A concept of the transition radiation detector for a hadron separation in a forward direction of the LHC experiment.

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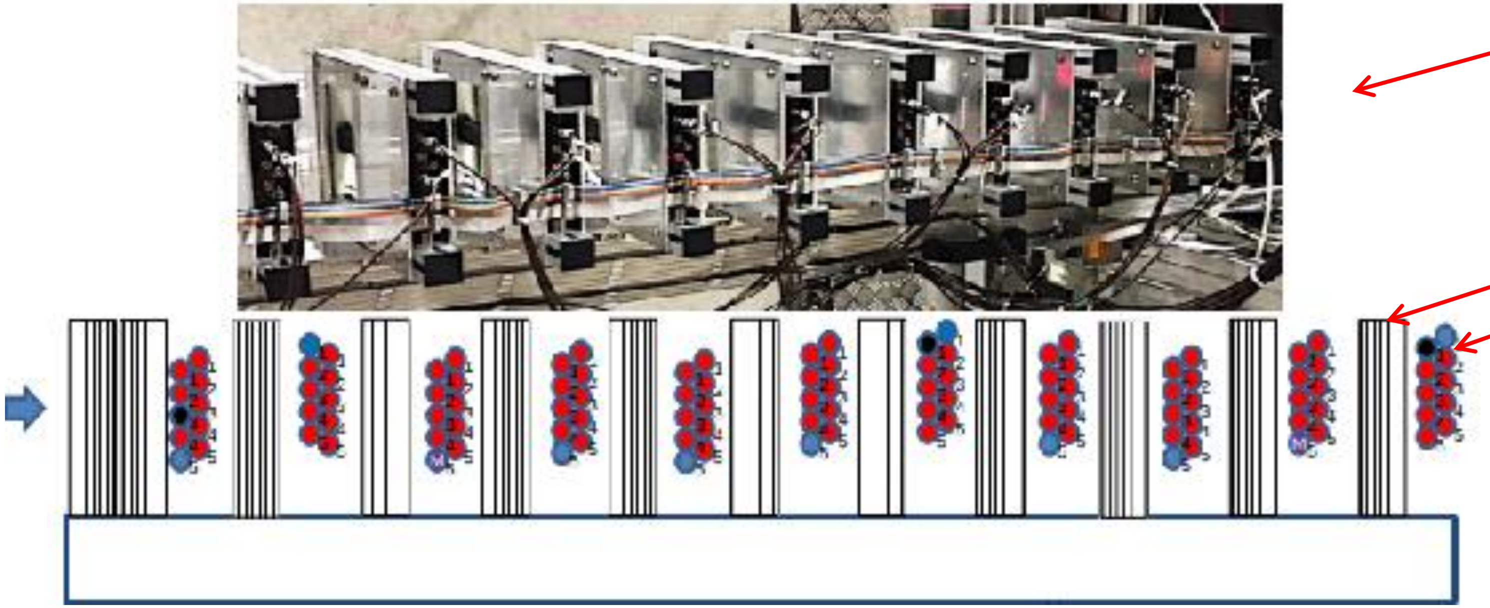
Motivation

- With growing energies of particles at modern and planned accelerator experiments as well as in various cosmic-ray experiments there is a need to identify particles including hadrons with Lorentz γ-factors up to $\sim 10^5$. An example of such an experiment can be the measurement of the inclusive cross sections in the forward region for the production of charged particles in pp, pN and NN interactions at center-of-mass energies of 14 TeV. In these collisions, secondary hadrons (mainly pions, kaons, protons) are produced with momenta in the TeV range. Since in this energy scale the secondary hadrons have the velocities $1-\beta < 10^{-5}$, identification methods using time-of-flight systems, Cherenkov detectors or particle ionization losses become ineffective. The only particle identification technique able to effectively separate hadrons with this energy range is based on the properties of the X-ray transition radiation (TR) production.
- A typical TRD consists of a multi-foil radiator followed by and X-ray (usually gaseous) detector. Most of the existing TRDs are designed to separate electrons from hadrons and they use the threshold effect of the TR production. In these detectors the TR yield starts to be significant at γ-factor of $\sim 5\times10^2$ and saturates due to interference effects in multi-foil radiators already at $\sim 2\times10^3$. But with the increase of particle energies at modern or planned experiments particle identification (PID) at much higher γ-factors is required. Main characteristics of emitted TR are defined by the foil thickness l_1, distances l_2 between foils and plasma frequency w_1 of the foil material. Both threshold and saturation γ-factors are functions of radiator parameters: $\gamma_{thr} \sim l_1 w_1/c$ and $\gamma_{sat} \sim 0.6\sqrt{l_1 l_2}/c$ respectively. By changing the parameters of the radiator, the sensitivity of a TRD can be tuned to a certain γ-factor range.

Motivation (2)

- Another possibility to expand the range of sensitivity to particle γ-factors is associated with the registration of the energy of TR photons. TR energy spectrum has many maxima and each maximum has its own γ-factor dependence. This feature can also be used to build a single detector with responses to a few γ-factor regions, which could significantly enhance its performance. And in any case to produce sufficient number of TR photons the set-up should contain quite a large number of radiator-detector blocks.
- In order to study these possibilities in detail, a dedicated TRD prototypes based on straw proportional tubes were built and tested at the CERN SPS accelerator. We investigated several types of radiators and studied the response of detectors to the passage of particles with different γ-factors. Taking into account the obtained experimental data, we developed a Monte Carlo model with a detailed description of the detector response. Here we shortly observed our test-beam measurements as well as corresponding Monte Carlo simulation model. On this basis the concept of full-scale TRD (LargeTRD) for hadron identification in TeV energy region is considered. Finally, we present the expected LargeTRD performance in identification of secondary hadrons produced in forward direction at the LHC.

Experimental set-up



	Foil material	Density, g/cm^3	Foil thickness, μm	Gap between foils, mm	Number of foils
1	Mylar	1.39	50	3	15
2	Polyethylene	0.95	67	2	15
3	Polyethylene	0.95	67	3	15
4	Polyethylene	0.95	91	2.3	15

- Set-up with TRD prototype in test beam 2018 is shown here as an example
- Double layers of straws, alternating with radiator blocks
- Straw diameter of 4 mm, gas mixture – 71.8% Xe, 25.6% CO_2, 2.6% O_2, gas gain – $2.5 \cdot 10^4$
- Calibration of straw energy deposition by ^{55}Fe source
- Beam particles:

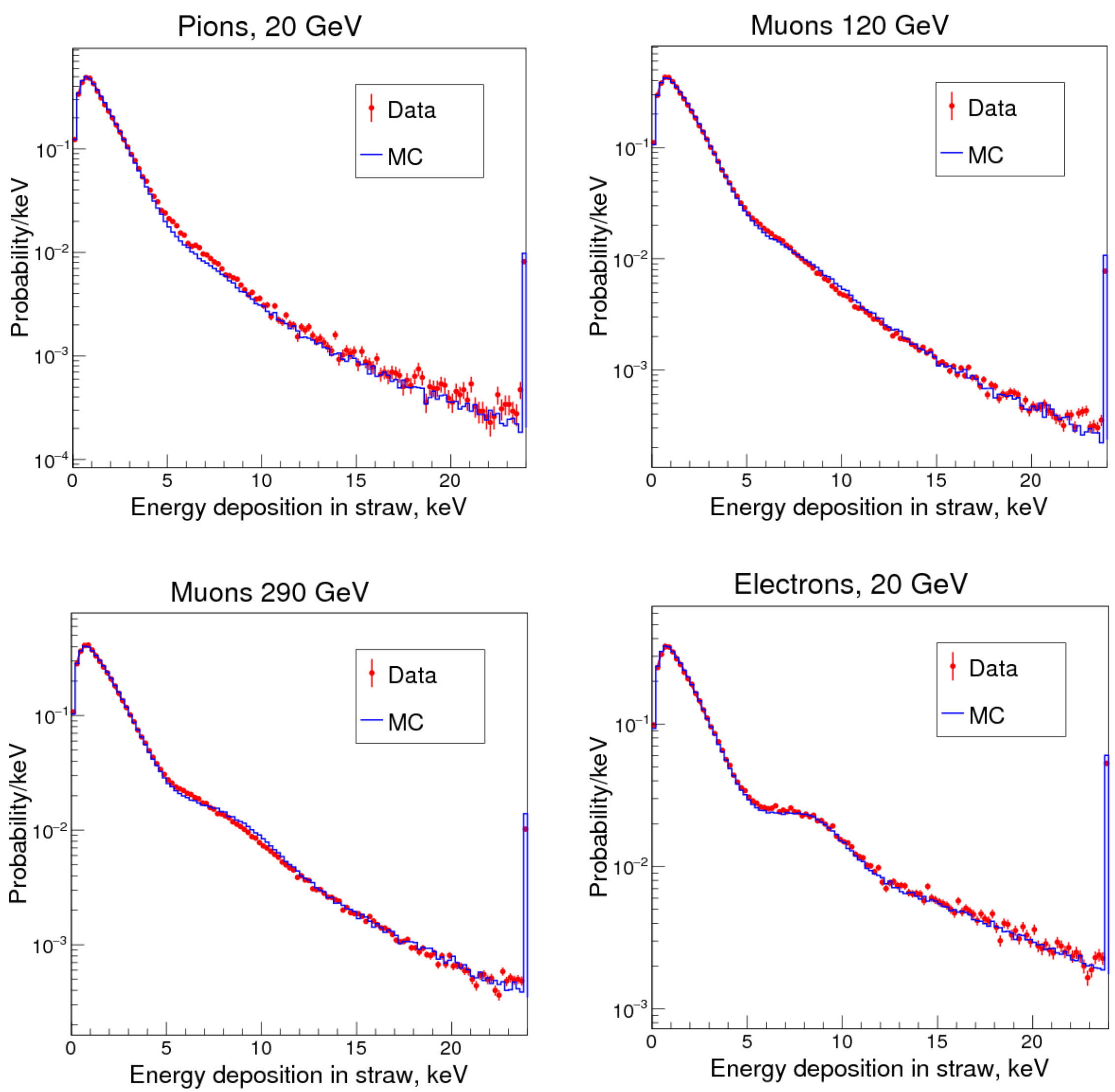
20 GeV pions
20 GeV electrons
120 GeV muons
180 GeV muons
290 GeV muons

- Different radiators to investigate.
- Some other prototypes, radiators, straw's gas mixture were tested in other test beam measurements

Monte Carlo model

- ATLAS-based core with possibility of geometry/materials description, PAI model for dE/dx and Garibian formula for TR simulation.
- Description of straw prototypes with different radiators.
- Many tiny instrumental/digitization effects were taken into account and tuned: space charge screening near anode wire; path of high energy δ- and photo-electrons in straw gas volume; TR generation on straw walls.
- Very good agreement with measured data for different prototypes/radiators/beam particles

Data/MC comparison

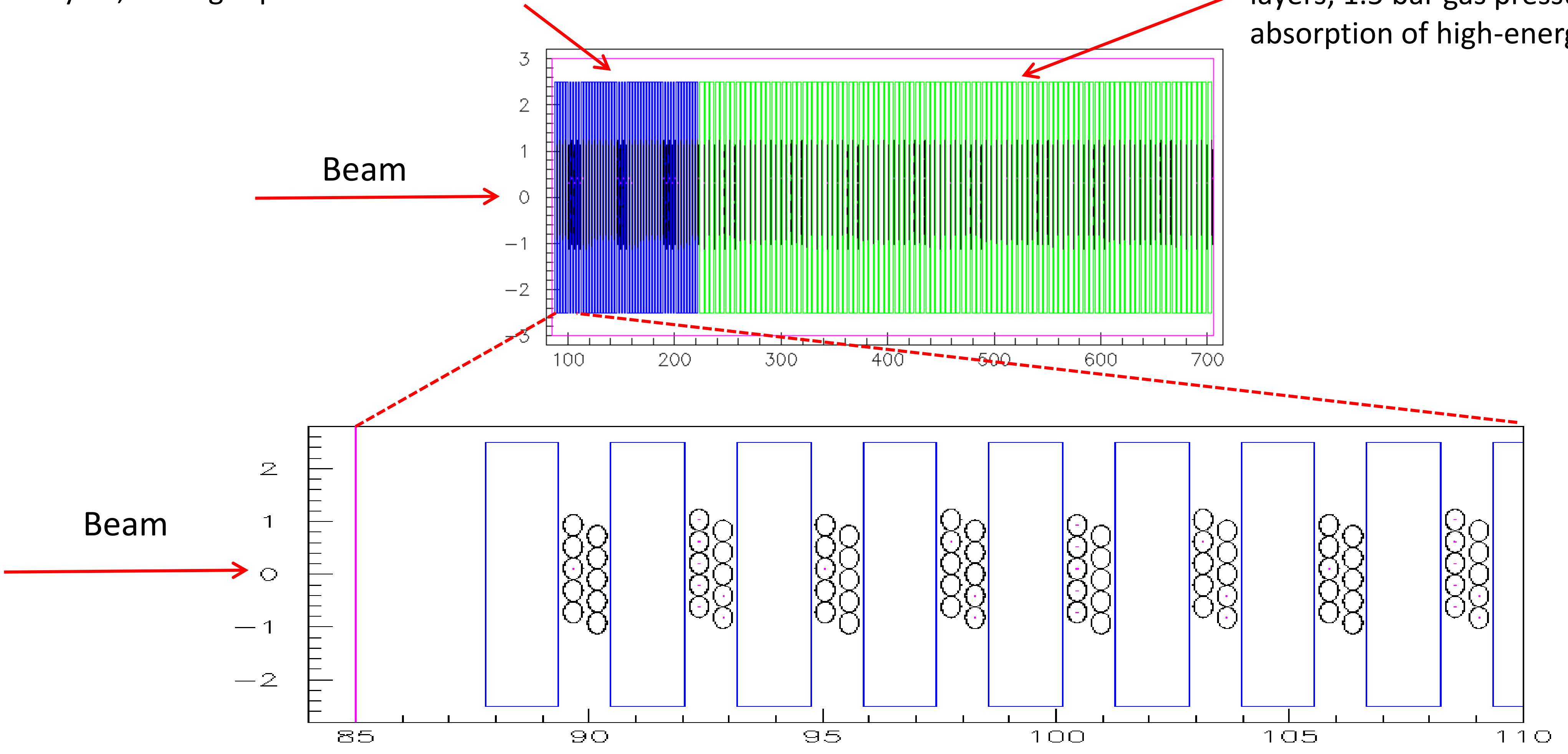


Different beam particles, Mylar radiators

LargeTRD configuration

Sub-detector 1 : PE radiator with 25 µm foils, 500 µm gap, 30 foils; 50 sections, 100 straw layers; 1 bar gas pressure

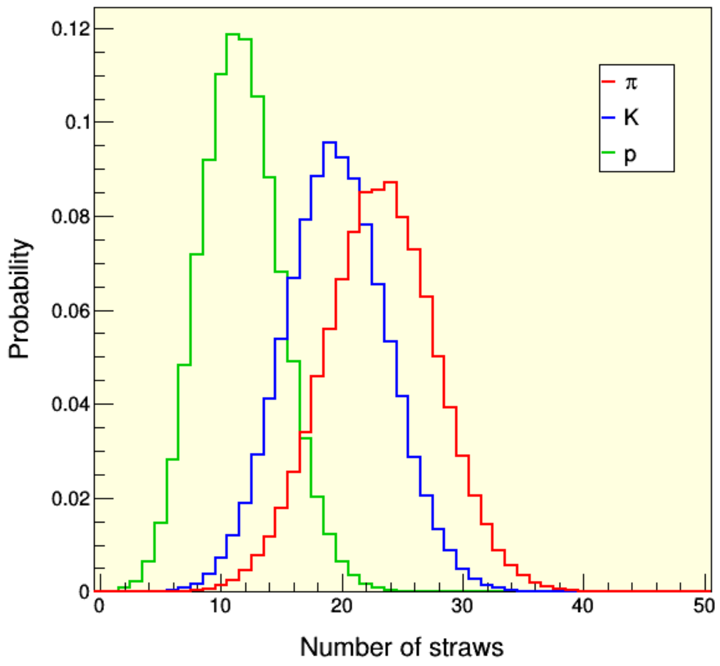
Sub-detector 2 : PE radiator with 75 µm foils, 3 mm gap, 12 foils; 100 sections, 200 straw layers; 1.5 bar gas pressure for better absorption of high-energy TR photons



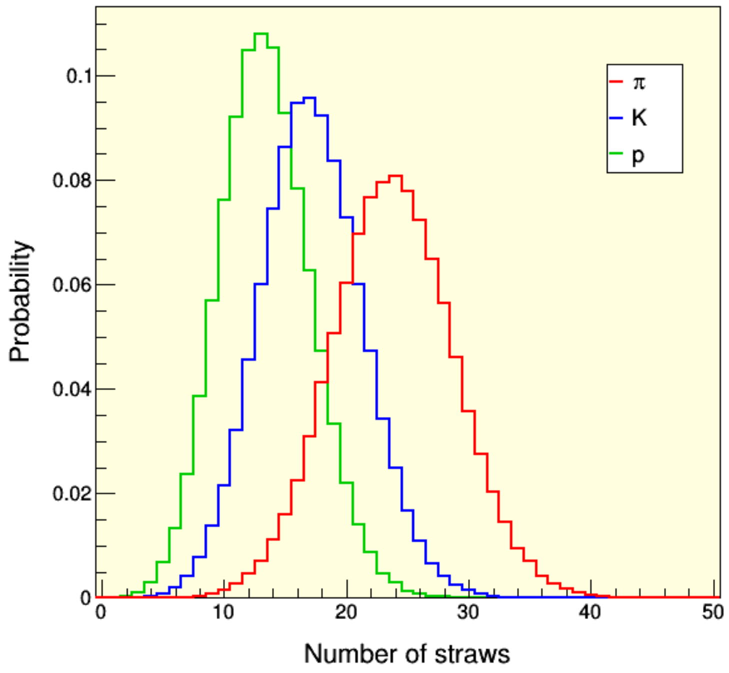
Particle identification methods

Example of number of “fired straws” distributions for 2 TeV particles

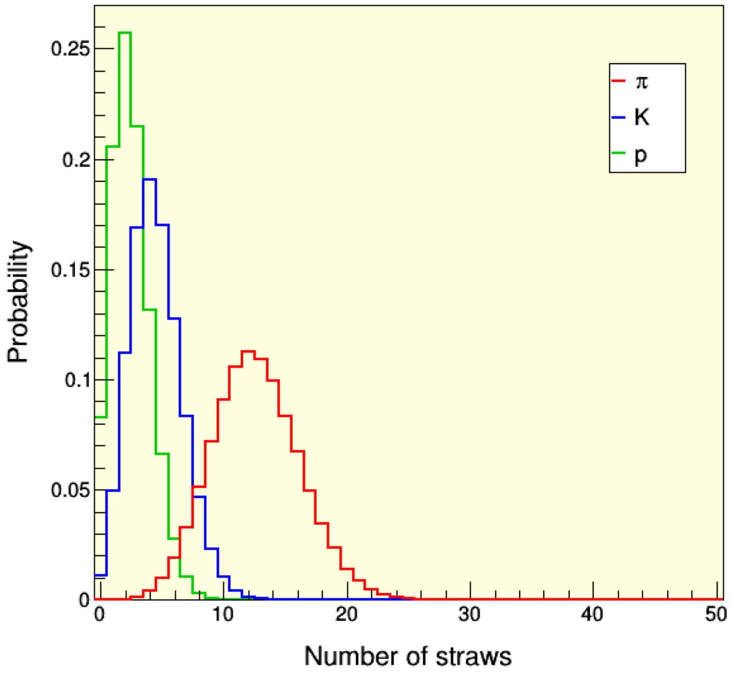
Sub-detector #1, E_{straw}> 6 KeV



Sub-detector #2, 8<E_{straw}< 17 KeV

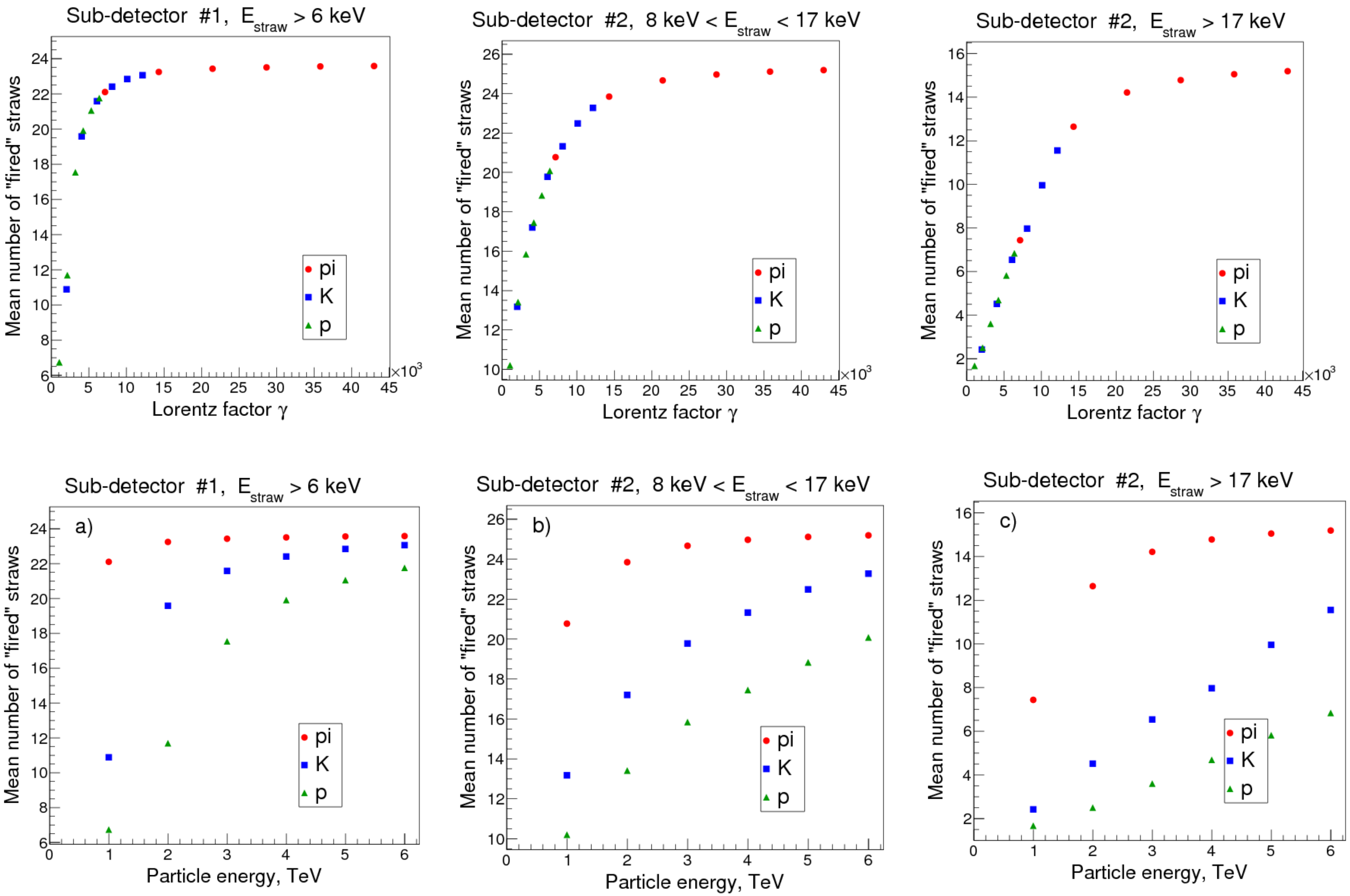


Sub-detector #2, E_{straw}> 17 KeV

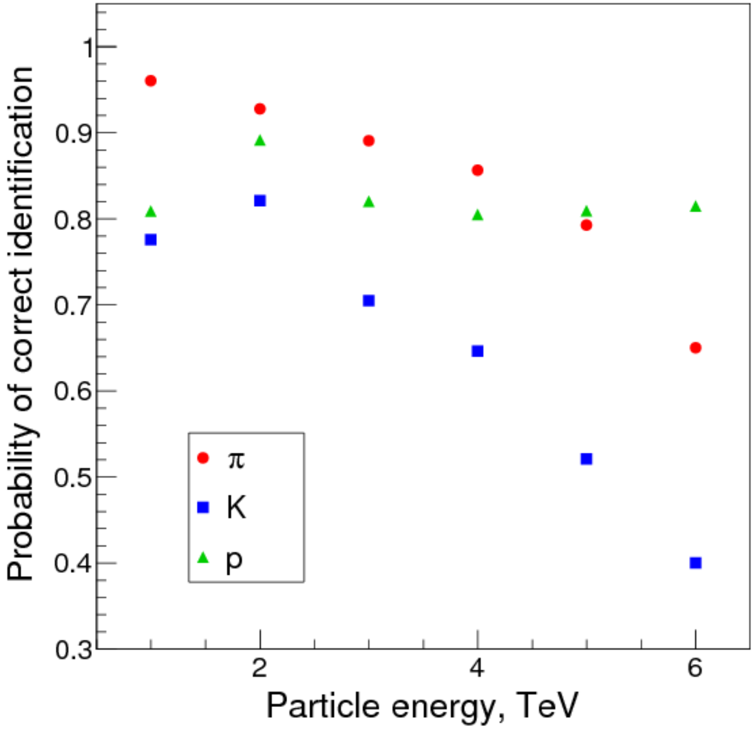


Particle identification (PID) methods are based on calculation of the number of straws on the identified particle track with certain, rather high, registered energy deposition (“fired straws”). The probability to get a hit in straw from a few keV to a few tens keV is depends mainly on the number and energy of absorbed TR photons which in turn is defined by the particle’s Lorentz factor. We are counting three numbers of fired straws”: in the first sub-detector with energy deposition above 6 keV, and in the second sub-detector – in energy interval 8-17 keV and above 17 keV.

Lorentz and energy dependencies



PID in individual events

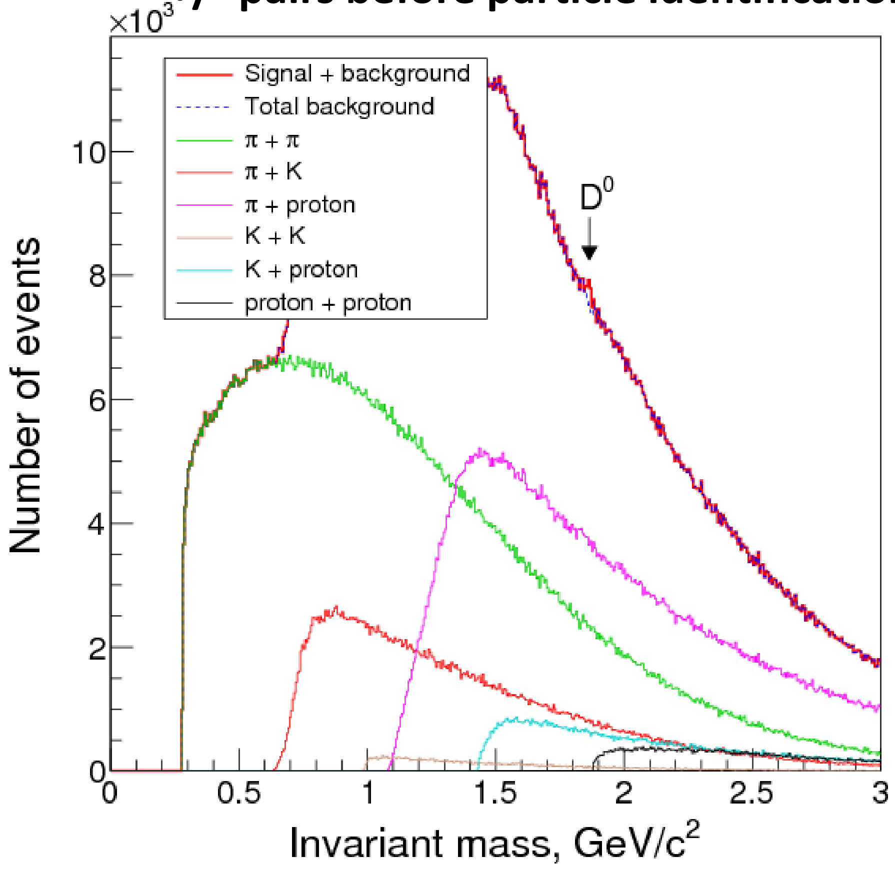


- To identify particles **in individual events** in the LargeTRD, the maximum likelihood method was used. Likelihood value for each particle type hypothesis was defined as a product of three probabilities: $L_i = P_{1i}P_{2i}P_{3i}$, where index *i* corresponds to hadron type: π, K, or proton, and P_1, P_2 and P_3 are probabilities to have in the event the observed number of the "fired straws" as it was defined above. When identified particle type in the event is assumed that the value of likelihood function L_i for which is larger than two others.
- This method is suitable for the cases when we need not extreme values of reconstruction efficiency and possible error in particle sort identification is not critical – e.g. for improvement in signal/background ratio in case of decaying particle via product invariant mass.
- The PID efficiency is defined as the fraction of particles of a given types that are identified correctly by our method.
- As might be expected, efficiency generally falls with increasing of particle energy due to gradual saturation of TR yield when γ-factors rise.
- Kaons have the lowest PID efficiency because of intermediate mass value and, as a consequence, high probability to be wrongly identified as a π or as a proton.

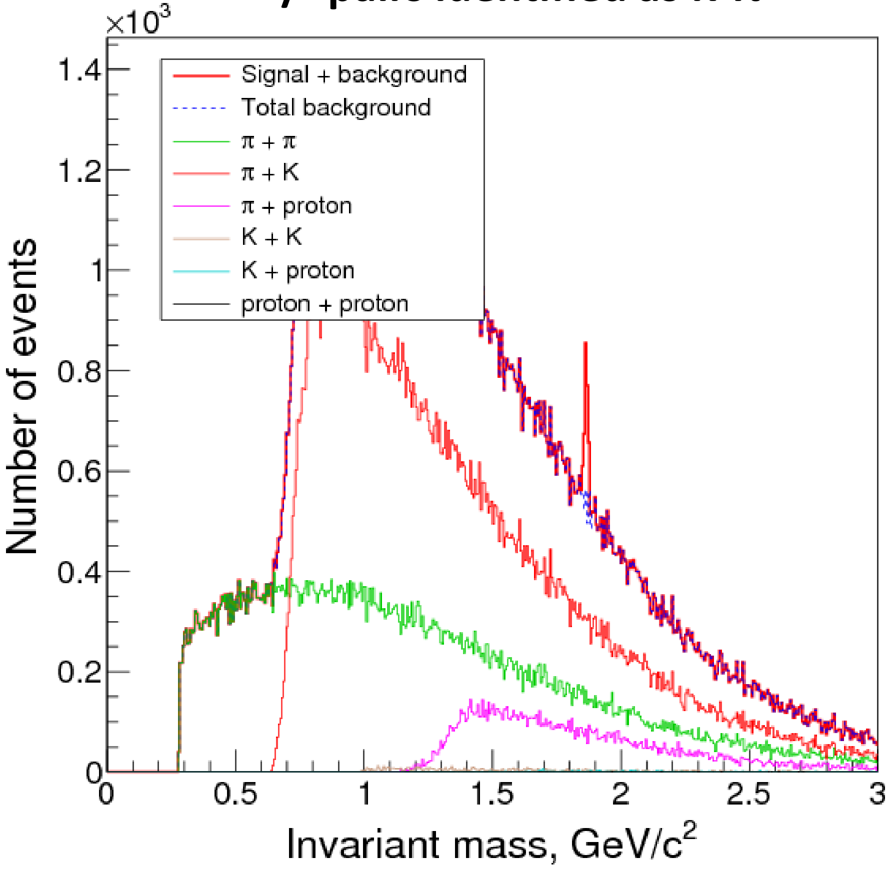
Example of $D^0 \to K^- \pi^+$ peak reconstruction

- An example of applied particle identification in the LargeTRD for reconstruction of D^0 invariant mass in $D^0 \to K^- \pi^+$ decay.
- Our PID procedure has improved signal/background ratio in D^0 peak region from ~0.02 to 0.21, with D^0 reconstruction efficiency of 74%.
- Note that the remaining background under D^0 peak is dominated by an irreducible yield of combinatorial $K^- \pi^+$ pairs

+/- pairs before particle identification

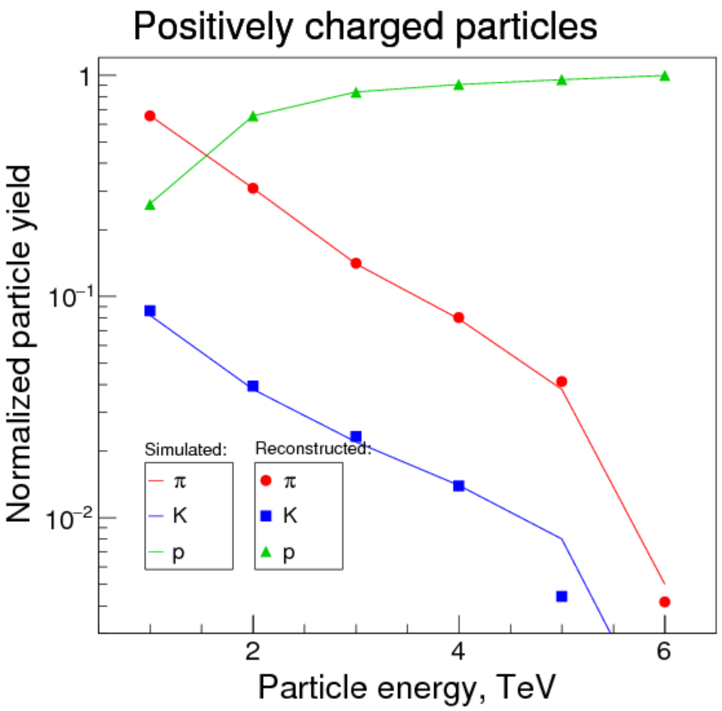


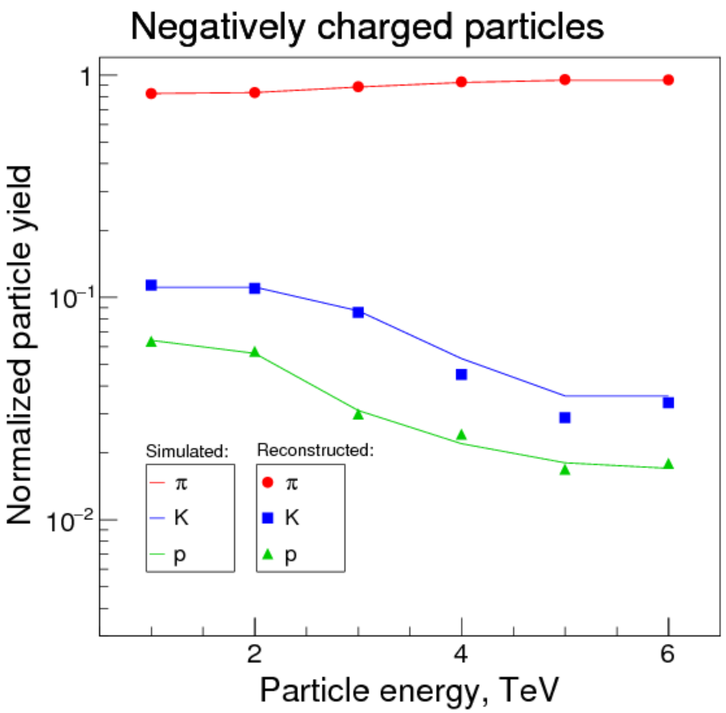
+/- pairs identified as $K^- \pi^+$



Reconstruction of integral particle composition

• Performance of the LargeTRD in **another type of PID tasks** was probed via reconstruction of expected composition of different particle types produced in very forward direction at the LHC. For this task a special PID method based on the Bayesian approach was implemented. The method consists in determining the values of the so-called priors, which serve as a 'best guess' of the true particle yields per event and can be determined from the iterative procedure.
• The LargeTRD with described approach allows to reconstruct the particle composition even though they differ by ~two orders of magnitude.





Conclusions

- Based on the experimental measurements and on the MC model developed on their basis, we have proposed a concept of large-scale TRD for identification of TeV energy hadrons produced in forward direction at the LHC.
- Detector parameters were tuned for effective particle identification both in individual events and for reconstruction of integral particle composition at different energies.
- The estimates performed show that the proposed detector is promising for the identification of hadrons in TeV energy range.

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