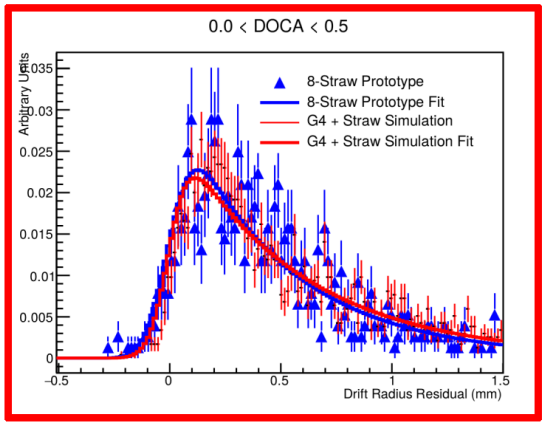

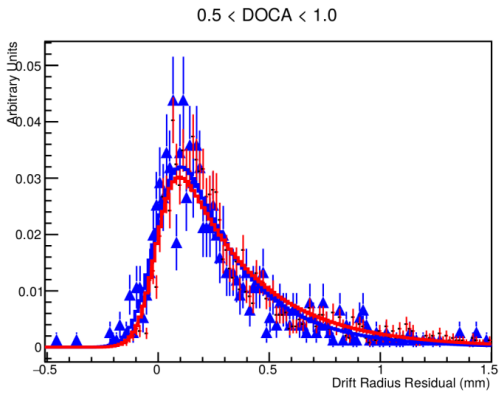

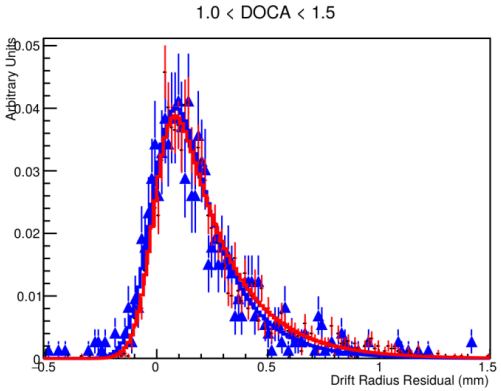

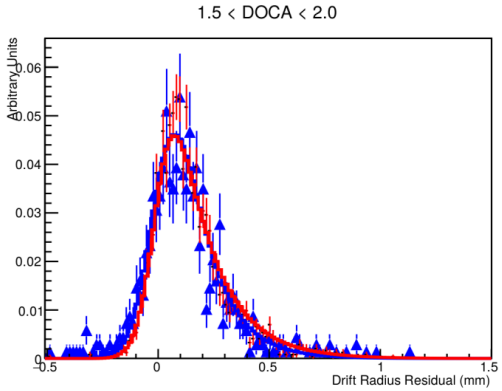

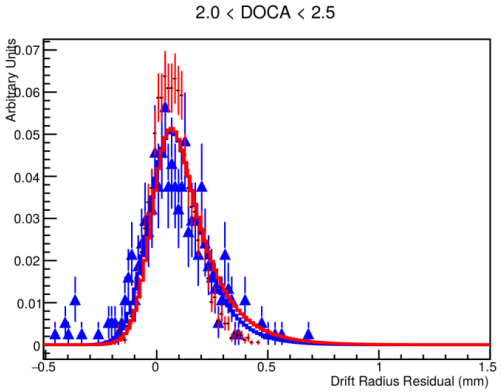

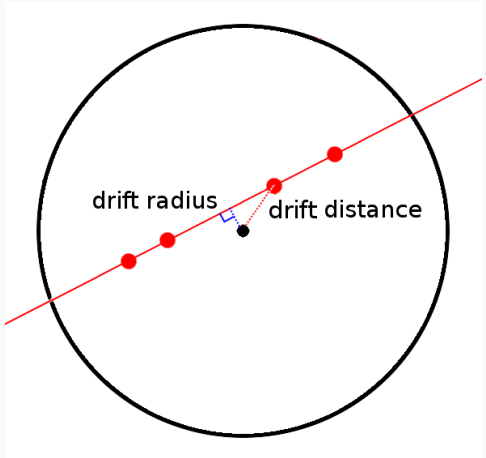

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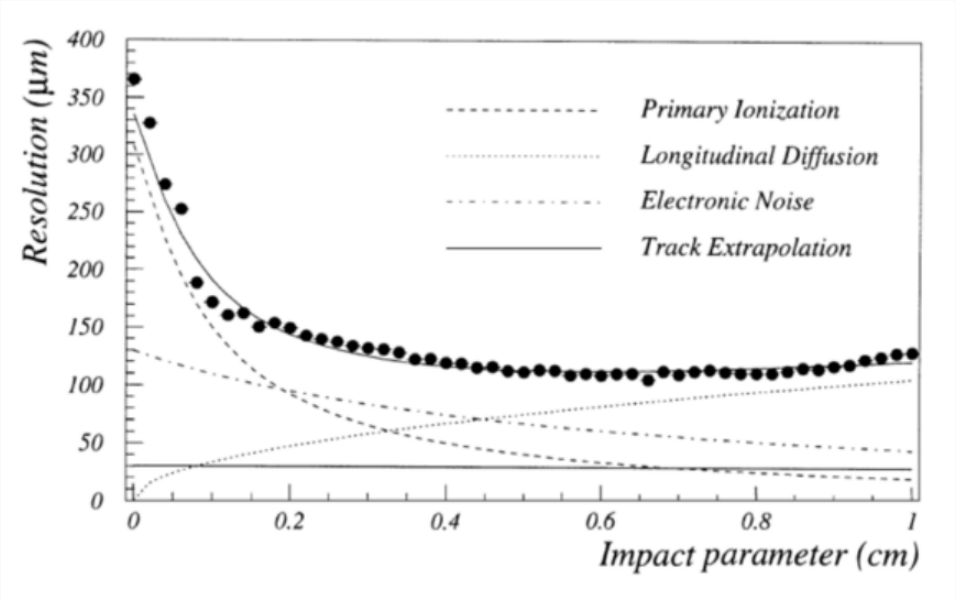
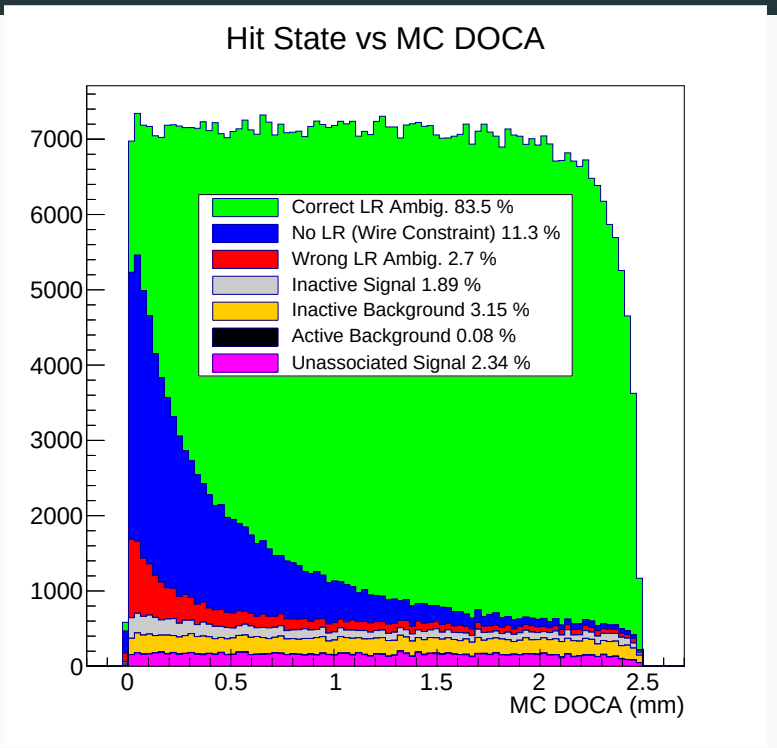
Drift resolution



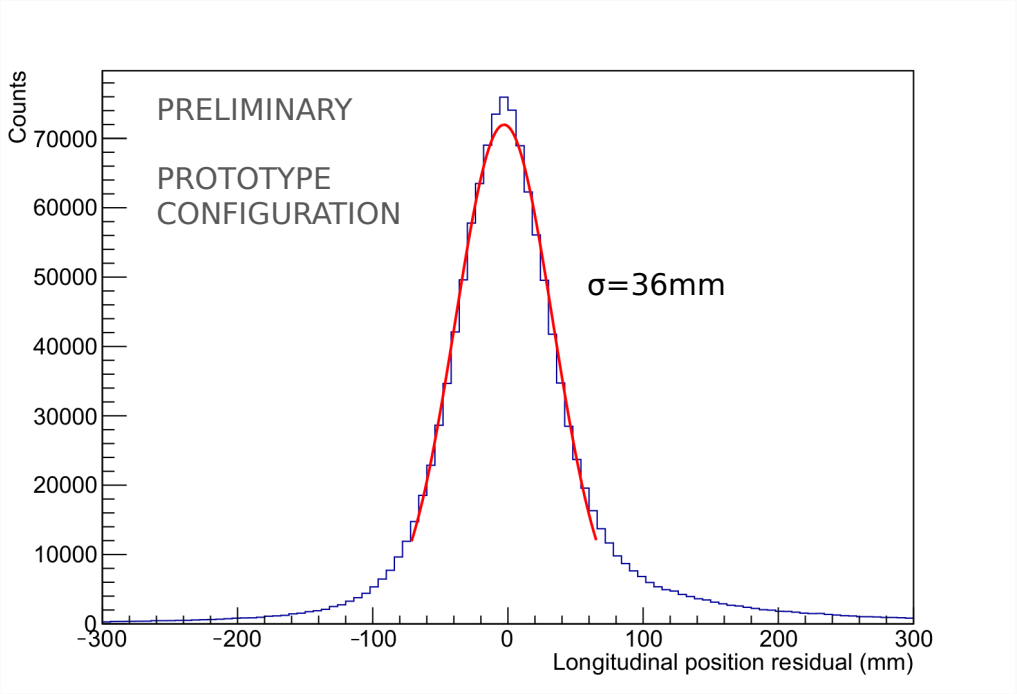
KLOE drift chamber (NIM A 461 (2001) 25-28)



Mu2e KinKal fit ambiguity assignment

- Primary ionization statistics
  - Tails - difficulties for reconstruction
- Diffusion during drift + electronics noise, shaping, threshold vs gas gain
  - Time resolution
  - $\times$ drift velocity for distance resolution

Longitudinal resolution



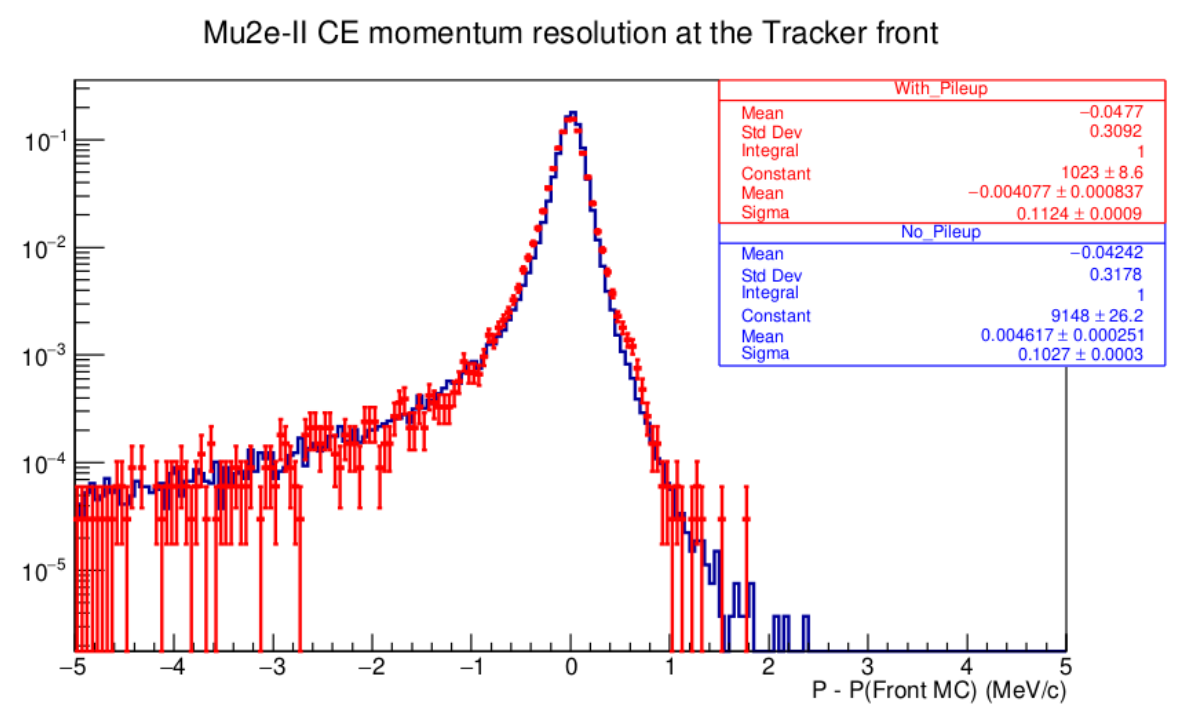
Mu2e VST plane resolution measurement

- Core from analog signal slope vs noise
- Tail from missing cluster on only one side
- Threshold optimization not necessarily the same as for drift (higher threshold → slower effective propagation speed)

Optimizations for Mu2e

- Trigger on ∼3rd cluster (15 clusters for 5mm path length)
  - >95% efficient for MIP, stable noise rates <10 khz
- Preamp bandwidth ∼150 MHz
  - EFD protection diodes and termination resistance limit max bandwidth
- Handle up to 250 KHz/straw on average, 2 MHz maximum

“Nominal” Mu2e-II

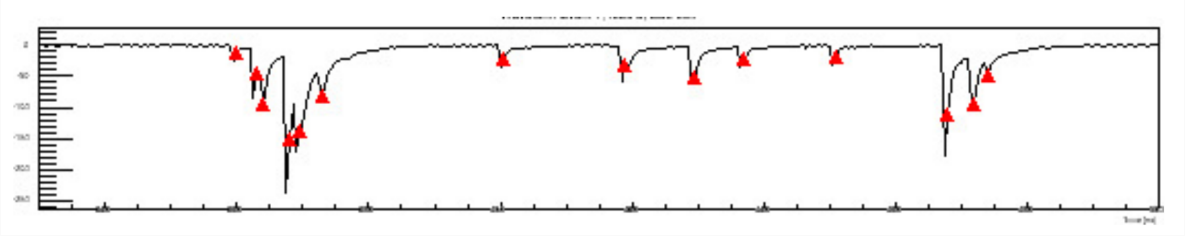


- Mu2e reco is pretty robust
- trigger efficiency?

Possible changes

- Lower gas pressure
  - worse ionization statistics, worse diffusion, higher gain
- Increase HV, thinner wire: increase gain, lower threshold
  - Trigger on single cluster?
  - Electrostatic stability, space charge effects?
- Slower gas
  - Better drift resolution, futher separate clusters, worse pileup
- Higher bandwith
  - Better rise time, longitudinal resolution, more noise
  - Termination resistance, ESD capacitance?
  - Thermal noise from wire resistance and ESD?
- Better shaping, digitization for TOT
  - accurately measure end of pulse
  - improvement on t_0 helps with pileup
- Cathode readout - additional measurement, 4x coincidence

Cluster counting?



G. Chiarello et al 2017 JINST 12 C07021, algorithm implemented on FPGA

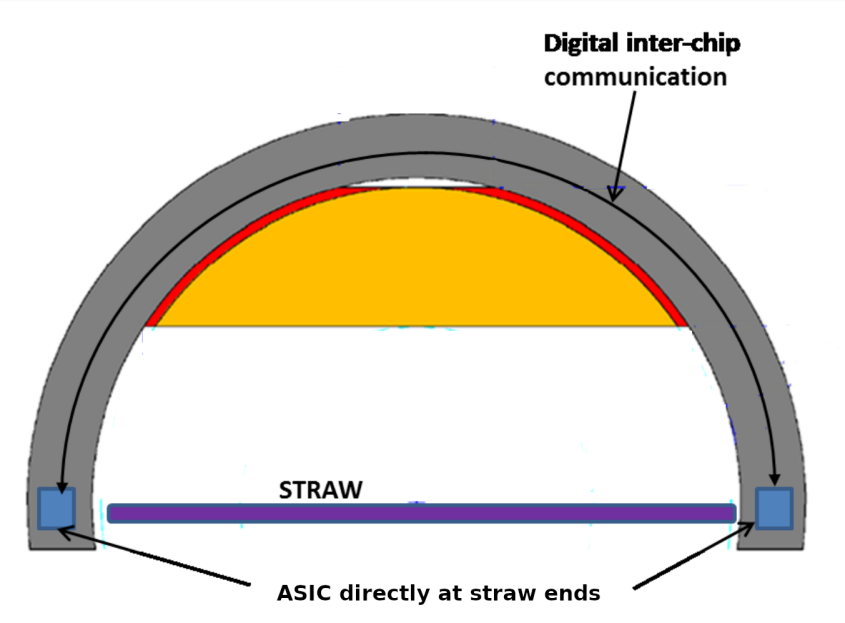
- A lot more information for reconstruction
  - Repeated measurements for drift, better t_0 than TOT
  - Longitudinal tail from missing cluster
  - Better PID (gain fluctuations vs cluster count)
- Mu2e - clusters <3 ns apart
- Faster digitization → power consumption
- switched capacitor digitizers (DRS4) cheaper and low power, but > μs deadtime

Radiation Tolerance

- Mu2e levels:
  - 500 KRad (12x safety factor)
  - 6e12 /cm^2 1mev eq NIEL (6x safety factor)
  - 1e11 /cm^2 >20mev SEE (6x safety factor) 3e9 per year
- Polarfire: 500 kRad, SEU negligible even at 10x, SEFI?
  - Stability, timing performance
- VTRx: 1 MRad
- ADC, DAC, DDR, DC-DC

ASIC?

- Lower power
- Radiation tolerance
- Faster (approaching timing limits on some parts of FPGA design)
- Routing of analog signals



Data rate and occupancy

- Mu2e: Average straw 100 KHz, hottest straw 400 KHz (+proton intensity fluctuations up to 6x that)
- Mu2e-II: 3-4x instantaneous? 1.6 MHz
- Relevant scales: 10 ns longitudinal propagation time, 50 ns drift time, 100 ns TDC deadtime
- On FPGA hit processing / filtering?
- VTRx+: 4 Gb/s $\rightarrow$ 10 Gb/s

Summary

- Mu2e-II will require new electronics design
  - Definitely for rates, maybe for radiation, possibly for performance?
- Changes to gas / HV impact resolution, tails
  - Garfield / SPICE simulations necessary
  - Some reco to see how pattern reco holds up