

Readout electronics for future Straw Trackers

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INSTR 2026

October 12-16, 2026 | Hefei, China

Existing and developing StrawTrackers

Running/Future Experiments: ATLAS, LHCb, Amber, NA64, Mu2e, COSY-TOF, Panda, CBM - winded straws
NA62, COMET, SHiP, DUNE, SPD, FCCee ... -UltraSonic Welding, USW

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

Advantages :

- **large area for a reasonable cost** (straw length up to 5 m)
- **small material budget** (15-40 μm Mylar/Kapton walls)
- good spatial resolution $\leq 150 \mu\text{m}/\text{hit}$
- vacuum tightness even for large area detectors (USW)

Limitations :

- rate limitation per straw $< O(\text{MHz})/\text{straw}$
but... adjustable with straw length, diameter (5-20 mm),...
- gas, HV ($\sim 2\text{kV}$)

more in talk by Temur Enik [1]

Design and readout electronics requirements for future Straw Trackers are defined by experiment requirements

However many common aspects

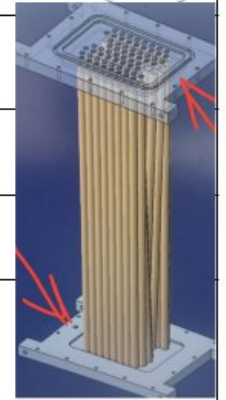
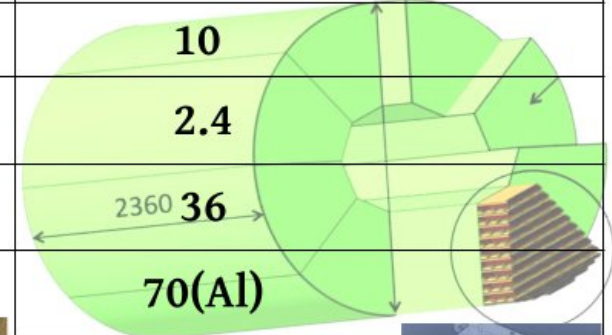
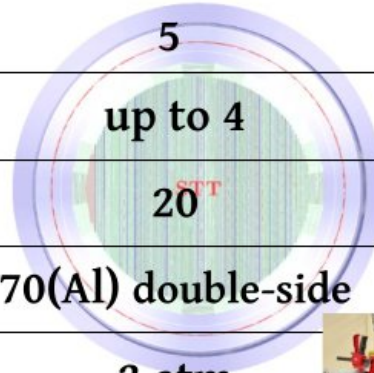
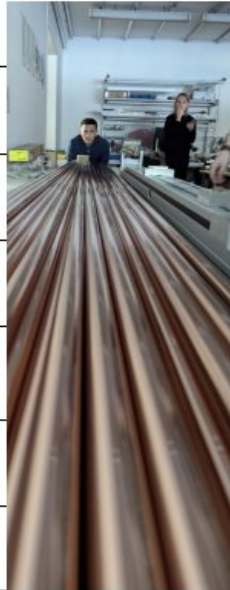
- straw production technologies and quality control
- straw design approaches
- common areas in read-out development and expertise
- shared production, R&D and operation experience

addressed by

*DRD1 Collaboration and
StrawTrackerRD team*

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

* SHiP : redundancy up to MHz

2: [SHiP Technical Proposal](#)

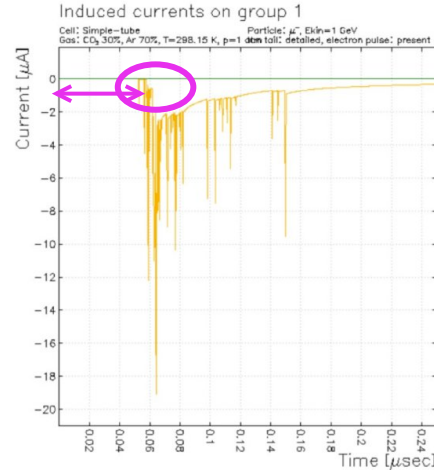
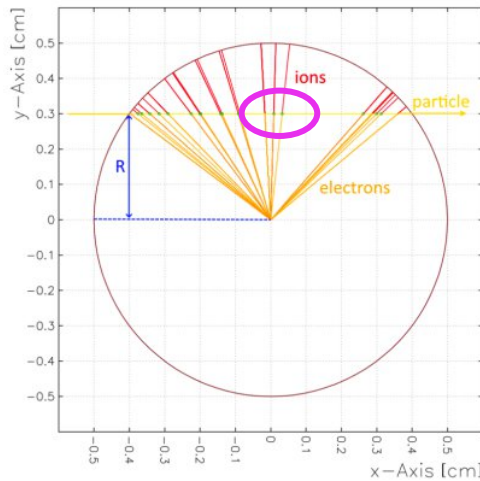
3: [DUNE Near Detector CDR](#)

4: [SPD TDR](#)

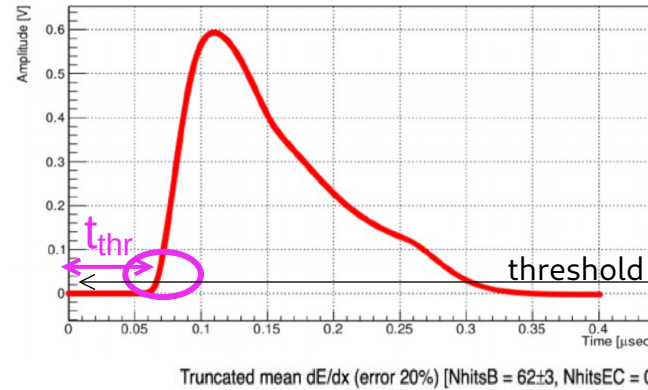
R&Ds on optimization and development of the straw readout (simulation studies and lab and testbeam measurements) by the StrawTrackerRD team are being done within several collaboration

Requirement to the readout electronics for tracking and PID

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

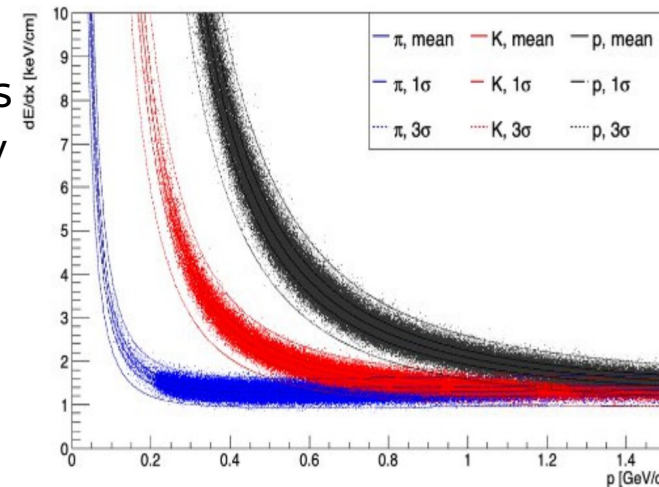


typical gas gain:
 $2-5 \times 10^4 e^-$



for given straw operation parameter and "negligible" noise ($ENC \sim 1-5 \cdot 10^3 e^-$) the smallest fluctuation of the measured drift time will be achieved with the smallest preamplifier peaking time

- Possible 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
 - cluster counting with fast electronics "dN/dX" - requires challenging
 - charge measurements "dE/dX"



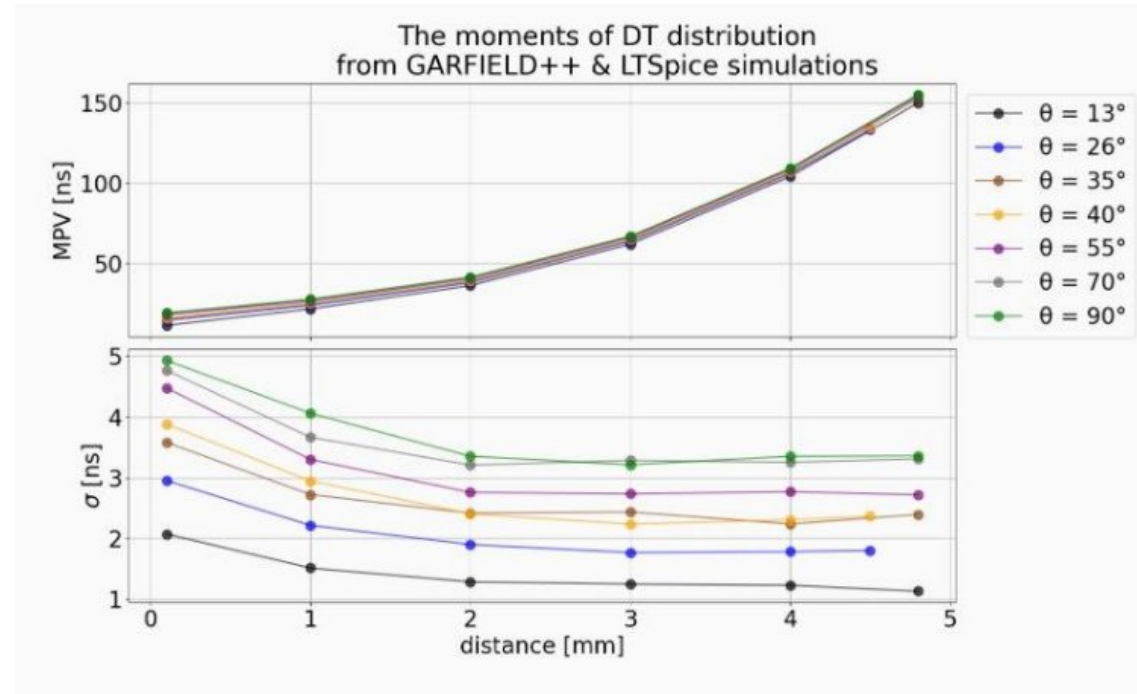
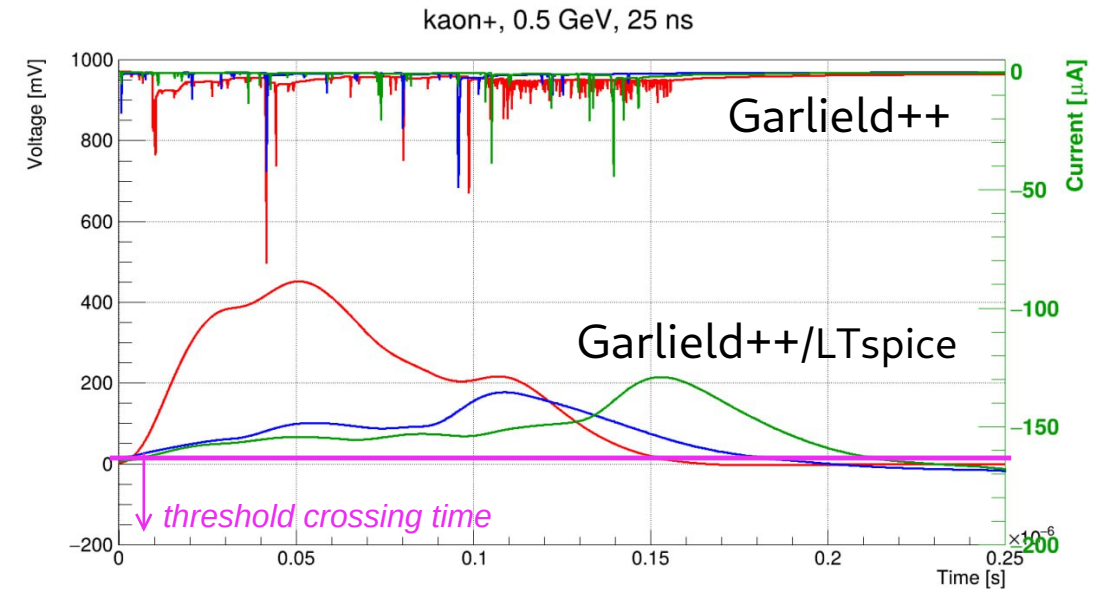
dE/dX : for given straw operation parameters, the smallest fluctuation of the measured induced charge will be achieved with the largest preamplifier peaking time

Readout solutions

- tracking only :
 - existing ASICs developed 10-20 years ago, often deprecated (for example, CARIOCA)
 - several relatively recent developments or upgrades
 - MPI : ASDv2 (ATLAS MDT upgrade), under development v3 (high rate, FCCee) [5]
 - NA64 straw readout by A. Solin [6]
 - VMM3a [7] - see poster by V. Bautin
- tracking + PID :
 - double-branch approach
 - Tiger [8] by University of Torino (designed for GEM readout and does not fit straw gas gain)
 - dedicated double branch approach for the straw readout by A. Solin, under development [9]
 - single branch with a compromising gain and peaking time
 - PASTTREC (Panda) [10]
 - ToRA by University of Torino - development ongoing [11]
 - v2 - expected next years - to be adopted for straw readout

Simulation studies

- Garfield++ 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, $\langle \text{gas gain} \rangle = 45\text{k}$
- use of the parameterized results in a general purpose MC package of a given experiment

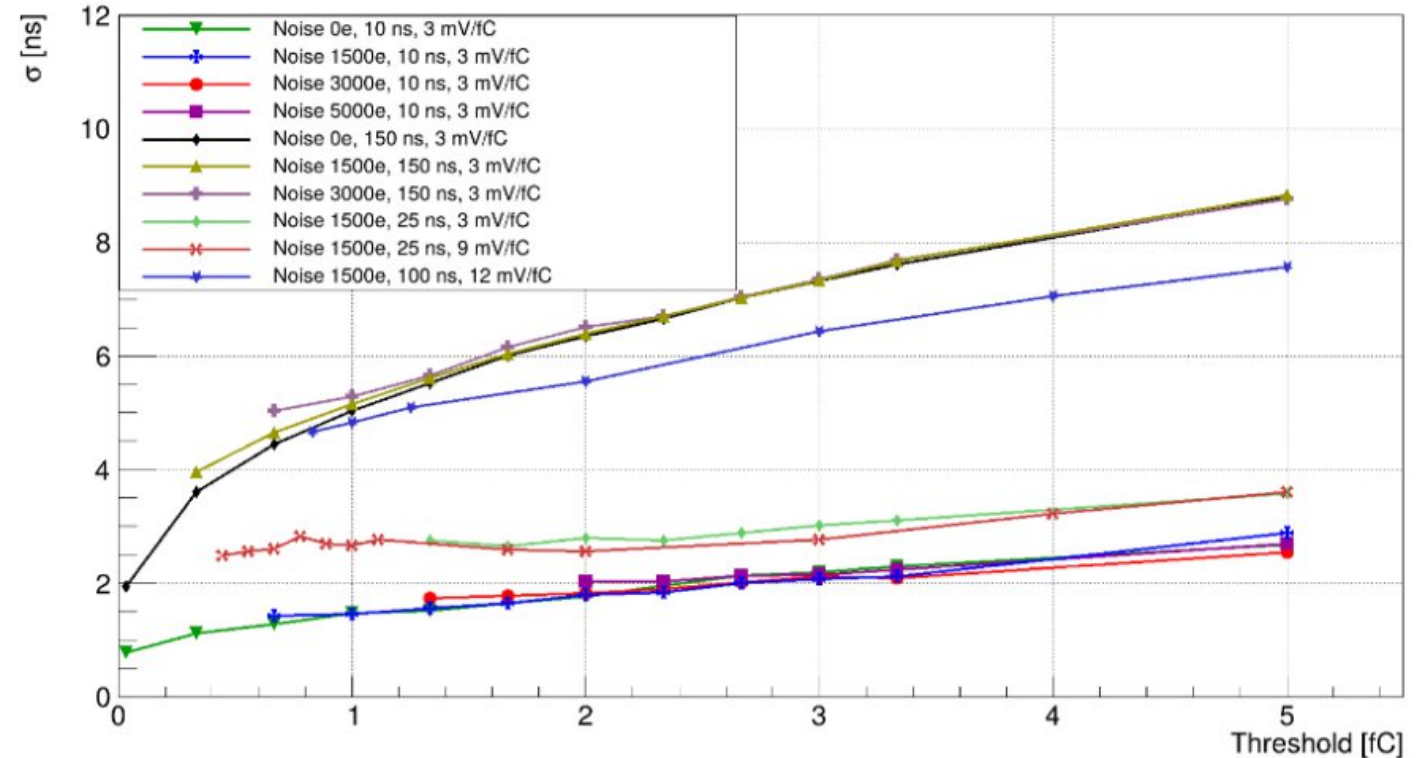


Simulation studies - tracking

Garfield/LTSpice studies with different readout models: straw time resolution as a function of the discriminator threshold

- basic amplifier/shaper model
- no realistic impedance implemented yet

10 GeV /c muon at 2 mm from the straw centre



compromising peaking time for single branch solution : good tracking + reasonable PID ?

Simulation studies - PID

Garfield++ 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

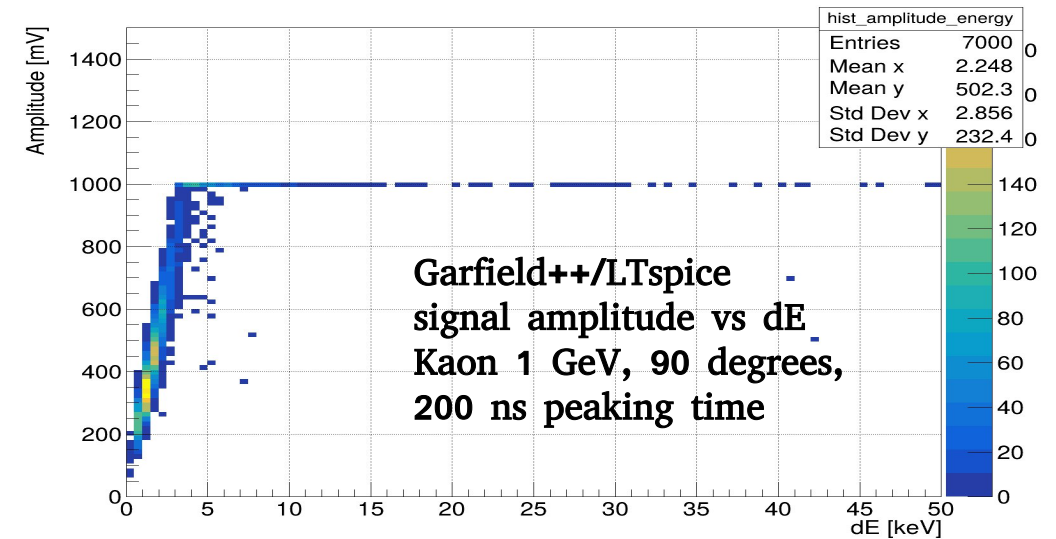
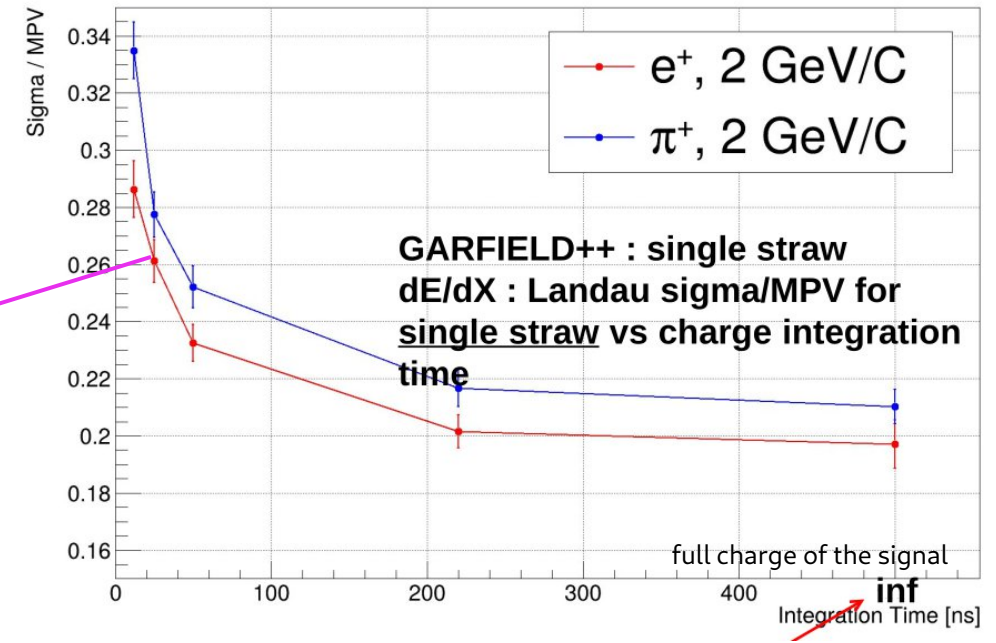
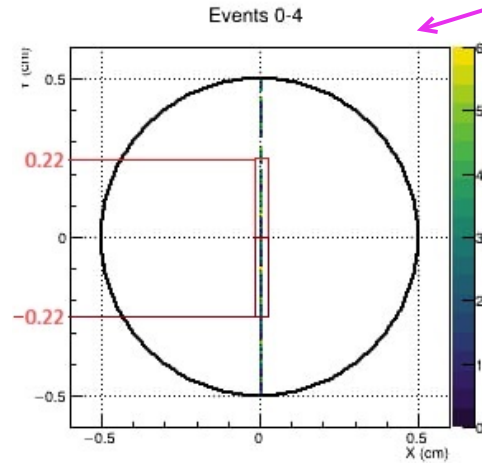
single straw; momentum choice for comparability with PS data

- **signal charge resolution**

- for rather large peaking time - slight dependence due to ion tail
- small peaking time - part of charge is lost - significantly larger fluctuations

- **finite dynamic range**

- important for low momenta PID
- small peaking time - less saturation...

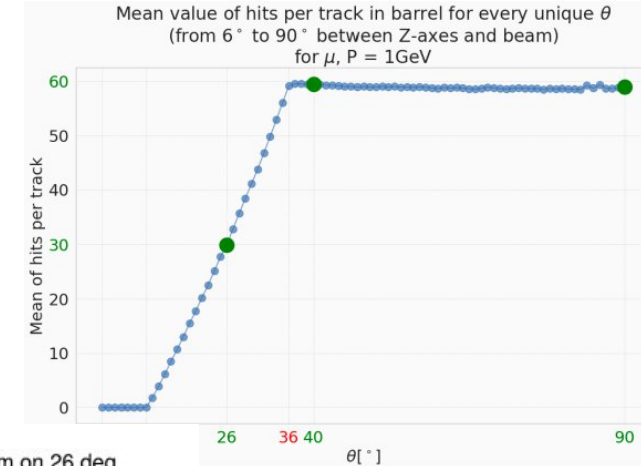
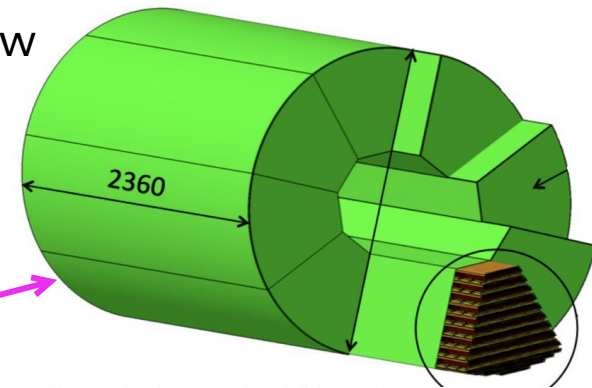
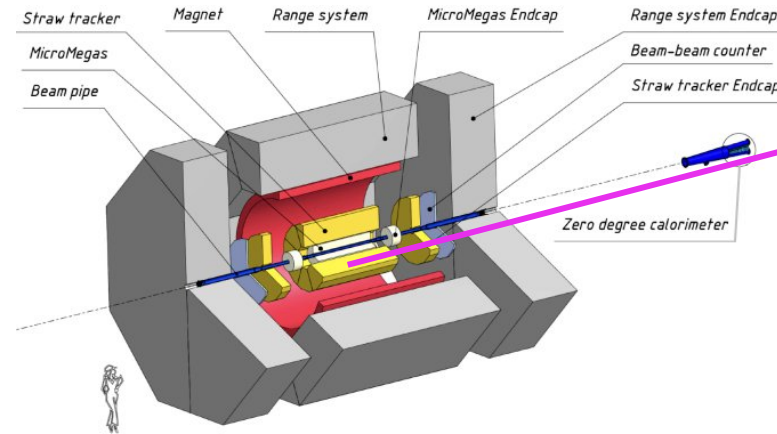


Simulation studies - PID

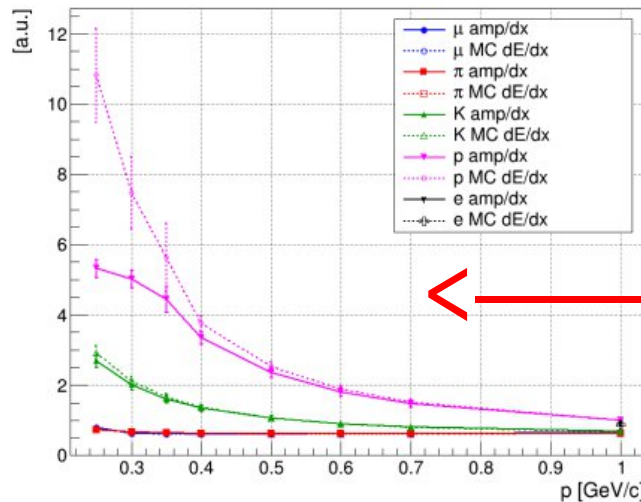
- Modelling for SPD Straw Tracker
 - Garfield++/LTspice parametrization to obtain electronics response vs dE
 - SPDroot realistic simulation
 - GEANT4->digitization accounting for the electronics response

VMM3a model **25 ns**, 3 mV/fC, 0.8 V saturation (**conservative**)
trimmed mean of all track hits - dE/dX (GEANT) and signal amplitudes;
bars correspond to trimmed mean distribution width

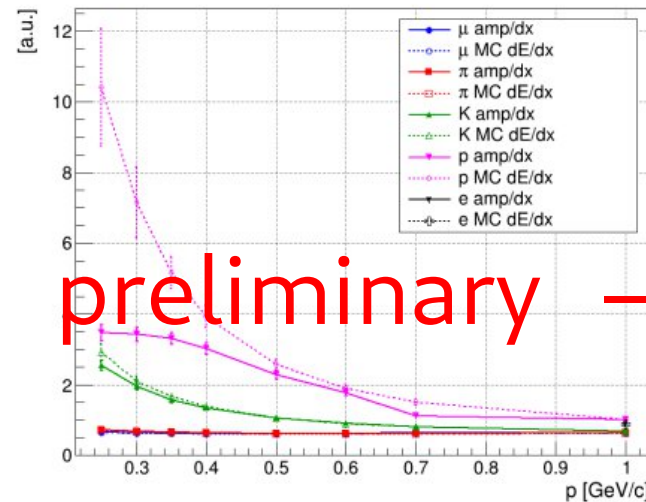
SPD TDR Barrel Straw Tracker geometry (outdated)



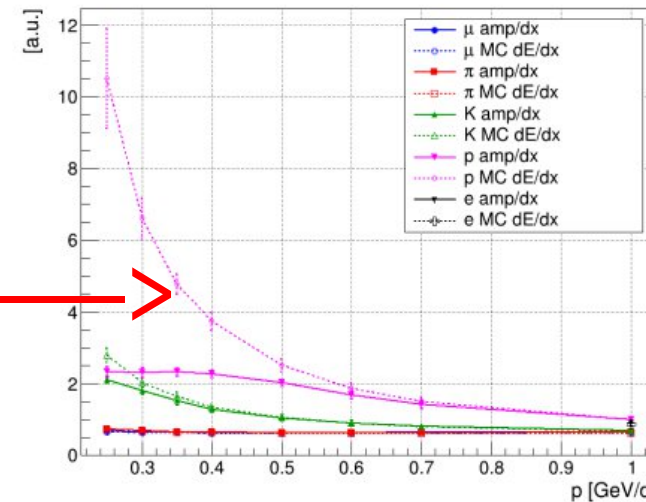
MC dE/dx and amp/dx vs momentum on 90 deg



MC dE/dx and amp/dx vs momentum on 40 deg



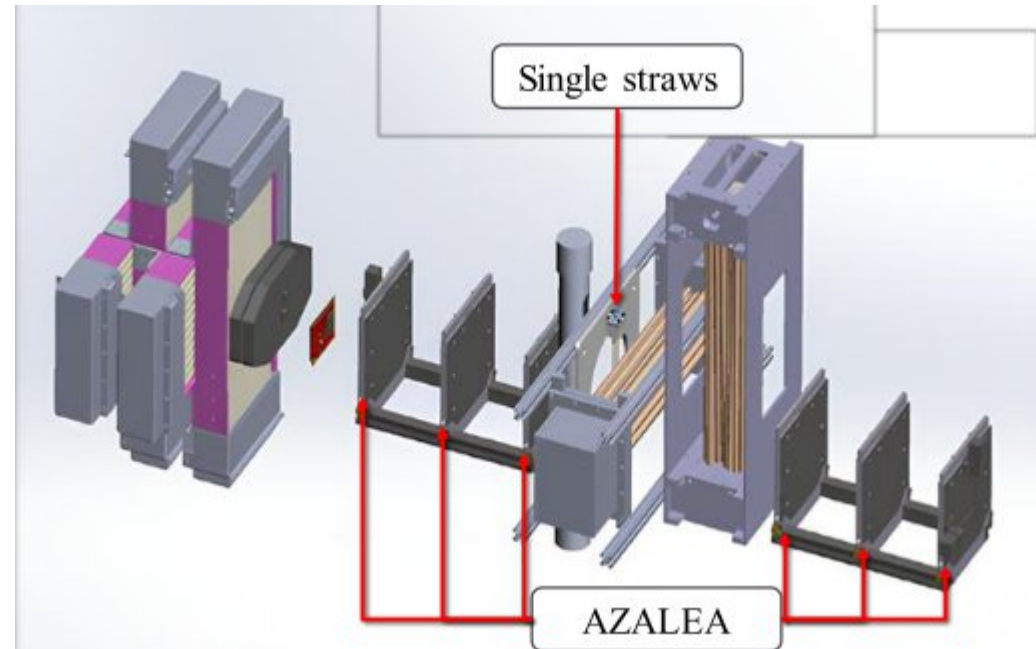
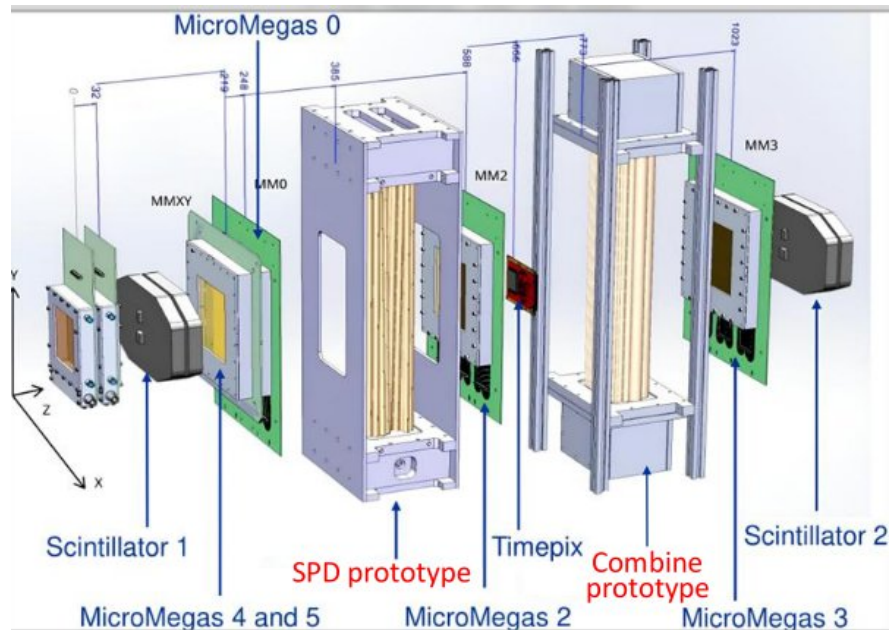
MC dE/dx and amp/dx vs momentum on 26 deg



preliminary

Testbeam studies

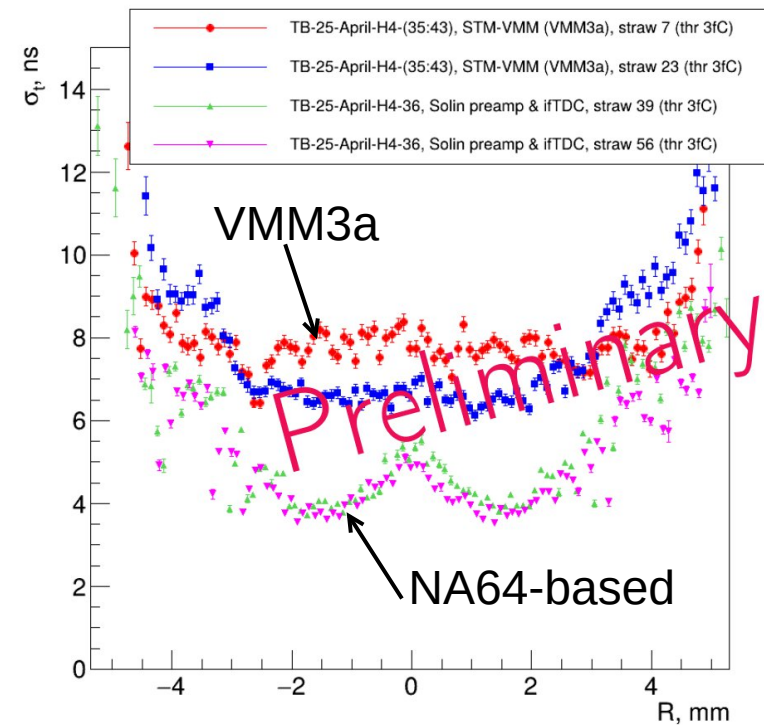
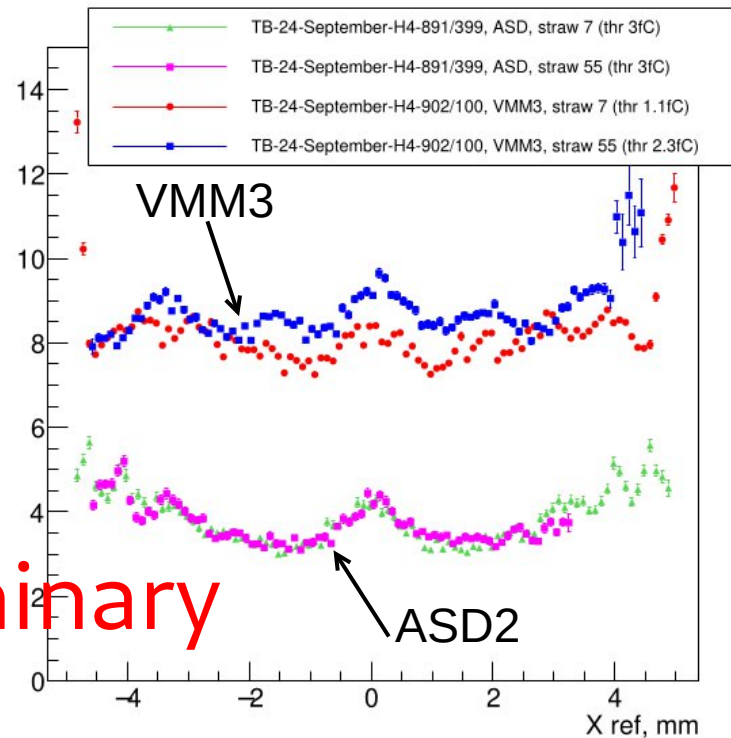
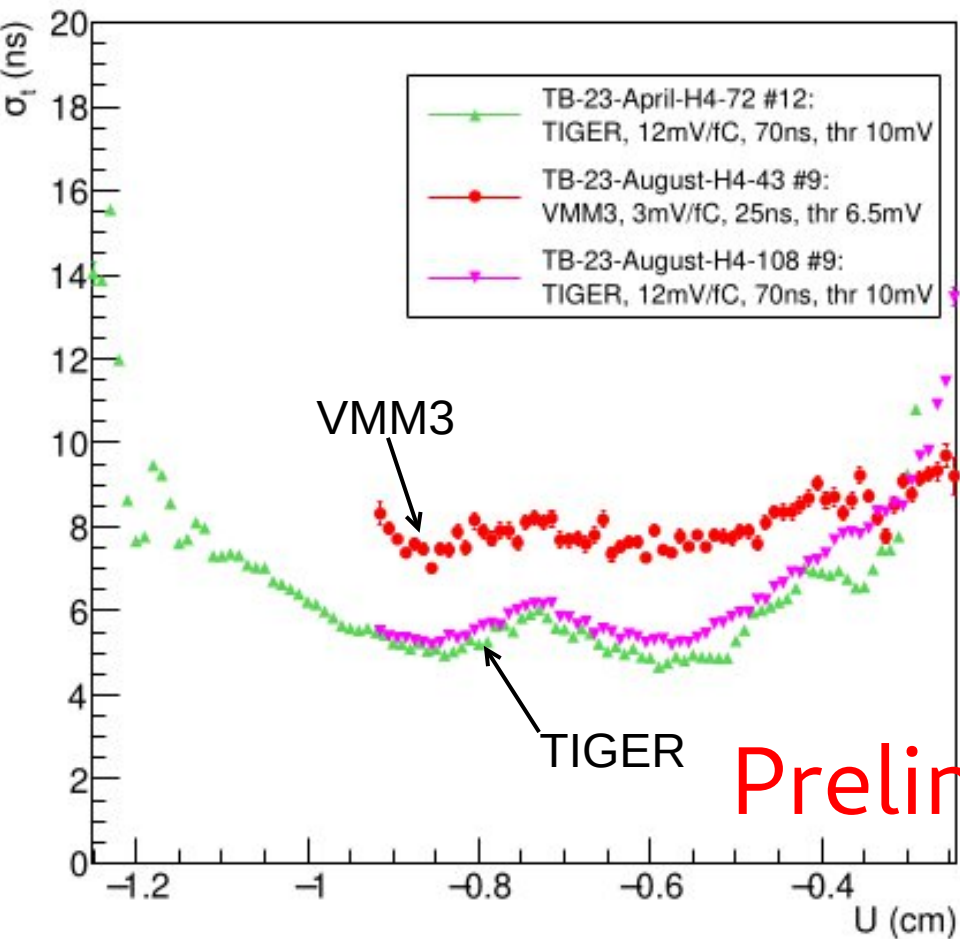
- small prototypes and single straws: 5, 10 and 20 mm straw diameter
- **time/spatial resolution** and tracking - at SPS at CERN with intense muon beam, at PS with 5-10 GeV hadrons
- **PID** - PS at CERN with 1-2 GeV hadrons and electrons
- StrawTrackerRD setup
 - reference tracking - MM-based or AZALEA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



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

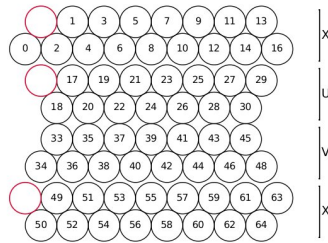
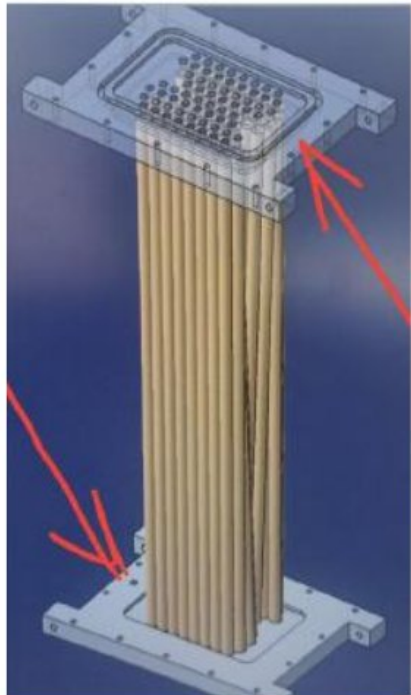
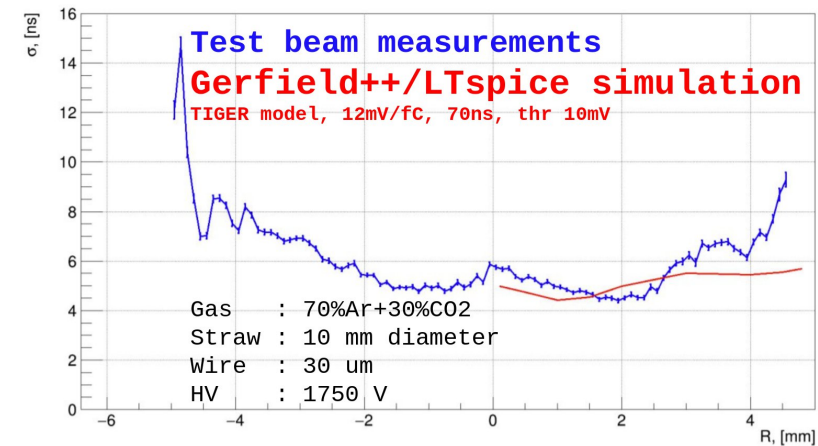
Measurement results (work-in-progress):

- 10 mm straw diameter, 30 μm wire, 70%/30% Ar/CO₂, $\langle \text{gas gain} \rangle \sim 45\text{k}$
- Tracking - several readout options : ASD2 (~ 10 ns peaking time), Tiger (70 ns), NA64-based (~ 10 ns), VMM3/3a-based (25 ns), thresholds 1-7 fC (depends on setup)
- no timewalk corrections

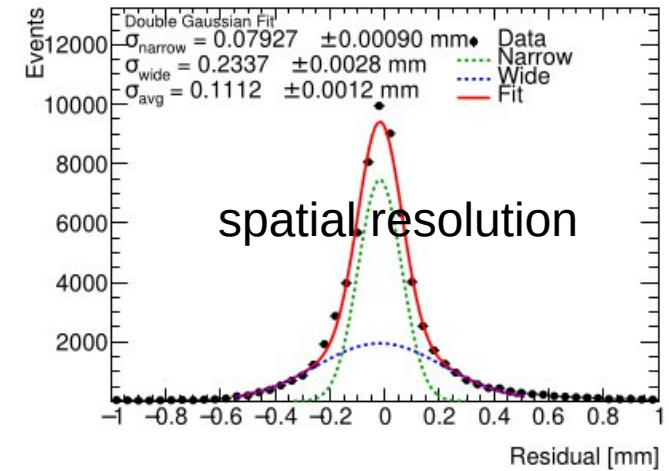
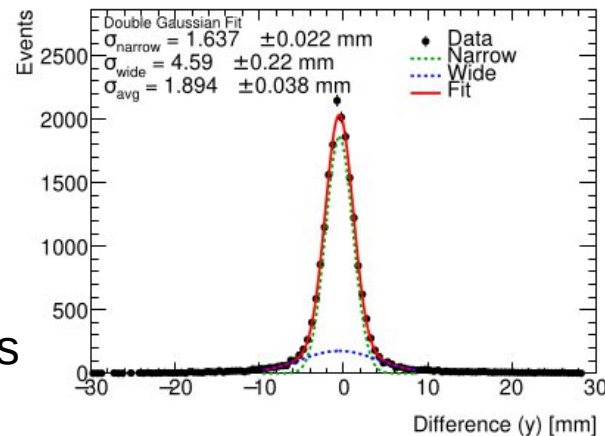
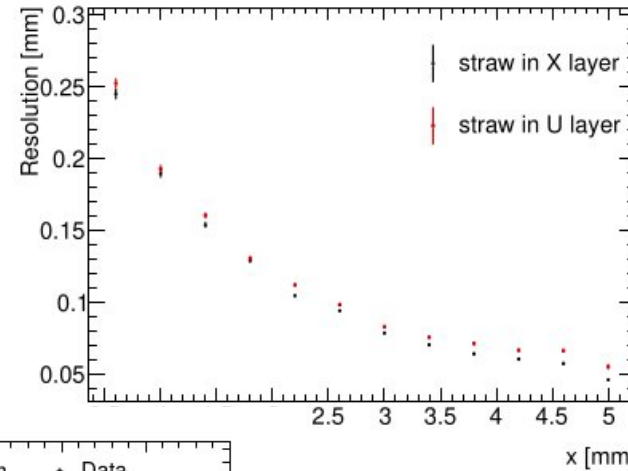


Measurement results (work-in-progress):

- MC vs Data
 - good agreement between MC and data for TIGER, comparable for ASD2, NA62
 - systematic discrepancy for VMM3 - under the investigation
- Best spatial resolution - **ASD2** [11] together with Michigan ATLAS sMDT team



second
coordinate
with 8 layers



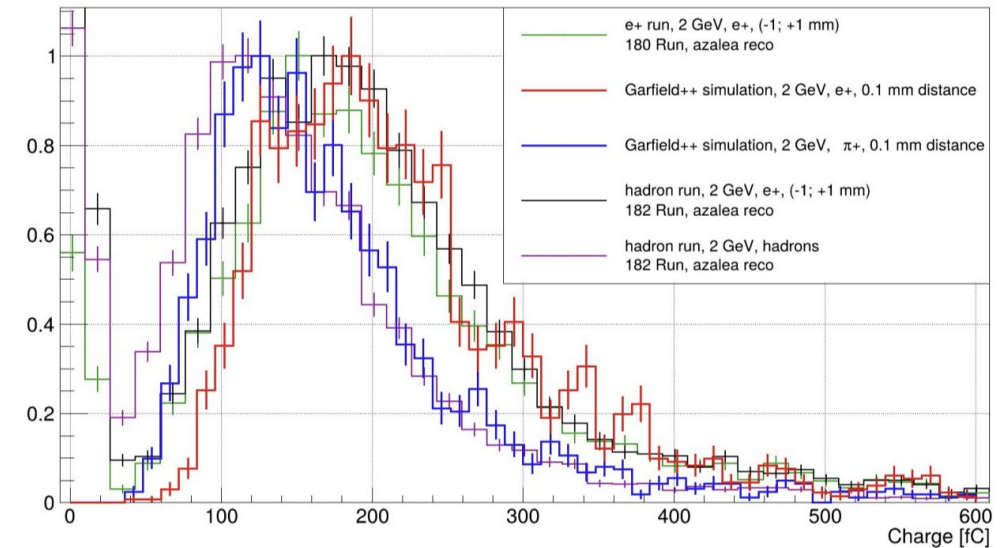
Measurement results - PID (work-in-progress):

- 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;
- VMM3a - 200 and 25 ns peaking time

Signal charge distribution for electrons and pions of 2 GeV/c passing the center of straw compared to Garfield++/LTSpice simulation results - custom PA 250 ns peaking time

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

*Preliminary results -
analysis in progress*



- Ongoing - measurements at PNPI (Gatchina, Russia) SC-1000 with 0.4-1 GeV/c protons

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:

There are a lot of teams we would like to thank for their support and expertise:

- SPS and PS Physics Coordination, beam line physicists, infrastructure and safety team
- Andre Rummler (CERN) for AZALEA operation
- Gianni Mazza, Maxim Alekseev and Chiara Alice (Tiger and ToRA developers and experts, Torino University)
- ATLAS sMDT (University of Michigan and MPI)
- DRD1 Collaboration