Rare Charm decays at LHCb

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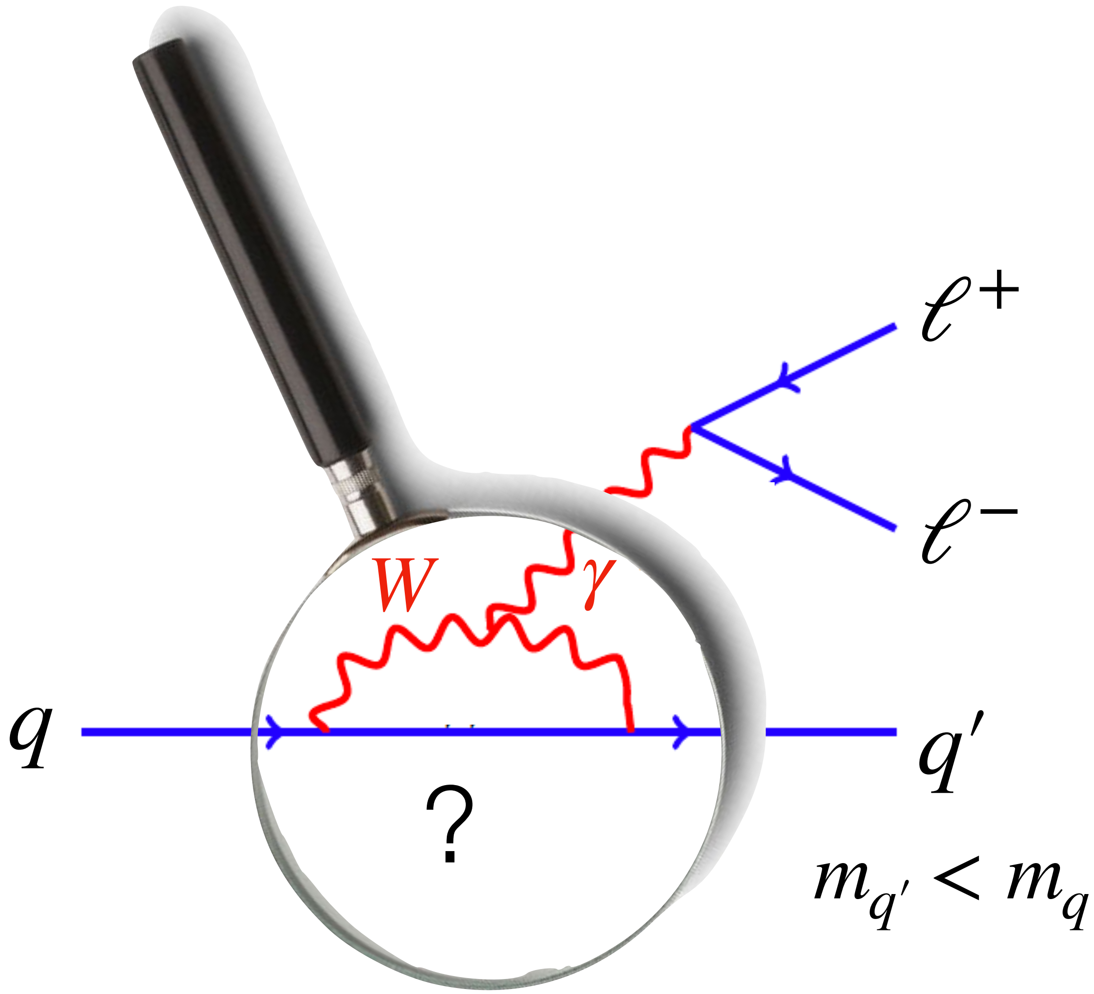
TU Dortmund

Jahrestreffen der LHCb Gruppen
[ex FSP-meeting]

07/10/2021

Search for New Physics in rare decays...



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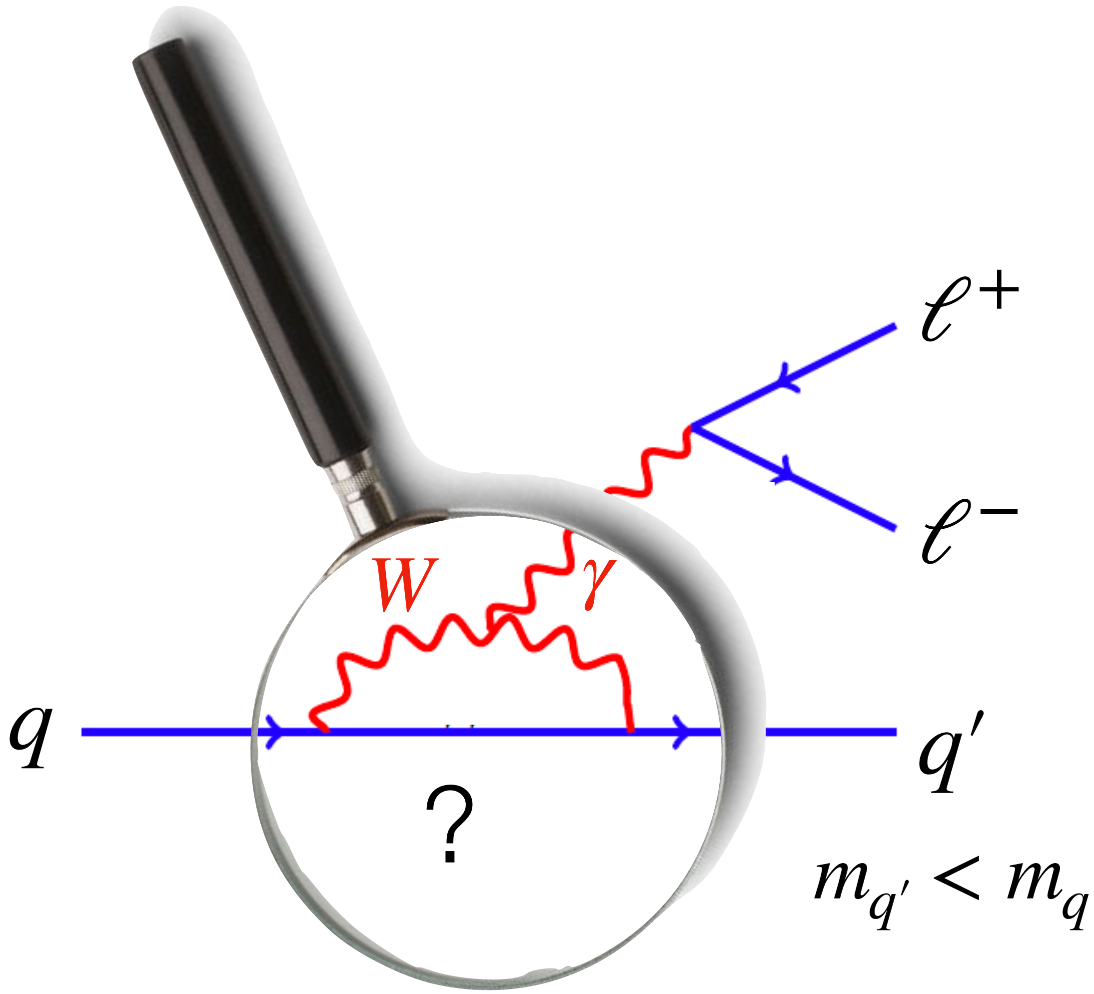

- Rates (branching fractions)

$$\sim \mathscr{A} = \mathscr{A}_0 \left(\frac{c_{SM}}{m_W^2} + \frac{c_{NP}}{\Lambda_{NP}^2} \right)$$

- CP Asymmetries

$$\sim |\mathscr{A}_{SM}||\mathscr{A}_{NP}| \sin \boldsymbol{\Delta\phi_{NP}}$$

- Angular distributions

~ Lorentz-Structure $\overline{\psi}\Gamma_{NP}\psi$

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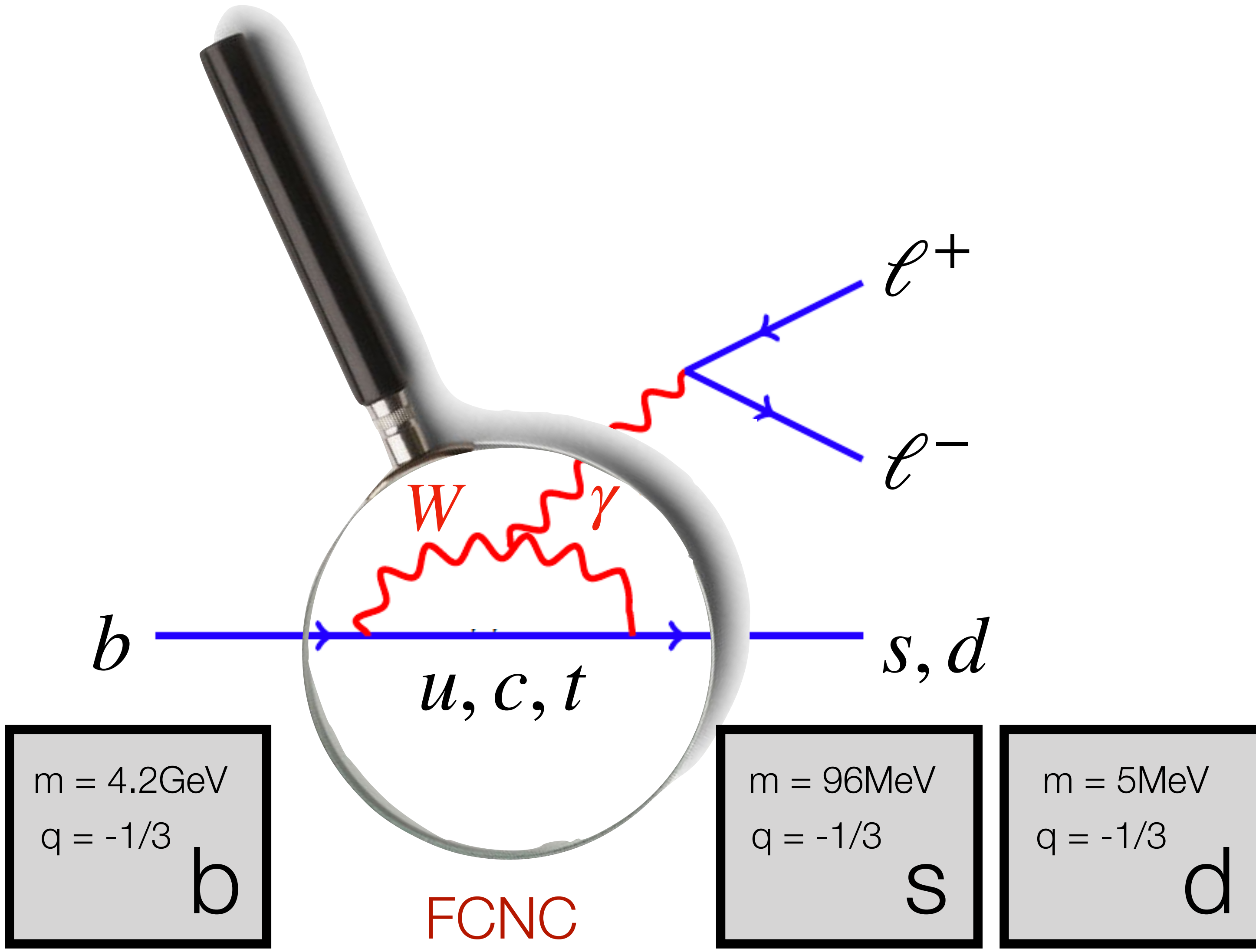

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B-physics: $b \to s\ell^+\ell^-$, $b \to d\ell^+\ell^-$

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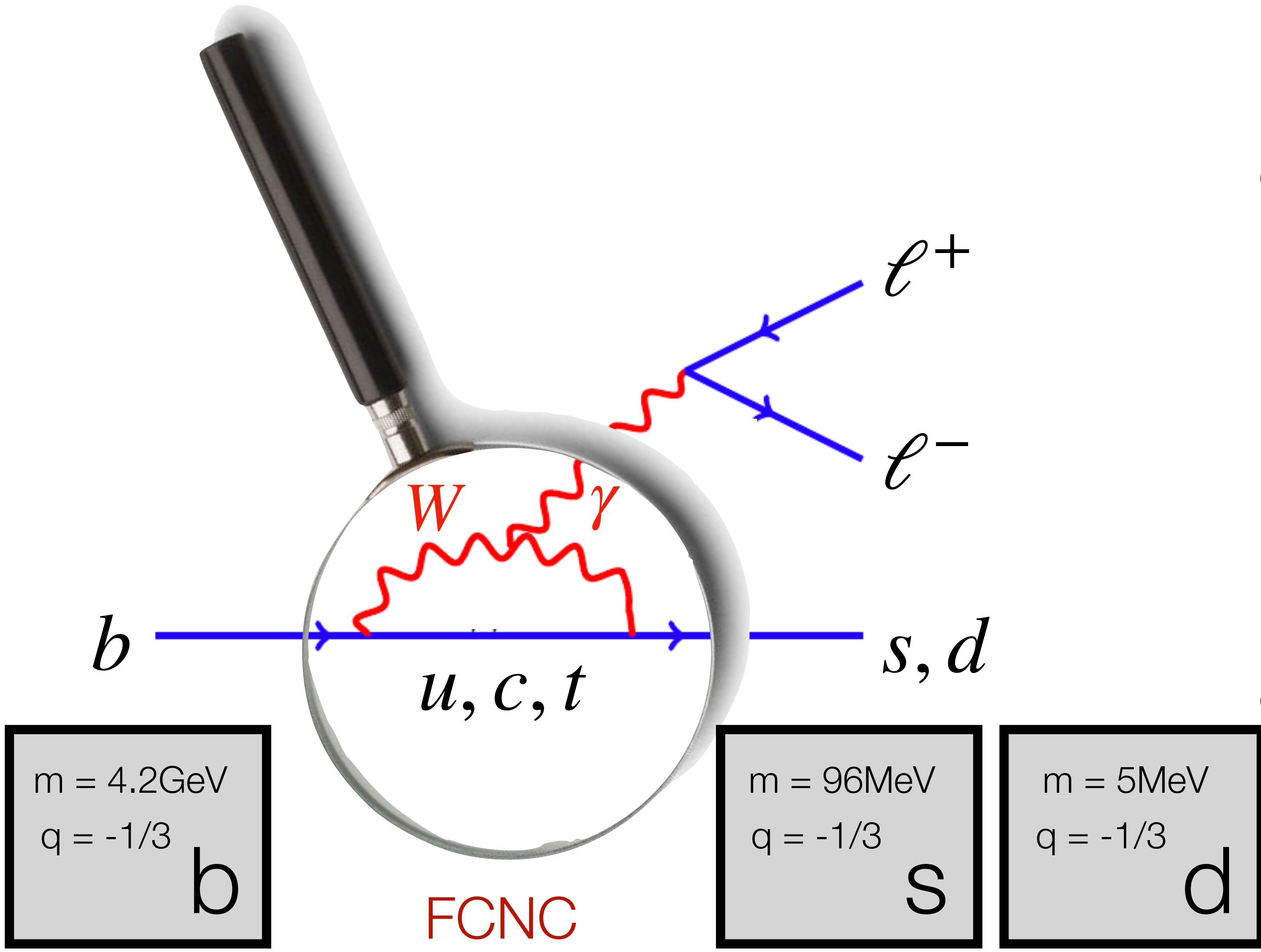

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Flavour anomalies in $b \to s\ell^+\ell^-$ transitions!

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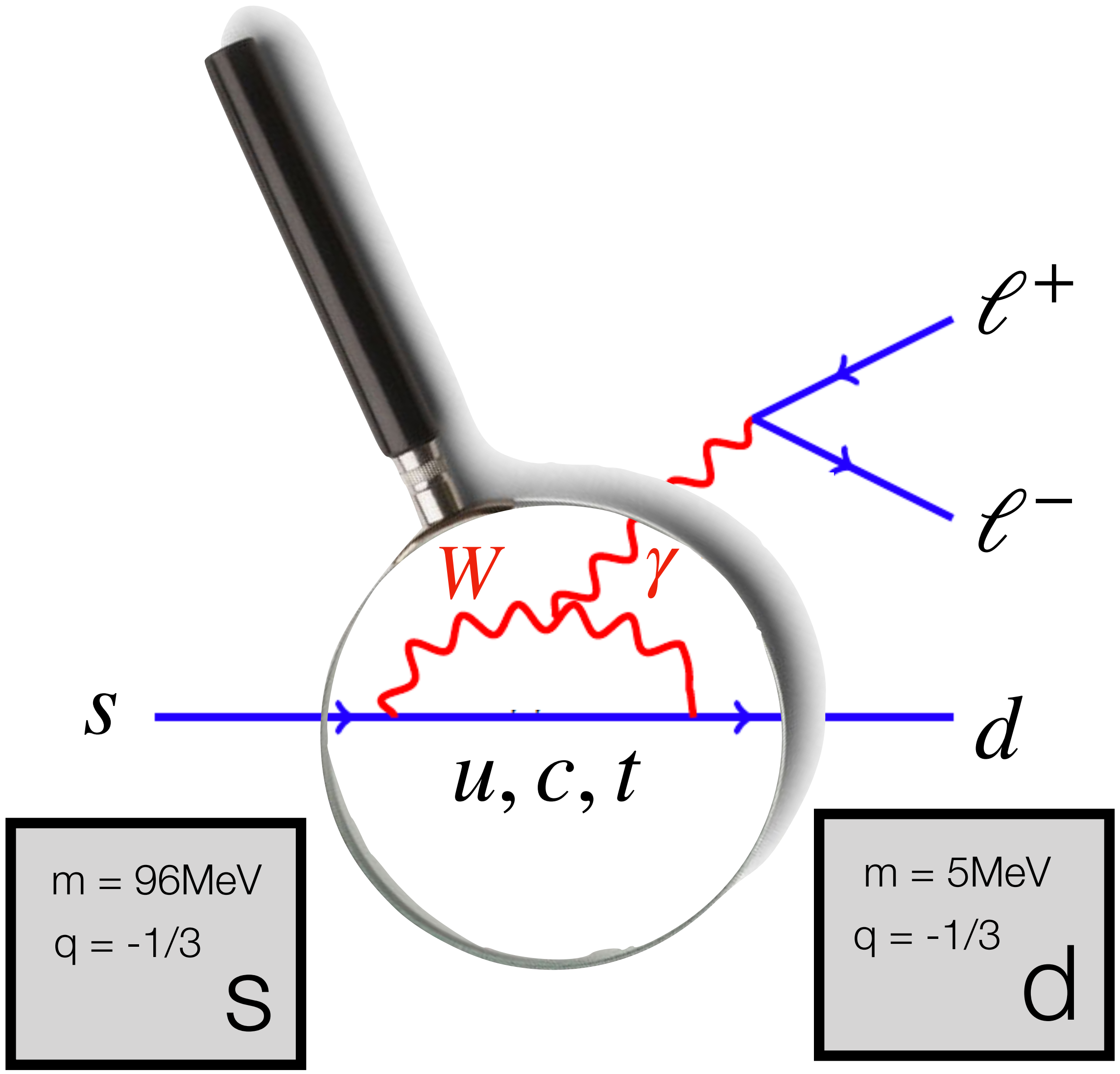

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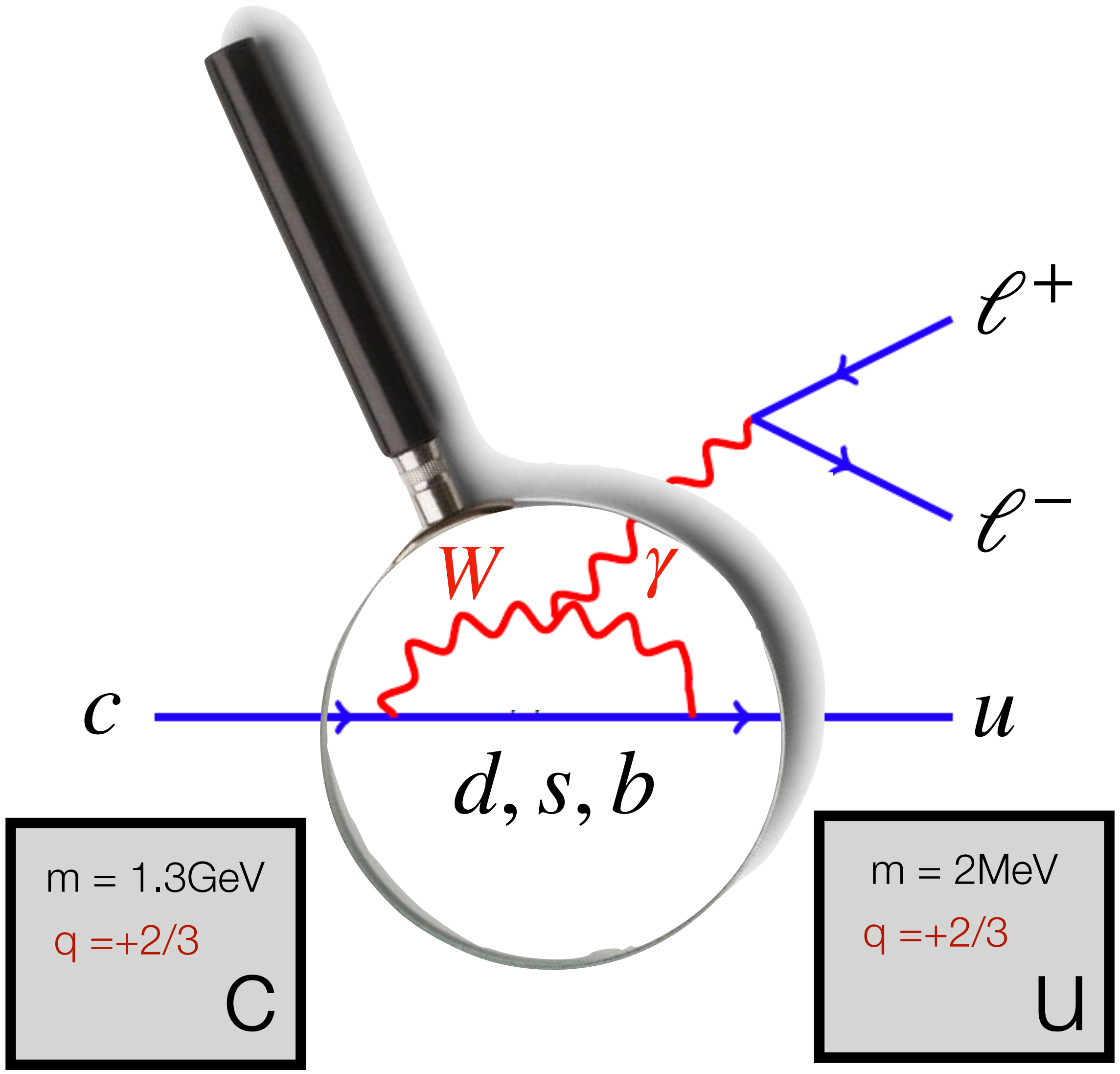

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Kaon-physics: $s \to d\ell^+\ell^-$

Charm-physics: $c \to u\ell^+\ell^-$

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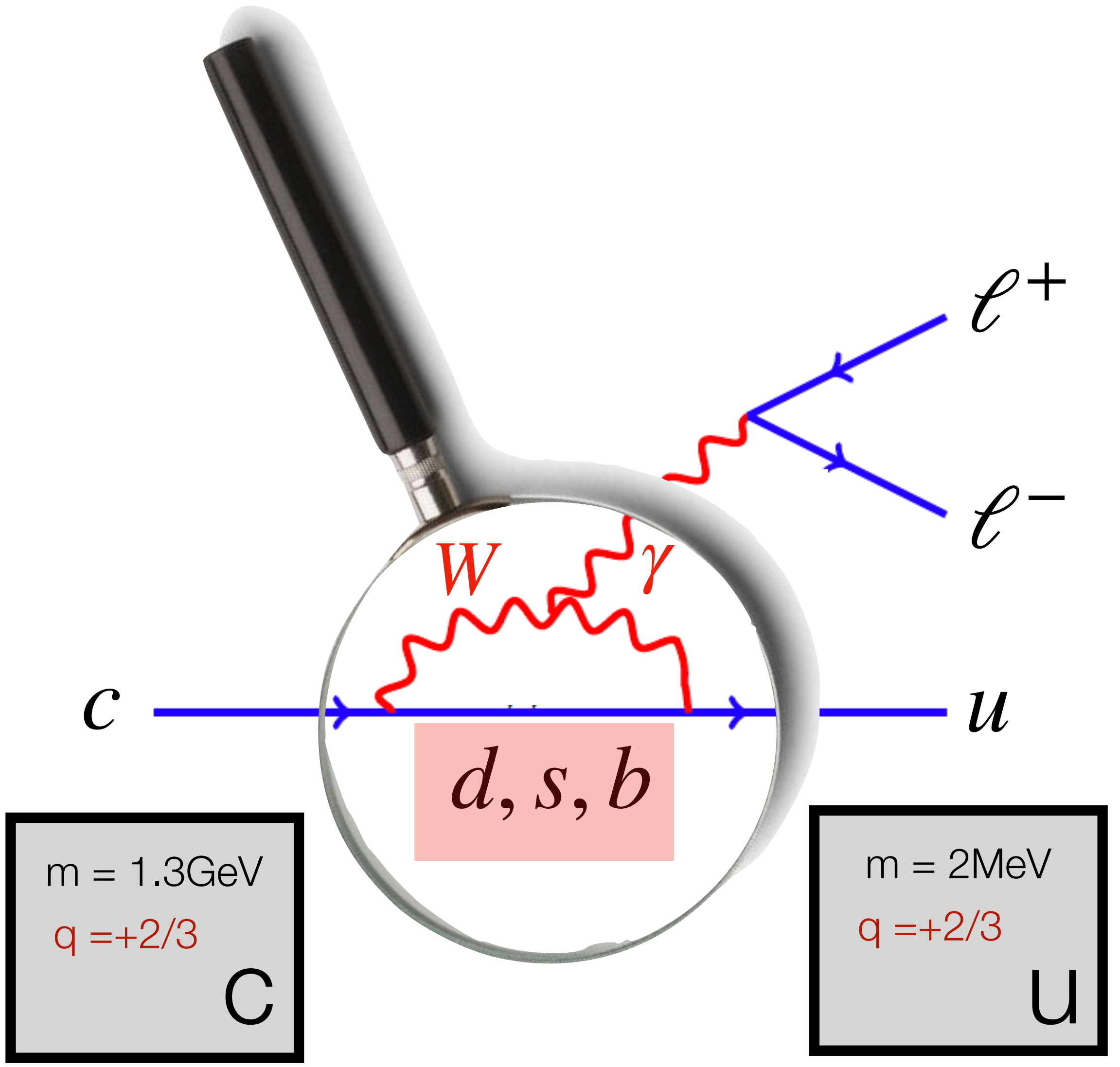


u-type quarks! → orthogonal couplings

Charm-physics: $c \rightarrow u\ell^+\ell^-$

- Rates (branching fractions)

  typically D→Xμ⁺μ⁻ ~O(10^{-12})
  (**extremely suppressed**)

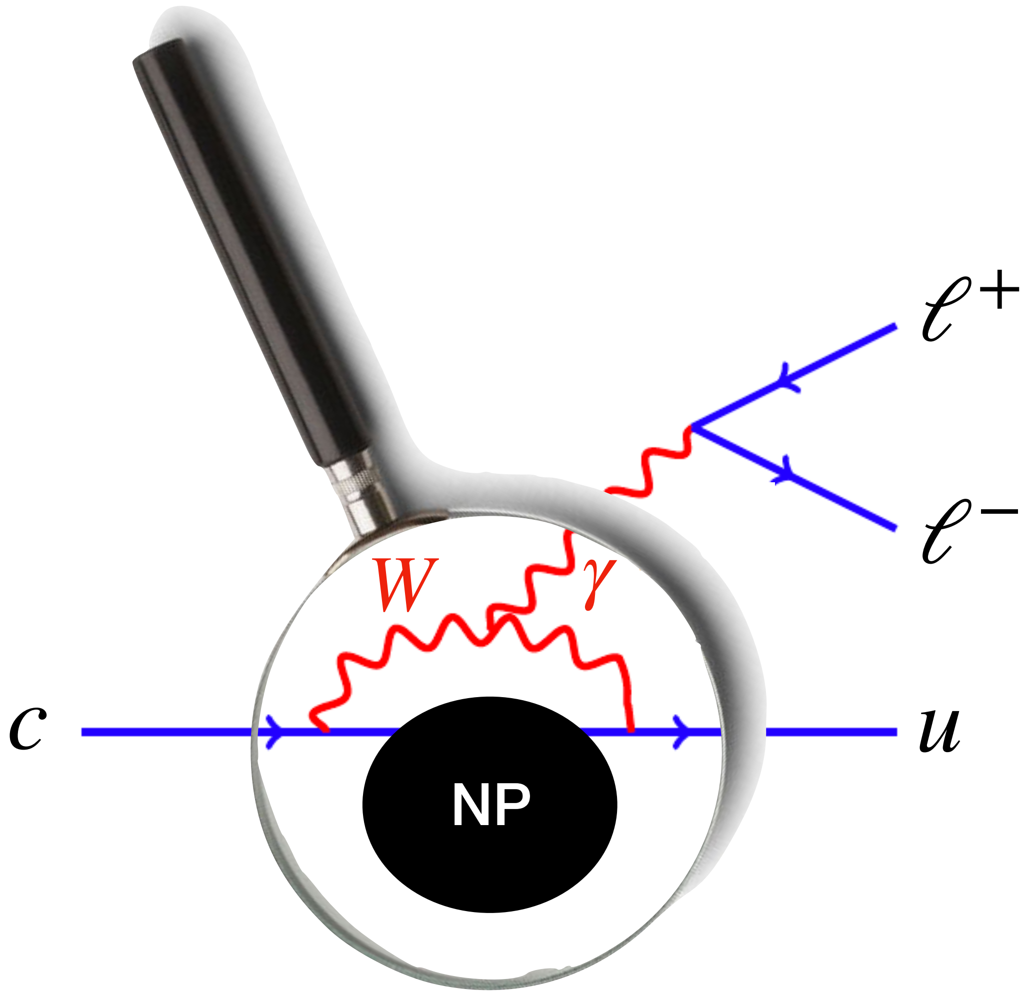
- CP Asymmetries

  $\mathrm{Im}(V^*_{cb}V_{ub}/V^*_{cd}V_{ud}) \sim 10^{-3}$
  A_{CP}~0

- Angular distributions

  no lepton axial vector coupling
  Parity conservation

Search for New Physics in rare decays...



u-type quarks! ⟶ orthogonal couplings

Charm-physics: $c \to u\ell^+\ell^-$

- Rates (branching fractions)

  D→Xl+l- up to O(10-7)*

- CP Asymmetries

  CPV effects up to few %*

- Angular distributions

  Modified*

*very much depending on the model

see eg. MPLA 36 (2021) 2130002

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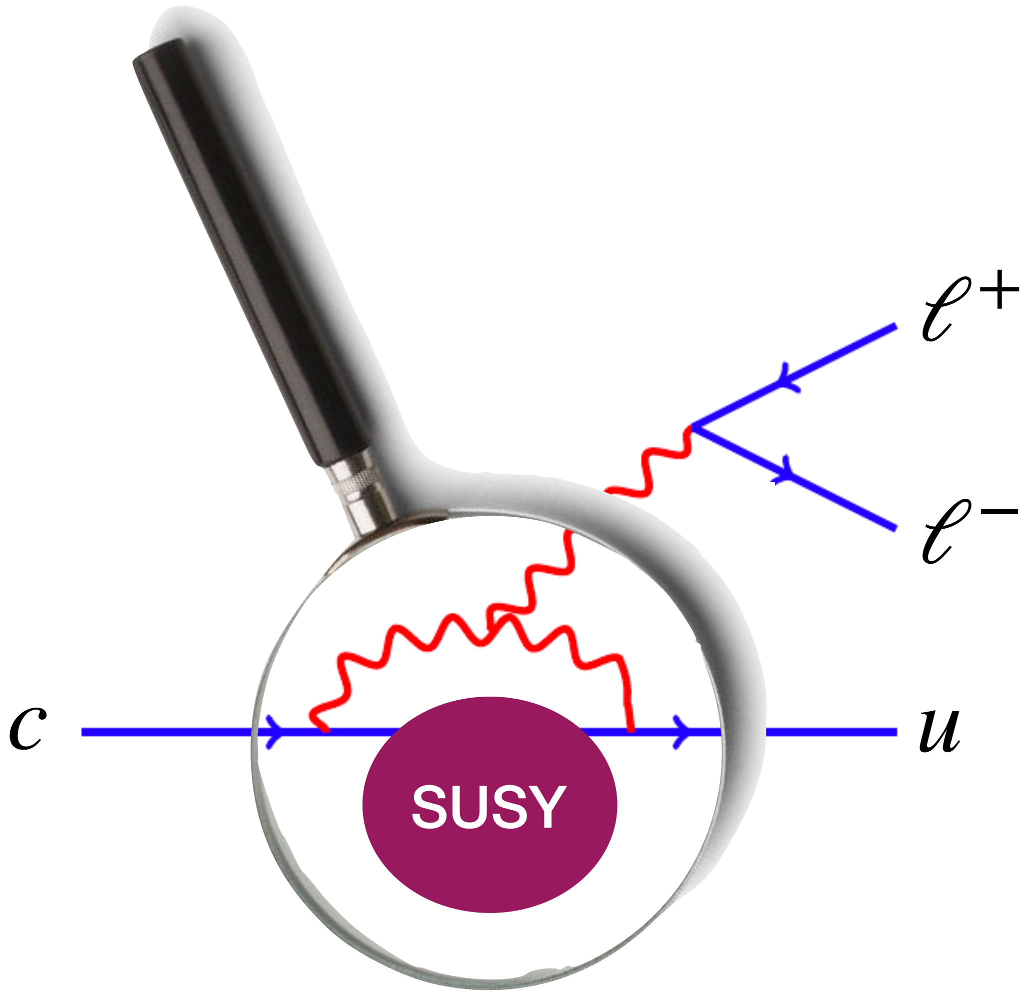

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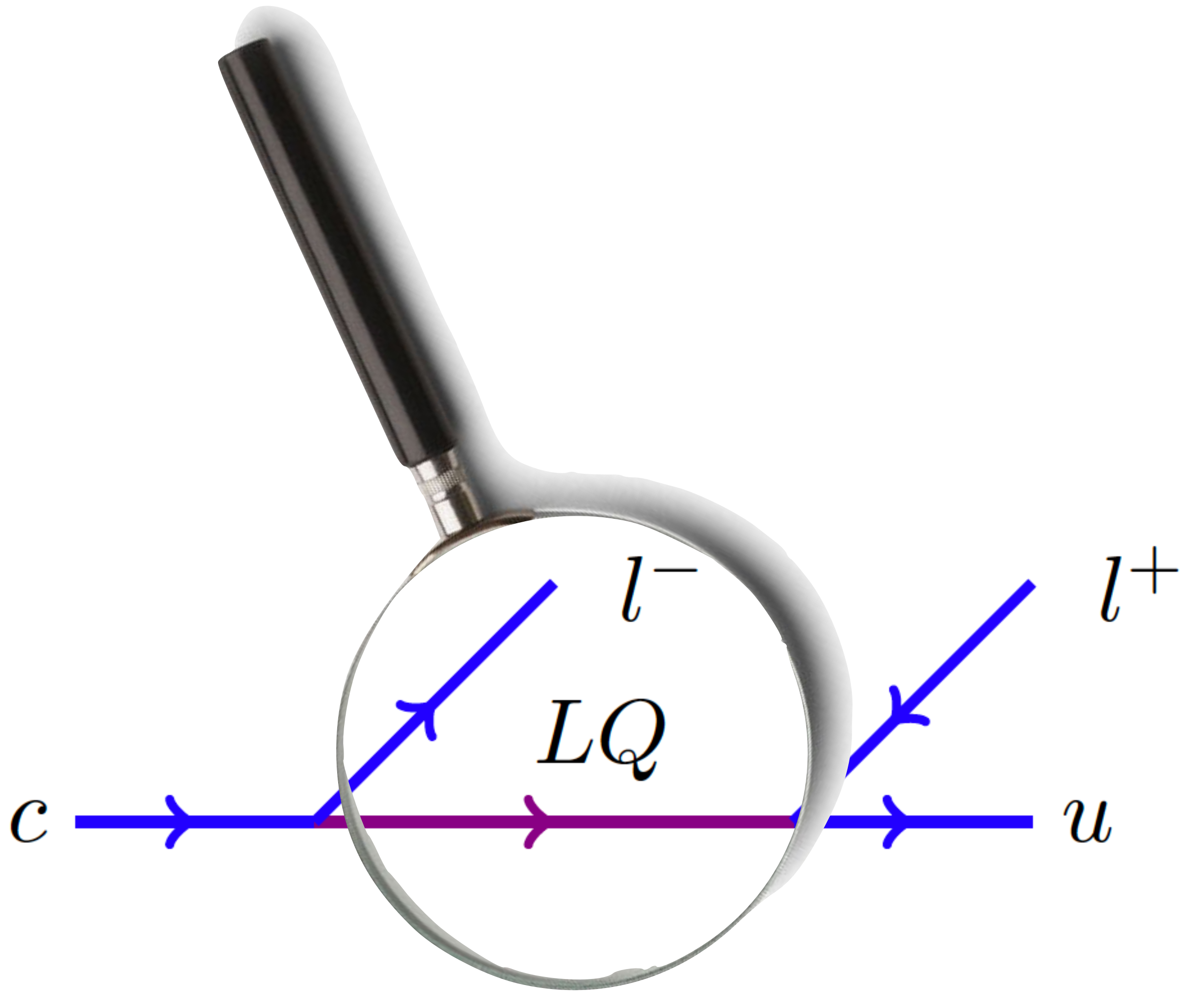

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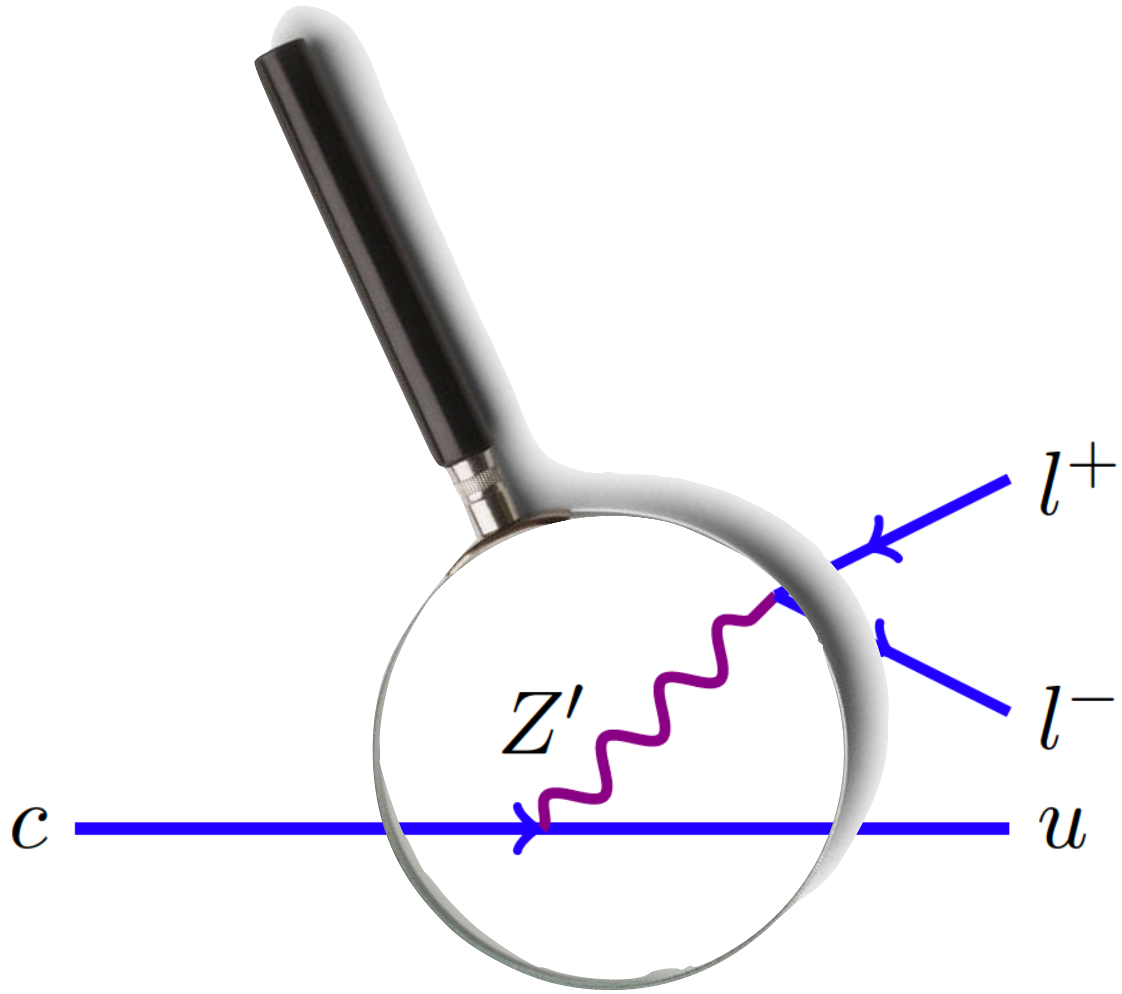

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LQ, Z' prominent explanations for flavour anomalies

Charm-physics: $c \to u\ell^+\ell^-$

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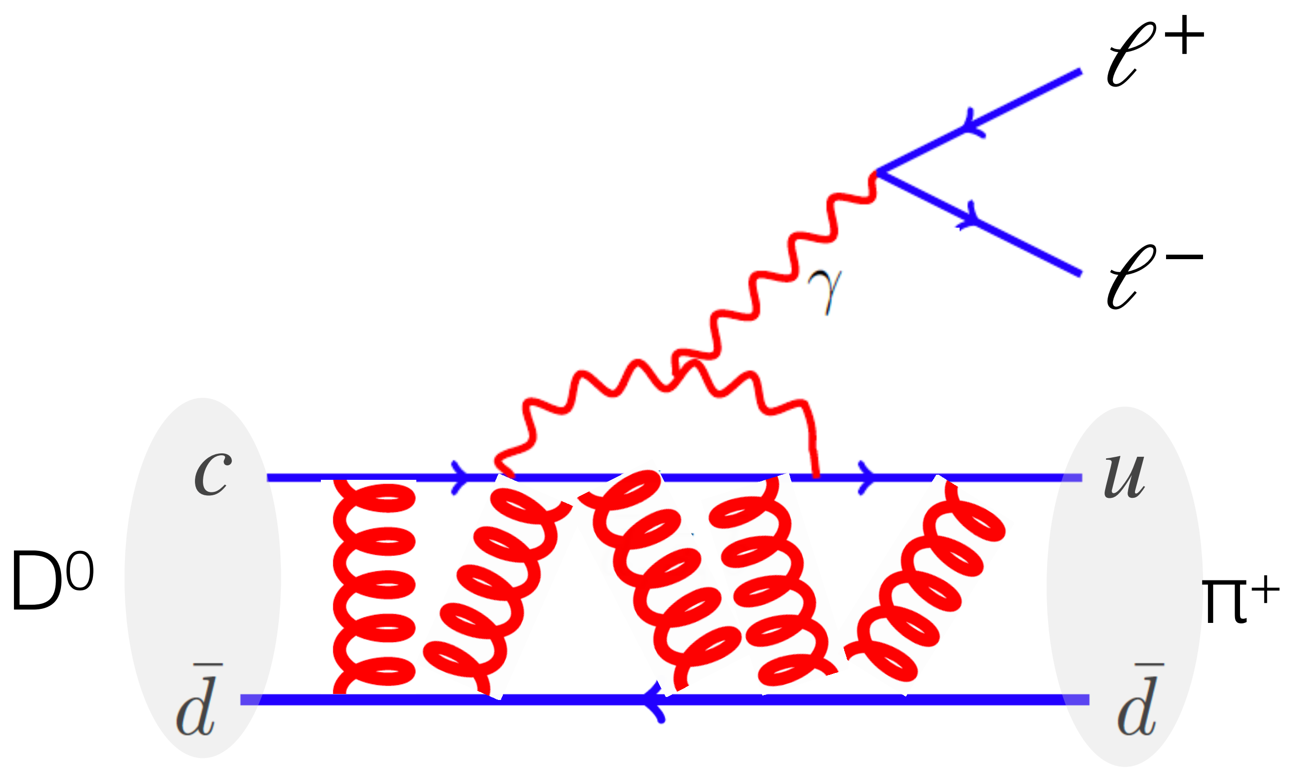
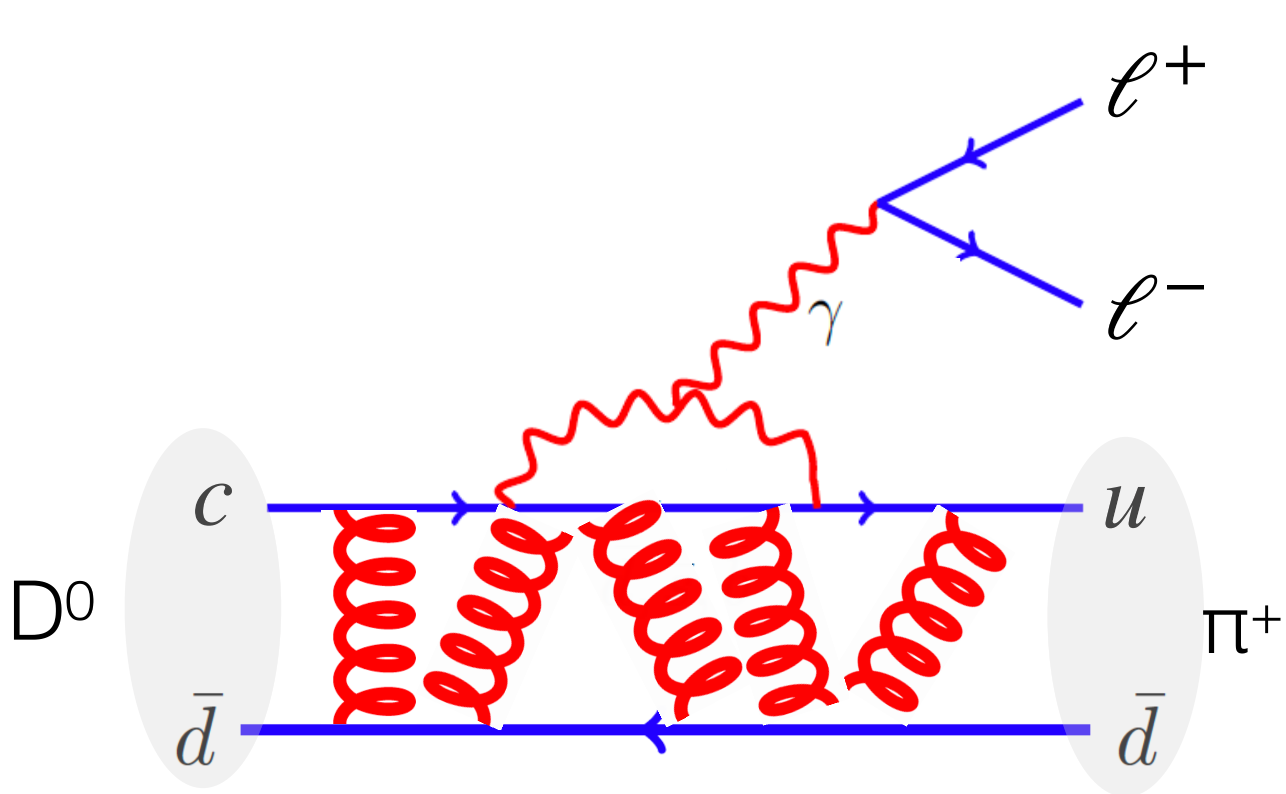
Long-distance QCD effects



$D \to \pi\ell^+\ell^-$

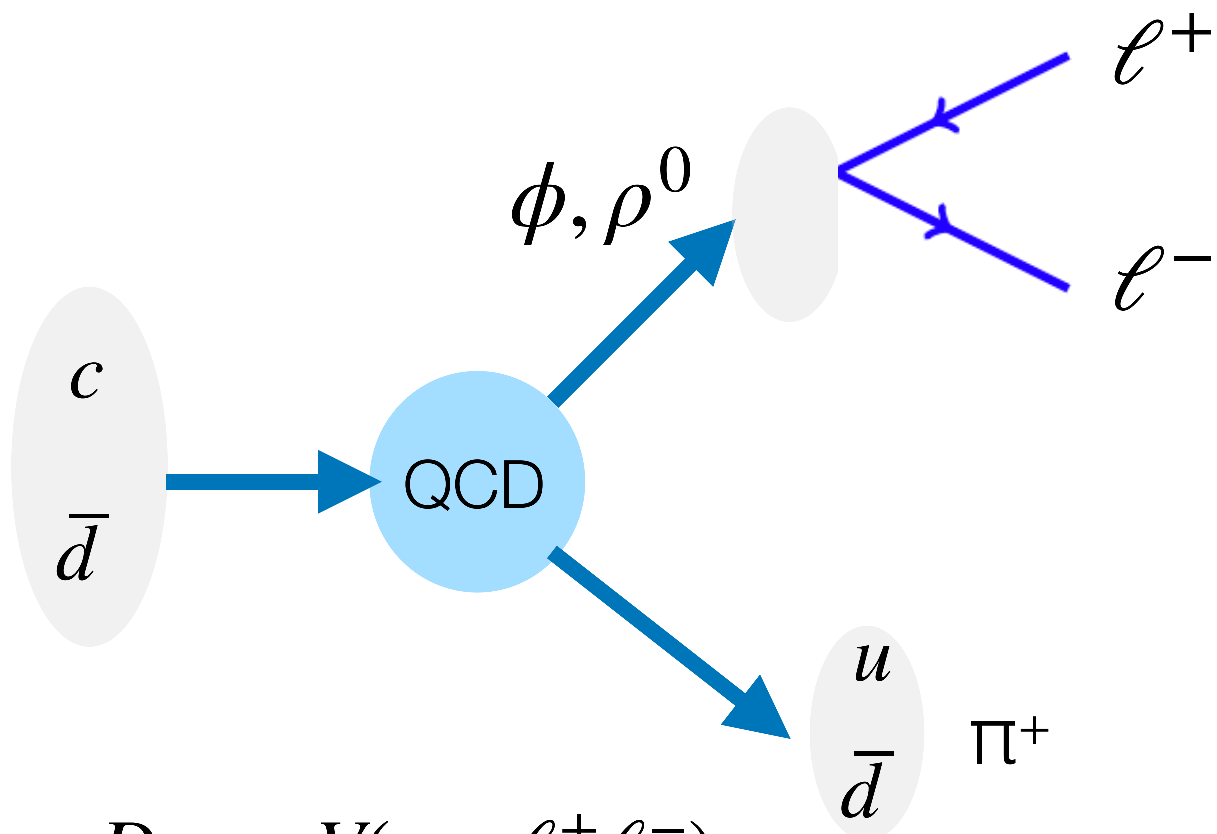
- $m_c \sim \Lambda_{QCD} \to$ large uncertainties coming from QCD effects

Long-distance QCD effects



$D \to \pi \ell^+ \ell^-$

$\mathscr{B} \sim \mathcal{O}(10^{-12})$



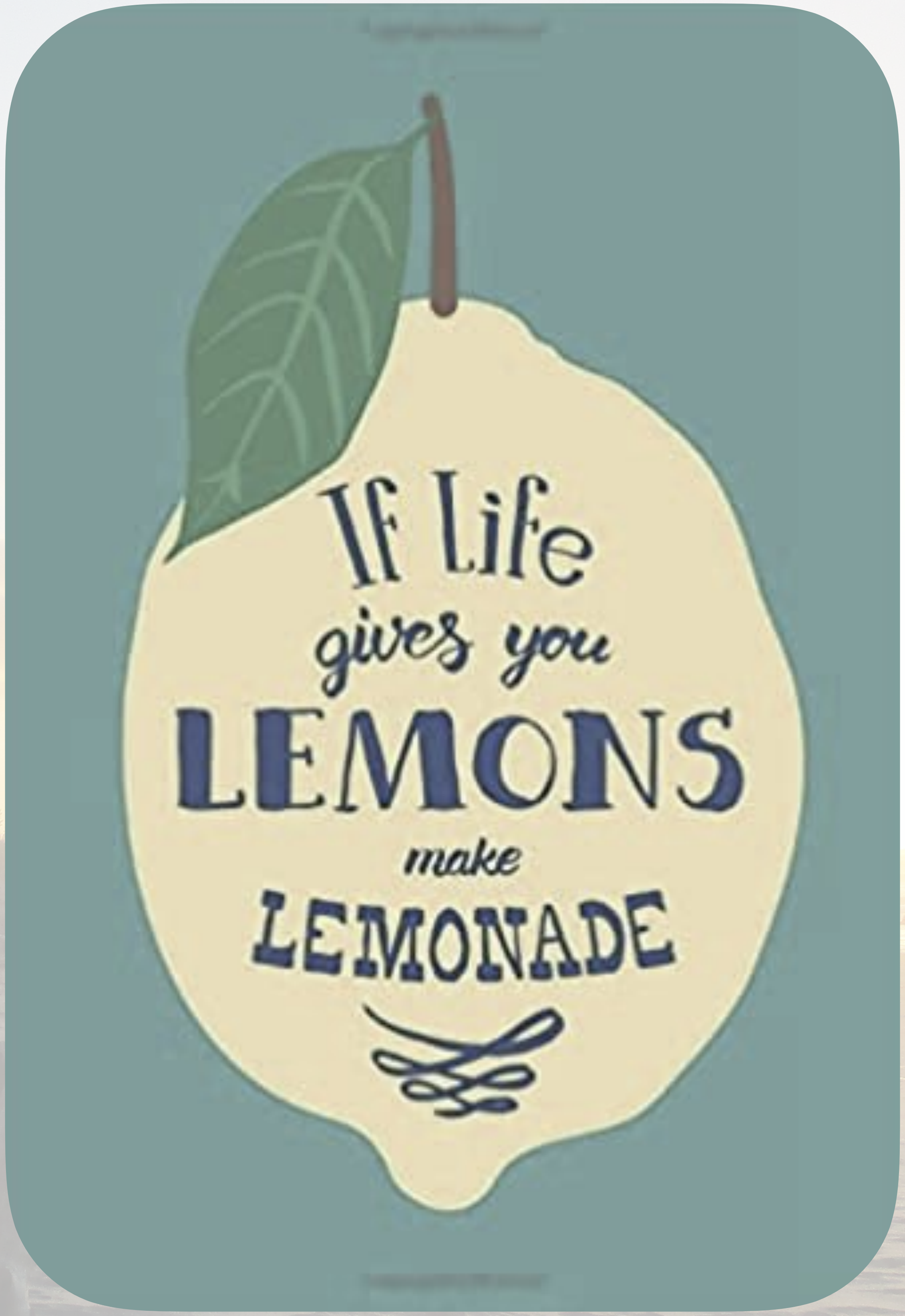
$D \to \pi V(\to \ell^+ \ell^-)$

$\mathscr{B} \sim \mathcal{O}(10^{-8} - 10^{-6})$

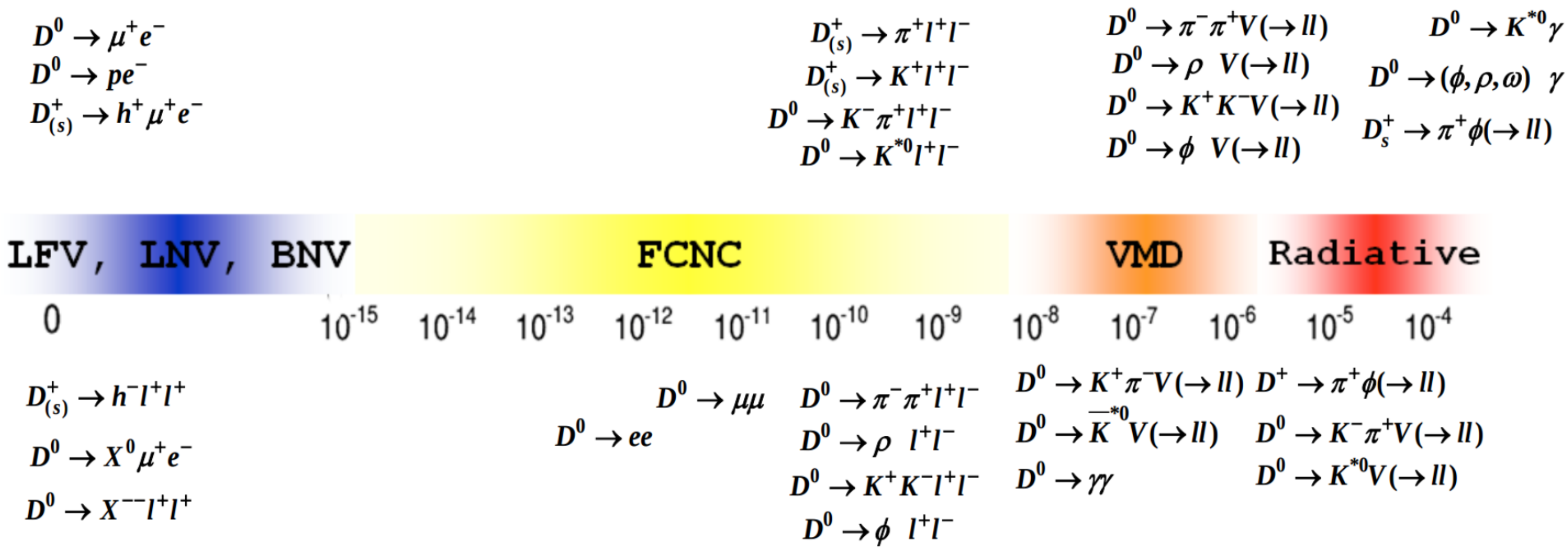
- $m_c \sim \Lambda_{QCD} \to$ large uncertainties coming from QCD effects
- Often, non-perturbative long distance (resonance) dynamics dominate!

For long, rare charm has been considered as less promising! (Disclaimer: It's not)

We need to find ways to overcome (even profit from) LD contributions



The landscape of decays



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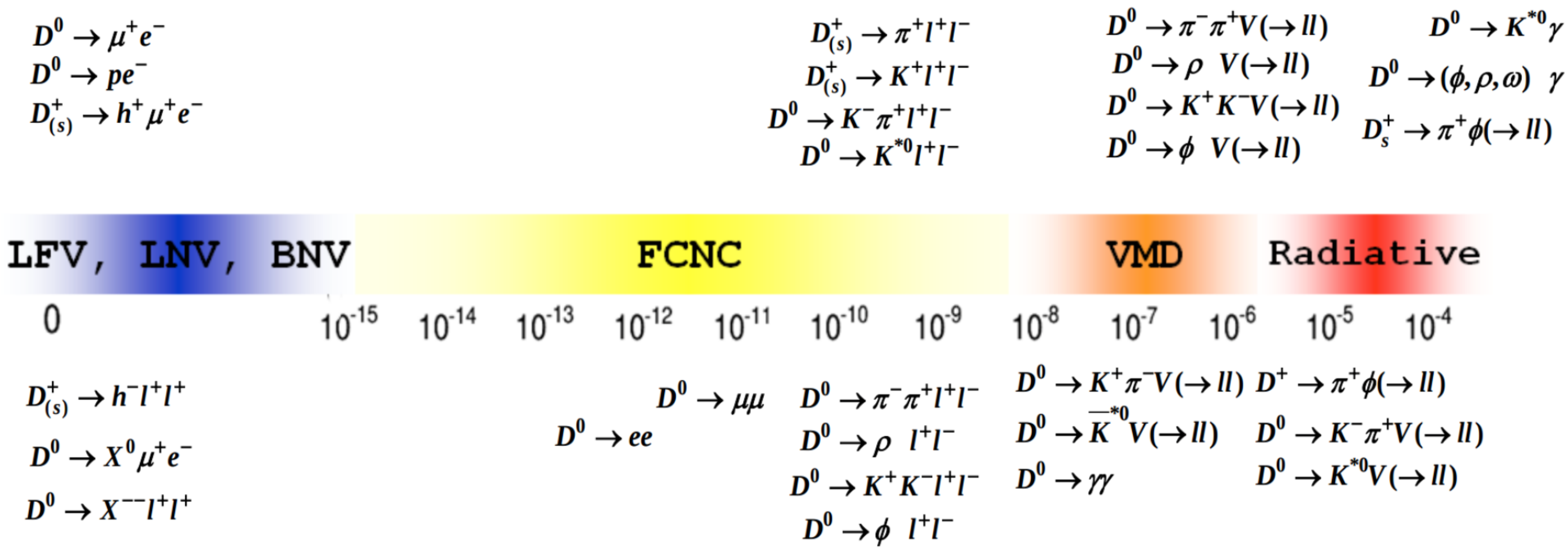


‘SM-Forbidden’ decays

- lepton-flavour violation
- lepton-number violation
- baryon-number violation

no SM background

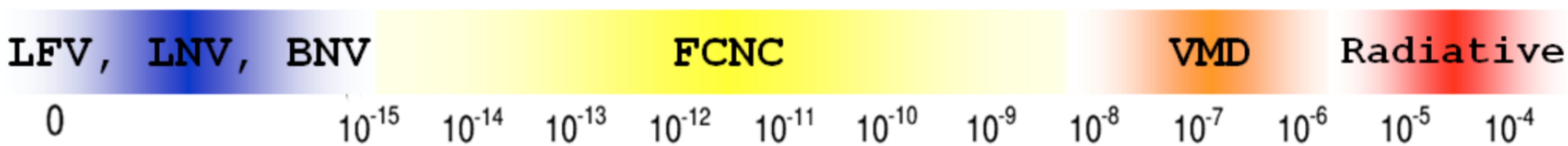
The landscape of decays

$D^0 \to \mu^+ e^-$
$D^0 \to p e^-$
$D^+_{(s)} \to h^+ \mu^+ e^-$

$D^+_{(s)} \to \pi^+ l^+ l^-$
$D^+_{(s)} \to K^+ l^+ l^-$
$D^0 \to K^- \pi^+ l^+ l^-$
$D^0 \to K^{*0} l^+ l^-$

$D^0 \to \pi^- \pi^+ V(\to ll)$
$D^0 \to \rho \; V(\to ll)$
$D^0 \to K^+ K^- V(\to ll)$
$D^0 \to \phi \; V(\to ll)$

$D^0 \to K^{*0} \gamma$
$D^0 \to (\phi, \rho, \omega) \; \gamma$
$D^+_s \to \pi^+ \phi(\to ll)$



$D^+_{(s)} \to h^- l^+ l^+$
$D^0 \to X^0 \mu^+ e^-$
$D^0 \to X^{--} l^+ l^+$

$D^0 \to \mu\mu$
$D^0 \to ee$

$D^0 \to \pi^- \pi^+ l^+ l^-$
$D^0 \to \rho \; l^+ l^-$
$D^0 \to K^+ K^- l^+ l^-$
$D^0 \to \phi \; l^+ l^-$

$D^0 \to K^+ \pi^- V(\to ll)$
$D^0 \to \overline{K}^{*0} V(\to ll)$
$D^0 \to \gamma\gamma$

$D^+ \to \pi^+ \phi(\to ll)$
$D^0 \to K^- \pi^+ V(\to ll)$
$D^0 \to K^{*0} V(\to ll)$

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Very rare decays

- purely leptonic
- local regions in decay phase space of multi-body decays

reduced hadronic uncertainties

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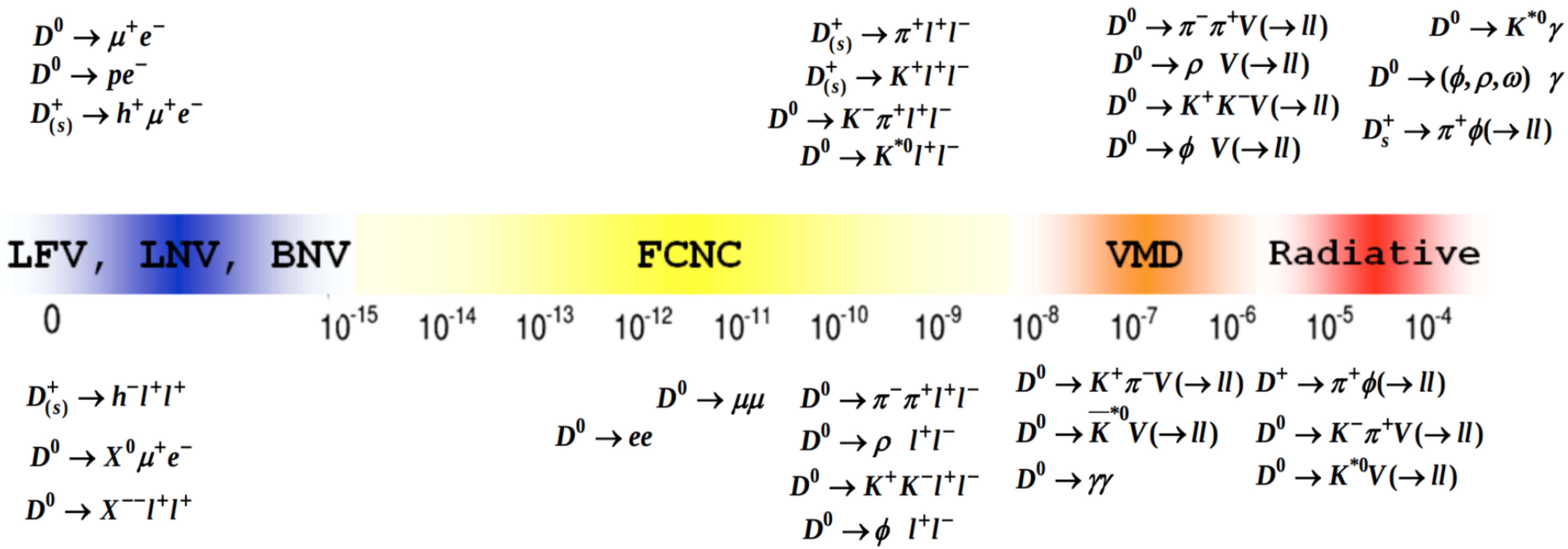

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reduced hadronic uncertainties

Rare resonance dominated & radiative decays

- test of lepton-universality
- CP asymmetries
- angular distributions

‘clean’ SM null-tests

Why rare charm at LHCb?

- Large production cross section at LHC ($\sigma(c\bar{c}) \sim 20 \times \sigma(b\bar{b})$)

Type	Exp	$\sqrt{s}$	L_{int}	$\sigma(c\bar{c})$	$N(c\bar{c})$
	prompt $c\bar{c}$				
Hadron colliders	LHCb	7, 8 TeV	3/fb	1.4 mb	3.6×10^{12}
		13 TeV	6/fb	2.6 mb	13.2×10^{12}
	CDF	2 TeV	10/fb	0.1 mb	2.3×10^{11}
	$c\bar{c}$ from continuum				
e^+e^- collider	Belle	10.6 GeV	1/ab	1.3 nb	1.3×10^{9}
	BaBar	10.6 GeV	550/fb	1.3 nb	0.7×10^{9}
	Charm factories at $D\bar{D}$ threshold				
	BESIII	3.7 GeV	3/fb	3 nb	20×10^{6}
	Cleo-c	3.7 GeV	0.8/fb	3 nb	5×10^{6}

A. Contu, Towards the Ultimate Precision in Flavour Physics, Durham, United Kingdom, 2 - 4 Apr 2019

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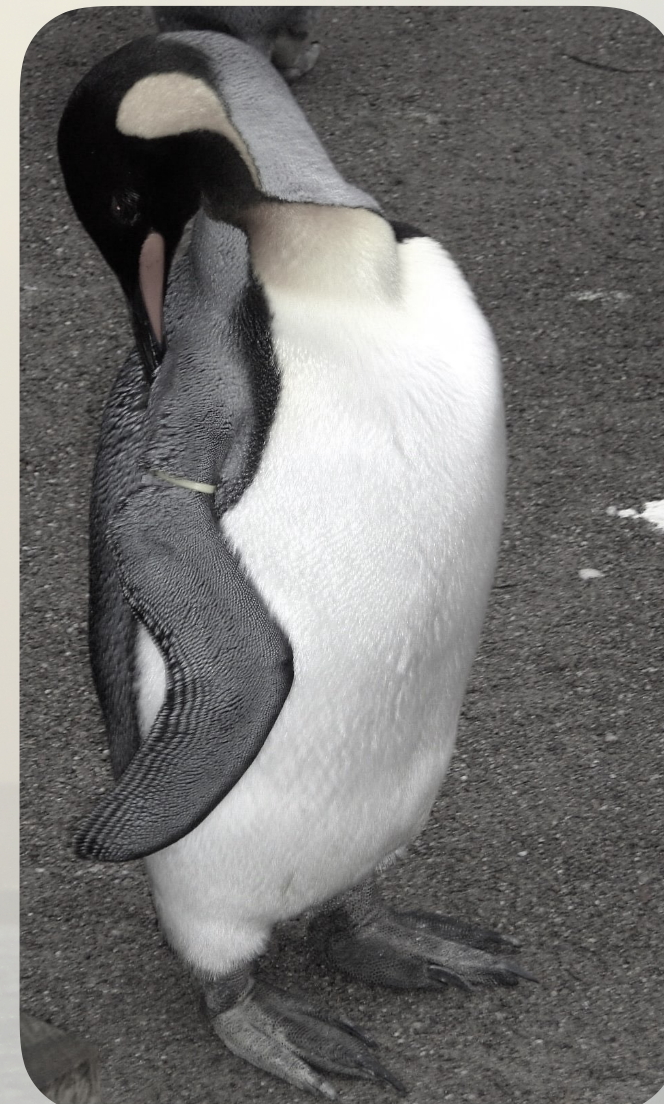
- Full charm zoo available at LHCb

$$|D^0\rangle = |c\bar{u}\rangle \quad |D^+\rangle = |c\bar{u}\rangle$$
$$|D_s^+\rangle = |c\bar{s}\rangle \quad |\Lambda_c^+\rangle = |cud\rangle$$
$$\ldots$$

LHCb is ideal place!

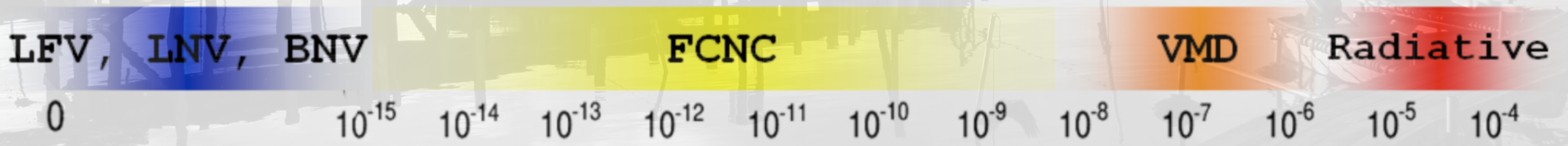
Searches in decay rates



Search for rare and forbidden semi-leptonic decays

Searches for 25 rare and forbidden decays of D^+ and D_s^+ mesons

JHEP 06 (2021) 44



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LFV, LNV, LNV & LFV

$D^+_{(s)} \to \pi^+\mu^\pm e^\mp$

$D^+_{(s)} \to K^+\mu^\pm e^\mp$

$D^+ \to K^-\mu^+e^+$

$D^+_{(s)} \to \pi^- e^+ e^+$

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$D^+ \to K^- e^+ e^+$

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clean null tests!

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very rare FCNC

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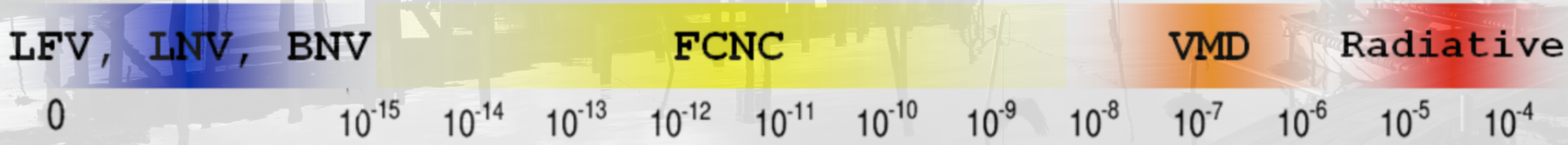

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$D_{(s)}^+ \to \pi^+\mu^+\mu^-$

$D_{(s)}^+ \to K^+ e^+ e^-$

$D_{(s)}^+ \to K^+\mu^+\mu^-$

rare resonance dominated (as reference)

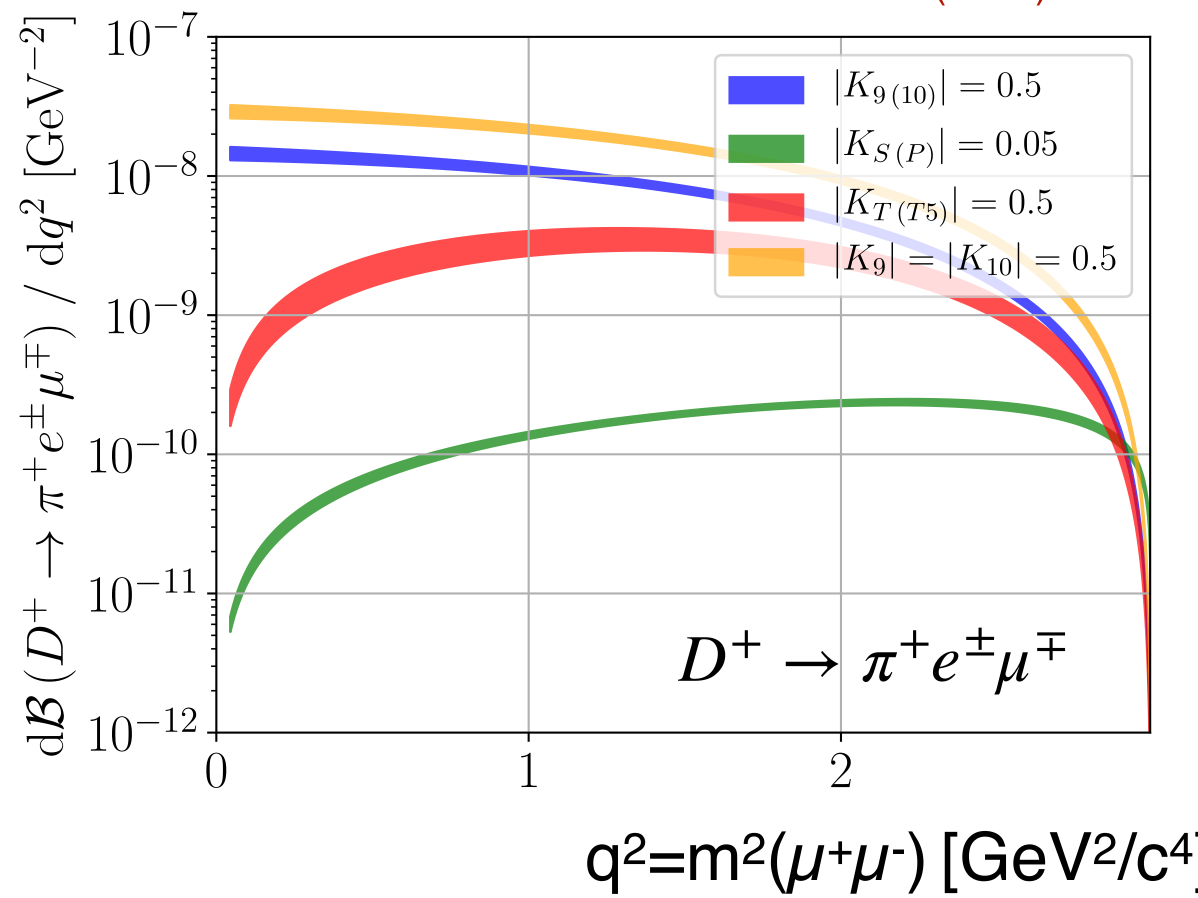
$D_{(s)}^+ \to \pi^+\phi[\mu^+\mu^-]$

$D_{(s)}^+ \to K^+\phi[e^+e^-]$

Search for the rare decays D→ hl±l(')∓

- For forbidden modes any signal = NP

EPJC 80 (2020) 65



Search for the rare decays $D \to h l^{\pm} l^{(')\mp}$

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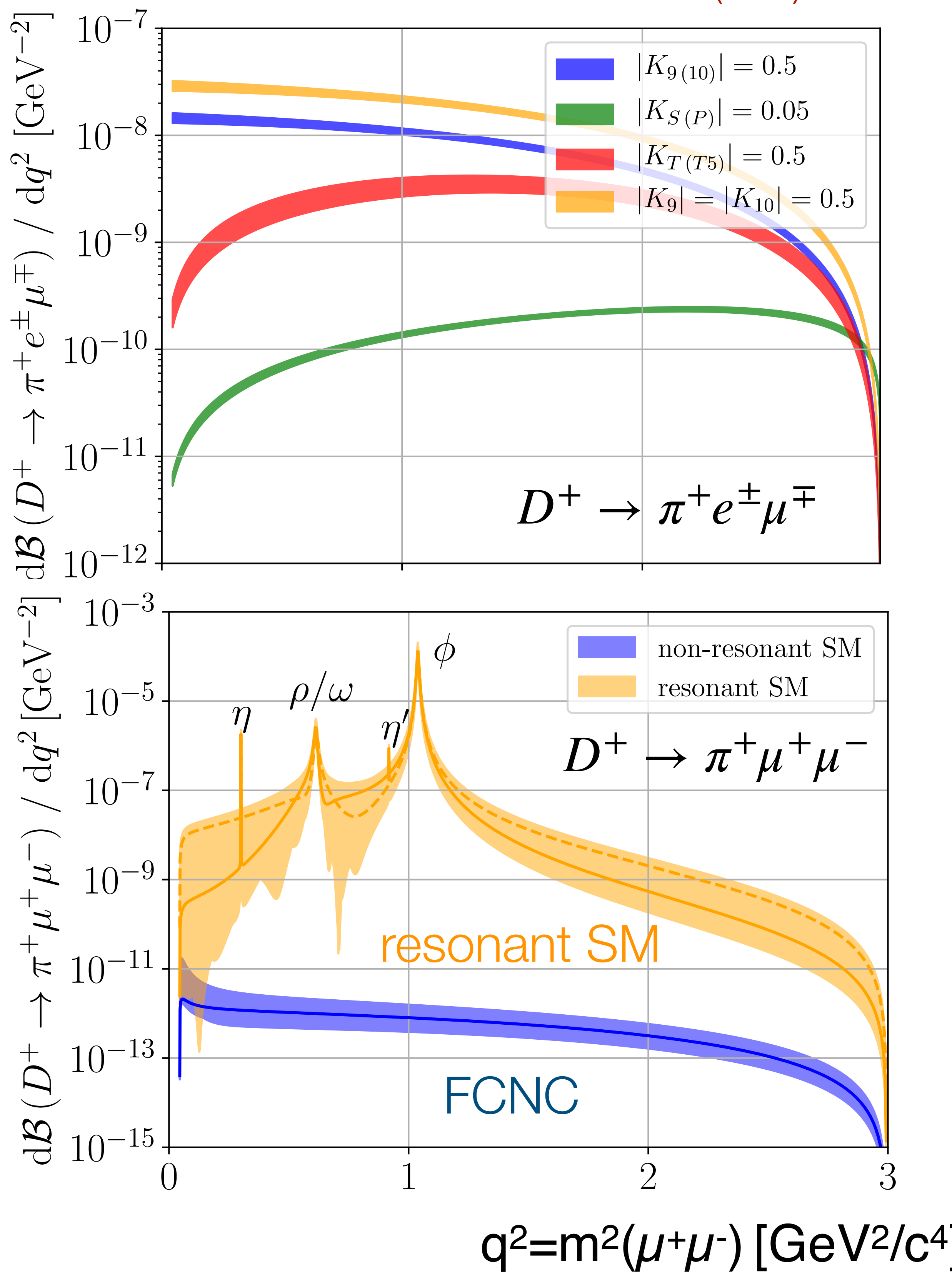
- Non-forbidden modes dominated by intermediate resonances

EPJC 80 (2020) 65



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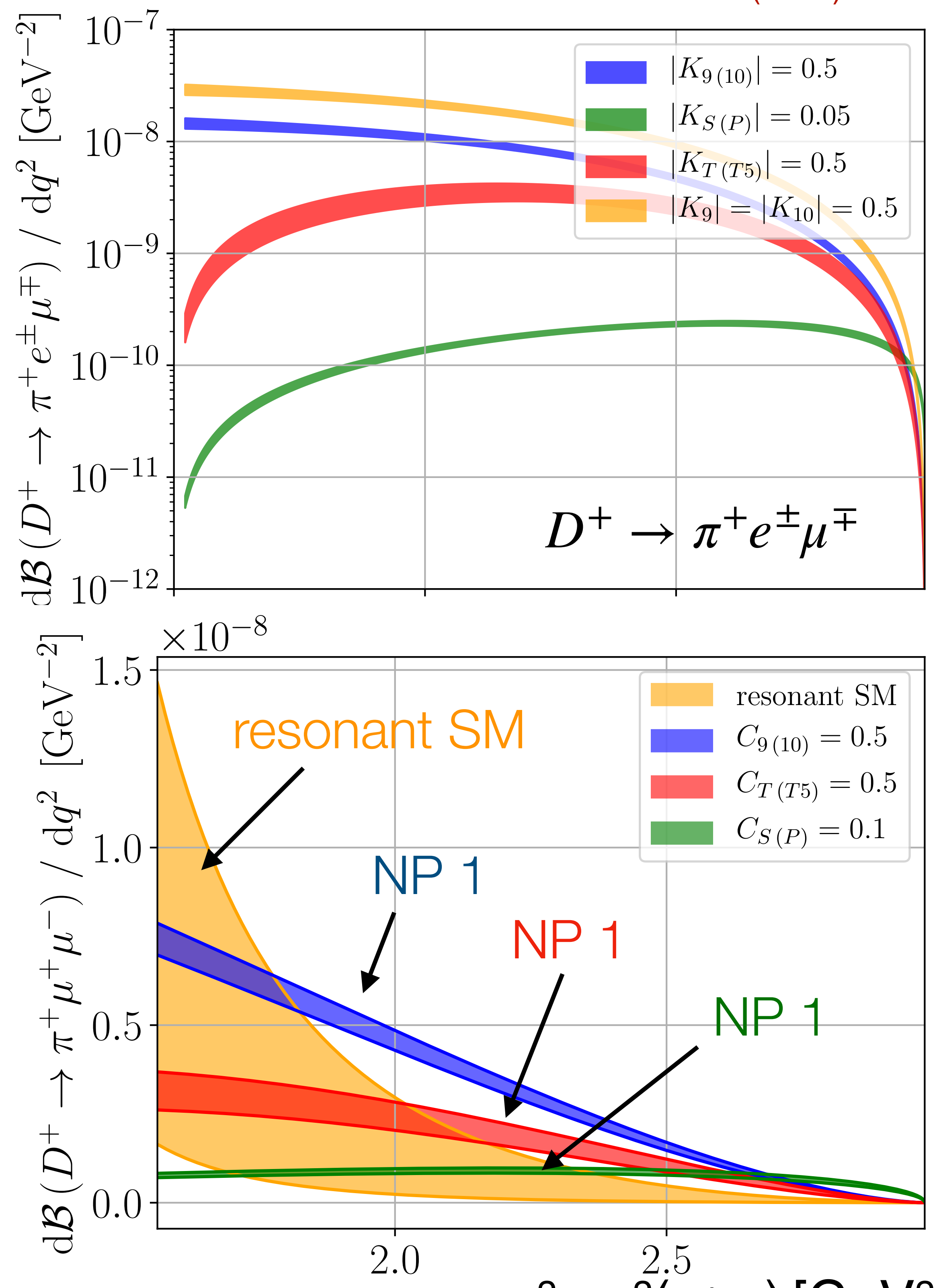

$q^2 = m^2(\mu^+\mu^-)$ [GeV^2/c^4]

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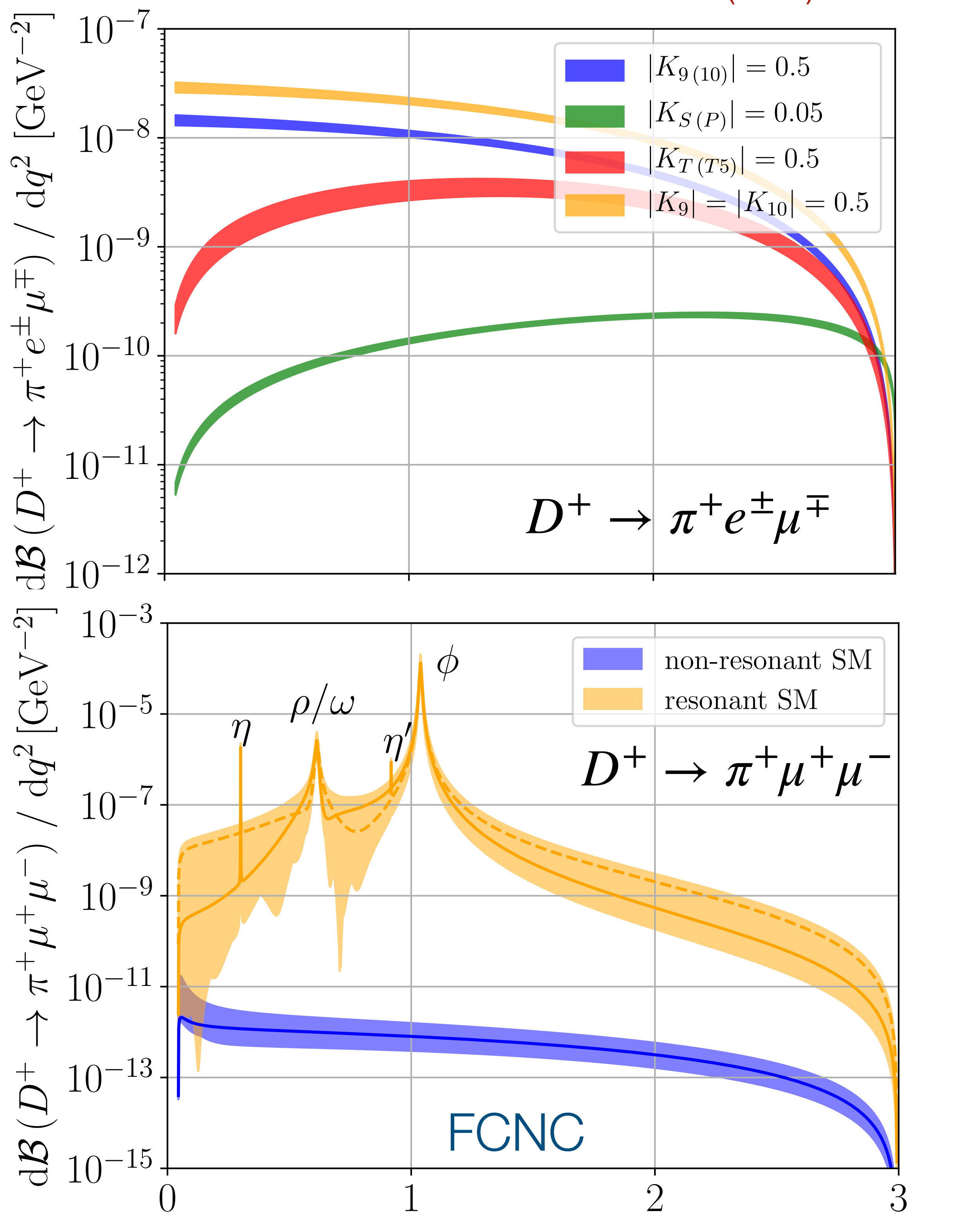

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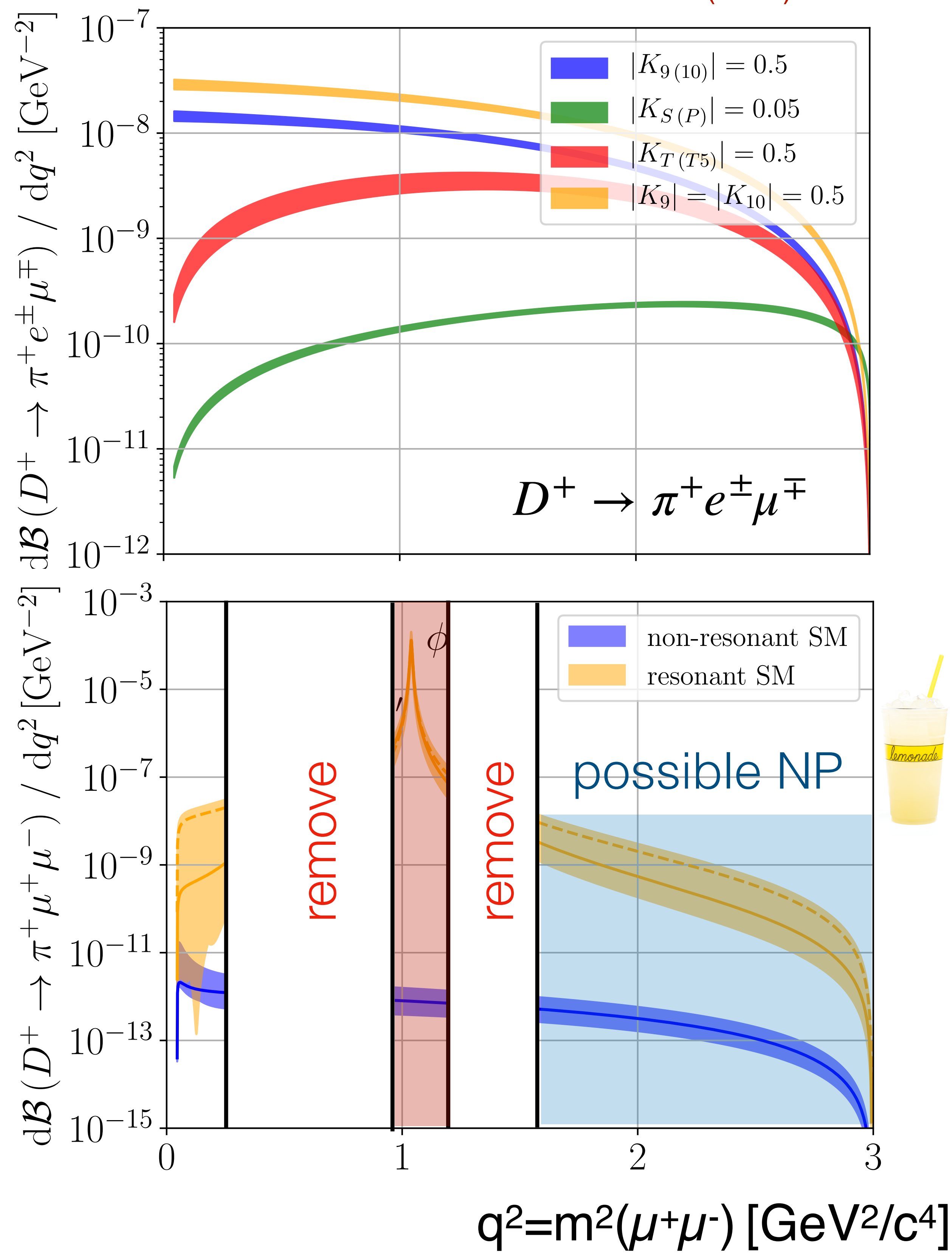

Search for the rare decays $D \to h l^{\pm} l^{(')\mp}$

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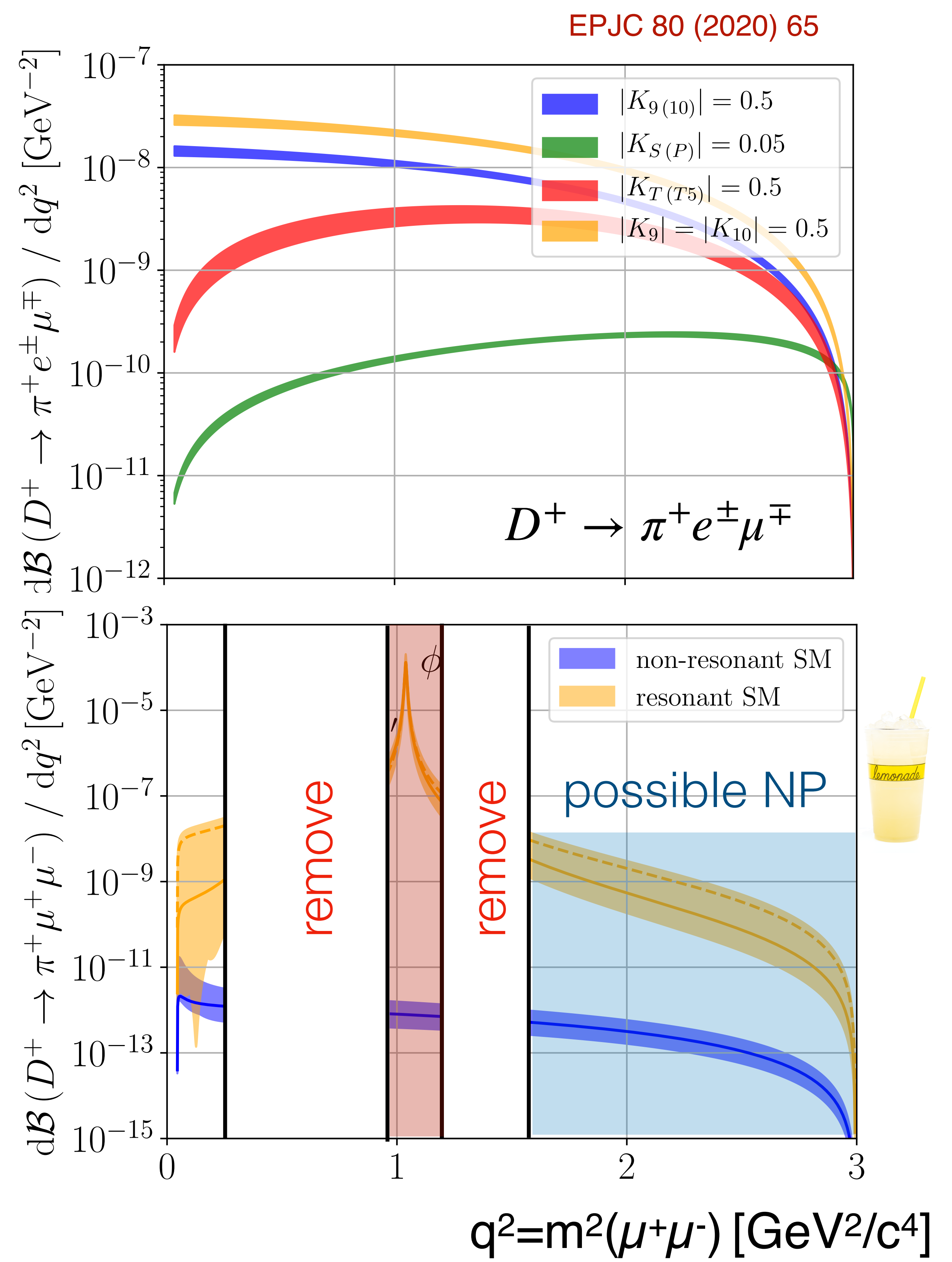
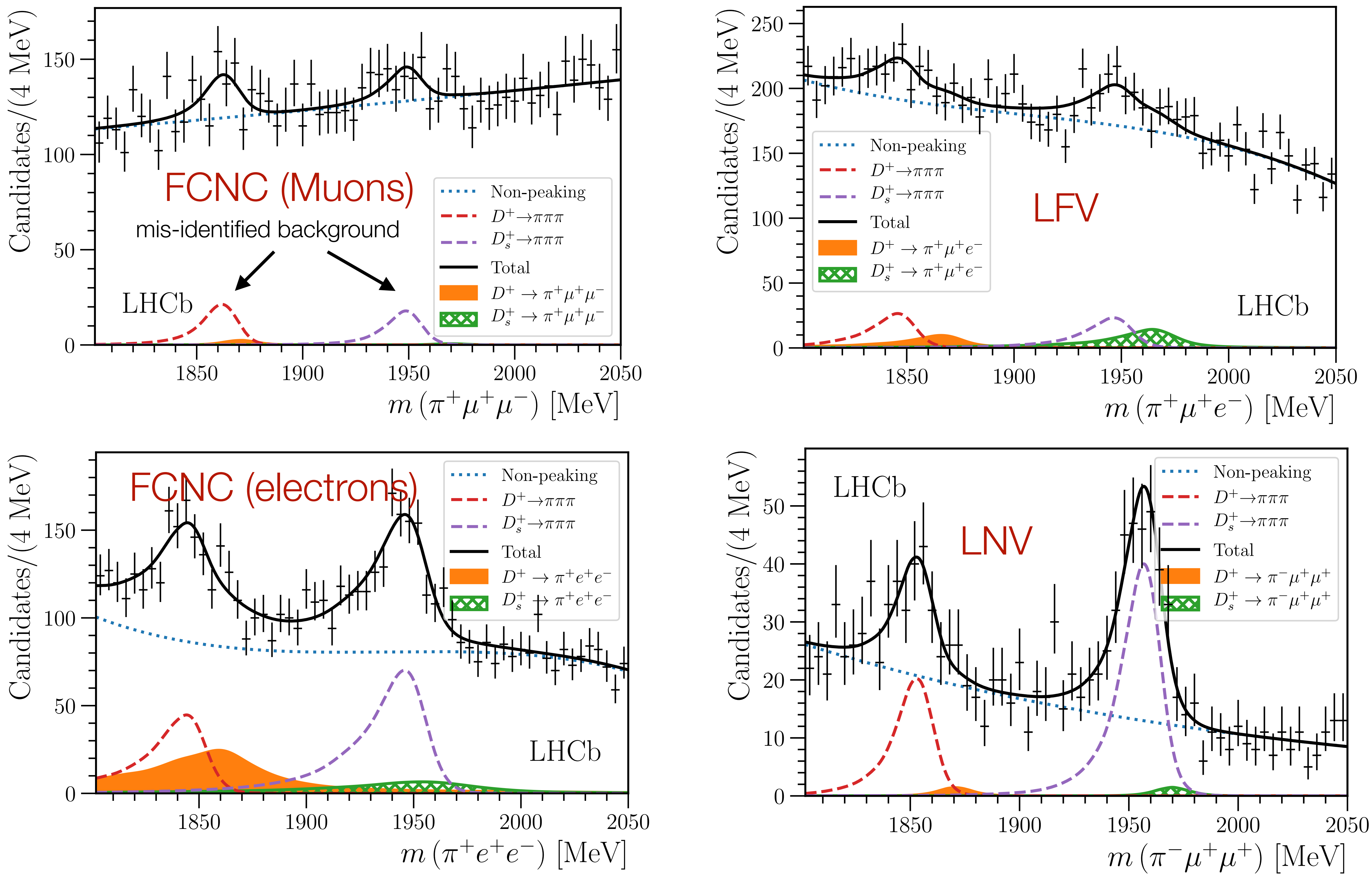
- Analysis presented uses 1.6/fb data collected in 2016 JHEP 06 (2021) 44



Search for the rare decays $D \to h l^{\pm} l^{(\prime)\mp}$

JHEP 06 (2021) 044



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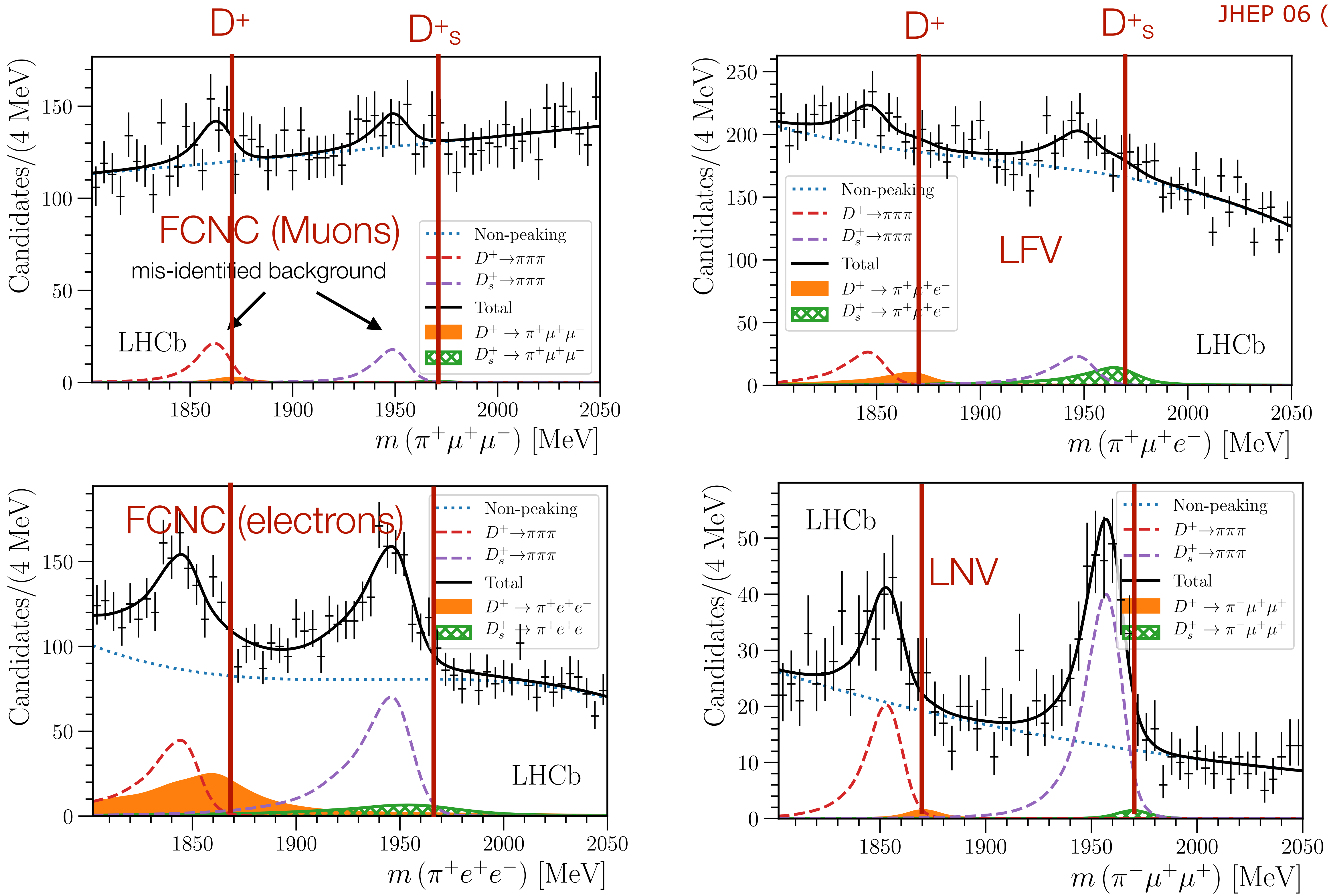
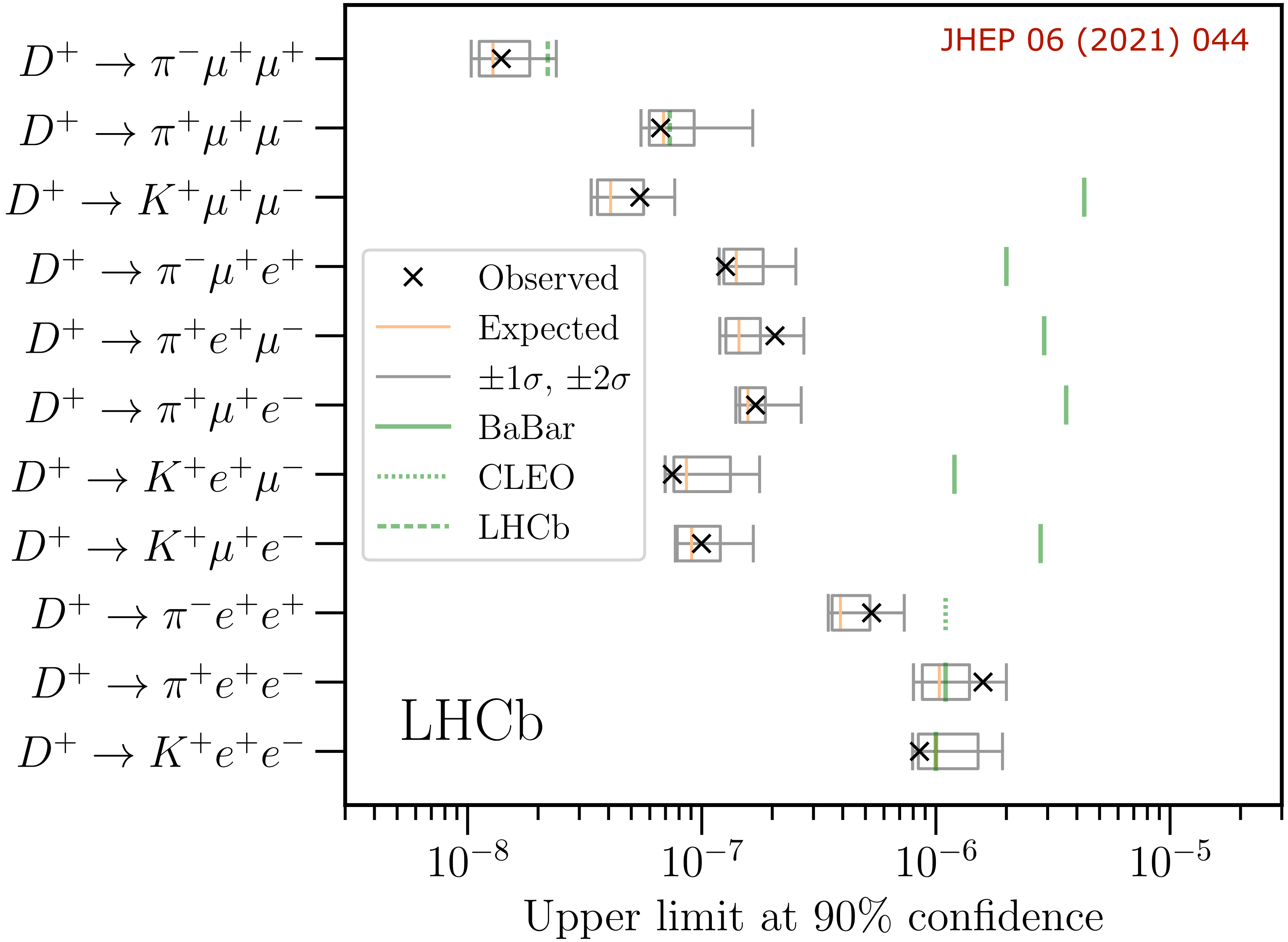


- All mass spectra well described by background only hypothesis

Search for the rare decays D→ hl±l(')∓

- No significant signal found [1.6/fb (2016)]
- Improved limits by several orders of magnitude
- See JHEP 06 (2021) 044 for limit on D_s^+ modes

update with full Run2 data set in preparation



More with rates: Lepton Universality

- Measure ratio of BF muon vs electron decay modes [smoking gun in B-physics!]

$$R^D_{P_1 P_2} = \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} d\mathcal{B}/dq^2(D \to P_1 P_2 \mu^+ \mu^-)}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} d\mathcal{B}/dq^2(D \to P_1 P_2 e^+ e^-)}$$

* in equal q^2 range

hadronic uncertainties cancel,
clean null test!

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hadronic uncertainties cancel, clean null test!

- Also in charm significant deviation from unity possible
  - mainly in non-resonant regions (far future)
  - ~O(15%) q^2 integrated (near future!)

Muonic modes observed, we are working on the electron modes

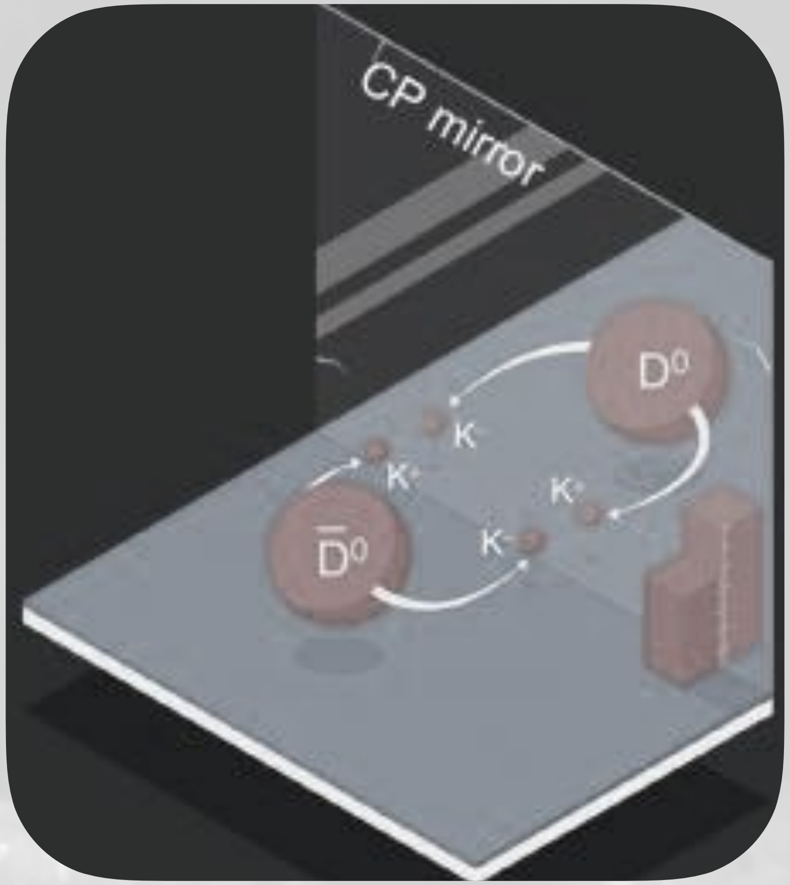
PRL 119 (2017) 181805

full q^2	SM	BSM	LQ	hi q^2 SM	LQs	lo q^2 SM	BSM
$R^D_{\pi\pi}$	$1.00 \pm \mathcal{O}(\%)$	0.85 ...0.99	SM-like	$1.00 \pm \mathcal{O}(\%)$	0.7 ...4.4		
R^D_{KK}	$1.00 \pm \mathcal{O}(\%)$	SM-like	SM-like	NA	NA	$0.83 \pm \mathcal{O}(\%)$	0.60..0.87

PRD98 (2018) 035041
EPJC 80 (2020) 65

G. Hiller , Angular distributions of rare D decays, Implications LHCb, CERN, October 17, 2018

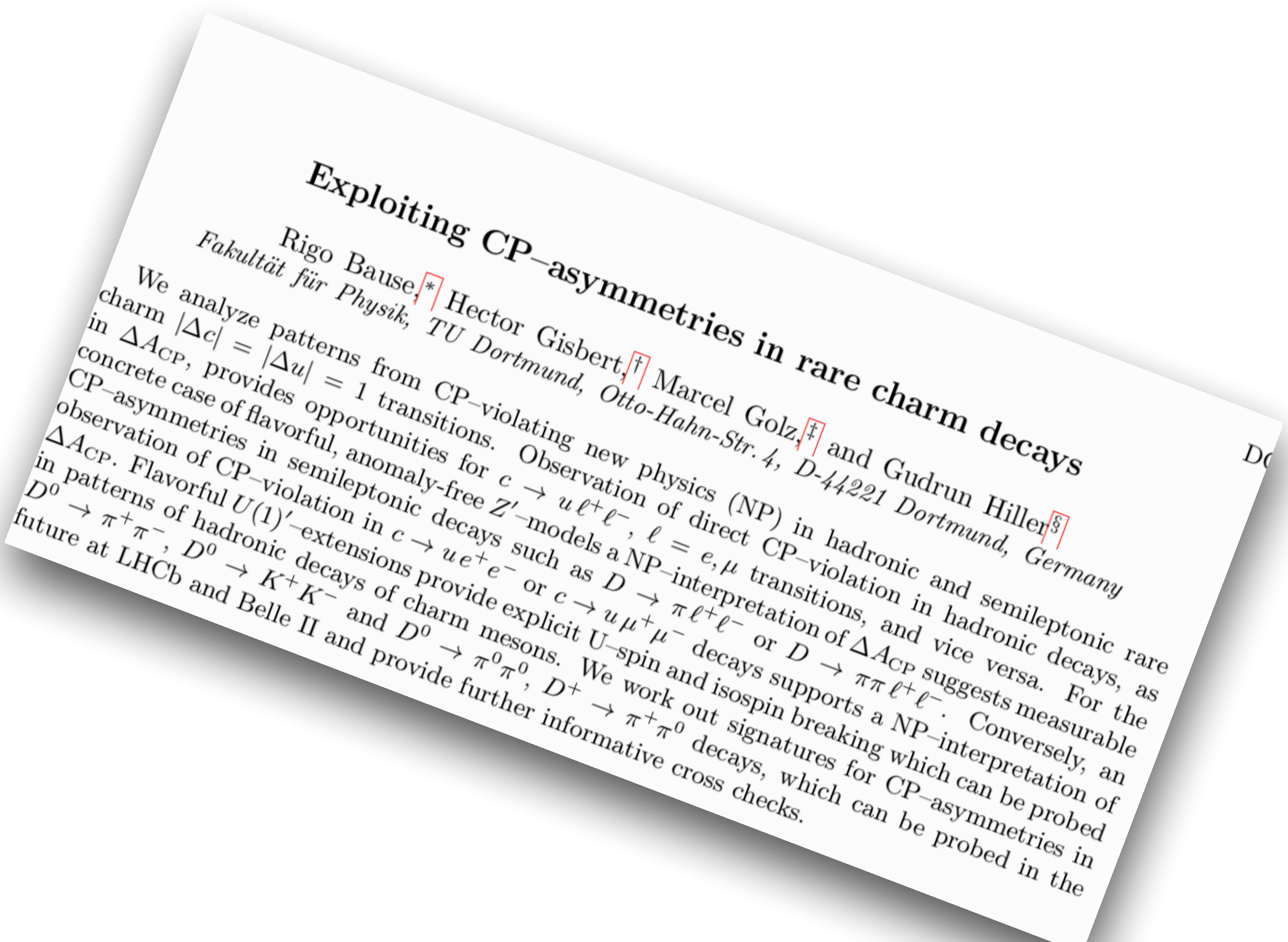
Searches for CP asymmetries



NP searches in CP asymmetries

- Observation of CPV [$\Delta A_{CP} = (15.4 \pm 2.9) \times 10^{-4}$] in charm leaves room for NP
  PRL 122 (2019) 211803

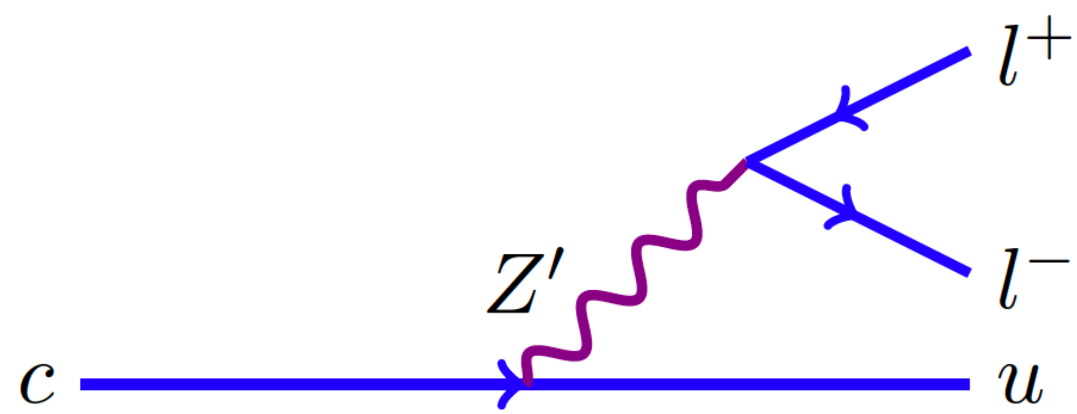
- NP interpretations → measurable CP asymmetries in rare charm (e.g Z' models)
  PRD 101 (2020) 115006



Exploiting CP–asymmetries in rare charm decays

Rigo Bause,* Hector Gisbert,† Marcel Golz,‡ and Gudrun Hiller§
Fakultät für Physik, TU Dortmund, Otto-Hahn-Str. 4, D-44221 Dortmund, Germany

We analyze patterns from CP-violating new physics (NP) in hadronic and semileptonic rare charm $|\Delta c| = |\Delta u| = 1$ transitions. Observation of direct CP-violation in hadronic decays, as in ΔA_{CP}, provides opportunities for $c \to u \ell^+\ell^-$, $\ell = e, \mu$ transitions, and vice versa. For the concrete case of flavorful, anomaly-free Z'-models a NP-interpretation of ΔA_{CP} suggests measurable CP-asymmetries in semileptonic decays such as $D \to \pi \ell^+\ell^-$ or $D \to \pi\pi \ell^+\ell^-$. Conversely, an observation of CP-violation in $c \to u e^+ e^-$ or $c \to u \mu^+\mu^-$ decays supports a NP-interpretation of ΔA_{CP}. Flavorful $U(1)'$-extensions provide explicit U-spin and isospin breaking which can be probed in patterns of hadronic decays of charm mesons. We work out signatures for CP-asymmetries in $D^0 \to \pi^+\pi^-$, $D^0 \to K^+K^-$ and $D^0 \to \pi^0\pi^0$, $D^+ \to \pi^+\pi^0$ decays, which can be probed in the future at LHCb and Belle II and provide further informative cross checks.



$$\cong A_{CP} \approx \mathcal{O}(\%)$$

remember: $A_{CP}^{SM} \approx 0$

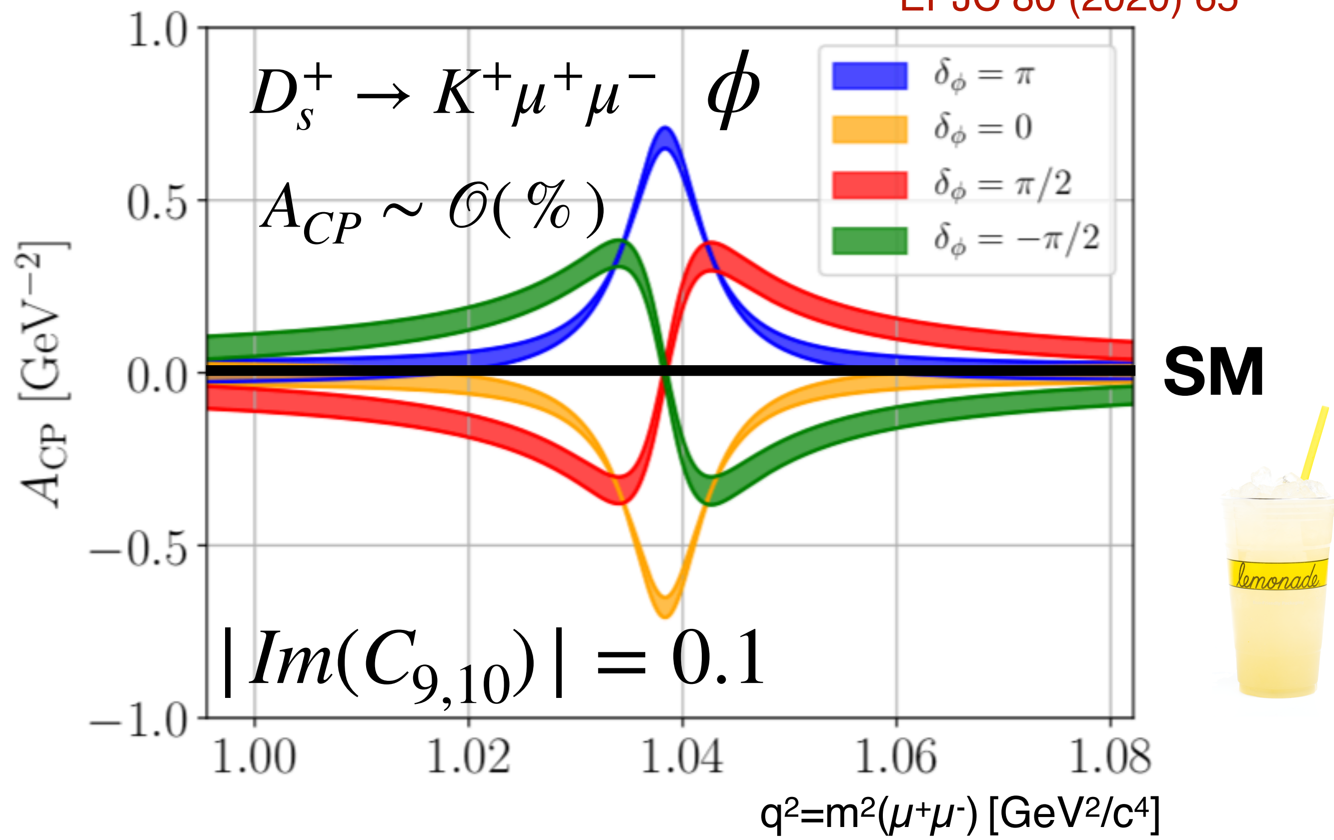
NP searches in CP asymmetries

- A_{CP} driven by interference of **NP** and **LD** contributions

- Local enhancement in vicinity of resonances, we profit from them

  "resonance enhanced"

EPJC 80 (2020) 65



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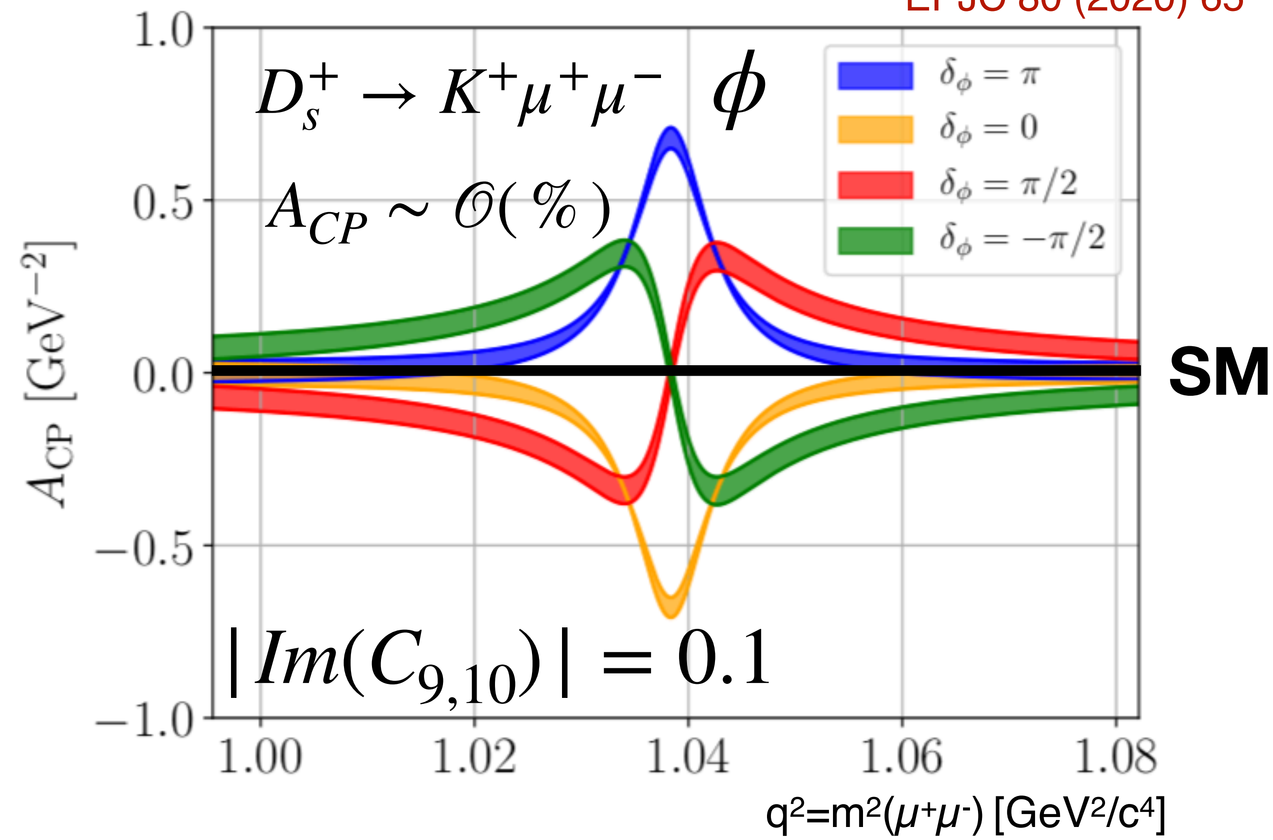
- Many opportunities at LHCb

  - $D^+ \to \pi^+\ell^+\ell^-$
  - $D_s^+ \to K^+\ell^+\ell^-$
  - $\Lambda_c \to p\ell^+\ell^-$
  - $D^0 \to \pi^+\pi^-\ell^+\ell^-$
  - $D^0 \to K^+K^-\ell^+\ell^-$
  - ....

all on our list!

EPJC 80 (2020) 65



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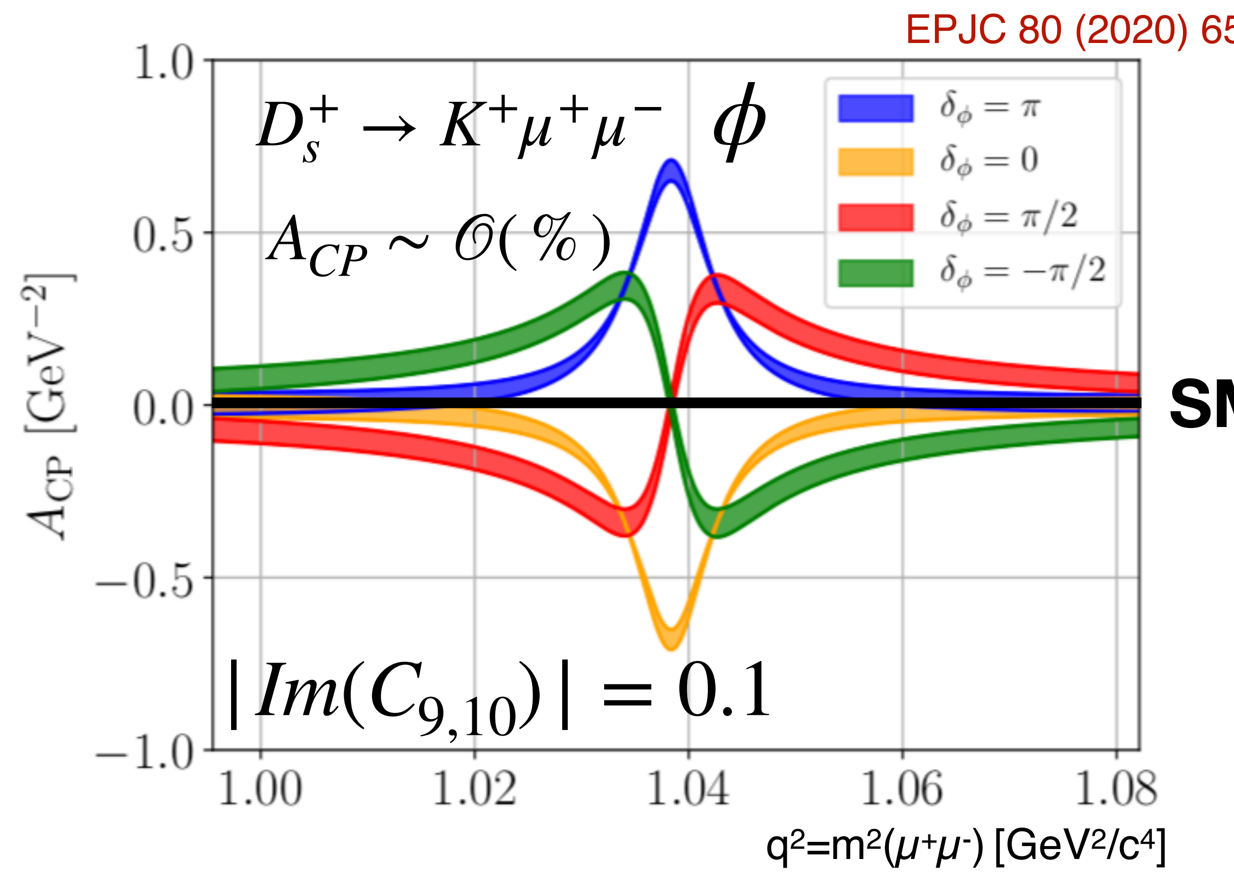

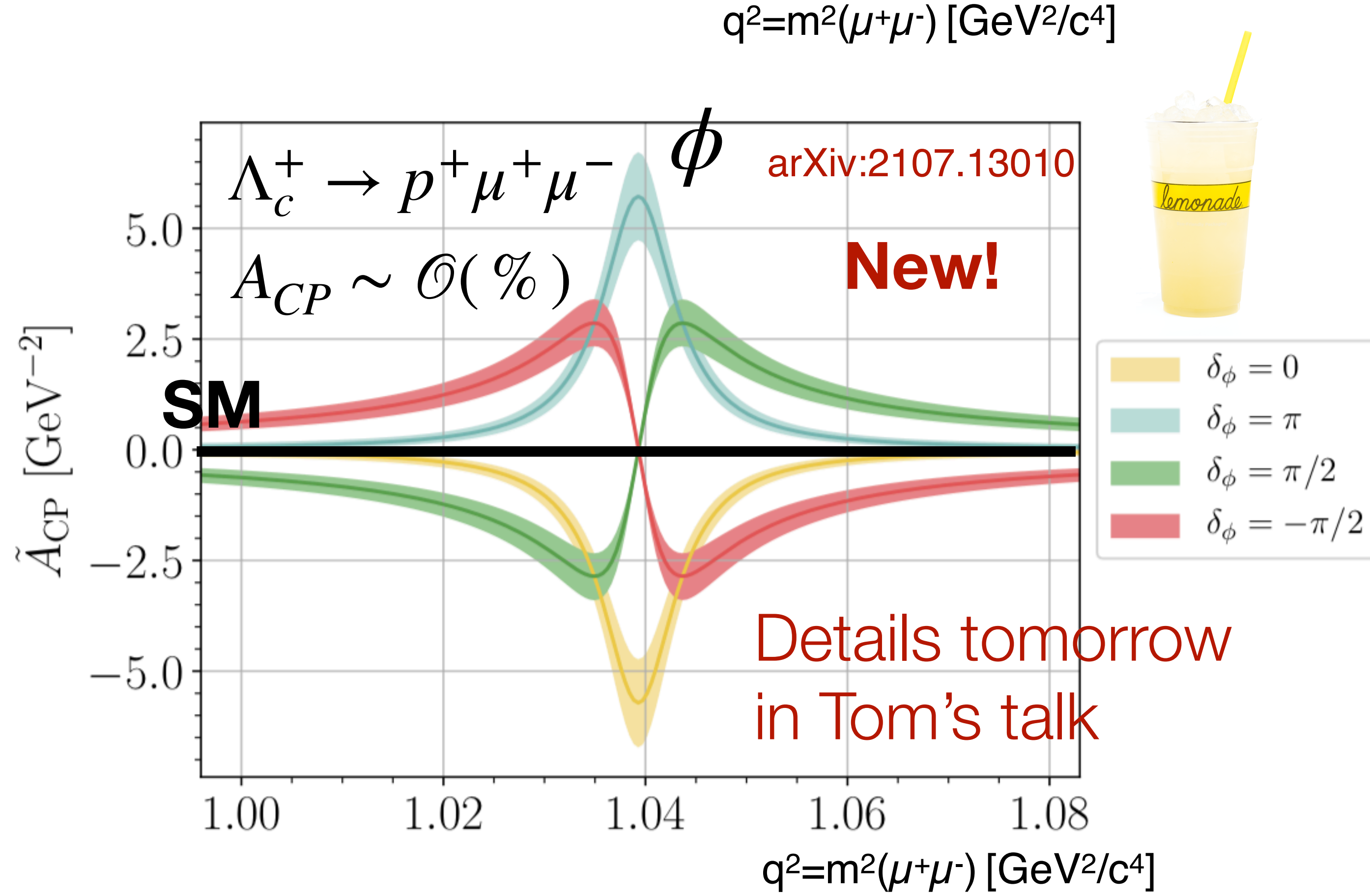

Details tomorrow in Tom's talk

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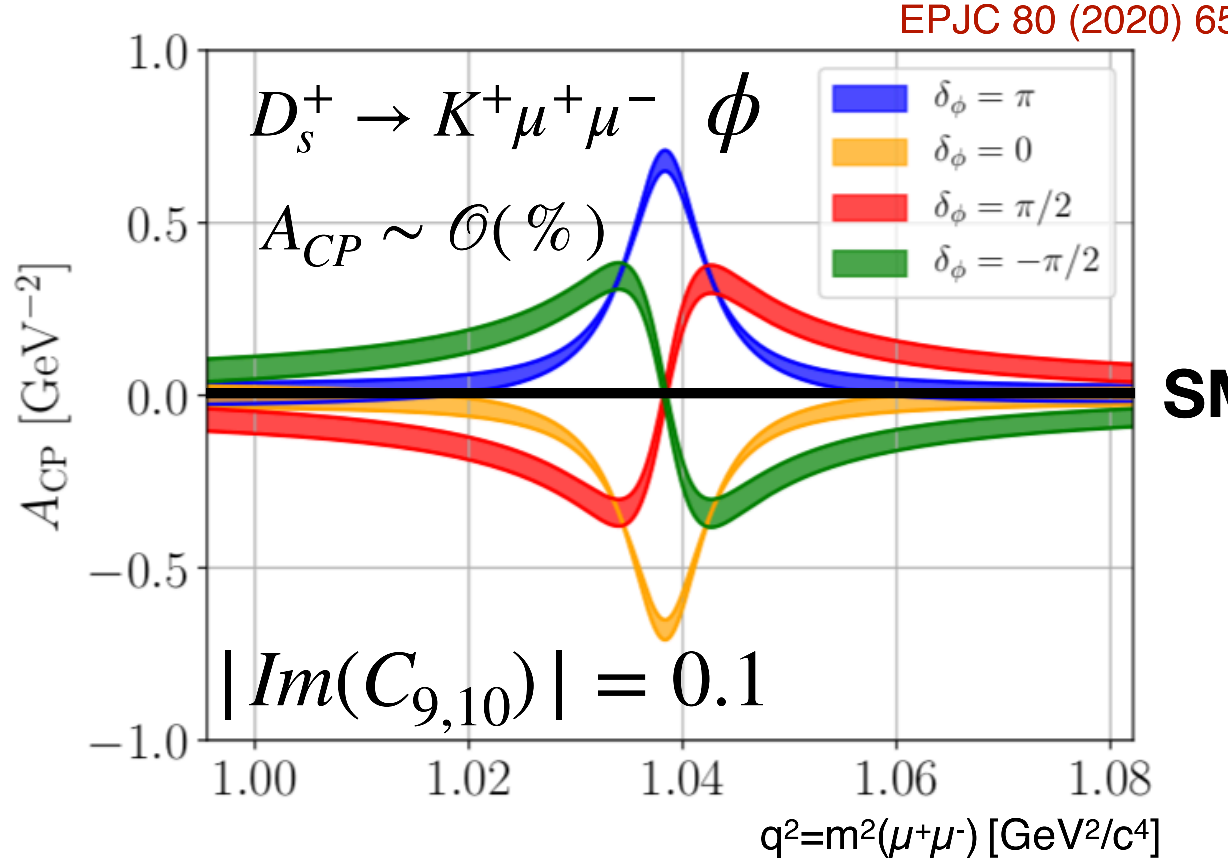
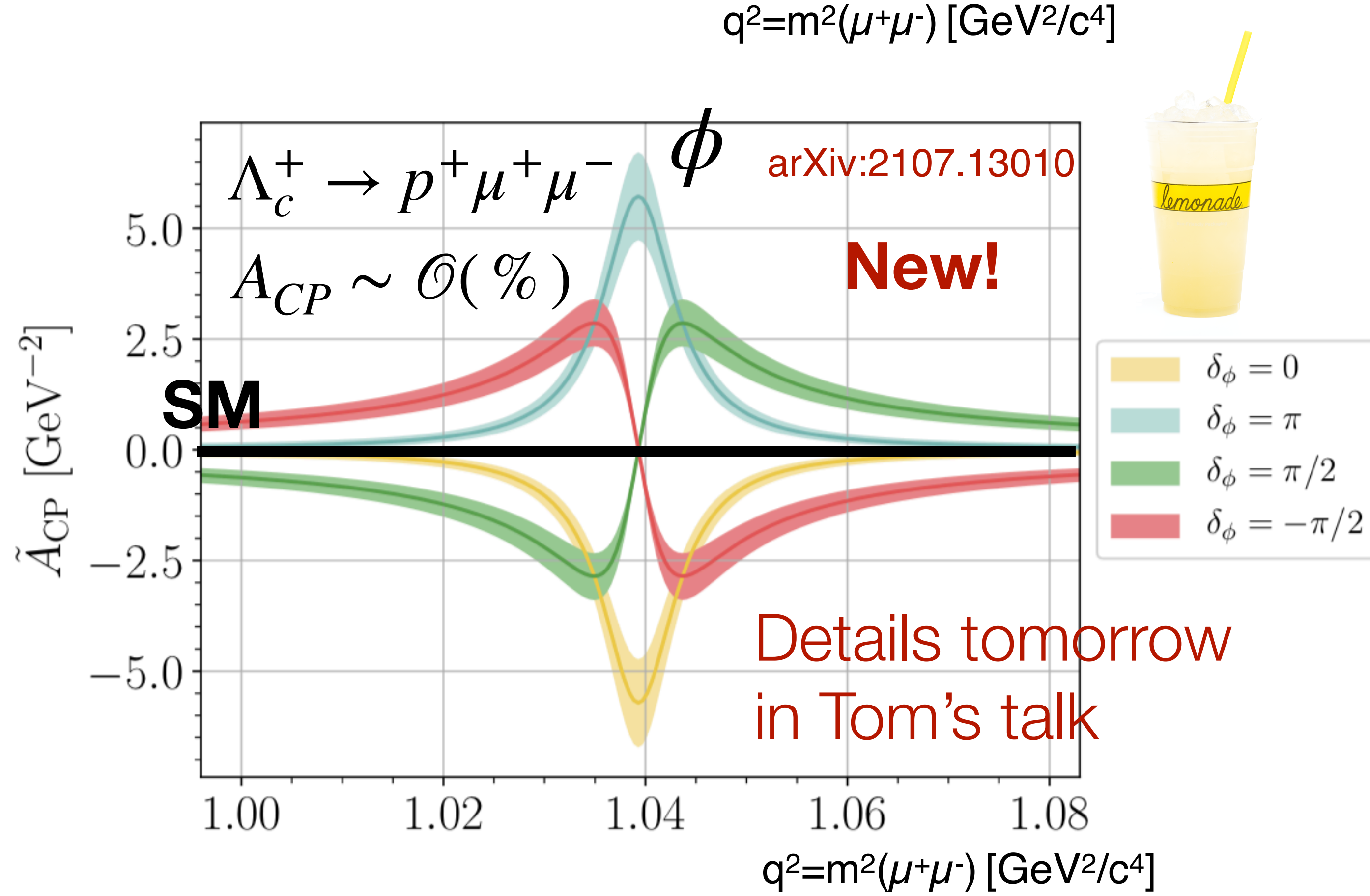
    PRL 121 (2018) 091801
  - ....

all on our list!

EPJC 80 (2020) 65





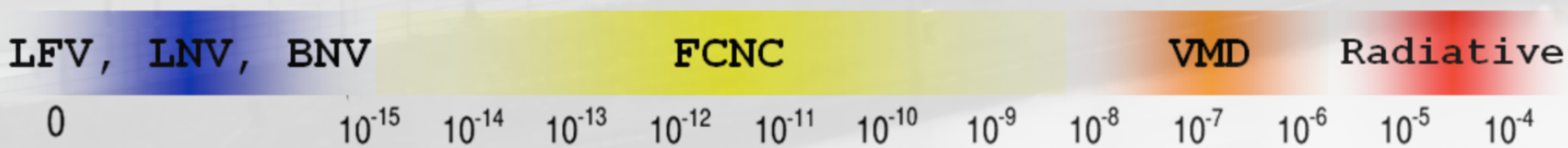
Details tomorrow in Tom's talk

Searches for CP asymmetries

“Angular and CP asymmetries in $D^0 \to \pi^-\pi^+\mu^+\mu^-$ and $D^0 \to K^-K^+\mu^+\mu^-$ decays”

PRL 121 (2018) 091801

$D^0 \to h^\pm h^\mp V(\mu^\pm\mu^\mp)$



CP Asymmetries in $D^0 \to h^+h^-\mu^+\mu^-$

- Rarest charm meson decays observed, dominated by resonant **LD** contributions

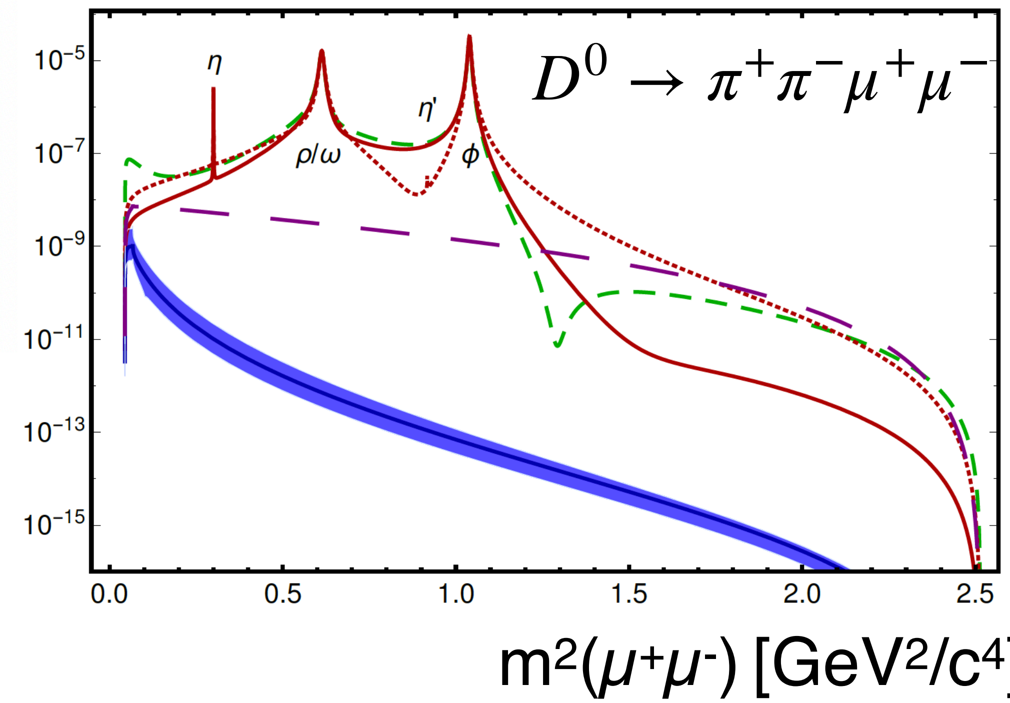
$$\mathcal{B}(D^0 \to \pi^-\pi^+\mu^+\mu^-) = (9.64 \pm 0.48 \pm 0.51 \pm 0.97) \times 10^{-7}$$

$$\mathcal{B}(D^0 \to K^-K^+\mu^+\mu^-) = (1.54 \pm 0.27 \pm 0.09 \pm 0.16) \times 10^{-7}$$

uncertainties are statistical, systematic and due to the BF of normalisation mode

PRL 119 (2017) 181805

PRD 98 (2018) 035041



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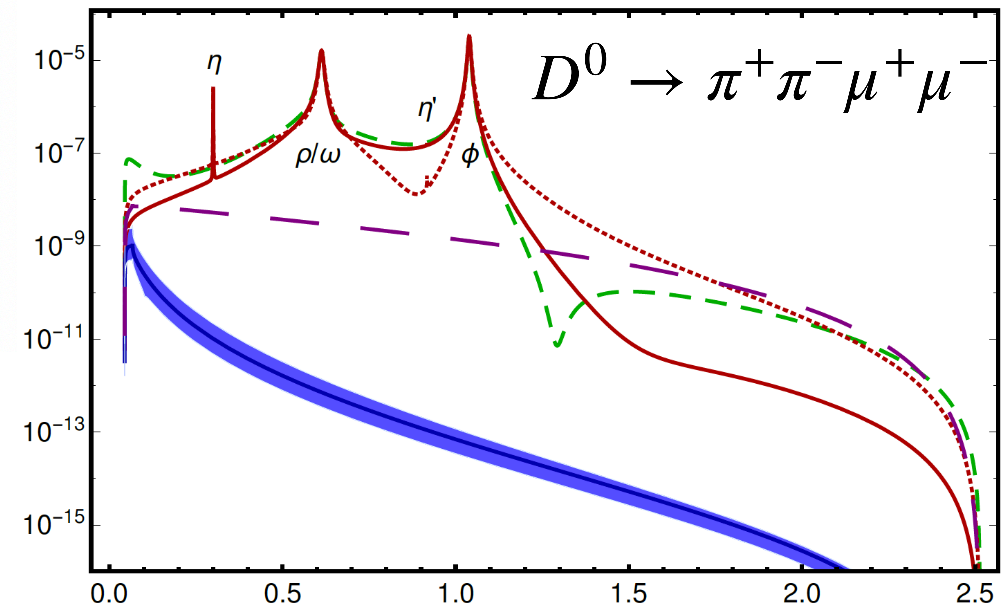
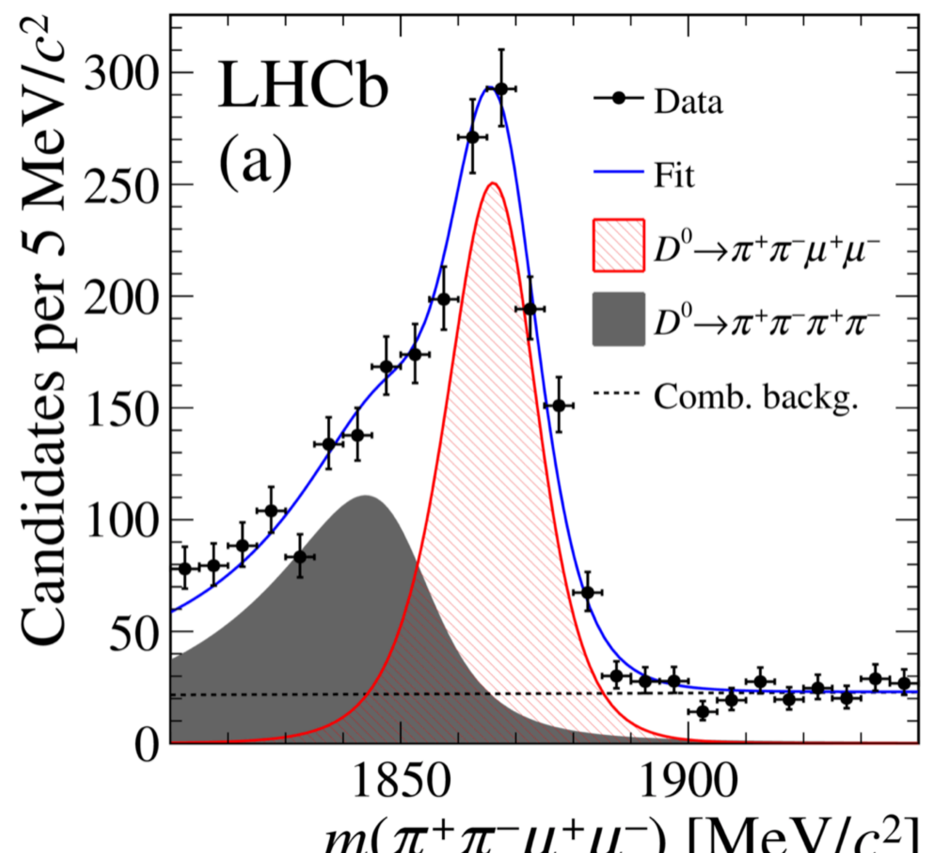


- Data: 5/fb from 2011-2016 PRL 121 (2018) 091801
- D^0 from $D^{*+} \to D^0\pi^+$ decays

  N($D^0 \to \pi\pi\mu\mu$) ~ 1000

  N($D^0 \to KK\mu\mu$) ~ 100

PRL 121 (2018) 091801



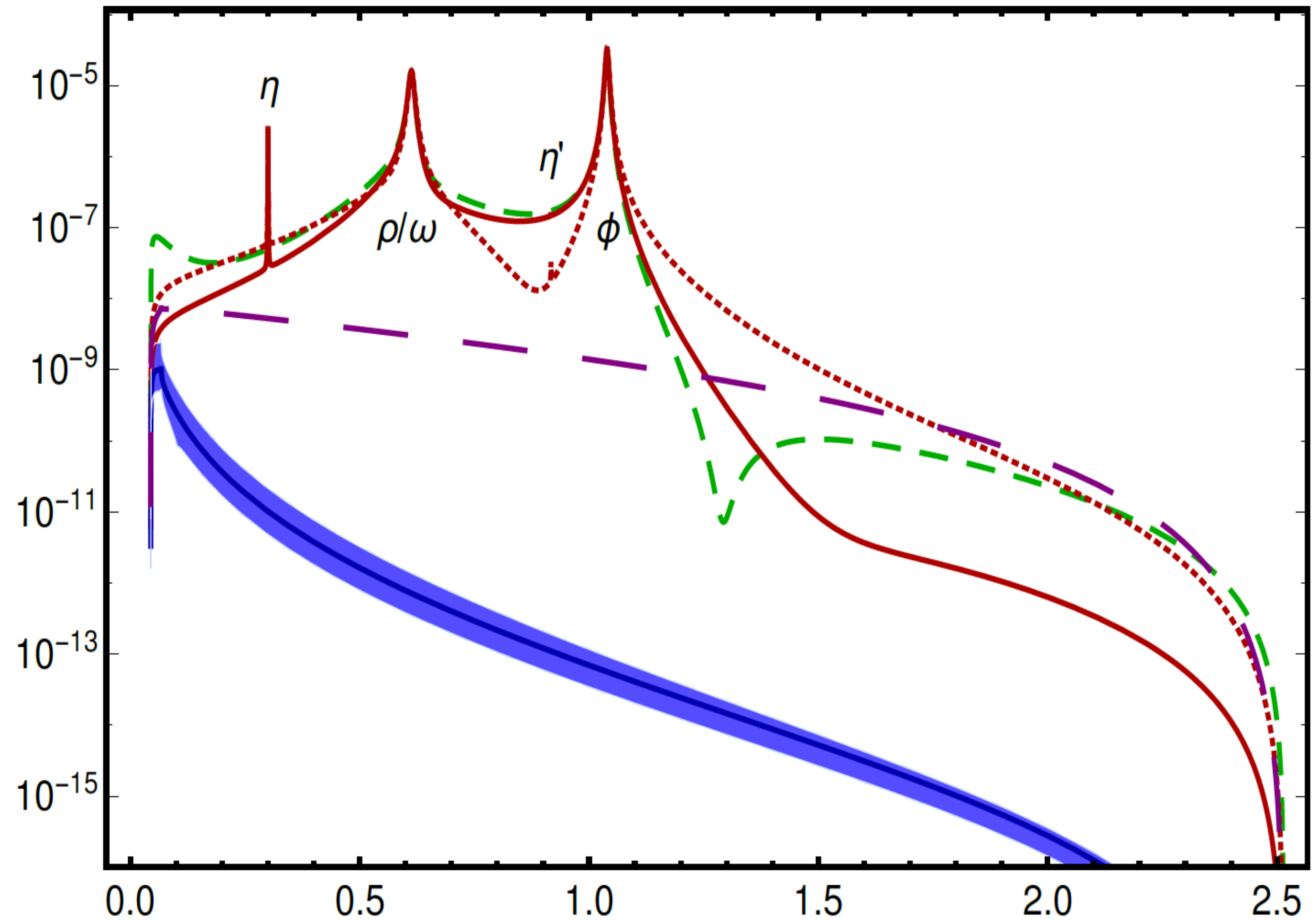
$$A_{CP} = \frac{N(D^0 \to h^+h^-\mu^+\mu^-) - N(\overline{D}^0 \to h^+h^-\mu^+\mu^-)}{N(D^0 \to h^+h^-\mu^+\mu^-) + N(\overline{D}^0 \to h^+h^-\mu^+\mu^-)}$$

Measured CP Asymmetries

- Measurement binned in regions of dimuon mass

bin	low mass	η	ρ/ω	ϕ	high mass
$m(\mu^+\mu^-)[MeV/c^2]$	< 525	$525 - 565$	$565 - 950$	$950 - 1100$	> 1100
$D^0 \to \pi^+\pi^-\mu^+\mu^-$	✓	✓	✓	✓	✓
$D^0 \to K^+K^-\mu^+\mu^-$	✓	✓	✓		

PRD 98 (2018) 035041



$m^2(\mu^+\mu^-)$ [GeV^2/c^4]

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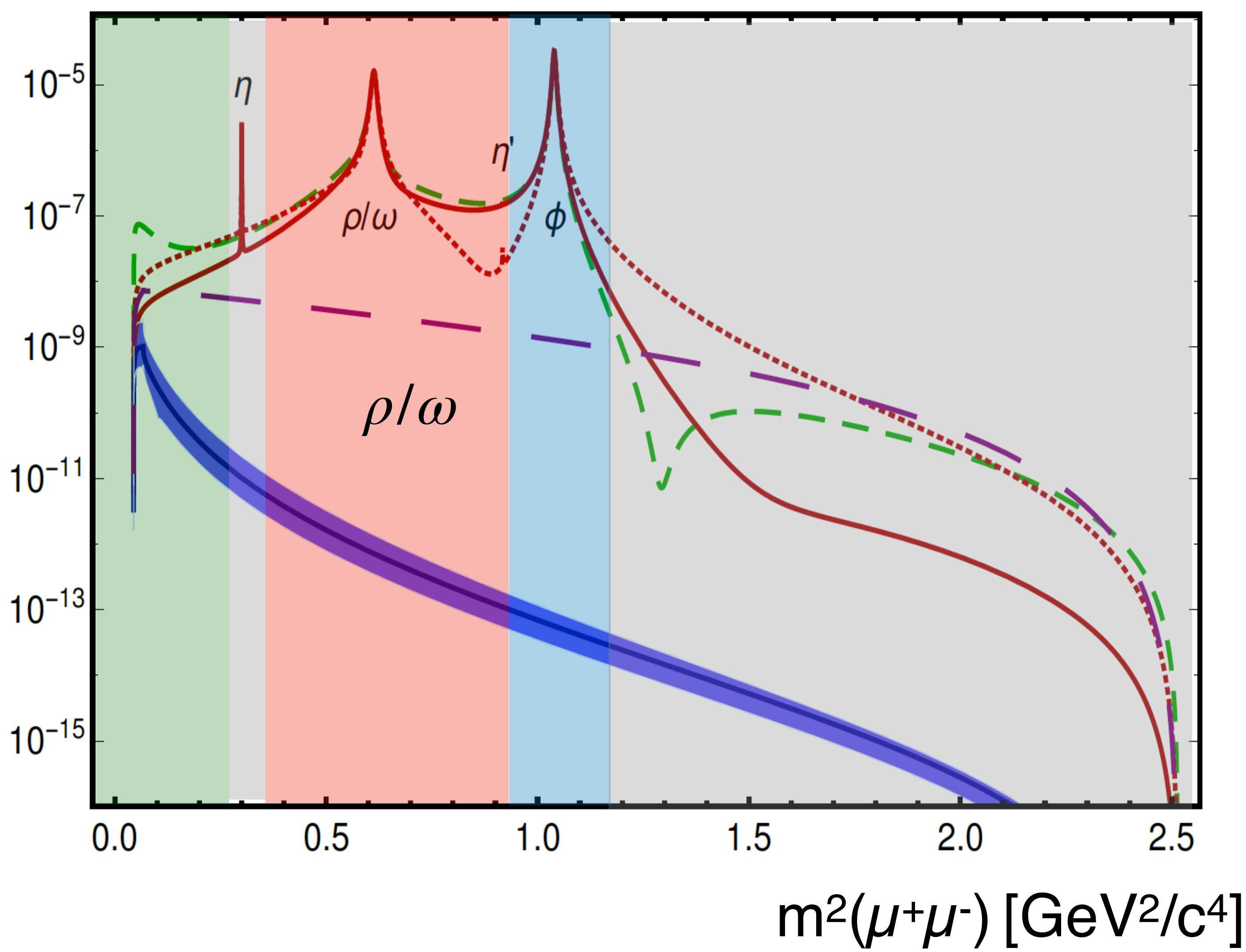
PRD 98 (2018) 035041



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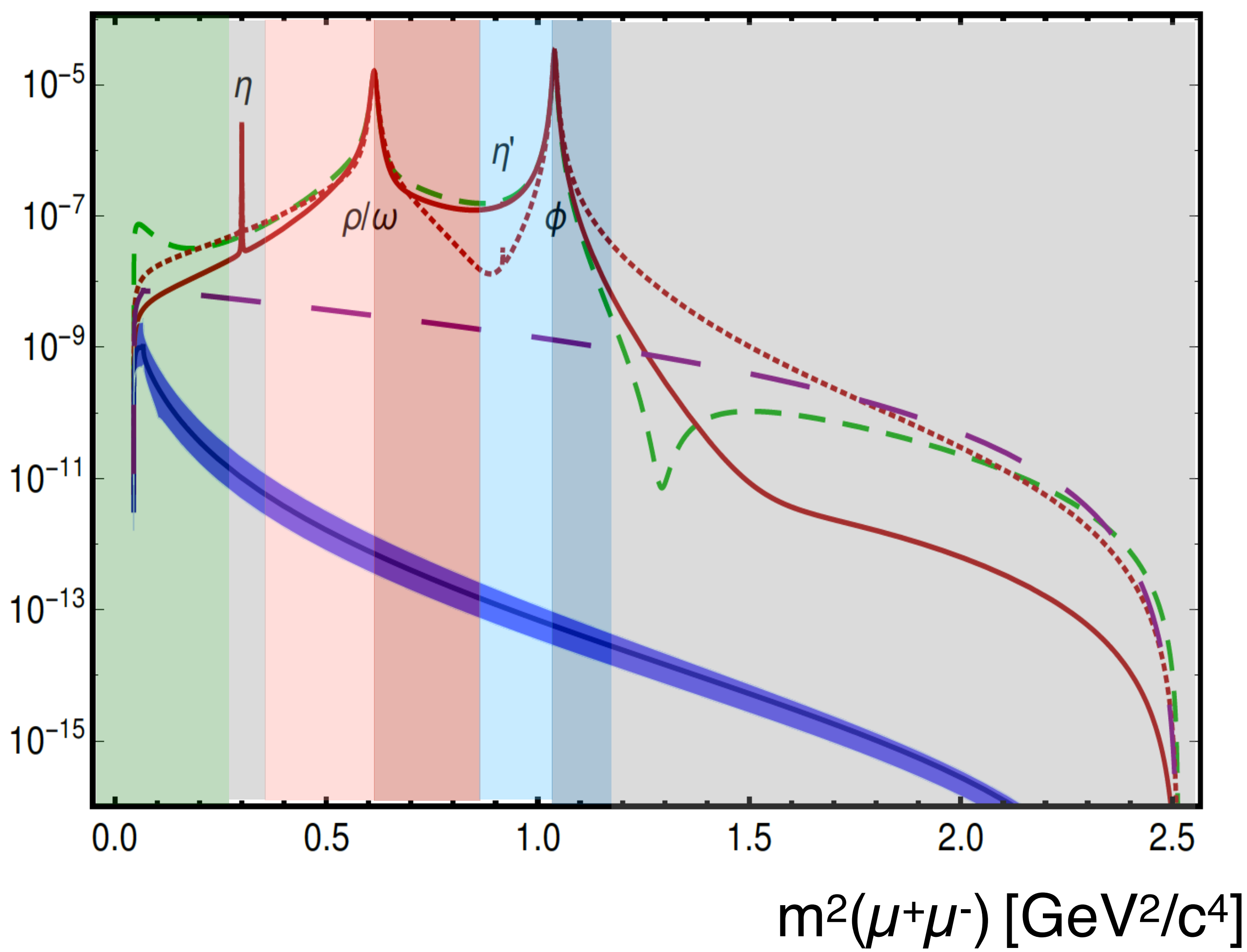
PRD 98 (2018) 035041



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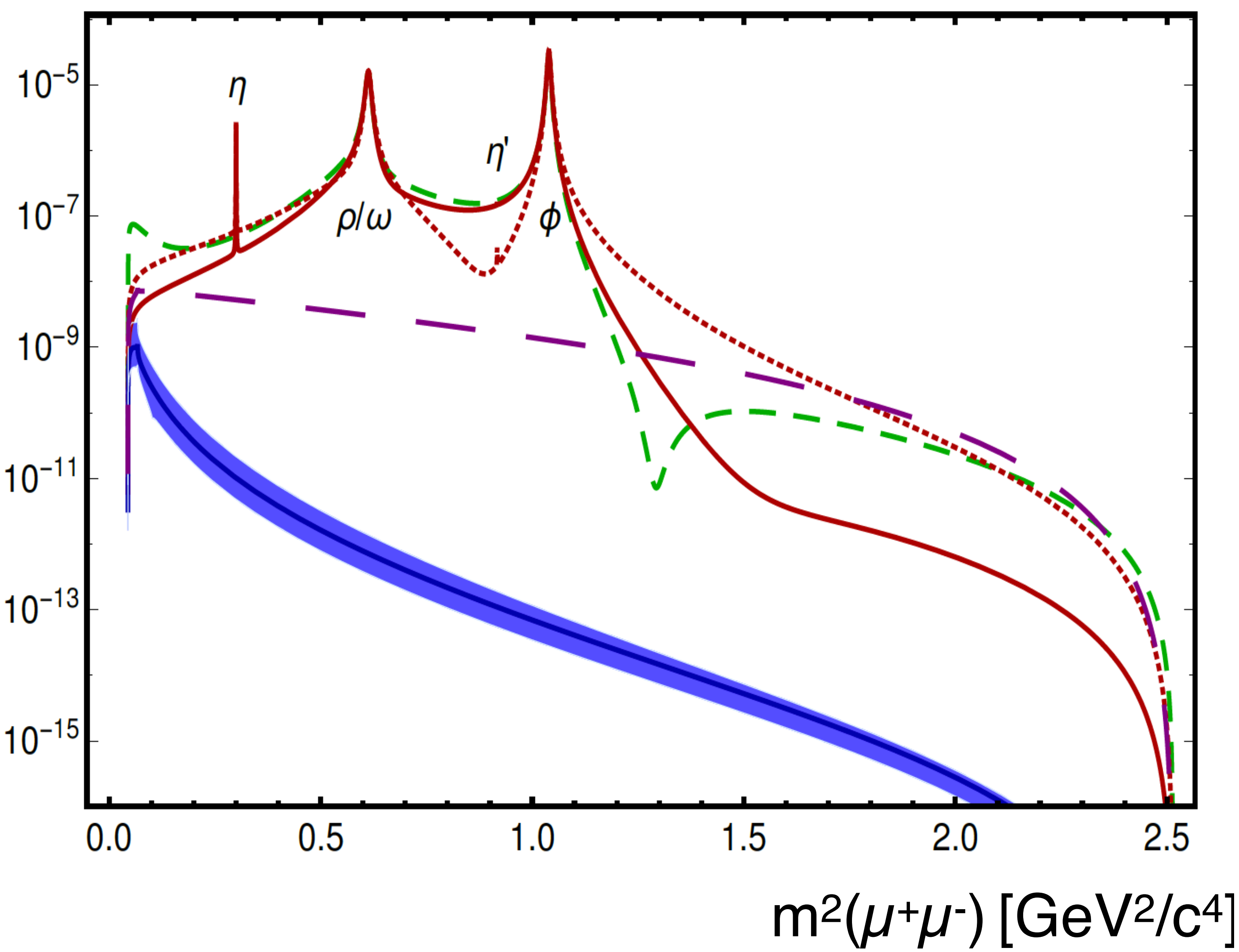
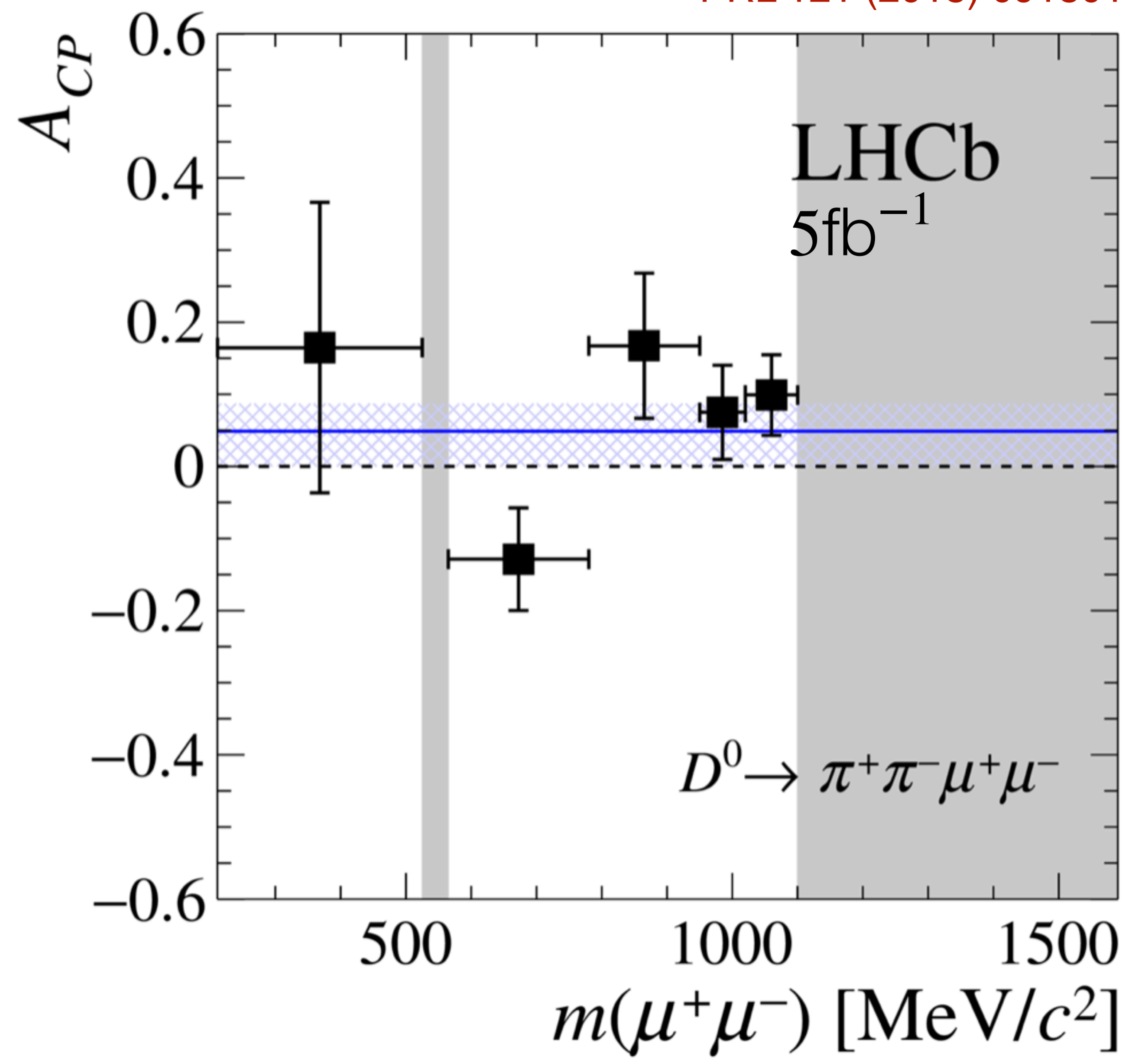


PRL 121 (2018) 091801



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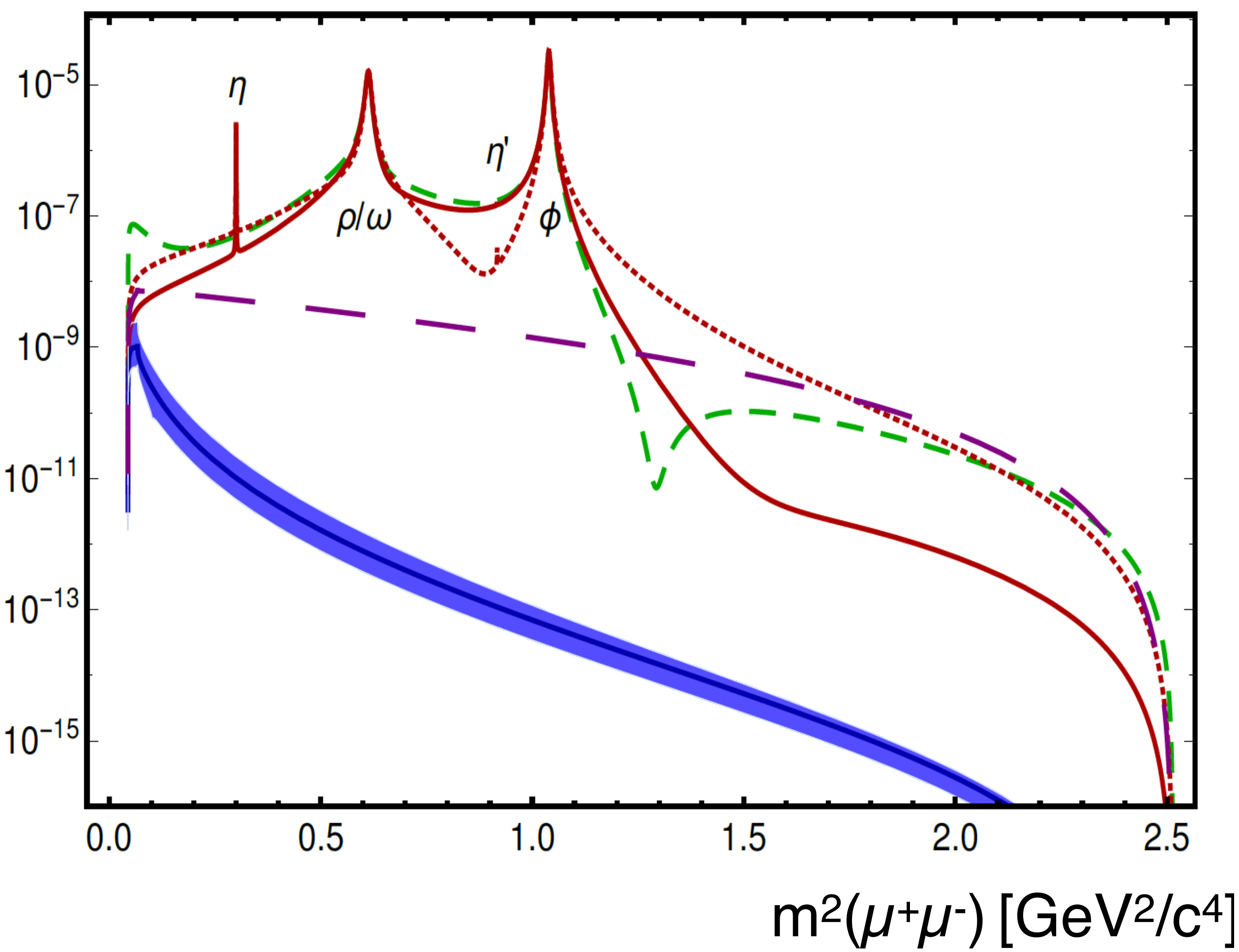

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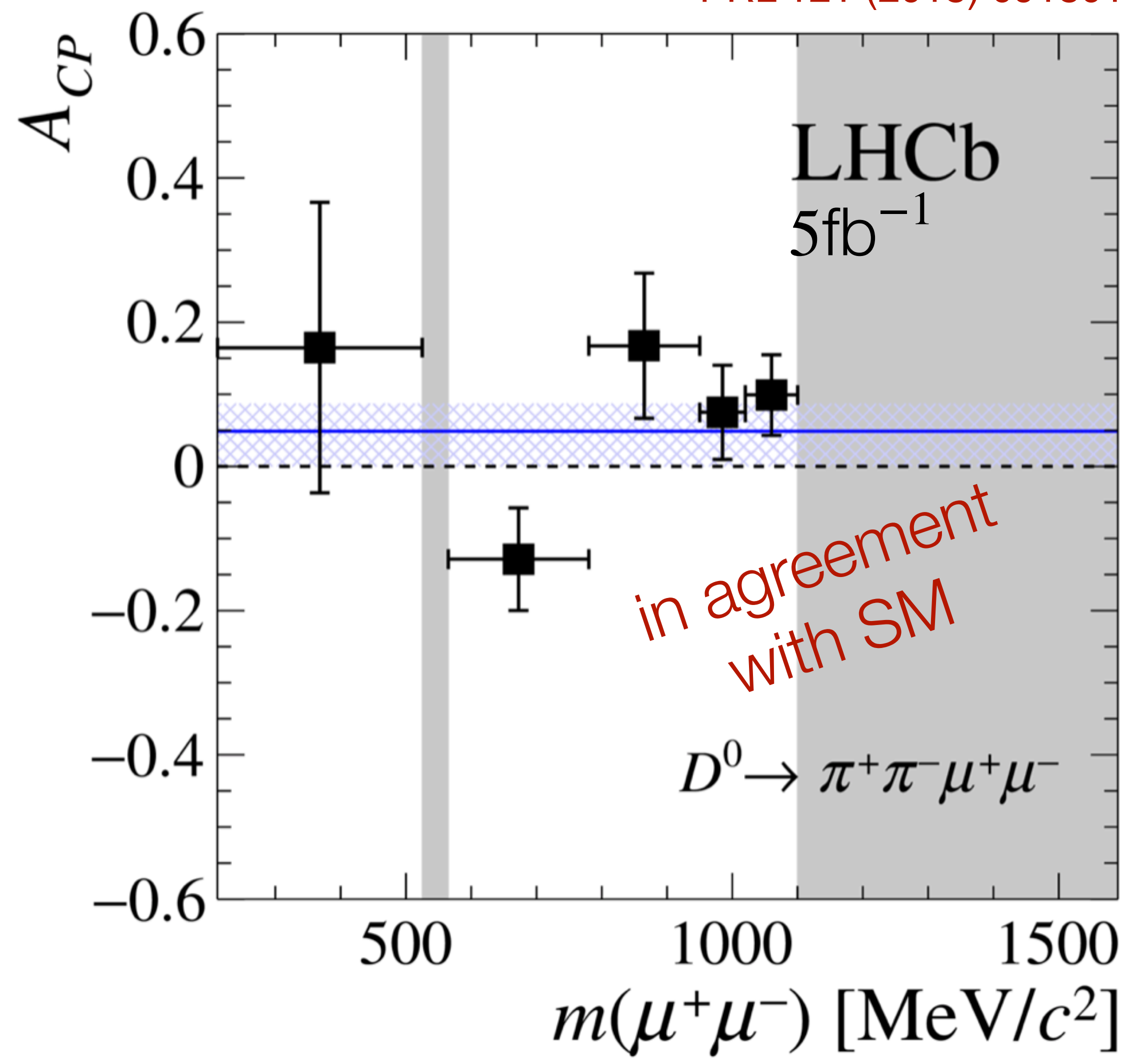

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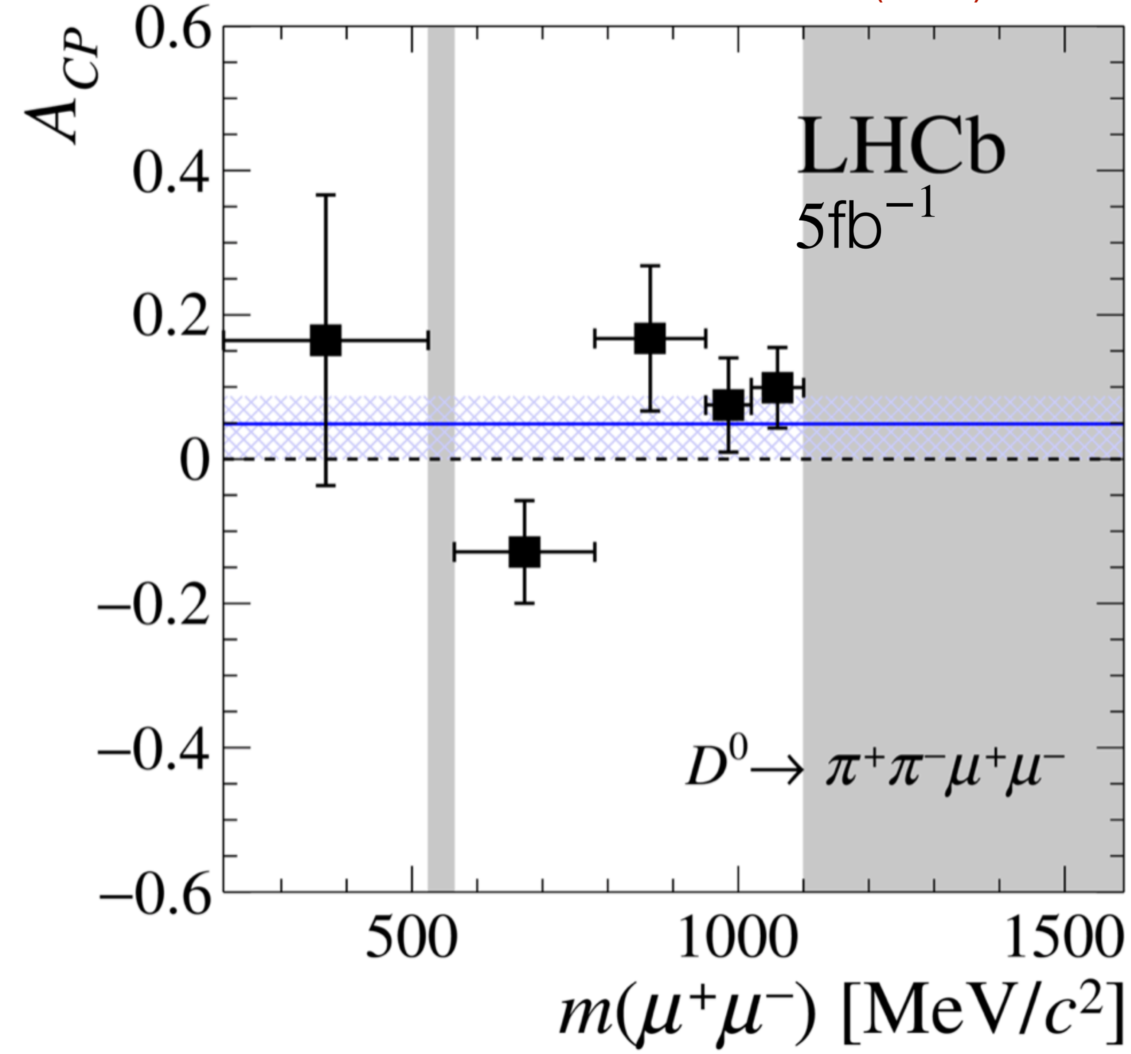
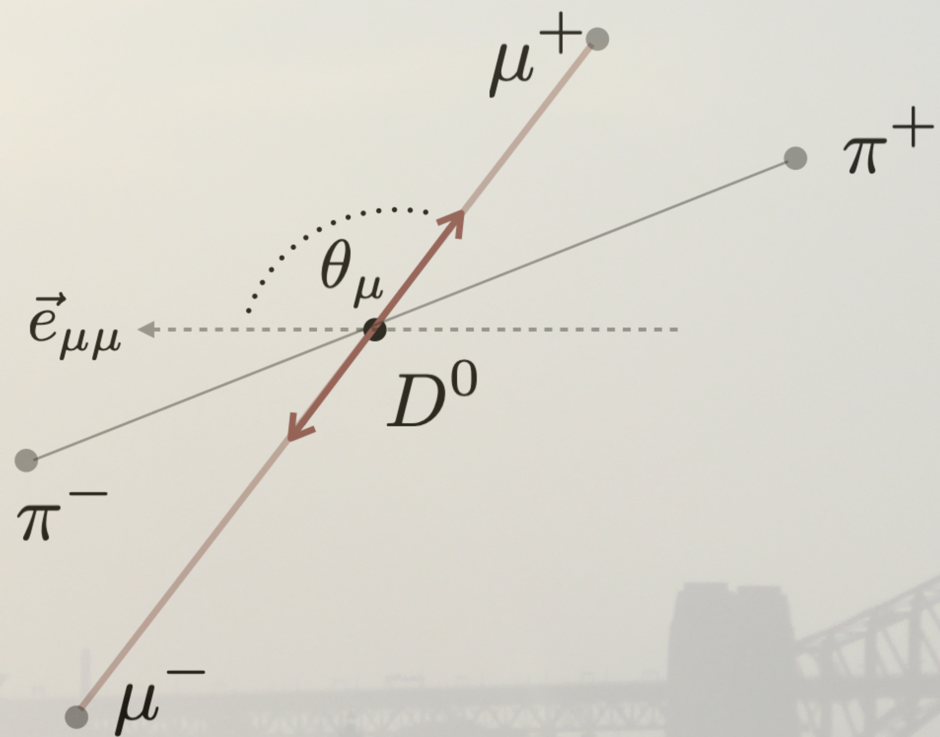
Update with full LHCb data set in the pipeline for Implications Workshop

LHCb-PAPER-2021-035
in preparation

PRL 121 (2018) 091801



Searches in angular distributions



Angular distributions in rare charm

- No axial vector couplings (pure vector current) in lepton system → parity conservation

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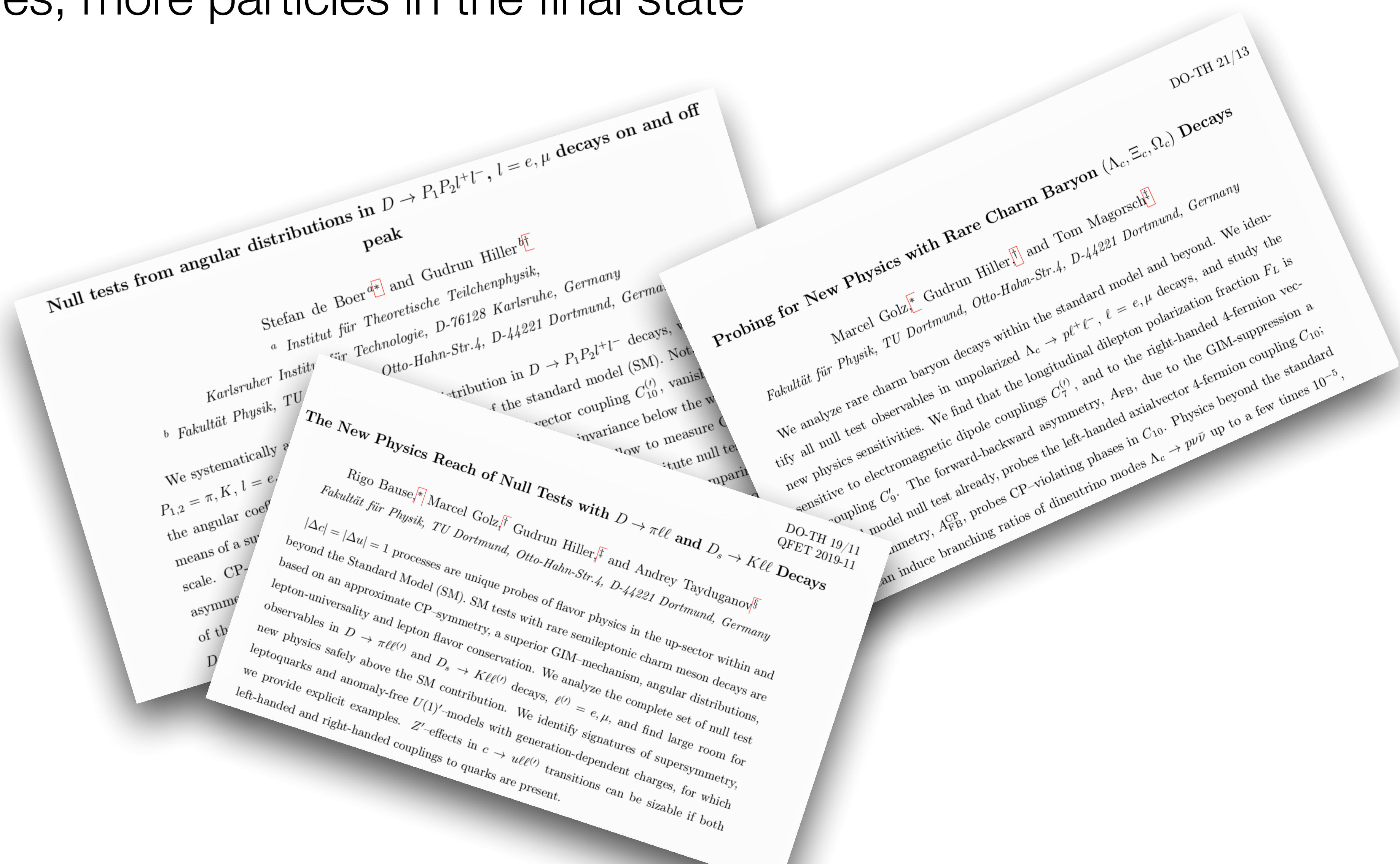
  - ....



Null tests from angular distributions in $D \to P_1P_2l^+l^-$, $l = e,\mu$ decays on and off peak

Stefan de Boer[a*] and Gudrun Hiller[b†]

[a] Institut für Theoretische Teilchenphysik, Karlsruher Institut für Technologie, D-76128 Karlsruhe, Germany

[b] Fakultät Physik, TU Dortmund, Otto-Hahn-Str.4, D-44221 Dortmund, Germany

DO-TH 21/13

Probing for New Physics with Rare Charm Baryon ($\Lambda_c, \Xi_c, \Omega_c$) Decays

Marcel Golz,* Gudrun Hiller,† and Tom Magorsch‡

Fakultät für Physik, TU Dortmund, Otto-Hahn-Str.4, D-44221 Dortmund, Germany

We analyze rare charm baryon decays within the standard model and beyond. We identify all null test observables in unpolarized $\Lambda_c \to p\ell^+\ell^-$, $\ell = e,\mu$ decays, and study the new physics sensitivities. We find that the longitudinal dilepton polarization fraction F_L is sensitive to electromagnetic dipole couplings $C_7^{(\prime)}$, and to the right-handed 4-fermion vector coupling C_9'. The forward-backward asymmetry, A_{FB}, due to the GIM-suppression a ... model null test already, probes the left-handed axialvector 4-fermion coupling C_{10}; ... metry, A_{FB}^{CP}, probes CP-violating phases in C_{10}. Physics beyond the standard ... an induce branching ratios of dineutrino modes $\Lambda_c \to p\nu\bar{\nu}$ up to a few times 10^{-5},

DO-TH 19/11
QFET 2019-11

The New Physics Reach of Null Tests with $D \to \pi\ell\ell$ and $D_s \to K\ell\ell$ Decays

Rigo Bause,* Marcel Golz,† Gudrun Hiller,‡ and Andrey Tayduganov§

Fakultät für Physik, TU Dortmund, Otto-Hahn-Str.4, D-44221 Dortmund, Germany

$|\Delta c| = |\Delta u| = 1$ processes are unique probes of flavor physics in the up-sector within and beyond the Standard Model (SM). SM tests with rare semileptonic charm meson decays are based on an approximate CP-symmetry, a superior GIM-mechanism, angular distributions, lepton-universality and lepton flavor conservation. We analyze the complete set of null test observables in $D \to \pi\ell\ell^{(\prime)}$ and $D_s \to K\ell\ell^{(\prime)}$ decays, $\ell^{(\prime)} = e,\mu$, and find large room for new physics safely above the SM contribution. We identify signatures of supersymmetry, leptoquarks and anomaly-free $U(1)'$-models with generation-dependent charges, for which we provide explicit examples. Z'-effects in $c \to u\ell\ell^{(\prime)}$ transitions can be sizable if both left-handed and right-handed couplings to quarks are present.

Angular distributions in rare charm

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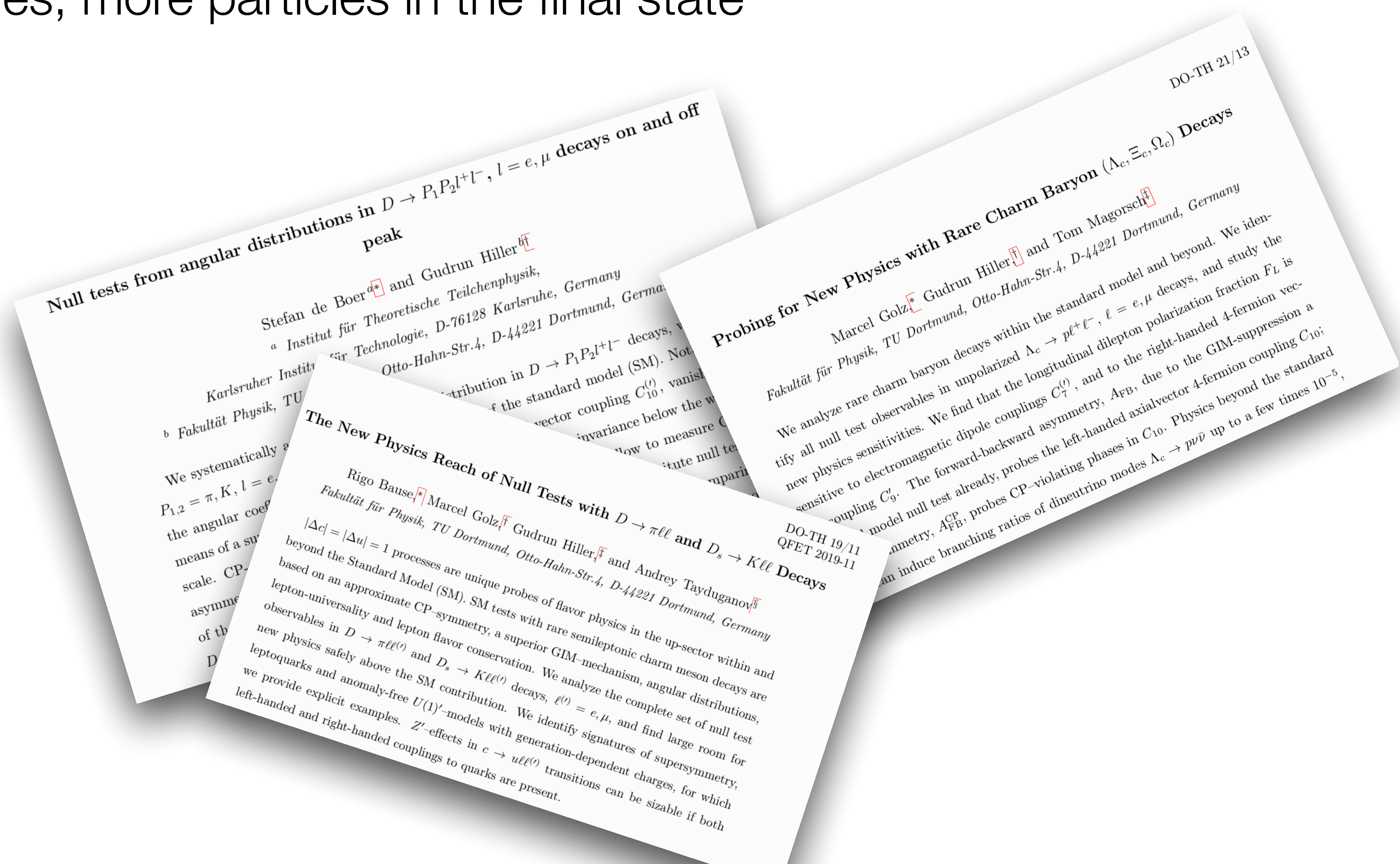
    PRL 121 (2018) 091801
  - ....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DO-TH 21/13

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DO-TH 19/11
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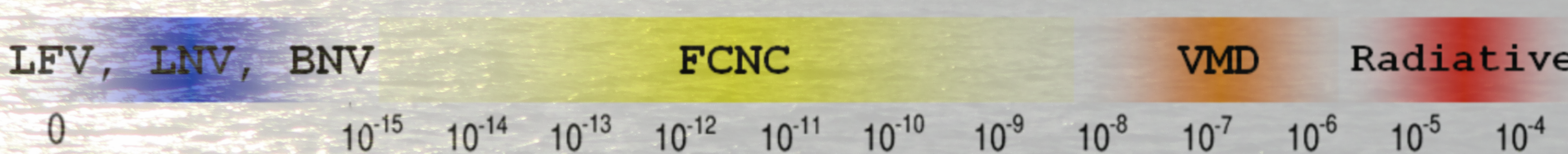
Searches in angular distributions

"Angular analysis of $D^0 \to \pi^-\pi^+\mu^+\mu^-$ and $D^0 \to K^-K^+\mu^+\mu^-$ and search for CPV"

BRAND NEW

LHCb-PAPER-2021-035
in preparation

$D^0 \to h^\pm h^\mp V(\mu^\pm\mu^\mp)$



Angular analysis $D^0 \to h^+h^-\mu^+\mu^-$

$$\frac{d\Gamma}{d\cos\theta_\mu d\cos\theta_h d\phi} = I_1 + I_2\cdot\cos 2\theta_\mu + I_3\cdot\sin^2 2\theta_\mu \cos 2\phi + I_4\cdot\sin 2\theta_\mu \cos\phi + I_5\cdot\sin\theta_\mu \cos\phi + I_6\cdot\cos\theta_\mu + I_7\cdot\sin\theta_\mu \sin\phi + I_8\cdot\sin 2\theta_\mu \sin\phi + I_9\cdot\sin^2\theta_\mu \sin 2\phi$$

I_5, I_6, I_7 clean null tests!

remark:

$[I = I(q^2, p^2, \cos\theta_h)]$

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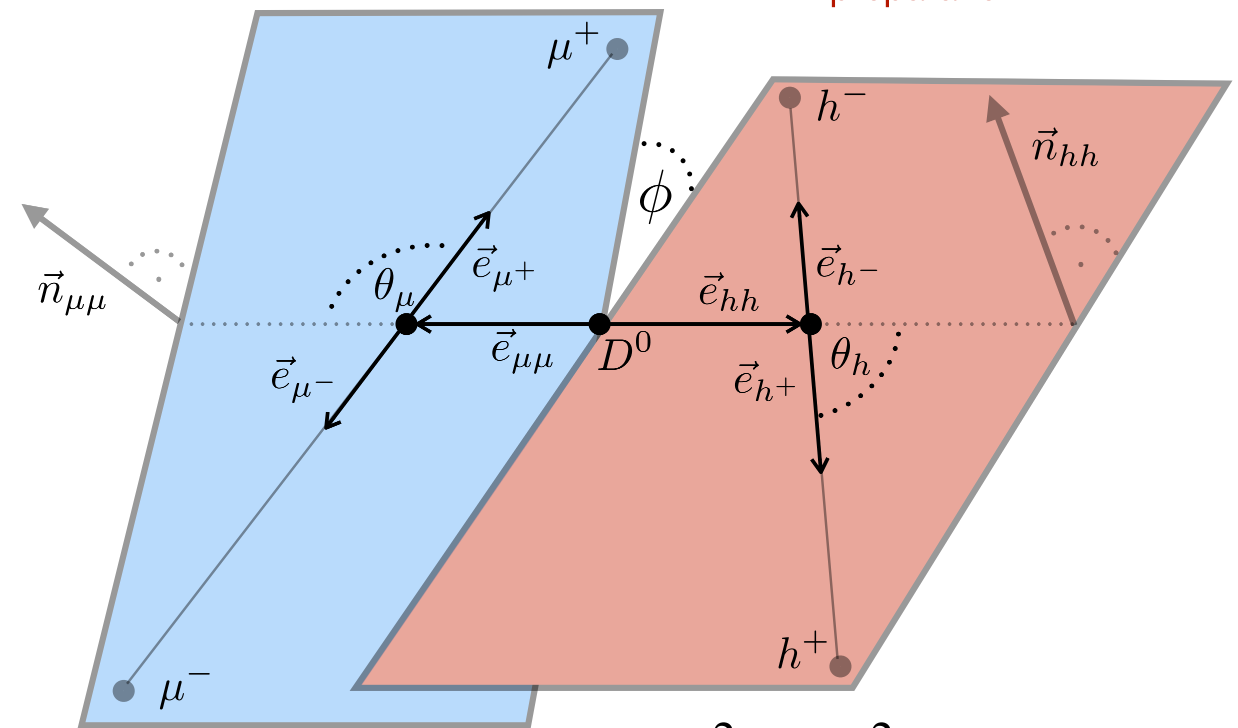

$p^2 = m^2(h^+h^-)$

$q^2 = m^2(\mu^+\mu^-)$

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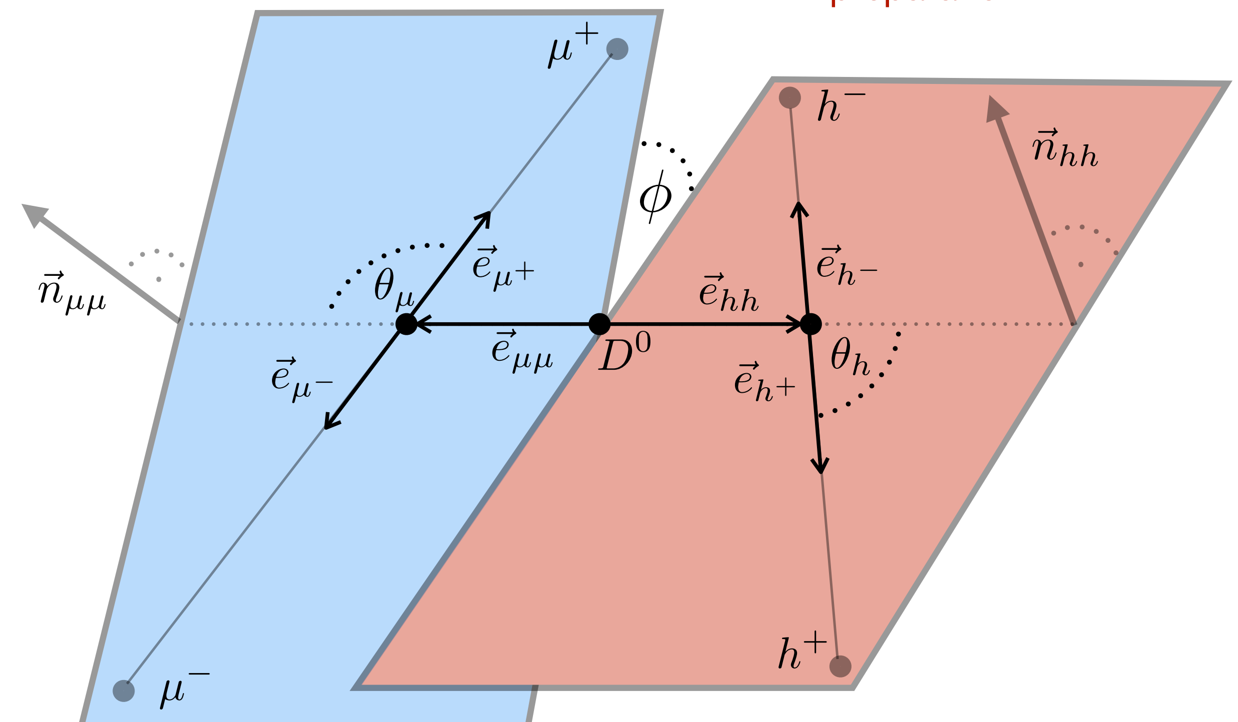
LHCb-PAPER-2021-035
in preparation



$p^2 = m^2(h^+h^-)$
$q^2 = m^2(\mu^+\mu^-)$

- Measure $q^2, p^2, \cos\theta_h$ integrated observables $\langle I_i \rangle$ for $D^0, \overline{D^0}$
- Full 9/fb from 2011-2018

N($D^0 \to \pi\pi\mu\mu$) ~3000

N($D^0 \to KK\mu\mu$) ~ 300

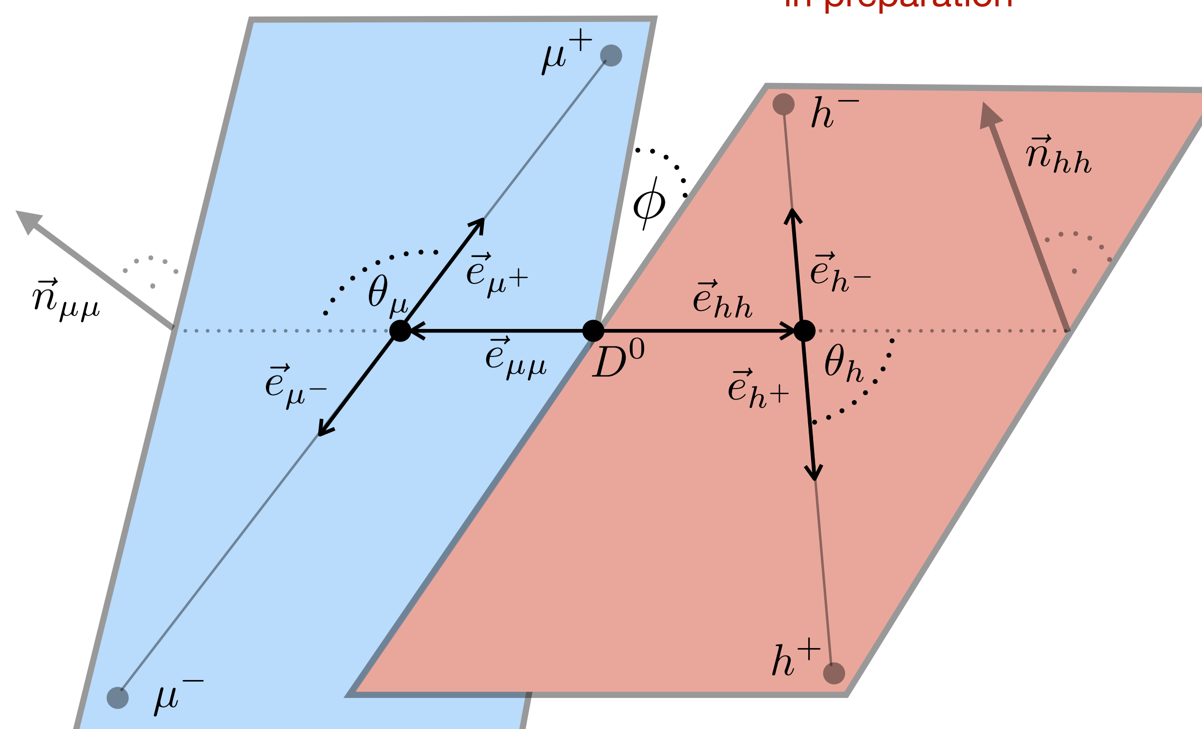
Angular analysis $D^0 \to h^+h^-\mu^+\mu^-$

$$\frac{d\Gamma}{d\cos\theta_\mu d\cos\theta_h d\phi} = I_1 + I_2\cdot\cos 2\theta_\mu + I_3\cdot\sin^2 2\theta_\mu\cos 2\phi + I_4\cdot\sin 2\theta_\mu\cos\phi + I_5\cdot\sin\theta_\mu\cos\phi + I_6\cdot\cos\theta_\mu + I_7\cdot\sin\theta_\mu\sin\phi + I_8\cdot\sin 2\theta_\mu\sin\phi + I_9\cdot\sin^2\theta_\mu\sin 2\phi$$

I_5, I_6, I_7 clean null tests!

remark:
$[I = I(q^2, p^2, \cos\theta_h)]$

LHCb-PAPER-2021-035
in preparation



$p^2 = m^2(h^+h^-)$
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- Measure $q^2, p^2, \cos\theta_h$ integrated observables $\langle I_i\rangle$ for $D^0, \overline{D^0}$
- Full 9/fb from 2011-2018

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$$\langle S_i\rangle = \frac{1}{2}\left[\langle I_i\rangle + (-)\langle \overline{I_i}\rangle\right] \qquad \langle S_{5,6,7}\rangle \overset{\text{SM}}{=} 0$$

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for CP even (CP odd) coefficients i=2,..,9

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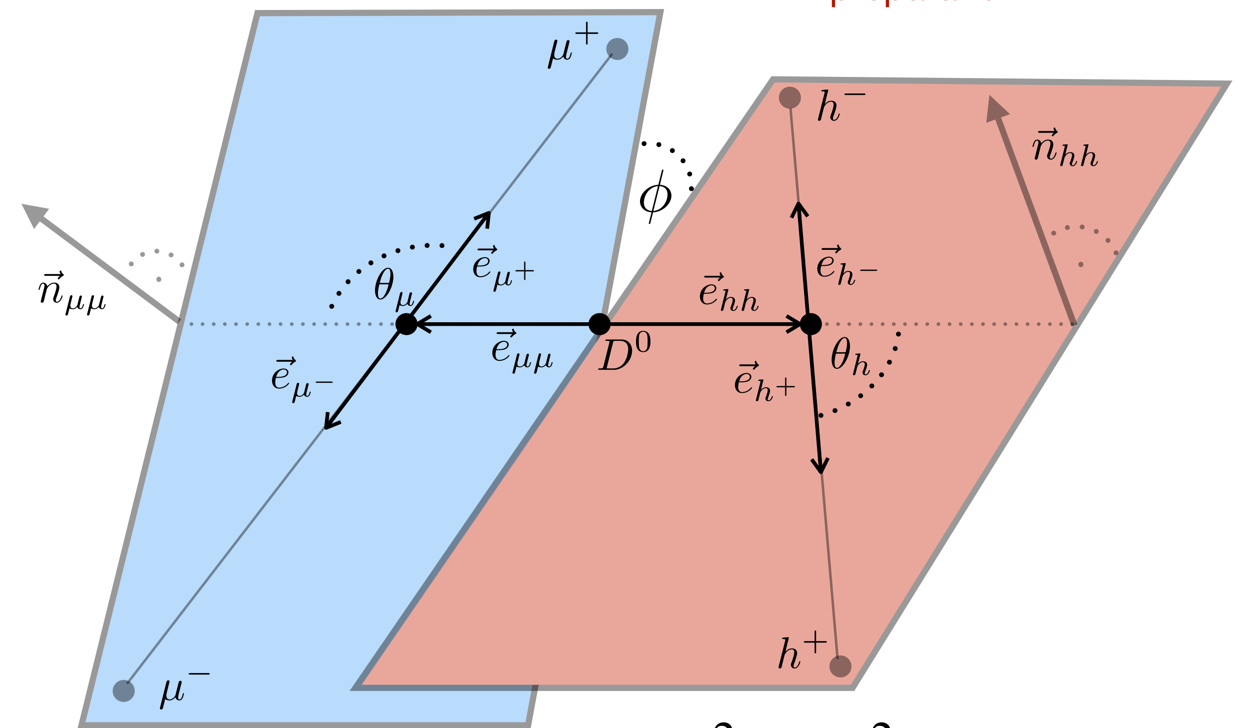
LHCb-PAPER-2021-035 in preparation



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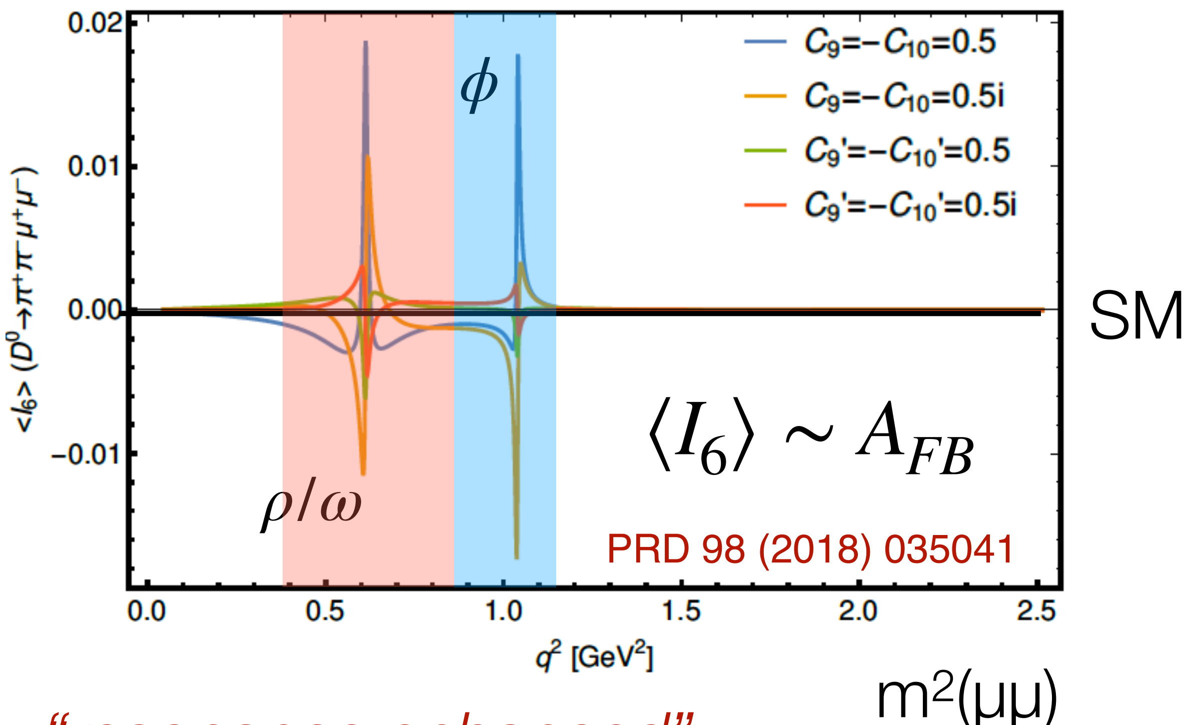
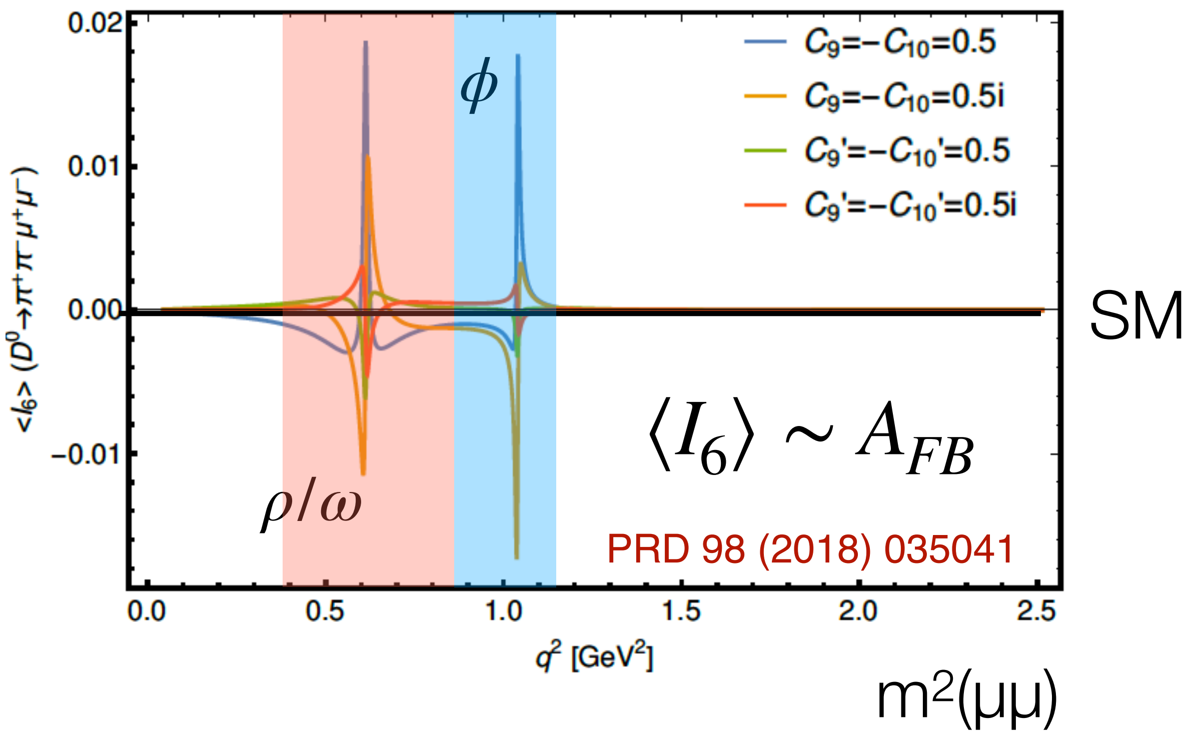
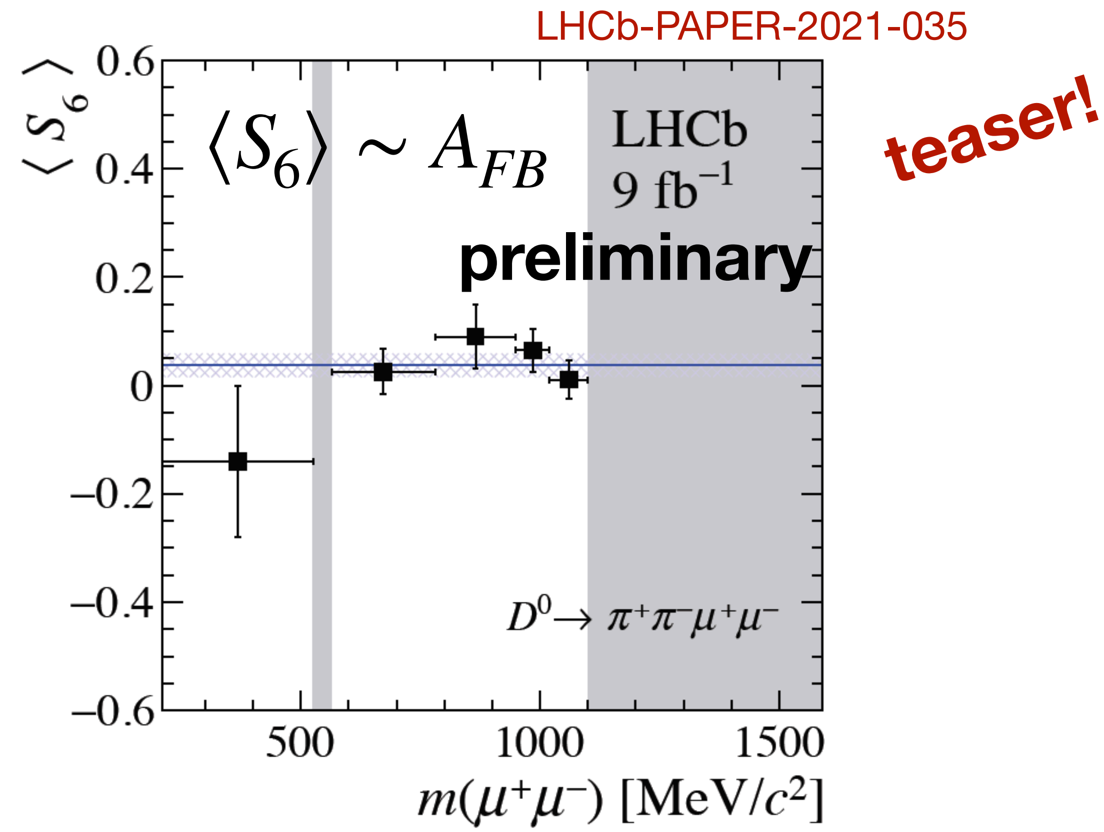


"resonance enhanced"

Angular analysis $D^0 \to h^+h^-\mu^+\mu^-$





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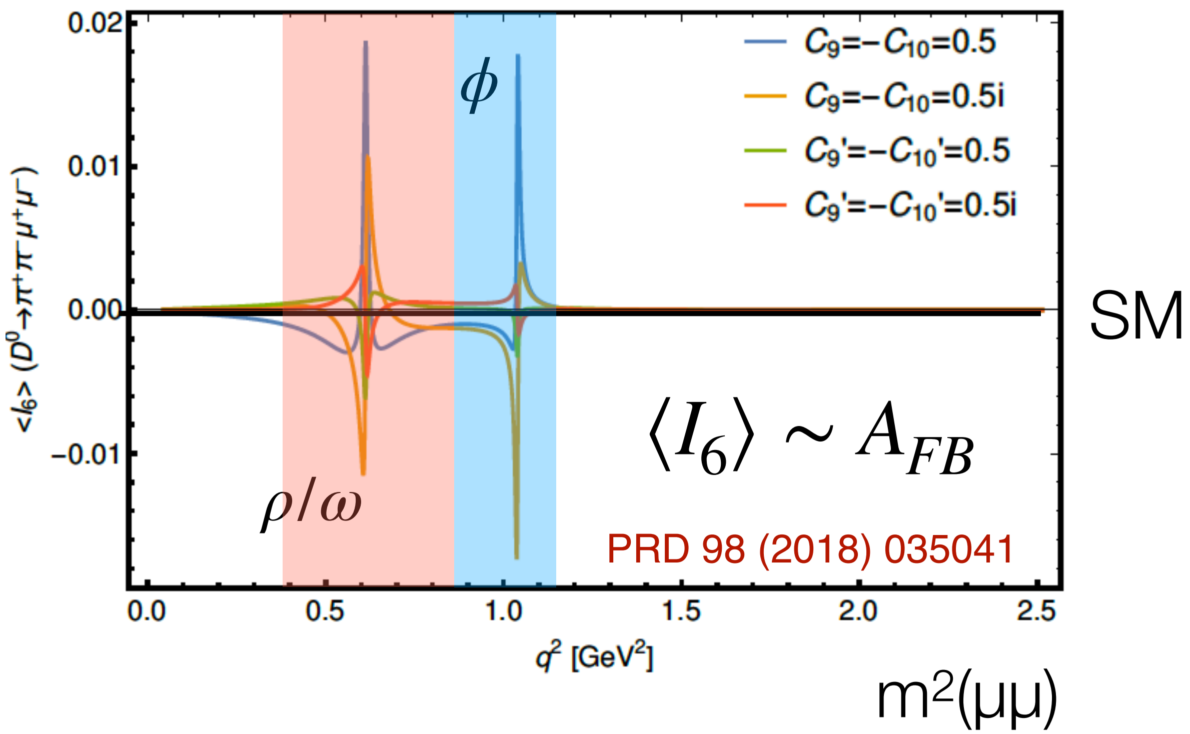
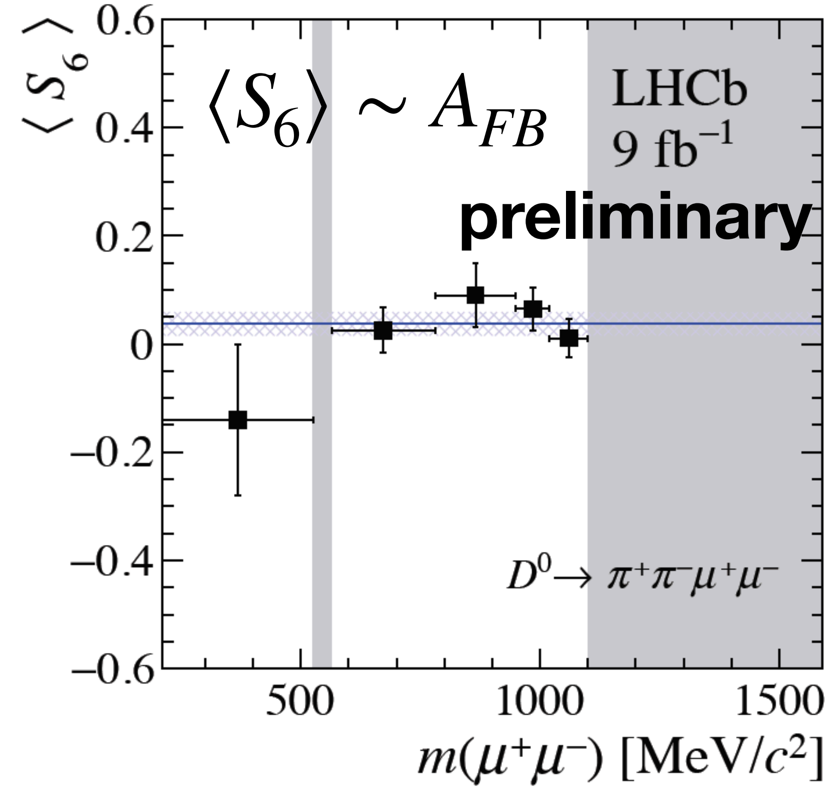
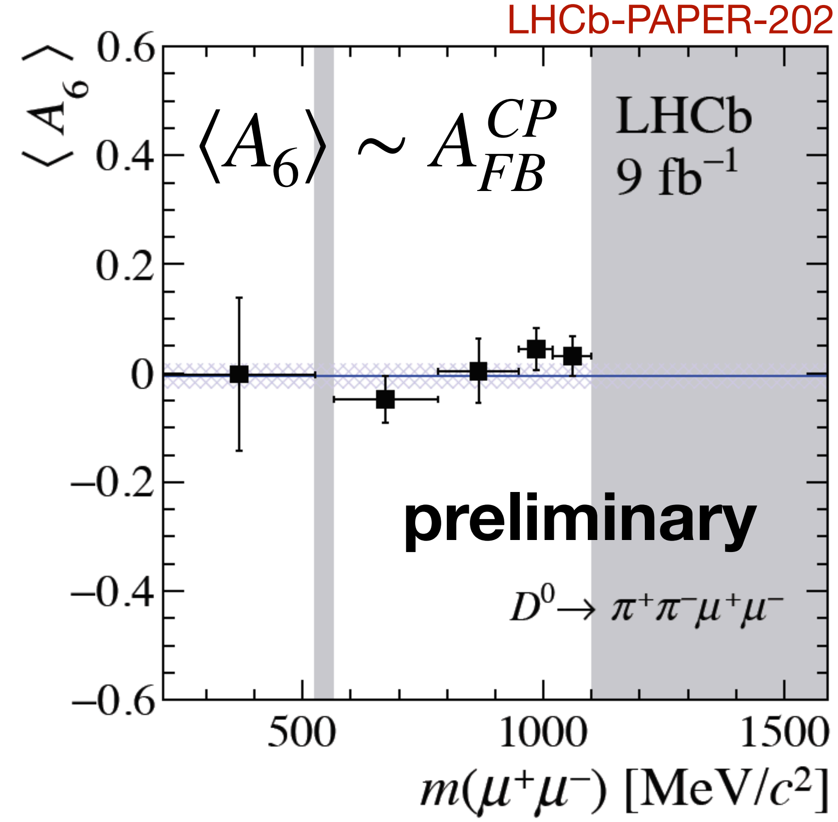


LHCb-PAPER-2021-035



teaser!

LHCb-PAPER-2021-035



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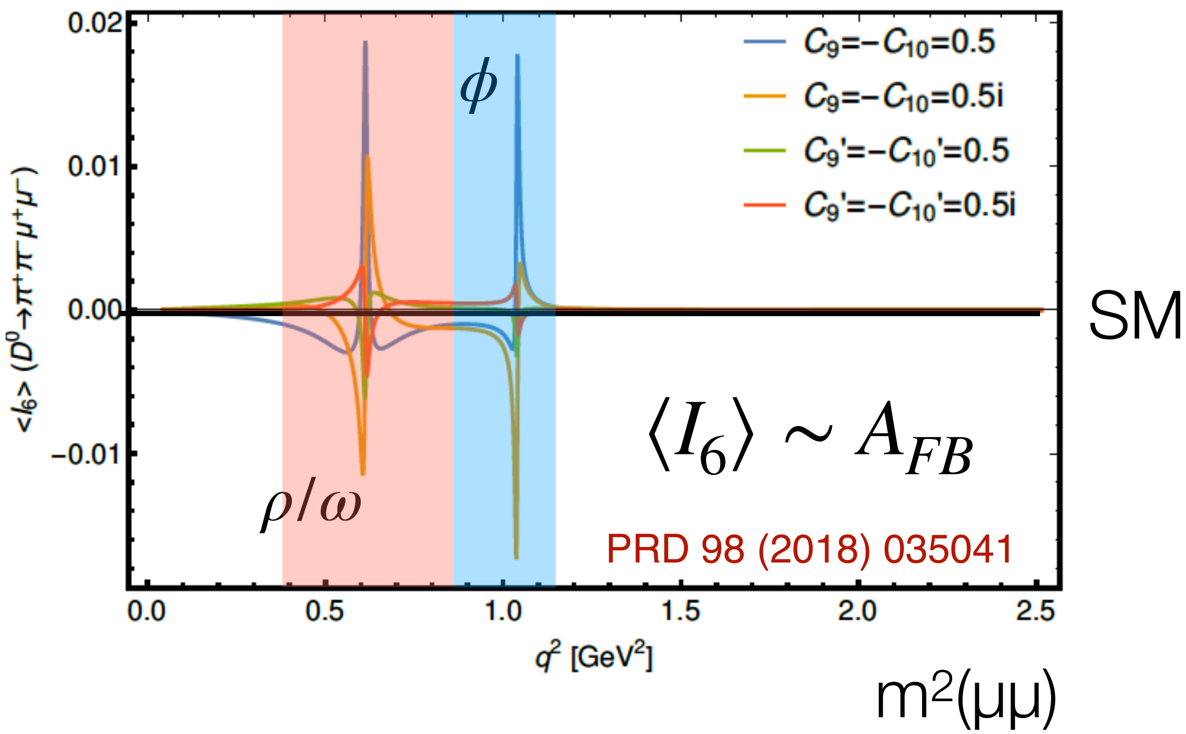
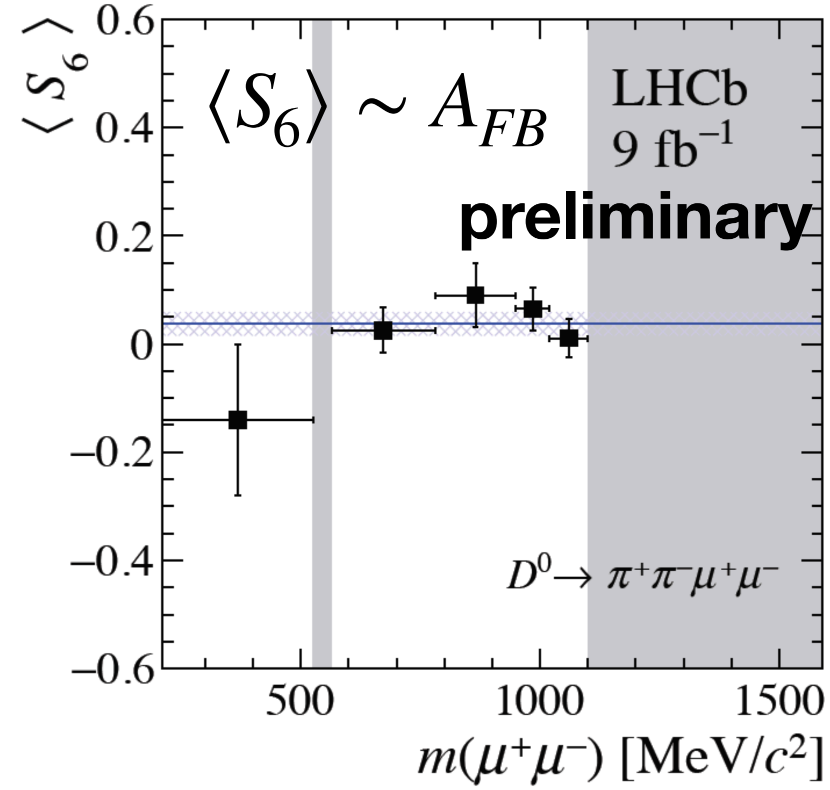


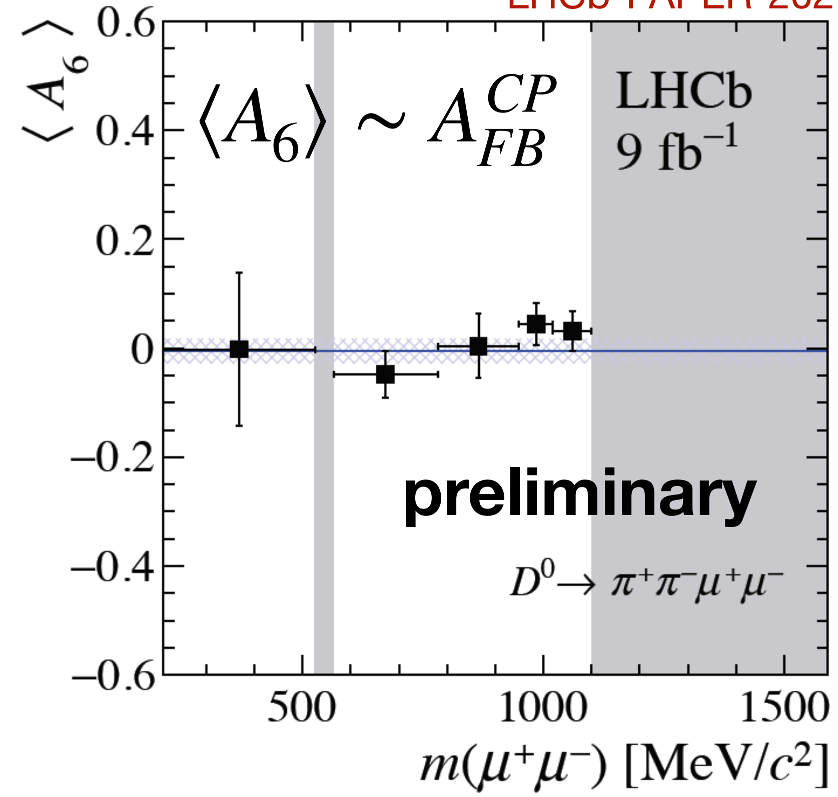
LHCb-PAPER-2021-035



teaser!

- First full angular analysis of rare charm decay ever!
- Can we make a systematic interpretation of the results?

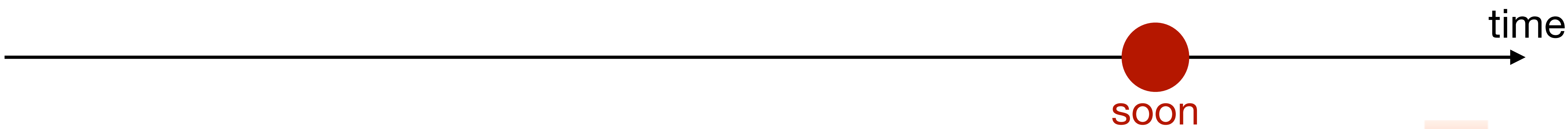
LHCb-PAPER-2021-035



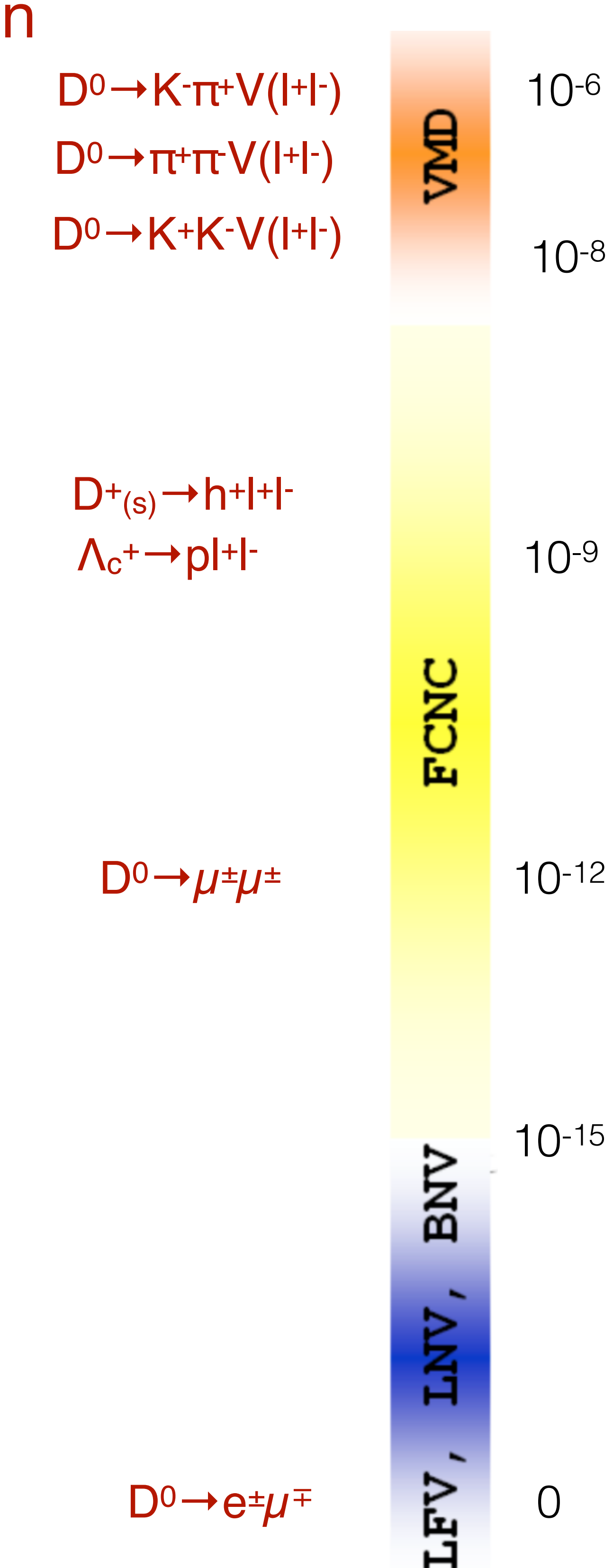
Wait for Implications Workshop to see all results!

LHCb-PAPER-2021-035 in preparation

What will come in the near future?



- Many analyses with full Run2 data in preparation/planned



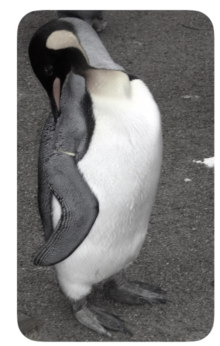
What will come in the near future?

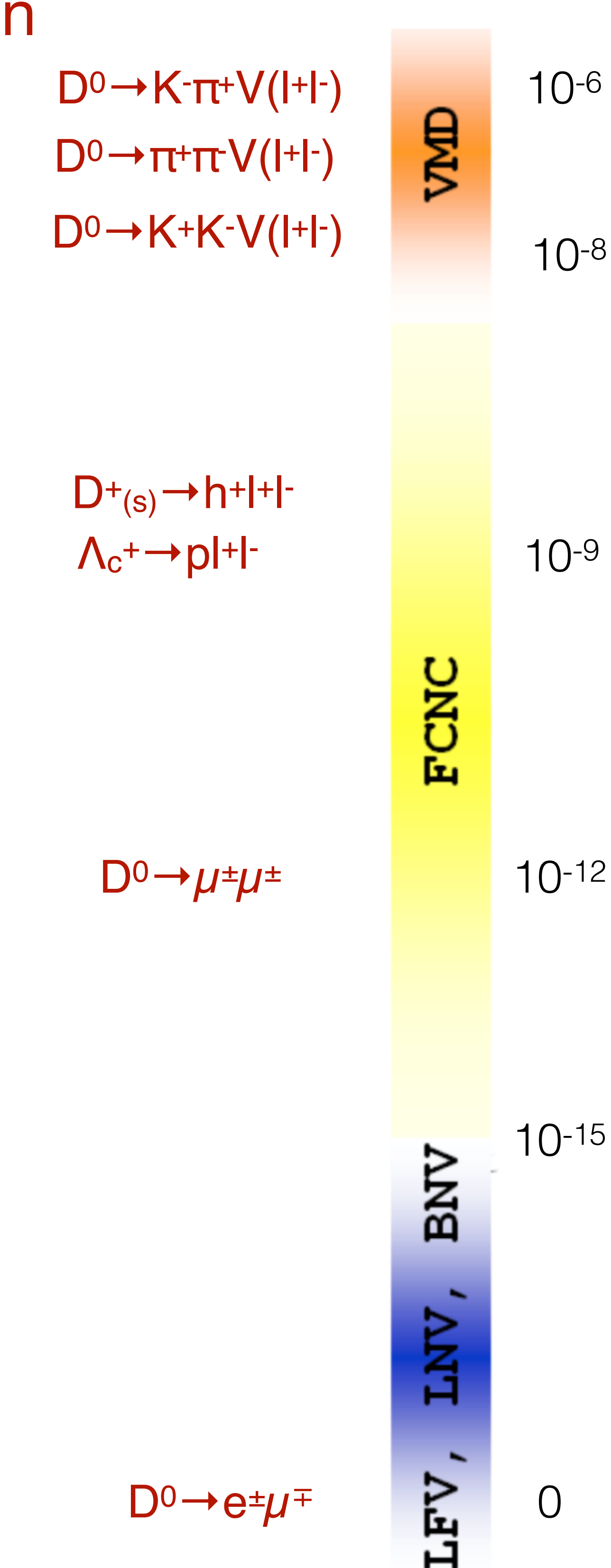
time

soon

- Many analyses with full Run2 data in preparation/planned

  - Searches for rare and forbidden decays
    - $D^0 \to \mu^+\mu^-$, $D^0 \to \mu e$ soon!
    - $D^0 \to h^+h^+\mu^+e^-$
    - $D^0 \to h^+h^+e^+e^-$ (Lepton universality!)
    - $D^+_{(s)} \to h\ell\ell^{(\prime)}$
    - $\Lambda_c \to p\ell\ell^{(\prime)}$
    - .....





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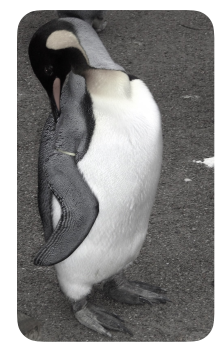
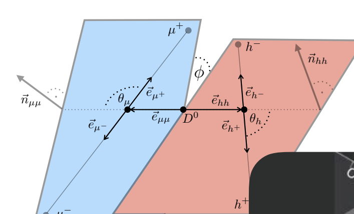
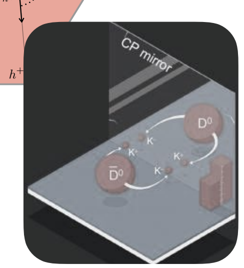


  - Angular and CP asymmetries
    - $D^0 \to V\gamma$
    - $D^+_{(s)} \to h^+\ell^+\ell^-$
    - $D^0 \to h^+h^-\mu^+\mu^-$ Implications Workshop!
    - …





$D^0 \to K^-\pi^+V(l^+l^-)$ | 10^-6
$D^0 \to \pi^+\pi^-V(l^+l^-)$
$D^0 \to K^+K^-V(l^+l^-)$ | 10^-8

$D^+_{(s)} \to h^+l^+l^-$
$\Lambda_c^+ \to pl^+l^-$ | 10^-9

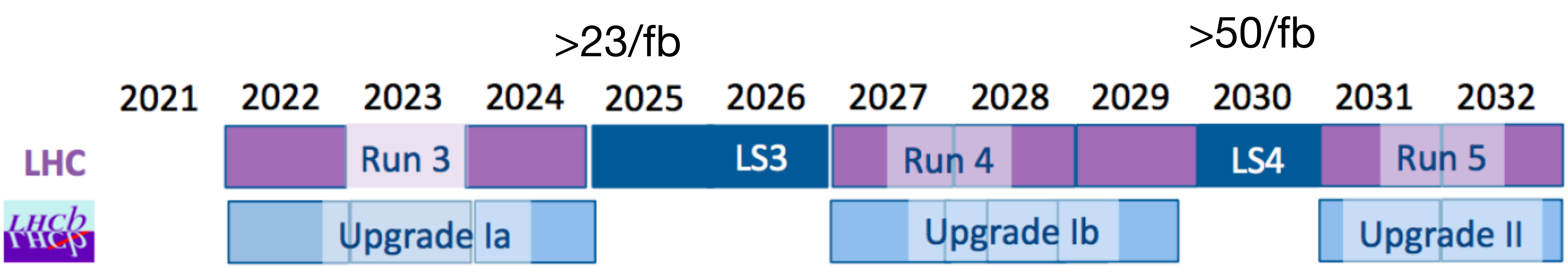
$D^0 \to \mu^\pm\mu^\pm$ | 10^-12

10^-15

$D^0 \to e^\pm\mu^\mp$ | 0

… in the (not so) near future?

- LHCb upgrade ahead with at least 5x statistics (50/fb) until 2030



LHCB-PUB-2018-009

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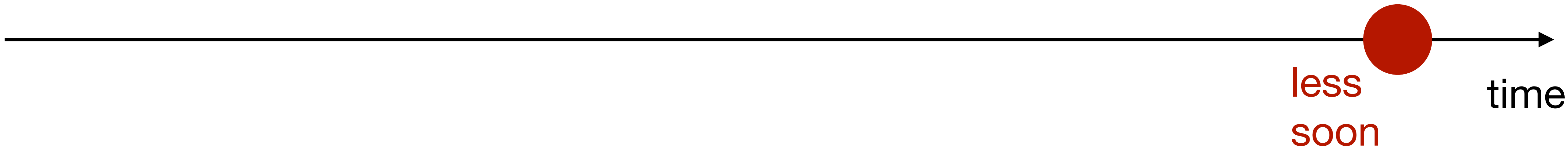

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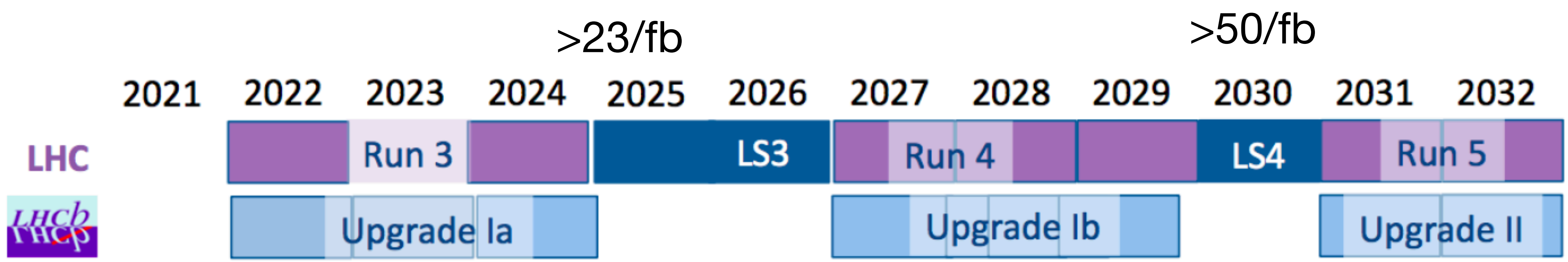

LHCB-PUB-2018-009

- Upgrade trigger design is NOW, so if there are ideas/priorities speak up!
  - $D^0 \to ee$, $D^0 \to e\tau$?
  - $D^0 \to h^+h^+\mu^-\mu^-$ with displaced $(h^+\mu^-)$ vertices?
  - $D_s^+ \to h^0h^+\mu^-\mu^-$?

Summary

dmitzel@cern.ch

- Low SM rates and unique phenomenology make the a field perfect place to look for NP

  - Complementary sensitivity wrt K and B physics, often (re)use of B physics methodology

  - Don't be afraid of LD effects! Clear SM null test allow for stringent NP searches

more in MPLA 36 (2021) 2130002

Summary

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- Low SM rates and unique phenomenology make the a field perfect place to look for NP
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more in MPLA 36 (2021) 2130002

- Great theoretical and experimental improvements over the last years
    - Still rather unexplored and promising
    - We are looking forward to pioneering the field together with Dortmund theory group
- "Charm is the new beauty… but beauty never goes out of style"

[G. Hiller@ LHCb implication workshop 2020]

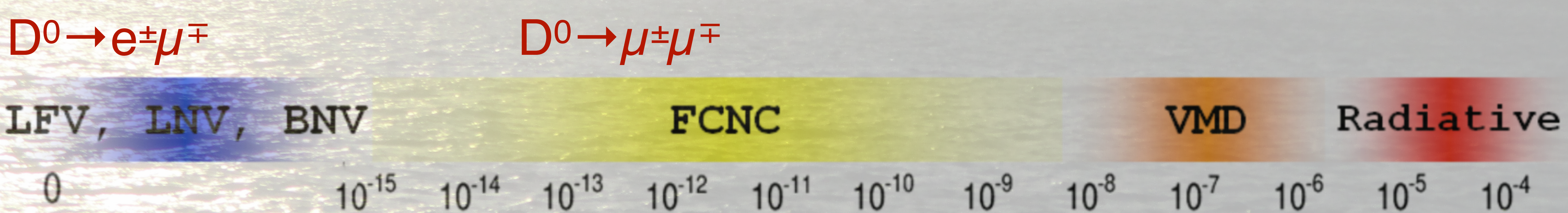
Stay tuned & wait for Implications Workshop

Thank you

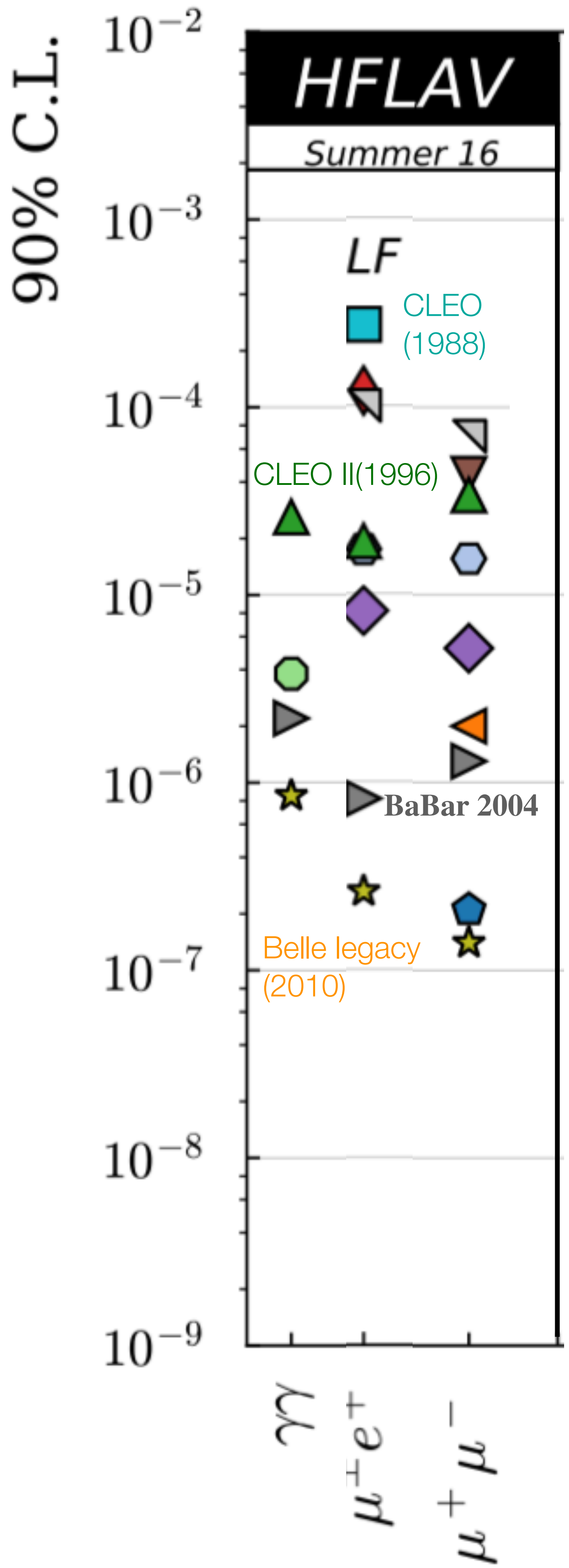
Search for forbidden and rare leptonic decays

"Search for the lepton-flavour violating decay $D^0 \to e\mu$" PLB 754 (2016) 167

"Search for the rare decay $D^0 \to \mu^+\mu^-$" PLB 725 (2013) 15-24



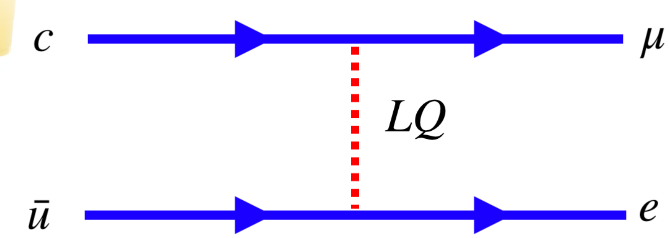
Forbidden and rare leptonic decays



$D^0 \rightarrow e^{\pm}\mu^{\mp}$

- strictly forbidden in the SM
  - any signal clear indication of NP
  - SM extensions: BF in [10^{-14}-10^{-6}]

clean null test!



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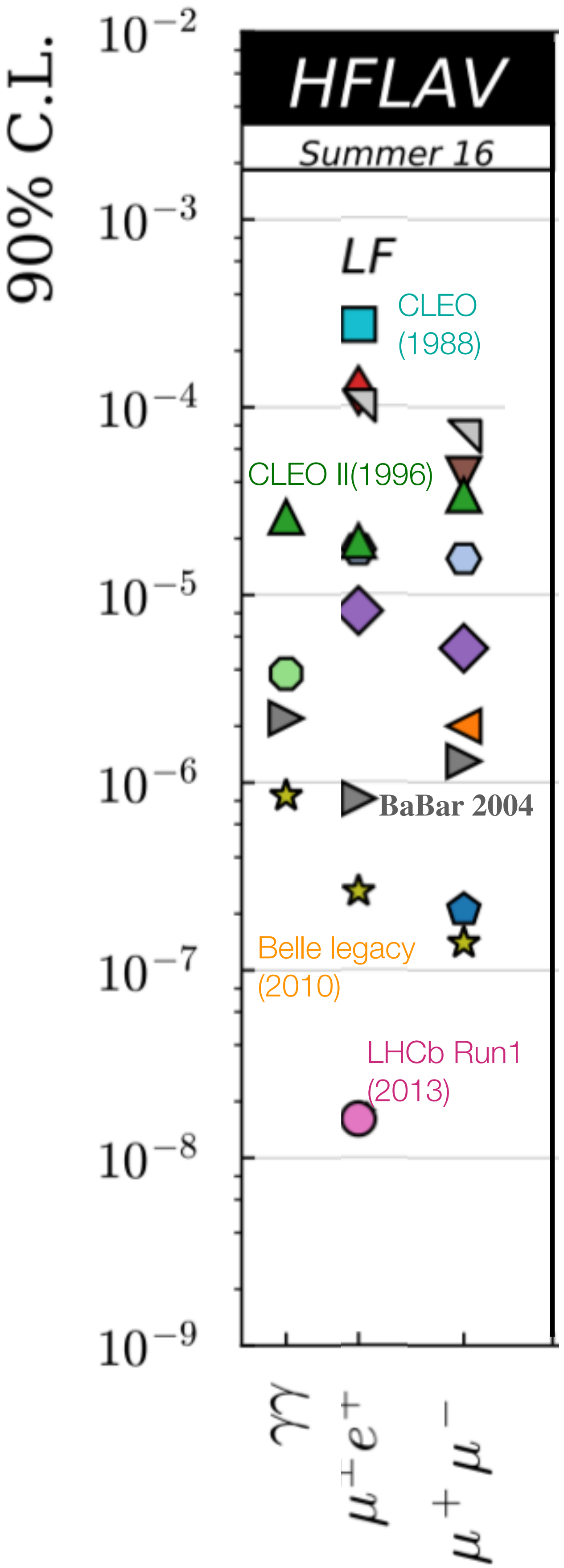

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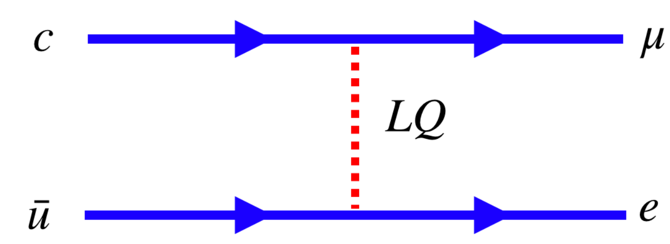
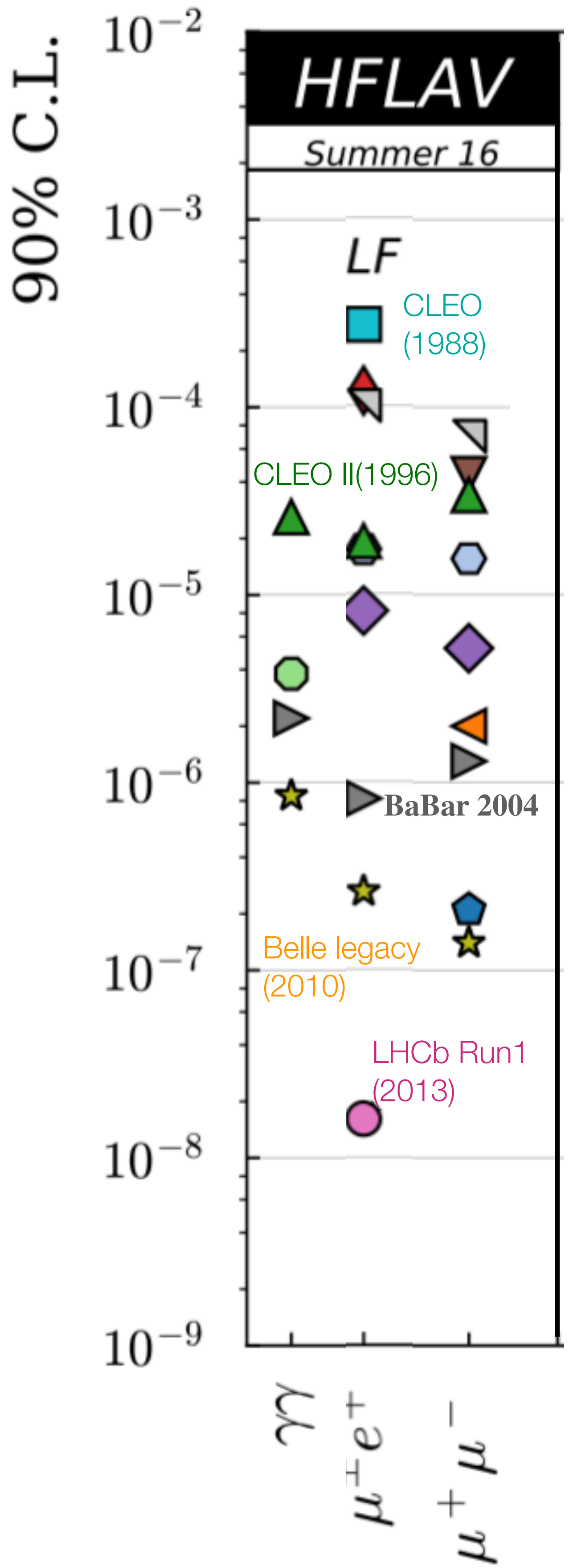


$$\mathcal{B}(D^0 \rightarrow e^{\pm}\mu^{\mp}) < 1.3 \times 10^{-8} \text{ at } 90\% \text{ CL}$$

(LHCb 3/fb Run1)

PLB 754 (2016) 167

Forbidden and rare leptonic decays



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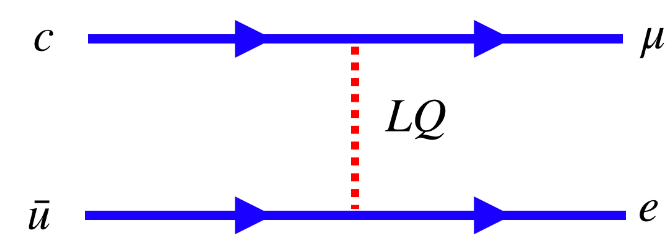

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PLB 754 (2016) 167

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- SM BF extremely low, dominated by two-photon intermediate state ~O(10^{-13})

PRD 66 (2002) 014009
PRD 79 (2009) 114030
PRD 82 (2010) 094006
PRD 93 (2016) 074001

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PLB 725 (2013) 15-24

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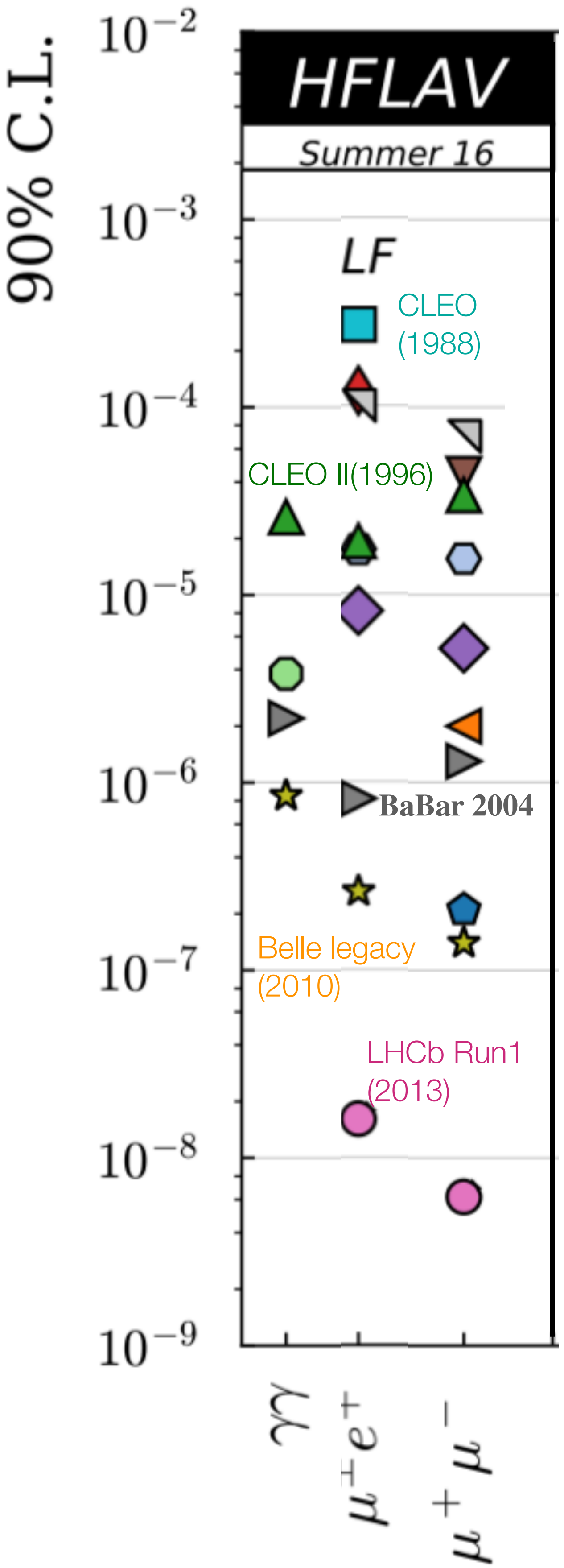

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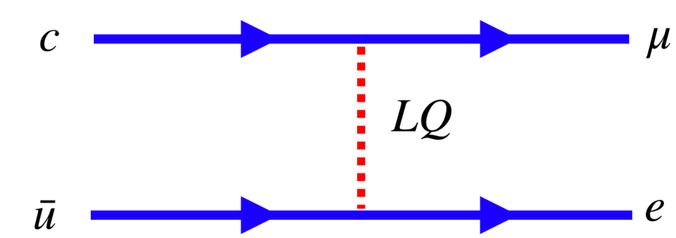

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PLB 725 (2013) 15-24

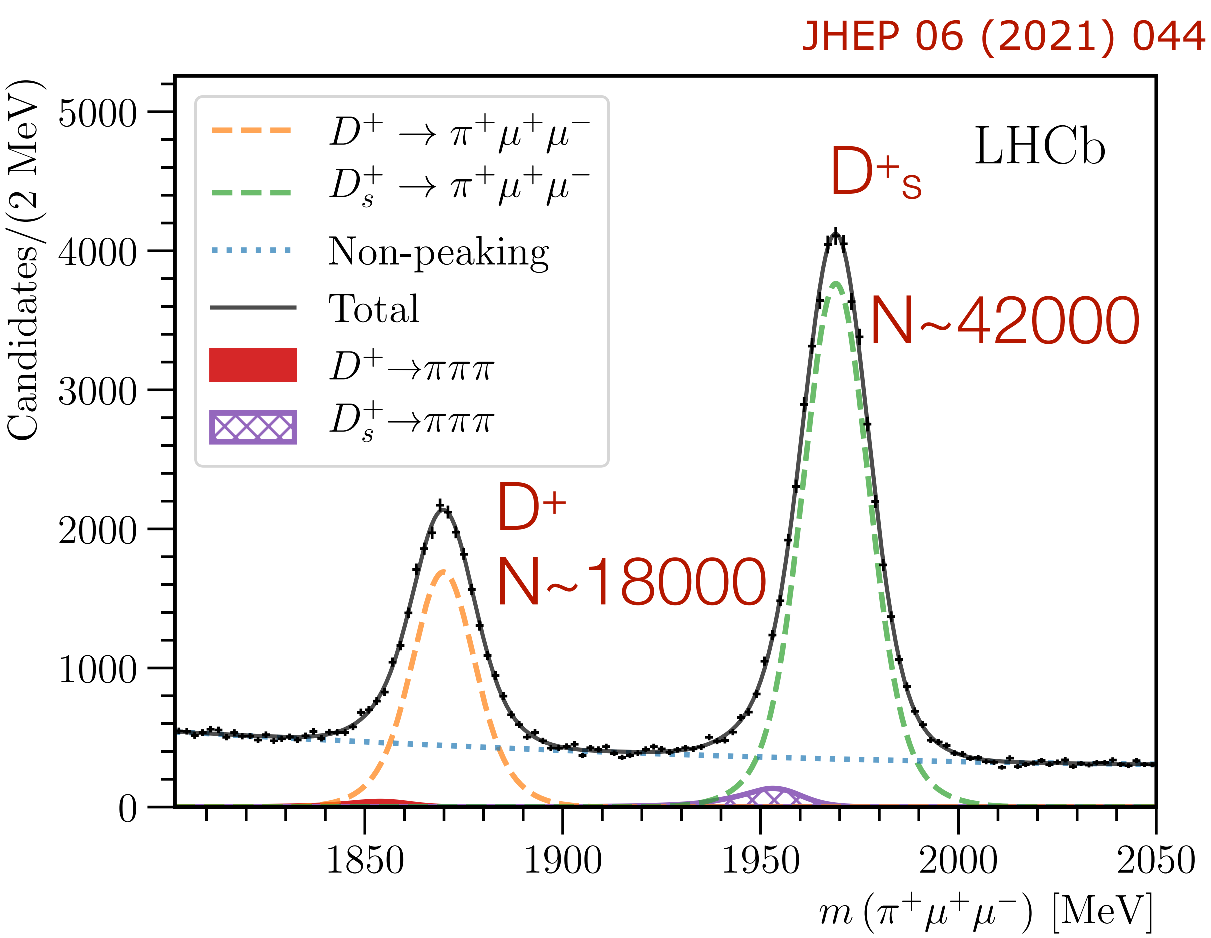
$$\mathcal{B}(D^0 \rightarrow \mu^+\mu^-) < 6.2 \times 10^{-9} \text{ at } 90\% \text{ CL}$$

(LHCb 1/fb Run1)

update in the pipeline with full LHCb data set

Search for the rare decays D→ hl±l(')∓

- analysis uses 1.6/fb data collected 2016
- normalisation modes $D^+_{(s)} \to \pi\phi[\ell^+\ell^-]$



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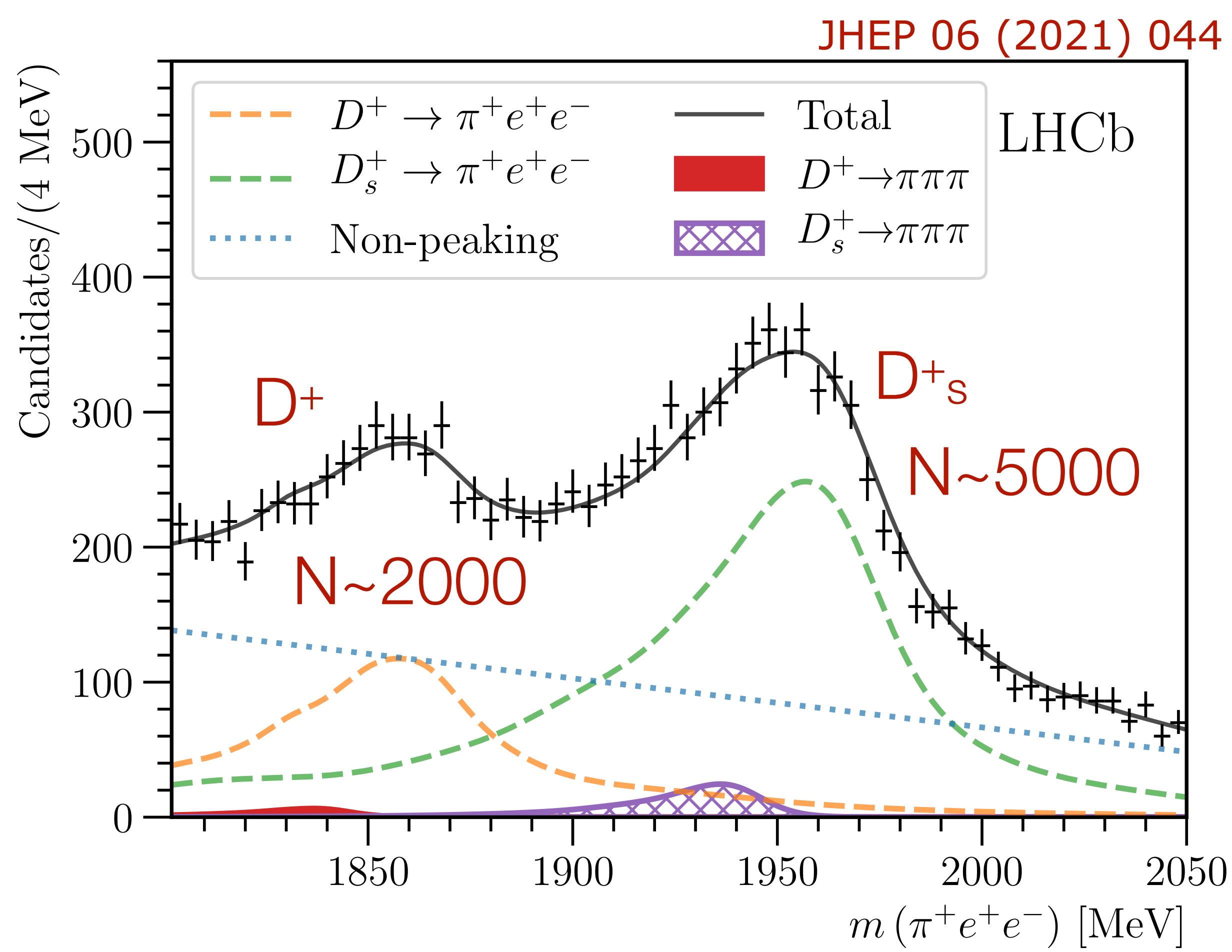
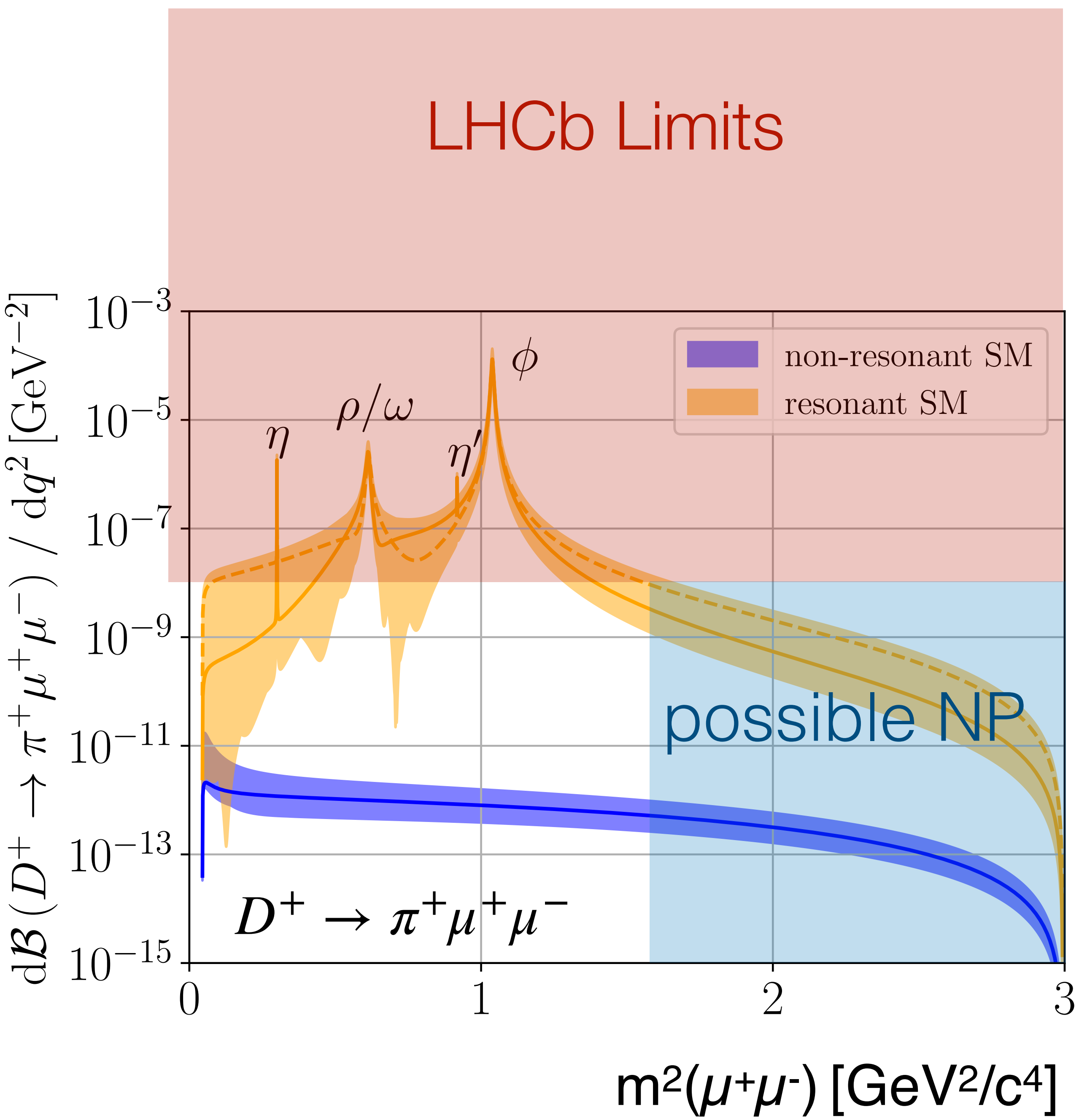
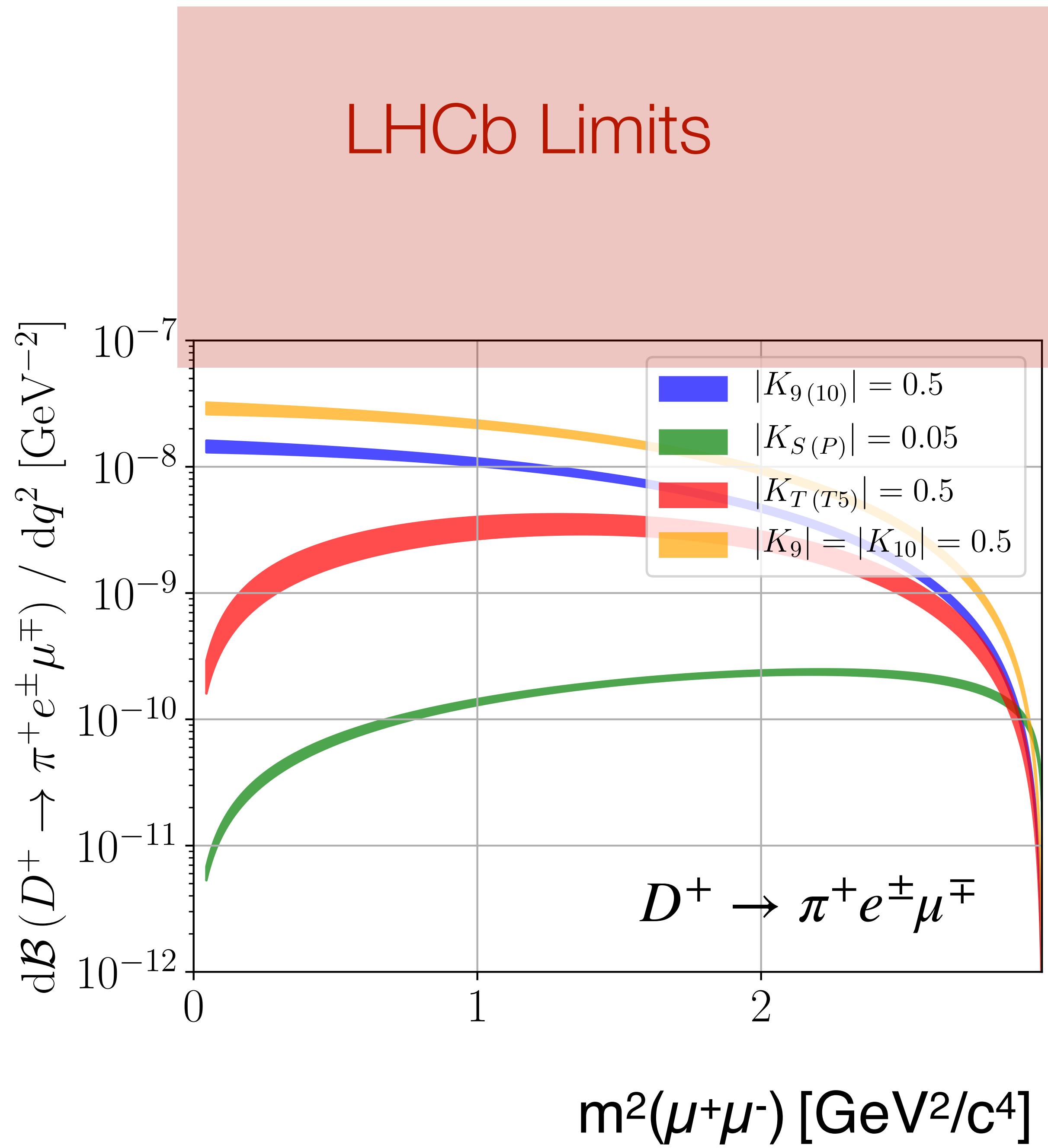


$D^+_{(s)} \to \pi\phi[e^+e^-]$

Search for the rare decays $D \rightarrow hl^{\pm}l^{(')\mp}$



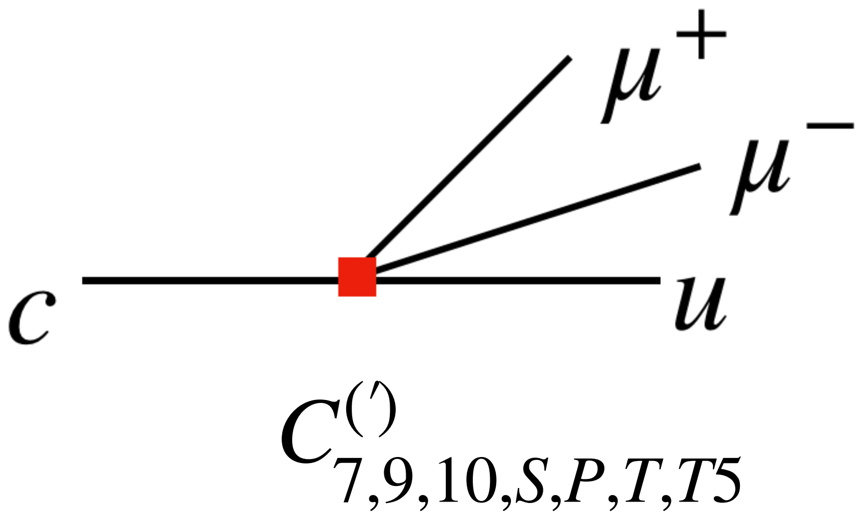


- We are coming close to possible NP contributions…
- … but also close to the resonance tails

Implications of the measurements

- Use measurement to set limits on effective NP couplings

$$H_{eff} \sim \sum C_i \cdot \mathcal{O}_i \qquad C_{10,S,P,T,T5} \overset{\text{SM}}{=} 0$$



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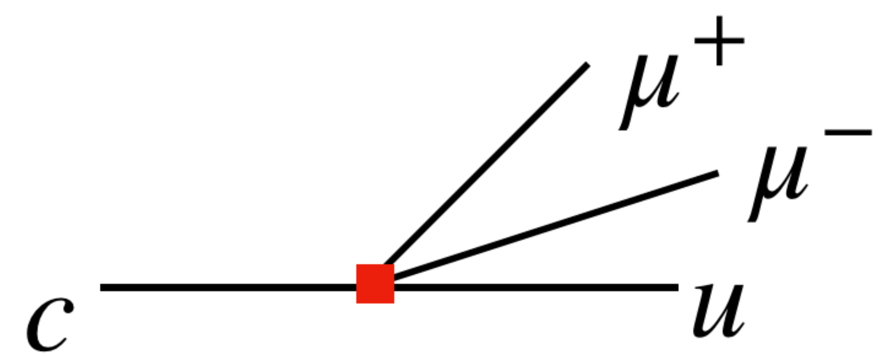

$C^{(\prime)}_{7,9,10,S,P,T,T5}$

- right handed quark currents

$C_i \to C_i'$ negligible in SM

- LFV possible

$C_i \to K_i^{\ell\ell'}$ absent in SM

- We need many decays to constrain all couplings!

$\mathcal{B}(D \to \ell\ell) \sim C_P, C_S$

$\mathcal{B}(D \to h\ell\ell) \sim C_i + C_i'$

$\mathcal{B}(D \to hhe\mu') \sim K_i^{e\mu} - K_i^{\prime e\mu}$

we work on this!

example:

$$|C_{9,10}^{\mu\mu\,(\prime)}| \lesssim 1\,, \quad |C_{9,10}^{ee\,(\prime)}| \lesssim 3\,,$$

comparable to B physics at least 10 years ago

Future sensitivities

Mode	Upgrade ($50\,\mathrm{fb}^{-1}$)	Upgrade II ($300\,\mathrm{fb}^{-1}$)
$D^0 \to \mu^+\mu^-$	4.2×10^{-10}	1.3×10^{-10}
$D^+ \to \pi^+\mu^+\mu^-$	10^{-8}	3×10^{-9}
$D_s^+ \to K^+\mu^+\mu^-$	10^{-8}	3×10^{-9}
$\Lambda \to p\mu\mu$	1.1×10^{-8}	4.4×10^{-9}
$D^0 \to e\mu$	10^{-9}	4.1×10^{-9}

Mode	Upgrade ($50\,\mathrm{fb}^{-1}$)	Upgrade II ($300\,\mathrm{fb}^{-1}$)
$D^+ \to \pi^+\mu^+\mu^-$	0.2%	0.08%
$D^0 \to \pi^+\pi^-\mu^+\mu^-$	1%	0.4%
$D^0 \to K^-\pi^+\mu^+\mu^-$	0.3%	0.13%
$D^0 \to K^+\pi^-\mu^+\mu^-$	12%	5%
$D^0 \to K^+K^-\mu^+\mu^-$	4%	1.7%

A. Contu, Towards the Ultimate Precision in Flavour Physics, Durham, United Kingdom, 2 - 4 Apr 2019