Search for invisible decays at BESIII

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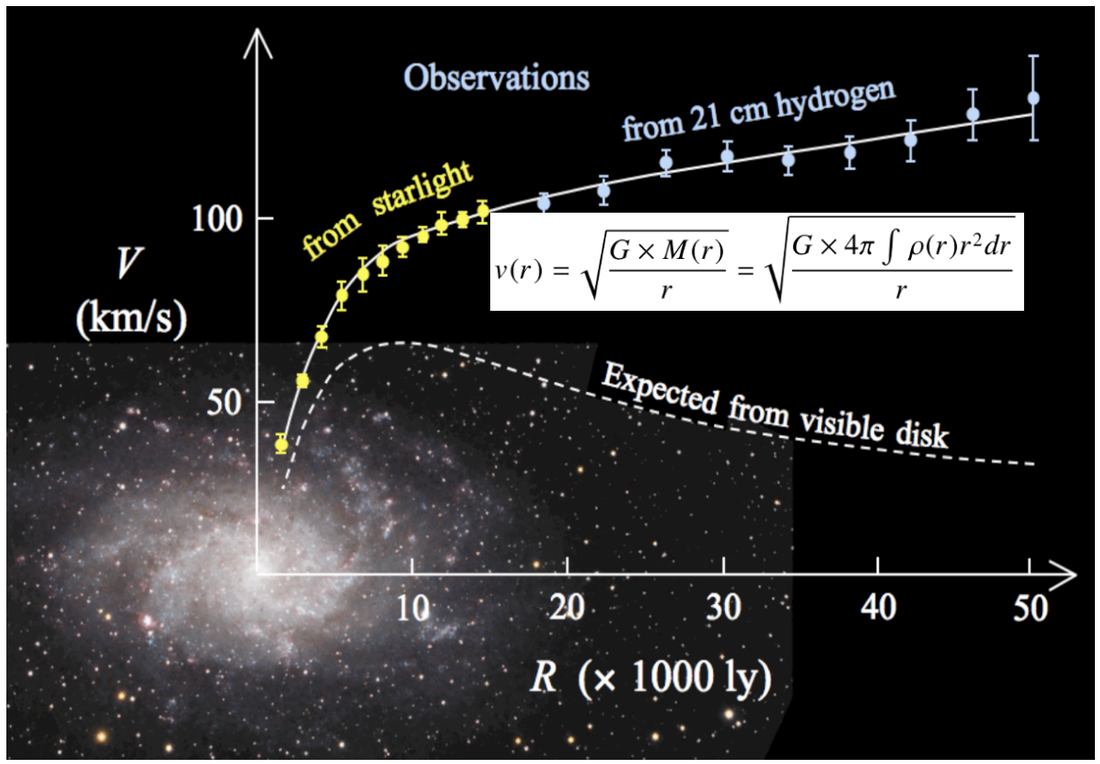
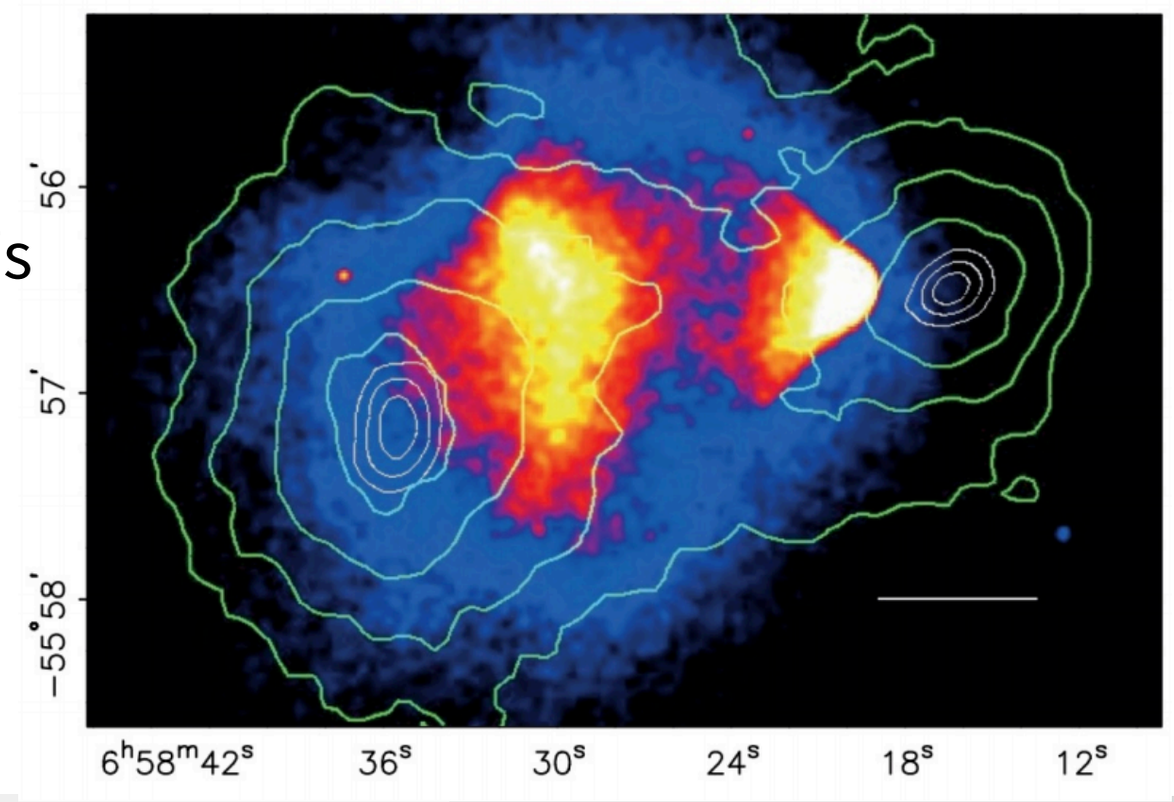
Why invisible decays



- ➔ 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.



Searches for invisible decays at BESIII

➔ Search for η and η' invisible decays in $J/\psi \to \phi\eta$ and $J/\psi \to \phi\eta'$.

- Phys. Rev. D 87, 012009 (2013)

➔ Search for invisible decays of $V(\omega, \phi)$ in $J/\psi \to V\eta$.

- Phys. Rev. D 98, 032001 (2018)

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

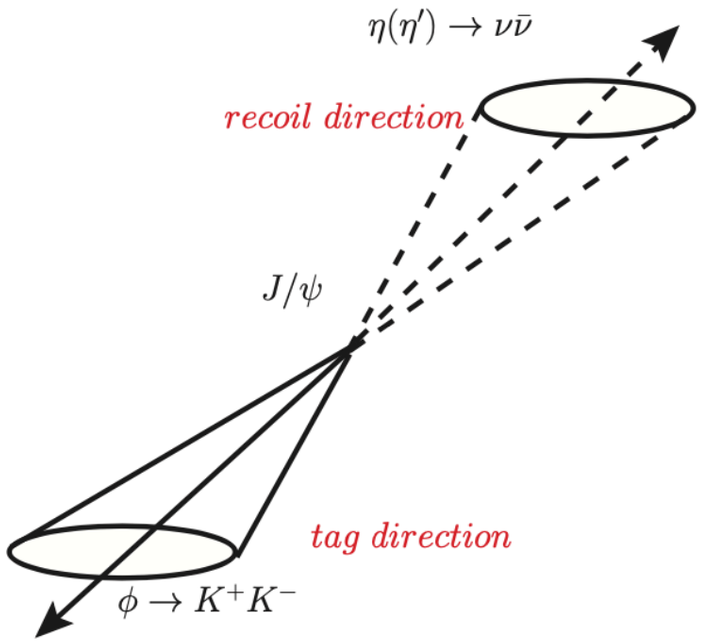
- Phys. Rev. D 101, 112005 (2020)

➔ Search for $\Lambda \to \text{invisible}$ in $J/\psi \to \Lambda\overline{\Lambda}$

- arXiv: 2110.06759

Search for η and η' invisible decays

- ➔ η/η' decay play special role in low energy scale QCD theory.
- ➔ Invisible and radiative decays offer a window for NP beyond SM.
- ➔ 225M J/ψ sample, large branching fraction of $J/\psi \to \phi\eta^{(\prime)}$ and narrow intermediate meson widths provide clean, large η/η' sample.



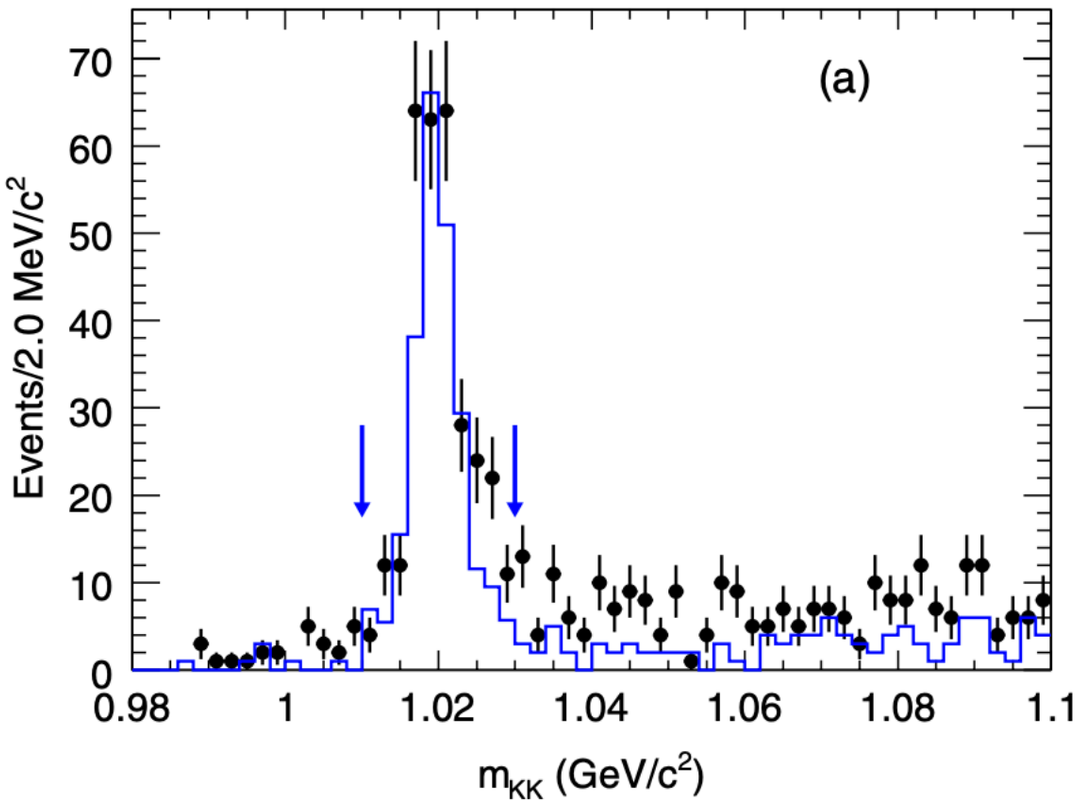
- ➔ Get the ratio of $\eta^{(\prime)} \to$ invisible decay relative to the $\eta^{(\prime)} \to \gamma\gamma$.

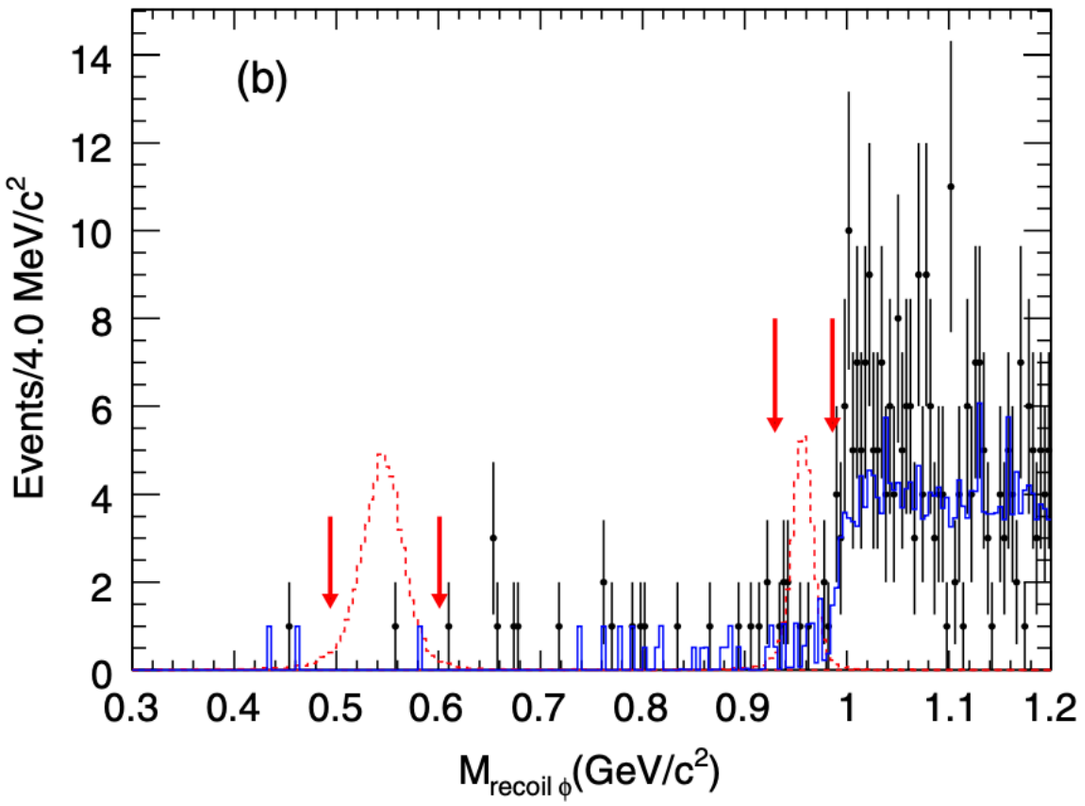
$$\frac{Br(\eta(\eta') \to invisible)}{Br(\eta(\eta') \to \gamma\gamma)}$$

- ➔ Many uncertainties will be canceled.

Search for η and η' invisible decays

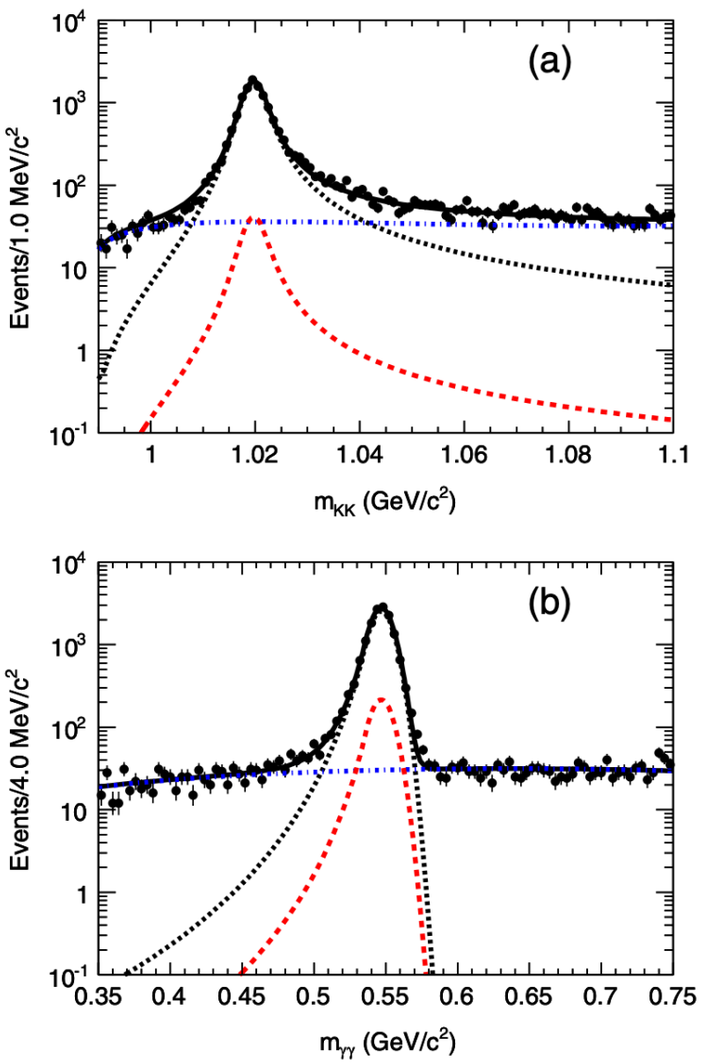
- ➔ Reconstruct K^+K^- to tag ϕ firstly, then search for signal.
- ➔ No charged tracks besides those of the $\phi \to K^+K^-$.
- ➔ $N_{\rm shower}$ are required to be zero inside a cone of 1.0 rad around the recoil direction against the ϕ candidate.
- ➔ $|\cos\theta_{\rm recoil} < 0.7|$ to ensure the $\eta^{(\prime)}$ decay particles are inside the fiducial volume of the detector.

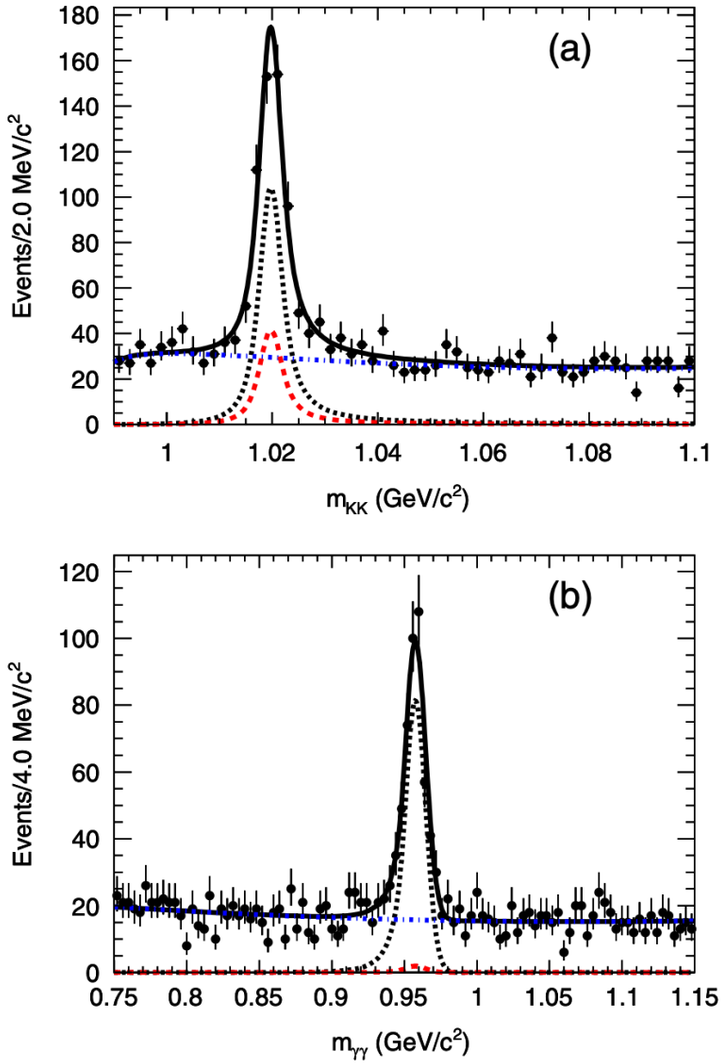




Search for η and η' invisible decays

➔ Reconstruct $\eta^{(\prime)} \to \gamma\gamma$ and $\phi \to K^+K^-$.





Br(η′→invisible)/Br(η′→γγ)<2.39×10⁻²
Br(η →invisible)/Br(η→γγ)<2.58×10⁻⁴

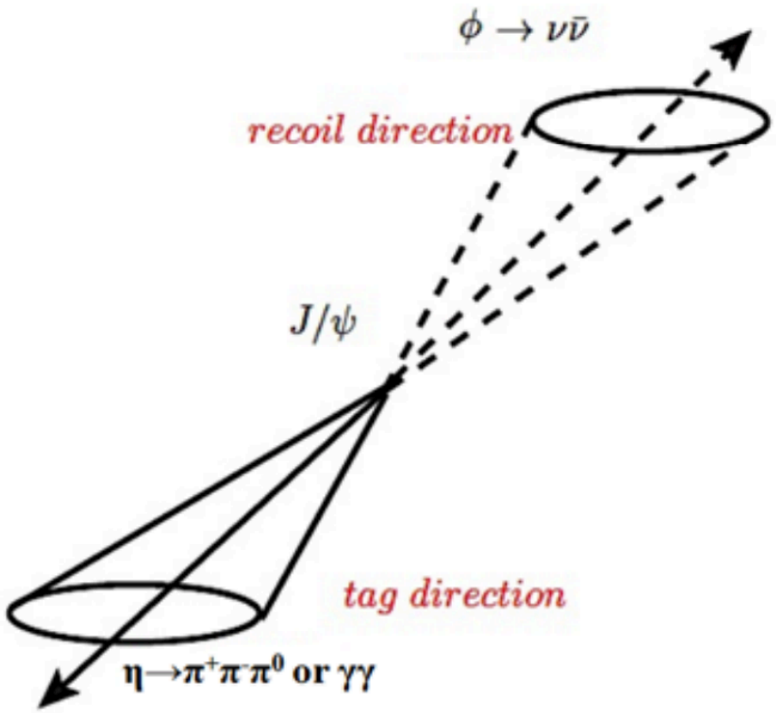
Br(η′→invisible)<5.21×10⁻⁴@90%C.L.
Br(η →invisible)<1.01×10⁻⁴@90%C.L.
Improved PDG Values

PDG : Br(η′→invisible)<9×10⁻⁴@90%C.L
Br(η →invisible)<6×10⁻⁴@90%C.L.

Theory : Br(η′→χχ) ~8.1×10⁻⁷
Br(η →χχ)~7.4×10⁻⁵
B. McElrath, PRD 72, 103508 (2005)

Search for ω and ϕ invisible decays

- ➔ 1.3B J/ψ sample, large branching fraction of $J/\psi \to \phi\eta$ and narrow intermediate meson widths provide clean, large ω/ϕ sample.
- ➔ Constrain the masses of the LDM particles and the coupling of a U boson to the light quark.

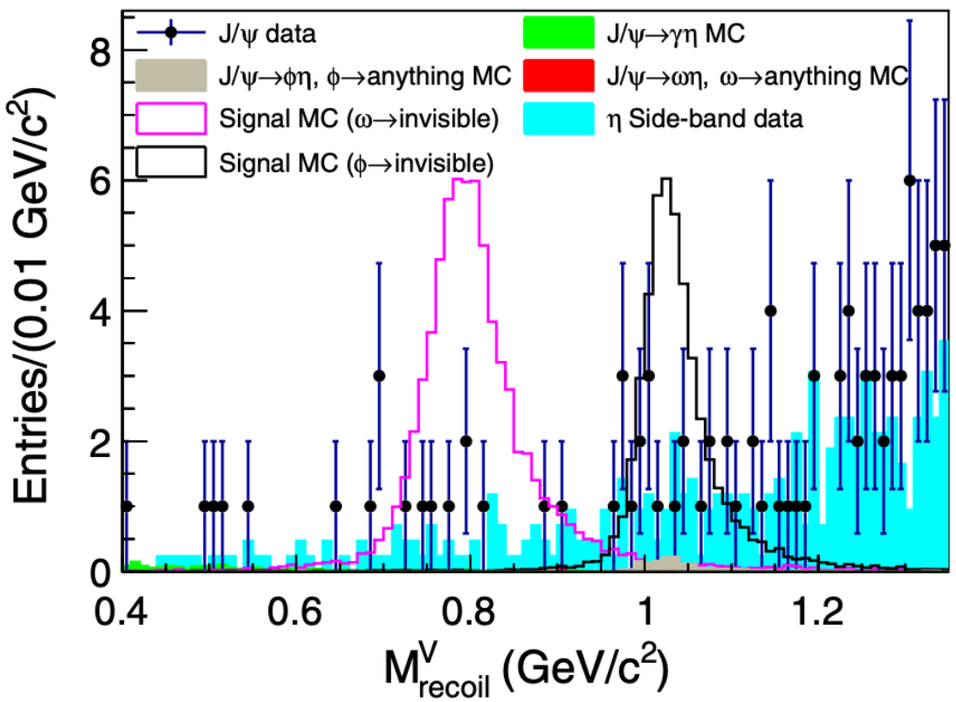


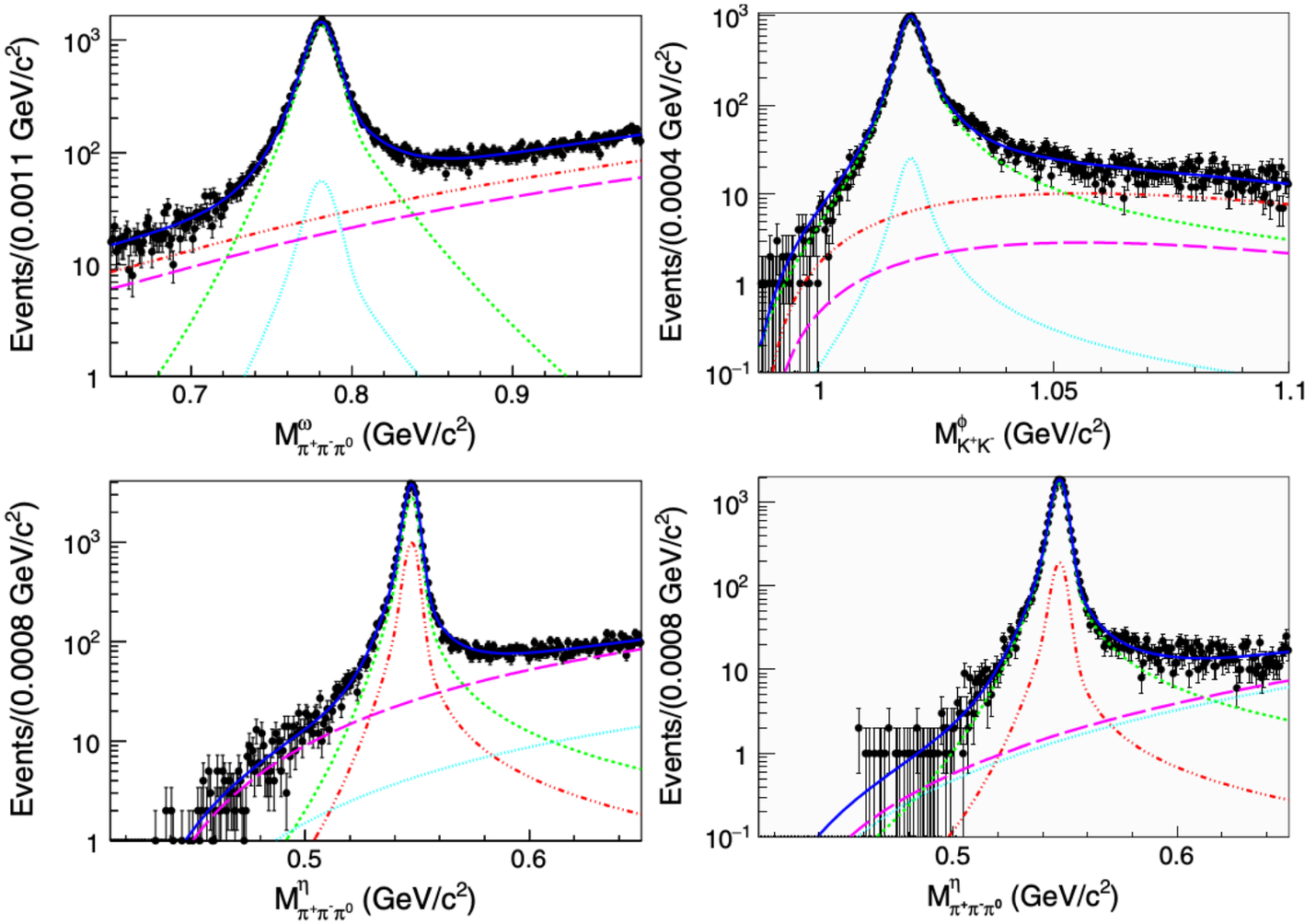
- ➔ Get the ratio of BF of the invisible decay to the visible decay:

$$\frac{\mathcal{B}(V \to \text{invisible})}{\mathcal{B}(V \to \text{visible})} = \frac{N_{\text{sig}}^{\text{invisible}} \cdot \epsilon^{\text{visible}}}{N_{\text{sig}}^{\text{visible}} \cdot \epsilon^{\text{invisible}}},$$

Search for ω and ϕ invisible decays

- ➔ Reconstruct $J/\psi \to V\eta,\ \eta \to \pi^+\pi^-\pi^0$.
- ➔ $|\cos\theta_{\text{recoil}} < 0.7|$ to ensure the $V(\phi, \omega)$ decay particles are inside the fiducial volume of the detector.
- ➔ $E_\gamma^{\text{Extra}} < 0.2\ \text{GeV}$, where E_γ^{Extra} is the sum of energies of the extra photons.





Search for ω and ϕ invisible decays

➔ No obvious signal for ω and ϕ invisible decays is observed.

➔ The UL is estimated with Bayesian approach.

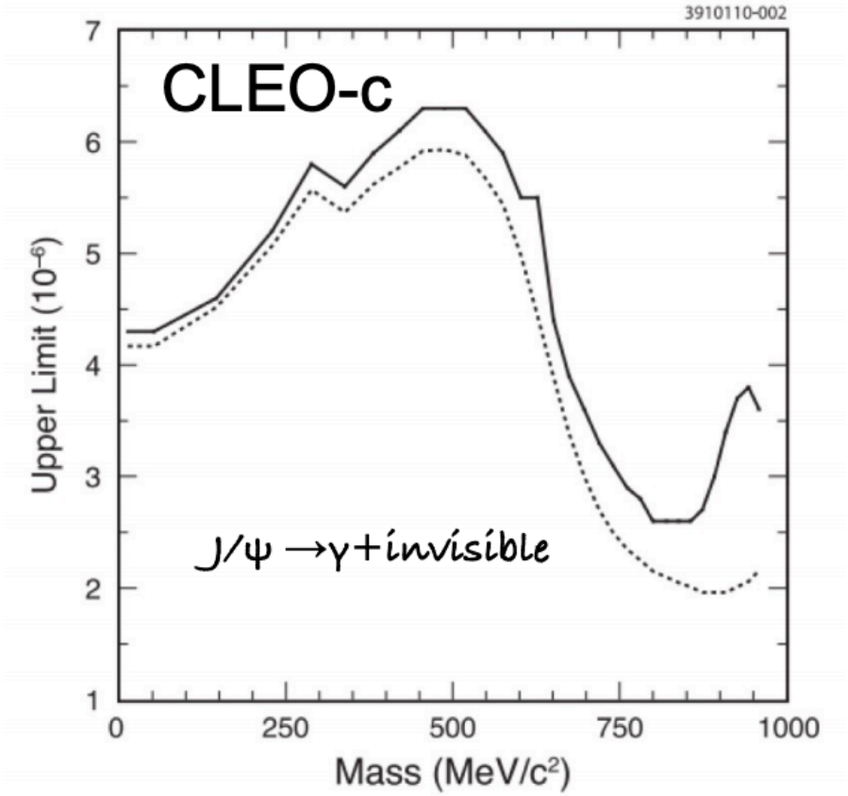
- $\dfrac{\mathcal{B}(\omega \to \text{invisible})}{\mathcal{B}(\omega \to \pi^+\pi^-\pi^0)} < 8.1 \times 10^{-5}$ at the 90% C.L.
- $\dfrac{\mathcal{B}(\phi \to \text{invisible})}{\mathcal{B}(\phi \to K^+K^-)} < 3.4 \times 10^{-4}$ at the 90% C.L.
- $\mathcal{B}(\omega \to \text{invisible}) < 7.3 \times 10^{-5}$ at the 90% C.L.
- $\mathcal{B}(\phi \to \text{invisible}) < 1.7 \times 10^{-4}$ at the 90% C.L.

Search for $J/\psi \to \gamma +$ invisible

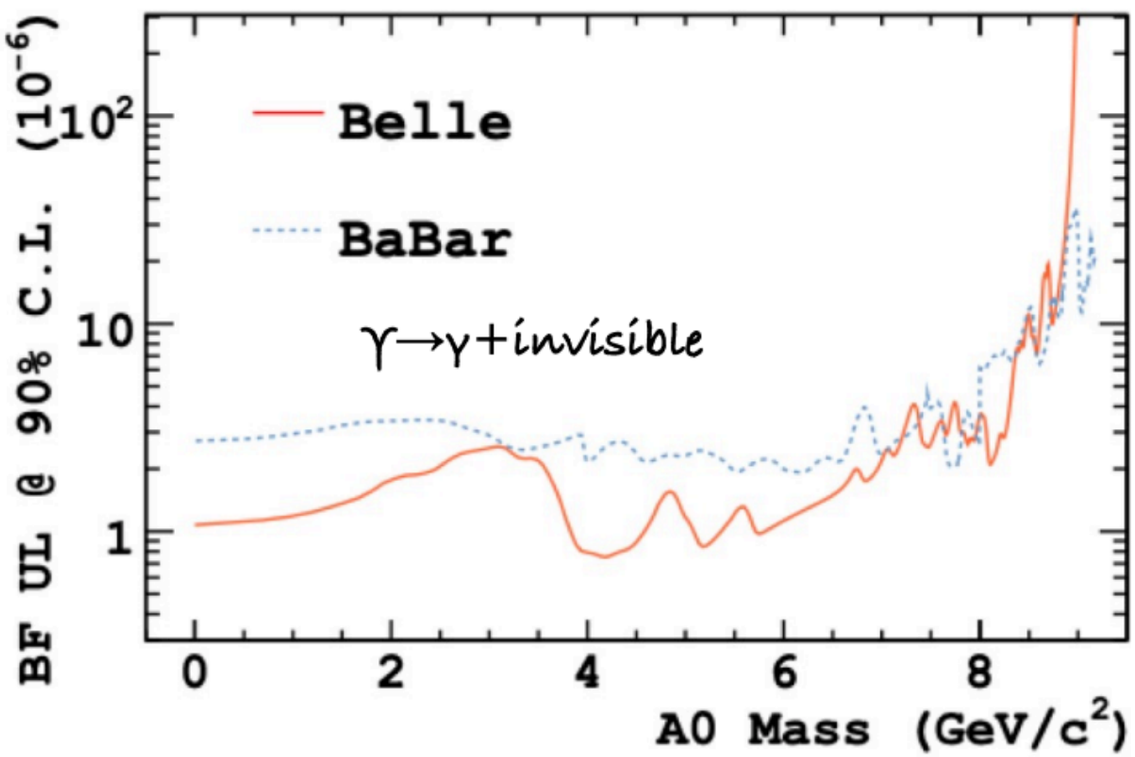
➔ A series of supersymmetric Standard Models, including Next-to-Minimal Supersymmetric Model, predict a CP-odd pseudoscalar Higgs (A^0). The A^0 can be produced in quarkonium rediative decay:

❖ $$\frac{\mathscr{B}(V \to \gamma A^0)}{\mathscr{B}(V \to \gamma\mu\mu)} = \frac{G_F m_q^2 g_q^2 C_{QCD}}{\sqrt{2}\pi\alpha}(1 - \frac{m_{A^2}^2}{m_V^2})$$

❖ A^0 can decay to two neutralinos, $g_c = \cos\theta_A/\tan\beta, g_b = \cos\theta_A/\tan\beta$.



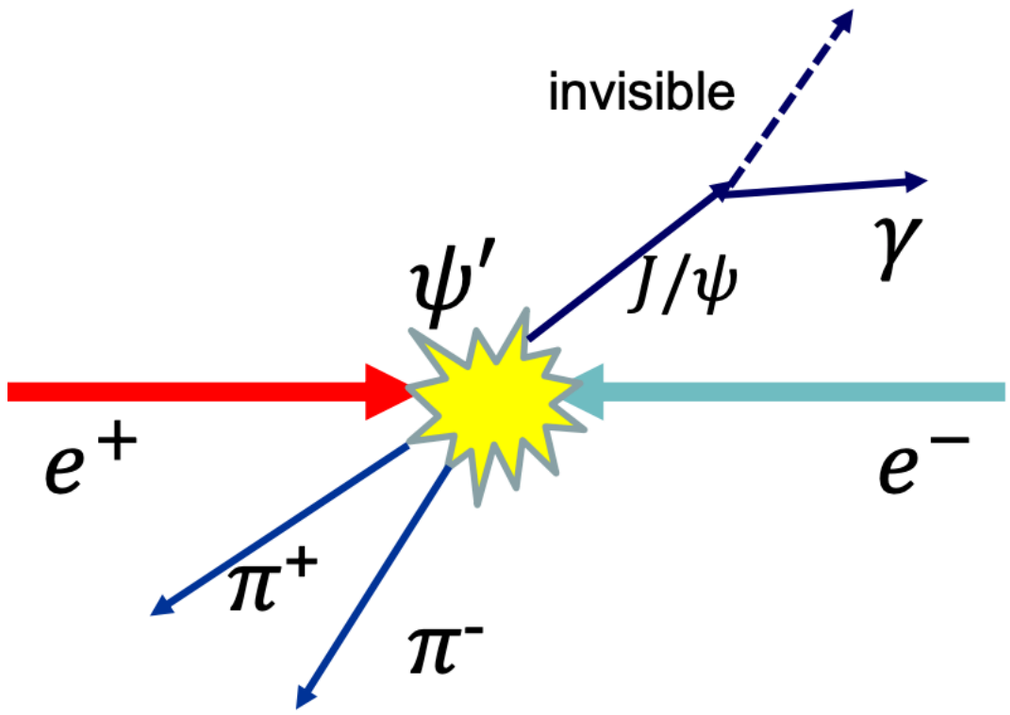
Phys. Rev. D 81,091101(R)(2010)



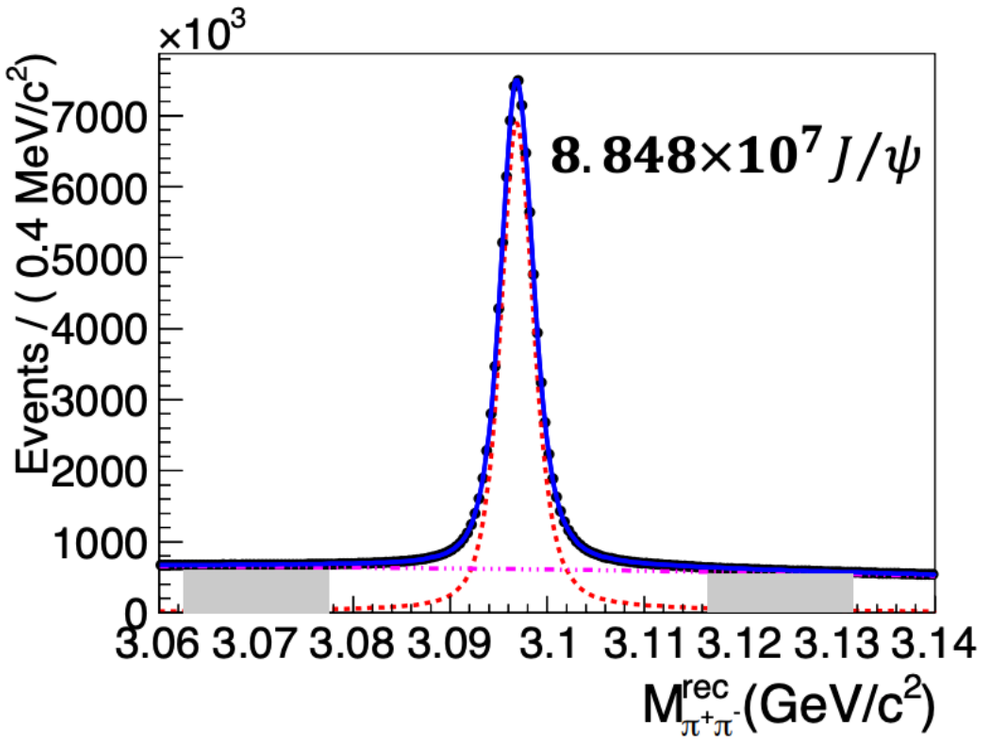
Phys. Rev. Lett 122 no.1 011801(2019)

Search for $J/\psi \to \gamma +$ invisible

- ➔ 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.
  - ❖ $\mathcal{B} = \dfrac{N_{sig} \cdot \epsilon_{J/\psi}}{N_{J/\psi} \cdot \epsilon_{sig}}$



- ➔ 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.



Search for $J/\psi \to \gamma +$ invisible

➔ Based on tagger J/ψ sample, search for $J/\psi \to \gamma +$ invisible.

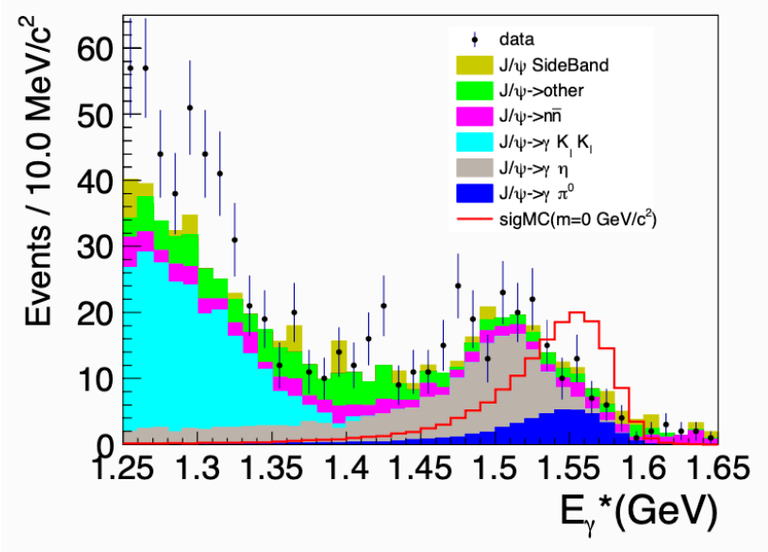
- ❖ Only $\pi^+\pi^-$ and one good shower (signal shower) in detector.
- ❖ Signal shower and recoiled invisible must direct to the barrel region.

➔ 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.

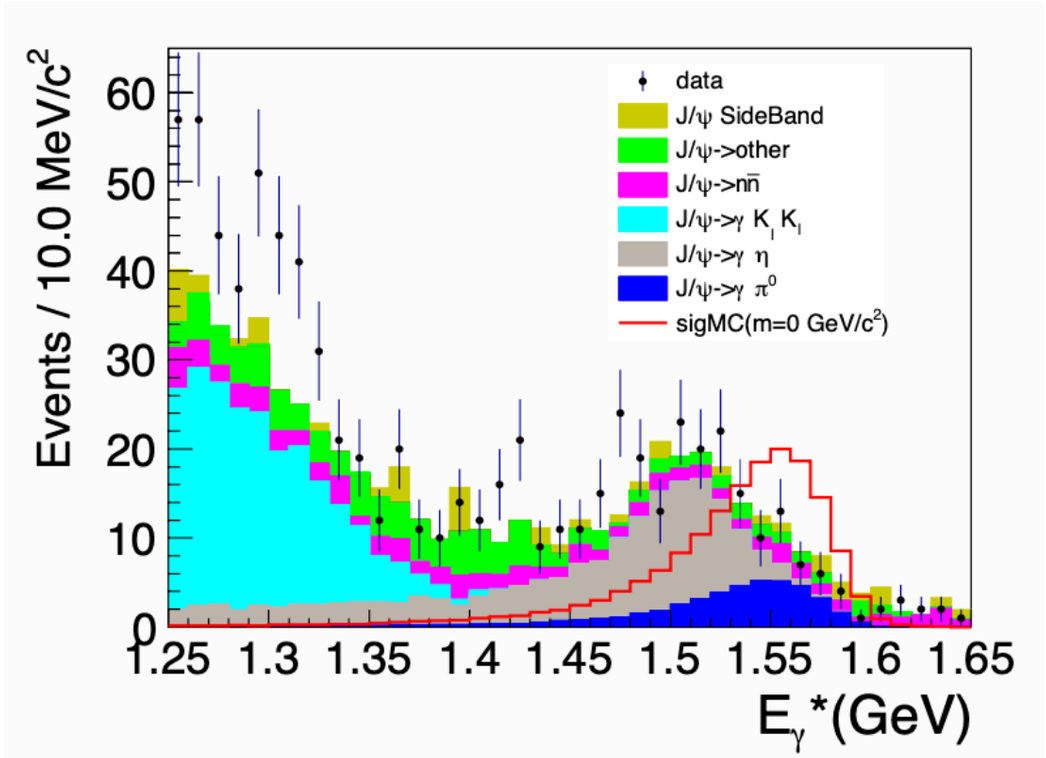
➔ Control Sample

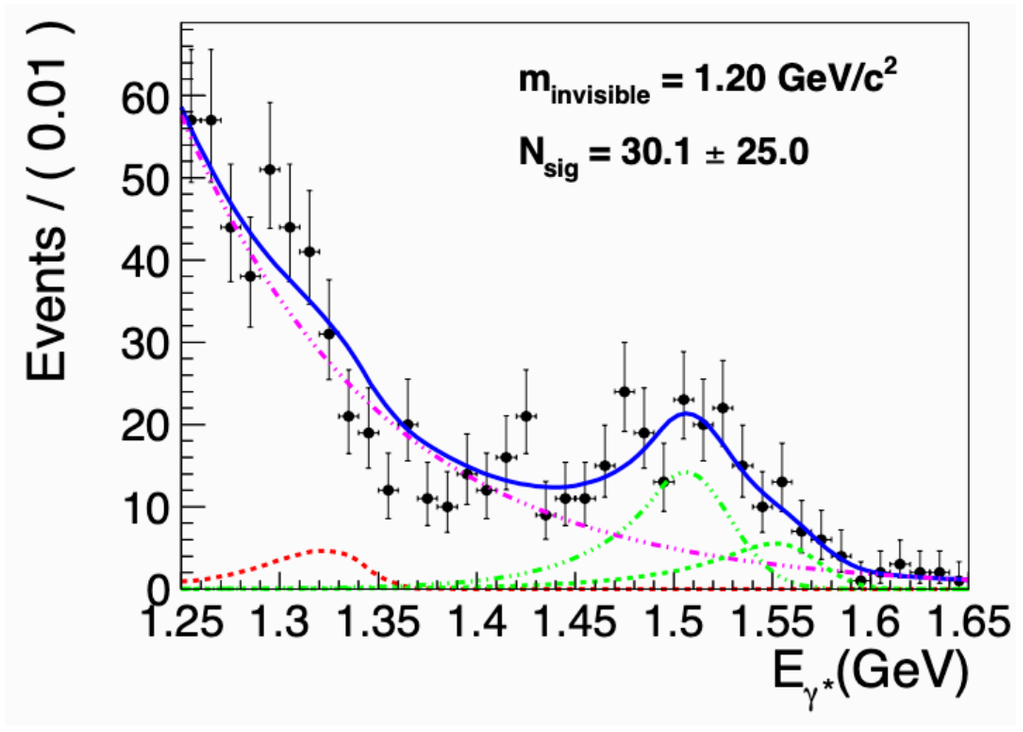
- ❖ $\gamma : J/\psi \to \rho^0\pi^0, \pi^0 \to \gamma\gamma$
- ❖ $n/\bar{n} : J/\psi \to p\pi n/\bar{n}$
- ❖ $K_L^0 : J/\psi \to K\pi K_L^0 \,\&\, J/\psi \to \pi\pi\phi, \phi \to K_S^0 K_L^0$



➔ Correct the shower energy and efficiency of $n, \bar{n}, K_L^0$ momentum dependently.

Search for $J/\psi \to \gamma +$ invisible

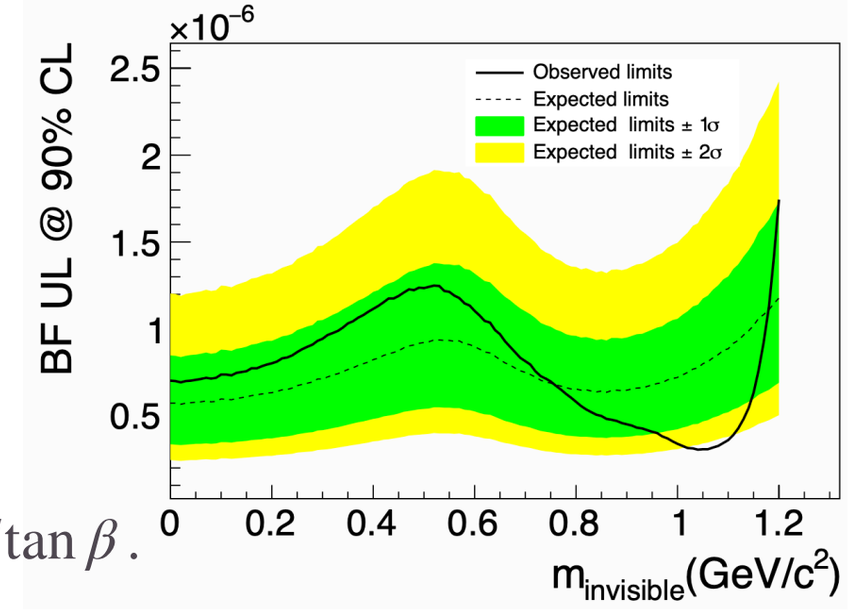


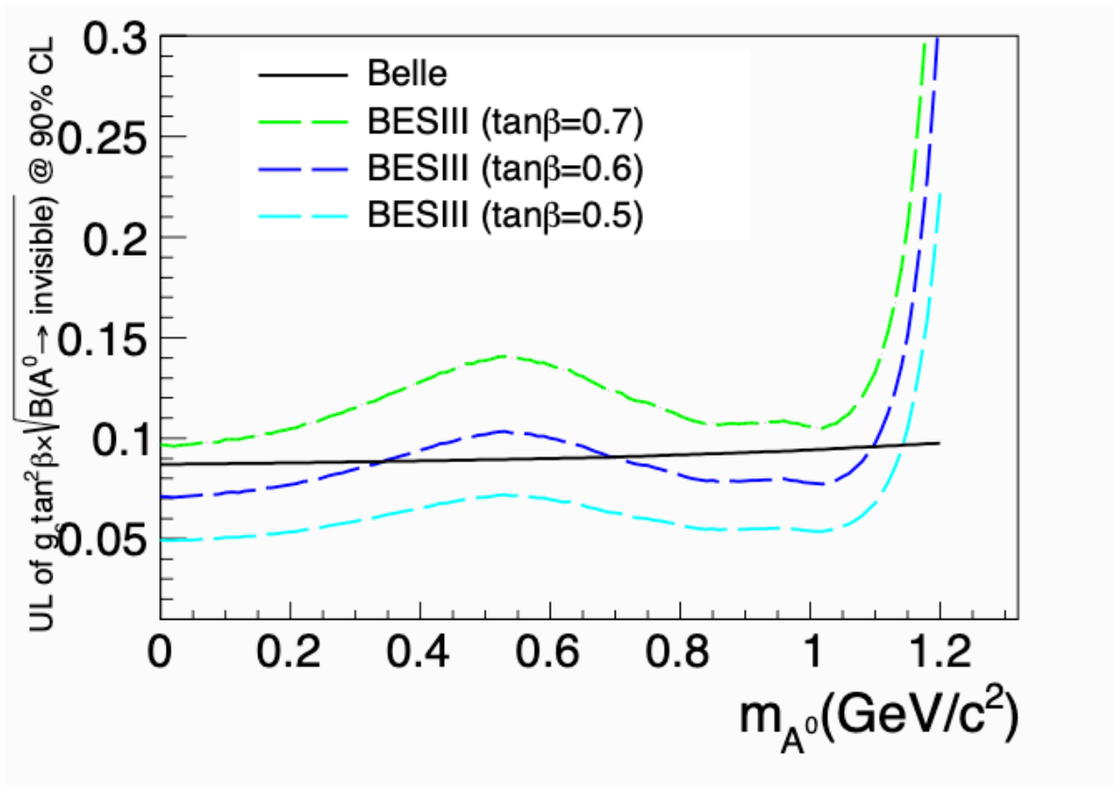


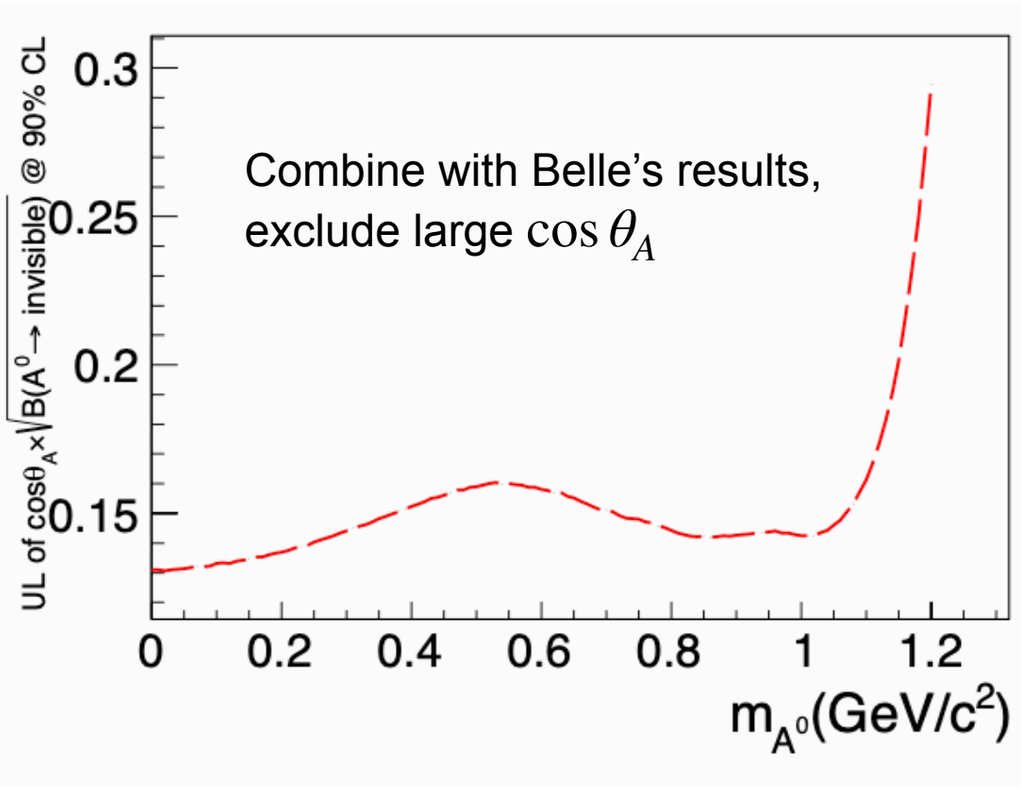
- ➔ Search signal on $E(\gamma)$ in J/ψ rest frame in [1.25, 1.65] GeV.
- ➔ Un-binned fit to extract signal.
- ➔ Signal: signal MC shape.
- ➔ Two peak bkg: fixed Crystal Ball, determined by fits on exclusive MC sample.
- ➔ Non-peak bkg: exponential function.
- ➔ Scan m(invisible) from $0 \sim 1.2\mathrm{GeV/c^2}$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

Search for $J/\psi \to \gamma +$ invisible

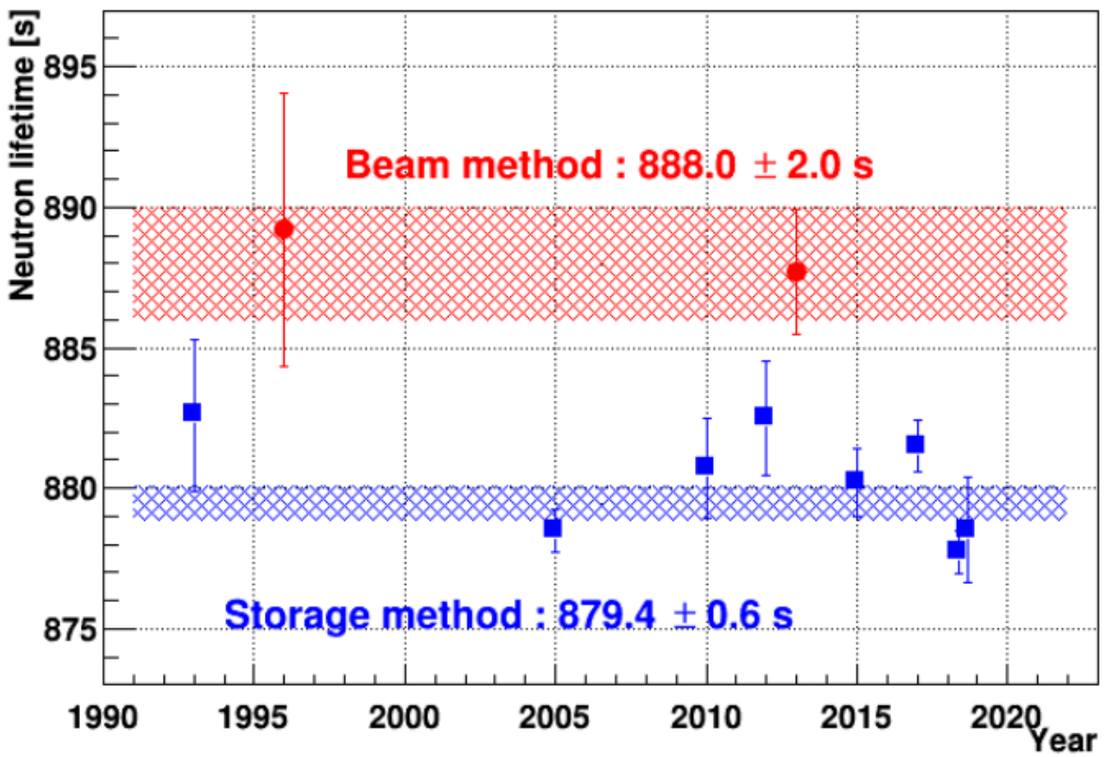
- ➔ Use the modified frequentist method to calculate upper limits.
- ➔ ~6.2 better than CLEO-c.
- ➔ Calculate UL for β and θ_A.
  - ❖ $$\frac{\mathcal{B}(V \to \gamma A^0)}{\mathcal{B}(V \to \gamma\mu\mu)} = \frac{G_F m_q^2 g_q^2 C_{QCD}}{\sqrt{2}\pi\alpha}(1 - \frac{m_{A^2}^2}{m_V^2})$$
  - ❖ A^0 can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







Search for $\Lambda \rightarrow$ invisible



JPS Conf.Proc. 33 (2021) 011056

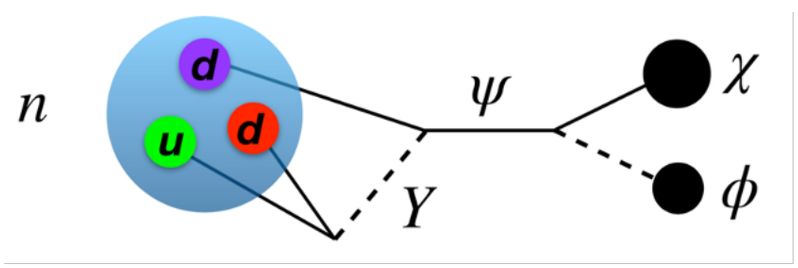
➔ $\tau(n)$ measured by beam method and storage method are different.

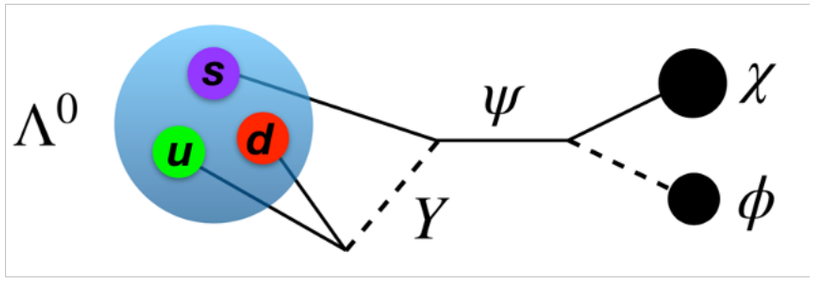
$$\tau_n^{beam} = \frac{\tau_n}{\mathcal{B}(n \rightarrow p + X)} > \tau_n^{bottle} \Rightarrow \mathcal{B}(n \rightarrow p + X) \approx 99\%$$

➔ 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.

BESIII New Physics Workshop @ Hengyang Oct.2018
New Physics in Charm Physics Fu-Sheng Yu

Neuton Lifetime

- Two types of measurements

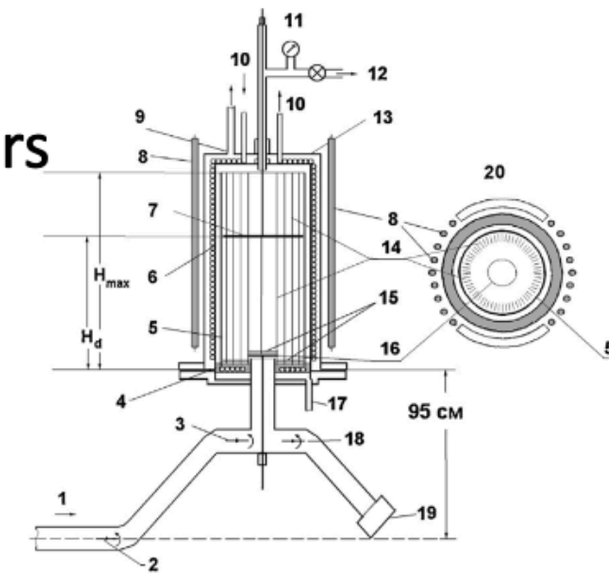
1. **bottle method**

$$n \rightarrow p + anything$$

counting neutron numbers

$$N_n(t) = N_n(0)e^{-t/\tau_n^{bottle}}$$

$$\tau_n^{bottle} = 879.6 \pm 0.6\ s$$

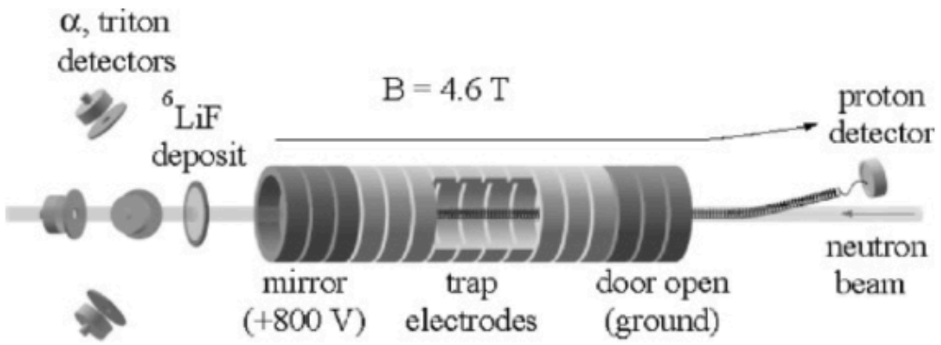


2. **beam method**

counting proton numbers

4σ discrepancy

$$\frac{1}{\tau_n^{beam}} = -\frac{1}{N_n}\frac{dN_p}{dt} = -\frac{Br(n\rightarrow p+anything)}{N_n}\frac{dN_n}{dt}$$



$$\tau_n^{beam} = 888.0 \pm 2.0\ s$$

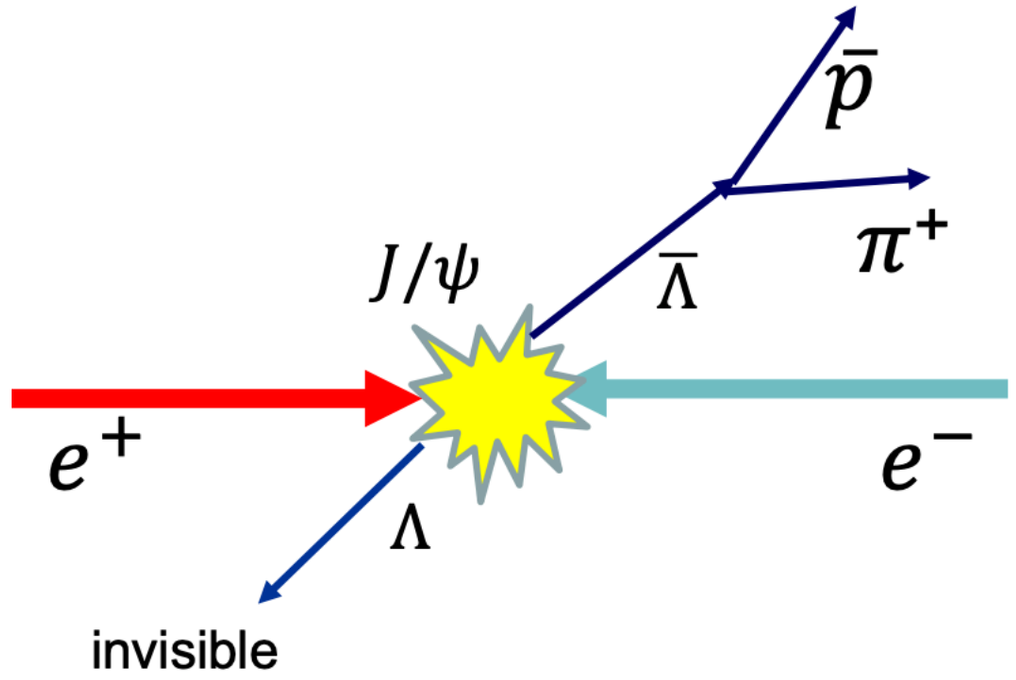
Phys. Lett. B 745 (2015), 79

Phys. Rev. Lett. 111, 222501 (2013).

Search for $\Lambda \to$ invisible

➔ Using $J/\psi \to \Lambda\overline{\Lambda}$ to get Λ sample.

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



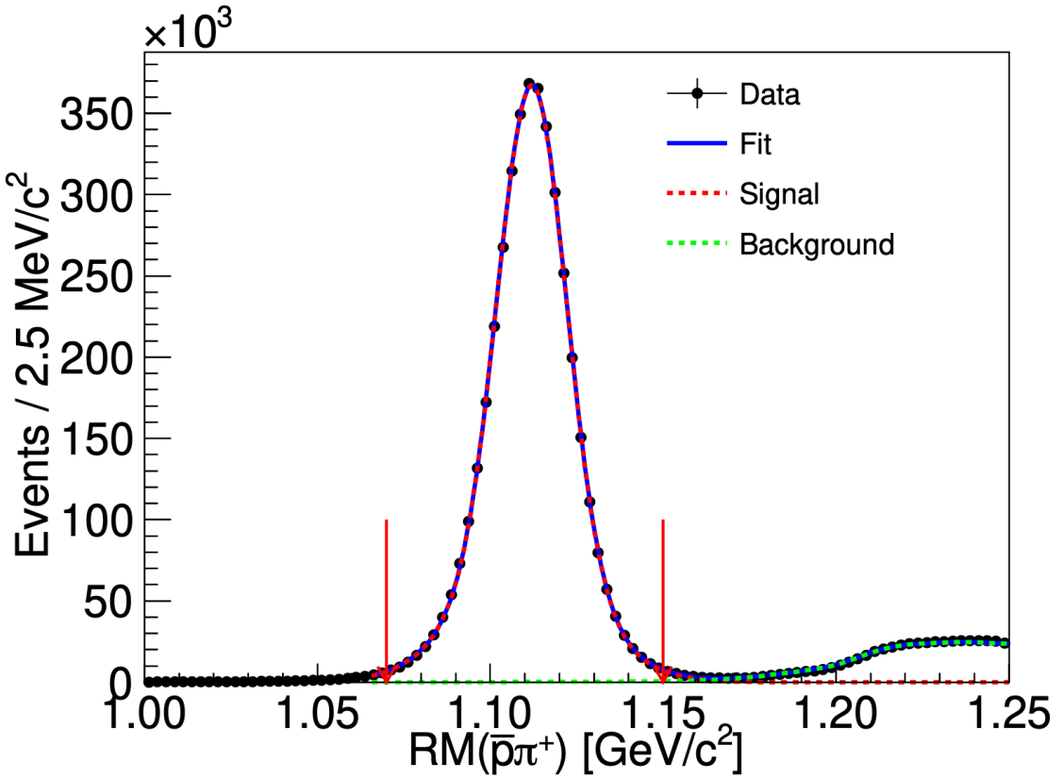
➔ Perform semi-blind procedure.

➔ Search for signal on total energy in EMC.

➔ Reconstruct $\bar{p}\pi^+$

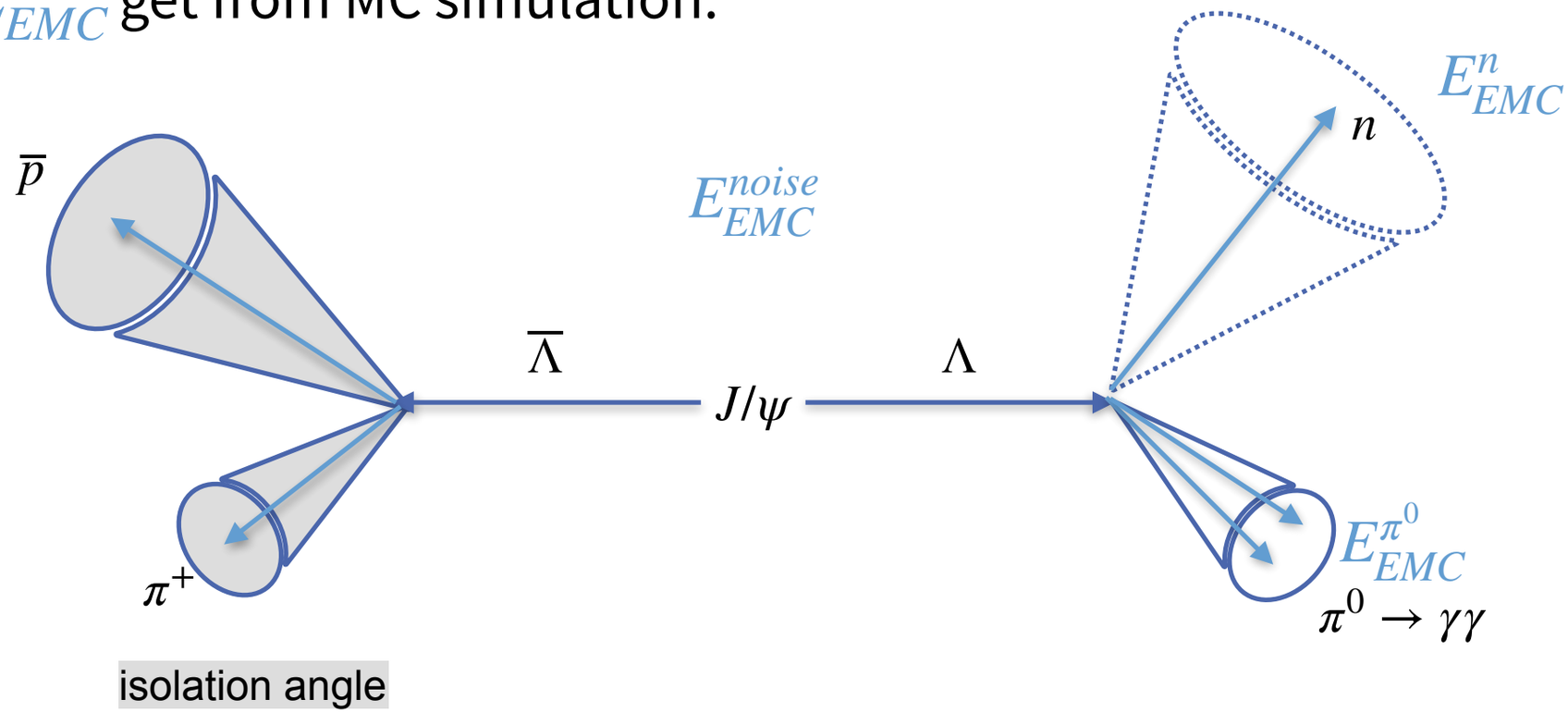
- ❖ Requiring TOF hit from charged tracks, to guarantee all showers are related to the event.

➔ Fit to the rec. mass of $\bar{p}\pi^+$, get 4.15×10^6 Λ.



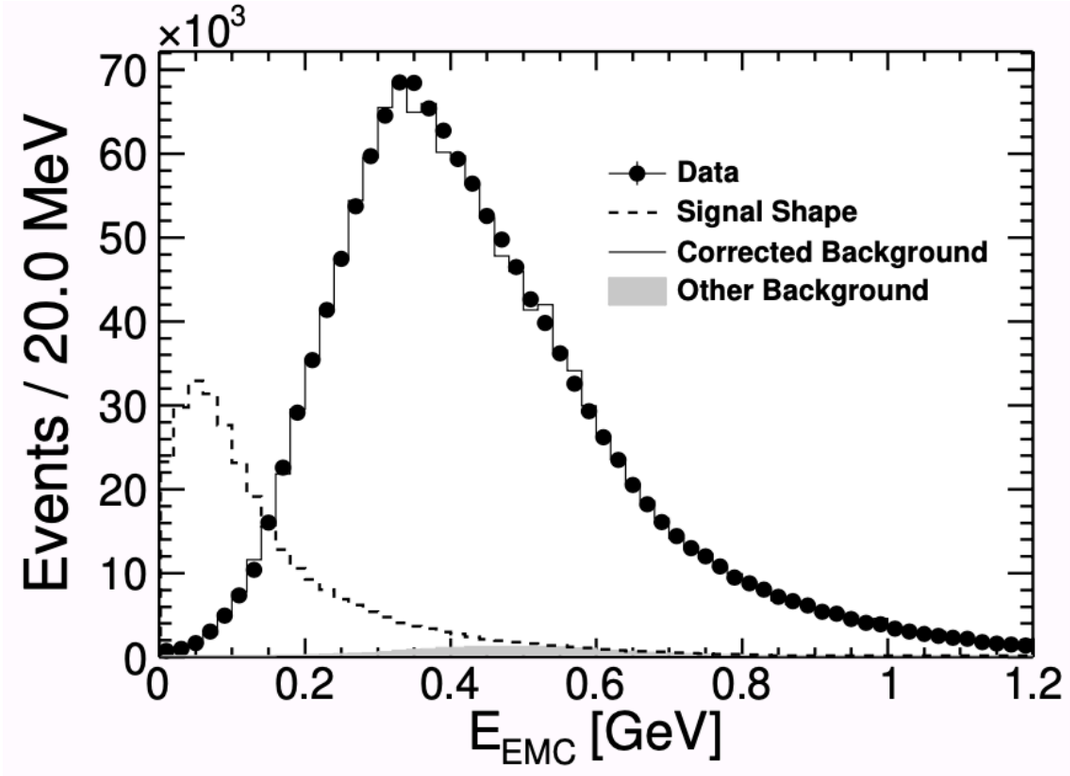
Search for $\Lambda \to$ invisible

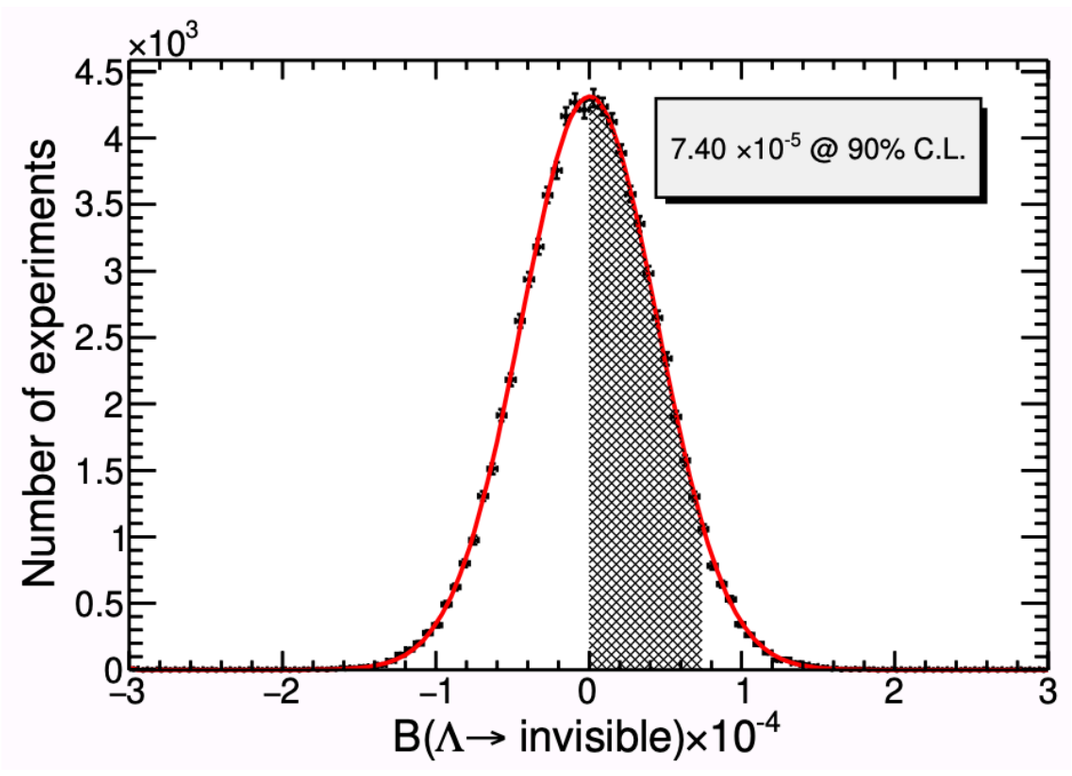
- ➔ Based on tagged Λ sample, no extra charger tracks are required.
- ➔ Search for signal on total energy in EMC(E_{EMC}).
- ➔ Main bkg is $\Lambda \to n\pi^0$. $E_{EMC} = E^{\pi^0}_{EMC} + E^{n}_{EMC} + E^{noise}_{EMC}$.
- ➔ Geant4 don't simulate n in EMC well. (Data Driven)
  - ❖ With control sample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



Search for $\Lambda \to$ invisible

- ➔ 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!