Visualization for physics analysis improvement and applications in BESIII

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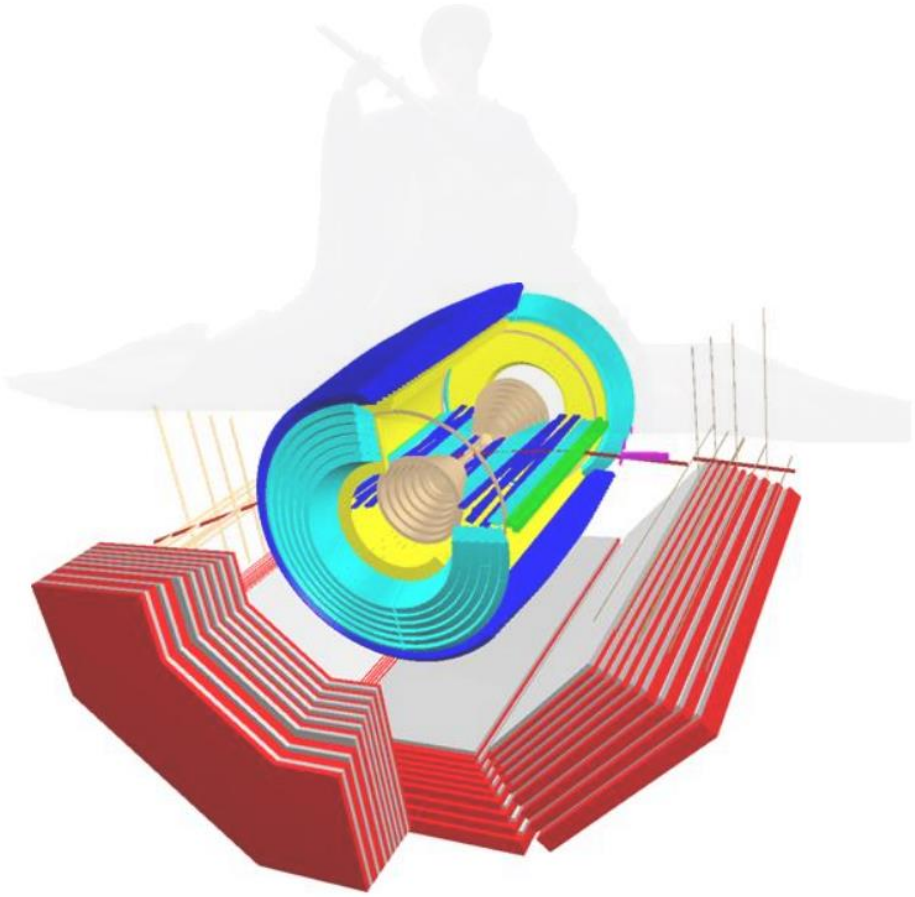
中山大學 SUN YAT-SEN UNIVERSITY

OUTLINE

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



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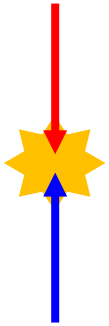
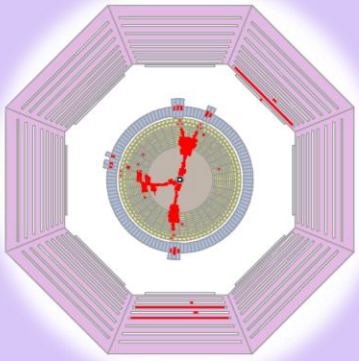
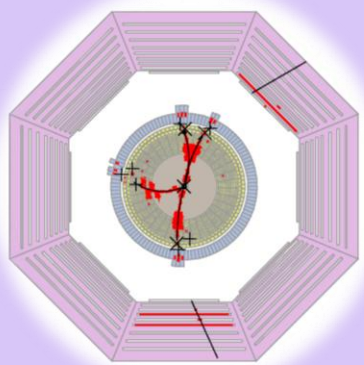
Statistical cut-based analysis



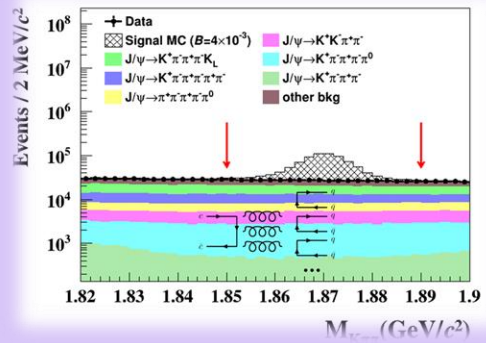
Data or simulation



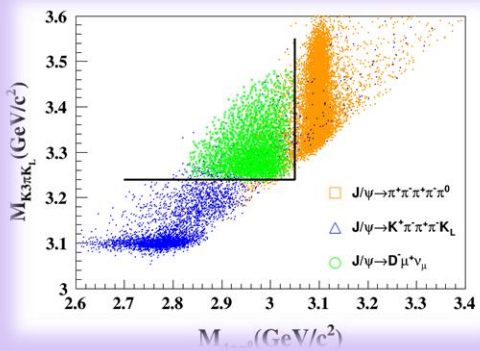
Raw hits



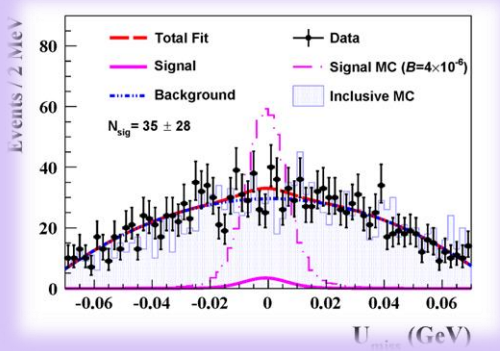
Event reconstruction



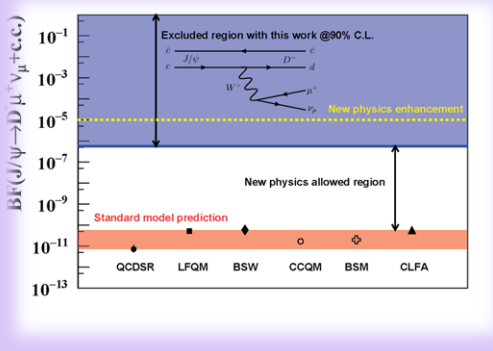
Physics reconstruction



Distinguish signal & bkg



Fit the selected data events



Physical result

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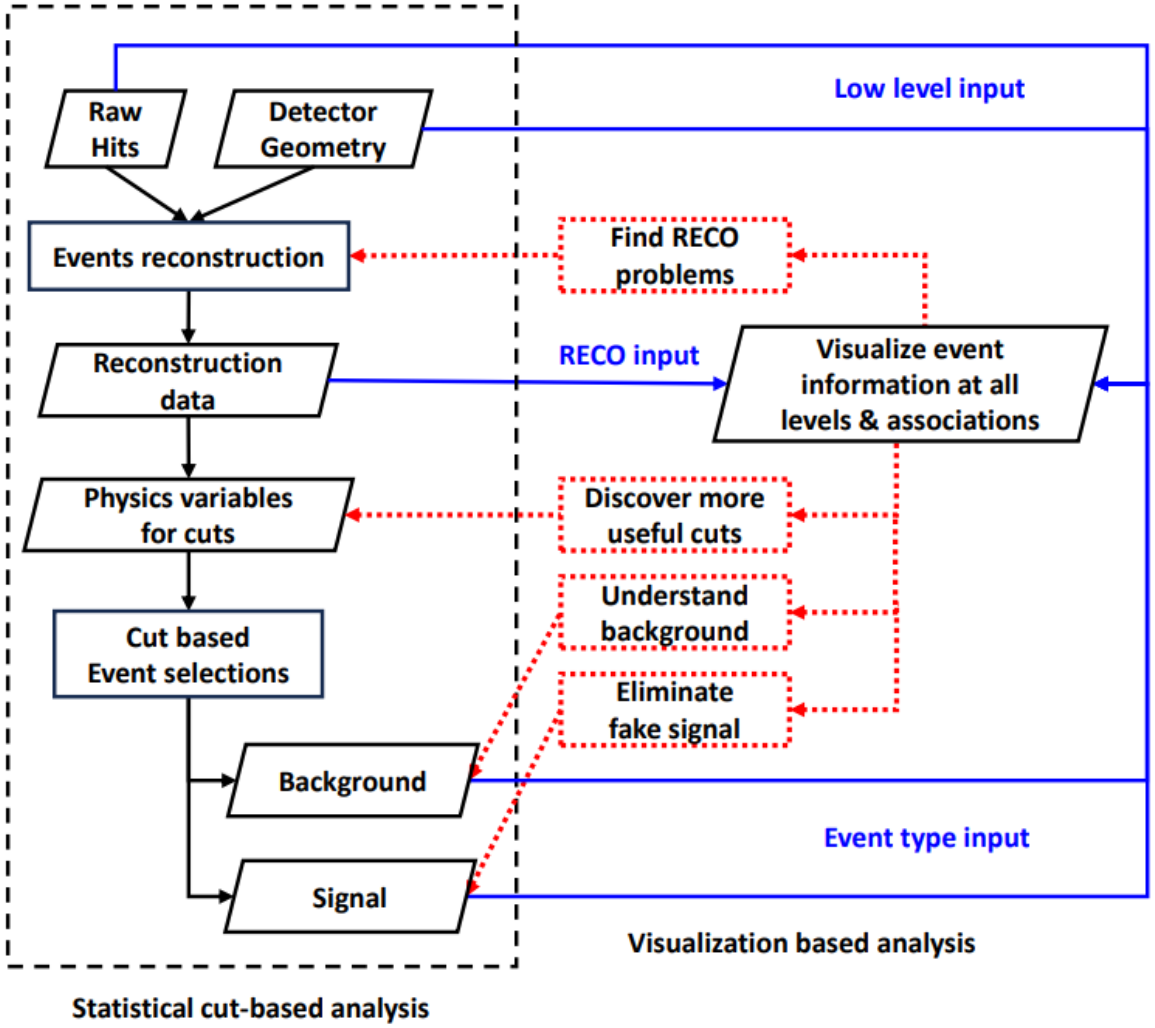
Visualization based analysis



Characteristic	Statistical cut-based analysis	Visualization
Processing a large number of events	✓	✗
Quantifying the statistical features of multiple events	✓	✗
Relying on other software and experience	✓	✗
Highly intuitive	✗	✓
Comprehensive detailed information for a single event	✗	✓

- **The statistical cut-based method is the basic data analysis method**
- **The visualization method can help further improve the physics analysis by overcoming the limitations of only using high-level event information with the statistical cut-based method**
- **The visualization method is a beneficial approach to complement the statistical cut-based method**
- **Direct application of visualization in specific physics analysis is still limited**

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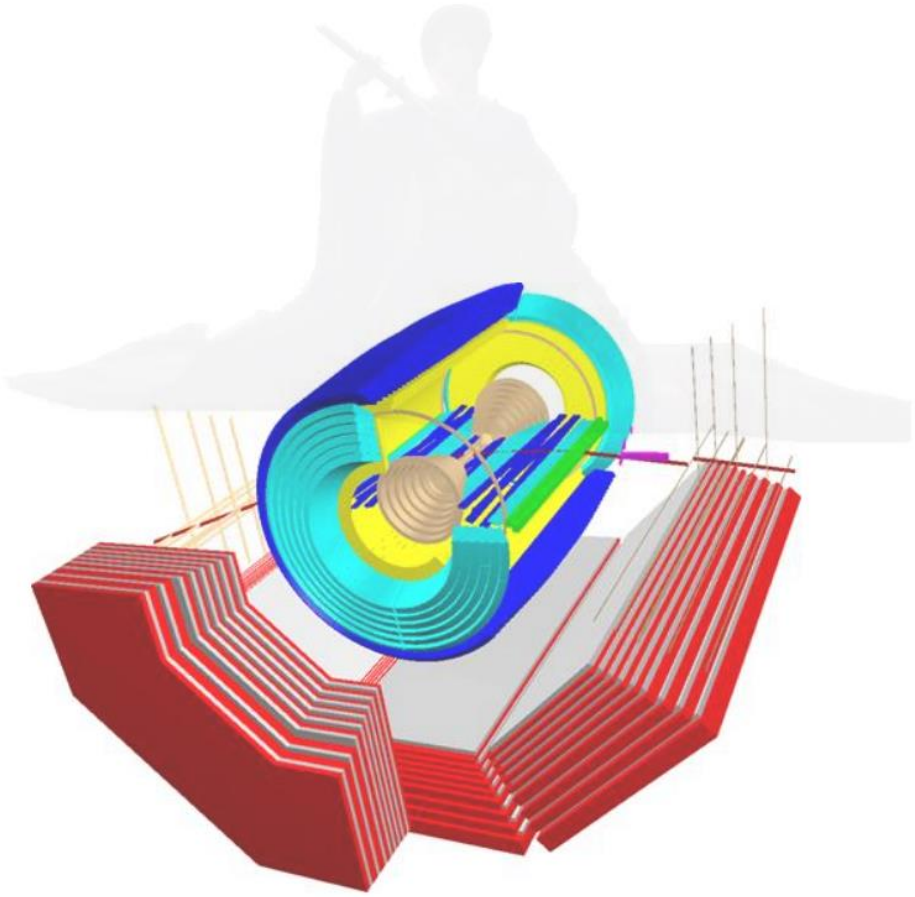

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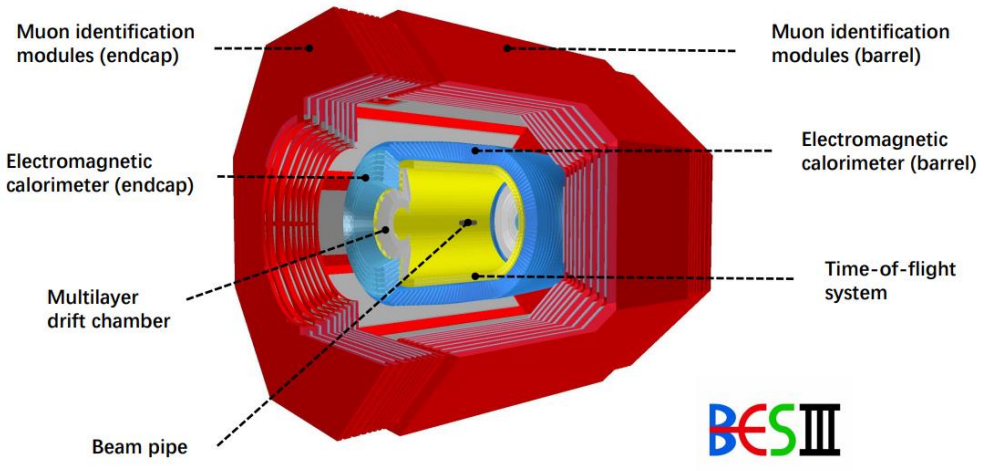
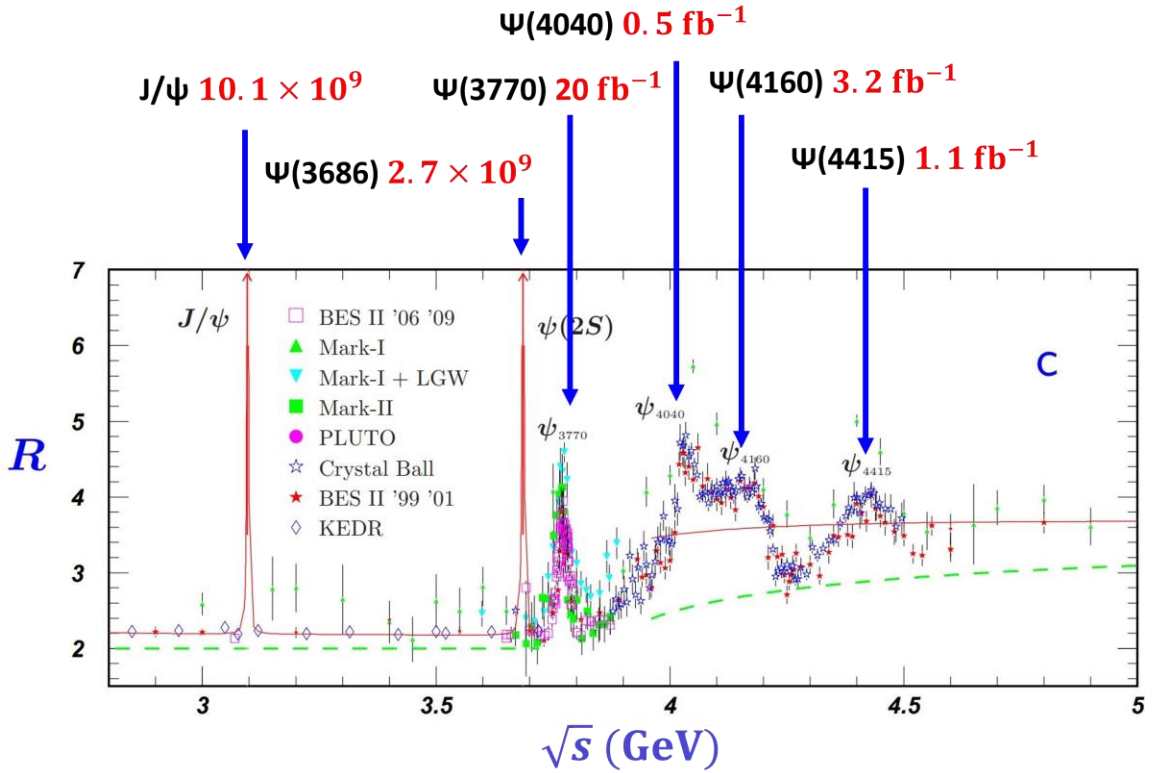
BESIII

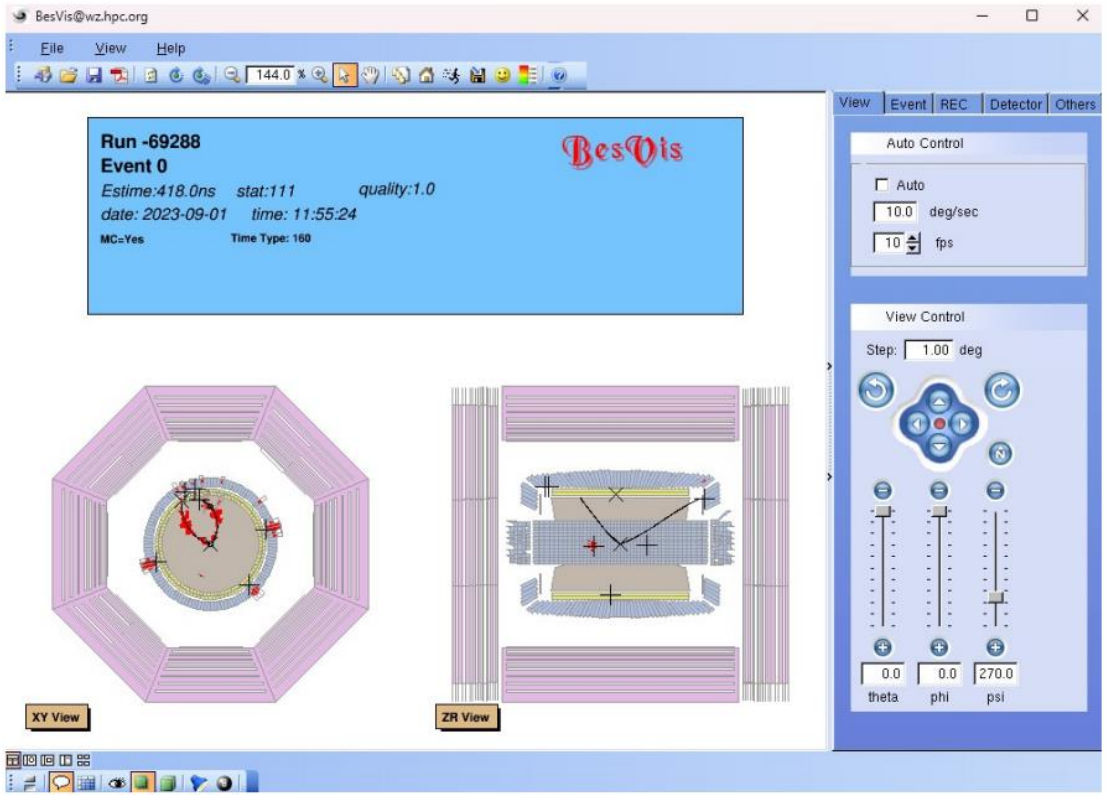


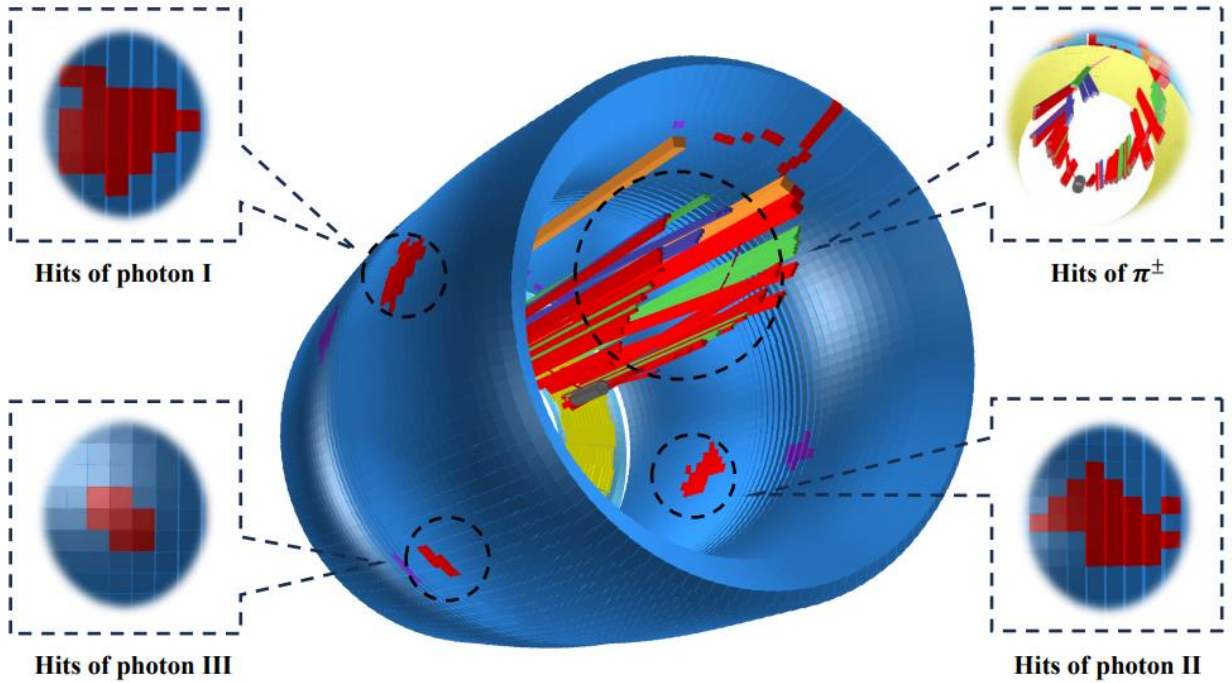


- ✓ **BE**ijing **S**pectrometers **III**
- ✓ **a general-purpose spectrometer for τ-charm physics study**
- ✓ **records symmetric e^+e^- collisions provided by the Beijing Electron Positron Collider II storage ring**

BesVis

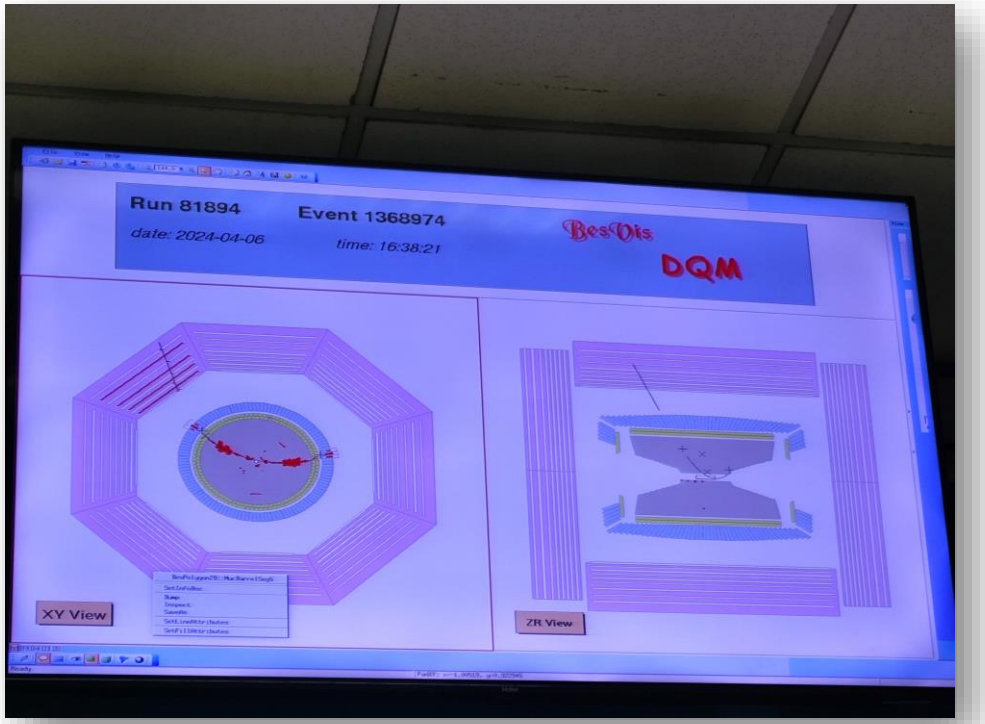
$$\psi(2S) \to \pi^+\pi^- J/\psi, J/\psi \to \gamma\eta_c, \eta_c \to \gamma\gamma$$



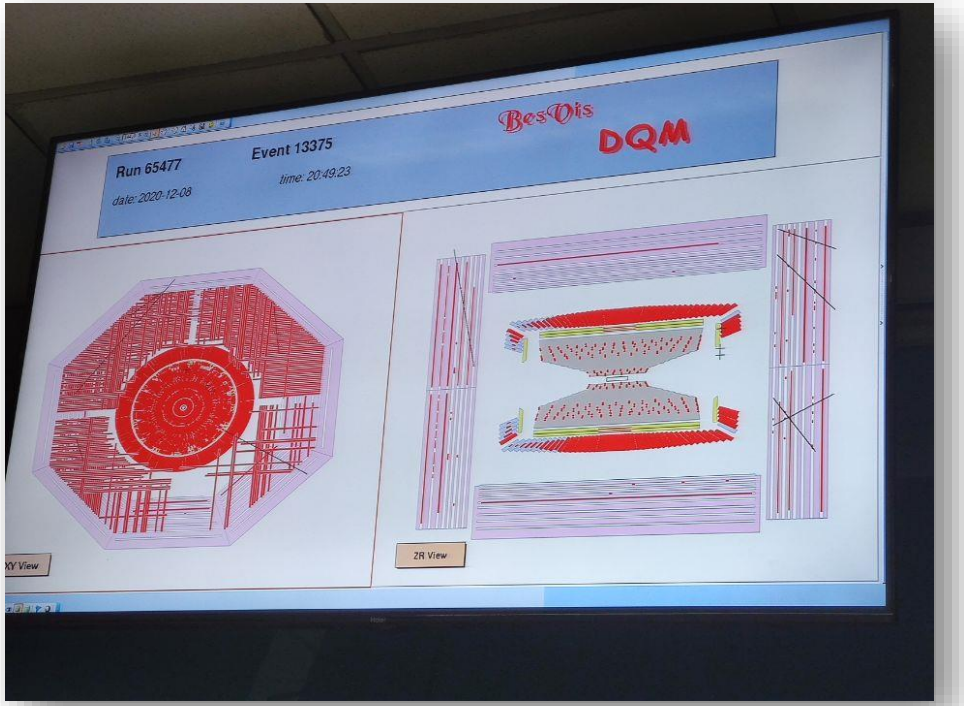


- **BESIII Visualization software**
  - ✓ Developed with ROOT

DQM

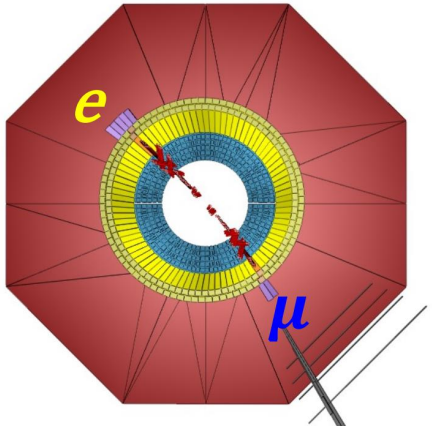


Poor data quality



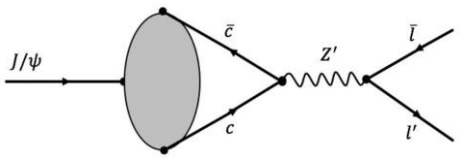
- **D**ata **Q**uality **M**onitoring (DQM)
  - ✓ Online monitoring of experimental status
  - ✓ Play an important role for DQM

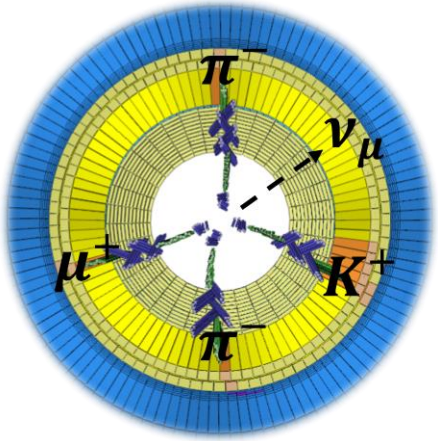
Schematic diagram for outreach or article



- Charged lepton flavor violation process

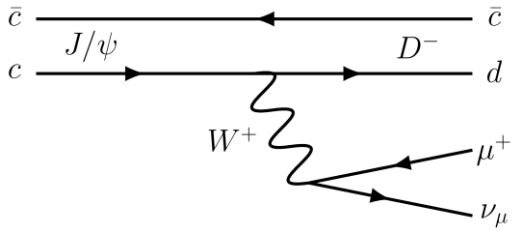
$J/\psi \to e^+\mu^-$



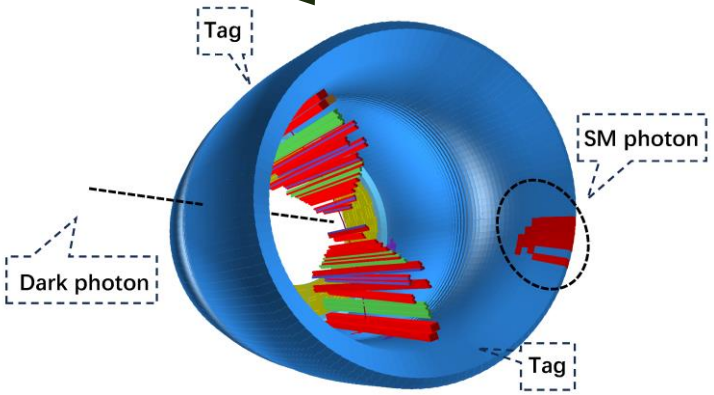


- Charmonium rare weak decay

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

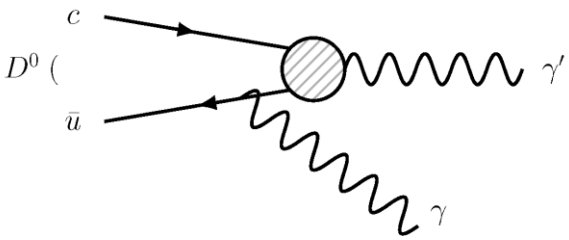


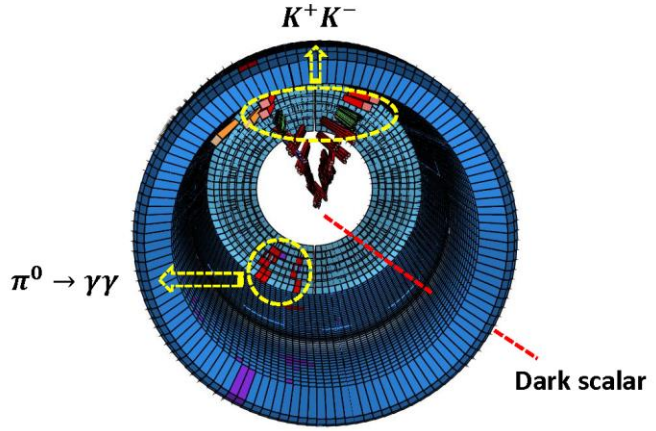
Poster 2-03



- Search for massless dark photon

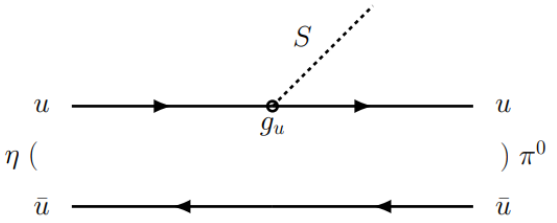
$D^0 \to \gamma\gamma'$





- Search for dark scalar

$\eta \to \pi^0 S$



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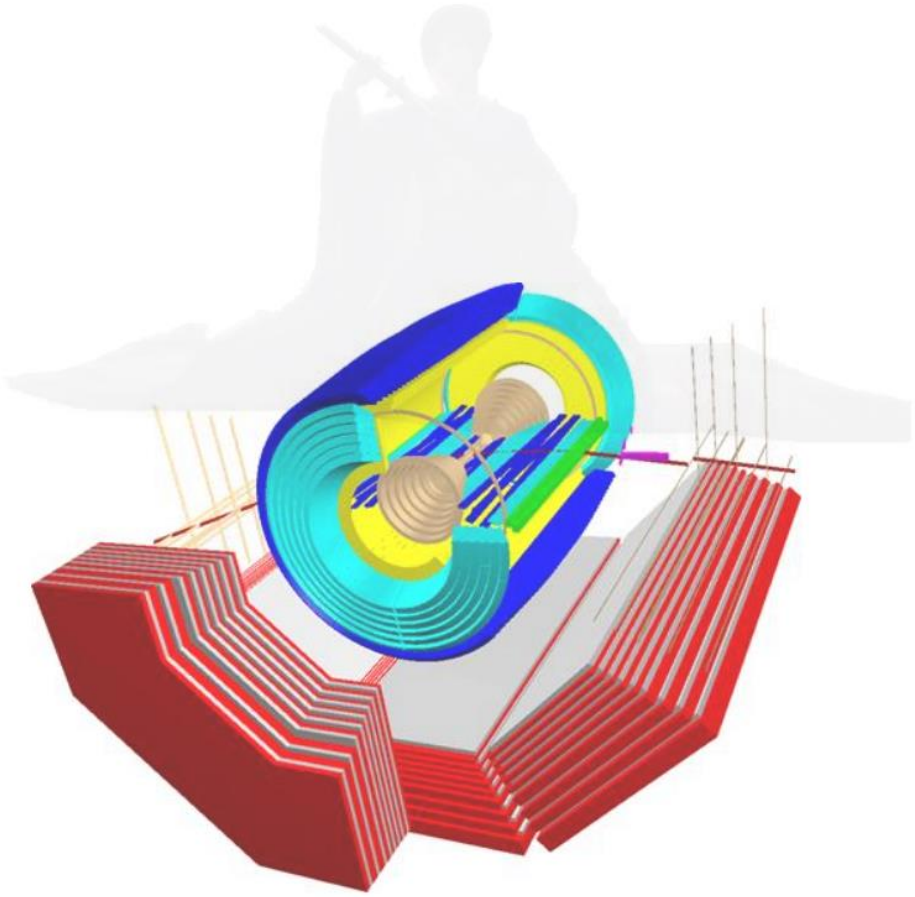

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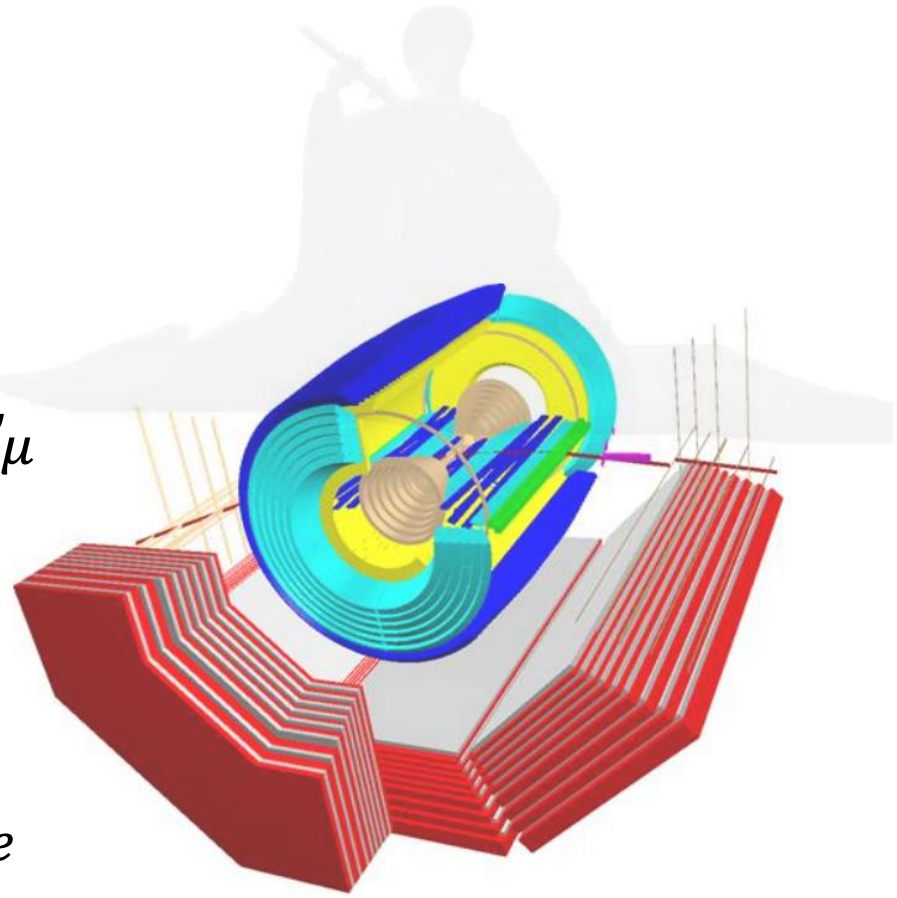
OUTLINE

- **Application in 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 $\Lambda_c^+ \to ne^+\nu_e$



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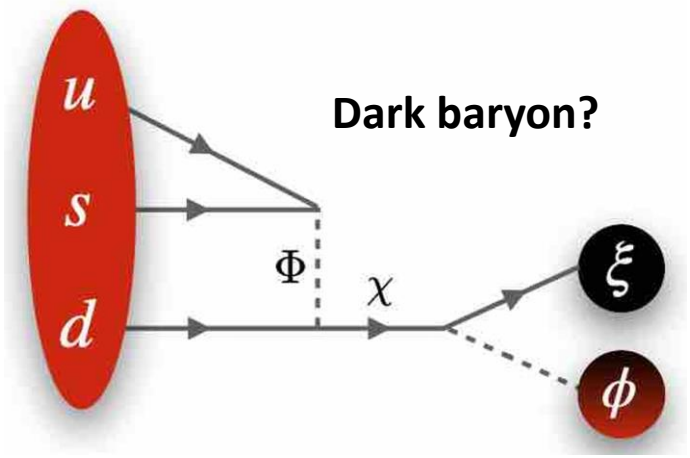
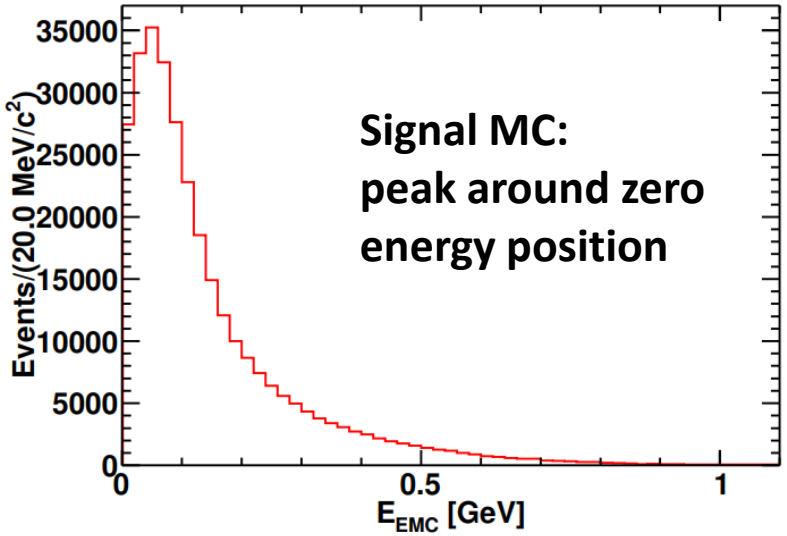
Invisible decay of Λ

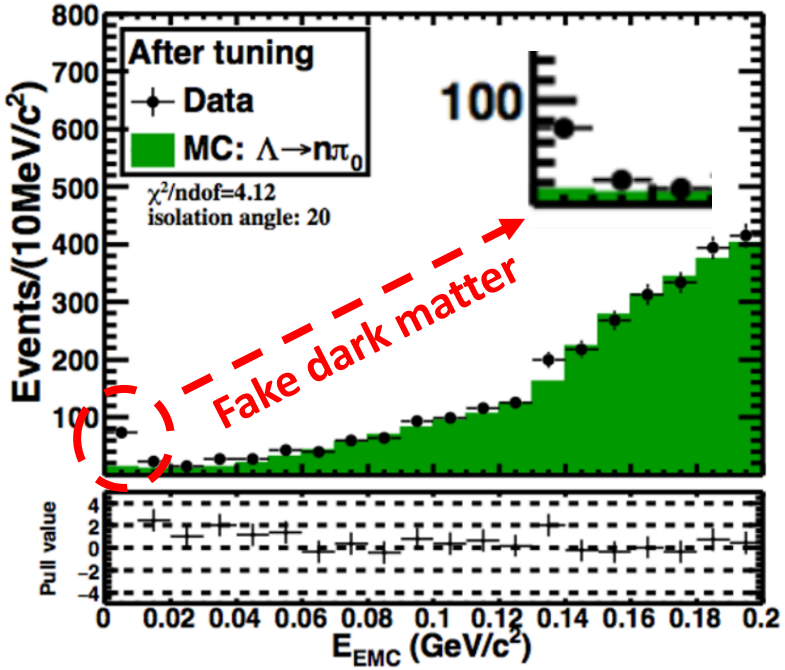


Dark baryon?

- $J/\psi \to \Lambda\bar{\Lambda}$
- Tag $\bar{\Lambda}$ with $\bar{\Lambda} \to \bar{p}\pi$
- **Λ invisible decay has no interaction with the detector**
- E_{EMC}: Energy sum of all the showers deposited in EMC
- Using E_{EMC} to extract the invisible signals



Signal MC:
peak around zero energy position

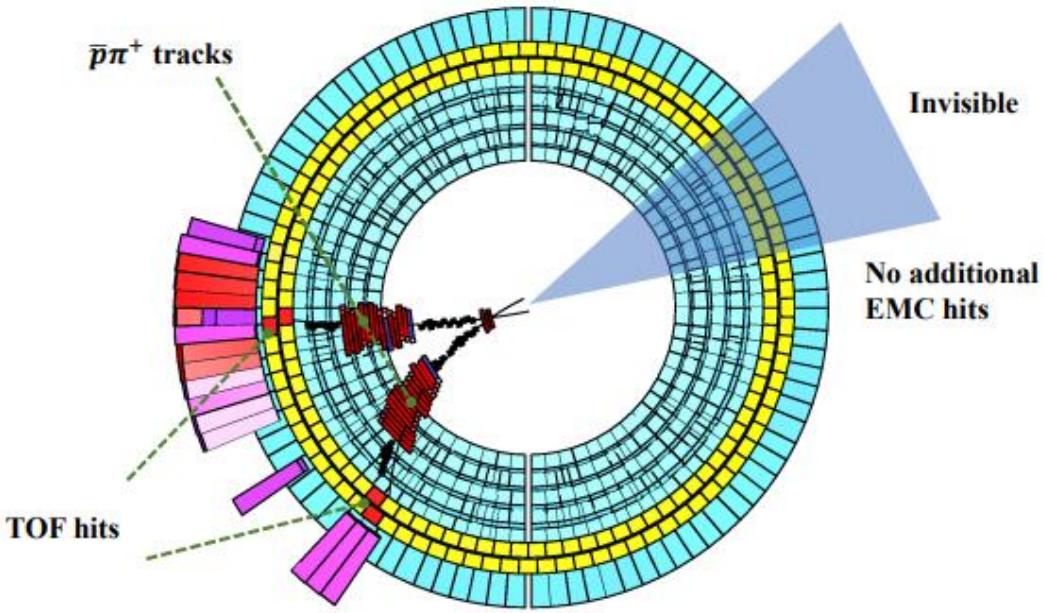


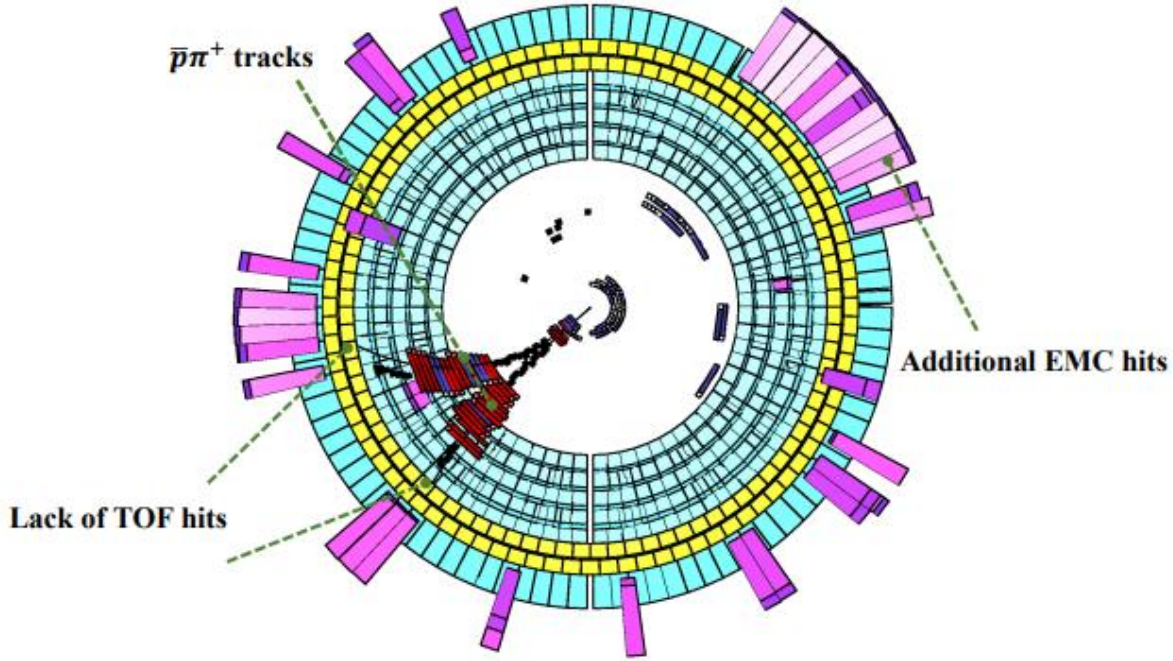
Data:
also peak around zero energy position

"Dark matter"?

PhysRevD.105.L071101

Check the “dark matter” with BesVis



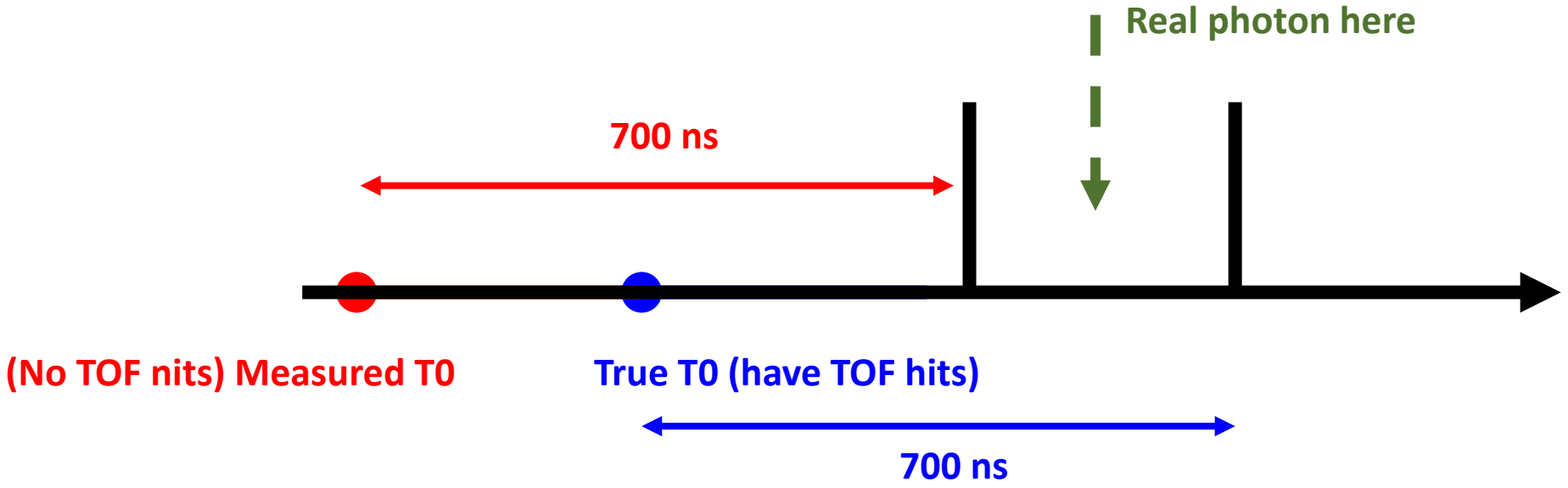


- **Signal simulation**
- **“dark matter” candidate**

Fake dark matter

PhysRevD.105.L071101

Check the “dark matter” with BesVis



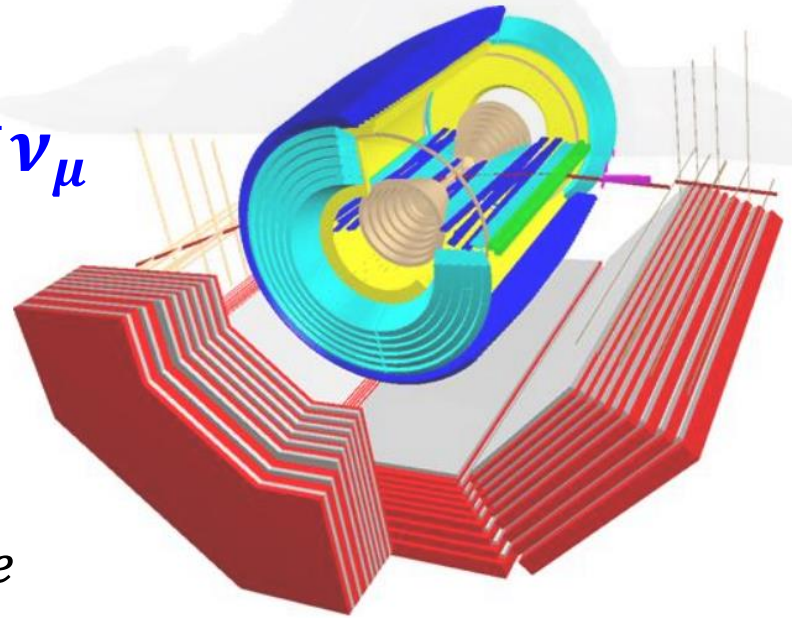
- Timing information from MDC and TOF are used to calculate the event start time T0.
- In case no TOF hit is associated with any tracks, **the T0 resolution will be large** and the shower out of the time window will be dropped.
- Requiring that $\bar{p}$ must leave cluster information in either of TOF layers $\Longrightarrow$ **“dark matter” disappear**

PhysRevD.105.L071101

OUTLINE

- **Application in 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 $\Lambda_c^+ \to n e^+ \nu_e$



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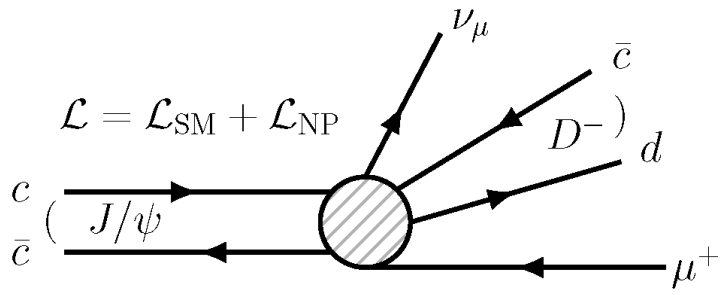
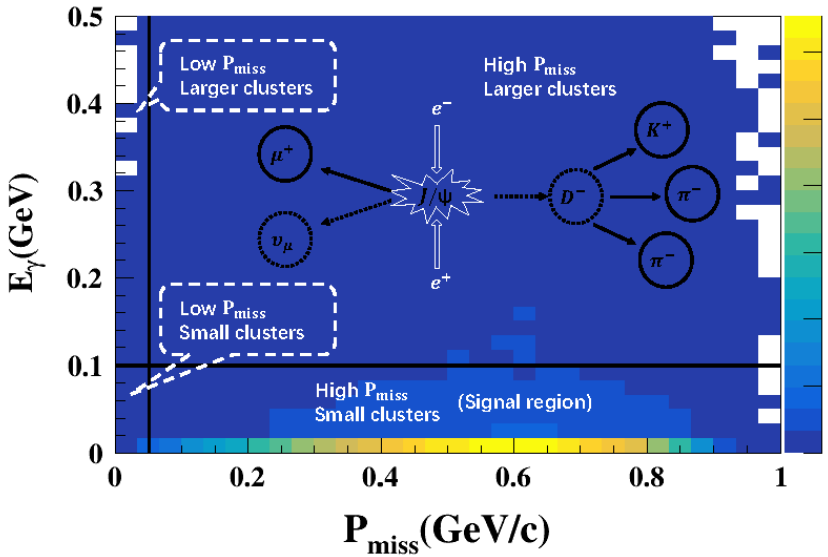
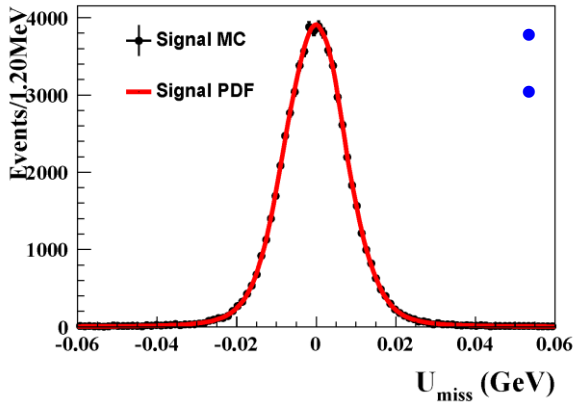
Rare weak decay $J/\psi \to D^- \mu^+ \nu_\mu$

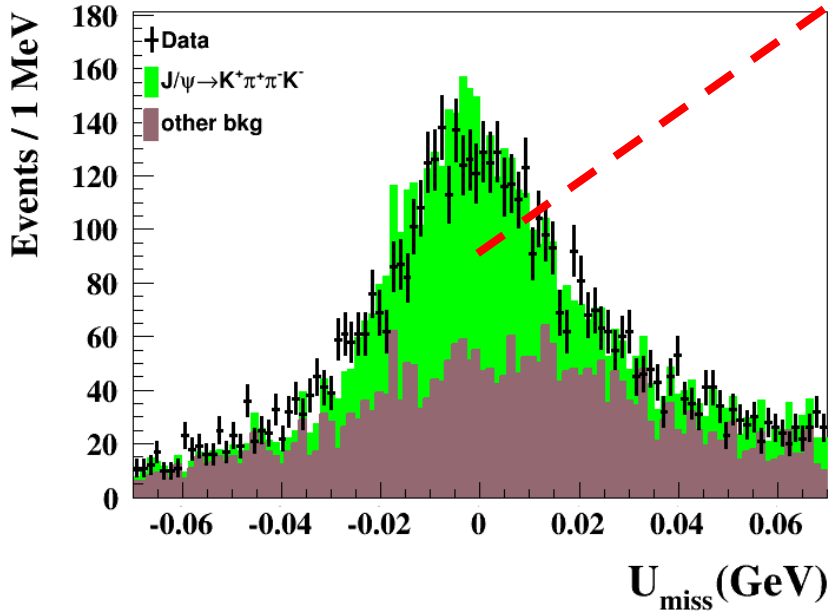




- **Statistical cut-based analysis**
- $J/\psi \to D^- \mu^+ \nu_\mu \to K^+ \pi^- \pi^- \mu^+ \nu_\mu$



- $U_{miss} = E_{miss} - P_{miss}$
- For neutrino, $U_{miss} \sim 0$



- **Peaking background from $K^+K^-\pi^+\pi^-$**
- **Why peaking?**

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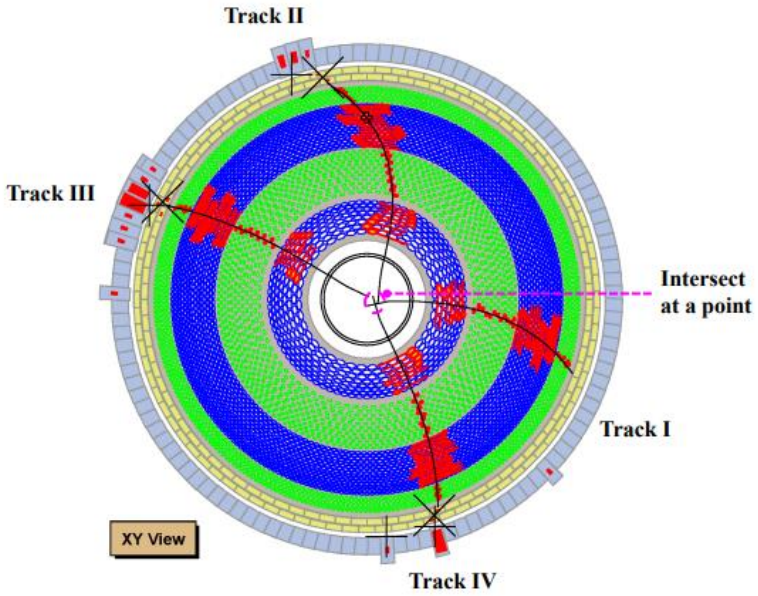
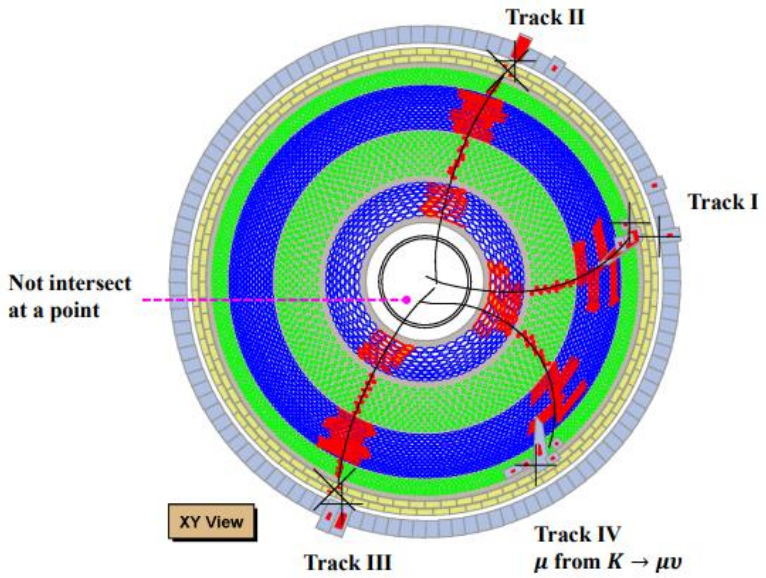
Check $K^+K^-\pi^+\pi^-$ background with BesVis



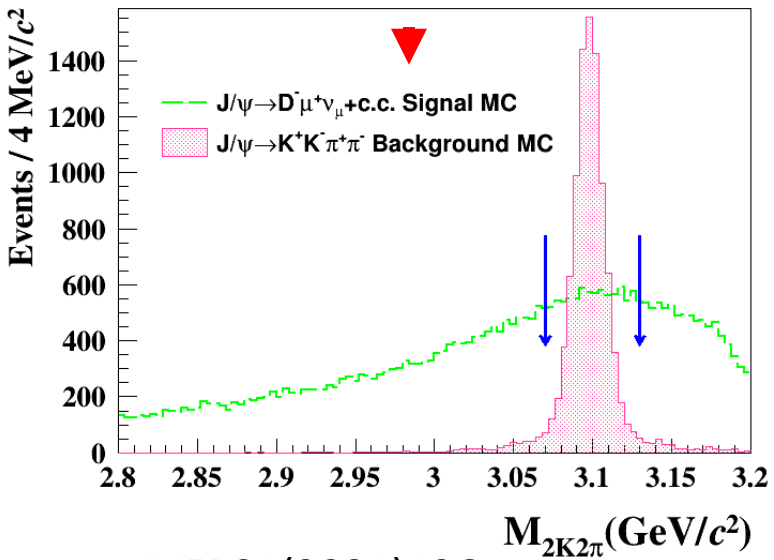
- Signal simulation
- the four charged tracks can intersect at a single point



- Background events
- the four charged tracks cannot intersect at a single point

One of the kaon have the decay: $K \to (\pi^0)\mu\nu$

After understanding the background, It's easy to construct some kinematic variables to suppress the background



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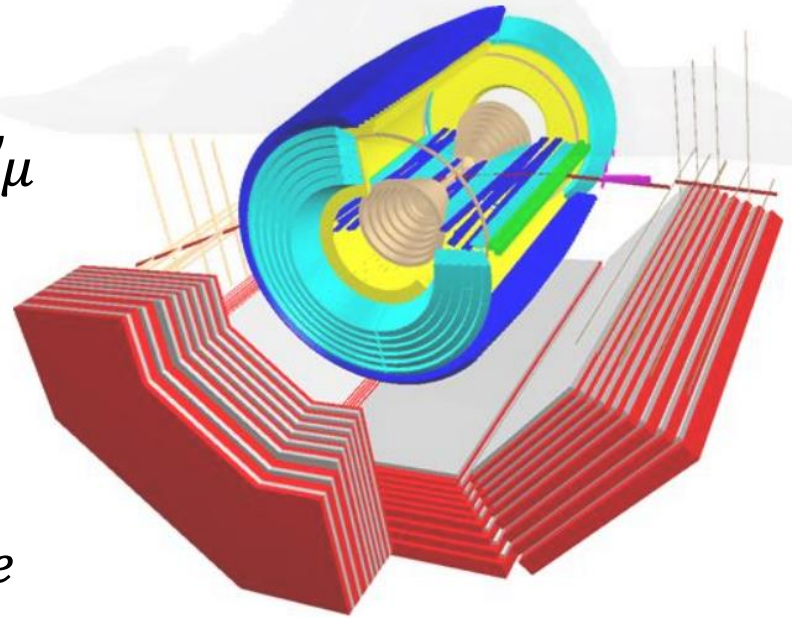
- **CLFV decay $\psi(2S) \to e^+ \mu^-$**
- Semi-leptonic decay $\Lambda_c^+ \to n e^+ \nu_e$



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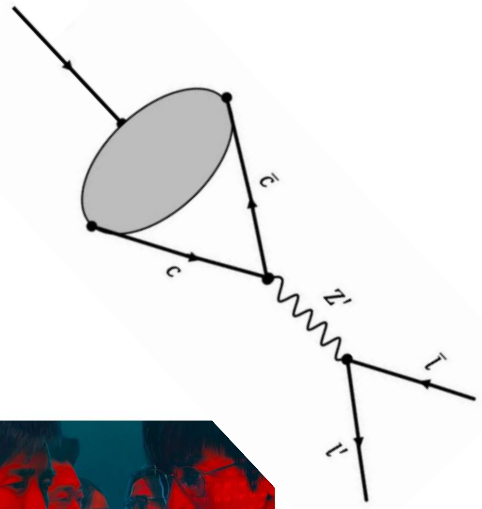
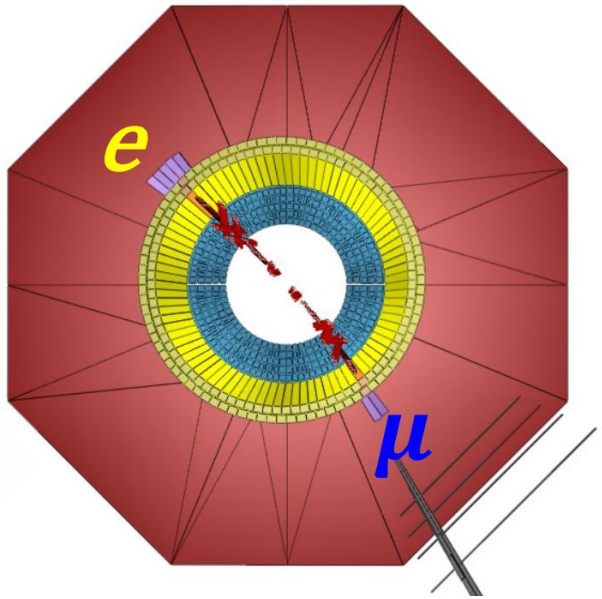
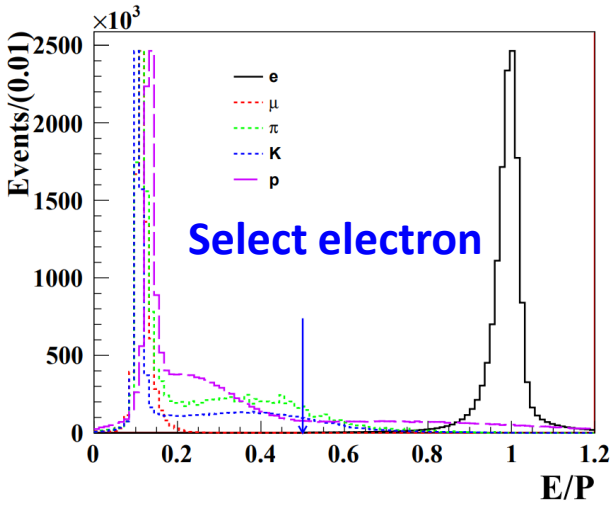
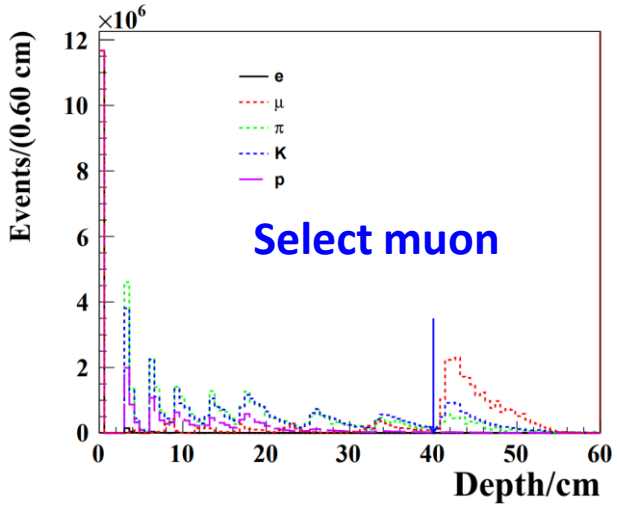
CLFV decay $\psi(2S) \to e^+\mu^-$





☐ **Cut based analysis:**





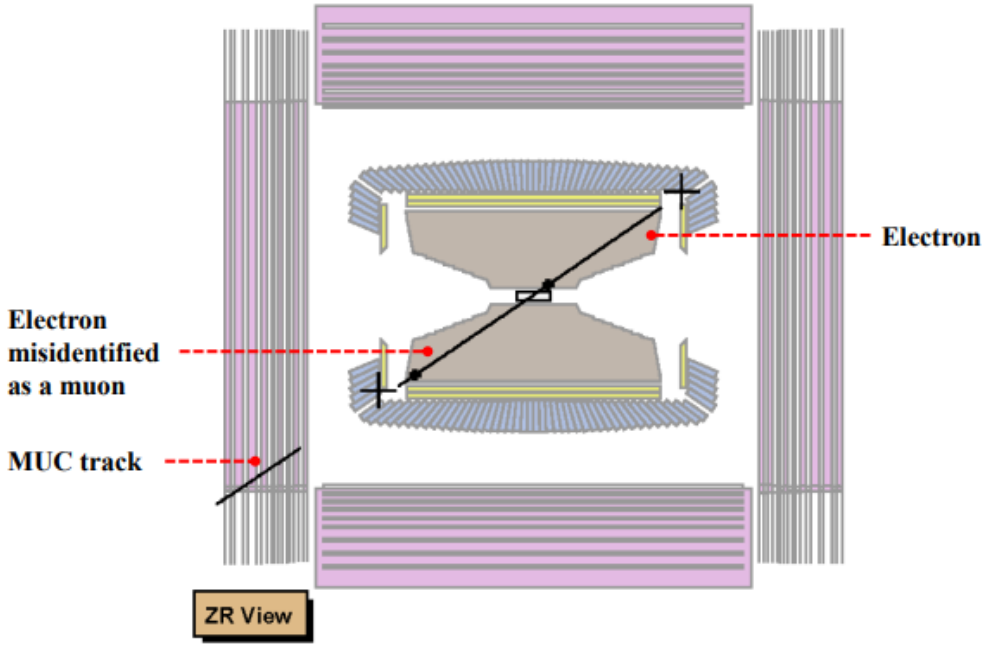
E: Energy deposited in EMC
P: Momentum

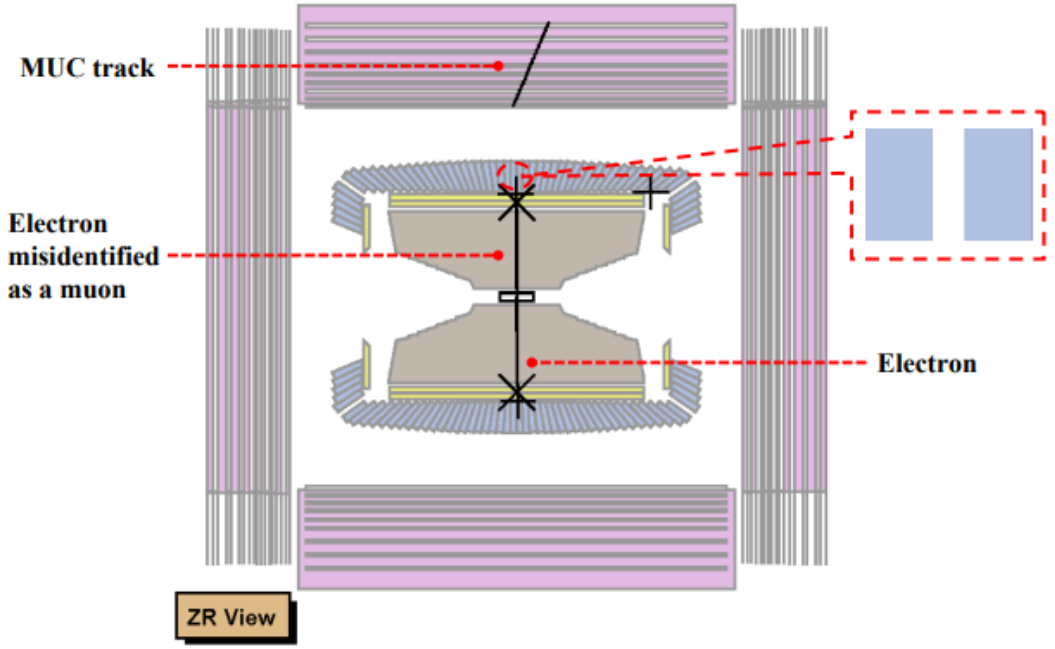
Depth in MUC

- **Select an electron and a muon**
- **Clear background**
- **Could further suppress the background? (important for the sensitivity of the NP)**

Check e^+e^- background with BesVis

- **Events from continue energy data**





- **Background type I**
- **Background type II**

✓ The electron escapes from the **EMC gap** with a small deposited energy in EMC

✓ The escaped electron interacts in the outer detector material and produces secondary particles hitting MUC ⟹ fake $e^+\mu^-$ signals, vetoed with angle cut

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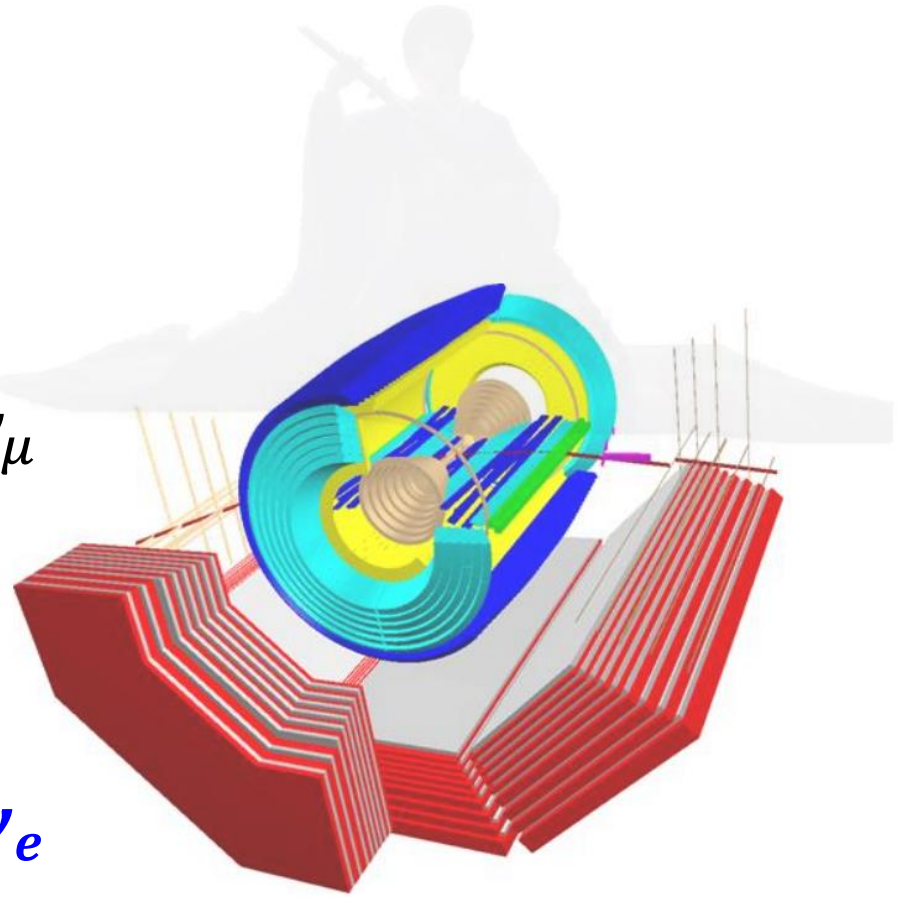

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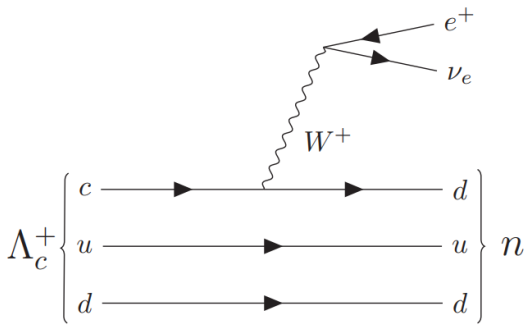
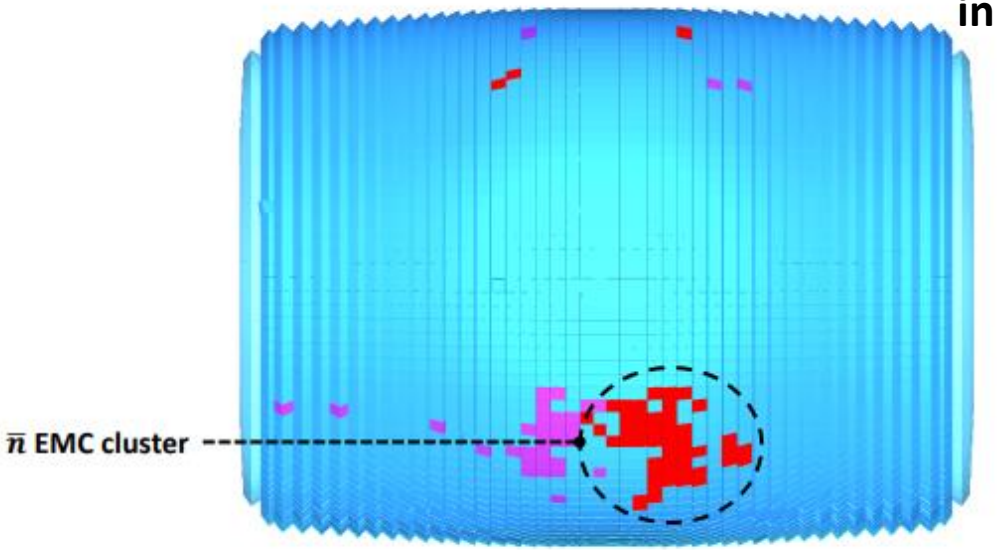
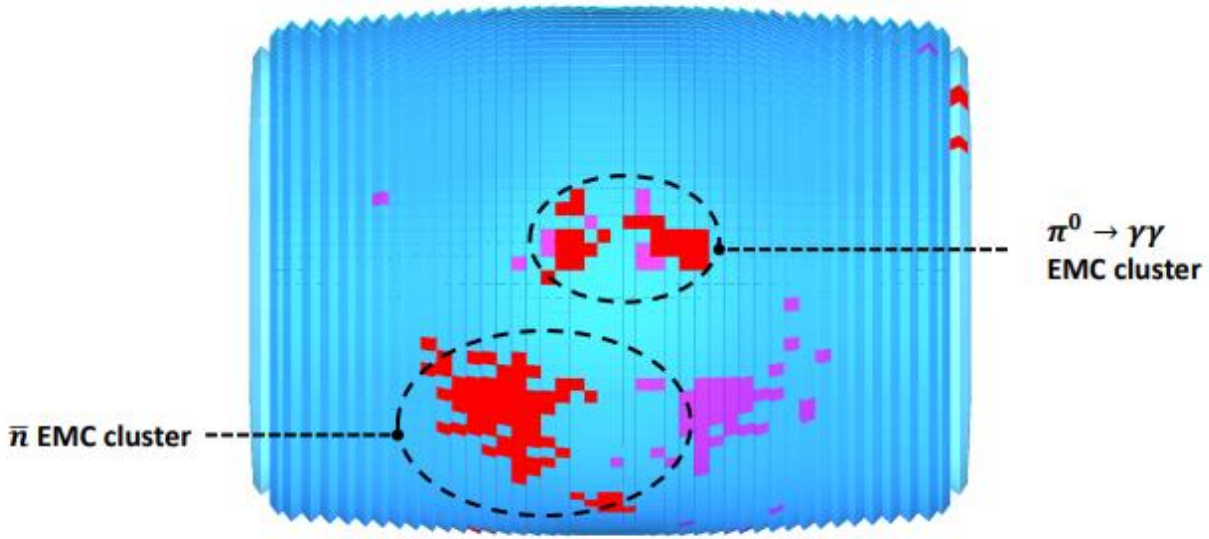
Semi-leptonic decay $\Lambda_c^+ \to n e^+ \nu_e$



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

- **The ability of EMC to identify the additional π^0 from the anti-neutron background will determine the feasibility of this analysis in BESIII.**

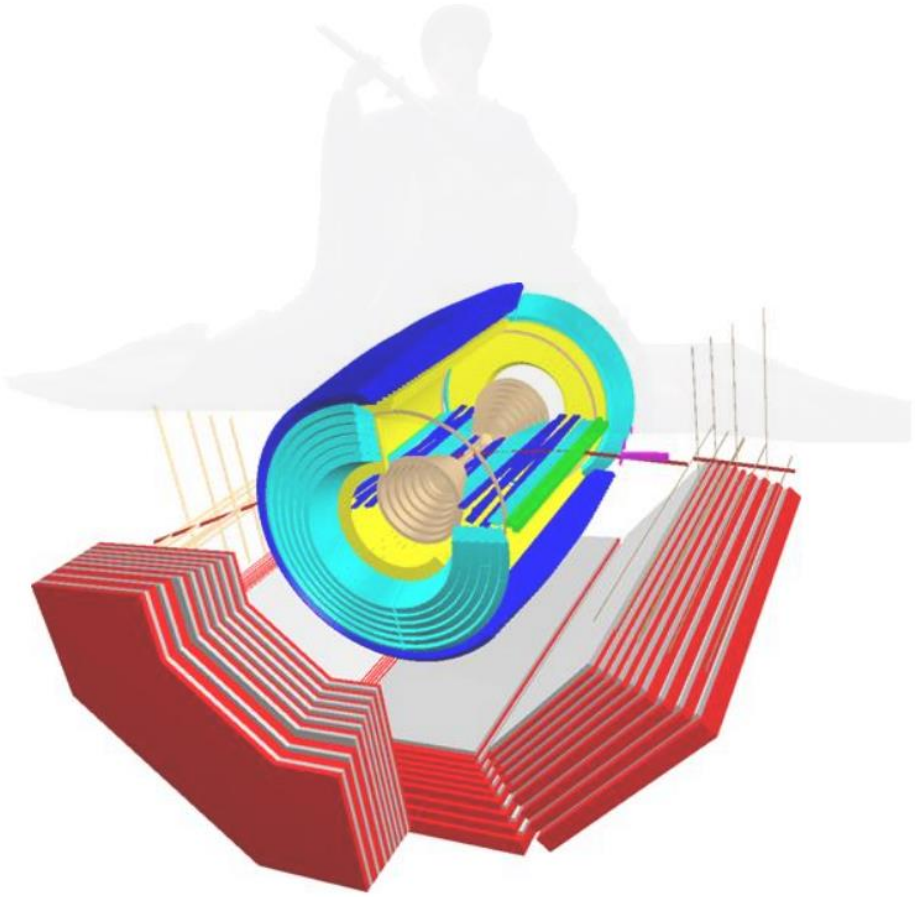




- **Distinguishing anti-neutron and anti-Lambda baryon with the EMC cluster shape is feasible.**
- **Feasible but achieving this task is still highly complex**

OUTLINE

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



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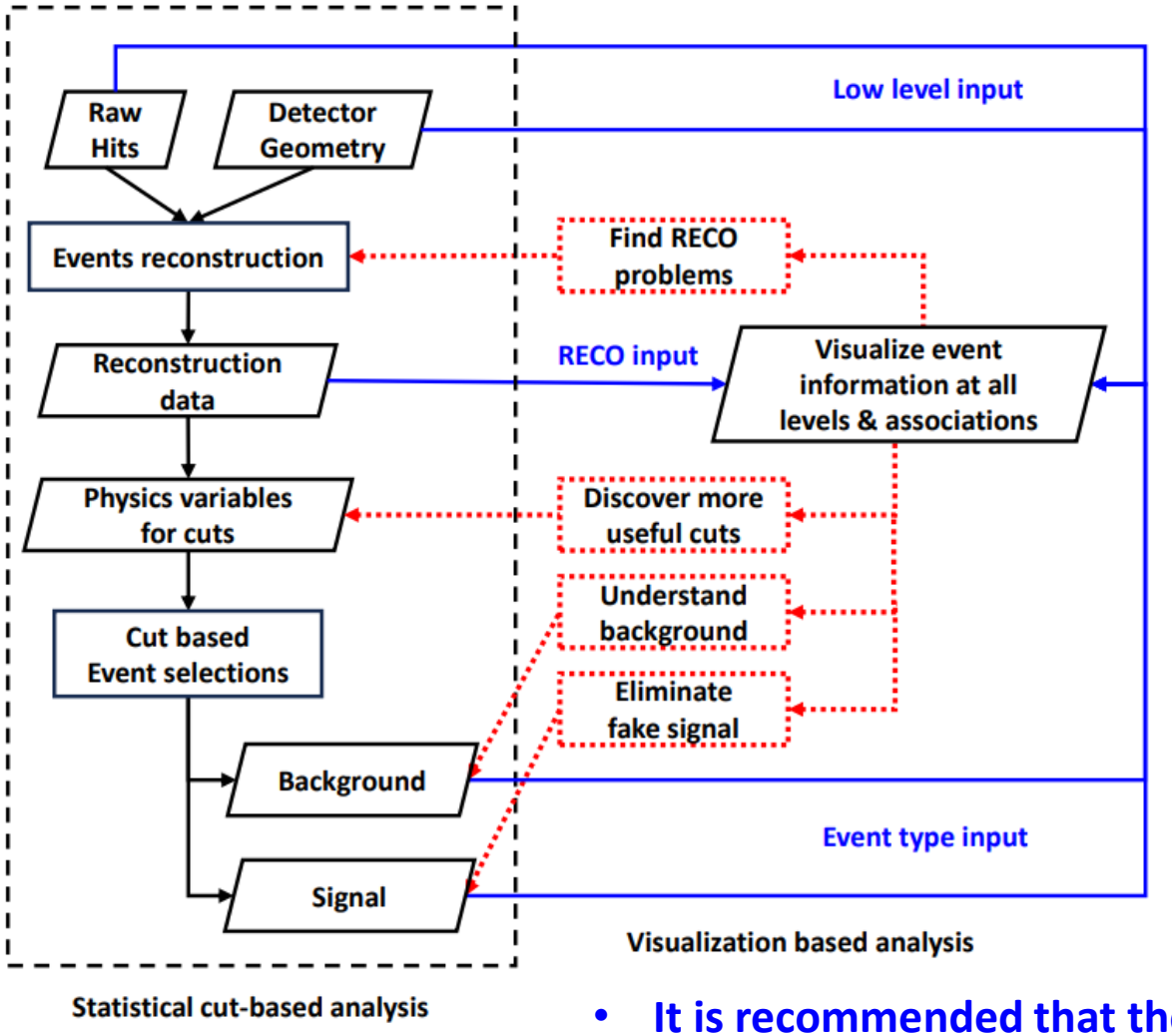
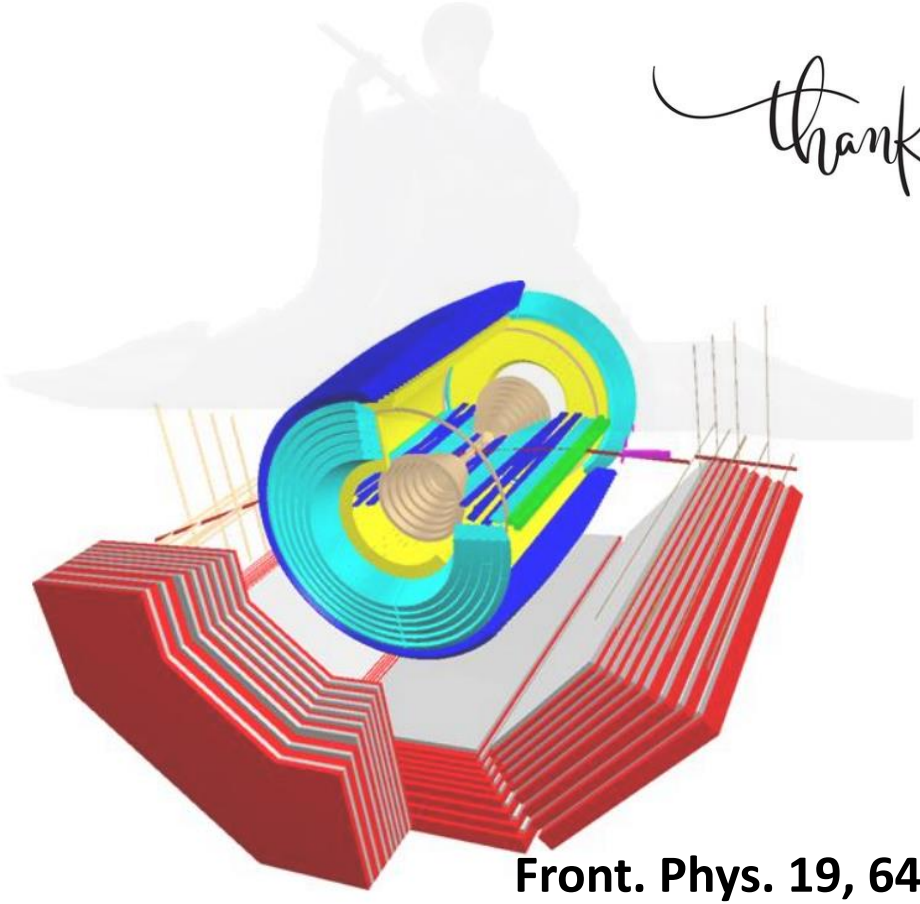
Summary





thank you

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arxiv: 2404.07951

- It is recommended that the visualization method be generally taken in physics analysis, especially in search for rare physics signals