Testbeam measurements and realistic simulation for the SPD straw drift tubes

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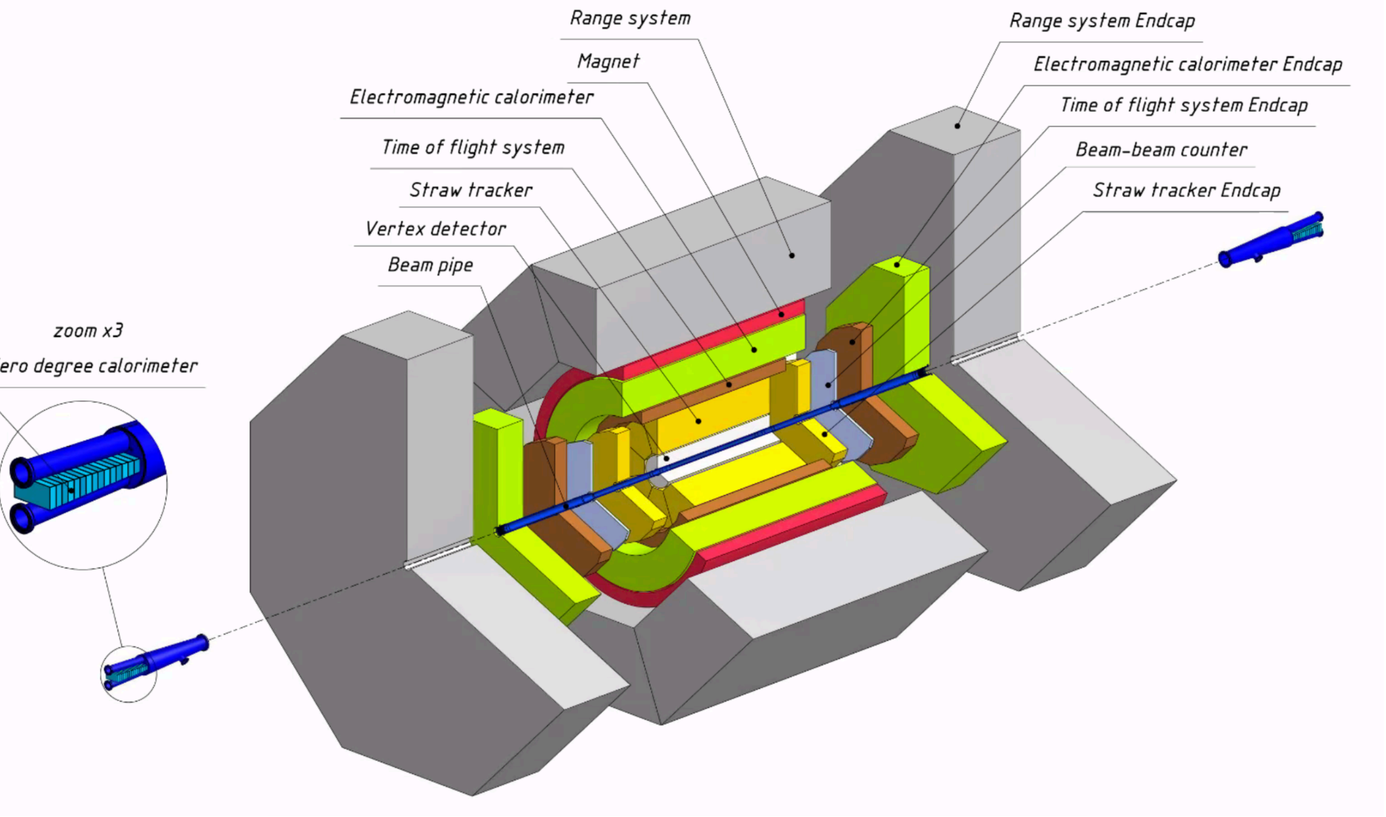
Outline

- Spin Physics Detector (SPD) @ NICA collider
  - SPD Straw Tracker
- Straw tubes
  - Main principles of operation
  - Readout electronics
  - Realistic simulation
- Testbeam measurements
- Summary

Testbeam main goals

- Optimisation of Straw Tracker readout of the **SPD** experiment @ NICA collider
- Comparison of different readout options for straw tubes (also in magnetic field)

SPD @ NICA

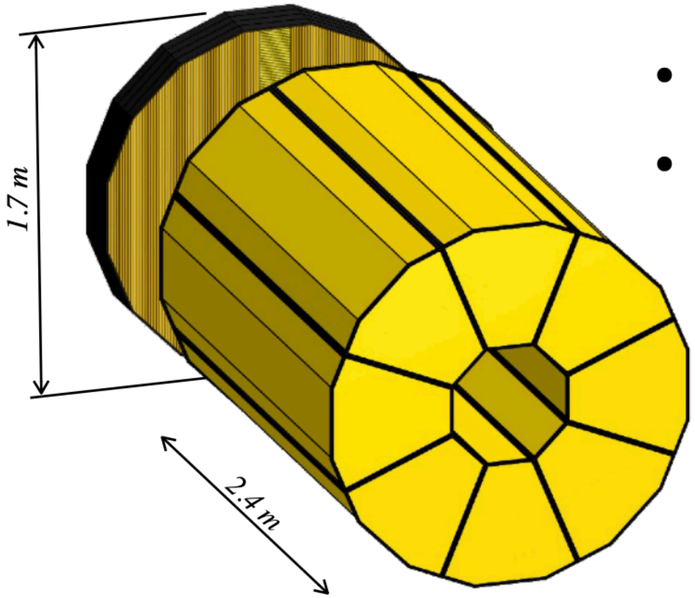


>300 participants
>30 institutions
>14 countries

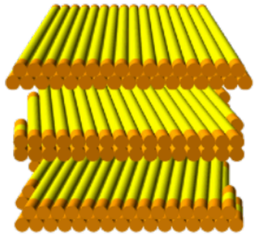
- **SPD** is a universal facility with the primary goal to study unpolarised and polarised gluon content of proton and deuteron
- **SPD** project was approved by PAC and had its first proto-collaboration meeting in 2019
- Conceptual Design Report (*CDR*) is approved at the beginning of 2021, arXiv:2102.00442
- Technical Design Report (*TDR*) of **SPD** to be prepared during 2021- beginning of 2023
- Beginning of data-taking for **SPD** after 2028

SPD Straw Tracker (ST)

- Main tracking system of SPD
- Spatial resolution of 150 μm
- Number of readout channels ~40k
- Can be used for particle identification (PID) if track ionisation losses are measured



- Barrel: 8 modules with up to 30 double-layers, *ZUV*
- Endcap: 12 double-layers, *XYUV* orientation

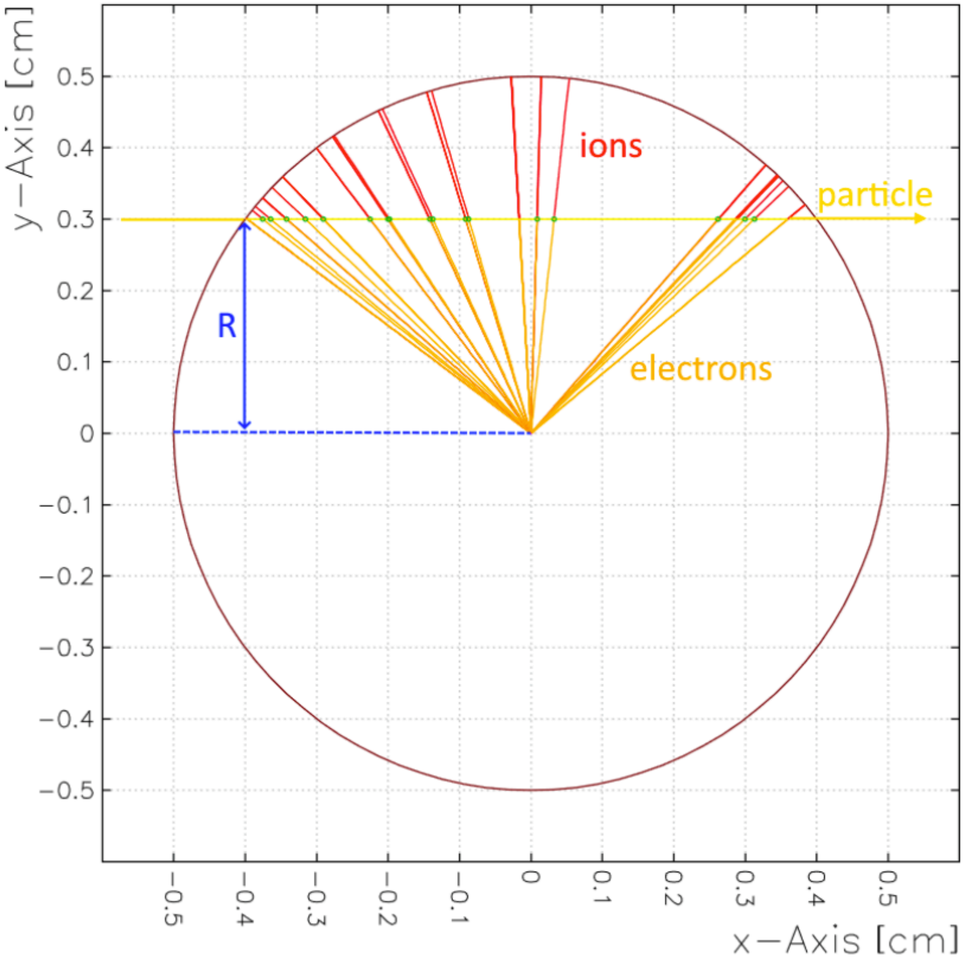


Small material budget and achievable large acceptance make the Straw Tracker attractive for the SPD experiment and future facilities like the Near Detector complex of the DUNE experiment and the Spectrometer Straw Tracker of the SHiP experiment.

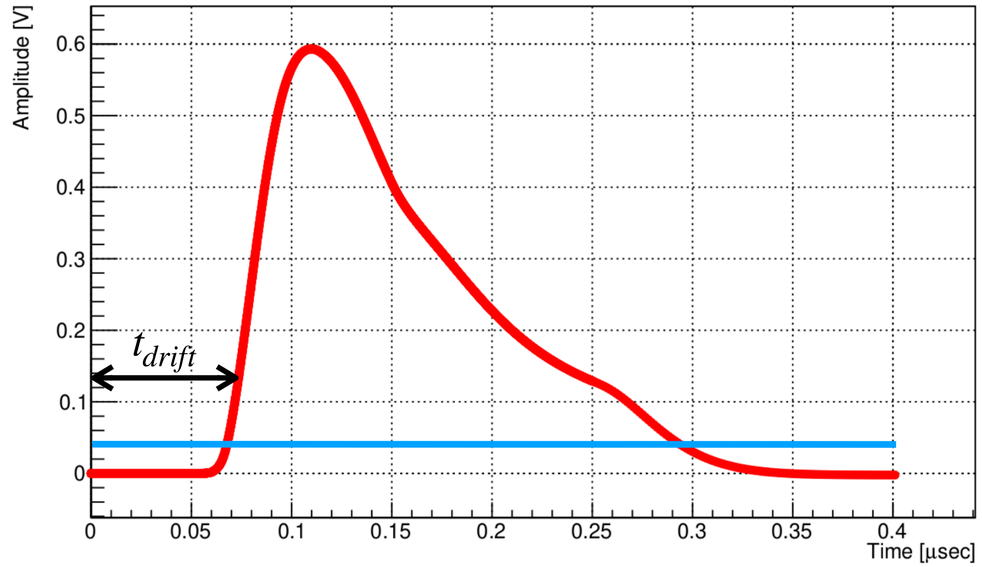
Straw Tubes

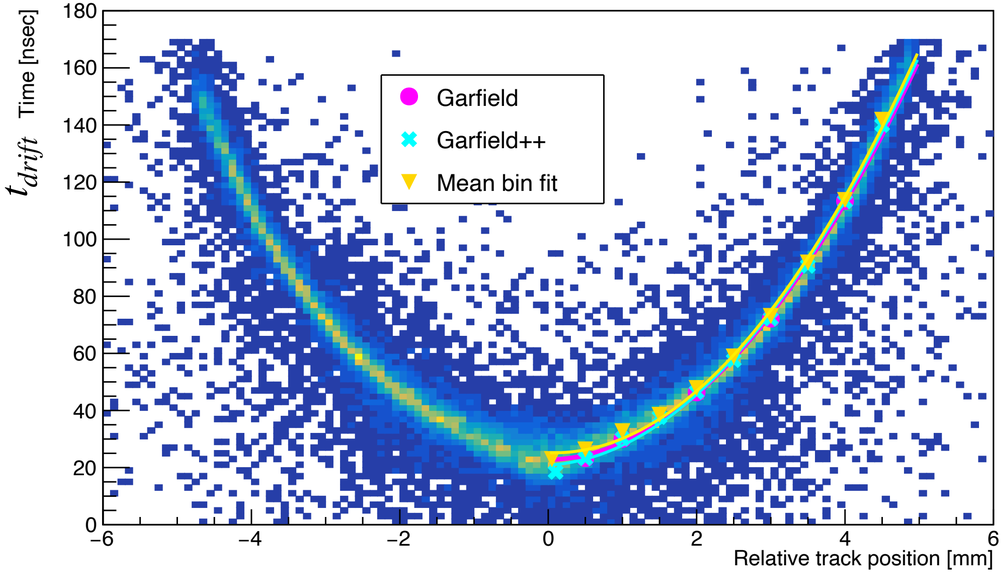
Straws are gas-filled cylindrical tubes with a conductive inner layer as cathode and an anode wire stretched along the cylinder axis.

Charged particles traversing a straw ionise the gas. The electrons drift towards the anode wire. Charge amplification occurs in the high electric field near the anode. The signal is further amplified, shaped and discriminated by read-out electronics.



Straw Tubes





- The drift time t_{drift} is measured as the difference between time t_0 when an ionising particle crossed the straw and the time when the induced straw signal exceeds a given threshold.
- Drift time of first (or second) closest to anode electrons represents quite well the distance between the track of the ionising particle R and anode wire
- The distance between the track and anode wire is obtained from a measured or simulated $R(t_{drift})$ dependence.

Example of the calibration $t_{drift}(R)$ dependence measured for an NA62 straw compared to *GARFIELD* simulation of the signal arrival time for first primary ionisation cluster.

GARFIELD + LTSpice allows to predict straw response for a given readout model.

Straw readout: TIGER vs VMM3

Multifunctional Application Specific Integrated Circuit (ASIC)

VMM3

- widely used as readout of micro-pattern gas detectors
- was a base for the production *VMM3a* version for the ATLAS New Small Wheel readout
- flexible settings of analogue input circuitry
- time measurements (nominally 8-bit TDC)
  - time-at-threshold (T@T)
  - time-at-peak (T@P)

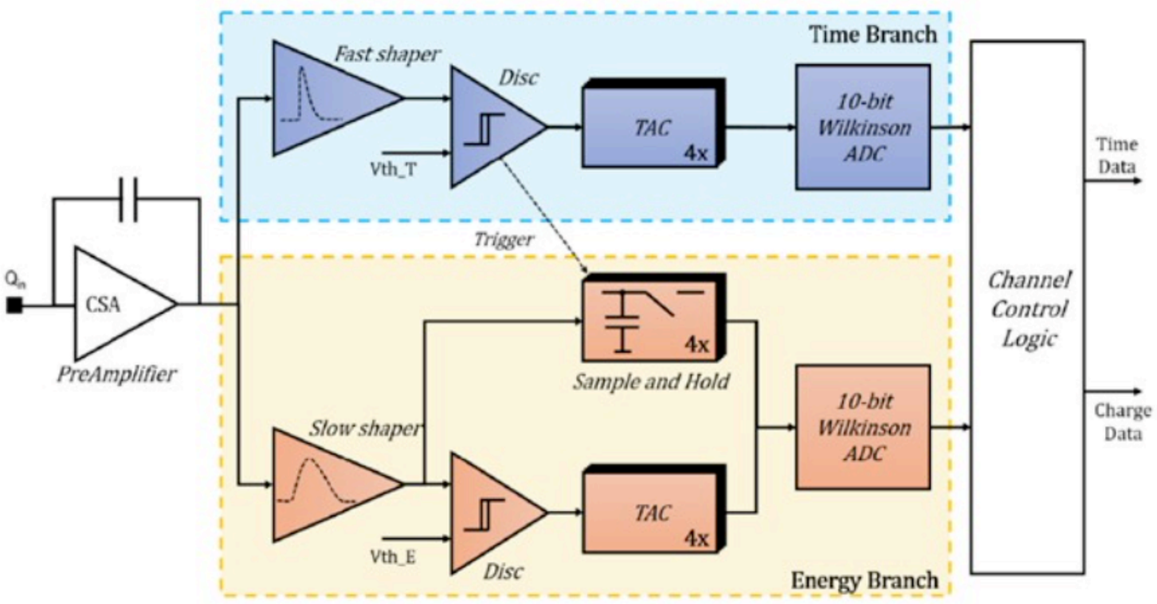
TIGER

- is used in BES-III GEM readout
- optimised architecture with two different shapers and thresholds for time and energy measurements
- precise 10-bit fine timing resolution
- charge measurement:
  - integration
  - time-over-threshold mode

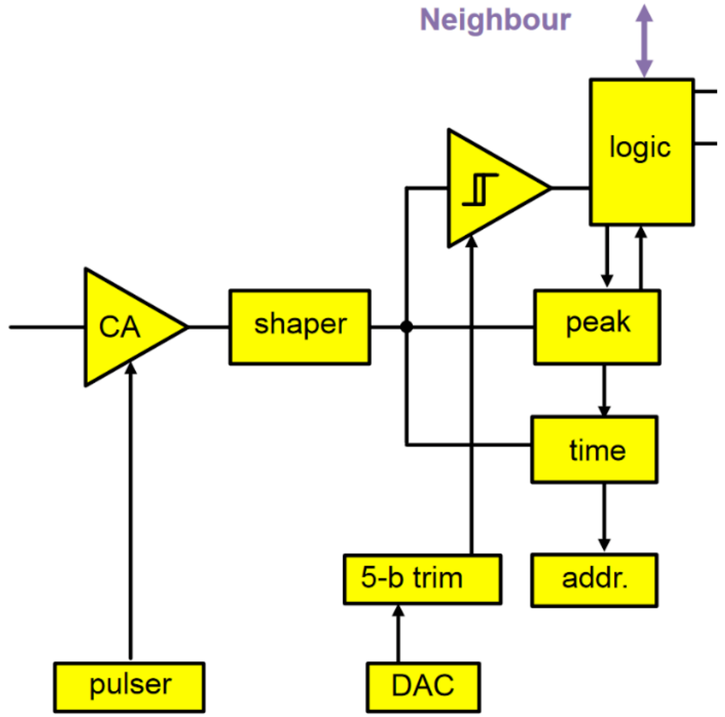
	VMM3	**TIGER**
Number of channels	64	64
Clock frequency	10...80 MHz	160...200 MHz
Input capacitance	<300 pF	<100 pF
Dynamic range	Linearity within ±2% up to 2 pC	50 fC
Gain	0.5, 1, 3, 6, 9, 12, 16 mV/fC	12 mV/fC
ENC (energy branch)	<3000 e^-	<1500 e^-
TDC binning	~1 ns	50 ps
Maximum event rate	140 kHz/ch	60 kHz/ch
Consumption	15 mW/ch	12 mW/ch

Straw readout: TIGER vs VMM3

TIGER Architecture



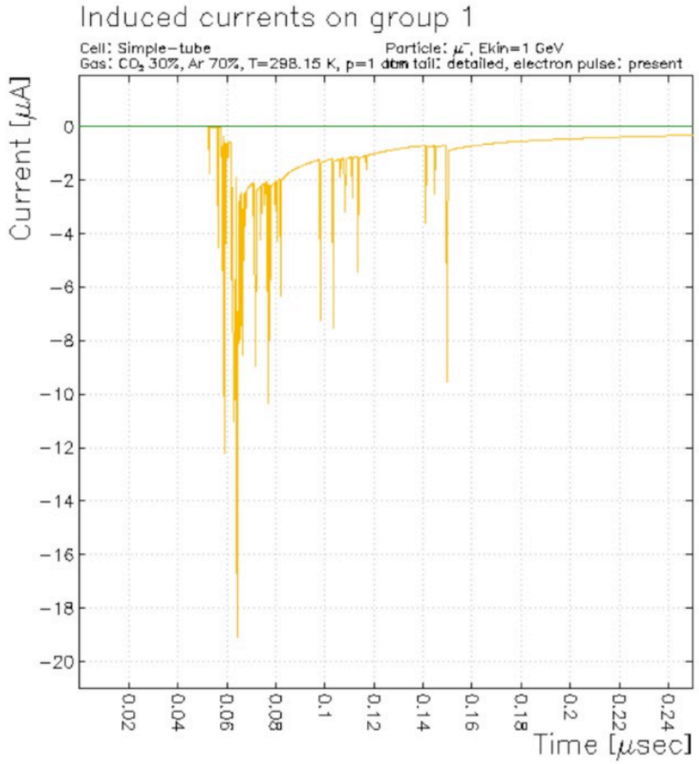
VMM3 Architecture



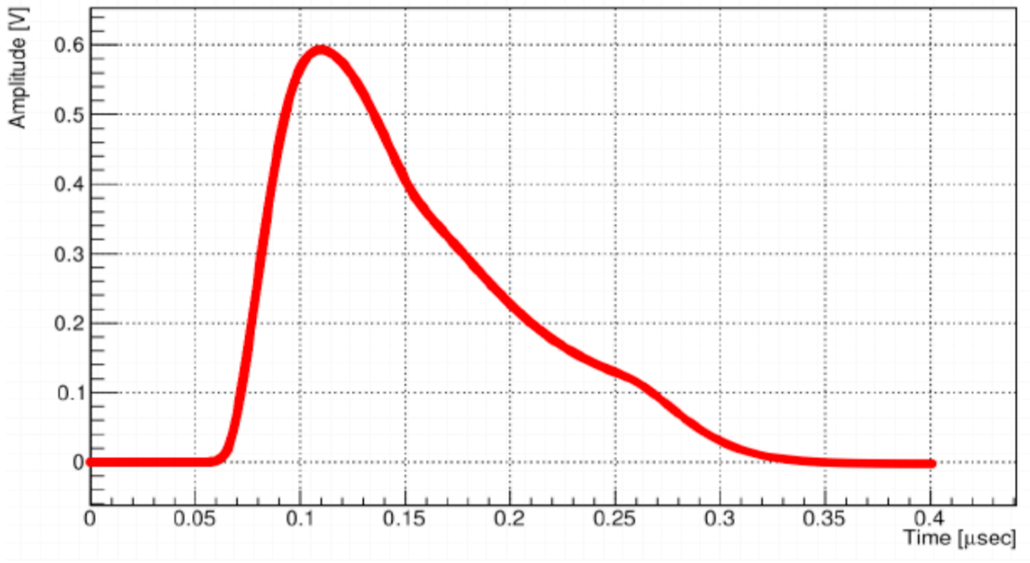
In contrast to *VMM,* the *TIGER* architecture has two different shapers for Time and Energy measurements. Two threshold levels are also possible.

Straw signal simulation

A combination of *GARFIELD* simulation of a straw tube response interfaced to the *LTSpice* electronics simulation package allows efficient optimisation of the signal circuit path and **VMM3**(a)/**TIGER** operation mode, and supports performance studies for Straw Trackers operated in the magnetic field and with different gas mixtures.

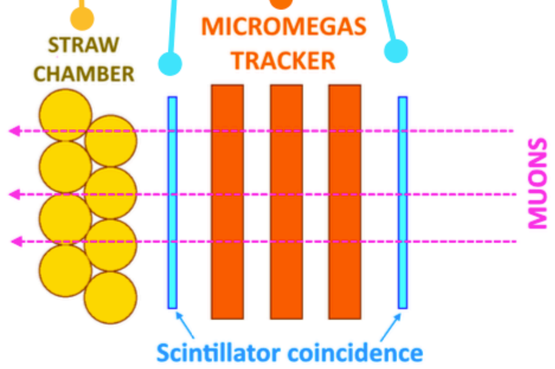


GARFIELD simulated signal
from straw tube

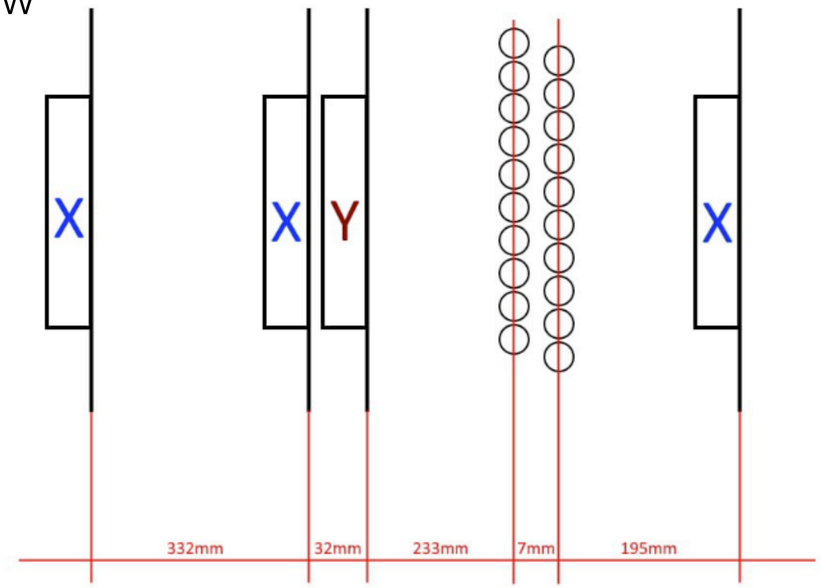


LTSpice amplifier & shaper response
to the signal provided by *GARFIELD*

Testbeam measurements



- All 3 existing readout options we study with SPS Testbeam
- For efficient data taking the following setup was developed:
  - Reference tracker: 3 GEMs or MicroMegas (3X + 1Y axis) with pitch of 250 μm
  - Reference timing: scintillator coincidence (two scintillators)
  - Straw chamber with 6mm straw



Testbeam measurements

Data taking periods

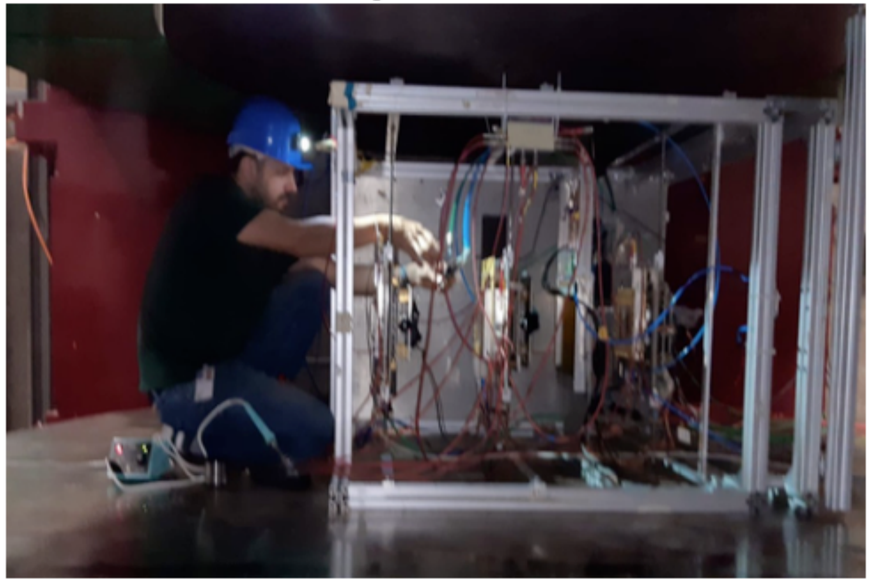
SETUP 1

- CERN, H4 (Nov 2021)
- 3 GEMs + straw station
- VMM3a readout

SETUP 2

- CERN, H4 (April–May + July 2022)
- 4 MMs w/ APV25 readout + straw station w/ VMM3 readout

SETUP 3



- CERN, H8 + H4 (Aug – Nov 2022)
- 4MMs + straw station
- TIGER readout

+ data taking in magnetic field

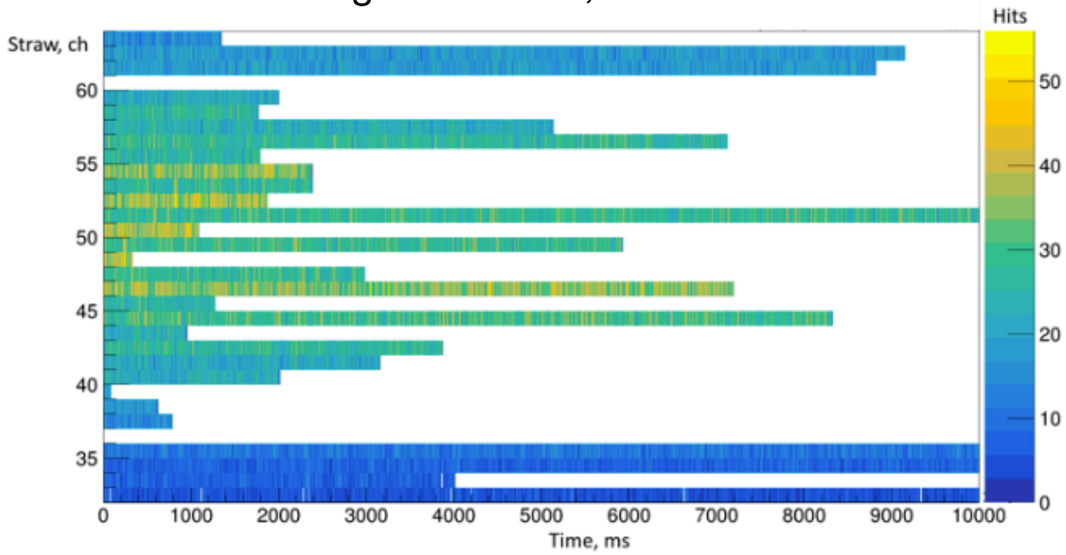
Testbeam measurements: SETUP1

VMM3a reliably operates in time-at-peak (T@P) mode only (ATLAS New Small Wheel). It was never used for time measurements in time-at-threshold (T@T) mode.

During our measurements at the Testbeam **VMM3a** "latching" in time-at-threshold (T@T) mode was observed. A possible explanation is an algorithmic problem in the cases when the time between the threshold crossing and signal peak is too short (<1 clock cycle).

Such type of "latching" makes impossible to use it with straws

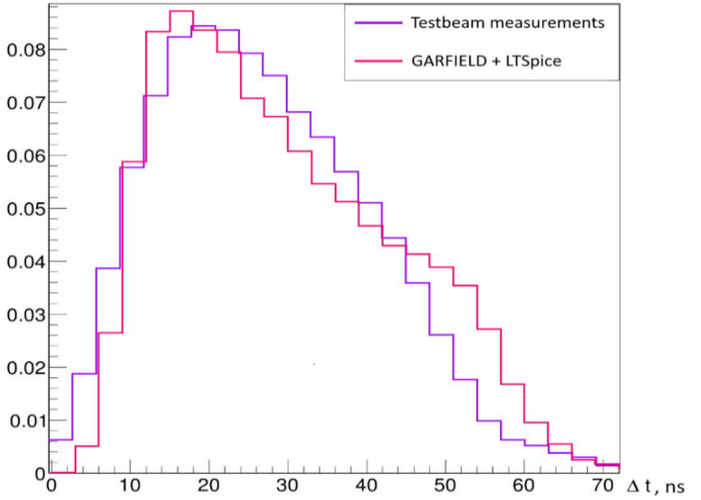
Peaking time 200ns, BC = 40MHz

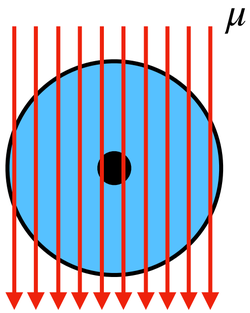


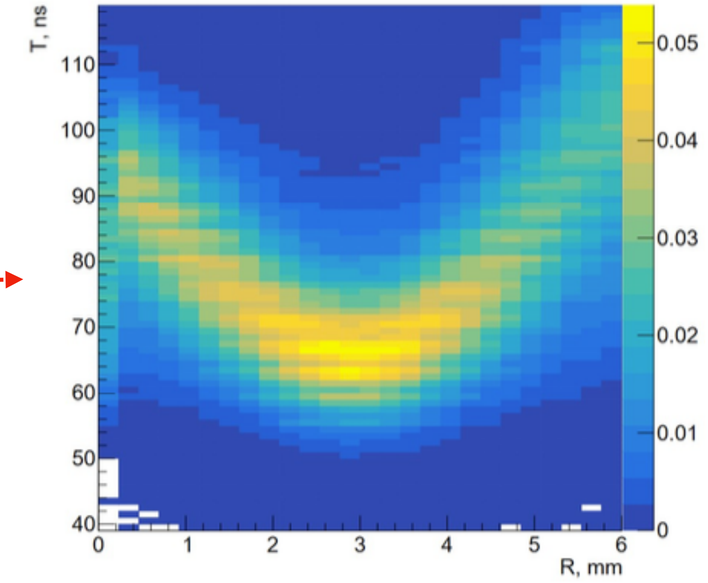
Testbeam measurements: SETUP2

No such effect was found with previous revision, **VMM3**. The logic of the T@T mode slightly differs between VMM3 and VMM3a

Very preliminary data (6mm straw, D_{wire} = 30um, HV = 1650V) and comparison of drift time distribution from muon beam *data* (magenta) with the *Garfield + LTSpice* predictions (red) shows a good agreement





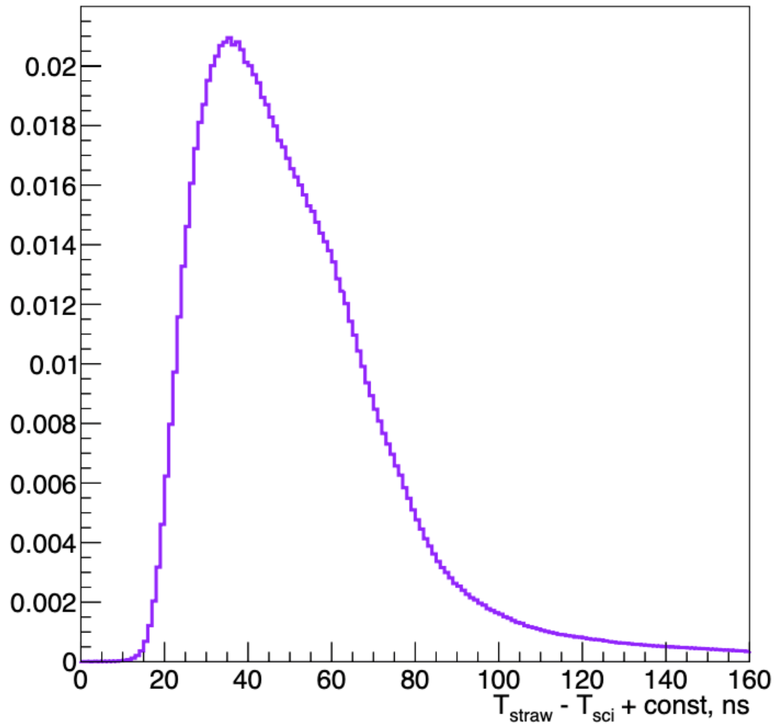


Preliminary results with the SETUP2 data

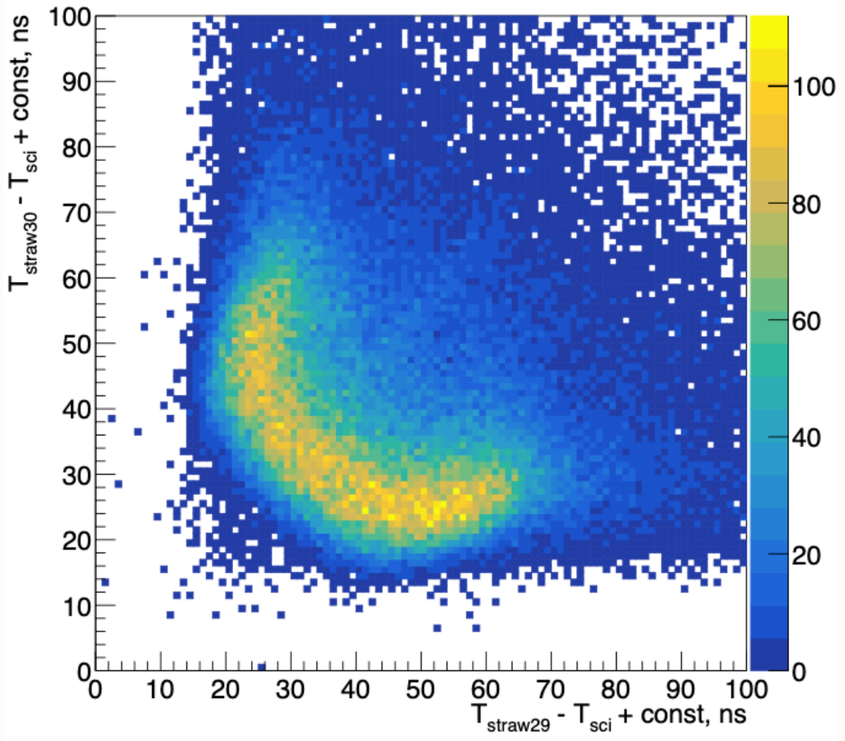
Reduced tracking information from **1 MicroMegas only** was used here

Testbeam measurements: SETUP3

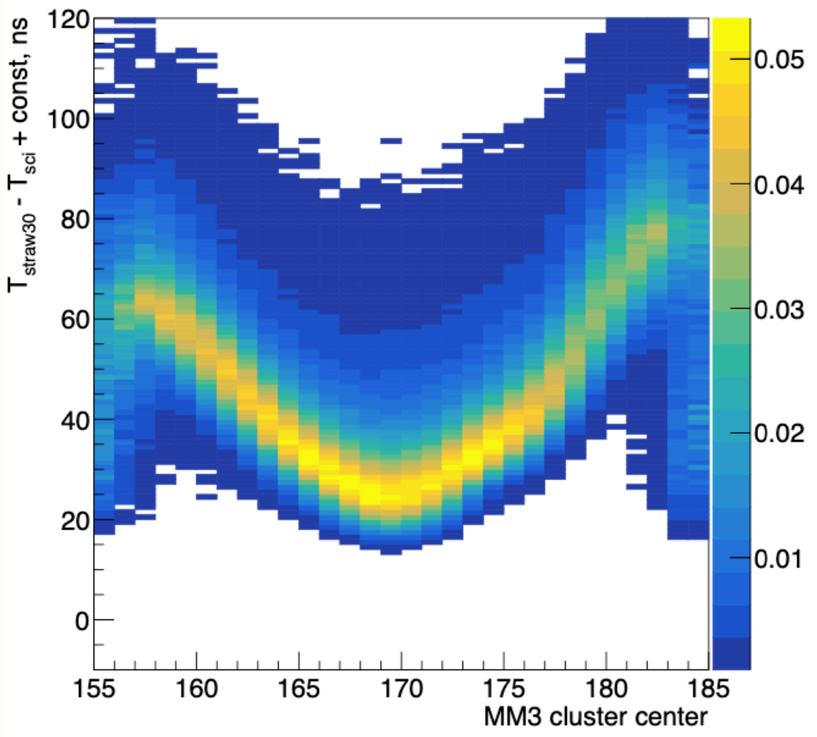
t_{drift}

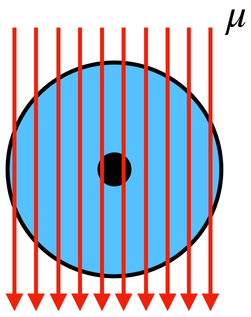


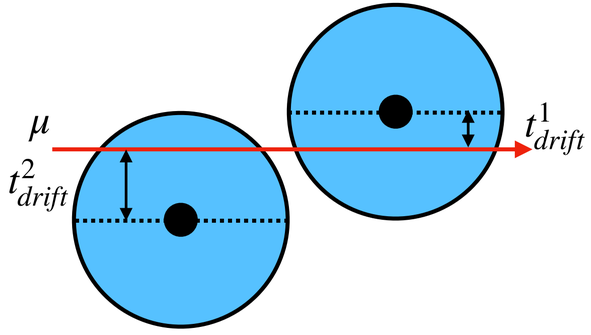
t^1_{drift} **vs** t^2_{drift}



$R(t_{drift})$







Preliminary results with the SETUP3 data

Summary

- A dedicated setup for Testbeam data taking was developed
- *VMM3a* "latching" in the **T@T** mode was observed during the November 2021 Testbeam. Such type of "latching" makes impossible to use it for straw readout. The effect was discussed with developers
- During April and July Testbeams the data with *VMM3* readout was acquired
- *TIGER*-based BES-III frontend boards were adapted for reading out the MicroMegas and straw tubes
- Data with *TIGER* readout was taken during the October Testbeam for different magnetic field strength
- Data analysis is ongoing
- These studies will be used for Optimisation of Straw Tracker of the **SPD** experiment @ NICA collider and will be included in the forthcoming TDR