Experimental status of rare D decays

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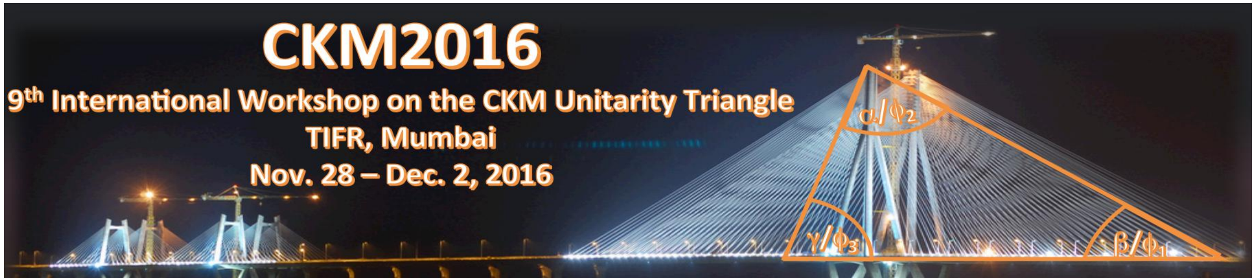
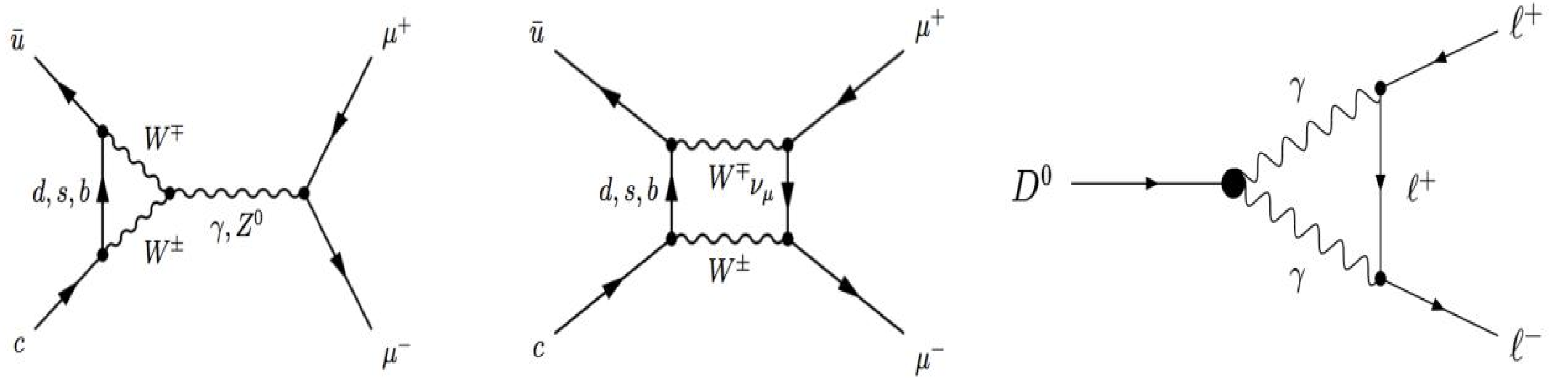
BESIII



Introduction

- **Flavor-changing neutral currents (FCNC)** are forbidden at tree level in the Standard Model (SM), only possible via loops, such as:



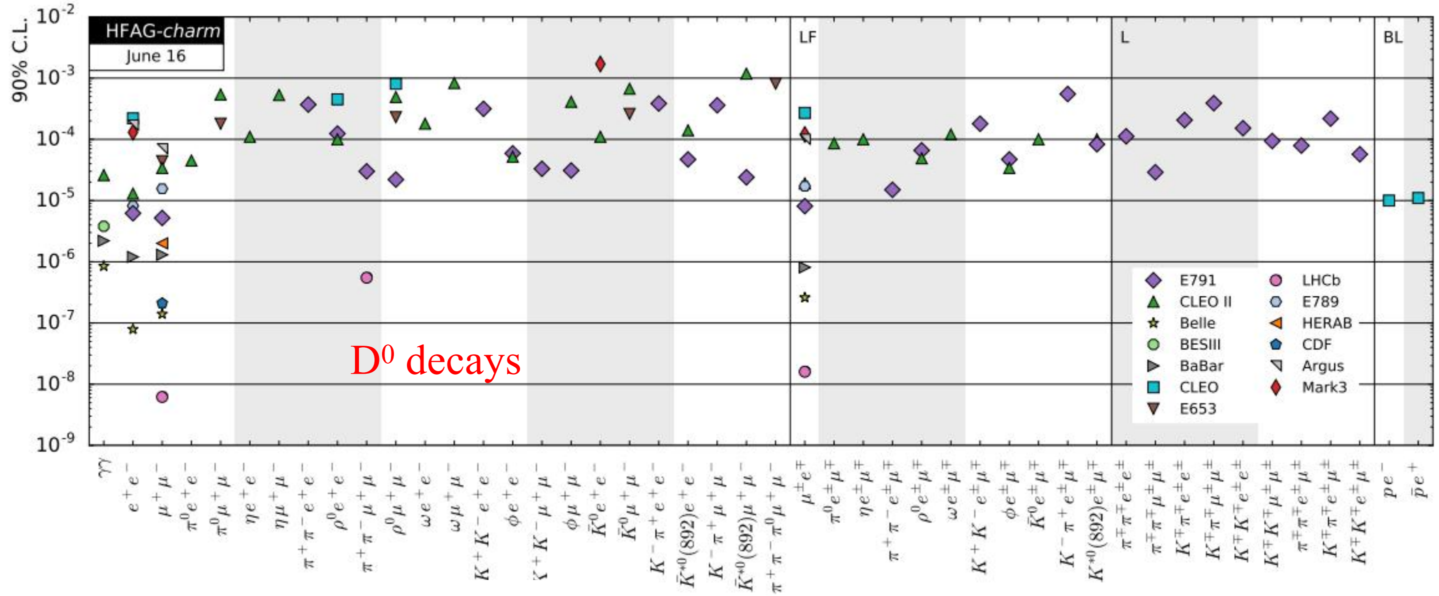
- Measured in K and B meson systems.

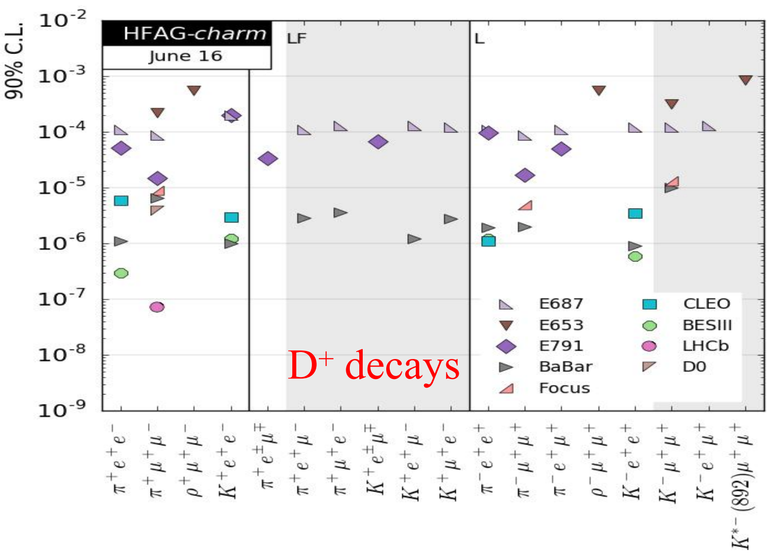
- Highly suppressed in charm sector by the Glashow-Iliopoulos-Maiani (GIM) mechanism due to the absence of high mass down-type quark. [PRD **2**, 1285 (1970)]

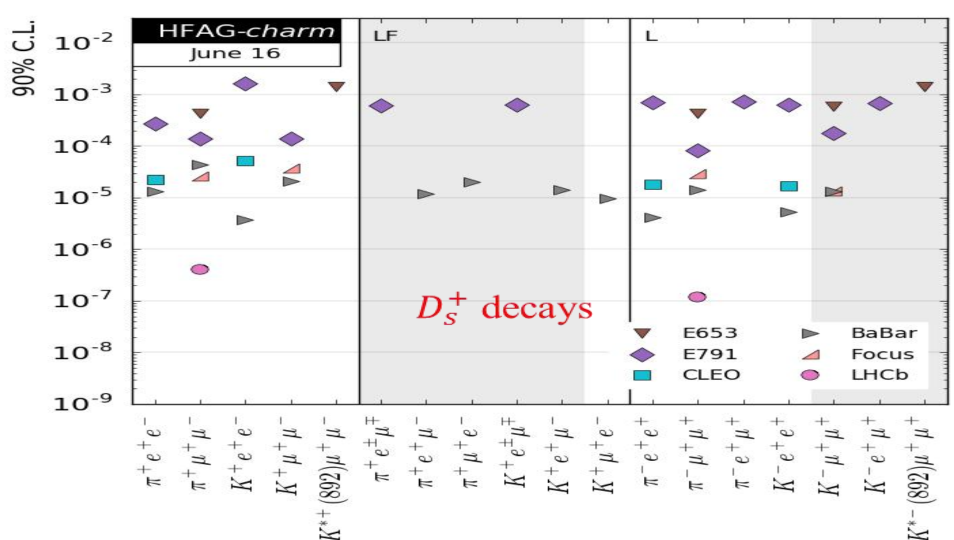
- Rare decays are highly sensitive to the searches of new physics effects.

- Charm is complementary to the B and K sectors, and a unique window on the new physics affecting the up-type quark dynamics.

Experimental status up to June 2016





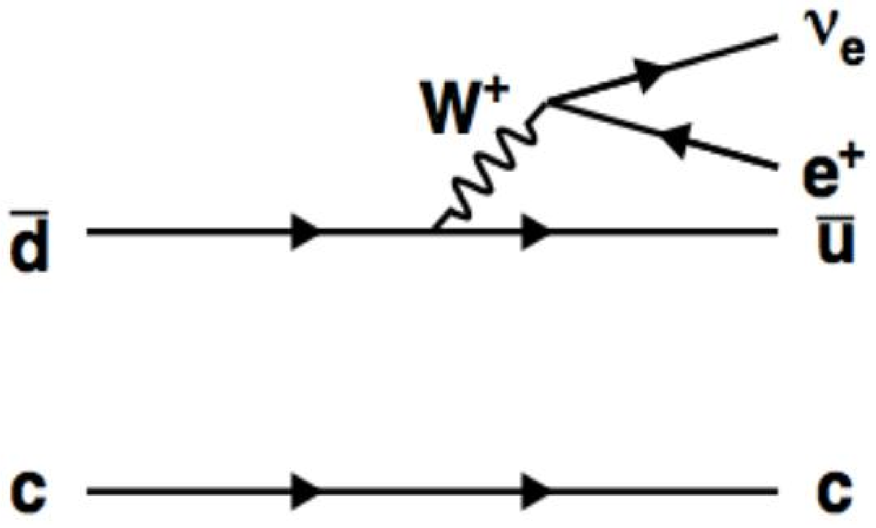


http://www.slac.stanford.edu/xorg/hfag/charm/

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

BESIII Preliminary

- In rare decays of $D^+ \to D^0 e^+ \nu_e$, the heavy-quark (c) remains unchanged, and the weak decays are managed by the light-quark sectors.



- In the limit of the flavour SU(3) symmetry of the light quark, the branching fraction of this decay mode is predicted to be about 2.78×10^{-13}. [EPJC **59**, 841-845(2009)]

- Measuring this decay can shed light on testing the SM predictions for the rare semi-leptonic decays.

- Use 2.92 fb^{-1} $\psi(3770)$ data collected by BESIII experiment to perform this search.

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

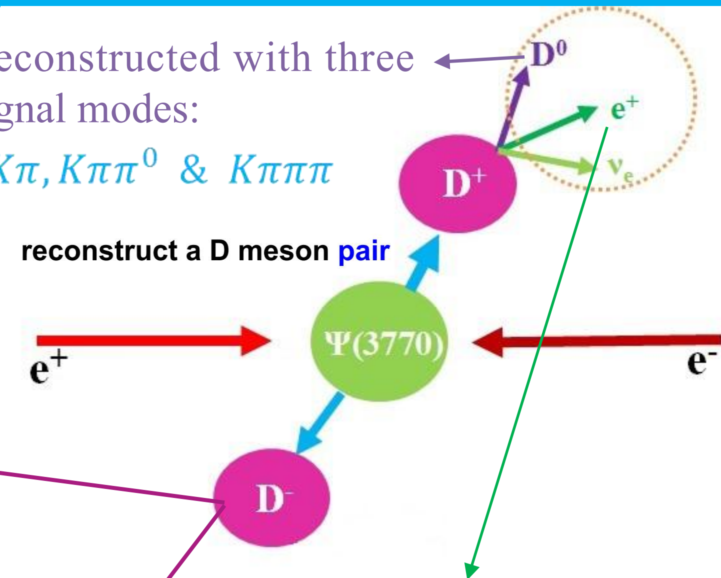
BESIII **Preliminary**

- The search uses a double tag technique pioneered by MARKIII collaboration. [PRL **56**, 2140 (1986)]
- M_{BC} and ΔE are used to identify D⁻:

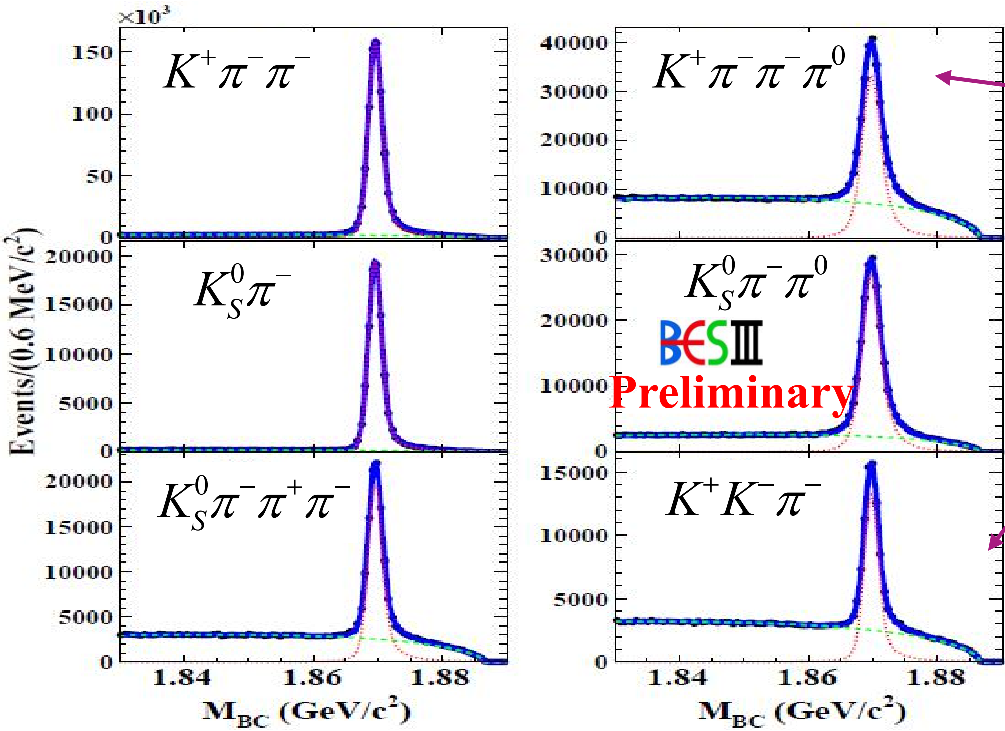
$$M_{BC} = \sqrt{E_{beam}^2/c^4 - |\vec{p}_{D^-}|^2/c^2}, \Delta E \equiv E_{D^-} - E_{beam}$$

Momentum   Energy   Beam energy

Reconstructed with three signal modes: $K\pi, K\pi\pi^0$ & $K\pi\pi\pi$



e+ is not detected due to very soft in BESIII detector.



Modeled with MC shape ⊗ Gaussian function + ARGUS function.

BESIII Preliminary

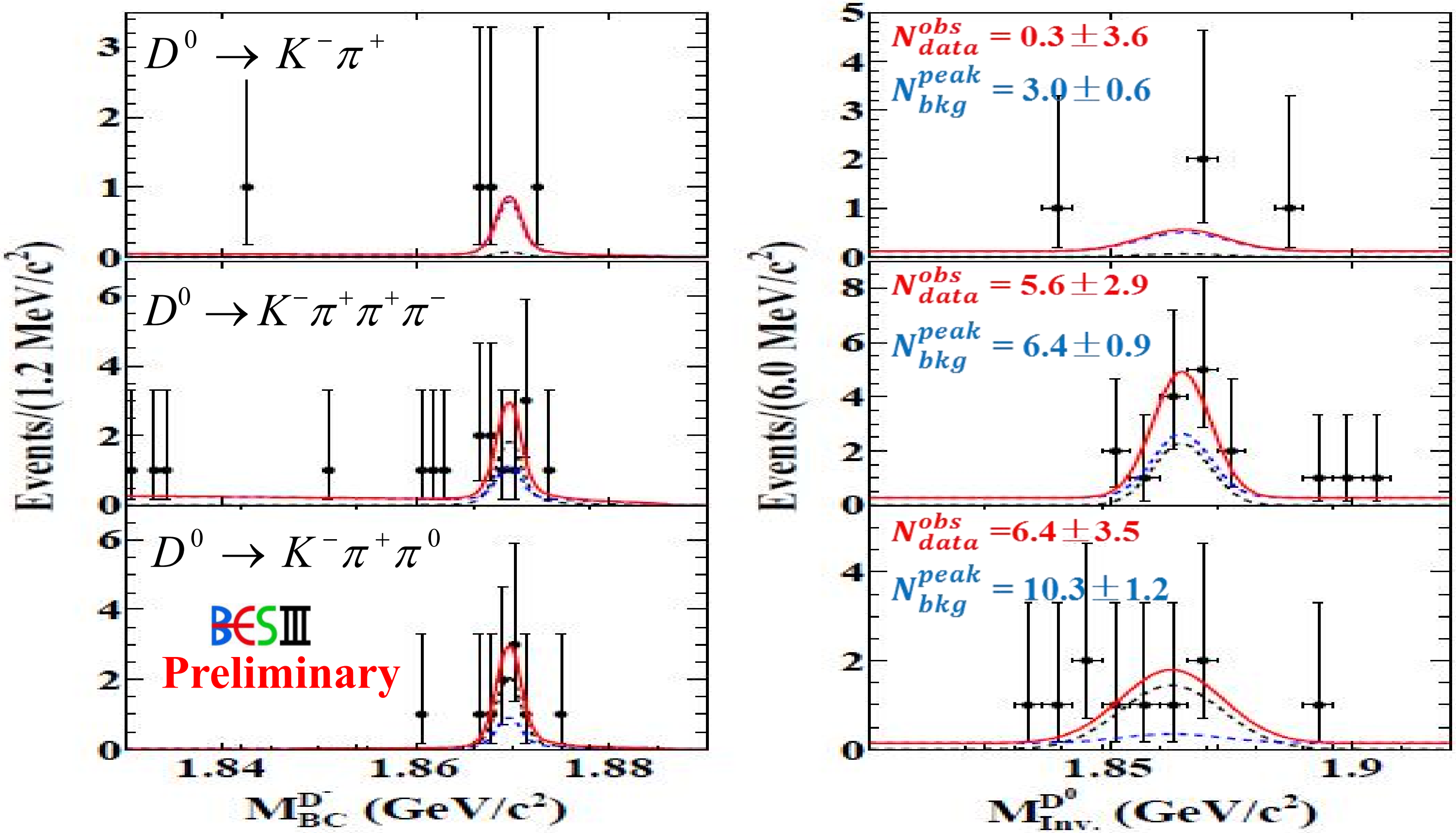
Mode j	ΔE (MeV)	N_{ST}^j	ϵ_{ST}^j(%)
$K^+\pi^-\pi^-$	$(-30, 30)$	809631 ± 962	51.88 ± 0.02
$K^+\pi^-\pi^-\pi^0$	$(-52, 39)$	234966 ± 659	23.76 ± 0.02
$K_S^0\pi^-$	$(-32, 32)$	95596 ± 323	52.83 ± 0.06
$K_S^0\pi^-\pi^0$	$(-57, 40)$	190313 ± 521	23.63 ± 0.03
$K_S^0\pi^-\pi^+\pi^-$	$(-34, 34)$	105782 ± 401	24.32 ± 0.04
$K^+K^-\pi^-$	$(-30, 30)$	72080 ± 349	42.35 ± 0.07

- Total single tag yield: $N_{ST}^{tot} = 1508368 \pm 1421$

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

BESIII **Preliminary**

Results



N_{data}^{obs} is computed while performing the 2D fit to the $m_{BC}^{D^-}$ and invariant mass distribution of the D^0 meson of the data.

N_{bkg}^{peak} is evaluated using inclusive MC sample.

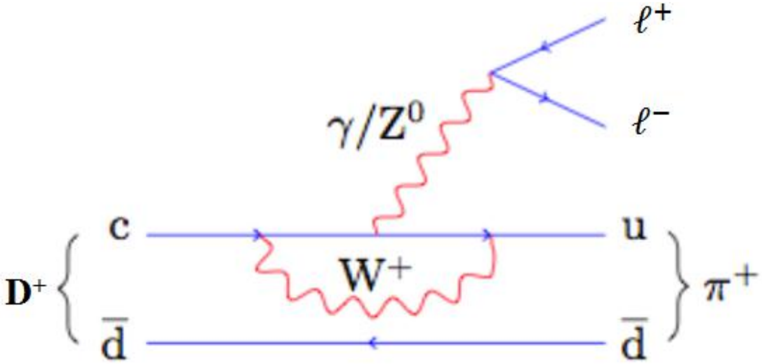
$N_{sig} = N_{data}^{obs} - N_{bkg}^{peak}$

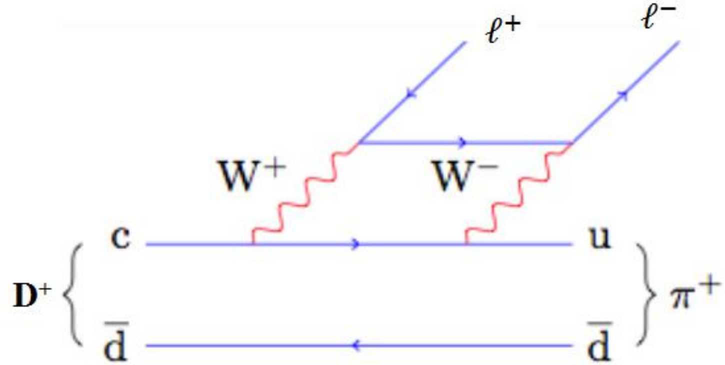
- No significant events are found in any decay modes.
- $\mathcal{B}(D^+ \to D^0 e^+ \nu_e) < 8.7 \times 10^{-5}$ @ 90% C.L. upper limit

$D^+ \to h^\pm e^+ e^\mp$ (h=K, π)

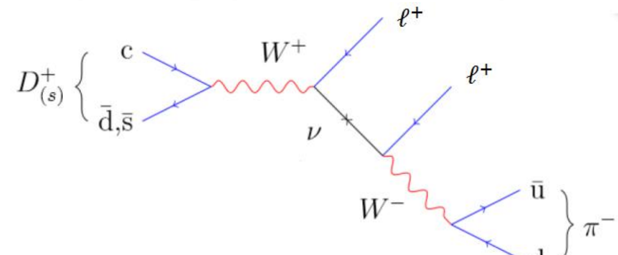
BESIII **Preliminary**

- The FCNC decays of $\mathbf{D^+ \to h^\pm e^+ e^\mp}$ are expected to be very rare due to not occur at tree level in the SM.





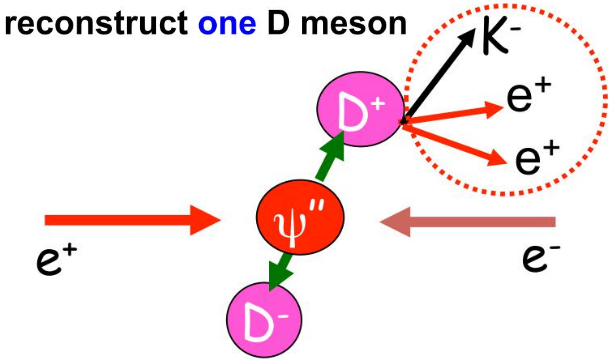
  - ✓ Branching fraction (BF) values due to short distance effect ($c \to u\ell^+\ell^-$): ~10^{-8}-10^{-6} [MPLA **8,** 967 (1993)]
  - ✓ BF values due to long distance effect ($D^+ \to h^+V, V \to \ell^+\ell^-$): 10^{-6}-10^{-5} [PRD **76**, 074010 (2007)]
- Lepton flavour process (LNV) of $\mathbf{D^+ \to h^- e^+ e^+}$ can only be explained by new physics models beyond the SM.
  - ✓ Majorana neutrino: ~10^{-30}-10^{-23} [PRD **64**, 114009 (2001)]
  - ✓ may be greatly enhanced: ~10^{-6}-10^{-5} [EPJC **71**, 1715 (2011)]



- Thus, the process of $\mathbf{D^+ \to h^\pm e^+ e^\mp}$ is an ideal framework for investigating the new physics beyond the SM.
- The large data set collected by BESIII experiment collected at ψ(3770) resonance can provide a better sensitivity on this decay process.

$D^+ \to h^\pm e^+ e^\mp$ (h=K, π)

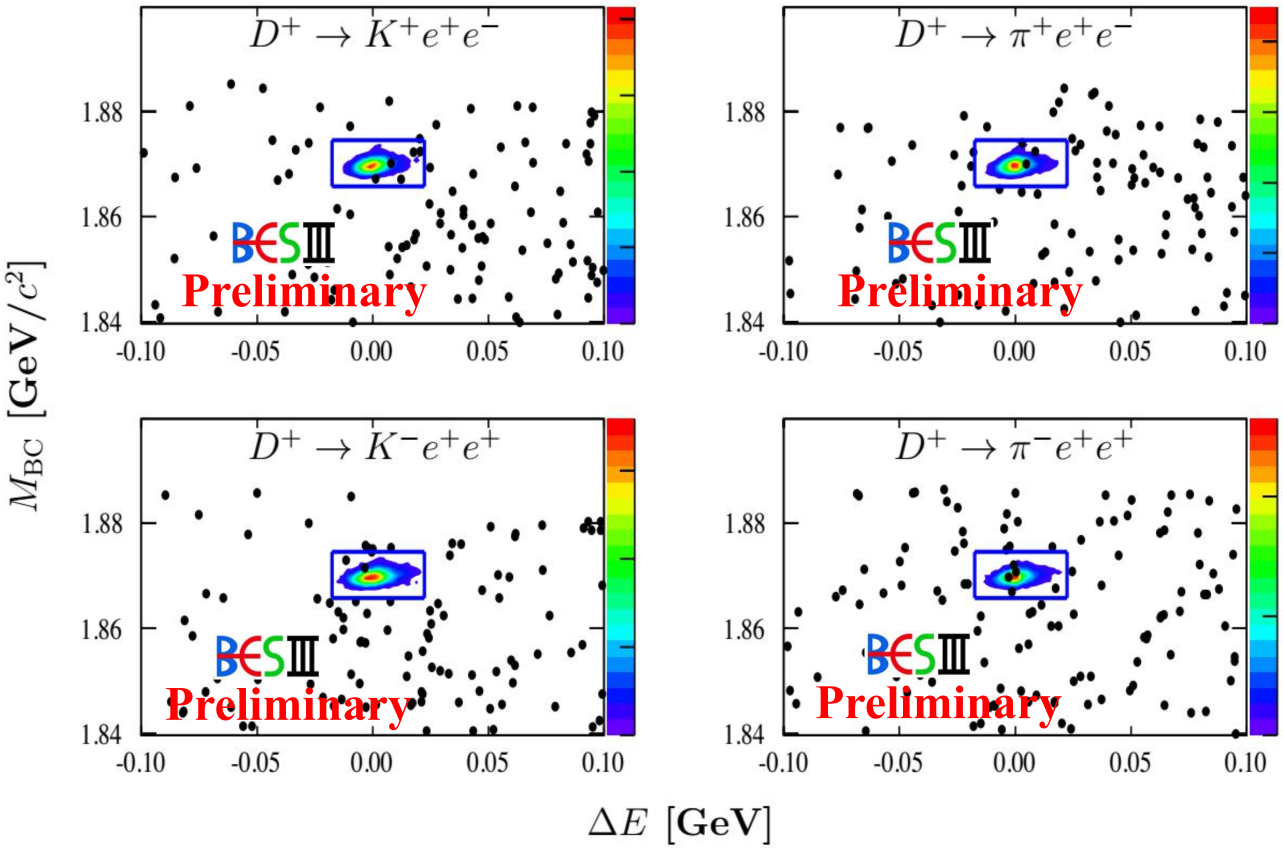
BESIII Preliminary



Use single tag method to perform the search using 2.92 fb^{-1} of ψ(3770) data

$$\Delta E = E_{\rm beam} - E_{h^\pm e^\mp e^+}$$

$$M_{\rm BC} \equiv \sqrt{E_{\rm b}^2/c^4 - p^2_{h^\pm e^\mp e^+}/c^2}$$



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

$D^+ \to h^\pm e^+ e^\mp$ (h=K, π)

BESIII **Preliminary**

Results

	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

BESIII **Preliminary**

Where s_{90} is estimated with a profile likelihood method, **TROLKE** program, incorporating the systematic uncertainties and detection efficiencies. [NIM **A551**, 493 (2005)]

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

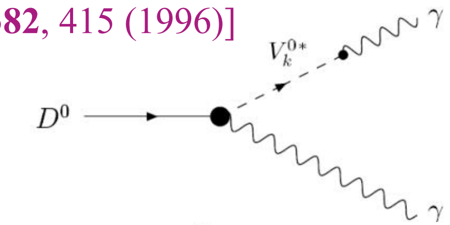
where $N^{tot}_{D^+} = 2 \cdot \mathcal{L} \cdot \sigma^{obs}_{D^+D^-} = (1.681 \pm 0.032) \times 10^7$

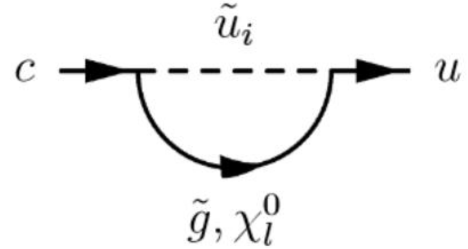
$\mathcal{B}(D^+ \to) \setminus [\times 10^{-6}]$	$K^+ e^+ e^-$	$K^- e^+ e^+$	$\pi^+ e^+ e^-$	$\pi^- e^+ e^+$
CLEO [PRD **82**, 092007 (2010)]	3.0	3.5	5.9	1.1
Babar [PRD **84**, 072006 (2011)]	1.0	0.9	1.1	1.9
PDG	1.0	0.9	1.1	1.1
This work	1.2	0.6	0.3	1.2

BESIII **Preliminary**

$D^0 \to \gamma\gamma$

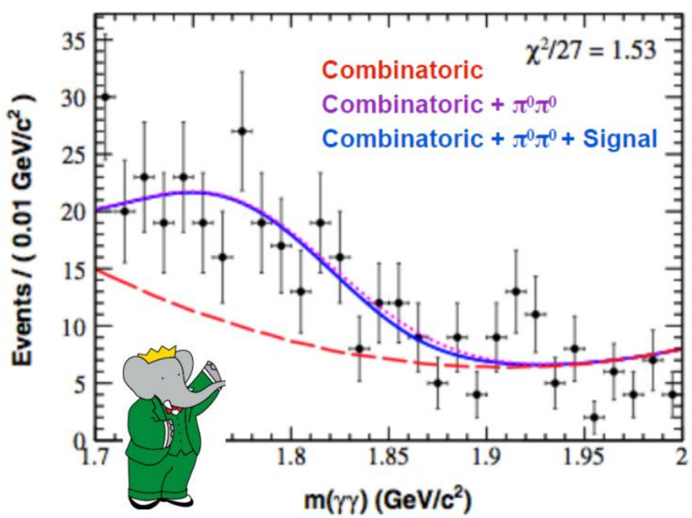
- The FCNC decay of $D^0 \to \gamma\gamma$ is strongly suppressed by GIM mechanism. [PRD **2**, 1285 (1970)]
  - ✓ Short-distance (an EM penguin transitions): **3×10^{-11}** [PLB **382**, 415 (1996)]
  - ✓ Long-distance (vector meson dominance model (VDM)): **$(1\text{-}3)\times10^{-8}$** [PRD **64**, 074008 (2001)]
  - ✓ Minimal Supersymmetric Standard Model (due to gluino exchange via $c \to u\gamma$ transitions): **6×10^{-6}** [PRD **82**, 094006 (2010)]





- **$\mathcal{B}(D^0 \to \gamma\gamma) < 2.9\times10^{-5}$** CLEO collab. [PRL **90**, 101801 (2003)]

Phys. Rev. D 85 (2012) 091107R



- 470.5 fb^{-1} of data used by BaBar experiment to perform the search for $D^0 \to \gamma\gamma$ decay.
- Select the D^0 meson candidate from $D^{*+} \to D^0(\to\gamma\gamma)\pi^+$
- Peaking background from $D^0 \to \pi^0\pi^0$
- $\mathcal{B}(D^0 \to \gamma\gamma) = \frac{N_{(D^0\to\gamma\gamma)}}{N_{(D^0\to K_S^0\pi^0)}} \times \frac{\varepsilon_{K_S^0\pi^0}}{\varepsilon_{\gamma\gamma}} \times \mathcal{B}(D^0 \to K_S^0\pi^0)$

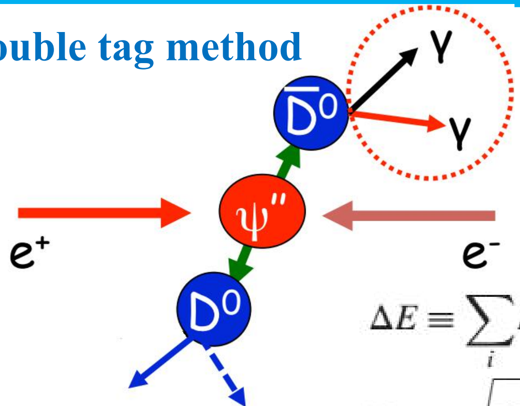
$\mathcal{B}(D^0 \to \gamma\gamma) < 2.2\times10^{-6}$ @ 90% C.L. upper limit

[PRD **85**, 091107(R) (2012)]

$D^0 \to \gamma\gamma$

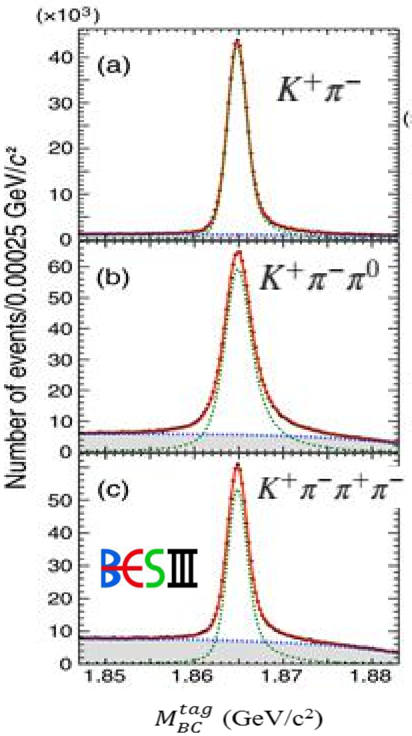
[PRD 91, 112015 (2015)]

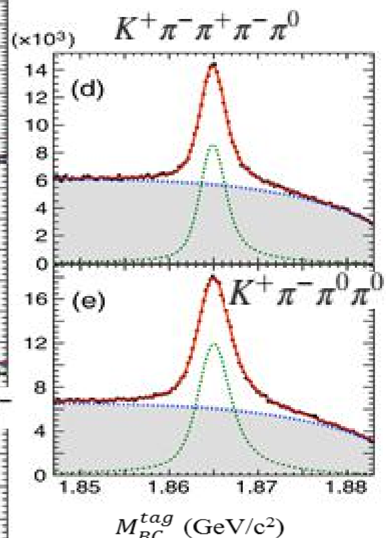
Double tag method

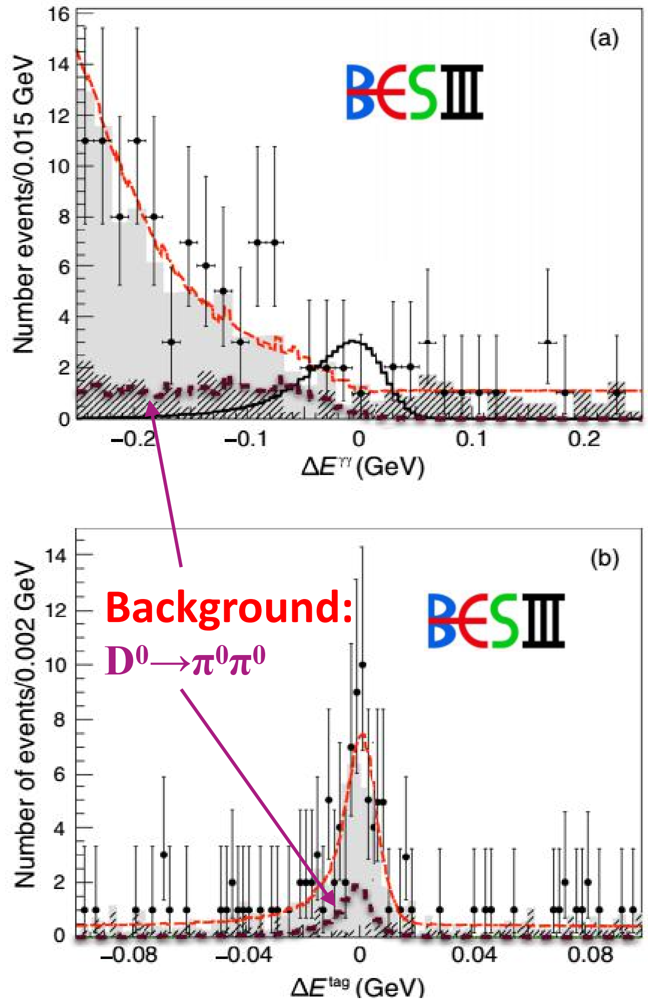


$$\Delta E \equiv \sum_i E_i - E_{\rm beam}$$

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







Use 2.92 fb^{-1} of ψ(3770) data

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

$$\mathcal{B}(D^0 \to \gamma\gamma) < 3.8 \times 10^{-6}$$ **@ 90% C.L. upper limit**

consistent with BaBar result [PRD 91, 112015 (2015)]

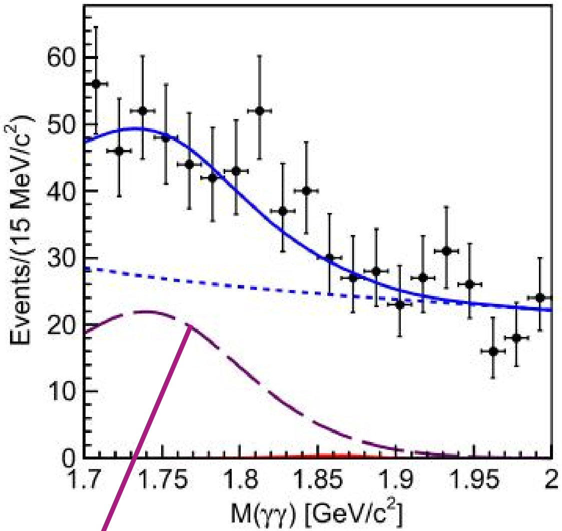
$D^0 \to \gamma\gamma$

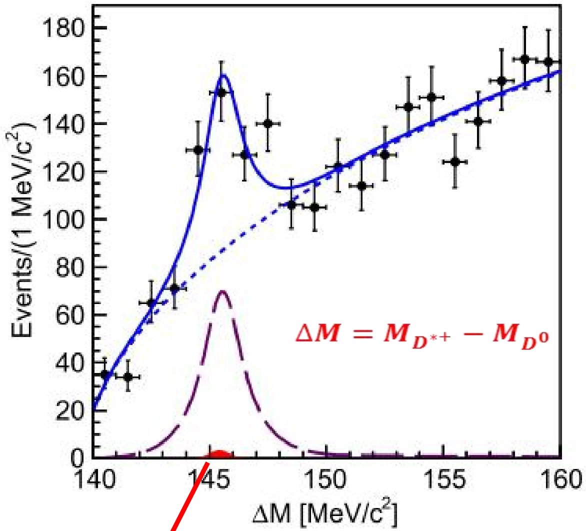
BELLE

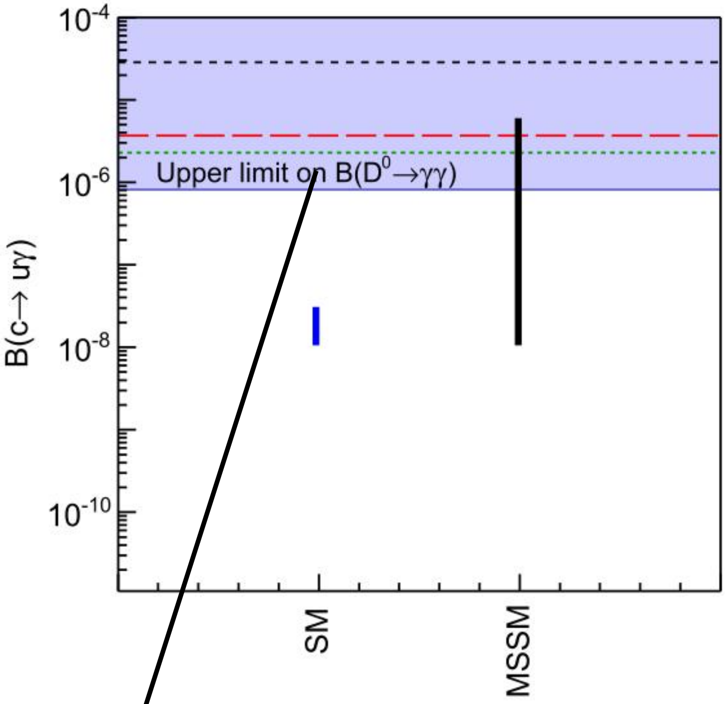
[PRD 93, 051102(R) (2016)]

- Select the D^0 meson candidate from $D^{*+} \to D^0 (\to \gamma\gamma)\pi^+$
- Peaking background from $D^0 \to \pi^0\pi^0$, $\eta\pi^0$, $\eta\eta$ etc.
- π^0 veto: reject all the photons which can be used for a good π^0
- Normalization to $D^0 \to K_S^0 \pi^0$

Use 832 fb^{-1} of data







Peaking background

Signal

$$\mathcal{B}(D^0 \to \gamma\gamma) < 8.5 \times 10^{-7}$$ @ 90% C.L. upper limit

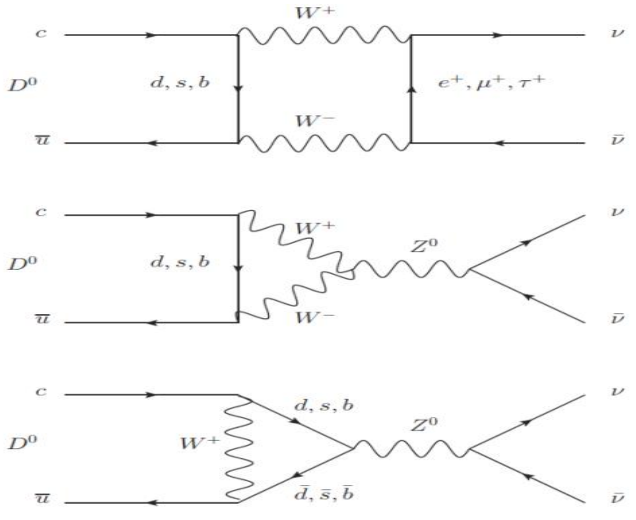
[PRD 93, 051102(R) (2016)]

- ✓ Most stringent exclusion limit to date
- ✓ Large date samples may further improve the measurements

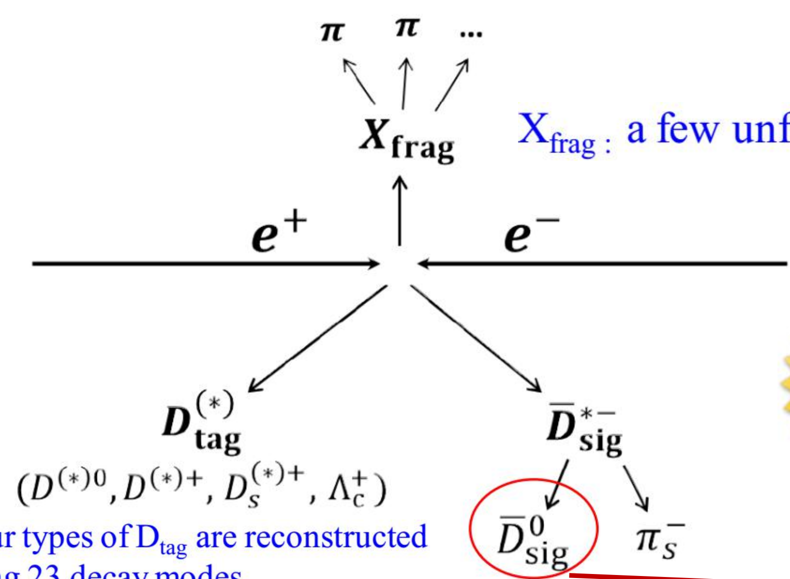
$D^0 \to$ invisible

Presented by C. Shen in Rencontres du Vietnam 2016

- The $D^0 \to \nu\bar{\nu}$ decay is helicity suppressed with the branching fraction of 1.1×10^{-30}. [PRD 82, 034005 (2010)]
- New physics models may enhance the branching fraction up to the level of 10^{-15}.
  PLB651, 374(2007); Phys.Rept.117,75(1985)
- Use a charm tagger method to select the D^0 candidate.



Decay diagrams of $D^0 \to \nu\bar{\nu}$.



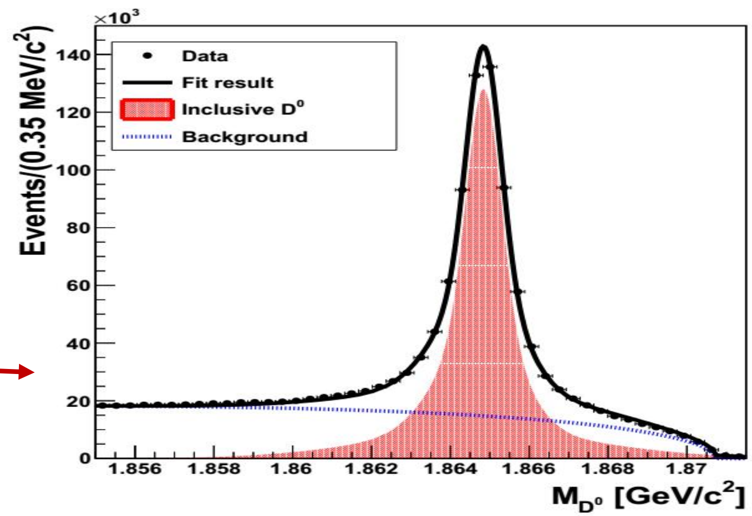
X_{frag} : a few unflavored mesons

NEW

Four types of D_{tag} are reconstructed using 23 decay modes

An illustration of the charm tagger method.

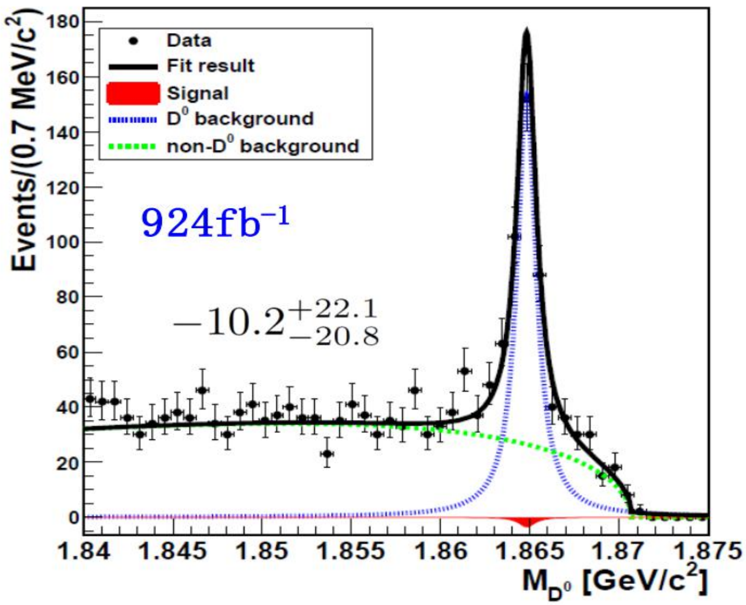
$$M_{D^0} \equiv M_{miss}(D_{tag}^{(*)} X_{frag} \pi_s^-)$$

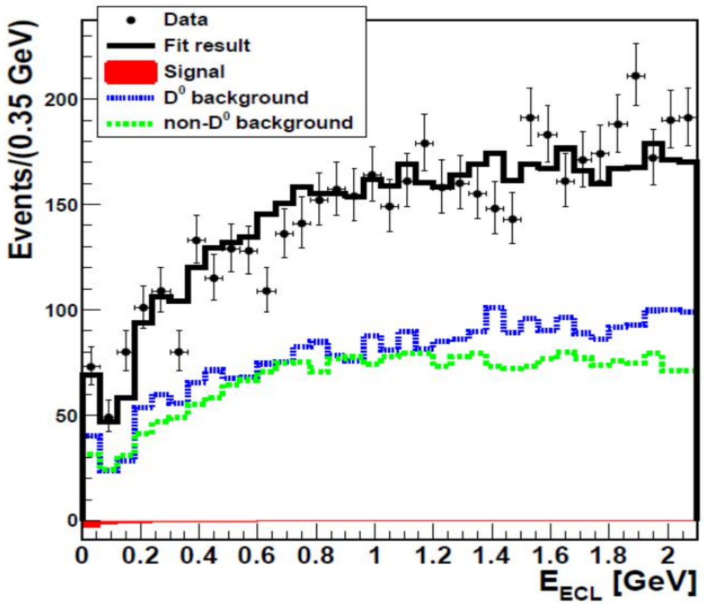


https://indico.cern.ch/event/559999/contributions/2262553/attachments/1343046/2023381/shen_chengping.pdf

$D^0\to$invisible

- $D^0\to$invisible decays are selected by requiring no remaining final states associated with $\overline{D^0_{tag}}$.
- The residual energy in the ECL, E_{ECL}, is used for signal extraction.
- 2D fit: M(D0), E_{ECL}.





- ✓ No significant signal yield is found.
- ✓ **$\mathcal{B}(D^0\to$invisible$) < 8.8\times10^{-5}$ @ 90% C.L. upper limit**

First exclusion limit on $D^0\to$ invisible decay

https://indico.cern.ch/event/559999/contributions/2262553/attachments/1343046/2023381/shen_chengping.pdf

Summary

- By using 2.92 fb^{-1} of $\psi(3770)$ data, BESIII has set one of the most stringent exclusive limits on the decay processes of $D^+ \to D^0 e^+ \nu_e$ and $D^+ \to h^{\pm} e^+ e^{\mp}$ (h=K,π).
- Large data samples collected by Belle experiment improve further the upper limit of $D^0 \to \gamma\gamma$ decay.
- Belle experiment has also reported recently the first experimental exclusion limit on $D^0 \to$invisible decay.
- Present upper limits are still above the SM predictions, no any signature of the new physics is found.
- Large data samples to be collected by current and future flavor physics collider experiments may further improve the results and provide the hint of new physics.

Thank you!

Back up Slide

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

BESIII Preliminary

$$\mathcal{B}_{D^+} = \frac{N_{sig}}{N_{ST}^{tot} \times \varepsilon^i \times \mathcal{B}^i}$$

Where i =0, 1, 2 represent the signal modes $D^0 \to K^-\pi^+, K^-\pi^+\pi^+\pi^-$ and $K^-\pi^+\pi^0$, respectively; N_{ST}^{tot} the total ST yield in data; ε^i the efficiency of reconstructing $D^+ \to D^0 e^+ \nu_e$ with the signal mode i, which is weighted by the ST yield; $\mathcal{B}^i$ the branching fraction of $D^0 \to K^-\pi^+, K^-\pi^+\pi^+\pi^-$ or $K^-\pi^+\pi^0$ from the PDG and $\mathcal{B}_{D^+}$ the branching fraction of $D^+ \to D^0 e^+ \nu_e$

Systematic uncertainties

Source	$D^0 \to K^-\pi^+$	$D^0 \to K^-\pi^+\pi^+\pi^-$	$D^0 \to K^-\pi^+\pi^0$
Tracking	2.0	4.0	2.0
PID	2.0	4.0	2.0
Quoted branching fraction	1.3	2.6	3.6
π^0 reconstruction	-	-	2.0
Summation of Signal side	3.1	6.2	5.0
Signal side		3.8	
Background estimation		11.5	
MC statistics		0.5	
M_{BC} fit (ST)		0.5	
Probability requirement		2.6	
2D fit		2.9	
Total		12.7	

BESIII Preliminary

BESIII Preliminary

Systematic uncertainties

Source	$D^+ \to K^+ e^+ e^-$	$D^+ \to K^- e^+ e^+$	$D^+ \to \pi^+ e^+ e^-$	$D^+ \to \pi^- e^+ e^+$
$N^{tot}_{D^+}$	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	1.2
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	6.6

BESIII Preliminary