Search for invisible decays and J/ψ weak decays at BESIII

在BESIII实验中寻找不可见衰变以及J/ψ稀有衰变

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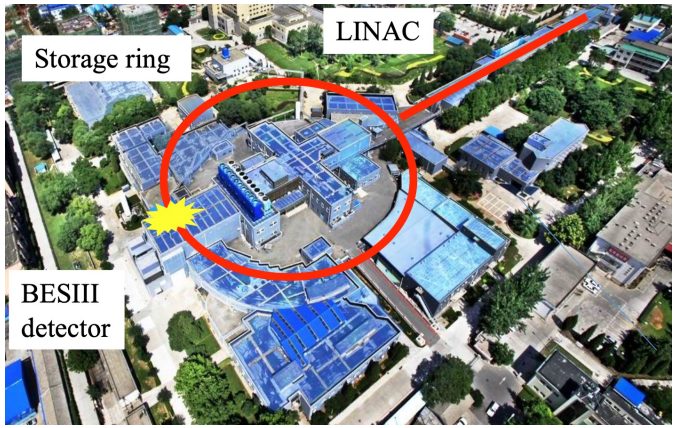
Outline

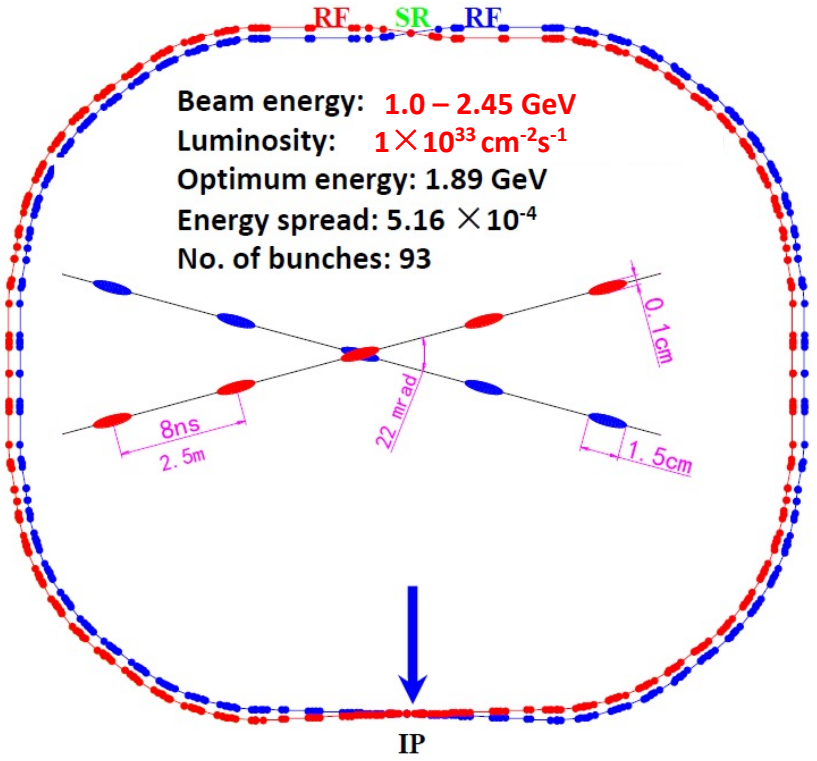
- Introduction of BEPCII & BESIII
- Invisible decays
  - Search for $J/\psi \to \gamma + invisible$
  - Search for $\eta^{(\prime)}$ invisible decays in $J/\psi \to \phi\eta^{(\prime)}$
  - Search for ω and ϕ invisible decays with $J/\psi \to V(\omega, \phi)\eta$
- J/ψ weak decays
  - Research status
  - $J/\psi \to D^- e^+ \nu_e$+c.c.
- Summary



BEPCII and BESIII

Beijing Electron Positron Collider II

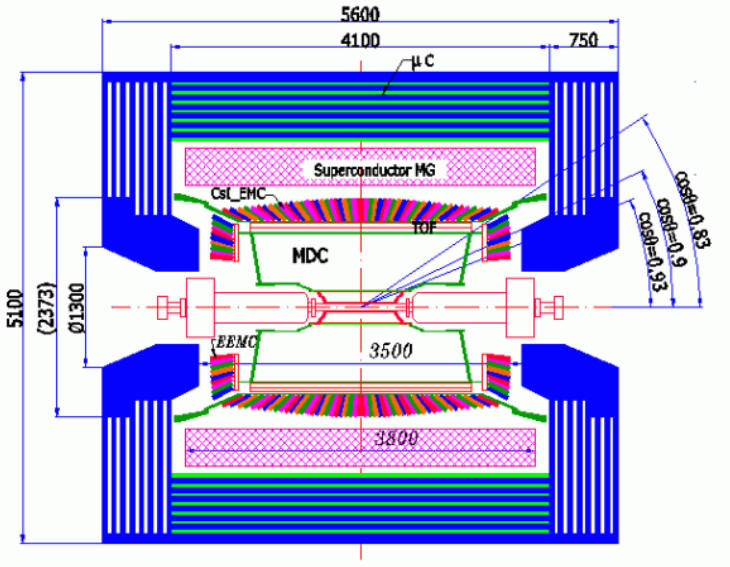
Charm Factory



BESIII Detector

MDC: p 0.5%@ 1GeV/c
dE/dx: 6%

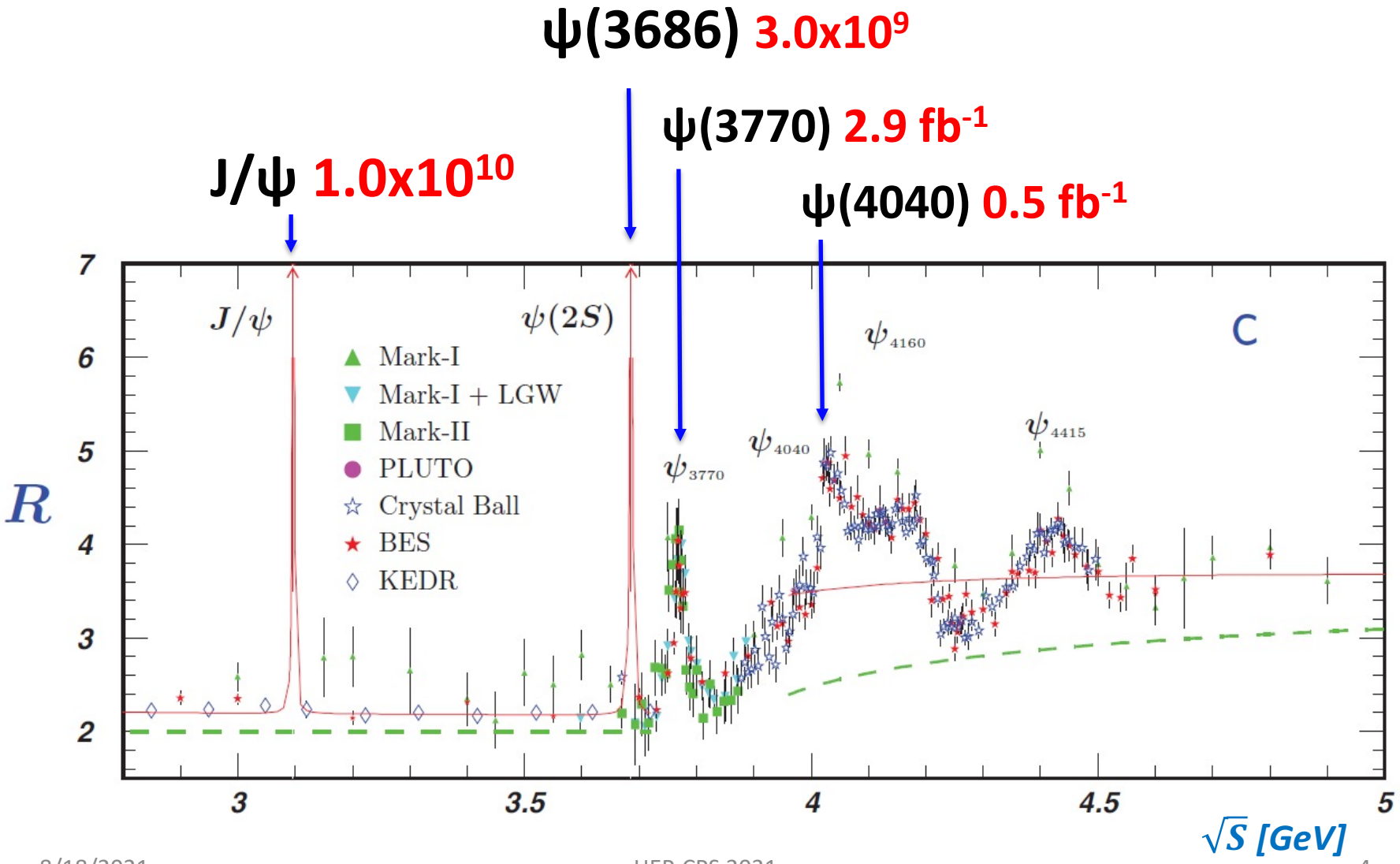
EMC: CsI (Tl) 2.5% (5.0%)
barrel (endcap) @ 1GeV



TOF: σT=68(65) ps
barrel (endcap)

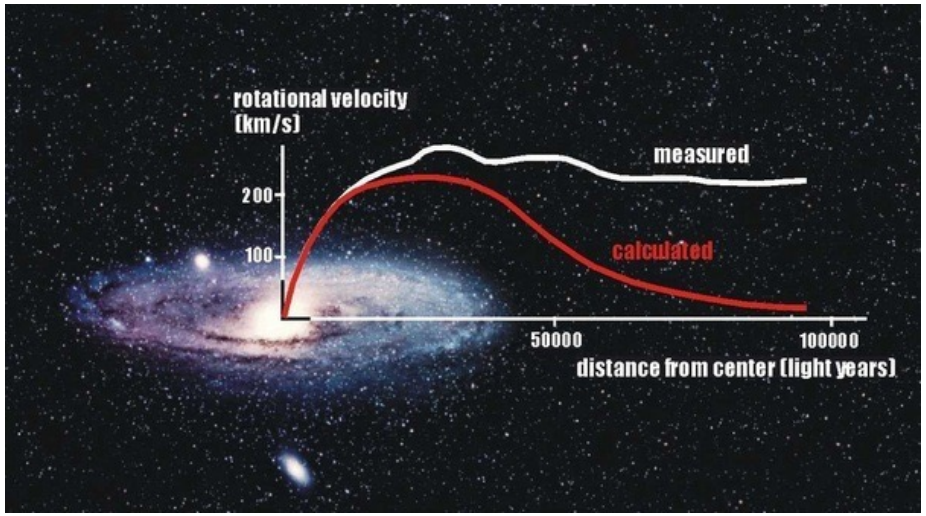
MUC: RPC 9 (8) layers
barrel (endcap)

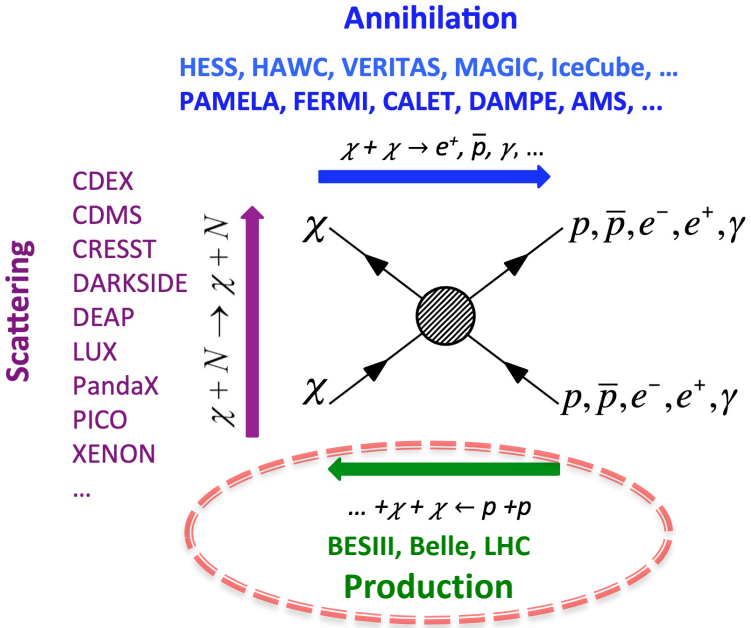
Charmonium data at BESIII



Invisible decays

- Many evidences for the existence of dark matter are observed in astronomy. But no evidence from the collider experiments.
- Search for invisible decays at colliders is one way to search for dark matter.





Search for $J/\psi \rightarrow \gamma +$ invisible : General

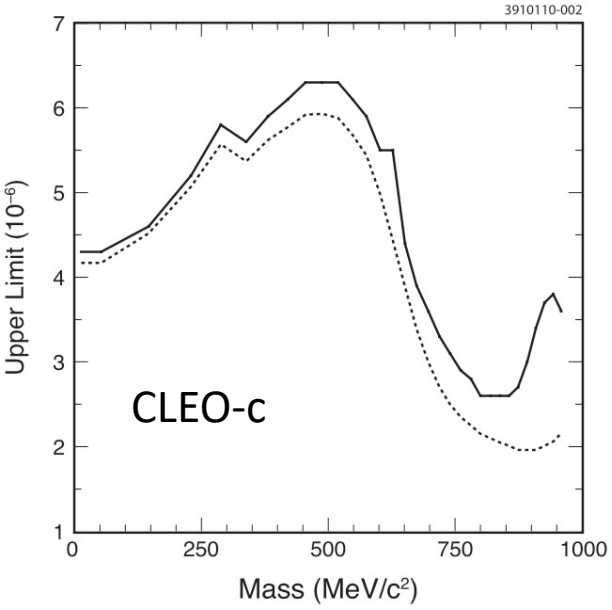
- A series of supersymmetric models, including Next-to-Minimal Supersymmetric Model, predict a CP-odd pseudoscalar Higgs(A^0). The A^0 can be produced in quarkonium radiative decay :

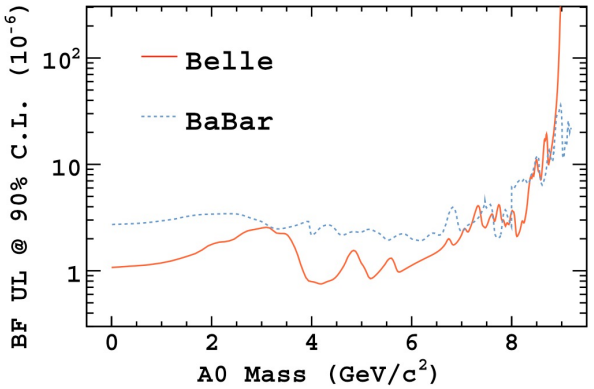
$$\frac{B(V \rightarrow \gamma A^0)}{B(V \rightarrow \mu^+\mu^-)} = \frac{G_F m_q^2 g_q^2 C_{QCD}}{2\pi\alpha}\left(1 - \frac{m_{A^0}^2}{m_V^2}\right)$$

  - g_q is the Yukawa coupling of the A^0 field to the quark-pair
  - $g_c = \cos\theta_A / \tan\beta$ for the charm quark
  - $g_b = \cos\theta_A \tan\beta$ for the bottom quark
  - $\tan\beta$ is the usual ratio of vacuum expectation values
  - θ_A is the Higgs mixing angle

- A^0 can decay to two neutralinos, which is invisible to detector

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



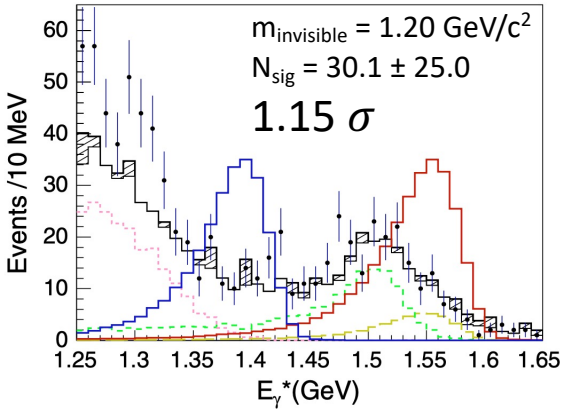


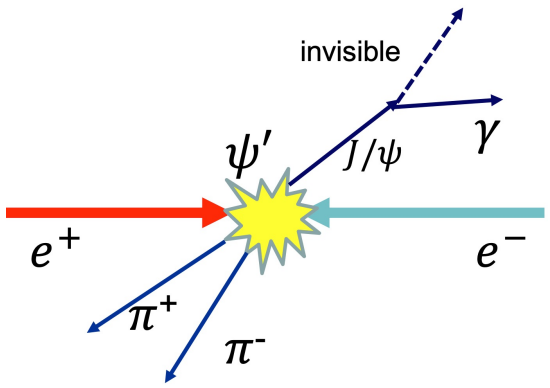
Phys. Rev. Lett 122 no.1 011801(2019)

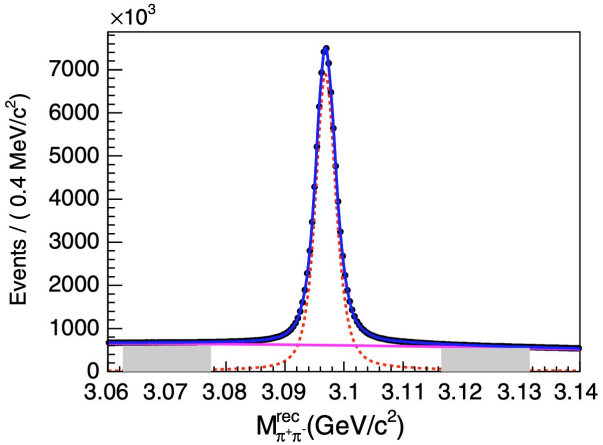
Search for $J/\psi \to \gamma +$ invisible : Analysis

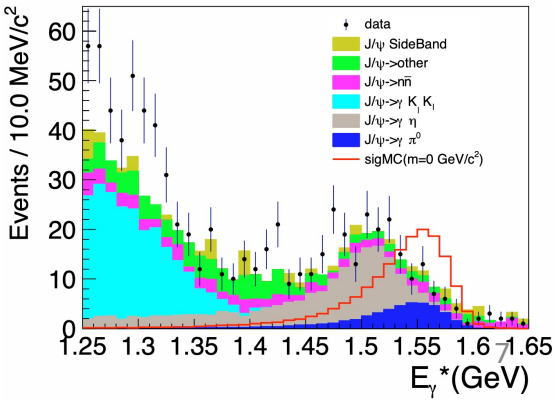
Phys. Rev. D 101, 112005 (2020)

- 4.481×10^8 $\psi(3686) \to \pi^+\pi^- J/\psi$ is used to get J/ψ sample
- Fit the recoiling mass of $\pi^+\pi^-$, get 8.848×10^7 J/ψ
- Search signal on E_γ^* in J/ψ rest frame in [1.25,1.65] GeV
  - Huge background from $\gamma K_L K_L$
  - Obvious peak from $\gamma\eta$, $\gamma\pi^0$
- No significant singal found
  - Signal : signal MC shape
  - Two peak bkg : fixed Crystal Ball
  - Non-peak bkg : exponential function
  - Scan m(invisible) from 0 ~ 1.2GeV/c^2



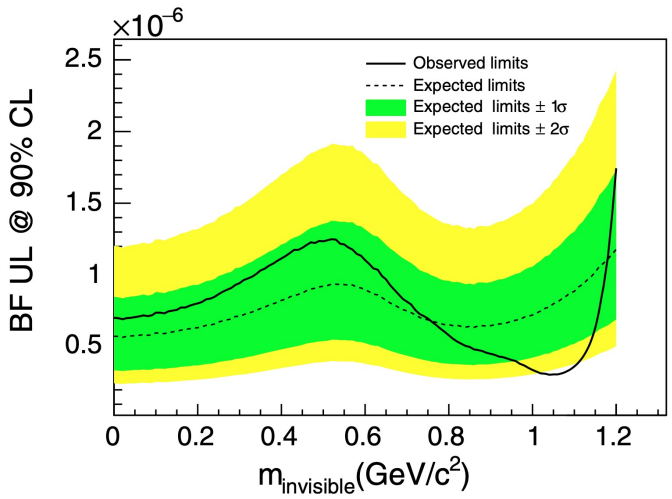






Search for $J/\psi \to \gamma +$ invisible : Result

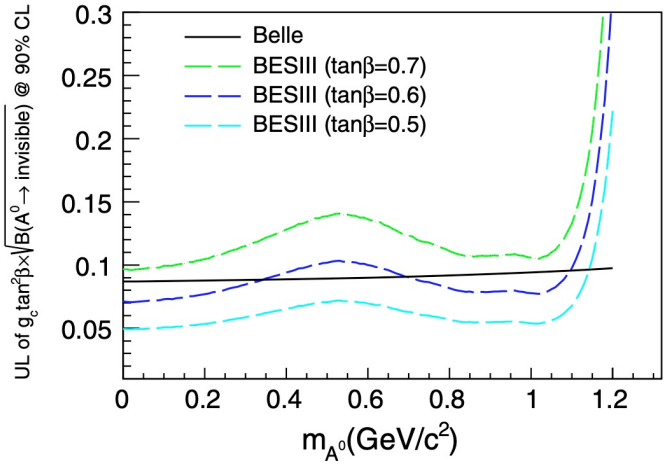
Phys. Rev. D 101, 112005 (2020)

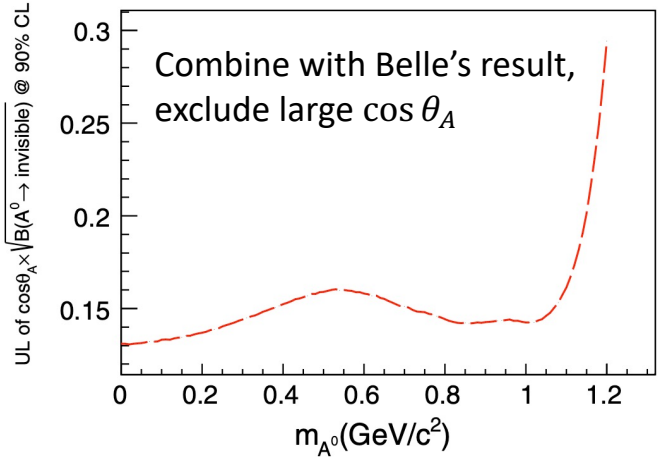


- Modified frequentist method is used to calculate upper limits @ 90% CL
  - The UL for a zero mass of the invisible particle is improved by a factor 6.2 compared to CLEO-c's
  - Obtain better sensitivity in the range $\tan\beta \leq 0.6$ compared to the Belle's

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

$$g_c = \cos\theta_A / \tan\beta\,,\; g_b = \cos\theta_A \tan\beta$$



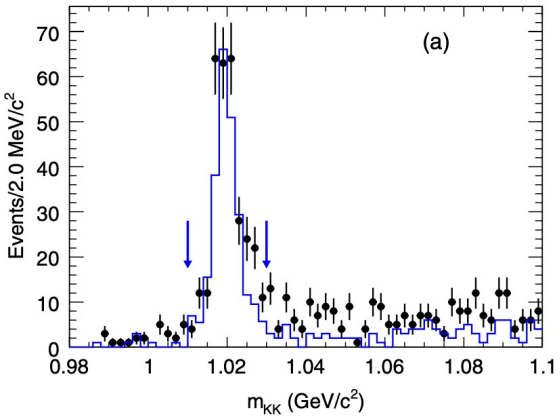


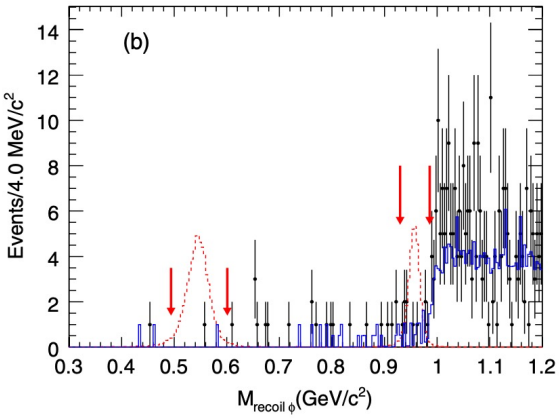
Search for $\eta^{(\prime)}$ invisible decays

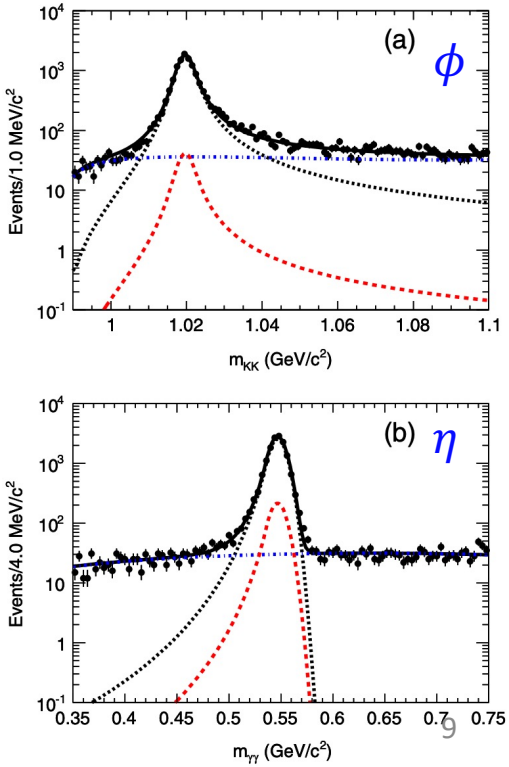
Phys. Rev. D 87, 012009 (2013)

- 225.3×10^6 $J/\psi \to \phi\eta^{(\prime)}$ and $\phi \to K^+K^-$is used to get $\eta^{(\prime)}$ sample
- No charged tracks besides those of the $\phi \to K^+K^-$
- No obvious signal is observed, upper limits is set
  - $Br(\eta \to invisible)/Br(\eta \to \gamma\gamma) < 2.58\times10^{-4}$ @ 90% $C.L.$
  - $Br(\eta' \to invisible)/Br(\eta' \to \gamma\gamma) < 2.39\times10^{-2}$ @ 90% $C.L.$
  - $Br(\eta \to invisible) < 1.01\times10^{-4}$ @ 90% $C.L.$
  - $Br(\eta' \to invisible) < 5.21\times10^{-4}$ @ 90% $C.L.$
- Improved PDG values

ratio to cancel uncerntainty



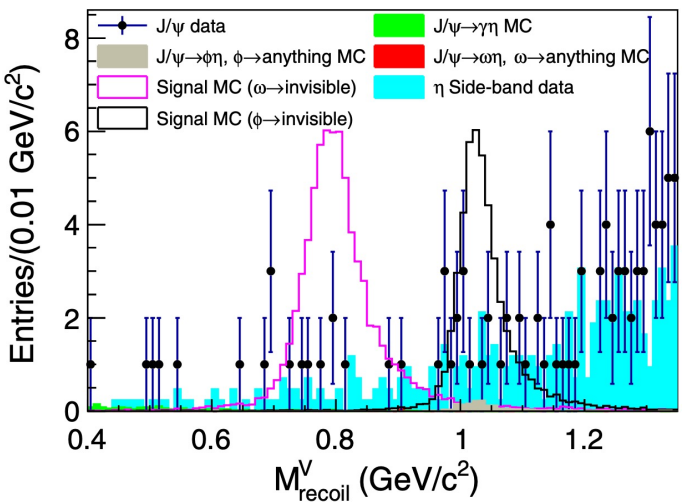


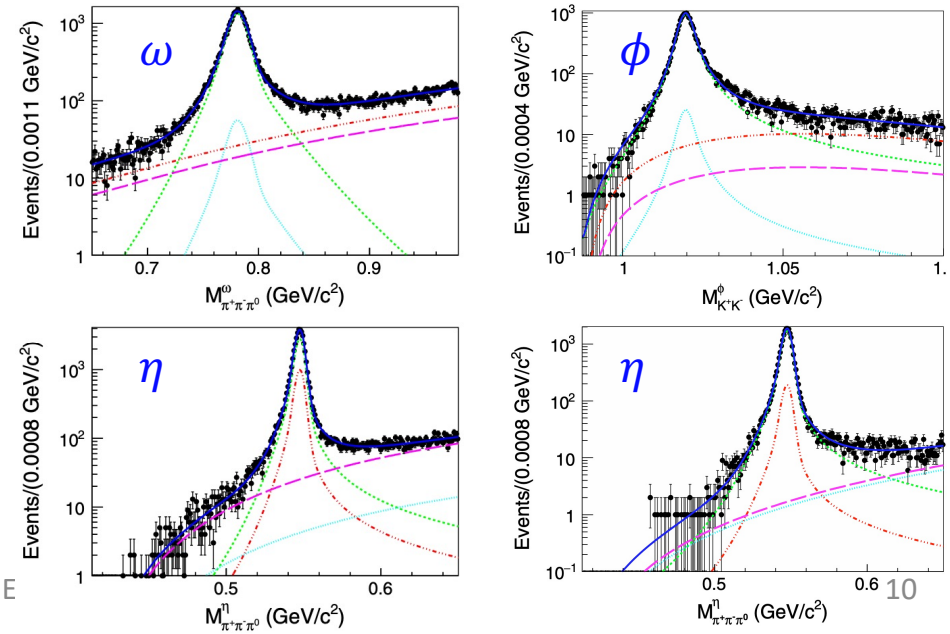


Search for ω and ϕ invisible decays

Phys. Rev. D 98, 032001 (2018)

- 1310.6×10^6 $J/\psi \to V(\omega,\phi)\eta$ and $\eta \to \pi^+\pi^-\pi^0$ is used to get V sample
- No obvious signal is observed, upper limits is set
  - $Br(\omega \to invisible)/Br(\omega \to \pi^+\pi^-\pi^0) < 8.1\times10^{-5}$ @ 90% $C.L.$
  - $Br(\phi \to invisible)/Br(\phi \to K^+K^-) < 3.4\times10^{-4}$ @ 90% $C.L.$
  - $Br(\omega \to invisible) < 7.3\times10^{-5}$ @ 90% $C.L.$
  - $Br(\phi \to invisible) < 1.7\times10^{-4}$ @ 90% $C.L.$





J/ψ weak decays

- Weak decays, due to the smallness of the strength of the weak interaction, are rare processes
- The decay rate is $\propto G_F^5\ m_c^5$, which is at the order of 10^{-11}

  EPJC,54:107 (2008); AHEP,2013:706543 (2013); AHEP,2016:5071671(2016); PRD,15:1958 (1977)
- The inclusive weak decay rate of J/ ψ : $Br \approx \frac{2/\tau_D}{\Gamma_{J/\psi}} \approx 10^{-8}$

  PRD, 60:014011 (1999); PLB,345:483 (1995); PRD,15:1958 (1977)
- New Physics model predict that Br can be enhanced to $10^{-8}\sim10^{-6}$
- Study of J/ψ weak decays
  - **Provide a further accurate examination of the mechanism**
  - **Probe new physics beyond the standard model**

Research status

- J/ψ weak decays at BESIII
  - Weak semi-leptonic decay
  - Hadronic decay
  - FCNC weak decay

Hadonic decay

	$J/\psi \to D_s^- \rho^+$	$J/\psi \to \bar{D}^0 \bar{K}^{*0}$
Exp.	BESIII	BESIII
$N_{J/\psi}$	225.3×10^6	225.3×10^6
$B(90\%)$	$< 13 \times 10^{-6}$	$< 2.5 \times 10^{-6}$

PRD 89, 071101 (2014)

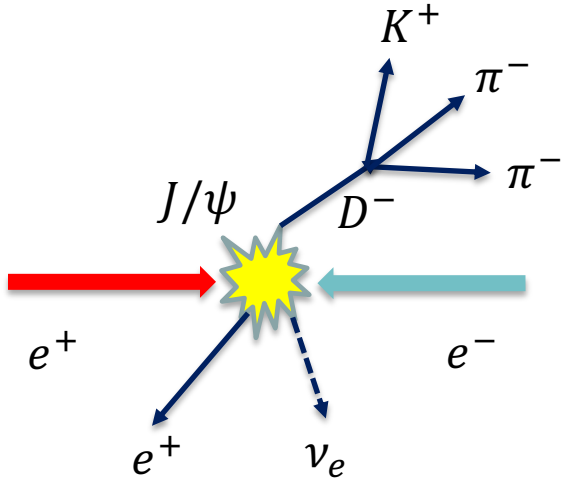
Weak semi-leptonic decay

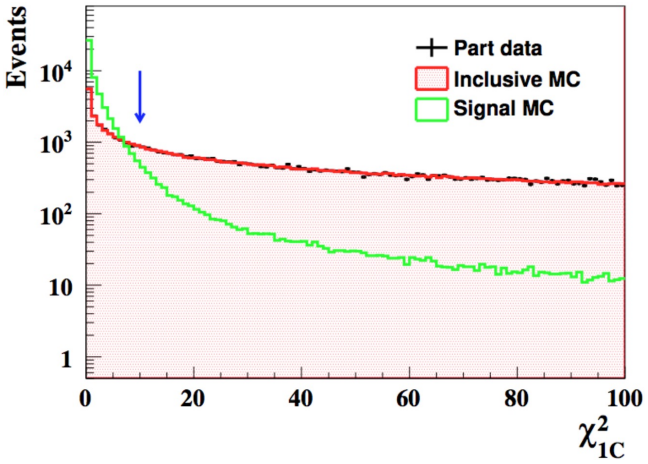
	$J/\psi \to D_s^- e^+ \nu_e$	$J/\psi \to D_s^{*-} e^+ \nu_e$	$J/\psi \to \bar{D}^0 e^+ e^-$	$J/\psi \to D^- e^+ \nu_e$
Exp.	BESIII	BESIII	BESIII	BESIII
$N_{J/\psi}$	225.3×10^6	225.3×10^6	1310.6×10^6	10.1×10^9
$B(90\%)$	$< 1.3 \times 10^{-6}$	$< 1.8 \times 10^{-6}$	$< 8.5 \times 10^{-8}$	$< 7.1 \times 10^{-8}$

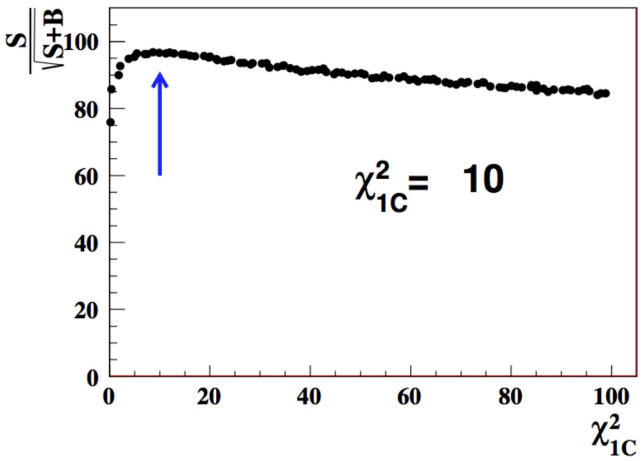
References : PLB 639, 418 (2006); PRD 90,112014 (2014); JHEP 06, 157 (2021).

$J/\psi \to D^- e^+ \nu_e$: Strategy

- 10 Billion J/ψ is used
- $D^-$is reconstructed via $K^+\pi^-\pi^-$
- $\mathrm{FOM} = \frac{s}{\sqrt{s+b}}$ is used to optimized cut
- Semi-blind analysis is used to avoid possible bias

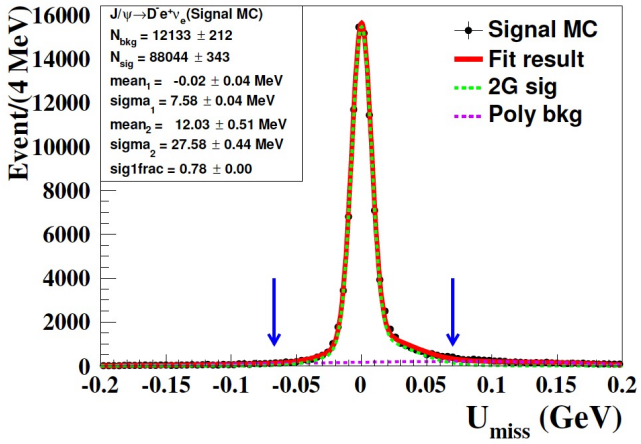


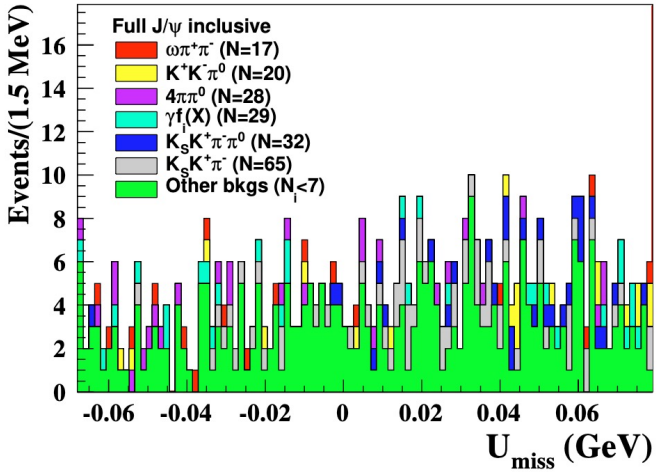


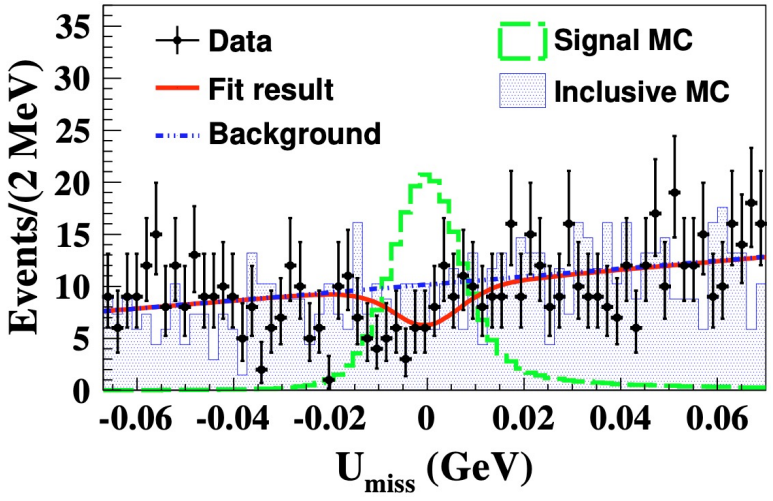


$J/\psi \rightarrow D^- e^+ \nu_e$: Analysis

- $U_{miss} = E_{miss} - P_{miss}$ is used to find signal
  - Obviously signal events would form a peak at $U_{miss} = 0$
- Fit to the U_{miss} of signal MC to get a 3σ region as signal region
- Background
  - Gamma conversion and particle misidentification
  - No peaking background
- No excess of events is observed







$J/\psi \to D^- e^+ \nu_e$: Result

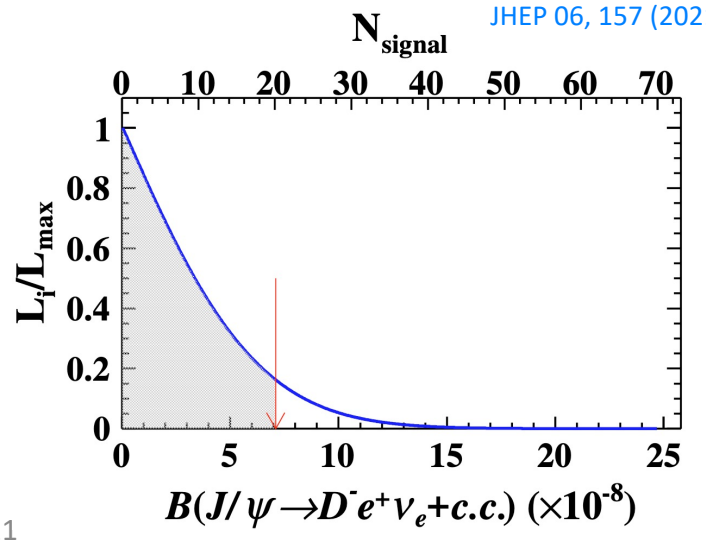
- Bayesian approach is used to calculate upper limits @ 90% CL
  - $Br(J/\psi \to D^- e^+ \nu_e + c.c.) < 7.1\times10^{-8}$
- Improves limit by a factor of 170
- Most sensitive search for this decay
- Compatible with the SM predictions
- Puts a stringent constraint on the parameter spaces for different new physics models

$$\mathcal{L}(\mathcal{B}) \propto \int_0^1 exp[-\frac{(\epsilon\mathcal{B}/\hat{\epsilon} - \hat{\mathcal{B}})^2}{2\sigma_{\mathcal{B}}^2}]\ exp[-\frac{(\epsilon - \hat{\epsilon})^2}{2\sigma_{\epsilon}^2}]\ d\epsilon$$

$\hat{\mathcal{B}}$: mean value of BF of Fit Line
$\sigma_{\mathcal{B}}$: statistical error of BF of Fit Line
$\hat{\epsilon}$: nominal efficiency
$\sigma_\epsilon = \Delta_{sys} \cdot \epsilon$: error of efficiency

Sources	Relative uncertainties
Tracking	4.0
Particle ID	4.0
Signal MC model	3.0
$E_\gamma^{\rm tot}$ requirement	2.1
E/p requirement	0.3
$\lvert\vec{p}_{\rm miss}\rvert$ requirement	0.3
BF of the $D^- \to K^+\pi^-\pi^-$ decay	1.7
Number of J/ψ events	0.5
Total	7.0

JHEP 06, 157 (2021)



Summary

- Several searches about invisible decays and J/ψ weak decays have been review.
- More data in BESIII. Many ongoing invisible searches and weak decays searches. More exciting results in future.
  - $J/\psi \to invisible, D^+ \to \pi^+ + invisible$
  - $\Lambda \to invisible, \Lambda_c^+ \to p + invisible$
  - $J/\psi \to D_s^- e^+ \nu_e, D^- u^+ \nu_u$
  - $J/\psi \to \bar{D}^0 \pi^0, \bar{D}^0 \rho^0, \bar{D}^0 \eta, D^- \pi^+, D^- \rho^+$
  - ψ' weak decay
  - …

Thank you!