Charm Rare Decays at BESIII

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(for BESIII Collaboration)

BESIII-LHCb Workshop, IHEP, Feb 8-9 2018

Why charm rare decays

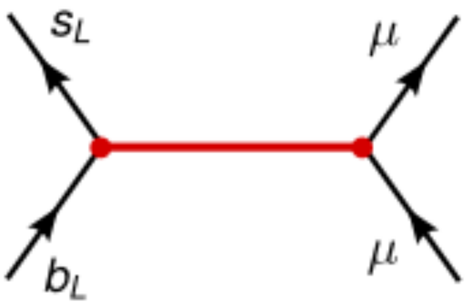
- **Rare charm decays offer the possibility to search for signals beyond Standard Model in the up-quark sector.**
  - There might be CP conserving and CP violating contributions within the Standard Model and beyond
  - There might be new particles/interactions through loops

- **Experimental explorations play important role**
  - First principle theoretical calculations have limitations
  - Non-perturbative hadronic effects
  - To calibrate theoretical tools, and searches in other sectors

- **Once NP appeared somewhere, it might well also in charm**
  - Complementary to s, b, l, ν sectors
  - Important ingredients of global "precision search"

Different NP models for "the B anomaly"

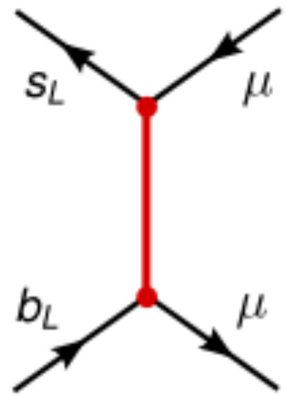
Model-building: EFT-type considerations =>Simplified models => UV completions



- **Z'** many …
- **$SU(2)_L$ singlet or triplet**
- **$U(1)_{L_\mu - L_\tau}$, $U(1)_{B_3 - L_\mu}$**

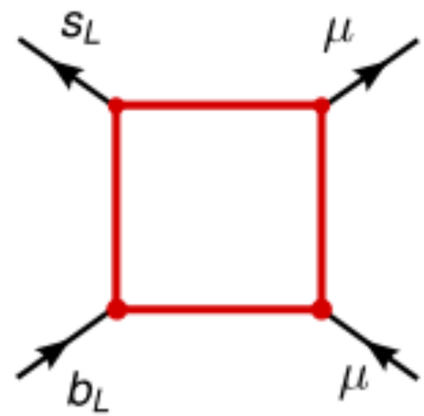
…

arXiv:1403.1269,1501.00993, 1503.03477, 1611.02703…



- **Leptoquark**
- **Scalar (S_1, S_3) or Vector (R_2, U_1, U_3)**

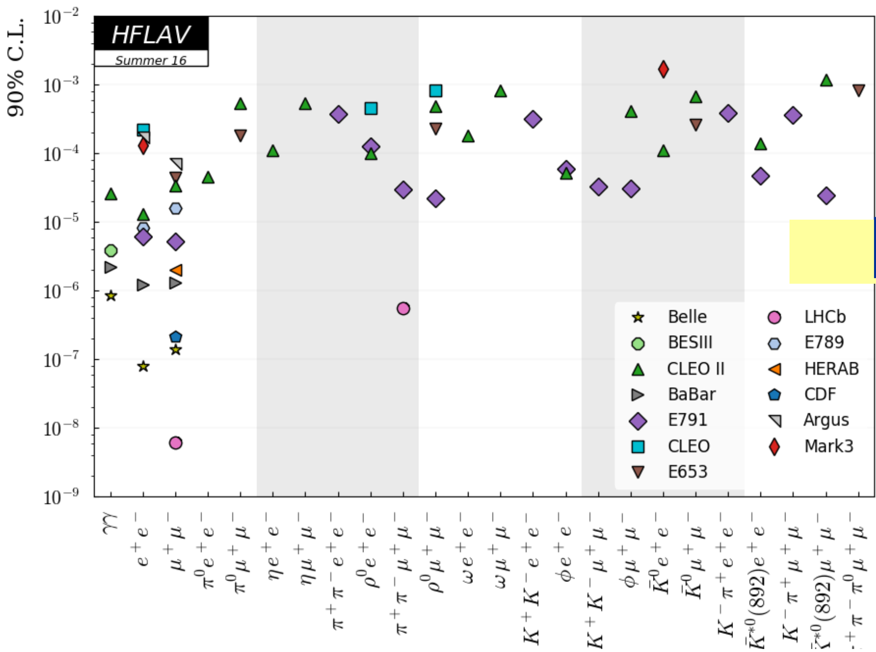
arXiv: 1511.01900, 1503.01084, 1704.05835 1512.01560, 1511.06024 1408.1627 …….

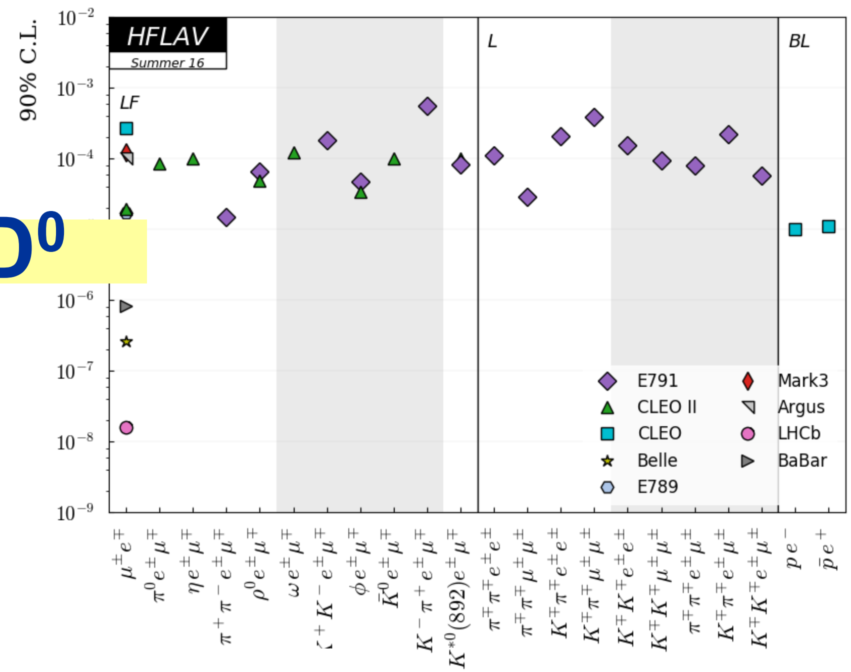


- **New Scalar or Vectors or leptoquarks possible**

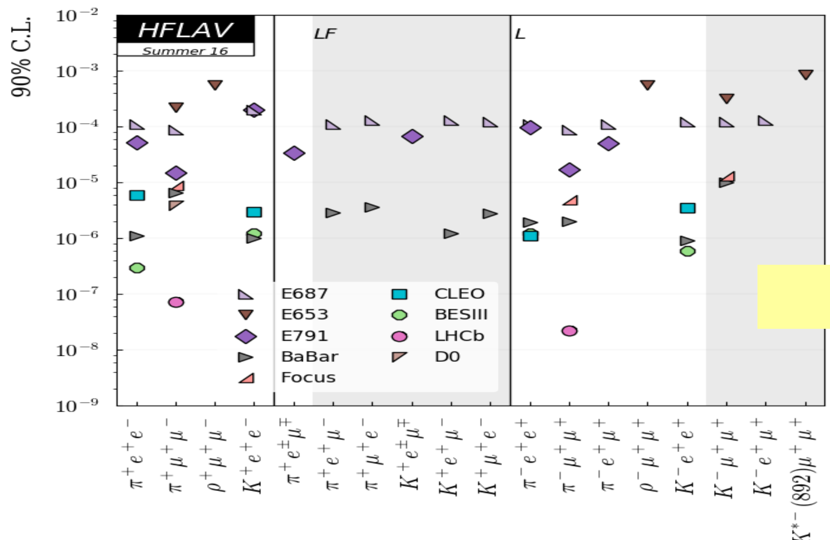
arXiv: hep-ph/0610037 1509.05020, 1608.07832 1704.05438, 1607.01659 1704.07845 …

Rare D Decays





D^0



D^+

Charm data samples(D)

	beam	Sample
E791	π 500 GeV	2.5×10^5 D
CDF	$p\bar{p}$ 1 GeV	1.5×10^6 D
FOCUS	γ 200 GeV	1×10^6 D
CLEO	e^+e^- $(\Upsilon(4s))$	1.5×10^5 D
CLEO-C	e^+e^- $(\psi(3770))$	881 nb $c\bar{c}$
BABAR	e^+e^- $(\Upsilon(4s))$	6×10^8 $c\bar{c}$
LEP	e^+e^- (Z^0)	1×10^5 D
BELLE	e^+e^- $(\Upsilon(4s))$	8×10^8 cc
BESIII	$e^+e^-(\psi(3770))$	~ 10^7 DD
LHCb	pp	~10^{10},

may further extend ~2031+ （V Vagnoni talk)

BESIII charm data samples

~ 0.5 B $\psi(3686)$ events ~ 24×CLEO-c

~ 1.3 B J/ψ events ~ 21×BESII

~ 2.9/fb $\psi(3770)$ ~ 3.5×CLEO-c yellow book: 90M DDbar

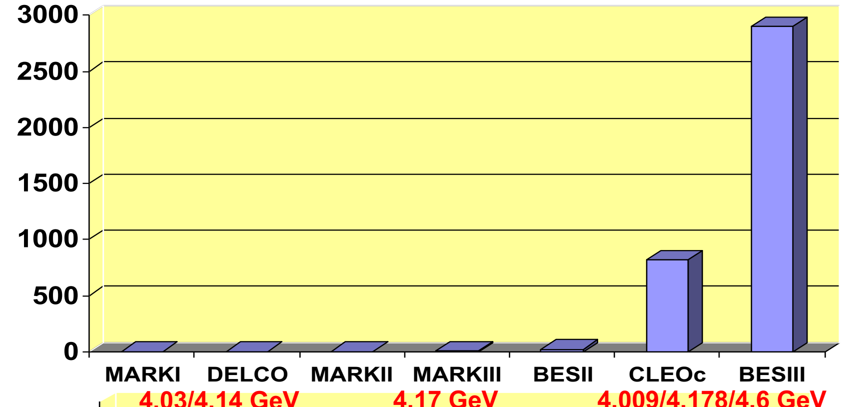
~ 0.482/fb 4.009 Ds study

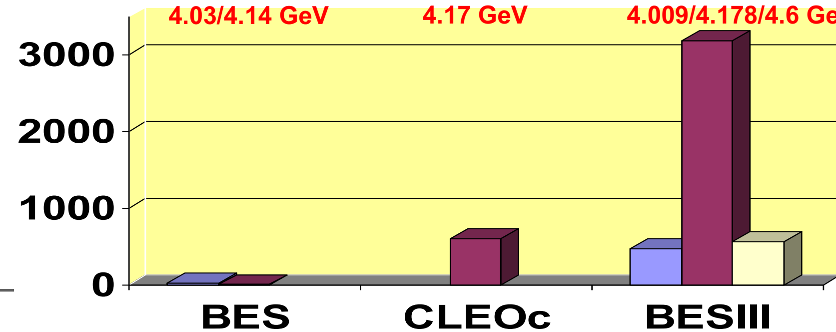
~ 0.6/fb Λ_c pairs at threshold Unique

~ 9/fb **XYZ** above 4 GeV

- 20 points for R &QCD Scan: 500/pb finished in May 2015
- Y(2175) resonance: 100 /pb
- 2016: 3/fb Ds data at 4170 MeV
  ~ 5×CLEO-c
- 2017: Y(4260), X(3872)
- 2018: 6-8B J/ψ (NEW)

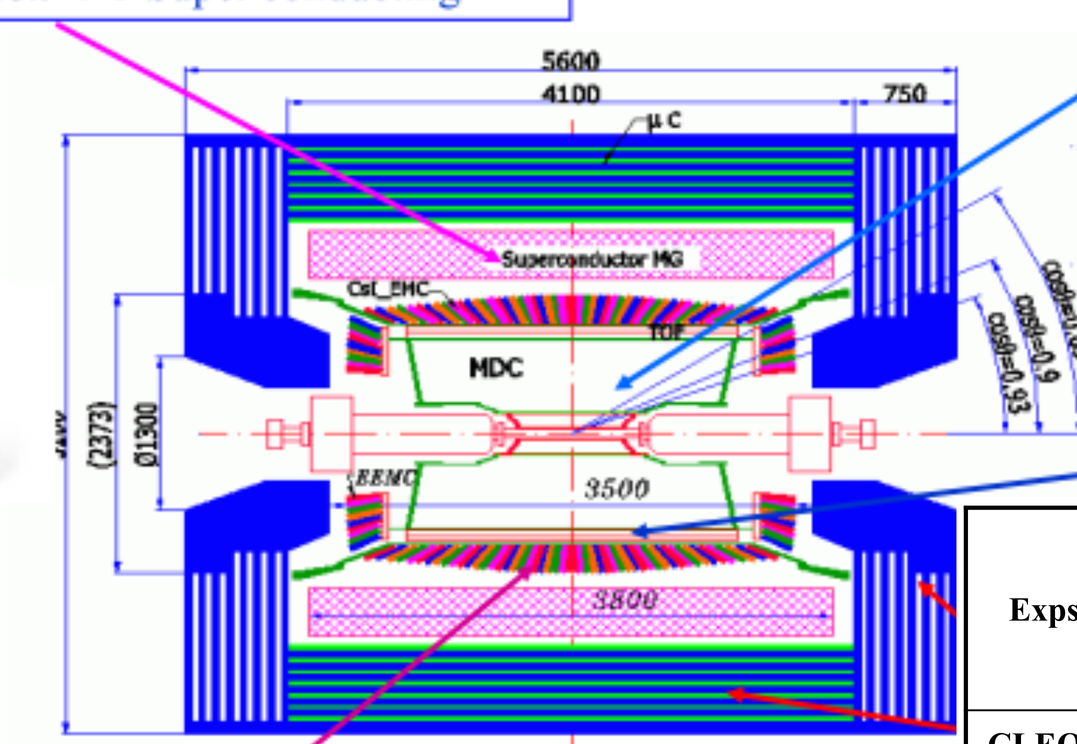
~ other data sets: tau, resonance scan and continuum, etc.





BESIII Detector

Magnet: 1 T Super conducting



Ref:
NIM A614, 345 (2010)

2015 ETOF upgrade: 60ps

2018/19: Inner tracker upgrade

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%

Clean environment and high luminosity at BESIII are helpful for indirect probe rare/forbidden decays

How BESIII compare to LHCb

in charm rare decay studies

	LHCb	BESIII
production	pp collision@LHC	e+e- annhilation@BEPCII
Cross section*L	10^{10}	10^{7}
Particle ID	good	good
Detector configuraiton	forward	hermetic
Trigger system	dedicated	comprehensive
uniqueness	Time-dependent	full kinematic constraint

Statistics@production Efficiency

Highlight/Uniqueness of BESIII

- Pair production near threshold in e+e-
  - Tagging, with extremely low background
  - systematics cancellation in DT,
  - absolute measurement
- Full kinematics available
  - Neutron/anti-neutron
  - Invisible signatures
- Low energy photons and electrons well reonstructed
  - Also pi0

Good complementary

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

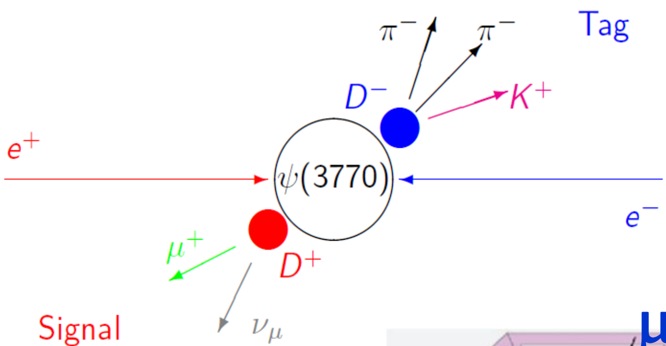
Scope of this talk

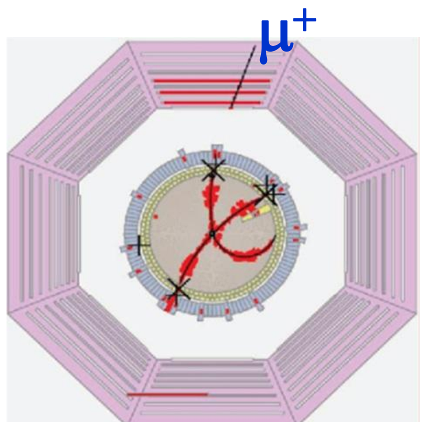
- **Many common techniques, refer to other BESIII talks:**

	QC measurements at BES III		Xiaokang Zhou
	BR measurements at BES III		Bai-Cian Ke
	Leptonic and semileptonic decays		Hailong Ma
	Ds+ -> pi+ pi+ pi- Inclusive		Liang Sun
	Λc running + measurements		Lei Li

- **With statistics up, BESIII is more involved for searches with charmonia, off resonances, dark sector etc.**
  - **Only cover charmed hadron decays in this talk**
- **As demonstrations, will focus on**
  - **Rare decays (with photons)**
  - **c->u e e, c->u v v (with e/pi0/missing)**
  - **LFV, LNV, LNV & BNV processes (with e)**

Tagging technique at threshold





$D^- \to K^+\pi^-\pi^-$ vs. $D^+ \to \mu^+\nu$

- $e^+e^- \to D\bar{D}$ ($\Lambda_c^+\Lambda_c^-$), near Thrs.
- Double tag analysis
  - ✓ Tagging D^- ($\bar{D}^0$), Λ_c^- from hadronic decay modes

$$M_{\rm BC} = \sqrt{E^2_{\rm beam} - p^2_{\bar{D}_{\rm tag}}}$$

  - ✓ (semi-)leptonic decay event can be well reconstructed in the recoil side of the tagged $\bar{D}$ (Λ_c^-)

$$M^2_{missing} = E^2_{miss} - p^2_{miss} \sim 0$$

$$U_{\rm miss} \equiv E_{\rm miss} - |\vec{p}_{\rm miss}| \sim 0$$

- ☐ Event is very clean
- ☐ High tagging efficiency
- ☐ Most systematic uncertainties can be cancelled
- ☐ Could measure absolute BFs

Charm rare decay with photons

$D^0\to\gamma\gamma$: Motivation

- FCNC mode, forbidden at tree level

→ Larger GIM suppression

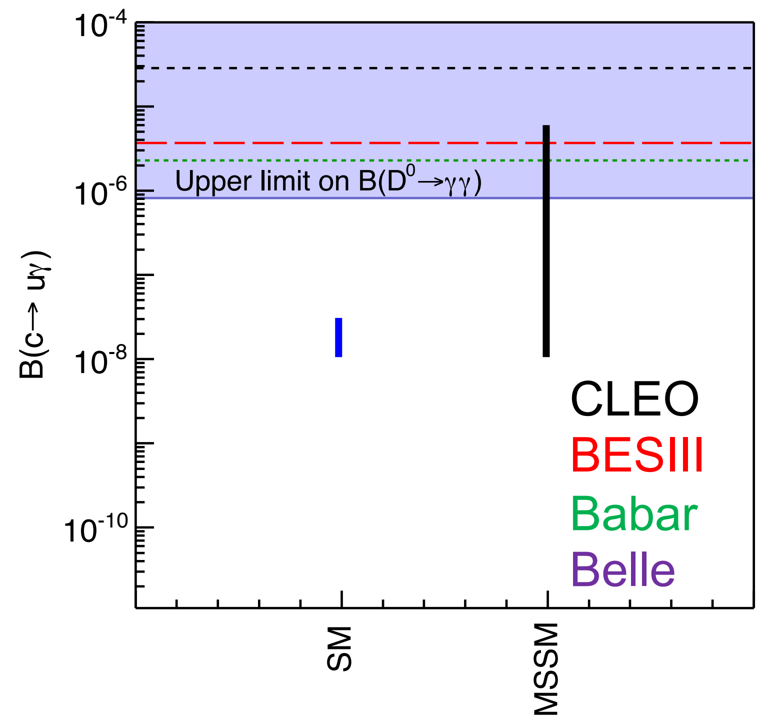
→ Short distance: $BF\sim10^{-11}$ [PRD66 (2002) 014009]

→ Long distance due to VMD: $BF\sim10^{-8}$ [PRD66 (2002) 014009]

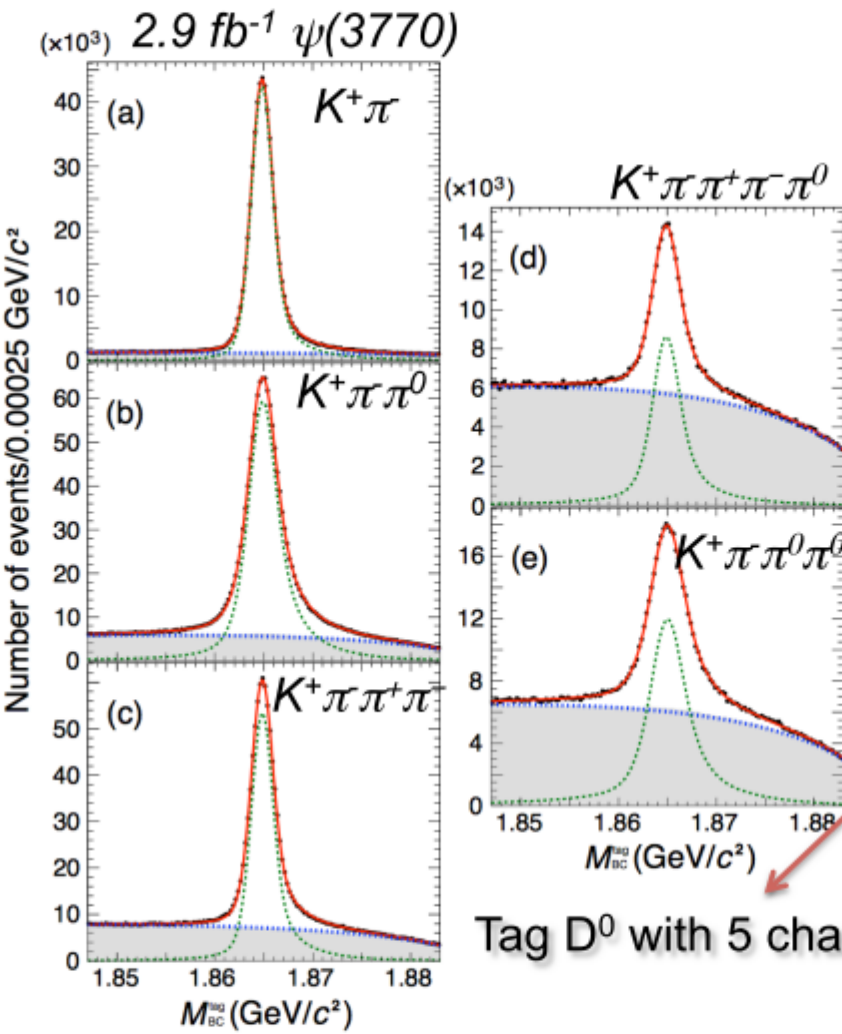
→ MSSM up to $BF\sim10^{-6}$ [PLB500(2001)304], i.e. $c\to u\gamma$ via gluino exchange

- **Measurements at B factories:**
  - Reconstruct through $D^{*+}\to D^0(\to\gamma\gamma)\pi^+$, normalized by $D^{*+}\to D^0(\to K_S\pi^0)\pi^+$.
  - Peaking background from $D^0\to\pi^0\pi^0$.

- **Measurement at BESIII**
  - **Double tag**
  - **Fitting delta(E)**
  - **Major background: D^0->pi^0pi^0**



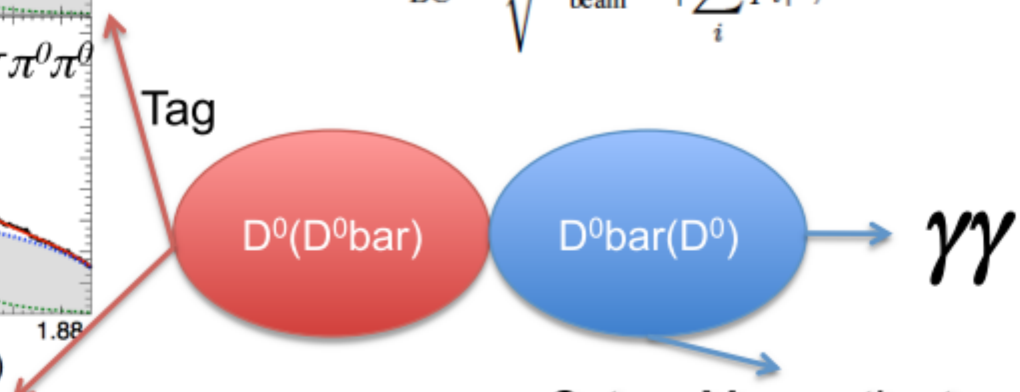
$D^0 \to \gamma\gamma$: analysis method



The $\psi(3770)$ resonance is below the threshold for $D\bar{D}\pi$ production, so the events from $e^+e^- \to \psi(3770) \to D\bar{D}$ have D mesons with energies equal to the beam energy ($E_{\rm beam}$) and known momentum. Thus, to identify $\bar{D}^0$ candidate, we define the two variables ΔE and $M_{\rm BC}$, the beam-constrained mass:

$$\Delta E \equiv \sum_i E_i - E_{\rm beam},$$

$$M_{\rm BC} \equiv \sqrt{E^2_{\rm beam} - |\sum_i \vec{p}_i|^2},$$



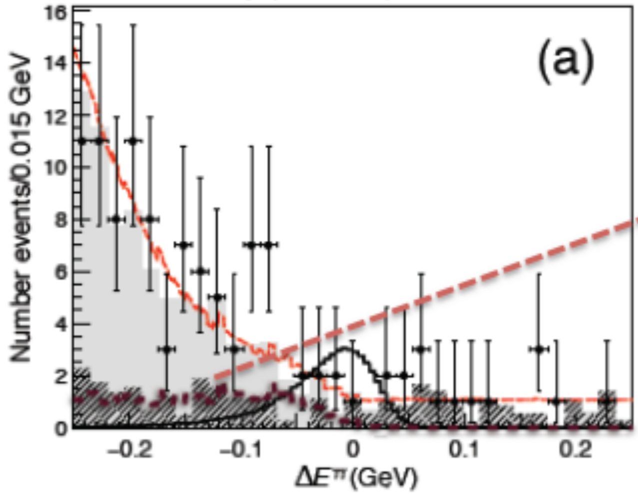
Tag D^0 with 5 channels on tag side.

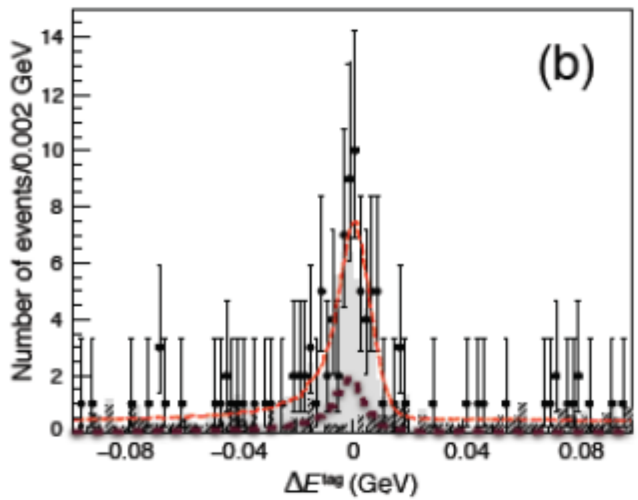
Cut on M_{BC} on the tag side, and search for $\gamma\gamma$ in $\Delta E_{\gamma\gamma}$ on the recoiling side

We could use similar technique to perform other D rare decay search, and estimate the sensitivity

D^0->γγ Results

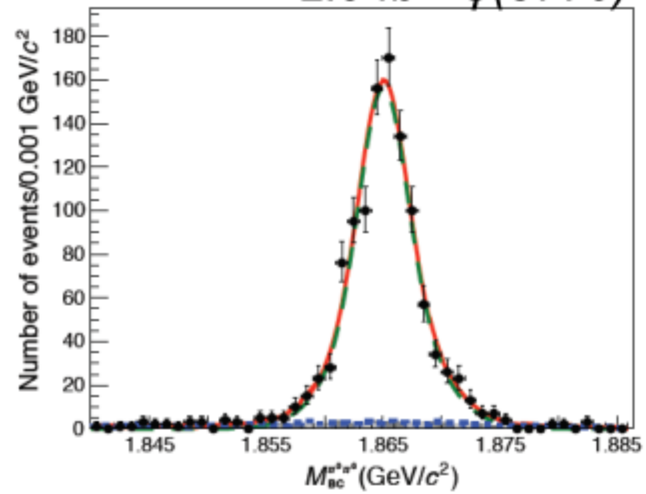
2.9 fb^{-1} ψ(3770)





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

2.9 fb^{-1} ψ(3770)



$B(D^0\to\pi^0\pi^0)=(8.24\pm0.21\pm0.30)\times10^{-4}$

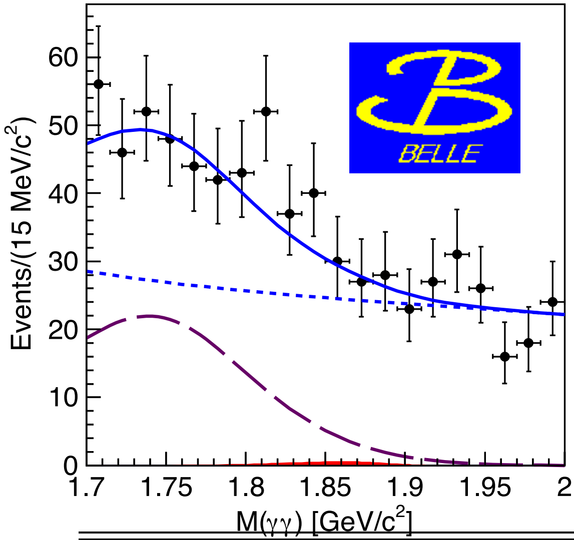
2-D fit to ΔE in both tag side and γγ sides to determine $D^0\to\gamma\gamma$ yield.

$B(D^0\to\gamma\gamma)<3.8\times10^{-6}$

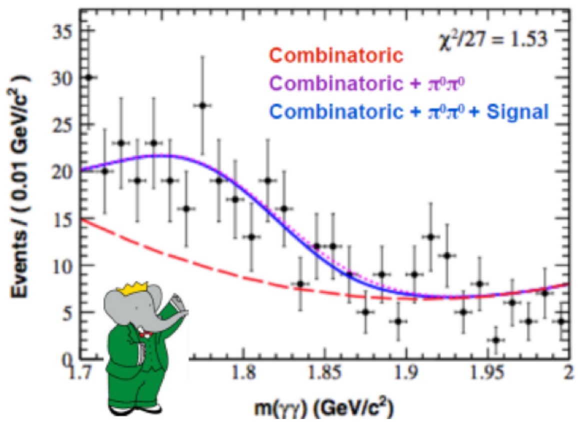
PRD91, 112015 (2015)

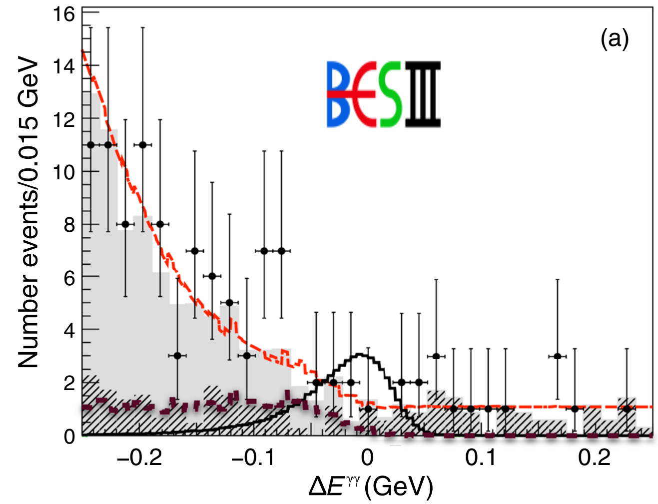
Comparison and prospects

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_S^0 reconstruction	$\pm 0.7\%$
π^0 identification	$\pm 4.0\%$
$\mathcal{B}(D^0 \to K_S^0 \pi^0)$	$\pm 3.3\%$

Uncertainties independent of fitting procedure

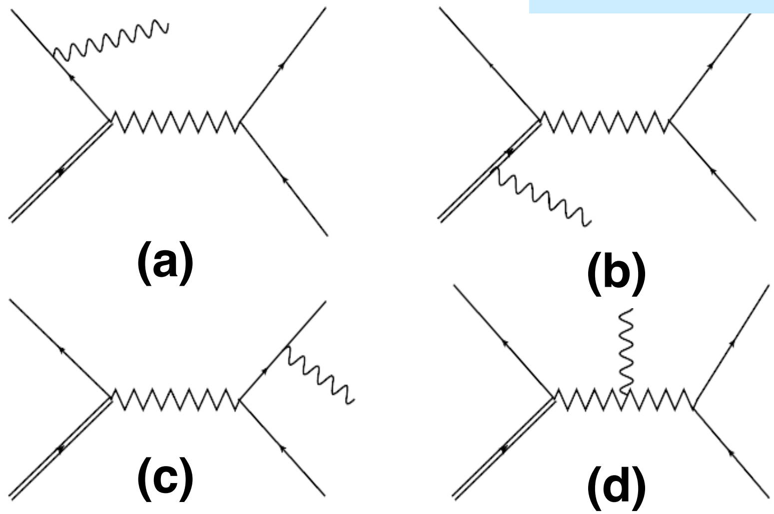
Source	Relative uncertainty (%)
Photon reconstruction	2.0
$M_{\rm BC}^{\gamma\gamma}$ requirement	3.1
ST D^0 yields	1.0
Total	3.8

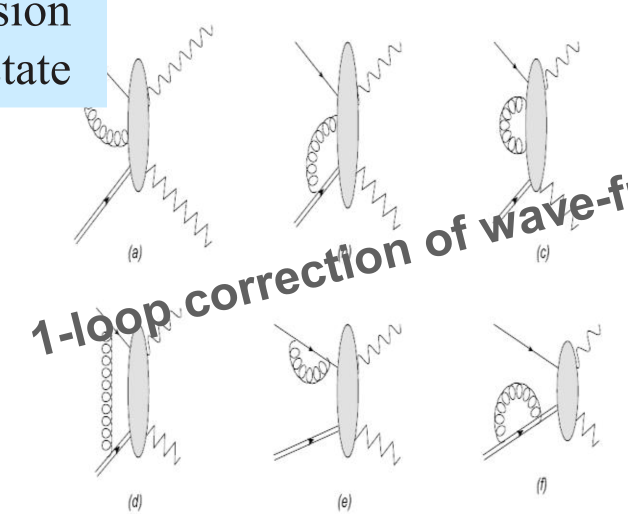
- BESIII has the least background contamination
- and very good control of systematics
- Could still be competitive with the final DDbar sample
- Detailed projection study is needed to check what is the critical points for DDbar sample size

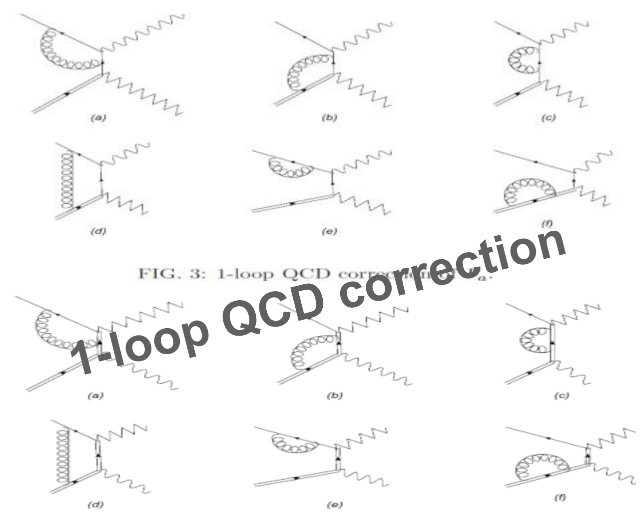
radiative decay $D^+ \to \gamma e^+ \nu_e$

- **Tree level**

No helicity suppression
No hadron in final state

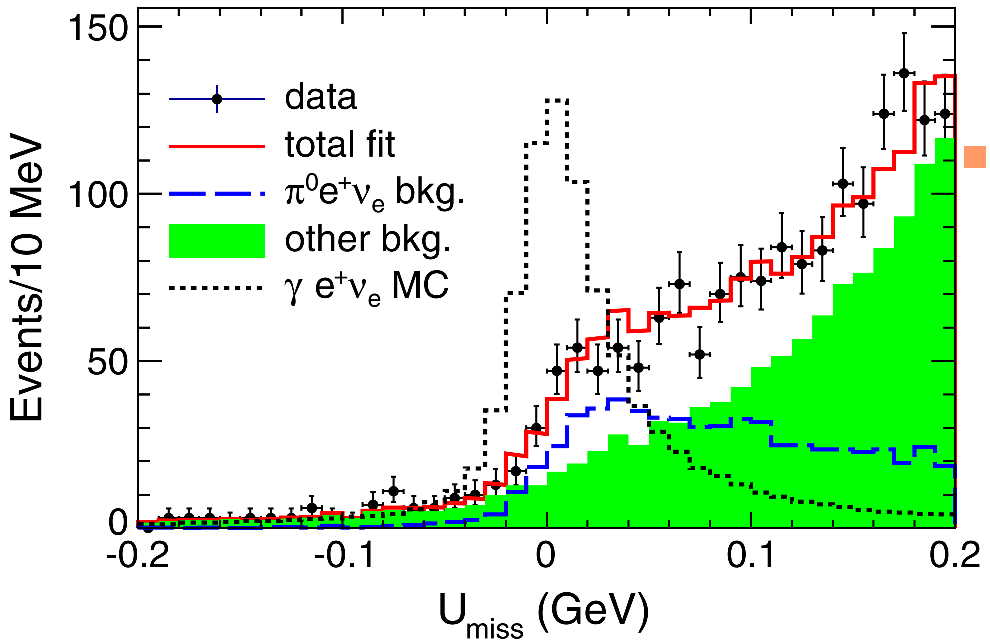






- **Figs. (a) and (b) are Structure-Dependent (SD) radiative decays,**
- **fig. (c) is the Internal Bremsstrahlung (IB) radiative decay.**
- **(d) Suppressed by a factor of $1/M_w^2$, thus can be neglected.**

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



- **Double Tag analysis with 2.9fb[-1] @3.773GeV**
- **pi0 e v background normalization with dedicate DT analysis**

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

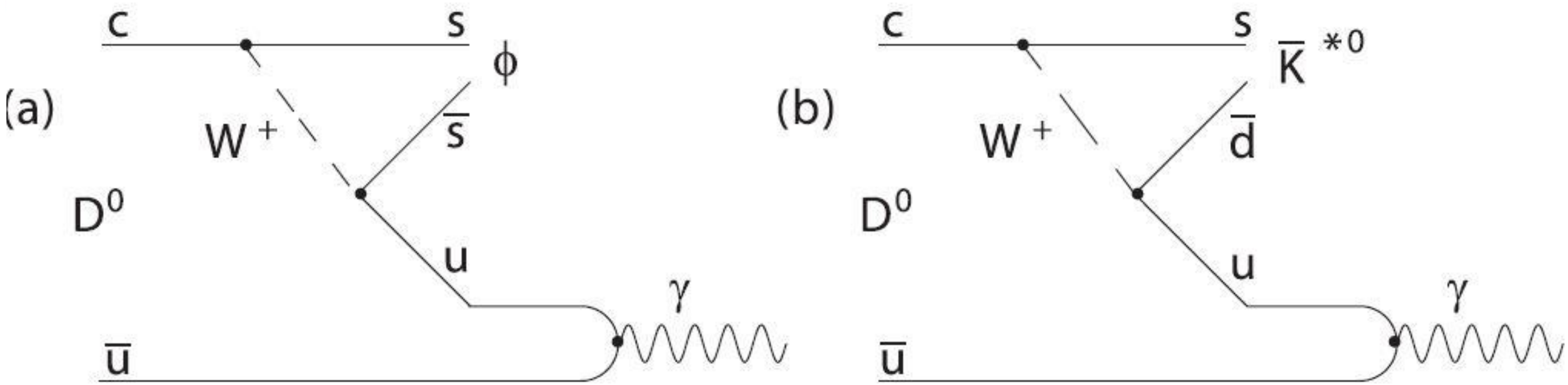
$$\mathcal{B}(D^+ \to \gamma e^+ \nu_e) < 3.0 \times 10^{-5}.$$

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]

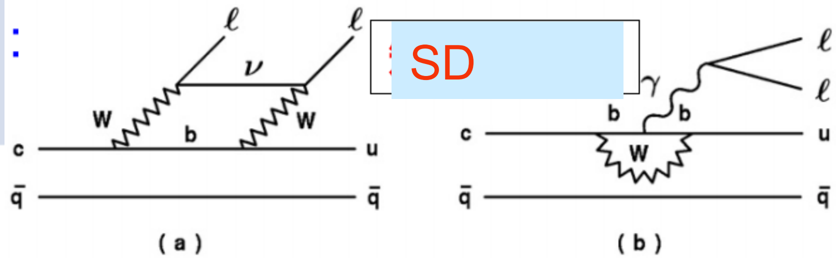
Search for $D^0 \to \gamma \bar{K}^{*0}(\phi)$



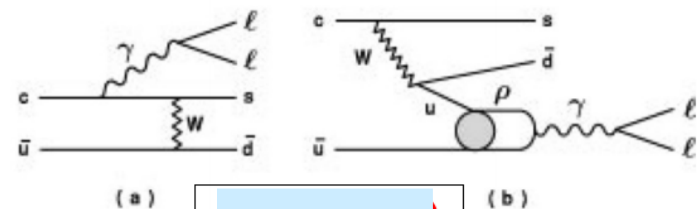
- Belle Collaboration (2004)
  - $B(D^0 \to \phi\gamma) = \left[2.60^{+0.70}_{-0.61}(stat)^{+0.15}_{-0.17}(syst)\right] \times 10^{-5}$
- BABAR Collaboration (2008)
  - $B(D^0 \to \phi\gamma) = (2.78 \pm 0.30 \pm 0.27) \times 10^{-5}$
  - $B(D^0 \to \bar{K}^{*0}\gamma) = (3.28 \pm 0.20 \pm 0.27) \times 10^{-4}$
- 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
- Not so comeptitive with more data

SD



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



LD

子

D->h(h')ee processes

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

- Flavor Changing Neutral Current (FCNC) (e.g. $D^+ \to h^+e^+e^-$) processes are expected to be very rare since it can not occur at tree level in the SM.

  Short distance: ~ $10^{-10\sim-9}$ level, MPLA8 (1993) 967

  Long distance: ~ $10^{-6\sim-5}$ level, PRD76 (2007) 074010
- Lepton Number Violation (LNV) (e.g. $D^+ \to h^-e^+e^+$) decays are forbidden in the SM, while beyond the SM, e.g.,

  Majorana neutrino: ~ $10^{-30\sim-23}$ level, PRD64 (2001) 114009

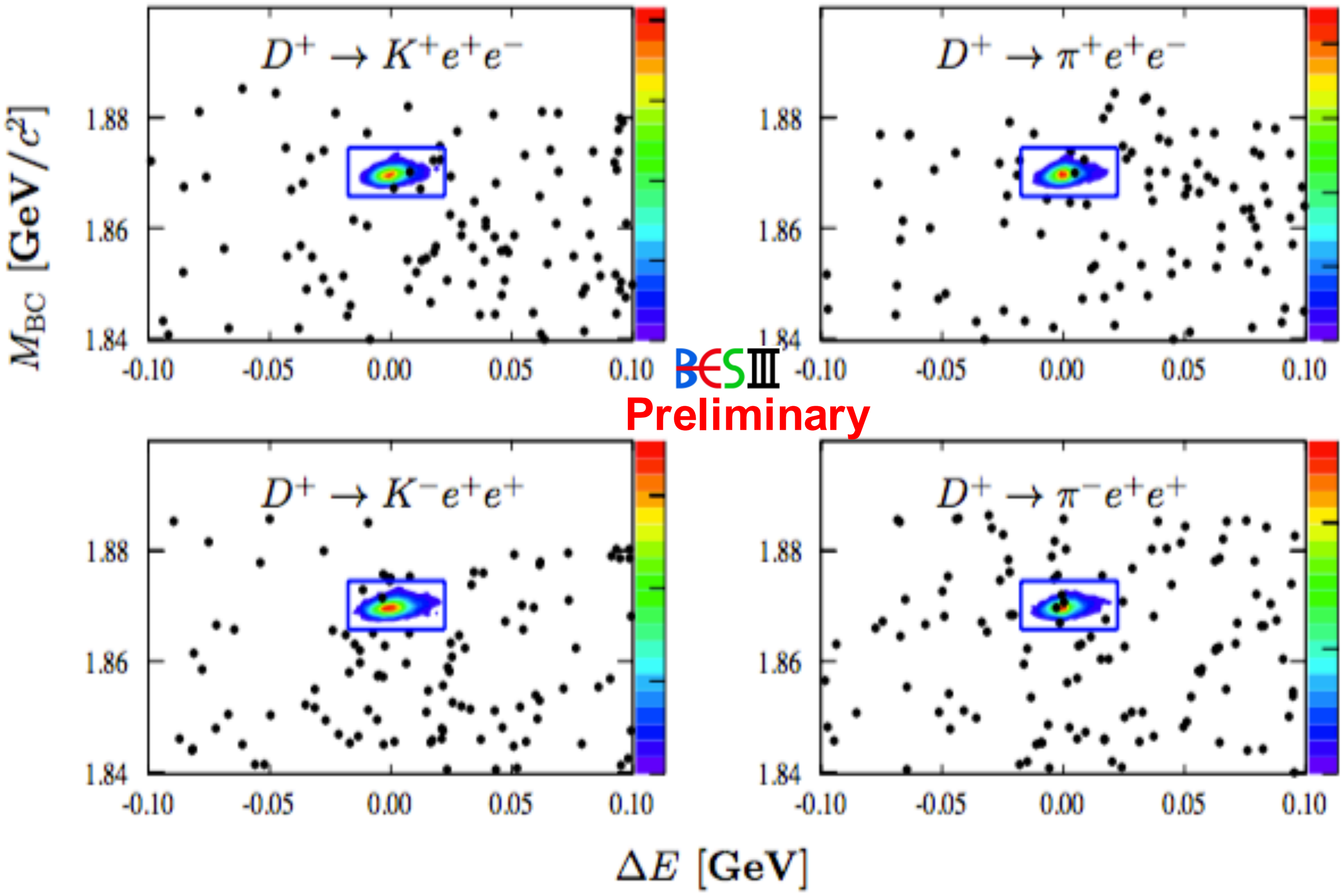
  may be greatly enhanced to ~$10^{-5\sim-6}$ with EPJC71 (2011) 1715)
- Thus, processes of the form $D^+ \to hee$ provide a sensitive and an ideal lab for investigating new physics within and beyond the SM. Any observation of definite signals would be clear evidence of NP.
- BESIII has collected a huge open charm data sample, it's expected to get better results for these decays.

Previous measurements

$\mathcal{B}(D^+ \to) \setminus [\times 10^{-6}]$	$K^+e^+e^-$	$K^-e^+e^+$	$\pi^+e^+e^-$	$\pi^-e^+e^+$
CLEO[1]	-	-	2600	-
MARK2[2]	4800	9100	2500	4800
E687[3]	200	120	110	110
E791[4]	200	-	52	96
CLEO[5]	3.0	3.5	5.9	1.1
Babar[6]	1.0	0.9	1.1	1.9
PDG[7]	1.0	0.9	1.1	1.1

[1] P. Haas et al. (CLEO Collaboration), Phys. Rev. Lett. 60, 1614 (1988).
[2] A. J. Weir et al. (MarkII Collaboration), Phys. Rev. D 41, 1384 (1990).
[3] P. L. Frabetti et al. (E687 Collaboration), Phys. Lett. B 398, 239 (1997).
[4] E. M. Aitala et al. (E791 Collaboration), Phys. Lett. B 462, 401 (1999).
[5] P. Rubin el al. (CLEO Collaboration), Phys. Rev. D 82, 092007 (2010).
[6] J. P. Lees el al. (BaBar Collaboration), Phys. Rev. D 84, 072006 (2011).
[7] K. A. Olive et al. (Particle Data Group), Chin. Phys. C, 38, 090001 (2014).

Preliminary results
(to be published)



Scatter plots for M_{BC} versus ΔE, where the signal regions are shown as a blue rectangle. The contours are determined from MC simulation to enclose 84% of signal events for each channel.

Systematic Errors

Source\[%]	$\mathcal{B}_{D^+\to K^+e^+e^-}$	$\mathcal{B}_{D^+\to K^-e^+e^+}$	$\mathcal{B}_{D^+\to \pi^+e^+e^-}$	$\mathcal{B}_{D^+\to \pi^-e^+e^+}$
$N^{tot}_{D^+}$	1.9	1.9	1.9	1.9
Tracking	3.0	3.0	3.0	3.0
Particle ID	1.2	1.2	1.2	1.2
MC modeling	1.1	1.1	1.8	1.8
Scale factor	3.7	4.6	4.2	5.3
E_{charge} Cut	0.1	0.1	0.1	0.1
M_{ee} Cut	0.1	0.1	0.1	0.1
Signal Box Cut	0.1	0.1	0.1	0.1
Total	5.4	6.1	5.9	6.8

BESIII Preliminary

D->h(h')ee processes

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]
$D^+ \to \pi^+ \pi^0 e^+ e^-$				
$D^+ \to \pi^+ K^0_S e^+ e^-$				
$D^+ \to K^+ \pi^0 e^+ e^-$				
$D^+ \to K^+ \overline{K}^0 e^+ e^-$				

- In unit of 10^{-6}
- BESIII could update all of them

D->h(h')ee: ongoing at BESIII

Signal decays	PDG [10] ($\times 10^{-5}$)
$D^+ \to \pi^+\pi^0 e^+e^-$	-
$D^+ \to K^+\pi^0 e^+e^-$	-
$D^+ \to K^0_S\pi^+ e^+e^-$	-
$D^+ \to K^0_S K^+ e^+e^-$	-
$D^0 \to K^-K^+ e^+e^-$	< 31.5
$D^0 \to \pi^+\pi^- e^+e^-$	< 37.3
$D^0 \to K^-\pi^+ e^+e^{-\dagger}$	< 38.5
$D^0 \to \pi^0 e^+e^-$	< 4.5
$D^0 \to \eta e^+e^-$	< 11
$D^0 \to \omega e^+e^-$	< 18
$D^0 \to K^0_S e^+e^-$	< 11
† in $M_{e^+e^-}$ regions:	
$[0.00,\ 0.20)$ GeV/c^2	-
$[0.20,\ 0.65)$ GeV/c^2	-
$[0.65,\ 0.90]$ GeV/c^2	-

- With double tag technique at threshold, both D0 and D+ FCNC are studied.
- UL for D+ 4-track events could be provided for 1st time
- other FCNC upper limits could be greatly improved
- divide the M(ee) distribution into 3 regions for Kpiee to help separate LD effect
- The results to be published

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

- FCNC transitions only occur at loop order in the SM
- Electro-magnetic dynamics is absent for the neutrinos
- LD contributions are suppressed to be lower than SD
- Much clean to study the FCNC transitions.

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}

Unique for BESIII, Work ongoing

Phys. Rev. D 66 014009

Belle B → h (∗) νν: Phys. Rev. Lett. 99, 221802 (2007).
BaBar B 0 →γνν: Phys. Rev. Lett. 93, 091802 (2004).

LFV, LNV, BNV processes

Incarnation in Charm

In Charm hadron decays

- Lepton Flavor Violation (LFV) processes
- Lepton Number Violation (LNV) processes
- Baryon Number Violatoin (BNV) processes

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

$\mu^\pm e^\mp$	LFV
$\pi^0 e^\pm \mu^\mp$	LFV
$\eta e^\pm \mu^\mp$	LFV
$\pi^+\pi^- e^\pm \mu^\mp$	LFV
$\rho e^\pm \mu^\mp$	LFV
$\omega e^\pm \mu^\mp$	LFV
$K^+K^- e^\pm \mu^\mp$	LFV
$\phi e^\pm \mu^\mp$	LFV
$\bar{K}^0 e^\pm \mu^\mp$	LFV
$K^-\pi^+ e^\pm \mu^\mp$	LFV
$\bar{K}^{*0} e^\pm \mu^\mp$	LFV
$\pi^\mp\pi^\mp e^\pm e^\pm$	LNV
$\pi^\mp\pi^\mp \mu^\pm \mu^\pm$	LNV
$K^\mp\pi^\mp e^\pm e^\pm$	LNV
$K^\mp\pi^\mp \mu^\pm \mu^\pm$	LNV
$K^\mp K^\mp e^\pm e^\pm$	LNV
$K^\mp K^\mp \mu^\pm \mu^\pm$	LNV
$\pi^\mp\pi^\mp e^\pm \mu^\pm$	LNV
$K^\mp\pi^\mp e^\pm \mu^\pm$	LNV
$K^\mp K^\mp e^\pm \mu^\pm$	LNV
$p e^-$	BNV+LNV
$\bar{p} e^+$	BNV+LNV

LFV and LNV processes

$\mathcal{B}(D^0 \to e^\pm \mu^\mp) < 1.5 \times 10^{-8}$ at 90% CL

$\mathcal{B}(D^+ \to \pi^- \mu^+ \mu^+) < 2.2 \cdot 10^{-8}$

$\mathcal{B}(D_s^+ \to \pi^- \mu^+ \mu^+) < 1.1 \cdot 10^{-8}$

Already very stringent limit, these are difficult for BESIII to be competetive,

but BESIII could probe

- Λ_c and Ds: LFV decays
- LNV: D->hee, hhee

- LNV : c→u$\mu^+\mu^+$ forbidden in SM

✓ Majorana neutrino: ~ $10^{-30\sim-23}$ level, PRD64 (2001) 114009

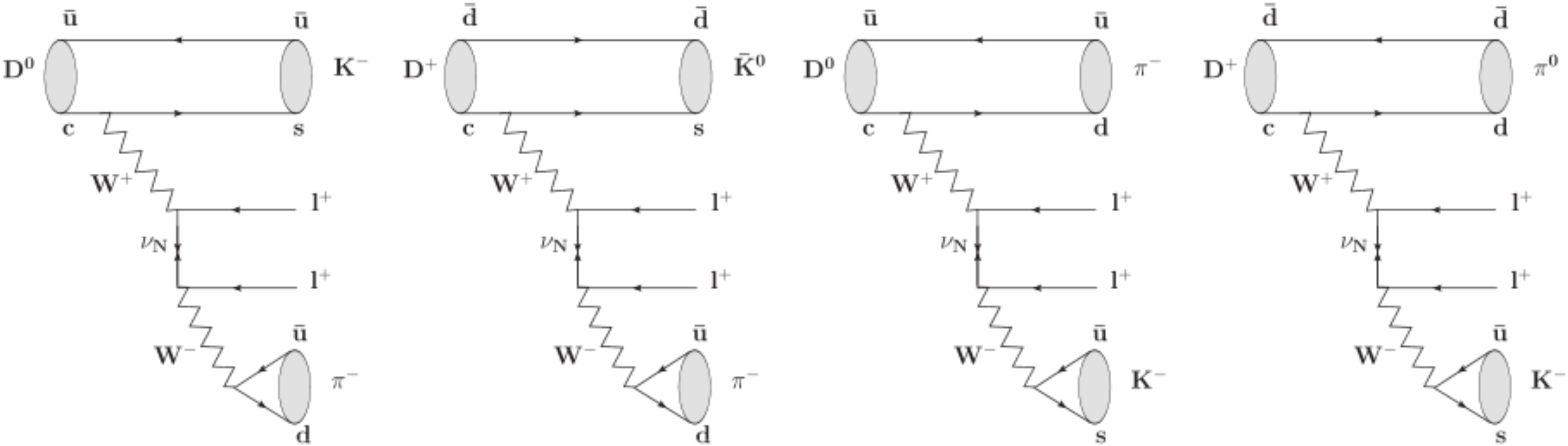
✓ May be greatly enhanced: ~$10^{-5\sim-6}$ with EPJC71 (2011) 1715)

H.R. Dong, F. Feng and H.B. Li, Chin, Phys. C **39** 013101 (2015)

- ☐ Sensitivity estimation based on MC
- ☐ comparable to the LNV B decays

LNV $D \to K\pi e^+e^+$ decays

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

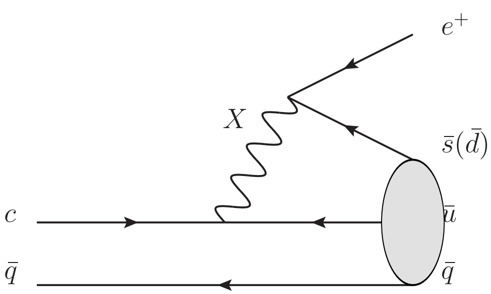


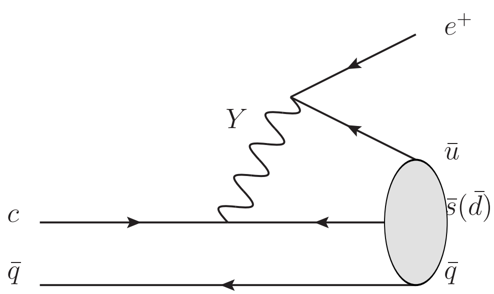
(a) $D^0 \to K^-\pi^-l^+l^+$ (CF) (b) $D^+ \to \bar{K}^0\pi^-l^+l^+$ (CF) (c) $D^0 \to K^-\pi^-l^+l^+$ (DCS) (d) $D^+ \to K^-\pi^0l^+l^+$ (DCS)

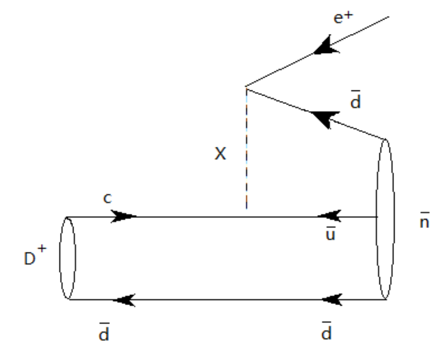
- **Lepton number violating(LNV) process ($\Delta L = 2$)**
  - **possibly due to a single Majorana neutrino exchange**
- **The best previous limit around $10^{-4} \sim 10^{-5}$ level by E791 [PRL 86, 3969(2001)].**
- **BESIII could improve it to $\sim 10^{-6}$**
- **Further constrain mass-dependent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

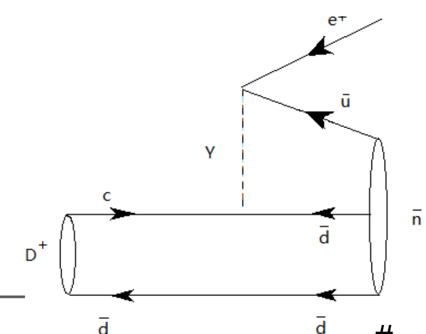
BNV & LNV processes

D+->Lambda-bar(Sigma-bar)e+
Ds->Lambda e
D+ ->nbar e+
D0 ->pbar e+
All started at BESIII, will benefit from the final charm dataset





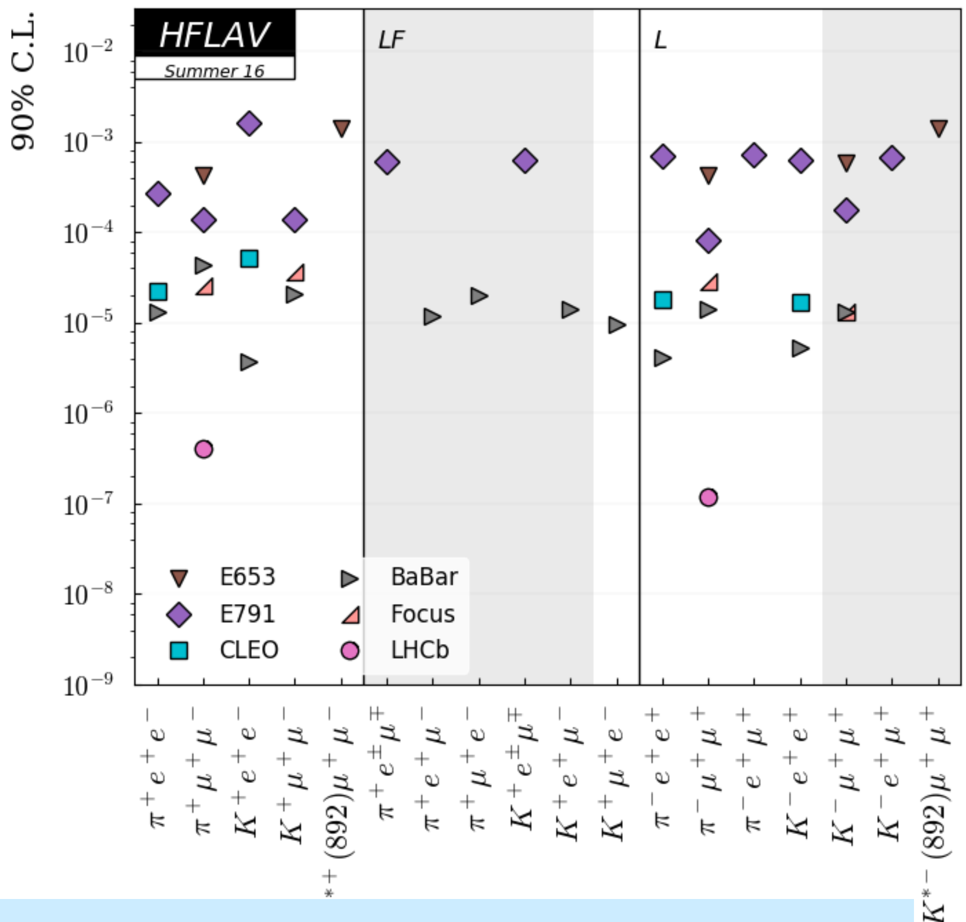


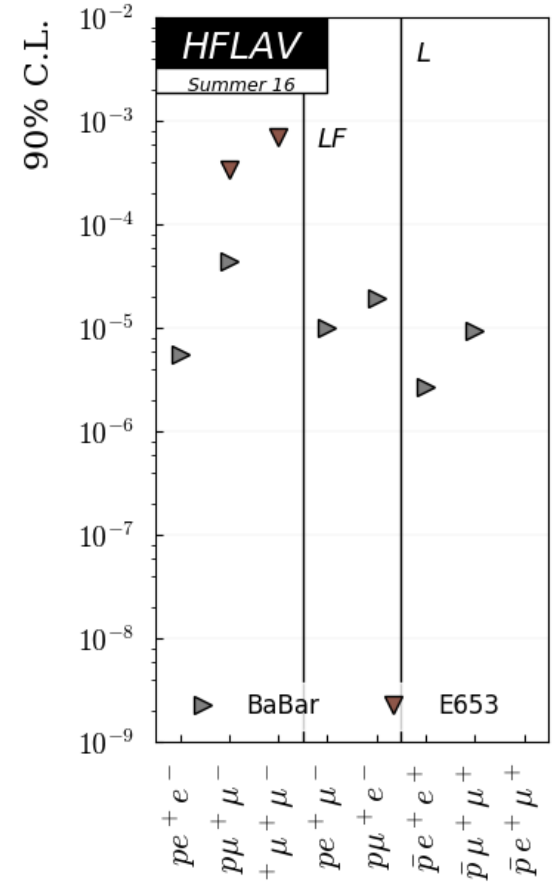


Many standard model (SM) extensions and Grand Unified Theories (GUTs) such as superstring models and SUSY predict proton decays. In this case, baryon number is violated while the difference $\Delta(\mathrm{B}-\mathrm{L})$ is conserved.

In the assumption of the heavy bosons X (4/3e) and Y (1/3e), there exists baryon number violation processes via $c(u)X\bar{u}$ or $c(u)Y\bar{d}(\bar{s})$ coupling.

Other rare D_s and Λ_c Decays





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

Special for BESIII: weak radiative decay

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

BESIII Reach of rare charm decays

SM predictions

Experimental reaches

SM predictions	Decays		Experimental reaches
10^{-1}			
10^{-2}	Cabibbo favored		
10^{-3}	Singly Cabibbo suppressed		
10^{-4}	Doubly Cabibbo suppressed		CLEO-c
10^{-5}			
10^{-6}	Radiative decays	$D^0 \to \overline{K}^{*0}\gamma / \phi\gamma / \rho\gamma / \omega\gamma$	BESIII
10^{-7}		$D^+ \to K^{*+}\gamma / \rho^+\gamma$ $\quad D_S^+ \to K^{*+}\gamma / \rho^+\gamma$	BESIII final/B factory
10^{-8}	Long distance: Vector meson Dominance	$D^0 \to \gamma\gamma / VV'(\to ll) / hV(\to ll) / hh'V(\to ll)$	LHCb
10^{-9}			Super-B
10^{-10}			Super-τ-charm
10^{-11}	Short distance FCNC	$D^0 / D^+ \to \gamma\gamma / Vl^+l^- / hl^+l^- / hh'l^+l^-$	
10^{-12}		$D^0 \to \mu^+\mu^-$	
10^{-13}		$D^0 \to e^+e^-$	
10^{-14}			
10^{-15}		$D \to (h)\mu^+e^-$	
	Forbidden decays: LNV, LFV, BNV	$D \to (hh)e^+e^+ / (hh)\mu^+\mu^+$	

Haibo Li

Thanks!

Extra slides…

Preliminary results (to update soon)

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

- Where s_{90} is estimated with **TROLKE** program, and the upper limit of branching fraction is calculated by

$$\mathcal{B} < \frac{s_{90}}{N^{tot}_{D^+}}$$

- where $N^{tot}_{D^+} = (1.681 \pm 0.032) \times 10^7$

FCNC processes $b \to (X)\mu^+\mu^-$: golden indirect probes of NP

clean exp signature; robust theory calc; high sensitivity

Effective theory: model independent descriptions

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{\text{tb}} V_{\text{tq}}^* \sum_i \underbrace{\mathcal{C}_i \mathcal{O}_i}_{\text{Left handed}} + \underbrace{\mathcal{C}'_i \mathcal{O}'_i}_{\text{Right handed, } \frac{m_s}{m_b} \text{ suppressed}} + \sum \frac{c}{\Lambda_{\text{NP}}^2} \mathcal{O}_{\text{NP}}$$

$i = 1, 2$	Tree
$i = 3-6, 8$	Gluon penguin
$i = 7$	Photon penguin
$i = 9, 10$	EW penguin
$i = S, P$	(Pseudo)scalar penguin

Different processes have sensitivities to different operators

Operator $\mathcal{O}_i$	$B_{s,d} \to X_{s,d}\mu^+\mu^-$	$B_{s,d} \to \mu^+\mu^-$	$B_{s,d} \to X_{s,d}\gamma$
$\mathcal{O}_7 \sim m_b(\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu}$	✓		✓
$\mathcal{O}_9 \sim (\bar{s}_L \gamma^\mu b_L)(\bar{\ell}\gamma_\mu \ell)$	✓		
$\mathcal{O}_{10} \sim (\bar{s}_L \gamma^\mu b_L)(\bar{\ell}\gamma_5\gamma_\mu \ell)$	✓	✓	
$\mathcal{O}_{S,P} \sim (\bar{s}b)_{S,P}(\bar{\ell}\ell)_{S,P}$	(✓)	✓	