Event simulation and reconstruction in the BM@N experiment

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on behalf of BERDS Group
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BM@N advantages:

- large aperture analyzing magnet
- sub-detector systems are resistant to high multiplicities of charged particles
- PID: "near to magnet" (TOF1), "far from magnet" (TOF2)
Simulation
Main features of simulation

1. **Event generators**: simple for tests, realistic for feasibility study, specific
2. **Transport code** to propagate particle through detector volume
3. **Type of geometry**: realistic or simplified
4. **Monte Carlo** information production (presence of classes to produce MC points)
5. **Realistic effects** inside detectors:
   - Avalanches/Smearing/Clustering production
   - Lorentz shifts for detectors in magnetic field
   - Detector misalignment
   - Channel inefficiency
   - Rest non-calibration (time for TDC, pedestals for ADC, ...)
6. **Digitizer** to convert MC data into detector format
Monte Carlo simulation in BmnRoot

Event Generators:
- Simple generators: BOX, ION, PART, ...
- Physics generators: UrQMD, DCM-QGSM, ...
- Specific generators: SRC (under implementation)

Transport codes:
- GEANT 3
- GEANT 4
- FLUKA

For all detector we have realistic geometry and classes to MC points and tracks production implemented
Upstream detectors

Barrel and Forward detectors
- No realistic effects
- No digitizer

Multi-Wires Proportional Chambers
- No realistic effects
- Digitizer is prepared
Inner tracking detectors

**Silicon planes**
- Simplified simulation based on Gaussian smearing (no misalignment, no inefficiency)
- Digitizer is implemented

**GEM planes**
- Realistic simulation based on Garfield+ (no misalignment, no inefficiency)
- Digitizer is implemented

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Downstream coordinate detectors

**Cathod Strip Chamber**
- Simplified simulation based on Gaussian smearing *(no misalignment, no inefficiency)*
- Digitizer is implemented

**Drift CHambers**
- Simplified simulation based on Gaussian smearing with distance dependence *(no misalignment, no inefficiency)*
- Digitizer is implemented
Time-of-Flight detectors

TOF-400
- Simulation effects: strips inefficiency, multichannel activation (no misalignment)
- No digitizer

TOF-700
- Simulation effects: strips inefficiency, multichannel activation (no misalignment)
- No digitizer
Calorimeters

**ECAL**
- Simple hit producer (energy collecting in towers) *(no misalignment, no inefficiency)*
- No digitizer

**ZDC**
- Simple hit producer (energy collecting in towers) *(no misalignment, no inefficiency)*
- No digitizer
Reconstruction
Main features of event reconstruction

1. **Raw data** converter (for experimental data)
2. **Cluster/Hit finders** inside detectors
3. **Local** track finder
4. **Global** matching
5. **Vertex** finder
6. **Particle identification**
First step (Data Converter):
- Read a **binary data file** with RAW-data.
- Create «**DAQ-digits**» (ADC, TDC, HRB, SYNC, etc.) accordingly **DAQ-data-format** and write them into a tree.
- Read **common parameters** (event number, run number, event type, etc.) and put them into the **Unified Database** on fly.
- Write the tree with «**DAQ-digits**» into ROOT-file.

Second step (Data Decoder):
- Read the ROOT-file with **DAQ-digits**
- Read **detector mappings** (channel-to-strip) from the **Unified Database**
- Calculate **pedestals** and **common modes** of channels
- Clear **noisy** channels
- Decode **DAQ-digits** into **detector-digits** (BmnGemDigit, BmnToFDigit, etc.)
- Write the tree with **detector-digits** to a ROOT-file
BM@N:
- One beam energy available for Ar-beam and three for Kr-beam
- Set of targets used Empty, C, Al, Cu, Sn, Pb
SRC:
- One beam energy available for C-beam
- More than half of the collected statistics can be used for analysis

Beam C (E = 3.17 GeV/n)
Total: 99.77 MEvents
- H2: 34.23 MEvents
- Pb: 51.52 MEvents
- No target: 14.02 MEvents
Monte Carlo data

- Generator: DCM-QGSM, \textit{ArPb} (T = 3.2 GeV/n), minbias, 10k events
- Magnetic field: \( B = 0.59 \) T
- Mean reconstructable multiplicity: 25
- Maximal reconstructable multiplicity: 50
Current realization of the BM@N tracking is

- based on cellular automaton
  R. Frühwirth et all arXiv:1202.2761
- using two connected hits on different stations as a **cell** (straight line segment).
- working with Silicon hits and with GEM hits as a whole.
Tracking quality. Efficiency

- **Reconstructable tracks** \( (N_{MC}) \): MC-track with more than 3 points
- **Reconstructed tracks** \( (N_{rec}) \): All reconstructed tracks
- **Well tracks** \( (N_{well}) \): Reconstructed tracks more than 60% of hits corresponded to same MC-track
- **Wrong tracks** \( (N_{wrong}) \): Reconstructed tracks less than 60% of hits corresponded to same MC-track
- **Split tracks** \( (N_{split}) \): Reconstructed tracks corresponded to same MC-track

**Efficiency**: \( \frac{N_{well} - N_{split}}{N_{MC}} \cdot 100\% \)

**Percent of ghosts**: \( \frac{N_{wrong}}{N_{rec}} \cdot 100\% \)

**Percent of clones**: \( \frac{N_{split}}{N_{rec}} \cdot 100\% \)
Why efficiency is not high enough?

Small example
Dependence on multiplicity

Artifitial example:
- Exact number of tracks was generated
- Uniform momentum range: 0.2-4 GeV/c
- Uniform polar angle range: 5°-20°
- Realistic effects are implemented

Efficiency
- is quite good in ArPb collision region
- is dramatically worse abroad this region
Momentum resolution

Simulated data

Experimental data

\[ \frac{\Delta P}{P} = 7.02\% \]

<table>
<thead>
<tr>
<th>h</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>940.9</td>
</tr>
<tr>
<td>Mean</td>
<td>7.976</td>
</tr>
<tr>
<td>Sigma</td>
<td>0.561</td>
</tr>
</tbody>
</table>
Downstream Matching
Common algorithm of matching

**Step 1. Alignment:**
- Propagate each track to plane with hits
- Create track-to-hit (all-to-all) connections
- Calculate and fit residuals → $\mu_x, \mu_y, \sigma_x, \sigma_y$
- Shift all hits by $\mu_x, \mu_y$

**Step 2. Matching:**
- Propagate each track to plane with hits
- Find the nearest hit in $\pm 3\sigma_x$ and $\pm 3\sigma_y$
- Update track parameters by connected hit information:
  - Track length
  - Last position, $T_x, T_y$ at last position, Momentum
  - Covariance matrix
  - $\chi^2$
  - Number of hits, NDF
  - Velocity ($\beta$) for TOF-700
Matching Efficiency

Efficiency (CSC example):
\[
\frac{N(\text{GEM+CSC+DCH1+TOF700+DCH2})}{N(\text{GEM+DCH1+TOF700+DCH2})}
\]

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Effect of matching. Momentum Resolution

**GEM only**

\[ \frac{\Delta P}{P} = 7.02\% \]

- **h**
  - Constant: 940.9
  - Mean: 7.976
  - Sigma: 0.561

**GEM + CSC + DCH1 + DCH2**

\[ \frac{\Delta P}{P} = 6.2\% \]

- **h**
  - Constant: 666
  - Mean: 8.002
  - Sigma: 0.4963
- **Full set of detectors** has realistic geometry in ROOT-format.
- Some set of detectors has **full chain of simulations** from MC-points to realistic digits.
- All **stand-alone** data decoders moved into one unified **decoding chain**.
- **Two tracking algorithms** implemented in BmnRoot software.
- Experimental momentum resolution is **in good agreement** with MC.
- Global tracking **significantly improves** quality of track parameters estimation.