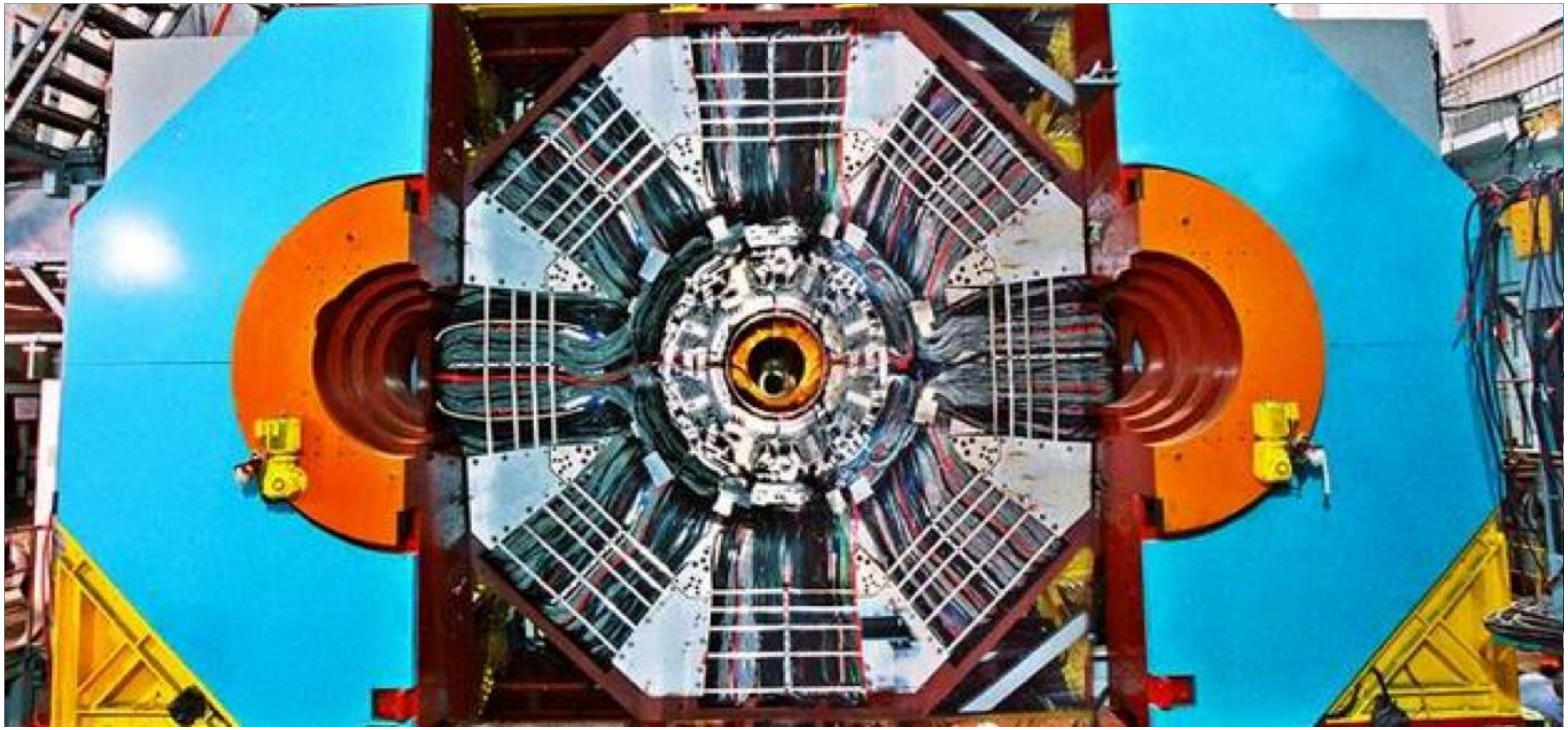

Charmed hadron decays BESIII

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(On behalf of the BESIII collaboration)

Outline

- **Introduction to the BESIII experiment**
- **Selected results on charmed hadron decays:**
  - ✓ **D decays (semi-)leptonically and form factors**
  - ✓ **D-Dbar mixing, $D^0 \to K\pi$ strong phase**
  - ✓ **Λ_c decay rates**
- **Summary**

The BEPCII Collider

Beam energy: 1.0 – 2.3 GeV

Peak Luminosity:

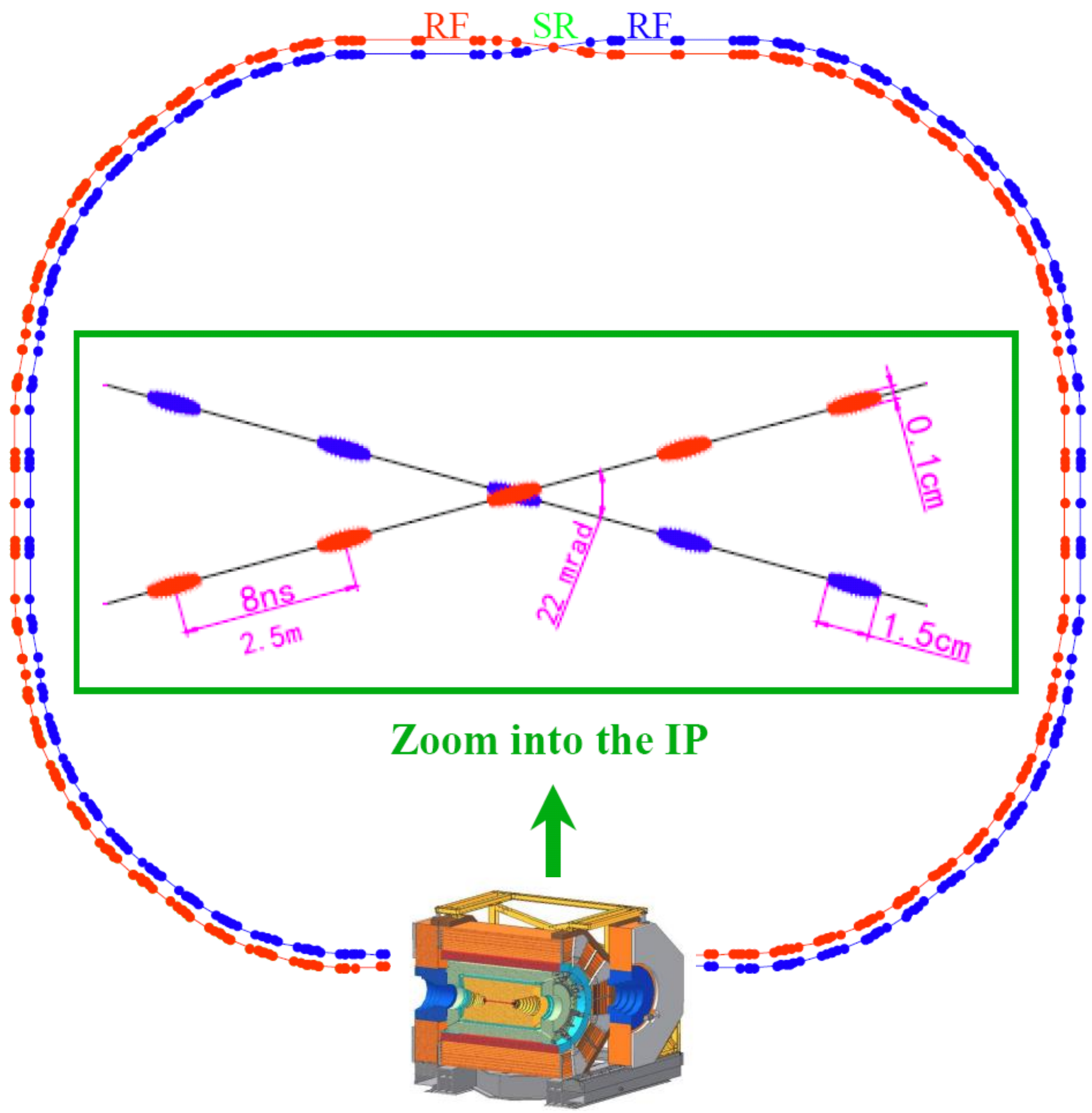
Design: **1×10^{33} cm^{-2}s^{-1}**

Achieved: **0.85×10^{33} cm^{-2}s^{-1}**

Optimum energy: 1.89 GeV

Energy spread: 5.16×10^{-4}

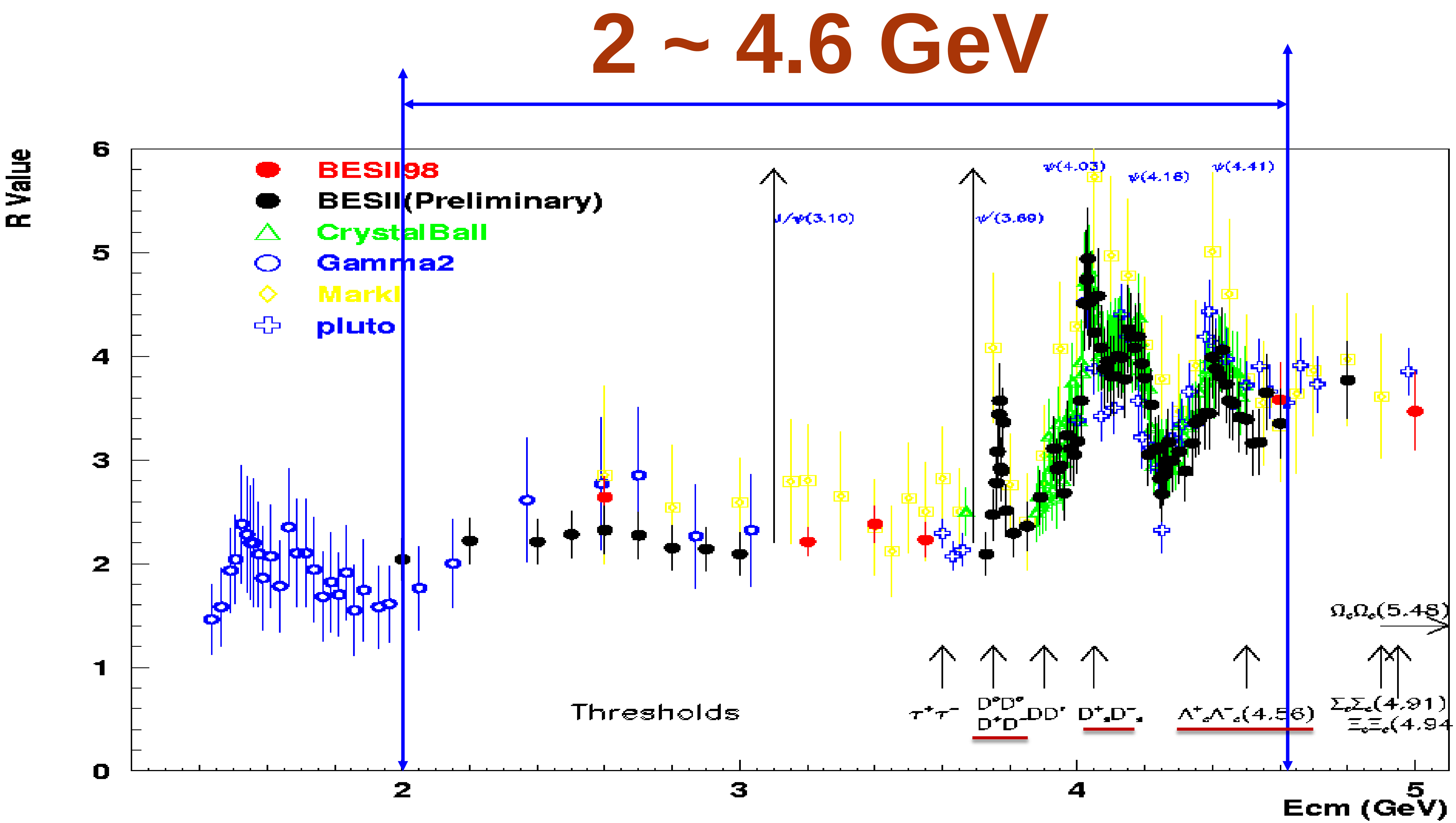
Circumference: 237 m



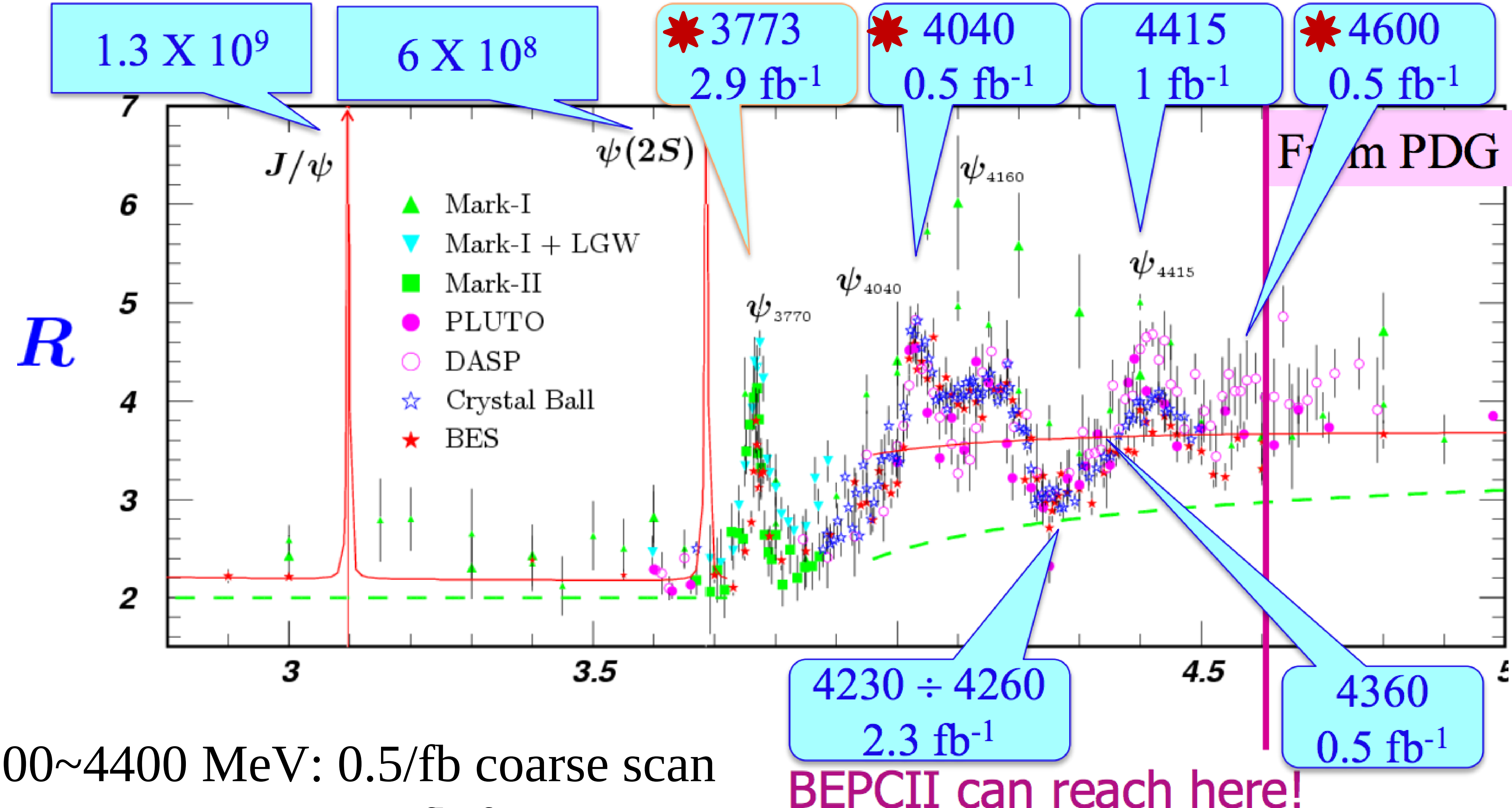
In 2015, BEPCII made successful test with top-up mode!

Beam energy measurement: Using Compton backscattering technique. Accuracy up to **5×10^{-5}**

Energies of the BEPCII Collider



BESIII data samples above 4GeV



- 4100~4400 MeV: 0.5/fb coarse scan
- 3850~4590 MeV: 0.5/fb fine scan
- In 2015, we finished energy scan at 2000~3000 MeV
- In 2016, we will take 3/fb Ds data about 4170 MeV (*about 5 times of CLEO-c data*)

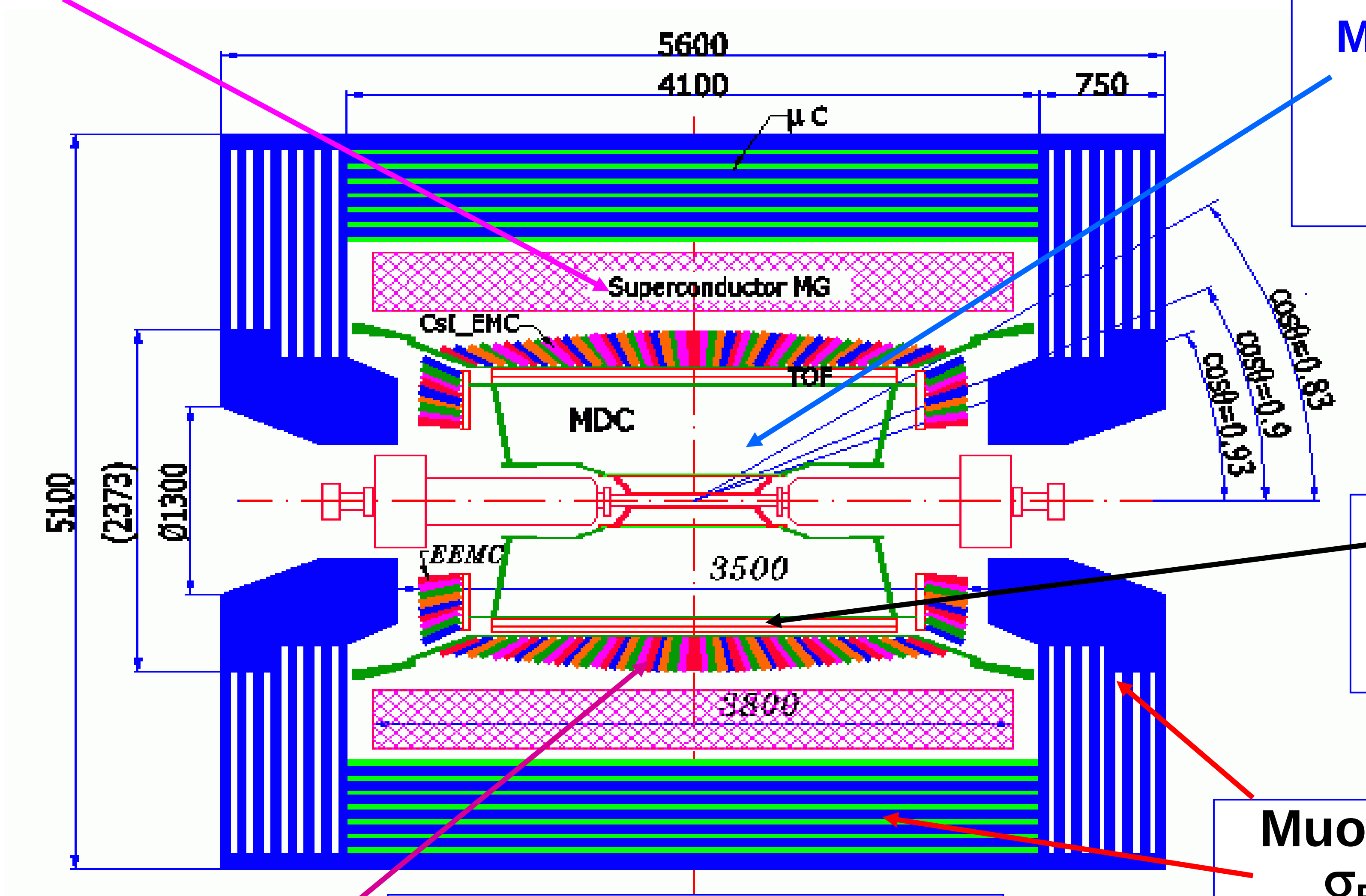
Machine luminosity is optimal near ψ" peak

NIM A614, 345 (2010)

The BESIII Detector

Magnet: 1 T Super conducting

MDC: small cell & He gas
σ_{xy}=130 μm
s_p/p = 0.5% @1GeV
dE/dx=6%



TOF:
σ_T = 90 ps Barrel
110 ps Endcap

Muon ID: 8~9 layer RPC
$\sigma_{R\Phi}$=1.4 cm~1.7 cm

EMCAL: CsI crystal
ΔE/E = 2.5% @1 GeV
$\sigma_{\varphi,z}$ = 0.5~0.7 cm/√E

Data Acquisition:
Event rate = 3 kHz
Throughput ~ 50 MB/s

Trigger: Tracks & Showers
Pipelined; Latency = 6.4 μs

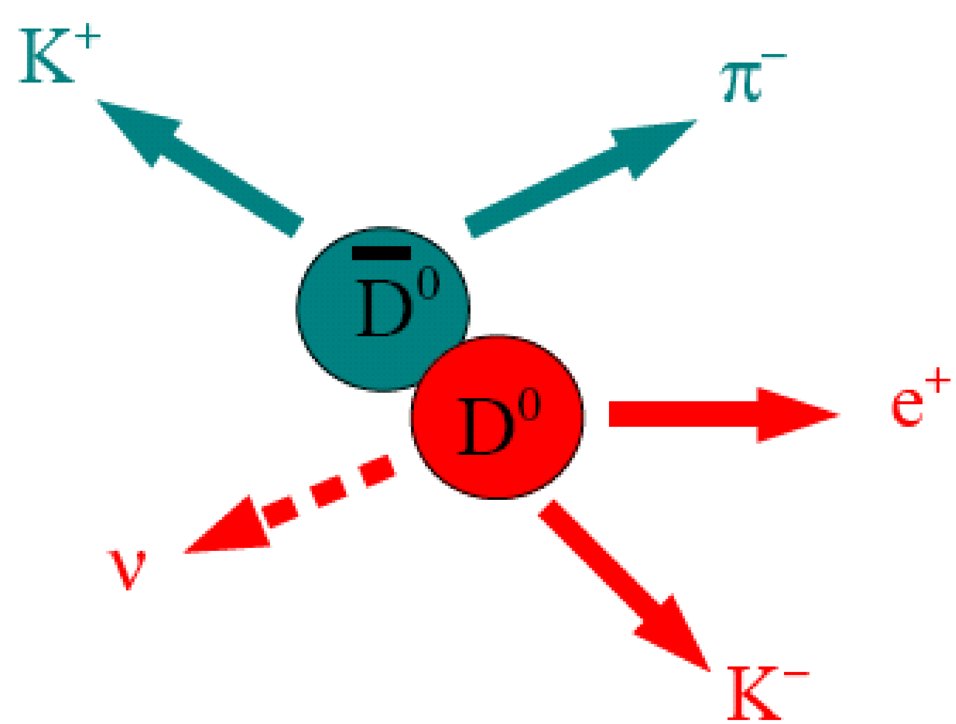
The new BESIII detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.

Charm Physics

- **Threshold production at 3.773, 4.03, 4.17 GeV, 4.6GeV**

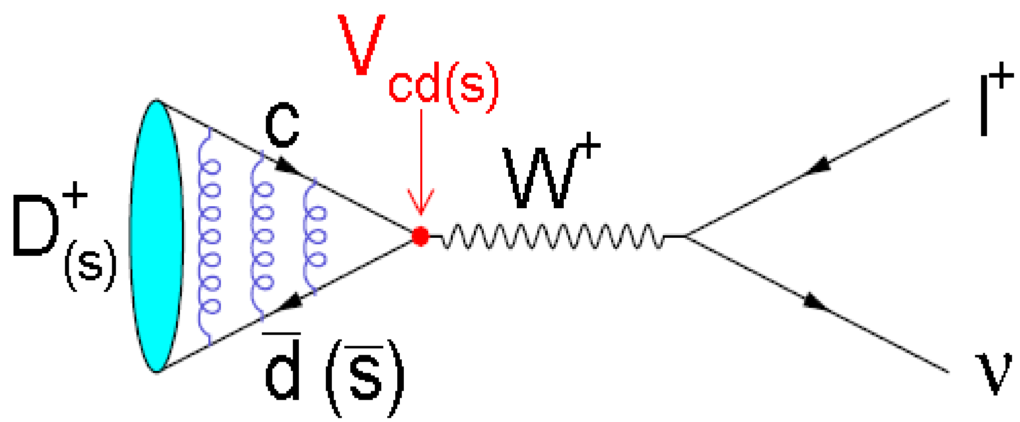
$$e^+e^- \rightarrow D\overline{D}, D_sD_s, D_sD_s^*, \Lambda_c^+\Lambda_c^-$$

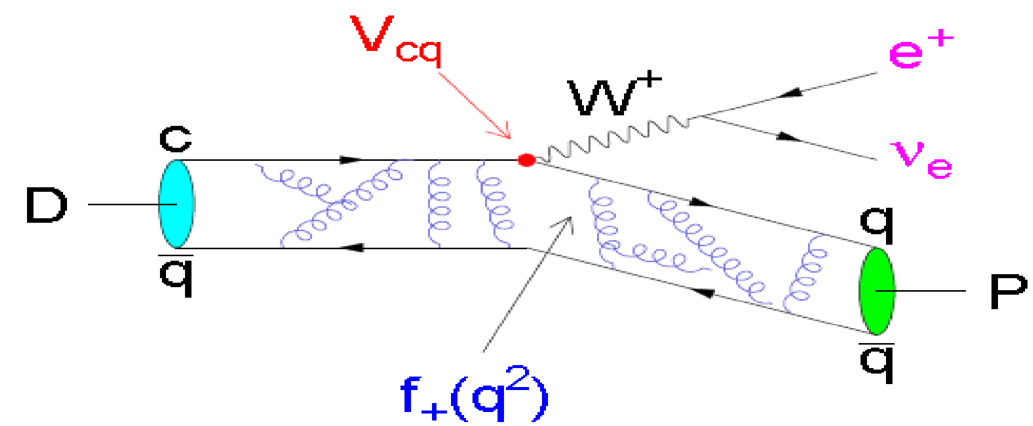
- **Double Tag techniques: (partial-)reconstruct both D mesons**
- **Charm events at threshold are very clean**
  - Ratio of signal to background is optimum
  - Lots of systematic uncertainties cancellation while applying double tag method



Why they are important?

D leptonic and semi-leptonic decays are ideal window to probe for weak and strong effects

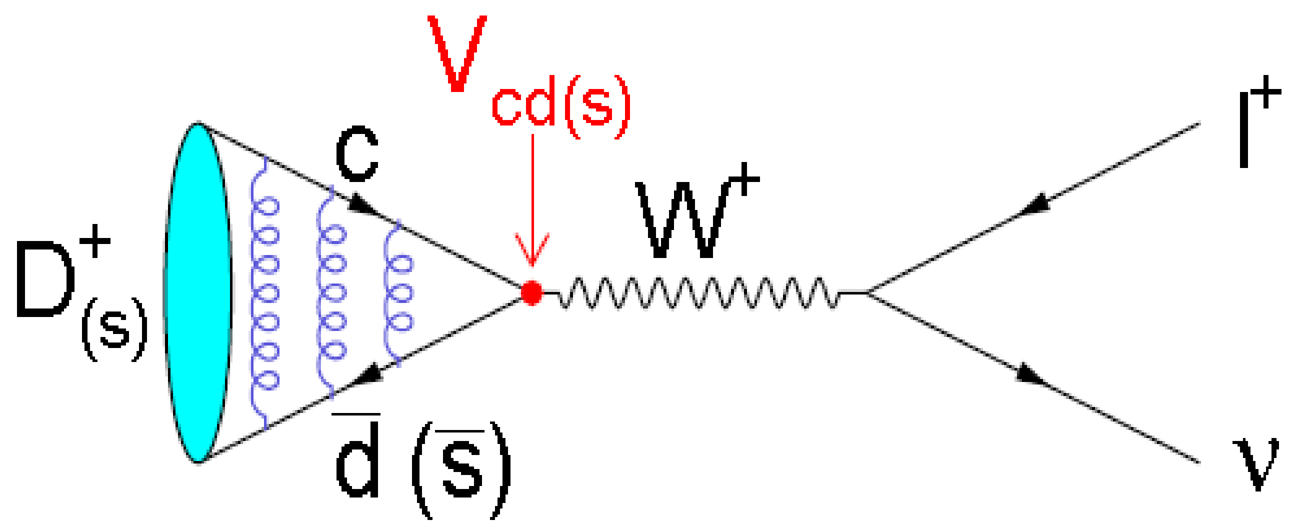




- **Precision measurements of decay constants f_{D+}, f_{Ds+}, form factors $f_+^{D\to K(\pi)}(q^2)$ of semi-leptonic decays of D mesons will calibrate LQCD calculations at higher accuracy. Once they pass experimental tests, the precise LQCD calculations of f_D/f_B, f_{Ds}/f_{Bs} and form factors will be helpful for measurement in B decay**

- **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 the CKM matrix element $|V_{cs(d)}|$, which are important for the unitarity test of the CKM matrix and search for NP beyond the SM**

D^+ Leptonic Decays



In the SM:

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

Bridge to precisely measure

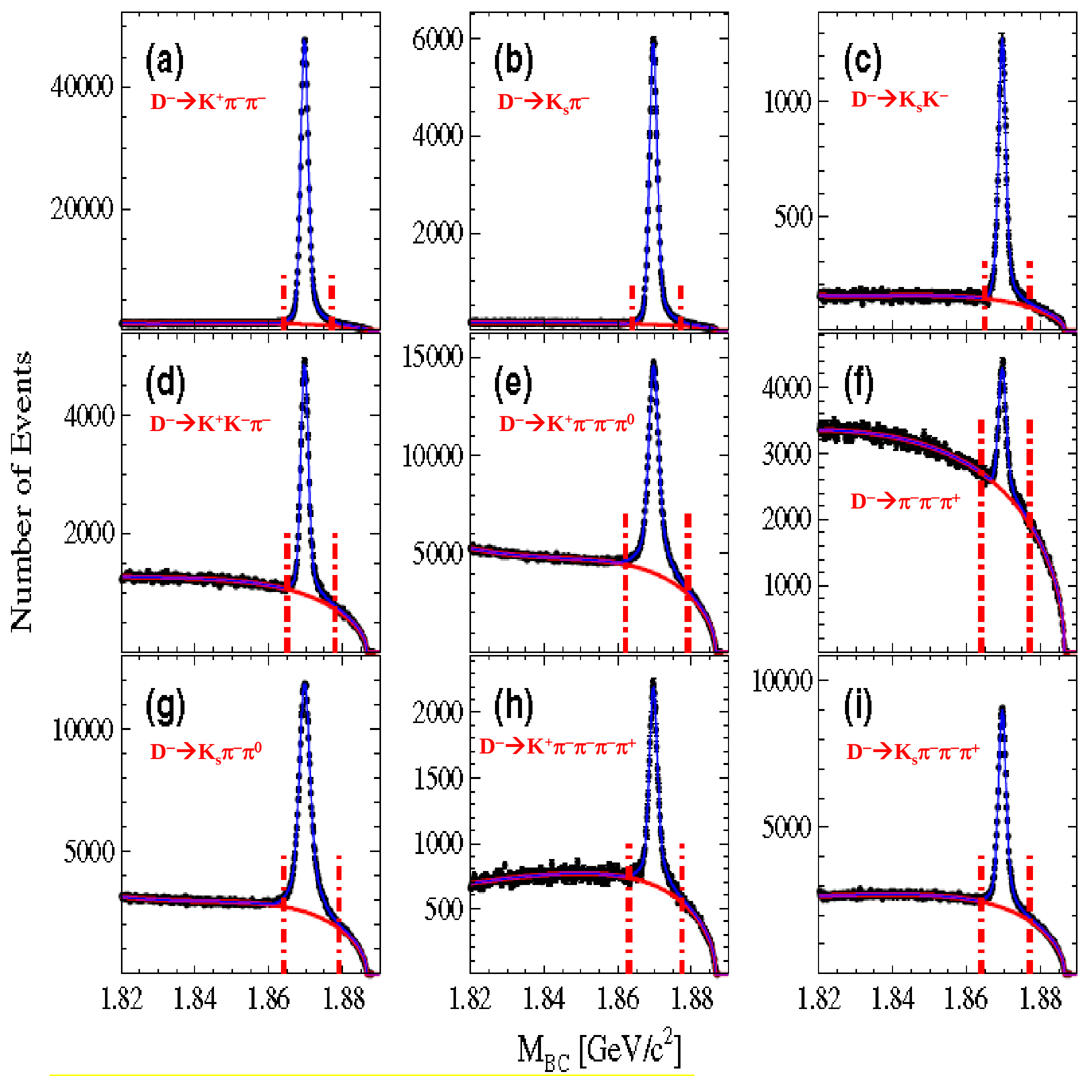
- **Decay constants $f_{D(s)+}$ with input $|V_{cd(s)}|^{CKMfitter}$**
- **CKM matrix element $|V_{cd(s)}|$ with input $f^{LQCD}_{D(s)+}$**

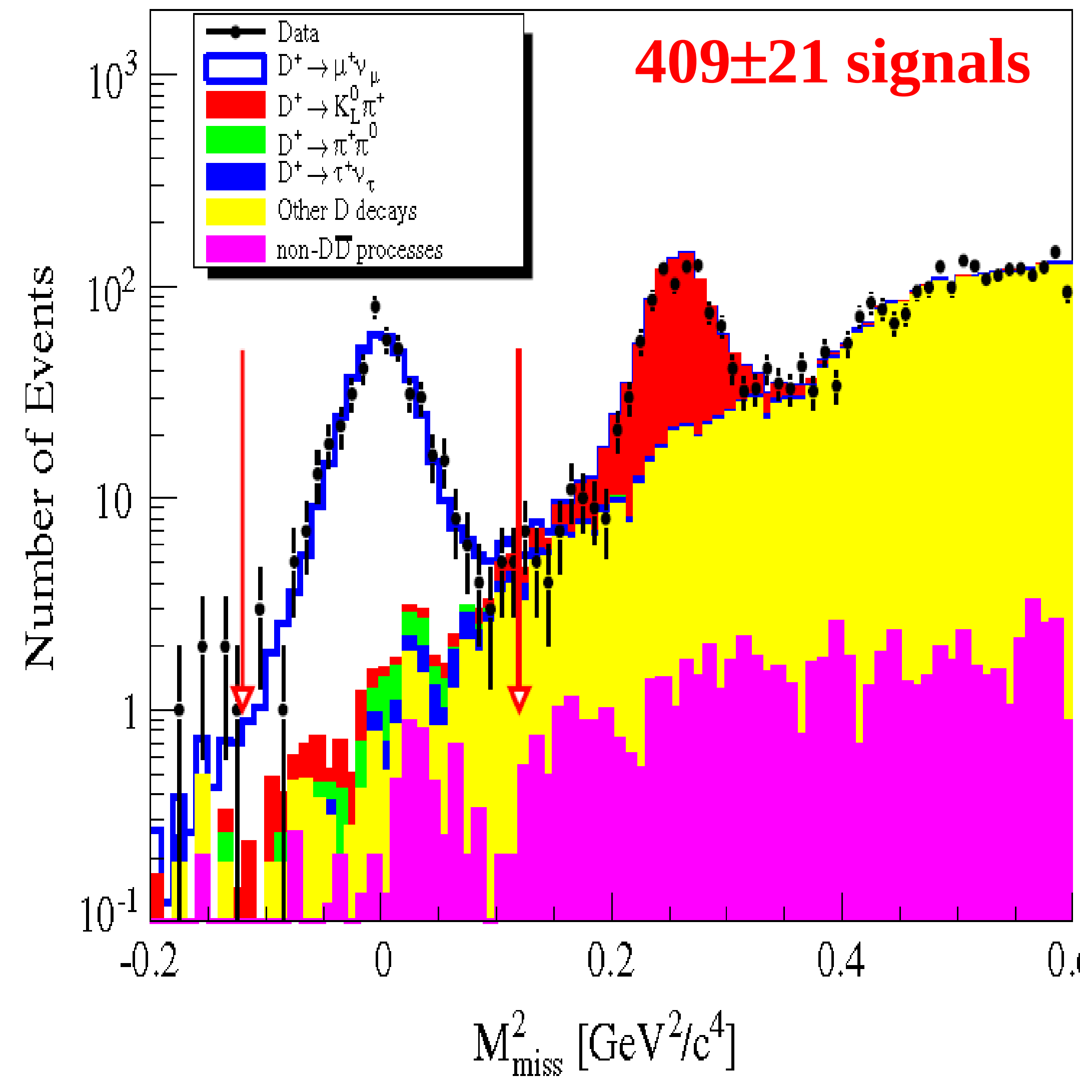
Measurement of B[$D^+ \rightarrow \mu^+ \nu$], f_{D+} and $|V_{cd}|$

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

2.92 fb^{-1} data@ 3.773 GeV

PRD89(2014)051104R





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

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

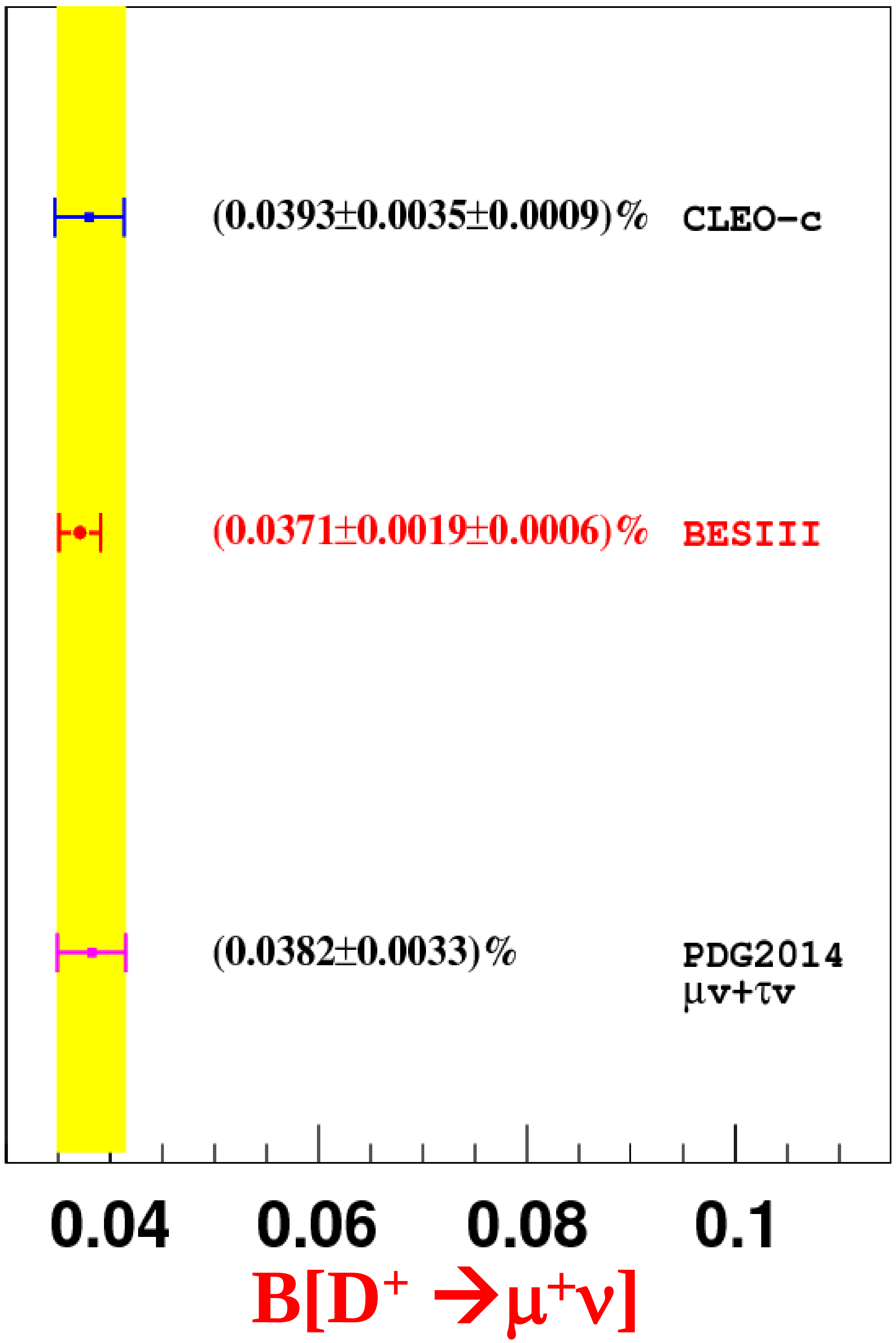
Input t_{D+}, m_{D+}, $m_{\mu+}$ on PDG and $|V_{cd}|$ of CKM-Fitter

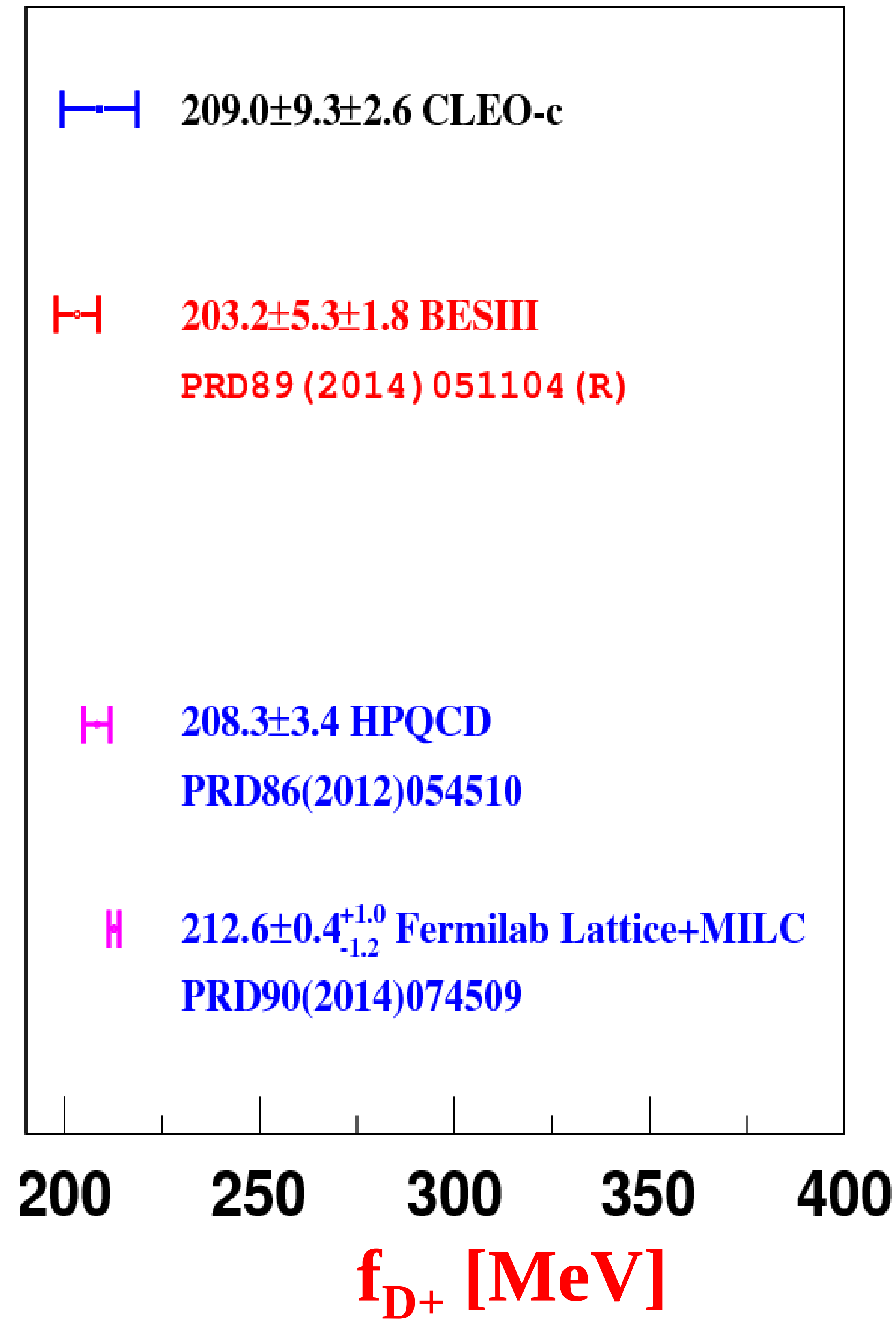
$f_{D+} = (203.2 \pm 5.3 \pm 1.8)$ MeV

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

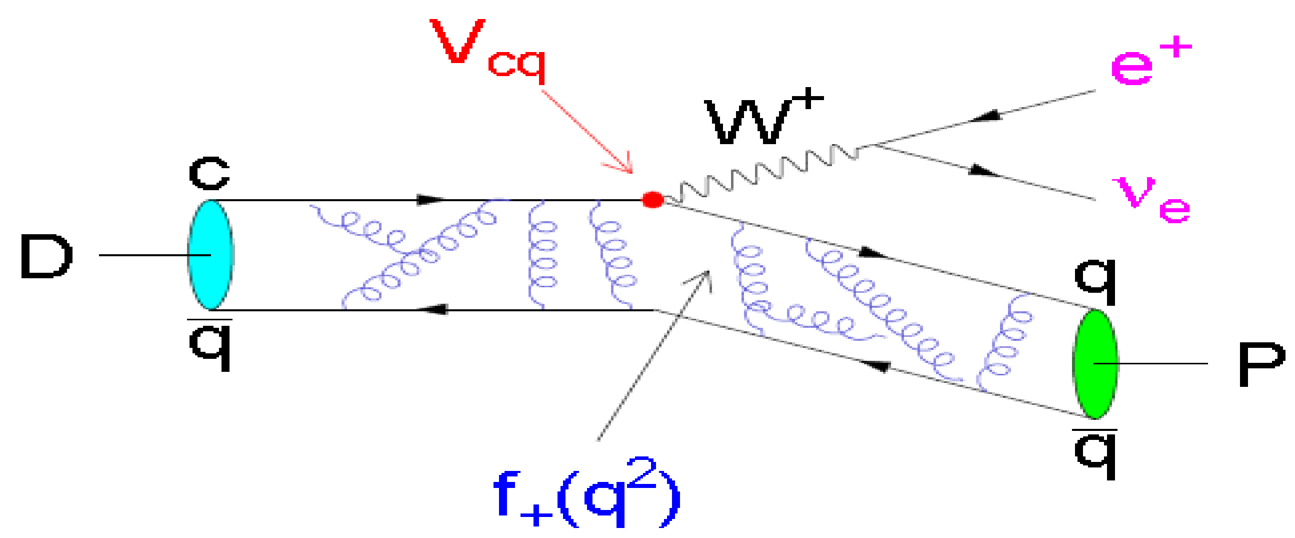
$|V_{cd}| = 0.2210 \pm 0.0058 \pm 0.0047$

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





D Semi-leptonic Decays



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

Bridge to precisely measure:

- **Form factors $f^{D\to K(\pi)}_+(q^2)$ with input $|V_{cd(s)}|^{CKMfitter}$**

  – **Single pole form**

  $$f_+(q^2) = \frac{f_+(0)}{1 - \frac{q^2}{M^2_{\rm pole}}}$$

  – **Modified pole model**

  $$f_+(q^2) = \frac{f_+(0)}{(1 - \frac{q^2}{M^2_{\rm pole}})(1 - \alpha\frac{q^2}{M^2_{\rm pole}})}$$

  – **ISGW2 model**

  $$f_+(q^2) = f_+(q^2_{\rm max})\left(1 + \frac{r^2_{\rm ISGW2}}{12}(q^2_{\rm max} - q^2)\right)^{-2}$$

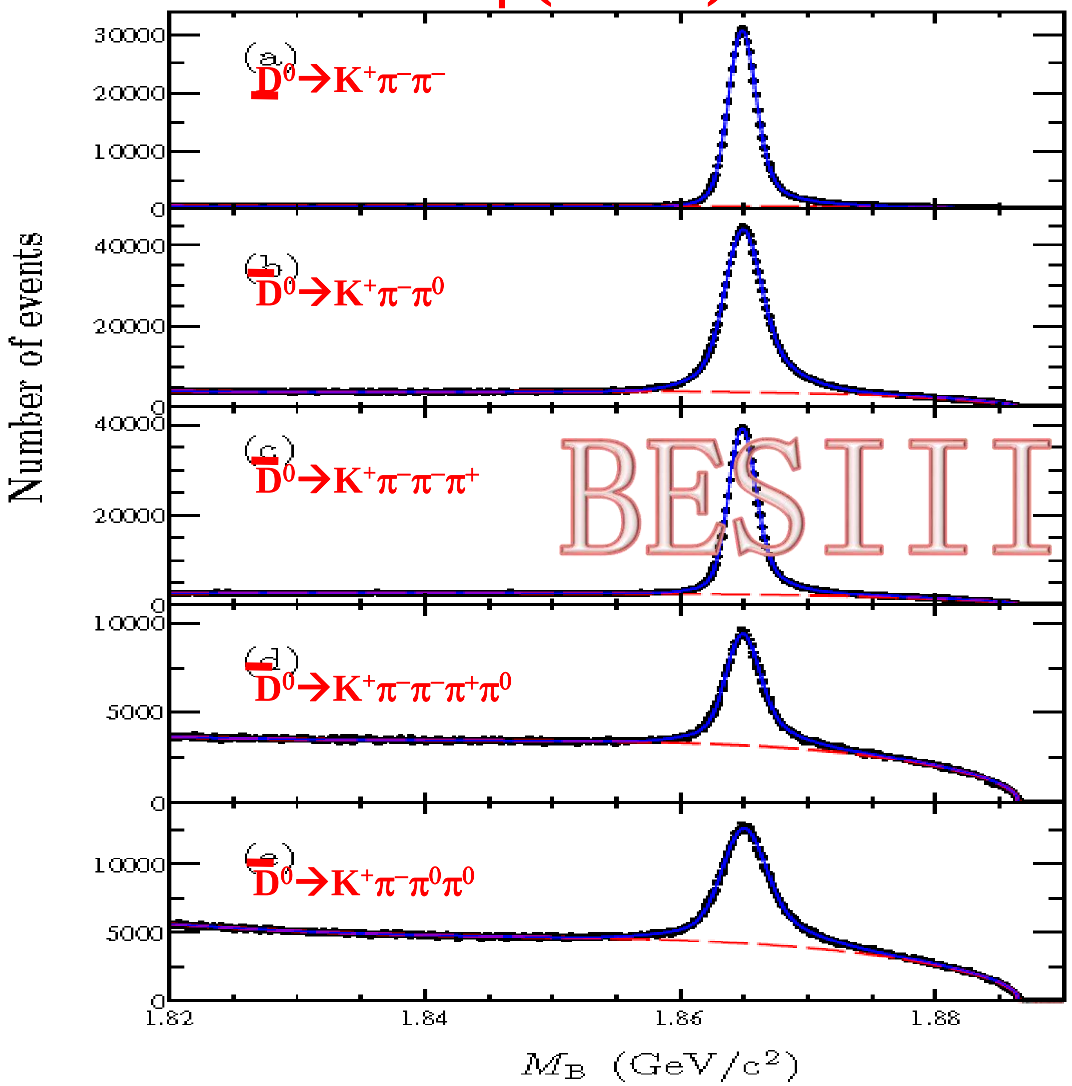
  – **Series expansion model**

  $$f_+(t) = \frac{1}{P(t)\Phi(t,t_0)}a_0(t_0)\left(1 + \sum_{k=1}^{\infty} r_k(t_0)[z(t,t_0)]^k\right)$$

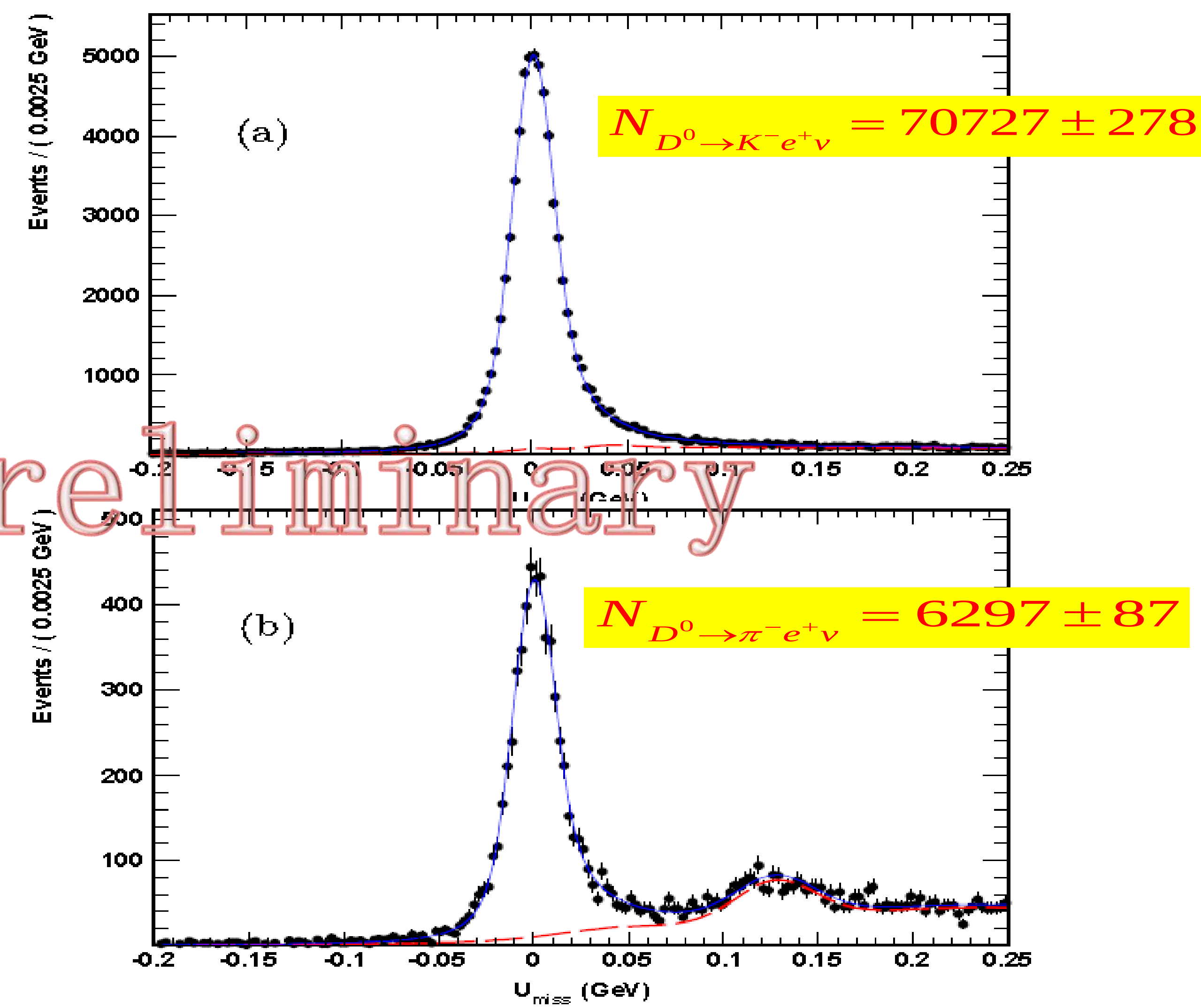
- **CKM matrix element $|V_{cs(d)}|$ with input $f^{LQCD,D\to K(\pi)}_+(0)$**

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

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



$U_{miss} = E_{miss} - p_{miss}$

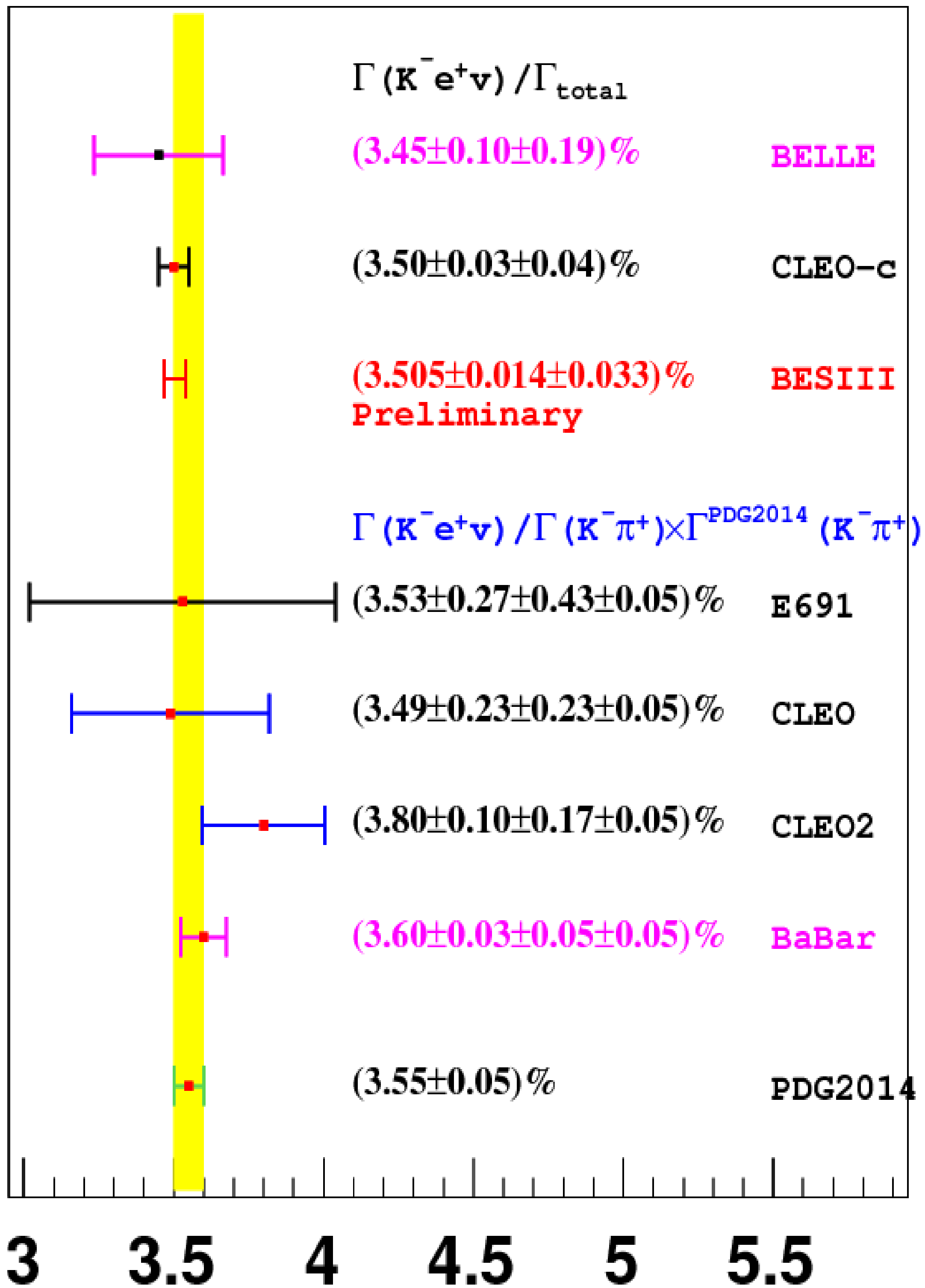


$$N_{\bar{D}^0_{tag}} = (279.33 \pm 0.37) \times 10^4$$

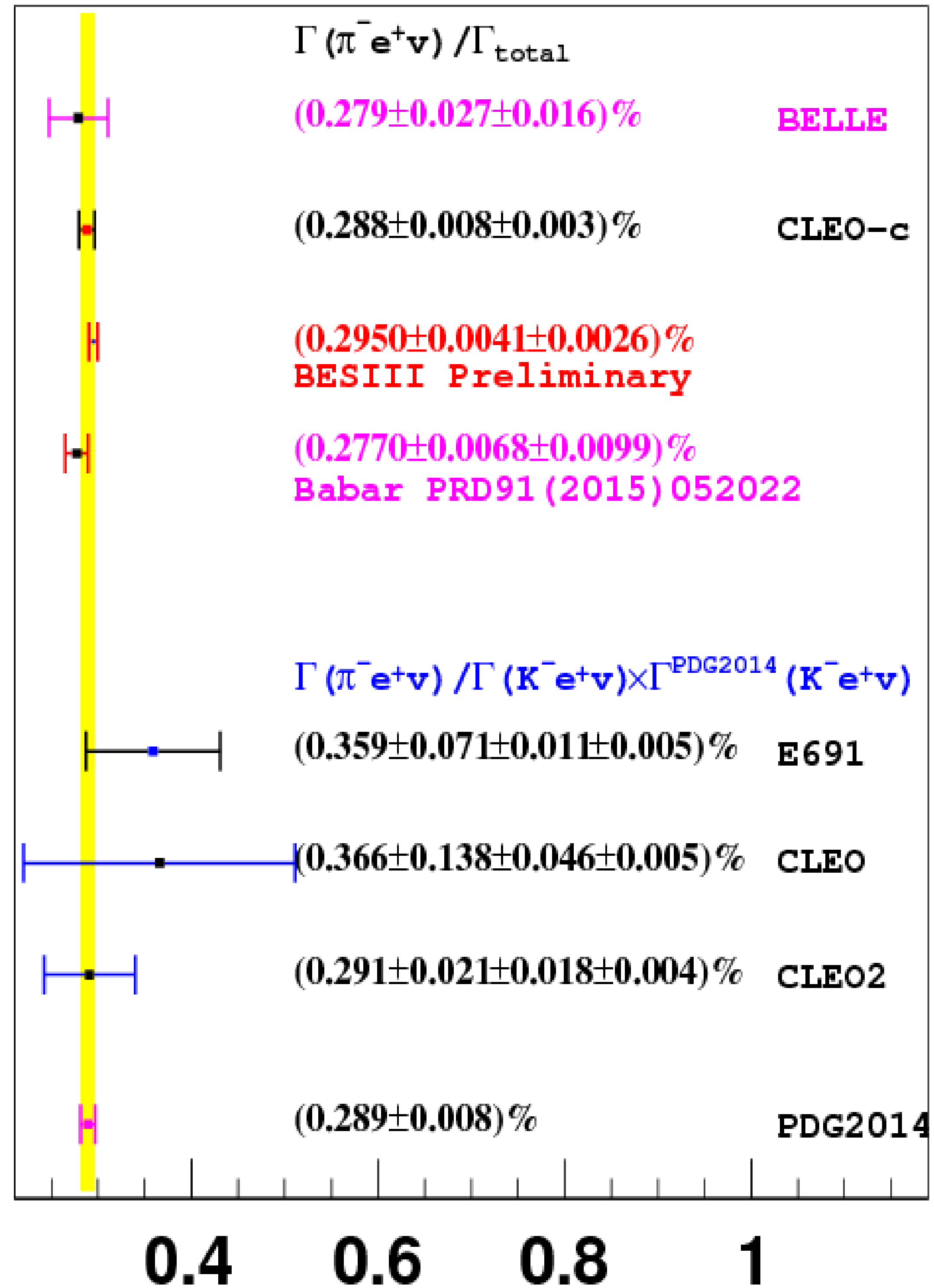
$$B_{D^0 \to K^- e^+ \nu} = (3.505 \pm 0.014 \pm 0.033)\%$$

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

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

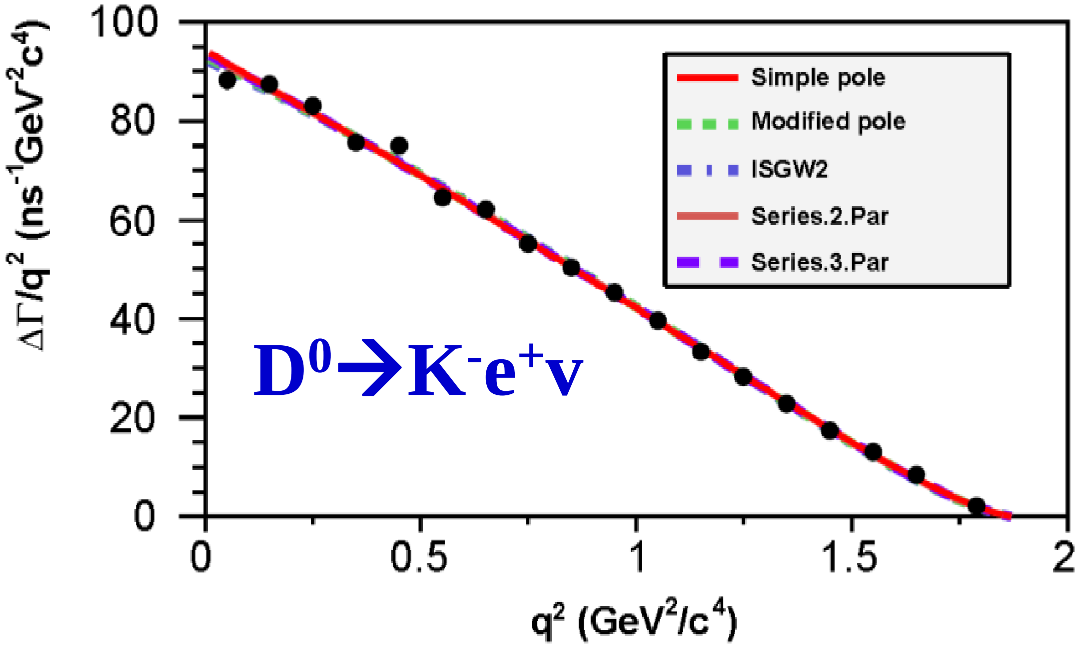


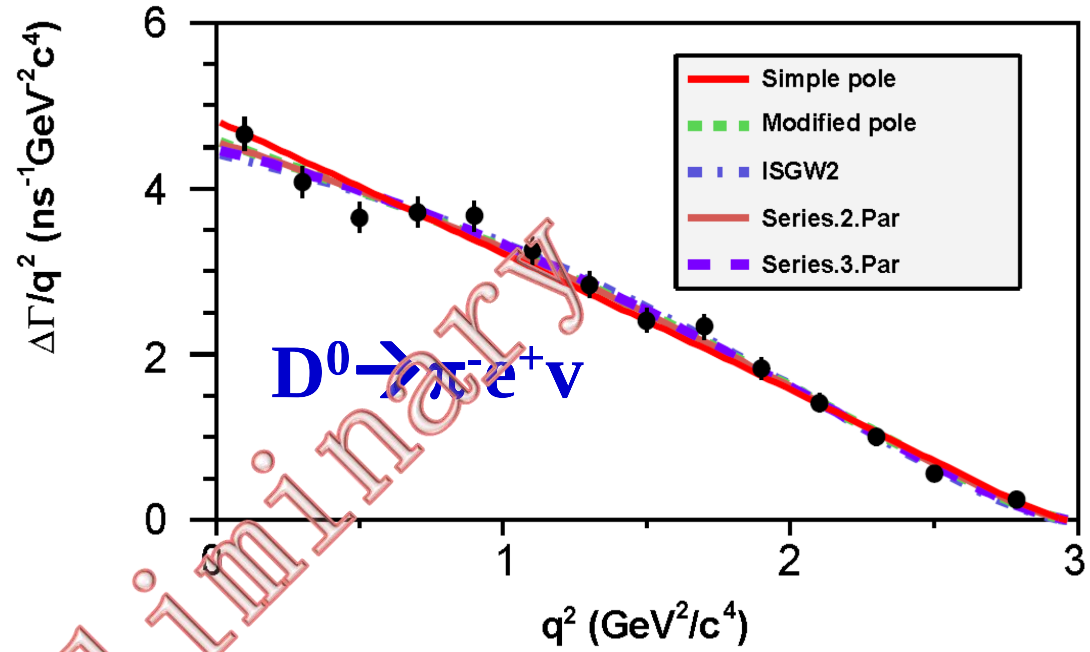
B[$D^0 \rightarrow K^- e^+ \nu$]



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

Extracted Parameters of Form Factors





		$D^0 \to K^- e^+ \nu$		$D^0 \to \pi^- e^+ \nu$
Simple Pole	$f_K^+(0)\|V_{cs}\|$	0.7209±0.0022±0.0033	$f_\pi^+(0)\|V_{cd}\|$	0.1475±0.0014±0.0005
	M_{pole}	1.9207±0.0103±0.0069	M_{pole}	1.9114±0.0118±0.0038
Mod. Pole	$f_K^+(0)\|V_{cs}\|$	0.7163±0.0024±0.0034	$f_\pi^+(0)\|V_{cd}\|$	0.1437±0.0017±0.0008
	α	0.3088±0.0195±0.0129	α	0.2794±0.0345±0.0113
ISGW2	$f_K^+(0)\|V_{cs}\|$	0.7139±0.0023±0.0034	$f_\pi^+(0)\|V_{cd}\|$	0.1415±0.0016±0.0006
	r_{ISGW2}	1.6000±0.0141±0.0091	r_{ISGW2}	2.0688±0.0394±0.0124
Series.2.Par	$f_K^+(0)\|V_{cs}\|$	0.7172±0.0025±0.0035	$f_\pi^+(0)\|V_{cd}\|$	0.1435±0.0018±0.0009
	r_1	-2.2278±0.0864±0.0575	r_1	-2.0365±0.0807±0.0260
Series.3.Par	$f_K^+(0)\|V_{cs}\|$	0.7196±0.0035±0.0041	$f_\pi^+(0)\|V_{cd}\|$	0.1420±0.0024±0.0010
	r_1	-2.3331±0.1587±0.0804	r_1	-1.8434±0.2212±0.0690
	r_2	3.4223±3.9090±2.4092	r_2	-1.3871±1.4615±0.4677

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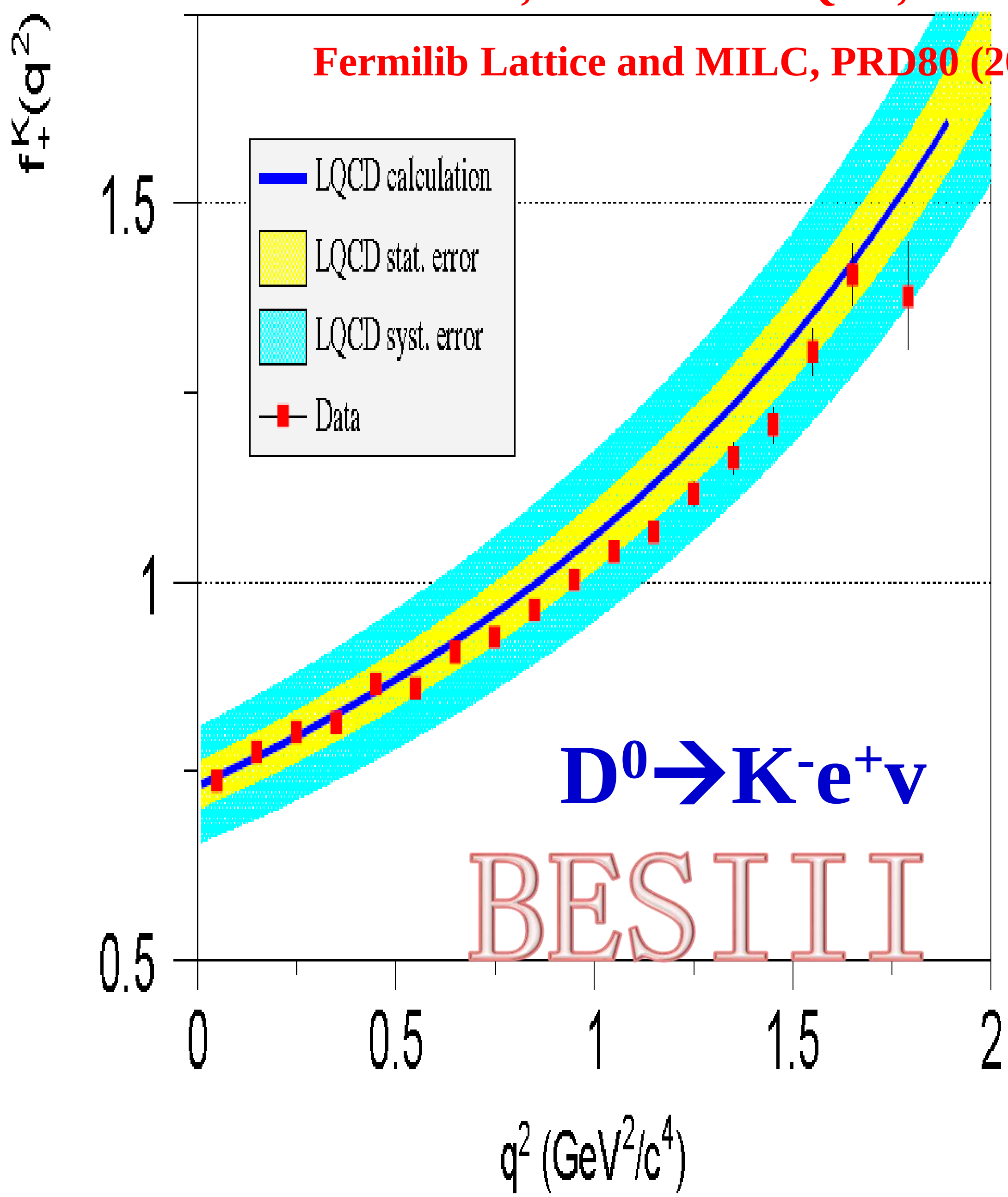
Measurement of $f_+^{K(\pi)}(q^2)$

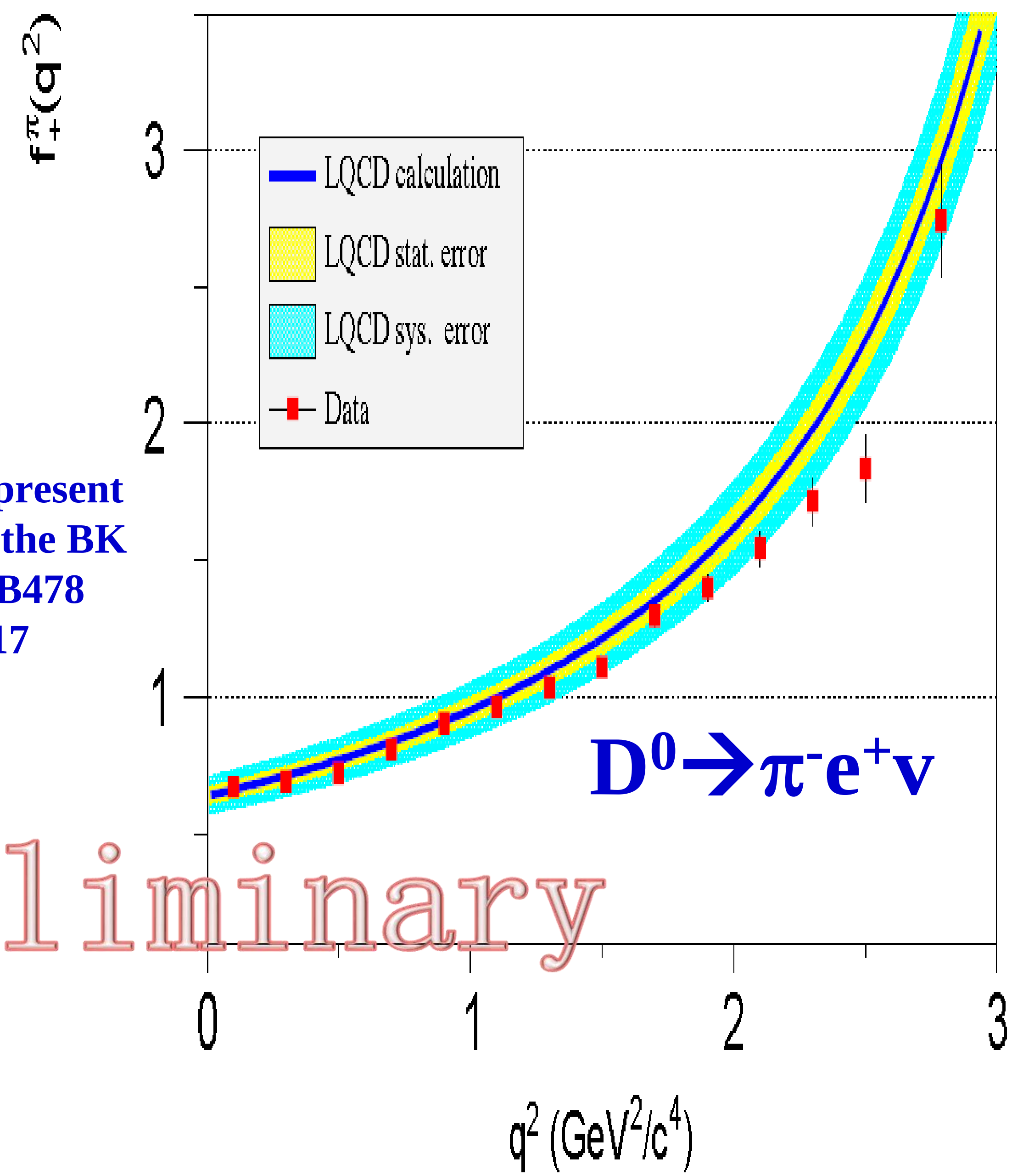
Experimental data calibrate LQCD calculation

Fermilib Lattice, MILC and HPQCD, PRL94 (2005) 011601

Fermilib Lattice and MILC, PRD80 (2009) 034026



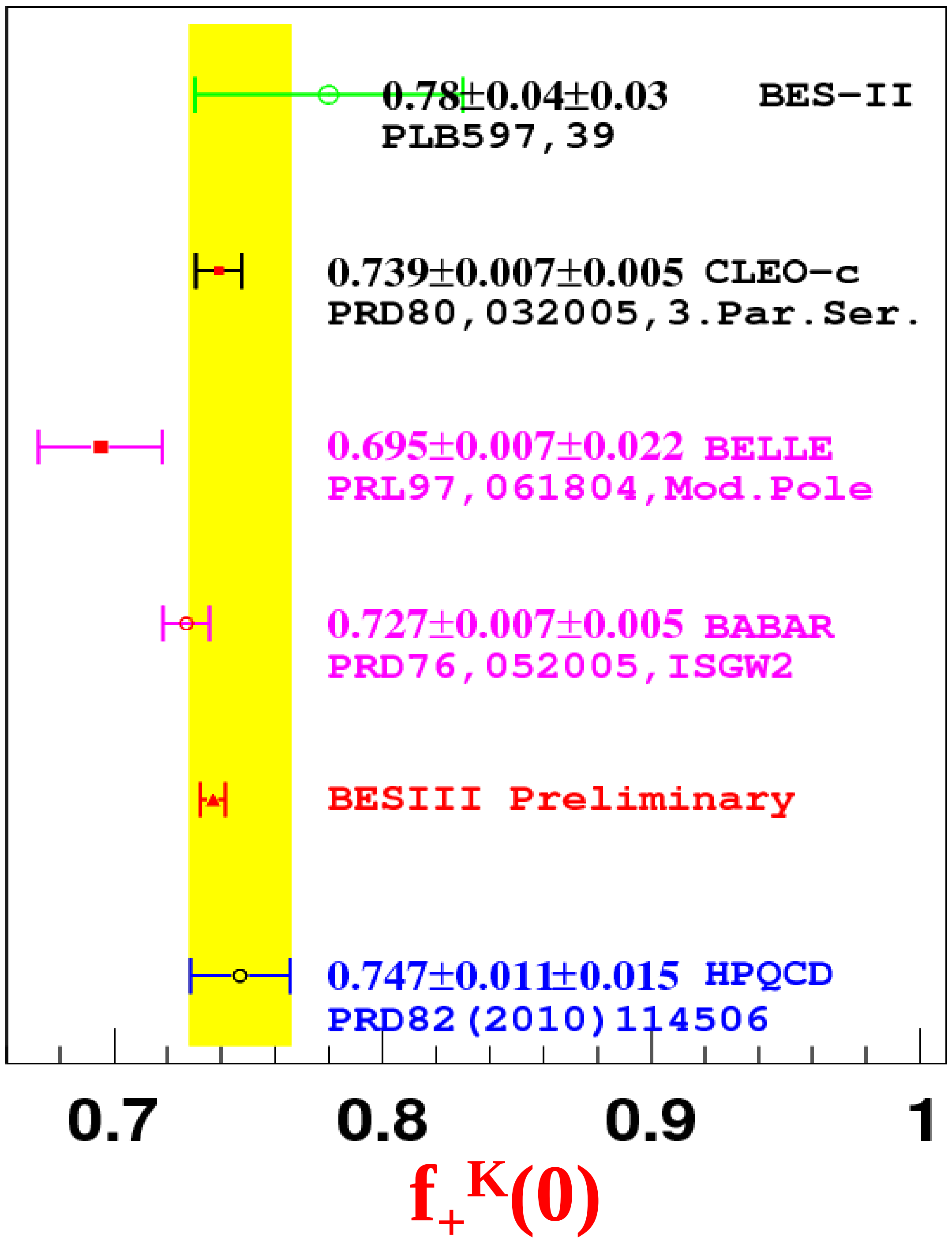
Solid lines represent LQCD fits to the BK model, PLB478 (2000)417

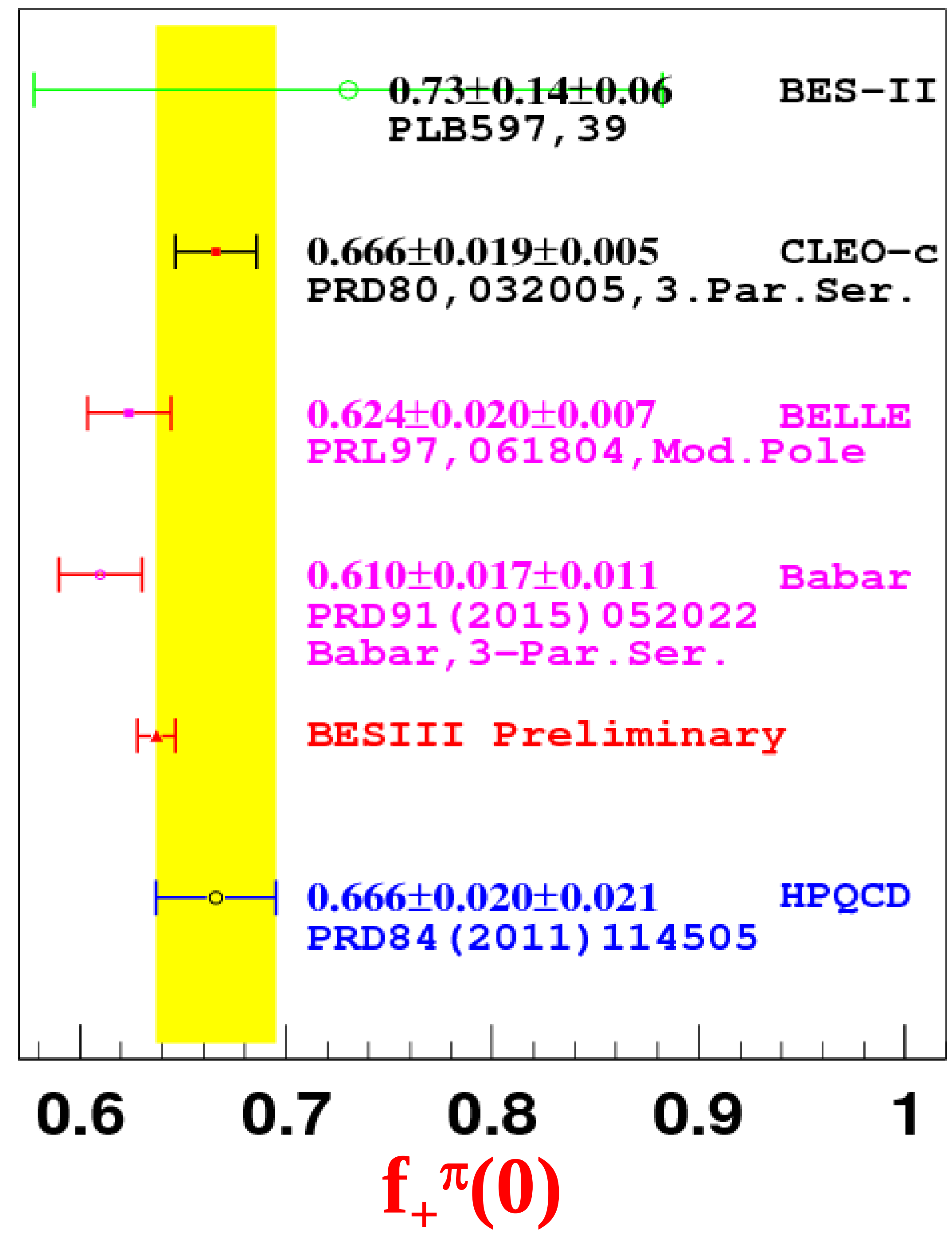


BESIII Preliminary

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

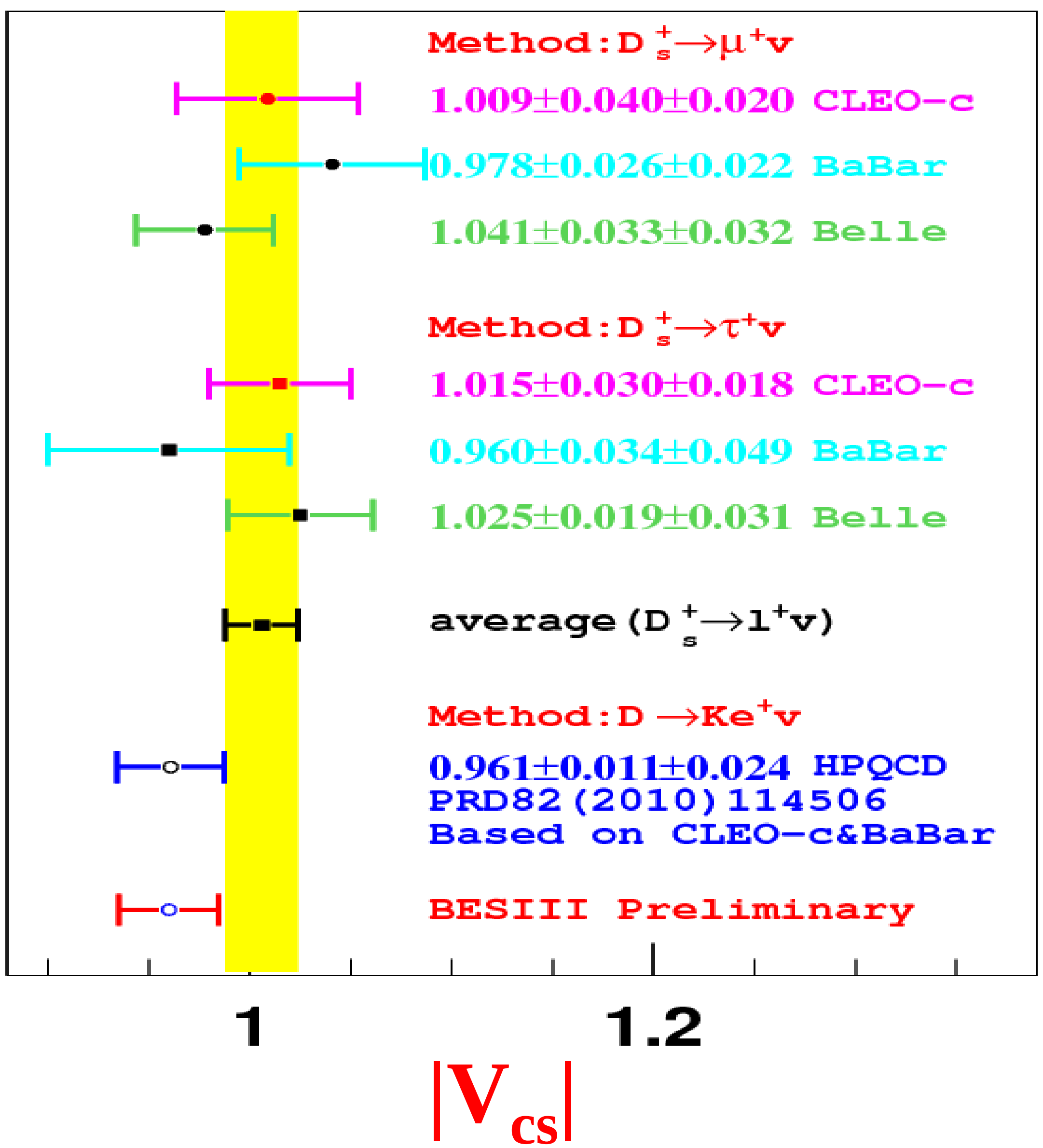
$f^{D\to K(\pi)}_+(0)|V_{cs(d)}|$ → Input $|V_{cs(d)}|$ of CKM-Fitter → $f^{D\to K(\pi)}_+(0)$

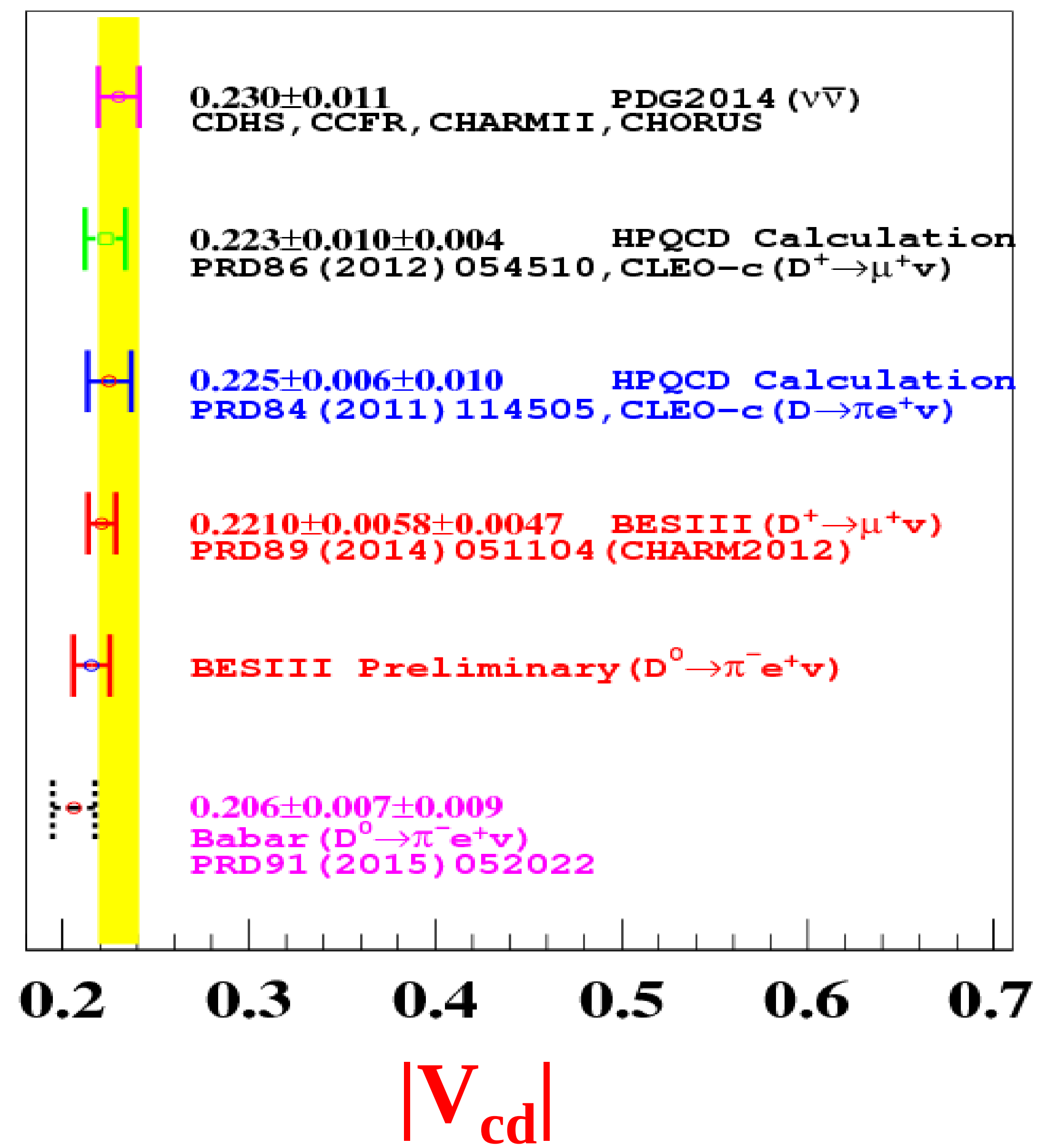




Measurement of $|V_{cs(d)}|$

- **Method 1** — $B[D_{(s)}^{+} \to l^{+}\nu]$ — Input t_{D+}, m_{D+}, $m_{\mu+}$ on PDG and LQCD calculated $f_{D(s)+}$ → $|V_{cd(s)}|$
- **Method 2** — $f^{D\to K(\pi)}_{+}(0)|V_{cs(d)}|$ — Input $f^{D\to K(\pi)}_{+}(0)$ of LQCD → $|V_{cs(d)}|$





Method 2 suffers larger theoretical uncertainty in $f_{+}^{D\to K(\pi)}(0)$ [1.7(4.4)%]

Study of $D^+ \rightarrow K_L e^+ \nu$

It is expected that $K^0 - \bar{K}^0$ mixing can give rise to a clean signal of *CP* violation with magnitude of -3.3×10^{-3} level in semileptonic decay $D^+ \rightarrow K_{S(L)} e^+ \nu_e$

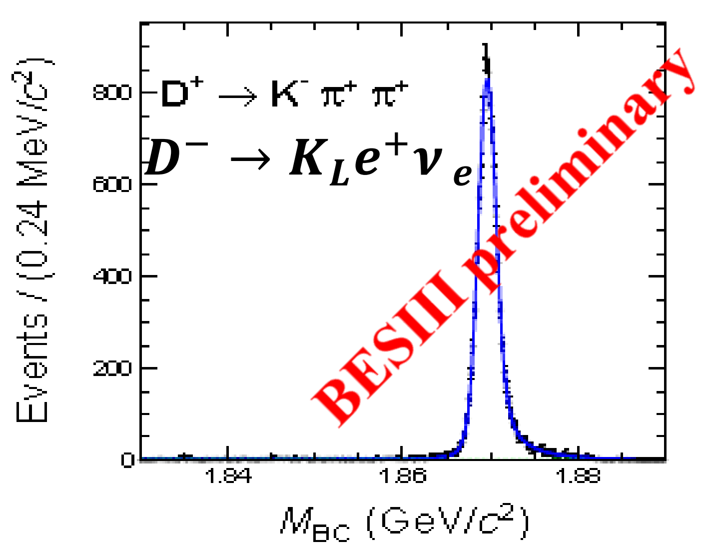
$\bar{B}(D^+ \rightarrow K_L e^+ \nu) = (4.482 \pm 0.027 \pm 0.103)\%$

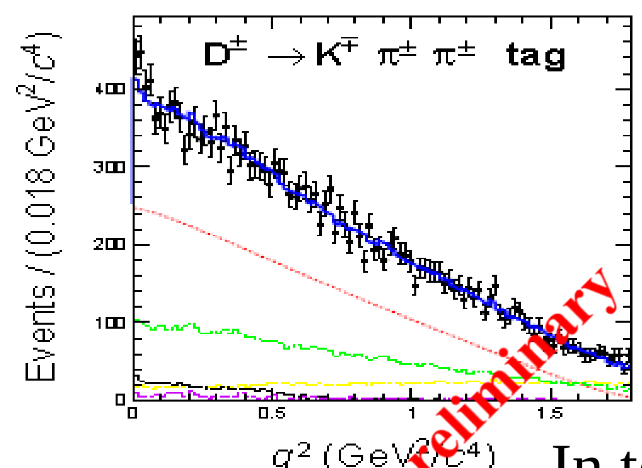
$$A_{CP} \equiv \frac{\mathcal{B}(D^+ \to K_L^0 e^+ \nu_e) - \mathcal{B}(D^- \to K_L^0 e^- \bar{\nu}_e)}{\mathcal{B}(D^+ \to K_L^0 e^+ \nu_e) + \mathcal{B}(D^- \to K_L^0 e^- \bar{\nu}_e)}$$

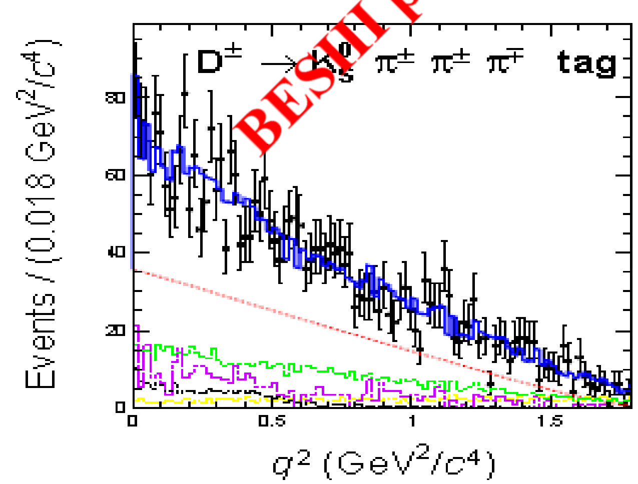
$A_{CP}^{D^+ \rightarrow K_L e^+ \nu} = (-0.59 \pm 0.60 \pm 1.50)\%$

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

- K_L is probed by interactions with EMC and thus gets position information
- we infer K_L four-momentum from its position information and the constraint $U_{miss} \rightarrow 0$







First measurements

In total 6 tag modes are used.

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

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

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

- **Fractions with >5σ significance**

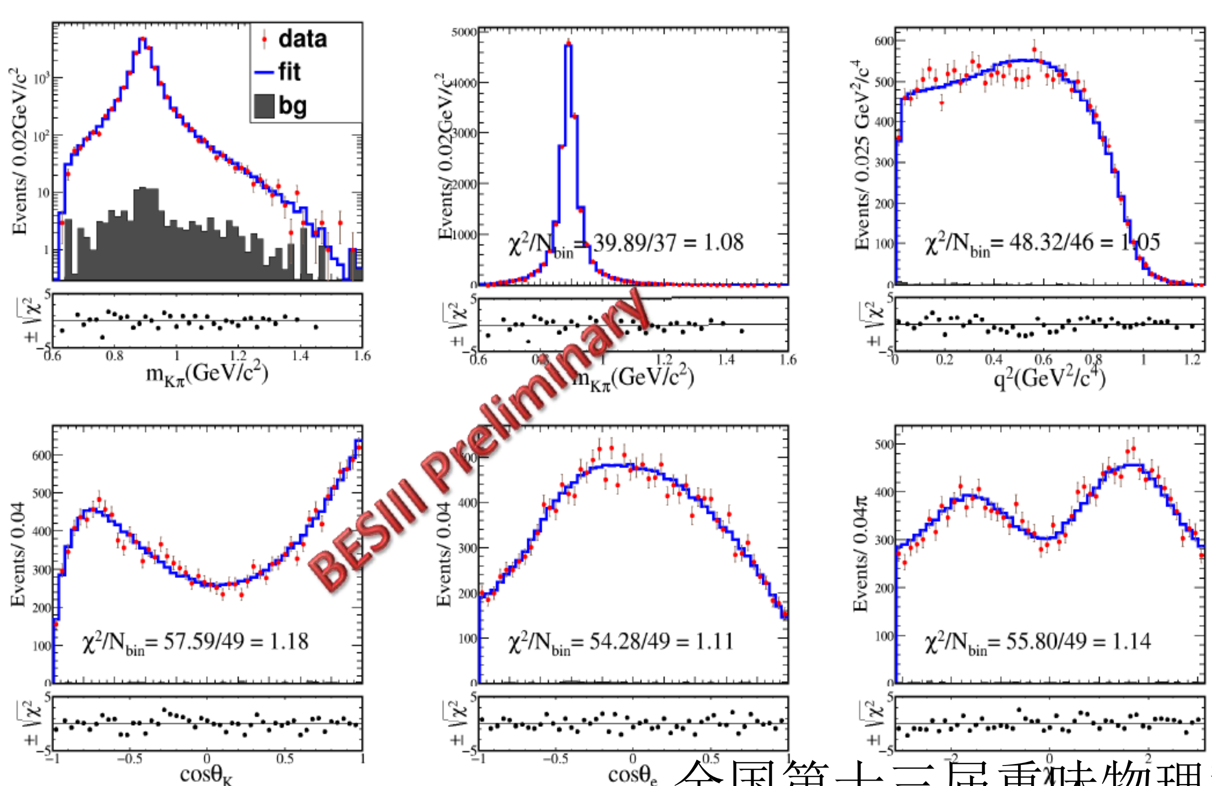
$$f(D^+ \to (K^-\pi^+)_{K^{*0}(892)}\, e^+\nu_e) = (93.93 \pm 0.22 \pm 0.18)\%$$

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

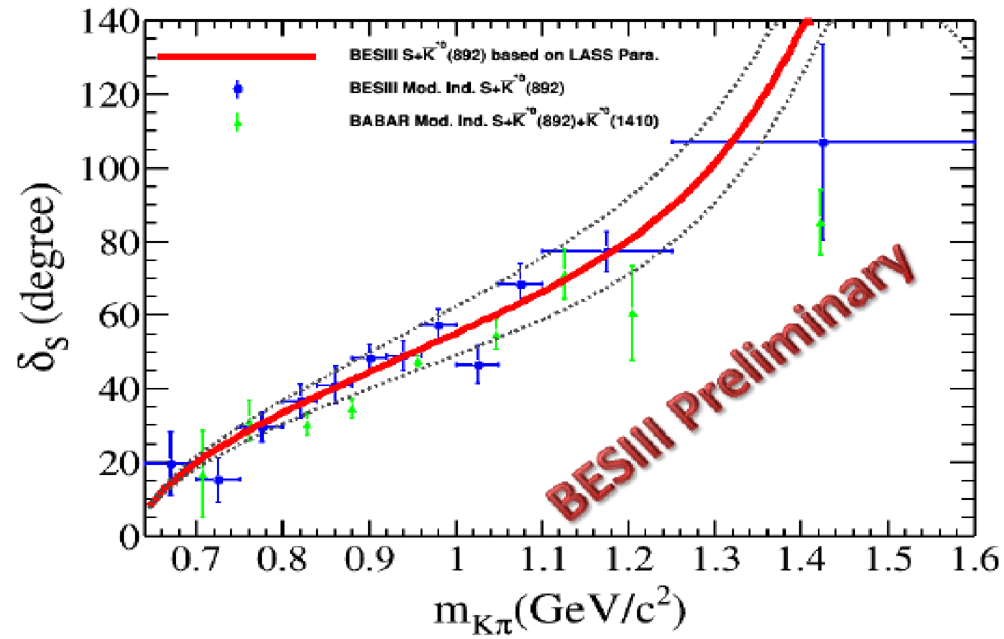
- **Measured parameters of $\bar{K}^*(892)$**

$$m_{K^{*0}(892)} = (894.60 \pm 0.25 \pm 0.08)\ \mathrm{MeV}/c^2$$
$$\Gamma_{K^{*0}(892)} = (46.42 \pm 0.56 \pm 0.15)\ \mathrm{MeV}/c^2$$
$$r_{BW} = (3.07 \pm 0.26 \pm 0.11)\ (\mathrm{GeV}/c)^{-1}$$

- **Comparison of data and fit with S+P in $D^+ \to K^-\pi^+e^+\nu$**



Model independent S-wave phase measurement



Form factors of $D^+ \to \bar{K}^*(892)e^+\nu$ by SPD model

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

$M_{V/A}$ is expected to $M_{D^*(1-/+)}$

$$m_V = (1.81^{+0.25}_{-0.17} \pm 0.02)\ \mathrm{GeV}/c^2$$
$$m_A = (2.61^{+0.22}_{-0.17} \pm 0.03)\ \mathrm{GeV}/c^2$$
$$A_1(0) = 0.573 \pm 0.011 \pm 0.020$$
$$r_V = V(0)/A_1(0) = 1.411 \pm 0.058 \pm 0.007$$
$$r_2 = A_2(0)/A_1(0) = 0.788 \pm 0.042 \pm 0.008$$

Study of D⁺→K⁻π⁺e⁺ν

- 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 [citation: CLEO collaboration, Phys. Rev. D 81, 112001 (2010)].

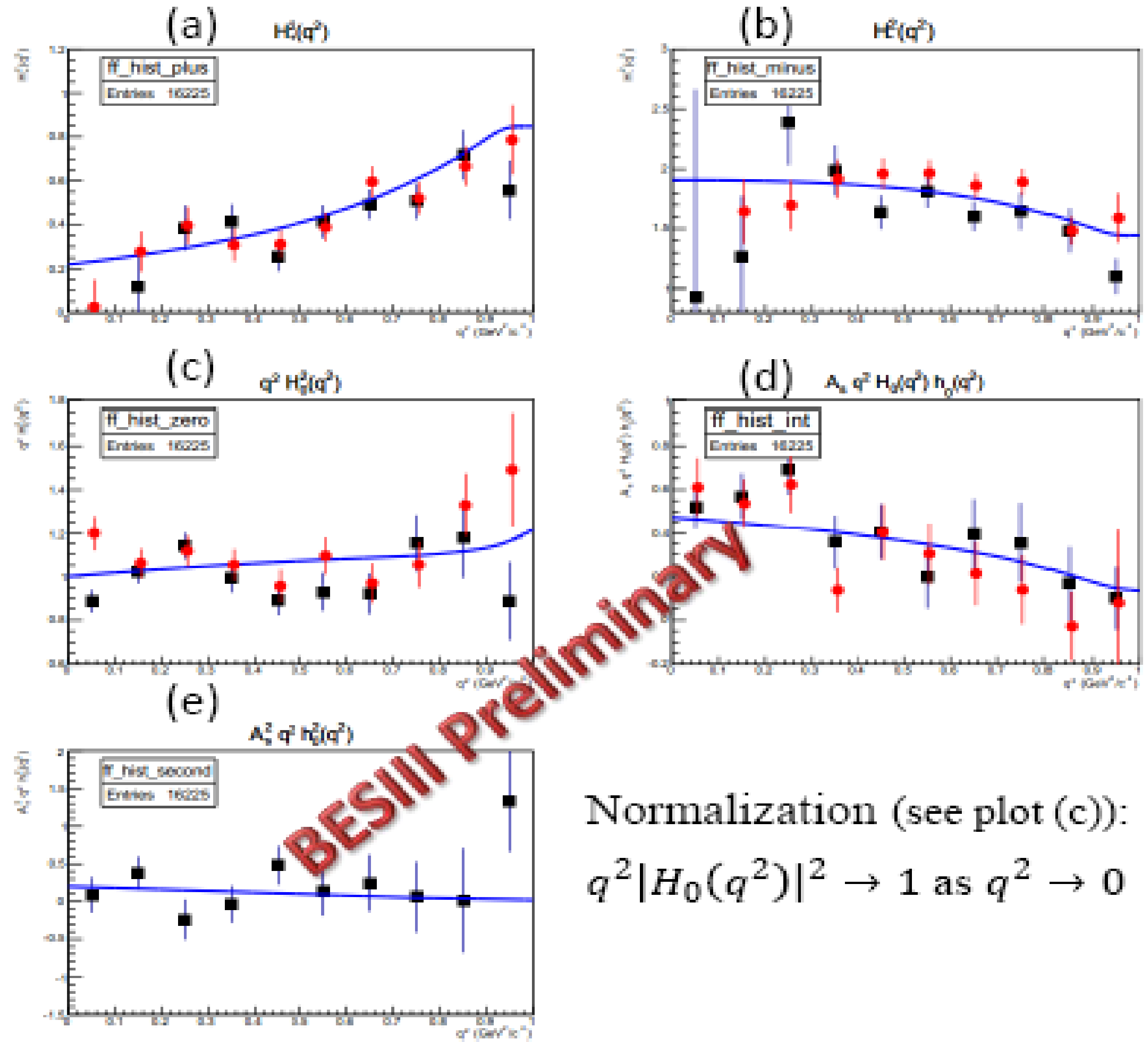
- Signal is assumed to be composed of $K^{*0}(892)$ and a non-resonant S-wave.

- Helicity basis form factors include:
  P-wave related: $H_{\pm,0}(q^2)$
  S-wave related: $h_0(q^2)$

- Five weighted q^2 histograms are built. Weight is assigned to each event based on $(q^2, cos\theta_K, cos\theta_e)$.

- Form factors are independently computed in each q^2 bin.

- The model-independent measurements are generally consistent with CLEO's report. And they are also consistent with the predicted trend based on the SPD model from amplitude analysis.



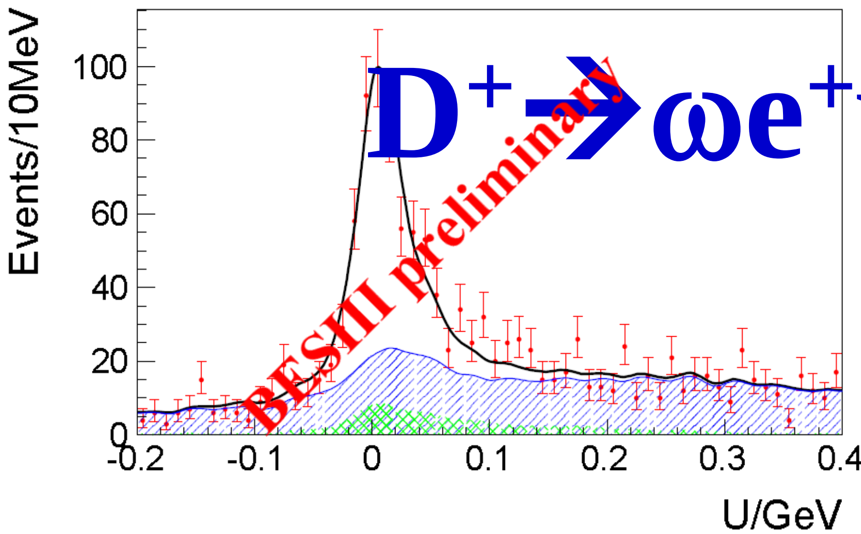
Normalization (see plot (c)):
$q^2|H_0(q^2)|^2 \to 1$ as $q^2 \to 0$

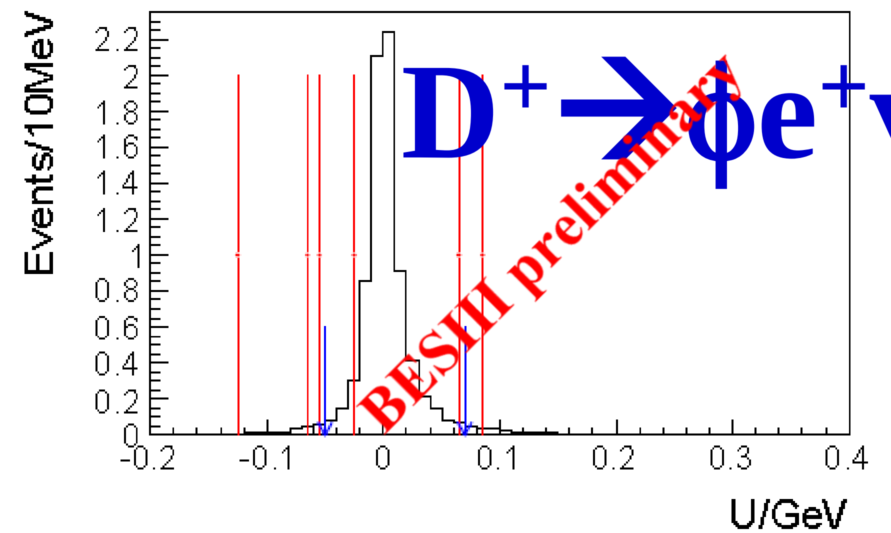
Red dots : BESIII model-independent measurement
Black dots : CLEO model-independent measurement
Blue Line : BESIII result from amplitude analysis, which is based on SPD model and mass-dependent S-wave

Notice: The lines are not simple fits of these dots!

Model independent measurement of form factors in D⁺→$\overline{K}^{*0}$(892)e⁺ν

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

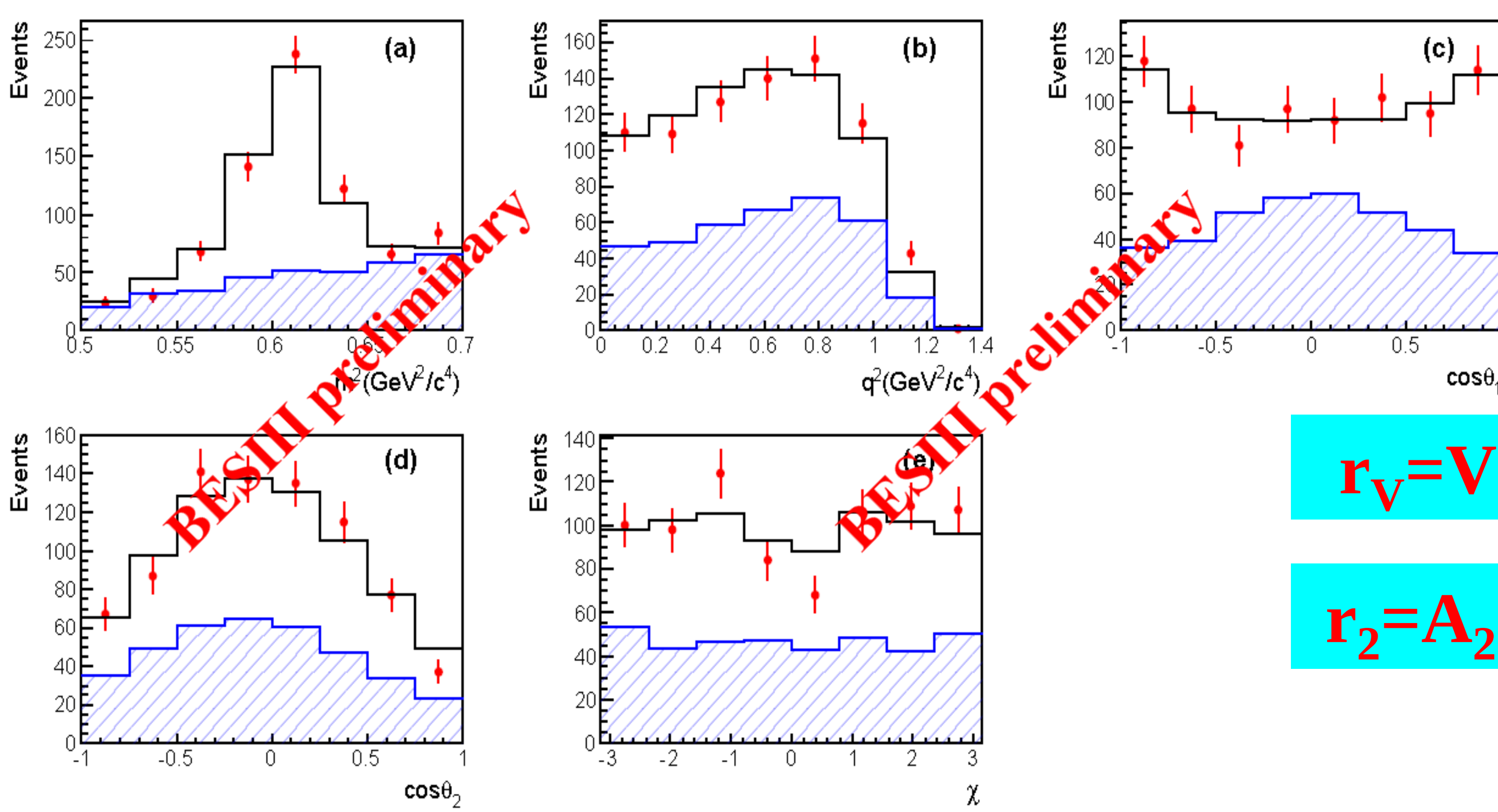




$B[D^+ \to \omega e^+ \nu] = (1.63 \pm 0.11 \pm 0.08) \times 10^{-3}$

$B[D^+ \to \phi e^+ \nu] < 1.3 \times 10^{-5}$ at 90% C.L.

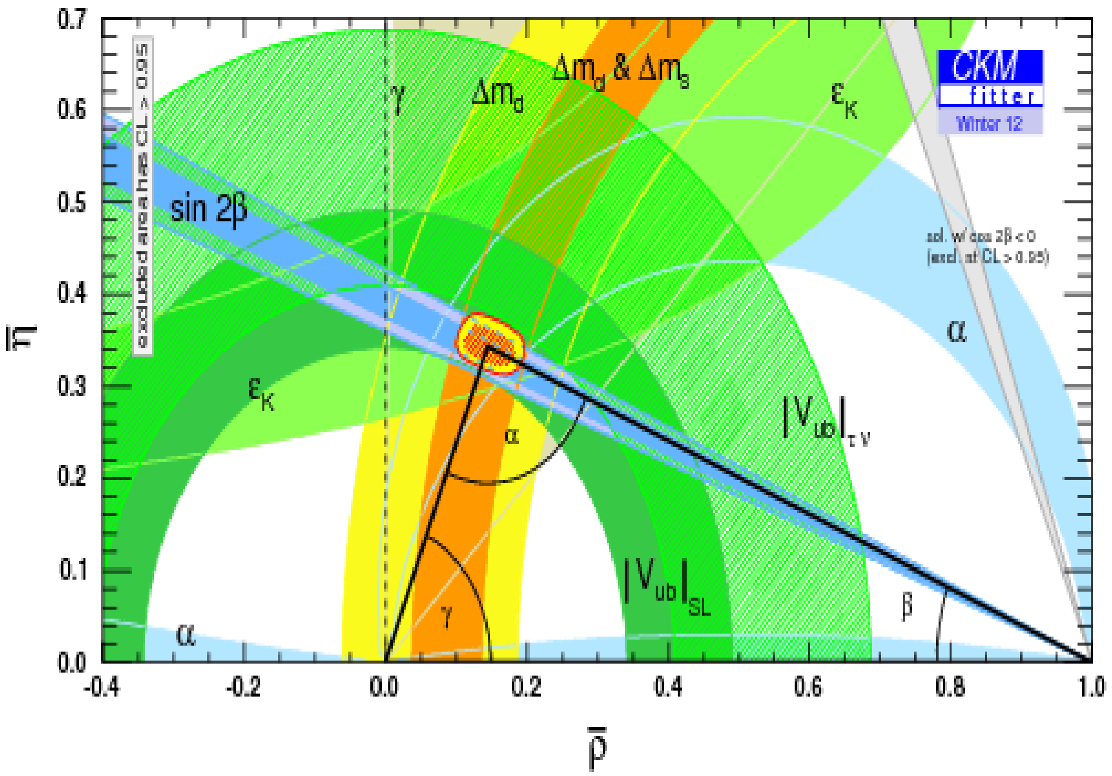
For the first time, form factors are extracted

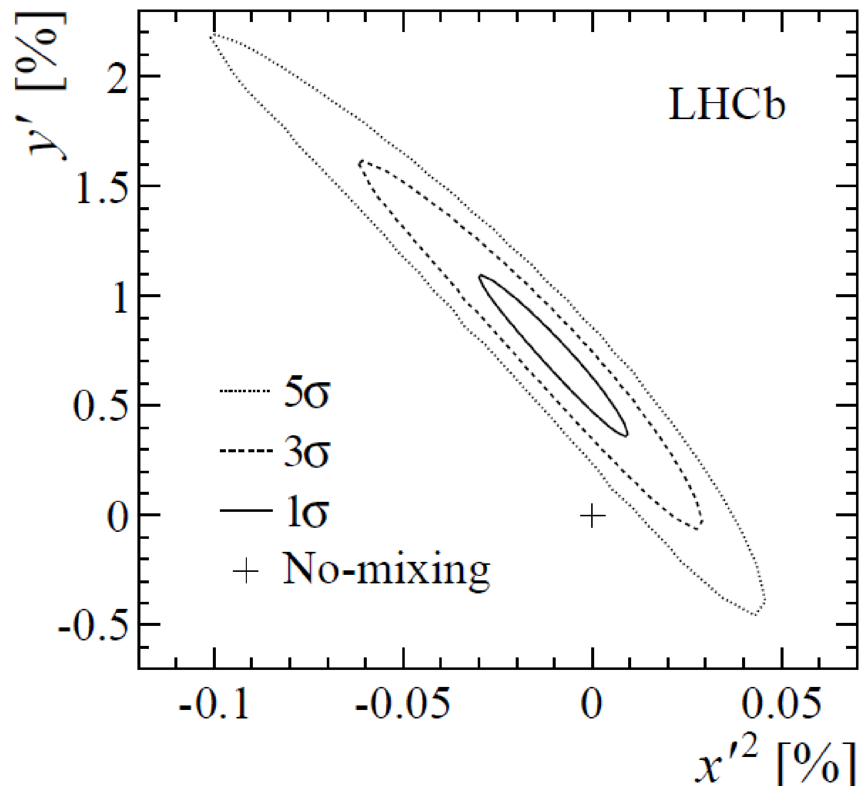


$r_V = V(0)/A_1(0) = 1.24 \pm 0.09 \pm 0.06$

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

QC inputs for Charm Physics





Precision CKM test

Charm Mixing & CP violation

- **inputs from Quantum Correlated (QC) $\psi(3770) \to D\bar{D}$ decays**
  - **(Averaged)Strong phase difference: δ_D**
  - **Coherent factors: R_D**
  - **(Averaged)Strong phase in Dalitz bins: c_i, s_i**
- ***B* factories, LHCb, Super *B* factories are the customers**

PLB 734, 227 (2014)

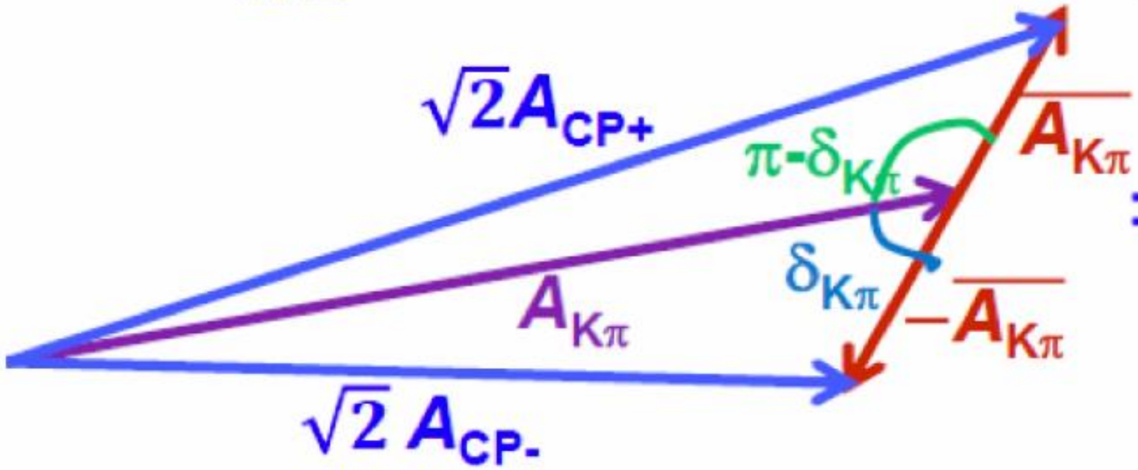
Strong Phase $\delta_{K\pi}$

(BESIII: 2.92 fb^{-1})

Strong phase: $$\frac{\langle K^-\pi^+|\overline{D}^0\rangle^{DCS}}{\langle K^-\pi^+|D^0\rangle^{CF}} \equiv -r_{K\pi}e^{-i\delta_{K\pi}}$$

Quantum correlation → Interference → access strong phase!

$$\langle K\pi|D_{CP\pm}\rangle = (\langle K\pi|D^0\rangle \pm \langle K\pi|\overline{D^0}\rangle)/\sqrt{2} \Rightarrow \sqrt{2}A_{CP\pm} = A_{K\pi} \pm \overline{A}_{K\pi}$$



$$\Rightarrow 2r_{K\pi}\cdot\cos\delta_{K\pi} \approx A_{CP\to K\pi} = \frac{|A_{CP-}|^2 - |A_{CP+}|^2}{|A_{CP-}|^2 + |A_{CP+}|^2}$$

$$= \frac{Br(D_{CP-}\to K\pi) - Br(D_{CP+}\to K\pi)}{Br(D_{CP-}\to K\pi) + Br(D_{CP+}\to K\pi)}$$

- Measuring $\delta_{K\pi}$ from rate differences if using external $r_{K\pi}$
- Reconstructed modes:
  - Flavor tags: $K^-\pi^+$, $K^+\pi^-$
  - CP+ tags (5 modes): K^-K^+, $\pi^+\pi^-$, $K_S^0\pi^0\pi^0$, $\pi^0\pi^0$, $\rho^0\pi^0$
  - CP- tags (3 modes): $K_S^0\pi^0$, $K_S^0\eta$, $K_S^0\omega$

Strong Phase $\delta_{K\pi}$

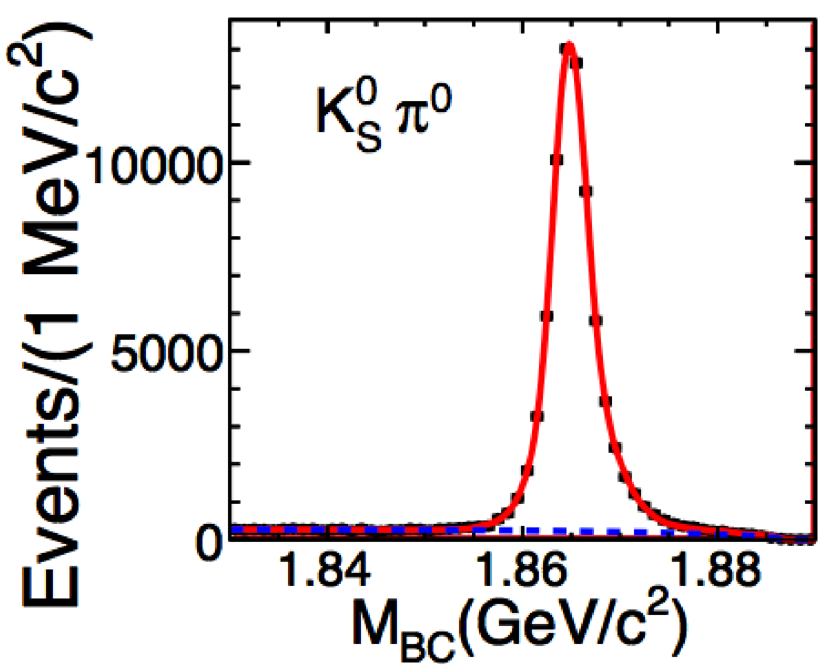
PLB 734, 227 (2014)

(BESIII: 2.92 fb^{-1})

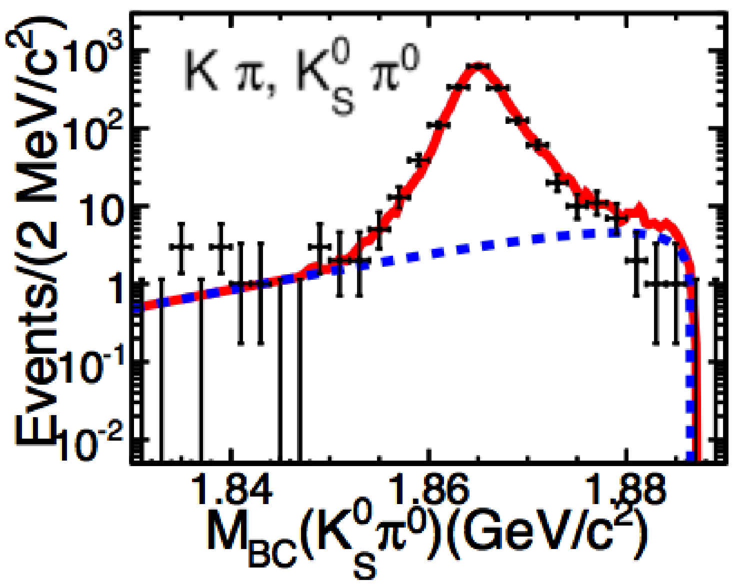
- **Signal reconstruction:**
  - Single Tag (ST): CP tags
  - Double Tag (DT) : $K\pi$ + CP Tag
  - Kinematic variable: Beam Constrained Mass (M_{BC})
  - Singal shape: $\sigma\otimes$MC-truth
  - Background shape: ARGUS function

- $$Br(D_{CP\pm} \to K\pi) = \frac{n_{K\pi,CP\pm}}{n_{CP\pm}} \cdot \frac{\varepsilon_{CP\pm}}{\varepsilon_{K\pi,CP\pm}}$$
  - $n_{K\pi,CP\pm}$ and $n_{CP\pm}$ are event yields for DT and ST from M_{BC} fit
  - $\varepsilon_{K\pi,CP\pm}$ and $\varepsilon_{CP\pm}$ are detection efficiencies of DT and ST from MC simulation
  - Most systematics cancelled for ratio $\varepsilon_{CP\pm}/\ \varepsilon_{K\pi,CP\pm}$

Single Tags



Double Tags



BESIII results:

$$\mathcal{A}_{CP\to K\pi} = (12.7 \pm 1.3 \pm 0.7) \times 10^{-2}$$

$\delta_{K\pi}$ in $D \to K\pi$

PLB 734, 227 (2014)

(BESIII: 2.92 fb^{-1})

- If we don't ignore the mixing effect
- $2r_{K\pi}\cos\delta_{K\pi} + y = (1 + R_{WS}) \cdot A_{CP\to K\pi}$
  - $R_{WS} \equiv \frac{\Gamma(D^0\to K^+\pi^-)}{\Gamma(D^0\to K^-\pi^+)} = r^2_{K\pi} + r_{K\pi}y' + \frac{(x^2+y^2)}{2}$
- External inputs from HFAG2013 and PDG
  - $r^2_{K\pi} = 0.347 \pm 0.006\%$,
  - $y = 0.66 \pm 0.09\%$,
  - $R_{WS} = 0.380 \pm 0.005\%$

CLEO-c results *[Phys. Rev. D 86 (2012) 112001]*

$$\cos\delta_{K\pi} = 0.81^{+0.22+0.07}_{-0.18-0.05}$$

$$\cos\delta_{K\pi} = 1.15^{+0.19+0.00}_{-0.17-0.08} \quad \text{(globalfit)}$$

BESIII results:

$$\cos\delta_{K\pi} = 1.02 \pm 0.11 \pm 0.06 \pm 0.01$$

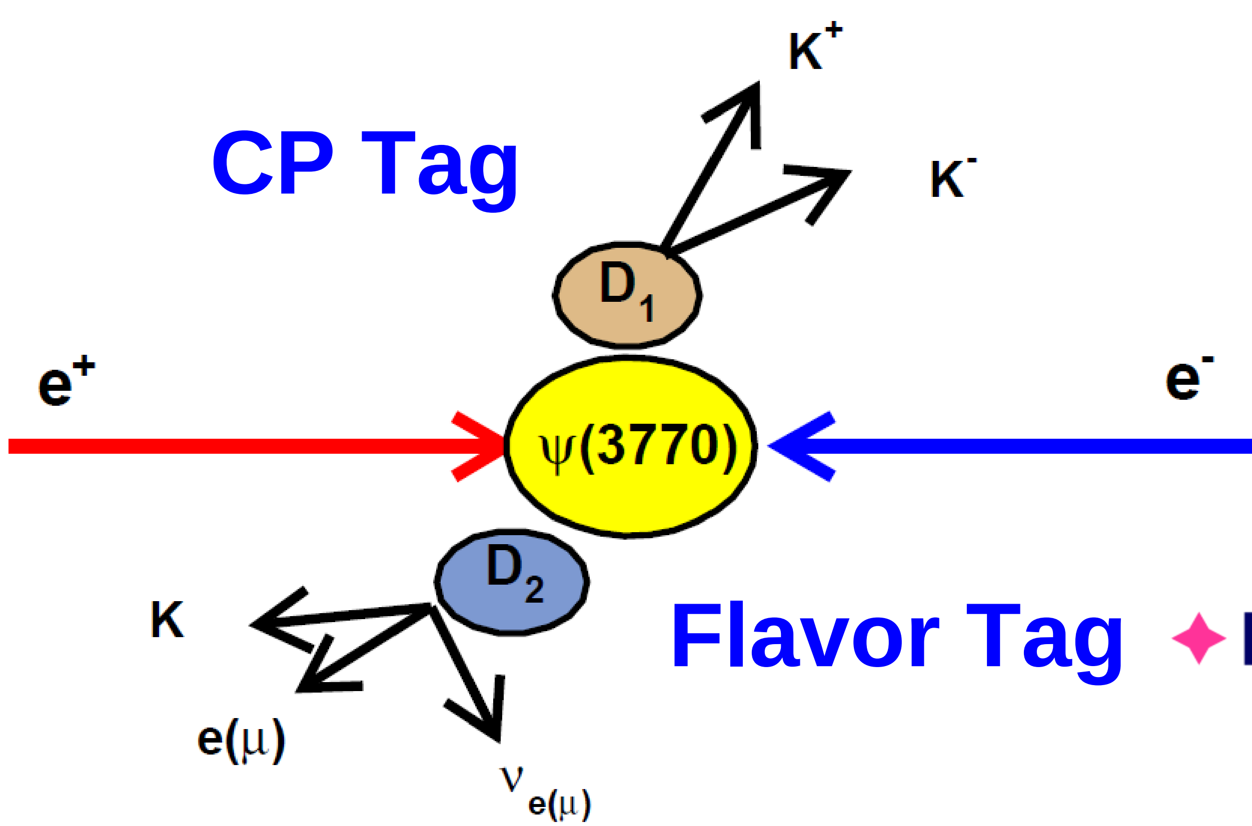
- The third error is due to the input parameters
- The statistical errors dominant the precision
- World best precision
- In 20 /fb BESIII data, precision of cos™k□ will reach ~0.04

y_{CP} measurement

PLB 744, 339 (2015)

(BESIII: 2.92 fb^{-1})

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



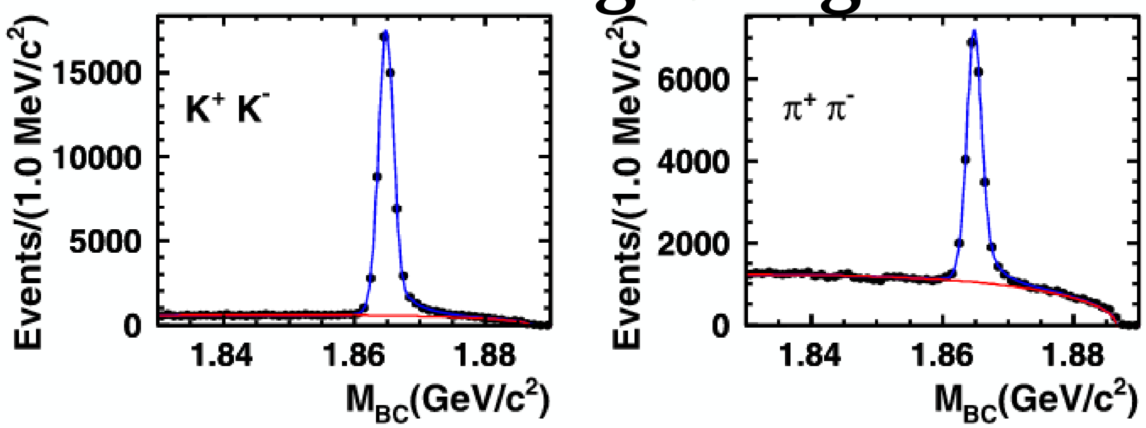
- **Single Tag decay rate (CP tags)**
  - $\Gamma_{CP\pm} \propto 2|A_{CP\pm}|^2(1 \mp y)$
- **Double Tag decay rate (Flavor tags + CP tags)**
  - $\Gamma_{l;CP\pm} \propto |A_l|^2 |A_{CP\pm}|^2$
- **Neglect term y^2 or higher order**
  - $y_{CP} \approx \frac{1}{4}\left(\frac{\Gamma_{l;CP+}\Gamma_{CP-}}{\Gamma_{l;CP-}\Gamma_{CP+}} - \frac{\Gamma_{l;CP-}\Gamma_{CP+}}{\Gamma_{l;CP+}\Gamma_{CP-}}\right)$

- **Reconstructed modes:**
  - **Flavor tags:** $Ke\nu_e$, $K\mu\nu_\mu$
  - **CP+ tags (3 modes):** K^-K^+, $\pi^+\pi^-$, $K_S^0\pi^0\pi^0$,
  - **CP- tags (3 modes):** $K_S^0\pi^0$, $K_S^0\eta$, $K_S^0\omega$

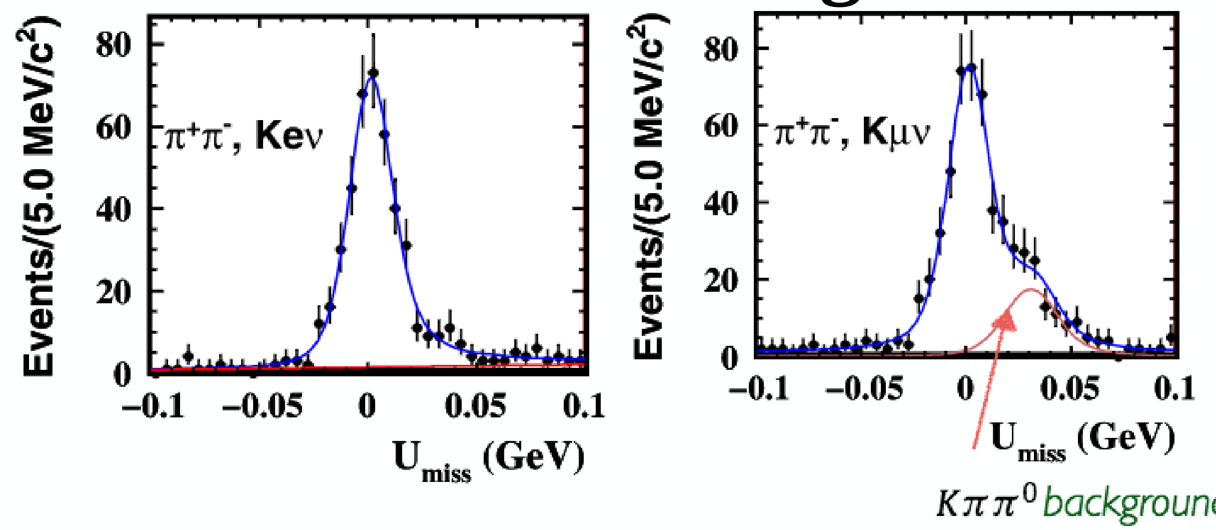
y_{CP} measurement

PLB 744, 339 (2015)

Single Tags



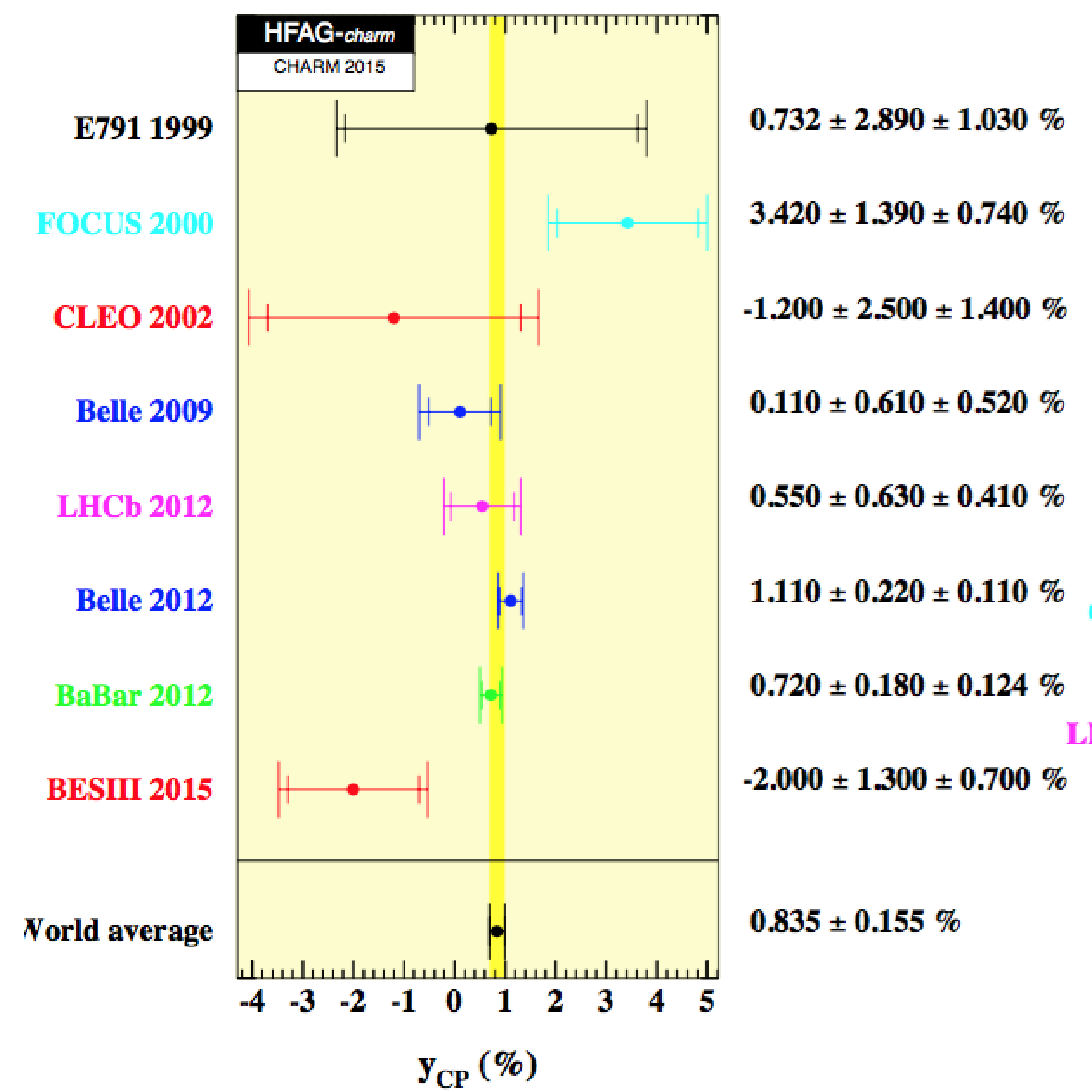
Double Tags



- **Signal reconstruction:**
  - **Single tag yields extraction:**
    - Singal shape: $\sigma\otimes$MC-truth
    - Background: ARGUS function
    - Kinematic variable: M_{BC}
  - **Double tag yields extraction:**
    - Singal shape: $\sigma\otimes$MC-truth
    - Background: Polynomial
    - $K\pi\pi^0$ background shape from data
    - Kinematic variable:

      $U_{miss} = E_{miss} - |\vec{P}_{miss}|$ (≈0 for signals)
- **BESIII preliminary results:**

  $y_{CP} = (-1.6 \pm 1.3 \pm 0.6)\%$
- **Most precise measurement with QC charm mesons**
- **In the limit of no CP violation: $y_{CP} = y$**



BESIII data taken

In 2014, BESIII took data above Λ_c pair threshold and run machine at 4.6GeV with excellent performance!
This is a marvelous achievement of BES!

available data set at BESIII

Energy(GeV)	lum.(1/pb)
4.575	~48
4.580	~8.5
4.590	~8.1
4.600	~567

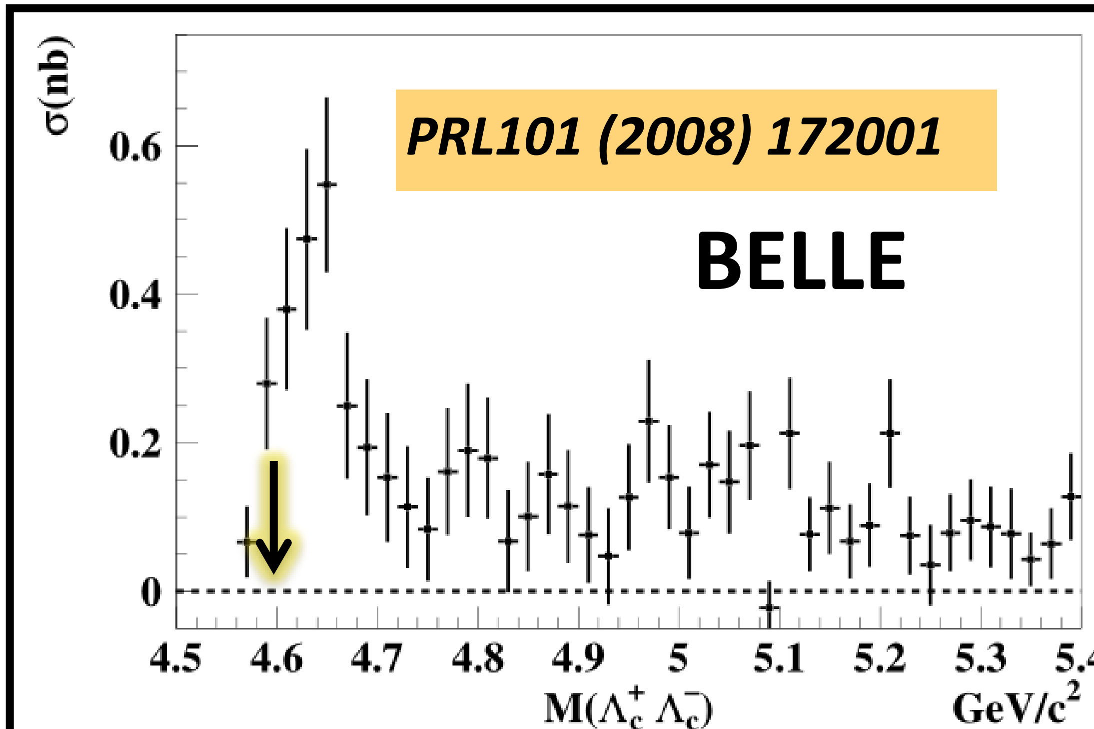


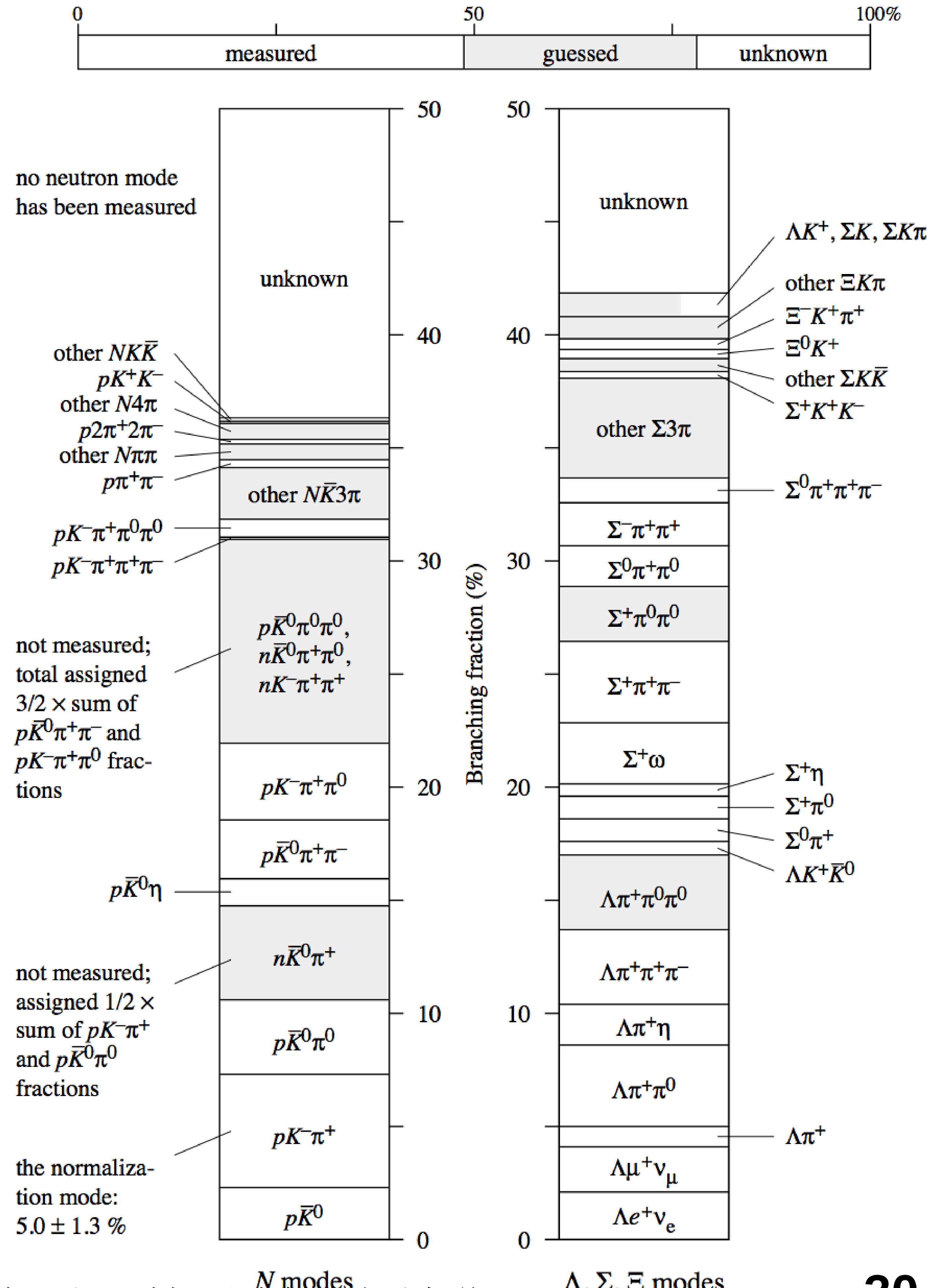
FIG. 4: The cross section for the exclusive process $e^+e^- \to \Lambda_c^+\Lambda_c^-$.

First time to systematically study charmed baryon at threshold!

Λ_c^+ decay rates

More reliable to be treated in HQET than mesons as it consists of a heavy quark and a spin and isospin zero light diquark

- absolute BF's has large uncertainties
- semi-leptonic decay modes have not been fully explored; The only measured BF($\Lambda_c \to \Lambda l^+ \nu_l$) has large uncertainties of $\delta B/B \sim 16\%$
- no neutron modes have been measured

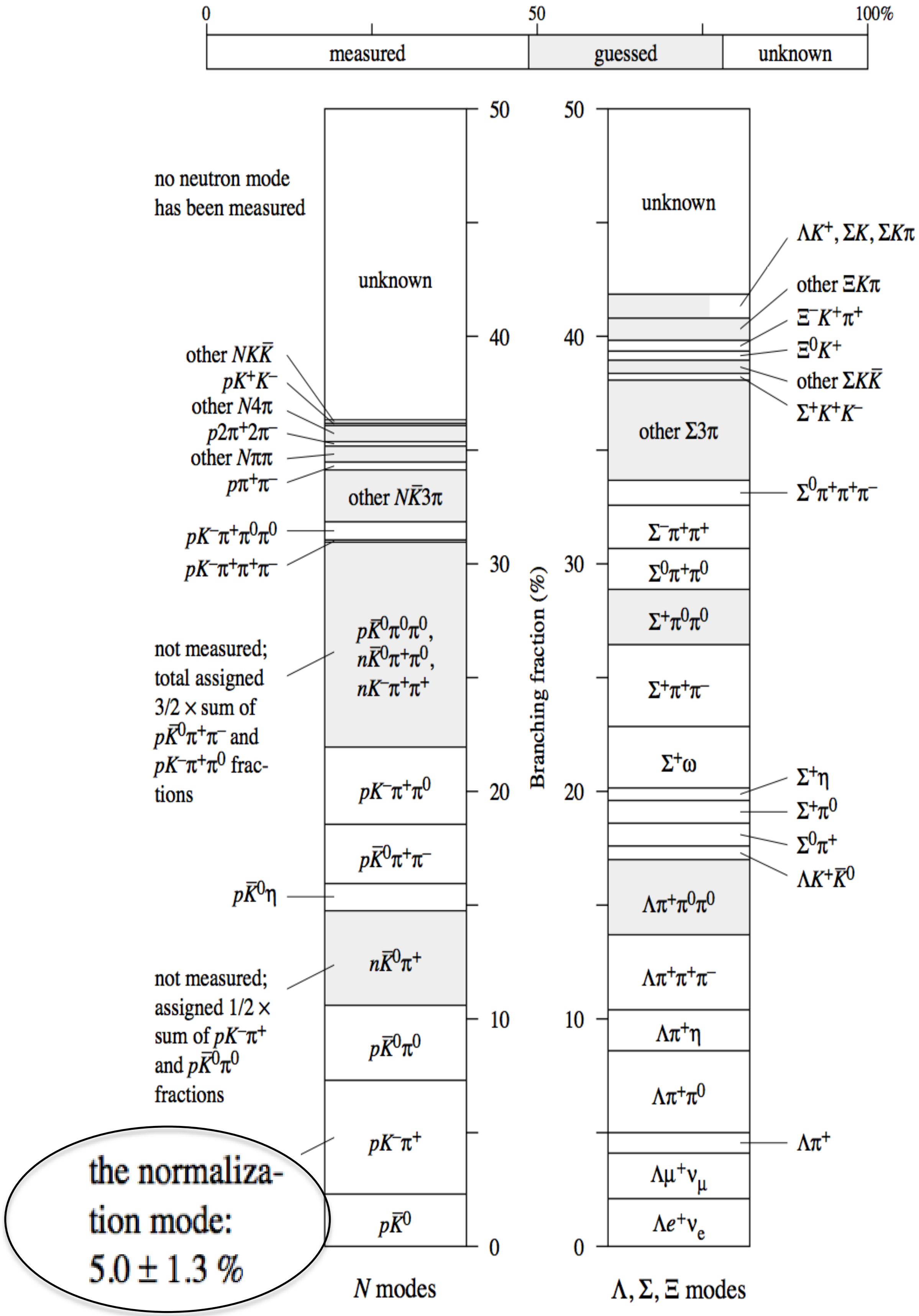


Absolute BF's of Λ_c^+ hadronic decays

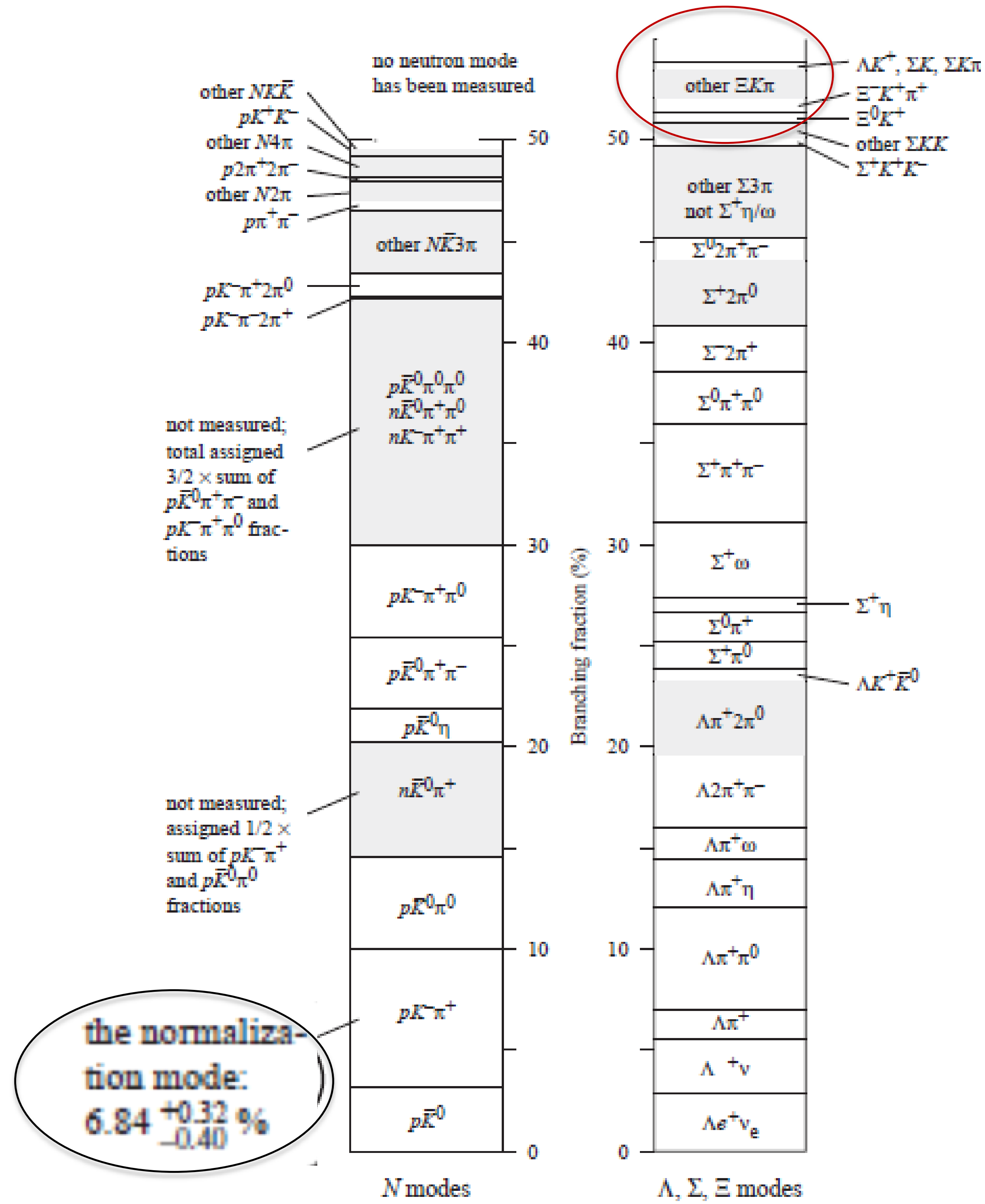
- Absolute branching fractions (BF) of Λ_c^+ decays are still not well determined since its discovery 30 years ago
  - BFs of all the decay modes (~85%) are measured relative to $\Lambda_c^+ \to pK^-\pi^+$
  - Charm counting ➔ test SM
  - However, no completely model-independent measurements of the absolute BF of $\Lambda_c^+ \to pK^-\pi^+$ (from Argus and CLEO very old results)
    uncertainties of BFs of Λ_c^+ decays are 25%~40% in PDG2014
- Until Belle's first "model-independent" measurement:
  $B(\Lambda_c^+ \to pK^-\pi^+) = (6.84 \pm 0.24^{+0.21}_{-0.27})\%$
  precision reaches to 4.7%
  [PRL113(2014)042002]
- However, measurement using the threshold pair-productions via e^+e^- annihilations is unique:
  the most simple and straightforward

Total BF overflow?

PDG2014



after adopting Belle's

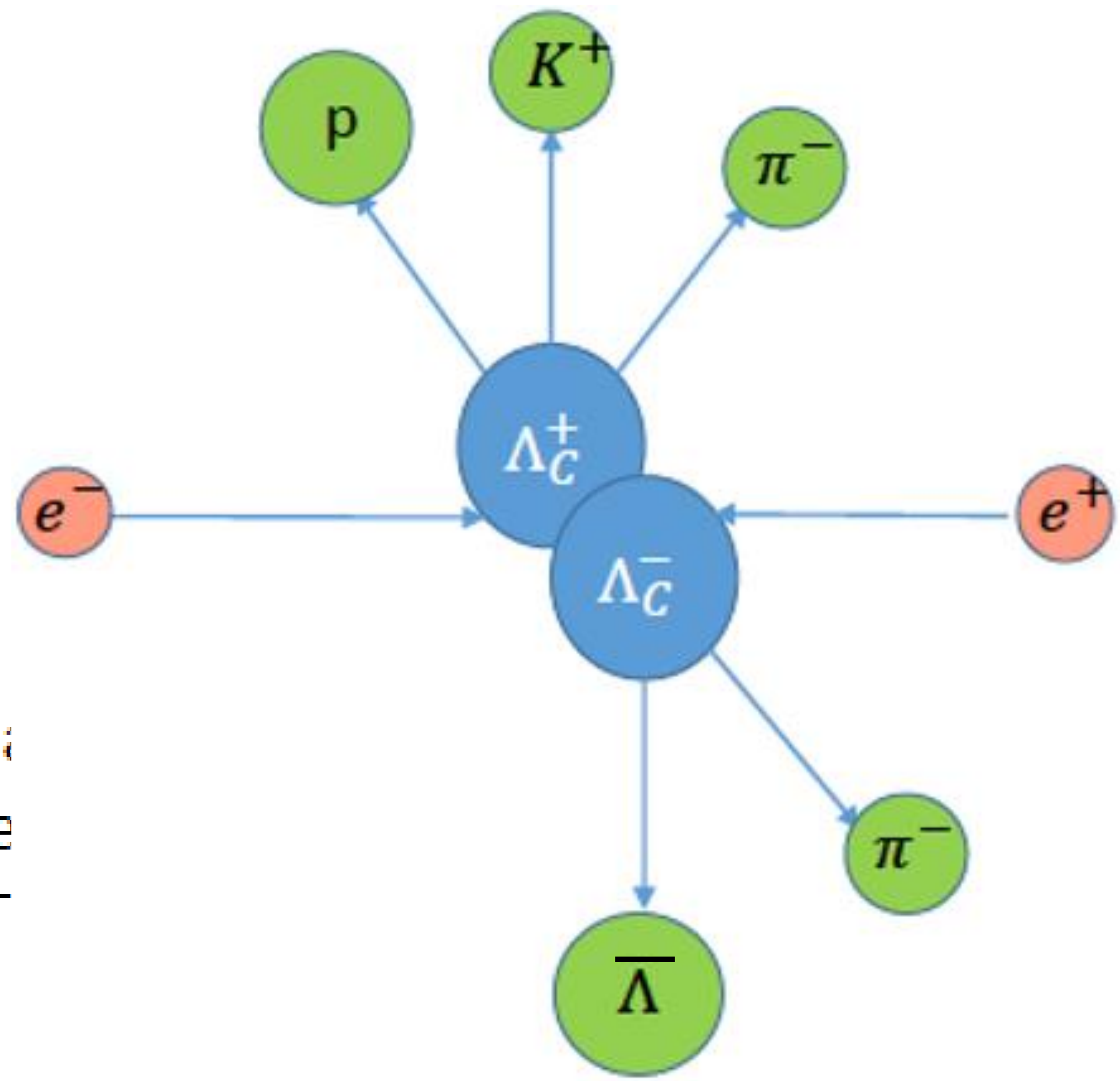


Measurements of hadronic BFs

- Produced in the pair production $e^+e^- \to \Lambda_c^+\Lambda_c^-$ at 4.6GeV ;
  - kinematics does not allow additional particle produced along with the $\Lambda_c^+\Lambda_c^-$ pair
  - fully reconstruct the pairs and take their yield ratios to measure the BFs:
    ratio of single tags (ST) and double tags (DT)
- 567/pb data consists of more than 100K $\Lambda_c^+\Lambda_c^-$ pairs
  - sensitivity of BF reaches to the level of 0.1%
- 12 hadronic modes are being measured at the same time based on a global fit *[Chinese Phys. C37(2013)106201]*

charge conjugate modes are implied in the following slides.

Detection of Λ_c pairs



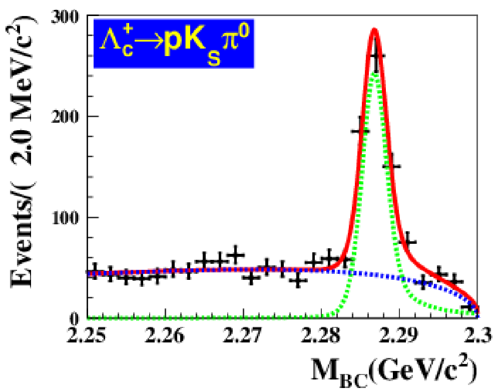
Constructing pa
from final state

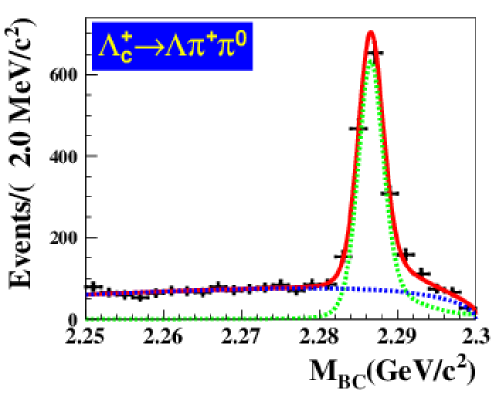
- $K_S \to \pi^+\pi^-$
- $\pi^0 \to \gamma\gamma$
- $\Lambda \to p\pi^-$
- $\Sigma^0 \to \Lambda\gamma$
- $\Sigma^+ \to p\pi^0$
- $\omega \to \pi^+\pi^-\pi^0$

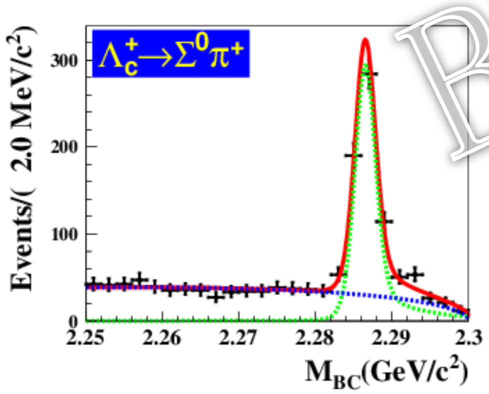
12 modes

pK_S
$pK^-\pi^+$
$pK_S\pi^0$
$pK_S\pi^+\pi^-$
$pK^-\pi^+\pi^0$
$\Lambda\pi^+$
$\Lambda\pi^+\pi^0$
$\Lambda\pi^+\pi^-\pi^+$
$\Sigma^0\pi^+$
$\Sigma^+\pi^0$
$\Sigma^+\pi^+\pi^-$
$\Sigma^+\omega$

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

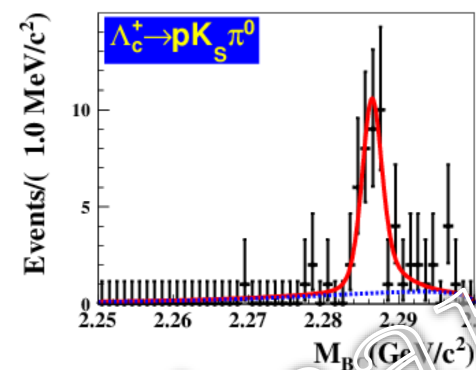


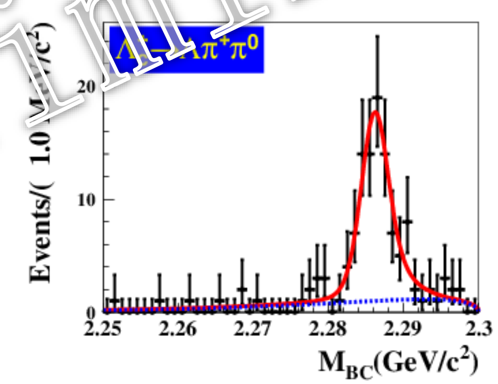


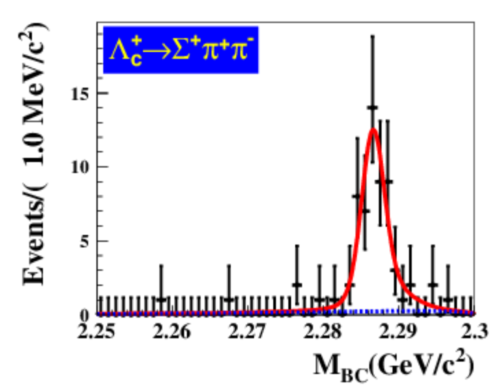


Single tags

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







Double tags

Decay modes	N_{-j}^{DT}
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

Very clean backgrounds

Hadronic branching fraction results

- a least square global fitter: simultaneous fit to the all tag modes while constraining the total Λ_c pair number, taking into account the correlations

Chinese Phys. C 37 , 106201 (2013)

BESIII prel.

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	

only stat. errors

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

BF of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

- $\Lambda_c^+ \to \Lambda e^+ \nu_e$ is a $c \to s l^+ \nu_l$ dominated process.
- Urgently needed for LQCD calculations.
- No direct absolute measurement for $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ available.

$$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (2.1 \pm 0.6)\% \qquad \text{PDG 2014}$$

scaling to (2.9±0.5)%, when taking the BELLE's B($pK^-\pi^+$)

However, this is not a direct measurement.

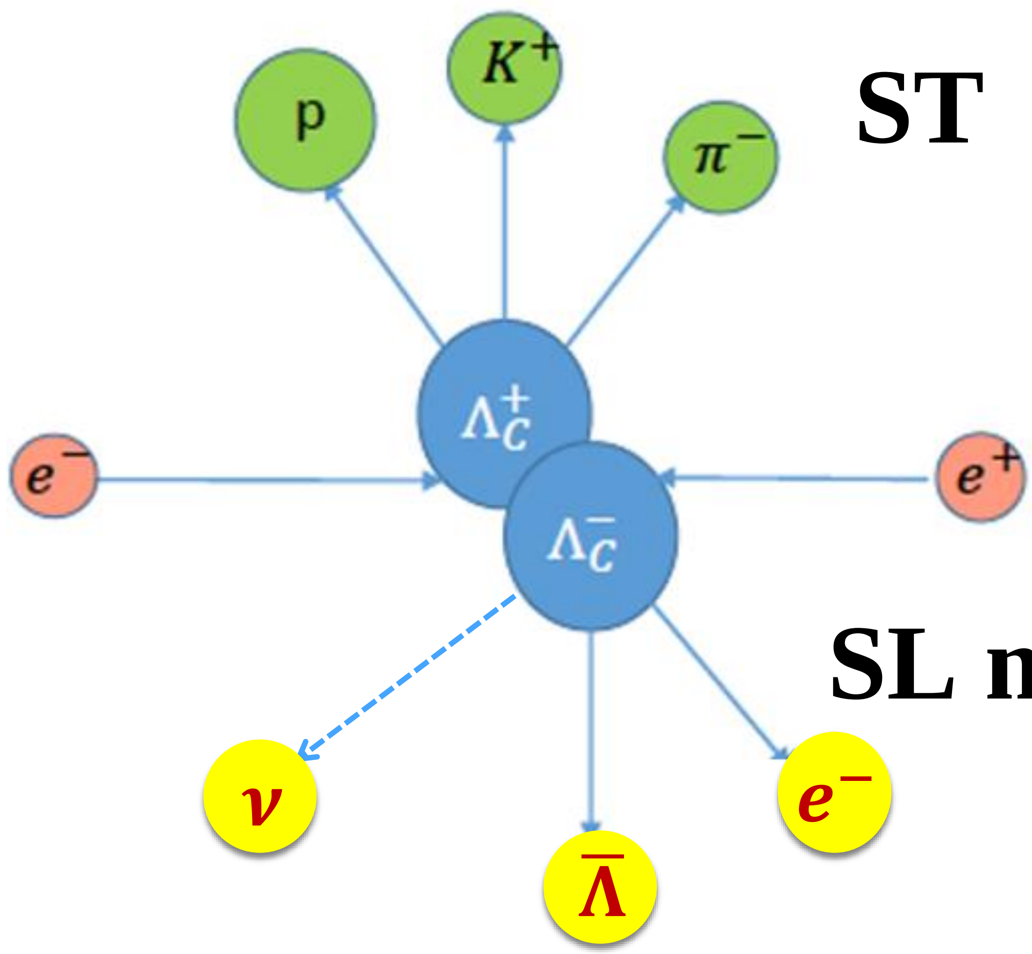
- Theoretical predications for branching fraction of $\Lambda_c^+ \to \Lambda e^+ \nu_e$ ranges from 1.4% to 9.2%.
- Thus, measuring $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ will provide very important experimental information for
  1) testing the theoretical predications for $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$.
  2) calibrating the LQCD calculations.
  3) addition information for determining CKM elements.

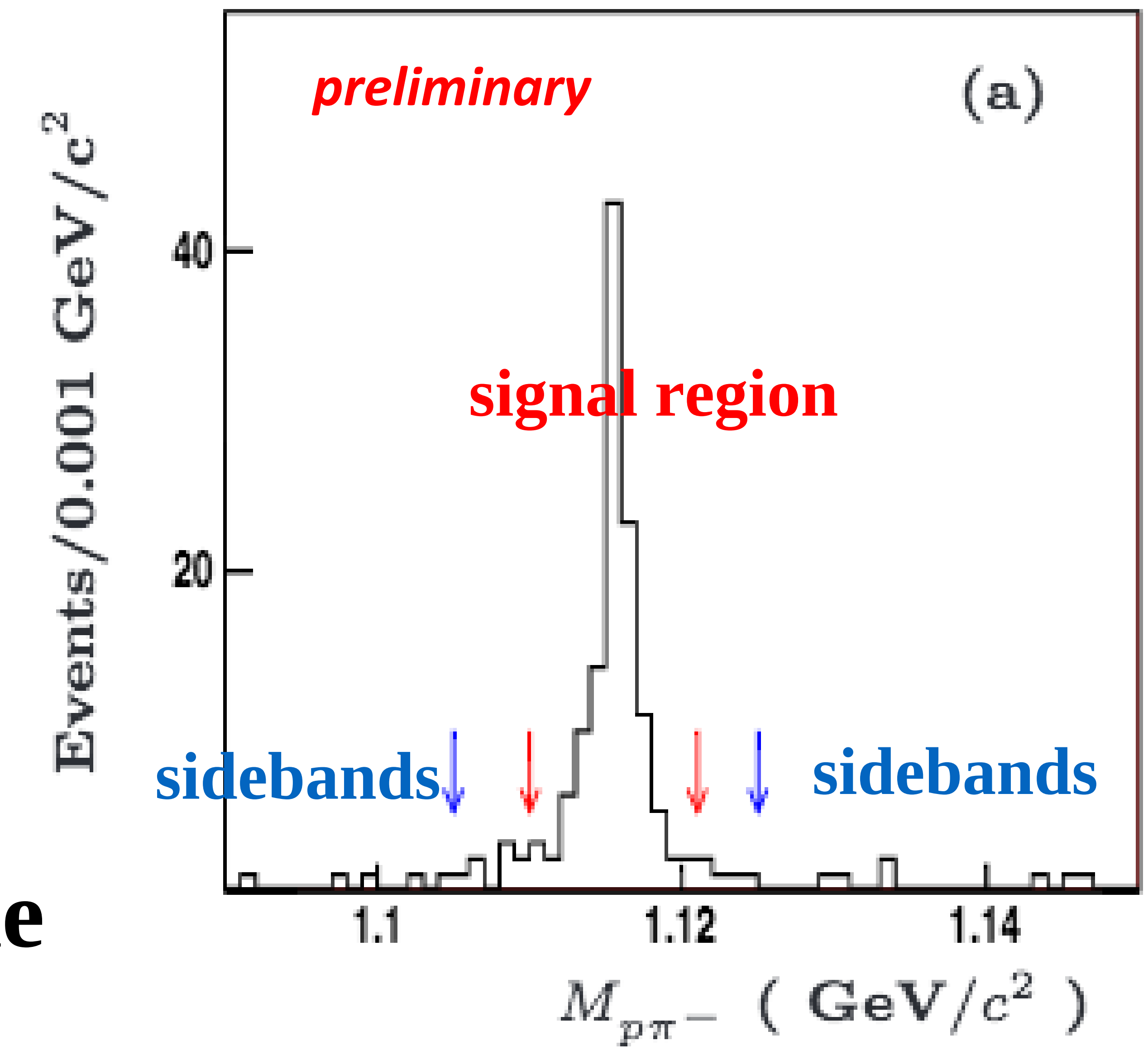
Candidate events for $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

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

567/pb @ 4.6 GeV

We detect a p, π^- and e^+ among the remaining tracks from the ST Λ_c^- and require p and π^- are from Λ.



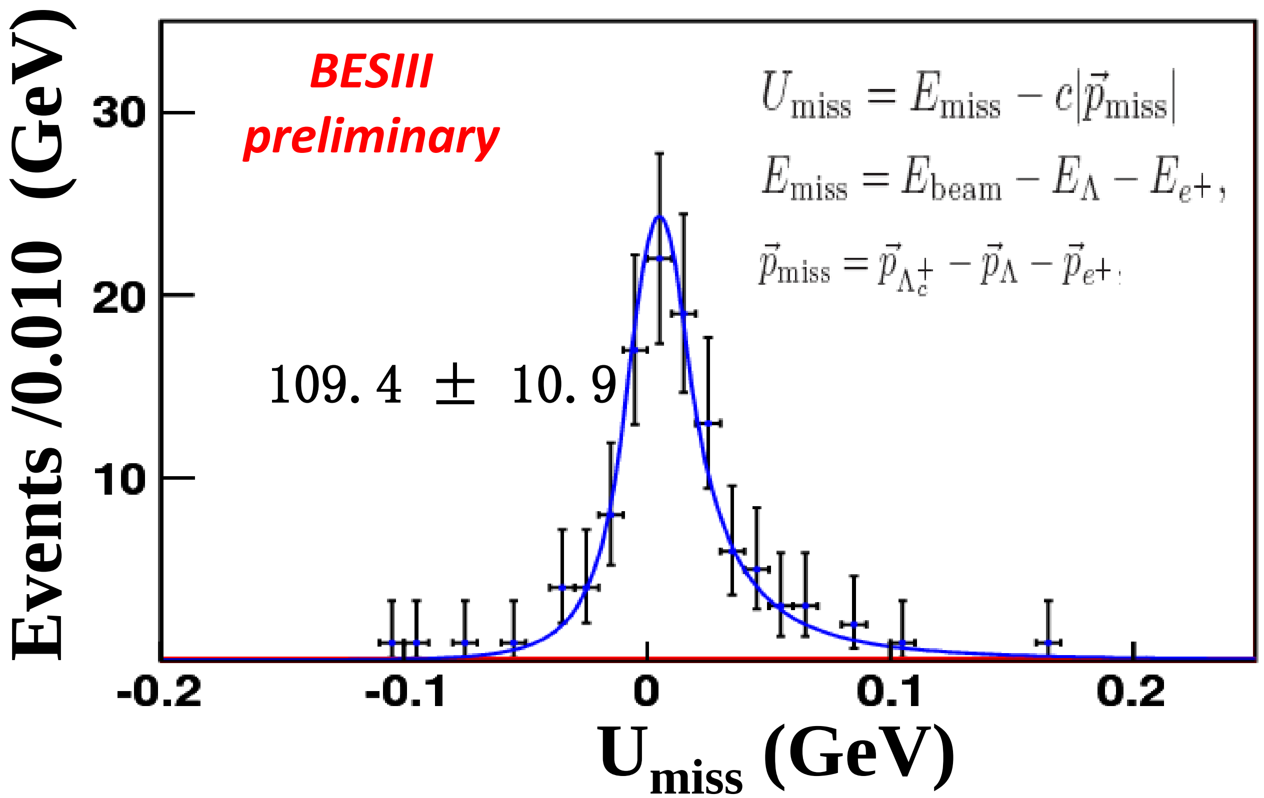


clean Λ peak

Candidate Events for $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

✓ Fitting function:

- signals: Gaussian with two power law tails
- backgrounds: 1st order polynomial



subtraction of backgrounds:

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

➔ **signal yields: 103.5 ± 10.9**

BESIII Prel. : $B(\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.??)\%$

scaled PDG
(2.9±0.5)%

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

What is more potentials at BESIII

- Is 4.6GeV the BEPCII's ultimate?
- How about to go to the XS peak @4635MeV
  - ✓ Belle's ISR data has large uncertainties of ~25%
  - ✓ reduce uncertainties of the XS line shapes
- Prospects of increased threshold data set (naively say x10 statistics)
  - ✓ the intermediate structures in three-body decays via dedicated PWA analysis
  - ✓ more SL modes: $nl\nu$, $\Lambda^* l\nu$, $\Sigma X l\nu\ldots$
  - ✓ decay asymmetry parameters in Λ_c^+ hadronic weak decays, such as $\Lambda_c^+ \to BP$ and $\Lambda_c^+ \to BV$
  - ✓ searching for Λ_c^+ low rate decays and rare decays, such as weak radiative decay $\Lambda_c^+ \to \gamma\Sigma^+$, FCNC $\Lambda_c^+ \to pl^+l^-$, LNV
  - ✓ the spin-parity of Λ_c^-

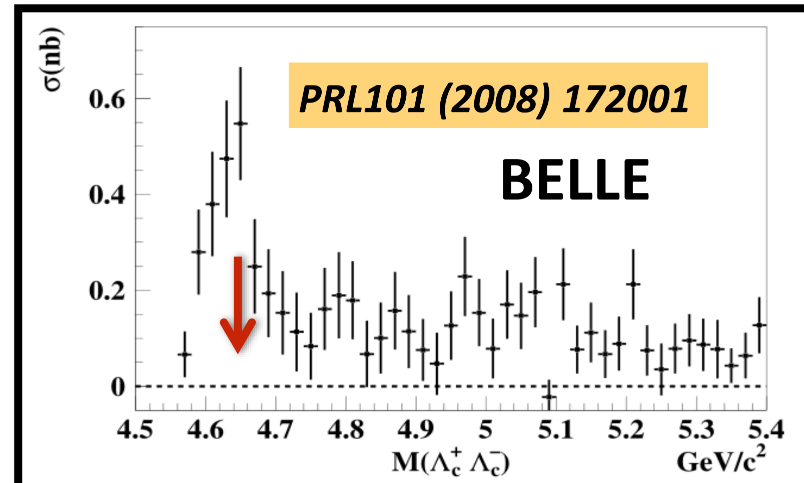
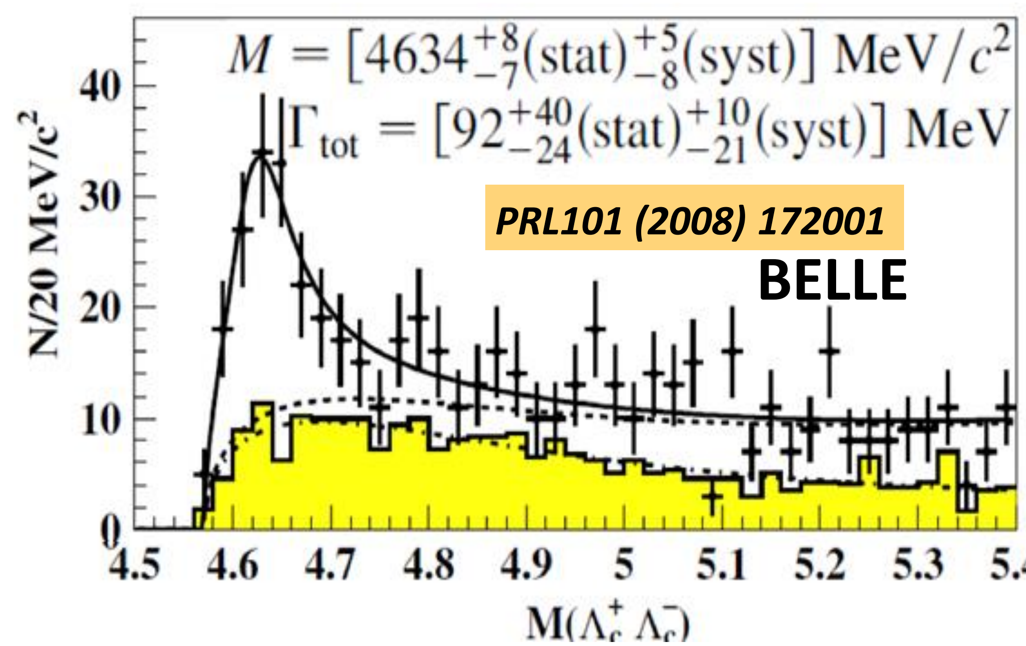


FIG. 4: The cross section for the exclusive process $e^+e^- \to \Lambda_c^+\Lambda_c^-$.



Other released results

- 1st observation of SCSD: $D \to \omega\pi$

Decay mode	This work	PDG value
$D^+ \to \omega\pi^+$	$(2.74 \pm 0.58 \pm 0.17) \times 10^{-4}$	$< 3.4 \times 10^{-4}$ 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.
$D^+ \to \eta\pi^+$	$(3.13 \pm 0.22 \pm 0.19) \times 10^{-3}$	$(3.53 \pm 0.21) \times 10^{-3}$
$D^0 \to \eta\pi^0$	$(0.67 \pm 0.10 \pm 0.05) \times 10^{-3}$	$(0.68 \pm 0.07) \times 10^{-3}$

Preliminary

- D Rare/Fobidden Decays at BESIII

$B(D0 \to \gamma\gamma) < 3.8 \times 10^{-6}$ compatible with BaBar result [PRD91 (2015) 11, 112015]

$\mathcal{B}(D^+ \to) \setminus [\times 10^{-6}]$	$K^+e^+e^-$	$K^-e^+e^+$	$\pi^+e^+e^-$	$\pi^-e^+e^+$
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

Preliminary

- $D_s \to \eta' X$ and $D_s+ \to \eta'\rho+$ [arXiv:1506.08952]

- **$BF(D_s^+ \to \eta' X)$ = (8.8±1.8±0.5)%, consistent with**
  PDG = (11.7±1.7±0.7)% within ~1σ.
- **$BF(D_s^+ \to \eta'\rho^+)/BF(D_s^+ \to K^+K^-\pi^+)$ = 1.04±0.25±0.07 or**
  $BF(D_s^+ \to \eta'\rho^+)$ = (5.8±1.4±0.4)%
  PDG = (12.5±2.2)% from PDG,
  confirming the CLEO-c result,

Summary

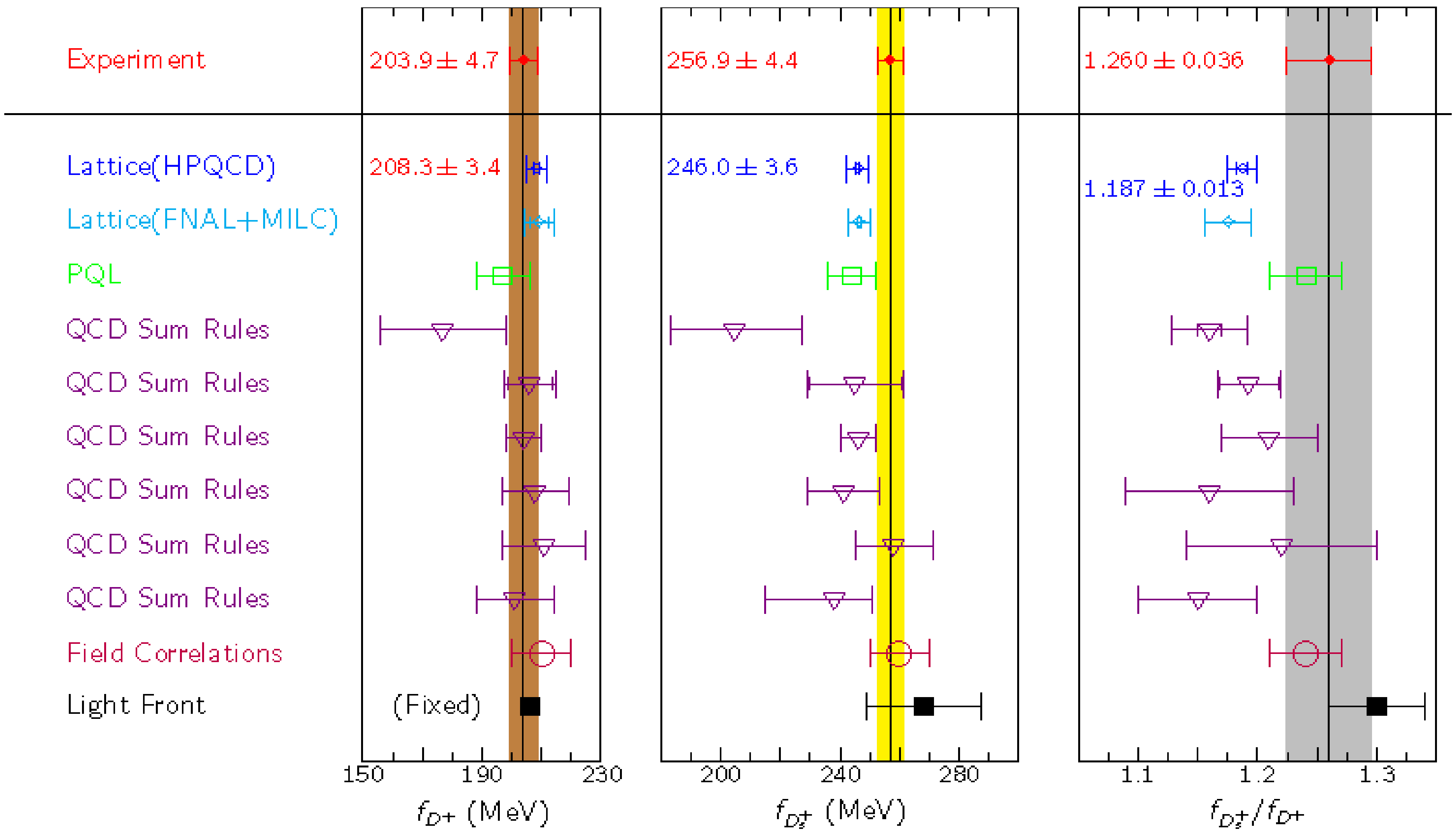
- BESIII produces many fresh results on charm hadron decays
- BEPCII/BESIII will accumulate more data set @4.17 and 4.6GeV
- More precision measurement and search studies
- BESIII also opens a new door for the charmed baryon Λ_c^+

  ➔ low backgrounds and high detection efficiency
- Study tunes!

Thank you!
谢谢！

Comparisons of f_{D+}, f_{Ds+} and f_{D+}:f_{Ds+}

Taken from Gang Rong's talk at CKM2014



- **Precisions of the LQCD calculations of f_{D+}, f_{Ds+}, f_{D+}:f_{Ds} reach 0.5%, 0.5% and 0.3%, which are challenging the experiments**
- **The experimentally measured and the theoretical expected f_{D+}, f_{Ds+}, f_{D+}:f_{Ds+} differ by about 2σ**

	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

- **Improving measurement with larger data sample is expected at BESIII!**

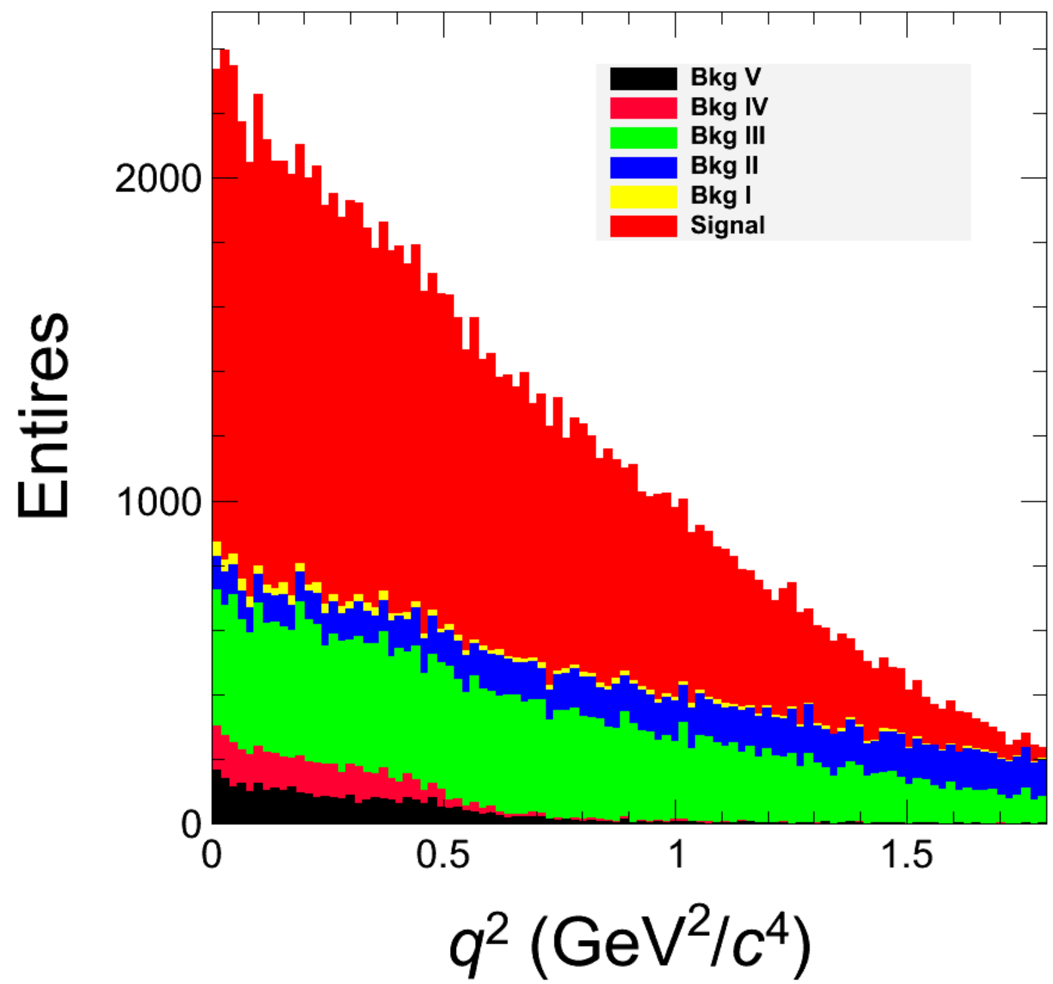
Estimation of Backgrounds in the Double Tag

By using MC-truth information of the K_L efficiency corrected $D\bar{D}$ MC samples, the double-tag D candidates can be divided into the following categories:

- **Signal: tag-side matched and signal-side matched signal events**
- **Background:**

- Bkg I: $D\bar{D}$ decays of which hadronic tag D is mis-reconstructed and non-$D\bar{D}$ processes. Its proportion varies from 1% to 12% according to the specific hadronic tag mode
- Bkg II: (~10%) $D^+ \to K_L e^+ \nu_e$ events of which K_L shower is mis-reconstructed.
- Bkg III: $D^+ \to Xe\nu_e$ non-signal events (~24%), which are from $D^+ \to \bar{K}^*(892)^0 e^+\nu_e$ (41.9%), $D^+ \to K_S e^+\nu_e$ (41.2%), $D^+ \to \pi^0 e^+\nu_e$ (10.2%), $D^+ \to \eta e^+\nu_e$(6.0%) and $D^+ \to \omega e^+\nu_e$ (0.7%)
- Bkg IV: $D^+ \to X\mu\nu_\mu$ events (~3%), consist of $D^+ \to K_L\mu^+\nu_\mu$ (65.2%), $D^+ \to \bar{K}^*(892)^0\mu^+\nu_\mu$ (23.3%) and $D^+ \to K_S\mu^+\nu_\mu$ (11.5%)
- Bkg V: Non-leptonic D decay events (~3%), which are from $D^+ \to \bar{K}^0\pi^+\pi^0$(78%) and $D^+ \to \bar{K}^0 K^*(892)^+$ (22%)

Composition of double-tag D candidates



In the determination of $B(D^+ \to K_L e^+ \nu_e)$, the peaking backgrounds consist of Bkg II~Bkg V. This estimation brings in 1.6% systematic uncertainty.

Simultaneous Fit to Event Density $I(q^2)$

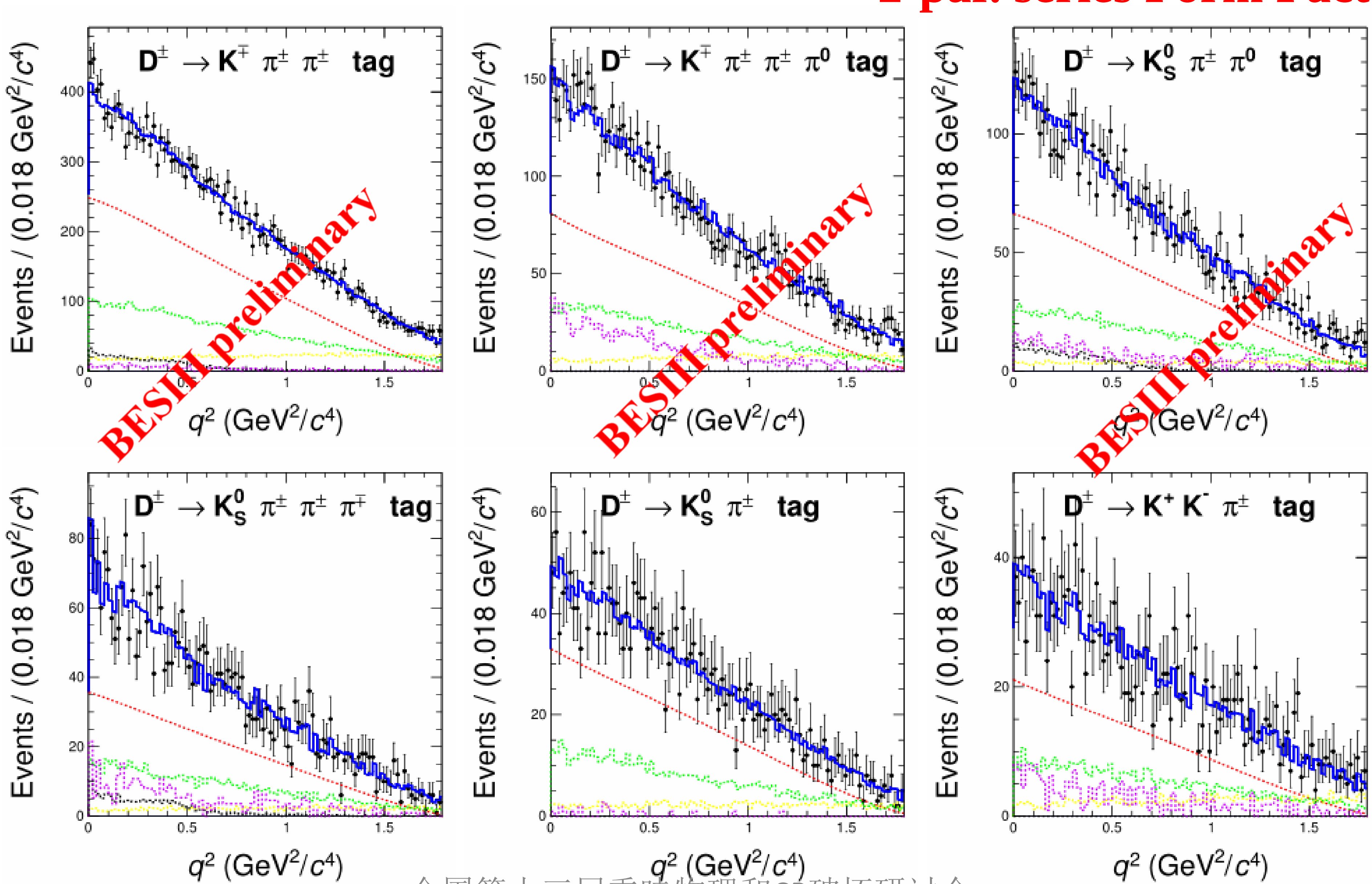
$$\frac{dn_{\text{observed}}}{dq^2} = AN_{\text{tag}}p^3(q'^2)|f_+(q'^2)|^2\epsilon(q'^2) \otimes \sigma(q'^2, q^2)$$

Series Expansion

Becher and Hill PLB 633, 61 ('06)

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

2-par. series Form Factor is used



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

Strong phase δ and γ/φ_3 in the CKM unitarity triangle

- **D hadronic parameters for a final state f:** $\frac{A(\bar{D}^0\to f)}{A(D^0\to f)} \equiv -r_D e^{-i\delta_D}$
- **Charm mixing parameters:** $x = \frac{\Delta M}{\Gamma}$, $y = \frac{\Delta\Gamma}{2\Gamma}$
  - Time-dependent WS $D^0 \to K^+\pi^-$ rate $\Rightarrow$ $y' = y\cos\delta_{K\pi} - x\sin\delta_{K\pi} = (0.72 \pm 0.24)\%$ (LHCb 2012)
  - $\delta_{K\pi}$: QC measurements from Charm factory
- γ/ϕ_3 measurements from $B \to D^0 K$
  - b→u : γ/ϕ_3 = argV^*_{ub}
  - most sensitive method to constrain γ/ϕ_3 at present
  - GLW method (Gronau & London, PLB253, 483 (1991); Gronau & Wyler, PLB265, 172 (1991))
  - ADS method (Atwood, Dunetz & Soni, PRL78, 3257 (1997); PRD63, 036005 (2001))
  - GGSZ (Dalitz) method (Giri, Grossman, Soffer & Zupan, PRD68, 054018 (2003))
- **GLW and ADS methods in $B \to D^0 K$**
  - D^0 to doubly Cabibbo suppressed decays $K^+\pi^-$, $K^+\pi^-\pi^0$
  - Decay rates:

$$\Gamma\left(B^\pm \to (f)_D K^\pm\right) \propto r_B^2 + r_D^2 + 2 r_B r_D \cos\left(\delta_B + \delta_D \pm \phi_3\right)$$

  - r_D, δ_D : QC measurements from Charm factory
  - (r_B, δ_B, ϕ_3) 3 unknowns, 4 measurements □