(Semi)leptonic charm-hadron decays at BESIII

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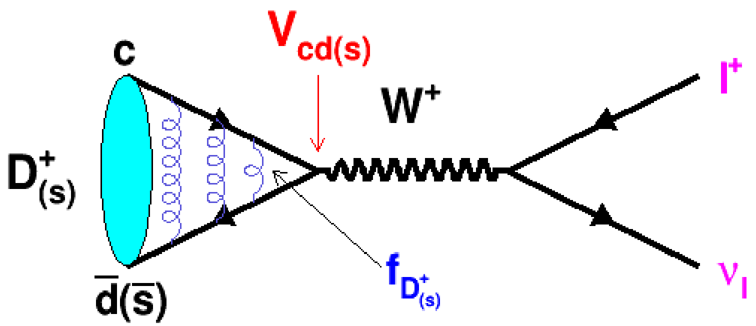
第三届重味物理和量子色动力学研讨会
2021年5月1-3日，天津

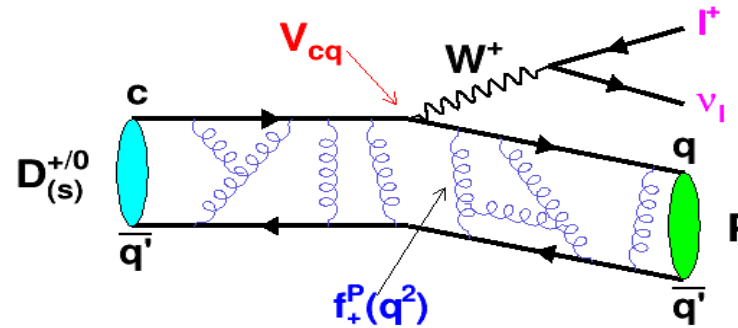
主要内容

- 物理意义
- BESIII
- 衰变常数、形状因子、$|V_{cs(d)}|$
- 轻子普适性检验
- 其他半轻衰变
- 总结

物理意义

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



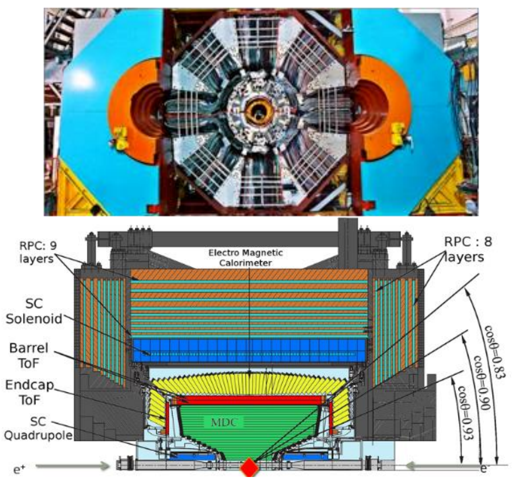


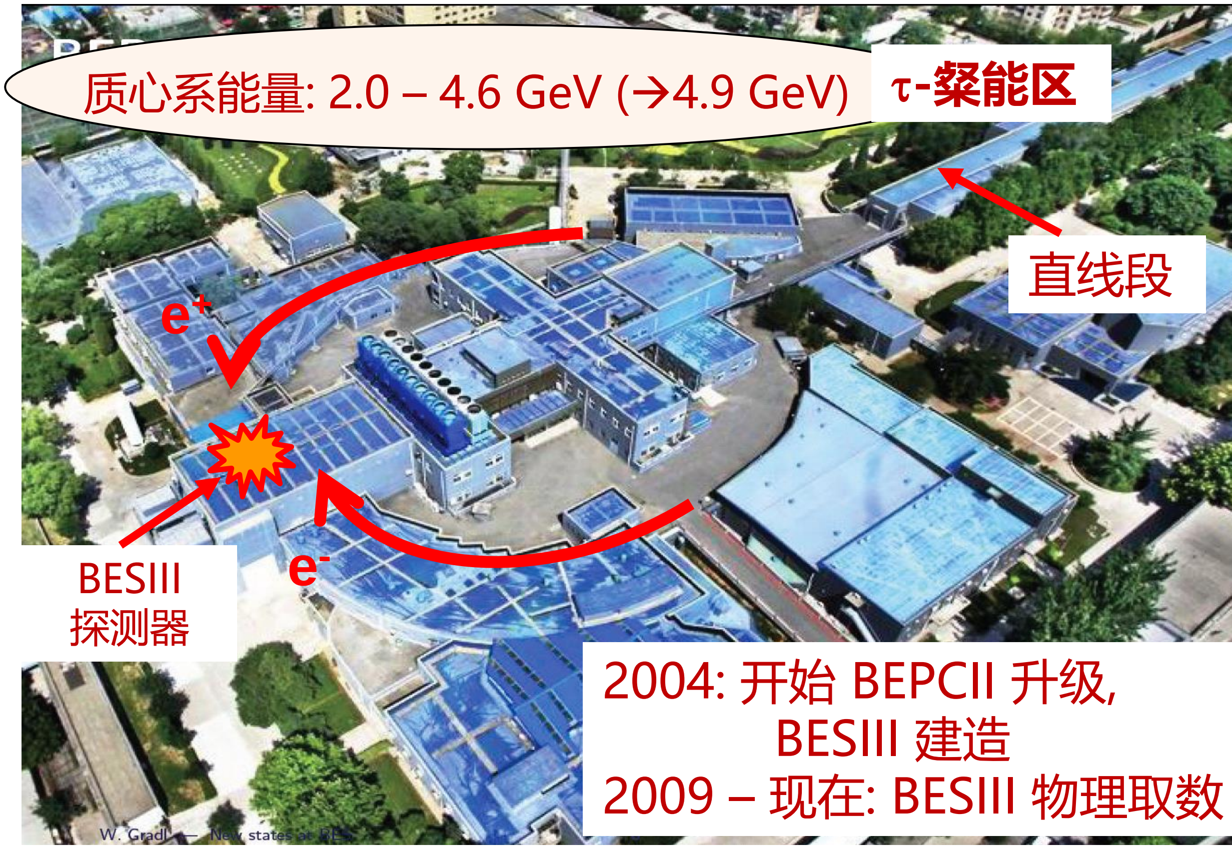
$$\Gamma(D_{(s)}^+ \to \ell^+\nu_\ell) = \frac{G_F^2 f_{D_{(s)}^+}^2}{8\pi}|V_{cd(s)}|^2 m_\ell^2 m_{D_{(s)}^+}\left(1-\frac{m_\ell^2}{m_{D_{(s)}^+}^2}\right)^2$$

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

- 衰变常数、形状因子 →刻度格点QCD等计算
- $|V_{cs}|$、$|V_{cd}|$ →检验CKM矩阵的幺正性
- 分支比之比$B_{\mu/e}$、$B_{\tau/\mu}$ →轻子普适性检验
- 稀有含轻衰变 →寻找新物理效应

北京谱仪实验III (BESIII) @ 北京正负电子对撞机 (BEPCII)





- 2015: 完成BESIII TOF端盖升级，时间分辨 120 ps → 60 ps
- 2016: 达到设计亮度， 1.00×10^{33} $cm^{-2}s^{-1}$
- 2019: 完成BEPCII全能量注入升级，取数效率提高30%-40%
- 2020: 完成BEPCII 能量升级，质心系能量 →4.95 GeV
- 新升级计划：亮度提升3-4倍，质心系能量 →5.6 GeV

4

BESⅢ 国际合作组

Europe (16)

Germany(6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster

Italy(3): Ferrara University, INFN, University of Turin,

Netherlands(1): KVI/University of Groningen

Russia(2): Budker Institute of Nuclear Physics, Dubna JINR

Sweden(1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK(2): University of Manchester, University of Oxford

USA(4)

Carnegie Mellon University
Indiana University
University of Hawaii
University of Minnesota

Pakistan(3)

COMSATS Institute of Information Technology
University of the Punjab,
University of Lahore

India(1)

Indian Institute of Technology madras

Thailand(1)

Suranaree University of Technology

Korea(1)

Seoul National University

Japan(1)

Tokyo University

Mongolia(1)

Institute of Physics and Technology

China (45)

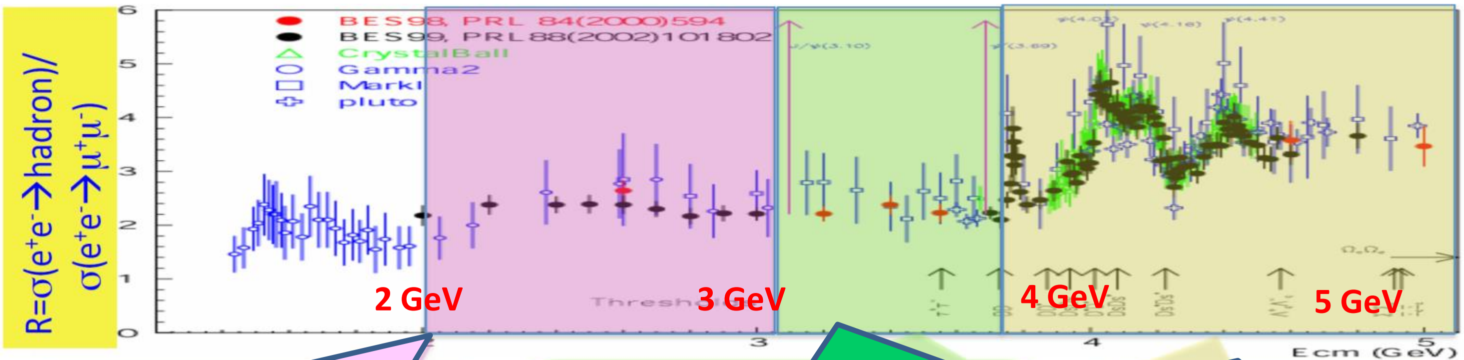
Beijing Institute of Petro-chemical Technology, Beihang University, China Center of Advanced Science and Technology, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Henan Normal University, Henan University of Science and Technology, Huazhong Normal University, Huangshan College, Hunan University, Hunan Normal University, Institute of High Energy Physics, Institute of Modern Physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu Normal University, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, Shanghai Jiao Tong University, Soochow University, South China Normal University, Southeast University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xinyang Normal University, Zhejiang University, Zhengzhou University

依托BESIII/BEPCII

~500 成员

来自15个国家的74个单位

τ - 粲能区丰富的物理



- Y(2175)
- Zs 态？
- QCD 检验

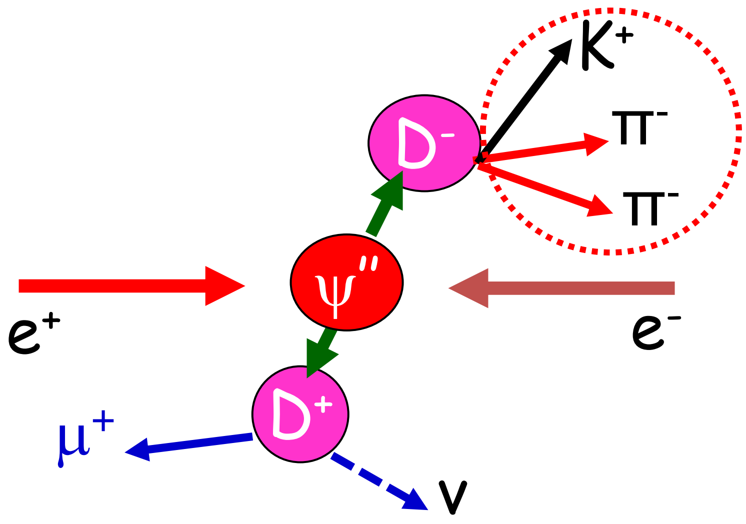
J/ψ, ψ’粲偶素衰变

- 轻强子谱
- 寻找胶球、混杂态和多夸克态

- XYZ
- 粲介子（检验QCD, CKM，中性D介子混合, CP破坏）
- 粲重子

- 丰富的共振态: 粲偶素粒子、粲介子、粲重子、XYZ……
- 阈上产生(τ, D, D_s, …成对产生) – 低本底、高截面
- 在微扰QCD和非微扰QCD的过渡区域，累计采集了约30 fb^{-1}

BESIII粲强子样本



世界上最大的近阈数据

对产生→双标记方法

背景低→系统误差小

中性D介子量子关联

质心能量 (GeV)	采集年份	亮度 (fb^{-1})	D^0 产额	D^+ 产额	D_s^+ 产额	Λ_c^+ 产额
3.773	2010-2011	2.93	2.5M	1.7M		
4.009	2011	0.5			13K	
4.18-4.23	2016, 2017, 2014	6.3			1.4M	
4.6(4.6-4.7)	2014(2020)	0.6(4.4)				15K

与Belle和LHCb优势互补

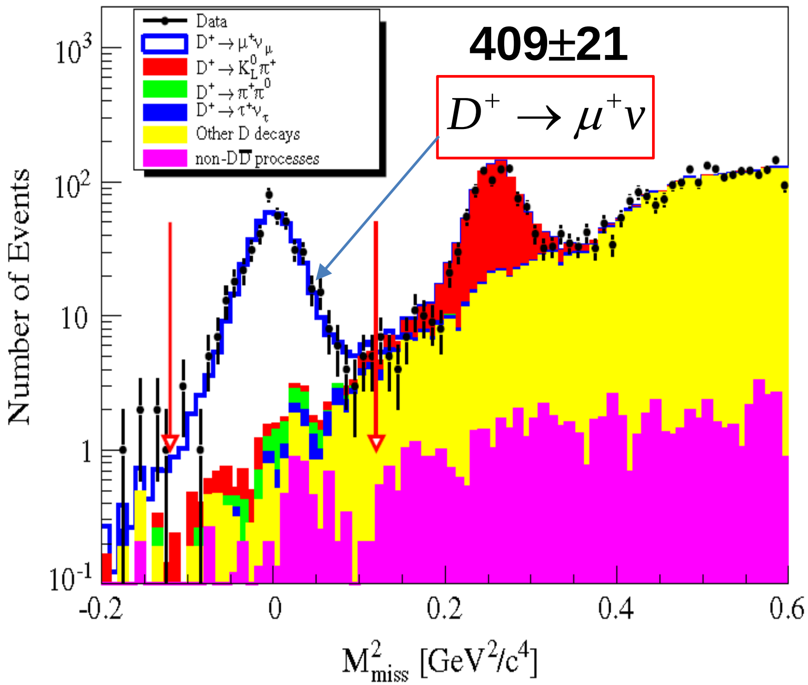
衰变常数、形状因子、$|V_{cs(d)}|$

$D^+ \to l^+\nu_l$ 研究

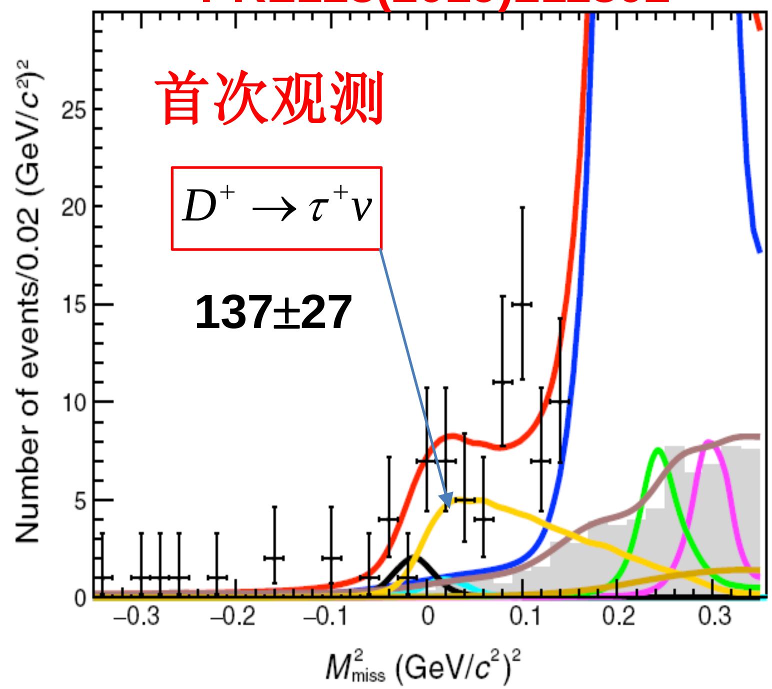
2.93 fb^{-1} data@ 3.773 GeV

Editor suggested

PRD89(2014)051104



PRL123(2019)211802



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

$$\mathrm{f}_{D^+}|\mathrm{V_{cd}}| = 46.7 \pm 1.2 \pm 0.4\ \mathrm{MeV}$$

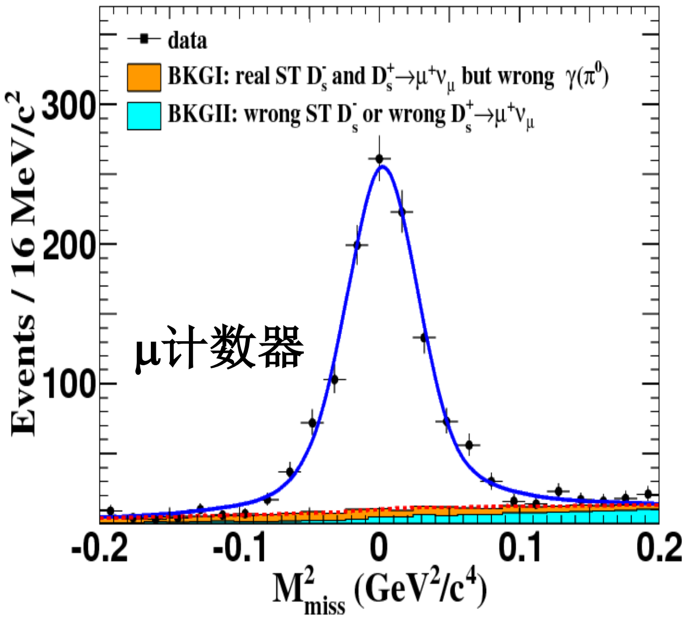
$$\mathrm{B}[D^+ \to \tau^+ v] = (1.20 \pm 0.24 \pm 0.12) \times 10^{-3}$$

$$\mathrm{f}_{D^+}|\mathrm{V_{cd}}| = 50.4 \pm 5.0 \pm 2.5\ \mathrm{MeV}$$

$D_s^+ \to l^+\nu_l$ 研究

3.19 fb^{-1}@4.18 GeV

PRL122(2019)071802



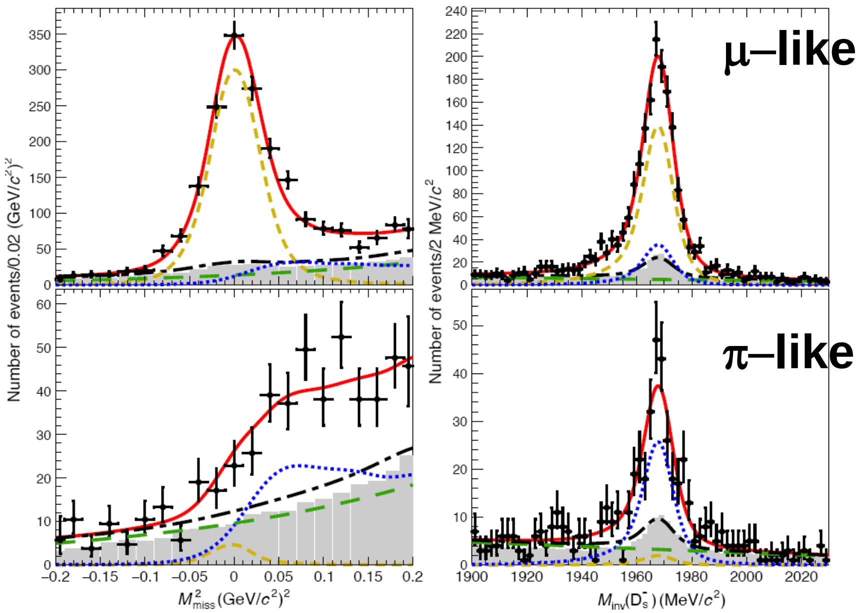
$$B[D_s^+ \to \mu^+ v] = (5.49 \pm 0.16 \pm 0.15) \times 10^{-3}$$

$$f_{D_s^+}|V_{cs}| = 242.5 \pm 3.5 \pm 3.7 \text{ MeV}$$

$$A_{CP}[\mu v] = \frac{B_{D_s^+\to\mu^+v} - B_{D_s^-\to\mu^-v}}{B_{D_s^+\to\mu^+v} + B_{D_s^-\to\mu^-v}}$$
$$= (2.0 \pm 3.0 \pm 1.2)\%$$

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

arXiv:2102.11734



$$B[D_s^+ \to \mu^+ v] = (5.35 \pm 0.13 \pm 0.16) \times 10^{-3}$$

$$B[D_s^+ \to \tau^+ v] = (5.22 \pm 0.25 \pm 0.17)\%$$

$$f_{D_s^+}|V_{cs}| = 243.1 \pm 3.0 \pm 3.7 \text{ MeV}[\mu]$$

$$f_{D_s^+}|V_{cs}| = 243.0 \pm 5.8 \pm 4.0 \text{ MeV}[\tau]$$

$$A_{CP}[\mu v] = (-1.2 \pm 2.7)\%$$

$$A_{CP}[\tau v] = (2.9 \pm 4.9)\%$$

$D \to P e^+ \nu_e$动力学研究

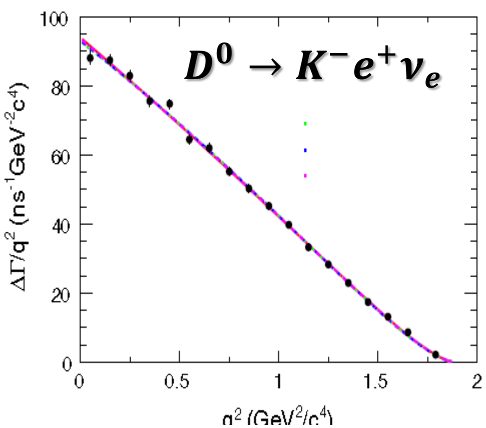
$$\frac{d\Gamma}{dq^2} = X \frac{G_F^2 |V_{cd(s)}|^2}{24\pi^3} p^3 |f_+(q^2)|^2 \xrightarrow{\text{动力学研究}} f_+^{D\to P}(0)|V_{cs(d)}|$$

形状因子参数化形式

- Single pole form $$f_+(q^2) = \frac{f_+(0)}{1 - \frac{q^2}{M_{\rm pole}^2}}$$
- Modified pole $$f_+(q^2) = \frac{f_+(0)}{(1 - \frac{q^2}{M_{\rm pole}^2})(1 - \alpha \frac{q^2}{M_{\rm pole}^2})}$$
- 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 $$f_+(t) = \frac{1}{P(t)\Phi(t,t_0)} a_0(t_0) \left(1 + \sum_{k=1}^{\infty} r_k(t_0)[z(t,t_0)]^k\right)$$

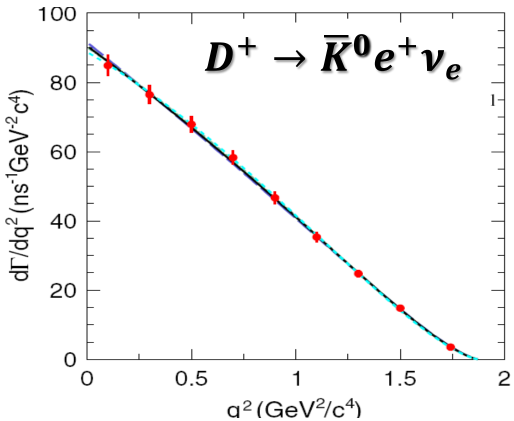
$c \to s l^+ \nu_l$型半轻衰变

PRD92(2015)072012



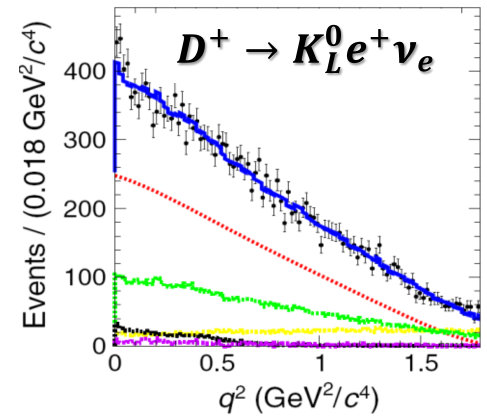
$f_+^{D\to K}(0)|V_{cs}| = 0.717(03)(04)$

PRD96(2017)012002



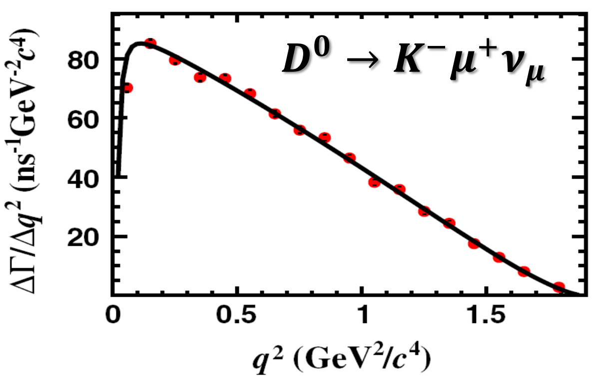
$f_+^{D\to K}(0)|V_{cs}| = 0.705(04)(11)$

PRD92(2015)112008



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

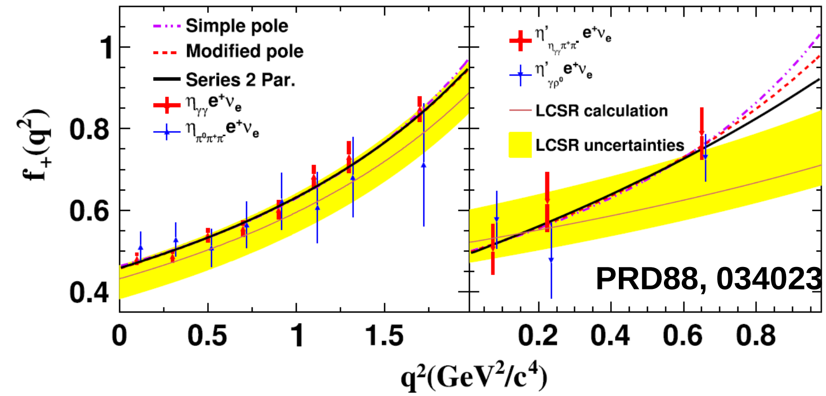
PRL122(2019)011804



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

$f_-^{D\to K}/f_+^{D\to K} = 0.6(8)(2)$

$D_s^+ \to \eta^{(\prime)} e^+ \nu_e$ **PRL123(2019)121801**

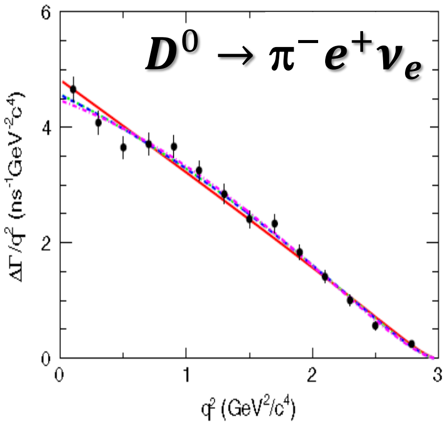


$f_+^{D_s\to\eta}(0)|V_{cs}| = 0.446(05)(04)$ 首次

$f_+^{D_s\to\eta'}(0)|V_{cs}| = 0.477(49)(11)$ 提取

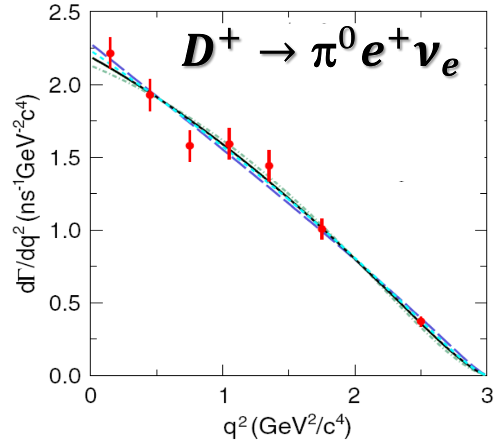
$c \to d l^+ \nu_l$型半轻衰变

PRD92(2015)072012



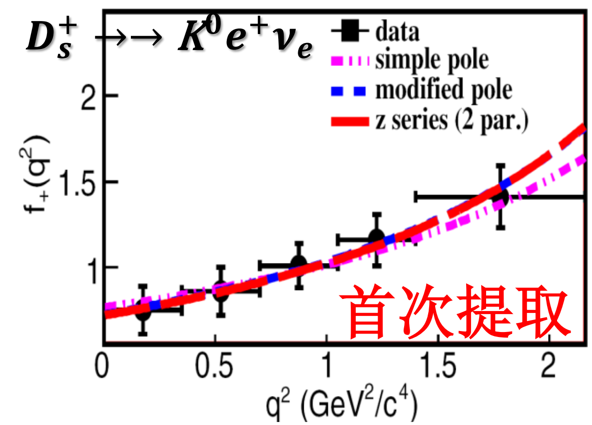
$f_+^{D\to\pi}(0)|V_{cd}| = 0.144(02)(01)$

PRD96(2017)012002



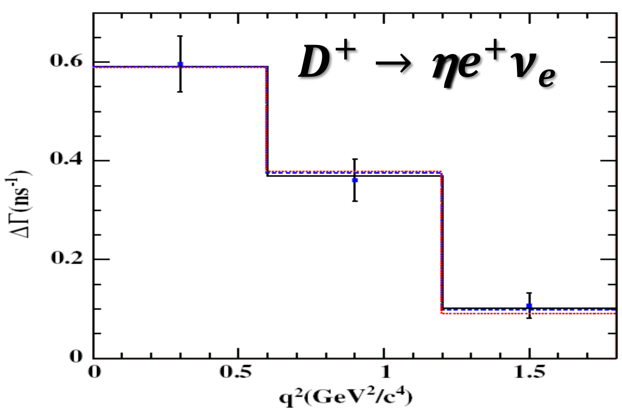
$f_+^{D\to\pi}(0)|V_{cd}| = 0.140(03)(01)$

PRL122(2019)061801



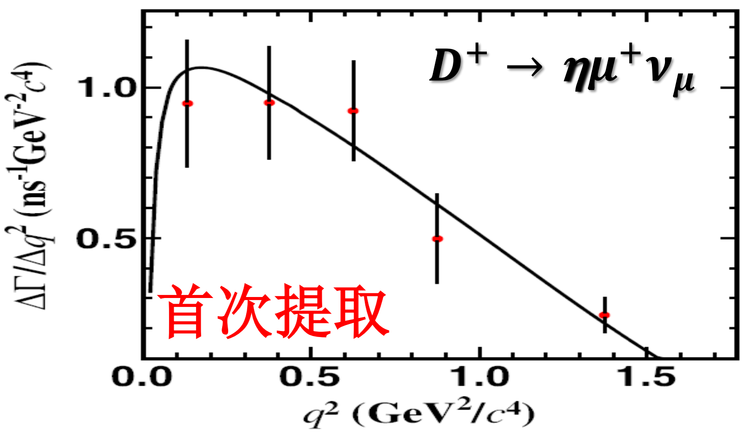
$f_+^{D_s\to K}(0)|V_{cd}| = 0.162(19)(03)$

PRD97(2018)092009



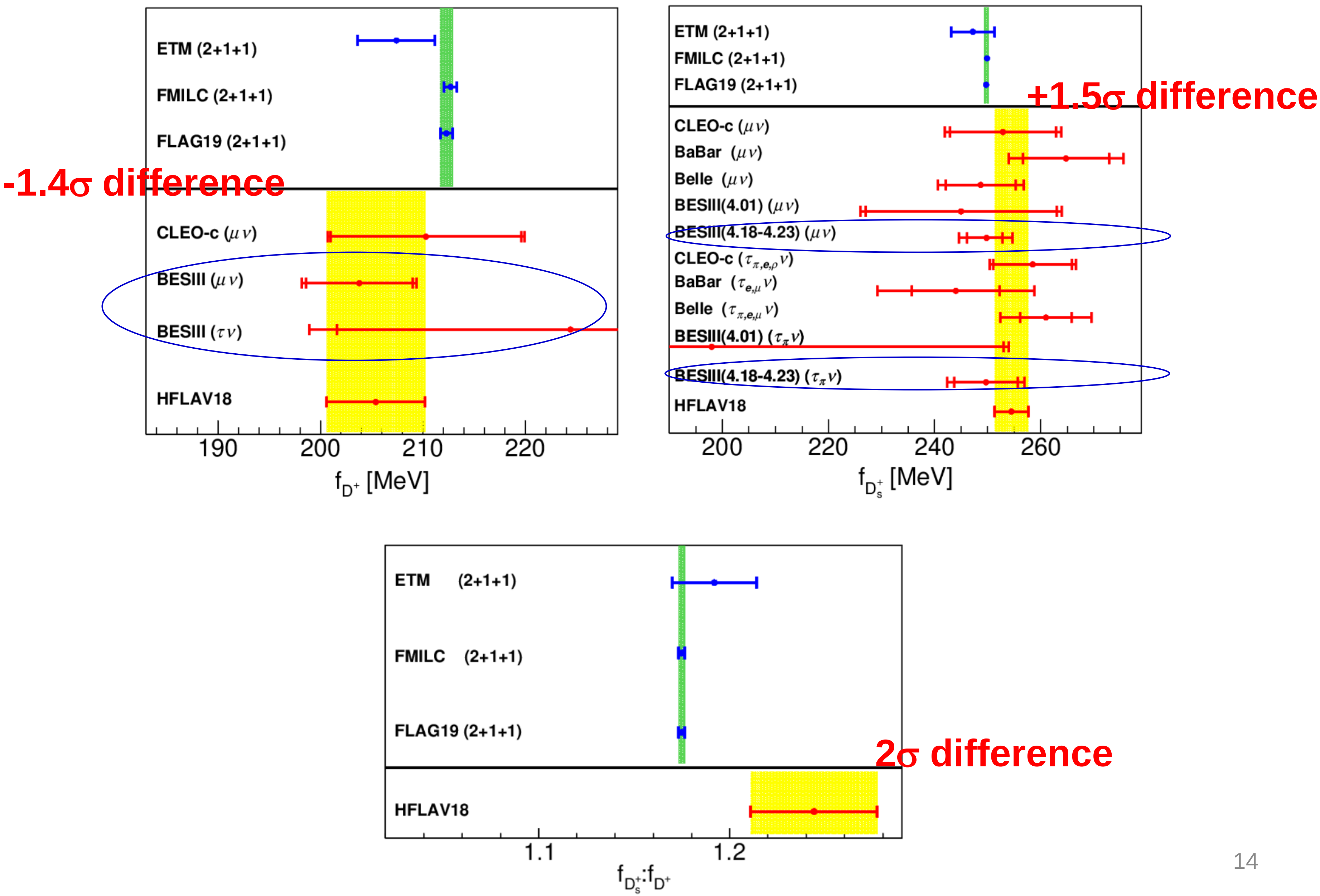
$f_+^{D\to\eta}(0)|V_{cd}| = 0.079(06)(02)$

PRL124(2020)231801

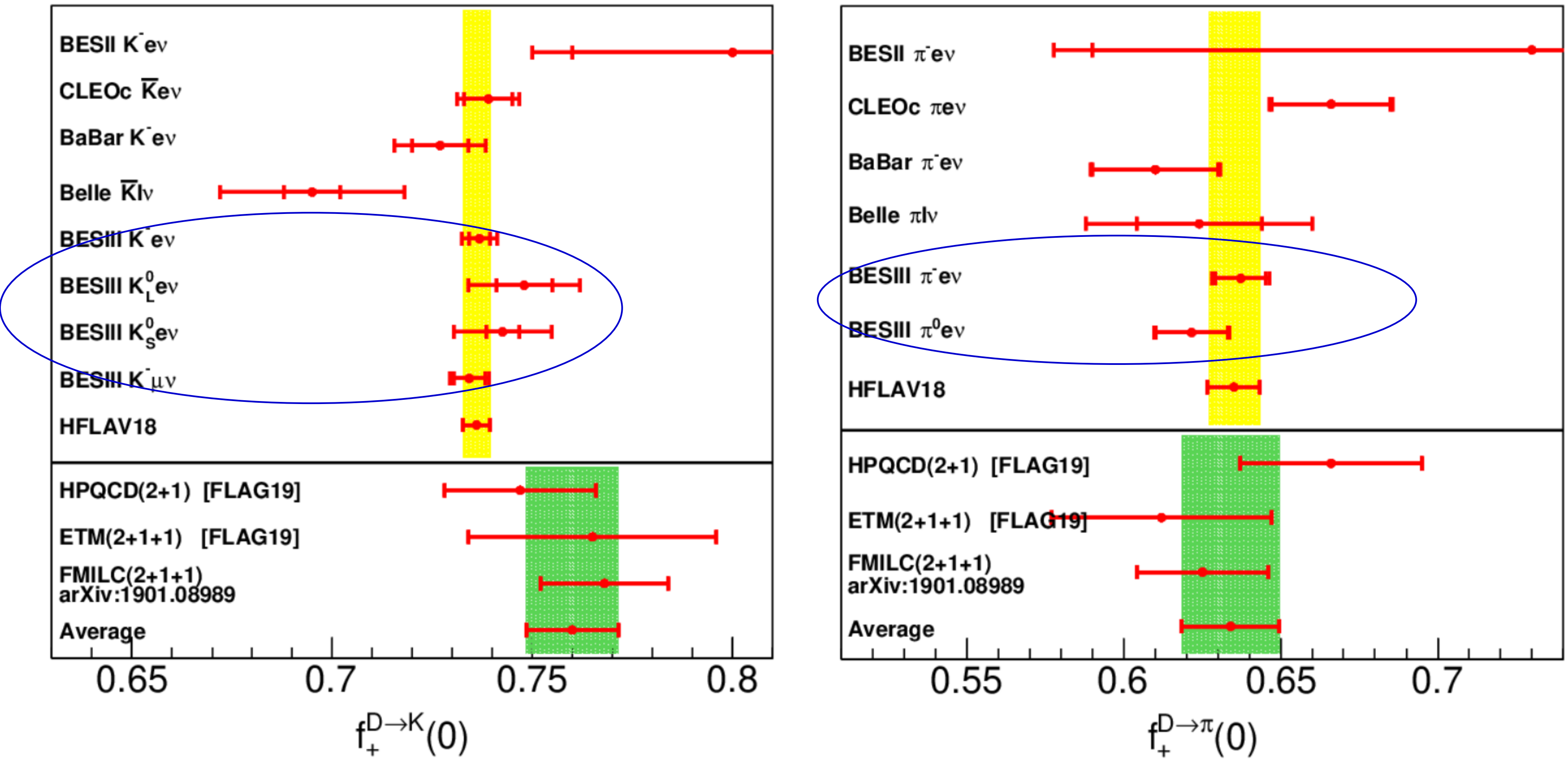


$f_+^{D\to\eta}(0)|V_{cd}| = 0.087(08)(02)$

f_{D^+} 和 $f_{D_s^+}$ 及其比值的比较

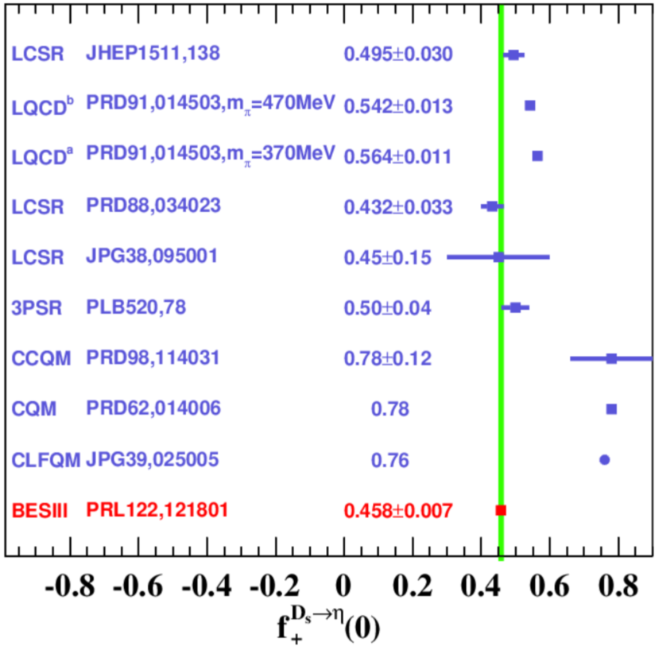


形状因子比较

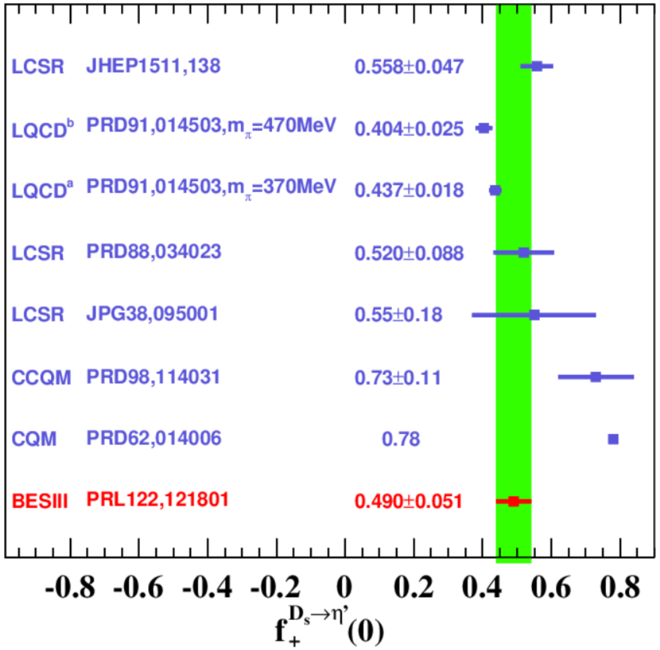


BESII $K^-e\nu$
CLEOc $\bar{K}e\nu$
BaBar $K^-e\nu$
Belle $\bar{K}l\nu$
BESIII $K^-e\nu$
BESIII $K^0_Le\nu$
BESIII $K^0_Se\nu$
BESIII $K^-\mu\nu$
HFLAV18
HPQCD(2+1) [FLAG19]
ETM(2+1+1) [FLAG19]
FMILC(2+1+1)
arXiv:1901.08989
Average
0.65
0.7
0.75
0.8
$f_+^{D\to K}(0)$
BESII $\pi^-e\nu$
CLEOc $\pi e\nu$
BaBar $\pi^-e\nu$
Belle $\pi l\nu$
BESIII $\pi^-e\nu$
BESIII $\pi^0e\nu$
HFLAV18
HPQCD(2+1) [FLAG19]
ETM(2+1+1) [FLAG19]
FMILC(2+1+1)
arXiv:1901.08989
Average
0.55
0.6
0.65
0.7
$f_+^{D\to\pi}(0)$

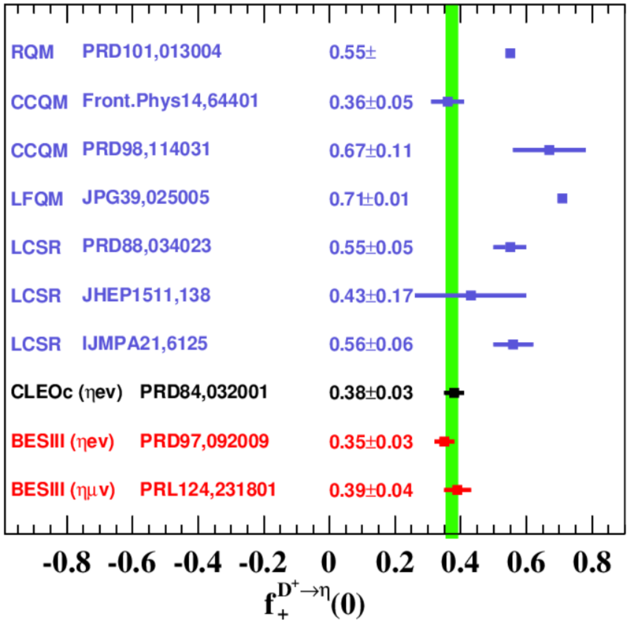
形状因子比较



LCSR JHEP1511,138 0.495±0.030
LQCD[b] PRD91,014503,m_π=470MeV 0.542±0.013
LQCD[a] PRD91,014503,m_π=370MeV 0.564±0.011
LCSR PRD88,034023 0.432±0.033
LCSR JPG38,095001 0.45±0.15
3PSR PLB520,78 0.50±0.04
CCQM PRD98,114031 0.78±0.12
CQM PRD62,014006 0.78
CLFQM JPG39,025005 0.76
BESIII PRL122,121801 0.458±0.007
-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8
$f_+^{D_s\to\eta}(0)$



LCSR JHEP1511,138 0.558±0.047
LQCD[b] PRD91,014503,m_π=470MeV 0.404±0.025
LQCD[a] PRD91,014503,m_π=370MeV 0.437±0.018
LCSR PRD88,034023 0.520±0.088
LCSR JPG38,095001 0.55±0.18
CCQM PRD98,114031 0.73±0.11
CQM PRD62,014006 0.78
BESIII PRL122,121801 0.490±0.051
-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8
$f_+^{D_s\to\eta'}(0)$

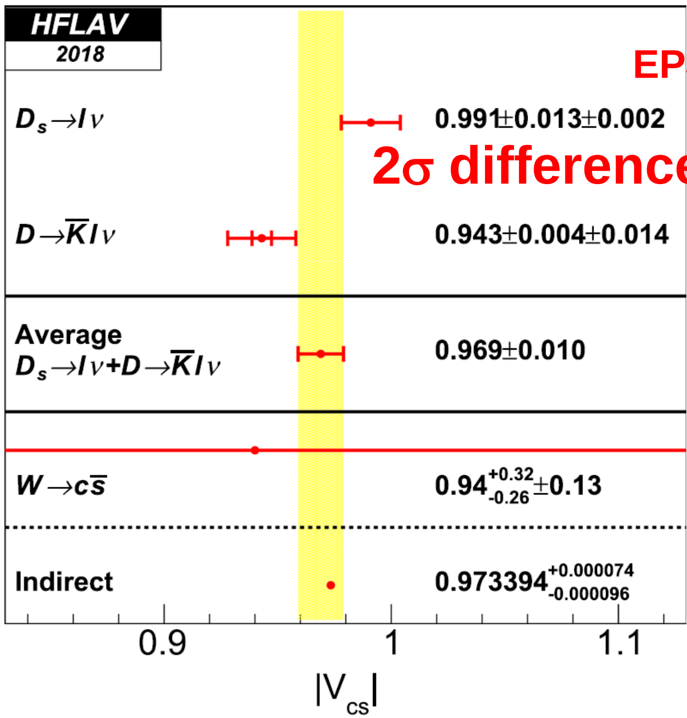


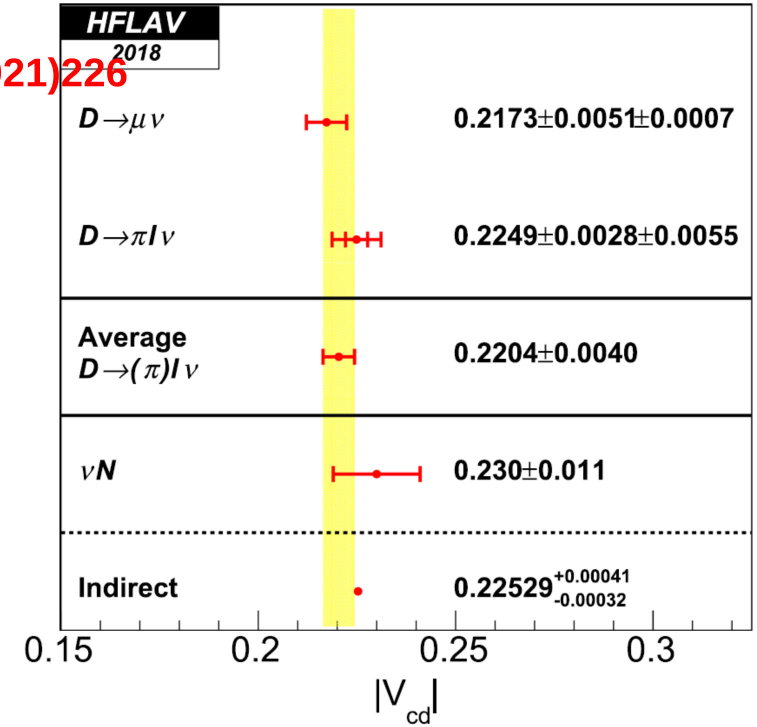
RQM PRD101,013004 0.55±
CCQM Front.Phys14,64401 0.36±0.05
CCQM PRD98,114031 0.67±0.11
LFQM JPG39,025005 0.71±0.01
LCSR PRD88,034023 0.55±0.05
LCSR JHEP1511,138 0.43±0.17
LCSR IJMPA21,6125 0.56±0.06
CLEOc (ηev) PRD84,032001 0.38±0.03
BESIII (ηev) PRD97,092009 0.35±0.03
BESIII (ημv) PRL124,231801 0.39±0.04
-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8
$f_+^{D^+\to\eta}(0)$

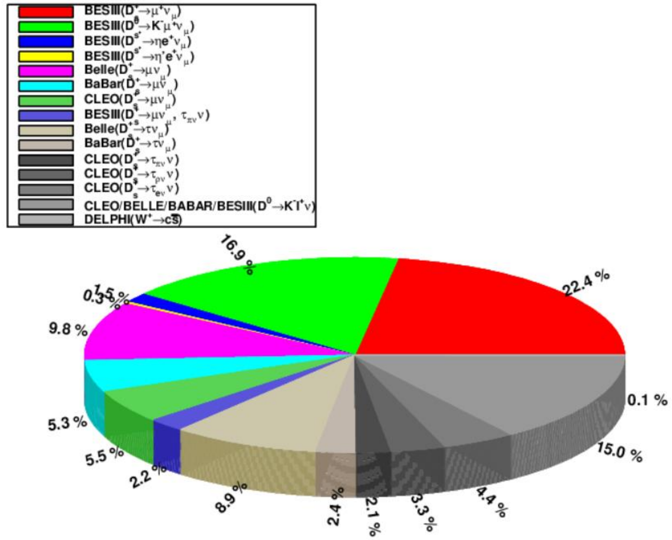
$|V_{cs\,(d)}|$比较

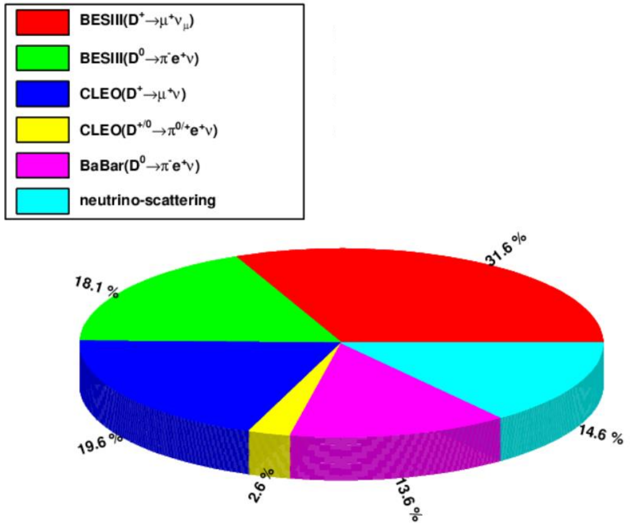
EPJC81(2021)226

2σ difference

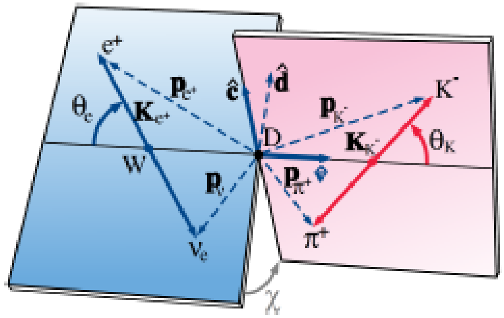








$D \to Ve^+\nu_e$形状因子测量



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

Decay rate depend on 5 variables and 3 form factors

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

- $X = p_{K\pi} m_D$, $p_{K\pi}$ 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 $H_{0,\pm}$:

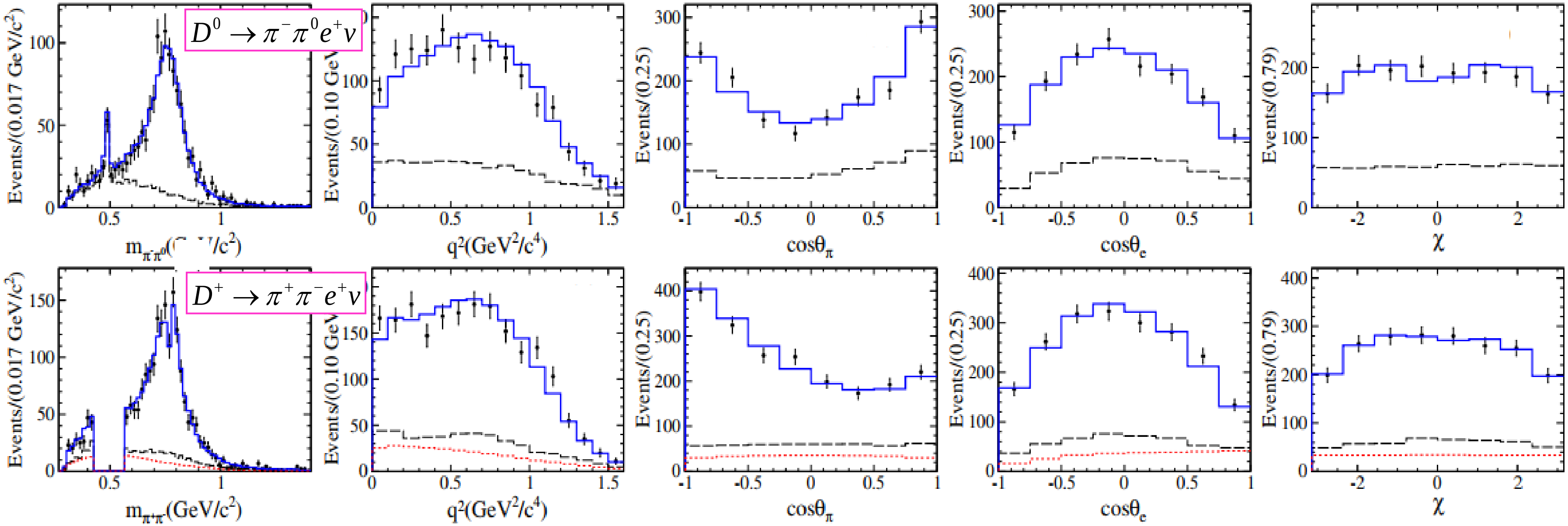
$$H_0(q^2) = \frac{1}{2mq}\left[(m_D^2 - m^2 - q^2)(m_D + m)A_1(q^2) - 4\frac{m_D^2 p_{K\pi}^2}{m_D + m} A_2(q^2)\right]$$

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

- 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 $r_2 = A_2(0)/A_1(0)$

$D^{0(+)} \to \pi\pi e^+\nu_e$衰变研究

PRL122(2019)062001



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

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

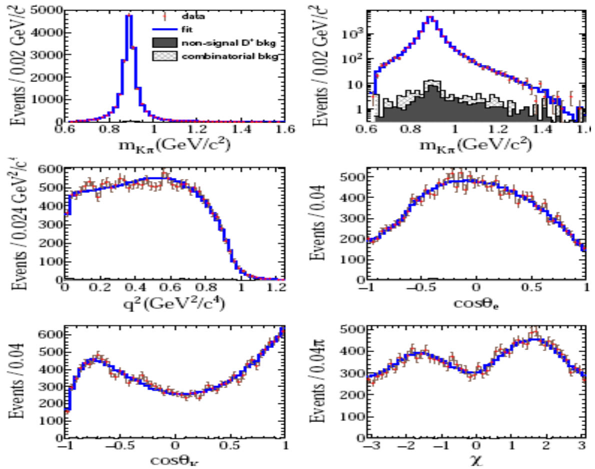
首次观测到$D^+ \to f_0(500) e^+\nu_e$

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

>2.7，支持标量介子四夸克态成分假定

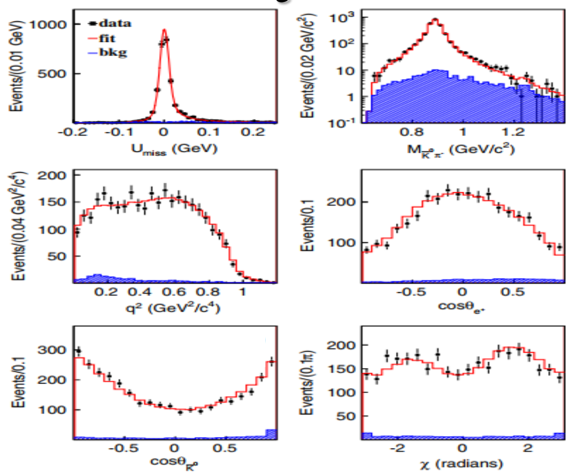
其他$D \to V e^+ \nu_e$衰变研究

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



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

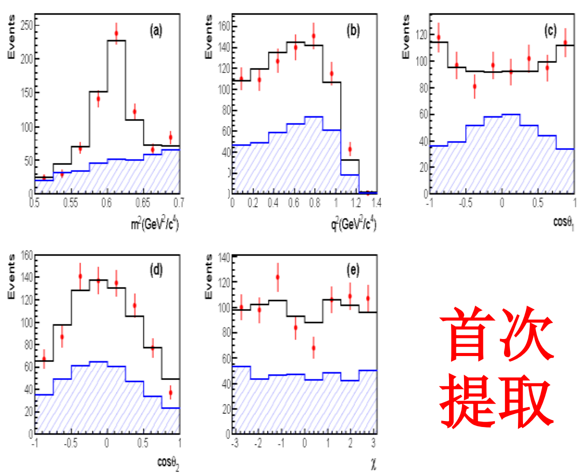
$D^0 \to K^{*-} e^+ \nu_e$ PRD99(2018)011103



首次提取

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

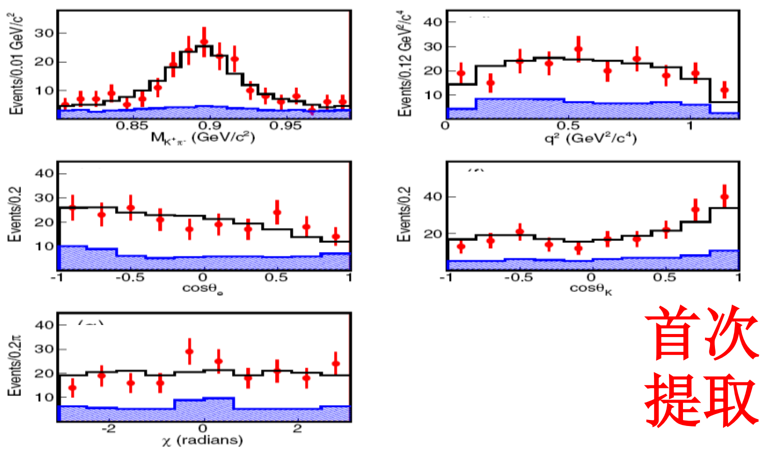
$D^+ \to \omega e^+ \nu_e$ PRD92(2015)071101



首次提取

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

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



首次提取

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

轻子普适性检验

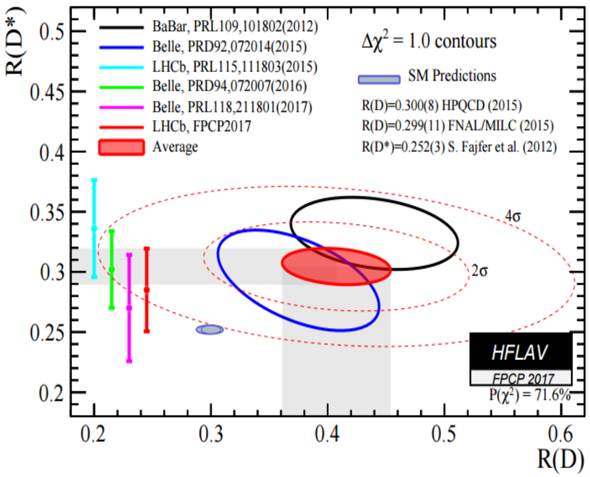
轻子普适性检验

tension in B physics

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

deviates from LFU prediction by 3.9σ

HFLAV17



tension in D physics

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

$$\frac{\Gamma^{\mathrm{PDG18}}[D^0 \to \pi^-\mu^+\nu]}{\Gamma^{\mathrm{PDG18}}[D^0 \to \pi^-e^+\nu]} = 0.82 \pm 0.08 \qquad \textbf{(2.1}\sigma\textbf{)}$$

SM prediction: 0.985

Recent progress can be found in Jibo's talk

https://indico.ihep.ac.cn/event/13976/session/3/contribution/8

BESIII之前粲强子遍举μ半轻衰变

- D介子：

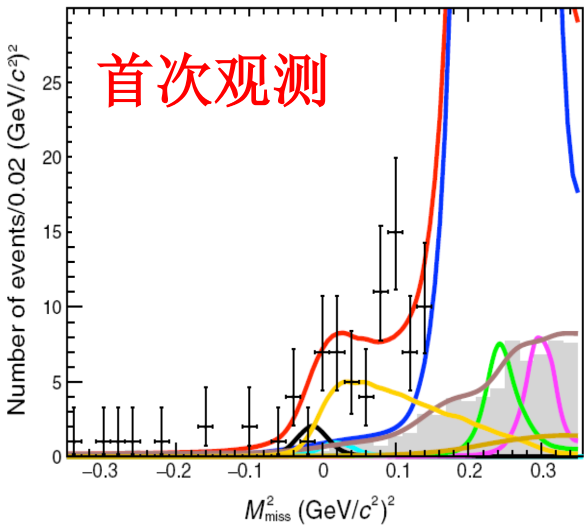
	D^0		D^+		D_s^+	
$c \to sl^+\nu$	K^-	4%[Belle]	$\bar{K}^0$	7%[FOCUS]	η	NA
	K^{*-}	13%[FOCUS]	$\bar{K}^{*0}$	3%[CLEOc]	η'	NA
					ϕ	NA
					f_0	NA
$c \to dl^+\nu$	π^-	10%[Belle]	π^0	NA	K^0	NA
	ρ^-	NA	ρ^0	17%[FOCUS]	K^{*0}	NA
			ω	NA		
			η	NA		
			η'	NA		

- Λ_c^+重子：

仅CLEO2和ARGUS对B[$\Lambda\mu^+\nu_\mu$]/B[pKπ]的测量，误差35%

$D^+_{(s)} \to l^+\nu_l$衰变的LFU检验

PRL123(2019)211802



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

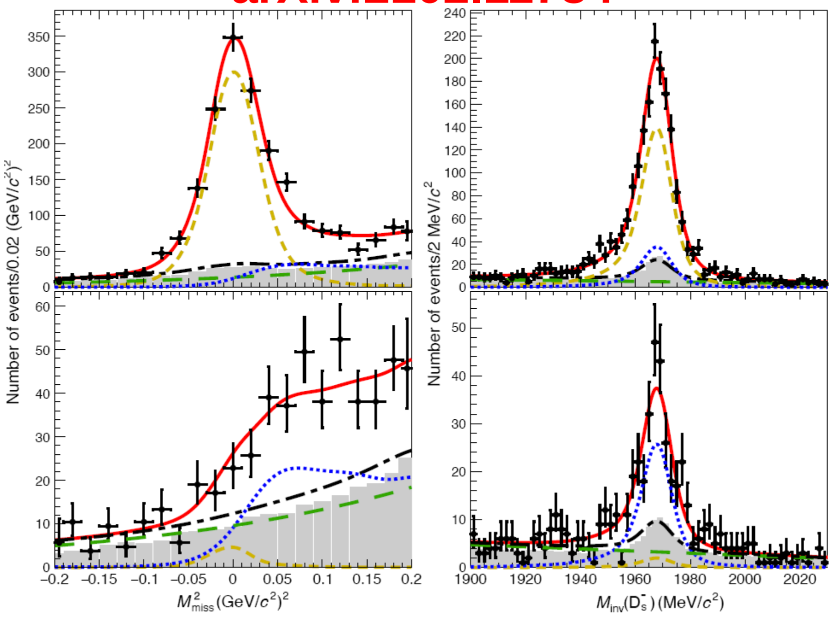
$$B^{PDG}[D^+ \to \mu^+ v] = (3.74 \pm 0.17) \times 10^{-4}$$

$$R_D = \frac{B[D^+ \to \tau^+ v]}{B[D^+ \to \mu^+ v]} = 3.21 \pm 0.64 \pm 0.43$$

SM prediction: 2.67

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

arXiv:2102.11734



Combined results:

$$B[D_s^+ \to \mu^+ v] = (5.43 \pm 0.15) \times 10^{-3}$$

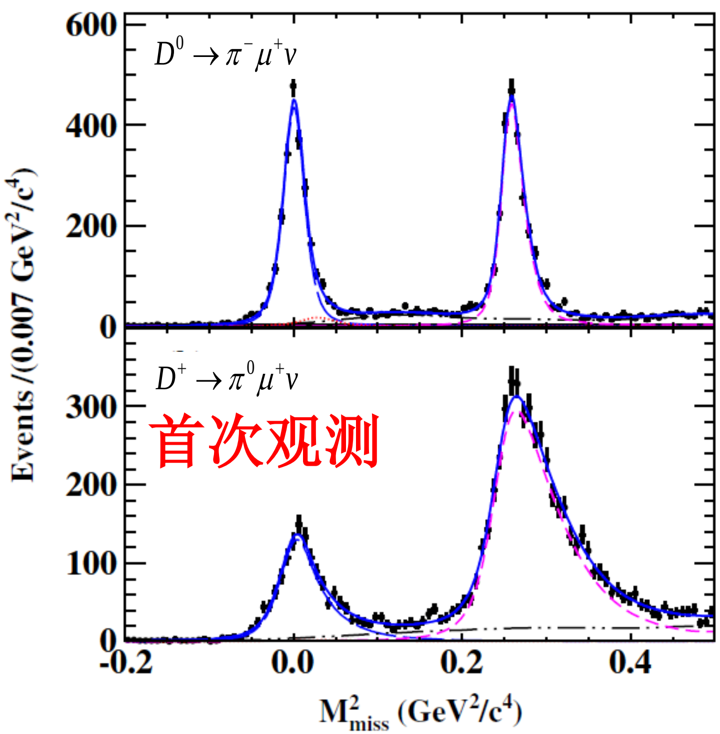
$$B[D_s^+ \to \tau^+ v] = (5.40 \pm 0.19)\%$$

$$R_{Ds} = \frac{B[D_s^+ \to \tau^+ v]}{B[D_s^+ \to \mu^+ v]} = 9.94 \pm 0.52$$

SM prediction: 9.75

$D^{0(+)} \to \pi l^+ \nu_l$衰变的LFU检验

PRL121(2018)171803



$$B[D^0 \to \pi^- \mu^+ \nu] = (0.272 \pm 0.008 \pm 0.006)\%$$

$$B[D^+ \to \pi^0 \mu^+ \nu] = (0.350 \pm 0.011 \pm 0.010)\%$$

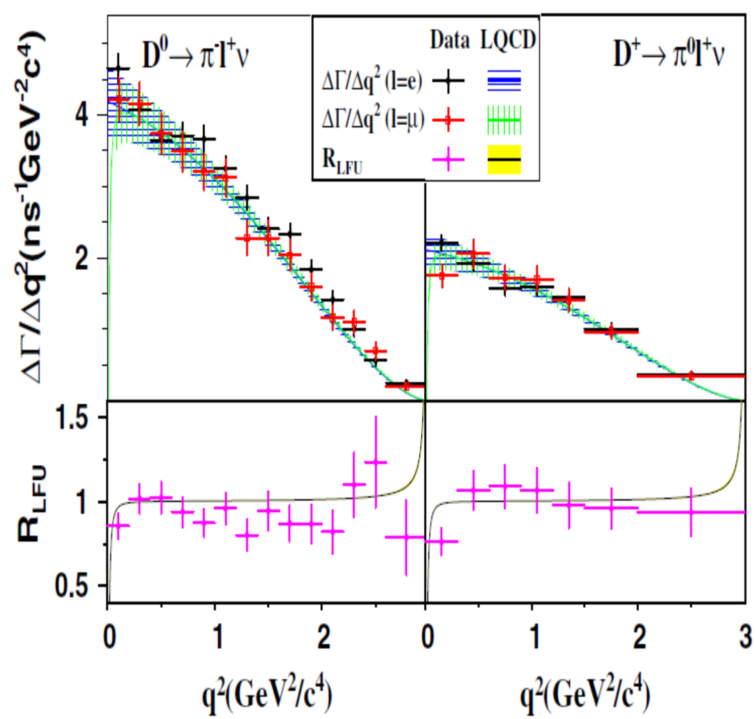
SM prediction: 0.985

(1.7σ)

$$R_{D\pi} = \frac{\Gamma[D^0 \to \pi^- \mu^+ \nu]}{\Gamma[D^0 \to \pi^- e^+ \nu]} = 0.922 \pm 0.030 \pm 0.022$$

(0.5σ)

$$R_{D\pi} = \frac{\Gamma[D^+ \to \pi^0 \mu^+ \nu]}{\Gamma[D^+ \to \pi^0 e^+ \nu]} = 0.964 \pm 0.037 \pm 0.026$$



$D^{0(+)} \to \bar{K} l^+ \nu_l$衰变中的LFU检验

EPJC76(2016)369

$$B[D^+ \to \overline{K}^0 \mu^+ v] = (8.72 \pm 0.07 \pm 0.18)\%$$

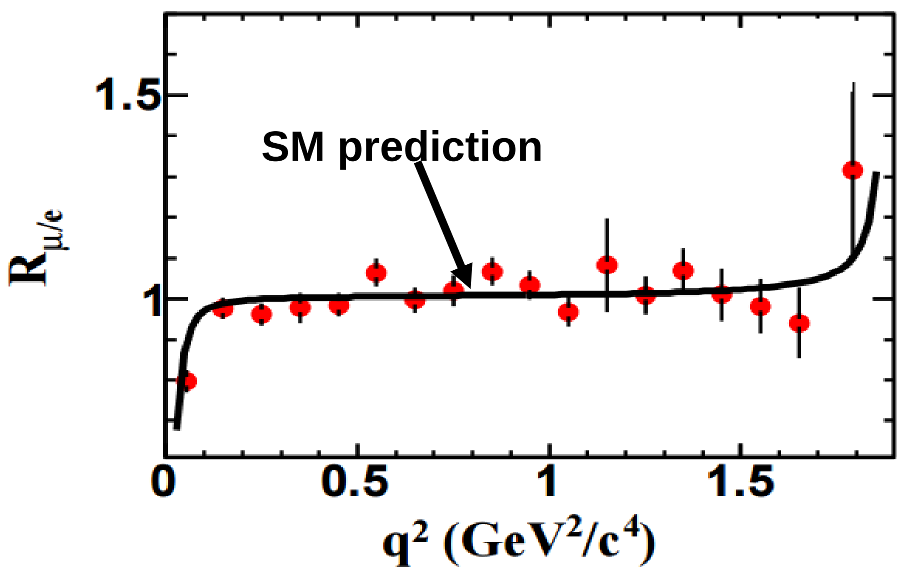
PRL122(2019)011804

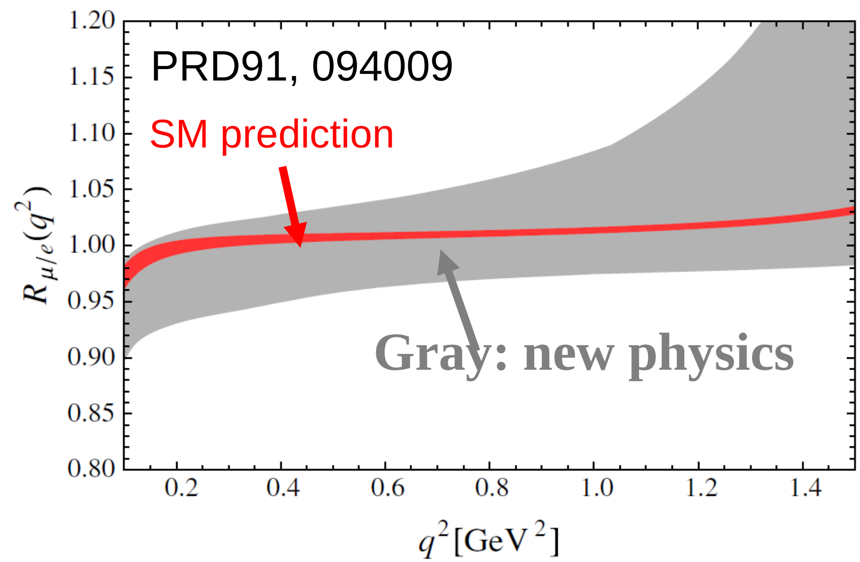
$$B[D^0 \to K^- \mu^+ v] = (3.413 \pm 0.019 \pm 0.035)\%$$

SM prediction: 0.97

$$R_{DK} = \frac{\Gamma[D^+ \to \overline{K}^0 \mu^+ v]}{\Gamma[D^+ \to \overline{K}^0 e^+ v]} = 1.00 \pm 0.03$$

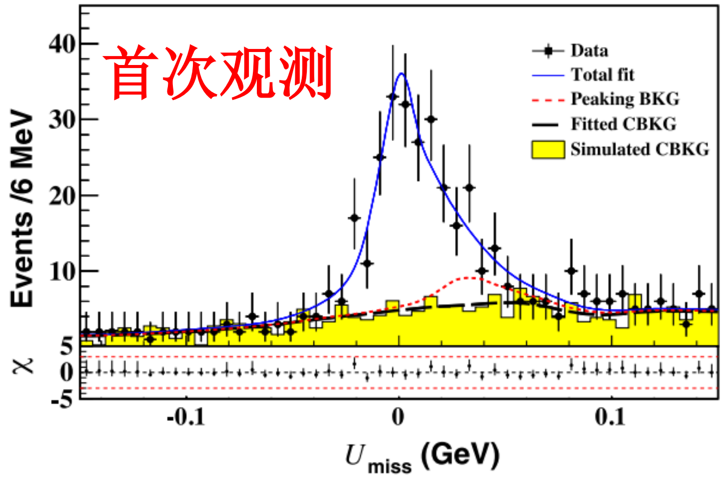
$$R_{DK} = \frac{\Gamma[D^0 \to K^- \mu^+ v]}{\Gamma[D^0 \to K^- e^+ v]} = 0.978 \pm 0.007 \pm 0.012$$



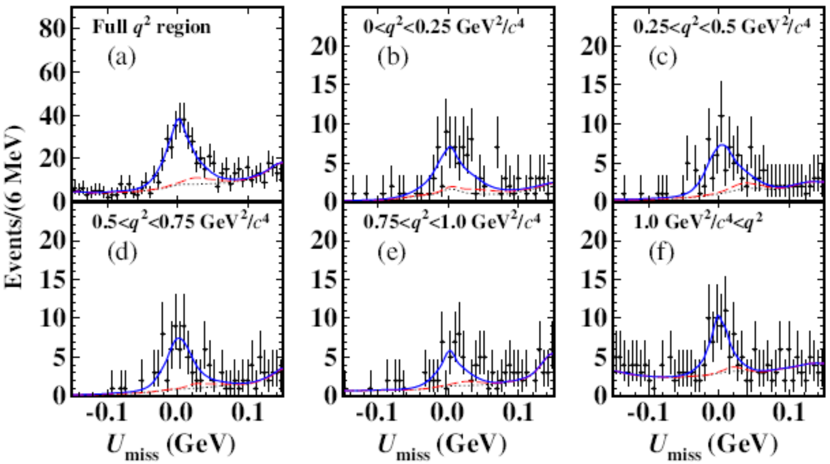


$D^+ \to (\omega,\eta)l^+\nu_l$的首次观测及LFU检验

PRD101(2020)072005



首次观测 PRL124(2020)231801



$$\mathrm{B}[D^+ \to \omega\mu^+ v] = (0.177 \pm 0.018 \pm 0.011)\%$$

$$\mathrm{B}[D^+ \to \eta\mu^+ v] = (0.104 \pm 0.010 \pm 0.005)\%$$

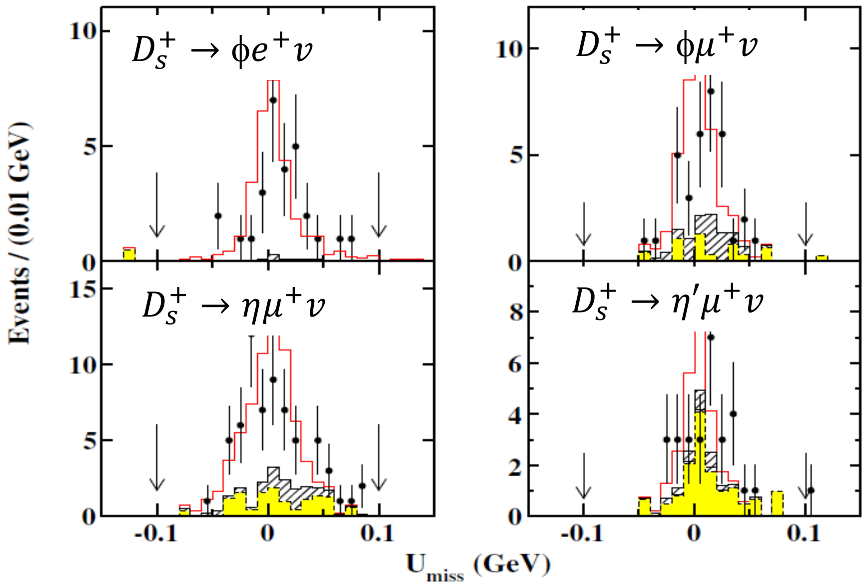
$$\mathrm{R}_{D\omega} = \frac{\Gamma[D^+ \to \omega\mu^+ v]}{\Gamma[D^+ \to \omega e^+ v]} = 1.05 \pm 0.14$$

$$\mathrm{R}_{D\eta} = \frac{\Gamma[D^+ \to \eta\mu^+ v]}{\Gamma[D^+ \to \eta e^+ v]} = 0.91 \pm 0.13$$

SM prediction: 0.93-0.96

$D_s^+ \to (\phi, \eta, \eta')l^+\nu_l$衰变的LFU检验

PRD97(2018)012006 **0.48 fb^{-1} @4.009 GeV**



首次测量:

$$B[D_s^+ \to \phi\mu^+ v] = (1.94 \pm 0.53 \pm 0.09)\%$$

$$B[D_s^+ \to \eta\mu^+ v] = (2.42 \pm 0.46 \pm 0.11)\%$$

$$B[D_s^+ \to \eta'\mu^+ v] = (1.06 \pm 0.54 \pm 0.07)\%$$

$$R_{Ds\phi} = \frac{\Gamma[D_s^+ \to \phi\mu^+ v]}{\Gamma[D_s^+ \to \phi e^+ v]} = 0.86 \pm 0.29$$

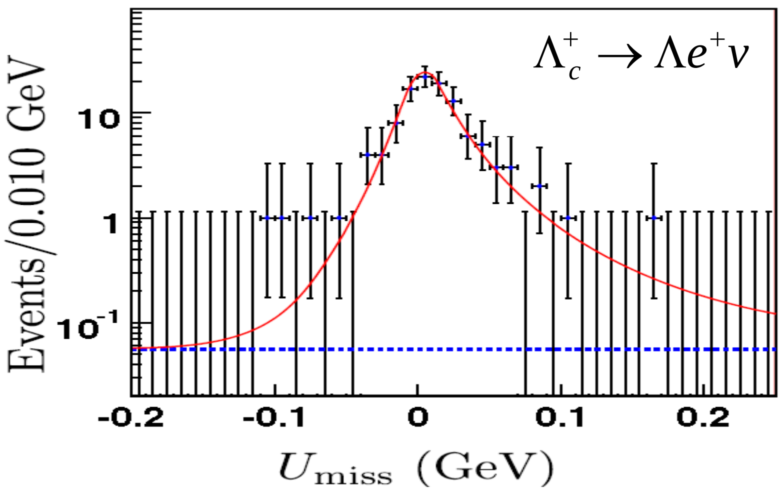
$$R_{Ds\eta} = \frac{\Gamma[D_s^+ \to \eta\mu^+ v]}{\Gamma[D_s^+ \to \eta e^+ v]} = 1.05 \pm 0.24$$

$$R_{Ds\eta'} = \frac{\Gamma[D_s^+ \to \eta'\mu^+ v]}{\Gamma[D_s^+ \to \eta' e^+ v]} = 1.14 \pm 0.68$$

$\Lambda_c^+ \to \Lambda l^+ \nu_l$衰变的LFU检验

0.567 fb^{-1} @4.6 GeV

PRL115 (2015) 221805



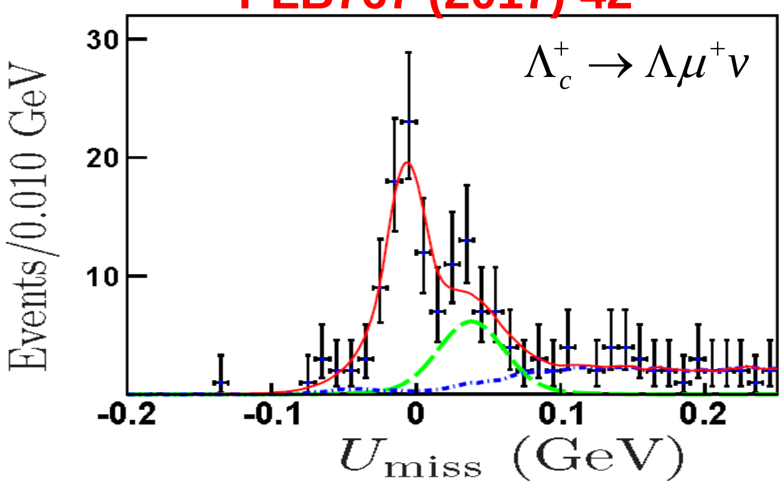
$$B[\Lambda_c^+ \to \Lambda e^+ v] = (3.63 \pm 0.38 \pm 0.20)\%$$

$$B[\Lambda_c^+ \to \Lambda \mu^+ v] = (3.49 \pm 0.46 \pm 0.26)\%$$

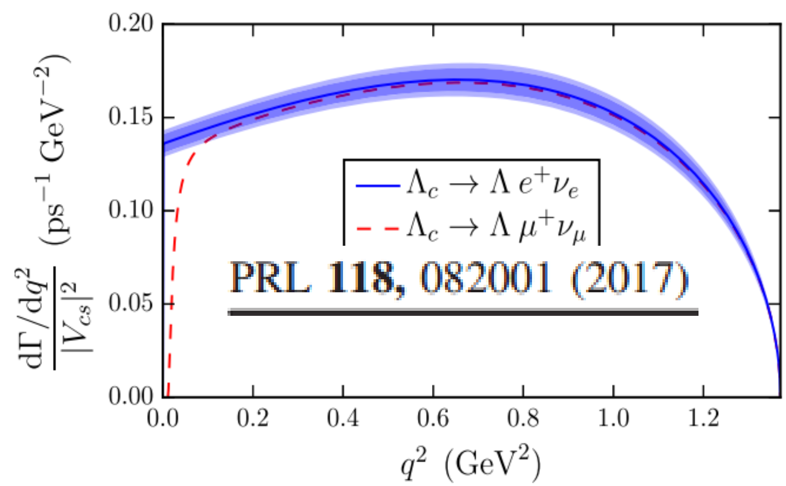
$$R_{\Lambda_c^+ \Lambda} = \frac{\Gamma[\Lambda_c^+ \to \Lambda \mu^+ v]}{\Gamma[\Lambda_c^+ \to \Lambda e^+ v]} = 0.96 \pm 0.16 \pm 0.04$$

Calibrate theoretical calculations: (1.4-9.2)%

PLB767 (2017) 42



Stimulate LQCD calculation



BESIII粲强子遍举μ半轻衰变小结

- **D介子：**

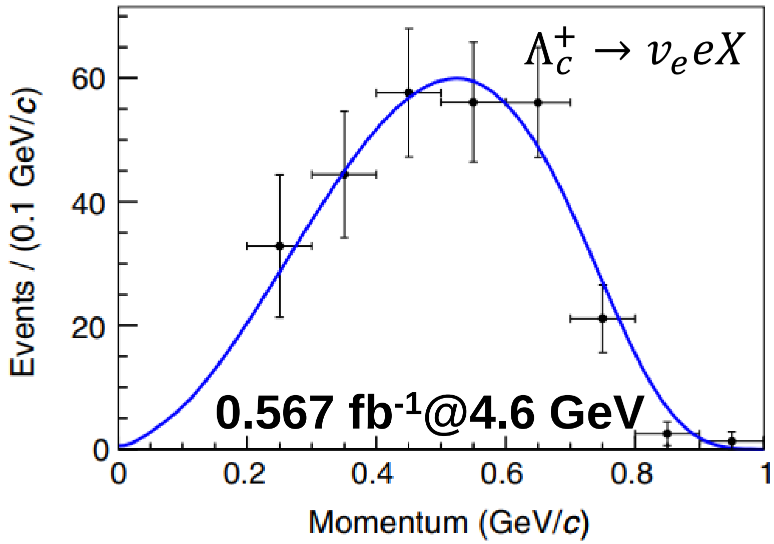
	D^0		D^+		D_s^+	
$c \to s l^+ \nu$	K^-	4%→1.3%	$\bar{K}^0$	7%→2.2%	η	19%[1st.obs]
	K^{*-}	13%[FOCUS]	$\bar{K}^{*0}$	3%[CLEOc]	η'	50%[1stmsr]
					ϕ	27%[1st.obs]
					f_0	Ongoing
$c \to d l^+ \nu$	π⁻	10%→3.7%	π^0	4.3%[1st.obs]	K^0	Ongoing
	ρ^-	10%[1st.obs]	ρ^0	17%[FOCUS]	K^{*0}	NA
			ω	12%[1st.obs]		
			η	11%[1st.obs]		
			η'	NA		

- **Λ_c^+重子：$\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu$精度35→15%**

其他半轻衰变

Λ_c^+和D_s^+单举电子衰变

PRL121(2018)251801

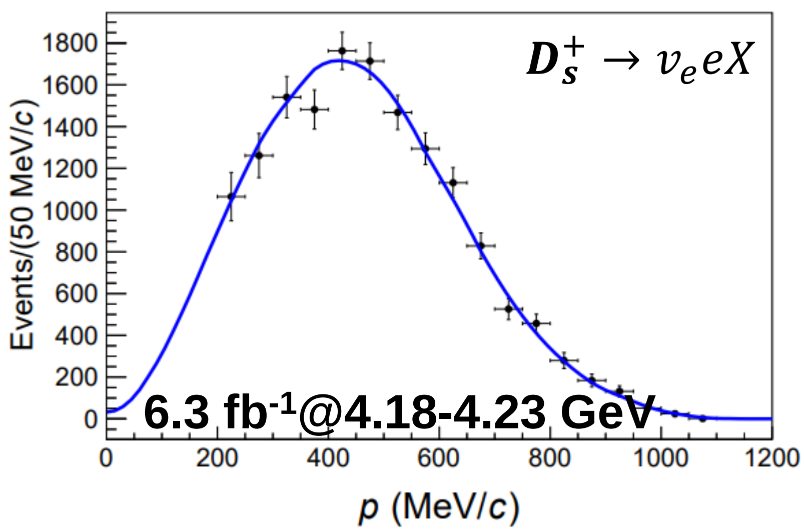


$$B_{\Lambda_c^+\to\nu_e eX} = (3.95 \pm 0.34 \pm 0.09)\%$$

$$B_{\Lambda_c^+\to\Lambda e\nu}/B_{\Lambda_c^+\to\nu_e eX} = (91.9 \pm 12.5 \pm 5.4)\%$$

Result	$\Lambda_c^+ \to X e^+ \nu_e$	$[\Gamma(\Lambda_c^+ \to X e^+ \nu_e)/\Gamma(D \to X e^+ \nu_e)]$
BESIII	3.95 ± 0.35	1.26 ± 0.12
MARK II [11]	4.5 ± 1.7	1.44 ± 0.54
Effective-quark method [8,9]		1.67
Heavy-quark expansion [10]		1.2

arXiv:2104.07311



$$B_{D_s^+\to\nu_e eX} = (6.30 \pm 0.13 \pm 0.10)\%$$

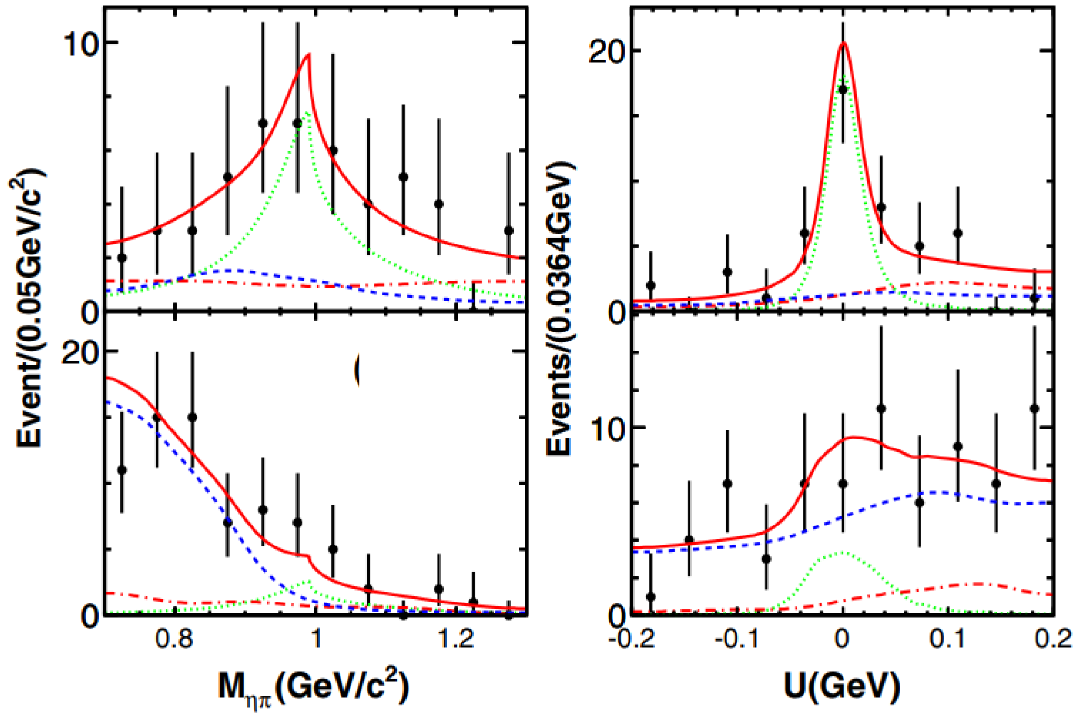
$$\Gamma_{D_s^+\to\nu_e eX}/\Gamma_{D^0\to\nu_e eX} = 0.790 \pm 0.016 \pm 0.020$$

与理论预期0.813[PRD83, 034025]很好一致

$D \to S e^+ \nu_e$型半轻衰变

PRL121(2018)081802

$D^+ \to a_0(980)^0 e^+ \nu [3.0\sigma]$ $D^0 \to a_0(980)^- e^+ \nu [6.5\sigma]$ 首次观测



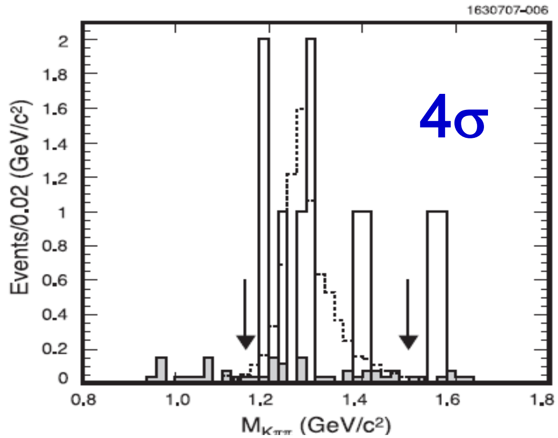
$$B_{D^+ \to a_0(980)^0 e^+ \nu} B_{a_0(980)^0 \to \eta\pi^0} = (1.66^{+0.81}_{-0.66} \pm 0.11) \times 10^{-4}$$

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

$$\frac{\Gamma_{D^0 \to a_0(980)^- e^+ \nu}}{\Gamma_{D^+ \to a_0(980)^0 e^+ \nu}} = 2.05 \pm 0.95 \pm 0.06$$

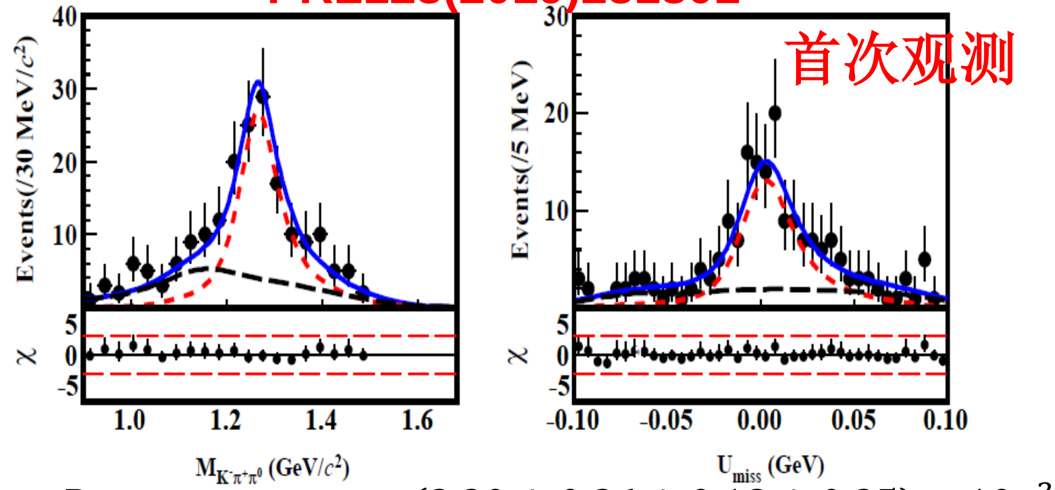
$D \to A e^+ \nu_e$型半轻衰变

CLEOc, PRL99(2007)91801



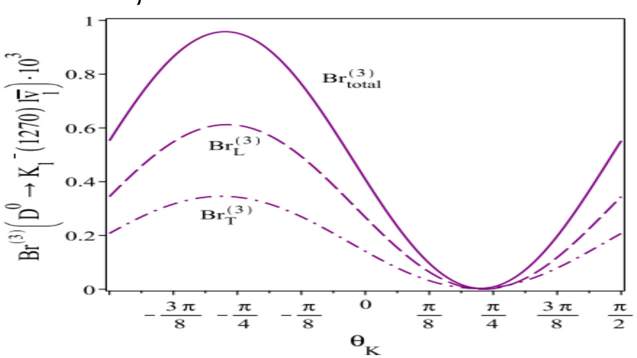
$$B_{D^0 \to K_1(1270)^- e^+ \nu} = (7.6^{+4.1}_{-3.0} \pm 0.6 \pm 0.7) \times 10^{-4}$$

PRL123(2019)231801

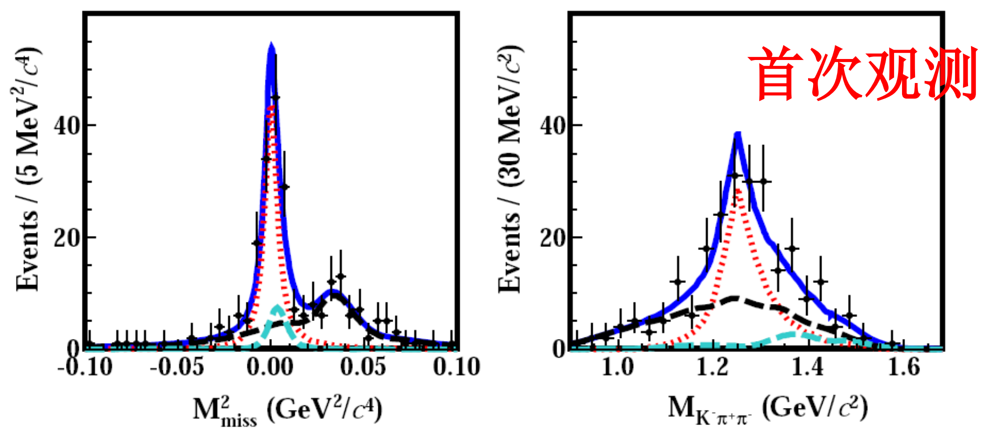


$$B_{D^+ \to \bar{K}_1^0(1270) e^+ \nu} = (2.30 \pm 0.26 \pm 0.18 \pm 0.25) \times 10^{-3}$$

JPG46,105006



arXiv:2102.10850



PRL125,051802

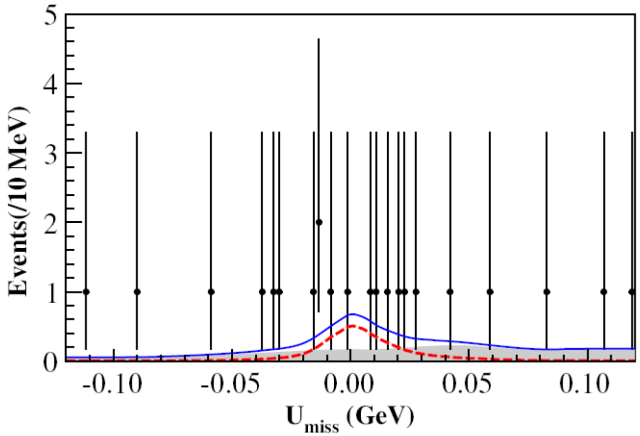
Combined analysis of $D \to \bar{K}_1\ e^+ \nu$ and B→γK$_1$ helps better access photon polarization in b→sγ

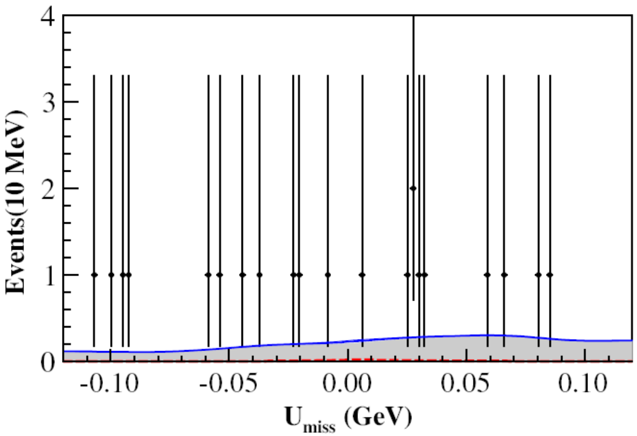
$$B_{D^0 \to K_1(1270)^- e^+ \nu} = (1.09 \pm 0.13 \pm 0.13 \pm 0.12) \times 10^{-3}$$

$$\frac{\Gamma_{D^0 \to K_1(1270)^- e^+ \nu}}{\Gamma_{D^+ \to \bar{K}_1^0(1270) e^+ \nu}} = 1.20 \pm 0.20 \pm 0.15$$

稀有含轻衰变的寻找

PRD101(2020)112005



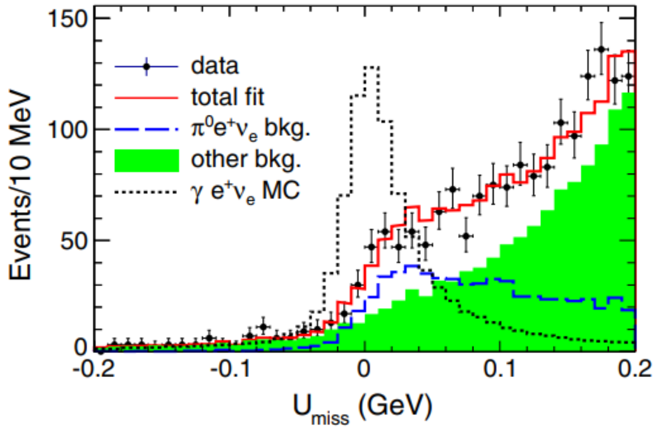


$\mathcal{B}_{D^0\to b_1(1235)^- e^+ \nu}\mathcal{B}_{b_1(1235)^-\to\omega\pi^-} < 1.12\times 10^{-4}$

$\mathcal{B}_{D^+\to b_1(1235)^0 e^+ \nu}\mathcal{B}_{b_1(1235)^0\to\omega\pi^0} < 1.75\times 10^{-4}$

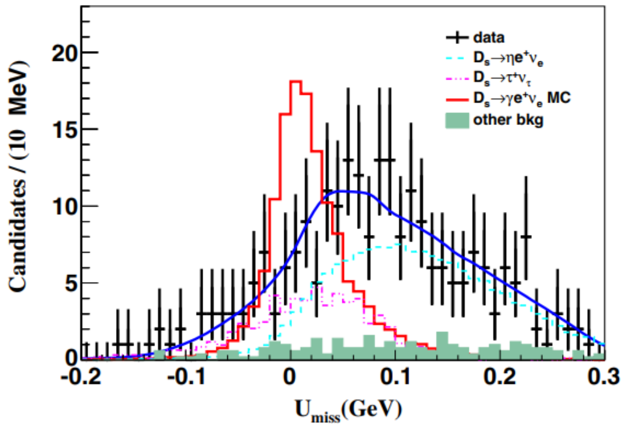
90% CL.

PRD95(2017)071102



$B_{D^+\to\gamma e^+\nu_e} < 3.0\times 10^{-5}$

PRD99(2019)072002

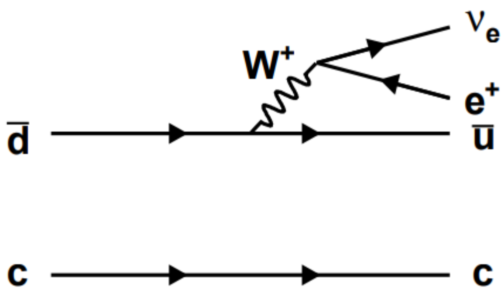


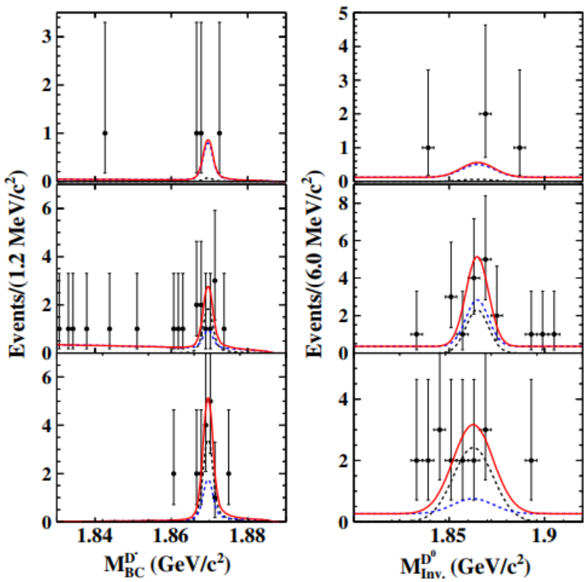
$B_{D_s^+\to\gamma e^+\nu_e} < 1.3\times 10^{-4}$

$E_\gamma > 10$ MeV

稀有含轻衰变的寻找

PRD96(2016)092002



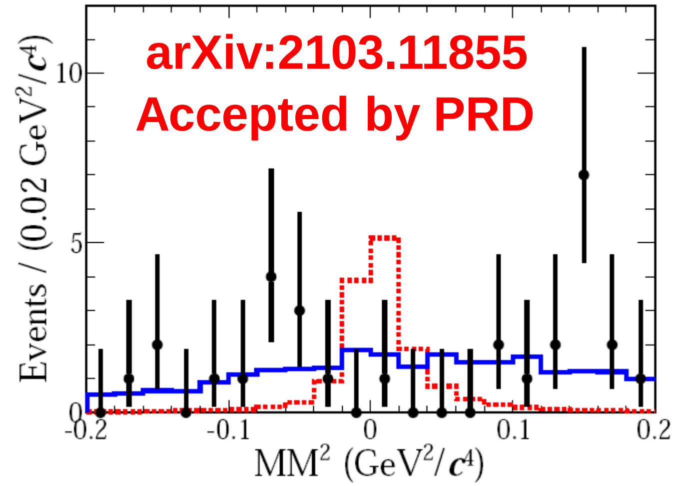


$$B_{D^+\to D^0e^+\nu_e} < 1.0\times10^{-4}$$

90% CL.

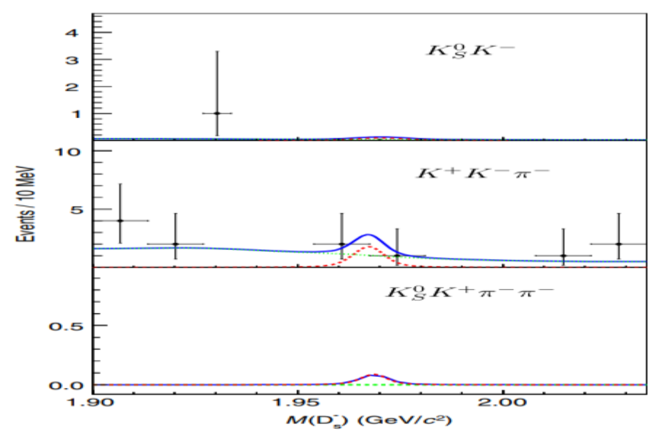
arXiv:2103.11855

Accepted by PRD



$$B_{D_s^+\to a_0(980)^0e^+\nu}B_{a_0(980)^0\to\eta\pi^0}$$
$$< 1.2\times10^{-4}$$

PRD100(2019)112008



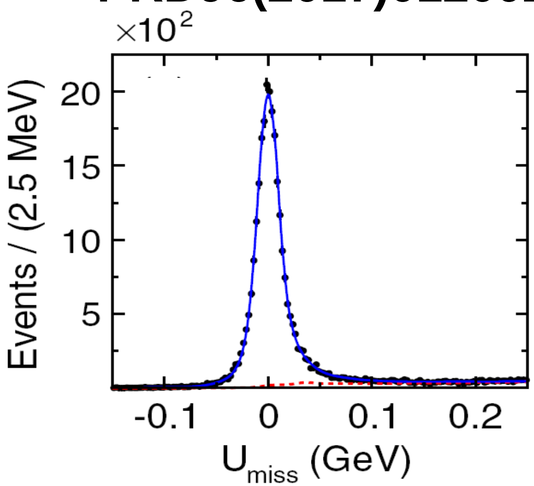
$$B_{D_s^+\to p\bar{p}e^+\nu_e} < 2.0\times10^{-4}$$

$D \to \bar{K} e^+ \nu_e$分支比测量

强子道标记方法

PRD92(2015)072012

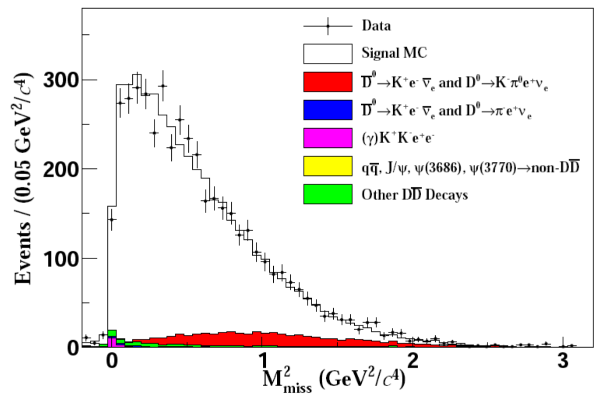
PRD96(2017)012002

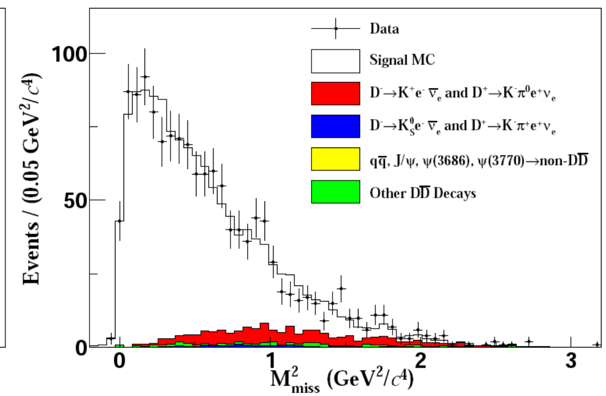


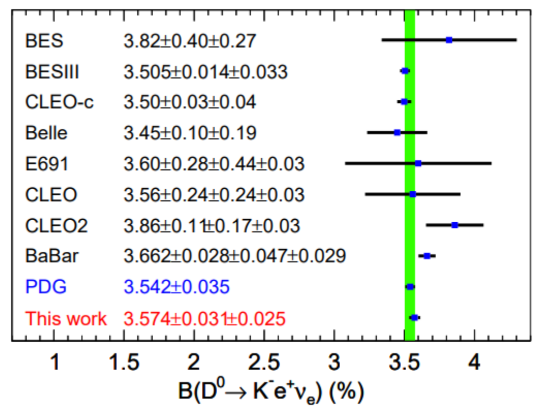
双半轻标记方法

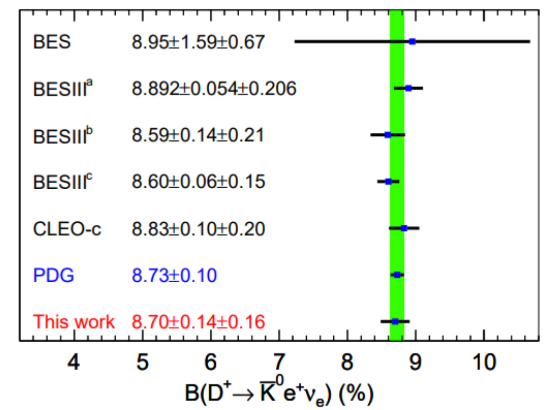
arXiv:2104.08081

$$\mathcal{B}_{\mathrm{SL}} = \sqrt{N_{\mathrm{DT}}/(N_{D\bar{D}} \cdot \epsilon_{\mathrm{DT}})}$$









联合BESIII结果

$$\frac{\bar{\Gamma}_{D^0 \to K^- e^+ \nu_e}}{\bar{\Gamma}_{D^+ \to \bar{K}^0 e^+ \nu_e}} = 1.040 \pm 0.021$$

总结

- BESIII取得世界最高精度的衰变常数、形状因子和$|V_{cs(d)}|$，发现或精密测量了多个含轻衰变，开展了轻子普适性检验

- 基于4.6-4.7 GeV约4.4 fb^{-1}大样本，粲重子衰变研究正积极开展

- 未来2年：计划在3.773 GeV积累到20 fb^{-1}的$D^{0(+)}$样本；另外希望采集更多D_s数据：f_{D+}、f_{Ds}、$|V_{cs(d)}|$、$f^{c\to s(d)}_{+}(0)\to$1%

CPC44(2020)040001

谢谢！

BEPCII

Beam energy: 1.0-2.3 GeV

Optimum energy: 1.89 GeV

Designed luminosity: 1.00×10^{33} $cm^{-2}s^{-1}$

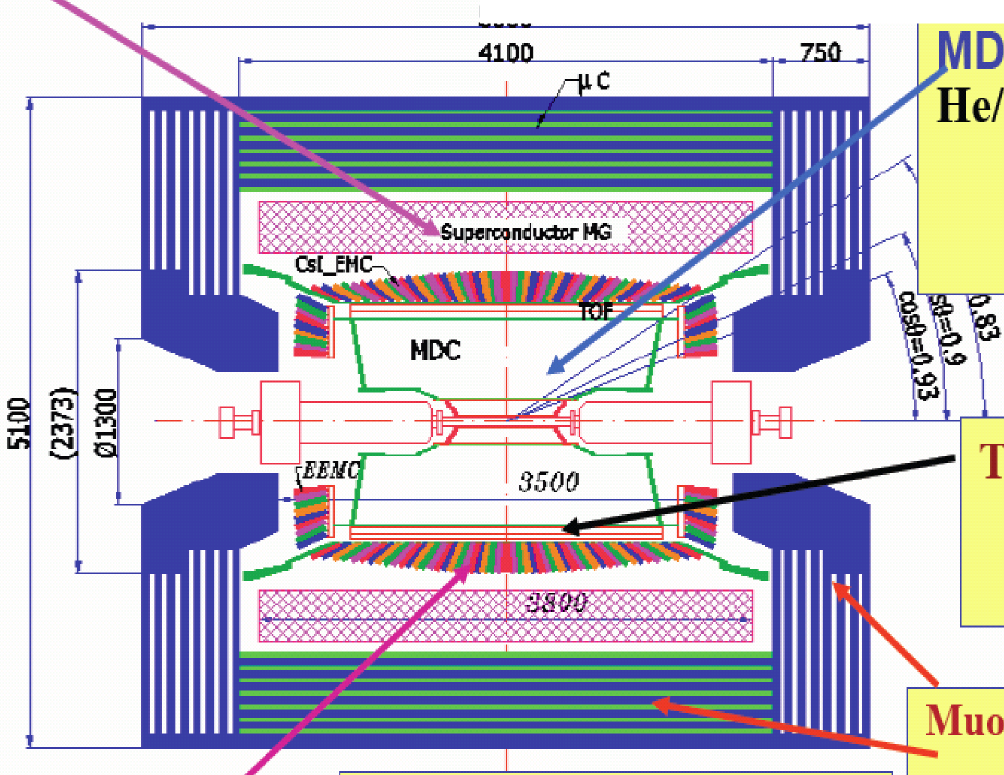
Data taken from: 2009

Achieved luminosity: 1.00×10^{33} $cm^{-2}s^{-1}$

BESIII

Magnet: 1 T Super conducting

Nucl. Instr. Meth. A614, 345 (2010)



MDC: small cell & Gas:
He/C_3H_8 (60/40), 43 layers
σ_{xy}=130 μm
σ_p/p = 0.5% @1GeV
dE/dx=6%

TOF:
σ_T = 100 ps Barrel
110 ps Endcap

Muon ID: 9 layers RPC
8 layers for endcap

EMC: CsI crystal, 28 cm
ΔE/E = 2.5% @1 GeV
σz = 0.6 cm/√E

Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

60 ps for ETOF after upgraded in 2015

其他半轻衰变

- $D^+ \to \bar{K}^0 e^+ \nu_e$ via $\bar{K}^0 \to \pi^+\pi^-$ CPC40, 113001
- $D_s^+ \to l^+ \nu_l$ @ 4.009 GeV PRD94(2016)072004
- $D_s^+ \to \eta^{(\prime)} e^+ \nu_e$ @ 4.009 GeV PRD94(2016)112003