Charm Physics at BESIII

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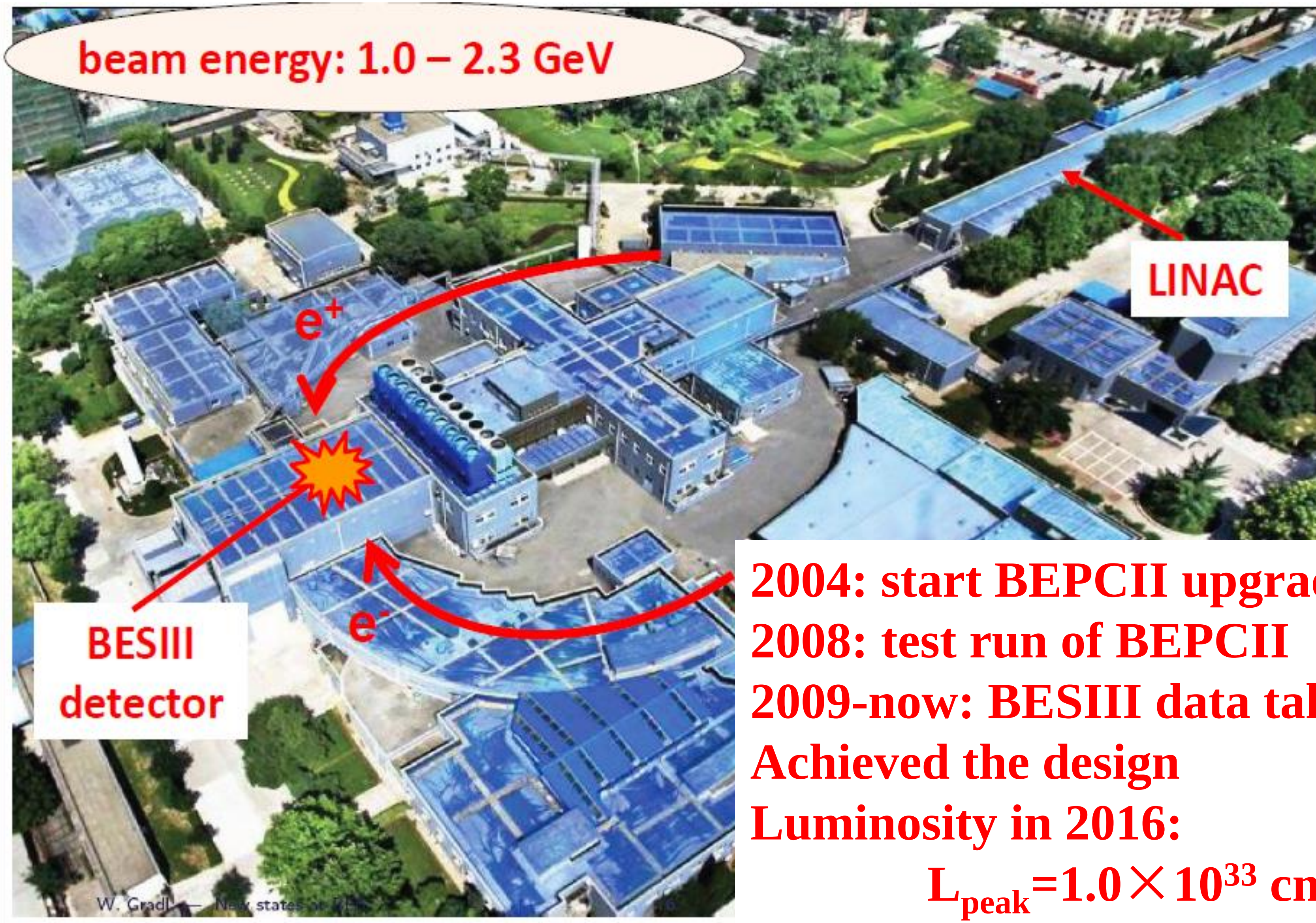
Outline

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

Beijing Electron Positron Collider (BEPCII)

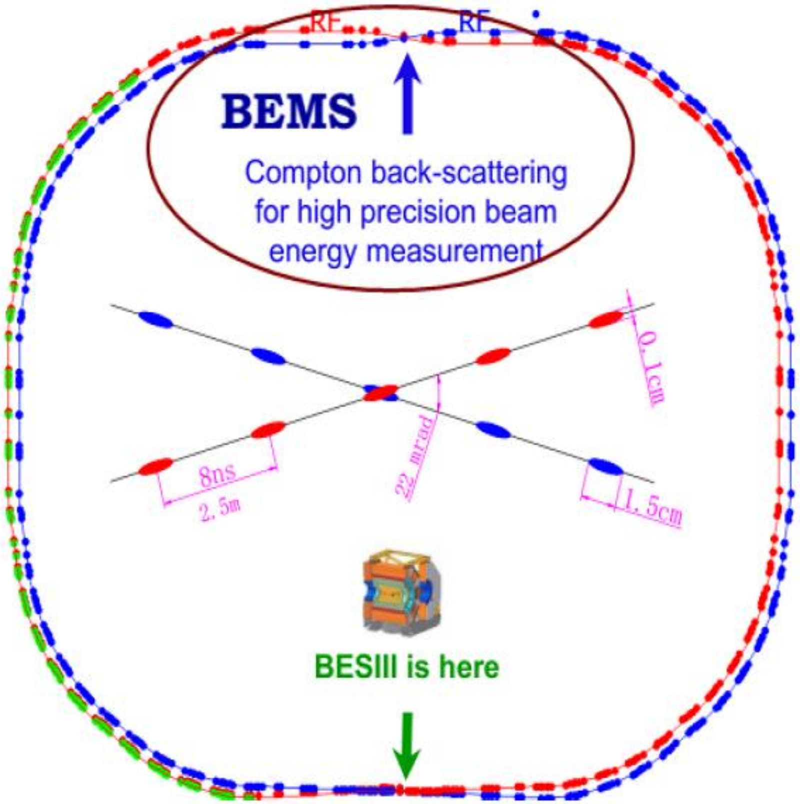


2004: start BEPCII upgrade
2008: test run of BEPCII
2009-now: BESIII data taking
Achieved the design Luminosity in 2016:

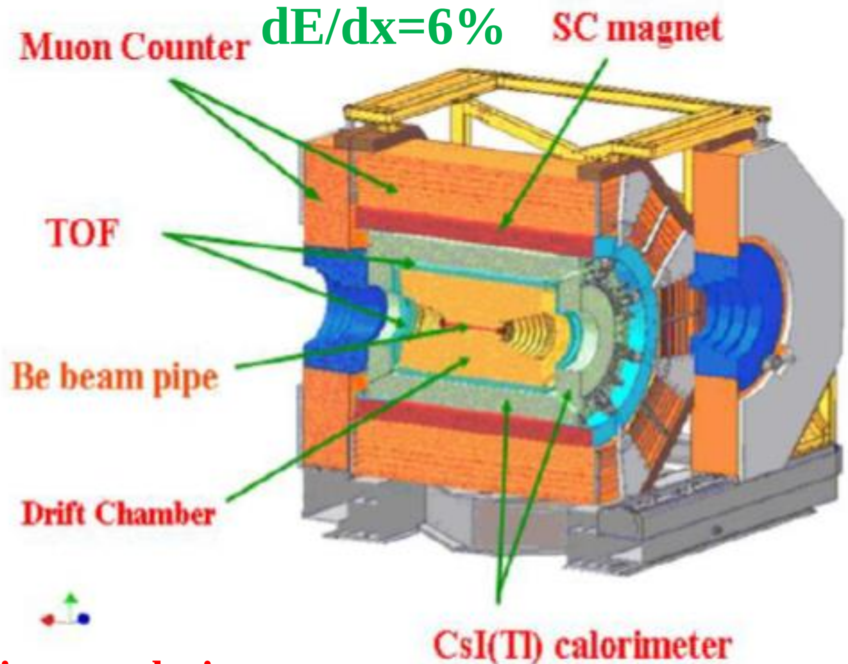
$$L_{peak}=1.0\times 10^{33}\ cm^{-2}s^{-1}$$

The BESIII Detector @ BEPCII

NIM A614, 345 (2010)



Excellent tracking:
δp/p=0.5%@1GeV
dE/dx=6%

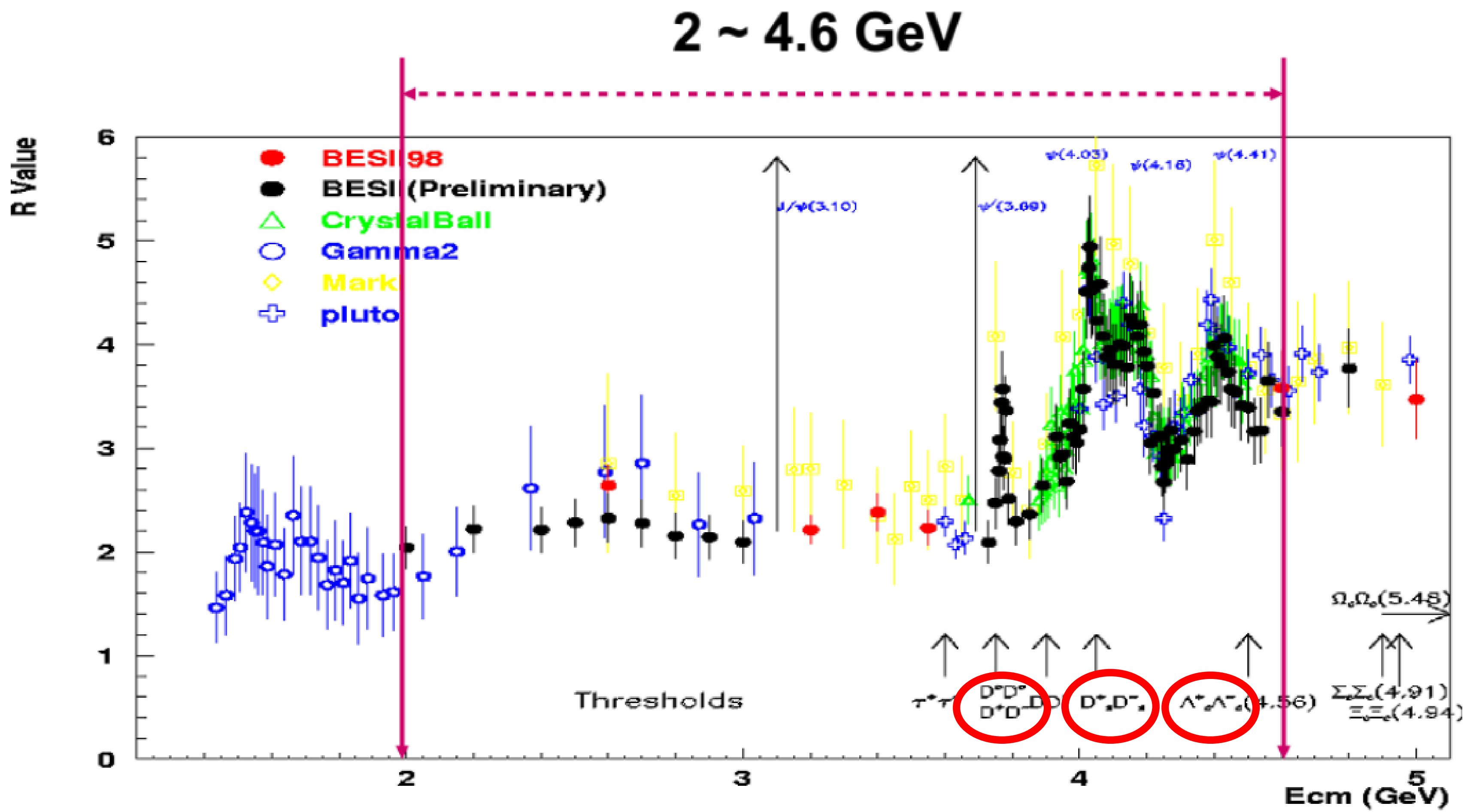


Time resolution:
90ps@BTOF
110ps@ETOF

Shower reconstruction:
δE/E=2.5%@1GeV

The new BESIII detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.

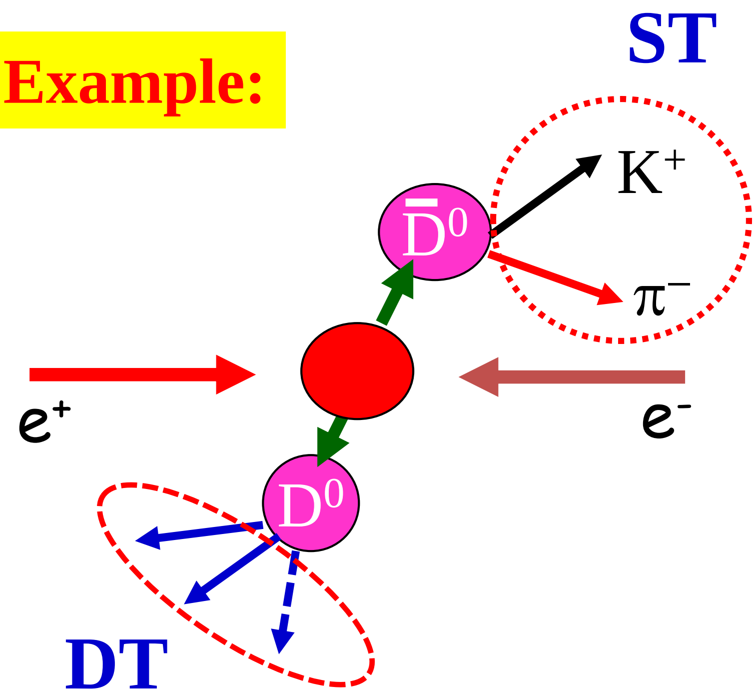
Data samples in this talk



- **0.57 fb^{-1} data@4.599 GeV for $\Lambda_c^+\Lambda_c^-$ production;**
- **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;**

Analysis Technique

Example:



ST: Find only one D/Λ_c

DT: Find both of them

$$\Delta E \equiv E_{D/\Lambda_c^+} - E_{\mathrm{beam}}$$

$$M_{BC} \equiv \sqrt{E_{\mathrm{beam}}^2/c^4 - \vec{p}^{\,2}_{D/\Lambda_c^+}/c^2}$$

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

The advantage of data at threshold:

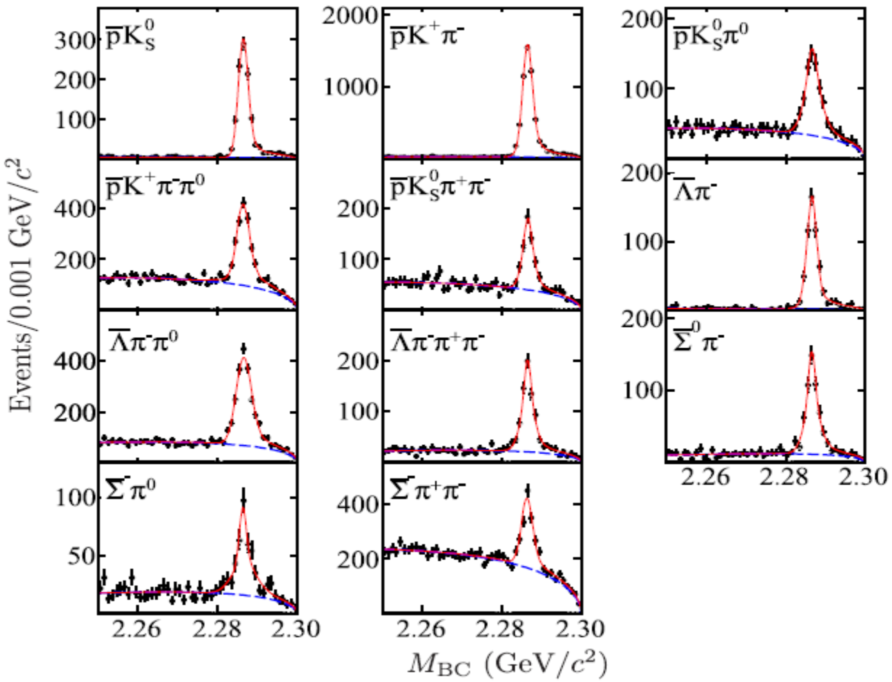
- **Charmed hadrons can be fully reconstructed by hadronic decays with large Branching Fractions(BF).**
- **Double Tag technique make one can access to absolute BFs and dynamics in the other side decays with clean background.**
- **Most systematic uncertainty in tag side are cancelled out.**

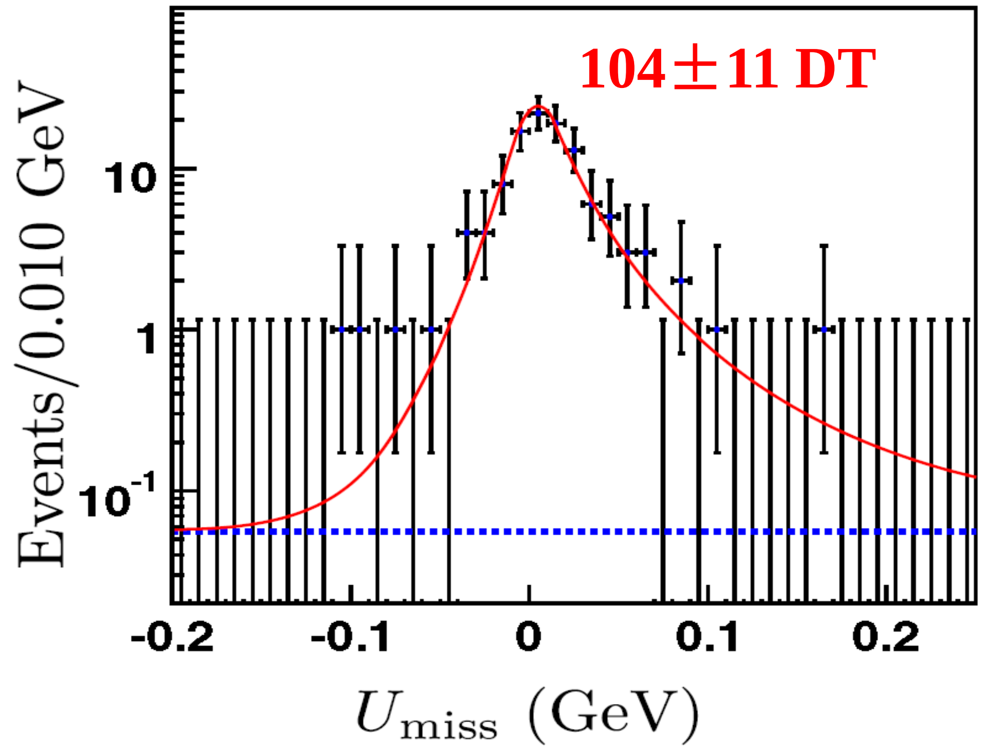
Absolute BF for $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

PRL115, 221805 (2015)

14415±159 events with 11 ST modes

Backgrounds are well controlled





- **First absolute measurement**

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

- **Important for test and calibrate the LQCD calculations**
- **Useful for determining CKM matrix elements**
- **Test the theoretical predications (ranges from 1.4% to 9.2%)**

Absolute BFs of Λ_c^+ hadronic decays

- **Measurement using the threshold pair-productions via e^+e^- annihilations is unique:**
  - the most simple and straightforward
  - kinematics do not allow additional particle produced along with the $\Lambda_c^+\Lambda_c^-$ pair

PRL116, 052001 (2016)

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	

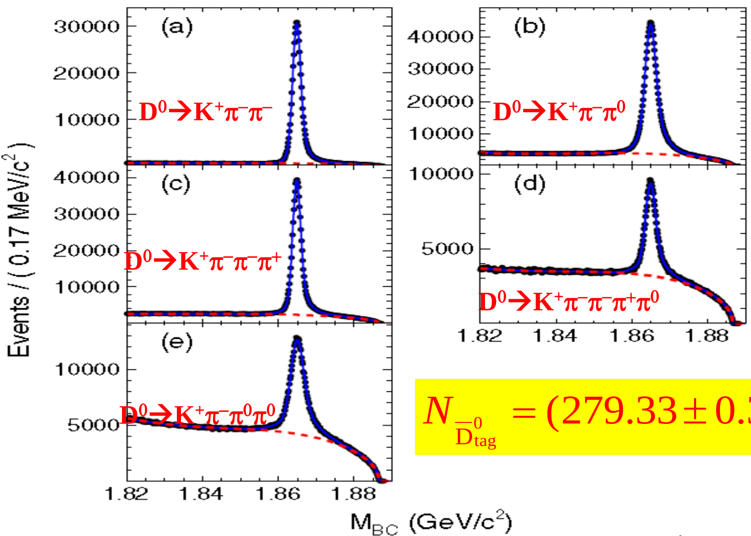
- **A global least-square fitter is utilized to improve the measured precision for 12 Λ_c^+ hadronic decay channels.**
- **BESIII BF for $\Lambda_c^+ \to pK^-\pi^+$ is smaller.**
- **Improved absolute BF of $pK^-\pi^+$ together with BELLE's result are key to calibrate other decays.**

- **The precision of absolute BFs of 12 modes are improved significantly.**

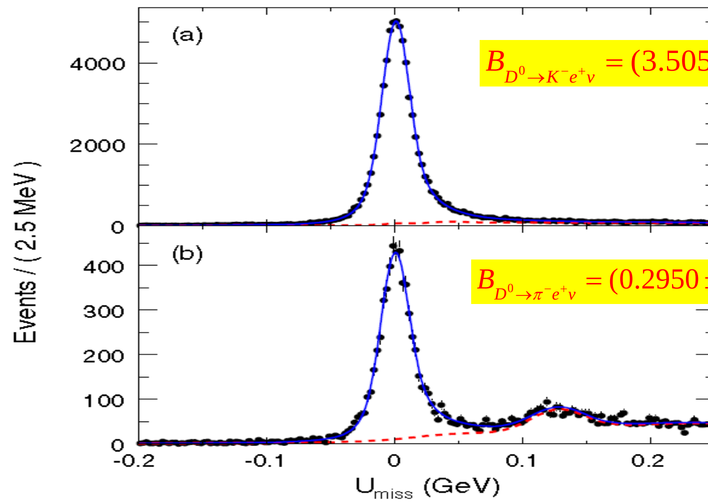
Measurement of $B[D^0 \to K(\pi)^- e^+ \nu]$ and $f_+^{K(\pi)}(0)$

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

PRD92,072012(2015)



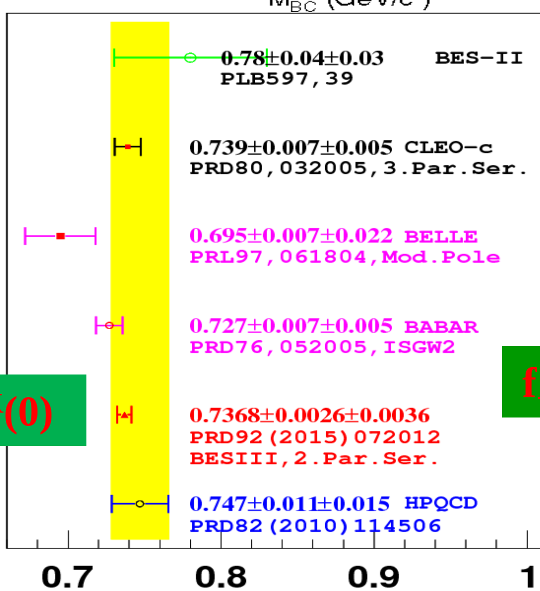
$N_{\bar{D}^0_{tag}} = (279.33 \pm 0.37) \times 10^4$



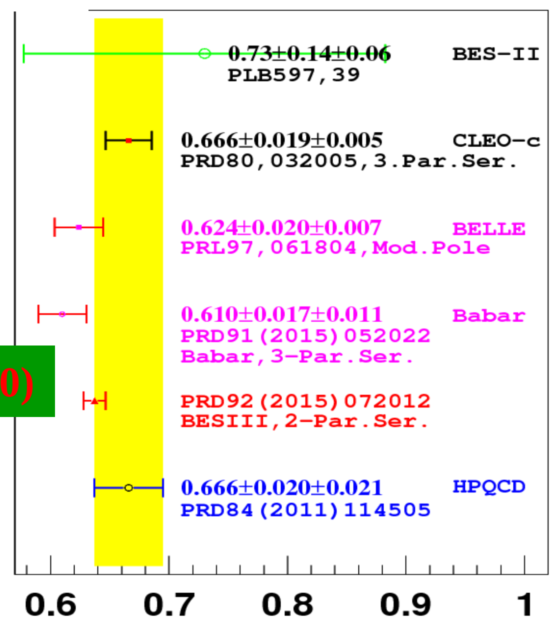
$B_{D^0 \to K^- e^+ \nu} = (3.505 \pm 0.014 \pm 0.033)\%$

$B_{D^0 \to \pi^- e^+ \nu} = (0.2950 \pm 0.0041 \pm 0.0026)\%$

$f_+^K(0)$



$f_+^\pi(0)$



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

$f^{D \to K(\pi)}_+(0)|V_{cs(d)}|$

Input $|V_{cs(d)}|$ of CKM-Fitter

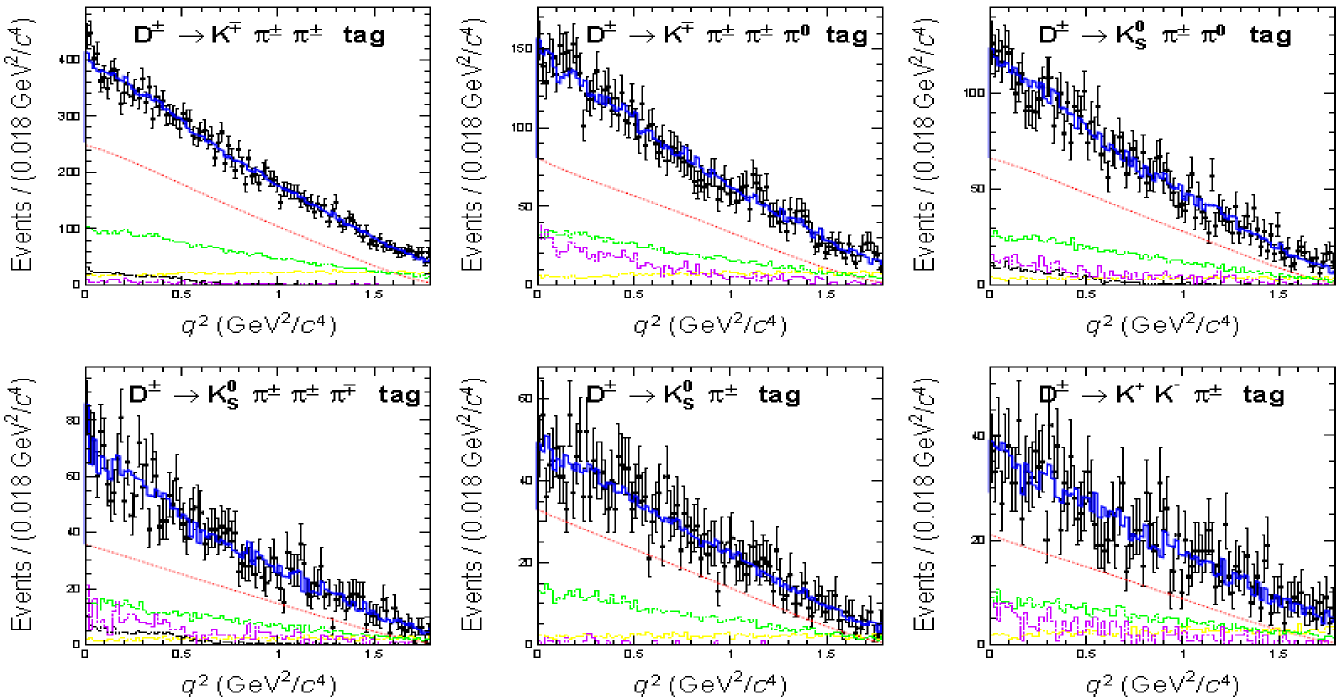
$f^{D \to K(\pi)}_+(0)$

The most precise form factor measurement to calibrate the LQCD

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

- **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 $U_{miss} \to 0$** **[PRD92, 112008(2015)]**

Simultaneous fit to observed numbers of DT candidates



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

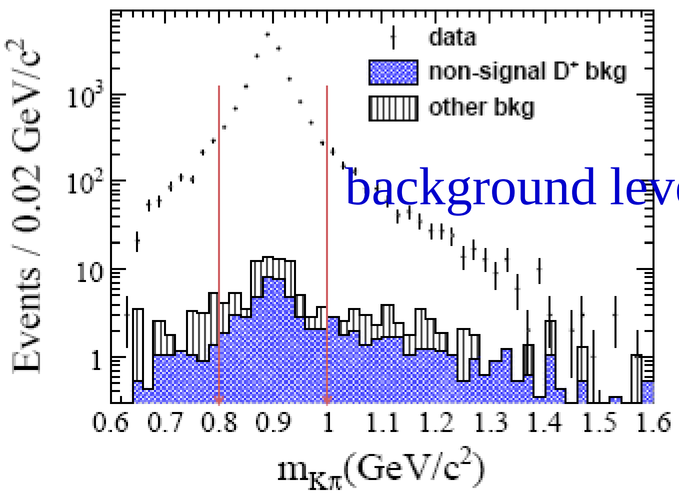
$f^K_+(0)|V_{cs}| = 0.728 \pm 0.006 \pm 0.011$

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

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

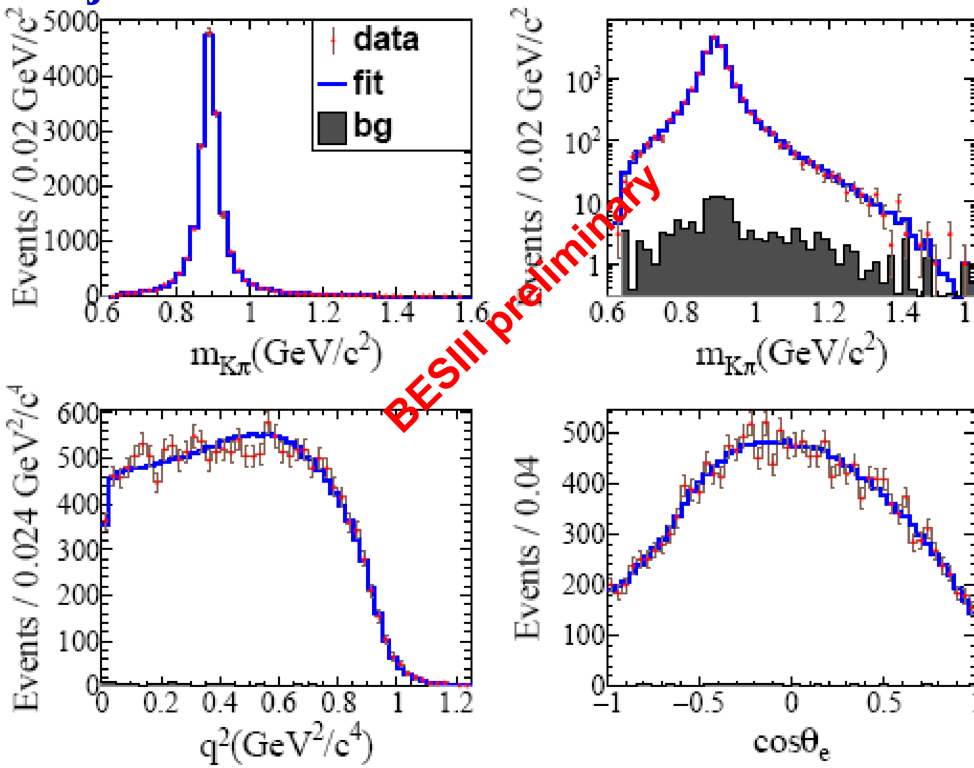
arXiv:1512.08627

$M_{K\pi}$ distribution



background level: 0.7%

Projections of data and fitted MC distributions



- **Fit Results of B**

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

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

- **Fitted fractions of the component**

$$f(D^+ \to (K^- \pi^+)_{K^{*0}(892)}\, e^+ \nu_e) = (93.93 \pm 0.22 \pm 0.18)\%$$
$$f(D^+ \to (K^- \pi^+)_{S-wave}\, e^+ \nu_e) = (6.05 \pm 0.22 \pm 0.18)\%$$

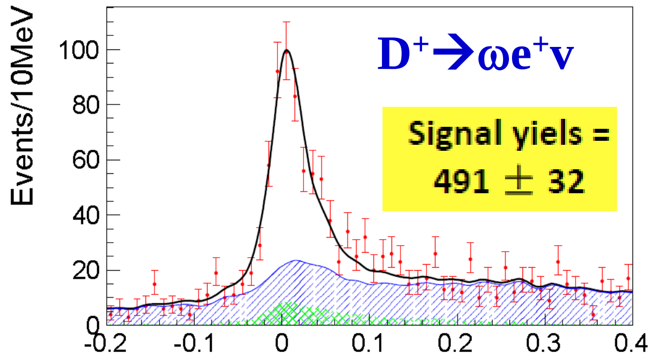
- **Parameters of $K^{*0}(892)$**

$$m_{K^{*0}(892)} = (894.60 \pm 0.25 \pm 0.08)\ \mathrm{MeV}/c^2$$
$$\Gamma_{K^{*0}(892)} = (46.42 \pm 0.56 \pm 0.15)\ \mathrm{MeV}/c^2$$

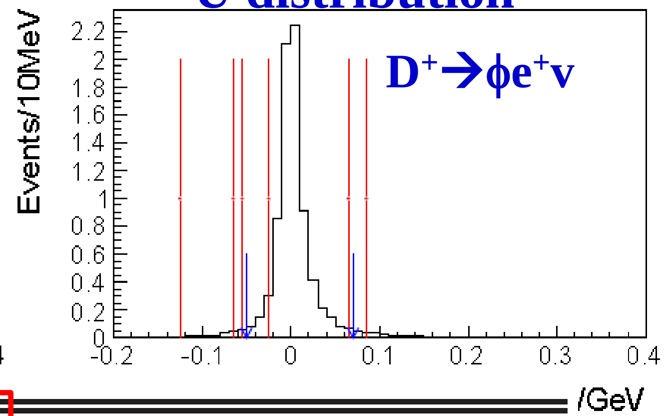
Study of $D^+ \to \omega e^+ \nu$ and search for $D^+ \to \phi e^+ \nu$

PRD92, 071101R(2015)

U distribution



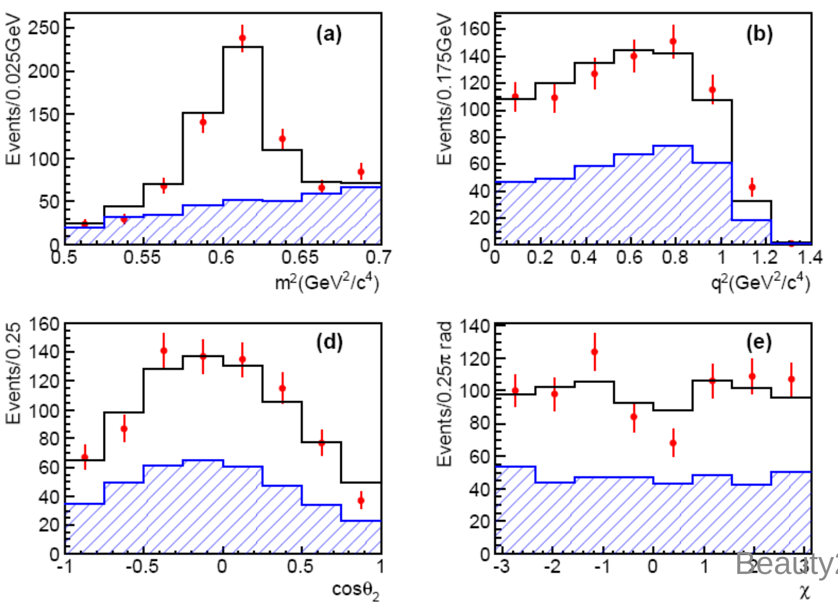
U distribution



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.)

- No significant excess of $D^+ \to \phi e^+ v$ is observed
- Better precision of BFs
- Amplitude analysis of $D^+ \to \omega e^+ v$ is performed for the first time



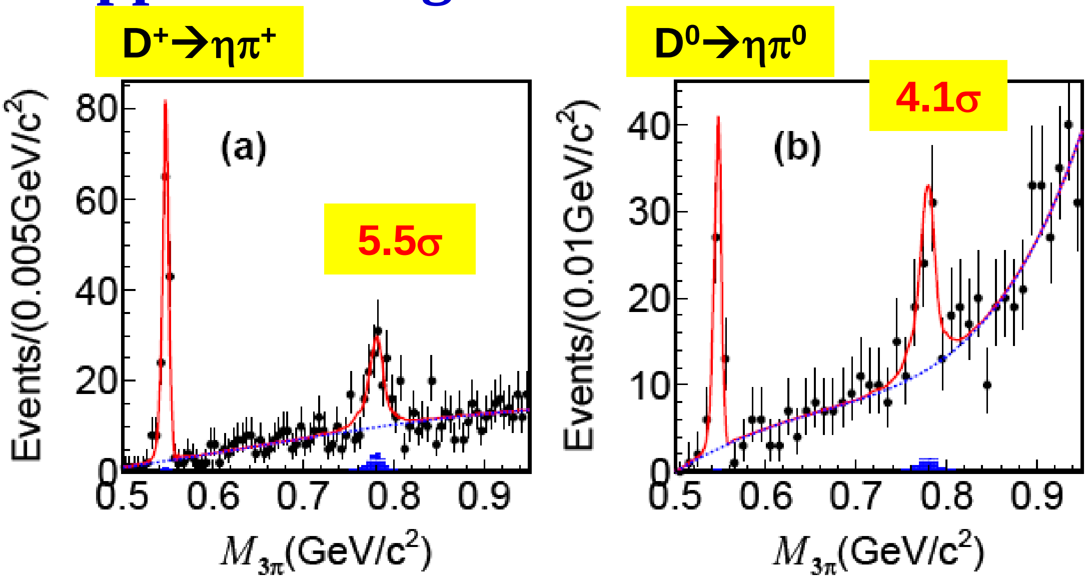
Results of form factor ratios:

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

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

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

Suppress background via DT method



PRL116, 082001 (2016)

- **Predications of B[D→ωπ] at 1.0 ×10^{-4} level.**
- **D→ωπ were studied at CLEO-c with ST method, but only set BF upper limits**
- **Improve understanding of SU(3) flavor symmetry breaking effects in D decays and benefitting theoretical prediction of CP violation in D decays**

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.
$D^+ \to \eta\pi^+$	$(3.07 \pm 0.22 \pm 0.13) \times 10^{-3}$	$(3.53 \pm 0.21) \times 10^{-3}$
$D^0 \to \eta\pi^0$	$(0.65 \pm 0.09 \pm 0.04) \times 10^{-3}$	$(0.68 \pm 0.07) \times 10^{-3}$

Other Results

$D^+ \to \mu^+ \upsilon_\mu$ (Phys. Rev. D **89**, 051104(R) (2014))

$D^+ \to K_S^0 \pi^+ \pi^0$ (Phys. Rev. D **89**, 052001 (2014))

$D^0 \to \gamma\gamma$ and $D^0 \to \pi^0 \pi^0$ (Phys. Rev. D **91**, 112015 (2015))

Strong phase difference in $D^0 \to K^- \pi^+$ (Phys. Lett. B **734**, 227(2014))

y_{cp} in $D^0 - \overline{D}^0$ oscillation (Phys. Lett. B **744**, 339 (2015))

BF of D^{*0} decay (Phys. Rev. D **91**, 031101(R) (2015))

BF($D_s^+ \to \eta' X$) and BF($D_s^+ \to \eta' \rho^+$) (arXiv:1506.08952 [hep-ex])

Observation of $\Lambda_c^+ \to n K_S^0 \pi^+$ [arXiv:1601.04241]

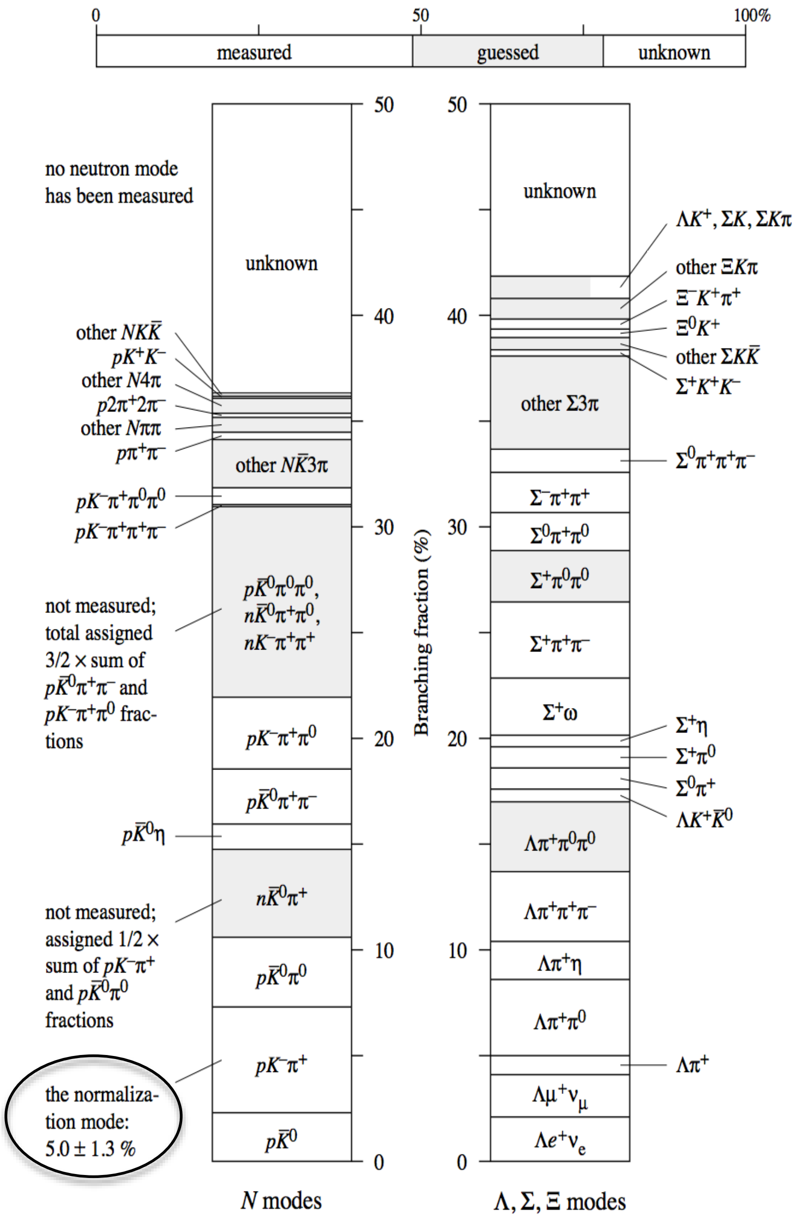
Summary

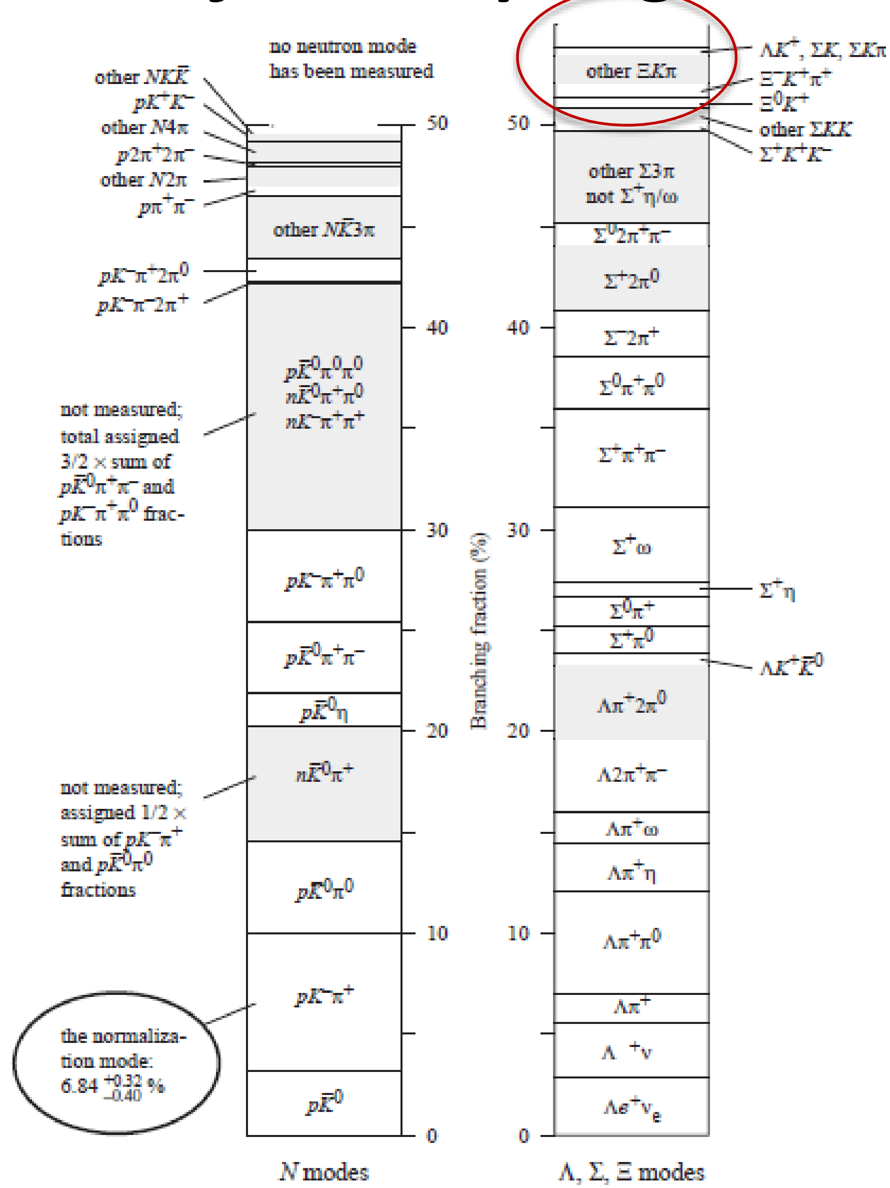
- **With 2.92fb^{-1} data taken at 3.773GeV, BESIII released many new results.**
- **BEPCII/BESIII accumulated 567pb^{-1} data set @4.6GeV**
- **Open a door to study the lowest charmed baryon state Λ_c^+**
  - low backgrounds and high detection efficiency
- **Several physic potentials has been and is being explored**
  - absolute BFs of hadronic decays model-independently
  - Λ_c semi-leptonic decays
- **BESIII is taking data at 4.18GeV to study the D_s^+decays**
- **More fruitful results will come out!**

Thanks

Backup slides

after adopting Belle's





Basic global fit logical

[Chinese Phys. C37(2013)106201]

$$N_i^{\mathrm{ST}} = N_{\Lambda_c^+\overline{\Lambda}_c^-} \cdot \mathcal{B}_i \cdot \varepsilon_i^{\mathrm{ST}}$$

$$N_{-j}^{\mathrm{DT}} = N_{\Lambda_c^+\overline{\Lambda}_c^-} \cdot \sum_i \mathcal{B}_i \cdot \mathcal{B}_j \cdot \varepsilon_{-j}^{\mathrm{DT}}$$

The efficiencies-corrected yields, denoted by $\mathbf{c} = \mathbf{E}^{-1}\mathbf{n}$

Based on the lease square principle, The χ^2 can be constructed as $\chi^2 \equiv (\mathbf{c} - \tilde{\mathbf{c}})^T \mathbf{V}_{\mathbf{c}}^{-1} (\mathbf{c} - \tilde{\mathbf{c}})$

motivation

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**

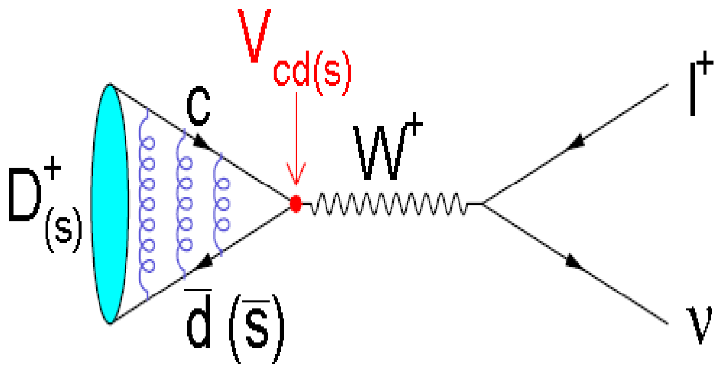
- **LQCD calibration: precise decay constant $f_{D(s)+}$, form factors $f_{D\rightarrow K(\pi)}(q^2)$ and others**

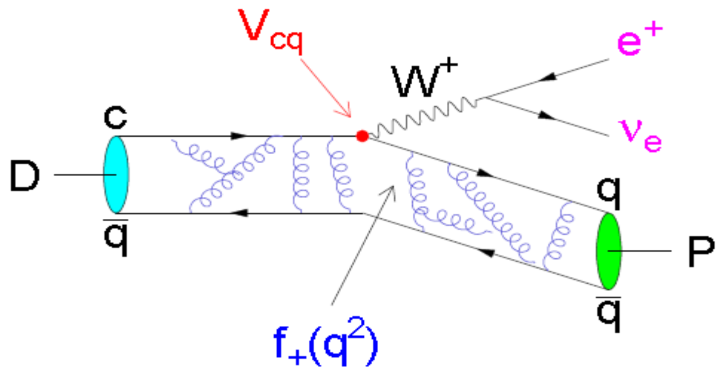
- **New physics BSM: evidence of rare decay/CP violation, or significant deviation of CKM untarity/LQCD calculation**

- **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 $|V_{cs(d)}|$





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

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

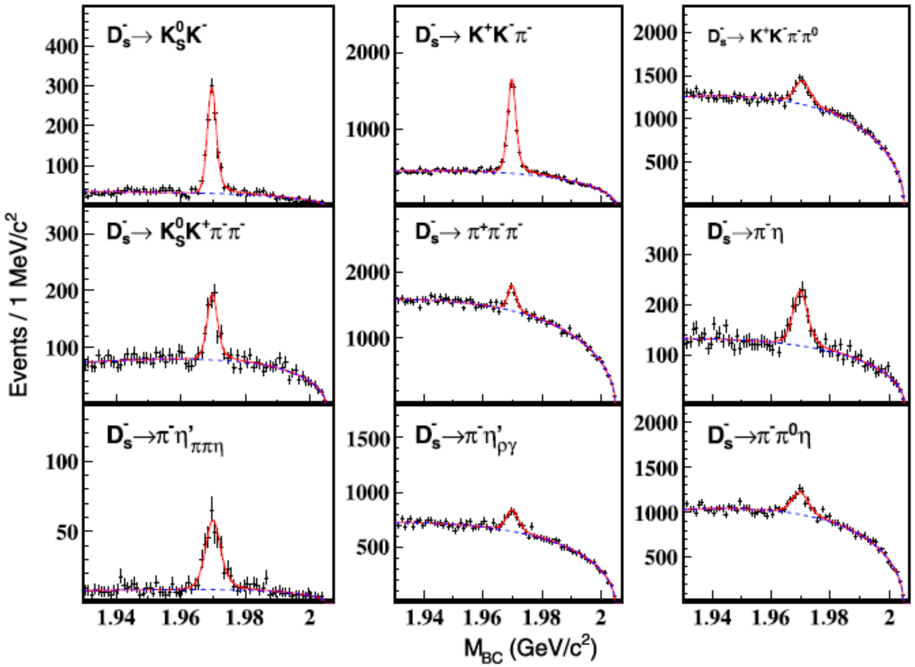
- **Improved $f_{D(s)+}$, $f_+^{D\to K(\pi)}(q^2)$ of D semi-leptonic decays calibrate LQCD calculations at higher accuracy. Once they pass experimental test, the precise LQCD calculations of f_D/f_B, f_{Ds}/f_{Bs} and form factor ratios are helpful for measurements in B decays**

- **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 $|V_{cs(d)}|$**

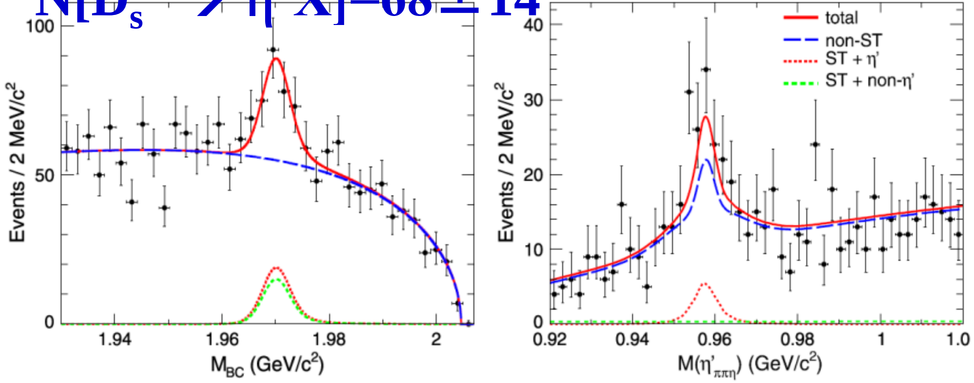
$D_s^+ \to \eta' X$ and $\eta'\rho^+$

PLB750 466(2015)

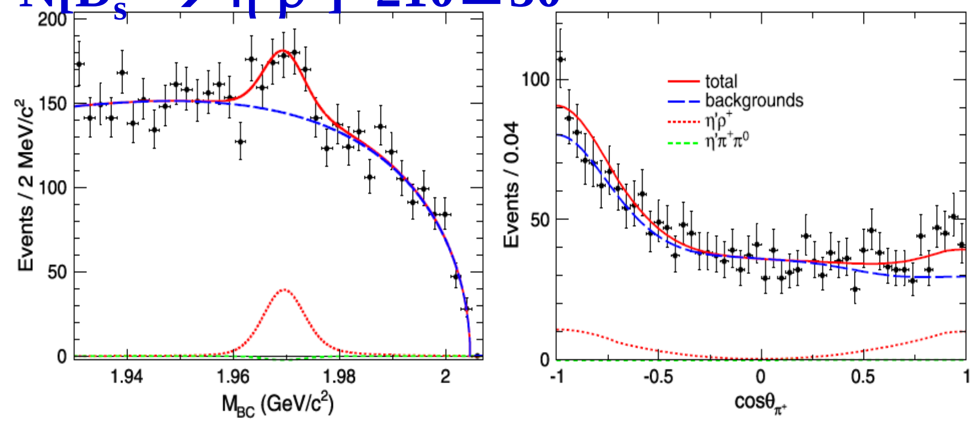
About 15.6 K ST D_s^- events by using 9 ST modes



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



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



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

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

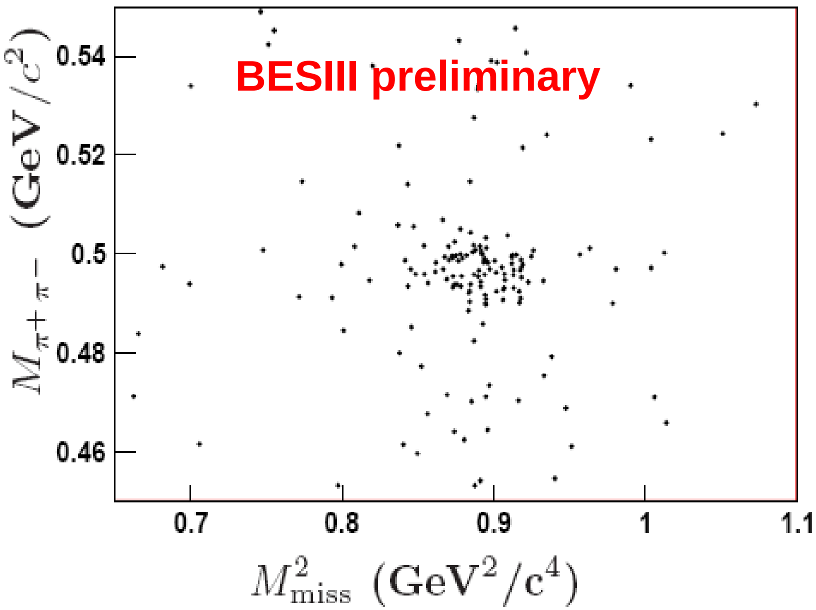
$B[D_s^+ \to \eta'\rho^+] = (5.8 \pm 1.4 \pm 0.4)\%$

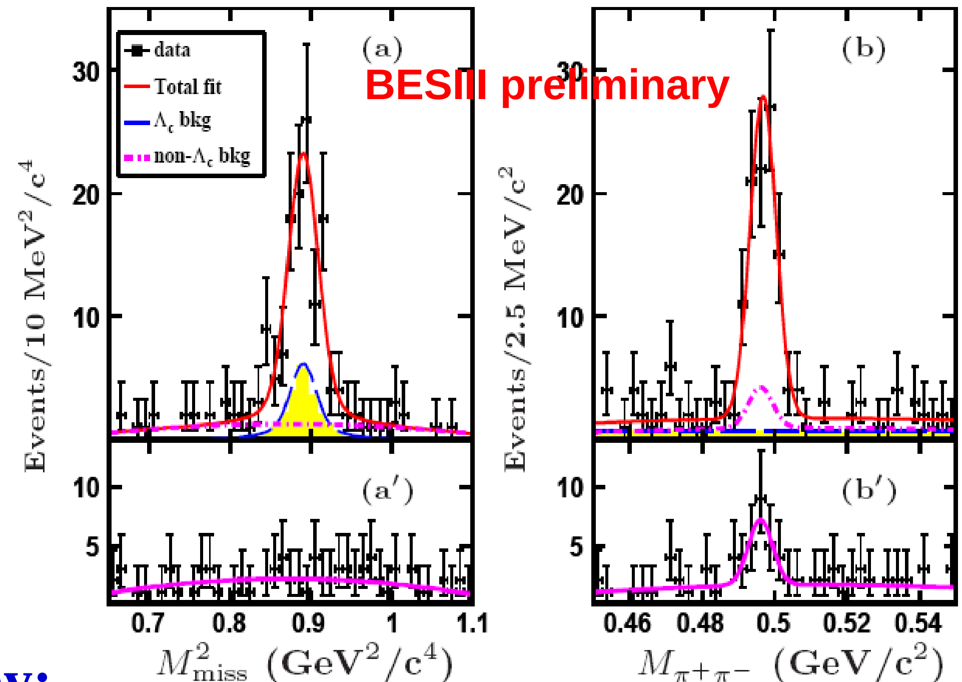
$B^{exp}[D_s^+ \to \eta'\rho^+] = (3.0 \pm 0.5)\%$ [PRD84 074019(2011)]

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)]

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

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





The missing neutron is detected by:

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

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.

83±11 net signal events

BESIII Preliminary results:

$B[\Lambda_c^+ \to nK_S^0\pi^+]=(1.82\pm0.23\pm0.11)\%$

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]