ICHEP 2022 BOLOGNA

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6 13 07 2022

(Semi) Leptonic $D_{(s)}$ decays at BESIII

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on behalf of the BESIII Collaboration

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(Semi) Leptonic $D_{(s)}$ decays at BESIII

$$\Gamma(D^+_{(s)} \to l^+ \nu_l) \propto |f_{D^+_{(s)}}|^2 \cdot |V_{cd(s)}|^2$$

$$\Gamma(D^+_{(s)} \to P\, l^+ \nu_l) \propto |f_+(q^2)|^2 \cdot |V_{cd(s)}|^2$$

CKM Matrix element

Unitarity & New Physics Beyond Standard Model

Decay Constant & **Form Factor**

Lattice QCD Calibration

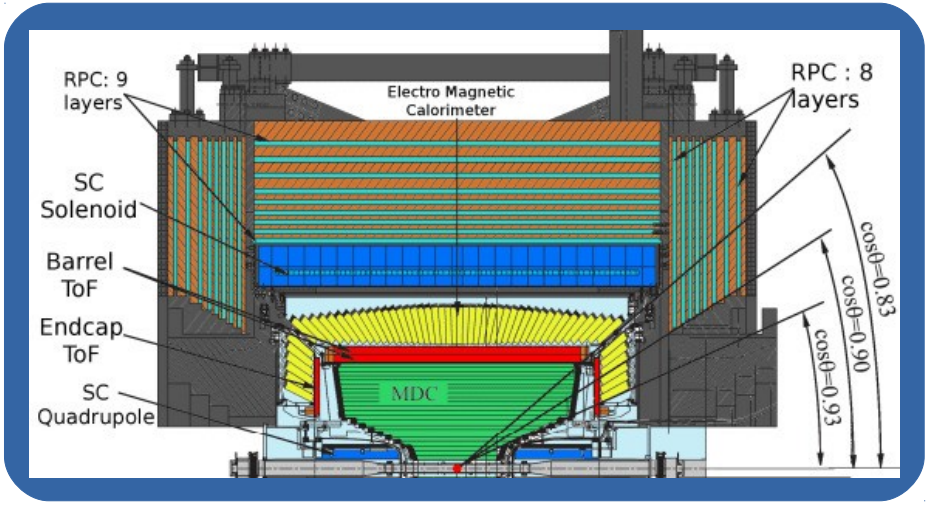
Lepton Flavour Universality

Compare the charm sector with B-mesons studies

*Lepton Flavour Violation at LHCb Lingzhu Bian 9 Jul 2022, 12:23

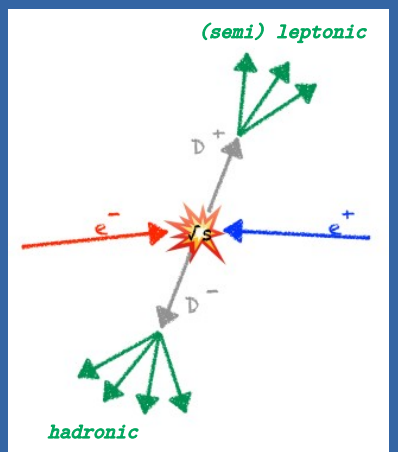
BESIII

- Multilayer Drift Chamber
- Time Of Flight
- ElectroMagnetic Calorimeter
- Magnetic Field 1T
- Muon Chamber



@ BEPCII - Institute of High Energy Physics, Beijing

$$2\,\mathrm{GeV} \leq \sqrt{s} \leq 4.9\,\mathrm{GeV}$$



$$M_{bc} = \sqrt{E^2_{beam} - p^2_{candidate}}$$

$$dE = E_{candidate} - E_{beam}$$

$$U_{miss} = E_{miss} - |\vec{p}_{\,miss}|$$

D *studies* $\quad \mathcal{L} = 2.93\,\mathrm{fb}^{-1}$ @ 3.773 GeV

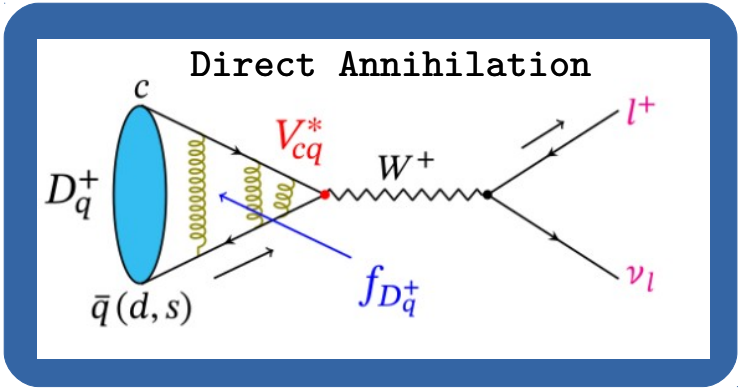
D_s *studies* $\quad \mathcal{L} = 6.32\,\mathrm{fb}^{-1}$ @ $4.178 - 4.226$ GeV

Double Tag

One D is tagged and reconstructed through hadronic decays and the other is searched in the desired channel

Leptonic Decays

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



→ **BR** —Direct access→ **Decay Constant** X **CKM Matrix element**

BESIII

$$D_s^+ \to \mu^+\nu_\mu$$
$$D_s^+ \to \tau^+\nu_\tau \quad \tau^+ \to \pi^+\bar{\nu}_\tau$$

$\mu\pi$ — Phys. Rev. D 104, 052009 Published 21 September 2021

$$D_s^+ \to \tau^+\nu_\tau \quad \tau^+ \to \pi^+\pi^0\bar{\nu}_\tau$$

$\pi\pi$ — Phys. Rev. D 104, 032001 Published 13 August 2021

$$D_s^+ \to \tau^+\nu_\tau \quad \tau^+ \to e^+\nu_e\bar{\nu}_\tau$$

$e\nu\nu$ — Phys. Rev. Lett. 127, 171801 Published 19 October 2021

$D_s^+ \to \tau^+\nu_\tau$ via $\tau^+ \to \pi^+\bar{\nu}_\tau$ & $D_s^+ \to \mu^+\nu_\mu$

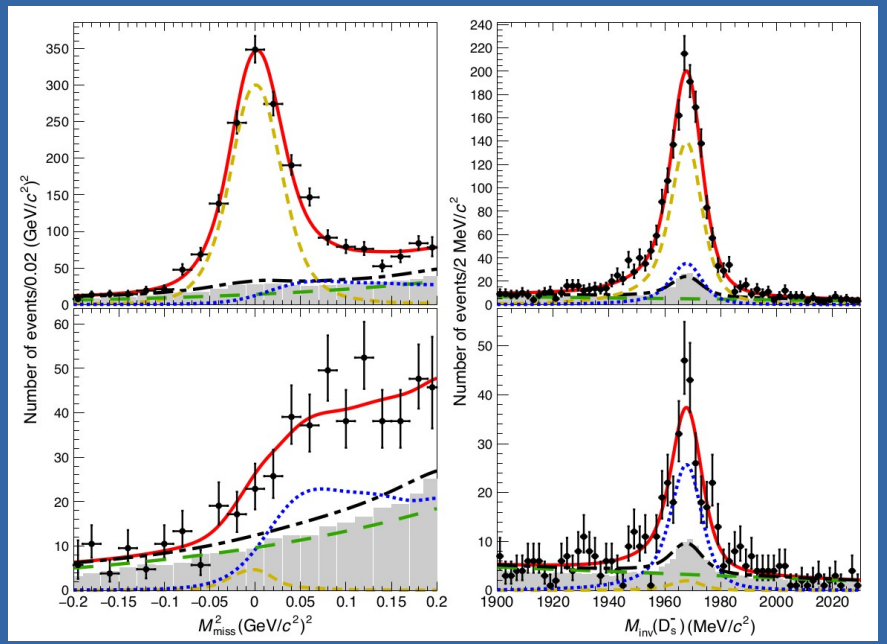
$\mu\pi$

Phys. Rev. D 104, 052009
Published 21 September 2021

Missing Mass Signal Side ⟷ **DT** ⟷ **Invariant Mass** Hadronic Tag

μ →

π →



$$M^2_{miss} = E^2_{miss} - |\vec{p}_{miss}c|^2$$

$$E_{miss} = E_{cm} - \sqrt{|\vec{p}_{tag}c|^2 + m^2_{D_s}c^4} - E_\gamma - E_{\mu/\pi}$$

2D Distributions:
unbinned simultaneous maximum likelihood fit

Here @4178 MeV with scaled MC components
Analysis performed on six energies points
4178, 4189, 4199, 4209, 4219, 4226 MeV

$$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu) = (5.35 \pm 0.13 \pm 0.16) \times 10^{-3}$$

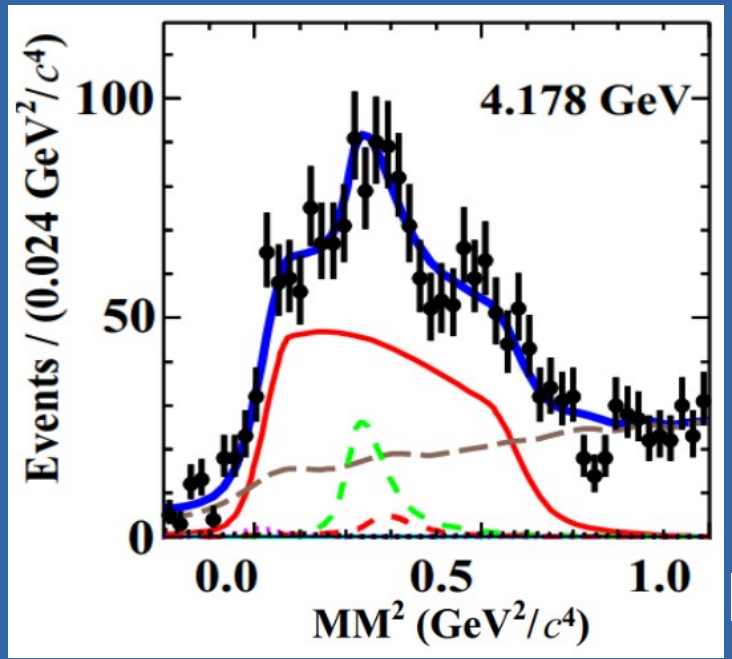
$$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau) = (5.21 \pm 0.25 \pm 0.17) \times 10^{-2}$$

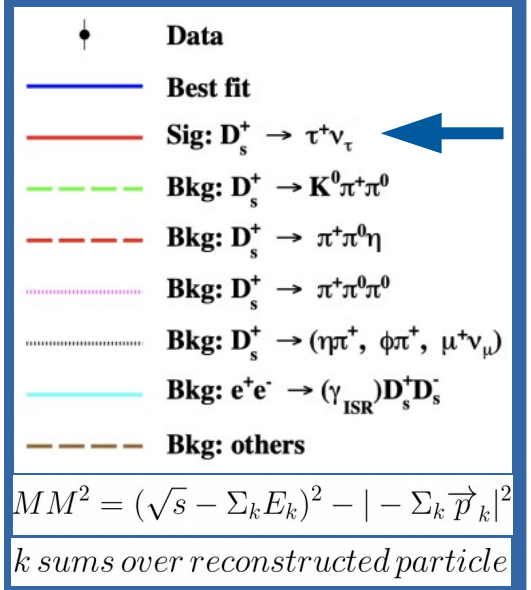
$D_s^+ \to \mu^+\nu_\mu$ **is the most precise measurement to date**

$D_s^+ \to \tau^+\nu_\tau$ via $\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau$

$\pi\pi$

Phys. Rev. D 104, 032001
Published 13 August 2021





$MM^2 = (\sqrt{s} - \Sigma_k E_k)^2 - |-\Sigma_k \vec{p}_k|^2$

k sums over reconstructed particle

1D simultaneous fit to squared missing mass of all the energies

Here @4178 MeV
Analysis performed on six energies points
4178, 4189, 4199, 4209, 4219, 4226 MeV

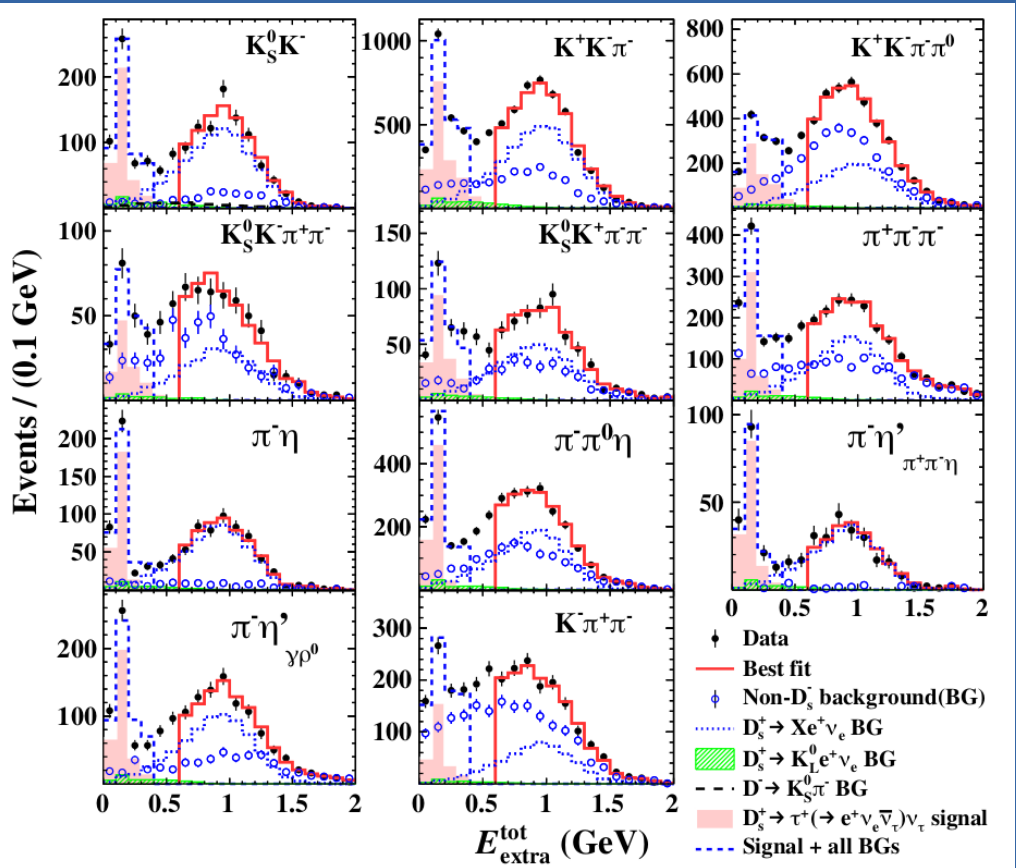
Common leptonic decay branching ratio

$$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau) = (5.29 \pm 0.25 \pm 0.20) \times 10^{-2}$$

$D_s^+ \to \tau^+\nu_\tau$ via $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$

Phys. Rev. Lett. 127, 171801
Published 19 October 2021

eνν



EXTRA TOTAL ENERGY

Energy of the EMC showers identified as good:

- **TIME** 700 ns from the start time of the event
- **ENERGY** > 20 (50) MeV in the barrel (end cap) region
- **ANGLE** >10° with the nearest charged track

Excluding ST D_s^- candidates and events within < 5° from the initial positron

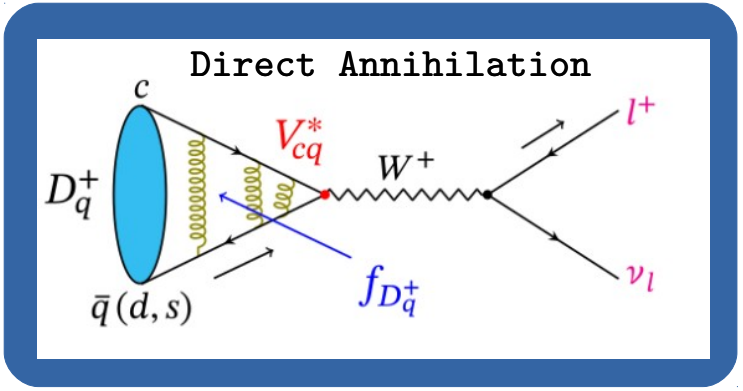
Fitting the background >0.6 GeV to extrapolate it below the signal region (<0.4 GeV)

$$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau) = (5.27 \pm 0.10 \pm 0.12) \times 10^{-2}$$

Most precise result to date

Leptonic Decays

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



→ **BR** —Direct access→ **Decay Constant** X **CKM Matrix element**

$$f^2_{D^+_{(s)}} \left|V_{cd(s)}\right|^2$$

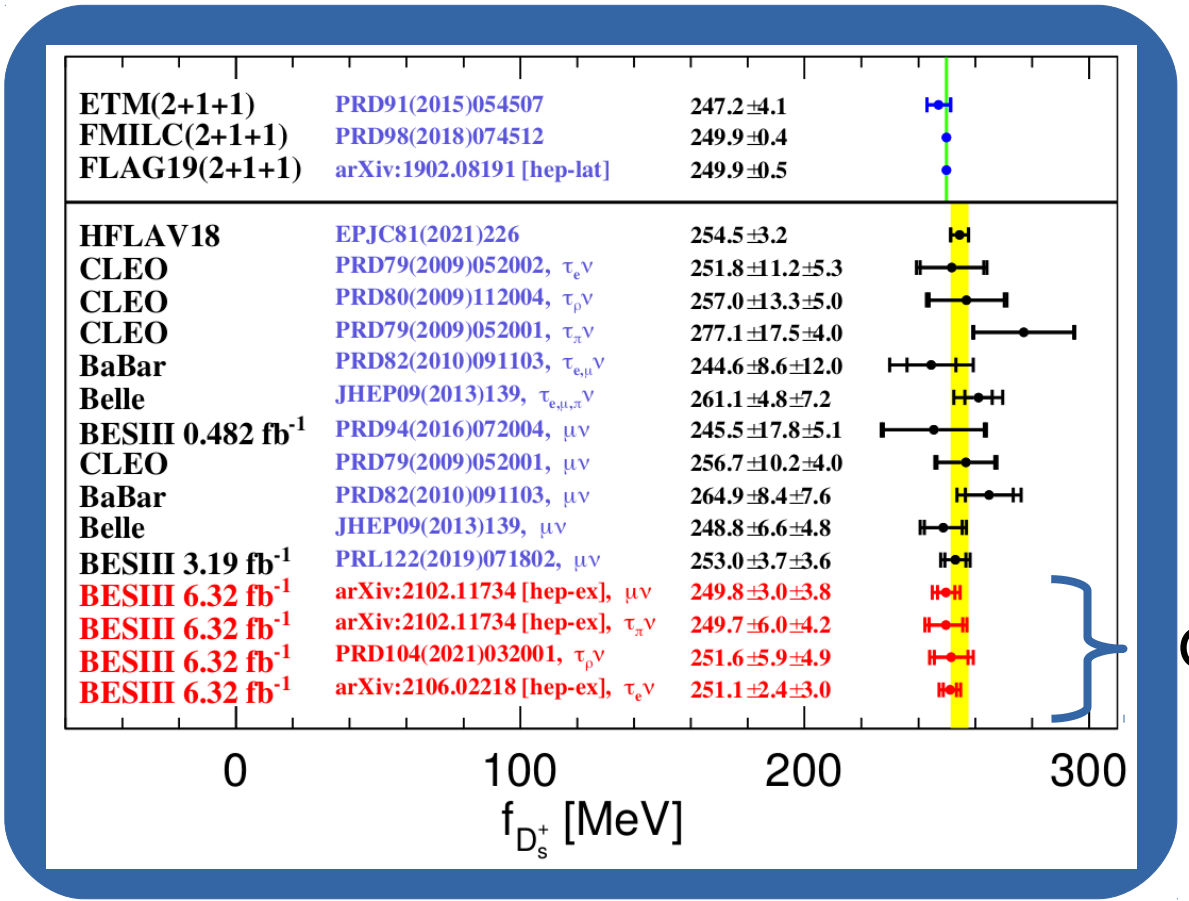
$\mu\pi$	243.2 ± 2.3 ± 3.3 ± 0.1 MeV
$\pi\pi$	244.8 ± 5.8 ± 4.8 MeV
$e\nu\nu$	244.4 ± 2.3 ± 2.9 MeV

* from external input parameters

SM
243.2 ± 0.5 MeV
From CKM global fit and LQCD calculations

→ **good agreement**

Leptonic Decays



Decay Constant

Comparison of $f^2_{D^+_{(s)}}$

From CKM global fit:

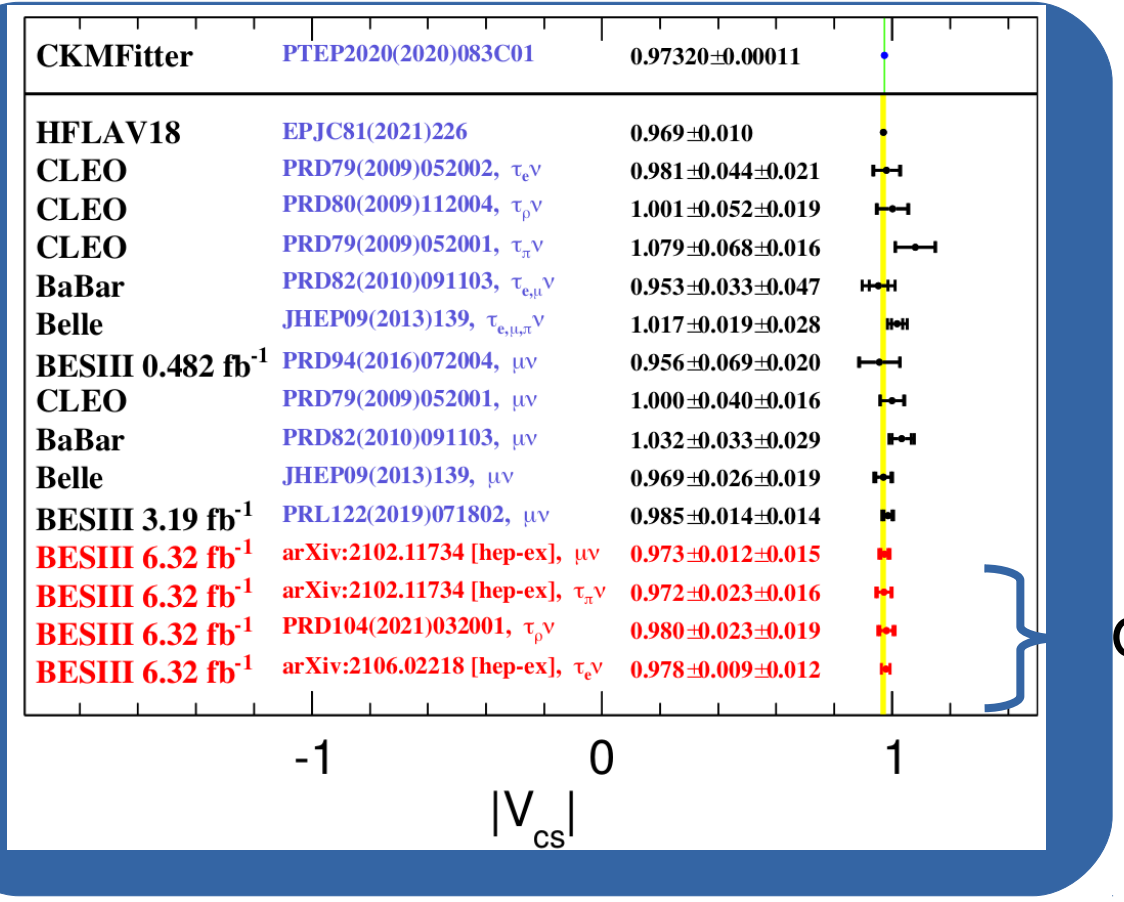
$$|V_{cs}|^2 = 0.97320 \pm 0.00011$$

Combined → 251.4 ± 1.8 ± 2.2

PoS EPS-HEP2021 (2022) 543 Mar 4, 2022 10.22323/1.398.0543

1% precision!

Leptonic Decays



CKM Matrix element

Comparison of $|V_{cs}|^2$

From LQCD calculations

(FLAVG19)

$$f_{D_s^+}^2 = 249.9 \pm 0.5$$

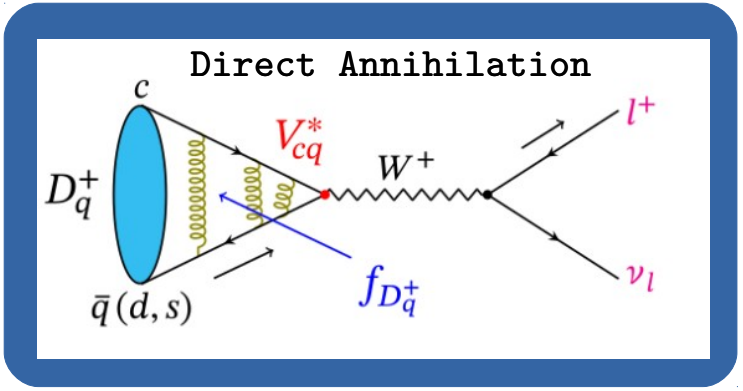
Combined → 0.979 ± 0.007 ± 0.008

PoS EPS-HEP2021 (2022) 543 Mar 4, 2022 10.22323/1.398.0543

1% precision!

Leptonic Decays

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



BR → Direct access → Decay Constant X CKM Matrix element

$$R = \frac{\Gamma(D_s^+ \to \tau^+\nu_\tau)}{\Gamma(D_s^+ \to \mu^+\nu_\mu)} = \frac{\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)} = \frac{m_\tau^2\left(1 - \frac{m_\tau^2}{m^2_{D_s}}\right)^2}{m_\mu^2\left(1 - \frac{m_\mu^2}{m^2_{D_s}}\right)^2}$$

Lepton Flavour Universality

$\mu\pi$	$9.73\ ^{+0.61}_{-0.58} \pm 0.36$
$\pi\pi$	9.89 ± 0.71
$e\nu\nu$	9.72 ± 0.37

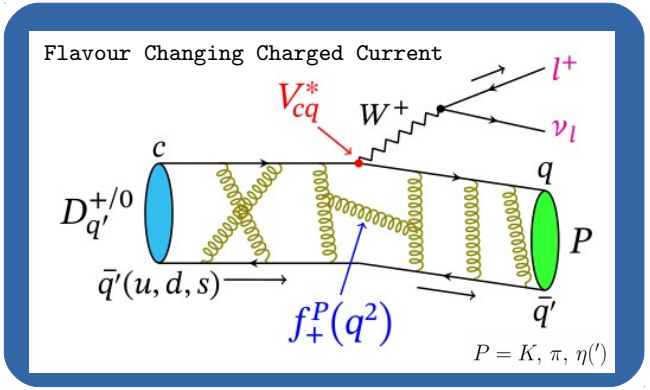
SM
9.75 ± 0.01
Calculated from PDG values

→ no violation at this precision

Semi-Leptonic Decays

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

$X = 1$ for K^-, π^-, $\bar{K}^0$, $\eta^{(\prime)}$
$X = \frac{1}{2}$ for π^0



BR —Direct access→ **Form Factor** x **CKM Matrix element** & **Structure Investigation**

BESIII

$$D^0 \to \rho^- \mu^+ \nu_\mu$$ — $\rho\,\mu$

Phys. Rev. D 104, L091103
Published 29 November 2021

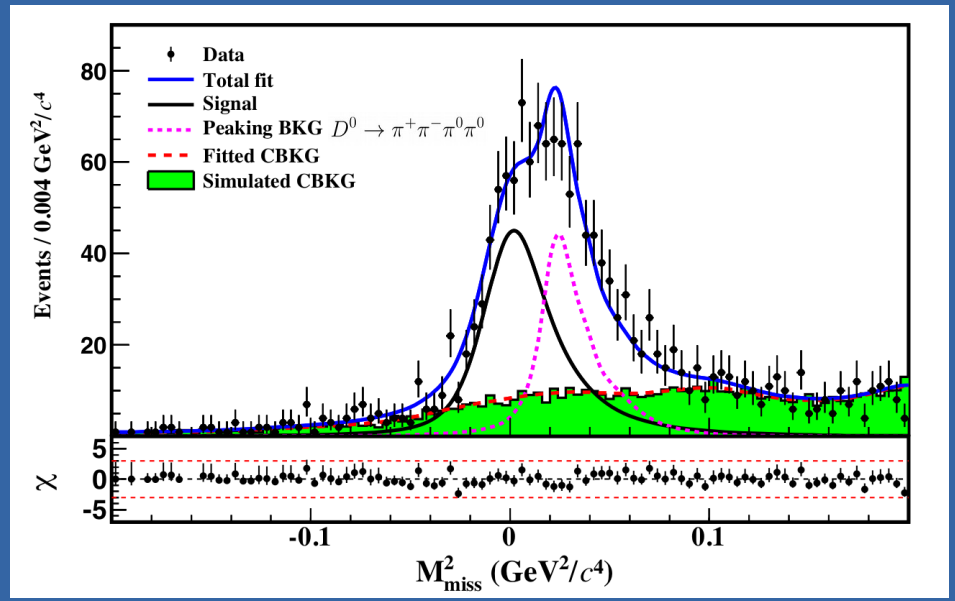
$$D_s^+ \to \pi^0 \pi^0 e^+ \nu_e$$
$$D_s^+ \to K_s^0 K_s^0 e^+ \nu_e$$
— $\pi\pi$, K_sK_s

Phys. Rev. D 105, L031101
Published 24 February 2022

$D^0 \to \rho^- \mu^+ \nu_\mu$

$\rho\,\mu$

Phys. Rev. D 104, L091103
Published 29 November 2021



$$M^2_{miss} = \frac{E^2_{miss}}{c^4} - \frac{|\overrightarrow{p}_{miss}|^2}{c^2}$$

$$E_{miss} = E_{beam} - E_{\rho^-} - E_{\mu^+}$$

$$\overrightarrow{p}_{miss} = \overrightarrow{p}_{D^0} - \overrightarrow{p}_{\rho^-} - \overrightarrow{p}_{\mu^+}$$

Observed for the first time

$$N_{DT} = 570 \pm 40_{stat}$$

$$\mathcal{B}(D^0 \to \rho^- \mu^+ \nu_\mu) = (1.35 \pm 0.09 \pm 0.09) \times 10^{-3}$$

$$\frac{\mathcal{B}(D^0 \to \rho^- \mu^+ \nu_\mu)}{\mathcal{B}(D^0 \to \rho^- e^+ \nu_e)} = (0.90 \pm 0.11)$$

Phys.Rev.Lett. 122 (2019) 6, 062001

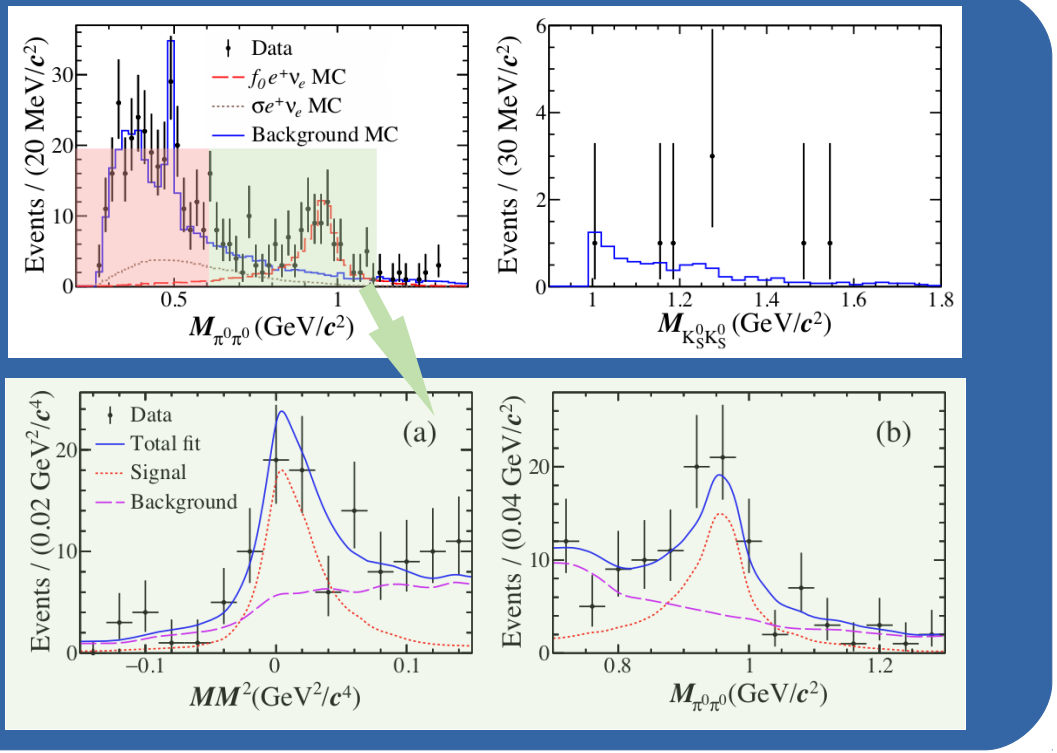
$$SM Prediction\,(0.93 - 0.96)$$

No LFU Violation within this current sensitivity

$D_s^+ \to \pi^0\,\pi^0 e^+\,\nu_e$ & $D_s^+ \to K_s^0\,K_s^0 e^+\,\nu_e$

$\pi\pi$
K_sK_s

Phys. Rev. D 105, L031101
Published 24 February 2022



$D_s^+ \to f_0(980) e^+\,\nu_e$
$f_0(980) \to \pi^0\,\pi^0$

2D unbinned simultaneous maximum likelihood fit

$$\mathcal{B}(D_s^+ \to f_0(980)\,(\to \pi^0\,\pi^0)\,e^+\nu_e) = (7.9 \pm 1.4 \pm 0.4) \times 10^{-4}$$

$$\mathcal{B}(D_s^+ \to \sigma\,(\to \pi^0\,\pi^0)\,e^+\nu_e) < 7.3 \times 10^{-4}\,@\,90\%\,C.L.$$

$$\mathcal{B}(D_s^+ \to K_sK_s\,e^+\nu_e) < 3.8 \times 10^{-4}\,@\,90\%\,C.L.$$

Compatible with previous analyses

Phys. Rev. D 86, 114010 (2012) Phys. Rev. D 80, 052009 (2009)
Phys. Rev. D 92, 054038 (2015)

f_0 compatible with admixture of $s\bar{s}$ and other light quarks

(Semi) Leptonic $D_{(s)}$ decays at BESIII

D *studies* $\mathcal{L} = 2.93\,\mathrm{fb}^{-1}$ @ 3.773 GeV D_s *studies* $\mathcal{L} = 6.32\,\mathrm{fb}^{-1}$ @ $4.178 - 4.226$ GeV

$\mu\pi$	$D_s^+ \to \tau^+\nu_\tau$, $\tau^+ \to \pi^+\bar{\nu}_\tau$	$D_s^+ \to \mu^+\nu_\mu$
$\pi\pi$	$D_s^+ \to \tau^+\nu_\tau$, $\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau$	
eνν	$D_s^+ \to \tau^+\nu_\tau$, $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$	
$\rho\,\mu$	$D^0 \to \rho^-\,\mu^+\,\nu_\mu$	
$\pi\pi$ K_sK_s	$D_s^+ \to \pi^0\,\pi^0 e^+\,\nu_e$	$D_s^+ \to K_s^0\,K_s^0 e^+\,\nu_e$

- Improved precision on the leptonic D_s decays
- $D^0 \to \rho^-\,\mu^+\,\nu_\mu$ First observation. It does not show LFU violation
- $f_0(980) \to \pi^0\,\pi^0$ studies to confirm previous analyses and its compatibility with an admixture of $s\bar{s}$ or other light quarks

(Semi) Leptonic $D_{(s)}$ decays at BESIII

FUTURE PLAN

+ 20 fb^{-1} @3.773 GeV
+ 3 fb^{-1} @4.178 GeV

Already started during this year of data taking and continuing in the next ones

It will help to improve the precision of the results presented and of many more

Some upgrades are planned and ongoing on the spectrometer

Thanks for your attention

Thanks for your attention

..For more D decays or more @BESIII

https://agenda.infn.it/event/28874/search?q=BESIII

Search for rare decays at BESIII

Based on 10 billion J/ψ events accumulated by the BESIII detector, we show searches for the rare process of J/ψ weak decays. We also search for other rare decay process, such as the FCNC process $D^0\to\pi^0\nu \bar{\nu}$, and the

Fabrizio Bianchi (Istituto Nazionale di Fisica Nucleare), Yunxuan Song (Peking University)
08 July 2022 20:10
Bologna, Italy
ICHEP 2022

Baryon/Lepton number violation searches at BESIII

The observed matter-antimatter asymmetry in the universe composes a serious challenge to our understanding of nature. BNV/LNV decays have been searched in many experiments to understand this large-scale observed fact, and few in the case of

Tengjiao Wang (Nankai University, Tianjin, P. R.China)
07 July 2022 15:55
Bologna, Italy
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Hadronic D decays at BESIII

BESIII has collected 2.93 and 6.32 fb^{-1} of e^+e^- collision data samples at 3.773 and at 4.178-4.226 GeV, respectively. We will report the observation of $D^0 -> \omega \phi$ and the transverse polarization determination, the observa

Fabrizio Bianchi (Istituto Nazionale di Fisica Nucleare), Anita Lavania (IIT Madras)
07 July 2022 15:38
Bologna, Italy
ICHEP 2022

Λ_c^+ decays at BESIII

BESIII has collected 4.4 fb^{-1} of e^+e^- collision data between 4.6 and 4.7 GeV. This unique data offers ideal oppurtunity to determine absolute branching fractions of Λ_c^+ decays. We will report the first observation of $\La

Cong Geng (Sun Yat-sen University)
07 July 2022 12:40
Bologna, Italy
ICHEP 2022

Recent XYZ results at BESIII

Using a scan sample taken at center-of-mass energies from 3.773 GeV to 4.95 GeV with an integrated luminosity of 22/fb, the properties of XYZ states are investigated at BESIII. The cross sections of $e^+e^- \to D^(*+) D^(*-)$ and $D^(+) D^*

Fabrizio Bianchi (Istituto Nazionale di Fisica Nucleare), Stefano Spataro (Istituto Nazionale di Fisica Nucleare)
09 July 2022 15:30
Bologna, Italy
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Light Meson Spectroscopy at BESIII

BESIII has the world's largest samples of J/ψ and $\psi(3686)$ events from $e^+ e^-$annihilations, which offer an ideal and clean laboratory to study light meson spectroscopy , in particular for the search for QCD exotics. Recent impor

Beijiang Liu (Institute of High Energy Physics), Fabrizio Bianchi (Istituto Nazionale di Fisica Nucleare), et al.
09 July 2022 18:00
Bologna, Italy
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Light flavor vector mesons between 2 and 3 GeV at BESIII

At BESIII, the lineshapes of $e^+e^- ->\phi \eta', \phi \eta, K K, \omega \pi^0, \eta \pi \pi$ and $\omega \pi \pi$ are measured from 2.0 to 3.08 GeV, where resonant structures are observed in these processes. Multiple lineshapes of interm

Fabrizio Bianchi (Istituto Nazionale di Fisica Nucleare), Hang Qi (USTC)
08 July 2022 20:10
Bologna, Italy
ICHEP 2022

Hyperon physics at BESIII

With the large datasets on e+e−annihilation at the J/ψ and ψ(3686) resonances collected at the BESIII experiment, multi-dimensional analyses making use of polarization and entanglement can shed new light on the production and decay pr

Fabrizio Bianchi (Istituto Nazionale di Fisica Nucleare), Beijiang Liu (IHEP, Beijing), et al.
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Bologna, Italy
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Recent results of Baryon electromagnetic form factors at BESIII

At BESIII, the electromagnetic form factors (EMFFs) and the pair production cross sections of various baryons have been studied. The proton EMFF ratio |GE/GM| is determined precisely and line-shape of |GE| is obtained for the first time. Th

Fabrizio Bianchi (Istituto Nazionale di Fisica Nucleare), Francesca De Mori (Università degli Studi di Torino e Istituto Nazionale di Fisica Nucleare)
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Bologna, Italy
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TIGER/GEMROC: a versatile and modular readout system for micro-pattern gaseous detectors

A special readout chain was developed for the data acquisition of an innovative cylindrical gas-electron multiplier (CGEM) [1], which is being built to replace the inner drift chamber of the BESIII [2] experiment. The whole system [3] was d

Gianluigi Cibinetto (Istituto Nazionale di Fisica Nucleare), Michela Greco (Istituto Nazionale di Fisica Nucleare), et al.
08 July 2022 12:45
Bologna, Italy
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Search for invisible decays at BESIII

BESIII has collected 2.5 billion $\psi(2S)$ events and 10 billion J/ψ events. The huge data sample provide an excellent chance to search for new physics. We report the search for the decay $J/\psi\to\gamma + invisible$, which is predic

Fabrizio Bianchi (Istituto Nazionale di Fisica Nucleare), Houbing Jiang
07 July 2022 12:30
Bologna, Italy
ICHEP 2022

(Semi-)leptonic D decays at BESIII

BESIII has collected 2.93 and 6.32 fb^-1 of e^+e^- collision data samples at 3.773 and 4.178-4.226 GeV, respectively. We will report precision measurements of f_{Ds}, $|V_{cs}|$ and test of lepton flavor universality by studying the l

Fabrizio Bianchi (Istituto Nazionale di Fisica Nucleare), Ilaria Balossino (Istituto Nazionale di Fisica Nucleare)
07 July 2022 12:23
Bologna, Italy
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Observation of new charmonium decays at BESIII

*Based on a 448 million $\psi(2S)$ sample, several decay channels of charmonium states have been searched for at BESIII recently. The decays of $\chi_{c1} -> \Xi^0 \bar{\Xi^0}$ and $\chi_{c2} -> \Xi^0 \bar{\Xi^0}$, $\psi(2S) -> \Xi^0(1530) *

Yong Xie (Shandong University)
08 July 2022 20:10
Bologna, Italy
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Light Meson decays at BESIII

The world's largest sample of J/ψ events accumulated at the BESIII detector offers a unique opportunity to investigate η and η′ physics via two body J/ψ radiative or hadronic decays. In recent years the BESIII experiment has made significan

Fabrizio Bianchi (Istituto Nazionale di Fisica Nucleare), Beijiang Liu (Institute of High Energy Physics), et al.
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R value measurements at BESIII

At BESIII, the R value is measured with a total of 14 data points with the corresponding c.m. energy going from 2.2324 to 3.6710 GeV. The statistical uncertainty of the measured R is less than 0.6%. Two different simulation models, the LUAR

Weiping Wang (USTC)
08 July 2022 09:00
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