New Physics Searches at BESIII

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The 10th Workshop on Hadron physics in China and Opportunities Worldwide

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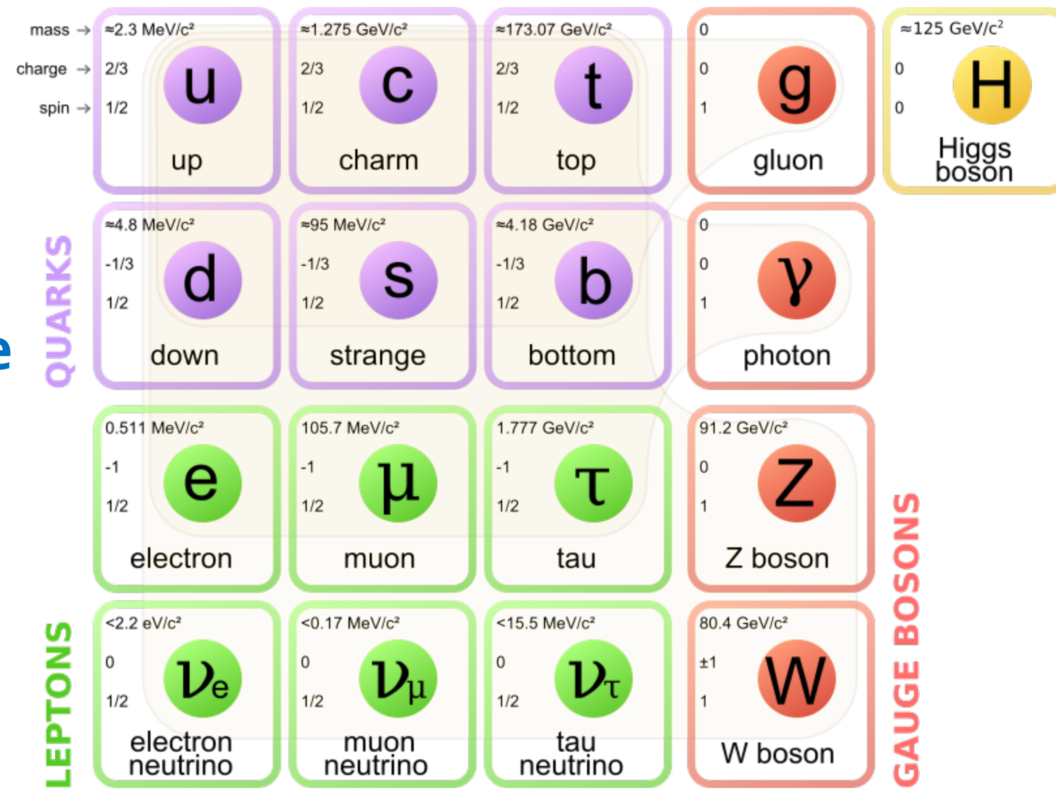
Searching for New physics BSM

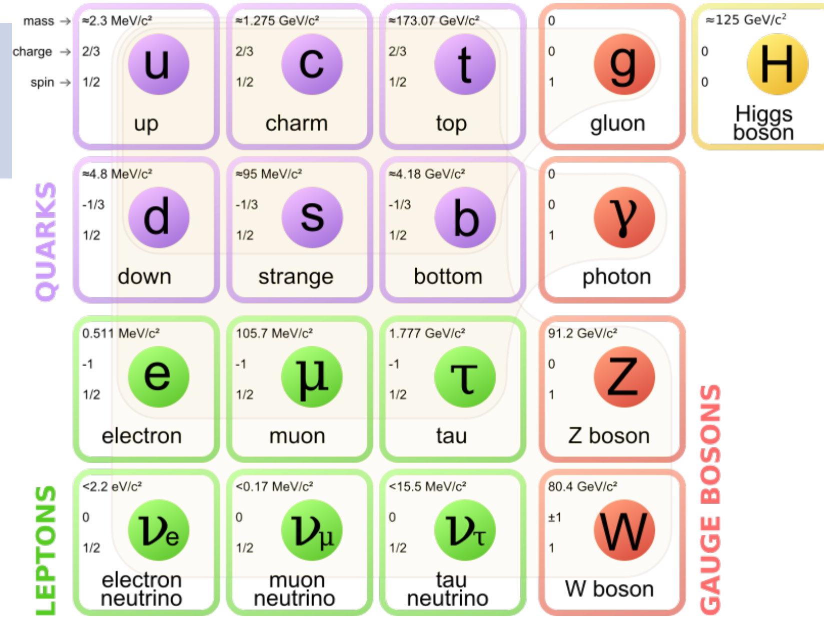
Big questions to address:

- Dark matter
- Neutrino mass
- Matter anti-matter asymmetry in the Universe
- Confinement mechanism
- … …



Standard model of particle physics

intensity frontier could play important roles



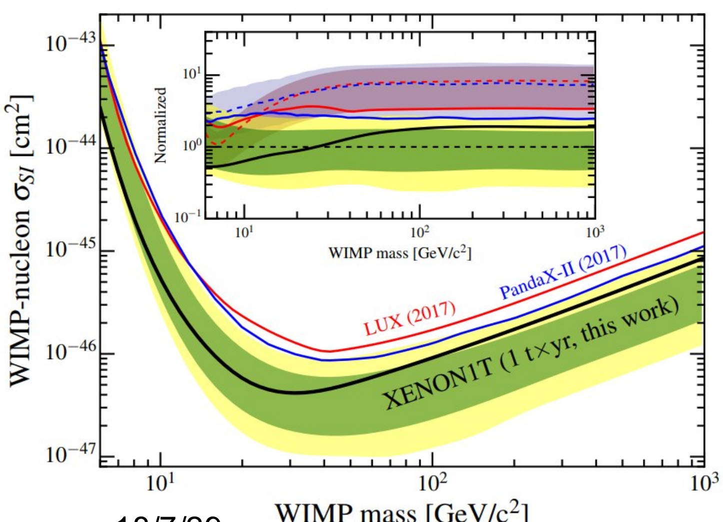
Opinion

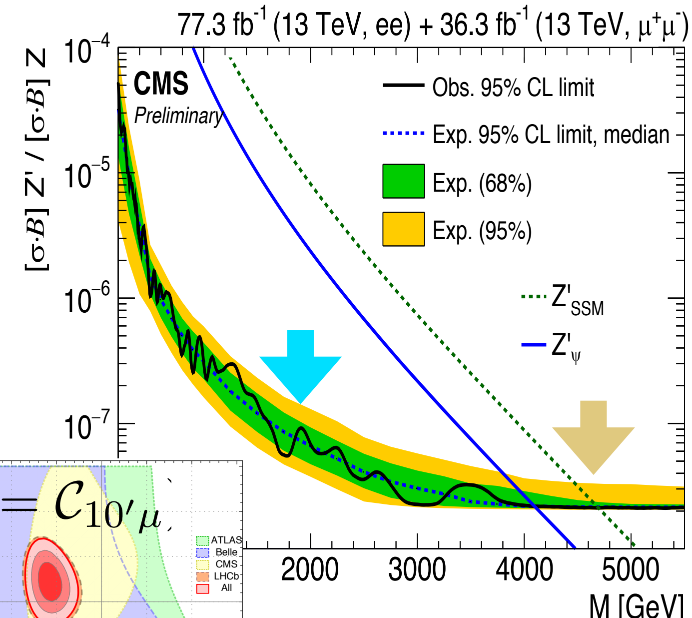
The New York Times

GRAY MATTER

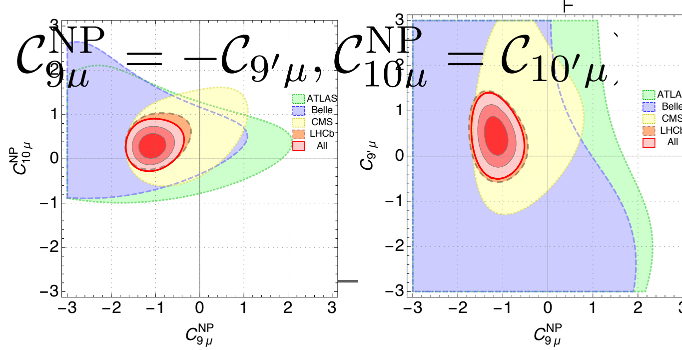
A Crisis at the Edge of Physics

By Adam Frank and Marcelo Gleiser





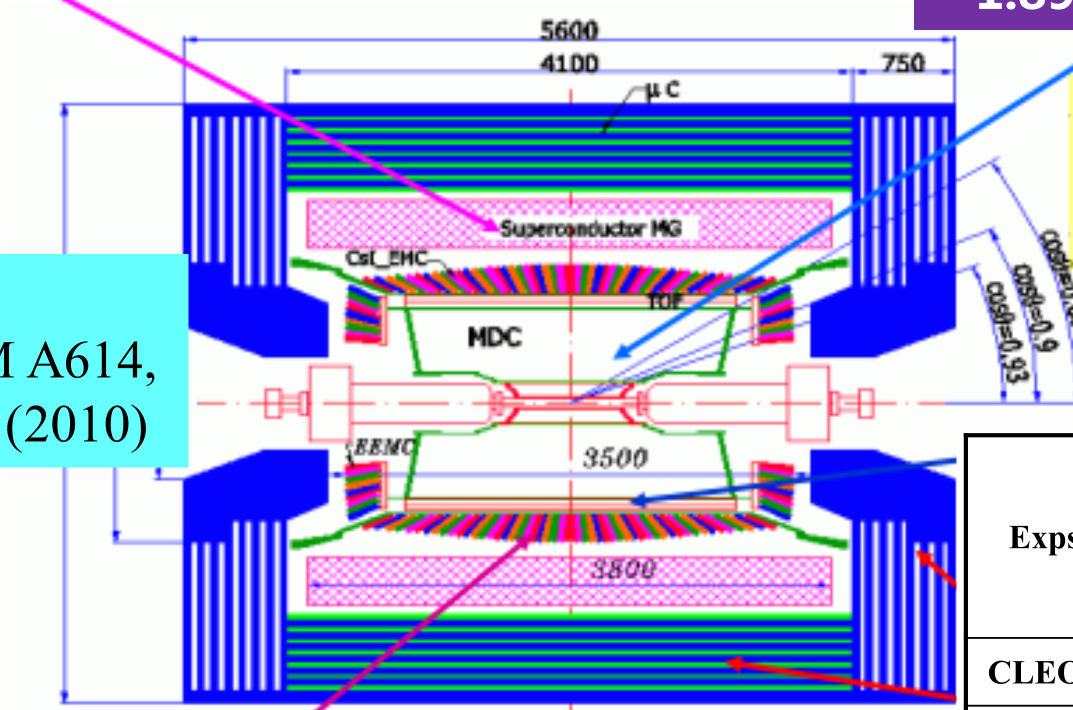
$$\mathcal{C}_{9\mu}^{NP} = -\mathcal{C}_{9'\mu}, \mathcal{C}_{10\mu}^{NP} = \mathcal{C}_{10'\mu}$$



BESIII@BEPCII

Magnet: 1 T Super conducting

peak lumi of 1x10^{33} cm^{-2}s^{-1} at 1.89GeV reached in April 2016



~ 1.3B +4.7B J/ψ ~ 100×BESII
~ 0.5 B $\psi(3686)$ ~ 24×CLEO-c
~ 2.9/fb $\psi(3770)$ ~ 3.5×CLEO-c

Data sets for results in this talk

Ref:
NIM A614, 345 (2010)

Exps.	MDC Spatial resolution	MDC dE/dx resolution	EMC Energy resolution
CLEO-c	110 μm	5%	2.2-2.4 %
BaBar	125 μm	7%	2.67 %
Belle	130 μm	5.6%	2.2 %
BESIII	115 μm	<5% (Bhabha)	2.4%

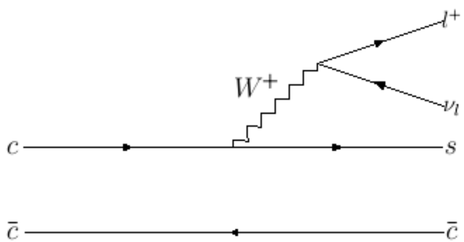
high lumi, large datasets, hermetic detector with good performance and clean environment at BESIII are helpful for probing BSM physics

competitive in channels with low energy electron/photons, neutrons, pi0's

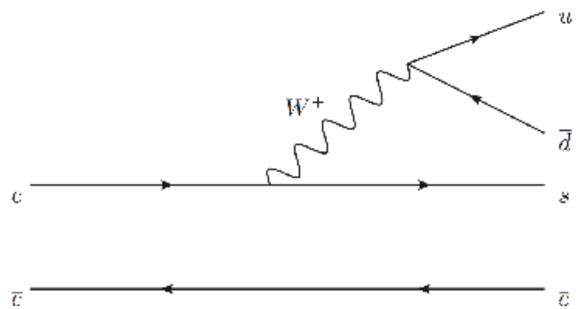
Selected topics from BESIII

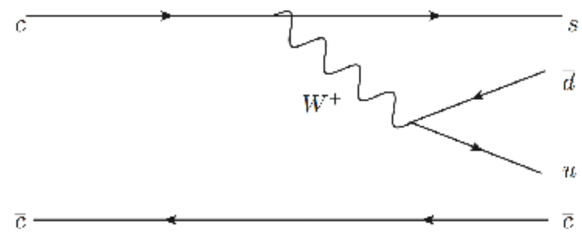
- **the processes that are allowed in the SM (but rare)**
  - Charmonia weak decays
  - Charm meson radiative decays
- processes that are not allowed in the SM at tree level
  - FCNC processes
- processes that are not allowed/existent in the SM
  - Charged lepton flavor violation(CLFV) processes
  - Baryon number violation(BNV) processes
  - C-violation EM processes and C and CP violation decays
  - Exotic resonance search: light Higgs/Dark photon etc
  - Invisible decays

J/ψ weak decays



$J/\psi \to D_s^{(*)-} e^+ \nu_e$

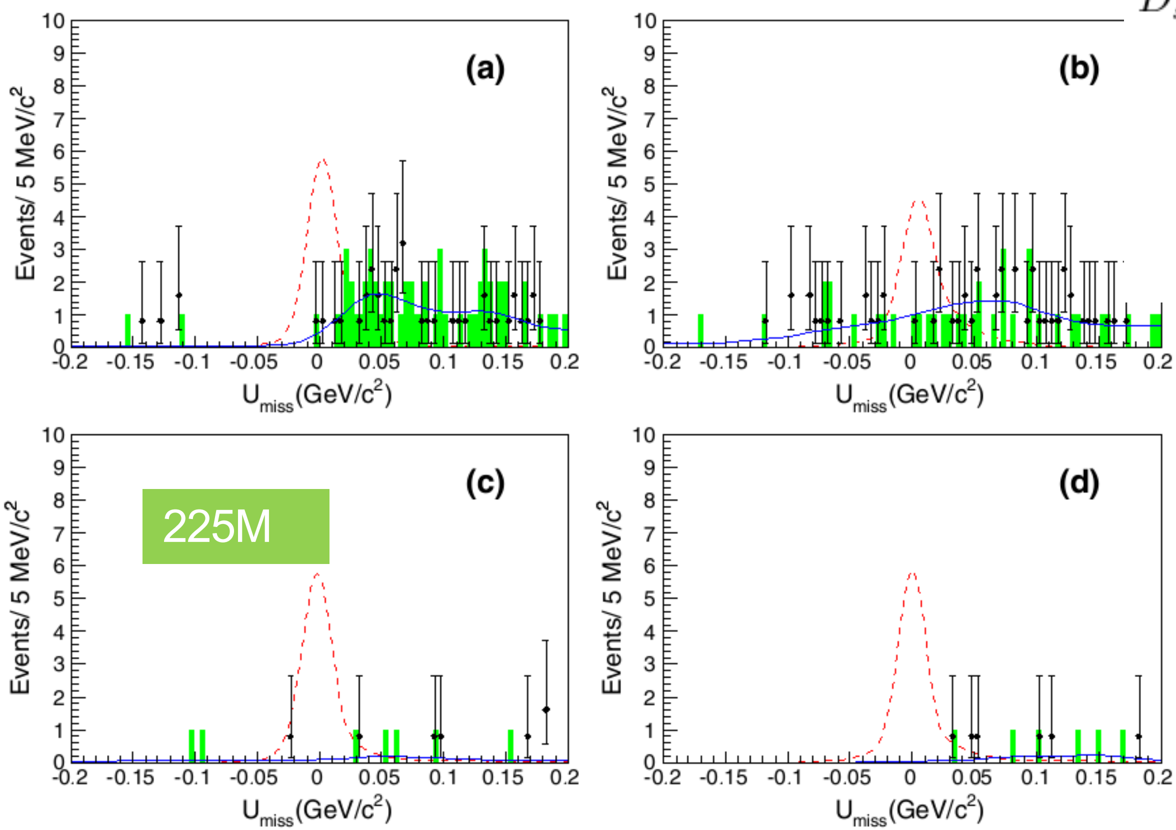




$J/\psi \to D_s^- \rho^+$ and $J/\psi \to \bar{D}^0 \bar{K}^{*0}$

- Hadronic, electromagnetic, and radiative decays of the J/ψ have been widely studied, weak decays seldom searched before, especially for purely hadronic processes.
- Kinematically, the J/ψ cannot decay to a pair of charmed D mesons, but can decay to a single D meson.
- The weak decay of charmonium are rare decays. Searches for weak decays of charmonium to single D or D_s mesons provide tests of standard model (SM) theory and serve as a probe of new physics.

J/ψ weak decays: semileptonic



D_s^- mesons are reconstructed by:

- $D_s^- \to K^+K^-\pi^-$
- $D_s^- \to K^+K^-\pi^-\pi^0$ & $\pi^0 \to \gamma\gamma$
- $D_s^- \to K_s^0 K^-$ & $K_s^0 \to \pi^+\pi^-$
- $D_s^- \to K_s^0 K^-\pi^+\pi^-$ & $K_s^0 \to \pi^+\pi^-$

$$D_s^{*-} \to D_s^-\gamma$$

$$\mathcal{B}(J/\psi \to D_s^- e^+\nu_e + \text{c.c.}) < 1.3 \times 10^{-6}$$

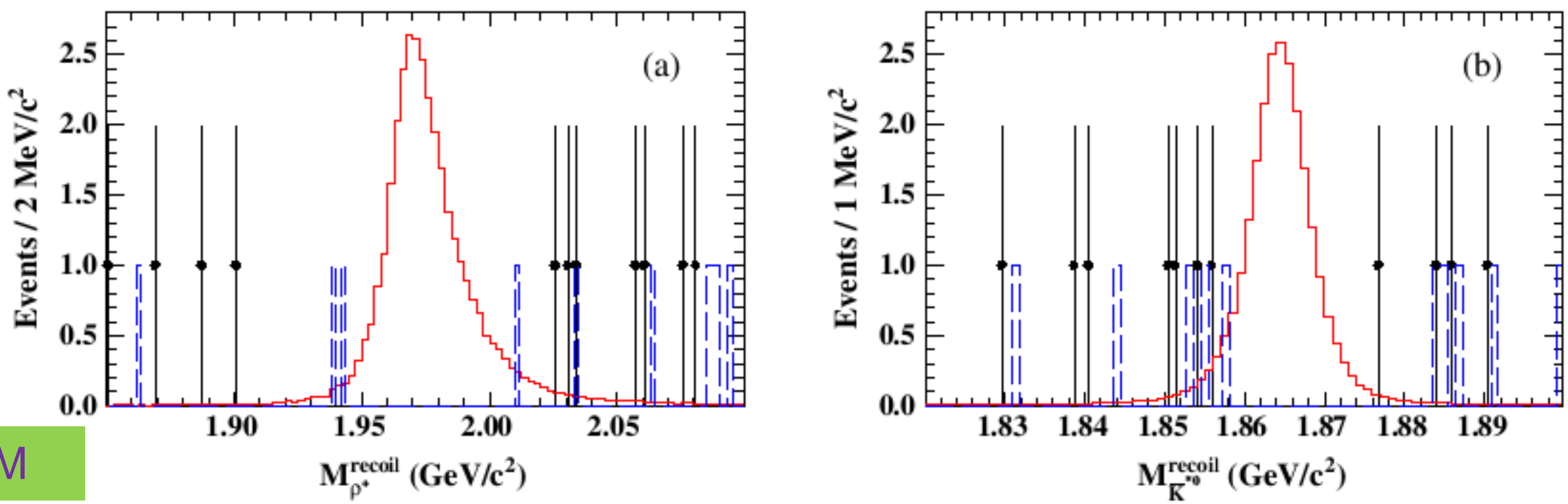
$$\mathcal{B}(J/\psi \to D_s^{*-} e^+\nu_e + \text{c.c.}) < 1.8 \times 10^{-6}$$

PHYSICAL REVIEW D90,112014 (2014)

J/ψ weak decays: hadronic

- $J/\psi \to D_s^- \rho^+$
- $\rho^- \to \pi^+ \pi^0$
- $D_s^+ \to \phi e^- \overline{\nu}_e$
- $\phi \to K^+ K^-$

- $J/\psi \to \overline{D}^0 \overline{K}^{*0}$
- $\overline{K}^{*0} \to K^- \pi^+$
- $\overline{D}^0 \to K^+ e^- \overline{\nu}_e$



225M

$$\mathcal{B}(J/\psi \to D_s^- \rho^+) < 1.3 \times 10^{-5}$$

$$\mathcal{B}(J/\psi \to \bar{D}^0 \bar{K}^{*0} + \text{c.c.}) < 2.5 \times 10^{-6}$$

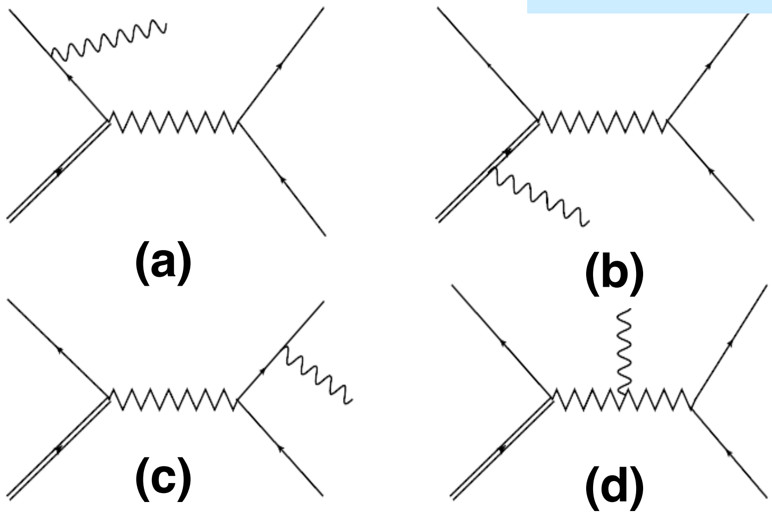
Searches with other states, Dpi, Deta Drho etc are in progress

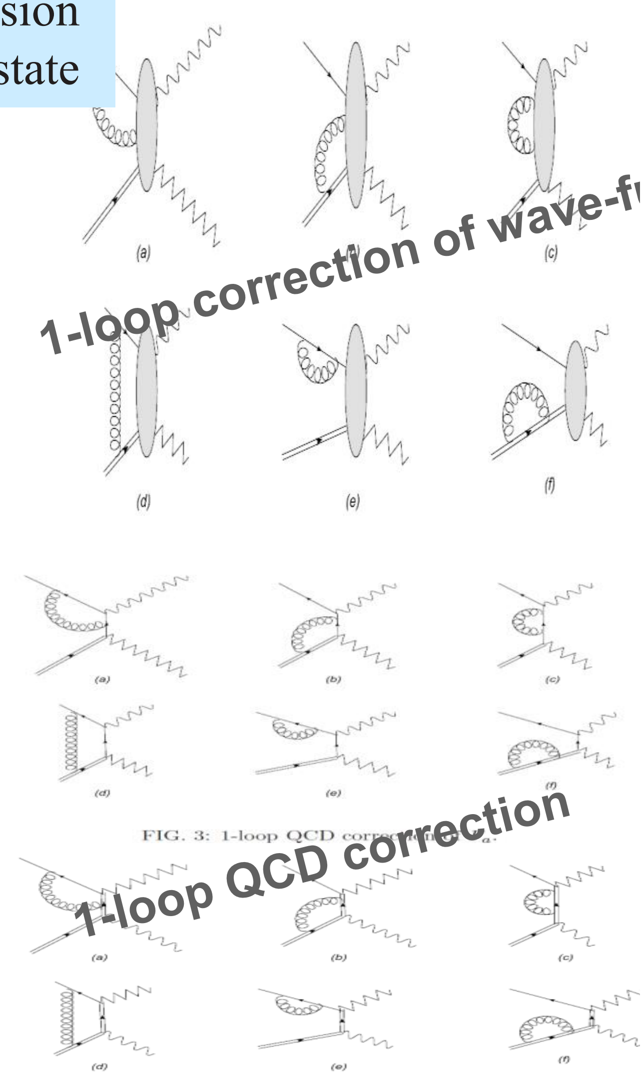
PHYSICAL REVIEW D89,071101(R) (2014)

radiative decay $D^+ \to \gamma e^+\nu_e$

- **Tree level**

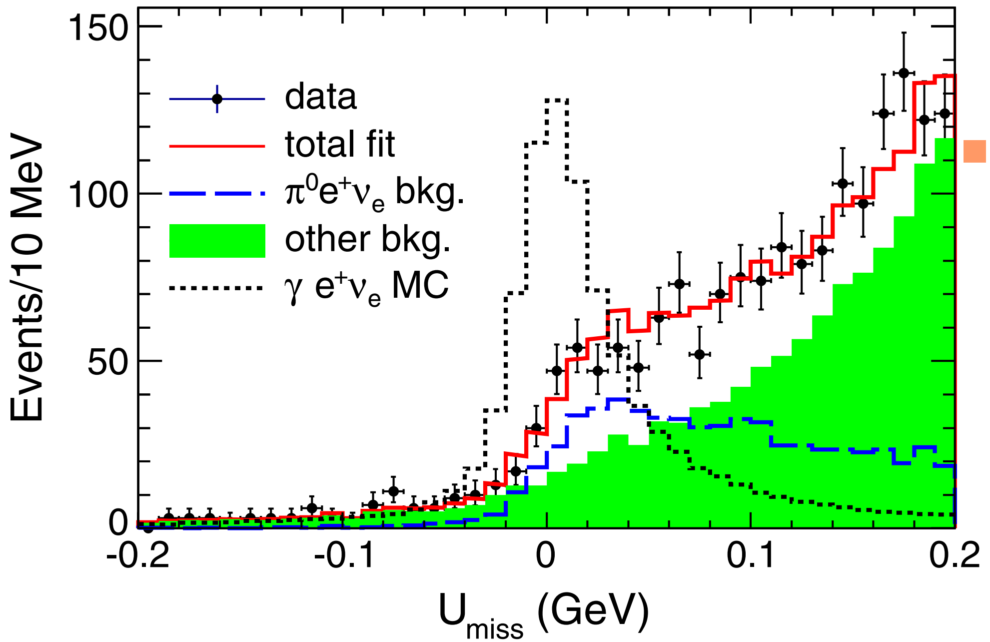
No helicity suppression
No hadron in final state





- **Figs. (a) and (b) are Structure-Dependent (SD) radiative decays,**
- **fig. (c) is the Internal Bremsstrahlung (IB) radiative decay.**
- **(d) Suppressed by a factor of $1/M_w^2$, thus can be neglected.**

$D^+ \to \gamma e^+ \nu_e$ search at BESIII



- Double Tag analysis with $2.9 fb^{-1}$ @3.773GeV
- pio e v background normalization with dedicate DT analysis

$$N_{\pi^0}^{\mathrm{exp}} = \frac{N_{\mathrm{DT}}^{\pi^0}}{\sum_i \frac{N_{\mathrm{ST}}^i}{\varepsilon_{\mathrm{ST}}^i} \varepsilon_{\mathrm{DT},\pi^0}^i} \sum_i \frac{N_{\mathrm{ST}}^i}{\varepsilon_{\mathrm{ST}}^i} \varepsilon_{\mathrm{DT},\pi^0}^{i,\gamma},$$

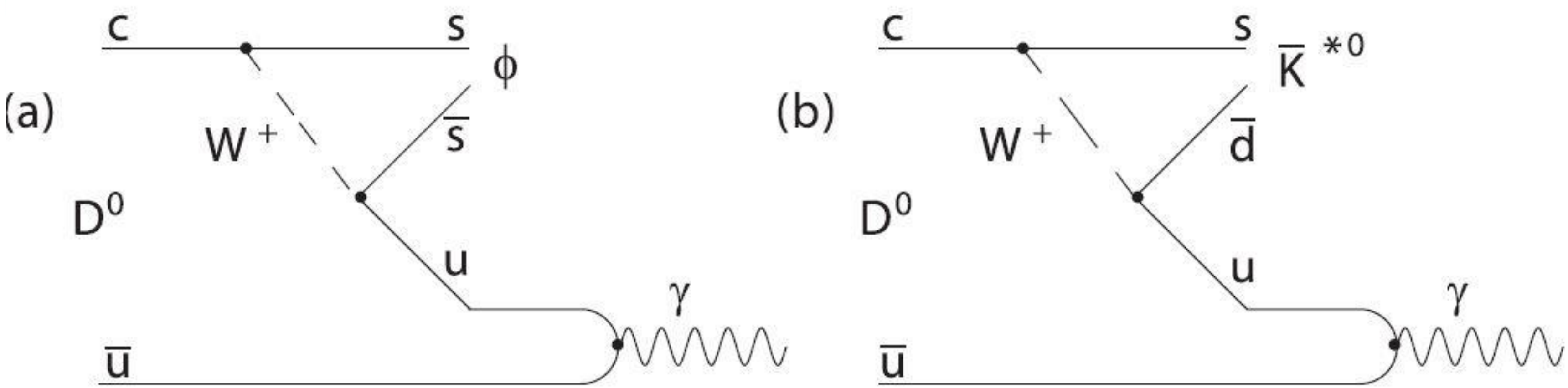
$$\mathcal{B}(D^+ \to \gamma e^+ \nu_e) < 3.0 \times 10^{-5}.$$

With E_γ>10MeV

PHYSICAL REVIEW D 95, 071102(R) (2017)

Source	Relative uncertainty (%)
Signal MC model	3.5
e^+ tracking	0.5
e^+ PID	0.5
γ reconstruction	1.0
Lateral moment	4.4
$\pi^0 e^+ \nu_e$ backgrounds	2.7[a]

Search for $D^0 \to \gamma \bar{K}^{*0}(\phi)$



- Belle Collaboration (2004)
  - $B(D^0 \to \phi\gamma) = \left[2.60^{+0.70}_{-0.61}(stat)^{+0.15}_{-0.17}(syst)\right] \times 10^{-5}$
- BABAR Collaboration (2008)
  - $B(D^0 \to \phi\gamma) = (2.78 \pm 0.30 \pm 0.27) \times 10^{-5}$
  - $B(D^0 \to \bar{K}^{*0}\gamma) = (3.28 \pm 0.20 \pm 0.27) \times 10^{-4}$
- Belle Collaboration (2017)
  - $B(D^0 \to \phi\gamma) = (2.76 \pm 0.19 \pm 0.10) \times 10^{-5}$
  - $B(D^0 \to \bar{K}^{*0}\gamma) = (4.66 \pm 0.21 \pm 0.21) \times 10^{-4}$

- BESIII work in progress
- With present data set, gamma K* could be within reach
- Difficult for phi, due to phi pi0 and phi KL backgrounds

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  - Exotic resonance search: light Higgs/Dark photon etc
  - Invisible decays

FCNC is suppressed in SM

PHYSICAL REVIEW D VOLUME 2, NUMBER 7 1 OCTOBER 1970

Weak Interactions with Lepton-Hadron Symmetry*

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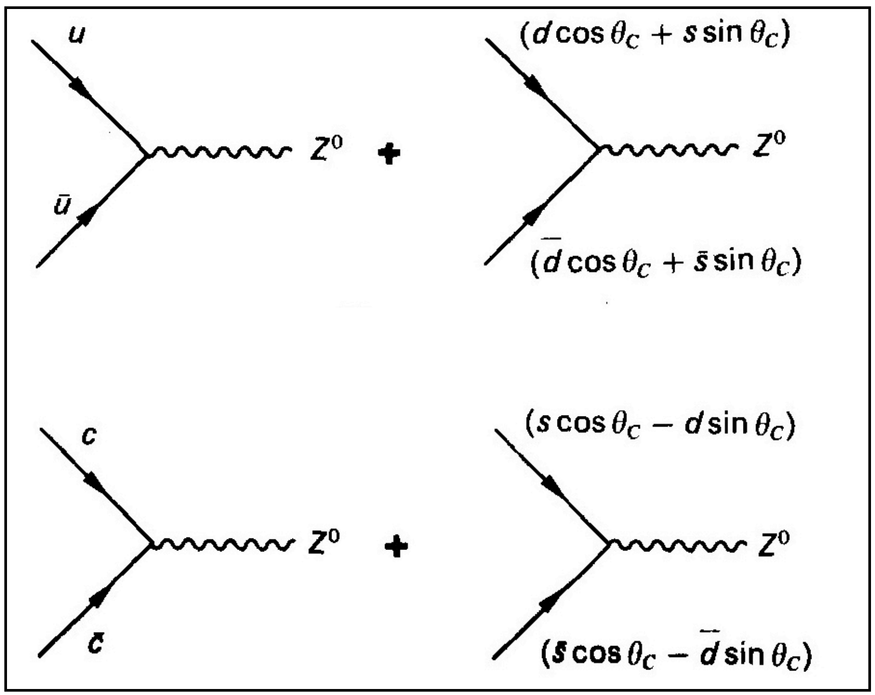
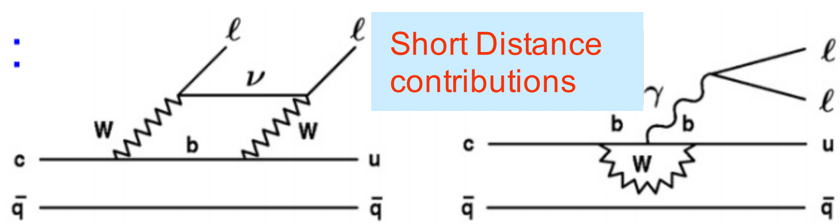
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02139

(Received 5 March 1970)

BESIII can probe c→ ull, esp c→ uee

Stronger diagram cancellation than down-types

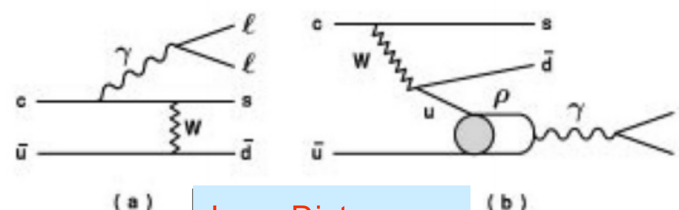




Short Distance contributions

$$\mathcal{L}_{eff}^{SD} = \frac{G_F}{\sqrt{2}} V_{cb}^{*} V_{ub} \sum_{i=7,9,10} C_i Q_i,$$

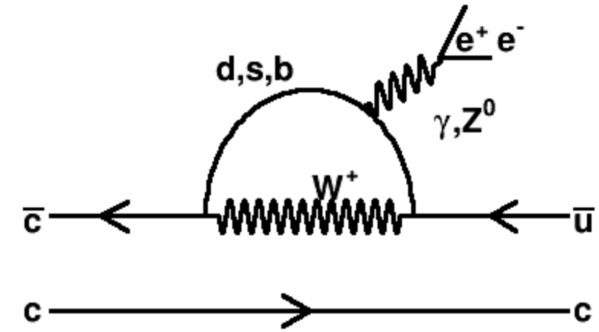
Sensitive to new physics



Long Distance contributions

D → hee

Search for the rare decays J/ψ→ $D^0e^+e^- + c.c.$ and ψ(3686)→ $D^0e^+e^- + c.c.$



dataset: 1310M J/ψ and 448M $\psi(3686)$

With D decay modes:

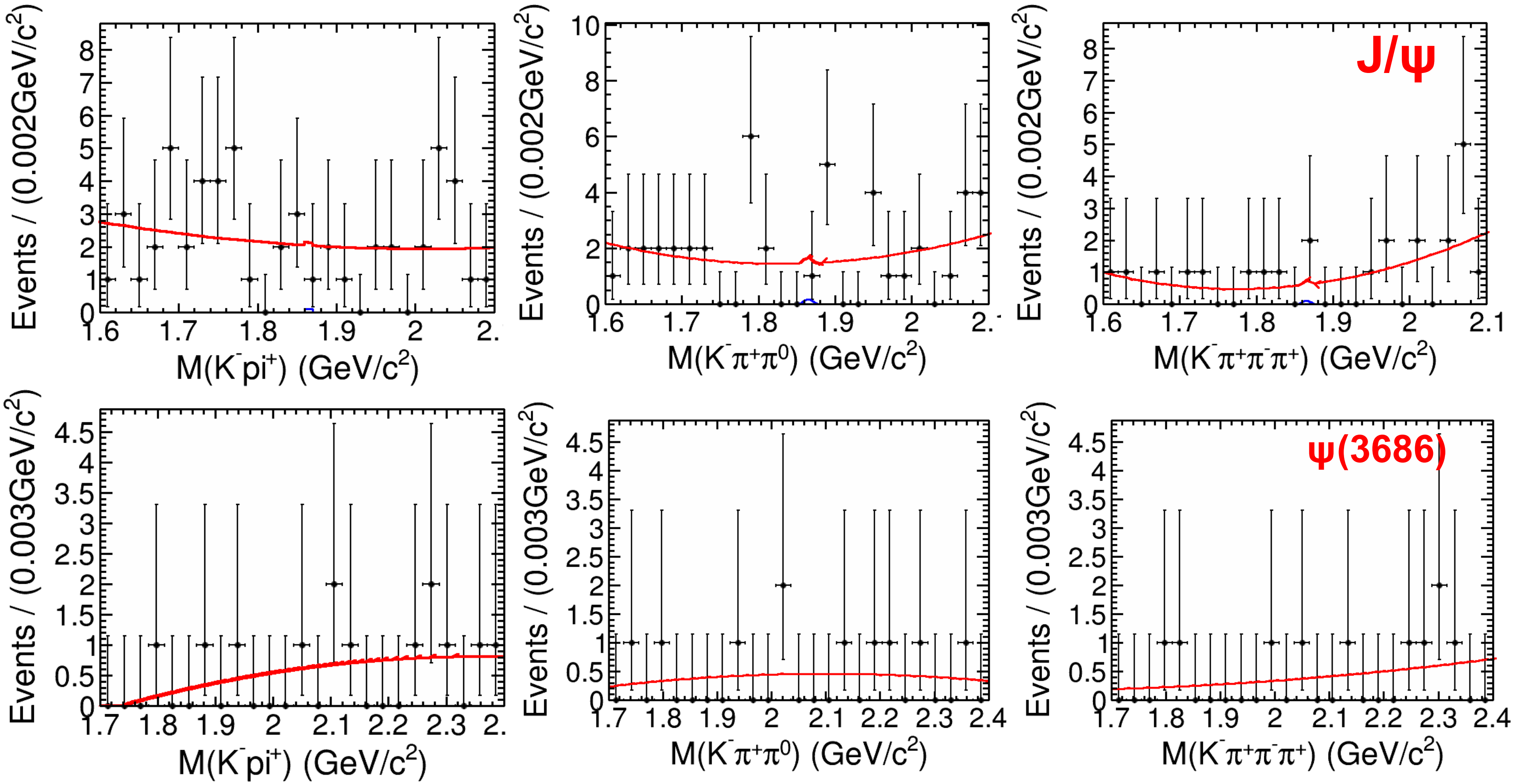
$$D^0 \to K^-\pi^+$$

$$D^0 \to K^-\pi^+\pi^0$$

$$D^0 \to K^-\pi^+\pi^+\pi^-$$

Published at Phys. Rev. D96,111101(2017) (RC)

Fitting of D^0 mass spectra



Simultaneous fit for three decay channels.

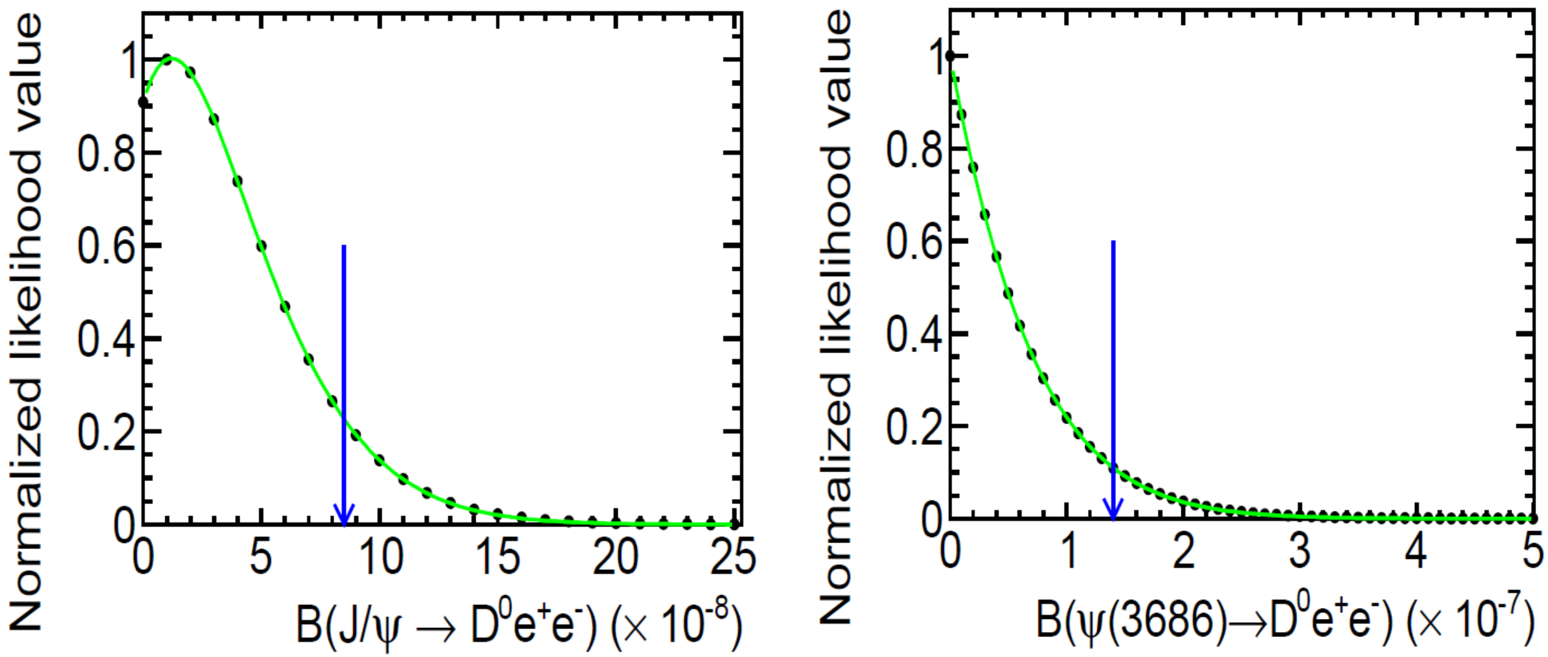
Systematic Uncertainties

	$D^0 \to K^-\pi^+$		$D^0 \to K^-\pi^+\pi^0$		$D^0 \to K^-\pi^+\pi^+\pi^-$	
	J/ψ	$\psi(3686)$	J/ψ	$\psi(3686)$	J/ψ	$\psi(3686)$
Tracking*	4.0	4.0	4.0	4.0	6.0	6.0
PID*	6.0	6.0	6.0	6.0	8.0	8.0
γ detection	...	...	1.2	1.2	...	...
Kinematic fit	1.7	1.6	1.1	1.8	2.2	2.0
Veto γ conversion*	1.7	1.7	1.7	1.7	1.7	1.7
Veto $K_S \to \pi^0\pi^0$	...	...	0.6	...	...	
Veto $K_S \to \pi^+\pi^-$	...	...	...	...	2.1	2.2
Veto $J/\psi \to e^+e^-$	...	0.1	...	...		...
Branching fraction	1.3	1.3	3.6	3.6	2.6	2.6
ψ total number*	0.55	0.62	0.55	0.62	0.55	0.62
Others	1.0	1.0	1.0	1.0	1.0	1.0
Total	7.8	7.8	8.5	8.7	11.0	10.9

The Upper Limits on BRs

combining three D decay channels

Phys. Rev. D96,111101(2017) (RC)

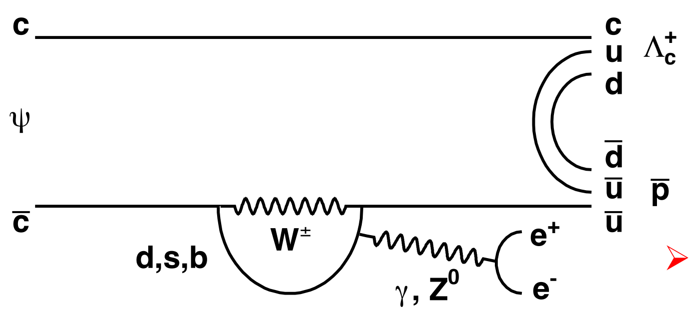


Considering the systematic uncertainty, at 90%C.L.

J/ψ→ $D^0e^+e^- + c.c.$ $< 8.5\times 10^{-8}$ more stringent by 2 orders in magnitude compared to the previous results Phys. Lett. B 639, 418 (2006).

ψ(3686)→ $D^0e^+e^- + c.c.$ $< 1.4 \times 10^{-7}$ set for the first time

Search $\psi(3686) \to \Lambda_c^+ \bar{p} e^+ e^- $ + c.c.



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

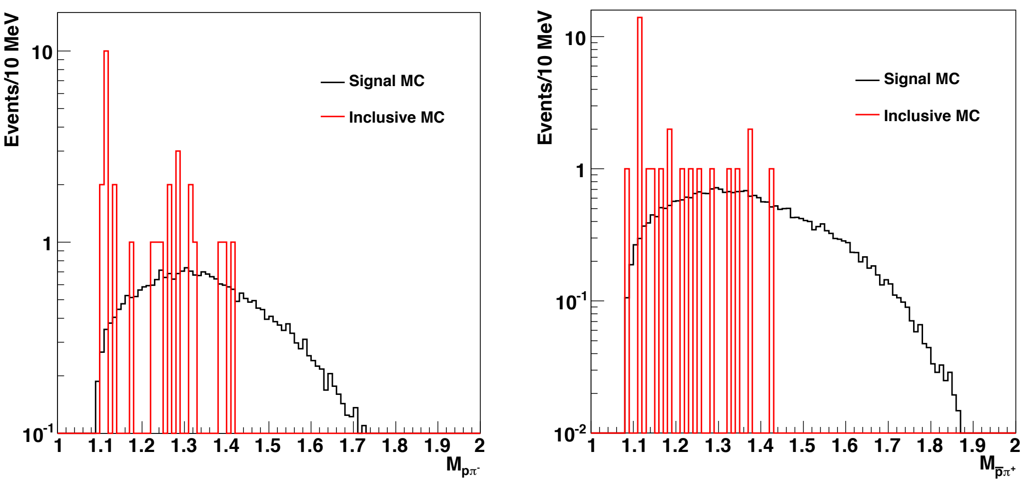
Phys. Rev. D 60, 014011(1999);
Nucl. Phys. 25, 461 (2001);

- 29 simulated events remain after 4C kinematic fit, from inclusive $\psi(3686)$ MC sample of 506 M events.
- Most of the background contain Λ or $\bar{\Lambda}$ particle.

Event selection

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

- At least 3 positive and 3 negative charged tracks are required with zero net charge
- partID, vertexFit, 4CFit
- Define 2.25≤ $m(\Lambda_c^+)$ ≤2.32 GeV as signal region (>99%)

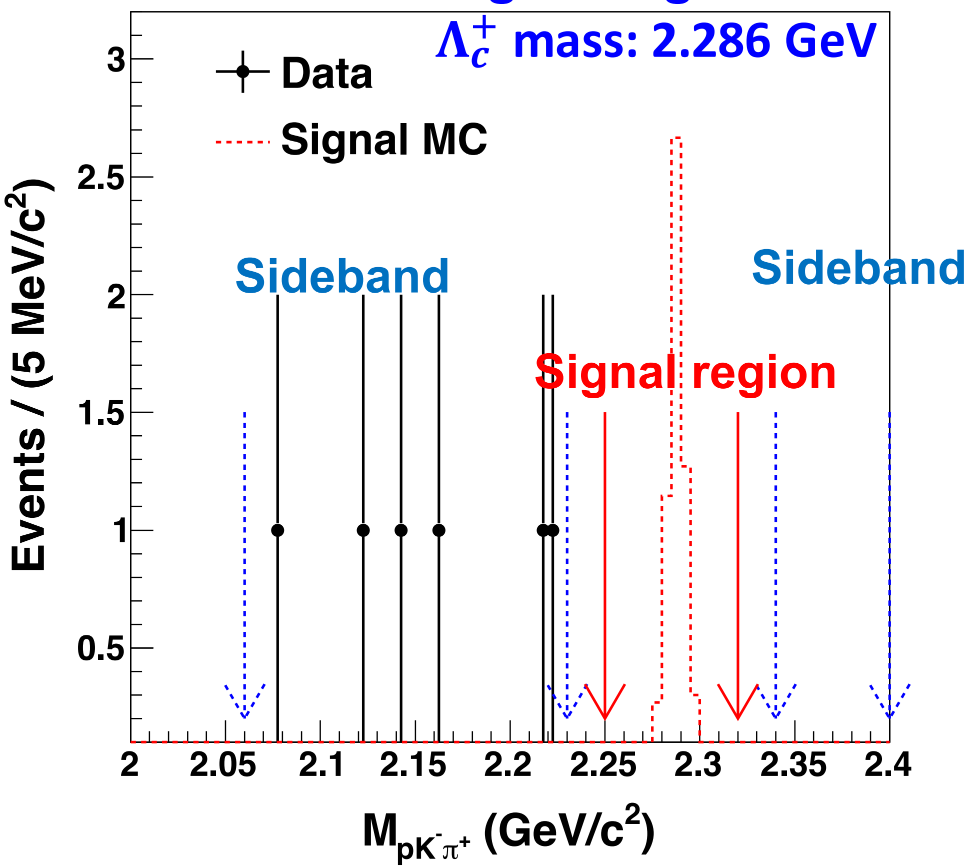


- To further remove the background,
  - $M(\bar{p}\pi^+)$>1.13 GeV and $M(p\pi^-)$> 1.13 GeV

The continuum background in the $\psi(3686)$ data is negligible.

$\psi(3686) \to \Lambda_c^+ \bar{p}\, e^+ e^-$ search result

Signal region:2.25-2.32 GeV.



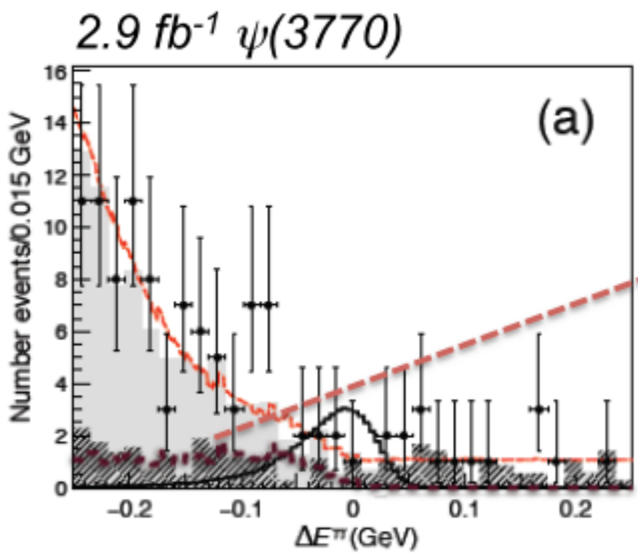
Phys. Rev. D 97, 091102(RC)(2018)

- No signal is found.
- the 90% C.L. upper limit (Nup=47.3) is obtained taking into account the efficiency and systematic uncertainties.

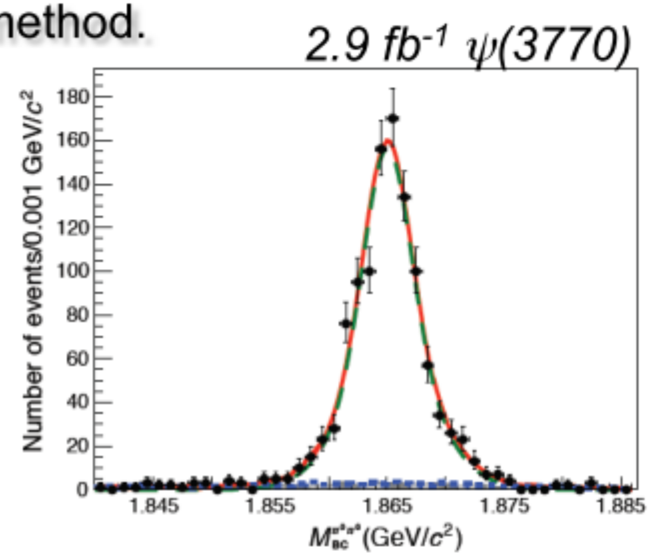
Nucl. Instrum. Methods A 551 (2005) 493– 503.

- The BF upper limit @90% C.L. is determined to be 1.7×10^{-6} with systematic uncertainties taken into account.

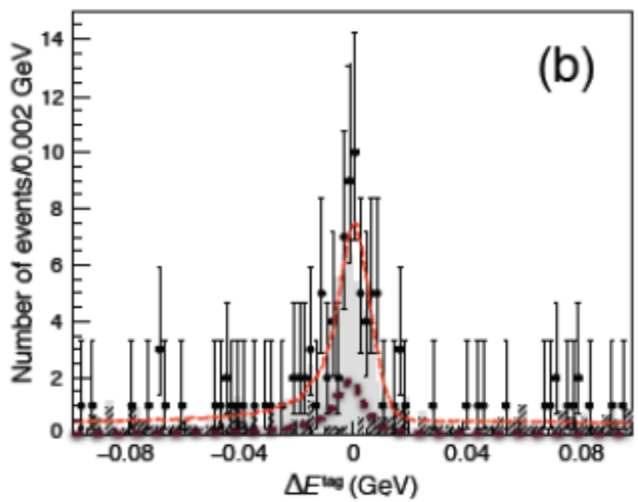
Search for D⁰->γγ: Results



Major background $D^0 \to \pi^0\pi^0$ is determined in data with similar double-tag method.



$B(D^0 \to \pi^0\pi^0) = (8.24 \pm 0.21 \pm 0.30) \times 10^{-4}$



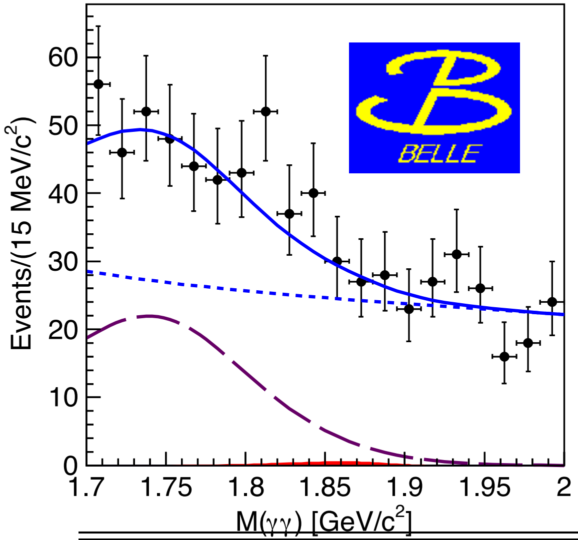
2-D fit to ΔE in both tag side and γγ sides to determine $D^0 \to \gamma\gamma$ yield.

$$B(D^0 \to \gamma\gamma) < 3.8 \times 10^{-6}$$

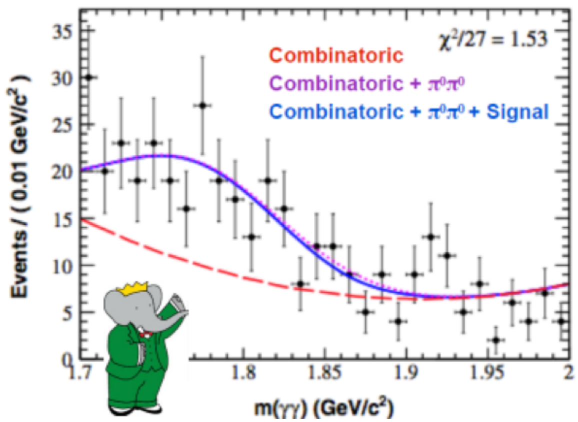
PRD91, 112015 (2015)

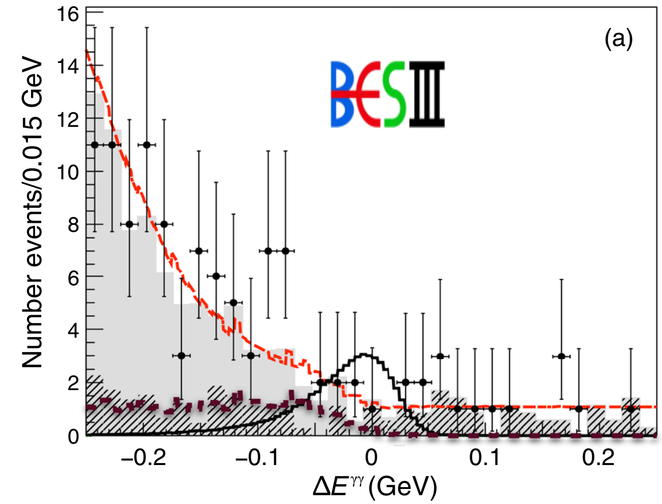
Comparison and prospects

PhysRevD(2016).93.051102



Phys. Rev. D 85 (2012) 091107R





Source	Contribution
Cut variation	$\pm 6.8\%$
PDF shape	$^{+4.0}_{-2.4}$ events
Photon detection	$\pm 4.4\%$
K^0_S reconstruction	$\pm 0.7\%$
π^0 identification	$\pm 4.0\%$
$\mathcal{B}(D^0 \to K^0_S \pi^0)$	$\pm 3.3\%$

Uncertainties independent of fitting procedure

Source	Relative uncertainty (%)
Photon reconstruction	2.0
$M_{\rm BC}^{\gamma\gamma}$ requirement	3.1
ST D^0 yields	1.0
Total	3.8

- BESIII has the least background contamination
- and very good control of systematics
- Could still be competitive with the final DDbar sample
- Detailed projection study is needed to check what is the critical points for DDbar sample size

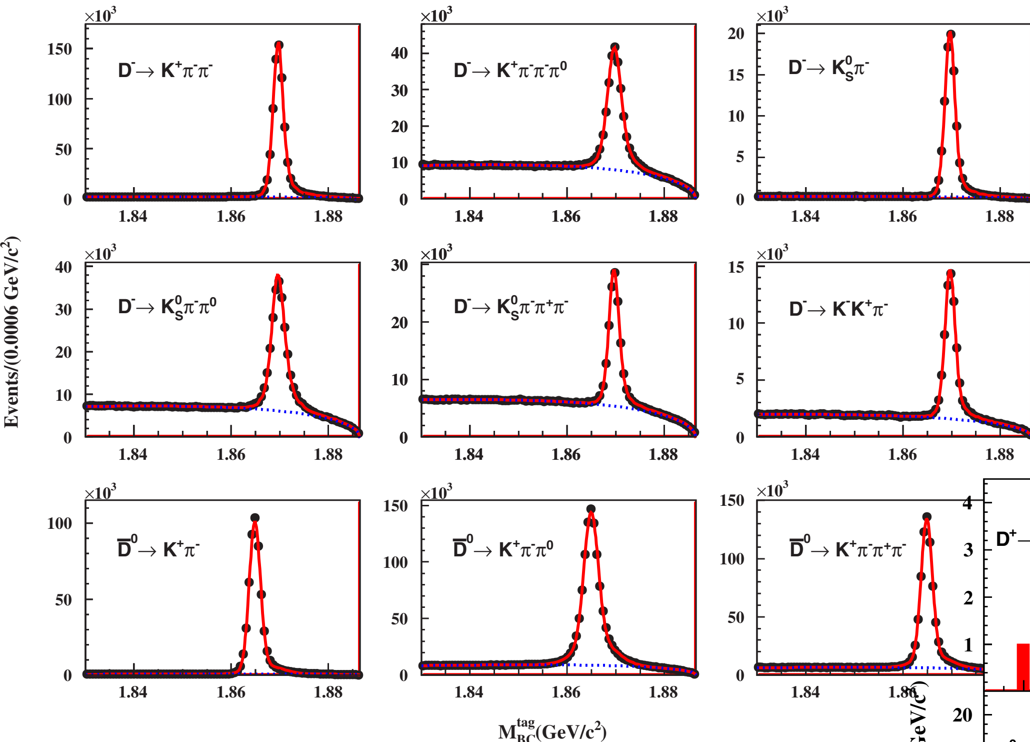
D->h(h')ee: previous results

Decay	Upper limit	Experiment	Year	Ref.
$D^0 \to \pi^0 e^+ e^-$	45.0	CLEO	1996	[14]
$D^0 \to \eta e^+ e^-$	110.0	CLEO	1996	[14]
$D^0 \to \omega e^+ e^-$	180.0	CLEO	1996	[14]
$D^0 \to \overline{K}^0 e^+ e^-$	110.0	CLEO	1996	[14]
$D^0 \to \rho e^+ e^-$	124.0	E791	2001	[15]
$D^0 \to \phi e^+ e^-$	59.0	E791	2001	[15]
$D^0 \to \overline{K}^{*0} e^+ e^-$	47.0	E791	2001	[15]
$D^0 \to \pi^+ \pi^- e^+ e^-$	370.0	E791	2001	[15]
$D^0 \to K^+ K^- e^+ e^-$	315.0	E791	2001	[15]
$D^0 \to K^- \pi^+ e^+ e^-$	385.0	E791	2001	[15]
$D^+ \to \pi^+ e^+ e^-$	1.1	BaBar	2011	[16]
$D^+ \to K^+ e^+ e^-$	1.0	BaBar	2011	[16]
$D^+ \to \pi^+ \pi^0 e^+ e^-$				
$D^+ \to \pi^+ K_S^0 e^+ e^-$				
$D^+ \to K^+ \pi^0 e^+ e^-$				
$D^+ \to K^+ \overline{K}^0 e^+ e^-$				

In unit of 10^{-6}

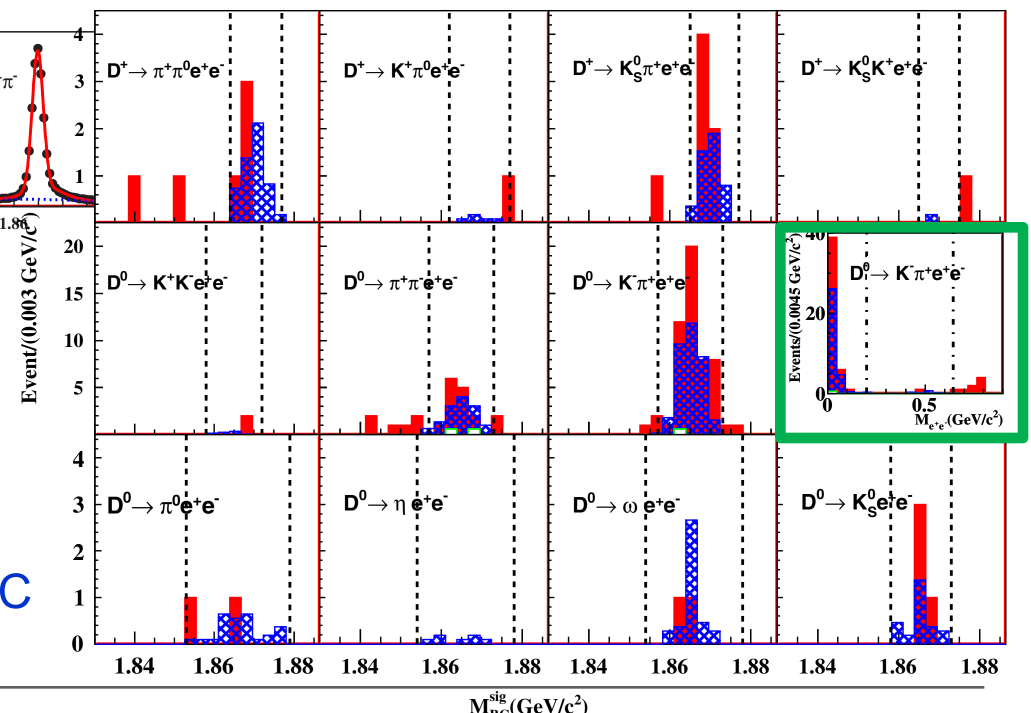
- Previous D^0 limits are in the level of $10^{-5} \sim 10^{-4}$
- D^+ limits are better, but only few three-body decays
- LHCb observed some four-body decays of $D^0 \to hh\mu^+\mu^-$ at 10^{-7} level
- BESIII could probe all of the above e+e- modes

Double tag(DT) analysis



DT: Fully make use of DD pair production at threshold

- Event is very clean, bkg low
- High tagging efficiency
- Many systematic uncertainties can be cancelled
- Could measure absolute BFs



Blind analysis based on Monte Carlo (MC) simulations to validate the analysis strategy,

Data
Inclusive MC
sideband

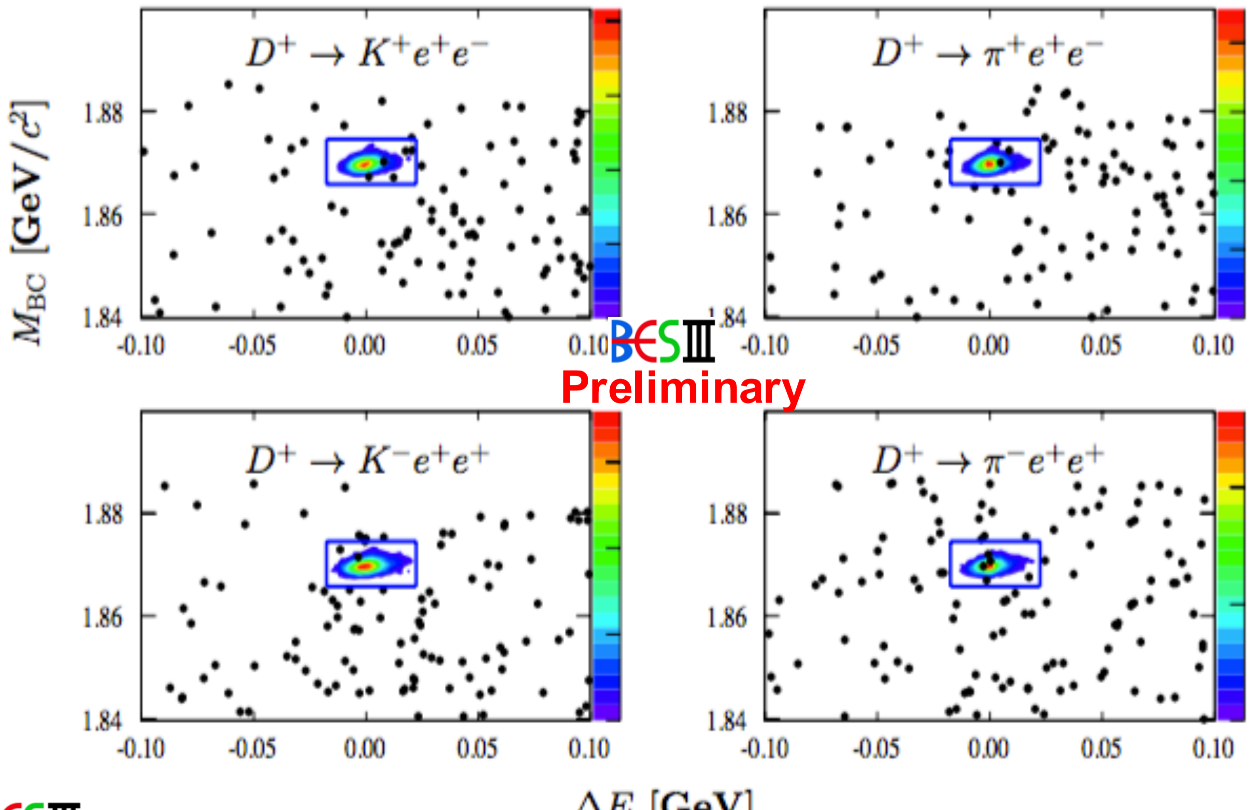
$D \to h(h')ee$: BESIII results

Signal decays	$\mathcal{B}$ ($\times 10^{-5}$)	PDG [9] ($\times 10^{-5}$)
$D^+ \to \pi^+\pi^0 e^+e^-$	<1.4	...
$D^+ \to K^+\pi^0 e^+e^-$	<1.5	...
$D^+ \to K^0_S\pi^+ e^+e^-$	<2.6	...
$D^+ \to K^0_S K^+ e^+e^-$	<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
$D^0 \to \pi^0 e^+e^-$	<0.4	<4.5
$D^0 \to \eta e^+e^-$	<0.3	<11
$D^0 \to \omega e^+e^-$	<0.6	<18
$D^0 \to K^0_S e^+e^-$	<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 $(1.0^{+0.5}_{-0.4})$	...

Phys. Rev. D 97, 072015 (2018)

- With double tag technique at threshold, both D^0 and D^+ FCNC are studied.
- UL for D^+ 4-track events are provided for 1st time
- other FCNC upper limits are greatly improved
- divide the M(ee) distribution into 3 regions for Kpiee to help separate LD effect

$D^+ \to h^+e^+e^-$ and $D^+ \to h^-e^+e^+$



BESIII Preliminary

	N^{data}_{inside}	$N^{data}_{outside}$	f_{scale}	ϵ [%]	Δ_{sys} [%]	s_{90}	$\mathcal{B}[\times 10^{-6}]$
$D^+ \to K^+e^+e^-$	5	69	0.08 ± 0.01	22.53	5.4	19.4	< 1.2
$D^+ \to K^-e^+e^+$	3	55	0.08 ± 0.01	24.08	6.1	10.2	< 0.6
$D^+ \to \pi^+e^+e^-$	3	65	0.09 ± 0.02	25.72	5.9	4.2	< 0.3
$D^+ \to \pi^-e^+e^+$	5	68	0.06 ± 0.02	28.08	6.8	20.5	< 1.2

Search for $D^0 \to \pi^0 \nu\bar{\nu}$:

- EM dynamics is absent
- LD contributions are much suppressed
- Much clean to probe FCNC transitions in charm
- Could be complementary to results from B mesons
  - Belle B → $h^{(*)}$ νν: Phys. Rev. Lett. 99, 221802 (2007).
  - BaBar B^0 →γνν: Phys. Rev. Lett. 93, 091802 (2004).

Decay mode	Experimental limit	$Br_{S.D.}$	$Br_{L.D.}$
$D^+ \to X_u^+ e^+ e^-$		2×10^{-8}	
$D^+ \to \pi^+ e^+ e^-$	$<4.5\times10^{-5}$		2×10^{-6}
$D^+ \to \pi^+ \mu^+ \mu^-$	$<1.5\times10^{-5}$		1.9×10^{-6}
$D^+ \to \rho^+ e^+ e^-$	$<1.0\times10^{-4}$		4.5×10^{-6}
$D^0 \to X_u^0 e^+ e^-$		0.8×10^{-8}	
$D^0 \to \pi^0 e^+ e^-$	$<6.6\times10^{-5}$		0.8×10^{-6}
$D^0 \to \rho^0 e^+ e^-$	$<5.8\times10^{-4}$		1.8×10^{-6}
$D^0 \to \rho^0 \mu^+ \mu^-$	$<2.3\times10^{-4}$		1.8×10^{-6}
$D^+ \to X_u^+ \nu\bar{\nu}$		1.2×10^{-15}	
$D^+ \to \pi^+ \nu\bar{\nu}$			5×10^{-16}
$D^0 \to \bar{K}^0 \nu\bar{\nu}$			2.4×10^{-16}
$D_s \to \pi^+ \nu\bar{\nu}$			8×10^{-15}

Pure neutral final state with missing momenta.
Unique for BESIII,
Work ongoing

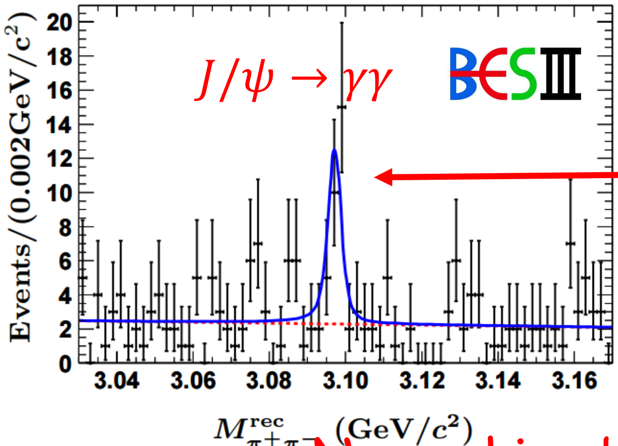
Phys. Rev. D 66 014009

Selected topics from BESIII

- the processes that are allowed in the SM (but rare)
  - Charmonia weak decays
  - Charm meson radiative decays
- processes that are not allowed in the SM at tree level
  - FCNC processes
- **processes that are not allowed/existent in the SM**
  - Charged lepton flavor violation(CLFV) processes
  - Baryon number violation(BNV) processes
  - C-violation EM processes and C and CP violation decays
  - Exotic resonance search: light Higgs/Dark photon etc
  - Invisible decays

Search for C-violation EM processes

PRD **90**,092002(2014)

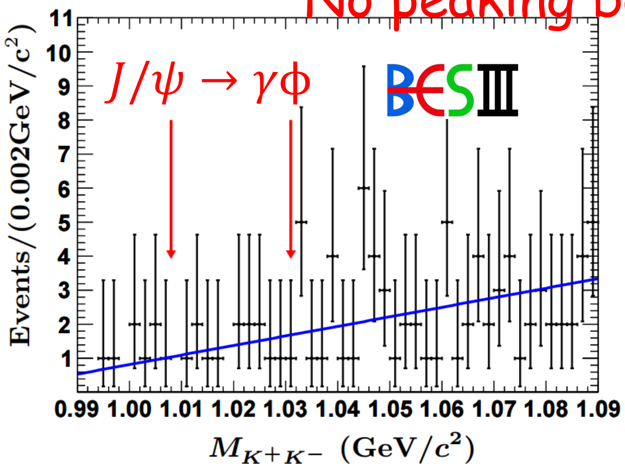


Peaking background

Background channel	Expected counts (N^{bkg})
$J/\psi \to \gamma\pi^0, \pi^0 \to 2\gamma$	18.5 ± 1.9
$J/\psi \to \gamma\eta, \eta \to 2\gamma$	24.6 ± 1.6
$J/\psi \to \gamma\eta_c, \eta_c \to 2\gamma$	1.3 ± 0.3
$J/\psi \to 3\gamma$	0.9 ± 0.3
Total	45.3 ± 2.5

$$\mathcal{B}(J/\psi \to f) < \frac{N^{up}_{sig}}{N^{tot}_{\psi(3686)} \times \epsilon \times \mathcal{B}_i \times (1 - \Delta_{sys})}$$

No peaking background



B($J/\psi \to \gamma\gamma$) < 5×10^{-6} CLEO: PRL 101, 101801 (2008)

B($J/\psi \to \gamma\gamma$) < 2.7×10^{-7}

- Improve a magnitude for $J/\psi \to \gamma\gamma$

B($J/\psi \to \gamma\phi$) < 1.4×10^{-6}

- Unique report for $J/\psi \to \gamma\phi$

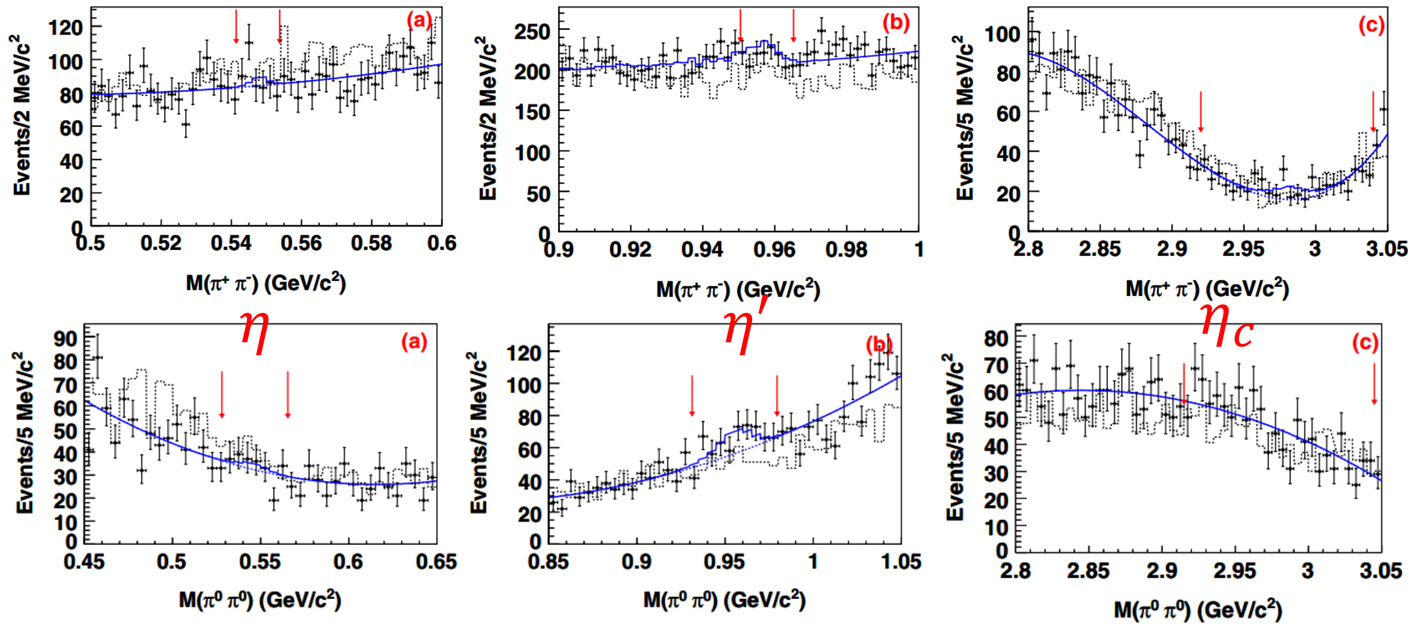
CP and P violating pseudoscalar decays

- SM predicted BR: ~10^{-27} (weak interaction only)
- BR can be enhanced to 10^{-17}~10^{-15} by introducing a CP violation term in QCD lagrangian or allowing a CP violation in the extended Higgs sector .
  - 225M J/ψ data: $J/\psi \to \gamma P, P \to \pi\pi$

PRD **84**,032006(2011)

$\pi^+\pi^-$

$\pi^0\pi^0$



Process	N_{sig}^{UP}	ε (%)	σ_{sys} (%)	S	$\mathcal{B}^{UP}$
$\eta \to \pi^+\pi^-$	48	54.28	7.3	0.8σ	3.9×10^{-4}
$\eta' \to \pi^+\pi^-$	32	53.81	8.6	0.1σ	5.5×10^{-5}
$\eta_c \to \pi^+\pi^-$	92	25.27	27	1.5σ	1.3×10^{-4}
$\eta \to \pi^0\pi^0$	36	23.75	8.6	0.6σ	6.9×10^{-4}
$\eta' \to \pi^0\pi^0$	110	23.18	8.5	2.6σ	4.5×10^{-4}
$\eta_c \to \pi^0\pi^0$	40	35.70	28	0.1σ	4.2×10^{-5}

(90%CL)

- η' and η_c results are the world best , provide experimental limits for theoretical study.

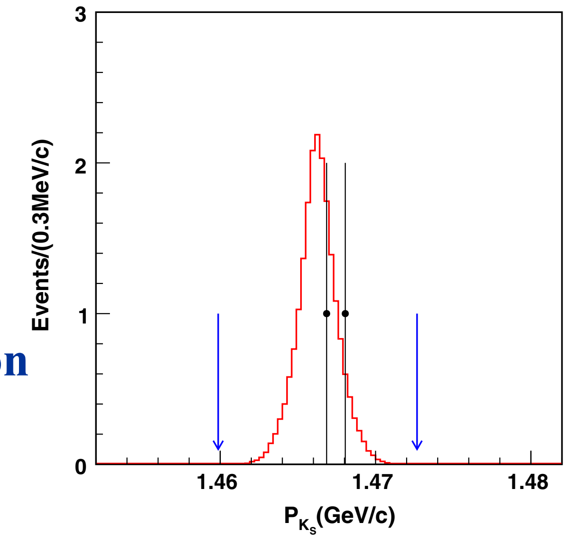
Search for $J/\psi \to K_S K_S$

testing EPR and K^0 oscillation model

Search for $J/\psi \to K_S K_S$

- CP and Bose-Einstein statistics violating process
- EPR: $\sim 10^{-8}$ level
- K^0 oscillation model: 10^{-9}
- Compared MARKIII and BESII, the upper limit is improved by 10^2 and reaches the order of EPR expectation

N_{obs}	2
N_{bkg}	2.4
N^{UL}	4.7
ϵ_{MC} (%)	25.7
$\mathcal{B}(J/\psi \to K_S K_S)$ (95% C.L.)	$< 1.4 \times 10^{-8}$



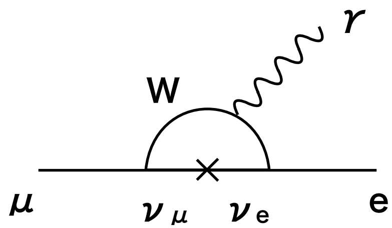
arXiv: 1710.05738
PRD 96, 112001 (2017)

Measurement of $\mathcal{B}(J/\psi \to K_S K_L)$

- $\mathcal{B}(J/\psi \to K_S K_L) = (1.91 \pm 0.01(stat.) \pm 0.05(syst.)) \times 10^{-4}$.
- the precision is improved from 19%(PDG) to 2.6%, while the central value consistent.

Search for Charge flavor lepton violation(cFLV) process

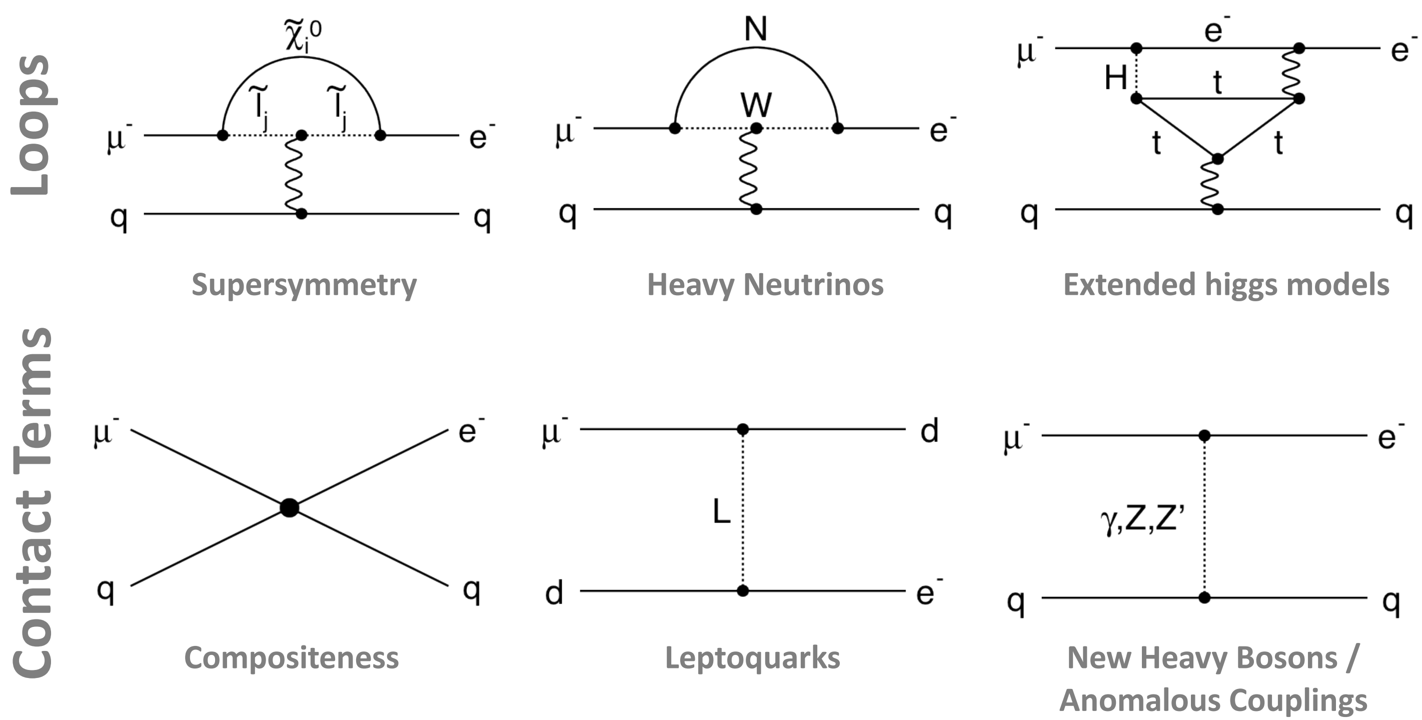
Considering neutrino mixing, extended νSM



$$\mathcal{M} \propto \sum_j U_{ej} U^*_{\mu j} \frac{m_j^2}{M_W^2}$$

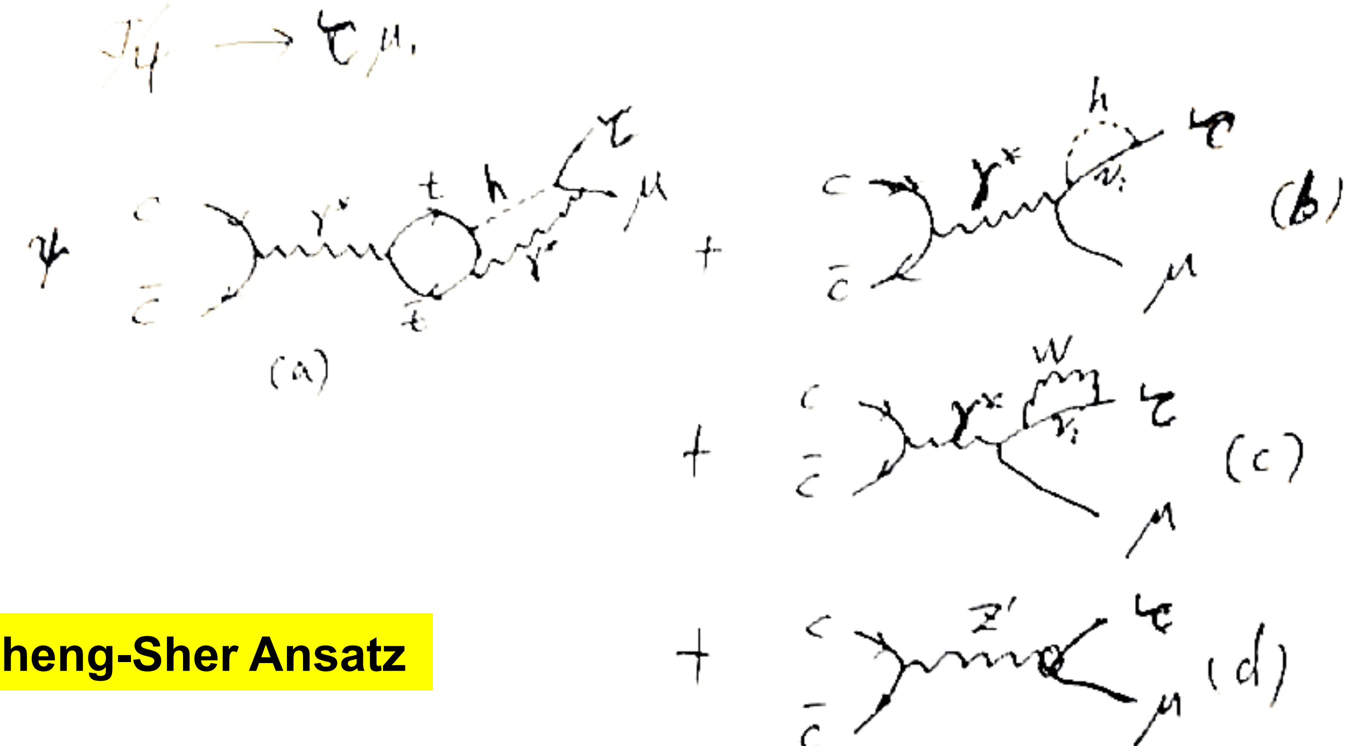
$$\sim \mathcal{O}(10^{-54})$$

Possible CLFV from NP models



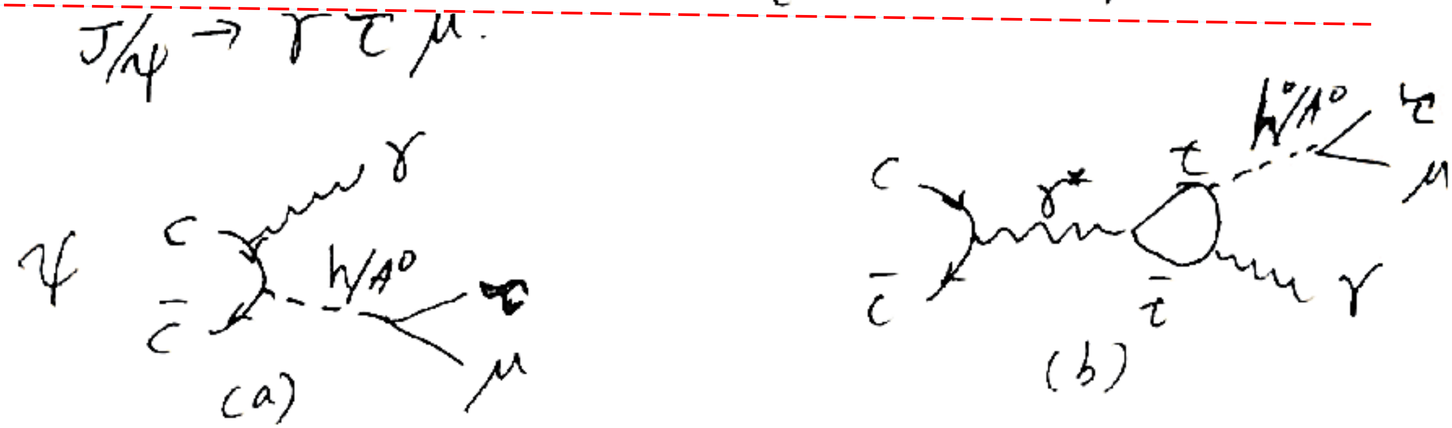
Possible Enhancements in Jpsi decays

$\Psi \to \tau\mu$

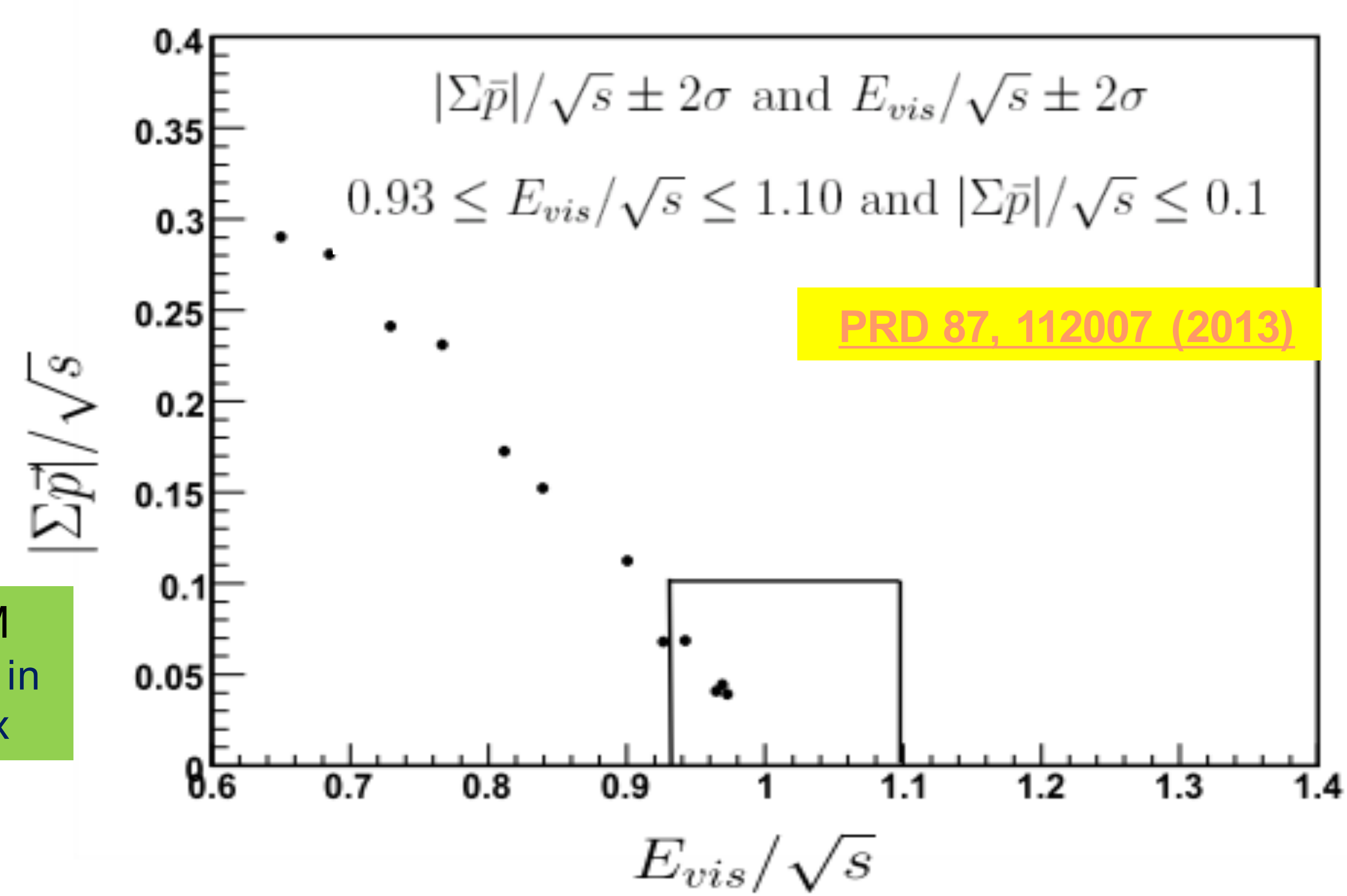


Inspired by Cheng-Sher Ansatz

$\Psi \to \gamma\tau\mu$



J/ψ → eμ: Unblinded Data and Results

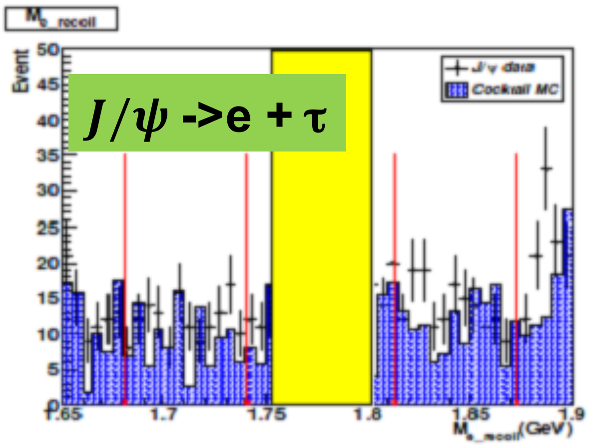


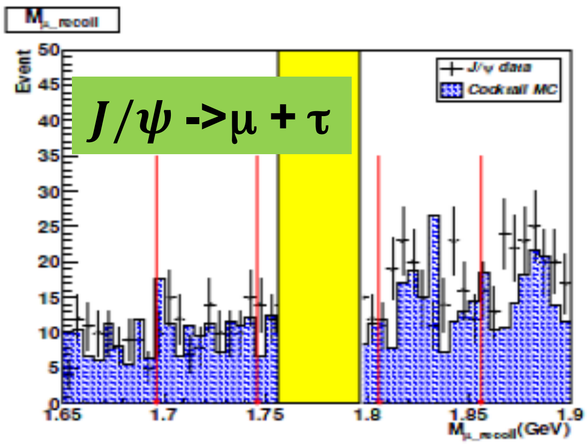
Among 225M J/ψ, 4 events in the signal box

$$\mathcal{B}(J/\psi \to e\mu) < 1.6 \times 10^{-7} \ (90\% \text{ C.L.})$$

cFLV searches in J/ψ: Prospects

$$\mathcal{A}(V \to \ell_1 \bar{\ell}_2) = \bar{u}(p_1, s_1)\left[A_V^{\ell_1\ell_2}\gamma_\mu + B_V^{\ell_1\ell_2}\gamma_\mu\gamma_5 + \frac{C_V^{\ell_1\ell_2}}{m_V}(p_2-p_1)_\mu + \frac{iD_V^{\ell_1\ell_2}}{m_V}(p_2-p_1)_\mu\gamma_5\right] v(p_2, s_2)\, \epsilon^\mu(p)$$





$J/\psi \to e(\mu)\,\tau$
$J/\psi \to e\,\mu$
$J/\psi \to \gamma\, e(\mu)\,\tau$
$\psi(2s) \to \gamma\, e(\mu)\,\tau$

Expected to *improve the UL by* $\sim 10^2$

$\ell_1\ell_2$	$\mu\tau$	$e\tau$	$e\mu$
Current UL	2.0×10^{-6}	8.3×10^{-6}	1.6×10^{-7}
BESIII projected(CC)	3.0×10^{-8}	4.5×10^{-8}	1.0×10^{-8}
BESIII projected(MVA/ML)	1.5×10^{-8}	2.5×10^{-8}	6.0×10^{-9}

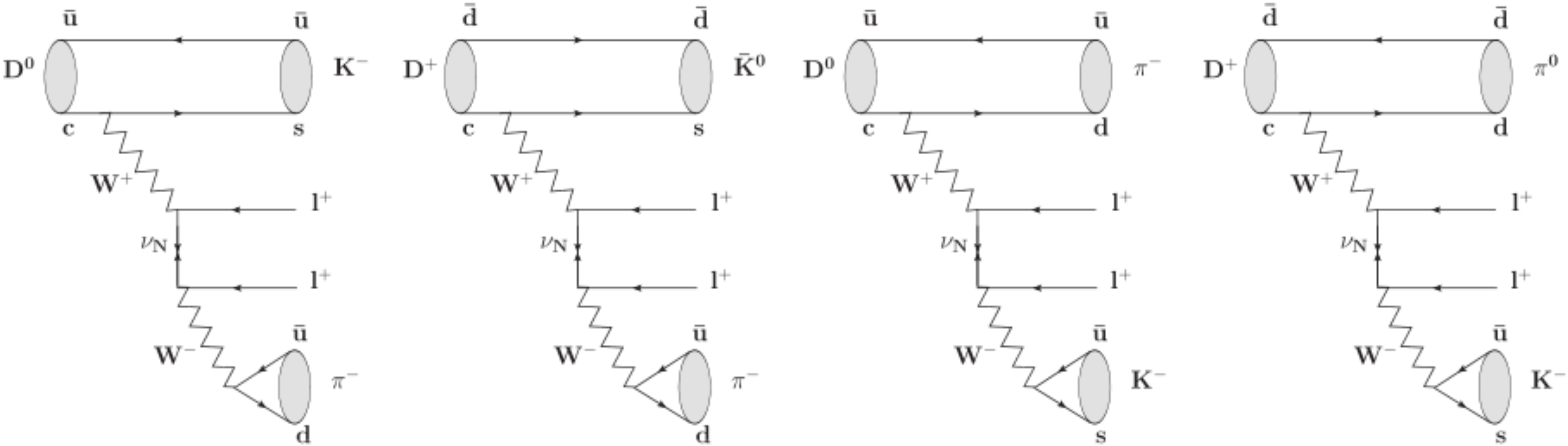
Wilson coeff (GeV^{-2})	Leptons $\ell_1\ell_2$	Constraints Current	Projected
$\left\lvert C_{VL}^{cc\ell_1\ell_2}/\Lambda^2\right\rvert$	$\mu\tau$	5.5×10^{-5}	$[5.0, 7.1]\times10^{-6}$
	$e\tau$	1.1×10^{-4}	$[6.5, 8.7]\times10^{-6}$
	$e\mu$	1.0×10^{-5}	$[2.8, 3.7]\times10^{-6}$

Phys. Rev. D **87**, 112007 (2013).

efficiencies ~30-35%

Search for LNV: D→Kπe⁺e⁺

H.R. Dong et al Chin, Phys. C **39** 013101 (2015).

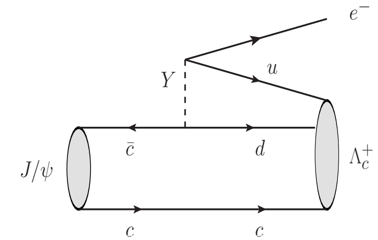


(a) $D^0 \to K^-\pi^-l^+l^+$ (CF) (b) $D^+ \to \bar{K}^0\pi^-l^+l^+$ (CF) (c) $D^0 \to K^-\pi^-l^+l^+$ (DCS) (d) $D^+ \to K^-\pi^0l^+l^+$ (DCS)

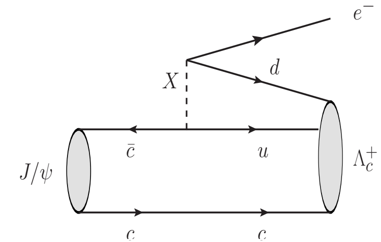
- **Lepton number violating(LNV) process (ΔL =2)**
  - **possibly due to a single Majorana neutrino exchange**
- **The best BR limit around 10^{-4} ~10^{-5} level by E791[PRL 86, 3969(2001)].**
- **BESIII could improve them to ~10^{-6}**
- **Further constrain mass-dependent D→$Ke^+\nu_N(\pi e^+)$ decay**
  - **constrain mixing matrix element $|V_{eN}|^2$**
- **Work in progress, the results to be published**

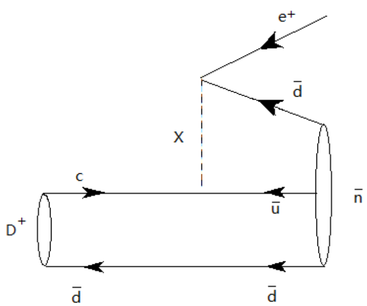
Search for BNV process

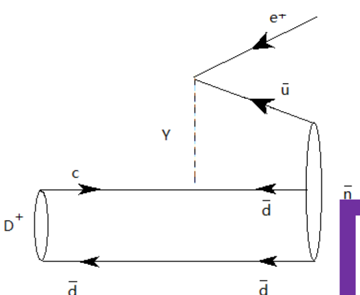
- The first of **"Sakharov conditions"**: "there must be BNV process"
- Many theory could have BNV, such as Georgi – Glashow GUT model, there are X and Y bosons with charges 4/3 and 1/3, which couples quarks and leptons and thus BNV and LNV

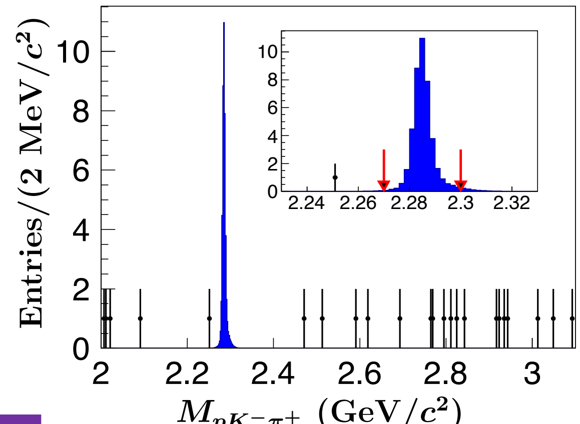


Phys.Rev.Lett. 32 (1974) 438-441









$\Delta B=1$, $\Delta(B-L)=0$

arxiv: 1803.04789
Submitted to PRL

$D^+ \to \bar{\Lambda}(\bar{\Sigma})e^+$
$D_s \to \Lambda$ e
$D^+ \to \bar{n}\, e^+$
$D^0 \to \bar{p}\, e^+$
All started at BESIII, will benefit from the final charm dataset

$B(J/\psi \to \Lambda_c^+ e^-) < 6.9 \times 10^{-8}$

expected UL with $10^{10} J/\psi$: 10^{-9}

light Higgs search:Motivation

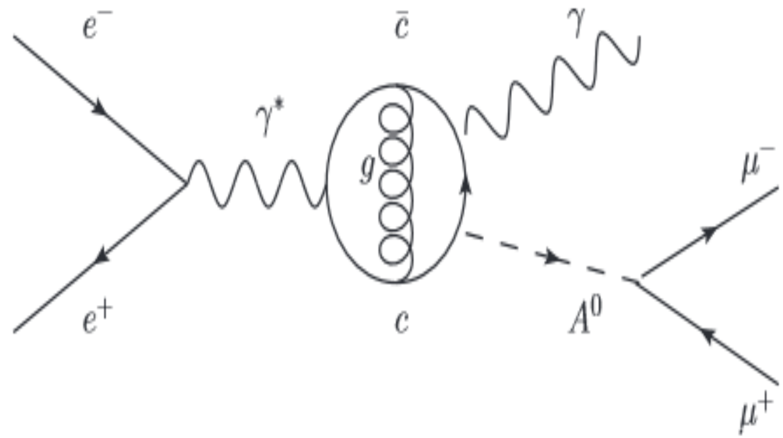
- Coupling of fermions and the CP-odd Higgs A^0 in the NMSSM:

$$L_{\text{int}}^{f\bar{f}} = -\cos\theta_A \tan\beta \frac{m_f}{v} A^0 \bar{d}(i\gamma_5)d,$$

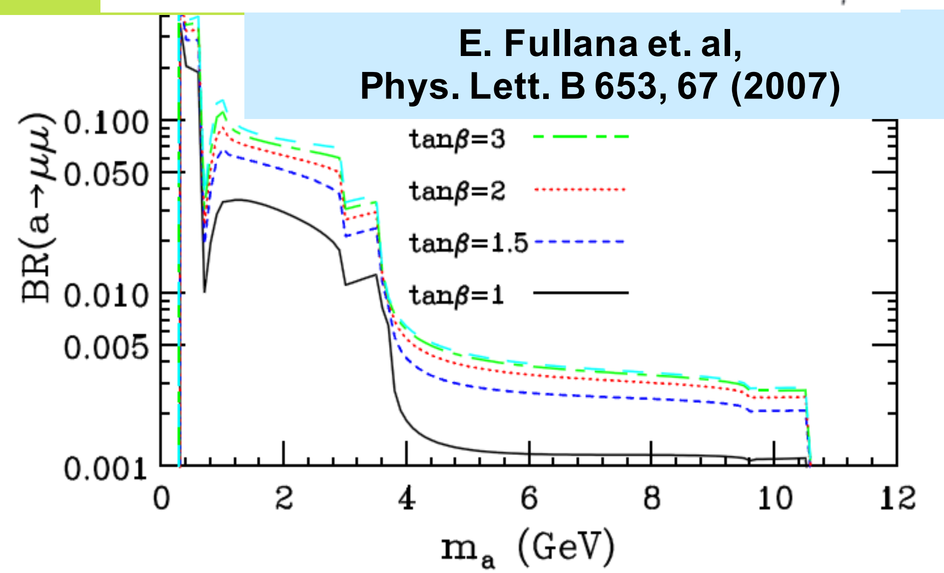
$d = d, s, \mathbf{b}, e, \mu, \tau$

$$L_{\text{int}}^{f\bar{f}} = -\cos\theta_A \cot\beta \frac{m_f}{v} A^0 \bar{u}(i\gamma_5)u,$$

$u = u, \mathbf{c}, t, \nu_e, \nu_\mu, \nu_\tau$



$$\tan\beta = \frac{v_u}{v_d}$$

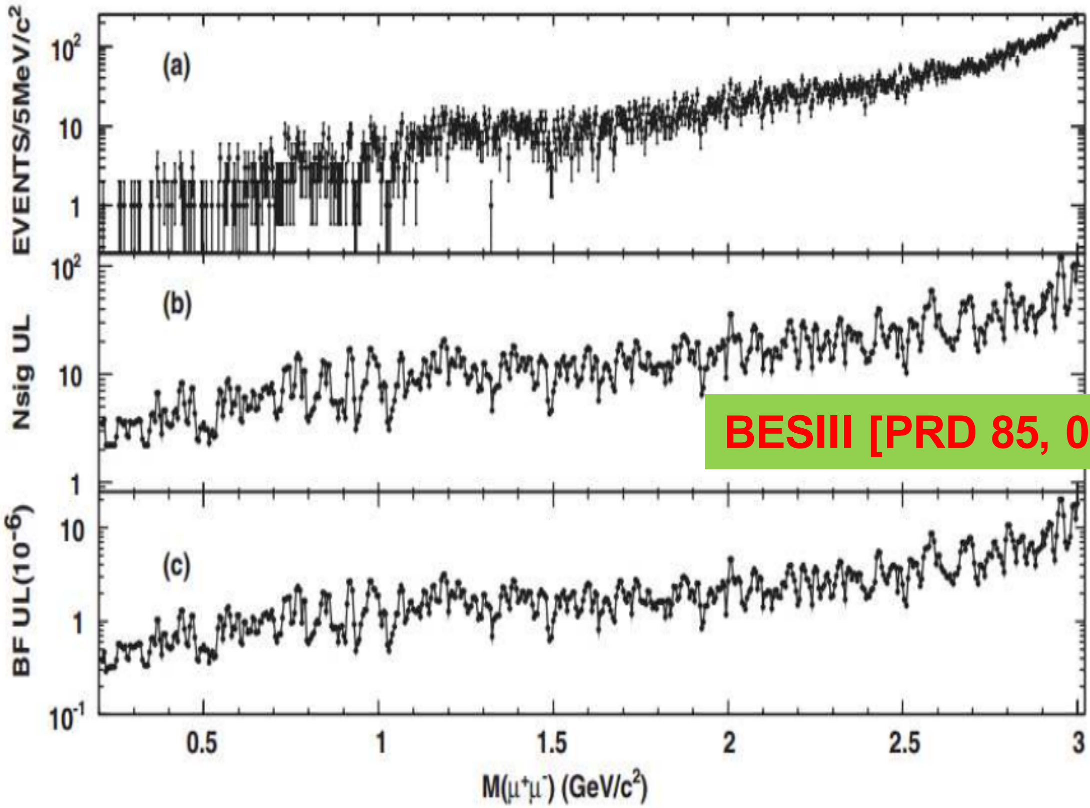


E. Fullana et. al,
Phys. Lett. B 653, 67 (2007)

37

Results with ψ' data in published in 2012

ψ'->pipi J/ψ, J/ψ→γA^0, A^0→$\mu^+\mu^-$



Coupling of c-quark to the A^0:

Expected BF: 10^{-7} -10^{-9}

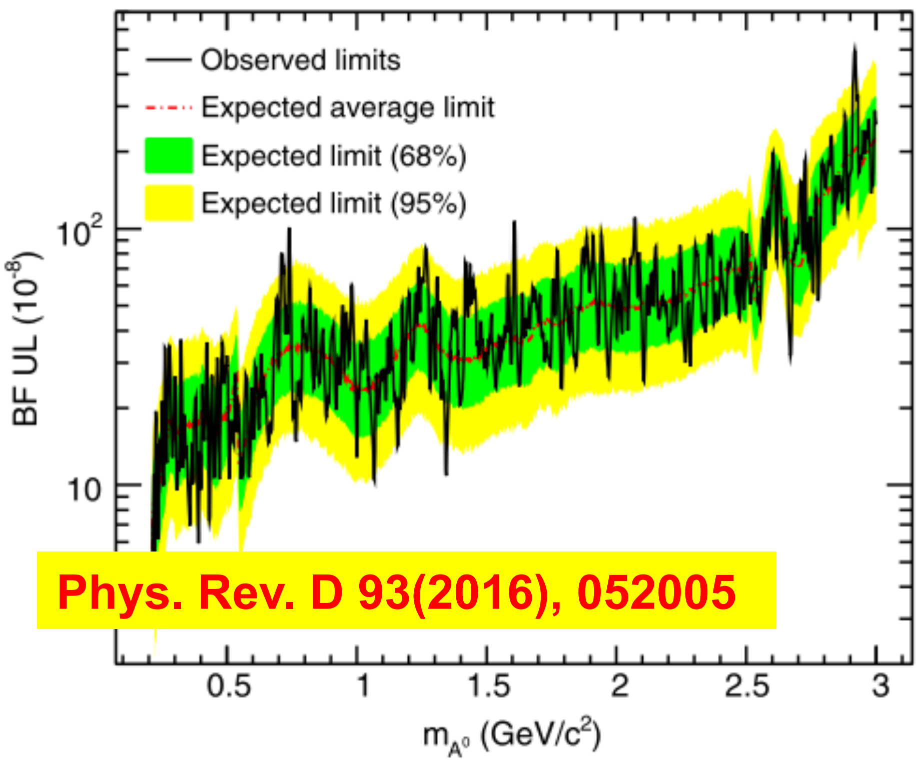
[PRD 76, 051105 (2007)]

BESIII [PRD 85, 092012 (2012)]

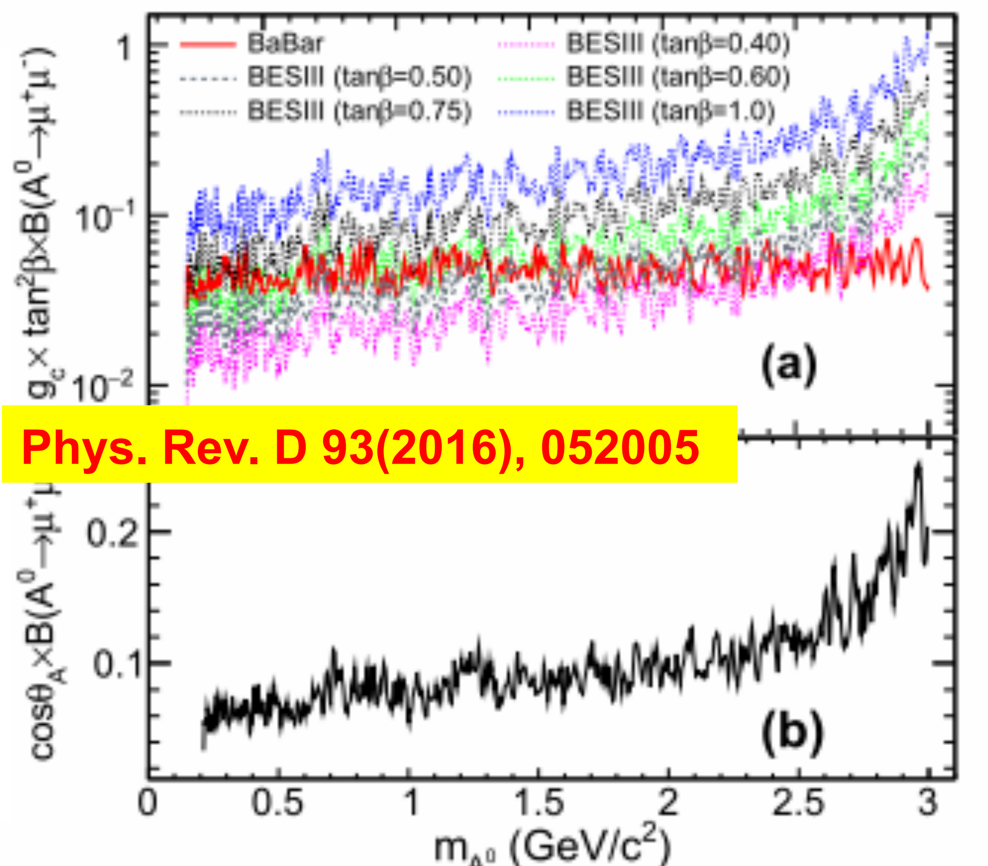
106M psi' data

BESIII exclusion limit ranges from 4×10^{-7} - 2.1×10^{-5} depending on A^0 mass points.

New BESIII Results(225M J/ψ)



Phys. Rev. D 93(2016), 052005



Phys. Rev. D 93(2016), 052005

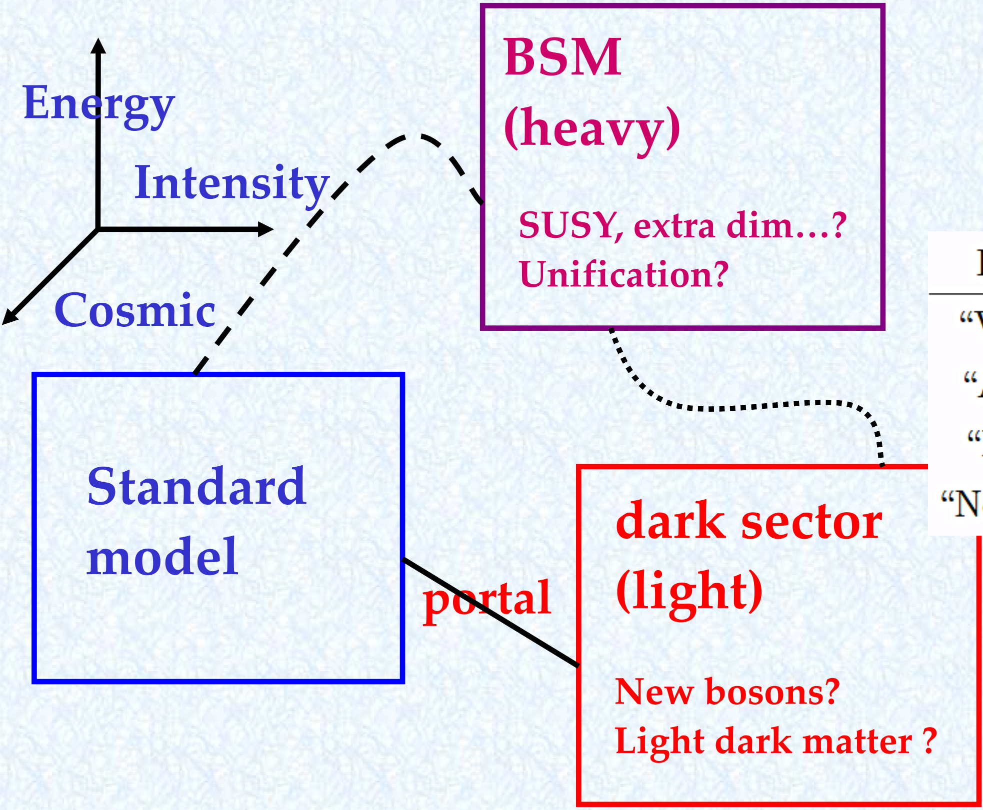
PRD 87, 031102 (R) (2013) (BaBar experiment)

The new limits are five times below our previous results (2012, Psip)

BESIII [PRD 85, 092012 (2012)]

BESIII vs. BaBar measurements comparison and combination, A0 is mostly singlet

Dark sector and portal



It is also referred as to heavy photon, hidden photon, A’, γ’ or U boson in the literature

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	$y_N LHN$

Dark Sectors 2016 Workshop: Community Report

Jim Alexander (VDP Convener),[1] Marco Battaglieri (DMA Convener),[2] Bertrand Echenard (RDS Convener),[3] Rouven Essig (Organizer),[4,*] Matthew Graham (Organizer),[5,†] Eder Izaguirre (DMA Convener),[6] John Jaros (Organizer),[5,‡] Gordan Krnjaic (DMA Convener),[7] Jeremy Mardon (DD Convener),[8] David Morrissey (RDS Convener),[9] Tim Nelson (Organizer),[5,§] Maxim Perelstein (VDP Convener),[1] Matt Pyle (DD Convener),[10] Adam Ritz (DMA Convener),[11] Philip Schuster (Organizer),[5,6,¶] Brian Shuve (RDS Convener),[5] Natalia Toro (Organizer),[5,6,**] Richard G Van De Water (DMA Convener),[12] … [15] David

arxiv: 1608.08632

The Jefferson Lab's Free-Electron Laser is a low-cost option in the bid to discover dark-se…

PARTICLE PHYSICS

Physicists hunt for dark forces

NATURE 2012.4

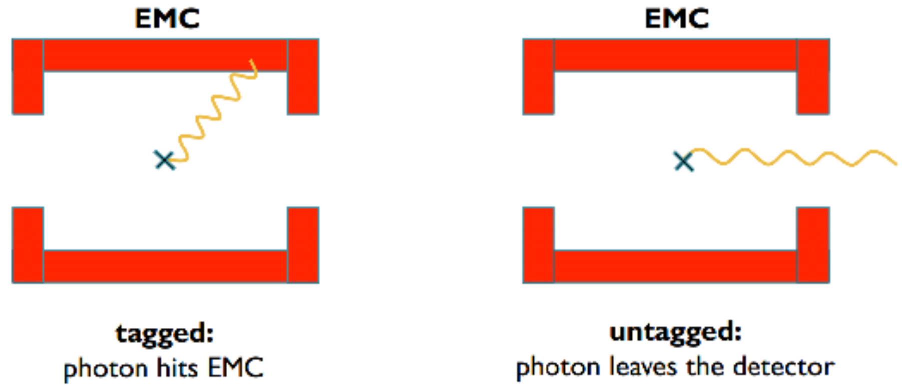
Dark photon search with ISR

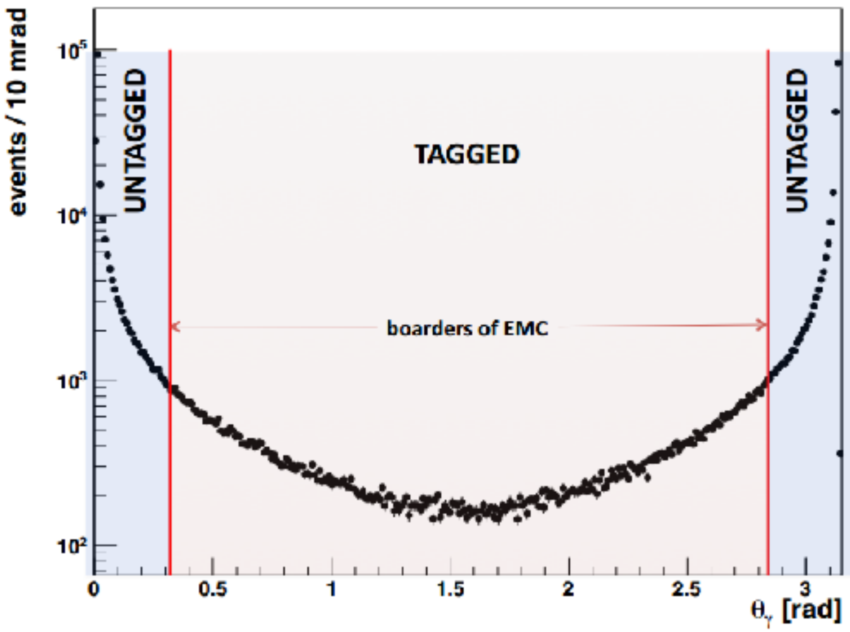
Search for narrow structure on top of the continuum QED background $e^+ e^- \to \gamma_{ISR} l^+ l^-$

- Use an untagged photon method to perform this analysis.

Event selection: $e^+e^- \to \mu^+\mu^-\gamma_{ISR}$ and $e^+e^- \to e^+e^-\gamma_{ISR}$

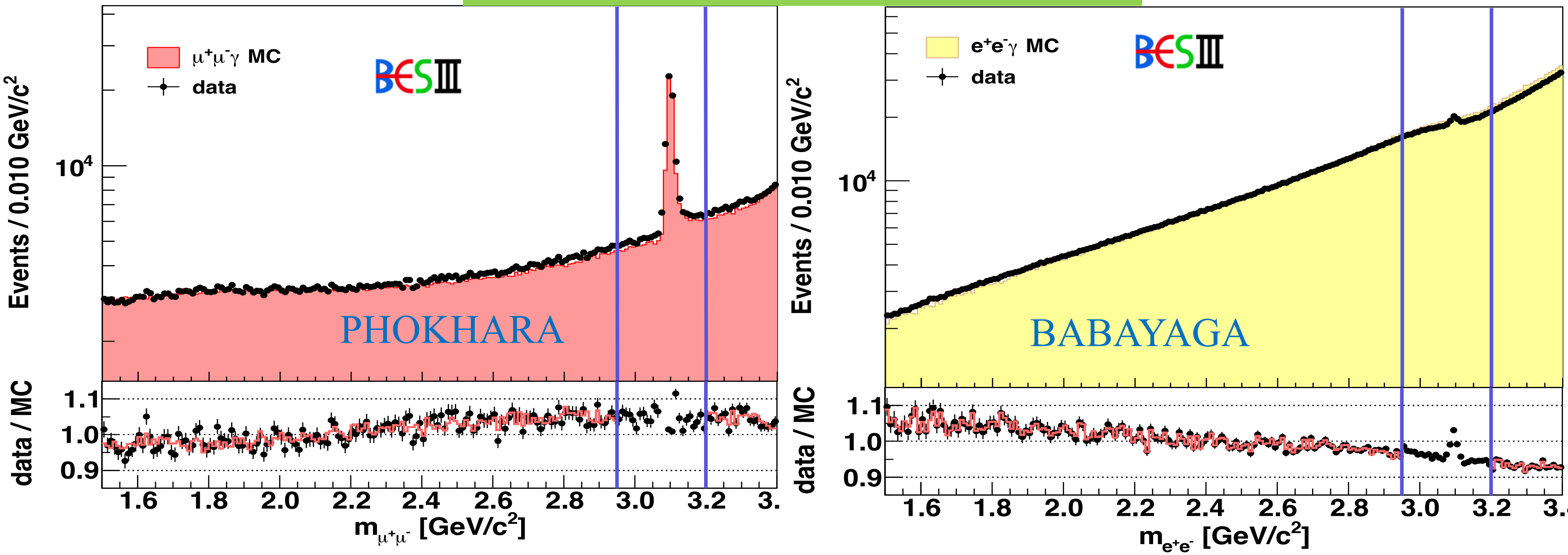
distance to interaction point	R_{xy} < 1.0 cm R_z < 10.0 cm
acceptance	0.4 rad < θ < $\pi - 0.4$ rad
to supress background	PID
# charged tracks	= 2
total charge	= 0
# photons	= 0 (untagged analysis)
missing photon angle	< 0.1 rad or > $\pi - 0.1$ rad
1C kinematic fit	$\chi^2_{1C} < 20$





Mass spectrum of mumu and ee

2.9fb^{-1} psi(3773) dataset(2010+2011)



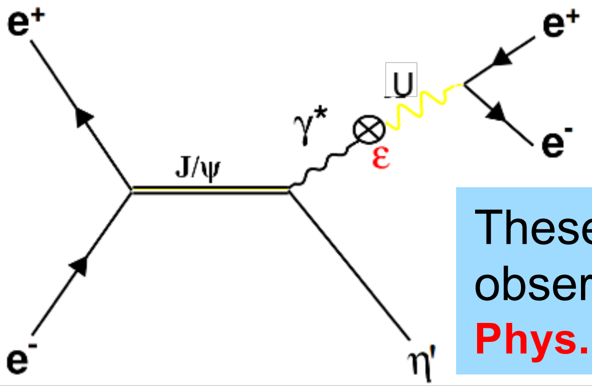
Cover mass region: 1.5 GeV/c 2 ~ 3.4 GeV/c

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

arXiv:1705.04265,
Phy. Lett. B 774, 252(2017)

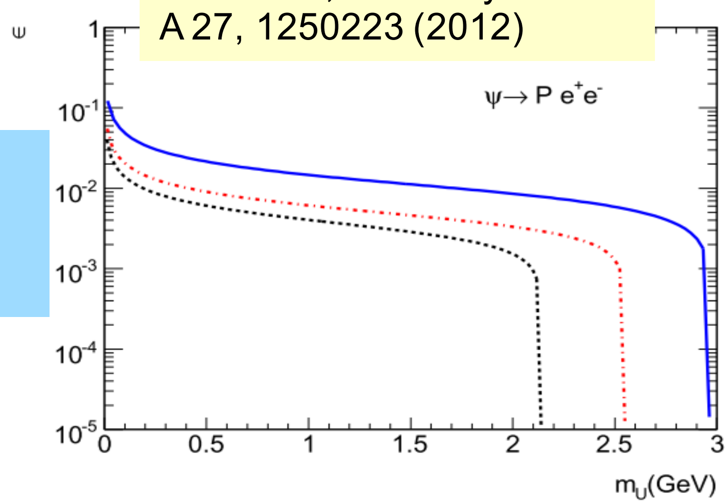
$$\frac{\sigma_i(e^+e^- \to \gamma' \gamma_{\rm ISR} \to l^+l^-\gamma_{\rm ISR})}{\sigma_i(e^+e^- \to \gamma^* \gamma_{\rm ISR} \to l^+l^-\gamma_{\rm ISR})} = \frac{N_i^{\rm up}(e^+e^- \to \gamma' \gamma_{\rm ISR} \to l^+l^-\gamma_{\rm ISR})}{N_i^{\rm B}(e^+e^- \to \gamma^* \gamma_{\rm ISR} \to l^+l^-\gamma_{\rm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

DP search through meson decays



These processes were first observed by BESIII
Phys. Rev. D 89, 092008 (2014)

J Fu et al., Mod. Phys. Lett. A 27, 1250223 (2012)



- $(1310.6 \pm 7.0) \times 10^6\ J/\psi$ data sample
  - $J/\psi \to \gamma'\eta' \to e^+e^-\eta'$
    - $\eta' \to \gamma\pi^+\pi^- /\ \eta\pi^+\pi^-$
    - η' window [0.93, 0.98] GeV/c^2
  - $J/\psi \to \gamma'\eta \to e^+e^-\eta$
    - $\eta \to \gamma\gamma\ /\ \pi^0\pi^+\pi^-$
    - η window [0.52, 0.57] GeV/c^2

With 1.3 billion J/ψ data, it is a good opportunity to search for the dark photon through decays $J/\psi \to \eta^{(\prime)}\ \gamma', \gamma' \to e^+e^-$ at BESIII.

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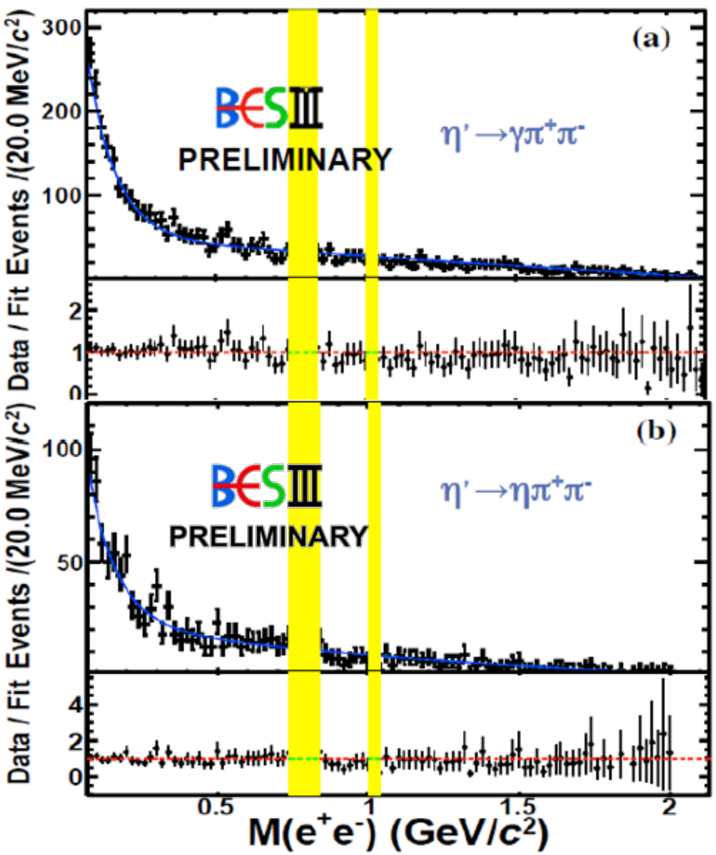
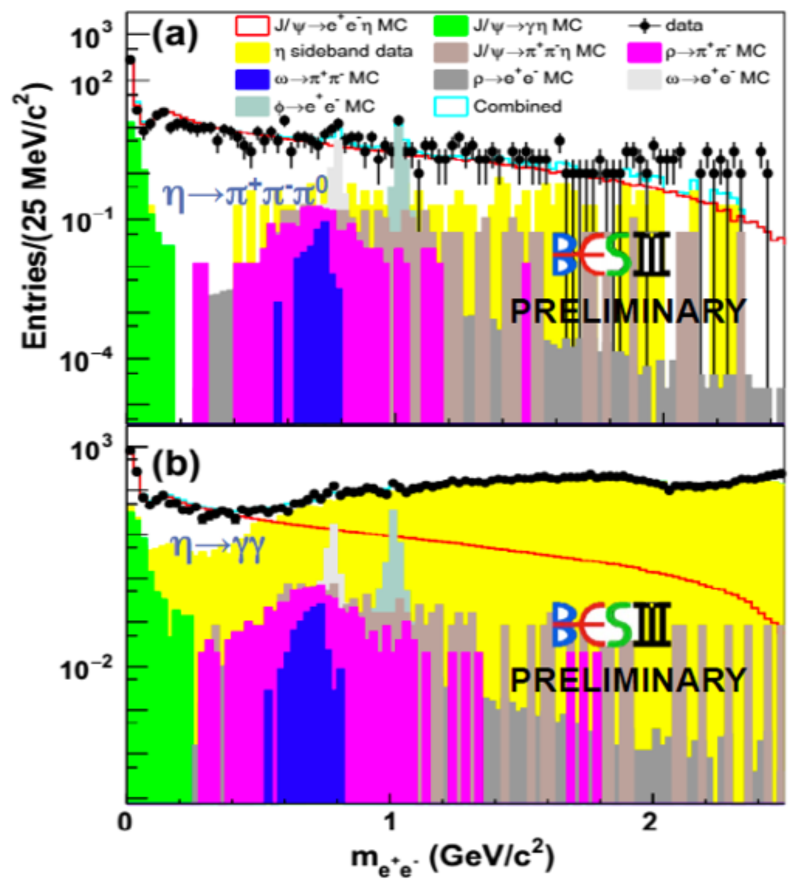
Mass spectrum of e^+e^-

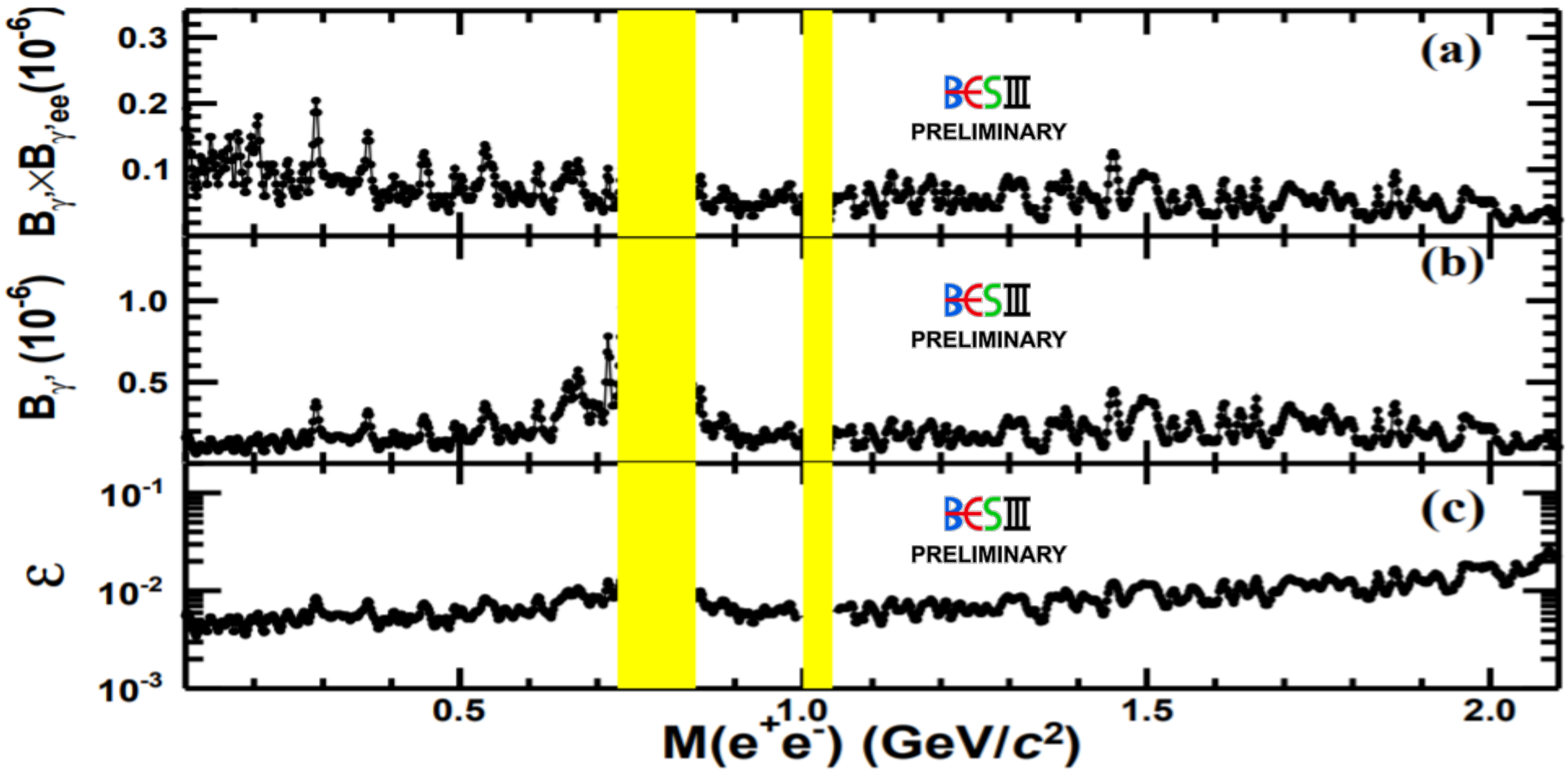




- $0.1 \sim 2.1$ / $0.01 \sim 2.4$ GeV/c^2
- Signal: Two crystal-ball function
- Background: $c_1 m + c_2 m^2 + e^{c_3 m}$ / 2nd polynomial or $c_1 m + c_2 m^2 + e^{c_3 m}$
- Exclude ρ/ω and ϕ mass region
- No unexpected peaking structure observed

Combined result for η'

Combined results of $\eta' \to \gamma\pi^+\pi^-$ and $\eta' \to \eta\pi^+\pi^-$

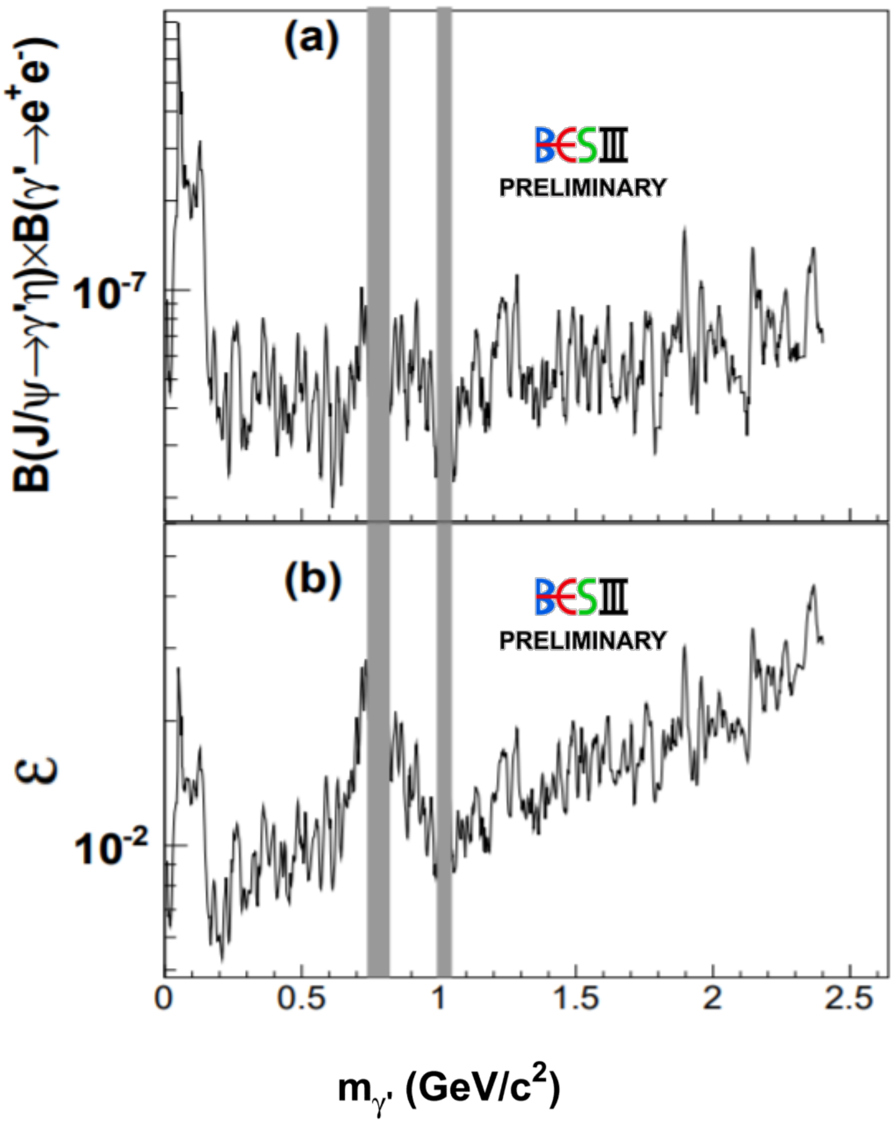


(a) $B(J/\psi \to \gamma'\eta') \times B(\gamma' \to e^+e^-)$: $< 1.8 \times 10^{-8} \sim 2.0 \times 10^{-7}$

(b) $B(J/\psi \to \gamma'\eta')$: $< 6.0 \times 10^{-8} \sim 7.8 \times 10^{-7}$

(c) ε : $< 3.4 \times 10^{-3} \sim 2.6 \times 10^{-2}$

Combined result for η

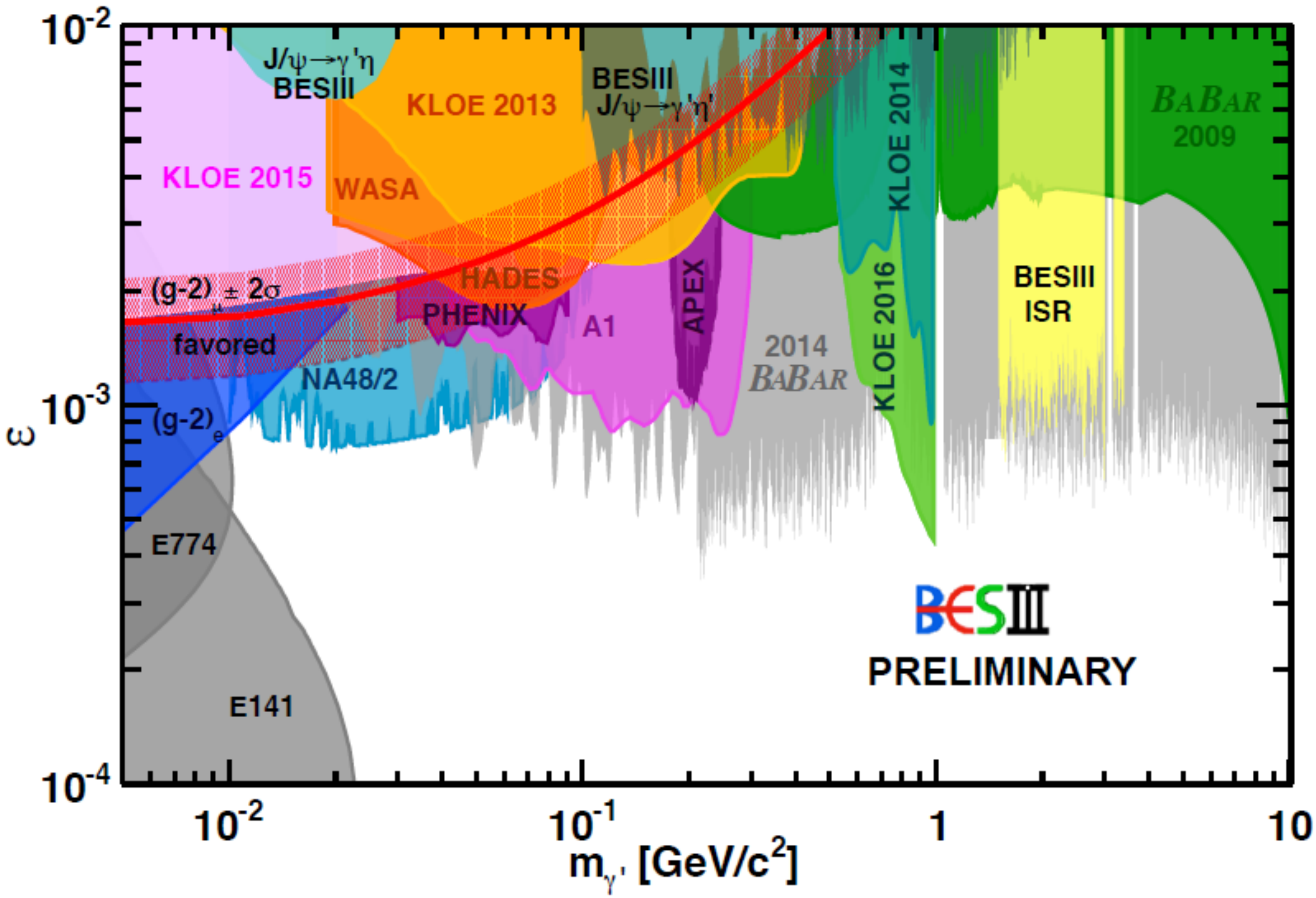


Combined results of
$\eta \rightarrow \gamma\gamma$ and $\eta \rightarrow \pi^0 \pi^+\pi^-$

(a) $B(J/\psi \rightarrow \gamma'\eta) \times B(\gamma' \rightarrow e^+e^-)$:
$< 1.9 \times 10^{-8} \sim 9.1 \times 10^{-7}$

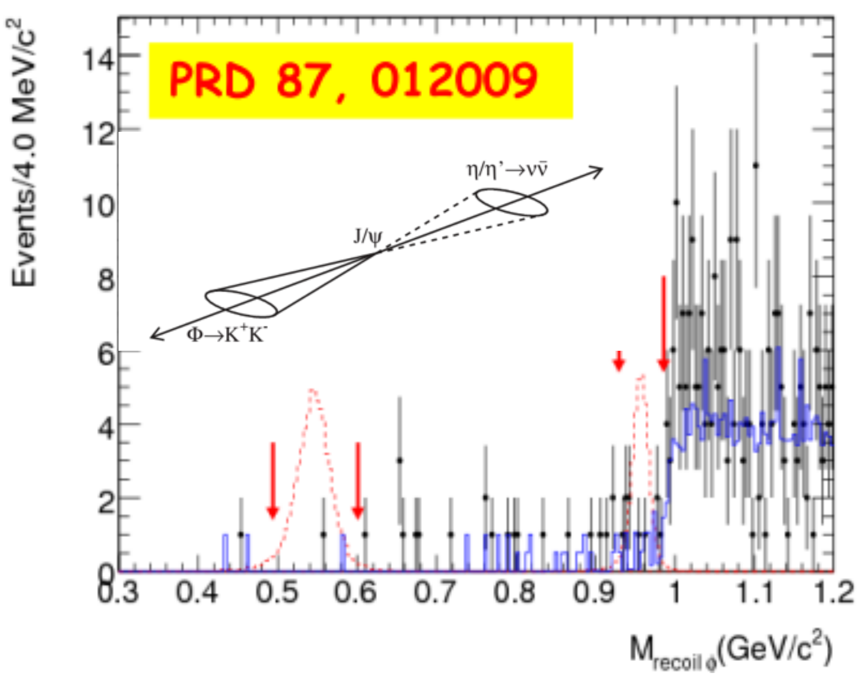
(b) ε : $< 10^{-3} \sim 10^{-2}$

BESIII Constraints on DP



Search for η /η′ invisible decays

- η/η' decay play special role in low energy scale QCD theory.
- Invisible and radiative decays offer a window for new physics beyond the SM.
- The observation of the 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 branching fraction of $J/\psi\to(\gamma/\phi)\eta/\eta'$ and narrow intermediate meson widths provide clean, large η/η' sample.



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

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

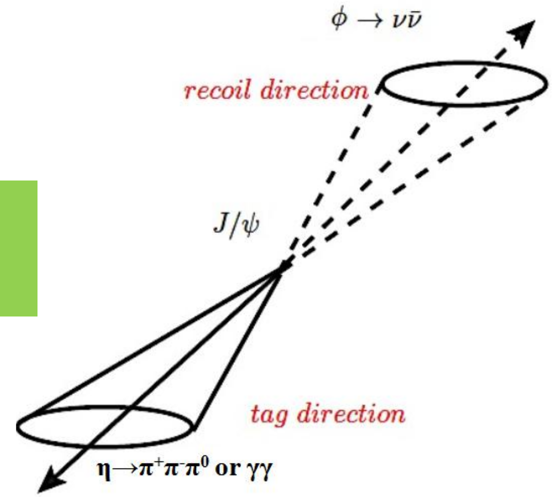
PDG : $Br(\eta'\to invisible)<9\times10^{-4}$@90%C.L
$Br(\eta\to invisible)<6\times10^{-4}$@90%C.L.

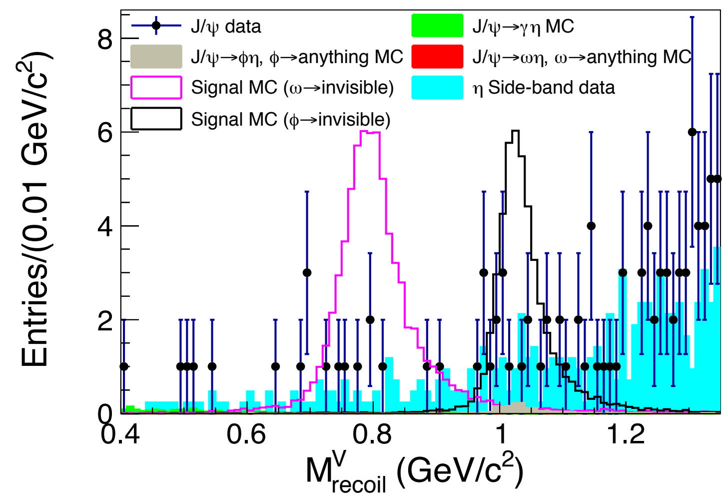
Theory : $Br(\eta'\to\chi\chi)$ ~8.1×10^{-7}
$Br(\eta\to\chi\chi)$~7.4×10^{-5}
B. McElrath, PRD 72, 103508 (2005)

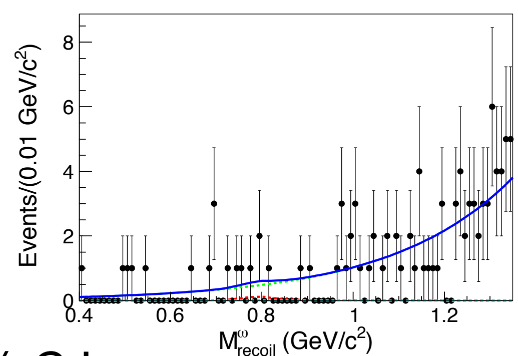
Omega and phi invisible decay

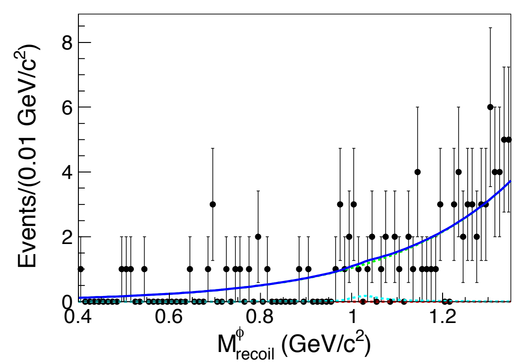
The first search of invisible decays of light vector mesons

arxiv:1805.05613
Accepted by PRD







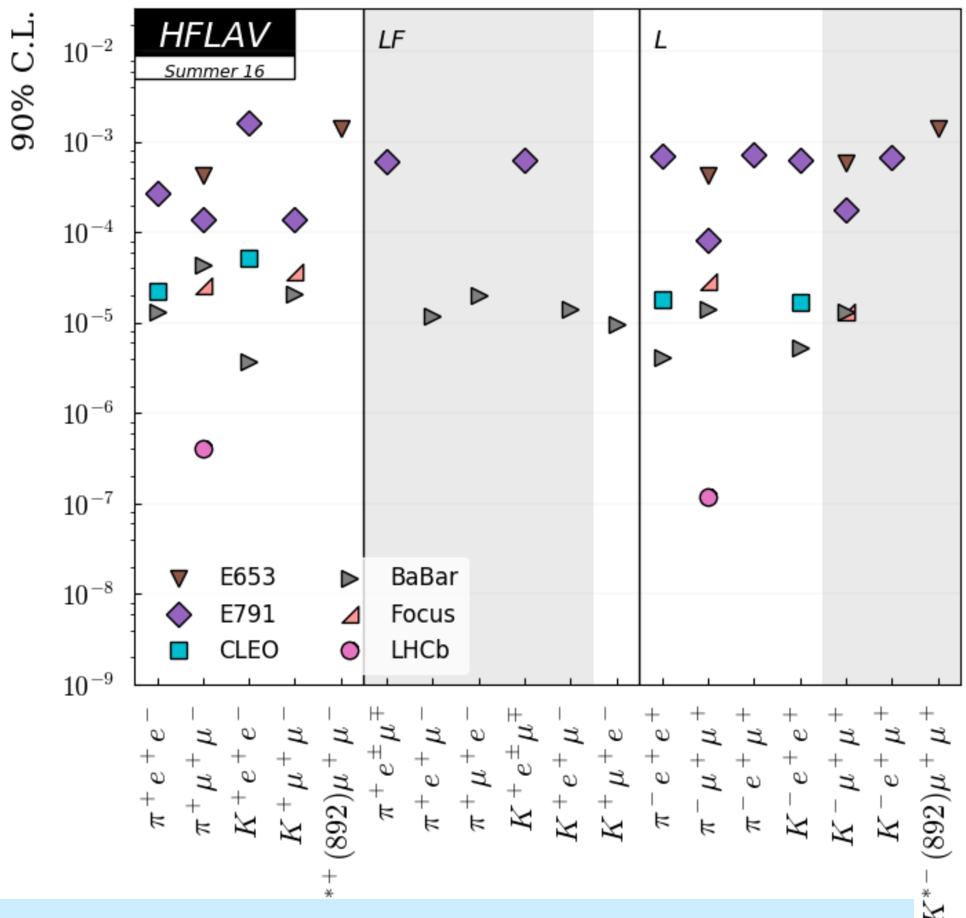


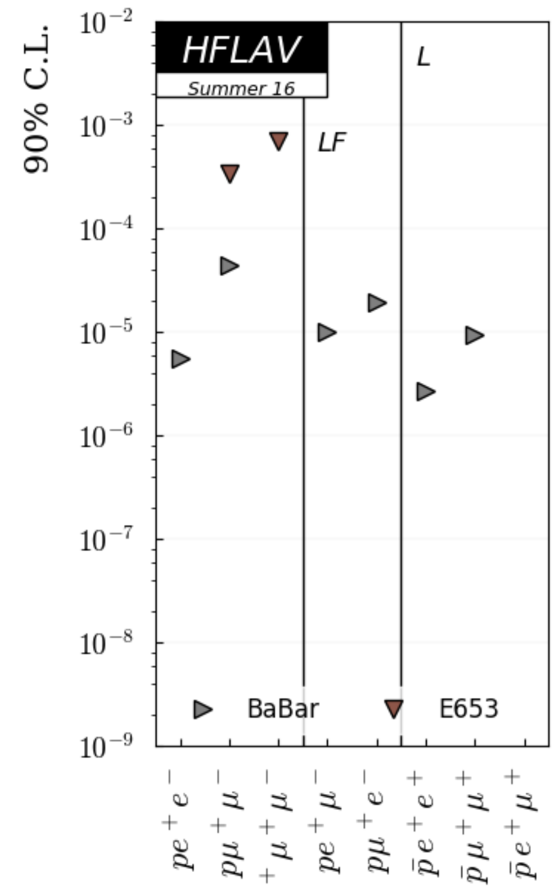
Upper limits set at 90% C.L.

$$\frac{\mathcal{B}(\omega\to\text{invisible})}{\mathcal{B}(\omega\to\pi^+\pi^-\pi^0)} < 8.1\times10^{-5} \qquad \frac{\mathcal{B}(\phi\to\text{invisible})}{\mathcal{B}(\phi\to K^+K^-)} < 3.4\times10^{-4}$$

$$\mathcal{B}(\omega \to \text{invisible}) < 7.3\times10^{-5} \qquad \mathcal{B}(\phi \to \text{invisible}) < 1.7\times10^{-4},$$

Rare D_s and Λ_c Decays





BESIII could probe FCNC with e+e-, and LFV with heμ in both Ds and Λ_c

Special for BESIII: weak radiative decay

$\Lambda_c^+ \to \gamma\Sigma^+$

Summary

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