Recent Highlights from the BESIII experiment

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BINP

BEPCII @ IHEP

$E_{\mathrm{cm}} = 2 - 4.95$ GeV

2004, started construction

2009-2024, BESIII Physics run

Design Luminosity:

$\mathcal{L}_D = 1 \times 10^{33}\mathrm{cm}^{-2}s^{-1}$@$E_{\mathrm{cm}}$= 3.773 GeV

Peak luminosity:

2016 achieved $1.0 \times \mathcal{L}_D$

2023 achieved $1.1 \times \mathcal{L}_D$

Jul. 1, 2024 – Aug. 31, 2028:

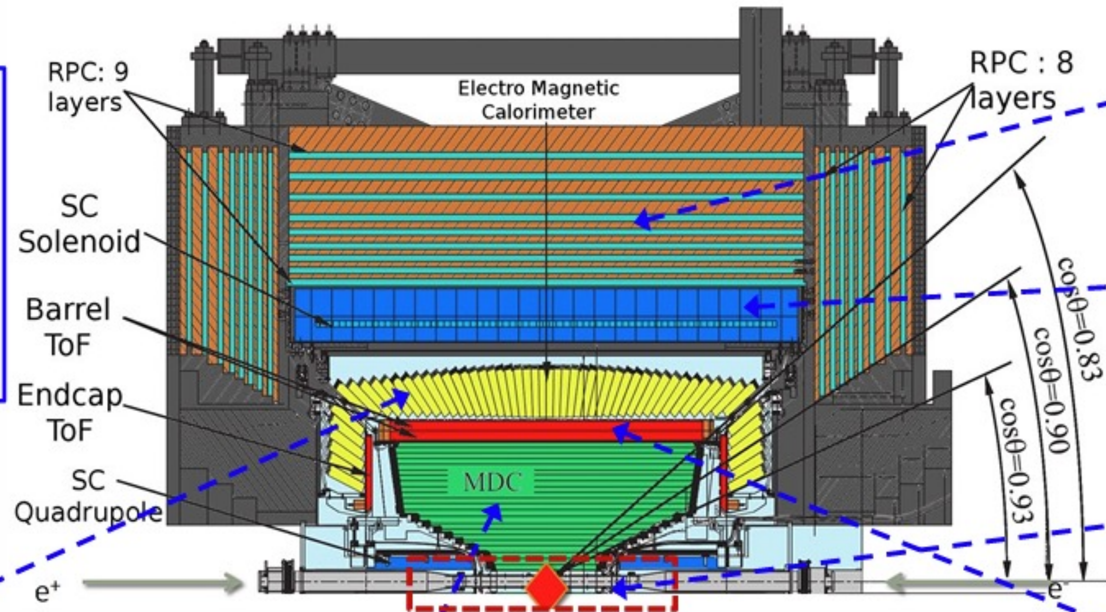
BEPCII upgrade → BEPCII-U

January 2025, restart

- Luminosity × 3 @E_{cm}= 4.7 GeV
- Beam energy up to 2.8 GeV (2028)

BESIII @ BEPCII

- **Optimized for flavor physics**
- **Cover 93% of 4π solid angle**



Muon counters (MUC)
$\sigma_{r\phi} = 1.4 - 1.7$ cm

Superconducting solenoid
1 Tesla Magnetic field

inner MDC

Electro Magnetic Calorimeter (EMC)
$\Delta E/E = 2.5\%$ @1.0 GeV
$\sigma_{\phi z} = 0.6$cm @ 1.0 GeV

Main Drift Chamber (MDC)
$\Delta P/P = 0.5\%$ @1.0 GeV
$\sigma_{xy} = 130$ um, $\sigma_{dE/dX} = 6 - 7\%$

Time Of Flight (TOF)
$\sigma_t = 90$ ps @ barrel
$\sigma_t = 60$ ps @ end cap (upgrade in 2016)

July 1 - December 31, 2024: Replace the inner MDC with 3 layers of cylindrical triple-GEM detectors

Europe (18)

Germany(6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster

Italy(3): Ferrara University, INFN, University of Turin

Russia(3): Budker Institute of Nuclear Physics, Dubna JINR, Lebedev Physical Institute

Sweden(1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK(2): University of Oxford, University of Bristol

Poland(2): National Centre for Nuclear Research, University of Silesia in Katowic

Pakistan(2)

Institute of Business Administration, University of the Punjab

India(1)

Indian Institute of Technology madras

Mongolia(1)

Institute of Physics and Technology

Korea(1)

Chung-Ang University

Thailand(1)

Suranaree University of Technology

USA(4)

Carnegie Mellon University
College of William and Mary
Indiana University
University of Hawaii

Chile(2)

University of Tarapaca, University of La Serena

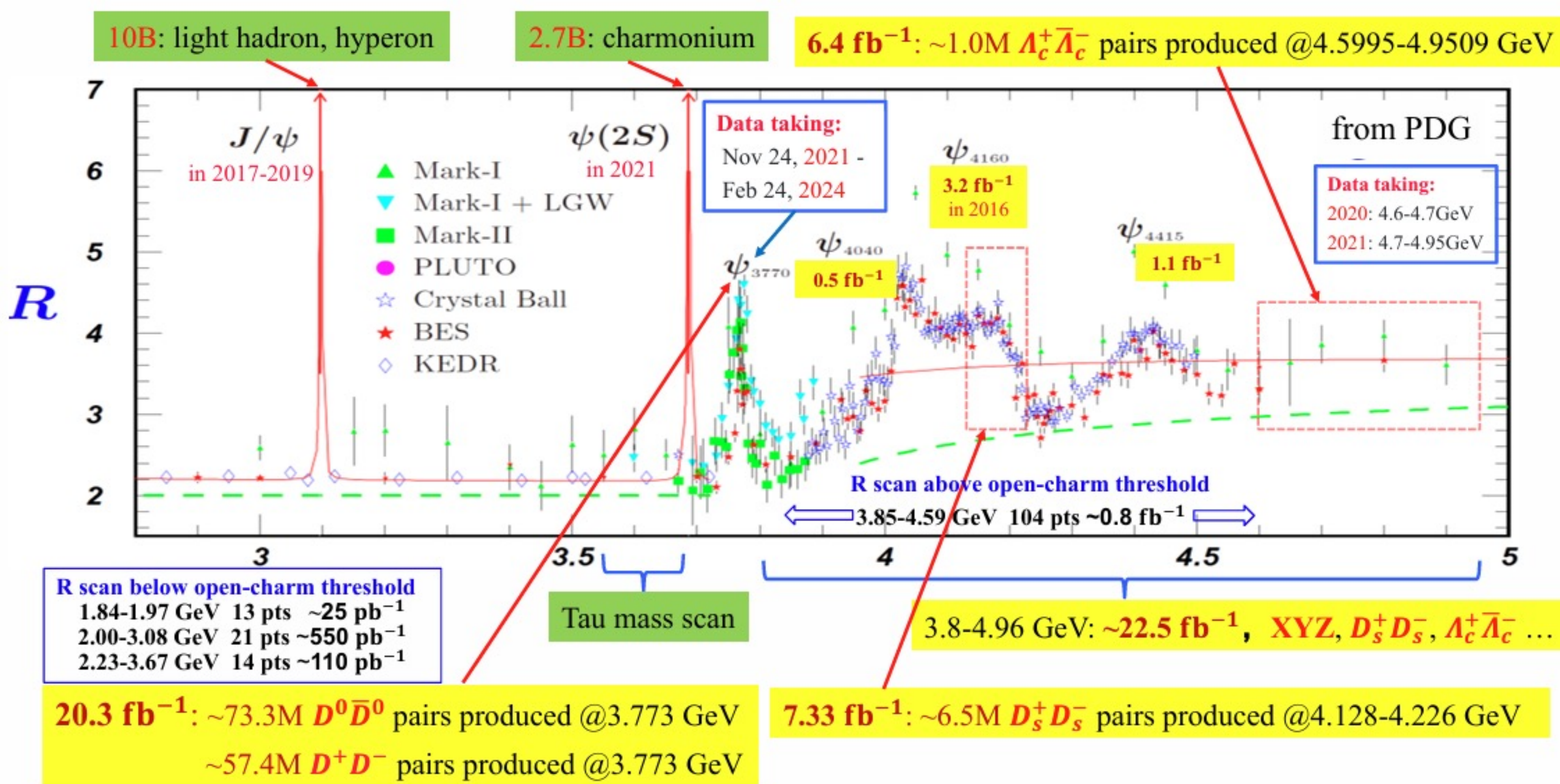
China (63)

Beihang University, Central China Normal University, Central South University, Chengdu University of Technology, China Center of Advanced Science and Technology, China University of Geosciences, Fudan University, Guangxi Normal University, Guangxi University, Guangxi University of Science and Technology, Hangzhou Normal University, Hebei University, Henan University, Henan Normal University, Henan University of Science and Technology, Henan University of Technology, Hengyang Normal University, Huangshan College, Hunan University, Hunan Normal University, Inner Mongolia University, Institute of High Energy Physics, Institute of Modern Physics, Jiangsu Ocean University, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Longyan University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu Normal University, Renmin University of China, Shaanxi Normal University, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Management University, Shandong Normal University, Shandong University, handong University of Technology, Shanghai Jiao Tong University, Soochow University, South China Normal University, Southeast University, Southwest University of Science and Technology, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xi'an Jiaotong University, Xinjiang University, Yantai University, Yunnan University, Zhejiang University, Zhengzhou University

BESIII

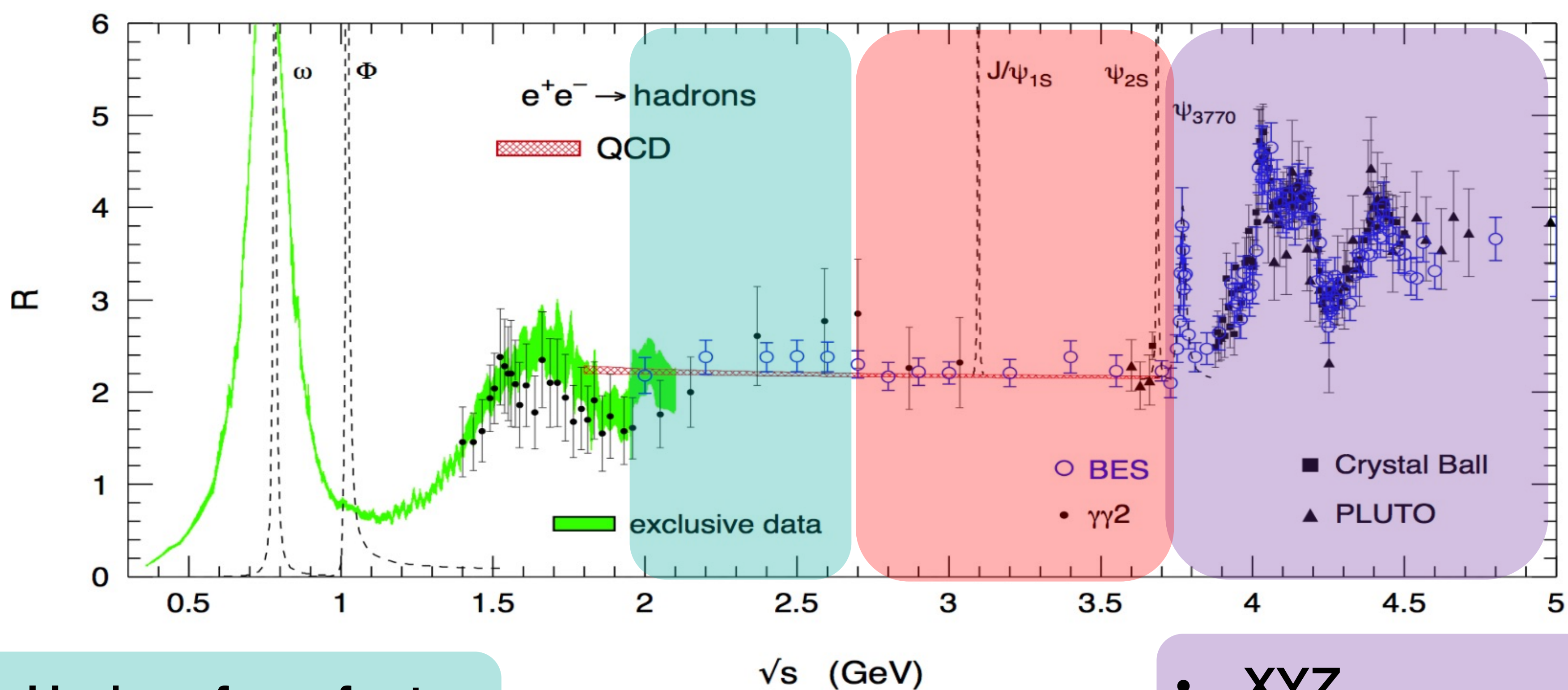
>600 members
From 93 institutions in 15 countries

Datasets (totally ~50 fb^{-1} from 1.84 - 4.95 GeV)



Rich Physics program at BESIII

- Light hadron spectroscopy
- Gluonic and exotic states
- Physics with tau lepton



- Hadron form factor
- R values and QCD

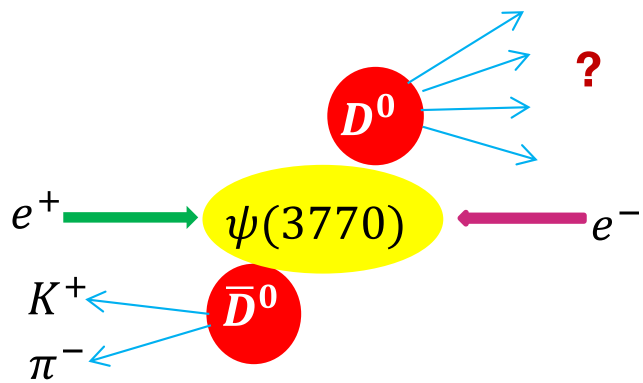
- XYZ
- Charmed hadrons

>700 publications

BESIII Data near Threshold

20.3 fb^{-1} at E$_{cm}$ 3.773 GeV: $e^+e^- \rightarrow \psi(3770) \rightarrow D\bar{D}$

Production of charm hadron pair



Fully reconstruction

Clean sample

Hadronic decays

Recoil four-momentum

missing particle (neutrino)

(Semi)-leptonic decays

Absolute branching fraction

Amplitude analysis

etc.

Recent highlights (selected) at BESIII

Charm physics （CKM measurements）

- Charmed hadron decays
- Charmed hadron structure

Hyperon physics

- Baryon Electromagnetic Form Factors
- Hyperon-nucleon interaction
- EDM

BESIII Prospects

STCF Prospects

Motivation

- **Charm Decays: The Best Probe of $|V_{cd}|$ and $|V_{cs}|$**

  Pure & semi-leptonic channels provide the most precise measurement.

$$V_{\mathrm{CKM}}^{\mathrm{PDG2024}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 0.97367 \pm 0.00032 & 0.22431 \pm 0.00085 & 0.00382 \pm 0.00020 \\ 0.221 \pm 0.004 & 0.975 \pm 0.006 & 0.0411 \pm 0.0012 \\ 0.0086 \pm 0.0002 & 0.0415 \pm 0.0009 & 1.010 \pm 0.027 \end{pmatrix}$$

- Verifying the unitarity of the CKM matrix to test the SM.

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = \mathbf{0.9984 \pm 0.0007} \quad \sim 0.07\%$$

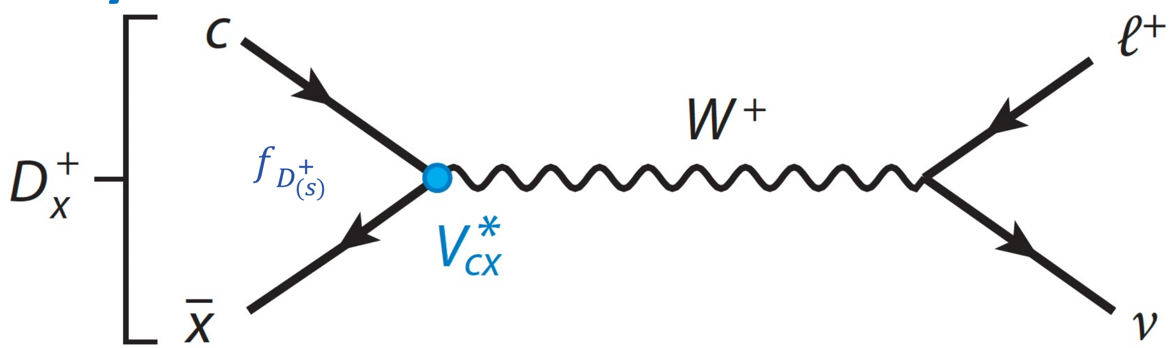
$$|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2 = \mathbf{1.001 \pm 0.012} \quad \sim 1\%$$

Precision of the second row is dominated by that of $|V_{cd}|$ and $|V_{cs}|$

Precise measurement of $|V_{cd}|$ and $|V_{cs}|$ is crucial

Leptonic decays of charmed mesons

Leptonic decays



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

- Exp. decay rate + LQCD $\Longrightarrow |V_{cd(s)}|$

  $\Longrightarrow$ Test CKM matrix unitarity

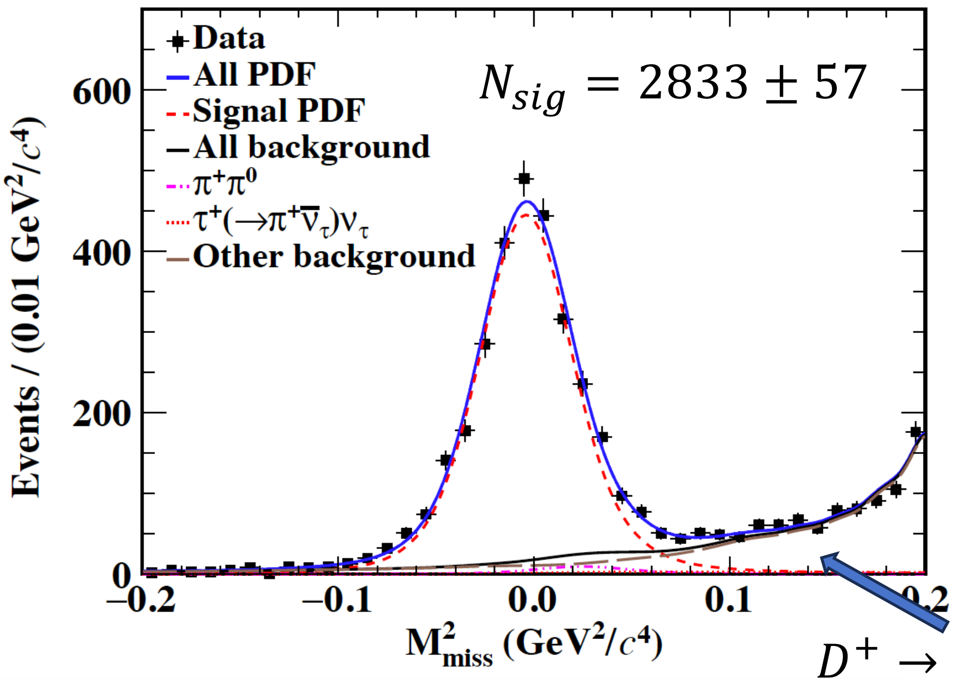
- Exp. decayrate + $|V_{cd(s)}|^{\text{CKMfitter}} \Longrightarrow$ Decay constant

  $\Longrightarrow$ Calibrate LQCD calculations

$D^+ \to \mu^+ \nu_\mu$

20.3 fb^{-1}@E_{cm}=3.773 GeV

PRL 135, 061081 (2025)



$D^+ \to \gamma\mu^+\nu_\mu$ background is simulated in the fit

- $\Gamma_{D^+\to\ell^+\nu_\ell} = \Gamma^0_{D^+\to\ell^+\nu_\ell}[1 + \frac{\alpha}{\pi} C_p] \Rightarrow$ Radiative correction term
  1. Short-distance electroweak correction increases BF by 1.8% [PRD98,074512, NPB196,83]
  2. Long-distance electroweak correction [inner bremsstrahlung and virtual photon] reduce BF by 2.5% with 0.6% uncertainty of unknown electromagnetic correction [PRD98,074512]

$$\mathcal{B}(D^+ \to \mu^+\nu_\mu) = (4.034 \pm 0.080 \pm 0.040)\times 10^{-4}$$

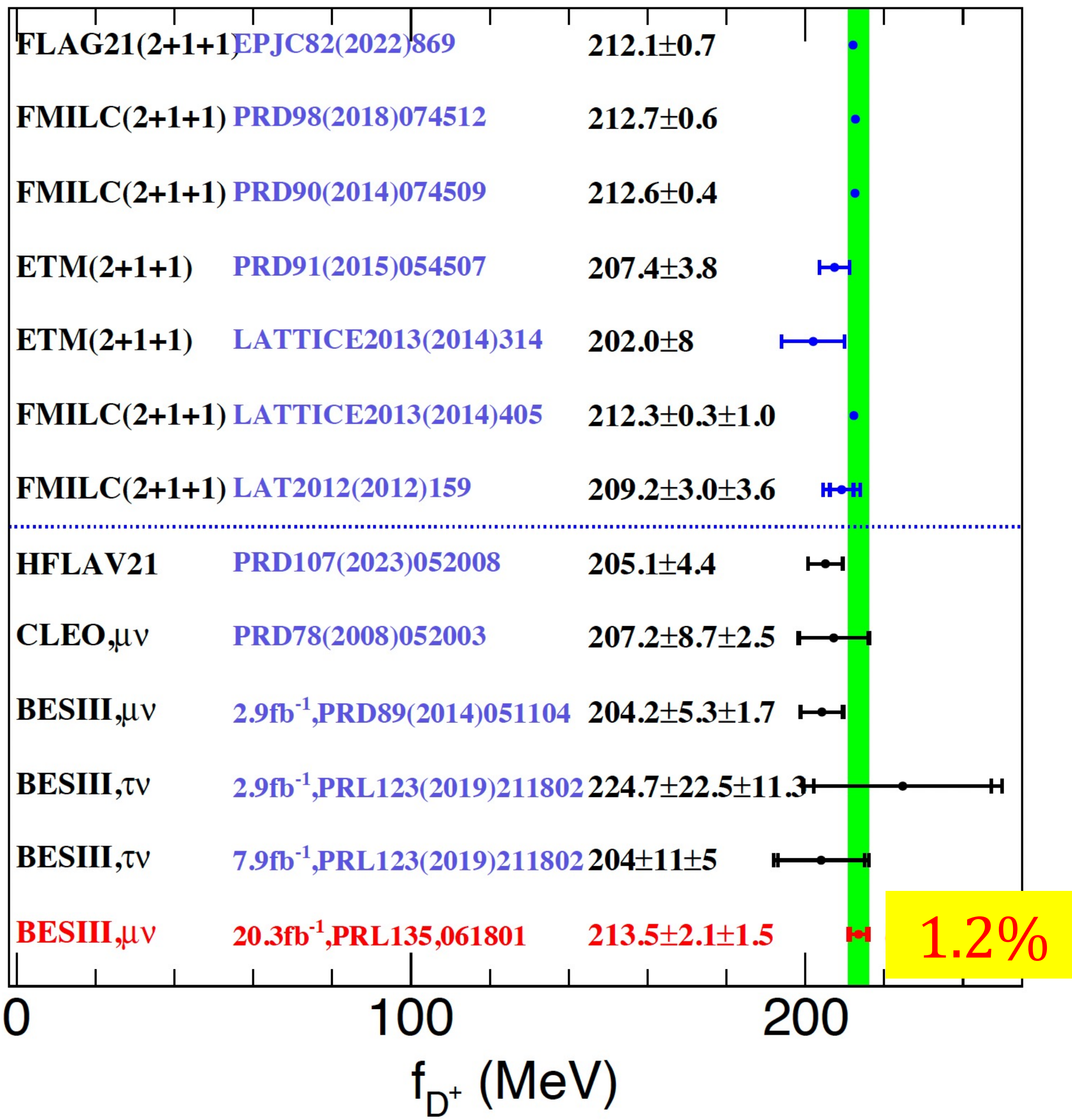
Precision is improved by 2.4x

$$f_{D^+}|V_{cd}| = (48.02 \pm 0.48 \pm 0.24 \pm 0.12_{\text{input}} \pm 0.15_{\text{EM}}) \text{ MeV}$$

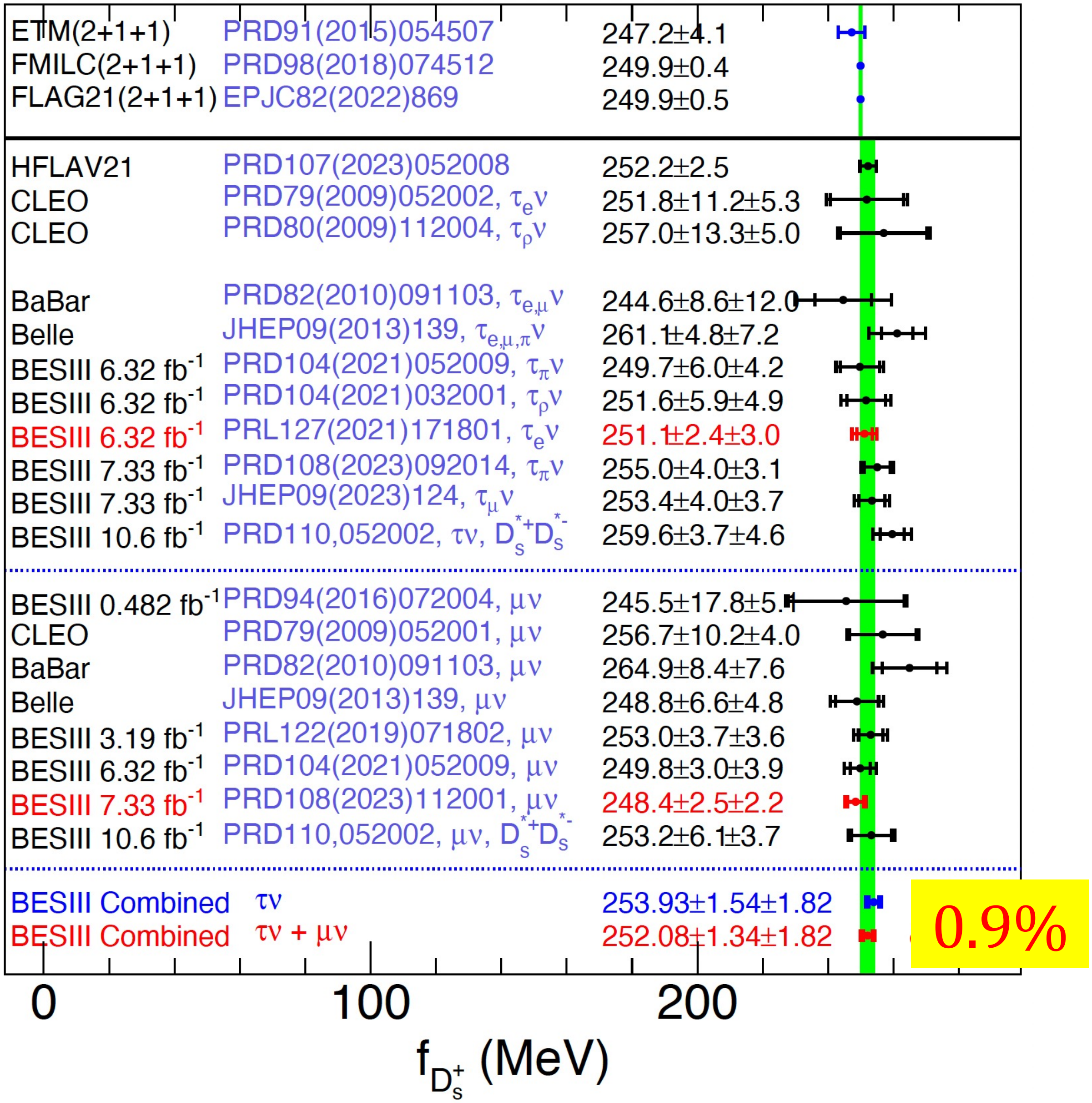
$$f_{D^+} = (213.5 \pm 2.1 \pm 1.1 \pm 0.8 \pm 0.7) \text{ MeV } (\sim 1.2\%)$$ Most precise

$$|V_{cd}| = (0.2265 \pm 0.0023 \pm 0.0011 \pm 0.0009 \pm 0.0007)$$

Comparison of f_{D^+}

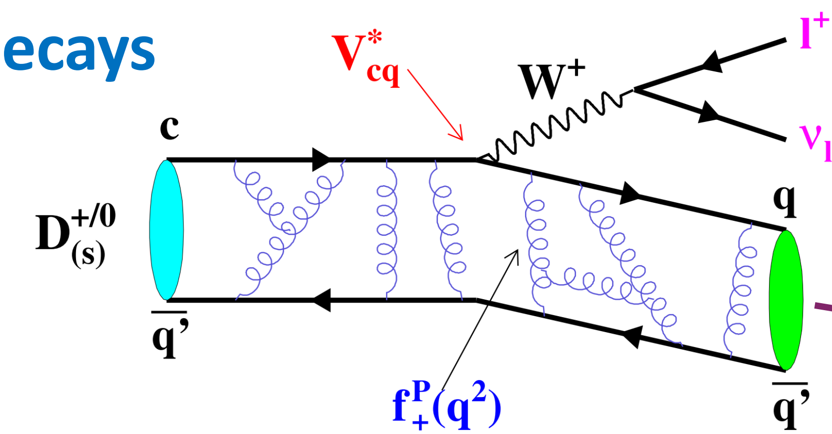


Comparison of $f_{D_s^+}$



Semileptonic decays of charmed mesons

Semileptonic decays



P, S, V, A
P = pseudoscalar
S = scalar
V = vector
A = axial-vector

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

Weak interaction: CKM matrix

Strong interaction: Form factor

- Exp. decay rate + LQCD $\Longrightarrow |V_{cd(s)}|$

  $\Longrightarrow$ Test CKM matrix unitarity

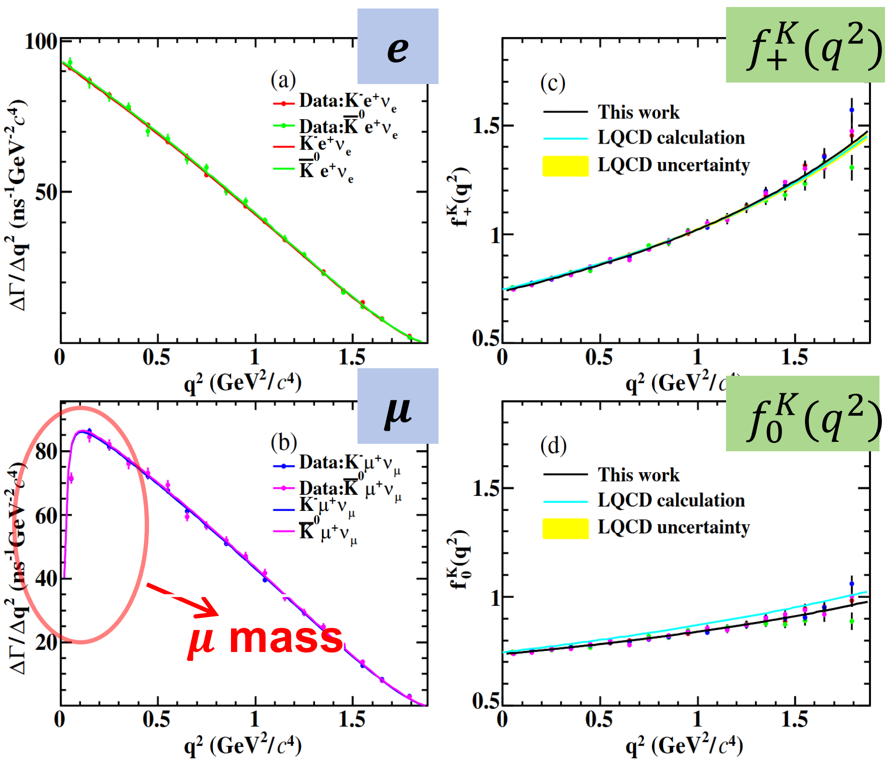
- Exp. decayrate + $|V_{cd(s)}|^{\text{CKMfitter}}$ $\Longrightarrow$ Form factors

  $\Longrightarrow$ Calibrate LQCD calculations

$D \to \bar{K}\ell^+\nu_\ell(\ell = e, \mu)$

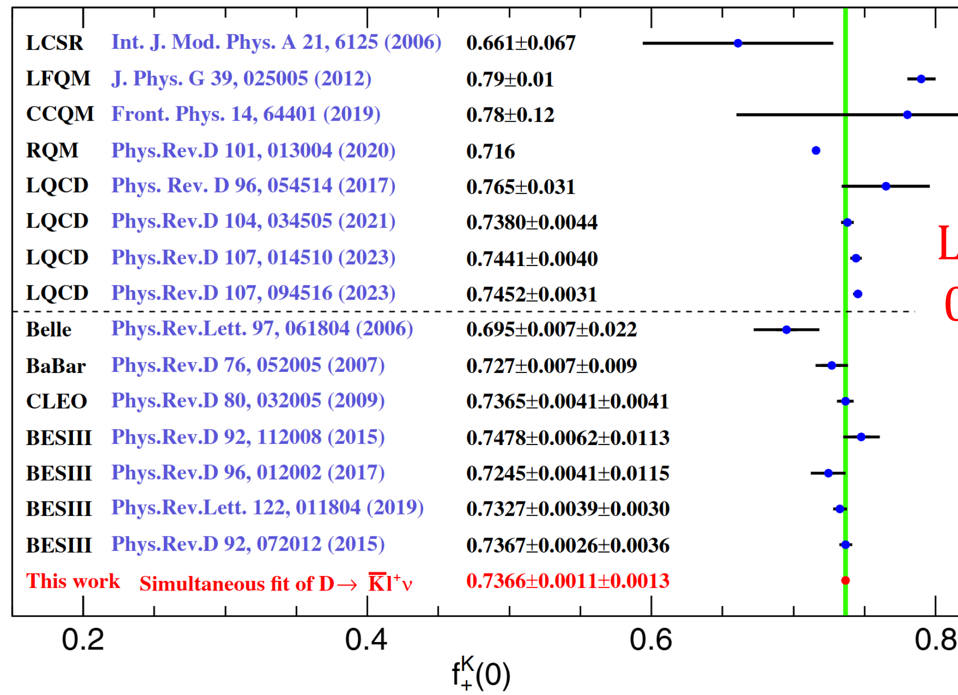
Simultaneous fit

PRD 110, 112006 (2024)



decay width in q^2 bin

Form factor in q^2 bin

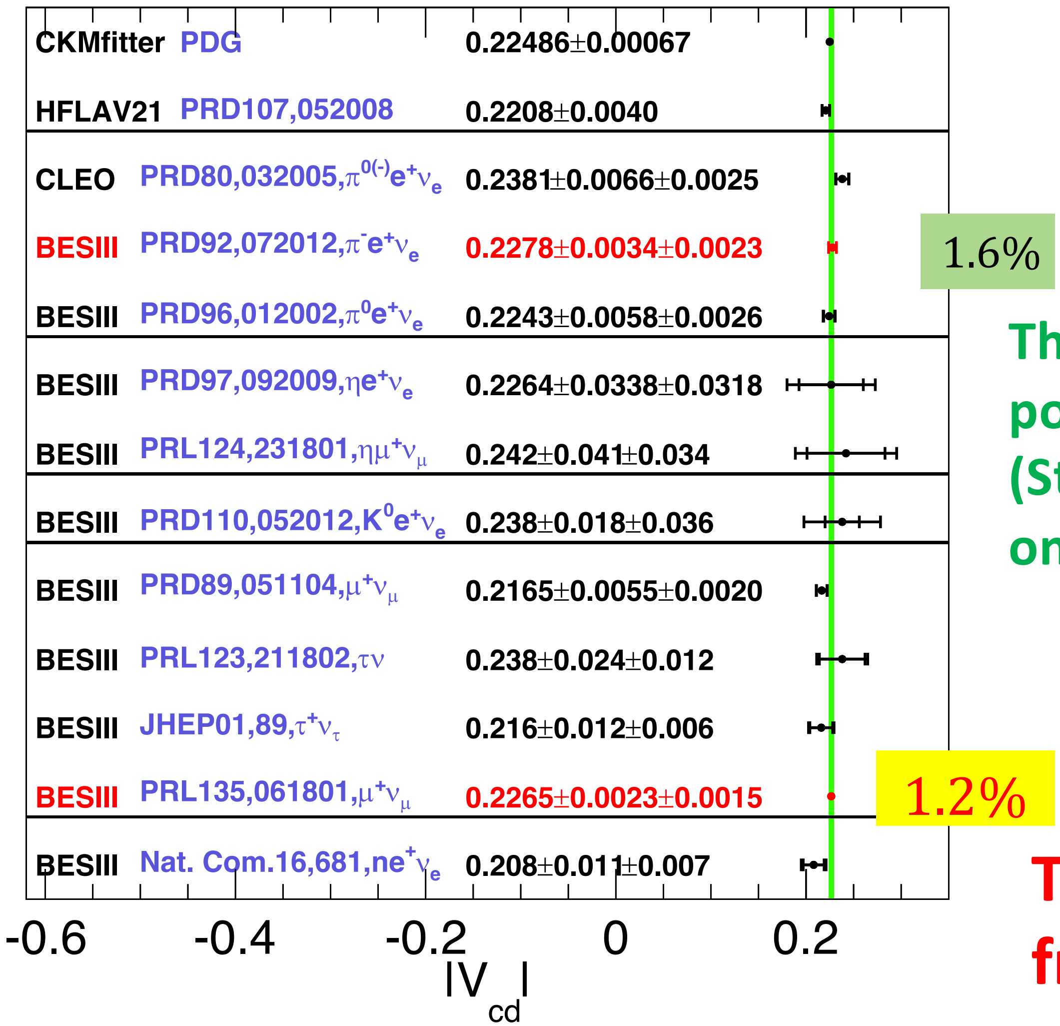


LQCD: 0.4%

- $f_+^K(0) = 0.7366 \pm 0.0011 \pm 0.0013$ (~0.24%) improved by > a factor of 2
- $|V_{cs}| = (0.9623 \pm 0.0015 \pm 0.0017 \pm 0.0040_{\mathrm{LQCD}})(\sim 0.48\%)$ most precise
- Main uncertainty of $|V_{cs}|$ from the LQCD calculations in the input $f_+^K(0)(\sim 0.42\%)$

(~2% before)

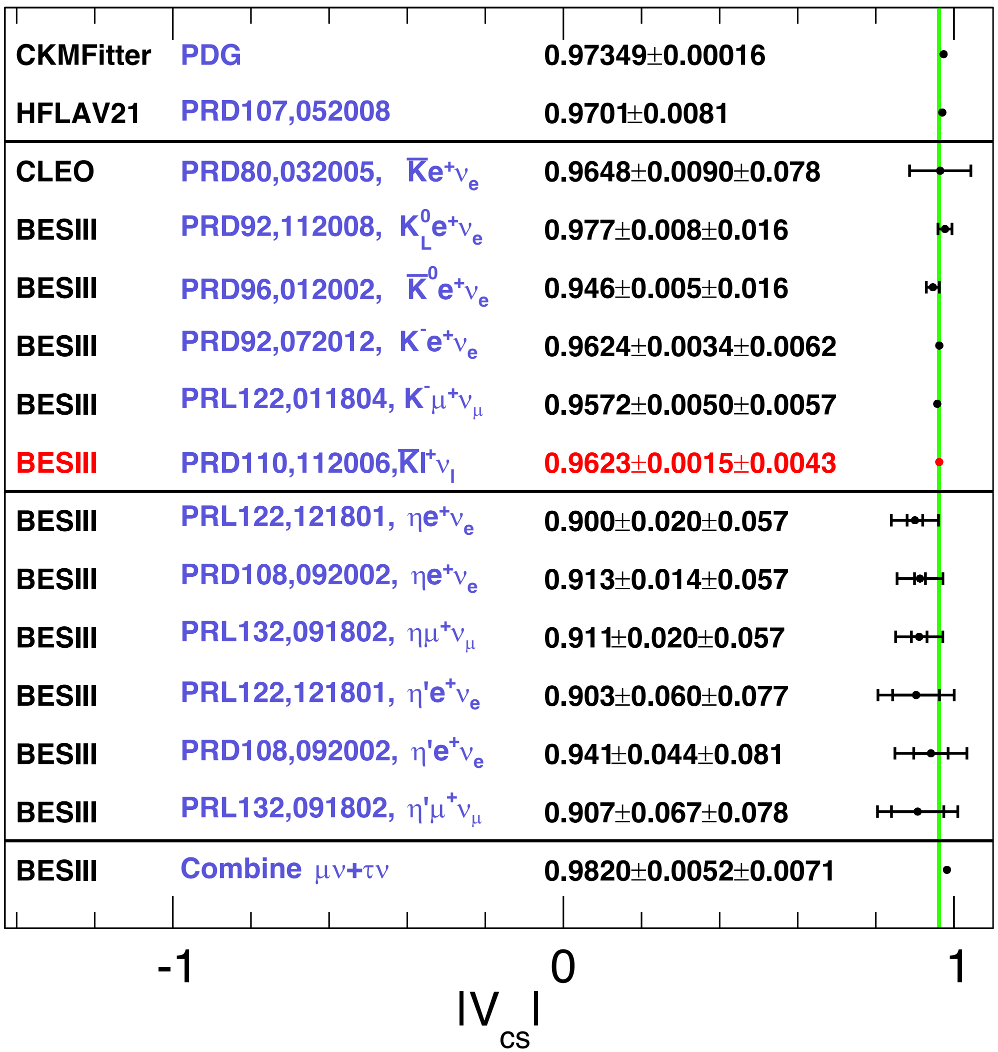
Comparison of $|V_{cd}|$



The semi-leptonic decays have potential to yield better precision (Stat. Uncertainty < 0.5%) depending on the uncertainty from LQCD.

The current best precision is from pure-leptonic decays

Comparison of $|V_{cs}|$



$\bar{K}\ell^+\nu_\ell$ simultaneous fit (stat sys~0.2%)

Main systematic uncertainty from the LQCD input $f_+^K(0)$)

0.5%

1.0%

The best precision for pure-leptonic decays is 1%

$D \to K^*(892)l^+\nu_l(\ell = e, \mu)$

- BF measurement:

7.93fb^{-1}@E_{cm}=3.773 GeV

$$\mathcal{B}(D^0 \to \bar{K}^0\pi^-\mu^+\nu_\mu) = (1.373 \pm 0.020 \pm 0.023)\%$$

PRL 134, 011803 (2025)

$$\mathcal{B}(D^0 \to \bar{K}^0\pi^-e^+\nu_e) = (1.444 \pm 0.022 \pm 0.024)\%$$

JHEP 03 (2025) 197

$$\mathcal{B}(D^+ \to K_S^0\pi^0e^+\nu_e) = (0.943 \pm 0.012 \pm 0.010)\%$$

JHEP 10 (2024) 199

$$\mathcal{B}(D^+ \to K_S^0\pi^0\mu^+\nu_\mu) = (0.896 \pm 0.017 \pm 0.008)\%$$

PRL 135, 171801 (2025)

- Using the Partial wave analysis method

$$\mathcal{B}(D^0 \to K^*(892)^-\mu^+\nu_\mu) = (2.062 \pm 0.039 \pm 0.032)\%$$

$$\mathcal{B}(D^0 \to K^*(892)^-e^+\nu_e) = (2.039 \pm 0.032 \pm 0.034)\%$$

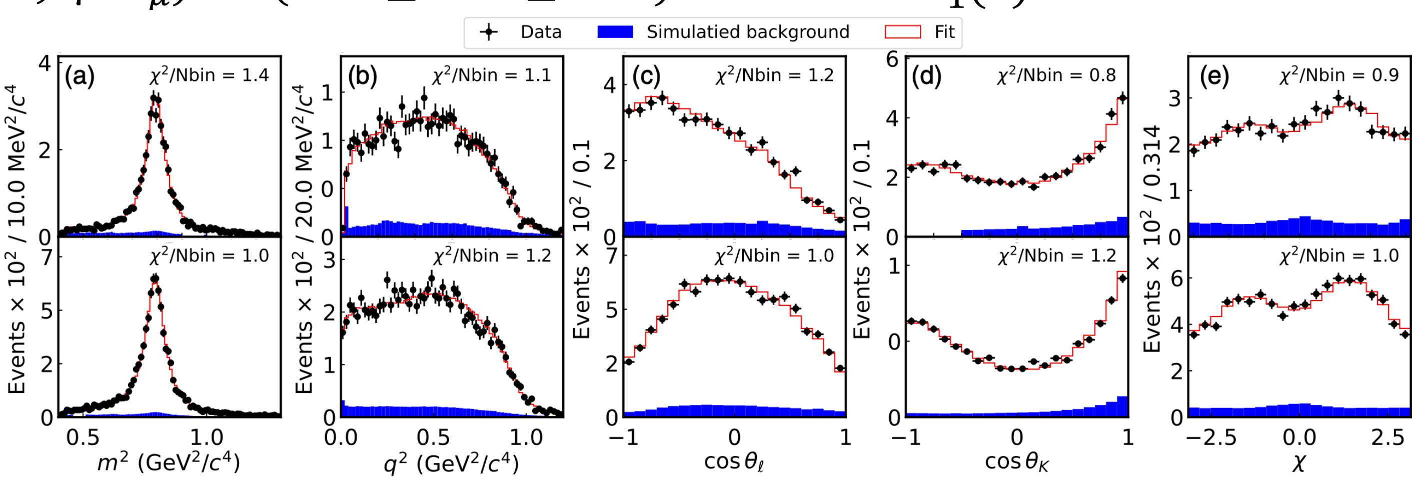
$$\mathcal{B}(D^+ \to K^*(892)^0e^+\nu_e) = (5.29 \pm 0.07 \pm 0.06)\%$$

$$\mathcal{B}(D^+ \to K^*(892)^0\mu^+\nu_\mu) = (5.00 \pm 0.10 \pm 0.06)\%$$

- **FF of $D \to K^*(892)$**

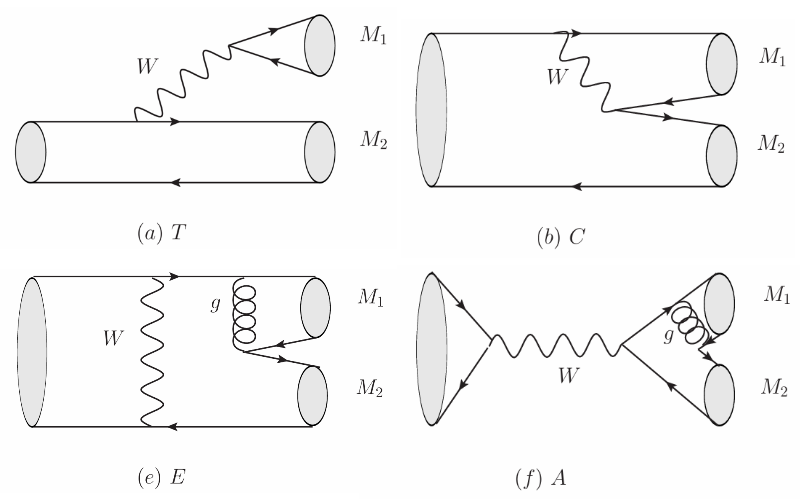
$$r_V = \frac{V(0)}{A_1(0)} = 1.42 \pm 0.03 \pm 0.02\ (3\% - 4\%)$$

$$r_2 = \frac{A_2(0)}{A_1(0)} = 0.75 \pm 0.03 \pm 0.01\ (5\% - 6\%)$$



Why study hadronic decays of charmed mesons?

- **Topological Diagram Approach**



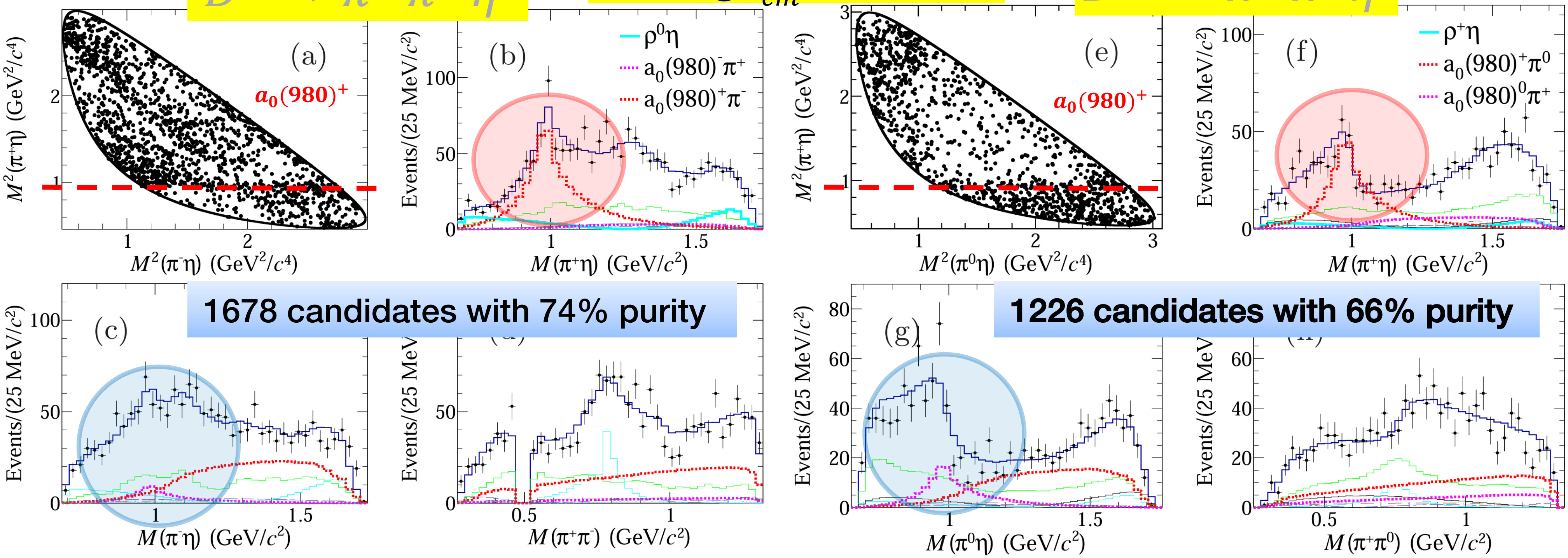
Mode	Amplitude
$D^0 \to K^+\pi^-$	$\lambda_{ds}(1.23T + E)$
$D^0 \to K^0\pi^0$	$\frac{1}{\sqrt{2}}\lambda_{ds}(C - E)$
$D^0 \to K^0\eta$	$\lambda_{ds}\left[\frac{1}{\sqrt{2}}(C+E)\cos\phi - E\sin\phi\right]$
$D^0 \to K^0\eta'$	$\lambda_{ds}\left[\frac{1}{\sqrt{2}}(C+E)\sin\phi + E\cos\phi\right]$
$D^+ \to K^0\pi^+$	$\lambda_{ds}(C + 0.71A)$
$D^+ \to K^+\pi^0$	$\frac{1}{\sqrt{2}}\lambda_{ds}(1.23T - 0.71A)$
$D^+ \to K^+\eta$	$\lambda_{ds}\left[\frac{1}{\sqrt{2}}(1.05T + A)\cos\phi - 0.81A\sin\phi\right]$
$D^+ \to K^+\eta'$	$\lambda_{ds}\left[\frac{1}{\sqrt{2}}(1.05T + A)\sin\phi + 0.81A\cos\phi\right]$
$D_s^+ \to K^0K^+$	$\lambda_{ds}(1.27T + 1.03C)$

- $D \to PP$: **high efficiency, low background, no interference, (usually) high precision. Good for Acp, η - η' mixing etc..**
- $D \to SP$, $D \to SV$, ($D \to SS$): **Understand the nature of light scalar mesons,** $a_0(980)$, $f_0(980)$, $K(700)$, $f_0(500)$ **etc..**
- $D \to VP$: **Clarifying the nonperturbative mechanism. Well defined quark content of V. Better than the PP and VV, due to the multiple-amplitude composition of P and the polarization in VV.**
- $D \to VV$: **Polarization in charmed decays.**
- $D \to AP$: **Study axial-vector mesons, a1(1260) K1(1400)etc..**

Observation of $D \to a_0(980)\pi$

Phys. Rev. D 110, L111102

$D^0 \to \pi^+\pi^-\eta$ 7.9fb^{-1}@E_{cm}=3.773 GeV $D^+ \to \pi^+\pi^0\eta$



$$\mathcal{B}(D^0 \to a_0(980)^+\pi^-)/\mathcal{B}(D^0 \to a_0(980)^-\pi^+) = 7.5 \,{}^{+2.5}_{-0.8}{}_{\text{stat.}} \pm 1.7_{\text{syst.}}$$

$$\mathcal{B}(D^+ \to a_0(980)^+\pi^0)/\mathcal{B}(D^+ \to a_0(980)^0\pi^+) = 2.6 \pm 0.6_{\text{stat.}} \pm 0.3_{\text{syst.}}$$

⟹ Disagrees with theoretical predictions by orders of magnitude

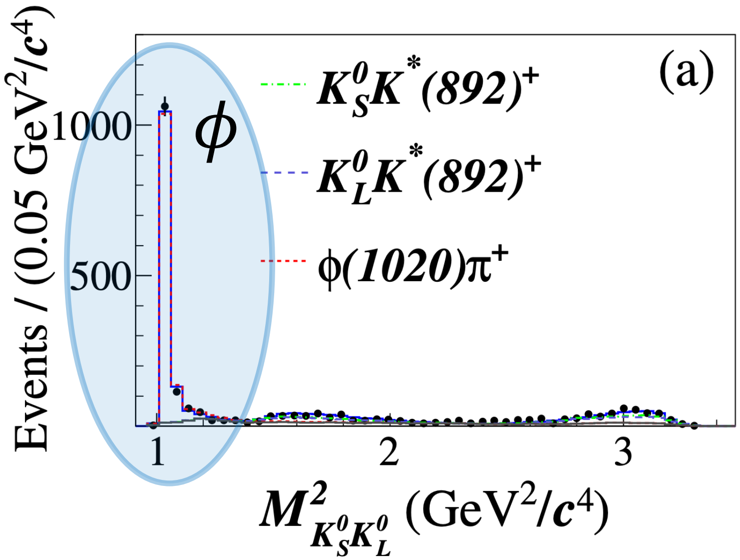
The external W-emission diagram dominates the $D \to a_0(980)\pi$ decays in the diquark scenario, contrary to expectations of its negligible contribution due to the very small $a_0(980)$ decay constant[1].

[1] Phys. Rev. D **105**, 033006(2022).

Amplitude analysis of $D_s^+ \to \phi(K_S^0 K_L^0)\pi^+$

$D_s^+ \to K_S^0 K_L^0 \pi^+$

Phys. Rev. Lett. 135, 161902 (2025)



Amplitude	Phase (rad)	FF (%)	BF (%)
$D_s^+ \to \phi\pi^+$	0.0(fixed)	$70.9 \pm 1.3 \pm 1.5$	$1.32 \pm 0.05 \pm 0.04$
$D_s^+ \to K_L^0 K^*(892)^+$	$0.68 \pm 0.17 \pm 0.21$	$22.8 \pm 1.3 \pm 1.5$	$0.42 \pm 0.03 \pm 0.03$
$D_s^+ \to K_S^0 K^*(892)^+$	$-2.40 \pm 0.18 \pm 0.31$	$17.4 \pm 1.2 \pm 0.9$	$0.31 \pm 0.02 \pm 0.02$

✓ Observation of the $K_S^0 - K_L^0$ asymmetry in the $D \to K^0_{S/L} V$

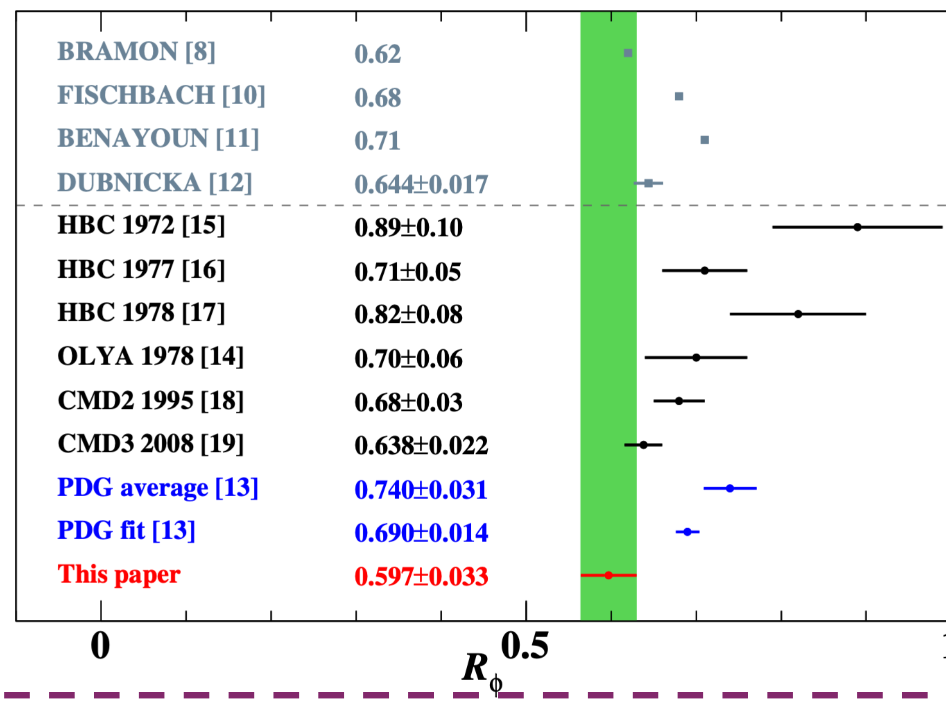
(Interefrence of CF and DCS decays)

- $$\frac{\mathcal{B}(D_s^+ \to K_S^0 K^*(892)^+) - \mathcal{B}(D_s^+ \to K_L^0 K^*(892)^+)}{\mathcal{B}(D_s^+ \to K_S^0 K^*(892)^+) + \mathcal{B}(D_s^+ \to K_L^0 K^*(892)^+)} = -0.134 \pm 0.05_{\text{stat.}} + 0.034_{\text{syst.}}$$

Model	DAT(F4)	DAT(F1′)
$D_s^+ \to \bar{K}^0 K^{*+}$	-0.164 ± 0.032	-0.159 ± 0.028

Predictions by H. Y. Cheng *et al.*, PRD109, 073008

✓ Measurement of ϕ

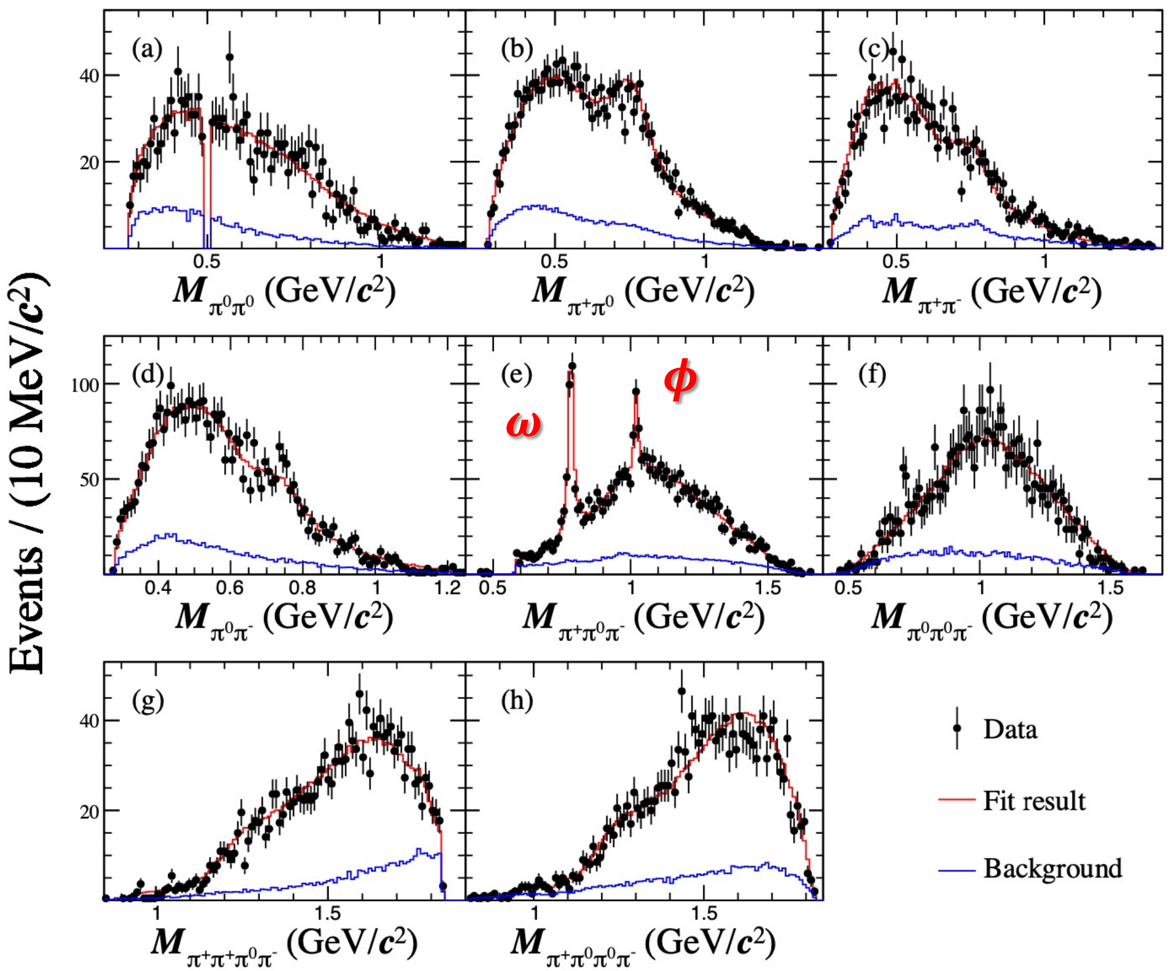


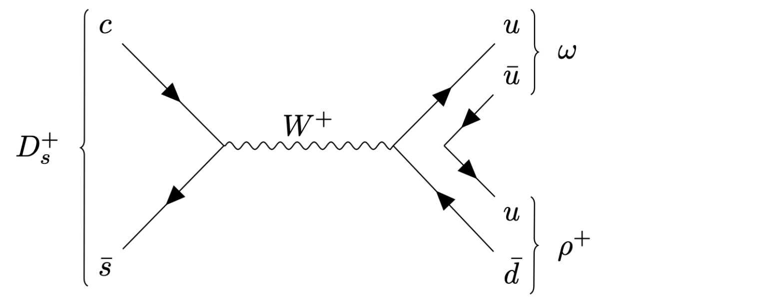
$$\frac{\mathcal{B}(\phi \to K_S^0 K_L^0)}{\mathcal{B}(\phi \to K^+ K^-)} = 0.597 \pm 0.023_{\text{stat}} \pm 0.024_{\text{syst}}$$

deviates from PDG (0.740 ± 0.033) by $> 3\sigma$.

$D \to VV$ in $D_s^+ \to \pi^+\pi^+\pi^-\pi^0\pi^0$

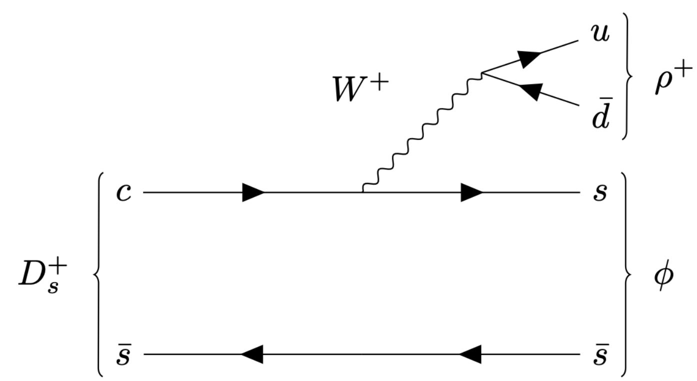
PRL 134, 201902 (2025)





pure W-annihilation $D_s^+ \to \omega\rho^+$

about 50% D-wave



Pure external W emission $D_s^+ \to \phi\rho^+$ dominated by S-wave

✓ Measurement of ϕ

$$\frac{\mathcal{B}(\phi\to\pi^+\pi^-\pi^0)}{\mathcal{B}(\phi\to K^+K^-)} = 0.222 \pm 0.019_{\text{stat}} \pm 0.016_{\text{syst}}$$

deviates from PDG (0.313 ± 0.010) % by $> 3\sigma$.

Larger than other WA decays

$$\mathcal{B}(D_s^+ \to \omega\rho^+) = (\mathbf{0.99} \pm 0.\mathbf{08} \pm 0.\mathbf{07})\%$$

$$\mathcal{B}(D_s^+ \to \phi\rho^+) = (\mathbf{3.98} \pm 0.\mathbf{33} \pm 0.21)\%$$

Quantum Correlation

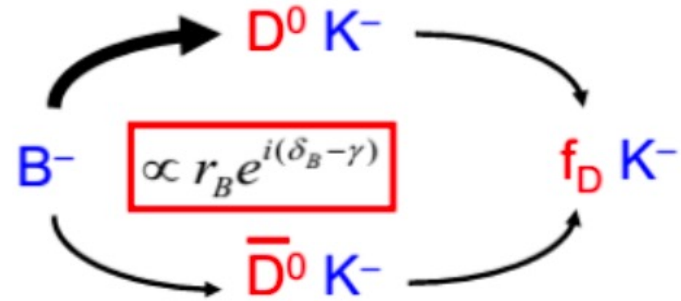
Quantum correlated data: $e^+e^- \rightarrow \psi(3770) \rightarrow D^0\bar{D}^0$

Best laboratory to measure strong-phase parameters

CP-odd: $\psi(3770) = \left(D^0\bar{D}^0 - D^0\,\bar{D}^0\right) = (D_+D_- - D_-D_+)$

$J^{PC} = 1^{--}$

CP-even CP-odd

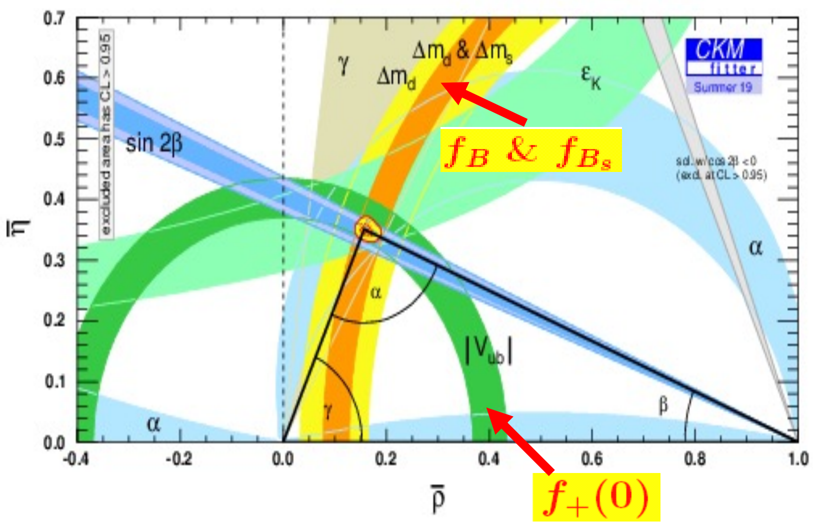


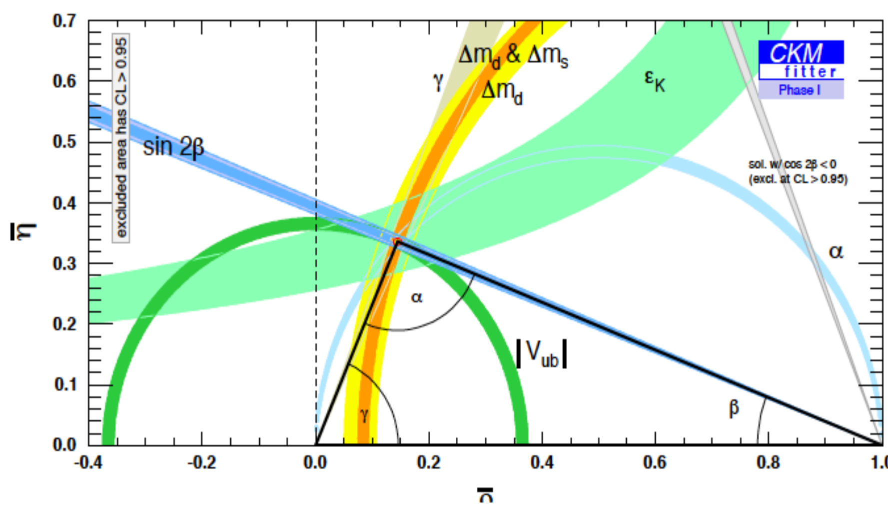
Inputs to LHCb measurement of γ/ϕ₃:

LHCb (arXiv:1808.08865v2):

< 1°, 50 fb^{-1}, phase-1 upgrade (2030),

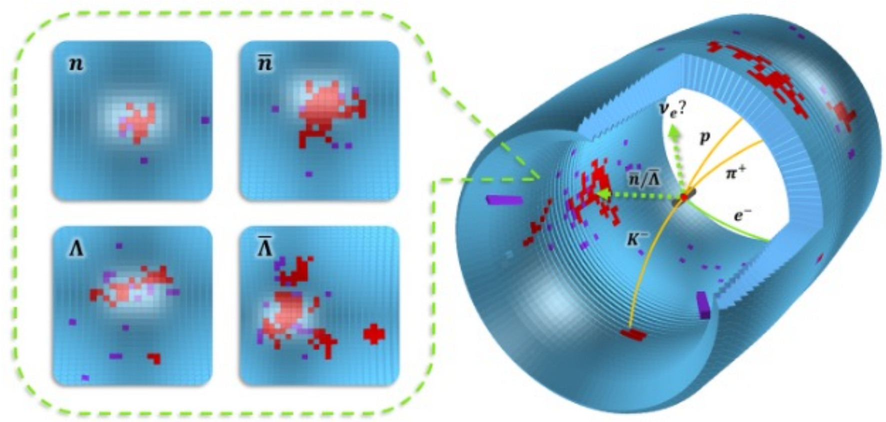
< 0.4°, 300 fb^{-1}, phase-2 upgrade (> 2035)

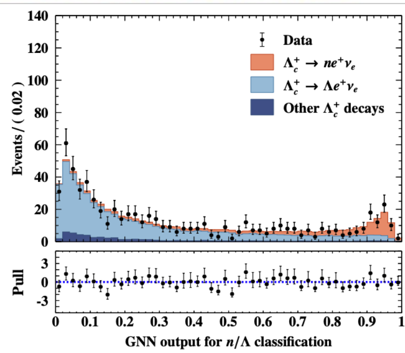


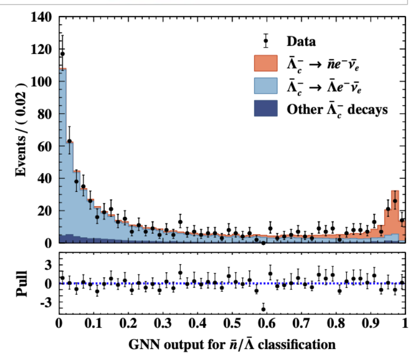


>year of 2030 (BESIII 20 fb^{-1} data as inputs)

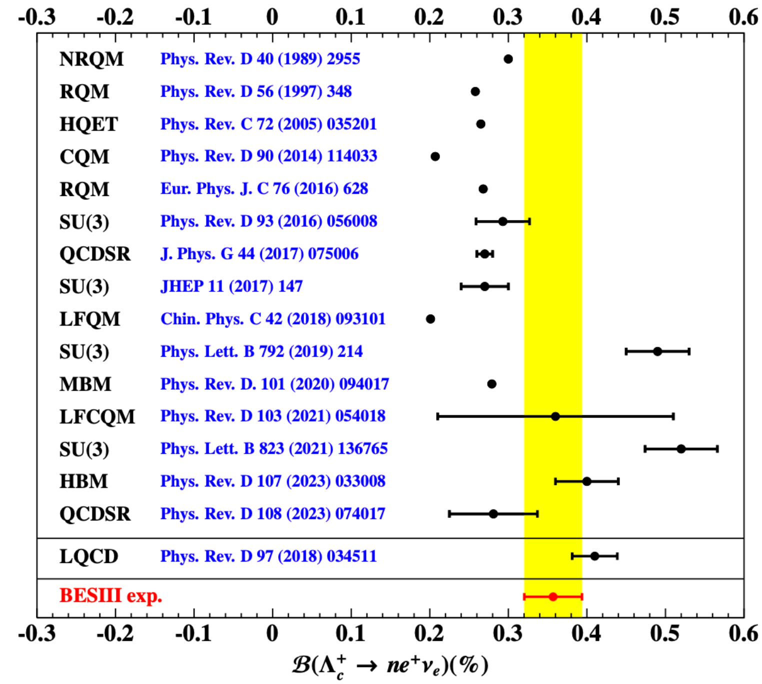
Observation of $\Lambda_c^+ \to n e^+ \nu_e$ with Machine Learning







Nature Comm. 16, 681 (2025)



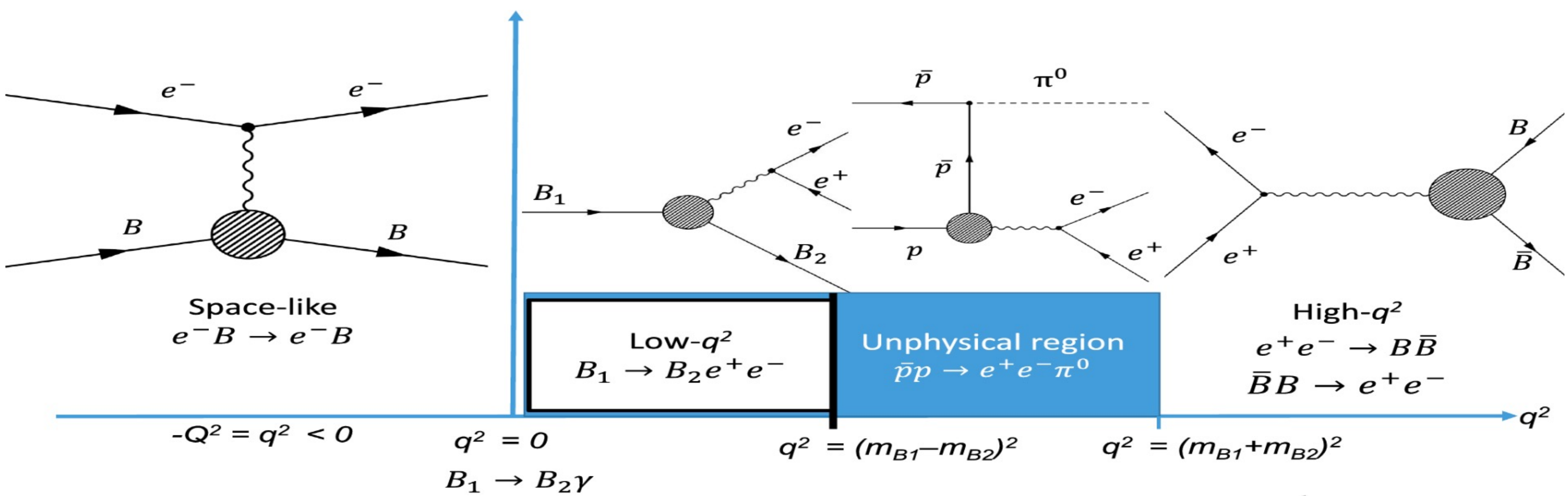
- A novel Deep Learning is utilized to separate signals from dominant background from $\Lambda_c^+ \to \Lambda(\to n\pi^0)e^+\nu$
- Train GNN with **ParticleNet** using control data based on 10B J/ψ decays
- First observation of $\Lambda_c^+ \to n e^+ \nu_e$

  $\mathcal{B}(\Lambda_c^+ \to n e^+ \nu_e) = \left(0.357 \pm 0.034_{\rm stat} \pm 0.014_{\rm syst}\right)\%\ (> 10\sigma)$
- Demonstrate a level of precision comparable to the LQCD prediction.

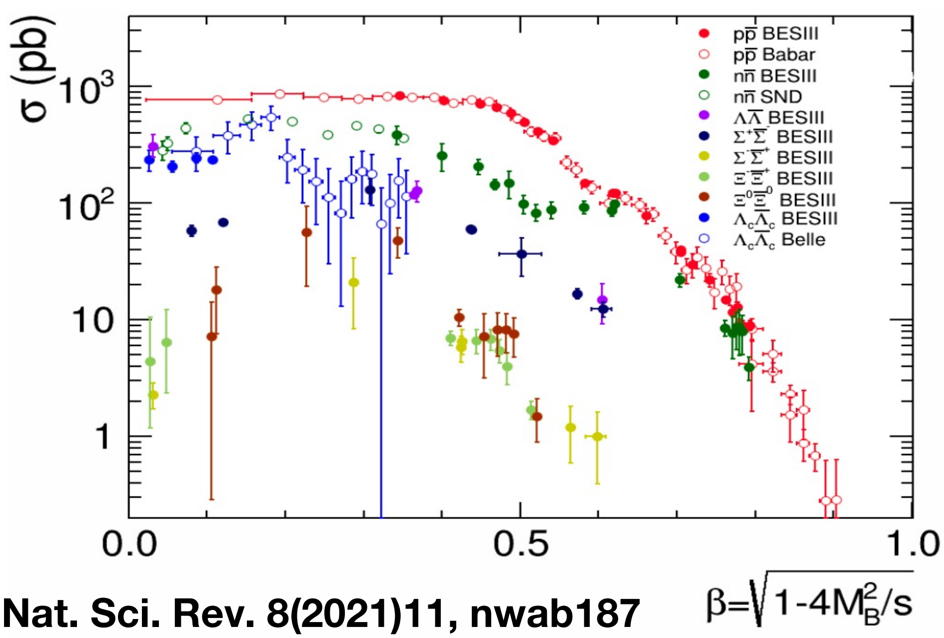
Hadron structure

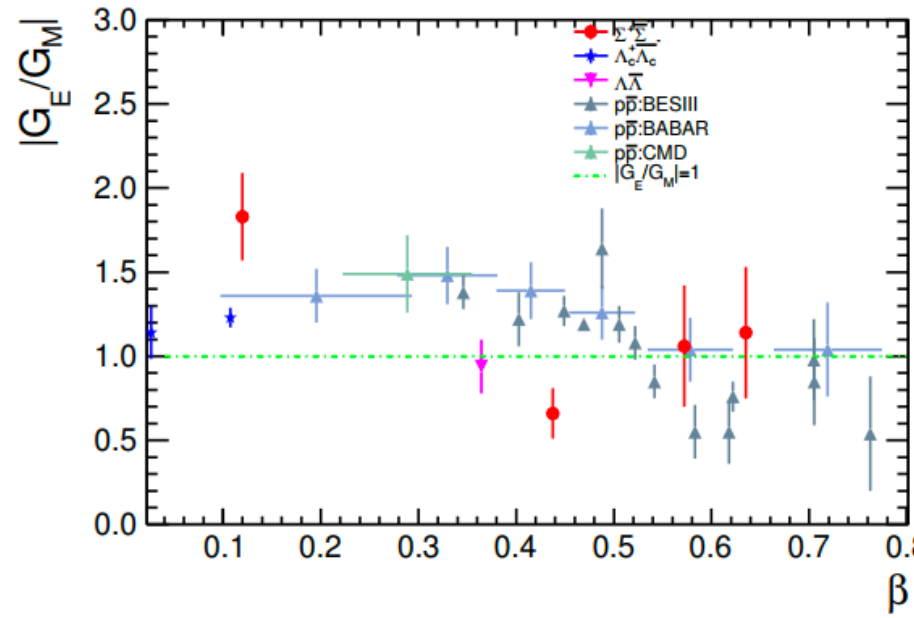
Quark confinement and non-perturbative feature in low-energy QCD region are big challenges

- **Electromagnetic Form Factors (EMFFs) describes the internal structure/shape of the non-point-like particle**
  - **Connected to charge, magnetization distribution**
  - **Crucial testing ground for baryon internal structures**
- **EMFFs measured in space-like and time-like regions**



Hadron structure



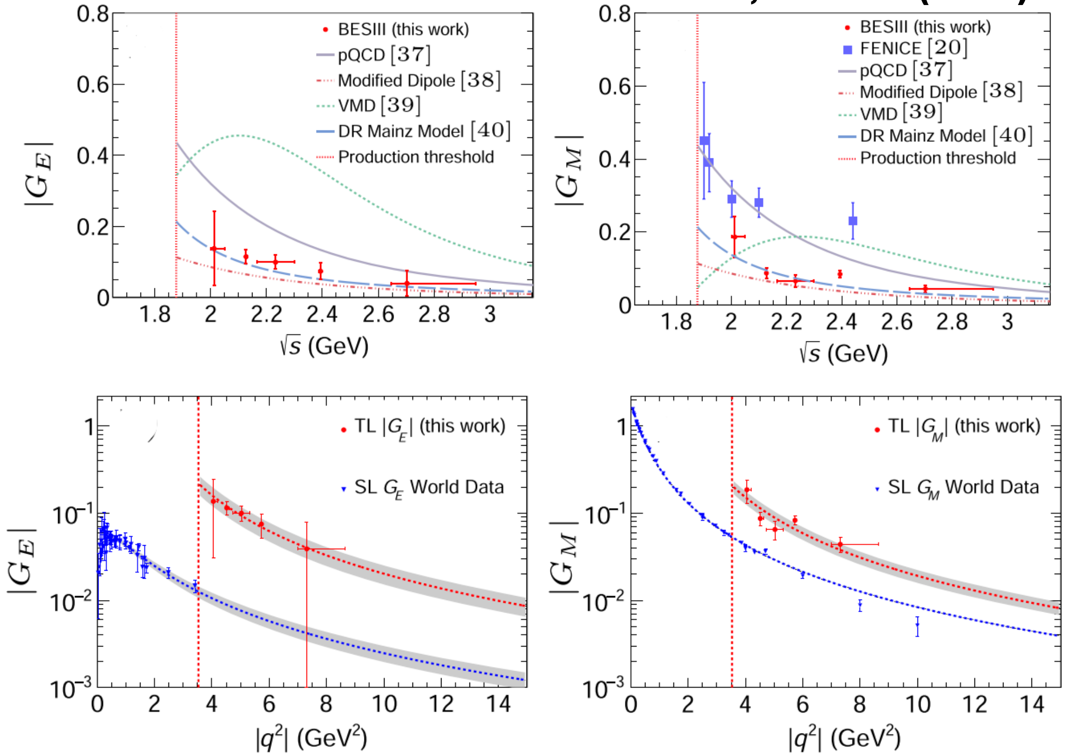


- **Abnormal threshold effects observed in various baryon pair production: $p\bar{p}$, $\Lambda\bar{\Lambda}$, $\Lambda_c^+\bar{\Lambda}_c^-$ …**
- **Oscillation structures observed**
- **$|G_E/G_M|$ ratio significantly larger than 1 at low beta for p, Λ_c^+, Σ^+ indicating large D-wave near threshold**
- **Relative phase angle of form factor $\Delta\phi$($\sin\Delta\phi$) measured.**

Hadron structure

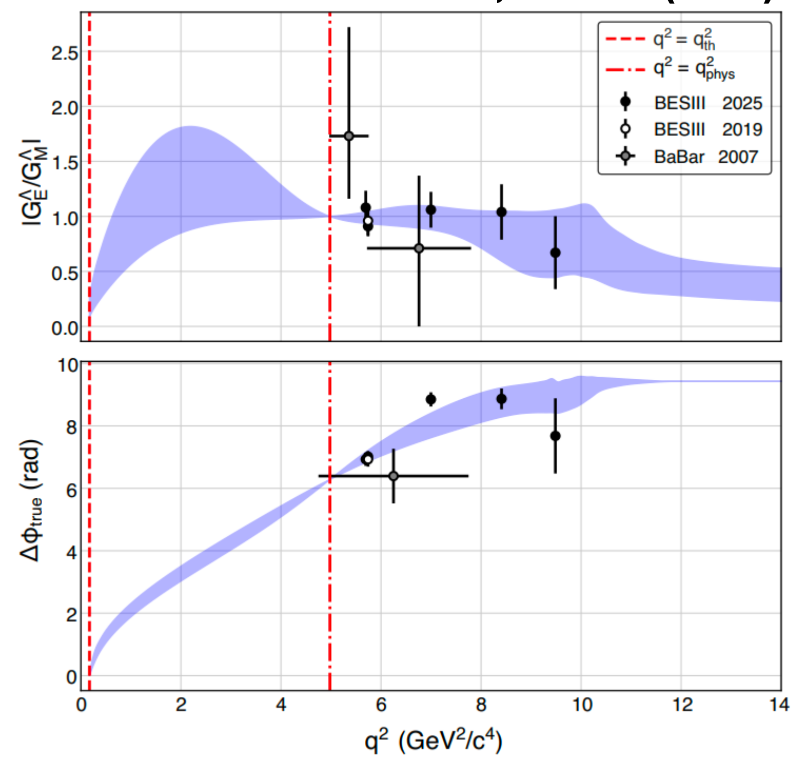
Neutron EMFFs

PRL 130, 151905 (2023)



Lambda EMFFs

PRL 135, 191902 (2025)



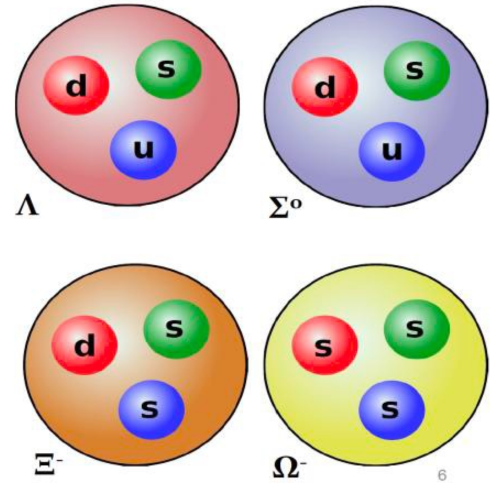
- **The |GM| values are smaller than FENICE by a factor of 2-3.**
- **The analyticity of SL and TL EMFFs:**
  $\mathcal{R}^E=5.18\pm1.18$; $\mathcal{R}^M=1.72\pm0.14$

$$\mathcal{R}^{E,M} \equiv |G^{TL}_{E,M}(q^2)/G^{SL}_{E,M}(-q^2)| \overset{|q^2|\to\infty}{\longrightarrow} 1$$

- **$R=|G_E(q^2)/G_M(q^2)|$remains constant, while ΔΦchanges by more than 90∘between 2.396 and 2.6544 GeV.**

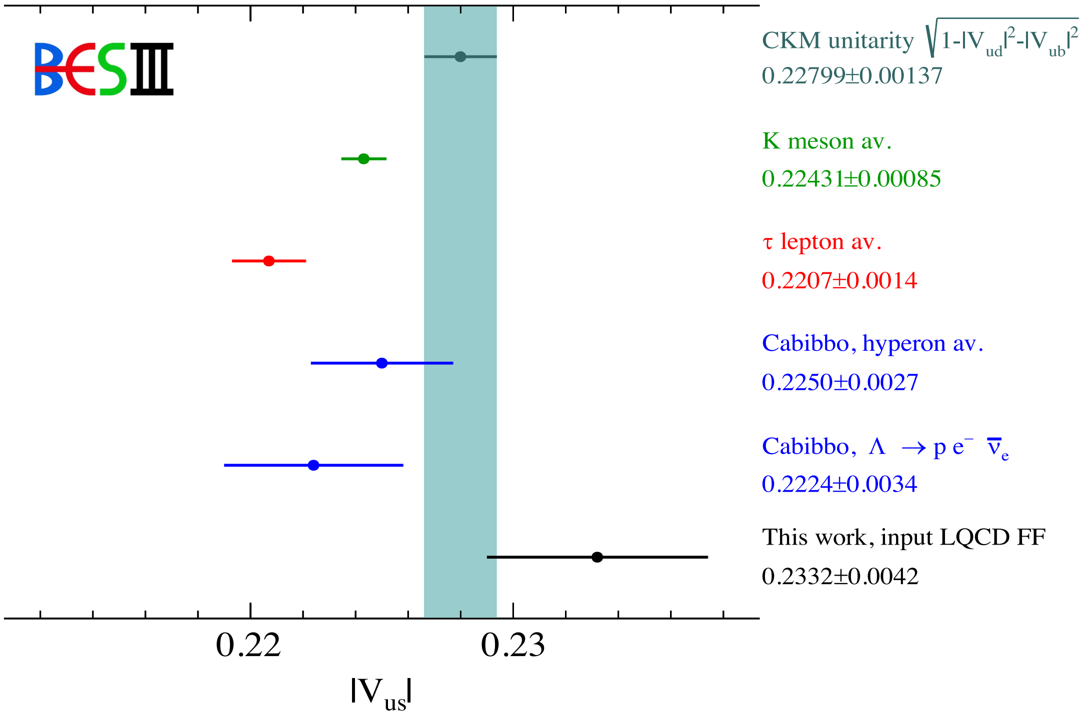
Hyperon Physics

- **Hyperon is any baryon containing one or more squarks, but no c, b or t quark.**
- **The 10B J/psi at BESIII provide large samples of hyperon.**

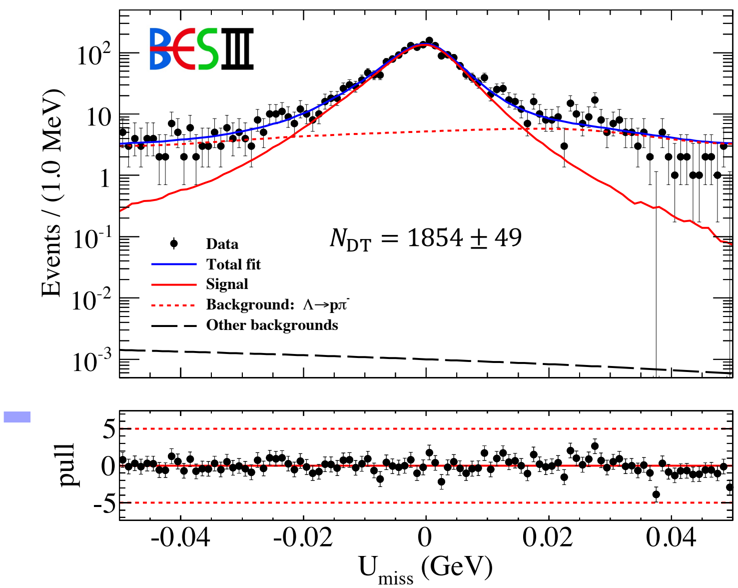


Decay mode	$\mathcal{B}(\times 10^{-3})$	$N_B\ (\times 10^6)$	Detection Efficiency	Number of reconstructed
$J/\psi \to \Lambda\bar{\Lambda}$	1.61 ± 0.15	16.1 ± 1.5	40%	4500 X 10^3
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	1.29 ± 0.09	12.9 ± 0.9	25%	600 X 10^3
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	1.50 ± 0.24	15.0 ± 2.4	24%	640 X 10^3
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}^+$ (or c.c.)	0.31 ± 0.05	3.1 ± 0.5		
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}(1385)^+$ (or c.c.)	1.10 ± 0.12	11.0 ± 1.2		
$J/\psi \to \Xi^0\bar{\Xi}^0$	1.20 ± 0.24	12.0 ± 2.4	14%	670 X 10^3
$J/\psi \to \Xi^-\bar{\Xi}^+$	0.86 ± 0.11	8.6 ± 1.0	19%	810 X 10^3
$J/\psi \to \Xi(1530)^0\bar{\Xi}^0$	0.32 ± 0.14	3.2 ± 1.4		
$J/\psi \to \Xi(1530)^-\bar{\Xi}^+$	0.59 ± 0.15	5.9 ± 1.5		
$\psi(2S) \to \Omega^-\bar{\Omega}^+$	0.05 ± 0.01	0.15 ± 0.03		

$\Lambda \to p e^- \nu_e$



arXiv:2509.09266, submit to Nature



First absolute BF measurement

$$\mathcal{B}(\Lambda \to p e^- \bar{\nu}_e) = (8.16 \pm 0.22 \pm 0.15)\times 10^{-4}$$

Determiantion of $|V_{us}|$

- Assume SU(3) is conserved, $f_1 = \sqrt{3/2}$ [PRL92(2004)251803]

$$|V_{us}|_{\text{SU(3)}} = 0.2199 \pm 0.0036_{\text{BESIII BF}} \pm 0.0087_{\text{BESIII FF}} \pm 0.0004_{\tau_\Lambda} \pm 0.0005_{\text{RC}}$$

- Using LQCD FF prediction [arXiv:2507.09970]

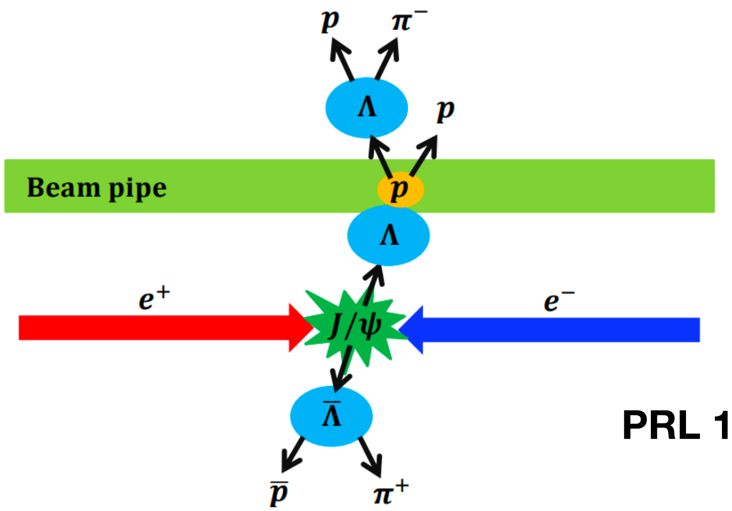
$$|V_{us}|_{\text{LQCD}} = 0.2332 \pm 0.0039_{\text{BESIII BF}} \pm 0.0004_{\tau_\Lambda} \pm 0.0006_{\text{RC}} \pm 0.0014_{\text{LQCD}}$$

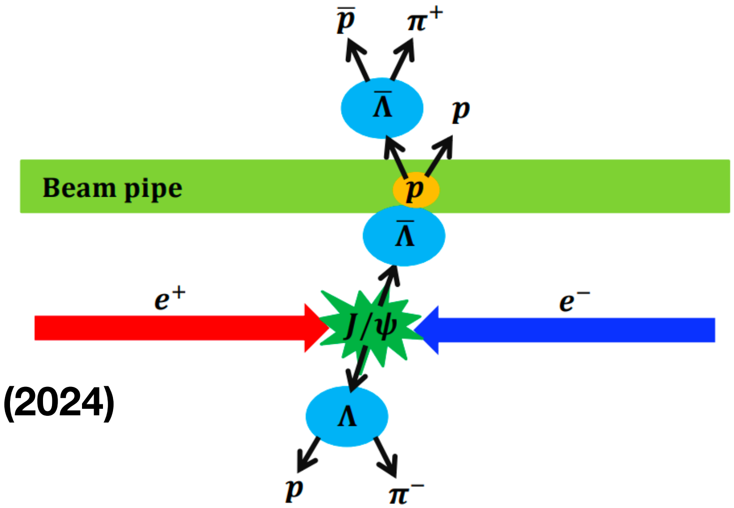
Hyperon-nucleon interaction

Particle source: Hyperons from J/ψ decays

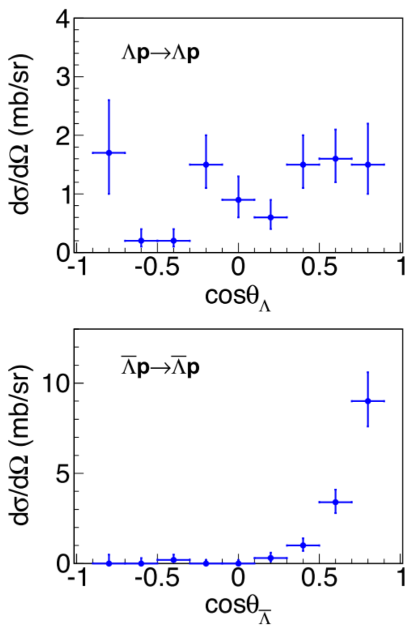
Target material: Beam pipe (Be); Detector: BESIII detector

Study of $\Lambda p \to \Lambda p$ and $\bar{\Lambda} p \to \bar{\Lambda} p$





PRL 132, 231902 (2024)



Cross sections in $-0.9 \le cos\theta \le 0.9$:

$$\sigma(\Lambda p \to \Lambda p) = (12.2 \pm 1.6 \pm 1.1)\ \text{mb}$$
$$\sigma(\bar{\Lambda} p \to \bar{\Lambda} p) = (17.5 \pm 2.1 \pm 1.6)\ \text{mb}$$

First measurement of antihyperon-nucleon scattering

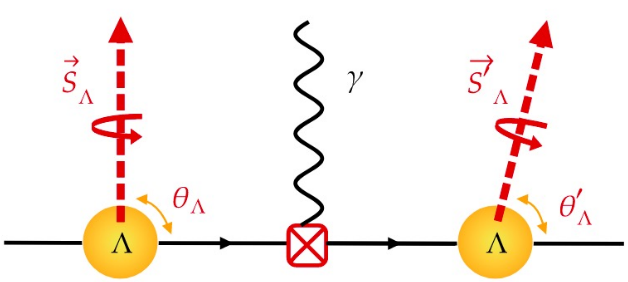
Λ EDM via Quantum entanglement

arXiv:2506.19180

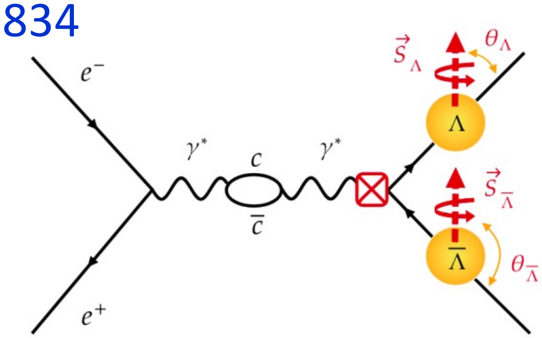
- **Challenges in Hyperon EDM Measurement:**
  - **Short lifetimes make traditional spin-precession measurements impractical**
  - **Prior direct Λ EDM limit (Fermilab, 1981): $|d\Lambda| < 1.5\times10^{-16}\ e\cdot\text{cm}$.**

- **New Approach @ BESIII:**
  - **Utilize entangled $\Lambda - \bar{\Lambda}$ pairs produced via $e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$**
  - **Extract EDM from CP-odd angular correlations in decay distributions**
  - **Angular variables sensitive to EDM via interference with CP-violating form factor H_T**

PLB 839(2023)137834



Spin precession method



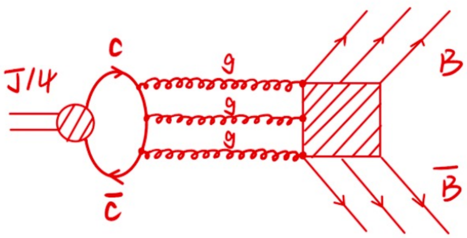
Extract EDM through CP-violating FF

Hyperon EDM at BESIII

X.G.He, J.P. Ma, PLB 839(2023)137834

Detailed dynamics in J/ψ decay to hyperon pair, have been studied:

$$\mathcal{A} = \epsilon_\mu(\lambda)\bar{u}(\lambda_1)\left(\boldsymbol{F_V}\gamma^\mu + \frac{i}{2M_\Lambda}\sigma^{\mu\nu}q_\nu\boldsymbol{H_\sigma} + \gamma^\mu\gamma^5\boldsymbol{F_A} + \sigma^{\mu\nu}\gamma^5 q_\nu\boldsymbol{H_T}\right)\nu(\lambda_2)$$



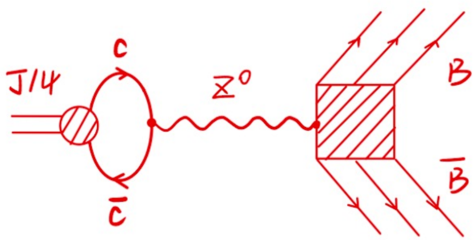
Dominant contribution

arXiv:hep-ph/0412158

Psionic form factor

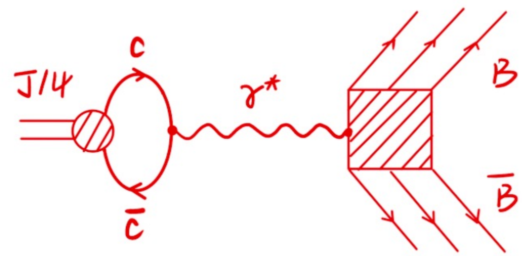
$\boldsymbol{F_V}$ and $\boldsymbol{H_\sigma}$

can also be represented as $\boldsymbol{G_1}$ and $\boldsymbol{G_2}$



P violation term

Complex form factor, $F_A \neq 0$ indicate P violation



$\boldsymbol{H_T}$ is included in this term

$$H_T(q^2) = \frac{2e}{3m_{J\psi}^2} g_V d_B(q^2)$$

Assuming $d_B(q^2) \equiv d_B(0)$

$d_B(q^2)$: electric dipole form factor

$d_B(0)$: electric dipole moment

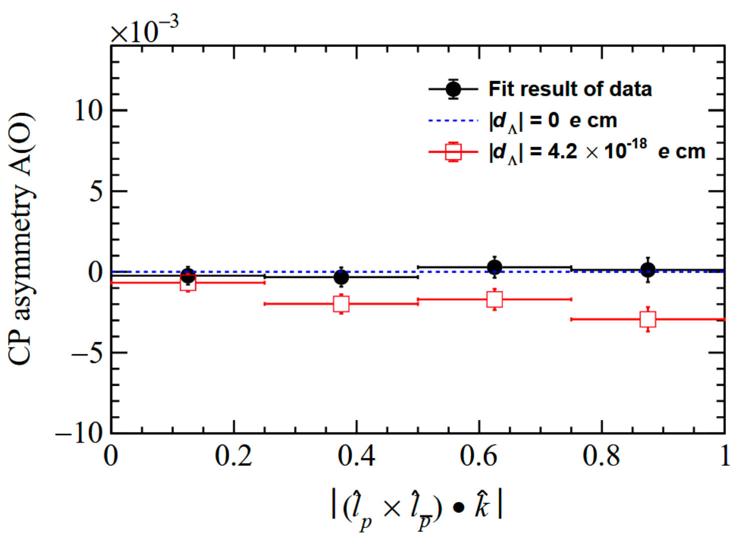
Physics Letters B 551 (2003) 16–26

Measurement of Λ EDM at BESIII

- **EDM extracted via angular analysis of entangled decays:**
  - $Re(d\Lambda) = -3.1 \pm 3.2 \pm 0.5 \times 10^{-19}\ e \cdot \text{cm}$
  - $Im(d\Lambda) = 2.9 \pm 2.6 \pm 0.6 \times 10^{-19}\ e \cdot \text{cm}$

which corresponds to $|d\Lambda| < 7.0 \times 10^{-19}\ e \cdot \text{cm}$ (95% CL)

- **Improves sensitivity by 3 orders of magnitude over previous best.**
- **First EDM constraint from strange quark system using quantum entanglement.**



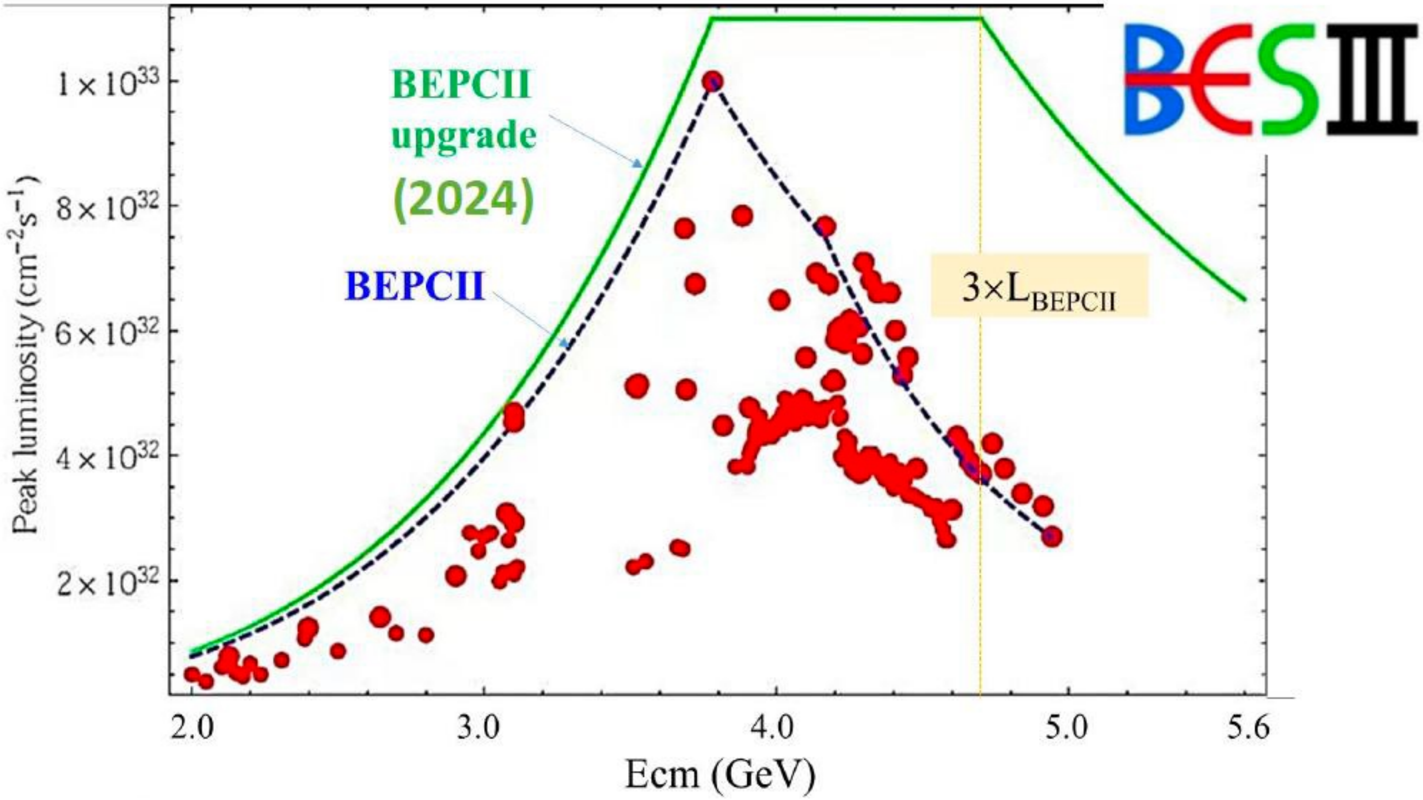
Triple-product asymmetry projection: EDM = 0 vs non-zero EDM hypothesis:

- Kinematic variable $O \equiv (\hat{l}_p \times \hat{l}_{\bar{p}}) \cdot \hat{k}$
- Triple-product asymmetry observable:

$$A(O) = \frac{N_{\text{event}}(O > 0) - N_{\text{event}}(O < 0)}{N_{\text{event}}(O > 0) + N_{\text{event}}(O < 0)}$$

- $\hat{l}_p(\hat{l}_{\bar{p}})$: unit momentum of $p(\bar{p})$ in $\Lambda(\bar{\Lambda})$ rest frame
- $\hat{k}$: unit momentum of Λ in J/ψ rest frame

Prospect of BESIII

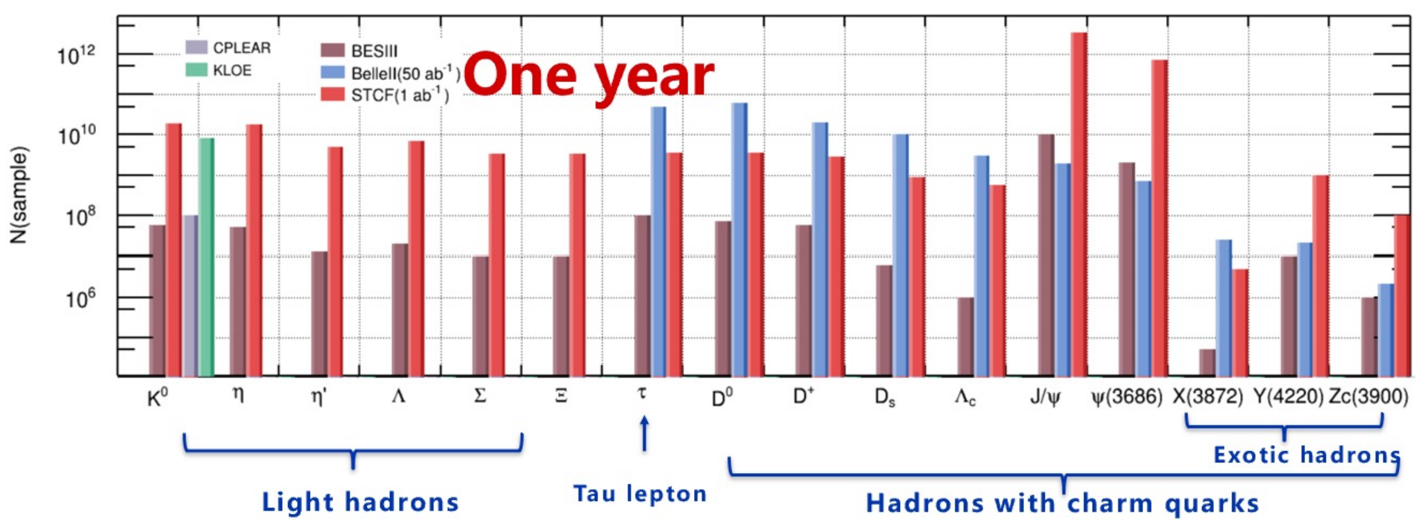


- **BEPCII upgrade**
- **Highest beam energy: 2.8 GeV**
- **Peak Lum.: 3.77 ~ 4.7 GeV : $1.2\times10^{33}cm^{-2}s^{-1}$**
- **5.0~5.6GeV: $(0.5\text{-}0.7)\times10^{33}cm^{-2}s^{-1}$**
- **BESIII: CGEM successfully installed.**

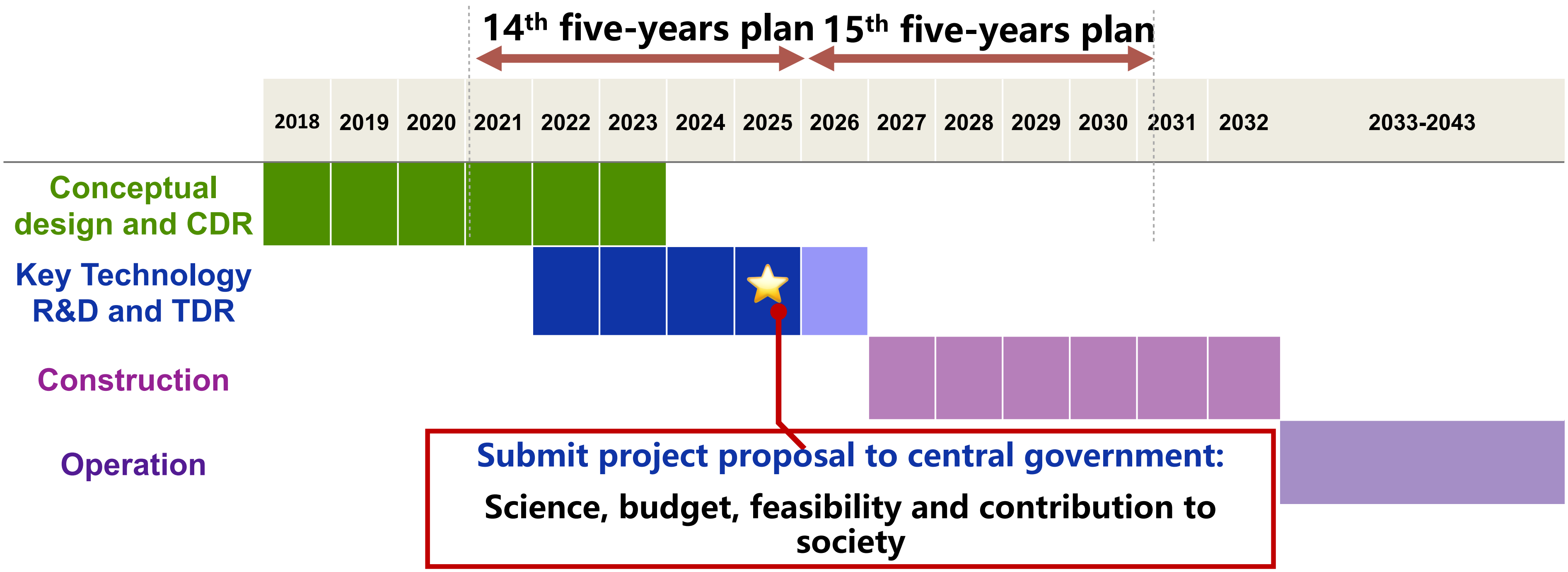
Prospect of Super tau charm factory

- **Electron-positron collider at $\sqrt{s} = 2\sim7$ GeV, peak lum. >0.5x10^{35} cm^{-2}s^{-1}, Integrated lum. 1 ab^{-1} per year.**
- **Generate trillions of ψ samples, billions of charmed hadron pairs and tau lepton pairs, a large number of XYZ particles.**
- **Unique characteristics such as continuously adjustable center-of-mass energy, pair threshold production, and quantum correlation.**

CME (GeV)	Lumi (ab^{-1})	Samples	σ(nb)	No. of Events	Remarks
3.097	1	J/ψ	3400	3.4×10^{12}	
3.670	1	$\tau^+\tau^-$	2.4	2.4×10^{9}	
3.686	1	$\psi(3686)$	640	6.4×10^{11}	
		$\tau^+\tau^-$	2.5	2.5×10^{9}	
		$\psi(3686)\to\tau^+\tau^-$		2.0×10^{9}	
3.770	1	$D^0\bar{D}^0$	3.6	3.6×10^{9}	
		$D^+\bar{D}^-$	2.8	2.8×10^{9}	
		$D^0\bar{D}^0$		7.9×10^{8}	Single tag
		$D^+\bar{D}^-$		5.5×10^{8}	Single tag
		$\tau^+\tau^-$	2.9	2.9×10^{9}	
4.009	1	$D^{*0}\bar{D}^0 + c.c$	4.0	1.4×10^{9}	$CP_{D^0\bar{D}^0} = +$
		$D^{*0}\bar{D}^0 + c.c$	4.0	2.6×10^{9}	$CP_{D^0\bar{D}^0} = -$
		$D_s^+D_s^-$	0.20	2.0×10^{8}	
		$\tau^+\tau^-$	3.5	3.5×10^{9}	
4.180	1	$D_s^{+*}D_s^-$+c.c.	0.90	9.0×10^{8}	
		$D_s^{+*}D_s^-$+c.c.		1.3×10^{8}	Single tag
		$\tau^+\tau^-$	3.6	3.6×10^{9}	
4.230	1	$J/\psi\pi^+\pi^-$	0.085	8.5×10^{7}	
		$\tau^+\tau^-$	3.6	3.6×10^{9}	
		$\gamma X(3872)$			
4.360	1	$\psi(3686)\pi^+\pi^-$	0.058	5.8×10^{7}	
		$\tau^+\tau^-$	3.5	3.5×10^{9}	
4.420	1	$\psi(3686)\pi^+\pi^-$	0.040	4.0×10^{7}	
		$\tau^+\tau^-$	3.5	3.5×10^{9}	
4.630	1	$\psi(3686)\pi^+\pi^-$	0.033	3.3×10^{7}	
		$\Lambda_c\bar{\Lambda}_c$	0.56	5.6×10^{8}	
		$\Lambda_c\bar{\Lambda}_c$		6.4×10^{7}	Single tag
		$\tau^+\tau^-$	3.4	3.4×10^{9}	
4.0–7.0	3	300-point scan with 10 MeV steps, 1 fb^{-1}/point			
> 5	2–7	Several ab^{-1} of high-energy data, details dependent on scan results			



Prospect of Super tau charm factory



- 14th five-years plan : **Conceptual design** and **R&D of Key technology**,
- 15th five-years plan : **Construction** 6 years
- Operating for 10-15 years, upgrade for 3 years, 10 more years operating