A series of meetings on future $\mu \to e\gamma$ experiments

Francesco Renga, INFN Roma

Scope of the meetings

- PSI is going toward the development of a High Intensity Muon Beam (HiMB) to be completed during a long shutdown in 2027-2028

- In 2021, PSI asked for the composition of a HiMB Science Case paper (arXiv:2111.05788)

  - some options for a next generation of $\mu \rightarrow e\gamma$ experiments at 10^9 - 10^{10} μ/s was presented

- On the basis of this work, a series of informal meetings was started in 2021 among people from MEG and Mu3e who contributed to the Science Case paper:

  - the main goal is to go deeper into these options, to **identify and direct future R&D efforts** that will be necessary to meet the requirements of such experiments

- In the meanwhile, a proposal for an Advanced Muon Facility (AMF) at FNAL was presented, that widen the interest on these activities

The radial TPC option for e^+e^- tracking in future $\mu \rightarrow e\gamma$ experiments with photon conversion

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Pair tracker requirements

- High efficiency on e^+e^- pairs down to a few MeV/c for the lowest momentum track and up to O(50 MeV/c) for the highest momentum track

  - efficiency loss ~ 20% if $E_{min} > 5$ MeV

- Large angular acceptance

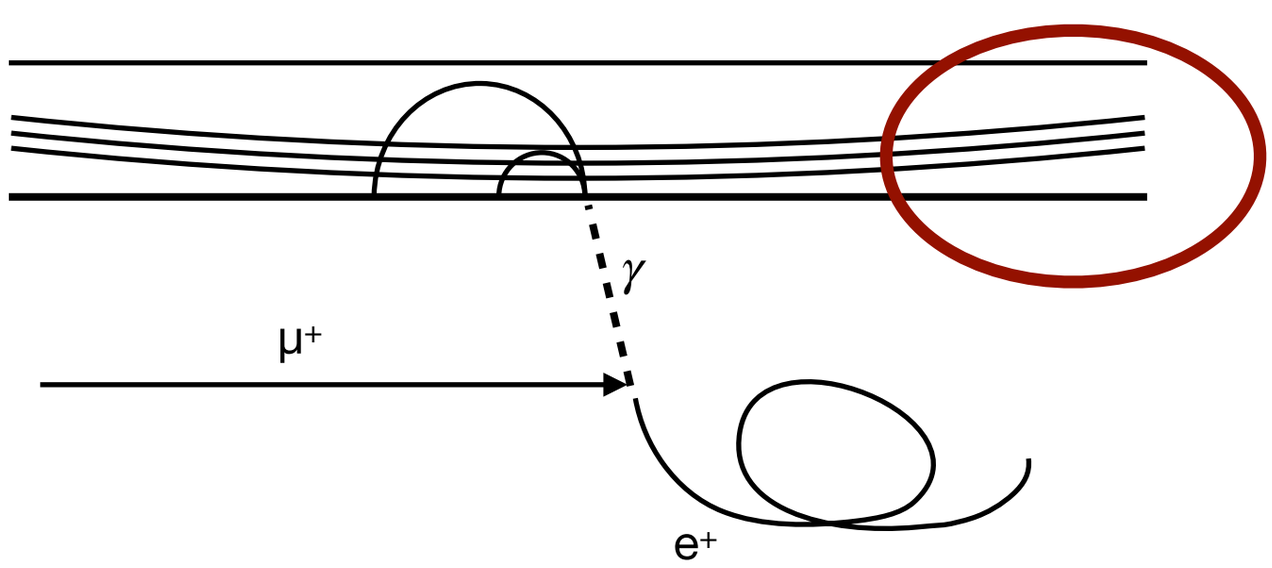
- Sum energy resolution O(100 keV)

- Scalability to multiple layers at a reasonable cost

Gaseous detector options

- A gaseous detector for e^+e^- tracking can balance good resolutions, large acceptance and low cost requirements

- A stereo wire chamber can be problematic from the point of view of the geometry (see here for more details)



Gaseous detector options

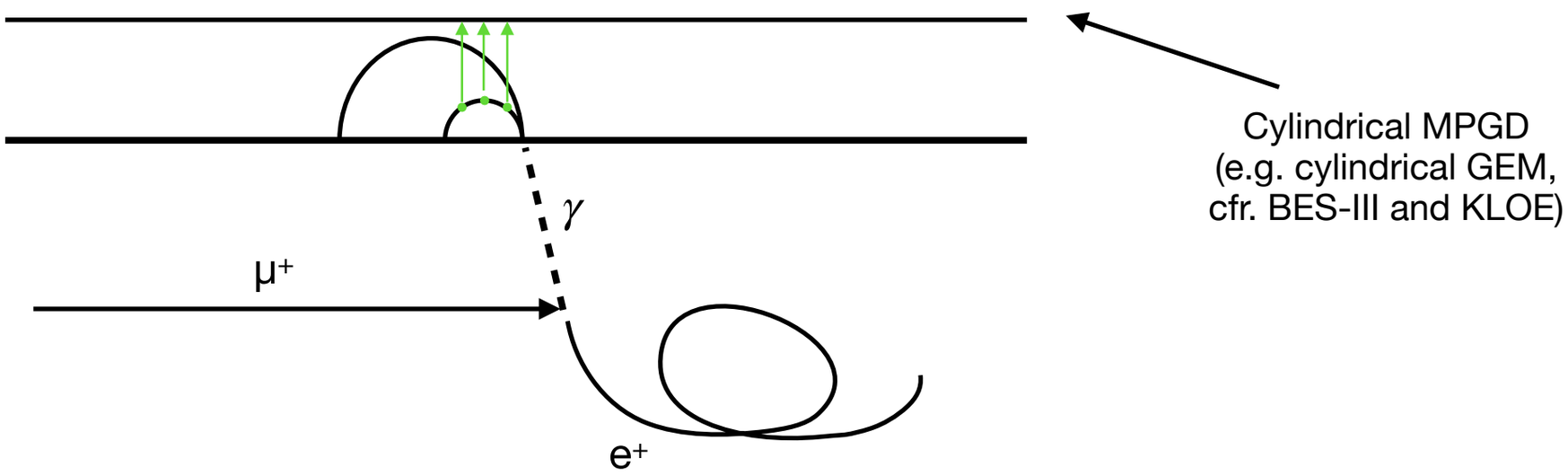
- A gaseous detector for e^+e^- tracking can balance good resolutions, large acceptance and low cost requirements

- A stereo wire chamber can be problematic from the point of view of the geometry (see here for more details)

- As an alternative a **radial TPC** can be considered

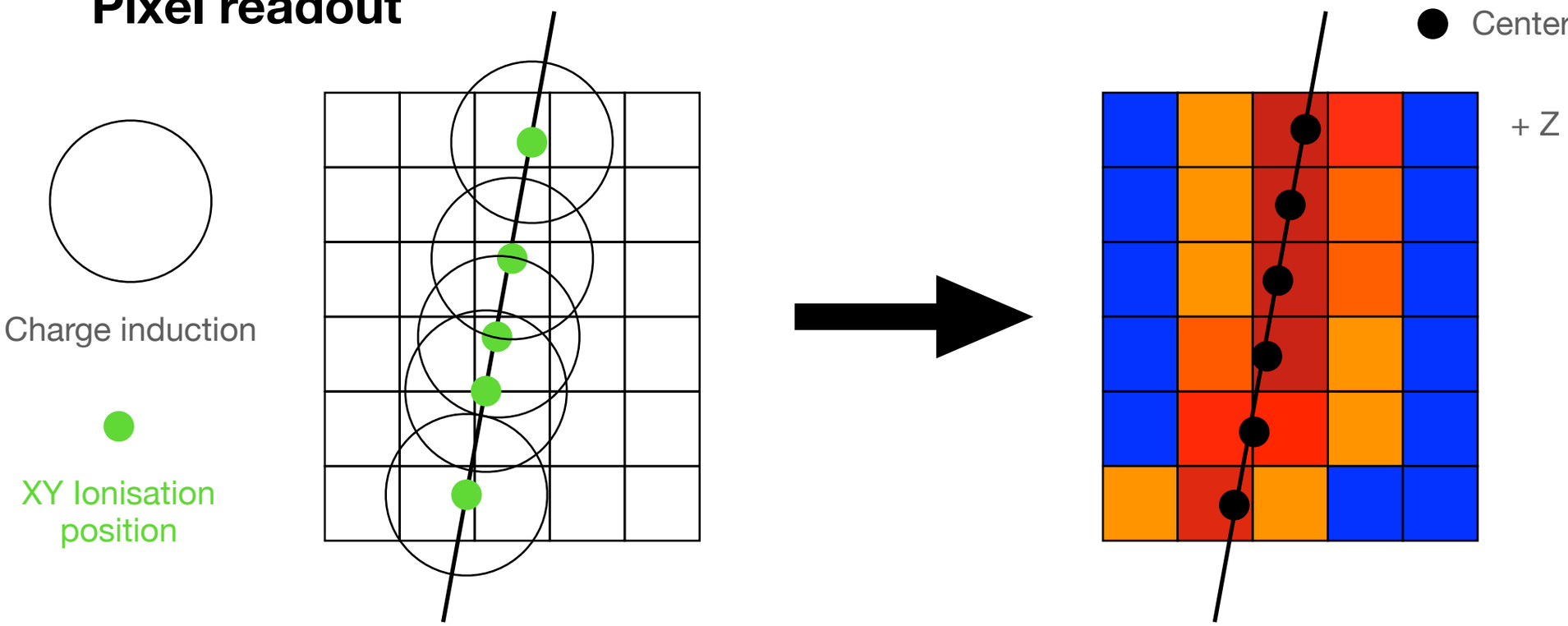
  - more uniform geometry

  - small drift distance w.r.t. a conventional, longitudinal TPC



Strip vs. Pixel Readout

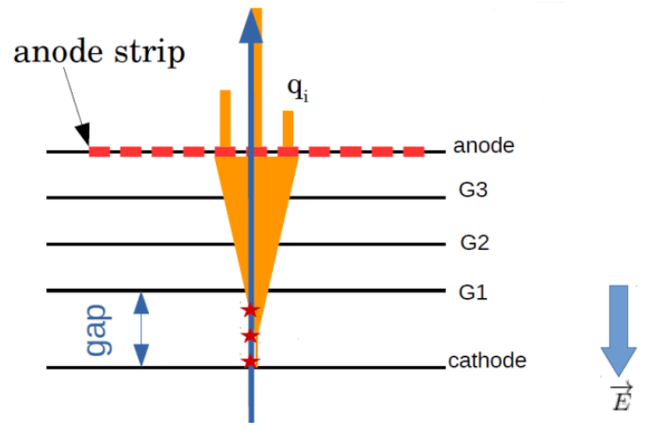
Pixel readout



Very challenging in a radial TPC, unless a lot of space for the electronics is reserved in the outer cylindrical surface

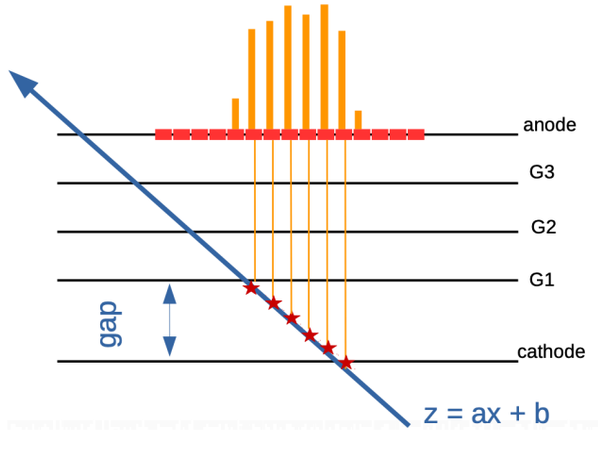
Stereo strip readout of thin-gap chambers

CoG



Doesn't work in a TPC due to track angle (several strips are on within the typical charge integration time of the electronics)

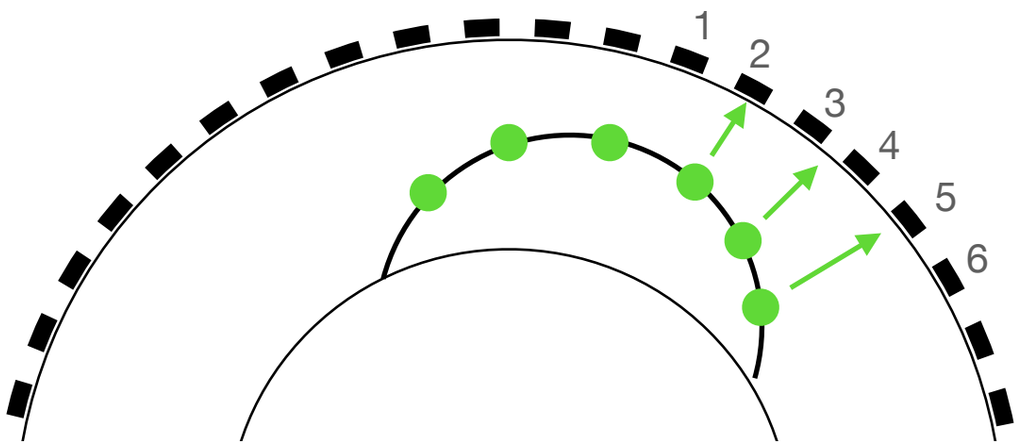
μTPC

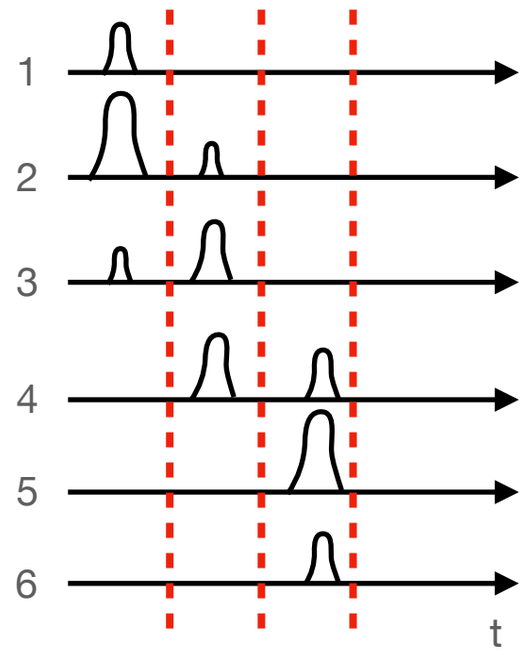


Suboptimal resolution with O(10cm) drift
(R: diffusion up to O(1 mm)
phi: strip granularity O(1/sqrt(12) mm))

Readout of a radial TPC

Stereo strip readout with time-resolved CoG measurement





CoG in bins of time
(ideal binning depends on ionization density, ~ 50 ns, diffusion effect, ~ 25 ns, and electronics shaping time)
+
radial coordinate from precise time measurements

Good resolutions can be achieved
(R: diffusion —> O(0.5 mm)
phi: CoG —> O(0.1 mm)
Z: CoG / sin(stereo) -> O(… mm))

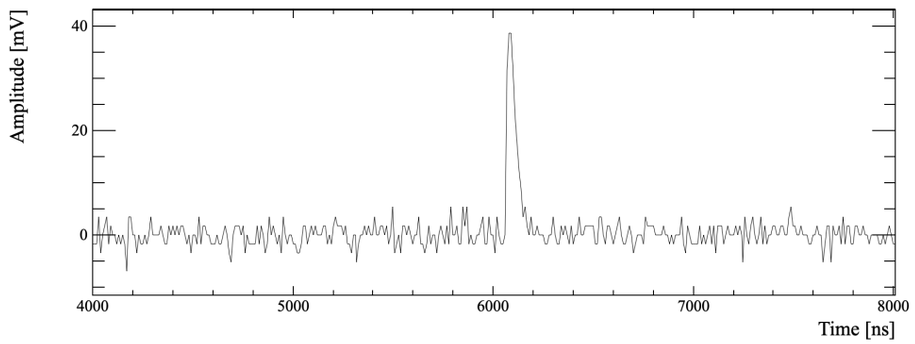
Requires electronics with:
- large digitization speed (>> 10 MSPS)
- short peaking time (<< 100 ns)
- ~ 10 us digitization depth

	PASA/ALTRO	AGET	Super-ALTRO	SAMPA
TPC	ALICE	T2K	ILC	ALICE upgrade
Pad size	4x7.5 mm^2	6.9x9.7 mm^2	1x6 mm^2	4x7.5 mm^2
Pad channels	5.7 x 10^5	1.25 x 10^5	1-2 x 10^6	5.7 x 10^5
Readout Chamber	MWPC	MicroMegas	GEM/MicroMegas	GEM
Gain	12 mV/fC	0.2-17 mV/fC	12-27 mV/fC	20/30 mV/fC
Shaper	CR-$(RC)^4$	CR-$(RC)^2$	CR-$(RC)^4$	CR-$(RC)^4$
Peaking time	200 ns	50 ns-1us	30-120 ns	80/160 ns
ENC	385 e	850 e @ 200ns	520 e	482 e @ 180ns
Waveform Sampler	ADC	SCA	ADC	ADC
Sampling frequency	10 MSPS	1-100 MSPS	40 MSPS	20 MSPS
Dynamic range	10 bit	12 bit(external)	10 bit	10 bit
Power consumption	32 mW/ch	<10 mW/ch	47.3 mW/ch	17 mW/ch
CMOS Process	250 nm	350 nm	130 nm	130 nm

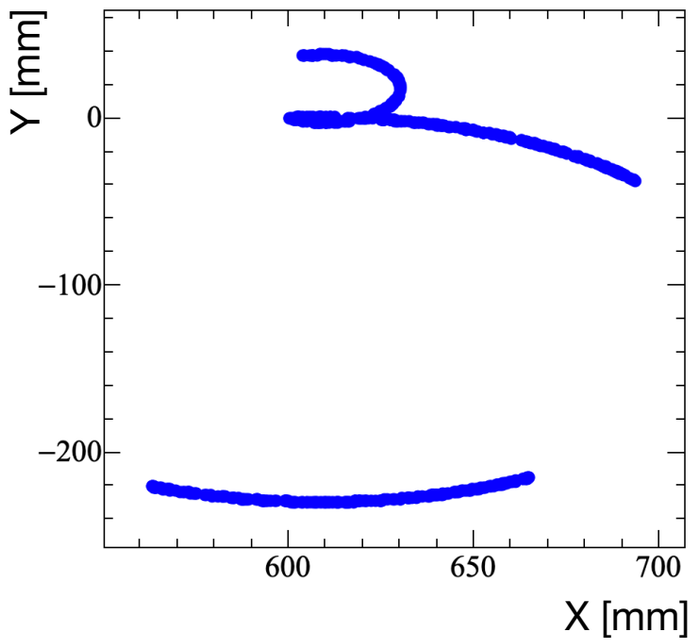
Simulation

- A simplified Geant4 simulation was developed assuming:
  - ionization and electron transport properties of a He:isobutane mixture (not optimal, but gas properties already available from simulations with Garfield and measurements)
  - Design and response of BES-III cylindrical GEMs (strip pitch = 650 μm, strip width = 350/80 μm, avg. gas gain = 6000, dispersion of induced charge = 400 μm)
  - Reasonable parameters of electronics response, inspired by existing ASICs

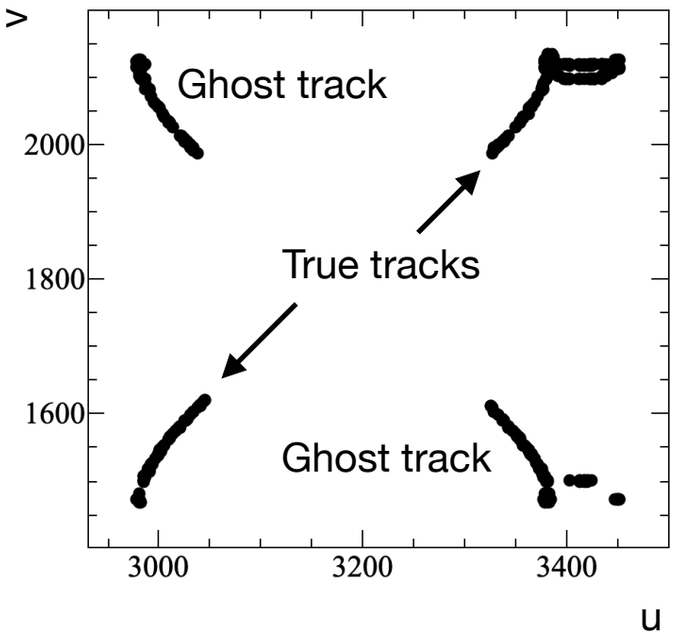
Typical waveform



True tracks



Reco track (time resolved CoG)



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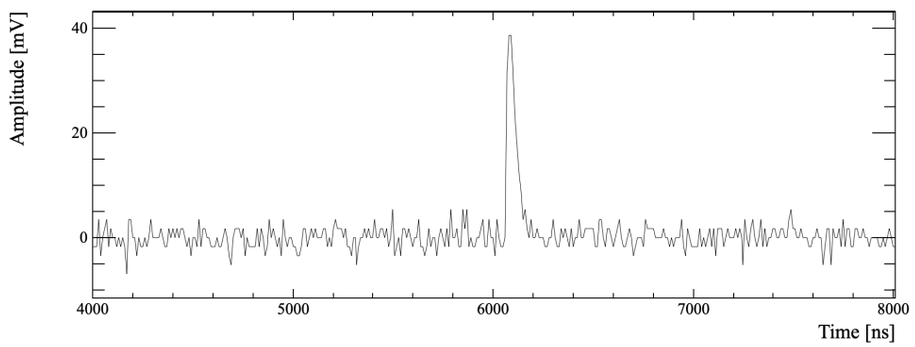

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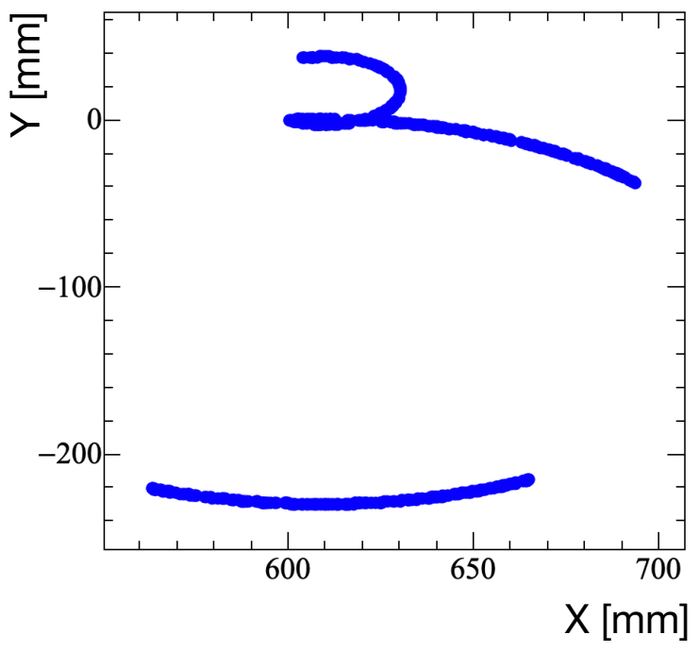

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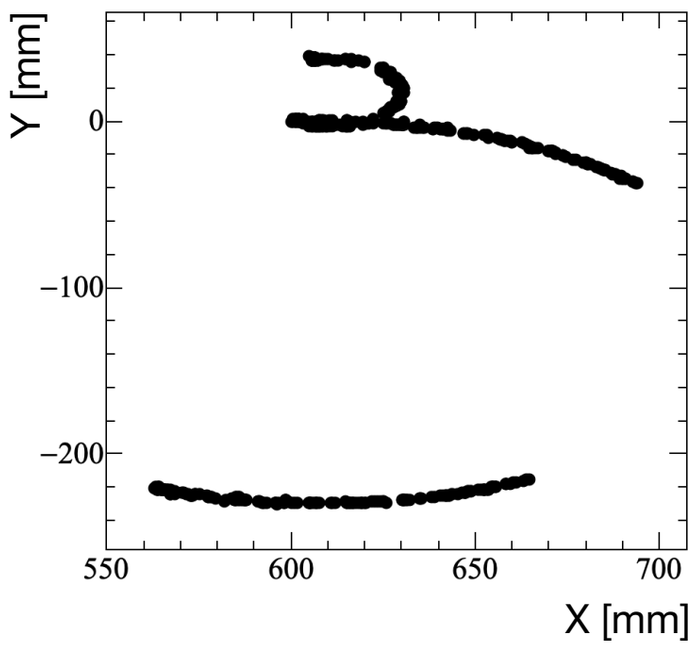
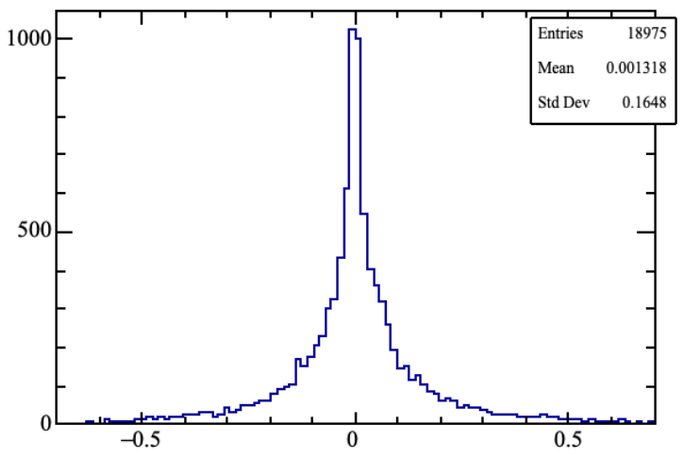
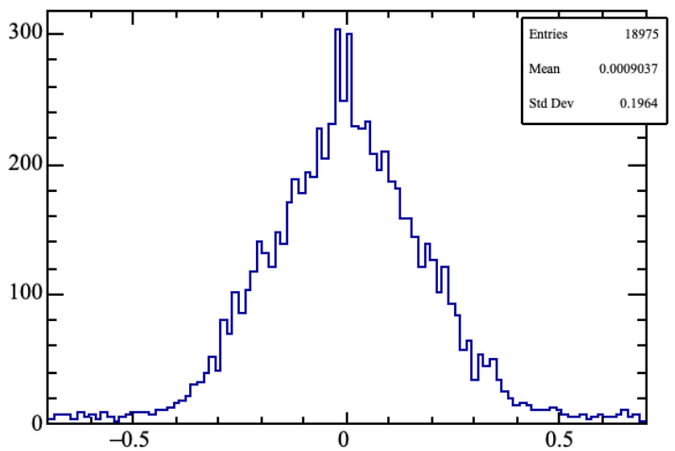


Resolution

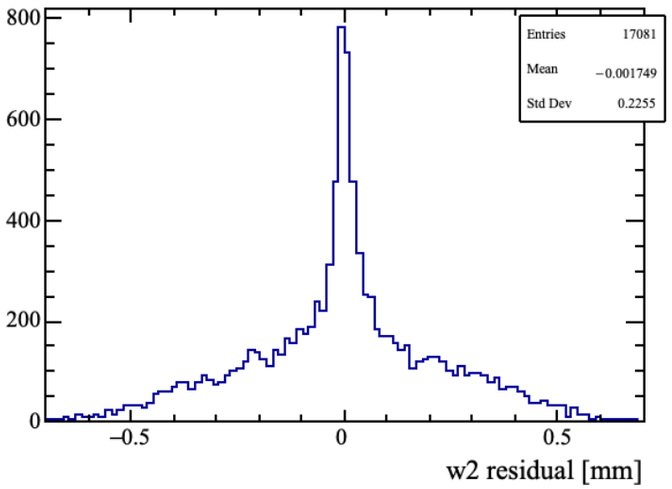
Resolutions are evaluated in two coordinates (w1, w2)
in a virtual plane orthogonal to the track,
with w2 almost parallel to z

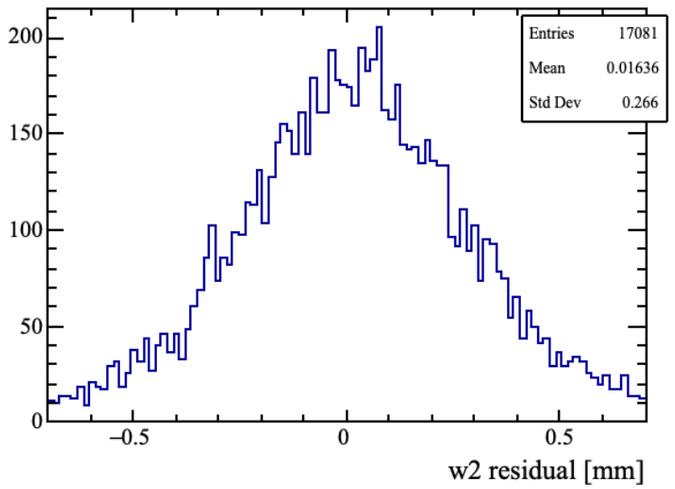
- Ideal case (no diffusion, very fast signal shape and electronics)

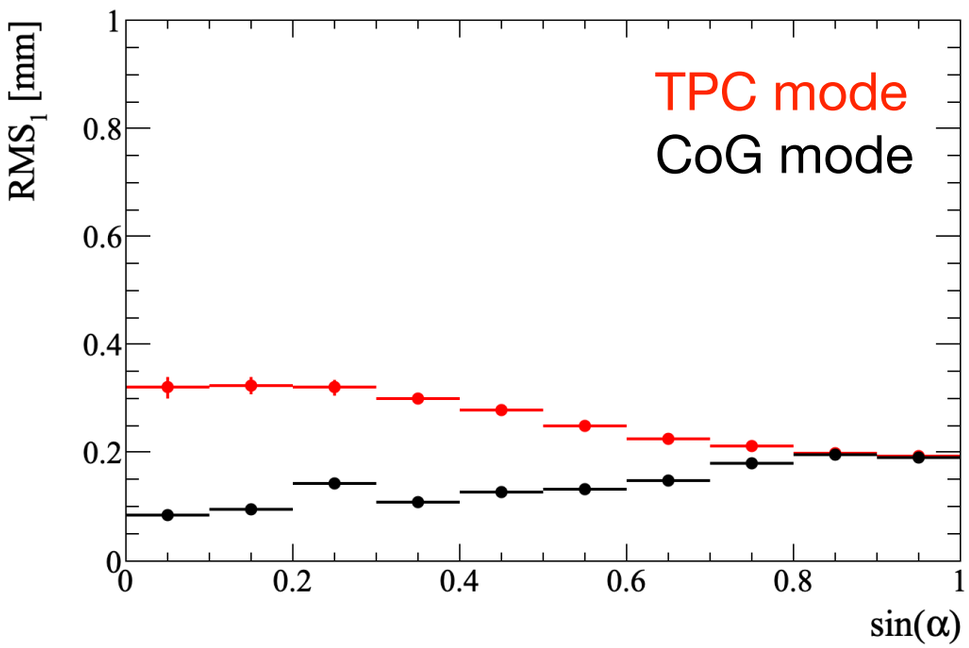




Signal rise/fall time = 10 ns
ADC sampling rate = 200 MSPS







α = angle btw. track and radial direction

Resolution

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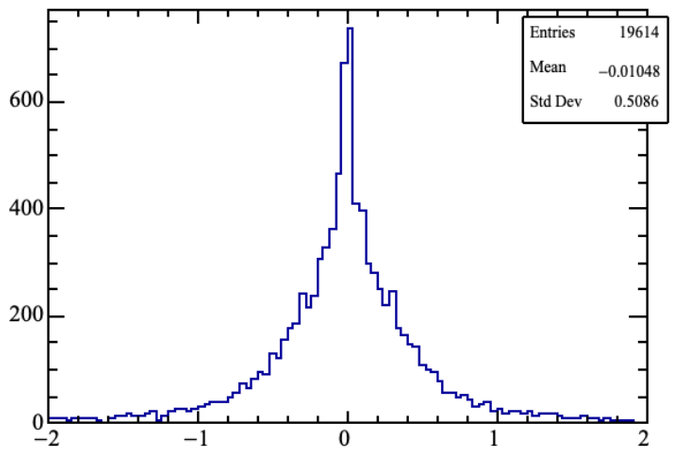
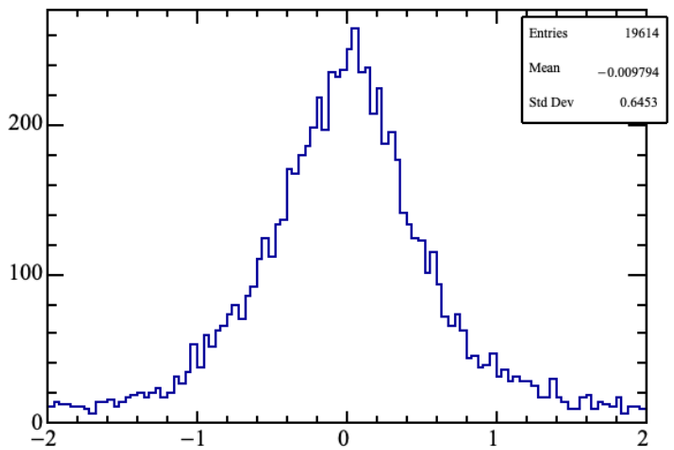
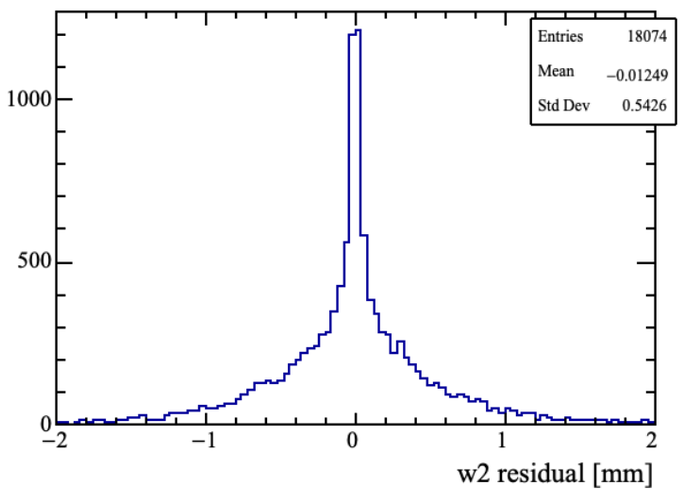
with w2 almost parallel to z

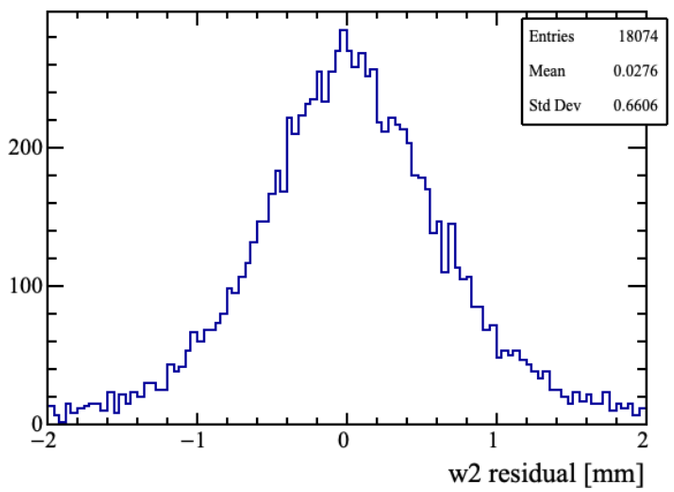
- Diffusion effect

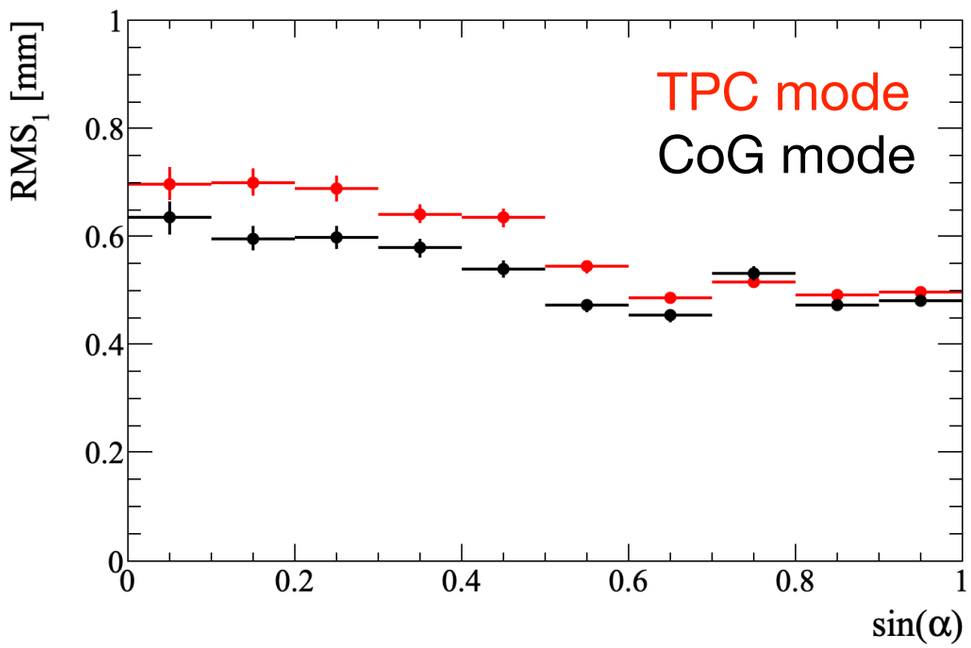




Signal rise/fall time = 10 ns
ADC sampling rate = 200 MSPS







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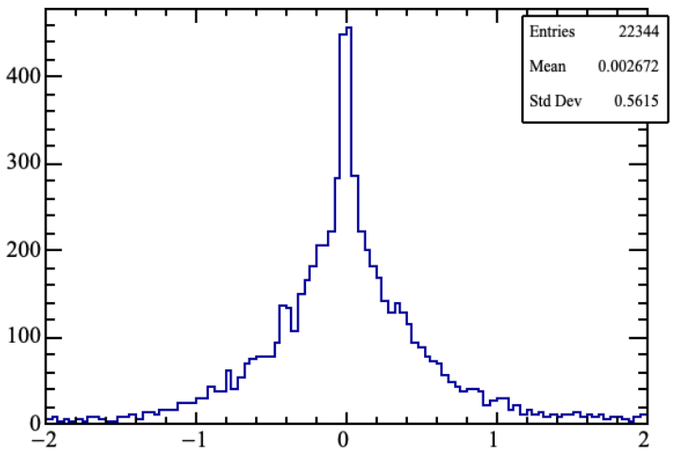
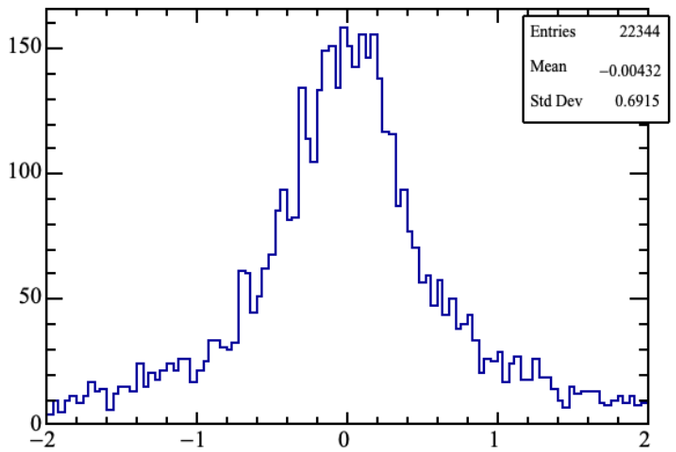
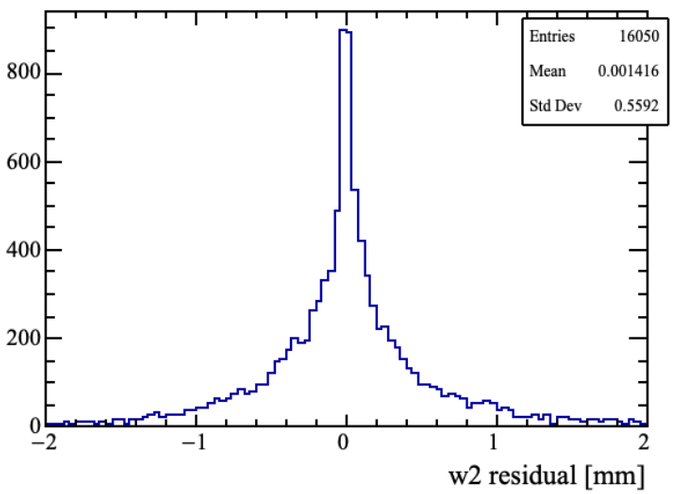
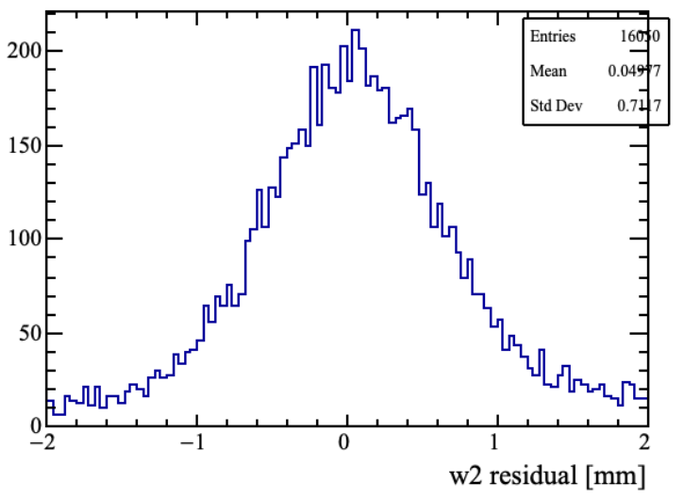
- Super-ALTRO specs

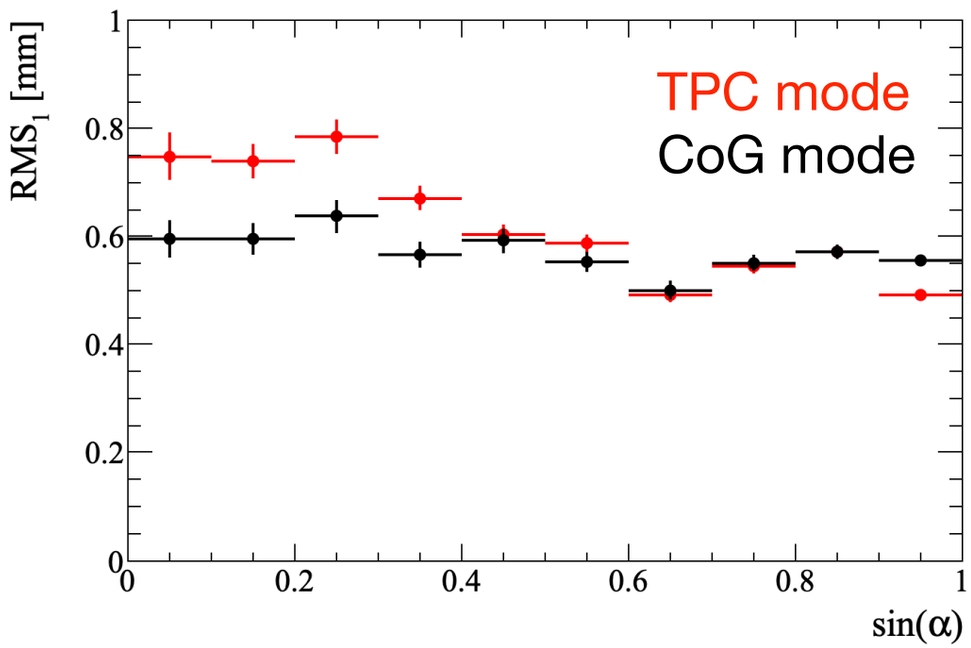




Signal rise/fall time = 30 ns
ADC sampling rate = 40 MSPS







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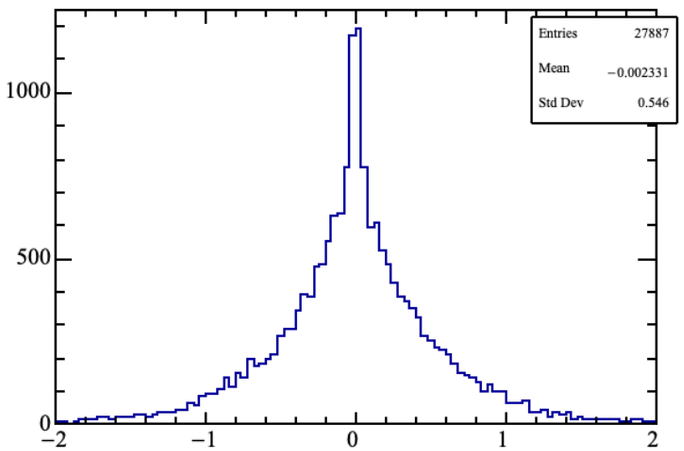
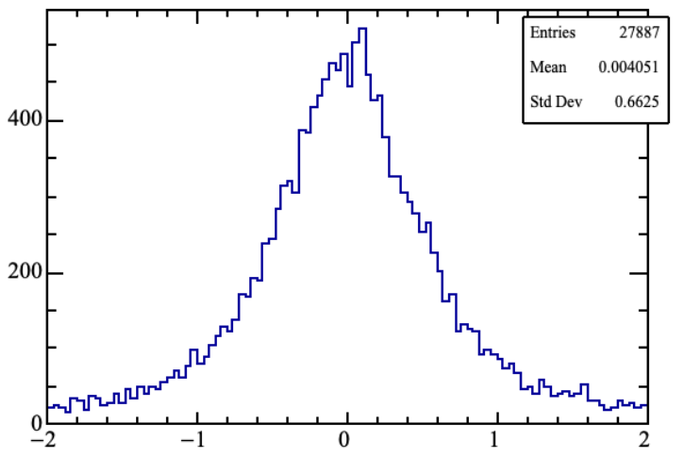
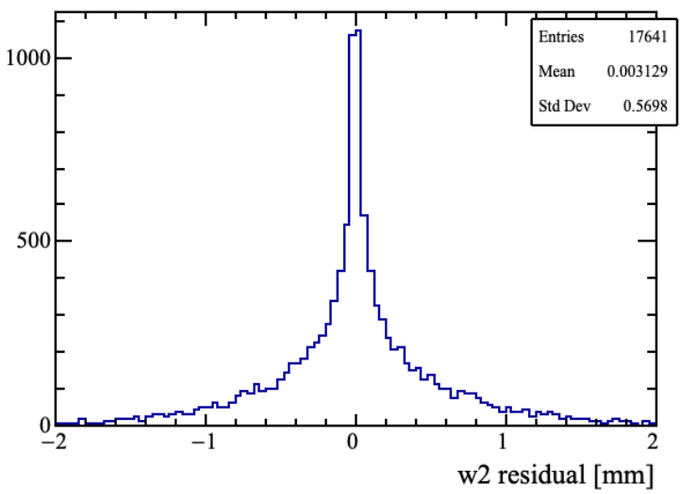
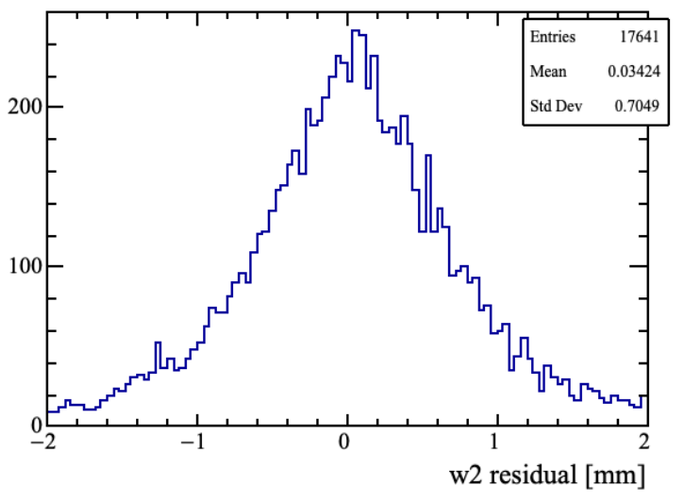
- Optimized electronics (max. sampling and min. rise/fall time of existing ASICs)

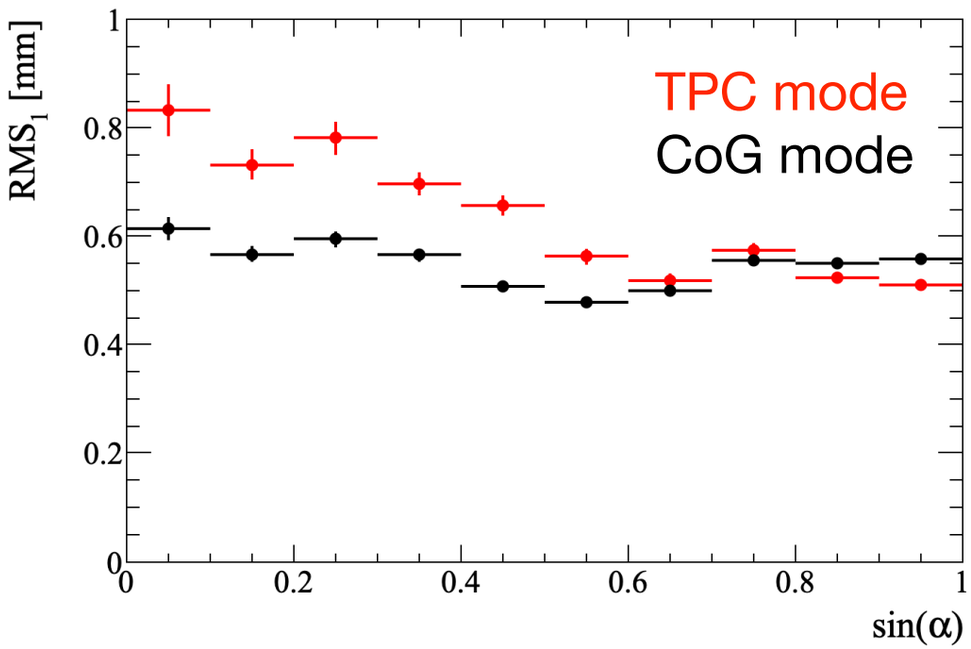




Signal rise/fall time = 30 ns
ADC sampling rate = 100 MSPS







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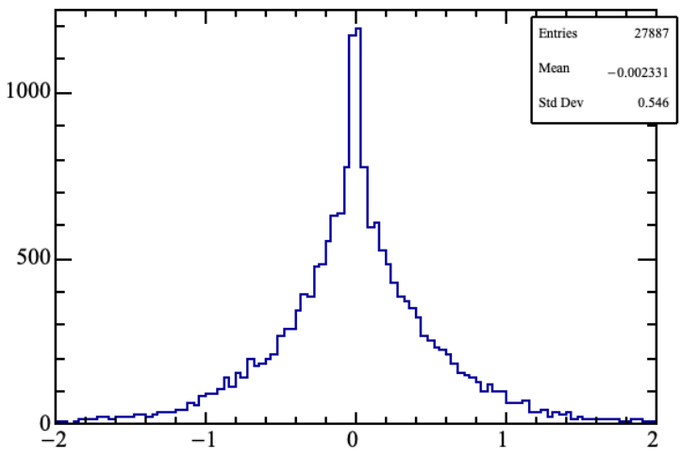

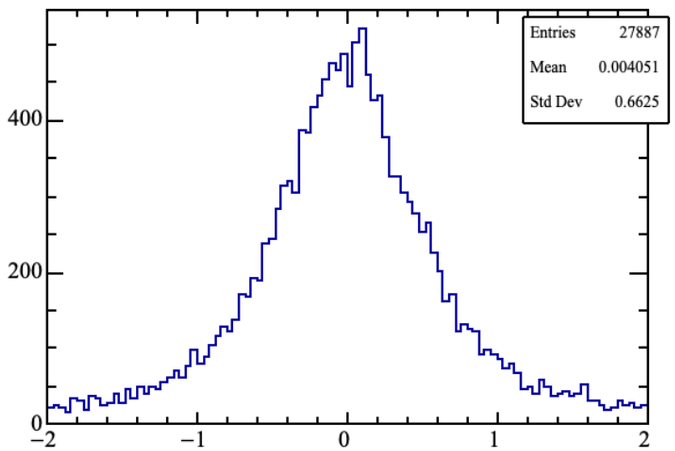

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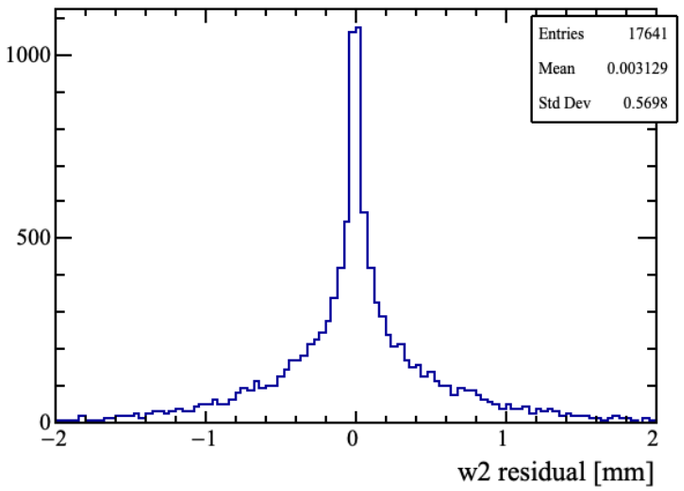

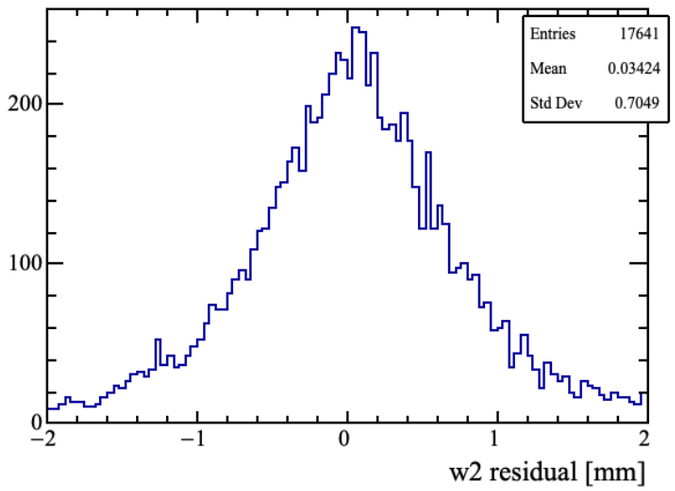

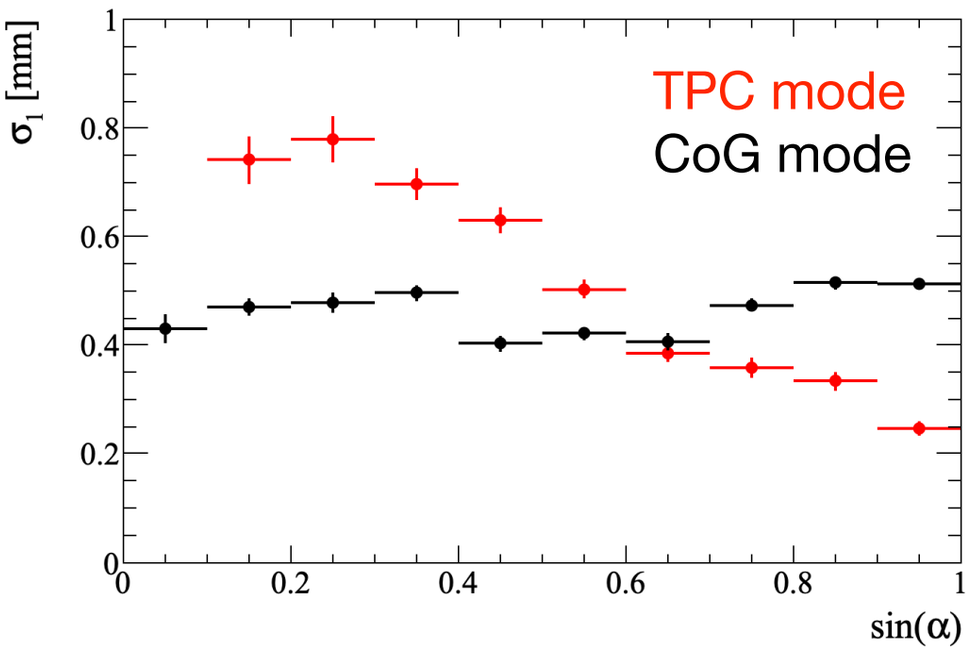

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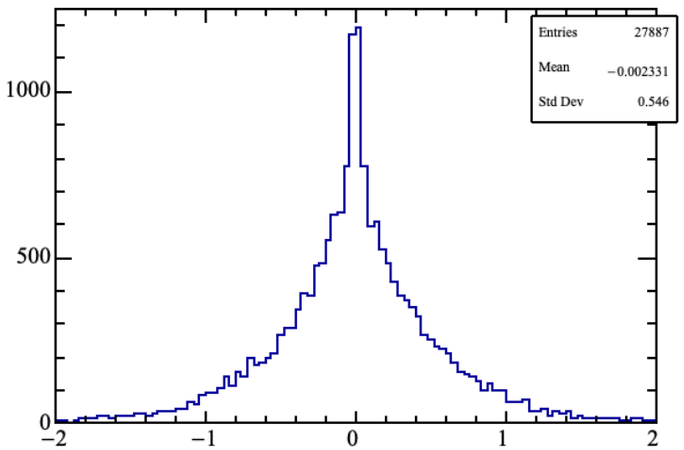
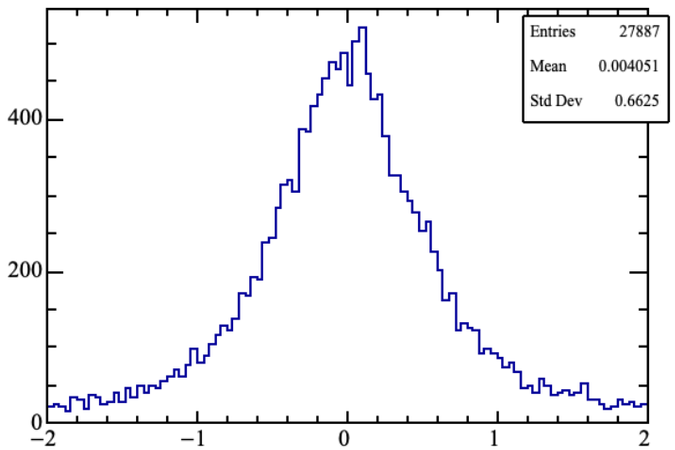
- Reduced diffusion by 25%





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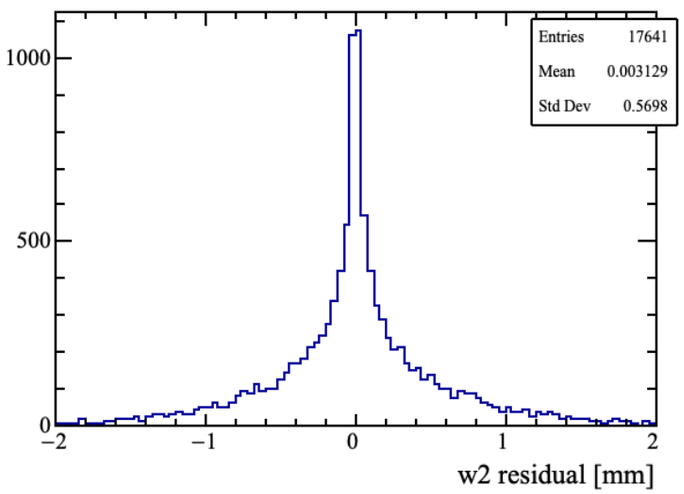

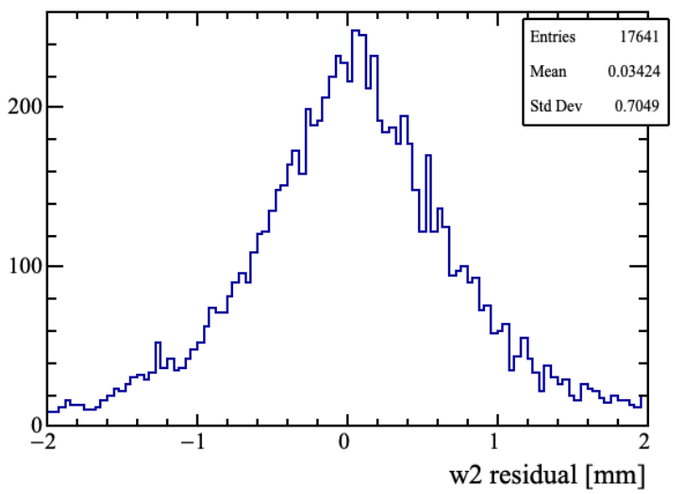

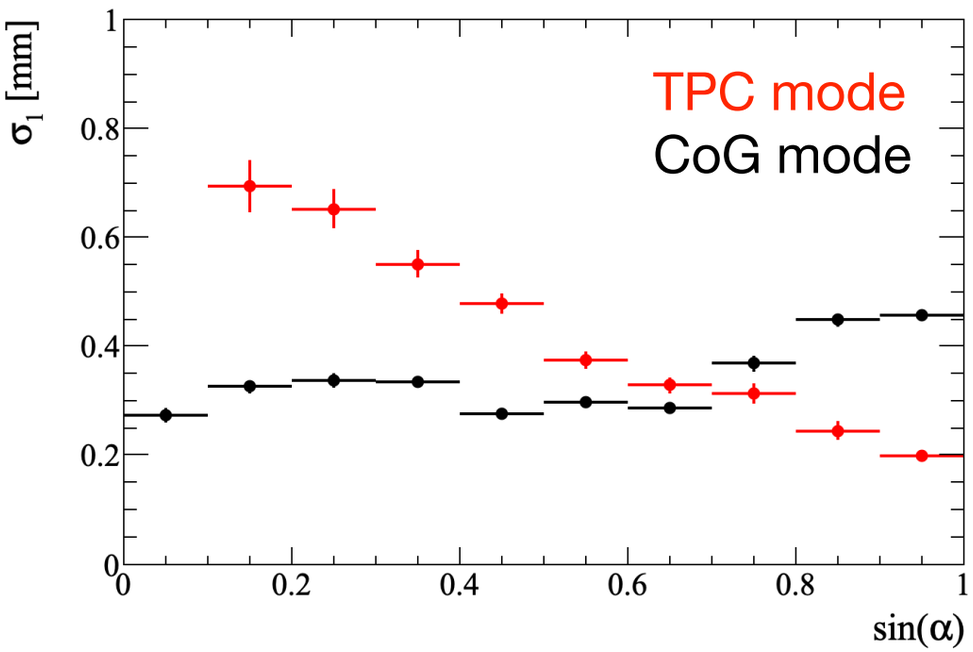

α = angle btw. track and radial direction

Discussion

- Gaseous detectors could be a good option for pair tracking in the photon conversion detector
  - Large acceptance, relatively low cost
- A simplified simulation + reconstruction for a radial TPC with strip readout was performed
  - Resolution ~ 0.4-0.6 mm with O(1 hit/mm)
  - Significant improvement with time-resolved CoG (more important if a gas mixture with lower diffusion is used)
  - Largest uncertainties from signal shape, S/N ratio, charge distribution in the GEMs
- Development of dedicated electronics is probably necessary
  - Tailored to the capacitance of long strips
  - Optimized for the time-resolved CoG
- Another group in Rome is building a flat TPC with 5 cm drift + μRWELL with strips
  - Some experimental validation of the methods could be possible within this year