Visualization for physics analysis improvement and applications in BESIII

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ONE QUESTION: HOW MANY DUCKS (DARK SECTOR)?

1. METHODOLOGIES

Modern particle physics data analyses usually rely on statistical methods with the selection criteria to screen physically interesting signal events, which is the basic data analysis method, while the visualization method, including the analysis by overcoming the limitations of only using high-level event information with the entire response of an event in the detector with highly intuitive, can help further improve the physics statistical cut-based method. However, direct application of visualization in specific physics analysis is still limited.

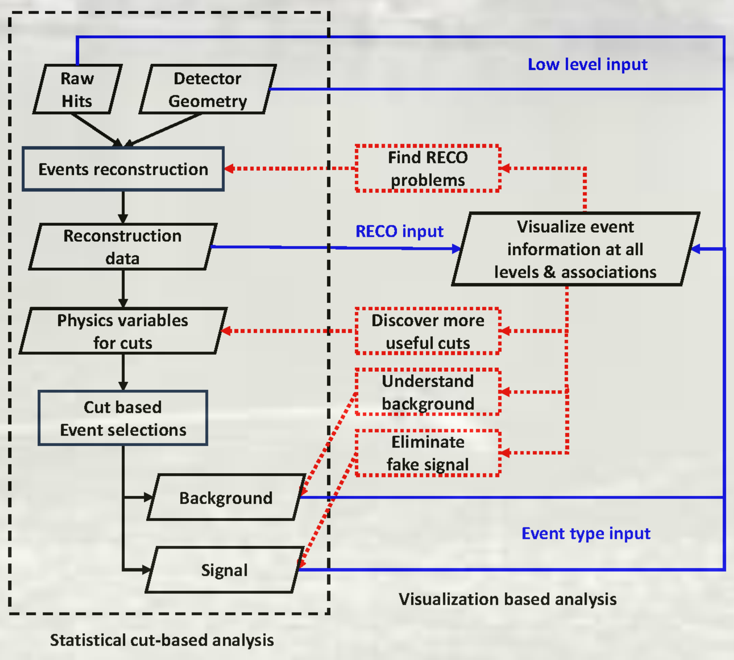

Fig.1 The supplement of visualization to the general statistical cut-based physics analysis .

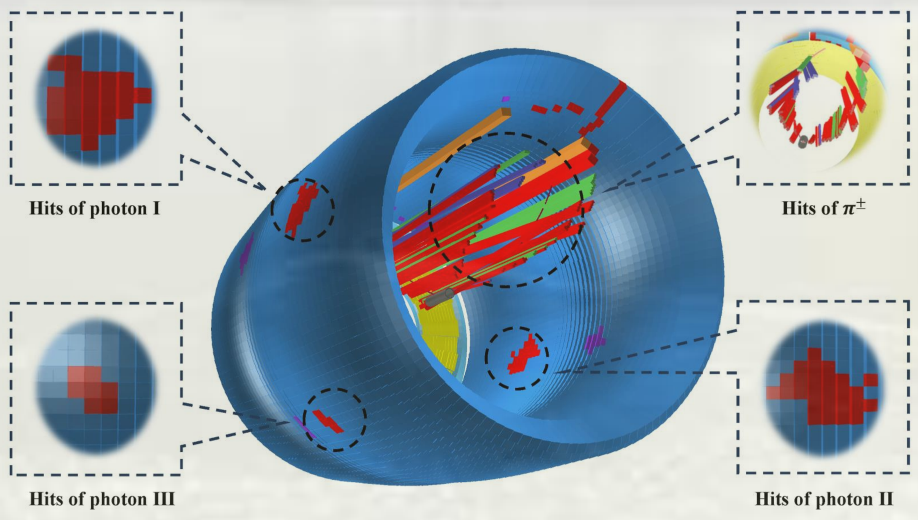

Fig.2 The visualization of $\psi(2S) \to \pi^+\pi^- J/\psi, J/\psi \to \gamma\eta_c$, $\eta_c \to \gamma\gamma$ from simulation.

2. BESIII EXPERIMENT AND BESVIS

Beijing Spectrometer III (BESIII) is a general-purpose spectrometer for τ-charm physics study. BESIII records symmetric e^+e^- collisions provided by the Beijing Electron Positron Collider II (BEPCII) storage ring and has collected large data samples from 2.0 to 4.7 GeV. BesVis is a visualization software in the BESIII experiment, which is developed with ROOT in the BESIII Offline Software.

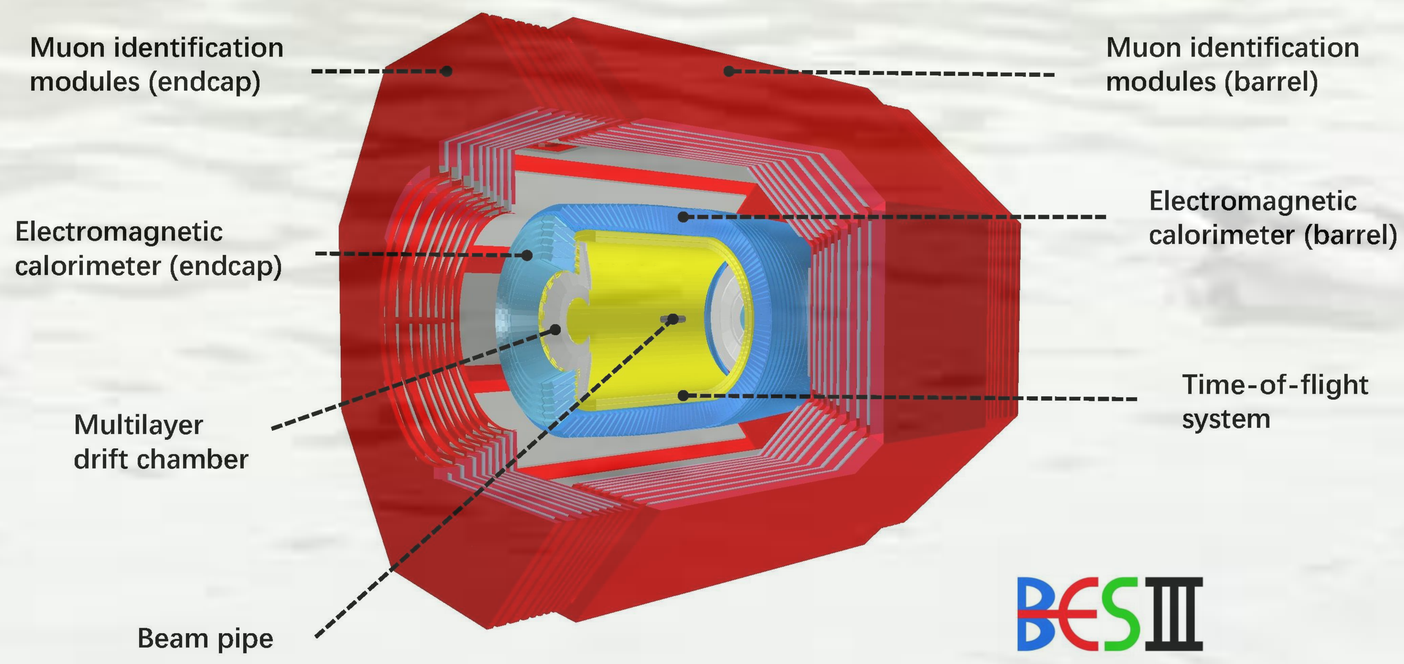

Fig.3 The visualization for the BESIII detector.

3. OBSERVATION OF THE DARK MATTER?

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We search for the dark matter with $\Lambda \to \xi\phi$, where Λ is tagged from $J/\psi \to \Lambda\bar{\Lambda}, \bar{\Lambda} \to \bar{p}\pi^+$ and the invisible signal is identified by "no signal" in the subdetector EMC. In the early study, a significant "dark matter" signal is observed with no hits found in the statistical cut-based method, but the visualization clearly show the additional EMC hits and the lack of TOF hits. Fake signal comes from the hidden selection issue and the "dark matter" disappear when requiring the TOF hits of the charged track. The visualization helps to eliminate the fake signal.

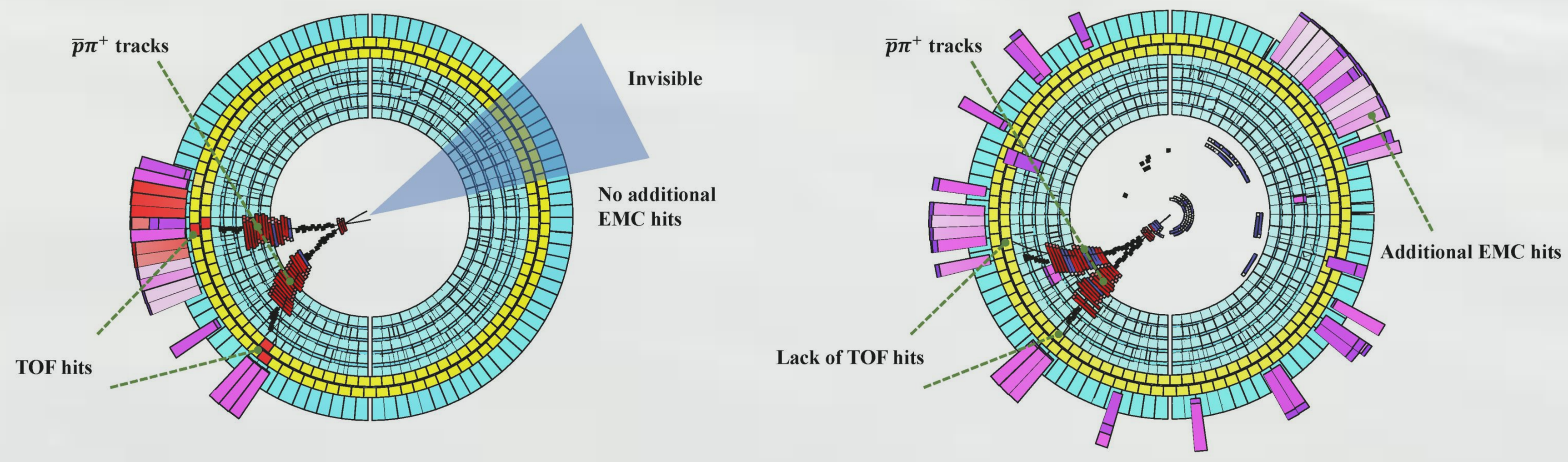

Fig.4 (Left) The signal simulation for $J/\psi \to \Lambda\bar{\Lambda}, \bar{\Lambda} \to \bar{p}\pi^+, \Lambda \to$ invisible. (Right) A dark matter candidate from $\Lambda \to$ invisible in the early physics analysis. The additional EMC hits indicate that this event is a false signal, and the lack of TOF hits implies the reason for the fake signal.

4. NEW EFFECTIVE COUPLINGS IN BSM?

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We search for the charmonium weak decay $J/\psi \to D^-\mu^+\nu_\mu + c.c.$ (rare decay in the SM, $\mathcal{B}\sim10^{-11}$, sensitive to the effective couplings in BSM), where the short-lifetime meson D^- is reconstructed with $D^- \to K^+\pi^-\pi^-$. The reconstructed final states includes four charged tracks along with a neutrino carrying missing information, and the variable $U_{miss} = E_{miss} - |\vec{P}_{miss}| \cdot c$ is used to characterize the signal. For the signal process, U_{miss} follows a Gaussian-like distribution centered 0. Based on the traditional statistical cut-based analysis, a clear peak was found in the U_{miss} spectrum near 0 while one of the charged tracks in the peaking background is not produced in the collision vertex studied by the visualization, which is actually from $J/\psi \to K^+K^-\pi^+\pi^-, K^+ \to \mu^+\nu_\mu$. The visualization helps to study the background and then remove it.

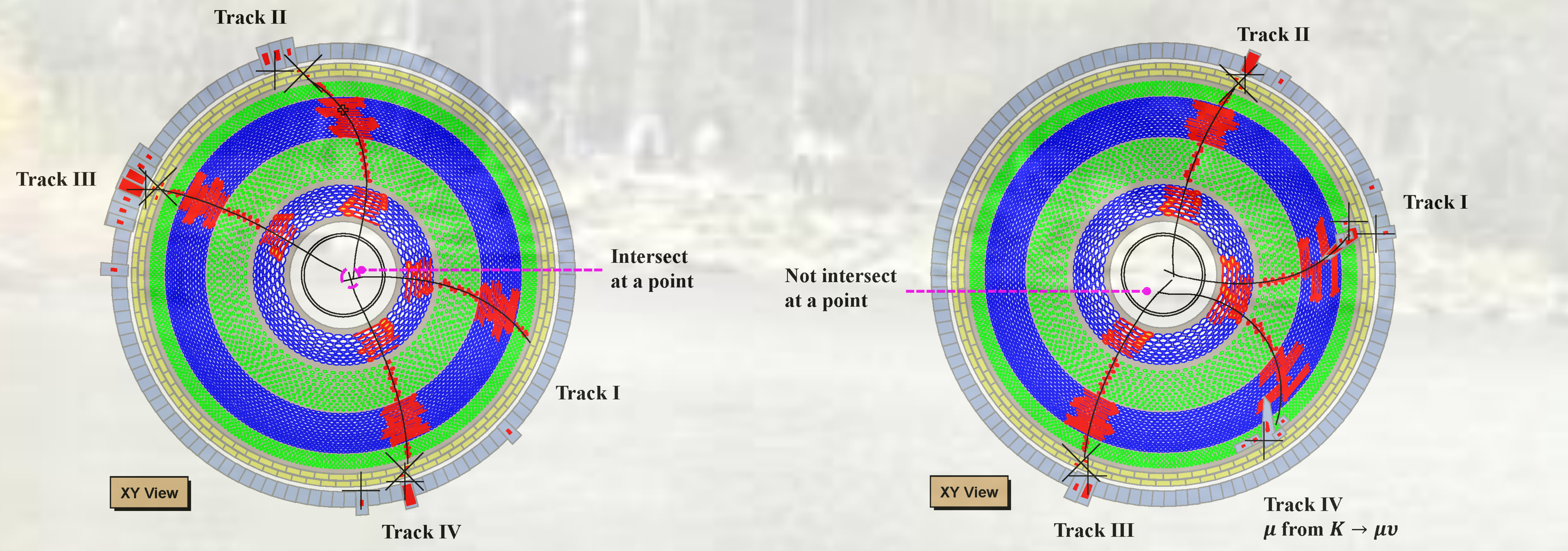

Fig.5 (Left) The signal simulation for $J/\psi \to D^-\mu^+\nu_\mu, D^- \to K^+\pi^-\pi^-$. (Right) The peaking background in the early analysis of $J/\psi \to K^+K^-\pi^+\pi^-, K^+ \to \mu^+\nu_\mu$, where the four charged tracks cannot intersect at a single point, indicating one of the particle is generated from a long-lifetime particle.

5. PHYSICS DOESN'T EXIST ANYMORE? -- from 《THREE-BODY》

The flavor violation of neutral leptons has been observed, while the charged lepton flavor violation (CLFV) is heavily suppressed in the SM. We search for CLFV process of $\psi(2S) \to e\mu$ based on the distinct characteristics of electrons and muons. For instance electrons tend to deposit a majority of their energy in EMC, while muons only deposit a small fraction of their energy. After the traditional statistical cut-based analysis, some remaining background flying to the gaps of EMC are highlighted with the visualization, where the real electrons only deposit a small fraction of their energy in EMC due to the gap, hit MUC and then are misidentified as muons. The visualization helps to discover more useful cuts to suppress the background.

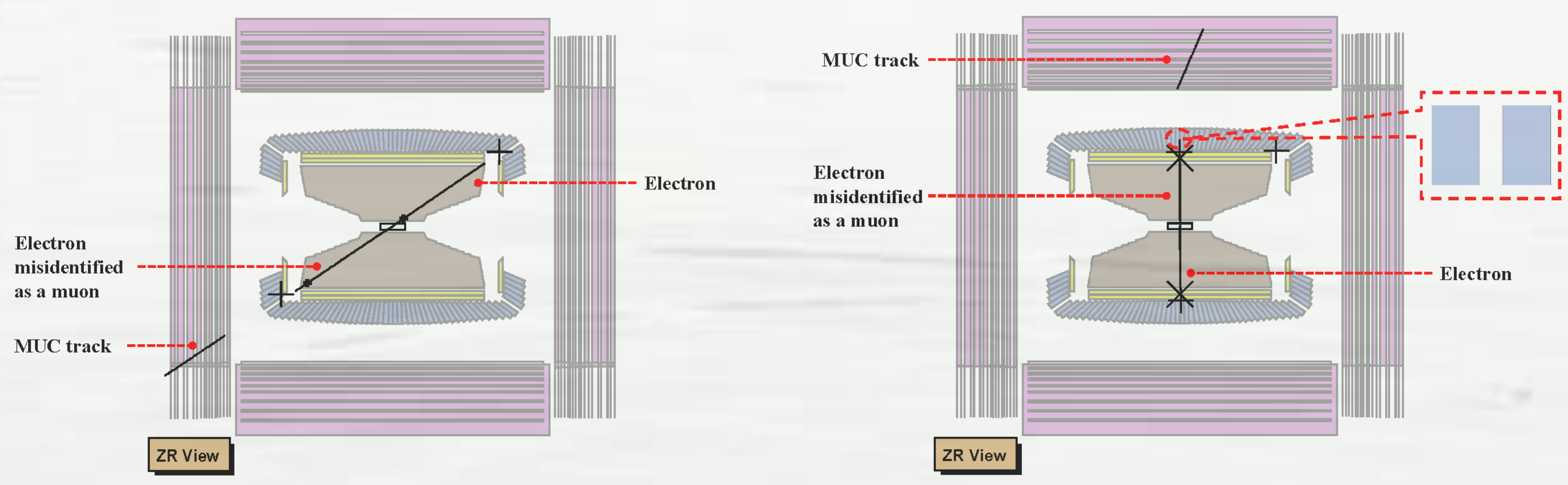

Fig.6 (Left) The background events flying to the direction of $cos\theta$~0.85. (Right) The background events flying to the the direction of $cos\theta$~0. In these two directions, there are gaps between EMC crystals, the electrons will traverse the gap and deposit only a small fraction of its energy in EMC.

6. WHAT'S THE LIMIT OF OUR DETECTOR?

The $\bar{\Lambda}_c^- \to \bar{n}l^-\bar{\nu}_l$ is a single Cabibbo-suppressed process, which branching fraction is much lower than the Cabibbo-flavor process $\bar{\Lambda}_c^- \to \bar{\Lambda}l^-\bar{\nu}_l$. Studying $\bar{\Lambda}_c^- \to \bar{n}l^-\bar{\nu}_l$ in BESIII presents significant challenges as BESIII lacks a dedicated hadron calorimeter, and detection of neutrons primarily relies on EMC. One key difficulty lies in distinguishing the $\bar{n}$ from the neutral $\bar{\Lambda} \to \bar{n}\pi^0$. The ability of EMC to identify the additional π^0 from the anti-neutron background will determine the feasibility of this analysis in BESIII, which could be checked by the visualization. The visualization method helps to showcase the potential limit of the detector.

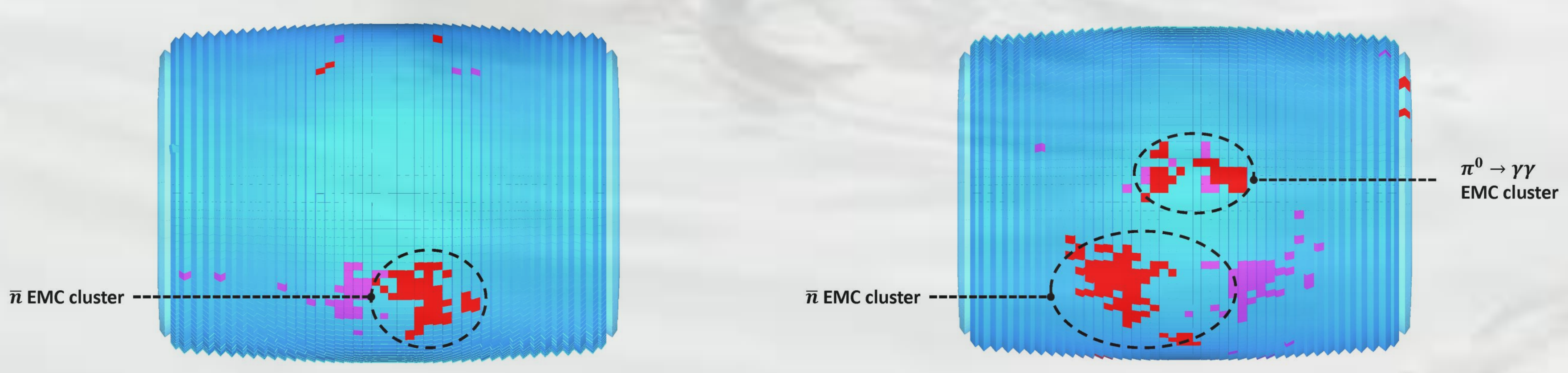

Fig.7 (Left) The signal simulation for $\bar{n}$ of $\bar{\Lambda}_c^- \to \bar{n}l^-\bar{\nu}_l$. (Right) The background simulation of $\bar{\Lambda} \to \bar{n}\pi^0$ of $\bar{\Lambda}_c^- \to \bar{\Lambda}l^-\bar{\nu}_l$. The large red hits in the lower half of the EMC are associated with anti-neutron, while the two smaller red hits in the upper half of the EMC in right plot come from $\pi^0 \to \gamma\gamma$ decay.

7. SUMMARY

Visualization can play a unique role in modern particle physics data analysis. In this poster, we introduce the potential value of visualization method for improvement of physics analysis. The applications of event display in several BESIII physics analyses have demonstrated its versatility and complementarity to the traditional statistical analysis method. It is recommended that the visualization method be generally taken in physics analysis, especially in search for rare physics signals in the current operational experiments and design of the next generation particle physics experiments. FINAL QUESTION: HOW MANY DUCKS?

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