Applications of Machine Learning at BESIII

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BEijing Spectrometer experiment (BESIII) at Beijing Electron Positron Collider (BEPCII)

- 2004: start BEPCII construction
- 2009-now: data taking
- Beam energy: 1.0-2.3 GeV
- Max luminosity: $10^{33} \text{cm}^{-2} \text{s}^{-1}$ (reached in 2016)

- A $\tau$-charm factory for hadron physics and flavor physics
- ~400 members
- 14 countries
World largest $J/\psi$, $\psi(3686)$, $\psi(3773)$, $\psi(4160)$, $Y(4260)$, … produced directly from $e^+e^-$ annihilation

Drift Chamber

- $\sigma_{r\phi} = 130 \, \mu m$ (single wire)
- $\sigma_{pt}/p_t = 0.5 \% @ 1 \, GeV$
- $\sigma_{dE/dx} = 6 \%$

Time of Flight

- $\sigma_t = 90 \, ps$ (barrel)
- $\sigma_t = 120 \, ps/60 \, ps$ (end caps)

EM Calorimeter

- $\sigma_E/E < 2.5\% @ 1 \, GeV$
  (barrel)
- $\sigma_E/E < 5\% @ 1 \, GeV$ (end caps)
- $\sigma_{xy} = (6 \, mm)/E^{1/2} @ 1 \, GeV$

- Hadron form factors
- $Y(2175)$
- $Z$ states?
- QCD tests
Particle Identification at BESIII

\[ \text{Likelihood} = \text{PDF}_{dE/dx} \cdot \text{PDF}_{TOF} \cdot \text{PDF}_{EMC} \cdot \text{PDF}_{MUC} \]

\[ \text{PDF}_{dE/dx(\text{TOF})} \], calculated from \( \chi^2 \) for different hypothesis of particle types

\[ \text{PDF}_{EMC(MUC)} \], histogram PDF of a shallow NN output

Drift Chamber
Time of Flight
EM Calorimeter
SC magnet
RPC Muon chamber
A new approach for muon identification

- DNN/CNN/XGBoost: choose to use XGBoost
- All reconstructed sub-detector information are used as inputs for EMC and MUC classifier
- A classifier to combine the PID results of dE/dx, TOF, EMC and MUC
A new approach for muon identification

Data sets: full simulation of $\mu$ and $\pi$, $p \in [0.1, 1.4]$ GeV, $\cos \theta \in [-0.8, 0.8]$

Comparison between the new approach with XGBoost and the default PID seems promising.
Reweighting: to create data-like MC

- Rich structures in data of hadron spectroscopy cannot be described by generic MC
- Amplitude analysis is mandatory to extract the resonances
- Data-like MC is useful to calculate efficiency or to estimated backgrounds
Reweighting with XGBoost

A classifier to distinguish Data and MC provide probabilities $p_{RD}(x)$ and $p_{MC}(x)$[1]

$$weight \ \ factor \ \ w(x) = \frac{f_{RD}(x)}{f_{MC}(x)} \sim \frac{p_{RD}(x)}{p_{MC}(x)}$$

We utilize this approach with XGBoost algorithm

Reweighting with XGBoost: Performance

- The discrepancy of PHSP MC and data can be significantly reduced by a reweighter of a XGBoost classifier
- For comparison, the symmetrized $\chi^2$ approach with GBDT [2] is also performed
  - It seems that the results of GBDT can be slightly improved by the our implementation

<table>
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<th>Detection Efficiency</th>
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<tr>
<td>‘Data’(DIY MC)</td>
<td>$(68.42\pm0.16)%$</td>
</tr>
<tr>
<td>PHSP MC</td>
<td>$(75.71\pm0.08)%$</td>
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<tr>
<td>Reweighted MC</td>
<td>67.94%</td>
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BESIII CGEM-IT

- Inner drift chamber shows aging effects [Ming-Yi Dong et al., Chinese Phys. C40(2016)0160010]

- CGEM is efficient, radiation hard and has high resolution, low aging

- BESIII will upgrade its inner tracker with 3 layers of cylindrical triple-GEMs in 2019
Cluster reconstruction of CGEM-IT

With Q: Charge Centroid

\[ < x > = \frac{\sum_i x_i q_i}{\sum_i q_i} \]

With T: Micro TPC

[Alexopoulos et al, NIM A617 (2010) 161]

\[ x = \frac{g a p - b}{2a} \]
Cluster reconstruction of CGEM-IT

- Correction of Lorentz angle
- Combine the results of charge centroid and micro TPC according to their resolutions
- Dependency of incident angle

Defocusing

Focusing

Lorentz Angle $\approx 26^\circ$
Cluster reconstruction of CGEM-IT with ML

- Use Q and T of the fired strips to measure the initial ionizing particle position X

- A regression problem

Set up

- Simulation with a standalone digitization code, based on GARFIELD results [R.Farinelli, L.Lavezzi, etc. arXiv:1807.01210]
  - B=1T
  - Incident angle [-30 °, 30 °]
  - 1 layer of planar Triple-GEM

- XGBoost regressor
Cluster reconstruction of CGEM-IT with ML
Cluster reconstruction of CGEM-IT with ML

- The resolution of QT combined output is better than the resolution of Q or T only
- The resolution from ML is better than that of charge centroid
- The Lorentz angle can be corrected by ML
- The dependency of incident angle is properly reflected
Work in progress

• e and mu Particle identification
  • Performance measured with control samples of real data (using reweighting to avoid p and cosθ dependency)
  • Estimation of systematic uncertainty (data/MC difference)

• CGEM tracking
  • Cluster reconstruction: position and direction
  • Background suppression in track finding: track segment building with 3 layers
Conclusions

• ML techniques work fine in
  • Reweighting of multi-dimensional distributions
  • Muon particle identification
  • Cluster reconstruction of CGEM inner tracker

• The results look very promising

Thank you for your attention