Charm Physics at BESIII

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For BESIII Collaboration

Beijing Institute of Petro-chemical Technology (BIPT)

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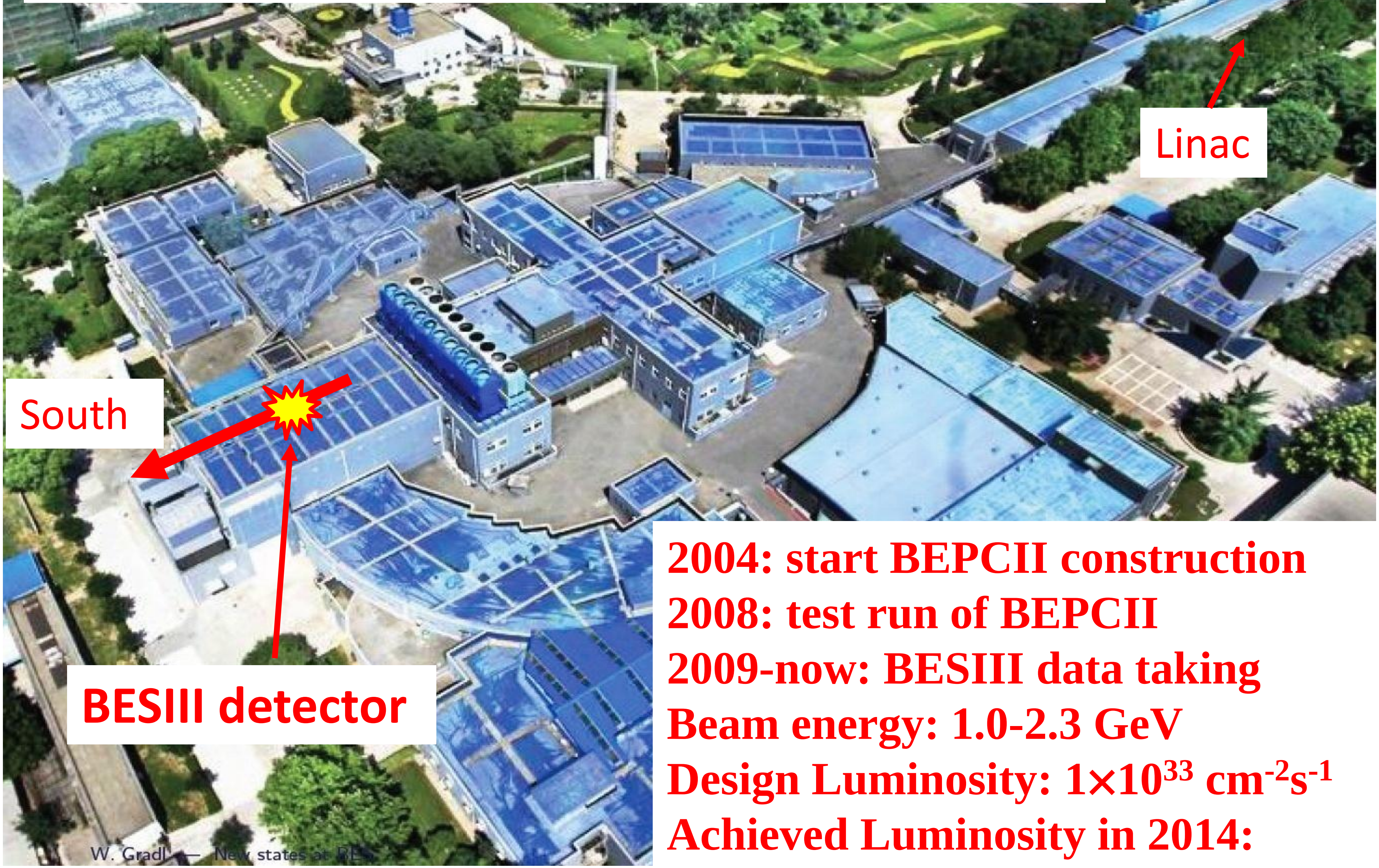
Outline

- Introduction
- D decays
  - D leptonic and semi-leptonic decays
  - D hadronic decays
- Λ_c^+ decays
  - Λ_c^+ semi-leptonic decays
  - Λ_c^+ hadronic decays
- Summary

Beijing Electron Positron Collider (BEPC)



2004: start BEPCII construction

2008: test run of BEPCII

2009-now: BESIII data taking

Beam energy: 1.0-2.3 GeV

Design Luminosity: 1×10^{33} $cm^{-2}s^{-1}$

Achieved Luminosity in 2014:

$L_{peak}=0.85\times10^{33}$ $cm^{-2}s^{-1}$

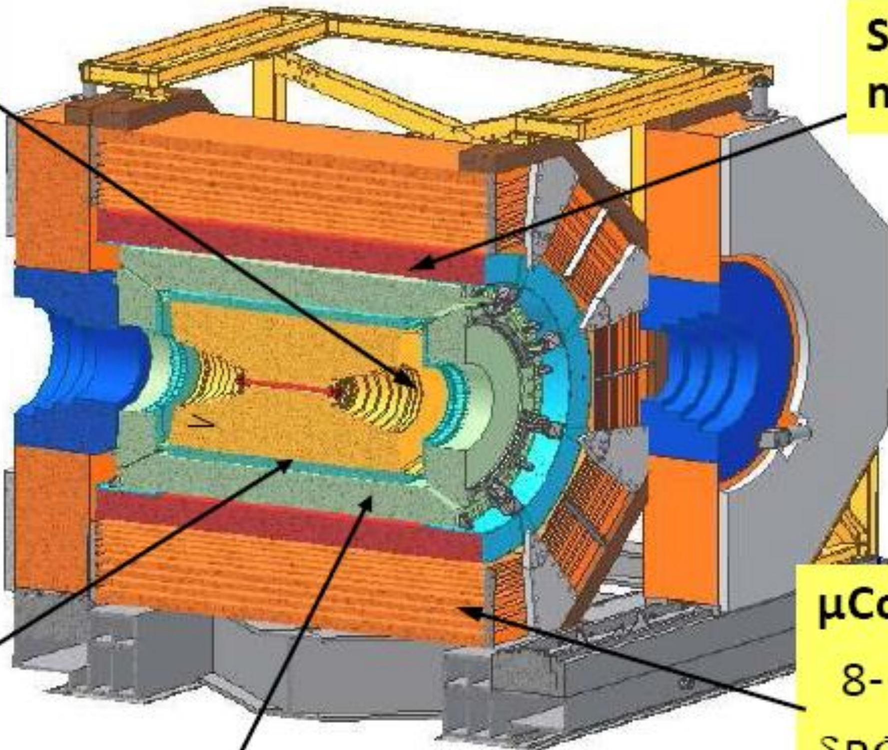
BESIII Detector

Drift Chamber (MDC)

$\sigma P/P\ (^0/_0) = 0.5\%(1\text{GeV})$

$\sigma_{dE/dx}\ (^0/_0) = 6\%$

Super-conducting magnet (1.0 tesla)



Time Of Flight (TOF)

σ_T: 90 ps Barrel

110 ps endcap

μCounter

8- 9 layers RPC

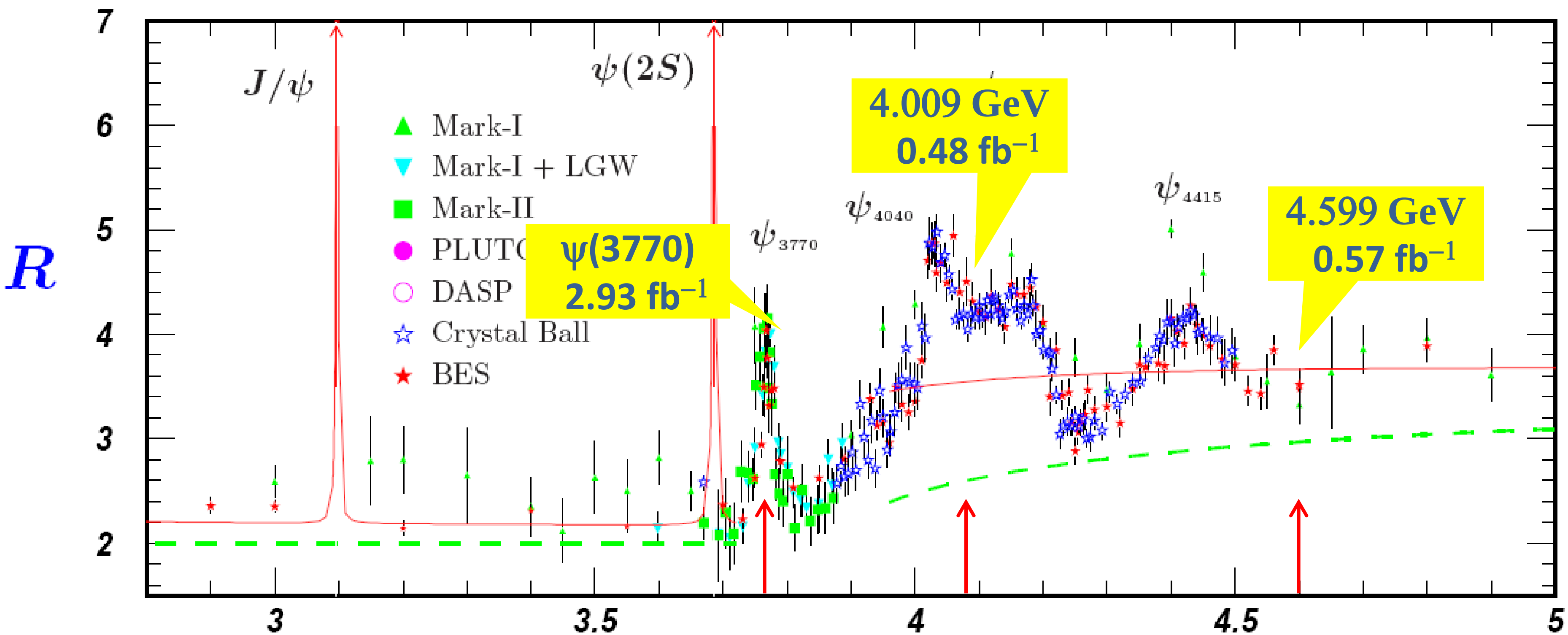
$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}(^0/_0)$ = 2.5 % (1 GeV)

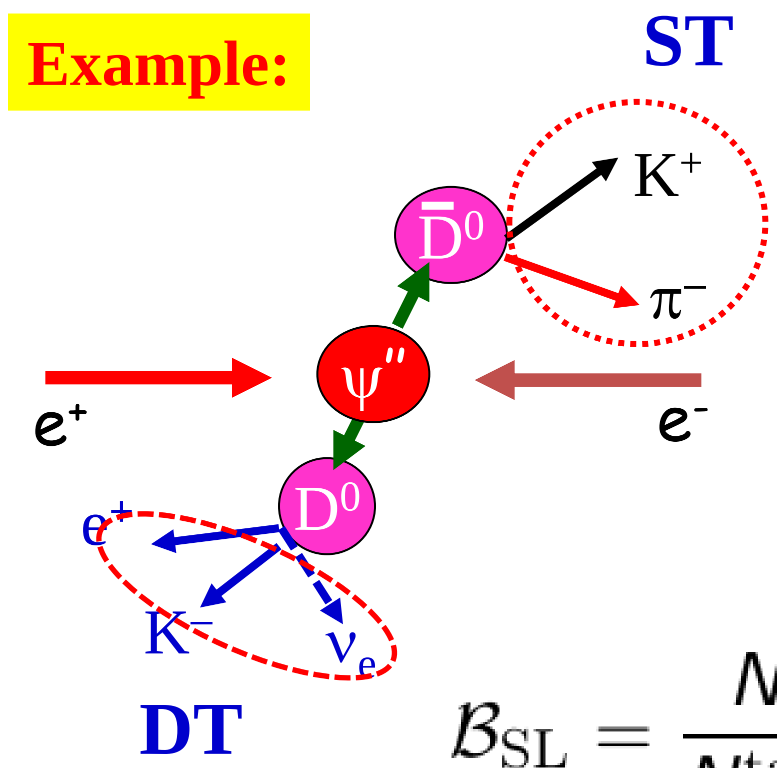
(CsI) $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$

Data samples in this talk

- 2.93 fb^{-1} data@3.773 GeV for $D^0\bar{D}^0$, D^+D^- production;
- 0.48 fb^{-1} data@4.009 GeV for $D_s^+D_s^-$ production;
- 0.57 fb^{-1} data@4.599 GeV for $\Lambda_C^+\bar{\Lambda}_C^-$ production;



Analysis Technique



Single Tags (ST)

$$M_{\rm bc} = \sqrt{E_{\rm beam}^2 - |\overrightarrow{p}_{\bar{D}^0}|^2}$$

Double Tags (ST)

$$U_{miss} = E_{miss} - c|\vec{p}_{miss}|.$$

[For Semi-Leptonic decays]

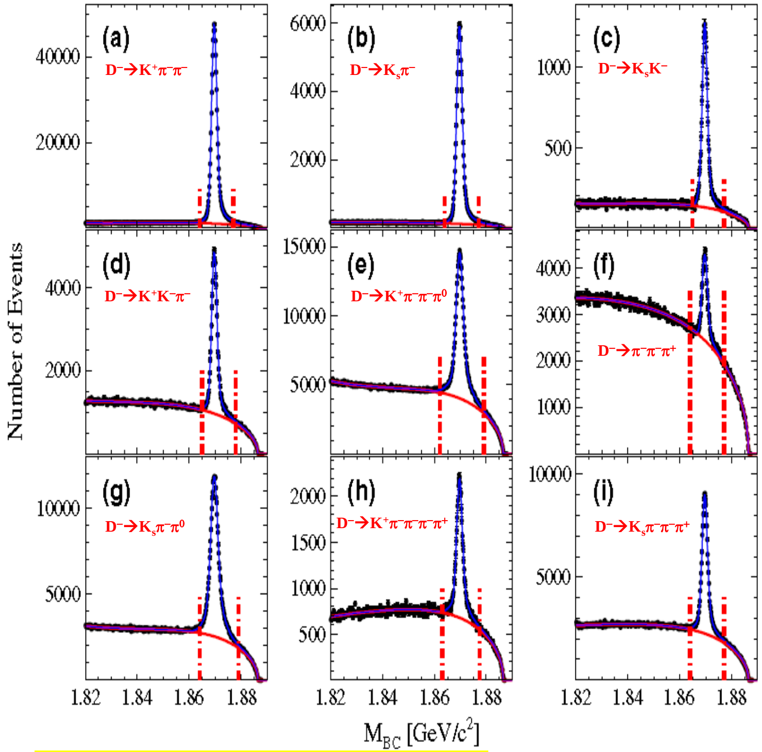
$$\mathcal{B}_{\rm SL} = \frac{N^{\rm semi}}{N^{\rm tag} \times \epsilon}$$

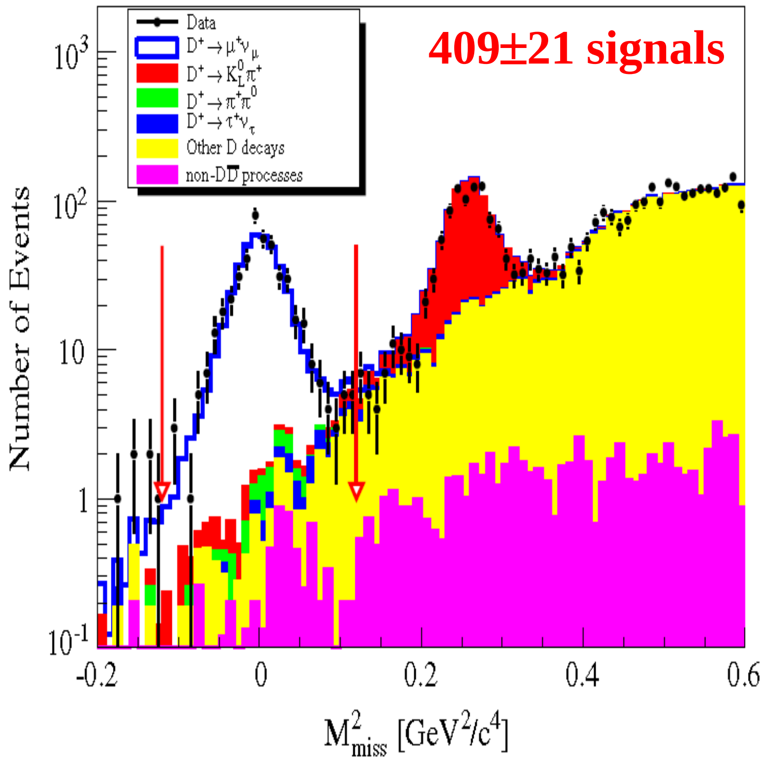
Clean sample of ST charmed hadrons can be fully reconstructed by hadronic decays with large BFs. Based on this, one can access to absolute BFs and dynamics in the decays.

Measurement of $B[D^+ \to \mu^+ \nu]$, f_{D^+} and $|V_{cd}|$

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

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





$N_{D^-_{tag}} = (170.31 \pm 0.34) \times 10^4$

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

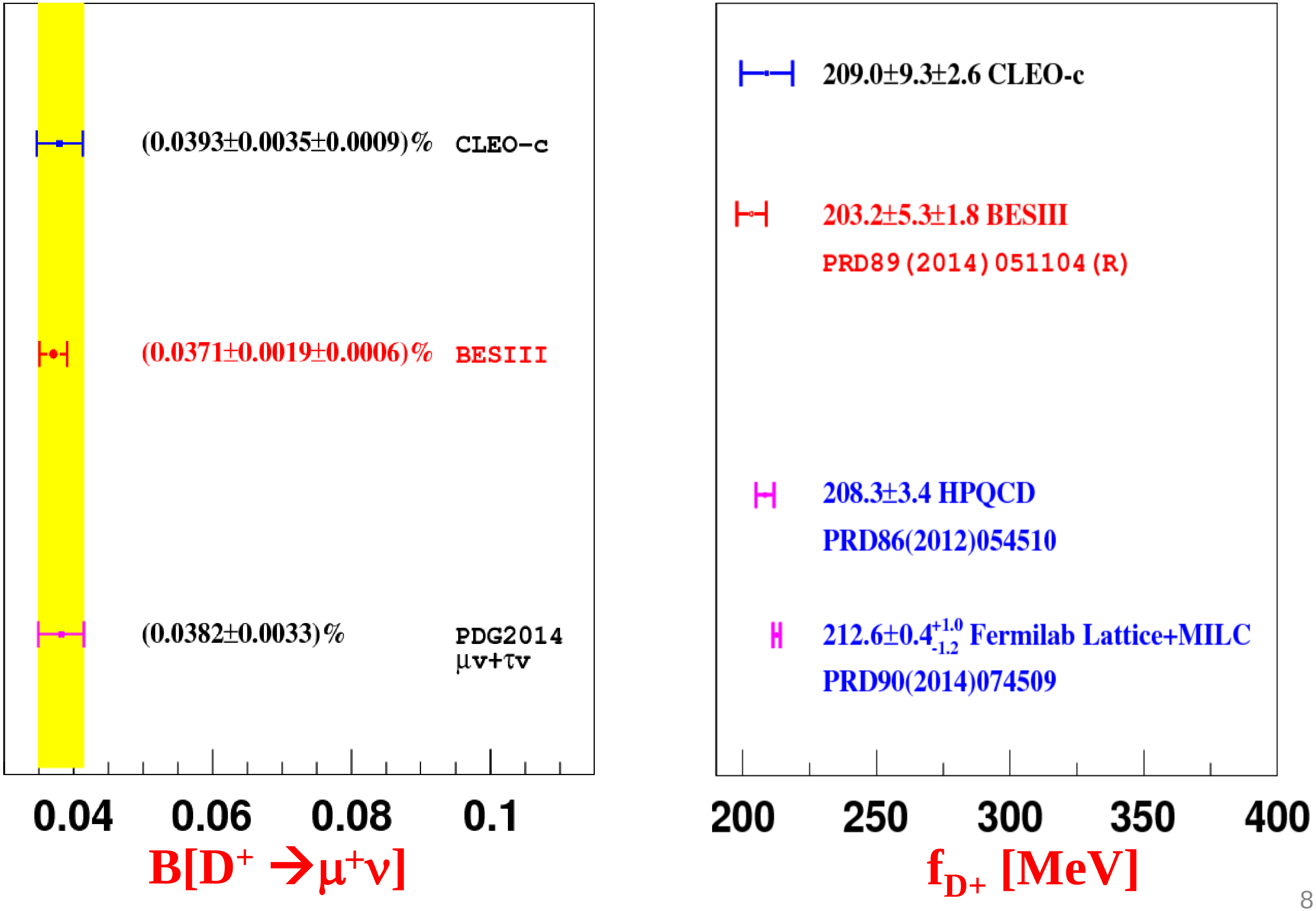
Input t_{D^+}, m_{D^+}, m_{μ^+} on PDG and $|V_{cd}|$ of CKM-Fitter

$f_{D^+} = (203.2 \pm 5.3 \pm 1.8)$ MeV

Input t_{D^+}, m_{D^+}, m_{μ^+} on PDG and LQCD calculated f_{D^+}=207±4 MeV[PRL100(2008)062002]

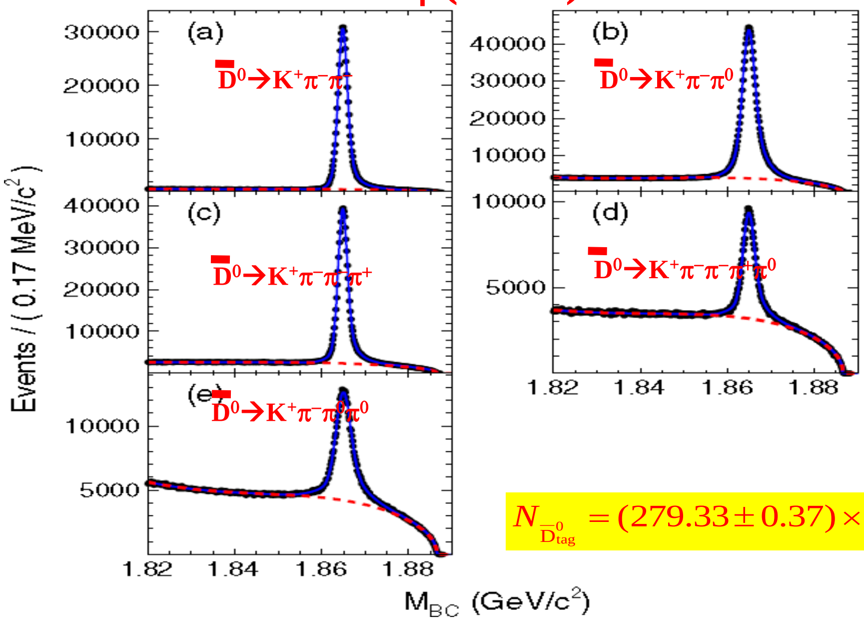
$|V_{cd}| = 0.2210 \pm 0.0058 \pm 0.0047$

Comparisons of $B[D^+ \to \mu^+ \nu_\mu]$ and f_{D^+}



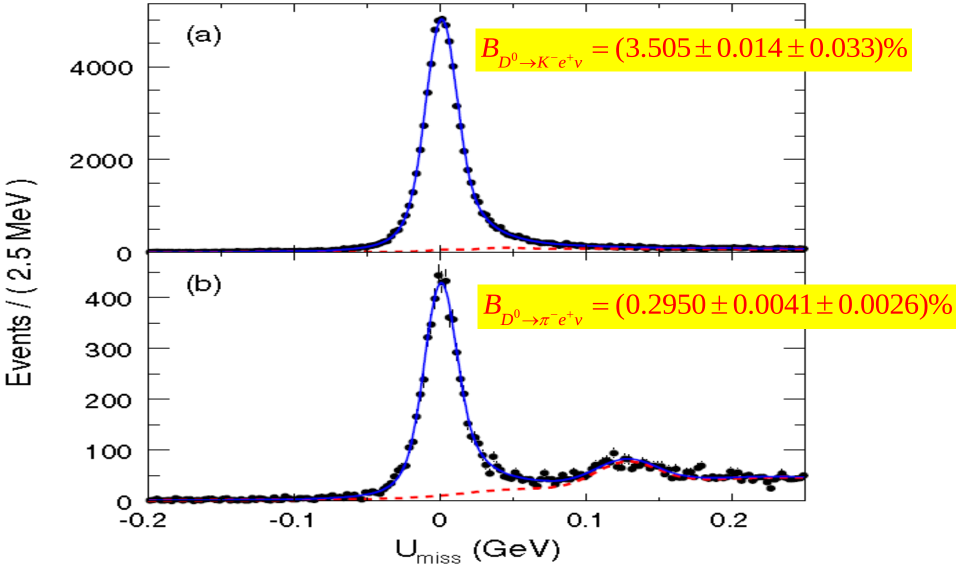
Measurement of B[$D^0 \rightarrow K(\pi)^- e^+ \nu$]

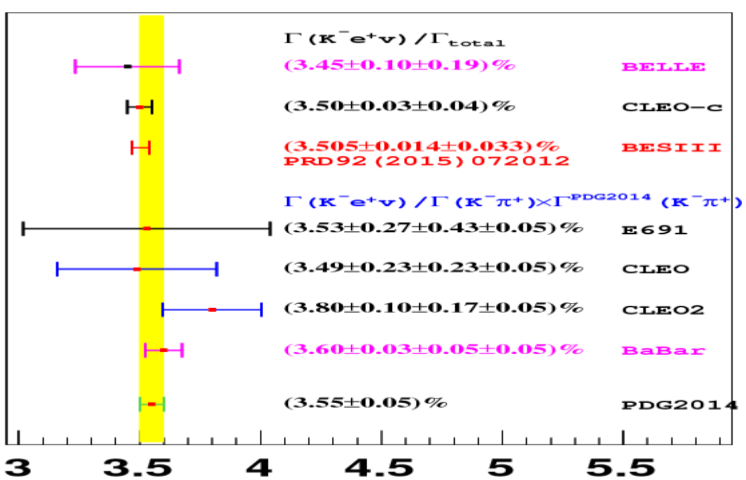
$e^+e^- \rightarrow \psi(3770) \rightarrow D^0\bar{D}^0$



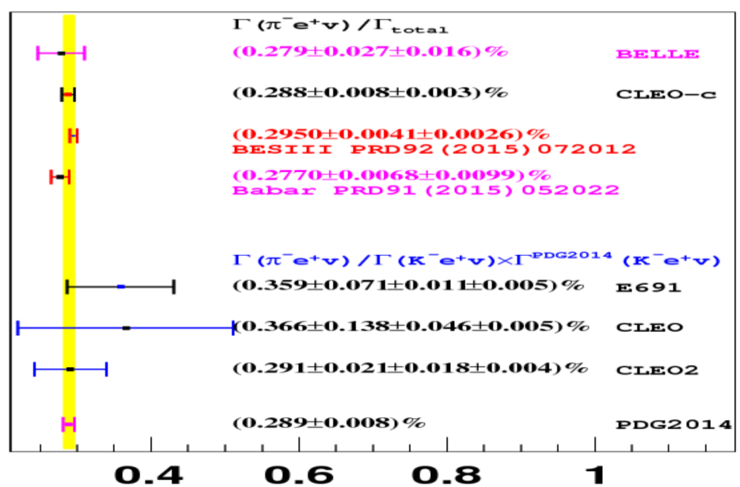
$N_{\bar{D}^0_{tag}} = (279.33 \pm 0.37) \times 10^4$

PRD92(2015)072012





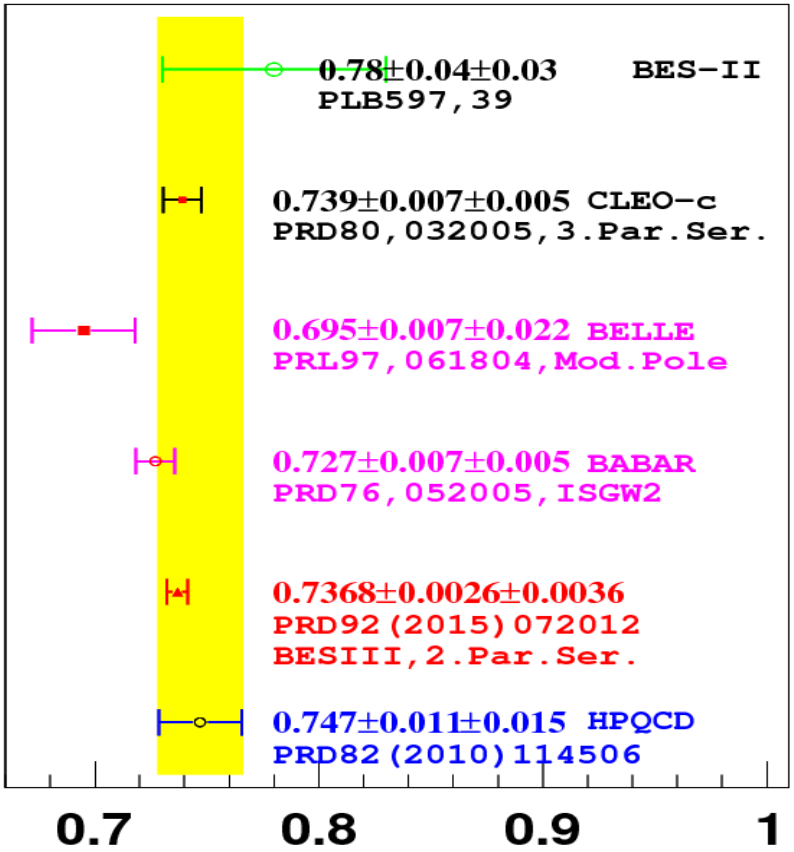
B[$D^0 \rightarrow K^- e^+ \nu$]



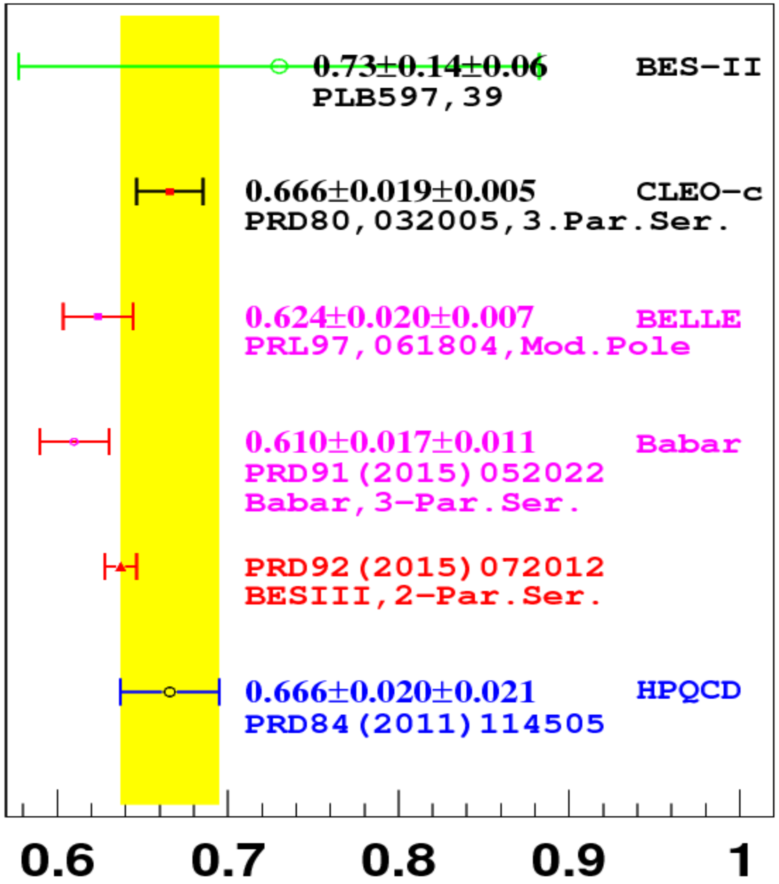
B[$D^0 \rightarrow \pi^- e^+ \nu$]

Measurement of $f_+^{K(\pi)}(0)$

$f^{D\to K(\pi)}_+(0)|V_{cs(d)}|$ → Input $|V_{cs(d)}|$ of CKM-Fitter → $f^{D\to K(\pi)}_+(0)$



$f_+^K(0)$



$f_+^\pi(0)$

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

[PRD92(2015) 112008]

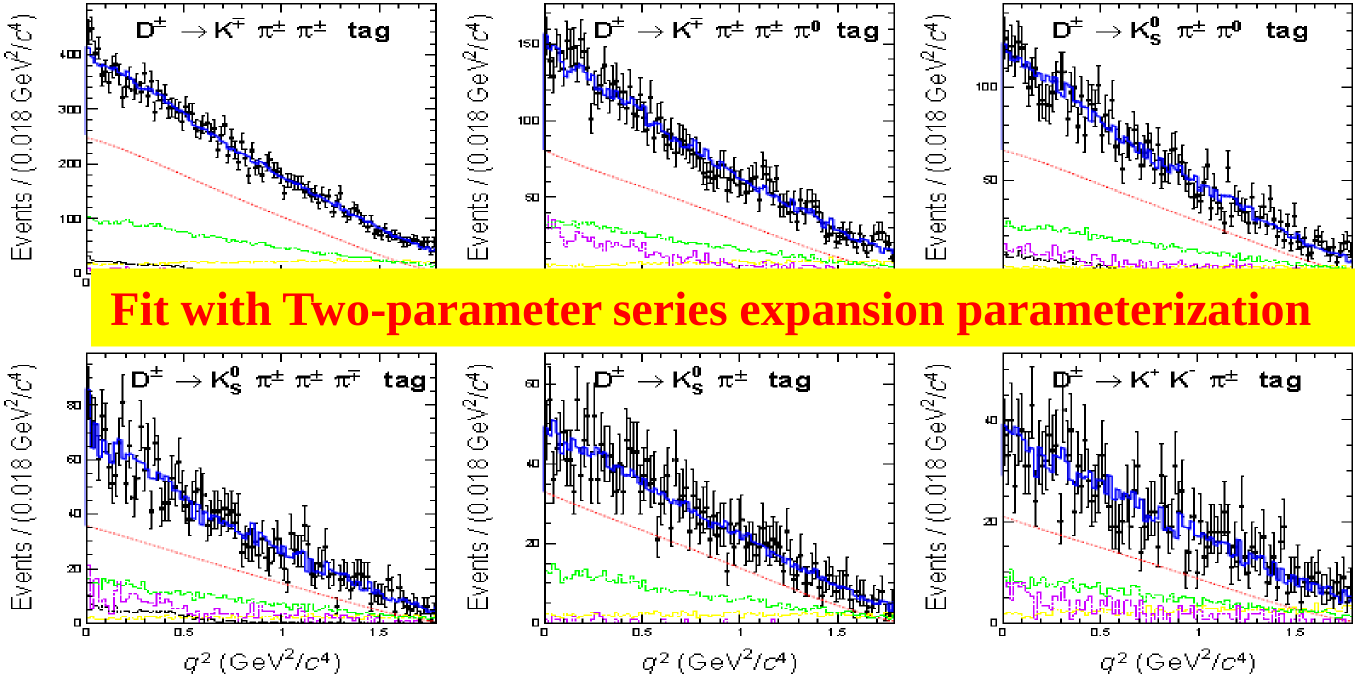
- **Regardless of long flight distance, K_L interact with EMC and deposit part of energy, thus giving position information**
- **After reconstructing all other particles, K_L can be inferred with position information and constraint $U_{miss} \rightarrow 0$**

$B(D^+ \rightarrow K_L e^+ v) = (4.482 \pm 0.027 \pm 0.103)\%$

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

$A_{CP}^{D+ \rightarrow KLe+v} = (-0.59 \pm 0.60 \pm 1.50)\%$

Simultaneous fit to observed numbers of DT candidates



Fit with Two-parameter series expansion parameterization

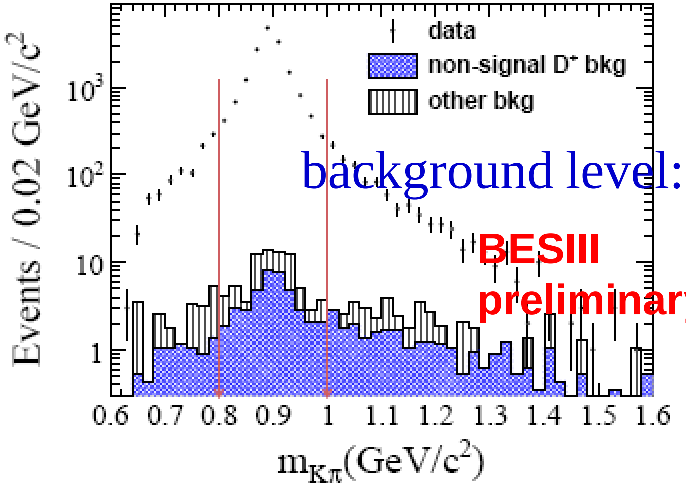
The first measurement of the BR for $D^+ \rightarrow K_L e^+ \nu_e$

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

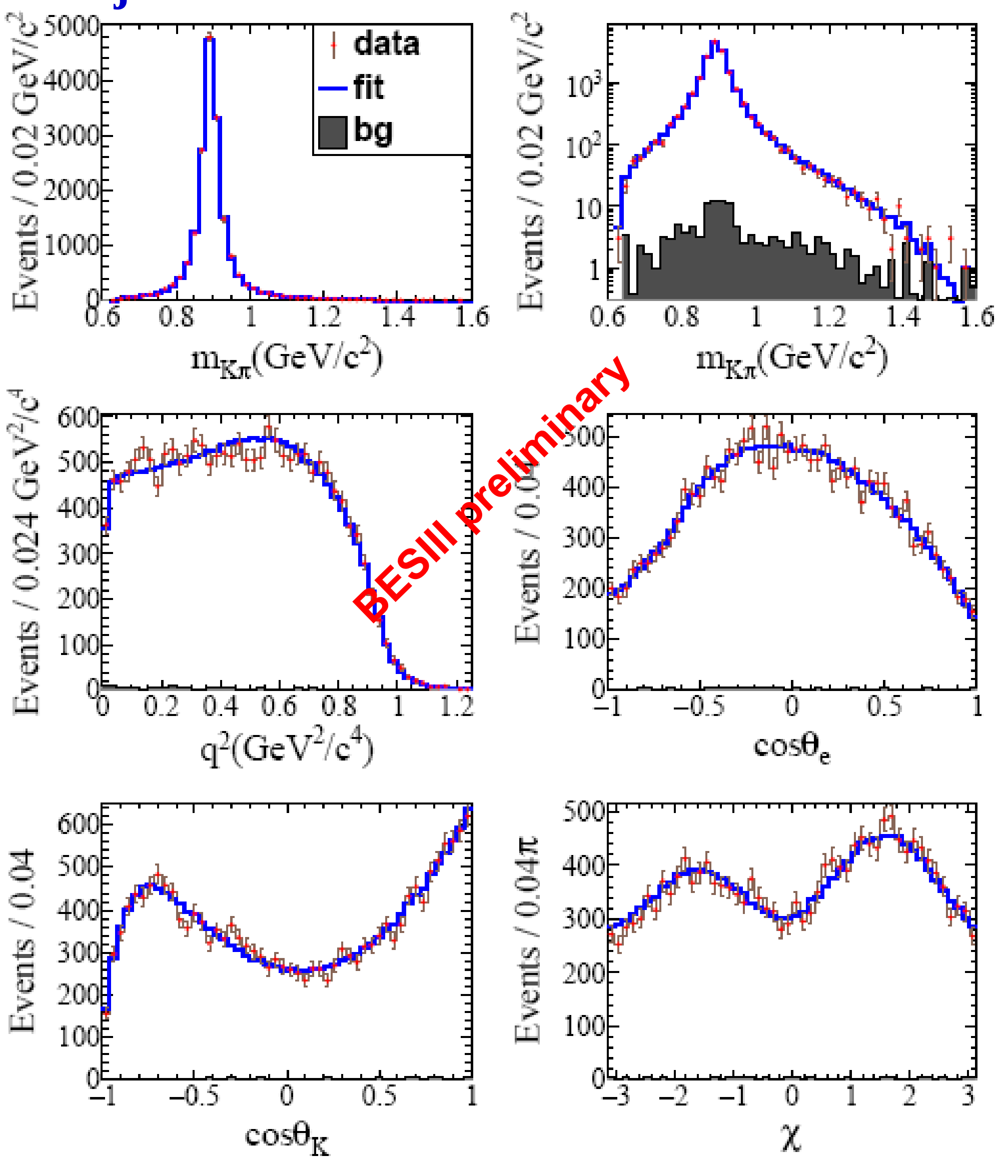
Analysis of $D^+ \to K^- \pi^+ e^+ \nu$

arXiv:1512.08627

$M_{K\pi}$ distribution



Projections of data and fitted MC distributions



$B(D^+ \to K^- \pi^+ e^+ \nu_e) = (3.71 \pm 0.03 \pm 0.08)\%$

$B(D^+ \to K^- \pi^+ e^+ \nu_e)_{[0.8,1]} = (3.33 \pm 0.03 \pm 0.07)\%$

Fit Results (Preliminary)

- **Fitted fractions of the component**

$f(D^+ \to (K^- \pi^+)_{K^{*0}(892)}\, e^+ \nu_e) = (93.93 \pm 0.22 \pm 0.18)\%$

$f(D^+ \to (K^- \pi^+)_{S-wave}\, e^+ \nu_e) = (6.05 \pm 0.22 \pm 0.18)\%$

- **Parameters of $K^{*0}(892)$**

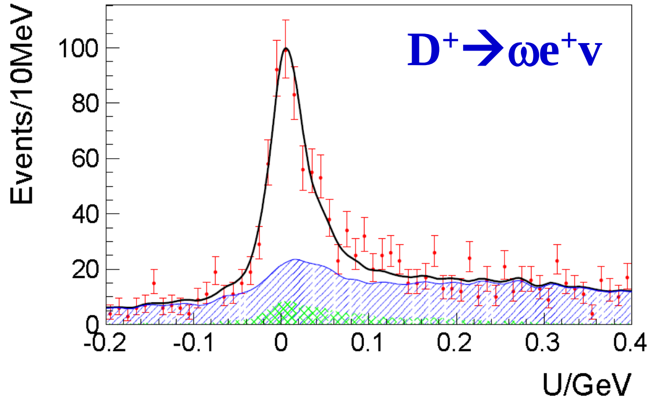
$m_{K^{*0}(892)} = (894.60 \pm 0.25 \pm 0.08)\ \mathrm{MeV}/c^2$

$\Gamma_{K^{*0}(892)} = (46.42 \pm 0.56 \pm 0.15)\ \mathrm{MeV}/c^2$

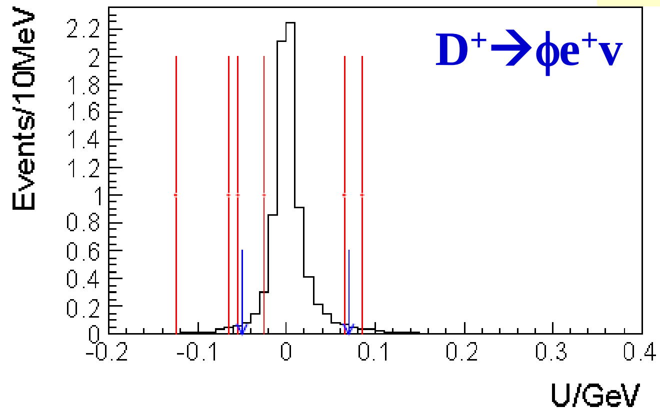
Study of $D^+ \to \omega e^+ \nu$ and search for $D^+ \to \phi e^+ \nu$

PRD92(2015) 071101R

U distribution



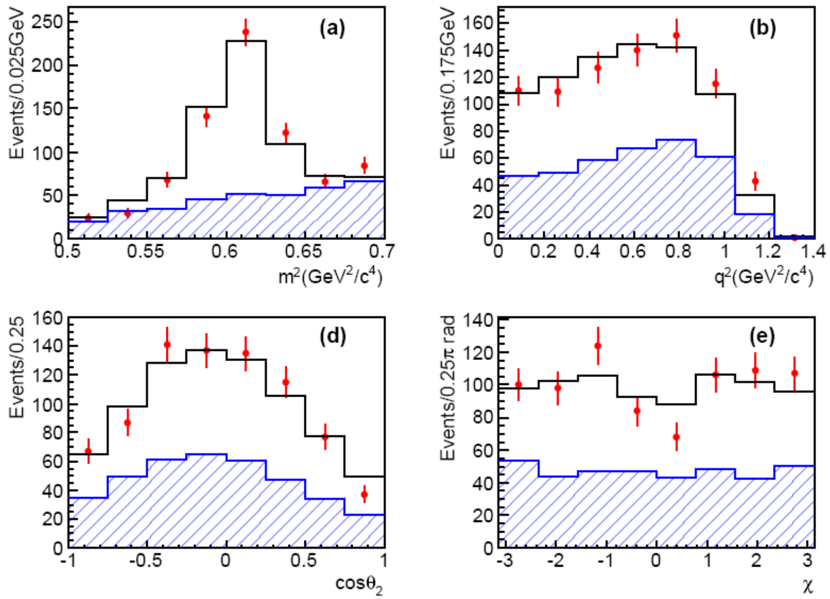
U distribution



Red dots: data;
Arrows: signal region.

Mode	This work	Previous
$\omega e^+ \nu_e$	$(1.63 \pm 0.11 \pm 0.08) \times 10^{-3}$	$(1.82 \pm 0.18 \pm 0.07) \times 10^{-3}$
$\phi e^+ \nu_e$	$< 1.3 \times 10^{-5}$ (90%C.L.)	$< 9.0 \times 10^{-5}$ (90%C.L.)

Better precision or sensitivity



Amplitude analysis of $D^+ \to \omega e^+ \nu$ is performed for the first time

Results of form factor ratios:

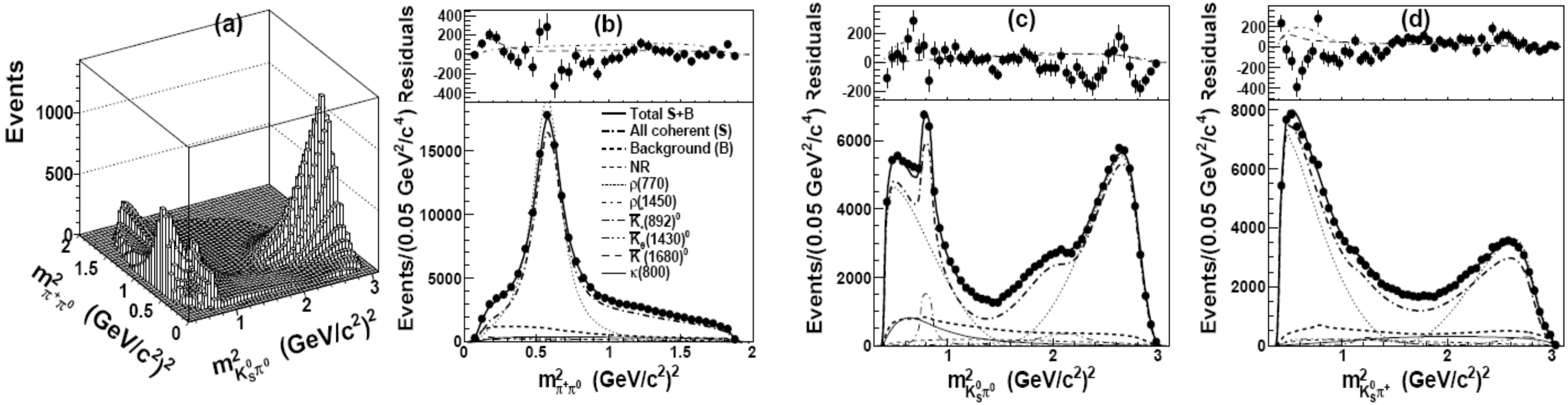
$$r_V = V(0)/A_1(0) = 1.24 \pm 0.09 \pm 0.06$$

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

Dalitz Plot Analysis of $D^+ \to K_s^0 \pi^+ \pi^0$

Distribution of (a) fitted p.d.f, and projections on (b) $M^2_{\pi+\pi0}$, (c) $M^2_{Ks0\pi0}$, and (d) $M^2_{Ks0\pi+}$.

PRD89(2014) 052001



Partial BFs calculated by combining fitted fractions with PDG's $B[D^+ \to K_S^0\pi^+\pi^0]$.

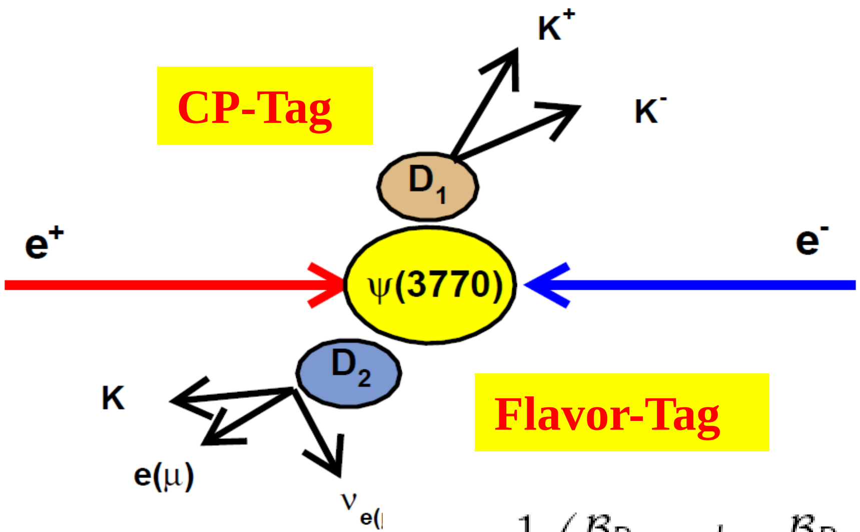
Mode	Partial Branching Fraction (%)
$D^+ \to K_S^0\pi^+\pi^0$ Non Resonant	$0.32\pm0.05\pm0.25^{+0.28}_{-0.25}$
$D^+ \to \rho^+ K_S^0, \rho^+ \to \pi^+\pi^0$	$5.83\pm0.16\pm0.30^{+0.45}_{-0.15}$
$D^+ \to \rho(1450)^+ K_S^0, \rho(1450)^+ \to \pi^+\pi^0$	$0.15\pm0.02\pm0.09^{+0.07}_{-0.11}$
$D^+ \to \overline{K}^*(892)^0\pi^+,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

Partial branching ratios are measured with higher precision than previous measurements.

$D\bar{D}$ mixing parameter y_{CP}

PLB 744, 339 (2015)

We measure the y_{CP} using CP-tagged semi-leptonic D decays, which allows to access CP asymmetry in mixing and decays.



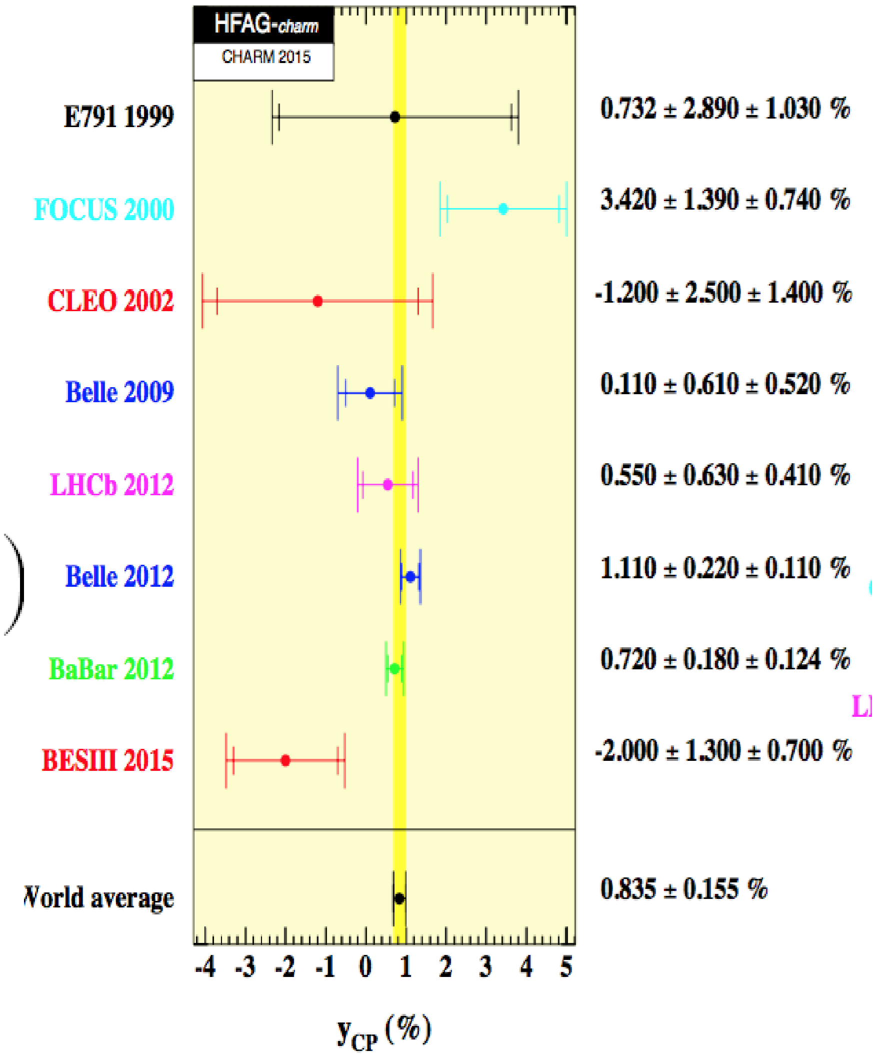
$$y_{CP} \approx \frac{1}{4}\left(\frac{\mathcal{B}_{D_{CP-}\to l}}{\mathcal{B}_{D_{CP+}\to l}} - \frac{\mathcal{B}_{D_{CP+}\to l}}{\mathcal{B}_{D_{CP-}\to l}}\right)$$

Reconstructed Modes:

Type	Mode
$CP+$	K^+K^-, $\pi^+\pi^-$, $K_S^0\pi^0\pi^0$
$CP-$	$K_S^0\pi^0$, $K_S^0\omega$, $K_S^0\eta$
Semileptonic	$K^\mp e^\pm\nu$, $K^\mp\mu^\pm\nu$

y_{CP}=(-2.1±1.3±0.7)%

Compatible with the previous measurements.

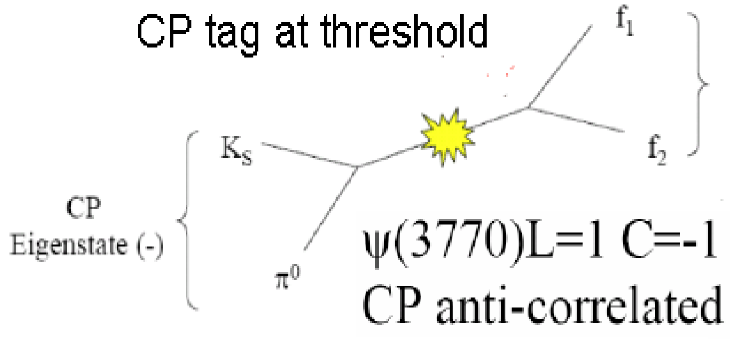


Strong phase difference $\delta_{K\pi}$

PLB 734, 227 (2014)

Quantum correlation → Interference → access strong phase!

If CP violation in charm is neglected: mass eigenstates = CP eigenstates

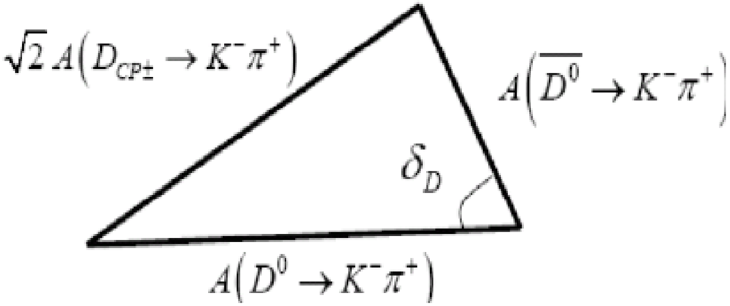


$$\mathcal{A}^{CP}_{K\pi} \equiv \frac{\mathcal{B}_{D^{S-}\to K^-\pi^+} - \mathcal{B}_{D^{S+}\to K^-\pi^+}}{\mathcal{B}_{D^{S-}\to K^-\pi^+} + \mathcal{B}_{D^{S+}\to K^-\pi^+}}.$$

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

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

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



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

Reconstructed Modes:

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

With external inputs of the parameters in HFAG2013 and PDG

$R_D = 3.47\pm0.06‰,\ y = 6.6\pm0.9‰ \quad R_{WS} = 3.80\pm0.05‰$

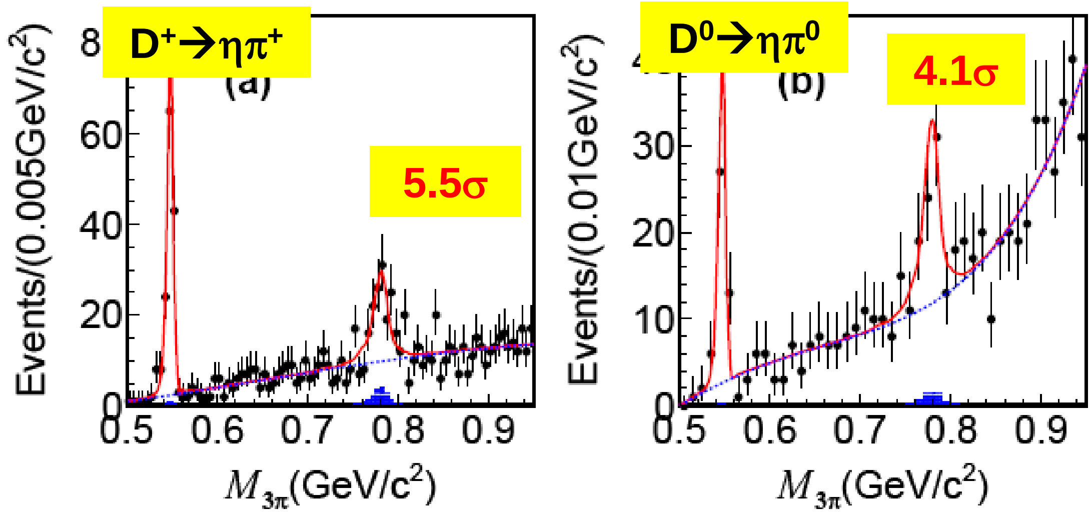
$\cos\delta_{K\pi}=1.02\pm0.11\pm0.06\pm0.01$

most precise to date

Observation/Evidence for SCS decay $D^{+(0)} \to \omega\pi^{+(0)}$

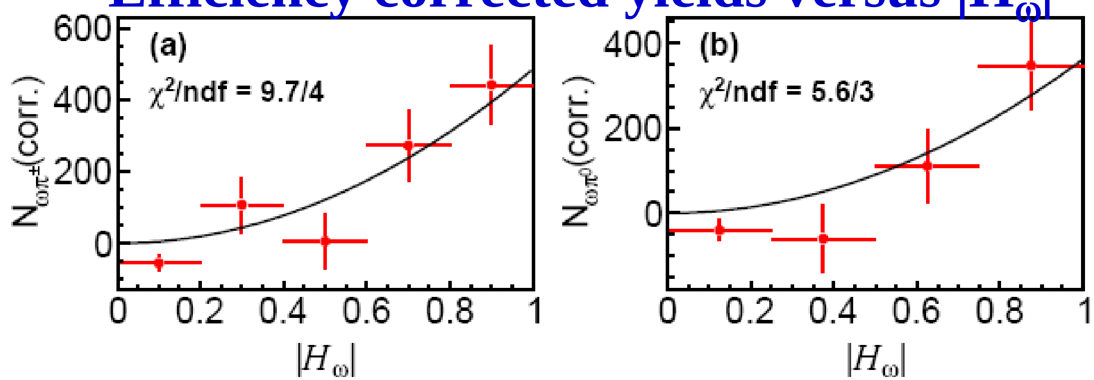
Suppress background via DT method

arXiv:1512.06998



- **Predications of B[$D \to \omega\pi$] at 1.0×10^{-4} level.**
- **$D \to \omega\pi$ were studied at CLEO-c with ST method, but only set BF upper limits**

Efficiency corrected yields versus $|H_\omega|$



Summary of BFs measurements

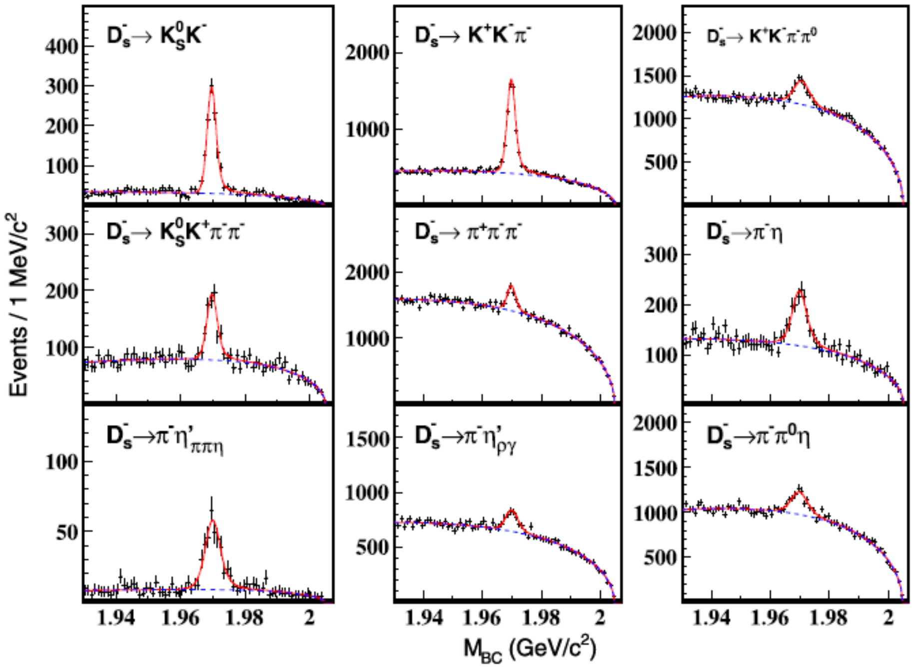
Mode	This work	Previous measurements
$D^+ \to \omega\pi^+$	$(2.79 \pm 0.57 \pm 0.16) \times 10^{-4}$	$< 3.4 \times 10^{-4}$ at 90% C.L.
$D^0 \to \omega\pi^0$	$(1.17 \pm 0.34 \pm 0.07) \times 10^{-4}$	$< 2.6 \times 10^{-4}$ at 90% C.L.
$D^+ \to \eta\pi^+$	$(3.07 \pm 0.22 \pm 0.13) \times 10^{-3}$	$(3.53 \pm 0.21) \times 10^{-3}$
$D^0 \to \eta\pi^0$	$(0.65 \pm 0.09 \pm 0.04) \times 10^{-3}$	$(0.68 \pm 0.07) \times 10^{-3}$

Improve understanding of U-spin and SU(3) flavor symmetry breaking effects in D decays and benefitting theoretical prediction of CP violation in D decays

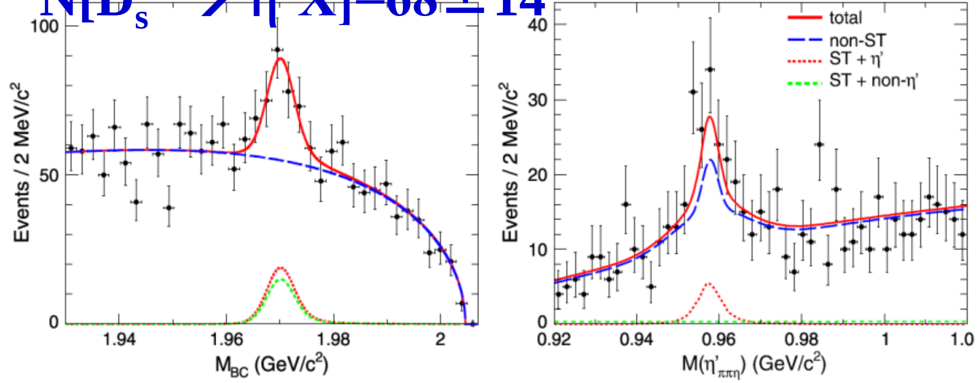
$D_s^+ \to \eta' X$ and $\eta' \rho^+$

PLB750 466(2015)

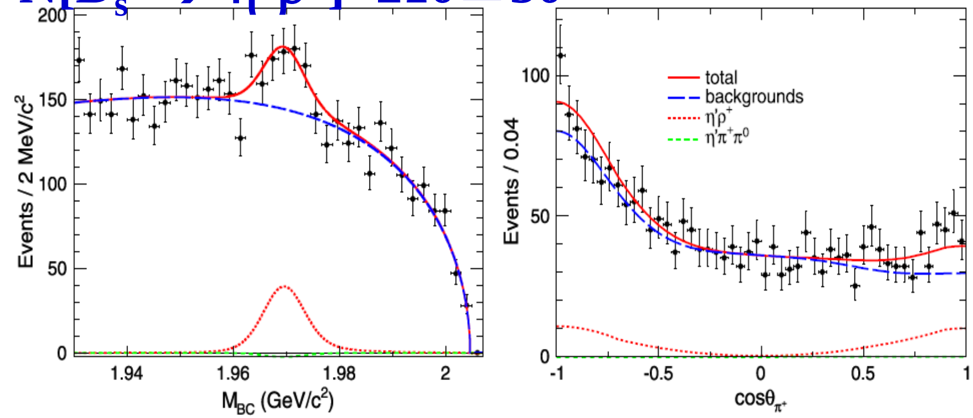
About 15.6 K ST D_s^- events by using 9 ST modes



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



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



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

Consistent with CLEO measurements $B[D_s^+ \to \eta' X] = (11.7 \pm 1.8)\%$ [PRD79 112008(2009)]

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

$B^{exp}[D_s^+ \to \eta' \rho^+] = (3.0 \pm 0.5)\%$ [PRD84 074019(2011)]

Resolve the disagreement between theoretical predication and CLEO-c's previous measurement. $B[D_s^+ \to \eta' \rho^+] = (12.5 \pm 2.2)\%$ [PRD58 052002(1998)]

Absolute BF for $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

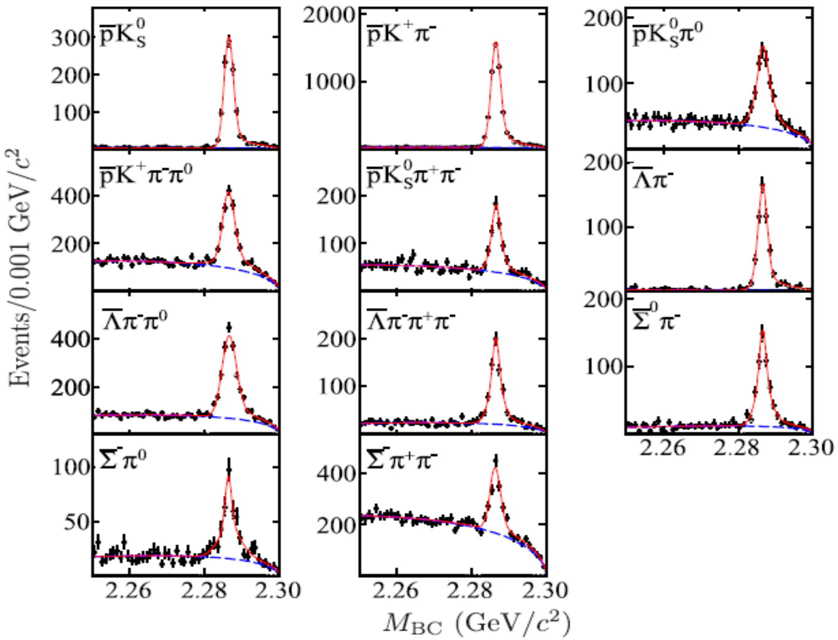
Theoretical calculations on the BF ranges from 1.4% to 9.2%

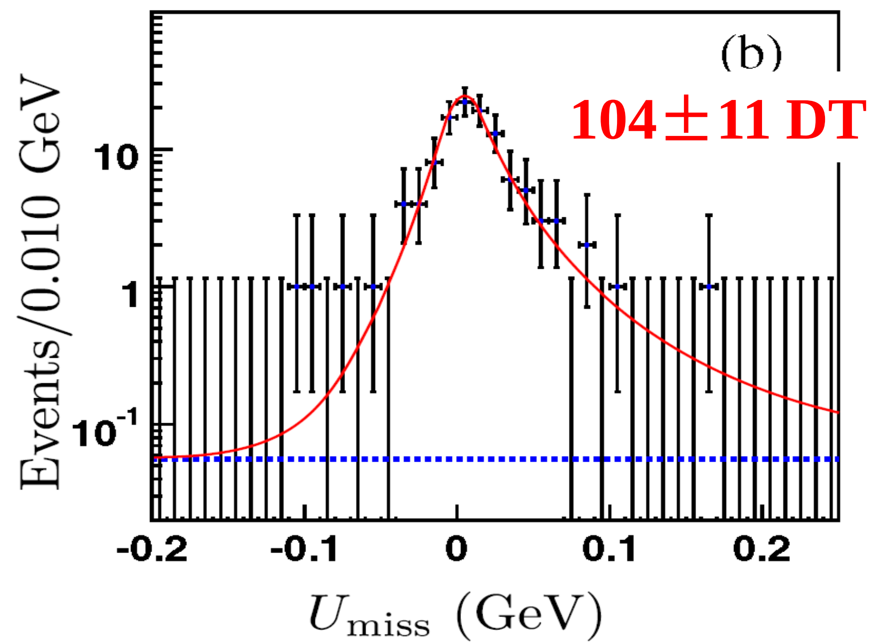
PDG2014: (2.1±0.6)%

PDG2015: (2.9±0.5)% ⬅ **Input $B[\Lambda_C^+ \rightarrow pK^-\pi^+] = (6.84^{+0.32}_{-0.40})\%$ by BELLE [PRL113,042002(2014)]**

14415±159 events with 11 ST modes

PRL115(2015)221805





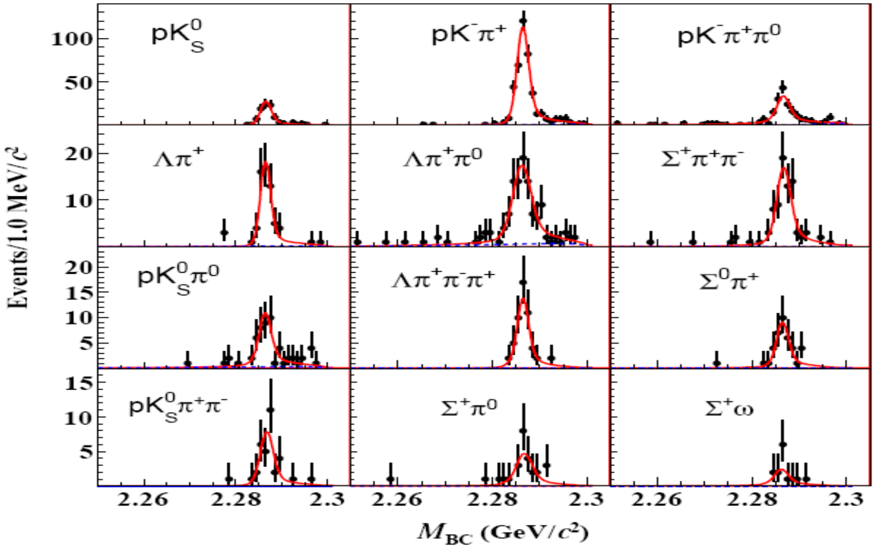
$B[\Lambda_c^+ \rightarrow \Lambda e^+ \nu] = (3.63 \pm 0.38 \pm 0.20)\%$ **First absolute measurement**

Important for test and calibrate the LQCD calculations.

Absolute BFs for Λ_c^+ hadron decays

Measurement using the threshold pair-productions via e^+e^- annihilation is unique: the most simple and straightforward

arxiV:1511.08380
Accepted by PRL



A global least-square fitter is utilized to improve the measured precision for 12 Λ_c^+ hadronic decay channels.

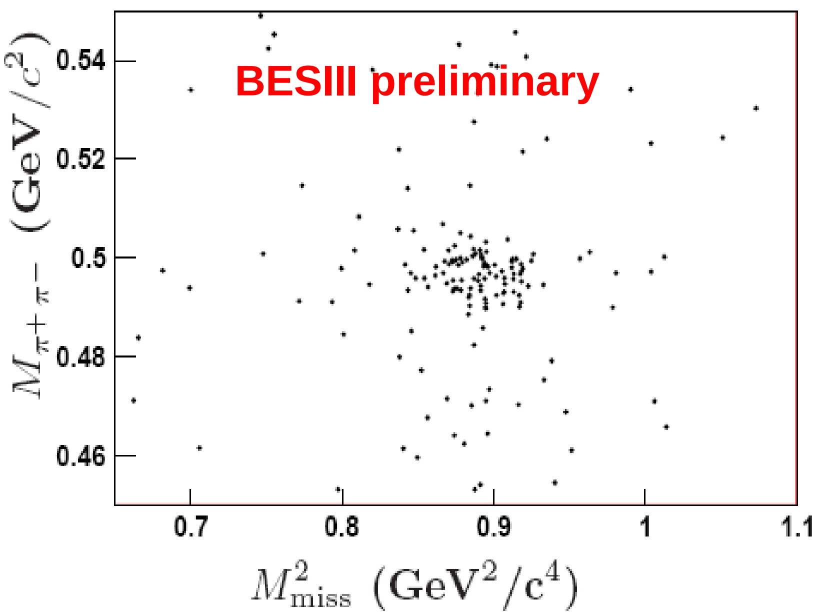
$$N_{-j}^{DT} = \sum_{i^+ \neq i} N_{i^+j^-}^{DT} + \sum_{i^- \neq i} N_{i^-j^+}^{DT} + N_{jj}^{DT}$$

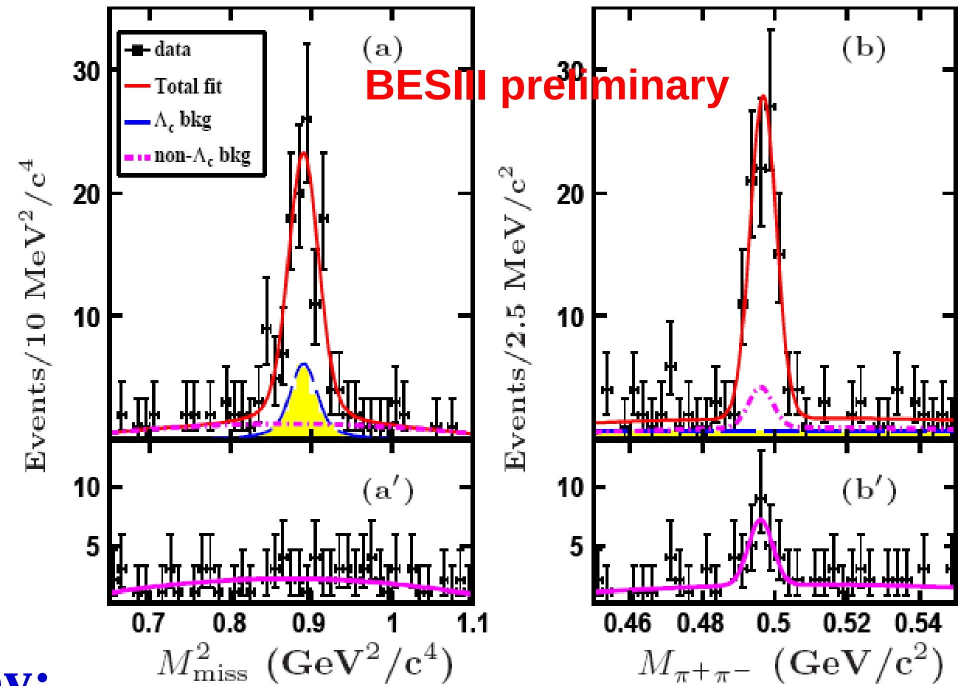
Mode	This work (%)	PDG (%)	Belle $\mathcal{B}$
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	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	

- ✓ **Absolute BFs are improved significantly.**
- ✓ **BESIII BF for $\Lambda_c^+ \rightarrow pK^-\pi^+$ is smaller.**
- ✓ **Improved absolute BF of $pK^-\pi^+$ together with BELLE's result are key to calibrate other decays.**

Observation of $\Lambda_c^+ \rightarrow nK_S^0\pi^+$

First observation of Λ_C^+ decays to final states involving the neutron.





The missing neutron is detected by:

$$M^2_{\rm miss} = (p_{\Lambda_c^+} - p_{K_S^0} - p_{\pi^+})^2 = E^2_{\rm miss} - c^2|\vec{p}_{\rm miss}|^2$$

83±11 net signal events

BESIII Preliminary results:

$B[\Lambda_c^+ \rightarrow nK_S^0\pi^+] = (1.82 \pm 0.23 \pm 0.11)\%$

Fit to $M^2_{\rm miss}$ and $M_{\pi+\pi}$ spectra in (a,b) $\bar{\Lambda}_c^-$ signal region and (a',b') $\bar{\Lambda}_c^-$ sideband region simultaneously.

The relative BF of neutron-involved mode to proton-involved mode is essential to test the isospin symmetry for Λ_c^+ decays. [arXiv:1601.04241]

Summary

- **BESIII provides important results on charm decays**
  - **leptonic and semi-leptonic decys**
  - **D hadronic decays**
  - **D^0 mixing and strong phase**
  - **Λ_C^+ hadronic and semi-leptonic decays**

  important to test LQCD calculations, CKM matrix UT, search for NP beyond SM

- **More fruitful results will come out!**

Thanks!

Introduction

Precision measurement of charm decays provide rich information to probe for strong and weak effects

- **Unitarity test of CKM matrix: direct access quark mixing matrix element $|V_{cs(d)}|$ or strong phase constrained γ/ϕ_3**

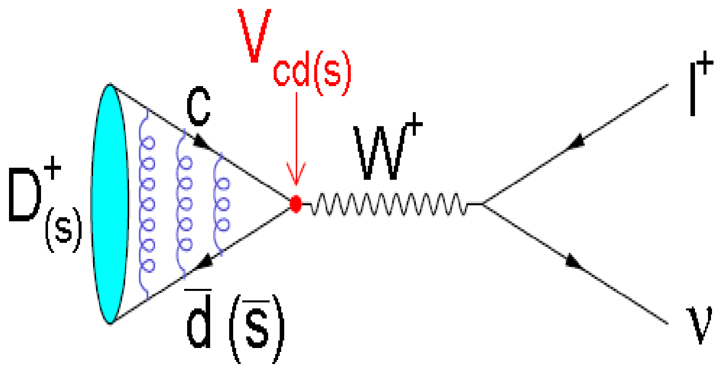
- **LQCD calibration: precise decay constant $f_{D(s)+}$, form factors $f_{D\rightarrow K(\pi)}(q^2)$ and others**

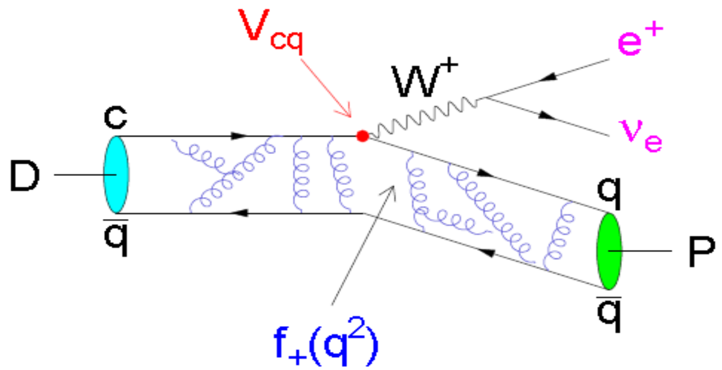
- **New physics BSM: evidence of rare decay/CP violation, or significant deviation of CKM untarity/LQCD calculation**

- **Important inputs for beauty physics: Significantly improved decay rates or dynamics**

D leptonic and semi-leptonic decays

Bridge to extract $D_{(s)}^{+}$ decay constant(s) $f_{D(s)+}$, form factors $f_{+}^{D\to K(\pi)}(q^2)$ and quark mixing matrix elements $|V_{cs(d)}|$





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

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

- **Improved $f_{D(s)+}$, $f_{+}^{D\to K(\pi)}(q^2)$ of D semi-leptonic decays calibrate LQCD calculations at higher accuracy. Once they pass experimental test, the precise LQCD calculations of f_D/f_B, f_{Ds}/f_{Bs} and form factor ratios are helpful for measurements in B decays**

- **Recent LQCD calculations on $f_{D(s)+}$[0.5(0.5)%], $f_{+}^{D\to K(\pi)}(0)$ [1.7(4.4)%] provide good chance to precisely measure $|V_{cs(d)}|$**

$$
\frac{d\Gamma}{dq^2 d\cos\theta_1 d\cos\theta_2 d\chi dm_{\pi\pi\pi}} = \frac{3}{8(4\pi)^4} G_F^2 |V_{cd}|^2 \frac{p_\omega q^2}{M_D^2} \mathcal{B}(\omega \to \pi\pi\pi) |\mathcal{BW}(m_{\pi\pi\pi})|^2
$$

$$
\begin{aligned}
&[(1+\cos\theta_2)^2 \sin^2\theta_1 |H_+(q^2, m_{\pi\pi\pi})|^2 \\
&+ (1-\cos\theta_2)^2 \sin^2\theta_1 |H_-(q^2, m_{\pi\pi\pi})|^2 + 4\sin^2\theta_2 \cos^2\theta_1 |H_0(q^2, m_{\pi\pi\pi})|^2 \\
&+ 4\sin\theta_2 (1+\cos\theta_2) \sin\theta_1 \cos\theta_1 \cos\chi H_+(q^2, m_{\pi\pi\pi}) H_0(q^2, m_{\pi\pi\pi}) \\
&- 4\sin\theta_2 (1-\cos\theta_2) \sin\theta_1 \cos\theta_1 \cos\chi H_-(q^2, m_{\pi\pi\pi}) H_0(q^2, m_{\pi\pi\pi}) \\
&- 2\sin^2\theta_2 \sin^2\theta_1 \cos 2\chi H_+(q^2, m_{\pi\pi\pi}) H_-(q^2, m_{\pi\pi\pi})].
\end{aligned}
$$

$$
\begin{aligned}
H_\pm(q^2) =& M A_1(q^2) \mp 2\frac{M_D p_\omega}{M} V(q^2) \\
H_0(q^2) =& \frac{1}{2m_{\pi\pi\pi}\sqrt{q^2}} [(M_D^2 - m_{\pi\pi\pi}^2 - q^2) M A_1(q^2) \\
& - 4\frac{M_D^2 p_\omega^2}{M} A_2(q^2)]
\end{aligned} \quad (3)
$$

where $M = M_D + m_{\pi\pi\pi}$. For the q^2 dependence, a single pole parameterization [24] is applied:

$$
V(q^2) = \frac{V(0)}{1 - q^2/m_V^2}\ ,\ A_{1,2}(q^2) = \frac{A_{1,2}(0)}{1 - q^2/m_A^2}\ , \quad (4)
$$

where the pole masses m_V and m_A are expected to be close to $M_{D^*(1^-)} = 2.01$ GeV$/c^2$ and $M_{D^*(1^+)} = 2.42$ GeV$/c^2$ [14] for the vector and axial form factors, respectively. The ratios of these form factors, evaluated at $q^2 = 0$, $r_V = \frac{V(0)}{A_1(0)}$ and $r_2 = \frac{A_2(0)}{A_1(0)}$, are measured in this paper.