Method of visualization based physics analysis and applications in BESIII

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2023.6.11

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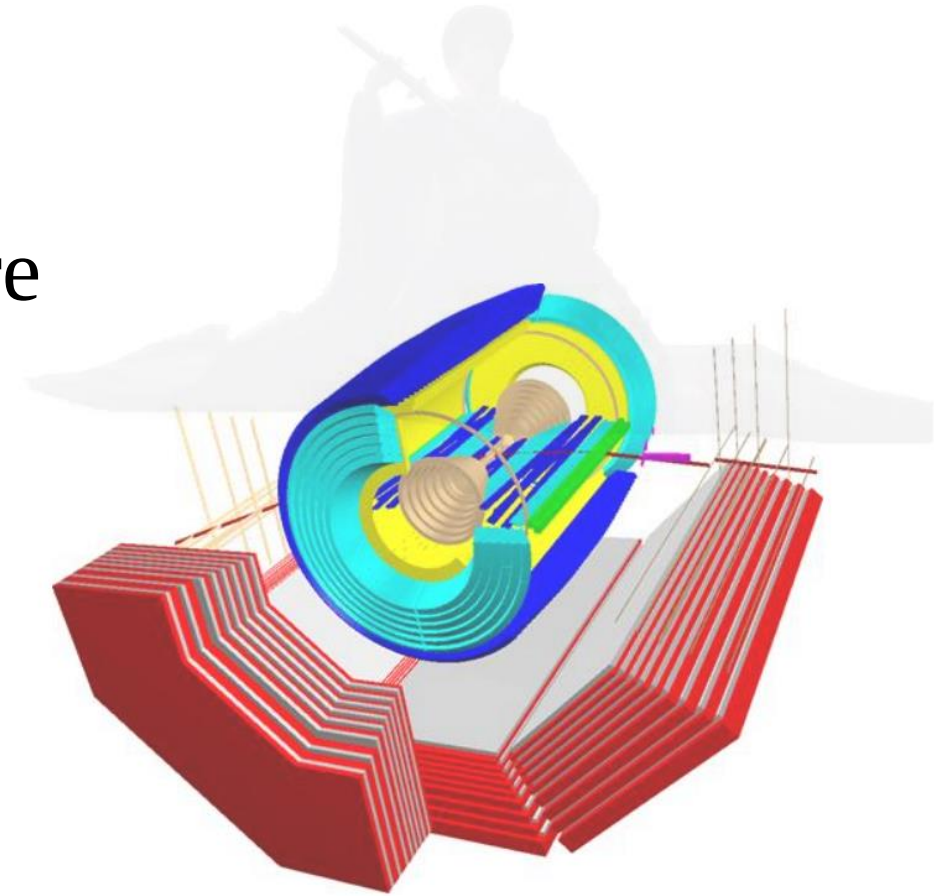
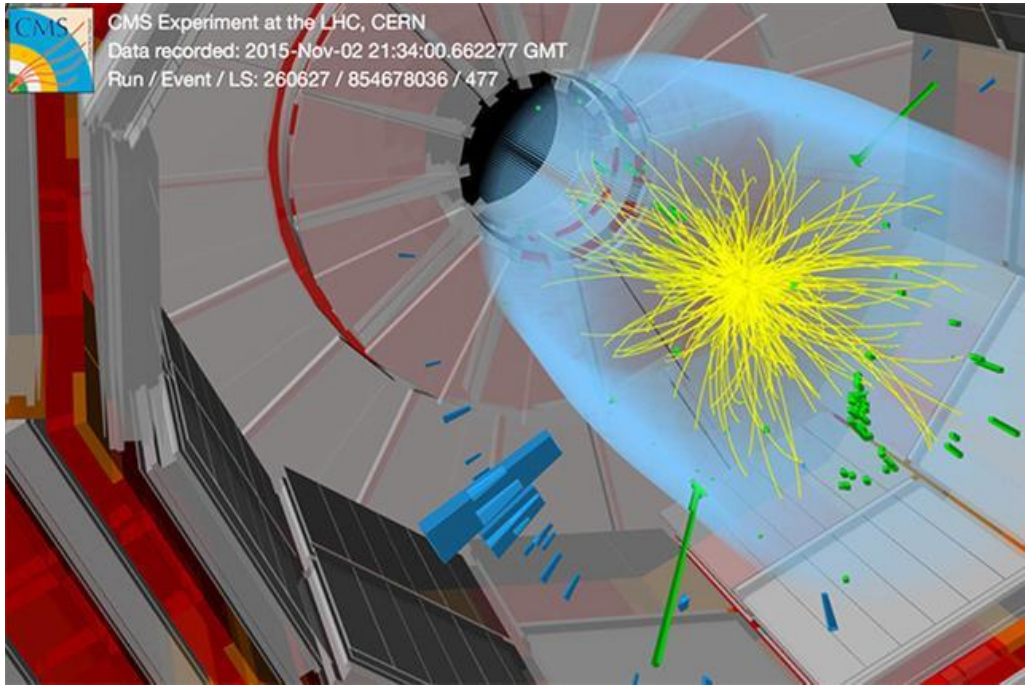
中山大學 SUN YAT-SEN UNIVERSITY

Outline

- **Introduction**
- BESIII visualization software
- Application in analysis
- Summary



Introduction

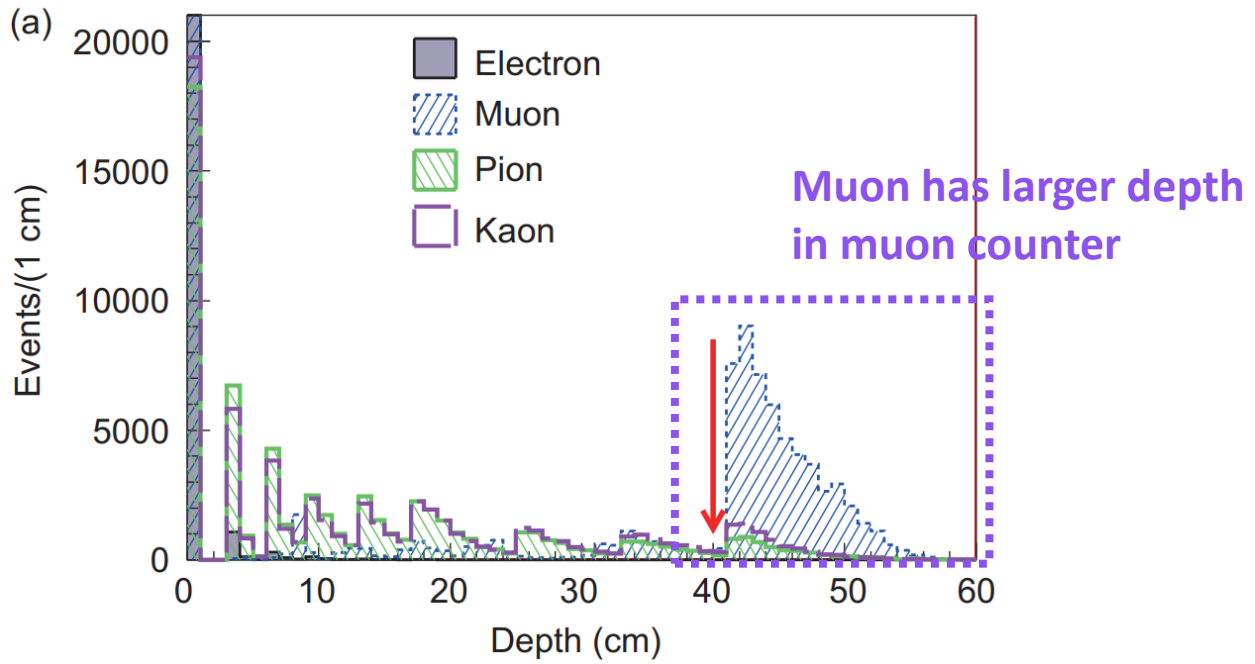


- ☐ Cloud chamber / bubble chamber
  - ✓ Good visual intuitiveness
  - ✓ Limited detection precision

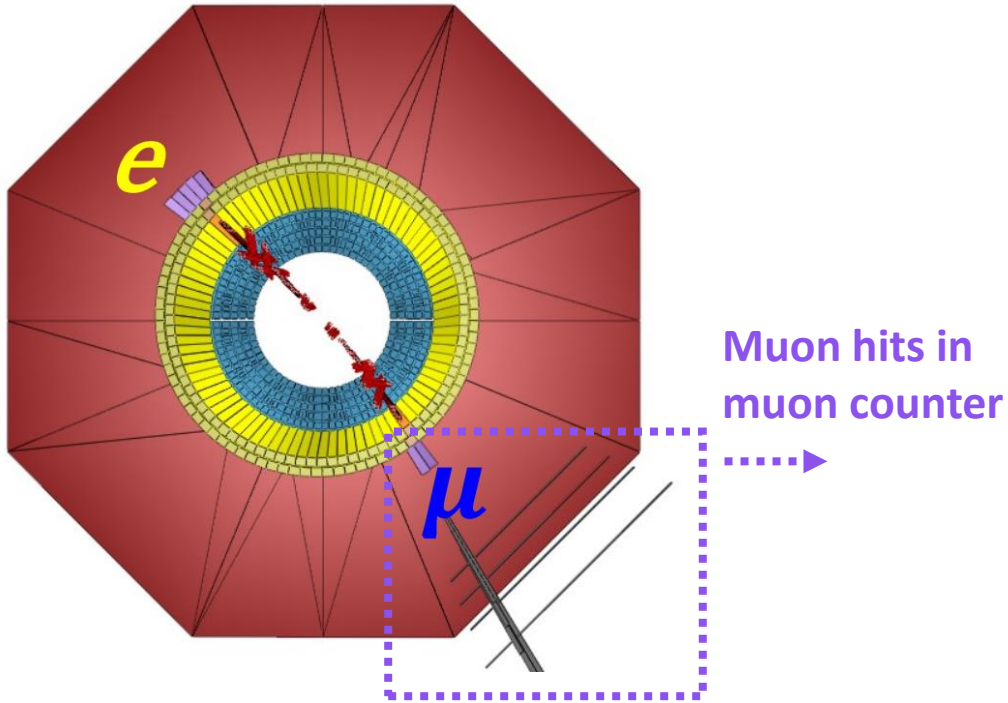
- ☐ Large-scale composite detector
  - ✓ High precision but poor visual intuitiveness
  - ☐ Visualization for analysis ⟹ also good visual intuitiveness

Introduction

Sci. China-Phys. Mech. Astron. 66, 221011 (2023)



Muon has larger depth in muon counter



Muon hits in muon counter

- ☐ Traditional cut based analysis
  - ✓ Multi-event analysis with high statistics
  - ✓ **Set cuts ⟹ reduce background ⟹ extract signals ⟹ analysis**

- ☐ Event display based analysis
  - ✓ Single-event analysis
  - ✓ **Display with good visual intuitiveness**
  - ✓ **But only with good visual intuitiveness?**
  - ✓ **Can help any more in physics analysis?**

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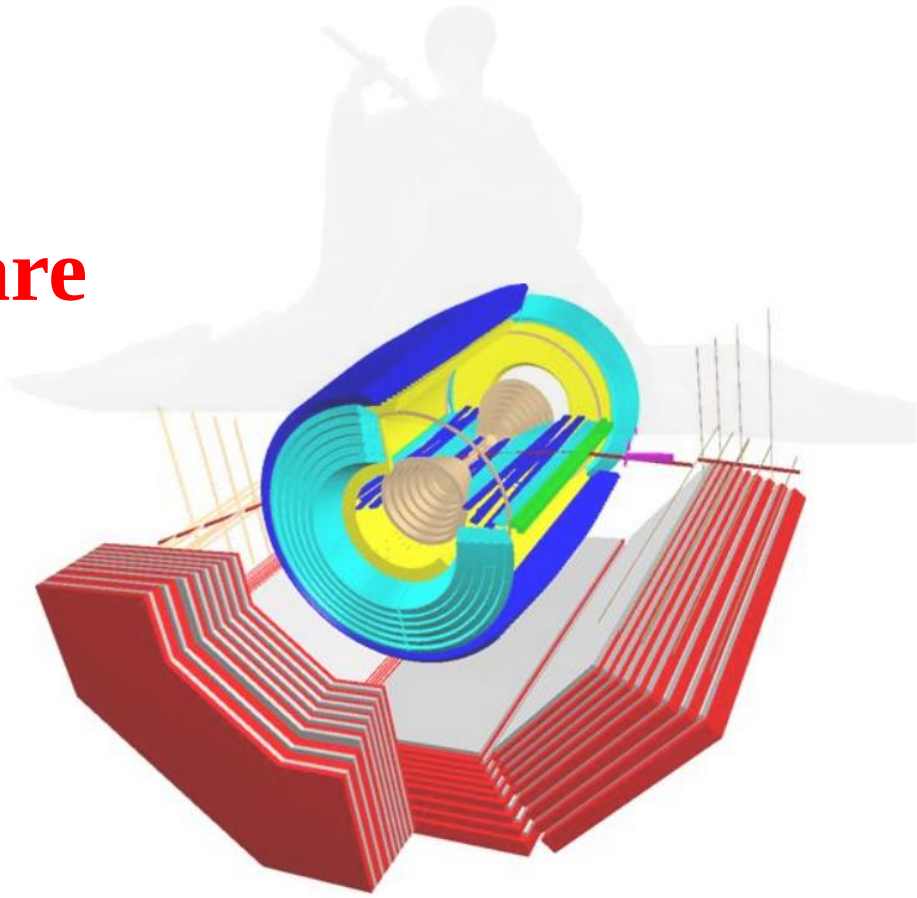
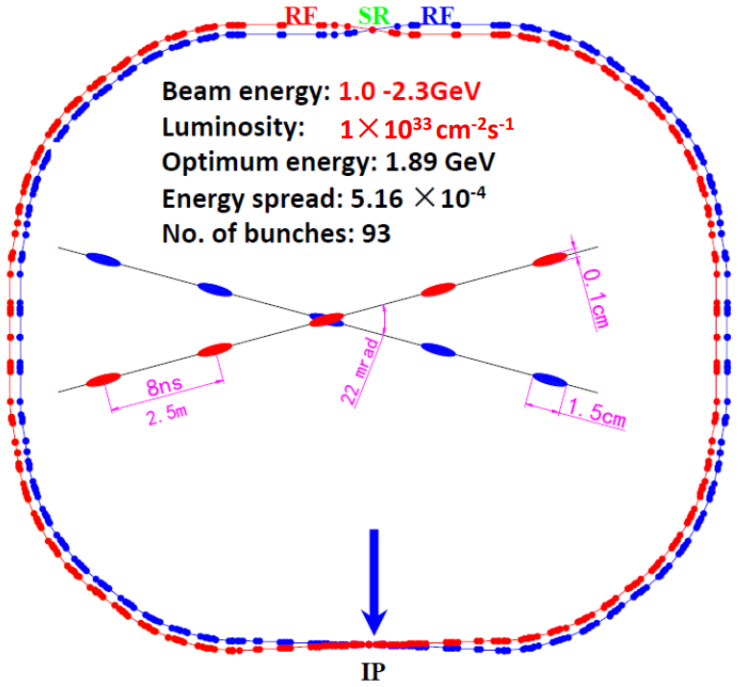
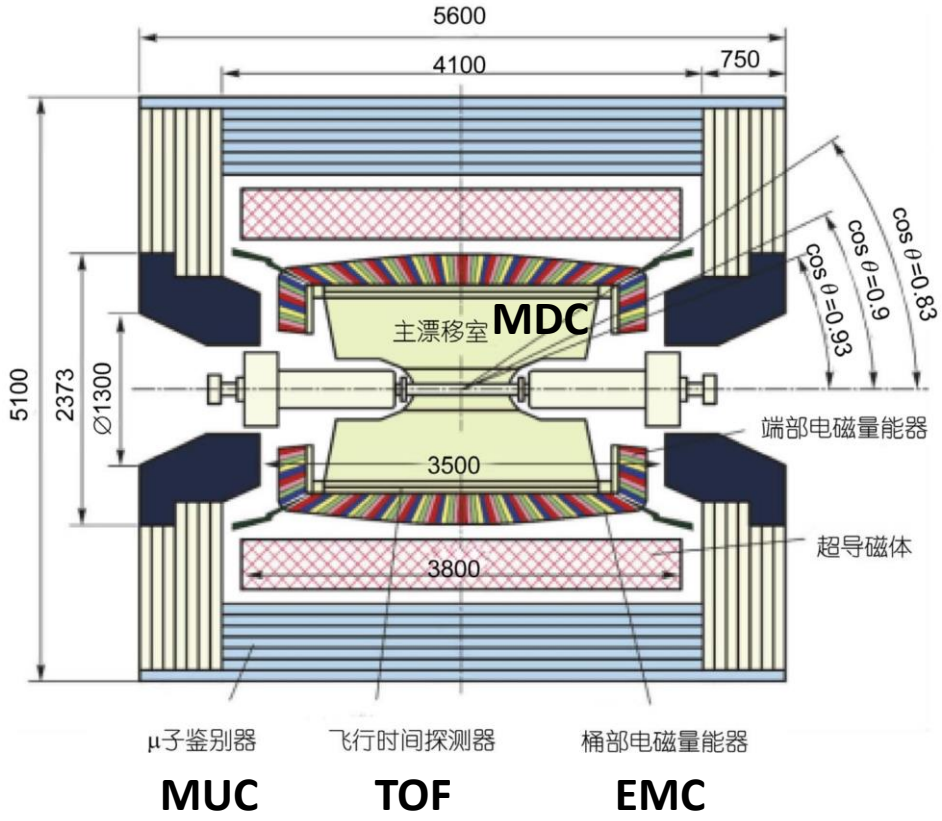


BEPCII and BESIII



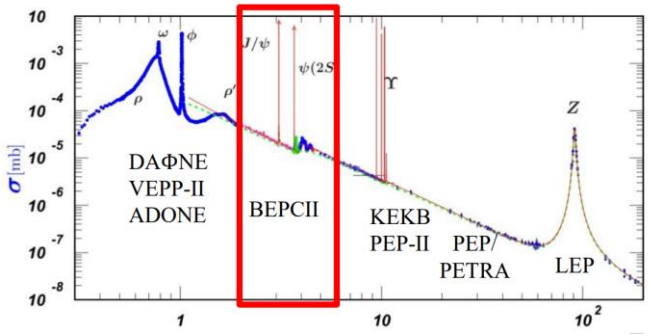


✓ **Beijing Electron Positron Collider II**

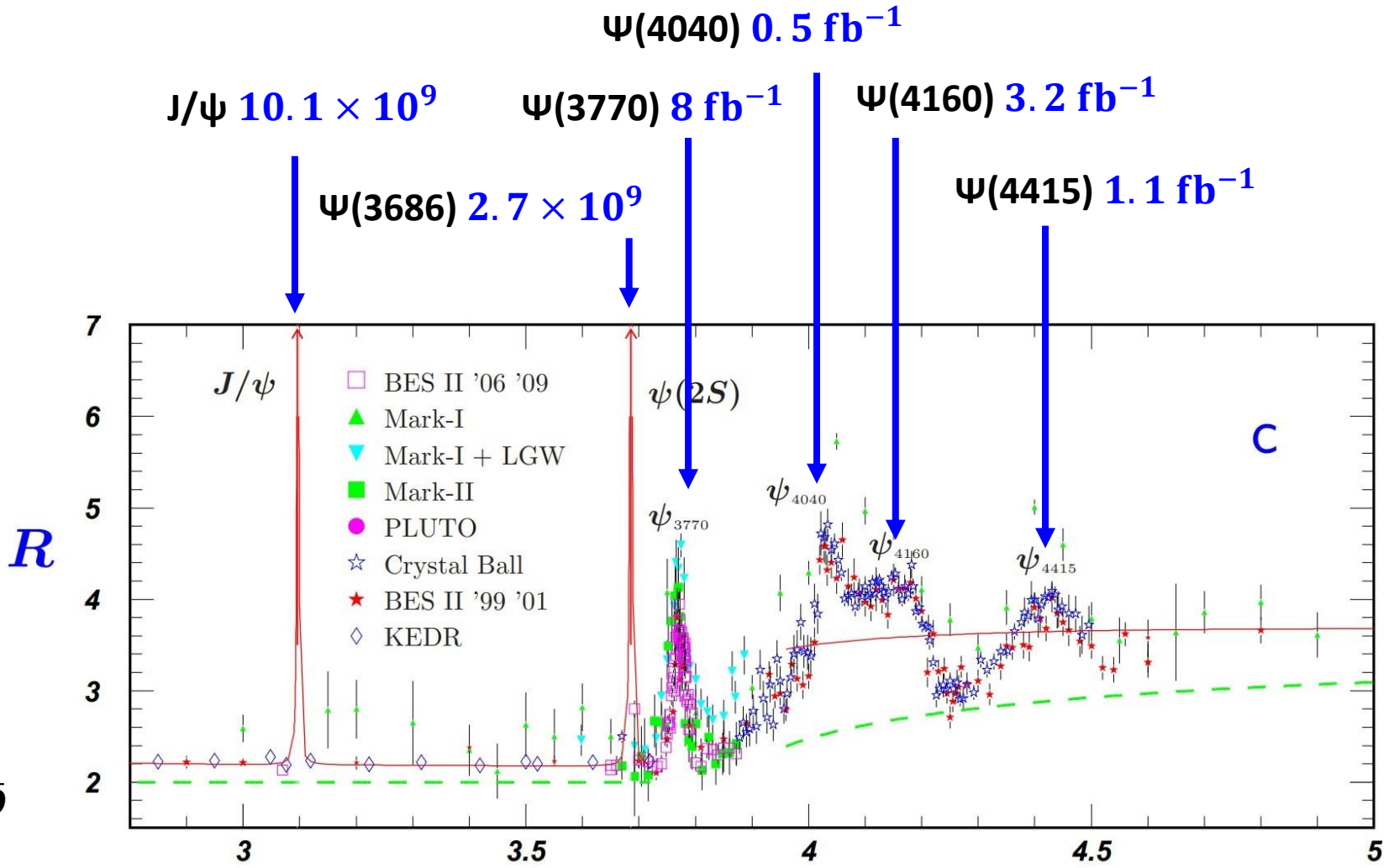
✓ **BE**ijing **S**pectrometers **III**

✓ **Visualization for detector**

Data samples at BESIII

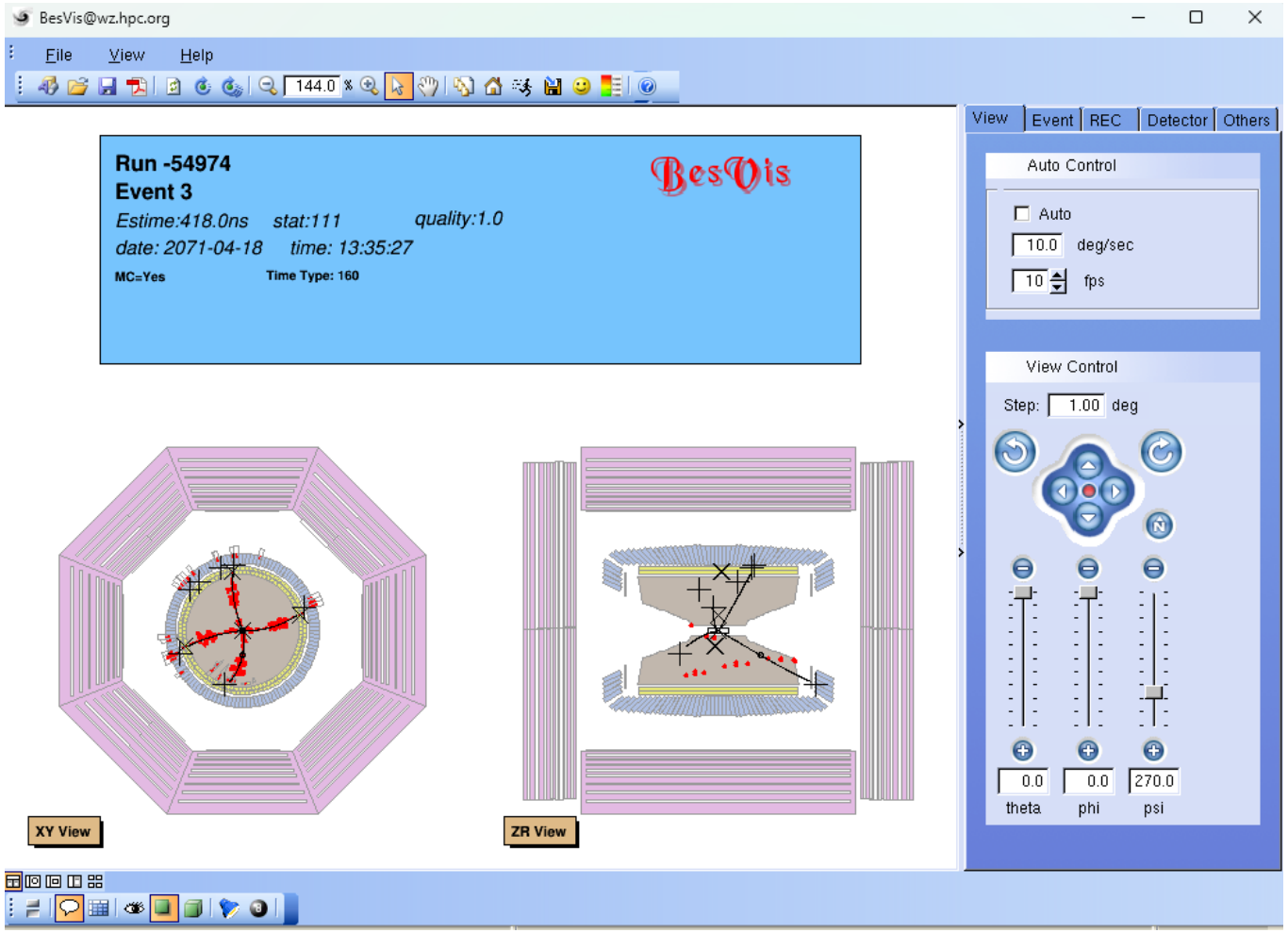


- ✓ BESIII have collected the largest charmonium data samples on threshold
- ✓ > 20 fb^{-1} data above 4.0 GeV in total
- ✓ **20 fb^{-1} Ψ(3770) will be coming in 2024, large D meson sample from $\psi \to D\bar{D}$**



✓ **Visualization for events**

BesVis

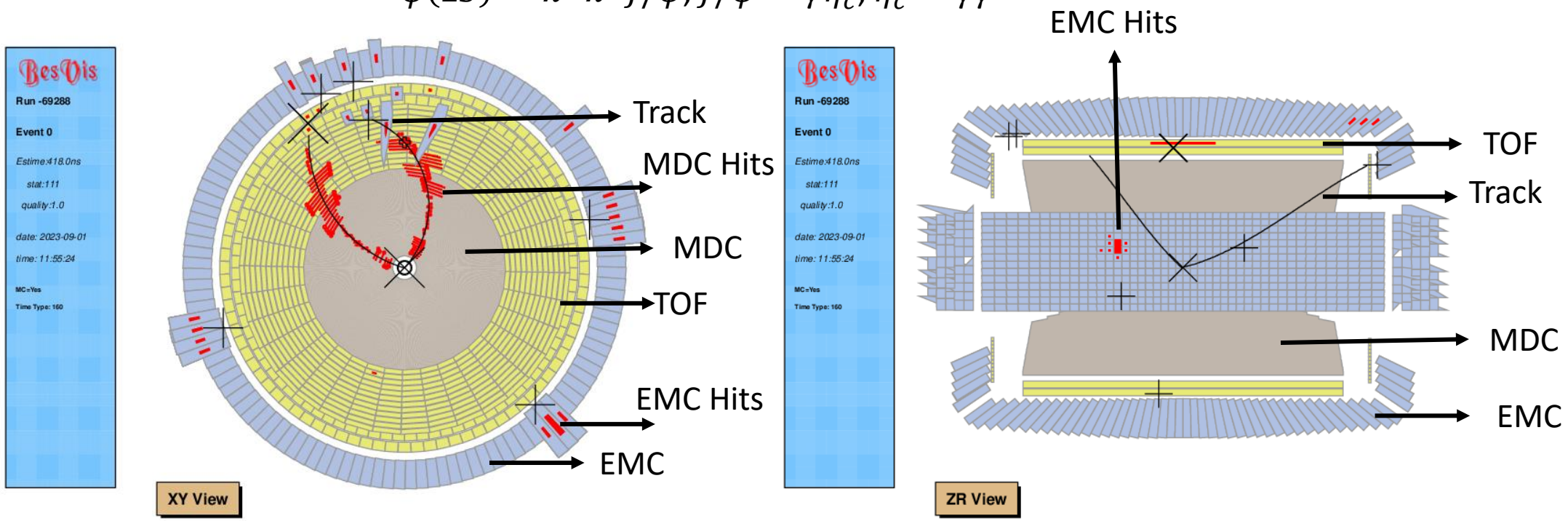


✓ Graphical interface of Event Display of BesVis

- **BESIII Visualization software**
- ✓ Developed with ROOT
- ✓ Geometry description: **G**eometry **D**escription **M**arkup **L**anguage (GDML) (same as simulation and reconstruction)
- ✓ Reads GDML files and generates ROOT geometry
- ✓ Graphical interface: base on ROOT GUI

2D visualization of BesVis

$$\psi(2S) \to \pi^+\pi^- J/\psi, J/\psi \to \gamma\eta_c, \eta_c \to \gamma\gamma$$

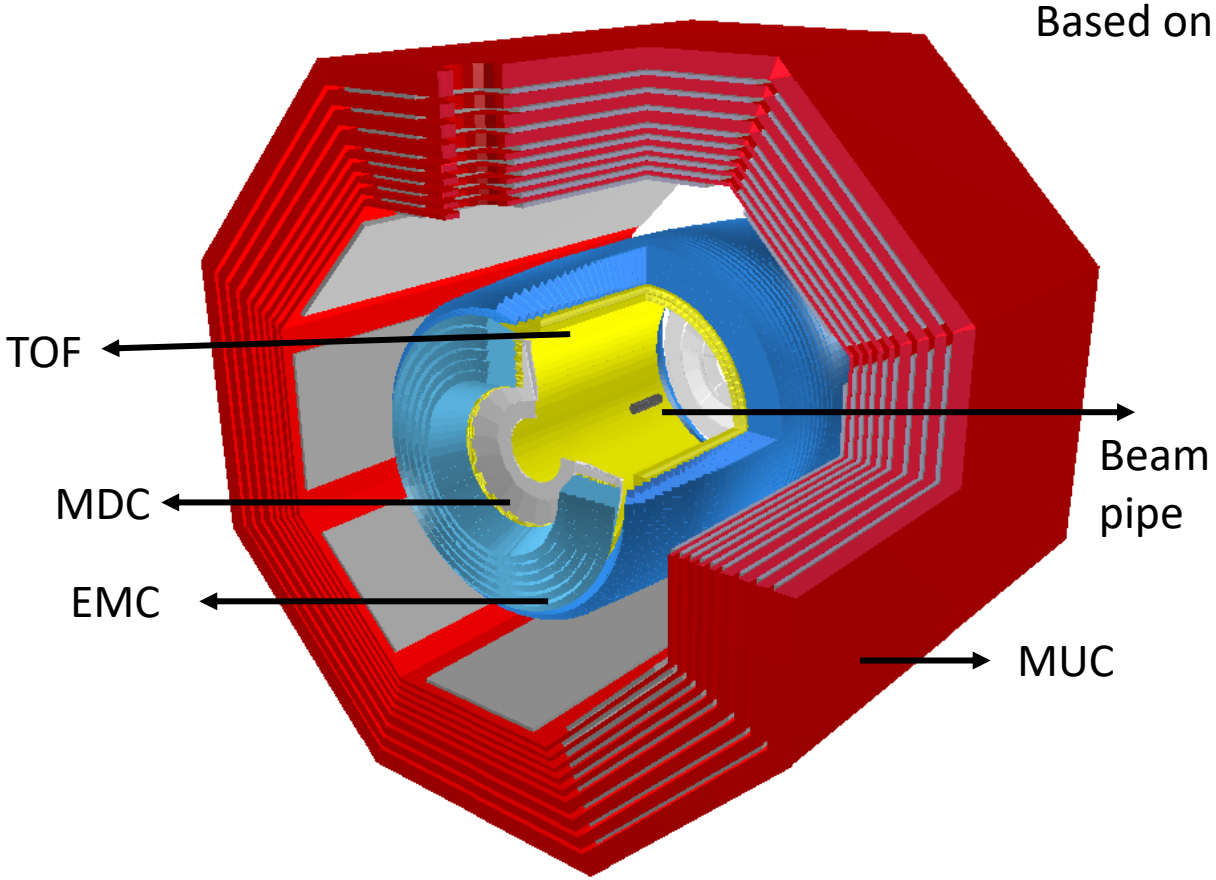


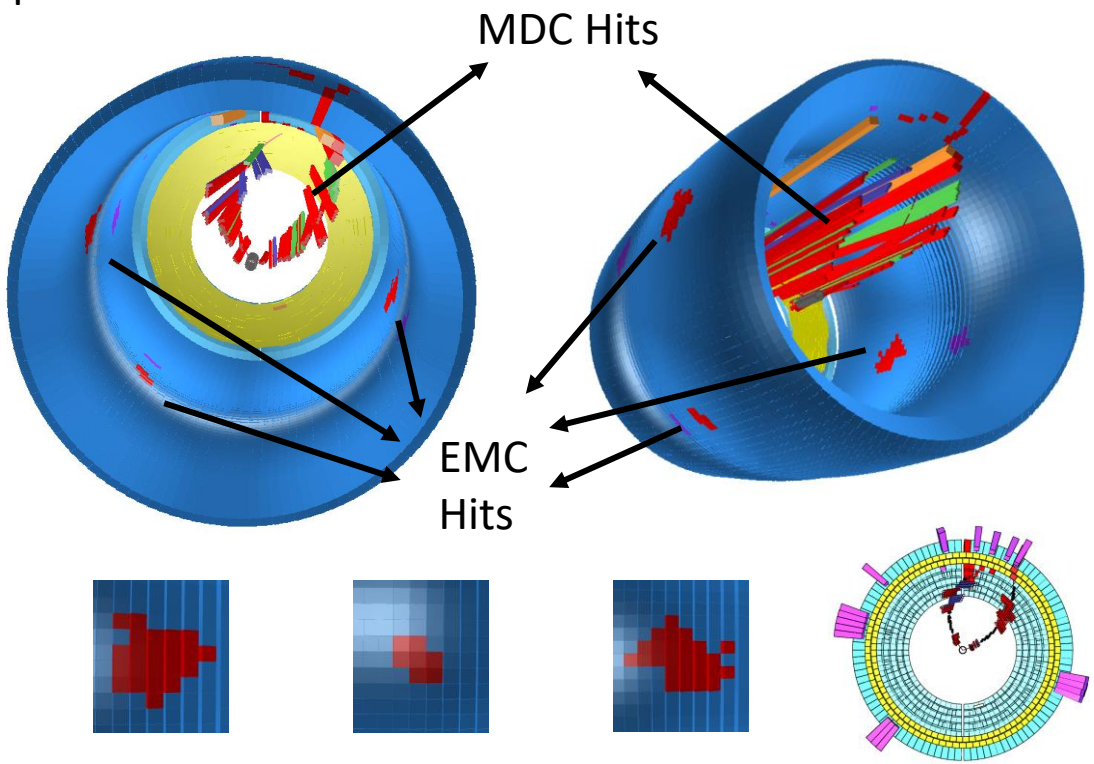
- ✓ **The 2D display is achieved by projection of geometry onto the XY (pipe) plane or ZR (vertical section) plane.**

3D visualization of BesVis

$\psi(2S) \to \pi^+\pi^- J/\psi, J/\psi \to \gamma\eta_c, \eta_c \to \gamma\gamma$

Based on OpenGL





✓ **3D Visualization for detector**

✓ **3D Visualization for events**

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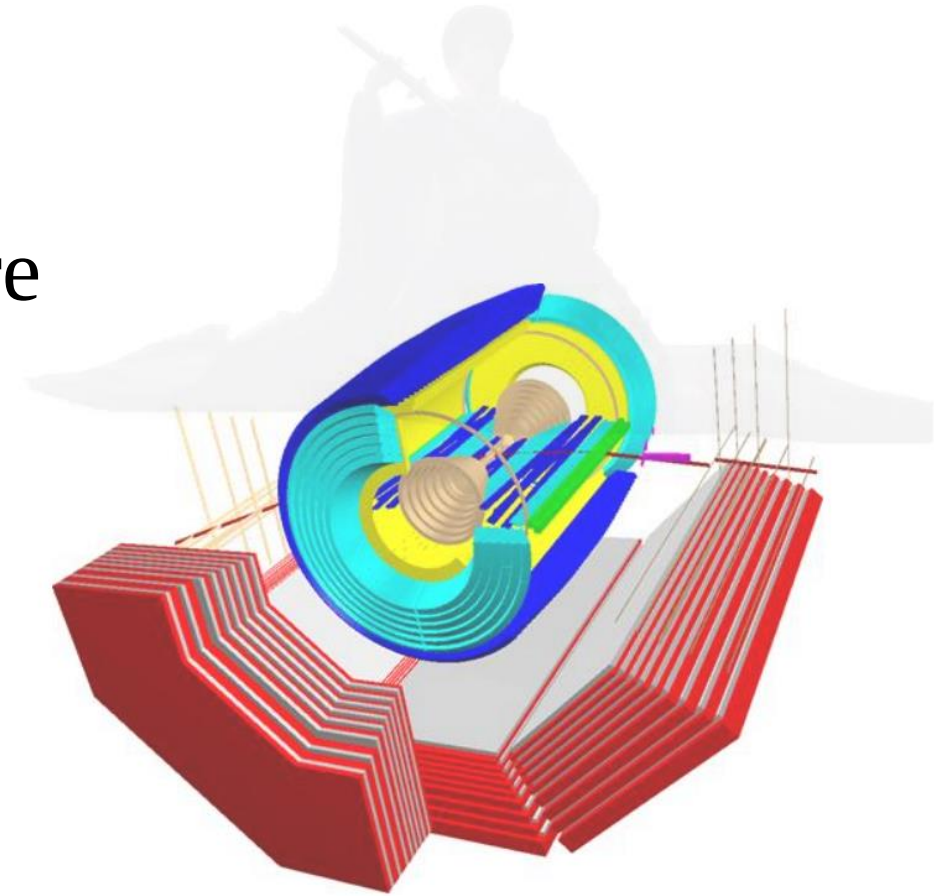

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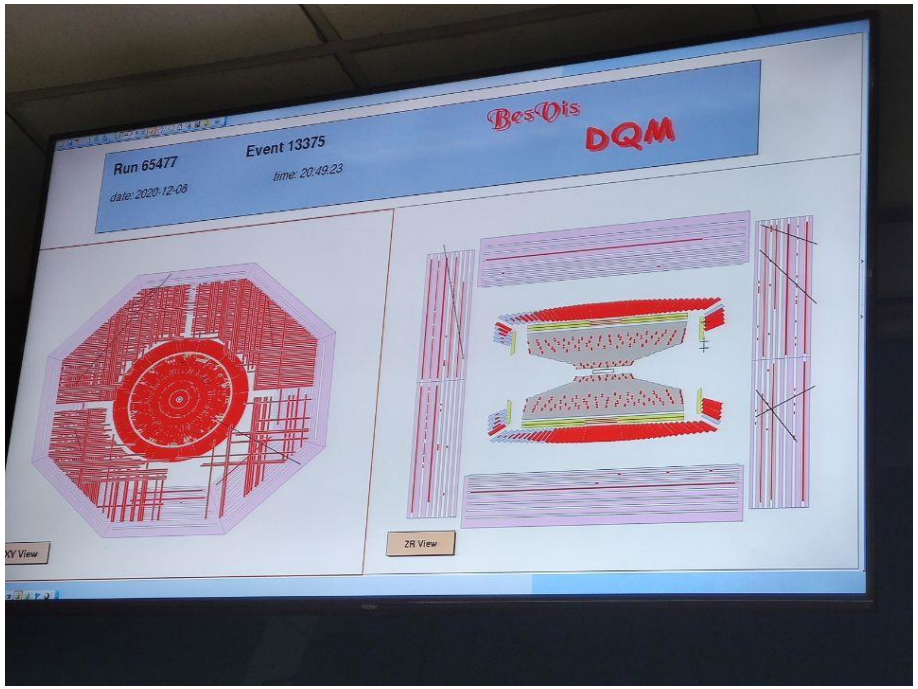
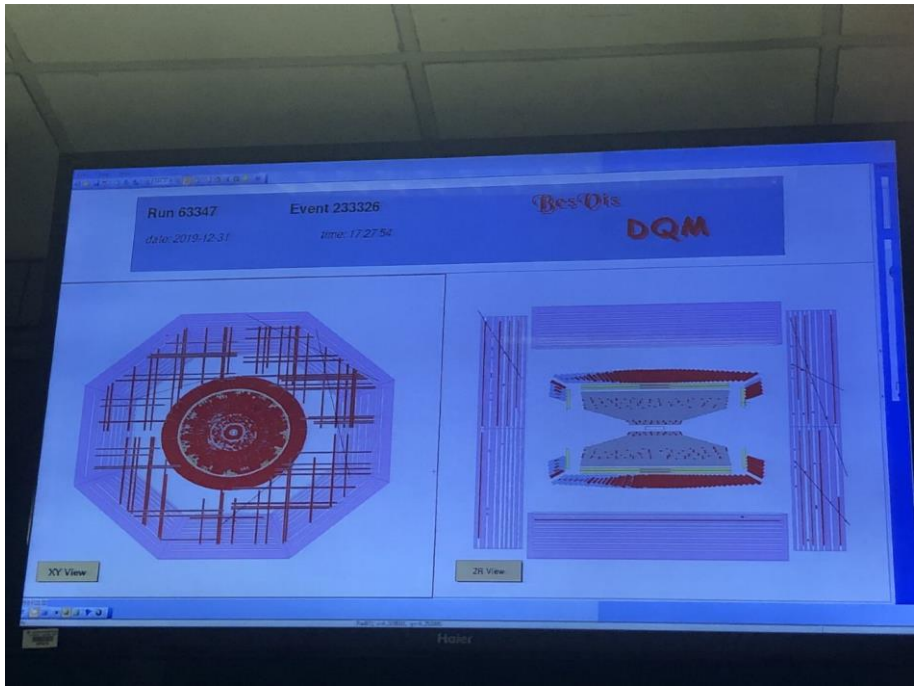
DQM

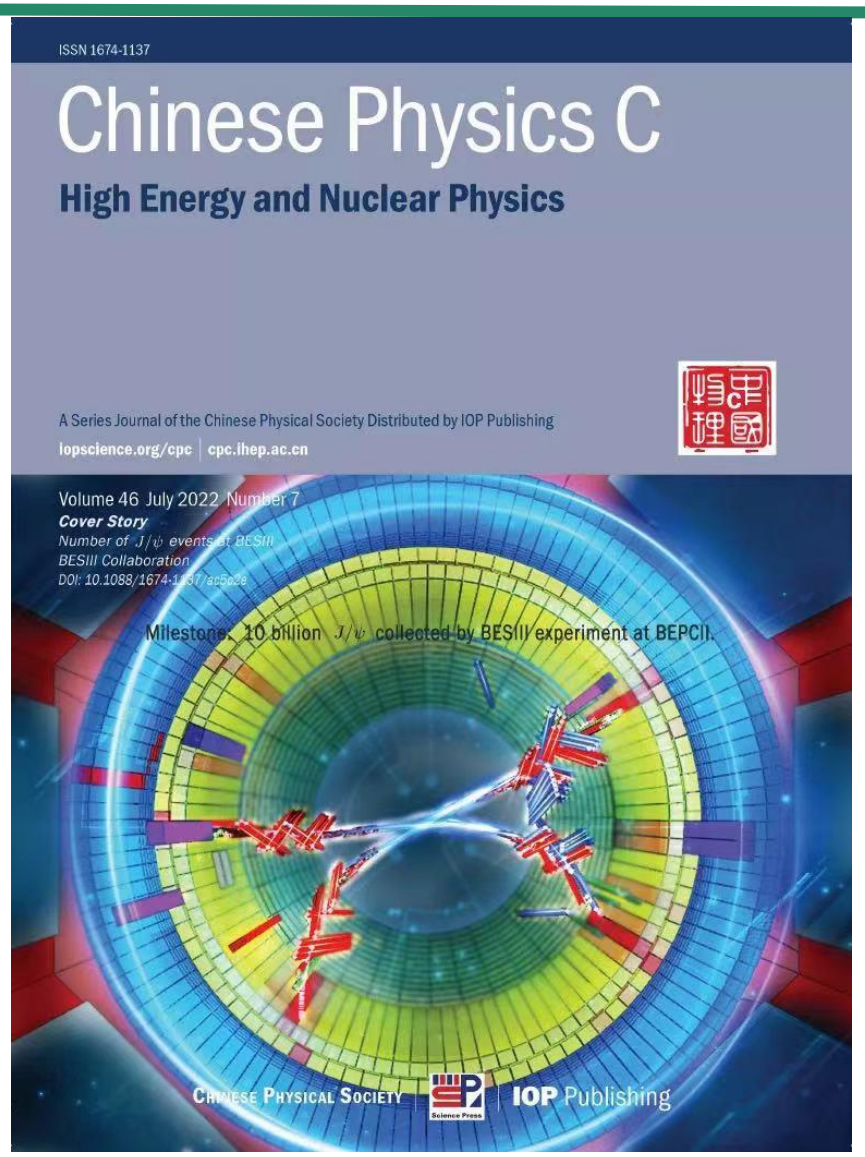
Wrong data quality



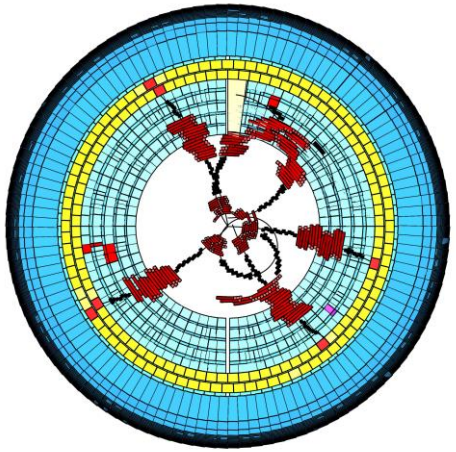


- **D**ata **Q**uality **M**onitoring (DQM)
  - ✓ Online monitoring of experimental status
  - ✓ plays an important role for DQM

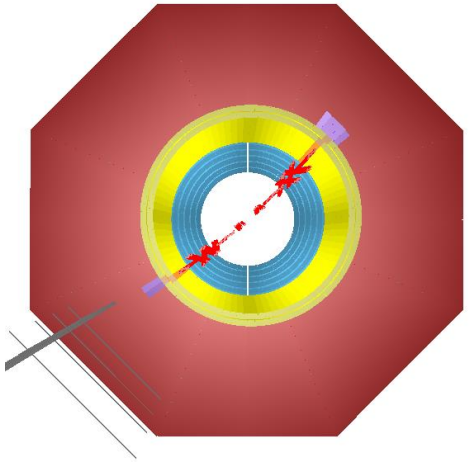
Journal cover



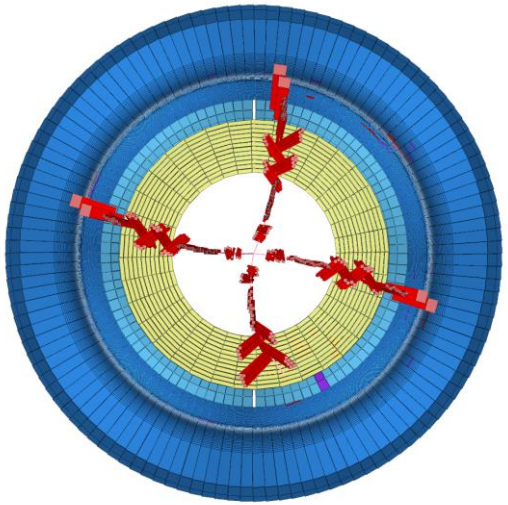
Schematic diagram for outreach or article



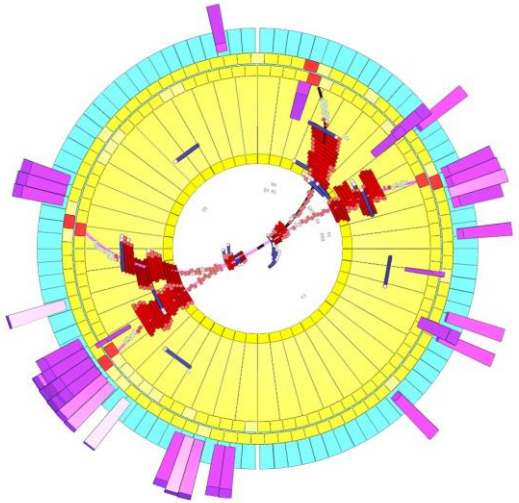
✓ $\Lambda_c^+ \to \Lambda\pi^+\pi^-e^+\upsilon_e$



✓ $J/\psi \to e^+\mu^-$



✓ $J/\psi \to D^-\mu^+\nu_\mu$



✓ $J/\psi \to \gamma\eta_c \to \gamma\Lambda\bar{\Lambda}$

Application in physics analysis

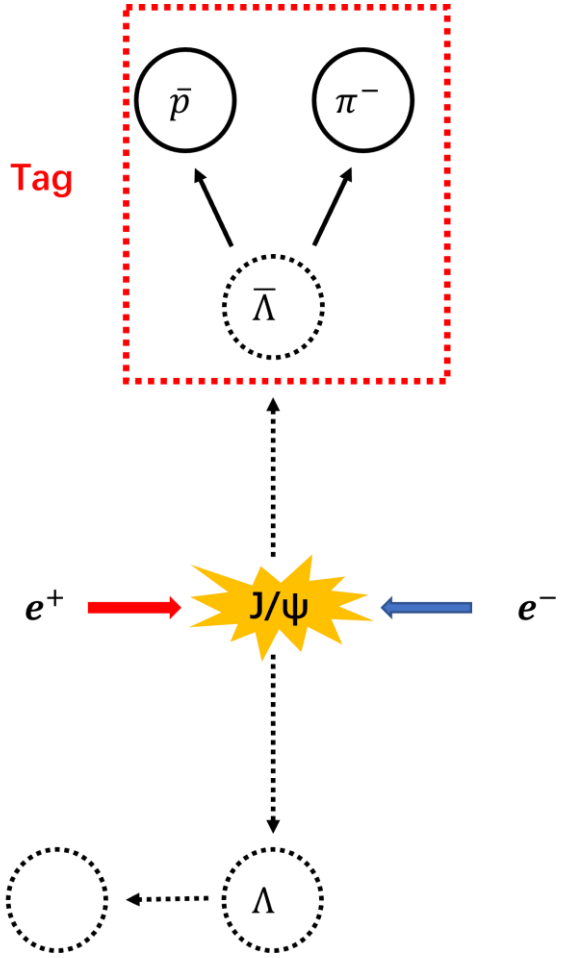
- Invisible decay of Λ
- Rare weak decay $J/\psi \to D^- \mu^+ \nu_\mu$
- CLFV decay $\psi(2S) \to e^+ \mu^-$
- Semi-leptonic decay $\Lambda_c^+ \to n e^+ \nu_e$

Application in physics analysis

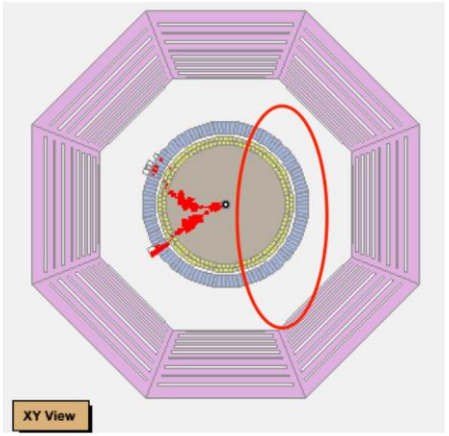
- **Invisible decay of Λ**
- **Rare weak decay $J/\psi \to D^- \mu^+ \nu_\mu$**
- **CLFV decay $\psi(2S) \to e^+ \mu^-$**
- **Semi-leptonic decay $\Lambda_c^+ \to n e^+ \nu_e$**

Invisible decay of Λ

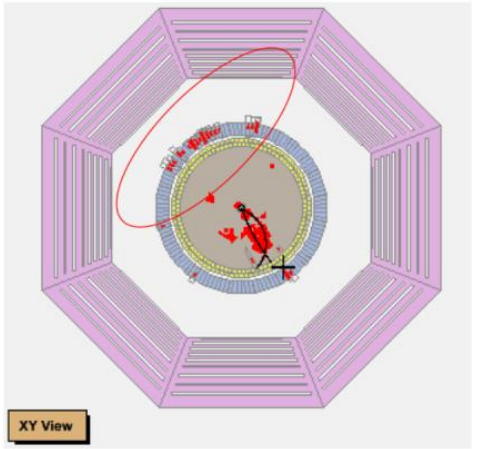
PhysRevD.105.L071101



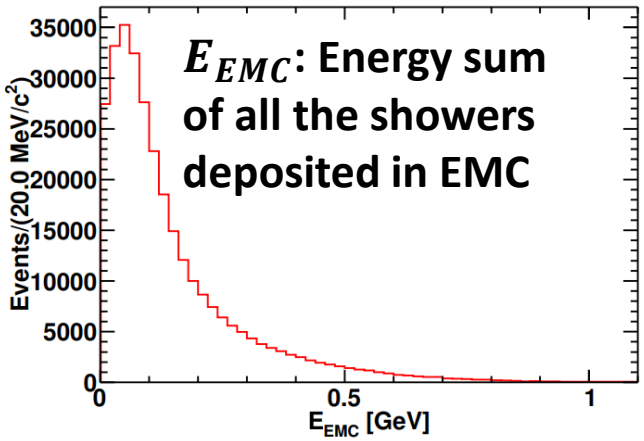
Invisible
eg. Dark matter



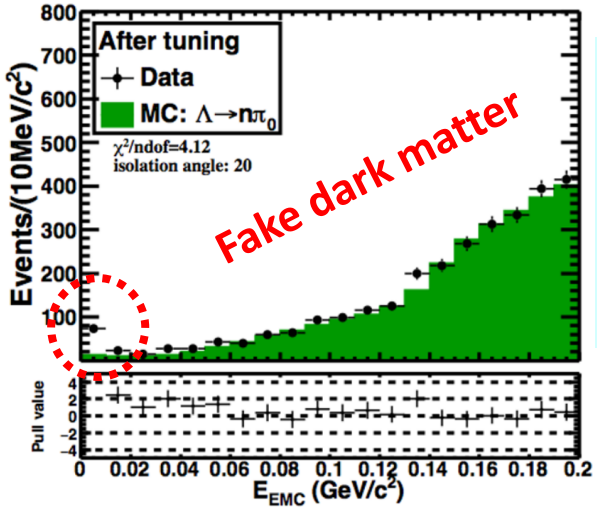
✓ $\Lambda \to invisible$ (MC)



✓ $\Lambda \to n\pi^0$ background



Signal MC:
peak around zero energy position

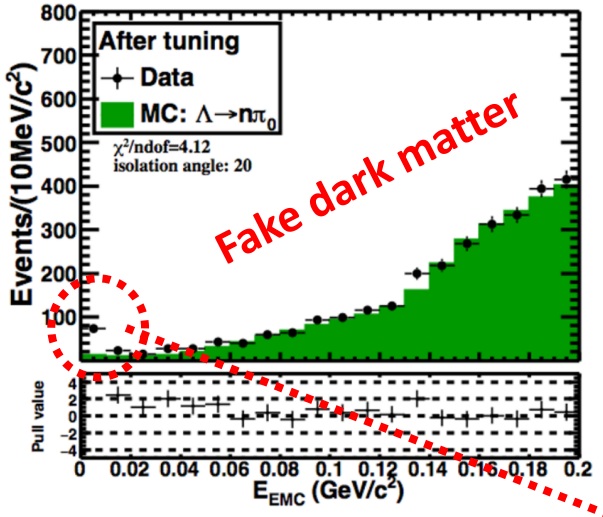


Data:
also peak around zero energy position

"Dark matter"?

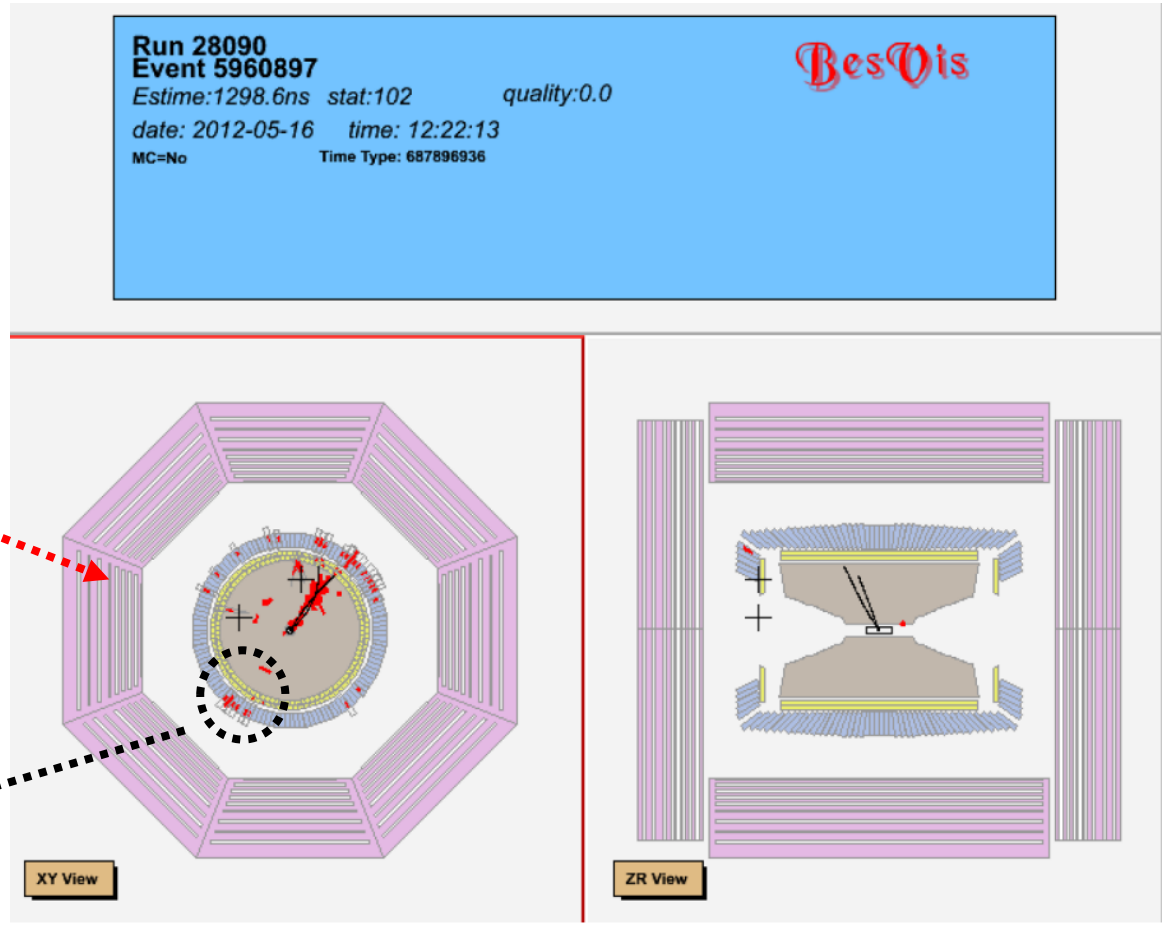
Check the “dark matter” with BesVis

PhysRevD.105.L071101



✓ **Use event display to check the “dark matter”**

Have EMC Hits!
Not real “dark matter”!



Why?

Timing information from MDC and TOF are used to calculate the event start time T0.

In case no TOF hit is associated with any tracks, the T0 resolution will be large and the shower out of the time window will be dropped.

Requiring that $\bar{p}$ must leave cluster information in either of TOF layers ⟹ **“dark matter” disappear**

If any new physics exists, visualization is essential.

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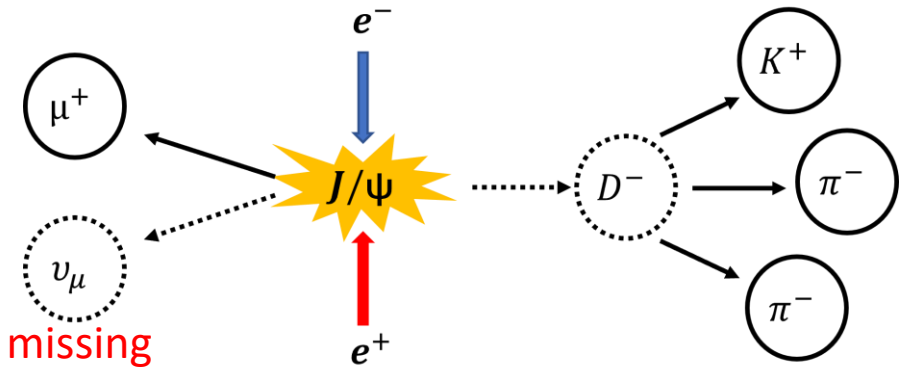
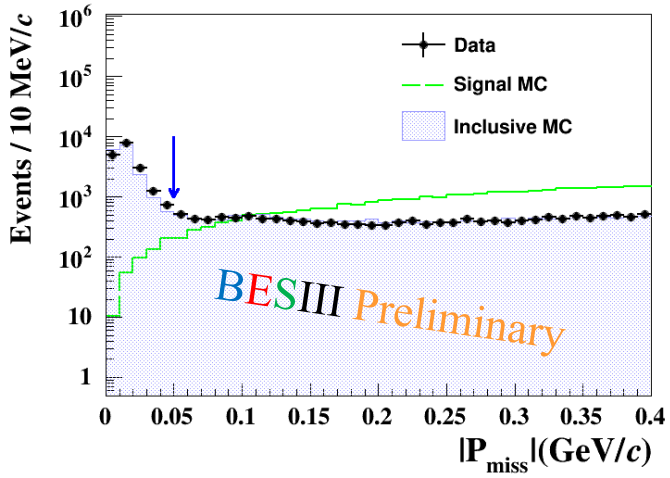
Rare weak decay $J/\psi \to D^- \mu^+ \nu_\mu$





- ✓ Cut based analysis:
- The distance of the vertex of the track from the IP in x-y plane: $|V_r| < 1.0$ cm
- The distance of the vertex of the track from the IP in z plane: $|V_z| < 10.0$ cm

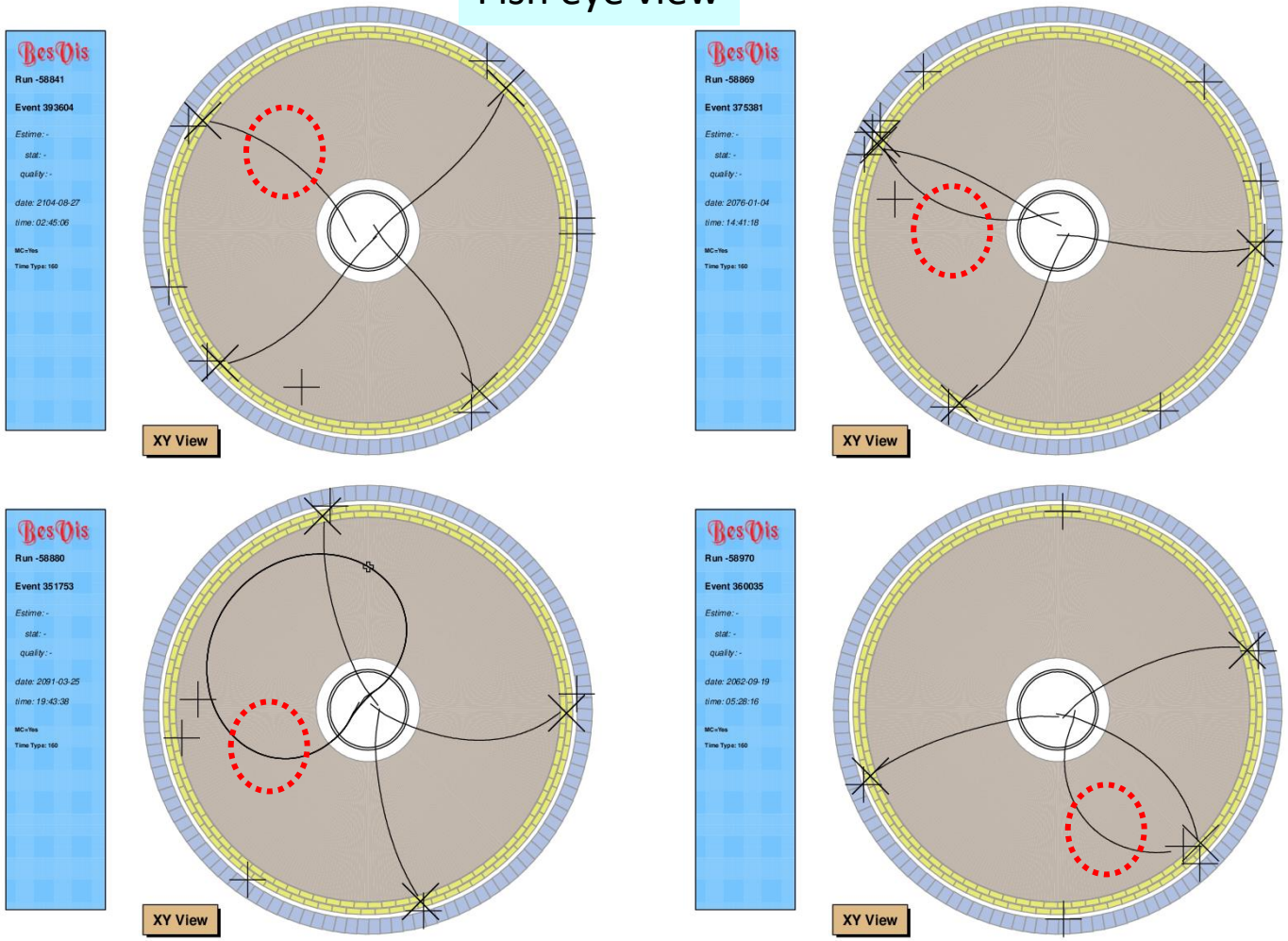
- ✓ Final particle: $K^+\pi^-\pi^-\mu^+\nu_\mu$
- ✓ **Kaon and pion have long lifetimes and are often regarded as stable particles in BESIII.**
- ✓ Have a missing neutrino

- ✓ Cut based analysis:
- **Missing momentum > 0.05 GeV/c**

☐ One main background found in analysis:
- ✓ $J/\psi \to K^+K^-\pi^+\pi^-$
- ✓ No missing particle
- ✓ It seems that one of kaons have bad reconstruction

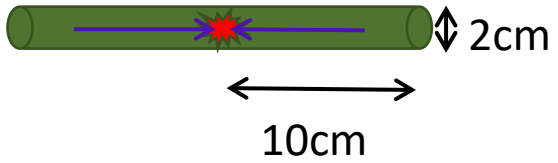
Check $K^+K^-\pi^+\pi^-$ background with BesVis

Fish eye view



- ✓ Assume $P = 1\ GeV/c$ of kaon
- ✓ Decay length $l_0 = \frac{P}{m}\tau = 7.5\ m$

- ☐ Good charged track(MDC):
- ✓ $|V_r| < 1.0\ cm, |V_z| < 10.0\ cm$



- ☐ The probability of decay in $|V_z|$
- ✓ $Prob = \left(1 - e^{-\frac{l}{l_0}}\right) \times BF\left(K^+ \to \mu^+\nu_\mu\right) = 0.0084$

- ☐ **Better understand and reduce the background with the study of BesVis**
- ☐ **Higher sensitivity to new physics**

One of the tracks is not generated from IP $\Longrightarrow$ $K^+ \to \mu^+\nu_\mu$ $\Longrightarrow$ can reduce it with the understanding by BesVis

Application in physics analysis

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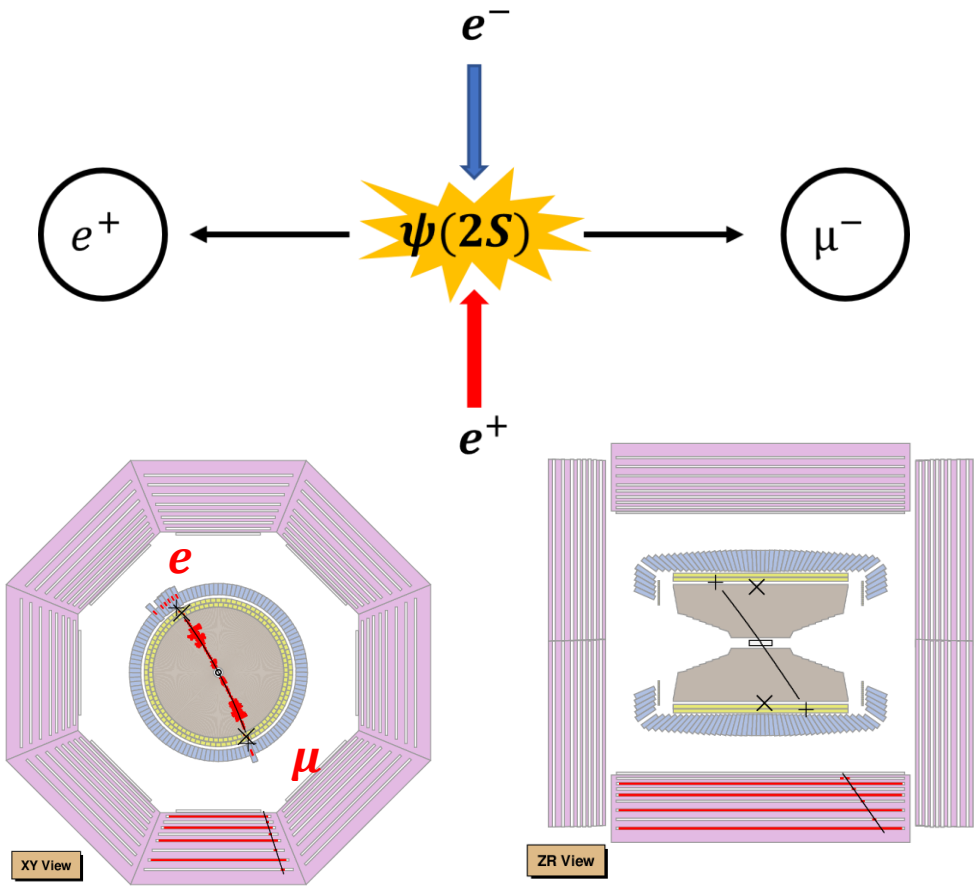
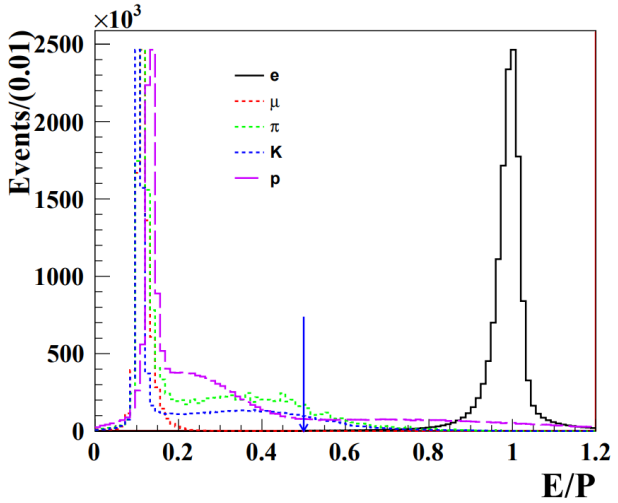
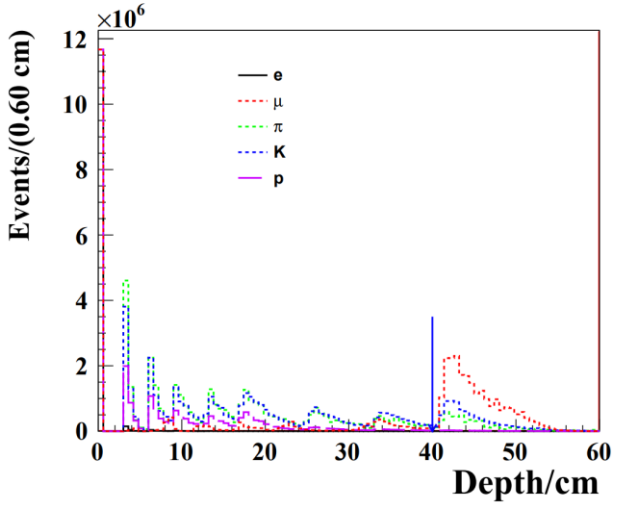
- Semi-leptonic decay $\Lambda_c^+ \to n e^+ \nu_e$

CLFV decay $\psi(2S) \rightarrow e^+\mu^-$



☐ **Cut based analysis:**





E: Energy deposited in EMC
P: Momentum

Depth in MUC

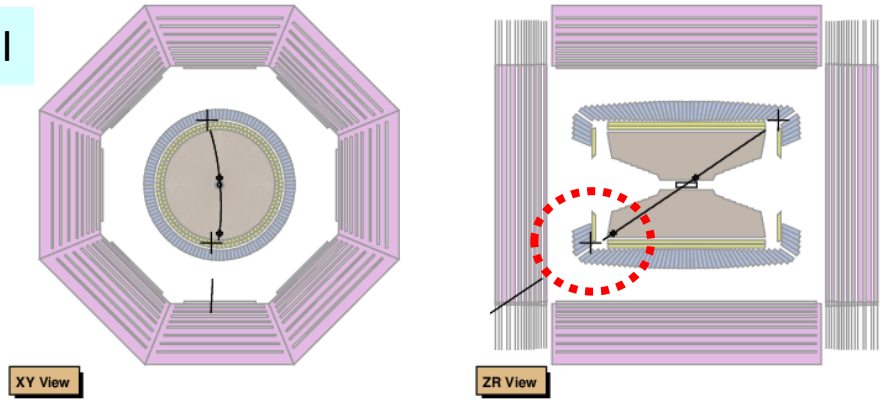
☐ The background will be very **clear** after the cut based analysis

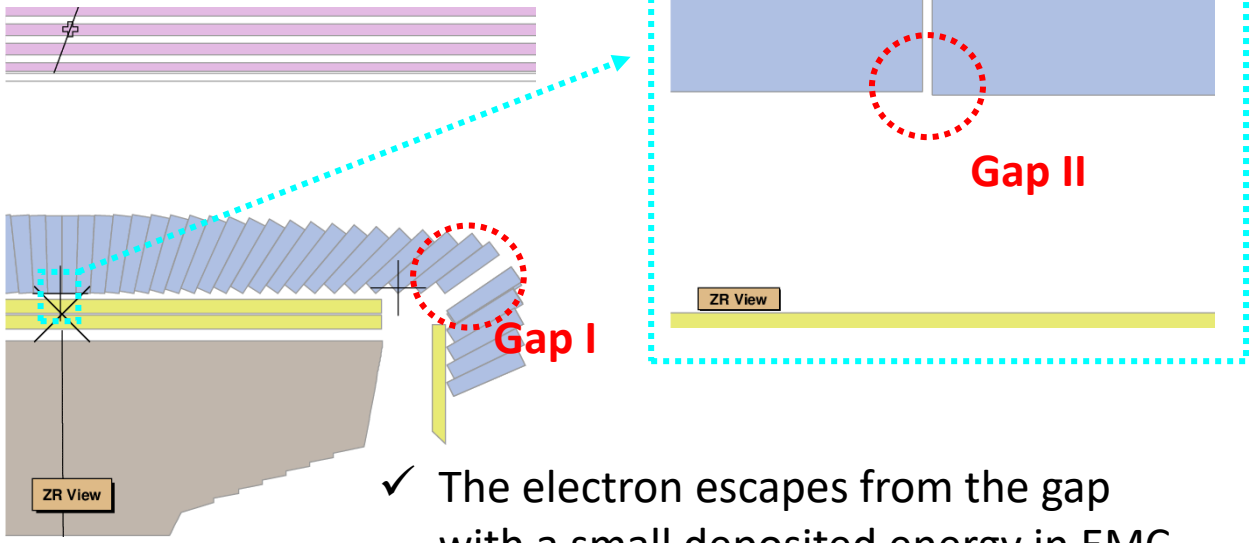
- Main background: $e^+e^- \rightarrow e^+e^-$
- **Can it be done better to search new physics? ⟹ BesVis!**

Check e^+e^- background with BesVis

- **Two kinds of background found with BesVis**
  - ✓ **Kind I: $cos\theta \sim 0.85$**
  - ✓ **Kind II: $cos\theta \sim 0$**

Kind I

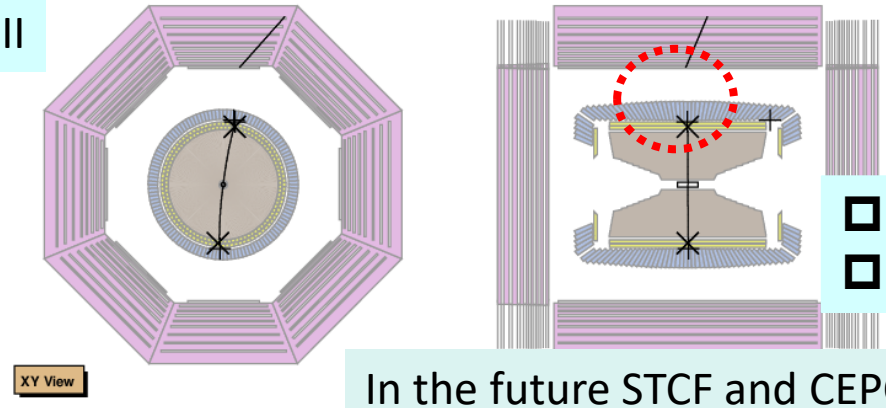




- ✓ The electron escapes from the gap with a small deposited energy in EMC
- ✓ Coincidence of cosmic ray muons with a large depth in MUC

$\Longrightarrow$ fake $e^+\mu^-$ signals

Kind II



- **Better understand and reduce the background with the study of BesVis**
- **Number of background: $56 \rightarrow 1$, Higher sensitivity to new physics**

In the future STCF and CEPC, it is important to use visualization tool to reduce the background and avoid the fake signals (eg. Search for $e^+e^- \rightarrow e^+\mu^-$ in high energy)

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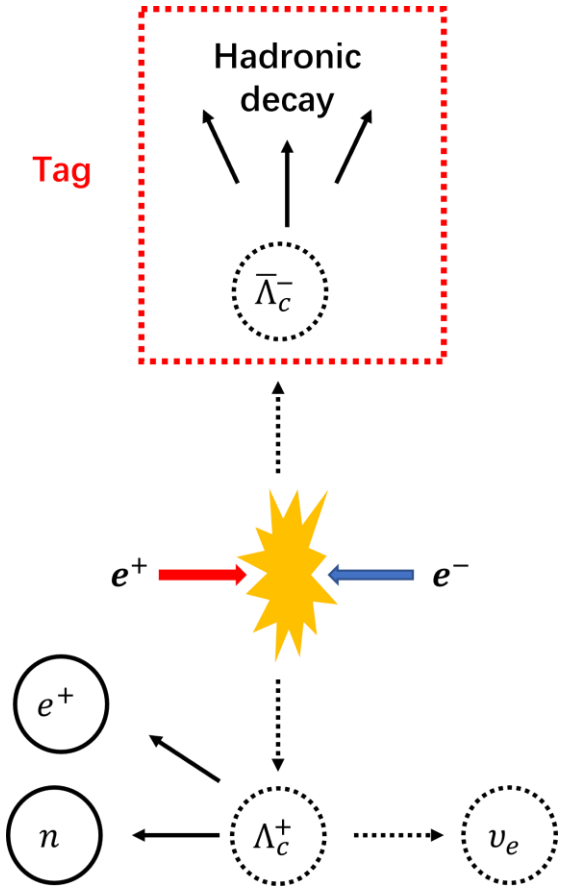
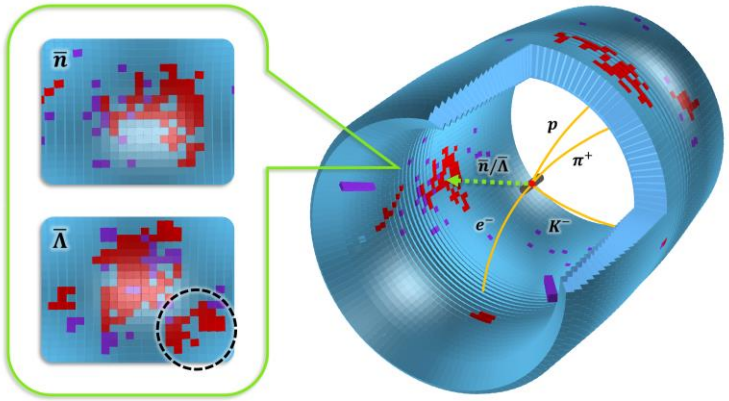
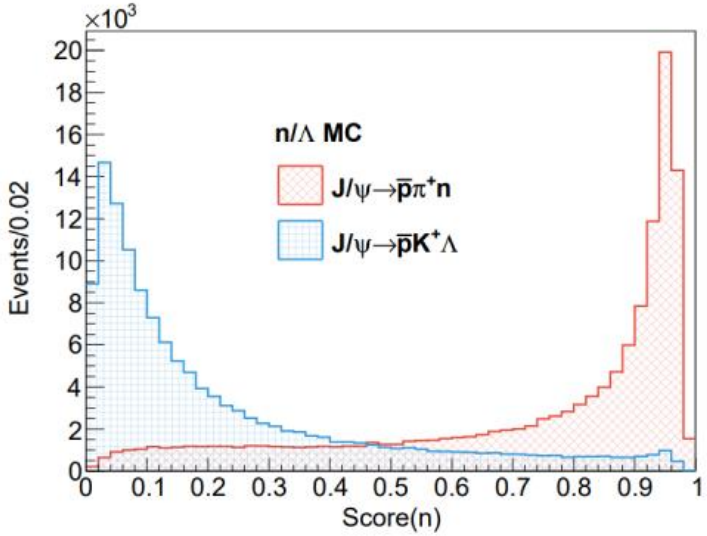
Semi-leptonic decay $\Lambda_c^+ \to ne^+\nu_e$



- ✓ BESIII has no hadron calorimeter
- ✓ Detection for neutron mainly relies on the EMC but complex
- ✓ **The main background** $\Lambda_c^+ \to \Lambda e^+\nu_e, \Lambda \to n\pi^0$



Check the difference between Λ and n with BesVis



- ✓ The features of showers can help to distinguish n and Λ (machine learning technique)

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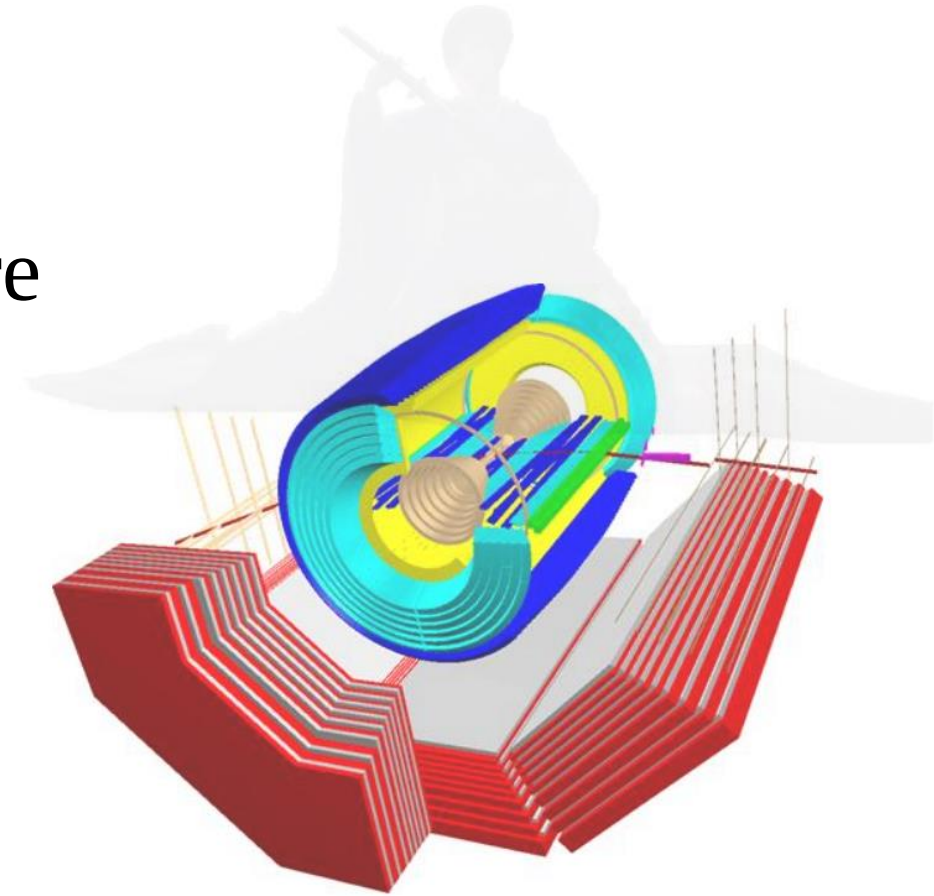

Summary

Visualization for analysis

- Good visual intuitiveness
- Validate new physics discovery
- Check background in analysis
- improve signal/background discrimination