Search for invisible decays at BESIII

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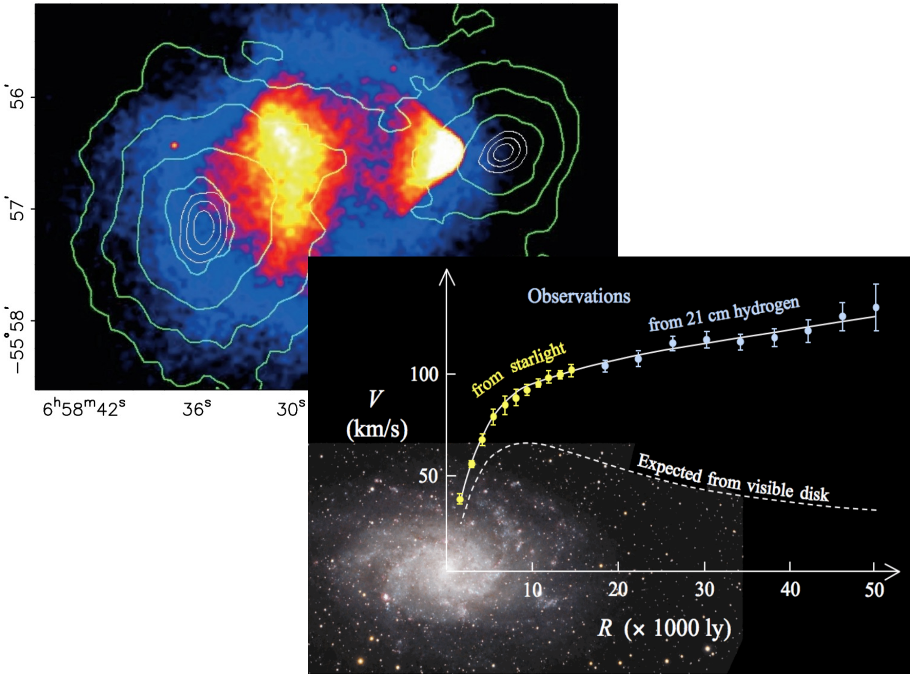
on behalf of the BESIII Collaboration
University of Science and Technology of China

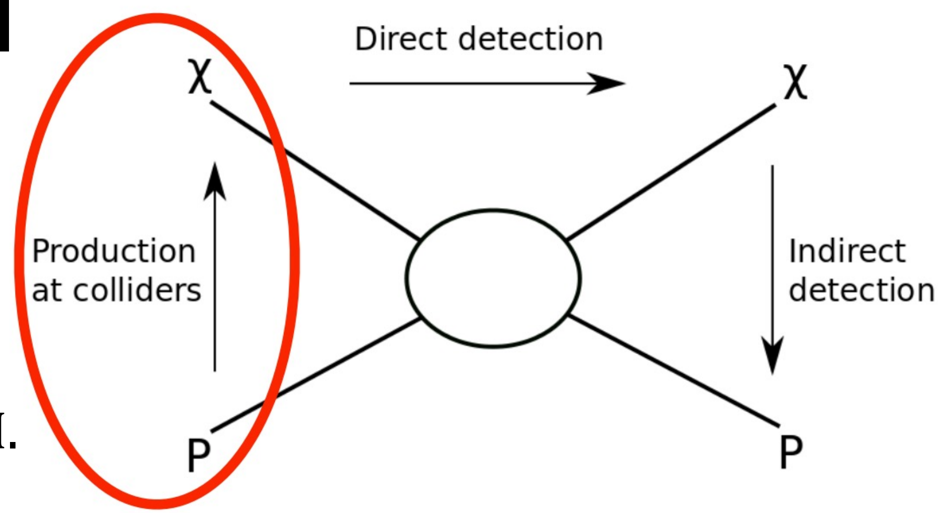
- Why invisible decays
- BEPCII/BESIII
- Search for $J/\psi \to \gamma + \text{invisible}$
- Search for $\Lambda \to \text{invisible}$
- Summary

Why invisible decays



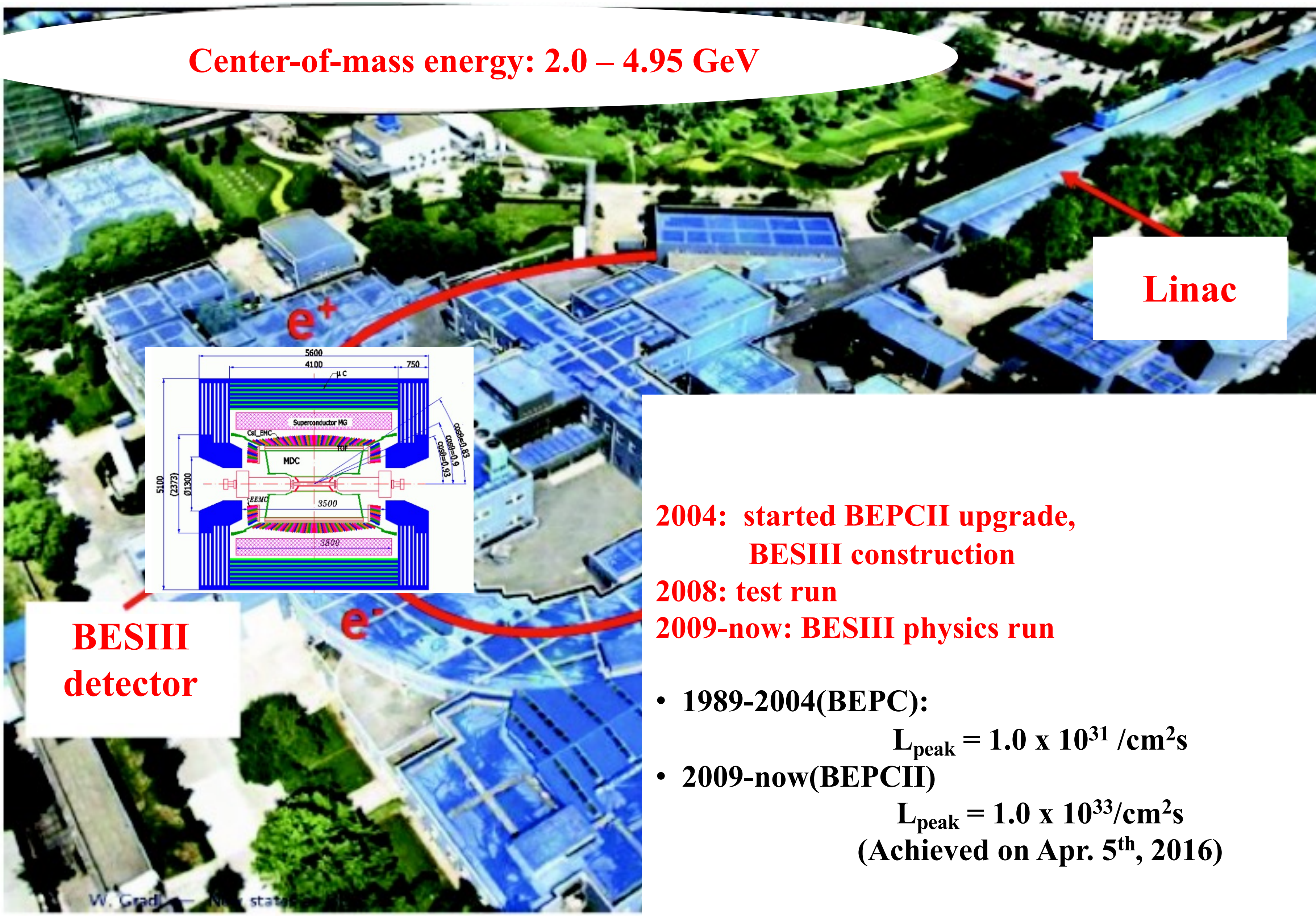
- ➢ Dark matter, one of compelling reasons to new physics.
- ➢ Many evidence in astronomy but no direct observation yet.

- ➢ Search for invisible decays at colliders is one way to search for dark matter.
- ➢ This talk focuses on recent search for hadron invisible decays at BESIII.



BEPCII: high luminosity double–ring collider

Center-of-mass energy: 2.0 – 4.95 GeV



2004: started BEPCII upgrade, BESIII construction
2008: test run
2009-now: BESIII physics run

- **1989-2004(BEPC):**
  $L_{peak} = 1.0 \times 10^{31} /cm^2s$
- **2009-now(BEPCII)**
  $L_{peak} = 1.0 \times 10^{33}/cm^2s$
  (Achieved on Apr. 5th, 2016)

BESIII detector

From inner to outside[1]:

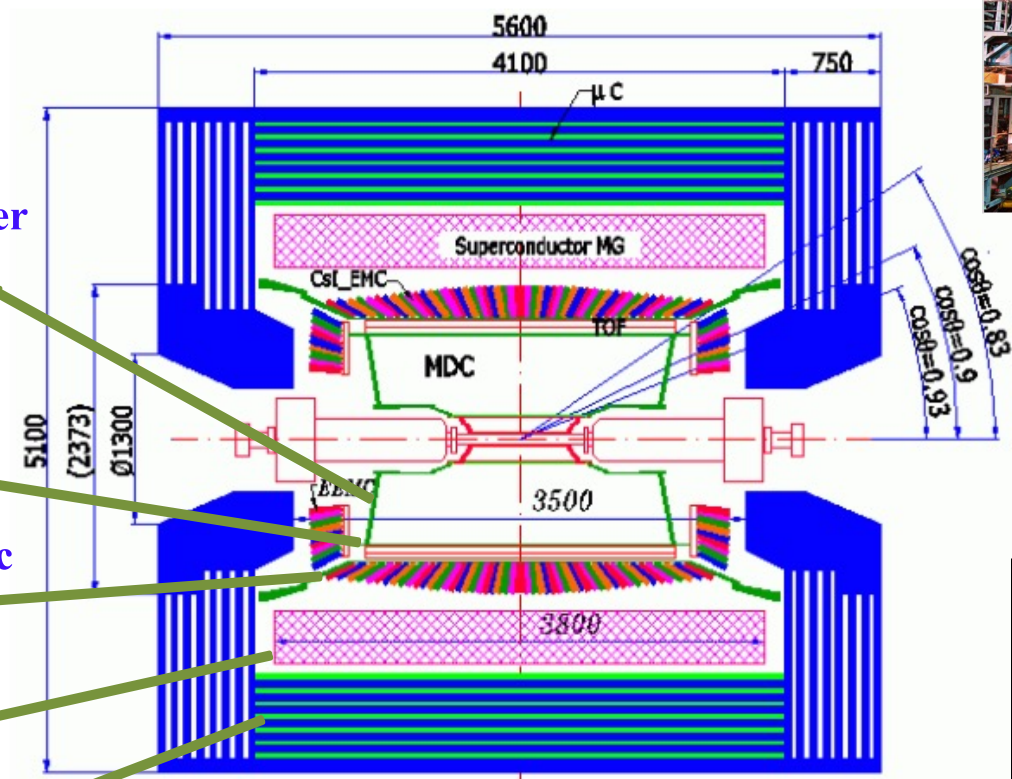
Helium-based multilayer drift chamber (MDC):

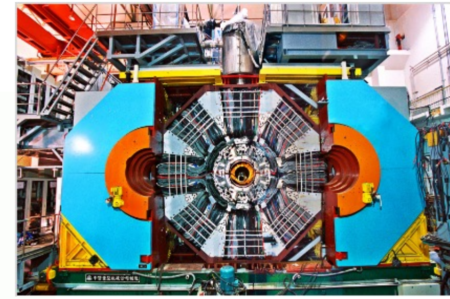
Plastic scintillator time-of-flight (TOF):

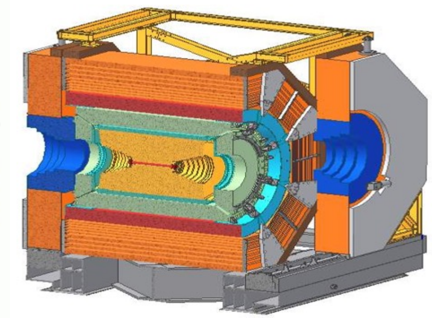
CsI (Tl) electromagnetic calorimeter (EMC):

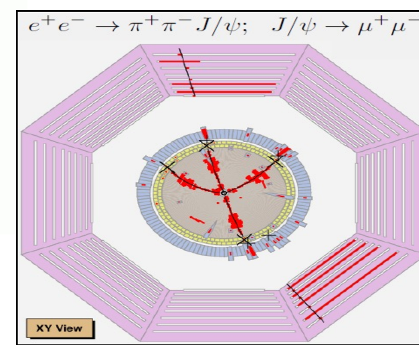
Superconducting solenoidal magnet:

Muon Counter (MUC):



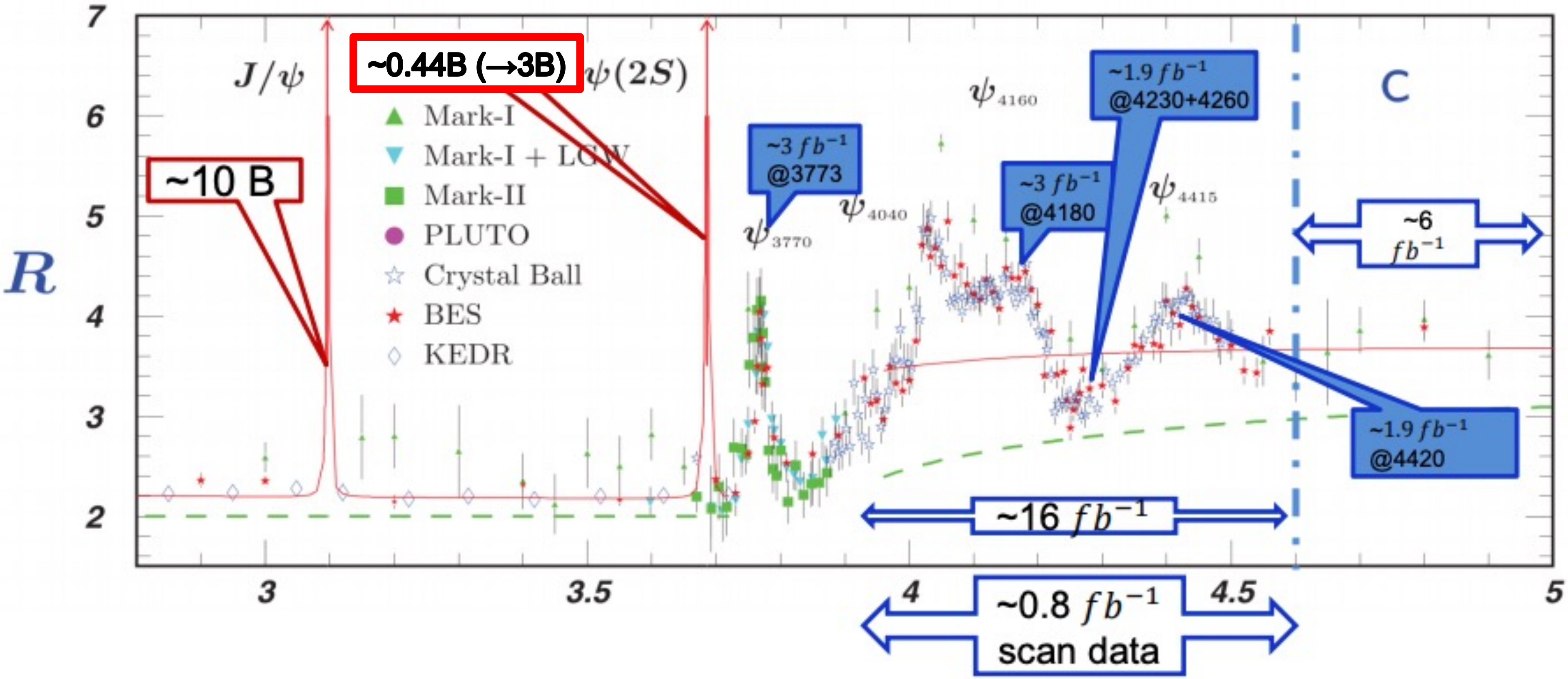






[1] M. Ablikim *et al*. (BESIII Collaboration), Nucl. Instr. Meth. A614, 345 (2010).

BESIII data

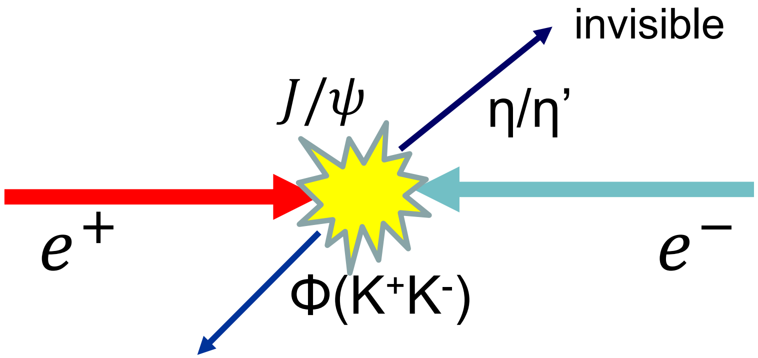


- Huge data set in τ-c region.
- World largest J/ψ, ψ’, ψ’’ data set by direct e^+e^- annihilation.

- In the near future, will have 3 B ψ’, 20 fb^{-1} ψ’’ in total.

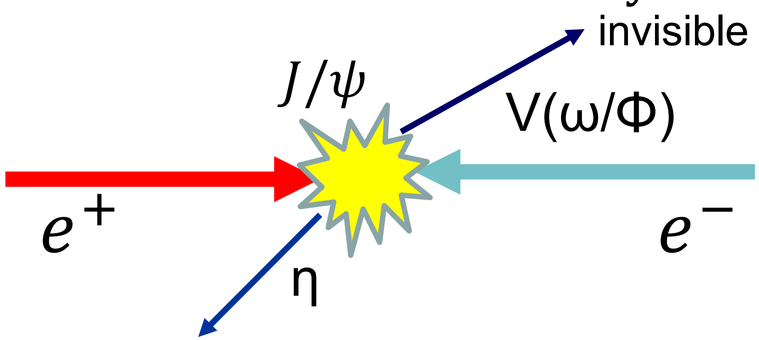
Searches for invisible decay at BESIII

- Search for η and η' invisible decays in J/ψ →Φη and Φη'



Phys. Rev. D 87, 012009 (2013)

- Search for the invisible decays of V(ω,Φ) in J/ψ →Vη decays



Phys. Rev. D 98, 032001 (2018)

- Search for J/ψ →γ+invisible

Phys. Rev. D 101, 112005 (2020)

In this talk!

- Search for Λ → invisible

Preliminary result

In this talk!

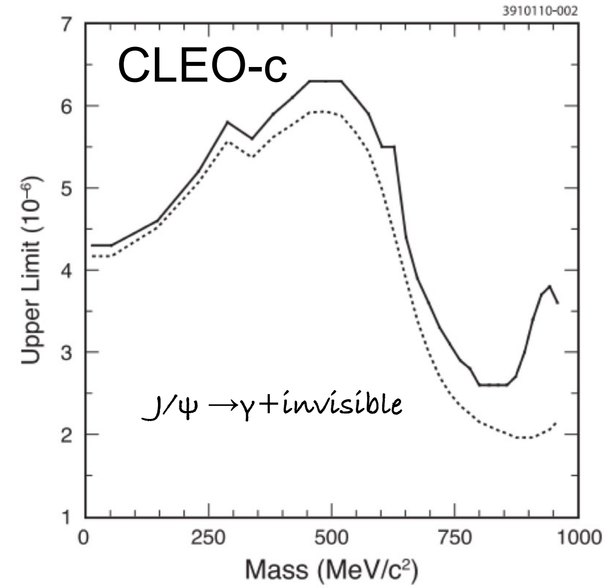
Search for J/ψ → γ+invisible

Phys. Rev. D 101, 112005 (2020)

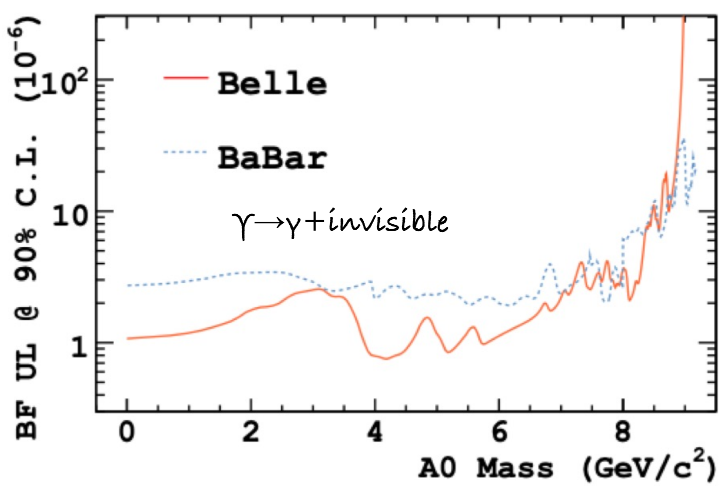
- A series of supersymmetric Standard Models, including Next-to-Minimal Supersymmetric Model, predict a CP-odd pseudoscalar Higgs (**A^0**). The **A^0** can be produced in quarkonium radiative decay:

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

where A^0 can decay to two neutralinos (invisible to detector), $g_c=\cos\theta_A/\tan\beta$, $g_b=\cos\theta_A\tan\beta$.

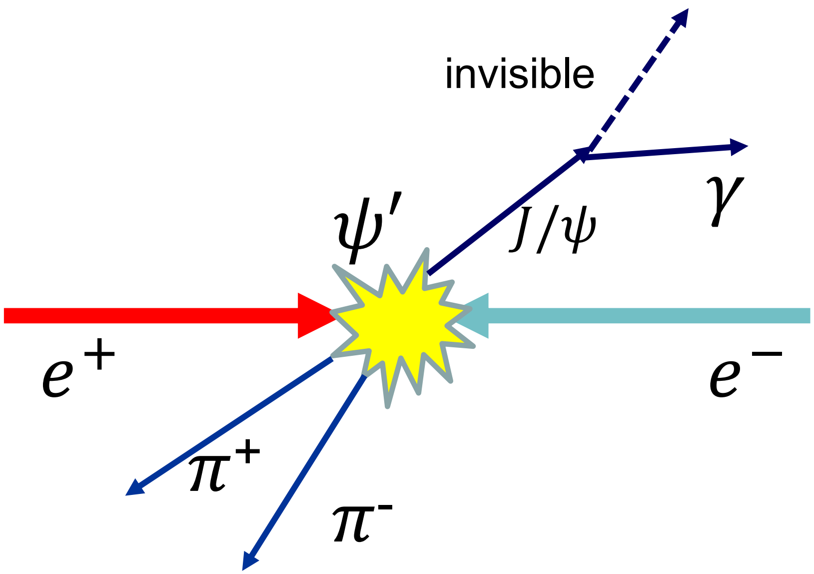


Phys. Rev. D 81,091101(R)(2010)



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

Search for J/ψ → γ+invisible



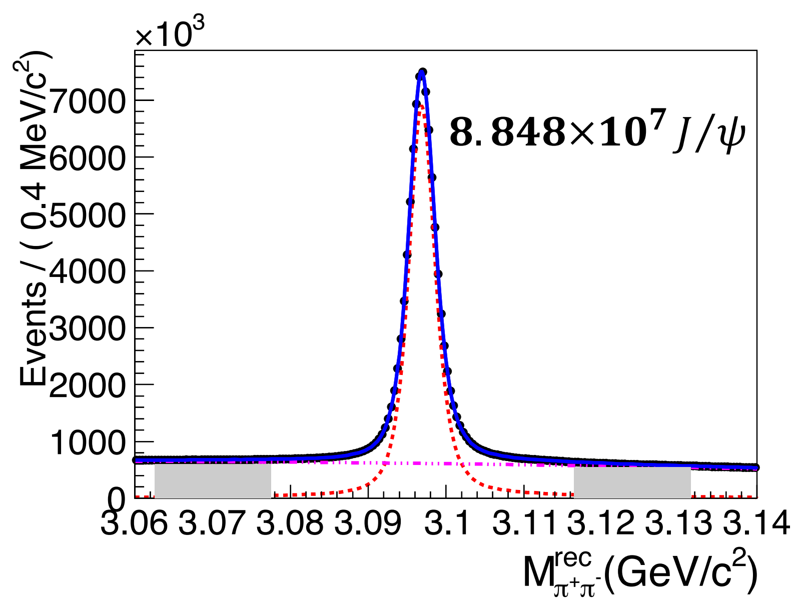
Analysis strategy:

- Using ψ' → $\pi^+\pi^-$J/ψ to get J/ψ sample.
  - ✓ The $\pi^+\pi^-$ provide excellent trigger.
  - ✓ Large BR (34.68%).
- Tag J/ψ first. Then search for signal.

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

- Perform semi-blind procedure.

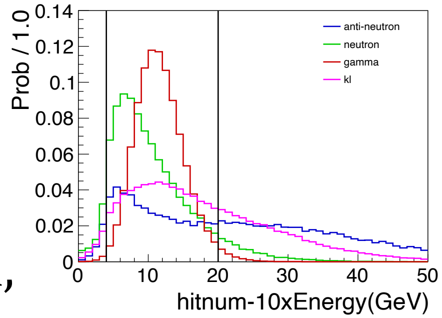
- Reconstruct $\pi^+\pi^-$ to tag J/ψ.
- Fit to the rec. mass of $\pi^+\pi^-$, get 8.848×10^7 J/ψ from 4.481×10^8 ψ' data set.



Search for J/ψ → γ+invisible

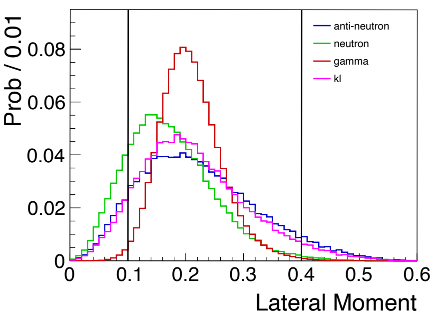
Based on tagged J/ψ sample, search for J/ψ→γ+invisible.

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

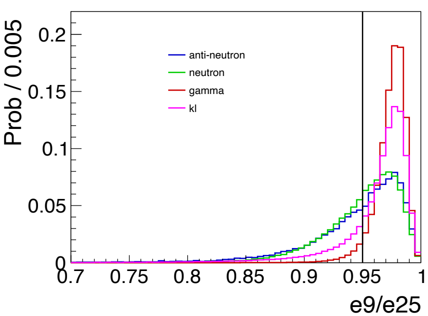


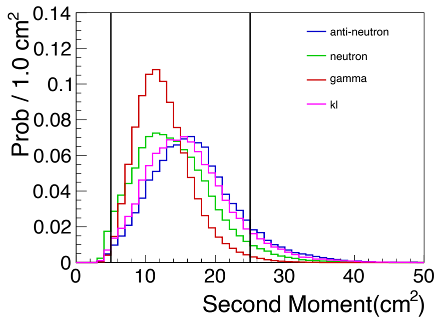
❖ Huge background from J/ψ → $n\bar{n}$, $\gamma n\bar{n}$, $\gamma K_L K_L$…

- Use shower shape to identify γ from n ,$\bar{n}$,K_L.
- BESIII simulation didn't simulate shower of n ,$\bar{n}$,K_L well,
- select control sample:
  - ✓ γ: J/ψ → ρπ,π^0 → γγ
  - ✓ $n/\bar{n}$: J/ψ → pπ $n/\bar{n}$
  - ✓ K_L: J/ψ → KπK_L & J/ψ → ππφ,φ → $K_S K_L$

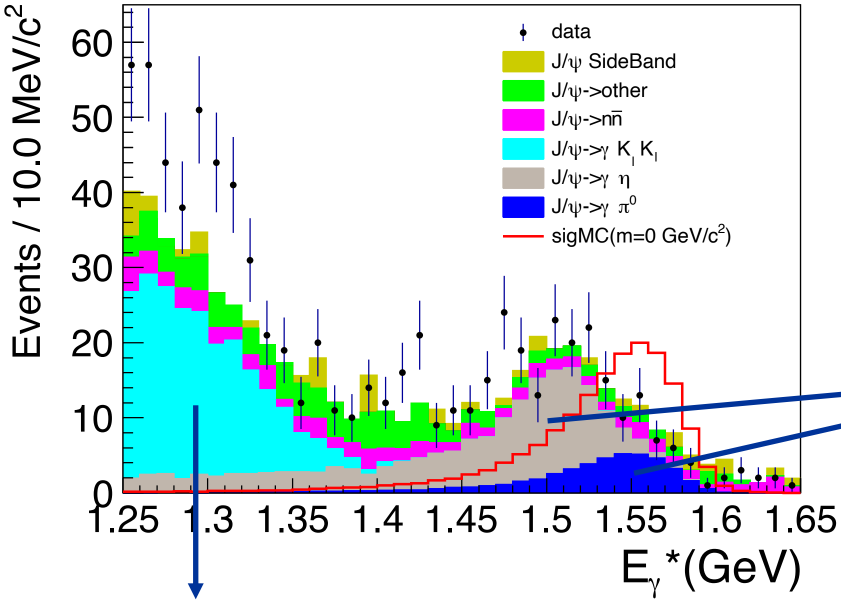


❖ For background MC, correct the shower energy and efficiency of n ,$\bar{n}$,K_L momentum dependently.

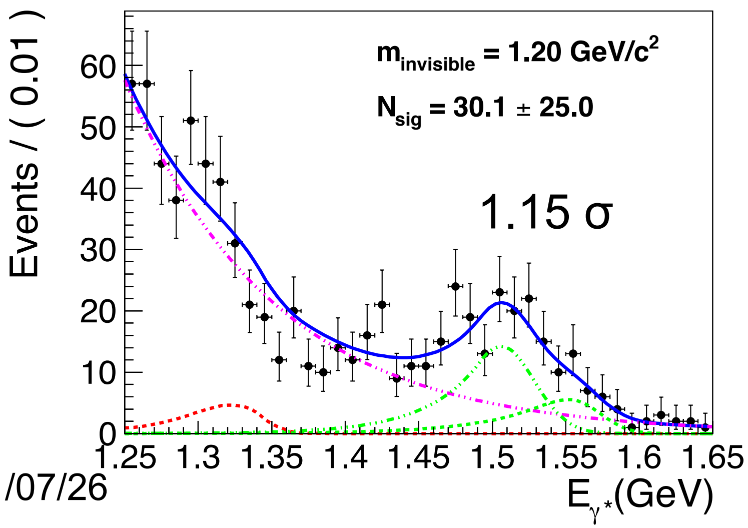




Search for J/ψ → γ+invisible



- ➢ Search signal on E(γ) in J/ψ's rest frame in [1.25, 1.65] GeV.
  - ○ Obvious peak from $\gamma\eta, \gamma\pi^0$.
  - ○ Huge bkg from $\gamma K_L K_L$, due to low efficiency of K_L.



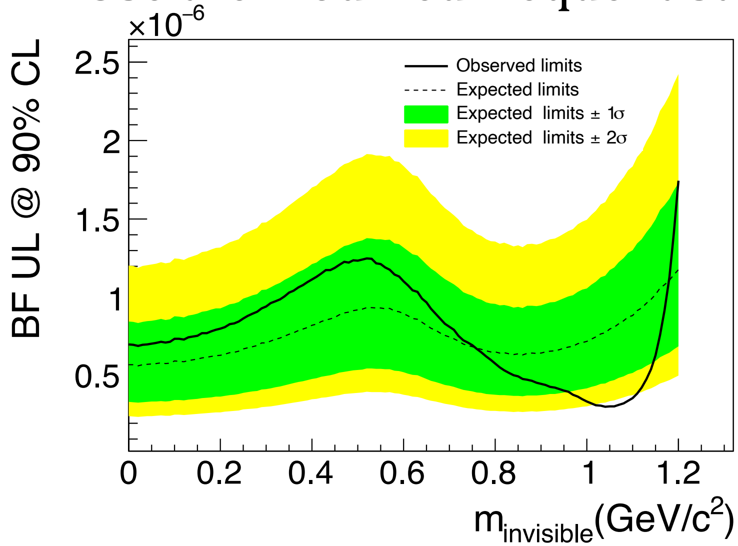
- ➢ Un-binned fit to extract signal:
- ➢ Signal : signal MC shape
- ➢ Two peak bkg: fixed Crystal Ball, determined by fits on exclusive MC
- ➢ Non-peak bkg: exponential function.
- ➢ Scan m(invisible) from 0~1.2 GeV/c².

- ➢ No significant signal found. Max significance is 1.15σ.

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

- Use the modified frequentist method (*CLs*) to calculate upper limits.

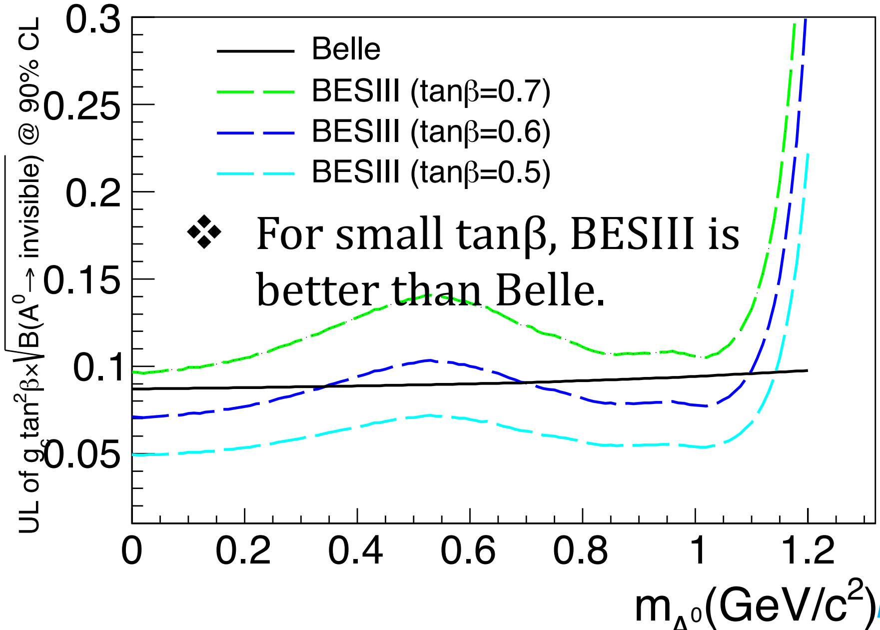
A.L. Read, J. Phys. G 28, 2693 (2002)



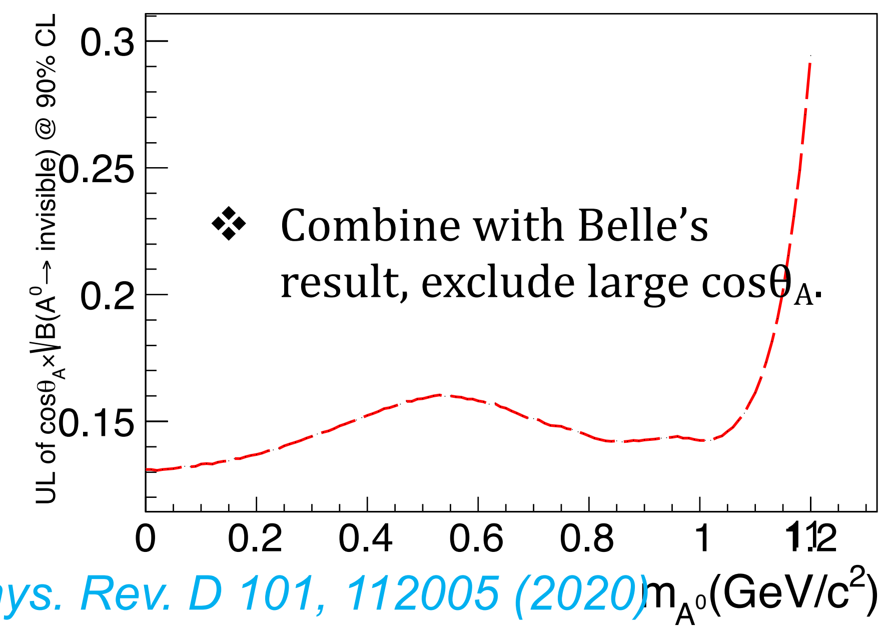
- ~6.2 better than CLEO-c's
- Data consistent with MC(H_0)
- ❖ Calculate UL for β and θ_A .

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

$$g_c = \cos\theta_A / \tan\beta \quad g_b = \cos\theta_A \tan\beta$$



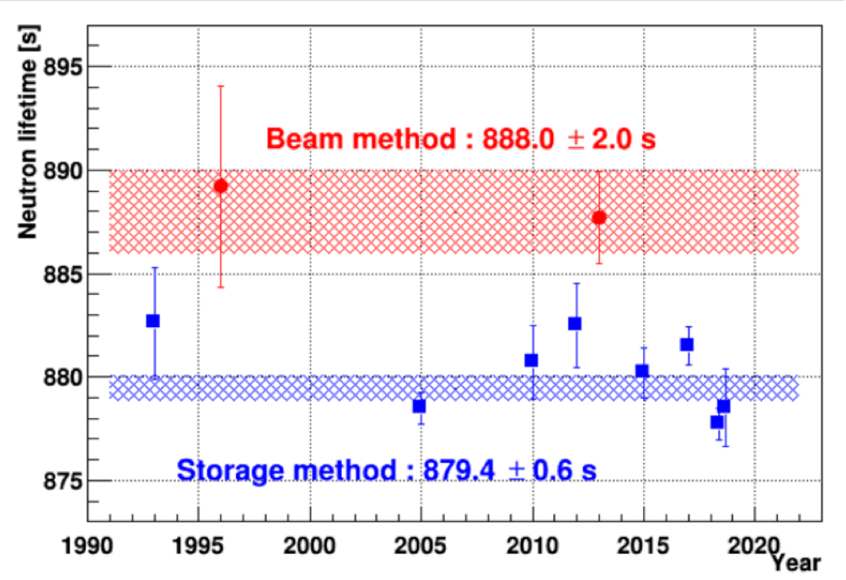
❖ For small tanβ, BESIII is better than Belle.



❖ Combine with Belle's result, exclude large $\cos\theta_A$.

Phys. Rev. D 101, 112005 (2020)

Search for Λ→ invisible



JPS Conf.Proc. 33 (2021) 011056

Preliminary result

- τ(n) measured by beam method and storage method are different.

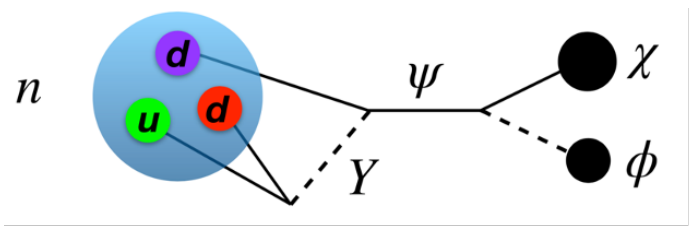
$$\tau_n^{beam} = \frac{\tau_n}{\mathcal{B}(n \to p + X)} > \tau_n^{bottle} \Rightarrow \mathcal{B}(n \to p + X) \approx 99\%$$

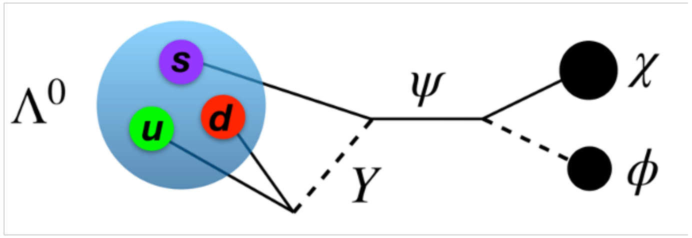
- If 1% n decays into dark matter, this can be understood.

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

- Some models predict baryon invisible decays:

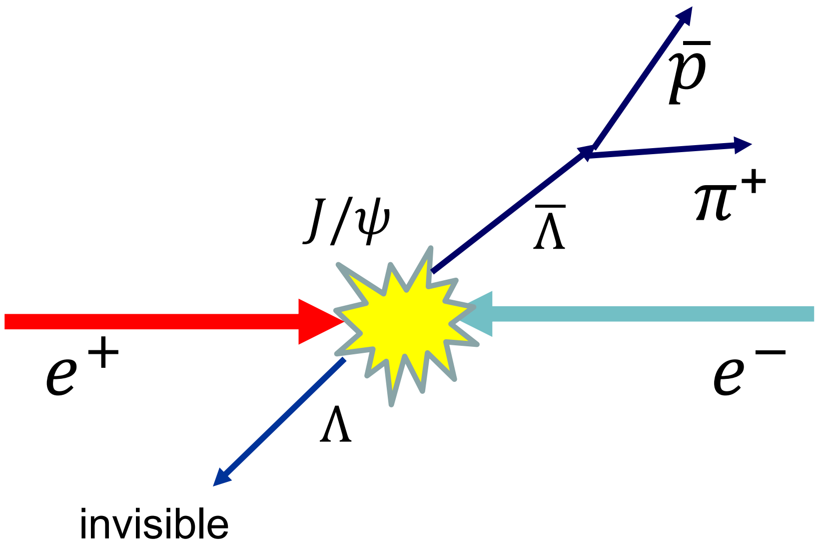
Phys. Rev.D 99(2019) 3, 035031





- No experimental search for baryon invisible decays until now.

Search for Λ→ invisible



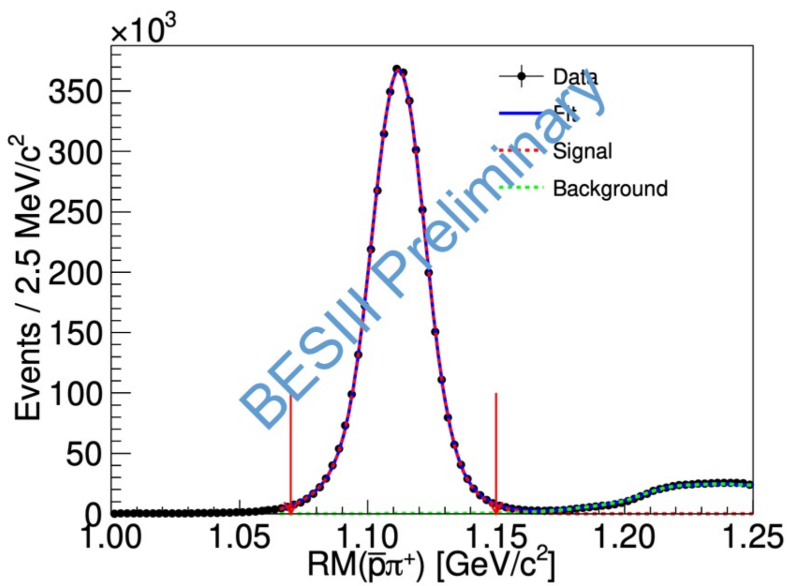
Analysis strategy:

- Using J/ψ → $\bar{\Lambda}\Lambda$ to get Λ sample from J/ψ data set.

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

- Perform semi-blind procedure.
- Search for signal on total energy in EMC.

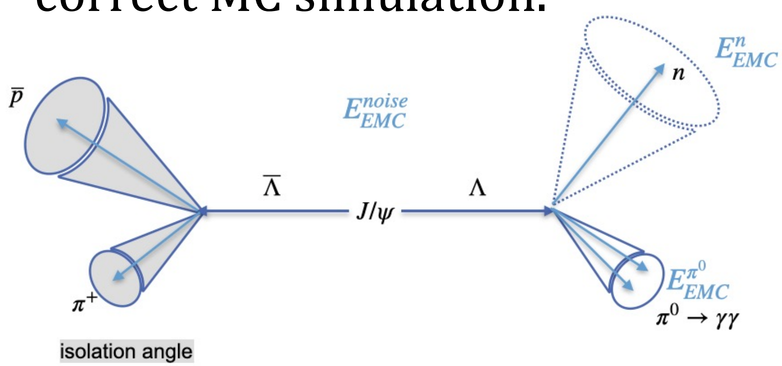
- Reconstruct $\bar{p}\pi^+$.
- Require TOF hit from charged tracks, to guarantee all showers are related to the event.
- Fit to the rec. mass of $\bar{p}\pi^+$, get 4.15×10^6 Λ.

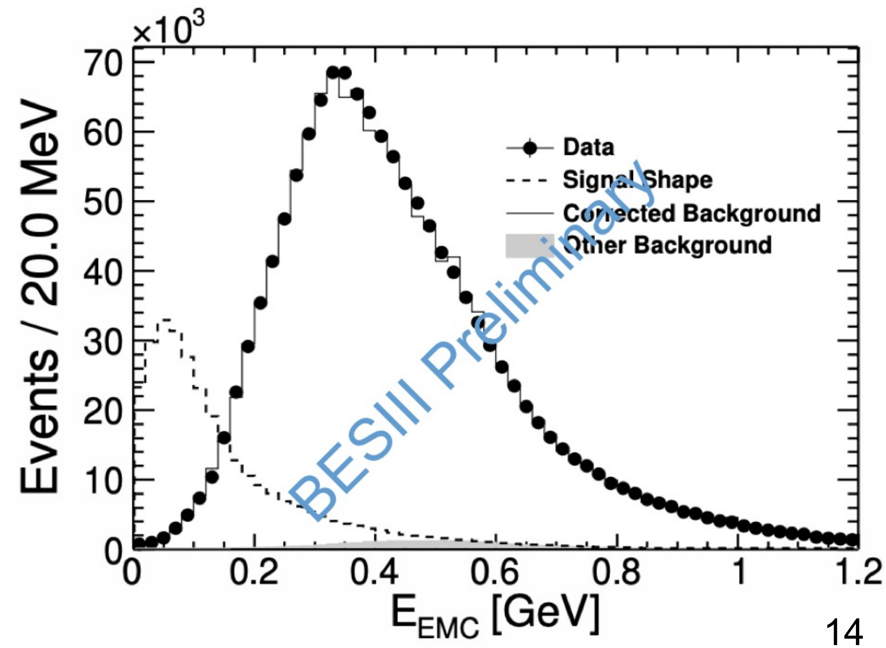


Search for Λ→ invisible

- Based on previous tagged Λ sample.
- No extra charged tracks.
- Search signal on total energy in EMC (E_{EMC}).

- Main background is $\Lambda \to n\pi^{0}$. E_{EMC} from π^{0}, n and noise.
- Current BESIII simulation didn't simulate n in EMC well.
- By control sample $J/\psi \to \bar{\Lambda}(\bar{p}\pi^{+})\Lambda(n\pi^{0})$, get precise n's and noise's E_{EMC} and correct MC simulation.



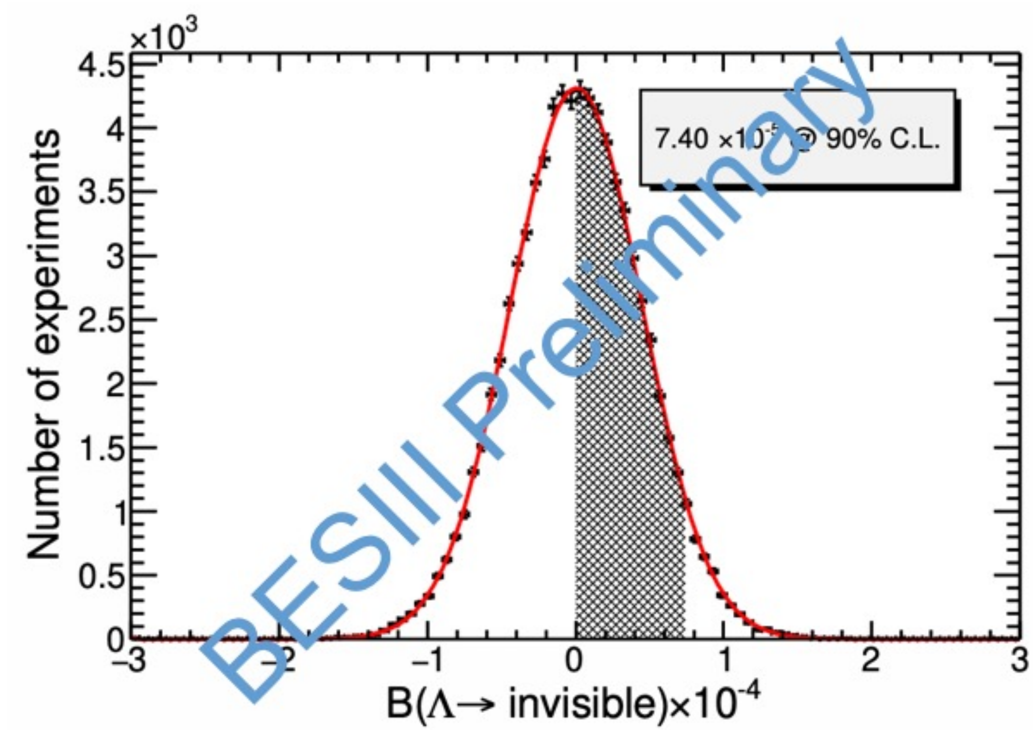


- Data consistent with MC well.
- No obvious signal.

Search for Λ→ invisible

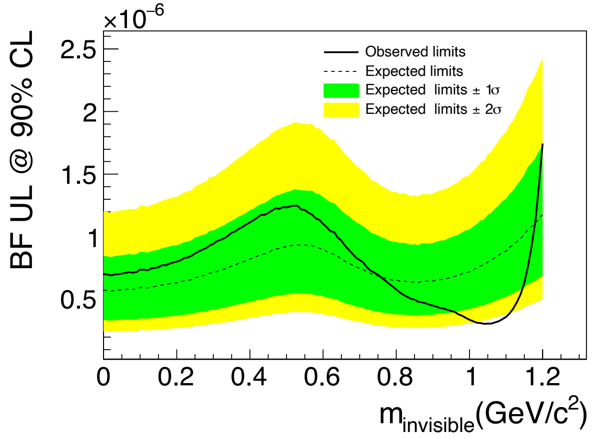
- Use the modified frequentist method (CLs) to calculate upper limits @ 90% confidence level.
- Get $\mathcal{B}(\Lambda \to \text{invisible}) < \mathbf{7.4} \times \mathbf{10^{-5}}$ with 10B J/ψ data.

❖ First search for baryon invisible decay. Will release soon.



Summary

- With 4.48B ψ' data sample, search for J/ψ → γ+invisible. No obvious signal found. Upper limits @ 90% confidence level for m(invisible) in [0,1.2] GeV/c^2, which is **~6.2** times better than previous results.



- With 10 B J/ψ data sample, search for Λ →invisible. No obvious signal found. Upper limit @ 90% confidence level: $\mathbf{7.4 \times 10^{-5}}$. **First search** for baryon invisible decay.

- More huge data in BESIII. Many ongoing invisible searches. More exciting results in future.

Thank you!

BACK-UP

Systematic uncertainty

Source	Uncertainty
Tagged J/ψ number	
Signal shape	0.1%
Background shape	0.1%
Fit bin size	0.3%
Fit range	0.6%
Signal efficiency	
Gamma reconstruction	1%
Only one good shower	0.6%
Extra showers' energy cut	Less than 0.1%
Shower shape cut	0.9%
Fit procedure	
Number of $\psi(3686) \to \pi^+\pi^- J/\psi, J/\psi \to \gamma\eta$	17%
Number of $\psi(3686) \to \pi^+\pi^- J/\psi, J/\psi \to \gamma\pi^0$	17%
Number of continuum background	4.4%

Search for Λ→ invisible

Summary of systematic uncertainty.

Source	Choice or uncertainty
Shower separation angle	18°, 20° and 22°
Bin width	10, 20, 30, 40, 50 MeV
No additional charged track	0.6%