BESIII粲物理研究进展

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中国科学院粒子物理前沿卓越创新中心第五次全体会议

2017年12月1日

粲物理实验主要目标

Leptonic and hadronic decays of charmed hadrons (D^0, D^+, D_s^+ and Λ_c^+) provide ideal test-beds to explore weak and strong effects

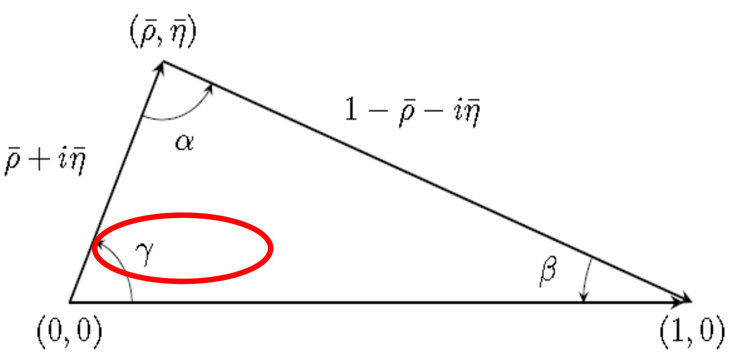
- **$D_{(s)}$ leptonic decays**

  1. **$f_{D(s)+}$, $f^{K(\pi)}_{+}(0)$: better calibrate LQCD**
  2. **$|V_{cs(d)}|$: better test on CKM matrix unitarity**
  3. **LFU test and search of rare SL decays→NP**

$$U = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & \boldsymbol{V_{cb}} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- **$D_{(s)}$ hadronic decays**

  1. **$D^0\bar{D}^0$ mixing parameters and CPV**
  2. **Strong phase difference in D^0 decays: Constrain γ/ϕ_3 measurement in B decays**
  3. **SU(3) symmetry and break effect**



- **Absolute BFs of Λ_c^+ decays**

  No absolute BF measurements of Λ_c^+ using near threshold data before BESIII

主要内容

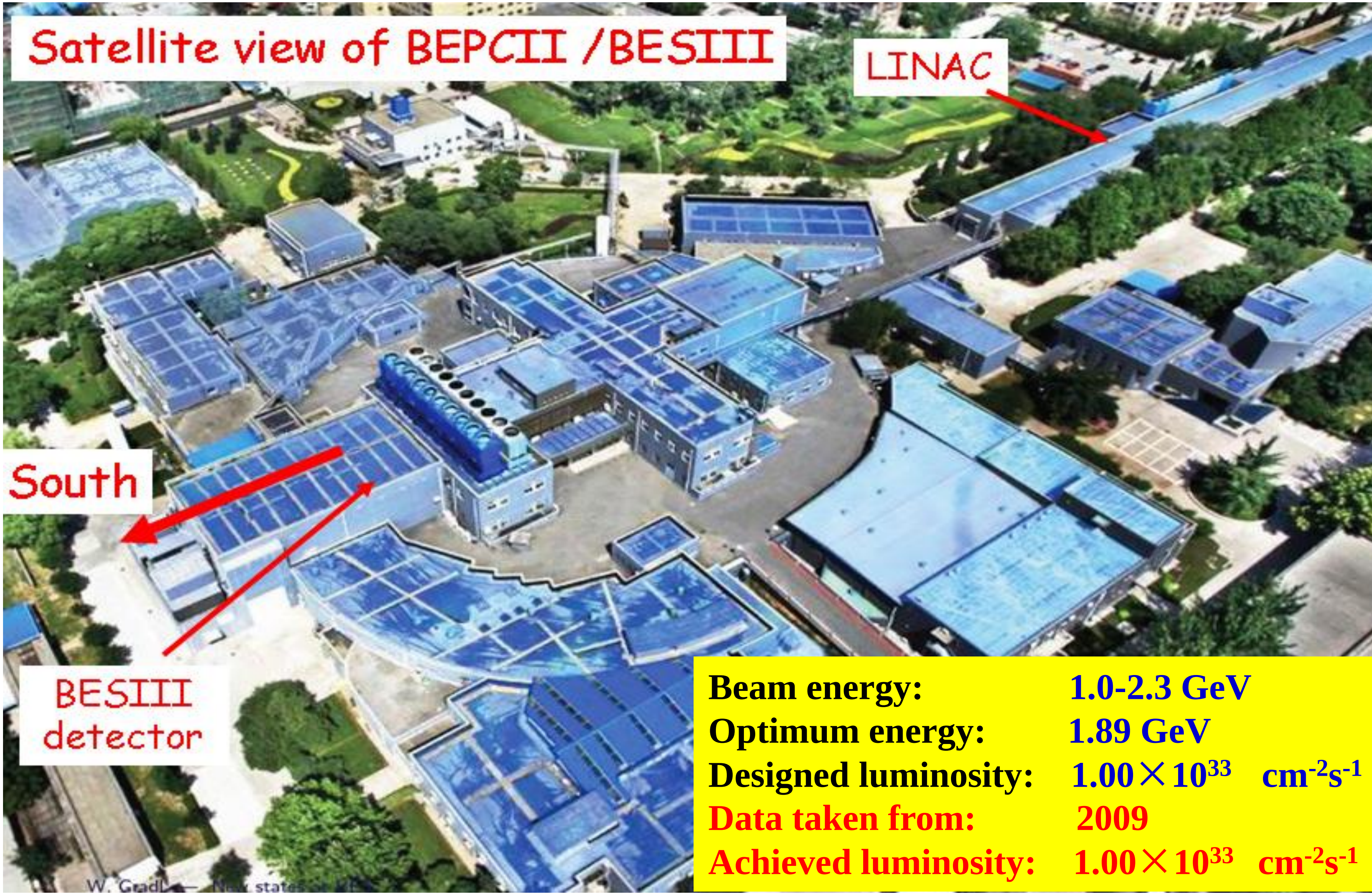
- Charm samples at BESIII
- (Semi-)leptonic $D_{(s)}$ decays
- Hadronic $D_{(s)}$ decays
- Λ_c^+ decays
- Summary

近十年来的粲物理实验

Taking from Longke Li's talk at joint workshop of BESIII/Belle/LHCb at Nankai

Experiment	Machine	C.M	Lumin.		N(D)	efficiency	advantage/disadvantage
CLEO	CESR (e^+e^-)	3.77 GeV	0.8 fb^{-1}		2.9×10^6 $2.3 \times 10^6 (D^\pm)$	~10-30%	☺ extremely clean enviroment ☺ pure D-beam, almost no bkg ☺ quantum coherence ☹ no CM boost, no T-dep analyses
		4.17 GeV	0.6 fb^{-1}		0.6×10^6		
BESIII	BEPC-II (e^+e^-)	3.77 GeV	2.92 fb^{-1}		10.5×10^6 8.4×10^6 $D^{0(+)}$		
		4.18 GeV	3 fb^{-1}	D_s^+	3×10[illegible]		
		4.6 GeV	**0.567 fb^{-1}**	Λ_c^+	★	★★★	
BELLE	KEKB (e^+e^-)	10.58 GeV	1 ab^{-1}		1.3×10^9	~5-10%	☺ clear event environment ☺ high trigger efficiency ☺ high-efficiency detection of neutrals ☺ many high-statistics control samples ☺ time-dependent analysis ☹ smaller cross-section than pp colliders
BaBar	PEP-II (e^+e^-)	10.58 GeV	0.5 ab^{-1}		6.5×10^8 ★★	★★	
CDF II	Tevatron ($p\bar{p}$)	1.96 TeV	9.6 fb^{-1}		1.3×10^{11}	<0.5%	☺ large production cross-section ☺ large boost: excellent time resolution ☹ dedicated trigger required ☹ hard to do neutrals and neutrinos
LHCb	LHC (pp)	7 TeV 8 TeV	1.0 fb^{-1} 2.0 fb^{-1}		5.0×10^{12} ★★★	★	

BEPCII加速器

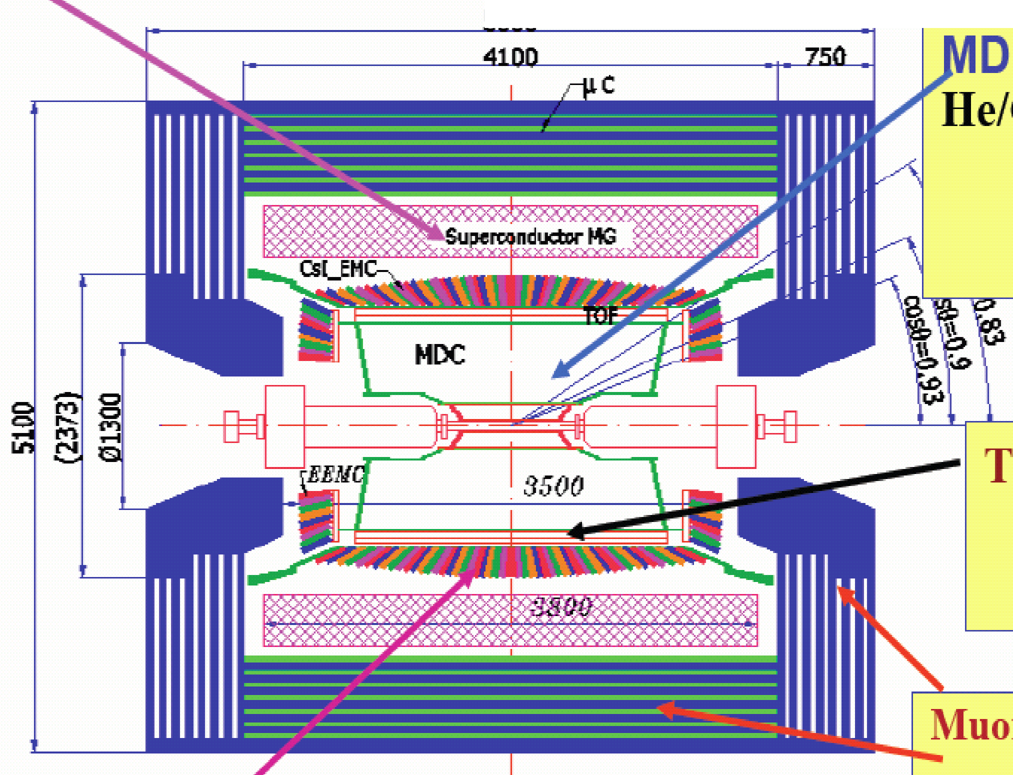


Beam energy: 1.0-2.3 GeV
Optimum energy: 1.89 GeV
Designed luminosity: 1.00×10^{33} $cm^{-2}s^{-1}$
Data taken from: 2009
Achieved luminosity: 1.00×10^{33} $cm^{-2}s^{-1}$

BESIII探测器

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

Magnet: 1 T Super conducting



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

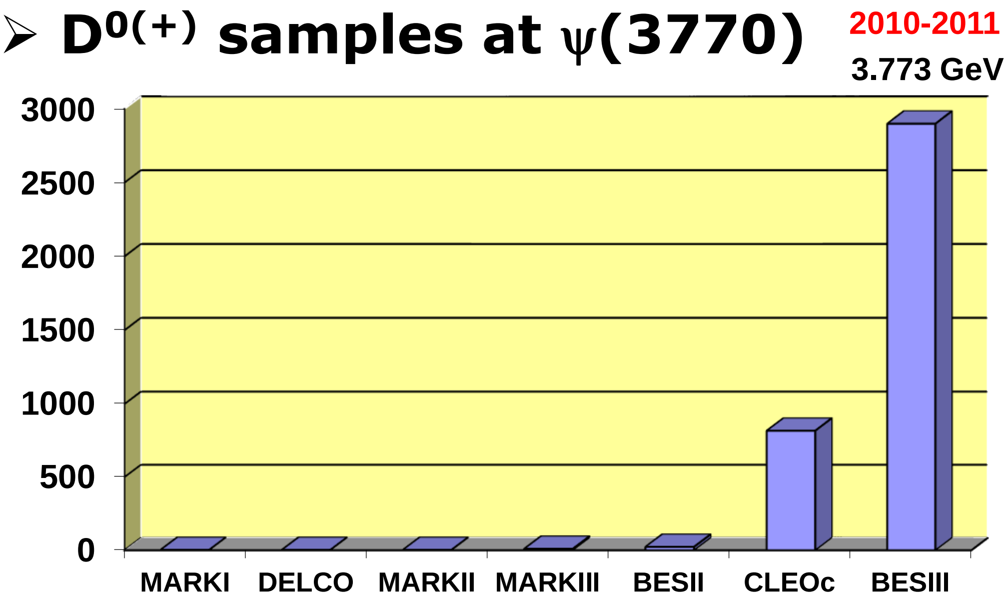
EMC: CsI crystal, 28 cm
ΔE/E = 2.5% @1 GeV
σz = 0.6 cm/√E

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

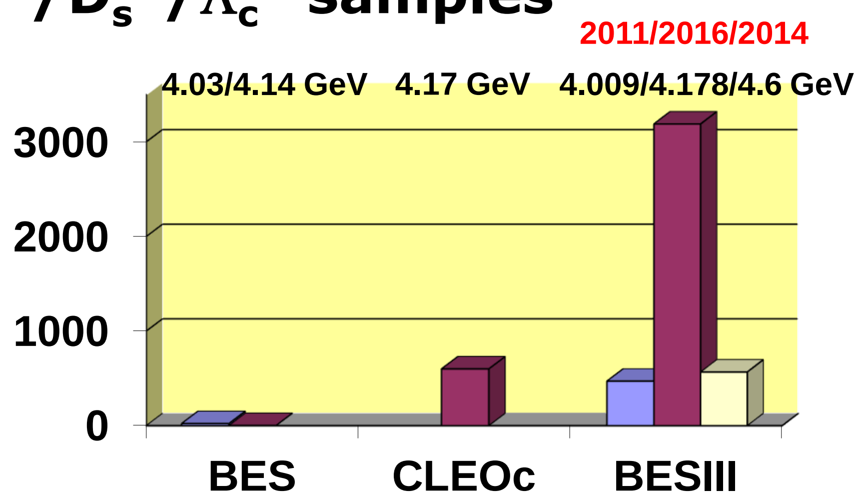
2015年ETOF升级改造后，分辨好于70 ps

BESIII $D^{0(+)}$, D_s^+和Λ_c^+ 样本

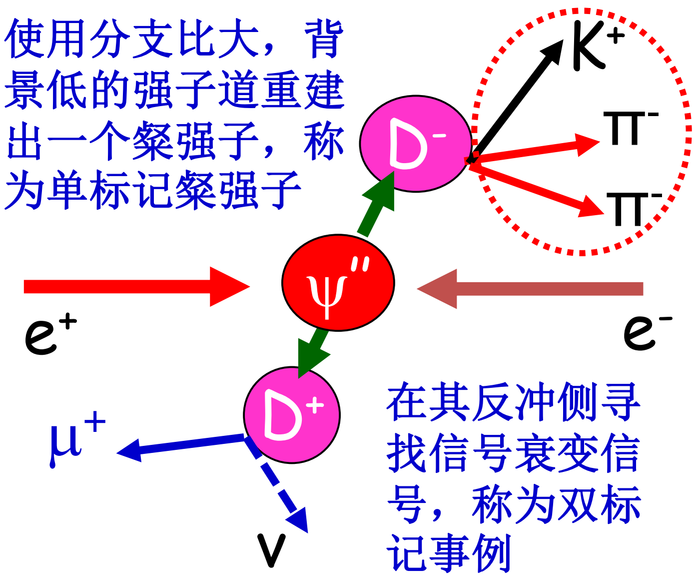
- $D^{0(+)}$ samples at $\psi(3770)$



- $D_s^+/D_s^+/\Lambda_c^+$ samples



使用分支比大，背景低的强子道重建出一个粲强子，称为单标记粲强子



在其反冲侧寻找信号衰变信号，称为双标记事例

联合单、双标记粲强子，测定绝对分支比，研究动力学机制

$$N^i_{\mathrm{ST}} = 2 \times N_{D\bar{D}} \times B^i_{\mathrm{ST}} \times \varepsilon^i_{\mathrm{ST}}$$

$$N^i_{\mathrm{DT}} = 2 \times N_{D\bar{D}} \times B^i_{\mathrm{ST}} \times B_{\mathrm{sig}} \times \varepsilon^i_{\mathrm{ST\ vs.sig}}$$

$$B_{\mathrm{sig}} = \frac{N^{\mathrm{tot}}_{\mathrm{DT}}}{N^{\mathrm{tot}}_{\mathrm{ST}} \times \bar{\varepsilon}_{\mathrm{sig}}}$$

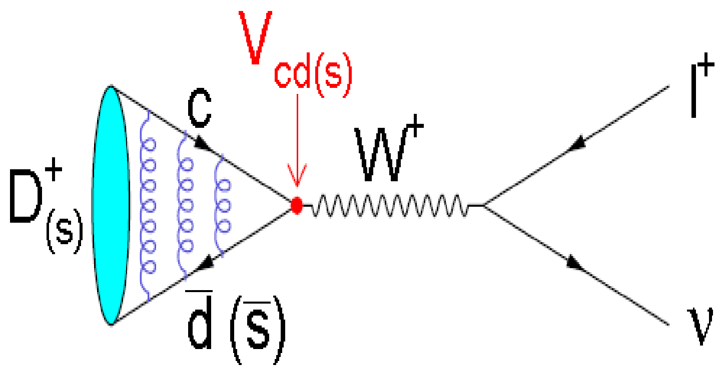
$$\bar{\varepsilon}_{\mathrm{sig}} = \sum_{i=1}^{N} (N^i_{\mathrm{ST}} \times \varepsilon^i_{\mathrm{ST\ vs.sig}} / \varepsilon^i_{\mathrm{ST}}) / \sum_{i=1}^{N} N^i_{\mathrm{ST}}$$

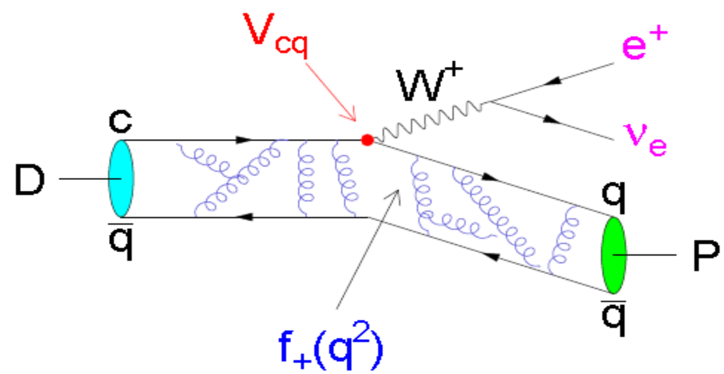
$D_{(s)}$轻子和半轻衰变

- l^+v
- P(赝标介子)l^+v → Some selected topics
- V(矢量介子)l^+v
- S(标量介子)l^+v
- Rare SL decays

$D_{(s)}$轻子和半轻衰变

在理论上，粲介子(半)轻子衰变中的强、弱作用能够被简单分离，分别用衰变常数(形状因子)、夸克混合矩阵元$|V_{cs(d)}|$的函数





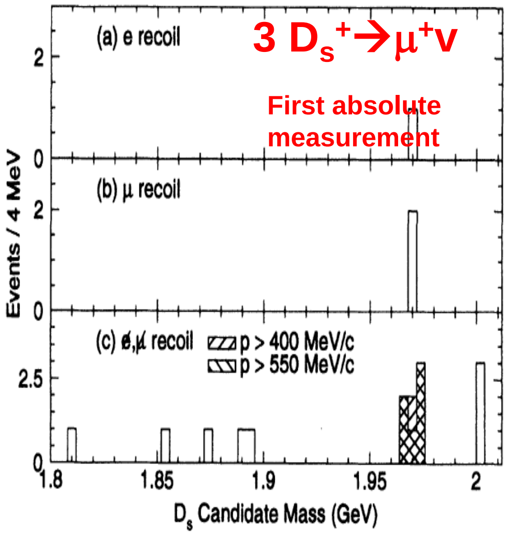
$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f_{D^+_{(s)}}^2}{8\pi}|V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}}\left(1-\frac{m_\ell^2}{m_{D^+_{(s)}}^2}\right)^2$$

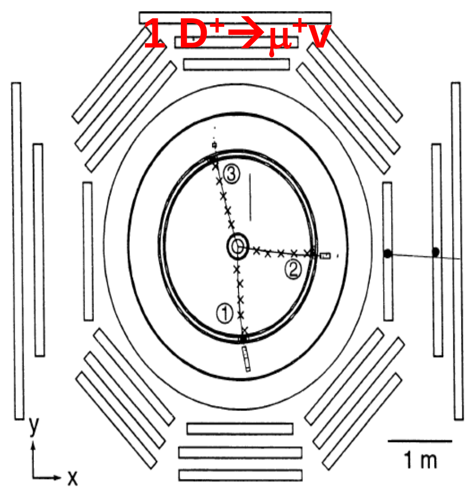
$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2|V_{cd(s)}|^2}{24\pi^3}p^3|f_+(q^2)|^2$$

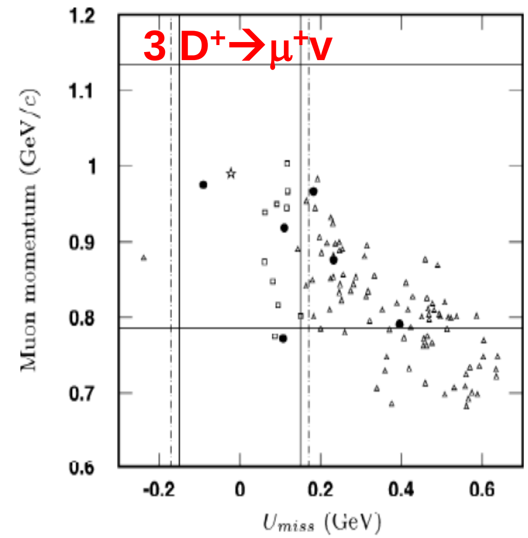
- 改进的$f_{D(s)+}$, $f_+^{D\to K(\pi)}(q^2)$能够在更高精度上检验格点QCD的计算
- 格点QCD计算精度的改善为精密测量$|V_{cs(d)}|$创造了条件

BESI/II上$D_{(s)}^+ \to l^+\nu$的寻找

22.3 pb^{-1} at 4.03 GeV	22.3 pb^{-1} at 4.03 GeV	33 pb^{-1} around $\psi(3770)$
PRL74(1995)4599	PLB429(1998)188	PLB610(2005)183







$$f_{D_s^+} = (430^{+150+40}_{-130-40})\ \text{MeV}$$

$$f_{D^+} = (300^{+180+80}_{-150-40})\ \text{MeV}$$

$$f_{D^+} = (371^{+129}_{-119} \pm 25)\ \text{MeV}$$

BESI | **BESI** | **BESII**

$D^+ \to l^+ \nu$最新实验进展

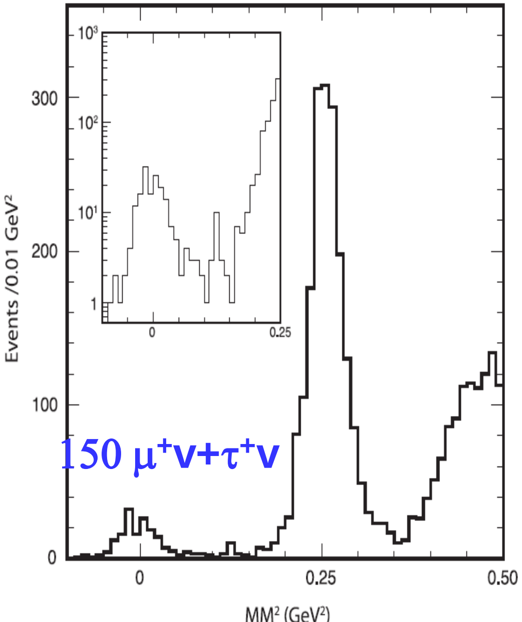
818 pb^{-1} at $\psi(3770)$
(2004–2008)

2.93 fb^{-1} data@ 3.773 GeV

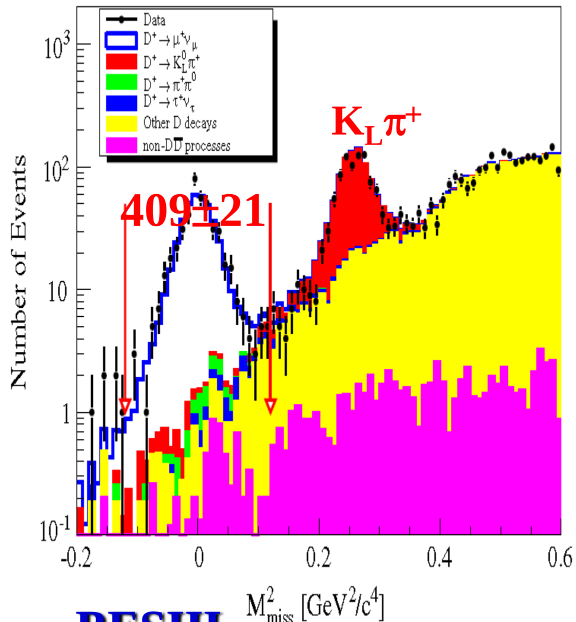
BESIII获得世界上单次测量精度最高的f_{D+}和$|V_{cd}|$

PRD78(2008)052003

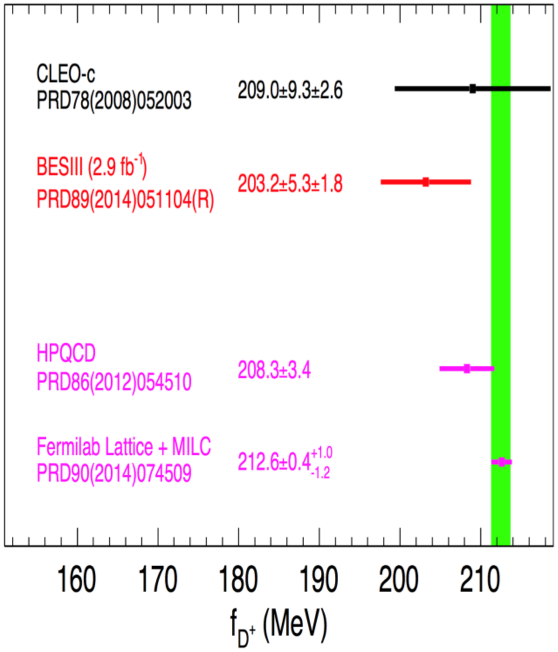
PRD89(2014)051104R



CLEO



BESIII



$B_{D+\to\mu+\nu}$=(3.82±0.32±0.09)×10^{-4}

f_{D+}=205.8±7.5±2.5 MeV

$B_{D+\to\mu+\nu}$=(3.71±0.19±0.06)×10^{-4}

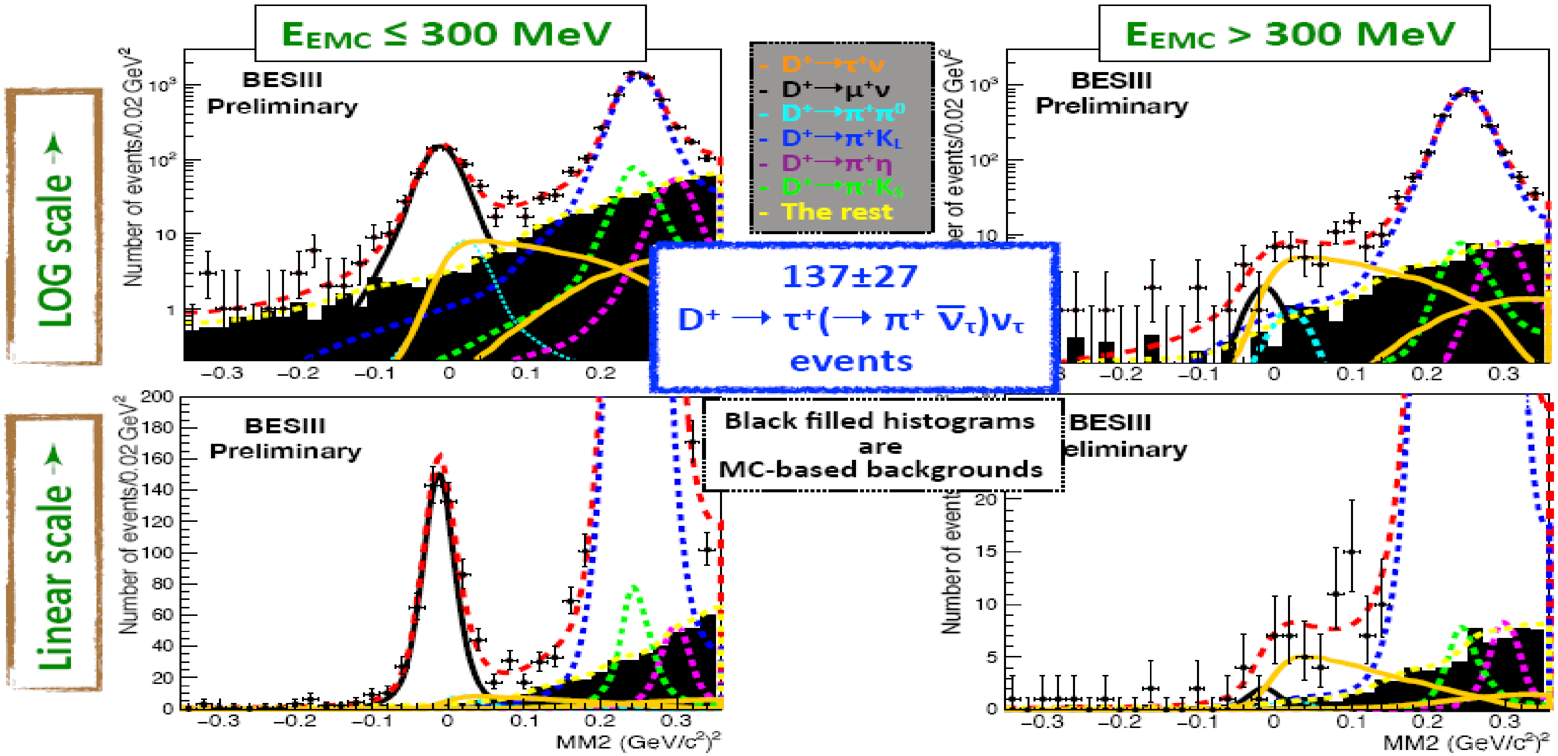
f_{D+}=(203.2±5.3±1.8) MeV

$|V_{cd}|$=0.2210±0.0058±0.0047

20 fb^{-1} 数据能够将f_{D+}统计误差降至1%

BESIII上$D^+ \to \tau^+ \nu$的寻找

Fitting to DATA



4σ

$$B[D^+ \to \tau^+ \nu] = (1.20 \pm 0.24_{stat.}) \times 10^{-3}$$

$$R \equiv \frac{\Gamma(D^+ \to \tau^+ \nu)}{\Gamma(D^+ \to \mu^+ \nu)} = \frac{m_{\tau^+}^2 \left(1 - \frac{m_{\tau^+}^2}{M_{D^+}^2}\right)^2}{m_{\mu^+}^2 \left(1 - \frac{m_{\mu^+}^2}{M_{D^+}^2}\right)^2}$$

SM prediction: 2.66

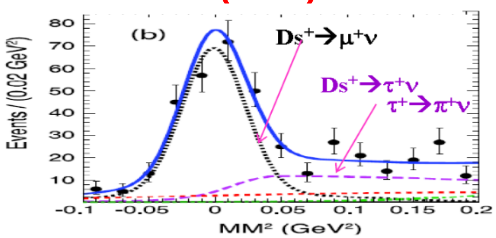
BESIII: 3.21±0.64

已有$D_s^+ \to l^+\nu$实验测量

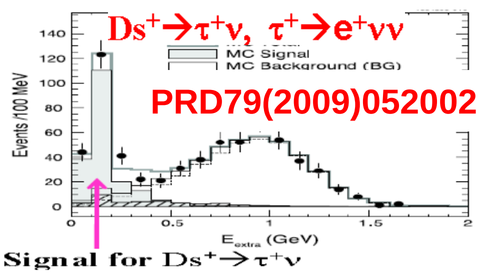
In the past 30 years, $D_s^+ \to l^+\nu$ has been studied by WA75, CLEOII, E653, BESI, L3, OPAL, ALPHA, CLEO-c, BELLE, Babar

- $D_s^{*+}D_s^-$, 600 pb^{-1} @ 4.17 GeV [697 $l^+\nu$]

PRD79(2009)052001

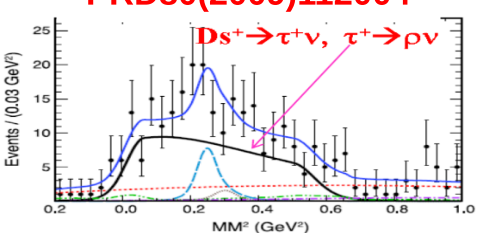


f_{Ds+}=263.3±8.2±1.9 MeV



f_{Ds+}=252.2±11.1±5.2 MeV

PRD80(2009)112004

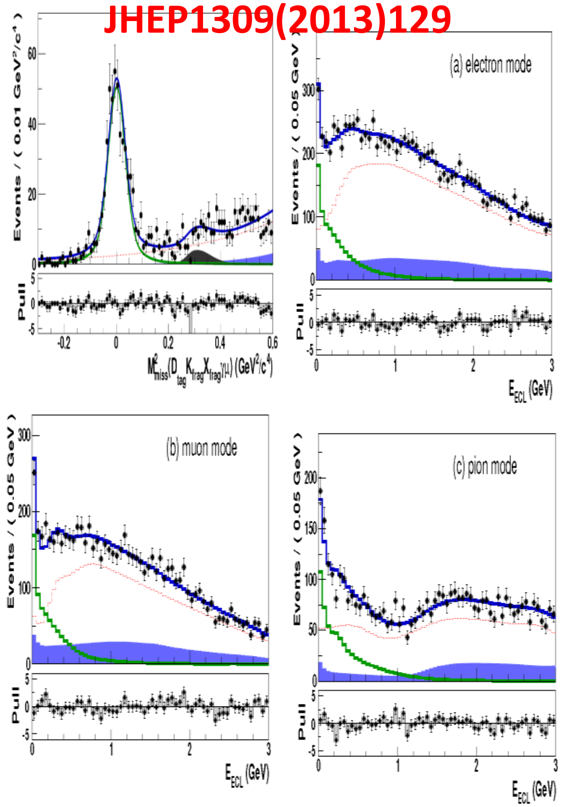


f_{Ds+}=257.8±13.3±5.2 MeV

- Belle, 913 fb^{-1} at 10.58 GeV [2698 $l^+\nu$]

$$e^+e^- \to DKXD_s^{*-}$$

JHEP1309(2013)129

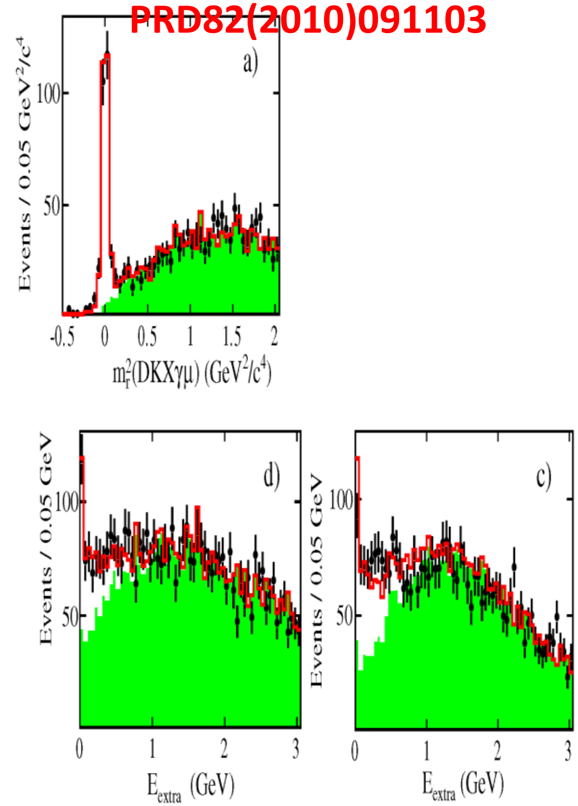


f_{Ds+}=255.5±4.2±5.1 MeV

- Babar, 521 fb^{-1} at 10.58 GeV [1023 $l^+\nu$]

$$e^+e^- \to DKXD_s^{*-}$$

PRD82(2010)091103



f_{Ds+}=258.6±6.4±7.5 MeV

f_{D+}, f_{Ds+}和f_{D+}:f_{Ds+}比较(2014)

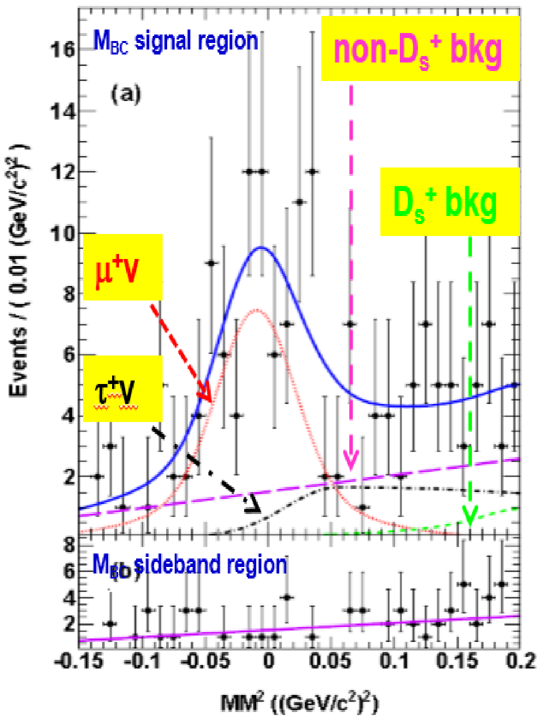
	Experiments	Femilab Lattice+MILC (2014)		HPQCD (2012)	
	Averaged	Expected	Δ	Expected	Δ
f_{D+}(MeV)	203.9±4.7	$212.6\pm0.4^{+1.0}_{-1.2}$	1.8σ	208.3±3.4	0.8σ
f_{Ds+}(MeV)	256.9±4.4	$249.0\pm0.3^{+1.1}_{-1.5}$	1.7σ	246.0±3.6	1.4σ
f_{D+}:f_{Ds+}	1.260±0.036	$1.1712\pm0.0010^{+0.0029}_{-0.0032}$	2.5σ	1.187±0.013	1.9σ

- 实验精度远小于理论精度(f_{D+}, f_{Ds+}, f_{D+}:f_{Ds}达0.5%,0.5%,0.3%)
- 实验与理论预期f_{D+}, f_{Ds+}, f_{D+}:f_{Ds+}偏离约2σ
- 期待实验上更精确的结果

BESIII $D^+ \to l^+ v$研究进展

0.48 fb^{-1} data@4.01 GeV

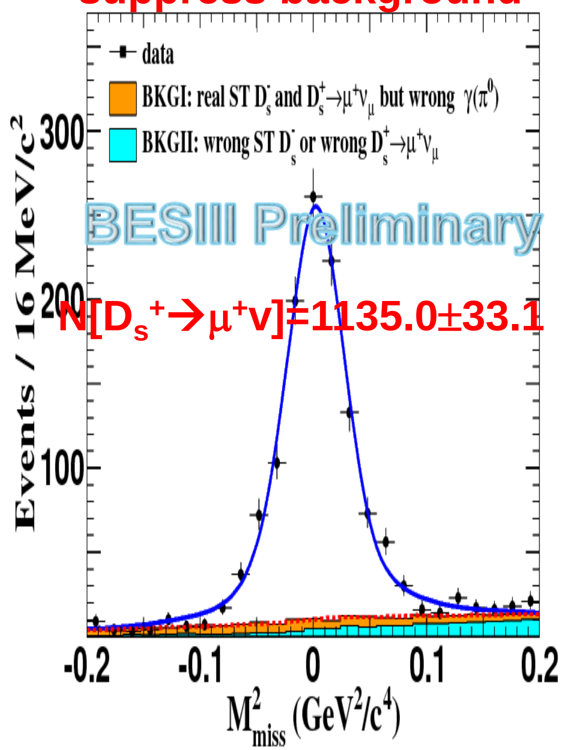
PRD94(2016)072004



f_{Ds+}=(241.0±16.3±6.6) MeV

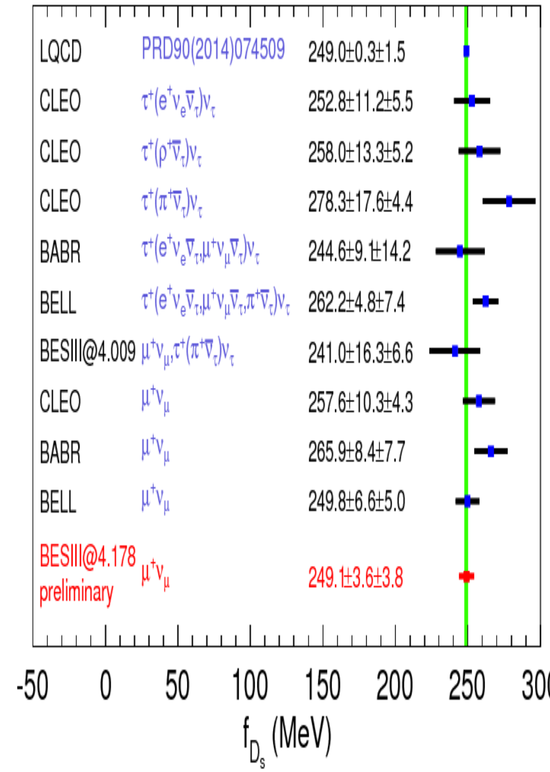
3.19 fb^{-1} data@4.178 GeV

Use μ counter to suppress background



$f_{Ds}|V_{cs}|$=242.5±3.5±3.7 MeV

BESIII获得世界上单次测量精度最高的f_{Ds+}和$|V_{cs}|$

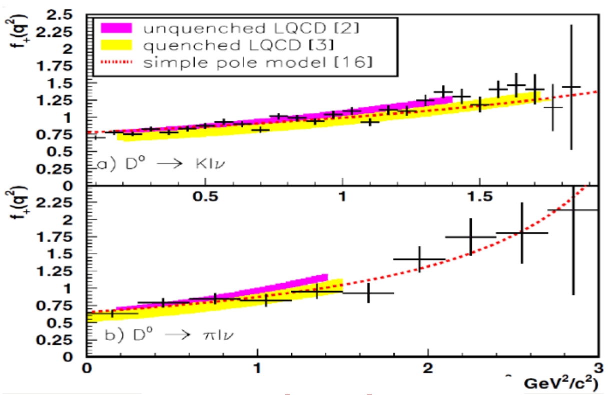


BESIII f_{Ds+}精度达2%，联合$\tau^+ v$研究，能够降至1.5%水平

已有D→K(π)l⁺v实验测量

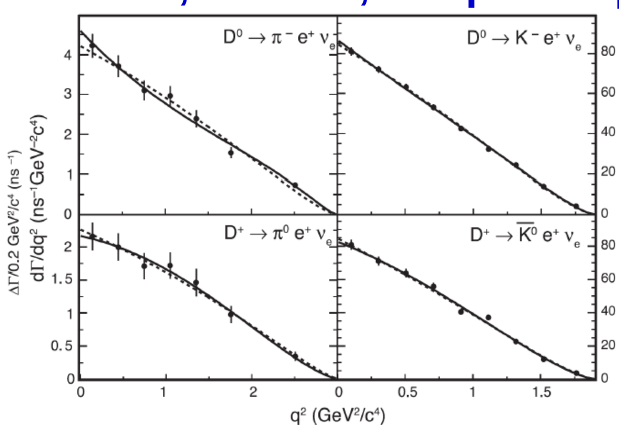
In the past 30 years, studies of D→K(π)l⁺v were made by MARKIII, E691, CLEO, CLEOII, BESII, FOCUS, BELLE, Babar and CLEO-c

- **BELLE, 282 fb^{-1} at 10.58 GeV**



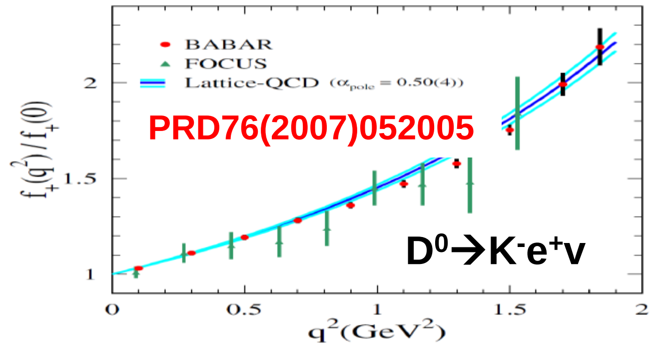
PRL97(2006)061804

- **2004-2009, CLEO-c, 818 pb^{-1} at ψ''**



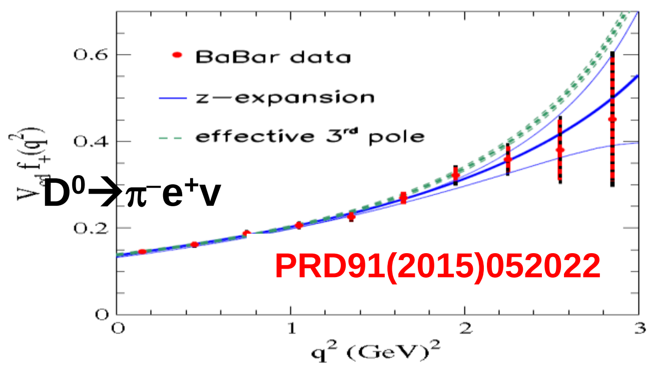
PRD80(2009)032005

- **Babar, 75 fb^{-1} at 10.58 GeV**



PRD76(2007)052005

- **Babar, 347.2 fb^{-1} at 10.58 GeV**

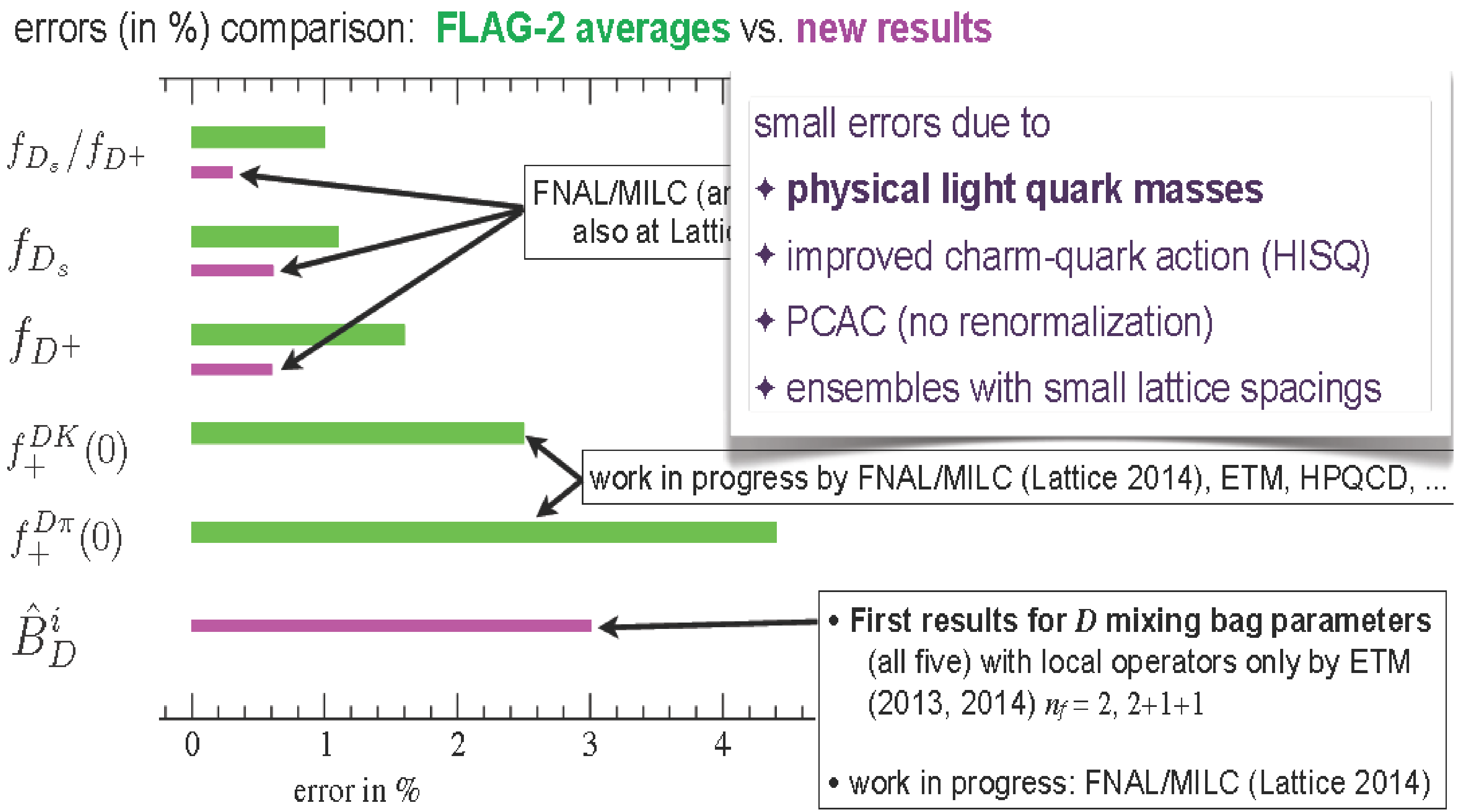


PRD91(2015)052022

Before 2010, the LQCD calculated $f_+^{D\to K(\pi)}(0)$ precision is at 10% level, thus limiting $|V_{cs(d)}|$ measurement

格点QCD计算取得重要进展

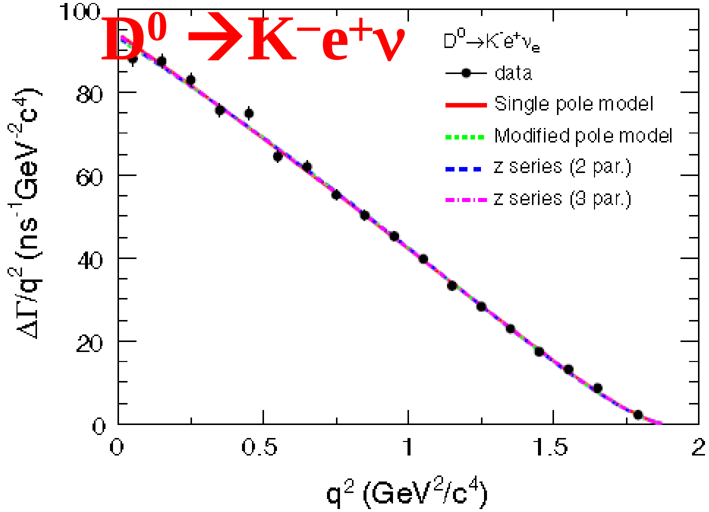
Taking from Aida X. El-Khadra's talk at Beauty2014

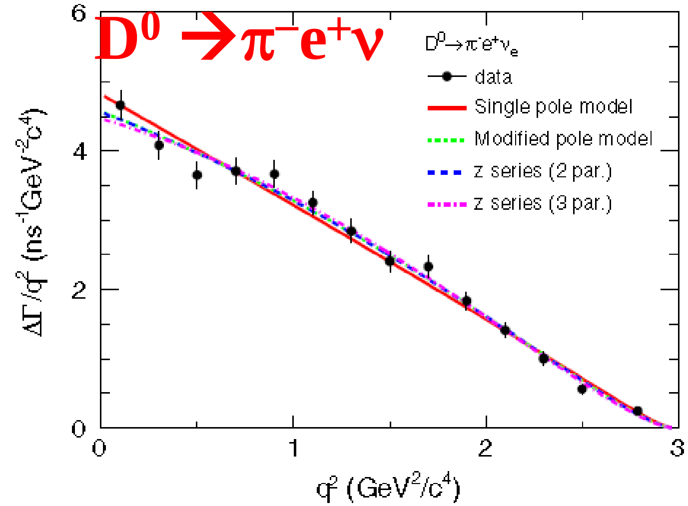


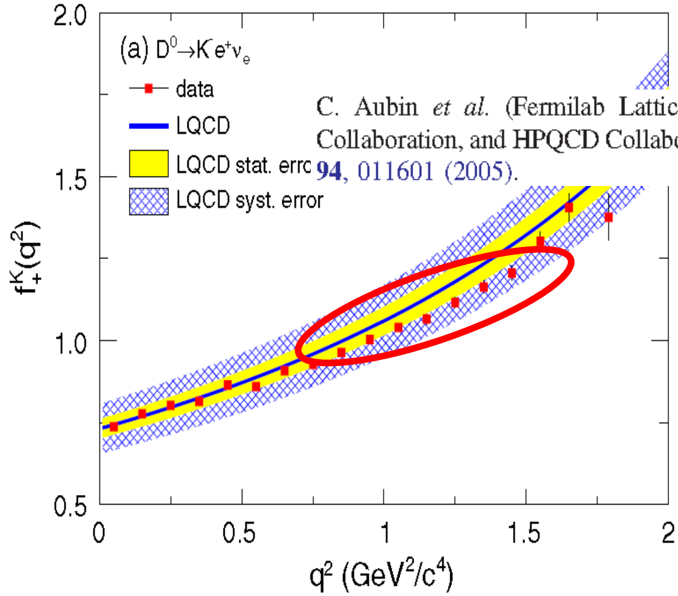
review by C. Bouchard @ Lattice 2014

BESIII更好检验了LQCD计算的$f_{+}^{D\to K(\pi)}(q^2)$

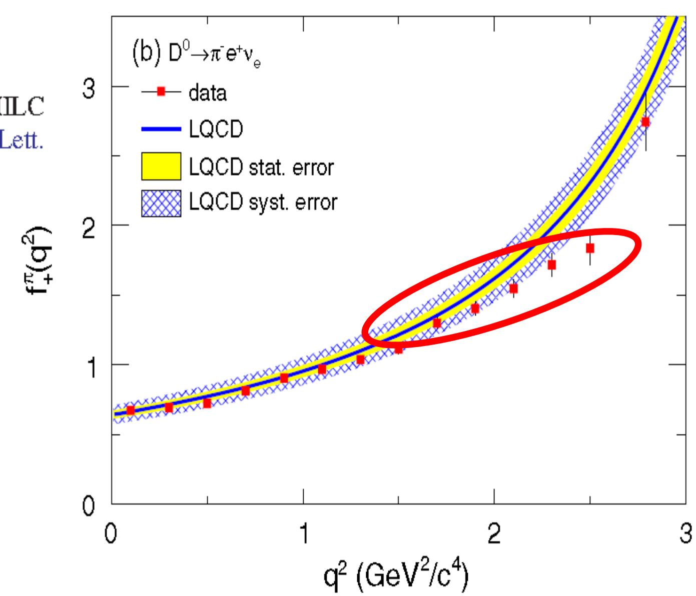
BESIII, PRD92(2015)072012



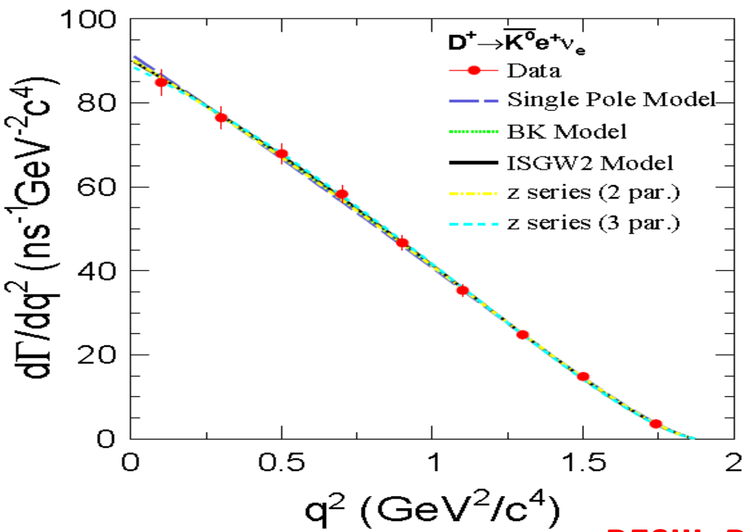


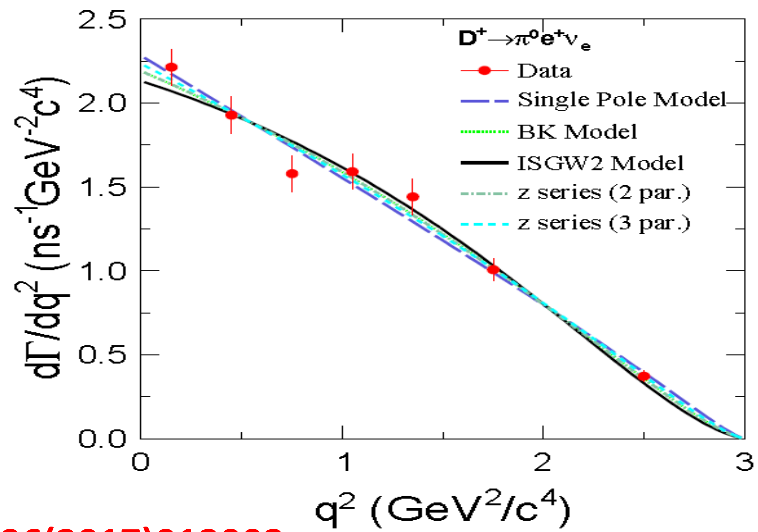


C. Aubin *et al.* (Fermilab Lattice Collaboration, MILC Collaboration, and HPQCD Collaboration), Phys. Rev. Lett. **94**, 011601 (2005).

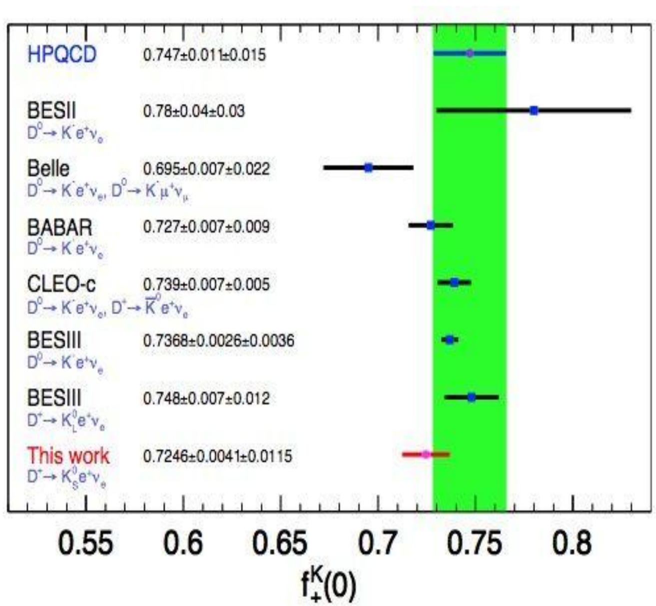


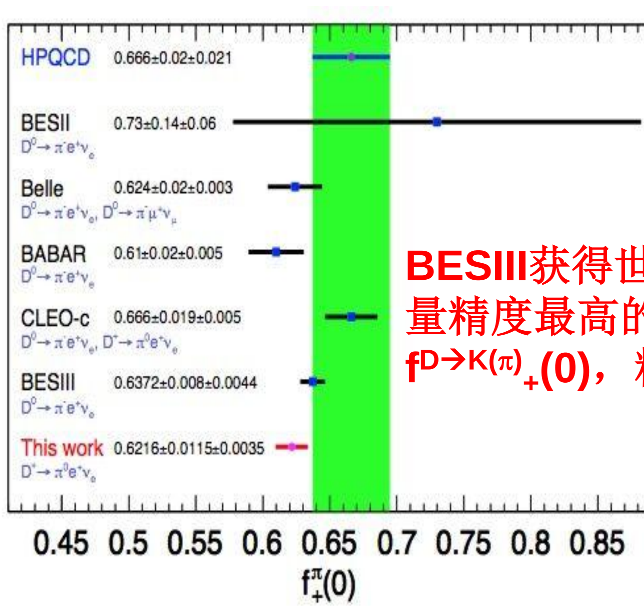
形状因子$f^{D\to K(\pi)}_{+}(0)$的比较





BESIII, PRD96(2017)012002

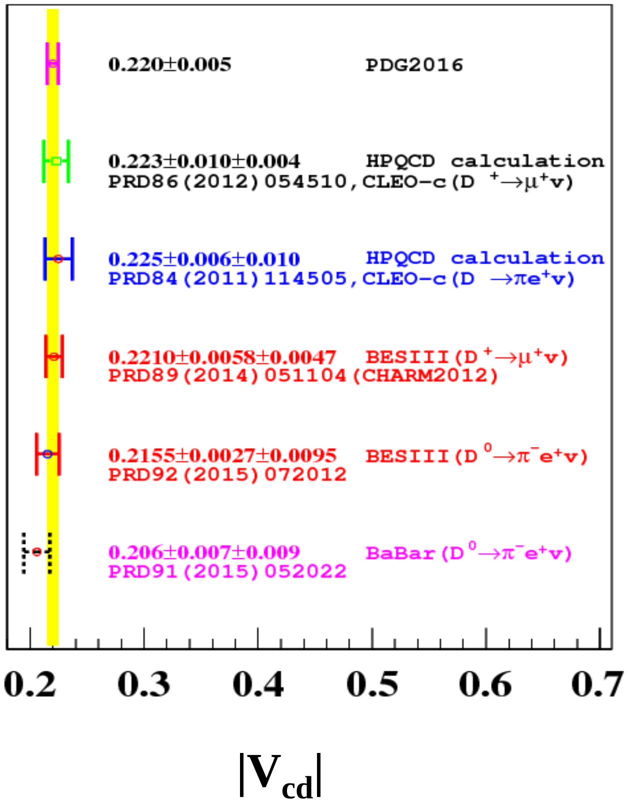


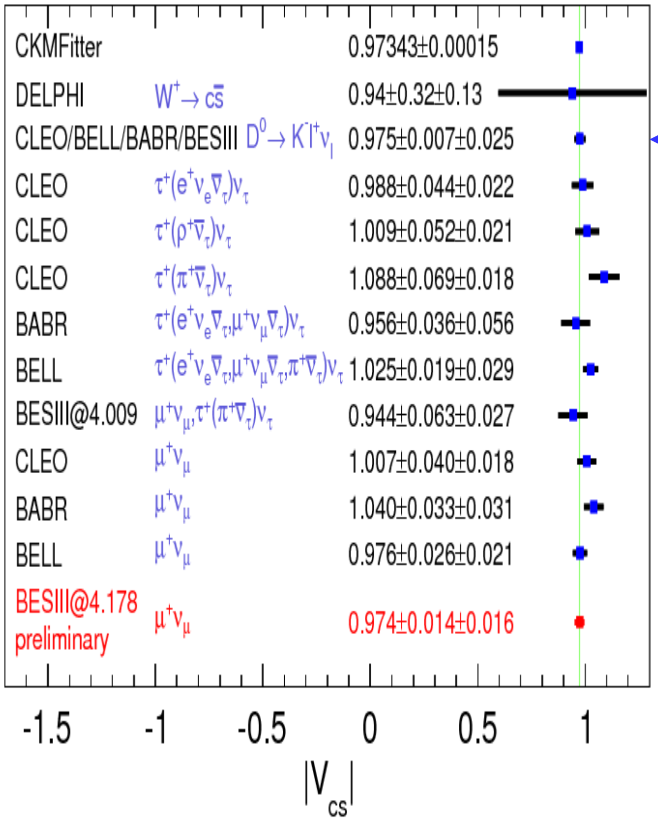


BESIII获得世界上单次测量精度最高的形状因子$f^{D\to K(\pi)}_{+}(0)$，精度好于1%

BESIII获得最高精度的$|V_{cs(d)}|$

- 纯轻方法　$f_{D(s)+}|V_{cd(s)}|$ → $|V_{cd(s)}|$
- 半轻方法　$f^{D\to K(\pi)}_{+}(0)|V_{cs(d)}|$ → $|V_{cs(d)}|$



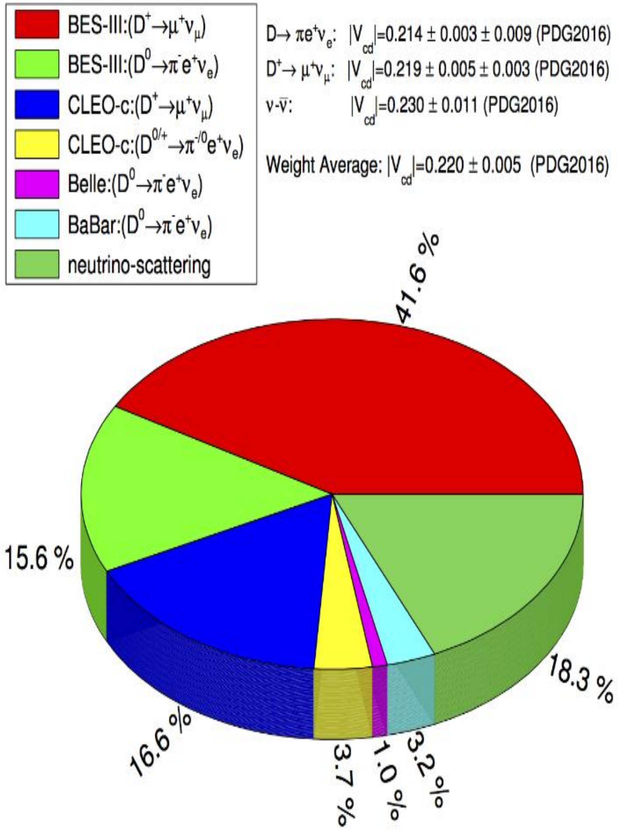


Taken from PDG, and the SL method suffers about 2.4% error from LQCD

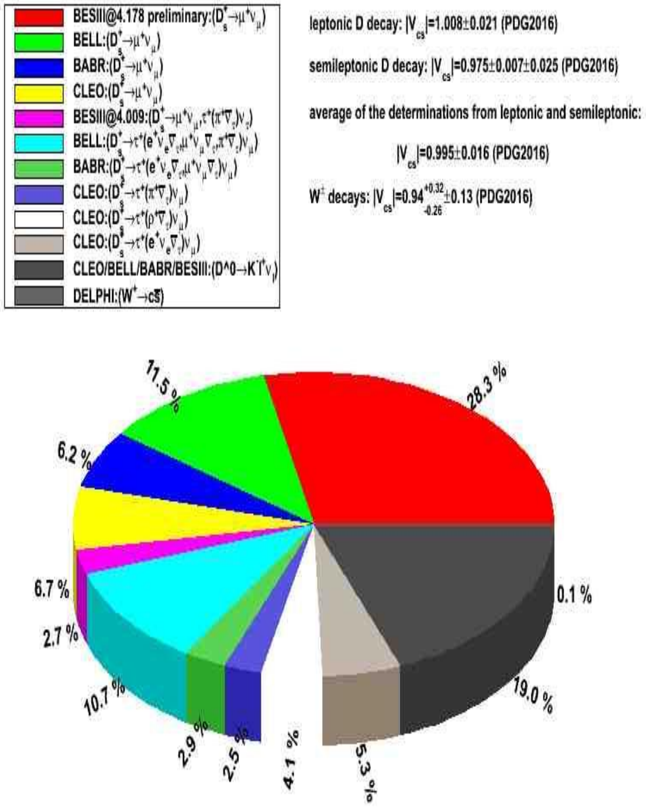
半轻方法受$f_{+}^{D\to K(\pi)}(0)$格点计算精度限制 [2.4(4.4)%]

各实验测量对$|V_{cs(d)}|$的权重

BESIII $|V_{cd}|$权重>50%



BESIII $D_s^+ \to \mu^+ \nu$对$|V_{cs}|$贡献的权重为28%

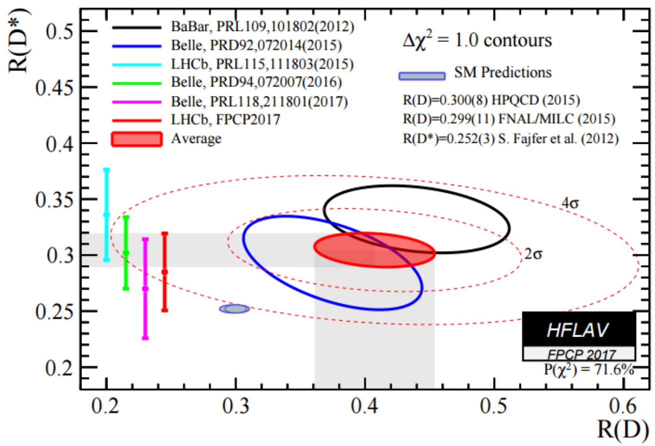


BESIII $D_s^+ \to \tau^+ \nu$研究完成后，对$|V_{cs}|$贡献的权重有望达到50%左右

BESIII对$D^{0(+)}\to\pi l^+\nu$轻子味道破坏的检验

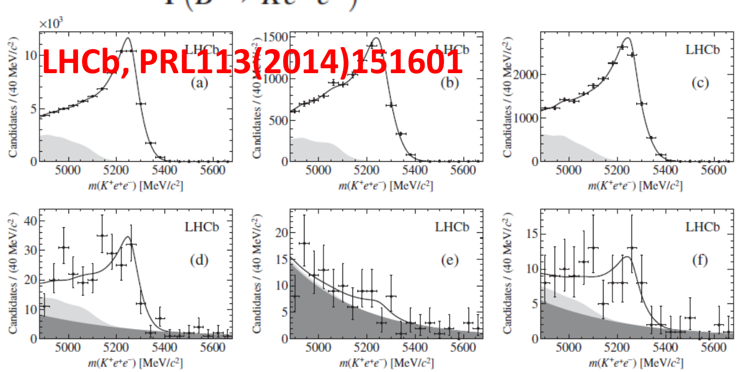
Evidence of LFV at 4σ in

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



Evidence of LFV at 2.6σ in FCNC decays $B^+\to K^+\mu^+\mu^-/K^+e^+e^-$

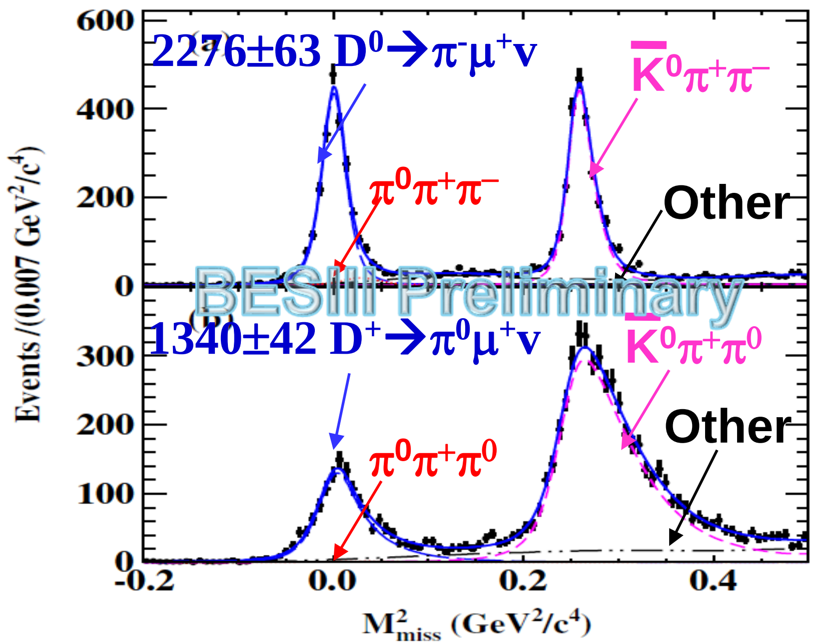
$$R_K = \frac{\Gamma(\bar{B}\to\bar{K}\mu^+\mu^-)}{\Gamma(\bar{B}\to\bar{K}e^+e^-)} = 0.745^{+0.090}_{-0.074}\pm 0.036$$



$$R^{0(+)}_{LU} = \frac{B(D^{0(+)}\to\pi^{-(0)}\mu^+\nu)}{B(D^{0(+)}\to\pi^{-(0)}e^+\nu)} \sim 0.97$$

B^{PDG16}: $R^0_{LU} = 0.82\pm0.08\ (\sim 2.0\sigma)$

$B(D^0\to\pi^-\mu^+\nu) = (0.237\pm0.024)\%$



改进测定$B[D^0\to\pi^-\mu^+\nu] = (0.267\pm0.007\pm0.007)\%$

首次测定$B[D^+\to\pi^0\mu^+\nu] = (0.342\pm0.011\pm0.010)\%$

$R^0_{LU}=0.918\pm0.036$ $R^+_{LU}=0.921\pm0.045$

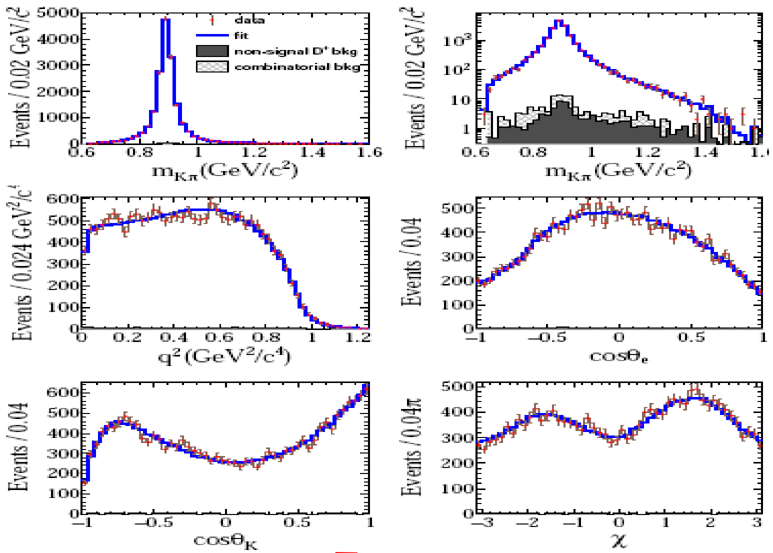
在1.5σ范围内和理论预期一致

半轻衰变$D^+ \to Ve^+v$振幅分析研究

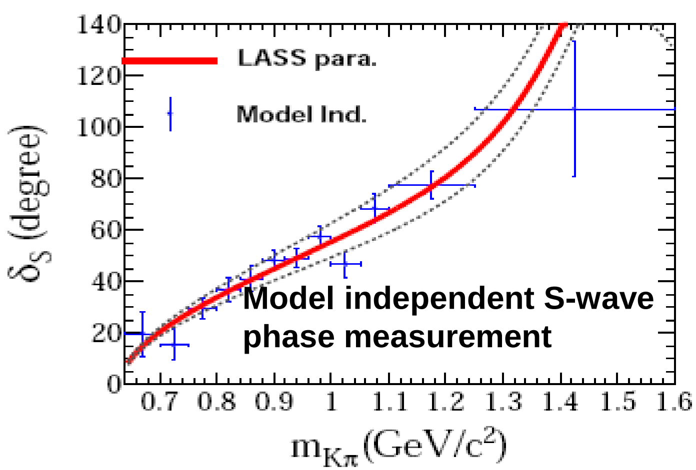
PRD94(2016)032001

PRD92(2015)071101(RC)

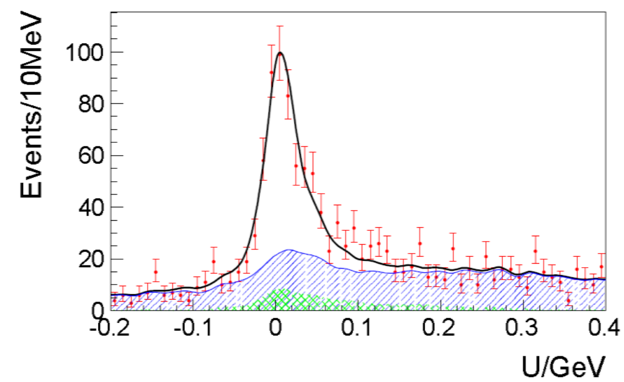
$D^+ \to K^-\pi^+e^+v$

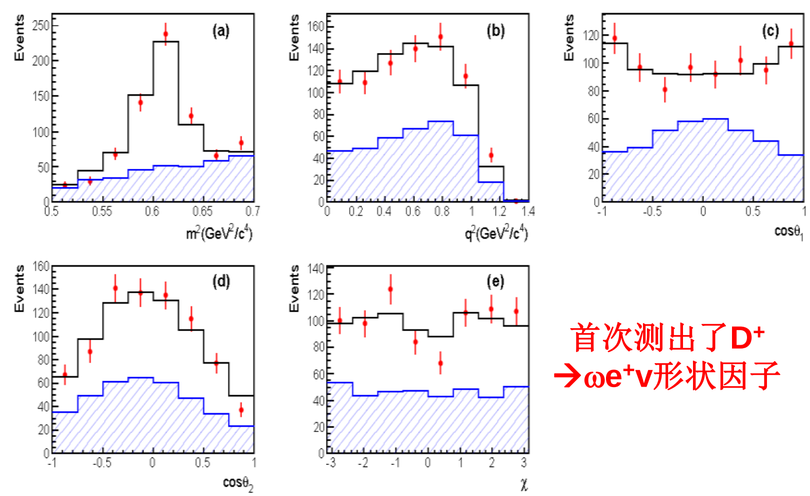


改进了$D^+ \to \bar{K}^{*0}e^+v$形状因子测量



$D^+ \to \omega e^+v$





首次测出了$D^+ \to \omega e^+v$形状因子

$r_V = V(0)/A_1(0) = 1.24 \pm 0.09 \pm 0.06$

$r_2 = A_2(0)/A_1(0) = 1.06 \pm 0.15 \pm 0.05$

$D^+ \to Se^+ v$型半轻衰变的首次观测

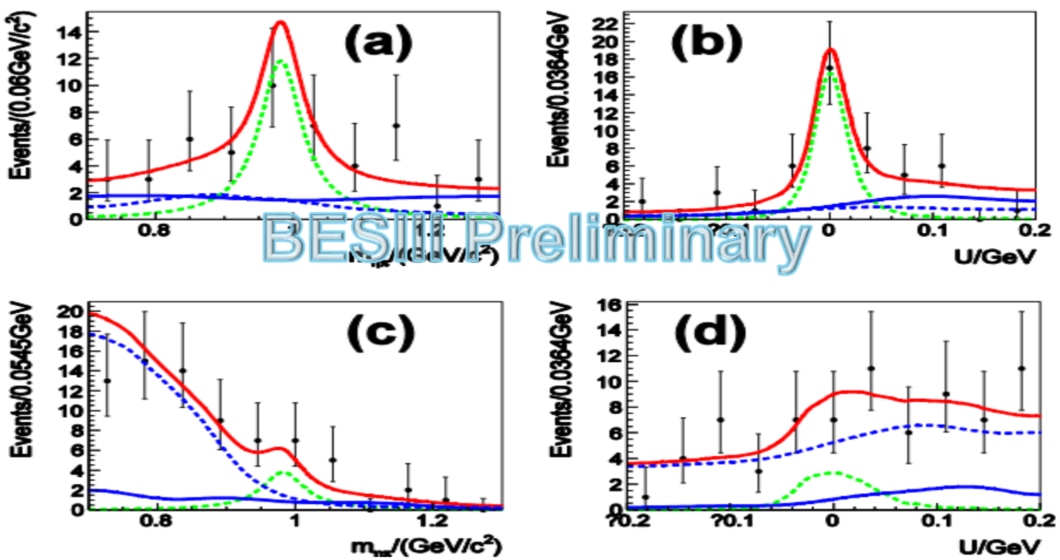
- Explore the nontrivial internal structure of light hadron mesons, traditional $q\bar{q}$ states, tetra quark system.

- With chiral unitarity approach in the coupled channels, BF is predicted to be order of $5(6)\times10^{-5}$ for $D^{0(+)}$ decays

- Improve understanding of classification of light scalar mesons

$$R \equiv \frac{B(D^+ \to f_0 l^+ \nu) + B(D^+ \to \sigma l^+ \nu)}{B(D^+ \to a_0 l^+ \nu)}$$

R=1(3) if traditional $q\bar{q}$ (tetra quark) system



- $B(D^0 \to a_0(980)^- e^+ \nu_e) \times B(a_0(980)^- \to \eta\pi^-)$

  $= (1.12^{+0.31}_{-0.28}(stat) \pm 0.10(syst)) \times 10^{-4}$ 5.9σ

- $B(D^+ \to a_0(980)^0 e^+ \nu_e) \times B(a_0(980)^0 \to \eta\pi^0)$

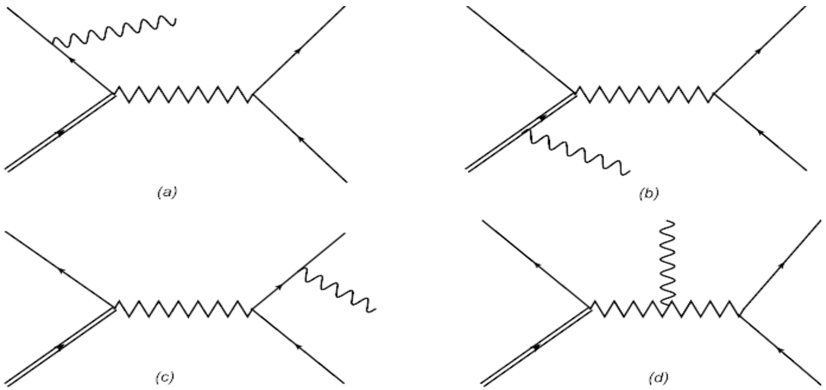
  $= (1.47^{+0.73}_{-0.59}(stat) \pm 0.14(syst)) \times 10^{-4}$ 3.0σ

- $B(D^+ \to a_0(980)^0 e^+ \nu_e) \times B(a_0(980)^0 \to \eta\pi^0)$

  $< 2.7 \times 10^{-4}$ @ 90% C.L.

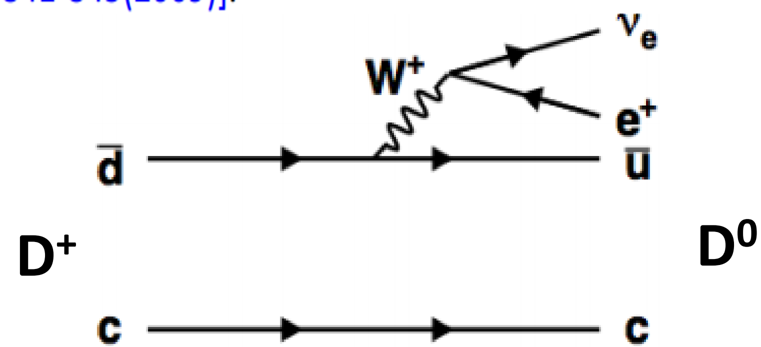
D介子稀有半轻衰变的寻找

Various theory models predict BFs in 10^{-6}–10^{-4}

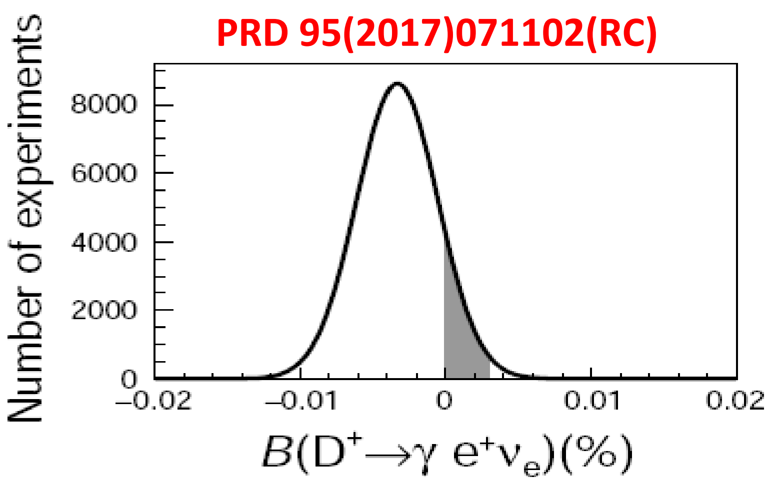


Tree level amplitudes

Applying the SU(3) symmetry for the light quarks, this rare decay branching fraction can be predicted by theoretical calculation and its theoretical value is 2.78×10^{-13} [EPJC, 59:841-845(2009)].

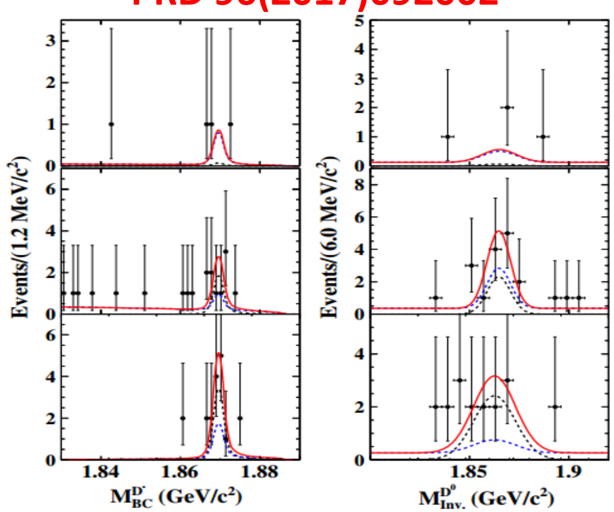


PRD 95(2017)071102(RC)



$B[D^+\to\gamma e^+\nu]|_{E\gamma>10\ MeV}<3.0\times10^{-4}$ @90%C.L.

PRD 96(2017)092002



$B[D^+\to D^0e^+\nu]<1\times10^{-4}$ @90%C.L.

$D_{(s)}$强子衰变

- $D^0\bar{D}^0$ mixing parameters
- Strong phase difference
- SU(3) symmetry and break effect

$D^0\bar{D}^0$混合和CP破坏

- Open-flavor neutral meson transforms to its anti-meson and vice versa:

$$K^0 \Leftrightarrow \overline{K^0},\ B^0_d \Leftrightarrow \overline{B^0_d},\ B^0_s \Leftrightarrow \overline{B^0_s},\ D^0 \Leftrightarrow \overline{D^0}$$

- Flavor eigenstate ($|D^0\rangle$, $|\overline{D^0}\rangle$) $\neq$ mass eigenstate $|D_{1,2}\rangle$ with $M_{1,2}$ and $\Gamma_{1,2}$)

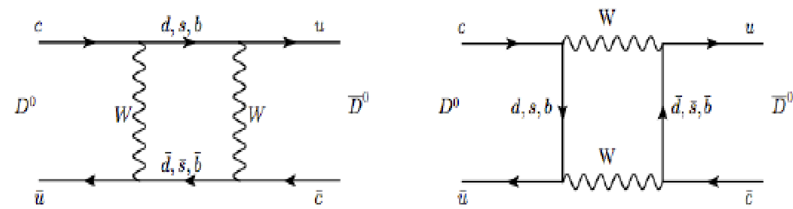
$$|D_{1,2}\rangle \equiv p|D^0\rangle \pm q|\overline{D^0}\rangle \text{ (CPT: } p^2+q^2=1)$$

- Mixing parameters definition:

$$\mathbf{x} \equiv \frac{M_1 - M_2}{\Gamma}, \quad \mathbf{y} \equiv \frac{\Gamma_1 - \Gamma_2}{2\Gamma}, \quad \Gamma \equiv \frac{\Gamma_1 + \Gamma_2}{2}$$

- under phase convention $CP|D^0\rangle = |\overline{D^0}\rangle$, $CP|\overline{D^0}\rangle = |D^0\rangle$,
- with CP conservation ($q = p = 1/\sqrt{2}$): $|D_{1,2}\rangle = |D_{+,-}\rangle$ (CP eigenstates)

- Unique: only the up-type meson for mixing
- Standard Model predicts: $\sim \mathcal{O}(1\%)$



(1) short distance ($<0.1\%$ by CKM and GIM)

(2) long distance ($\sim 1\%$)

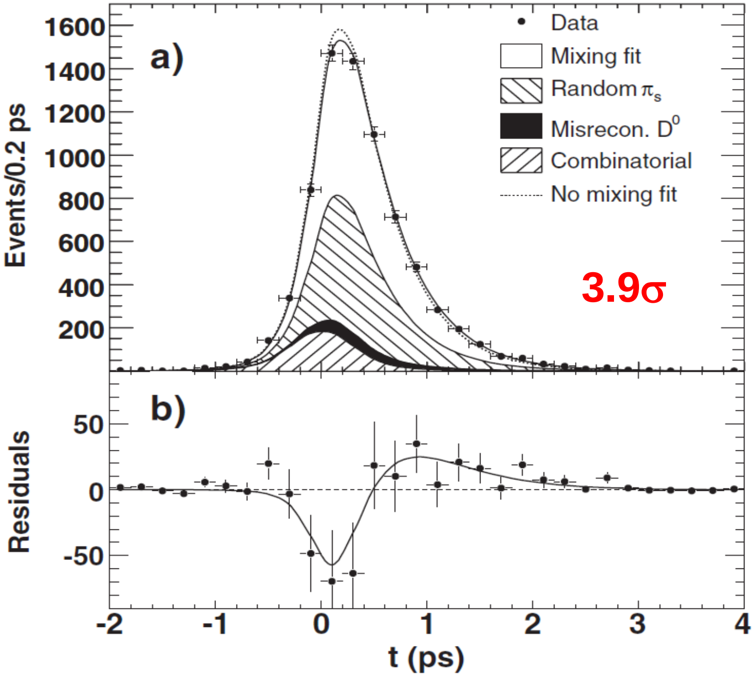
- Precise measurement of x, y: effectively limit New Physics(NP) modes;
- search for NP, eg: $|x| \gg |y|$

$D^0\bar{D}^0$混合的迹象

- **Babar, 384 fb^{-1}@10.58 GeV**

PRL98(2007)211802

$$\frac{T_{WS}(t)}{e^{-\Gamma t}} \propto R_D + \sqrt{R_D}y'\Gamma t + \frac{x'^2 + y'^2}{4}(\Gamma t)^2$$



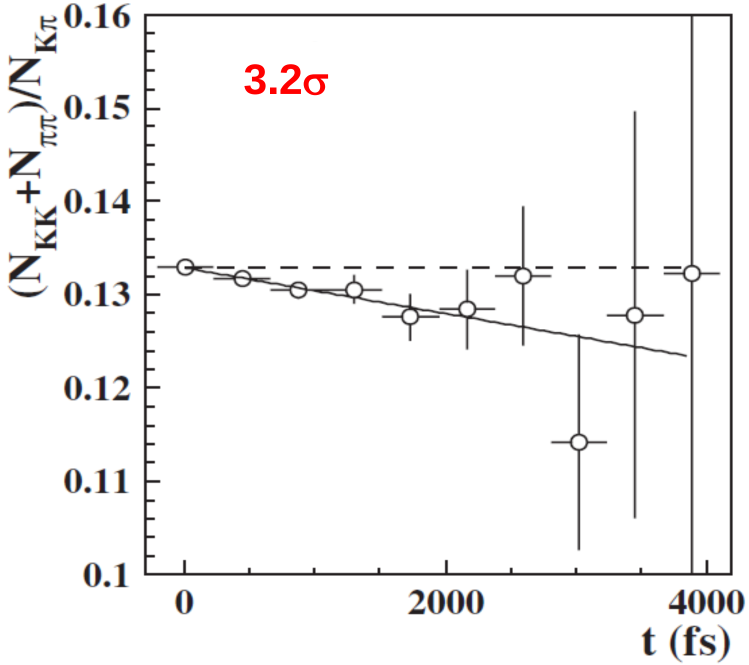
R_D=(0.303±0.016(stat)±0.010(syst))%
x'^2=(-0.22±0.30(stat)±0.21(syst))×10^{-3}
y'=(9.7±4.4(stat)±3.1(syst))×10^{-3}
(x'^2, y') with correlation -0.95

- **BELLE, 540 fb^{-1}@10.58 GeV**

PRL98(2007)211803

$$y_{CP} = \frac{\tau(K^-\pi^+)}{\tau(K^+K^-)} - 1$$

$$A_\Gamma = \frac{\tau(\bar{D}^0 \to K^-K^+) - \tau(D^0 \to K^+K^-)}{\tau(\bar{D}^0 \to K^-K^+) + \tau(D^0 \to K^+K^-)}$$



$$A_\Gamma = [0.01 \pm 0.30(\text{stat}) \pm 0.15(\text{syst})]\%.$$

$$y_{CP} = [1.31 \pm 0.32(\text{stat}) \pm 0.25(\text{syst})]\%.$$

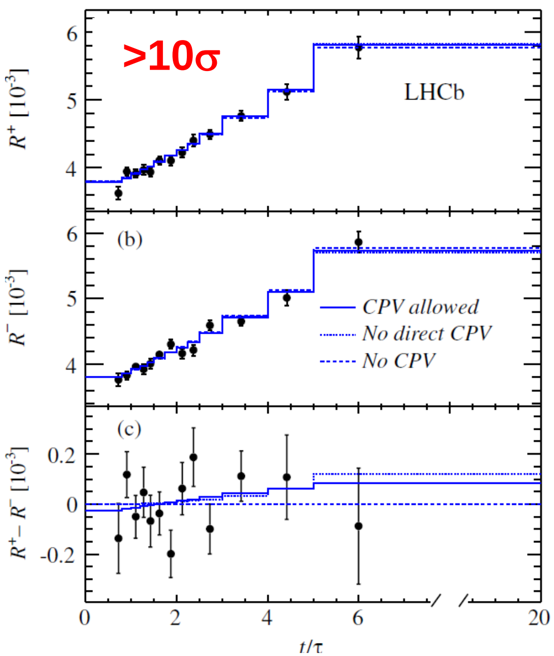
$D^0\bar{D}^0$混合的确认

- **LHCb, 3 fb^{-1} $p\bar{p}$ at 7/8 TeV**

PRL110(2013)101802 (1fb^{-1})

PRL111(2013)251801

$$R(t) \approx R_D + \sqrt{R_D}y'\frac{t}{\tau} + \frac{x'^2+y'^2}{4}\left(\frac{t}{\tau}\right)^2$$



$$x'^2 = (5.5 \pm 4.9) \times 10^{-5},$$

$$y' = (4.8 \pm 1.0) \times 10^{-3}$$

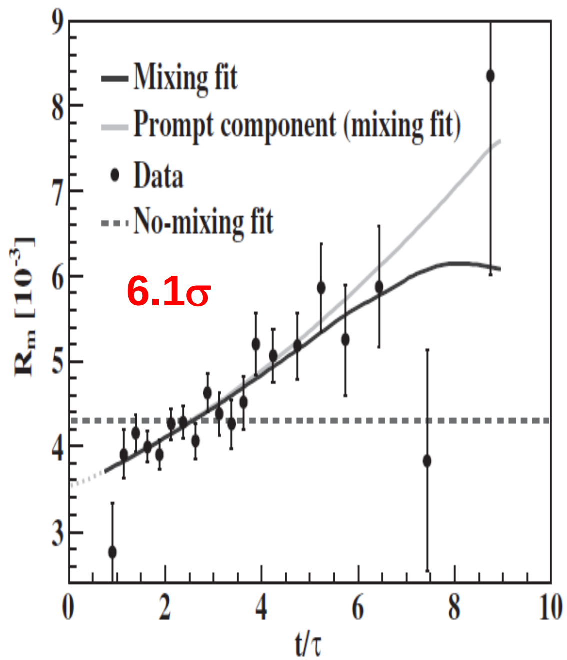
$$R_D = (3.568 \pm 0.066) \times 10^{-3}$$

- **CDFII, 9.6 fb^{-1} $p\bar{p}$ at 1.96 TeV**

PRL100(2008)121802(1.5 fb^{-1})

PRL111(2013)231802

$$R(t/\tau) = R_D + \sqrt{R_D}y'(t/\tau) + \frac{x'^2+y'^2}{4}(t/\tau)^2.$$



$$x'^2 = (0.08 \pm 0.18) \times 10^{-3}.$$

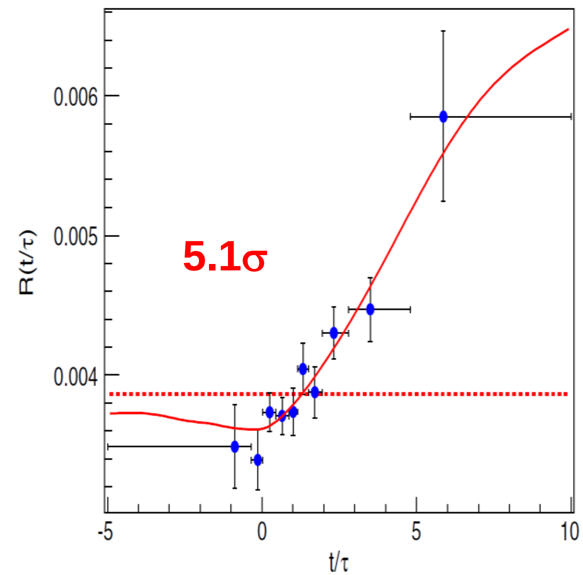
$$y' = (4.3 \pm 4.3) \times 10^{-3},$$

$$R_D = (3.51 \pm 0.35) \times 10^{-3}$$

- **Belle, 976 fb^{-1} at 10.58 GeV**

PRL112(2014)111801

$$R(\tilde{t}/\tau) = \frac{\Gamma_{WS}(\tilde{t}/\tau)}{\Gamma_{RS}(\tilde{t}/\tau)} \approx R_D + \sqrt{R_D}y'\frac{\tilde{t}}{\tau} + \frac{x'^2+y'^2}{4}\left(\frac{\tilde{t}}{\tau}\right)^2$$



$$x'^2 = (0.09 \pm 0.22) \times 10^{-3}$$

$$y' = (4.6 \pm 3.4) \times 10^{-3}$$

$$R_D = (3.53 \pm 0.13) \times 10^{-3}$$

$D^0\bar{D}^0$混合和CP破坏参数

Decay Mode	Observables	Relationship
$D^0 \to K^+K^-/\pi^+\pi^-$	y_{CP} A_Γ	$2y_{CP} = (\lvert q/p\rvert + \lvert p/q\rvert)\, y\cos\phi - (\lvert q/p\rvert - \lvert p/q\rvert)\, x\sin\phi$ $2A_\Gamma = (\lvert q/p\rvert - \lvert p/q\rvert)\, y\cos\phi - (\lvert q/p\rvert + \lvert p/q\rvert)\, x\sin\phi$
$D^0 \to K^0_S\pi^+\pi^-$	x y $\lvert q/p\rvert$ ϕ	
$D^0 \to K^+\ell^-\nu$	R_M	$R_M = (x^2+y^2)/2$
$D^0 \to K^+\pi^-\pi^0$ (Dalitz plot analysis)	x'' y''	$x'' = x\cos\delta_{K\pi\pi} + y\sin\delta_{K\pi\pi}$ $y'' = y\cos\delta_{K\pi\pi} - x\sin\delta_{K\pi\pi}$
"Double-tagged" branching fractions measured in $\psi(3770)\to DD$ decays	R_M y R_D $\sqrt{R_D}\cos\delta$	$R_M = (x^2+y^2)/2$
$D^0 \to K^+\pi^-$	$x'^2,\ y'$ $x'^{2+},\ x'^{2-}$ $y'^+,\ y'^-$	$x' = x\cos\delta + y\sin\delta$ $y' = y\cos\delta - x\sin\delta$ $A_M \equiv (\lvert q/p\rvert^4 - 1)/(\lvert q/p\rvert^4 + 1)$ $x'^{\pm} = [(1\pm A_M)/(1\mp A_M)]^{1/4}\times (x'\cos\phi \pm y'\sin\phi)$ $y'^{\pm} = [(1\pm A_M)/(1\mp A_M)]^{1/4}\times (y'\cos\phi \mp x'\sin\phi)$
$D^0 \to K^+\pi^-/K^-\pi^+$ (time-integrated)	$\frac{\Gamma(D^0\to K^+\pi^-)+\Gamma(\overline{D}^0\to K^-\pi^+)}{\Gamma(D^0\to K^-\pi^+)+\Gamma(\overline{D}^0\to K^+\pi^-)}$ $\frac{\Gamma(D^0\to K^+\pi^-)-\Gamma(\overline{D}^0\to K^-\pi^+)}{\Gamma(D^0\to K^+\pi^-)+\Gamma(\overline{D}^0\to K^-\pi^+)}$	R_D A_D
$D^0 \to K^+K^-/\pi^+\pi^-$ (time-integrated)	$\frac{\Gamma(D^0\to K^+K^-)-\Gamma(\overline{D}^0\to K^+K^-)}{\Gamma(D^0\to K^+K^-)+\Gamma(\overline{D}^0\to K^+K^-)}$ $\frac{\Gamma(D^0\to \pi^+\pi^-)-\Gamma(\overline{D}^0\to \pi^+\pi^-)}{\Gamma(D^0\to \pi^+\pi^-)+\Gamma(\overline{D}^0\to \pi^+\pi^-)}$	$A_K + \frac{\langle t\rangle}{\tau_D} A_{CP}^{\rm indirect}\quad (A_{CP}^{\rm indirect} \approx -A_\Gamma)$ $A_\pi + \frac{\langle t\rangle}{\tau_D} A_{CP}^{\rm indirect}\quad (A_{CP}^{\rm indirect} \approx -A_\Gamma)$

混合参数:x,y

间接CPV参数:|q/p|,ϕ

直接CPV参数:A_D,A_K,A_π

R_D

强相差参数:$\delta_{K\pi}$, $\delta_{K\pi\pi0}$

BESIII测得$D^0\bar{D}^0$混合参数y_{CP}

- **BESIII, 3 fb^{-1} at 3.773 GeV**

PLB744(2015)339

For D decay to CP eigenstates:

$$R_{CP\pm} \propto |A_{CP\pm}|^2(1 \mp y_{CP})$$

$$y_{CP} = \frac{1}{2}[y\cos\phi(|\frac{q}{p}| + |\frac{p}{q}|) - x\sin\phi(|\frac{q}{p}| - |\frac{p}{q}|)]$$

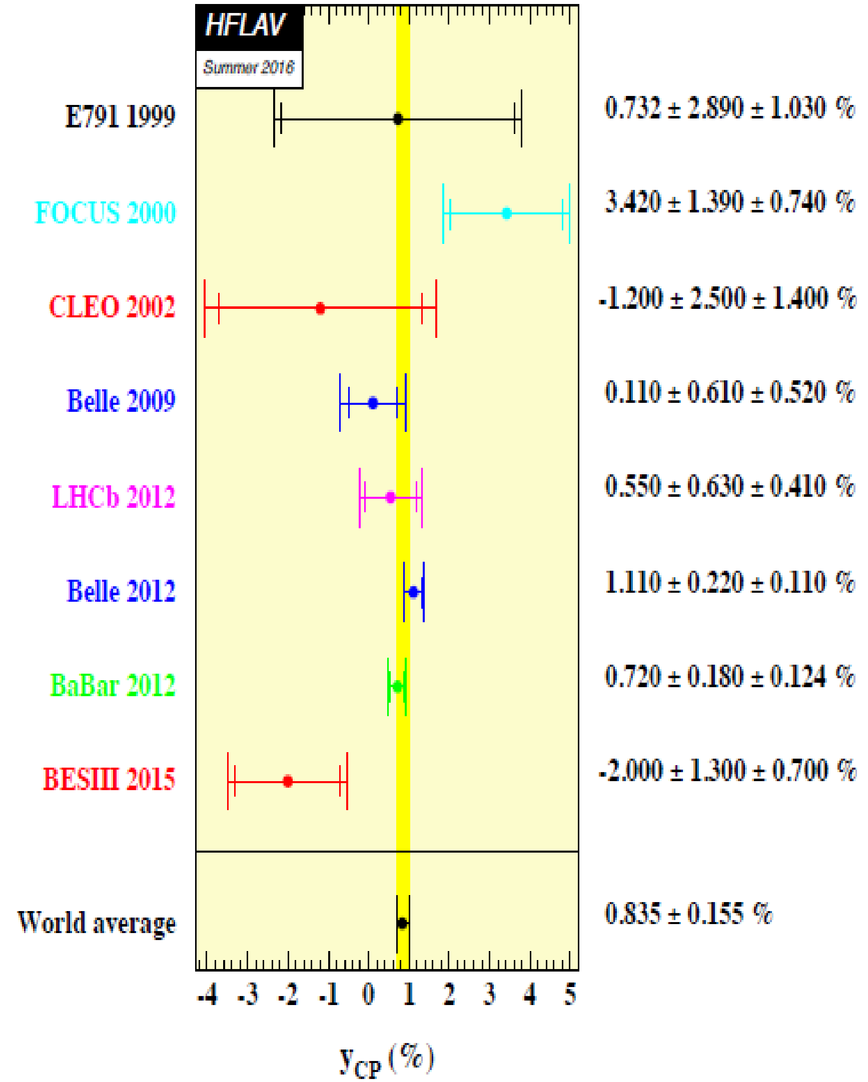
For CP tagged semileptonic D decays:

$$R_{l,CP\pm} \propto |A_l|^2|A_{CP\pm}|^2$$

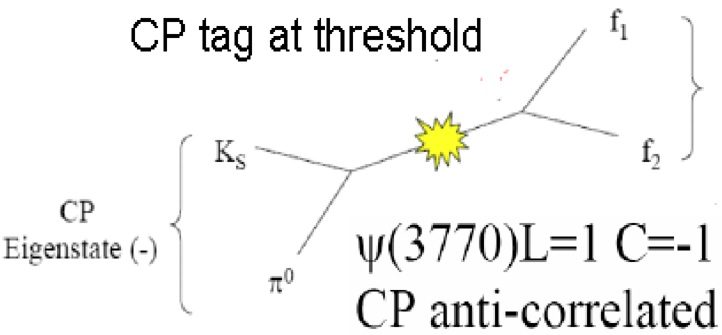
$$y_{CP} \approx \frac{1}{4}(\frac{R_{l;CP+}R_{CP-}}{R_{l;CP-}R_{CP+}} - \frac{R_{l;CP-}R_{CP+}}{R_{l;CP+}R_{CP-}})$$

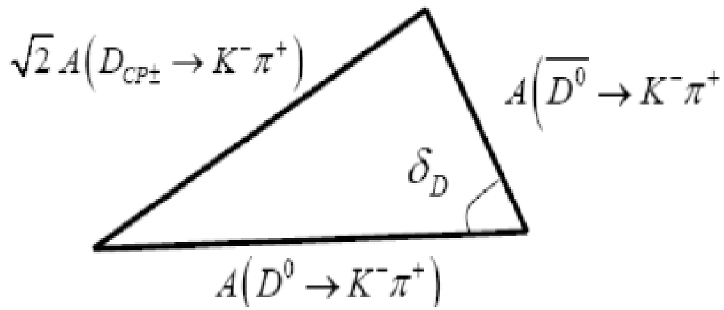
Type	Modes
CP^+	K^+K^-, $\pi^+\pi^-$, $K_S\pi^0\pi^0$
CP^-	$K_S^0\pi^0$, $K_S^0\omega$, $K_S^0\eta$
$l^\pm$	$Ke\nu$, $K\mu\nu$

y_{CP}=(-2.0±1.3±0.7)%



BESIII测得$D^0\bar{D}^0$混合参数$\delta_{K\pi}$





$$\mathcal{A}_{CP\to K\pi} = \frac{\mathcal{B}_{D_2\to K^-\pi^+} - \mathcal{B}_{D_1\to K^-\pi^+}}{\mathcal{B}_{D_2\to K^-\pi^+} + \mathcal{B}_{D_1\to K^-\pi^+}}.$$

$$2r\boxed{\cos\delta_{K\pi}} + y = (1 + R_{\rm WS}) \cdot \mathcal{A}_{CP\to K\pi},$$

$$|D_1\rangle \equiv \frac{|D^0\rangle + |\overline{D}^0\rangle}{\sqrt{2}} \quad |D_2\rangle \equiv \frac{|D^0\rangle - |\overline{D}^0\rangle}{\sqrt{2}}.$$

Type	Mode
Flavored	$K^-\pi^+, K^+\pi^-$
$CP+$	$K^+K^-, \pi^+\pi^-, K^0_S\pi^0\pi^0, \pi^0\pi^0, \rho^0\pi^0$
$CP-$	$K^0_S\pi^0, K^0_S\eta, K^0_S\omega$

$\delta_{K\pi}$ is related to mixing parameters x and y from x' and y'

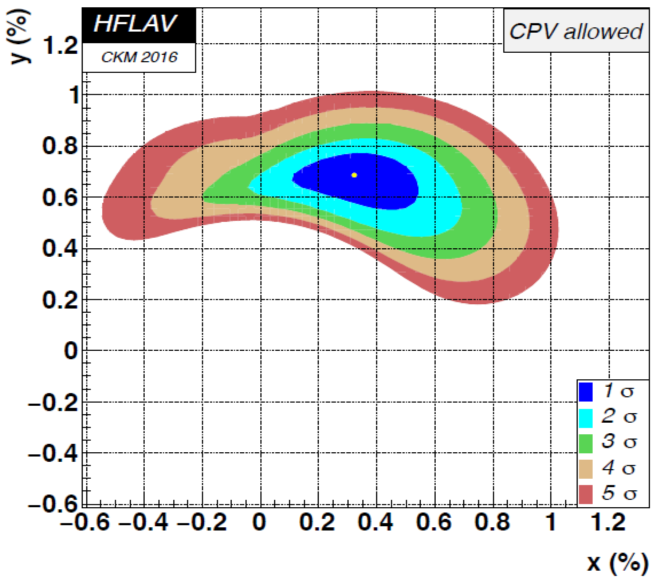
目前最精确结果

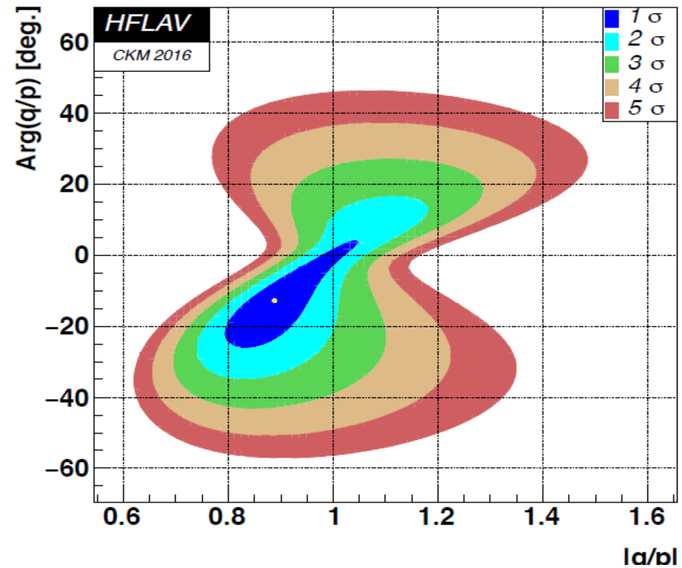
$A^{K\pi}_{CP}=(12.7\pm1.3\pm0.7)\times10^{-2}$

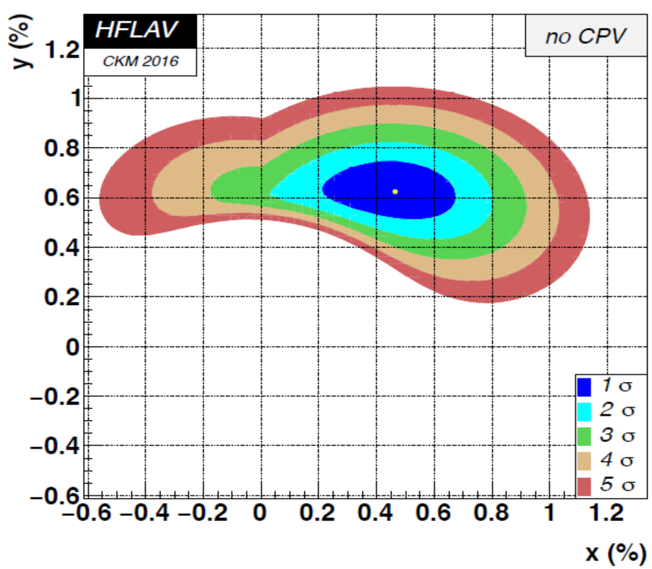
$\cos\delta_{K\pi}=1.02\pm0.11\pm0.06\pm0.01$

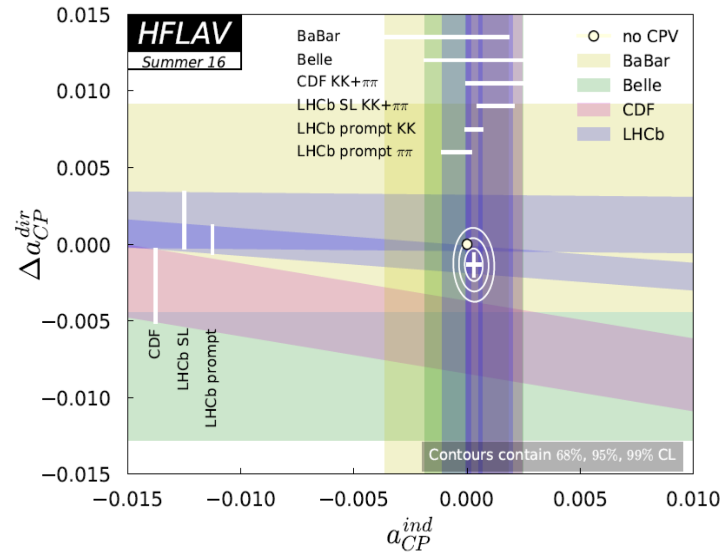
PLB734(2014)227

$D^0\bar{D}^0$混合和CP破坏主要参数平均







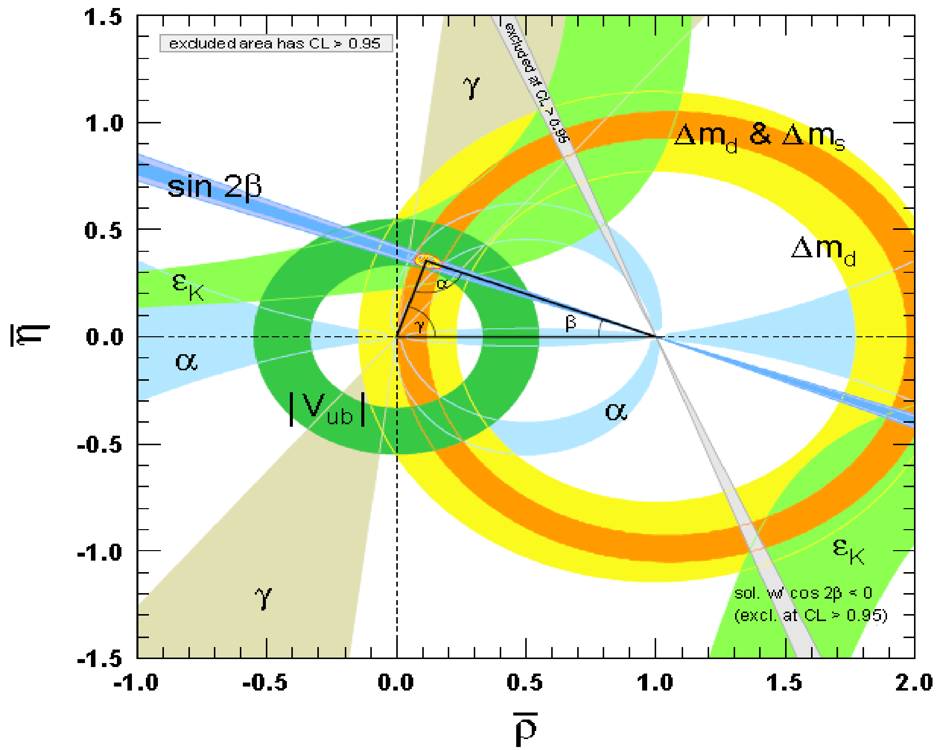


$D^0\bar{D}^0$ mixing is observed, no direct CPV is found

D^0衰变强相差: 约束γ/ϕ_3的理想桥梁

Direct measurement

$$\alpha/\phi_2 = \left(85.4^{+4.0}_{-3.9}\right)^\circ$$
$$\beta/\phi_1 = \left(21.38^{+0.79}_{-0.77}\right)^\circ$$
$$\gamma/\phi_3 = \left(68^{+8.0}_{-8.5}\right)^\circ$$

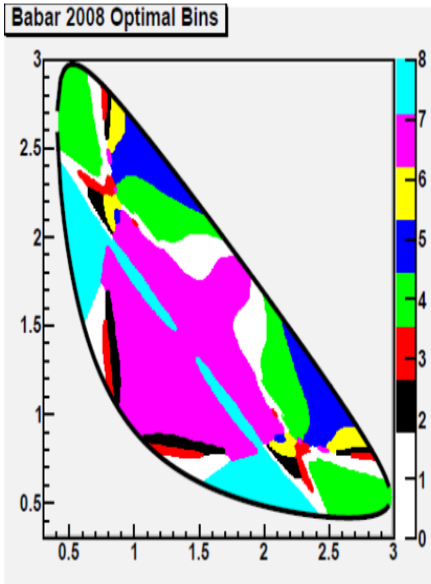


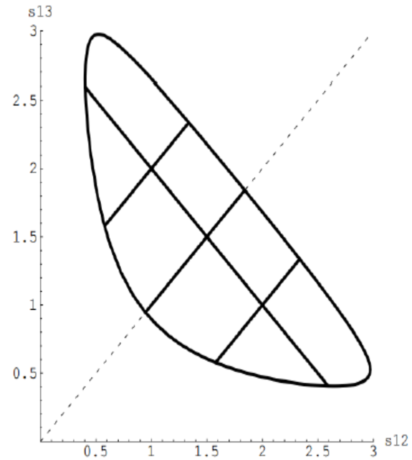
γ is the worst measured angle, mostly due to systematic error

Significant deviation from UT will imply NP beyond SM

- **Quantum correlated $D^0\bar{D}^0$ decays in $\psi(3770)$**
  - **CP asymmetry in mixing and decays**
  - **Interference → strong phase parameters → Constrain γ/ϕ_3, which is important for CKM UT**

$D^0 \to K_S\pi^+\pi^-$衰变强相差研究



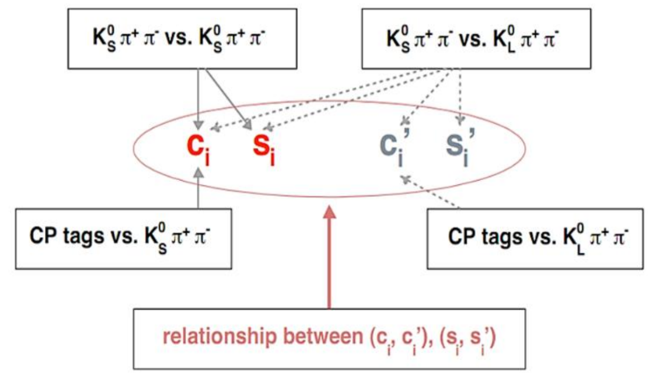


Mirrored binning over x=y makes it so $c_i=c_{-i}$ and $s_i=-s_{-i}$

- T_i : Bin yield measured in flavor decays
- r_B : color suppression factor~0.1
- δ_B : strong phase of B decay
- c_i, s_i : weighted average of $\cos(\Delta\delta_D)$ and $\sin(\Delta\delta_D)$ respectively where $\Delta\delta_D$ is the difference between phase of D^0 and $\bar{D}^0$

Measured at B-Factories

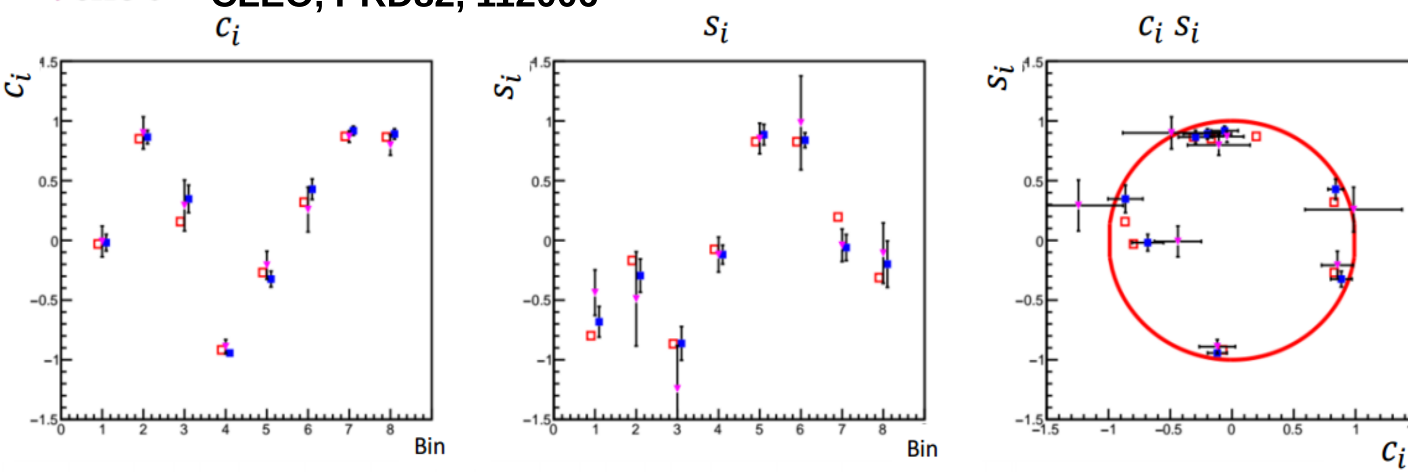
Through $D^0 \to K_S\pi^+\pi^-$ analysis



Model prediction
BESIII
CLEO-c

BESIII preliminary

CLEO, PRD82, 112006



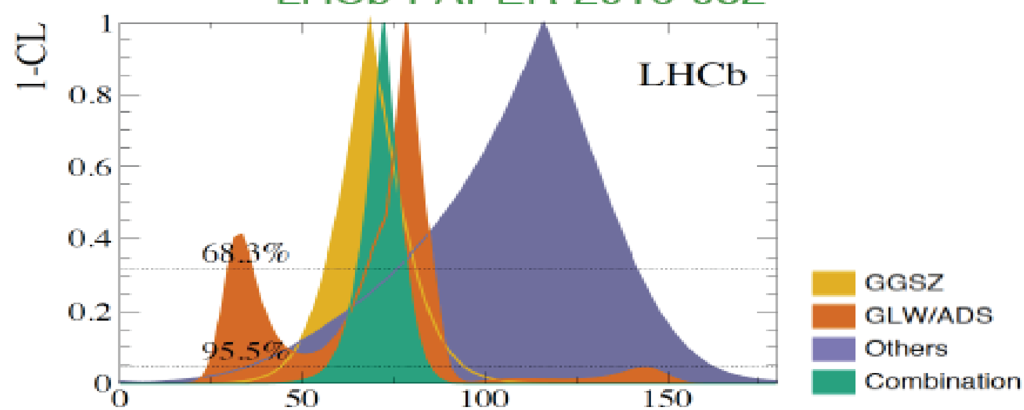
D^0衰变强相差对γ/ϕ_3的约束及前景

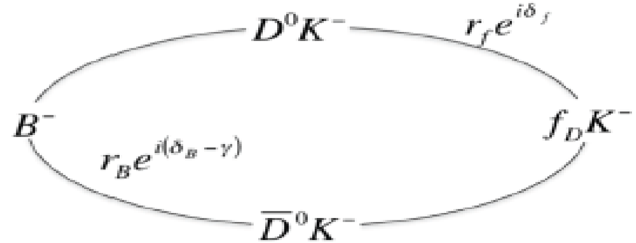
taken from Liming Zhang's talk at FPCPV2016

γ combination at LHCb

Determine γ from CPV measurements

LHCb-PAPER-2016-032





$\gamma = (72.2^{+6.8}_{-7.3})^\circ$ syst. included

BaBar: $\gamma = (70\pm18)^\circ$

Belle: $\gamma = (73^{+13}{}_{-15})^\circ$

Used D decay modes

GLW: $D\to K^+K^-$, $\pi^+\pi^-$, $K_S\pi^0$

ADS: $D\to \pi^-K^+$

quasi-ADS $D\to \pi^-K^+\pi^+\pi^-$, $\pi^-K^+\pi^0$

quasi-GLW $D\to \pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^0$, $\pi^+\pi^-\pi^0$

GGSZ $D\to K_S\pi^+\pi^-$, $K_SK^+K^-$

GLS $D\to K_SK^-\pi^+$, $K_S\pi^-K^+$

Prospects

Sample	$\sigma_{stat}(\gamma)^\circ$
Run 1	8
Run 2	4
Upgrade	~ 1
Future upgrade	<0.5

- Current one syst. ~2° from CLEO strong phase measurements
- 15-20 fb^{-1} ψ(3770) data from BESIII are desired to avoid syst. limitation for upgrade scenario

More 15 fb^{-1} ψ(3770) data@BESIII will avoid syst. limitation for γ/ϕ_3 measurement

SU(3)对称性及破坏效应

- Ratio of branching fractions of D to KK and pi pi

$$R = \frac{Br(D^0 \to K^+K^-)}{Br(D^0 \to \pi^+\pi^-)} \approx 2.8$$

  - R=1 in the SU(3) flavour symmetry limit

- Branching fraction of $\mathcal{B}(D^0 \to K^0\overline{K}^0) = (0.320 \pm 0.038) \times 10^{-3}$

  vanishes in the SU(3) limit

- DDbar mixing parameters

$$x, y \sim \sin^2\theta_C \times [SU(3)\ \text{breaking}]^2$$

  - Non-zero mixing parameters indicate large SU(3) breaking effect

两体D衰变分支比的理论计算

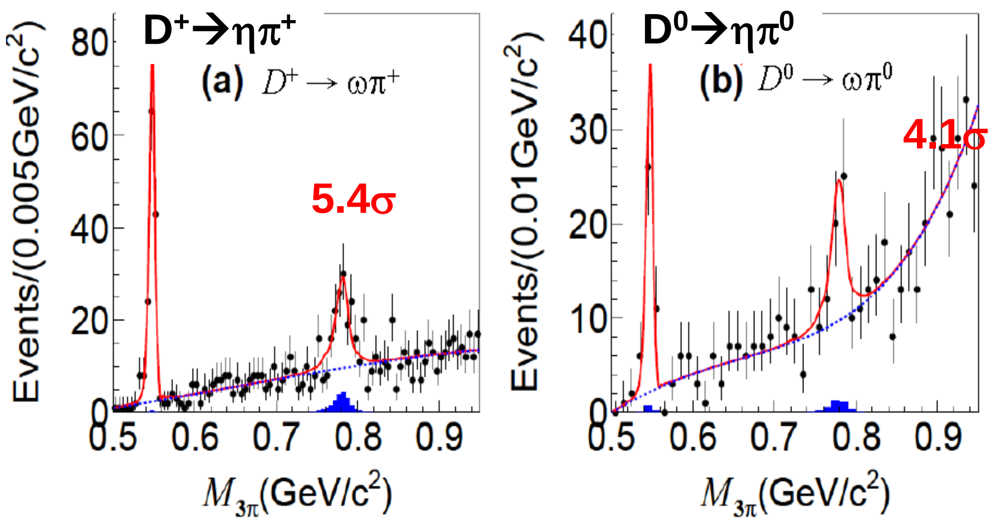
Modes	Amplitudes	Br(FSI)	Br(diagrammatic)	Br(pole)	Br(FAT)	Br(FAT[mix])	Br(exp)
$D^0 \to \pi^+\rho^-$	$T_V, (E_P)$	6.5	3.92 ± 0.46	3.5 ± 0.6	4.74	4.66	4.96 ± 0.24
$D^0 \to \pi^0\rho^0$	$C_P, C_V, (E_P, E_V)$	1.7	2.96 ± 0.98	1.4 ± 0.6	3.55	3.83	3.72 ± 0.22
$D^0 \to \pi^0\omega$	$C_P, C_V, (E_P, E_V)$	0.08	0.10 ± 0.18	0.08 ± 0.02	0.85	0.18	< 0.26
$D^0 \to \pi^0\phi$	C_P	1.1	1.22 ± 0.08	1.0 ± 0.3	1.11	1.11	1.31 ± 0.10
$D^0 \to \pi^-\rho^+$	$T_P, (E_V)$	8.2	8.34 ± 1.69	10.2 ± 1.5	10.2	10.0	9.8 ± 0.4
$D^0 \to K^+K^{*-}$	$T_V, (E_P)$	2.8	1.99 ± 0.24	1.6 ± 0.3	1.72	1.73	1.56 ± 0.12
$D^0 \to K^0\overline{K}^{*0}$	E_P, E_V	0.99	0.29 ± 0.22	0.16 ± 0.05	1.1	1.1	< 1
$D^0 \to \overline{K}^0 K^{*0}$	E_P, E_V	0.99	0.29 ± 0.22	0.16 ± 0.05	1.1	1.1	< 0.56
$D^0 \to K^-K^{*+}$	$T_P, (E_V)$	4.5	4.25 ± 0.86	4.7 ± 0.8	4.37	4.37	4.38 ± 0.21
$D^0 \to \eta\rho^0$	$C_P, C_V, (E_P, E_V)$	0.24	1.11 ± 0.86	0.05 ± 0.01	0.54	0.45	
$D^0 \to \eta\omega$	$C_P, C_V, (E_P, E_V)$	1.9	3.08 ± 1.42	1.2 ± 0.3	2.4	2.0	
$D^0 \to \eta\phi$	$C_P, (E_P, E_V)$	0.57	0.31 ± 0.10	0.23 ± 0.06	0.19	0.18	0.14 ± 0.05
$D^0 \to \eta'\rho^0$	$C_P, C_V, (E_P, E_V)$	0.10	0.14 ± 0.02	0.08 ± 0.02	0.21	0.27	
$D^0 \to \eta'\omega$	$C_P, C_V, (E_P, E_V)$	0.001	0.07 ± 0.02	0.0001 ± 0.0001	0.04	0.02	
$D^+ \to \pi^+\rho^0$	$T_V, C_P, (A_P, A_V)$	1.7		0.8 ± 0.7	0.42	0.58	0.81 ± 0.15
$D^+ \to \pi^+\omega$	$T_V, C_P, (A_P, A_V)$	0.35		0.3 ± 0.3	0.95	0.80	< 0.34
$D^+ \to \pi^+\phi$	C_P	5.9	6.21 ± 0.43	5.1 ± 1.4	5.65	5.65	$5.42^{+0.22}_{-0.24}$
$D^+ \to \pi^0\rho^+$	$T_P, C_V, (A_P, A_V)$	3.7		3.5 ± 1.6	2.7	2.5	
$D^+ \to K^+\overline{K}^{*0}$	$T_V, (A_V)$	2.5		4.1 ± 1.0	3.61	3.60	$3.675^{+0.14}_{-0.21}$
$D^+ \to \overline{K}^0 K^{*+}$	$T_P, (A_P)$	1.70		12.4 ± 2.4	11	11	32 ± 14
$D^+ \to \eta\rho^+$	$T_P, C_V, (A_P, A_V)$	0.002		0.4 ± 0.4	0.7	2.2	< 15
$D^+ \to \eta'\rho^+$	$T_P, C_V, (A_P, A_V)$	1.3		0.8 ± 0.1	0.7	0.8	
$D_s^+ \to \pi^+K^{*0}$	$T_V, (A_V)$	3.3		1.5 ± 0.7	2.52	2.35	2.25 ± 0.39
$D_s^+ \to \pi^0K^{*+}$	$C_V, (A_V)$	0.29		0.1 ± 0.1	0.8	1.0	
$D_s^+ \to K^+\rho^0$	$C_P, (A_P)$	2.4		1.0 ± 0.6	1.9	2.5	2.7 ± 0.5
$D_s^+ \to K^+\omega$	$C_P, (A_P)$	0.72		1.8 ± 0.7	0.6	0.07	< 2.4
$D_s^+ \to K^+\phi$	$T_V, C_P, (A_V)$	0.15		0.3 ± 0.3	0.166	0.166	0.184 ± 0.045
$D_s^+ \to K^0\rho^+$	$T_P, (A_P)$	19.5		7.5 ± 2.1	9.1	9.6	
$D_s^+ \to \eta K^{*+}$	$T_P, C_V, (A_P, A_V)$	0.24		1.0 ± 0.4	0.2	0.2	
$D_s^+ \to \eta' K^{*+}$	$T_P, C_V, (A_P, A_V)$	0.24		0.6 ± 0.2	0.2	0.2	

[Qin, Li, Lu, FSY, PRD2014]

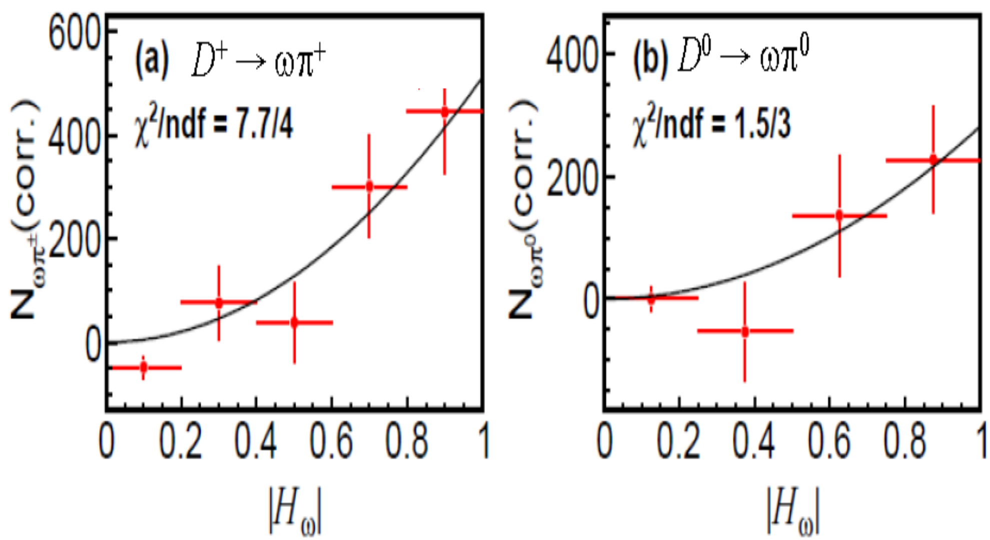
D→VP衰变ωπ的首次确认

Double tag method

PRL116(2016)082001



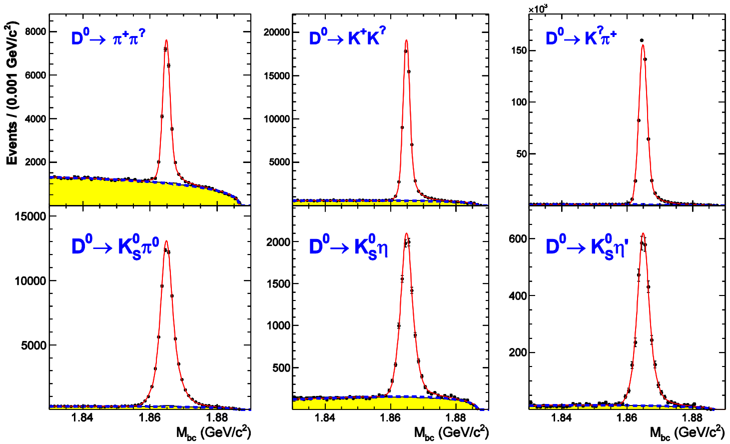
Decay mode	This work	Previous meausurements
$D^+ \to \omega\pi^+$	$(2.74 \pm 0.58 \pm 0.17) \times 10^{-4}$	$< 3.4 \times 10^{-4}$ at 90% C.L.
$D^0 \to \omega\pi^0$	$(1.05 \pm 0.41 \pm 0.09) \times 10^{-4}$	$< 2.6 \times 10^{-4}$ at 90% C.L.
$D^+ \to \eta\pi^+$	$(3.13 \pm 0.22 \pm 0.19) \times 10^{-3}$	$(3.53 \pm 0.21) \times 10^{-3}$
$D^0 \to \eta\pi^0$	$(0.67 \pm 0.10 \pm 0.05) \times 10^{-3}$	$(0.68 \pm 0.07) \times 10^{-3}$

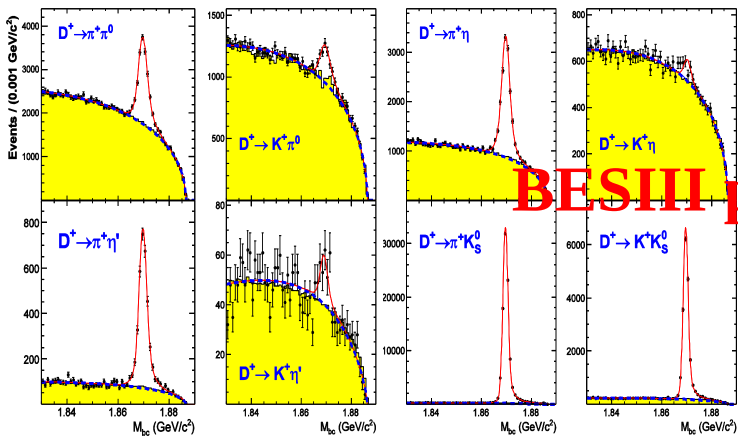


Studies of singly cabibbo-suppressed decays is limited by data set and background

Benefit the understanding of SU(3) symmetry breaking and CP violation, improve theory calculation

D⁰⁽⁺⁾→PP分支比的改进测量





BESIII preliminary

- The study of the hadronic decays of charmed D mesons is of great significance in the study of the strong and weak interactions in D decays.
- The analysis on $D \to PP$ modes will provide materials for the study of SU(3) breaking effect[1]. And the observation of CP violation in D decay is commonly believed to be indications of new physics.
- $D^0 \to K^-\pi^+$ is an important normalization mode.
- Most of the D decays have been studied by CLEO in 2010[2], other measurements come from Belle[3], BaBar[4] and CDF[5], etc.
- Some of the branching fractions (BFs) are not well established. With the 2.93 fb^{-1} data taken at 3.773 GeV within BESIII, the results will help to improve these measurements.

Mode	N^{net}_{signal}	ε (%)	$\mathcal{B}\pm$(stat)$\pm$(sys)	$\mathcal{B}_{PDG}$
$\pi^+\pi^-$	21105 ± 249	66.03 ± 0.25	$(1.505 \pm 0.018 \pm 0.031) \times 10^{-3}$	$(1.421 \pm 0.025) \times 10^{-3}$
K^+K^-	[illegible] ± 273	62.82 ± 0.32	$(4.229 \pm 0.020 \pm 0.087) \times 10^{-3}$	$(4.01 \pm 0.07) \times 10^{-3}$
$K^-\pi^+$	537745 ± 767	64.98 ± 0.09	$(3.896 \pm 0.006 \pm 0.073)$ %	(3.93 ± 0.04) %
$K^0_S\pi^0$	66539 ± 302	38.06 ± 0.17	$(1.236 \pm 0.006 \pm 0.032)$ %	(1.20 ± 0.04) %
$K^0_S\eta$	9532 ± 126	31.96 ± 0.14	$(5.149 \pm 0.068 \pm 0.134) \times 10^{-3}$	$(4.85 \pm 0.30) \times 10^{-3}$
$K^0_S\eta'$	3007 ± 61	12.66 ± 0.08	$(9.562 \pm 0.197 \pm 0.379) \times 10^{-3}$	$(9.5 \pm 0.5) \times 10^{-3}$
$\pi^0\pi^+$	10108 ± 267	48.98 ± 0.34	$(1.259 \pm 0.033 \pm 0.025) \times 10^{-3}$	$(1.24 \pm 0.06) \times 10^{-3}$
π^0K^+	1834 ± 168	51.52 ± 0.42	$(2.171 \pm 0.198 \pm 0.060) \times 10^{-4}$	$(1.89 \pm 0.25) \times 10^{-4}$
$\eta\pi^+$	11636 ± 215	46.96 ± 0.25	$(3.790 \pm 0.070 \pm 0.075) \times 10^{-3}$	$(3.66 \pm 0.22) \times 10^{-3}$
ηK^+	439 ± 72	48.21 ± 0.31	$(1.393 \pm 0.228 \pm 0.124) \times 10^{-4}$	$(1.12 \pm 0.18) \times 10^{-4}$
$\eta'\pi^+$	3088 ± 83	21.49 ± 0.18	$(5.122 \pm 0.140 \pm 0.210) \times 10^{-3}$	$(4.84 \pm 0.31) \times 10^{-3}$
$\eta'K^+$	87 ± 25	22.39 ± 0.22	$(1.377 \pm 0.428 \pm 0.202) \times 10^{-4}$	$(1.83 \pm 0.23) \times 10^{-4}$
$K^0_S\pi^+$	93884 ± 352	51.38 ± 0.18	$(1.591 \pm 0.006 \pm 0.033) \times 10^{-2}$	$(1.53 \pm 0.06) \times 10^{-2}$
$K^0_SK^+$	17704 ± 151	48.45 ± 0.14	$(3.183 \pm 0.028 \pm 0.065) \times 10^{-3}$	$(2.95 \pm 0.15) \times 10^{-3}$

$$\mathcal{B} = \frac{N^{signal}_{net}}{2 \cdot N_{D^0\bar{D}^0(D^+D^-)} \cdot \varepsilon},\ N_{D^0\bar{D}^0} = (10{,}621 \pm 29_{(stat)}) \times 10^3,\ N_{D^+D^-} = (8{,}296 \pm 31_{(stat)}) \times 10^3$$

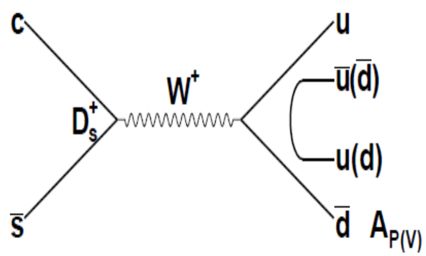
quoted from Derrick's talk given at APS2014

The $\mathcal{B}(D^0 \to K^-\pi^+)$ has been corrected by the PDG value of $\mathcal{B}(D^0 \to K^+\pi^-)$.

For $D^0 \to K^0_S\eta$, $D^+ \to \pi^0\pi^+$, $D^+ \to \eta\pi^+$, $D^+ \to \eta'\pi^+$, $D^+ \to K^0_S\pi^+$ and $D^+ \to K^0_SK^+$, it shows better precision than the present values.

D_s^+介子纯湮灭衰变和重子衰变的确认

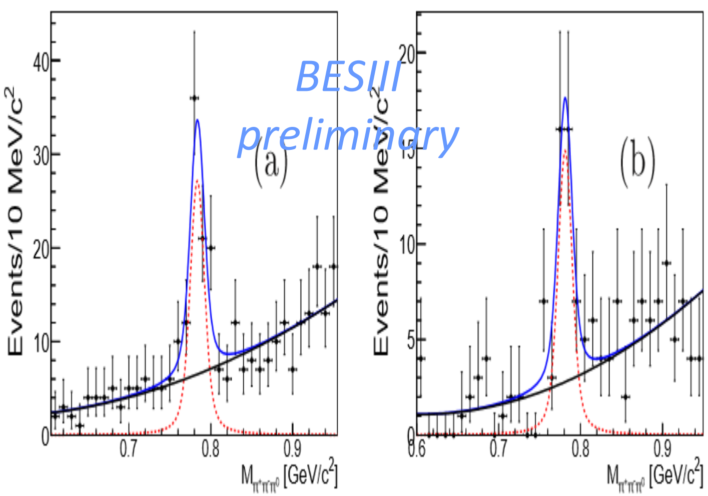
首次确认纯湮灭衰变$D_s^+ \to \omega\pi^+$
并首次测定$D_s^+ \to \omega K^+$



Under the model-independent approach:

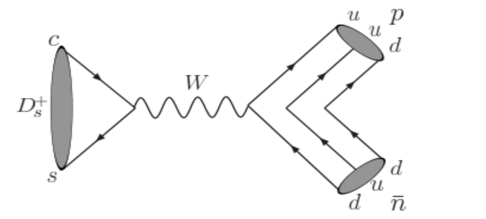
$$A(D_s^+ \to \omega\pi^+) = \frac{1}{\sqrt{2}}(A_P + A_V)$$

($A_{P,V}$: P, V contain $\bar{q}'$ of $q\bar{q}'$ configuration)

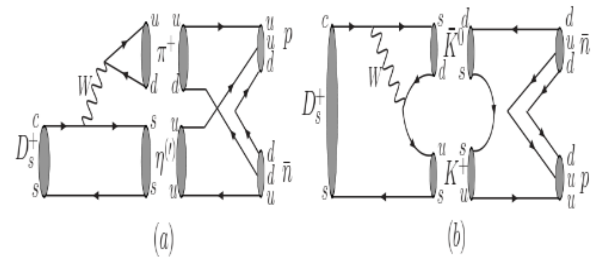


Signal mode	Branching fraction (10^{-3})
$D_s^+ \to \omega\pi^+$	$1.85 \pm 0.30(stat.) \pm 0.19(sys.)$
$D_s^+ \to \omega K^+$	$1.13 \pm 0.24(stat.) \pm 0.14(sys.)$

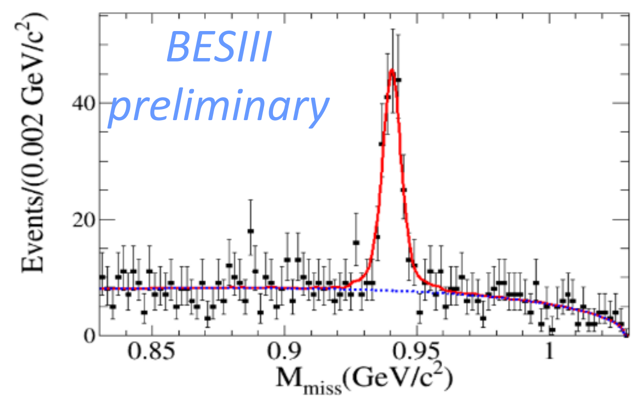
首次确认重子衰变$D_s^+ \to p\bar{n}$



(a) Short-distance effects



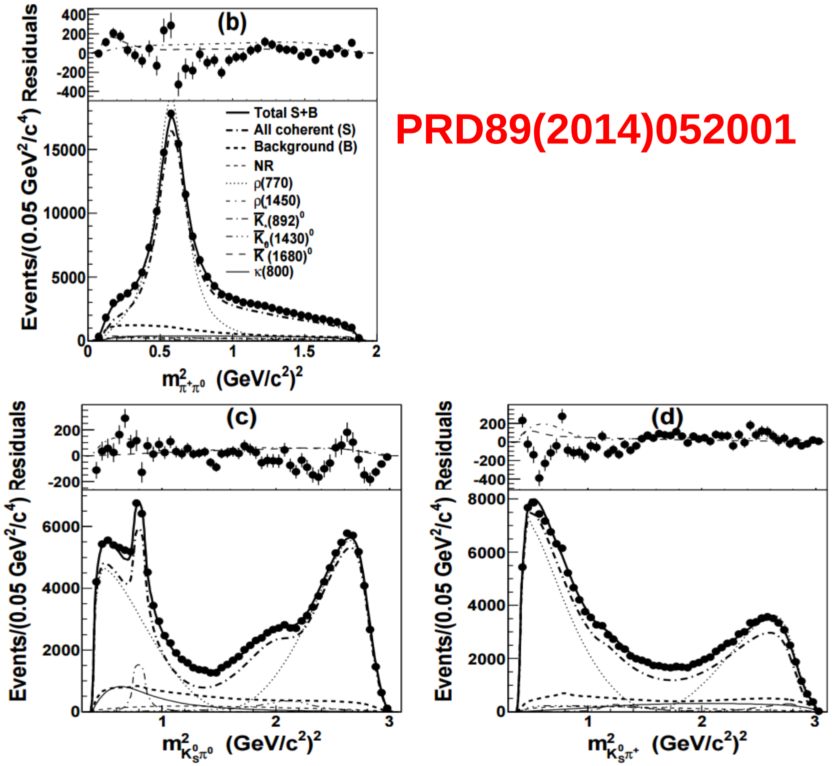
(b) Long-distance effects



$$\mathcal{B}_{D_s^+ \to p\bar{n}} = (1.22 \pm 0.10) \times 10^{-3}$$

多体D衰变振幅分析:VP/VV/SP/…两体衰变

$D^+ \rightarrow K_S \pi^+ \pi^0$



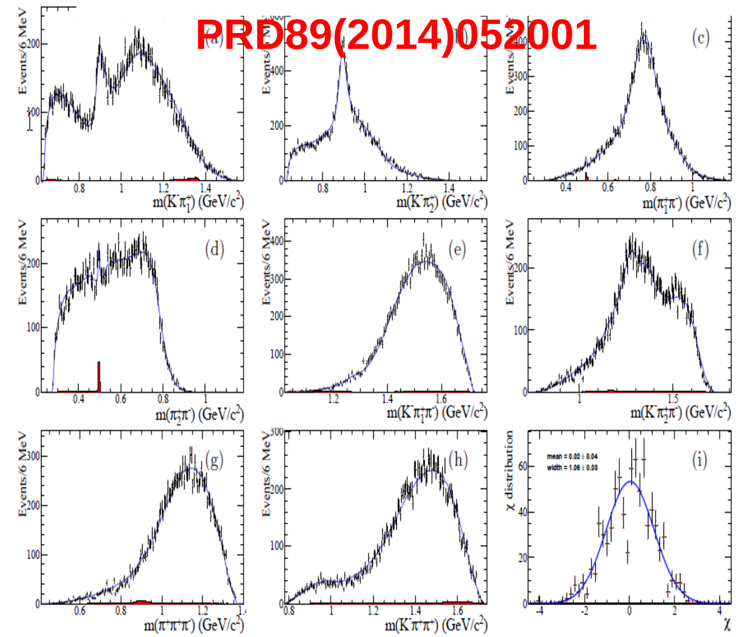
PRD89(2014)052001

Mode	Partial Branching Fraction (%)
$D^+ \to K^0_S\pi^+\pi^0$ Non Resonant	$0.32\pm0.05\pm0.25^{+0.28}_{-0.25}$
$D^+ \to \rho^+ K^0_S, \rho^+ \to \pi^+\pi^0$	$5.83\pm0.16\pm0.30^{+0.45}_{-0.15}$
$D^+ \to \rho(1450)^+ K^0_S, \rho(1450)^+ \to \pi^+\pi^0$	$0.15\pm0.02\pm0.09^{+0.07}_{-0.11}$
$D^+ \to \overline{K}^*(892)^0\pi^+, \overline{K}^*(892)^0 \to K^0_S\pi^0$	$0.250 \pm 0.012 \pm 0.015^{+0.025}_{-0.024}$
$D^+ \to \overline{K}^*_0(1430)^0\pi^+, \overline{K}^*_0(1430)^0 \to K^0_S\pi^0$	$0.26 \pm 0.04 \pm 0.05 \pm 0.06$
$D^+ \to \overline{K}^*(1680)^0\pi^+, \overline{K}^*(1680)^0 \to K^0_S\pi^0$	$0.09 \pm 0.01 \pm 0.05^{+0.04}_{-0.08}$
$D^+ \to \overline{\kappa}^0\pi^+, \overline{\kappa}^0 \to K^0_S\pi^0$	$0.54 \pm 0.09 \pm 0.28^{+0.36}_{-0.19}$
$NR+\overline{\kappa}^0\pi^+$	$1.30\pm0.12\pm0.12^{+0.12}_{-0.30}$
$K^0_S\pi^0$ S-wave	$1.21\pm0.10\pm0.16^{+0.19}_{-0.27}$

$D^0 \rightarrow K^-\pi^+\pi^+\pi^-$

Help to determine the absolute BF, strong phase, benefit γ/φ₃

Previous analyses only from MarkIII and E691

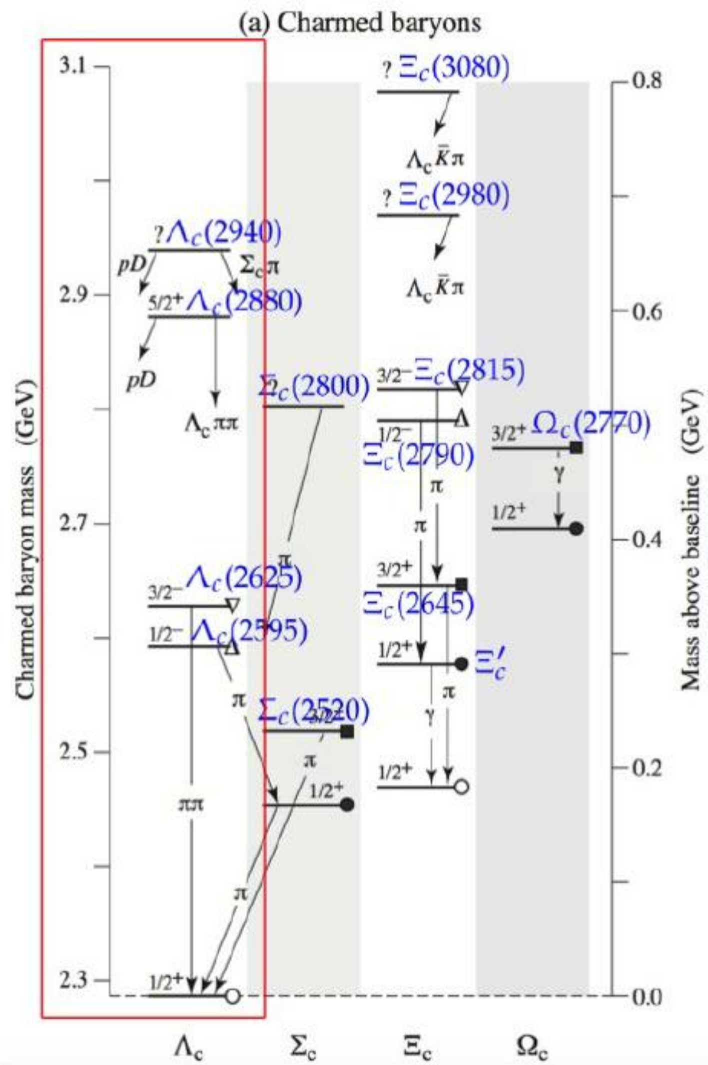


PRD89(2014)052001

Component	Branching fraction (%)	PDG value (%)
$D^0 \to \bar{K}^{*0}\rho^0$	$0.99 \pm 0.04 \pm 0.04 \pm 0.03$	1.05 ± 0.23
$D^0 \to K^- a_1^+(1260)(\rho^0\pi^+)$	$4.41 \pm 0.22 \pm 0.30 \pm 0.13$	3.6 ± 0.6
$D^0 \to K_1^-(1270)(\bar{K}^{*0}\pi^-)\pi^+$	$0.07 \pm 0.01 \pm 0.02 \pm 0.00$	0.29 ± 0.03
$D^0 \to K_1^-(1270)(K^-\rho^0)\pi^+$	$0.27 \pm 0.02 \pm 0.04 \pm 0.01$	
$D^0 \to K^-\pi^+\rho^0$	$0.68 \pm 0.09 \pm 0.20 \pm 0.02$	0.51 ± 0.23
$D^0 \to \bar{K}^{*0}\pi^+\pi^-$	$0.57 \pm 0.03 \pm 0.04 \pm 0.02$	0.99 ± 0.23
$D^0 \to K^-\pi^+\pi^+\pi^-$	$1.77 \pm 0.05 \pm 0.04 \pm 0.05$	1.88 ± 0.26

粲重子Λ_c^+衰变

2014年前粲重子研究



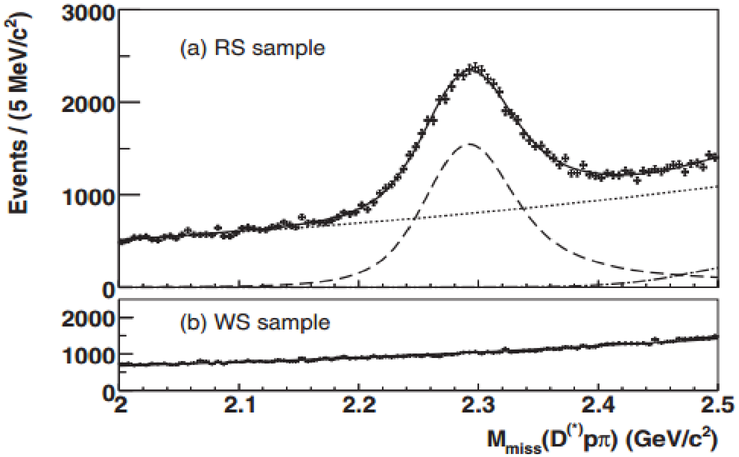
- **Λ_c^+ was observed in 1979**
- **All decays of Λ_c^+ were measured with high energy data and relative to $pK^-\pi^+$, which suffers an error of 25%. No absolute measurement using threshold Λ_c^+ data**
- **Only about 60% decays are known**

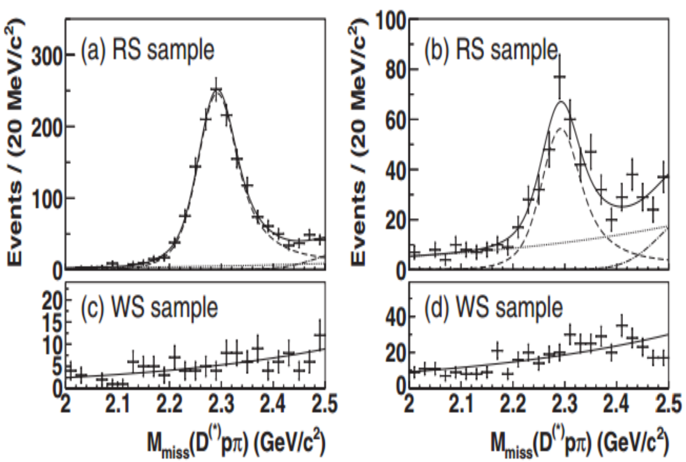
Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes with a p: $S = -1$ final states				
$p\overline{K}^0$		(2.3 ± 0.6) %		873
$pK^-\pi^+$	[a]	(5.0 ± 1.3) %		823
$p\overline{K}^*(892)^0$	[b]	(1.6 ± 0.5) %		685
$\Delta(1232)^{++}K^-$		(8.6 ± 3.0) $\times 10^{-3}$		710
$\Lambda(1520)\pi^+$	[b]	(1.8 ± 0.6) %		627
$pK^-\pi^+$ nonresonant		(2.8 ± 0.8) %		823
$p\overline{K}^0\pi^0$		(3.3 ± 1.0) %		823
$p\overline{K}^0\eta$		(1.2 ± 0.4) %		568

Systematic studies of Λ_c^+, search for new decays, absolute BF measurements are important to explore Λ_c^+ decay mechanisms

$\Lambda_c^+ \to$强子衰变绝对分支比的改进测量

BELLE, PRL113(2014)042002

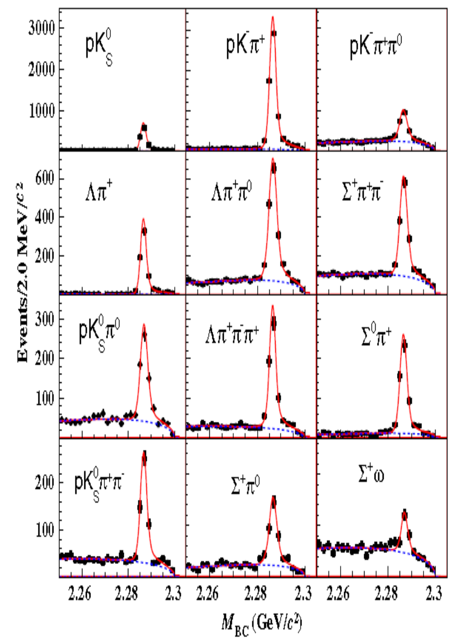




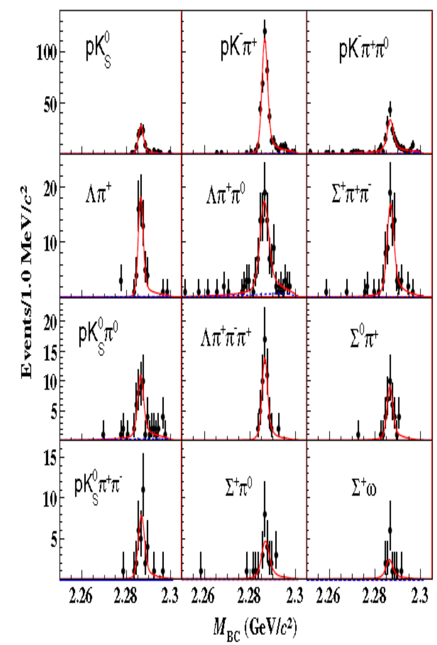
$B[\Lambda_c^+ \to pK^-\pi^+]=(6.84\pm0.24^{+0.21}_{-0.27})\%$

BESIII, PRL116(2016)052001

ST: ~15000



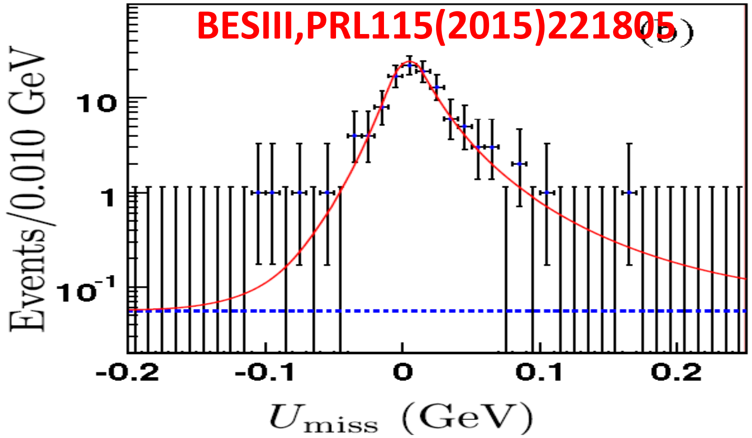
DT: ~1000



Mode	This work (%)	PDG (%)
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28
$\Lambda\pi^+\pi^0$	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3
$\Lambda\pi^+\pi^-\pi^+$	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7
$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34
$\Sigma^+\pi^+\pi^-$	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0
$\Sigma^+\omega$	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0

Much better precision

首次测定半轻衰变$\Lambda_c^+ \to \Lambda l^+ \nu$的绝对分支比

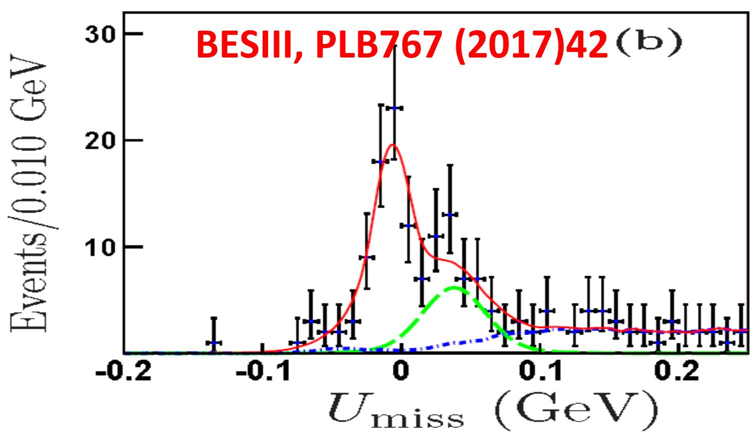


$B[\Lambda_c^+ \to \Lambda e^+ \nu] = (3.63 \pm 0.38 \pm 0.20)\%$

3 fb^{-1} data help to explore FF studies

Calibrate theoretical calculations: (1.4-9.2)%

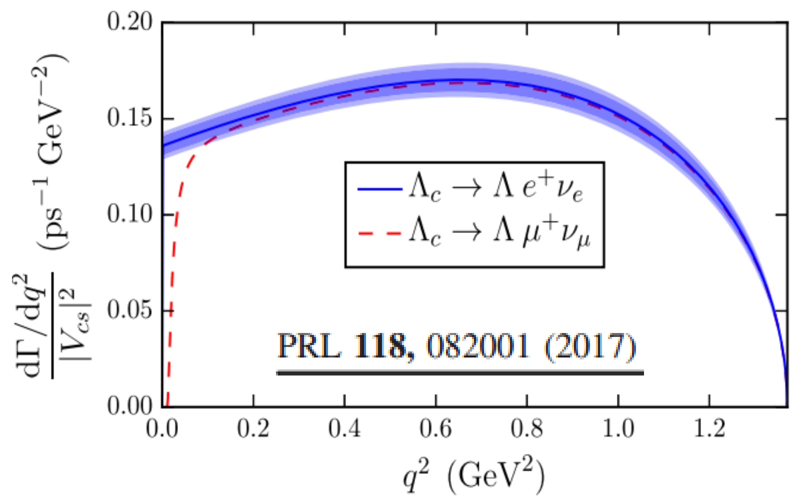
Theoretical Models	predicated branching fraction for $\Lambda_c^+ \to \Lambda e^+ \nu_e$
MBM [1]	1.9%
NRQM [1]	2.6%
SU(4)-symmetry limit [2]	9.2%
RSQM [3]	4.4%
QCM [4]	5.62%
SQM [5]	1.96%
NRQM2 [6]	2.15%
NRQM3 [7]	1.42%
QCD SR1 [8]	$(3.0 \pm 0.9)\%$
QCD SR2 [9]	$(2.6 \pm 0.4)\%$
QCD SR3 [9]	$(5.8 \pm 1.5)\%$
STSR [10]	2.22% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
STNR [10]	1.58% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
HOSR [10]	4.72% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
HONR [10]	4.2% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
LCSRs [11]	$(3.0 \pm 0.3)\%$ for $\Lambda_c^+ \to \Lambda l^+ \nu_l$ (CZ-type)
PDG 2014 [14]	$(2.1 \pm 0.6)\%$
BESIII	$(3.63 \pm 0.38 \pm 0.20)\%$



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

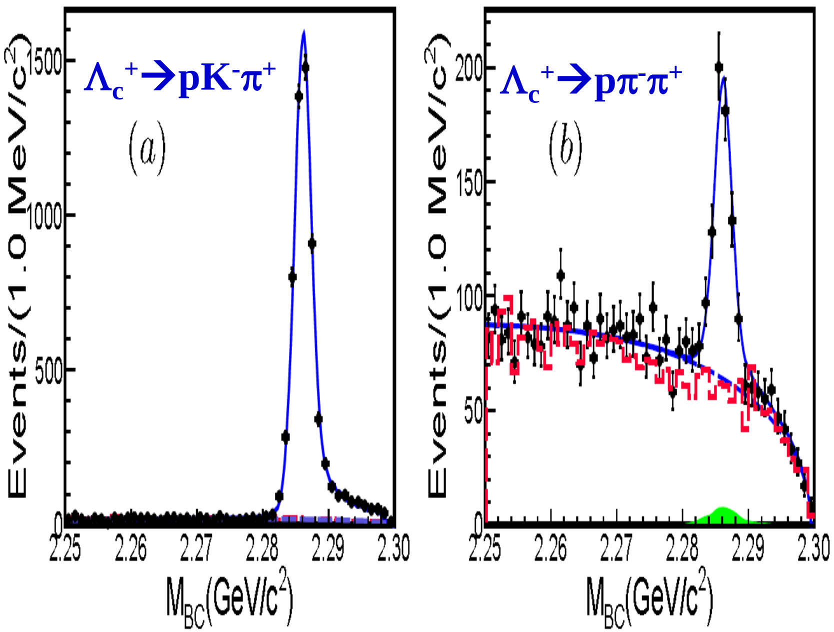
$\Gamma[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu]/\Gamma[\Lambda_c^+ \to \Lambda e^+ \nu_e] = 0.96 \pm 0.16 \pm 0.04$

促进LQCD对形状因子的计算

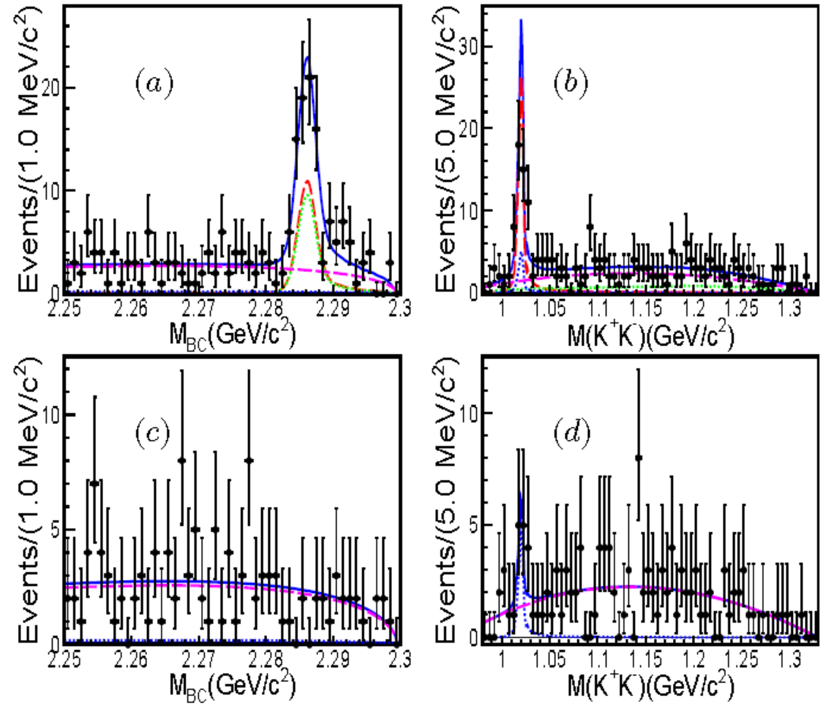


改进测定$\Lambda_c^+ \to pK^+K^-/p\pi^+\pi^-$绝对分支比

BESIII,PRL117(2016)232002



$\Lambda_c^+ \to pK^-K^+$

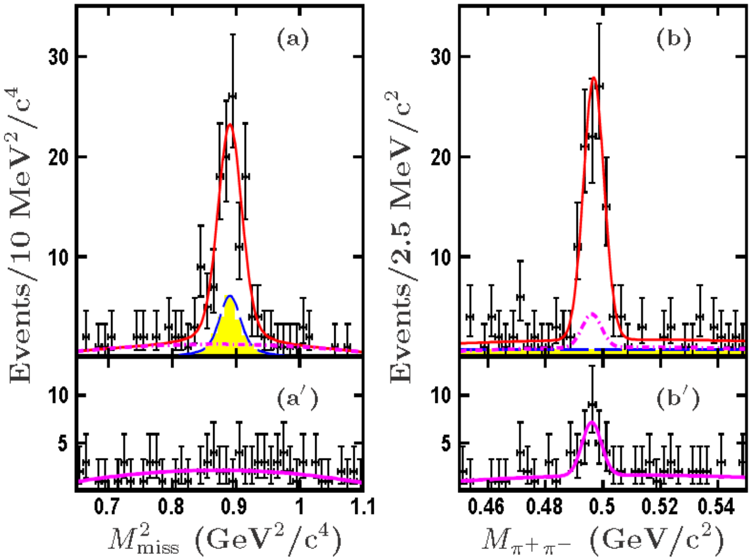


These help to distinguish predictions from different theoretical models and understand contributions from factorizable effects

Decay modes	$\mathcal{B}_{\rm mode}/\mathcal{B}_{\rm ref.}$	$\mathcal{B}_{\rm mode}$	$\mathcal{B}$(PDG)
$\Lambda_c^+ \to p\pi^+\pi^-$	$(6.70 \pm 0.48 \pm 0.25) \times 10^{-2}$	$(3.91 \pm 0.28 \pm 0.15 \pm 0.24) \times 10^{-3}$	$(3.5 \pm 2.0) \times 10^{-3}$
$\Lambda_c^+ \to p\phi$	$(1.81 \pm 0.33 \pm 0.13) \times 10^{-2}$	$(1.06 \pm 0.19 \pm 0.08 \pm 0.06) \times 10^{-3}$	$(8.2 \pm 2.7) \times 10^{-4}$
$\Lambda_c^+ \to pK^+K^-$ (non-ϕ)	$(9.36 \pm 2.22 \pm 0.71) \times 10^{-3}$	$(5.47 \pm 1.30 \pm 0.41 \pm 0.33) \times 10^{-4}$	$(3.5 \pm 1.7) \times 10^{-4}$

首次观测到含中子衰变$\Lambda_c^+ \to nK_S\pi^+$

BESIII,PRL118(2017)112001



$B[\Lambda_c^+ \to nK_S\pi^+]=(1.82\pm0.23\pm0.11)\%$

$\Gamma[\Lambda_c^+ \to n\bar{K}^0\pi^+]/\Gamma[\Lambda_c^+ \to pK^-\pi^+]=0.62\pm0.09$

$\Gamma[\Lambda_c^+ \to n\bar{K}^0\pi^+]/\Gamma[\Lambda_c^+ \to p\bar{K}^0\pi^+]=0.97\pm0.16$

First measurement of BF of Λ_c^+ decay containing neutron

$$\cos\delta = -0.24 \pm 0.08$$

$$|I^{(1)}|/|I^{(0)}| \quad 1.14 \pm 0.11$$

involving a neutron. Under the isospin symmetry, its amplitude is related to those of the most favored proton modes $\Lambda_c^+ \to pK^-\pi^+$ and $\Lambda_c^+ \to p\bar{K}^0\pi^0$ as $\mathcal{A}(n\bar{K}^0\pi^+) + \mathcal{A}(pK^-\pi^+) + \sqrt{2}\mathcal{A}(p\bar{K}^0\pi^0) = 0$. Hence, precise measure-

[2,3]. In the three-body Λ_c^+ decay to $N\bar{K}\pi$, the total decay amplitudes can be decomposed into two isospin amplitudes of the $N\bar{K}$ system as isosinglet ($I^{(0)}$) and isospin-one ($I^{(1)}$). In the factorization limit, the color-allowed tree diagram, in which the π^+ is emitted and the $N\bar{K}$ is an isosinglet, dominates $I^{(0)}$, and $I^{(1)}$ is expected to be small compared to $I^{(0)}$ as it can only proceed through the color-suppressed tree diagrams. Though the factorization scheme is spoiled in

Help to understand SU(3) and isospin symmetry and determine strong phase

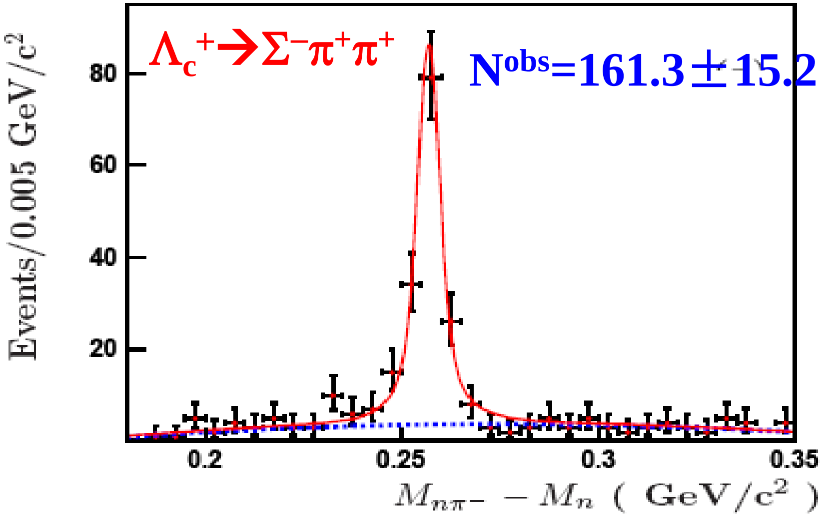
Cai-Dian Lv et al, PRD93(2016)056008

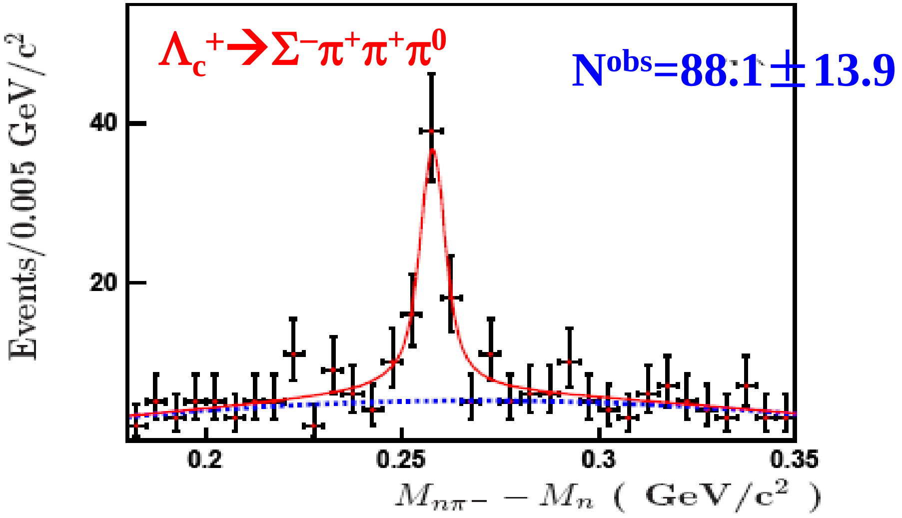
$$\cos\delta = \frac{\mathcal{B}(n\bar{K}^0\pi^+) - \mathcal{B}(pK^-\pi^+)}{2\sqrt{\mathcal{B}(p\bar{K}^0\pi^0)(\mathcal{B}(pK^-\pi^+) + \mathcal{B}(n\bar{K}^0\pi^+) - \mathcal{B}(p\bar{K}^0\pi^0))}}$$

$$R_p = \frac{\mathcal{B}(\Lambda_c \to p\bar{K}^0\pi^0)}{\mathcal{B}(\Lambda_c \to pK^-\pi^+)}, \qquad R_n = \frac{\mathcal{B}(\Lambda_c \to n\bar{K}^0\pi^+)}{\mathcal{B}(\Lambda_c \to pK^-\pi^+)}$$

首次测定$\Lambda_c^+ \to \Sigma^- \pi^+ \pi^+ \pi^0$

BESIII, PLB772(2017)388





Preliminary results :

$B[\Lambda_c^+ \to \Sigma^- \pi^+ \pi^+]$ =(1.81±0.17±0.09)%

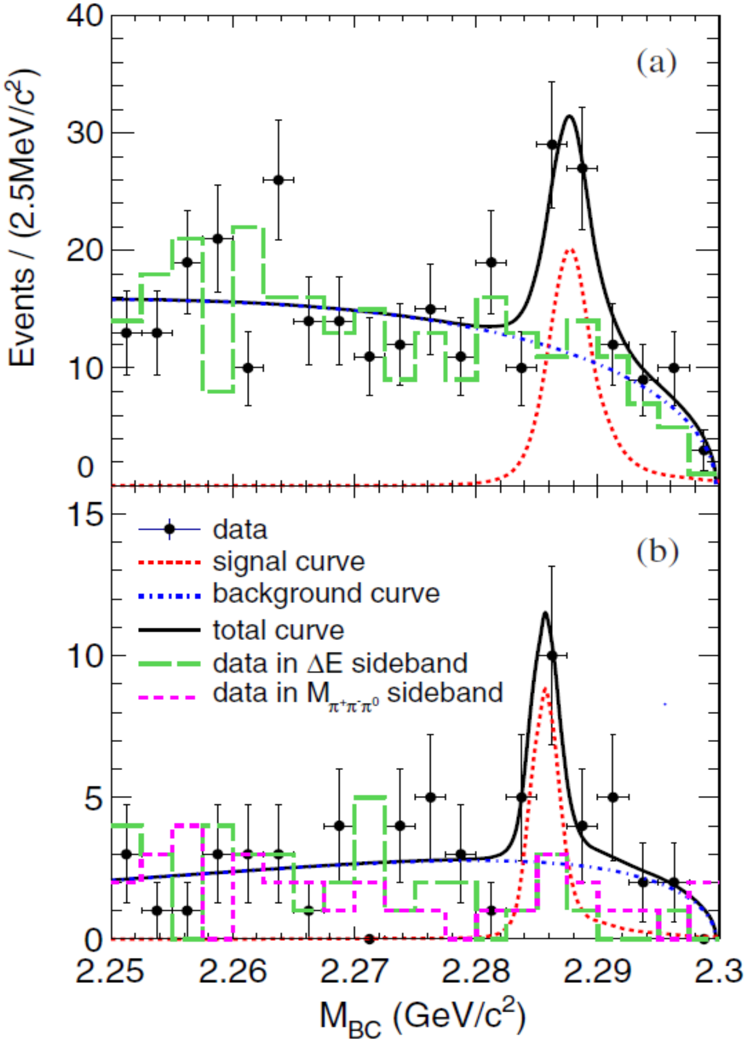
$B[\Lambda_c^+ \to \Sigma^- \pi^+ \pi^+ \pi^0]$=(2.11±0.33±0.14)% **[First observation]**

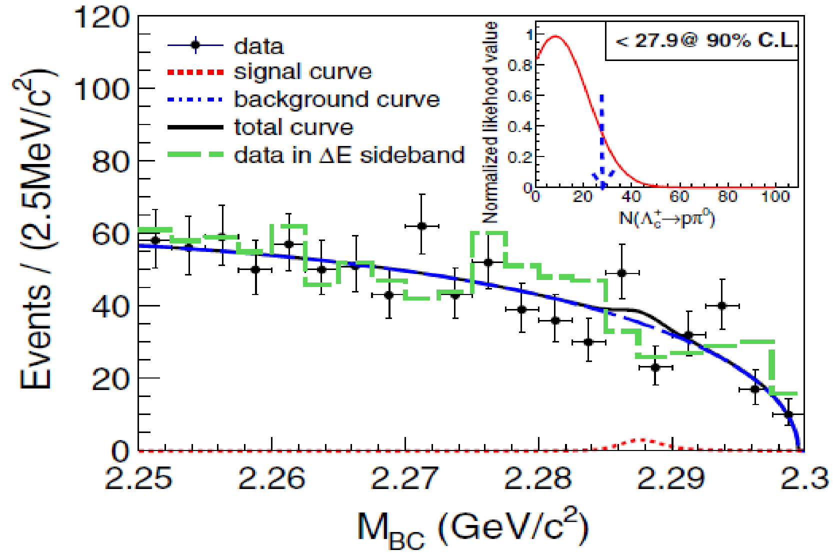
The previous one is consistent with and more precise than the PDG value of $[\Lambda_c^+ \to \Sigma^- \pi^+ \pi^+]$=(2.3±0.4)%.

首次测定$\Lambda_c^+ \to p\eta$并寻找$\Lambda_c^+ \to p\pi^0$

BESIII, PRD95(2017)111102(RC)

4.2σ





$B[\Lambda_c^+ \to p\pi^0] < 2.7\times10^{-4}$ 90%CL

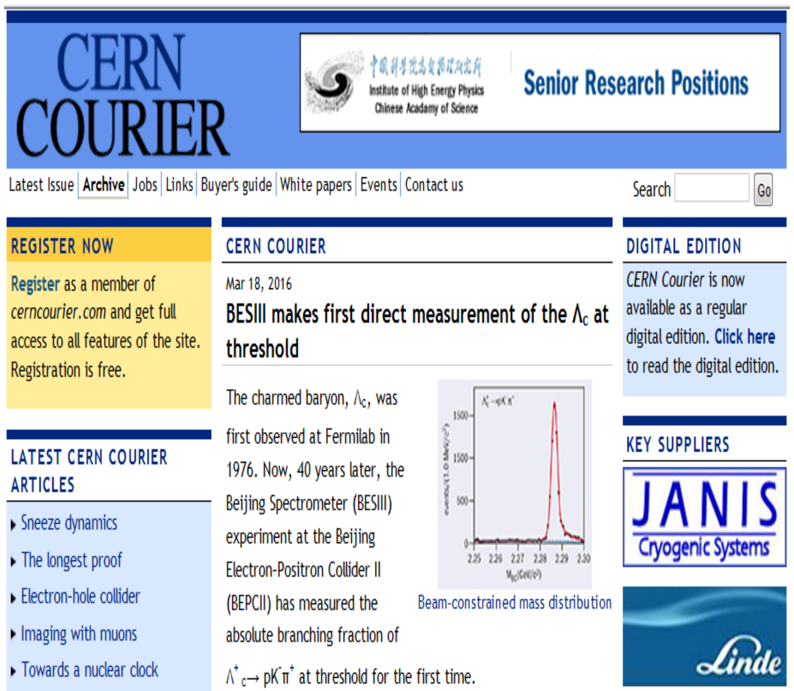
	$\Lambda_c^+ \to p\eta$	$\Lambda_c^+ \to p\pi^0$	$\frac{\mathcal{B}_{\Lambda_c^+ \to p\pi^0}}{\mathcal{B}_{\Lambda_c^+ \to p\eta}}$
BESIII	1.24 ± 0.29	<0.27	<0.24
Sharma *et al.* [3]	$0.2^{a}(1.7^{b})$	0.2	$1.0^{a}(0.1^{b})$
Uppal *et al.* [4]	0.3	0.1–0.2	0.3–0.7
S. L. Chen *et al.* [12]	...	$0.11–0.36^{c}$	...
Cai-Dian Lü *et al.* [13]	...	0.45	...

[a]Assumed to have a positive sign for the p-wave amplitude of $\Lambda_c^+ \to \Xi^0 K^+$.
[b]Assumed to have a negative sign for the p-wave amplitude of $\Lambda_c^+ \to \Xi^0 K^+$.
[c]Calculated relying on different values of parameters b and α.

$B[\Lambda_c^+ \to p\eta] = (1.24\pm0.28\pm0.10)\times10^{-3}$

Larger threshold Λ_c^+ data at BESIII

国际粲重子Λ_c^+衰变实验研究的里程碑：BESIII开辟使用近阈数据绝对测量Λ_c^+衰变的新领域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Mar 18, 2016
BESIII makes first direct measurement of the Λ_c at threshold

The charmed baryon, Λ_c, was first observed at Fermilab in 1976. Now, 40 years later, the Beijing Spectrometer (BESIII) experiment at the Beijing Electron-Positron Collider II (BEPCII) has measured the absolute branching fraction of $\Lambda^+_c \to pK^-\pi^+$ at threshold for the first time.

Beam-constrained mass distribution

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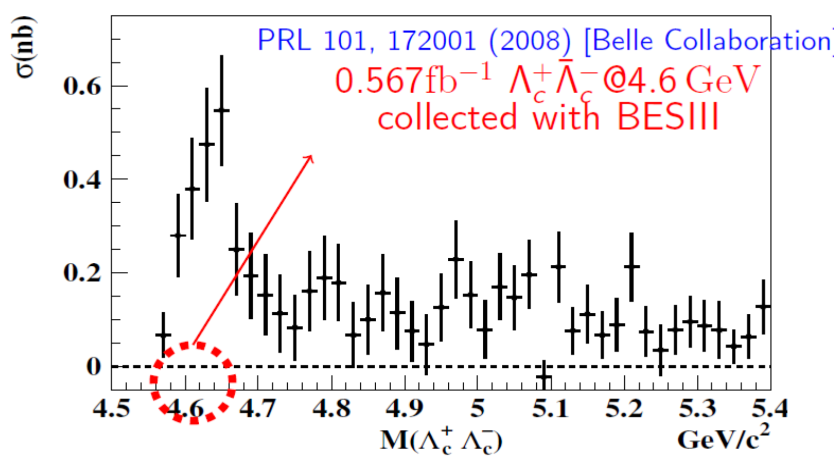
KEY SUPPLIERS
JANIS Cryogenic Systems
Linde

一个月左右数据已发表7篇物理文章，其中4篇PRL

与PDG14比，Λ_c^+衰变测量精度普遍改进3-5倍。但与粲介子的测量精度(1-2%)水平比，统计误差仍是制约因素

	Golden hadronic mode	δB/B	Golden SL mode	δB/B
D^0	B(Kπ)=(3.88±0.05)%	1.3%	B(Kev)=(3.55±0.05)%	1.4%
D^+	B(Kππ)=(9.13±0.19)%	2.1%	B(K⁰ev)=(8.83±0.22)%	2.5%
D_s	B(KKpi)=(5.39±0.21)%	3.9%	B(φev)=(2.49±0.14)%	5.6%
Λ_c	B(pKπ)=(5.0±1.3)%(PDG2014) =(6.8±0.36)% (BELLE) =(5.84±0.35)% (BESIII) =(6.46±0.24)% (HFAG)	26% 5.3% 6.0% 3.7%	B(Λev)=(2.1±0.6)%(PDG2014) =(3.63±0.43)% (BESIII) =(3.18±0.32)% (HFAG)	29% 12% 10%

更高能量4.65 GeV，更大近阈Λ_c^+样本，进一步系统研究Λ_c^+，寻找40%未知衰变(半轻、含中子和光子衰变)…



Observation of DCS decay of $\Lambda_c^+ \to pK^+\pi^-$

BELLE, PRL117(2016)011801

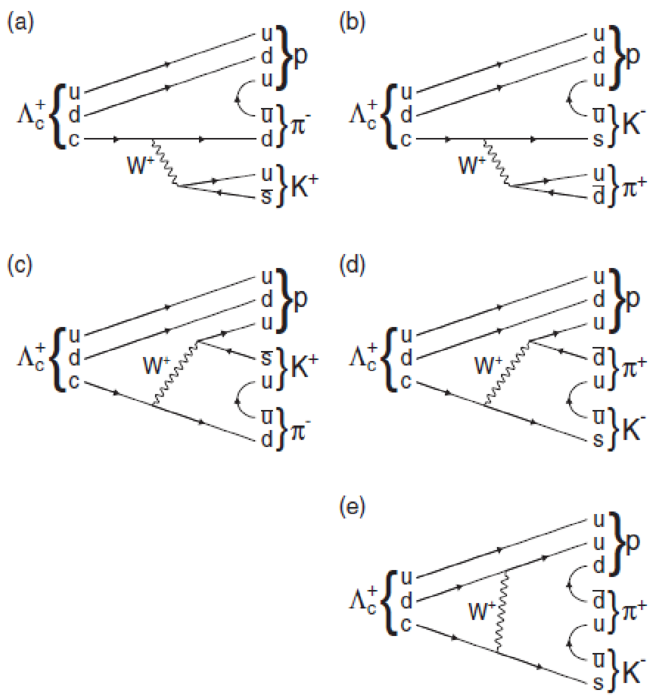
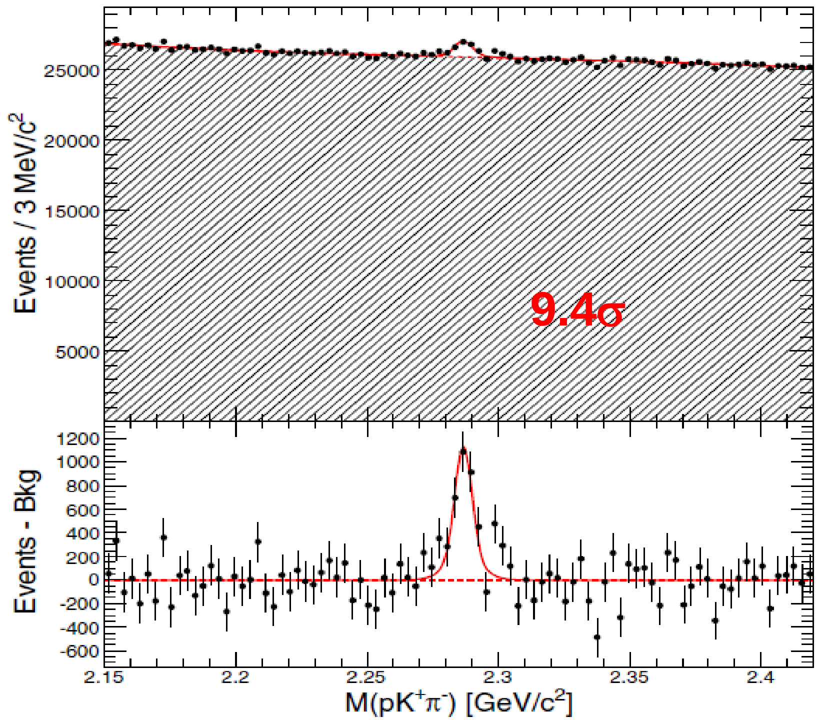


FIG. 1. Typical external (internal) W-emission diagrams for (a) [(c)] $\Lambda_c^+ \to pK^+\pi^-$ and (b) [(d)] $\Lambda_c^+ \to pK^-\pi^+$, and (e) a typical W-exchange diagram of $\Lambda_c^+ \to pK^-\pi^+$.



$B[\Lambda_c^+ \to pK^+\pi^-]/B[\Lambda_c^+ \to pK^-\pi^+] \sim (2.35\pm0.27\pm0.21)\%$

$B[\Lambda_c^+ \to pK^+\pi^-]/B[\Lambda_c^+ \to pK^-\pi^+] \sim \tan^4\theta_c$

$\sin\theta_c \sim 0.225\pm0.001$

Search for penta-quark in $\Lambda_c^+ \to pK^+K^-\pi^0$

BELLE, PRD96(2016)051102(RC)

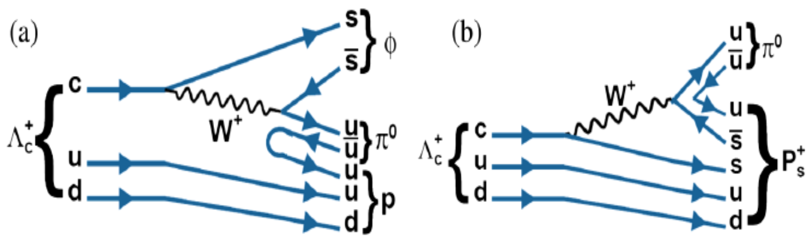
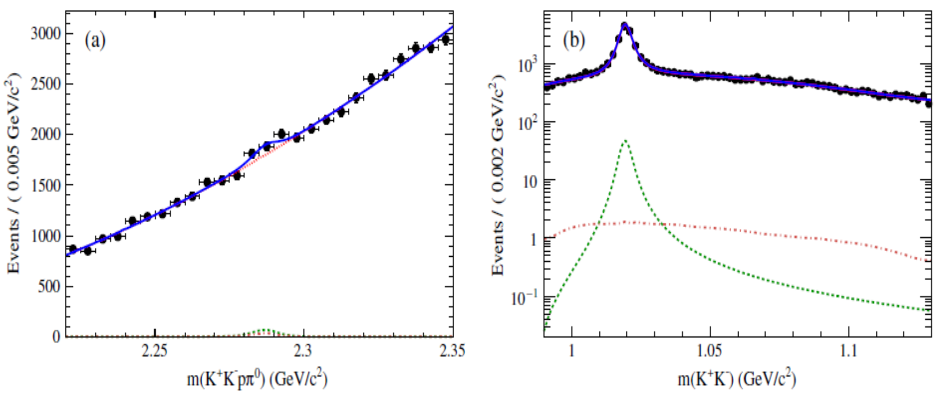
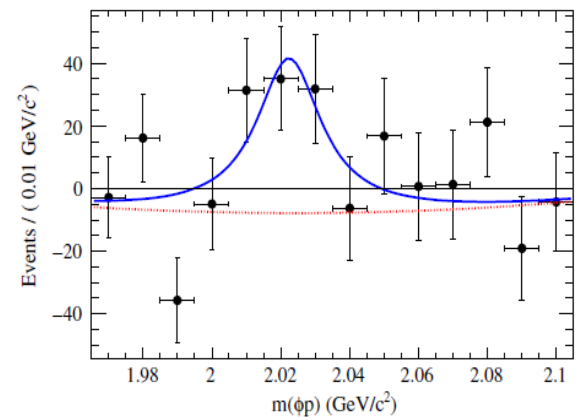


FIG. 1. Feynman diagram for the decay (a) $\Lambda_c^+ \to \phi p \pi^0$ and (b) $\Lambda_c^+ \to P_s^+ \pi^0$.

Inspired by the observation of two hidden-charm pentaquark states $P_c^+(4380)$ and $P_c+(4450)$ in $J/\psi p$ invariant mass spectrum at LCHb

Search for hidden-stangeness pentaquark states in ϕp invariant mass spectrum





$$\mathcal{B}(\Lambda_c^+ \to \phi p \pi^0) < 15.3 \times 10^{-5},$$ **@90%C.L.**

$$\mathcal{B}(\Lambda_c^+ \to K^+K^- p\pi^0)_{NR} < 6.3 \times 10^{-5}.$$

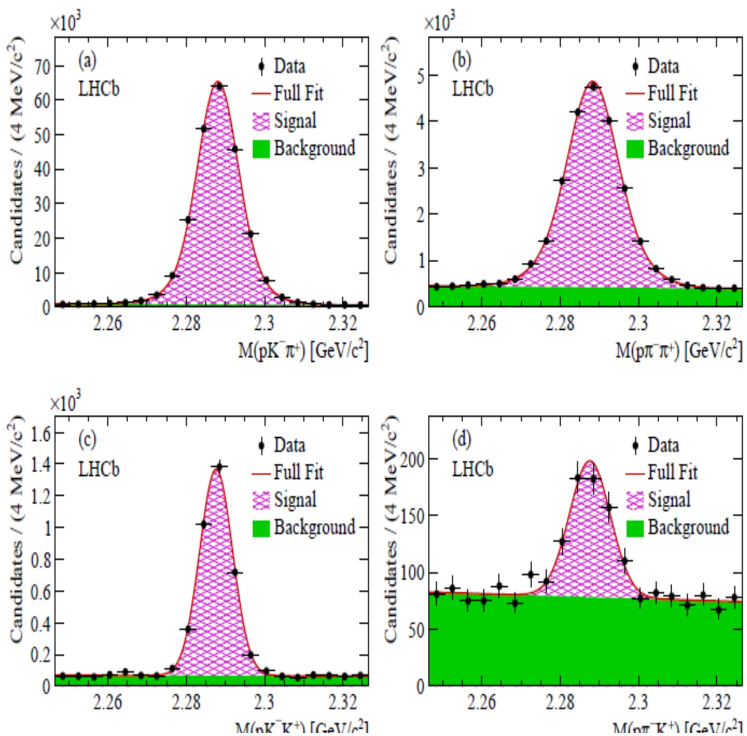
$$\mathcal{B}(\Lambda_c^+ \to P_s^+\pi^0) \times \mathcal{B}(P_s^+ \to \phi p) < 8.3 \times 10^{-5}$$

Measurements of $\Lambda_c^+ \to pK^+K^-/p\pi^+\pi^-/pK^+\pi^-$

LHCb, 1711.01157[hep-ex]

1 fb^{-1} data @ 7 TeV

$\Lambda_b^0 \to \Lambda_c^+(phh')\mu^-\overline{\nu}_\mu$ selection

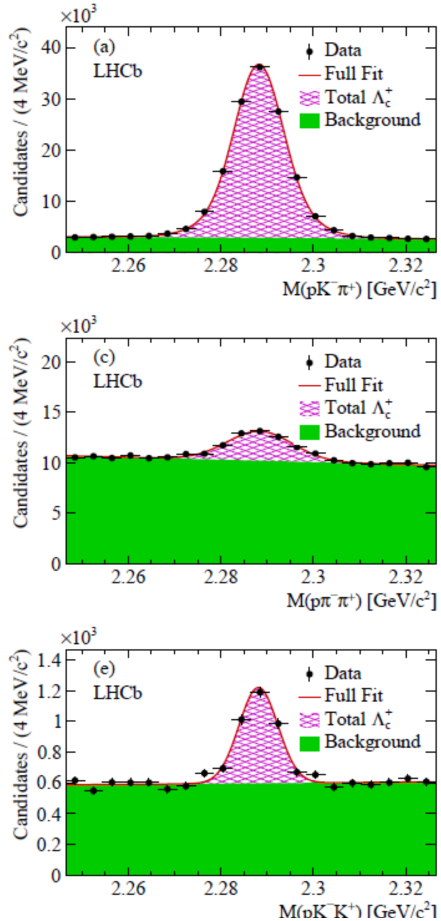


$$\frac{\mathcal{B}(\Lambda_c^+ \to p\pi^-\pi^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (7.44 \pm 0.08 \pm 0.18)\,\%,$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to pK^-K^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (1.70 \pm 0.03 \pm 0.03)\,\%,$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to p\pi^-K^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (0.165 \pm 0.015 \pm 0.005)\,\%,$$

Prompt $\Lambda_c^+ \to phh'$ selection



$$\mathcal{B}(\Lambda_c^+ \to p\pi^-\pi^+) = (4.72 \pm 0.05 \pm 0.11 \pm 0.25) \times 10^{-3},$$

$$\mathcal{B}(\Lambda_c^+ \to pK^-K^+) = (1.08 \pm 0.02 \pm 0.02 \pm 0.06) \times 10^{-3},$$

$$\mathcal{B}(\Lambda_c^+ \to p\pi^-K^+) = (1.04 \pm 0.09 \pm 0.03 \pm 0.05) \times 10^{-4},$$

BESIII粲物理研究总结

- $D^{0(+)}$研究取得一些重要物理成果

  --D^+衰变常数f_{D+}

  --形状因子$f^{D\to K(\pi)}_+(q^2)$

  --CKM矩阵元$|V_{cs(d)}|$

  --$D^0\bar{D}^0$混合参数y_{CP}, $\delta_{K\pi}$

  --$D^0\to K_S\pi^+\pi^-$强相差初步结果

  →精密检验格点QCD计算和CKM矩阵幺正性、探讨$D^0\bar{D}^0$混合、约束γ/ϕ_3测量

- Λ_c^+衰变的系统研究结束了其发现近40年来无近阈数据绝对测量的历史

- 2016年，在4.178 GeV采集了3.2 fb^{-1} D_s^+数据。已取得D_s^+衰变常数f_{Ds+}、CKM矩阵元$|V_{cs}|$等初步结果

- 更多物理结果将在未来1–2年完成

谢谢！

Analysis of $D^+ \to K_L e^+ v$

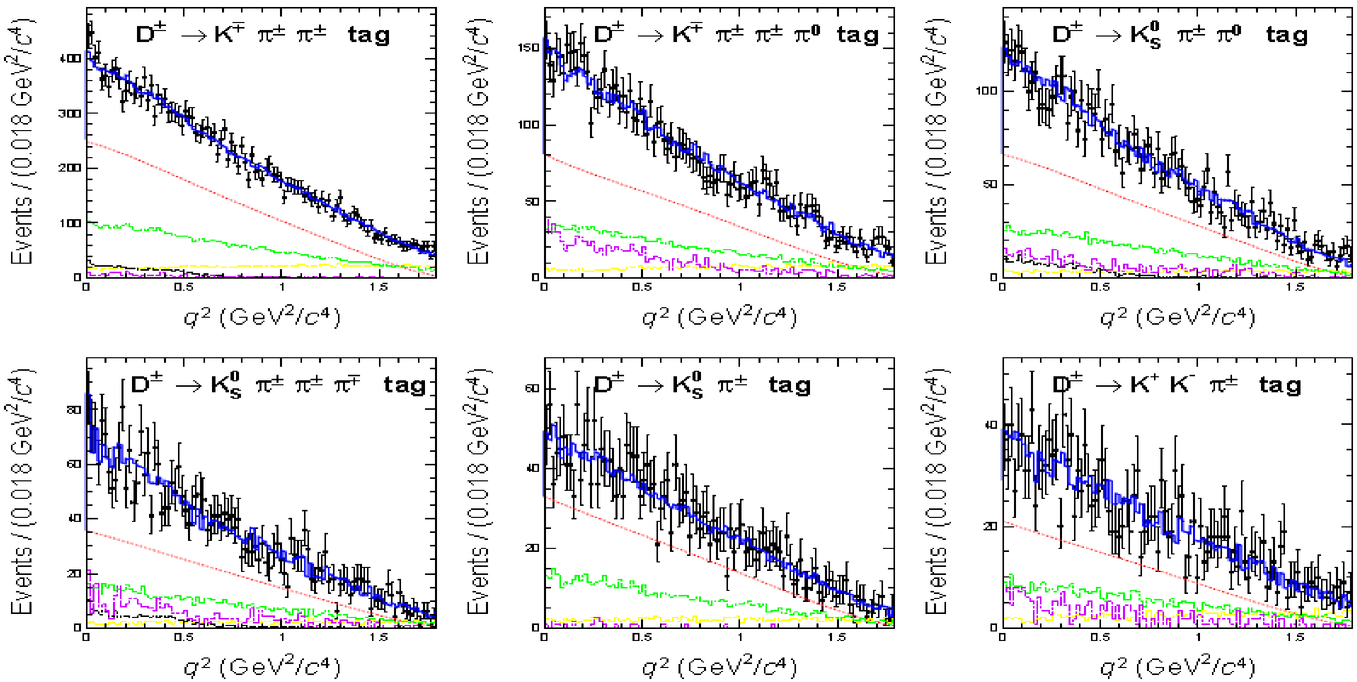
- Regardless of long flight distance, K_L interact with EMC and deposit part of energy, thus giving position information
- After reconstructing all other particles, K_L can be inferred with position information and constraint $U_{miss} \to 0$

$\bar{B}(D^+ \to K_L e^+ v) = (4.482 \pm 0.027 \pm 0.103)\%$

$$A_{CP} \equiv \frac{\mathcal{B}(D^+ \to K_L^0 e^+ \nu_e) - \mathcal{B}(D^- \to K_L^0 e^- \bar{\nu}_e)}{\mathcal{B}(D^+ \to K_L^0 e^+ \nu_e) + \mathcal{B}(D^- \to K_L^0 e^- \bar{\nu}_e)}$$

$A_{CP}^{D^+ \to K_L e^+ v} = (-0.59 \pm 0.60 \pm 1.50)\%$

Simultaneous fit to event density $I(q^2)$ with 2-par. series Form Factor



$D^+ \to K_L e+v$ is measured for the first time

PRD92(2015)112008

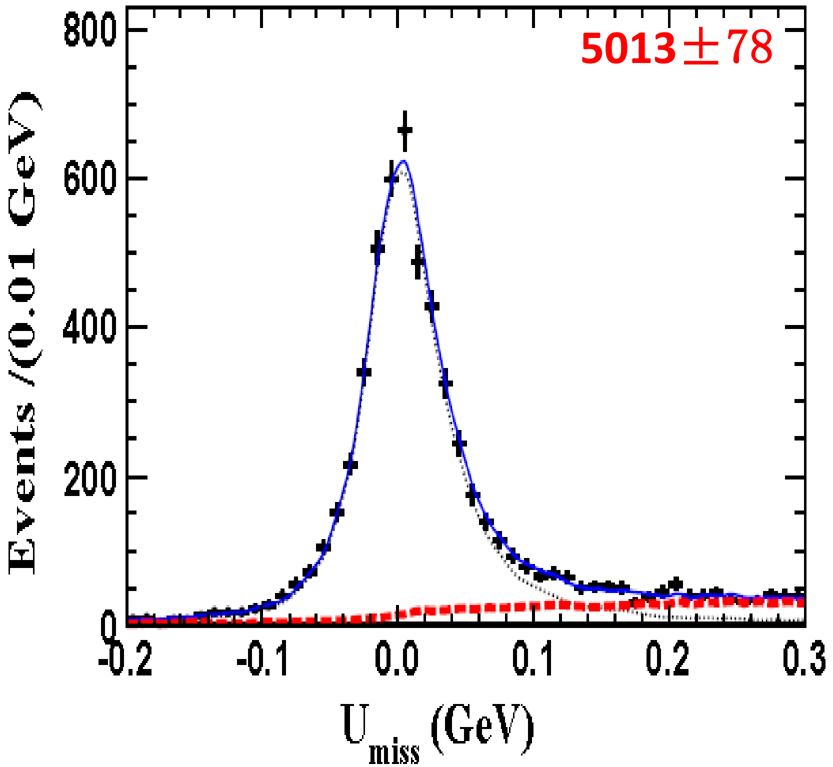
With 6 dominant D^- single tag

$f^K_+(0)|V_{cs}| = 0.728 \pm 0.006 \pm 0.011$

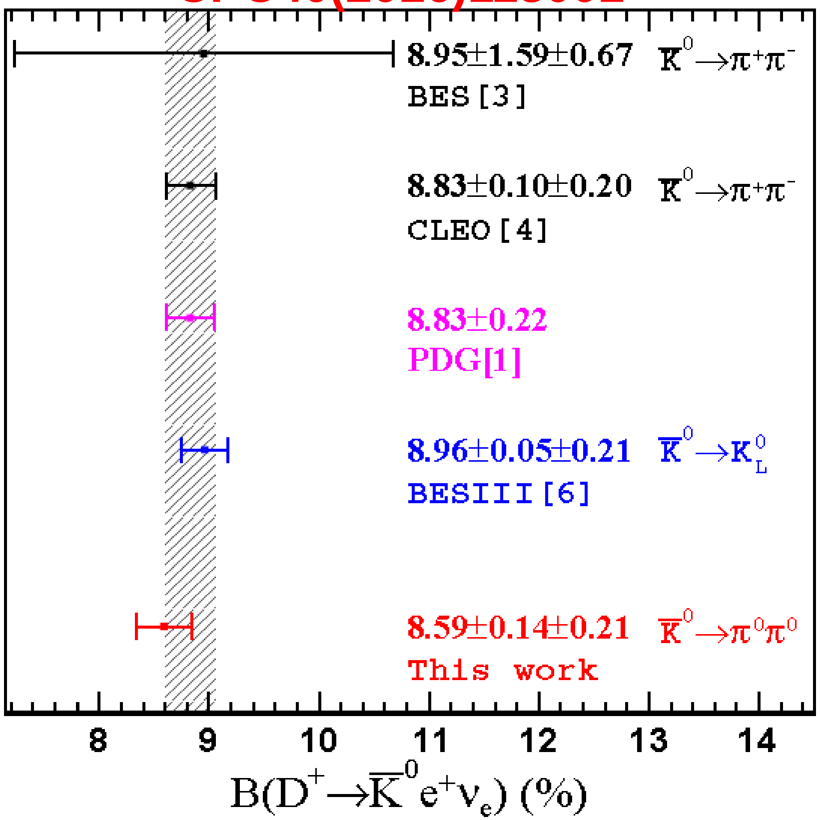
$r_1 = a_1/a_0 = -1.91 \pm 0.33 \pm 0.24$

Absolute BF for $D^+ \to \bar{K}^0 e^+ \nu$ via $\bar{K}^0 \to \pi^0 \pi^0$

With 6 dominant D^- single tag



CPC40(2016)113001



Taking τ_{D+}, τ_{D0}, $B[D^0 \to K^- e^+ \nu]$ and $B[D^+ \to \bar{K}^0 e^+ \nu]$ from the PDG as input

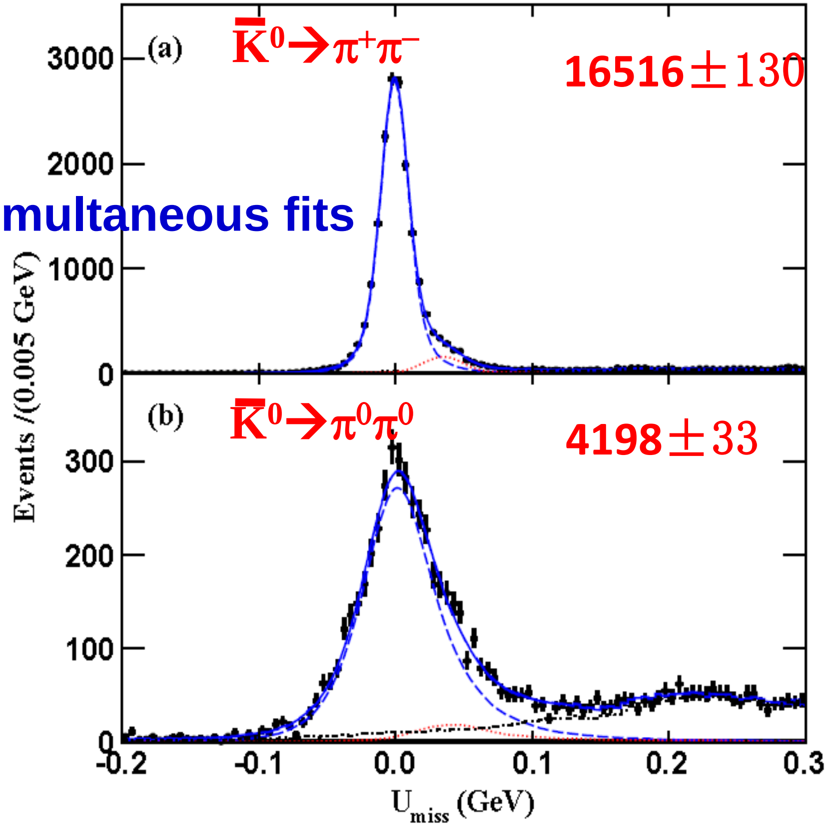
$$\frac{\Gamma[D^0 \to K^- e^+ \nu]}{\Gamma[D^+ \to \bar{K}^0 e^+ \nu]} = 0.969 \pm 0.025$$

Agrees with isospin conservation within 1.2σ

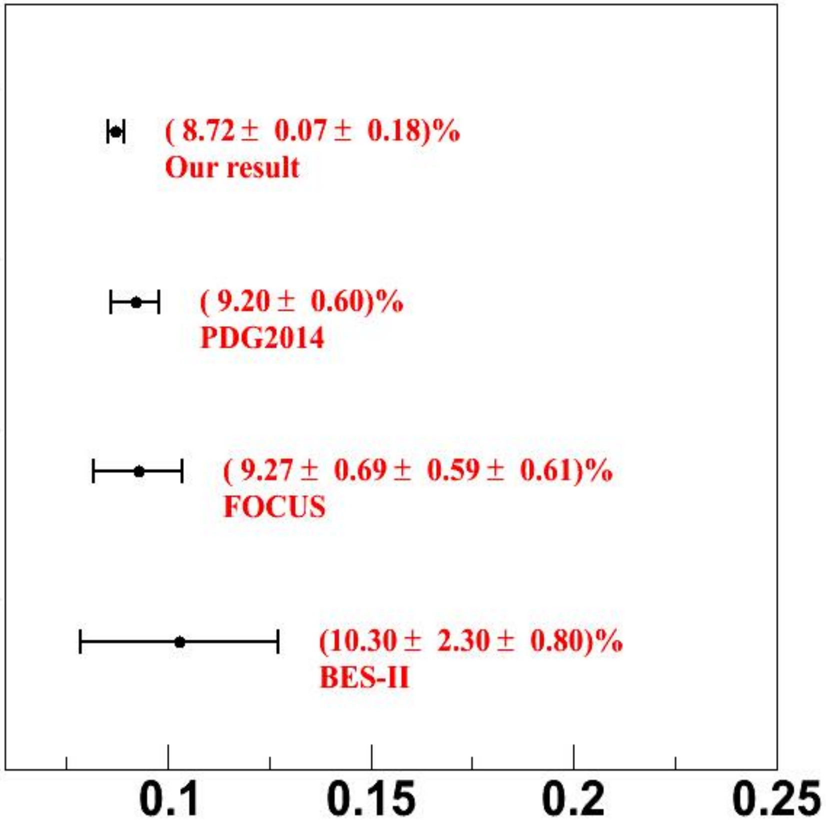
Improved BF for $D^+ \to \bar{K}^0 \mu^+ \nu$

With 6 dominant D^- single tag

Simultaneous fits



EPJC76(2016)369



Taking B[$D^0 \to K^-\mu^+\nu$] and B[$D^+ \to \bar{K}^0 e^+\nu$] from the PDG as input

$$\frac{\Gamma[D^0 \to K^-\mu^+\nu]}{\Gamma[D^+ \to \bar{K}^0\mu^+\nu]} = 0.963 \pm 0.044$$

Support isospin conservation in these two decays within errors

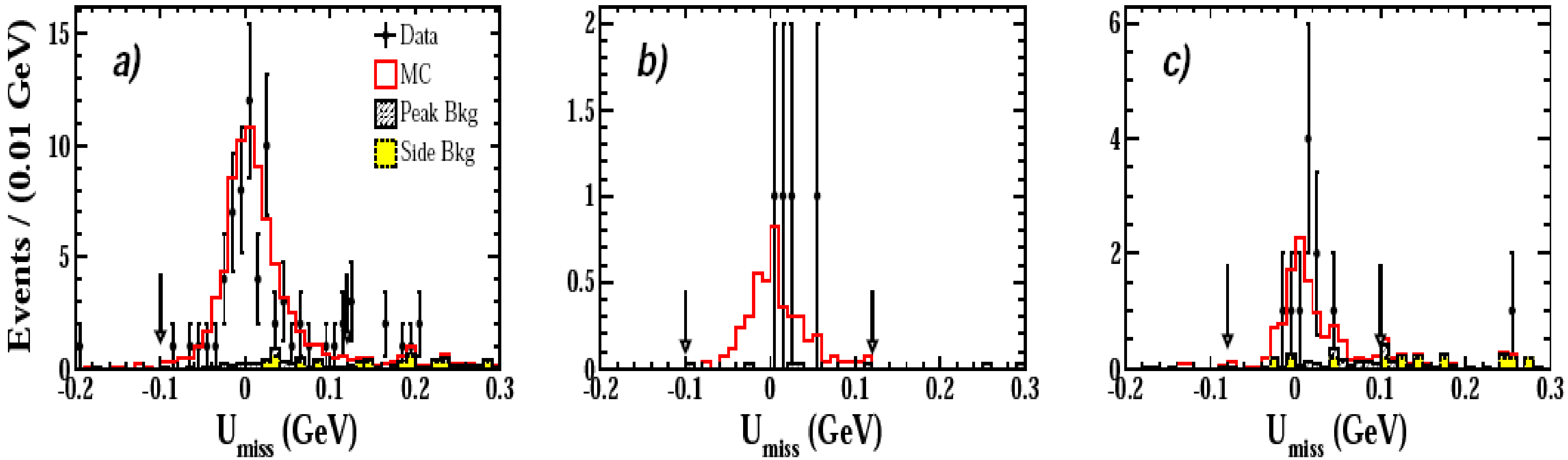
$$\frac{\Gamma[D^+ \to \bar{K}^0\mu^+\nu]}{\Gamma[D^+ \to \bar{K}^0 e^+\nu]} = 0.988 \pm 0.033$$

Consistent with theory prediction 0.97 within error

Measurements of BFs of $D_s^+ \to \eta^{(\prime)} e^+ \nu$

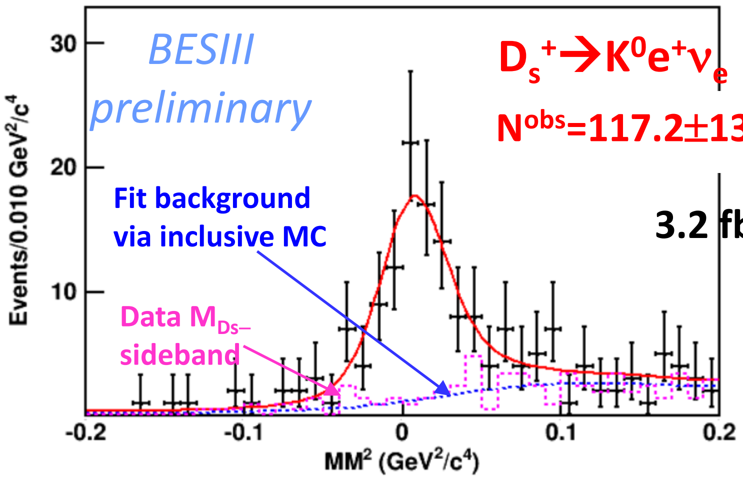
- Benefit the understanding of the source of difference of inclusive decay rates of $D^{0(+)}$ and D_s^+
- Complementary information to understand η–η' mixing

482 pb^{-1} data@4.009 GeV, PRD94(2016)112003

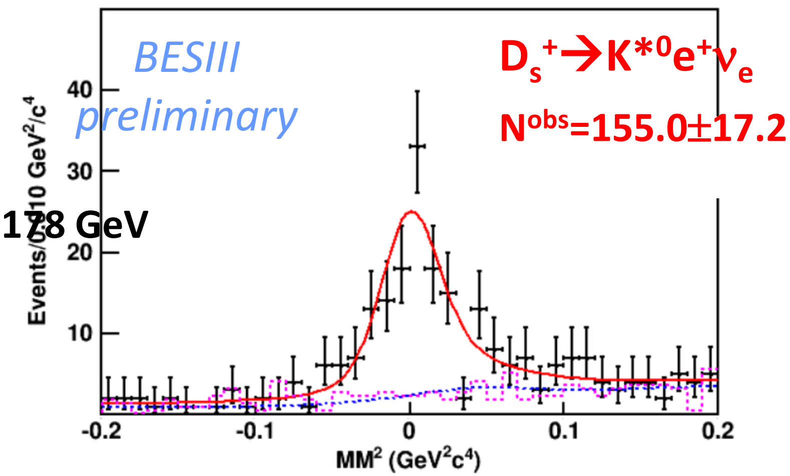


	BESIII	CLEOII 95	CLEOc09	CLEOc15	PDG [4]
$B(D_s^+ \to \eta e^+ \nu_e)[\%]$	$2.30 \pm 0.31 \pm 0.08$	—	$2.48 \pm 0.29 \pm 0.13$	$2.28 \pm 0.14 \pm 0.20$	2.67 ± 0.29
$B(D_s^+ \to \eta' e^+ \nu_e)[\%]$	$0.93 \pm 0.30 \pm 0.05$	—	$0.91 \pm 0.33 \pm 0.05$	$0.68 \pm 0.15 \pm 0.06$	0.99 ± 0.23
$\frac{B(D_s^+ \to \eta' e^+ \nu_e)}{B(D_s^+ \to \eta e^+ \nu_e)}$	$0.40 \pm 0.14 \pm 0.02$	$0.35 \pm 0.09 \pm 0.07$	—	—	—

Studies of $D_s^+ \to K^{(*)0} e^+ \nu$ at 4.178 GeV



3.2 fb^{-1} data@4.178 GeV

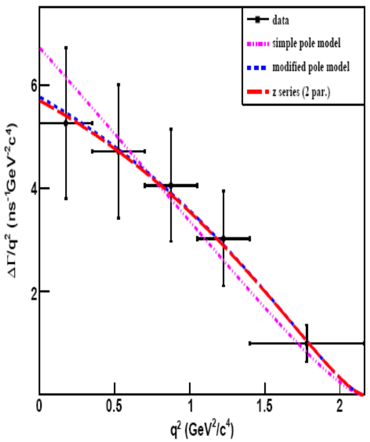


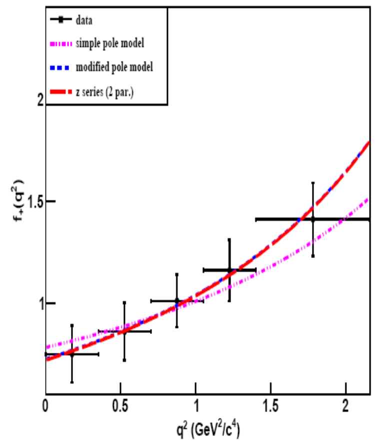
$B[D_s^+ \to K^0 e^+ \nu_e] = (3.25 \pm 0.38_{stat} \pm 0.14_{syst}) \times 10^{-3}$

$(3.9 \pm 0.9) \times 10^{-3}$ [PDG17]

$B[D_s^+ \to K^{*0} e^+ \nu_e] = (2.38 \pm 0.26_{stat} \pm 0.12_{syst}) \times 10^{-3}$

$(1.8 \pm 0.4) \times 10^{-3}$ [PDG17]

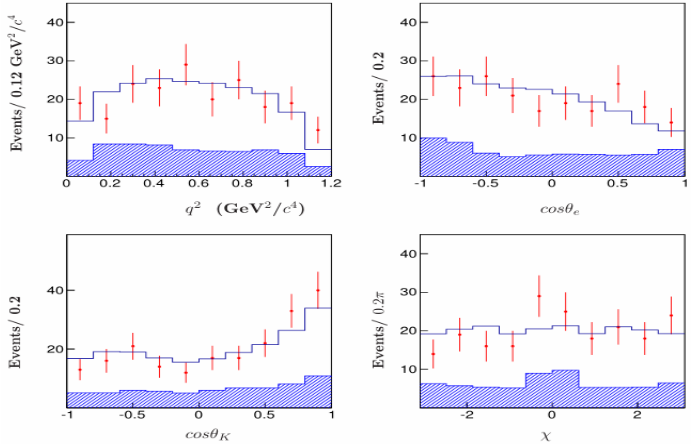




Model	Parameter	Value	$f_+(0)$
Simple pole	$f_+(0)\vert V_{cd}\vert$	$0.175 \pm 0.010 \pm 0.001$	$0.778 \pm 0.044 \pm 0.004$
Modified pole model	$f_+(0)\vert V_{cd}\vert$	$0.163 \pm 0.017 \pm 0.003$	$0.725 \pm 0.076 \pm 0.013$
	α	$0.45 \pm 0.44 \pm 0.02$	
Series two parameters	$f_+(0)\vert V_{cd}\vert$	$0.162 \pm 0.019 \pm 0.003$	$0.720 \pm 0.084 \pm 0.013$
	r_1	$-2.94 \pm 2.32 \pm 0.14$	

Taking $|V^{CKMfitter}_{cd}|$ as input

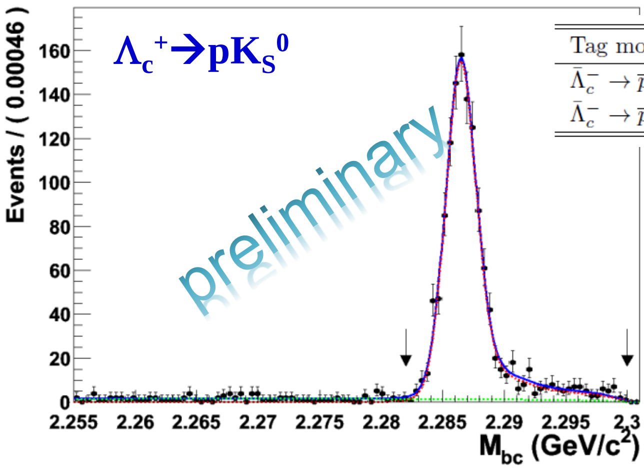
Four dimensional un-binned likelihood fit is performed. K* paramters are fixed



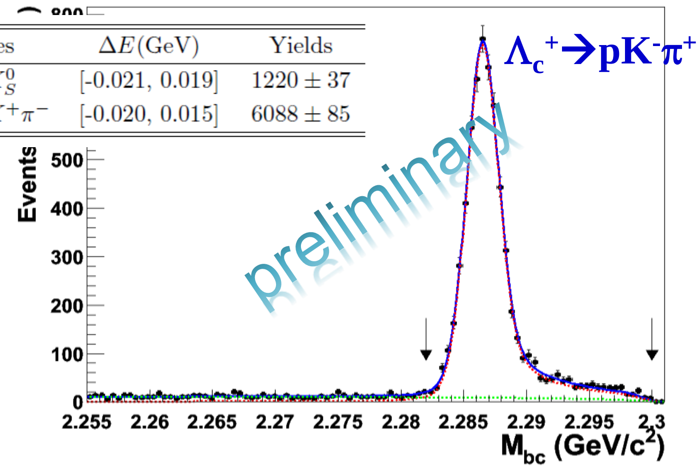
$r_V = 1.67 \pm 0.34 \pm 0.16$

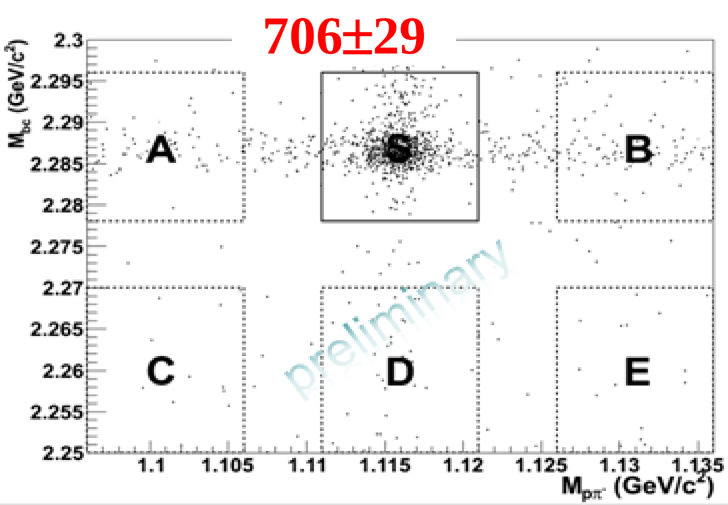
$r_2 = 0.77 \pm 0.28 \pm 0.07$

Inclusive decay $\Lambda_c^+ \to \Lambda X$



Tag modes	ΔE(GeV)	Yields
$\bar{\Lambda}_c^- \to \bar{p}K_S^0$	[-0.021, 0.019]	1220 ± 37
$\bar{\Lambda}_c^- \to \bar{p}K^+\pi^-$	[-0.020, 0.015]	6088 ± 85





Help to explore the source of missing decays and search for new decay. Better input for charm baryon and B physics

$$N_{sig} = N_S - (N_A + N_B)/2 - r \cdot N_D + r \cdot (N_C + N_E)/2$$

$\mathcal{B}(\Lambda_c^+ \to \Lambda + X) = (36.98 \pm 2.18)\%$ **stat. only**

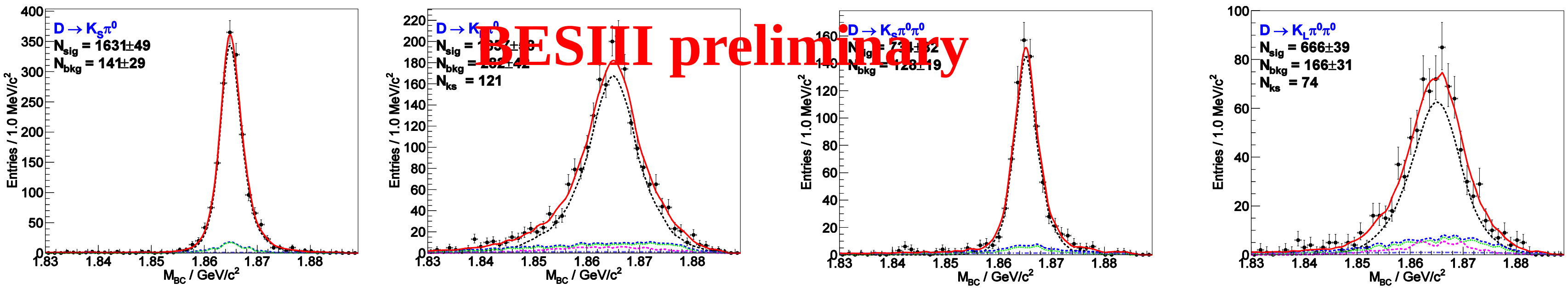
Agrees with PDG2015 value (35±11)%,

$$\mathcal{A}_{CP} = \frac{\mathcal{B}(\Lambda_c^+ \to \Lambda + X) - \mathcal{B}(\bar{\Lambda}_c^- \to \bar{\Lambda} + X)}{\mathcal{B}(\Lambda_c^+ \to \Lambda + X) + \mathcal{B}(\bar{\Lambda}_c^- \to \bar{\Lambda} + X)}.$$

Decay mode	Branching fraction(%)	$\mathcal{A}_{CP}$
$\Lambda_c^+ \to \Lambda + X$	38.02 ± 3.24	0.02 ± 0.06
$\bar{\Lambda}_c^- \to \bar{\Lambda} + X$	36.70 ± 3.04	

Absolute BFs and y_{CP} of $D^0 \to K_{S/L}\pi^0(\pi^0)$

- Two dimensional fits to M_{BC}(tag) versus M_{BC}(signal)
- Projections of DT evens on the M_{BC}(sig) vs. $K\pi$ (for example)



Branching fractions and asymmetries

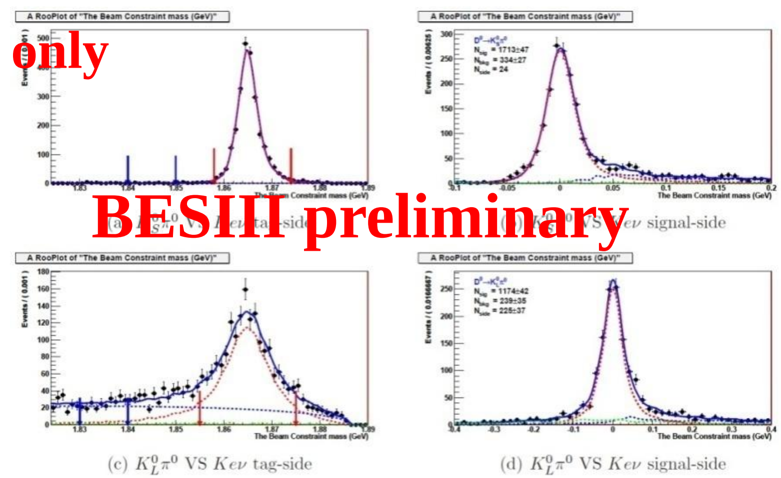
Statistical only

$$R(D \to K_{S,L} + \pi's) = \frac{Br(D \to K_S\pi's) - Br(D \to K_L\pi's)}{Br(D \to K_S\pi's) + Br(D \to K_L\pi's)}$$

Table 10: Decay rates and the asymmetries of $D \to K^0_{S,L}\pi^0$ and $D \to K^0_{S,L}\pi^0\pi^0$.

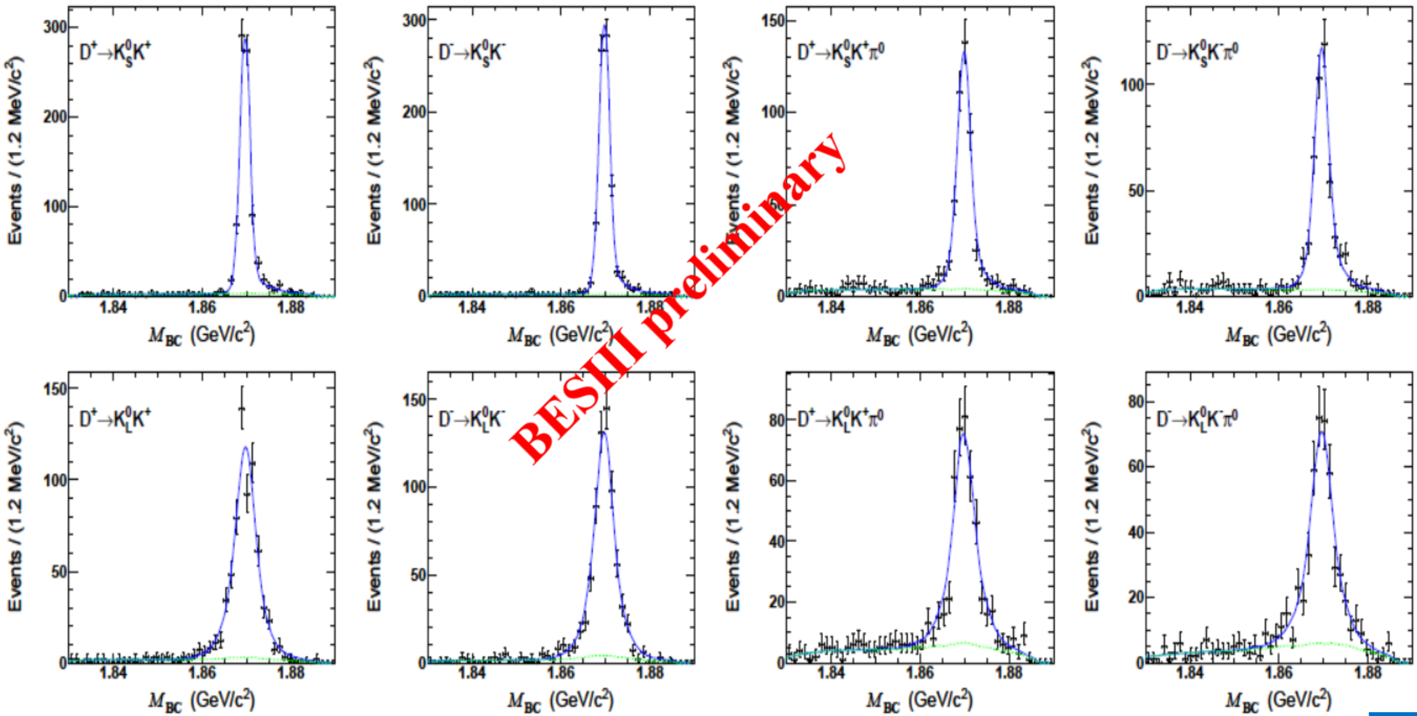
$D \to K^0_{S,L}\pi^0$			
	$Br_{K_S\pi^0}(\%)$	$Br_{K_L\pi^0}(\%)$	$R(D \to K_{S,L}\pi^0)$
$K\pi$	1.208±0.041	1.061±0.038	0.0646±0.0245
$K3\pi$	1.212±0.037	0.985±0.036	0.1035±0.0237
$K\pi\pi^0$	1.251±0.028	0.953±0.029	0.1351±0.0186
All	1.230±0.020	0.991±0.019	0.1077±0.0125

$D \to K^0_{S,L}\pi^0\pi^0$			
	$Br_{K_S2\pi^0}(\%)$	$Br_{K_L2\pi^0}(\%)$	$R(D \to K_{S,L}2\pi^0)$
$K\pi$	1.024±0.049	1.299±0.080	-0.1183±0.0385
$K3\pi$	0.887±0.043	1.097±0.073	-0.1060±0.0409
$K\pi\pi^0$	1.010±0.036	1.158±0.060	-0.0681±0.0313
All	0.975±0.024	1.175±0.040	-0.0929±0.0209



- y_{CP} (($K_S\pi^0$, $K_L\pi^0$) vs. $Ke\nu$) = (0.98±2.43)%

Absolute BFs and A_{CP} of $D^+ \to K_{S/L}K^+(\pi^0)$



The first and second uncertainties are statistical and systematic

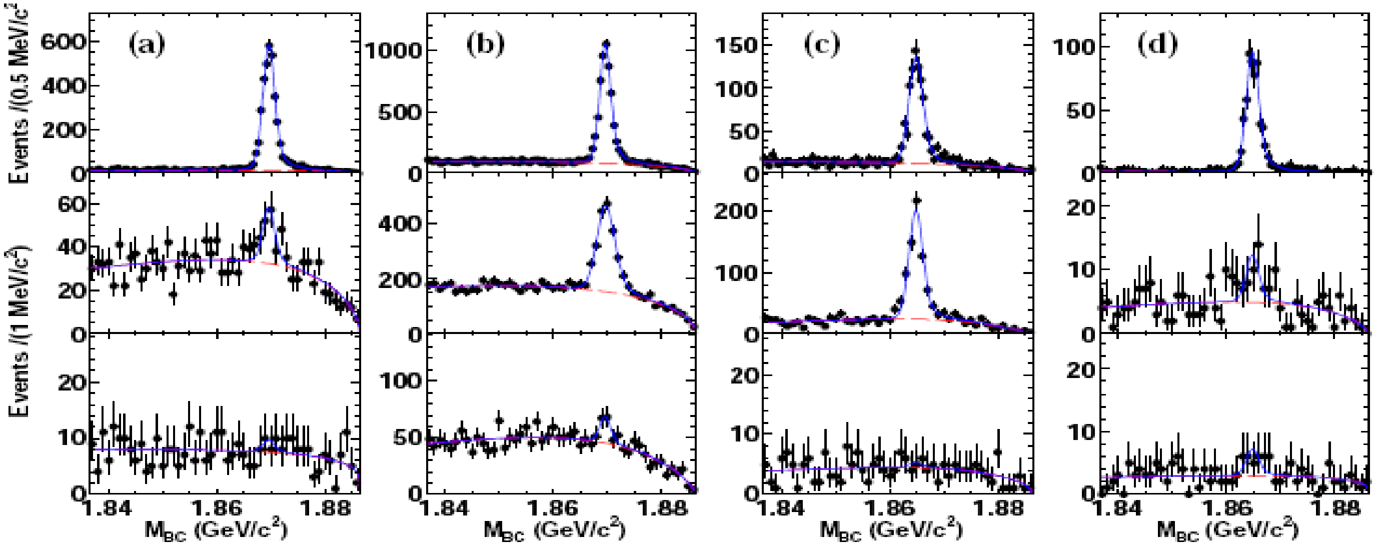
$$\mathcal{A}_{CP} = \frac{\mathcal{B}(D^+) - \mathcal{B}(D^-)}{\mathcal{B}(D^+) + \mathcal{B}(D^-)}$$

Mode	$\mathcal{B}(D^+)$ $(\times 10^{-3})$	$\mathcal{B}(D^-)$ $(\times 10^{-3})$	$\overline{\mathcal{B}}$ $(\times 10^{-3})$	$\mathcal{A}_{CP}$ (%)
$K_S^0 K^\pm$	$3.01 \pm 0.12 \pm 0.10$	$3.10 \pm 0.12 \pm 0.10$	$3.06 \pm 0.09 \pm 0.10$	$-1.5 \pm 2.8 \pm 1.6$
$K_S^0 K^\pm \pi^0$	$5.23 \pm 0.28 \pm 0.24$	$5.09 \pm 0.29 \pm 0.22$	$5.16 \pm 0.21 \pm 0.23$	$1.4 \pm 4.0 \pm 2.4$
$K_L^0 K^\pm$	$3.13 \pm 0.14 \pm 0.13$	$3.32 \pm 0.15 \pm 0.13$	$3.23 \pm 0.11 \pm 0.13$	$-3.0 \pm 3.2 \pm 1.2$
$K_L^0 K^\pm \pi^0$	$5.17 \pm 0.30 \pm 0.21$	$5.26 \pm 0.30 \pm 0.20$	$5.22 \pm 0.22 \pm 0.21$	$-0.9 \pm 4.1 \pm 1.6$

BFs of $D^+ \to 2K_S K(\pi)^+$ and $D^0 \to 2(3)K_S$

Comprehensive or improved measurements of 3-body decays benefit the understanding of the interplay between weak and strong interactions in multibody decays, where theory is poor than 2-body decays

BF of $D^0 \to K_S K_S$ will be helpful to explore the SU(3) symmetry breaking in D decays



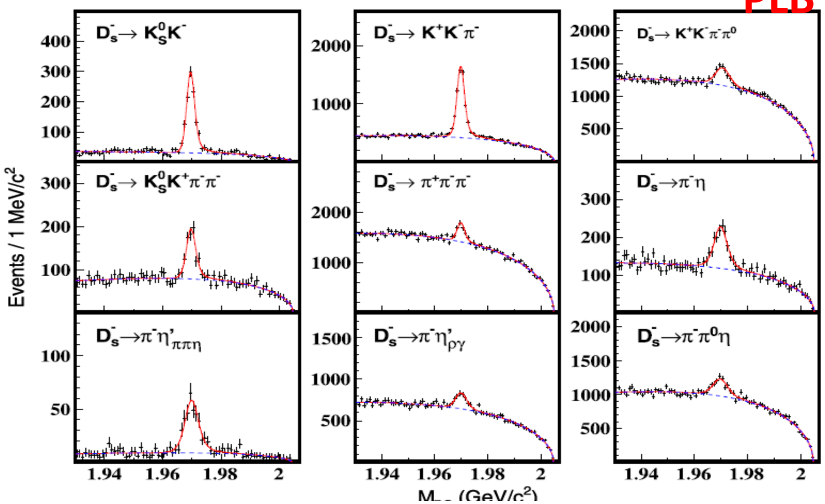
Comparisons of the branching fractions (in 10^{-4}) measured in this work with the PDG values

Decay modes	This work	PDG
$D^+ \to K^0_S K^0_S K^+$	$25.4 \pm 0.5 \pm 1.2$	45 ± 20
$D^+ \to K^0_S K^0_S \pi^+$	$27.0 \pm 0.5 \pm 1.2$	–
$D^0 \to K^0_S K^0_S$	$1.67 \pm 0.11 \pm 0.11$	1.7 ± 0.4
$D^0 \to K^0_S K^0_S K^0_S$	$7.21 \pm 0.33 \pm 0.44$	9.1 ± 1.3

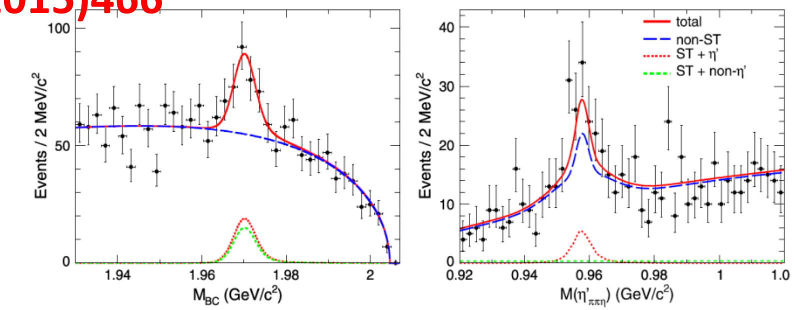
PLB765(2017)231

$D_s^+ \to \eta' X$ and $\eta'\rho^+$

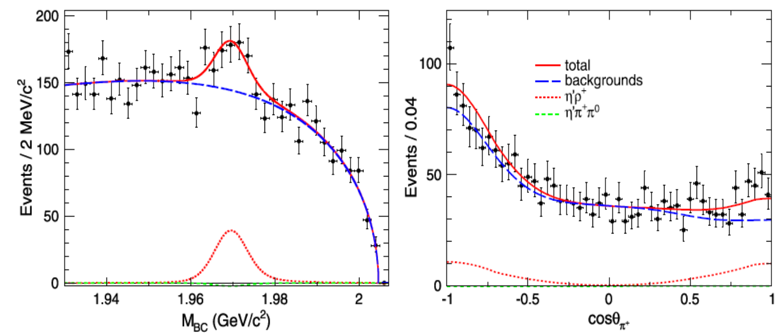
PLB 750(2015)466



~15.6 K ST



$N[D_s^+ \to \eta' X] = 68 \pm 14$



$N[D_s^+ \to \eta'\rho^+] = 210 \pm 50$

$B_{CLEO}[D_s^+ \to \eta'\rho^+] = (12.5 \pm 2.2)\%$

PRD58(1998)052002

是理论预期$(3.0 \pm 0.5)\%$的4倍

F.S.Yu PRD84(2011)074019

$B^{PDG14}_{SUM}[D_s^+ \to \eta' X] = (18.6 \pm 2.3)\%$

$B_{MSR}[D_s^+ \to \eta' X] = (11.7 \pm 1.8)\%$

PRD79(2009)112008

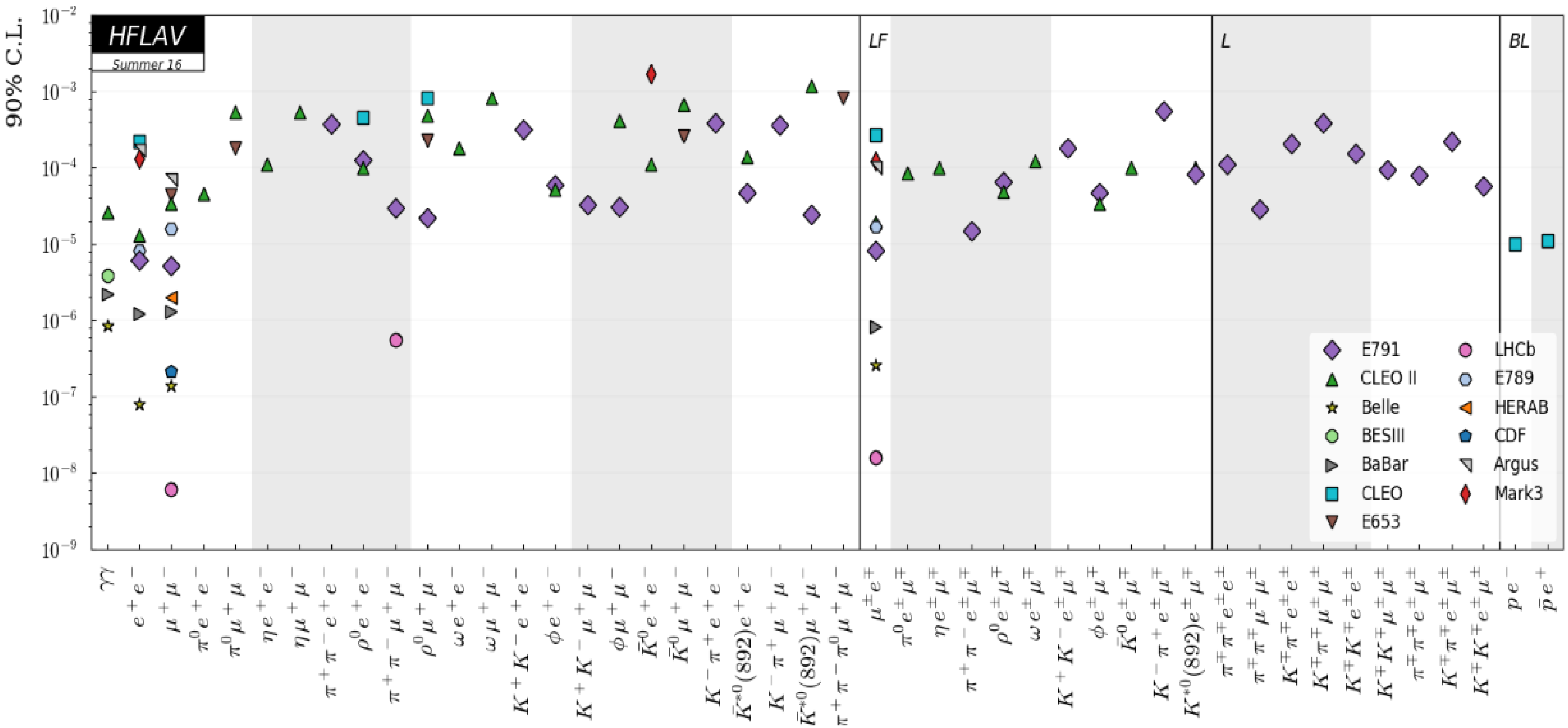
$B[D_s^+ \to \eta' X] = (8.8 \pm 1.8 \pm 0.5)\%$

$B[D_s^+ \to \eta'\rho^+] = (5.8 \pm 1.4 \pm 0.4)\%$

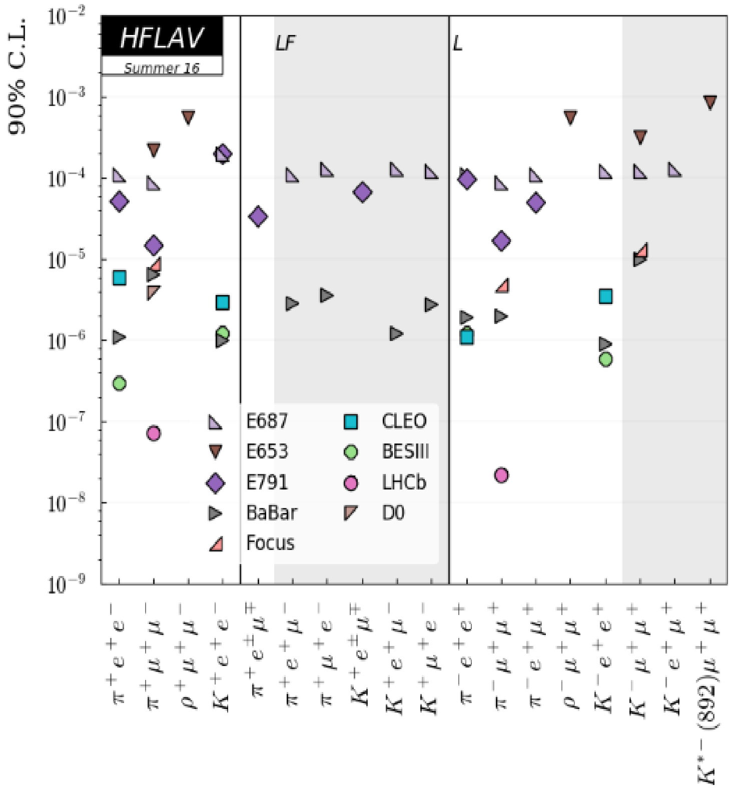
与CLEOPRD88(2013)032009一致

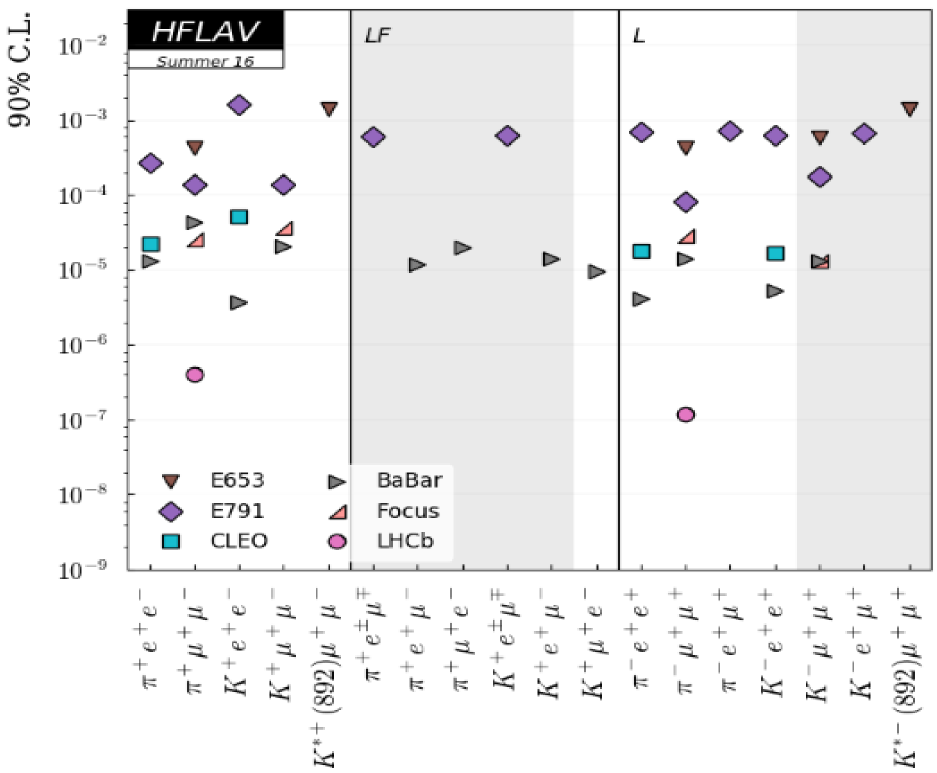
新实验结果解决了实验和理论不一致的矛盾

Status of rare D^0 decays



Status of rare $D_{(s)}^+$ decays

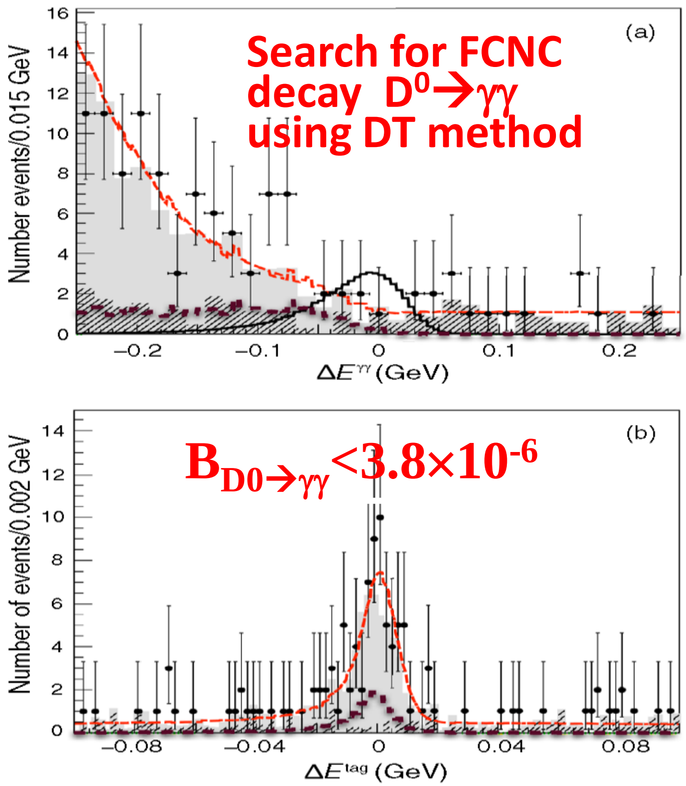




So far, no rare D decay is found

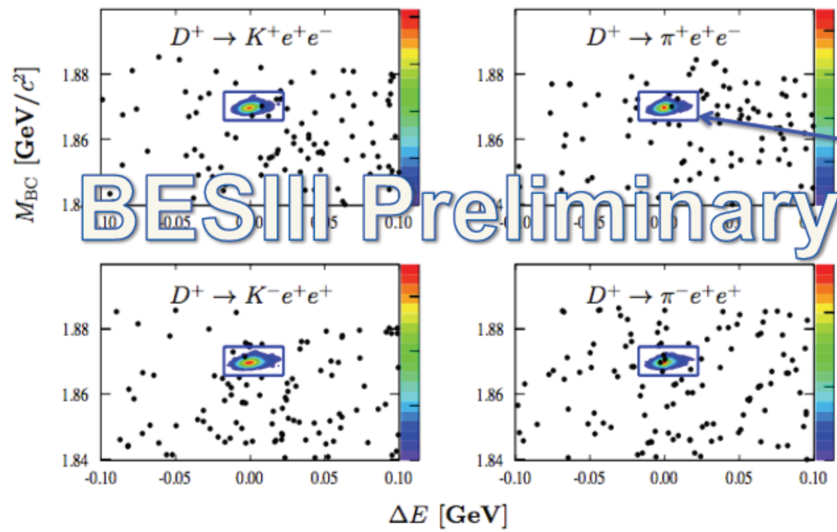
Search for rare D decays

In SM, the BFs of charm rare decay are expected to be less than 10^{-6}



PRD 91(2015)112015

Consistent with Babar result



FCNC decay

Blinding signal region, optimize cuts and study backgrounds based on MC and sideband data.

LNV decay

ST method

$\mathcal{B}(D^+ \to) \setminus [\times10^{-6}]$	$K^+e^+e^-$	$K^-e^+e^+$	$\pi^+e^+e^-$	$\pi^-e^+e^+$
CLEO	3.0	3.5	5.9	1.1
Babar	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