BESIII上含轻衰变的研究

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味物理讲座，2025年10月9日

Main contents

- Introduction
- Data samples
- Leptonic D decays
- Semileptonic D decays
- Summary

$D \to Pl^+\nu_l$　　P: 赝标量介子，如K、π、η、η'

$D \to Vl^+\nu_l$　　V: 矢量介子，如K^*、ρ、ω、ϕ

$D \to Sl^+\nu_l$　　S: 标量介子，如$a_0(980)$、$f_0(980)$、$f_0(500)$

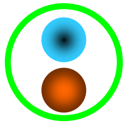
$D \to Al^+\nu_l$　　A: 轴矢量介子，如$K_1(1270)$、$b_1(1235)$

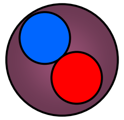
Three quark model in earlier stage

1974年前，人们认识到强子是由两种或三种不同的夸克组成的

- one up quark (charge +2/3) : u
- one down quark (charge -1/3) : d
- one strange quark (charge -1/3): s

Meson : $(q\bar{q})$

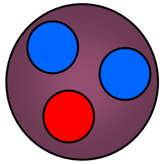




Charged pion

$\pi^+ (u\bar{d})$

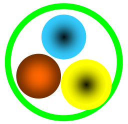
$\pi^- (\bar{u}d)$

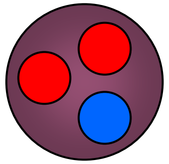


proton

p(uud)

Baryon: (qqq)





neutron

n(udd)

三夸克模型于1964年分别由盖尔曼(Gell-Mann)和兹韦格(Zweig)独立提出 [SU(3)模型]

Three quark model in earlier stage

Y为超荷，I_3为同位旋第三分量

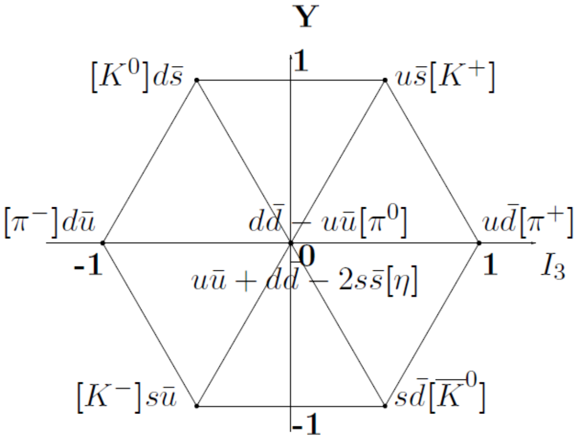


图 1-1 赝标介子八重态。

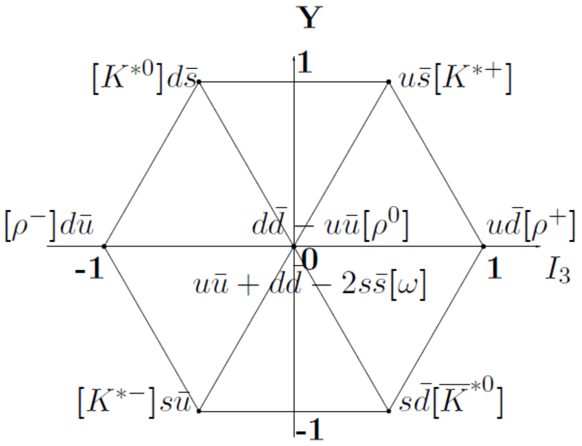


图 1-2 矢量介子八重态。

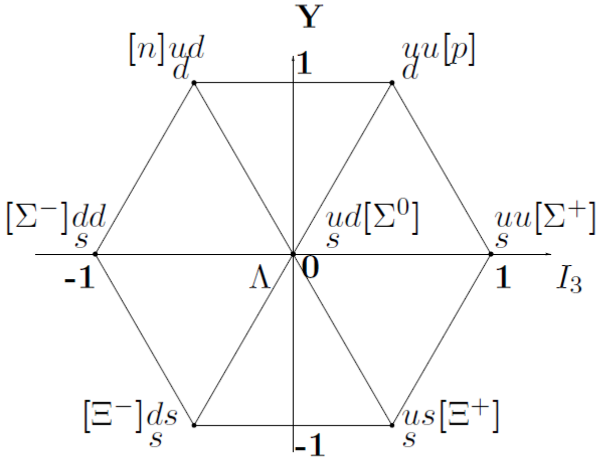


图 1-3 重子八重态。

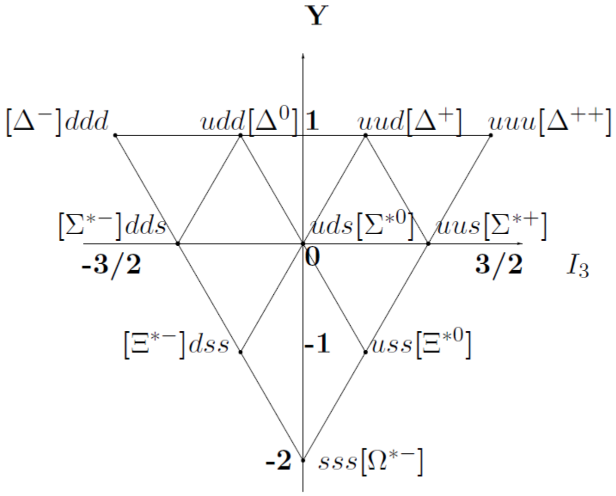


图 1-4 重子十重态。

该模型理论成功的解释了当时已知的强子谱并成功地描述相互作用的一些特征。它预言的粒子也相继被发现。当时的强子世界恢复了简单的图像

Introduce of charm quark

实验上观测不到奇异数改变(|ΔS|=1)的中性流过程，例如：

$$K^+ \to \pi^+ \nu \bar{\nu}$$

分支比的上限为： $$\frac{\Gamma(K^+ \to \pi^+ \nu \bar{\nu})}{\Gamma(K^+ \to \pi^0 \mu^+ \nu_\mu)} \le 10^{-5}$$

为了解释这一实验现象，1970年 GIM (Glashow, Illiopoulos & Maiani) 在理论上引入一个新夸克，即 “c”夸克

Phys. Lett. 11 (1964) 255

Phys. Rev. D2 (1970) 1285

PHYSICAL REVIEW D VOLUME 2, NUMBER 7 1 OCTOBER 1970

Weak Interactions with Lepton-Hadron Symmetry*

S. L. Glashow, J. Iliopoulos, and L. Maiani†
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02139
(Received 5 March 1970)

We propose a model of weak interactions in which the currents are constructed out of four basic quark fields and interact with a charged massive vector boson. We show, to all orders in perturbation theory, that the leading divergences do not violate any strong-interaction symmetry and the next to the leading divergences respect all observed weak-interaction selection rules. The model features a remarkable symmetry between leptons and quarks. The extension of our model to a complete Yang-Milis theory is discussed.

INTRODUCTION

WEAK-INTERACTION phenomena are well described by a simple phenomenological model

may readily be extended to a massive Yang-Mills model, which may be amenable to renormalization with modern techniques. The second problem concerns the selection rules and the relationships among coupling

根据夸克模型的理论， 如果存在c夸克， 就应当存在一系列由$c\bar{c}$组成的强子

Observation of $c\bar{c}$ charmonium states

被喻为粒子物理界“十一月革命”的J/ψ的发现

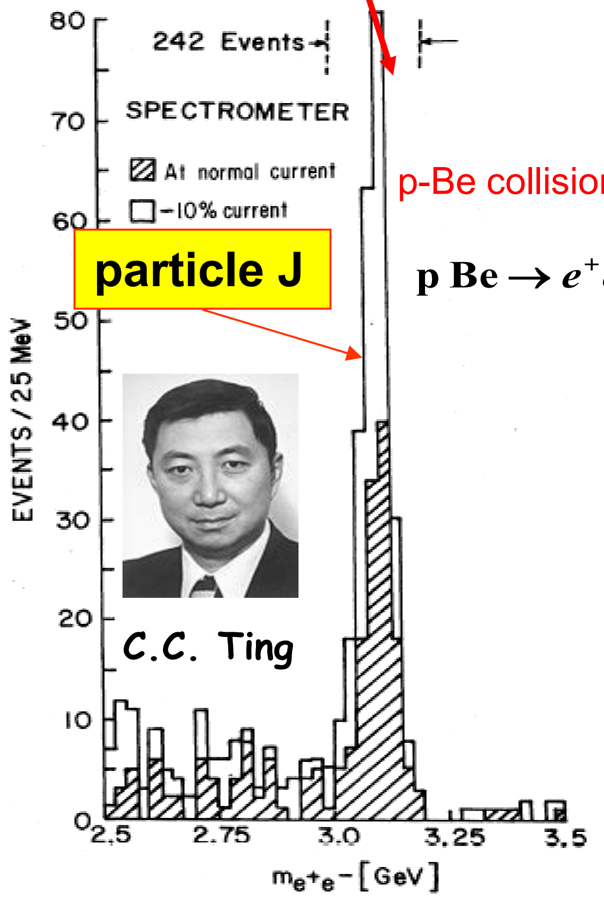
Discovery of ψ(3770)

“November Revolution of Particle Physics!”

Charmonium：bound states of $c\bar{c}$

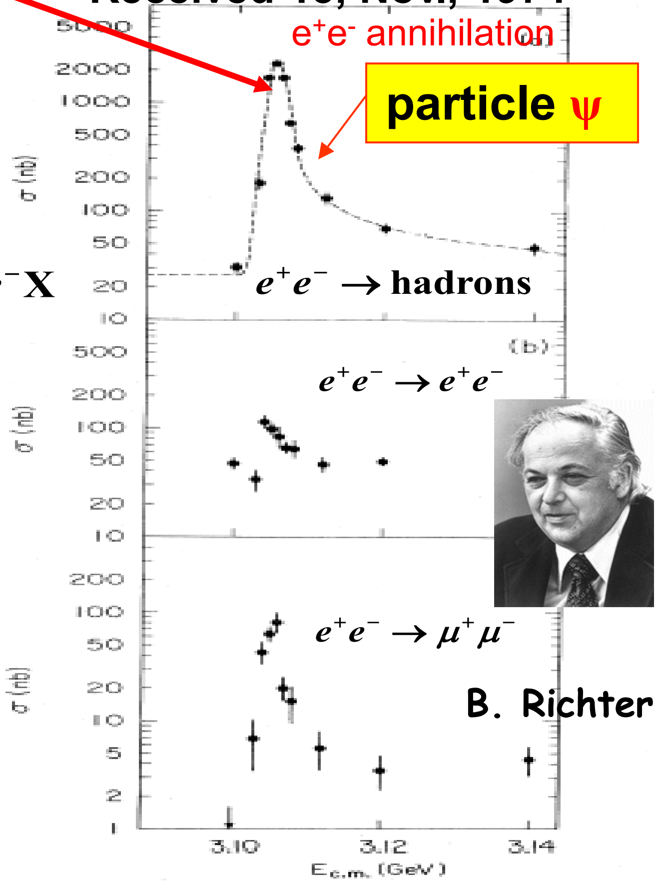
PRL33, 1404 (1974)

Received 12, Nov., 1974

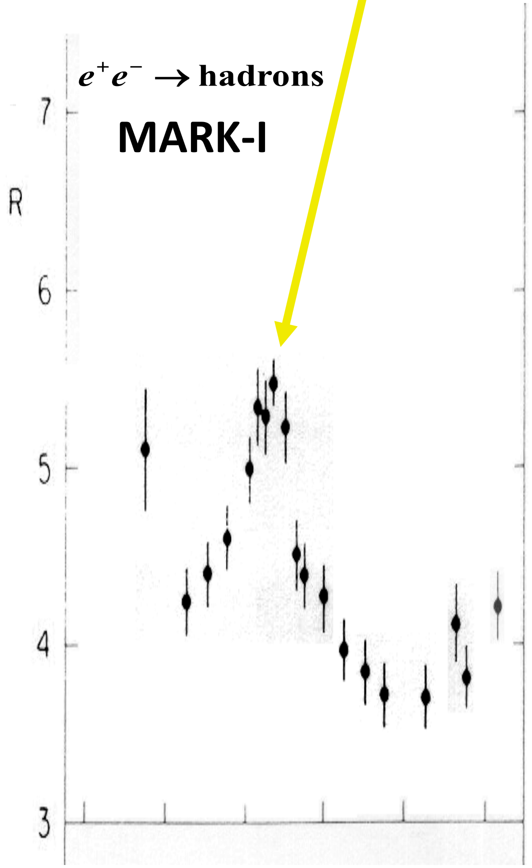


PRL33, 1406 (1974)

Received 13, Nov., 1974



PRL39, 526 (1977)



Observation of *D* meosns

根据夸克模型的理论，既然存在c夸克， 也应当存在一系列由c和其它夸克($\bar{u}$, $\bar{d}$, $\bar{s}$)组成的强子，及其反粒子

1976年工作在美国Stanford 直线加速器中心、SPEAR e^+e^-对撞机上的MARK-I（SLAC-LBL）实验组

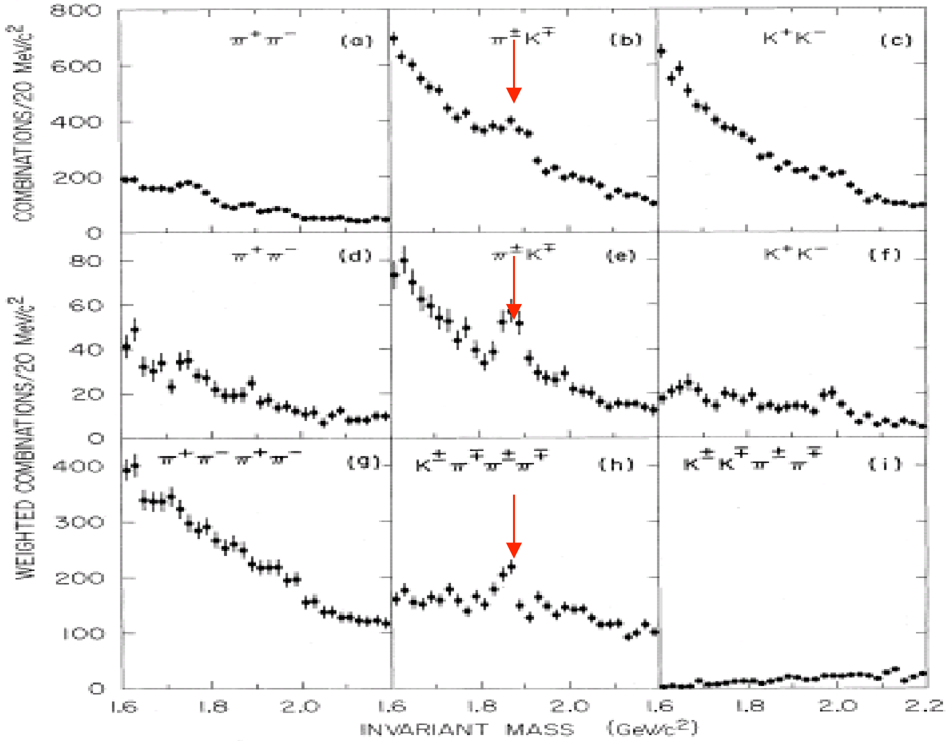


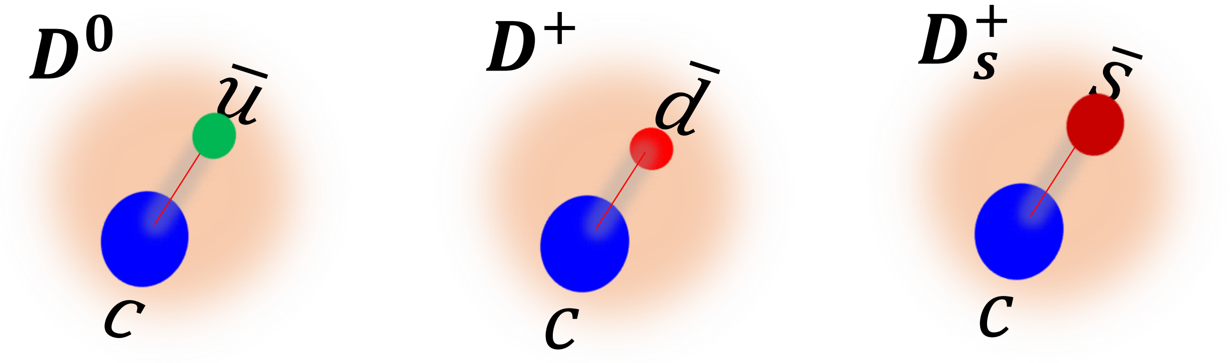
FIG. 1. Invariant-mass spectra for neutral combinations of charged particle. (a) $\pi^+\pi^-$ assigning π mass to all tracks, (b) $K^\mp\pi^\pm$ assigning K and π masses to all tracks, (c) K^+K^- assigning K mass to all tracks, (d) $\pi^+\pi^-$ weighted by $\pi\pi$ TOF probability, (e) $K^\pm\pi^\mp$ weighted by $K\pi$ TOF probability, (f) K^+K^- weighted by KK TOF probability, (g) $\pi^+\pi^-\pi^+\pi^-$ weighted by 4π TOF probability, (h) $K^\pm\pi^\mp\pi^\pm\pi^\mp$ weighted by $K3\pi$ TOF probability, (i) $K^+K^-\pi^+\pi^-$ weighted by $KK\pi\pi$ TOF probability.

在3.90—4.60 GeV 区间实验工作，从$K^\mp\pi^\pm$和$K^\mp\pi^\pm\pi^\pm\pi^\mp$组合中发现了中性$D^0$介子

此后， D^+ 、D_s^+介子和粲重子等一系列粲粒子相继地被发现

Quark components of D mesons

Charmed meson is the
bound state of c quark and
one of the light $\bar{q}$ quarks

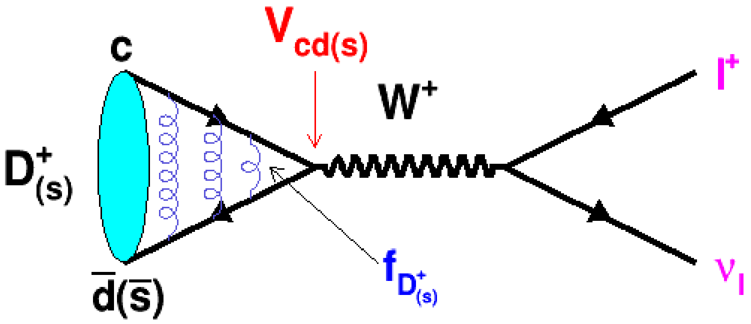


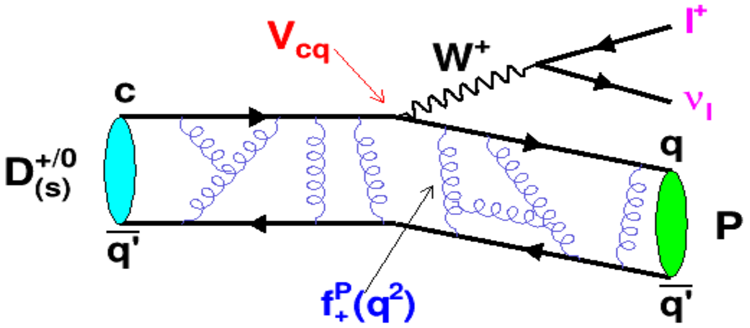
Quark content	$c\bar{u}$	$c\bar{d}$	$c\bar{s}$	$\bar{c}u$	$\bar{c}d$	$\bar{c}s$
Pseudoscalar	D^0	D^+	D_S^+	$\overline{D}^0$	D^-	D_S^-
Vector	D^{*0}	D^{*+}	D_S^{*+}	$\overline{D}^{*0}$	D^{*-}	D_S^{*-}

高激发态粲介子 …

(Semi)leptonic *D* decays

探讨夸克和轻子相互作用的理想桥梁，检验标准模型的理想探针之一





$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi}|V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}}\left(1 - \frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$

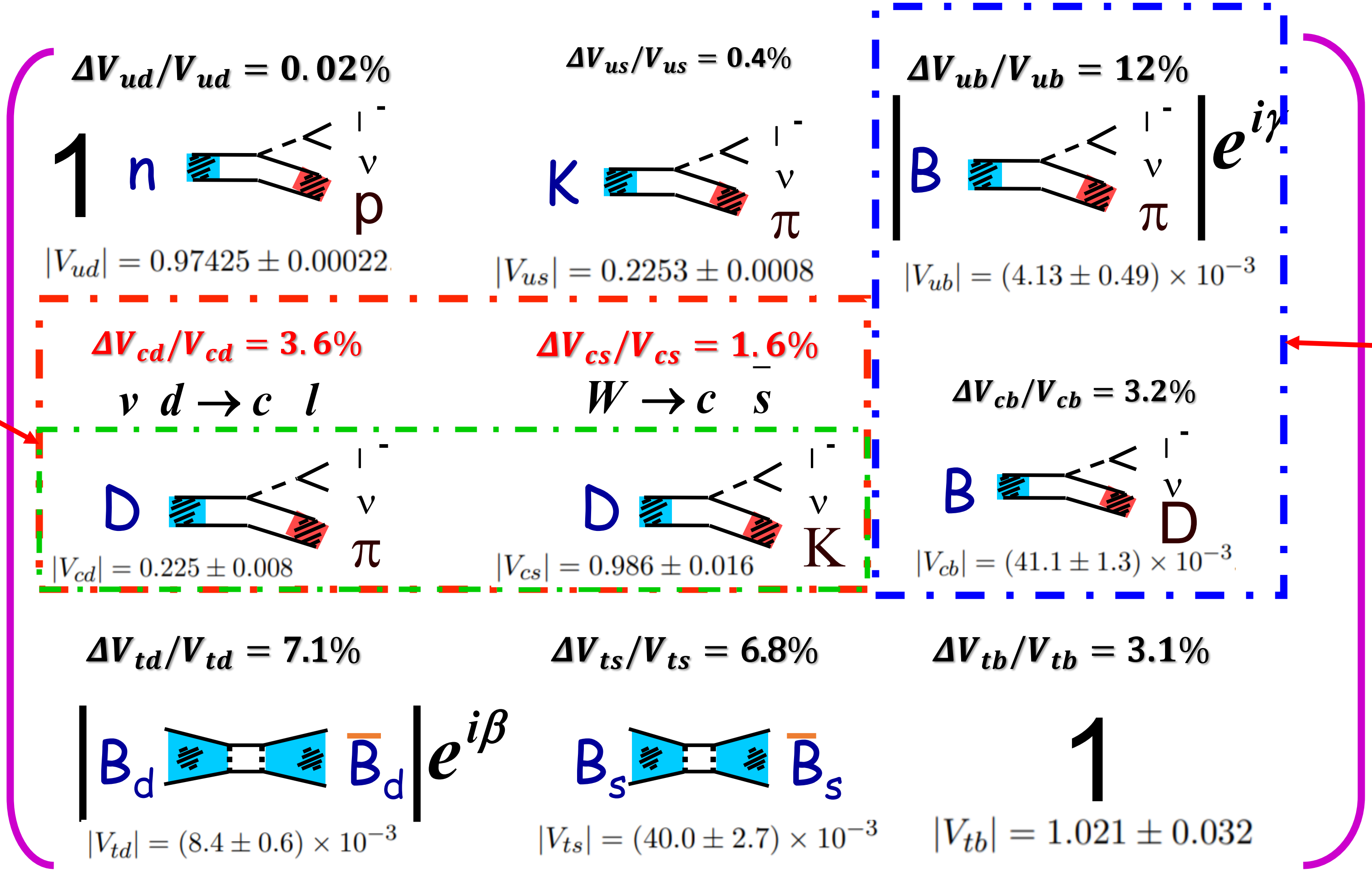
$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2|V_{cd(s)}|^2}{24\pi^3}p^3|f_+(q^2)|^2$$

- 衰变常数、半轻衰变形状因子 →精密刻度格点QCD等计算
- CKM矩阵元$|V_{cs}|$、$|V_{cd}|$ →在更高精度下检验CKM矩阵的幺正性
- 分支比之比$B_{\mu/e}$、$B_{\tau/\mu}$ →精确检验轻子普适性
- 稀有含轻衰变 →寻找超出标准模型的新物理效应

$|V_{cs(d)}|$ measurements before BESIII

PDG2014

Direct measurement: (semi)leptonic D decays



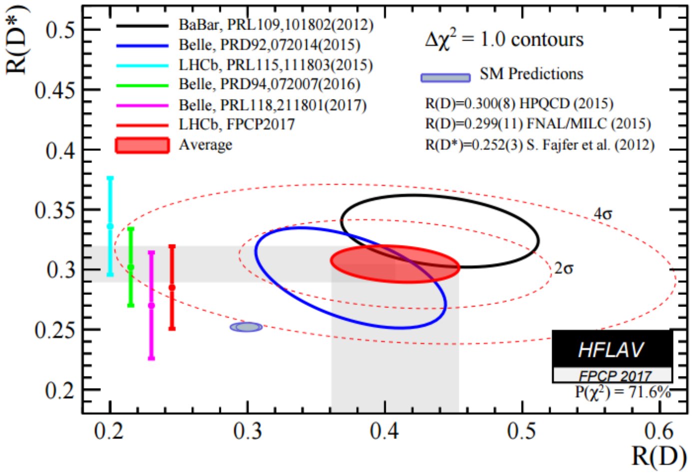
Indirect constraint: Hadronic D decays

V_{ud}, V_{us} and V_{cb} are the best determined due to flavor symmetries: I, SU(3), HQS. Charm (V_{cd} & V_{cs}) and rest of the beauty sector (V_{ub}, V_{td}, V_{ts}) are poorly determined. Theoretical errors on hadronic matrix element dominate.

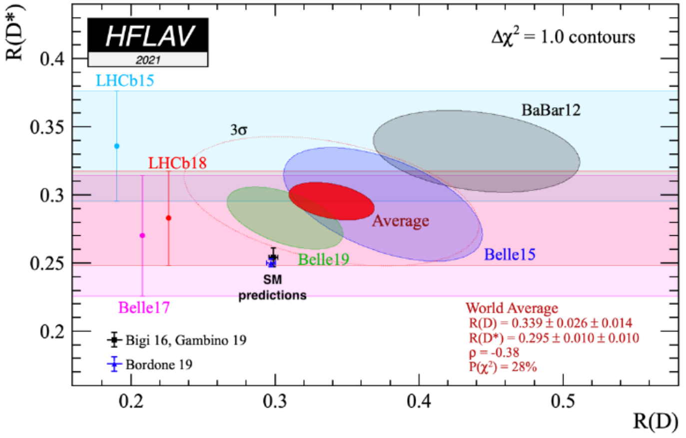
LFU tests in (semi)leptonic D decays before BESIII

Tension in B physics

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\,\tau\nu_\tau)}{\mathcal{B}(B \to D^{(*)}\,l\,\nu_l)}$$



3.9σ



3.3σ

Tension in D physics

$$\mathrm{B}^{\mathrm{PDG18}}[D^0 \to \pi^-\mu^+\nu] = (0.237 \pm 0.024)\%$$

$$\frac{\Gamma^{\mathrm{PDG18}}[D^0 \to \pi^-\mu^+\nu]}{\Gamma^{\mathrm{PDG18}}[D^0 \to \pi^- e^+\nu]} = 0.82 \pm 0.08$$

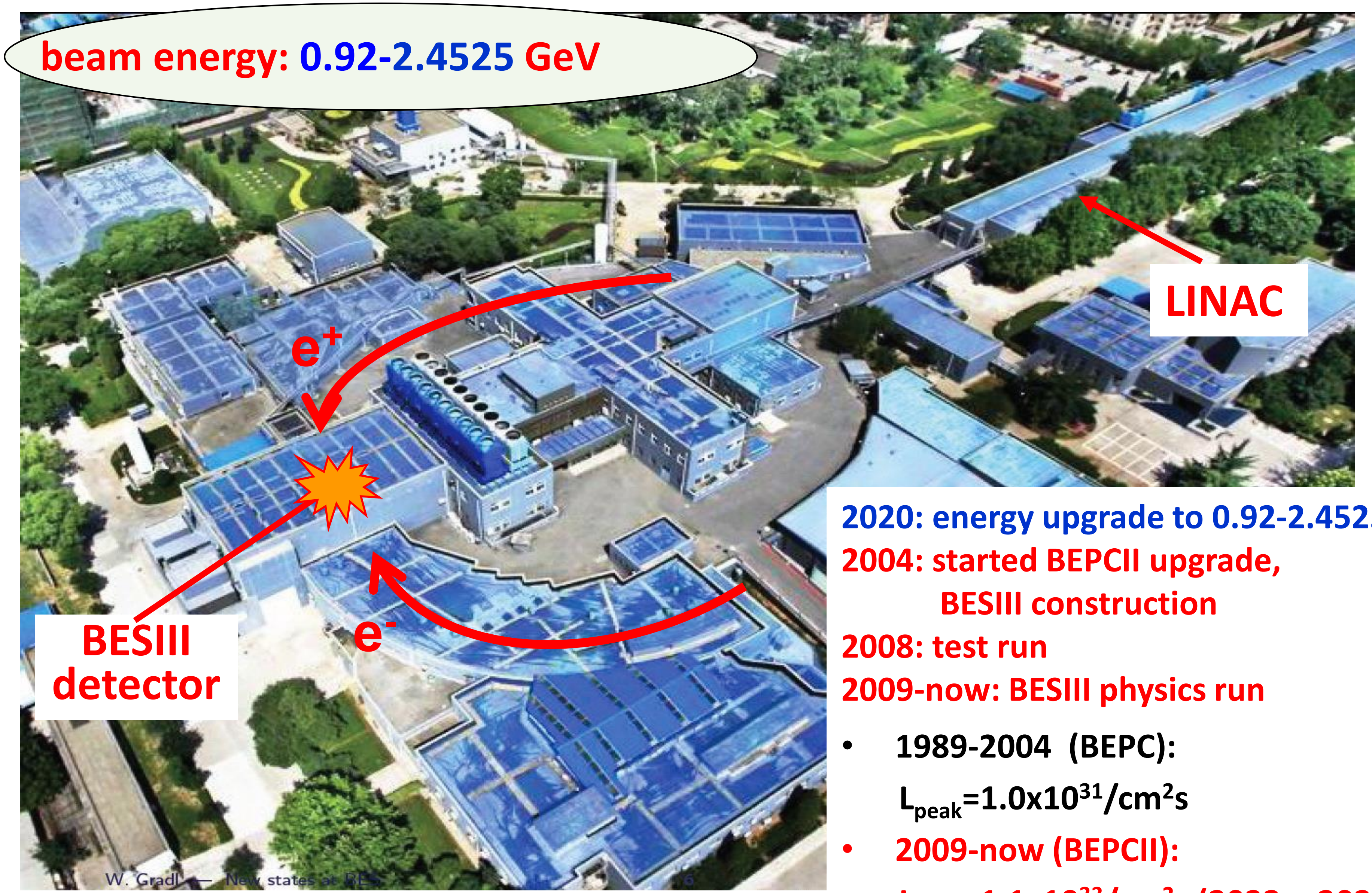
(2.1σ)

SM prediction: 0.985

The knowledge of semimuonoic charm meson decays is very poor

	D^0		D^+		D_s^+	
$c \to sl^+\nu$	K^-	4%[Belle]	$\bar{K}^0$	7%[FOCUS]	η	NA
	K^{*-}	13%[FOCUS]	$\bar{K}^{*0}$	3%[CLEOc]	η'	NA
	K_1^-	NA	$\bar{K}_1^0$	NA	ϕ	NA
					f_0	NA
$c \to dl^+\nu$	π^-	10%[Belle]	π^0	NA	K^0	NA
	ρ^-	NA	ρ^0	17%[FOCUS]	K^{*0}	NA
			f_0	NA		
			ω	NA		
			η	NA		
			η'	NA		

Beijing Electron Positron Collider (BEPCII)



2020: energy upgrade to 0.92-2.4525 GeV

2004: started BEPCII upgrade,
BESIII construction

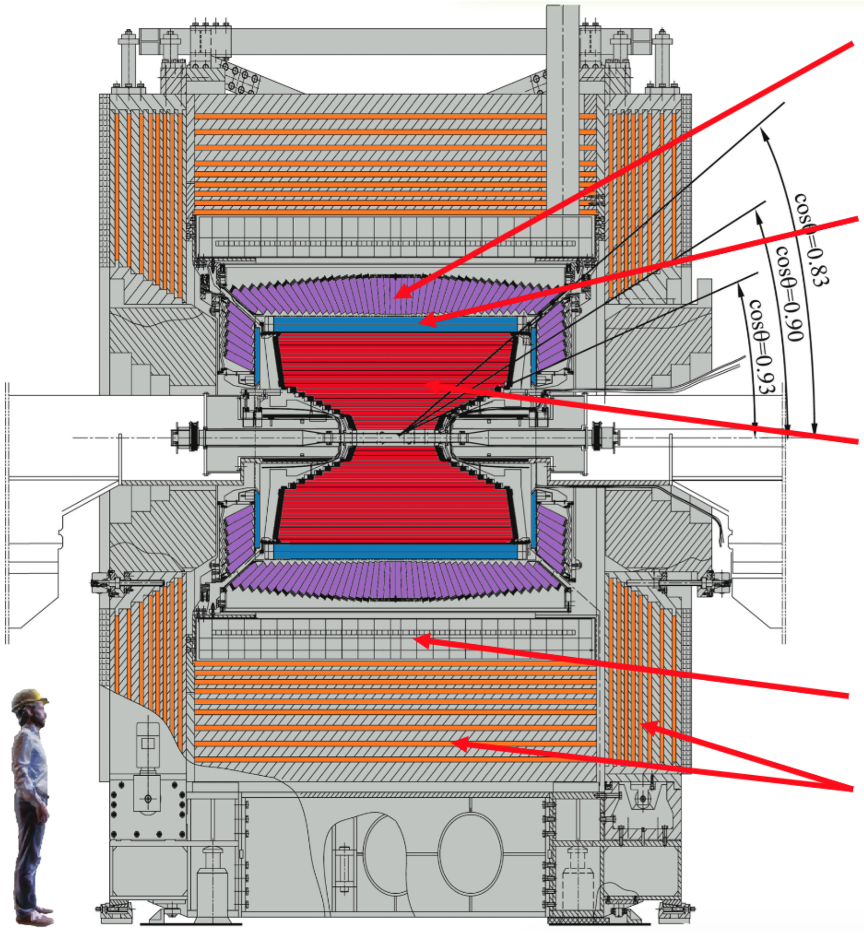
2008: test run

2009-now: BESIII physics run

- 1989-2004 (BEPC):
  L_{peak}=1.0x10^{31}/cm^{2}s
- 2009-now (BEPCII):
  L_{peak}=1.1x10^{33}/cm^{2}s (2022、2023)

BESIII detector

NIMA614(2010)345



EMC: CsI crystals
$\Delta E/E$ = 2.5% @ 1 GeV - Barrel
$\Delta E/E$ = 5.0% @ 1 GeV - Endcaps

TOF:
σ_T = 80 ps Barrel
σ_T = 110 (60) ps Endcap

MDC: small cell & He gas
σ_{xy}= 130 μm
σ_p/p = 0.5% @1GeV
dE/dx = 6%

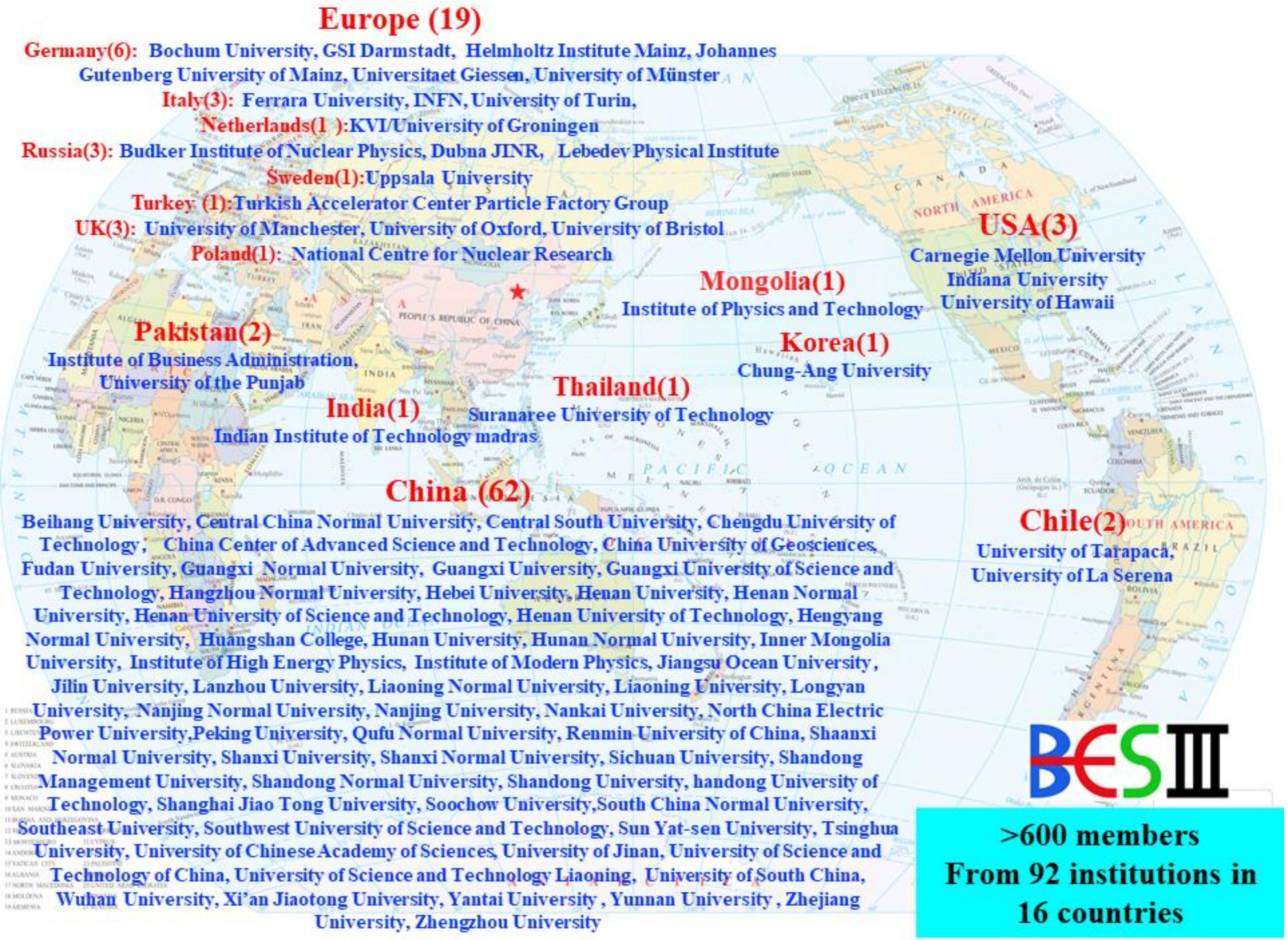
Magnet: 1T Super conducting

Muon ID: 9 layer RPC

Trigger: Tracks & Showers

Excellent resolution, particle identification, and large coverage for neutral and charged particles

BESIII collaboration



>600 members From 92 institutions in 16 countries

Data samples at BESIII

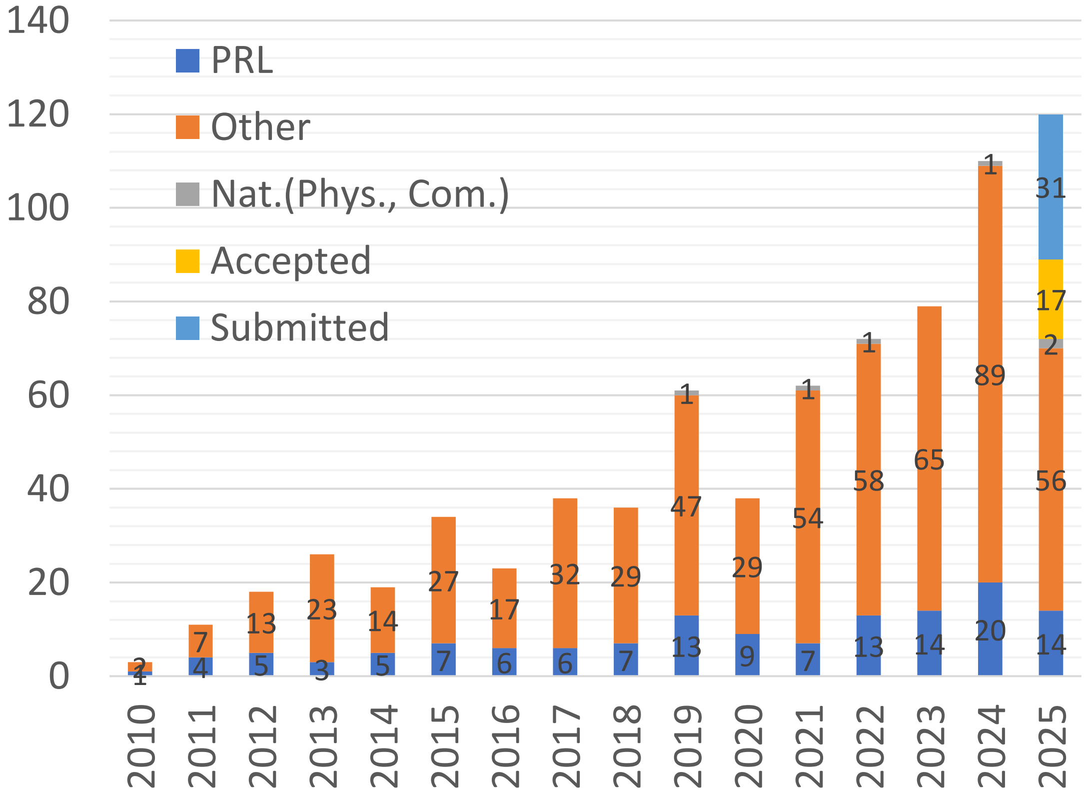
2009: 106M $\psi(3686)$
225M J/ψ
2010: 0.98 fb^{-1} **$\psi(3770)$**
2011: 2.93 fb^{-1} $\psi(3770)$ ($D^{0(+)}$, total)
0.48 fb^{-1} @4.01 GeV
2012: 0.45B $\psi(3686)$ (total)
1.30B J/ψ (total)
2013: 1.09 fb^{-1} @4.23 GeV (XYZ&D_s^+)
0.83 fb^{-1} @4.26 GeV
0.54 fb^{-1} @4.36 GeV
10×0.05 fb^{-1} XYZ scan@3.81-4.42 GeV
2014: 1.03 fb^{-1} @4.42 GeV
0.11 fb^{-1} @4.47 GeV
0.11 fb^{-1} @4.53 GeV
0.05 fb^{-1} @4.575 GeV
0.57 fb^{-1} @4.60 GeV (XYZ&Λ_c^+)
0.80 fb^{-1} R scan @3.85-4.59 GeV
2009: 106M $\psi(3686)$
2015: R-scan 2-3 GeV+2.175 GeV

2016: 3.20 fb^{-1} @4.178 GeV (XYZ&D_s^+)
2017: 7×0.50 fb^{-1} @4.19-4.22 GeV (XYZ&D_s^+),
@4.24-4.27 (XYZ)
2018: More J/ψ+tuning new RF cavity
2019: 10B J/ψ (total)
8×0.50 fb^{-1} XYZ scan@4.13, 4.16 (XYZ&D_s^+),
4.29-4.44 GeV
2020: 3.8 fb^{-1} @ 4.61-4.7 GeV (XYZ&Λ_c^+)
2021: 2.0 fb^{-1} @ 4.74-4.946 GeV
2.7B $\psi(3686)$ (total)
2022: 0.4 fb^{-1} @3.650 GeV
0.4 fb^{-1} @3.682 GeV
2.9→7.9 fb^{-1} $\psi(3770)$ ($D^{0(+)}$, total)
2023-2024: 7.9→20.3 fb^{-1} $\psi(3770)$ (for $D^{0(+)}$, total)
2×0.42 fb^{-1} $\psi(3770)$ scan
0.14 fb^{-1} @3.800-3.885 GeV
0.13 fb^{-1} @3.554 GeV
0.025 fb^{-1} @1.84-2.00 GeV

>50 fb^{-1} at E_{cm} between 1.84 and 4.95 GeV in 15 year running

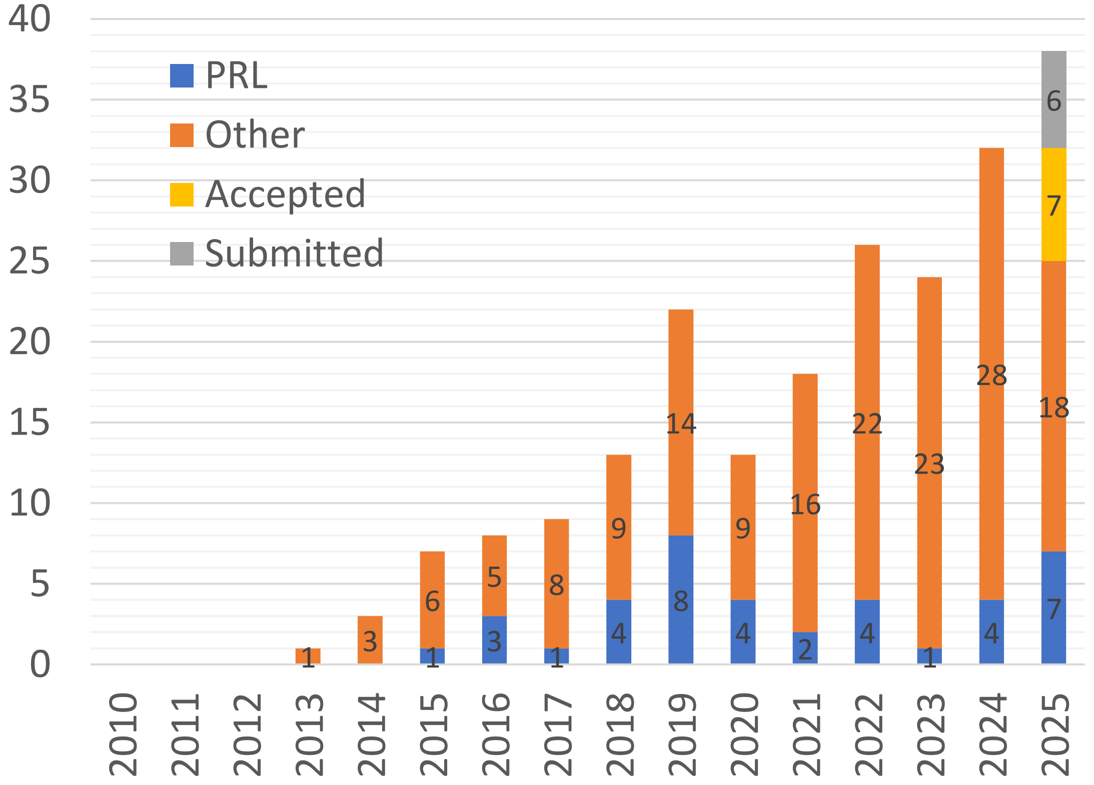
Publications of BESIII (as of Oct. 8 2025)

BESIII physics



702 papers and 133 in PRL

Charm physics at BESIII

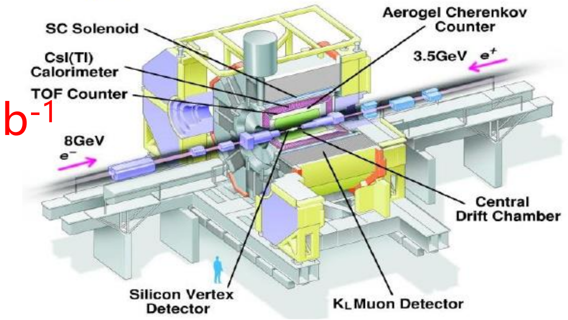


201 papers and 39 in PRL

Experiments and data for charmed mesons

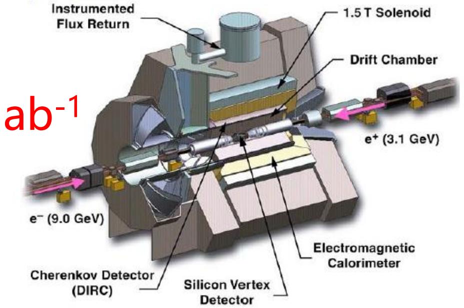
Belle @ KEKB
e^+e^- : ~10.6 GeV ($\Upsilon(4S)$)
$\sigma(e^+e^- \to cc)$ = 1.3 nb
$L_{peak} = 2 \times 10^{34}\ cm^{-2}\ s^{-1}$

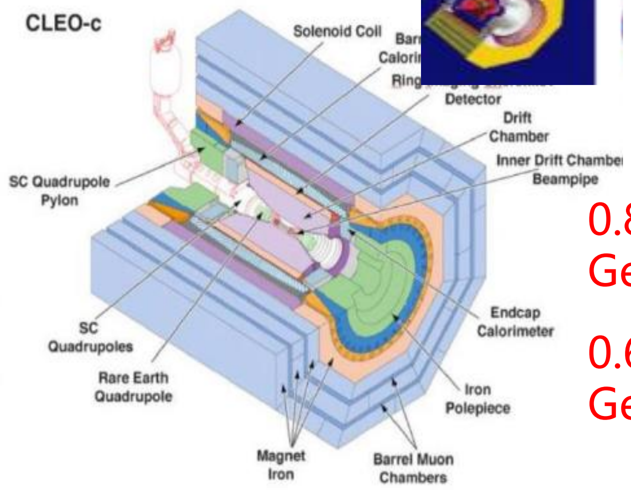
0.98 ab^{-1}



BaBar @ PEP-II
e^+e^- : ~10.6 GeV ($\Upsilon(4S)$)
$\sigma(e^+e^- \to cc)$ = 1.3 nb
$L_{peak} = 1 \times 10^{34}\ cm^{-2}\ s^{-1}$

0.54 ab^{-1}





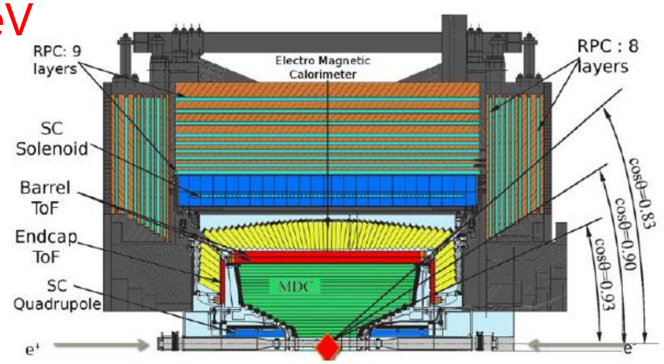
0.8 fb^{-1}@3.774 GeV

0.6 fb^{-1}@4.170 GeV

BESIII @ BEPC II
e^+e^- : 2-4.6 GeV
$\sigma(e^+e^- \to cc)$ = 3 nb
$L_{peak} = 1 \times 10^{33}\ cm^{-2}\ s^{-1}$

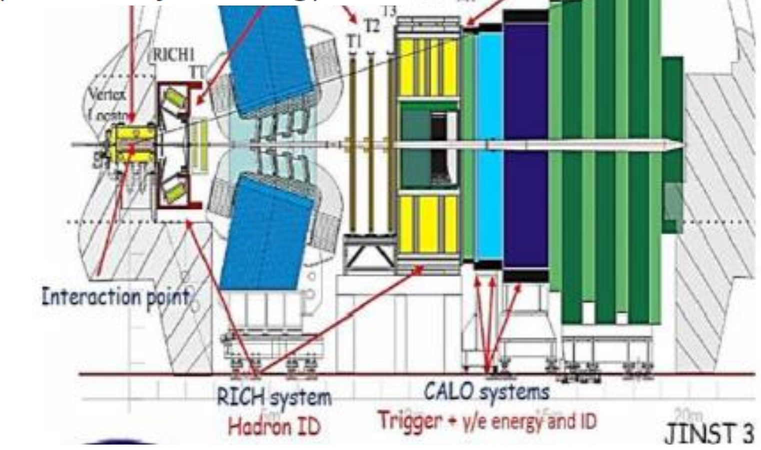
2.9→20.3 fb^{-1}@3.773 GeV

7.33 fb^{-1}@4.13-4.23 GeV



LHCb @ LHC
pp : 7-13 TeV
$\sigma(cc)$ = 1.4-2.6 mb
$L_{peak} = 4 \times 10^{32}\ cm^{-2}\ s^{-1}$
(luminosity leveling)

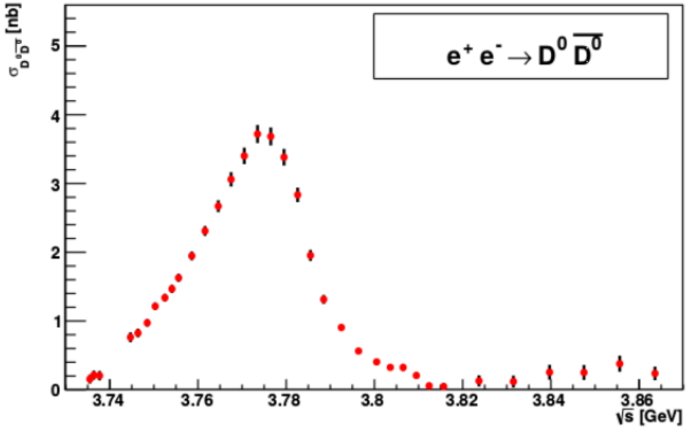
9 fb^{-1}

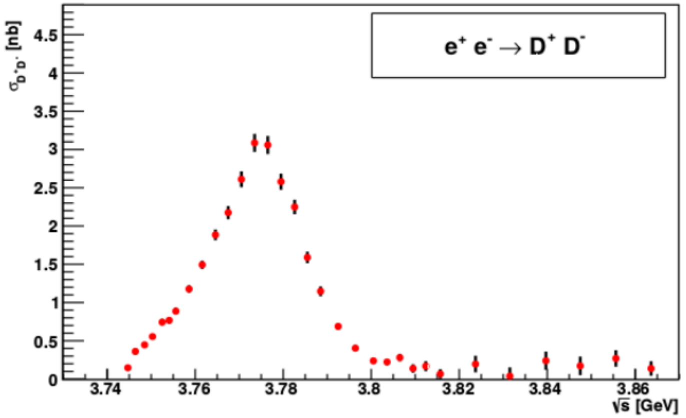


Production of charmed mesons at BESIII

$e^+e^- \to \psi(3770) \to D\bar{D}$

2.93→20.3 fb^{-1}@3.773 GeV

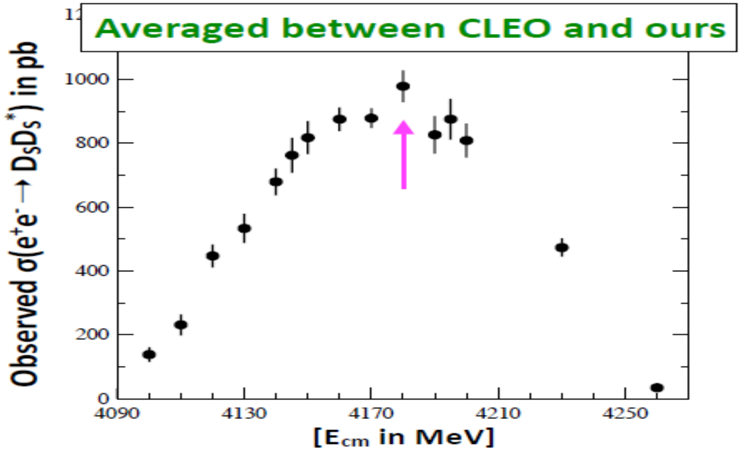




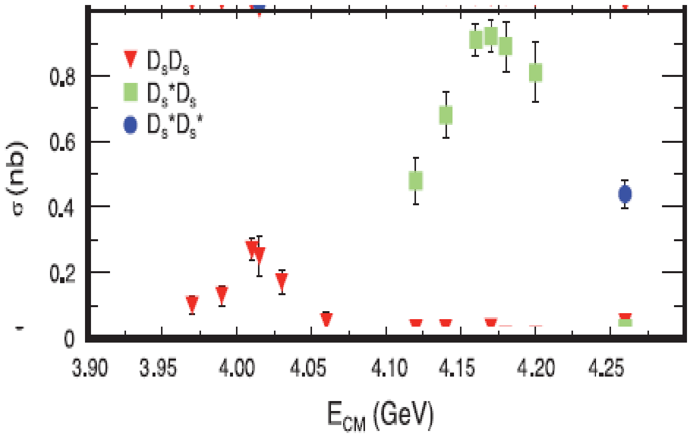
ψ(3770)质量刚刚高于$D^0\bar{D}^0$和D^+D^-对产生阈能量，是研究D介子衰变的最理想的源

$e^+e^- \to \psi(4160) \to D_s^+ D_s^{*-} + c.c.$

3.19→7.33 fb^{-1}@4.13-4.23 GeV

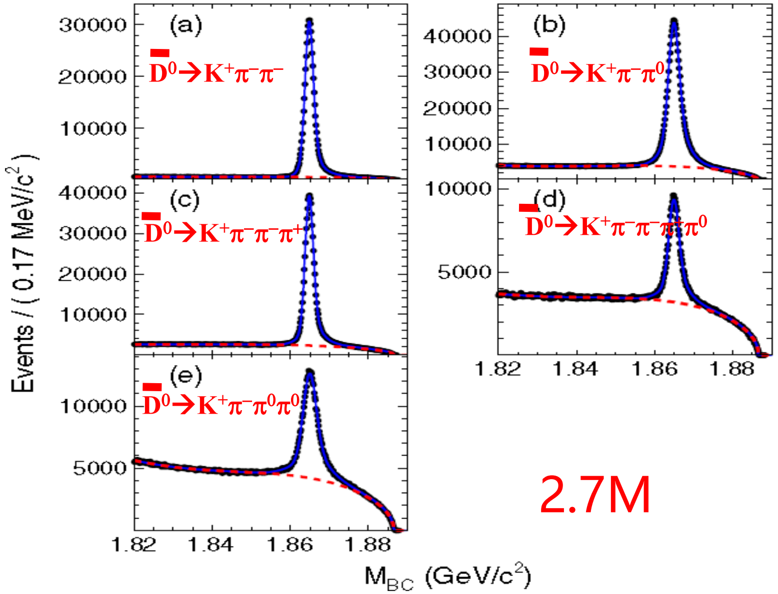


CLEO, PRD80, 072001 (2009)



Single-tag charmed mesons at BESIII

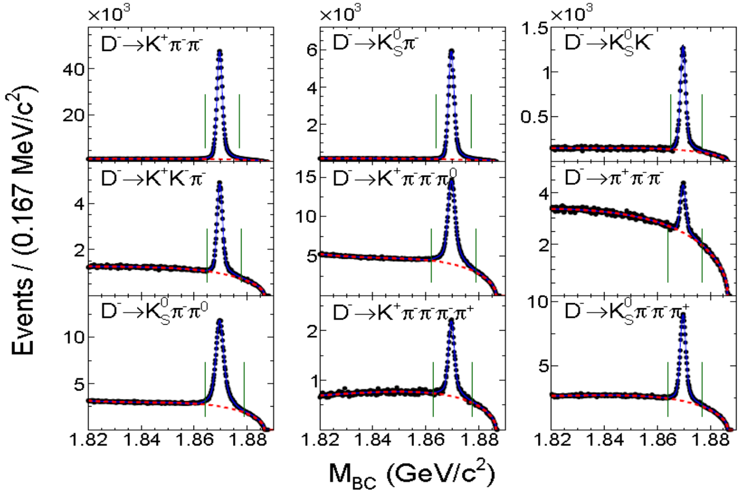
$e^+e^- \to \psi(3770) \to D^0\bar{D}^0$



2.93→20.3 fb^{-1}
@3.773 GeV

2.7M

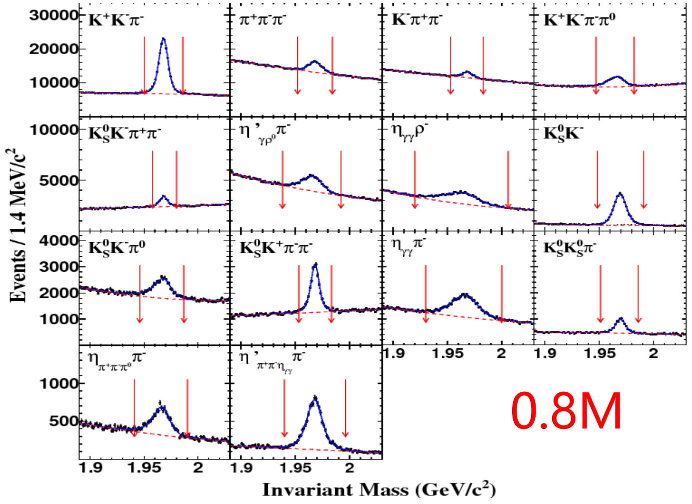
$e^+e^- \to \psi(3770) \to D^+D^-$



2.93→20.3 fb^{-1}
@3.773 GeV

1.7M

$e^+e^- \to \psi(4160) \to D_s^+ D_s^{*-} + c.c.$

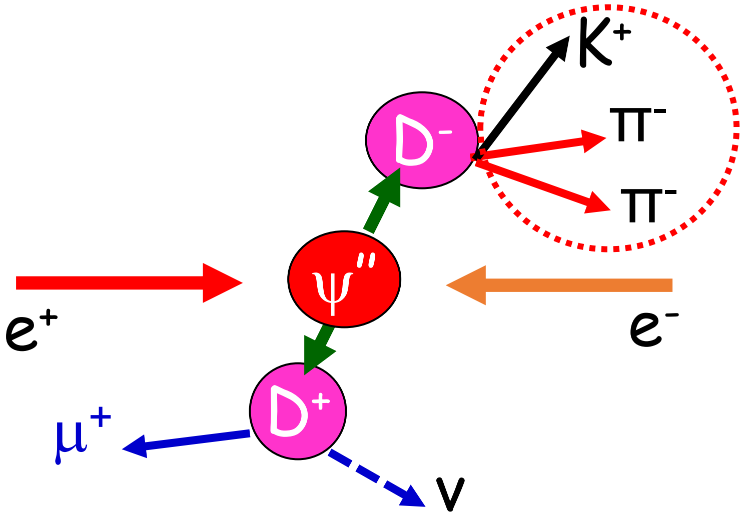


3.19→7.33 fb^{-1}
@4.13-4.23 GeV

0.8M

The total single-tag yields of $\bar{D}^0$, D^-, and D_s^- are >20, >20, and 9 times CLEO-c, respectively

The world largest threshold charmed mesons at BESIII



Produced in pair → Double tag method

Low background → low systematic uncertainties

Quantum correlation for $\psi(3770) \to D^0\bar{D}^0$ pairs

Yields of Singly Tagged (ST) charmed hadrons

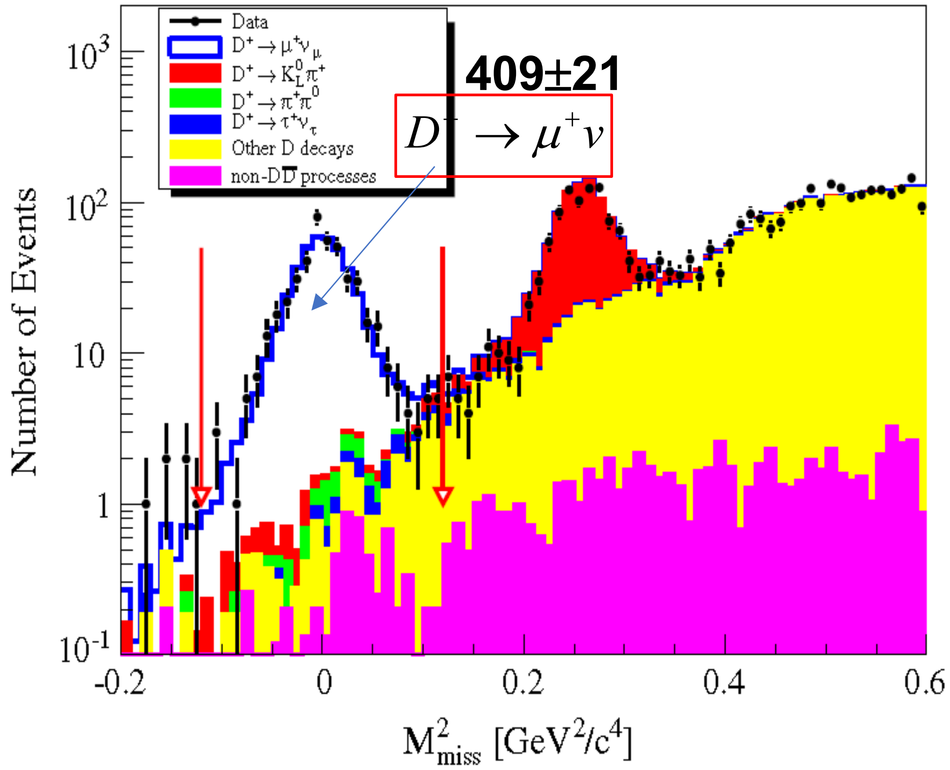
E_{cm} (GeV)	Data taking year	L (fb^{-1})	ST D^0 yield	ST D^+ Yield	ST D_s^+ yield
3.773	2010-11 (→2022-24)	2.93 → 20.3	2.7M (~7×)	1.7M (~7×)	
4.009	2011	0.48			13K
4.13-4.23	2016,2017,2012,2019	7.33			0.8M

Total yields of various charmed hadrons at BESIII are lower than Belle and LHCb by 2-3 orders.
However, BESIII, Belle and LHCb have complimentary advantages in various charm physics

Leptonic D decays

Studies of $D^+ \to \mu^+\nu_\mu$

PRD89(2014)051104, 2.93 fb^{-1}@3.773 GeV

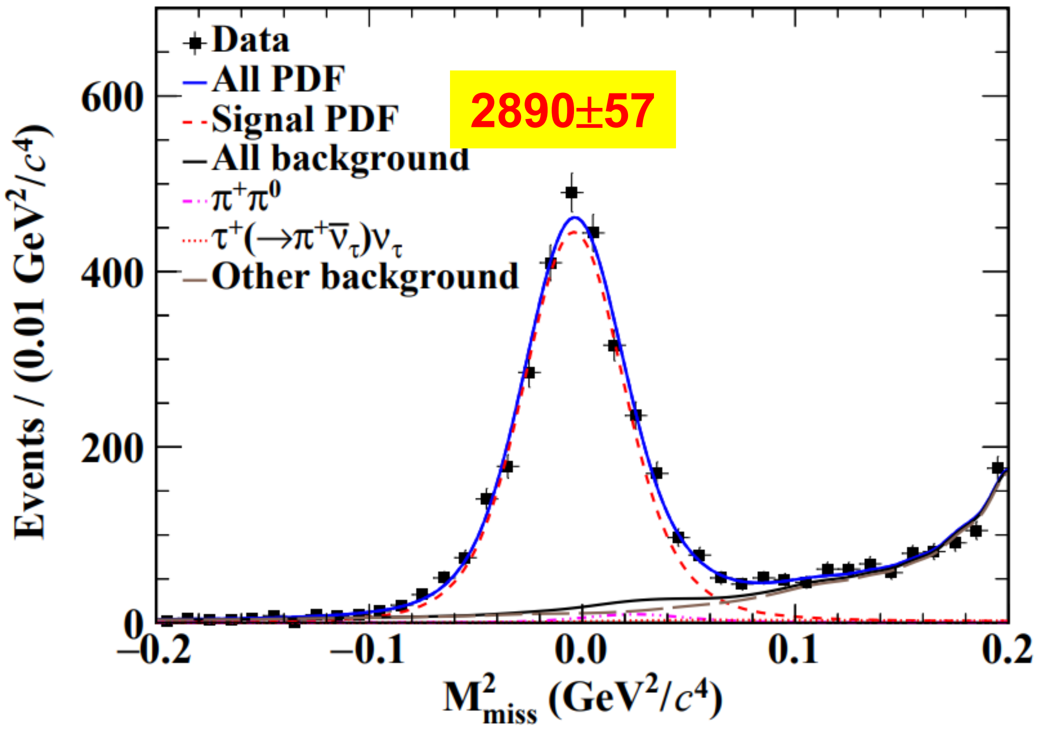


$$B[D^+ \to \mu^+ \nu] = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$$

$$f_{D^+}|V_{cd}| = 46.7 \pm 1.2 \pm 0.4 \text{ MeV}$$

Precision~2.7% **首次提出使用纯轻衰变测量$|V_{cd}|$**

PRL135(2025)061801, 20.3 fb^{-1}@3.773 GeV



The most precise to date

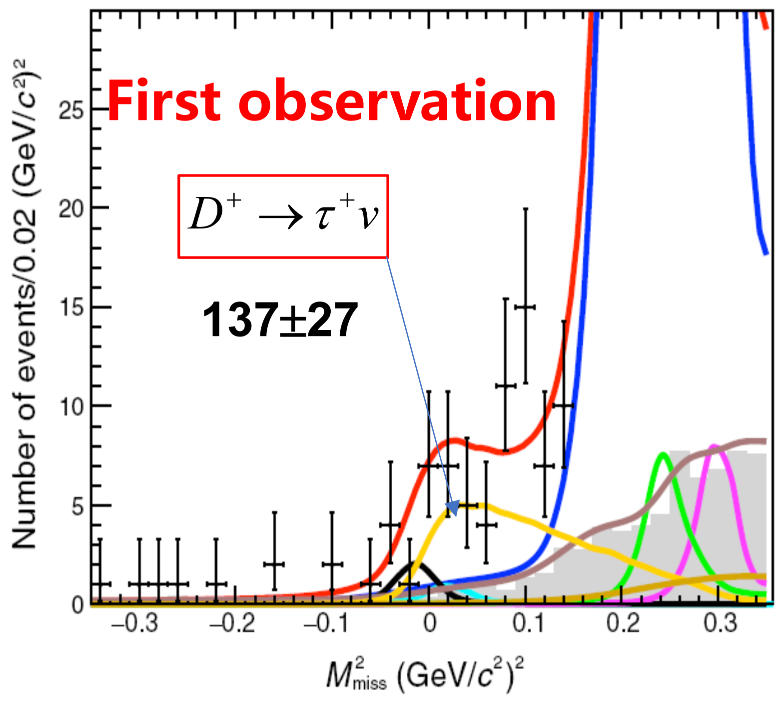
$$B[D^+ \to \mu^+ \nu] = (4.03 \pm 0.08 \pm 0.04) \times 10^{-4}$$

$$f_{D^+}|V_{cd}| = 48.52 \pm 0.48 \pm 0.19 \text{ MeV}$$

Precision~1.2%

Studies of $D^+ \to \tau^+\nu_\tau$ and LFU test

PRL123(2019)211802, 2.93 fb^{-1}@3.773 GeV

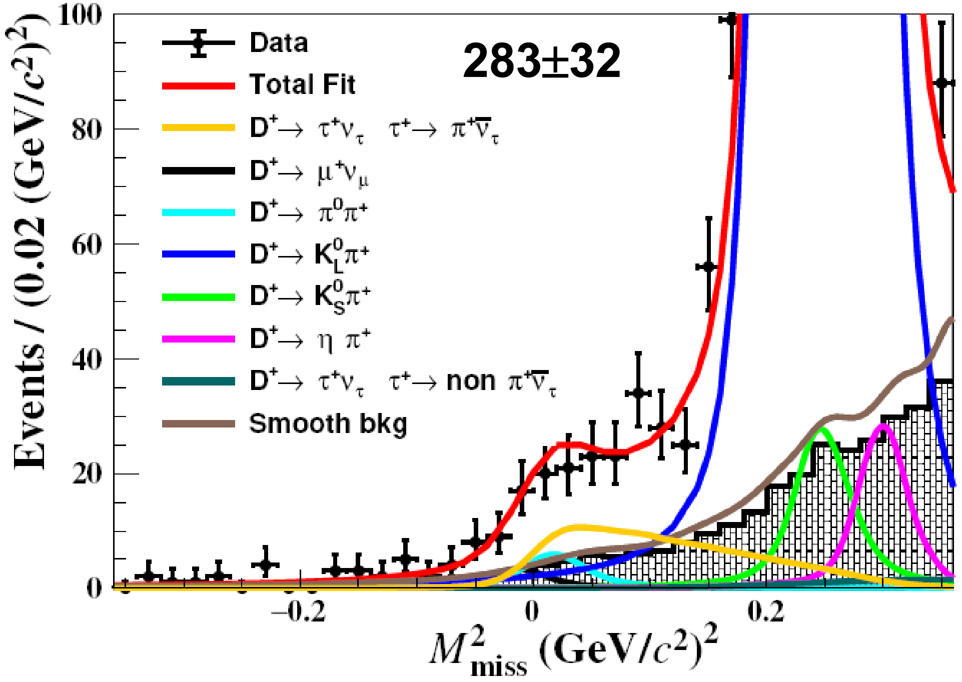


$$B[D^+ \to \tau^+ v] = (1.20 \pm 0.24 \pm 0.12) \times 10^{-3}$$

$$\mathbf{f_{D^+}|V_{cd}| = 50.4 \pm 5.0 \pm 2.5\ MeV}$$

Precision~11%

JHEP01(2025)089, 7.9 fb^{-1}@3.773 GeV



$$B[D^+ \to \tau^+ v] = (9.1 \pm 1.1 \pm 0.5) \times 10^{-4}$$

$$\mathbf{f_{D^+}|V_{cd}| = 45.9 \pm 2.5 \pm 1.2\ MeV}$$

Precision~5.5%

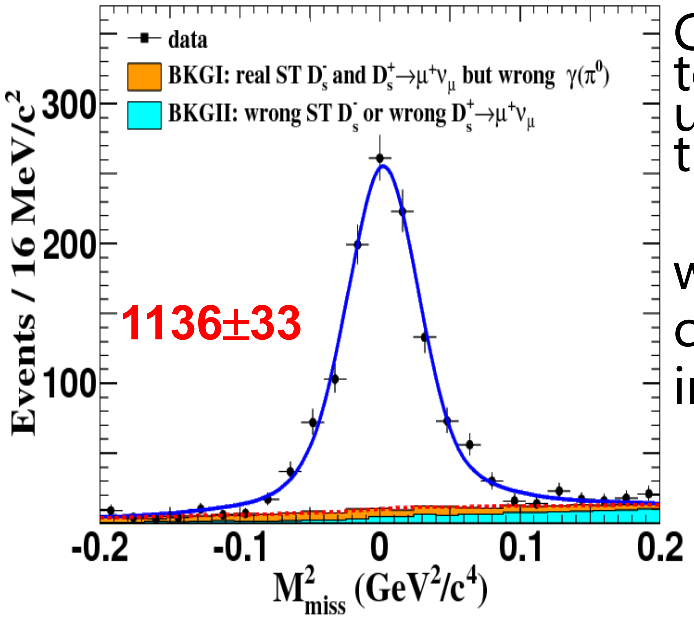
$$R_D = \frac{B[D^+ \to \tau^+ v]}{B[D^+ \to \mu^+ v]} = 2.49 \pm 0.31$$

SM prediction: 2.67

Studies of $D_s^+ \to \mu^+ \nu_\mu$

3.19 fb^{-1}@4.18 GeV

PRL122(2019)071802



Constrained fit to matched and un-matched transition $\gamma(\pi^0)$

with μ counter information

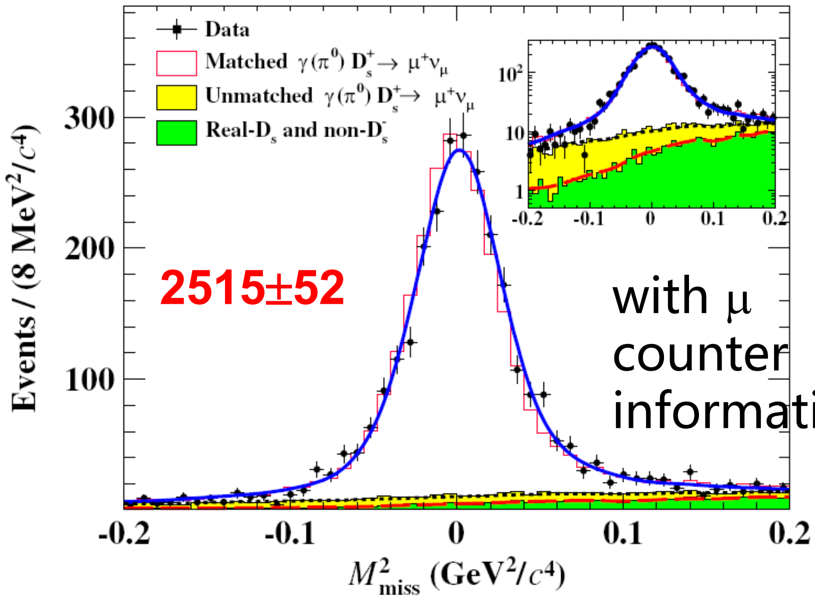
$$B[D_s^+ \to \mu^+ v] = (5.49 \pm 0.16 \pm 0.15) \times 10^{-3}$$

$$f_{D_s^+}|V_{cs}| = (246.2 \pm 3.6 \pm 3.5)\ \text{MeV}$$

Precision~2.1%

PRD104(2021)052009, 6.3 fb^{-1}@4.18-4.23GeV

PRD108(2023)112001, 7.33 fb^{-1}@4.18-4.23GeV



with μ counter information

$$B[D_s^+ \to \mu^+ v] = (5.29 \pm 0.11 \pm 0.09) \times 10^{-3}$$

$$f_{D_s^+}|V_{cs}| = (241.8 \pm 2.5 \pm 2.2)\ \text{MeV}$$

Precision~1.4%

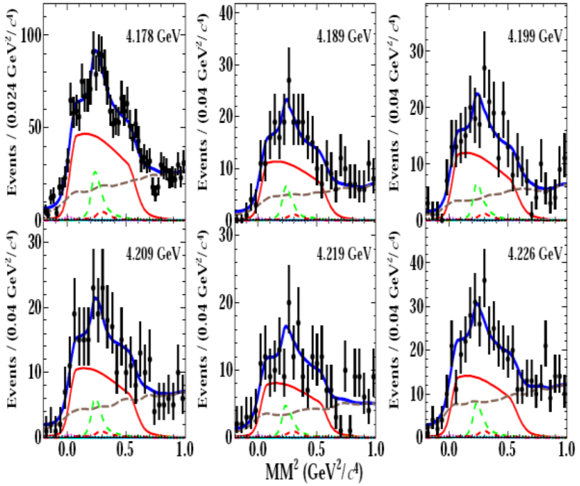
The most precise to date

Studies of $D_s^+ \to \tau^+\nu_\tau$ and LFU test

$D_s^+ \to \tau^+(\rho^+\nu)\nu$

PRD104(2021)032001,
6.3 fb^{-1}@4.18-4.23GeV

1745±84



$B[D_s^+ \to \tau^+\nu] = (5.29 \pm 0.25 \pm 0.20)\%$

$f_{D_s^+}|V_{cs}| = (244.8 \pm 5.8 \pm 4.8)$ MeV

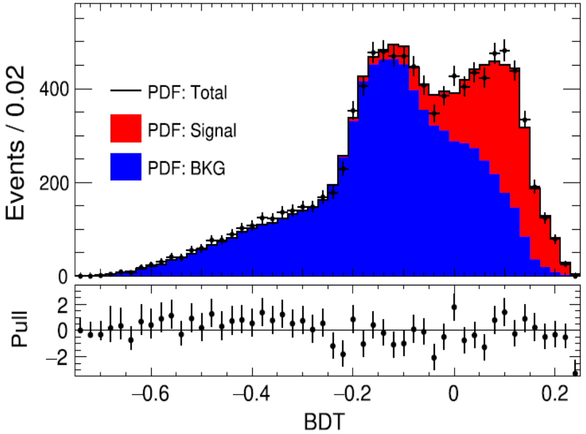
Precision~3.1%

$D_s^+ \to \tau^+(\pi^+\nu)\nu$

PRD104(2021)052009,
6.3 fb^{-1}@4.18-4.23GeV

PRD108(2023)092014,
7.33 fb^{-1}@4.18-4.23GeV

BDT 2411±75



$B[D_s^+ \to \tau^+\nu] = (5.44 \pm 0.17 \pm 0.13)\%$

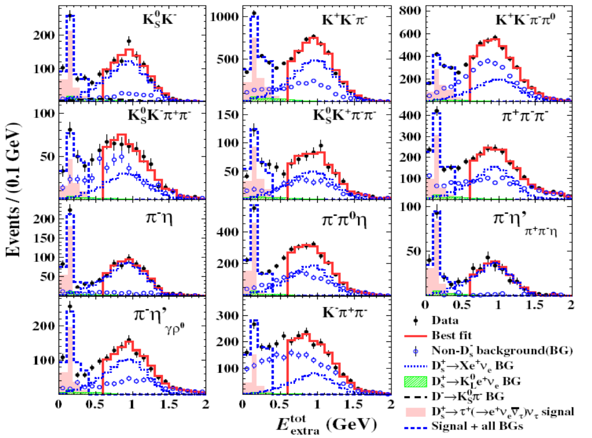
$f_{D_s^+}|V_{cs}| = (248.3 \pm 3.9 \pm 3.2)$ MeV

Precision~2.0%

$D_s^+ \to \tau^+(e^+\nu\nu)\nu$

PRL127(2021)171801,
6.3 fb^{-1}@4.18-4.23GeV

4940±97



$B[D_s^+ \to \tau^+\nu] = (5.27 \pm 0.10 \pm 0.12)\%$

$f_{D_s^+}|V_{cs}| = (244.4 \pm 2.3 \pm 2.9)$ MeV

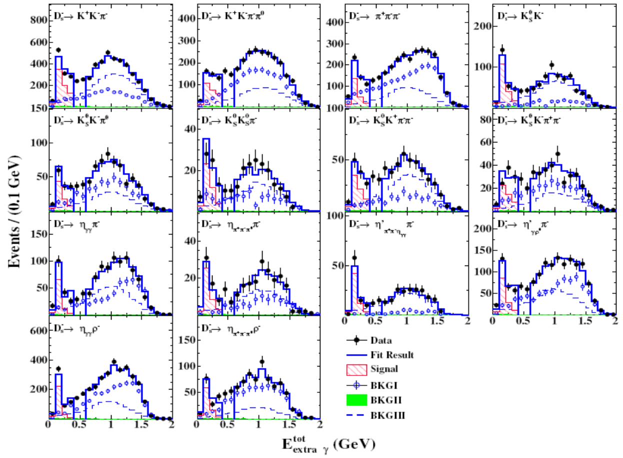
Precision~1.5%

The most precise to date

$D_s^+ \to \tau^+(\mu^+\nu\nu)\nu$

JHEP09(2023)124,
7.33 fb^{-1}@4.18-4.23GeV

2281±73



$B[D_s^+ \to \tau^+\nu] = (5.37 \pm 0.17 \pm 0.15)\%$

$f_{D_s^+}|V_{cs}| = (246.7 \pm 3.9 \pm 3.6)$ MeV

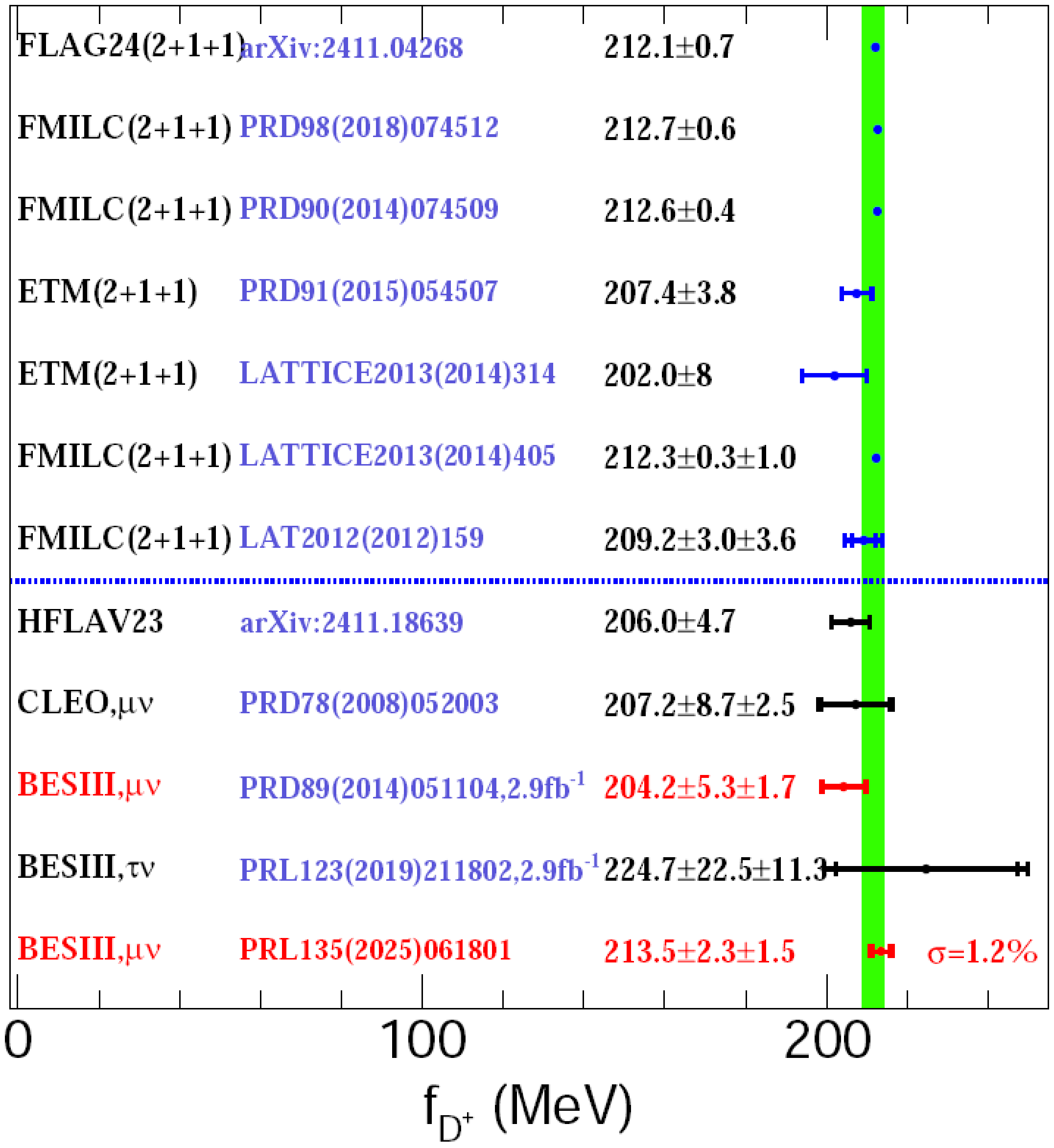
Precision~2.2%

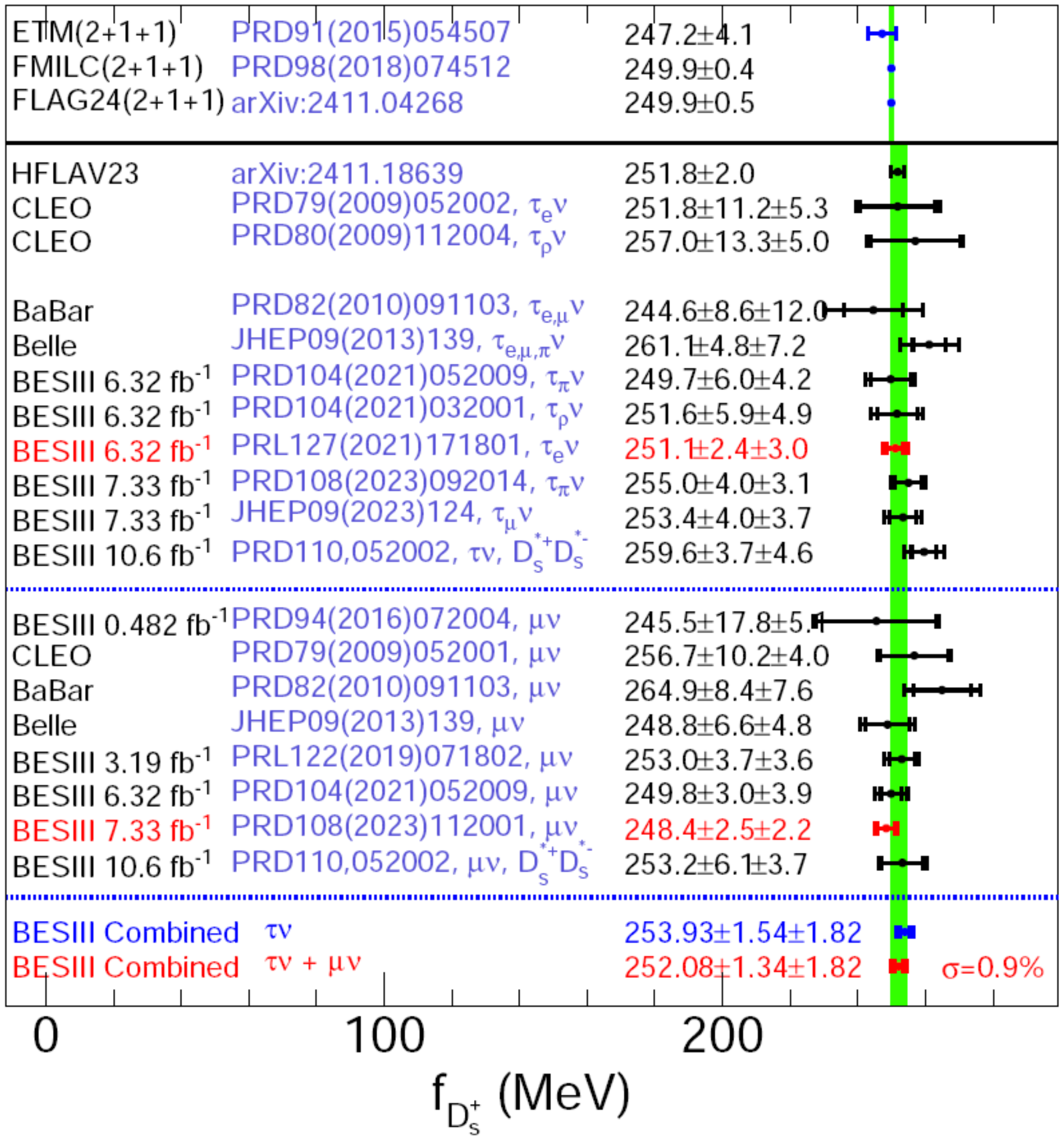
$B^{BESIII}[D_s^+ \to \tau^+\nu] = (5.32 \pm 0.07 \pm 0.07)\%$

$$R_{Ds} = \frac{B[D_s^+ \to \tau^+\nu]}{B[D_s^+ \to \mu^+\nu]} = 10.05 \pm 0.35$$

SM prediction: 9.75

Comparisons of f_{D^+} and $f_{D_s^+}$

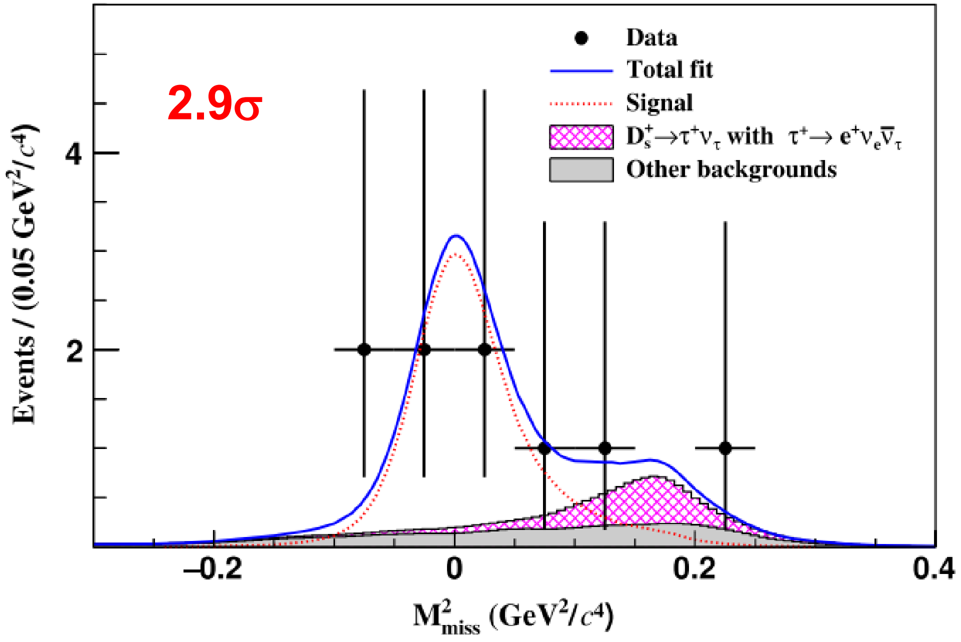




First experimental study of $D_s^{*+} \to e^+\nu_e$

PRL131 (2023) 141802

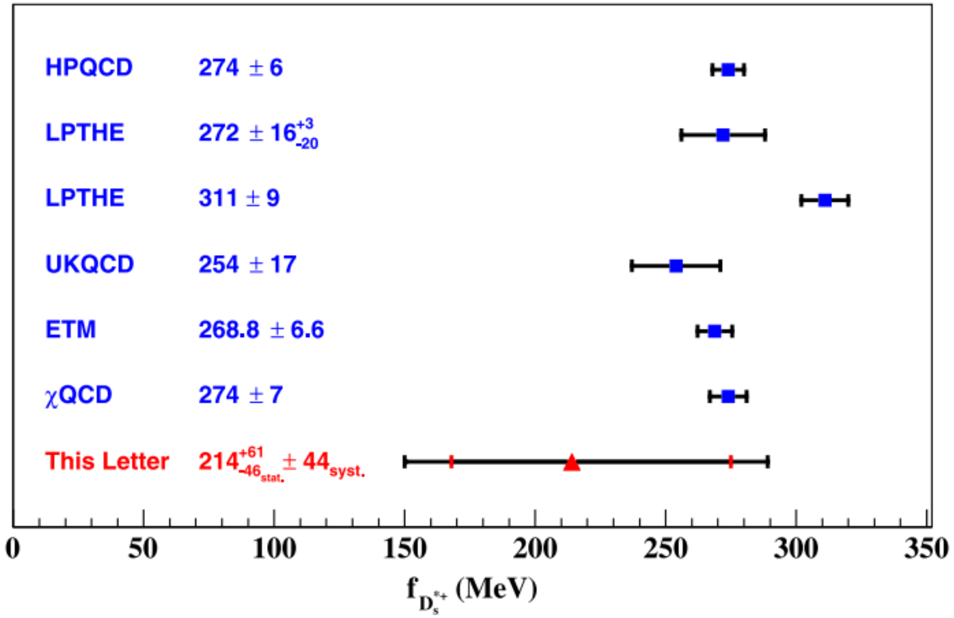
7.33 fb^{-1}@4.13-4.23 GeV



$$\mathcal{B}(D_s^{*+} \to e^+\nu_e) = (2.1^{+1.2}_{-0.9\,\mathrm{stat}} \pm 0.2_{\mathrm{syst}}) \times 10^{-5}$$

$$\Gamma(D_s^{*+} \to \ell^+\nu_\ell) = \frac{G_F^2}{12\pi}|V_{cs}|^2 f^2_{D_s^{*+}} m^3_{D_s^{*+}} \left(1 - \frac{m^2_{\ell^+}}{m^2_{D_s^{*+}}}\right)^2 \times \left(1 + \frac{m^2_{\ell^+}}{2m^2_{D_s^{*+}}}\right),$$

联合格点QCD计算的D_s^{*+}总宽度，首次抽取D_s^{*+}衰变常数



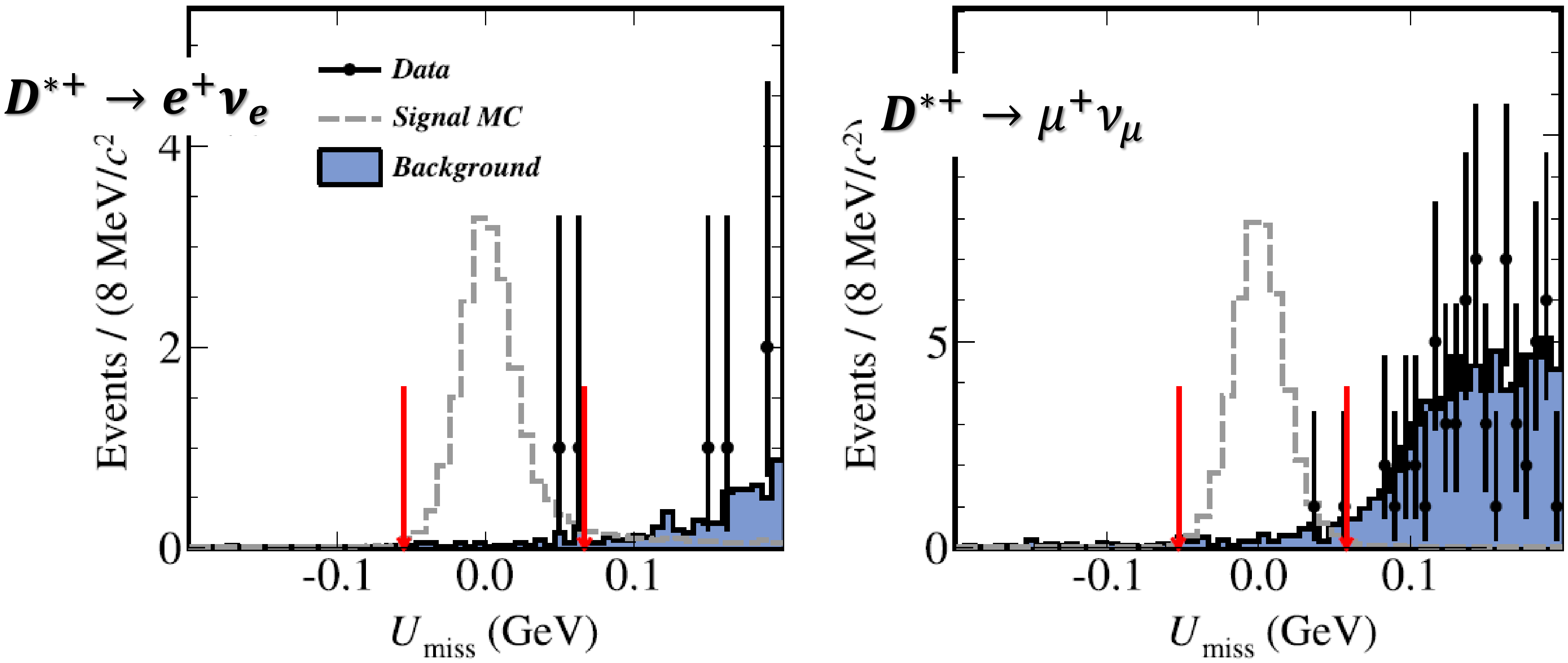
→ 为约束格点QCD计算的D_s^{*+}衰变常数首次提供实验依据

→ 对D_s^{*+}宽度上限的约束改进3个量级

Search for $D^{*+} \to l^+ \nu_l$

6.3 fb^{-1}@4.18-4.23 GeV

PRD110 (2024) 012003



$B[D^{*+} \to e^+ v] < 1.1 \times 10^{-5}$

$B[D^{*+} \to \mu^+ v] < 4.3 \times 10^{-6}$

@90% CL

Semileptonic D decays

- Semileptonic decays of $D \to Pe^+\nu_e$
- Semileptonic decays of $D \to Se^+\nu_e$
- Semileptonic decays of $D \to Ve^+\nu_e$
- Semileptonic decays of $D \to Ae^+\nu_e$

$D \to P/Sl^+\nu_l$半轻衰变的研究

Dynamic study

$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2|V_{cd(s)}|^2}{24\pi^3}p^3|f_+(q^2)|^2 \longrightarrow f_+^{D\to P/S}(0)|V_{cs(d)}|$$

Form factor parameterizations:

– Single pole form $$f_+(q^2) = \frac{f_+(0)}{1-\frac{q^2}{M^2_{\rm pole}}}$$

– Modified pole $$f_+(q^2) = \frac{f_+(0)}{(1-\frac{q^2}{M^2_{\rm pole}})(1-\alpha\frac{q^2}{M^2_{\rm pole}})}$$

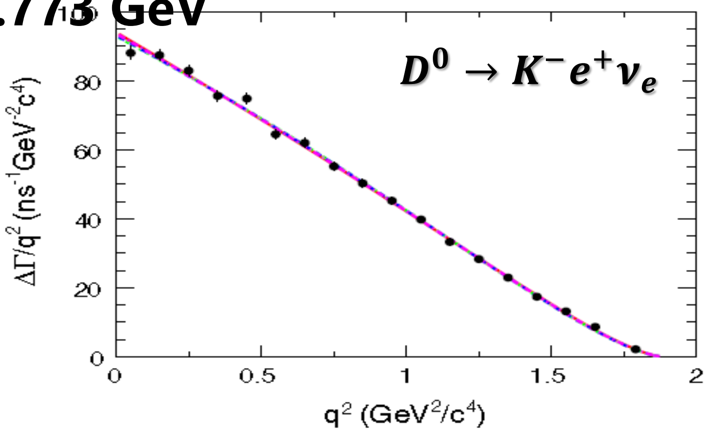
– ISGW2 $$f_+(q^2) = f_+(q^2_{\rm max})\left(1+\frac{r^2_{\rm ISGW2}}{12}(q^2_{\rm max}-q^2)\right)^{-2}$$

– Series expansion $$f_+(t) = \frac{1}{P(t)\Phi(t,t_0)}a_0(t_0)\left(1+\sum_{k=1}^{\infty}r_k(t_0)[z(t,t_0)]^k\right)$$

Studies of $c \to s l^+ \nu_l$ semileptonic decays

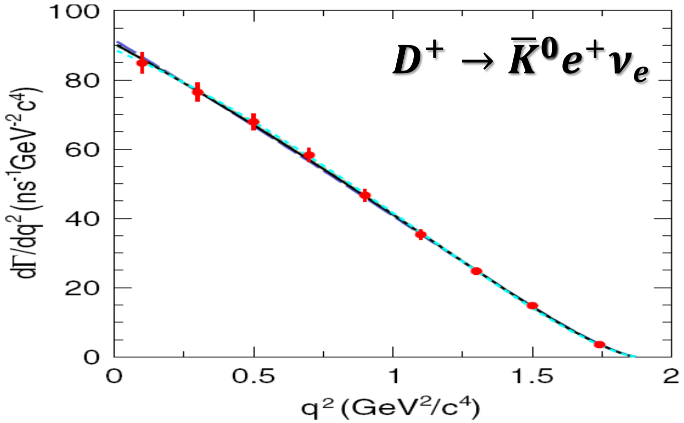
2.93 fb^{-1} @3.773 GeV

PRD92(2015)072012



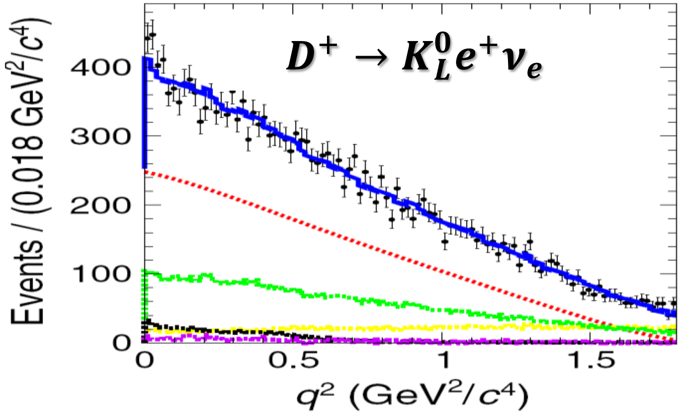
$f_+^{D\to K}(0)|V_{cs}| = 0.717(03)(04)$

PRD96(2017)012002



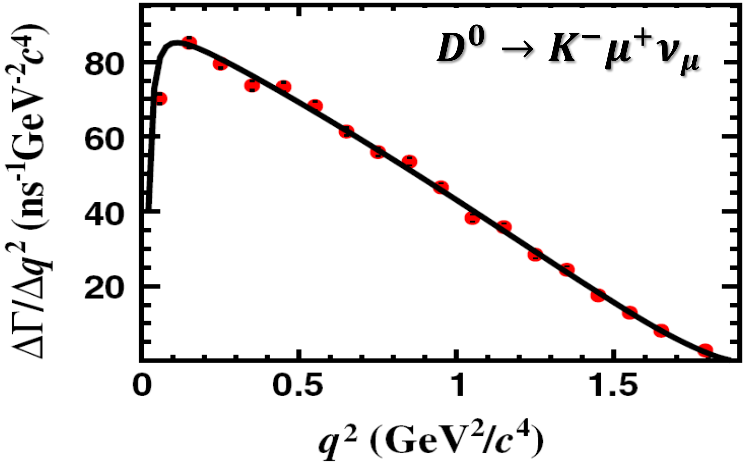
$f_+^{D\to K}(0)|V_{cs}| = 0.705(04)(11)$

PRD92(2015)112008



$f_+^{D\to K}(0)|V_{cs}| = 0.728(06)(11)$

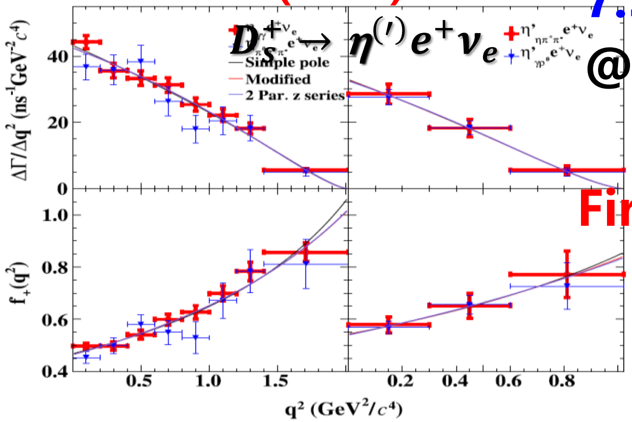
PRL122(2019)011804



$f_+^{D\to K}(0)|V_{cs}| = 0.7148(38)(29)$

PRL123(2019)121801→
PRD108(2023)092003

7.33 fb^{-1} @4.13-4.23 GeV

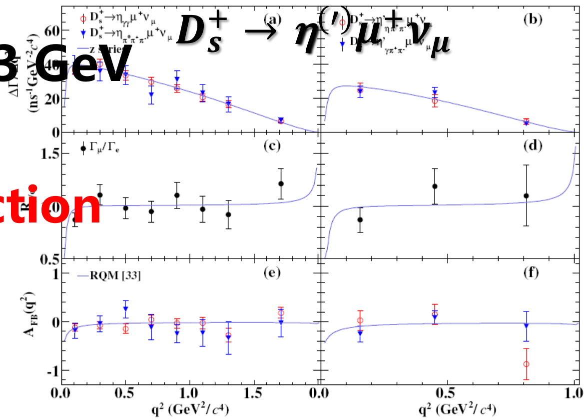


$f_+^{D_s\to\eta}(0)|V_{cs}| = 0.452(07)(07)$

$f_+^{D_s\to\eta'}(0)|V_{cs}| = 0.525(24)(09)$

First extraction

PRL132(2024)091802

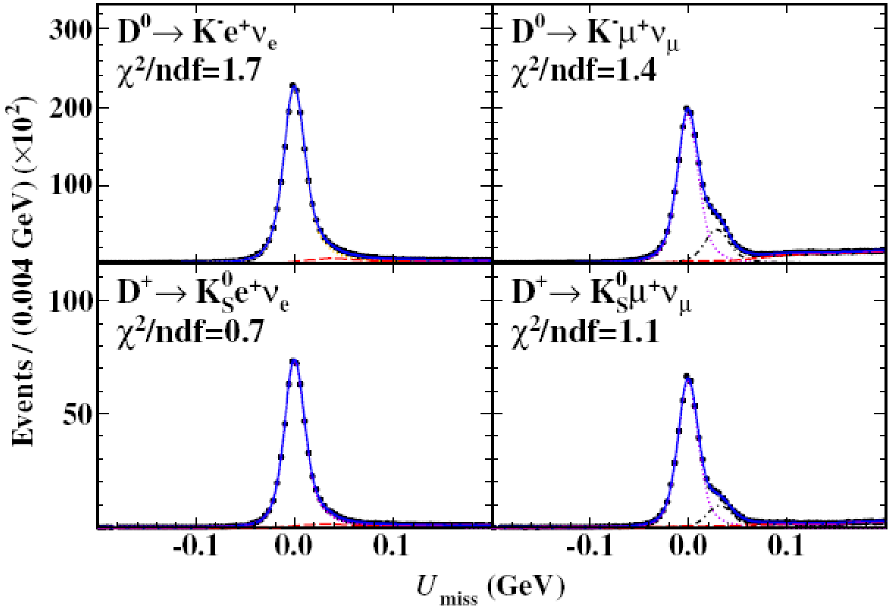


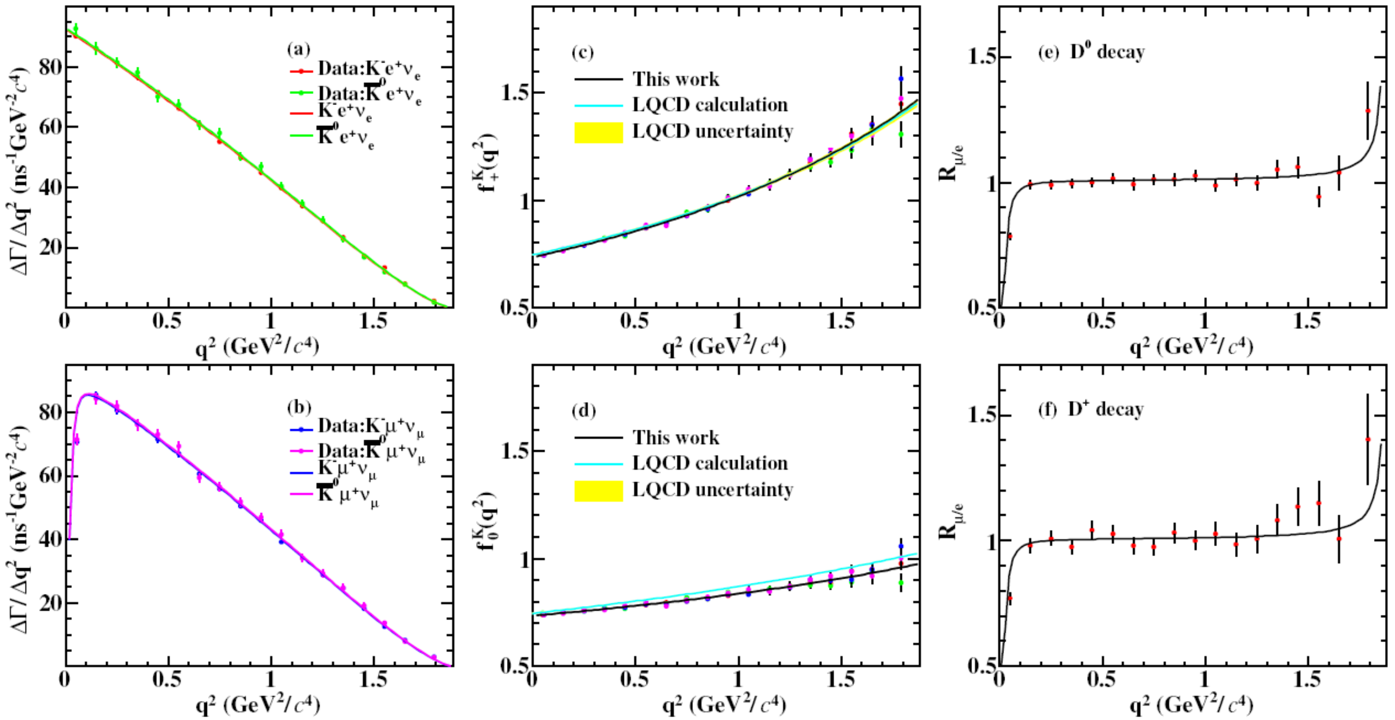
$f_+^{D_s\to\eta}(0)|V_{cs}| = 0.451(10)(08)$

$f_+^{D_s\to\eta'}(0)|V_{cs}| = 0.506(37)(11)$

Latest results of $D^{0(+)} \to \bar{K}\ell^+\nu_\ell$ ($\ell = e$ or μ)

7.9 fb^{-1} @3.773 GeV **PRD110(2024)112006**



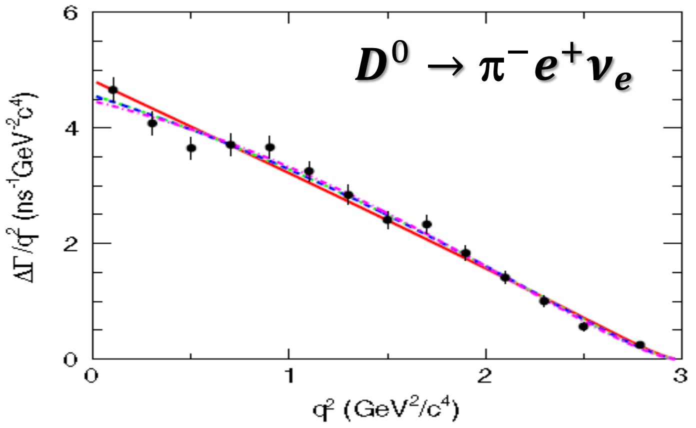


Decay	$N_{\rm DT}$	$\bar{\varepsilon}_{\rm sig}$ (%)	$\mathcal{B}_{\rm sig}$ (%)
$D^0 \to K^-e^+\nu_e$	190605 ± 471	68.79 ± 0.03	$3.509 \pm 0.009 \pm 0.013$
$D^0 \to K^-\mu^+\nu_\mu$	147596 ± 488	54.85 ± 0.03	$3.408 \pm 0.011 \pm 0.013$
$D^+ \to \bar{K}^0e^+\nu_e$	57846 ± 256	15.74 ± 0.01	$8.856 \pm 0.039 \pm 0.078$
$D^+ \to \bar{K}^0\mu^+\nu_\mu$	47229 ± 248	13.14 ± 0.01	$8.661 \pm 0.046 \pm 0.080$

Case	Decay	$f_+^K(0)\|V_{cs}\|$	$r_1(t_0)$	$\rho_{2\rm par}$	χ^2/ndf
Individual fit	$D^0 \to K^-e^+\nu_e$	$0.7168 \pm 0.0016 \pm 0.0014$	$-2.30 \pm 0.05 \pm 0.03$	0.53	16.3/16
	$D^0 \to K^-\mu^+\nu_\mu$	$0.7150 \pm 0.0022 \pm 0.0016$	$-2.28 \pm 0.08 \pm 0.02$	0.67	17.2/16
	$D^+ \to \bar{K}^0e^+\nu_e$	$0.7204 \pm 0.0027 \pm 0.0033$	$-2.13 \pm 0.10 \pm 0.07$	0.30	13.1/16
	$D^+ \to \bar{K}^0\mu^+\nu_\mu$	$0.7122 \pm 0.0035 \pm 0.0030$	$-2.41 \pm 0.12 \pm 0.08$	0.46	10.4/16
Simultaneous fit	$D \to \bar{K}\ell^+\nu_\ell$	$0.7162 \pm 0.0011 \pm 0.0012$	$-2.28 \pm 0.04 \pm 0.02$	0.48	61.2/70

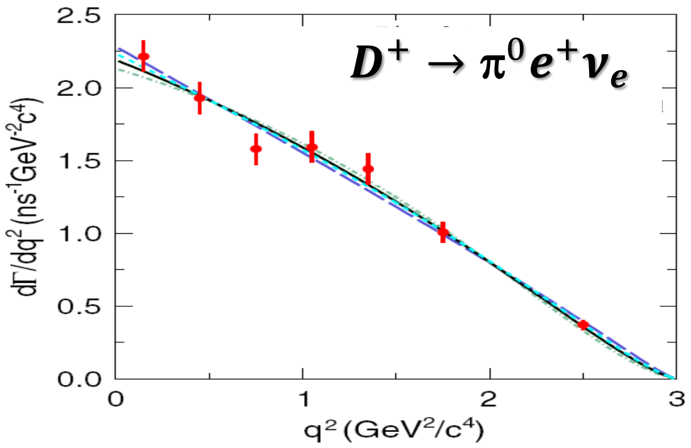
Studies of $c \to d l^+ \nu_l$ semileptonic decays

PRD92(2015)072012



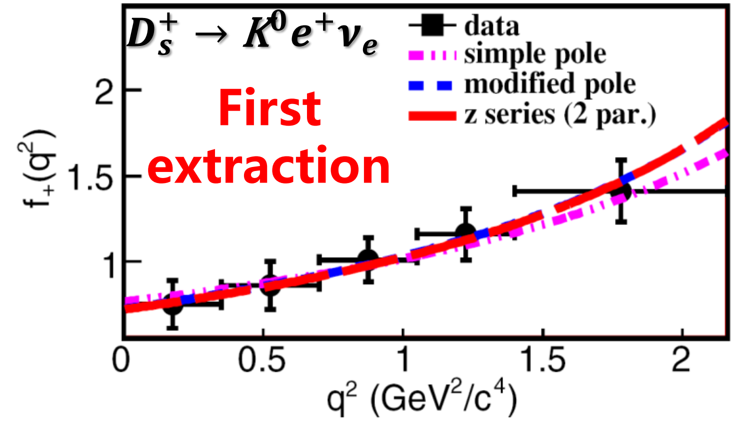
$f_+^{D\to\pi}(0)|V_{cd}| = 0.144(02)(01)$

PRD96(2017)012002



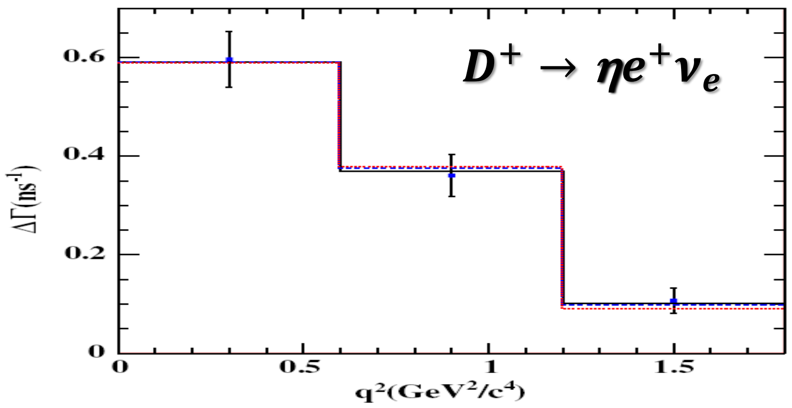
$f_+^{D\to\pi}(0)|V_{cd}| = 0.140(03)(01)$

PRL122(2019)061801



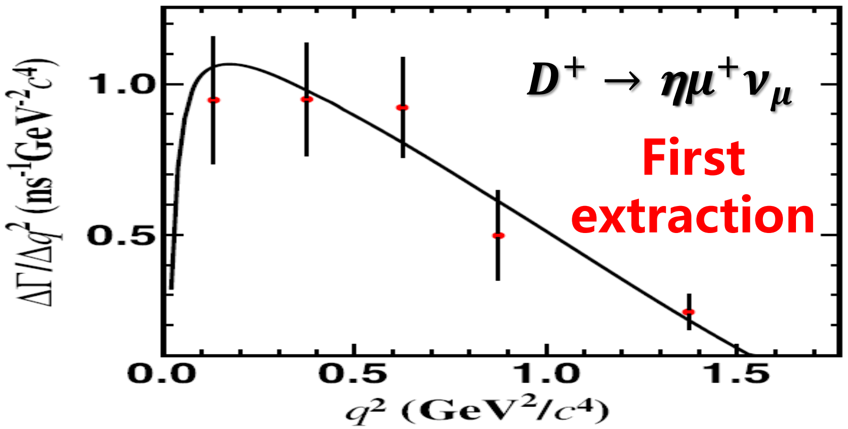
$f_+^{D_s\to K}(0)|V_{cd}| = 0.162(19)(03)$

PRD97(2018)092009



$f_+^{D\to\eta}(0)|V_{cd}| = 0.079(06)(02)$

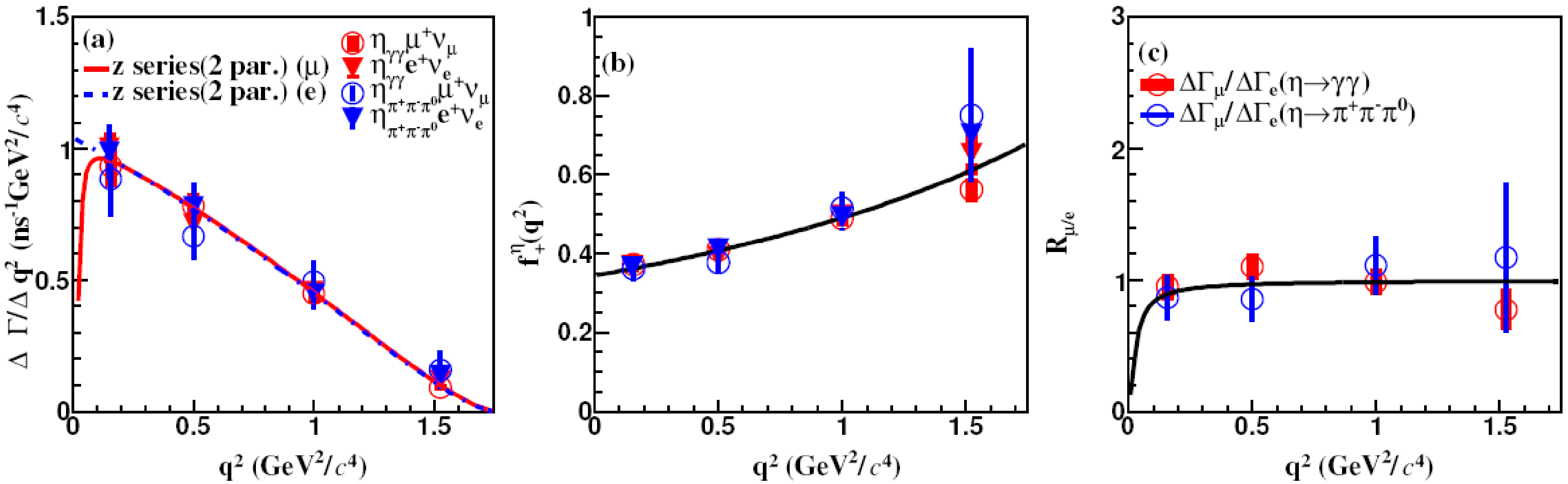
PRL124(2020)231801



$f_+^{D\to\eta}(0)|V_{cd}| = 0.087(08)(02)$

Recent study of $D^+ \to \eta\ell^+\nu_\ell$ ($\ell = e$ or μ)

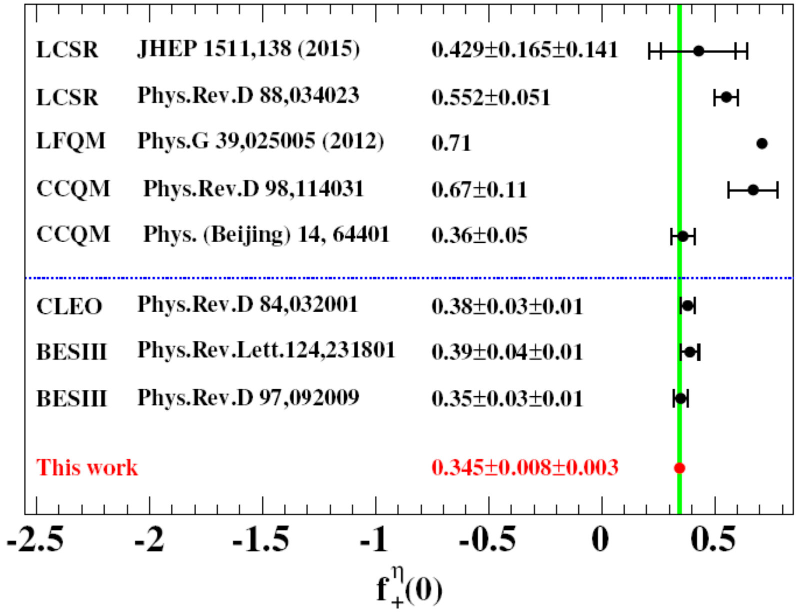
20.3 fb^{-1} @3.773 GeV，arXiv:2506.02521



$$\mathcal{B}(D^+ \to \eta e^+\nu_e) = (9.75 \pm 0.29 \pm 0.28) \times 10^{-4},$$

$$\mathcal{B}(D^+ \to \eta\mu^+\nu_\mu) = (9.08 \pm 0.35 \pm 0.23) \times 10^{-4}$$

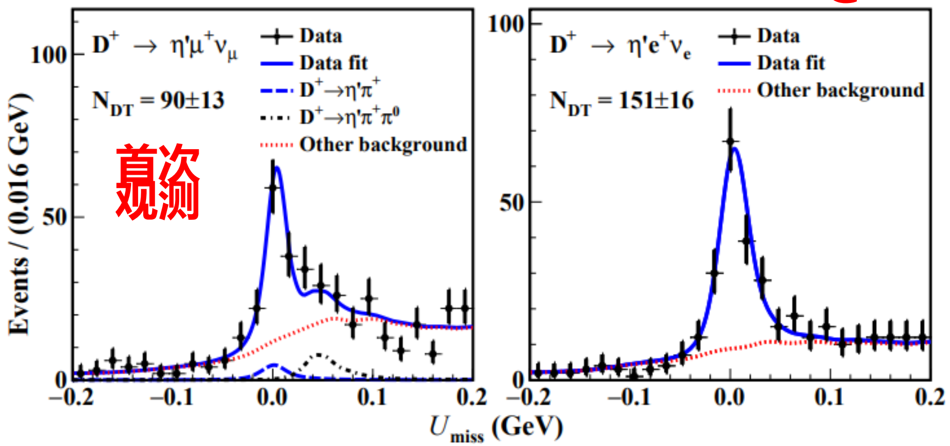
$$f_+^{D\to\eta}(0)|V_{cd}| = (7.8 \pm 0.2 \pm 0.1)\%$$



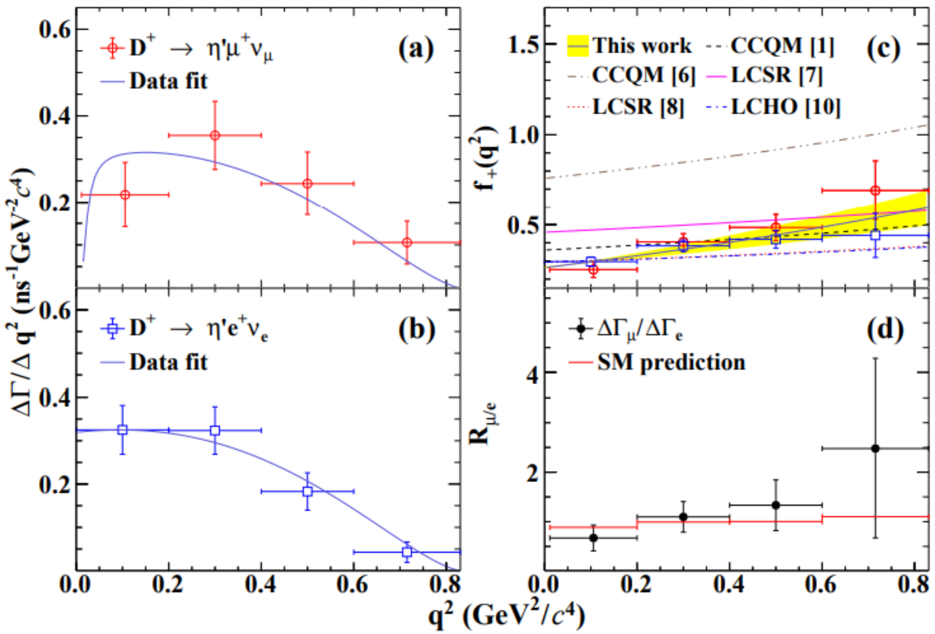
分支比精度比此前最好测量改进2倍、
$D^+ \to \eta$形状因子精度改进3.4倍

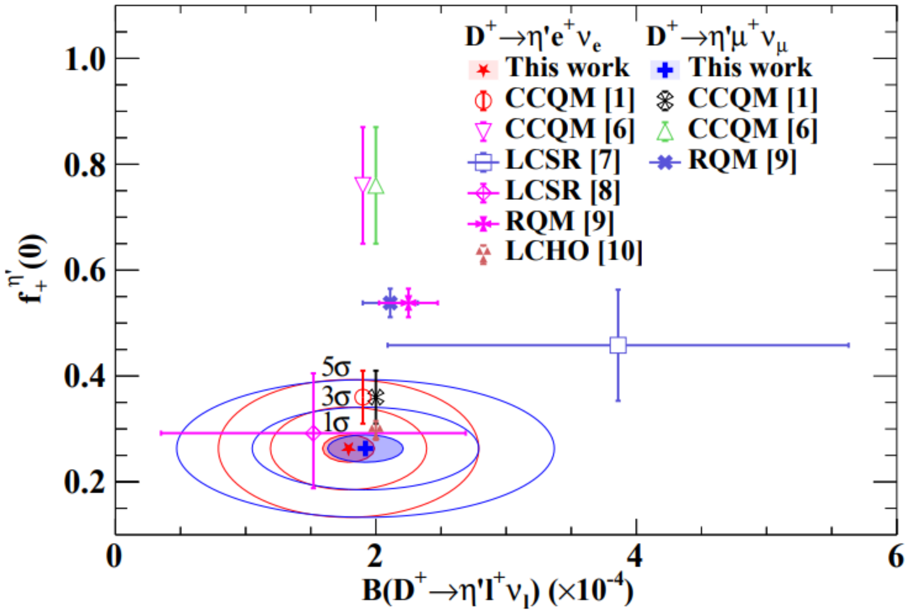
Recent study of $D^+ \to \eta' \ell^+ \nu_\ell$ ($\ell = e$ or μ)

20.3 fb^{-1} @3.773 GeV，PRL134(2025)111801



Decay	$\eta'\mu^+\nu_\mu$		$\eta' e^+\nu_e$	
η' decay	$\eta\pi^+\pi^-$	$\gamma\pi^+\pi^-$	$\eta\pi^+\pi^-$	$\gamma\pi^+\pi^-$
$\epsilon_{\rm sig}$ (%)	1.77±0.01	2.77±0.01	2.70±0.01	5.50±0.01
$N_{\rm DT}$	90±13		151±16	
Significance	8.6σ		12.9σ	
$\mathcal{B}$ ($\times10^{-4}$)	$1.92 \pm 0.28 \pm 0.08$		$1.79 \pm 0.19 \pm 0.07$	



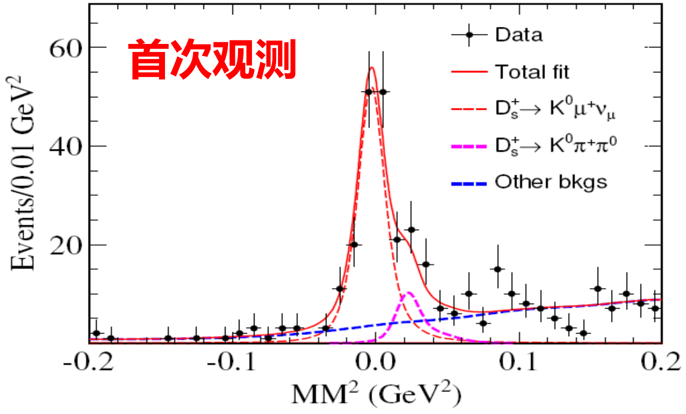


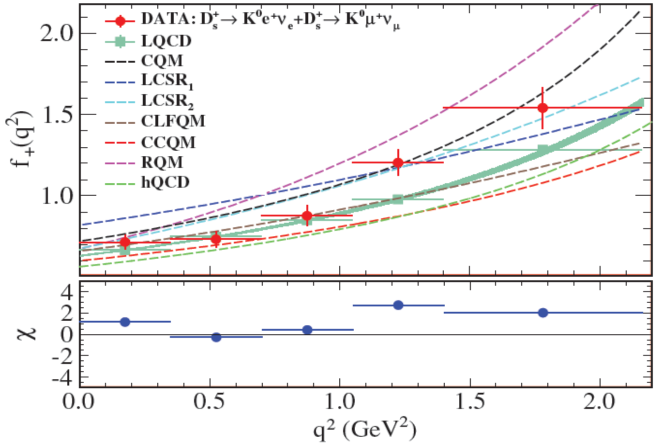
$f_+^{D\to\eta'}(0)|V_{cd}| = (5.92 \pm 0.56 \pm 0.13)\%$

首次抽取$D^+ \to \eta'$形状因子，为检验理论计算提供了重要依据

Most recent results of $D_s^+ \to K^0\ell^+\nu_\ell$ ($\ell = e$ or μ)

7.33 fb^{-1} @4.128-4.226 GeV, arXiv:2510.05904

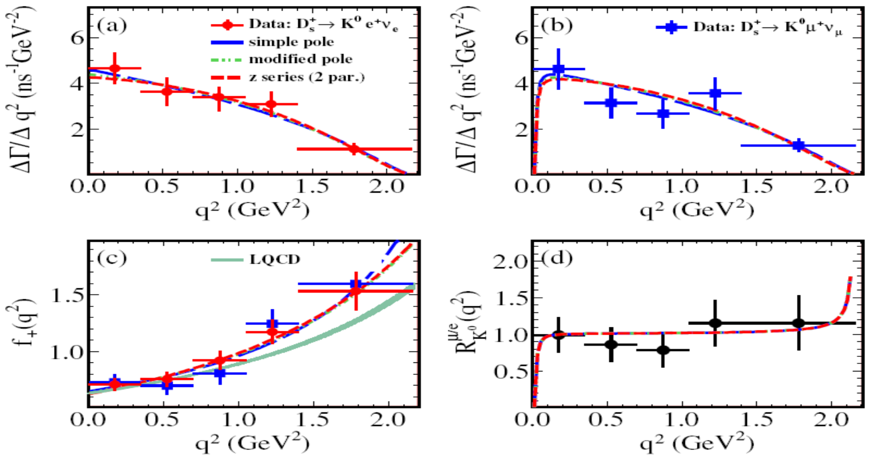


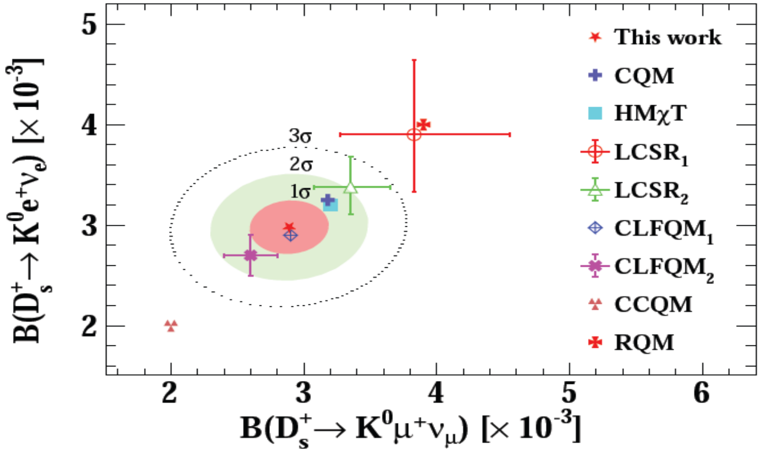


$$B(D_s \to K^0e^+\nu_e) = (2.89 \pm 0.27 \pm 0.12) \times 10^{-3}$$

$$f_+^{D_s\to K^0}(0)|V_{cd}| = (14.0 \pm 0.8 \pm 0.2)\%$$

精确测量$D_s^+ \to K^0$形状因子





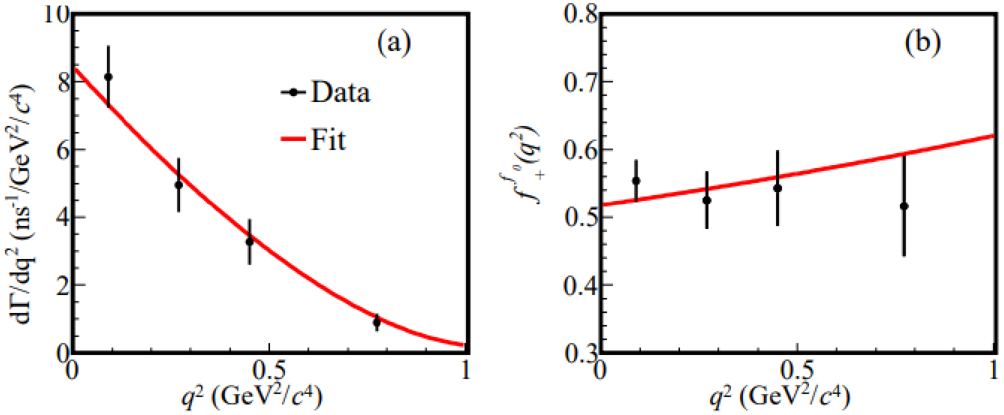
$$R_{D_s^+K^0} = \frac{\Gamma[D_s^+ \to K^0\mu^+\nu]}{\Gamma[D_s^+ \to K^0e^+\nu]} = 0.97 \pm 0.12 \pm 0.04$$

First studies of $D^+_{(s)} \to f_0 l^+ \nu_l$ decay dynamics

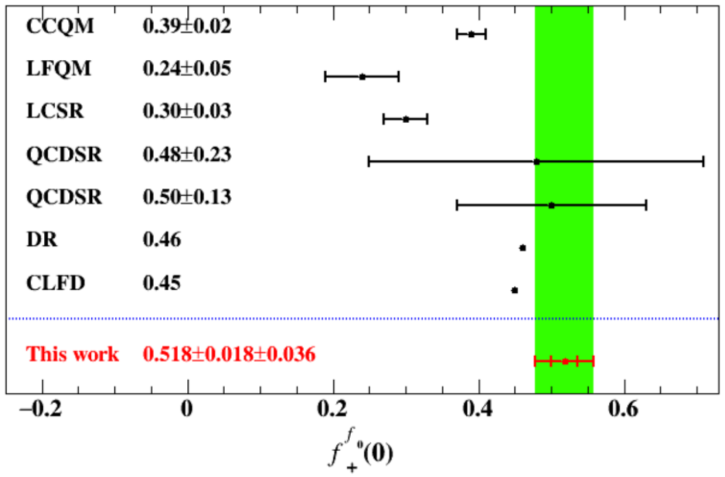
首次开展末态为标量介子动力学研究

7.33 fb^{-1}@4.13-4.23 GeV

$D_s^+ \to f_0(980)^0 e^+ \nu_e$ **PRL132(2024)141901**

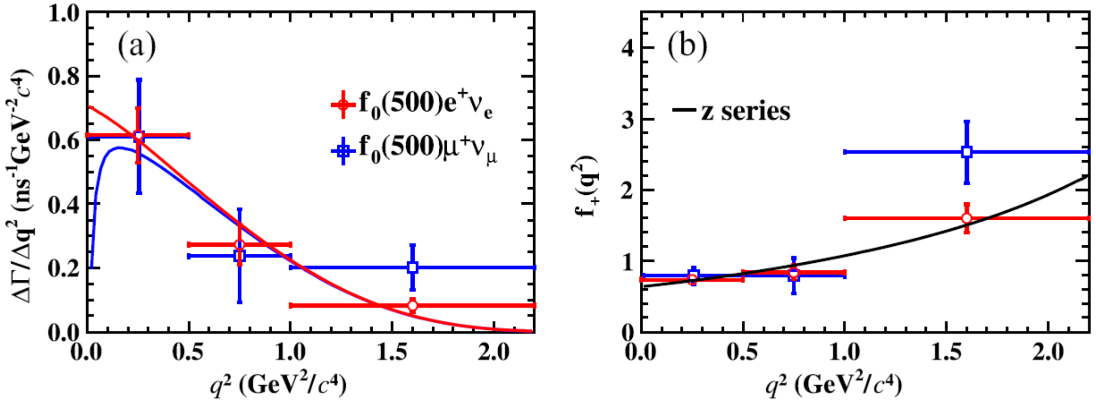


$$f_+^{D_s \to f_0(980)}(0)|V_{cs}| = 0.504(17)(35)$$

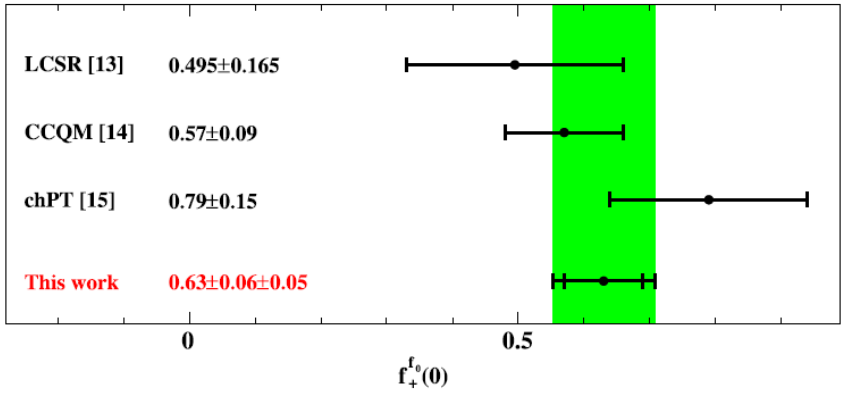


2.9 fb^{-1} @3.773 GeV

$D^+ \to f_0(500)^0 e^+ \nu_e$ **PRD110(2024)092008**

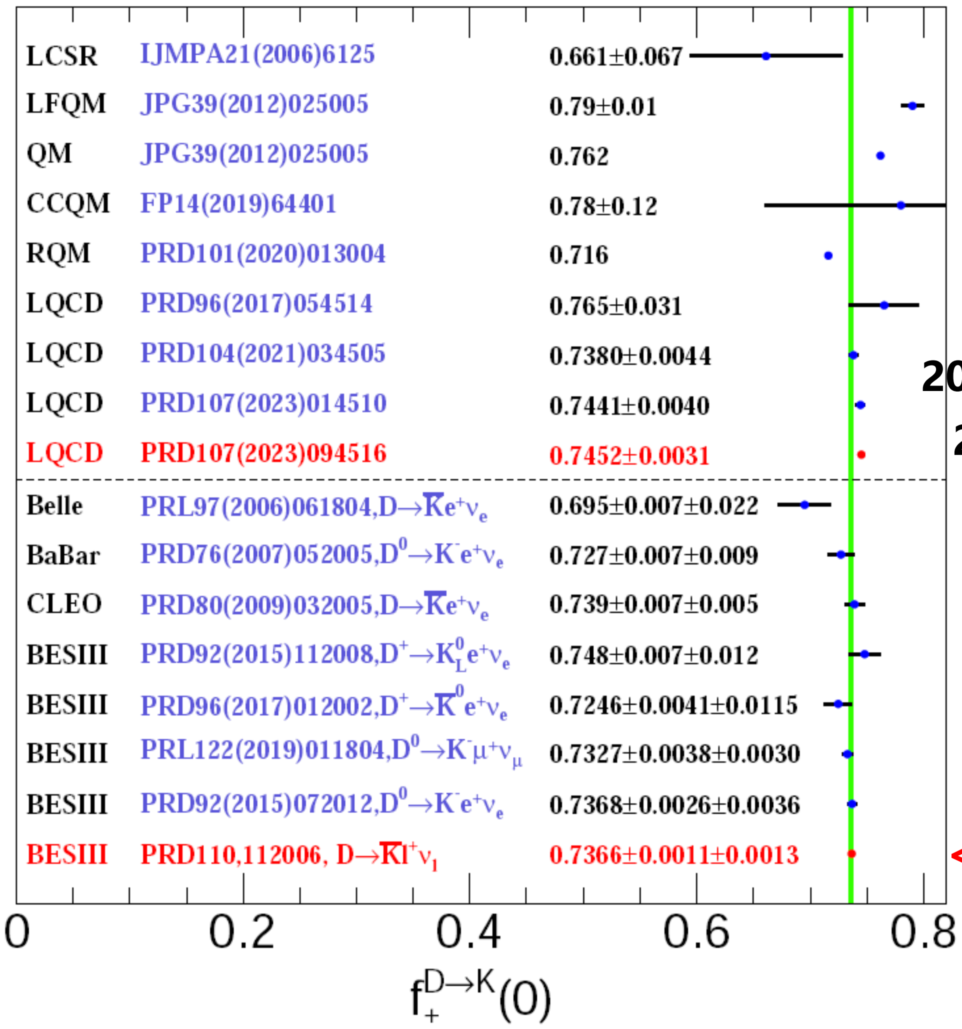


$$f_+^{D^+ \to f_0(500)}(0)|V_{cd}| = 0.143(14)(11)$$



实验测量值与理论基于f_0是两夸克成分假定时的理论计算明显偏离，暗示它们可能含有四夸克态成分

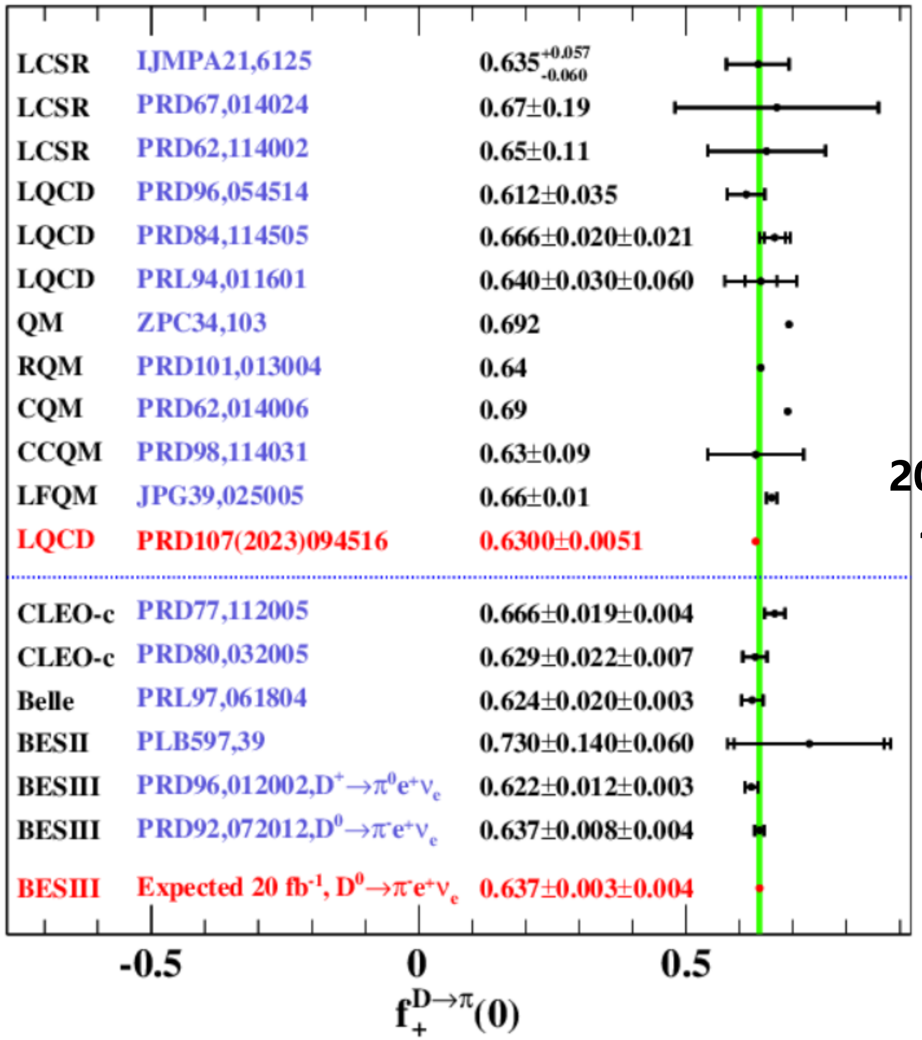
Comparisons of $f_+^{D\to K}(0)$ and $f_+^{D\to\pi}(0)$



2010→2023

2.4→0.4%

<0.3%



2011→2023

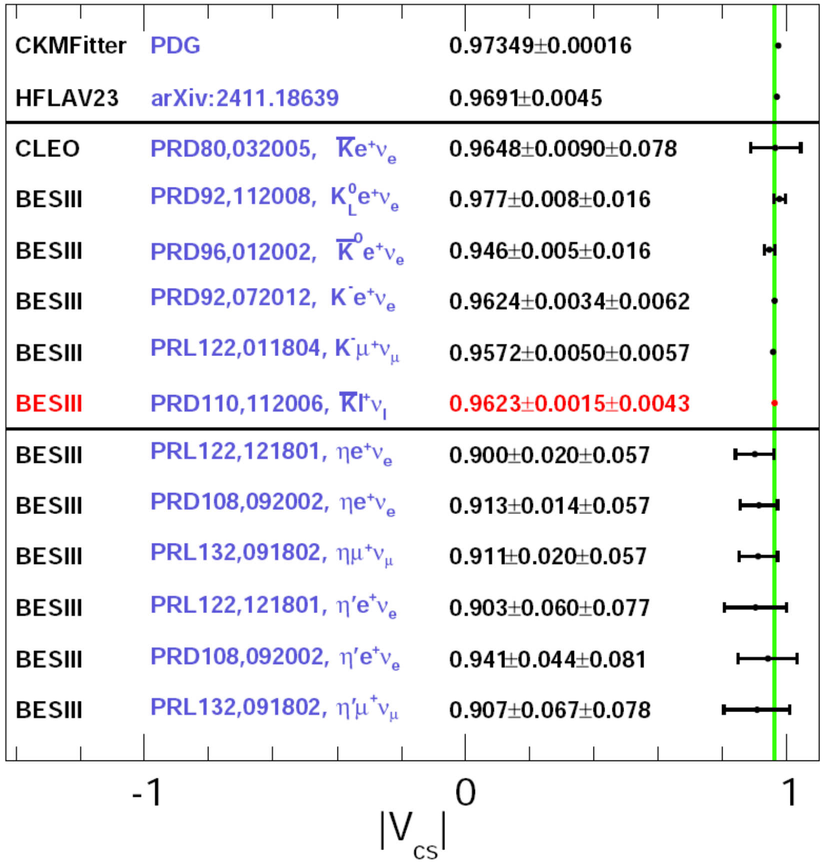
4.4→0.8%

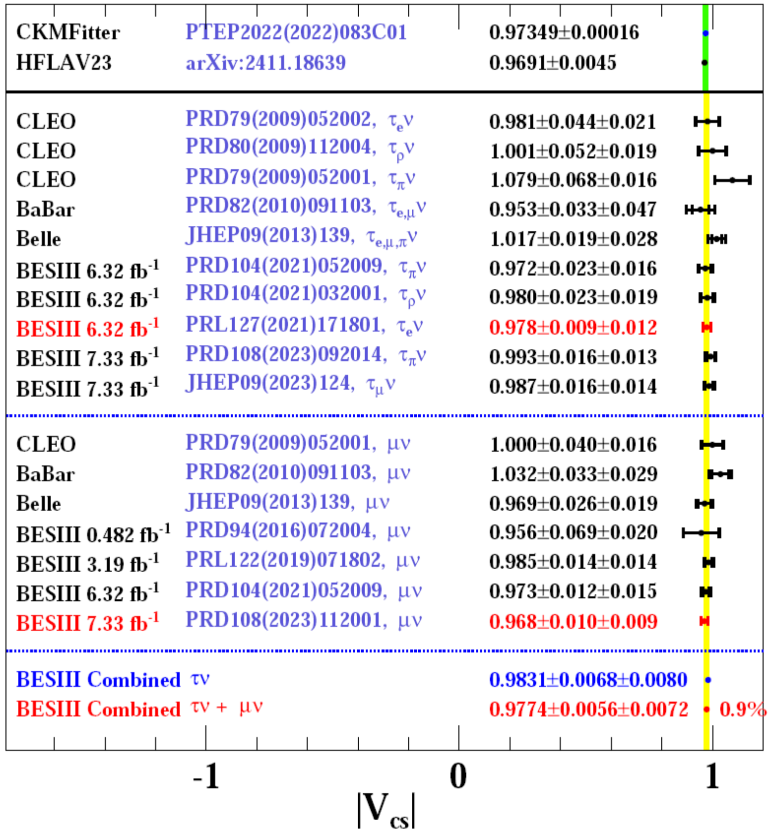
1.6%

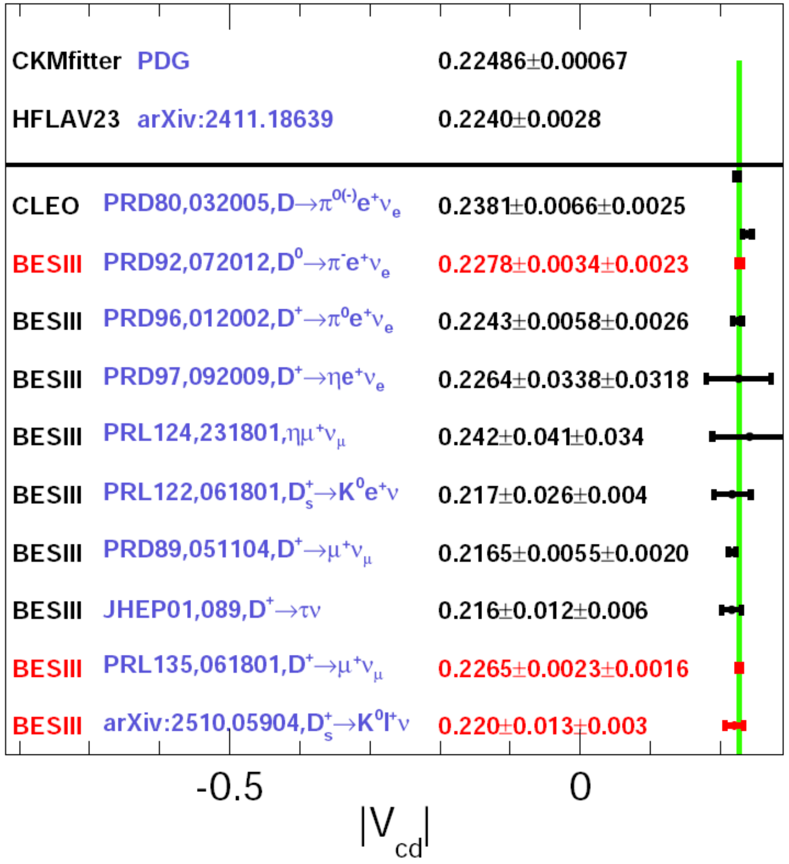
Experimental precision of $f_+^{D\to K}(0)$ is comparable to the latest LQCD precision

Experimental precision of $f_+^{D\to\pi}(0)$ is still dominated by statistical uncertainties

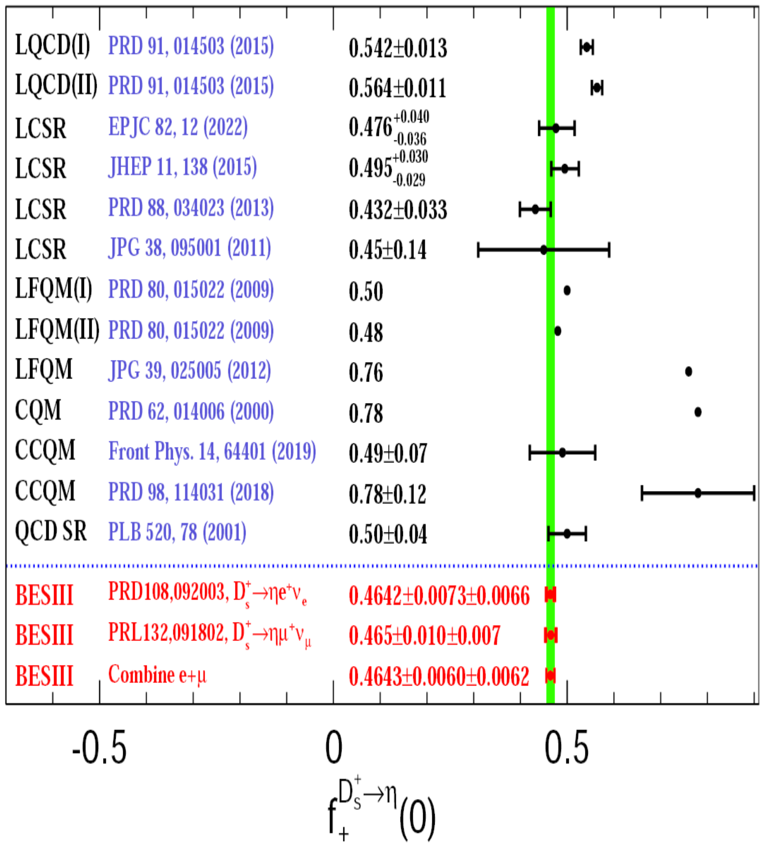
Comparisons of $|V_{cs}|$ and $|V_{cd}|$

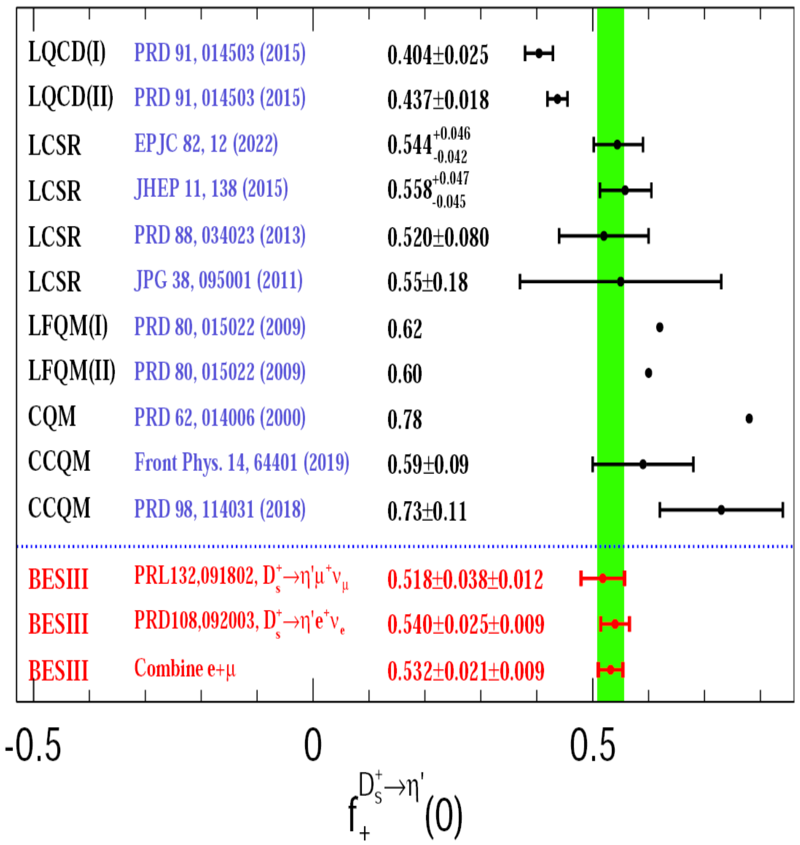


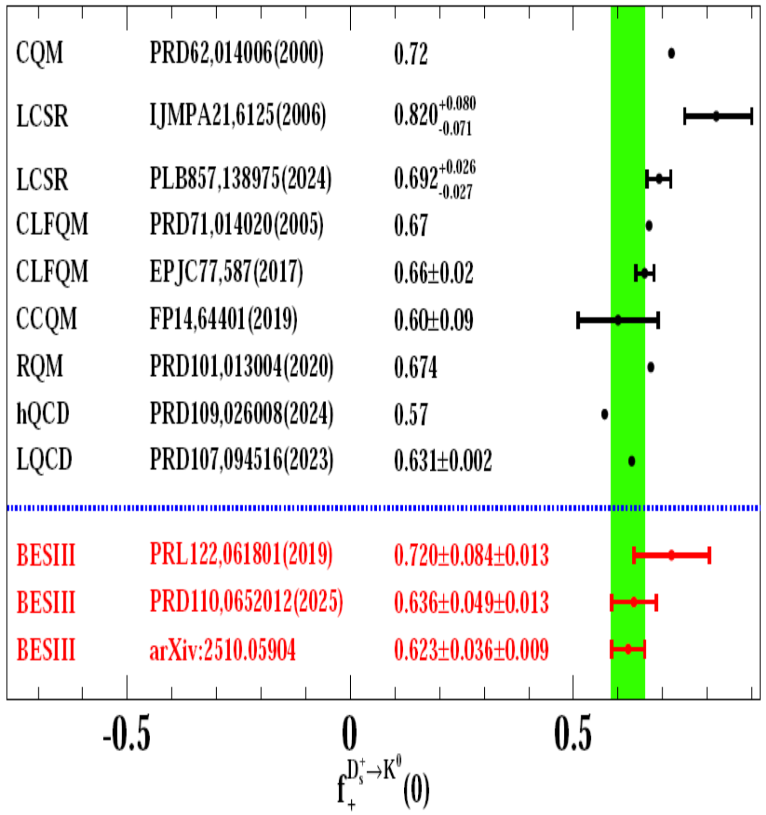




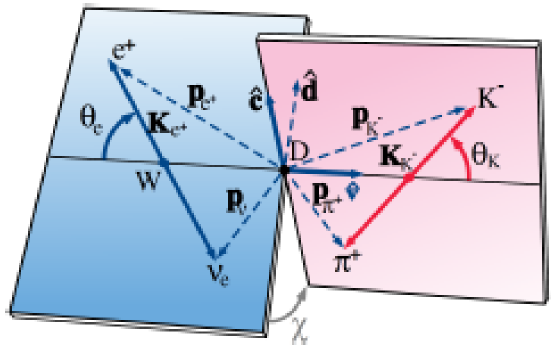
Comparisons of other $D \to P$ form factors







$D \to Ve^+\nu_e$半轻衰变的研究



- $m^2 = (p_{\pi^+} + p_{K^-})^2$
- $\cos(\theta_K) = \frac{\mathbf{D}\cdot\mathbf{K}_{K^-}}{|\mathbf{K}_{K^-}|}$
- $\cos(\chi) = \hat{c}\cdot\hat{d}$
- $q^2 = (p_{e^+} + p_{\nu_e})^2$
- $\cos(\theta_e) = -\frac{\mathbf{D}\cdot\mathbf{K}_{e^+}}{|\mathbf{K}_{e^+}|}$
- $\sin(\chi) = (\hat{c}\times\mathbf{D})\cdot\hat{d}$

Decay rate depend on 5 variables and 3 form factors

$$d^5\Gamma = \frac{G_F^2|V_{cs}|^2}{(4\pi)^6 m_D^2} X\beta\mathcal{I}(m^2, q^2, \theta_K, \theta_e, \chi)dm^2dq^2d\cos(\theta_K)d\cos(\theta_e)d\chi$$

- $X = p_{K\pi}m_D$, $p_{K\pi}$ is the momentum of the $K\pi$ system in the D rest frame
- $\beta = 2p^*/m$, p^* is the breakup momentum of the $K\pi$ system in its rest frame
- $\mathcal{I}$ can be expressed in terms of helicity amplitudes $H_{0,\pm}$:

$$H_0(q^2) = \frac{1}{2mq}\left[(m_D^2 - m^2 - q^2)(m_D + m)A_1(q^2) - 4\frac{m_D^2 p_{K\pi}^2}{m_D+m}A_2(q^2)\right]$$

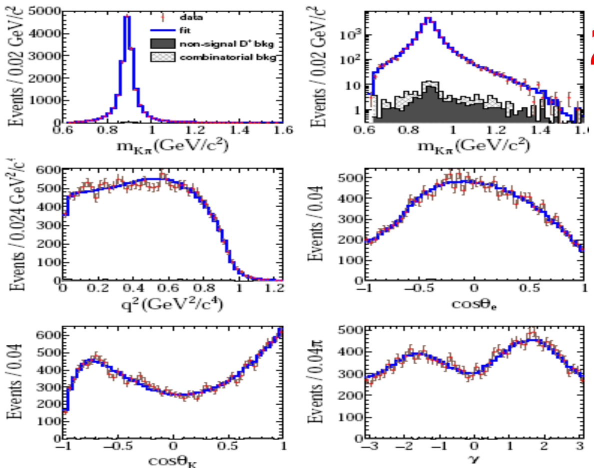
$$H_\pm(q^2) = (m_D + m)A_1(q^2) \mp \frac{2m_D p_{K\pi}}{m_D+m}V(q^2)$$

- Vector form factor: $V(q^2) = \frac{V(0)}{1-q^2/m_V^2}$; or: FF ratio $r_V = V(0)/A_1(0)$
- Axial-vector form factor: $A_1(q^2) = \frac{A_1(0)}{1-q^2/m_A^2}$, $A_2(q^2) = \frac{A_2(0)}{1-q^2/m_A^2}$; or: FF ratio $r_2 = A_2(0)/A_1(0)$

Earlier studies of $D \to V e^+ \nu_e$

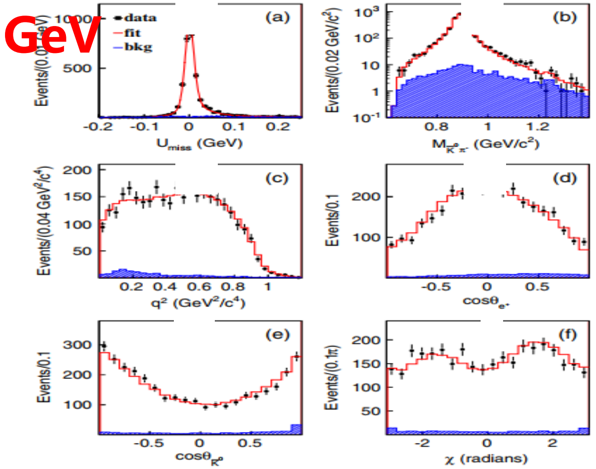
$D^+ \to \bar{K}^{*0} e^+ \nu_e$ PRD94(2016)032001

2.9 fb^{-1} @3.773 GeV



$r_V = 1.411 \pm 0.058 \pm 0.007$ $r_2 = 0.788 \pm 0.042 \pm 0.008$

$D^0 \to K^{*-} e^+ \nu_e$ PRD99(2018)011103

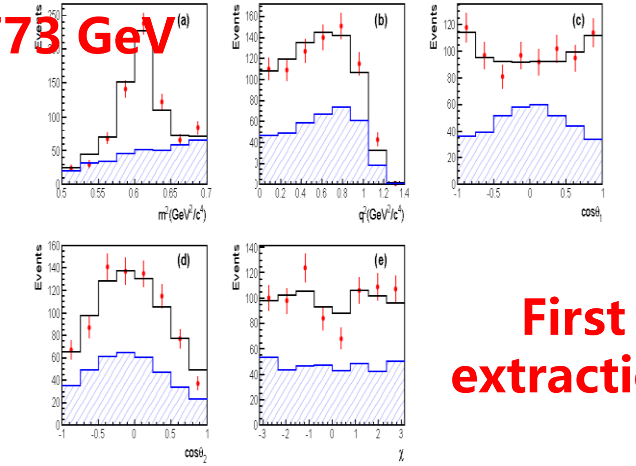


First extraction

$r_V = 1.46 \pm 0.07 \pm 0.02$ $r_2 = 0.67 \pm 0.06 \pm 0.01$

$D^+ \to \omega e^+ \nu_e$ PRD92(2015)071101

2.9 fb^{-1} @3.773 GeV

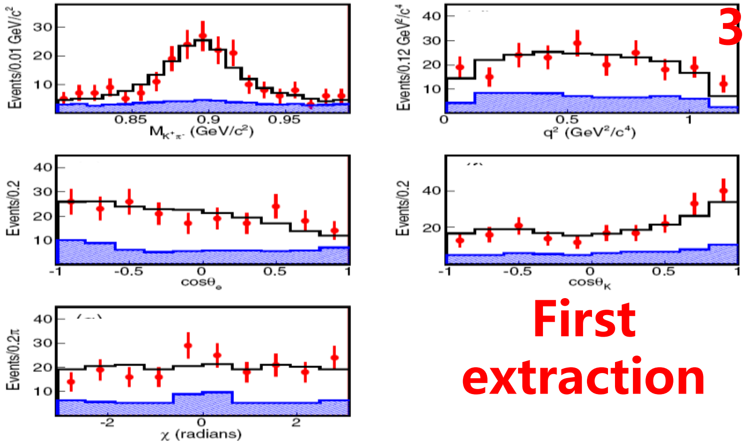


First extraction

$r_V = 1.24 \pm 0.09 \pm 0.06$ $r_2 = 1.06 \pm 0.15 \pm 0.05$

$D_s^+ \to K^{*0} e^+ \nu_e$ PRL122(2019)061801

3.19 fb^{-1}@4.178 GeV



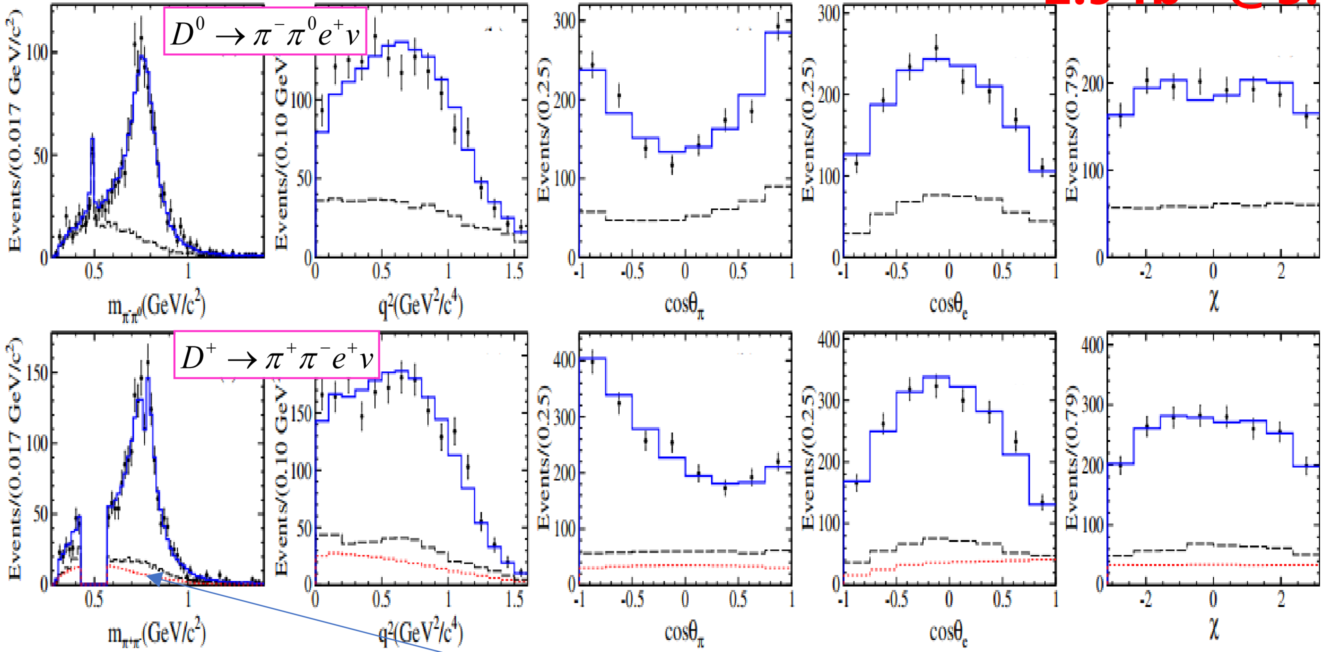
First extraction

$r_V = 1.67 \pm 0.34 \pm 0.16$ $r_2 = 0.77 \pm 0.28 \pm 0.07$

Analysis of $D^{0(+)} \to \pi\pi e^+\nu_e$ and observation of $D \to S e^+\nu_e$

PRL122(2019)062001

2.9 fb^{-1} @3.773 GeV



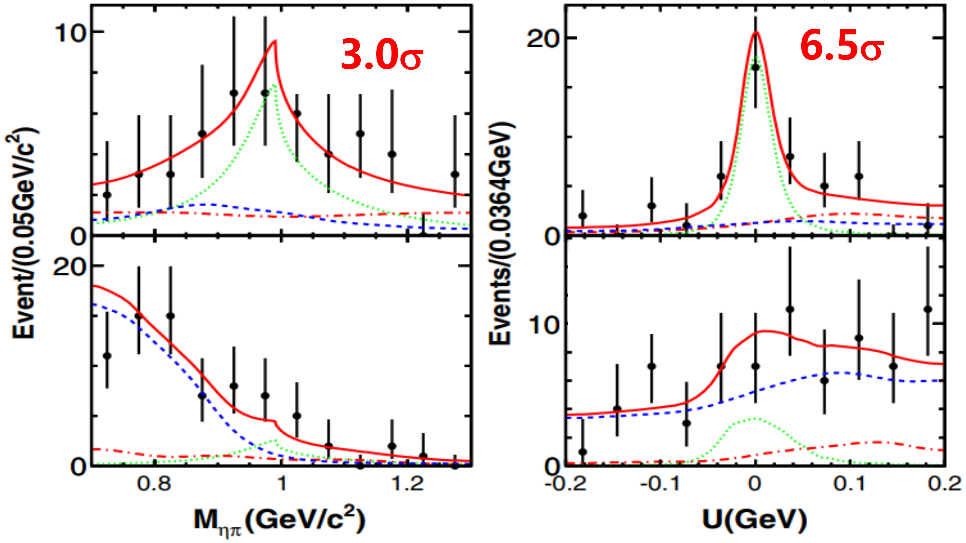
$r_V = 1.695 \pm 0.083 \pm 0.051$ $\qquad r_2 = 0.845 \pm 0.056 \pm 0.039$

Observation of $D^+ \to f_0(500)\, e^+\nu_e$

Signal mode	This analysis ($\times 10^{-3}$)
$D^0 \to \pi^-\pi^0 e^+\nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^0 \to \rho^- e^+\nu_e$	$1.445 \pm 0.058 \pm 0.039$
$D^+ \to \pi^-\pi^+ e^+\nu_e$	$2.449 \pm 0.074 \pm 0.073$
$D^+ \to \rho^0 e^+\nu_e$	$1.860 \pm 0.070 \pm 0.061$
$D^+ \to \omega e^+\nu_e$	$2.05 \pm 0.66 \pm 0.30$
$D^+ \to f_0(500) e^+\nu_e$, $f_0(500) \to \pi^+\pi^-$	$0.630 \pm 0.043 \pm 0.032$
$D^+ \to f_0(980) e^+\nu_e$, $f_0(980) \to \pi^+\pi^-$	<0.028

PRL121(2018)081802

$D^+ \to a_0(980)^0 e^+\nu_e$ $\qquad D^0 \to a_0(980)^- e^+\nu_e$



$B_{D^0\to a_0(980)^- e^+\nu} B_{a_0(980)^-\to\eta\pi^-} = (1.33^{+0.33}_{-0.29} \pm 0.09) \times 10^{-4}$

$B_{D^+\to a_0(980)^0 e^+\nu} B_{a_0(980)^0\to\eta\pi^0} = (1.66^{+0.81}_{-0.66} \pm 0.11) \times 10^{-4}$

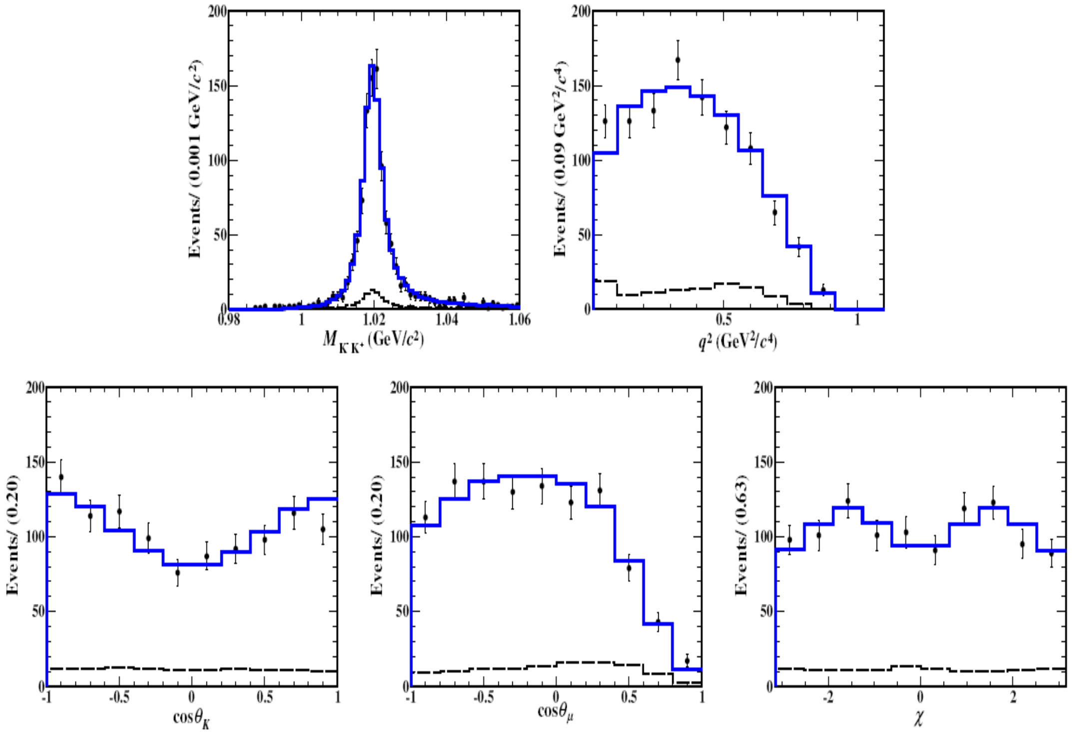
$[B_{D^+\to f_0(500) e^+\nu} + B_{D^+\to f_0(980) e^+\nu}] / B_{D^+\to a_0(980)^0 e^+\nu} > 2.7$

Supports tetraquark assumption for light mesons of a_0 and f_0

Study of $D_s^+ \to \phi\mu^+\nu_\mu$

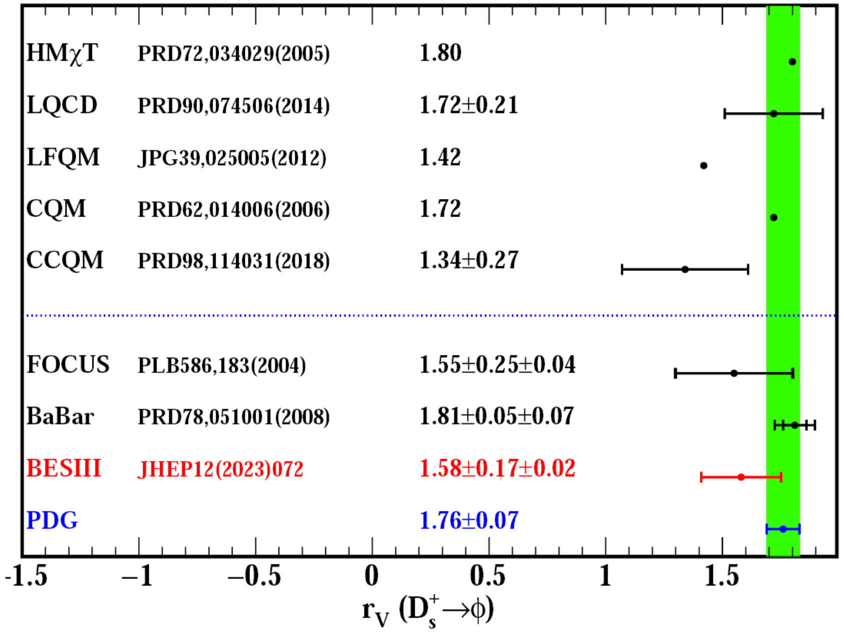
7.33 fb^{-1}@4.13-4.23 GeV

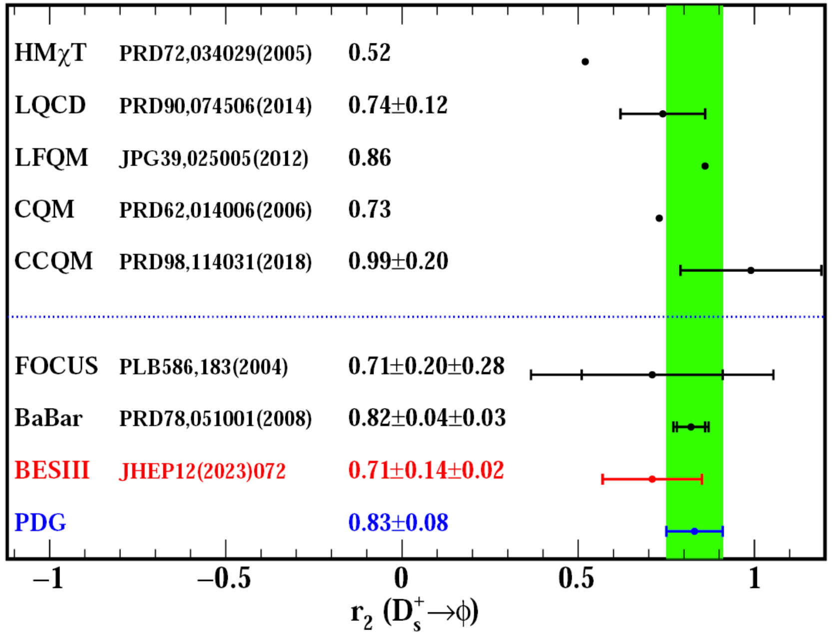
$D_s^+ \to \phi\mu^+\nu_\mu$ **JHEP12(2023)072**



$$r_V = 1.58 \pm 0.17 \pm 0.02$$

$$r_2 = 0.71 \pm 0.14 \pm 0.02$$

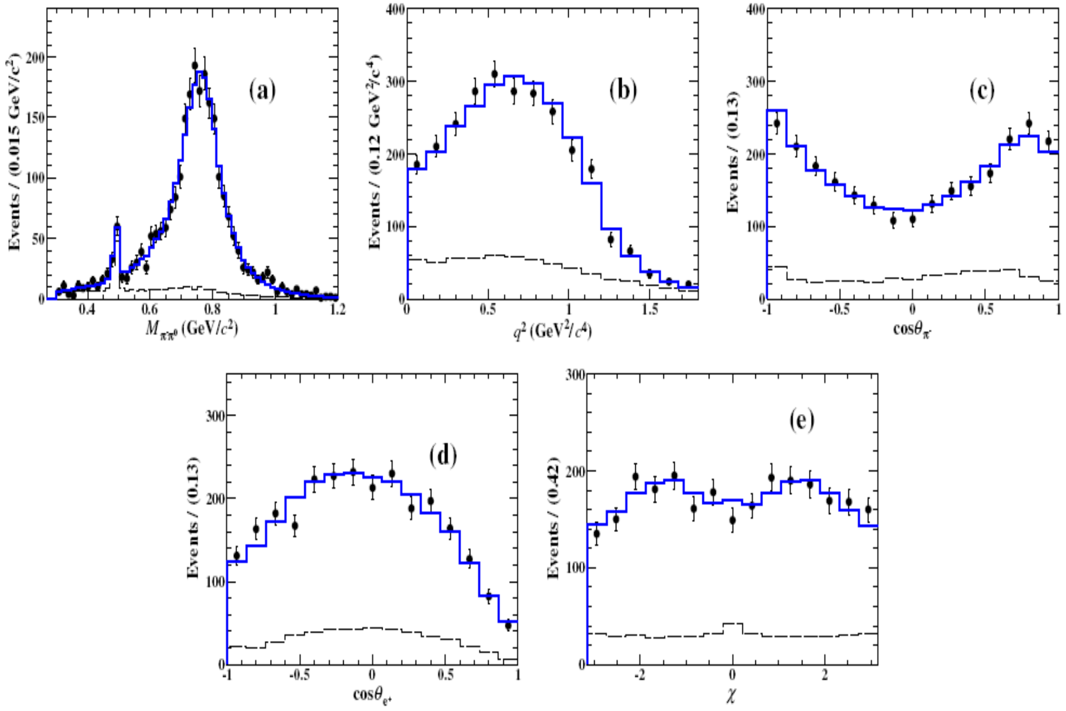




Study of $D^0 \to \rho^- e^+ \nu_e$

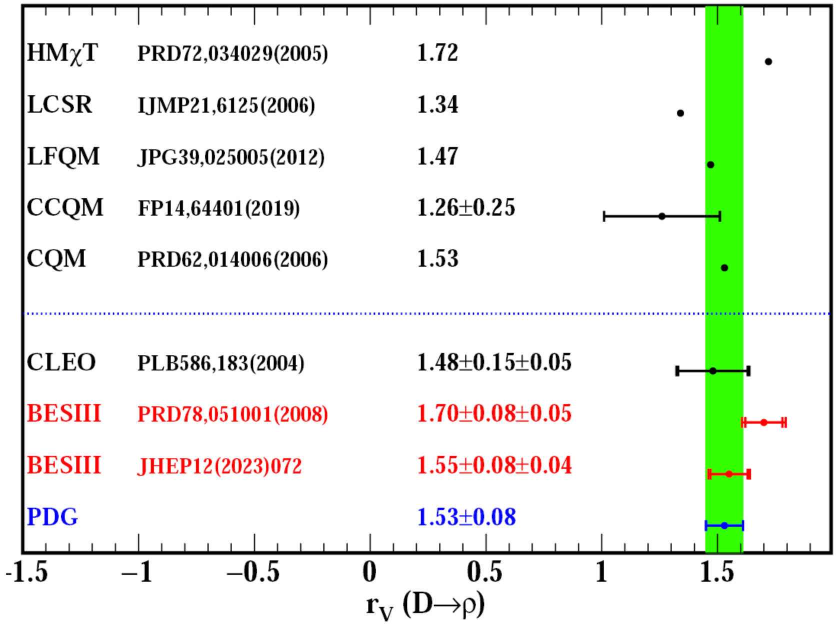
7.9 fb^{-1}@3.773 GeV

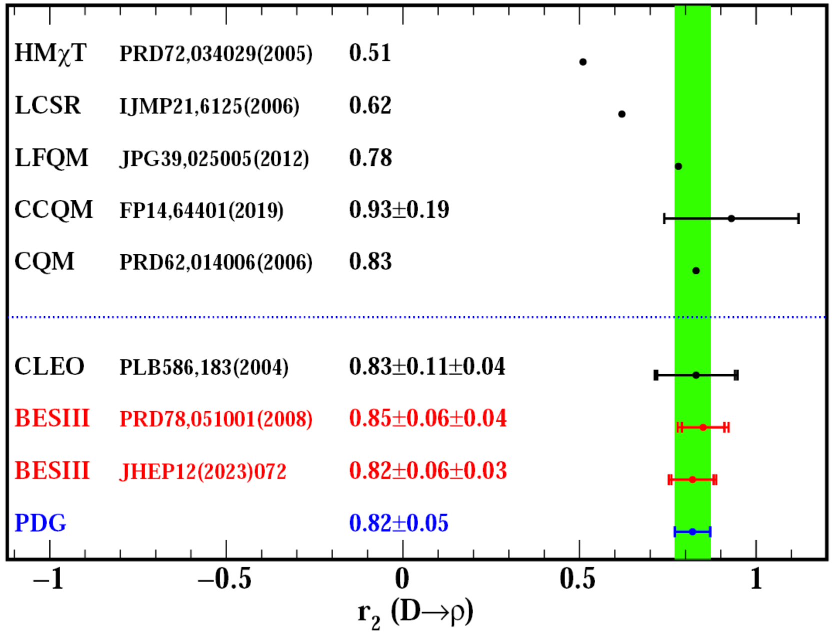
$D^0 \to \rho^- e^+ \nu_e$ **PRD110(2024)112018**



$$r_V = 1.55 \pm 0.08 \pm 0.04$$

$$r_2 = 0.82 \pm 0.06 \pm 0.03$$



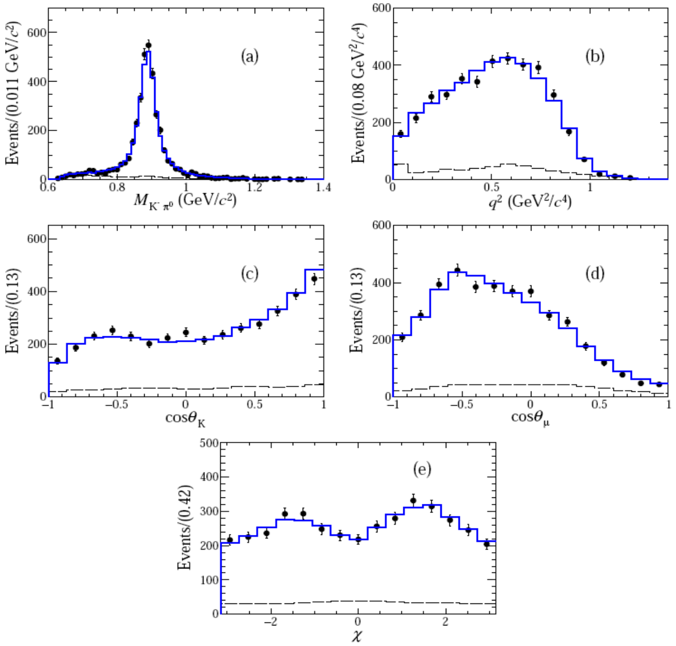


Recent results of $D^0 \to K^{*-} l^+ \nu_l$

7.9 fb^{-1}@3.773 GeV

$D^0 \to K^{*-}(K^- \pi^0)\mu^+\nu_\mu$

PRL134(2025)011803

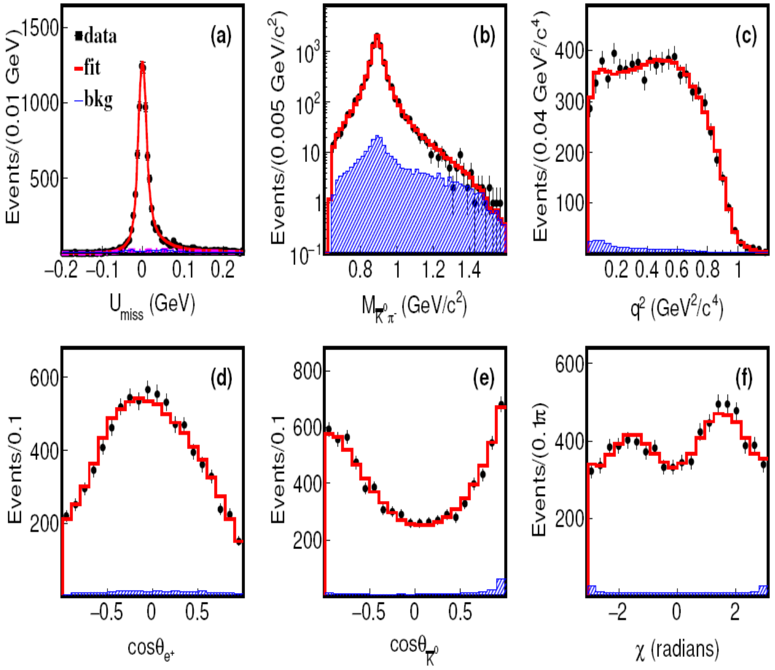


$$r_V = 1.37 \pm 0.09 \pm 0.03$$

$$r_2 = 0.76 \pm 0.06 \pm 0.02$$

$D^0 \to K^{*-}(K^0_S \pi^-)e^+\nu_e$

JHEP03(2024)197

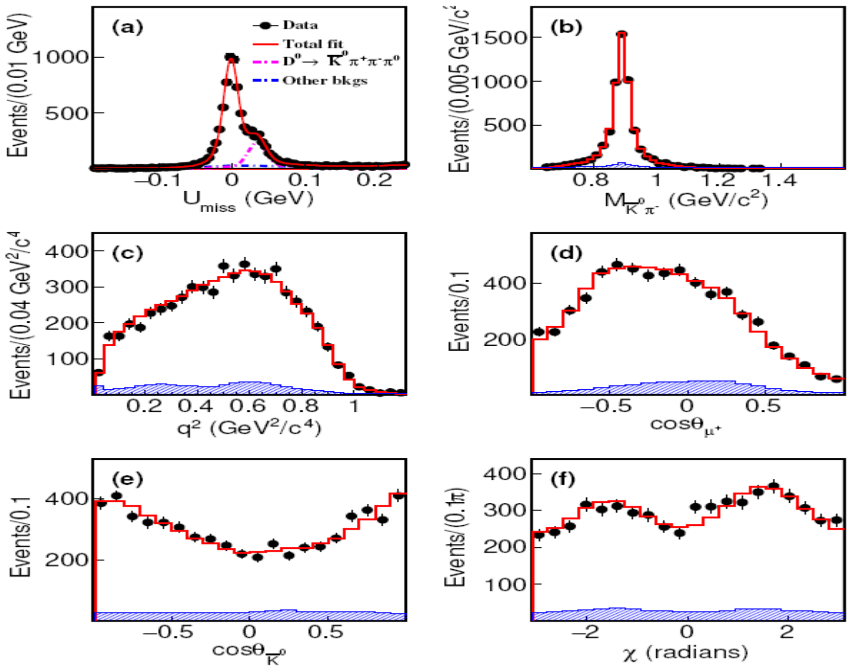


$$r_V = 1.48 \pm 0.05 \pm 0.02$$

$$r_2 = 0.70 \pm 0.04 \pm 0.02$$

$D^0 \to K^{*-}(K^0_S \pi^-)\mu^+\nu_\mu$

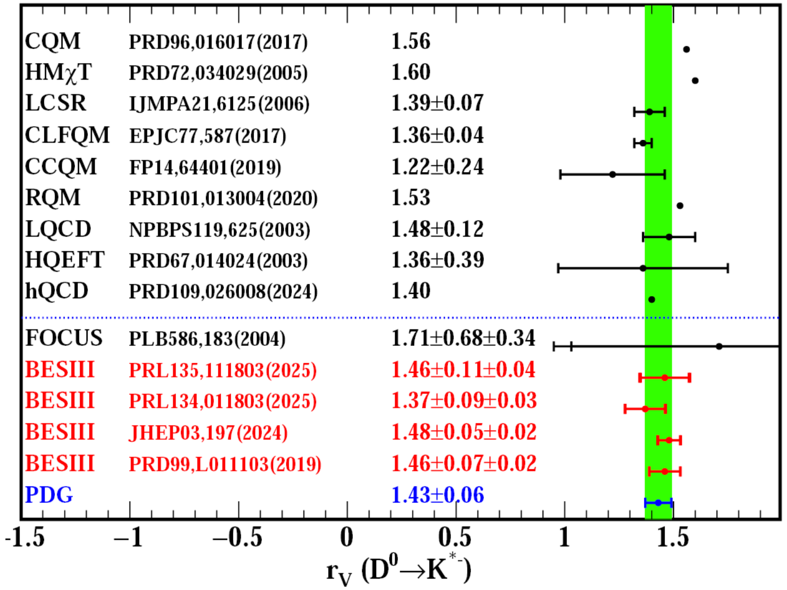
PRL135(2025)111803

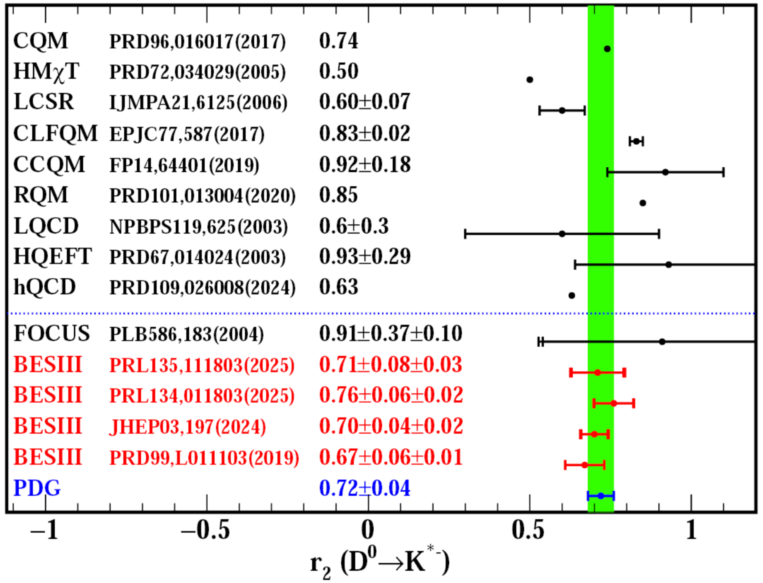


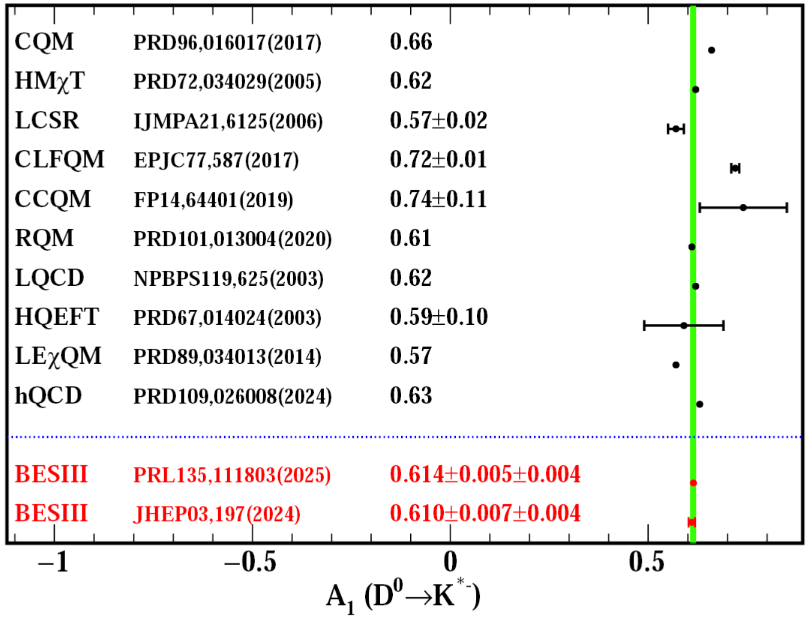
$$r_V = 1.46 \pm 0.11 \pm 0.03$$

$$r_2 = 0.71 \pm 0.08 \pm 0.03$$

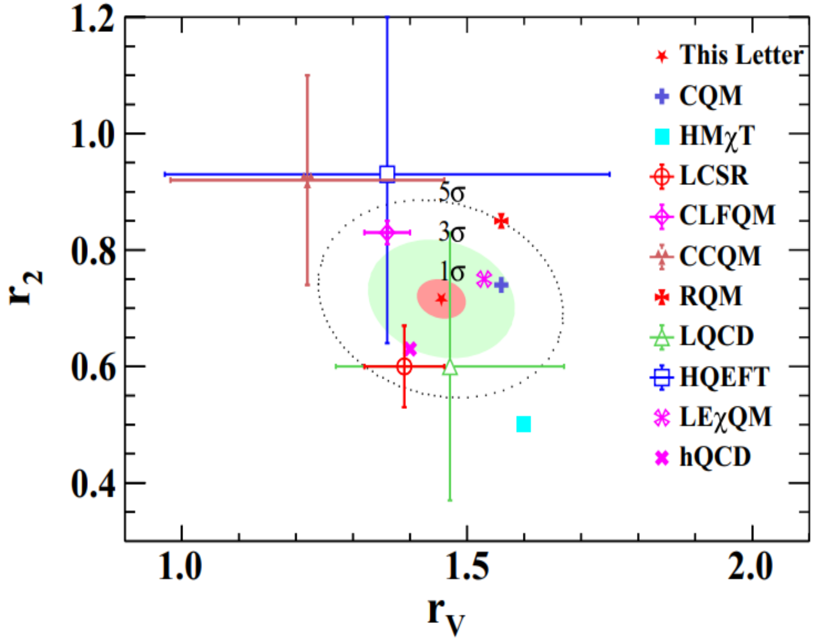
Comparison of form factors of $D^0 \to K^{*-}$







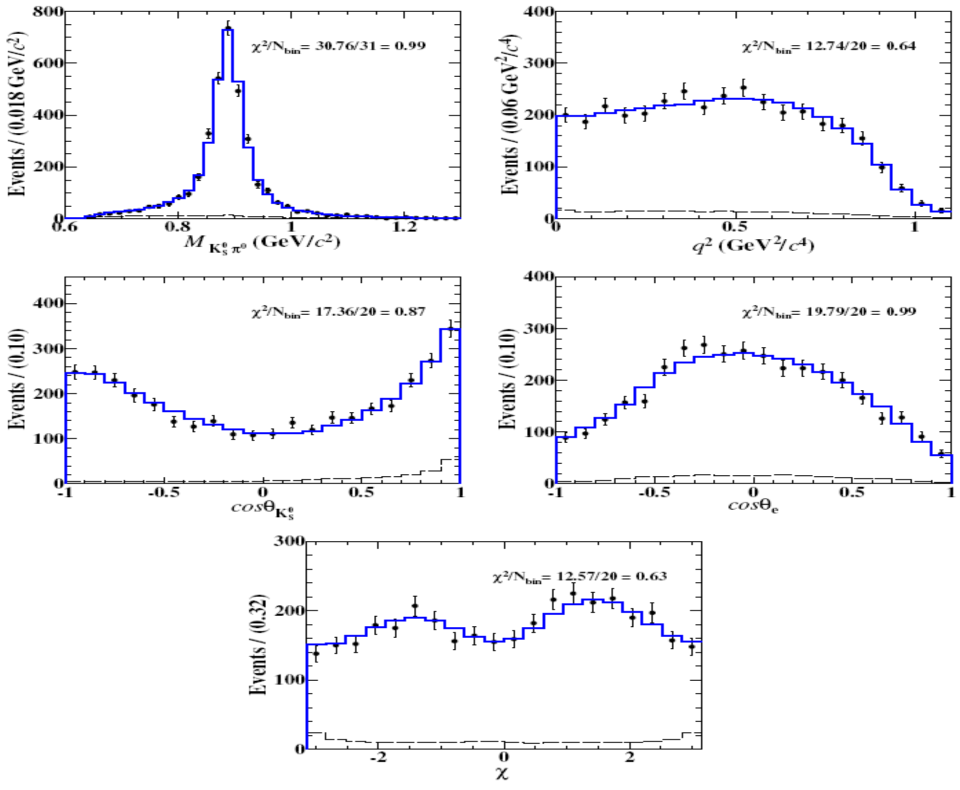
PRL135(2025)111803



Recent results of $D^+ \to \bar{K}^{*0} e^+ \nu_e$

$D^+ \to \bar{K}^{*0}(K_S^0\pi^0)e^+\nu_e$

JHEP10(2024)199 **7.9 fb^{-1}@3.773 GeV**



$r_V = 1.43 \pm 0.07 \pm 0.03$

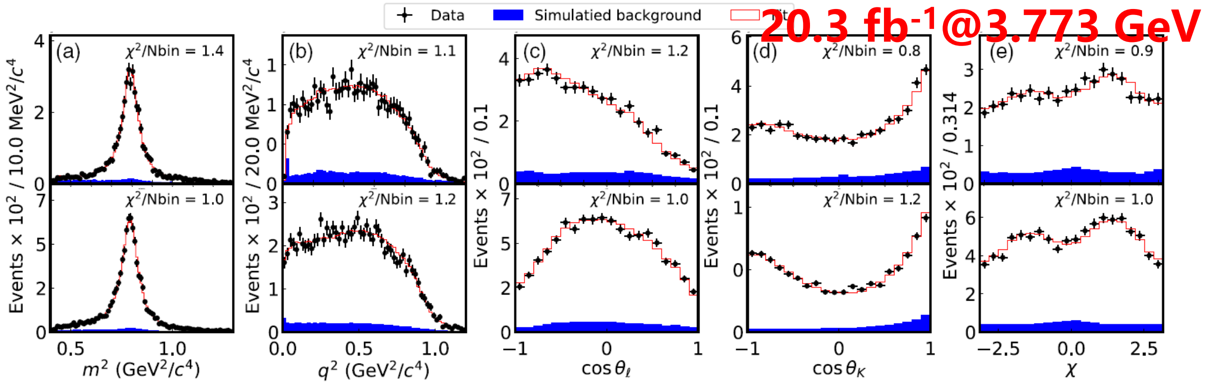
$r_2 = 0.72 \pm 0.06 \pm 0.02$

首次观测

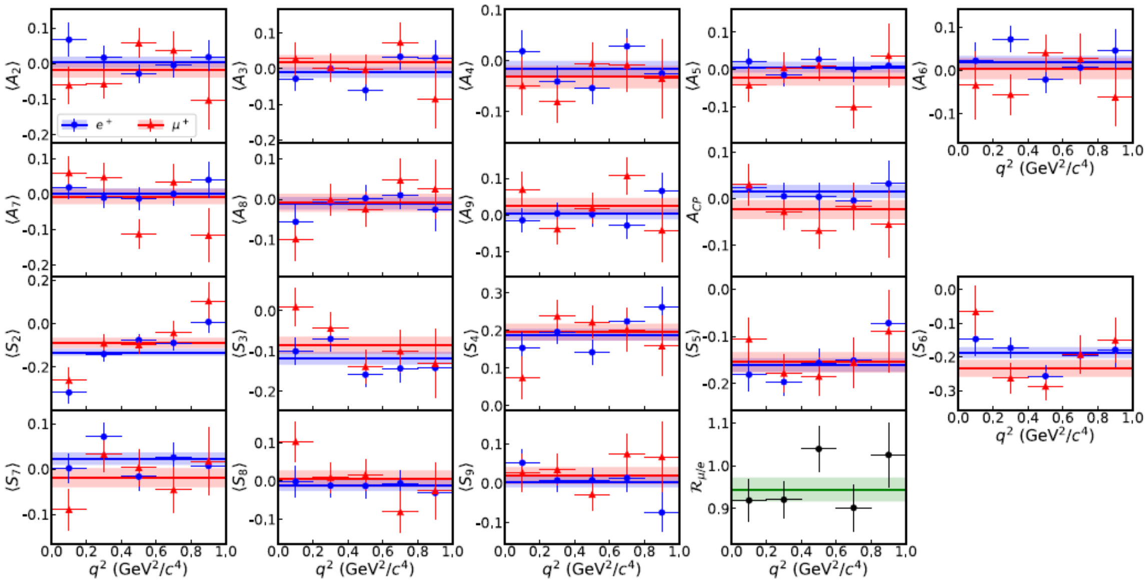
$D^+ \to \bar{K}^{*0}(K_S^0\pi^0)l^+\nu_l$

arXiv:2506.05761, accepted by PRL

20.3 fb^{-1}@3.773 GeV

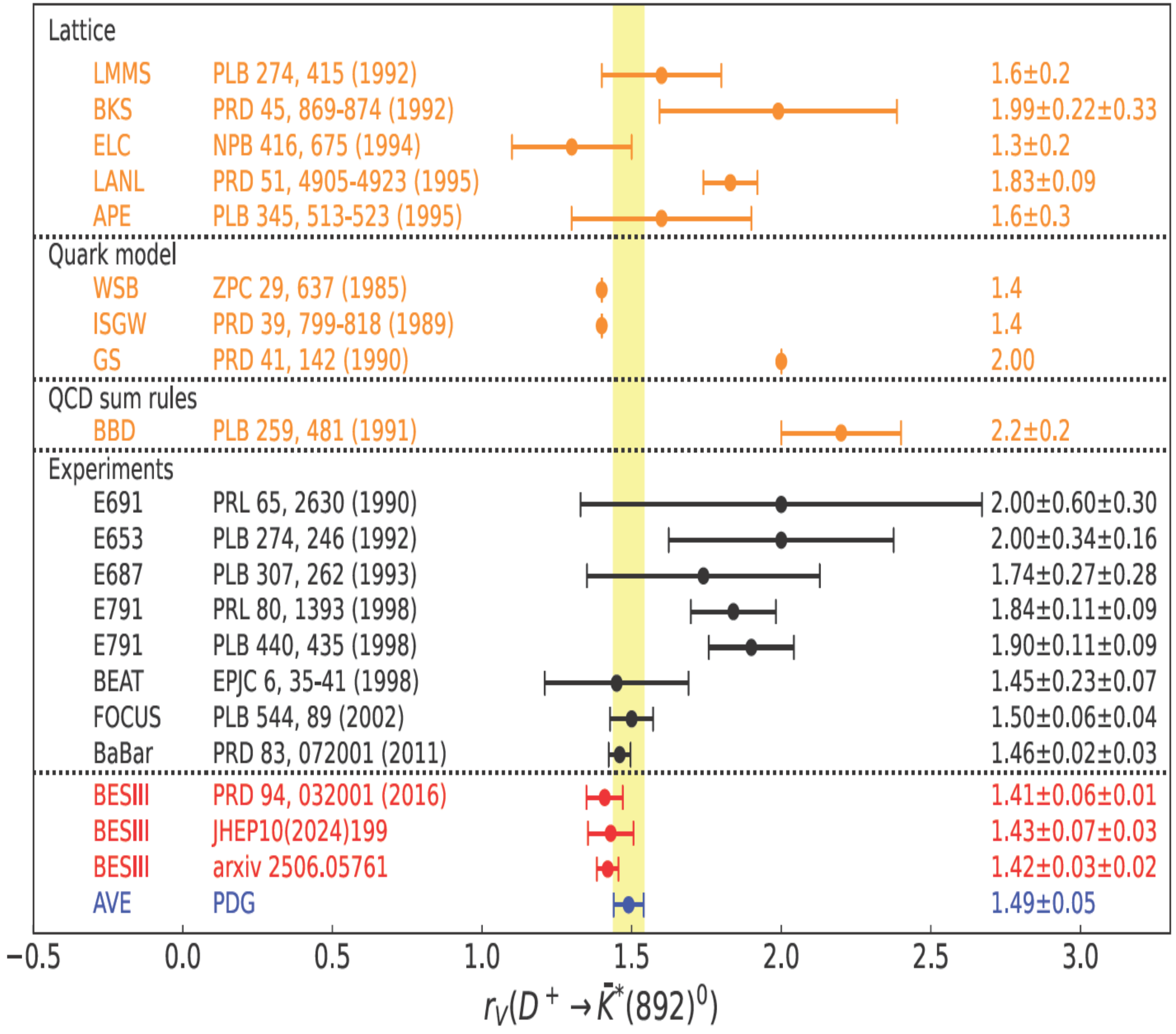


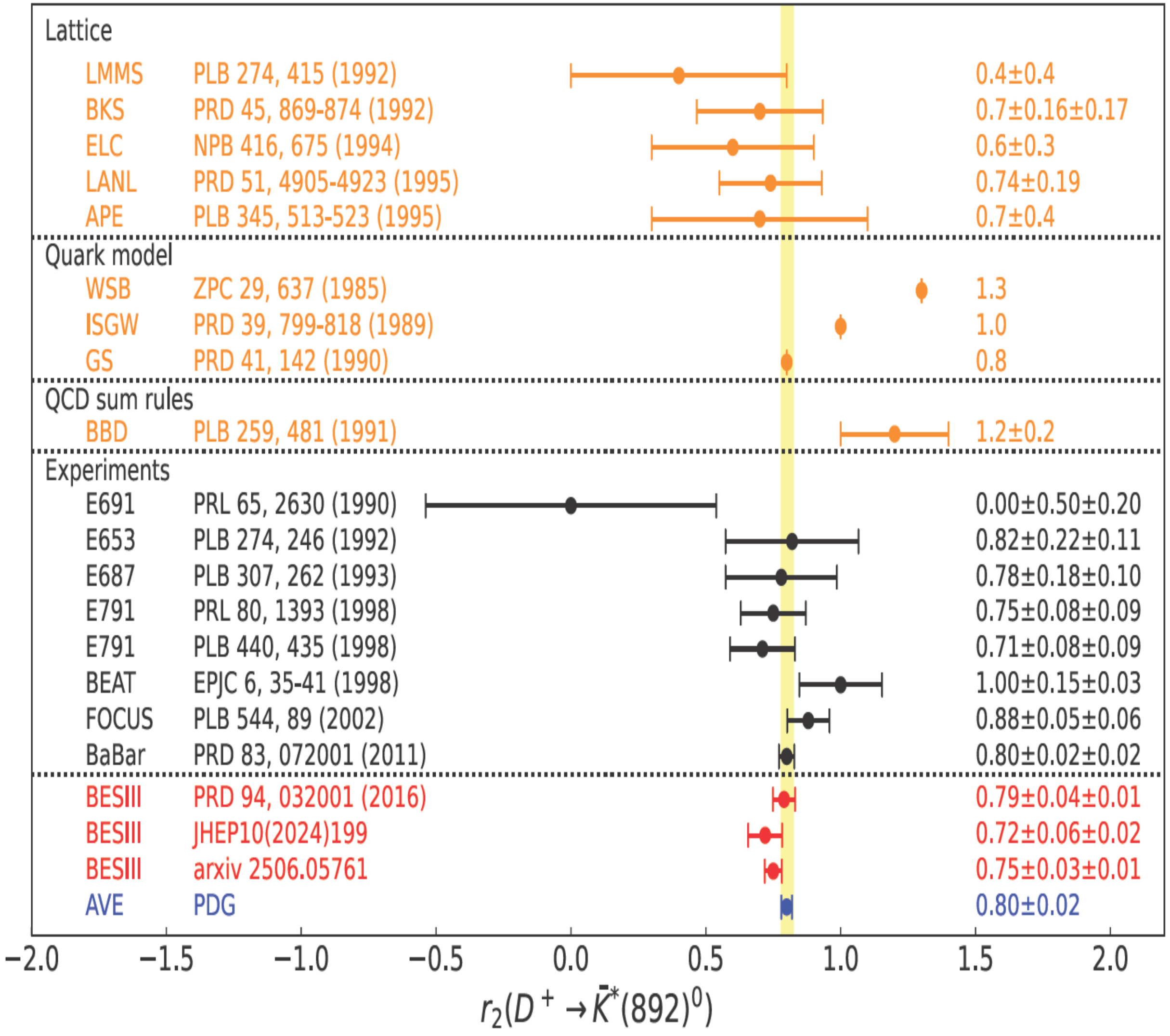
$r_V = 1.42 \pm 0.03 \pm 0.02 \quad r_2 = 0.75 \pm 0.03 \pm 0.01$



角分布+振幅分析 → 首次在粲衰变中抽取到多个角分布变量和CP破坏参数

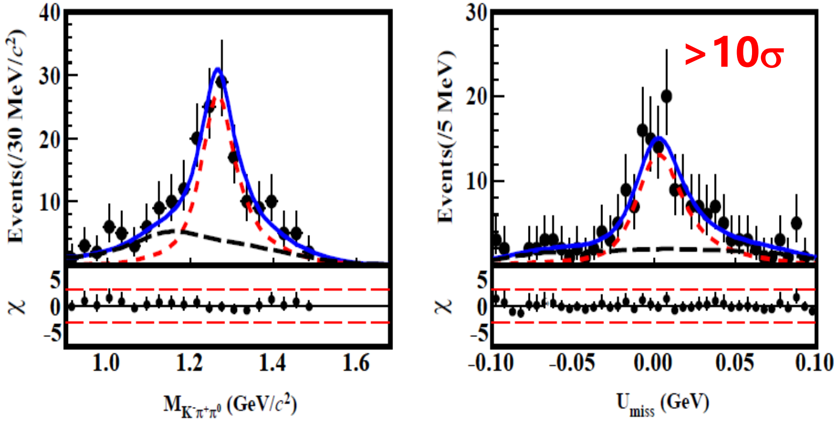
Comparison of form factors of $D^+ \to \bar{K}^{*0}$





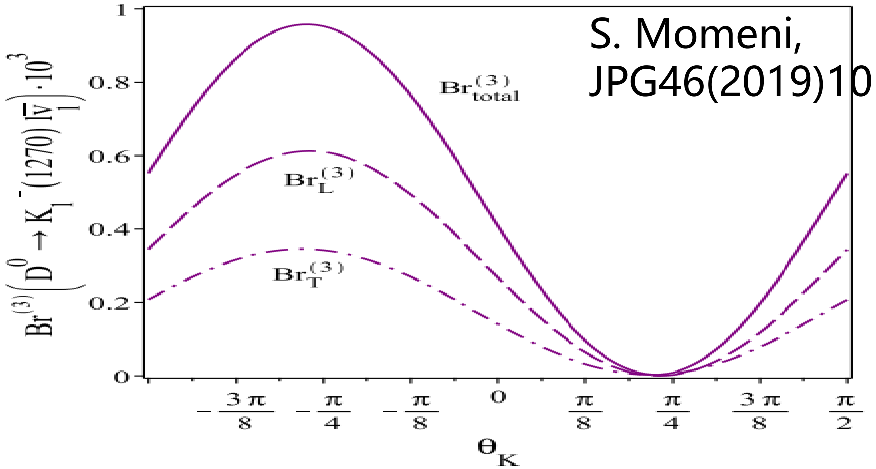
Observation of $D \to \bar{K}_1(1270)e^+\nu_e$

$D^+ \to \bar{K}_1(1270)^0 e^+\nu_e$ PRL123(2019)231801



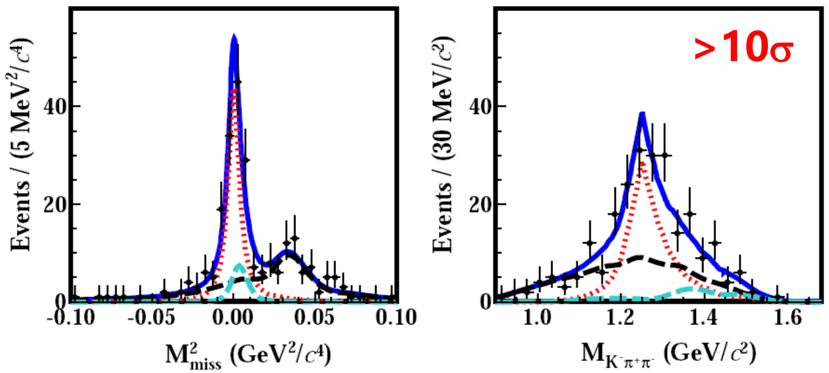
$$B_{D^+\to\bar{K}_1^0(1270)e^+\nu_e} = (2.30\pm0.26\pm0.18\pm0.25)\times10^{-3}$$

Helps to test various theoretical calculations which are sensitive to K_1 mixing angle



S. Momeni, JPG46(2019)105006

$D^0 \to K_1(1270)^- e^+\nu_e$ PRL127(2021)131801



$$B_{D^0\to K_1(1270)^- e^+\nu_e} = (1.09\pm0.13\pm0.13\pm0.12)\times10^{-3}$$

New window to explore the property and nature of K_1 and K_1 mixing angle

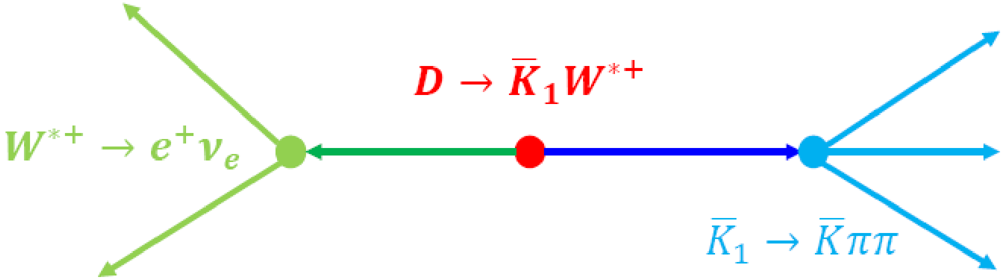
Combined analysis of $D \to \bar{K}_1 e^+\nu$ and $B \to \gamma\bar{K}_1$ helps to constrain new physics effect in the studies of photon polarization in $b \to s\gamma$ process

Wei Wang et al. PRL125(2020)051802

Decay dynamics of $D \to \bar{K}_1(1270)e^+\nu_e$

Decay formalism of $D \to Ae^+\nu_e, A \to P_1P_2P_3$

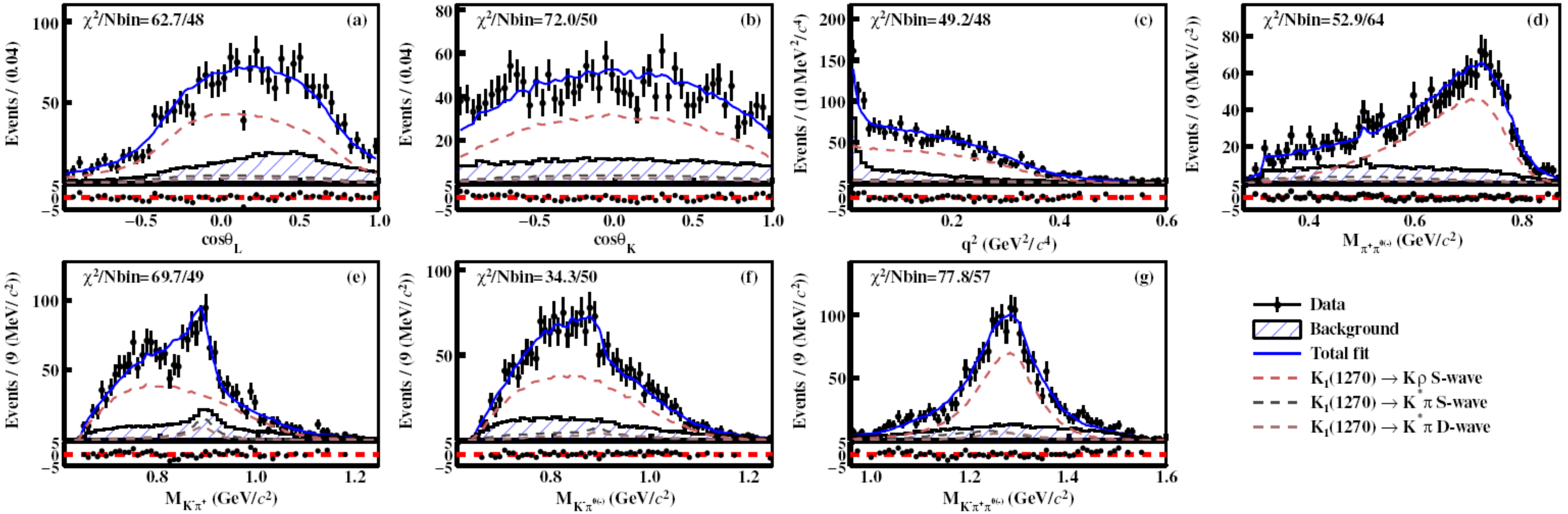
$$M = (V-A)^{\mu\eta} \cdot \left[\sum_{\lambda_{W^*}} \epsilon^*(\lambda_{W^*})_\mu \epsilon(\lambda_{W^*})_\rho\right] \cdot \left[\sum_{\lambda_{\bar{K}_1}} \epsilon^*(\lambda_{\bar{K}_1})_\eta \epsilon(\lambda_{\bar{K}_1})_\sigma\right] \cdot R_{\bar{K}_1} \cdot J^\sigma \cdot [\bar{u}_\nu \gamma^\rho (1-\gamma_5) v_l]$$



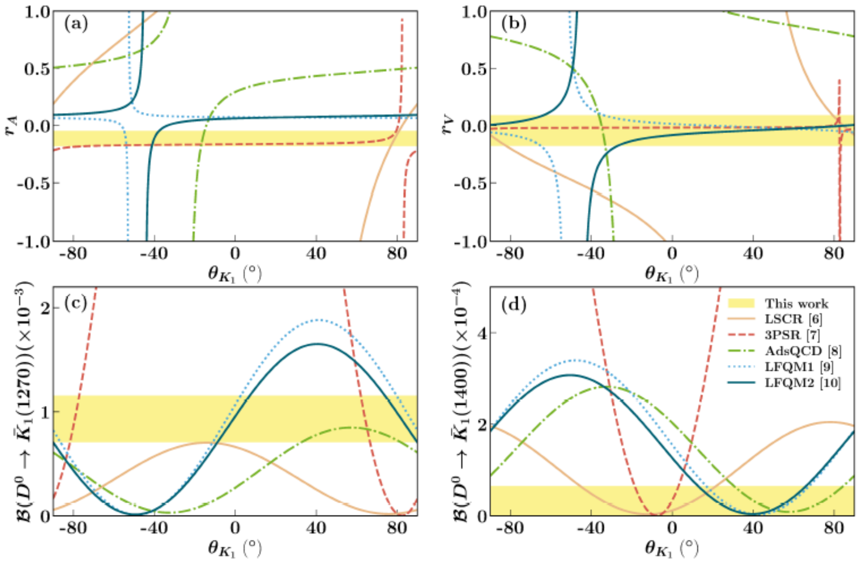
- More independent kinematic variables of **five body** semi-leptonic decay → general formalism is required!
- $D \to \bar{K}_1 W^{*+}$: $\langle \bar{K}_1 | s\gamma_\mu(1-\gamma_5) | D \rangle$, cited from PRD 104, 053003 (2021) → $V_{1,2}$ & A → $r_A = \frac{A(0)}{V_1(0)}$ & $r_V = \frac{V_2(0)}{V_1(0)}$
- $\bar{K}_1 \to \bar{K}\pi\pi$: Constructed in covariant tensor formalism, following Eur. Phys. J. A 16, 537(2003)
- $m_e \to 0$: $q^\mu [\bar{u}_\nu \gamma_\mu (1-\gamma_5) v_l] = 0$ is used.

Study of $D^{0(+)} \to \bar{K}_1(1270)/\bar{K}_1(1400)e^+\nu_e$

20.3 fb^{-1} @3.773 GeV **PRL135(2025)091801**



Variable	Value
r_A $(\times 10^{-2})$	$-11.2 \pm 1.0 \pm 0.9$
r_V $(\times 10^{-2})$	$-4.3 \pm 1.0 \pm 2.5$
$f^{D^+}_{\rho K^-}$ (%)	$79.3 \pm 2.0 \pm 25.7$
$f^{D^+}_{\pi \bar{K}^*(892)}$ (%)	$10.9 \pm 1.2 \pm 3.0$
$f^{D^+}_{\bar{K}_1(1400)}$ (%)	< 5
$f^{D^0}_{\rho K^-}$ (%)	$71.8 \pm 2.3 \pm 23.9$
$f^{D^0}_{\pi \bar{K}^*(892)}$ (%)	$19.5 \pm 1.9 \pm 5.2$
$f^{D^0}_{\bar{K}_1(1400)}$ (%)	< 9
$m_{K_1(1270)}$ (MeV/c^2)	$1271 \pm 3 \pm 7$
$\Gamma_{K_1(1270)}$ (MeV)	$168 \pm 10 \pm 20$



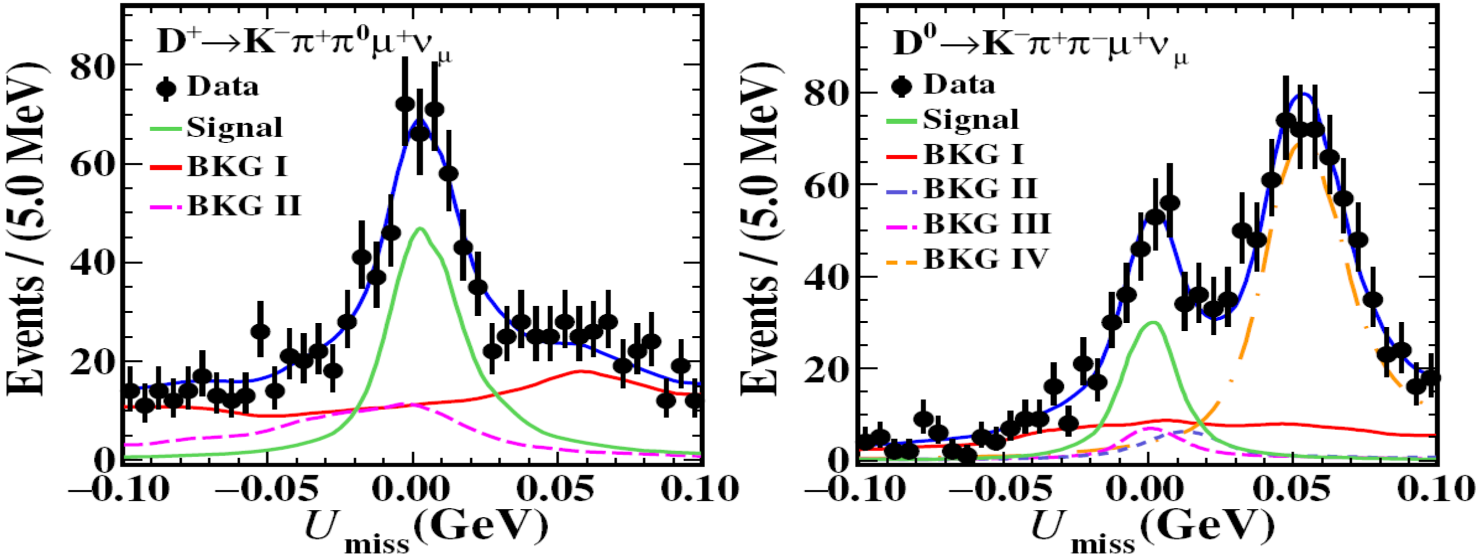
- 首次抽取到$D \to A$半轻跃迁形状因子；
- 精确测量$D \to \bar{K}_1(1270)e^+\nu_e$分支比，首次寻找$D \to \bar{K}_1(1400)e^+\nu_e$；
- 有助于深入探讨轴矢量介子的性质、约束K_1混合角

→有效约束末态包含K_1的τ、D、B等相关的理论计算

First observation of $D \to \bar{K}_1(1270)\mu^+\nu_\mu$

7.9 fb^{-1} @3.773 GeV

PRD110(2025)L052012



$$B(D^0 \to K_1(1270)^-\mu^+\nu_\mu) = (2.36 \pm 0.20^{+0.18}_{-0.27} \pm 0.48) \times 10^{-4}$$

$$B(D^+ \to \bar{K}_1(1270)^0\mu^+\nu_\mu) = (0.78 \pm 0.11^{+0.05}_{-0.09} \pm 0.15) \times 10^{-4}$$

$$\Gamma(D^0 \to K_1(1270)^-\mu^+\nu_\mu)/\Gamma(D^0 \to K_1(1270)^-e^+\nu_e) = 1.03 \pm 0.14^{+0.11}_{-0.15}$$

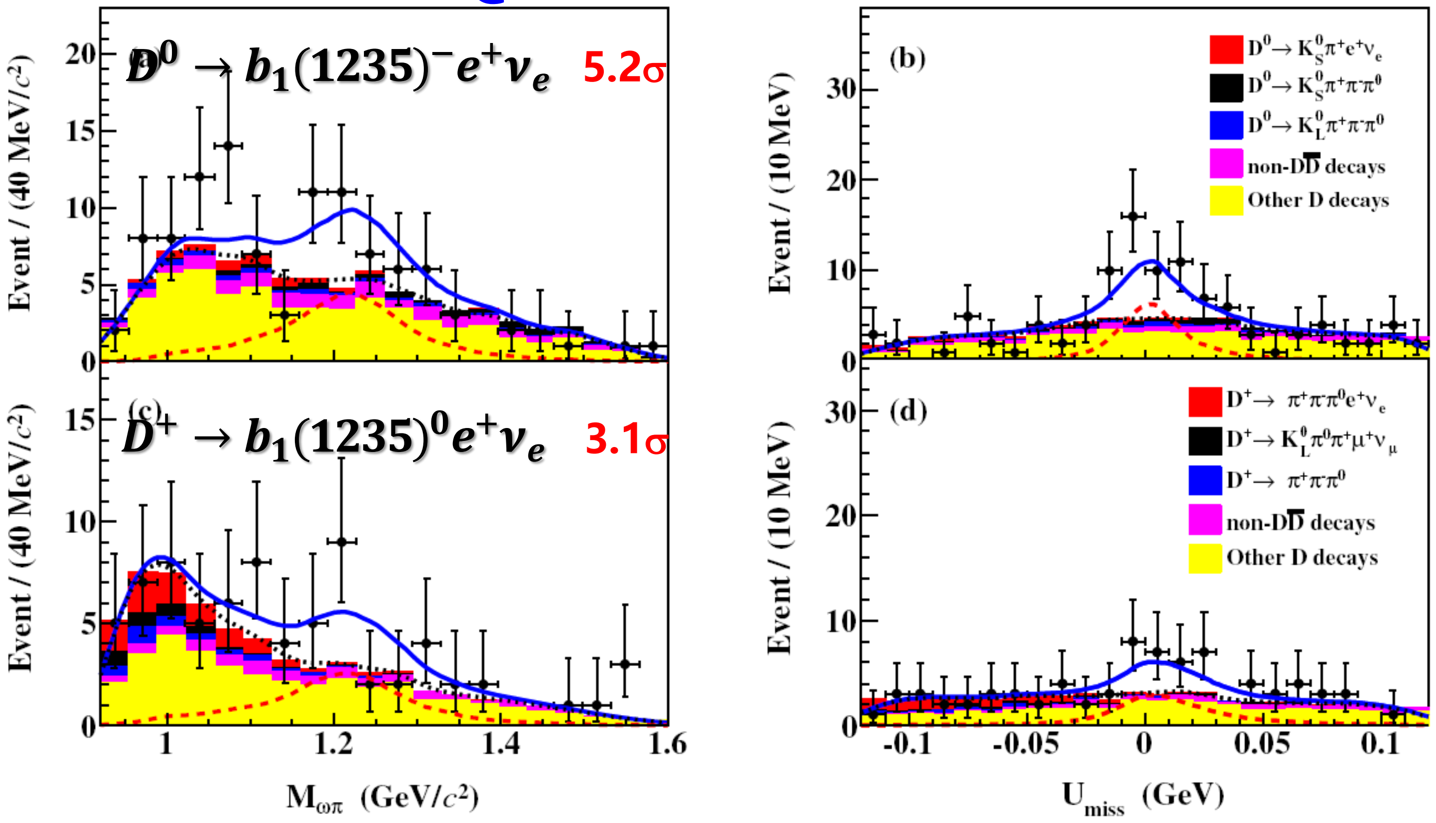
$$\Gamma(D^+ \to \bar{K}_1(1270)^0\mu^+\nu_\mu)/\Gamma(D^+ \to \bar{K}_1(1270)^0e^+\nu_e) = 0.74 \pm 0.13^{+0.08}_{-0.13}$$

在约20%的精度下检验了$D \to A$型半轻衰变中μ-e轻子普适性成立

Observation of $D \to b_1(1235)e^+\nu_e$

7.9 fb^{-1} @3.773 GeV

arXiv:2407.20551



$$B(D^0 \to b_1(1235)^- e^+\nu_e) \times B(b_1(1235)^- \to \omega\pi^-) = (0.72 \pm 0.18^{+0.06}_{-0.08}) \times 10^{-4}$$

$$B(D^+ \to b_1(1235)^0 e^+\nu_e) \times B(b_1(1235)^0 \to \omega\pi^0) = (1.16 \pm 0.44 \pm 0.16) \times 10^{-4}$$

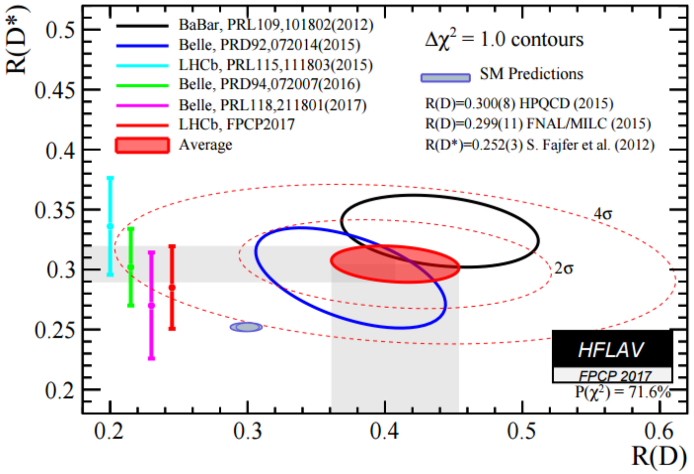
$$\Gamma(D^0 \to b_1(1235)^- e^+\nu_e)/2\Gamma(D^+ \to b_1(1235)^0 e^+\nu_e) = 0.78 \pm 0.19^{+0.04}_{-0.05}$$

支持ωπ是b_1主导衰变模式

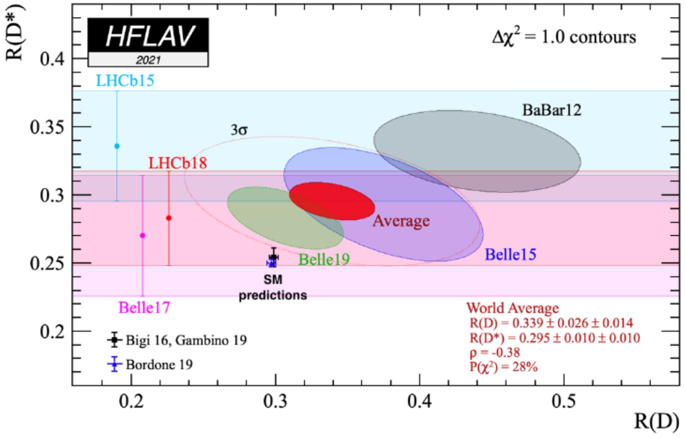
LFU tests in (semi)leptonic D decays before BESIII

Tension in B physics

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\, \tau \nu_\tau)}{\mathcal{B}(B \to D^{(*)}\, l\, \nu_l)}$$



3.9σ



3.3σ

Tension in D physics

$$\mathrm{B}^{\mathrm{PDG18}}[D^0 \to \pi^- \mu^+ \nu] = (0.237 \pm 0.024)\%$$

$$\frac{\Gamma^{\mathrm{PDG18}}[D^0 \to \pi^- \mu^+ \nu]}{\Gamma^{\mathrm{PDG18}}[D^0 \to \pi^- e^+ \nu]} = 0.82 \pm 0.08$$

(2.1σ)

SM prediction: 0.985

The knowledge of semimuonic charm meson decays is very poor

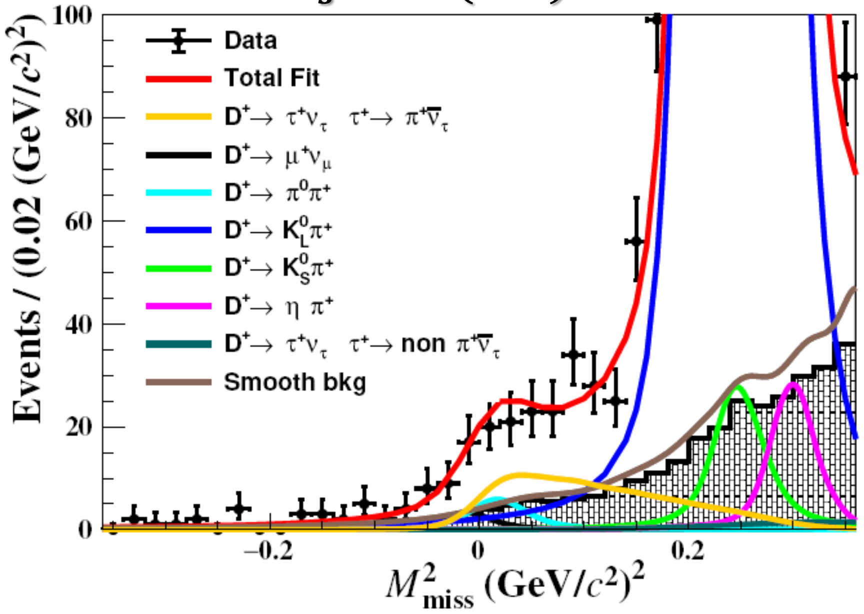
	D^0		D^+		D_s^+	
$c \to s l^+ \nu$	K^-	4% [Belle]	$\bar{K}^0$	7% [FOCUS]	η	NA
	K^{*-}	13% [FOCUS]	$\bar{K}^{*0}$	3% [CLEOc]	η’	NA
	K_1^-	NA	$\bar{K}_1^0$	NA	ϕ	NA
					f_0	NA
$c \to d l^+ \nu$	π^-	10% [Belle]	π^0	NA	K^0	NA
	ρ^-	NA	ρ^0	17% [FOCUS]	K^{*0}	NA
			f_0	NA		
			ω	NA		
			η	NA		
			η’	NA		

τ–μ LFU tests via leptonic charm decays

PRL123(2019)211802

→ JHEP01(2015)089

$D_s^+ \to \tau^+(\pi^+ v)v$



$$B^{BESIII}[D^+ \to \tau^+ v] = (9.9 \pm 1.1 \pm 0.5) \times 10^{-4}$$

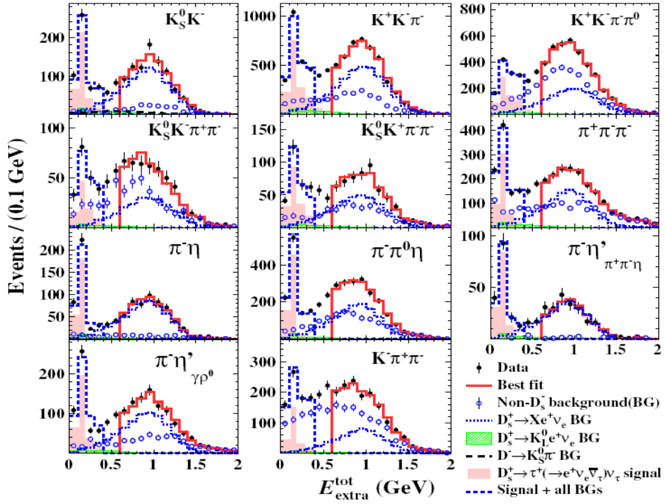
$$B^{BESIII}[D^+ \to \mu^+ v] = (3.98 \pm 0.09) \times 10^{-4}$$

$$R_D = \frac{B[D^+ \to \tau^+ v]}{B[D^+ \to \mu^+ v]} = 2.49 \pm 0.31$$

SM prediction: 2.67

PRD108(2023)112001 $D_s^+ \to \mu^+ v$

PRL127(2021)171801, $D_s^+ \to \tau^+(e^+ vv)v$,
PRD108(2023)092014, $D_s^+ \to \tau^+(\pi^+ v)v$,
PRD104(2021)032001, $D_s^+ \to \tau^+(\rho^+ v)v$,
JHEP09(2023)124 $D_s^+ \to \tau^+(\mu^+ vv)v$



$$B^{BESIII}[D_s^+ \to \mu^+ v] = (5.294 \pm 0.108 \pm 0.085) \times 10^{-3}$$

$$B^{BESIII}[D_s^+ \to \tau^+ v] = (5.32 \pm 0.07 \pm 0.07)\%$$

$$R_{Ds} = \frac{B[D_s^+ \to \tau^+ v]}{B[D_s^+ \to \mu^+ v]} = 10.05 \pm 0.35$$

SM prediction: 9.75

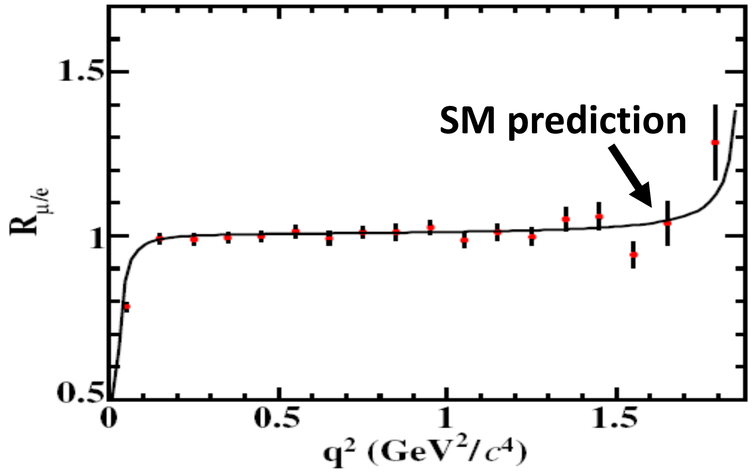
Overall status of studies of semimuonic D decays

	D^0		D^+		D_s^+	
$c \to s l^+ \nu$	K^-	4%→0.6%	$\bar{K}^0$	7%→1.1%	η	NA→3.3%
	K^{*-}	13%→2.5%	$\bar{K}^{*0}$	3%→2.1%	η’	NA→7.7%
	K_1^-	NA→25%	$\bar{K}_1^0$	NA→25%	ϕ	NA→5.0%
					$f_0(980)$	NA→ongoing
$c \to d l^+ \nu$	π^-	10%→3.7%	π^0	NA→4.2%	K^0	NA→10%
	ρ^-	NA→9.4%	ρ^0	17%→10%	K^{*0}	NA→ongoing
			$f_0(500)$	NA→21%		
			ω	NA→12%		
			η	NA→4.6%		
			η’	NA→15%		

首次观测到10多个含轻衰变新模式；以世界最高精度测量了其它含轻衰变

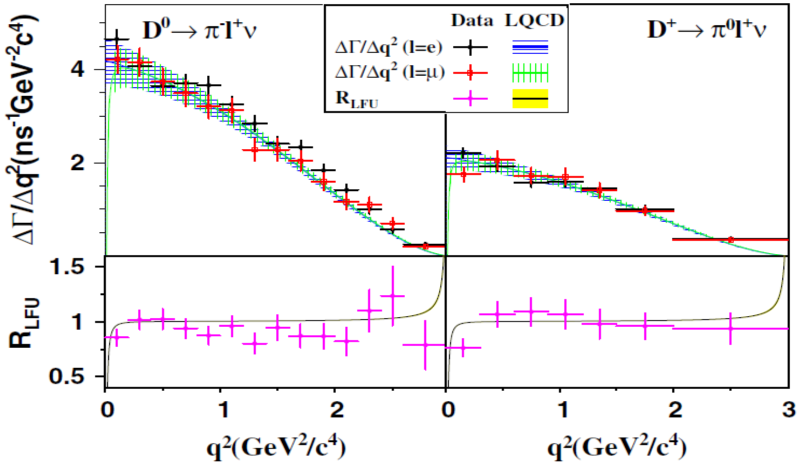
μ-e LFU tests with semileptonic decays in different q² bins

$D^0 \to K^- \mu^+ \nu_\mu$ PRL122(2019)011804 → PRD110(2024)012006

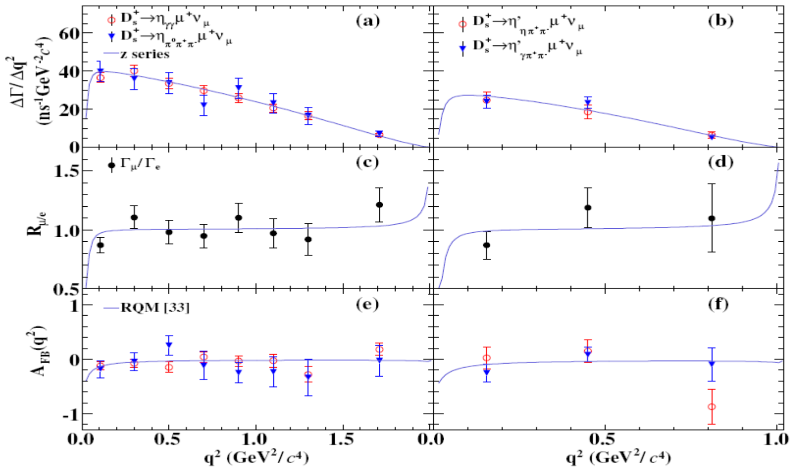


SM predictions: 0.93-0.99

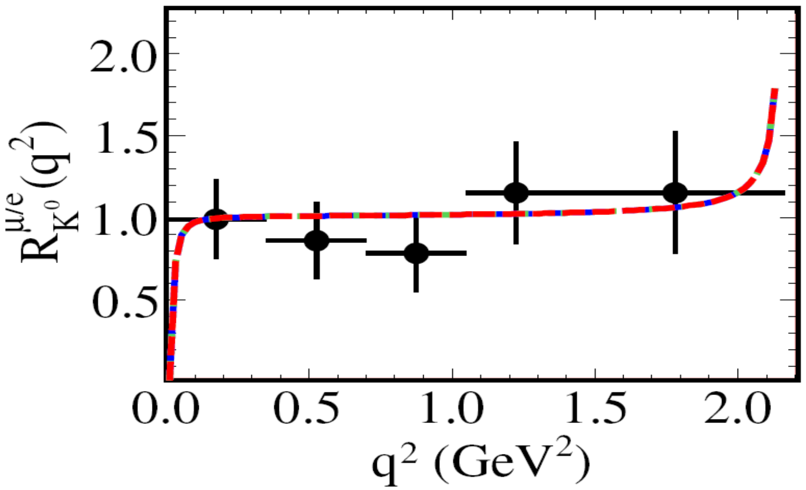
$D^{0,+} \to \pi^{-,0} \mu^+ \nu_\mu$ PRL121(2018)171803



$D_s^+ \to \eta^{(\prime)} \mu^+ \nu_\mu$ PRD97(2018)012006 → PRL132(2024)091802



$D_s^+ \to K^0 \mu^+ \nu_\mu$ arXiv:2510.05904



Summary of LFU tests

		Branching fraction ratio	Reference
μ/e	$D^0 \to K^-$	$0.971 \pm 0.004 \pm 0.005$	PRD110(2024)112006
	$D^0 \to \pi^-$	$0.922 \pm 0.030 \pm 0.022$	PRL121(2018)171803
	$D^0 \to \rho^-$	0.90 ± 0.11	PRD104(2021)L091003
	$D^+ \to \bar{K}^0$	$0.978 \pm 0.007 \pm 0.012$	PRD110(2024)112006
	$D^+ \to \pi^0$	$0.964 \pm 0.037 \pm 0.026$	PRL121(2018)171803
	$D^+ \to \eta$	0.91 ± 0.13	PRL124(2020)231801
	$D^+ \to \eta'$	$1.07 \pm 0.19 \pm 0.03$	PRL134(2025)111801
	$D^0 \to K^{*-}$	$0.955 \pm 0.022 \pm 0.017$	PRL135(2025)111803
		$1.020 \pm 0.030 \pm 0.028$	PRL134(2025)011803
	$D^+ \to \bar{K}^{*0}(K_S^0\pi^0)$	$0.94 \pm 0.02 \pm 0.01$	arXiv:2506.05761, accepted by PRL
	$D^0 \to K_1^-$	$0.74 \pm 0.13 \pm 0.13$	PRD111(2025)L071101
	$D^+ \to \bar{K}_1^0$	$1.03 \pm 0.14 \pm 0.015$	PRD111(2025)L071101

SM predictions for semileptonic decays: 0.90-0.99

No deviation greater than 1.7σ is found!

		Branching fraction ratio	Reference
μ/e	$D^+ \to \omega$	1.05 ± 0.14	PRD101(2020)072005
	$D^+ \to f_0$	1.14 ± 0.28	PRD110(2024)092008
	$D^+ \to \rho^0$	0.88 ± 0.10	PRD110(2024)092008
	$D_s^+ \to \eta$	$0.984 \pm 0.028 \pm 0.016$	PRL132(2024)091802
	$D_s^+ \to \eta'$	$0.989 \pm 0.082 \pm 0.034$	
	$D_s^+ \to K^0$	$0.97 \pm 0.12 \pm 0.04$	arXiv:2510.05904
	$D_s^+ \to \phi$	0.94 ± 0.08	JHEP12(2023)072
τ/μ	$D^+ \to \tau^+$	2.49 ± 0.31	JHEP01(2025)089
	$D_s^+ \to \tau^+$	10.05 ± 0.35	PRL127(2021)171801

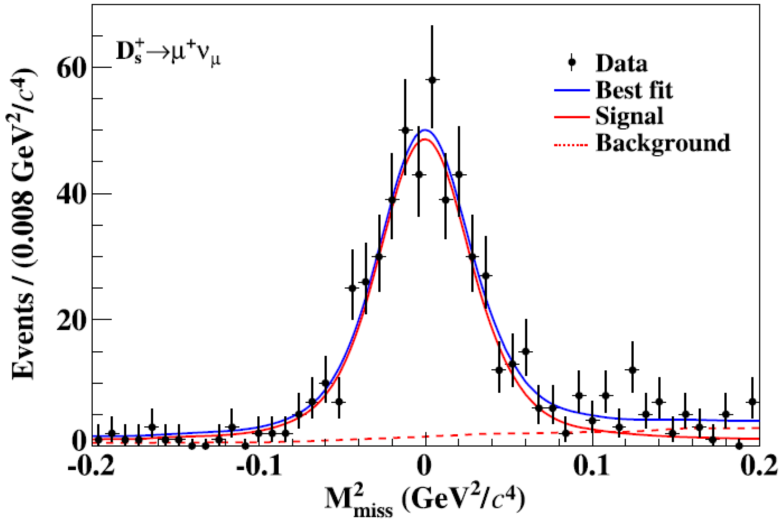
Summary

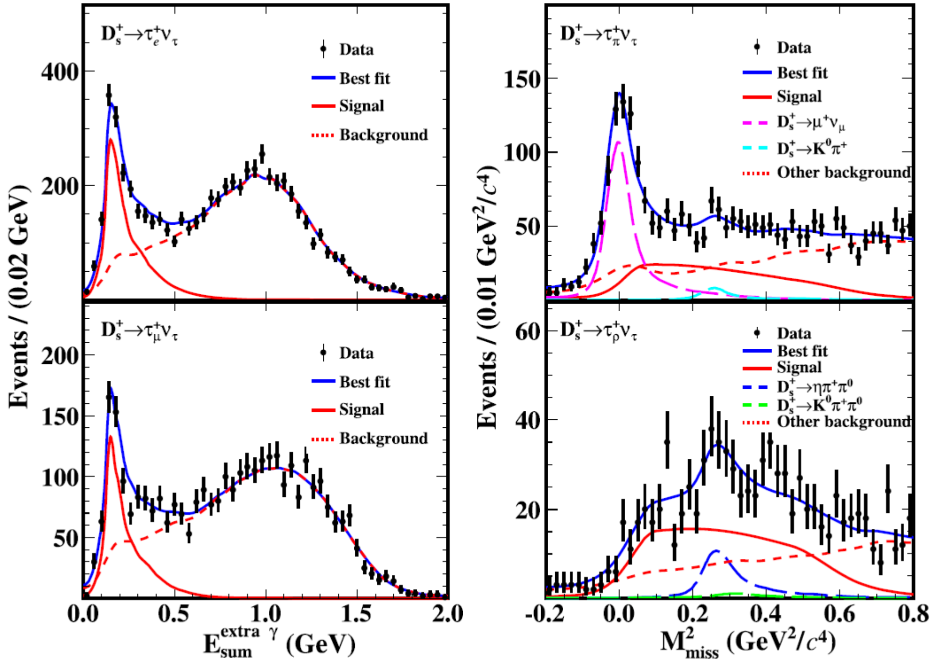
- **In recent years， many important results have been achieved in charm meson physics at BESIII：**
  - Decay constants, form factors, $|V_{cs}|$ and $|V_{cd}|$: (0.4-1.5)%；
  - LFU test: <1%.
- **Some physics results based on 20.3 fb^{-1}@3.773 GeV data have been published**
- **More results are expected in the near future**

谢谢!

基于$e^+e^- \to D_s^{*+}D_s^{*-}$研究$D_s^+$纯轻衰变

PRD110 (2024) 052002





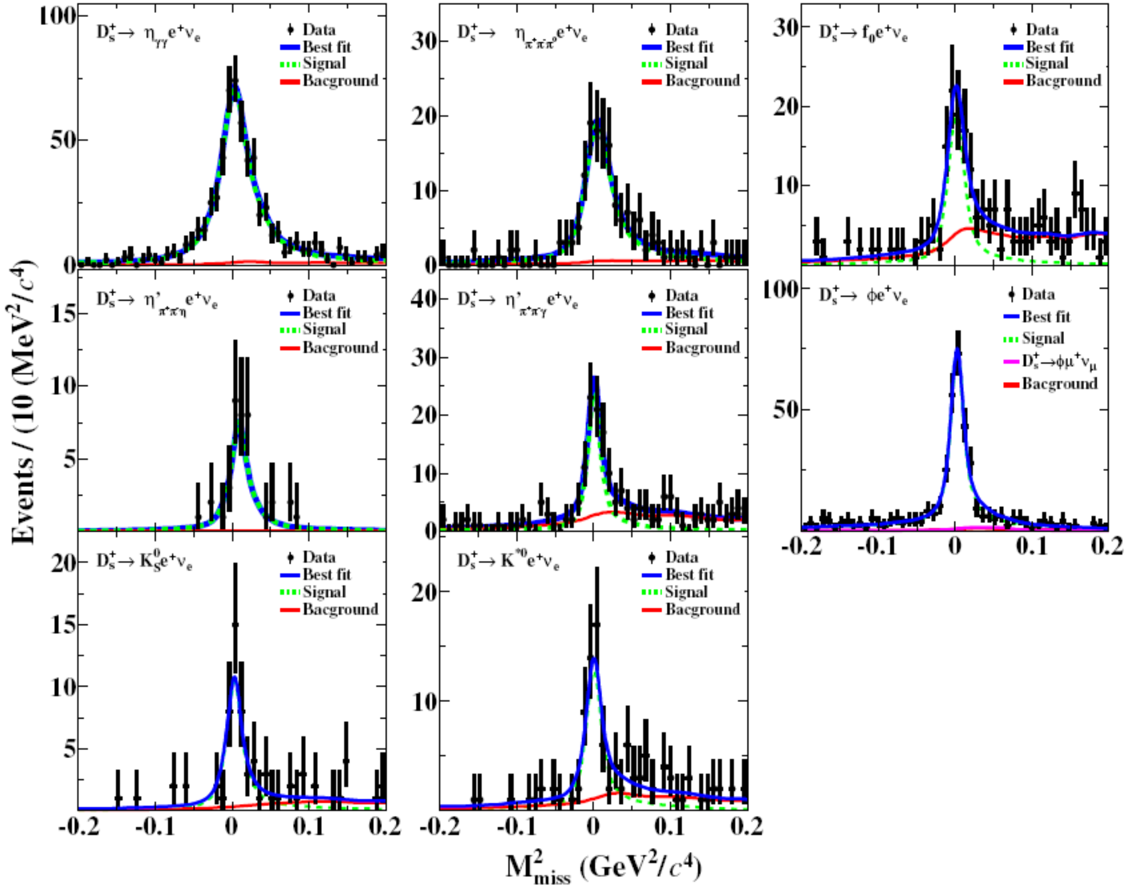
基于4.23-4.7 GeV 10.6 fb^{-1}数据，挖掘现有及未来BESIII数据潜力

		No lepton universality constraint		Lepton universality constraint	
Signal decay	$\bar{\epsilon}_{sig}$ (%)	N_{DT}	$\mathcal{B}$ (%)	N_{DT}^{SM}	$\mathcal{B}^{SM}$ (%)
$D_s^+ \to \tau_e^+\nu_\tau$	7.81 ± 0.02	2845 ± 83	$5.60 \pm 0.16 \pm 0.20$	2754 ± 69	$5.39 \pm 0.14 \pm 0.20$
$D_s^+ \to \tau_\mu^+\nu_\tau$	18.57 ± 0.04				
$D_s^+ \to \tau_\pi^+\nu_\tau$	8.93 ± 0.02				
$D_s^+ \to \tau_\rho^+\nu_\tau$	6.11 ± 0.02				
$D_s^+ \to \mu_b^+\nu_\mu$	94.76 ± 0.20	579 ± 34	$0.491 \pm 0.029 \pm 0.020$	641 ± 16	$0.553 \pm 0.014 \pm 0.021$
$D_s^+ \to \mu_a^+\nu_\mu$	74.67 ± 0.16	507 ± 26	$0.547 \pm 0.026 \pm 0.016$	...	...

基于$e^+e^- \to D_s^{*+}D_s^{*-}$的$D_s^+$半轻衰变的研究

基于4.23-4.7 GeV 10.6 fb^{-1}数据，挖掘现有及未来BESIII数据潜力

arXiv:2406.01332,
accepted by PRD



Decay	ϵ_{sig} (%)	N_{DT}	$\mathcal{B}$ (%)
$D_s^+ \to \eta_{\gamma\gamma} e^+\nu_e$	50.78 ± 0.12	716.2 ± 33.8	$2.35 \pm 0.11 \pm 0.10$
$D_s^+ \to \eta_{\pi^+\pi^-\pi^0} e^+\nu_e$	20.42 ± 0.08		
$D_s^+ \to \eta'_{\pi^+\pi^-\eta} e^+\nu_e$	22.35 ± 0.07	133.7 ± 14.5	$0.82 \pm 0.09 \pm 0.04$
$D_s^+ \to \eta'_{\pi^+\pi^-\gamma} e^+\nu_e$	32.48 ± 0.09		
$D_s^+ \to \phi_{K^+K^-} e^+\nu_e$	25.48 ± 0.07	350.2 ± 24.5	$2.21 \pm 0.16 \pm 0.11$
$D_s^+ \to f_{0\,\pi^+\pi^-} e^+\nu_e$	46.24 ± 0.11	91.0 ± 14.1	$0.15 \pm 0.02 \pm 0.01$
$D_s^+ \to K^0 e^+\nu_e$	46.21 ± 0.11	50.5 ± 8.4	$0.24 \pm 0.04 \pm 0.01$
$D_s^+ \to K^{0\star} e^+\nu_e$	41.78 ± 0.10	65.4 ± 10.9	$0.19 \pm 0.03 \pm 0.01$