Tracker intrinsic resolution, electronics, readout

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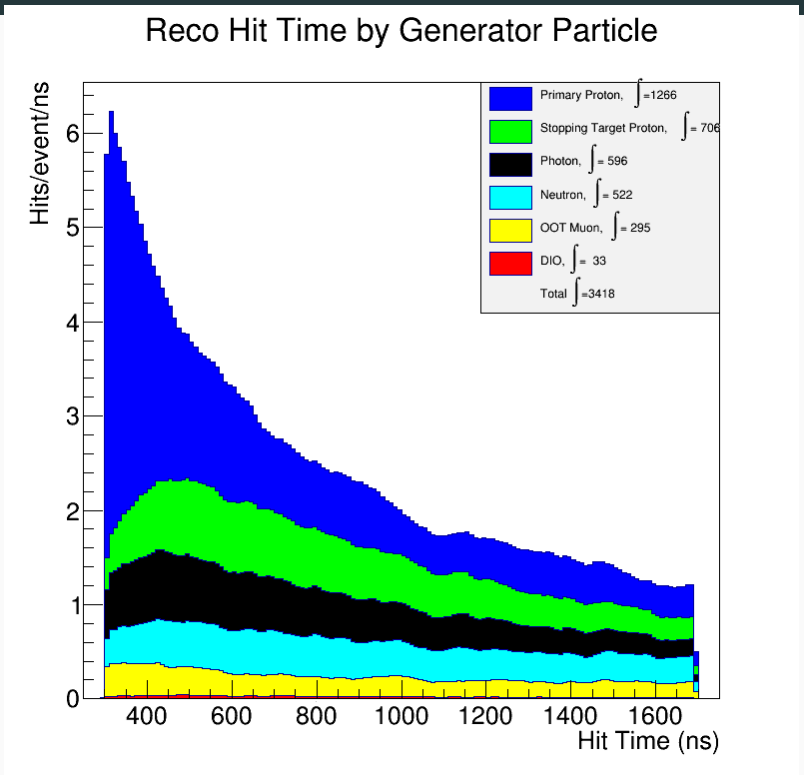
AMF tracking environment



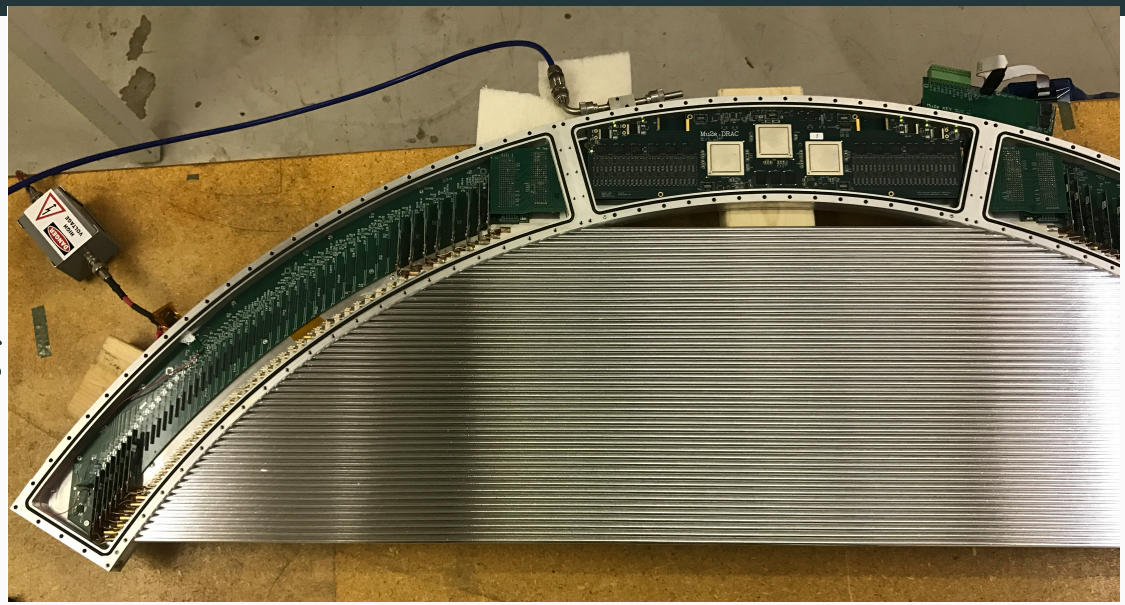
$\rightarrow$??

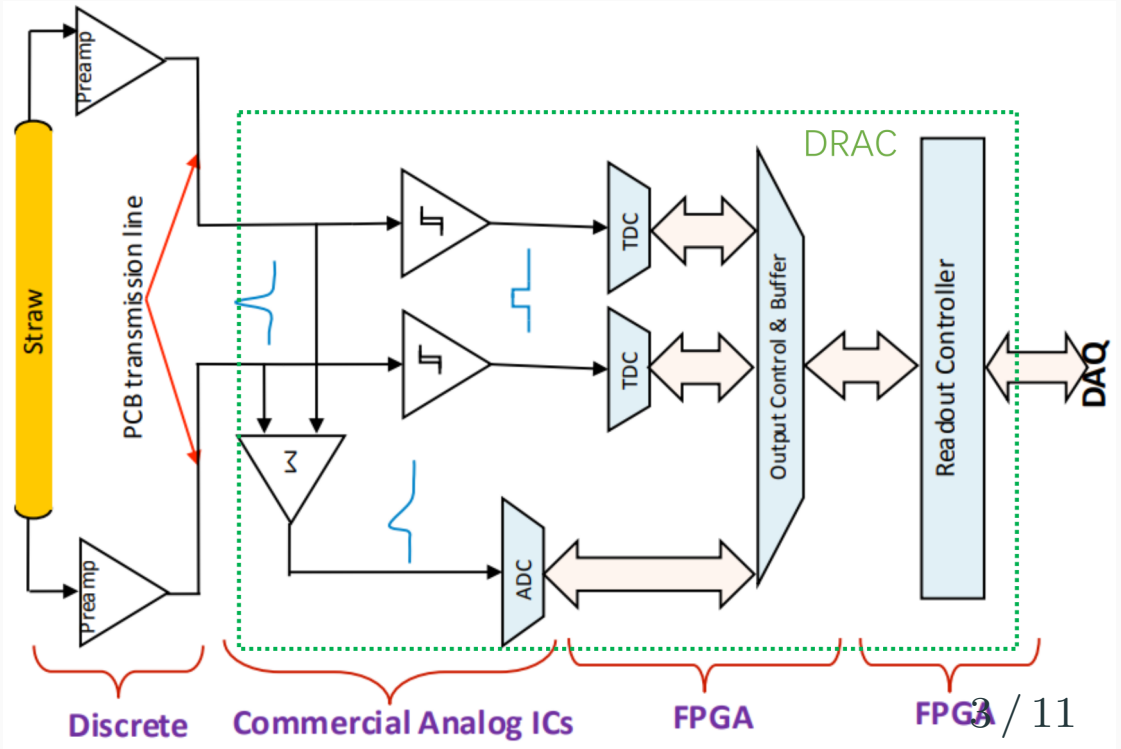
- What makes it to the tracker? Expected rates?
- Radiation tolerance / charge accumulation problems minimized?
- Annular detector?
- Time division requirements?

Time to go *track* to the drawing board!

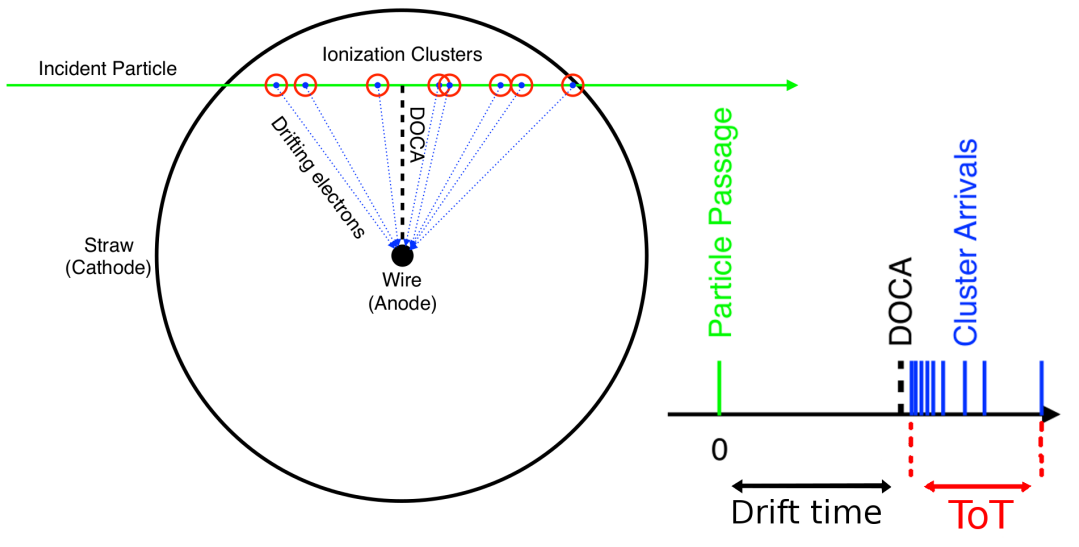
Mu2e setup

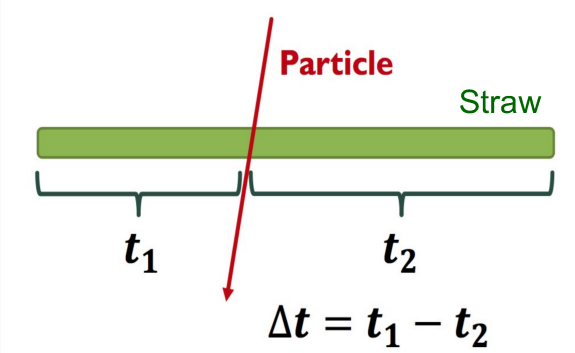
- Preamp at straw end, analog routed to central digitizer
- Comparator for applying threshold for time measurement
- 50 MHz digitizers
- 3x Microsemi PolarFire FPGAs w/ firmware TDC
- VTRx optical transciever





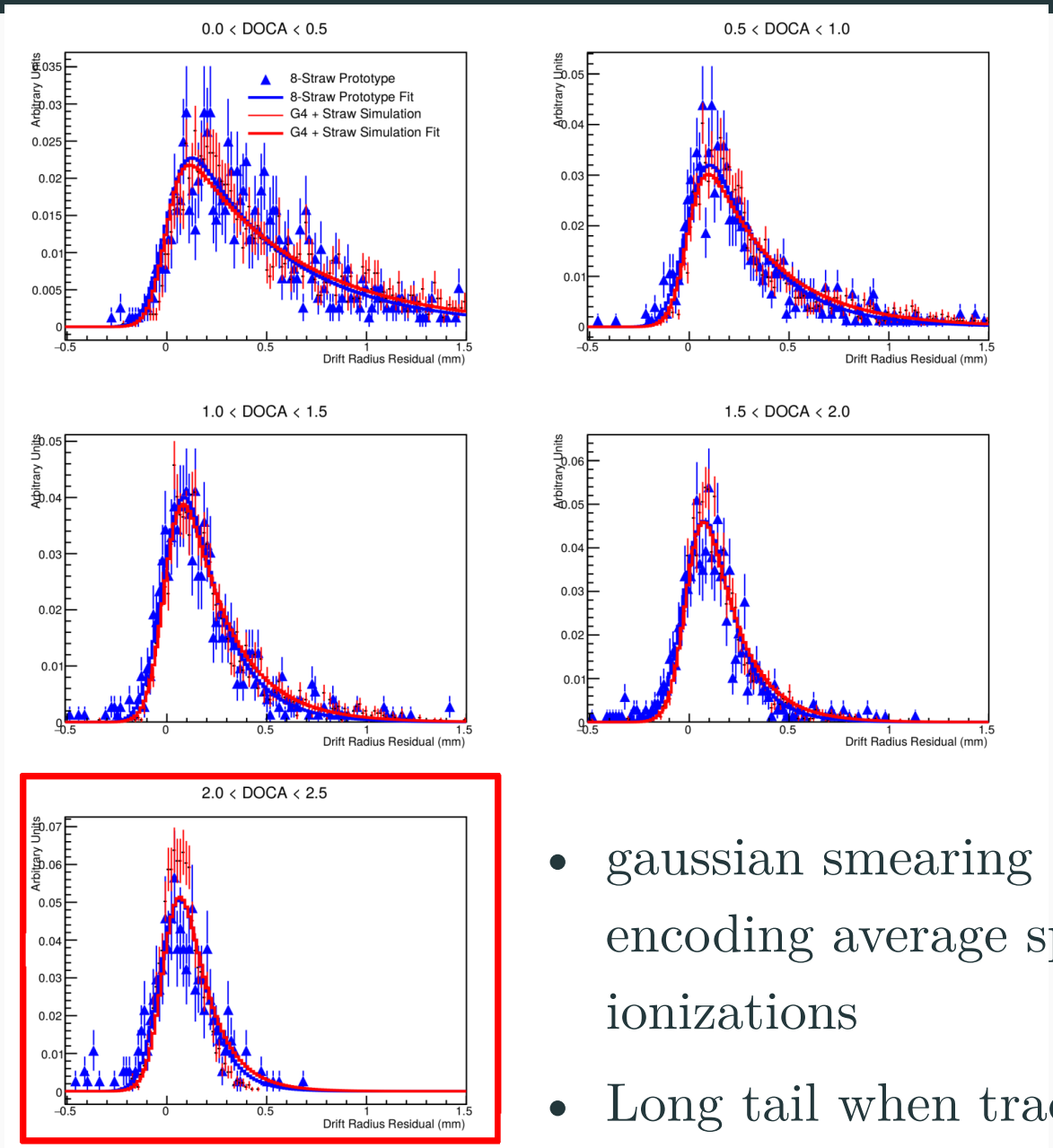
Mu2e measurements from each hit straw

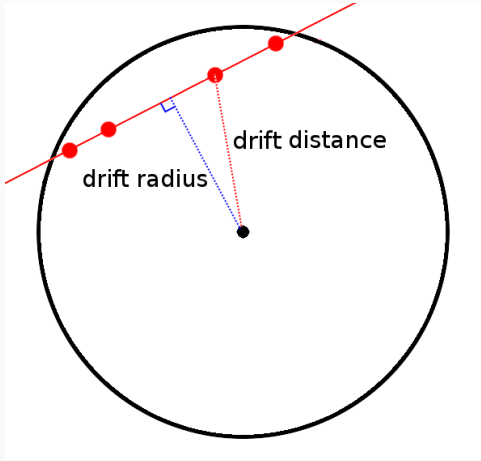




- Drift time ∼2.5 ns → transverse radius ∼150 μm
- Time division ∼400 ps → longitudinal position ∼4 cm
- Time-over-threshold to 4 ns → t_0 ∼7 ns
- 50 MHz digitized waveform → energy deposition ∼10%

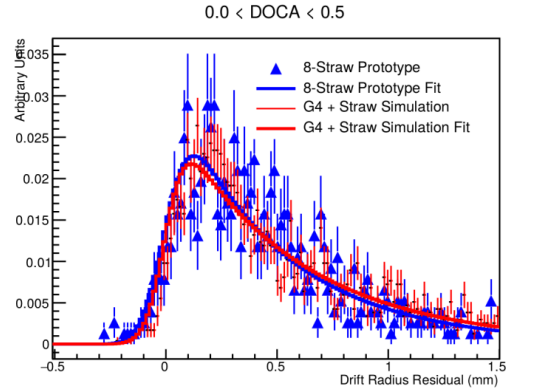
Drift response in Mu2e

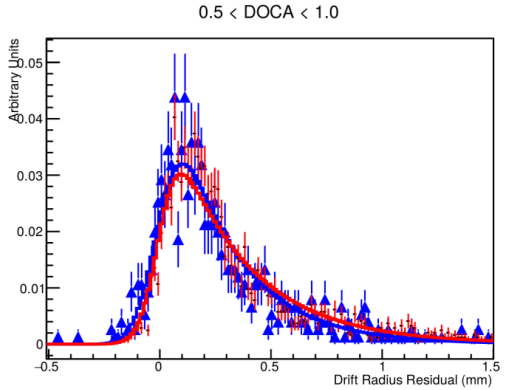


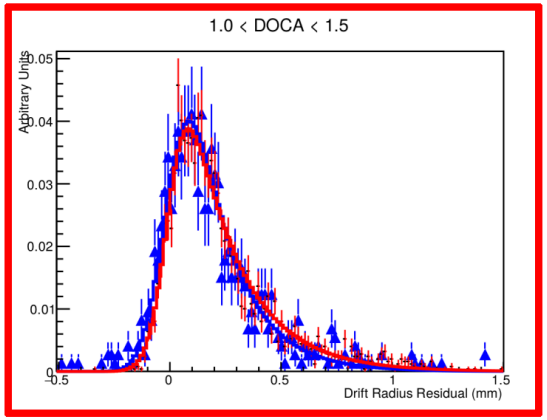


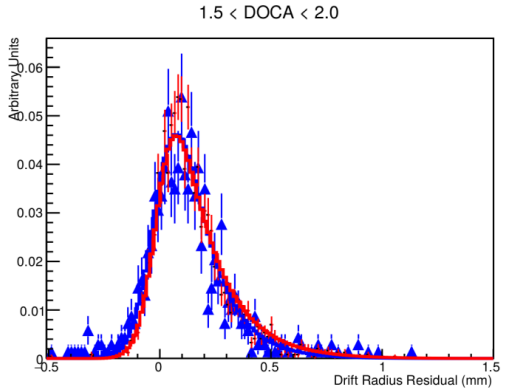
- gaussian smearing × exponential encoding average spacing between ionizations
- Long tail when track near wire

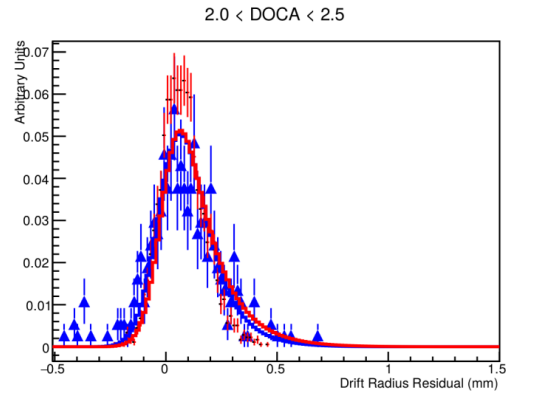
Drift response in Mu2e

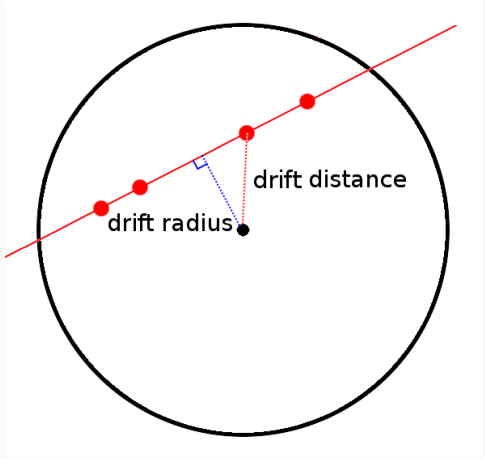












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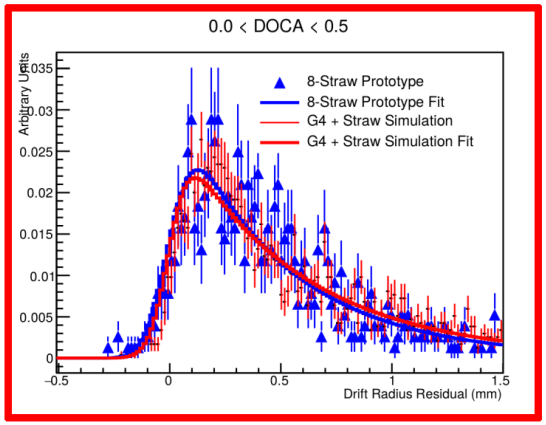

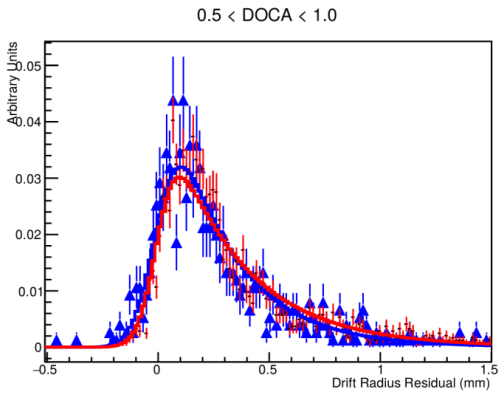

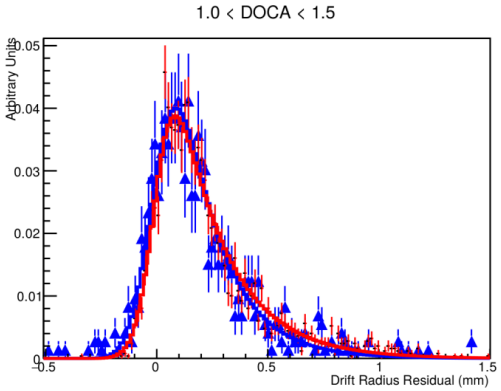

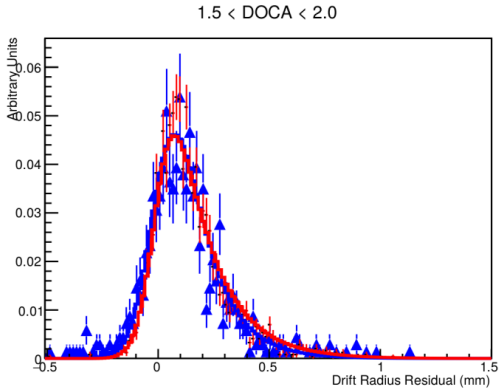

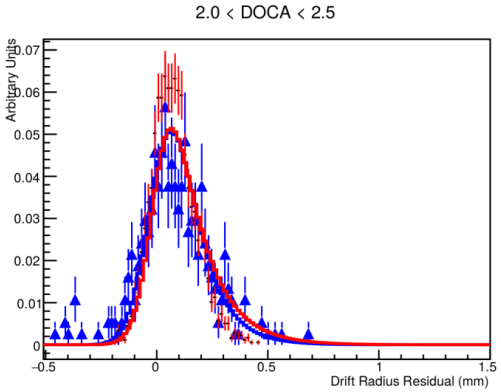

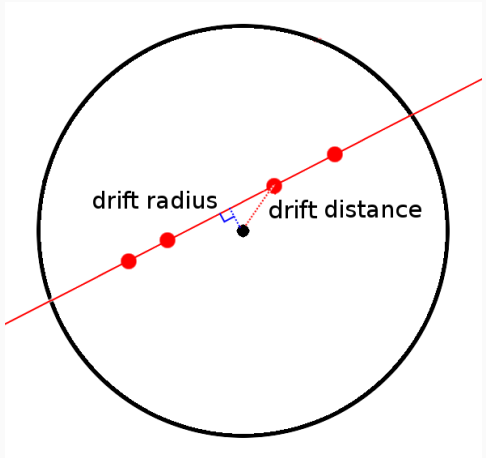

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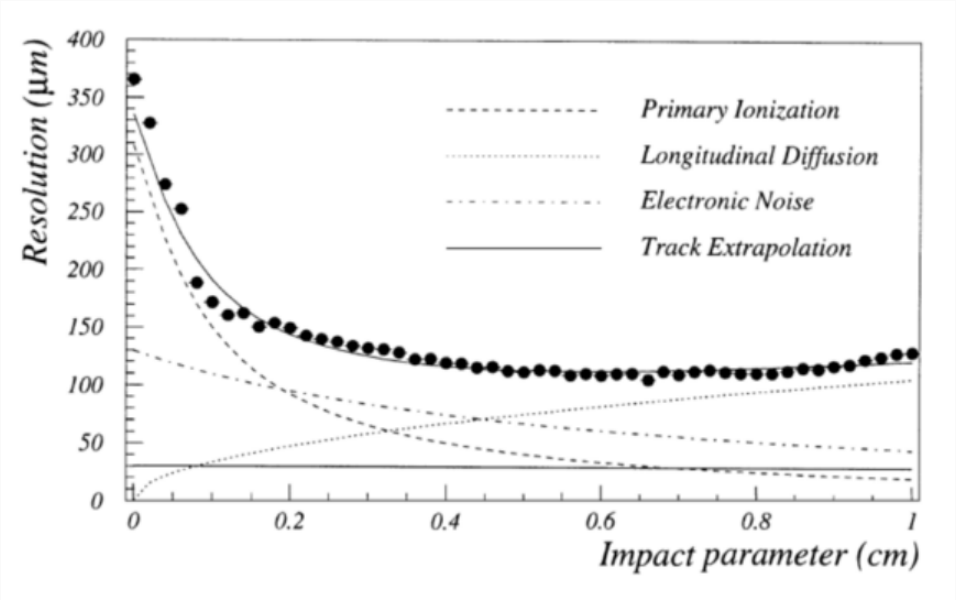
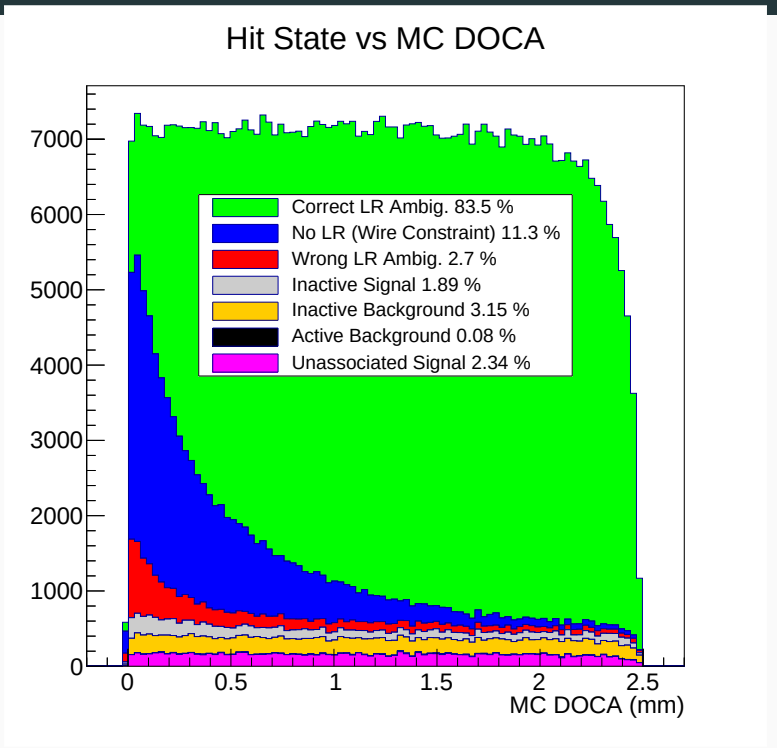
Drift resolution



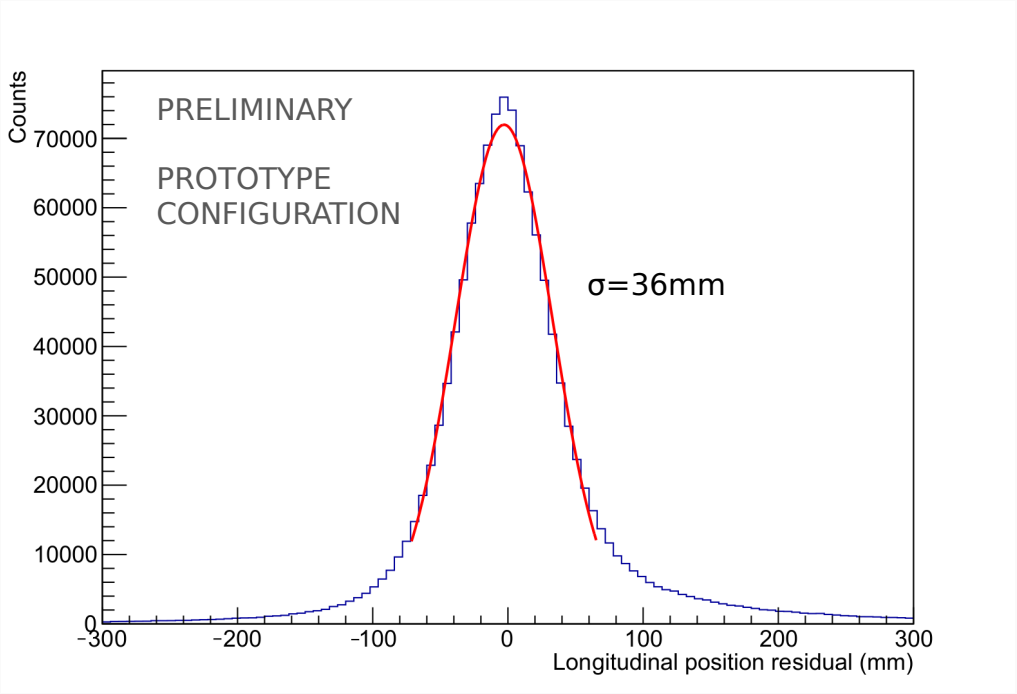
KLOE drift chamber (NIM A 461 (2001) 25-28)



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

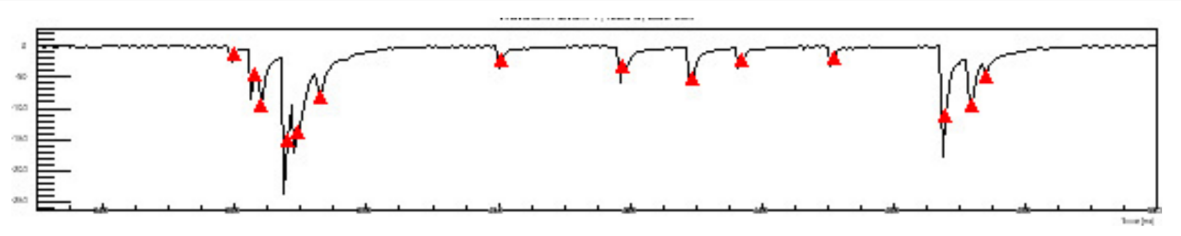
MEG-II

- 1 GHz bandwidth, 2GSPS
- charge and time division
- 150 mW per channel
- Drift cells 7-9mm square, 90:10 He isobutane, 13 primary ionizations per cm
- 110 μm resolution
- 600μs deadtime
- 15 Hz trigger (<1 μs trigger latency)

Possible changes

- Lower gas pressure, lighter gas
  - 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
- 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

Cluster counting?



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

- A lot more information for reconstruction
- With He or lower gas pressure, best way to recover resoluution?
  - 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 $\rightarrow$ power consumption
- switched capacitor digitizers (DRS4) cheaper and low power, but $> \mu$s deadtime
  - Could we have a low enough rate fast trigger?