Muon Detection with SPD Range System

Status and Plans

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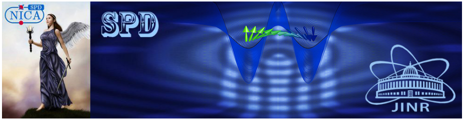
Outline

- SPD Range System (RS);
- Muon identification and background estimation using RS;
- Range System Prototype R&D Program;
- Current status and Plans.



Muons

Parameter are well-known:

- Charge ± 1
- Mass 105.6583745 MeV
- Lifetime 2.1969811 μs (considered as stable in Geant4)
- Decay ($\approx$ 100%) $\mu \to e\nu\nu$
- No strong interaction

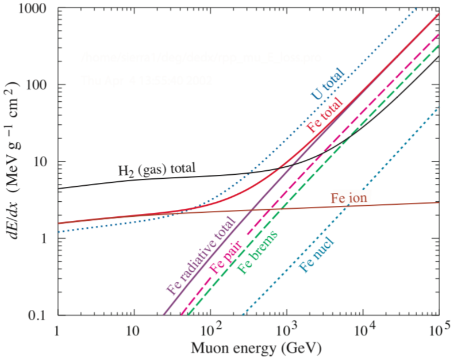
Major sources of muons:

- accelerators
  - muons produced by mesons decay;
  - primary muons (Drell-Yan, process for search);
- cosmic
  - 80% of flux at sea level (decays of pions $\pi \to \mu\nu$)

  $\sim 10^2$ muons/m^2 sec, $E > 1$ GeV.

Muon detection

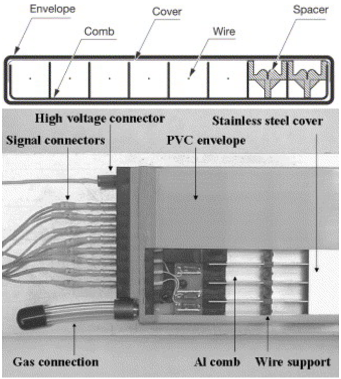
- Muons are detected by their interactions with the traversed medium.
- Muon energy loss is defined by electromagnetic interactions:
  - Ionisation (dE/dx);
  - e^+e^- pair production;
  - Bremsstrahlung radiation;
  - Photo-nuclear reactions.



Mini-Drift Tubes

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

- cell size ~ 1 cm;
- total number of cells $\sim 10^4 - 10^6$;
- gas (Ar/CO_2) amplification near anode wire provides detectible signal ($\sim 1\mu A$);
- individual chambers with various number of cells up to 10 m long can be assembled to have $\sim 10^2 - 10^3$ cells in a plane.

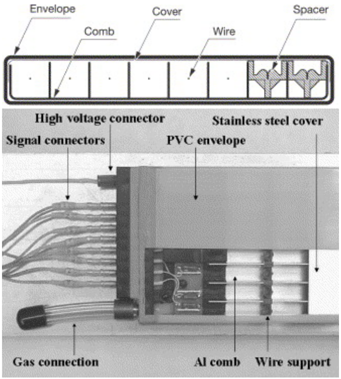


Mini-Drift Tubes (cont'd)

- Hit map provides muon tracking;
- In order to define muon location with high precision electron drift time is measured.

Advantages

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

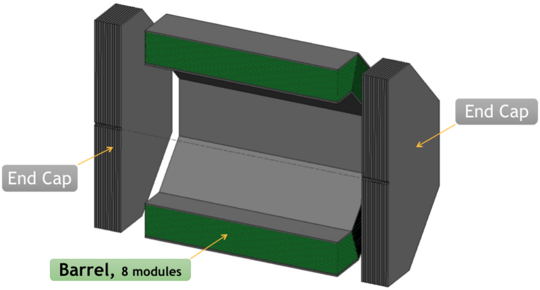


SPD Muon Range System concept

- SPD/NICA Muon System is based on a range system technique – good Particle ID system for muon/hadron separation.
- works in full SPD energy range of secondary particles (at $\sqrt{s}_{pp} = 12 - 27$ GeV).
- resolves muons and hadrons with ∼100% efficiency ("zero" hadron contamination) above ∼1 GeV by obviously different response pattern.
- Main purpose:
    - muon identification;
    - separation of muons from hadron contamination
- Important feature: the range system may be used as a coarse sampling hadron calorimeter
(Layers of 30mm to 60mm – typical sampling).

SPD Muon Range System concept (cont'd)

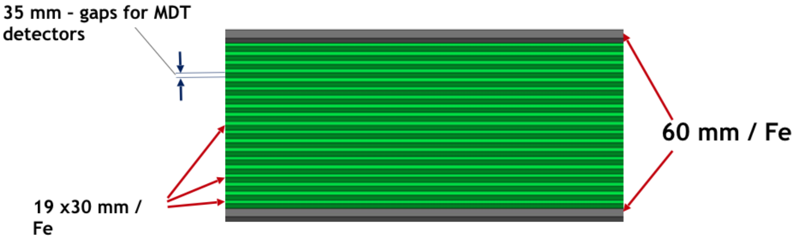
- The Muon Range System structure is a well known solution for detecting the muons stopped by the absorber and those crossing the iron
- In first case, one may even roughly estimate the energy of muon. The stopping power of iron is about 1.5 GeV per meter of absorber for the relativistic muons with $dE/dx = 2$ MeV/g.
- The iron absorber sampling is 30mm, and presently being discussed.



3D model of the SPD RS concept. (Preliminary)

SPD Muon Range System concept (cont'd)

Barrel and EndCaps Structure (cross section)



$2{\times}60$ mm $+$ 19 layers $\times$ 30 mm $\rightarrow 4\ \lambda_i$

(Preliminary, presently being discussed)

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
- zero "bi-layers"

SPD Muon Range System R&D program:

- Perform calibration of the system response to various particles at different energies
- Muon/hadron separation algorithm testing
- Digitization tuning

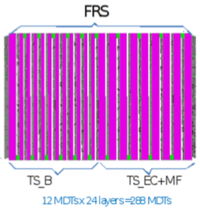
A2DB-32 cards for wire R/O
(2160 channels)

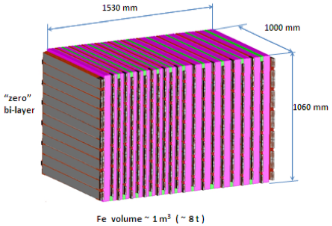
ADB-32 cards for strip R/O
(764 channels)

Range System Prototype (cont'd)

Range System Prototype

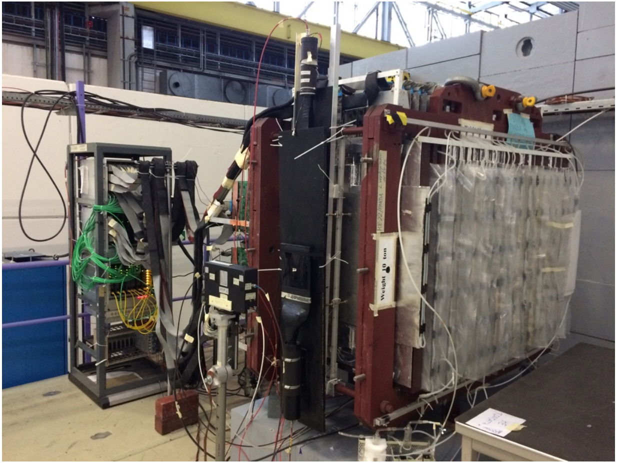
- It is designed as '2 in 1' device: the structure of absorber plates reproduces Barrel or Endcap – depending on the particular direction of the test beam and number of engaged layers;
- Initially designed for PANDA structure, RSP is perfectly suitable for SPD tasks;
- MDT detectors 288 units $\sim$ 1 m long;
- Strip boards 22 units with $\sim$ 1 m $\times$ 1 m 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 scan'.





Range System Prototype (cont'd)

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

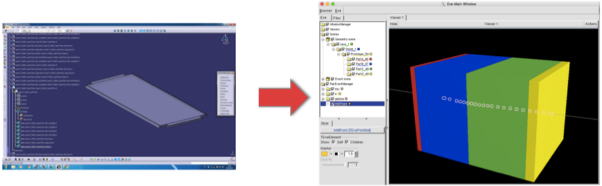
Current status and tasks

Current state:

- RS Prototype fully equipped with R/O electronics and beam scan detectors;
- Cosmics dataset (mostly for electronics tuning);
- Test beam dataset $p^{beam} = 0.5 \div 10.0$ GeV/c $(e^{\pm}, \mu^{\pm}, \pi^{\pm}, p^{\pm}, n)$ collected between 2017 – 2018;
- Geant4 model of the RS Prototype for MC.

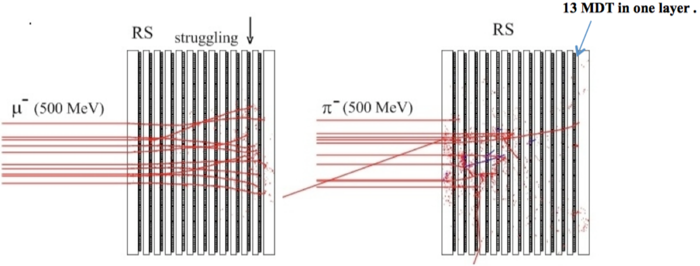
Current tasks:

- Electronics tuning for 2^{nd} coordinate (strip) readout;
- μ and hadron tracking and separation (Kalman Filter, Pattern recognition algos, NN);
- Hadron detection and calorimetry (Pattern recognition algos, NN);
- Digitization parameters extraction for MC tuning.



Prototype MC: π/μ separation

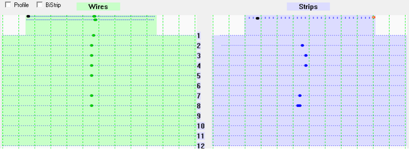
- Muon track finding is a straightforward procedure of fitting hits using Kalman Filter algorithm (with magnetic field) or simply line (no magnetic field).
- There are three sources of muon background given the same (muon-like) signal in RS:
  1. pions traversing the passive material and iron absorber by energy losses process only;
  2. cascade muons from pions giving a shower in passive material or iron absorber;
  3. muons from pion decay (in flight) before electromagnetic calorimeter.



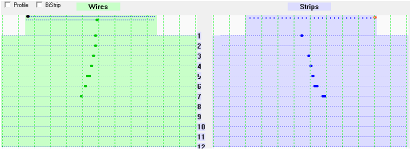
Prototype data: π/μ separation

A hit profile in RSP corresponding to a particular kind of particles with a certain momentum has a specific pattern.

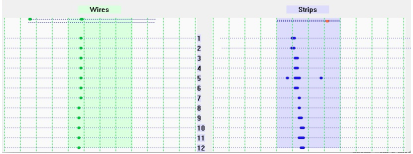
Low momentum pions ($p < 1.0$ GeV/c) almost indistinguishable from muons with the same momentum.



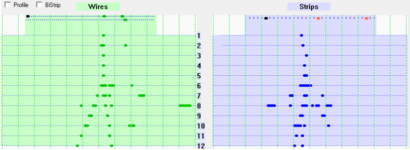
μ^- : 0.5 GeV/c



π^- : 0.5 GeV/c



μ^- : 10.0 GeV/c

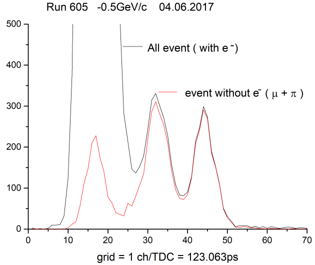


π^- : 10.0 GeV/c

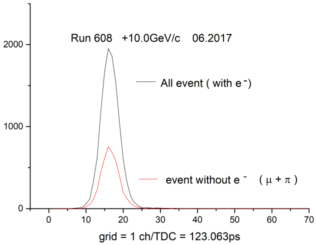
The increasing energy of pions significantly changes the profile of hits, forming a hadron shower of secondary particles.

Prototype data: π/μ separation (cont'd)

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.



Time-of-flight distribution of the particles for the beam with momentum 0.5 GeV/c (zoom)

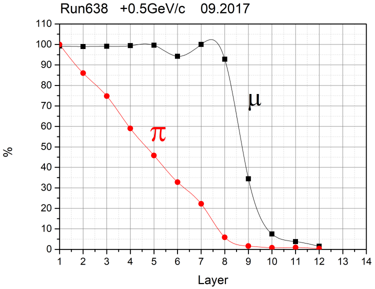


Time-of-flight distribution of the particles for the beam with momentum 10.0 GeV/c

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

Prototype data: π/μ separation (cont'd)

Finding variables sensitive to differences in such patterns, is directly connected to the possibility of separation between muons and pions, e.g. the depth of the full energy deposition of the particles in the layered structure of the Range System.



Only $(20 - 25)$ % of pions reach the 7^{th} plane, while almost all of the muons have the energy exceeding the threshold. The presence of hits above the 8^{th} layer with a high degree of probability suggests that the particle is a muon, since no more than $(1 - 2)$ % of pions reach the 9^{th} plane.

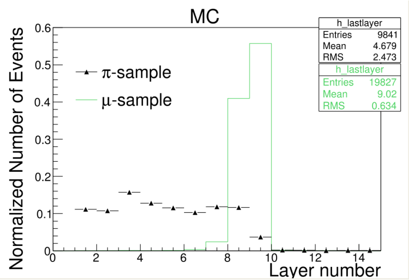
Prototype MC vs. data: π/μ separation (cont'd)

Preliminary prototype data/MC comparison.

Last number of triggered (fired) layer in the prototype.

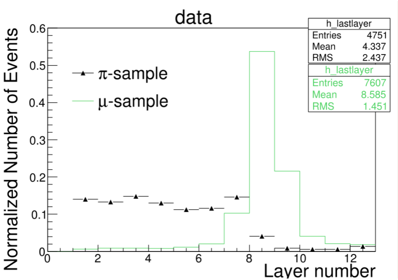
Event selection: Layer# ≥ 7.

27% - pion contamination;
99% - muon efficiency



FairBoxGenerator, PandaROOT
$p = 0.5$ GeV/c

22% - pion contamination;
93% - muon efficiency



Run 605, autumn 2017
$p = 0.5$ GeV/c

EPJ WoC, Volume 177 (2018) 04001

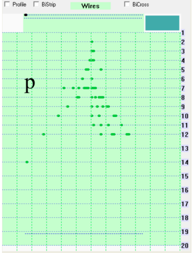
Prototype data: Hadron separation

Probability density function for distance until hadron interactions:

$$\Phi(x)dx = \frac{1}{\lambda_I} e^{-x/\lambda_I} dx$$

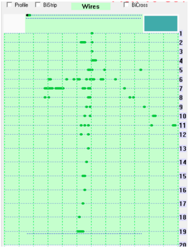
1. Measurement of mean free path of a proton before undergoing a nuclear interaction will be used for reference (more likely to be deposited within RS, and has no muon contamination in the beam);
2. Measurement of mean free path of a pion (muon contamination in the beam is possible!)

Proton in Fe: $\lambda_I = 16.77$ cm



p : 10 GeV/c

Pion in Fe: $\lambda_I = 20.42$ cm



π : 10 GeV/c

Summary

- The SPD Muon Range System being based on the Mini-Drift Tubes as a detector and iron plates as 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 $(e^{\pm}, \mu^{\pm}, \pi^{\pm}, p^{\pm}, n)$;
  - Geant4 simulation model of the RS Prototype for MC;
- Plans:
  - perform optimal separation from background contamination (π/μ);
  - perform hadron calorimetry $(p/n/\pi)$;
  - tuning MC signal digitization parameters using real test beam data.

Backup