Invisible decays at BESIII

Presented by

Amit Pathak

Institute of High Energy Physics Chinese Academy of Sciences

on behalf of BESIII collaboration

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Outline

- Motivation
- BEPCII / BESIII detector
- Data Set and Analysis Techniques
- Recent Highlights
  1. Dark Matter Searches in $J/\psi \rightarrow \gamma$ + Invisible, Phys. Rev. D 101, 112005 (2020)
  2. Search for Invisible decays of Λ baryon, Phys. Rev. D 105, L071101 (2022)

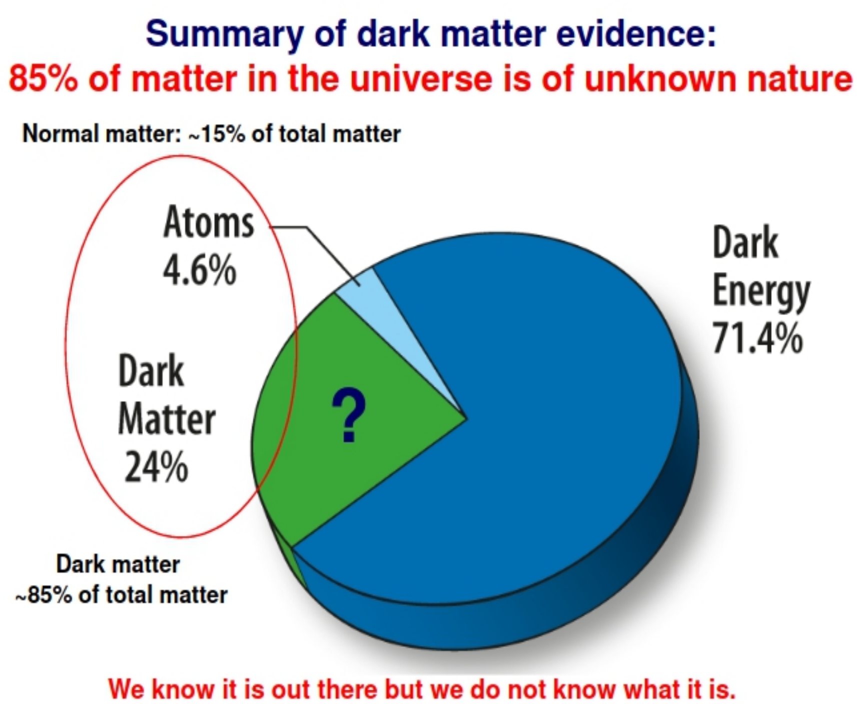
Motivation

- Standard Model (SM) describes successfully the matter constituents and their interactions. But some phenomenon still remains unexplained:

  1). Standrad Model doesn’t describe the matter-antimatter asymmetry.

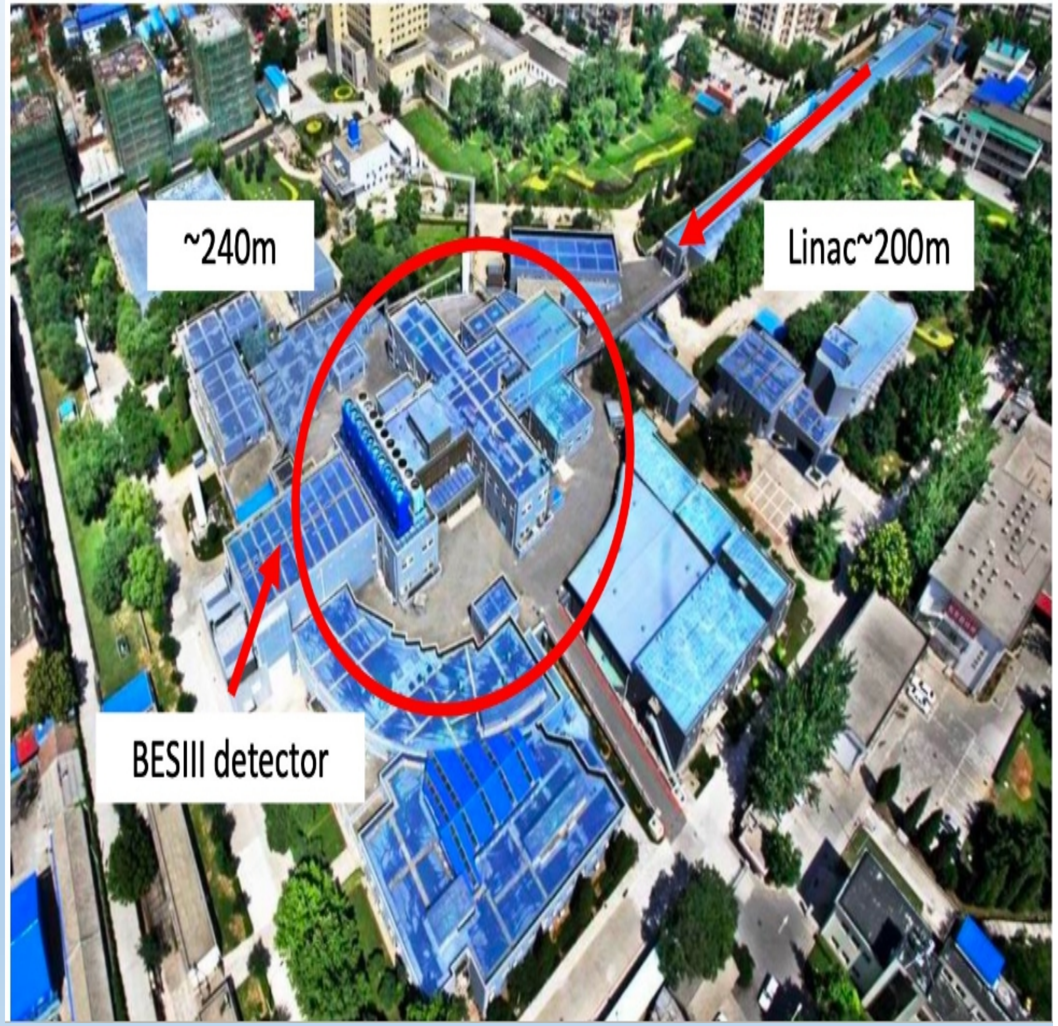
  2). dark matter problem and

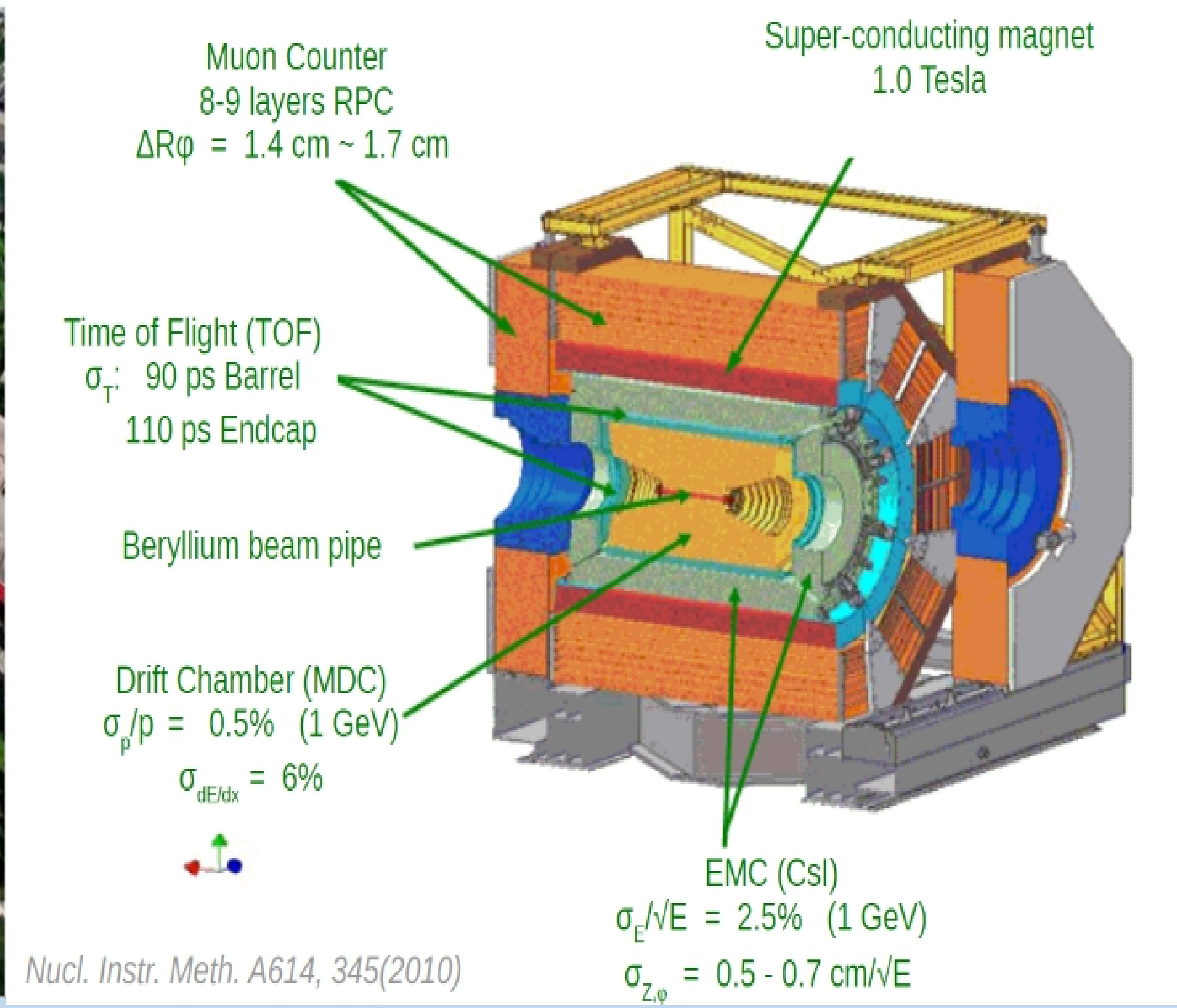
  3). many more.!



- The cosmological observations about DM could be explained by Physics beyond the SM.
- Dark Matter can also be searched by invisible decays.
- It might open a window for new physics which lie beyond the SM.
- DM can be searched in e^+e^- collider experiments like BESIII.
- These experiments have the clean environment and fixed CM energy.

BEPCII and BESIII Detector



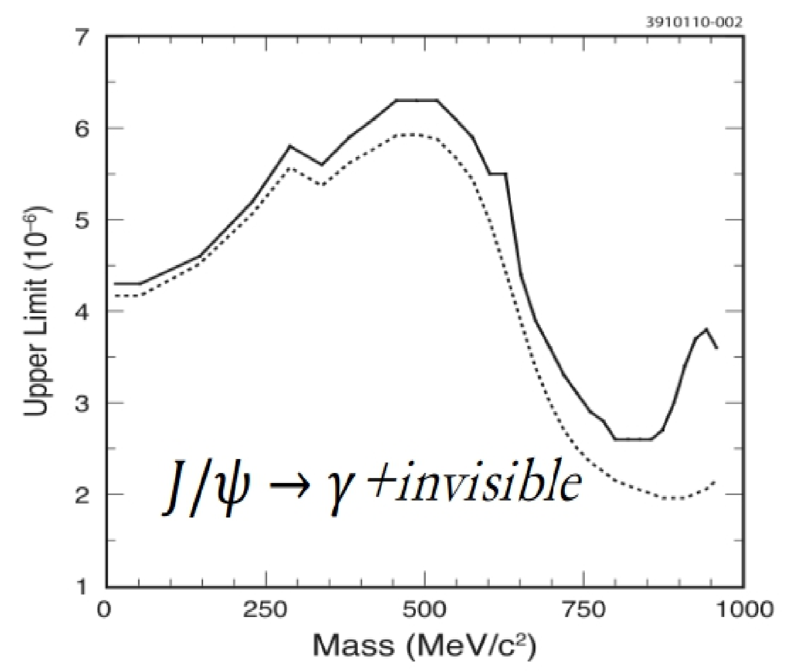


Search for the decay J/ψ → γ + Invisible

- **Motivation:** the supersymmetric Standard Models, including Next-to-Minimal Supersymmetric Models (NMSSM), predict a CP-odd pseudoscalar Higgs A^0. The A^0 can be produced in quarkonium radiative decay;

$$\frac{\mathcal{B}(V \to \gamma A^0)}{\mathcal{B}(V \to \mu^+\mu^-)} = \frac{G_F m_q^2 g_q^2 C_{\rm QCD}}{\sqrt{2}\pi\alpha}\left(1 - \frac{m_{A^0}^2}{m_V^2}\right),$$

- where m_{A^0}, m_V and m_q are the masses of the A^0, the quarkonium state, and the corresponding quark, respectively.
  - Yukawa coupling of the A^0 field to the quark-pair: $g_c = \cos\theta_A / \tan\beta$ and $g_b = \cos\theta_A \cdot \tan\beta$;
  - The A^0 can decay to two neutralinos which is assumed to be DM candidates.
  - Search for the J/ψ radiative decay into a weakly interacting neutral particle in this process.



Phys. Rev. D 81, 091101

Search for the decay $J/\psi \rightarrow \gamma$ + Invisible

- **Data Samples:** 448.1 x 10^6 $\psi(3686)$;

- **Analysis Stratetegy:**

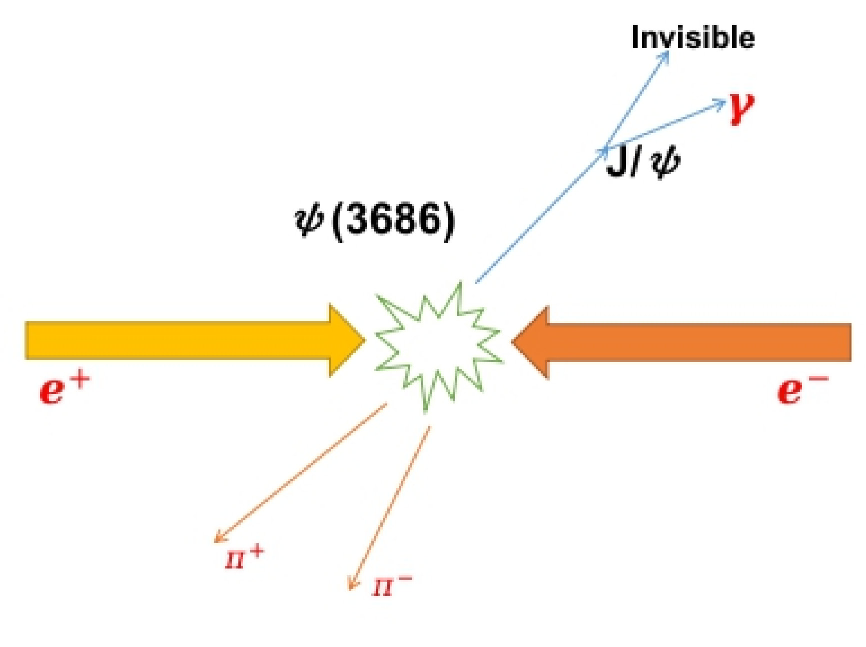
  1). Search for $J/\psi \rightarrow \gamma$ + Invisible with J/ψ from the decay mode $\psi(3686) \rightarrow \pi^+\pi^- J/\psi$;

  2). first tag J/ψ events by selecting two oppositely charged pions, and then to search for the decay $J/\psi \rightarrow \gamma$ + Invisible within the tagged J/ψ sample.

  3). The branching fraction of the decay $J/\psi \rightarrow \gamma$ + Invisible is calculated using:

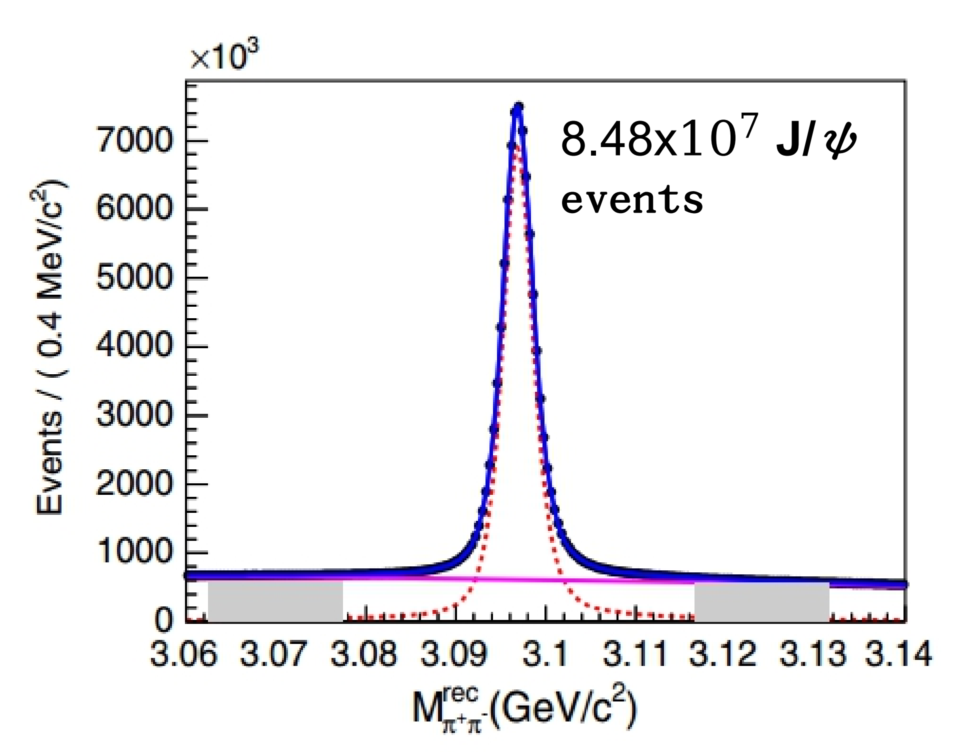
$$\mathcal{B} = \frac{N_{\rm sig} \cdot \epsilon_{J/\psi}}{N_{J/\psi} \cdot \epsilon_{\rm sig}},$$

  4). A semiblind analyses is performed to avoid possible bias.



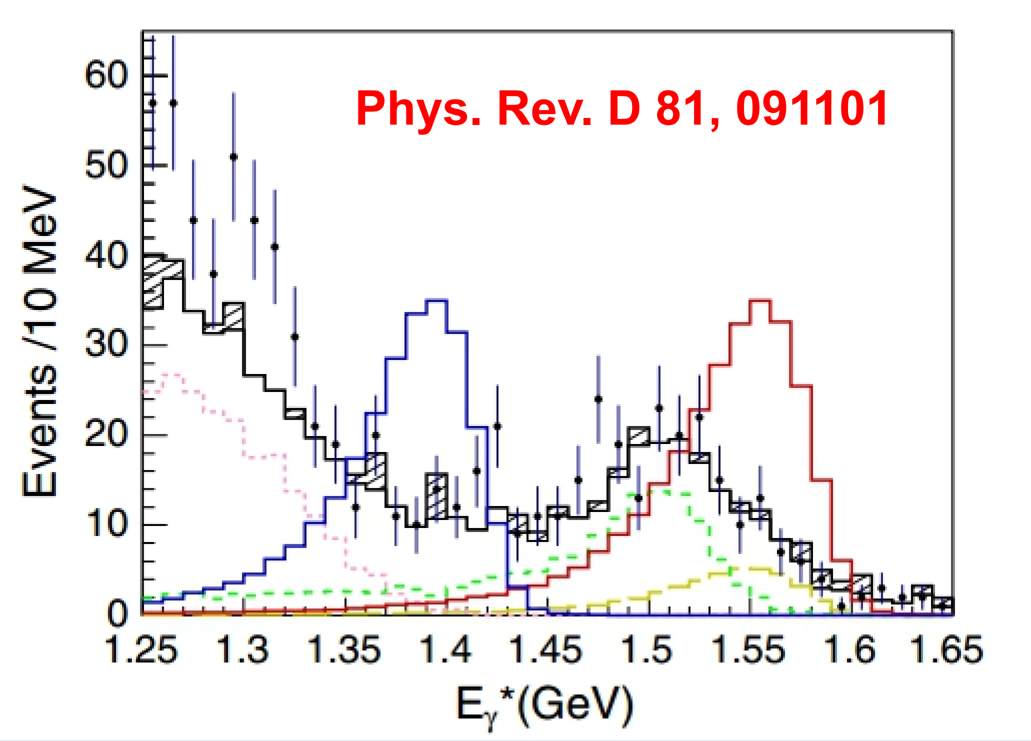
Search for the decay J/ψ $\rightarrow$ γ + Invisible

- **Selections:**
  only $\pi^+\pi^-$ and one good shower is required;
  Signal shower and recoiled invisible mass must direct to the barrel region (| $cos\ \theta$ | < 0.8);
- Fit to the recoil mass RM($\pi^+\pi^-$), There are 8.848×10^7 J/ψ events;
- Huge backgrounds from J/$\psi \rightarrow n\bar{n}$, $\gamma n\bar{n}$, $\gamma K_L K_L$:
  Using shower shape in EMC to identify γ from n , $\bar{n}$, K_L ;
  The EMC shapes are studied using control samples;
  γ : $J/\psi \rightarrow \rho\ \pi^0\ (\pi^0 \rightarrow\ \gamma\gamma)$
  $n/\bar{n}$: $J/\psi \rightarrow p\ \pi\ n$
  K_L : $J/\psi \rightarrow K\ \pi\ K_L$ and
  $J/\psi \rightarrow \pi\ \pi\ \varphi\ (\varphi \rightarrow\ K_S\ K_L)$;



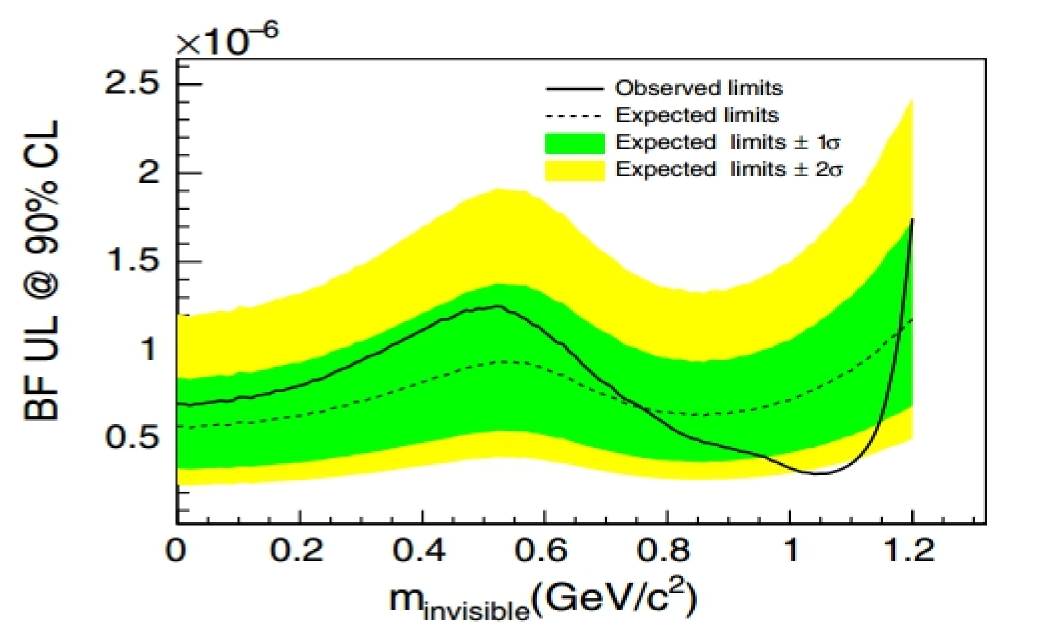
Search for the decay $J/\psi \rightarrow \gamma$ + Invisible

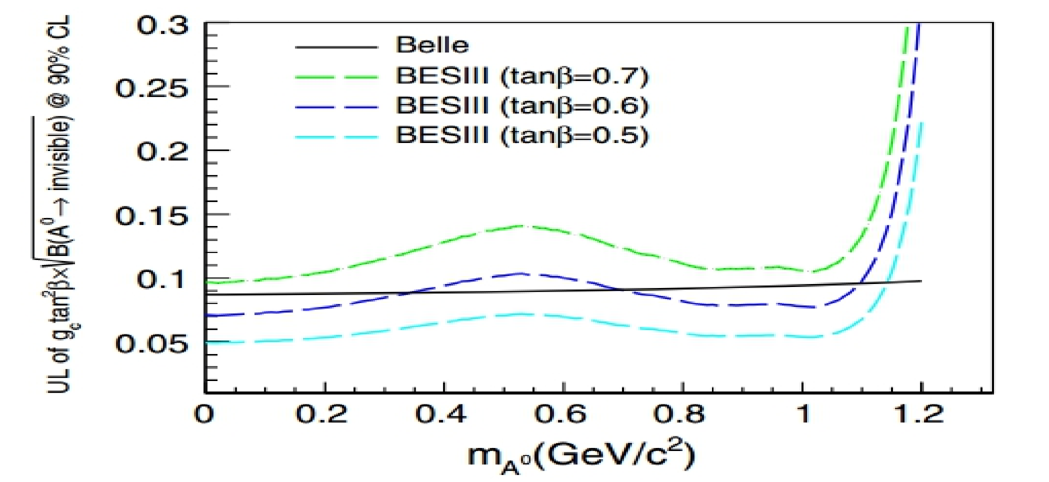
1. **Signal extraction :** **The signal are searched on the $E_\gamma{}^*$ range from 1.25 to 1.65 GeV, corresponding to a mass from 0 to 1.2 GeV/c^2 for the invisible particle;**
2. **Fit method:**
   - **For signal: Signal MC shape;**
   - **For peaking background from $J/\psi \rightarrow \gamma\ \pi^0/\eta$: fixed;**
   - **For non-peak: exponential function;**
3. **No significant signal, max significance is 1.2σ;**



Search for the decay J/ψ $\rightarrow$ γ + Invisible

- **Upper limits :** Use the modified frequentist method to calculate upper limits of branching fraction $\mathcal{B}(J/\psi \rightarrow \gamma + \text{invisible})$.
- For the zero mass assumption of the invisible particle , the upper limit is 7.0×10^{-7} at 90% C.L., which is improved by a factor 6.2 compared to the previous CLEO result.
- The upper limits of $g_c \times \tan^2\beta \times \sqrt{\mathcal{B}(J/\psi \rightarrow \gamma + \text{invisible})}$ for $\tan\beta = 0.5, 0.6$ *and* 0.7 are also reported. We obtain better sensitivity in the range $\tan\beta < 0.6$ compared to the Belle result.





Search for invisible decays of Λ baryon

- **Motivation:**

The baryon matter density and the dark matter density are similar, which may hint at a common origin of these two unsolved questions.

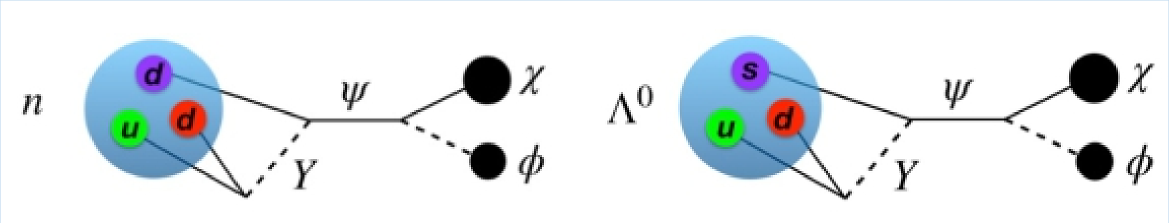
Dark matter may be represented by baryon matter with invisible final state.

Many potential theories suggest a correlation between baryon asymmetry and dark sector. Phys. Rev. D 105, 115005

These models usually contain a neutron portal operator.

Such operators can generally introduce B violation to the Standard Model sector.

Discrepancy of neutron lifetime in beam method and the storage methods (4.1σ); can be explained by 1% of the neutron decay into dark matter.



Phys. Rev. D 99, 035031

This is the first study of invisible baryon decays.

Search for invisible decays of Λ baryon

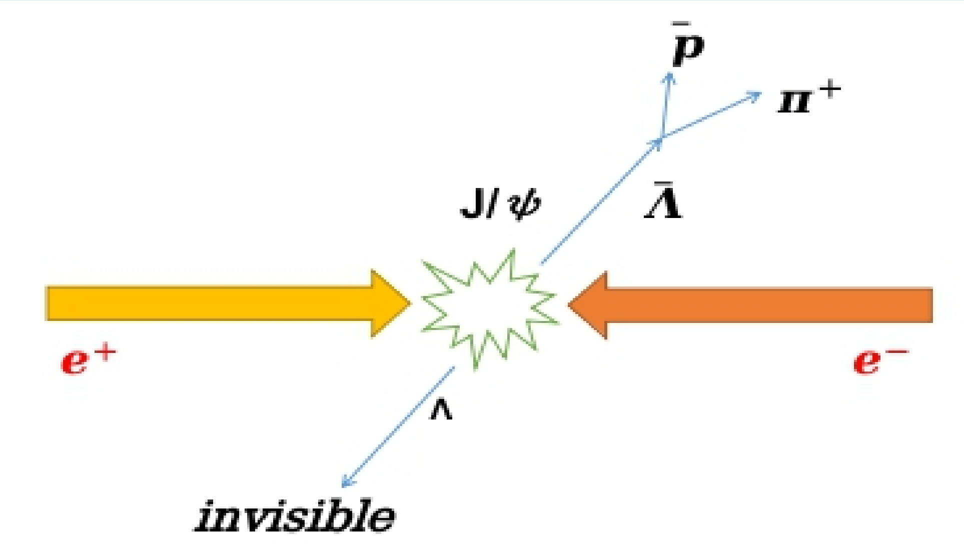
- **Data sample**: 10B J/ψ events;
- **Analysis strategy:**

J/ψ → $\Lambda\bar{\Lambda}$ provide a clean environment for Λ invisible decay;

Double tag method is used:

- Tag side: $\bar{\Lambda}$ is tagged by $\bar{\Lambda} \rightarrow \bar{p}\pi^{+}$;
- Signal side: Λ decays invisibly;

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

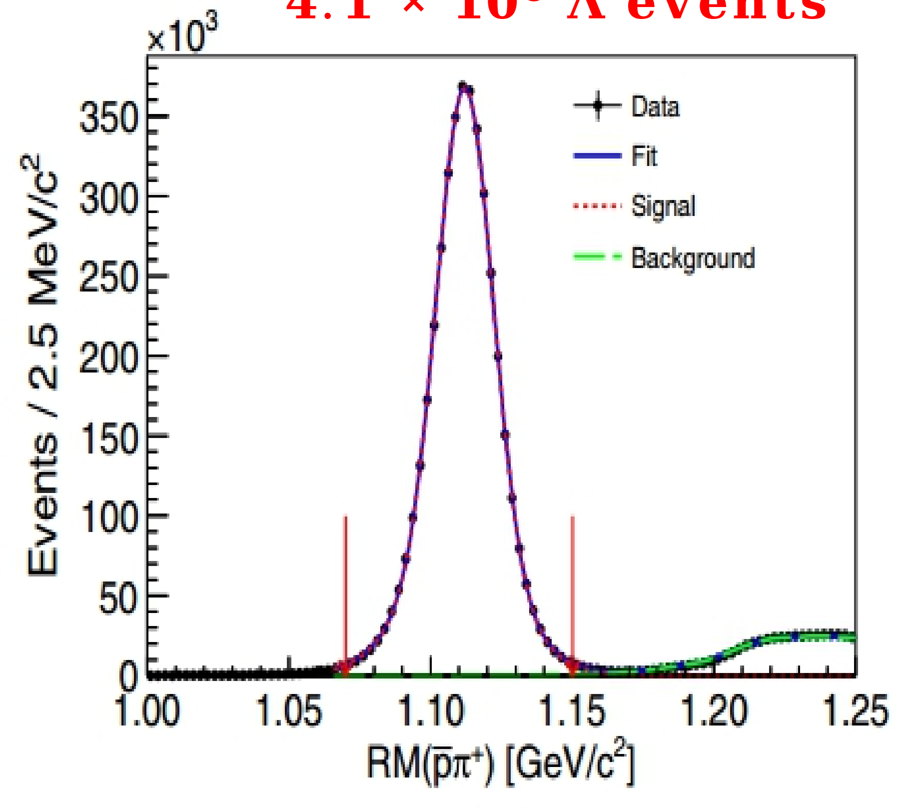


- The $\bar{\Lambda}$ invisible decay has not been carried out, because the dominant background from $\bar{\Lambda} \rightarrow \bar{n}\pi^{0}$ is hard to estimate and simulate too;

Search for invisible decays of Λ baryon

- **Tag side selections:**
  - Reconstruct $\bar{p}$, π^+, $|cos\ (\theta_{\bar{\Lambda}})|$ < 0.7;
  - One of tracks is required TOF hit for good resolution of the event start time;
  - Fit on RM($\bar{p}\pi^+$) to obtain the $\bar{\Lambda}$ signal yield;
- **Signal side selections:** No additional charged track;

4.1×10^6 Λ events



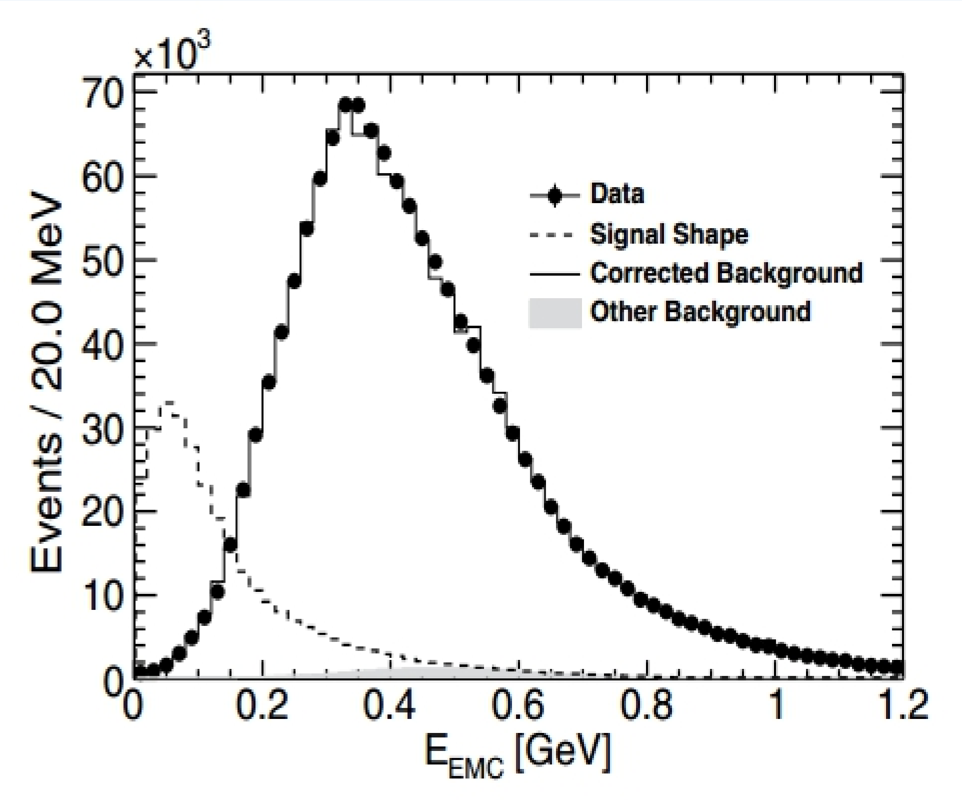
Search for invisible decays of Λ baryon

- **Signal extraction :** Search for signal on total energy in EMC (not charged tracks);
  - Dominate background: $\Lambda \rightarrow n\ \pi^0$;

$$E_{\mathrm{EMC}} = E_{\mathrm{EMC}}^{\pi^0} + E_{\mathrm{EMC}}^{n} + E_{\mathrm{EMC}}^{\mathrm{noise}},$$

  - $E^{\pi^0}{}_{EMC}$: Based on the MC simulations;
  - $E^{\eta}{}_{EMC}$ + $E^{noise}{}_{EMC}$: retained bases on control sample.

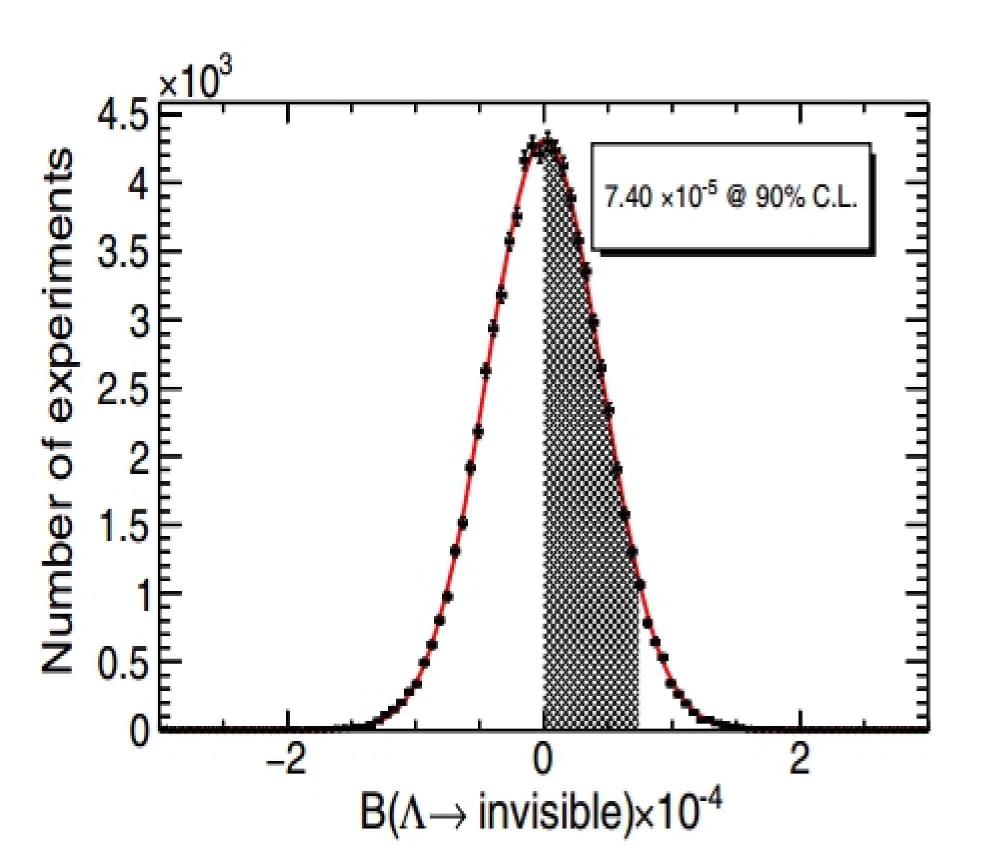
$$J/\psi \rightarrow \Lambda\ (n\ \pi^0)\ \bar{\Lambda}\ (\bar{p}\ \pi^+)$$



- The corrected E_{EMC} for $\Lambda \rightarrow n\ \pi^0$ is derived by combining $E^{\pi^0}{}_{EMC}$ with a random value of the sum of $E^{\eta}{}_{EMC}$ + $E^{noise}{}_{EMC}$;
- No obvious signals are observed.

Search for invisible decays of Λ baryon

1. **Upper limit :** A modified frequentist approach is adopted to estimate the UL of $\mathcal{B}(\Lambda \rightarrow invisible)$;
2. The upper limit is $\mathcal{B}(\Lambda \rightarrow invisible)$ < 7.4×10^{-5} at 90% C.L.;
3. The UL is consistent with the prediction of 4.4×10^{-7} from the mirror model.
4. This result sheds light on the neutron lifetime measurement puzzle and helps to constrain dark sector models related to the baryon asymmetry.



Summary

- Searching for descrepancies with the SM is the first priority of the current eperimental investigations.
- The search for invisible decays is one of the important ways to search for physics beyond SM.
- We have reported in this talk:

  $J/\psi \rightarrow \gamma + \text{invisible}$: We have searched using 448.1 x 10^6 ψ(3686) data sample, no obvious signal is observed. The upper limits @ 90% C.L. mass (invisible) in [0,1.2] GeV/c^2 are measured, which is 6.2 times improvement compared to the previous result.

  $\Lambda \rightarrow invisible$: With 10 B J/ψ data sample, first search for

  $\Lambda \rightarrow invisible$ decay and no obvious signals are observed. The upper limit is $\mathcal{B}(\Lambda \rightarrow invisible) < 7.4 \times 10^{-5}$ at 90% C.L. The result helps to constrain dark sector models related to the baryon asymmetry.

- With the world's largest e^+e^- annihilation, more exciting results is ongoing and will come soon.

Thank You for listening..!