Tests of Lepton Flavor Universality at BESIII

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(On behalf of BESIII Collaboration)

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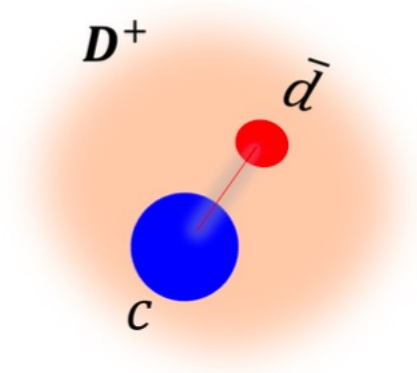
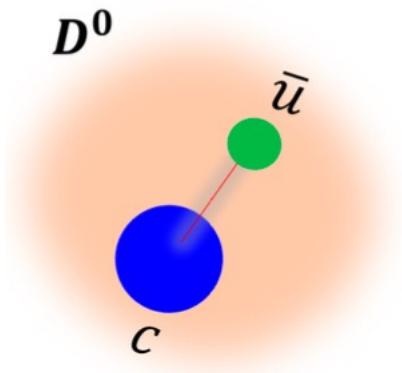
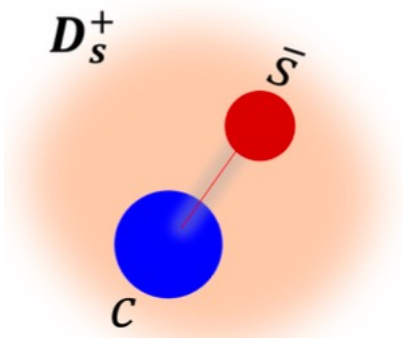
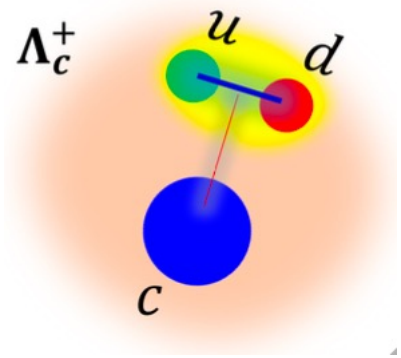
Outline

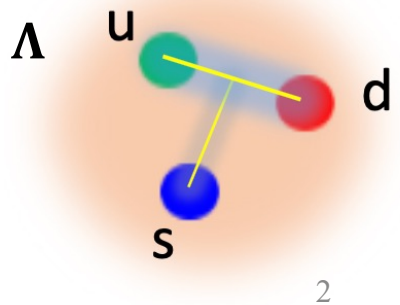
- Introduction
- Pure leptonic decays ($\frac{\tau}{\mu}$)
  - $D_{(s)}^{+}$ mesons
- Semi-leptonic decays ($\frac{\mu}{e}$)
  - $D_{(s)}$ mesons
  - Λ_c^+ bayon
  - Λ bayon
- Summary





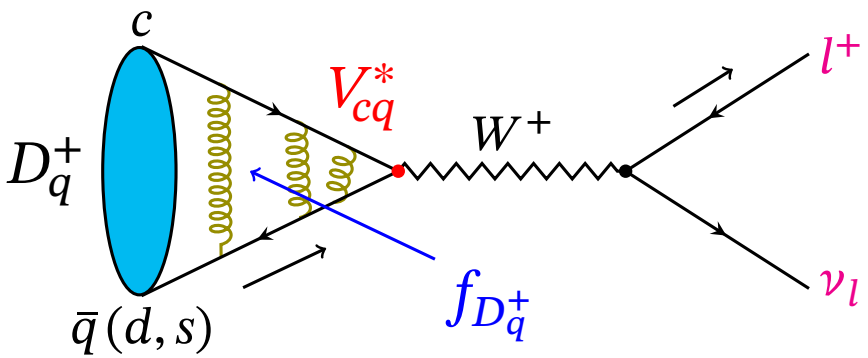






Lepton flavor universality (LFU)

In the SM, ignoring radiative corrections, the decay width of pure leptonic $D^+_{(s)}$ decay ($\ell = e, \mu, \tau$) is given by a simple form [1,2]:



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

[1] D. Silverman, and H. Yao, Phys. Rev. D 38, 214 (1988).
[2] H. B. Li, and X. R. Lyu, arXiv:2103.00908 [hep-ex].

Ratio:

$$R = \frac{\Gamma\left(D_{(s)}^{+} \to \tau^{+}\nu_{\tau}\right)}{\Gamma\left(D_{(s)}^{+} \to \mu^{+}\nu_{\mu}\right)} = \frac{m_{\tau^{+}}^{2}\left(1 - \frac{m_{\tau^{+}}^{2}}{m_{D_{(s)}^{+}}^{2}}\right)^{2}}{m_{\mu^{+}}^{2}\left(1 - \frac{m_{\mu^{+}}^{2}}{m_{D_{(s)}^{+}}^{2}}\right)^{2}}$$

Expectations in the SM:

$$R\left(D^{+} \to \tau^{+}\nu_{\tau}:\ \mu^{+}\nu_{\mu}:\ e^{+}\nu_{e}\right) = 2.67:\ 1:\ 2.35\times10^{-5}$$

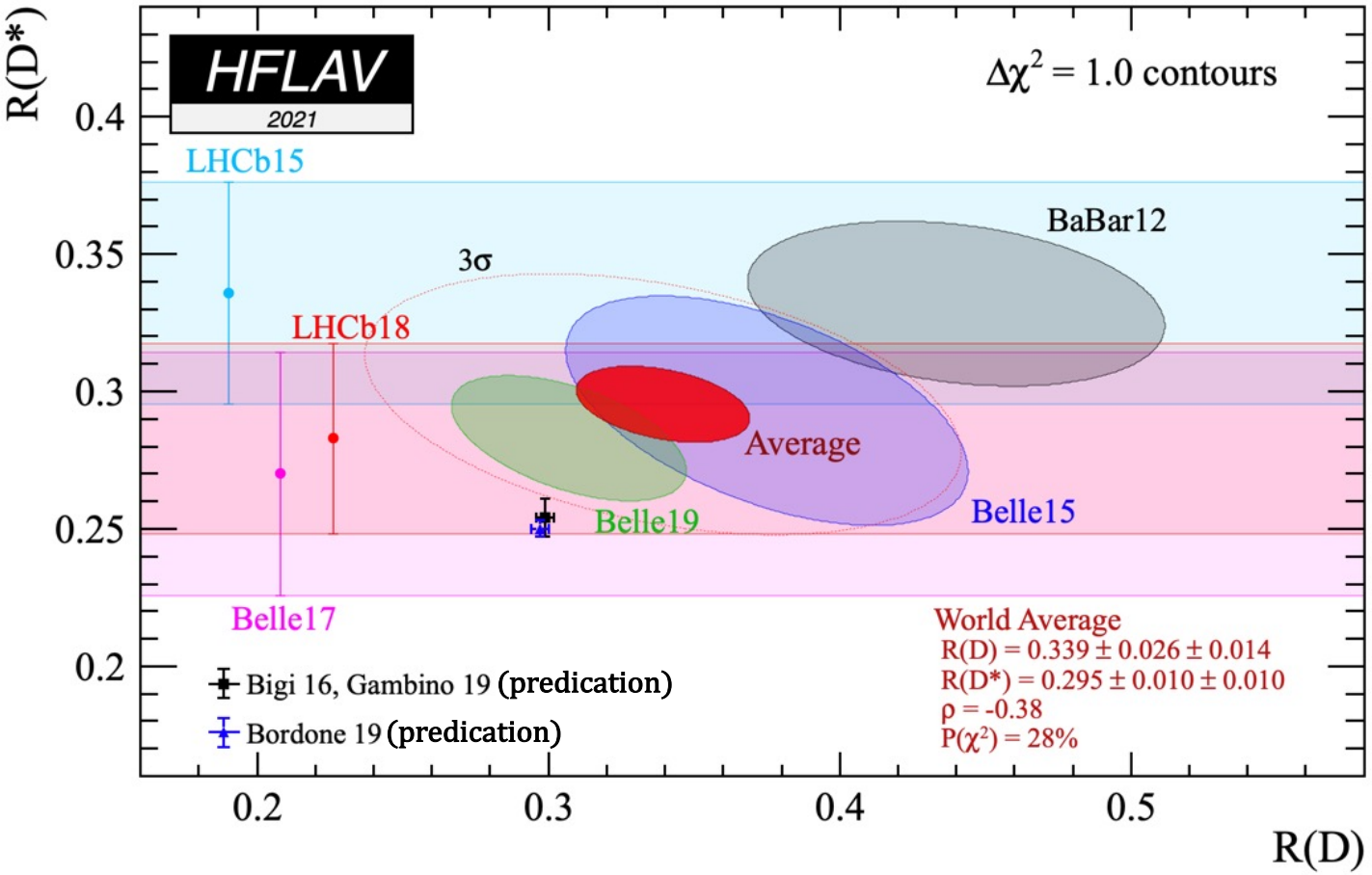
$$R\left(D_{s}^{+} \to \tau^{+}\nu_{\tau}:\ \mu^{+}\nu_{\mu}:\ e^{+}\nu_{e}\right) = 9.75:\ 1:\ 2.35\times10^{-5}$$

Any deviation from experimental measurements potentially indicates the existence of New Physics beyond SM.

SM predicted: $B(D_{(s)}^{+} \to e^{+}\nu_{e}) < 10^{-8}$, not yet experimentally observed.

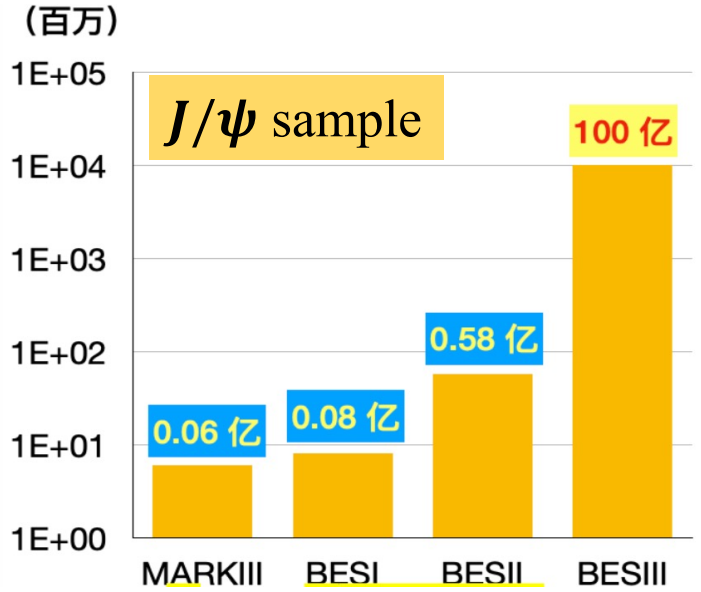
Hints of LFU violation in *B* decays

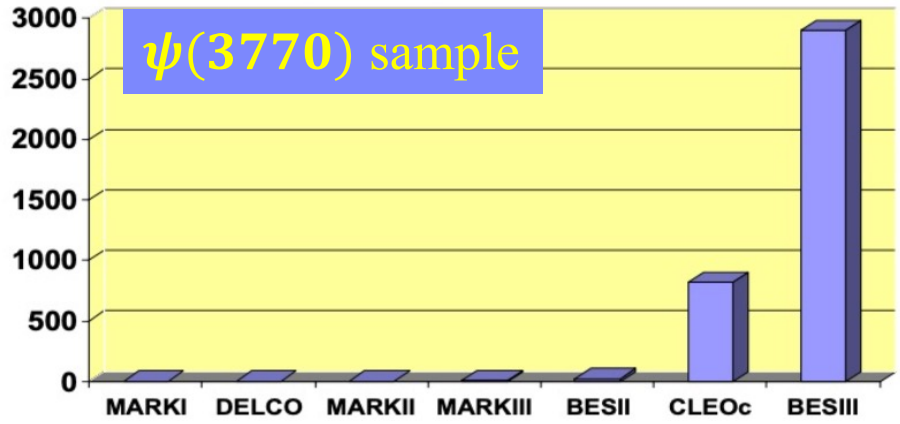
$$R(D^*) = \mathrm{BF}(B \to D^{(*)}\tau\nu_\tau)/\mathrm{BF}(B \to D^{(*)}\ell\nu_\ell)$$

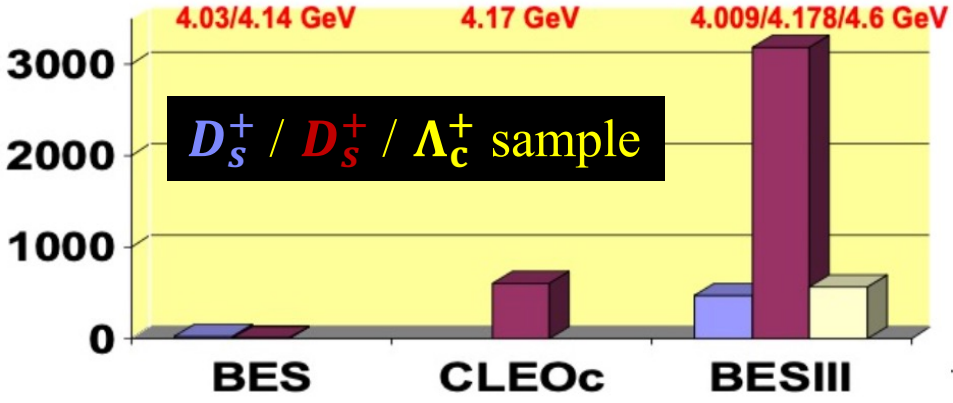


Data sets

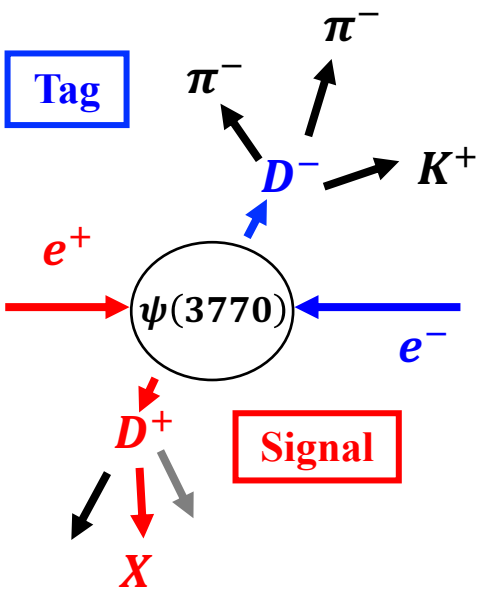
E_{cms} (GeV)	Luminosity (fb^{-1})	Decay of interest
3.097	3.2	$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$
3.773	2.93	$e^+e^- \to \psi(3770) \to D\bar{D}$
4.178	3.189	$e^+e^- \to D_s D_s^*$
4.19 ~ 4.23	3.13	
4.599	0.567	$e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c^-$







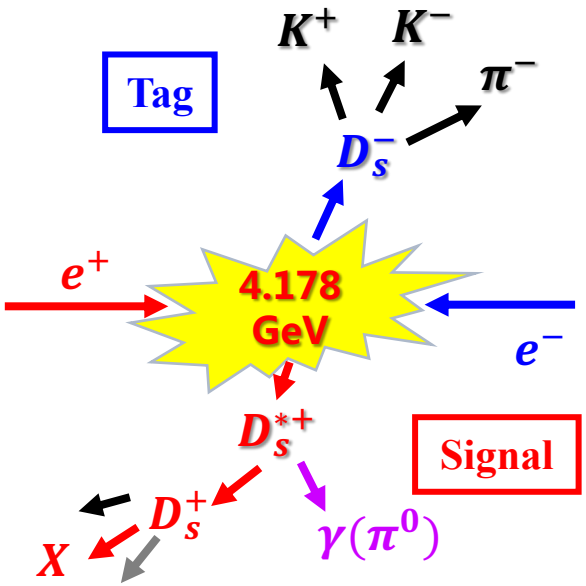
Analysis technique



Charge conjugated processes are implied

Measured branching fraction

$$B_{\rm sig} = \frac{N^{\rm signal}_{\rm DT}}{N^{\rm ST}_{D_{(s)}} \times \bar{\epsilon}_{sig}}$$



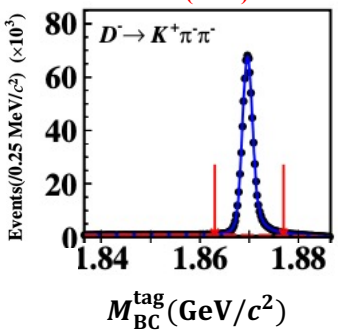
● Single tag (ST):

fully reconstruct one D^-

$$\Delta E = E_{D^-} - E_{\rm beam}$$

$$M_{\rm BC} = \sqrt{E^2_{\rm beam} - |\vec{p}_{D^-}|^2}$$

PRL124(2020)231801



◻ Double tag (DT):

in the recoil ST $D^-_{(s)}$, analyze the signal $D^+_{(s)}$

$${\rm MM}^2 = E^2_{\rm miss} - |\vec{p}_{\rm miss}|^2$$

$$E_{\rm miss} = E_{\rm cm} - \sqrt{\left|\vec{p}_{D^-_{(s)}}\right|^2 + M^2_{D_{(s)}}} - E_X$$

$$\vec{p}_{\rm miss} = -\vec{p}_{D^-_{(s)}} - \vec{p}_X$$

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

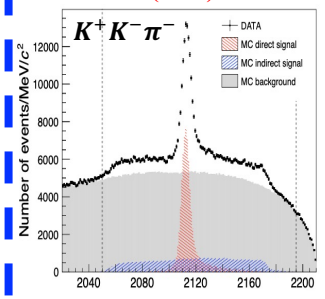
or other variables

● Single tag (ST):

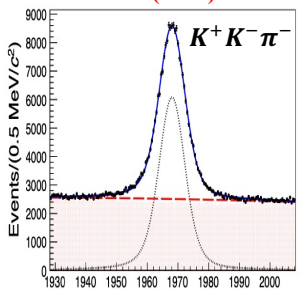
fully reconstruct one D_s^-

$$M_{\rm rec} = \sqrt{\left(E_{\rm cm} - \sqrt{|\vec{p}_{D_s^-}|^2 + m^2_{D_s^-}}\right)^2 - |-\vec{p}_{D_s^-}|^2}$$

PRD104(2021)052009



PRD 104 (2021) 012003



Pure leptonic decays

- ✍ $D^+ \to \mu^+\nu_\mu$ PRD 89 (2014) 051104(R)
- ✍ $D^+ \to \tau^+\nu_\tau$ PRL 123 (2019) 211802 Editors' Suggestion

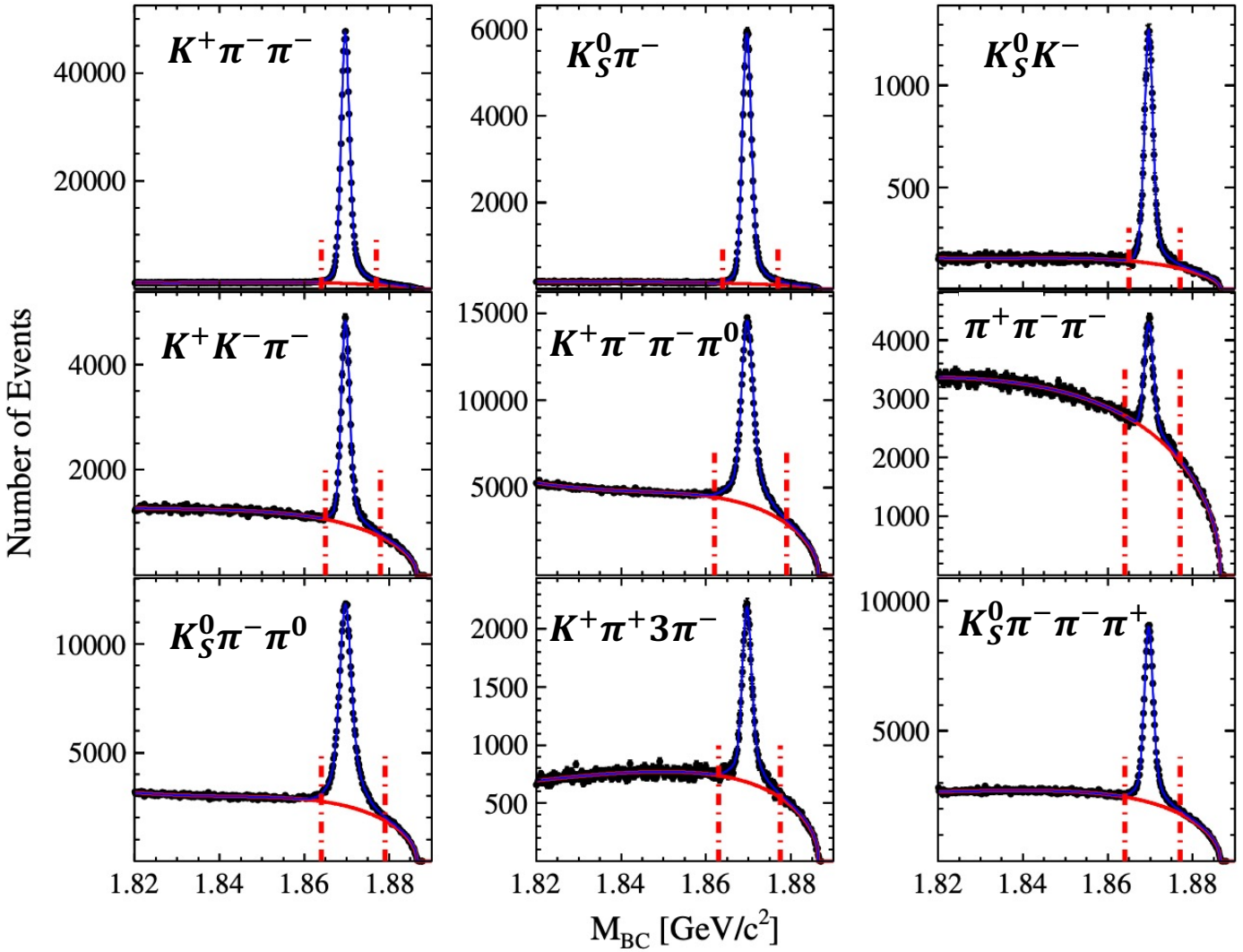
- ✍ $D_s^+ \to \mu^+\nu_\mu$ PRL 122 (2019) 071802 PRD 104 (2021) 052009
- ✍ $D_s^+ \to \tau^+\nu_\tau$
  - $\tau^+ \to \pi^+\bar{\nu}_\tau$ PRD 104 (2021) 052009
  - $\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau$ PRD 104 (2021) 032001
  - $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$ PRL 127 (2021) 171801

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

$$M_{\rm BC} = \sqrt{E^2_{\rm beam} - |\vec{p}_{D^-}|^2}$$

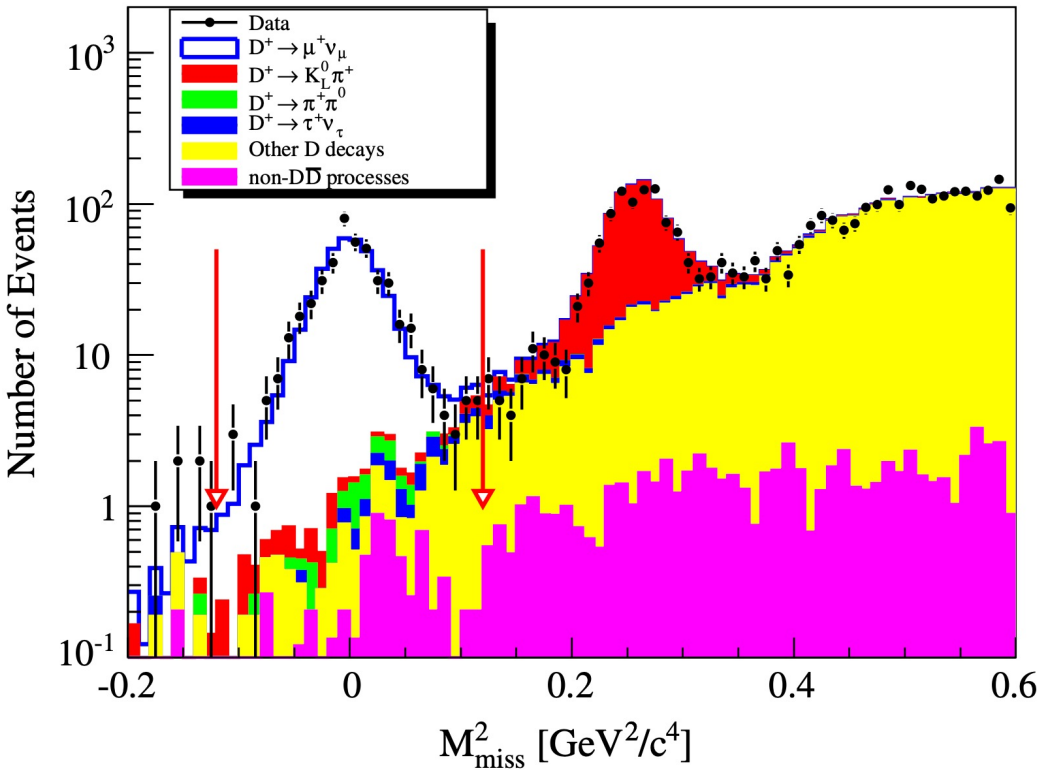
$N_{D^-_{\rm tag}} = 1703054 \pm 3045$

PRD 89 (2014) 051104(R)



DT events:

- μ candidate: use the hit depth in the muon counter
- $M^2_{\rm miss} = E^2_{\rm miss} - |\vec{p}_{\rm miss}|^2$ $\quad E_{\rm miss} = E_{\rm beam} - E_\mu$, $\vec{p}_{\rm miss} = -\vec{p}_{D^-} - \vec{p}_\mu$
- DT yield: $N^{\rm net}_{\rm sig} = 409.0 \pm 21.2 \pm 2.3$ after subtracting background yields.
- Subtracting about 1.0% contribution of radiative $D^+ \to \gamma\mu^+\nu_\mu$ from the signal, $B_{D^+\to\mu^+\nu_\mu} = \left(3.71 \pm 0.19_{\rm stat.} \pm 0.06_{\rm syst.}\right)\times 10^{-4}$



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

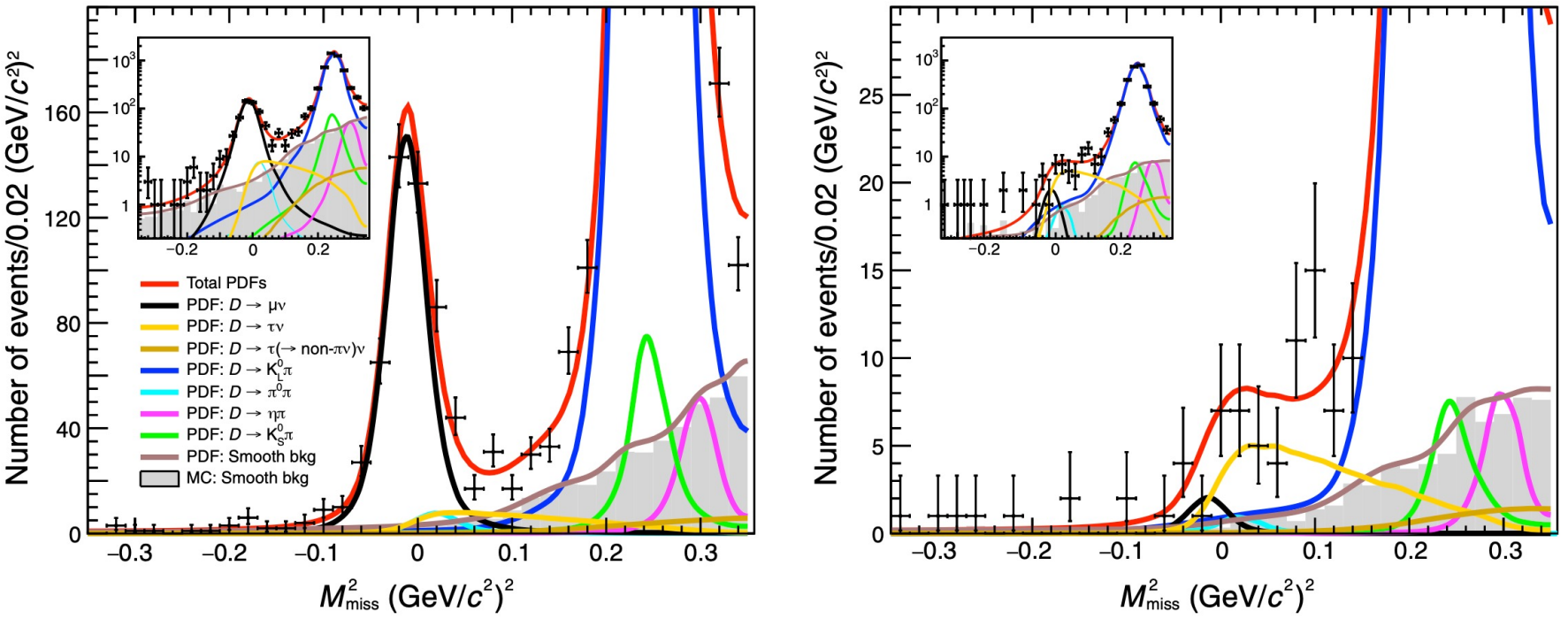
PRL 123 (2019) 211802

- **Only one good charged track, split two parts:**
  - ✓ μ^+-like: $E_{\rm EMC} \leq 300$ MeV ; π^+-like: $E_{\rm EMC} > 300$ MeV
- **Unbinned simultaneous maximum likelihood fit to $M^2_{\rm miss}$**
  - ✓ Fixed $B_{D^+\to\mu^+\nu_\mu} = (3.74 \pm 0.17)\times10^{-4}$

μ^+-like

$N^{\tau^+}_{\rm DT} = 137 \pm 27$

π^+-like



- **The signal significance including the systematic uncertainty is $5.1\,\sigma$**
- **The first measurement to date.**

$$B_{D^+\to\tau^+\nu_\tau} = \left(1.20 \pm 0.24_{\text{stat.}} \pm 0.12_{\text{syst.}}\right)\times 10^{-3}$$

$$R_{\tau/\mu} = \frac{\Gamma\left(D^+ \to \tau^+\nu_\tau\right)}{\overline{\Gamma}\left(D^+ \to \mu^+\nu_\mu\right)} = 3.21 \pm 0.64_{\text{stat.}} \pm 0.43_{\text{syst.}}$$

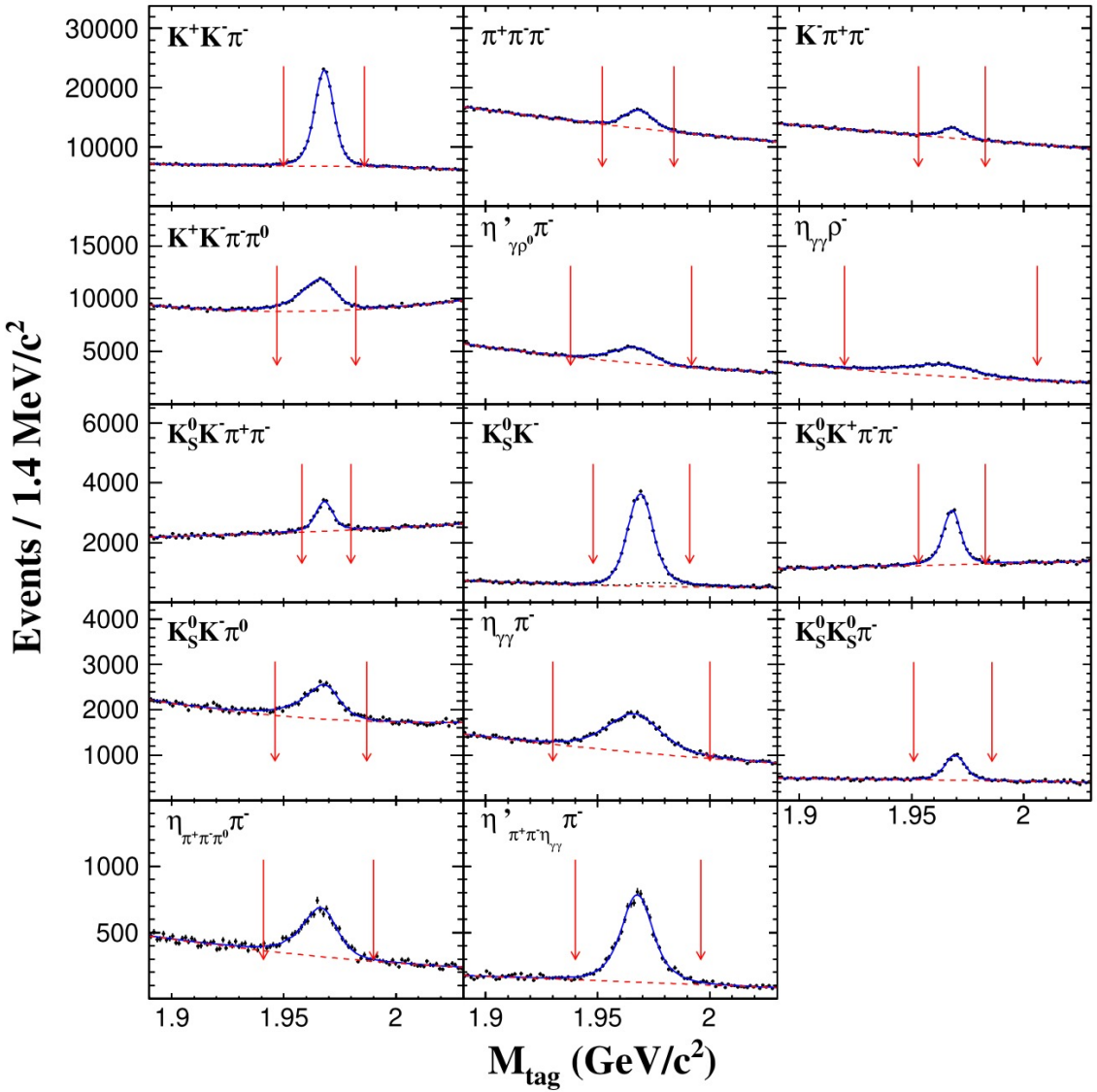
- **Consistent with the SM predicted value of 2.67, and no LFU violation in $\tau - \mu$ flavors with the current precision.**

$D_s^+ \to \mu^+ \nu_\mu$

@4.178 GeV

$N_{D_s^-} = 388660 \pm 2592$

PRL 122 (2019) 071802

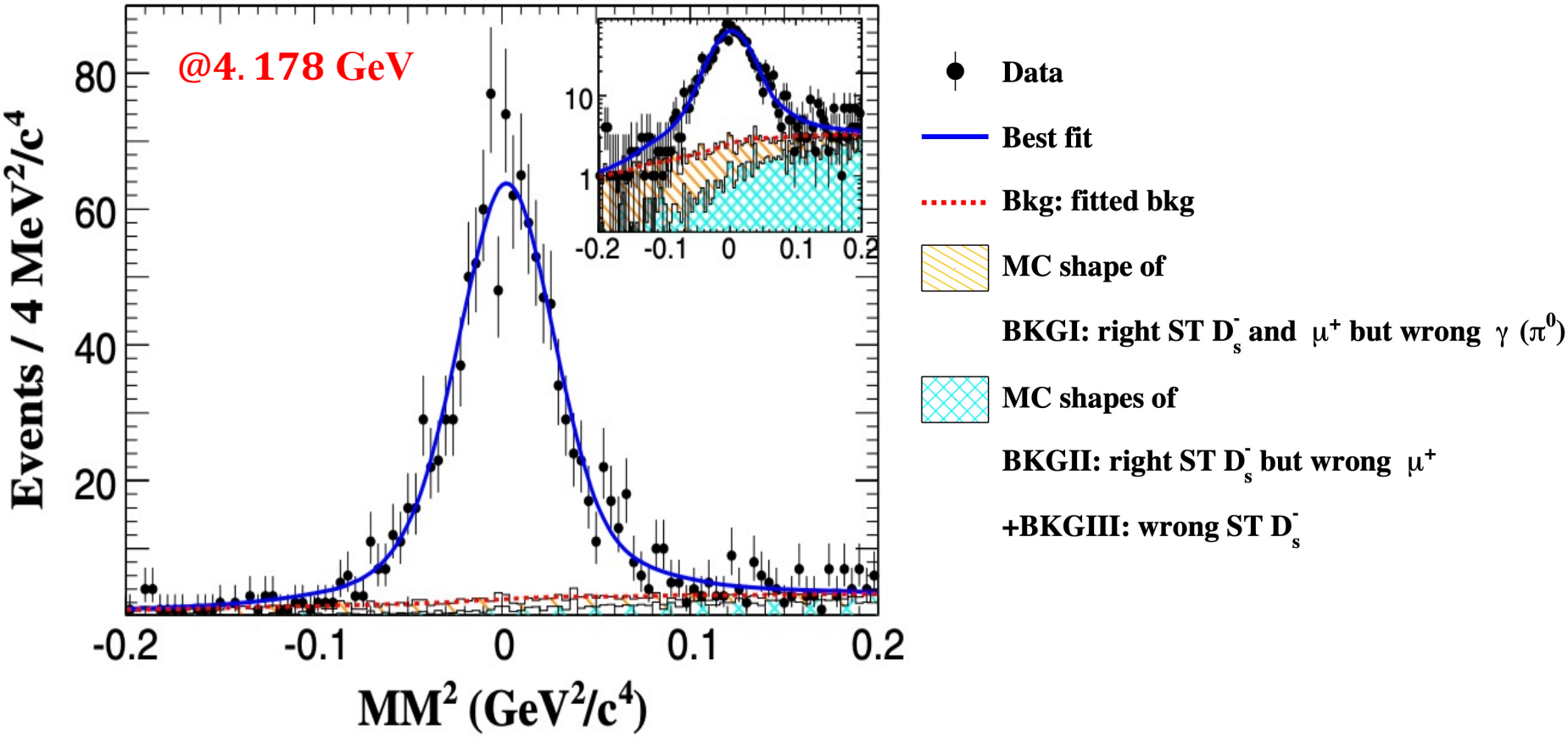


- μ candidate: use the hit depth in the muon counter

PRL 122 (2019) 071802

- An unbinned constrained fit to MM^2
  - ✓ The ratio of the signal yield over BKGI yield is constrained to the value from signal MC events.

$$N\left(D_s^+ \to \mu^+ \nu_\mu\right) = 1135.9 \pm 33.1$$



$$B_{D_s^+ \to \mu^+ \nu_\mu} = \left(5.49 \pm 0.16_{\text{stat.}} \pm 0.15_{\text{syst.}}\right) \times 10^{-3}$$

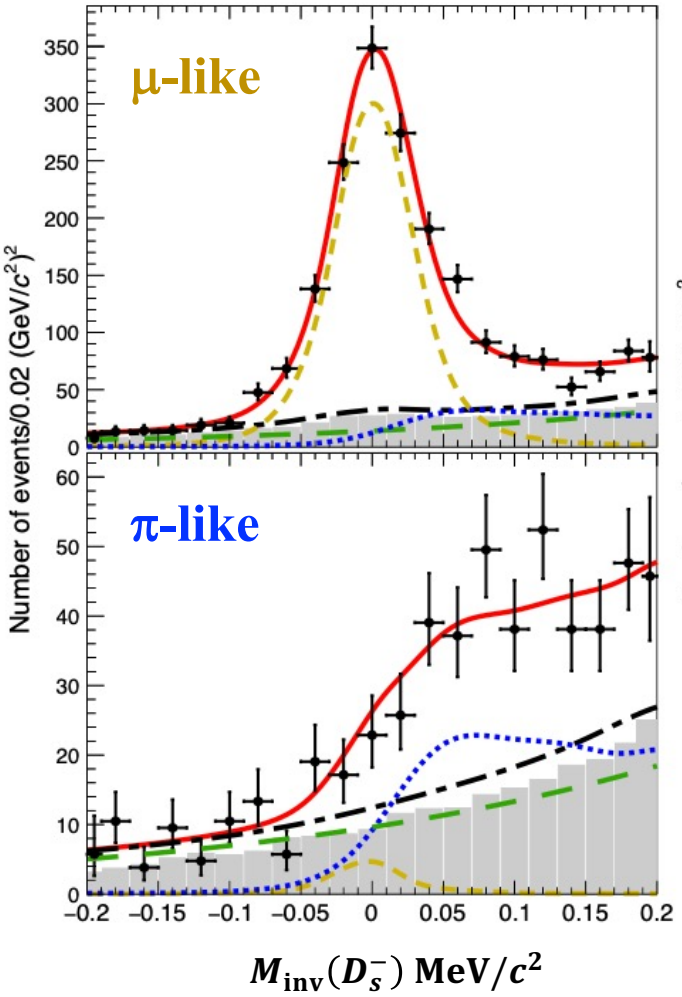
$D_s^+ \to \tau^+\nu_\tau$ via $\tau^+ \to \pi^+\bar{\nu}_\tau$ and $D_s^+ \to \mu^+\nu_\mu$

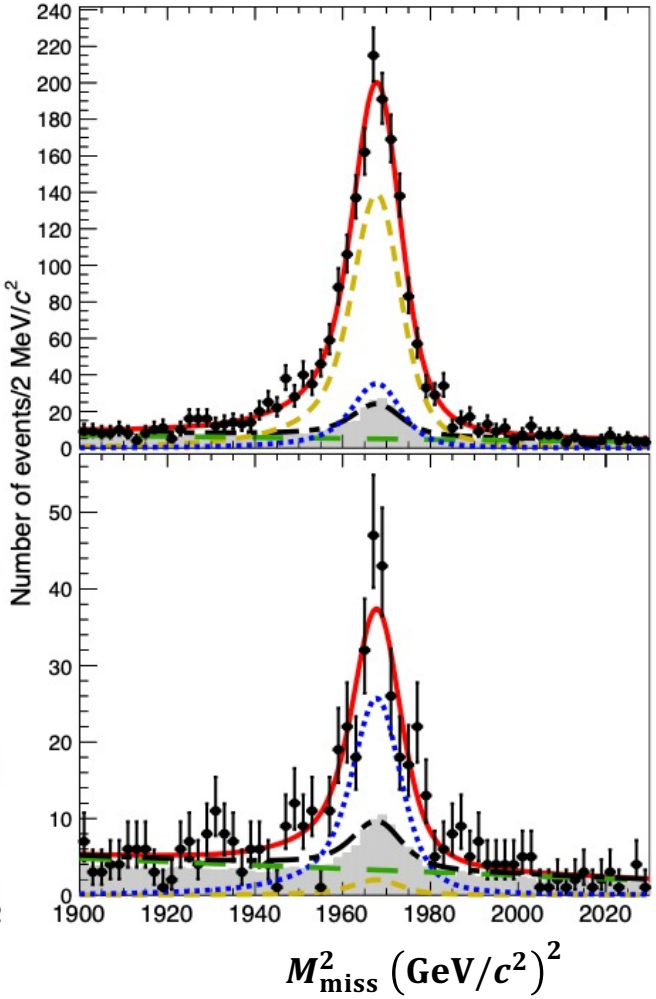
@4.178 ~ 4.23 GeV

PRD 104 (2021) 052009

$N(D_s^+ \to \tau^+\nu_\tau) = 946^{+46}_{-45}$

$B_{D_s^+ \to \tau^+\nu_\tau} = (5.21 \pm 0.25_{\text{stat.}} \pm 0.17_{\text{syst.}}) \times 10^{-2}$





Simultaneous unbinned maximum likelihood

Only show @ 4.178 GeV

- Data
- Best fit
- Sig: $D_s^+ \to \tau^+\nu_\tau$ via $\tau \to \pi^+\nu_\tau$
- Sig: $D_s^+ \to \mu^+\nu_\mu$
- Total background
- Bkgs: both tag and signal are wrong
- 40 × MC sample scaled

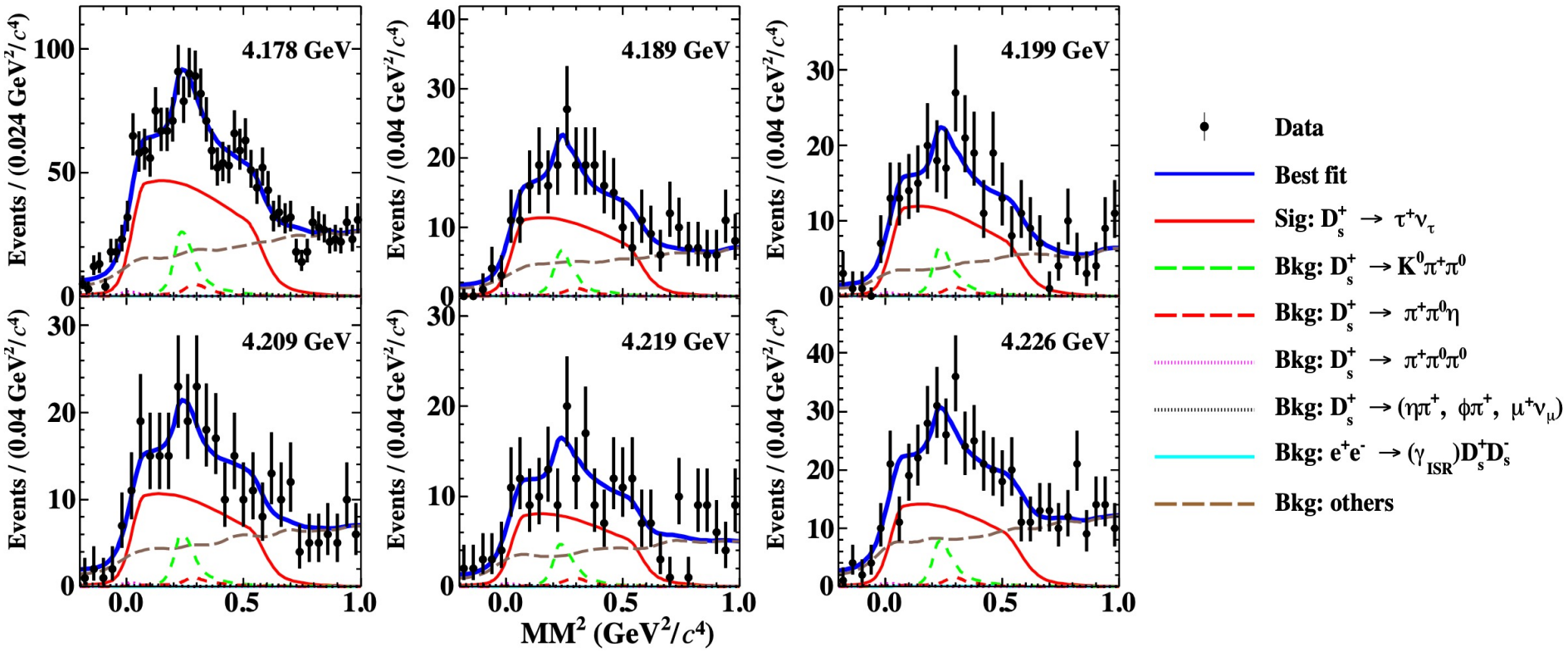
$D_s^+ \to \tau^+\nu_\tau$ via $\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau$

@4.178 ~ 4.23 GeV

PRD 104 (2021) 032001

A simultaneous fit to the MM^2 for six energy points shared with a common leptonic branching fraction.

$$N(D_s^+ \to \tau^+\nu_\tau) = 1745 \pm 84$$



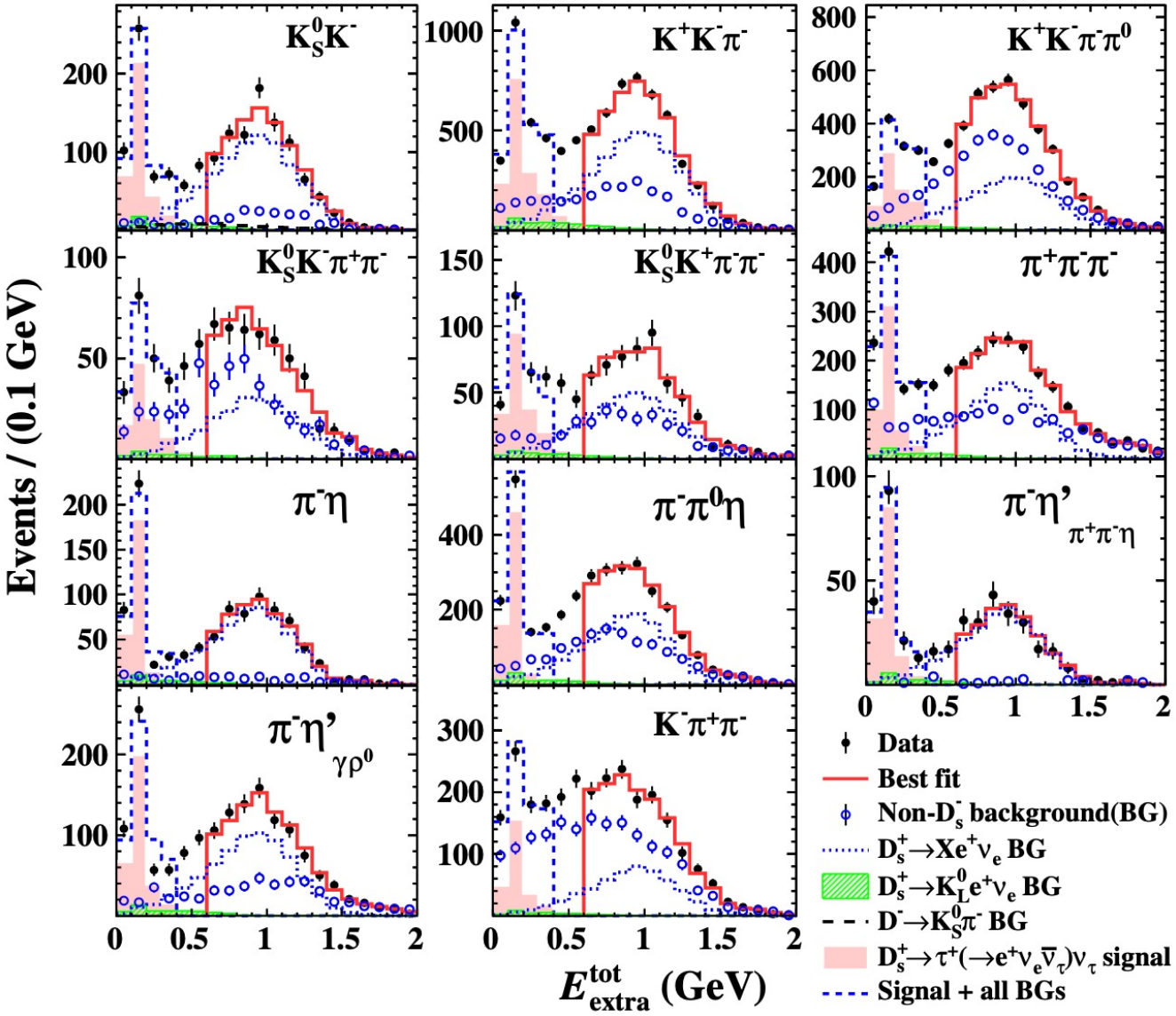
$$B_{D_s^+ \to \tau^+\nu_\tau} = \left(5.29 \pm 0.25_{\text{stat.}} \pm 0.20_{\text{syst.}}\right)\%$$

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

PRL 127 (2021) 171801

@4.178 ~ 4.23 GeV

$$B_{D_s^+\to\tau^+\nu_\tau} = \left(5.27 \pm 0.10_{\text{stat.}} \pm 0.12_{\text{syst.}}\right)\%$$



Combine results from BESIII measurements with $6.32\ \mathrm{fb}^{-1}$ and PDG2021

$$R_{\tau/\mu} = \frac{\overline{\Gamma}(D_s^+ \to \tau^+ \nu_\tau)}{\overline{\Gamma}(D_s^+ \to \mu^+ \nu_\mu)} = 9.67 \pm 0.34[1]$$

Consistent with the SM predicted value of 9.75

No LFU violation in $\tau - \mu$ flavors with the current precision.

[1] X. Y. Shen, Charm Physics at BESIII/BEPCII Experiment, talk at Charm 2020, Mexico City, Mexico, May 18-22, 2021.

Semi-leptonic decays

- $D^{0(+)} \to \pi^{-(0)} \mu^+ \nu_\mu$ PRL 121 (2018) 171803
- $D^0 \to K^- \mu^+ \nu_\mu$ PRL 122 (2019) 011804
- $D^+ \to \eta\ \mu^+ \nu_\mu$ PRL 124 (2020) 231801
- $D^0 \to \rho^- \mu^+ \nu_\mu$ arXiv:2106.02292 [hep-ex], accepted by PRD
- $D^+ \to \omega\, \mu^+ \nu_\mu$ PRD 101 (2020) 072005
- $D_s^+ \to \eta/\eta'/\phi \ell^+ \nu_\ell$ PRD 97 (2018) 012006 PRL 122 (2019) 121801
- $\Lambda_c^+ \to \Lambda \ell^+ \nu_\ell$ PRL 115 (2015) 221805 PLB 767 (2017) 42
- $\Lambda \to p \mu^- \bar{\nu}_\mu$ PRL 127 (2021) 121802

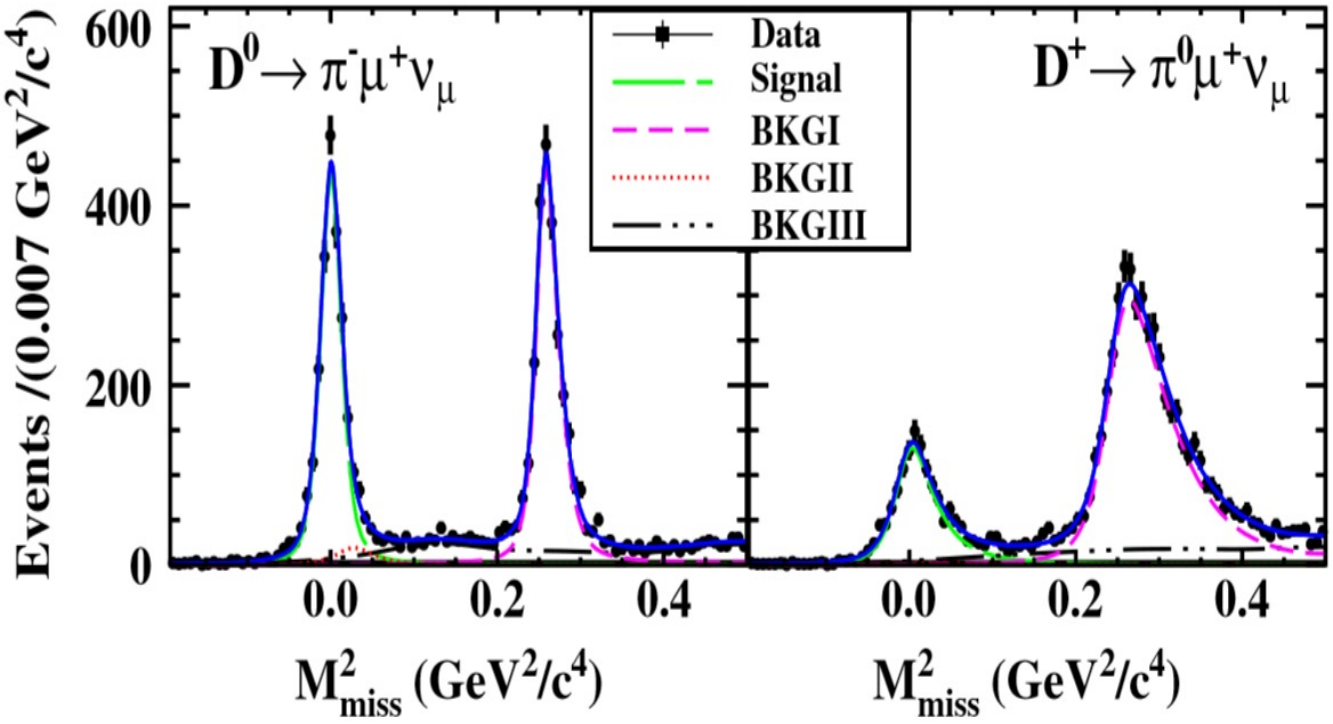
$D^{0(+)} \to \pi^{-(0)}\mu^+\nu_\mu$

Unbinned maximum likelihood fit

PRL 121 (2018) 171803

$$N(D^0 \to \pi^-\mu^+\nu_\mu) = 2265 \pm 63$$

$$N(D^+ \to \pi^0\mu^+\nu_\mu) = 1335 \pm 42$$



$$B_{D^0\to\pi^-\mu^+\nu_\mu} = (0.272 \pm 0.008_{\text{stat.}} \pm 0.006_{\text{syst.}})\%$$

$$B_{D^+\to\pi^0\mu^+\nu_\mu} = (0.350 \pm 0.011_{\text{stat.}} \pm 0.010_{\text{syst.}})\%$$

SM expectation: 0.985 ± 0.002 [1]

PRL 121 (2018) 171803

Overall

$$R_{LFU}^{\pi^-} = \frac{\Gamma(D^0 \to \pi^- \mu^+ \nu_\mu)}{\Gamma(D^0 \to \pi^- e^+ \nu_e)}$$

$= 0.922 \pm 0.030_{\text{stat}} \pm 0.022_{\text{syst}}$

1.7σ consistent

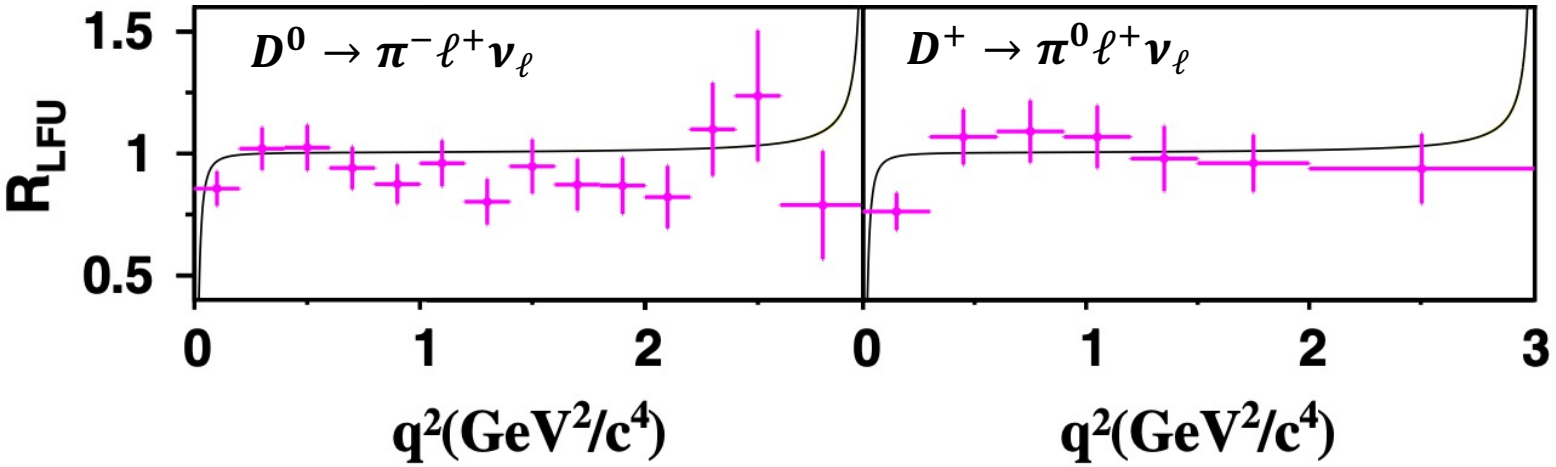
$$R_{LFU}^{\pi^0} = \frac{\Gamma(D^+ \to \pi^0 \mu^+ \nu_\mu)}{\Gamma(D^+ \to \pi^0 e^+ \nu_e)}$$

$= 0.964 \pm 0.037_{\text{stat}} \pm 0.026_{\text{syst}}$

0.5σ consistent

Local

Consistent within 2σ

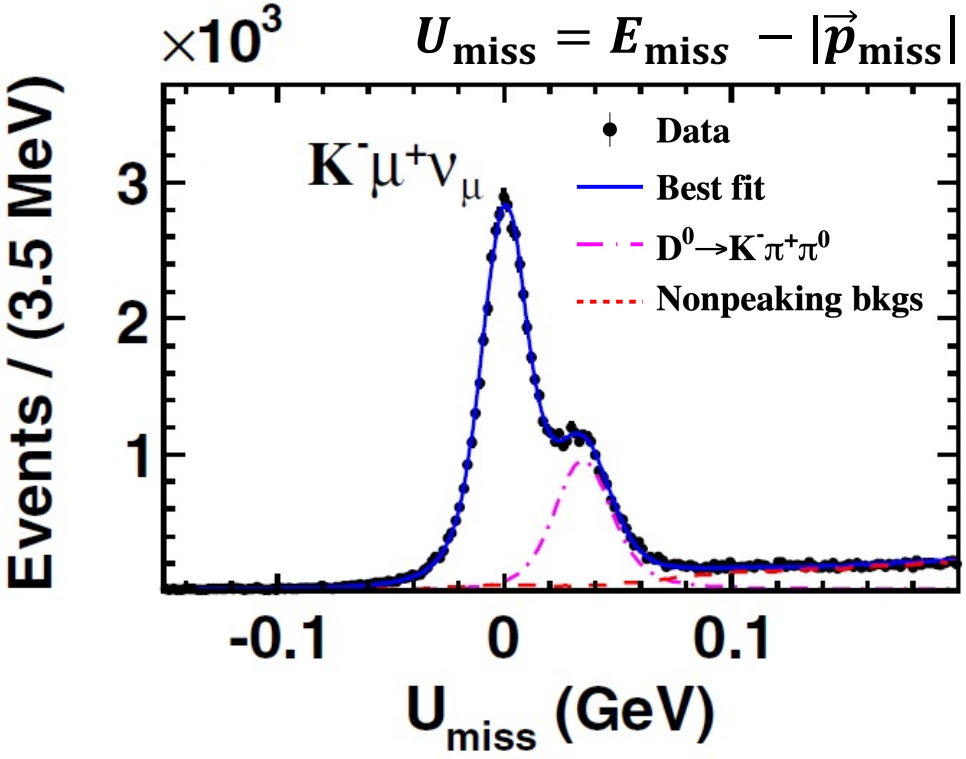


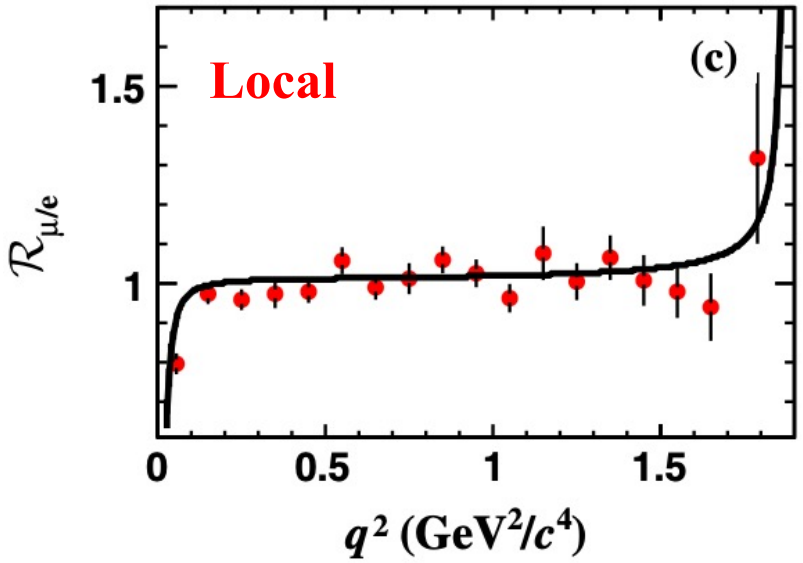
[1] L. Riggio, G. Salerno, and S. Simula, EPJC 78, 501 (2018).

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

$N(D^0 \to K^- \mu^+ \nu_\mu) = 47100 \pm 259$

PRL122(2019)011804





$B_{D^0 \to K^- \mu^+ \nu_\mu} = (3.413 \pm 0.019_{\text{stat.}} \pm 0.035_{\text{syst.}})\%$

$$R_{\mu/e} = \frac{\Gamma(D^0 \to K^- \mu^+ \nu_\mu)}{\Gamma(D^0 \to K^- e^+ \nu_e)} = 0.974 \pm 0.007_{\text{stat}} \pm 0.012_{\text{syst}}$$

Overall

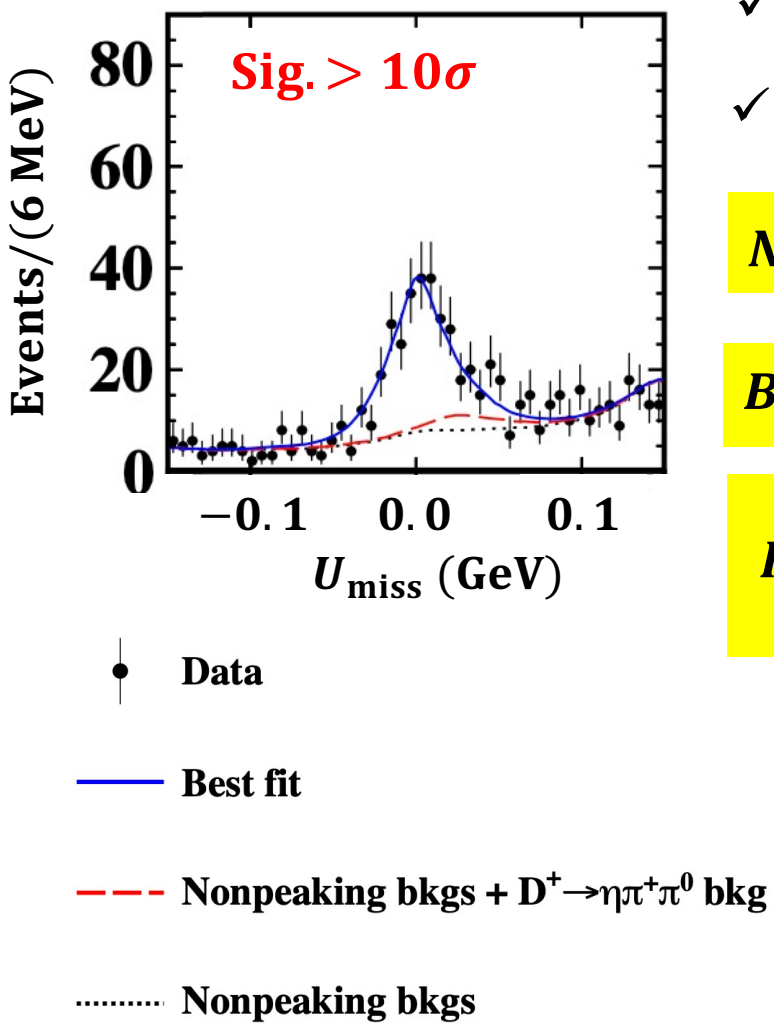
SM expectation: 0.975 ± 0.001 [1]

[1] L. Riggio, G. Salerno, and S. Simula, EPJC 78, 501 (2018).

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

PRL124(2020)231801

- Verification of LFU via $c \to d\, l^+\nu_l$



✓ $\eta \to \gamma\gamma$

✓ Unbinned fit to $U_{\rm miss}$

$$N_{\rm DT}^{\rm signal} = 234 \pm 22$$

$$B_{D^+\to\eta\mu^+\nu_\mu} = \left(10.4 \pm 1.0_{\rm stat.} \pm 0.5_{\rm syst.}\right)\times 10^{-4}$$

$$R_{\mu/e} = \frac{B_{D^+\to\eta\mu^+\nu_\mu}}{B^{PDG}_{D^+\to\eta e^+\nu_e}} = 0.91 \pm 0.13$$

SM prediction: $(0.97 - 1.00)$

No LFU violation within current sensitivity.

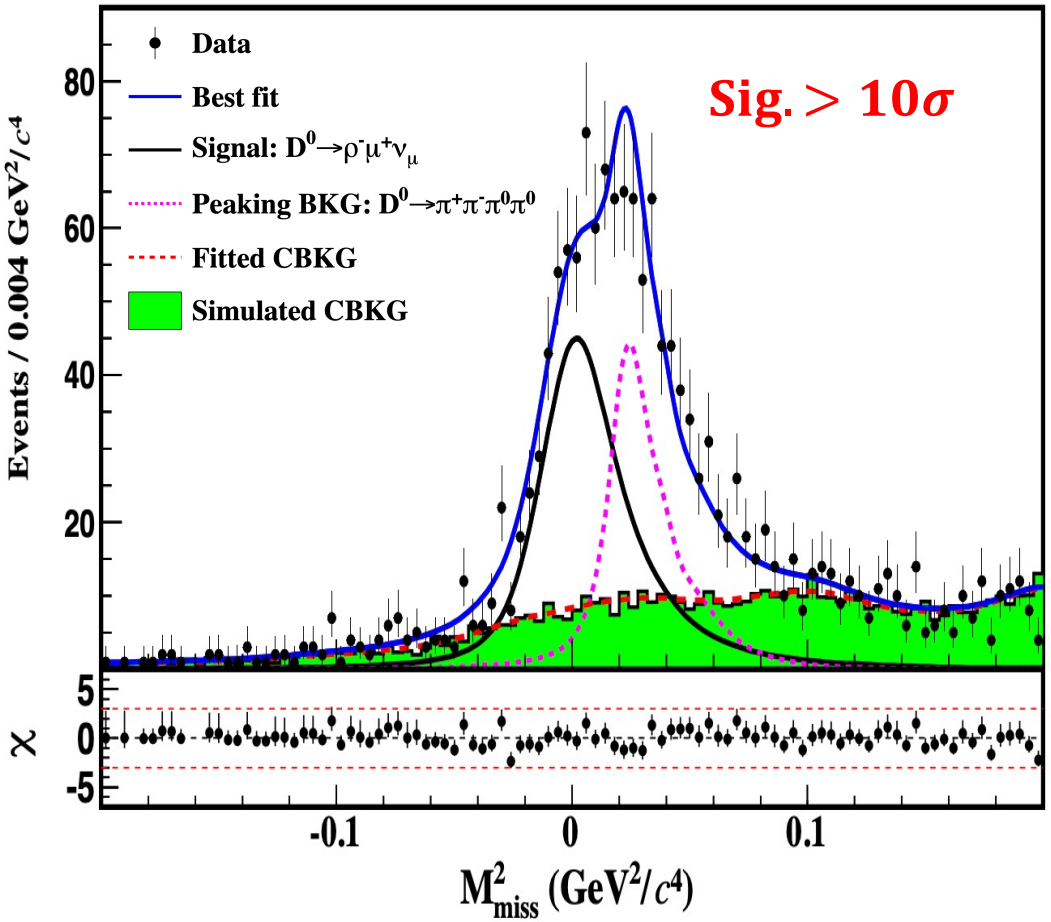
$D^0 \to \rho^- \mu^+ \nu_\mu$

✓ $\rho^- \to \pi^- \pi^0$

arXiv:2106.02292 [hep-ex], accepted by PRD

$N_{\rm DT}^{\rm signal} = 570 \pm 40$

$B_{D^0 \to \rho^- \mu^+ \nu_\mu} = (1.35 \pm 0.09_{\rm stat.} \pm 0.09_{\rm syst.}) \times 10^{-4}$



$$R_{\mu/e} = \frac{B_{D^0 \to \rho^- \mu^+ \nu_\mu}}{B^{PDG}_{D^0 \to \rho^- e^+ \nu_e}} = 0.90 \pm 0.11$$

consistent

SM prediction: $(0.93 - 0.96)$

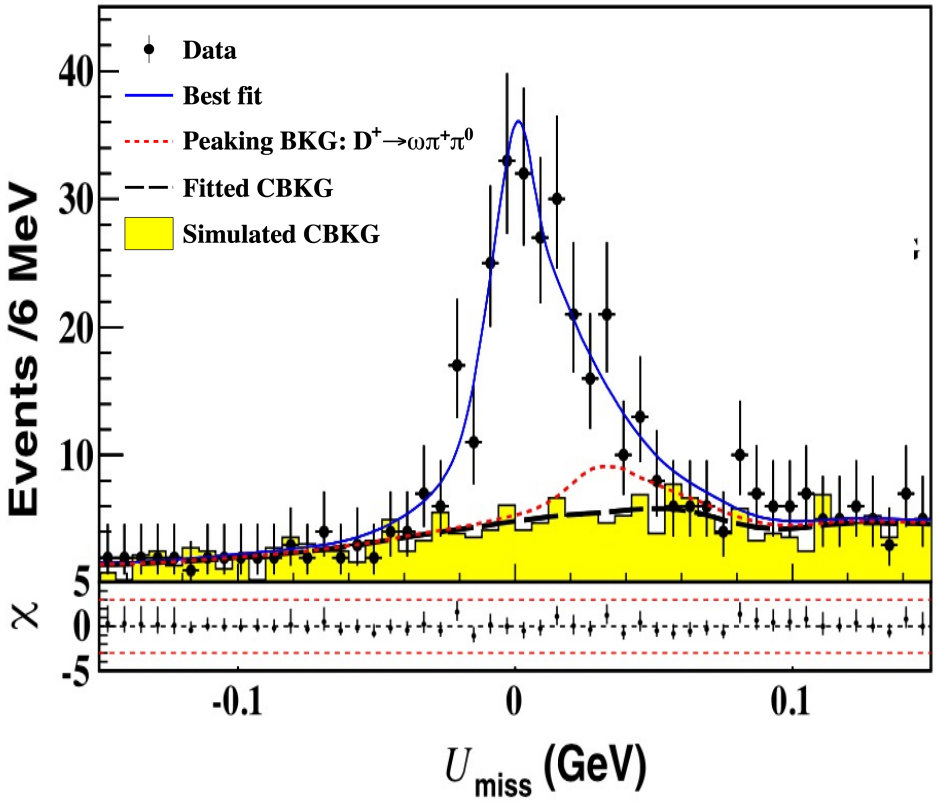
$D^+ \to \omega\, \mu^+ \nu_\mu$

✓ $\omega \to \pi^+\pi^-\pi^0$

PRD 101 (2020) 072005

$N_{\rm DT}^{\rm signal} = 194 \pm 20$

$B_{D^+\to\omega\mu^+\nu_\mu} = \left(17.7 \pm 1.8_{\rm stat.} \pm 1.1_{\rm syst.}\right)\times 10^{-4}$



$$R_{\mu/e} = \frac{B_{D^+\to\omega\mu^+\nu_\mu}}{B^{PDG}_{D^+\to\omega e^+\nu_e}} = 1.05 \pm 0.14$$

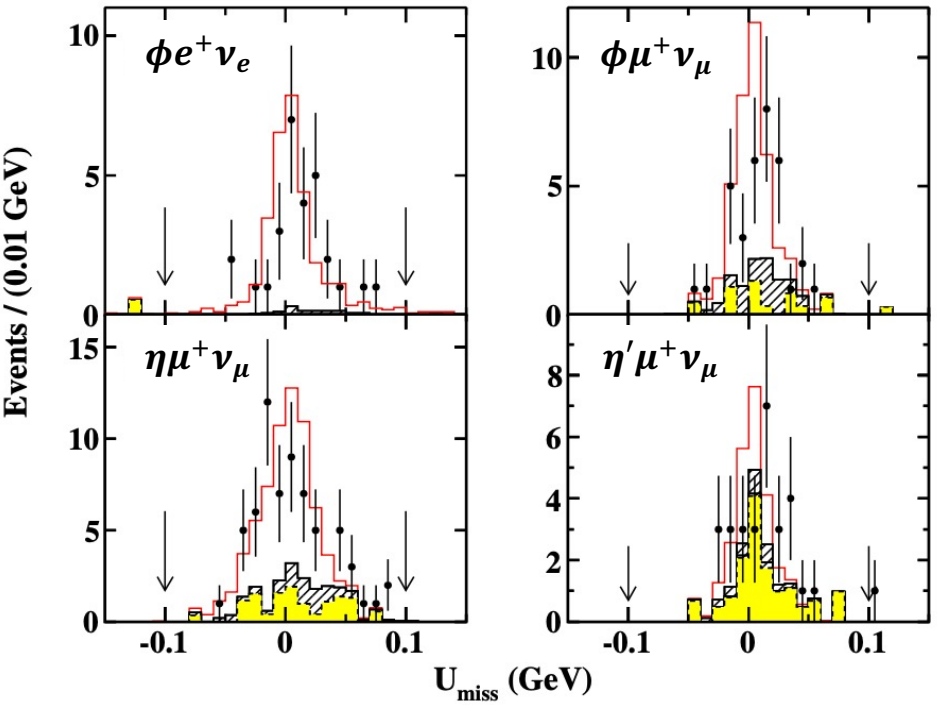
consistent

SM prediction: $(0.93 - 0.99)$

$D_s^+ \to \eta/\eta'/\phi\ell^+\nu_\ell$

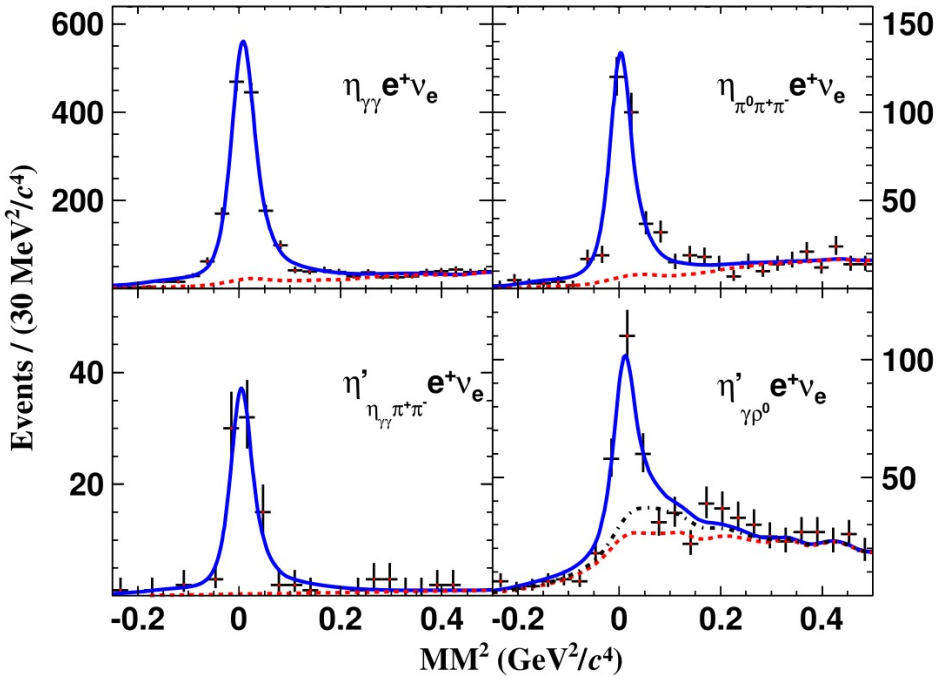
PRD 97 (2018) 012006

@4.009 GeV, 0.482 fb^{-1}



PRL 122 (2019) 121801

@4.178 GeV, 3.189 fb^{-1}



$$\frac{B_{D_s^+\to\phi\mu^+\nu_\mu}}{B_{D_s^+\to\phi e^+\nu_e}} = 0.86 \pm 0.29$$

$$\frac{B_{D_s^+\to\eta'\mu^+\nu_\mu}}{B_{D_s^+\to\eta' e^+\nu_e}} = 1.29 \pm 0.67$$

$$\frac{B_{D_s^+\to\eta\mu^+\nu_\mu}}{B_{D_s^+\to\eta e^+\nu_e}} = 1.04 \pm 0.21$$

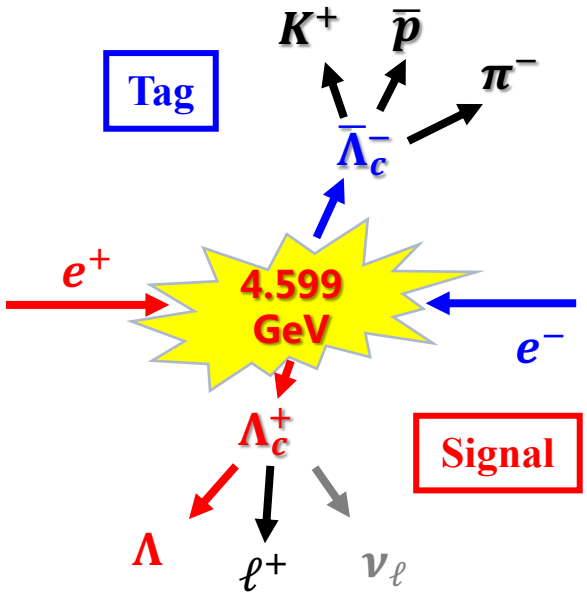
Consistent with unity within uncertainty, no obvious LFU violation is observed.

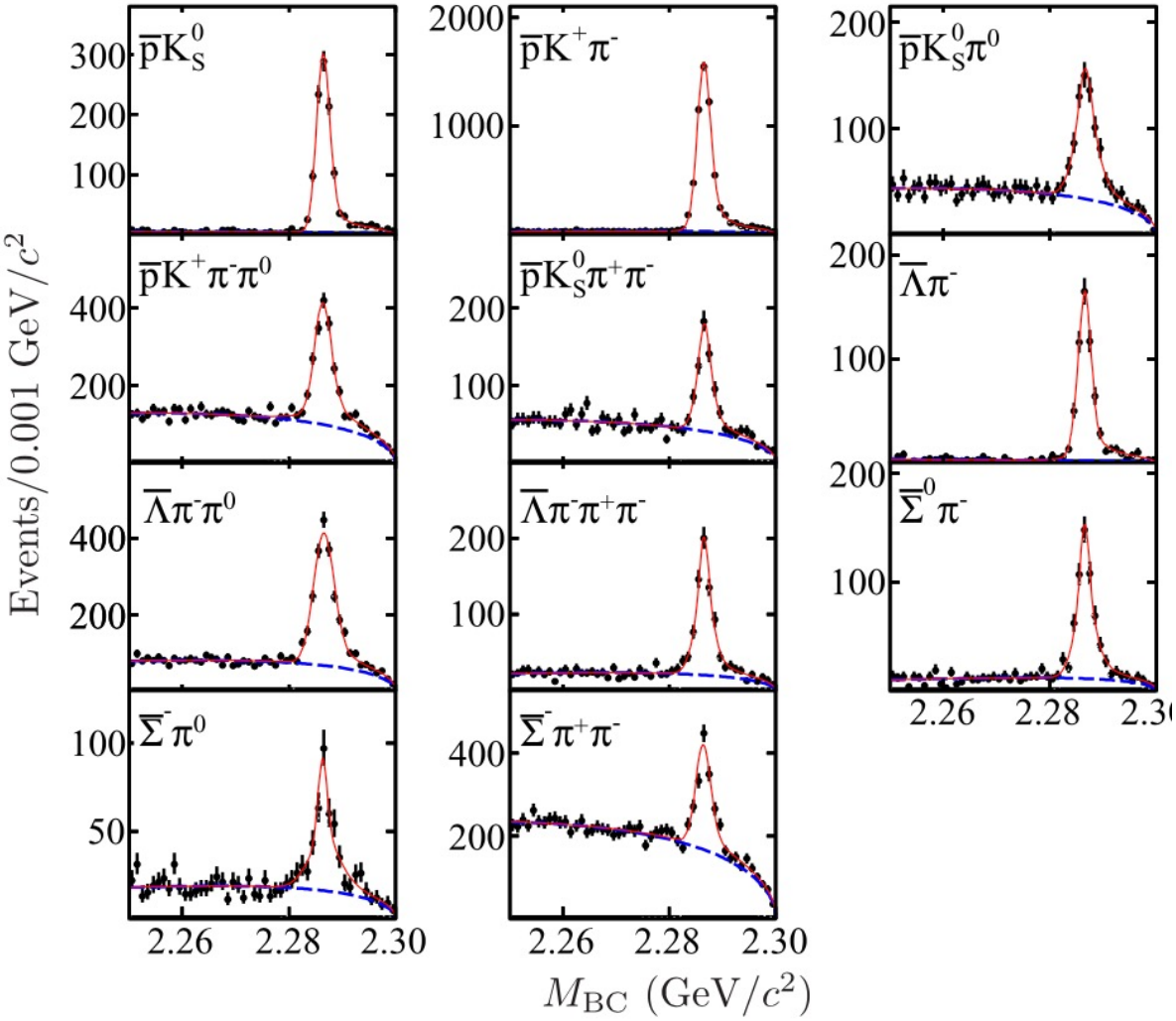
$\Lambda_c^+ \to \Lambda \ell^+ \nu_\ell$

@4.599 GeV, 0.567 fb^{-1}

PRL 115 (2015) 221805 PLB 767 (2017) 42

$N_{\bar{\Lambda}_c^-} = 14415 \pm 159$

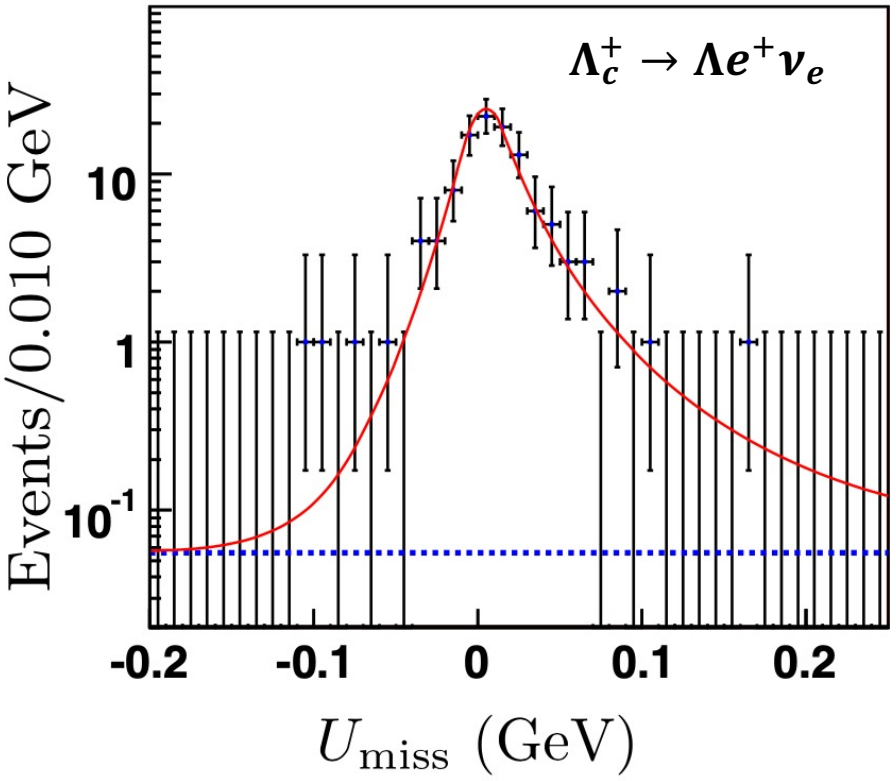




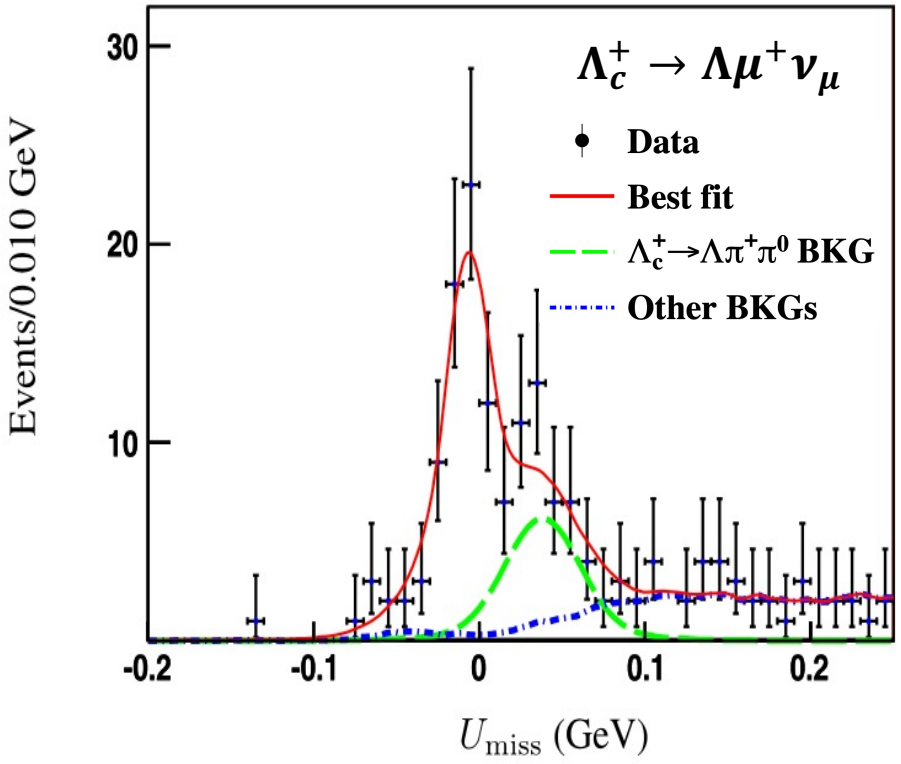
PRL 115 (2015) 221805

PLB 767 (2017) 42

$N^{\text{signal}}_{\Lambda_c^+ \to \Lambda e^+ \nu_e} = 103.5 \pm 10.9$



$N^{\text{signal}}_{\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu} = 78.7 \pm 10.5$



$$\frac{B_{\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu}}{B_{\Lambda_c^+ \to \Lambda e^+ \nu_e}} = 0.96 \pm 0.16_{\text{stat}} \pm 0.04_{\text{syst}}$$

Consistent with unity.

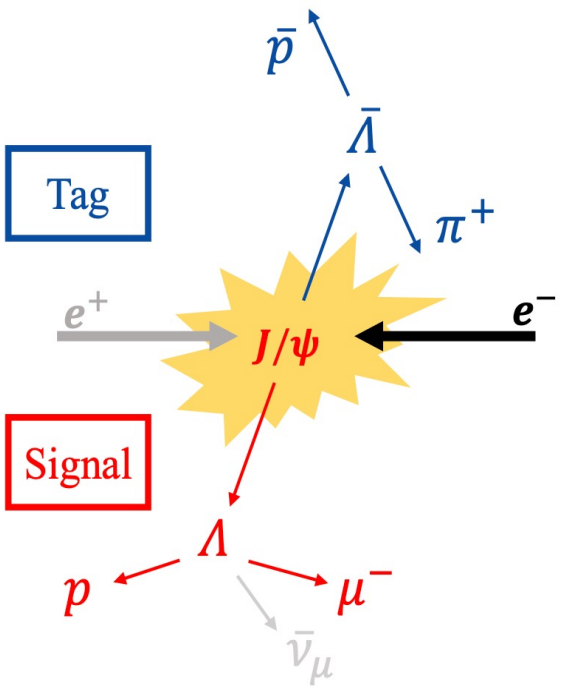
$\Lambda \to p\mu^-\bar{\nu}_\mu$

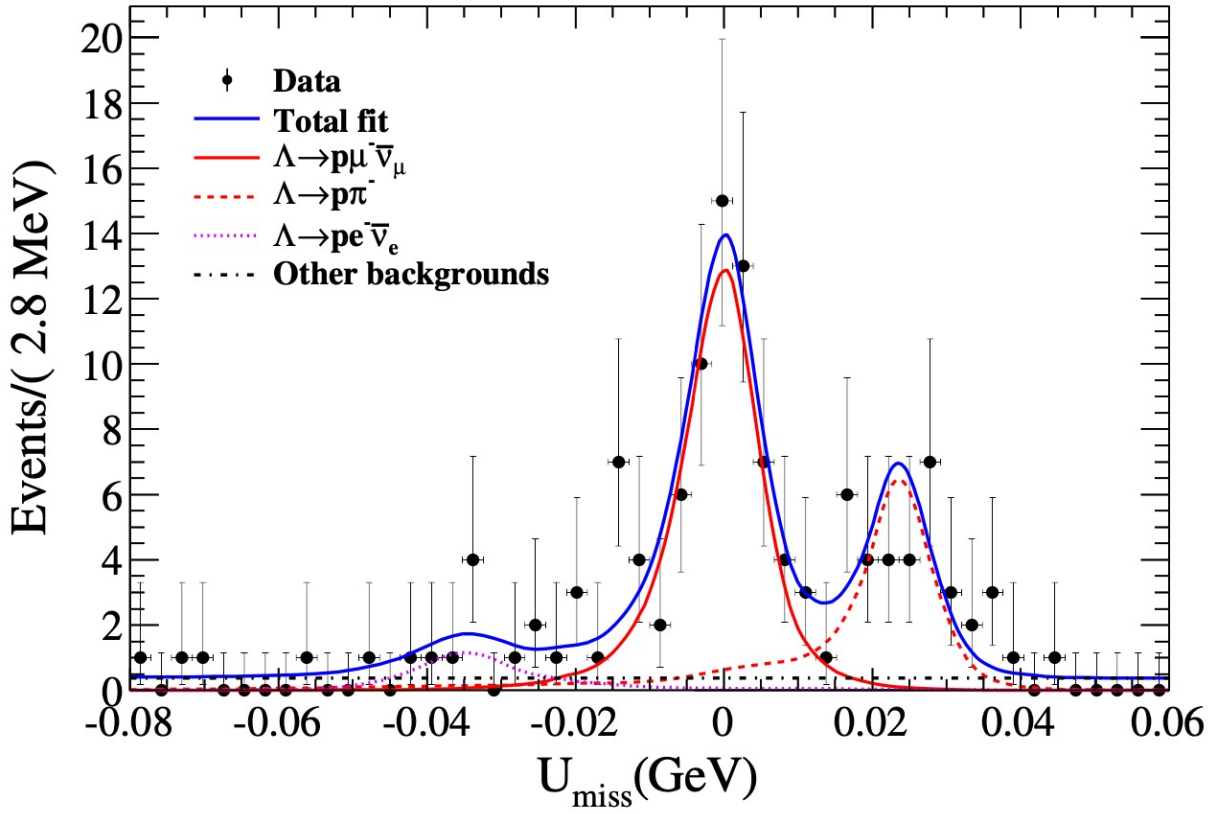
PRL 127 (2021) 121802

10 billion J/ψ events

$N_{\bar{\Lambda}} = 14,609,800 \pm 7,117$

$N^{\text{signal}}_{\Lambda\to p\mu^-\bar{\nu}_\mu} = 64 \pm 9$





$$\frac{\Gamma_{\Lambda\to p\mu^-\bar{\nu}_\mu}}{\Gamma^{PDG}_{\Lambda\to pe^-\bar{\nu}_e}} = 0.178 \pm 0.028$$

Consistent

0.153 ± 0.008 (SM expectation)

Summary

- With data samples of 2.93 fb^{-1} @ 3.773 GeV, 6.32 fb^{-1} from 4.178-4.23 GeV, 0.567 fb^{-1} from 4.599 GeV, and 10 billion J/ψ events, BESIII have tested the LFU.

BESIII Signal	Ratio ($\frac{\mu}{e}$)		Deviation
	Measurement	Expectation	
$D^0 \to \pi^- \mu^+ \nu_\mu$ [PRL121(2018)171803]	$0.922 \pm 0.030 \pm 0.022$	0.985 ± 0.002	1.7σ
$D^+ \to \pi^0 \mu^+ \nu_\mu$ [PRL121(2018)171803]	$0.964 \pm 0.037 \pm 0.026$		0.5σ
$D^0 \to K^- \mu^+ \nu_\mu$ [PRL122(2019)011804]	$0.974 \pm 0.007 \pm 0.012$	0.975 ± 0.001	0.1σ
$D^+ \to \eta \mu^+ \nu_\mu$ [PRL124(2020)231801]	0.91 ± 0.13	$0.97 - 1.00$	0.7σ
$D^0 \to \rho^- \mu^+ \nu_\mu$ arXiv:2106.02292 [hep-ex], accepted by PRD	0.90 ± 0.11	$0.93 - 0.96$	0.5σ
$D^+ \to \omega \mu^+ \nu_\mu$ [PRD101(2020)072005]	1.05 ± 0.14	$0.93 - 0.99$	0.9σ

BESIII Signal	Ratio (R)		Deviation
	Measured	SM Expected	
$D^+ \to \ell^+ \nu_\ell$ [PRL123(2019)211802] [PRD89(2014)051104(R)]	$\frac{\tau}{\mu} = 3.21 \pm 0.64 \pm 0.43$	2.67	0.7σ
$D_s^+ \to \ell^+ \nu_\ell$ [PRL122(2019)071802] [PRL127(2021)171801] [PRD104(2021)032001] [PRD104(2021)052009]	$\frac{\tau}{\mu} = 9.67 \pm 0.34$	9.75	0.2σ
$D_s^+ \to \eta \ell^+ \nu_\ell$ [PRL122(2019)121801] [PRD97(2018)012006]	$\frac{\mu}{e} = 1.04 \pm 0.21$	1.0	0.2σ
$D_s^+ \to \eta' \ell^+ \nu_\ell$ [PRL122(2019)121801] [PRD97(2018)012006]	$\frac{\mu}{e} = 1.29 \pm 0.67$		0.4σ
$D_s^+ \to \phi \ell^+ \nu_\ell$ [PRD97(2018)012006]	$\frac{\mu}{e} = 0.86 \pm 0.29$		0.5σ
$\Lambda \to p \mu^- \overline{\nu}_\mu$ [PRL127(2021)121802]	$\frac{\mu}{e} = 0.178 \pm 0.028$	0.153 ± 0.008	0.9σ
$\Lambda_c^+ \to \Lambda \ell^+ \nu_\ell$ [PRL115(2015)221805] [PLB767(2017)42]	$\frac{\mu}{e} = 0.96 \pm 0.16 \pm 0.04$	1.0	0.1σ

- **No obvious LFU violation is observed with the current precision.**
- **In the near future, BESIII will collect 20 $\mathbf{fb^{-1}}$ @ 3.773 GeV data sample, another 3 $\mathbf{fb^{-1}}$ @ 4.178 GeV, and 15 $\mathbf{fb^{-1}}$ @ 4.6-4.9 GeV, the single precisions for $\boldsymbol{D_{(s)}}$ and $\boldsymbol{\Lambda_c}$ decays will be further improved.**

Thanks for your attention!

Backup

Planned future data set

Table 7.1: List of data samples collected by BESIII/BEPCII up to 2019, and the proposed samples for the remainder of the physics program. The most right column shows the number of required data taking days in current (T_C) or upgraded (T_U) machine. The machine upgrades include top-up implementation and beam current increase.

Energy	Physics motivations	Current data	Expected final data	T_C / T_U
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A	0.1 fb^{-1} (fine scan)	60/50 days
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
✓ J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)	3.2 fb^{-1} (10 billion)	N/A
✓ $\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
$\psi(3770)$ peak	$D^0/D^\pm$ decays	2.9 fb^{-1}	20.0 fb^{-1}	610/360 days
3.8 - 4.6 GeV	R values XYZ/Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ/Open charm	3.2 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
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

From Prof. Beijiang Liu

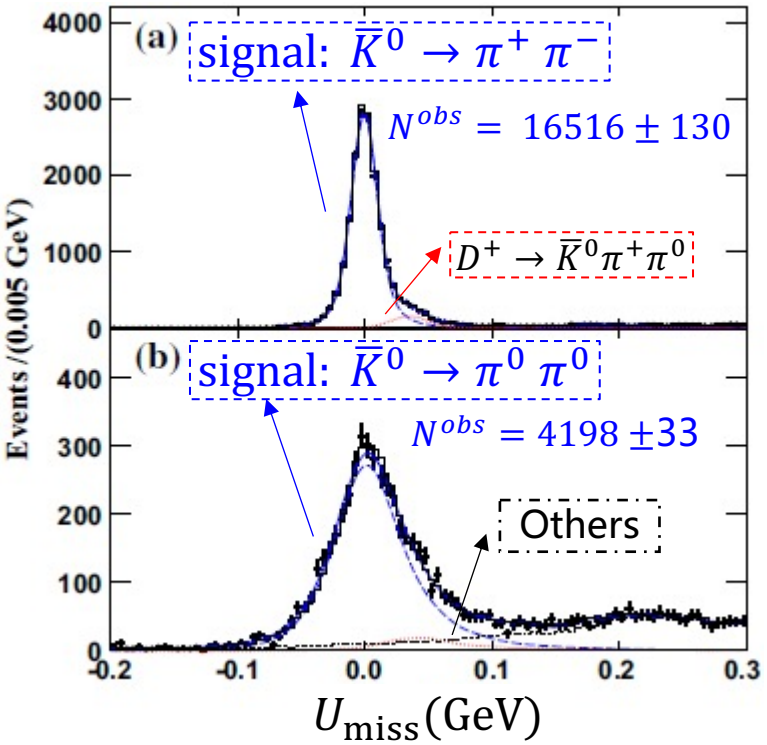
to be complete in 2022-23

~55 fb^{-1}

$D^+ \to \bar{K}^0 \mu^+ \nu_\mu$

EPJC 76(2016) 369

Simultaneous fit: The double tag production yield has been constrained to be same for the two modes, which is corrected by the detector efficiency and daughter decay branching fractions:



$$N_{DT}^{\rm prd} = 132712 \pm 1041$$

$$B\left(D^+ \to \bar{K}^0 \mu^+ \nu_\mu\right) = (8.72 \pm 0.07 \pm 0.18)\%$$

Lepton universality:

$$\frac{\Gamma(D^+ \to \bar{K}^0 \mu^+ \nu_\mu)}{\Gamma(D^+ \to \bar{K}^0 e^+ \nu_e)} = 0.988 \pm 0.033$$ consistent

$B(D^+ \to \bar{K}^0 e^+ \nu_e)$ is from PDG