Ionization losses in straws measured at PS and SC1000

S. Bulanova[1], V. Bautin[2], A. Chubykin[1], A. Chukanov[2], T. Enik[2], A. Fetisov[1], A. Gurova[3], V. Kim[1], N. Korotkova[4], E. Kuznetsova[1], A. Lapkin[2], O. Maev[1], S. Romakhov[2], D. Sosnov[1]

[1]NRC Kurchatov Institute – PNPI, [2]Joint Institute for Nuclear Research, Dubna, [3]National Research Nuclear University MEPhI, [4]Skobeltsyn Institute of Nuclear Physics of the Moscow State University

The goal of the test beam measurements and simulation studies is to explore PID possibilities of a single straw and small tracker prototype for different straw readout options.

Data avaliable:

- **CERN PS** T9 beamline (low momentum hadrons and electrons): pions & electrons at 1-2 GeV/c
  - **single straw** + custom PA (1 mV/fC, 220 ns peaking time) + CAEN digitizer (November, 2025)
    —> analysis done by S. Bulanova [ref.]
  - **tracker prototype** + ST-VMM (March 2026):
    - preamp. 0.5 mV/fC & 200 ns peaking time configuration (optimal for PID);
    - preamp. 3 mV/fC & 25 ns peaking time configuration (optimal for spatial resolution)

    —-> analysis by S. Bulanova is ongoing

- **PNPI SC-1000** P3 beamline - proton momentum scan in range of 0.45-1.7 GeV/c (Ek 0.1-1 GeV),
  - **single straw** + custom preamp. (1 mV/fC & 2 mV/fC; 220 ns peaking time) + CAEN digitizer (Sept.-Oct., 2025) —-> analysis by N. Korotkova is ongoing
  - **tracker prototype** + ST-VMM readout (expect data taking by the end of 2026)

Simulation:

Garfield++ & LTSpice Monte Carlo simulation was performed to compare with all experimental setups.

Conditions at PS

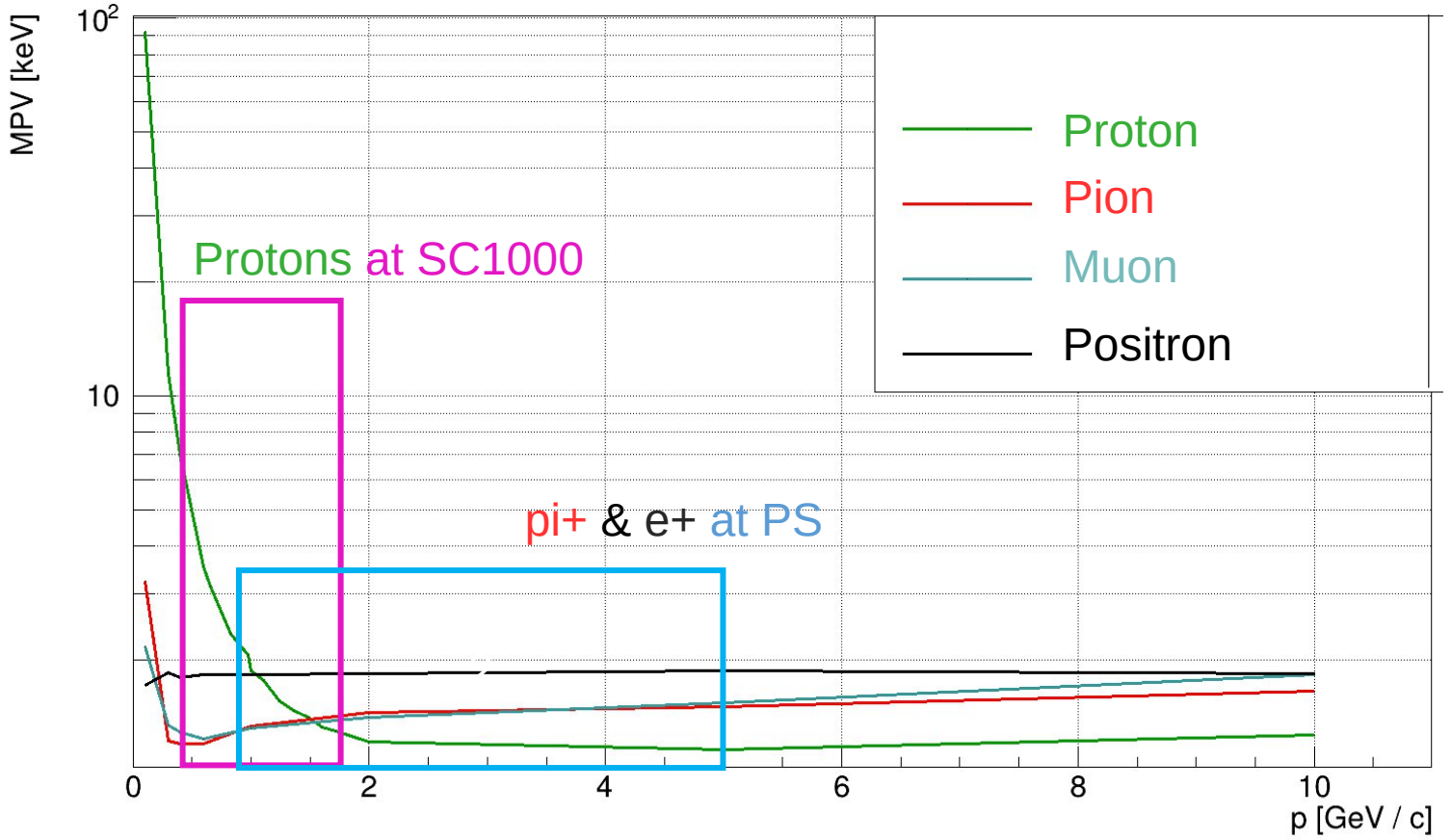
- Mixture of pions and electrons
- The lowest available momentum ~ 1 GeV/c
- Efficient PID separation using a Cherenkov tag from beamline instrumentation.

Conditions at SC1000

- Protons
- Momentum range:
  0.45 - 1.7 GeV/c
  (E_k~ 100 MeV - 1 GeV)

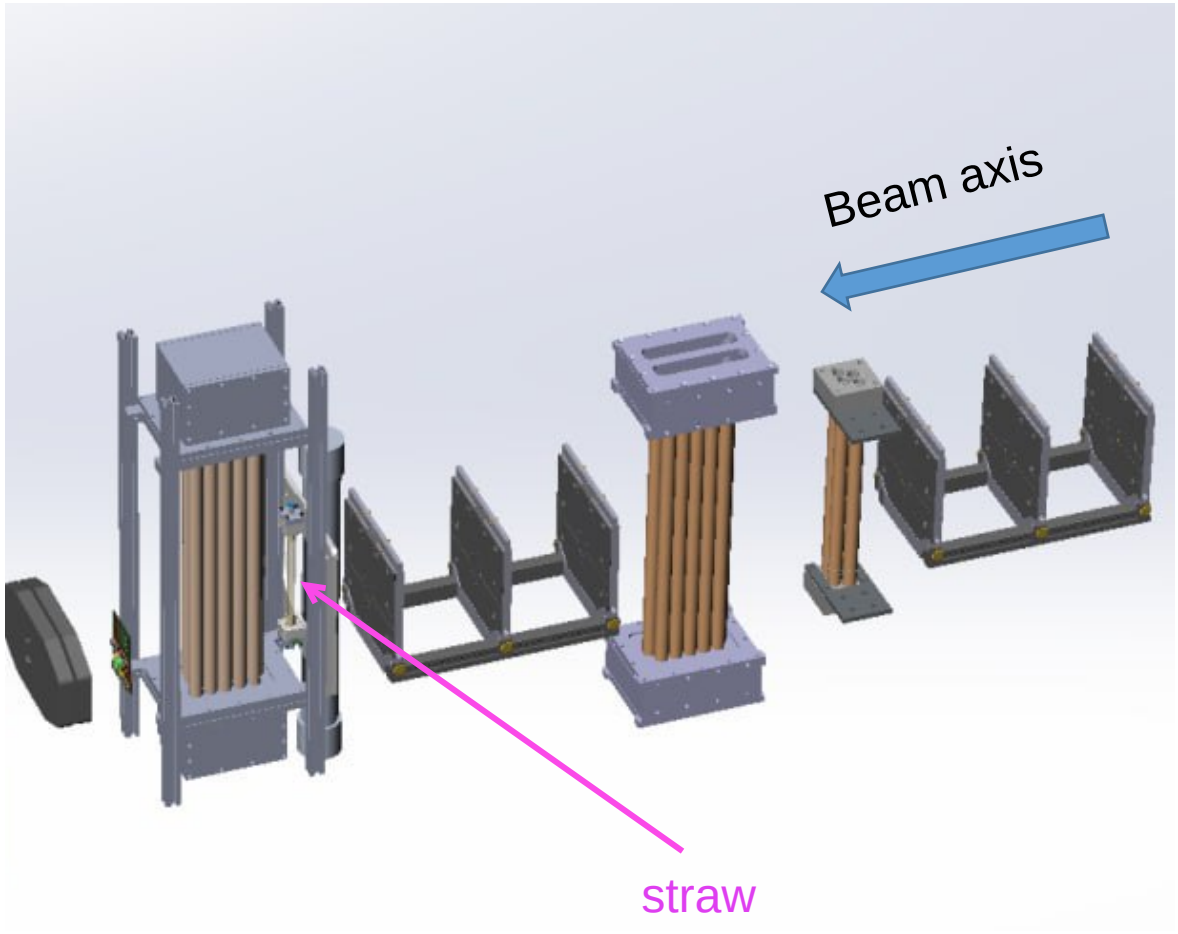
GARFIELD++ dE/dx simulation for a single straw

MPV of Landau fit vs momentum



PS Testbeam setup — single straw

November, 2025



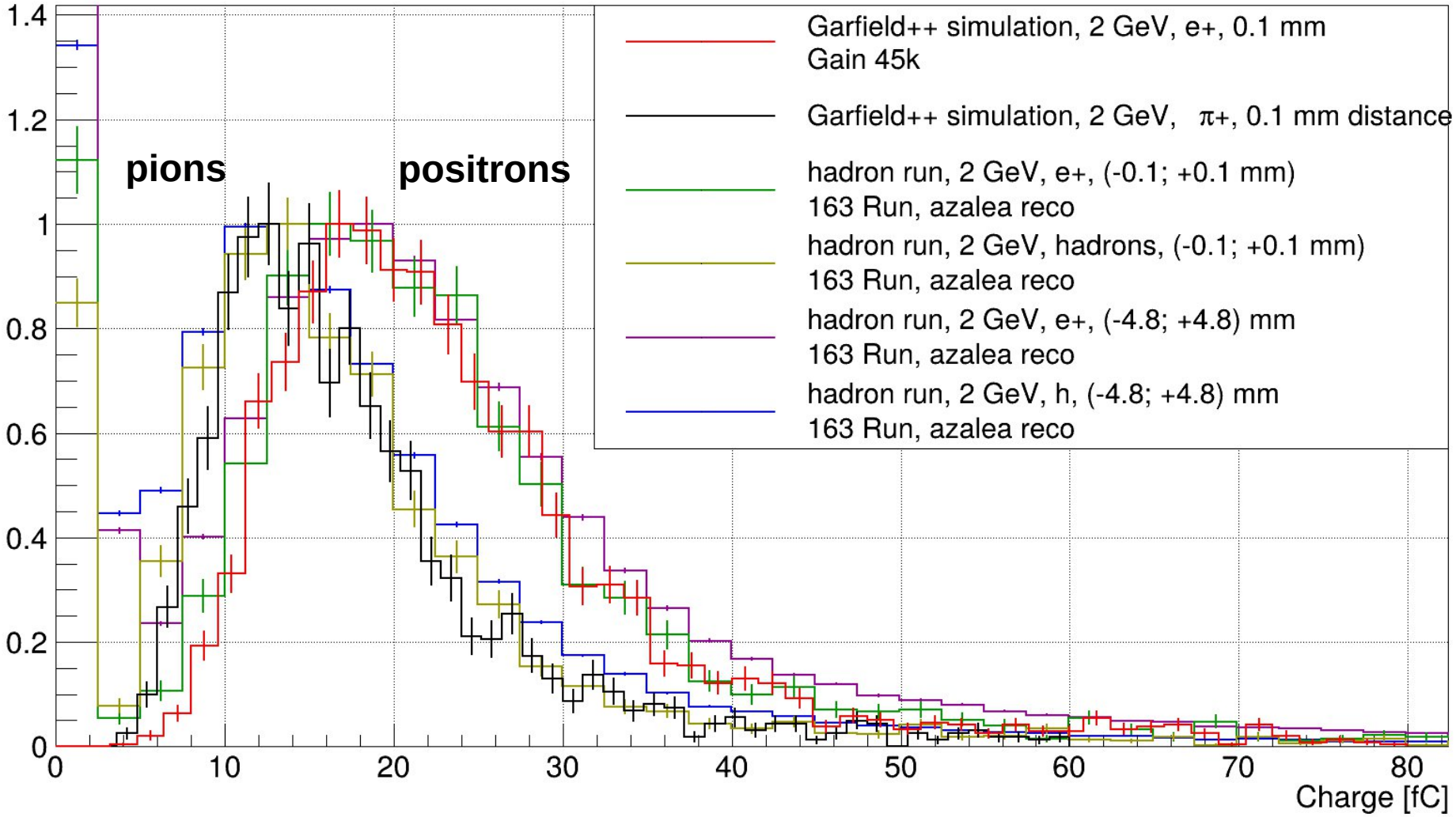
- **single straw**
- with custom PA (O.Minko, JINR)
  ~220 ns peaking time
- CAEN digitizer
- Reference PID with Cherenkov detector
- Reference tracking for dE/dx measurements using 6 Azalea silicon planes

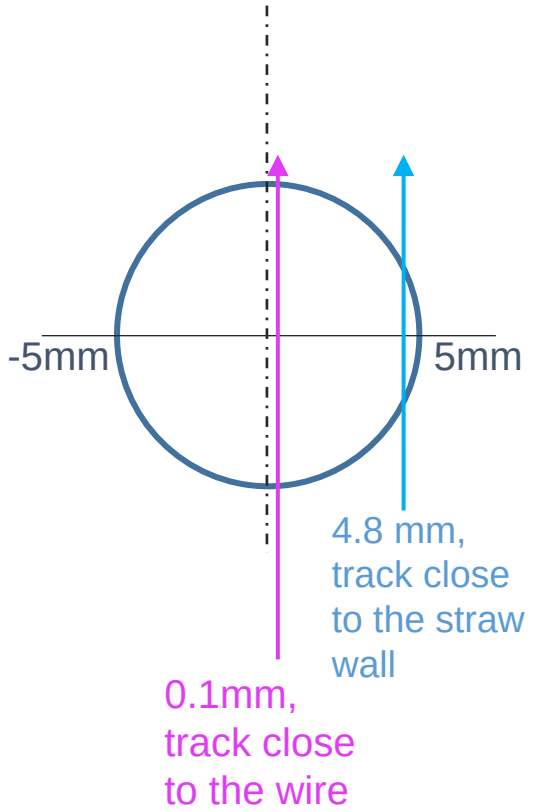
Two beam types:

- e+ run, p = 1, 2 GeV/c
- hadron run, p = 1, 2, 10 GeV/c

Comparison of analysis and simulation results (S. Bulanova)

Measured charge per unit length for **positrons** and **pions** of **2 GeV/*c***





Comparison of analysis and simulation results

The charge distributions were fitted using Landau function.
The results of the fit (MPV and Sigma) are presented in the table.

Fit results	MPV	Sigma	Sigma / MPV
Garfield++, e+	17,70	3,80	0,21
data, e+	18,40	4,11	0,22
Garfield++, pi	12,60	2,93	0,23
data, pi	12,80	3,10	0,24

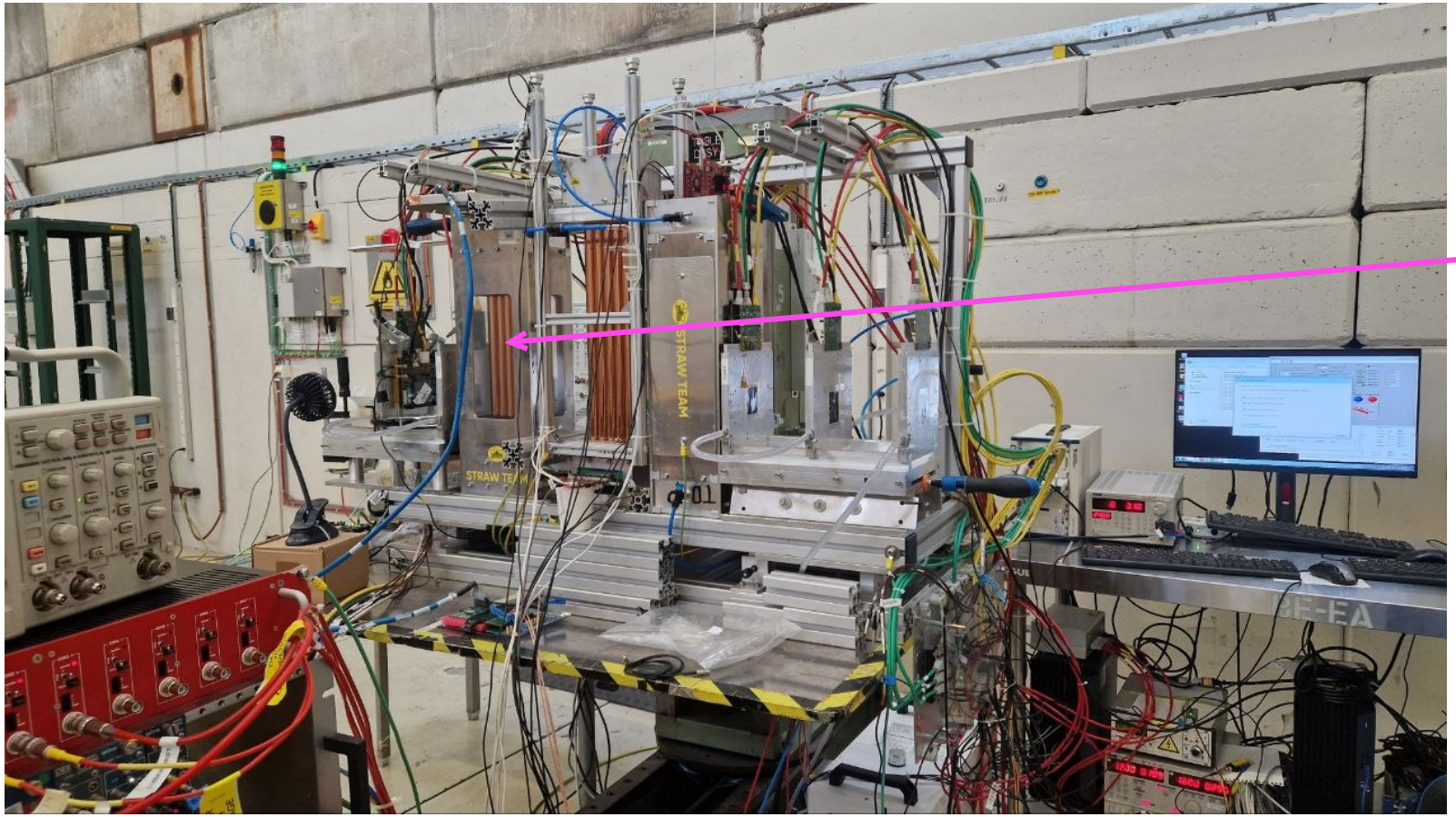
MPV of pi+ / MPV of e+
Garfield: 0,71
Experiment: 0,70

Brief conclusion: perfect agreement between Monte Carlo and testbeam data.
[ref. to report in May, 2026]

PS Testbeam setup — tracker prototype

March-April, 2026

- **Small tracker prototype**
- with ST-VMM readout:
  - Peaking time: **200 ns,**
    Gain: 0.5 mV/fC
  - Peaking time: **25 ns,**
    Gain: 3 mV/fC & 12 mV/fC



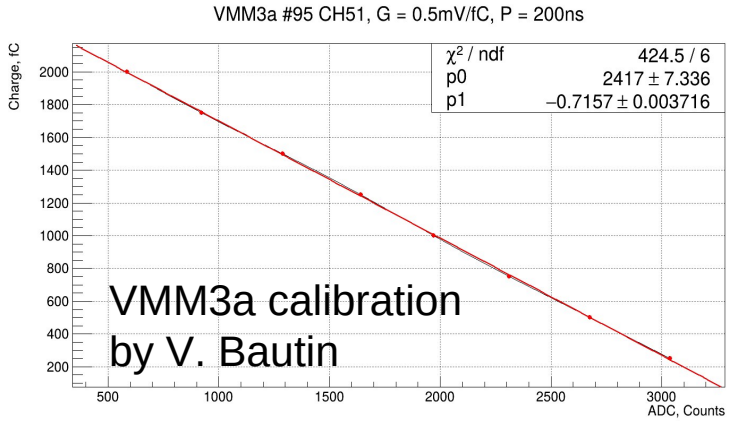
8x8 straws prototype with variable readout parameters

Analysis is ongoing.
(S.Bulanova)

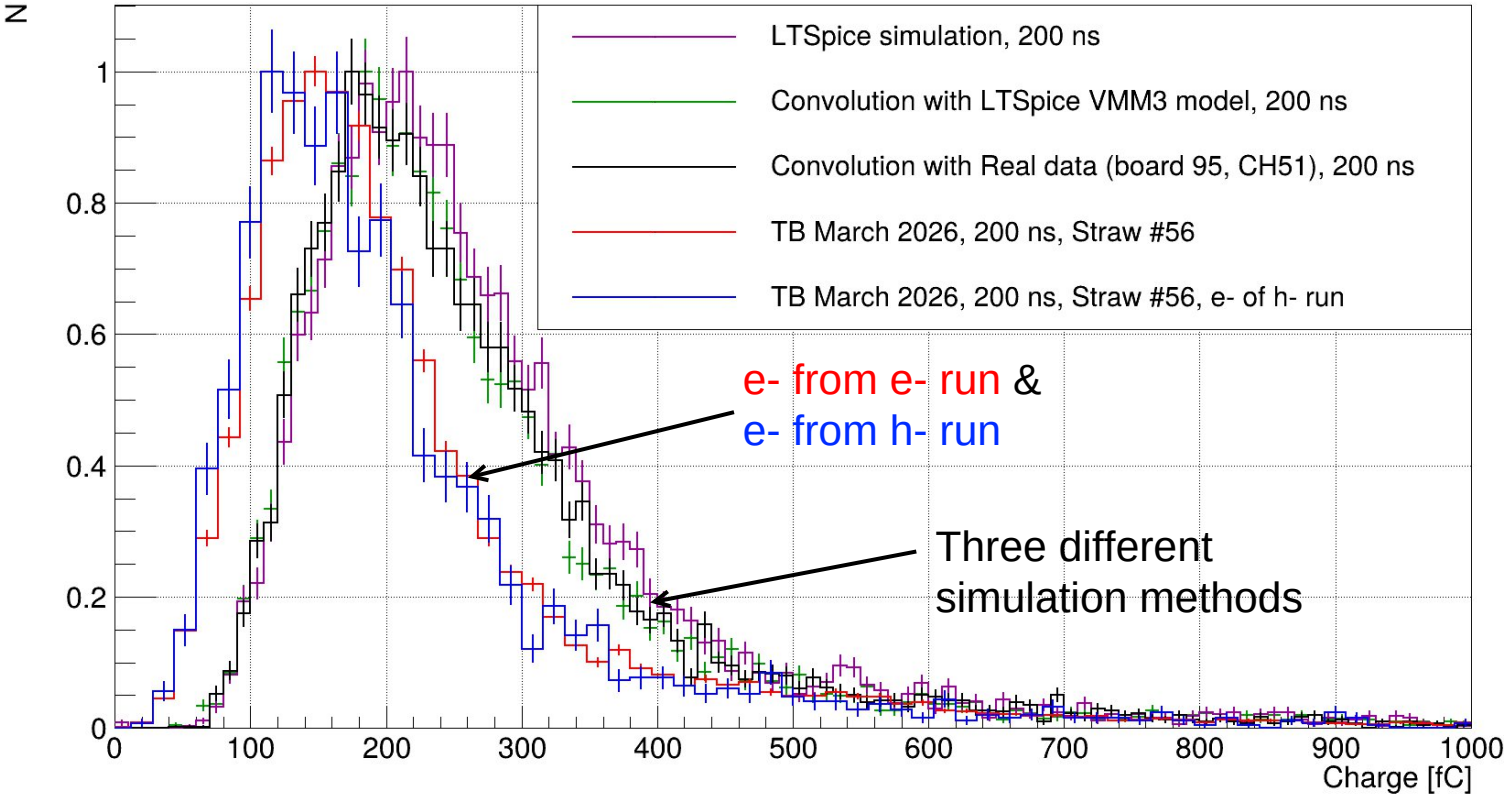
Comparison of analysis and simulation results (S. Bulanova)

Three simulation methods were applied and compared:

1. Garfield++ and LTSpice direct simulation;
2. Garfield++ signal convolution with LTSpice readout model;
3. Garfield++ signal convolution with real board transfer function.



Measured charge per unit length for **electrons** (**200 ns** peaking time)

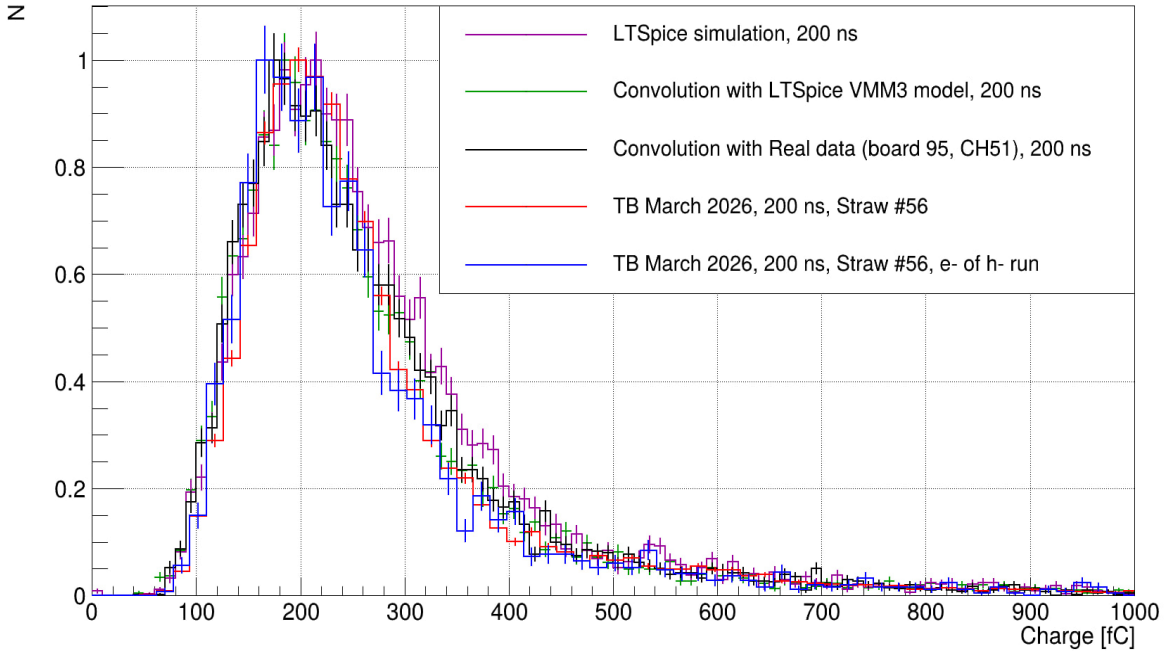


Brief conclusions:

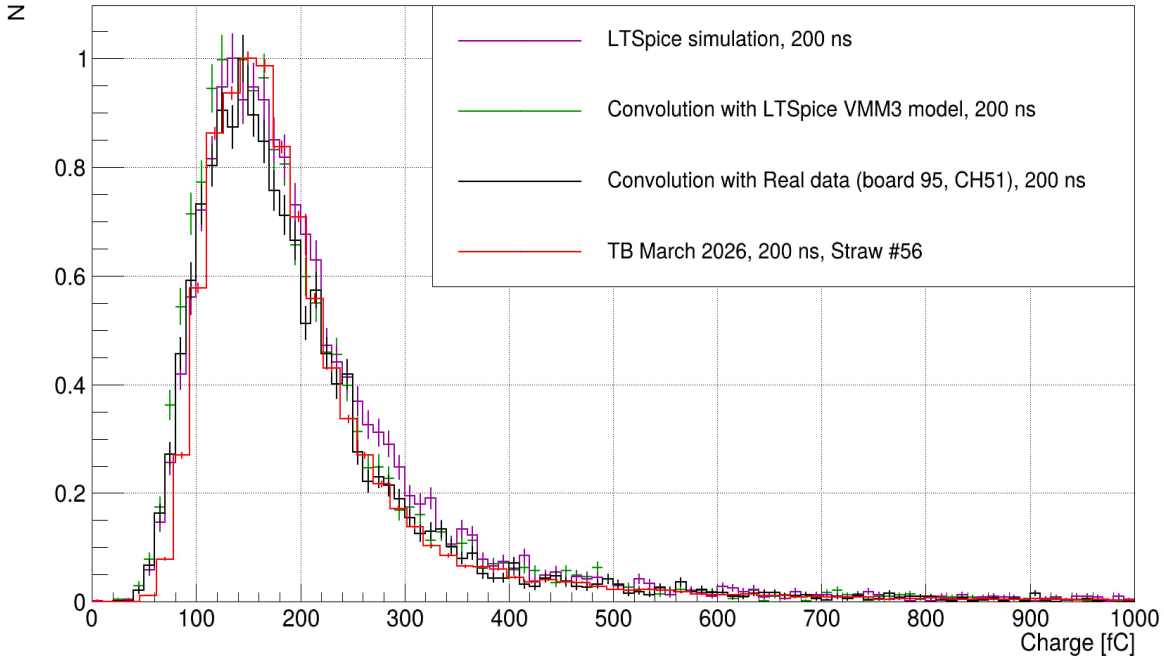
- A good agreement between charge distributions of e- from hadron run and e- from electron run shows a good efficiency of Cherenkov tag;
- The charge distributions obtained via different simulation methods are in a perfect agreement;
- The shapes of experimental and simulated charge distributions are similar, but...
- There is a shift of app. 50 fC between the experimental and simulation data

Comparison of analysis and simulation results after applying a **50 fC offset** to the absolute values obtained from the experimental results

Electrons from e- and h- runs & 3 simulations



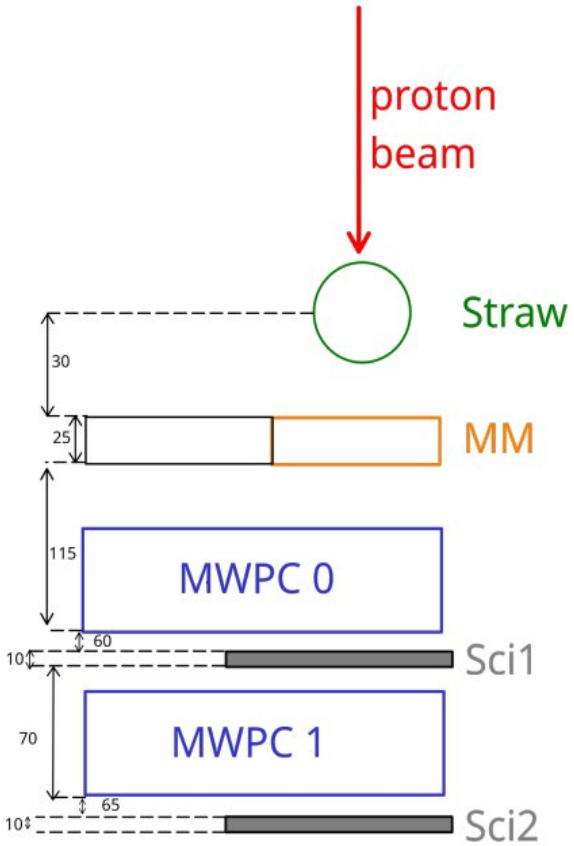
Pions & 3 simulations



- The shapes of experimental and simulated charge distributions are similar.
- After applying a 50 fC shift to the absolute values, the experimental and simulation data show good agreement.
- The physical meaning of this 50 fC offset remains to be studied.

SC1000 testbeam setup – single straw

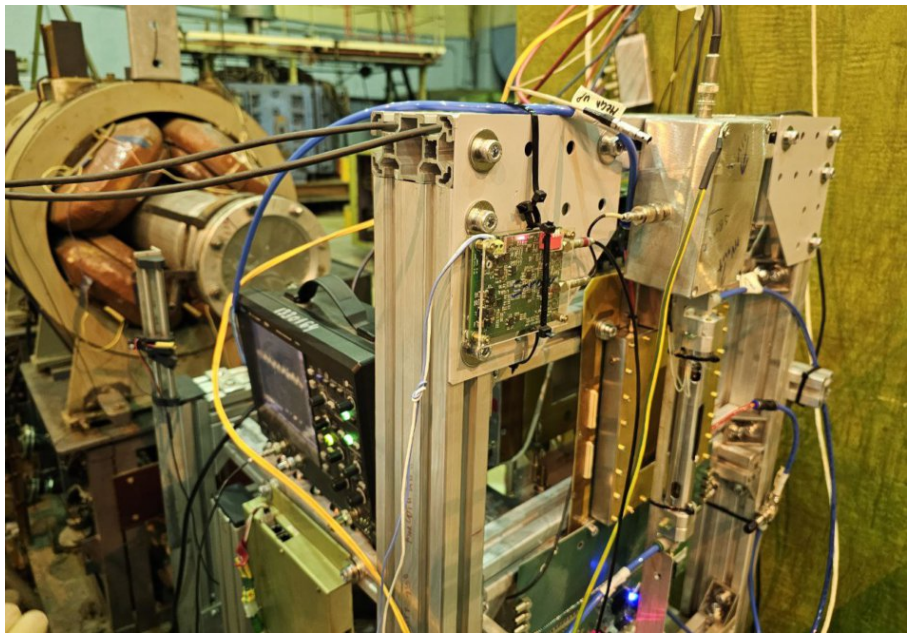
Gatchina, September-October, 2025

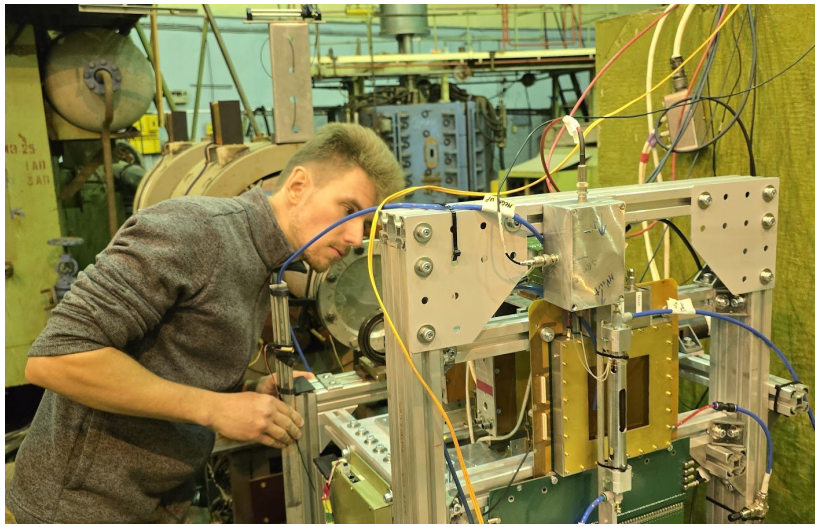


- **single straw**
- with custom PA (O.Minko, JINR),
  ~**220 ns** peaking time
- CAEN digitizer
- reference tracking:
  - MicroMegas plane with VMM3 readout
  - MWPC with CROSS3 readout (PNPI)
    (under development, to be included
    in the future tests)
- trigger: Scintillator coincidence

The beam:

- protons
- Momentum 0.45-1.7 GeV/c
  or Ek 100 MeV - 1 GeV

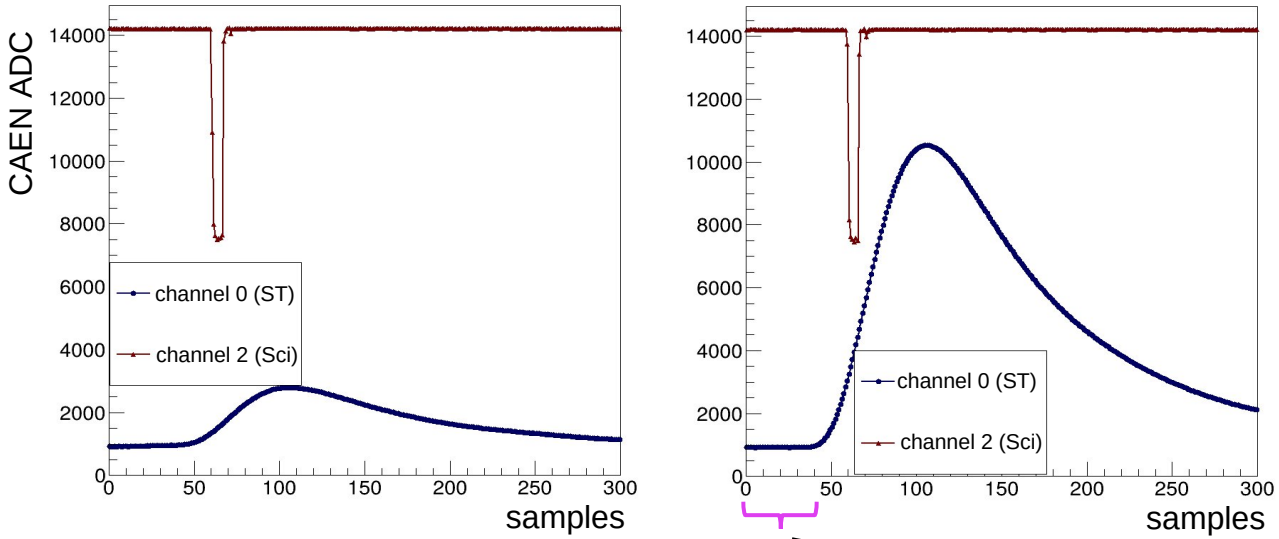


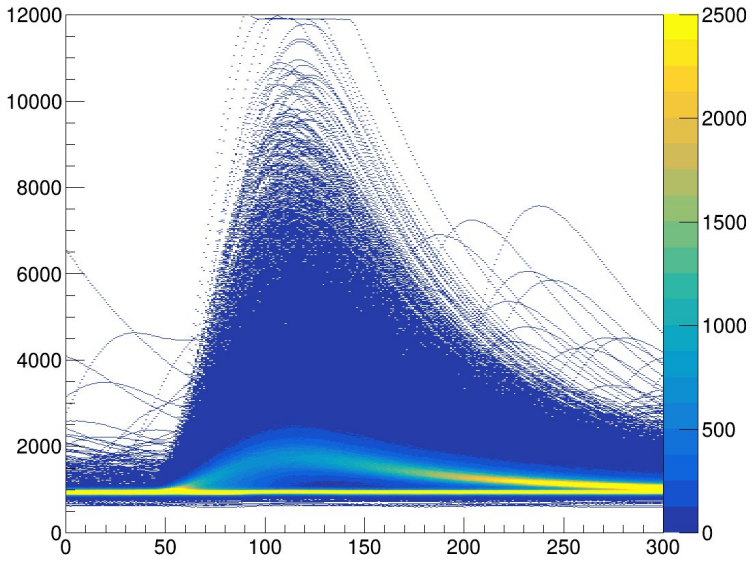




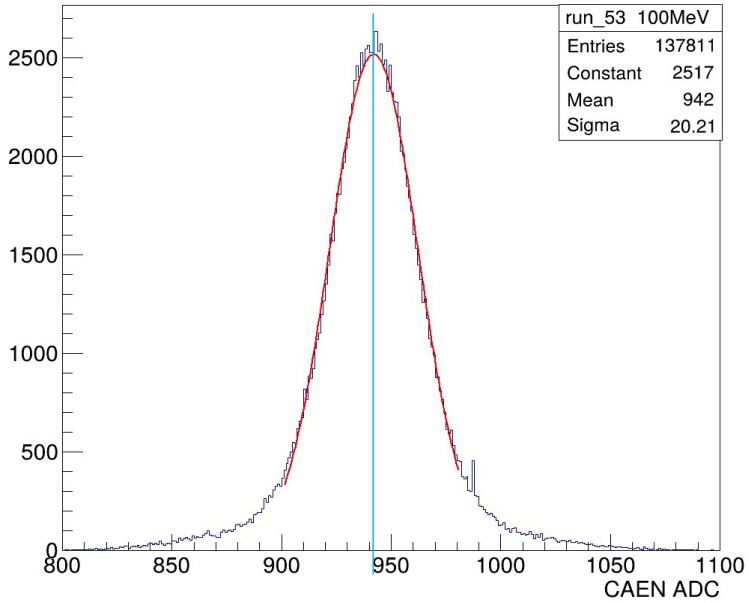
Signal from straw and scintillators

2 channels out of the 8 available were used in the test: 0-straw, 2-sci. trigger
Sampling rate for CAEN digitizer used in SC1000 testbeam: 250 MS/s





Straw signal baseline distribution, calculated based on the first 40 (or 50) samples



For the analysis, a dynamic baseline is used, which is calculated for each waveform based on its initial segment before the signal actually started.

Reference tracking (with only MM plane)

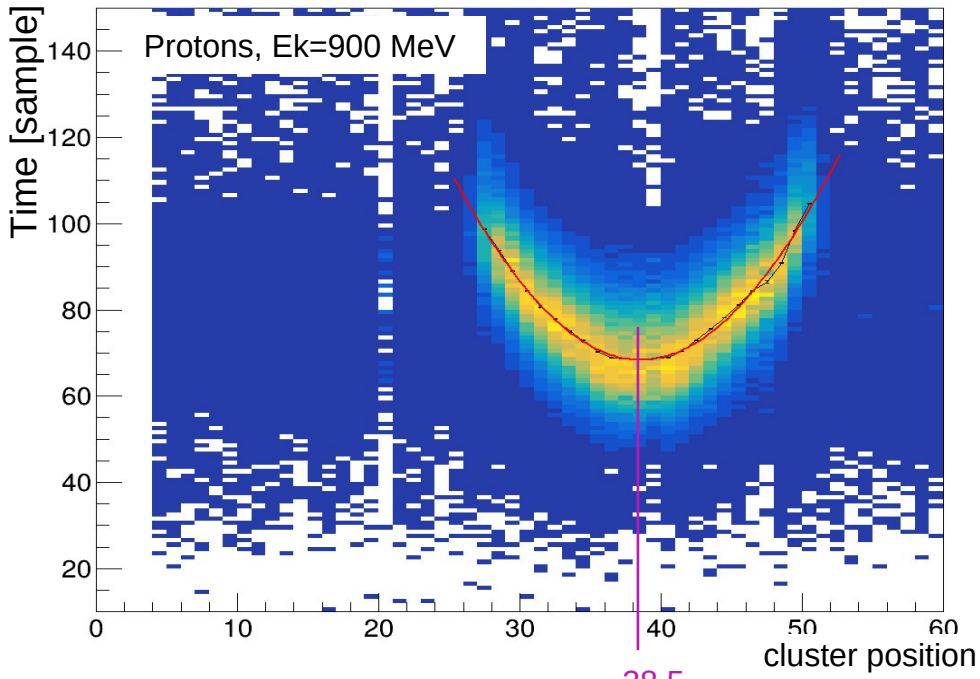
Clustering - grouping adjacent hit channels (strips) into a cluster, taking into account that some channels are dead and a cluster can continue beyond a dead channel.
95% of all events contain only one cluster.
The position of the cluster is defined as the number of the strip in which the cluster center is located.

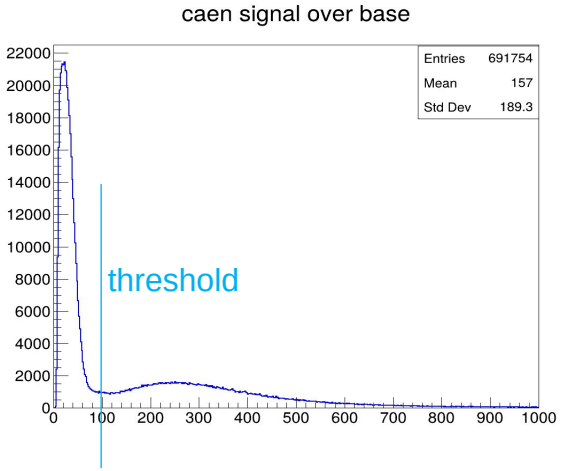
Plotting RT curve:

- To check the analysis for consistency (straw is also a track detector).
- To evaluate the straw position, which is needed for signal normalization per unit length.

The straw position will be cross - checked using straw edges

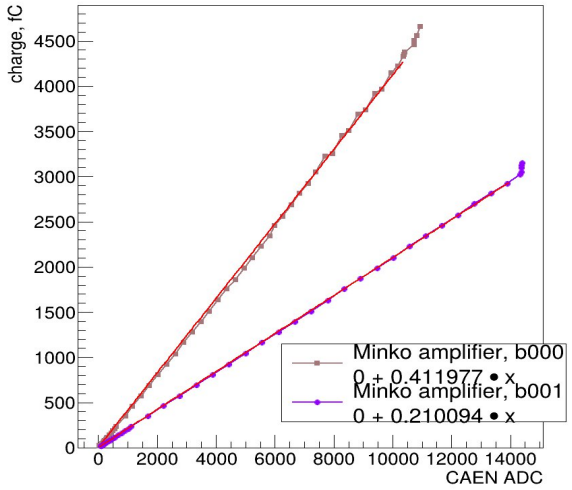
Measured drift time at the moment the signal crosses the certain threshold vs MM cluster position.



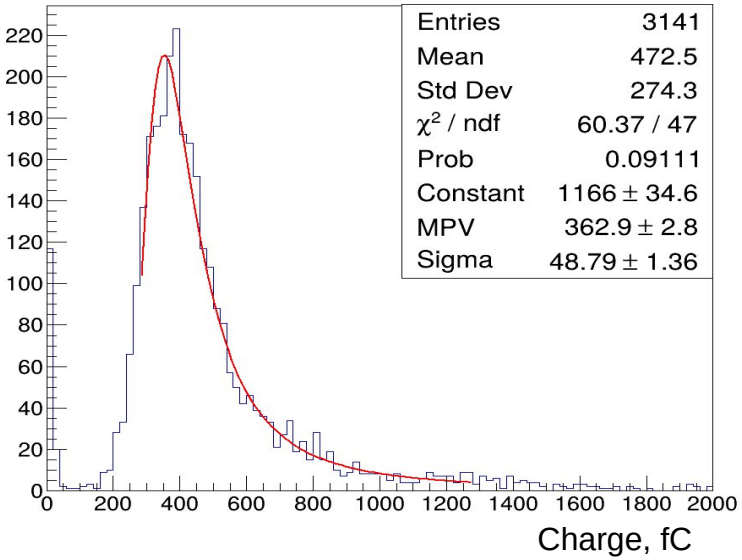


Measured charge distribution

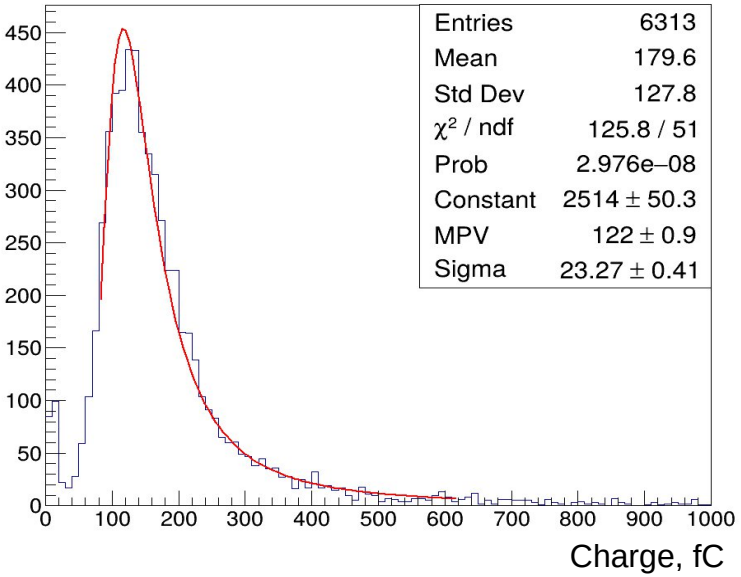
- We plot the signal distribution for each bin across the tube.
  One bin corresponds the width of a MM strip (0.4 mm), so we collect all the tracks which form MM clusters located within this strip.
- Knowing the position of the straw relative to the plane, we normalize the signal by the track length within the tube.
- Recalculate the signal using preamplifier calibration ——>



Protons Ek= 100 MeV
track position within ~ 0.2 mm from the straw center (38 strip)



Protons Ek= 900 MeV
track position within ~ 0.2 mm from the straw center (38 strip)



The resulting distributions are well approximated by a Landau function.

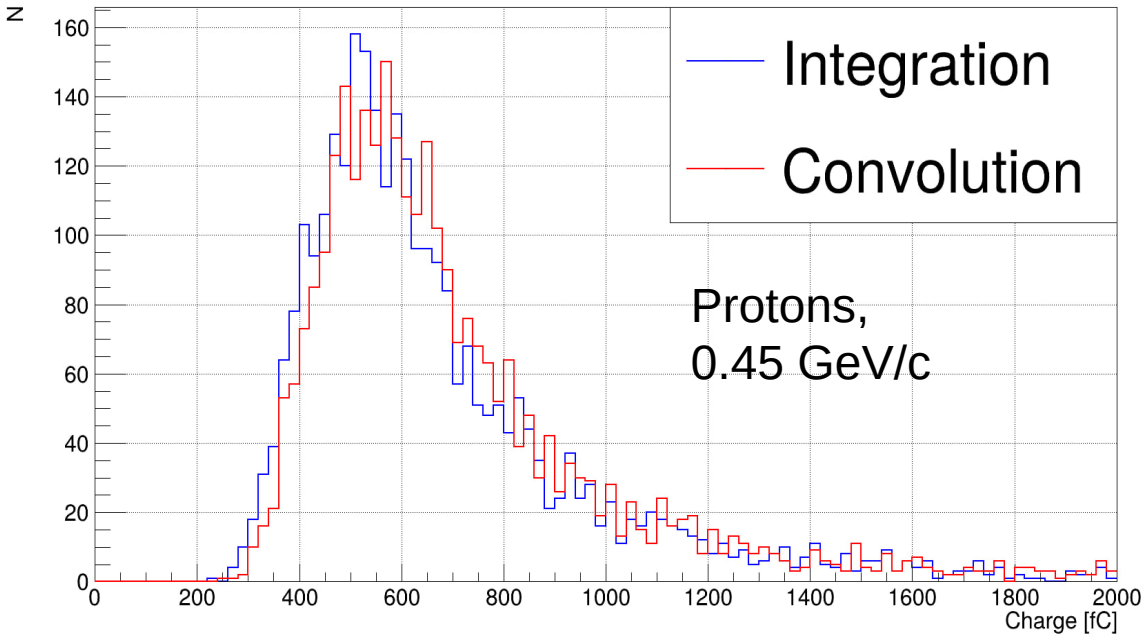
Simulation support (S. Bulanova)

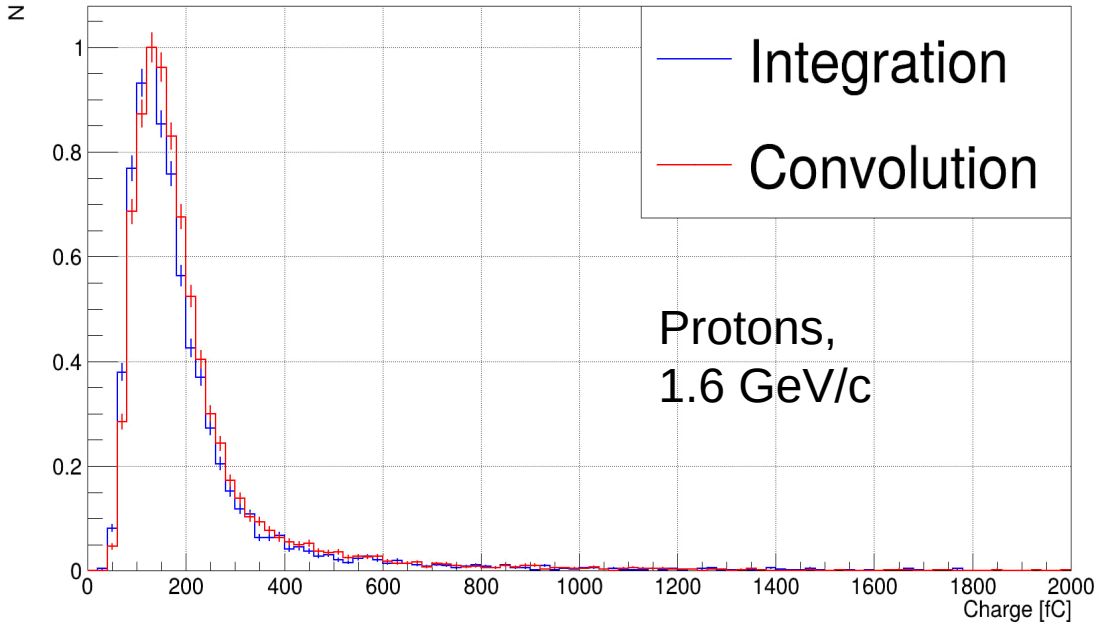
The simulation MC studies were performed using Garfield++ software.

During the single straw analysis with peaking time ~220 ns a direct **integration** of induced charge method was used.

To implement a more physically accurate and less time-consuming technique, a transfer function from the board used during the testbeam measurements was obtained. A **convolution** with the transfer function was performed using Garfield++.

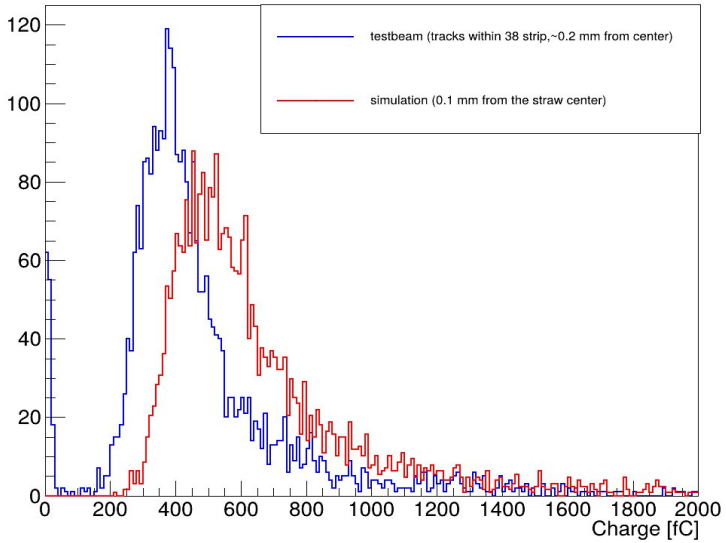
Simulations using both methods – integration & convolution - were performed for 0.45 GeV/c and 1.6 GeV/c protons.



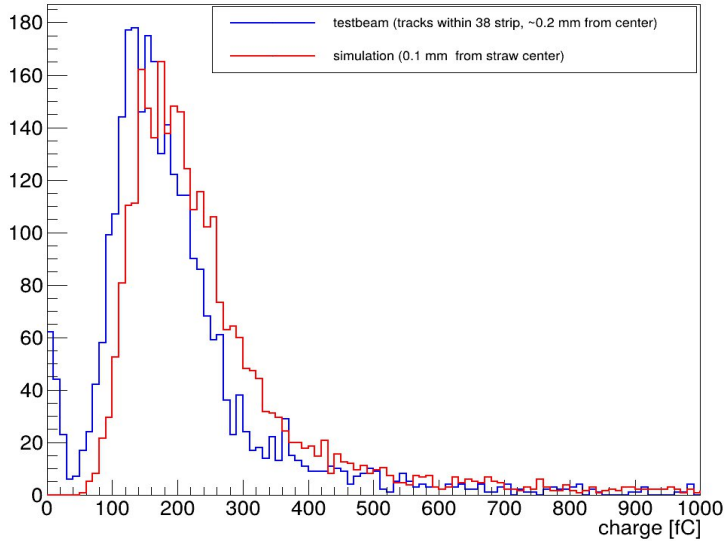


Comparison of experimental results with simulation: charge distributions

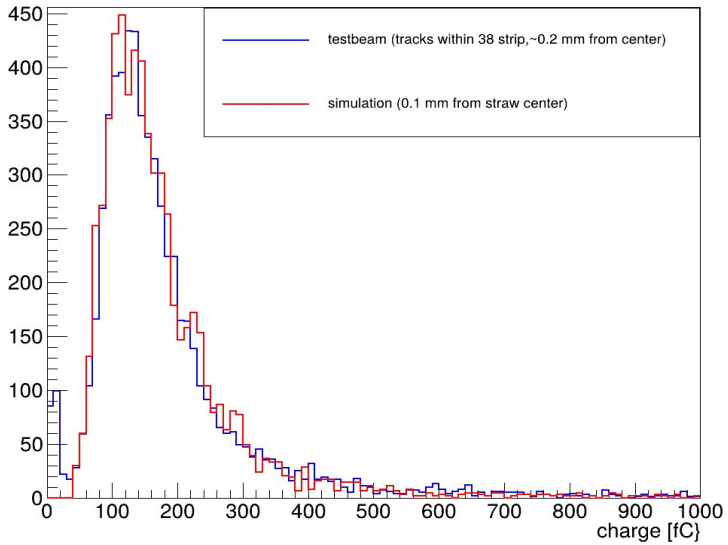
Ek=100 MeV, p=0.44 GeV/c



Ek=400 MeV , p=0.95 GeV/c



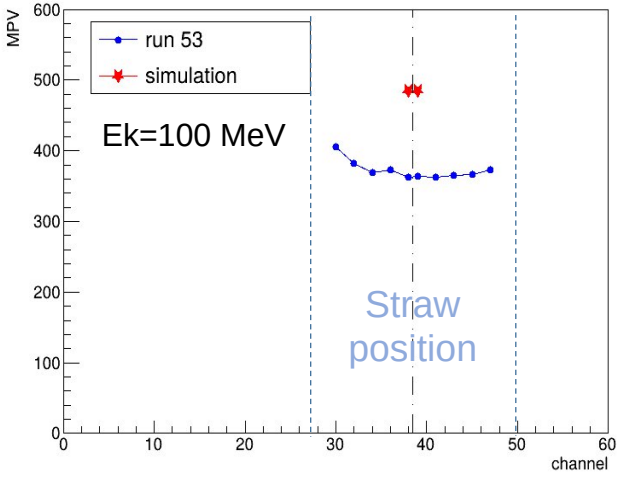
Ek=900 MeV, p=1.58 GeV/c

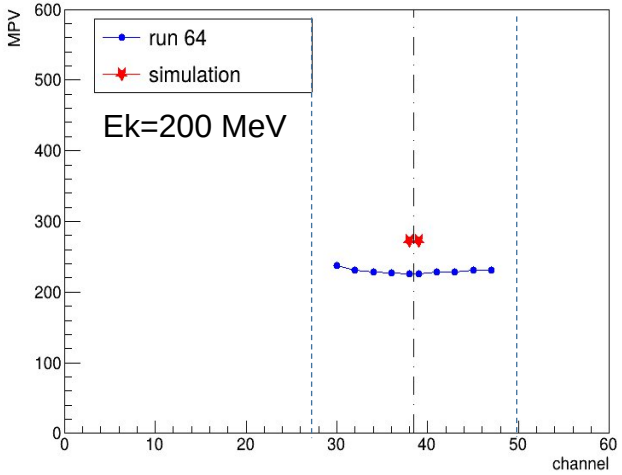


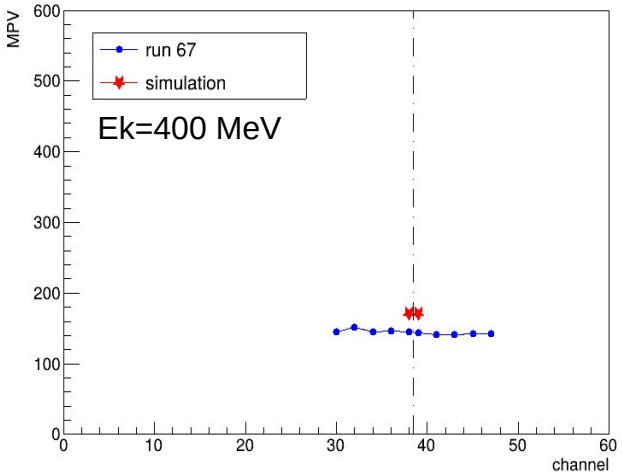
Good agreement between experimental data and simulation is observed higher energies Ek, but deteriorates at the energy decreases.

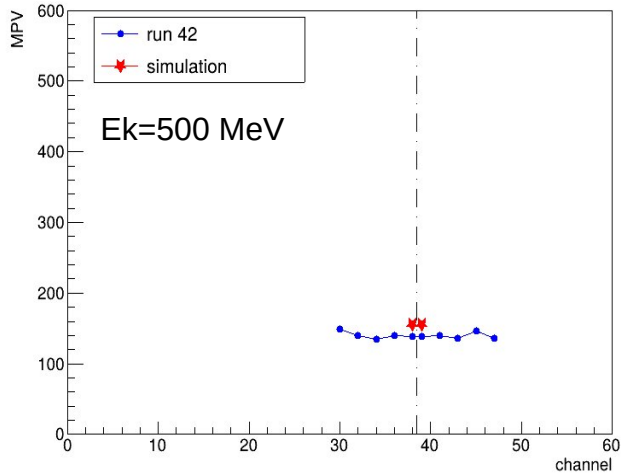
Comparison of experimental results with simulation:
MPV of measured charge distribution vs track position within a straw (MM cluster position)

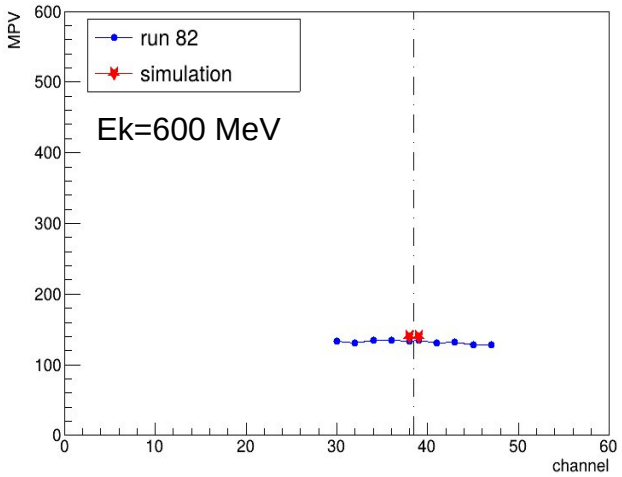
Protons Ek=100-900 MeV, p=0.44-1.58 GeV/c, preamp. 1mV/fC

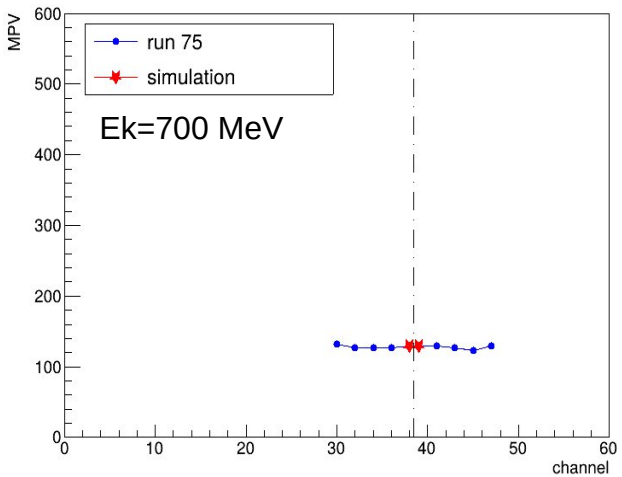


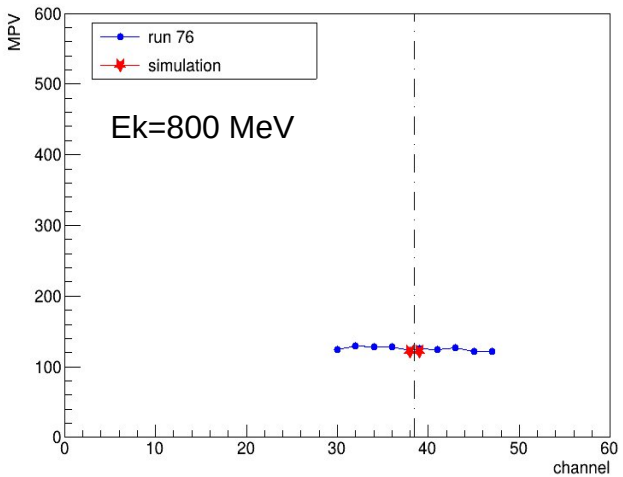


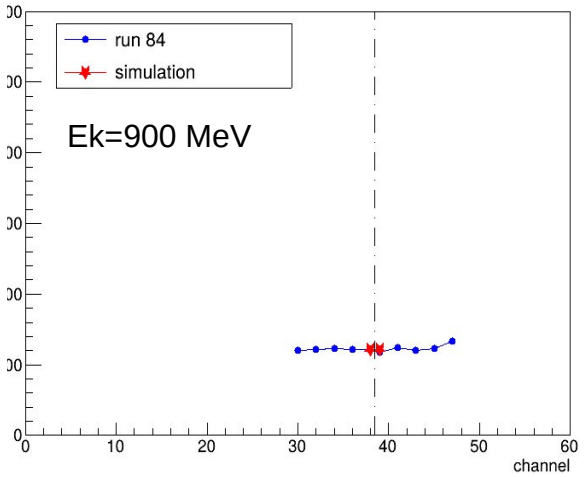






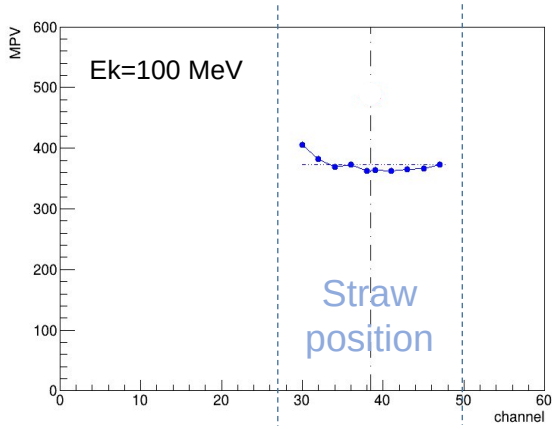


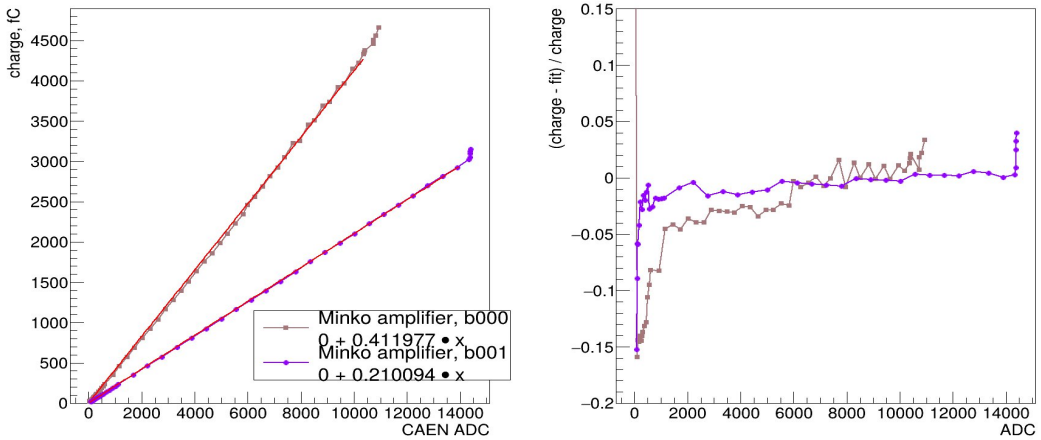




Possible systematic errors sources

- Dependence on track position relative to the straw center (i.e. the length of the track inside the tube needed for signal normalization per unit length) (it is estimated from the MPV distribution across the tube and included in the resulting plot).
- The error in determining the position of the center of the straw is negligibly small and the same for all energies (not included in the resulting plot)
- Preamplifier calibration inaccuracy in low energy range (not included in the resulting plot, calibration will be improved)
- Testbeam momentum spread up to 12% at low energies (not included in the resulting plot)

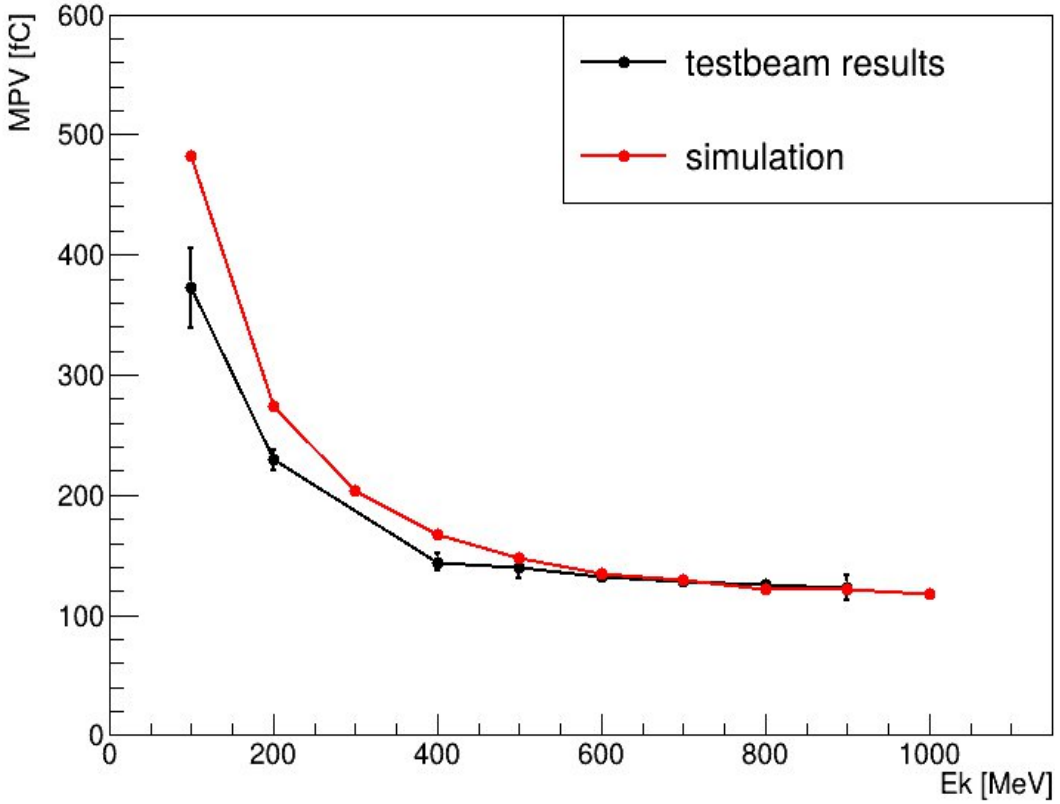




The parameters of the proton beam with variable energy

E, MeV	I, s^{-1}	$\Delta p/p$, %	σ_x, cm	σ_z, cm
1 000	$3.0 \cdot 10^{12}$	0.67	0.64	0.64
800	$1.675 \cdot 10^{10}$	1.27	0.690	1.547
600	$4.333 \cdot 10^{9}$	1.96	1.265	1.406
400	$1.393 \cdot 10^{9}$	3.29	2.265	1.442
200	$2.063 \cdot 10^{8}$	7.93	2.462	1.374
100	$4.600 \cdot 10^{7}$	12.27	3.627	1.368
60	$1.533 \cdot 10^{7}$	14.93	2.996	1.407

Comparison of experimental results with simulation:
MPV of charge distribution as a function of proton kinetic energy



- The error bars at the experimental curve include only systematic errors related to the track position within the straw.
- So far, good agreement between experimental data and simulation is observed only for energies above 500 MeV.
- A possible reasons for the discrepancy at lower energies could be a multiple scattering from the extra material located upstream the beam pipe or test beam impurities. The study is ongoing.

Conclusions

From the PS testbeam data analysis:

- The data obtained from the single straw with custom preamplifier with peaking time ~220 ns show a good agreement with simulation.
- Shapes of charge distributions obtained from the VMM3a readout with 200 ns peaking time are in agreement with different methods of simulation.
- Absolute values offset remains to be studied.
- Further hardware and simulation studies will be devoted to search the possible reason of a 50 ns shift.

From the SC1000 testbeam data analysis:

- The data obtained from the single straw with custom preamplifier with peaking time ~220 ns, reduced reference tracker (only one MM plane) show a good agreement with simulation at proton momenta above 1 GeV/c.
- A possible reason for the discrepancy at lower momenta will be analyzed. The study is ongoing.