Georgy Golovanov

on behalf of SPD/NICA Muon Group

SPD/NICA Range System (Muon System)

The Conference

"RFBR Grants for NICA"

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Outline

- Introduction
- SPD Range System (Muon System) concept
- Range System Prototype R&D program
- Muon reconstruction and separation from hadrons
- Hadron calorimetry and neutron identification with SPD Range System

Polarized beams at NICA collider

Basic specification of polarization states and combinations available at NICA:

- longitudinal and transverse polarization with respect to a particle velocity direction;
- deuterons: vertical direction of polarization at 90° up to 4 GeV/c momentum;
- possibility to collide any available polarized particles: proton-proton, proton-deuteron, deuteron-deuteron.
- possible asymmetric collisions should be considered as an option for the future.

The polarization control system:

- longitudinal and transverse polarization degree up to 70%;

- collision luminosity of $\sim 10^{30} - 10^{32}\ cm^2 s^{-1}$ over the particle momentum range from 2 to 13.5 GeV/c;

Physics Motivation

The SPD project is under preparation at the 2nd interaction point of NICA collider.

The main purpose of this experiment is to study the nucleon spin structure with high intensity polarized proton and deuteron beams.

Both beams are supposed to be effectively polarized.

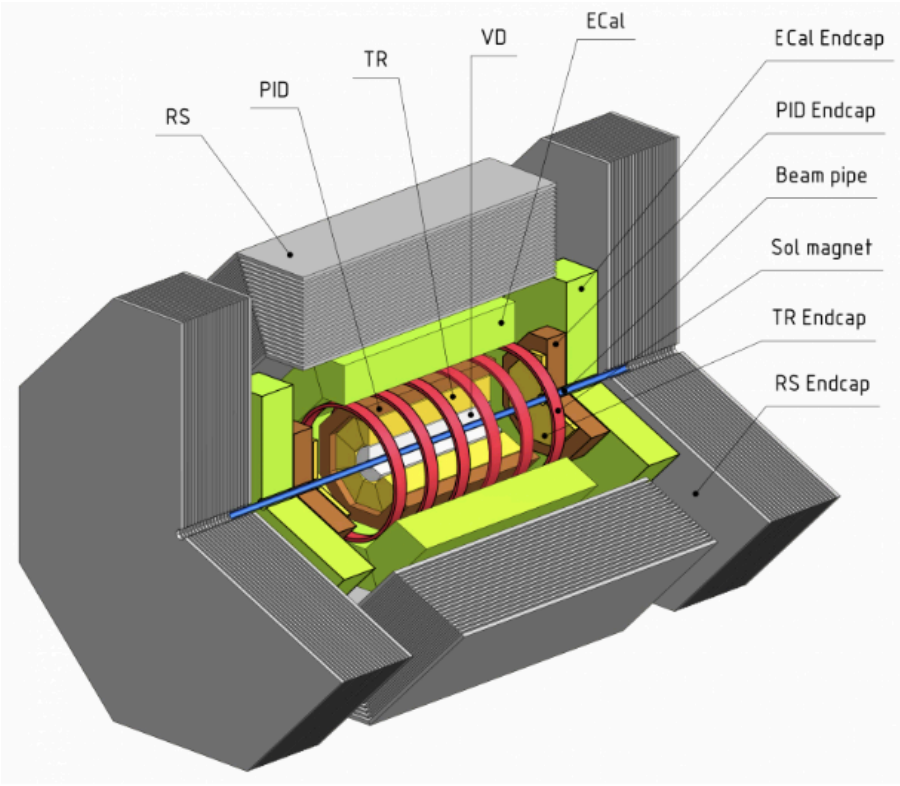
Unique possibilities to investigate a wide range of polarized phenomena:

- charmonia production;
- direct photons;
- studies of elastic reactions;
- spin effects in one and two hadron production processes;
- spin effects in inclusive high-p_T reactions.

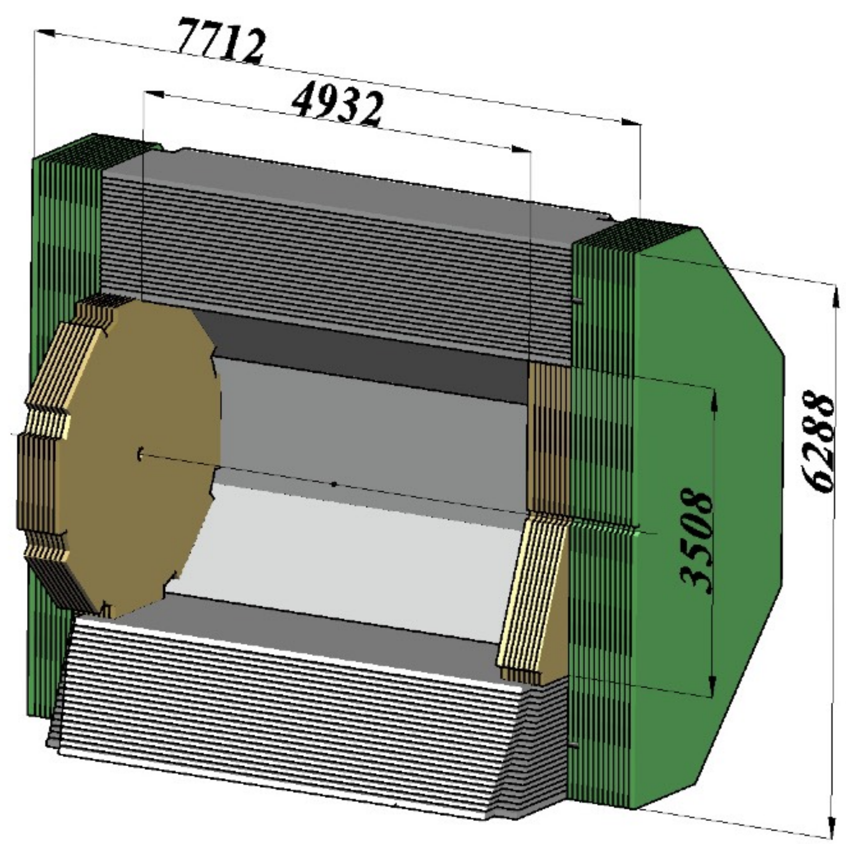
SPD Range System Concept

SPD/NICA Muon System is based on a range system technique:

- good particle ID system;
- resolves muons and hadrons with high efficiency;
- works in full SPD energy range of secondary particles (at $\sqrt{S_{pp}} = 12 - 27$ GeV).



Main purpose:
- muon identification;
- separation of muons from hadron contamination (below 1 GeV is less efficient and requires test beam measurements for calibration).



Important feature:
the range system may be used as a coarse sampling hadron calorimeter
(Layers of 30mm to 60mm typical sampling)
very important for neutron registration.

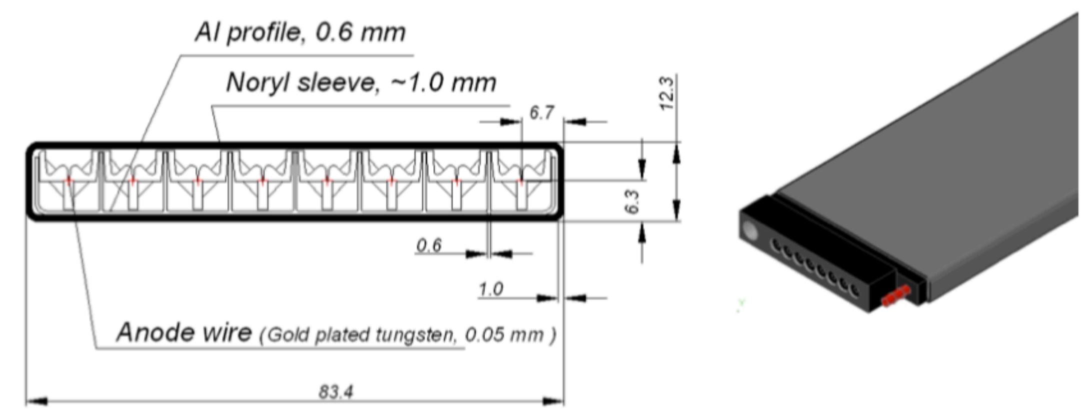
Mini-Drift Tubes

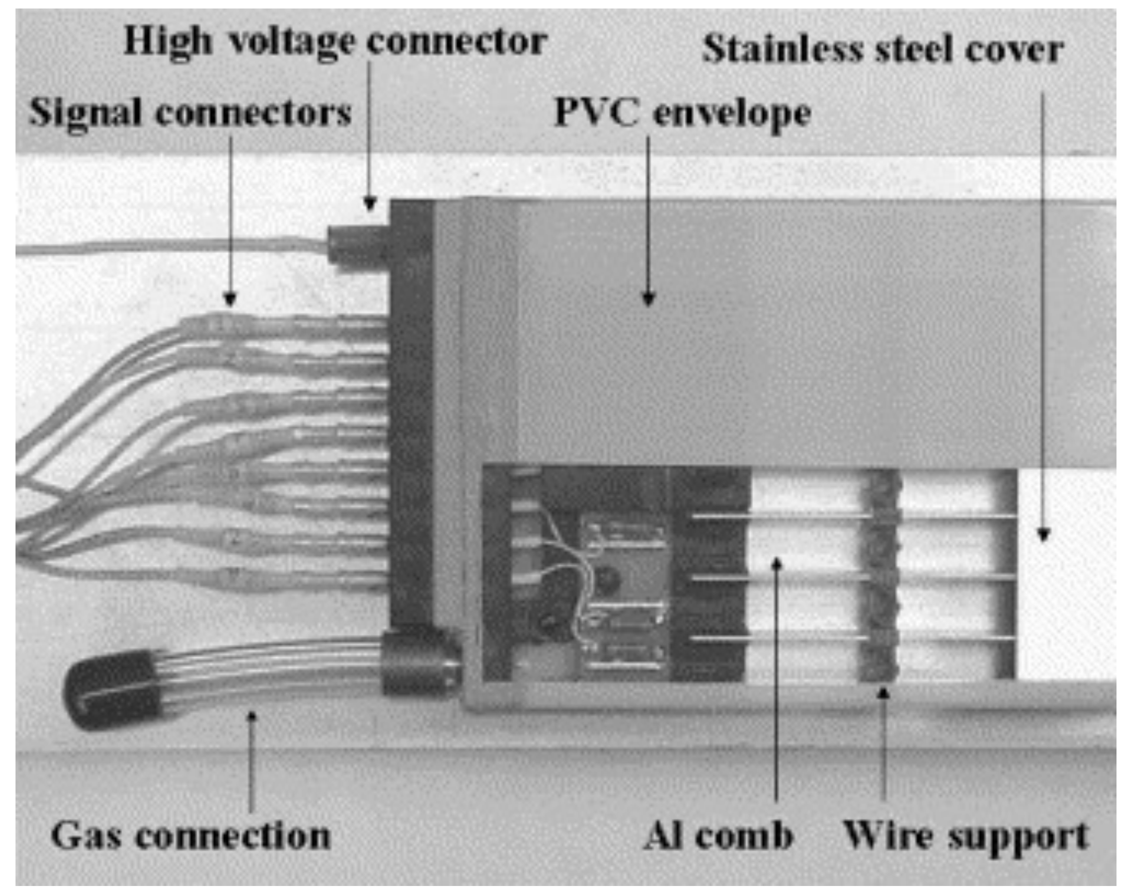
Mini-Drift Tubes (MDT) tracking detector:
consists of an array of cells with anode wire in the center (aluminum Iarocci tubes operating in proportional mode).

- cell size ~ 1cm;
- total number of cells ~$10^4 - 10^5$;
- Ar/CO_2 gas (70/30 %) amplification near anode wire provides detectable signal (3-7 μA);
- hit map provides muon tracking and hadron pattern;
- in order to define muon location with high precision electron drift time may be used.

Advantages:
- the detector is made of simple repetitive cells with properties defined by individual cell;
- broken wires are localized inside a cell;
- aluminum cell walls create self-supporting rigid detector element.

cross-section MDT





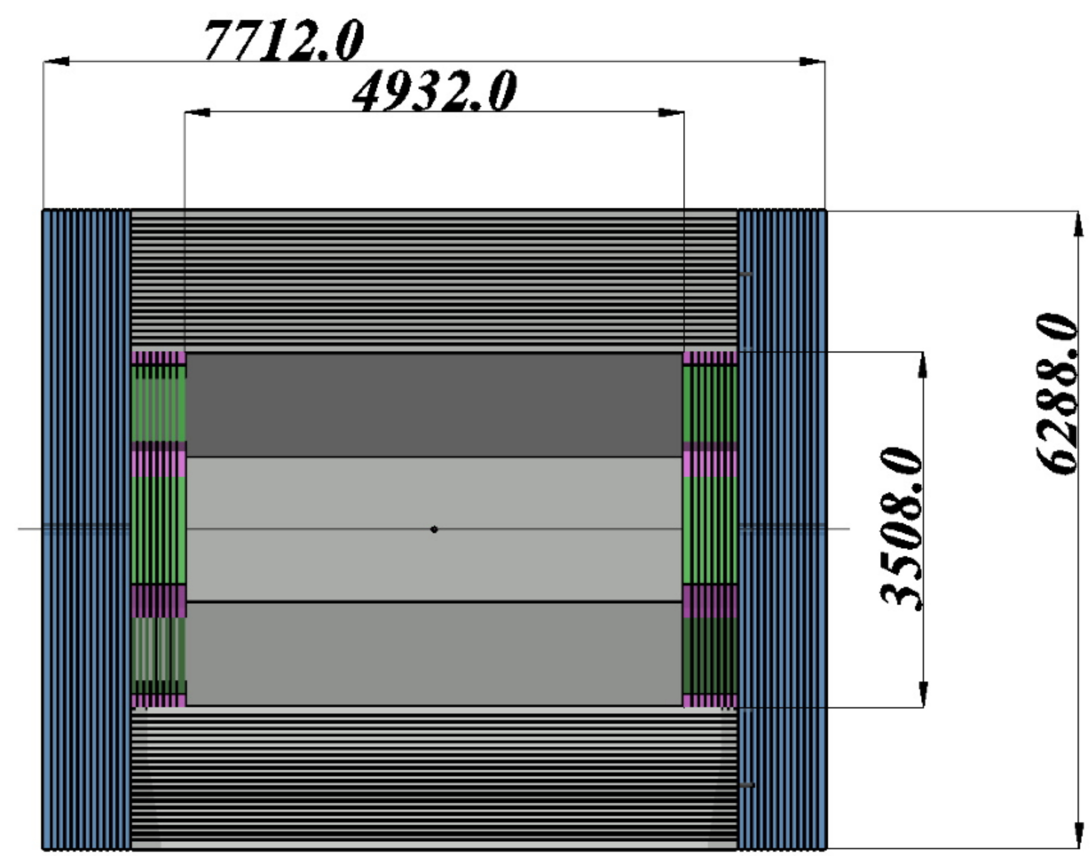
Mini-Drift Tube cross section

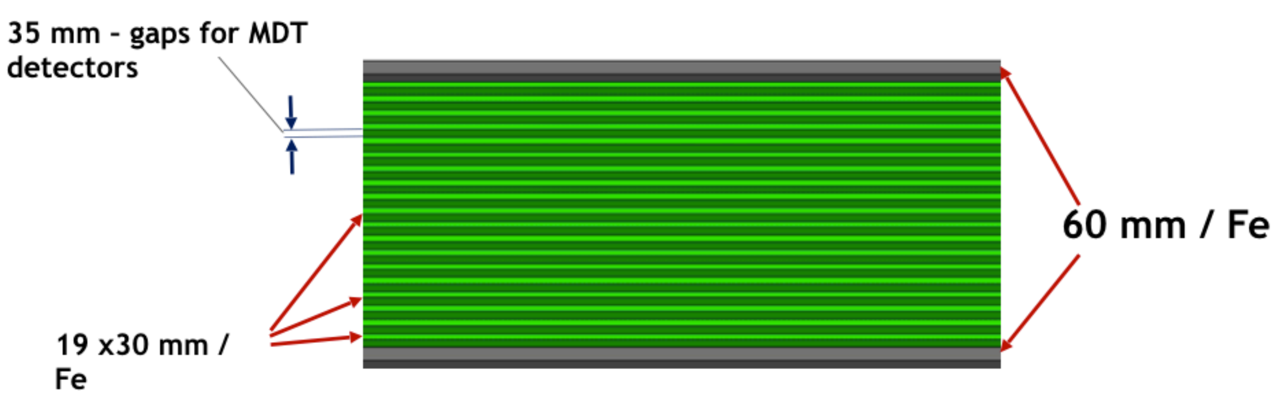
SPD Range System Concept

The Muon Range System structure is a proven solution for detecting muons stopped by the absorber and those crossing the iron:

- in first case (stopped muons), one may even roughly estimate the energy of muon; the stopping power of iron is about 1.5 GeV per meter of absorber for the relativistic muons with $dE/dx = 2$ MeV / g;

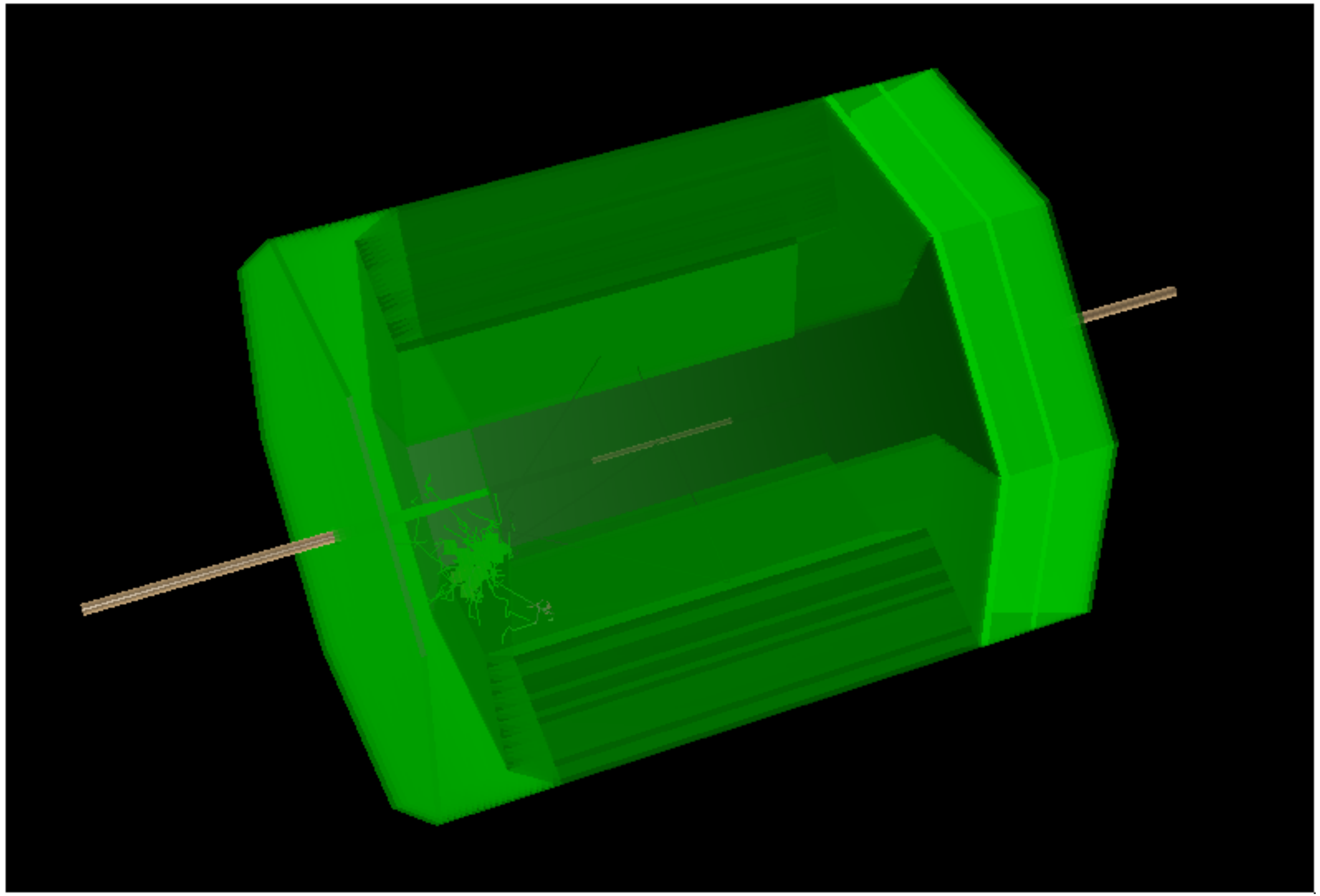
- the iron absorber sampling is 30 mm with 60 mm at both ends (for constructional reason).





Layered structure 60+19x30+60 mm ($\sim 4\lambda_I$);
Air gaps 35 mm;
Weight Fe+MDTs = 780+30 =810 ton.

Geant4 RS Modeling in SPDRoot

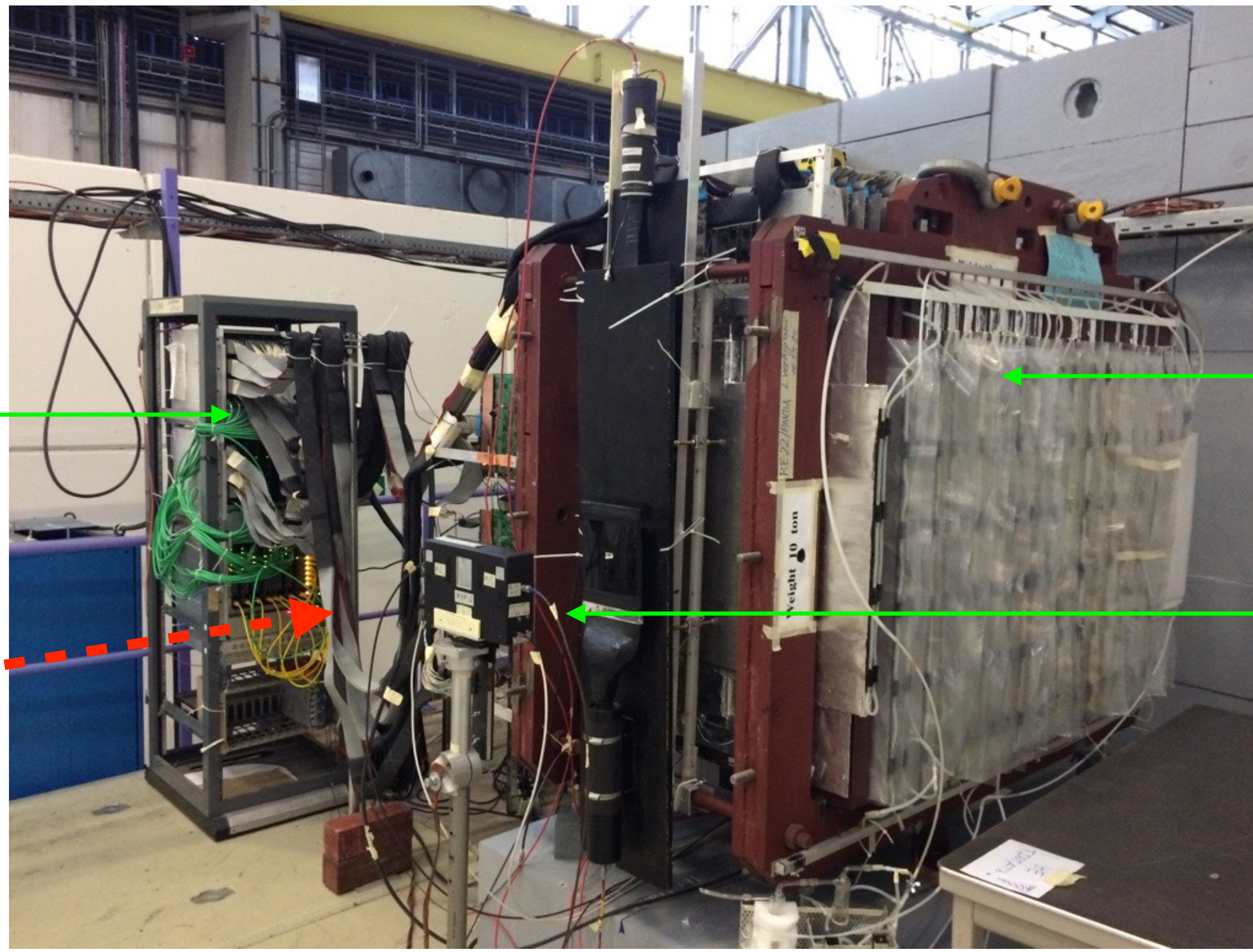


Range System model:

- A preliminary Range System model was created and simulated using Geant4 and encapsulated within SPDRoot framework;
- It consists of a barrel and two end-caps with equal thickness ~ $4\lambda_I$.

Range System Prototype

The T9 secondary monochromatic beam of particles with momenta up to 15 GeV/c is generated at the PS accelerator (CERN).



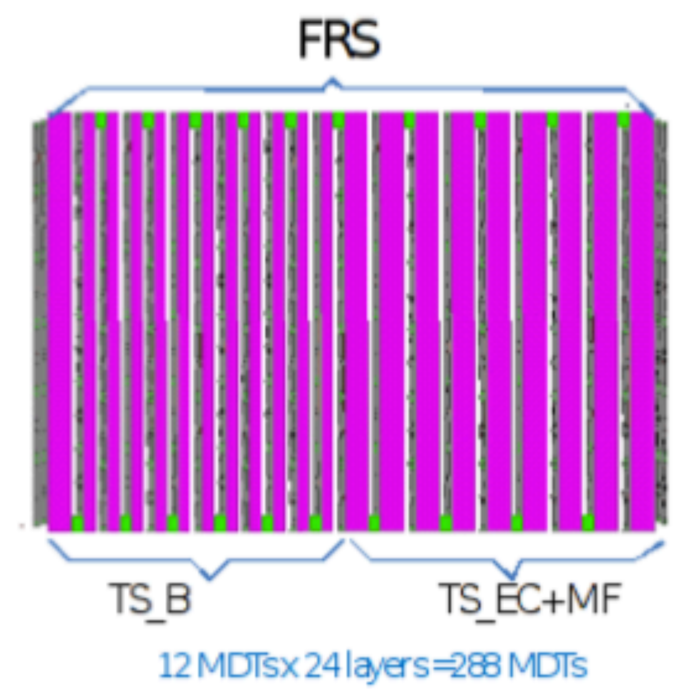
RSP with DAQ rack installed on the T9/PS test beam @ CERN

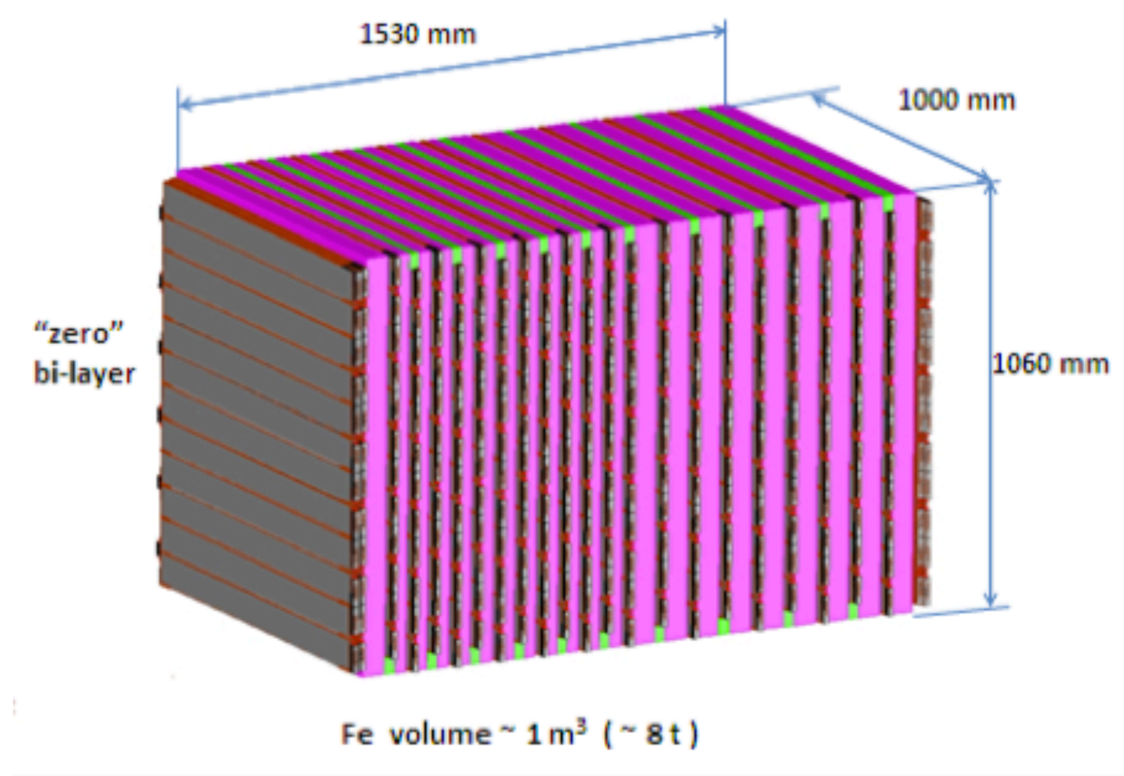
Range System Prototype

Range System Prototype (3D model)

Initially designed for PANDA spectrometer, RSP is reasonably suitable for SPD tasks.

- MDT detectors 288 units ~ 1 m long;
- strip boards 22 units with ~ 1m x 1m size;
- corresponding front-end electronics (2160 channels for wire readout and 764 for strip readout);
- additionally equipped with TOF system and Cherenkov detector for beam particle ID.





Range System Prototype

Range System Prototype (Project RE-22):

- 10 ton weight;
- absorber plates (30 and 60 mm thick);
- 22 detecting layers (MDTs);
- wire and strip readout.

Calibration of RSP response to various particles at different energies:

- muon/hadron separation algorithm testing;
- direct hadron energy calibration;
- digitization tuning.

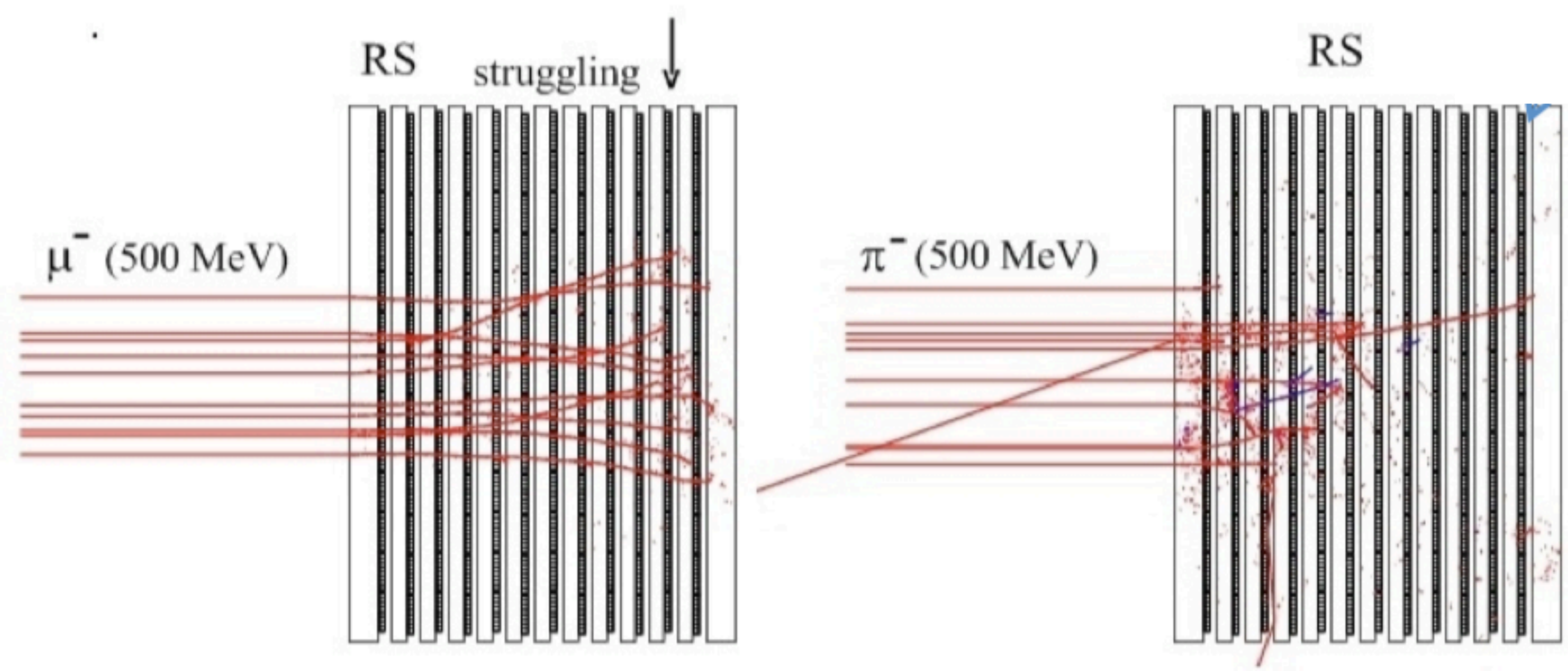
A2DB-32 cards for wire Readout (2160 channels)

ADB-32 cards for strip Readout (764 channels)

Muon Reconstruction

There are three sources of muon background giving the same (muon-like) signal in RS:

1. pions (and other hadrons) traversing the iron absorber with ionization energy losses only;
2. muons from pion decay (in flight);
3. decay muons from pions giving a shower in iron absorber.

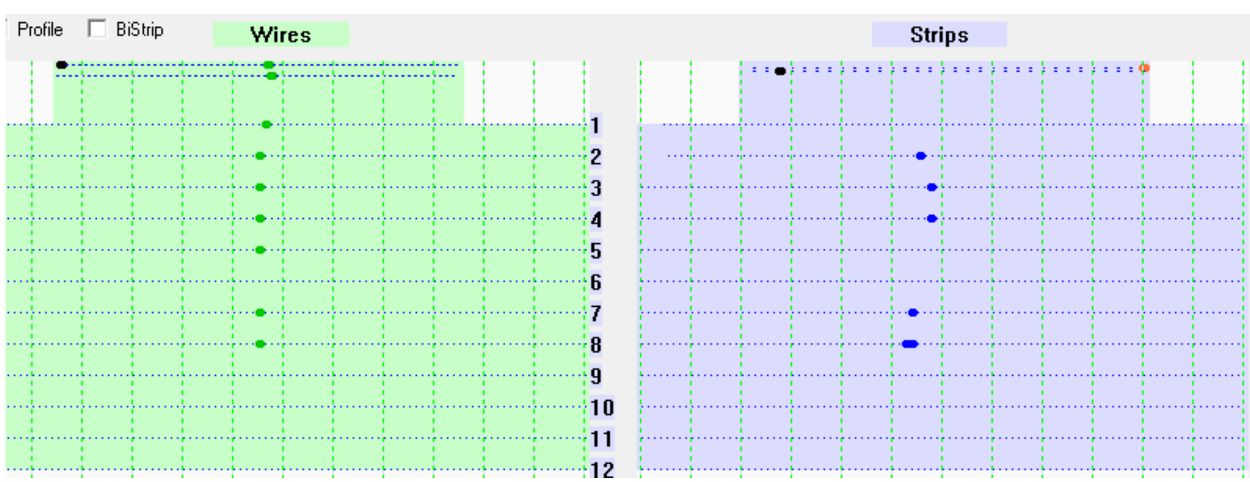


Muons/Hadrons Separation

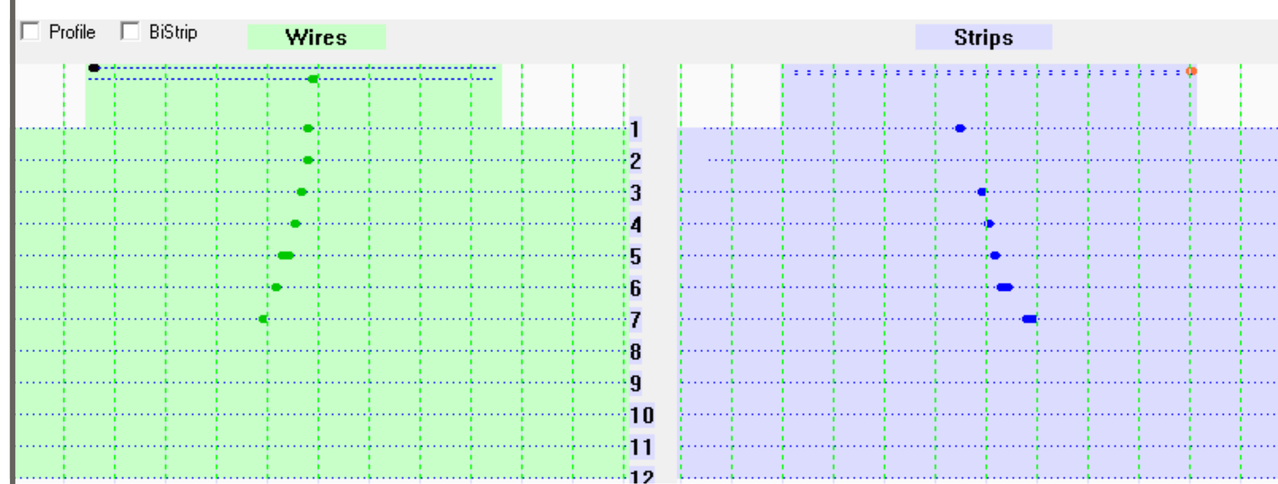
Hit profile in RSP corresponding to a particular kind of particles with a certain momentum has a specific pattern (green points - wire hits, blue points - strip hits).

Low momentum pions ($p < 1.0$ GeV/c) almost indistinguishable from muons with the same momentum.

$\mu^- : 0.5\ GeV/c$

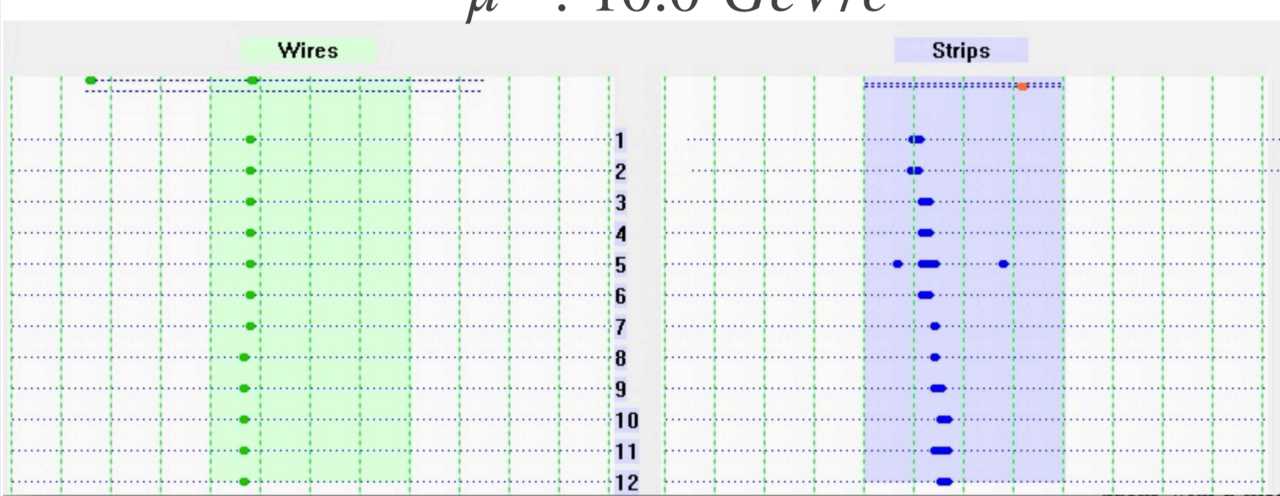


$\pi^- : 0.5\ GeV/c$

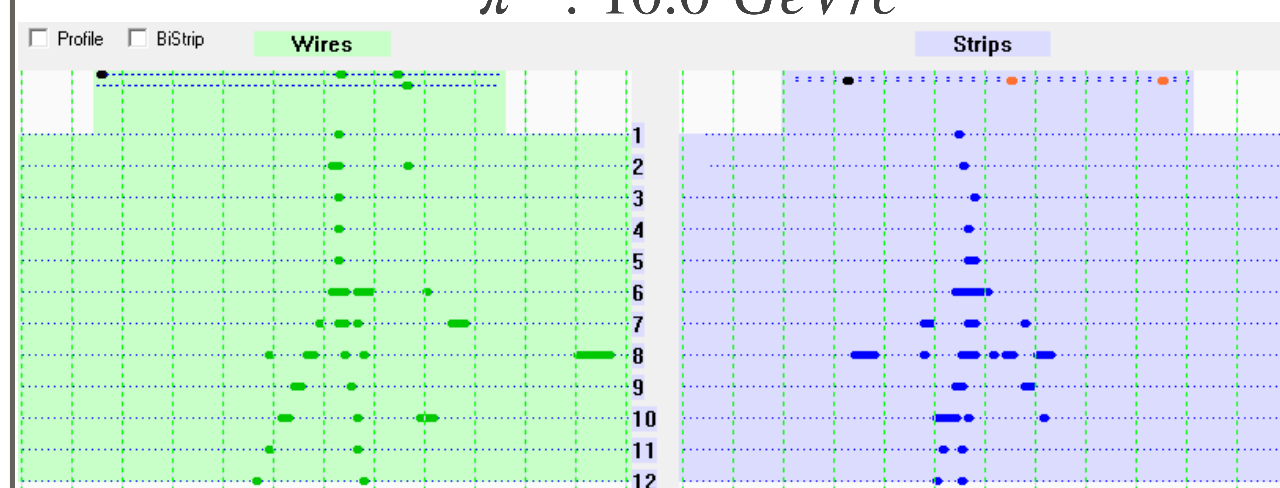


The increasing energy of pions significantly changes the profile of hits, forming a hadron shower of secondary particles for pions with momentum up to 10.0 GeV/c.

$\mu^- : 10.0\ GeV/c$



$\pi^- : 10.0\ GeV/c$



Muons/Hadrons Separation

Finding variables sensitive to differences in such patterns, is directly related to the efficiency of separation between muons and hadrons. It can be used as an input to various Machine Learning techniques.

Variables:

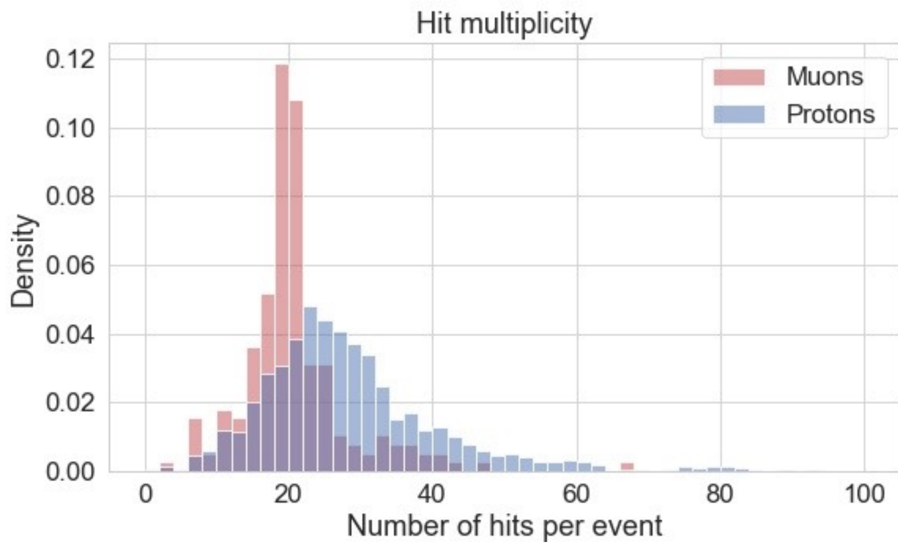
1. hit multiplicity in an event;
2. last fired layer;
3. splitting layer number (first layer with ≥ 2 hits per layer);
4. first fired layer;
5. number of hits in last layer.

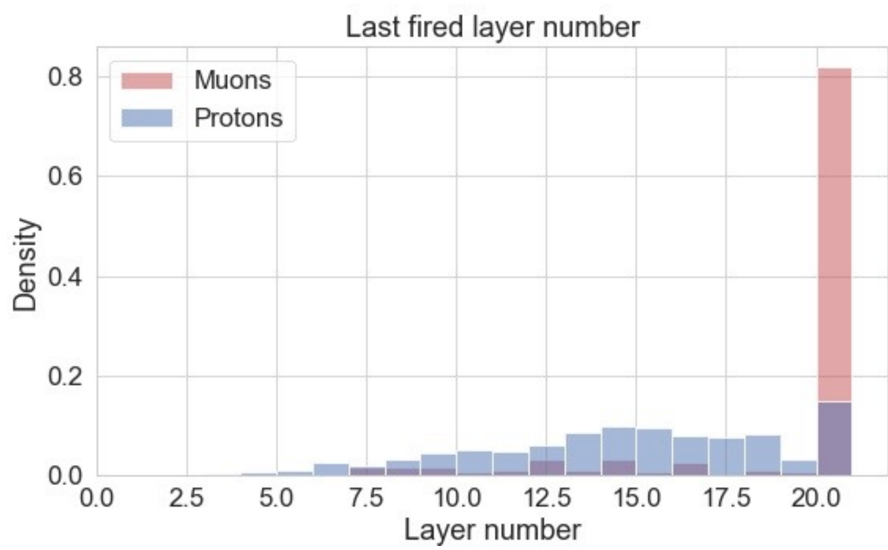
The list will be extended…

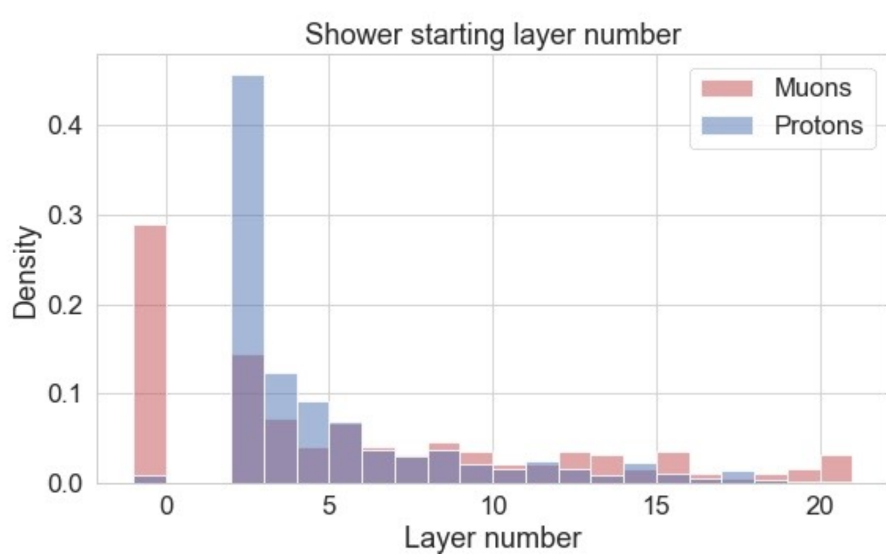
A basic **Decision Tree** classification algorithm is used to separate between signal (muon) and background (protons/pions) samples in Data and MC:

- good for binary classification (*DecisionTreeClassifier* from *scikit-learn* library);
- robust and transparent technique;
- 75/25 % events training/validation sets;
- hyper-parameters optimization: tree-depth, information gain, etc.

Discriminative Variables







Data sample
(RS Prototype beam tests):

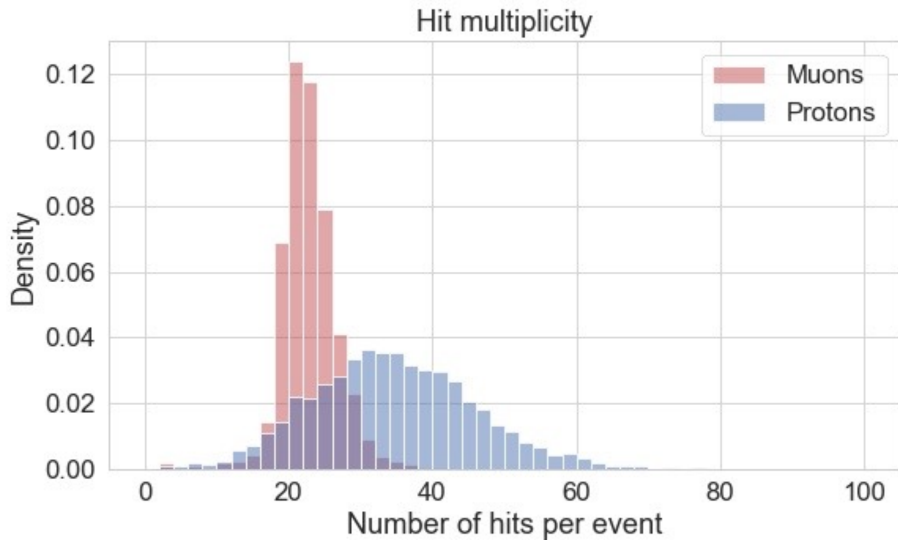
Signal sample: '**muons**' 6 GeV/c
(with admixture of pions and electrons)
Background sample: **protons** 6 GeV/c

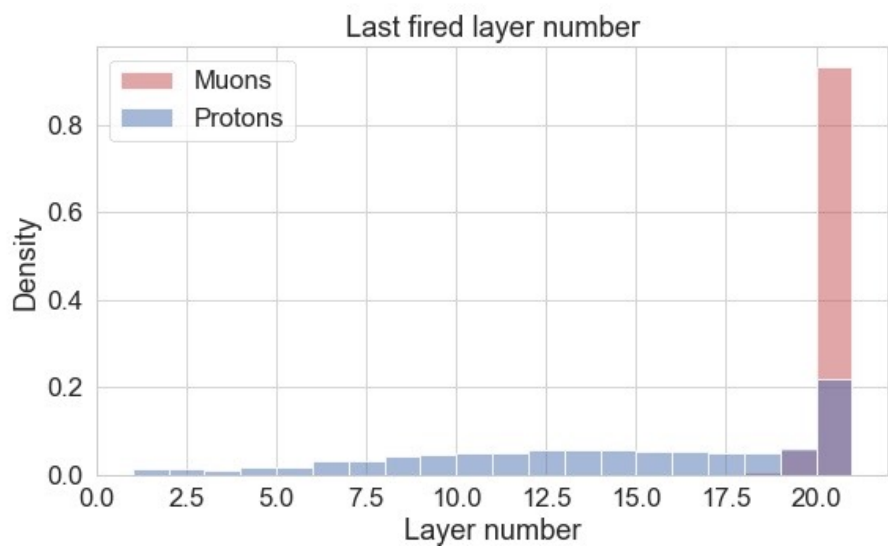
Events in both samples are labeled using Time Of Flight (TOF) detectors only. Later the Cerenkov counter tags will be used to fix the muons.

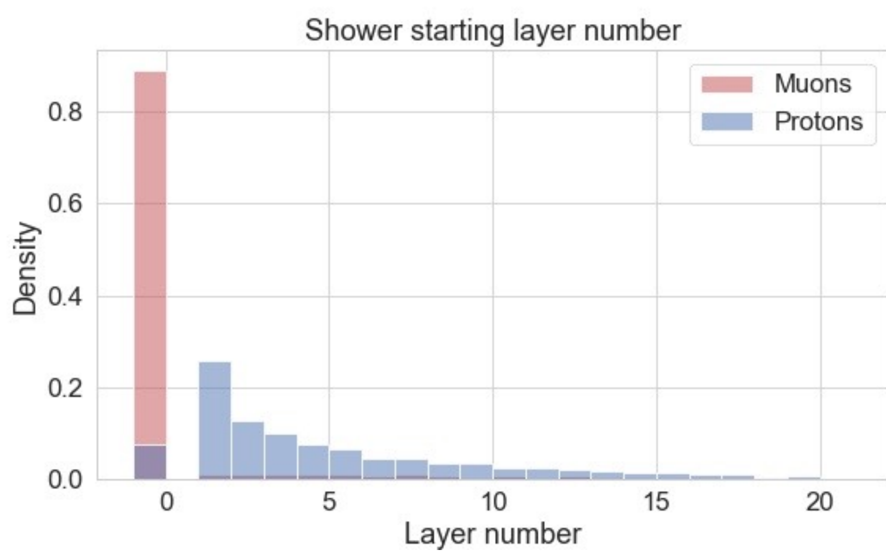
Accuracy = 0.93 **(Preliminary)**

	feature	importance
2	lastFiredLayer	0.612
0	hitMultiplicity	0.234
3	splittingLayer	0.078
1	firstFiredLayer	0.052
4	hitsAtLastLayer	0.024

Discriminative Variables







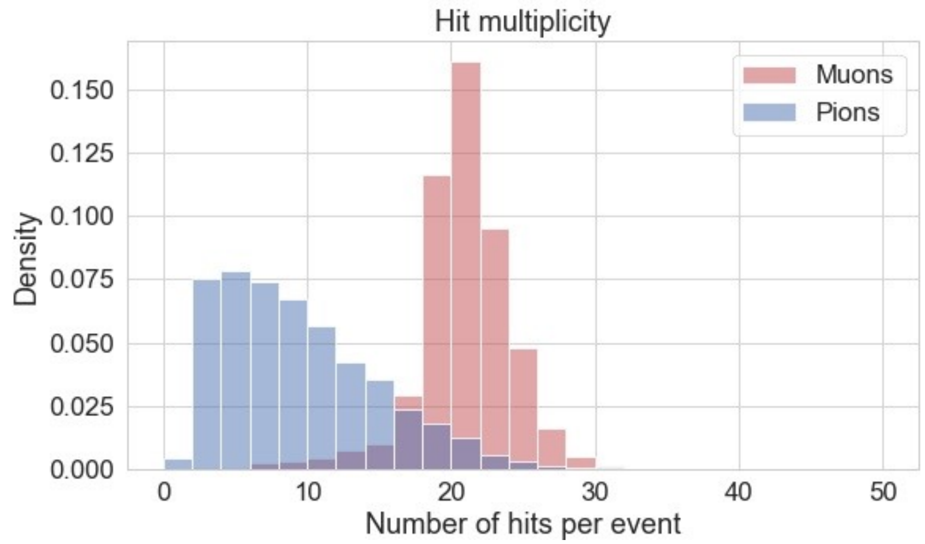
MC sample
(RS simulation in SPDRoot):

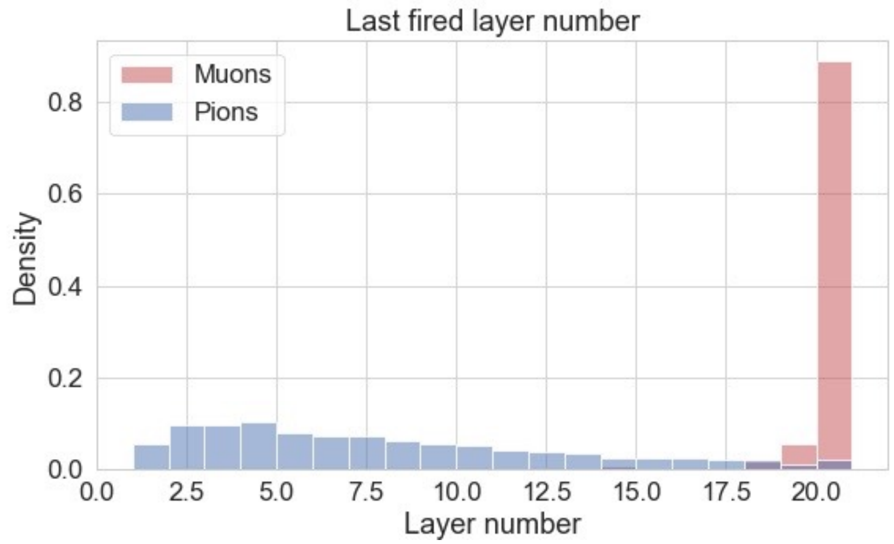
Signal sample: **muons** 6 GeV/c
Background sample: **protons** 6 GeV/c

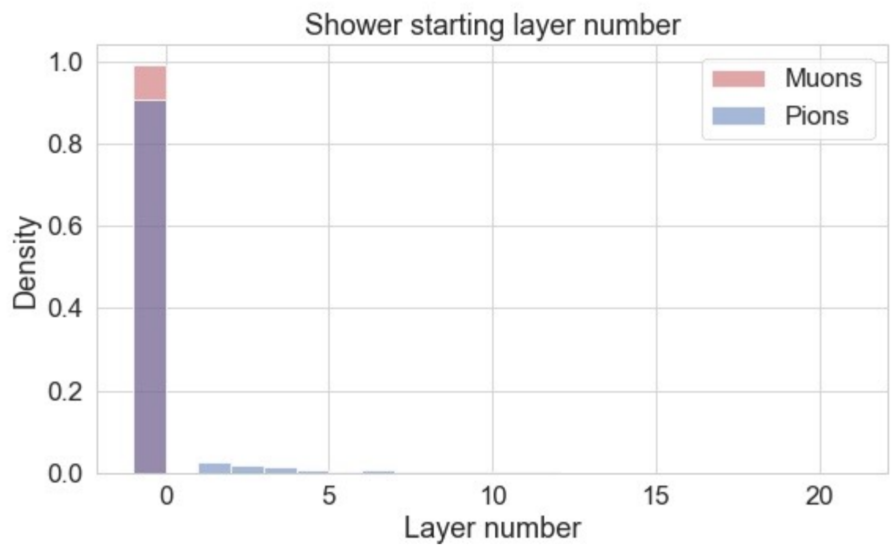
Accuracy = 0.94 **(Preliminary)**

	feature	importance
3	splittingLayer	0.797
2	lastFiredLayer	0.124
0	hitMultiplicity	0.060
1	firstFiredLayer	0.016
4	hitsAtLastLayer	0.003

Discriminative Variables







MC sample
(RS simulation in SPDRoot):

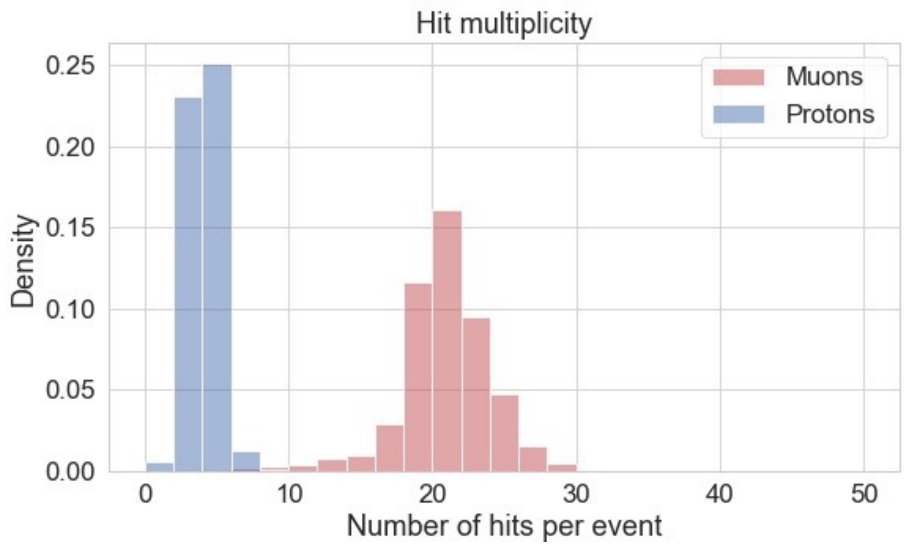
Signal sample: **muons** 1 GeV/c
Background sample: **pions** 1 GeV/c

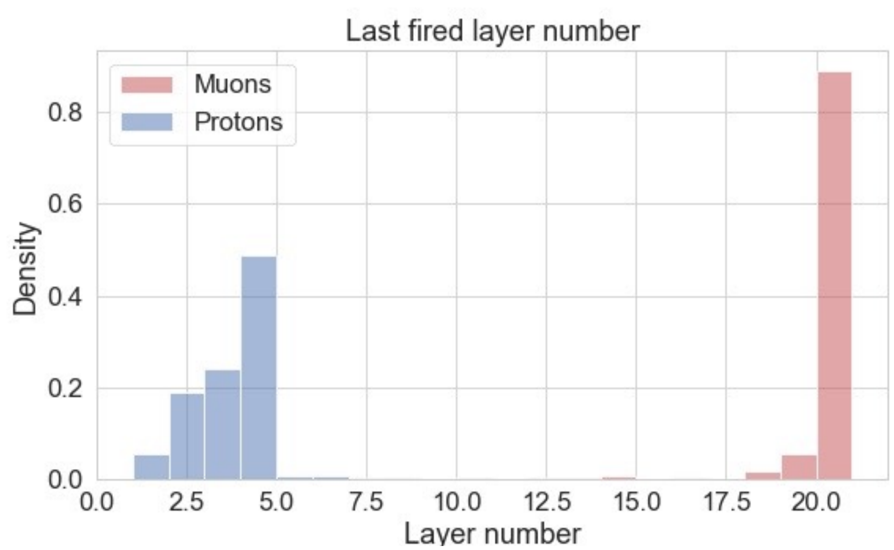
Accuracy = 0.97

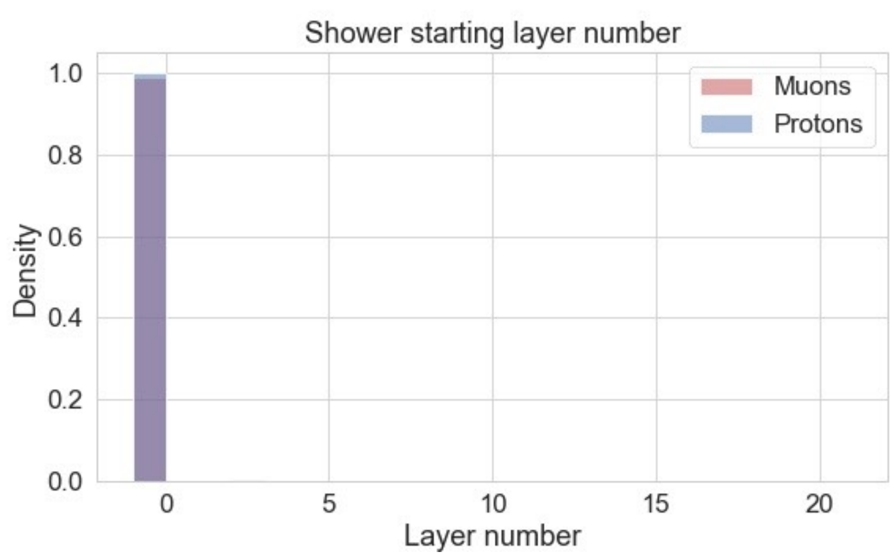
(Preliminary)

	feature	importance
2	lastFiredLayer	0.935
4	hitsAtLastLayer	0.039
0	hitMultiplicity	0.014
1	firstFiredLayer	0.012
3	splittingLayer	0.000

Discriminative Variables







MC sample

(RS simulation in SPDRoot):

Signal sample: **muons** 1 GeV/c

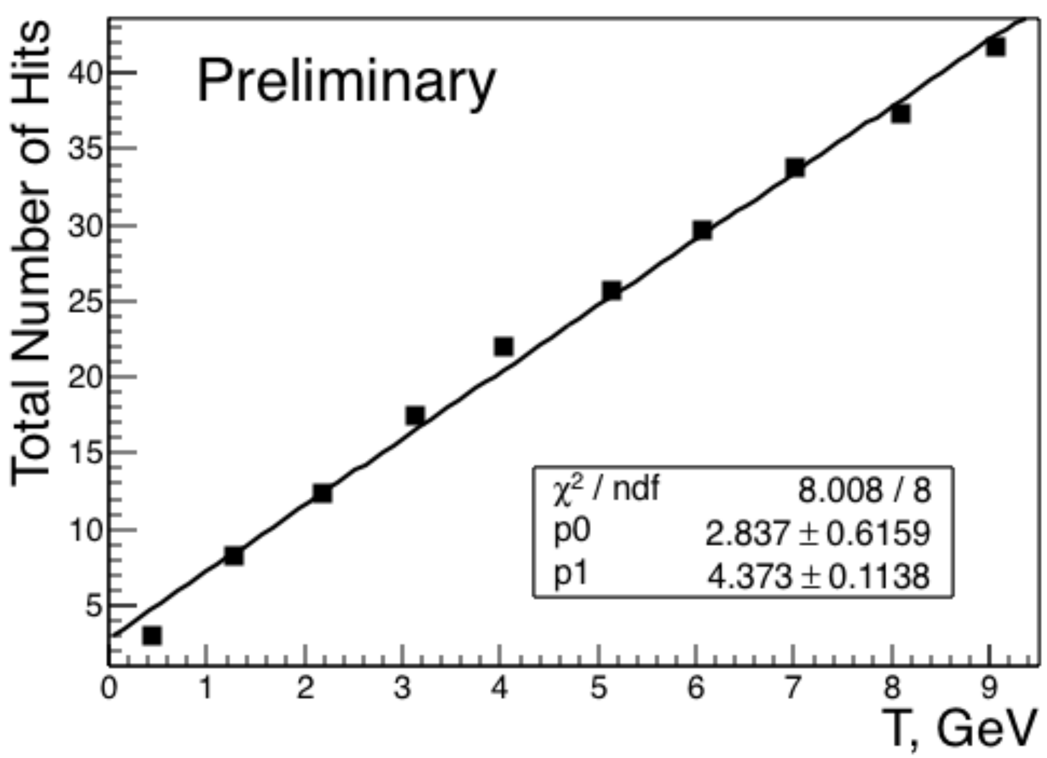
Background sample: **protons** 1 GeV/c

Accuracy = 0.99 **(Preliminary)**

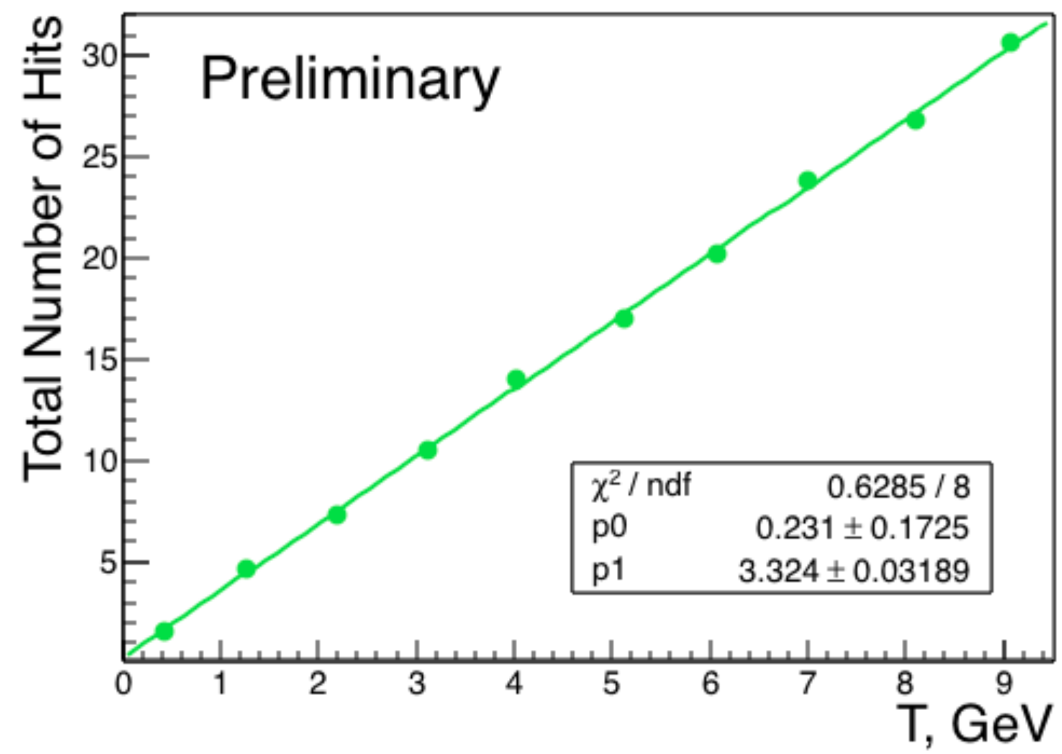
	feature	importance
0	hitMultiplicity	0.988
1	firstFiredLayer	0.008
2	lastFiredLayer	0.004
3	splittingLayer	0.000
4	hitsAtLastLayer	0.000

Work in progress…

Hadron calorimetry is implemented by measuring the total number of hits in an event.



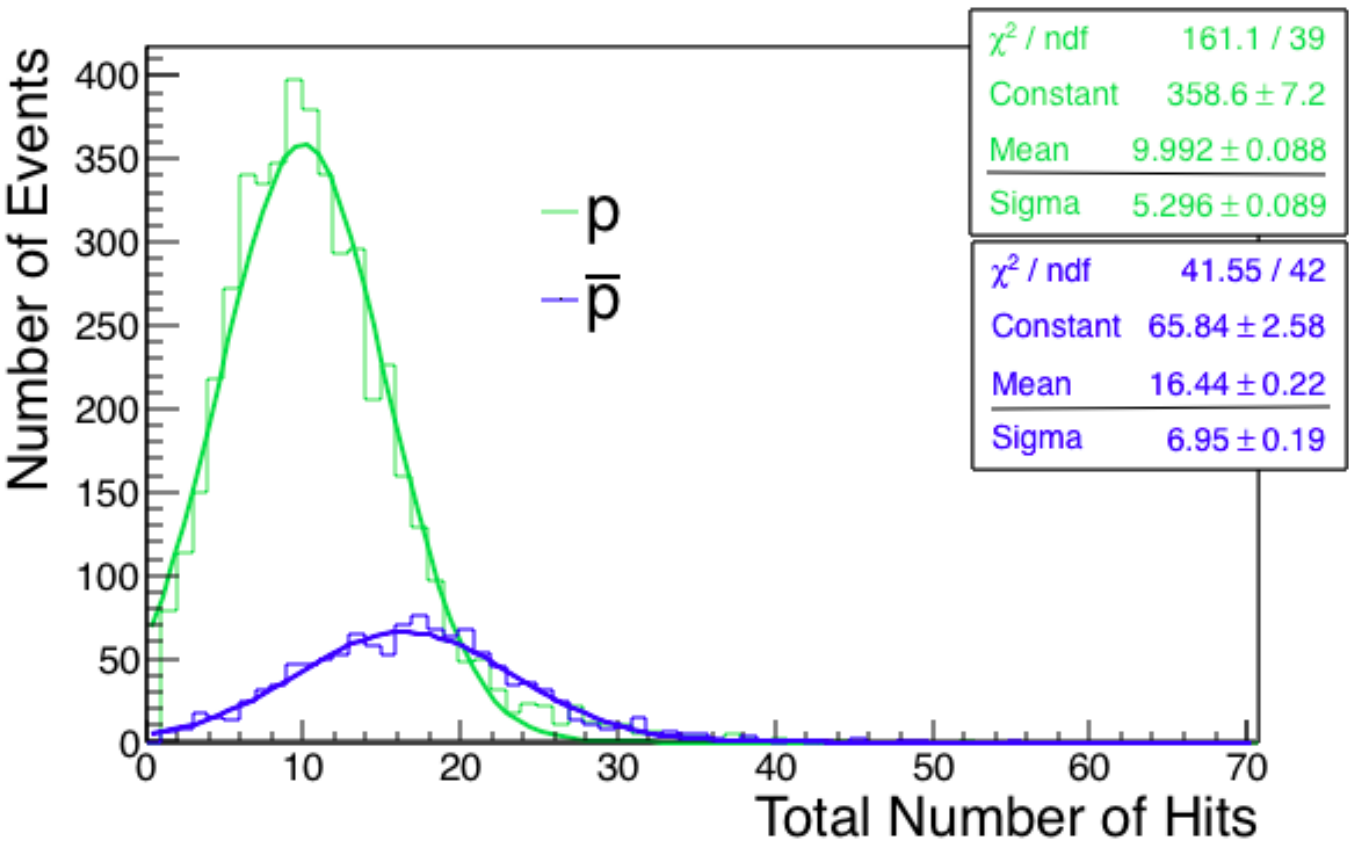
Sampling: 60mm (Fe). Nuclear interaction length $\lambda_I \approx 5.2$

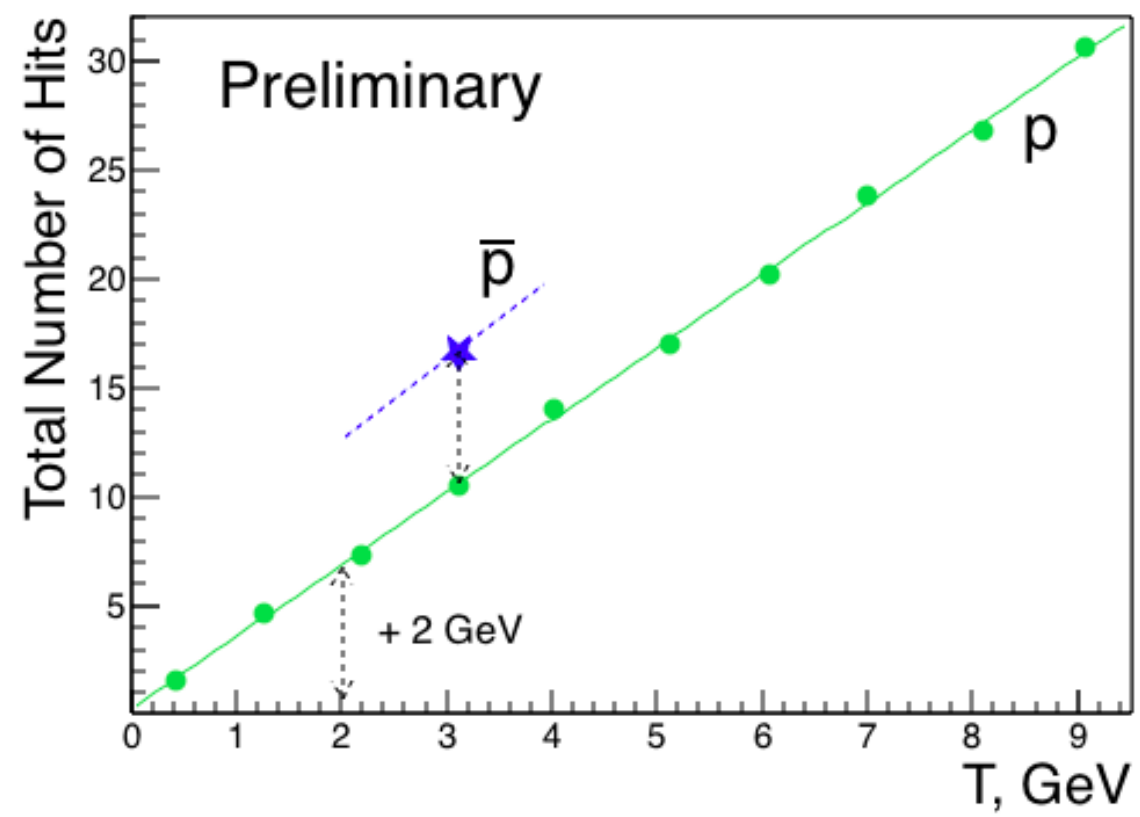


Sampling: 30mm (Fe). Nuclear interaction length $\lambda_I \approx 2.3$

Analogous calibrations will be made once the SPD Muon Range System prototype is ready for beam tests at the Nuclotron.

Demonstration of antiproton calibration response.





Comparison of the total number of hits for protons and antiprotons.

Sampling: 30mm (Fe). Nuclear interaction length $\lambda_I \approx 2.3$

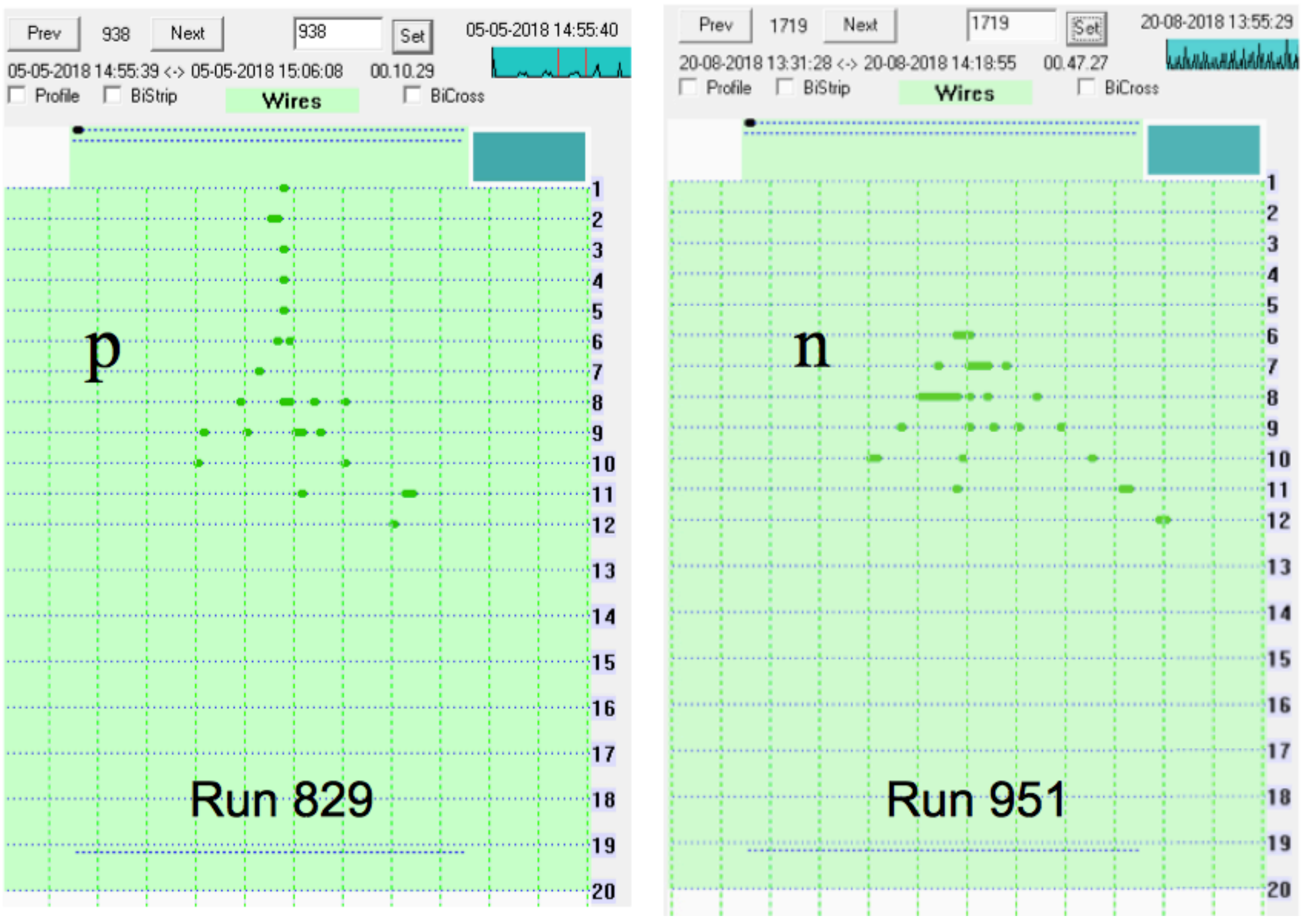
NEUTRON REGISTRATION

Another important feature of the Range System is a possibility to identify neutrons:

- use of the same proton monochromatic beam @ T9/PS;

- carbon target as a neutron source installed in front of prototype;

- scintillators for vetoing protons.



Comparison of hit profile in the Range System Prototype for a proton (left) and neutron (right).

SUMMARY

The SPD Muon Range System:
being based on the Mini-Drift Tubes as a detector,
iron plates as an absorber,
followed by a robust analogue amplifier/discriminator technique,
supplemented by a digital end-stage for data transfer to the DAQ
- are up to its tasks.

Status:
- the RS Prototype is fully equipped and functional;
- test beam and cosmics data collected from 2017-2019 ($e^{\pm}, \mu^{\pm}, \pi^{\pm}, p/\bar{p}, n$).
- Geant4 model of the SPD/NICA RS for MC studies is implemented;
- preliminary estimates for muon/hadron separation on beam test data and MC using DecisionTree were made.

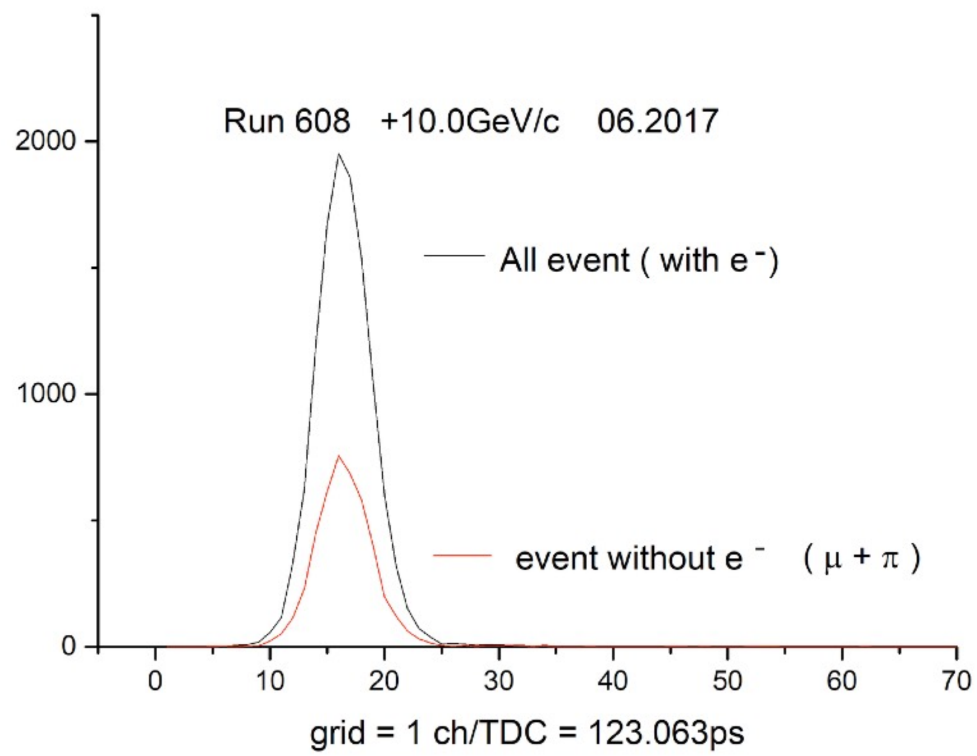
Plans:
- search for optimal μ/π separation algorithm in a wide range of particle momenta (0.5 - 10.0 GeV/c);
- perform hadron calorimetry ($p/\bar{p}, n, \pi$) as a function of hadron momentum;
- tuning MC signal digitization parameters using real test beam data.

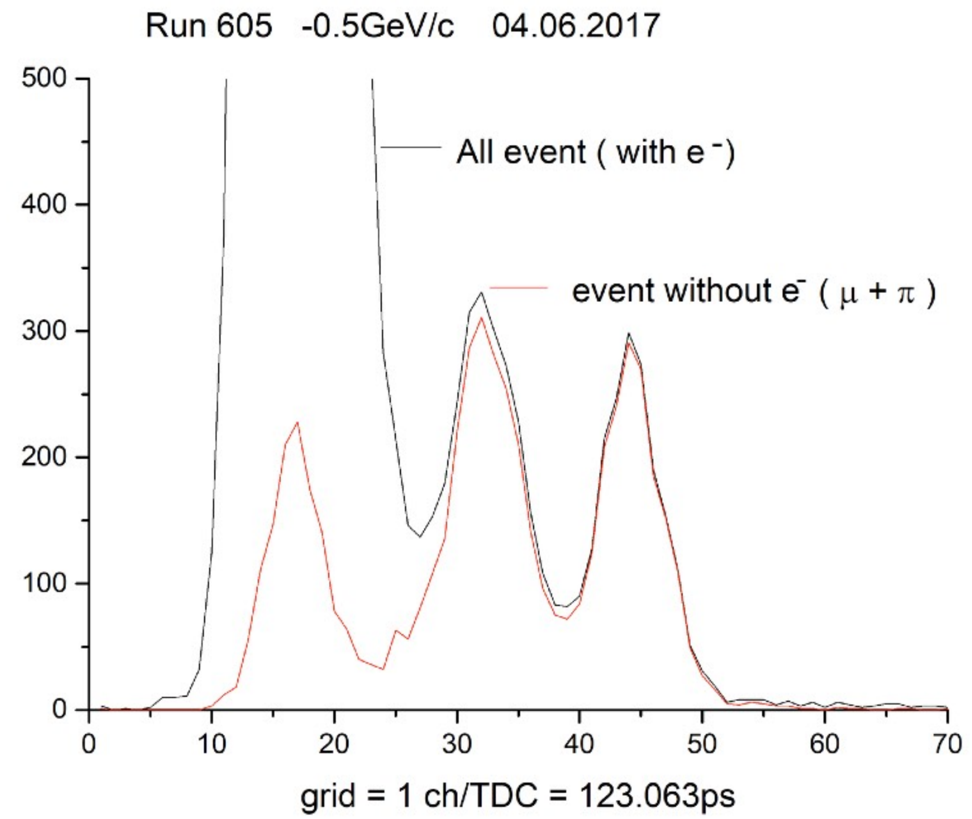
Thank You!

BackUp

Beam Particle ID

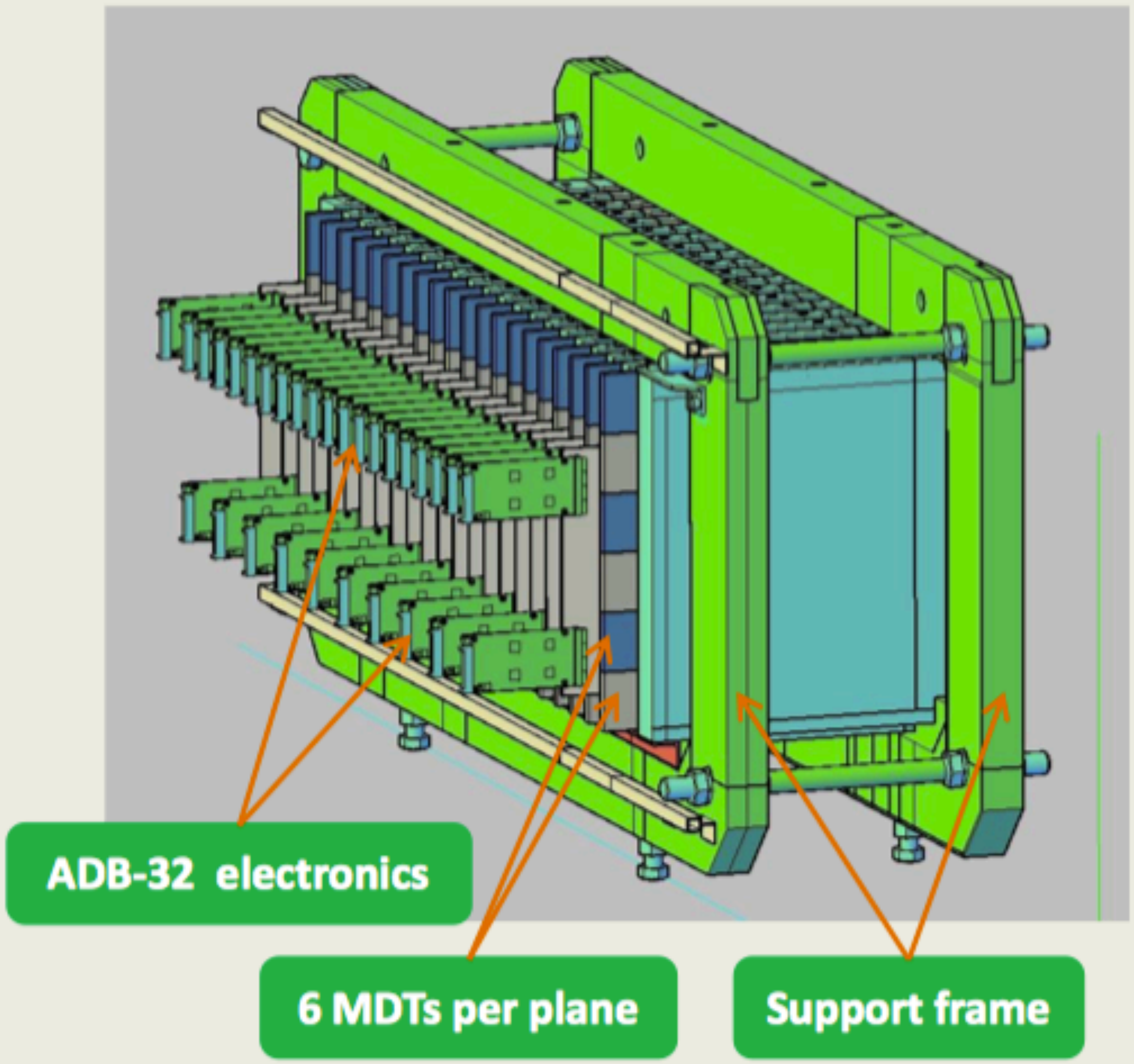
A study of the Range System Prototype response to a variety of passing particles with different momenta.
The prototype is also equipped with TOF for particle-id and Cherenkov counters for vetoing electrons.





With the increasing beam energy a possibility of particles separation by TOF detector is significantly reduced but we may use Cherenkov counters.

SPD Range System Prototype



96 MDTs, 768 wire R/O channels,
256 strips

60mm + 15 layers x 30mm + 60mm;
total thickness ~3.5λ_I

Cerenkov Counter

Pressurized gas Cerenkov counter (CO_2 up to 60 atm) for SPD/NICA test beam area @ Nuclotron.