Search for invisible decays at BESIII

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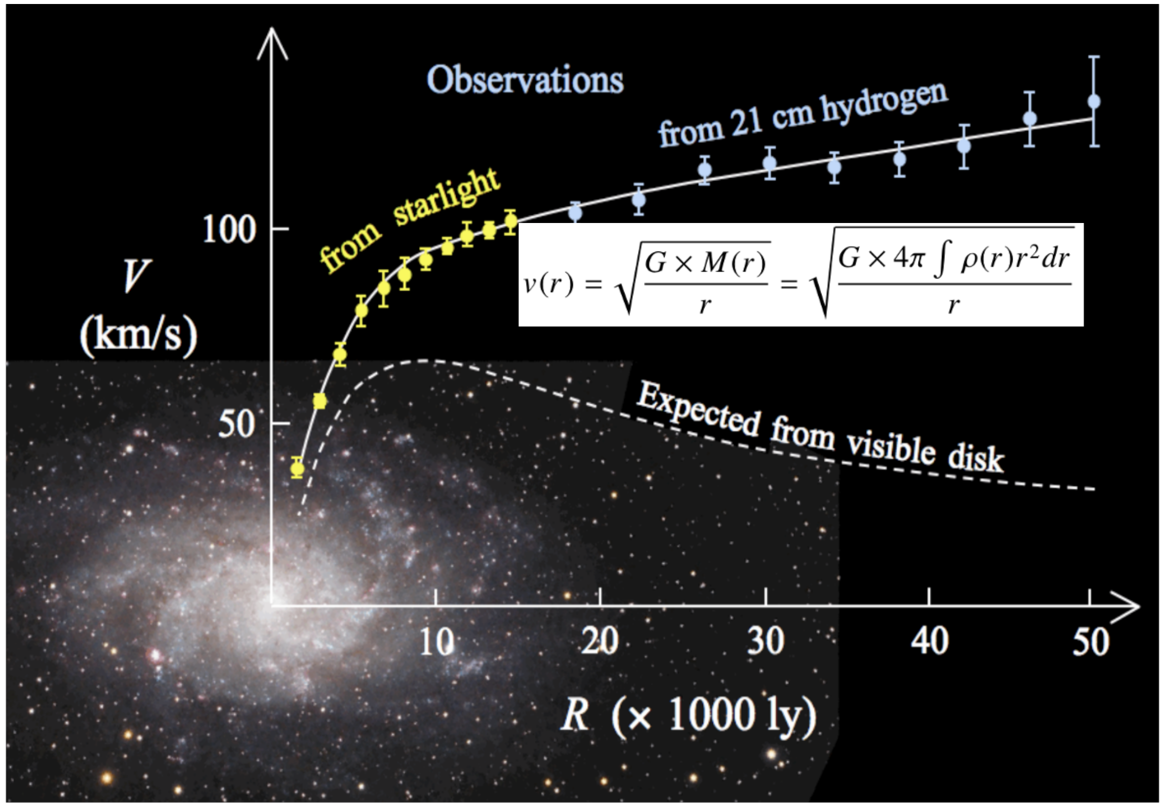
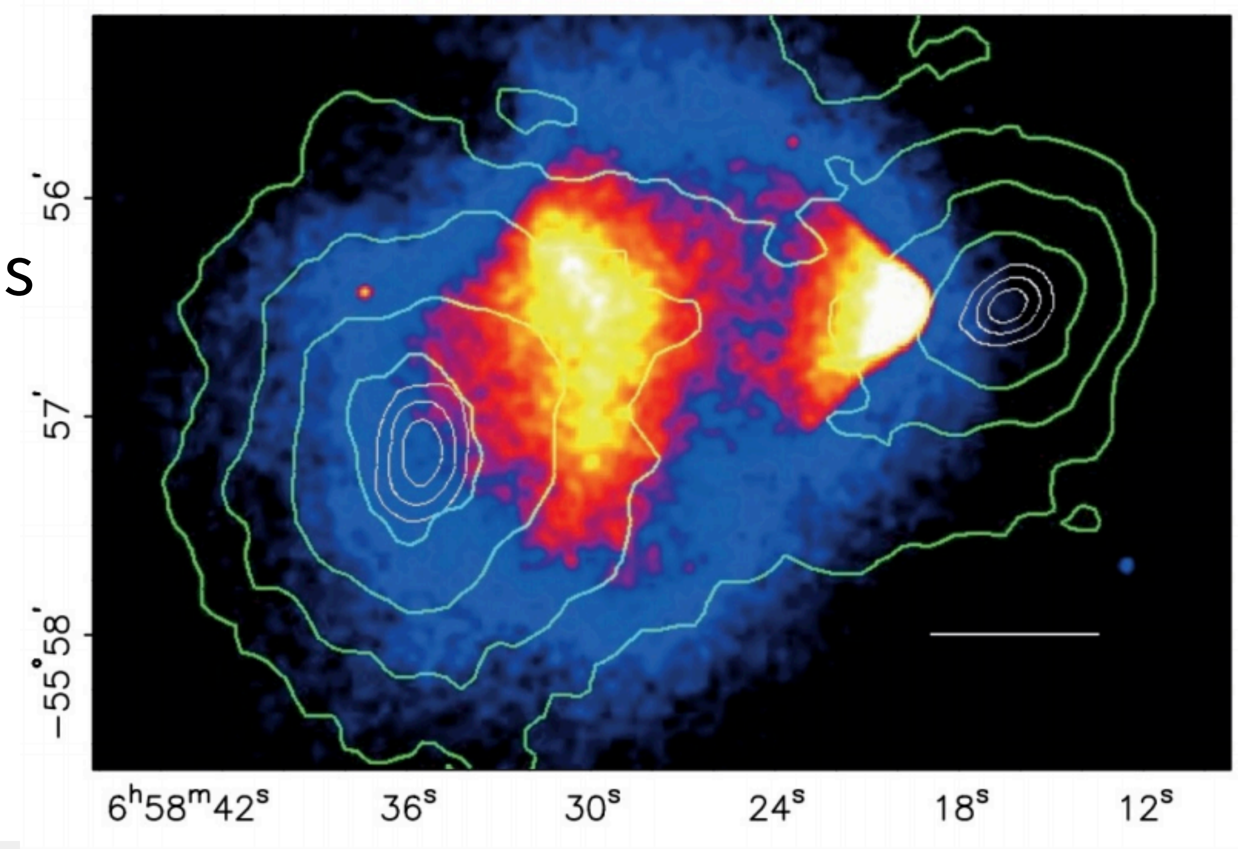
(On behalf of the BESIII collaboration)

Why invisible decays

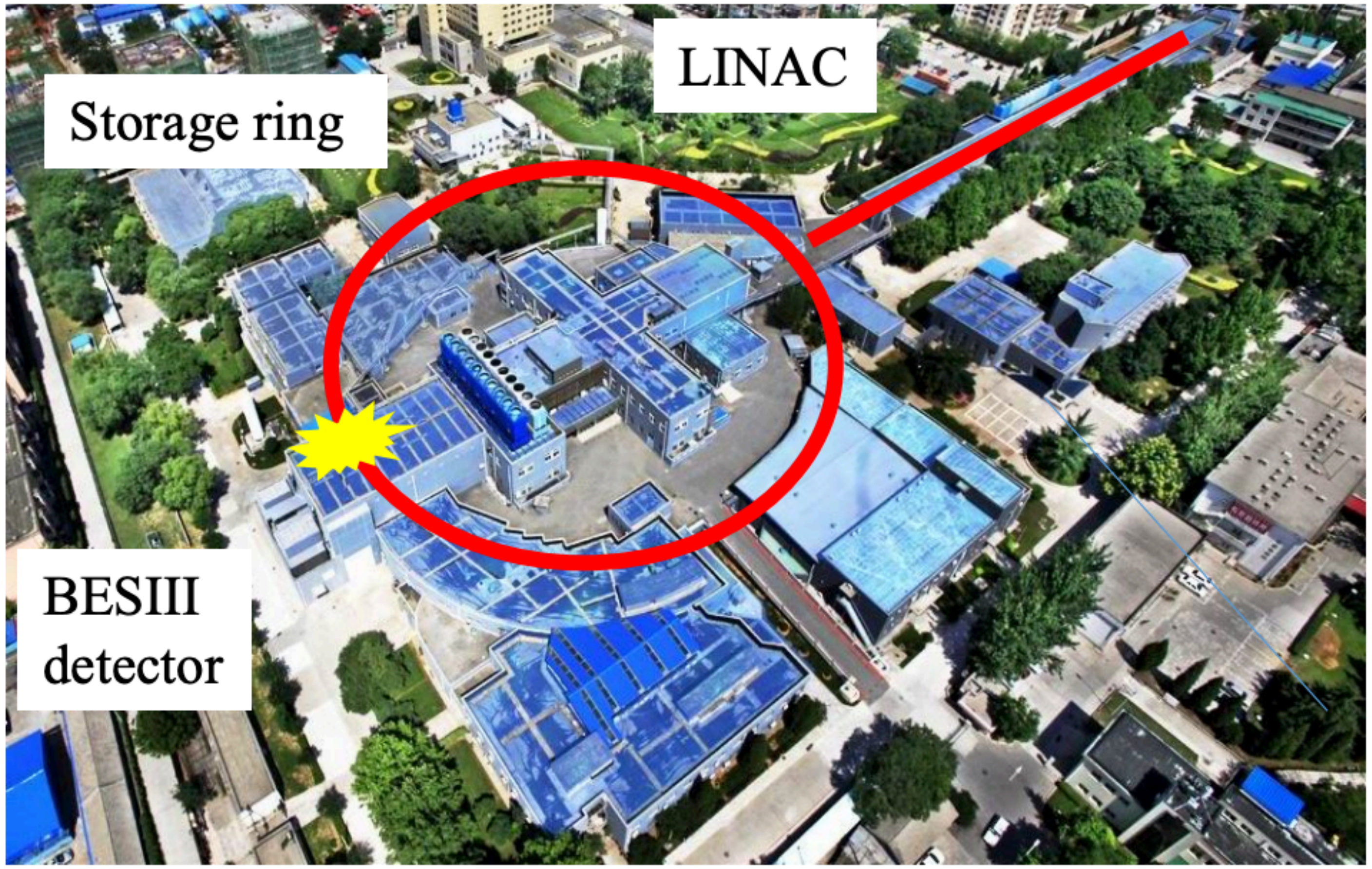


- ➔ Understanding DM is one of the highly topical subjects in both astronomy and particle physics.
- ➔ Many evidences for the existence of DM are observe in astronomy. There is no evidence in collider experiments.
- ➔ DM, one of compelling reasons to NP.

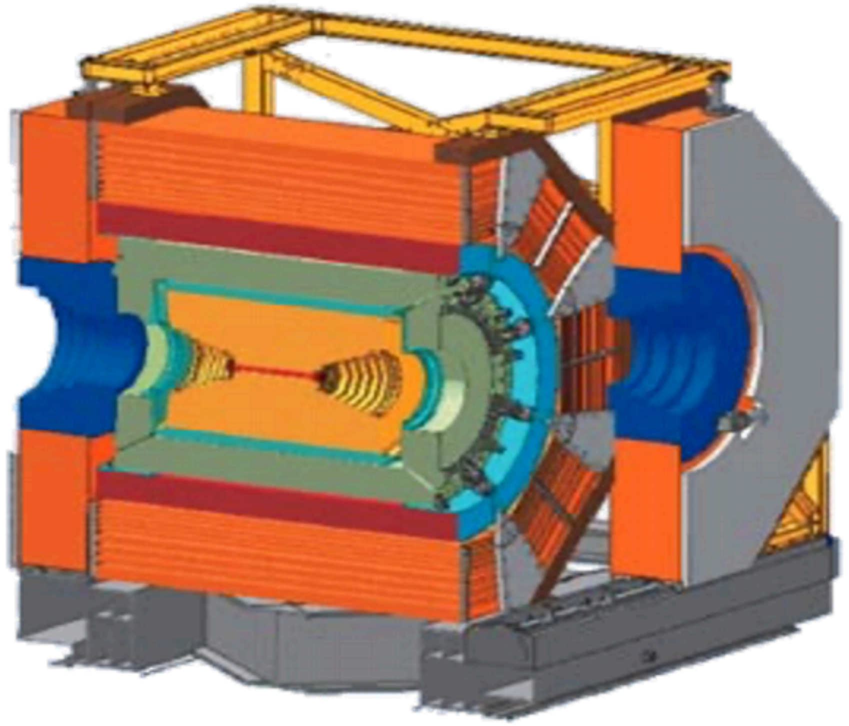


- ➔ Search for invisible decays at colliders is one way to search for DM.
- ➔ This talk focuses on recent search for invisible decays at BESIII.

BEPCII and BESIII



BEPCII:
- First collision in 2008, physics run in 2009
- Energy region: 2.0 – 4.95 GeV
- Designed luminosity: $1\times10^{33}\ cm^{-2}s^{-1}$ @ $\psi(3770)$, reach in April 2016



MDC
- small cell & Gas, He/C_3H_8 (60/40)
- σ_{xy} = 120 μm
- σ_p/p = 0.5% @ 1 GeV/c
- dE/dx = 6%

TOF
- σ_t = 80 ps (Barrel)
  60 ps(Endcap)

EMC:
- CsI(Tl)
- $\Delta E/E$ = 2.5% @ 1 GeV
- σ_z=0.6 cm

MUC
- 9 layers RPC for barrel
- 8 layers RPC for endcap

Superconducting magnet (1T)

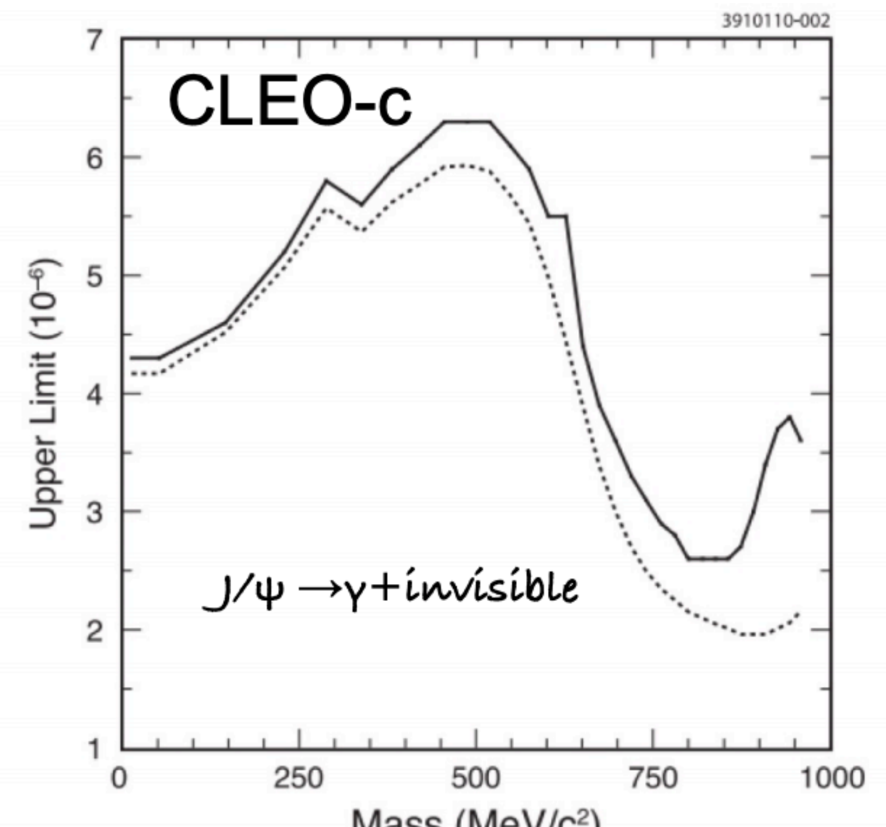
Search for $J/\psi \to \gamma + \text{invisible}$

Phys. Rev. D 101, 112005 (2020)

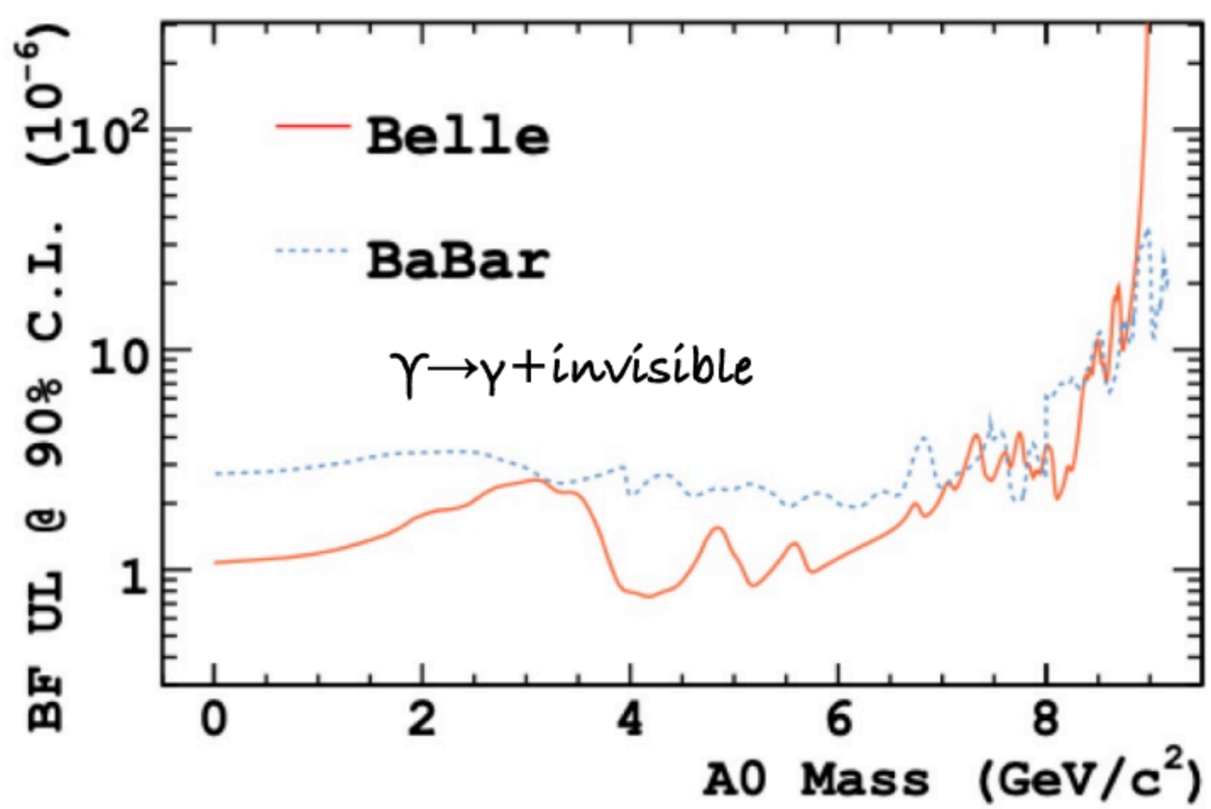
Introduction

- A series of supersymmetric Standard Models, including Next-to-Minimal Supersymmetric Model, predict a CP-odd pseudoscalar Higgs (A^0). The A^0 can be produced in quarkonium rediative decay:

  - $$\frac{\mathcal{B}(V \to \gamma A^0)}{\mathcal{B}(V \to \gamma\mu\mu)} = \frac{G_F m_q^2 g_q^2 C_{QCD}}{\sqrt{2}\pi\alpha}\left(1 - \frac{m_{A^2}^2}{m_V^2}\right)$$
  - A^0 can decay to two neutralinos, $g_c = \cos\theta_A / \tan\beta$, $g_b = \cos\theta_A / \tan\beta$.



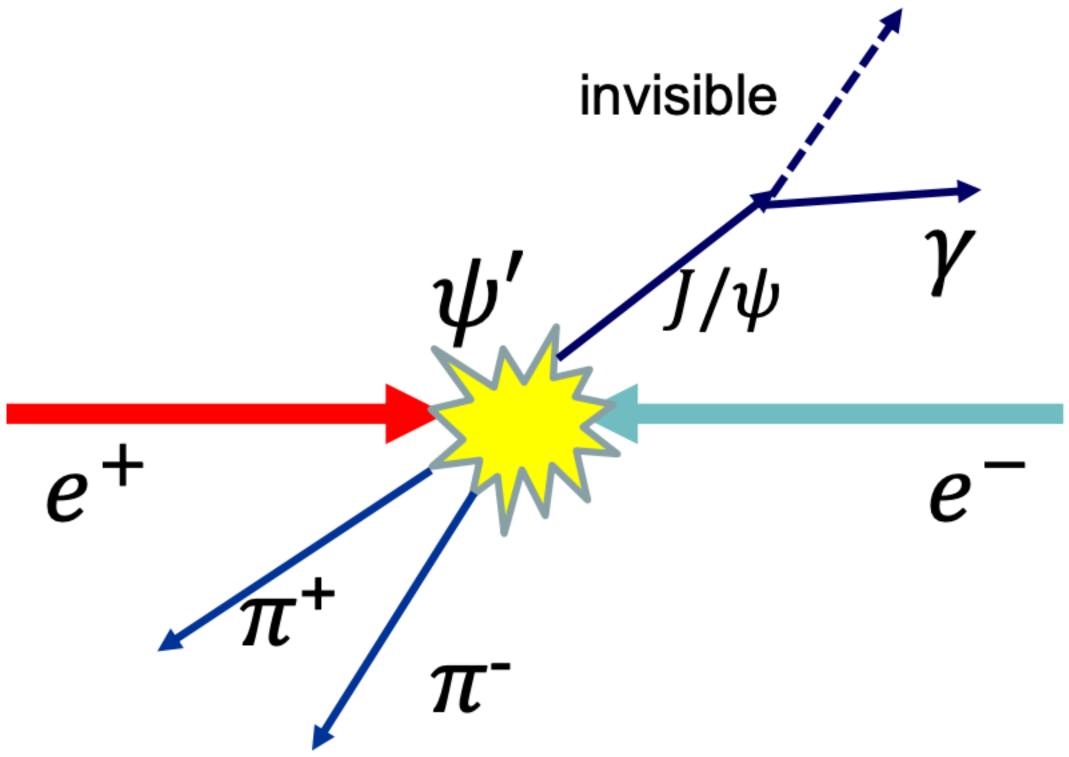
Phys. Rev. D 81,091101(R)(2010)

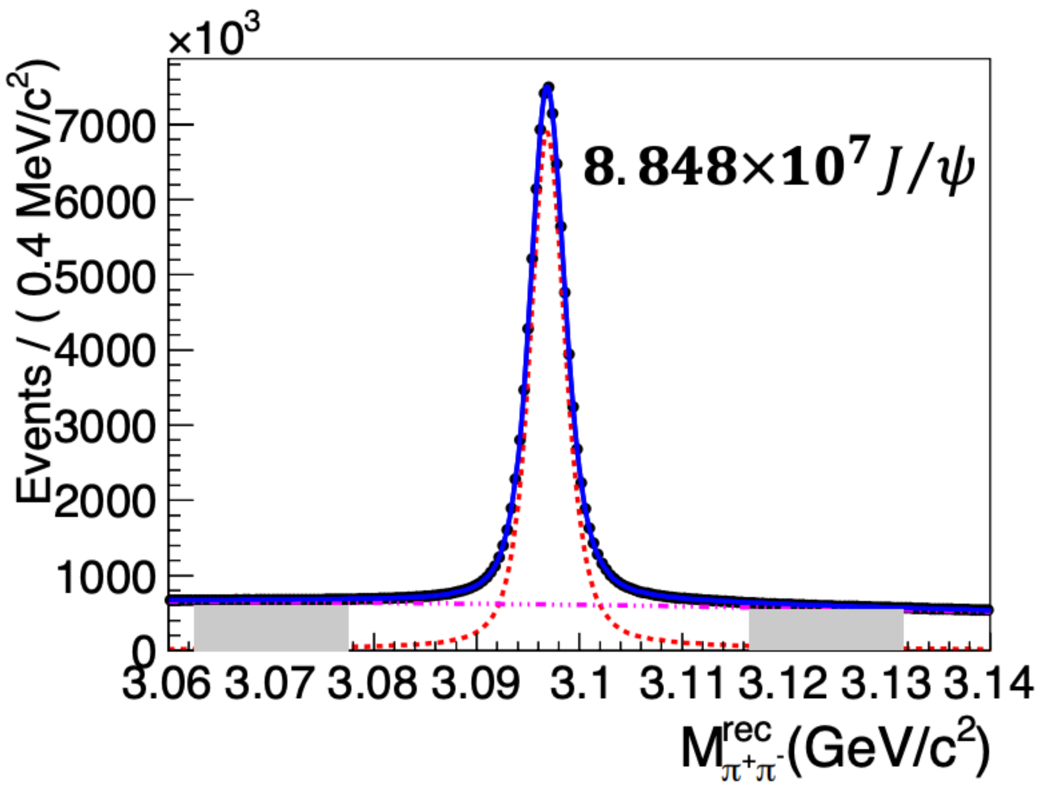


Phys. Rev. Lett 122 no.1 011801(2019)

Strategy

- Using $\psi' \to \pi^+\pi^- J/\psi$ to get J/ψ sample.
  - The $\pi^+\pi^-$ provide excellent trigger.
  - Large BR (34.68%)
- Reconstruct $\pi^+\pi^-$ to tag J/ψ firstly, then search for signal.
  - $\mathscr{B} = \dfrac{N_{sig} \cdot \epsilon_{J/\psi}}{N_{J/\psi} \cdot \epsilon_{sig}}$
- Fit to the recoil mass of $\pi^+\pi^-$, get $8.848 \times 10^7 J/\psi$ from $4.481 \times 10^8 \psi'$ data set.

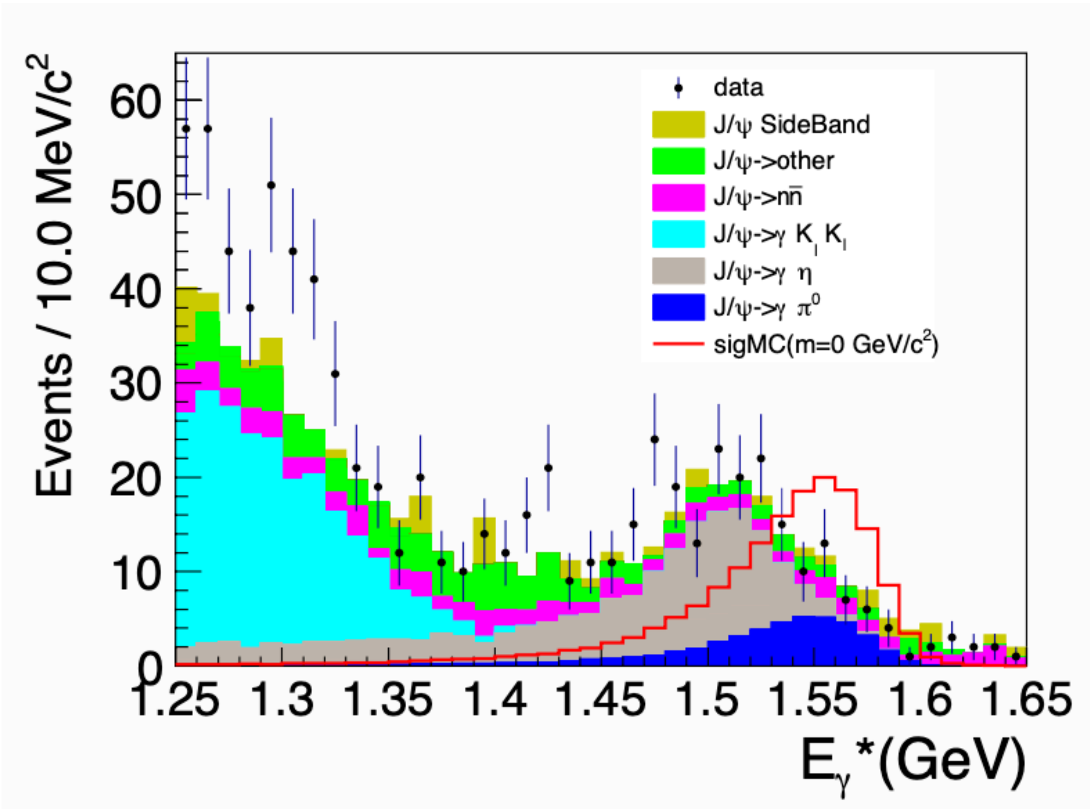


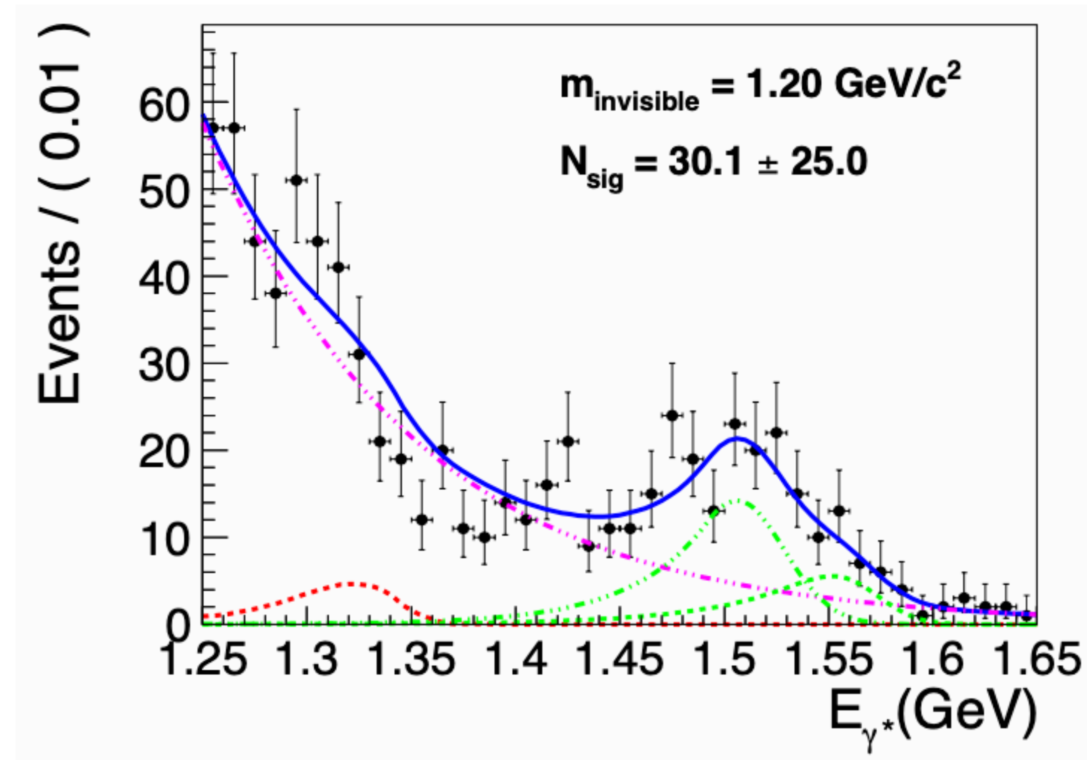


Background Estimation

- Based on tagger J/ψ sample, search for $J/\psi \to \gamma + \text{invisible}$.
  - Only $\pi^+\pi^-$ and one good shower (signal shower) in detector.
  - Signal shower and recoiled invisible must direct to the barrel region.
- Huge background from $J/\psi \to n\bar{n}, J/\psi \to \gamma n\bar{n}, J/\psi \to \gamma K_L^0 K_L^0 \ldots\ldots$
- Separate γ from $n, \bar{n}, K_L^0$ with shower shape. However, $n, \bar{n}, K_L^0$ induced shower didn't simulate well.
- Control Sample
  - $\gamma : J/\psi \to \rho^0\pi^0, \pi^0 \to \gamma\gamma$
  - $n/\bar{n} : J/\psi \to p\pi n/\bar{n}$
  - $K_L^0 : J/\psi \to K\pi K_L^0$ & $J/\psi \to \pi\pi\phi, \phi \to K_S^0 K_L^0$
- Correct the shower energy and efficiency of $n, \bar{n}, K_L^0$ momentum dependently.

UL Estimation

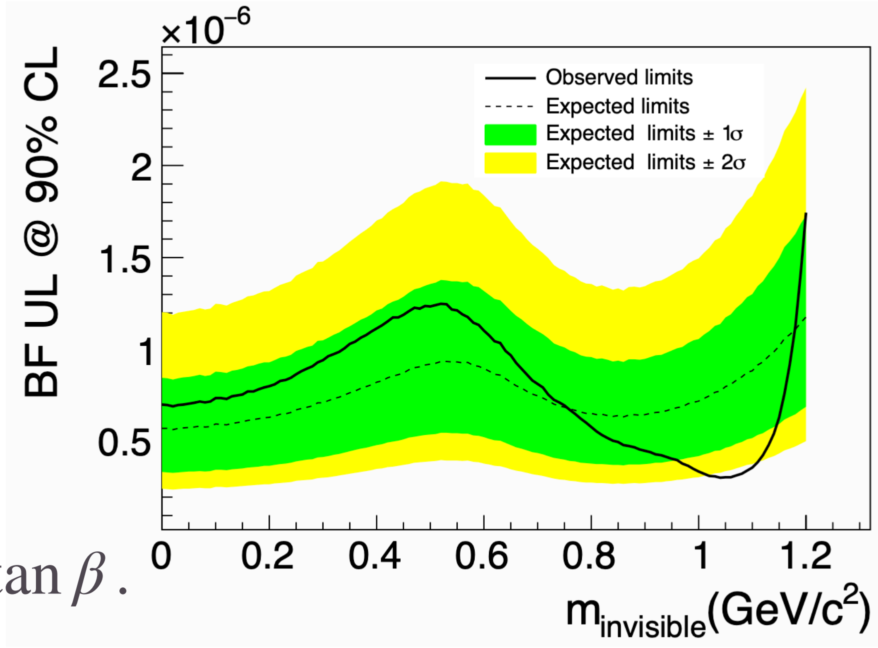


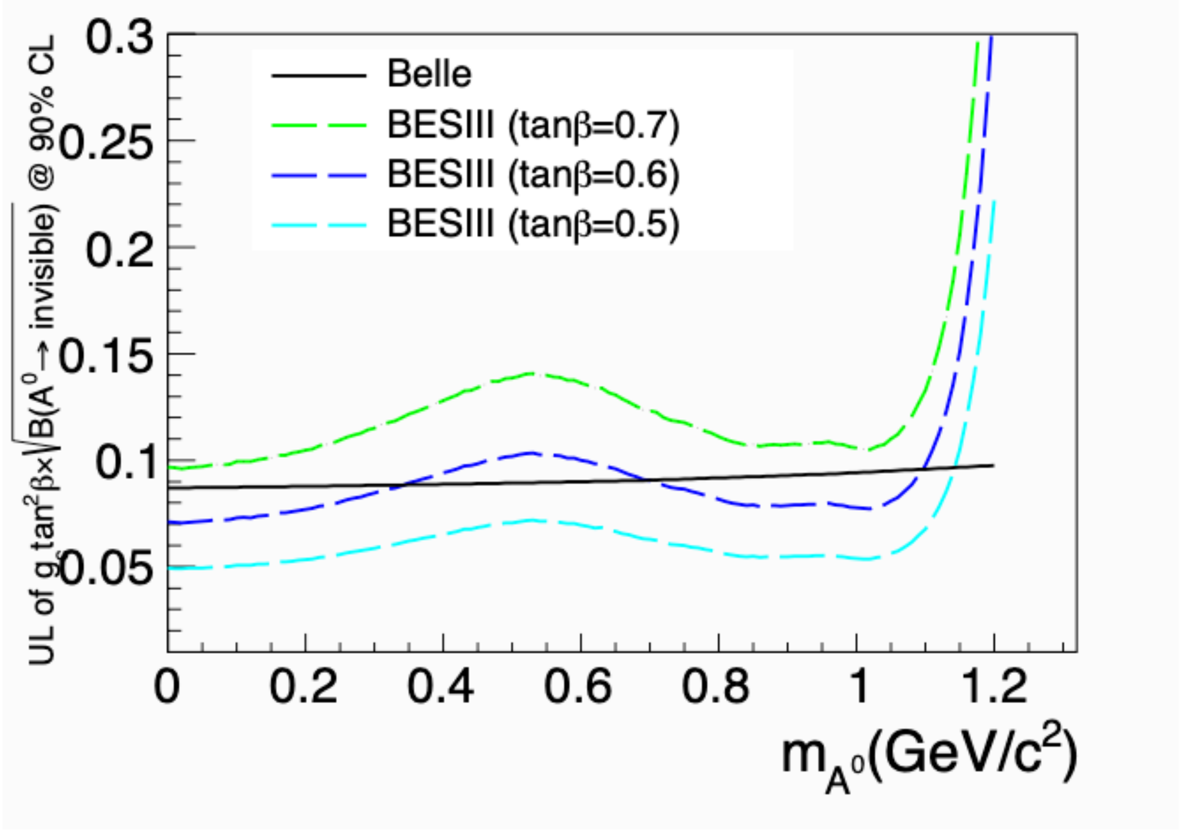


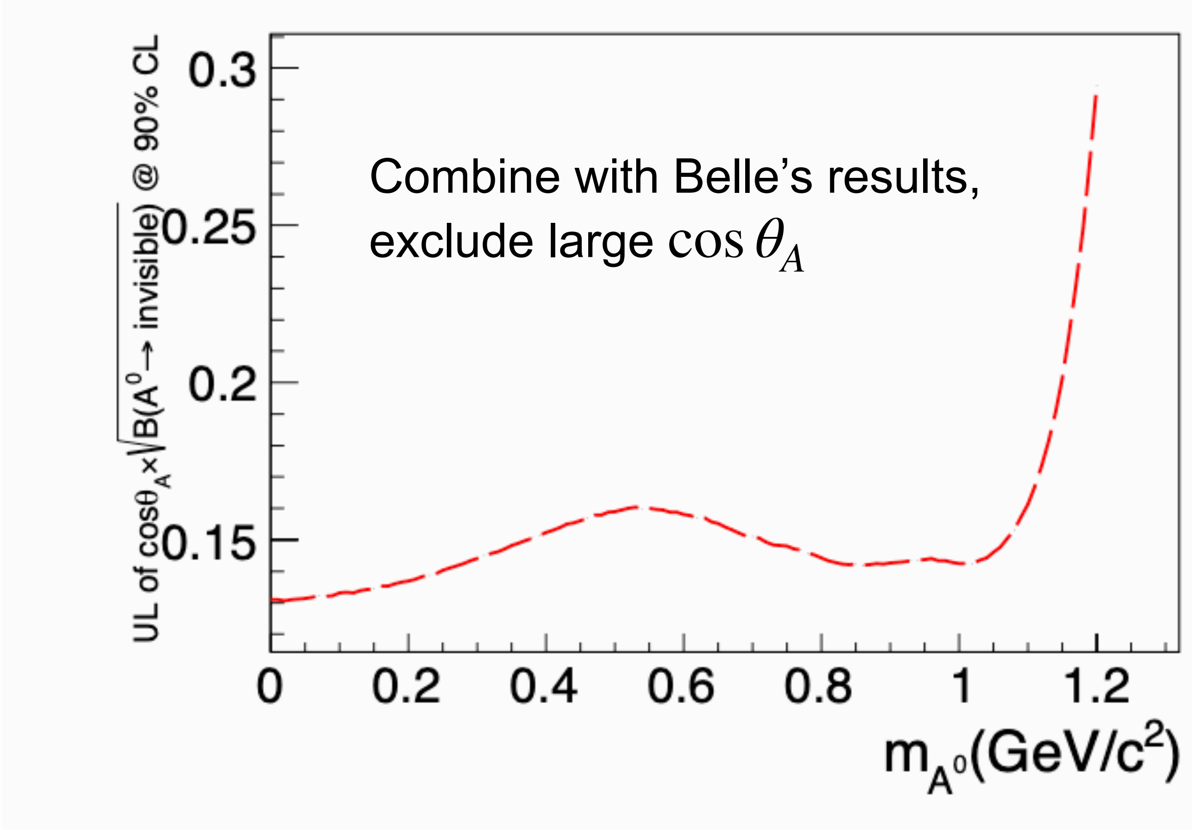
- ➔ Search signal on $E(\gamma)$ in J/ψ rest frame in [1.25, 1.65] GeV.
- ➔ Un-binned fit to extract signal.
- ➔ Signal: signal MC shape.
- ➔ Two peak bkg: fixed Crystal Ball, determined by fits on exclusive MC sample.
- ➔ Non-peak bkg: exponential function.
- ➔ Scan m(invisible) from $0 \sim 1.2 \mathrm{GeV/c^2}$
- ➔ No significant signal found. Max significant is 1.15σ.

Results

- ➔ Use the modified frequentist method to calculate upper limits.
- ➔ ~6.2 better than CLEO-c.
- ➔ Calculate UL for β and θ_A.
  - ❖ $$\frac{\mathscr{B}(V \to \gamma A^0)}{\mathscr{B}(V \to \gamma\mu\mu)} = \frac{G_F m_q^2 g_q^2 C_{QCD}}{\sqrt{2}\pi\alpha}(1 - \frac{m_{A^2}^2}{m_V^2})$$
  - ❖ A^0 can decay to two neutralinos, $g_c = \cos\theta_A/\tan\beta$, $g_b = \cos\theta_A/\tan\beta$.





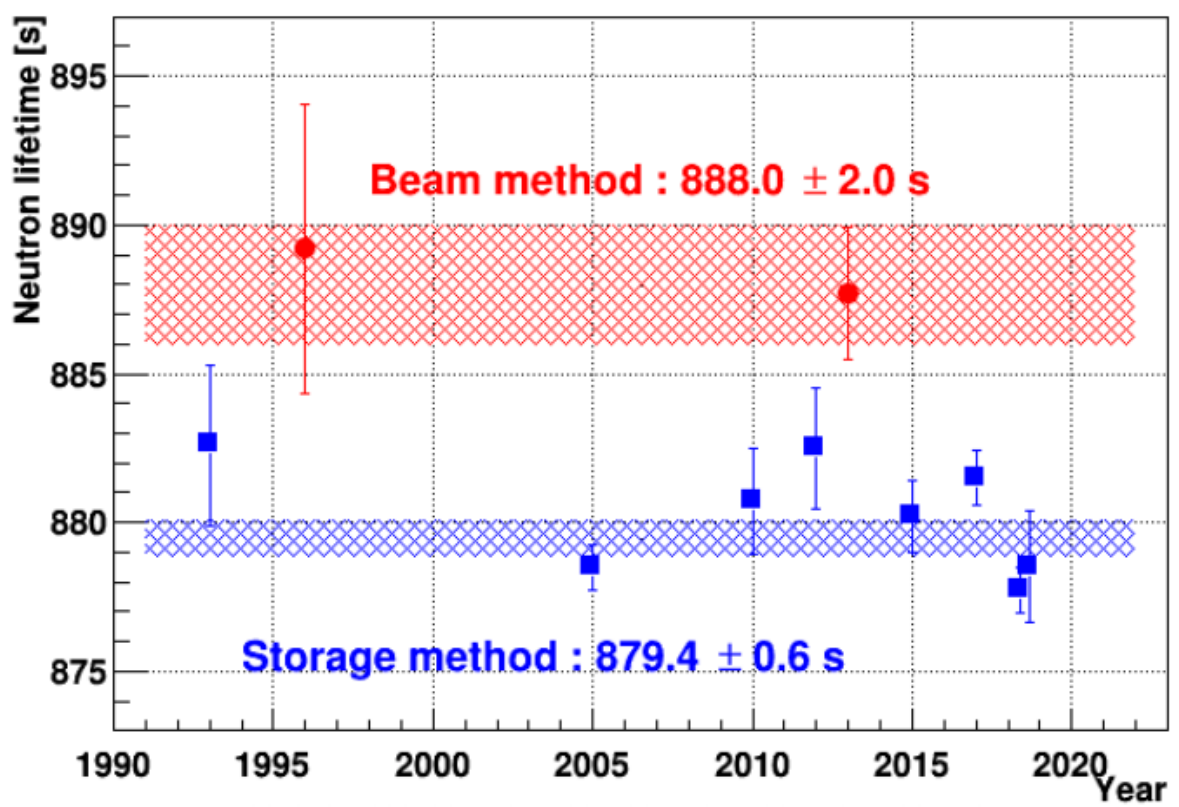


Search for $\Lambda \to \text{invisible}$

arXiv: 2110.06759

Introduction

2110.06759



JPS Conf.Proc. 33 (2021) 011056

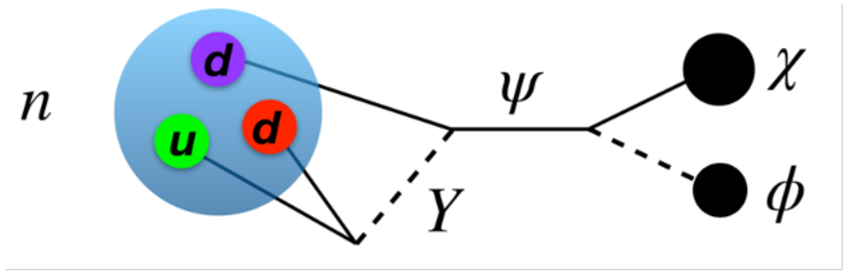
- ➔ $\tau(n)$ measured by beam method and storage method are different.

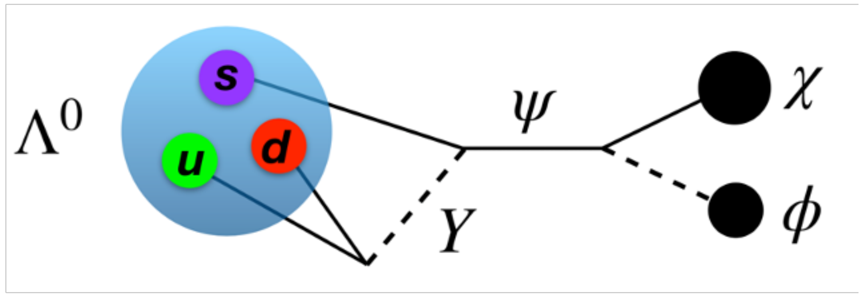
$$\tau_n^{beam} = \frac{\tau_n}{\mathcal{B}(n \to p + X)} > \tau_n^{bottle} \Rightarrow \mathcal{B}(n \to p + X) \approx 99\%$$

- ➔ The discrepancy can be explained by requiring 1% of the neutron decays into dark matter.

- ➔ Some models predict baryon invisible decays

Phys. Lett. B 745 (2015), 79
Phys. Rev. Lett. 111, 222501 (2013)





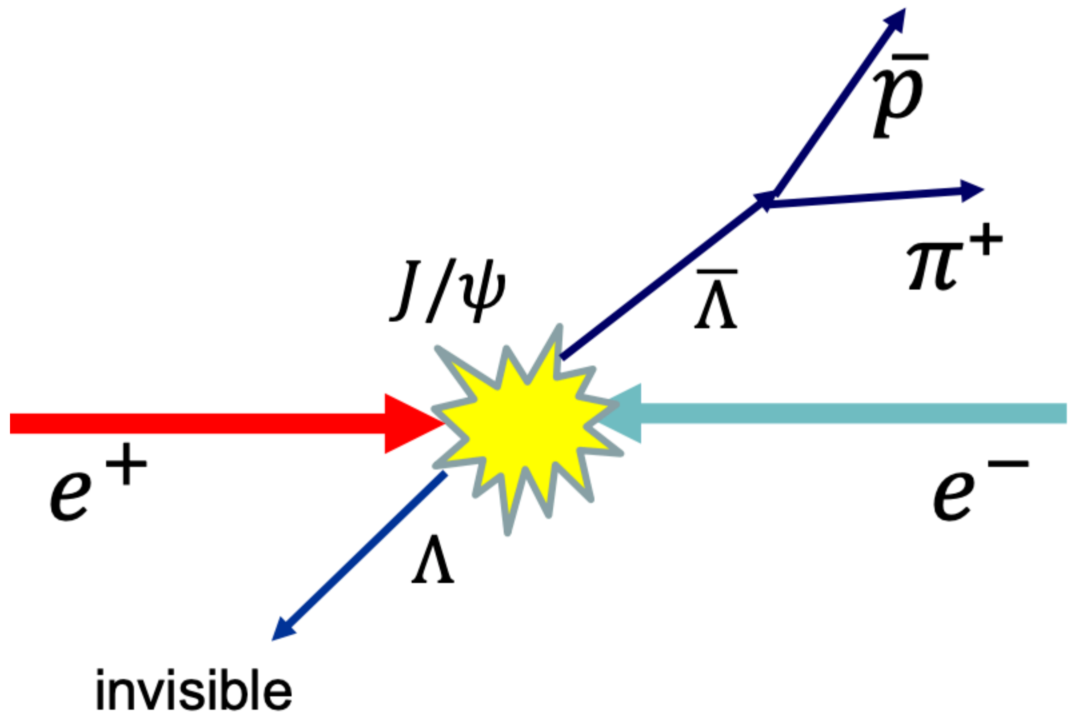
- ➔ No experimental search for baryon invisible decays until now.

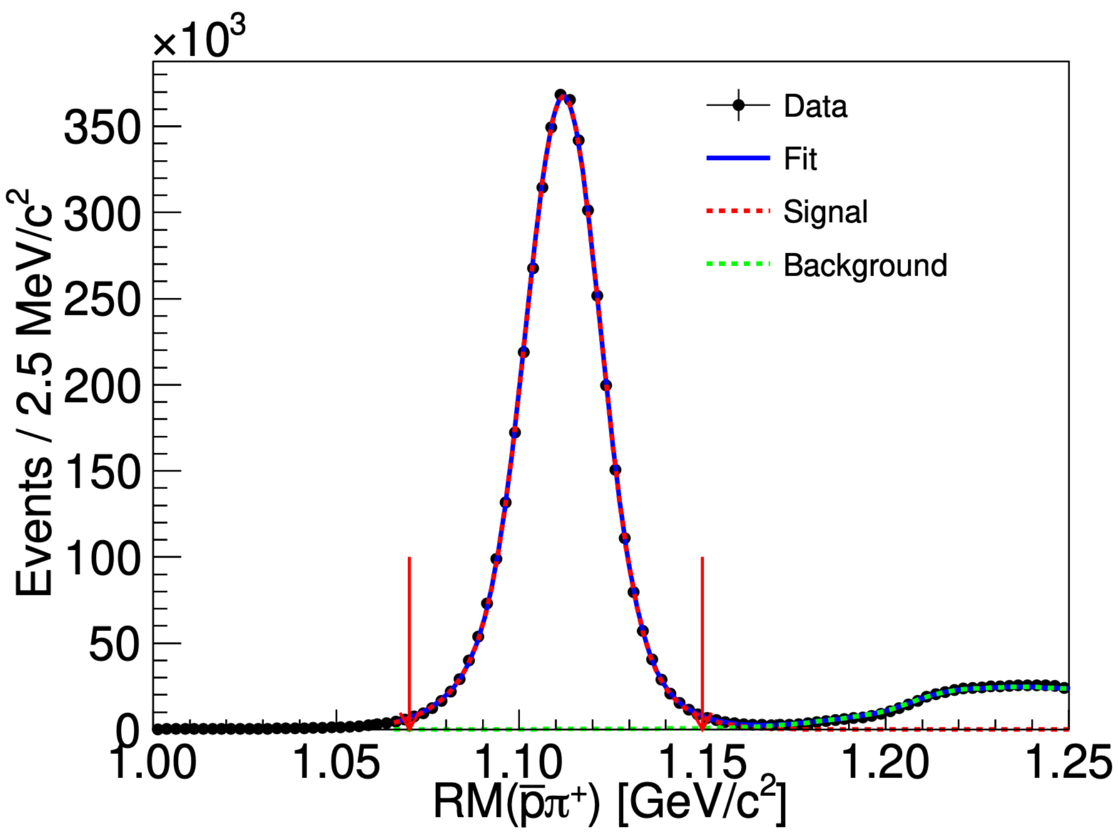
Strategy

- Using $J/\psi \to \Lambda\bar{\Lambda}$ to get Λ sample.

$$\mathcal{B}(\Lambda \to \text{invisible}) = \frac{N_{\text{sig}}}{N_{\text{tag}} \cdot (\varepsilon_{\text{sig}}/\varepsilon_{\text{tag}})}$$

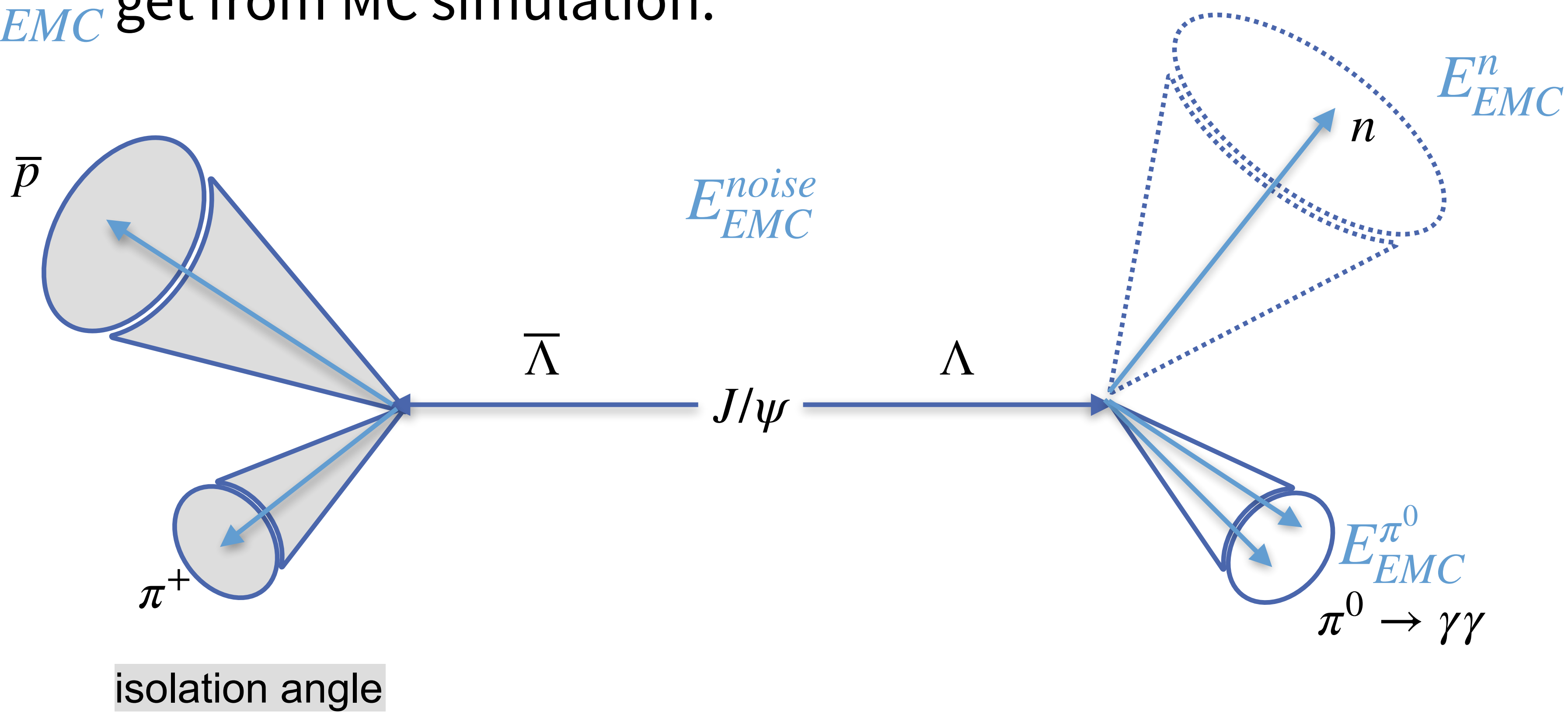
- Perform semi-blind procedure.
- Search for signal on total energy in EMC.
- Reconstruct $\bar{p}\pi^+$
  - Requiring TOF hit from charged tracks, to guarantee all showers are related to the event.
- Fit to the rec. mass of $\bar{p}\pi^+$, get 4.15×10^6 Λ.





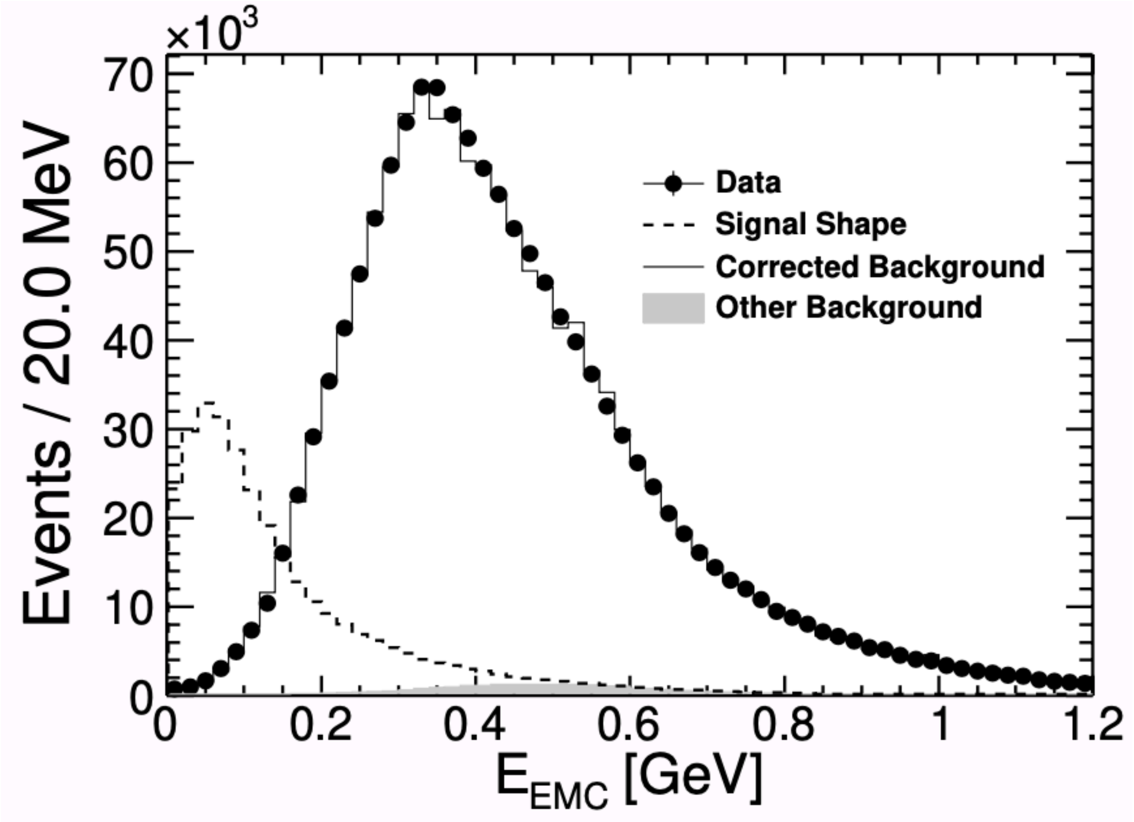
Background Estimation

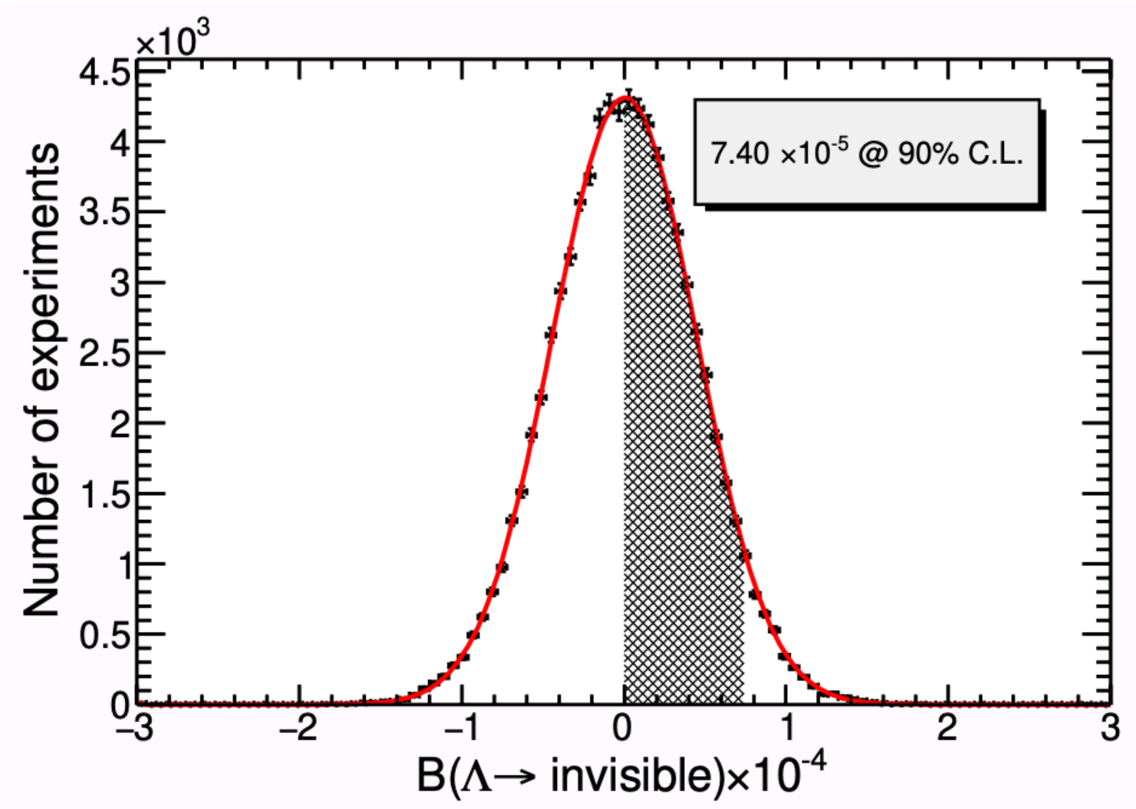
- ➔ Based on tagged Λ sample, no extra charger tracks are required.
- ➔ Search for signal on total energy in EMC(E_{EMC}).
- ➔ Main bkg is $\Lambda \to n\pi^0$. $E_{EMC} = E_{EMC}^{\pi^0} + E_{EMC}^{n} + E_{EMC}^{noise}$.
- ➔ Geant4 don't simulate n in EMC well. (Data Driven)
  - ❖ With control sample $J/\psi \to \Lambda(n\pi^0)\overline{\Lambda}(\overline{p}\pi^+)$, get precise $E_{EMC}^{n} + E_{EMC}^{noise}$.
  - ❖ $E_{EMC}^{\pi^0}$ get from MC simulation.



Results

- Data consistent with MC well. No obvious signal.
- Use the modified frequentist method to calculate upper limits.
- $\mathscr{B}(\Lambda \to \text{invisible}) < 7.4 \times 10^{-5}$ with 10B J/ψ data.
- First search for baryon invisible decay.





Summary

- ➔ We review several searches about invisible decays.
- ➔ Large data sample, large BF, narrow intermediate hadron widths provide excellent opportunity to search for invisible decays at BESIII.
- ➔ More huge data in BESIII. Many ongoing invisible searches. More exciting results in future.

Thank you!