Charmed hadron decays at BESIII and future STCF

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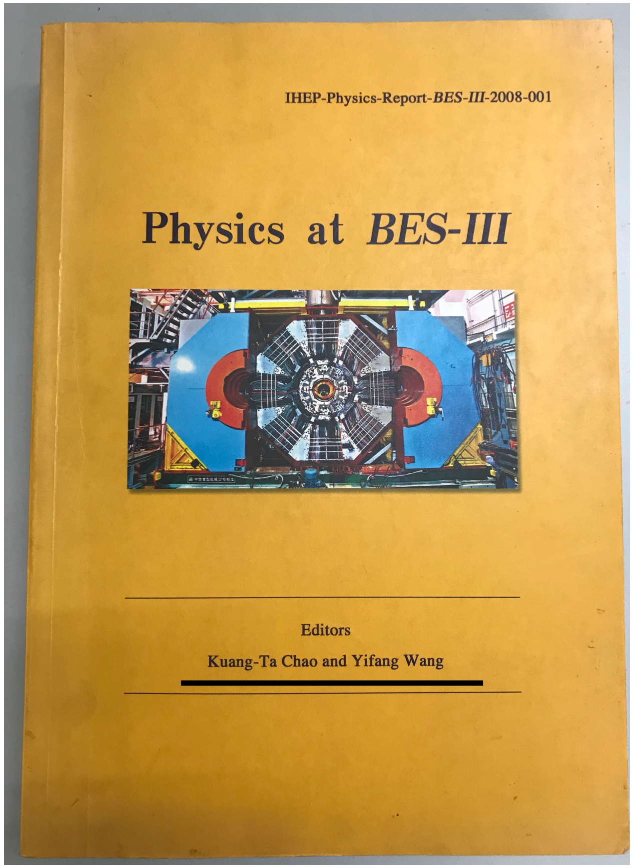
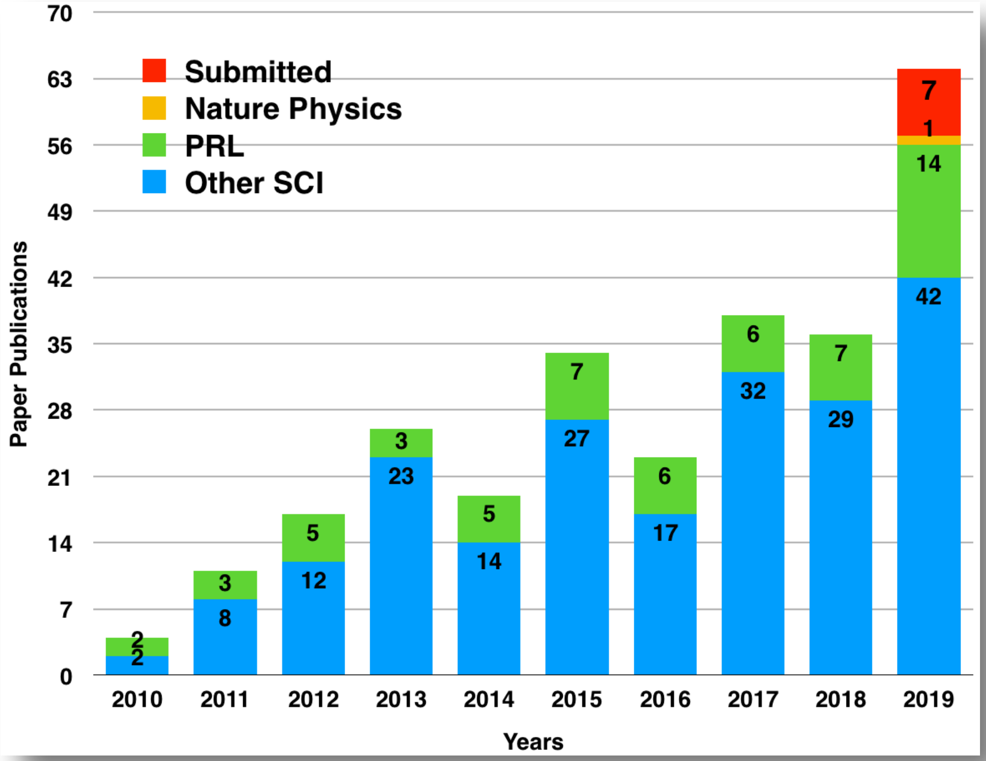
(On behalf of the BESIII collaboration)

赵老师与北京谱仪III实验



今年是北京谱仪实验的30周年

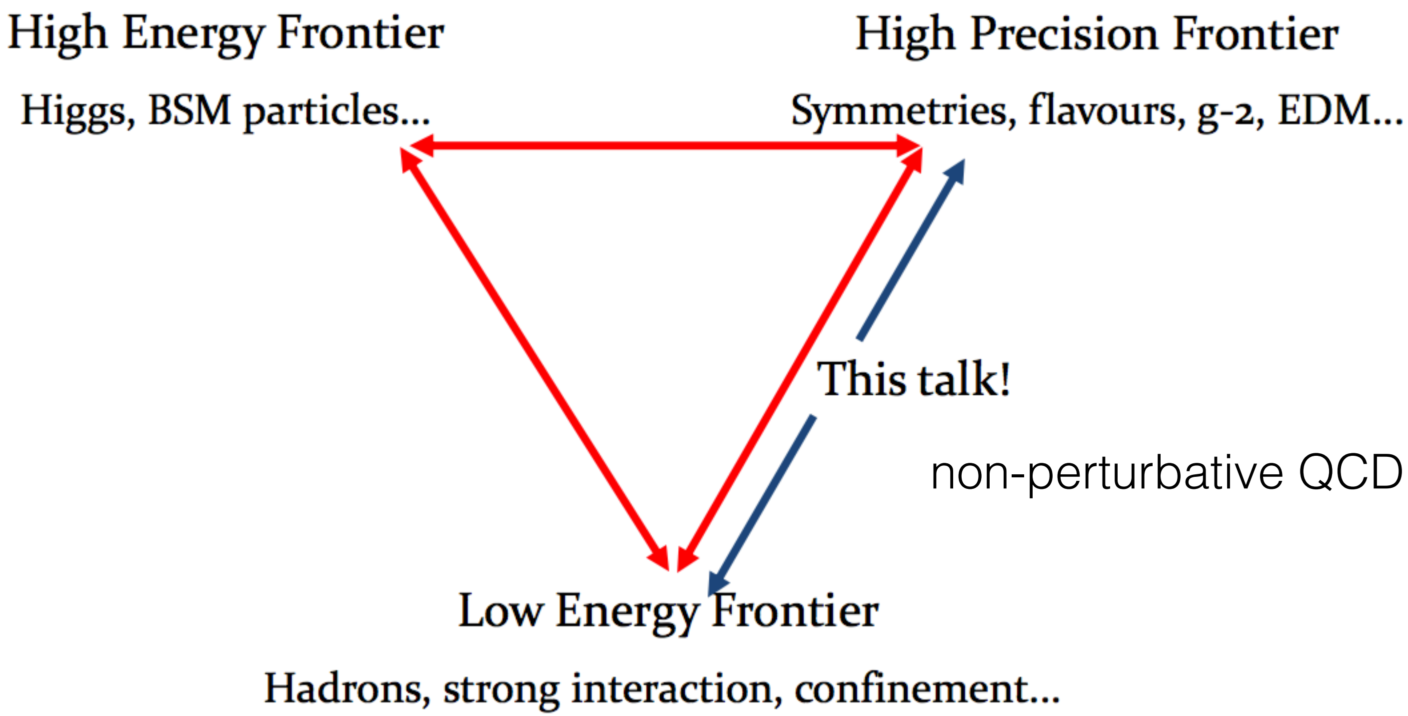


BESIII实验丰硕成果，为赵老师八十华诞祝寿！
祝赵老师身体健康、学术上耕耘不辍

Outline

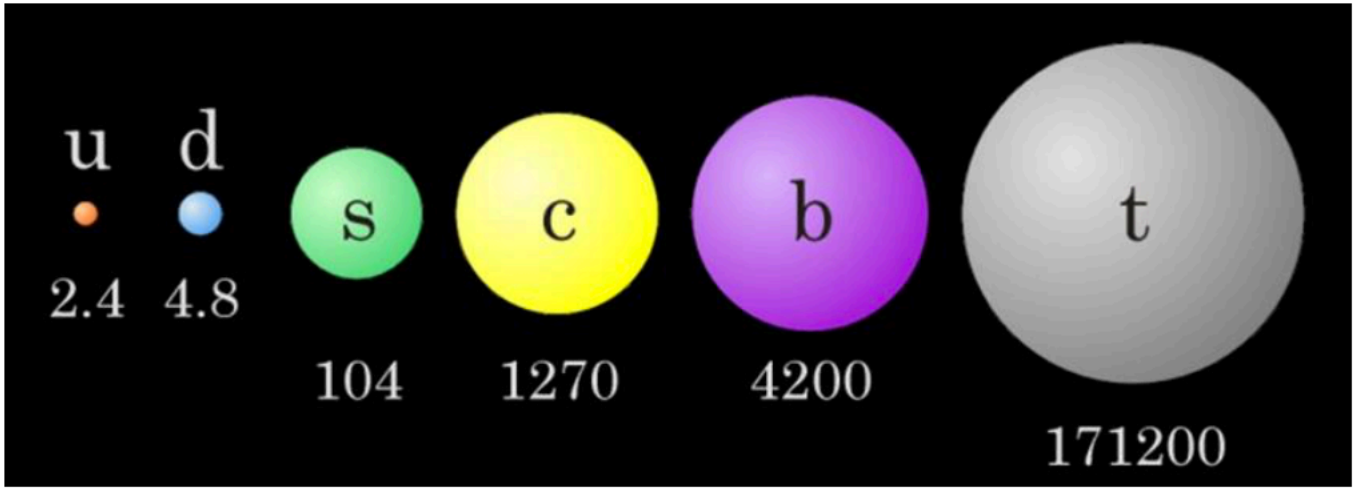
- Introduction
- BEPCII/BESIII
- Charmed hadron decays at BESIII
- Future prospects at STCF
- Summary and Outlook

Frontiers of the Standard Model

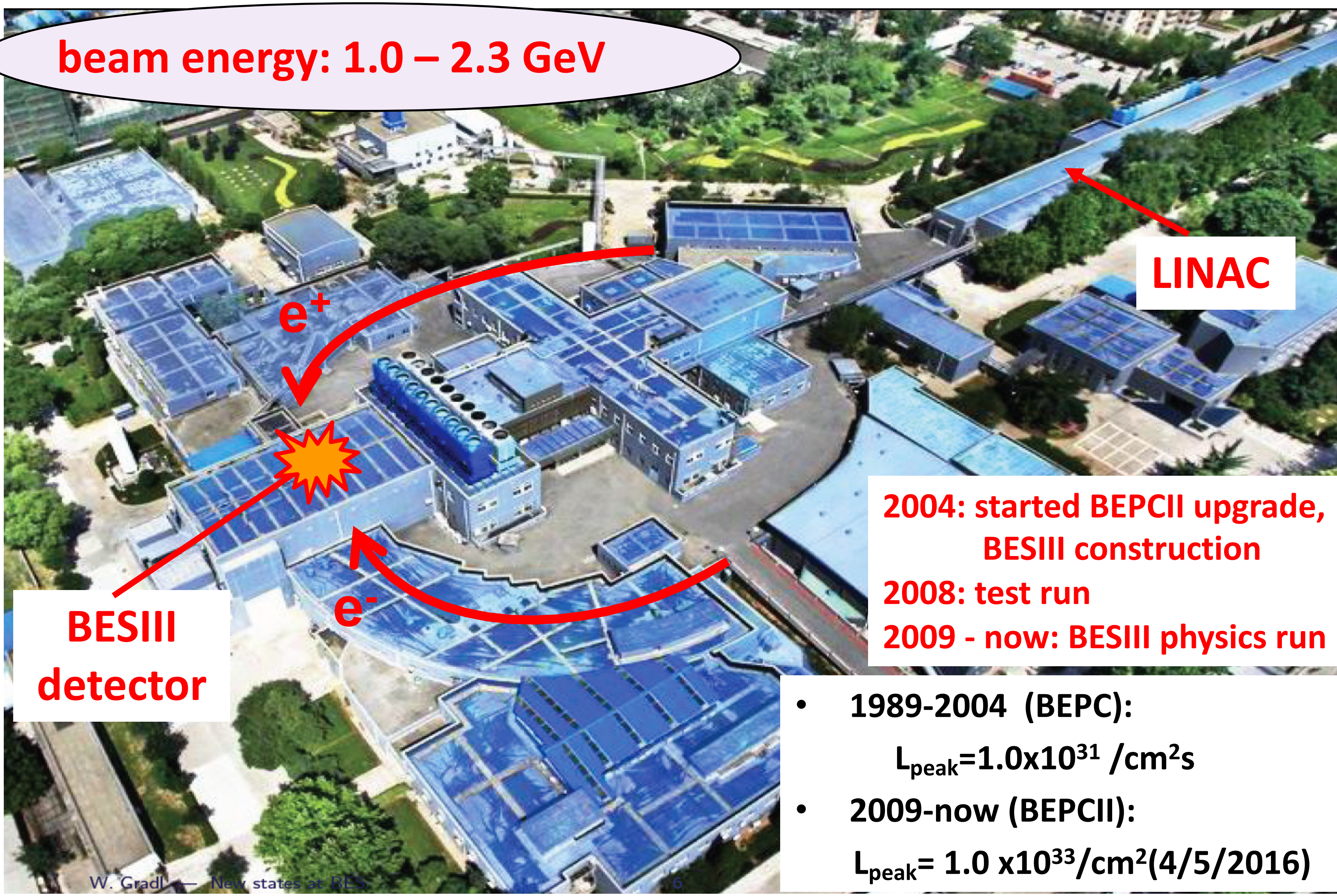


Charmed hadron
– key to the strong interaction

- Systems with strangeness
  - Scale: $m_s \approx 100$ MeV ~ $\Lambda_{QCD} \approx 200$ MeV: Relevant degrees of freedom?
  - **Probes QCD in the confinement domain.**
- Systems with charm
  - Scale: $m_c \approx 1300$ MeV: Quarks and gluons more relevant.
  - **Probes QCD just below pQCD.**



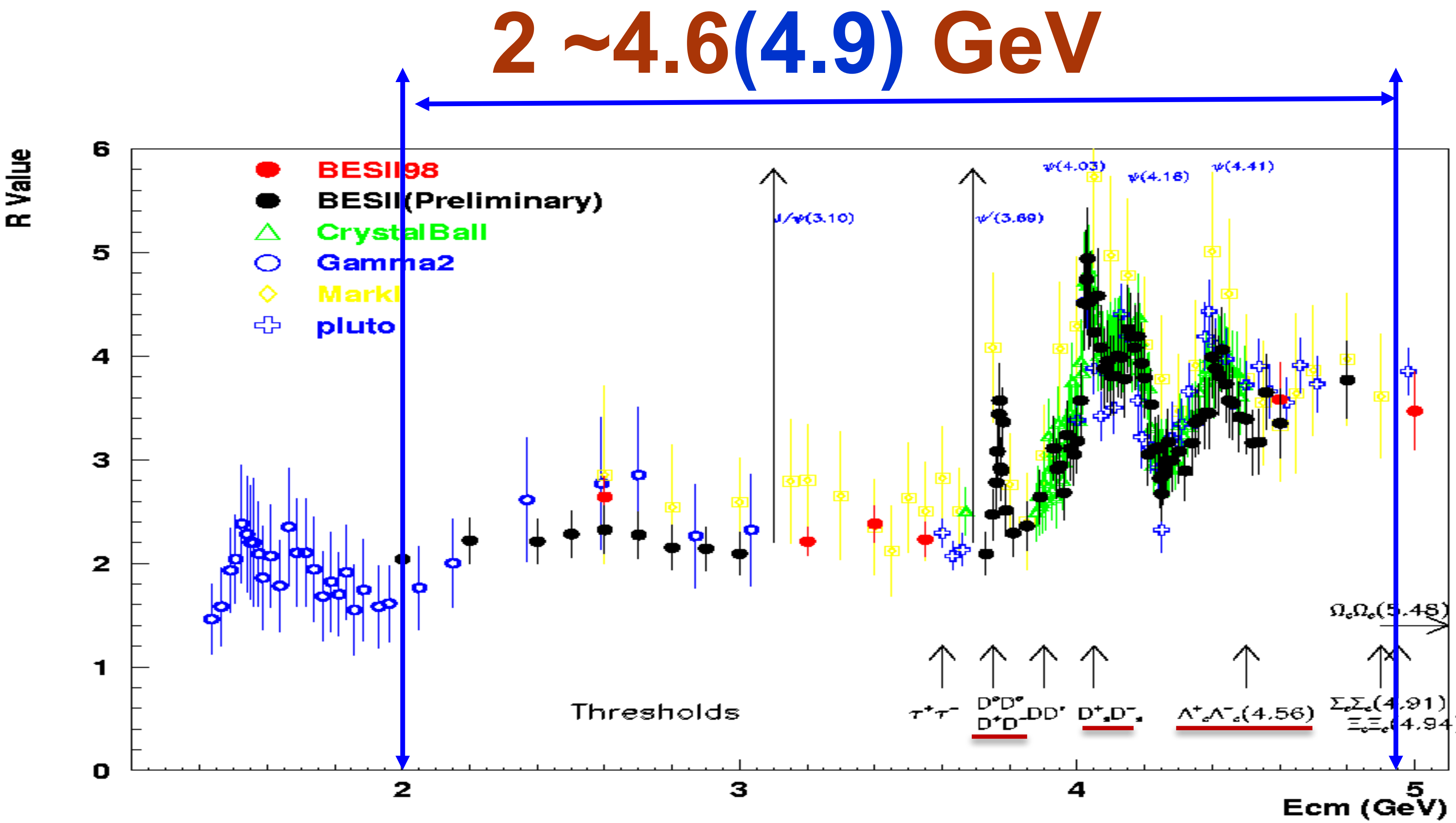
Beijing Electron Positron Collider (BEPC)



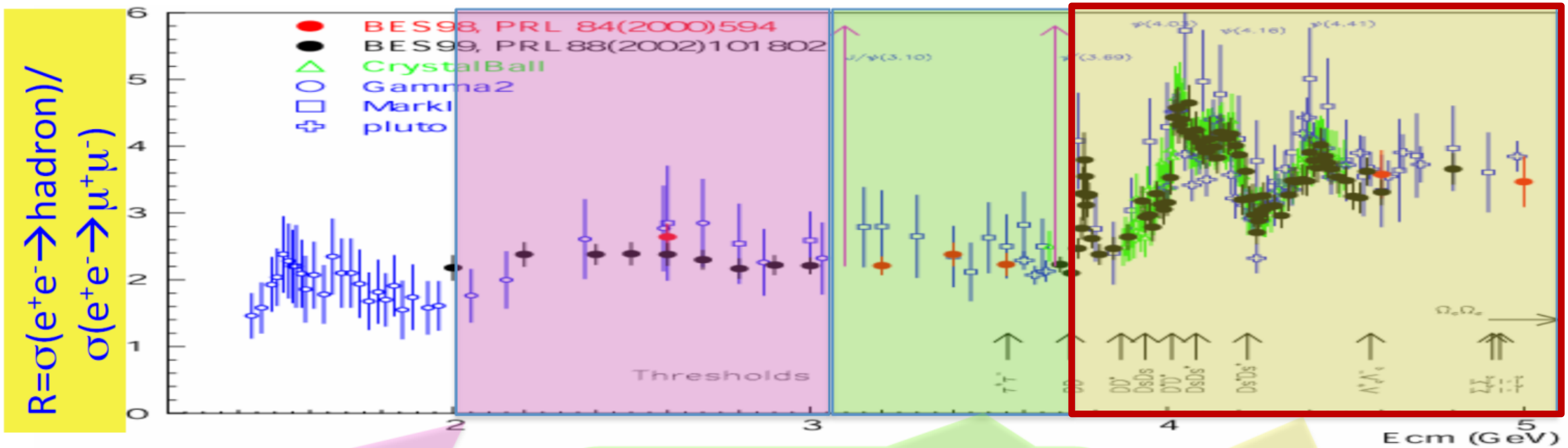
2004: started BEPCII upgrade, BESIII construction
2008: test run
2009 - now: BESIII physics run

- 1989-2004 (BEPC):
  L_{peak}=1.0x10^{31} /cm^{2}s
- 2009-now (BEPCII):
  L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)

Energies of the BEPCII Collider



Physics at tau-charm Energy Region



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

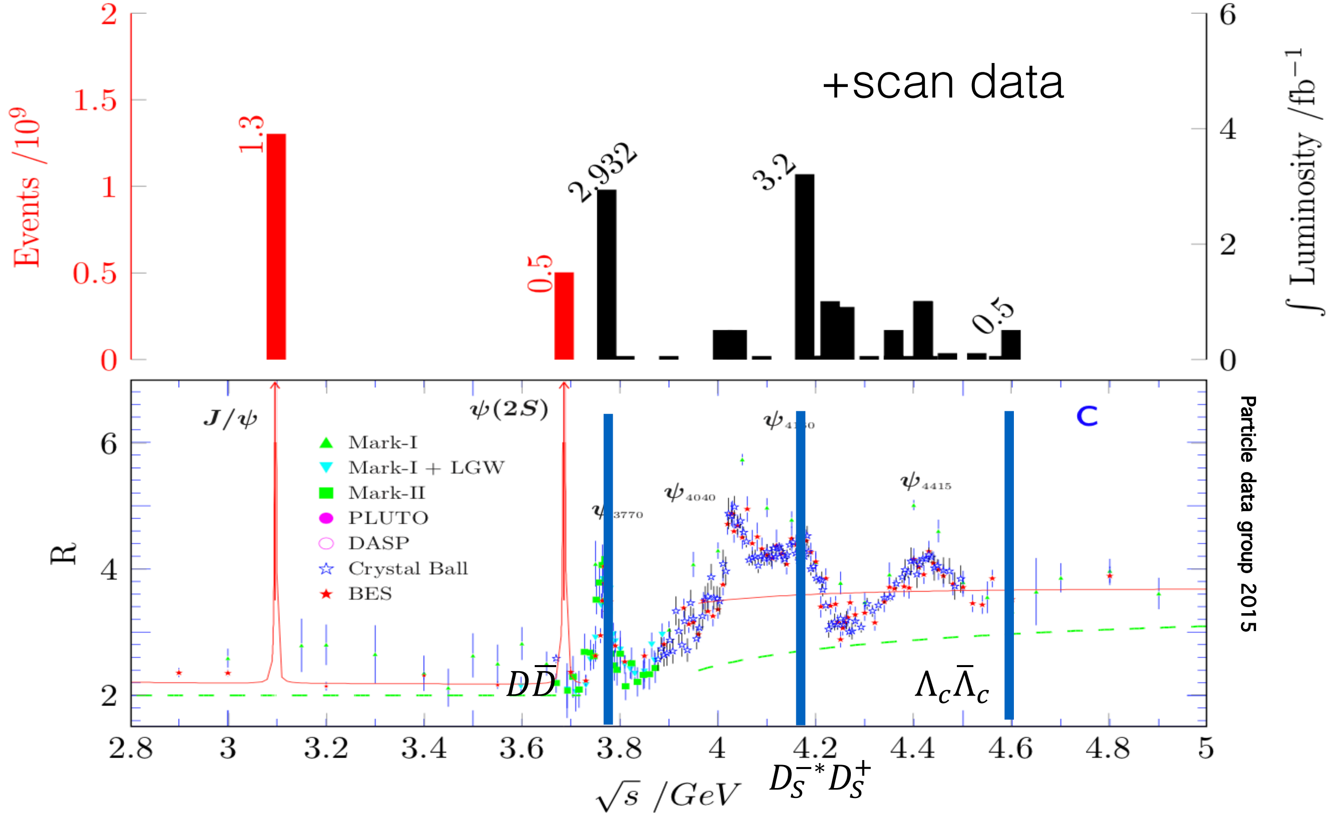
- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

- XYZ particles
- D mesons
- f_D and f_{Ds}
- D_0-D_0 mixing
- Charm baryons

Data for studying charmed hadron decays

$D_{(s)}$ & Λ_c decays:

- (semi-)leptonic decays
- hadronic decays



Precision measurement of CKM elements -- Test EW theory

CKM matrix elements are fundamental SM parameters that describe the mixing of quark fields due to weak interaction.

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CKM matrix

BESIII + B factories + LQCD

Three generations of quark?

Unitary matrix?

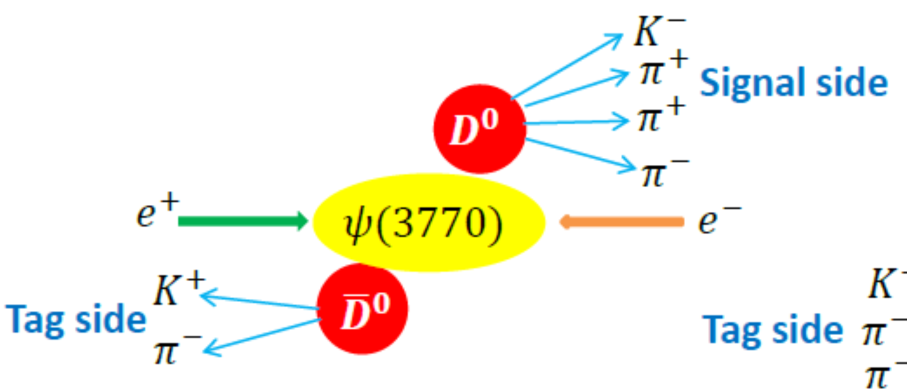
BESIII + B factories + LHCb + LQCD

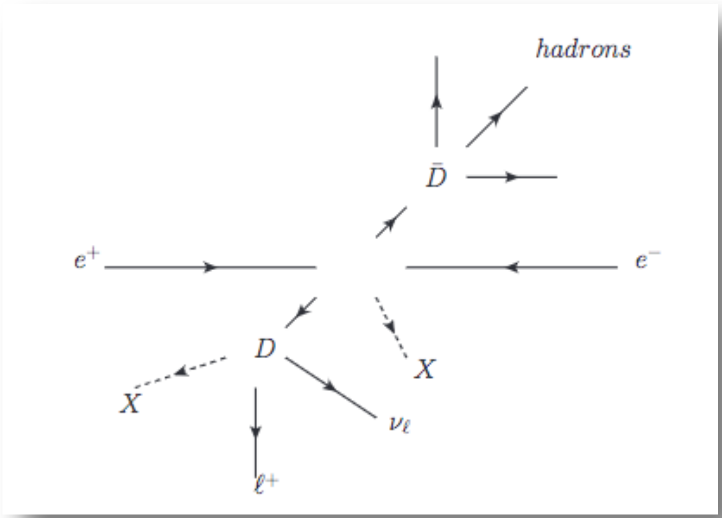
Expected precision < 2% at BESIII

- **Precision measurement of CKM matrix elements**
- **A precise test of SM model**
- **New physics beyond SM?**

Double Tag (DT) techniques

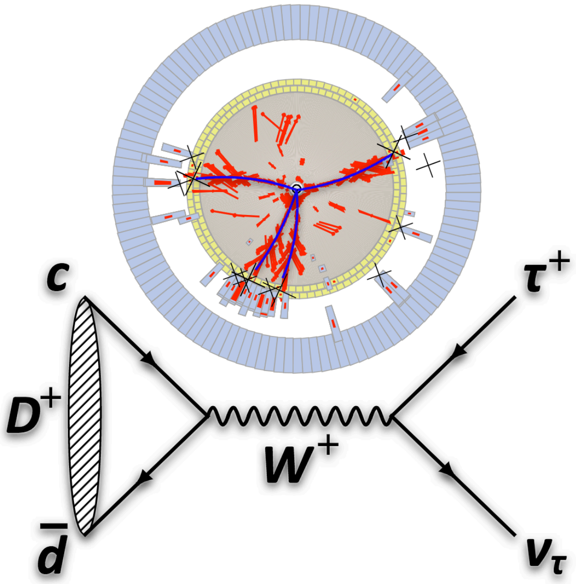
- 100% of beam energy converted to D pair (Clean environment, kinematic constrains ν Recon.)
- $D_{(S)}$ generated in pair $\Rightarrow$ absolute Branching fractions
- Fully reconstruct about 15% of $D_{(S)}$ decays





◆ **Double tag techniques: Hadronic tag on one side, on the other side for missing-mass studies (Double tag efficiency is high.)**

Charmed meson decays



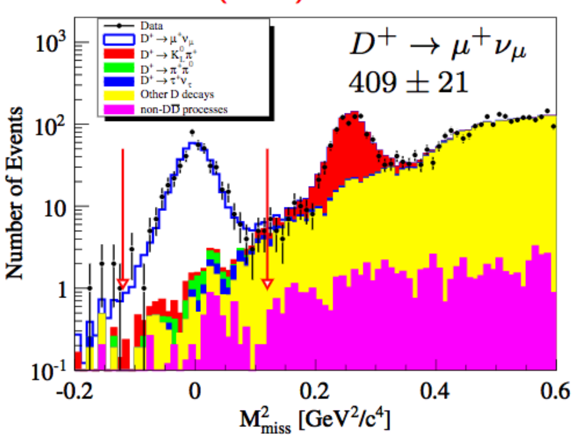
$D_{(S)}$ Leptonic decays

Purely Leptonic:

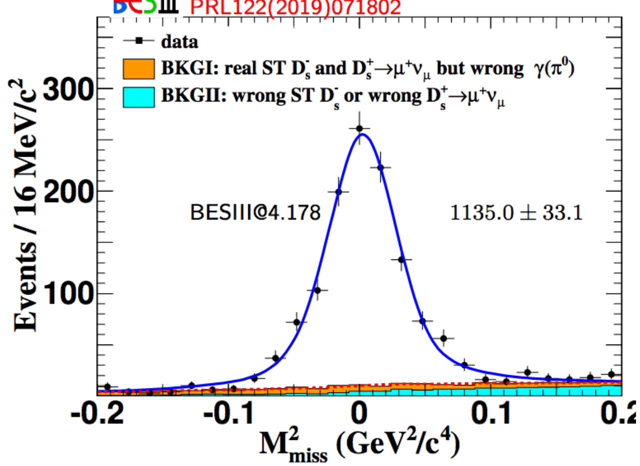
- Extract decay constant $f_{D(s)}$ incorporates the strong interaction effects (wave function at the origin)
- To validate Lattice QCD calculation of $f_{D(s)}$ and provide constrain of CKM-unitarity

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

BESIII PRD89(2014)051104

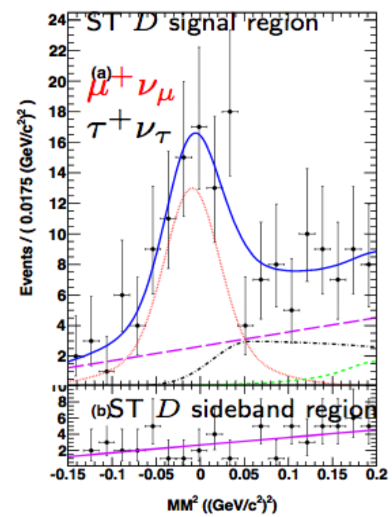


BESIII PRL122(2019)071802



BESIII PRD94(2016)072004

BESIII@4.009

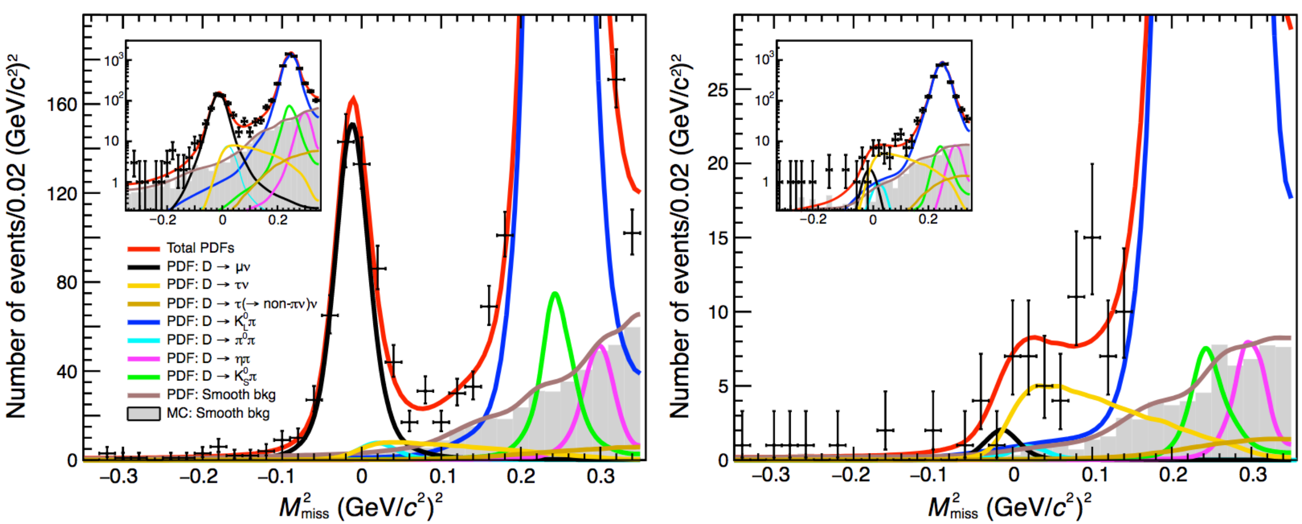


Will be updated using 4178 MeV data

Observation of $D^+ \to \tau^+\nu, \tau^+ \to \pi^+\bar{\nu}$

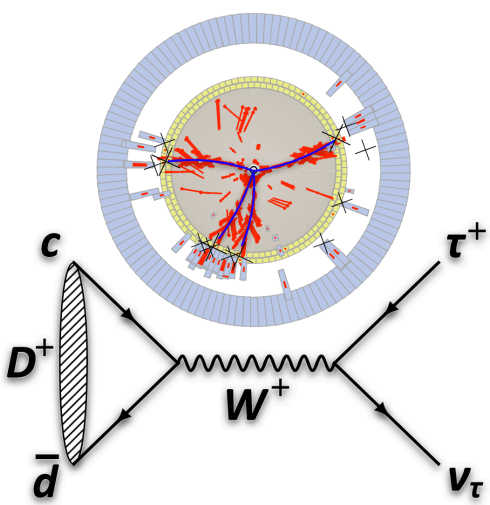
arXiv:1908.08877 [hep-ex]
accepted by PRL

μ-like tracks ($E_{\mathrm{EMC}} \leq 300$ MeV) | π-like tracks ($E_{\mathrm{EMC}} > 300$ MeV).



137±27 signals

5.1σ significance



$$\mathcal{B}(D^+ \to \tau^+\nu_\tau) = (1.20 \pm 0.24 \pm 0.12) \times 10^{-3}$$

$$R_{D^+} = \frac{\Gamma(D^+ \to \tau^+\nu_\tau)}{\Gamma(D^+ \to \mu^+\nu_\mu)} = 3.21 \pm 0.64 \pm 0.43$$

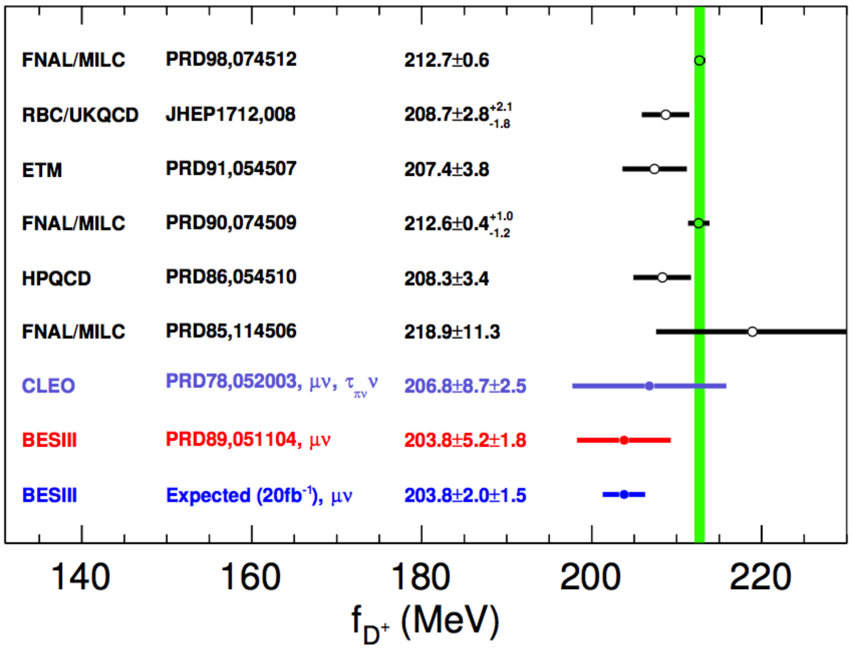
SM prediction 2.67 ± 0.01.

Decay constant $f_{D(s)}$

Inputs:

PDG2018 from CKM unitarity:

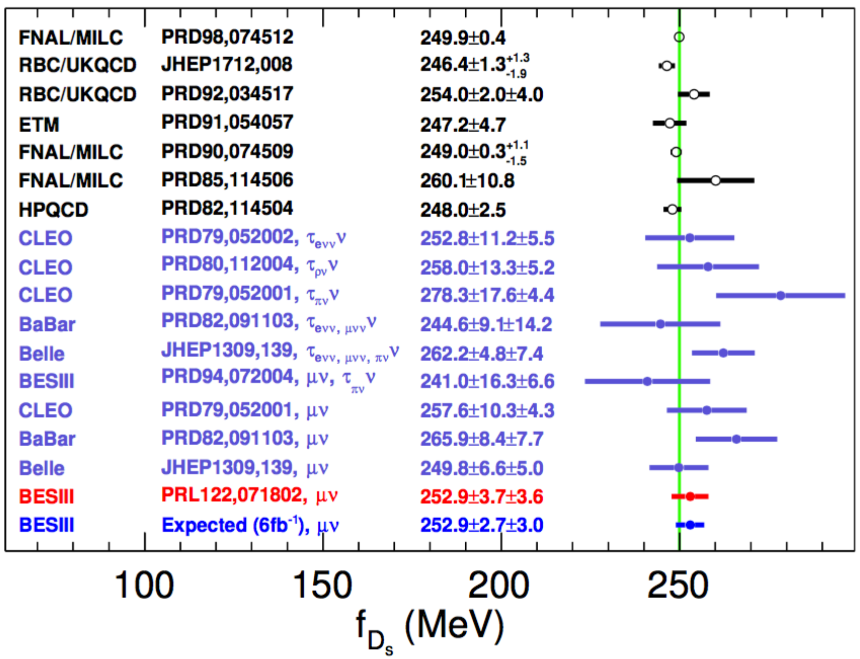
$|V_{cd}| = 0.22438 \pm 0.00044$



Inputs:

PDG2018 from CKM unitarity:

$|V_{cs}| = 0.97359^{+0.00010}_{-0.00011}$



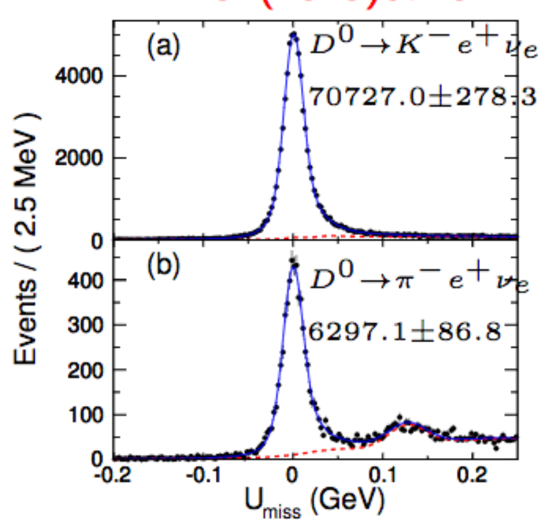
- Precisions of LQCD results are superior to experimental ones
- Hint of slight tension between exp. & LQCD results

$D_{(S)}$ Semi-Leptonic decays: *e*-mode

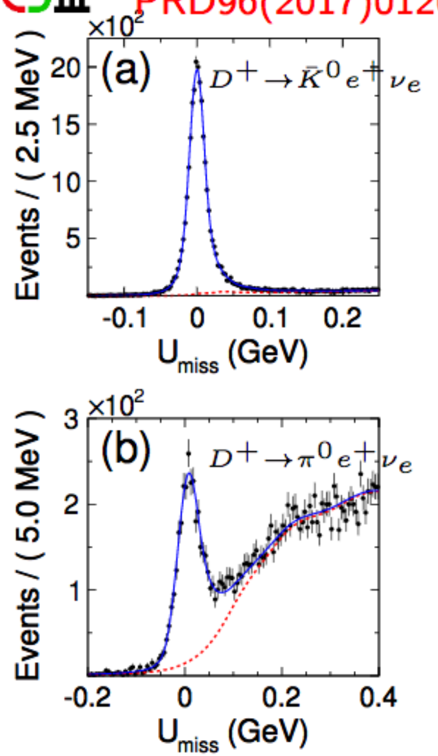
Semi-leptonic: form factor (FF)

- Measure $|V_{cx}|$ x FF
- Charm physics:
  - CKM-unitarity ⇒ $|V_{cx}|$, extract FF, test LQCD
  - Input LQCD FF to test CKM-unitarity

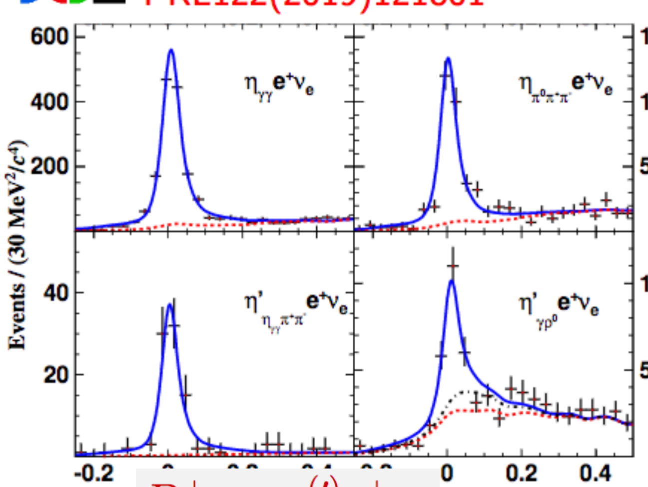
PRD92(2015)072012



PRD96(2017)012002



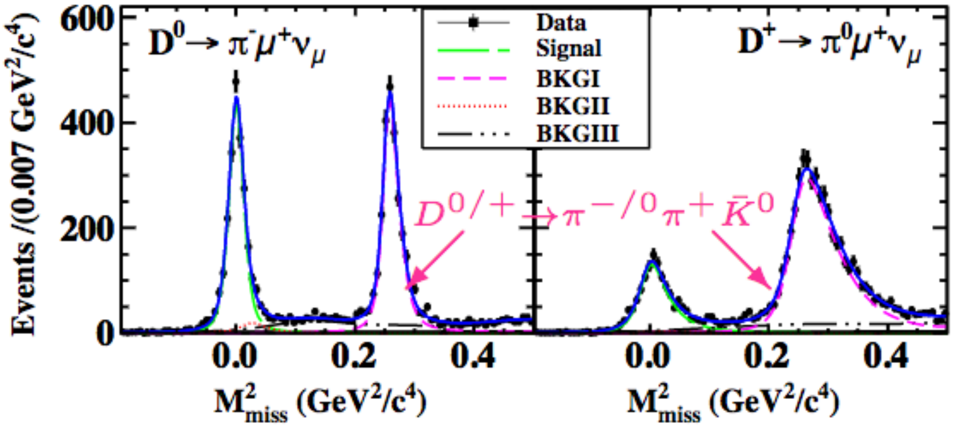
PRL122(2019)121801



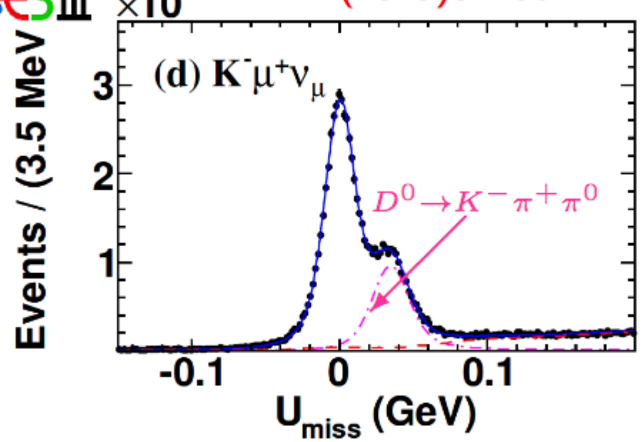
$D_s^+ \to \eta^{(\prime)} e^+ \nu_e$

$D_{(S)}$ Semi-Leptonic decays: μ-mode

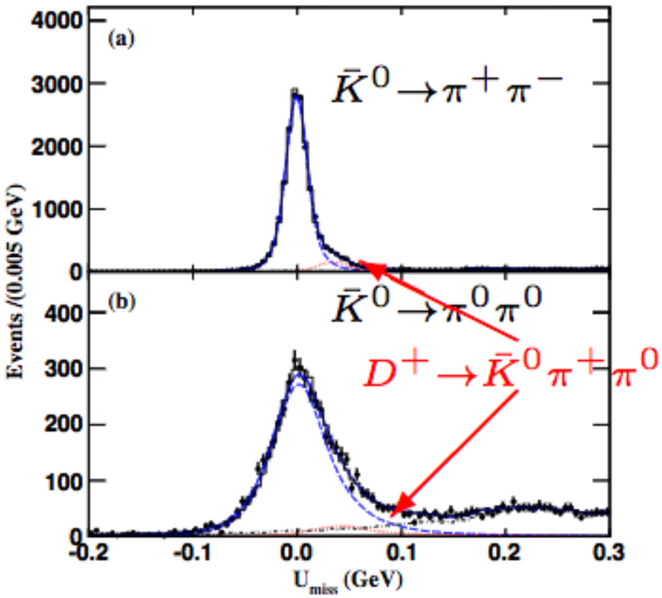
PRL121(2018)171803



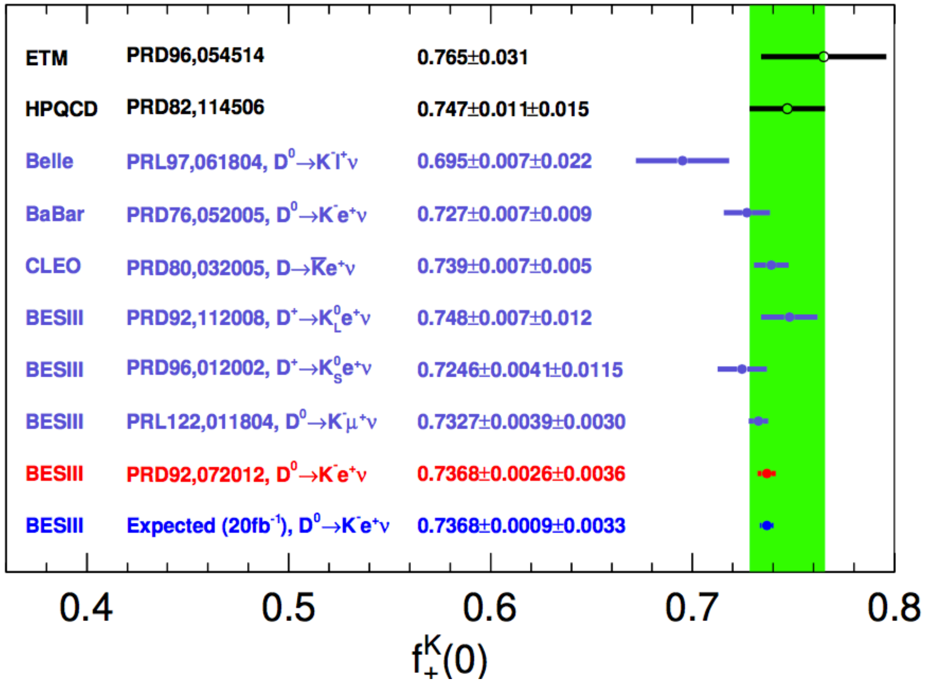
PRL122(2019)011804

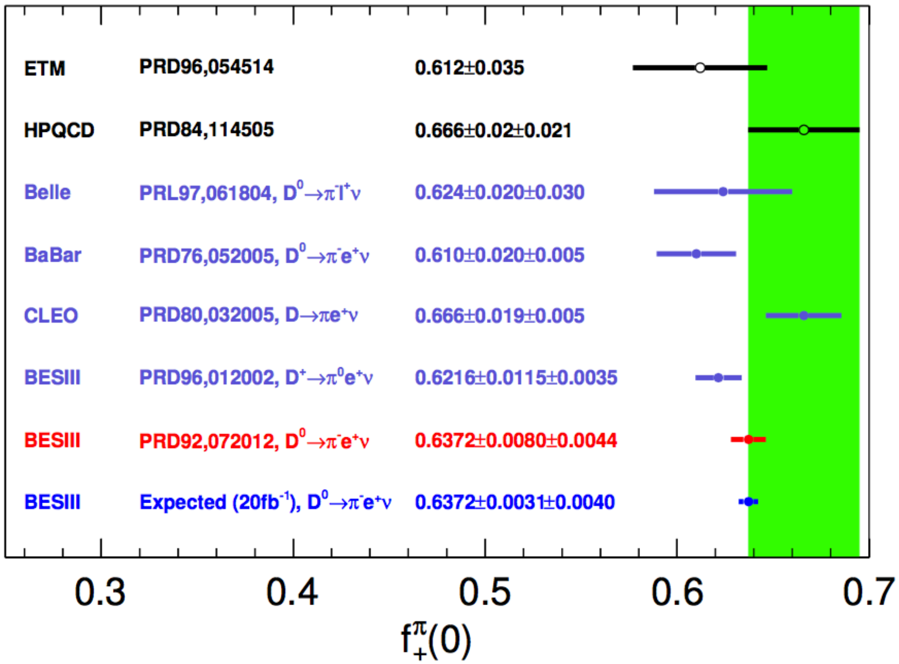


EPJC76(2016)369



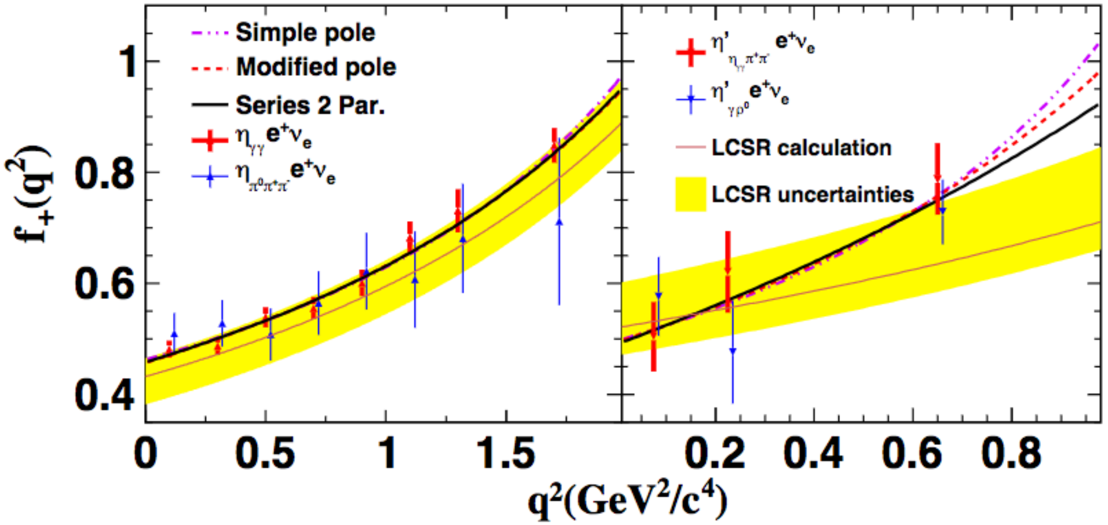
Form factors $f_+^{D\to h}$

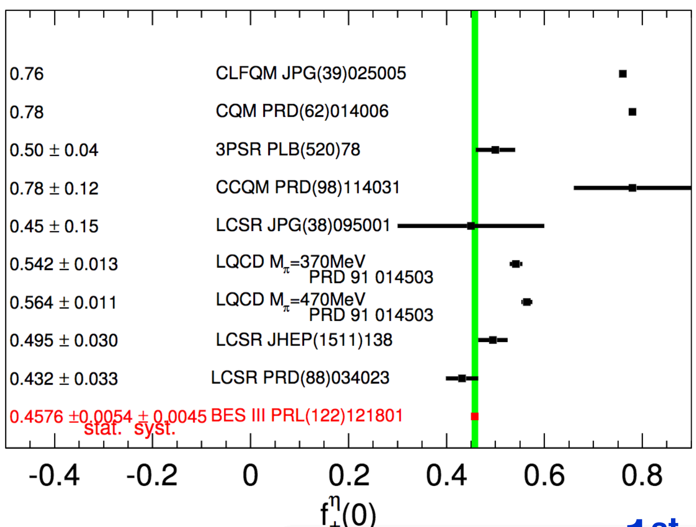


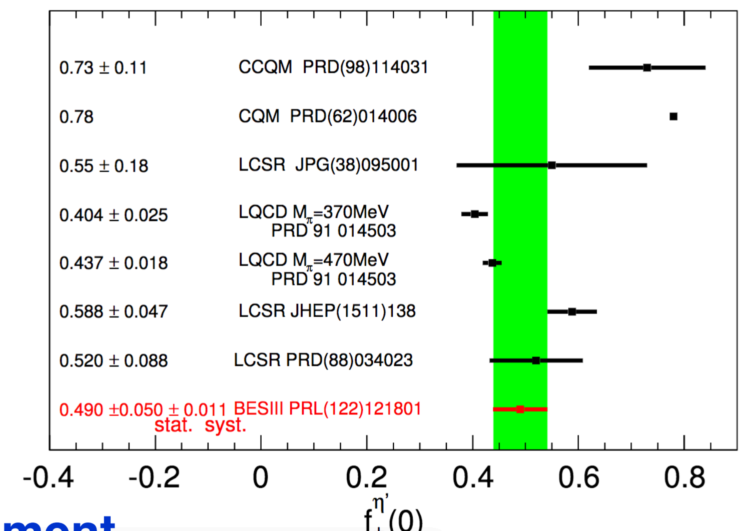


Precisions better than those of LQCD results

Form factors $f_+^{D_s\to\eta^{(\prime)}}$

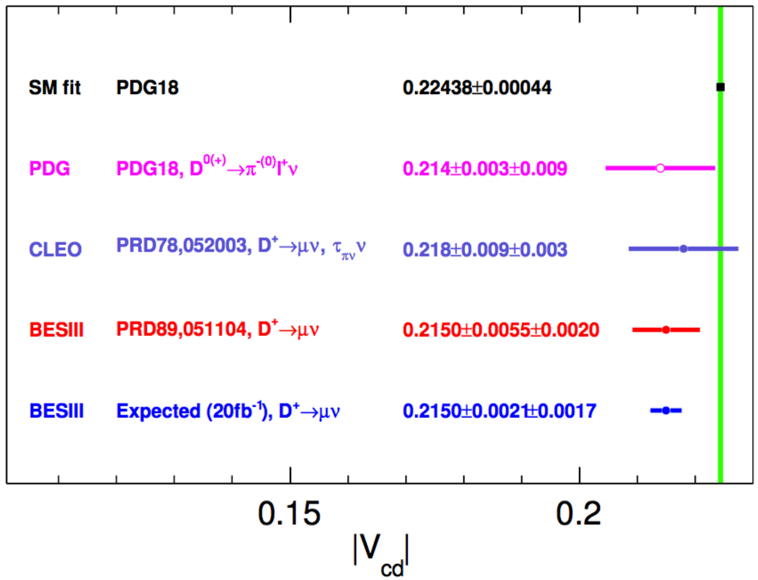




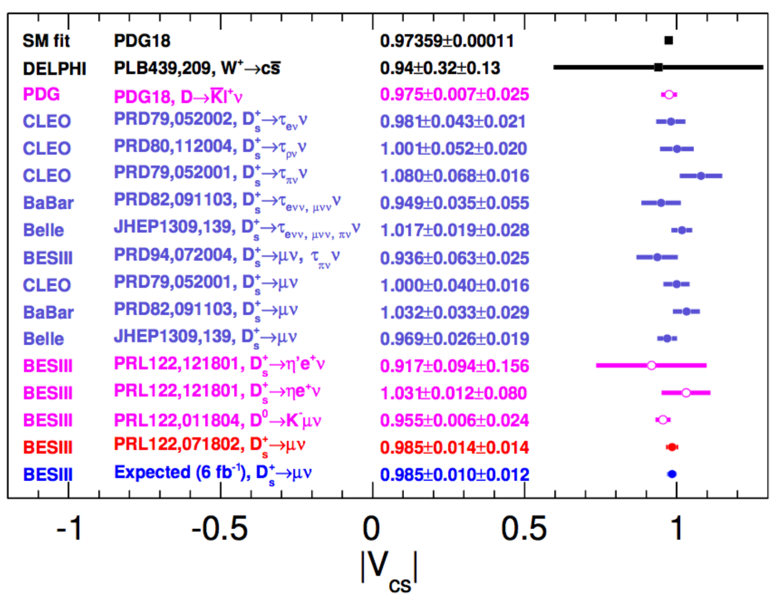


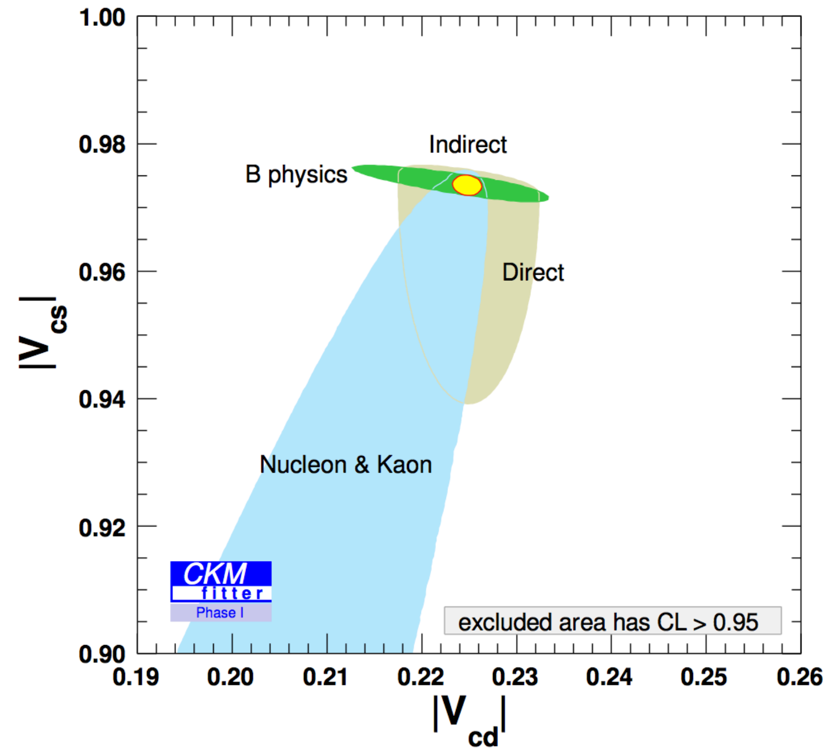
1st measurement

Vcs and Vcd



BESIII: best precision and systematic dominant





BESIII Tests of lepton flavor universality

$$R_{D^+_{(s)}} = \frac{\Gamma(D^+_{(s)} \to \tau^+\nu_\tau)}{\Gamma(D^+_{(s)} \to \mu^+\nu_\mu)} = \frac{m^2_{\tau^+}\left(1-\frac{m^2_{\tau^+}}{m^2_{D^+_{(s)}}}\right)^2}{m^2_{\mu^+}\left(1-\frac{m^2_{\mu^+}}{m^2_{D^+_{(s)}}}\right)^2}.$$

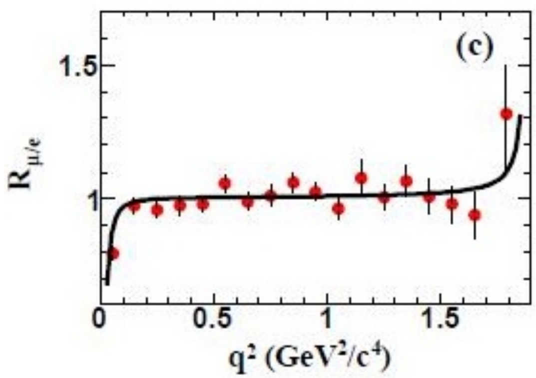
SM prediction: R_D =2.67±0.01

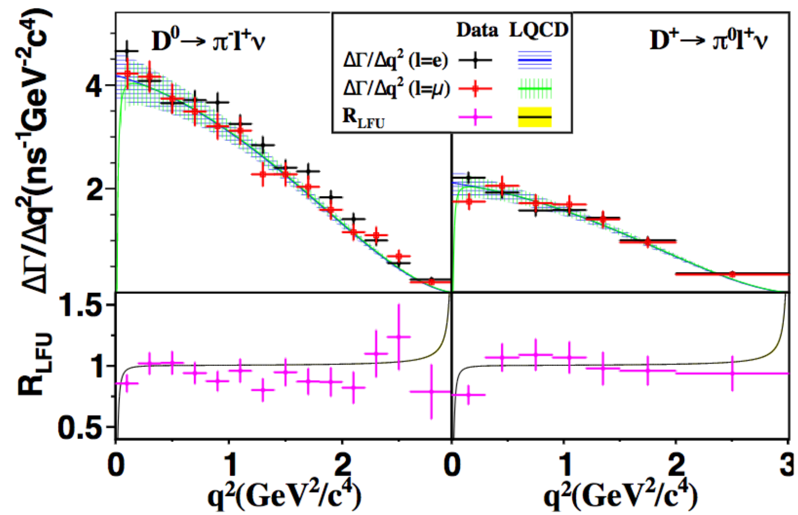
BESIII: R_D =3.21±0.64 ±0.43

1σ difference?

Semi-leptonic modes

$$R_{\mu/e} = \Gamma_{D^0\to K^-\mu^+\nu_\mu}/\Gamma_{D^0\to K^-e^+\nu_e}$$





2.93/fb@3773MeV;
3.19/fb @
4178MeV

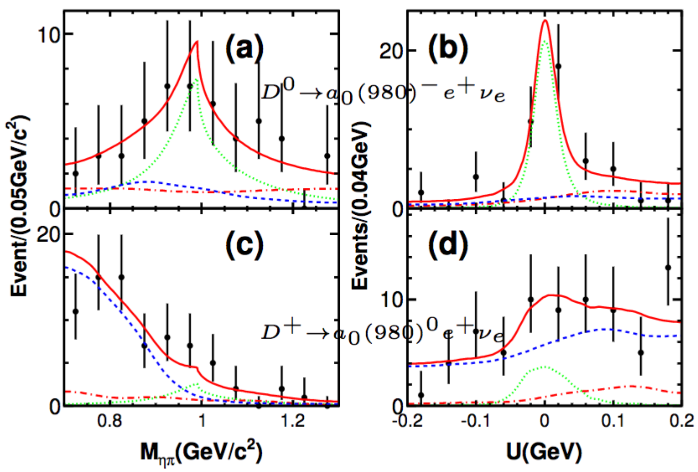
	$R(D_s^+)$	$R(D^+)$	$R(K^-)$	$R(\bar{K}^0)$	$R(\pi^-)$	$R(\pi^0)$
SM	9.74(1)	2.66(1)	0.975(1)	0.975(1)	0.985(2)	0.985(2)
BESIII	10.19(52)	3.21(64)	0.974(14)	1.013(29)	0.922(37)	0.964(45)

2σ difference?

Future 20/fb @3773MeV data will improve these test.

SL decays for spectroscopy study

$D \to a_0(980)e^+\nu_e$ PRL121(2018)081802



A model-independent way to study the nature of light scalar mesons proposed by PRD82(2016)034016

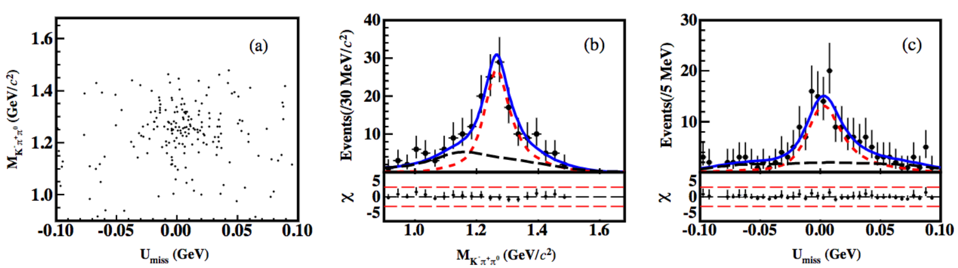
$$R = \frac{\mathcal{B}(D^+ \to f_0(980)e^+\nu_e) + \mathcal{B}(D^+ \to f_0(500)e^+\nu_e)}{\mathcal{B}(D^+ \to a_0(980)^0 e^+\nu_e)}$$

$R = 1.0 \pm 0.3$ for two-quark description;
$R = 3.0 \pm 0.9$ for tetraquark description.

We have $R > 2.7$ @90% C.L. at BESIII
Which favors the tetraquark description.

$D^+ \to \bar{K}_1(1270)^0 e^+\nu_e$

BESIII arXiv:1907.11370, accepted by PRL



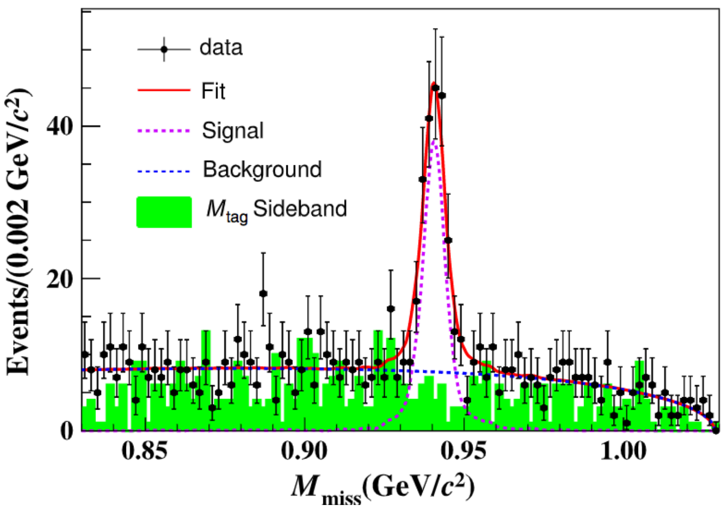
$$\mathcal{B}(D^+ \to \bar{K}_1(1270)^0 e^+\nu_e) = (2.30 \pm 0.26 \pm 0.18 \pm 0.25) \times 10^{-3}$$

Studies on $D_s^+ \to p\,\bar{n}$ and $\omega\pi^+$

3.19 fb^{-1} @E_{cm} = 4.178 GeV

- understanding the dynamical enhancement of W-annihilation
  - Short-distance vs Long-distance

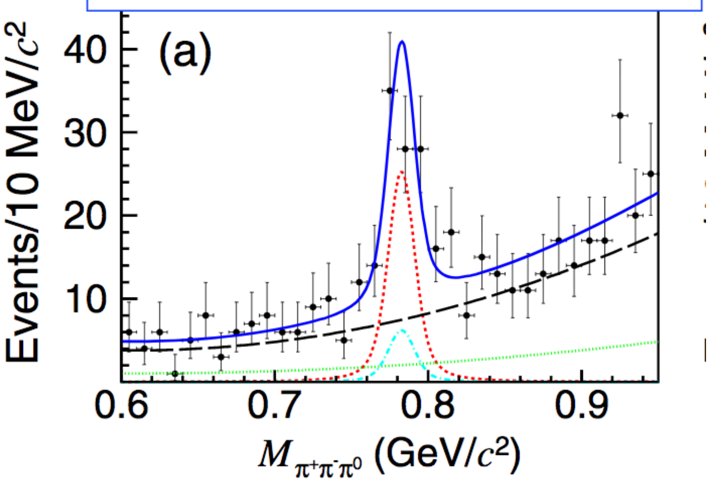
PRD99, 031101(R) (2019)



BF = (1.21±0.10±0.05)×10^{-3}

PRD 99, 091101 (R) (2019)

ωπ:65.0±11.6 evts (6.7σ)

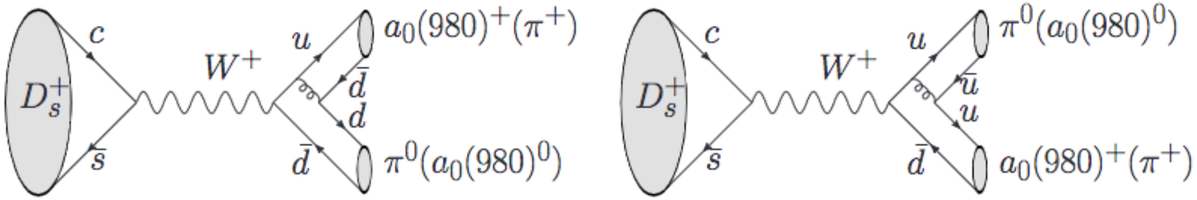


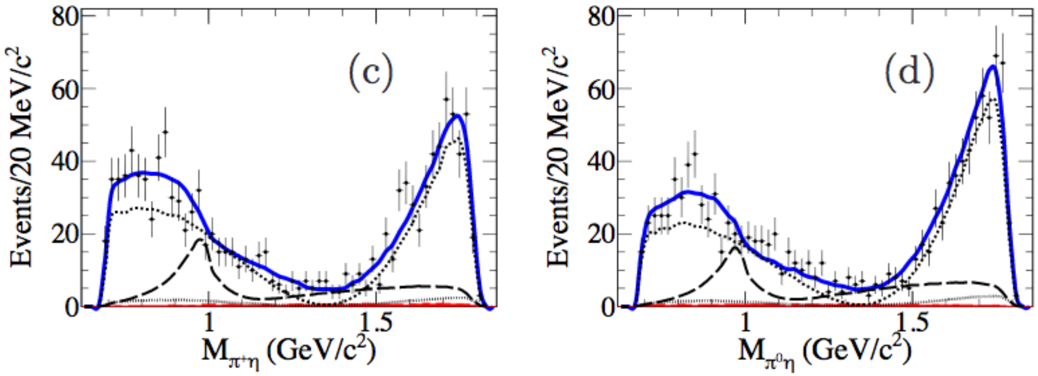
= (1.77±0.32±0.13)×10^{-3}

BF enhanced BR due to long-distance effect via hadronic loop

Dalitz analysis of $D_s^+ \to \pi^+\pi^0\eta$

PRL 123, 112001 (2019)





- First measurement (16.2σ stat. significance)!

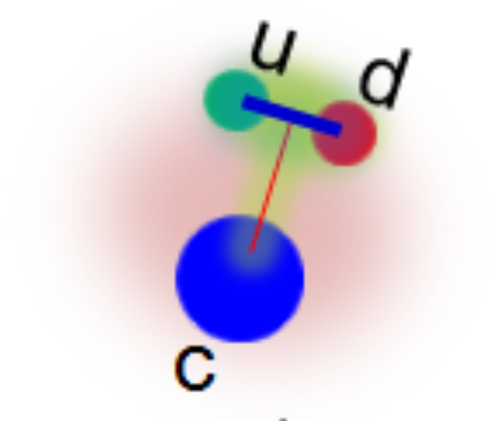
  BF($D_s^+ \to a_0(980)^{+(0)}\pi^{0(+)}$, $a_0(980)^{+(0)} \to \pi^{+(0)}\eta$) = (1.46±0.15±0.23)%

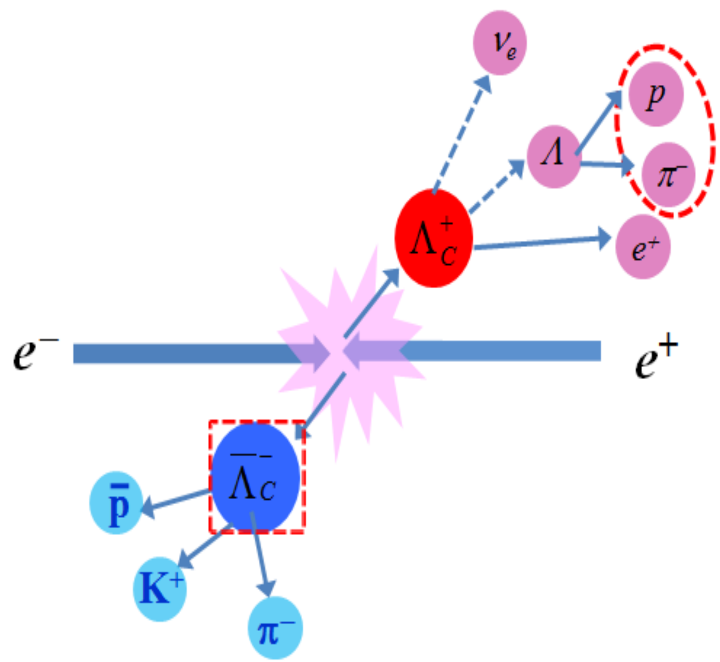
  Very large BF, compared to other W-annihilation decays (e.g., $D_s \to p\bar{n}/\omega\pi$ are all at 10^{-3} level).

One interpretation by Yu-Kuo Hsiao et al, arXiv:1909.07327

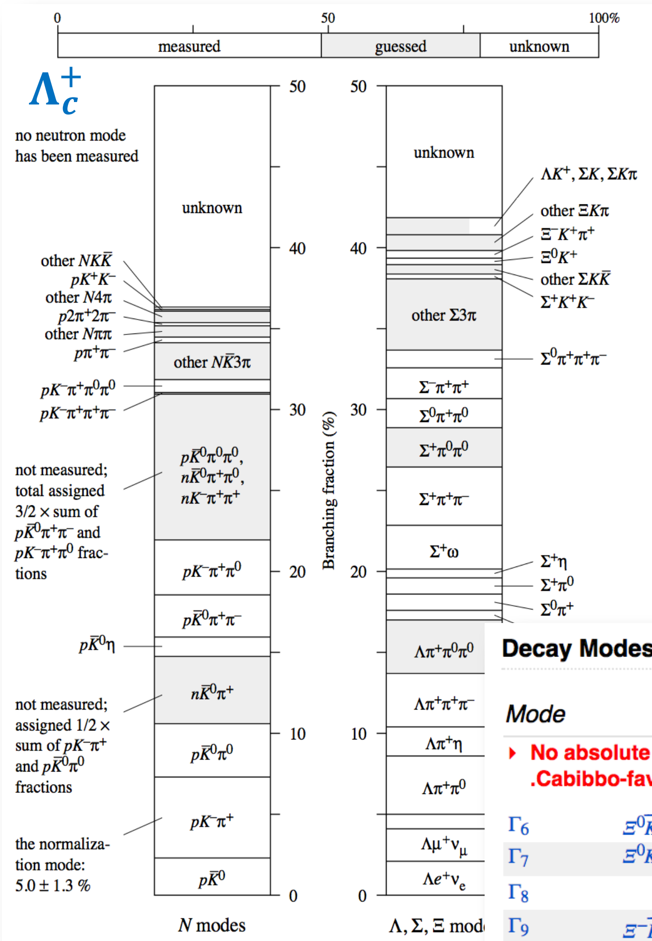
Evidence for $a_0(980)$ as tetraquark

The Λ_c^+ decays





BESIII 2015年之前的粲重子衰变信息



Ξ_c^+: relative to the decay of $\Xi^-2\pi^+$

	Mode	Fraction (Γ_i/Γ)
No absolute branching fractions have been measured.The following are branching to $\Xi^-\pi^+$ .Cabibbo-favored ($S=-2$) decays – relative to $\Xi^-\pi^+$		
Γ_1	$p2K_S^0$	0.087 ± 0.021
Γ_2	$\Lambda\bar{K}^0\pi^+$	
Γ_3	$\Sigma(1385)^+\bar{K}^0$	1.0 ± 0.5
Γ_4	$\Lambda K^-2\pi^+$	0.323 ± 0.033
Γ_5	$\Lambda\bar{K}^*(892)^0\pi^+$	< 0.16
Γ_6	$\Sigma(1385)^+K^-\pi^+$	< 0.23
Γ_7	$\Sigma^+K^-\pi^+$	0.94 ± 0.10
Γ_8	$\Sigma^+\bar{K}^*(892)^0$	0.81 ± 0.15
Γ_9	$\Sigma^0K^-2\pi^+$	0.27 ± 0.12
Γ_{10}	$\Xi^0\pi^+$	0.55 ± 0.16
Γ_{11}	$\Xi^-2\pi^+$	**DEFINEDAS1**
		< 0.10
		2.3 ± 0.7
		1.7 ± 0.5
		$2.3^{+0.7}_{-0.8}$
		0.07 ± 0.04
…ative to $\Xi^-\pi^+$		
		0.21 ± 0.04
		0.116 ± 0.030
		0.48 ± 0.20
		0.18 ± 0.09
		0.15 ± 0.06

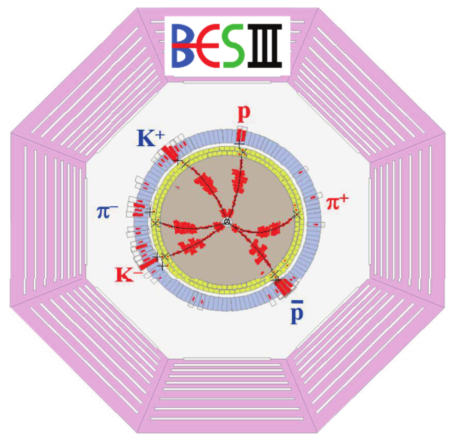
Decay Modes Ω_c^0

	Mode	Fraction (Γ_i/Γ)
No absolute branching fractions have been measured.The following are branching ra… .Cabibbo-favored ($S=-3$) decays – relative to $\Omega^-\pi^+$		
Γ_6	$\Xi^0\bar{K}^0$	1.64 ± 0.29
Γ_7	$\Xi^0K^-\pi^+$	1.20 ± 0.18
Γ_8	$\Xi^0\bar{K}^{*0}$, $\bar{K}^{*0} \to K^-\pi^+$	0.68 ± 0.16
Γ_9	$\Xi^-\bar{K}^0\pi^+$	2.12 ± 0.28
Γ_{10}	$\Xi^-K^-2\pi^+$	0.63 ± 0.09
Γ_{11}	$\Xi(1530)^0K^-\pi^+$, $\Xi^{*0} \to \Xi^-\pi^+$	0.21 ± 0.06
Γ_{12}	$\Xi^-\bar{K}^{*0}\pi^+$	0.34 ± 0.11
Γ_{13}	$\Sigma^+K^-K^-\pi^+$	< 0.32
Γ_{14}	$\Lambda\bar{K}^0\bar{K}^0$	1.72 ± 0.35

Λ_c threshold production at BESIII

In 2014, BESIII took data above Λ_c pair threshold and run machine at 4.6GeV with excellent performance.

Energy(GeV)	lum.(1/pb)
4.575	47.67
4.580	8.54
4.590	8.16
4.600	567.93



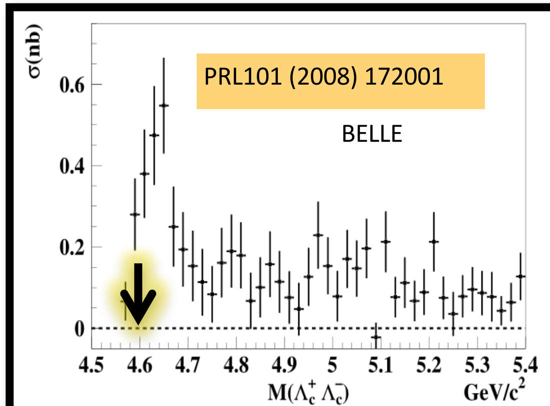


FIG. 4: The cross section for the exclusive process $e^+e^- \rightarrow \Lambda_c^+\Lambda_c^-$.

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

First time to systematically study charmed baryon at threshold!

Physics output on the Λ_c^+

- Published 17 papers (7 **PRLs**)
- … more will be coming

Hadronic decay

$\Lambda_c^+ \to pK^-\pi^+$ + 11 CF hadronic modes	PRL 116, 052001 (2016)
$\Lambda_c^+ \to pK^+K^-$, $p\pi^+\pi^-$	PRL 117, 232002 (2016)
$\Lambda_c^+ \to nK_S\pi^+$	PRL 118, 12001 (2017)
$\Lambda_c^+ \to p\eta$, $p\pi^0$	PRD 95, 111102(R) (2017)
$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$	PLB 772, 388 (2017)
$\Lambda_c^+ \to \Xi^{0(*)}K^+$	PLB783, 200 (2018)
$\Lambda_c^+ \to$ …	PRD99, 032010 (2019)
Λ_c^+ …	
Λ_c^+ …	

New gateway to charmed baryon for BESIII
One of the highlight BESIII results!

Semi-leptonic decay

$\Lambda_c^+ \to \Lambda e^+\nu_e$	PRL 115, 221805(2015)
$\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$	PLB 767, 42 (2017)

Inclusive decay

$\Lambda_c^+ \to \Lambda X$	PRL121, 062003 (2018)
$\Lambda_c^+ \to e^+X$	PRL 121 251801(2018)

Production

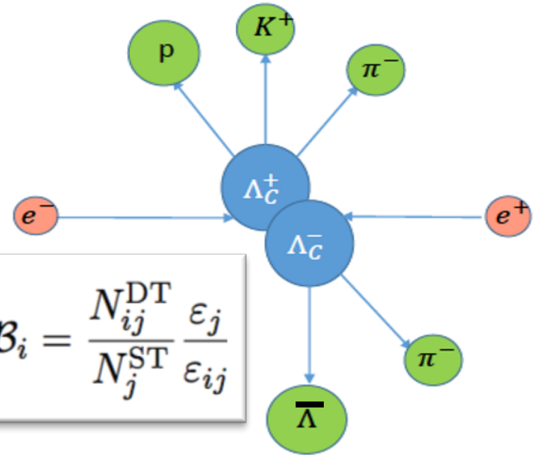
$\Lambda_c^+\bar{\Lambda}_c^-$ cross section	PRL 120,132001(2018)

Absolute BFs of Λ_c^+ hadronic decays

- Absolute BF of Λ_c^+ decays are still not well determined since its discovery 30 years ago. PDG2014: δB/B ~25%; BELLE2014: δB/B ~4.7%
- Tagging technique @BESIII will provide *the most simple and straightforward measurement*

567/pb @ 4.6 GeV

PRL 116, 052001 (2016)



$$\mathcal{B}_i = \frac{N_{ij}^{\mathrm{DT}}}{N_j^{\mathrm{ST}}} \frac{\varepsilon_j}{\varepsilon_{ij}}$$

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	

- The absolute BF can be obtained by the ratio of double tag yields to single tag yields.
- a global least square fit to 12 hadronic modes [Chin. Phys. C37(2013)106201]

✓ **First direct measurement on Λc BFs at threshold**

✓ **$B(pK^-\pi^+)$: BESIII precision comparable with Belle's**

✓ **Improved precisions of the other 11 modes significantly**

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

567/pb @ 4.6 GeV

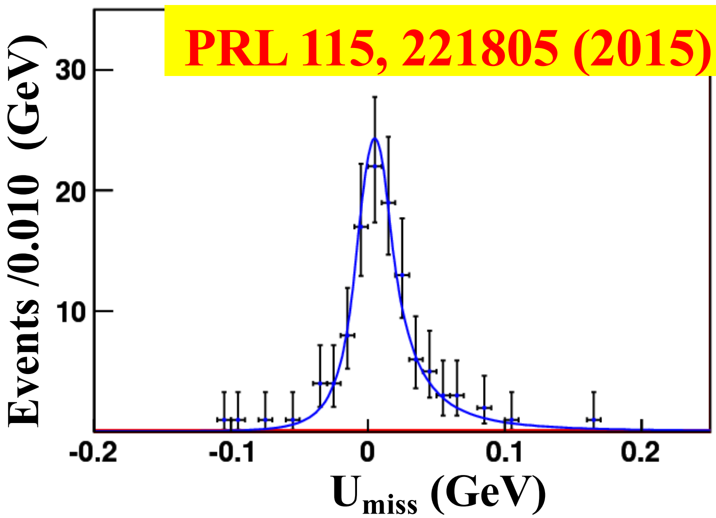
The tagging method and missing-mass technique at threshold.

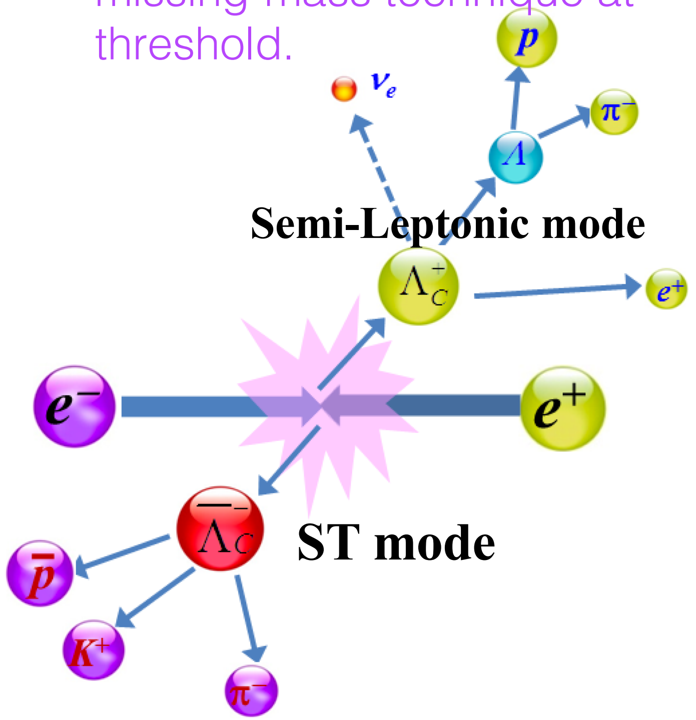
- $\Lambda_c^+ \to \Lambda e^+ \nu_e$ is a $c \to s l^+ \nu_l$ dominated process.
- Urgently needed for LQCD calculations.
- No direct absolute measurement for $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ available.

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

11 hadronic single tag modes are used

PRL 115, 221805 (2015)





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

- First absolute measurement of the semi-leptonic decay
- Statistics limited
- Best precision to date: twofold improvement
- We also measure the muonic mode [PLB 767, 42 (2017)]

The first Lattice calculation on Λ_c^+ SL decays

PRL 118, 082001 (2017) PHYSICAL REVIEW LETTERS week ending 24 FEBRUARY 2017

$\Lambda_c \to \Lambda l^+ \nu_l$ Form Factors and Decay Rates from Lattice QCD with Physical Quark Masses

Stefan Meinel
Department of Physics, University of Arizona, Tucson, Arizona 85721, USA and RIKEN BNL Research Center, Brookhaven National Laboratory, Upton, New York 11973, USA
(Received 1 December 2016; published 21 February 2017)

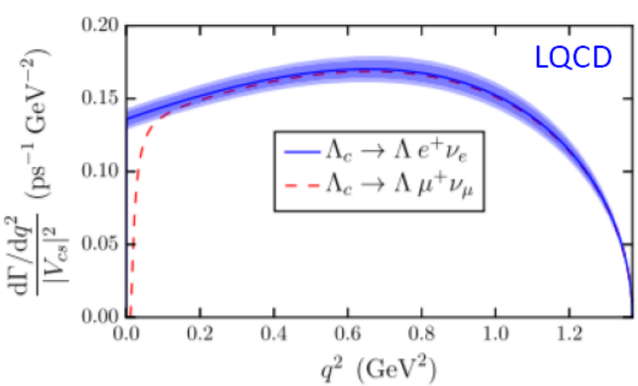
- Input the measured BFs from BESIII

Triggered by BESIII

$$\mathcal{B}(\Lambda_c \to \Lambda \ell^+ \nu_\ell) = \begin{cases} 0.0363(38)(20), & \ell = e, \\ 0.0349(46)(27), & \ell = \mu. \end{cases}$$

- The first LQCD calculations on BFs and form factors

$$\mathcal{B}(\Lambda_c \to \Lambda \ell^+ \nu_\ell) = \begin{cases} 0.0380(19)_{\rm LQCD}(11)_{\tau_{\Lambda_c}}, & \ell = e, \\ 0.0369(19)_{\rm LQCD}(11)_{\tau_{\Lambda_c}}, & \ell = \mu, \end{cases}$$



✓ The first determination of $|V_{cs}|$ based on BFs of $\Lambda_c^+ \to \Lambda l^+ \nu_l$ measured by BESIII

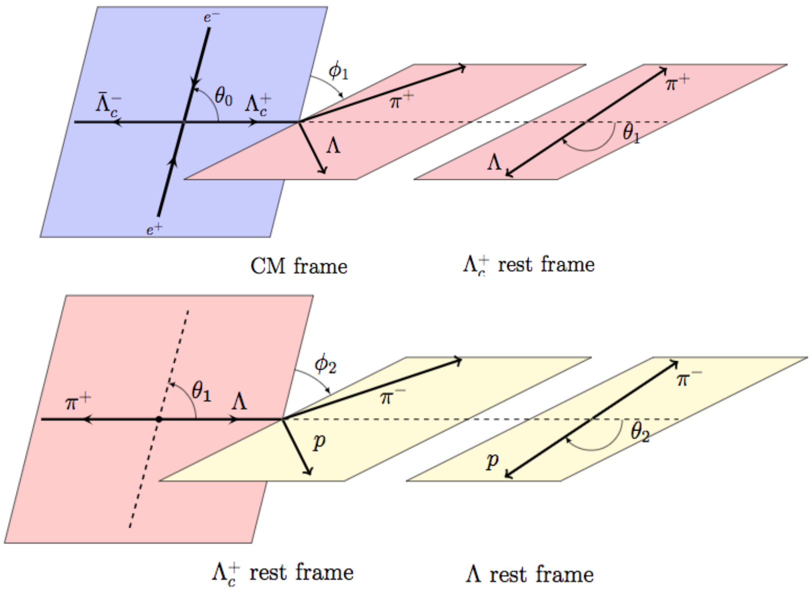
$$|V_{cs}| = \begin{cases} 0.951(24)_{\rm LQCD}(14)_{\tau_{\Lambda_c}}(56)_{\mathcal{B}}, & \ell = e, \\ 0.947(24)_{\rm LQCD}(14)_{\tau_{\Lambda_c}}(72)_{\mathcal{B}}, & \ell = \mu, \\ 0.949(24)_{\rm LQCD}(14)_{\tau_{\Lambda_c}}(49)_{\mathcal{B}}, & \ell = e, \mu, \end{cases}$$

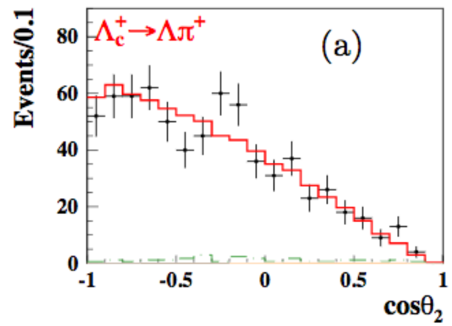
✓ More data on Λ_c^+ will be collected at BESIII

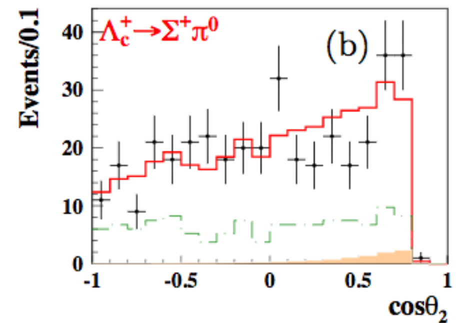
Λ_c decay asymmetries

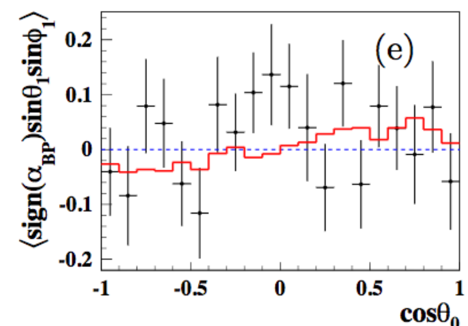
PRD100, 072004 (2019)

- 4(6)-fold angular analysis of the cascade decays of $\Lambda_c \to pK_s, \Lambda\pi^+, \Sigma^+\pi^0$ and $\Sigma^0\pi^+$ based on 567/pb data









$\Lambda_c^+ \to$		pK_S^0	$\Lambda\pi^+$	$\Sigma^+\pi^0$	$\Sigma^0\pi^+$
$\alpha_{BP}^{\Lambda_c^+}$	Predicted	−1.0 [16], 0.51 [11]	−0.70 [16], −0.67 [11]	0.71 [16], 0.92 [11]	0.70 [16], 0.92 [11]
		−0.49 [10], −0.90 [10]	−0.95 [10], −0.99 [10]	0.79 [10] −0.49 [10]	0.78 [10], −0.49 [10]
		−0.49 [17], −0.97 [18]	−0.96 [17], −0.95 [18]	0.83 [17], 0.43 [18]	0.83 [17], 0.43 [18]
		−0.66 [19], −0.90 [30]	−0.99 [19], −0.86 [30]	0.39 [19], −0.76 [30]	0.39 [19], −0.76 [30]
		−0.99 [20], −0.91 [31]	−0.99 [20], −0.94 [31]	−0.31 [20], −0.47 [31]	−0.31 [20], −0.47 [31]
	PDG [2]		-0.91 ± 0.15	-0.45 ± 0.32	
	This work	$0.18 \pm 0.43 \pm 0.14$	$-0.80 \pm 0.11 \pm 0.02$	$-0.57 \pm 0.10 \pm 0.07$	$-0.73 \pm 0.17 \pm 0.07$

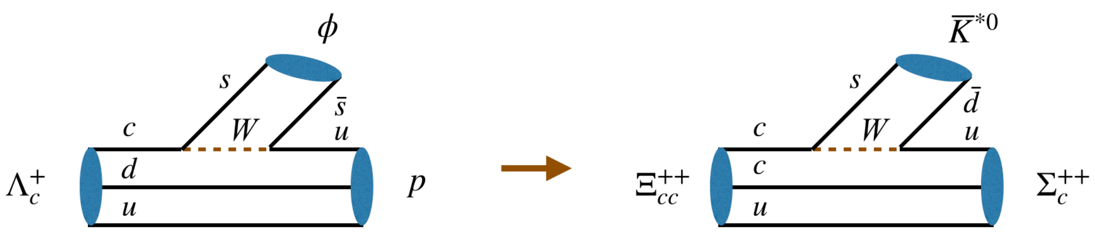
$\sin\Delta_0 = -0.28 \pm 0.13 \pm 0.03$

- Best precisions on the hadronic weak decay asymmetries
- The transverse polarization is firstly studied and found to be non-zero with 2.1σ

A theoretical Framework for Charmed Hadrons

from Fu-Sheng Yu

- Topological diagrams + Symmetries + Experimental inputs $\Rightarrow$ to understand the decaying dynamics, predicting double-charm baryon decays, CPV, etc. (predictive power)
  - Λ_c^+ branching fractions used for global analysis $\Rightarrow$ $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_c^+ \pi^+$ are large enough for observation.



$Br(\Lambda_c^+ \to p\phi)/|V_{us}|^2 = 2\ \%$ → $Br\left(\Xi_{cc}^{++} \to \Sigma_c^{++} \overline{K}^{*0}\right) = O(\%)$

[PRL 117, 232002 (2016)]

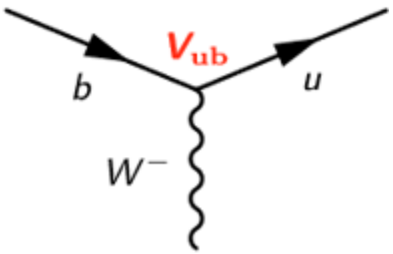
↓

$\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+ K^- \pi^+$

Large enough for observation

Λ_c^+ BFs from BESIII → Stronger predictive power

CKM matrix element V_{ub}



$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}, \quad \frac{\sigma(V_{CKM})}{V_{CKM}}^{\text{PDG 2014}} \sim \begin{pmatrix} 0.02\% & 0.3\% & 12\% \\ 4\% & 2\% & 2\% \\ 7\% & 7\% & 3\% \end{pmatrix}$$

$$\underbrace{\frac{\mathcal{B}(\Lambda_b \to p\mu^-\nu_\mu)}{\mathcal{B}(\Lambda_b \to \Lambda_c^+\mu^-\nu_\mu)}}_{\text{Measure this experimentally}} = \frac{|V_{ub}|^2}{|V_{cb}|^2} \times \underbrace{\frac{G(\Lambda_b \to p\mu^-\nu_\mu)}{G(\Lambda_b \to \Lambda_c^+\mu^-\nu_\mu)}}_{\text{Get this from theory}}$$

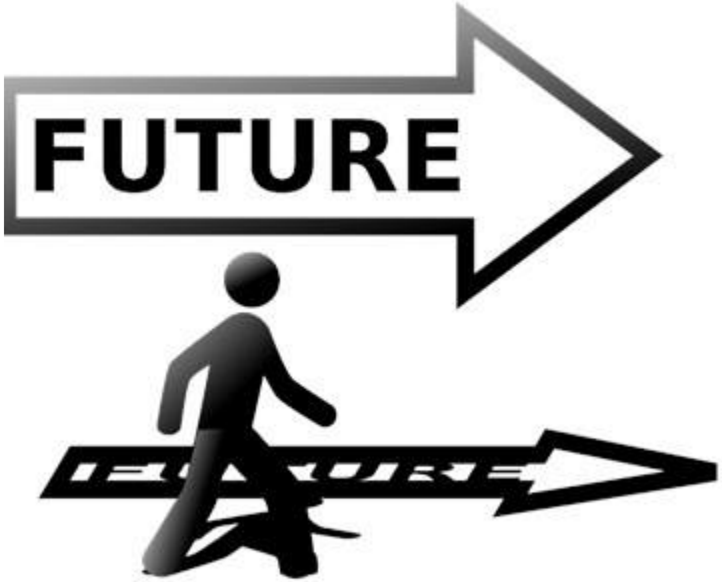
Nature Physics 11, 743 (2015)

Source	Relative uncertainty (%)
$\mathcal{B}(\Lambda_c^+ \to pK^+\pi^-)$	$^{+4.7}_{-5.2}$
Trigger	3.2
Tracking	3.0
Λ_c^+ selection efficiency	3.0
$\Lambda_b^0 \to N^*\mu^-\overline{\nu}_\mu$ shapes	2.3
Λ_b^0 lifetime	1.5
Isolation	1.4
Form factor	1.0
Λ_b^0 kinematics	0.5
q^2 migration	0.4
PID	0.2
Total	$^{+7.8}_{-8.2}$

- $B(pK^-\pi^+)$ quoted BELLE's result
- 10x Λ_c data → < 2%

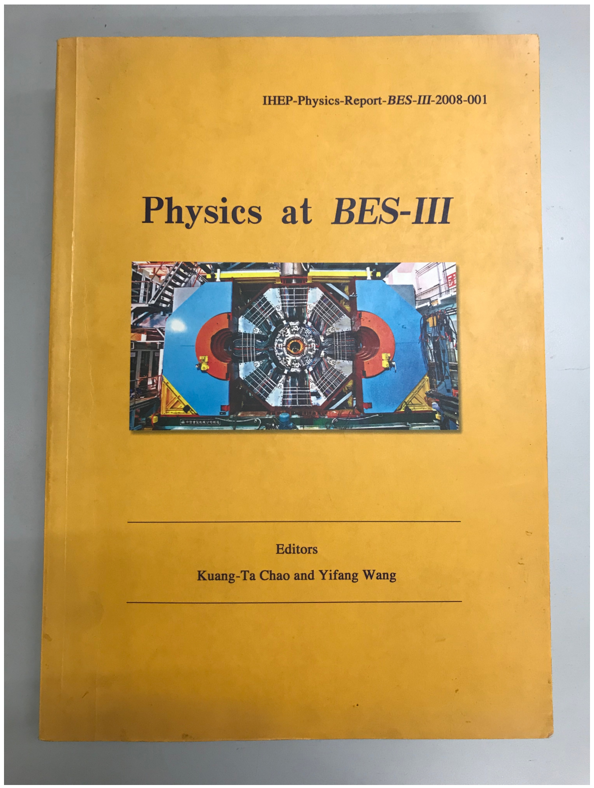
Yet unknowns

- Many of the following modes are not measured (~40%)
  - most of the semileptonic (SL) modes
  - the singly Cabibbo-Suppressed (CS) and doubly CS hadronic modes
  - the neutron- and K_L-involved channels
- Amplitude analysis of the three- and four-body decays
  - important to study the excited hyperons
  - to study the decay types of $B\left(\frac{1}{2}^{+}\right)V$ and $B(\frac{3}{2}^{+})P$
  - not much have been done yet

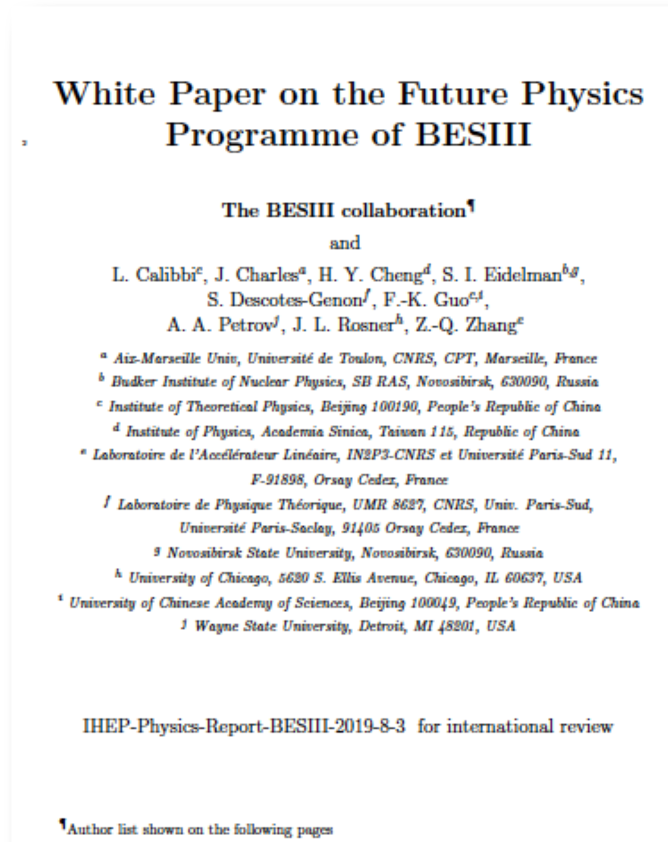

FUTURE

From BESIII physics (yellow) book to BESIII white paper

2008



2019



White Paper on the Future Physics Programme of BESIII

The BESIII collaboration[¶]

and

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IHEP-Physics-Report-BESIII-2019-8-3 for international review

[¶]Author list shown on the following pages

High precision charm physics at thresholds

Observables	Exp. measure	BESIII	Belle-II	LHCb
$B(D^+ \to l\nu)$	$f_D\|V_{cd}\|$	1.1%	1.4%	N/A
$B(D_S^+ \to l\nu)$	$f_{Ds}\|V_{cs}\|$	1.0%	1.0%	N/A
$\frac{B(D^+ \to l\nu)}{B(D_S^+ \to l\nu)}$	$\frac{f_D\|V_{cd}\|}{f_{Ds}\|V_{cs}\|}$	1.0%	1.4%	N/A
$d\Gamma(D \to \pi l\nu)/dq^2$	$f_{D\to\pi}(0)\|V_{cd}\|$	0.6%	1.0%	N/A
$d\Gamma(D \to K l\nu)/dq^2$	$f_{D\to K}(0)\|V_{cs}\|$	0.5%	0.9%	N/A
$d\Gamma(D_S \to K l\nu)/dq^2$	$f_{Ds\to K}(0)\|V_{cd}\|$	1.3%	N/A	N/A
$d\Gamma(D_S \to \phi l\nu)dq^2$	$f_{Ds\to\phi}(0)\|V_{cs}\|$	1.0%	N/A	N/A

Belle: 2.5%

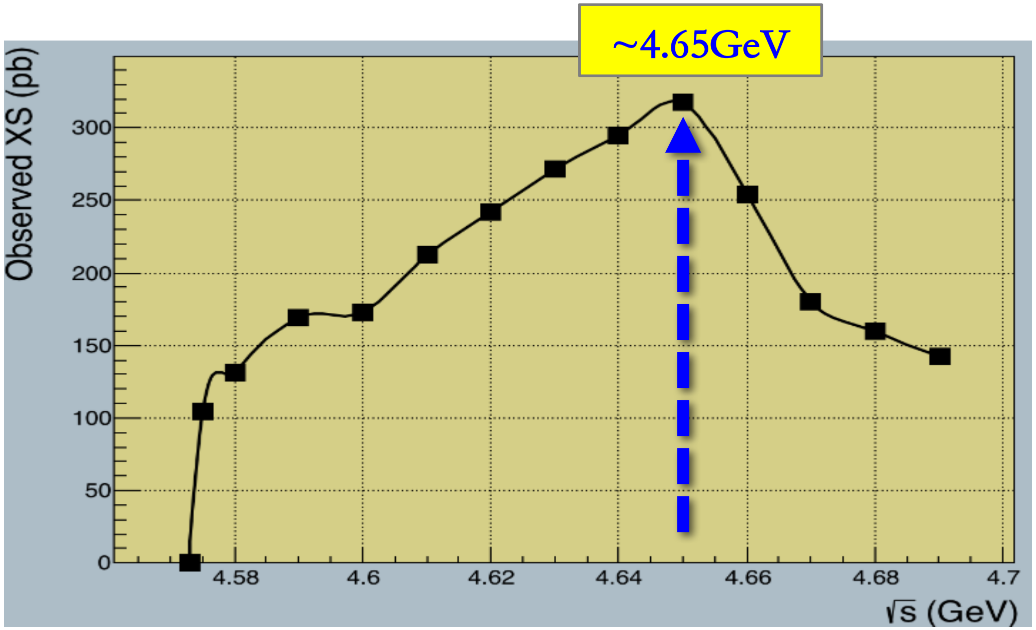
BESIII: 20fb^{-1} @ 3770 MeV, 6fb^{-1} @ 4180 MeV, arXiv: 0809.1869 (BESIII physics book)

Belle-II: 50 ab^{-1} @ Y(4S) arXiv: 1808.10567 (Belle-II physics book)

LHCb: : arXiv:1808.08865 for upgrade-II

Approved data taking between 4.6~4.7 GeV in 2020

- We will accumulate at least 10~20x more Λ_c pairs (1~2 M)
- Irreplaceable sample to systematically refresh the whole Λ_c knowledge and impact relevant theoretical and experimental studies



Impacts on Λ_c decay data

BESIII

D_s^+ BRANCHING RATIOS

A number of older, now obsolete results have been omitted. They may be found in earlier editions.

Inclusive modes

$\Gamma(e^+ \text{semileptonic})/\Gamma_{\text{total}}$ — Γ_1/Γ

This is the purely e^+ semileptonic branching fraction: the e^+ fraction from τ^+ decays has been subtracted off. The sum of our (non-... fractions — ... $e^+\nu_e$ with an η, η', ϕ, K^0, or K^{*0} — is 5.99 ± 0.3... %.

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
$6.52\pm0.39\pm0.15$	536 ± 29	[1] ASNER	10	CLEO	e^+e^- at 37... MeV

[1] Using the D_s^+ and D^0 lifetimes, ASNER 10 finds that the ratio of the D_s^+ and D^0 semileptonic widths is $0.828 \pm 0.051 \pm 0.025$.

$\Gamma(\pi^+ \text{anything})/\Gamma_{\text{total}}$ — Γ_2/Γ

Events with two π^+'s count twice, etc. But π^+'s from $K_S^0 \to \pi^+\pi^-$ are not included.

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
$119.3\pm1.2\pm0.7$	DOBBS 09	CLEO	e^+e^- at 4170 MeV

$\Gamma(\pi^- \text{anything})/\Gamma_{\text{total}}$ — Γ_3/Γ

Events with two π^-'s count twice, etc. But π^-'s from $K_S^0 \to \pi^+\pi^-$ are not included.

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
$43.2\pm0.9\pm0.3$	DOBBS 09	CLEO	e^+e^- at 4170 MeV

$\Gamma(\pi^0 \text{ anything})/\Gamma_{\text{total}}$ — Γ_4/Γ

Events with two π^0's count twice, etc. But π^0's from $K_S^0 \to$ ... are not included.

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
$123.4\pm3.8\pm5.3$	DOBBS 09	CLEO	e^+e^- at 4170 MeV

$\Gamma(K^- \text{anything})/\Gamma_{\text{total}}$ — Γ_5/Γ

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
$18.7\pm0.5\pm0.2$	DOBBS 09	CLEO	e^+e^- at 4170 MeV

$\Gamma(K^+ \text{anything})/\Gamma_{\text{total}}$ — Γ_6/Γ

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
$28.9\pm0.6\pm0.3$	DOBBS 09	CLEO	e^+e^- at 4170 MeV

$\Gamma(K_S^0 \text{ anything})/\Gamma_{\text{total}}$ — Γ_7/Γ

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
$19.0\pm1.0\pm0.4$	DOBBS 09	CLEO	e^+e^- at 4170 MeV

$\Gamma(\eta \text{ anything})/\Gamma_{\text{total}}$ — Γ_8/Γ

This ratio includes η particles from η' decays.

VALUE (units 10^{-2})	EVTS	DOCUMENT ID	TECN	COMMENT
$29.9\pm2.2\pm1.7$		DOBBS 09	CLEO	e^+e^- at 4170 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$23.5\pm3.1\pm2.0$	674 ± 91	HUANG 06B	CLEO	See DOBBS 09

$\Gamma(\omega \text{ anything})/\Gamma_{\text{total}}$ — Γ_9/Γ

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
$6.1\pm1.4\pm0.3$	DOBBS 09	CLEO	e^+e^- at 4170 MeV

$\Gamma(\eta' \text{ anything})/\Gamma_{\text{total}}$ — Γ_{10}/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID	TECN	COMMENT
10.3 ± 1.4 OUR AVERAGE Error includes scale factor of 1.1.				
$8.8\pm1.8\pm0.5$	68	ABLIKIM 15Z	BES3	48 pb^{-1}, 4009 MeV
$11.7\pm1.7\pm0.7$		DOBBS 09	CLEO	e^+e^- at 4170 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$8.7\pm1.9\pm0.8$	68	HUANG 06B	CLEO	See DOBBS 09

$\Gamma(f_0(980) \text{ anything}, f_0 \to \pi^+\pi^-)/\Gamma_{\text{total}}$ — Γ_{11}/Γ

VALUE (units 10^{-2})	CL%	DOCUMENT ID	TECN	COMMENT
<1.3	90	DOBBS 09	CLEO	e^+e^- at 4170 MeV

$\Gamma(\phi \text{ anything})/\Gamma_{\text{total}}$ — Γ_{12}/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID	TECN	COMMENT
$15.7\pm0.8\pm0.6$		DOBBS 09	CLEO	e^+e^- at 4170 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$16.1\pm1.2\pm1.1$	398 ± 27	HUANG 06B	CLEO	See DOBBS 09

$\Gamma(K^+K^- \text{anything})/\Gamma_{\text{total}}$ — Γ_{13}/Γ

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
$15.8\pm0.6\pm0.3$	DOBBS 09	CLEO	e^+e^- at 4170 MeV

CLEOc dominants the D_s Branching Fraction measurements. (Sys. Err. Dominates CF modes. Many SCS&DCS modes observed.)

Baryon Particle Listings

Λ_c^+

$\Gamma(\Lambda\pi^+)/\Gamma(pK^-\pi^+)$ — Γ_{28}/Γ_2

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.208 ± 0.009 OUR FIT Error includes scale factor of 1.2.						
0.204 ± 0.019 OUR AVERAGE						
$0.217\pm0.013\pm0.020$		750	LINK	05F	FOCS	γ nucleus, $\bar{E}_\gamma \approx 180$ GeV
$0.18\pm0.03\pm0.04$			ALBRECHT	92	ARG	$e^+e^- \approx 10.4$ GeV
$0.18\pm0.03\pm0.03$		87	AVERY	91	CLEO	e^+e^- 10.5 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.33	90		ANJOS	90	E691	γBe 70–260 GeV
<0.16	90		ALBRECHT	88C	ARG	e^+e^- 10 GeV

$\Gamma(\Lambda\pi^+\pi^0)/\Gamma_{\text{total}}$ — Γ_{29}/Γ

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
7.0 ± 0.4 OUR FIT Error includes scale factor of 1.1.					
$7.01\pm0.37\pm0.19$	1497	ABLIKIM	16	BES3	$e^+e^- \to \Lambda_c\bar{\Lambda}_c$, 4.599 GeV

$\Gamma(\Lambda\pi^+\pi^0)/\Gamma(pK^-\pi^+)$ — Γ_{29}/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
1.13 ± 0.06 OUR FIT Error includes scale factor of 1.1.					
$0.73\pm0.09\pm0.16$	464	AVERY	94	CLE2	$e^+e^- \approx \Upsilon(3S), \Upsilon(4S)$

$\Gamma(\Lambda\rho^+)/\Gamma(pK^-\pi^+)$ — Γ_{30}/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.95	95	AVERY	94	CLE2	$e^+e^- \approx \Upsilon(3S), \Upsilon(4S)$

$\Gamma(\Lambda\pi^-2\pi^+)/\Gamma_{\text{total}}$ — Γ_{31}/Γ

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
3.61 ± 0.29 OUR FIT Error includes scale factor of 1.1.					
$3.81\pm0.24\pm0.18$	609	ABLIKIM	16	BES3	$e^+e^- \to \Lambda_c\bar{\Lambda}_c$, 4.599 GeV

$\Gamma(\Lambda\pi^-2\pi^+)/\Gamma(pK^-\pi^+)$ — Γ_{31}/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.58 ± 0.05 OUR FIT Error includes scale factor of 2.0.					
0.522 ± 0.032 OUR AVERAGE					
$0.508\pm0.024\pm0.024$	1356	LINK	05F	FOCS	γ nucleus, $\bar{E}_\gamma \approx 180$ GeV
$0.65\pm0.11\pm0.12$	289	AVERY	91	CLEO	e^+e^- 10.5 GeV
$0.82\pm0.29\pm0.27$	44	ANJOS	90	E691	γBe 70–260 GeV
$0.94\pm0.41\pm0.13$	10	BARLAG	90D	NA32	π^- 230 GeV
$0.61\pm0.16\pm0.04$	105	ALBRECHT	88C	ARG	e^+e^- 10 GeV

$\Gamma(\Sigma(1385)^+\pi^+\pi^-, \Sigma^{*+} \to \Lambda\pi^+)/\Gamma(\Lambda\pi^-2\pi^+)$ — Γ_{32}/Γ_{31}

VALUE	DOCUMENT ID		TECN	COMMENT
$0.28\pm0.10\pm0.08$	LINK	05F	FOCS	γ nucleus, $\bar{E}_\gamma \approx 180$ GeV

$\Gamma(\Sigma(1385)^-2\pi^+, \Sigma^{*-} \to \Lambda\pi^-)/\Gamma(\Lambda\pi^-2\pi^+)$ — Γ_{33}/Γ_{31}

VALUE	DOCUMENT ID		TECN	COMMENT
$0.21\pm0.03\pm0.02$	LINK	05F	FOCS	γ nucleus, $\bar{E}_\gamma \approx 180$ GeV

$\Gamma(\Lambda\pi^+\rho^0)/\Gamma(\Lambda\pi^-2\pi^+)$ — Γ_{34}/Γ_{31}

VALUE	DOCUMENT ID		TECN	COMMENT
$0.40\pm0.12\pm0.12$	LINK	05F	FOCS	γ nucleus, $\bar{E}_\gamma \approx 180$ GeV

$\Gamma(\Sigma(1385)^+\rho^0, \Sigma^{*+} \to \Lambda\pi^+)/\Gamma(\Lambda\pi^-2\pi^+)$ — Γ_{35}/Γ_{31}

VALUE	DOCUMENT ID		TECN	COMMENT
$0.14\pm0.09\pm0.07$	LINK	05F	FOCS	γ nucleus, $\bar{E}_\gamma \approx 180$ GeV

$\Gamma(\Lambda\pi^-2\pi^+ \text{nonresonant})/\Gamma(\Lambda\pi^-2\pi^+)$ — Γ_{36}/Γ_{31}

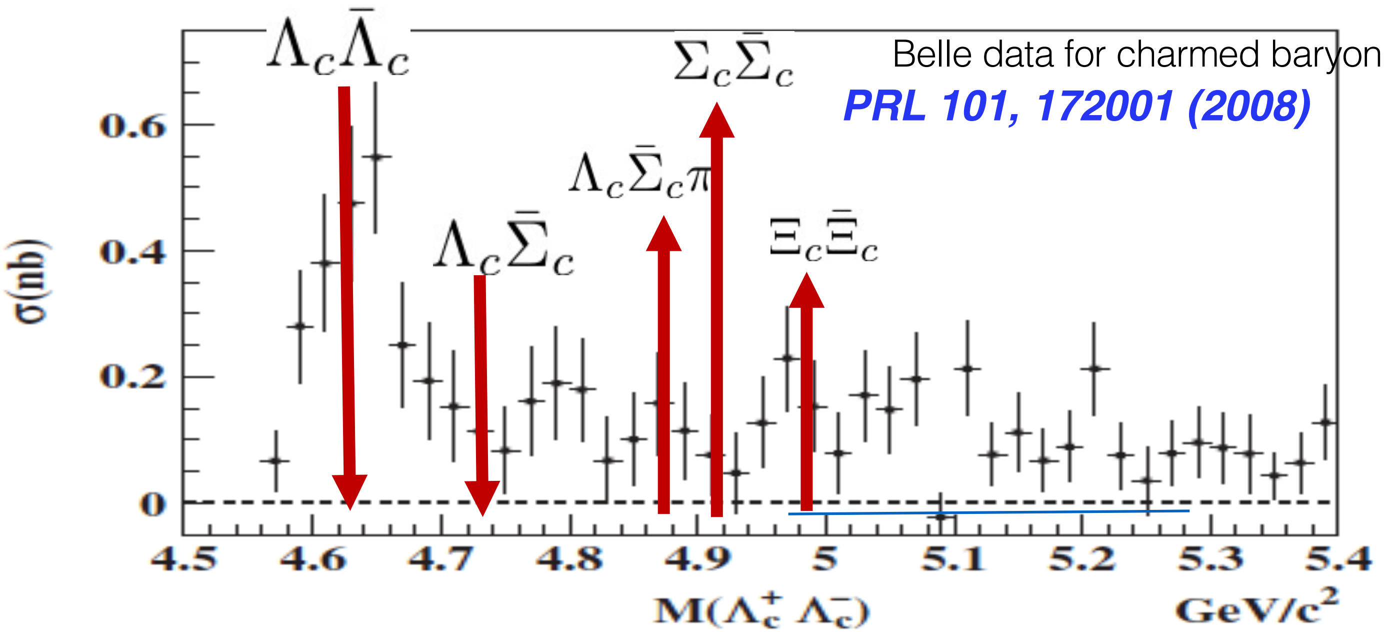
VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.3	90	LINK	05F	FOCS	γ nucleus, $\bar{E}_\gamma \approx 180$ GeV

Can BESIII **dominate Λ_c**? Most Brs are Stat. Error dominated. Many SCS &DCS modes NOT observed.

Future data taking proposals

A simple reference table (can be modified according to future machine status)

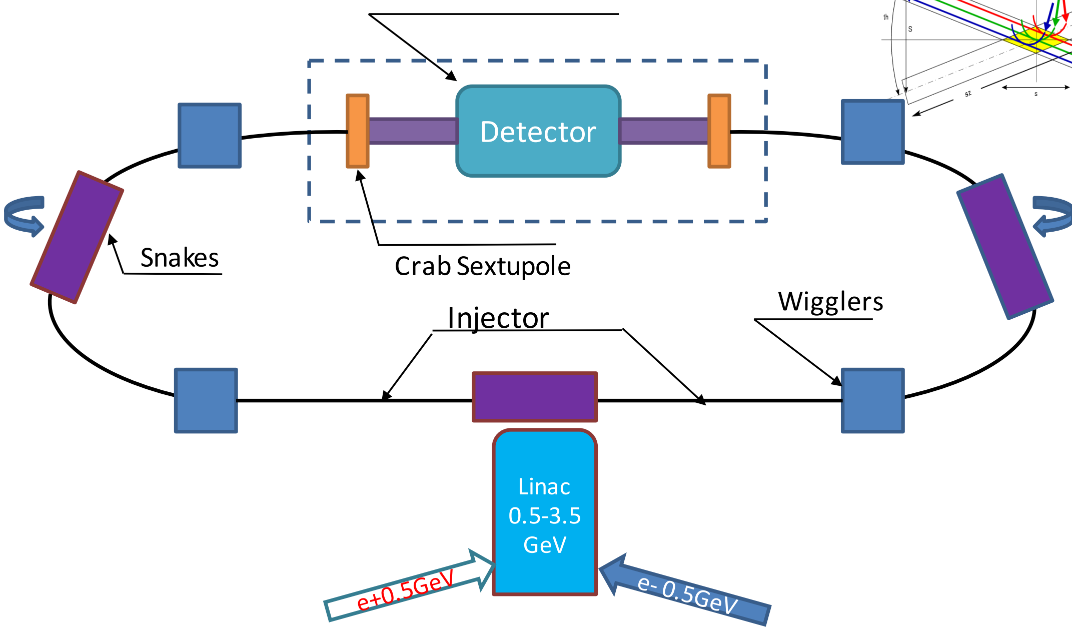
Energy	Physics motivations	Current data	Expected final data	T_C / T_U
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days

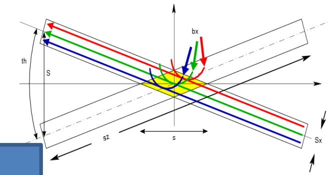


Belle data for charmed baryon
PRL 101, 172001 (2008)

Prospects at the STCF

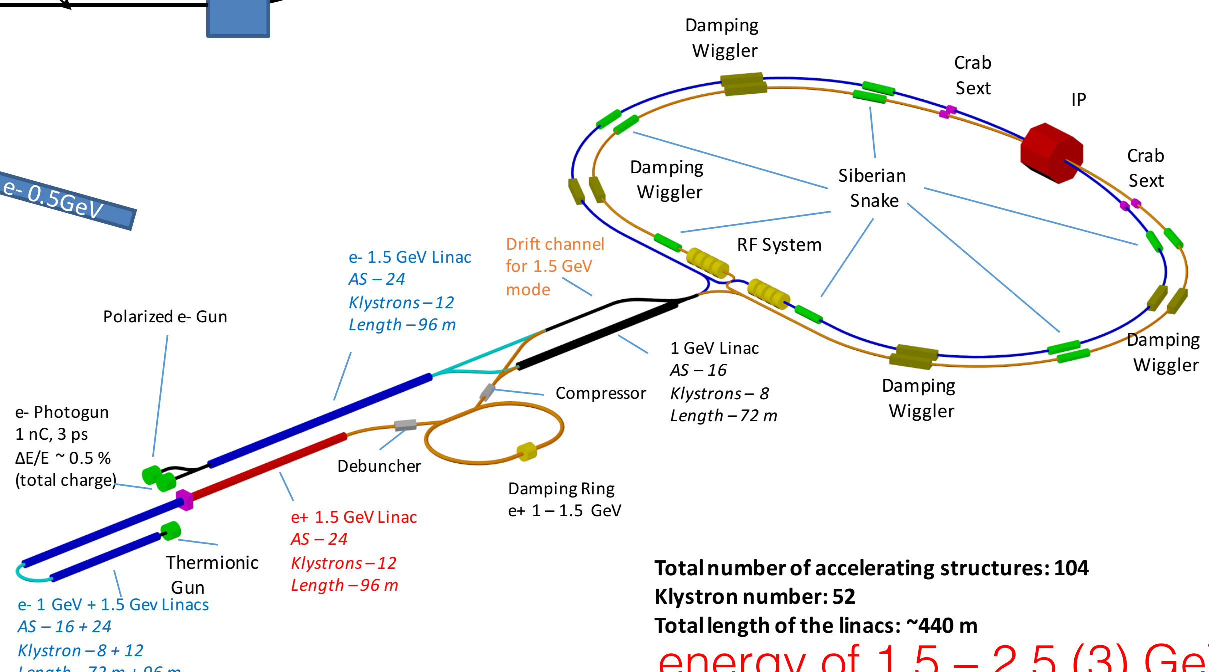
Proposals of the Super Tau-Charm Factory (STCF)





HIEPA in China

Super-CT Project in Russia



Total number of accelerating structures: 104
Klystron number: 52
Total length of the linacs: ~440 m

energy of 1.5 – 2.5 (3) GeV

Prospects at the STCF

Data samples with 1 ab^{-1} integral luminosity

	STCF					Belle II		
Data Set	process	σ/nb	N	ST eff./%	ST N	σ/nb	N	Tag N
J/ψ	–	–	1.0×10^{12}	–	–	–	–	–
$\psi(2S)$	–	–	3.0×10^{11}	–	–	–	–	–
D^0	$D^0\bar{D}^0(3.77)$	~ 3.6	3.6×10^9	10.8	0.78×10^9	–	1.4×10^9	–
D^+	$D^+D^-(3.77)$	~ 2.8	2.8×10^9	9.4	0.53×10^9	–	7.7×10^8	–
D_s	$D_sD_s^*(4.18)$	~ 0.9	0.9×10^9	6.0	0.11×10^9	–	2.5×10^8	–
τ^+	$\tau^+\tau^-(3.68)$	~ 2.4	2.4×10^9	–	–	0.9	0.9×10^9	–
	$\tau^+\tau^-(4.25)$	~ 3.6	3.5×10^9	–	–	–	–	–
Λ_c	$\Lambda_c\Lambda_c(4.64)$	~ 0.6	5.5×10^8	5.0	0.55×10^8	–	1.6×10^8	$3.6 \times 10^{4*}$

The luminosity is 1.0 ab^{-1}. * process $e^+e^- \to D^{(*)-}\bar{p}\pi^+\Lambda_c^+$.

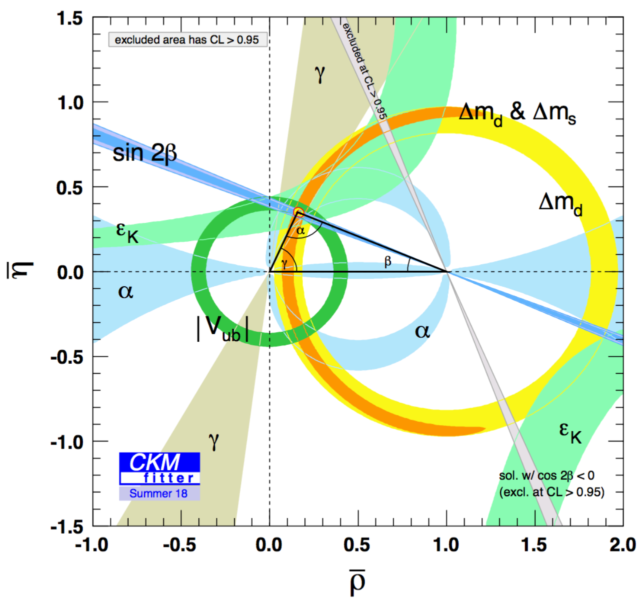
- Belle-II (50/ab) has 50~100 times more statistics
- STCF is expected to have higher detection efficiency
- STCF has low backgrounds for productions at threshold

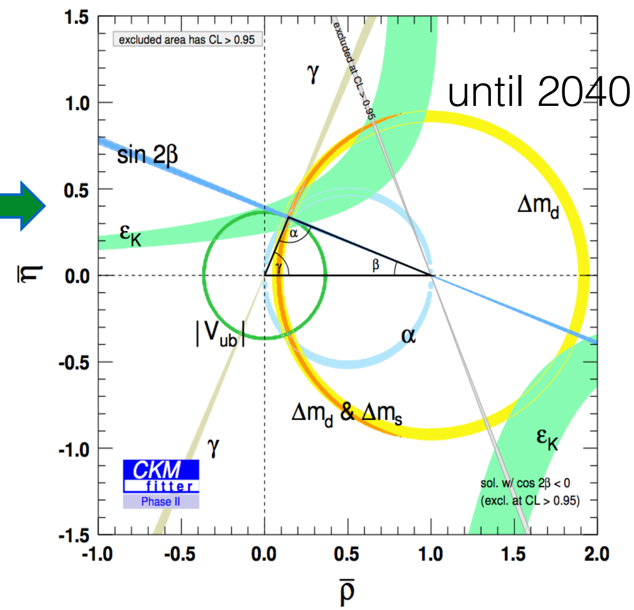
Sensitivities of the charmed meson decays

	BESIII	STCF	Belle II
Luminosity	2.92 fb^{-1} at 3.773 GeV	1 ab^{-1} at 3.773 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D^+ \to \mu^+\nu_\mu)$	$5.1\%_{\mathrm{stat.}}\ 1.6\%_{\mathrm{syst.}}$ [6]	$0.28\%_{\mathrm{stat.}}$	–
f_{D^+} (MeV)	$2.6\%_{\mathrm{stat.}}\ 0.9\%_{\mathrm{syst.}}$ [6]	$0.15\%_{\mathrm{stat.}}$	–
$\|V_{cd}\|$	$2.6\%_{\mathrm{stat.}}\ 1.0\%^{*}_{\mathrm{syst.}}$ [6]	$0.15\%_{\mathrm{stat.}}$	–
$\mathcal{B}(D^+ \to \tau^+\nu_\tau)$	$20\%_{\mathrm{stat.}}\ 10\%^{\dagger}_{\mathrm{syst.}}$ [7]	$0.41\%_{\mathrm{stat.}}$	–
$\frac{\mathcal{B}(D^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D^+ \to \mu^+\nu_\mu)}$	$21\%_{\mathrm{stat.}}\ 10\%^{\dagger}_{\mathrm{syst.}}$ [7]	$0.50\%_{\mathrm{stat.}}$	–
Luminosity	3.2 fb^{-1} at 4.178 GeV	1 ab^{-1} at 4.009 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)$	$2.8\%_{\mathrm{stat.}}\ 2.7\%_{\mathrm{syst.}}$ [8]	$0.30\%_{\mathrm{stat.}}$	$0.8\%_{\mathrm{stat.}}\ 1.8\%_{\mathrm{syst.}}$
$f_{D_s^+}$ (MeV)	$1.5\%_{\mathrm{stat.}}\ 1.6\%_{\mathrm{syst.}}$ [8]	$0.15\%_{\mathrm{stat.}}$	–
$\|V_{cs}\|$	$1.5\%_{\mathrm{stat.}}\ 1.6\%_{\mathrm{syst.}}$ [8]	$0.15\%_{\mathrm{stat.}}$	–
$f_{D_s^+}/f_{D^+}$	$3.0\%_{\mathrm{stat.}}\ 1.5\%_{\mathrm{syst.}}$ [8]	$0.21\%_{\mathrm{stat.}}$	–
$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$	$2.2\%_{\mathrm{stat.}}\ 2.6\%^{\dagger}_{\mathrm{syst.}}$	$0.24\%_{\mathrm{stat.}}$	$0.6\%_{\mathrm{stat.}}\ 2.7\%_{\mathrm{syst.}}$
$f_{D_s^+}$ (MeV)	$1.1\%_{\mathrm{stat.}}\ 1.5\%^{\dagger}_{\mathrm{syst.}}$	$0.11\%_{\mathrm{stat.}}$	–
$\|V_{cs}\|$	$1.1\%_{\mathrm{stat.}}\ 1.5\%^{\dagger}_{\mathrm{syst.}}$	$0.11\%_{\mathrm{stat.}}$	–
$\overline{f}^{\mu\&\tau}_{D_s^+}$ (MeV)	$0.9\%_{\mathrm{stat.}}\ 1.0\%^{\dagger}_{\mathrm{syst.}}$	$0.09\%_{\mathrm{stat.}}$	$0.3\%_{\mathrm{stat.}}\ 1.0\%_{\mathrm{syst.}}$
$\|\overline{V}^{\mu\&\tau}_{cs}\|$	$0.9\%_{\mathrm{stat.}}\ 1.0\%^{\dagger}_{\mathrm{syst.}}$	$0.09\%_{\mathrm{stat.}}$	–
$\frac{\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)}$	$3.6\%_{\mathrm{stat.}}\ 3.0\%^{\dagger}_{\mathrm{syst.}}$	$0.38\%_{\mathrm{stat.}}$	$0.9\%_{\mathrm{stat.}}\ 3.2\%_{\mathrm{syst.}}$

Determination of γ/ϕ_3 angle in CKM

STCF will provide complementary information on the strong phase and allow detailed comparisons in different models

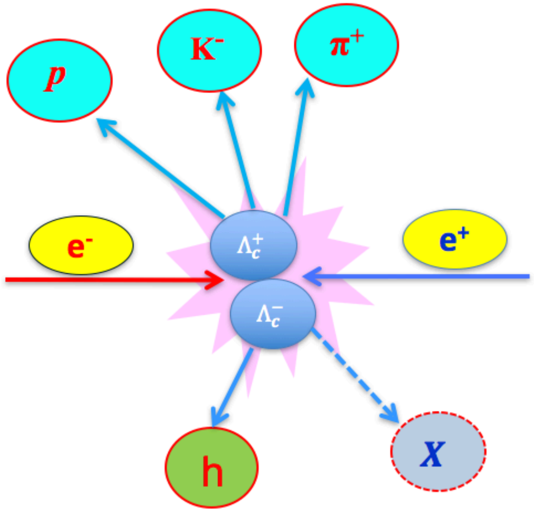




Decay mode	Quantity of interest
$D \to K^0_S \pi^+\pi^-$	c_i and s_i
$D \to K^0_S K^+K^-$	c_i and s_i
$D \to K^\pm\pi^\mp\pi^+\pi^-$	R, δ
$D \to K^+K^-\pi^+\pi^-$	c_i and s_i
$D \to \pi^+\pi^-\pi^+\pi^-$	F_+ or c_i and s_i
$D \to K^\pm\pi^\mp\pi^0$	R, δ
$D \to K^0_S K^\pm\pi^\mp$	R, δ
$D \to \pi^+\pi^-\pi^0$	F_+
$D \to K^0_S \pi^+\pi^-\pi^0$	F_+, c_i and s_i
$D \to K^+K^-\pi^0$	F_+
$D \to K^\pm\pi^\mp$	δ

Charmed Baryons at STCF

Charmed baryons are produced via $e^+e^- \to B_{1c}B_{2c}$ with $B_{ic} = n_1 n_2 c$



	Structure	J^P	Mass, MeV	Width,MeV	Decay
Λ_c^+	udc	$(1/2)^+$	2286.46 ± 0.14	(200 ± 6) fs	weak
Ξ_c^+	usc	$(1/2)^+$	$2467.8^{+0.4}_{-0.6}$	(442 ± 26) fs	weak
Ξ_c^0	dsc	$(1/2)^+$	$2470.88^{+0.34}_{-0.8}$	112^{+13}_{-10} fs	weak
Σ_c^{++}	uuc	$(1/2)^+$	2454.02 ± 0.18	2.23 ± 0.30	$\Lambda_c^+\pi^+$
Σ_c^+	udc	$(1/2)^+$	2452.9 ± 0.4	< 4.6	$\Lambda_c^+\pi^0$
Σ_c^0	ddc	$(1/2)^+$	2453.76 ± 0.18	2.2 ± 0.4	$\Lambda_c^+\pi^-$
$\Xi_c'^+$	usc	$(1/2)^+$	2575.6 ± 3.1	—	$\Xi_c^+\gamma$
$\Xi_c'^0$	dsc	$(1/2)^+$	2577.9 ± 2.9	—	$\Xi_c^0\gamma$
Ω_c^0	ssc	$(1/2)^+$	2695.2 ± 1.7	(69 ± 12) fs	weak
Σ_c^{*++}	uuc	$(3/2)^+$	2518.4 ± 0.6	14.9 ± 1.9	$\Lambda_c^+\pi^+$
Σ_c^{*+}	udc	$(3/2)^+$	2517.5 ± 2.3	< 17	$\Lambda_c^+\pi^0$
Σ_c^{*0}	ddc	$(3/2)^+$	2518.0 ± 0.5	16.1 ± 2.1	$\Lambda_c^+\pi^-$
Ξ_c^{*+}	usc	$(3/2)^+$	$2645.9^{+0.5}_{-0.6}$	< 3.1	$\Xi_c\pi$
Ξ_c^{*0}	dsc	$(3/2)^+$	2645.9 ± 0.5	< 5.5	$\Xi_c\pi$
Ω_c^{*0}	ssc	$(3/2)^+$	2765.9 ± 2.0	—	$\Omega_c^0\gamma$

- Systematic measurement of absolute decay BFs with well controlled systematics and low backgrounds

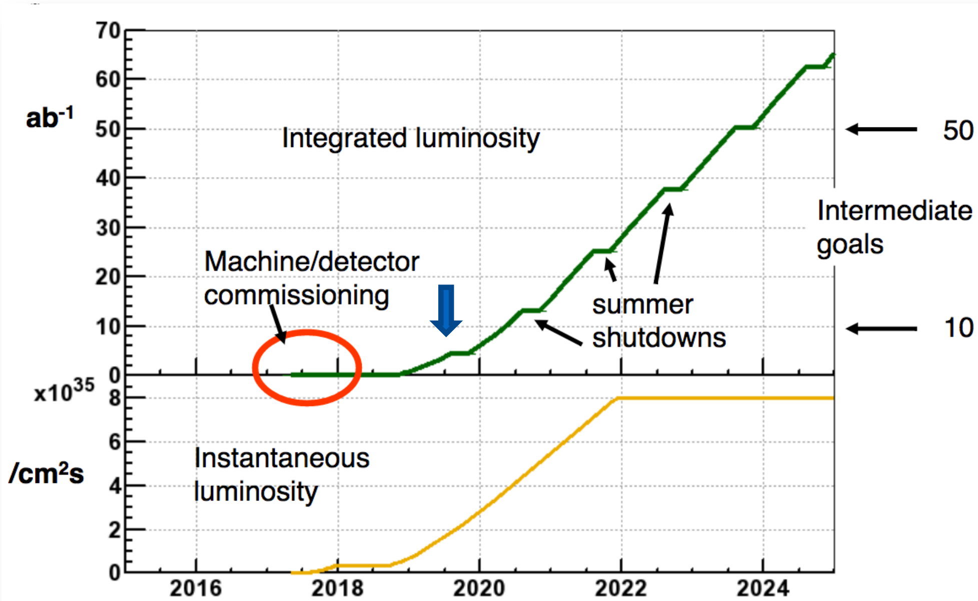
Summary and Outlook

- The charm program at BESIII is well proceeding.
- Near threshold production is unique to directly measure the decay properties of the charmed hadrons, such as D, Ds, Λ_c
  - Most precise measurements of decay constant and form factors
  - Firstly mapping out the full picture of **Λ_c decay patterns**.
- More data will be accumulated in the future 5-10 years
  - To improve our knowledge on NPQCD in charmed region
- Opportunities to study Ξ_c @4.95 GeV
- More comprehensive precision studies will be promising at STCF

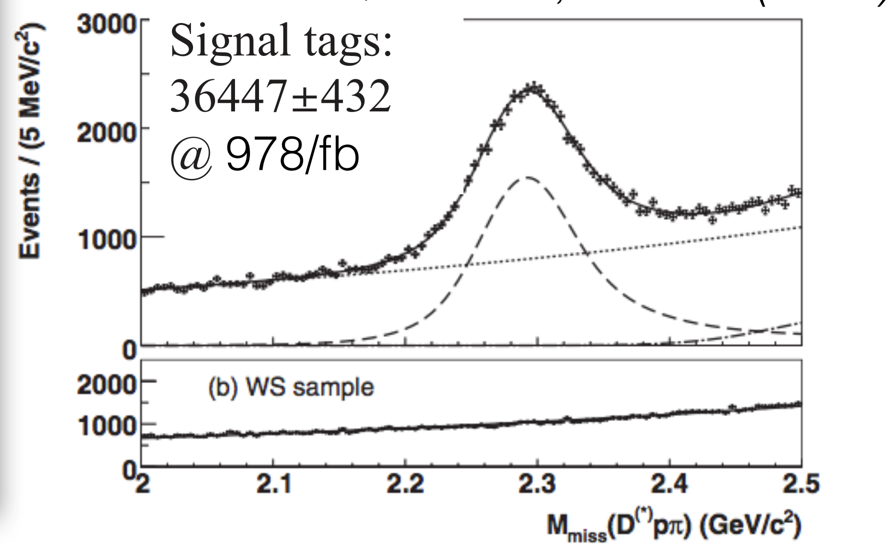
Thank you!

谢谢！

Competition from Belle & BelleII



Belle, PRL113, 042002 (2014)



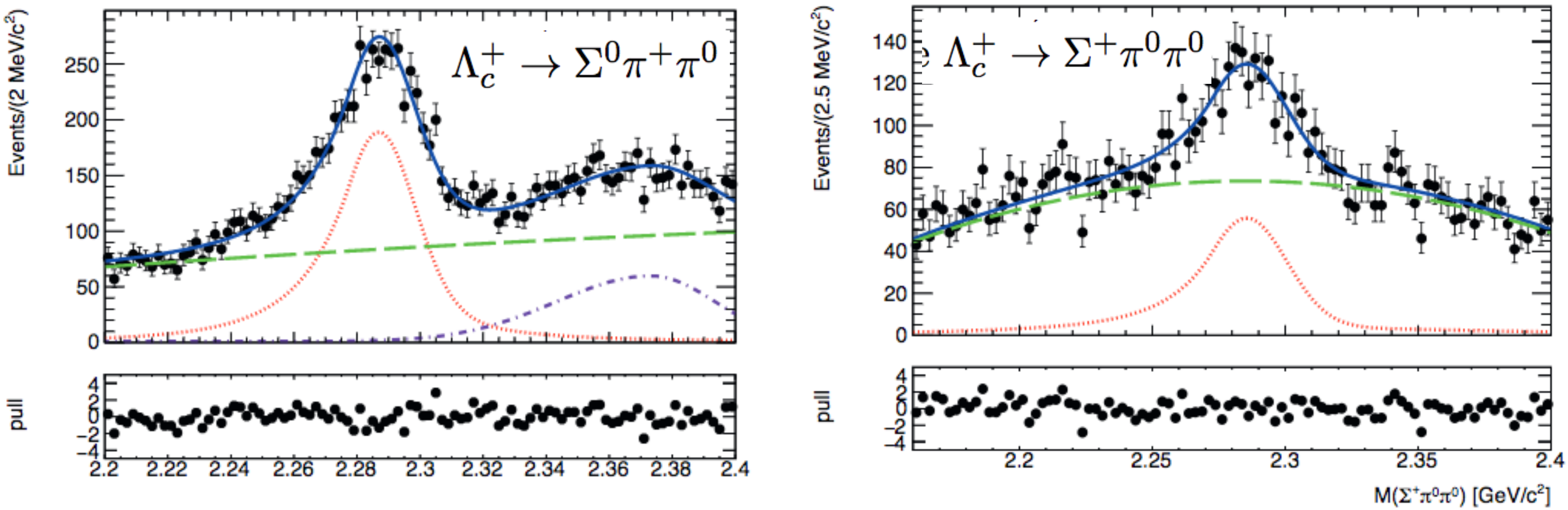
- Belle tags ~36K Λ_c^+, while BESIII now tags 15K Λ_c^+ (567/pb@4.6GeV)
- By middle of 2019, BELLEII will have 5/ab data, 5x of BELLE data;
  ➔ 180K tagged Λ_c^+;
- We will have 150K tagged Λ_c^+, however, BESIII is very clean
- Many precise measurements at BESIII will reach to the level of systematic dominated
  ➔ BESIII has advantages on backgrounds and systematics

World campaign on the Λ_c^+

	BESIII	Belle(-II)	LHCb
Λ_c^+ total yields	★★★	★★★★	★★★★★
S/B ratio	★★★★★	★★	★★
Systematic error	★★★★★	★★★	★★
Systematic research	★★★★★	★★★	★
Semi-leptonic mode	★★★★★	★★★	★
n/K_L-involved mode	★★★★★	★★	☆
Photon final state	★★★★★	★★★★	☆
Absolute measurement	★★★★★	★★★	☆

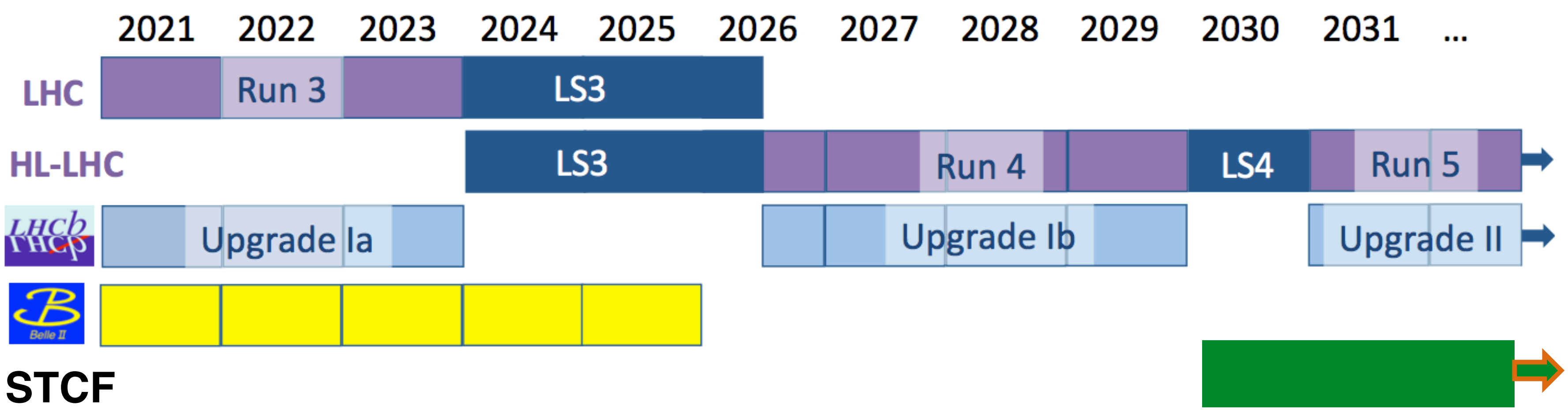
- The threshold data at BESIII have systematic advantage over Belle(-II) and LHCb in the Λ_c^+ studies.
- This proposal holds an optimal time window to maximize the visibility of BESIII physics.

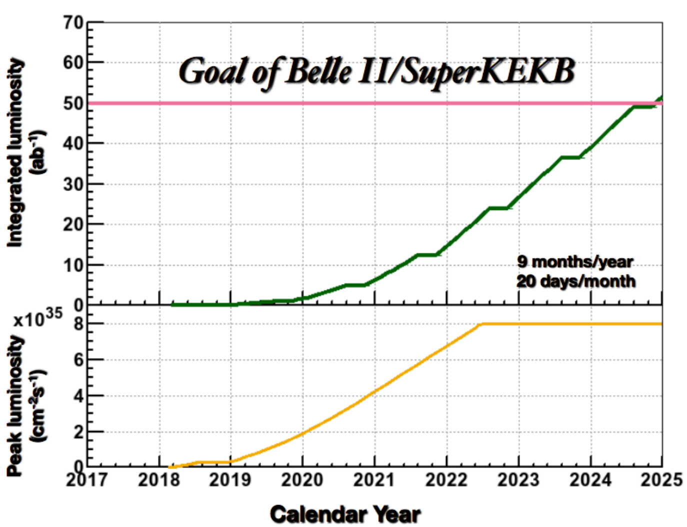
Measurement of the Decays $\Lambda_c \to \Sigma\pi\pi$ at Belle

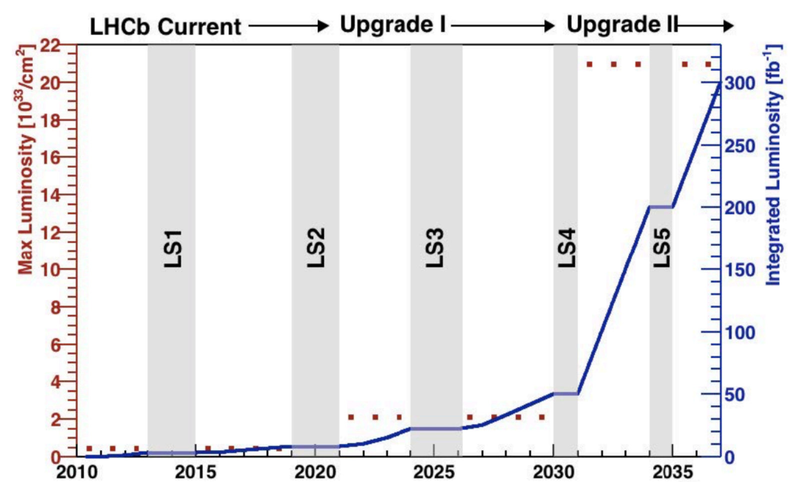


arXiv: 1802.03421

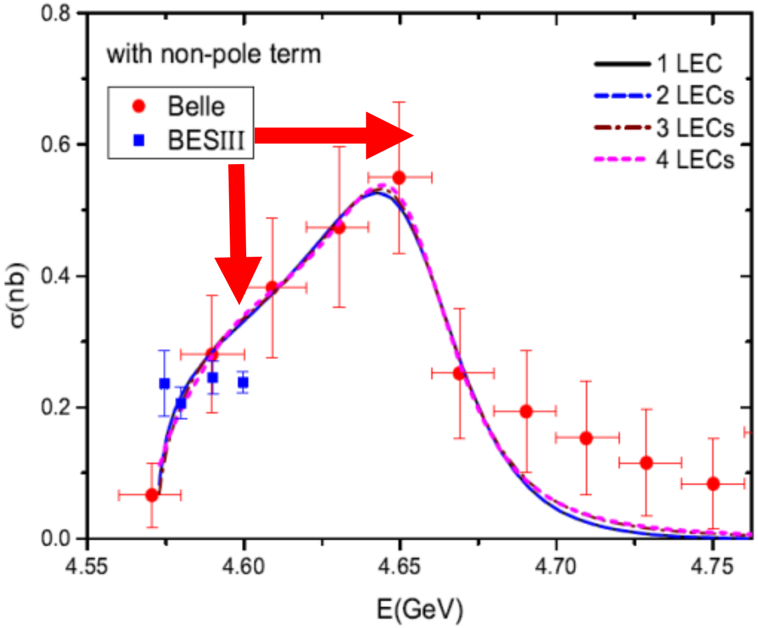
Future Facilities for Charm study







Lineshape of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$



Belle: PRL101, 172001 (2008)
BESIII: PRL120,132001(2018)

Machine upgrades:

- ✓ **Energy upgrades**
- ✓ **Lumi improvement @ higher energy**
- ✓ **“Topup” injections**

Some tensions between Belle and BESIII data on $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$
BESIII future data above 4.6 GeV will follow a sharp rise of the Y(4660) or a flat cross section near threshold?

Charmed baryons productions

from Marek Karliner

In the charmed baryon system, the light quarks are more like di-quarks

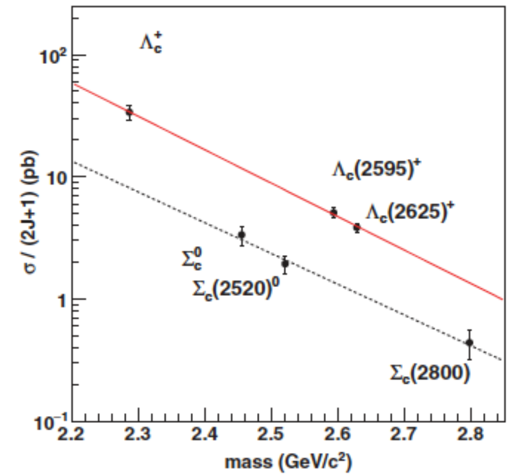
$$\Lambda_c^+(c[ud]_{spin=0}),\ \Sigma_c(c[ud]_{spin=1})$$

The spin-0 diquarks: "good" diquarks

The spin-1 one : "bad" diquarks.

The bad diquarks are heavier. So if the hadronization from the initial (ccbar) proceeds in one step, by attaching diquarks, it will provide a simple and natural explanation for the fact that the Λ_c cross section is much bigger than that of Σ_c.

Belle, arXiv:1706.06791



Then how about the behaves at the threshold, and to test it at BESIII will be very interesting!