Charmed Hadron Decays at BESIII

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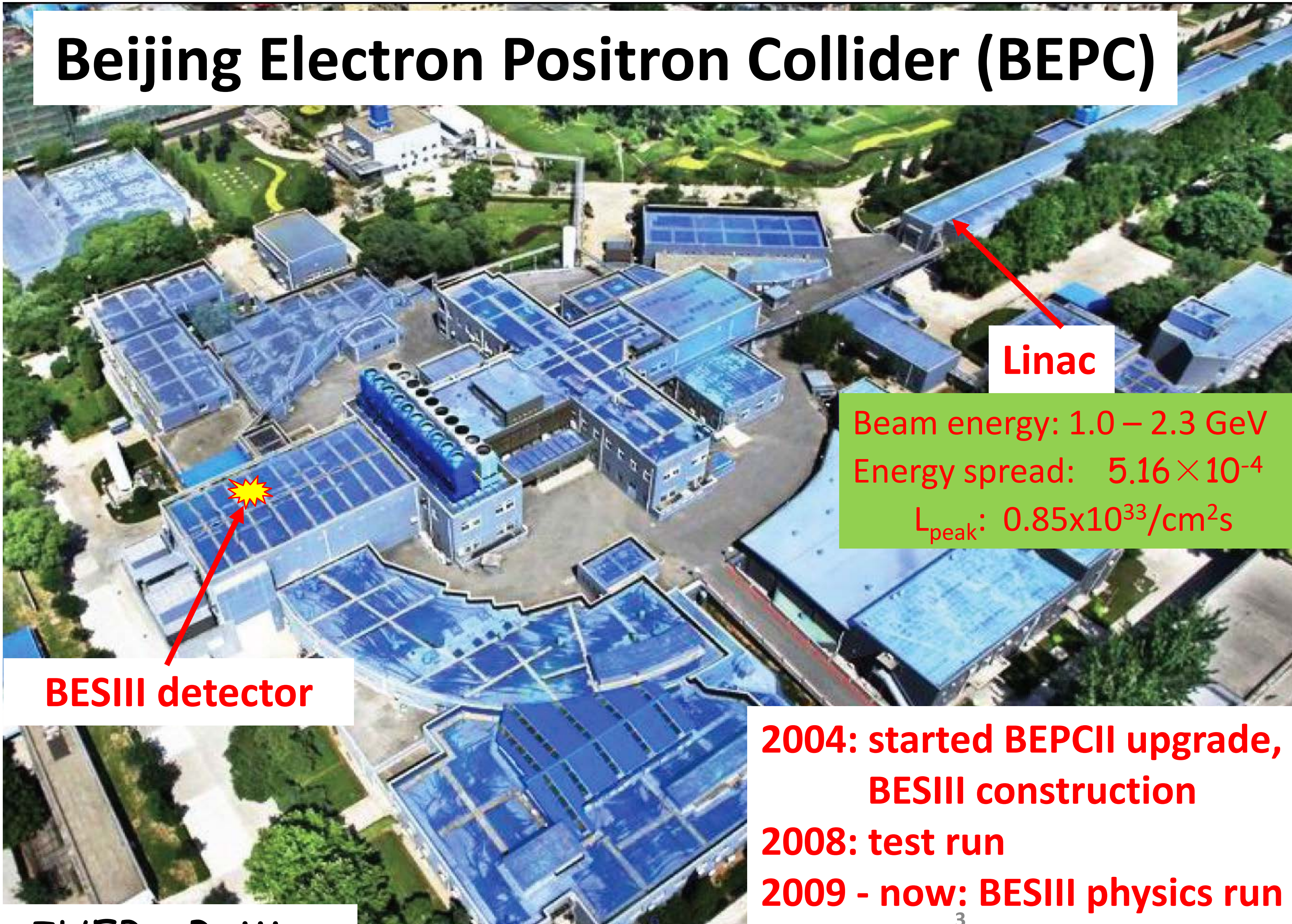
Outline

- ***D*** **semileptonic decays (data@ψ(3770))**
  - Branching fraction of $D^+ \to K^-\pi^+e^+\upsilon_e$ and form factors
  - Branching fraction of $D^+ \to \omega(\phi)e^+\upsilon_e$ and form factors
  - Branching fraction of $D^+ \to K_Le^+\upsilon_e$ and form factor
- $\mathbf{\Lambda_c^+}$ **hadronic and semileptonic decays (data@4600)**
  - Branching fractions of 12 hadronic modes
  - Branching fraction of $\Lambda_c^+ \to \Lambda e^+\upsilon_e$

charge conjugated modes are implied in this talk.

Beijing Electron Positron Collider (BEPC)



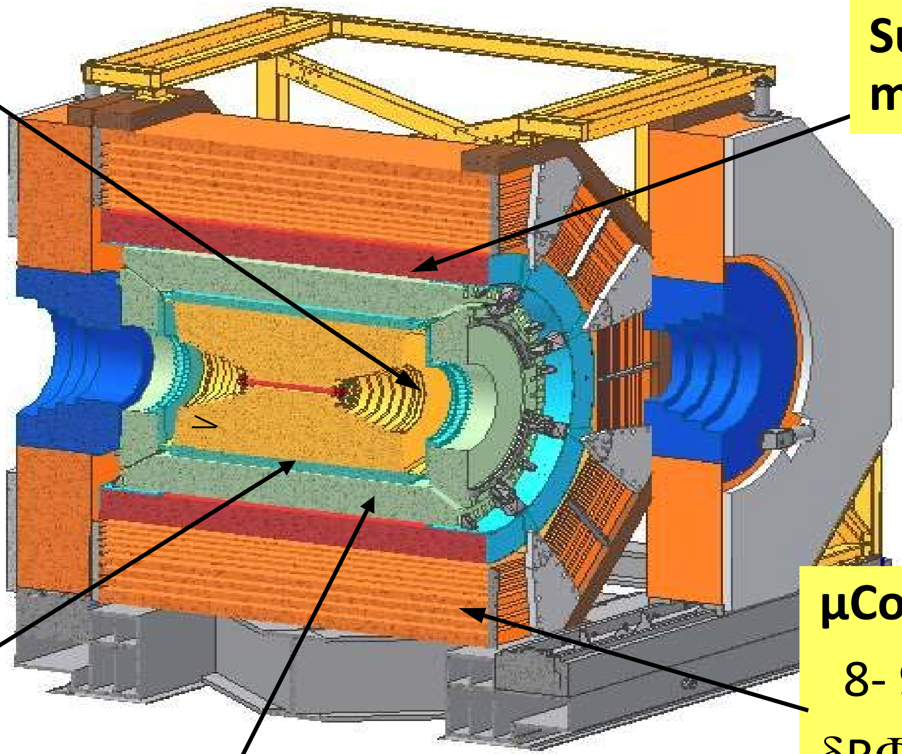
IHEP, Beijing

The BESIII Detector

NIM A614, 345 (2010)

Drift Chamber (MDC)
$\sigma P/P$ ($^0/_0$) = 0.5%(1GeV)
$\sigma_{dE/dx}$ ($^0/_0$) = 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/$\sqrt{E}$

e^+e^- annihilation samples in this talk

- **At E_{cm} = 3.773GeV. Accumulated luminosity = 2920 pb^{-1}.**
  $D^0\overline{D}^0$ and D^+D^- are produced in pair at mass threshold.
- **At E_{cm} = 4.6GeV, Accumulated luminosity = 567 pb^{-1} .**
  $\Lambda_c^+\Lambda_c^-$ are produced in pair at mass threshold.

Analysis technique

- **Typically, two ways to obtain the D/Λ_c yields:**
  1. **Single Tag (ST) :** Find only one D/Λ_c.
  2. **Double Tag (DT):** Find both of them.
- **Tags are selected based on two variables:**

$$\Delta E = E_{D/\Lambda_c} - E_{beam}, \; m_{BC} = \sqrt{E_{beam}^2 - |\vec{p}_{D/\Lambda_c}|^2} .$$

- **For semileptonic decays, to identify a missing neutrino, we adopt a kinematic variable:** $U_{miss} = E_{miss} - c|\vec{p}_{miss}|$,

E_{miss} and $\vec{p}_{miss}$ are missing energy and momentum carried by the neutrino, respectively.

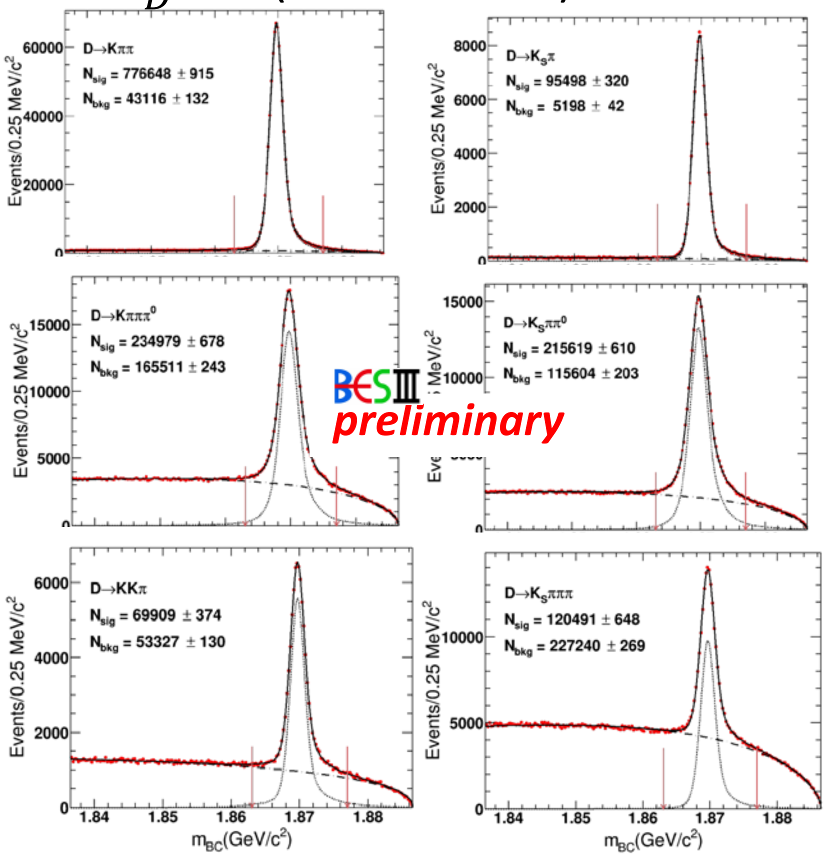
Study of $D^+ \to K^-\pi^+e^+\nu_e$

Purposes:

- Measure the branching fractions of $D^+ \to K^-\pi^+e^+\nu_e$ and $D^+ \to \overline{K}^{*0}(892)e^+\nu_e$.
- Measure the fractions and properties of different $K\pi$ (non-)resonant amplitudes.
- Measure q^2 dependent transition form factors in $D^+ \to \overline{K}^{*0}(892)e^+\nu_e$ (q^2 is the invariant mass of $e^+\nu_e$) .

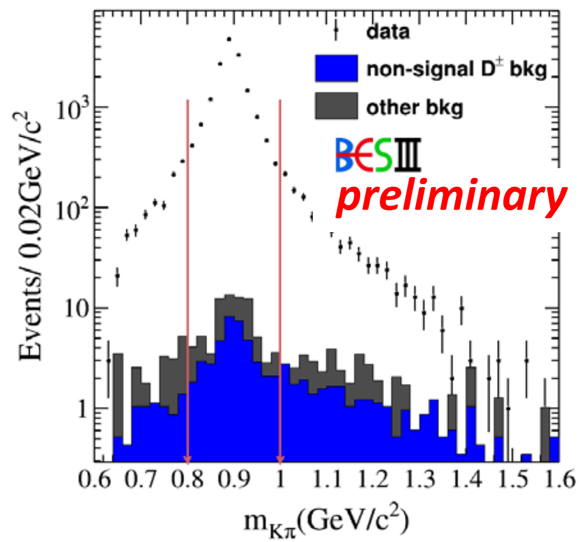
Tagged D^- decays(Six modes):

$N_{D^-}^{tag}$ = (1.513+0.002)X10^{-6}



Signal side $D^+ \to K^-\pi^+e^+\nu_e$ decays:

$N_{D^+}^{obs}$ = 18262 (16181 in K^* region)



background level is about 0.7% (0.4% in K^* region)

Branching fractions results (preliminary):

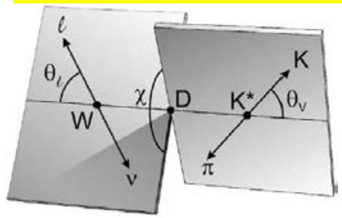
$\mathcal{B}(D^+ \to K^-\pi^+e^+\nu_e) = (3.71 \pm 0.03 \pm 0.09)\%$

$\mathcal{B}(D^+ \to K^-\pi^+e^+\nu_e)_{[0.8,1]} = (3.33 \pm 0.03 \pm 0.08)\%$

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

The differential decay width of the $D^+ \to K^-\pi^+e^+\nu_e$ decay can be described using: Phys. Rev. 137, B438 (1965)

- $m^2_{K\pi}$ - $K\pi$ mass square
- q^2 - $e^+\nu_e$ mass square
- θ_K, θ_e, χ angles



Fit Results (preliminary)

Non-resonant S-wave amplitude: Phase δ_S is parameterized as that defined in LASS scattering experiment [Nucl. Phys. B296, 493 (1988)]

- **Fitted fractions of the components:**

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

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

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

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

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

- **Form factors of $D^+ \to \bar{K}^{*0}(892)e^+\nu_e$ by SPD model:** $V(q^2) = \frac{V(0)}{1-q^2/m_V^2}$, $A_{1,2}(q^2) = \frac{A_{1,2}(0)}{1-q^2/m_A^2}$

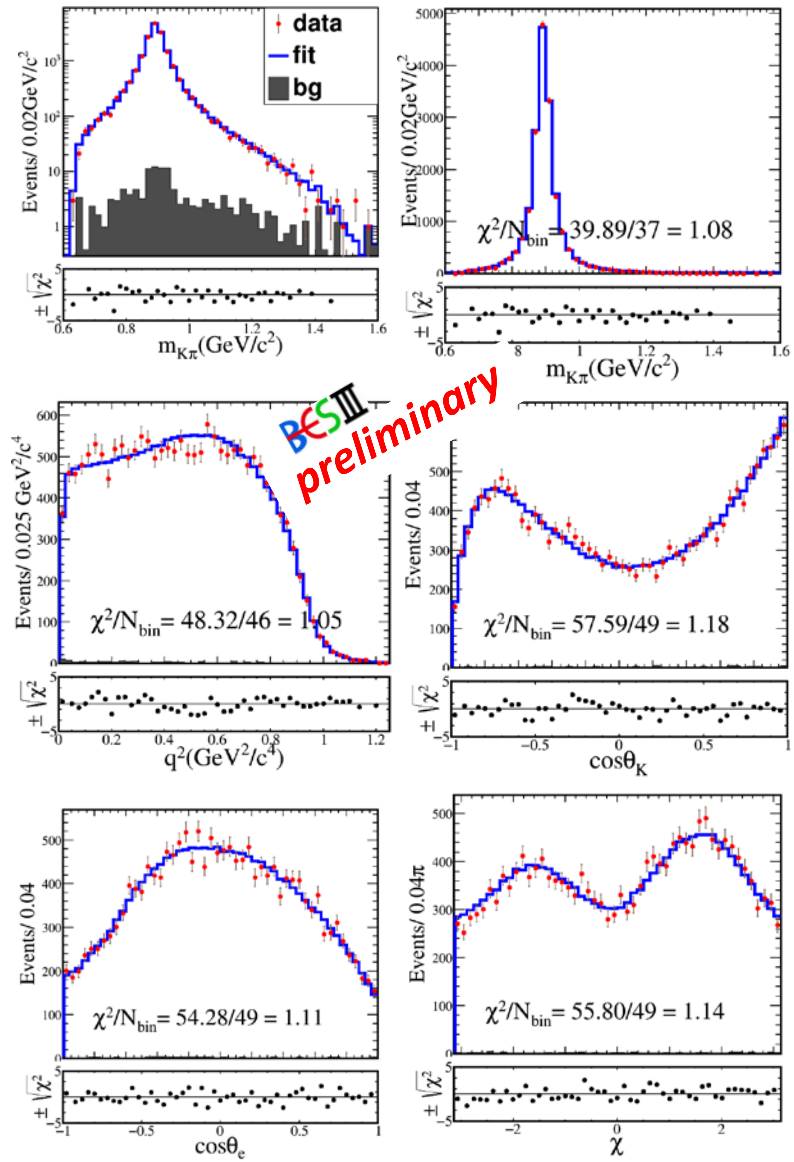
  $m_V = (1.81^{+0.25}_{-0.17} \pm 0.02)\ \mathrm{GeV}/c^2$ (first measurement)

  $m_A = (2.61^{+0.22}_{-0.17} \pm 0.03)\ \mathrm{GeV}/c^2$

  $A_1(0) = 0.573 \pm 0.011 \pm 0.020$

  $r_V = V(0)/A_1(0) = 1.411 \pm 0.058 \pm 0.007$

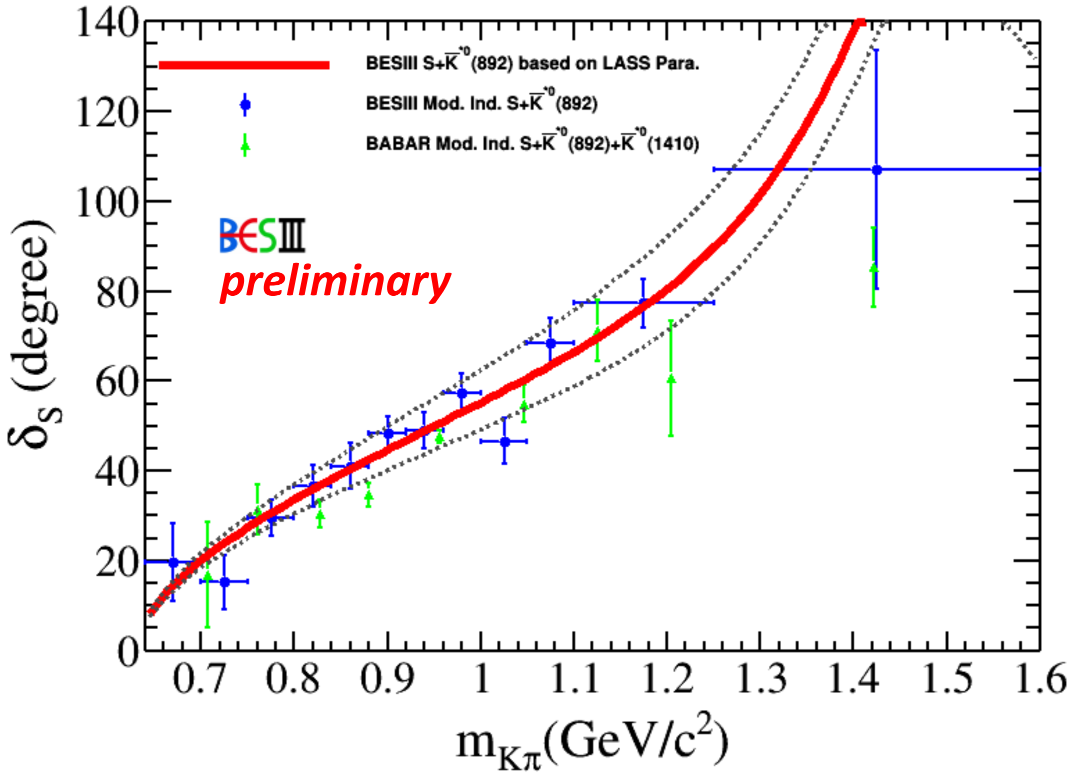
  $r_2 = A_2(0)/A_1(0) = 0.788 \pm 0.042 \pm 0.008$



Projections of data and fitted MC distribution

Model-Independent Measurement of S-wave Phase

We fit the phase in different $m_{K\pi}$ intervals, assuming δ_S remains constant within each interval.



Blue dots:

BESIII Model-independent measurement with S+$\bar{K}^{*0}(892)$

Red and dotted lines:

Predicted by BESIII amplitude analysis based on LASS parameterization

Nucl. Phys. B296, 493 (1988)

Green dots:

BABAR Model-independent measurement with S+$\bar{K}^{*0}(892) + \bar{K}^{*0}(1410)$

Phys. Rev. D 83, 072001 (2011)

Model-independent measurements of BESIII are consistent with the results from BESIII amplitude analysis within 1σ.

Model-Independent Measurement of Form Factors

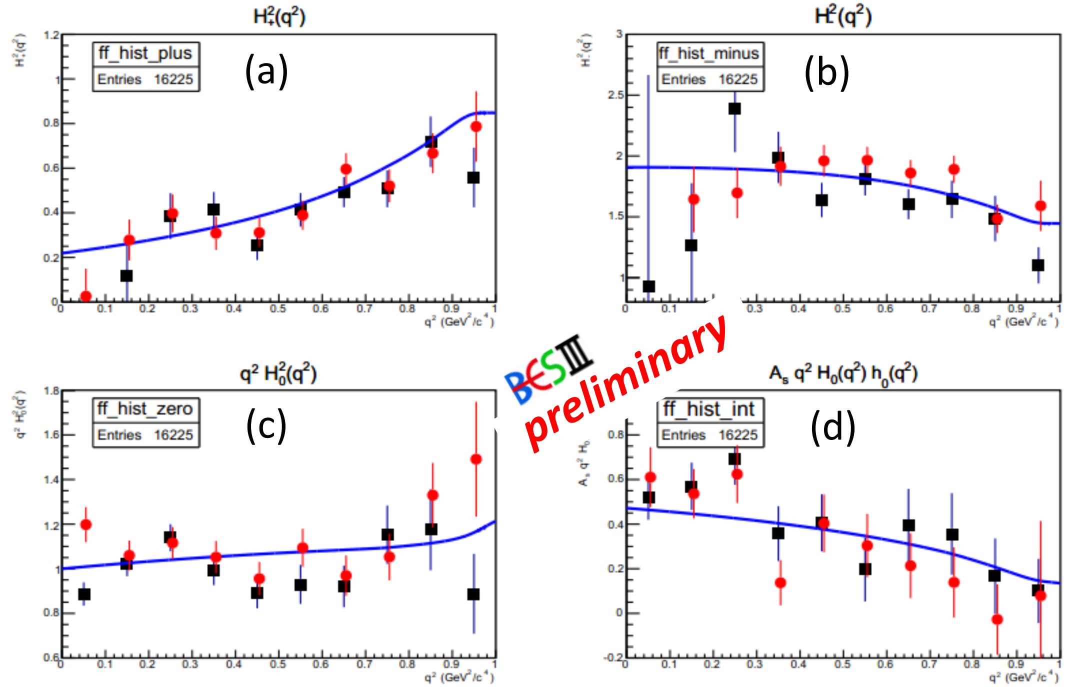
- Events located in the $K^{*0}(892)$ window $[0.8,1]$ GeV/c^2, are used to measure the form factors by a Projective Weighting Technique. [Phys. Rev. D 81, 112001 (2010)]

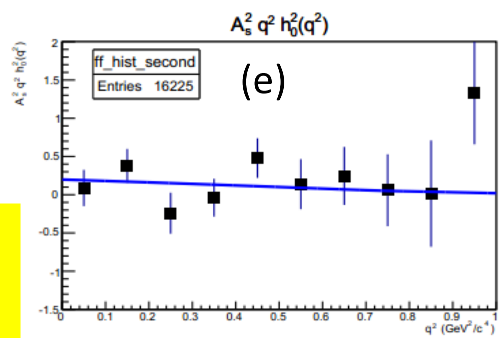
- Signal is assumed to be composed of $K^{*0}(892)$ and a non-resonant S-wave.

- $D^+ \to \bar{K}^{*0}(892)e^+\nu_e$ decay can be described in terms of 3 helicity basis form factors:

  P-wave related: $H_{\pm,0}(q^2)$

  S-wave related: $h_0(q^2)$





Normalization (see plot (c)):

$q^2|H_0(q^2)|^2 \to 1$ as $q^2 \to 0$

The model-independent measurements are generally consistent with CLEO's results.

And they are also consistent with the predicted trend based on the SPD model from BESIII amplitude analysis.

Red dots : BESIII model-independent measurement
Black dots : CLEO model-independent measurement
Blue Line : BESIII result from amplitude analysis, which is based on SPD model.

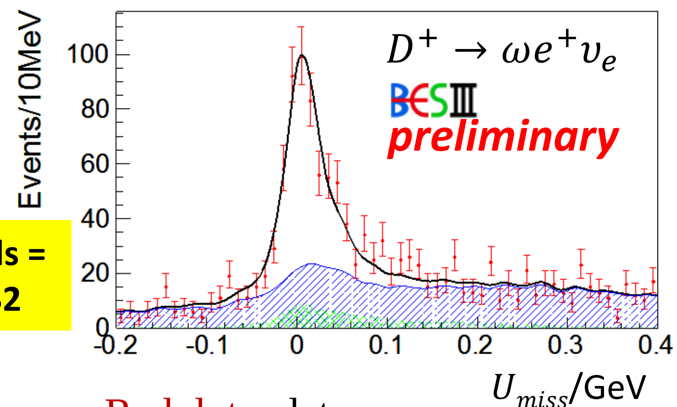
Study of $D^+ \to \omega(\phi)e^+\upsilon_e$

Current status:

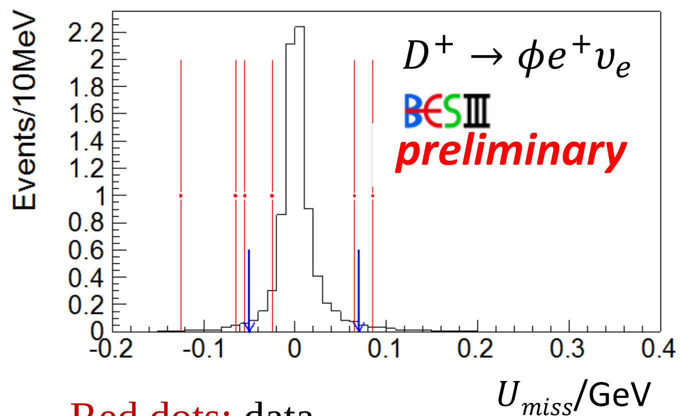
Form factors in $D^+ \to \omega e^+\upsilon_e$ have never been measured before.
No significant excess of $D^+ \to \phi e^+\upsilon_e$ is observed.

U_{miss} distributions:

Signal yiels = 491 ± 32



Red dots: data,
Black line: fit result,
Blue area: total background,
Green area: peaking background.



Red dots: data,
Black histogram: signal MC simulation,
Arrows: signal region.

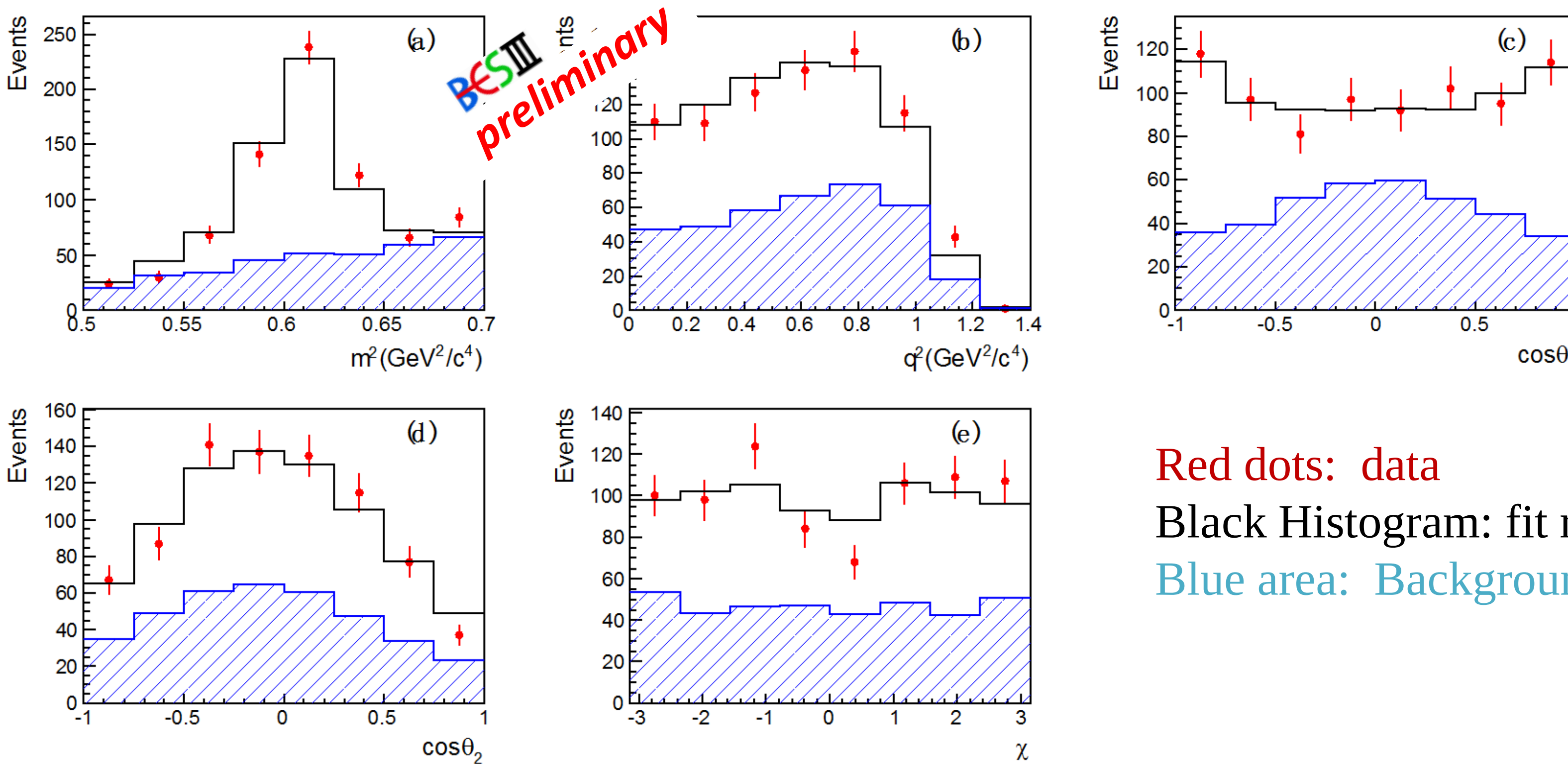
Branching fractions are compared with the world average value.

[PDG, Chin. Phys. C, 527 38, 090001 (2014)]

Mode	This work **(preliminary)**	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%$C.L.$)

Form Factors in $D^+ \to \omega e^+ \upsilon_e$

Form factors in $D^+ \to \omega e^+ \upsilon_e$ decay can be parameterized similarly as those in the $D^+ \to K^- \pi^+ e^+ \upsilon_e$ decay.



Red dots: data

Black Histogram: fit results

Blue area: Background

Results of form factor parameters (preliminary):

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

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

Study of $D^+ \to K_L e^+ \upsilon_e$

Experimental study of $D^+ \to K_L e^+ \nu_e$ is important to test

- the theoretical calculation of $A_{CP}^{D^+ \to K_L e^+ \nu_e}$,
- the LQCD calculation on $f_+^K(0)$,
- and the unitarity of the CKM matrix.

We study the $D^+ \to K_L e^+ \upsilon_e$ decays for the first time.

Branching fractions:

- Branching fractions are calculated separately for each charm and tag mode using:

$$\mathcal{B}_{\rm sig} = \frac{N_{\rm DT}(1 - f_{\rm bkg}^{\rm peak})}{\epsilon N_{\rm ST}}$$

- CP asymmetry is determined using:

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

BESIII preliminary

$D^+ \to K_L^0 e^+ \nu_e$					
Tag Mode	$N_{\rm ST}$	$N_{\rm DT}$	$f_{\rm bkg}^{\rm peak}(\%)$	$\epsilon(\%)$	$\mathcal{B}_{\rm sig}(\%)$
$D^- \to K^+\pi^-\pi^-$	410200 ± 670	10492 ± 103	41.83 ± 0.28	33.96 ± 0.10	4.381 ± 0.050
$D^- \to K^+\pi^-\pi^-\pi^0$	120060 ± 457	3324 ± 64	44.78 ± 0.49	33.14 ± 0.19	4.613 ± 0.103
$D^- \to K_S^0\pi^-\pi^0$	102136 ± 378	2658 ± 56	38.93 ± 0.58	35.67 ± 0.21	4.456 ± 0.108
$D^- \to K_S^0\pi^-\pi^-\pi^+$	59158 ± 303	1459 ± 41	40.84 ± 0.76	32.51 ± 0.27	4.488 ± 0.145
$D^- \to K_S^0\pi^-$	47921 ± 225	1287 ± 36	38.90 ± 0.88	35.07 ± 0.32	4.679 ± 0.155
$D^- \to K^+K^-\pi^-$	35349 ± 239	905 ± 32	44.64 ± 0.97	30.98 ± 0.35	4.575 ± 0.190
Averaged					4.455 ± 0.038

$D^- \to K_L^0 e^- \bar{\nu}_e$					
Tag Mode	$N_{\rm ST}$	$N_{\rm DT}$	$f_{\rm bkg}^{\rm peak}(\%)$	$\epsilon(\%)$	$\mathcal{B}_{\rm sig}(\%)$
$D^+ \to K^-\pi^+\pi^+$	407666 ± 668	10354 ± 103	40.44 ± 0.29	34.02 ± 0.11	4.447 ± 0.051
$D^+ \to K^-\pi^+\pi^+\pi^0$	117555 ± 450	3264 ± 63	42.28 ± 0.52	33.19 ± 0.19	4.829 ± 0.107
$D^+ \to K_S^0\pi^+\pi^0$	101824 ± 378	2642 ± 55	39.06 ± 0.58	35.92 ± 0.21	4.402 ± 0.104
$D^+ \to K_S^0\pi^+\pi^+\pi^-$	59046 ± 303	1533 ± 42	39.68 ± 0.77	33.44 ± 0.27	4.683 ± 0.147
$D^+ \to K_S^0\pi^+$	48240 ± 226	1217 ± 35	38.50 ± 0.88	35.20 ± 0.32	4.408 ± 0.147
$D^+ \to K^+K^-\pi^+$	35742 ± 240	942 ± 32	44.04 ± 0.95	32.40 ± 0.36	4.552 ± 0.181
Averaged					4.508 ± 0.038

Results (preliminary):

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

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

Form Factor in $D^+ \to K_L e^+ \upsilon_e$

Signal shape of q^2 distribution can be described using

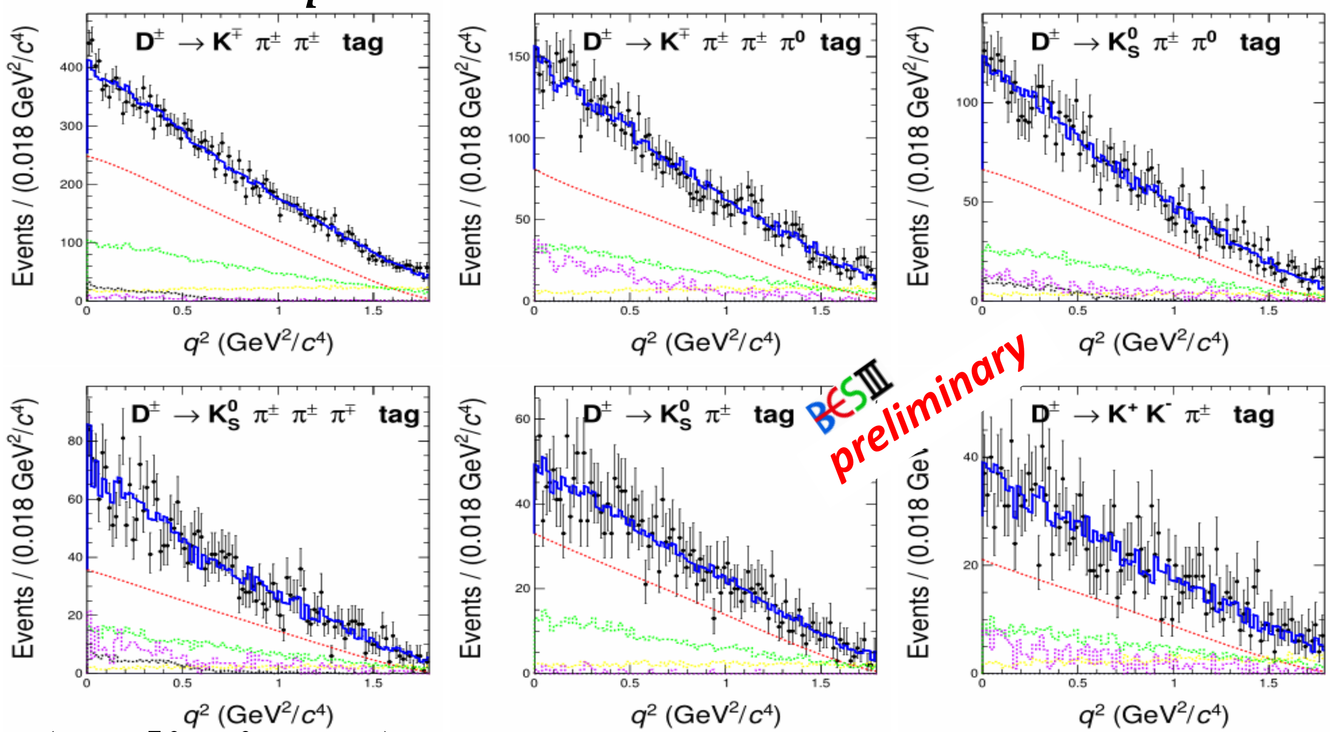
$$\frac{dn_{\mathrm{observed}}}{dq^2} = A N_{\mathrm{tag}} p^3(q'^2)|f_+(q'^2)|^2 \epsilon(q'^2) \otimes \sigma(q'^2, q^2)$$

2-par. Series Expansion is used for form factor $f_+(q^2)$:

[Becher and Hill, Phys. Lett. B 633, 61 (2006)]

$$f_+(q^2) = \frac{1}{P(q^2)\phi(q^2,t_0)} \sum_{k=0}^{\infty} a_k(t_0) \left[z(q^2,t_0) \right]^k$$

Simultaneous fit to q^2 distributions of observed DT candidates:



Results (preliminary):

$f_+^K(0)|V_{cs}| = 0.728 \pm 0.006 \pm 0.011$, $r_1 \equiv a_1/a_0 = -1.91 \pm 0.33 \pm 0.24$

Measurements of $\Lambda_c^{\pm}$ Hadronic Branching Fractions

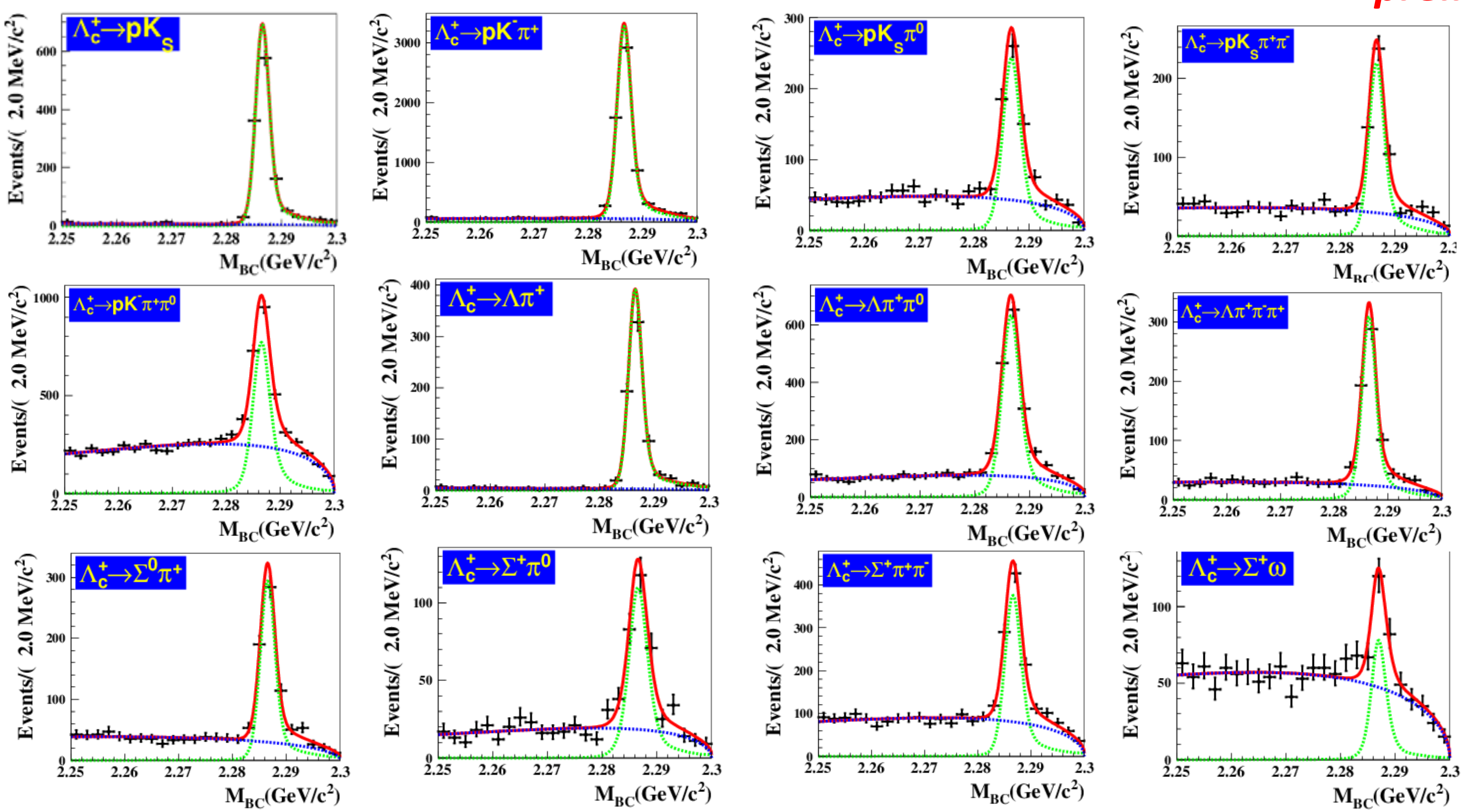
Absolute branching fractions of Λ_c^+ decays are still not well determined.

Belle measurement: $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (6.84 \pm 0.24^{+0.21}_{-0.27})\%$. *PRL 113(2014) 042002*

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

ST $\Lambda_c^{\pm}$ yields in data

BESIII ***preliminary***



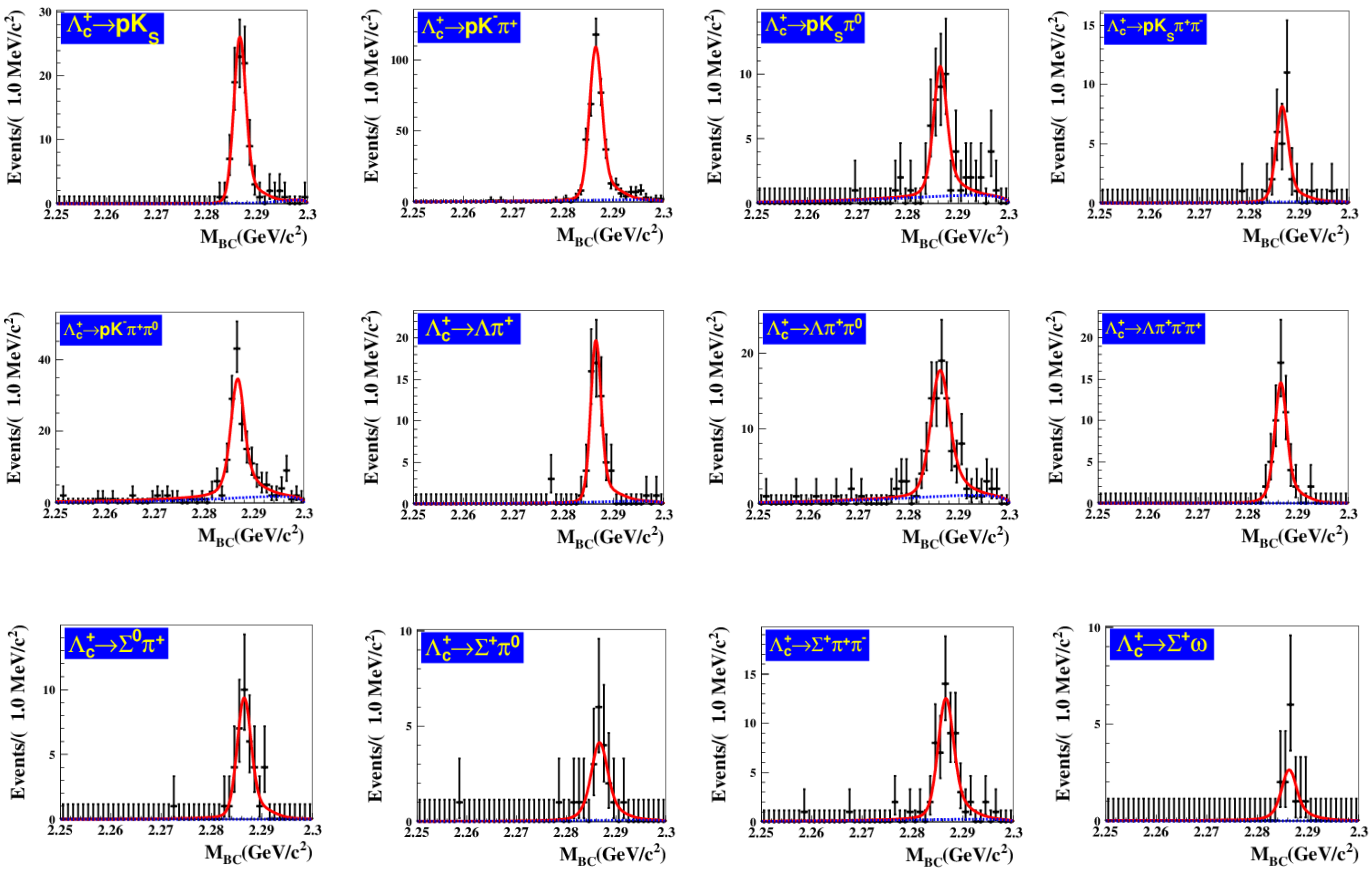
modes	N_i^{ST}
pK_S	1243 ± 37
$pK^-\pi^+$	6308 ± 88
$pK_S\pi^0$	558 ± 33
$pK_S\pi^+\pi^-$	454 ± 28
$pK^-\pi^+\pi^0$	1849 ± 71
$\Lambda\pi^+$	706 ± 27
$\Lambda\pi^+\pi^0$	1497 ± 52
$\Lambda\pi^+\pi^-\pi^+$	609 ± 31
$\Sigma^0\pi^+$	586 ± 32
$\Sigma^+\pi^0$	271 ± 25
$\Sigma^+\pi^+\pi^-$	836 ± 43
$\Sigma^+\omega$	157 ± 22

ST sum:~15K

DT yields in data

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

Where, N^{DT}_{i+j-} is the DT yield with $\Lambda_c^+ \to$ i and $\Lambda_c^- \to$ j.



BESIII *preliminary*

Decay modes	N^{DT}_{-j}
pK_S	89 ± 10
$pK^-\pi^+$	390 ± 21
$pK_S\pi^0$	40 ± 7
$pK_S\pi^+\pi^-$	29 ± 6
$pK^-\pi^+\pi^0$	148 ± 14
$\Lambda\pi^+$	59 ± 8
$\Lambda\pi^+\pi^0$	89 ± 11
$\Lambda\pi^+\pi^-\pi^+$	53 ± 7
$\Sigma^0\pi^+$	39 ± 6
$\Sigma^+\pi^0$	20 ± 5
$\Sigma^+\pi^+\pi^-$	56 ± 8
$\Sigma^+\omega$	13 ± 3

Hadronic branching fraction results (preliminary)

We perform a simultaneous fit to all tag modes while constraining the total Λ_c^+ pair number, taking into account the correlations.

Decay modes	global fit $\mathcal{B}$	PDG $\mathcal{B}$	Belle $\mathcal{B}$
pK_S	1.48 ± 0.08	1.15 ± 0.30	
$pK^-\pi^+$	5.77 ± 0.27	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S\pi^0$	1.77 ± 0.12	1.65 ± 0.50	
$pK_S\pi^+\pi^-$	1.43 ± 0.10	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	4.25 ± 0.22	3.4 ± 1.0	
$\Lambda\pi^+$	1.20 ± 0.07	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	6.70 ± 0.35	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	3.67 ± 0.23	2.6 ± 0.7	
$\Sigma^0\pi^+$	1.28 ± 0.08	1.05 ± 0.28	
$\Sigma^+\pi^0$	1.18 ± 0.11	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	3.58 ± 0.22	3.6 ± 1.0	
$\Sigma^+\omega$	1.47 ± 0.18	2.7 ± 1.0	

stat. errors only

- ✓ **$\mathcal{B}(pK^-\pi^+)$: BESIII precision comparable with Belle's result**
- ✓ **BESIII rate $\mathcal{B}(pK^-\pi^+)$ is smaller**
- ✓ **Improved precisions of the other 11 modes significantly**

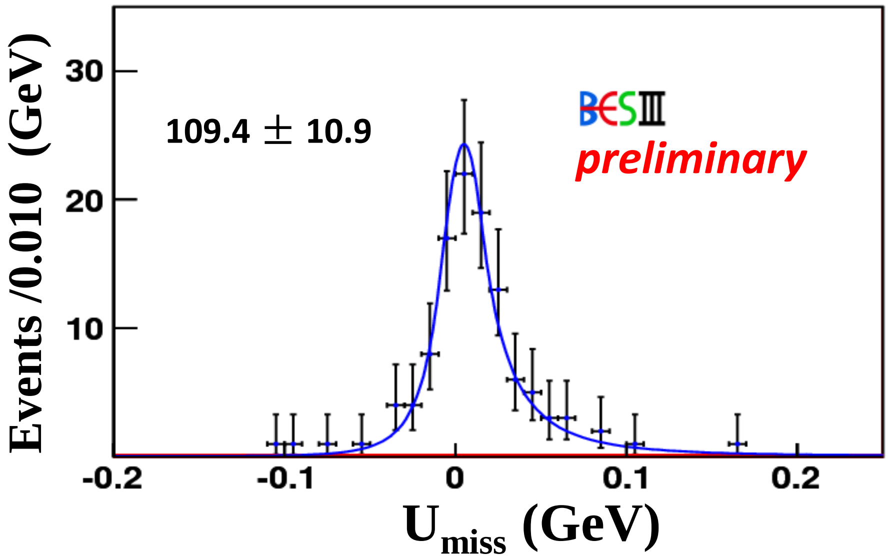
Measurement of the Branching Fraction for $\Lambda_c^+ \to \Lambda e^+ \upsilon_e$

Measuring $\Lambda_c^+ \to \Lambda e^+ \upsilon_e$ will provide experimental information for

- testing the theoretical predication for $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \upsilon_e)$,
- and calibrating the LQCD calculations.

We perform the first absolute measurement of $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \upsilon_e)$.

11 ST modes are used, except $\Sigma^+\omega$



subtraction of backgrounds:

- non-ST events: negligible
- Λ sidebands: 1.4 ± 0.8
- $\Lambda\mu^+\nu + \Lambda\pi^+\pi^0 + \Lambda\pi^+ = 4.5 \pm 0.5$

➔ **signal yields: 103.5 ± 10.9**

Result (preliminary) : $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \upsilon_e) = (3.63 \pm 0.38 \pm 0.??)\%$

scaled PDG
(2.9±0.5)%

- Statistics limited measurement.
  ➔ systematic error smaller than statistical error
- Best precision to date: twofold improvement

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))
- $D^0 \to K^- e^+ \upsilon_e$ and $D^0 \to \pi^- e^+ \upsilon_e$ (to be submitted soon)
- $D^0 \to \gamma\gamma$ 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])

Summary

1. BESIII released many new results with the world largest D meson sample at ψ(3770).

2. BESIII started study of Λ_c^+ decays using the world largest data at Λ_c^+-pair threshold (4.6GeV).

3. BESIII will take 3 fb^{-1} data at 4.17GeV in 2016 to study the D_s^+ decays.

4. Many new exciting results are on their way !

Thank you !