Novel method for in-situ drift velocity measurement in large-volume TPCs

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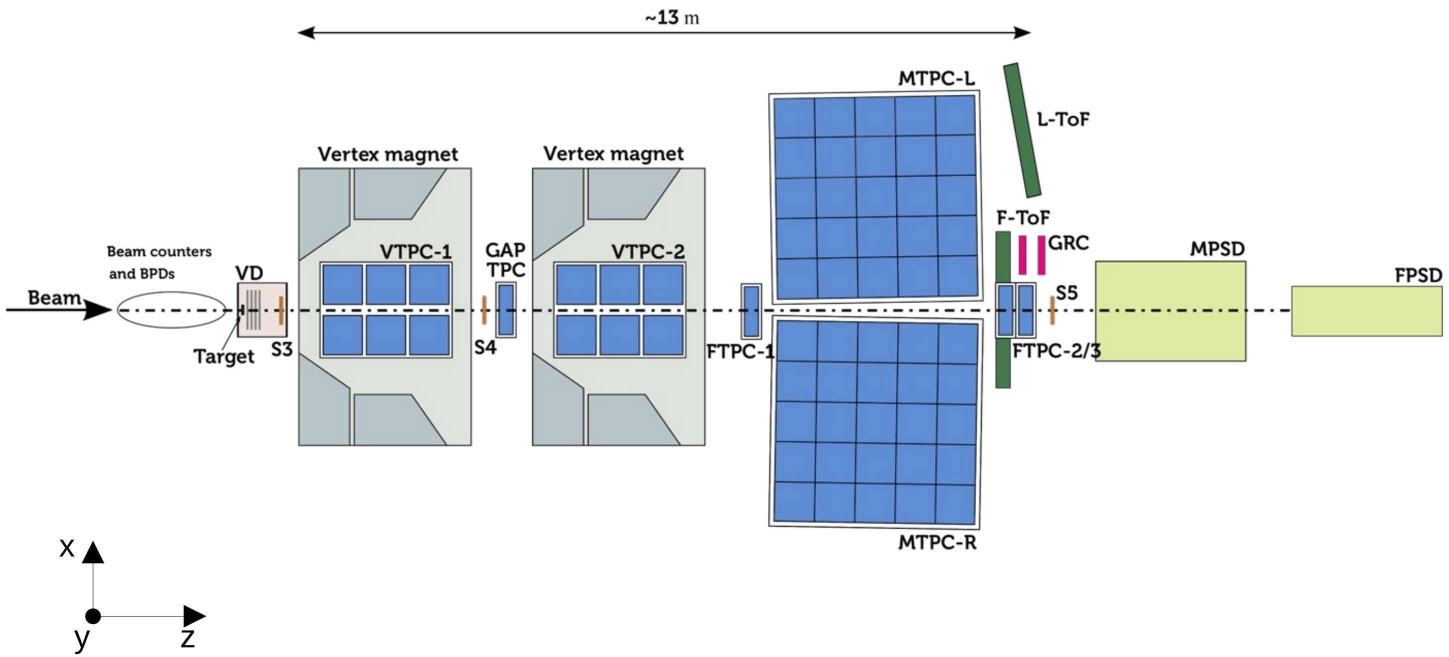
arXiv:2405.01285

Motivation:

- In experiments involving TPCs, electron drift velocity is a key parameter.
- E.g. NA61/SHINE at CERN SPS has TPCs with ~40m^3, 4 large + 4 small chambers.



- Due to ~1m drift length, permil v_{drift} accuracy is needed for ~1mm precision. The v_{drift} has to be remeasured every ~5minutes due to ambient changes.
- During LS2, chambers were moved, so alignment etc also has to be calibrated.

In various experiments, typical methods involve:

- The so-called bottom point method. Needs in advance t_0 and effective drift length.

  → Prone to systematic bias.

- Exhaust analyzer chamber method. Needs in-situ pressure, temperature, drift field measurement, and perfect quality exhaust collection.

  → Prone to systematic bias.

- Cosmic ray track start and endpoint. Needs t_0 and effective drift length.

  → Prone to systematic bias.

- UV laser tracks. Self-contained, high precision, e.g. ALICE, STAR etc.

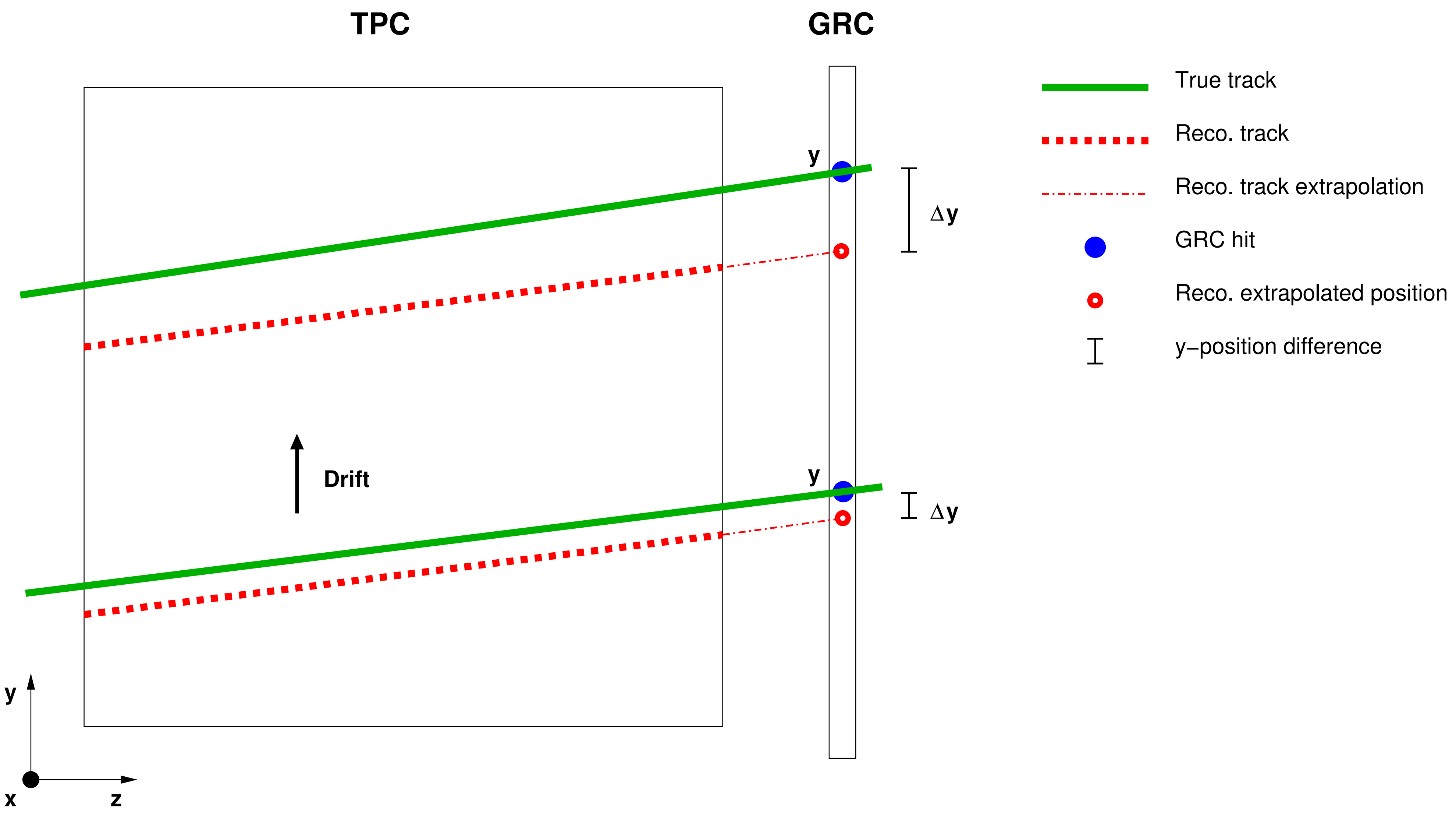
  → Very good accuracy. But NA61/SHINE does not have such a system.

- Can we do something similar to UV laser system, with minimal added complexity?

  → Yes, put a known segmented reference detector after the TPC.

  (Geometry Reference Chamber, GRC)

The GRC concept:

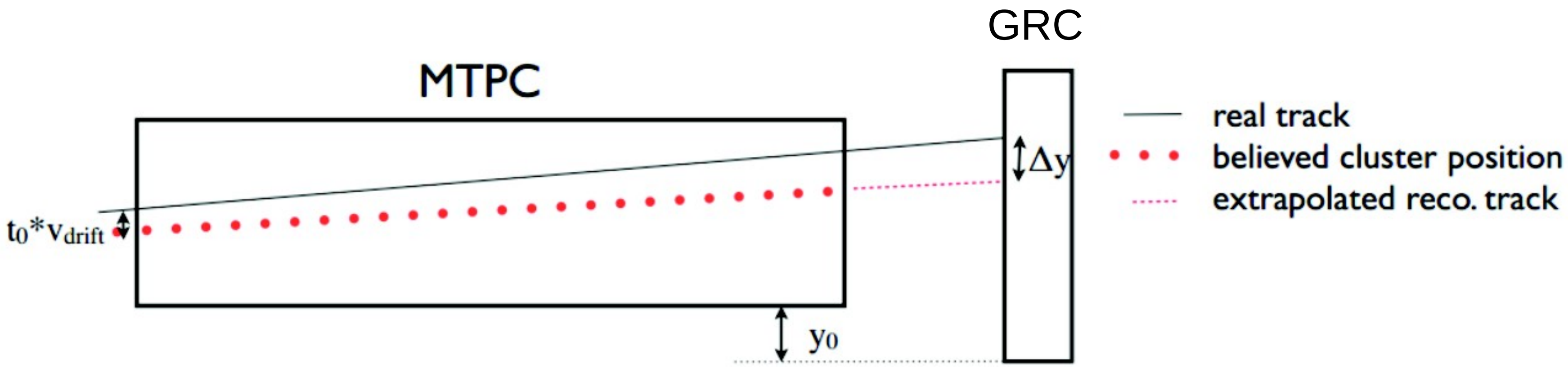


Quantitatively:

- Reconstruction of TPC drift (y) coordinate:

  $y_{true} = y_{0,true} - (t_{0,true} + t_{drift}) * v_{drift,true}$ and $y_{TPC,rec} = y_{0,assumed} - (t_{0,assumed} + t_{drift}) * v_{drift,assumed}$

- Match TPC track to GRC hit with some tolerance window:

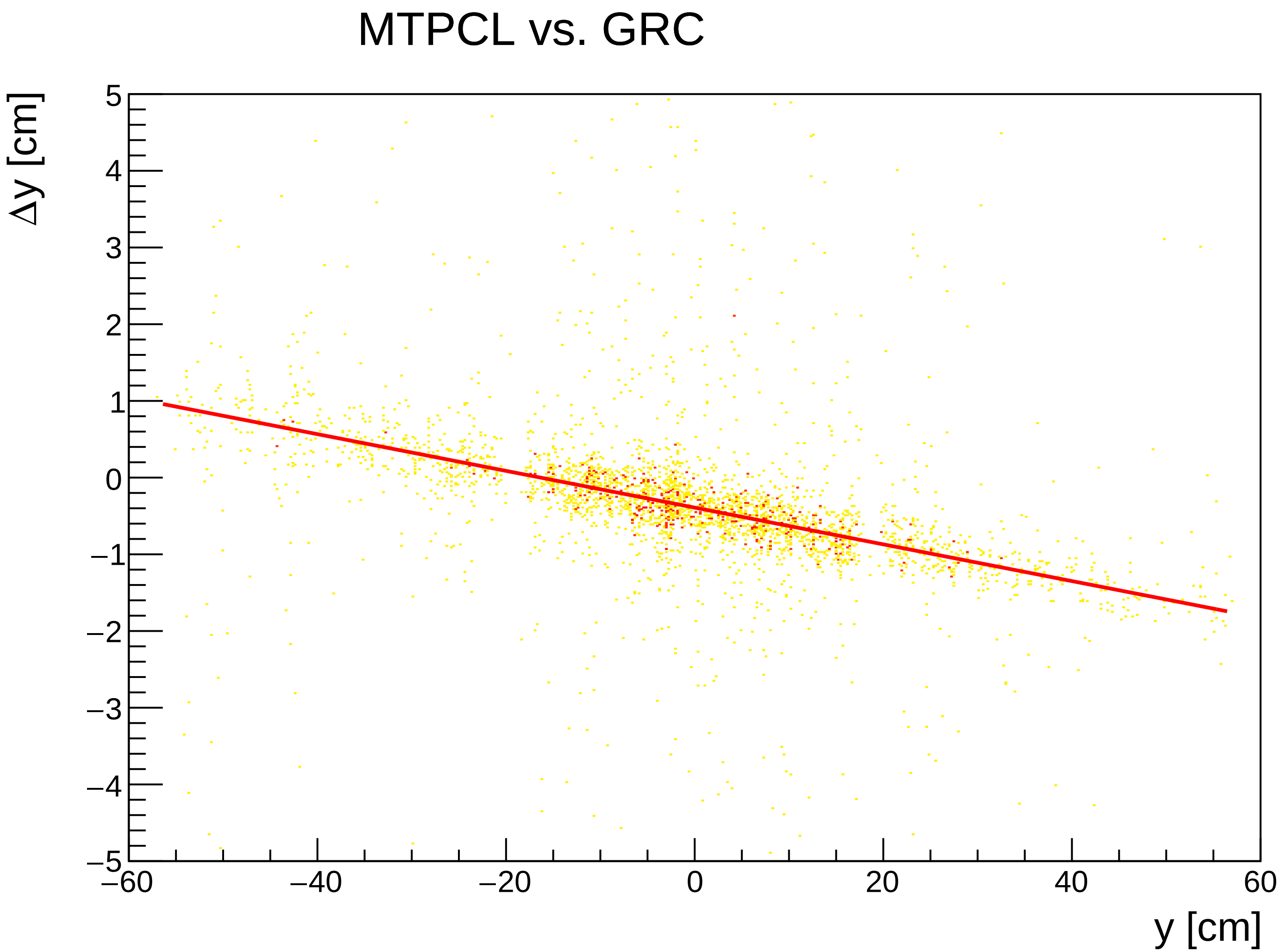


- Check TPC-GRC drift coordinate mistmatch as a function of GRC coordinate.

$$\Delta y = (v_{drift,assumed} / v_{drift,true} - 1) * y_{true}$$

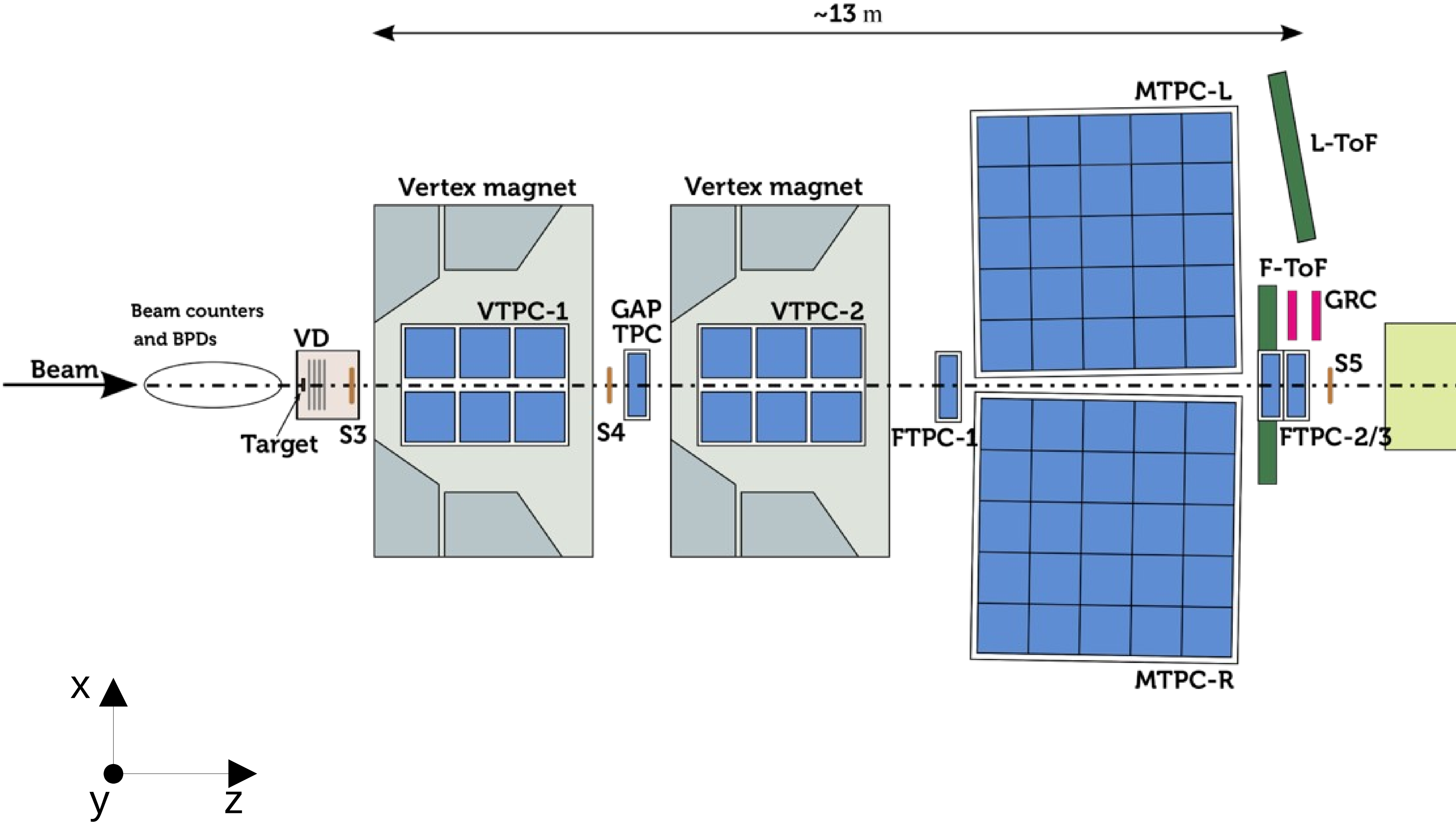
$$+ (y_{0,assumed} - v_{drift,assumed} * t_{0,assumed} + v_{drift,assumed} * t_{0,true} - v_{drift,assumed} / v_{drift,true} * y_{0,true})$$

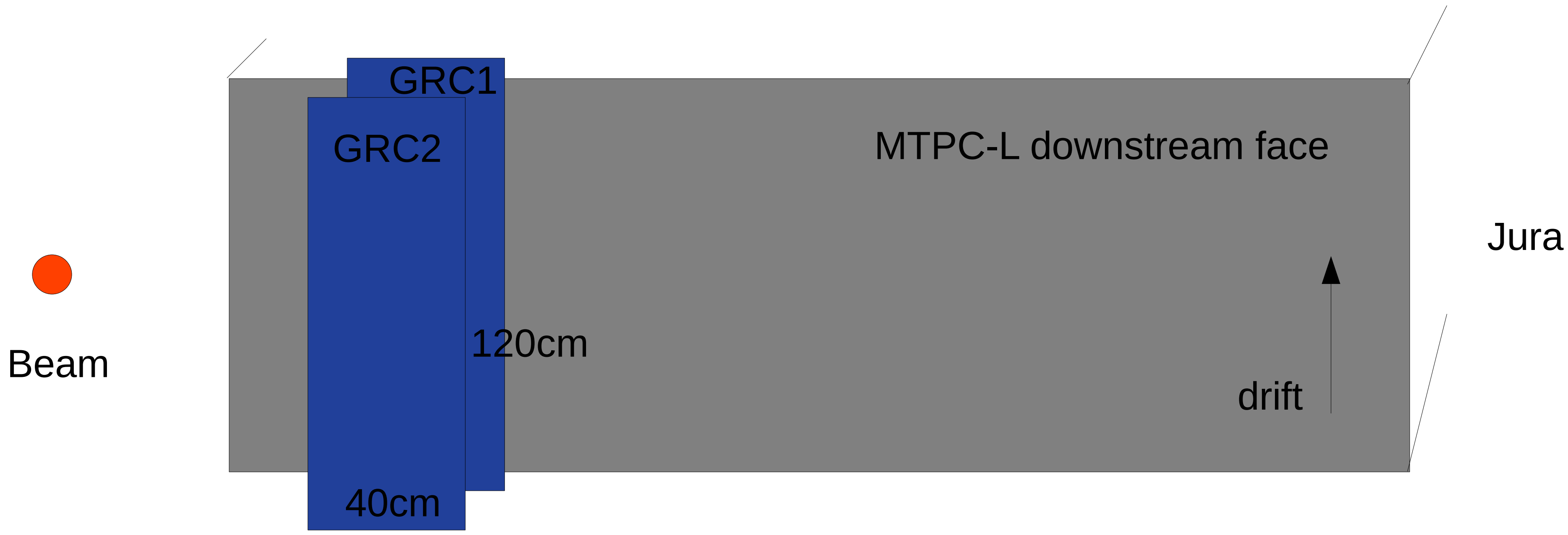
(And do this for every ~5minutes of data taking.)


MTPCL vs. GRC
Δy [cm]
y [cm]
5
4
3
2
1
0
−1
−2
−3
−4
−5
−60
−40
−20
0
20
40
60

Implementation:

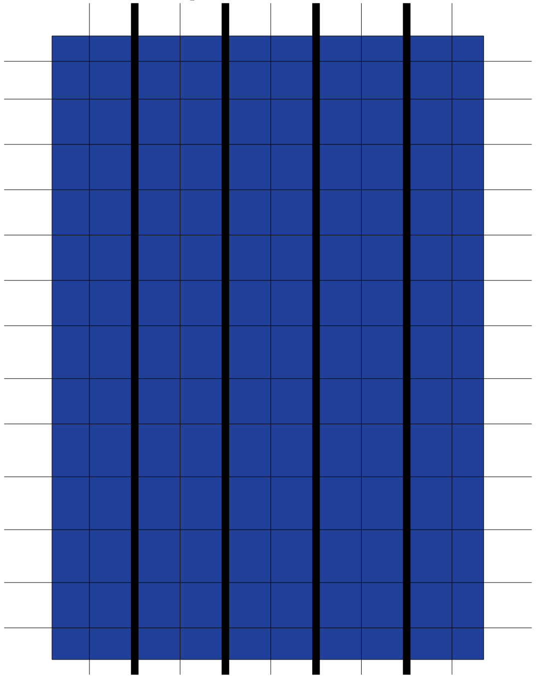
- In spring 2022, GRC1 and GRC2 chambers were constructed and installed:




GRC1
GRC2
MTPC-L downstream face
Jura
Beam
120cm
drift
40cm

- Minimal complexity: 40 x 120 cm MWPC, Cartesian readout,
  the readout with TPC electronics as „fake TPC".
- FieldWires and PickupWires are read out.
- Low multiplicity → large enough acceptance.
- High multiplicity → „narrowable" chamber via switching off some SenseWires.

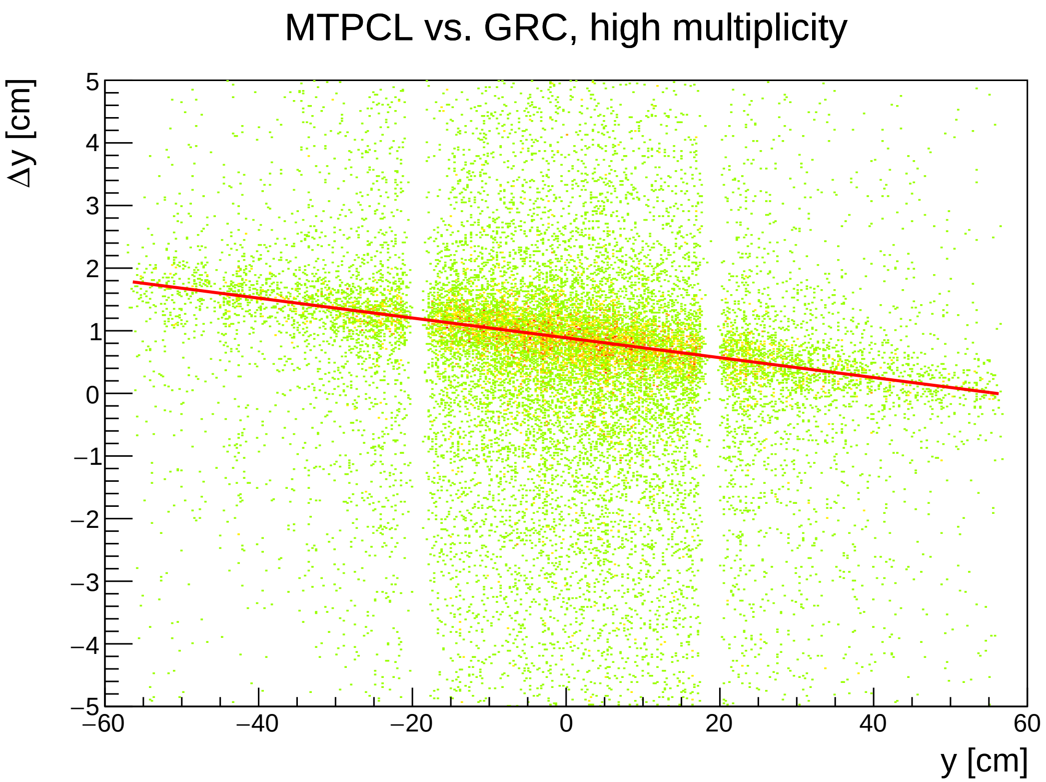
FW/SW (FW can be read out as one coordinate)

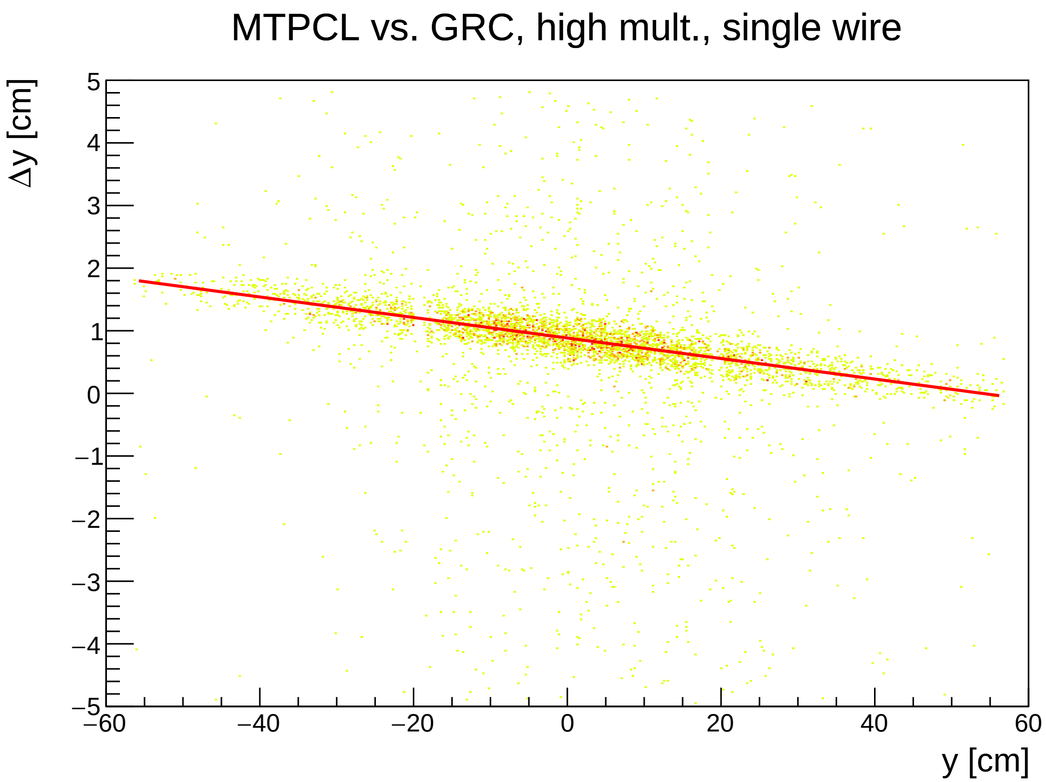


horizontal pickup wires can be read out as other coord

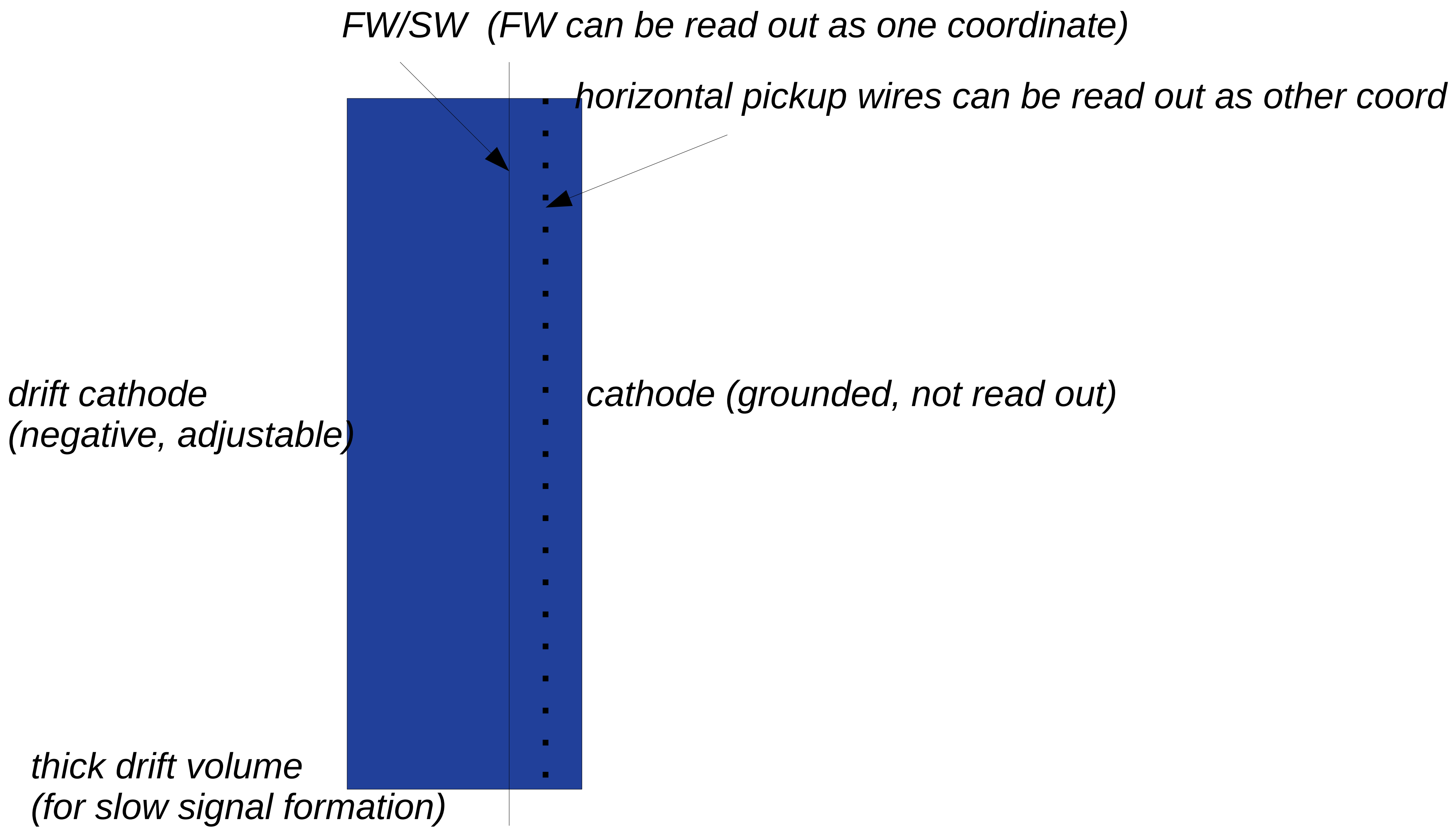
For high mult.run switch off some SW (make chamber narrow)

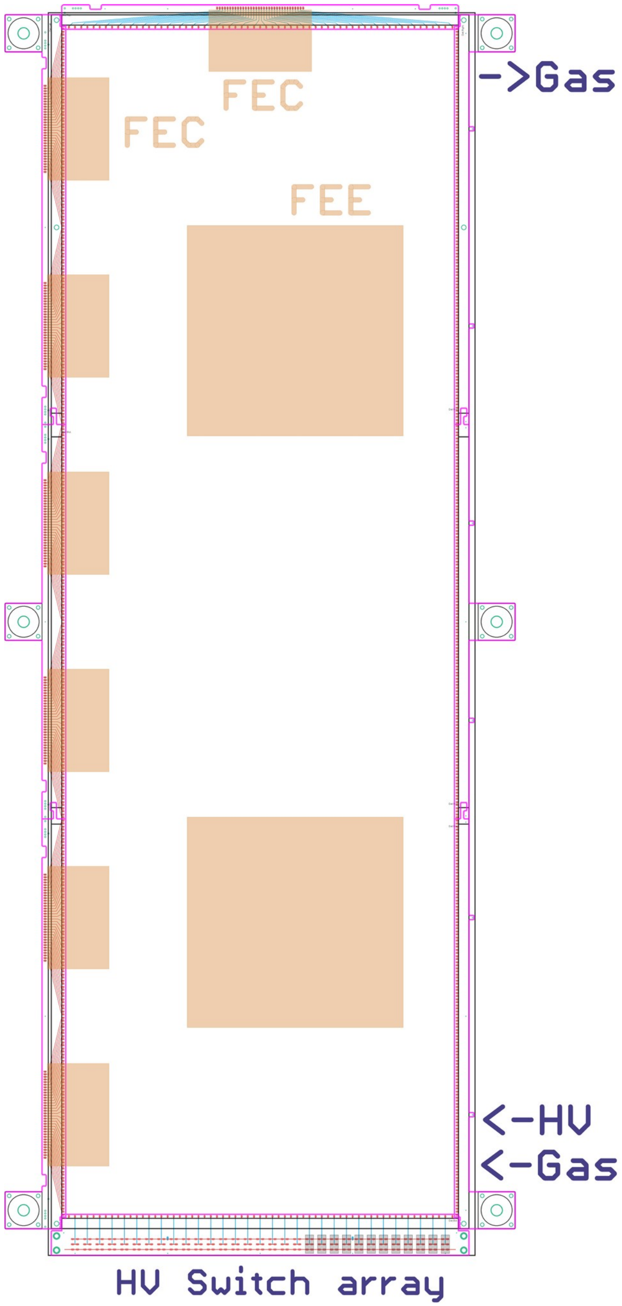
For high multiplicity runs, SenseWire disabling helps a lot:



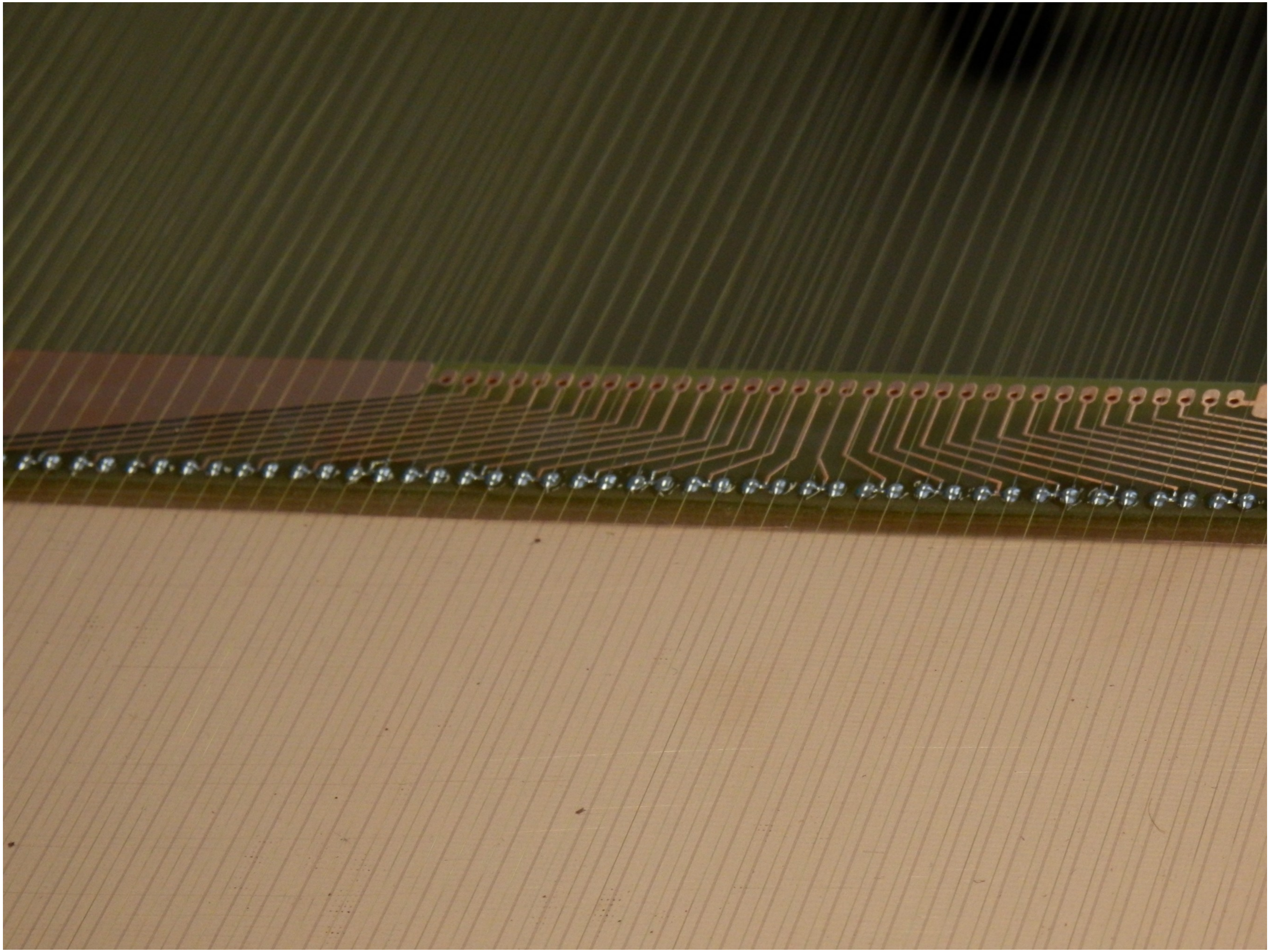


- But, TPC readout is slow: thick drift volume and adjustable drift field used to match long delay of TPC FEE (i.e. signal formation is not too early). Side view:

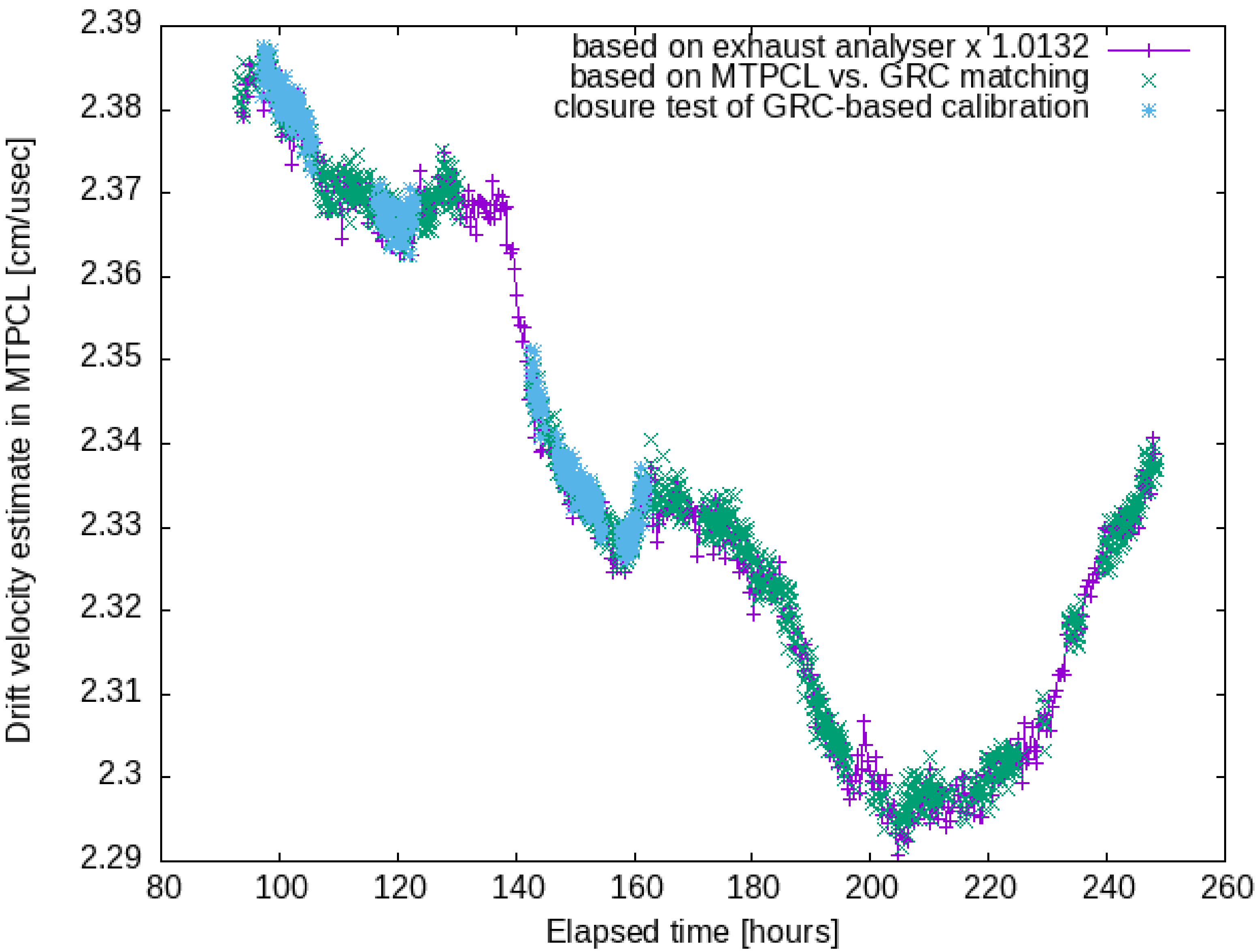



->Gas
FEC
FEC
FEE
<-HV
<-Gas
HV Switch array

(An assembly step)



Validation:



based on exhaust analyser x 1.0132
based on MTPCL vs. GRC matching
closure test of GRC-based calibration
Drift velocity estimate in MTPCL [cm/usec]
2.39
2.38
2.37
2.36
2.35
2.34
2.33
2.32
2.31
2.3
2.29
80
100
120
140
160
180
200
220
240
260
Elapsed time [hours]

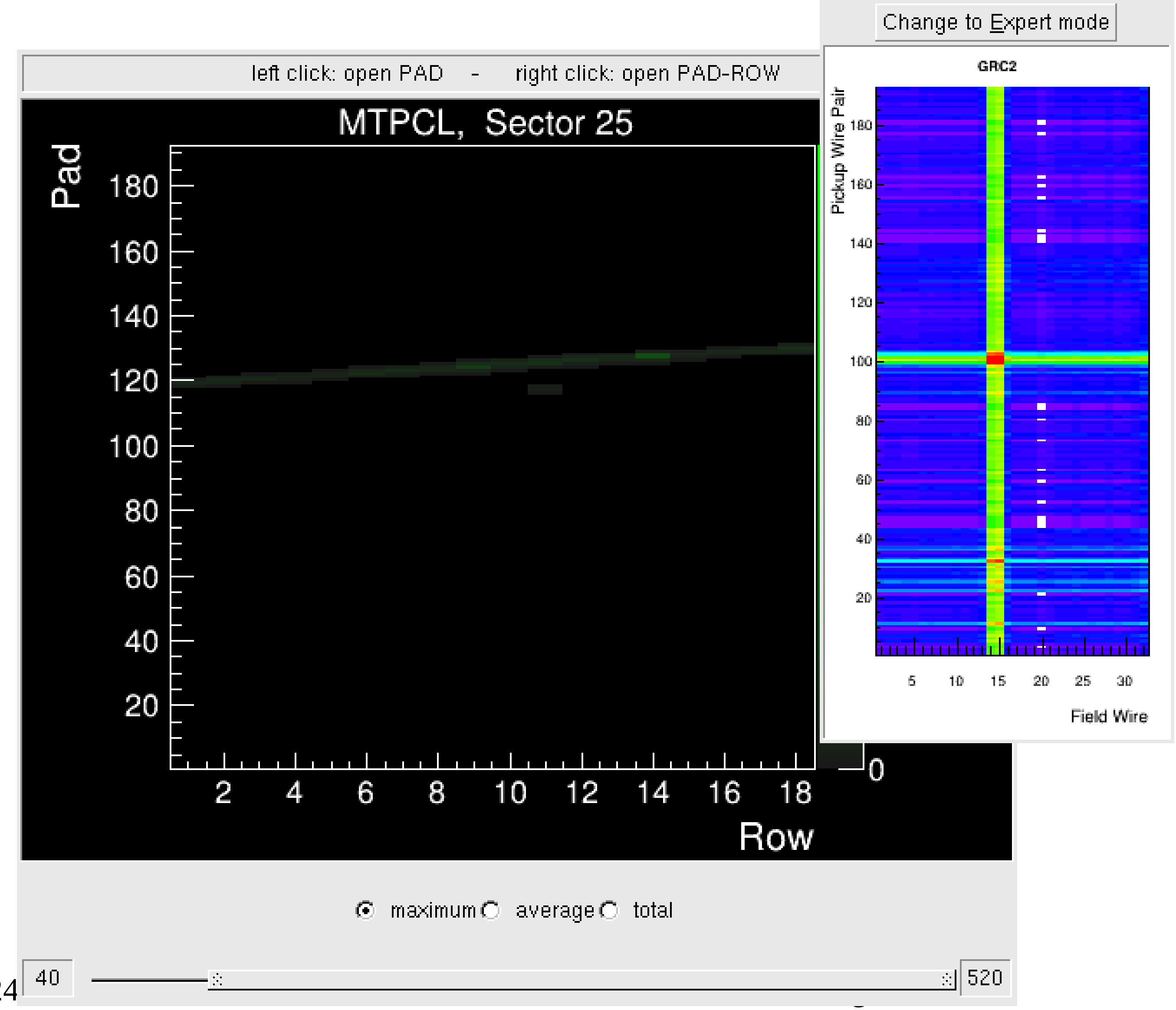
Summary:

- Permil accuracy v_{drift} calibration was necessary for NA61/SHINE (~1m drift).
- Bottom point method, exhaust method etc considered, but prone to systematics.
- Developed the GRC concept as a minimal complexity analogy of the UV laser method.
- Permil accuracy was achieved.
- The method can be even improved for t_0 and alignment calibration.
- See also arXiv:2405.01285

BACKUP

Commissioning and reco optimization

- Beam bent to GRC:



The t0 calibration:

- Original calibration equation of ΔYvsY analysis is:

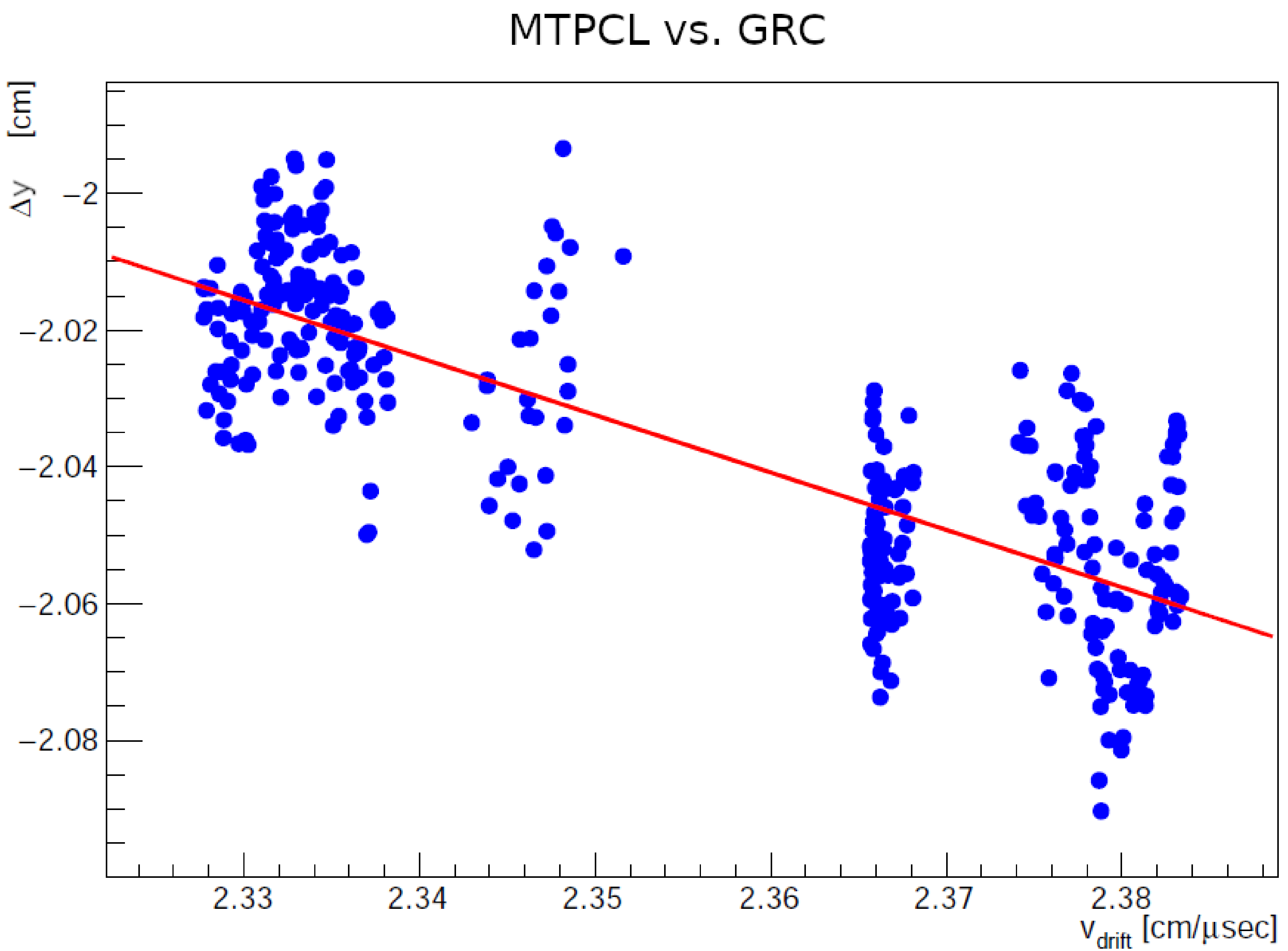
$$\Delta y = (v_{drift,assumed} / v_{drift,true} - 1) * y_{true}$$
$$+ (y_{0,assumed} - v_{drift,assumed}*t_{0,assumed} + v_{drift,assumed}*t_{0,true} - v_{drift,assumed}/v_{drift,true}*y_{0,true})$$

  - After vdrift is calibrated, $v_{drift,assumed} \approx v_{drift,true}$, i. e.:

    $$\Delta y = (t_{0,true} - t_{0,assumed}) * v_{drift} - (y_{0,true} - y_{0,assumed})$$

    (Δy then has no y_{true} dependence).

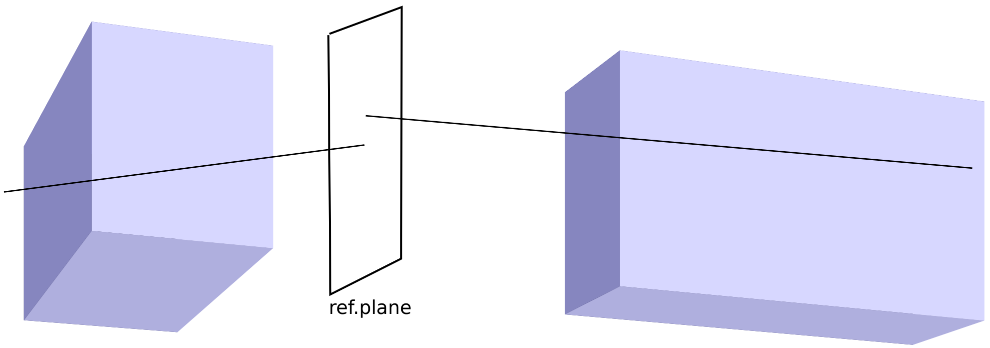
  - If v_{drift} is varying, slope and offset of Δy against v_{drift} gives t_0 and y_0 correction.


MTPCL vs. GRC
Δy [cm]
−2
−2.02
−2.04
−2.06
−2.08
2.33
2.34
2.35
2.36
2.37
2.38
v_drift [cm/μsec]

Alignment calibration:

- Misalignment biases dY vs Y analysis, and alignment is needed anyway.
- Developed alignment calibration tool using field-off data.

  Take main-vertex tracks, dissect to local tracks, refit them locally, check mismatch.



- Each chamber has 8 unknowns: θx,θy,θz, x0,z0, vDrift, t0, y0.
- Assume that e.g. downstream chamber is calibrated (except for t0,y0): our reference.
- Each straight track piece determined by four params (Nx,Ny,Mx,My) at ref.plane (by convention, we call it z=const plane).
- From data, we get corresponding (ΔNx,ΔNy,ΔMx,ΔMy) mismatch scatter field as a function of params (Nx,Ny,Mx,My).

- To first order in $\theta x, \theta y, \theta z$, x0,z0, (vDriftCorr-1), t0Corr, y0 corrections, one has:

  $\Delta Nx = (Nx^2+1)*\theta y+Ny*(Nx*\theta x+\theta z)$,

  $\Delta Ny = (\theta x+\theta y)*Ny^2+(vDriftCorr-1)*Ny-Nx*\theta z+\theta x$,

  $\Delta Mx = (\theta x*My+\theta y*Mx+z0)*Nx+\theta y*z+\theta z*My-x0$,

  $\Delta My = (My*\theta x+Mx*\theta y+z0)*Ny+\theta x*z-\theta z*Mx-y0$
  $+(My-yAnodeRec)*(vDriftCorr-1)-t0Corr*vDriftRec$

  (derived using Maple).

- For $|Ny| \approx 0$ tracks:

  $\Delta Nx = (Nx^2+1)*\theta y$,

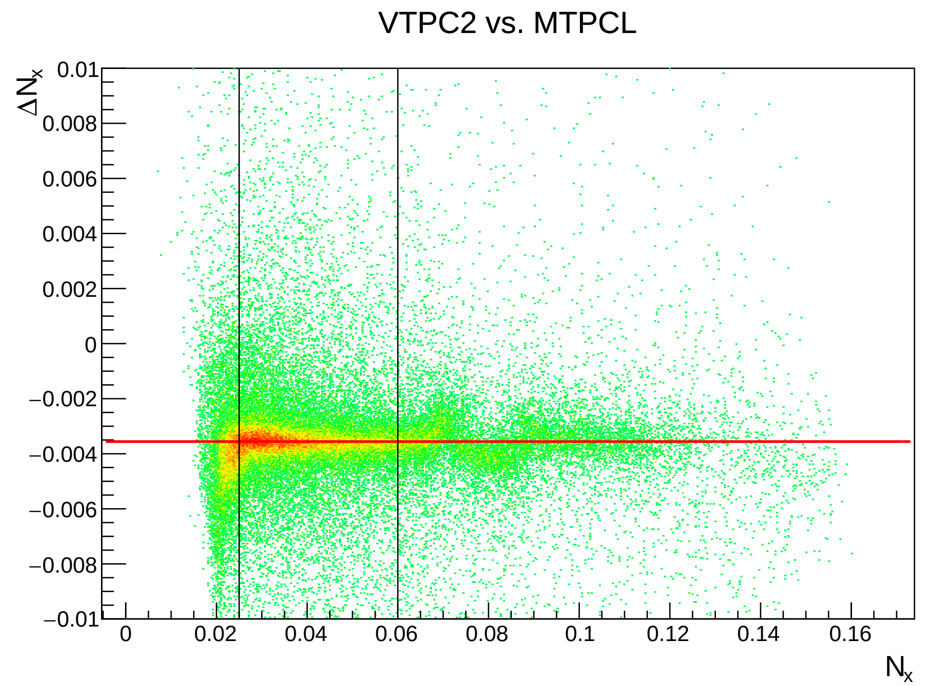
  $\Delta Ny = -Nx*\theta z+\theta x$ → one can extract $\theta x, \theta y, \theta z$ correction.

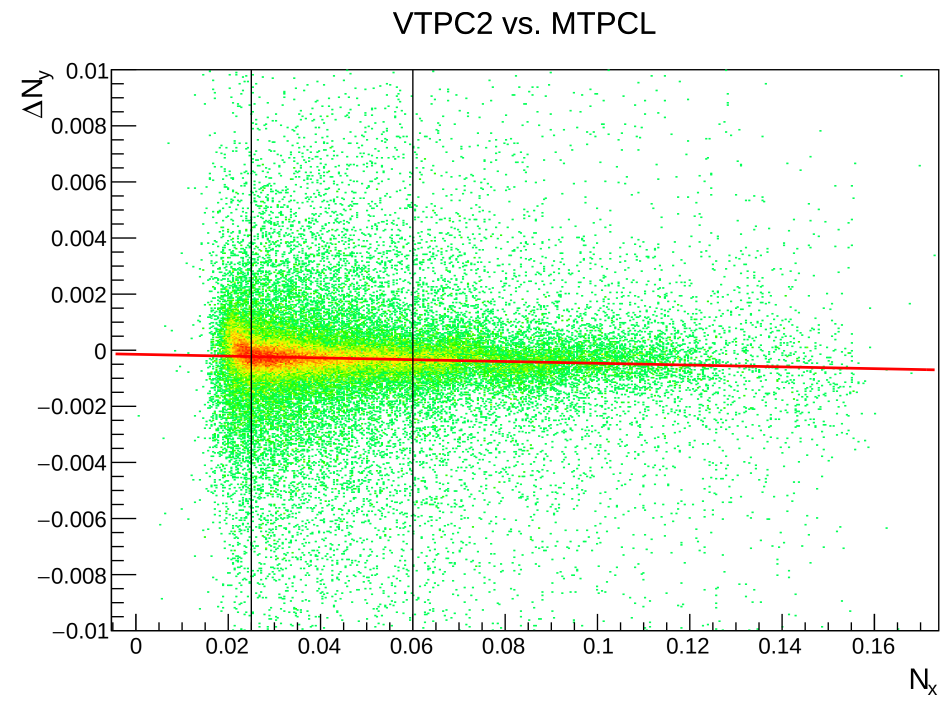
- After:

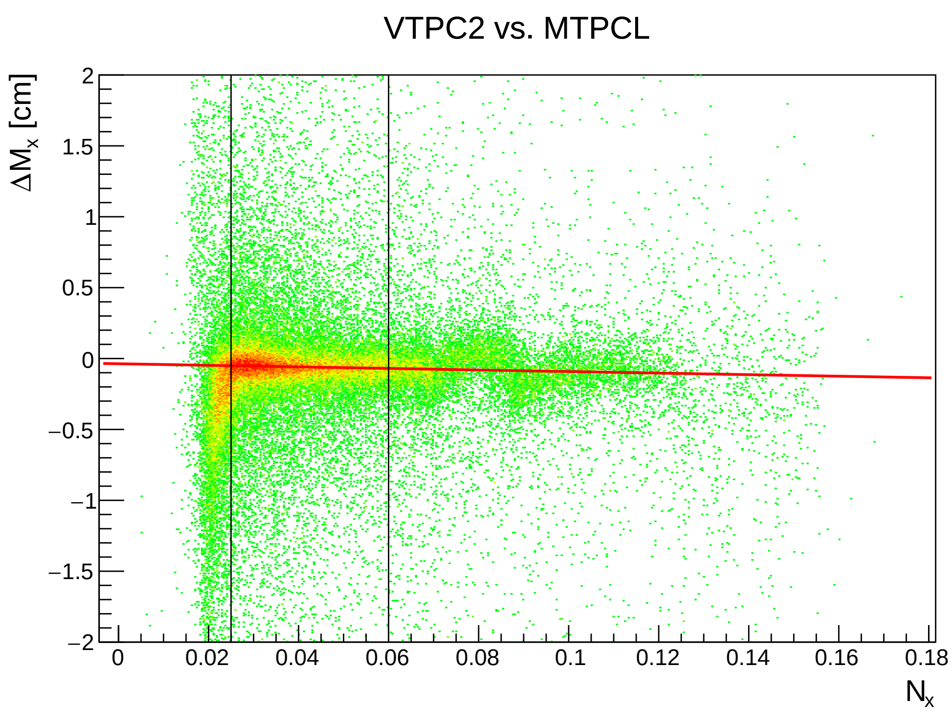
  $\Delta Mx = z0*Nx-x0$ → one can extract x0,z0 correction.

- After:
  $\Delta My = My*(vDriftCorr-1) + (-yAnodeRec*(vDriftCorr-1)-t0Corr*vDriftRec-y0)$
  → usual Δy vs y analysis for vDrift correction.

- After:
  $\Delta My = -t0Corr*vDrift - y0$
  → usual Δy vs v_{drift} analysis for t0 and y0 corrections.


VTPC2 vs. MTPCL
ΔN_x
N_x


VTPC2 vs. MTPCL
ΔN_y
N_x


VTPC2 vs. MTPCL
ΔM_x [cm]
N_x