Straw Tracker R&D – ongoing activities and further steps

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for the Straw Tracker Team

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ongoing and starting activities

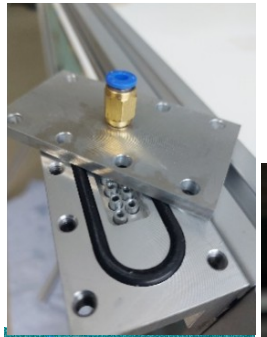
- Mechanics and geometry (not covered here) - ongoing
- **Prototyping - ongoing**
- **Lab and testbeam measurements - ongoing**
  + establishing approaches for:
    - Prototype quality control – initiated
    - Electrical connections - initiated
  - Defining parameters of the readout electronics - ongoing
- **Garfield/LTSpice simulation studies – well developed**
  - Validation with lab/testbeam measurements with the known electronics
  - Prediction of the readout performance for various readout options
  - Prediction for various operation conditions (field, particle momentum, angle)
- **Defining requirements and conceptual design of the readout electronics - ongoing**
  - Stage2 – fast, optional charge measurements
  - Stage1 - ~10 times lower max occupancy, good charge measurements
- **Realistic simulation of the tracker response in SPDroot - ongoing**
  - Realistic parametrization based on Garfield/LTSpice – started
  - Implementing realistic noise, finite TDC/ADC, finite dynamic range - scheduled
  - Pattern recognition also with realistic noise – needed…

material test and prototyping

Component and assembly tests

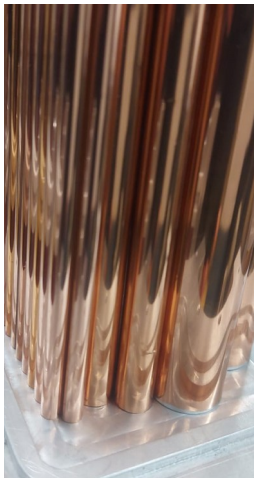
- Foil tests, wire test
- Crimping: anode pins, crimpers
- Straw end-plugs
- Adhesives and sealing





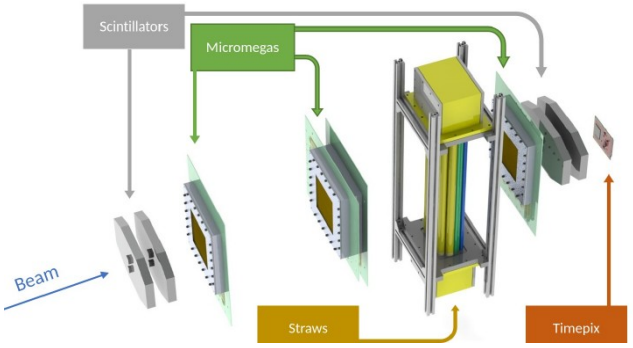

First prototypes:

- General R&D – straws of different metallization and diameter 5, 10 and 20 mm => 110 straws
- ZUV (~110 straws) - ongoing

SPS testbeam measurements

setup-23



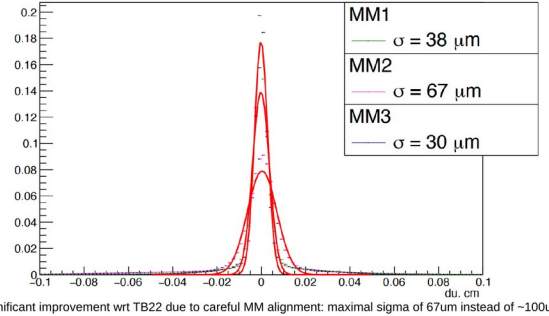
Reference tracking:

- MM detectors (250 um) + Tiger readout (Torino University)
- Timepix4 – 50um x 50um

Under the test: a combined straw tracker prototype with the Tiger and mu2e (VMM3) readouts

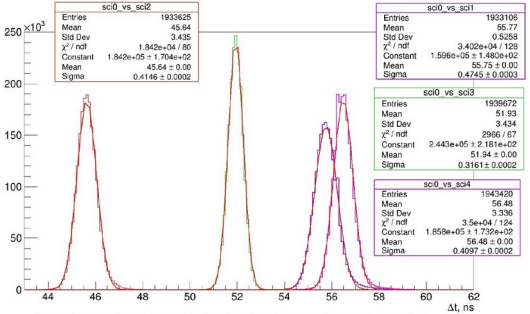
Good data taking with MM+straw and success in integrating the Timepix4

Reference tracking -- residuals



Significant improvement wrt TB22 due to careful MM alignment: maximal sigma of 67um instead of ~100um

Time resolution -- T0



Significant improvement wrt TB22: four scintillators with adjusted thresholds/delays each with sigma ~ 400/1.4 ps wrt ~1ns in 2022

Reference tracking (MM only): **better than 70 um**
work on adding the timepix layer in the analysis is ongoing
Reference time (T0): **better than ~300 ps**

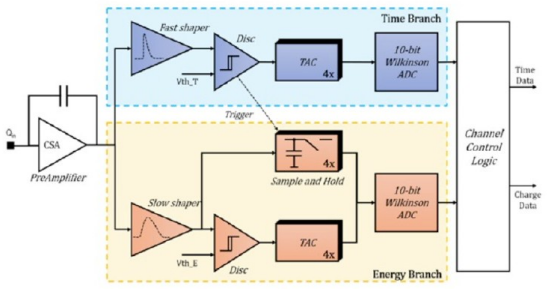
goals

- Precise measurement of the **spatial resolution** for different readout parameters (gas and electronics gain, thresholds, pressure,...)
- **Validation of the simulation results**
- Evaluation of the **realistic tracker readout parameters** (noise, cross-talks)
- Evaluation of the **charge measurements performance** (MIP) with the available electronics
  - Direct charge measurements (VMM3, equivalent number of bits~8)
  - Time-over-threshold measurements (Tiger)
- Developing a set of measurements for the prototype quality control
- Preparation for the charge measurements at PS in 2024

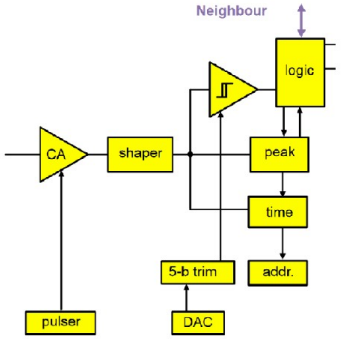
SPS testbeam measurements

"Existing" ASICs

TIGER Architecture



VMM3 Architecture



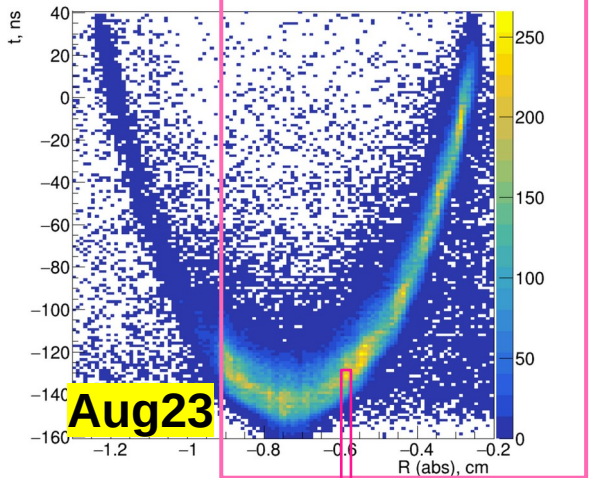
	VMM3	TIGER
Number of channels	64	64
Clock frequency	10…80 MHz	160…200 MHz
Input capacitance	<300 pF	<100 pF
Dynamic range	Linearity within ±2% up to 2 pC	50 fC
Gain	0.5, 1, 3, 6, 9, 12, 16 mV/fC	12 mV/fC
ENC (energy branch)	<3000	<1500
TDC binning	~1 ns	50 ps
Maximum event rate	140 kHz/ch	60 kHz/ch
Consumption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

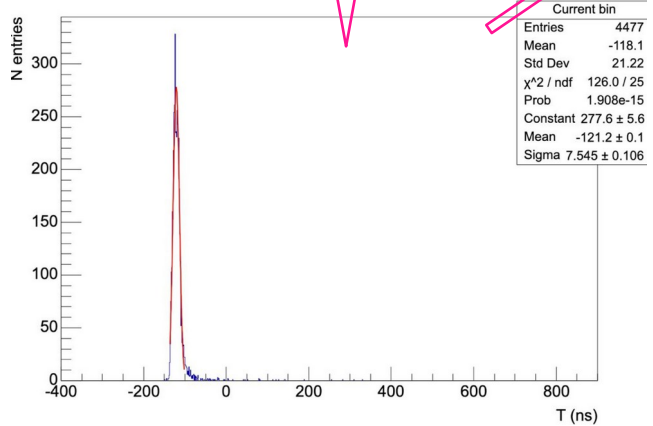
- Time measurements – TIGER, VMM3@25 ns
- Charge measurements
  - VMM3@200 ns
  - TIGER with time-over-threshold (under development)

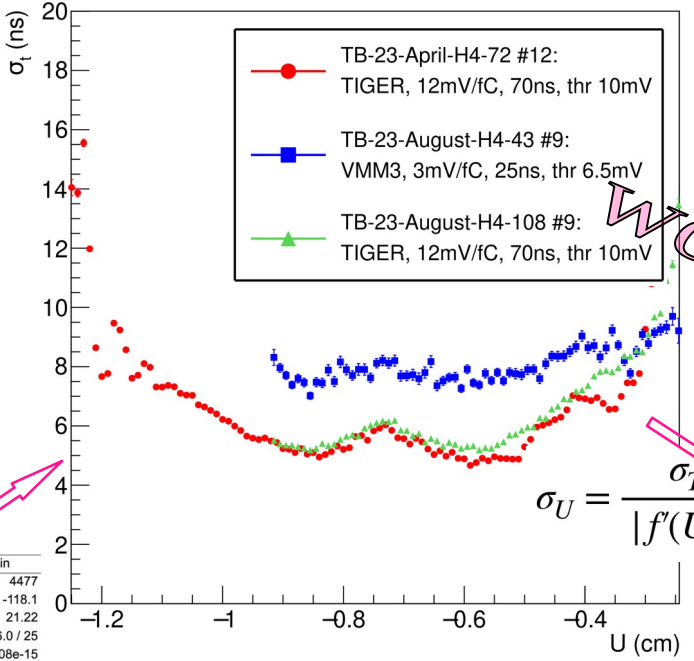
SPS testbeam measurements – spatial resolution

D.Sosnov, A.Zelenov

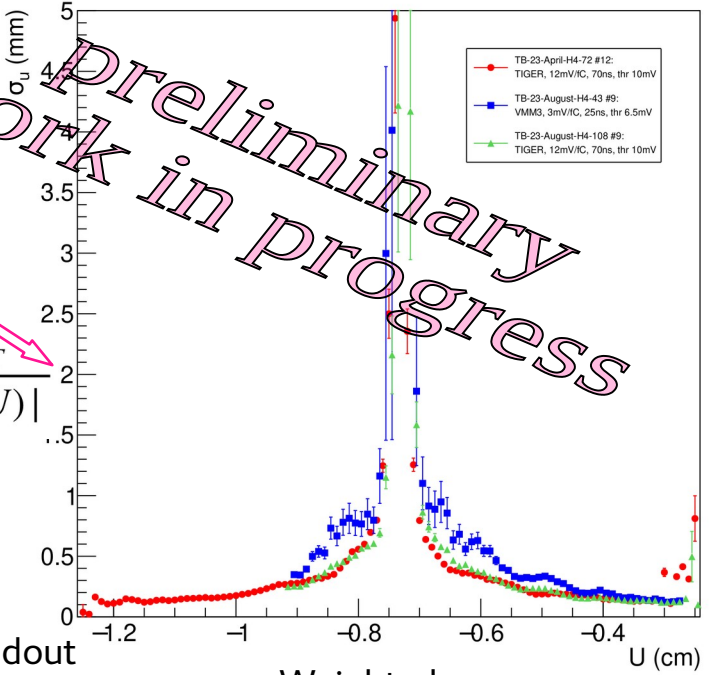
Area of good tracking performance







$$\sigma_U = \frac{\sigma_T}{|f'(U)|}$$



Preliminary work in progress

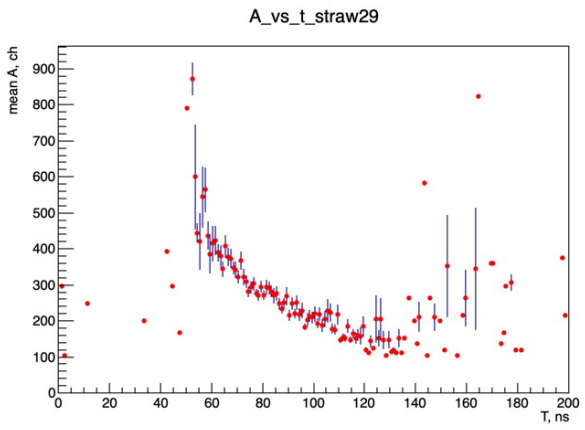
- perfect resproducibility
- better performance of the TIGER readout
- work in progress, analysis ongoing
  - Selection optimization
  - Analysis of the resolution vs threshold

Weighted mean (one side):
TIGER ~160 um
VMM3 ~ 173 um

SPS testbeam measurements - signal charge measurements

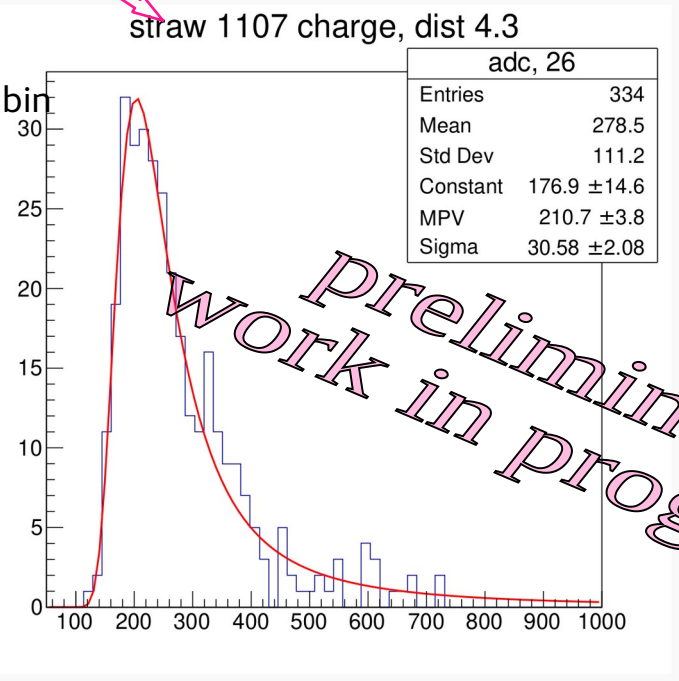
- VMM3 data with 200 ns peaking time
- Relativistic muons
- Charge distribution in every 100 um bin
- **Analysis ongoing**

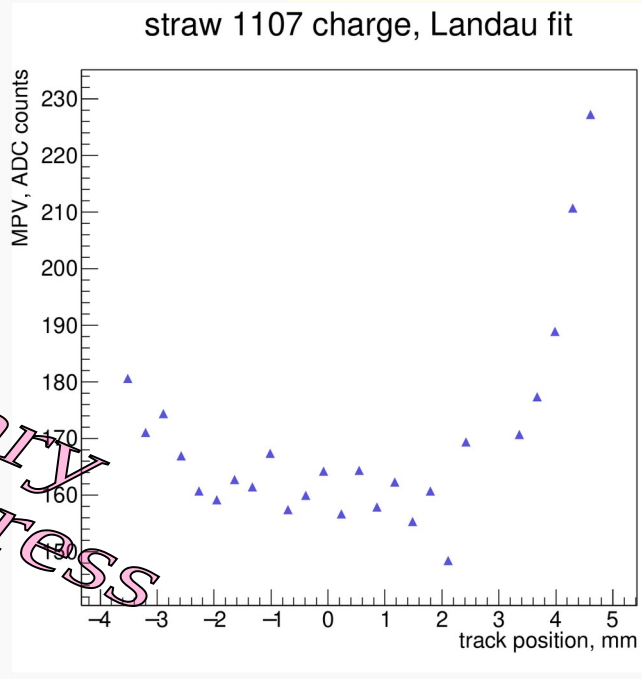
V.Maleev



Charge in a single straw per 1 cm

A.Chukanov





preliminary
work in progress

Garfield/LTSpice

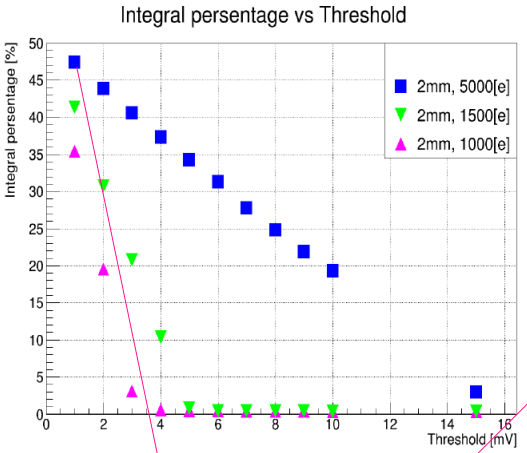
Noise studies, VMM3

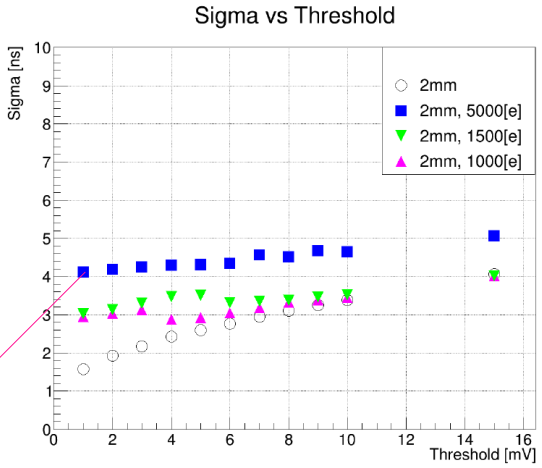
V.Bautin, S.Bulanova, A.Mukhamejanova,

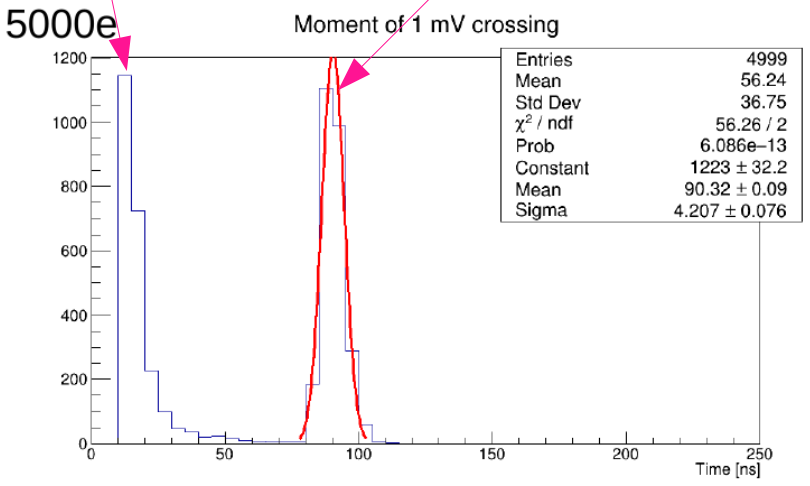
- Garfield – some fixes is needed (gain)
  - communication with the developers
  - X-checks with lab measurements
- LTSpice
  - Models of VMM3, Tiger
  - Validation with TB data
- Accounting for noise
- Next steps:

  => input to SPDroot (together with digitization, dynamic range etc)

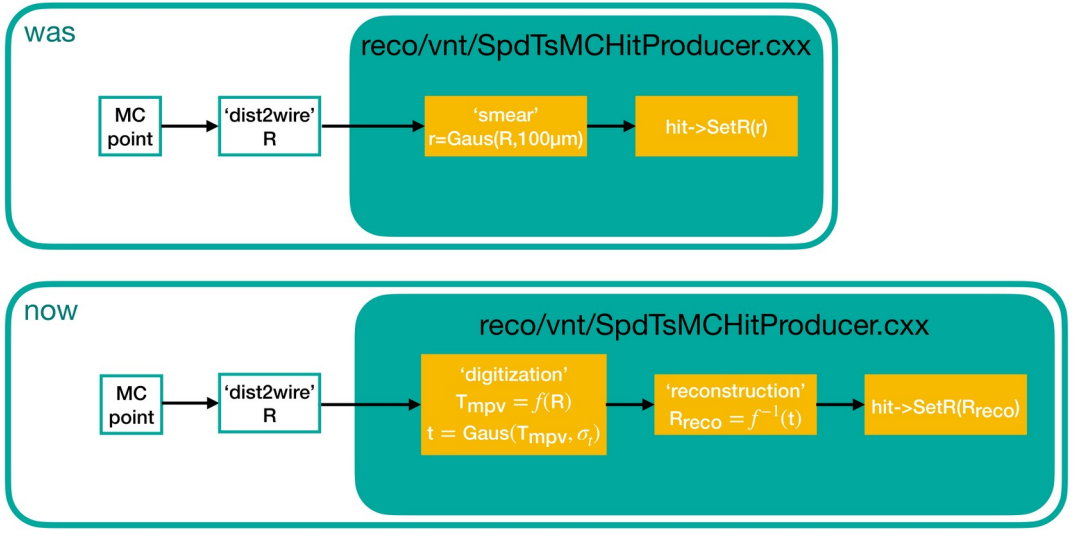
  => ready for modelling custom readout (further development)



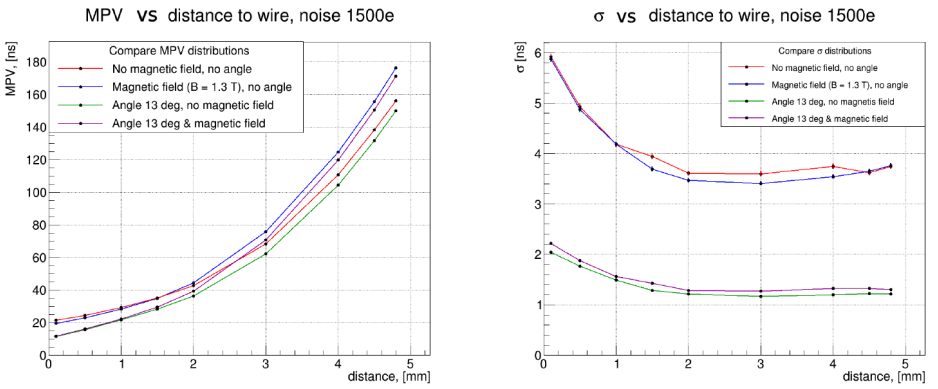




Realistic signal simulation for SPD root



S.Bulanova, E.Mosolova. A.Zelenov



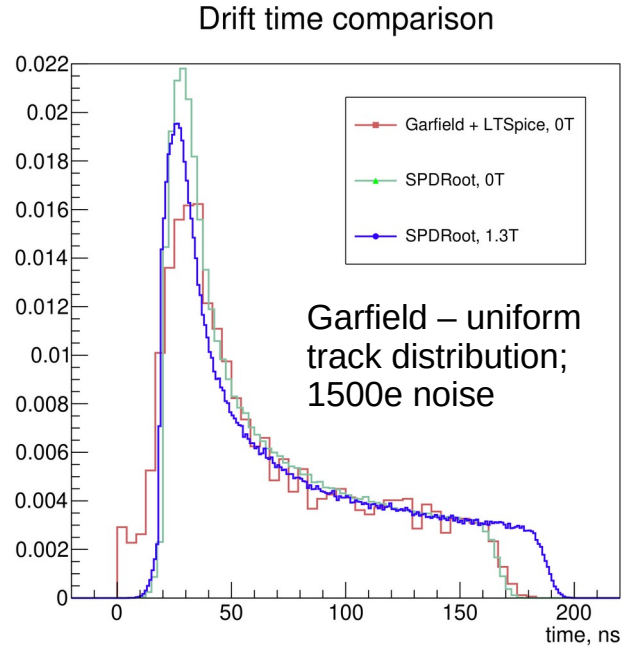
Response parametrization, VMM3

Рис. 13: (a) Зависимость MPV (ns) и (b) σ (ns) временных распределений от расстояния между треком и анодой проволокой.

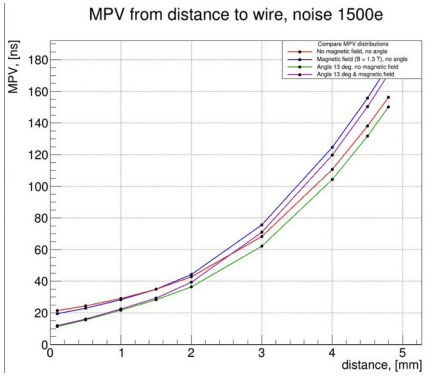
- Parametrization in SPDRoot: perpendicular tracks, 0 T and 1.3 T;
- First MC test with particle gun 1 GeV muons, theta=90 degree, uniform phi
- MC thruth vs reconstructed hits
- Next steps:
  - Track reconstruction
  - Detailed parametrization (different particles, momenta, magnetic field)

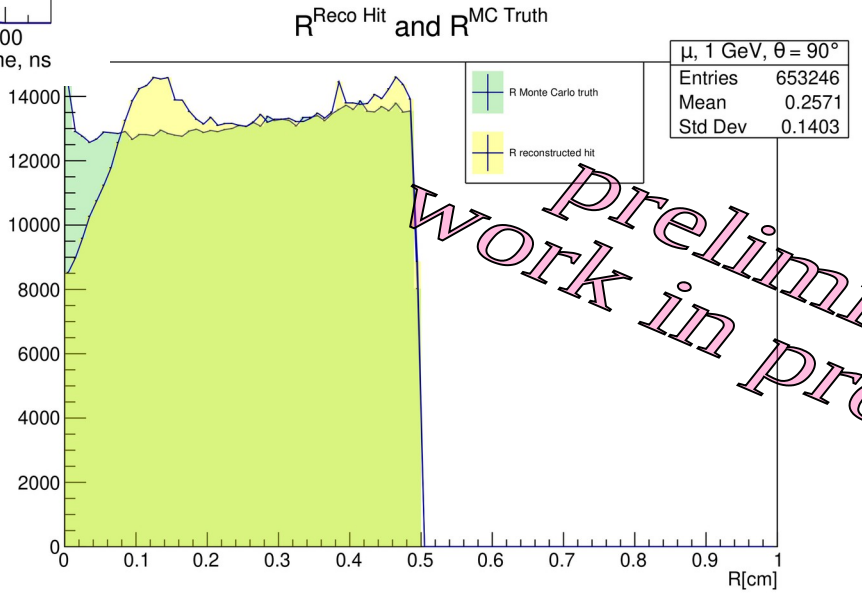
Realistic signal simulation for SPD root

S.Bulanova,
E.Mosolova, A.Zelenov



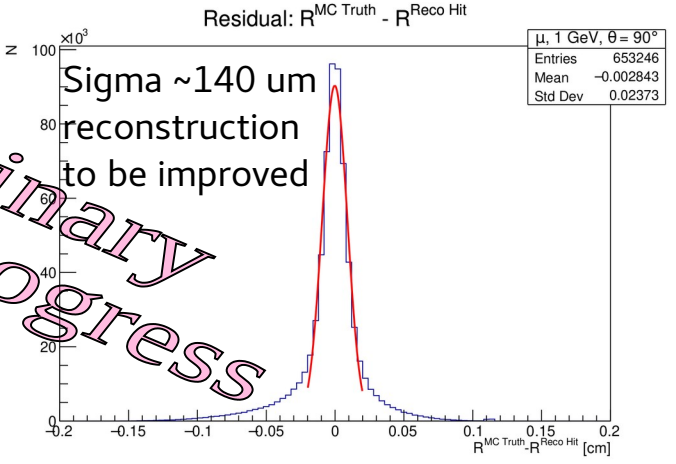
- The parametrization approach works well, but does not include the specifics of noise “fakes” – to be accounted for additionally
- As was shown in Garfield/LTSpice studies, the magnetic field plays the role – should be accounted for in simulation and, the most important, reconstruction (to be done)





preliminary
work in progress

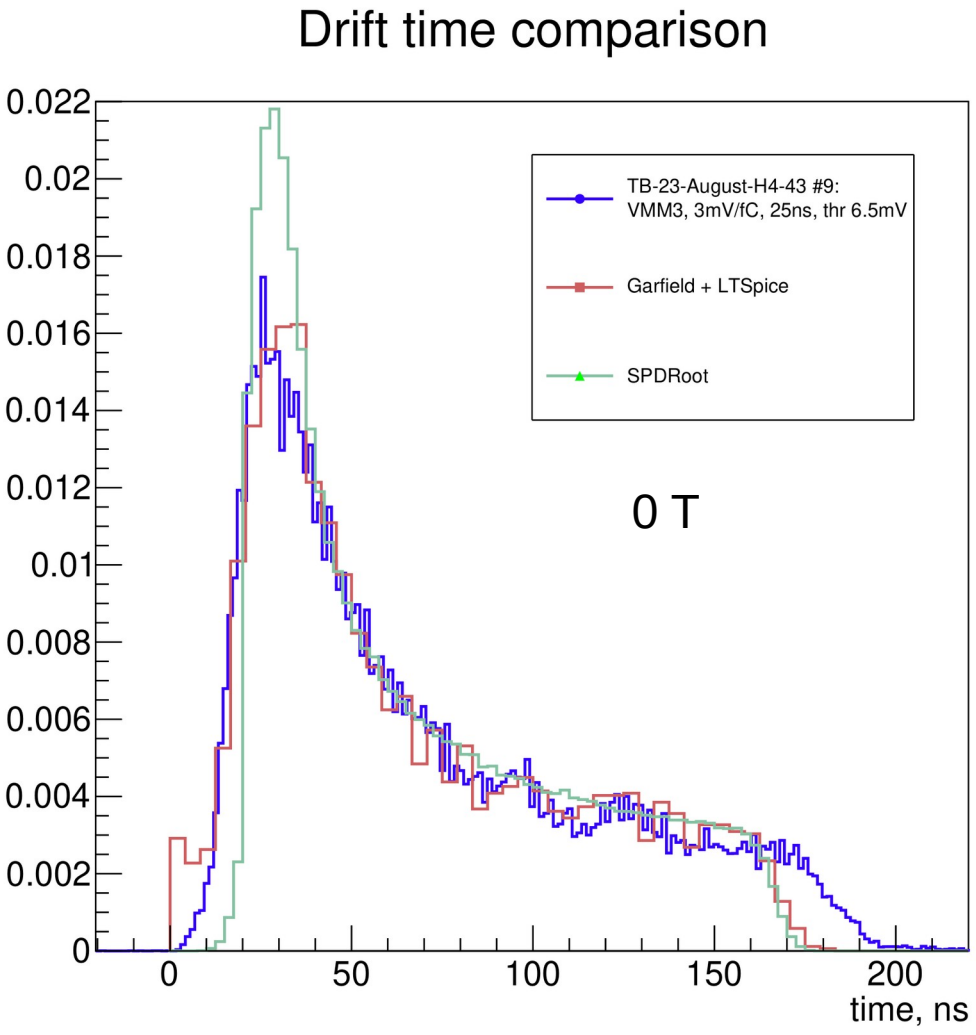
1.3 T parametrization



Just started – very first steps

Oct 24, 2023

Testbeam – Garfield/LTSpice – SPDRoot

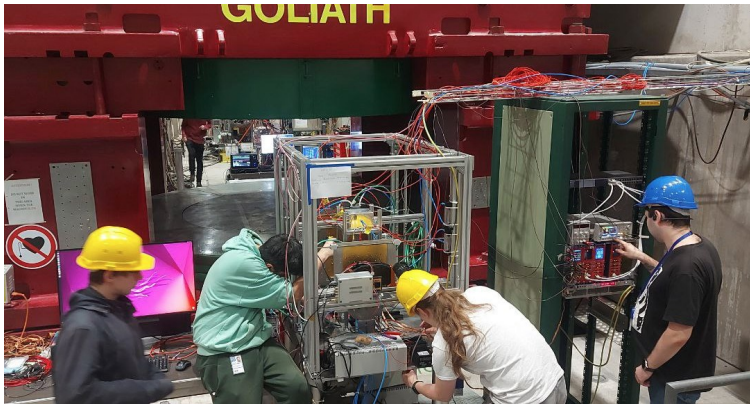


- Converging!
- Still a lot of work in all fields, nevertheless – the synergy does help
- Next steps
  - More detailed simulation + improved hit reconstruction
  - Implementation of the signal charge simulation + measurement into SPDRoot
    - TB analysis (MIP) – started
    - TB analysis (low energy hadrons + electrons) – planned for 2024 at PS (CERN) and PNPI
    - Garfield/LTSpice - started

Summary

Complimentary studies are ongoing:

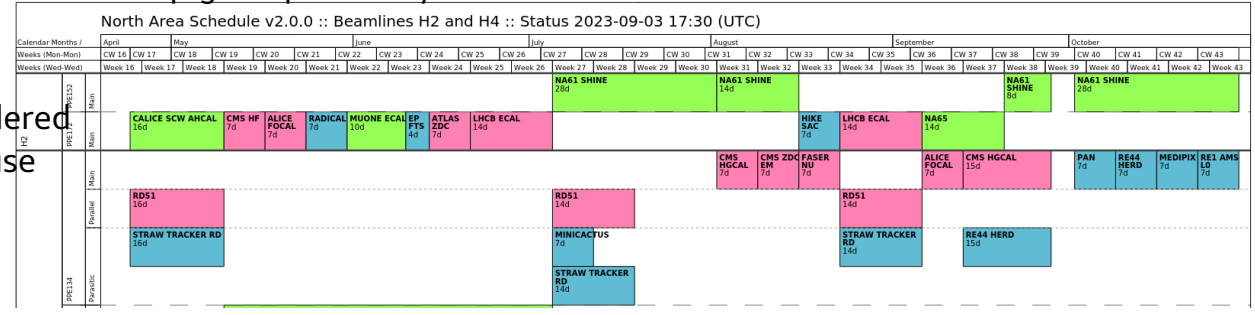
- **prototyping and material studies**
- **lab and testbeam measurements**
- **Garfield/LTSpice simulation**
- **development of the readout concept**



Advanced test setup is developed, combining up to three independent DAQ systems synchronized for offline merging and providing the good reference time (~300 ps) and spatial (better than 70 um even without the timepix layer) resolutions.

A significant part of the measurements is done during the scheduled SPS test beam periods (3x2 week of intense muon beam) – including the possibility to use dedicated electronics (VMM3, Tiger, Timepix4). Extra-time at the beam dump gives possibility for debugging + slow remote data taking

Measurements dedicated to PID (E(h)<GeV) are considered to be done next year with the PS beam. Possibility to use synchrocyclotron beam at PNPI is also considered.



Understanding the influence of the measured expected straw+readout performance on the track/charge reconstruction requires support with simulation studies

Work of **S.Bulanova, V.Maleev, D.Sosnov and A.Zelenov** was supported by
программа целевого финансирования научно-исследовательских работ научных групп, отрудничающих в рамках **мегапроекта «Комплекс NICA»**,

The group made significant contribution to

- Test beam data taking (D.Sosnov)
- Test beam data analysis (A.Zelenov, D.Sosnov and V.Maleev)
- Garfield simulations (S.Bulanova)

The marked results were obtained within the work supported by the program

backup

Readout electronics concept

Other (non-SPD) developments

Dune:
- triggerless
- identical requirements for time resolution
- similar requirements to charge measurements
- significantly lower bandwidth (<kHz)

Torino (post-Tiger):
- triggerless
- charge measurements adopted for MWPC/straws
- worse time resolution

Other options:
- Time-Over-Threshold for charge measurements?

Though no direct match, the experience of the ongoing R&Ds is useful

Possible solution:

Alexandr Solin

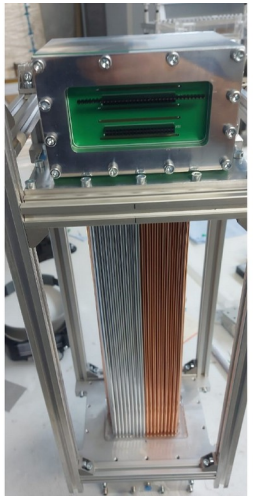
Параметры быстрого, временного канала		
Время формирования быстрого канала, нс	6÷10	
Разрешение временного канала, нс	1	
Регулировка порога дискриминатора, фК	0.5÷15	
ENC (r.m.s.), e Cd=60 пФ	<1000	
Временное окно TAC, нс	500÷5000	
Параметры медленного, амплитудного канала		
Коэффициент преобразования медленного канала, мВ/фК	straw	micromegas
	1/3	3/6/9
Время формирования медленного канала, нс	straw	micromegas
	75/150	75/150/250
Ширина сигнала по основанию, нс	300/600	300/600/1000
Порядок формирователя	4	
Разрядность АЦП, бит	10	
ENC (r.m.s.), e Cd=60 пФ	<1000	

Параметры детектора	
Диапазон входных зарядов, фК	+/-(0÷1000)
Емкость straw детектора, пФ	20÷100
Загрузка на канал, кГц	150
Режим работы	Бестриггерный

Model exists
- can be used in Garfield/LTSpice

Expected to be designed by April next year

prototyping



Combined prototype

Straw and wire diameters:

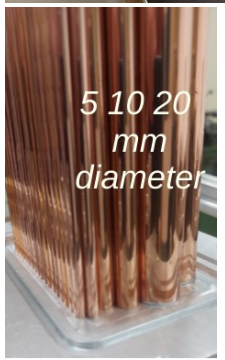
20mm / 30um : SHiP type

10mm / 30um : SPD type

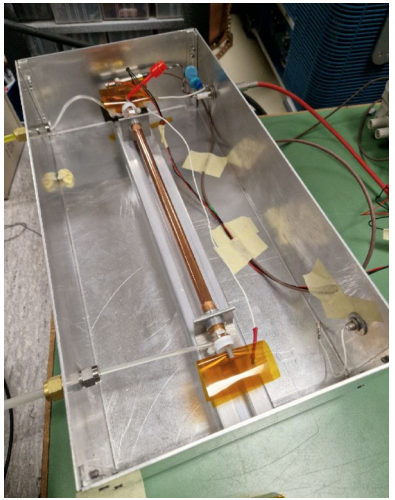
5mm / 20um :

NA62 upgrade (Cu/Au coating)

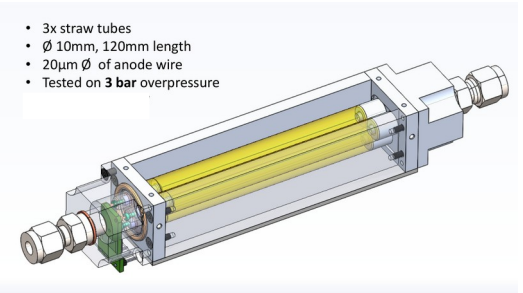
DUNE (Al metallisation)



- Dedicated small size prototype for testbeam measurements and alignment control studies
- Good for x-check with existing measurements (NA62, SHiP)
- Tests of x-talks, impedance measurements etc
- Lessons learned
  - Calibration/termination connector from opposite side
  - ….



Various single straw or small assembly setups



Laboratory tests with sources:

- Gas gain measurements
- Tests with different custom readout
- Tests with different gas mixtures

Further prototypes

- Single straw max length for lab tests
- Assembly with a stereo-angle? Which angle??