Pair Tracker options for a future $\mu \to e\gamma$ experiment with photon conversion

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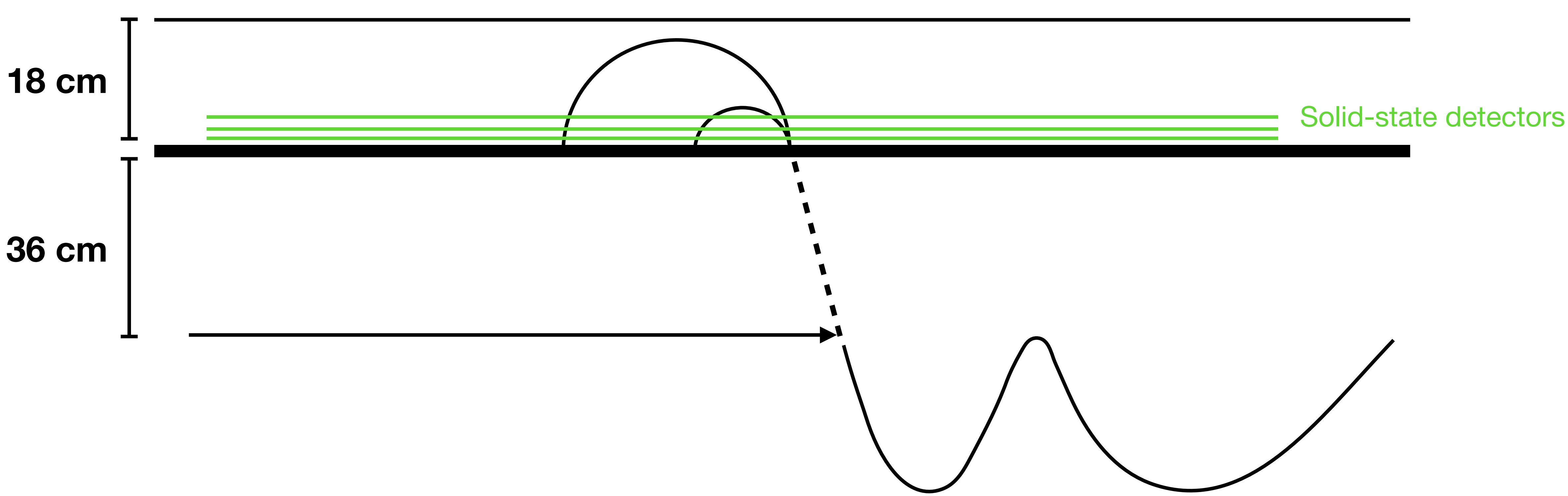
Pair tracker requirements

- 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

Momentum acceptance

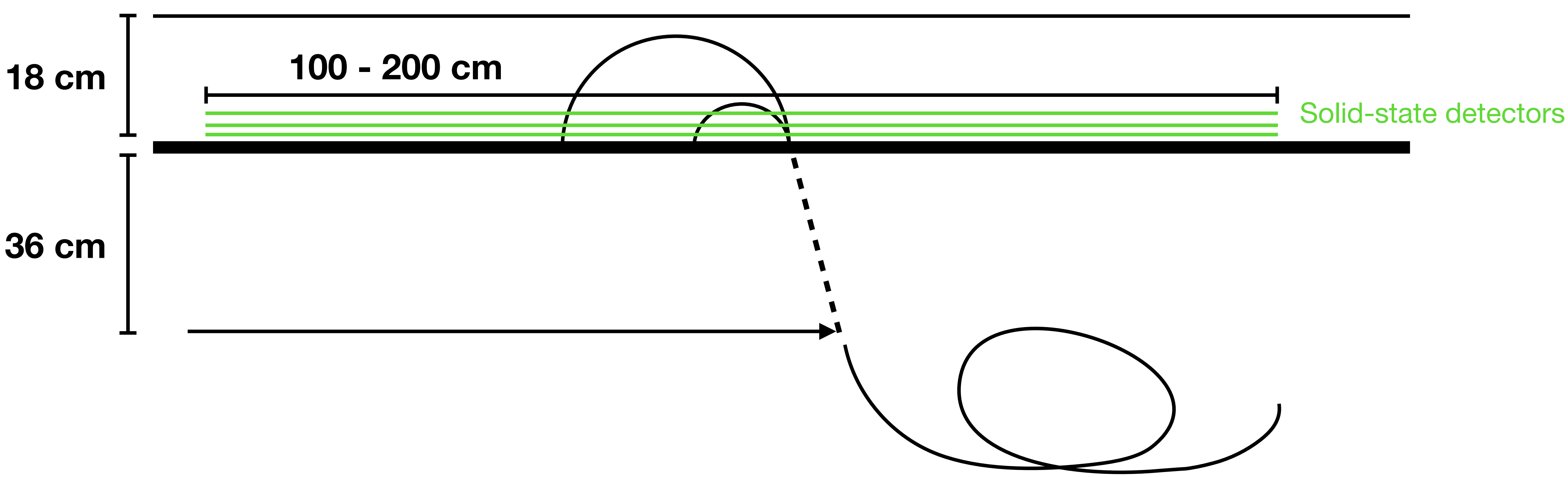
- In a magnetic field of 1 T, the curvature of electrons with p_T = 5 MeV/c is 1.7 cm
  - at least 2-3 detector layers to be stacked in ~ 1.5 cm
- The curvature of 50 MeV/c (p_T) electrons is 17 cm
  - at least ~ 18 cm between two conversion layers



Angular acceptance

- With an inner radius of ~ 37 cm and a length of 200 cm (100 cm), the angular acceptance would be ~ 94% (80%)

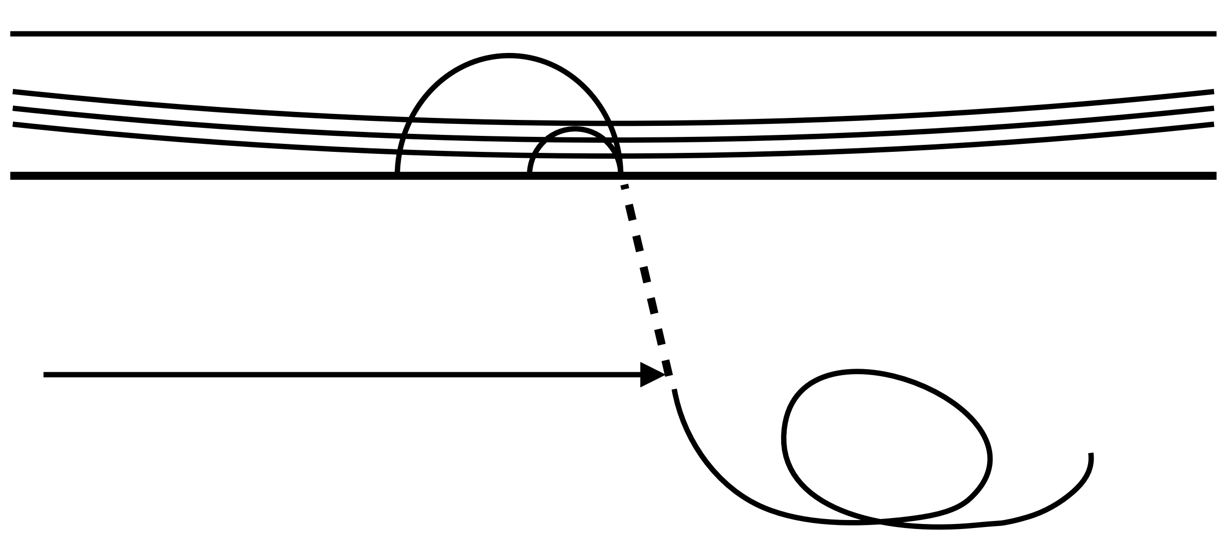
1st pair tracker surface: 7.5 - 15 m2
2st pair tracker surface: 10 - 20 m2
...



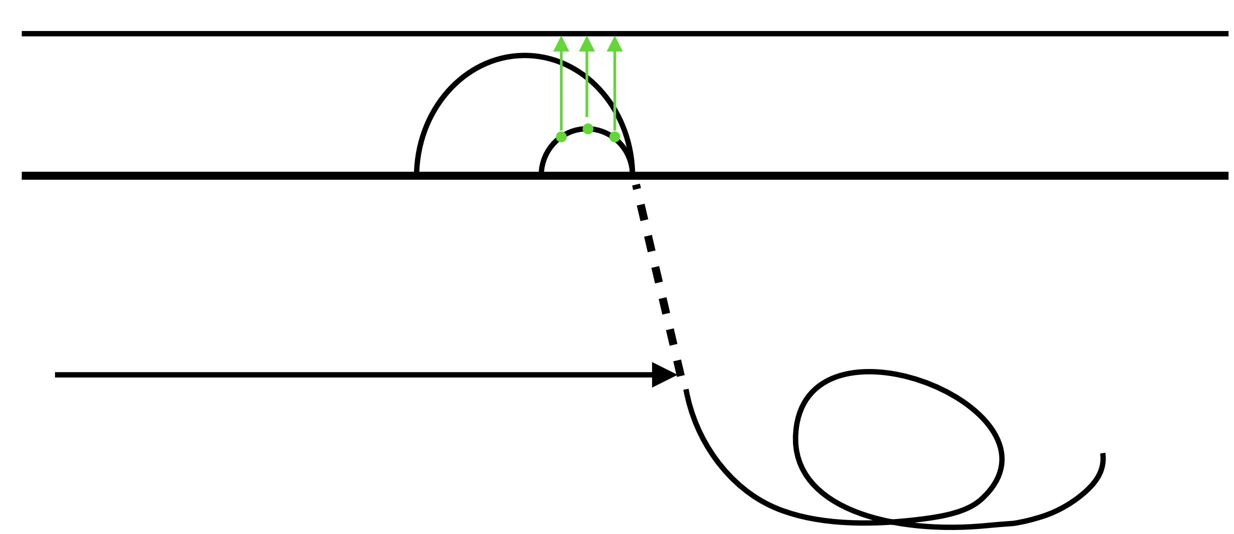
Gaseous detector options

- At such low momenta, two options can be considered:
  - stereo wire chamber
  - radial time projection chamber
- Maybe also a transverse wire chamber?

STEREO WIRE CHAMBER

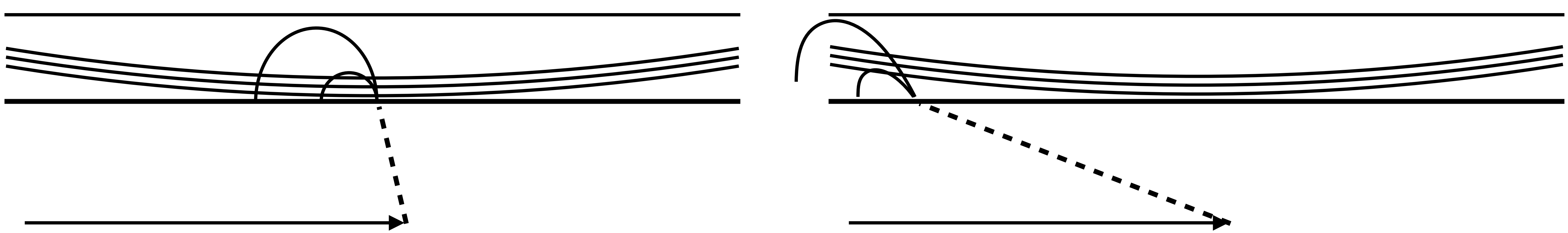


RADIAL TPC



Stereo wire chamber

- The strongest limitation of a stereo wire chamber is the increase of the radial position at large Z due to the stereo configuration
    - reduced transverse momentum acceptance at large Z
    - worsen situation if magnetic field is larger and dimensions smaller



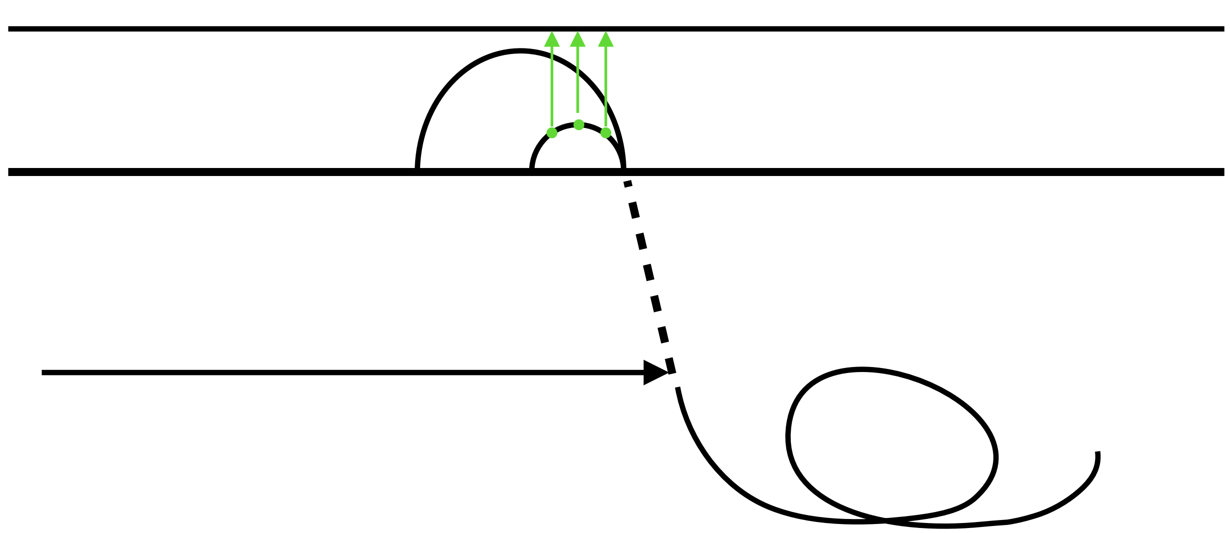
- A magnetic field gradient helps to recover the acceptance at large Z
- A good compromise between momentum acceptance (larger with small stereo angles) and resolution (better with large stereo angles) has to be found

Some numerical example

L [cm]	$B_{Z=0}$ [T]	$B_{Z=L/2}$ [T]	R_{IN} [cm]	Smallest cell size at Z = 0 [cm]	Inner layer stereo [º]	$P_{T,MIN}$ at Z = 0 [MeV]	$P_{T,MIN}$ at Z = L/2 [MeV]	σ_Z [mm]	Angular accept.
200	1	1	36.7	0.7	12	**6**	**24**	0.7	94%
200	1	0.6	36.7	0.7	12	**6**	**15**	0.7	94%
100	1	0.8	36.7	0.7	11	**6**	**8**	0.8	80%

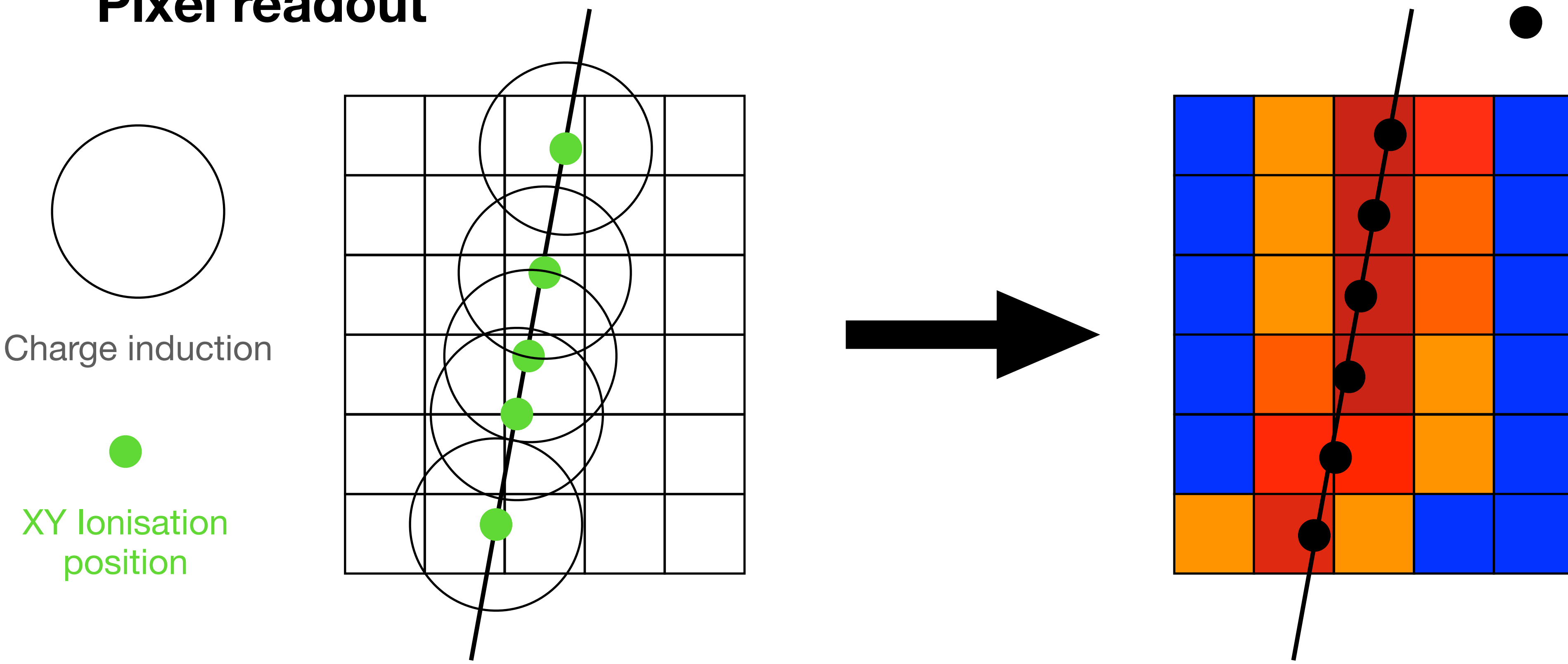
Radial TPC

- A radial GEM-TPC would ensure large angular and uniform p_T acceptance
- The small conversion rate would produce low occupancy
  - a strip readout, as in existing (KLOE, BESIII) cylindrical GEMs, would be adequate —> much easier integration w.r.t. a pixel readout
- More hits but worse resolutions w.r.t. a wire chamber
  - Performances could be limited by diffusion and modelling of drift trajectories



Strip vs. Pixel Readout

Pixel readout



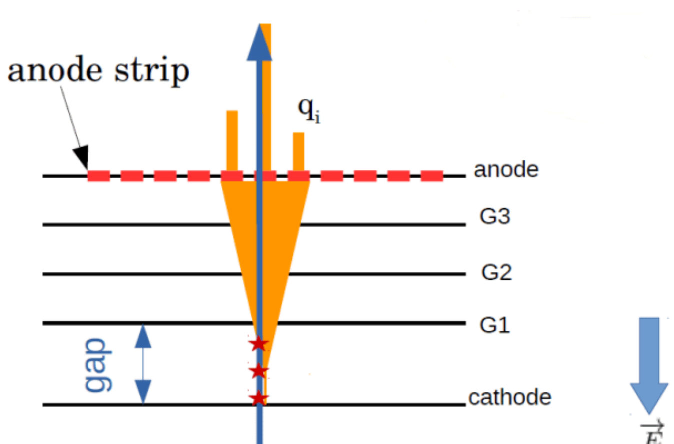
● Center of Gravity (CoG)

+ Z position from drift time

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

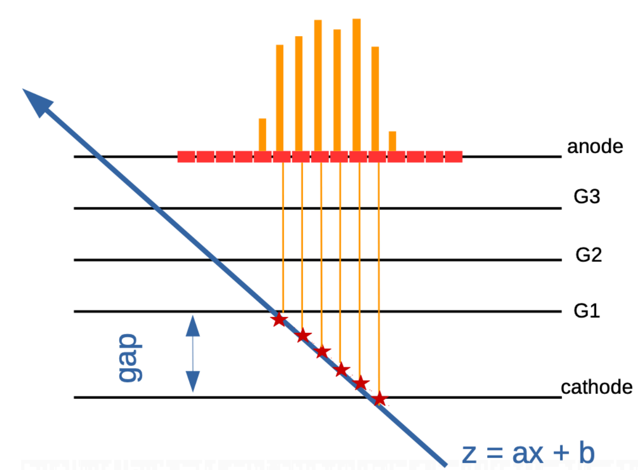
Stereo strip readout of thin-gap chambers

CoG



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

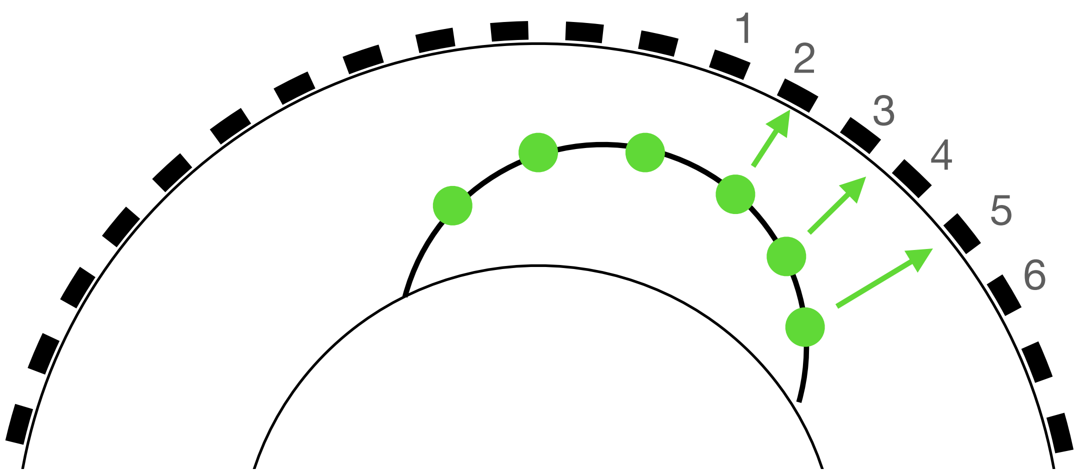
µTPC



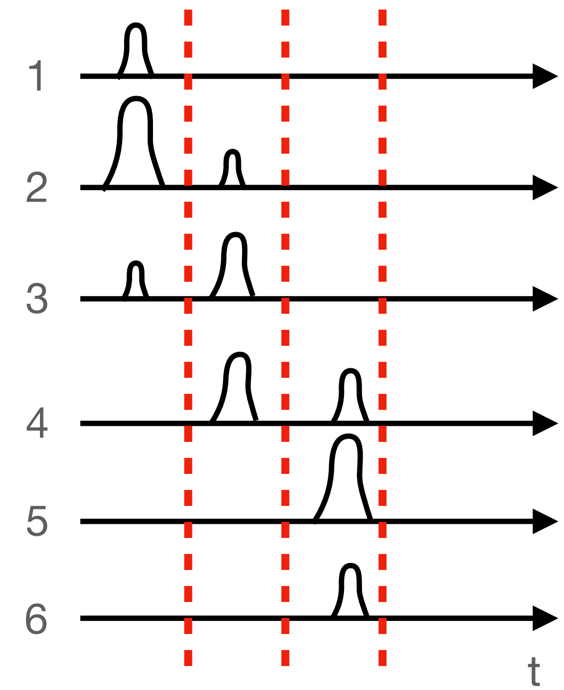
Bad resolution with O(10cm) drift
(R: diffusion —> O(0.5 mm)
phi: strip granularity —> O(1 mm))

Readout of a radial TPC

Stereo strip readout with time-resolved CoG measurement



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



CoG in bins of time
(ideal binning depends on ionization density, ~ 35 ns, diffusion effect, ~ 25 ns and electronics shaping time)
+
radial coordinate from precise time measurements

Requires electronics with:

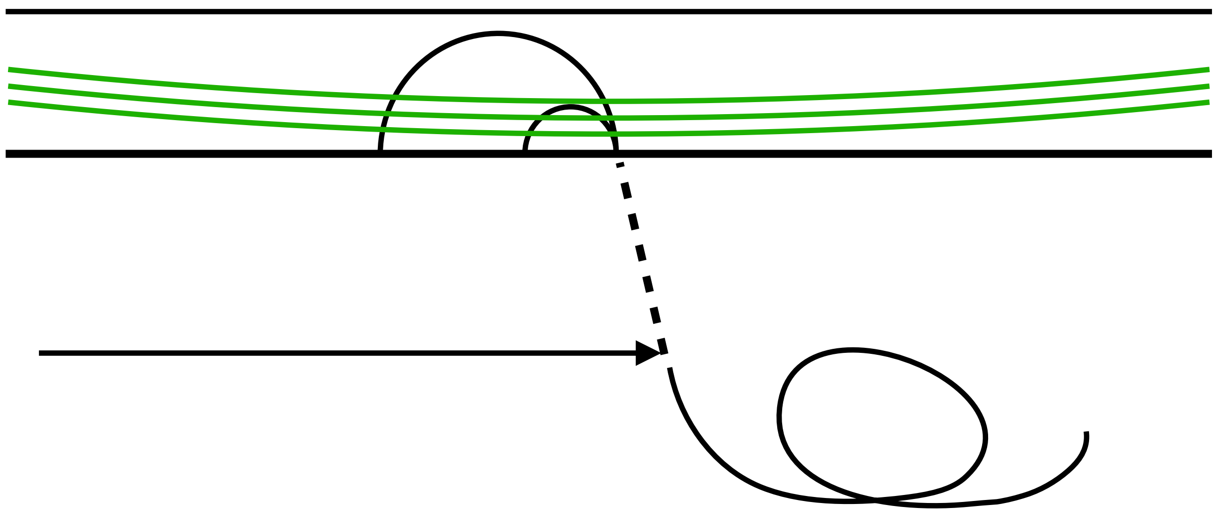
- large digitisation speed (>> 10 MSPS)
- short peaking time (<< 100 ns)
- > 10 us digitisation depth

	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

Fast Simulation

- Both wire drift chamber and TPC w/ time-resolved CoG can be approximately simulated with radial layers (hyperboloid or cylinder), corresponding to **cell layers** and **time bins**, respectively
  - wire chamber: 2D hits, one per layer (7 mm), O(150 μm) Rφ resolution, O(800 μm) Z resolution
  - TPC: 3D hits, one per time bin (e.g. 100 ns), O(500 μm) R resolution, O(200 μm) Rφ resolution, O(800 μm) Z resolution

STEREO WIRE CHAMBER



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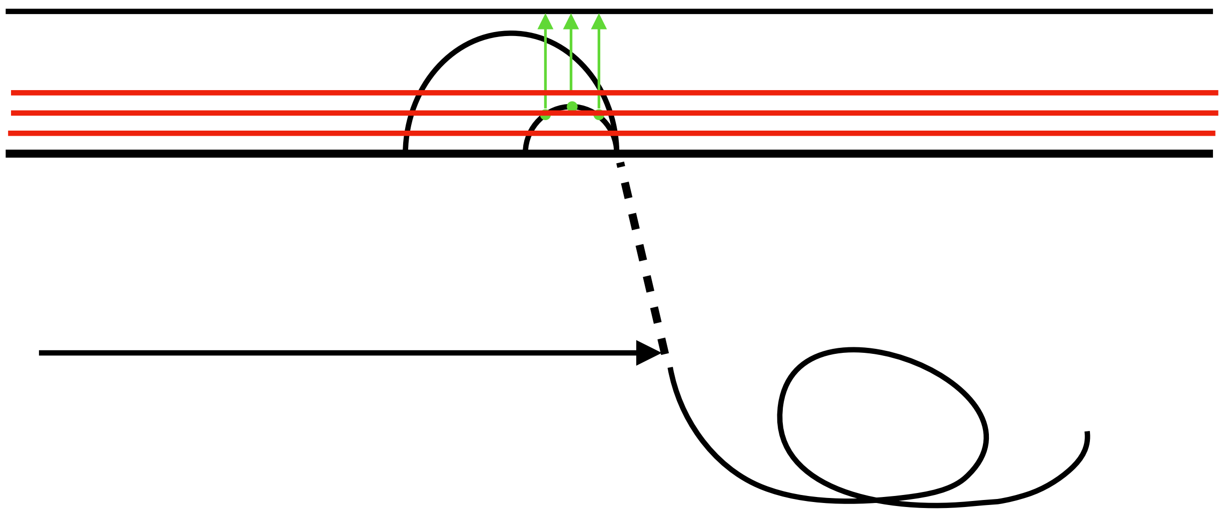

Discussion

- Gaseous detectors could be a good option for pair tracking in the photon conversion detector
  - large acceptance, relatively low cost
- Wire chambers:
  - PRO: solid technology (MEGII CDCH in a milder environment), excellent resolutions
  - CONTRA: acceptance constraints due to the stereo geometry
  - good for large detectors in a small magnetic field
- Radial TPC:
  - PRO: large and uniform momentum and angle acceptance, 3D reconstruction (but with slightly worse single-hit resolutions)
  - CONTRA: less consolidated approach (both hardware and reconstruction), R&D needed for the readout technique (maybe a custom ASIC to be developed)
  - better for smaller detectors in a larger magnetic field