Dark sector search at BESIII

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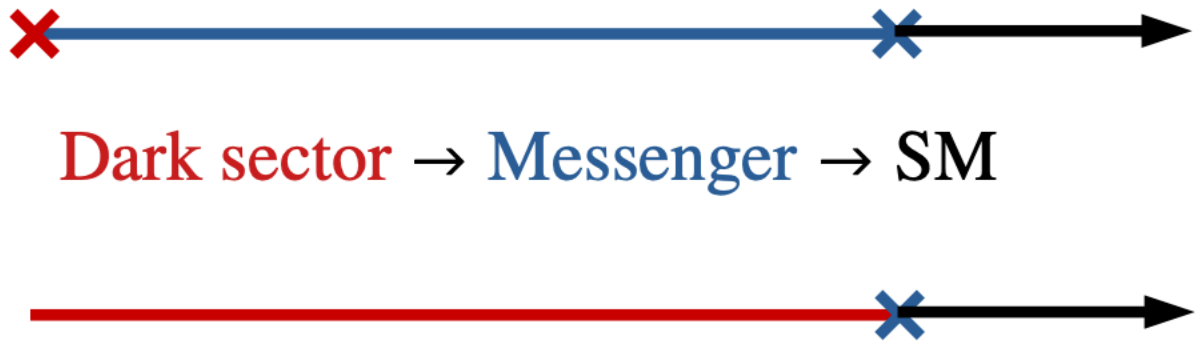
Dark Sector

- Dark sector refers to a hypothetical collection of particles and forces that do not interact with ordinary matter in the same way as we observe through electromagnetic interactions.
- We have to search for the dark sector with SM based techniques.
- The search of dark sector would have significant implications for our understanding of the nature of dark matter and the structure of the universe.



Data Samples at BESIII

2009: 106M $\psi(2S)$
225M J/ψ
2010: 0.98 fb^{-1} $\psi(3770)$ (for $D^{0(+)}$)
2011: 2.93 fb^{-1} $\psi(3770)$ (for $D^{0(+)}$, total)
0.48 fb^{-1} @4.01 GeV
2012: 0.45B $\psi(2S)$ (total)
1.30B J/ψ (total)
2013: 1.09 fb^{-1} @4.23 GeV
0.83 fb^{-1} @4.26 GeV
0.54 fb^{-1} @4.36 GeV
10×0.05 fb^{-1} XYZ scan@3.81-4.42 GeV
2014: 1.03 fb^{-1} @4.42 GeV
0.11 fb^{-1} @4.47 GeV
0.11 fb^{-1} @4.53 GeV
0.05 fb^{-1} @4.575 GeV
0.57 fb^{-1} @4.60 GeV (for Λ_c^+)
0.80 fb^{-1} R scan @3.85-4.59 GeV

2015: R-scan 2-3 GeV+2.175 GeV
2016: 3.20 fb^{-1} @4.178 GeV (for D_s^+)
2017: 7×0.50 fb^{-1} XYZ scan@4.19-4.27 GeV
2018: More J/ψ+tuning new RF cavity
2019: 10B J/ψ (total)
8×0.50 fb^{-1} XYZ scan@4.13, 4.16, 4.29-4.44 GeV
2020: 3.8 fb^{-1} @ 4.61-4.7 GeV (XYZ&Λ_c^+)
2021: 2.0 fb^{-1} @ 4.74-4.946 GeV
2021: 2.7B $\psi(2S)$ (total)
2022: 2×0.4 fb^{-1}@3.65, 3.682 GeV,
8 fb^{-1} $\psi(3770)$ (for $D^{0(+)}$, total)

More than 37 fb^{-1} of data taken between 2 and 4.95 GeV

More opportunities for Dark Sector

Invisible Decay of Λ baryon

Phys. Rev. D **105**, L071101 (2022)

- Motivated by the puzzle in neutron life time.
- 4M Λ baryons (in $J/\psi \to \Lambda\bar{\Lambda}$) are obtained to probe invisible decays.

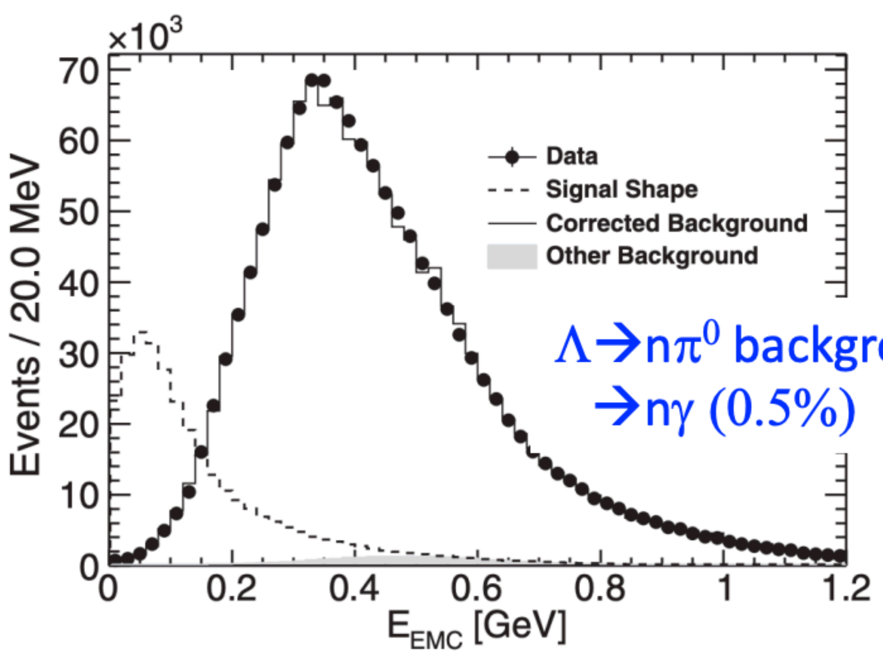
$$\mathcal{B}(\Lambda \to \text{invisible}) = \frac{N_{\text{sig}}}{N_{\text{tag}} \cdot (\varepsilon_{\text{sig}}/\varepsilon_{\text{tag}})}$$

- Fit to the deposit energy distribution in calorimeter.(Signal is expected to peak close to zero)

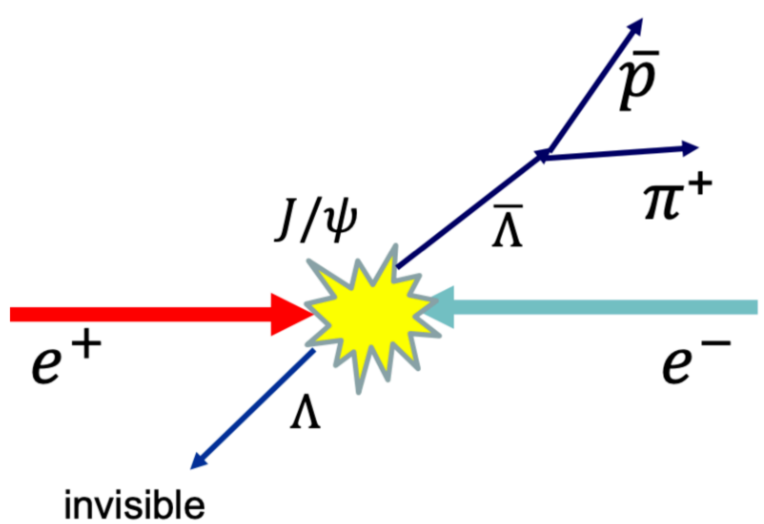
$$E_{\text{EMC}} = E_{\text{EMC}}^{\pi^0} + E_{\text{EMC}}^{n} + E_{\text{EMC}}^{\text{noise}}$$

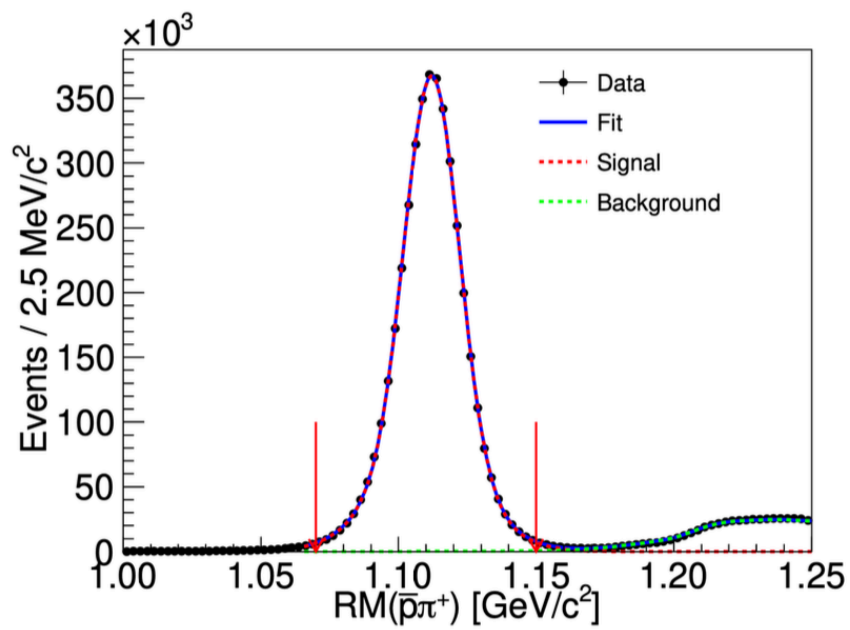
- Data-driven approach is adopted to improve the background modeling.

Calorimeter should be silent for signals



$\Lambda \to n\pi^0$ background
$\to n\gamma$ (0.5%)



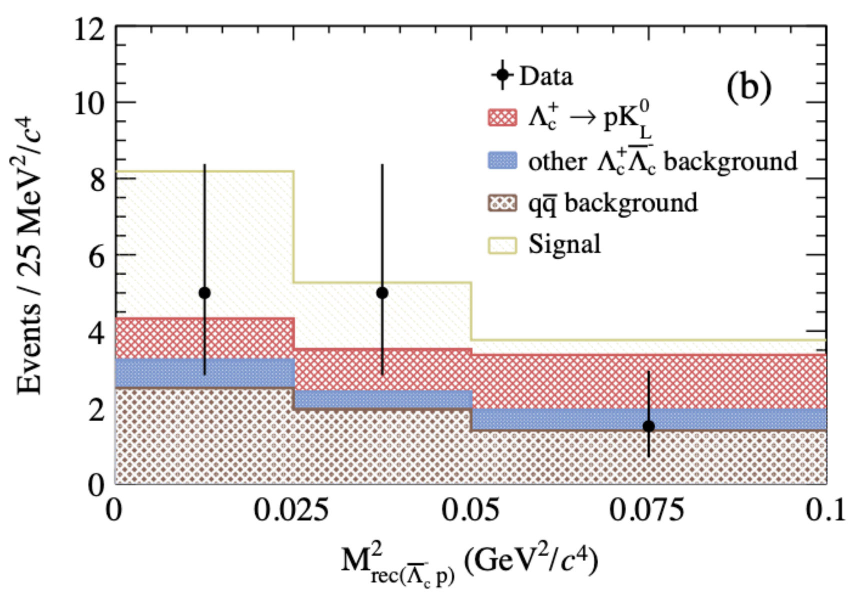


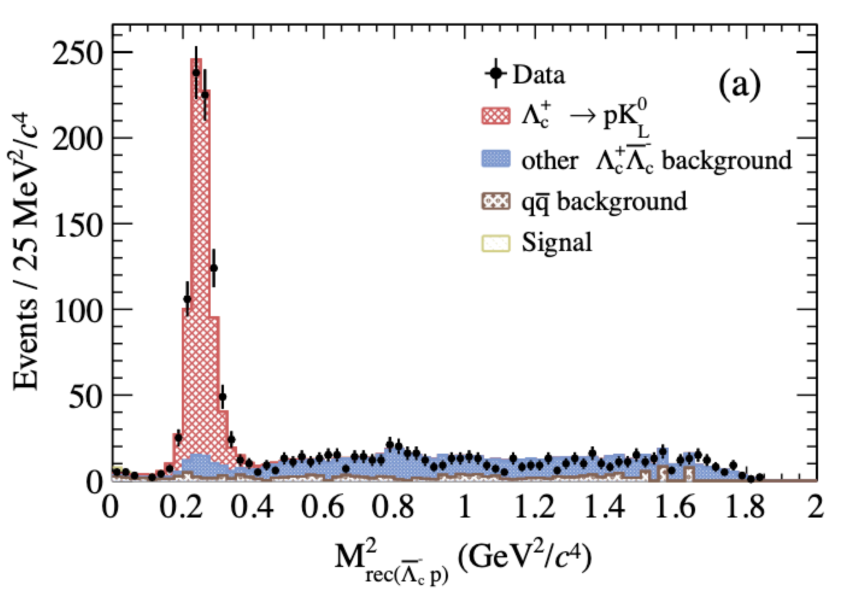
$\mathcal{B}(\Lambda \to \text{invisible}) < 7.4 \times 10^{-5}$

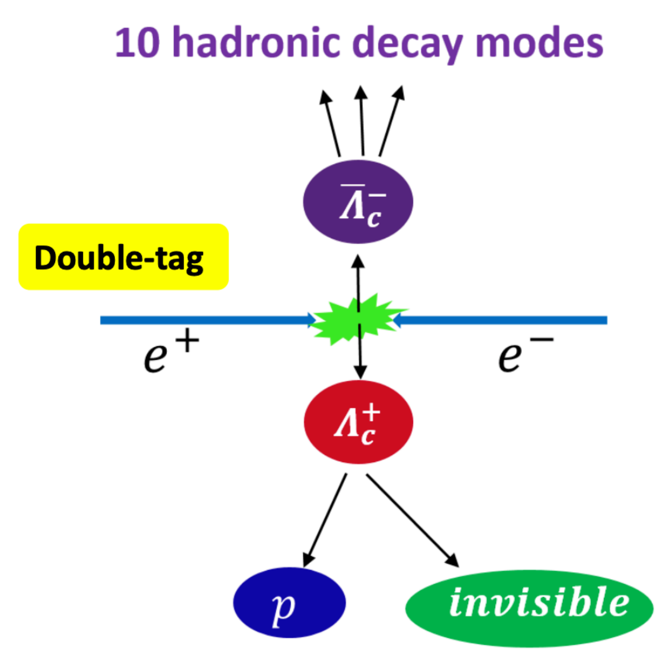
Massless dark photon in $\Lambda_c^+ \to p\gamma'$

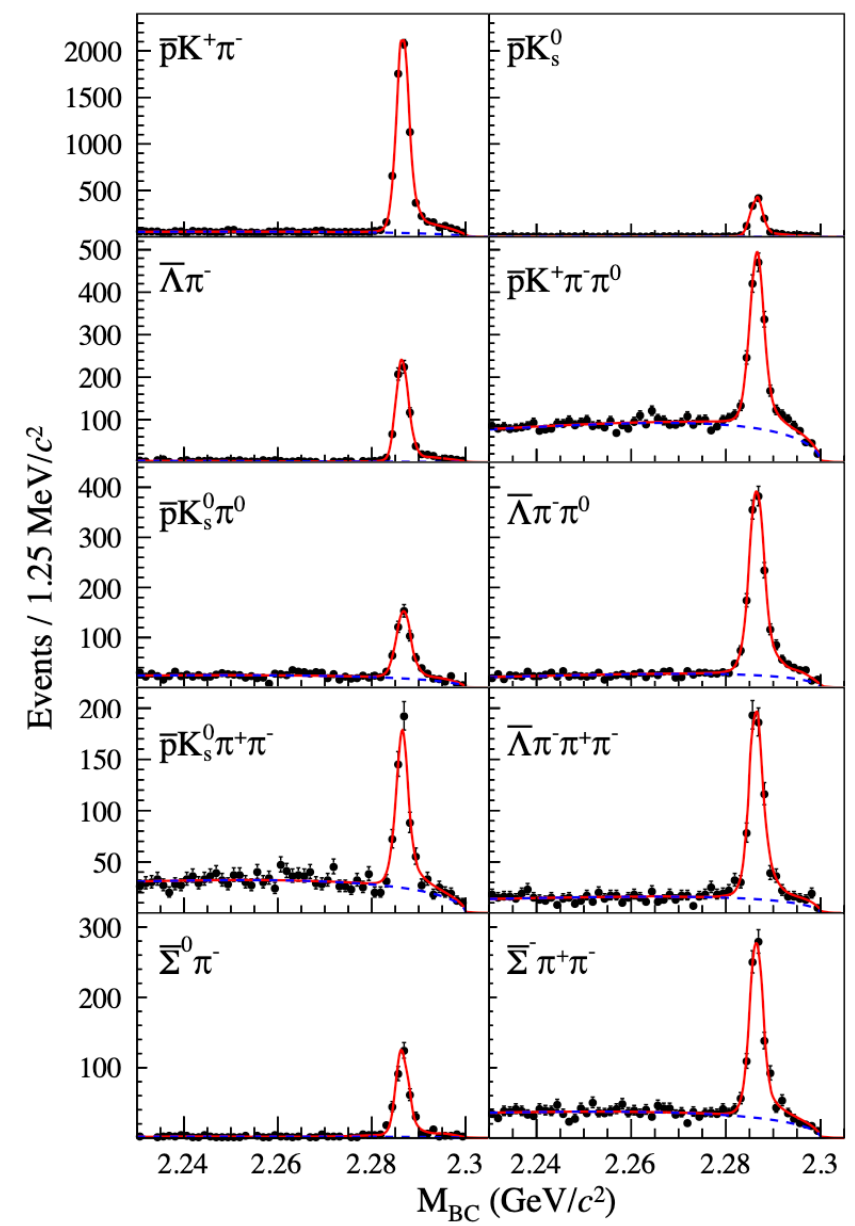
Phys. Rev. D 106, 072008 (2022)

- The symmetric structure of BESIII allows us to reconstruct the lost energy carried away by dark photon.
- The result disfavors the existence of massless dark photon under the scenario of extra U(1) gauge group stays unbroken.







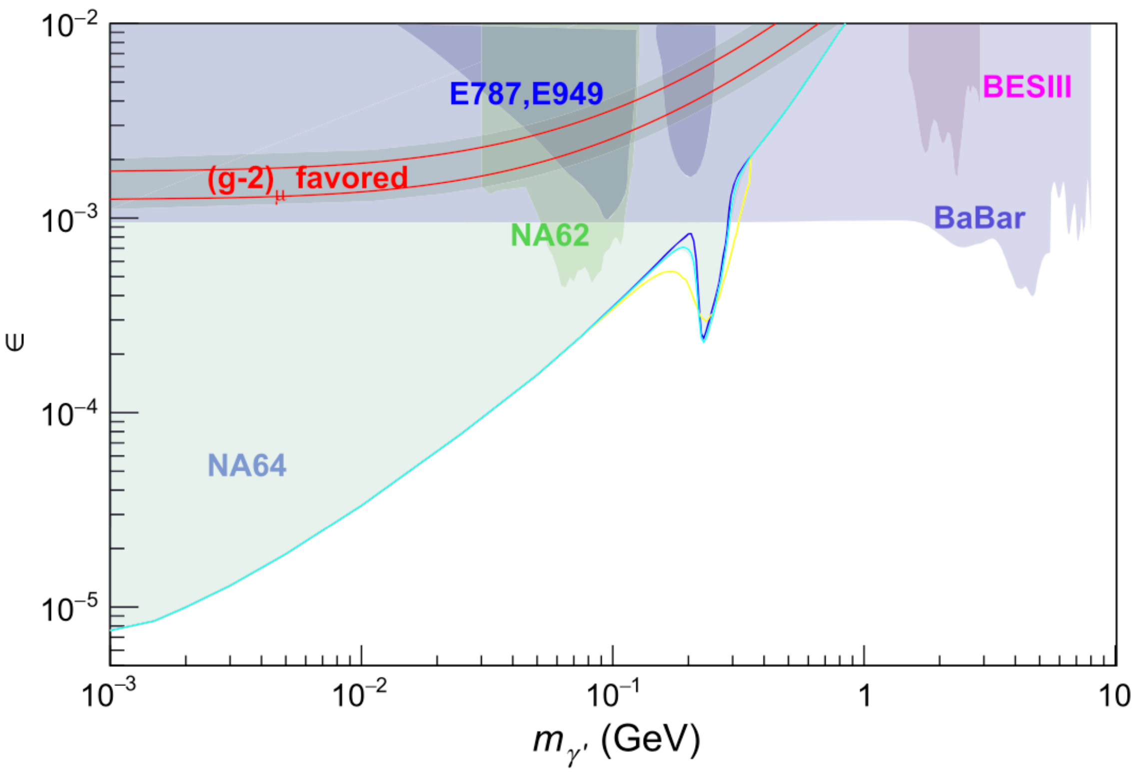


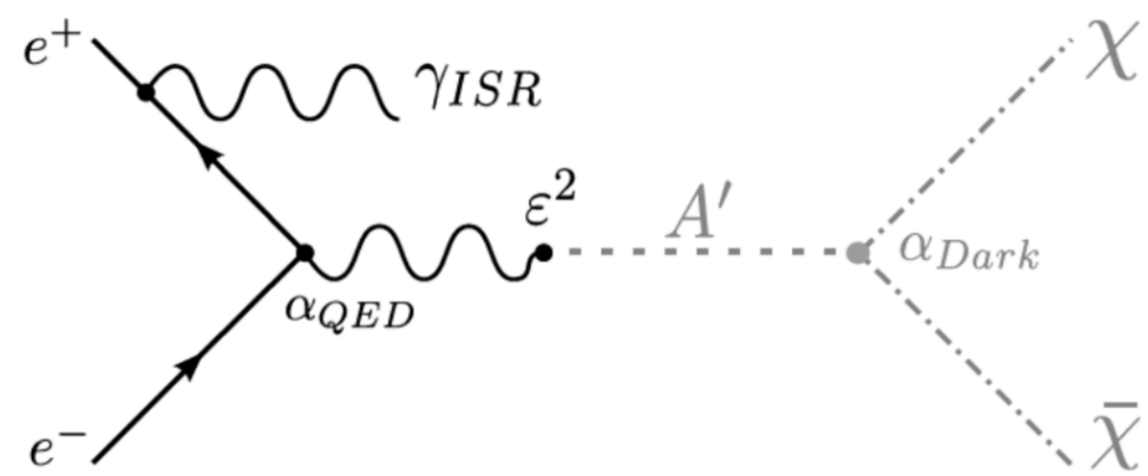
$$\mathscr{B}(\Lambda_c^+ \to p\gamma') < 8 \times 10^{-5}$$

Dark photon in e^+e^- annihilation

Physics Letters B 839 (2023) 137785

- Dataset: Center of mass energies from 4.13 to 4.6 GeV $(14.9\mathrm{fb}^{-1})$
- Trigger of single photon enables the search of dark photon.
- The exclusion limits are below the $(g-2)_\mu$ anomaly values and are consistent with what already excluded by BaBar in the mass range between 1.5 and 2.9 GeV.





$$\varepsilon_{trigger} = (99.40 \pm 0.01)\ \%$$

Light Higgs (A^0) in $J/\psi \to \gamma A^0$

Phys. Rev. D **105**,012008 (2022)

- The CLEO, CMS, BESIII and BABAR experiments have reported negative results for $A^0 \to \mu^+\mu^-$.
- The $90\,\%$ CL upper limits on the $\mathscr{B}(J/\psi \to \gamma A^0) \times \mathscr{B}(A^0 \to \mu^+\mu^-)$ is set to be $(1.2 - 778.0) \times 10^{-9}$ ($m_{A^0} = (0.212, 3.0)$ GeV).
- The new measurement is a 6-7 times improvement over BESIII previous measurement and is also better than BABAR measurement in the low-mass region for $\tan\beta = 1$.

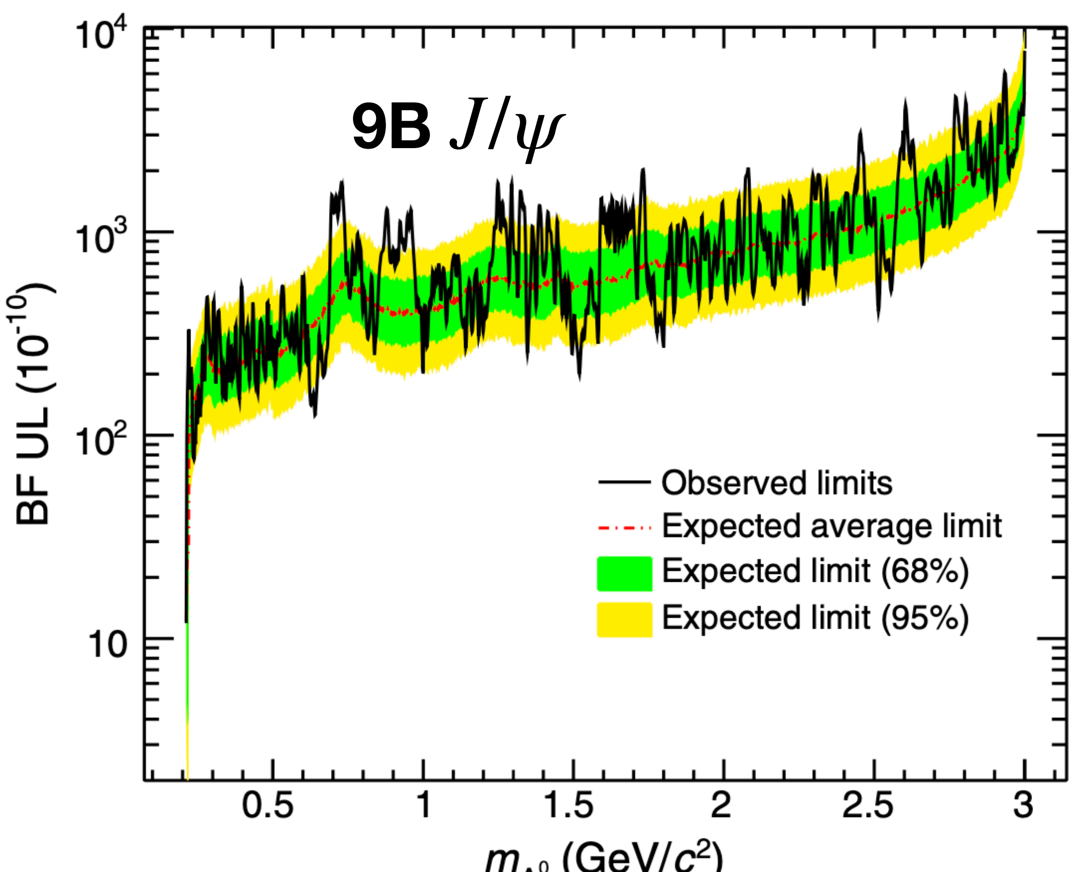
$$\frac{\mathcal{B}(V \to \gamma A^0)}{\mathcal{B}(V \to l^+ l^-)} = \frac{G_F m_q^2 g_q^2 C_{\mathrm{QCD}}}{\sqrt{2}\pi\alpha}\left(1 - \frac{m_{A^0}^2}{m_V^2}\right)$$

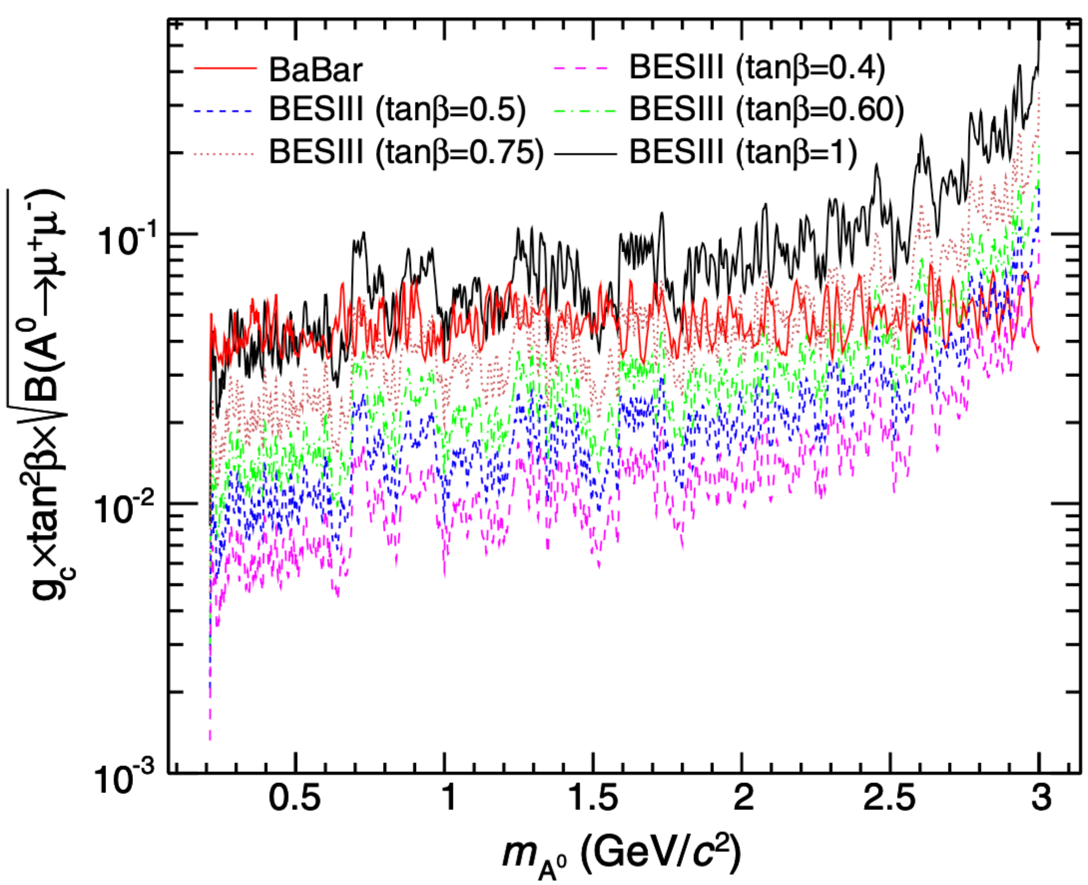
$$g_b(= g_c \tan^2\beta) \times \sqrt{\mathscr{B}(A^0 \to \mu^+\mu^-)}$$

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

$$g_b = \cos\theta_A \tan\beta$$

Expected $\mathscr{B}(J/\psi \to \gamma A^0) \sim 10^{-9} - 10^{-7}$





Summary

- Searching for the discrepancies with the SM is the first priority of the current experimental investigations.
- BESIII plays an active role in dark sectors search experiments.
- Conduct dark sectors searches via visible & invisible approach.
- The future of Dark Sector is Bright !

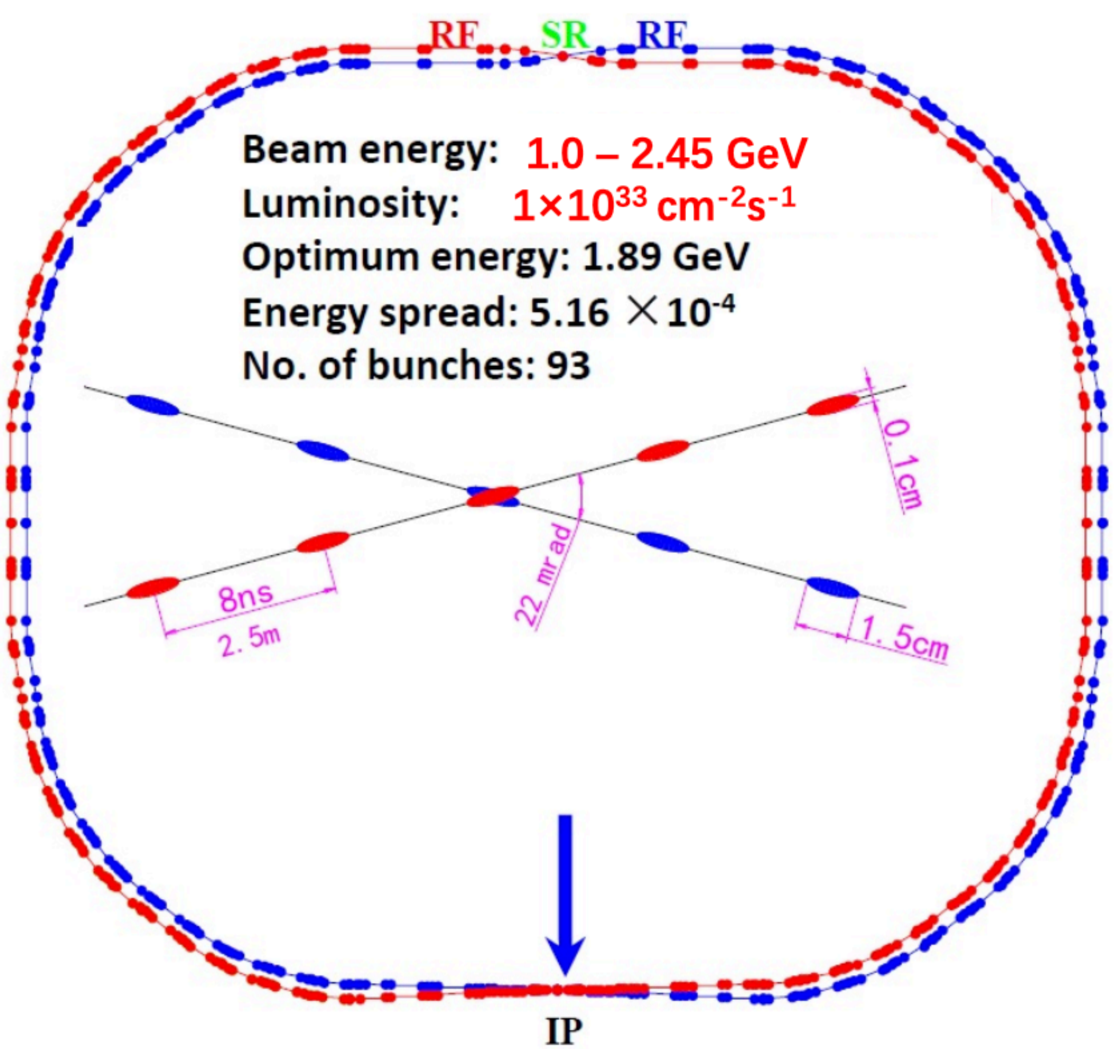
Backup

BEPCII and BESIII

Center-of-mass energy:

$$\sqrt{s} = 2.0 \sim 4.95 \text{ GeV}$$

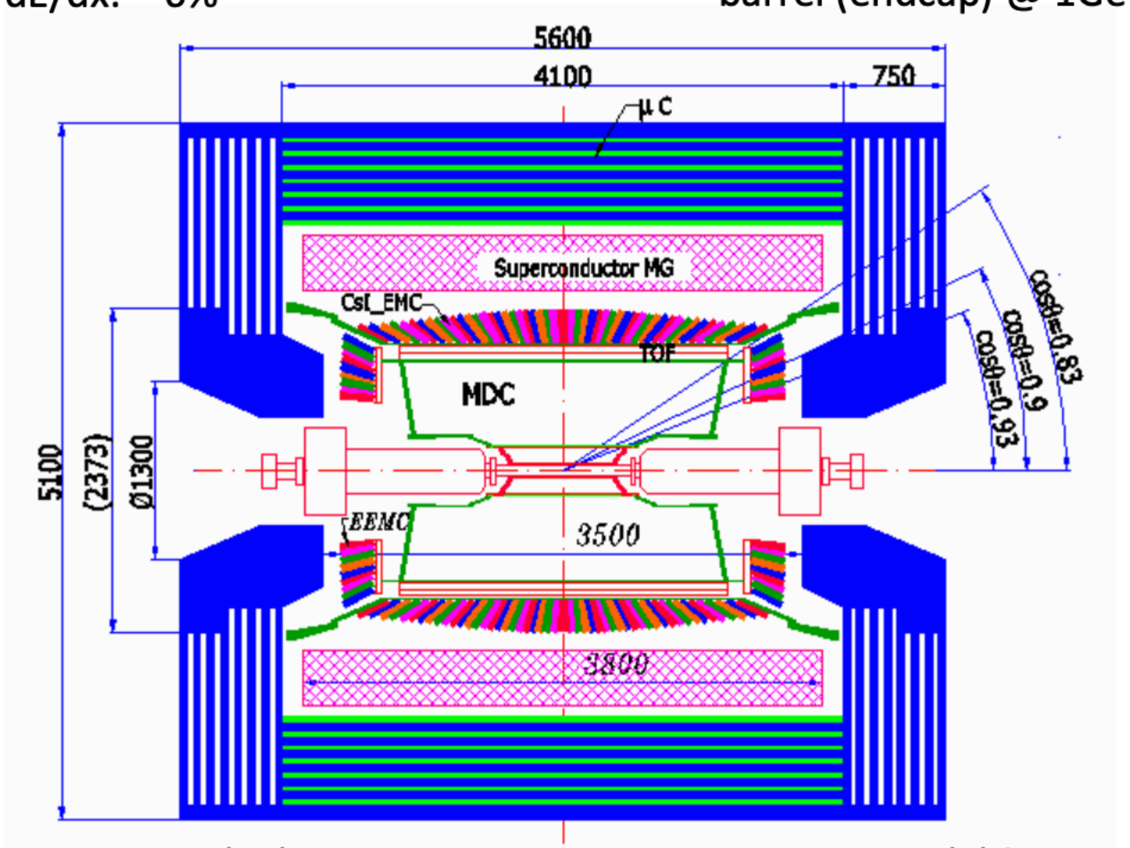
Beijing Electron Position Collider II



BESIII Detector

MDC: Δp/p =0.5% @ 1GeV/c
dE/dx: ~ 6%

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



TOF: σT=68 (60) ps
barrel (endcap)

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