Embedding procedure as an instrument used for optimal reconstruction of particle trajectories from $\Lambda^0$ decay in the BM@N experiment

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Fixed target BM@N experiment at the NICA complex

Setup used in the last experimental run

Central tracker (Silicon + GEM) inside analyzing magnet to reconstruct AA-interactions

Outer tracker (CPC, DCH) behind magnet to link tracks from central tracker to ToF detectors

TOF1 & TOF2 system based on mRPC and T0 detectors to identify hadrons and light nuclei

Motivation of embedding:

- Looks as a necessary step when trying to make agreement between existing experimental data and Monte Carlo simulation (description) of the setup.
- Allows us to improve tracking procedure (primary and secondary vertices, reconstructed track parameters and so on).
- Helps to do "fine" adjustments of reconstruction algorithms aimed at, in particular, maximizing of reconstructed $\Lambda^0$'s from experimental data.
Embedding of $\Lambda^0 \rightarrow \pi^- + p$ decay products, algorithm:

1. Input
- Creating stores with $\Lambda^0$
- Creating a list of reconstructed events where $V_p$ is reconstructed

2. Simulation
- Passing the stores to BM@N Central Tracker simulations
- Finding at least one $\Lambda^0$ to be reconstructed for a given vertex in considering event

3. Monitoring
- If necessary, having possibilities to know all information on Monte Carlo decay products (momentum, num. of hits ...) to be used for embedding.

4. Digitization and embedding
- Creating digits from $\Lambda^0$ decay products corresponding to considering event
- Doing correspondence between digits from decay products to channel and serial numbers of ADC
Monitoring events with embedded products from $\Lambda^0$ decay

To get info on eventId, used store, vertex index and, namely, event for embedding

EmbeddingMonitor.id

EmbeddingMonitor.vertex

EmbeddingMonitor.store

EmbeddingMonitor.event
Creating digits from $\Lambda^0$ decay products

MC points from $\Lambda^0$ decay products

Cluster sizes, GEM, Lay 2 (X, hot zone)

Cluster sizes, GEM, Lay 0 (X, big zone)
Doing correspondence between digits from $\Lambda^0$ decay products to a channel and a serial number of ADC

### Central Tracker, mappings

<table>
<thead>
<tr>
<th>Serial</th>
<th>Ch_lo</th>
<th>Ch_hi</th>
<th>GEM_id</th>
<th>Station</th>
<th>Module</th>
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<tbody>
<tr>
<td>0x76CD410</td>
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<td>2047</td>
<td>100</td>
<td>1</td>
<td>3</td>
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</tbody>
</table>

### Digit:

#### Monte Carlo (physical):
- Station
- Module
- Layer
- Strip
- Signal

#### ADC (electronics):
- Serial
- Channel
- Sample
- Amplitude

### Main idea:
- To do a transition from Monte Carlo (physical) digits from $\Lambda^0$ decay products to ADC digits using mappings
- To have a stable procedure used for rescaling Monte Carlo amplitudes
Embedded signal for the BM@N Central Tracker

Embedded signal has a constant amplitude per each stip forming a cluster from $\Lambda^0$ decay products on elements of BM@N Central Tracker

Embedded signal for SILICON part of the tracker looks wider (if comparing with GEM) due to more significant fluctuations of Command Mode when decoding.
QA of the embedding procedure

XZ SI-GEM profile, id = 257

YZ SI-GEM profile, id = 257

GEM: X vs. Y, stat# 0

GEM: X vs. Y, stat# 1

GEM: X vs. Y, stat# 2

GEM: X vs. Y, stat# 3

GEM: X vs. Y, stat# 4

GEM: X vs. Y, stat# 5

SILICON: X vs. Y, stat# 0

SILICON: X vs. Y, stat# 1

SILICON: X vs. Y, stat# 2

SILICON: X vs. Y, stat# 3
Integral probability correspondence approach

- Strip signal histograms are created for Monte Carlo and real data
- Integral probability distributions are built separately for each element of the Central Tracker.
- For each MC digit probability value is taken
- The value of Exp signal corresponding to that probability value is considered as rescaled MC signal.

Working cycle

MC signal

\[
\downarrow \quad MC = \text{experimental integral probability} \quad \downarrow
\]

rescaled "experimental" signal
Average efficiency for each plane of GEM tracker is more than 90%
Going to $\Lambda^0$ reconstruction ...

- Reconstruction of $V_p$ and $V_0$
- Reconstructed $\Lambda^0$'s from embedded and real experimental data
Reconstructed $V_p$ (primary vertices)

- **Average $V_p$ resolution along Z is close to 3 mm for all targets (2.6 - 3.4 mm)**
- **The resolution has approximately the same trend for all trigger conditions**

See ICPPA-2020, S.Merts, to get more detail on algorithm and trigger dependence
A pair of two tracks with different signs of $Q_p$ is considered as a candidate to be from $\Lambda^0$ decay.

The chosen tracks are put into a corridor of relatively big width along Z-axis.

The corridor is separated into small parts by virtual planes corresponding to some values of Z.

The tracks are extrapolated to those Z by the Kalman filter mechanism aimed at calculating 2d-distance between.

A set of calculated distances corresponding to the known Z-values is approximated with $P(z) = az^2 + bz + c$. It allows one to reject pairs that can produce a non-desirable edge minimum ($a < 0$) occurred widely when processing pairs.

If a considering pair has a $P(z)$ parameterization with $a > 0$, a found minimum is considered as approximation to $V_0$. The minimum is taken from available calculated distances but not the parameterization used.

The corridor is divided by factor 2 to reproduce the steps of algorithm already mentioned. The algorithm works till to the corridor width is less than a chosen threshold or the pair does not become to satisfy restrictions.
Reconstructed $V_0$ (secondary vertices)
Reconstruction of embedded $\Lambda^0$

**BT+BD1+FD2**

Invariant mass: $\Lambda^0 \rightarrow p + \pi$

- Mass = 1.1161
- Sigma = 0.0028
- All, 20788
- Background, 16316
- Numb. of $\Lambda^0$ = 4471

Embedded $\Lambda^0 = 7990$

Eff = 4471. / 7990 = 0.56

**BT+BD3**

Invariant mass: $\Lambda^0 \rightarrow p + \pi$

- Mass = 1.1159
- Sigma = 0.0031
- All, 19921
- Background, 9259
- Numb. of $\Lambda^0$ = 3501

Embedded $\Lambda^0 = 7667$

Eff = 3501. / 7667 = 0.46

**BT+FD3**

Invariant mass: $\Lambda^0 \rightarrow p + \pi$

- Mass = 1.1163
- Sigma = 0.0025
- All, 12761
- Background, 9259
- Numb. of $\Lambda^0$ = 3493

Embedded $\Lambda^0 = 7665$

Eff = 3493. / 7665 = 0.46

- Embedded $\Lambda^0$ look to be reconstructed for all trigger conditions used with approximately the same efficiency
- A room how to fit background and signal regions of spectrum exists ...
- Efficiencies extracted from Monte Carlo (related to tracking procedure) should be calculated and implemented in a more precise manner ...

Obtained results allowed us to improve tracking procedure!
Λ⁰ in experimental data (Preliminary)

Events with \(N_{\text{rec.tracks}} > 1\) [MEvents]

<table>
<thead>
<tr>
<th></th>
<th>BD1 + FD2</th>
<th>BD2</th>
<th>BD3</th>
<th>FD2</th>
<th>FD3</th>
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</thead>
<tbody>
<tr>
<td>Pb</td>
<td>2.13</td>
<td>-</td>
<td>1.16</td>
<td>-</td>
<td>2.75</td>
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<tr>
<td>Sn</td>
<td>4.81</td>
<td>0.20</td>
<td>1.88</td>
<td>0.56</td>
<td>5.59</td>
</tr>
<tr>
<td>Cu</td>
<td>4.61</td>
<td>0.24</td>
<td>1.89</td>
<td>0.56</td>
<td>5.68</td>
</tr>
<tr>
<td>Al</td>
<td>5.23</td>
<td>0.24</td>
<td>2.13</td>
<td>0.80</td>
<td>5.63</td>
</tr>
<tr>
<td>C</td>
<td>1.94</td>
<td>0.42</td>
<td>0.54</td>
<td>0.60</td>
<td>1.86</td>
</tr>
</tbody>
</table>

With primary vertex cut: \(\approx 5\)
Cut on \(V_p: -3 < V_p(Z) < 3\) cm

Reco track:
\(n\text{Hits} = n\text{SiliconHits} + n\text{GemHits}\)

Λ⁰-signal became visible.
Trying to increase number of reconstructed Λ⁰’s...