New Physics Searches at BESIII

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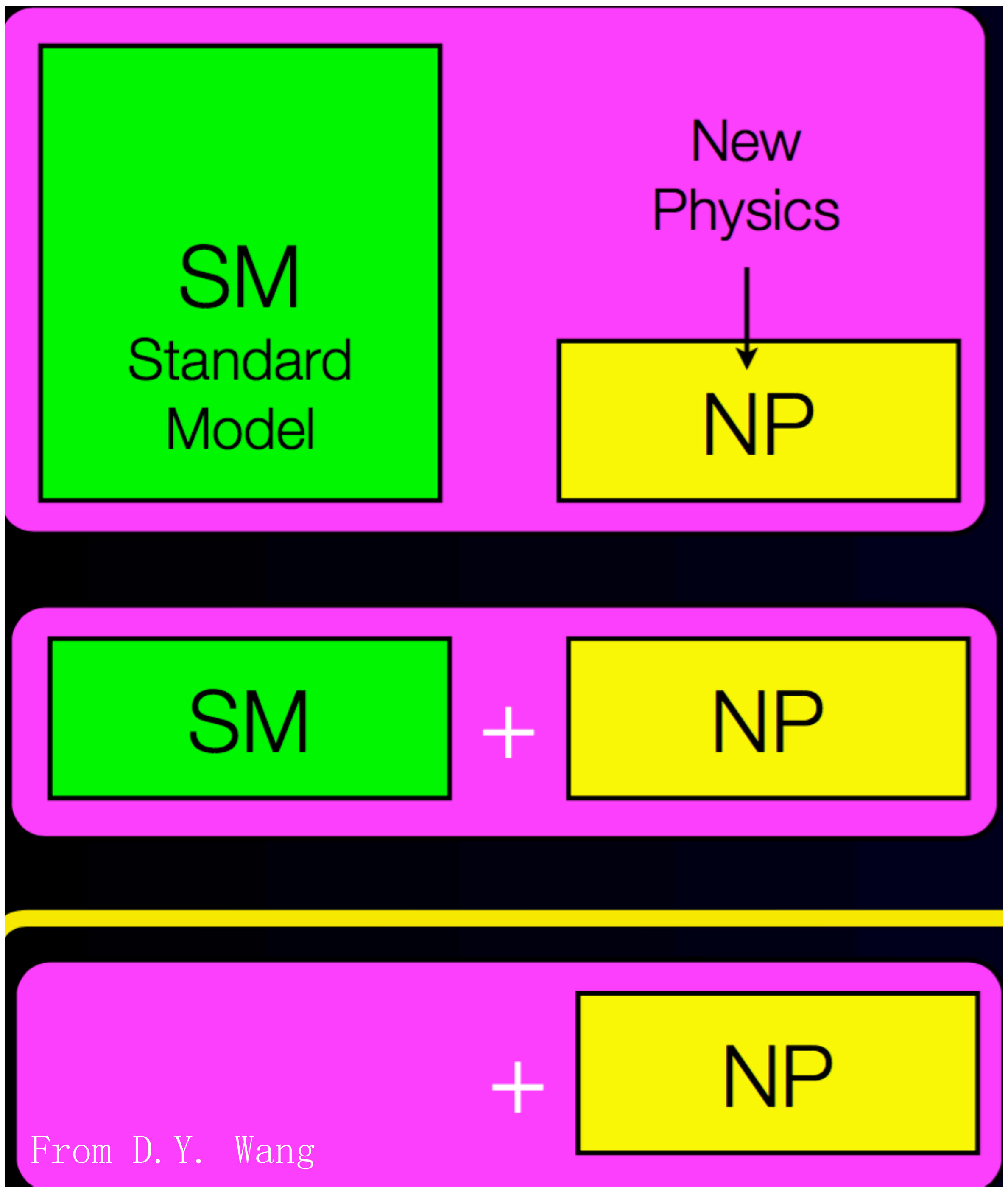
New Physics Searching at BESIII

新物理效应微小，稀有过程更敏感



利用BESIII 采集的大统计量、高质量数据，特别是含有100 亿J/ψ粒子和独特的粲介子和粲重子近阈样本，在极高的实验精度下研究各种稀有或禁戒的过程，从而对各种BSM的理论进行检验。

SM contribution is dominant.

SM contribution is highly suppressed.

SM contribution is forbidden.

BESIII Experiment

Europe (17)

Germany (6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster

Italy (3): Ferrara University, INFN, University of Torino

Netherlands (1): KVI/University of Groningen

Russia (2): Budker Institute of Nuclear Physics, Dubna JINR

Sweden (1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK (2): University of Manchester, University of Oxford

Poland (1) National Centre for Nuclear Research

Asia (6)

Pakistan (2): COMSATS Institute of Information Technology University of the Punjab, University of Lahore

Mongolia (1): Institute of Physics and Technology

Korea (1): Chung-Ang University

India (1): Indian Institute of Technology madras

Thailand (1): Suranaree University of Technology

USA(4)

Carnegie Mellon University

Indiana University

University of Hawaii

University of Minnesota

South America (1)

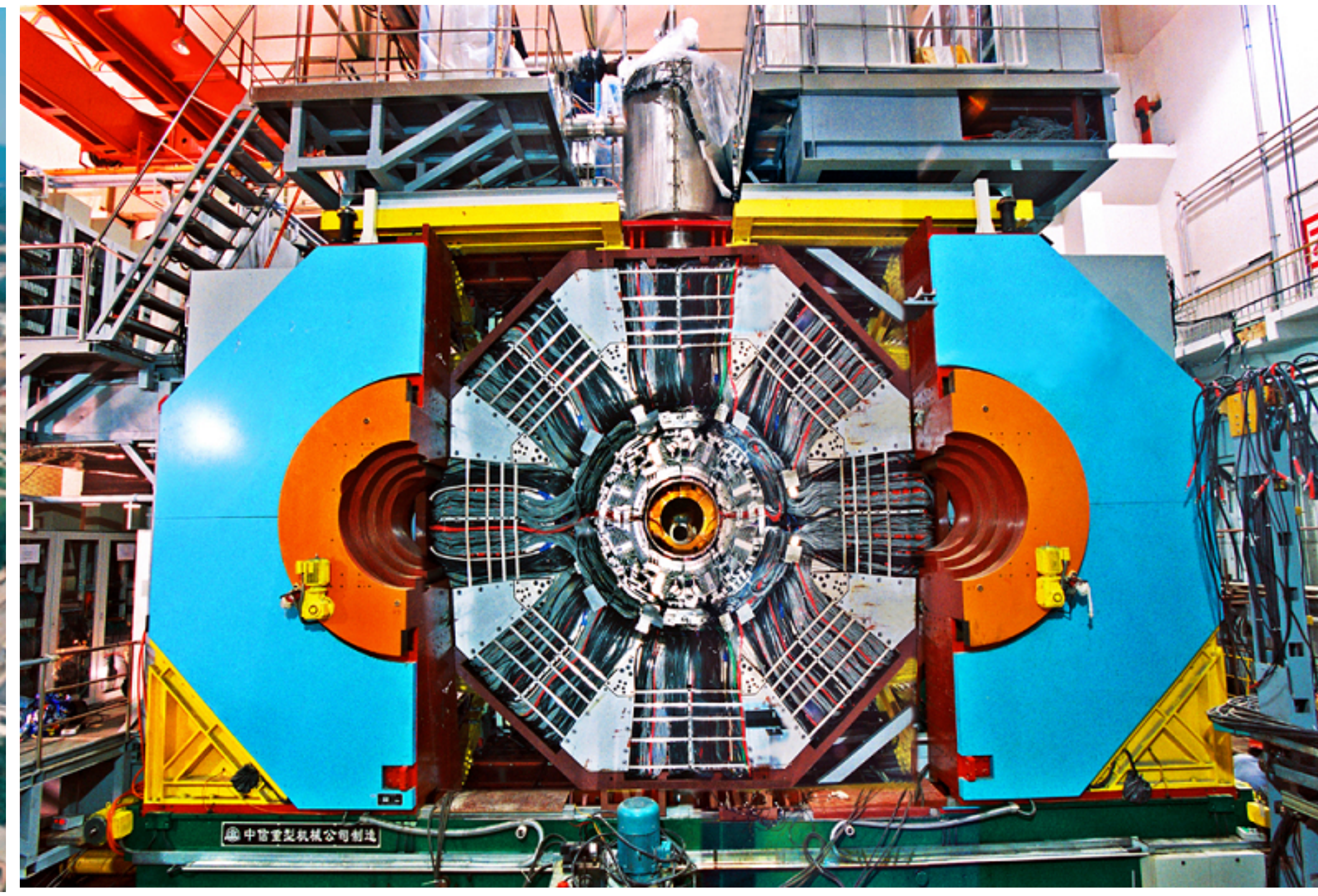
Chile: University of Tarapaca

China (48)

Institute of High Energy Physics (146), other units(221): Beijing Institute of Petro-chemical Technology, Beihang University, China Center of Advanced Science and Technology, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Henan Normal University, Henan University of Science and Technology, Huazhong Normal University, Huangshan College, Hunan University, Hunan Normal University, Henan University of Technology Institute of modern physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu normal university, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, Shanghai Jiaotong Univeristy, Soochow University, South China Normal University, Southeast University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xinyang Normal University, Zhejiang University, Zhengzhou University,YunNan University , China University of Geosciences

~500 members from 76 institutes in 16 countries

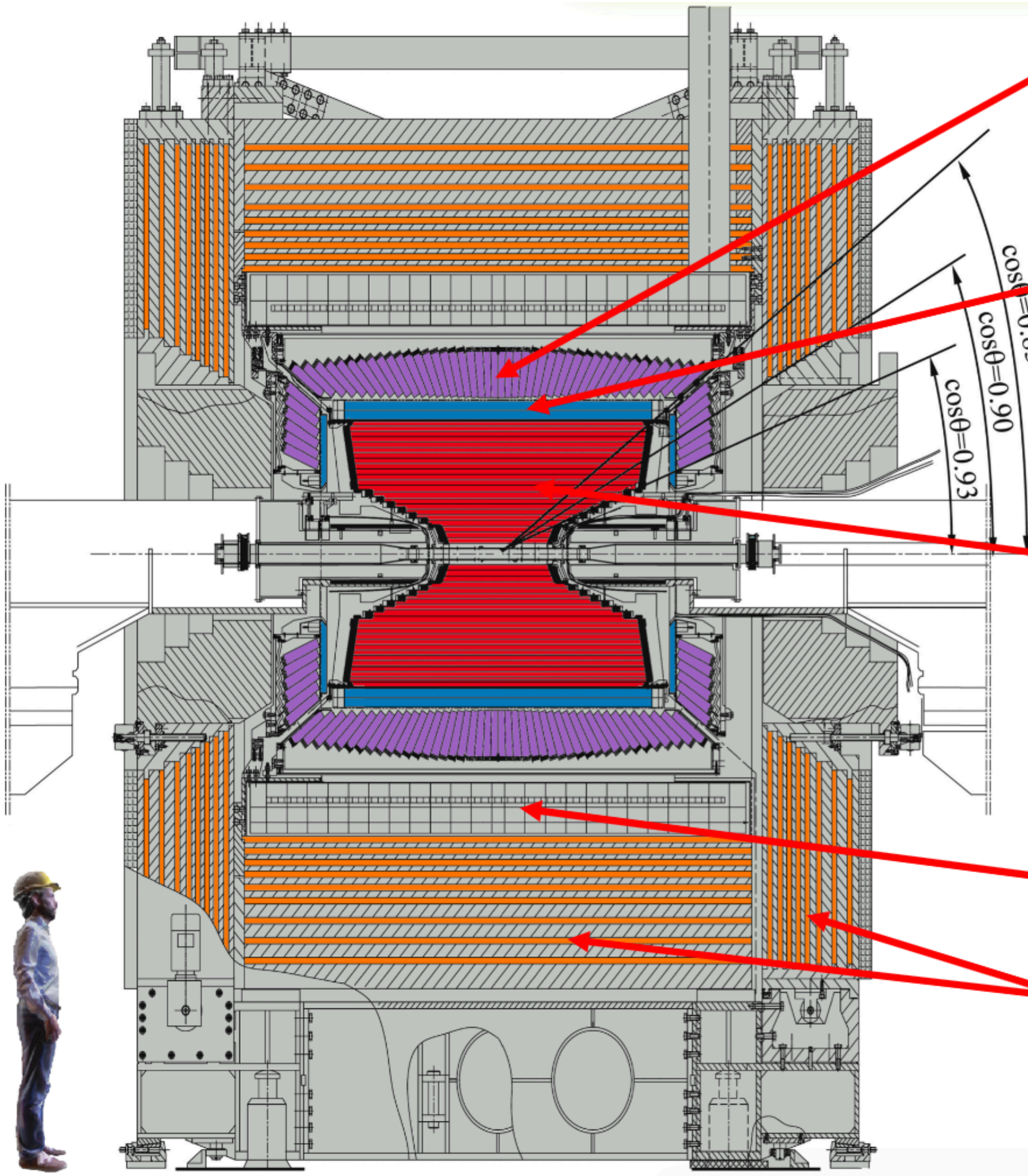
BEPCII and BESIII



- BEPCII is an e^+e^- collider operating at τ-charm energy region
- First collision in 2008, physics program started in 2009
- BEPCII reached designed luminosity of 1×10^{33} $cm^{-2}s^{-1}$@1.89GeV in April 2016
- BESIII collaboration includes ~500 collaborators from 15 countries, still growing
- Suitable for New Physics: high luminosity, low background, large statistics, hermetic detector with good performance

BESIII Detector

NIMA614(2010)345



EMC: CsI crystals

$\Delta E/E$ = 2.5% @ 1 GeV - Barrel

$\Delta E/E$ = 5.0% @ 1 GeV - Endcaps

TOF:

σ_T = 80 ps Barrel

σ_T = 110 (60) ps Endcap

MDC: small cell & He gas

σ_{xy}= 130 μm

σ_p/p = 0.5% @1GeV

dE/dx = 6%

Magnet: 1T Super conducting

Muon ID: 9 layer RPC

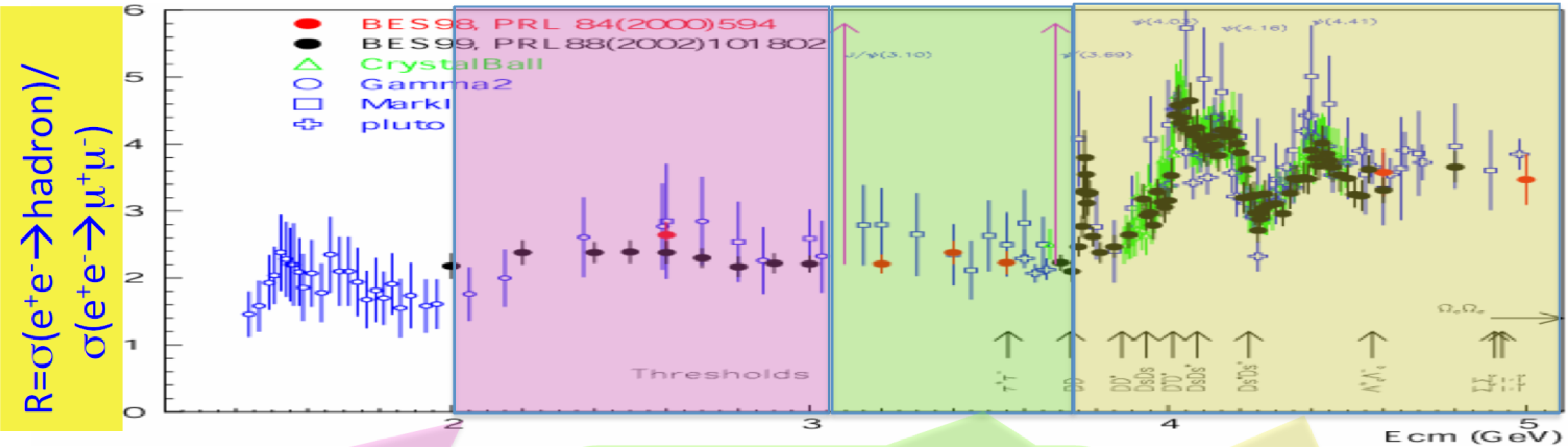
Trigger: Tracks & Showers

Clean environment and high luminosity at BESIII are helpful for "indirect searching" of new physics

BESIII Detector

Sub detector		Design Performance	Achieved Performance
MDC		$\sigma_{r\phi} = 130\mu m$ $\Delta p/p = 0.5\%@1GeV$ (B=1T) $\sigma_{dE/dx} = 6\%$	$\sigma_{r\phi} = 115\mu m$ $\Delta p/p = 0.47\%@1GeV$ (B=1T) $\sigma_{dE/dx} = 5.2\%$
TOF	Barrel	$\sigma_T = 80{\sim}90\ ps$	$\sigma_T = 67{\sim}70\ ps$
	Endcap	$\sigma_T = 110{\sim}120ps$ (before upgrade) $80ps{\sim}100ps$ (after upgrade)	$\sigma_T = 138ps$ (before upgrade) $60ps{\sim}70ps$ (after upgrade)
EMC		$\Delta E/E = 2.5\%\ @1GeV$ $\sigma = 6\ mm/\sqrt{E}$	$\Delta E/E = 2.5\%\ @1GeV$ $\sigma = 6\ mm/\sqrt{E}$
MUC		$\sigma_{r\phi} = 14mm{\sim}17mm$ $\sigma_z{\sim}17mm$	$\sigma_{r\phi} = 14mm{\sim}15mm$ $\sigma_z{\sim}17mm$

Physics at BESIII



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

- XYZ particles
- D mesons
- f_D and f_{Ds}
- D_0-D_0 mixing
- Charm baryons

World largest threshold J/ψ, ψ(3686), ψ(3770), … data samples

More than 430 papers with ~80 in Phys. Rev. Lett.

High Statistics Data

2009: 106M $\psi(3686)$
225M J/ψ
2010: 0.98 fb^{-1} $\psi(3770)$
2011: 2.93 fb^{-1} $\psi(3770)$ (for $D^{0(+)}$, total)
0.48 fb^{-1} @4.01 GeV
2012: 0.45B $\psi(3686)$ (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 (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 $\psi(3686)$ (total)
2022 : 8.0 fb^{-1} $\psi(3770)$ (total)

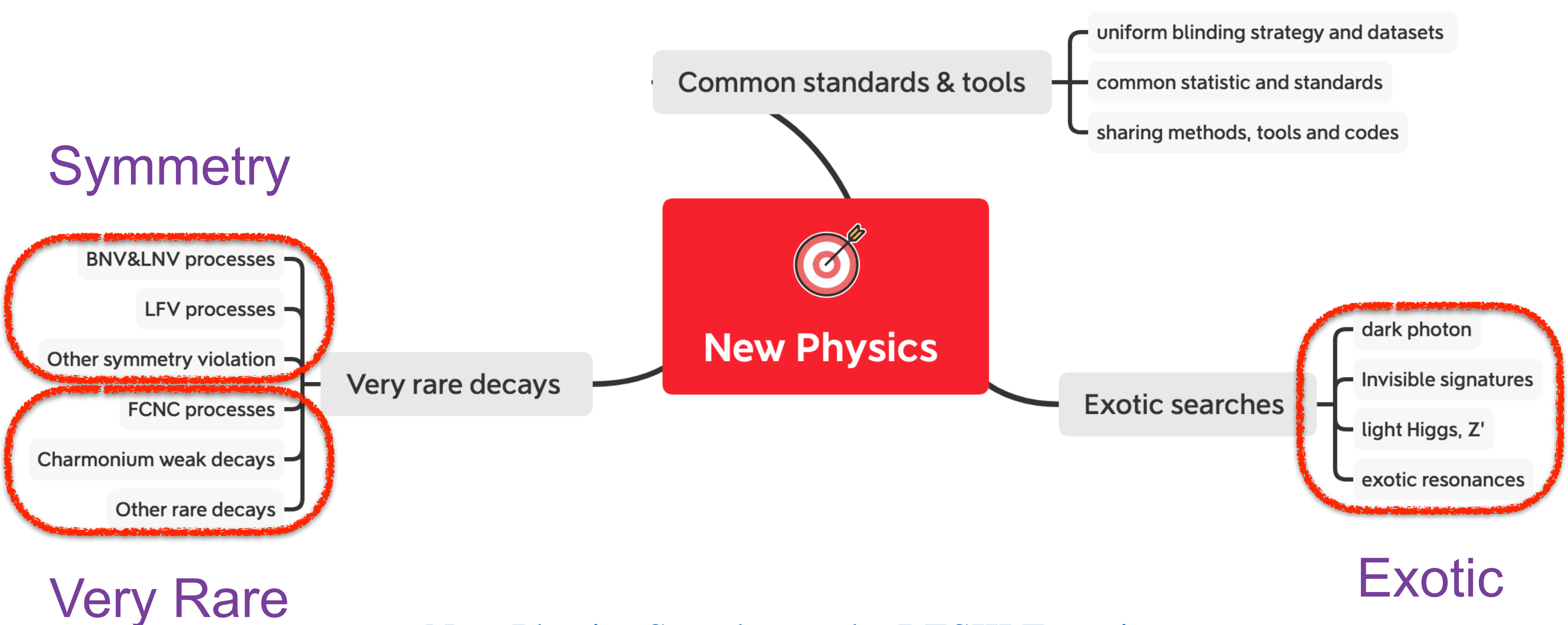
Totally about 40 fb^{-1} at E_{cm} between 2 and 4.95 GeV in 13 year running

High Statistics Data

	Data Sample	Comparison
J/ψ	10 B	170 BESII
ψ(3686)	2.7 B	120 CLEO-c
D Data	8.0 /fb	9.6 CLEO-c
Ds Data	3.2 (6) /fb	5 (10) CLEO-c
XYZ data	26.6 /fb	Unique

… and huge sub-samples, such as $\eta,\ \eta',\ \omega,\ \phi,\ K_S^0$ **…**

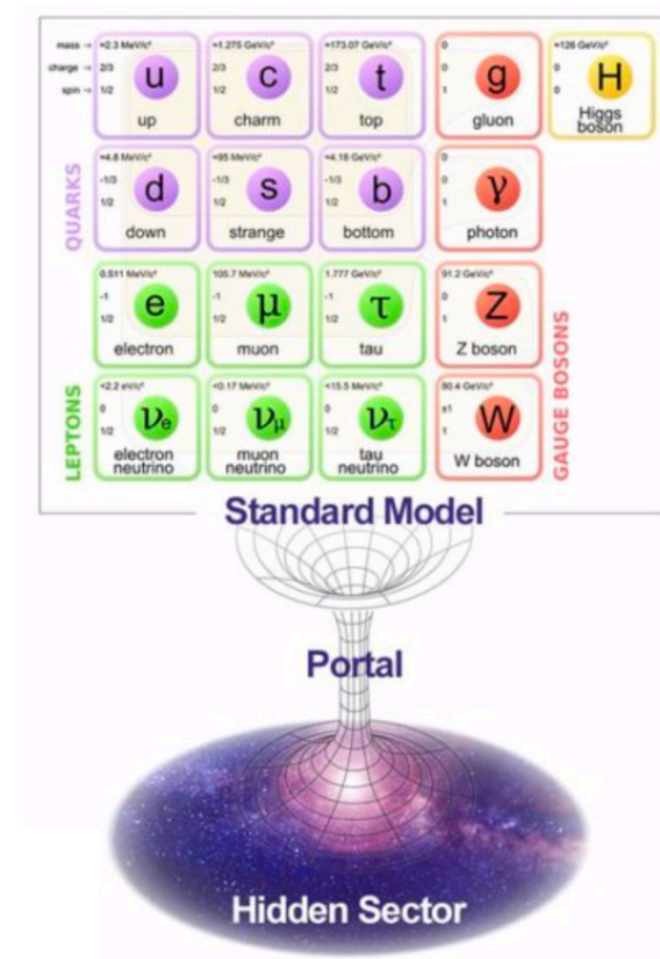
New Physics Searches at BESIII



- New Physics Searches at the BESIII Experiment, Shenjian Chen and Stephen Olsen, Nation Science Review 8, nwab189 (2021), arXiv: 2102.13290
- New Physics Program of BES, Dayong Wang, in "30 Years of BES Physics"

Dark Photon

- Numerous astrophysical observations strongly suggest the existence of Dark Matter(DM) which provides a hint of dark sector (hidden sector).
- There might exist some "portals" that connect the SM sector to DM sector

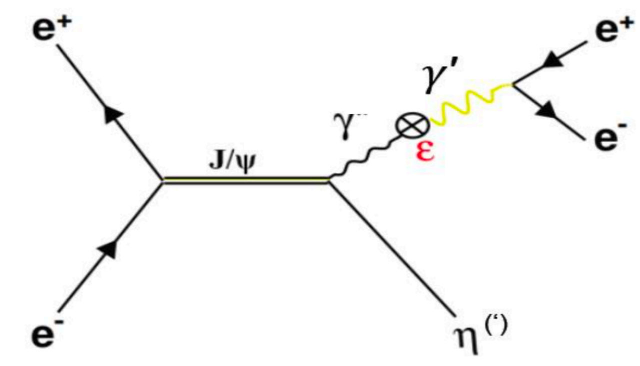


Portal	Particles	Operator(s)
"Vector"	Dark photons	$-\frac{\epsilon}{2\cos\theta_W}B_{\mu\nu}F'^{\mu\nu}$
"Axion"	Pseudoscalars	$\frac{a}{f_a}F_{\mu\nu}\widetilde{F}^{\mu\nu}$, $\frac{a}{f_a}G_{i\mu\nu}\widetilde{G}_i^{\mu\nu}$, $\frac{\partial_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$
"Higgs"	Dark scalars	$(\mu S+\lambda S^2)H^\dagger H$
"Neutrino"	Sterile neutrinos	$y_N LHN$

R. Essig et al., arXiv: 1311.0029 (2013)

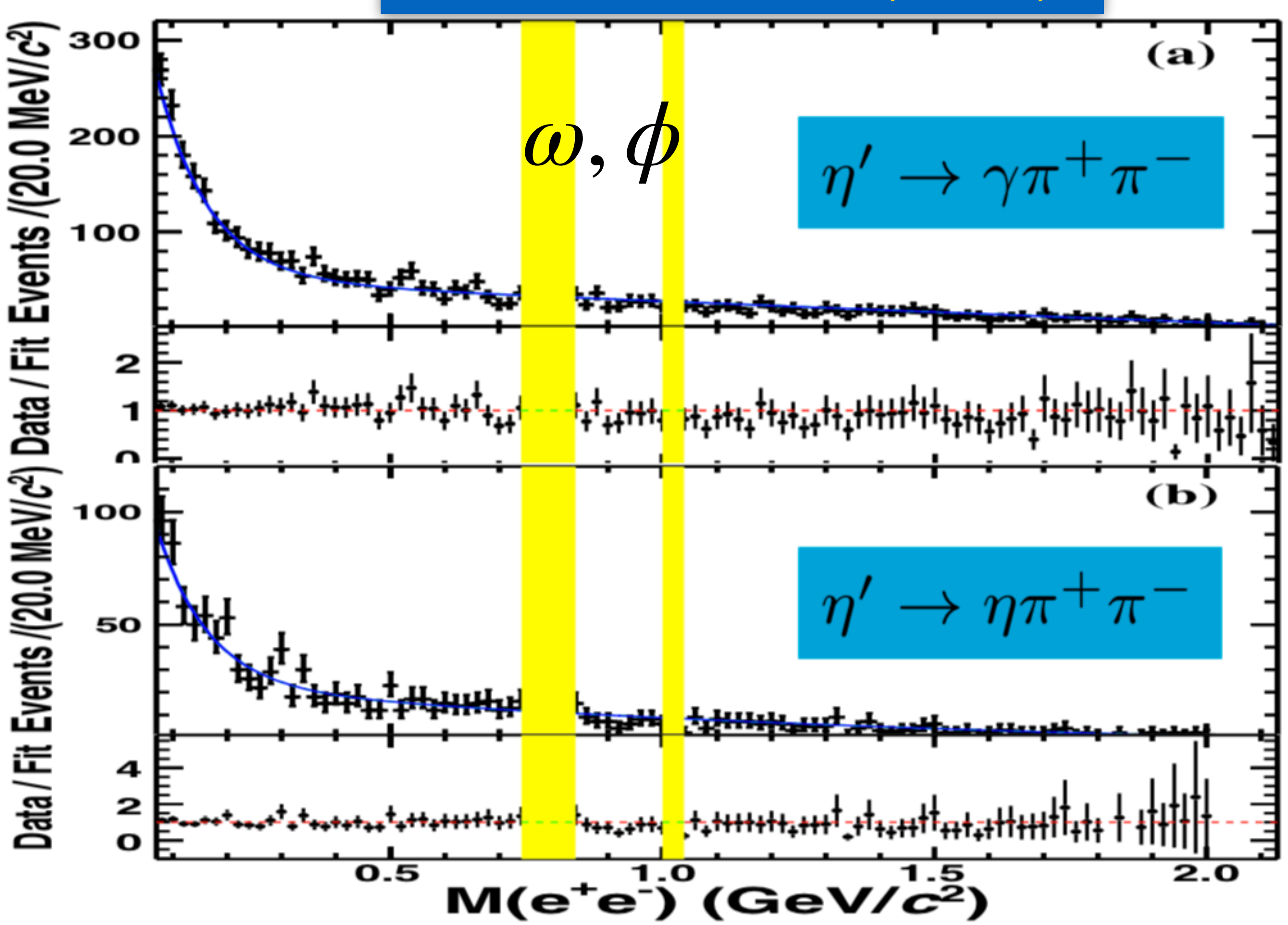
Dark Photon

- First search for dark photon in E.M. Dalitz decays
  - $J/\psi \to \eta\gamma', \gamma' \to e^+e^-$ PRD99, 012013 (2019)
  - $J/\psi \to \eta'\gamma', \gamma' \to e^+e^-$ PRD99, 012006 (2019)

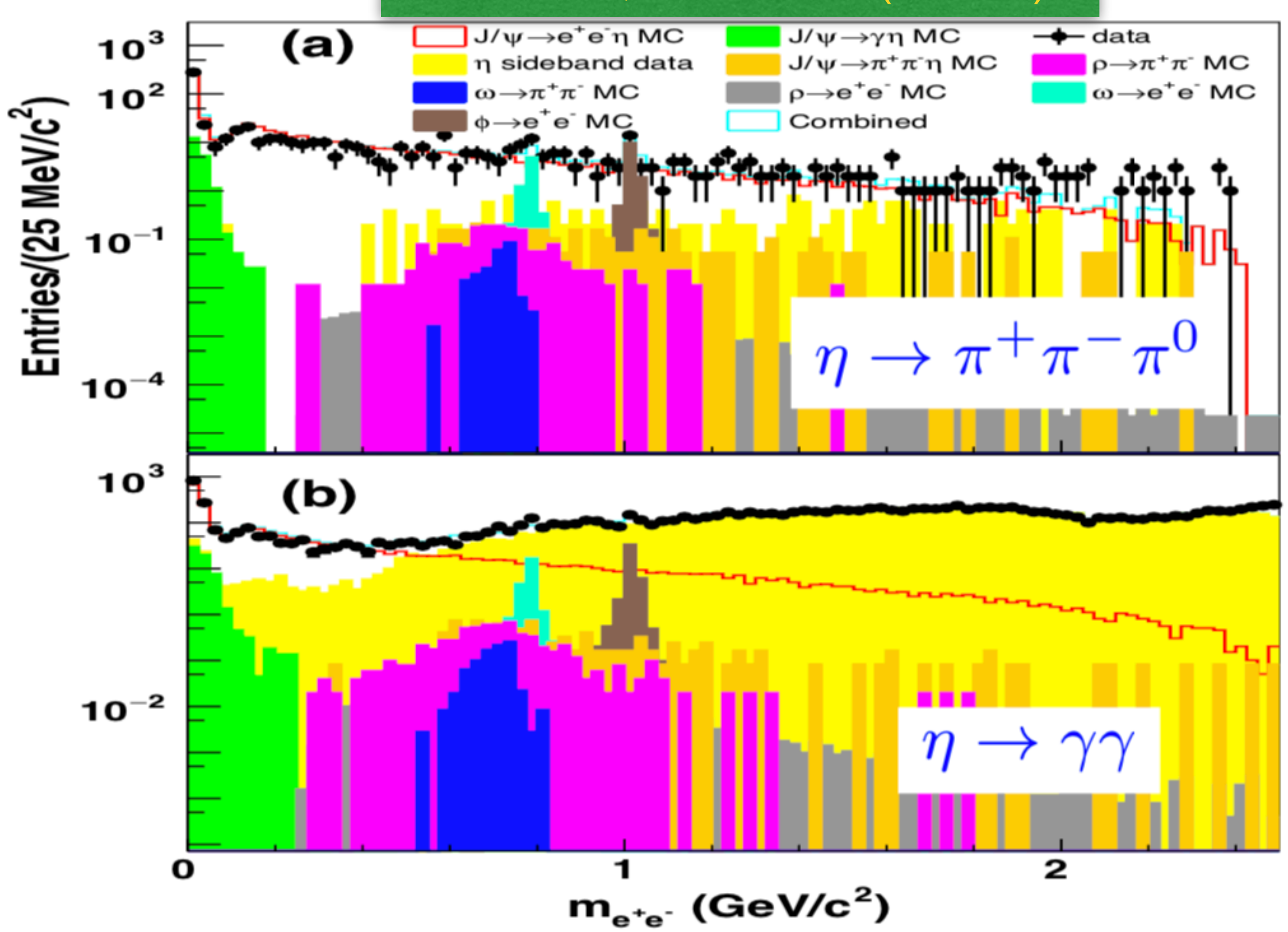


- Check narrow peaking structures in the $m_{e^+e^-}$ distribution

PRD99, 012006 (2019)

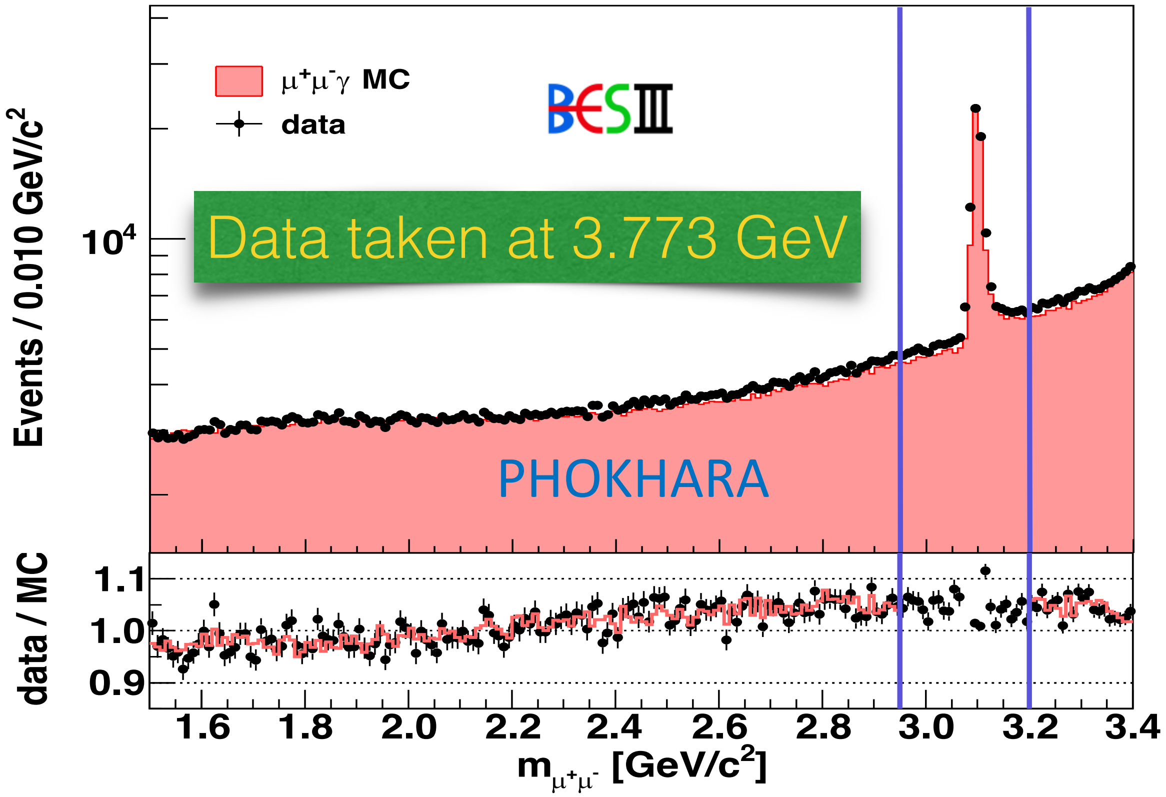


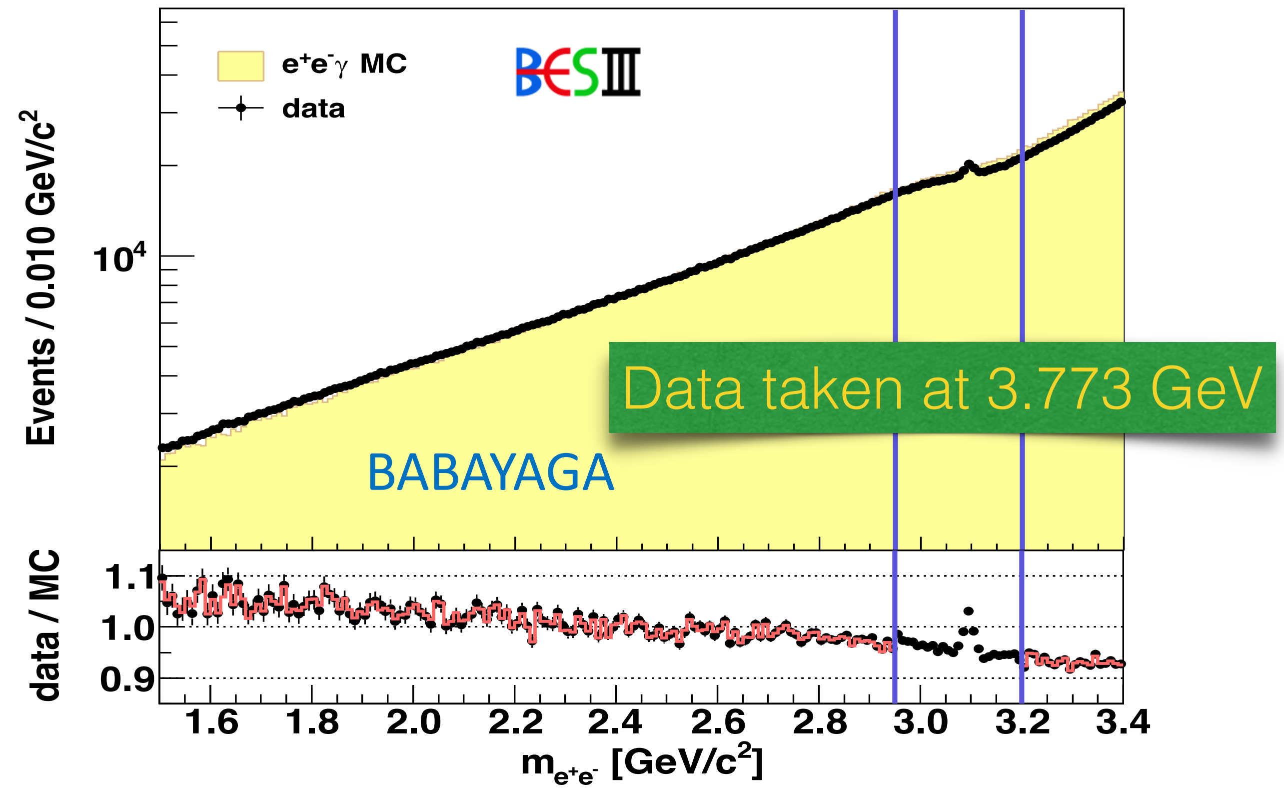
PRD99, 012013 (2019)



Dark Photon

- Search for narrow structure on top of the continuum QED background





Cover mass region: 1.5 GeV/c 2 ~ 3.4 GeV/c

- <1.5 GeV/c 2 : $\pi^+\pi^-$ background dominates
- >3.4 GeV/c 2 : hadronic qq-bar process

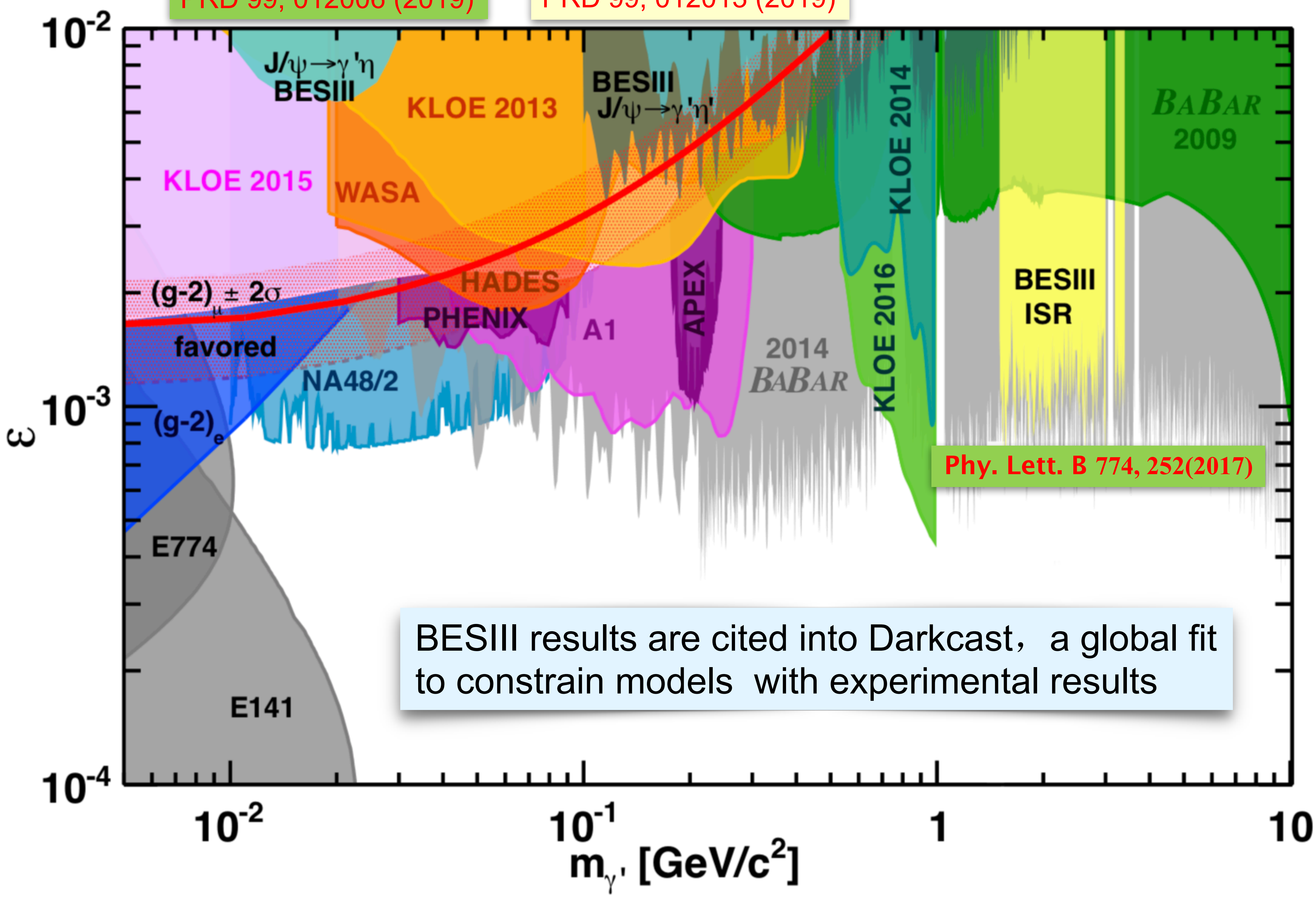
Phy. Lett. B 774, 252(2017)

$$\frac{\sigma_i(e^+e^- \to \gamma'\,\gamma_{\rm ISR} \to l^+l^-\gamma_{\rm ISR})}{\sigma_i(e^+e^- \to \gamma^*\,\gamma_{\rm ISR} \to l^+l^-\gamma_{\rm ISR})} = \frac{N_i^{\rm up}(e^+e^- \to \gamma'\,\gamma_{\rm ISR} \to l^+l^-\gamma_{\rm ISR})}{N_i^{\rm B}(e^+e^- \to \gamma^*\,\gamma_{\rm ISR} \to l^+l^-\gamma_{\rm ISR})} \cdot \frac{1}{\epsilon} = \frac{3\pi \cdot \varepsilon^2 \cdot m_{\gamma'}}{2N_f^{l^+l^-}\alpha \cdot \delta_m^{l^+l^-}}$$

Dark Photon

PRD 99, 012006 (2019)

PRD 99, 012013 (2019)



BESIII results are cited into Darkcast, a global fit to constrain models with experimental results

Invisible Decay

- In the SM, quarkonium states can decay into neutrino and anti-neutrino pair via virtual Z^0 boson with very low expected BFs

$$\mathscr{B}(\omega \to \nu\nu) = 8.4 \times 10^{-14}, \mathscr{B}(\phi \to \nu\nu) = 5.8 \times 10^{-12}$$

- If singlet scalar, pseudo-scalar or vector (portals) exists, and mediates the SM-DM interaction, it can allow invisible decays of SM particles to DM particles.
- The branching fraction of invisible decay might be enhanced in the presence of light DM particles.

mode	s-wave	p-wave
$\mathrm{BR}(\Upsilon(1S) \to \chi\chi)$	4.2×10^{-4}	1.8×10^{-3}
$\mathrm{BR}(\Upsilon(1S) \to \nu\bar{\nu})$	9.9×10^{-6}	
$\mathrm{BR}(J/\Psi \to \chi\chi)$	2.5×10^{-5}	1.0×10^{-4}
$\mathrm{BR}(J/\Psi \to \nu\bar{\nu})$	2.7×10^{-8}	
$\mathrm{BR}(\eta \to \chi\chi)$	3.4×10^{-5}	1.4×10^{-4}
$\mathrm{BR}(\eta' \to \chi\chi)$	3.7×10^{-7}	1.5×10^{-6}
$\mathrm{BR}(\eta_c \to \chi\chi)$	1.3×10^{-7}	5.3×10^{-7}
$\mathrm{BR}(\chi_{c0}(1P) \to \chi\chi)$	2.7×10^{-8}	1.2×10^{-7}
$\mathrm{BR}(\phi \to \chi\chi)$	1.9×10^{-8}	7.8×10^{-8}
$\mathrm{BR}(\omega \to \chi\chi)$	7.2×10^{-8}	3.0×10^{-8}

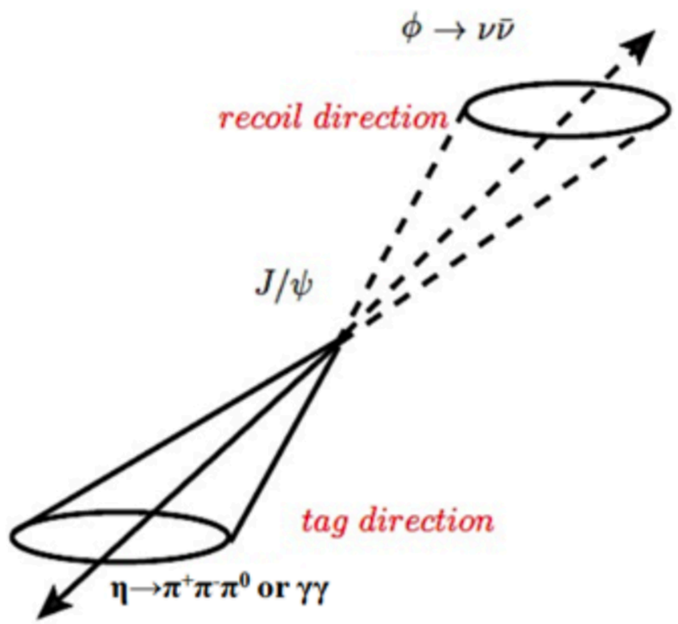
B. McElrath, eConf C070805, 19 (2007)

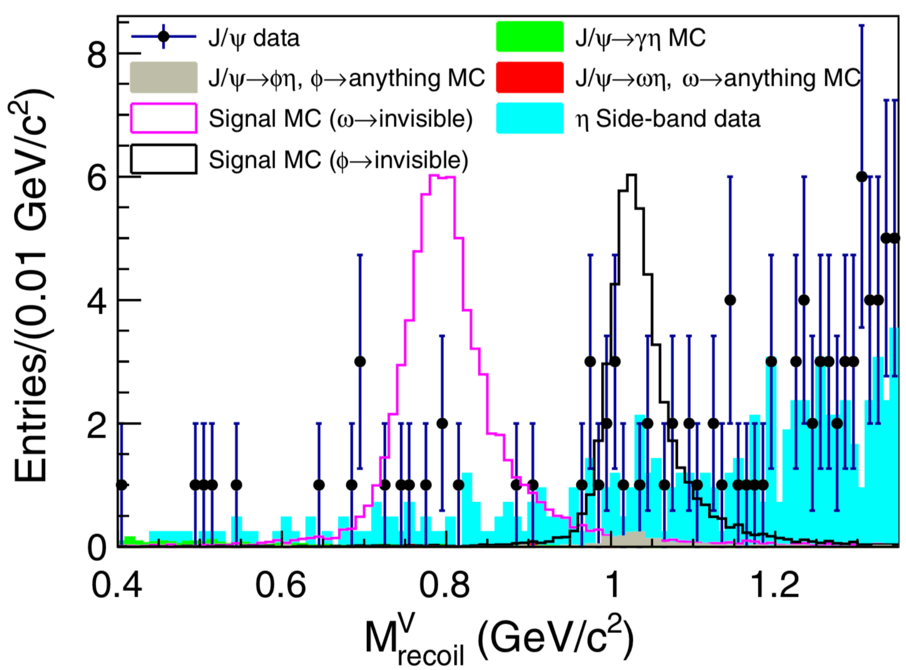
Invisible Decay

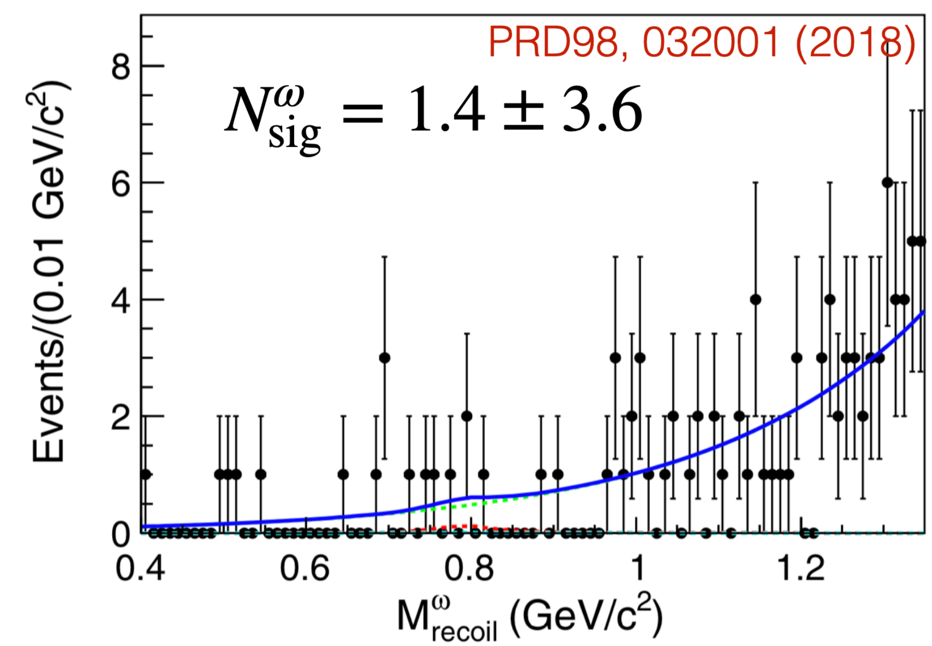
- First search for $J/\psi \to \eta\omega/\phi$, $\omega/\phi \to invisible$

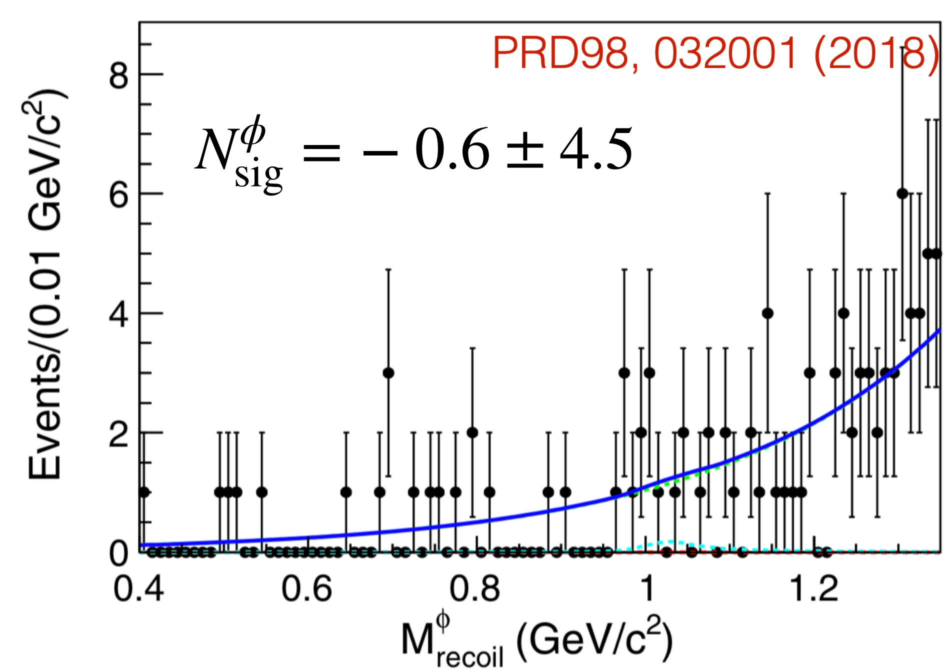
PRD98, 032001 (2018)

- Recoiling mass (against η) is defined as $M^{V}_{\text{recoil}} \equiv \sqrt{(E_{\text{CM}} - E_{3\pi})^2 - |\vec{p}\,|^2_{3\pi}}$









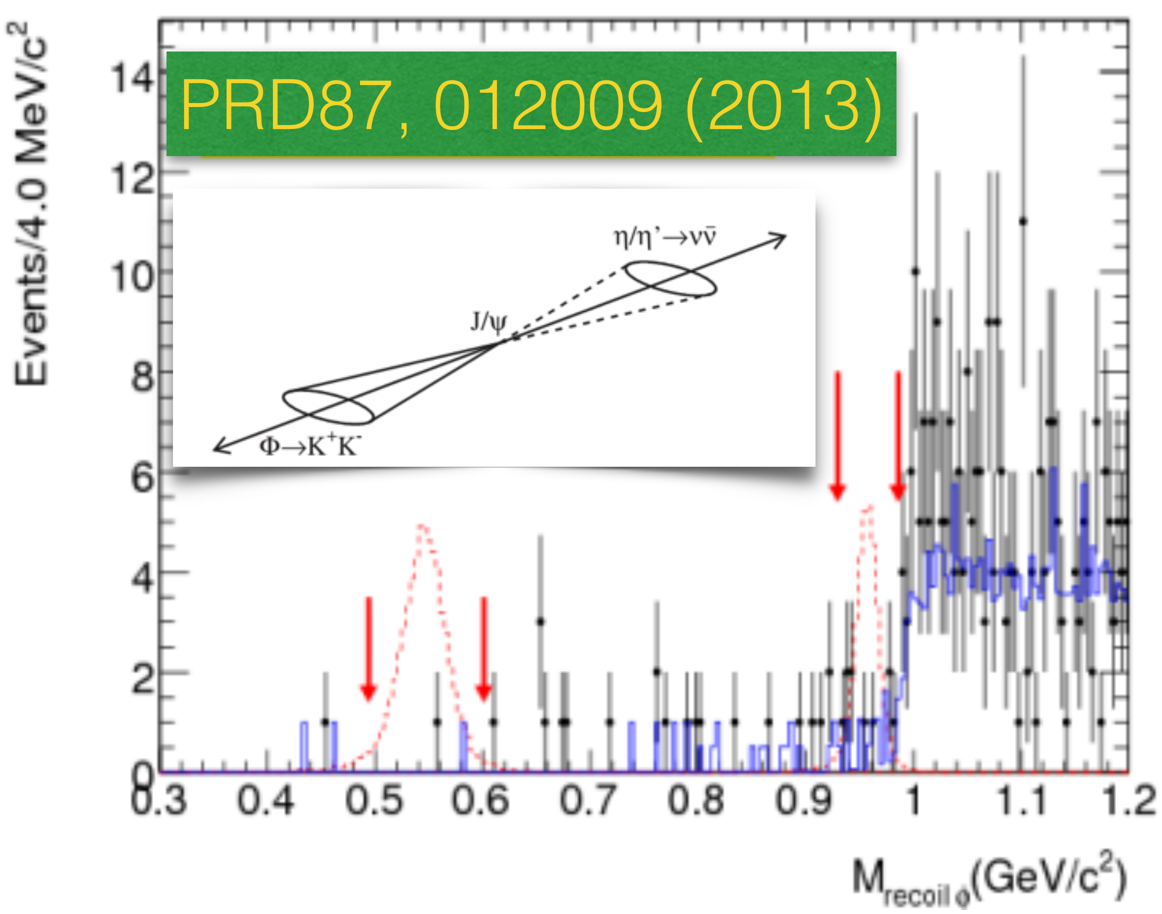
- Upper limits set at 90% C.L.

$$\frac{\mathcal{B}(\omega\to\text{invisible})}{\mathcal{B}(\omega\to\pi^+\pi^-\pi^0)} < 8.1\times 10^{-5} \quad \frac{\mathcal{B}(\phi\to\text{invisible})}{\mathcal{B}(\phi\to K^+K^-)} < 3.4\times 10^{-4}$$

$$\mathcal{B}(\phi \to \text{invisible}) < 1.7\times 10^{-4}, \quad \mathcal{B}(\omega \to \text{invisible}) < 7.3\times 10^{-5}$$

Invisible Decay

- η/η' decay play special role in low energy scale QCD theory
- Invisible and radiative decays offer a window for new physics BSM
- Observation of invisible final states provide information for light dark matter states χ, spin-0 axions, and light spin-1 U bosons
- Huge J/ψ sample, large $\mathscr{B}(J/\psi \to (\gamma/\phi)\eta/\eta')$ and narrow intermediate meson provide clean, large η/η' sub-sample



$Br(\eta'\to \text{invisible})/Br(\eta'\to\gamma\gamma)<2.39\times10^{-2}$
$Br(\eta \to \text{invisible})/Br(\eta\to\gamma\gamma)<2.58\times10^{-4}$

$Br(\eta'\to \text{invisible})<5.21\times10^{-4}$@90%C.L.
$Br(\eta \to \text{invisible})<1.01\times10^{-4}$@90%C.L.
Improved PDG Values

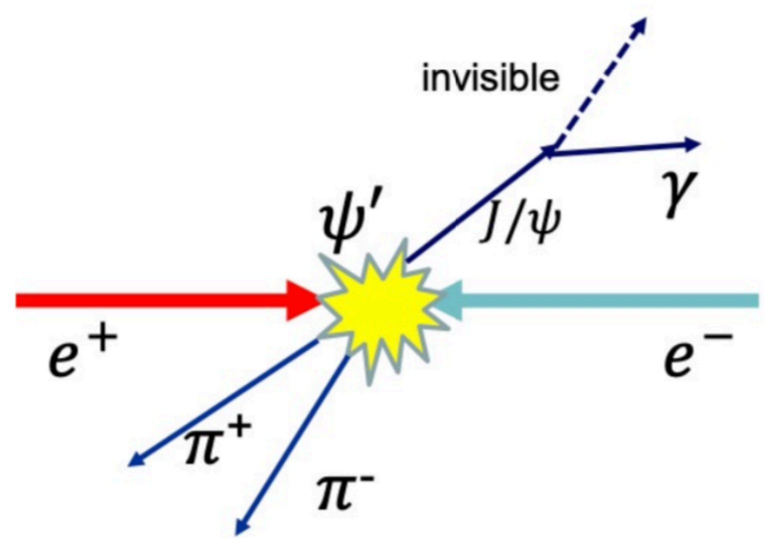
PDG : $Br(\eta'\to \text{invisible})<9\times10^{-4}$@90%C.L
$Br(\eta \to \text{invisible})<6\times10^{-4}$@90%C.L.

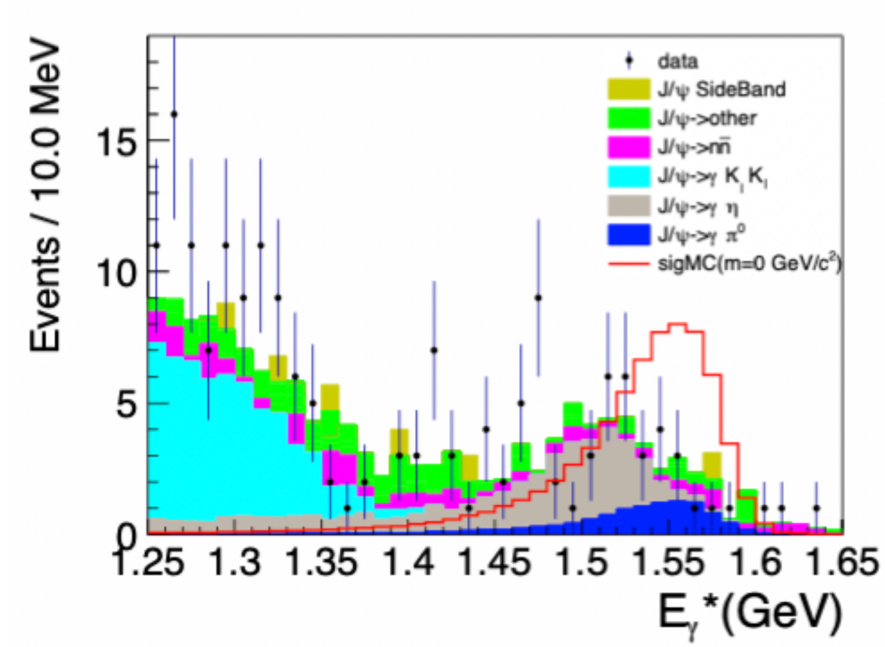
Theory : $Br(\eta'\to\chi\chi)$ ~8.1×10^{-7}
$Br(\eta \to\chi\chi)$~7.4×10^{-5}
B. McElrath, PRD 72, 103508 (2005)

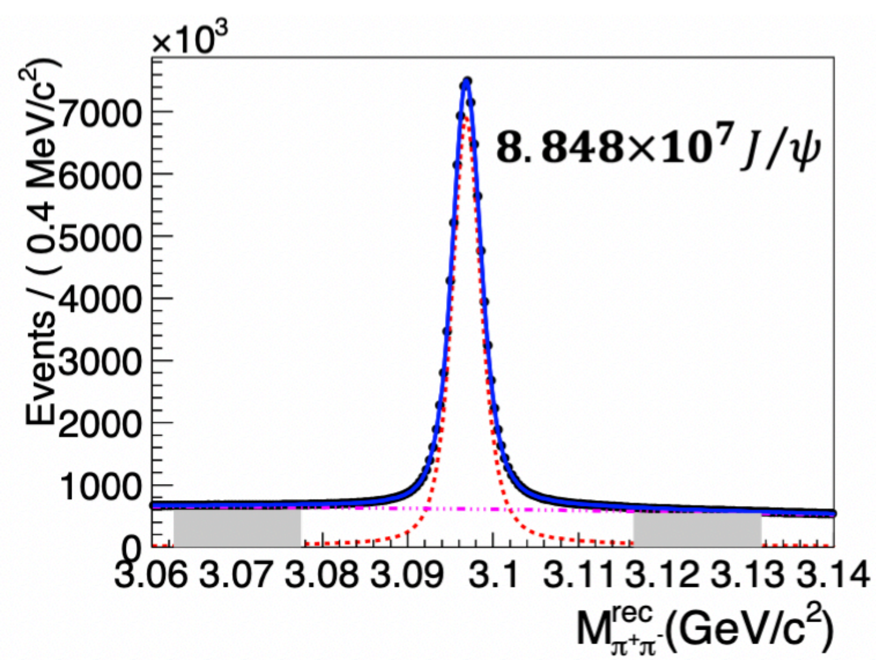
Invisible Decay

PRD101, 112005 (2020)

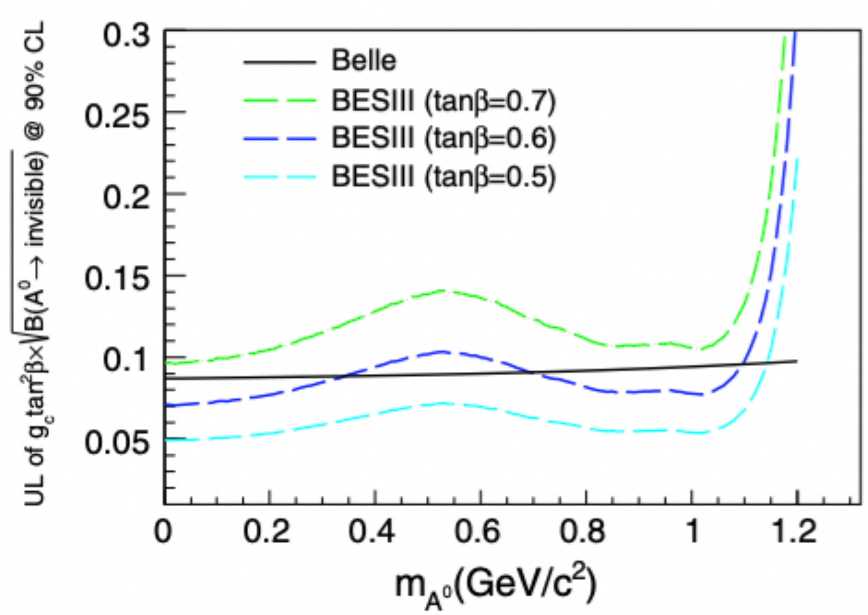
- the supersymmetric Standard Models predict a CP-odd pseudoscalar Higgs A^0. The A^0 can be produced in quarkonium radiative decay; Yukawa coupling of the A^0 field to the quark-pair: $g_c = cos\theta_A/tan\beta$, $g_b = cos\theta_A tan\beta$
- The A^0 can decay into two neutralinos
- Search for $J/\psi \to$ gamma invisible via $\psi(3686) \to \pi^+\pi^- J/\psi$







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



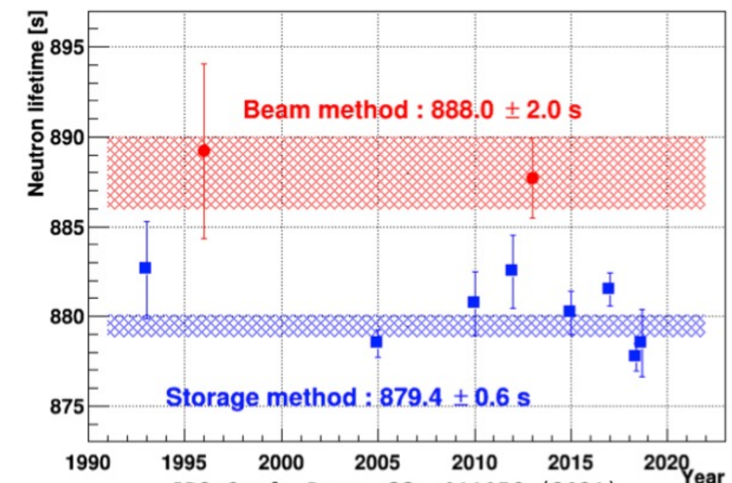
$B(J/\psi \to \gamma\ \text{invisible}) < 7.0 \times 10^{-7}$

Invisible Decay

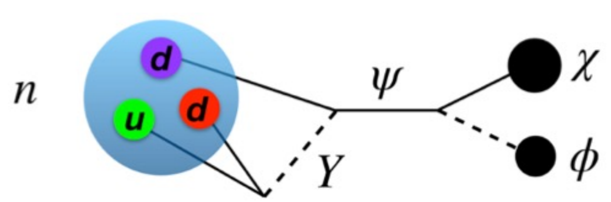
- Dark matter may be represented by baryon matter with invisibles, and theories suggest a potential correlation between baryon symmetry and dark sector (Phys. Rev. D 105, 115005)
- Discrepancy of neutron lifetime in beam method and the storage methods (4.1σ);

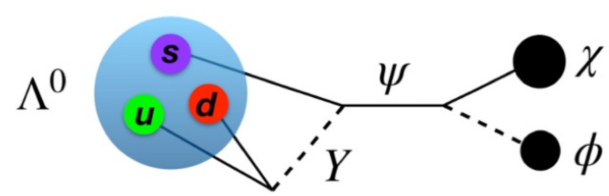
$$\boxed{\tau_n^{beam} = \frac{\tau_n}{\mathcal{B}(n \to p + X)} > \tau_n^{bottle}} \Rightarrow \boxed{\mathcal{B}(n \to p + X) \approx 99\%}$$

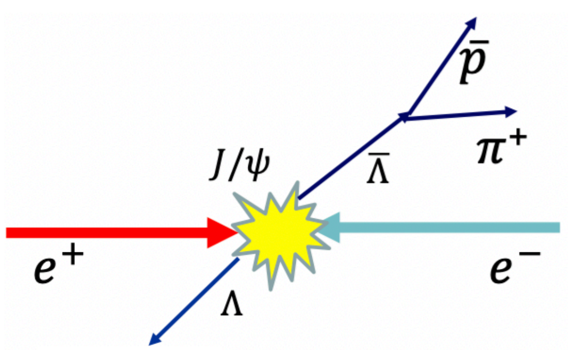
can be explained by 1% of the neutron decay into dark matter *Phys. Rev. D* 99, 035031



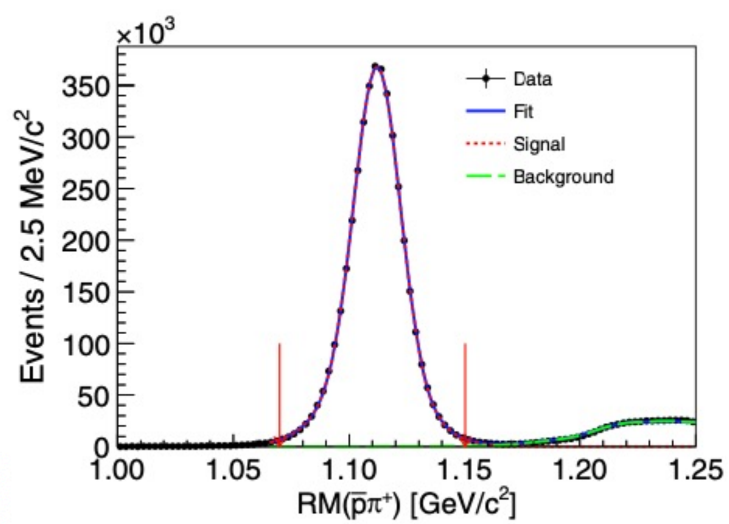
JPS Conf. Proc. 33, 011056 (2021)

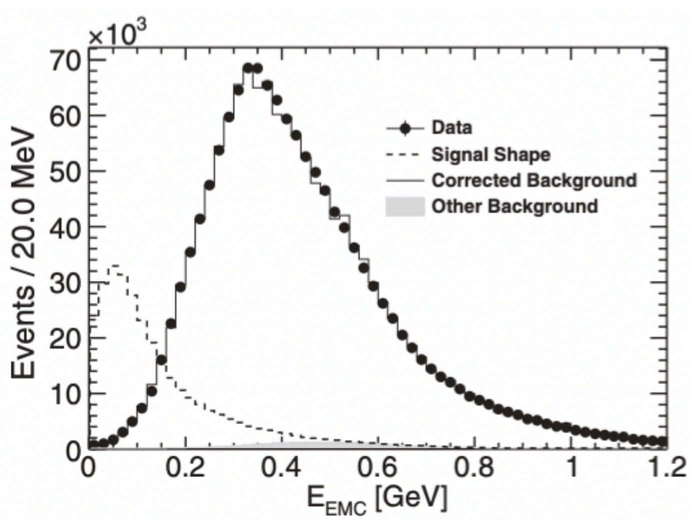


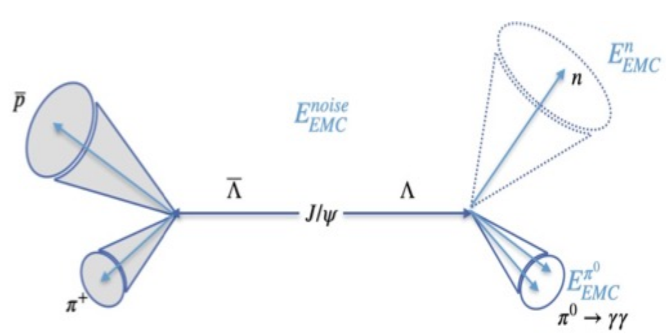




invisible







PRD105, L071102 (2022)

- Dominate background: $\Lambda \to n\pi^0$;

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

- $E^{\pi^0}_{EMC}$: Based on the MC simulations;
- E^{n}_{EMC}+ E^{noise}_{EMC}: retained bases on control sample $J/\psi \to \Lambda(n\pi^0)\bar{\Lambda}(\bar{p}\pi^+)$;

✓ The corrected $\mathrm{E_{EMC}}$ for $\Lambda \to \mathrm{n}\pi^0$ is derived by combining $\mathrm{E^{\pi^0}_{EMC}}$ with a random value of the sum of $\mathrm{E^{n}_{EMC}}$+ $\mathrm{E^{noise}_{EMC}}$;

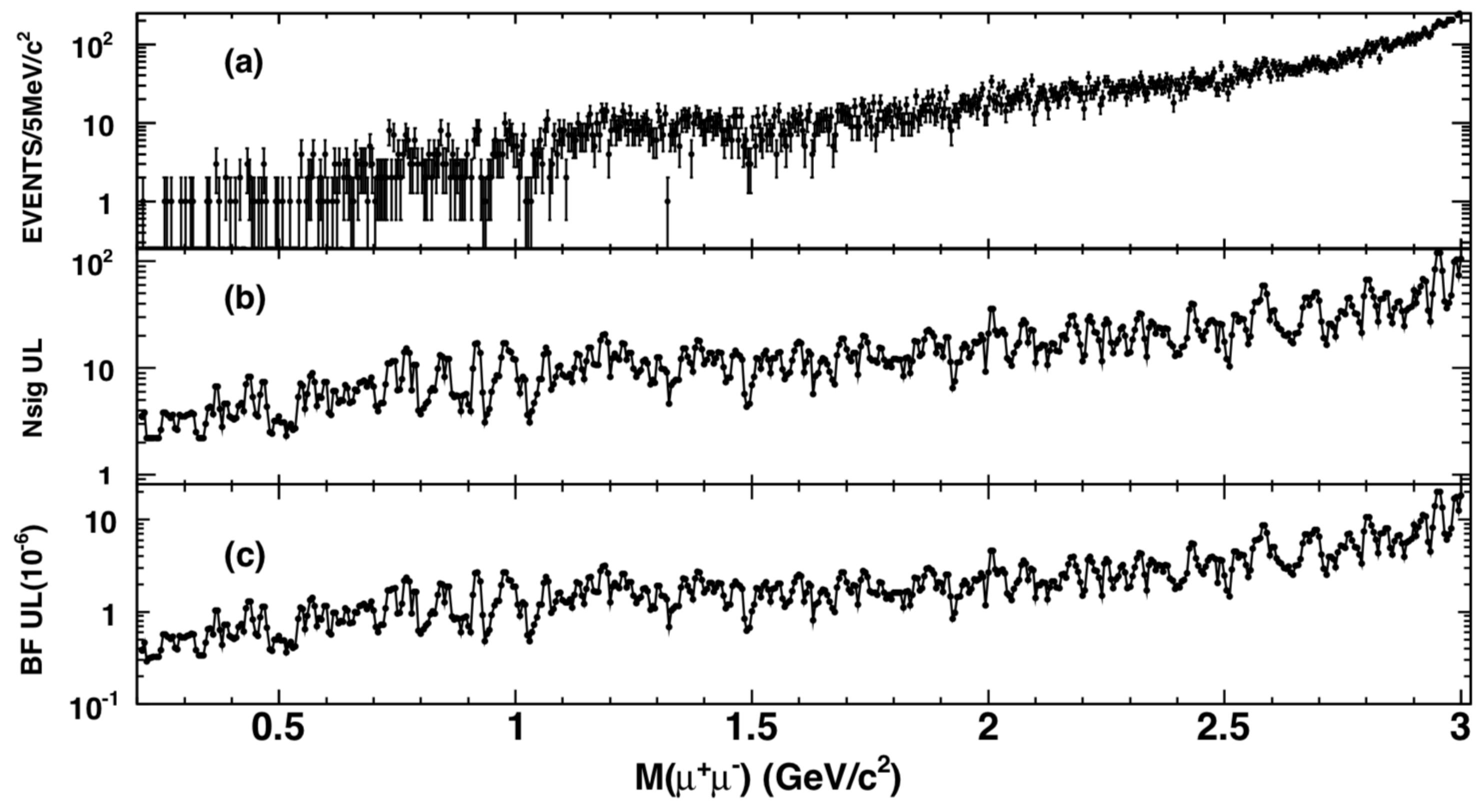
✓ No obvious signals are observed;

$$\mathcal{B}(\Lambda \to invisible) < 7.4\times10^{-5}$$

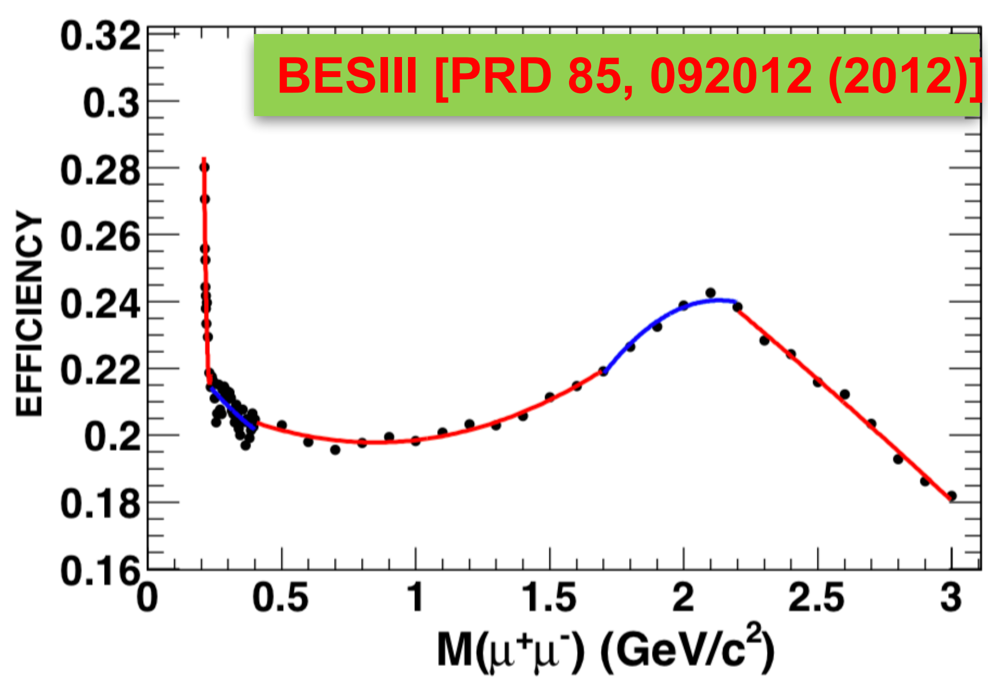
Light Higgs

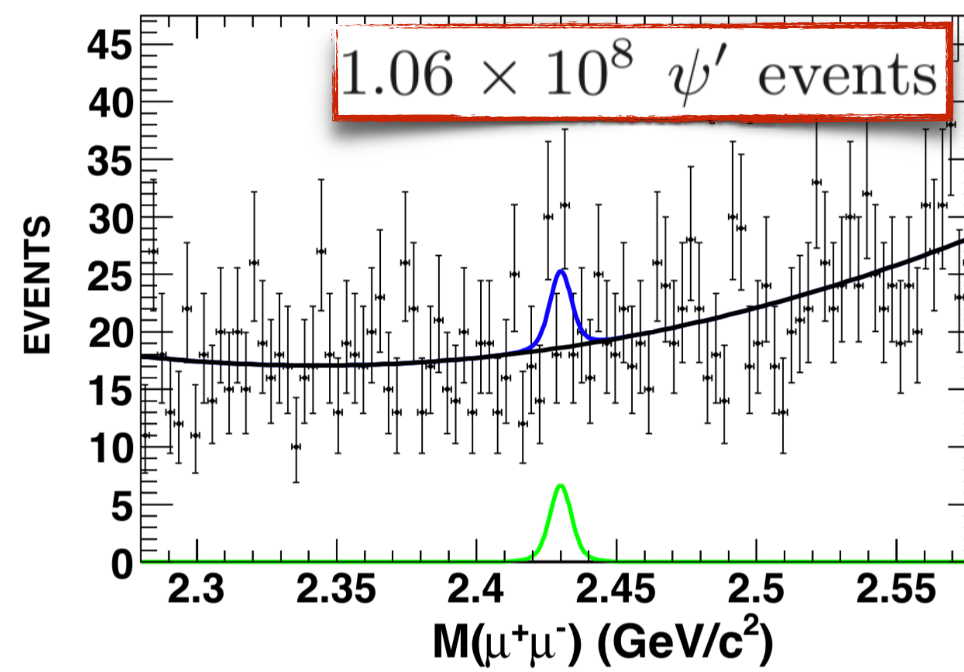
- Search for a Higgs-like boson in $\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to \gamma X$, $X \to \mu^+\mu^-$

The light particle X could be a Higgs-like boson $A0$, a spin-1 U boson, or a pseudoscalar sgoldstino particle. In this analysis, we find no evidence for any $\mu^+\mu^-$ mass peak between the mass threshold and 3.0 GeV



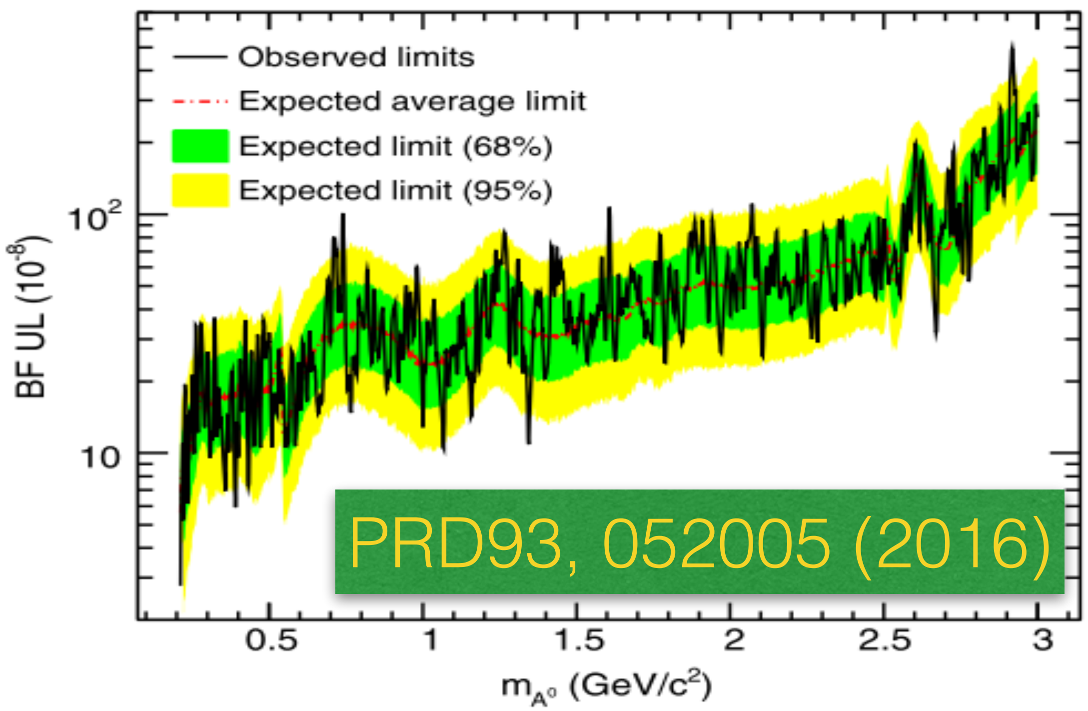
The limits are five times below BESIII's previous results ($\psi(3686) \to \pi\pi J/\psi$)



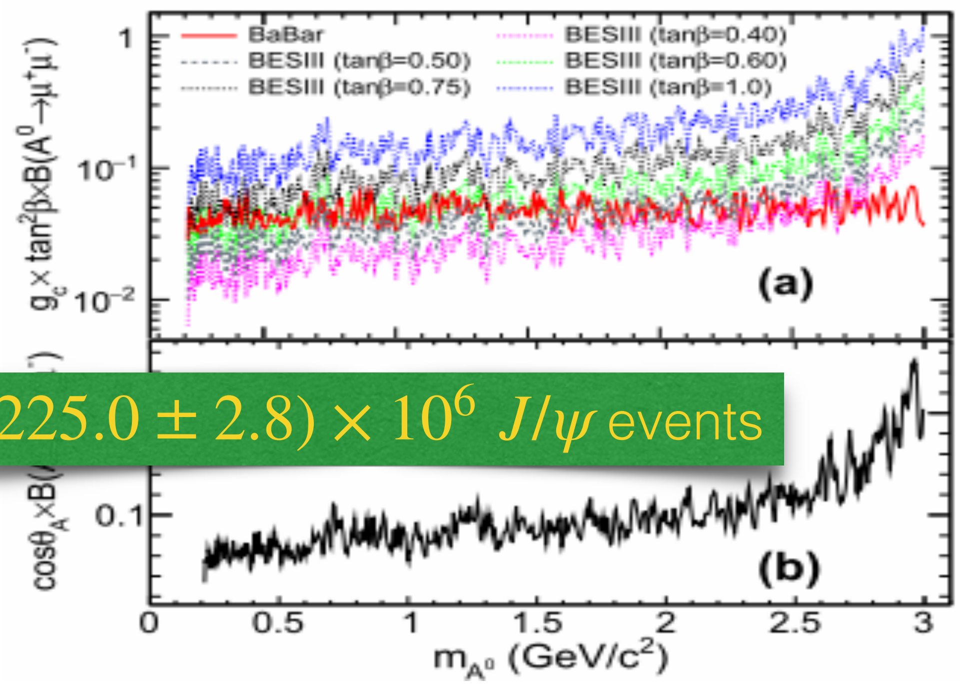


Light Higgs

- Search for a CP-odd Higgs boson in $J/\psi \to \gamma A^0$, $A^0 \to \mu^+\mu^-$

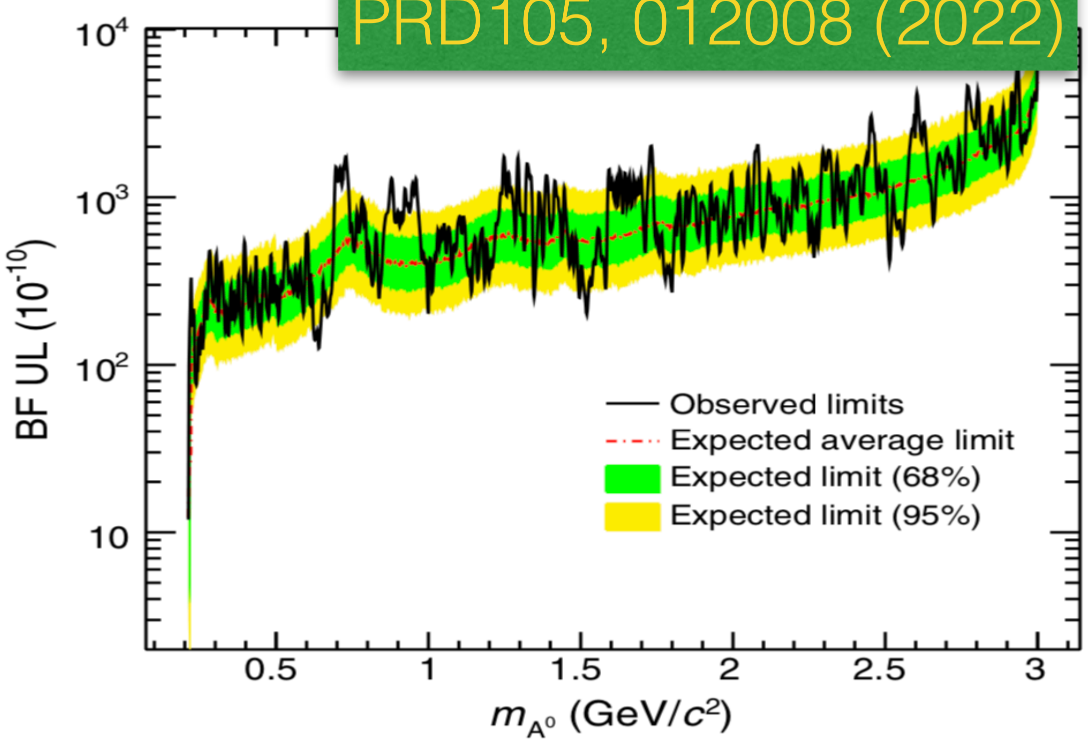


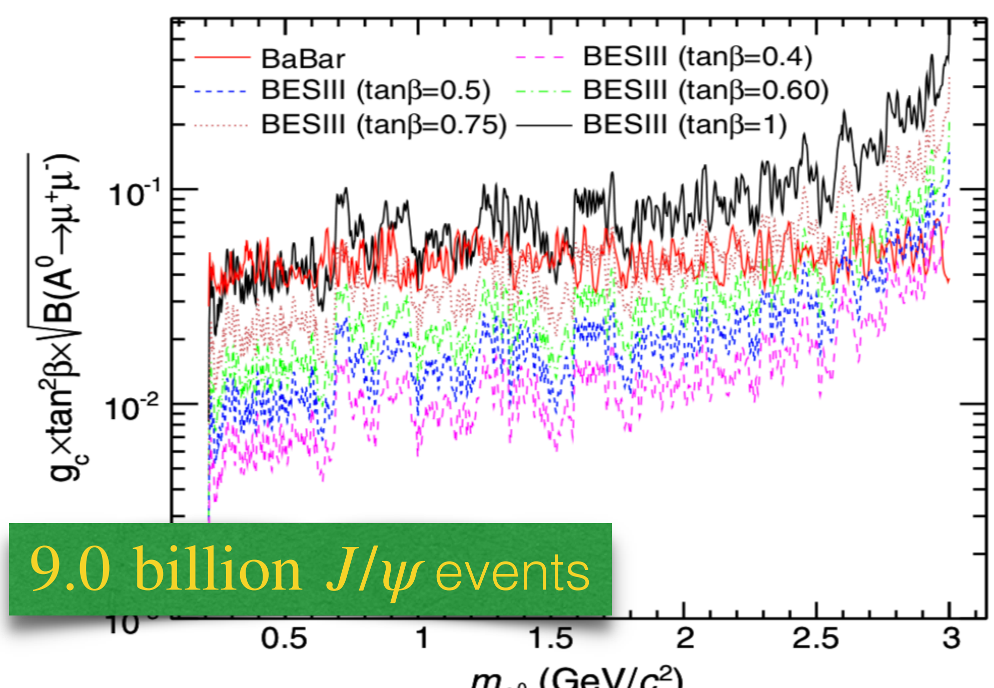
PRD93, 052005 (2016)



$(225.0 \pm 2.8) \times 10^6$ J/ψ events

PRD105, 012008 (2022)



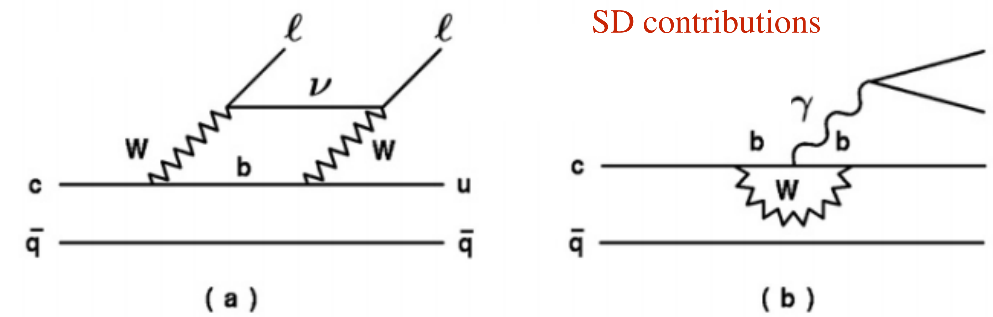


9.0 billion J/ψ events

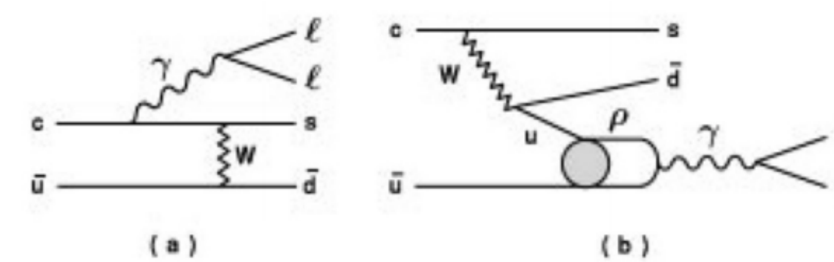
Flavor Changing Neutral Current

- In SM, FCNC is strongly suppressed by GIM mechanism and can happen only through loop diagram, leading to a very small BF, 10^(-9), theoretically
- The suppression in charm decays is much stronger than those in B and K system due to stronger diagram cancellation than the down-type quarks
- However, it can reach 10^(-6) under LD contribution
- Sensitive to New Physics

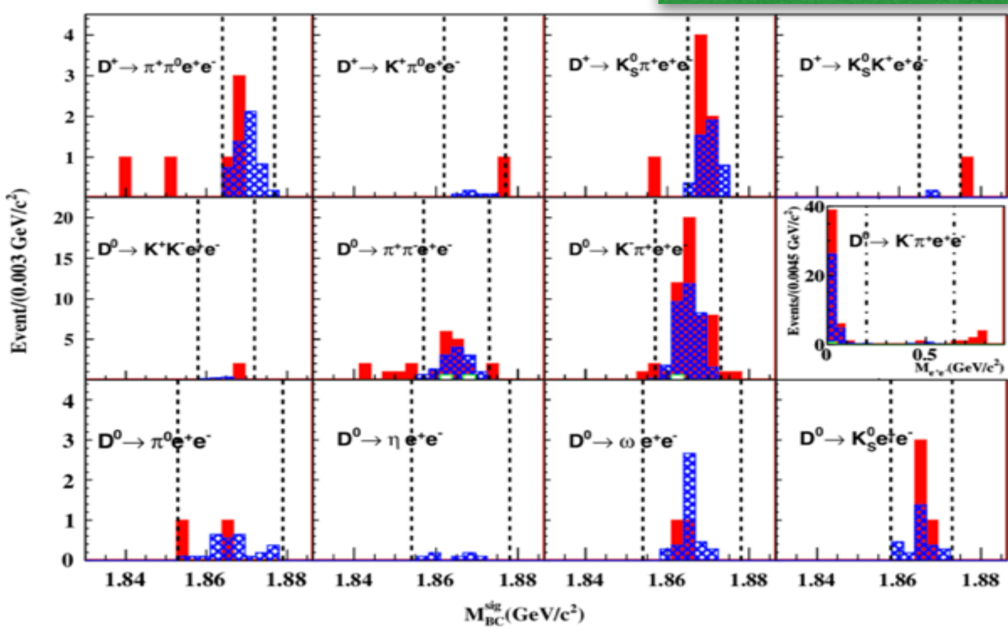
SD contributions



LD contributions



PRD97, 072015 (2018)



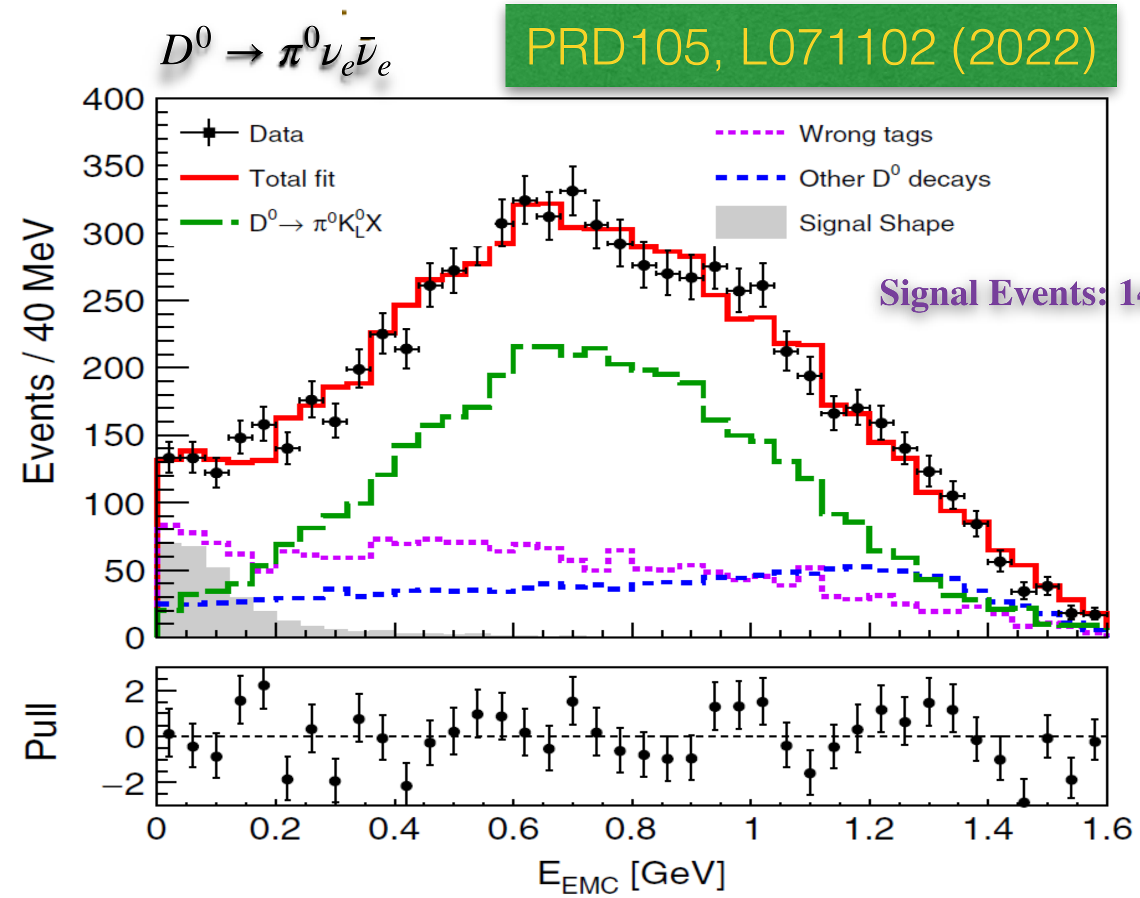
Signal decays	$\mathcal{B}$ ($\times10^{-5}$)	PDG [9] ($\times10^{-5}$)
$D^+\to\pi^+\pi^0e^+e^-$	<1.4	···
$D^+\to K^+\pi^0e^+e^-$	<1.5	···
$D^+\to K^0_S\pi^+e^+e^-$	<2.6	···
$D^+\to K^0_SK^+e^+e^-$	<1.1	···
$D^0\to K^-K^+e^+e^-$	<1.1	<31.5
$D^0\to\pi^+\pi^-e^+e^-$	<0.7	<37.3
$D^0\to K^-\pi^+e^+e^{-\dagger}$	<4.1	<38.5
$D^0\to\pi^0e^+e^-$	<0.4	<4.5
$D^0\to\eta e^+e^-$	<0.3	<11
$D^0\to\omega e^+e^-$	<0.6	<18
$D^0\to K^0_Se^+e^-$	<1.2	<11
† in $M_{e^+e^-}$ regions:		
$[0.00, 0.20)$ GeV/c^2	<3.0 $(1.5^{+1.0}_{-0.9})$	···
$[0.20, 0.65)$ GeV/c^2	<0.7	···
$[0.65, 0.90)$ GeV/c^2	<1.9 $(1.0^{+0.5}_{-0.4})$	···

- UL for D⁺ are obtained for the first time.
- UL for D^0 are greatly improved.
- Divide the M_{ee} distribution of $K^-\pi^+e^+e^-$ into 3 regions to help separate LD effect.

Theoretical[JHEP04, 135 (2014)]: $\mathscr{B}^{LD} = 1.6\times10^{-5}$

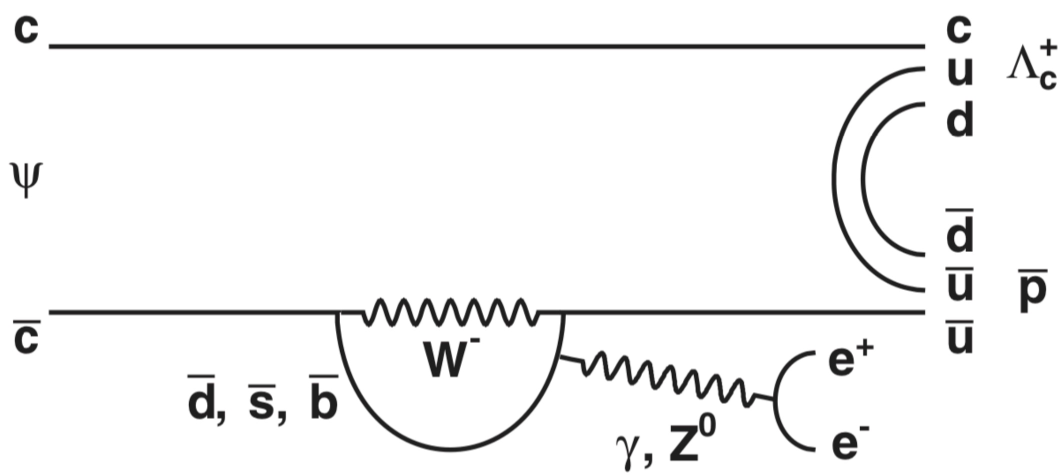
Experiment: $\mathscr{B}(D^0\to K^-\pi^+e^+e^-)^{LD} = (2.5\pm1.1)\times10^{-5}$ 2.6σ

PRD105, L071102 (2022)



$$\mathscr{B}(D^0\to\pi^0\nu_e\bar{\nu}_e) < 2.1\times10^{-4}$$

Flavor Changing Neutral Current



New physics models predict the BR could reach ~10^{-6}

Phys. Rev. D 60, 014011(1999);
Nucl. Phys. 25, 461 (2001);

$(448.1 \pm 2.9) \times 10^6\ \psi(3686)$ decays

Event selection

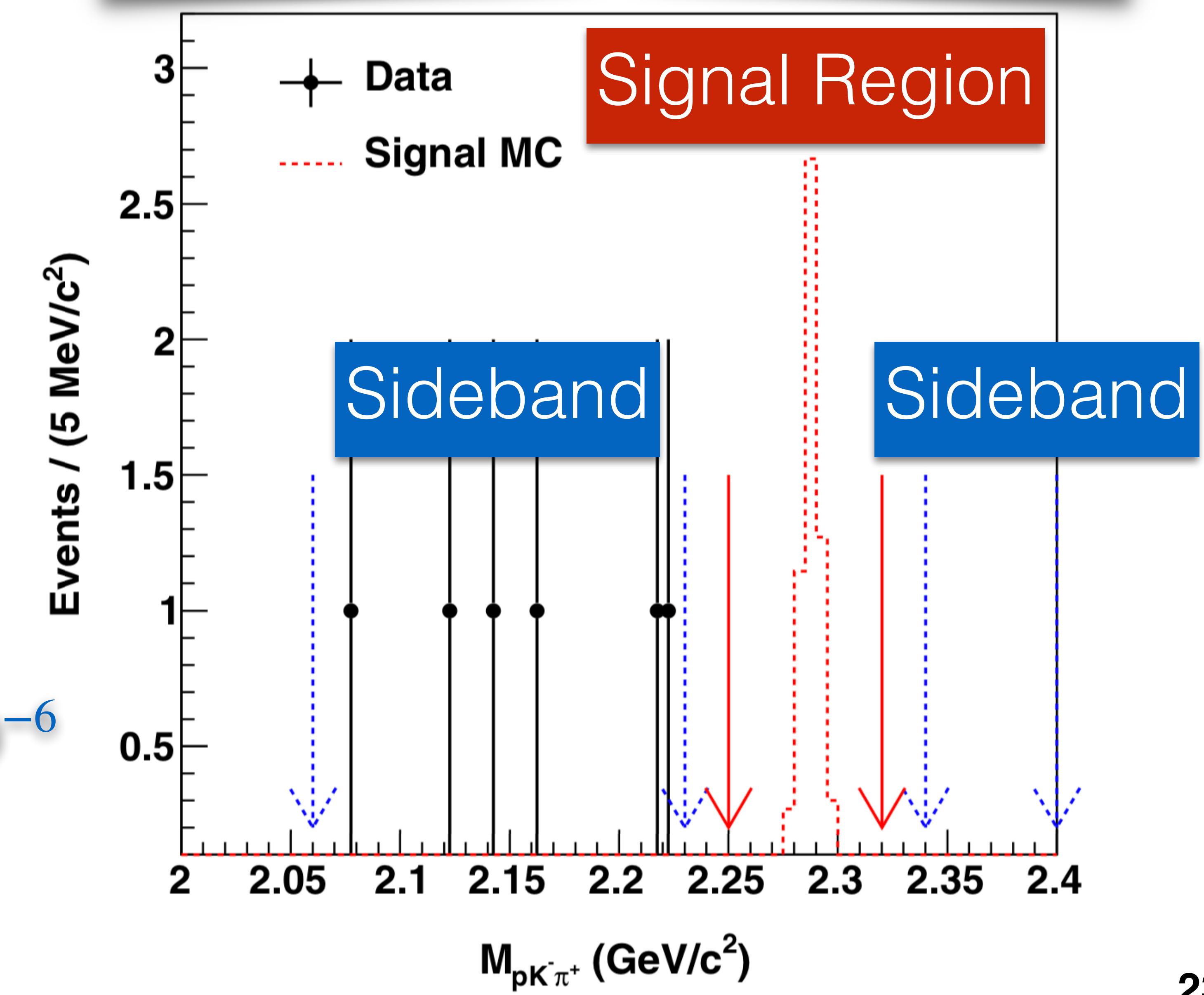
- $\psi(3686) \to \Lambda_c^+ \bar{p}\, e^+ e^-$ + c.c.
  - $\Lambda_c^+ \to p K^- \pi^+$
- Final state
  - $p \bar{p} K^- \pi^+ (K^+ \pi^-) e^+ e^-$

PRD97, 091102 (2018)

- Upper limits set at 90% C.L.

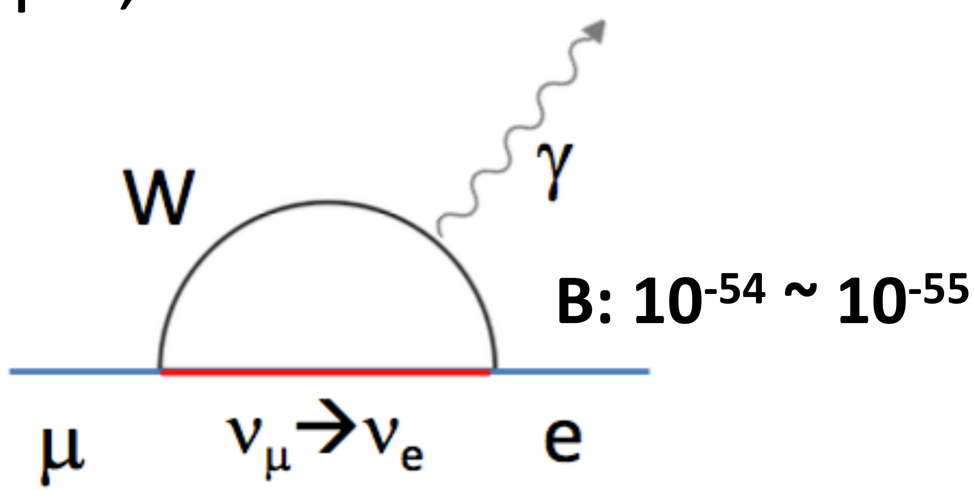
$$B(\psi(3686) \to \Lambda_c^+ \bar{p} e^+ e^-) < 1.7 \times 10^{-6}$$

Current Limits are within the SM expectation, no evidence for NP

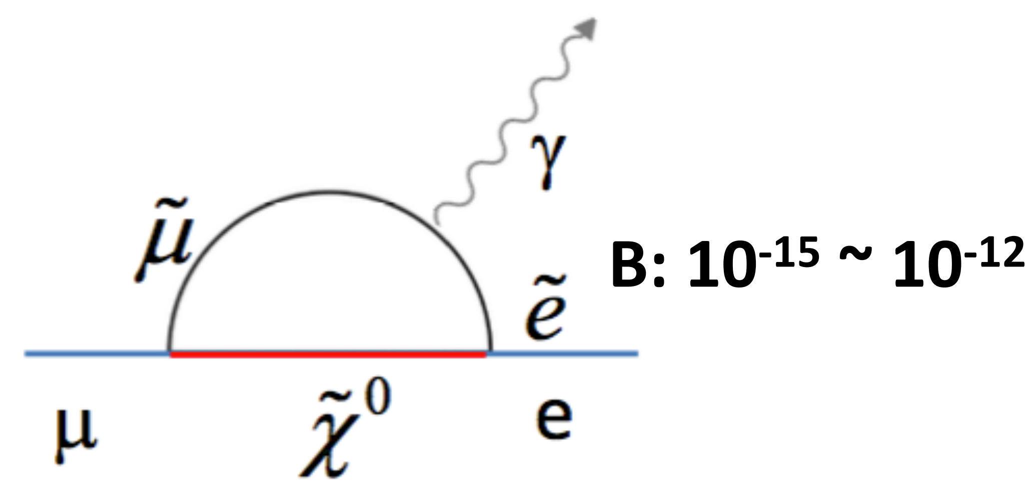


Charged Lepton Flavor Violation

- The non-zero neutrino masses and mixing can introduce flavor transitions, but the expected branching fractions are at an extremely rare level. For example, with the present knowledge on neutrino mixing parameters, the branching fraction of the cLFV process $\mu \to e\gamma$ is only about 10^{-55}.
- Thus, searching for the cLFV events which are SM forbidden would be clear signal of physics beyond the SM.
- For example,



- SM prediction
- SM + ν oscillation



- Beyond SM (e.g. SUSY)

Charged Lepton Flavor Violation

- LFV in meson decays

Channel	Upper limit	Experiment
$\pi^0 \to \mu^\pm e^\mp$	3.59×10^{-10}	KTeV
$\eta \to \mu^\pm e^\mp$	6×10^{-6}	Saturne SPES2
$K_L^0 \to \pi^0\mu^\pm e^\mp$	7.56×10^{-11}	KTeV
$K_L^0 \to 2\pi^0\mu^\pm e^\mp$	1.64×10^{-10}	KTeV
$K_L^0 \to \mu^+ e^-$	4.7×10^{-12}	BNL E871
$K^+ \to \pi^+\mu^+ e^-$	1.3×10^{-11}	BNL E865, E777
$D^+ \to \pi^+\mu^\pm e^\mp$	3.4×10^{-5}	Fermilab E791
$D^+ \to K^+\mu^\pm e^\mp$	6.8×10^{-5}	Fermilab E791
$D^0 \to \mu^\pm e^\mp$	8.1×10^{-7}	BaBar
$D_s^+ \to \pi^+\mu^\pm e^\mp$	6.1×10^{-4}	Fermilab E791
$D_s^+ \to K^+\mu^\pm e^\mp$	6.3×10^{-4}	Fermilab E791
$B^0 \to \mu^\pm e^\mp$	9.2×10^{-8}	BaBar (347 fb^{-1})
$B^0 \to \tau^\pm e^\mp$	1.1×10^{-4}	CLEO (9.2 fb^{-1})
$B^0 \to \tau^\pm \mu^\mp$	3.8×10^{-5}	CLEO (9.2 fb^{-1})
$B^+ \to K^+ e^\pm \mu^\mp$	9.1×10^{-8}	BaBar (208 fb^{-1})
$B^+ \to K^+ e^\pm \tau^\mp$	7.7×10^{-5}	BaBar (348 fb^{-1})
$B_s^0 \to e^\pm \mu^\mp$	6.1×10^{-6}	CDF (102 pb^{-1})

Nucl. Phys. B Supp. 188, 303

- LFV in quarkonium decays

$\ell_1\ell_2$	$\mu\tau$	$e\tau$	$e\mu$
$\mathcal{B}(\Upsilon(1S) \to \ell_1\ell_2)$	6.0×10^{-6}	–	–
$\mathcal{B}(\Upsilon(2S) \to \ell_1\ell_2)$	3.3×10^{-6}	3.2×10^{-6}	–
$\mathcal{B}(\Upsilon(3S) \to \ell_1\ell_2)$	3.1×10^{-6}	4.2×10^{-6}	–
$\mathcal{B}(J/\psi \to \ell_1\ell_2)$	2.0×10^{-6}	8.3×10^{-6}	1.6×10^{-7}
$\mathcal{B}(\phi \to \ell_1\ell_2)$	n/a	n/a	4.1×10^{-6}

Charged Lepton Flavor Violation

- The cLFV search in lepton decay, pseudoscalar meson decay and vector meson decay etc with no evidence. Equally important to search it in heavy quarkonium decays.

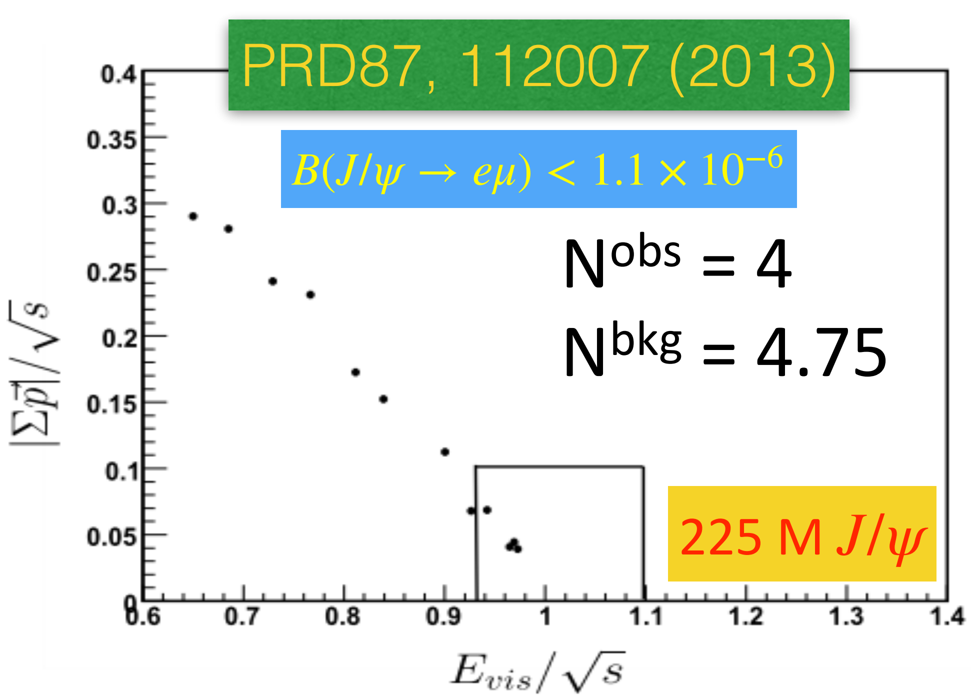
- The cLFV decays of vector mesons $V \to l_i l_j$ are also predicted in various of extension models of SM[1]:

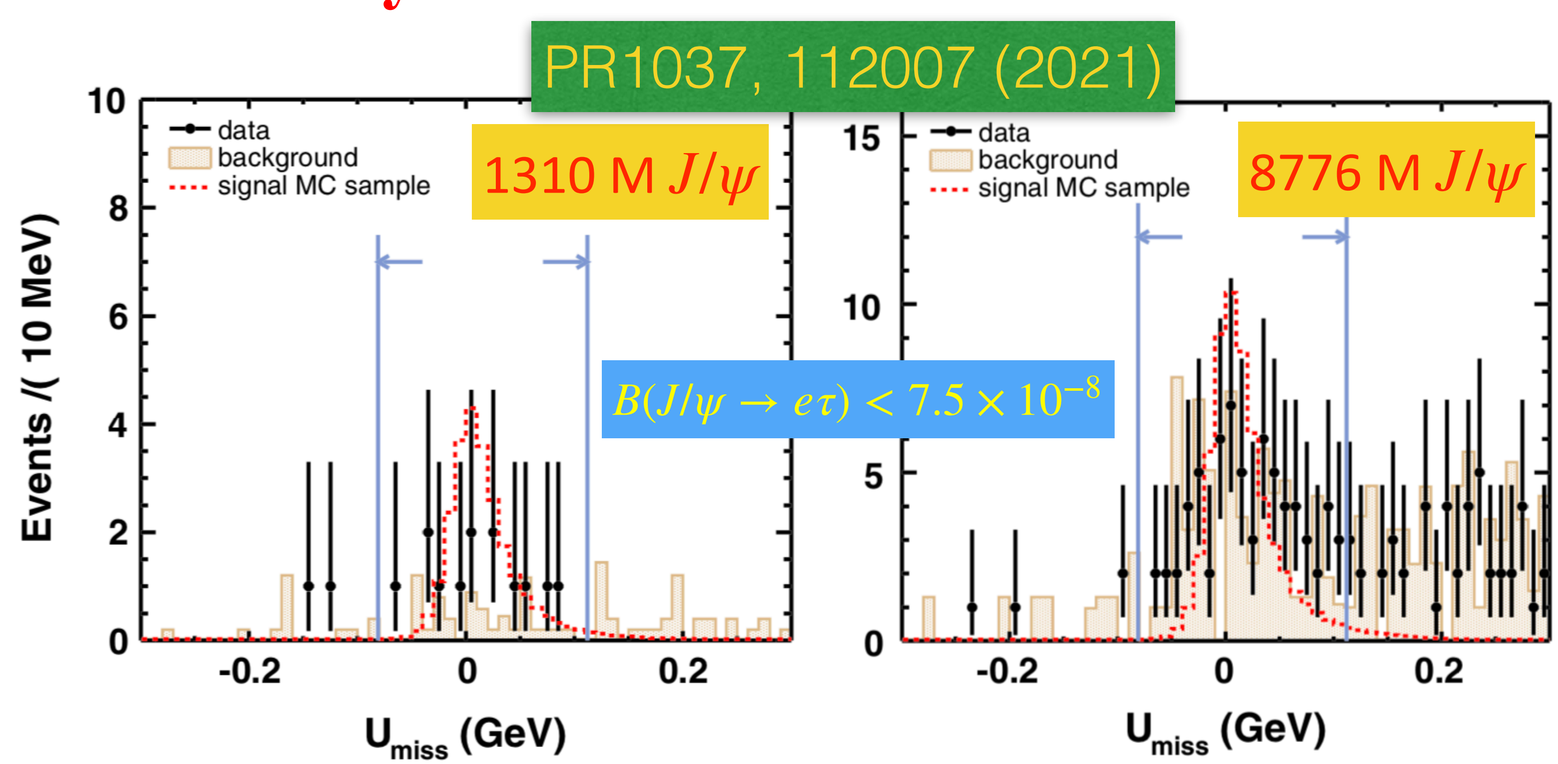
$$\mathcal{B}_{UL}^{90}(J/\psi \to e\mu) < 10^{-13}$$

$$\mathcal{B}_{UL}^{90}(J/\psi \to e(\mu)\tau)) < 10^{-9}$$

[1]: Phys. Rev. D 63, 016003, Phys. Rev. D 83, 115015, Phys. Lett. A 27, 1250172, Phys. Rev. D 97, 056027

- J/ψ LFV decays have been measured by BES collaboration.

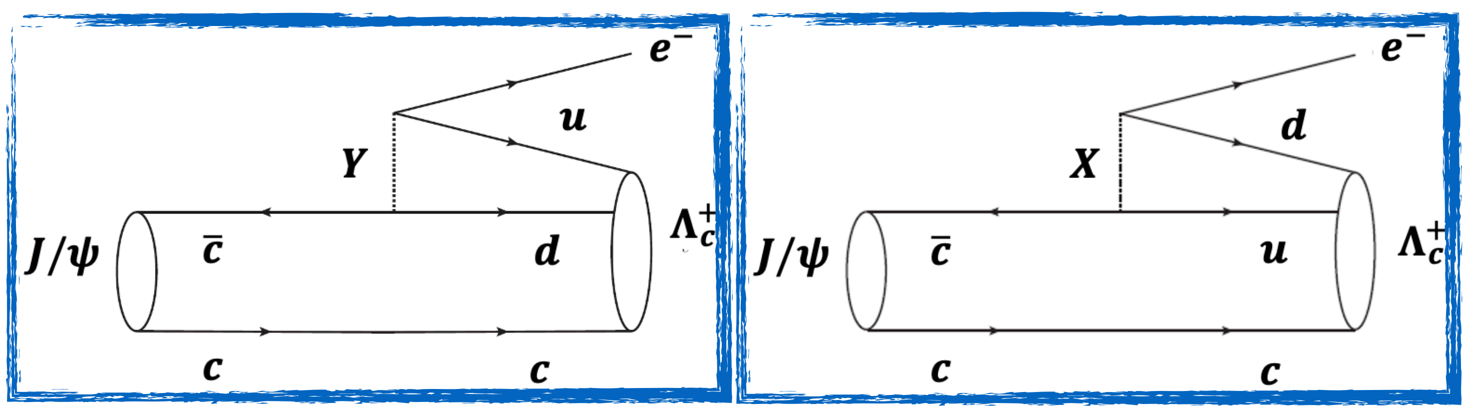


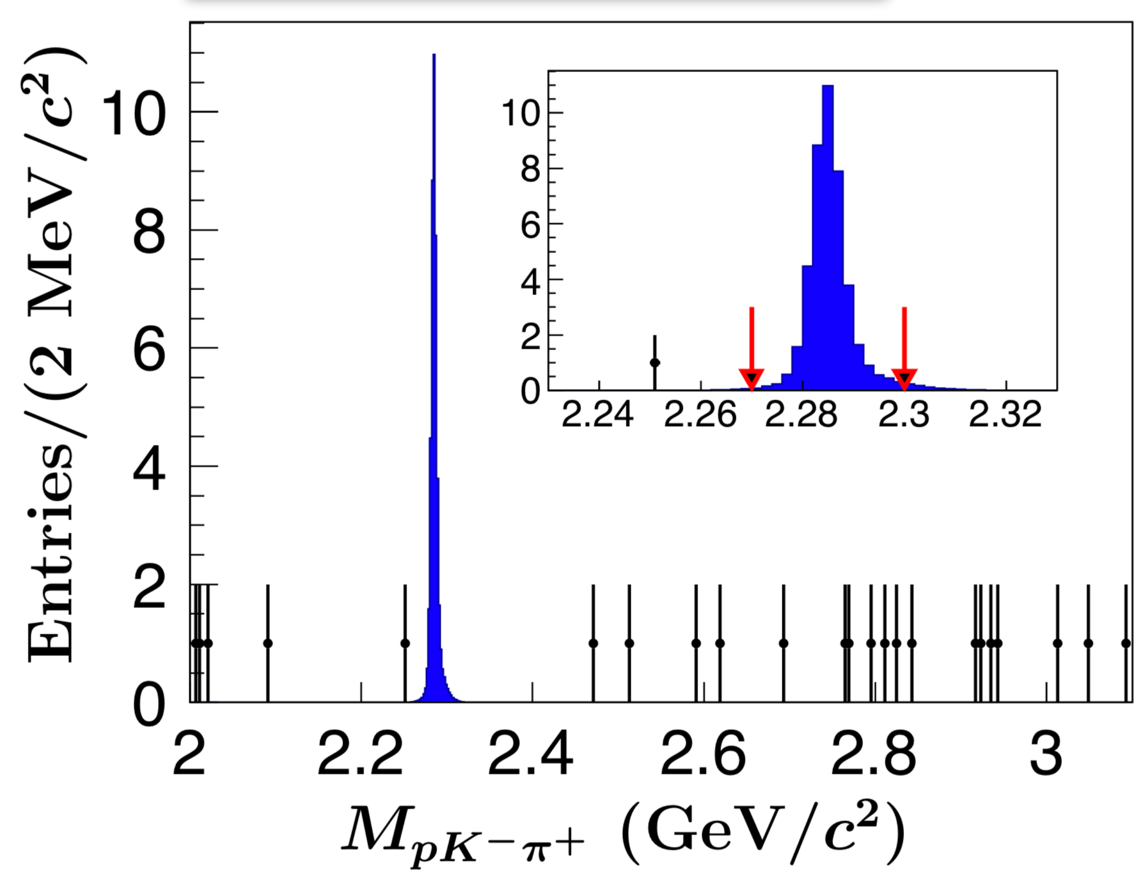


Baryon Number Violation

- Many SM extensions and Grand Unified Theories, such as superstring or SUSY, predict proton decays. In this case, baryon number is violated while the difference Δ(B-L) is conserved.
- Since the matter–antimatter asymmetry in the universe is an observable fact, the negative result from proton decay experiment does not imply BN is conserved.
- Searches for new physics at collider experiments are complementary to those at specifically designed non-collider experiments.

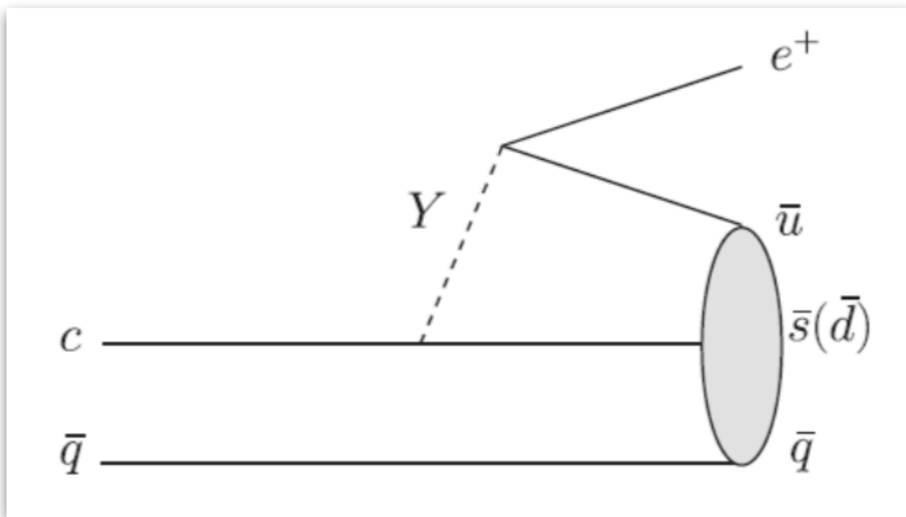
PRD99, 072006 (2019)

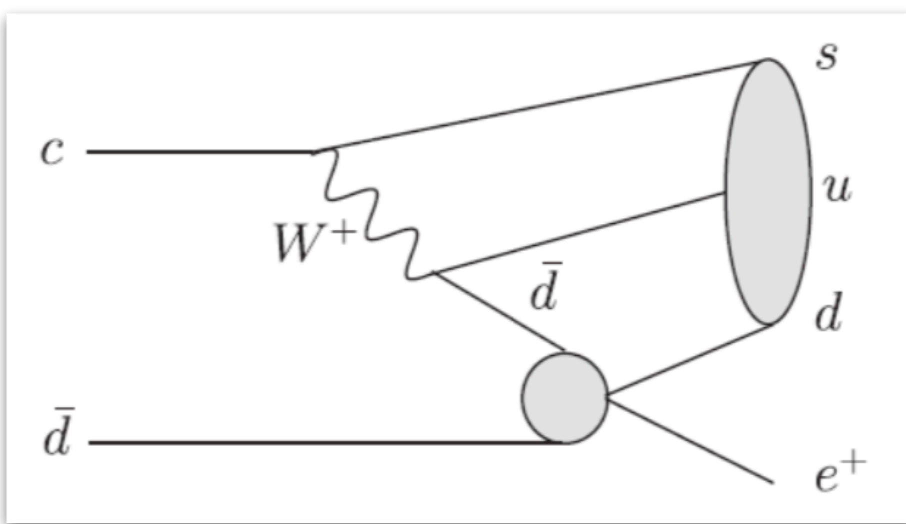




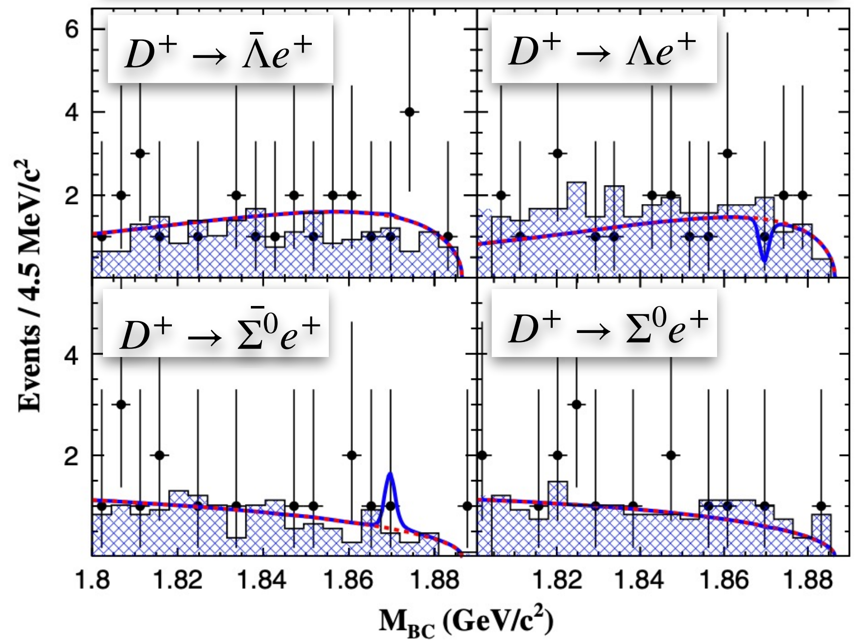
- First search for $J/\psi \to \Lambda_c^+ e^- + c.c.$
- The first BNV search in quarkonium decay products.
- $\mathscr{B}(J/\psi \to \Lambda_c^+ e^- + c.c.) < 6.9 \times 10^{-8}$

Baryon Number Violation



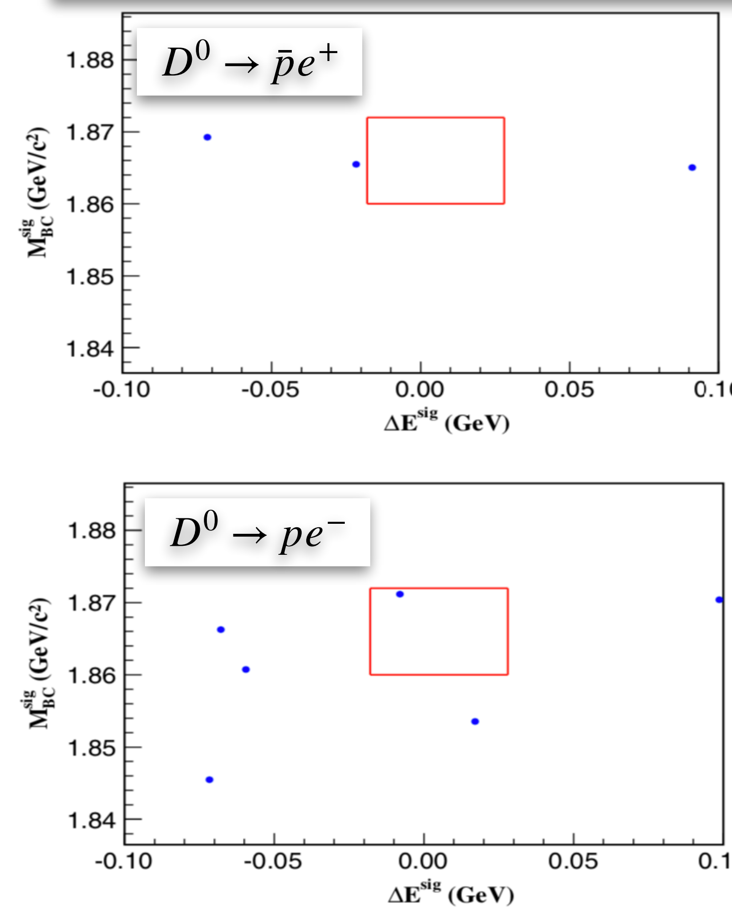


PRD101, 031102 (2020)



Channels	Upper Limit
$D^+ \to \Lambda\, e^+$	1.1×10^{-6}
$D^+ \to \bar{\Lambda}\, e^+$	6.5×10^{-7}
$D^+ \to \Sigma^0\ e^+$	1.7×10^{-6}
$D^+ \to \bar{\Sigma}^0\ e^+$	1.3×10^{-6}

PRD105, 032006 (2022)

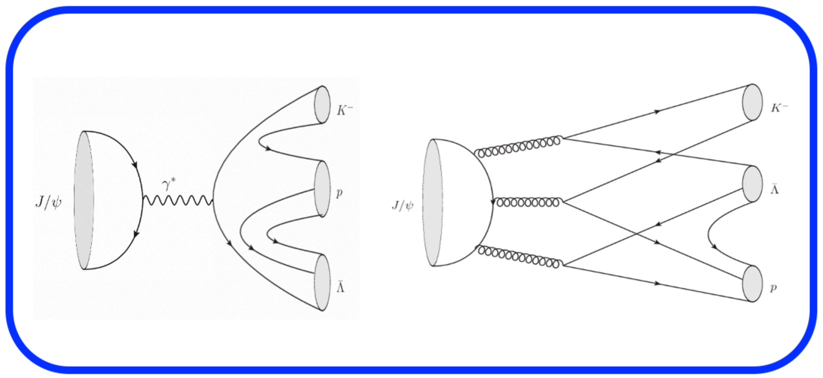


Channels	Upper Limit
$D^0 \to \bar{p}e^+$	1.2×10^{-6}
$D^+ \to pe^-$	2.2×10^{-6}

Current Limits are far above the theoretical prediction

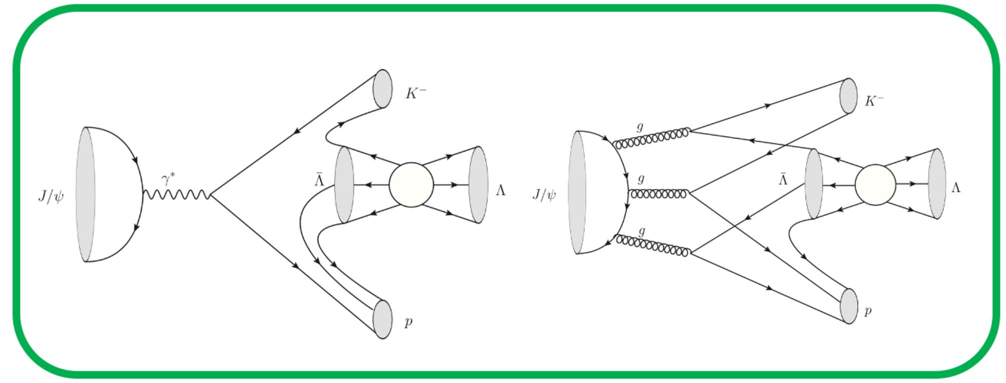
Baryon Number Violation

- The discoveries of neutrino oscillations have made $N-\bar{N}$ oscillation to be quite plausible theoretically[PRL96, 061801(2006)] if small neutrino masses are to be understood as a consequence of the seesaw mechanism, which indicates the existence of Δ(B-L)=2 interactions.
- The theoretical advantage for using $\Lambda-\bar{\Lambda}$ is it has a second generation quark, which can give different knowledge with the result of proton decay which only have the first generation quark.



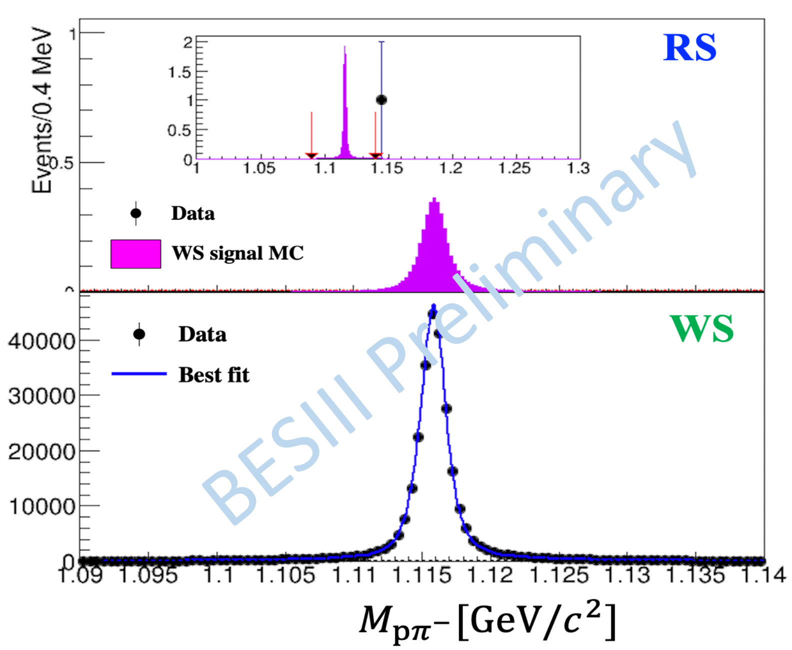
Right Sign Channel (Opposite Charge)

$J/\psi \to pK^-\bar{\Lambda} \to pK^-(\bar{p}\pi^+)$



Wrong Sign Channel (Same Charge)

$J/\psi \to pK^-\Lambda \to pK^-(p\pi^-)$



- Upper limit on oscillation rate (90% CL) BESIII Preliminary

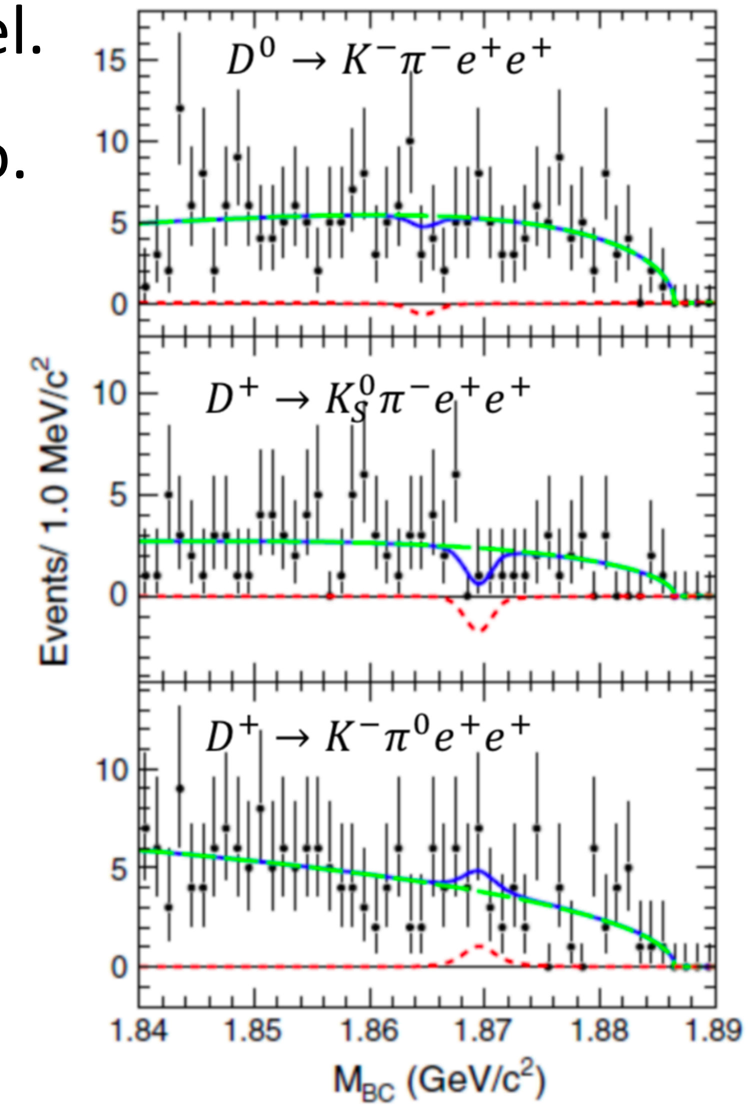
$$P(\Lambda) = \frac{\mathrm{B}(J/\psi \to pK^-\Lambda)}{\mathrm{B}(J/\psi \to pK^-\bar{\Lambda})} < 4.4\times10^{-6}$$

- Oscillation parameter (90% CL) BESIII Preliminary

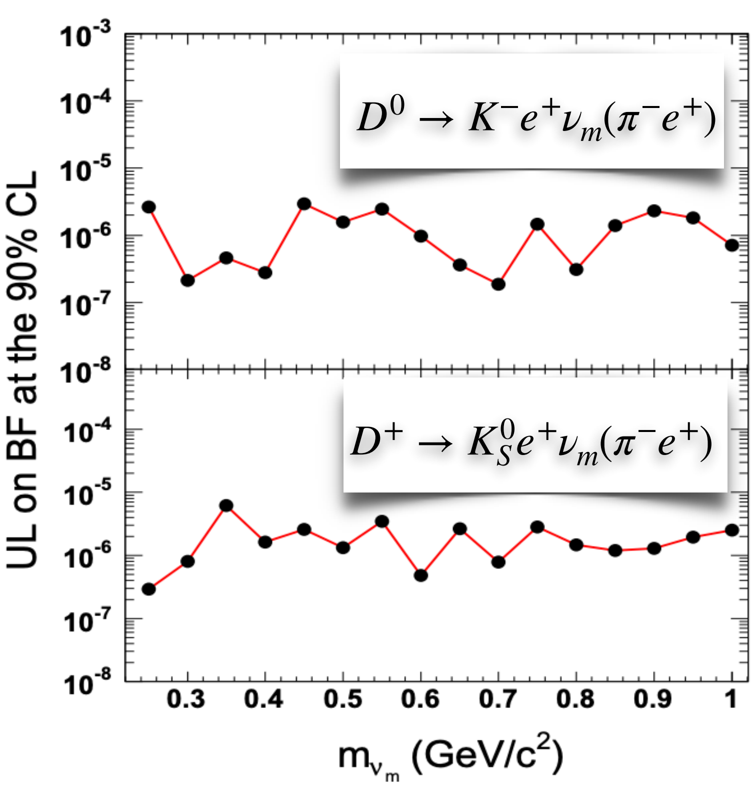
$$\delta m_{\Lambda\bar{\Lambda}} < 3.8\times10^{-15}\ \mathrm{MeV}$$

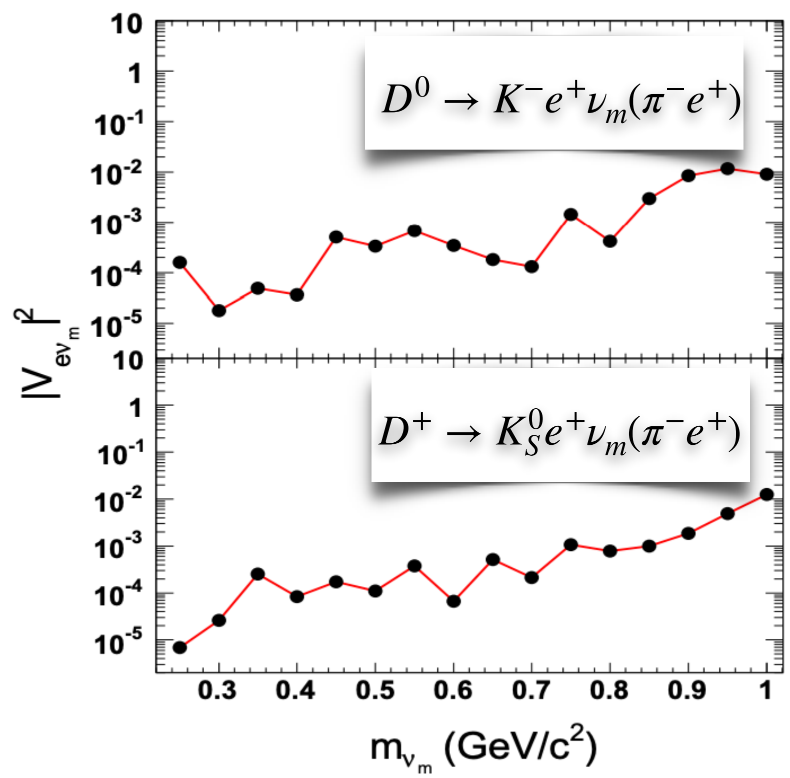
Lepton Number Violation

- Lepton number (LN) is conserved in the Standard Model.
- Neutrino oscillation → m_ν≠0 → New Physics scenario.
- Nature of neutrino: Majorana or Dirac?
- Majorana neutrino can violate LN by two unit
- LNV is introduced in many New Physics models



PRD99, 112002 (2019)



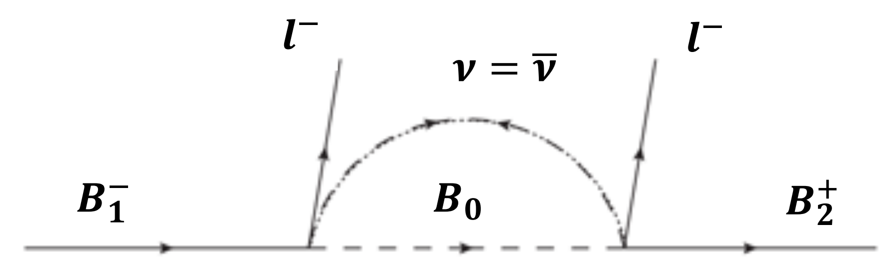


Channels	Upper Limit
$D^0 \to K^-\pi^-e^+e^+$	2.8×10^{-6}
$D^+ \to K_S^0\pi^-e^+e^+$	3.3×10^{-6}
$D^+ \to K^-\pi^0e^+e^+$	8.5×10^{-6}

best limits on these channels up to now

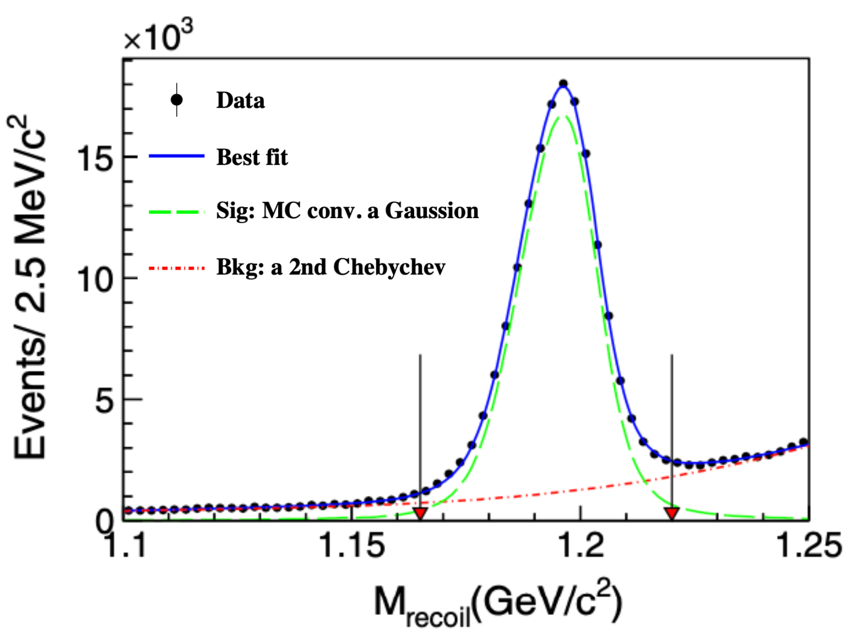
Lepton Number Violation

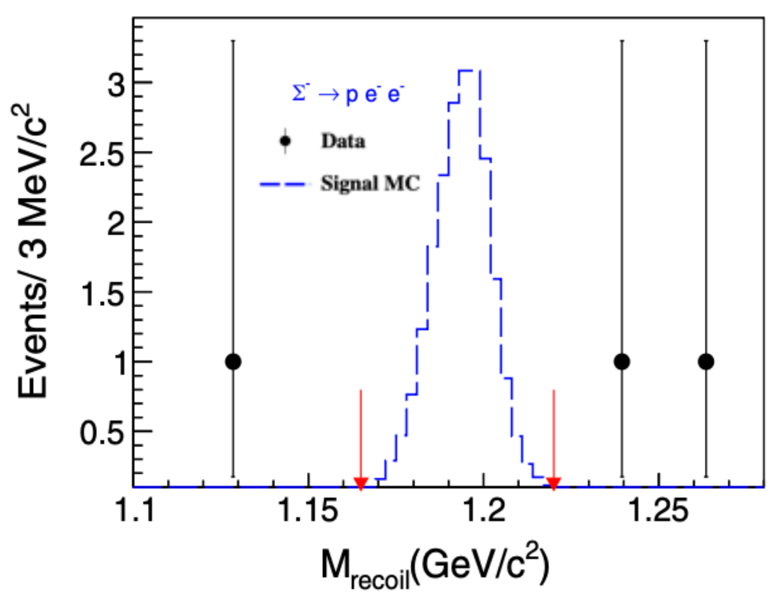
PRD 103 (2021) 052011

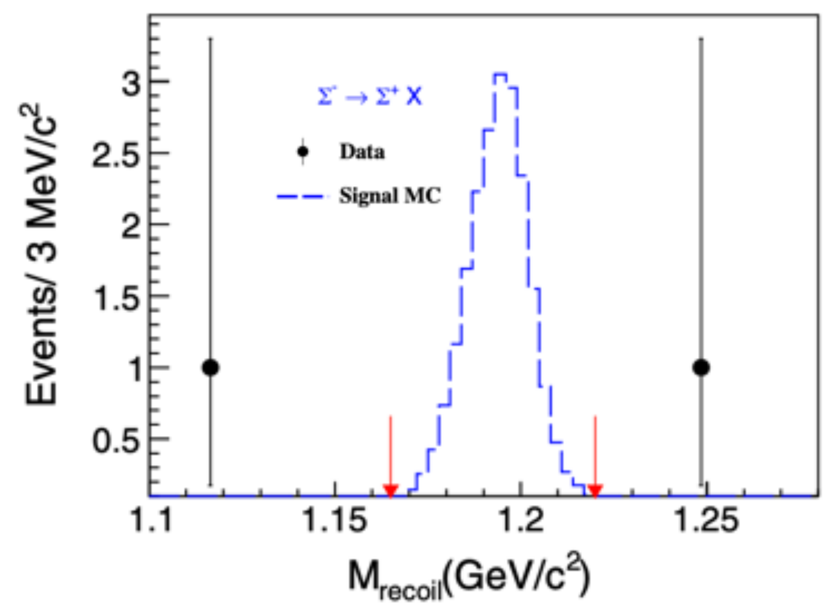


- **Two down-type (d or s) quarks convert into two up-quarks[PLB556, 98; PRD76, 116008], similar to 0νββ**
- **ST events: J/ψ→Σ̄(1385)^+ Σ^-+c.c., Σ̄(1385)^+→π^+ Λ̄(→p̄π^+), save all Σ̄(1385)^+ candidates; fit the recoil mass of Σ̄(1385)^+.**
- **DT events: in the recoil side of the ST events, searching for Σ^- → pe^- e^-; Σ^- → Σ^+ (→p π^0)X**

PRD103, 052001 (2021)







$N_{ST} = 147743 \pm 563_{stat.}$

$B(\Sigma^- \to p e^- e^-) < 6.7 \times 10^{-5}$

$B(\Sigma^- \to \Sigma^+ X) < 1.2 \times 10^{-4}$

Summary

- BESIII has performed wide range of searches to probe new physics BSM.
  - Exotic resonance search: light Higgs/Dark photon etc
  - Invisible decays
  - FCNC processes
  - Charged lepton flavor violation(CLFV) processes
  - Baryon number violation(BNV) processes
  - Lepton number violation(LNV) processes
  - Charmonia weak decays
  - Charm meson radiative decays
  - C-violation EM processes
  - C and CP violation decays
  - ……
- BESIII has great potential with unique (and increasing) datasets and analysis technique
  - More to come, stay tuned!
  - More ideas/collaborations are welcome!

谢谢大家！