Status of CGEM offline software

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On behalf of CGEM-IT software working group

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Outline

• Introduction
• Simulation of CGEM-IT
• Track reconstruction with CGEM-IT and ODC
  – CGEM-IT cluster reconstruction
  – CGEM-IT track segment finding
  – Track matching
  – Global tracking with Hough transformation
  – Track fitting with Kalman Filter
• Release of CgemBoss
• Time schedule
• Summary
CGEM offline software
part of the BESIII Offline Software System (BOSS)
-- a data analysis framework that many tasks base on

- Calibration & alignment
  - Resolution
  - Geometry correction

- Raw data

- Simulation
  - Detector description (Geometry/material)
  - Digitization

- MC

- Reconstruction
  - Cluster reconstruction
  - Track segment finding with CGEM
  - Track matching
  - Global track finding with Hough transformation
  - Track fitting

- DST

- Physics analysis

Benchmark channels analysis (refer to the talk by Cristina Morales)
Virtual CGEM detector constructed with Geant4

1st version by Qinglei XIU & Xudong JU (2014~2015)
# Geometry updates with the final design

by Lia LAVEZZI (2016)

### GEM

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### Anode

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**Strips construction**

![X-strips](image1.jpg)

![V-strips](image2.jpg)
CGEM geometry service package and gdml file

- Unique package for CGEM geometry description/function (Simulation/reconstruction/analysis)
- Parameters changeable for a certain layout/structure (controlled by a text input file)

CgemGeomSvc
- Contains geometry/material description
- Can be used in CGEM construction
- used in Kalman Filter

by Huang Zhen (2017)
A simplified model was implemented (by Yue GUO & Liangliang WANG in 2015): projection of the track segment in the drift region onto the readout plane with a 0 Lorentz angle (non-0 angle is optional) and non-diffusion. => a model considers the geometric effects and gives a resolution reasonable in magnitude. => allows a rapid move to the subsequent software development.
A simple direct cluster-sampling module is prepared recently:

- to control the resolution/efficiency directly (e.g. to reflect the results obtained by the beam tests)
- to start the study of benchmark channels with CGEM-IT

Rough efficiency, resolution can be considered here (default 100% and 130 \( \mu \text{m} \))
A more delicate digitization model is in preparation which is needed finally to reach a detailed consistency with data.

Simulation with Geant4 → trajectory and energy loss in CGEM → Primary ionizations

Firing strips → Induction → Drift & multiplication (loop all primary ionizations)

Models for one electron can be abstracted from Garfield simulation
CGEM digitization (III) - Garfield simulation

Drift time distributions also obtained
Track Reconstruction with CGEM-IT + ODC

- CGEM cluster reconstruction
- CGEM track segment finding
- Track segments matching
- Outer-DC hits
- Tracking in outer-DC
- Global tracking with Hough transformation
- Complete tracks
  - Track fitting with Kalman Filter method

Adopted algorithm for MDC
But need optimization (Yao ZHANG, Jin ZHANG, Nannan Miao)
CGEM cluster reconstruction
by Guo Yue, Liangliang WANG & Linghui WU (2015)

1. Continuous firing strips in X (or V):
   X-cluster (or V-cluster)

2. Intersection between X and V clusters:
   XV-cluster

3. Charge centroid of a XV-cluster:

   \[
   X = \frac{\sum_{i=1}^{N_X} X_i Q_i}{\sum_{i=1}^{N_X} Q_i} \\
   V = \frac{\sum_{i=1}^{N_V} V_i Q_i}{\sum_{i=1}^{N_V} Q_i}
   \]

1 GeV/c muon

(a) RMS~217\(\mu\)m

(b) \(\sigma\sim130\(\mu\)m

\[
\delta_X = X_{\text{rec}} - X_{\text{truth}} \text{ (mm)}
\]

\[
\delta_V = V_{\text{rec}} - V_{\text{truth}} \text{ (mm)}
\]
Track segment finding in CGEM-IT

By Xinhua SUN, Liangliang WANG & Linghui WU (Sep 2015~Mar 2016)

Steps:

- Introduce two kinds of variables: $\delta \phi$ and $\delta Z$
- Study the patterns of the distributions
- Parameterization of the distributions using mu track
- Define the selection criteria for track segments
- Segment selection with the predefined criteria

An explicit method by parameterization:
find patterns for the 3 clusters from individual charged tracks
**δφ pattern and parameterization**

\[ \delta \phi_{21} = \phi_1 - \phi_2 \]
\[ \delta \phi_{23} = \phi_3 - \phi_2 \]

\[ \mu^- \text{ with } p_t = 0.05\text{~}1 \text{ GeV/c} \]

**Linear reference line**

**Fit to**

\[ c_0 + c_2(\delta L)^2 + c_4(\delta L)^4 \]

**Fit to**

\[ c_1 \delta L + c_3(\delta L)^3 \]
**δZ pattern and parameterization**

- **Fit to a linear line**
- Weak $p_t$ dependence

- **Slope is studied as a function of $p_t$**
- **Mean (consistent with 0) and resolution are studied as a function of both $\delta L_{\delta Z}$ and $p_t$**
- **A merged area covering $\pm 3\sigma$ of track segments with $p_t=0.05$~1 GeV/c**

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**Graphs:**
- **μ− with $p_t \sim 0.2$ GeV/c**
- **σ**
- **Fit to $c_0 + c_2 \cdot (\delta L)^2$**
Track segment selection in CGEM-IT

Before selection:

After selection:

Efficiency 99.1%~99.7%:
Track segment fitting

Track segment in CGEM-IT is fitted to a helix model with 5 parameters

- Least Square Method (MINUIT)
- Residual distributions of the five parameters (μ with pt~0.8GeV/c as an example)
- Results are reasonable and unbiased
Matching of the tracks between CGEM-IT and Outer-DC

\[ \chi^2_{\text{match}} = \frac{(H_{\text{CGEM-IT}} - H_{\text{ODC}})^2}{\sigma_{\text{CGEM-IT}}^2 + \sigma_{\text{ODC}}^2} \]

is calculated between track segments in CGEM-IT and Outer-DC to evaluate the consistency quantitatively.

Examples for \( \mu^\pm \) with \( p_t = 0.8 \text{ GeV/c} \)
Matching of the tracks between CGEM-IT and Outer-DC (conti.)

Proper requirements are chosen for different parameters and momenta.
Efficiency for track segment finding and matching

- Efficiency for track segment finding with CGEM-IT >99%
- Relative efficiency for track matching ~99%
- Tracking with Outer-DC needs optimization (for tracks with large polar angle and low momentum)
Tracking efficiency with Outer-DC only

- Tracking efficiency loss at large $|\cos \theta|$ with ODC only
- Reason: close to the acceptance boundary of stereo wires of ODC
- The improvement of the tracking codes with ODC only is in progress

studied by Nannan Miao, Yao Zhang
Global tracking with Hough transformation

Isabella GARZIA & Giulio MEZZADRI (started in 2015)

- Complementary tracking module: in the case of no good track (segment) candidate found in either CGEM-IT or Outer-DC
- Transformation procedure in practice tracking:
  - Circle (image space) \( X=\frac{2x}{x^2+y^2} \), \( Y=\frac{2y}{x^2+y^2} \)
  - Line (image space) \( \rho=X\cos\theta+Y\sin\theta \)
  - Point (parameter space)

- Tracking => Peak (point) finding
  - Define a matrix \((\rho, \theta)\)
  - If line passes through a cell → add one vote
  - Search for maximum values

(technique details are ignored here)
Global tracking with Hough transformation

- Combine 3 clusters in CGEM-IT and 5 hits in Outer-DC to search for the peak (track finding)

One example

Efficiency \( \sim 99\% \) for muons with \( p_t > 0.1 \text{ GeV/c} \)
Track fitting with Kalman Filter

by Yue GUO & Liangliang WANG (Sep 2014~Mar 2015), updated by Huang Zhen (2017)

- The Kalman-Filter-based track fitting package for MDC is extended to be able to process CGEM clusters and MDC hits
- New geometry and material description of CGEM implemented according to the final design recently (2017)
Releases of CgemBoss
By Linghui Wu, Yao Zhang, Liangliang Wang (2015~present)

- CgemBoss: a special BESIII Offline Software System for CGEM
- CgemBossCVS: archive the developments of CGEM related software packages
  http://docbes3.ihep.ac.cn/viewvc/cgi-bin/viewvc.cgi/BESIII/CgemBossCvs/
- Different CgemBOSS versions are released to provide the environments for the test/validation and further development
- The other updates in standard BOSS releases are traced and incorporated in CgemBOSS releases to test/keep the compatibility of CGEM packages.

see the tutorial talk by Yao Zhang in the CGEM parallel session
## schedule for 3.2 offline software

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<thead>
<tr>
<th>Module</th>
<th>Efforts (month)</th>
<th>Start</th>
<th>End</th>
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<tr>
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<td>Garfield simulation &amp; BT</td>
<td>Lia LAVEZZI, Riccardo Farinelli, L.H. Wu, N.N. Miao, L.L. Wang</td>
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Summary and plan

✓ CGEM simulation and most reconstruction modules have been developed
✓ CgemBoss are released regularly

Recently:
✓ Geometry and material description are updated according to the final design
✓ Simulation and the existing reconstruction packages are revised and integrated
✓ The performances of single mu simulation/reconstruction are reasonable
✓ ODC tracking is improved
✓ The final digitization modeling started (gain, drift properties are obtained by Garfield simulation)
✓ Progress on Global tracking with Hough transformation
✓ Benchmark channel studies have started for MDC (soon for CGEM+ODC)

Plan:
● Release soon a new CgemBoss version for the benchmark channels studies
● Finish incomplete parts
● Optimization

Thanks for your attention!