Charm Rare Decays at BESIII

Dayong Wang
dayong.wang@pku.edu.cn
(for BESIII Collaboration)

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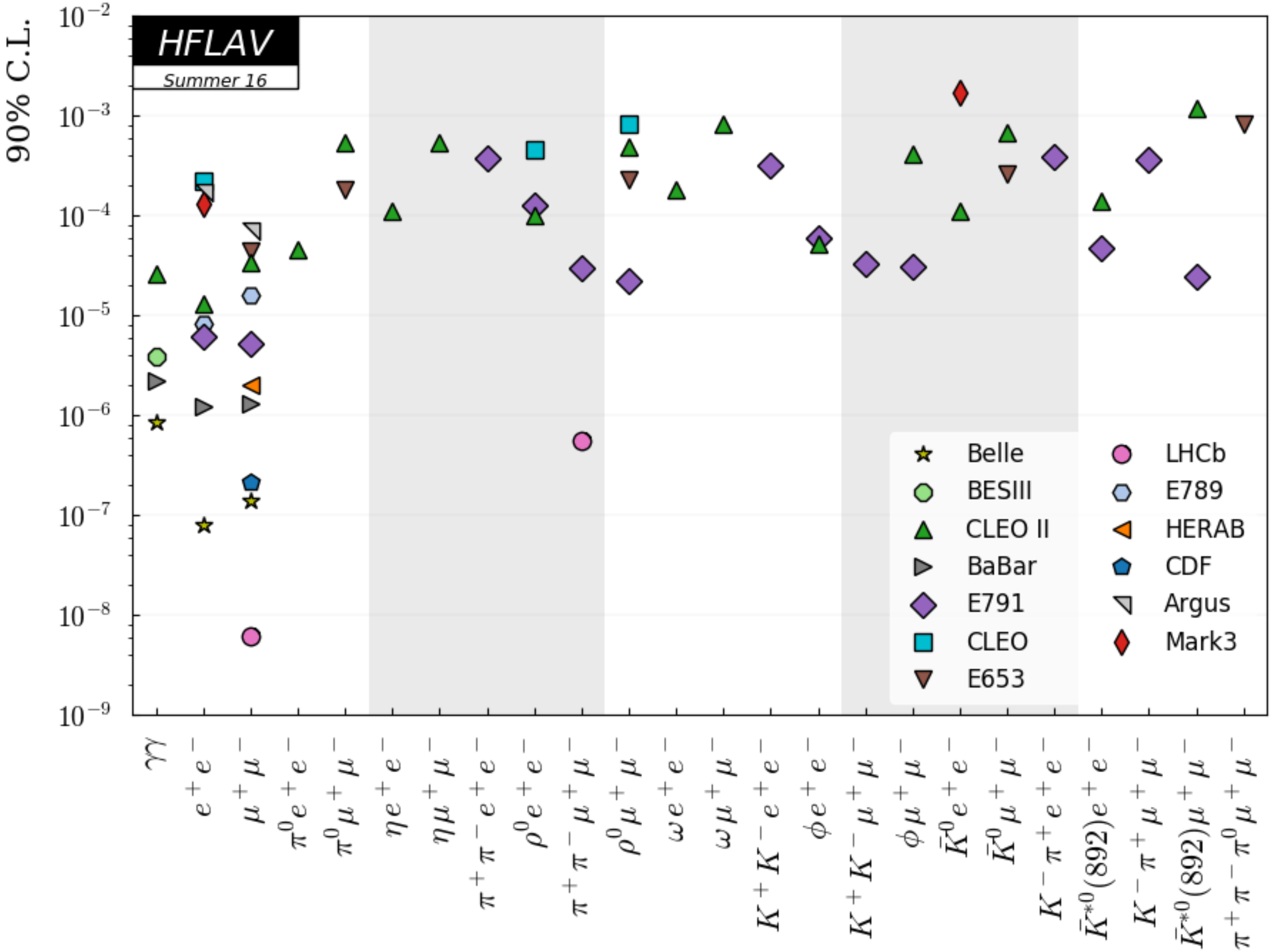
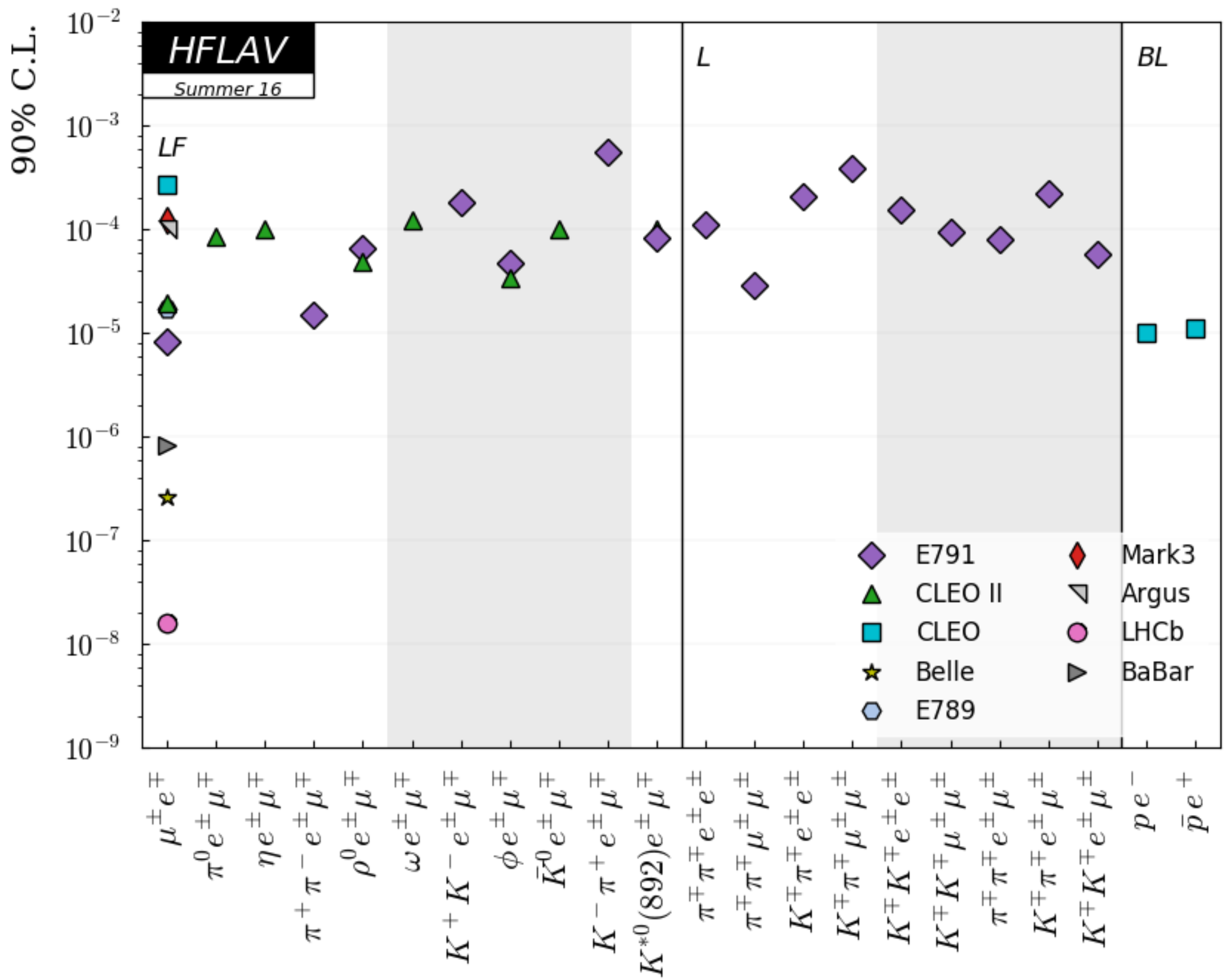
- **Rare charm decays offer the possibility to search for signals beyond Standard Model in the up-quark sector.**
  - **There might be CP conserving and CP violating contributions within the Standard Model and beyond**
- **Will focus on**
  - **FCNC c->u： c->u l l, c->u gamma**
  - **LFV, LNV, LNV & BNV**
- **Refer to other BESIII talks:**

	BESIII 实验上粲重子 Λc+研究现状		李培荣
	BESIII D0/+介子纯轻和半轻实验研究		方易
	BESIII DS+衰变实验研究		李蕾
	prospect of Charm physics at BESIII		吕晓睿

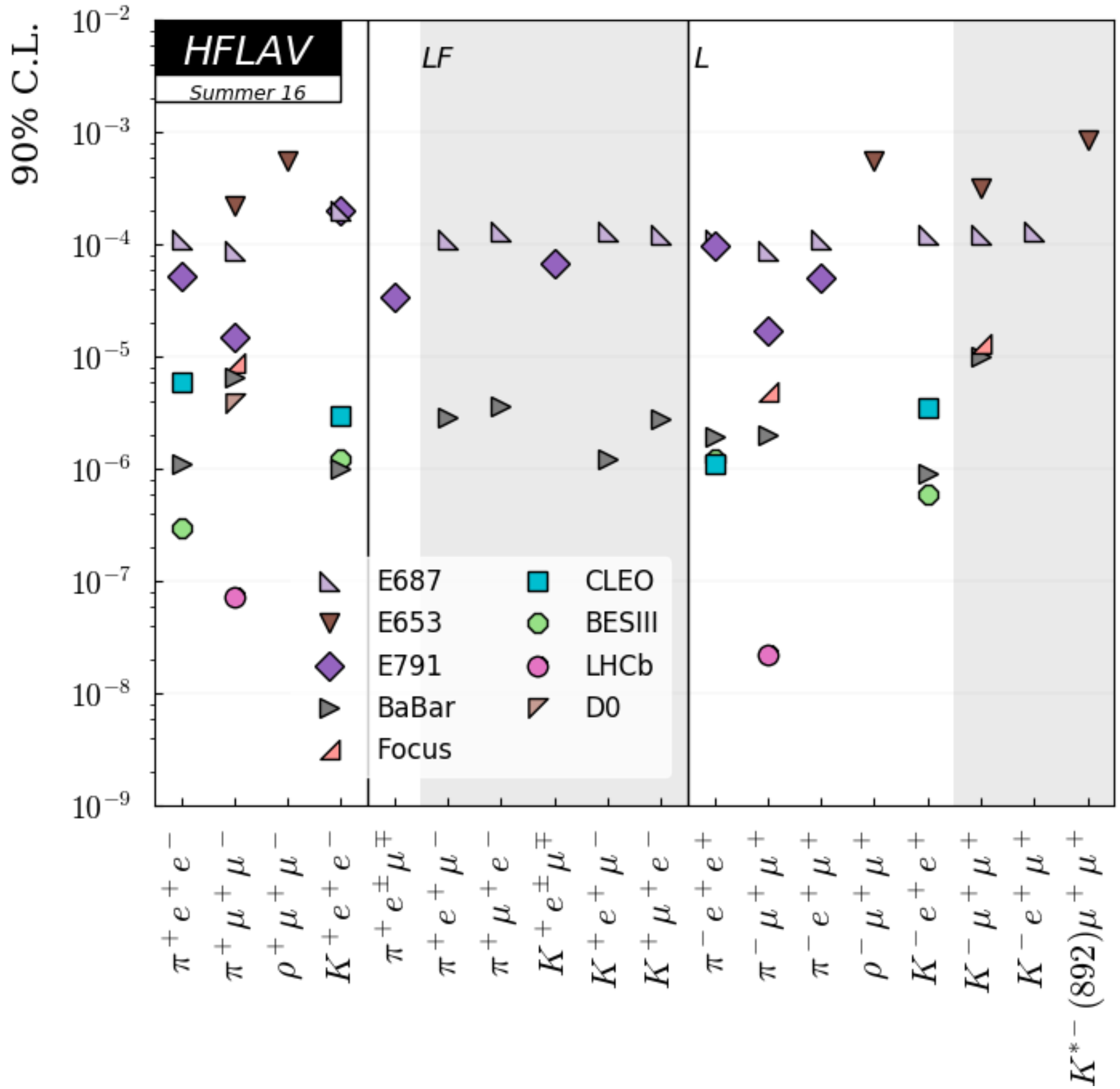
Rare D^0 Decays (I)



Rare D^0 Decays (II)



Rare D^+ Decays



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	$e^+e^-(\psi(3770))$	1.4×10^8 DD
LHCb	pp	$\sim10\times10^9$

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

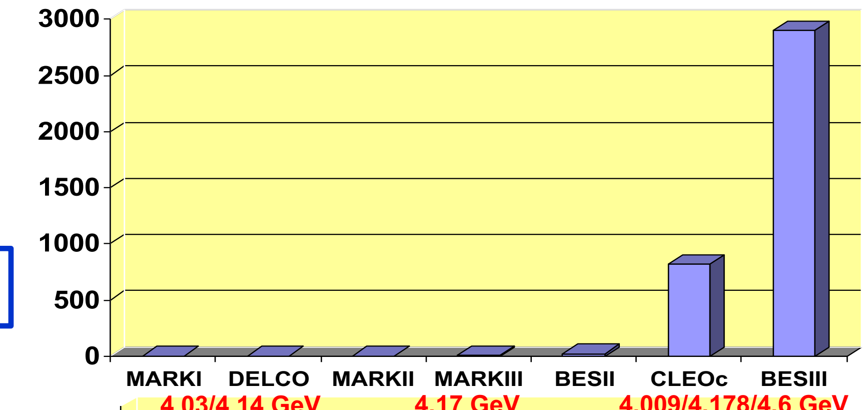
~ 0.482/fb 4.009 Ds study

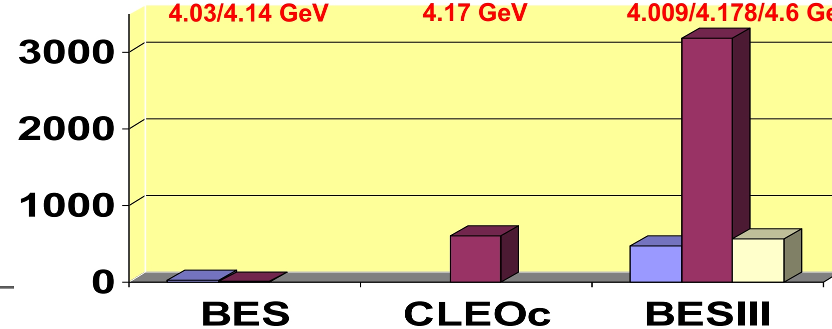
~ 0.6/fb Λ_c pairs at threshold Unique

~ 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)

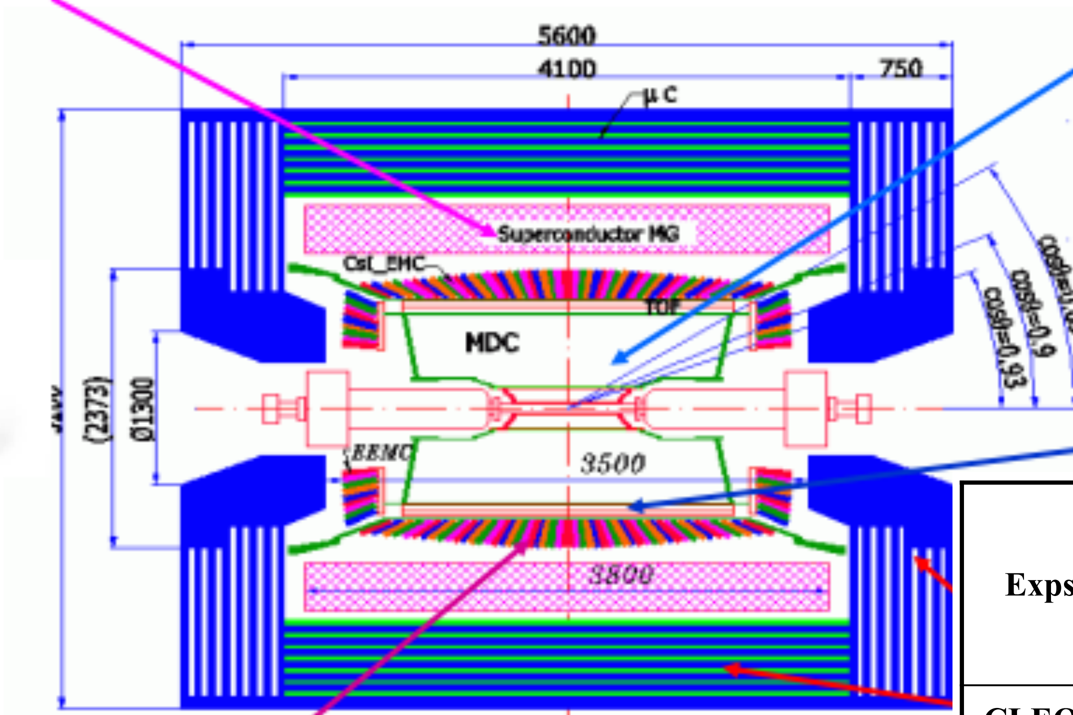
~ other data sets: tau, resonance scan and continuum, etc.





BESIII Detector

Magnet: 1 T Super conducting



Ref:
NIM A614, 345 (2010)

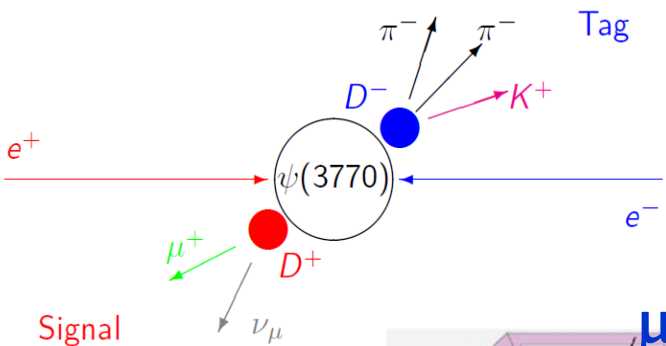
2015 ETOF upgrade: 60ps

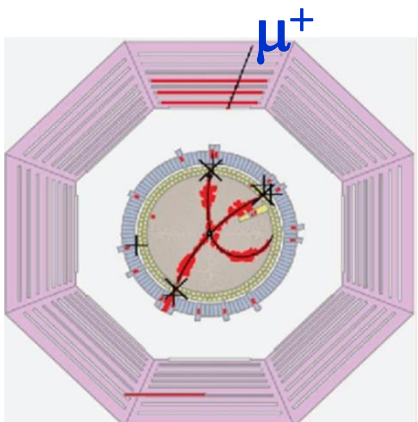
2018: Inner upgrade?

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

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

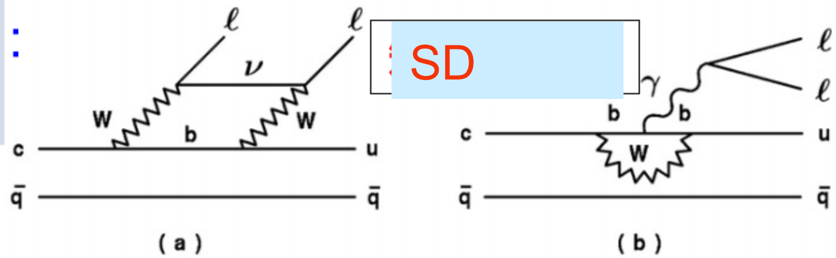
$$M_{\rm BC} = \sqrt{E^2_{\rm beam} - p^2_{\bar{D}_{\rm tag}}}$$

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

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

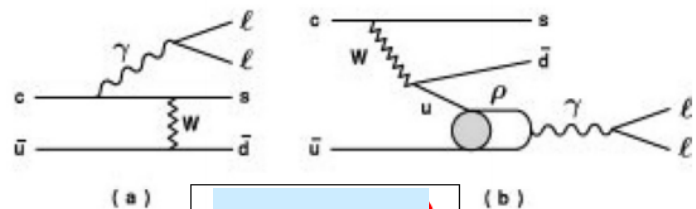
$$U_{\rm miss} \equiv E_{\rm miss} - |\vec{p}_{\rm miss}| \sim 0$$

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



SD

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



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LD

FCNC processes

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}

Phys. Rev. D 66 014009

Unique for BESIII

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

D^0->γγ: Motivation

- FCNC mode, forbidden at tree level

→ Larger GIM suppression

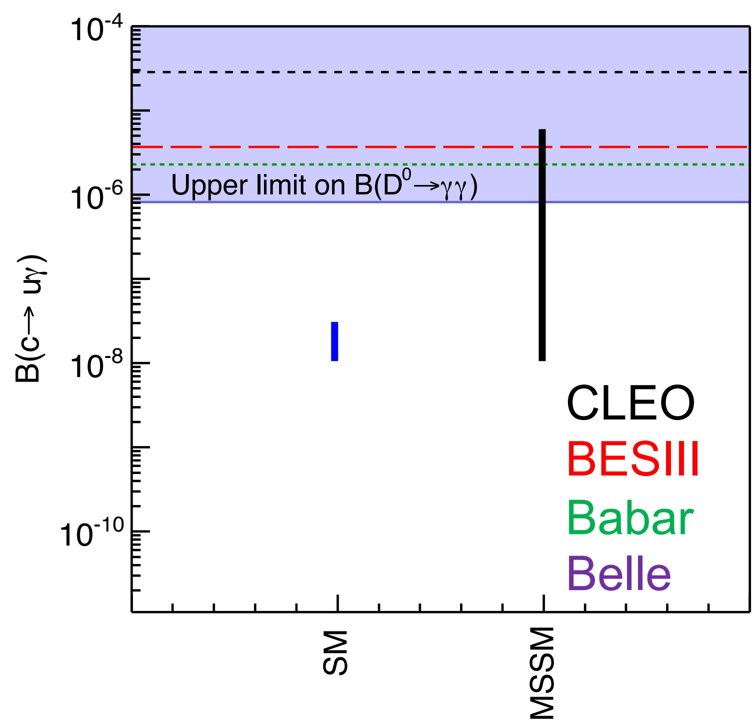
→ Short distance: BF~10^{-11} [PRD66 (2002) 014009]

→ Long distance due to VMD: BF~10^{-8} [PRD66 (2002) 014009]

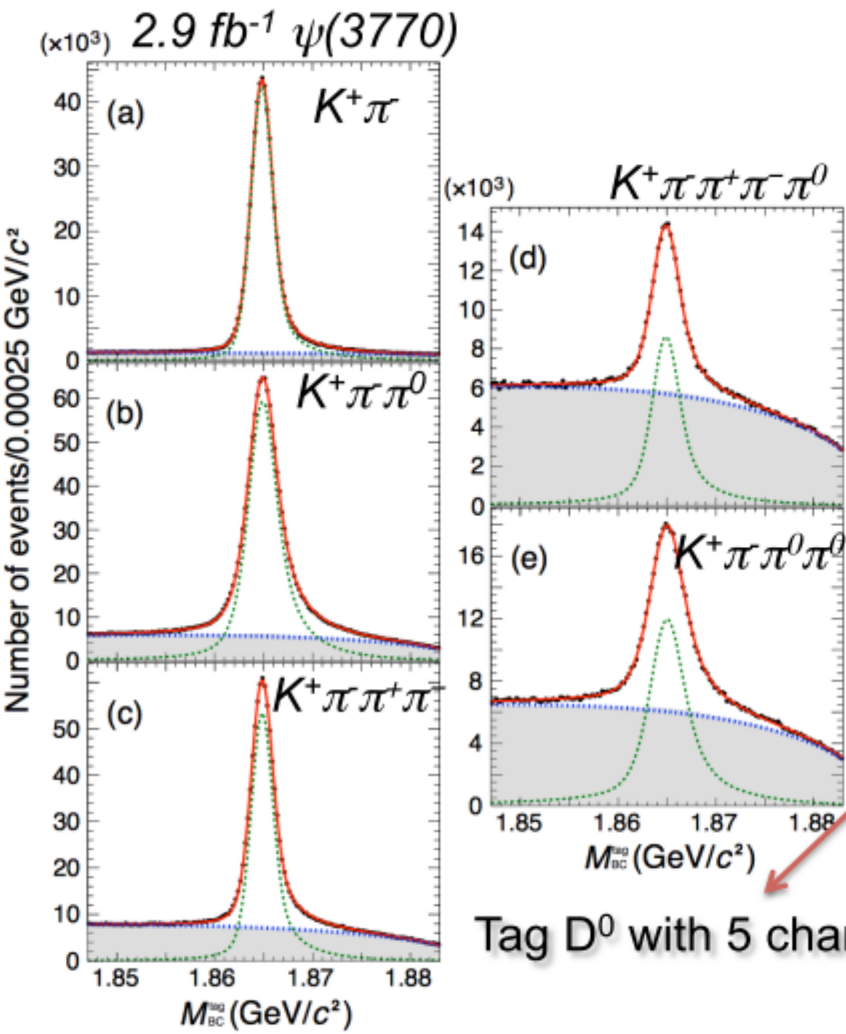
→ MSSM up to BF~10^{-6} [PLB500(2001)304], i.e. c→uγ via gluino exchange

- **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^{0}pi^0**



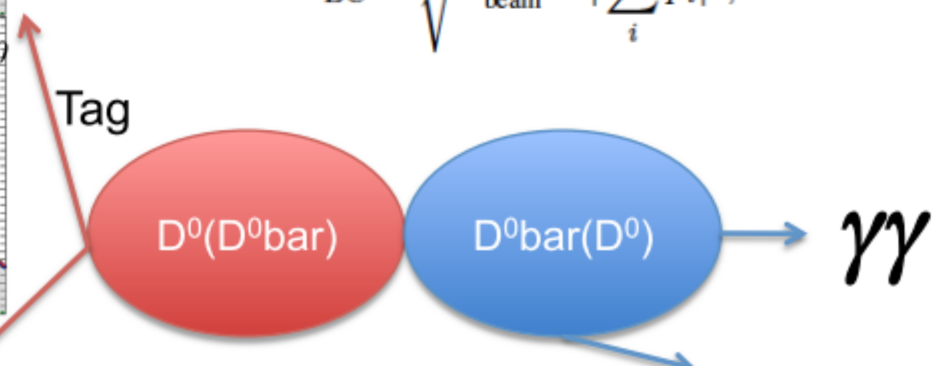
$D^0 \to \gamma\gamma$: analysis method



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:

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

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



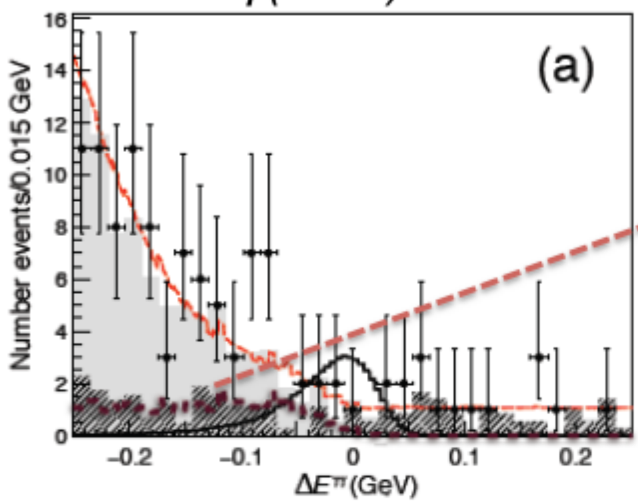
Tag D^0 with 5 channels on tag side.

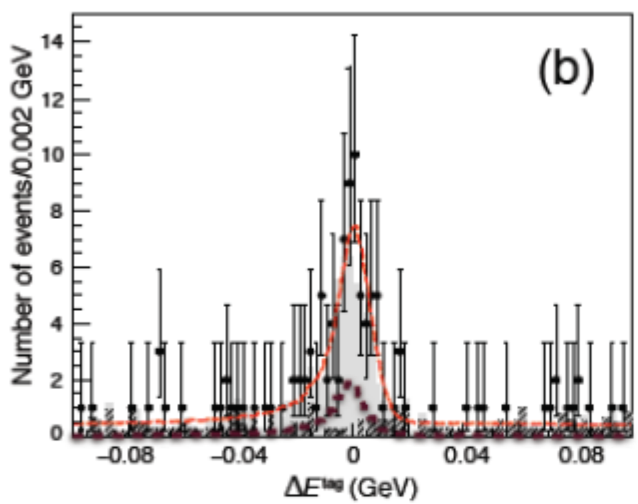
Cut on M_{BC} on the tag side, and search for $\gamma\gamma$ in $\Delta E_{\gamma\gamma}$ on the recoiling side

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

$D^0 \to \gamma\gamma$ Results

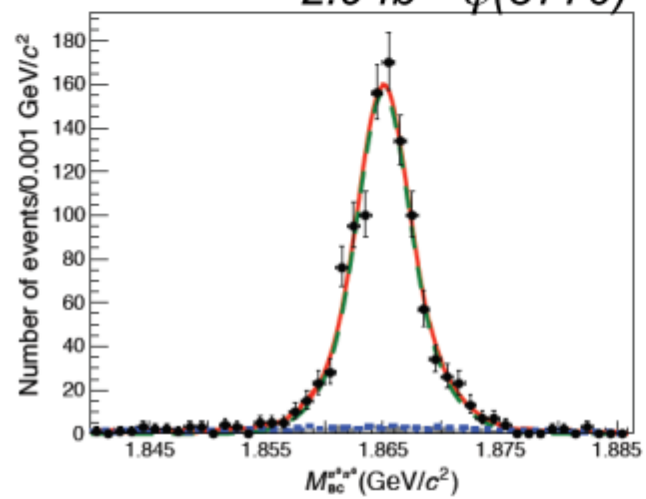
2.9 fb^{-1} $\psi(3770)$





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

2.9 fb^{-1} $\psi(3770)$



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

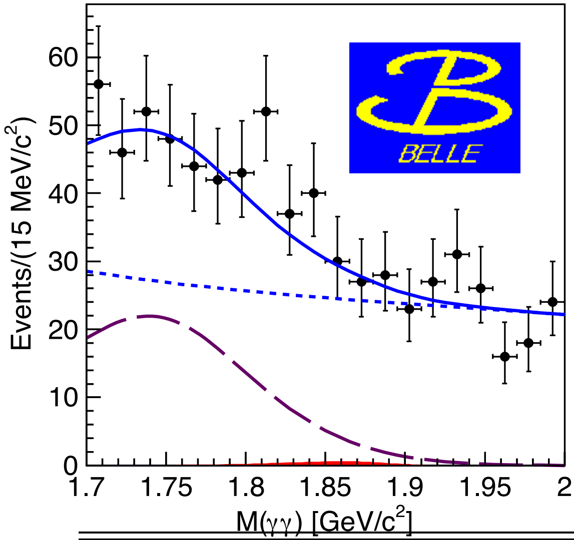
2-D fit to ΔE in both tag side and $\gamma\gamma$ sides to determine $D^0 \to \gamma\gamma$ yield.

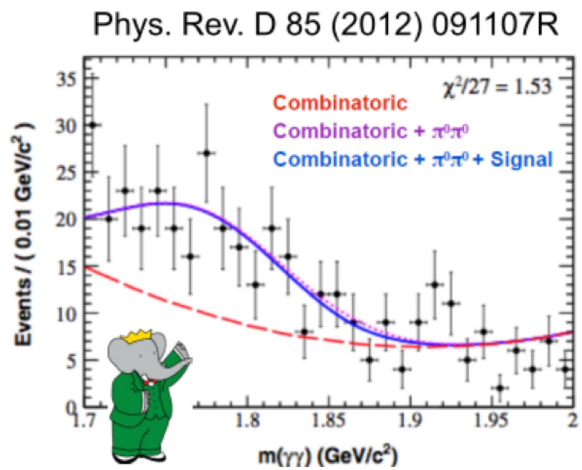
$$B(D^0 \to \gamma\gamma) < 3.8 \times 10^{-6}$$

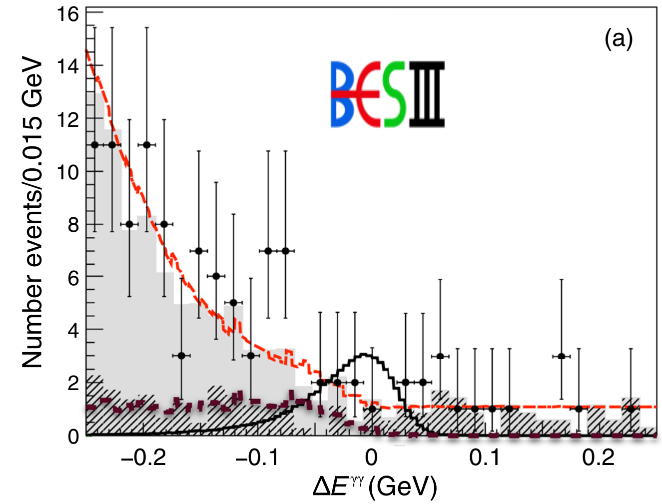
PRD91, 112015 (2015)

Comparison and prospects

PhysRevD(2016).93.051102







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
$M_{BC}^{\gamma\gamma}$ requirement	3.1
ST D^0 yields	1.0
Total	3.8

- BESIII has the least background contamincation
- 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 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
- Work in progress, will come soon

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

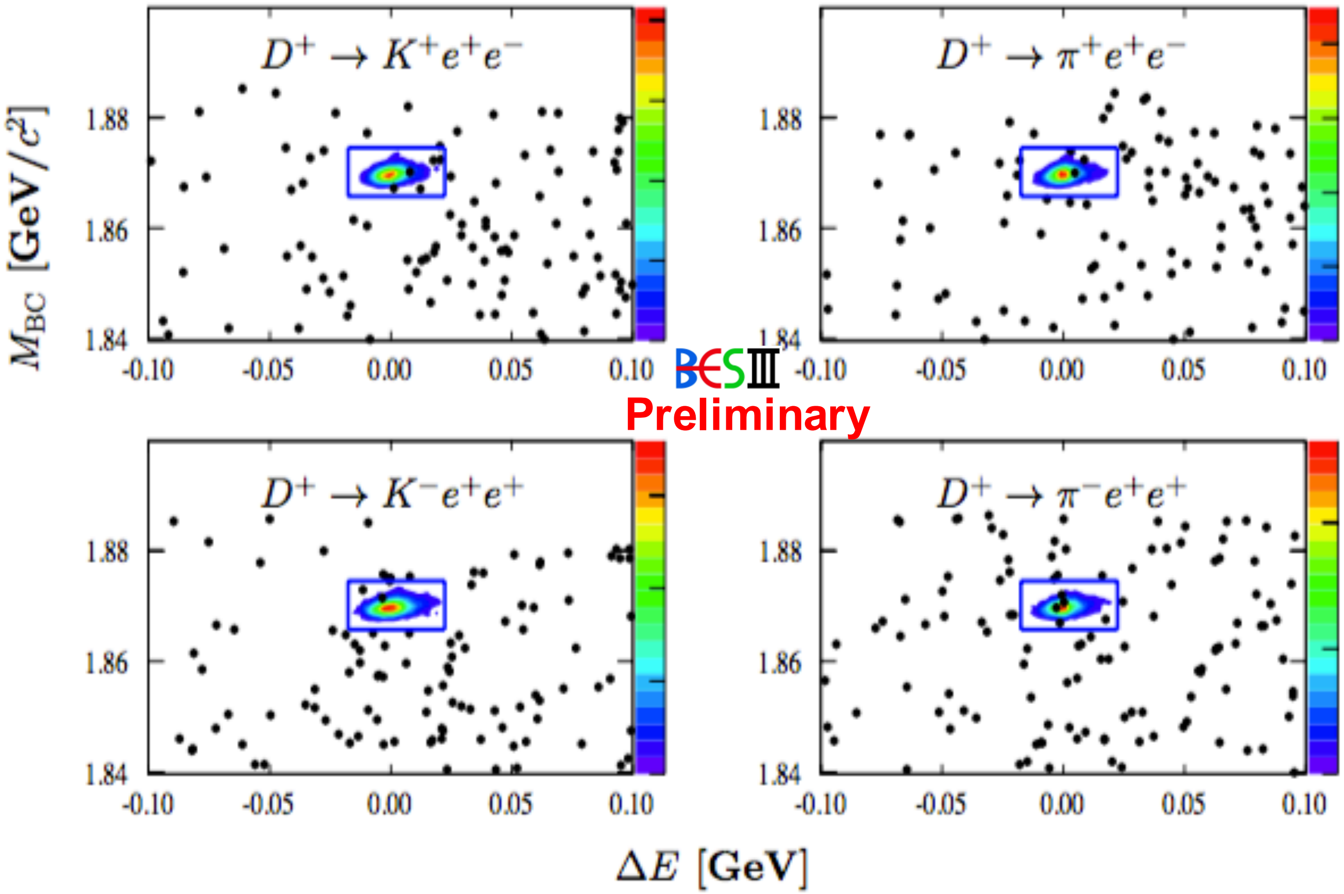
  may be greatly enhanced to ~$10^{-5\sim-6}$ with EPJC71 (2011) 1715)
- Thus, processes of the form $D^+ \to hee$ provide a sensitive and an ideal lab for investigating new physics within and beyond the SM. Any observation of definite signals would be clear evidence of NP.
- BESIII has collected a huge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

Current Status

$\mathcal{B}(D^+ \to) \setminus [\times 10^{-6}]$	$K^+e^+e^-$	$K^-e^+e^+$	$\pi^+e^+e^-$	$\pi^-e^+e^+$
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 update soon)



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.

Preliminary results (to update soon)

BESIII Preliminary

	$N_{\mathrm{inside}}^{\mathrm{data}}$	$N_{\mathrm{outside}}^{\mathrm{data}}$	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

$$\mathcal{B} < \frac{s_{90}}{N_{D^+}^{\mathrm{tot}}}$$

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

Systematic Errors

BESIII Preliminary

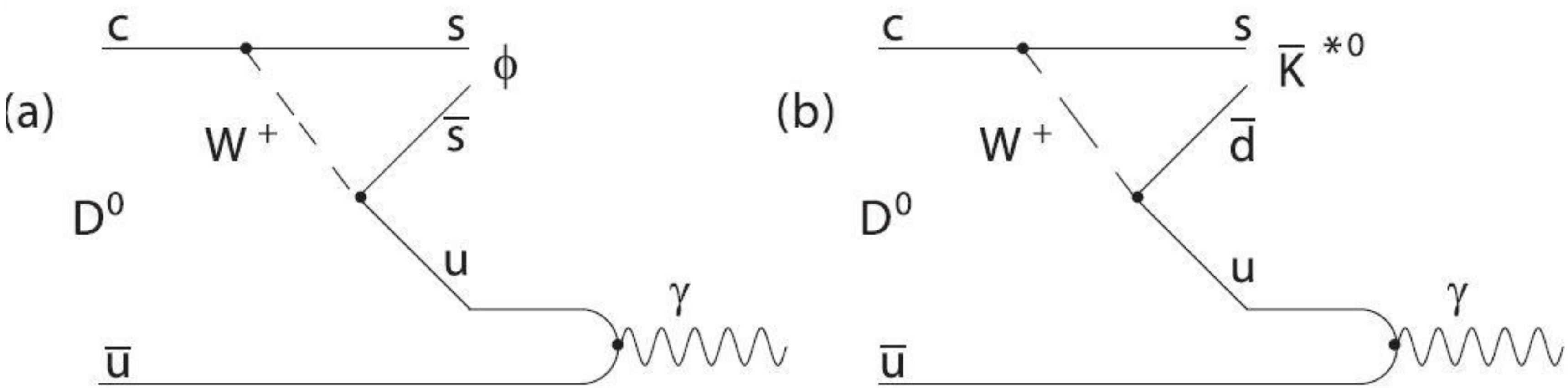
Source\[%]	$\mathcal{B}_{D^+\to K^+e^+e^-}$	$\mathcal{B}_{D^+\to K^-e^+e^+}$	$\mathcal{B}_{D^+\to \pi^+e^+e^-}$	$\mathcal{B}_{D^+\to \pi^-e^+e^+}$
$N_{D^+}^{\rm tot}$	1.9	1.9	1.9	1.9
Tracking	3.0	3.0	3.0	3.0
Particle ID	1.2	1.2	1.2	1.2
MC modeling	1.1	1.1	1.8	1.8
Scale factor	3.7	4.6	4.2	5.3
$E_{\rm charge}$ 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

More FCNC decays in 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**
- **Work in progress, to come out soon**

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

Symmetry breaking processes

Symmetry breaking process: possibilities

In Charm meson 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
pe^-	BNV+LNV
$\bar{p}e^+$	BNV+LNV

Lepton number violation

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

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

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

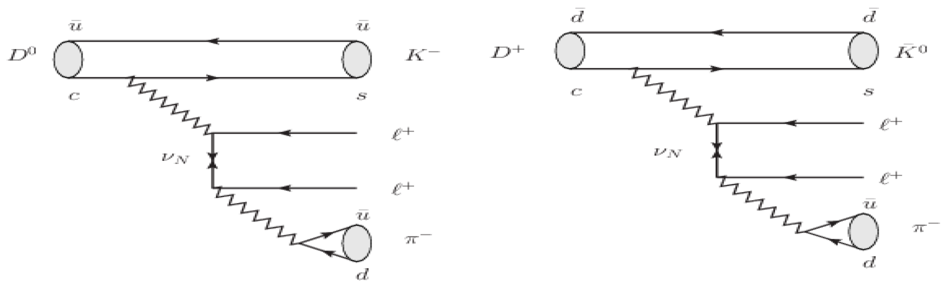
These are difficult for BESIII to be competetive,

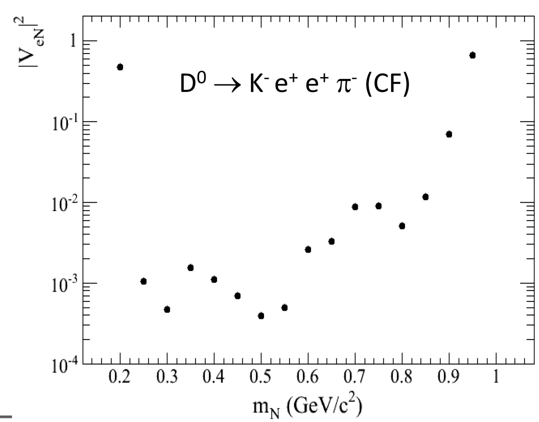
- LNV : $c \to u\mu^+\mu^+$ forbidden in SM

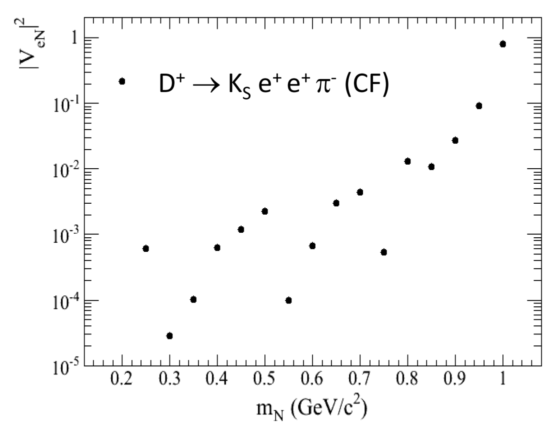
✓ Majorana neutrino: ~ $10^{-30\sim-23}$ level, PRD64 (2001) 114009

✓ 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)



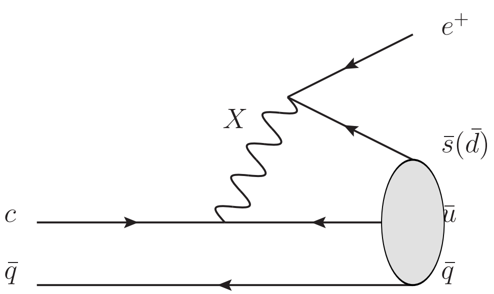


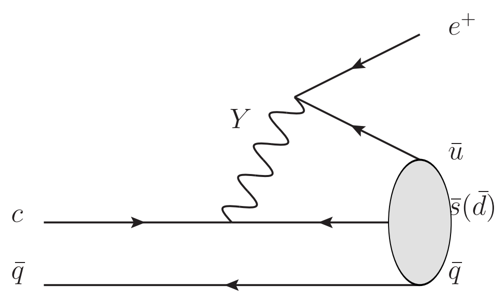


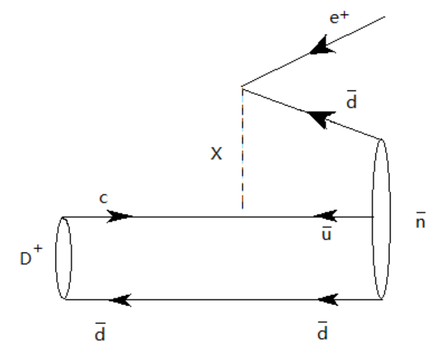
- ☐ Sensitivity estimation based on MC
- ☐ competitive to the LNV B decays
- ☐ Work is ongoing

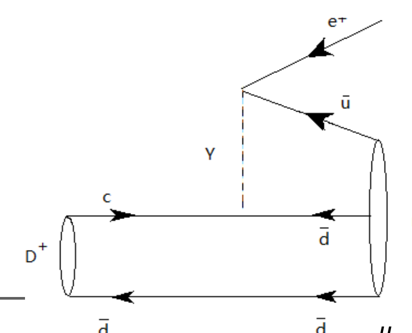
BNV & LNV processes

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





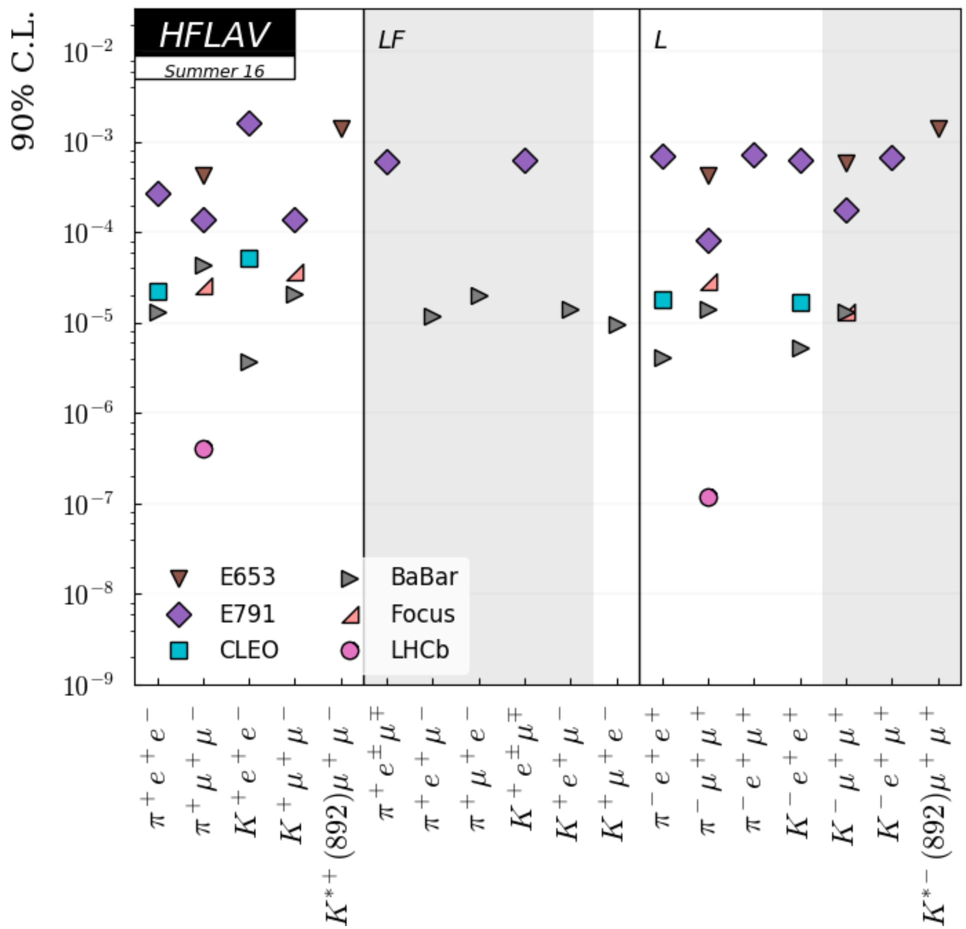


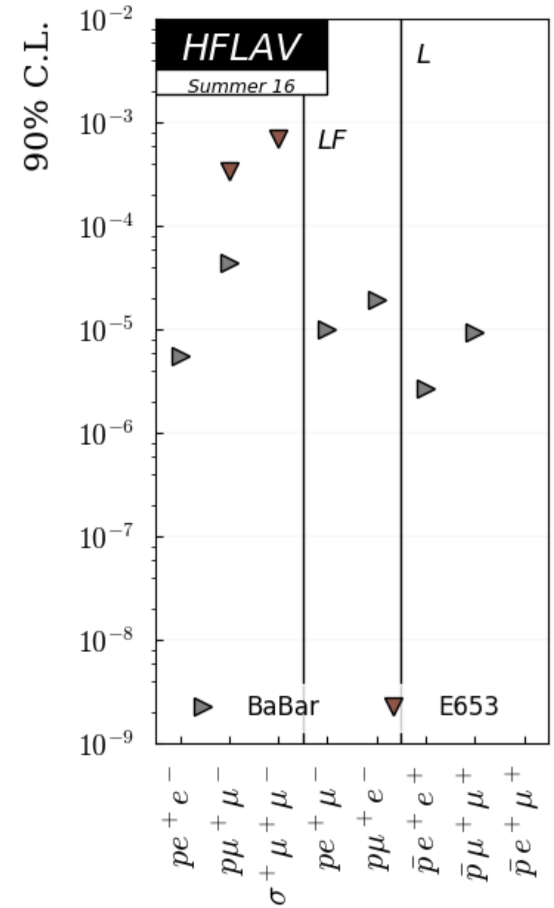


Many standard model (SM) extensions and Grand Unified Theories (GUTs) such as superstring models and SUSY predict proton decays. In this case, baryon number is violated while the difference $\Delta(\mathrm{B}-\mathrm{L})$ is conserved.

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.

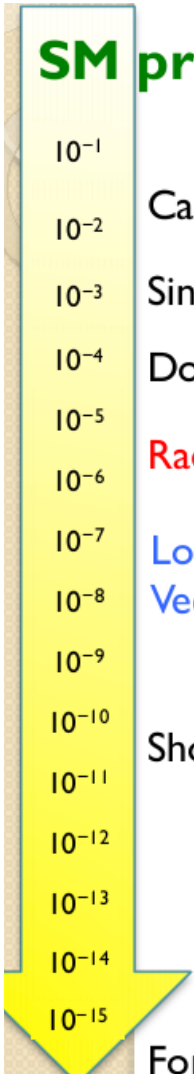
Rare D_s and Λ_c Decays





Special for BESIII: $\Lambda_c^+ \to \gamma\Sigma^+$

Reach of rare charm decays



SM predictions

Experimental reaches

Cabibbo favored

Singly Cabibbo suppressed

Doubly Cabibbo suppressed

Radiative decays $D^0 \to \overline{K}^{*0}\gamma / \phi\gamma / \rho\gamma / \omega\gamma$

$D^+ \to K^{*+}\gamma / \rho^+\gamma \quad D_S^+ \to K^{*+}\gamma / \rho^+\gamma$

Long distance:
Vector meson Dominance $D^0 \to \gamma\gamma / VV'(\to ll) / hV(\to ll) / hh'V(\to ll)$

CLEO-c
BESIII
BESIII final/B factory

LHCb
Super-B
Super-τ-charm

Short distance FCNC $D^0 / D^+ \to \gamma\gamma / Vl^+l^- / hl^+l^- / hh'l^+l^-$

$D^0 \to \mu^+\mu^-$

$D^0 \to e^+e^-$

Haibo Li

$D \to (h)\mu^+e^-$

Forbidden decays: LNV, LFV, BNV $D \to (hh)e^+e^+ / (hh)\mu^+\mu^+$

Thanks!

Extra slides…

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

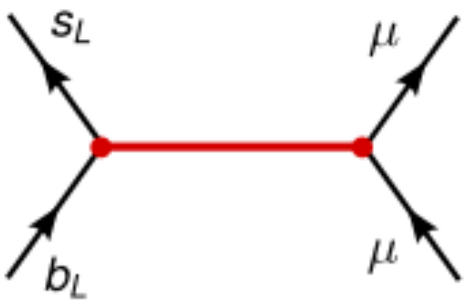
$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{\rm tb} V_{\rm tq}^* \sum_i \underbrace{\mathcal{C}_i \mathcal{O}_i}_{\text{Left handed}} + \underbrace{\mathcal{C}_i' \mathcal{O}_i'}_{\text{Right handed, } \frac{m_s}{m_b} \text{ suppressed}} + \sum \frac{c}{\Lambda_{\rm NP}^2} \mathcal{O}_{\rm NP}$$

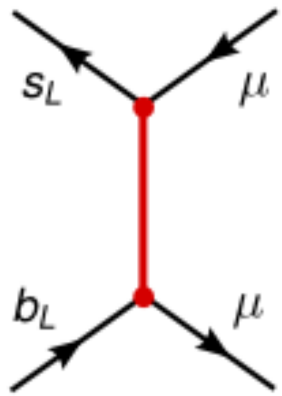
$i = 1, 2$	Tree
$i = 3-6, 8$	Gluon penguin
$i = 7$	Photon penguin
$i = 9, 10$	EW penguin
$i = S, P$	(Pseudo)scalar penguin

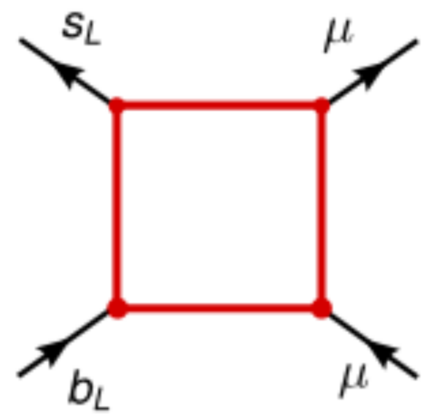
Different processes have sensitivities to different operators

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

Different NP models







- **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 …