Requirements to the read-out electronics for future Straw Trackers and the straw performance measurements with muon, hadron and electron test beams

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Existing and developing StrawTrackers

Running/*Future Experiments*: ATLAS, LHCb, Amber, NA64, Mu2e, COSY-TOF, Panda, CBM (winded),

NA62, COMET, SHiP, DUNE, SPD, FCCee … (UltraSonic Weldigng, USW)

Other possible applications : muon tomography, cosmic rays physics, beam diagnostics

Very attractive - large area, small material budget, reasonable cost, good spatial resolution (~150 um/hit and potentially even less), vacuum tightness even for large area detectors (USW)

Limitations - rate limitation -up to O(MHz/straw), depends on the gas and readout, defines the straw diameter (the number of readout channelss)

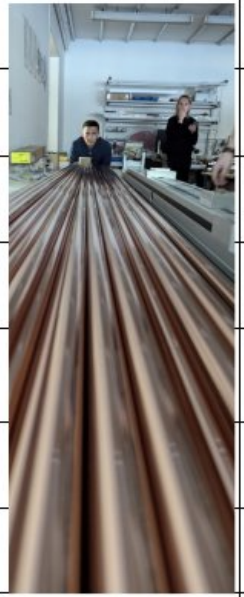
- Straw Tracker R&Ds have specifics defined by the experiment requirements
- However, there are
  - many common aspects which can be addressed by DRD1 R&Ds
    - straw production technologies and quality control
    - straw design approaches
    - common areas in read-out development and expertise

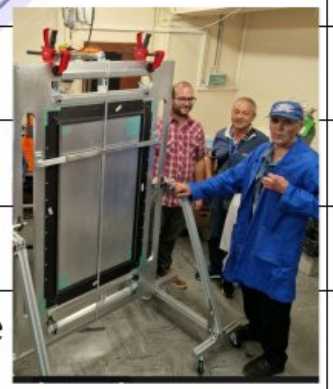
    } - *see talk by T.Enik on Thursday [1]*

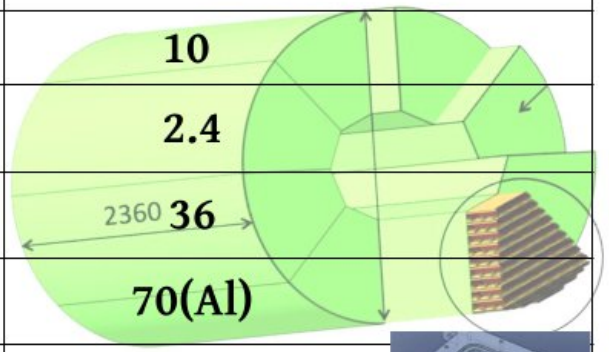
  - shared production, R&D and operation experience

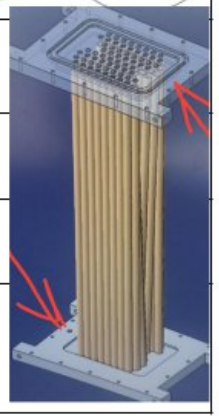
Examples of developing Straw Trackers based on USW

	SHiP @ SPS [2]	DUNE (SAND) [3]	SPD @ NICA [4]
Diameter [mm]	20	5	10
Length [m]	4	up to 4	2.4
Film thickness [um]	36	20	36
Metalization [nm]	50(Cu)+20(Au)	70(Al) double-side	70(Al)
Operation pressure	1 atm	2 atm	1 atm
N of straws	~20 000	~250 000	~30 000
Occupancy [kHz]	10-100	<1	15-150
Readout (under development)	time + time-over-threshold, rising edge shape (optional)	time + charge (PID)	time + charge (PID)









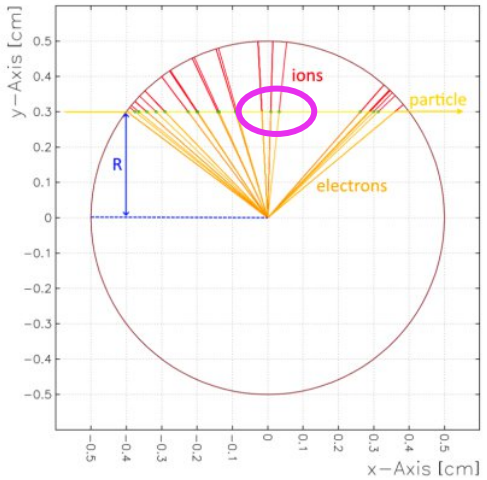
due to developing design, the tracker parameters may change in the future

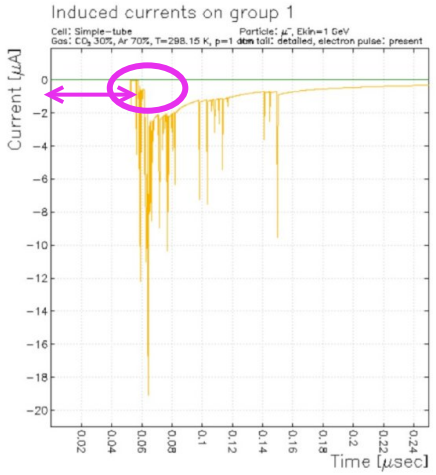
2: SHiP Technical Proposal
3: DUNE Near Detector CDR
4: SPD TDR

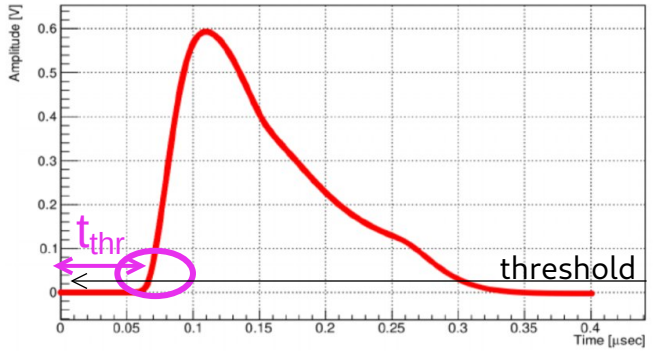
R&Ds on optimization and development of the straw readout (simulation studies and lab and testbeam measurements) by the StrawTrackerRD team are being done within several collaboration

Requirement to the readout electronics for tracking and PID

- Basic requirement - tracking
  local hit coordinate is reconstructed from the drift time measurement t_{thr}

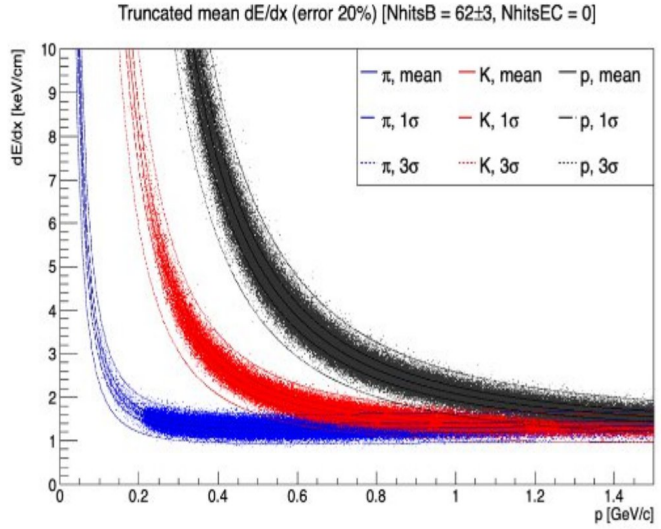






for given straw operation parameters, and negligible noise, the smallest fluctuation of the measured drift time will be achieved with the smallest preamlifier peaking time

- Additional option - PID for low-momentum charged particles:
  operated in the proportional mode straws can provide measurements of the ionization energy loss and serve PID if the number of tracker layers is sufficient



for given straw operation parameters, the smallest fluctuation of the measured induced charge will be achieved with the largest preamlifier peaking time

Searching for solution

- if tracking only : the most of operating trackers

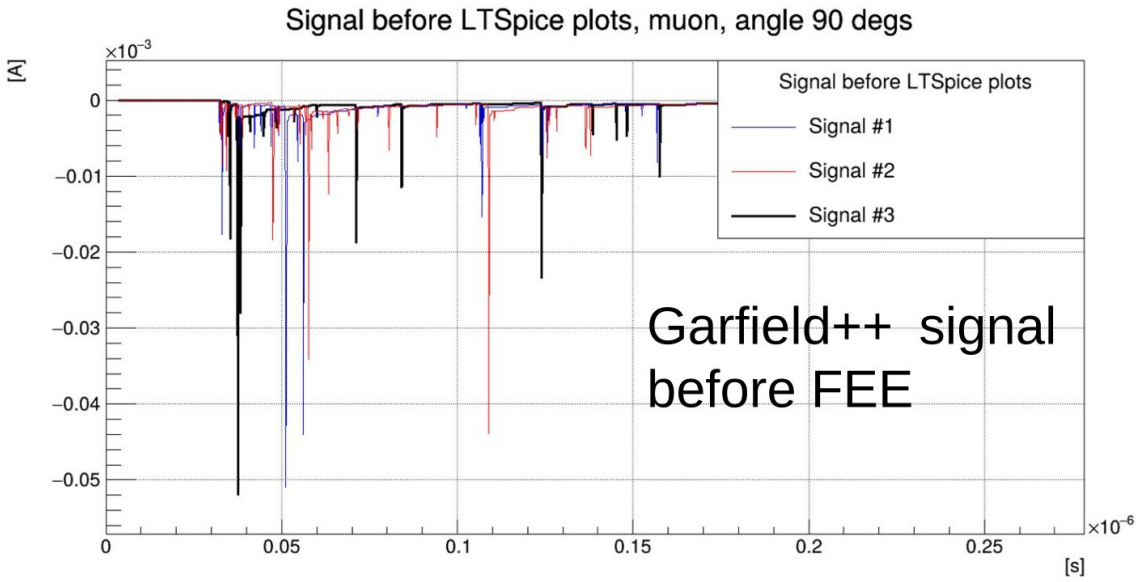
  - the readout electronics developed 10-20 years ago, many ASICs are deprecated (for example, CARIOCA)
  - several (relatively) recent developments or upgrades
    - MPI : ASDv2 (ATLAS sMDT upgrade), v3 (high rate) [4]
    - NA64 straw readout - analogue part (A.Solin) [5]
    - VMM3a [6] - see the next talk by V.Bautin [7]
    - ToRa - in the talk by Chiara Alice on Monday [8]
      v2, more adopted for straw readout, is expected next years

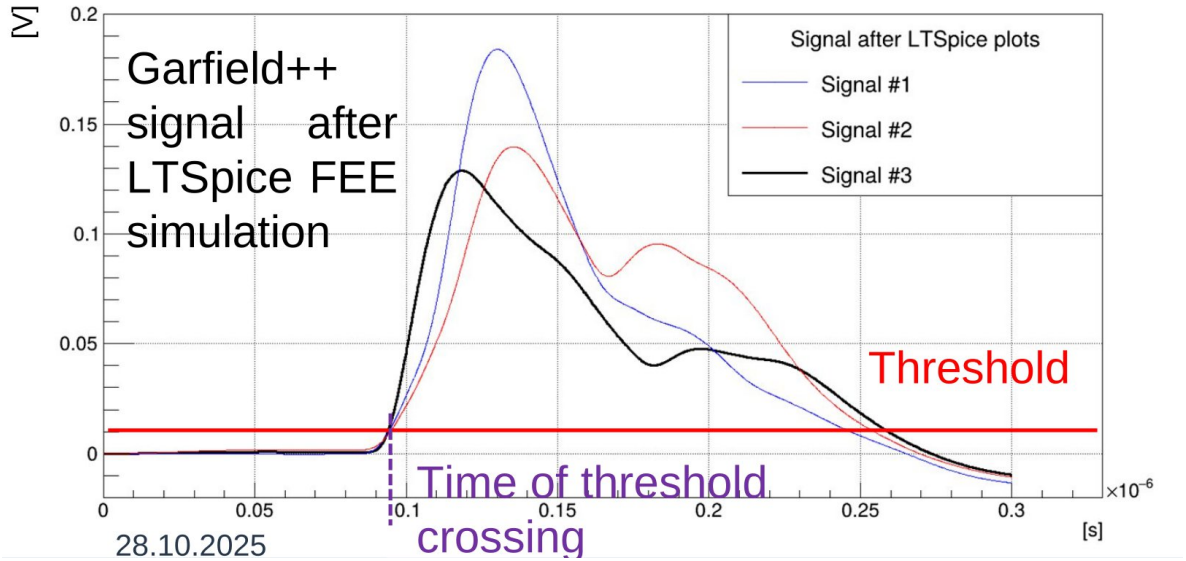
- tracking + PID :

  - double-branch approach
    - Tiger [9] - exists, though not the straw case
    - dedicated double branch approach for straw readout by A. Solin, under development [4]
  - single branch with a compromising gain and peaking time
    - PASTTREC (Panda) [10]

Simulation studies

- Garlield++ for straw response
- Electronics emulation - LTSpice or Garfield++ transfer function validated with LTSpice for the readout model and parameters of interest

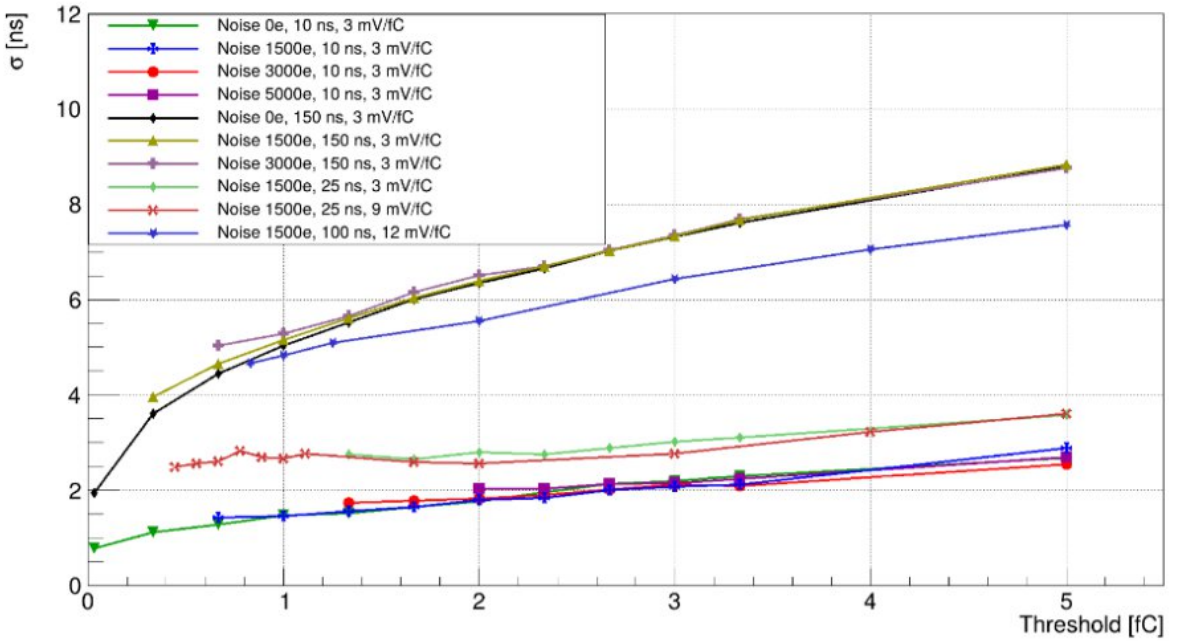




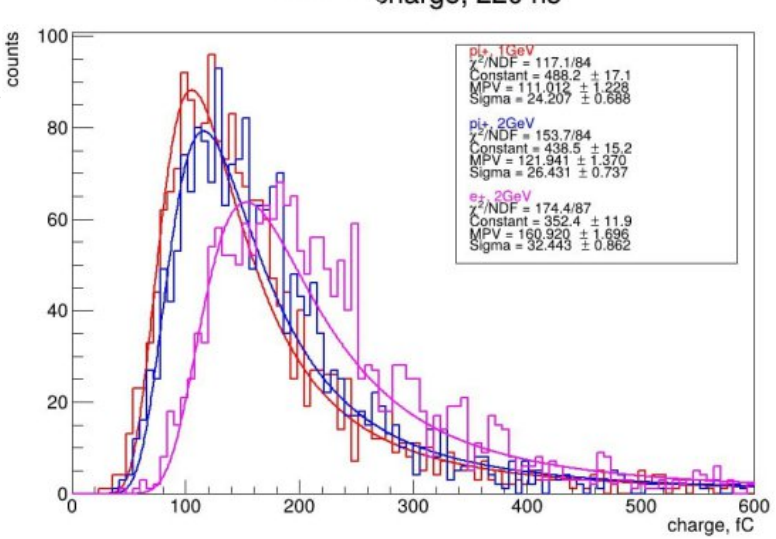
- accounting for a given noise level
- relatively large sample simulation for statistical analysis
- statistical treatment of threshold crossing time (tracking) or signal maximum (PID) distribution
- examples of the simulation results - for 10 mm straw diameter, 70/30 Ar/CO2, <gas gain> = 45k

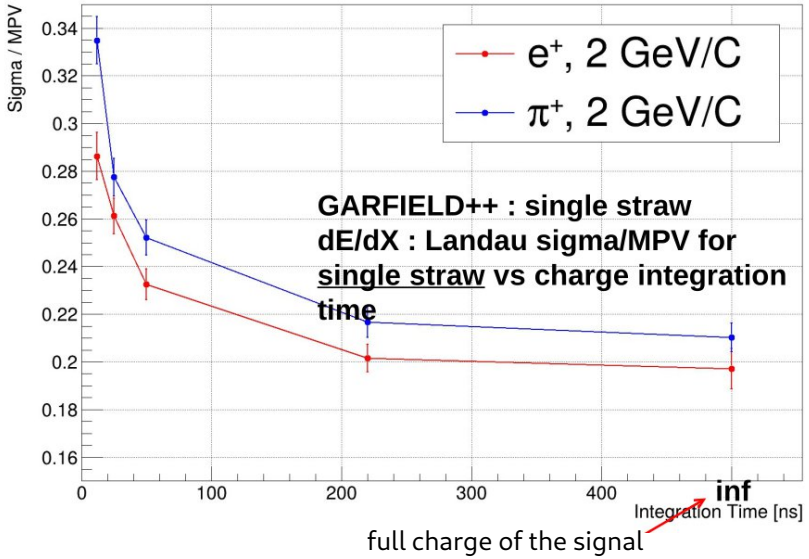
Simulation studies

Garfield/LTSpice studies with different readout models: straw time resolution as a function of the discriminator threshold for VMM3a-like architecture with different peaking time and gain options.
10 GeV /c muon at 2 mm from the straw centre

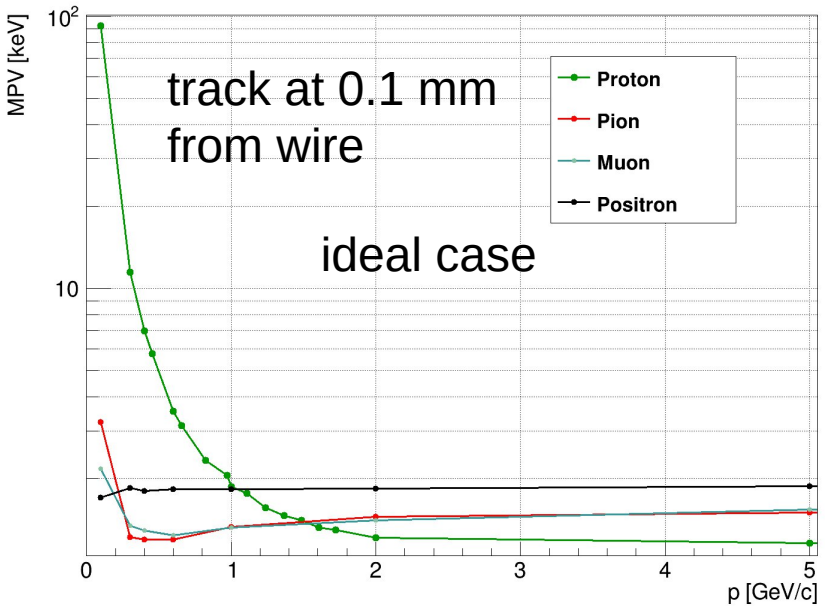


Garfield++ straw signal charge, integrated within a given peaking time for electrons and pions of 1 and 2 GeV/c at 0.1 mm from the straw centre, and the charge resolution sigma/MPV as a function of the integration time

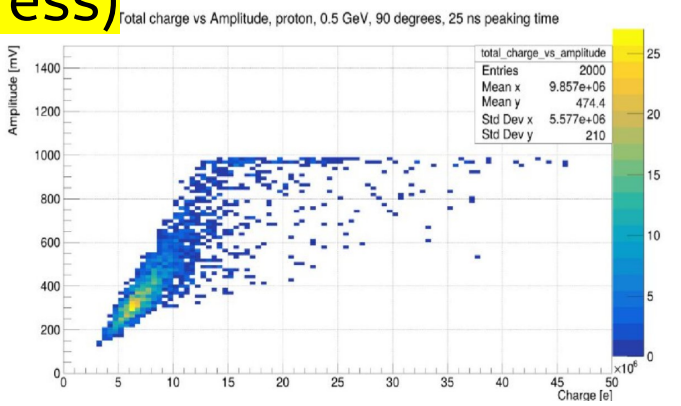


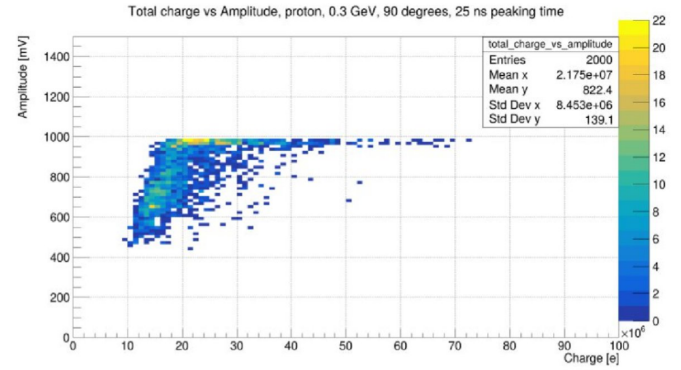


Simulation studies - electronics dynamic range (work-in-progress)

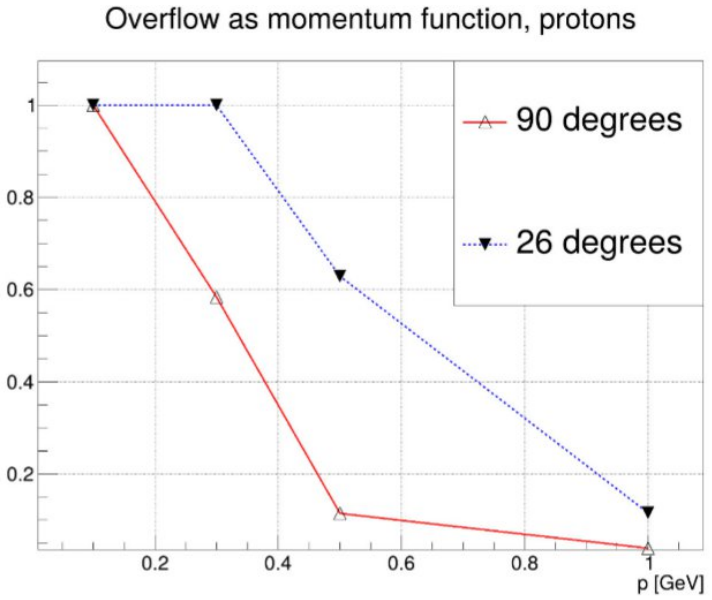


LTSpice response of a VMM3a-like readout depending on the total charge of the straw response (Garfield++) - 0.5 and 0.3 GeV/c protons at 0.1 mm from the straw centre





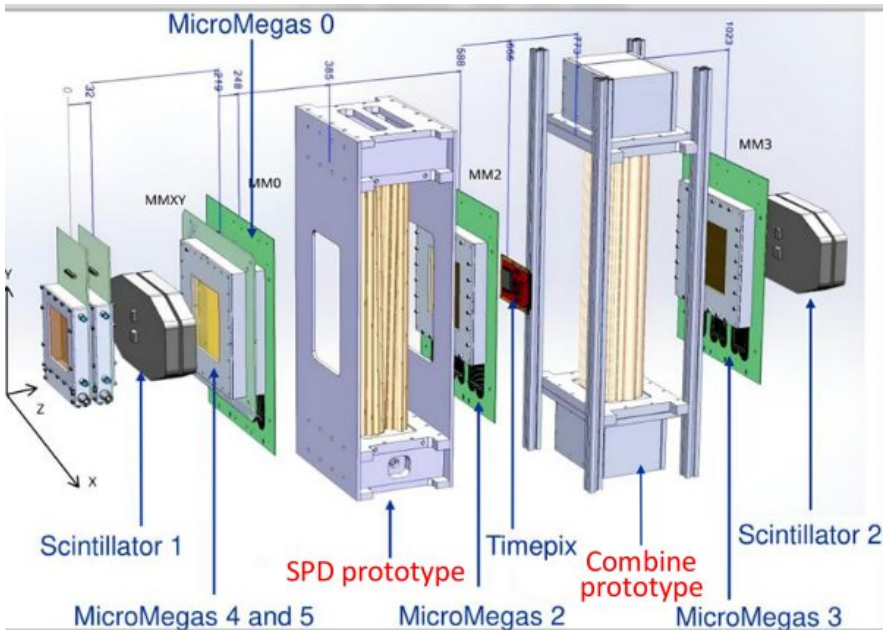
PA saturation cases as functions of the proton momentum for VMM3a-like readout model and pessimistic saturation threshold (800 mV)

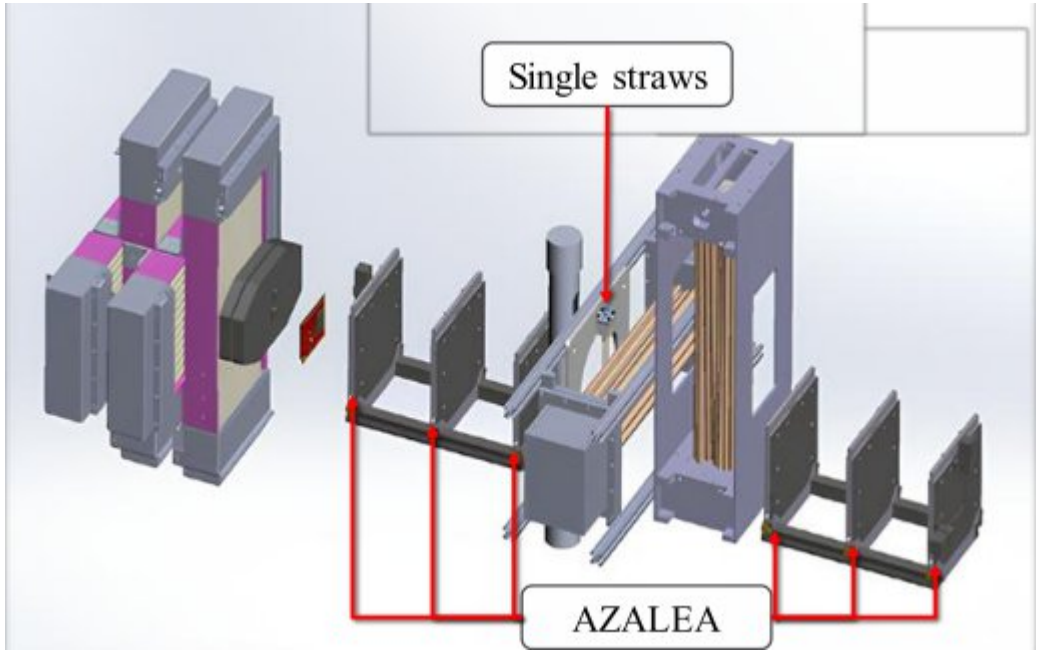


work-in-progress the obtained results can be used as parallelization for a general purpose detector simulation package to check the influence of the certain electronics model on the Straw Tracker PID performance

Testbeam studies

- small prototypes and single straws: 5, 10 and 20 mm straw diameter diameter
- time/spatial resolution and tracking - at SPS at CERN with intense muon beam, at PS with 5-10 GeV hadrons
- PID - PS at CERN with 1-2 GeV hadrons and electrons
- StrawTrackerRD setup
  - reference tracking - MM-based or AZALEA telescope + 1 plane Timepix4
  - reference timing - scintillators with resolution <1 ns

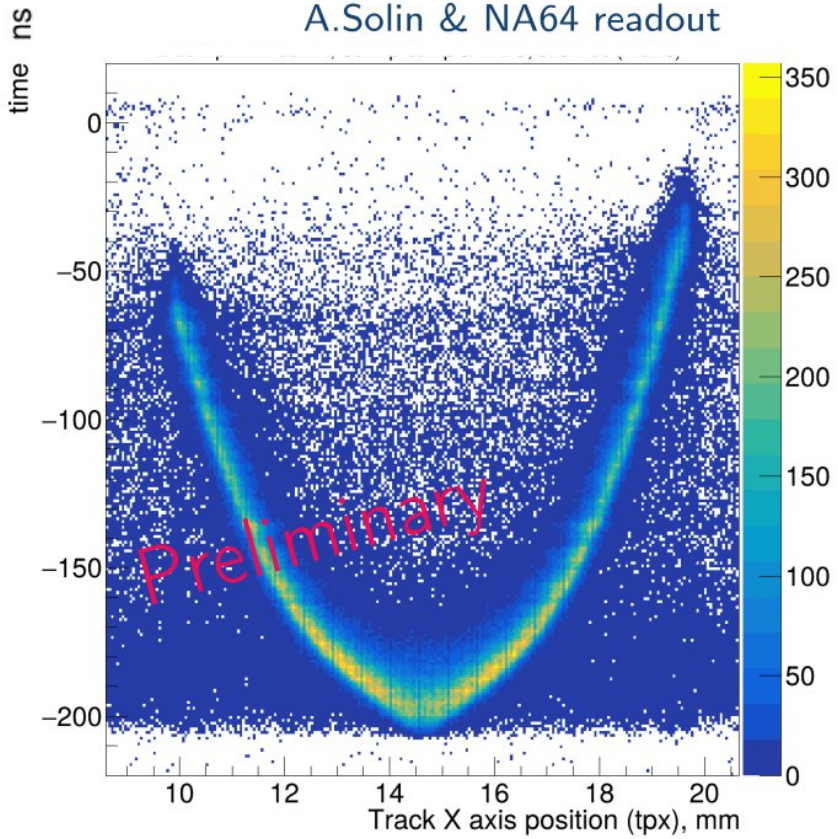


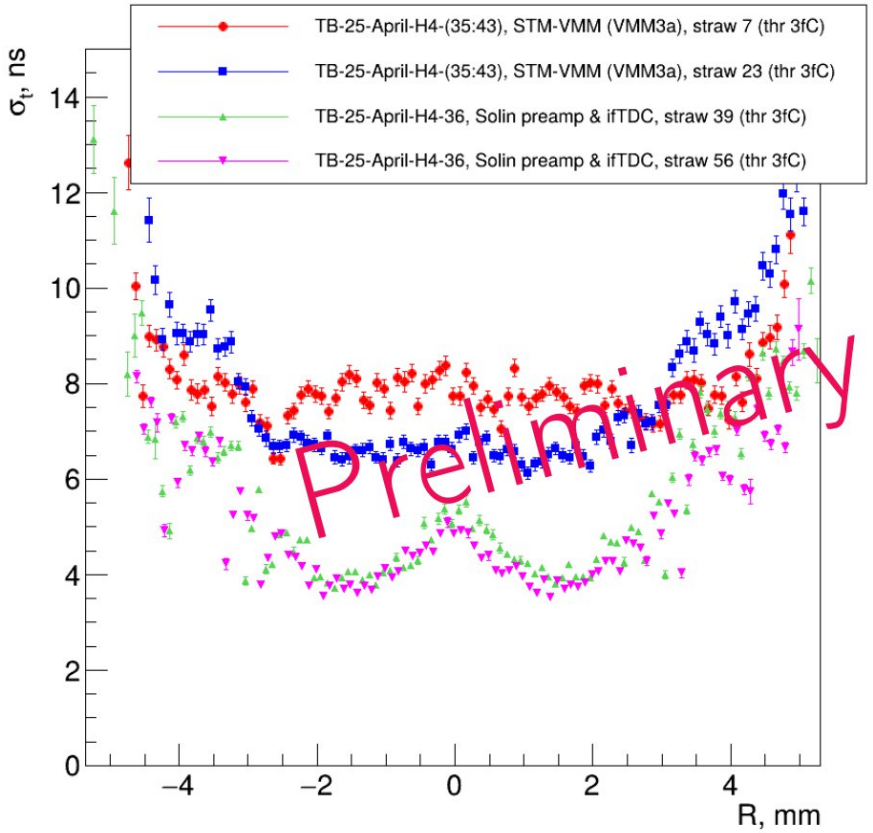


- PID - complementary studies at PNPI (Gatchina) with 0.5-1.2 GeV protons

Measurement results (work-in-progress):

- Tracking - several readout options - ASD (~10 ns peaking time), NA64-based (~10 ns), VMM3a-based (25 ns)





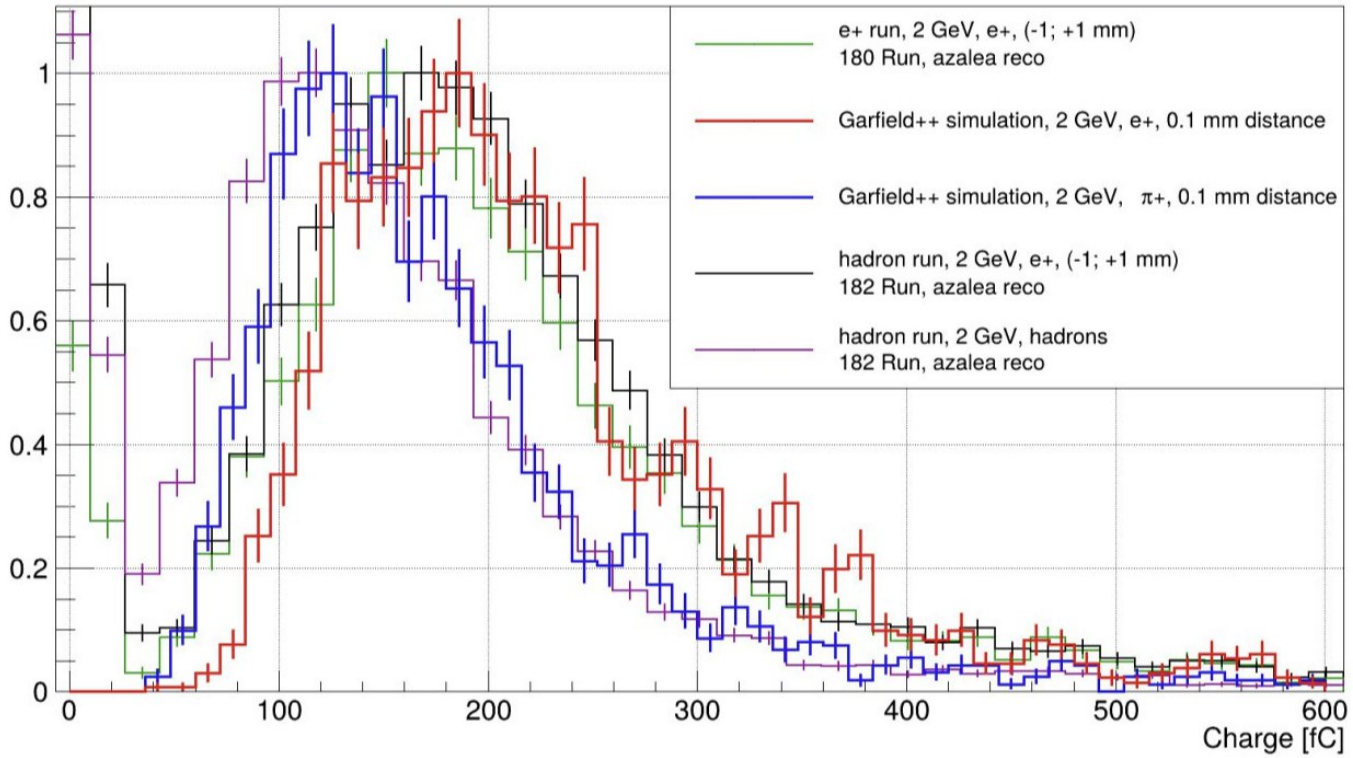
Preliminary results for first STM-VMM readout prototype - see next talk! and NA64-based readout

- 10 mm diameter straw, Ar/CO2 70/30, 30 um wire, atm pressure
- April data - no precise tracking
- advanced measurements from November 2025 prototype - analysis in progress

Measurement results (work-in-progress):

- ionization losses with electrons and pions and 10 mm single straw at PS T09
  - hadron beam - electrons, pions and muon and pure electron beam
  - PS limitation - large electron contribution in “hadron beam” - ~50% at 2 GeV, increases for smaller momenta
  - perfect tag with Cherenkov low pressure detector 99-96 % efficiency
  - cross-check with electron beam
- custom PA (JINR) with peaking time ~250 ns

Signal charge distribution for electrons and pions of 2 GeV/c passing the center of straw compared to Garfield++/LTSpice simulation results

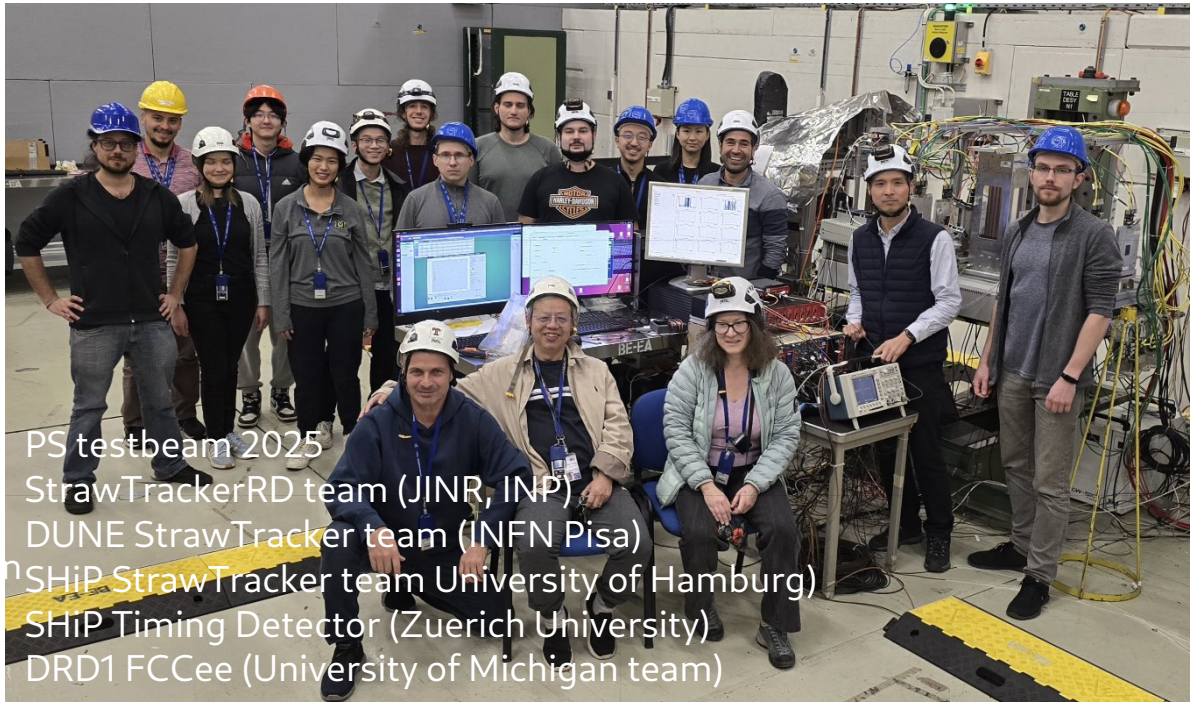


	MPV pi / MPV e+
august:	0,72
november:	0,71
november with azalea:	0,73
simulation:	0,76

Preliminary results - analysis in progress

Summary:

- Simulation studies based on Garfield++ and LTSpice are an efficient tool for exploring possible readout options for developing Straw Trackers
- Validation with testbeam measurements guarantees reliability of the simulation results
- Studies addressing common areas of individual experiments R&Ds allow efficient knowledge exchange and facilitate the individual R&Ds



Acknowledgments:

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- DRD1 Collaboration