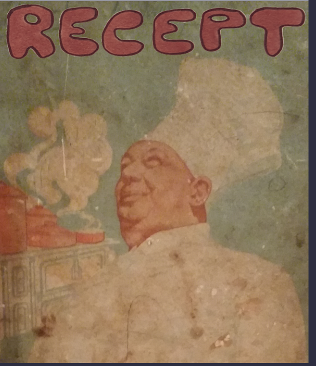


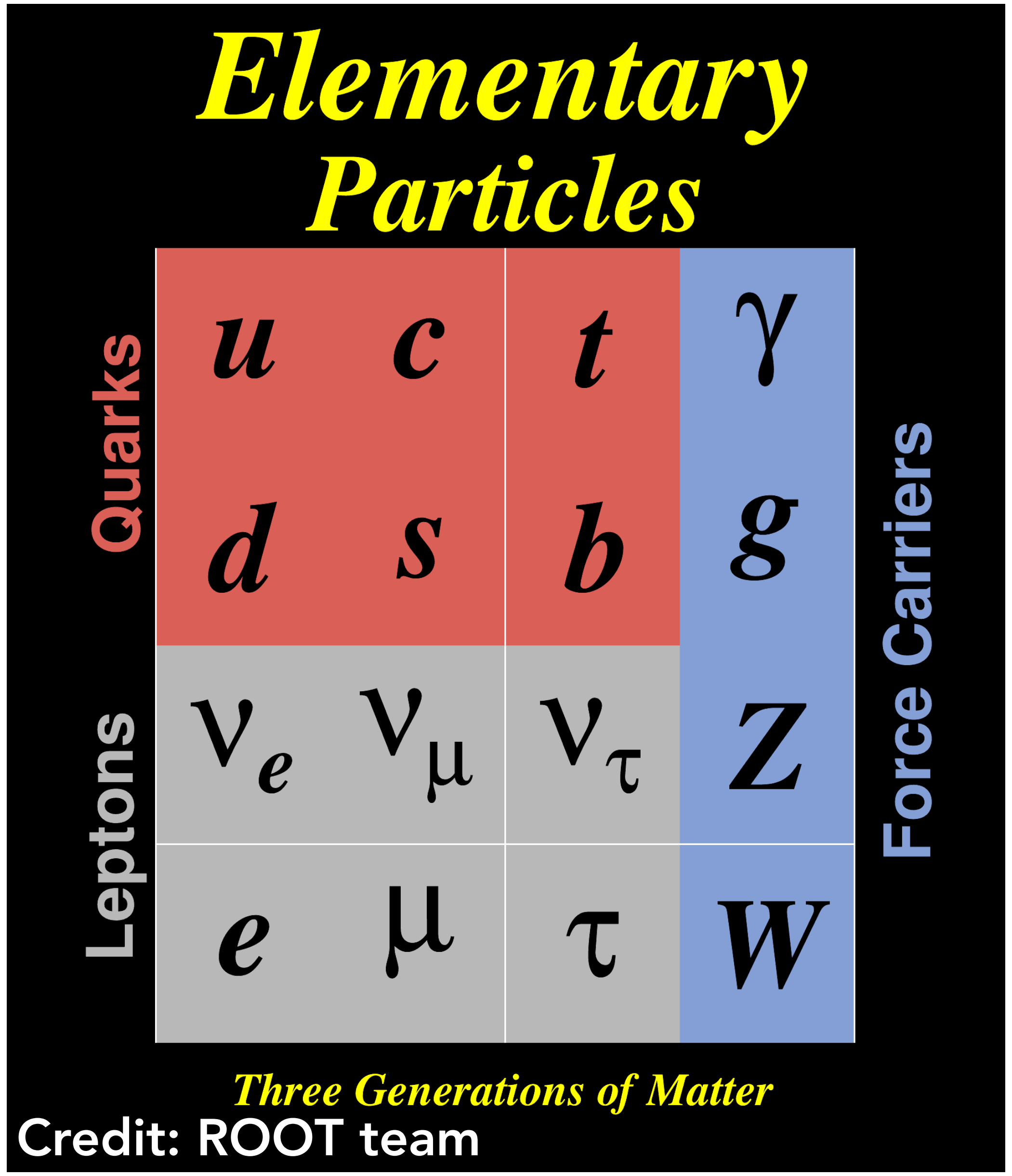
Overview of quark flavour results

Vladimir V. Gligorov, CNRS/LPNHE

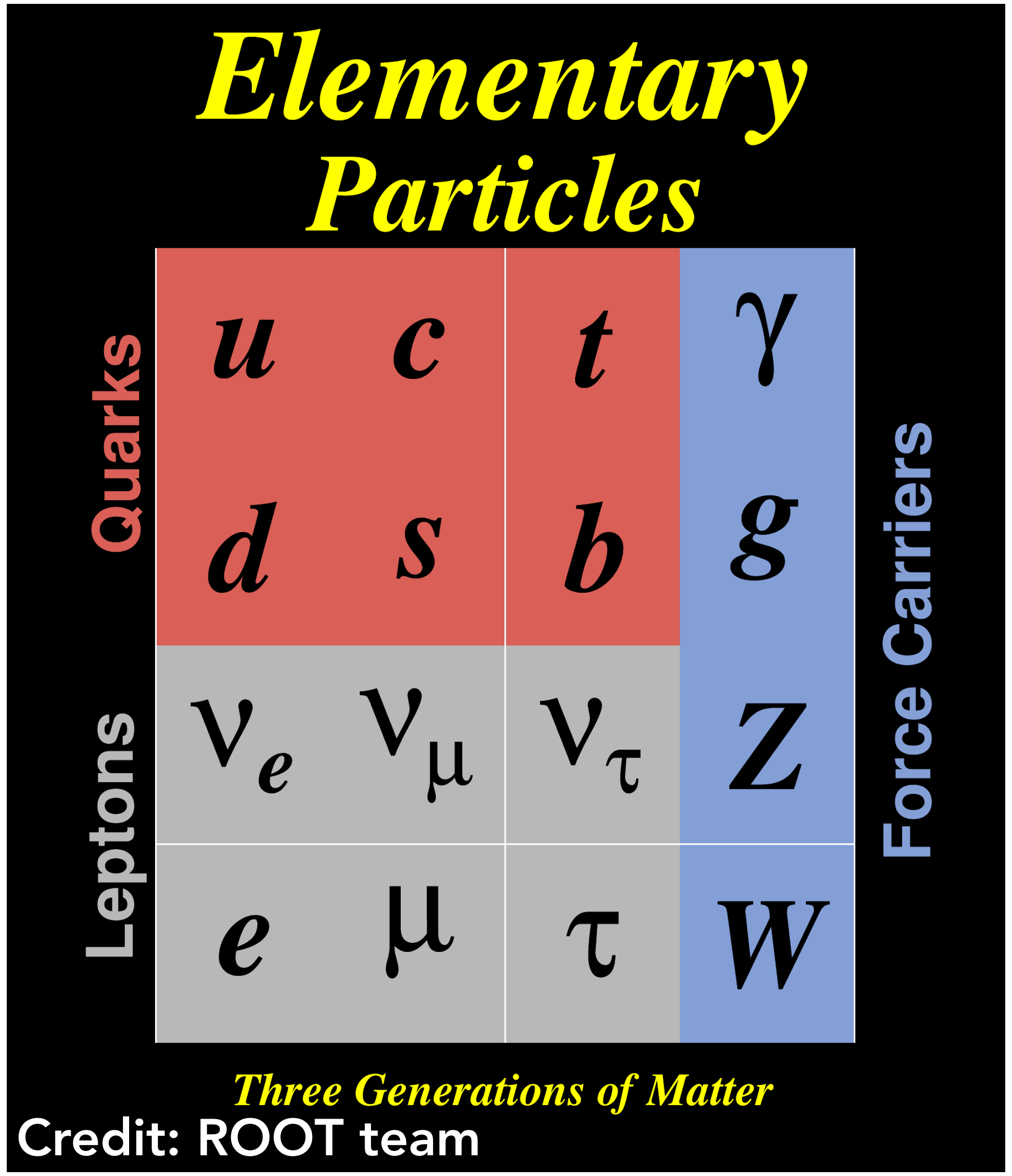
With material from the LHCb, CMS, ATLAS, BES III, NA62, BaBar, Belle & Belle II experimental collaborations & the HFLAV, CKMFitter, and UTFit averaging groups

ICHEP 2022, Bologna, 12.07.2022

Object of study

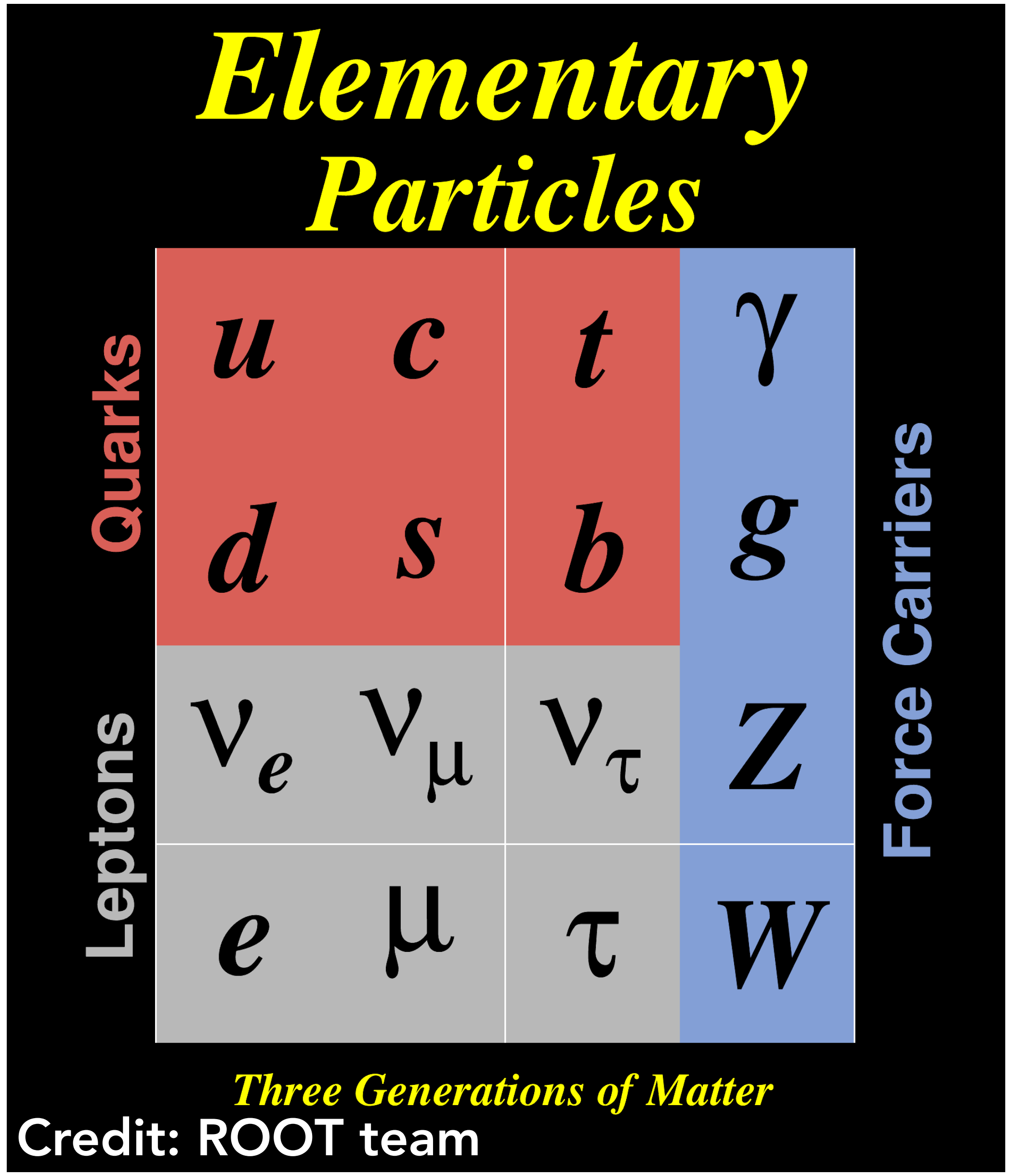


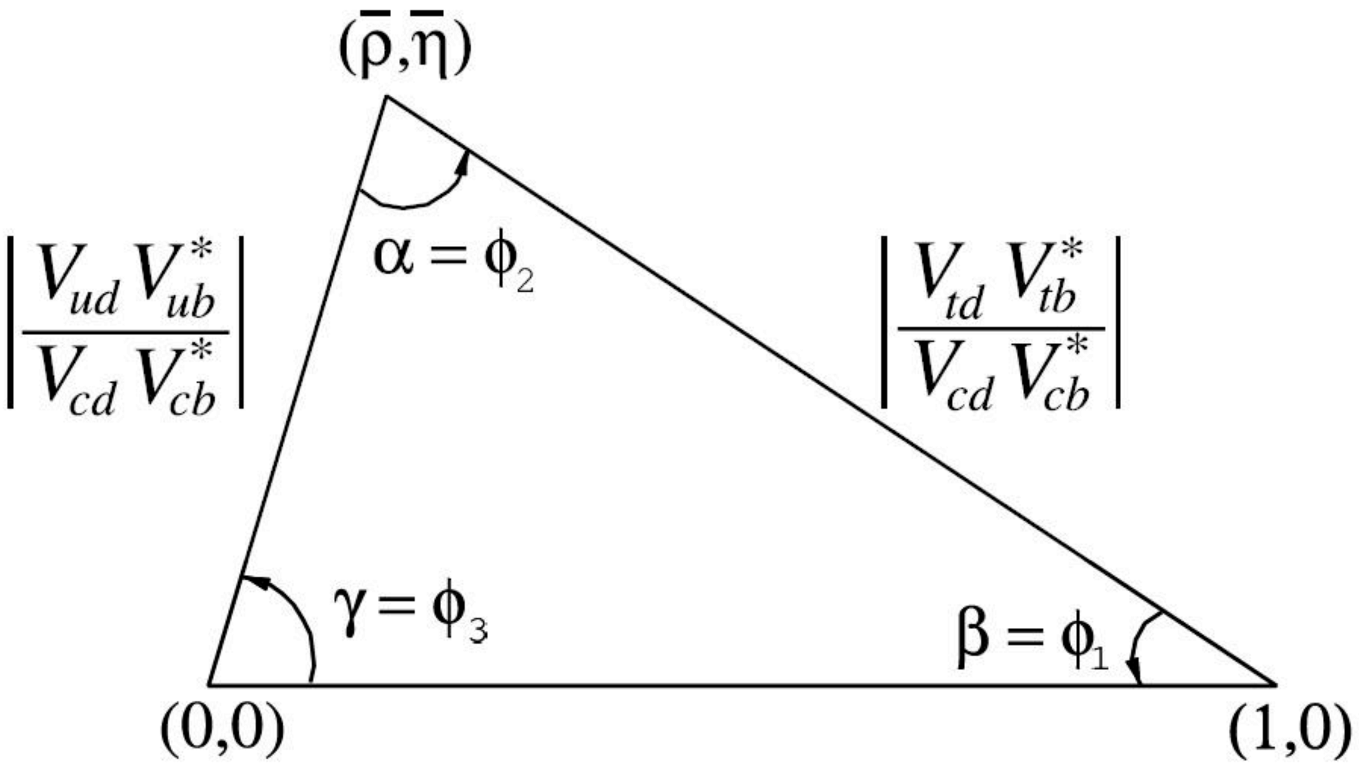
Object of study



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

Object of study

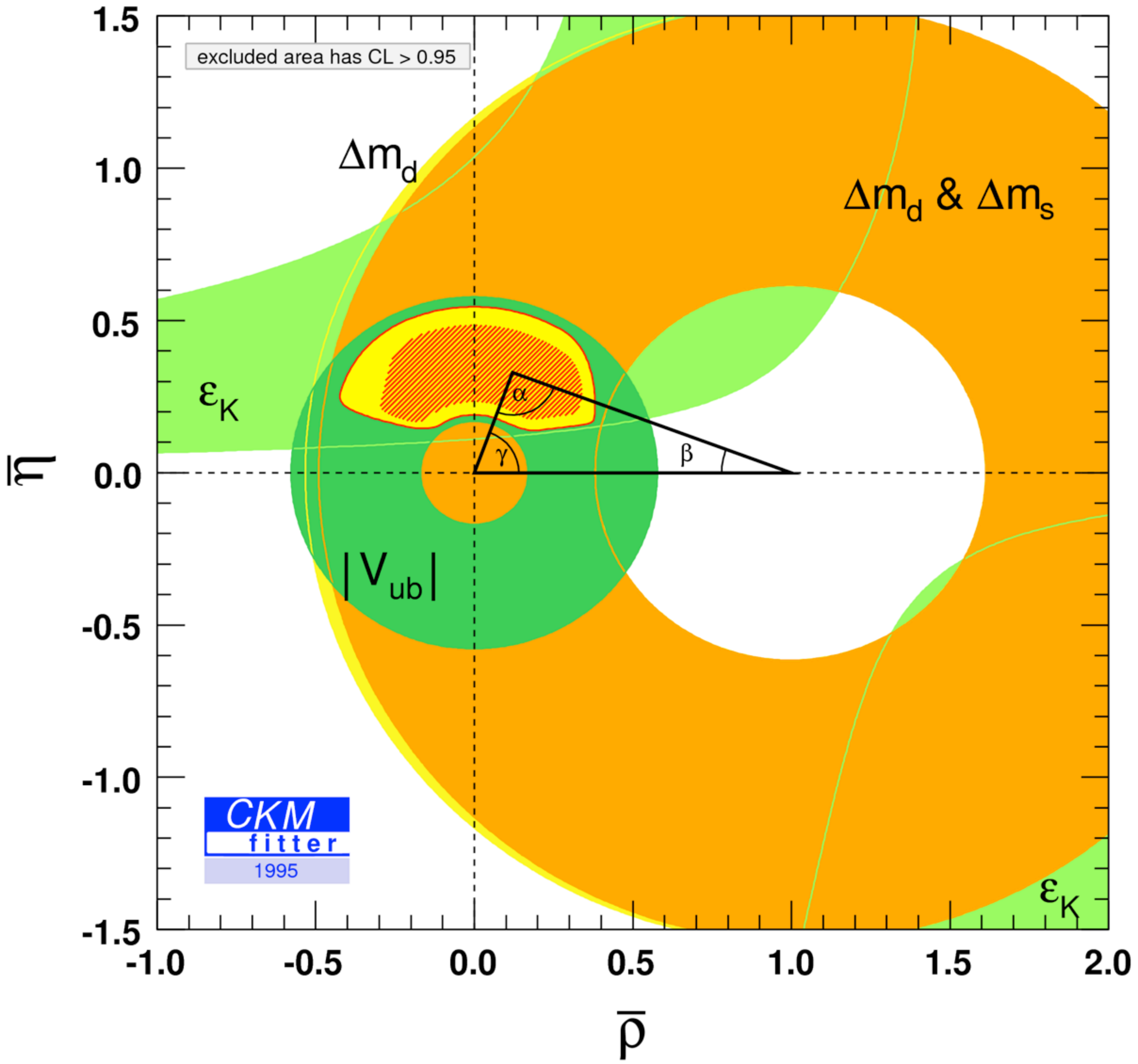




Mapping the apex

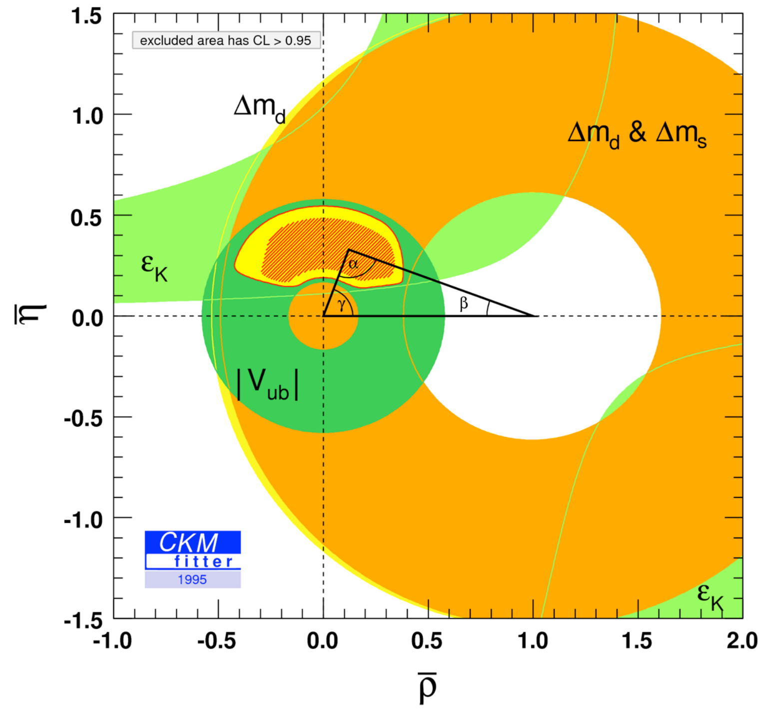
Berwyn mountain,
Wales

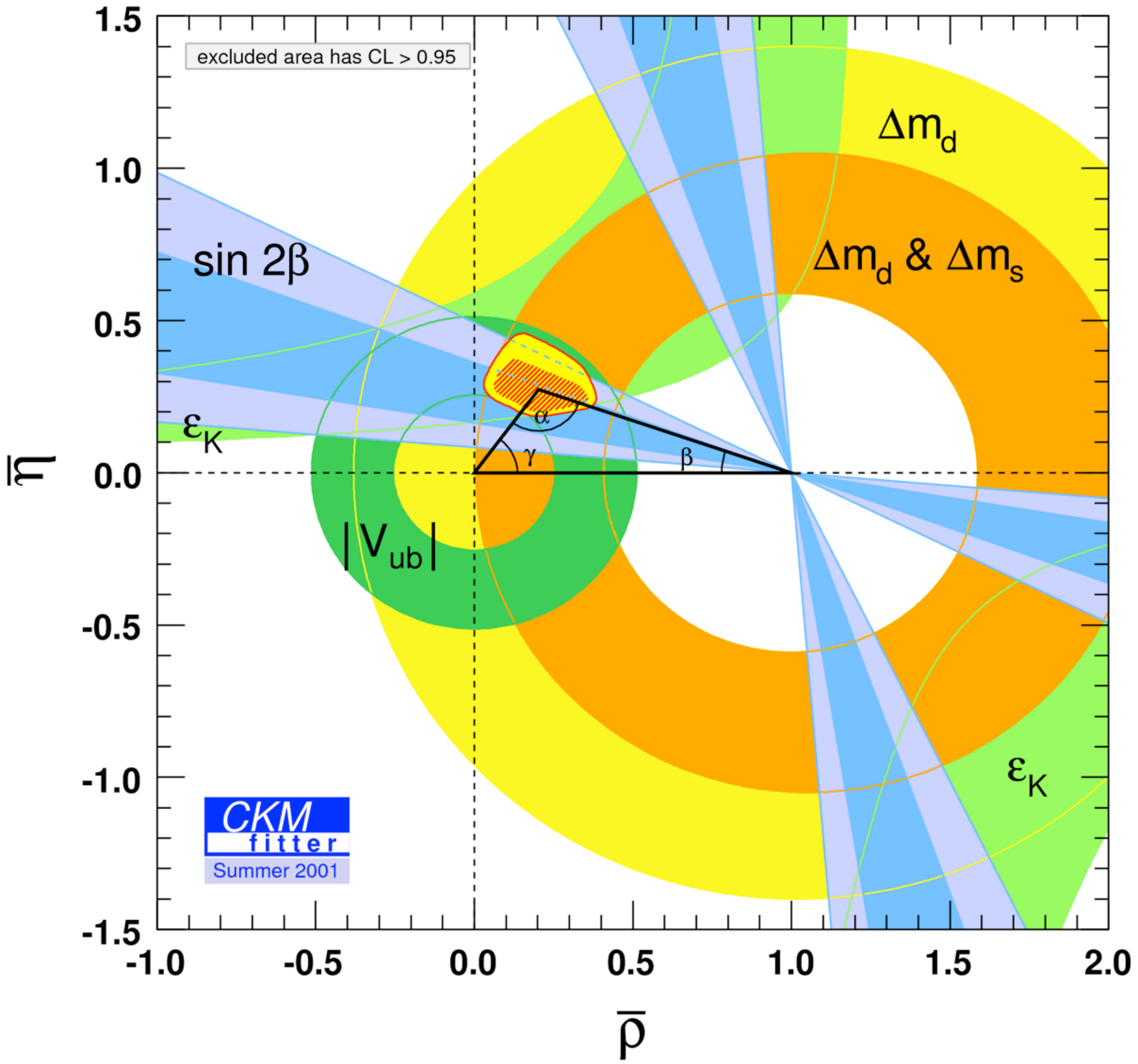
Three decades of immense progress…



Three decades of immense progress…

1995





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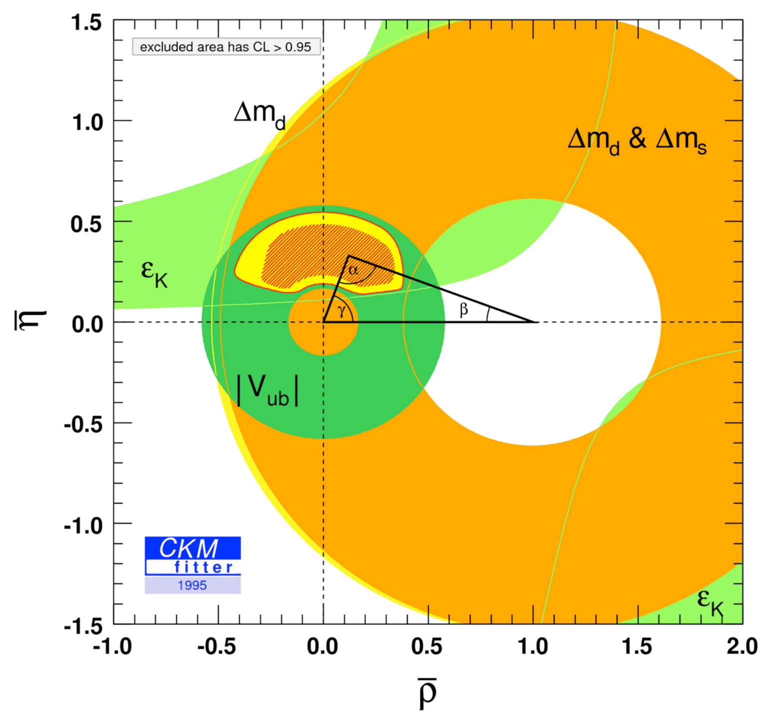

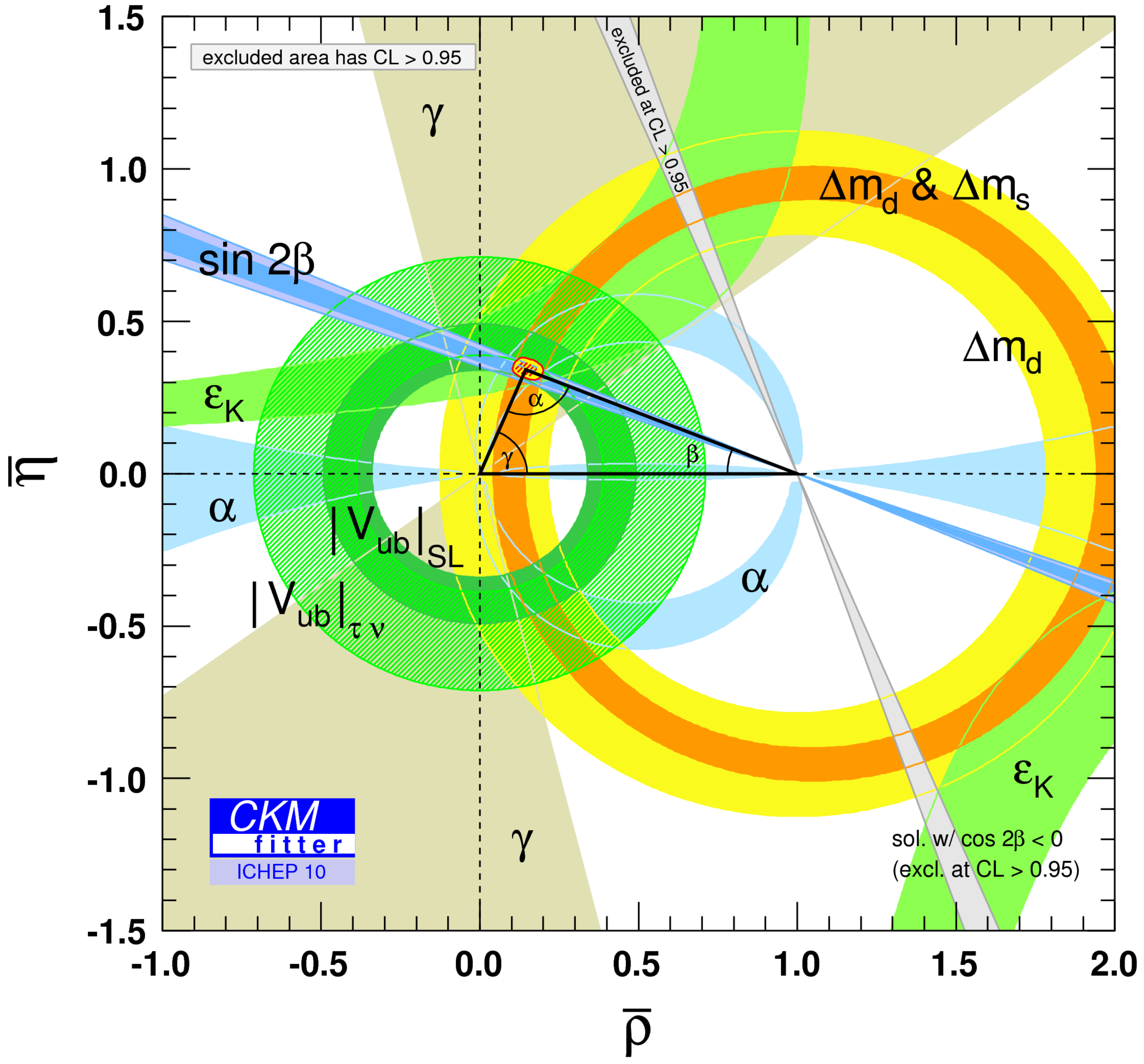

Three decades of immense progress…

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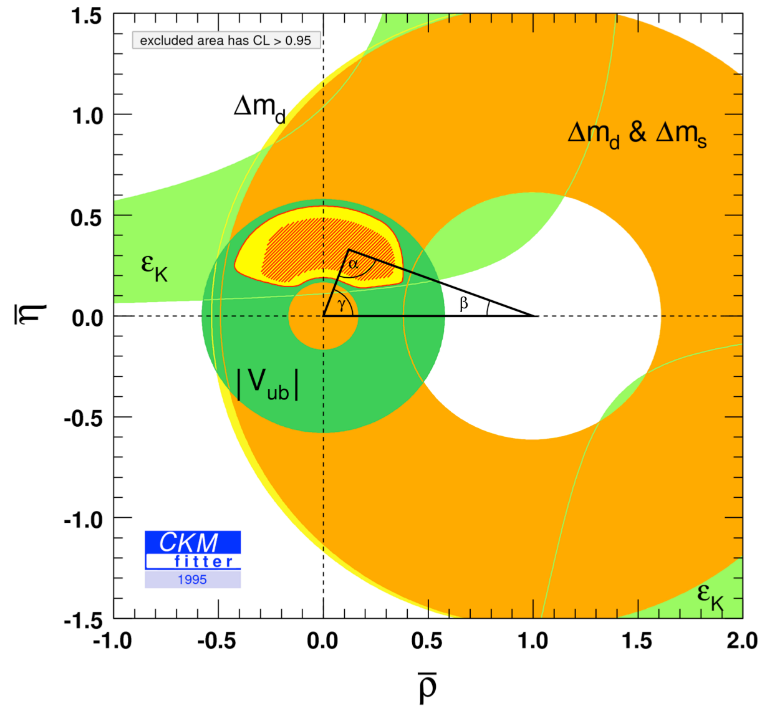
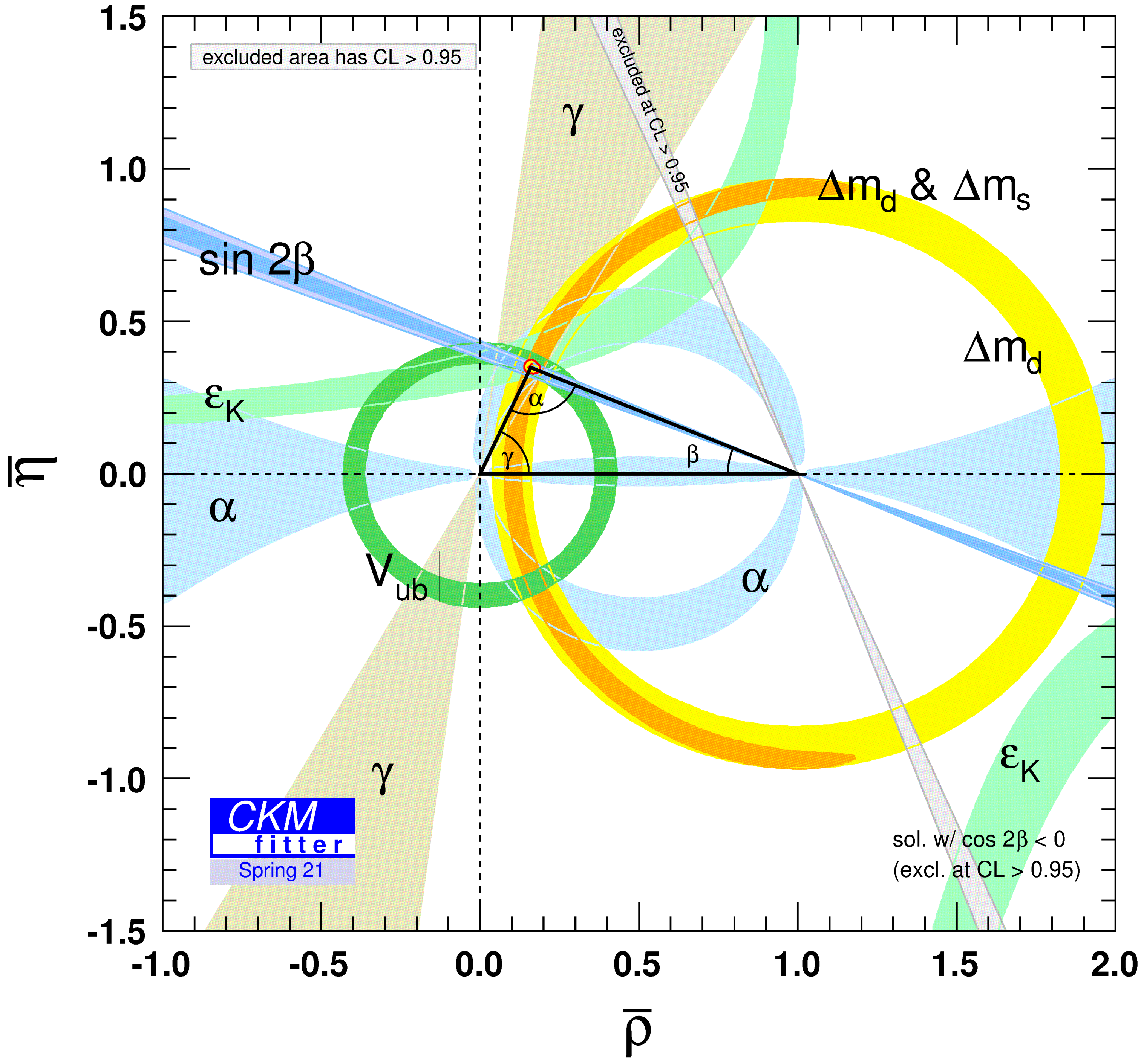
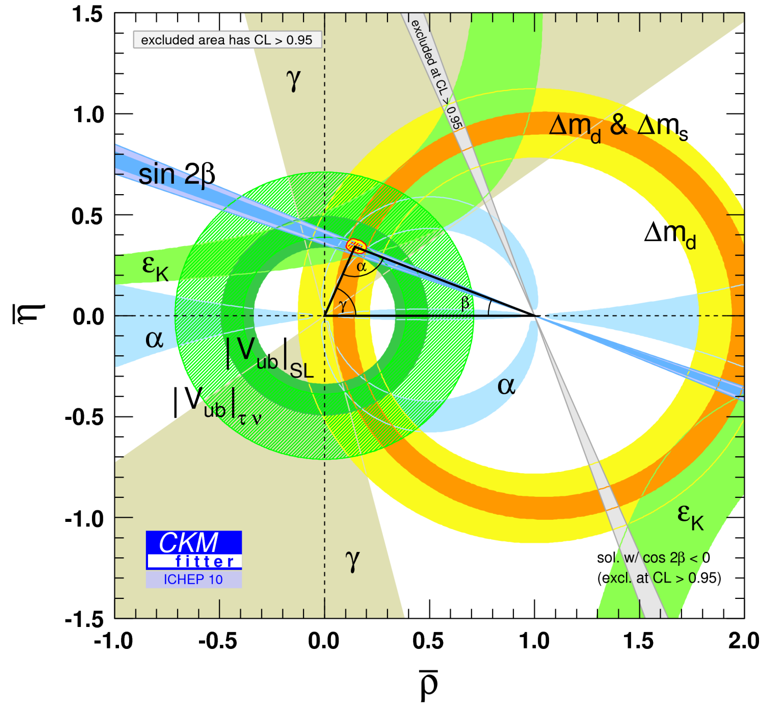
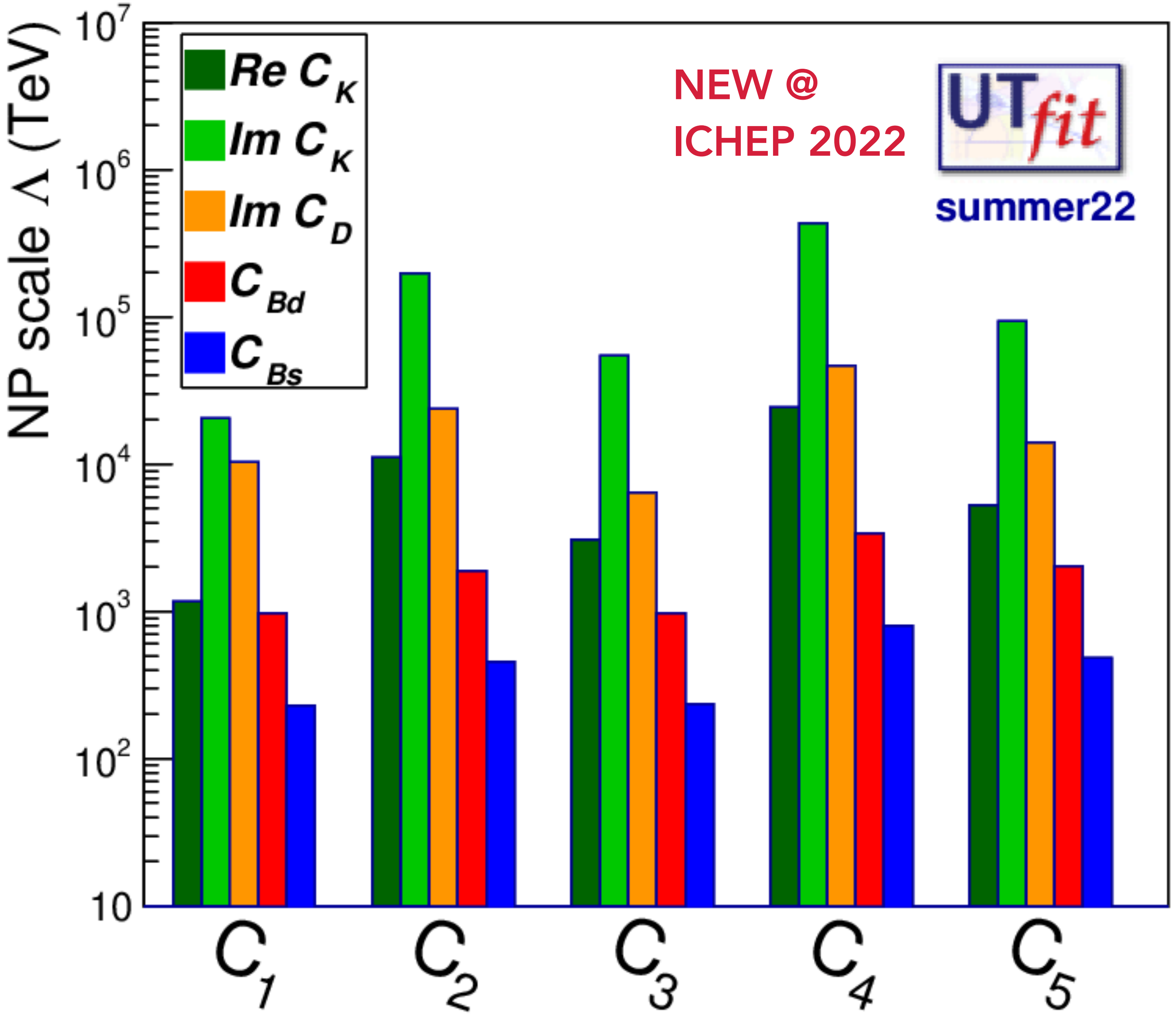




2010

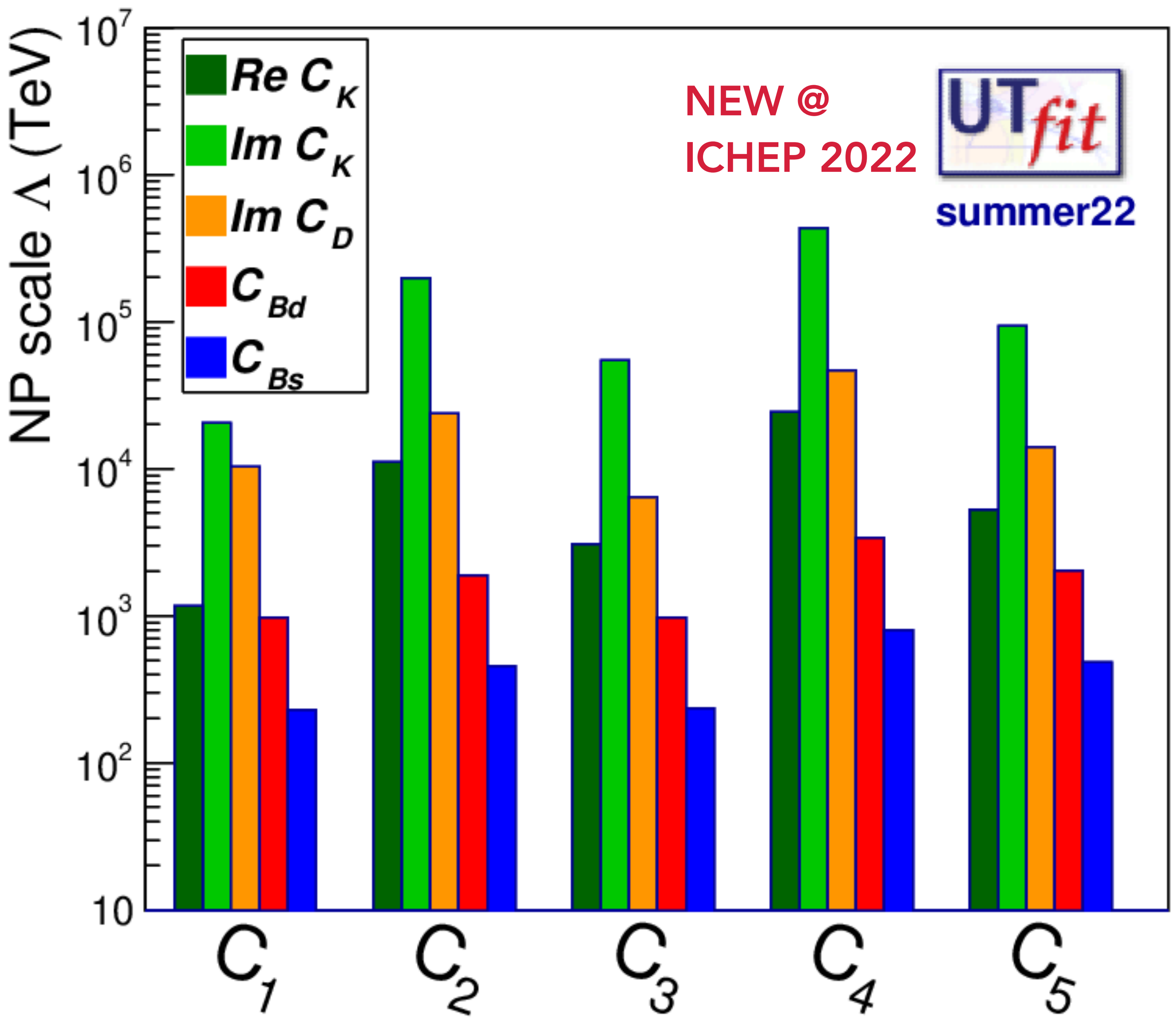


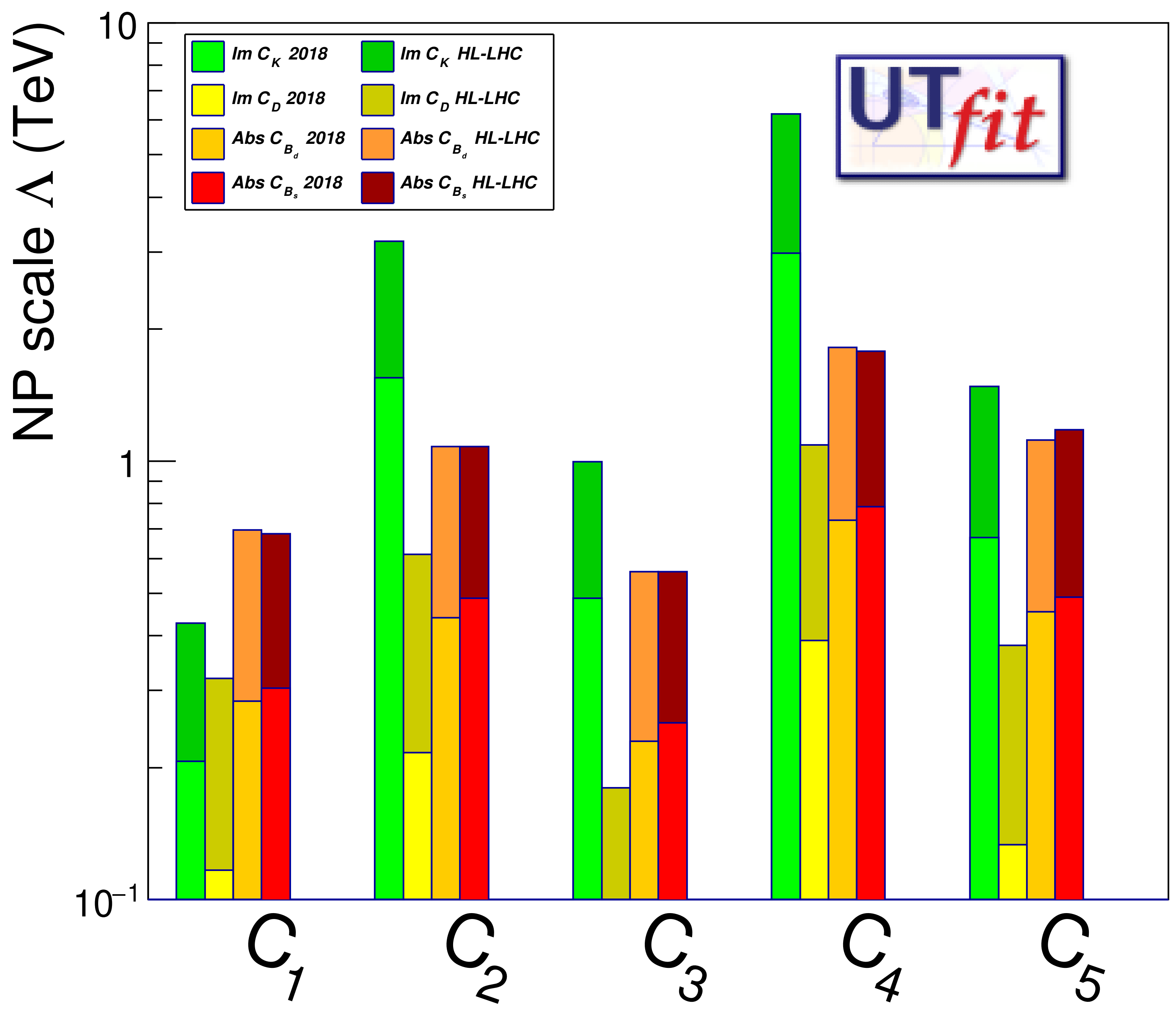
...teaching us the scale of BSM physics...



We know that BSM physics with generic flavour couplings is ruled out to 10^5 TeV!

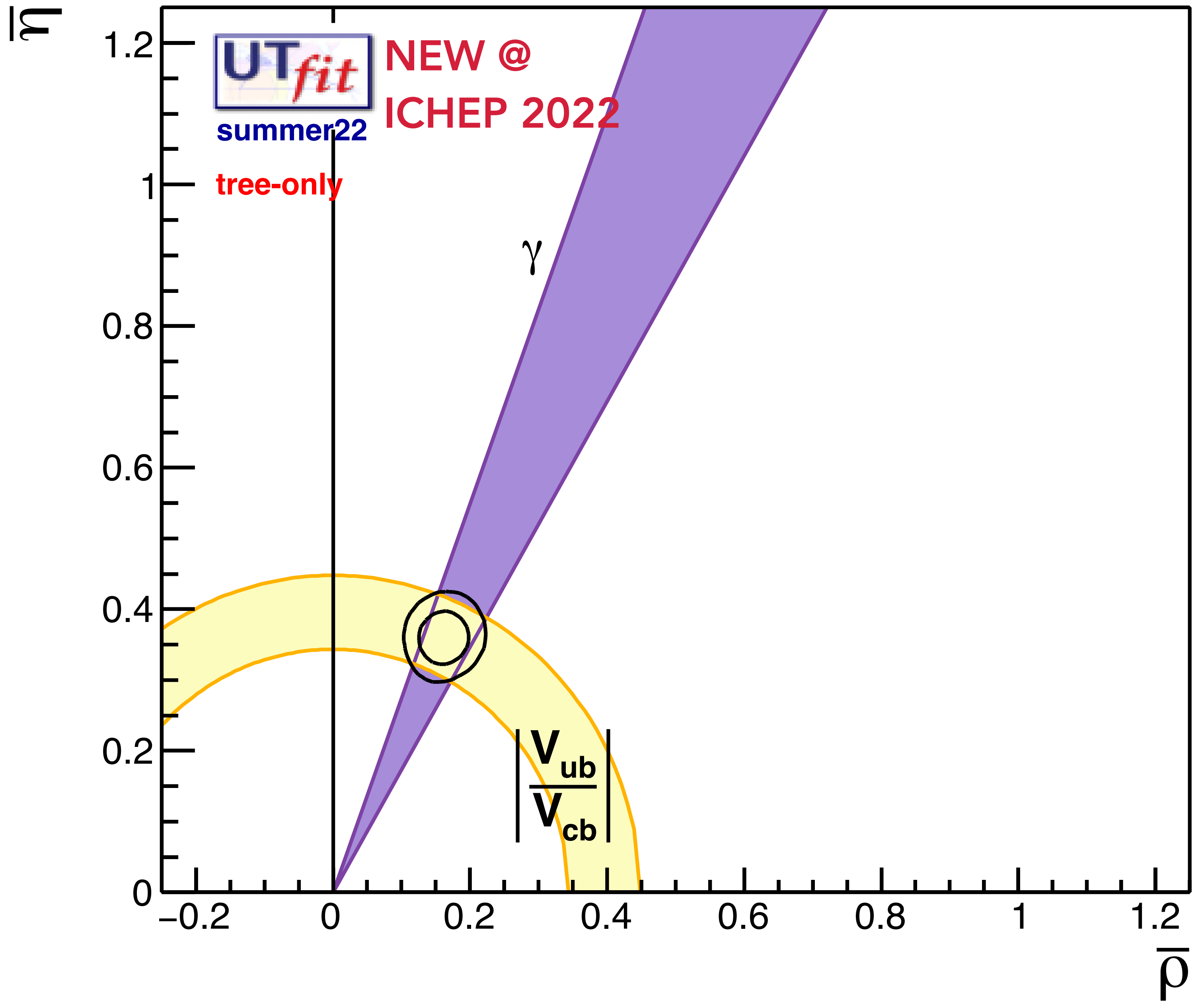
…and giving motivation for the future!



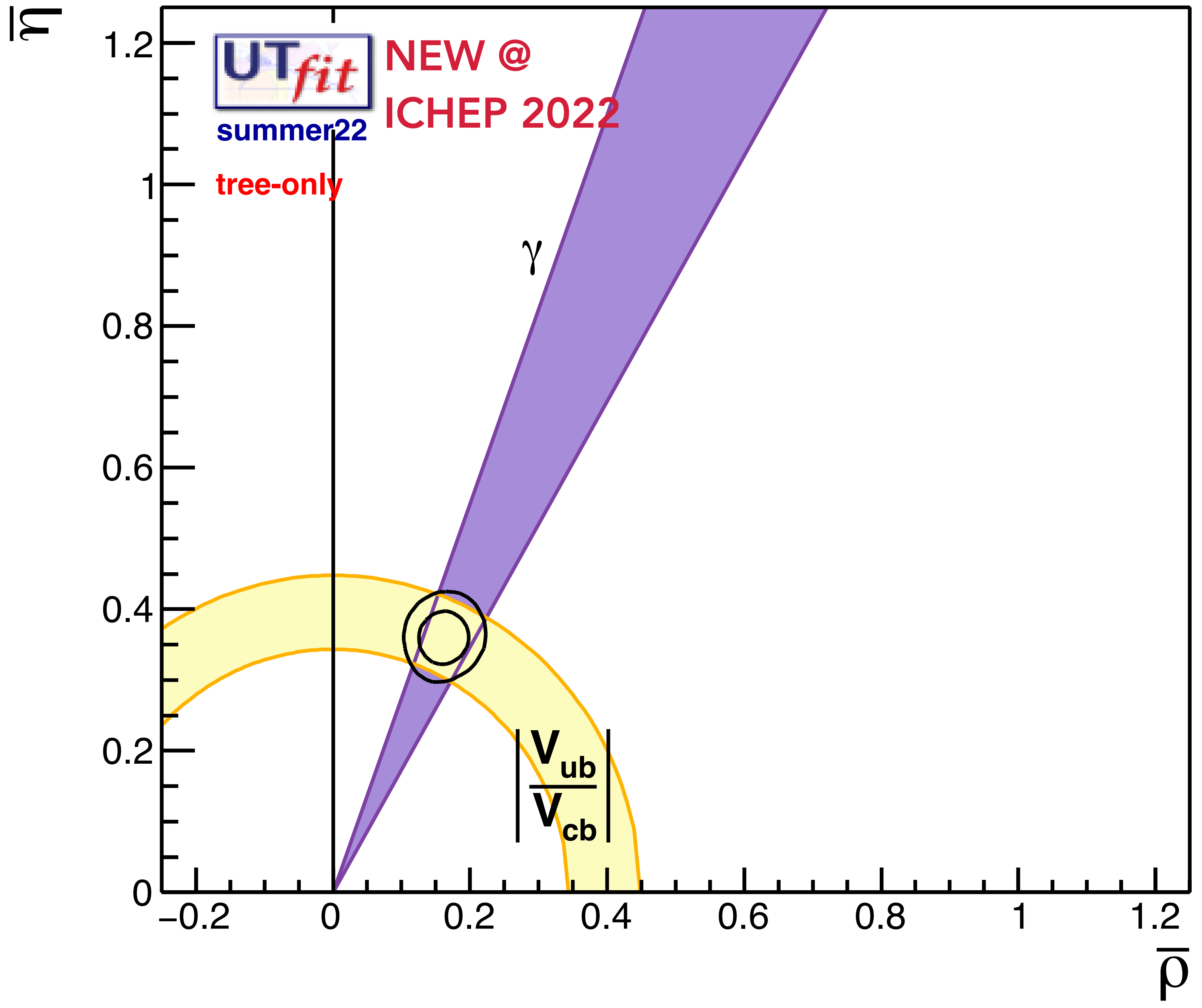


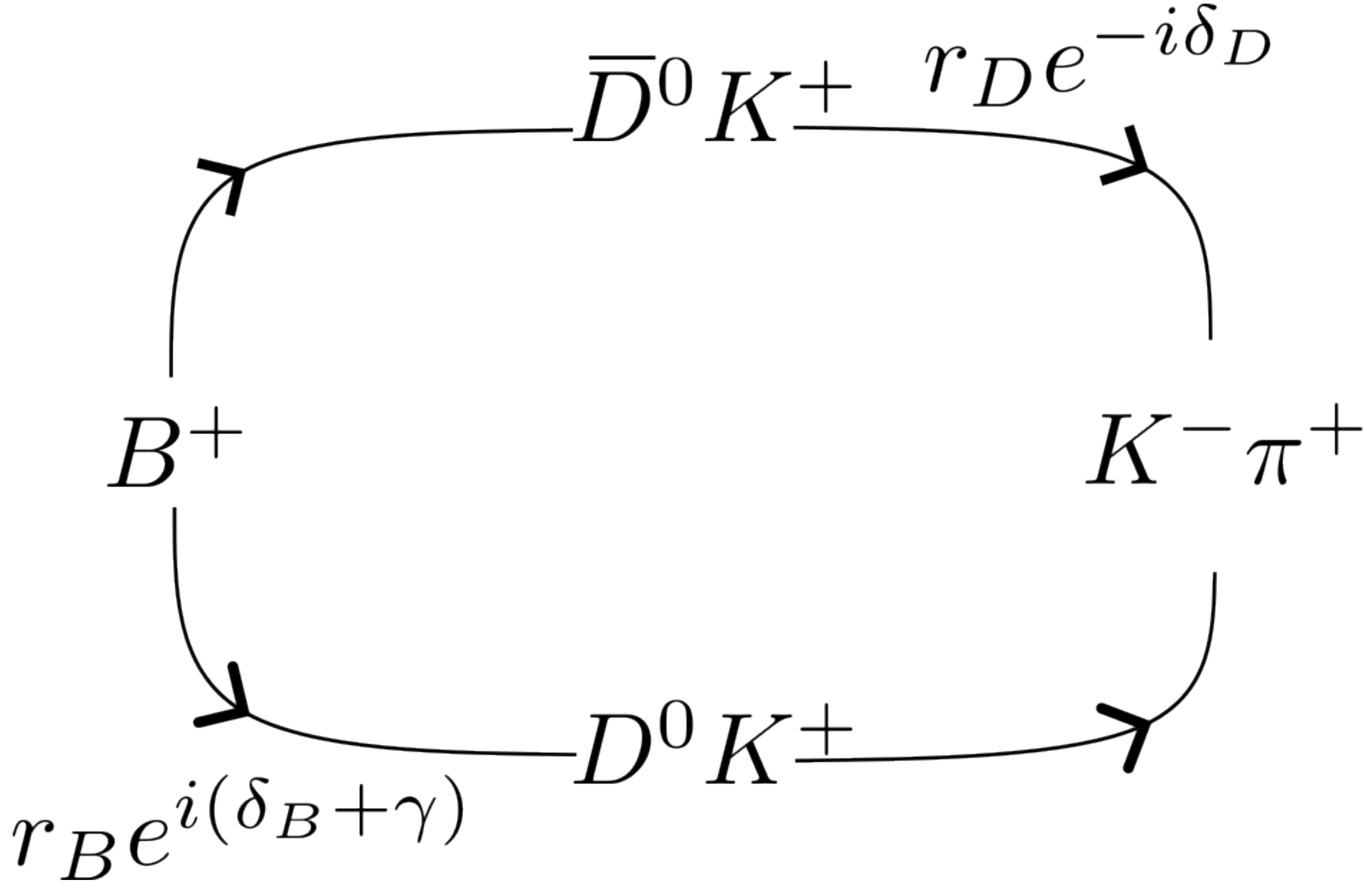
The apex of the CKM triangle remains one of the safest long-term paths to constraining generic NP models!

The tree-level path to the apex



The tree-level path to the apex





~10^{-7} (!) theory uncertainty on the interpretation of experimental observables in terms of the CKM angle γ! (Zupan & Brod 1308.5663)

It takes many ingredients to measure γ

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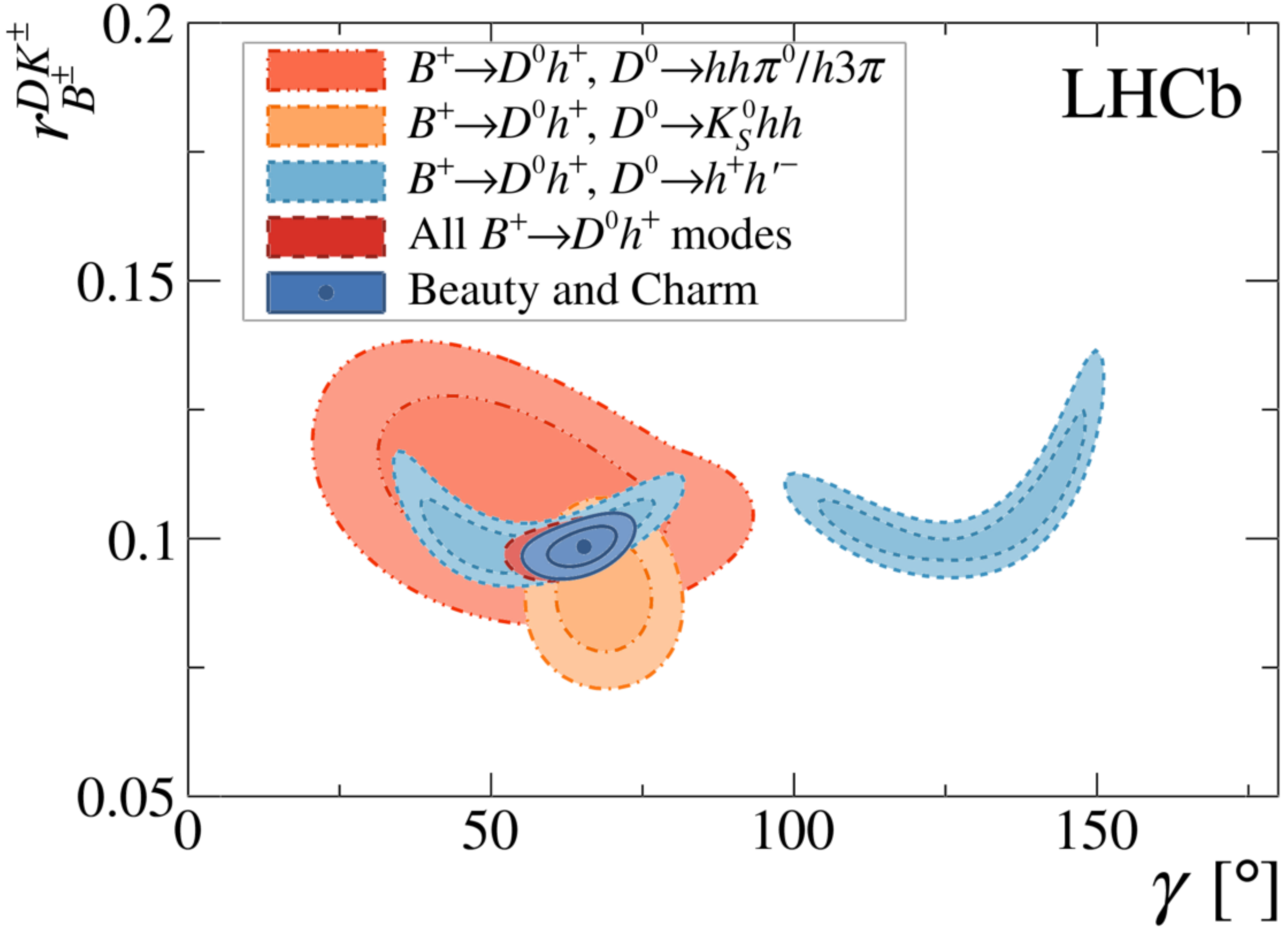
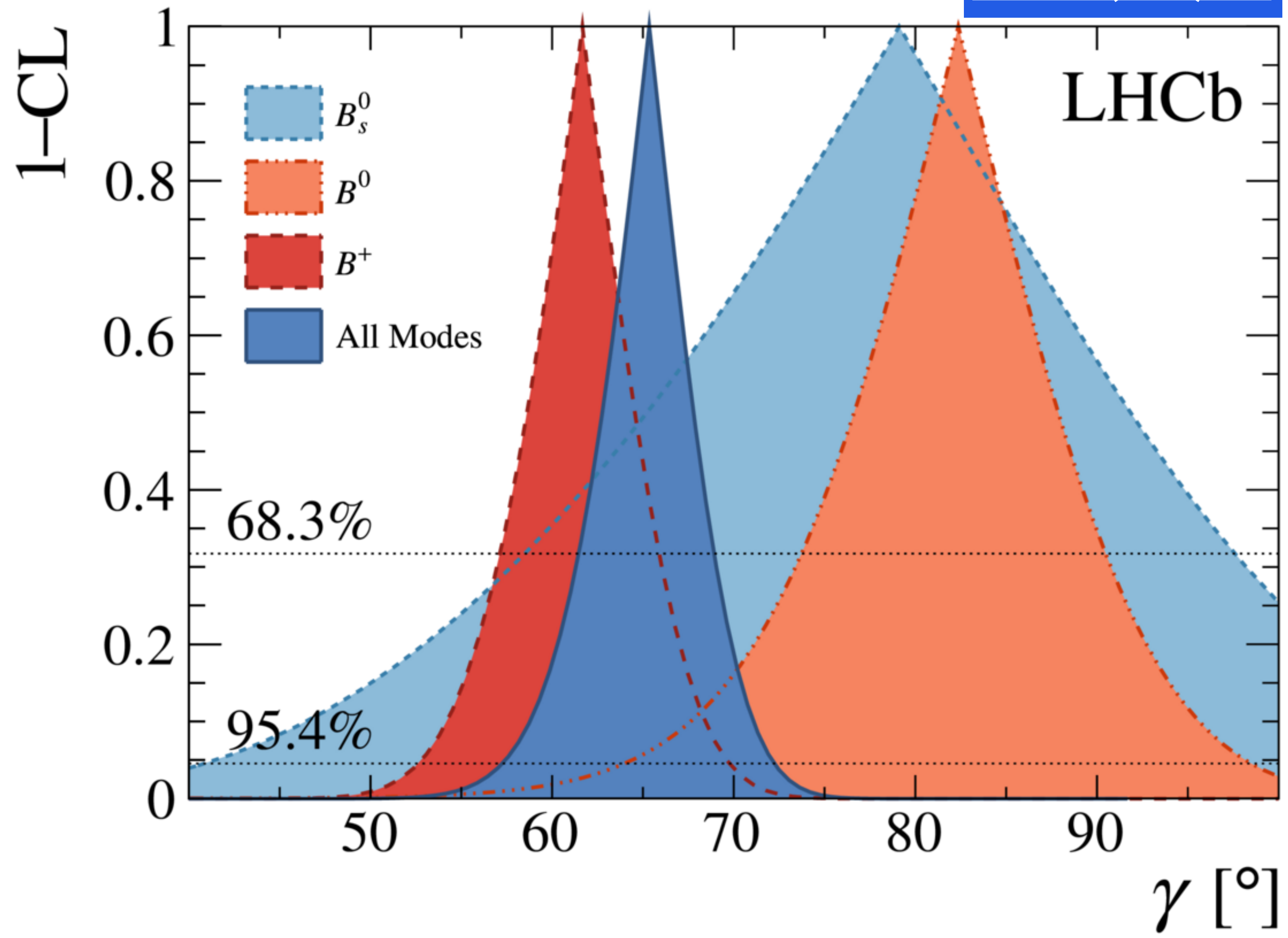
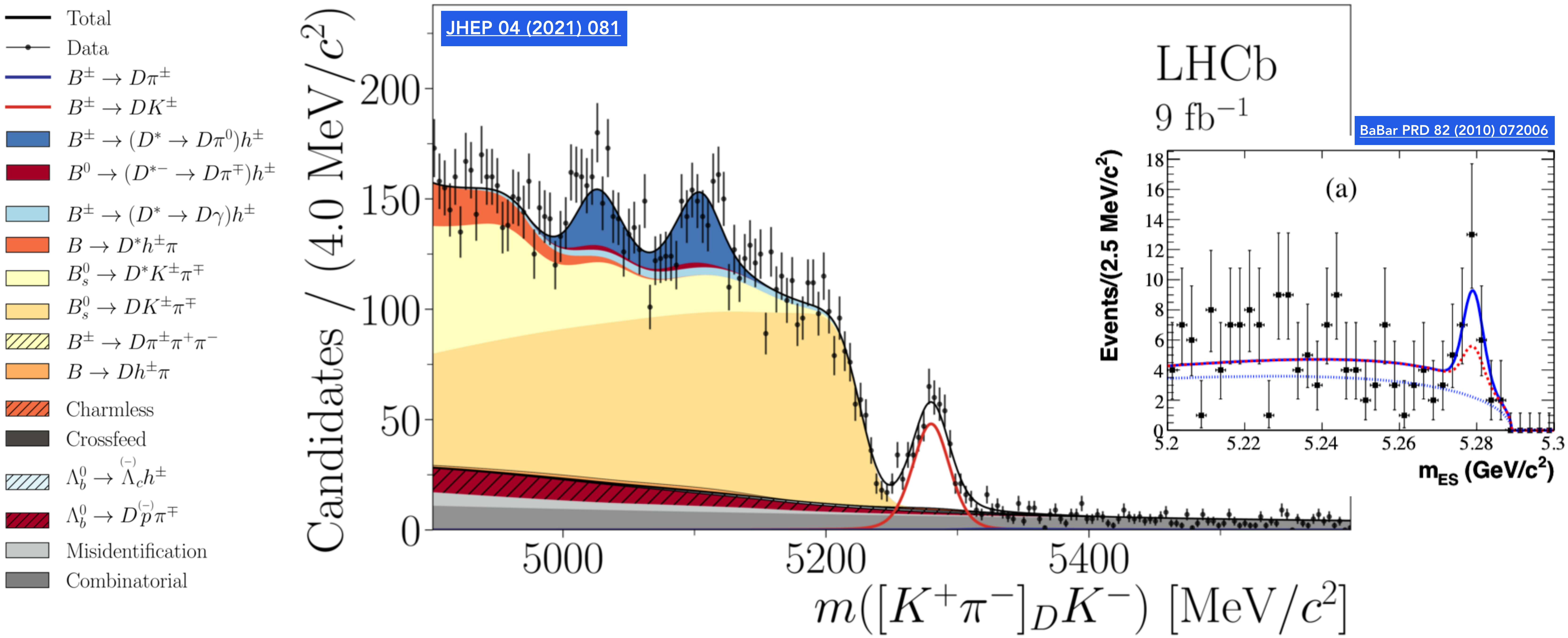




$$\gamma = (65.4^{+3.8}_{-4.2})^\circ$$

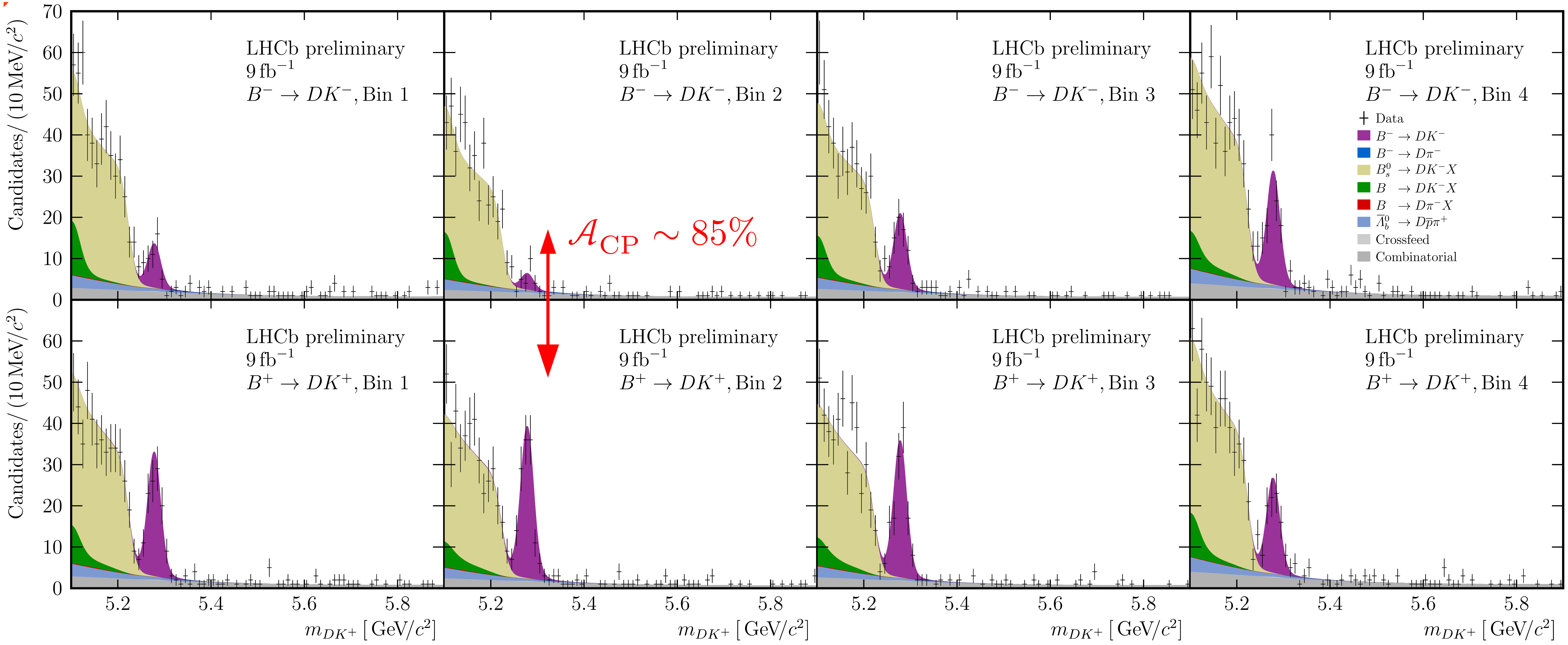
We are approaching the 5% uncertainty level on γ from direct measurements

The experimental road has been long



But the pieces are coming together now

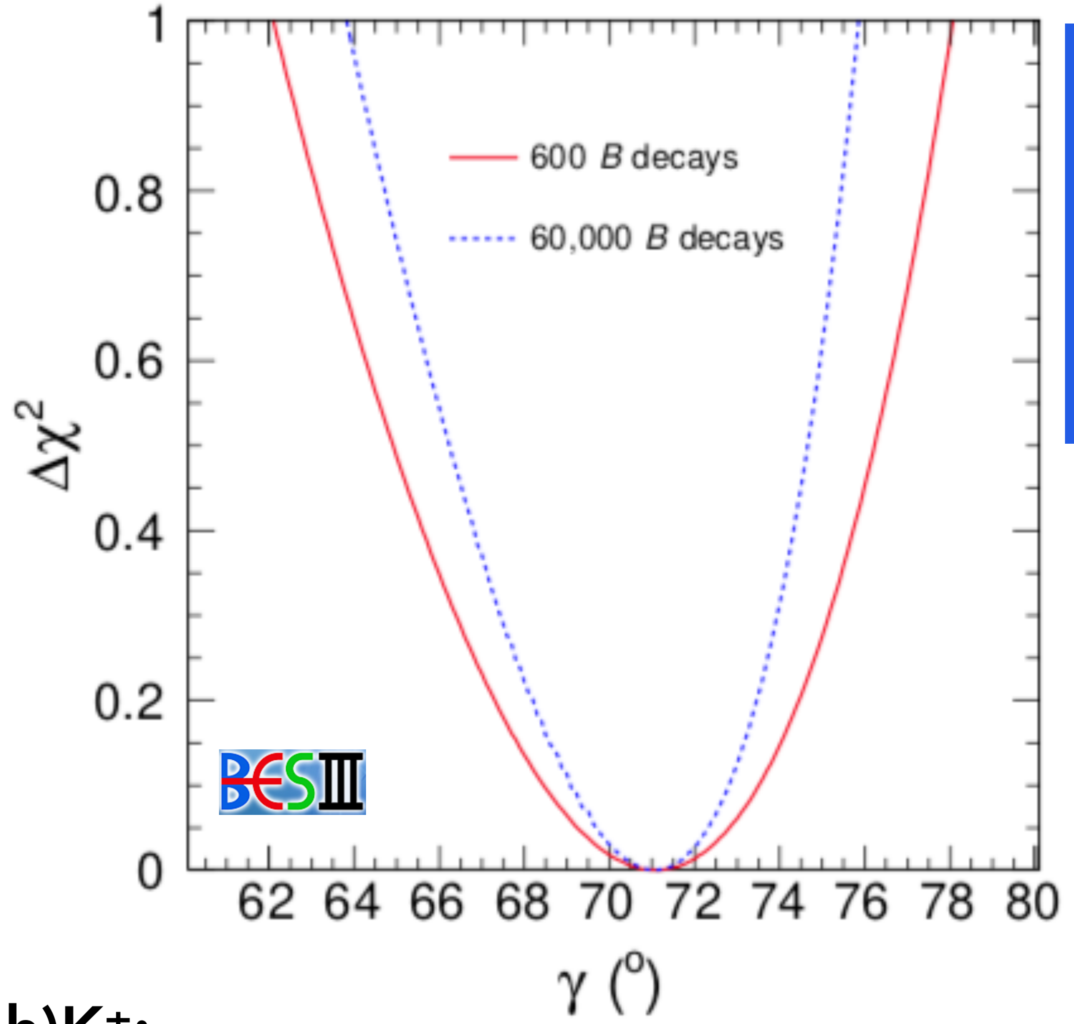
Legacy LHCb Run 1+2 analysis of B→D(4H)K decays



$$\gamma = \left(54.8 \begin{smallmatrix} +6.0 \\ -5.8 \end{smallmatrix} \begin{smallmatrix} +0.6 \\ -0.6 \end{smallmatrix} \begin{smallmatrix} +6.7 \\ -4.3 \end{smallmatrix}\right)^\circ$$

Tim Evans @ ICHEP 2022

Permille level γ will require teamwork!



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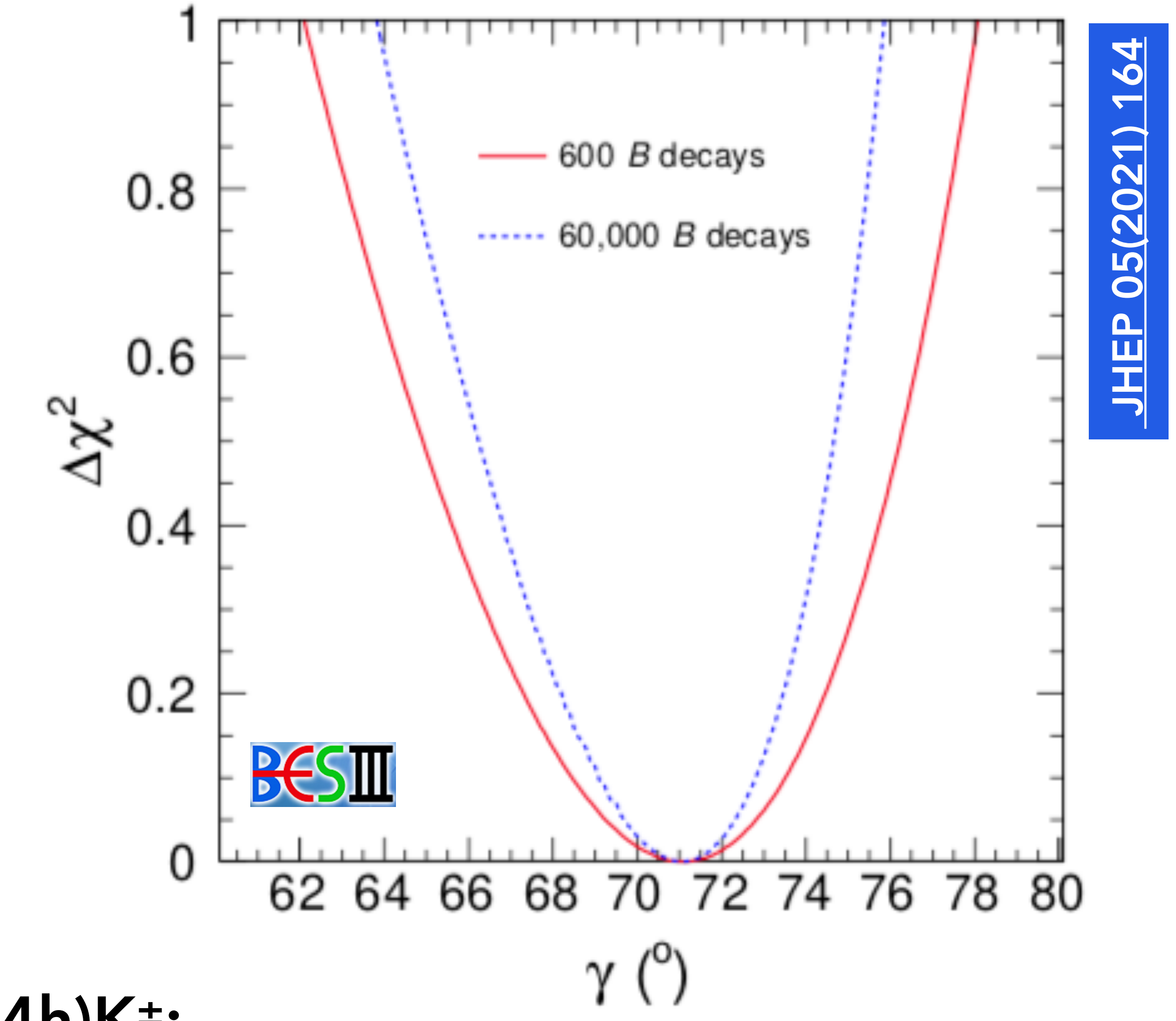
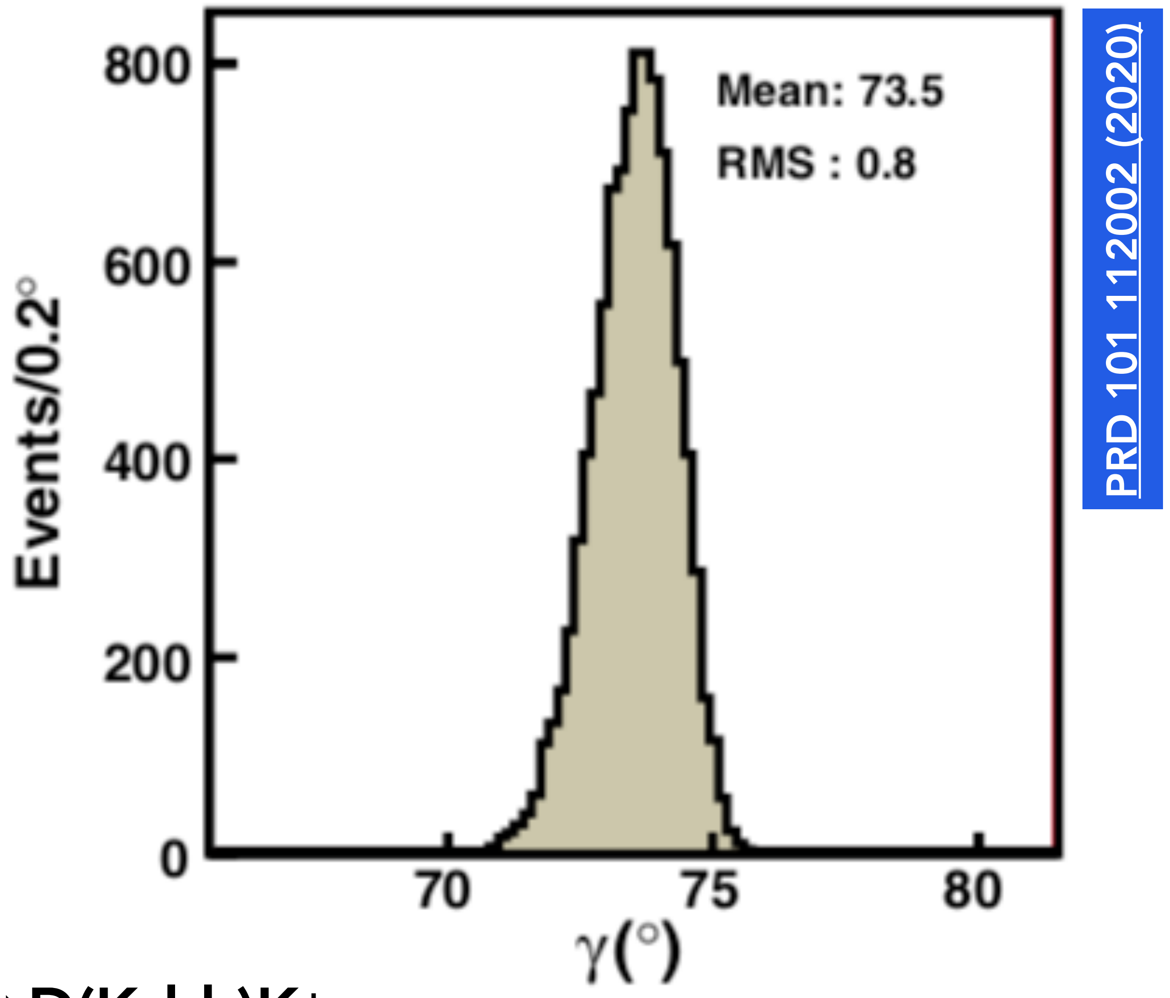
$B^{\pm} \rightarrow D(4h)K^{\pm}$:

4h modes could eventually rival $K_S HH$ (!!) if strong phases would be measured better, but will be limited very quickly if they cannot!

Permille level γ will require teamwork!





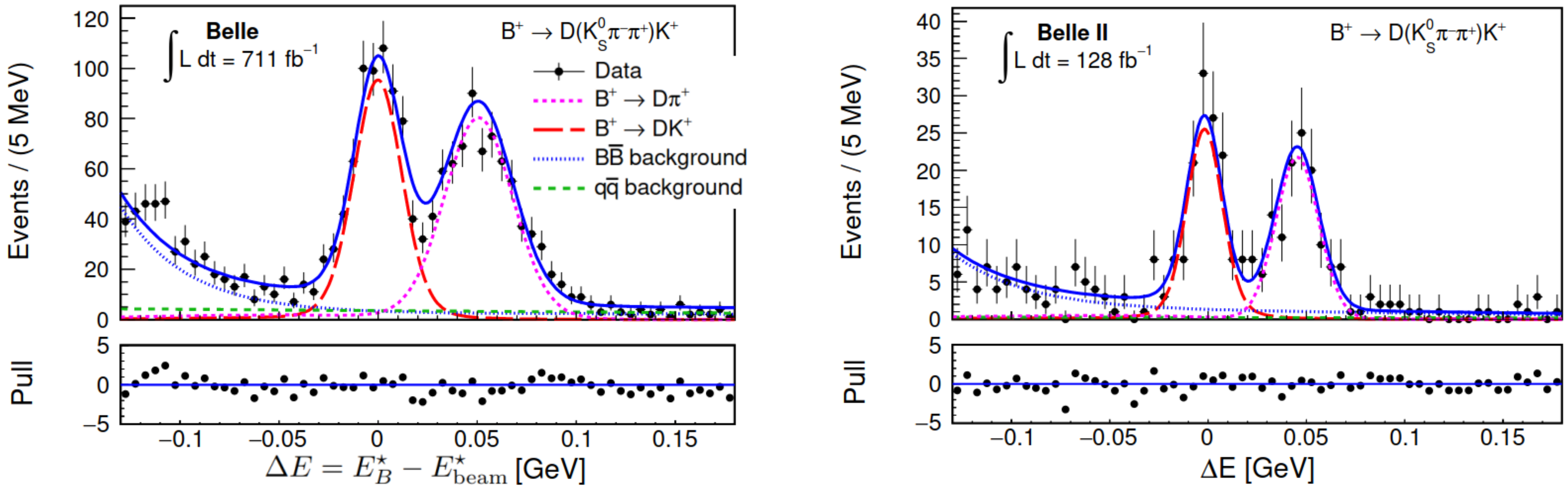
$B^\pm \to D(4h)K^\pm$:

4h modes could eventually rival $K_S HH$ (!!) if strong phases would be measured better, but will be limited very quickly if they cannot!

$B^\pm \to D(K_S hh)K^\pm$:

Will eventually be limited at 1 degree level by current BESIII measurements, therefore vital that BESIII goes ahead and collects 10x the current $\psi(3770)$ dataset!

Belle II is also showing its capabilities



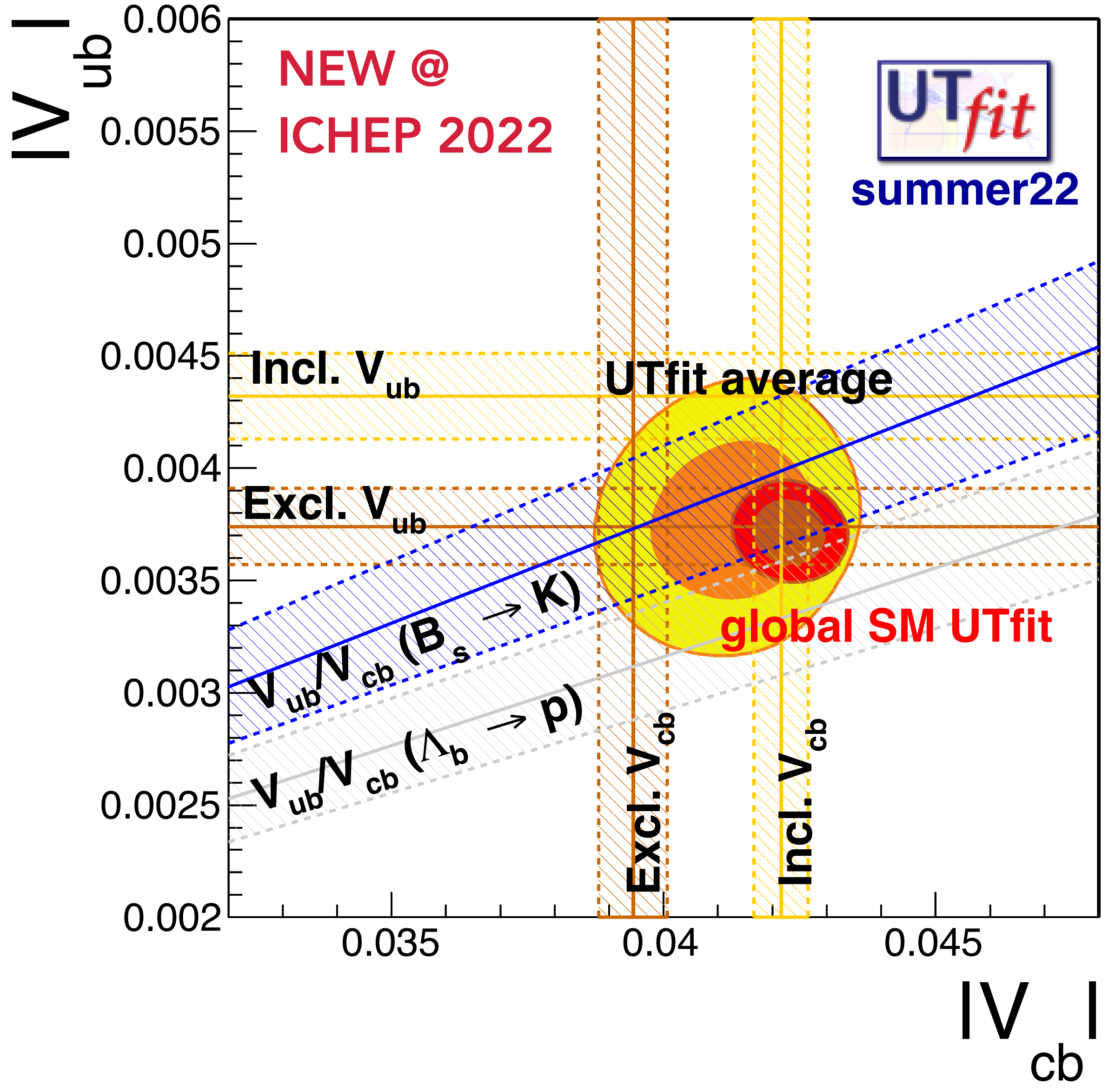
JHEP02 (2022) 063

$$\gamma = (78.4 \pm 11.4\ (\text{stat.})\ \pm 0.5\ (\text{syst.})\ \pm 1.0\ (\text{ext.}))^\circ$$

Joint analysis of B→D(K$_s$HH)K decays with Belle + Belle II data

Significantly improved mass resolution! Not competitive yet but promising for future.

The quest for V_{ub} & V_{cb}



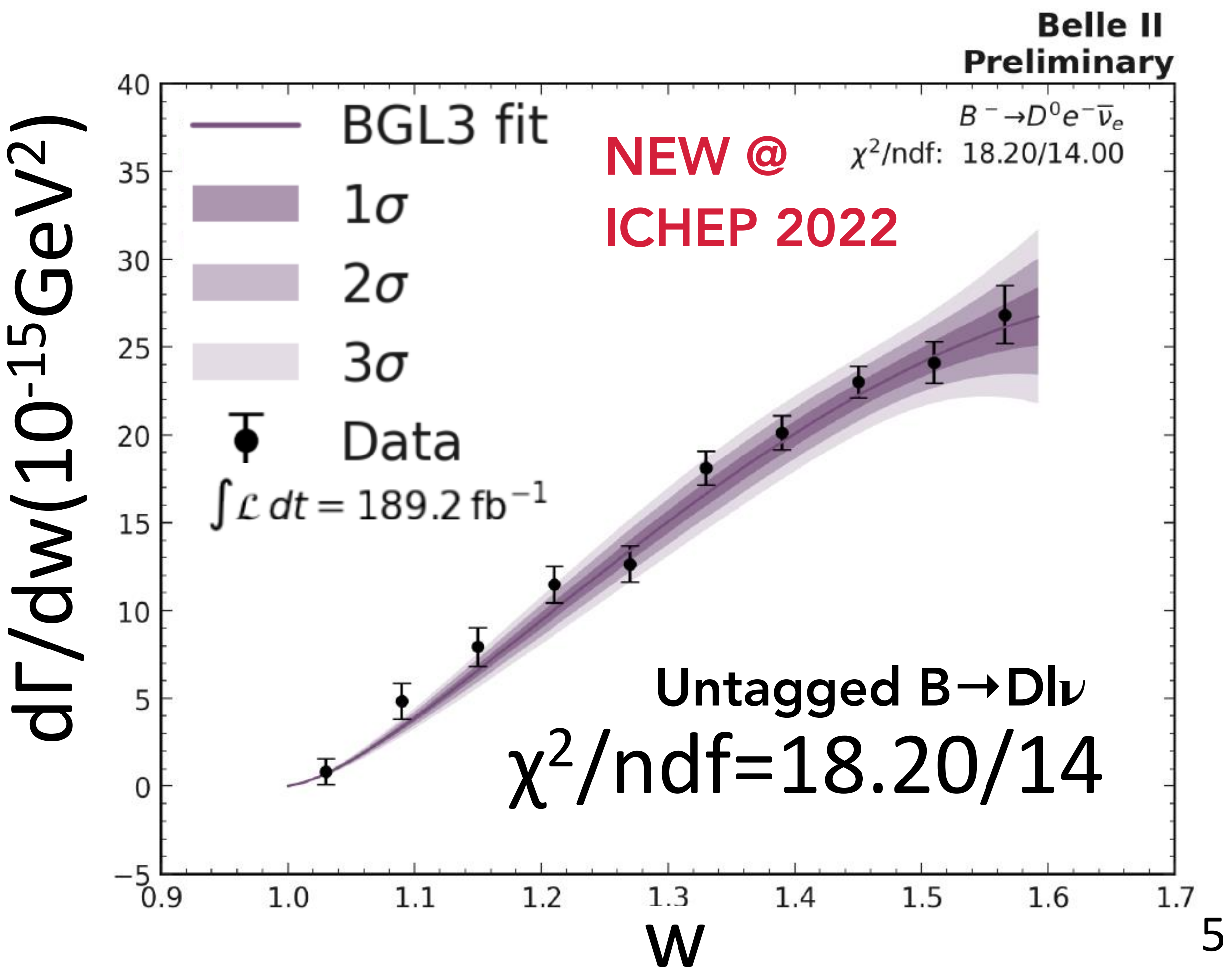
Inclusive-exclusive tensions remain in V_{cb}, are reduced in V_{ub}

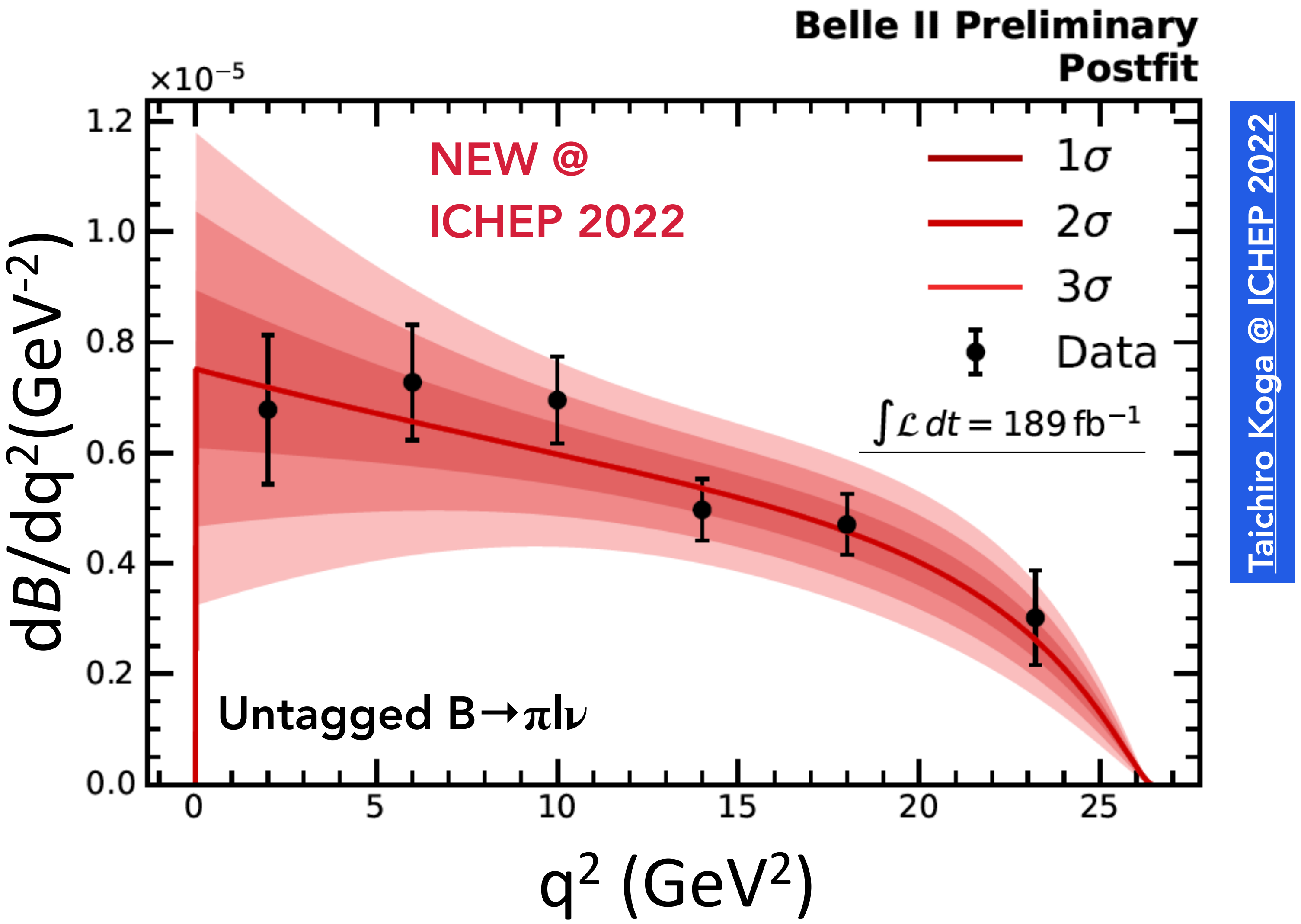
Tension in Vub is around 2-3 sigma depending on inputs

V_{cb} remains at 3 sigma, further experimental input must be matched by theory/lattice progress

Note: this inclusive-exclusive discrepancy is what we call a "puzzle", not what we call an "anomaly"…

Belle II enters the quest for V_{ub} & V_{cb}





$$\eta_{\rm EW}|V_{cb}| = (38.53 \pm 1.15) \times 10^{-3}$$

stat.+sys.+theo.

$$|V_{ub}|_{B^0\to\pi^-\ell^+\nu_\ell} = (3.54 \pm 0.12_{\rm stat} \pm 0.15_{\rm sys} \pm 0.16_{\rm theo}) \times 10^{-3}$$

Excellent showcase of Belle II capabilities, precisions approaching B-factories in some places

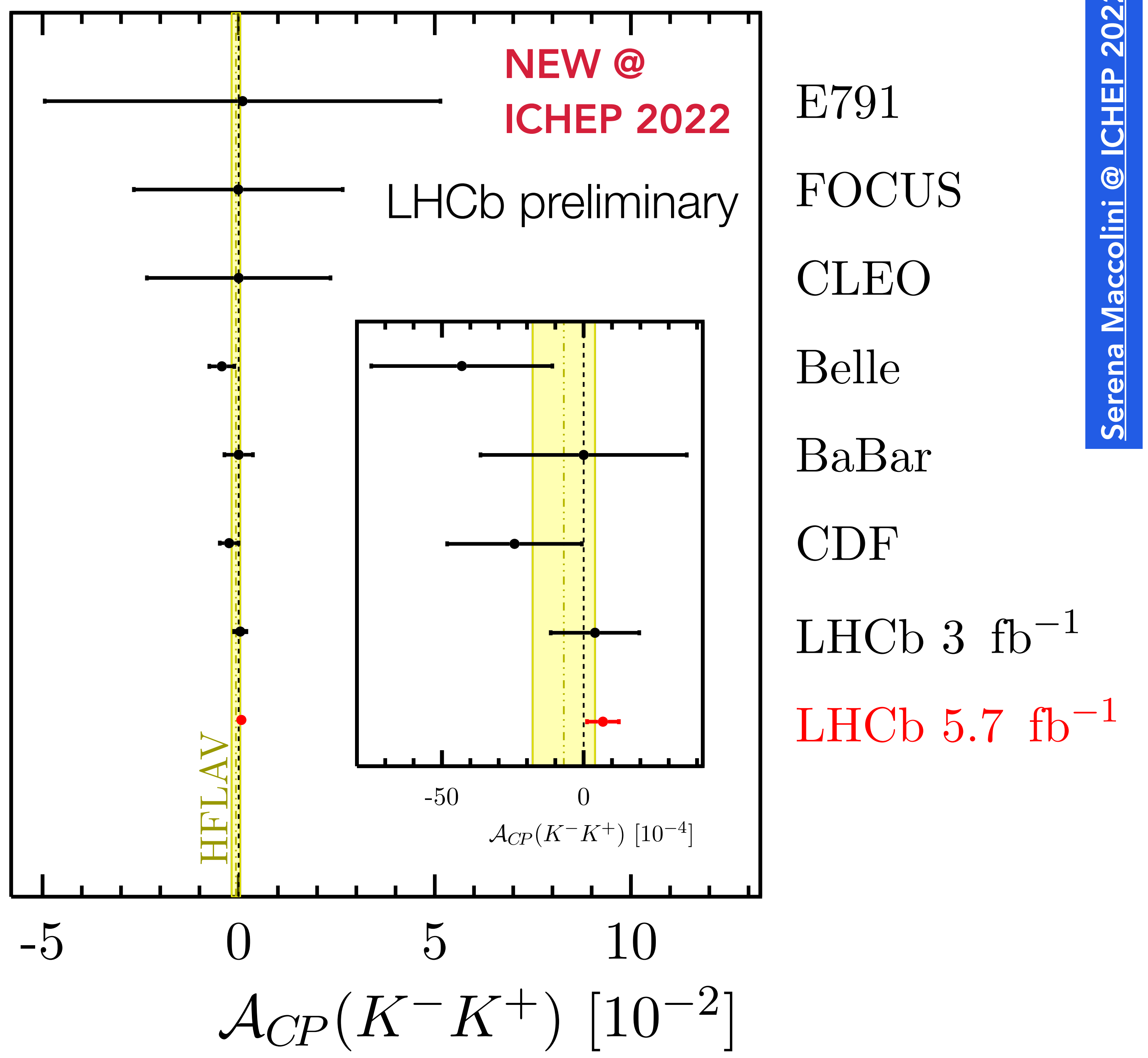
The up sector

Socotra island,
Yemen

Charm CPV: discovery to characterization

CPV in charm observed by LHCb in the difference of CP asymmetries for the $\pi\pi$ and KK final states

Now beginning to characterise the individual asymmetries with exquisite precision and systematics control!



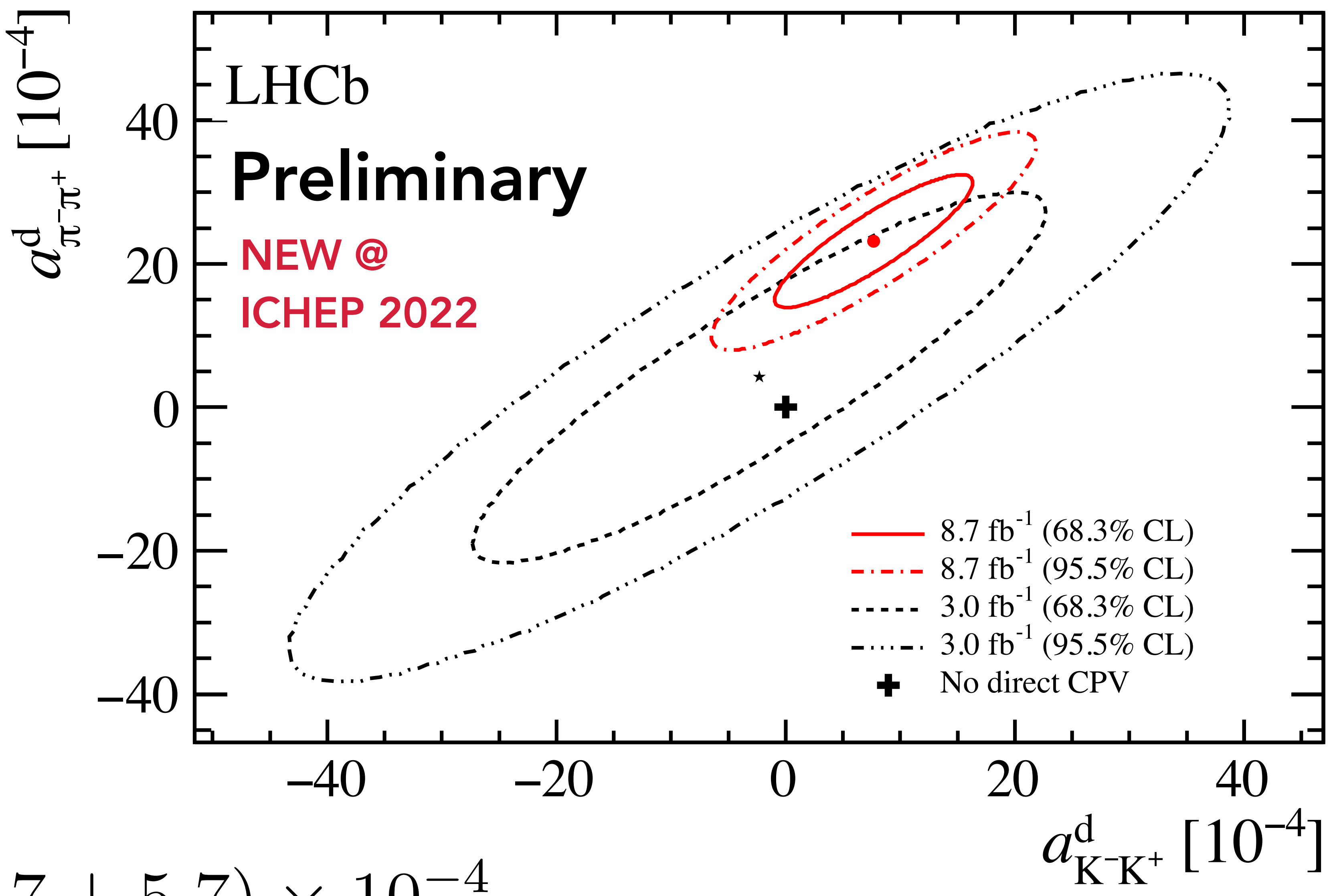
Serena Maccolini @ ICHEP 2022

Measurements limited by control mode yields — must collect all charm at the LHC with real-time analysis!

Charm CPV: discovery to characterization

Combination of the measurement of CP violation in the KK mode with the difference between KK and ππ leads to the first single-mode evidence (3.8σ) of CPV in ππ

Systematics controlled at the 10^{-4} level — essential to scale to 10^{-5}



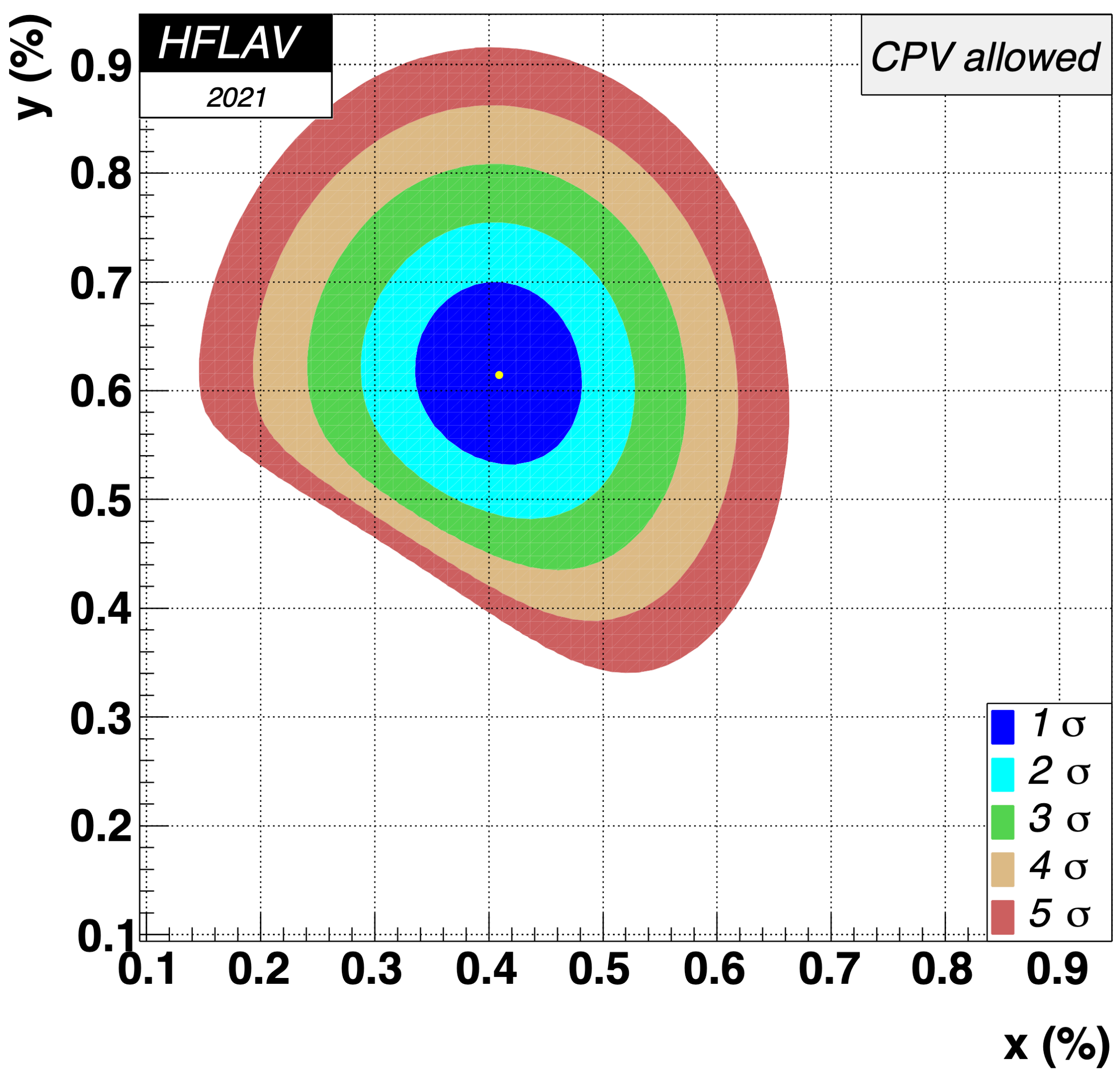
Serena Maccolini @ ICHEP 2022

$$a^d_{K^-K^+} = (\ 7.7 \pm 5.7) \times 10^{-4}$$
$$a^d_{\pi^-\pi^+} = (23.2 \pm 6.1) \times 10^{-4}$$

with $\rho(a^d_{KK}, a^d_{\pi\pi}) = 0.88$

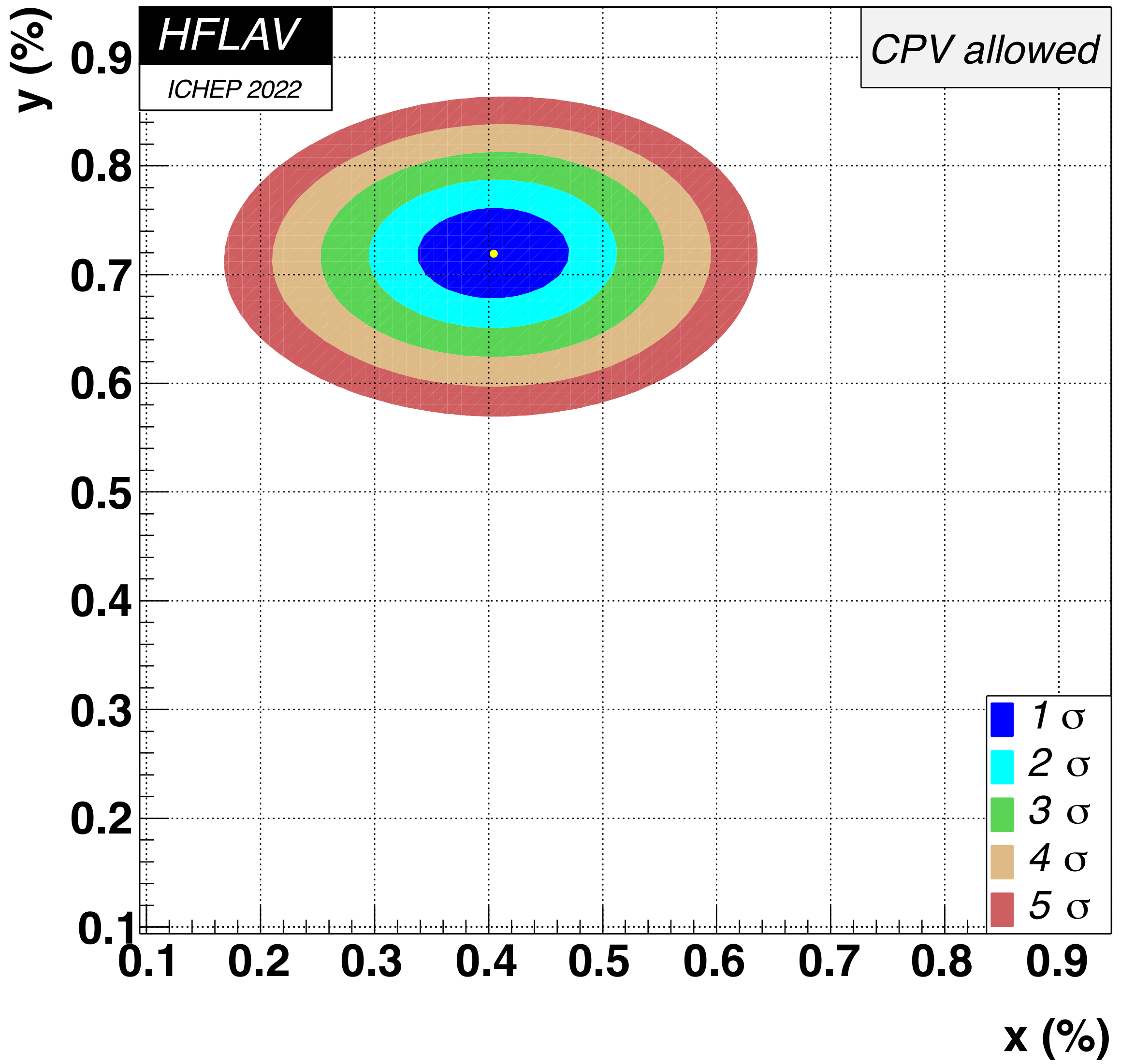
Measurements limited by control mode yields — must collect all charm at the LHC with real-time analysis!

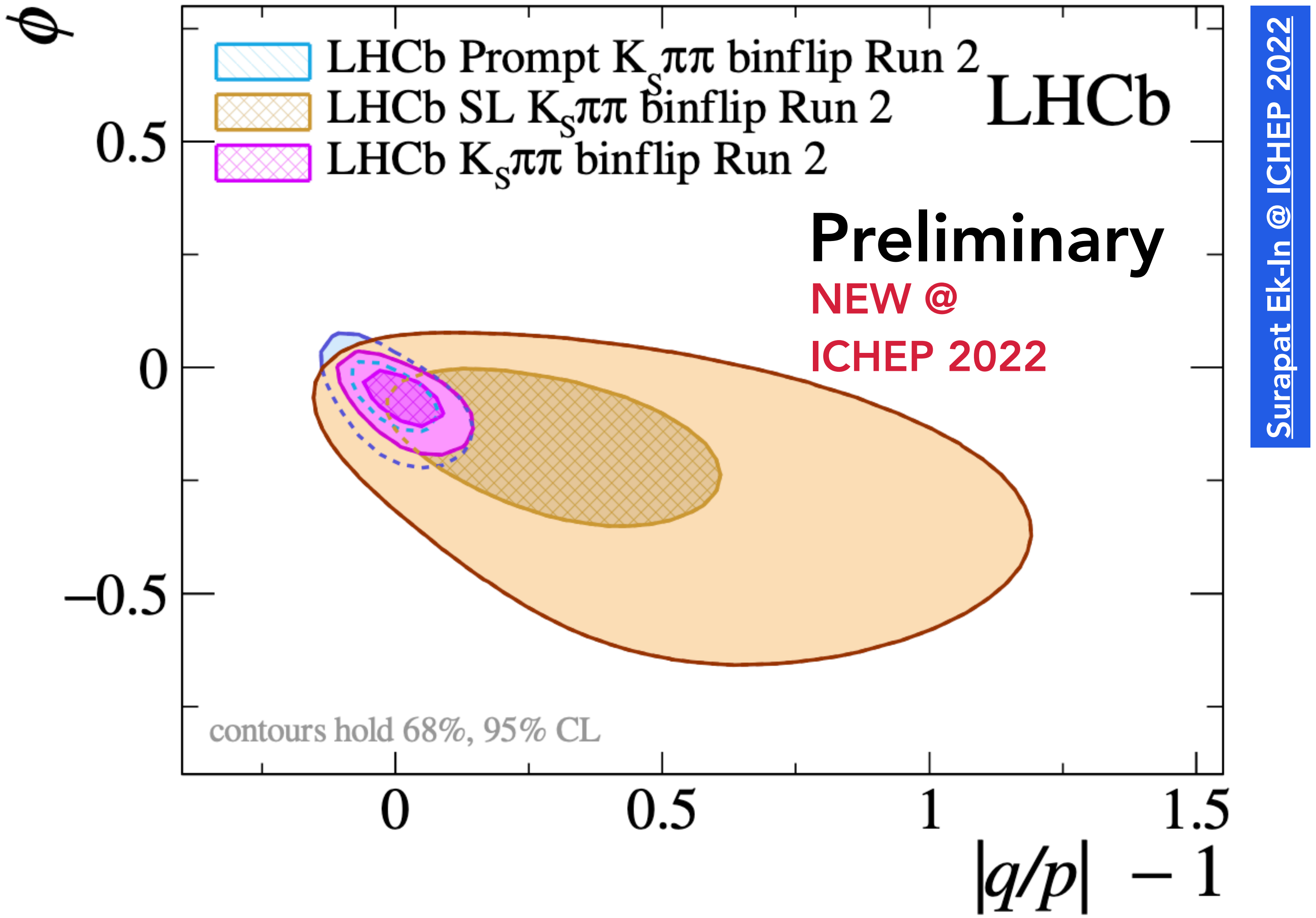
Charm mixing and CPV



Charm mixing well-established since more than a decade!

Charm mixing and CPV



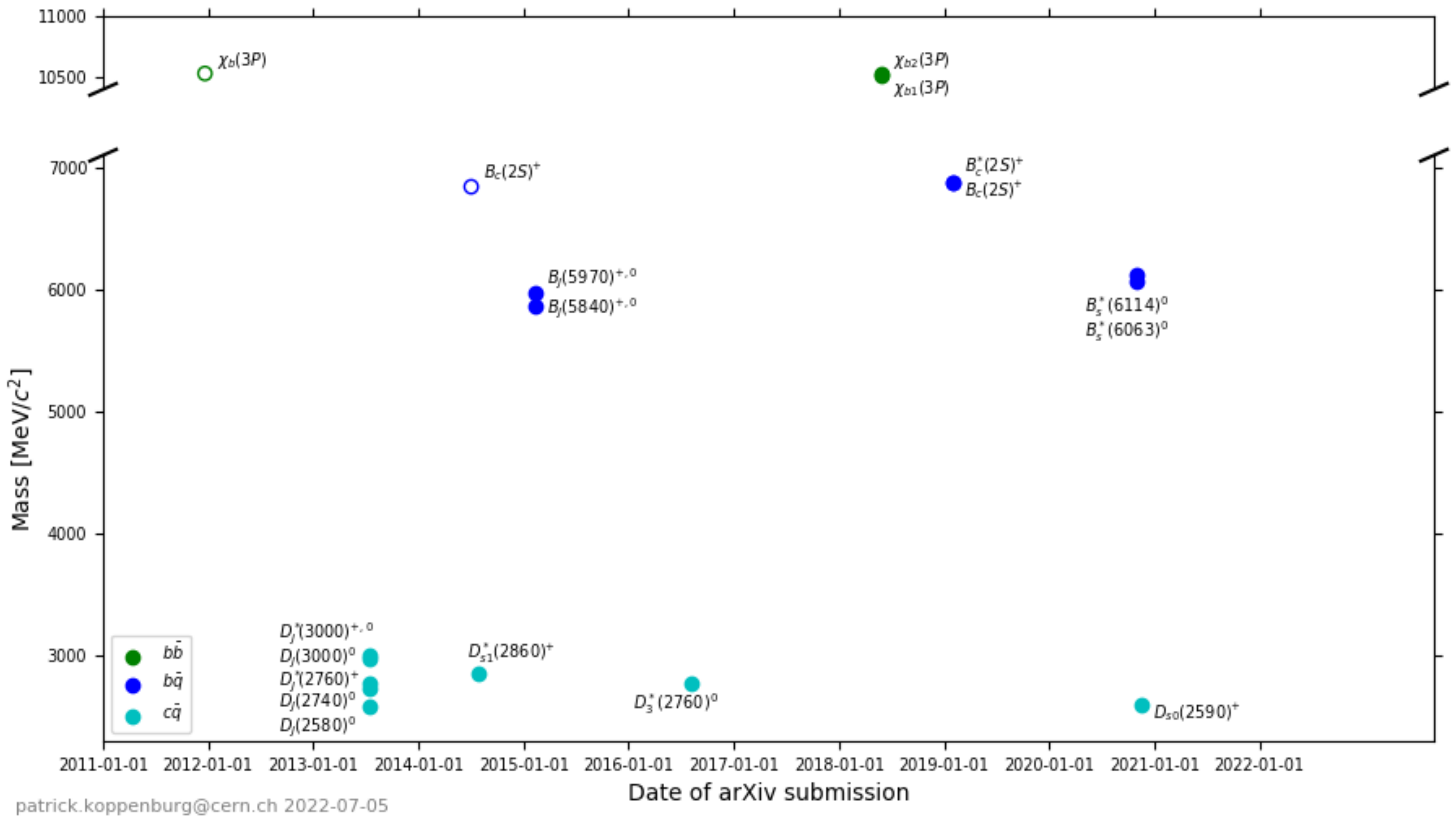


Charm mixing well-established since more than a decade! Experimental diversity & consistency key to long-term systematics control.

Improved BESIII inputs again crucial to long-term sensitivity!

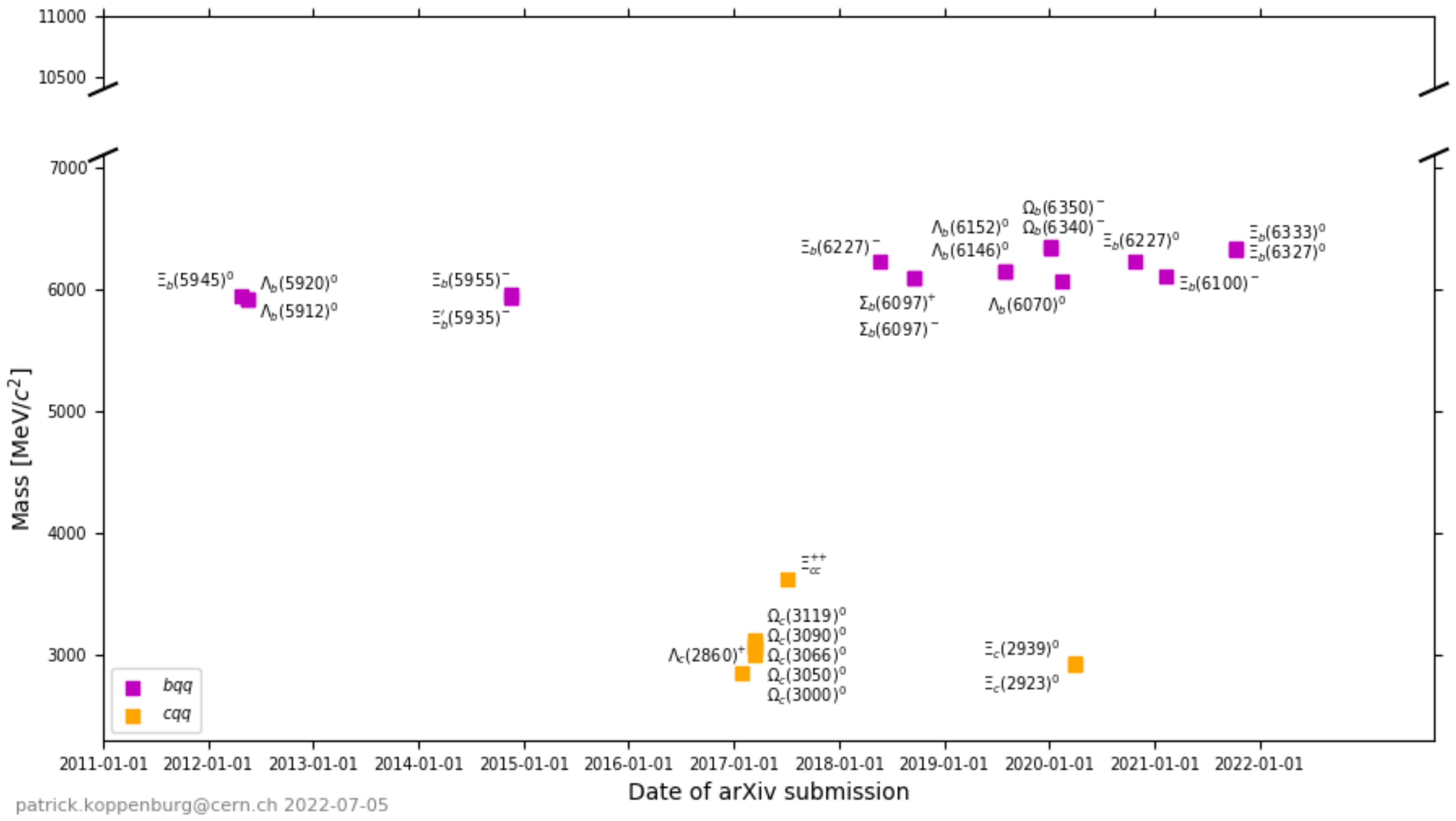

Flavour discoveries
rose-veiled fairy wrasse

New conventional mesons @ LHC



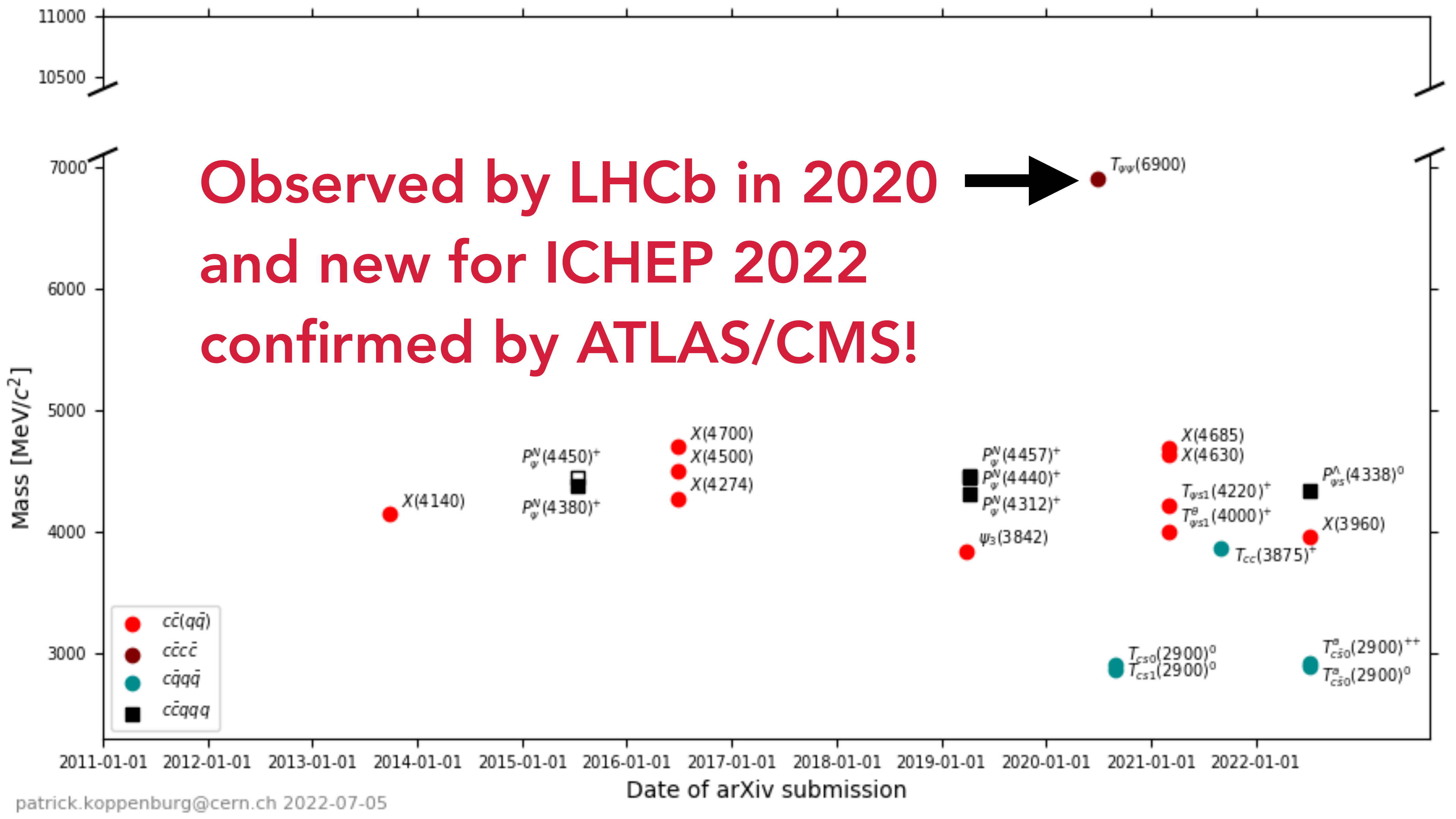
Credit to Patrick Koppenburg https://www.nikhef.nl/~pkoppenb/particles.html

New conventional baryons @ LHC

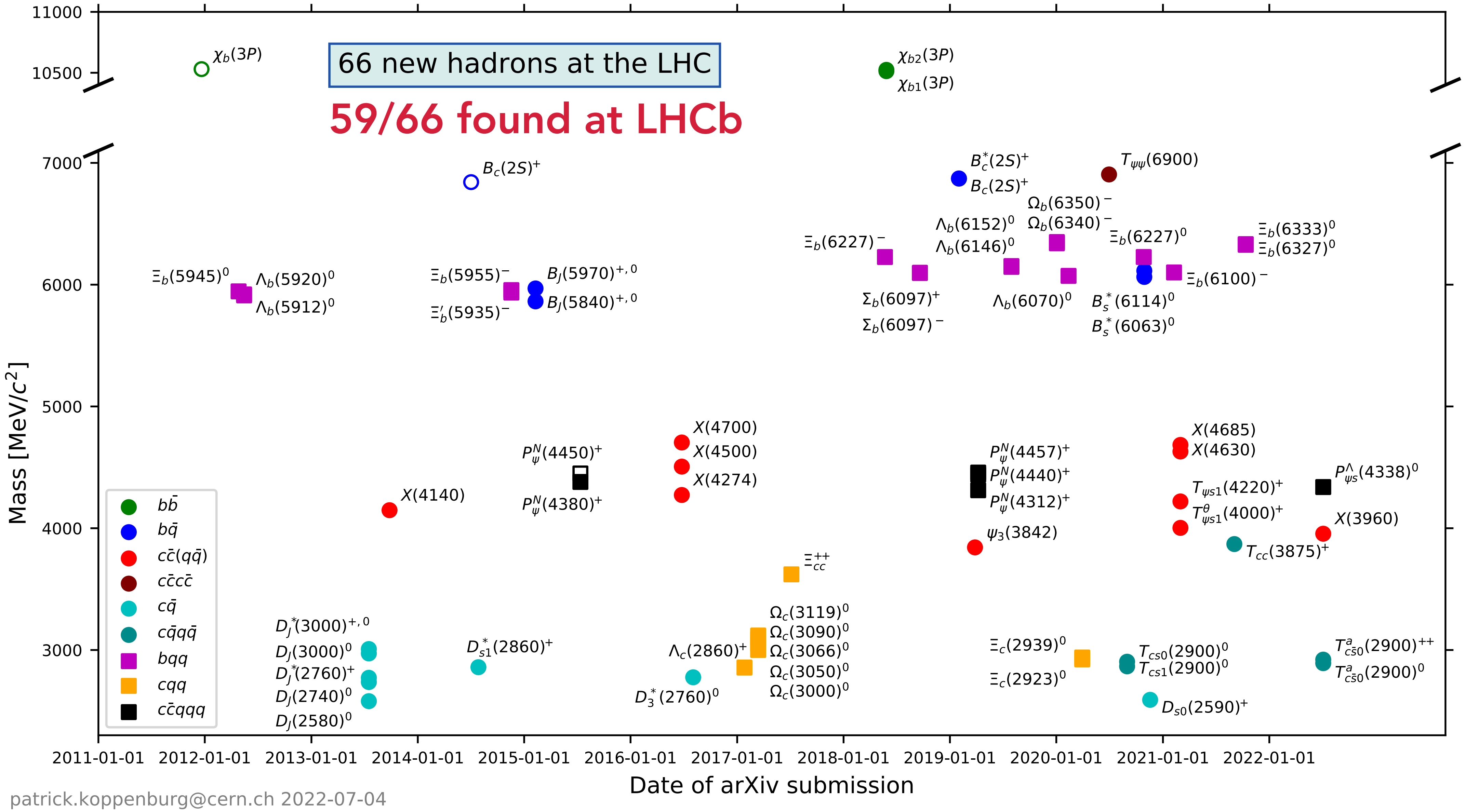


Credit to Patrick Koppenburg https://www.nikhef.nl/~pkoppenb/particles.html

New exotics @ LHC



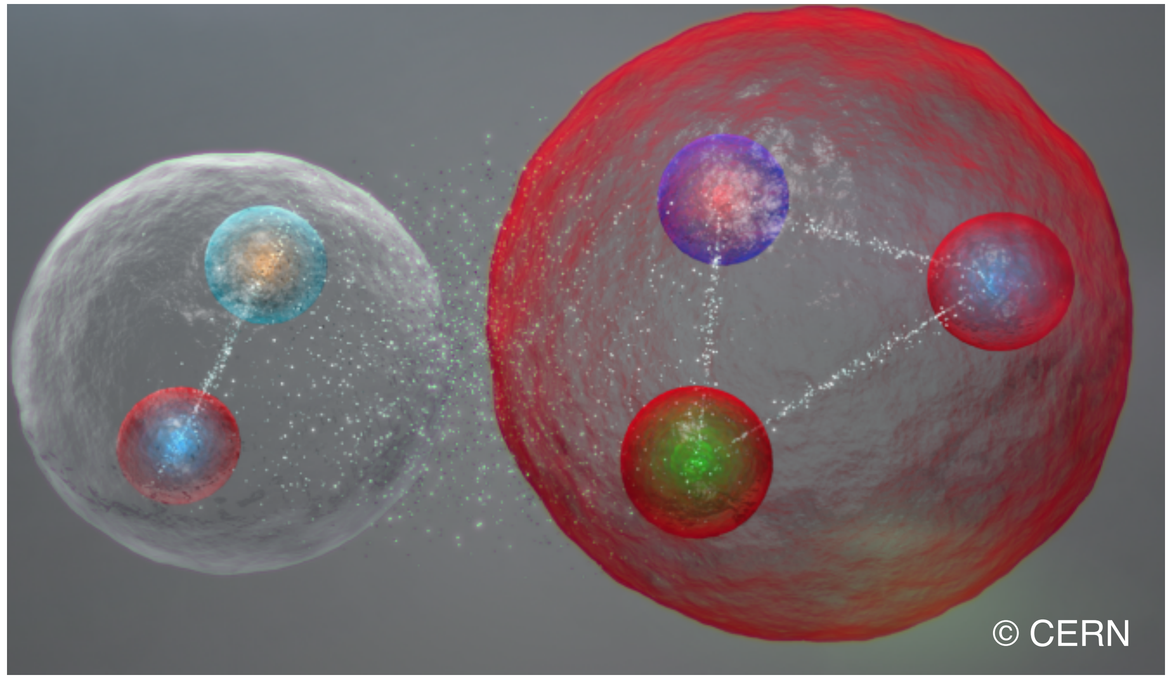
The LHC is quite the hadron factory!



Featuring the new proposed naming scheme from LHCb

But what are these 4,5-quark states?

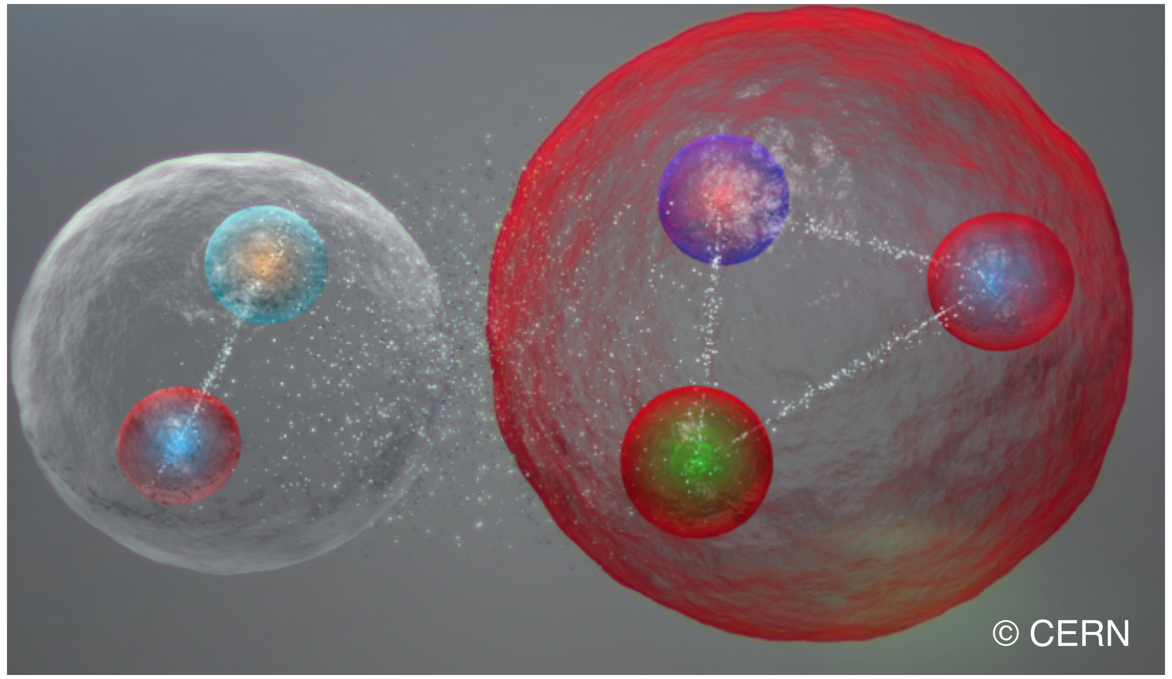
Molecule model - nuclear forces



F.-K. Guo et al., Rev. Mod. Phys. 90 (2018) 015004

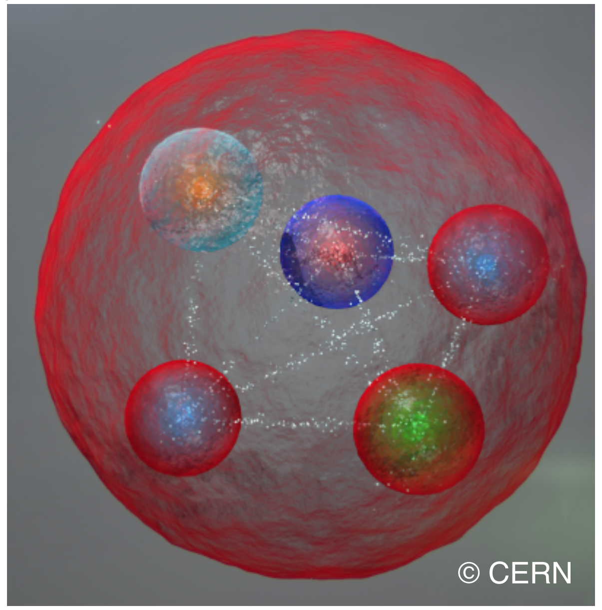
But what are these 4,5-quark states?

Molecule model - nuclear forces



F.-K. Guo et al., Rev. Mod. Phys. 90 (2018) 015004

Tightly bound quarks - color forces



A. Esposito, A Pilloni, A. D. Polosa, Phys. Rept. 668 (2017) 1
J.-M. Richard, Few Body Syst. 57 (2016) 1185

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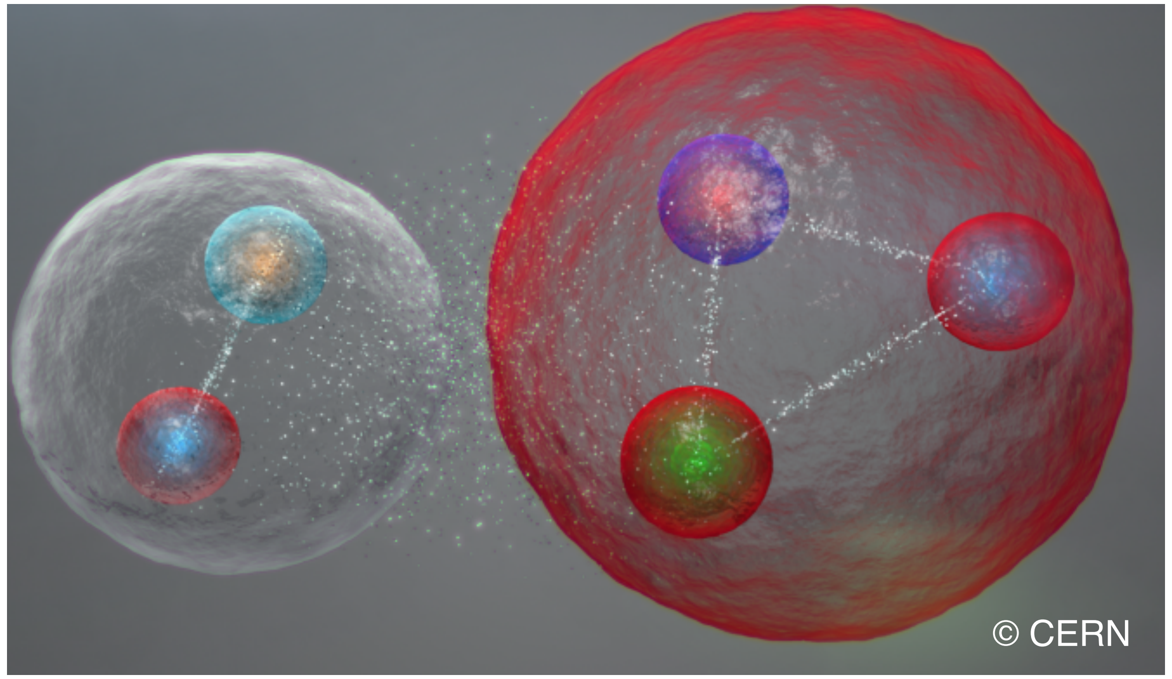
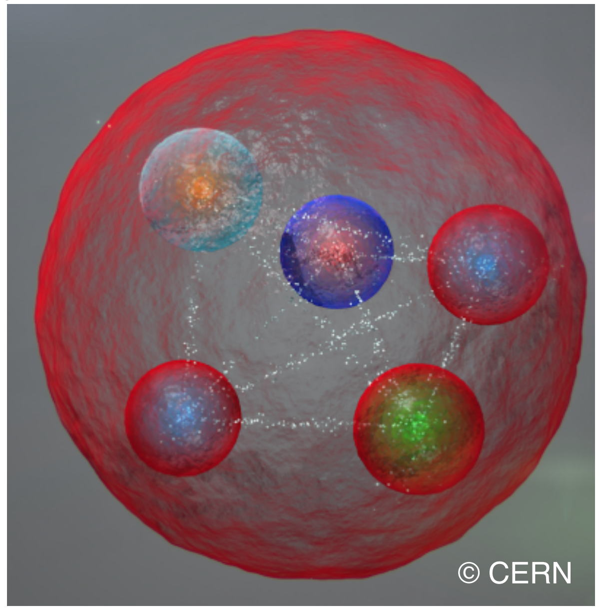


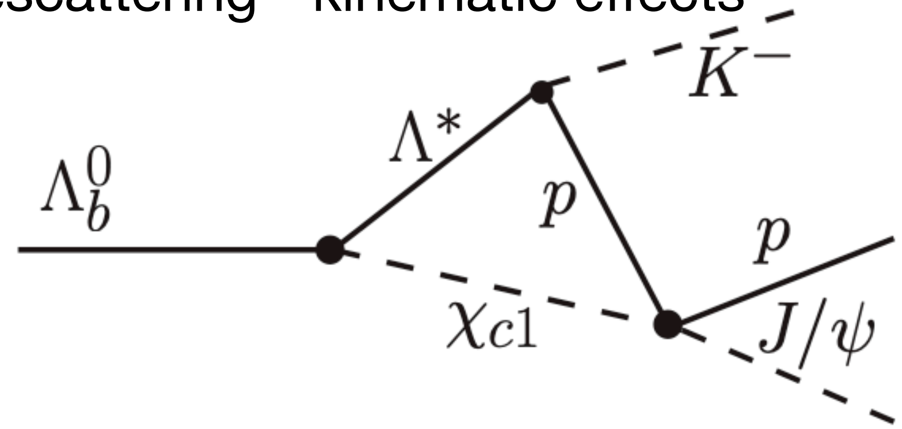
F.-K. Guo et al., Rev. Mod. Phys. 90 (2018) 015004

Tightly bound quarks - color forces



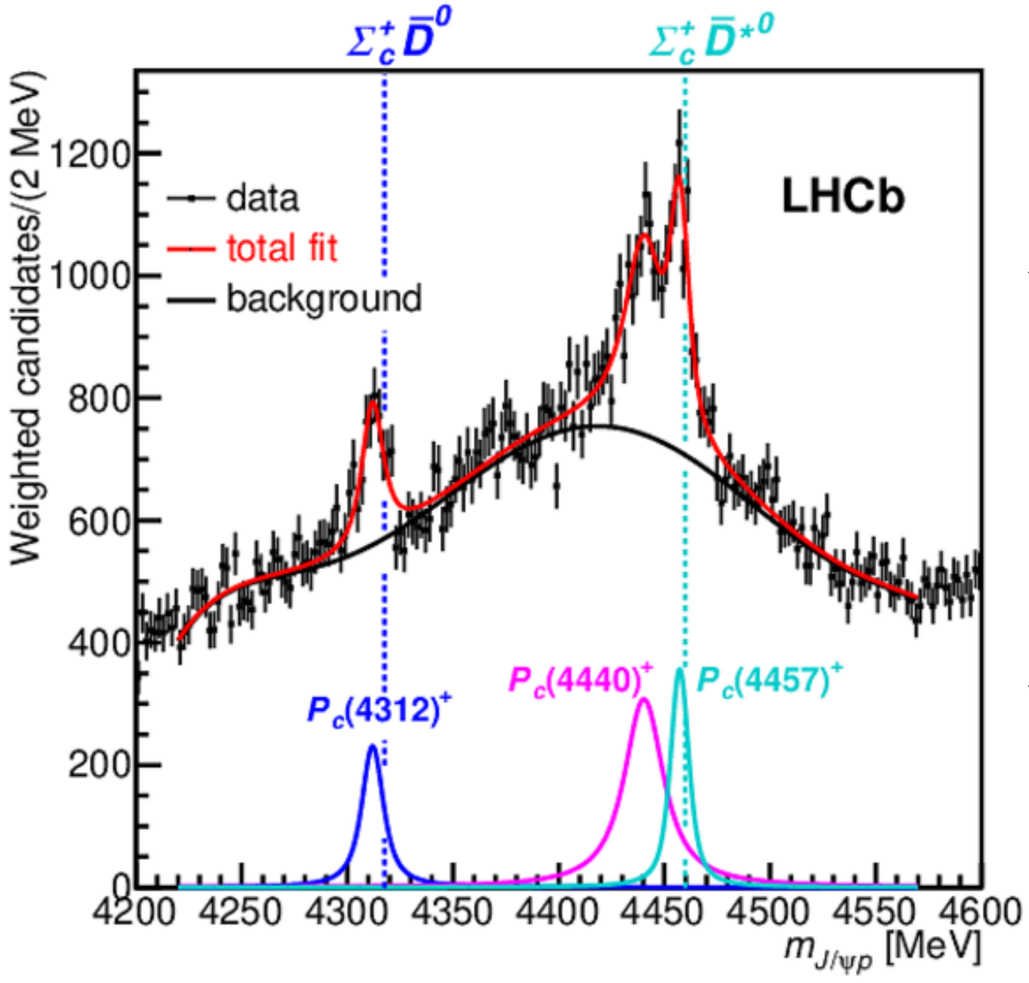
A. Esposito, A Pilloni, A. D. Polosa, Phys. Rept. 668 (2017) 1
J.-M. Richard, Few Body Syst. 57 (2016) 1185

Rescattering - kinematic effects



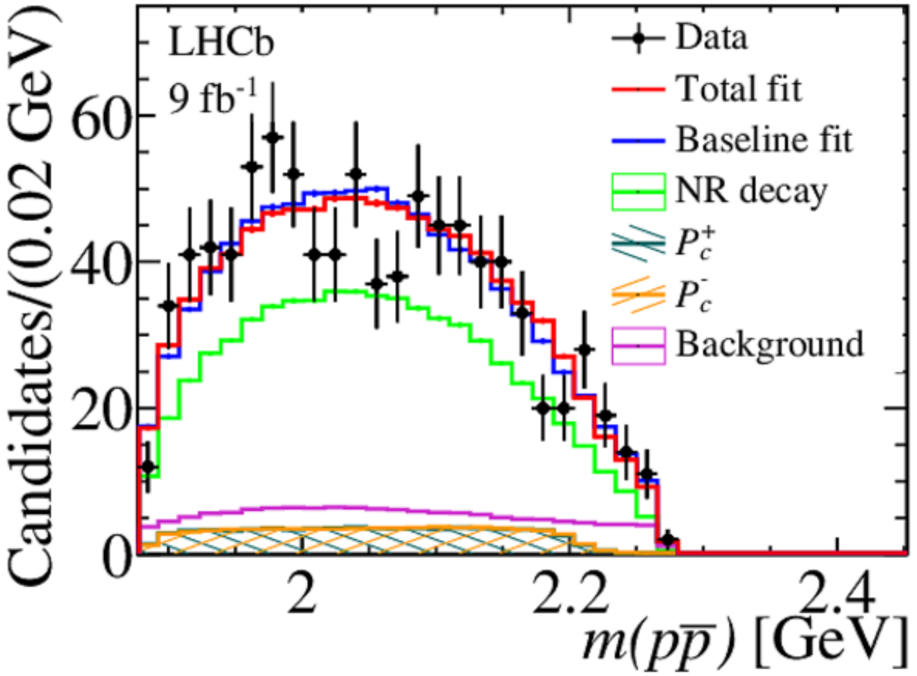
F. Guo et al., Phys. Rev. D 92, 071502 (2015)

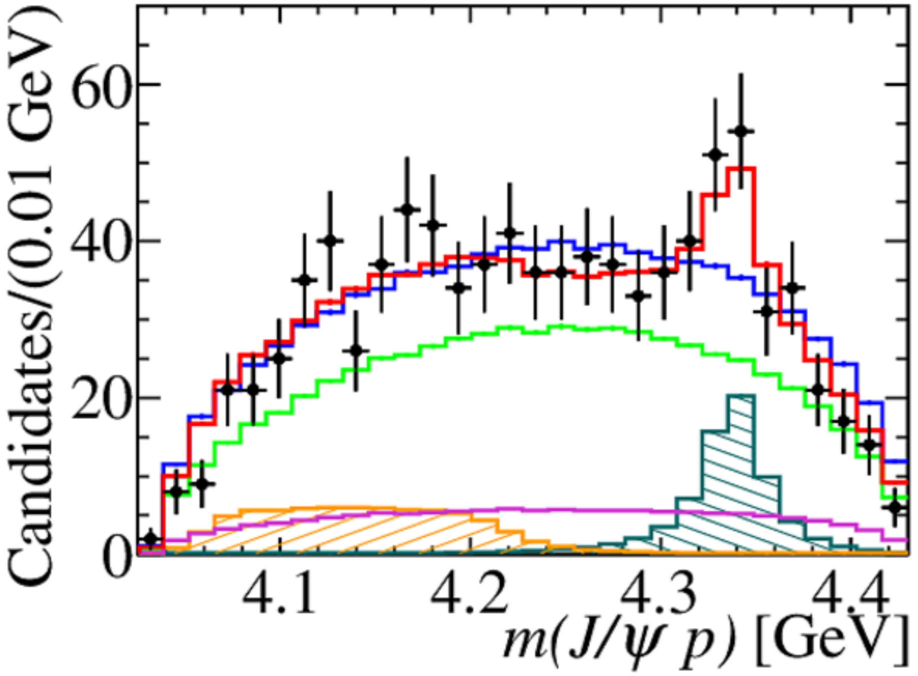
5-quark states: a discovery and more hints



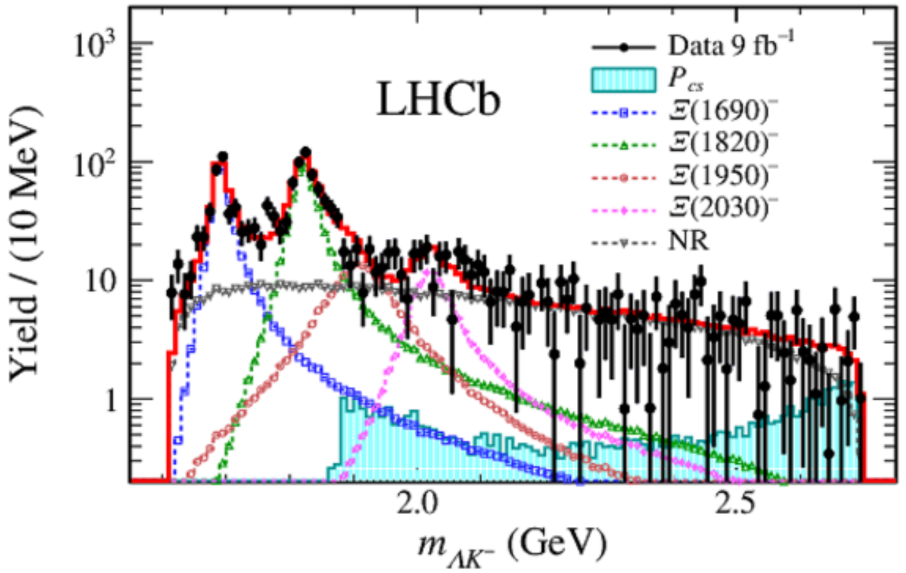
PHYS. REV. LETT. 122 (2019) 222001

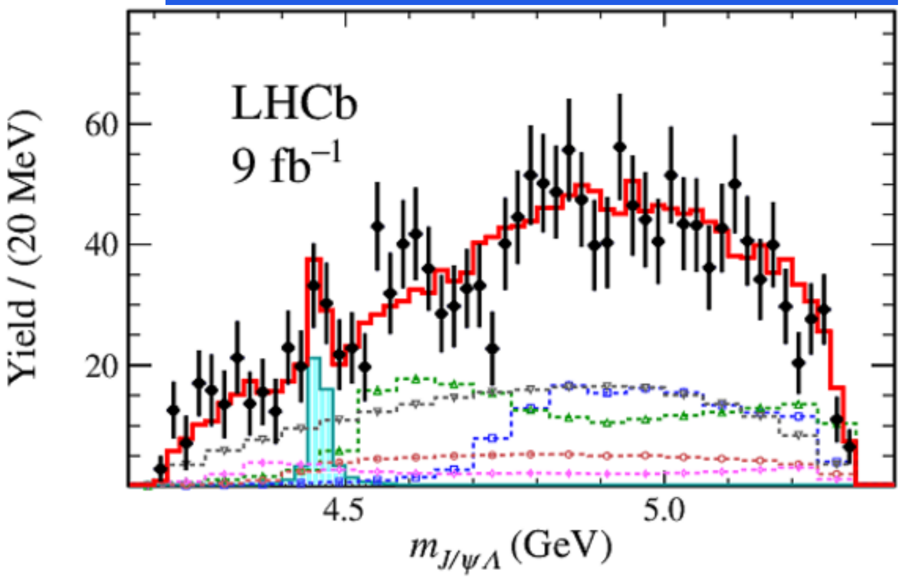
Phys.Rev.Lett.128(2022):062001





SCIENCE BULLETIN 66 (2021) 1278





The latest member of the zoo: $P^{\Lambda}_{\psi s}(4338)$

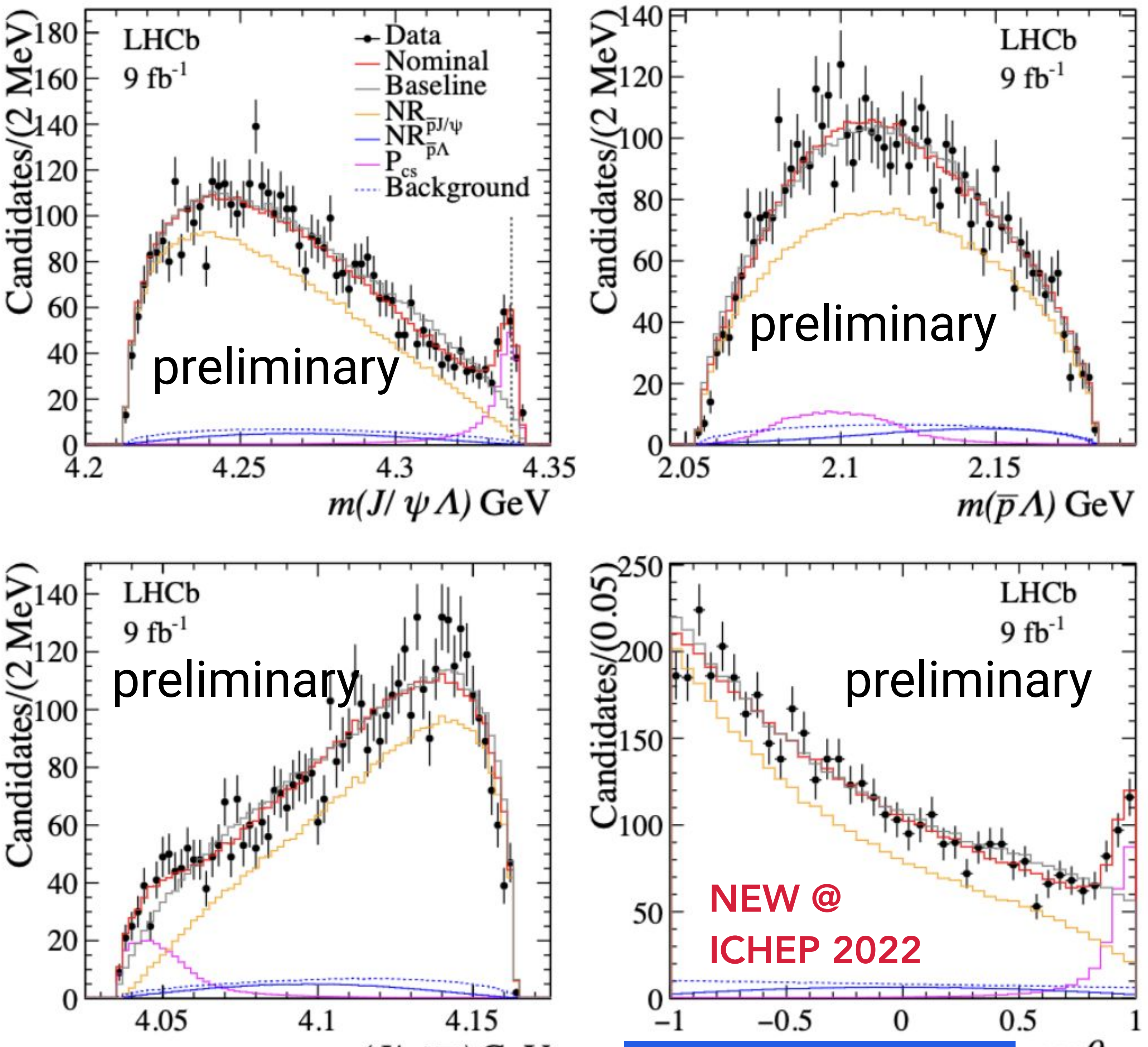
Clear observation of a five-quark state decaying into $J/\psi\Lambda$

Based on a 10x bigger dataset than previous CMS analysis of the same $B \to J/\psi\Lambda p$ final state

Full amplitude analysis testing numerous alternative hypotheses

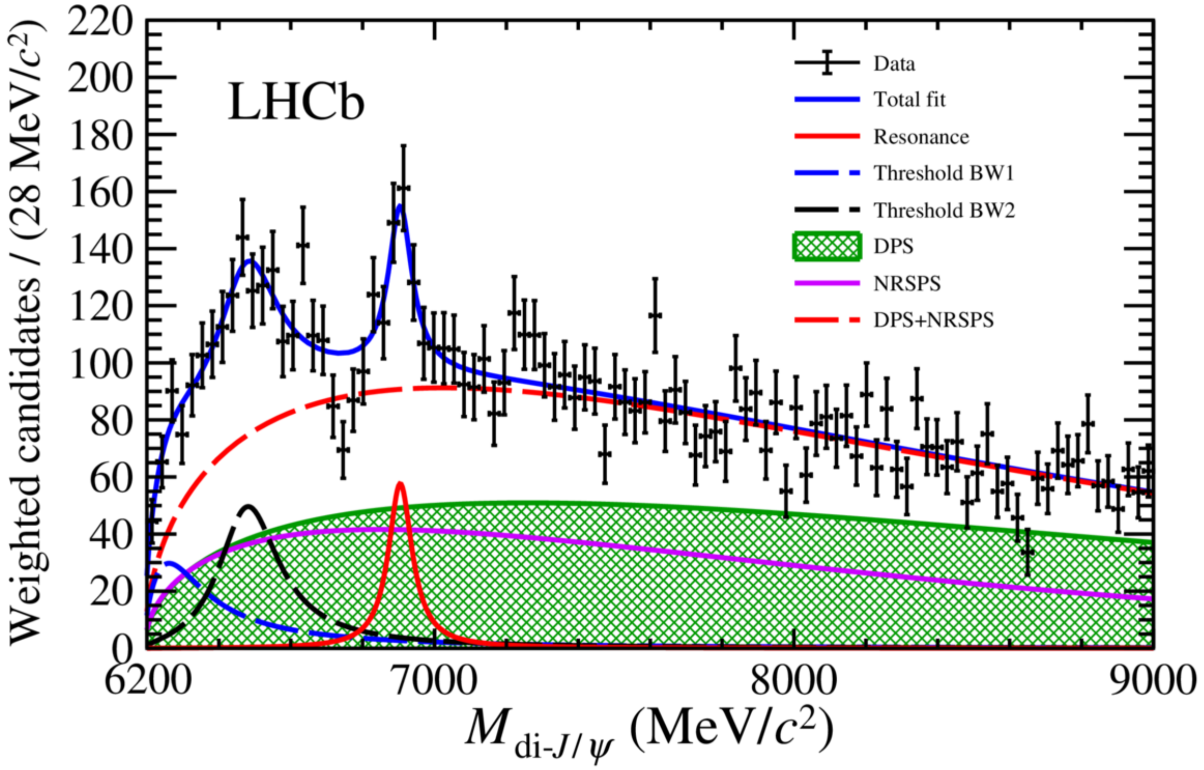
J = 1/2 assigned, P=-1 preferred

$$M_{P_{cs}} = 4338.2 \pm 0.7 \pm 0.4\,\mathrm{MeV}$$
$$\Gamma_{P_{cs}} = 7.0 \pm 1.2 \pm 1.3\,\mathrm{MeV}$$

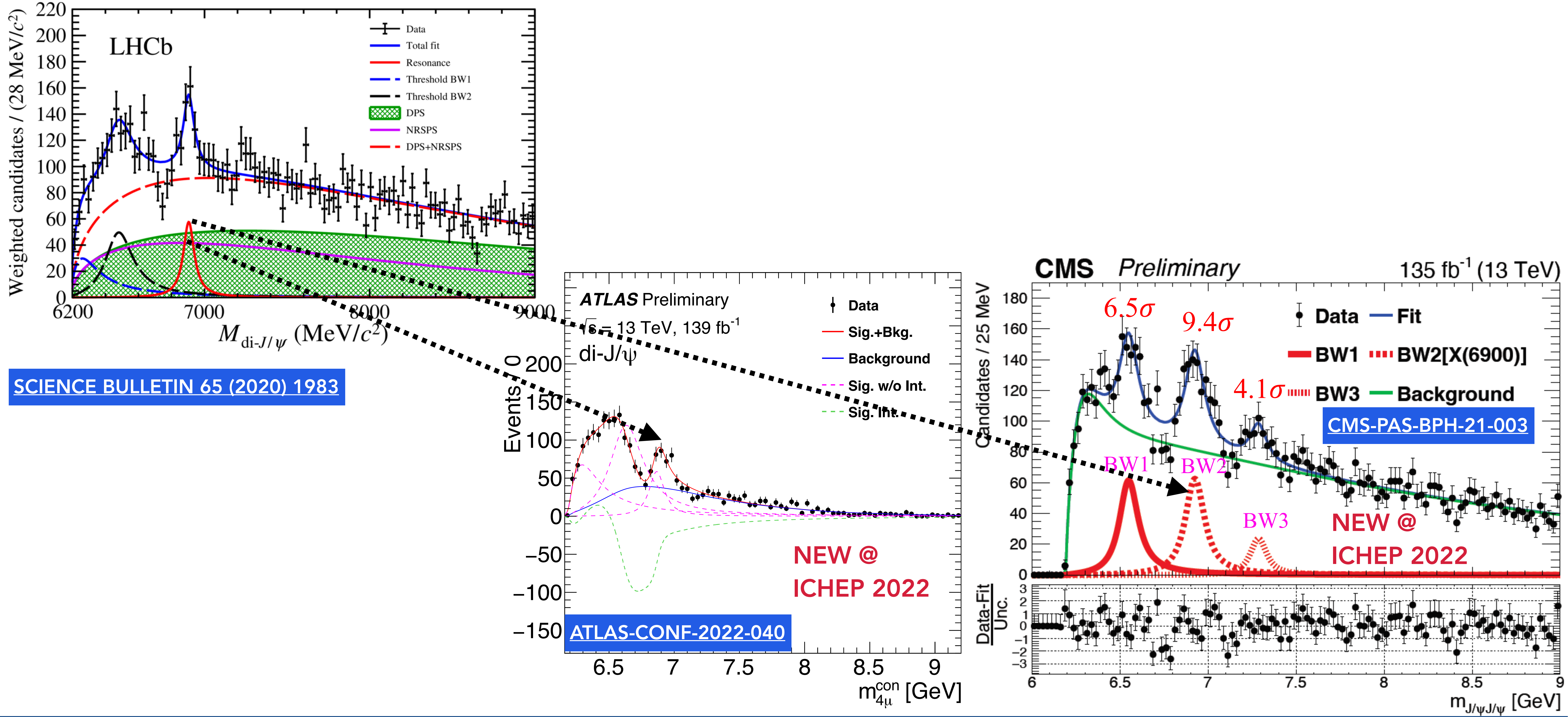


Nicola Neri @ ICHEP 2022

4-quark states: a growing family



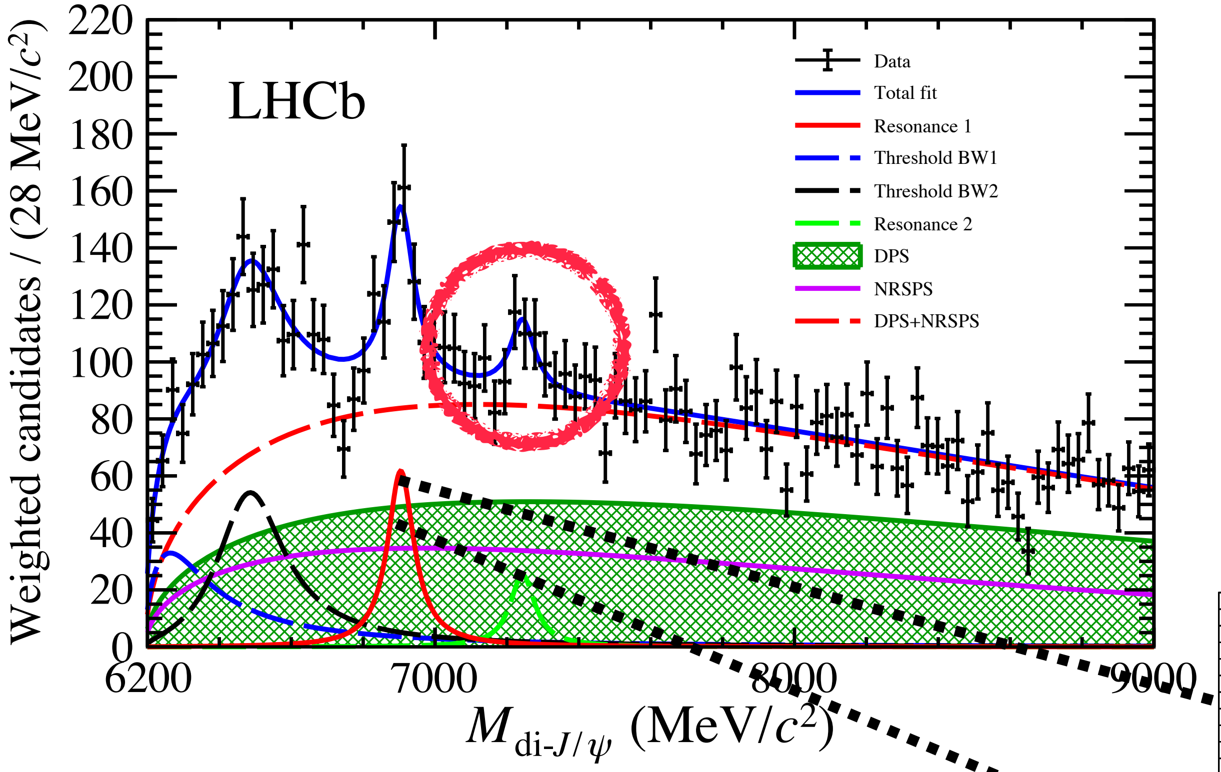
4-quark states: a growing family



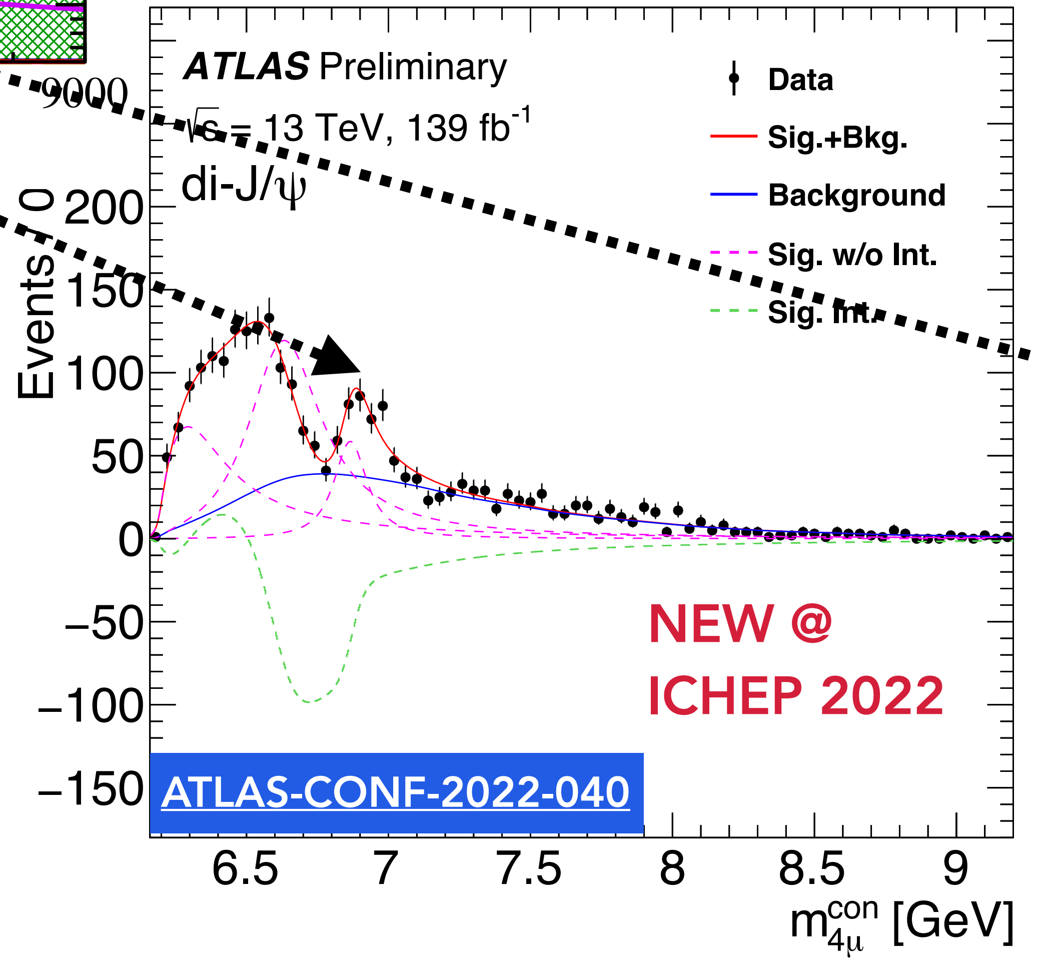
Spectacular confirmation of LHCb's double-J/Ψ signal from ATLAS and CMS, and new discovery!

4-quark states: a growing family

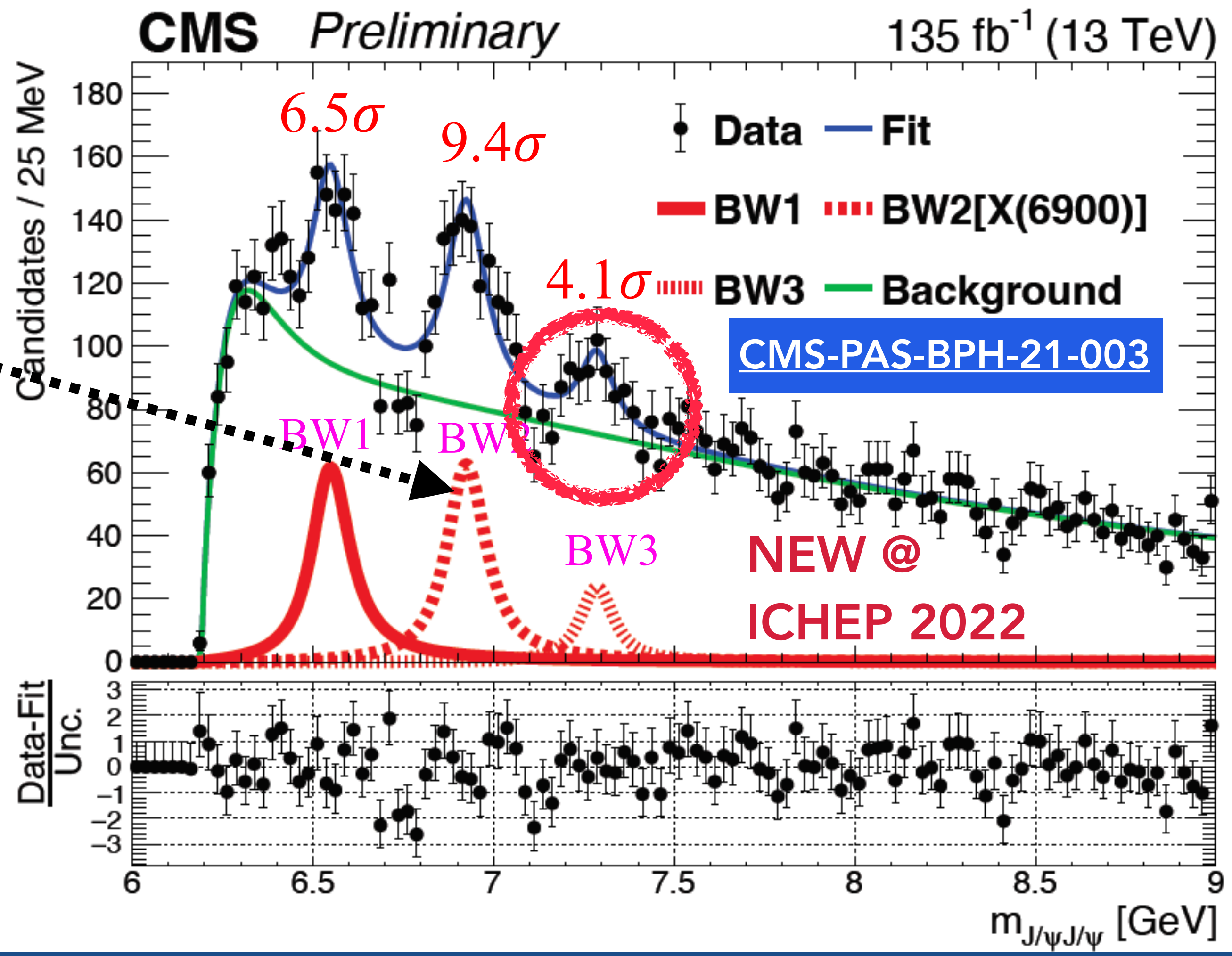
Bump on right-hand side of 6900 is prominent in CMS data and a hint exists in LHCb?



SCIENCE BULLETIN 65 (2020) 1983

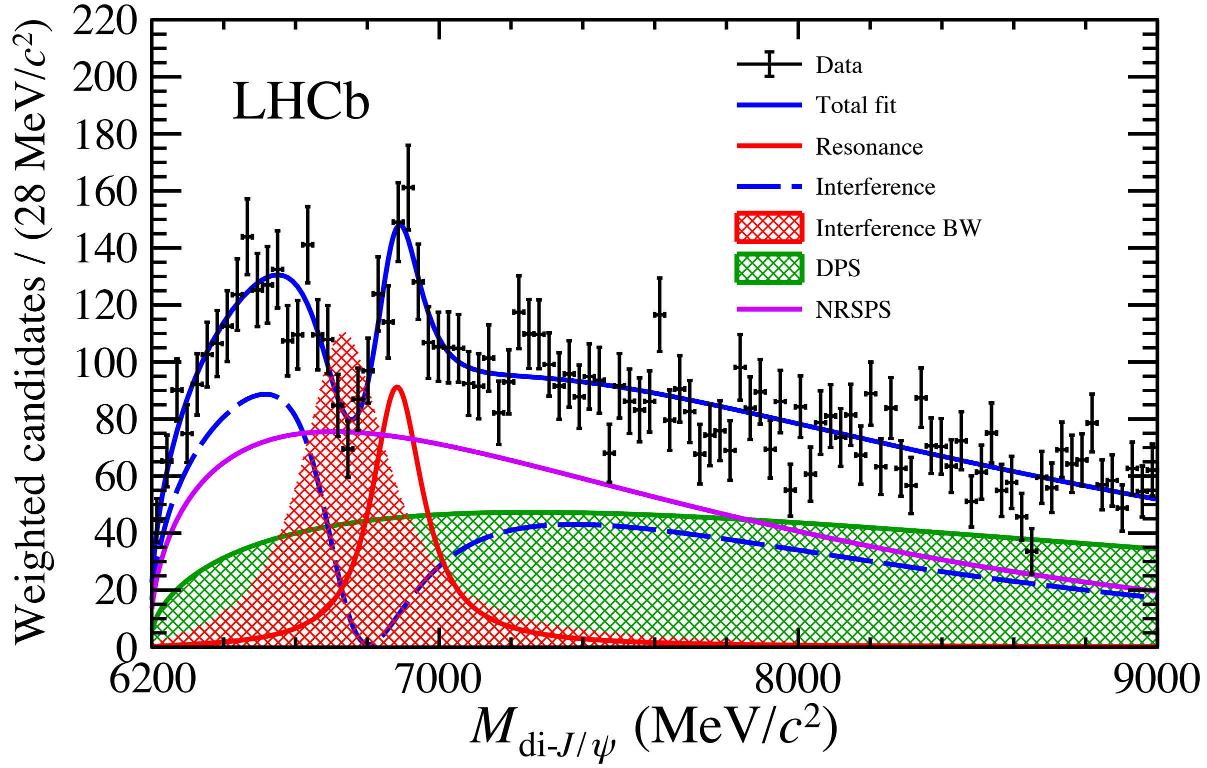


ATLAS-CONF-2022-040



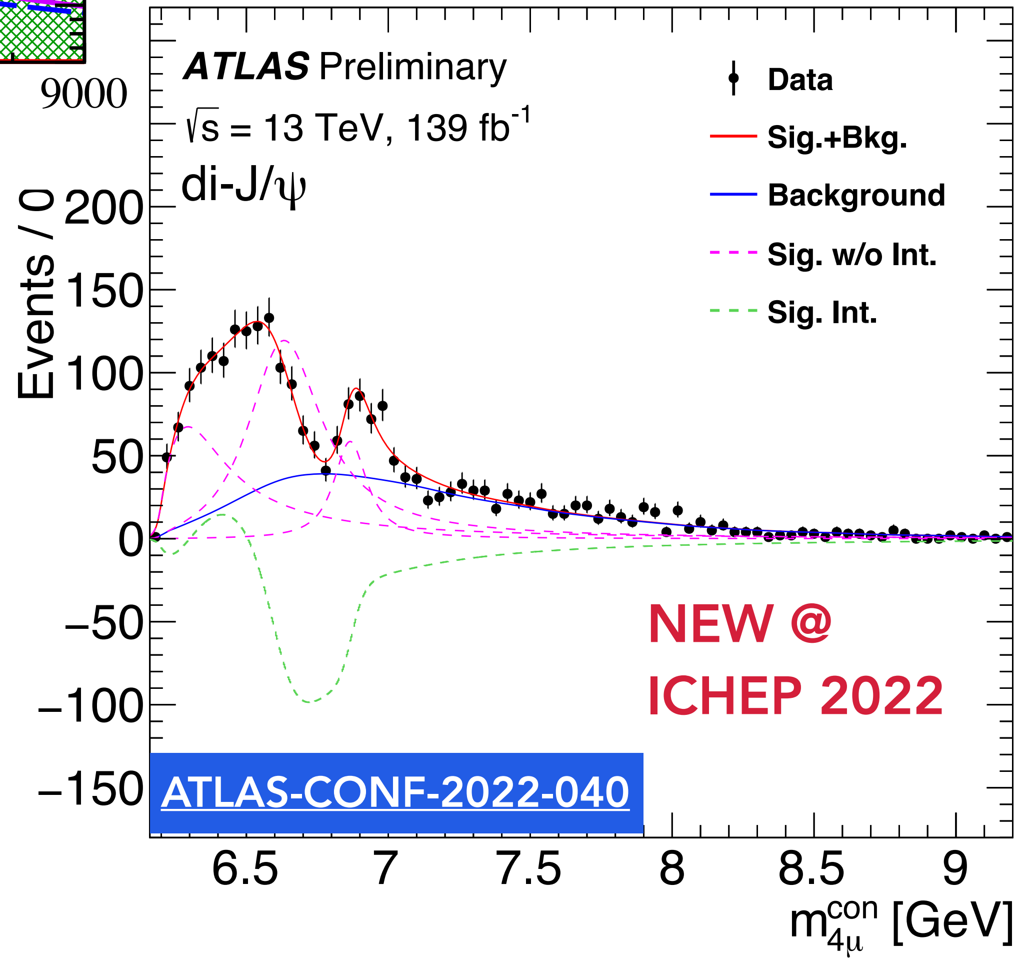
CMS-PAS-BPH-21-003

4-quark states: a growing family

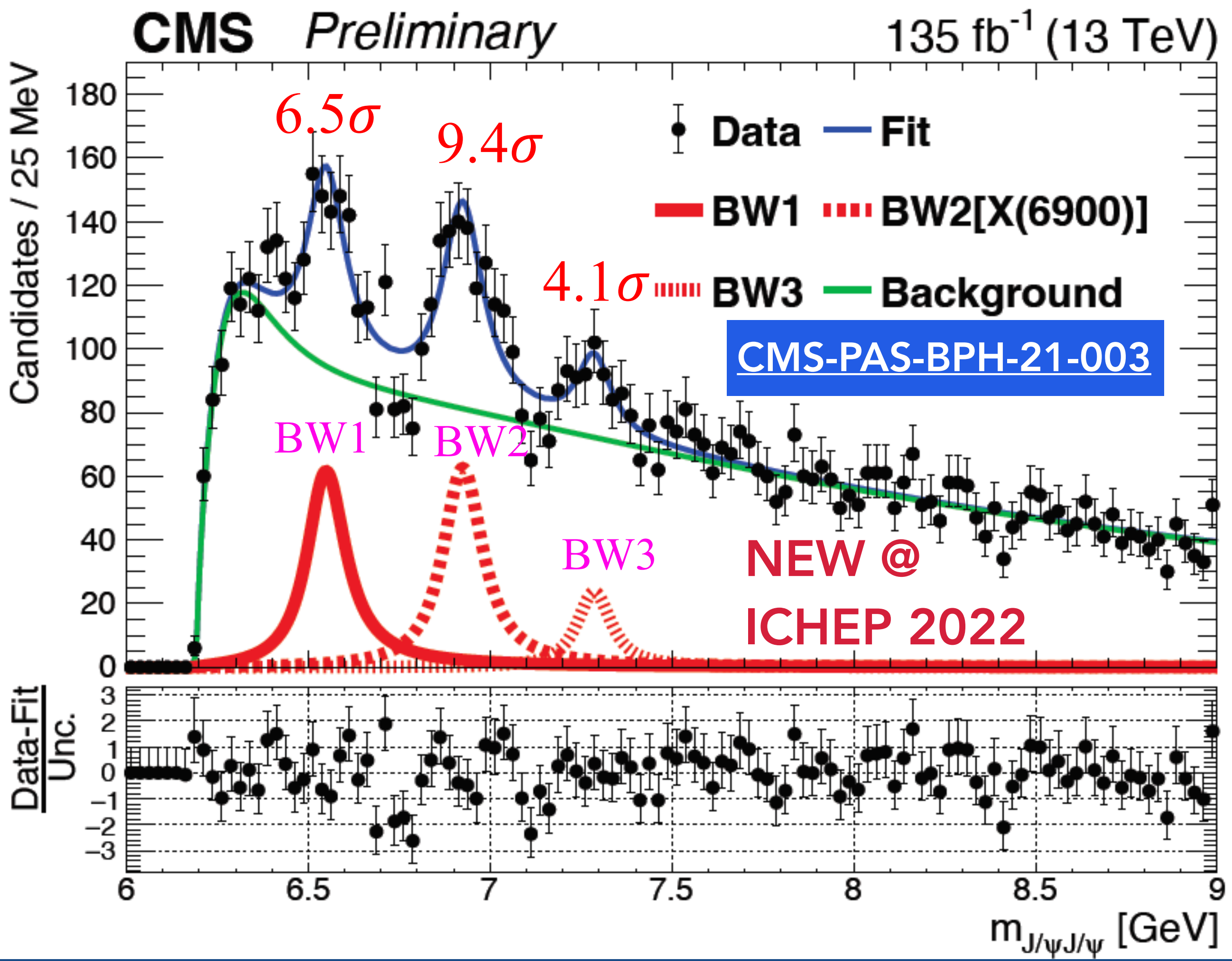


SCIENCE BULLETIN 65 (2020) 1983

Both ATLAS and CMS fit their data with various models also explored in the LHCb paper.
The data is suggestive of interference effects, however further study and more data is needed!

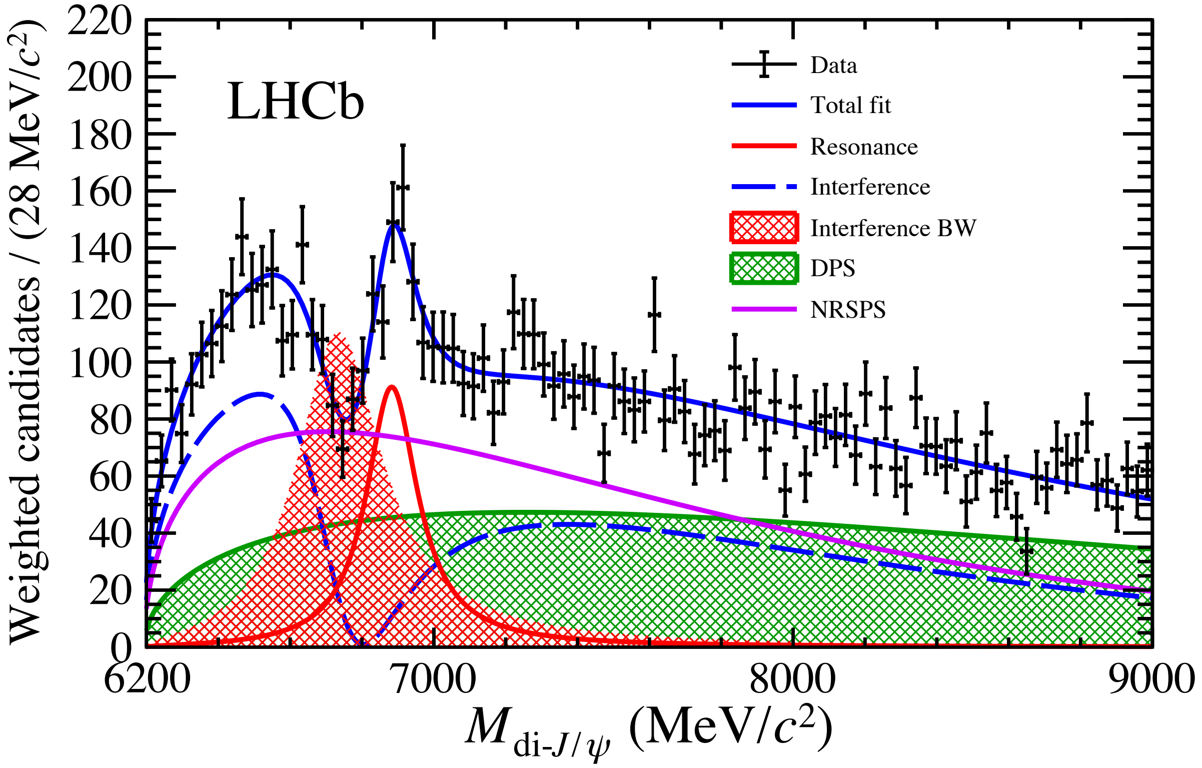


ATLAS-CONF-2022-040



CMS-PAS-BPH-21-003

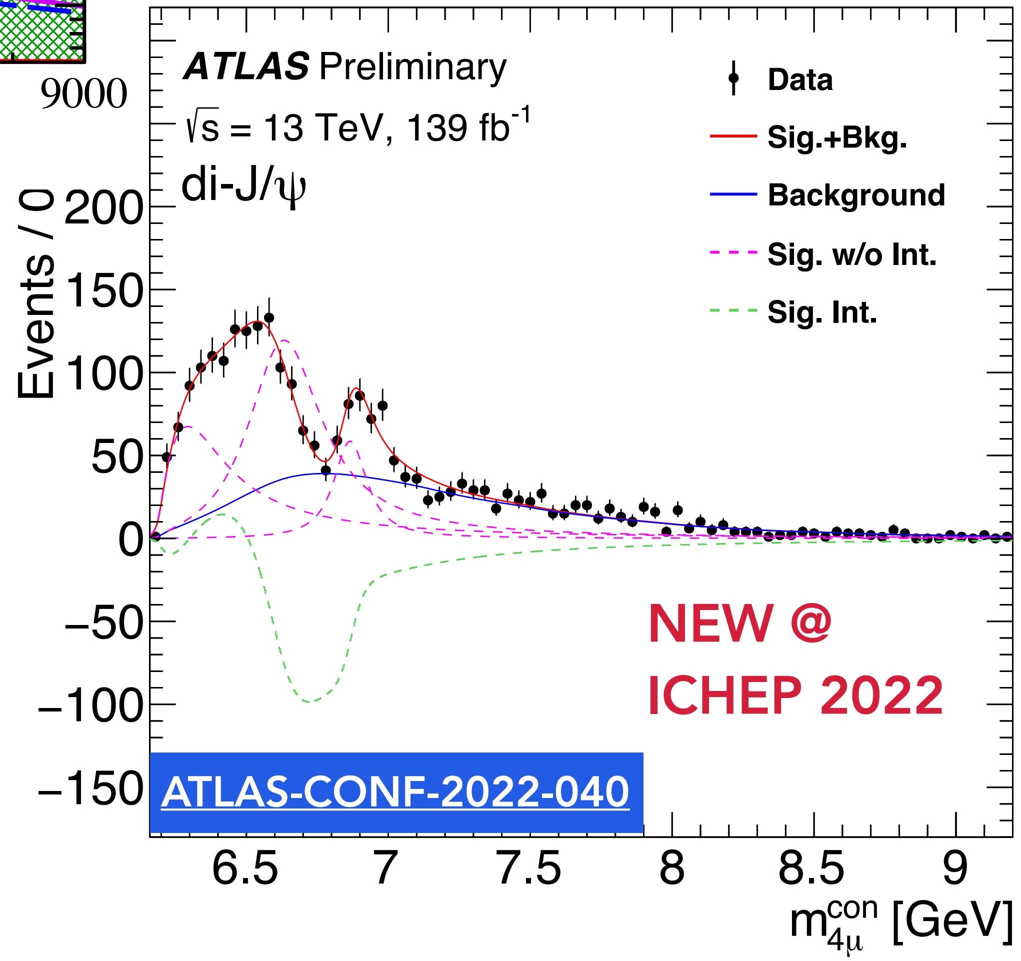
4-quark states: a growing family



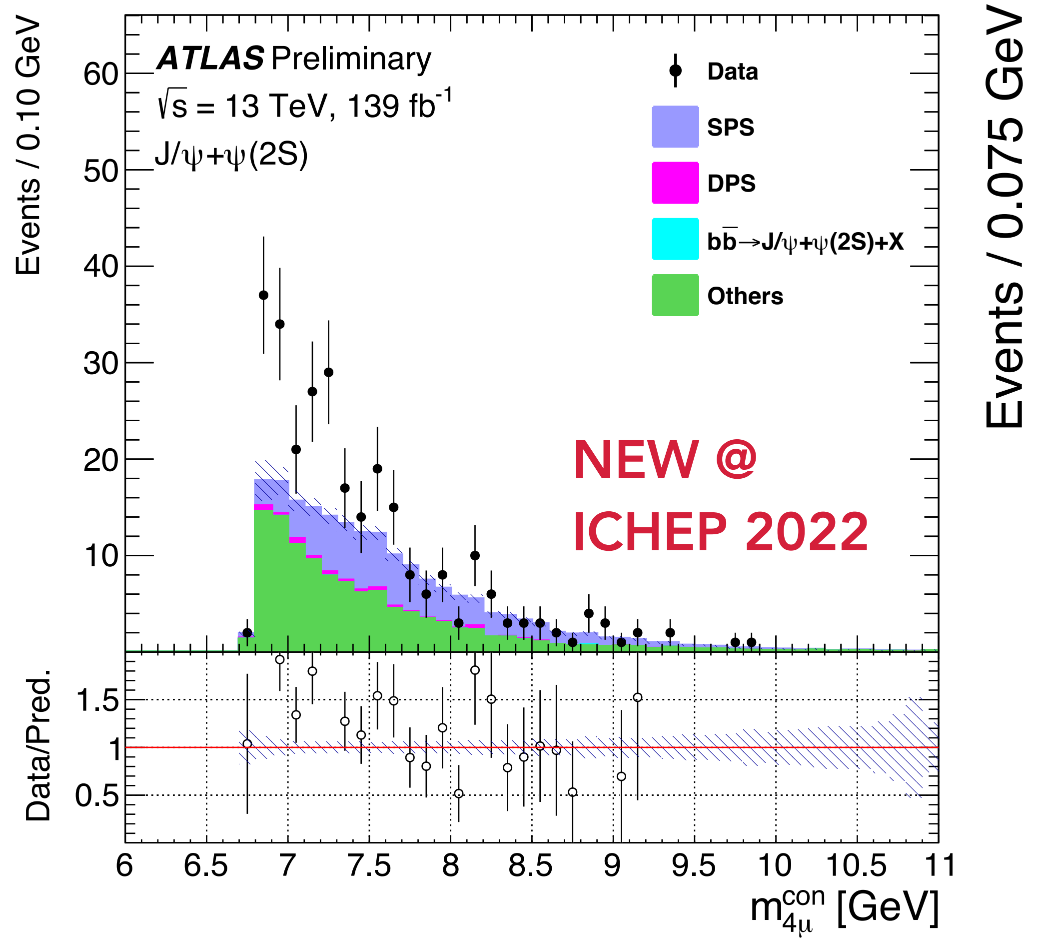
SCIENCE BULLETIN 65 (2020) 1983

ATLAS also see an excess in $J/\Psi+\Psi(2S)$, precise nature and composition are for the moment unclear

Any structure in $J/\Psi+\Psi(2S)$ could appear in $J/\Psi+J/\Psi$ as a partially reconstructed decay



ATLAS-CONF-2022-040



Latest 4-quark states from LHCb

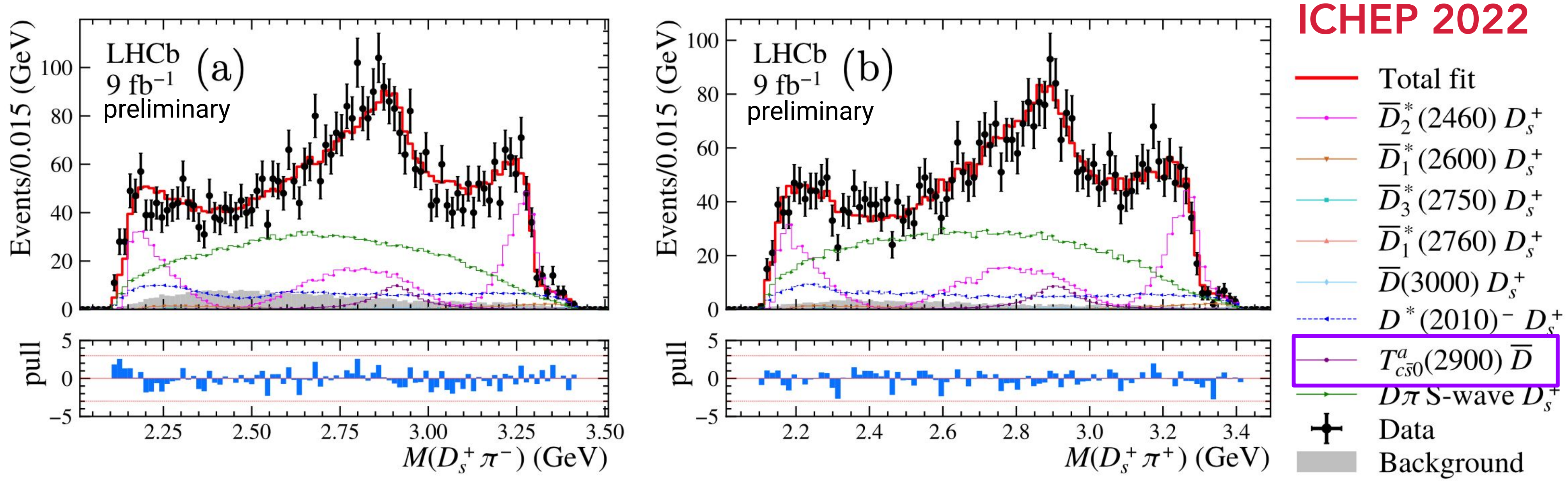
Observation of isospin triplet [csud] 4-quark states

X(3960) and X_{c0}(3930) are either not the same resonance, or they are the same non-conventional charmonium-like state

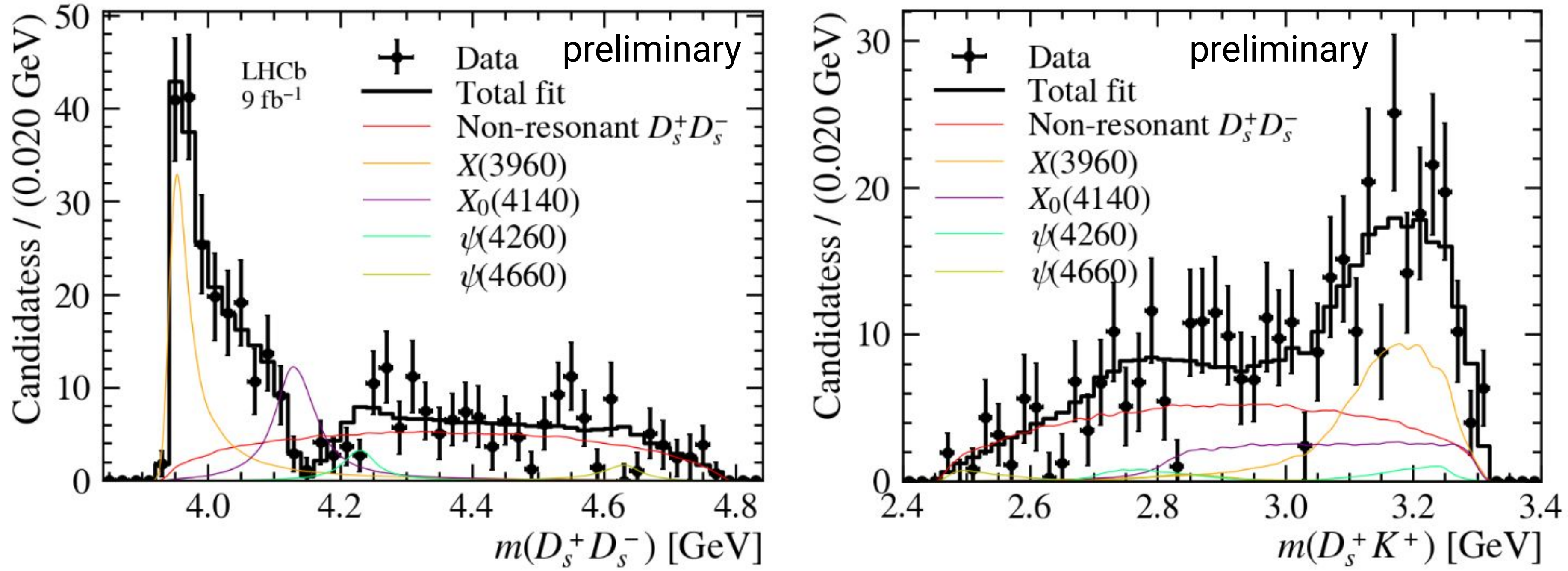
A lot of work remains to determine the properties of these particles

$B^0 \to \bar{D}^0 D_s^+ \pi^-$ $B^+ \to D^- D_s^+ \pi^+$

NEW @ ICHEP 2022



$M(D_s\pi)$ well described by adding a $J^P = 0^+$ $T^a_{c\bar{s}0}(2900)$ in each channel

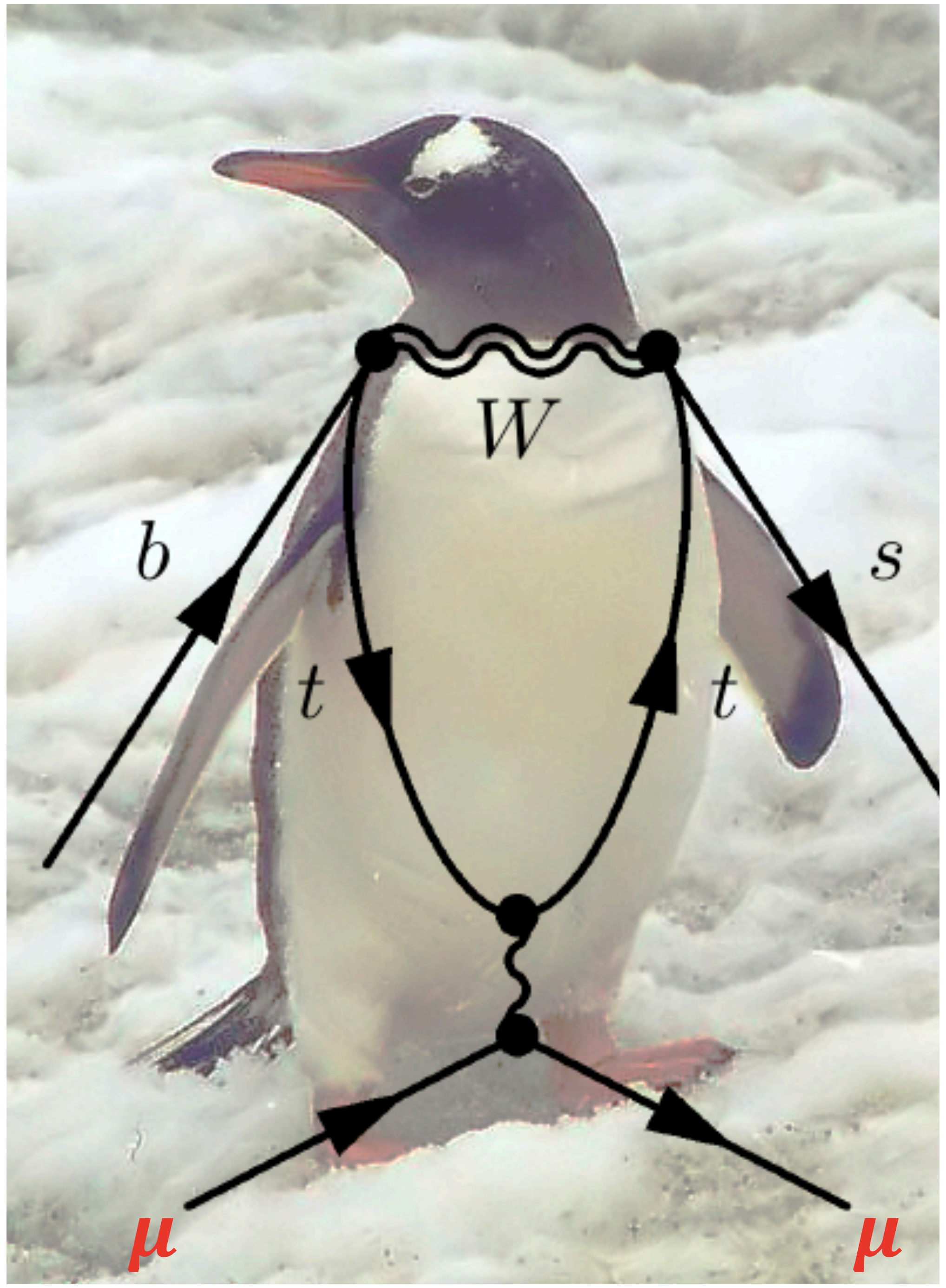


Anomalous couplings

$B^0, B_s^0 \to \mu\mu$: the king penguin

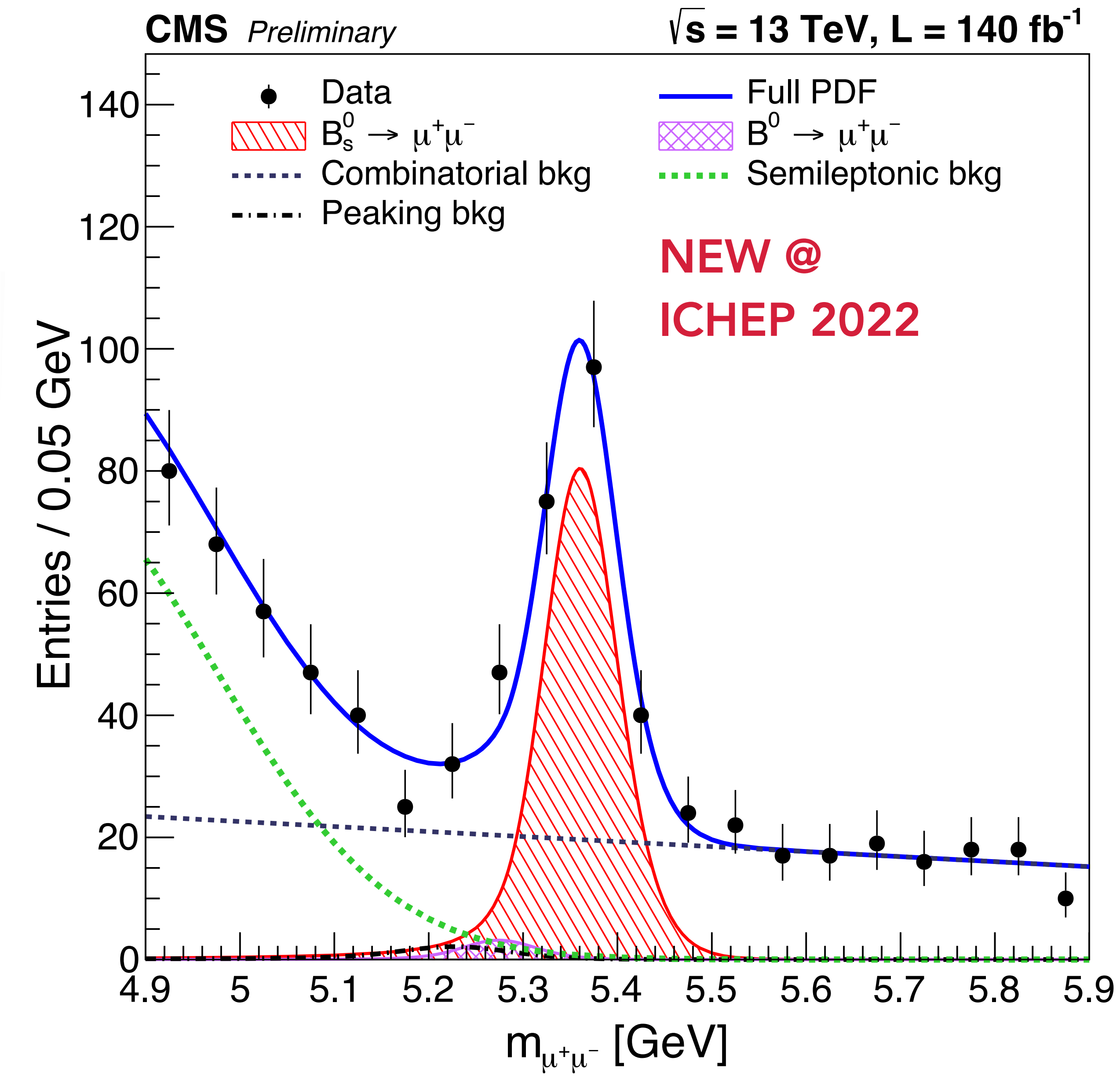
The ultimate experimental beauty hadron decay for probing BSM effects

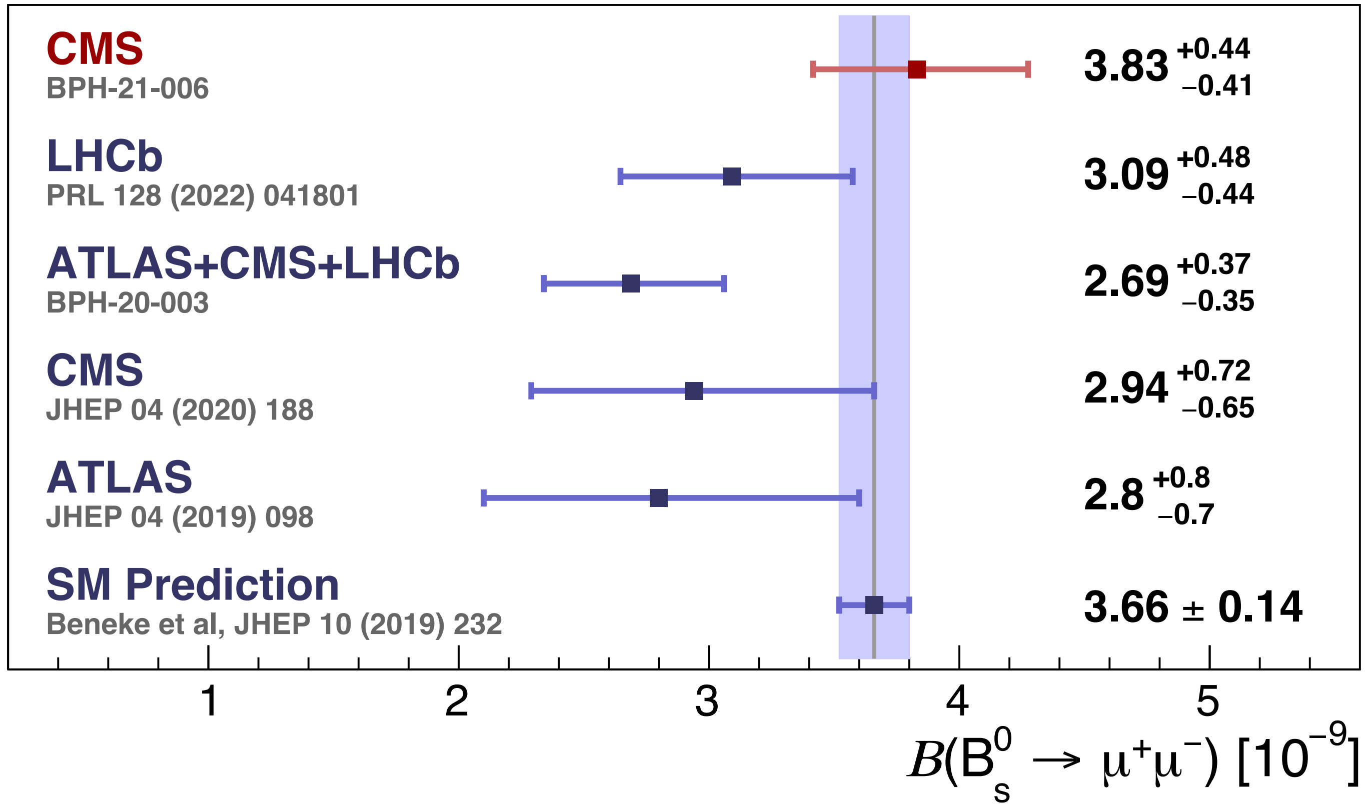
1. Highly suppressed in the SM
2. Highly enhanceable elsewhere
3. Experimentally accessible
4. Theoretically pristine

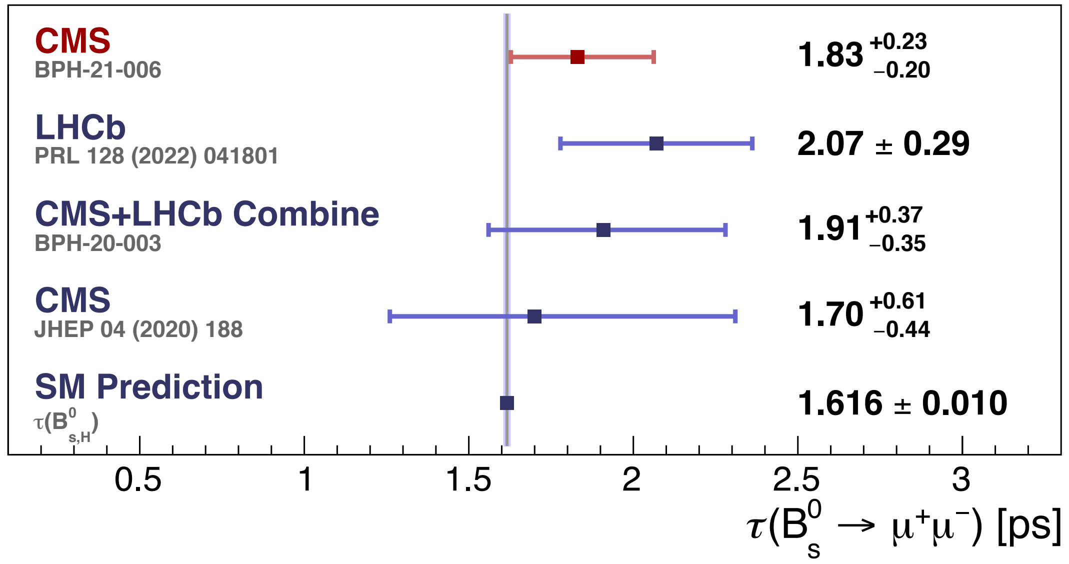


Status with new world-best CMS result

CMS-PAS-BPH-21-006

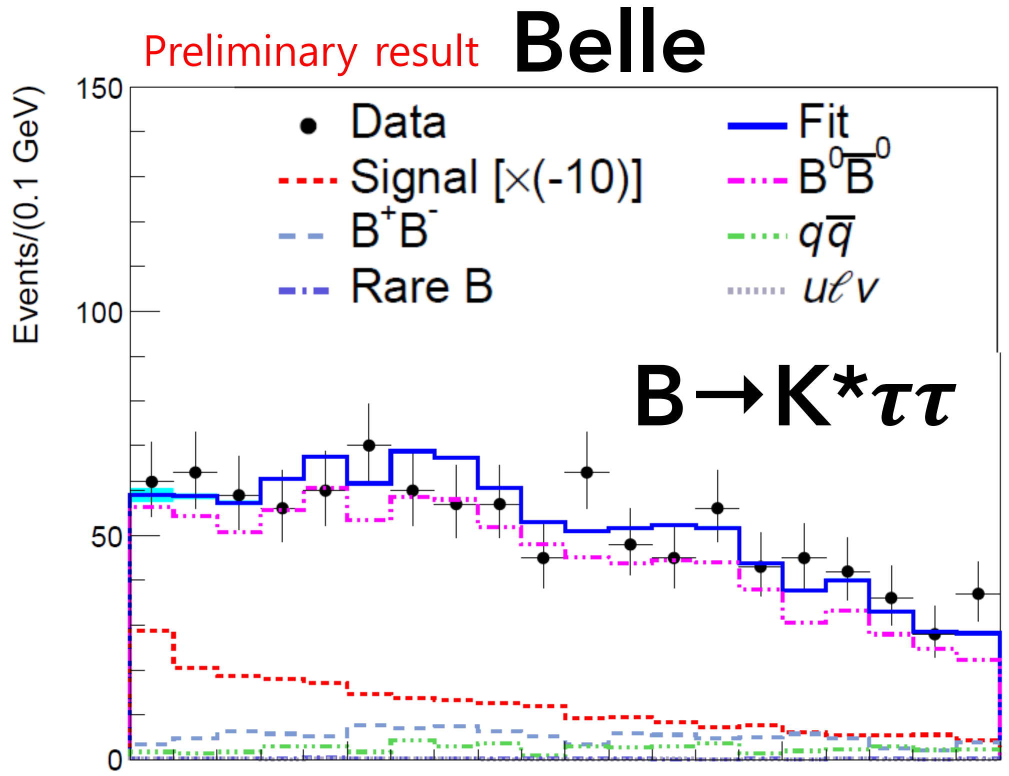




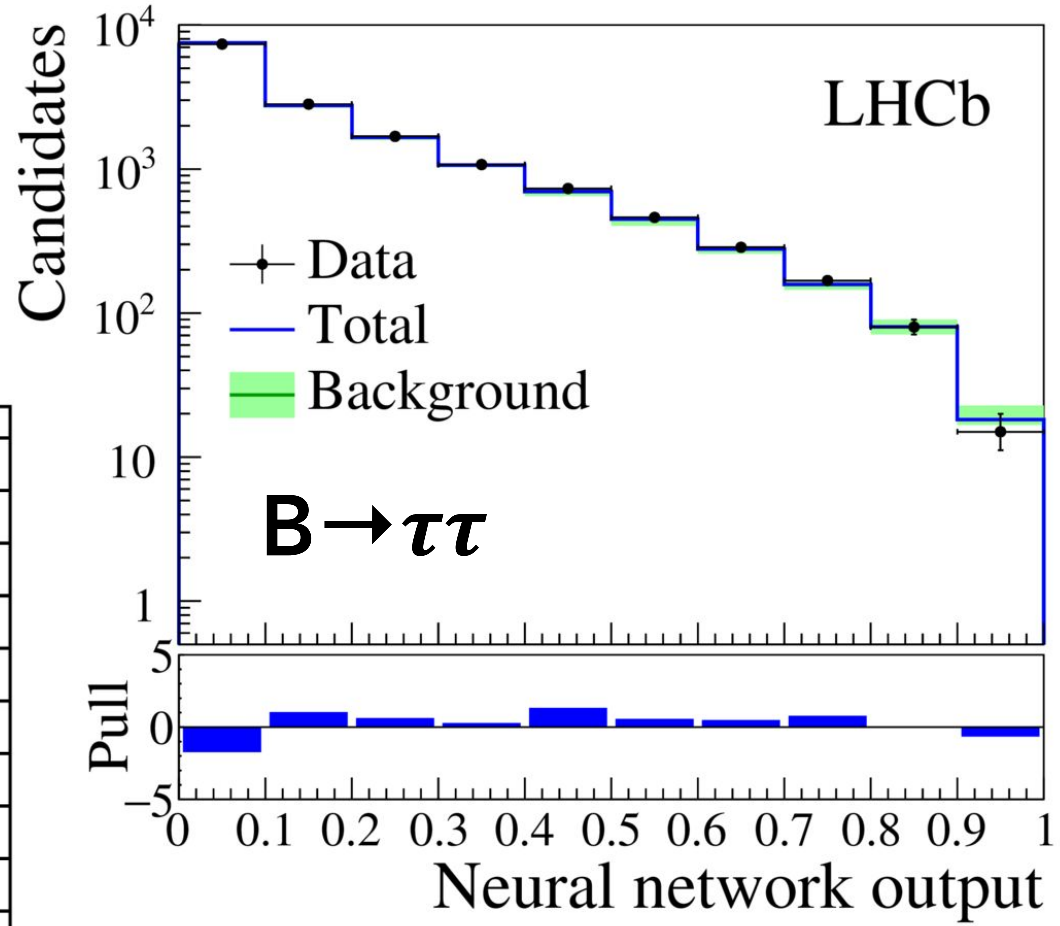


2/3 pieces of the LHC Run 1+2 legacy now in place. Excellent agreement with SM but a great deal of work ahead to observe $B^0 \to \mu\mu$ and eventually also $b \to \mu\mu\gamma$?

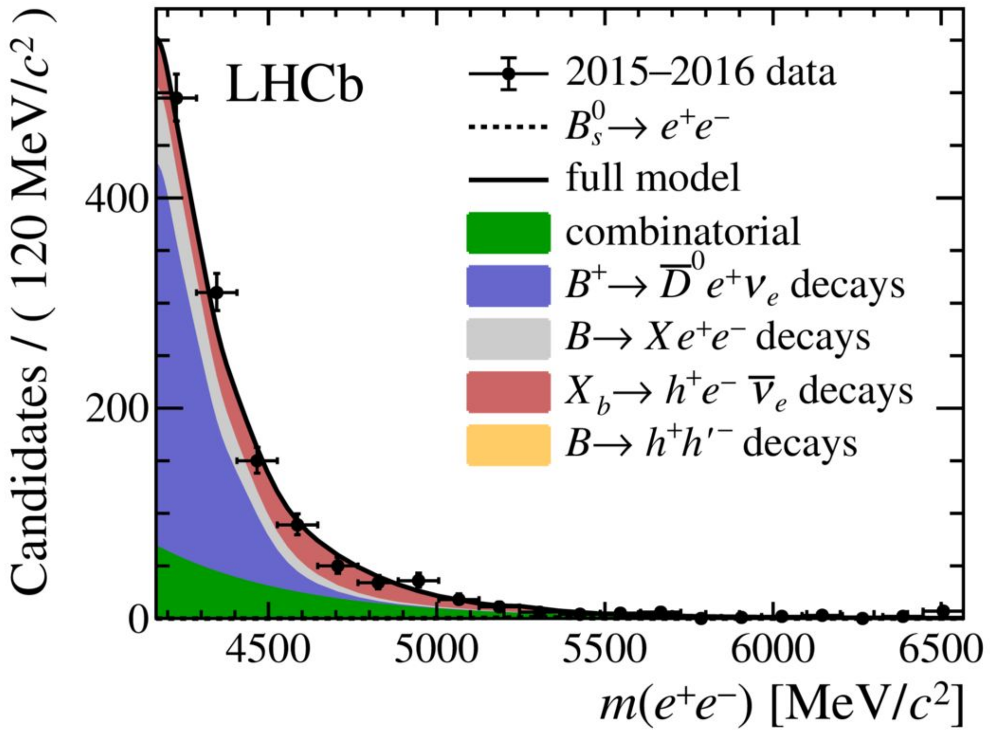
Beyond $\mu\mu$: other leptonic b decays



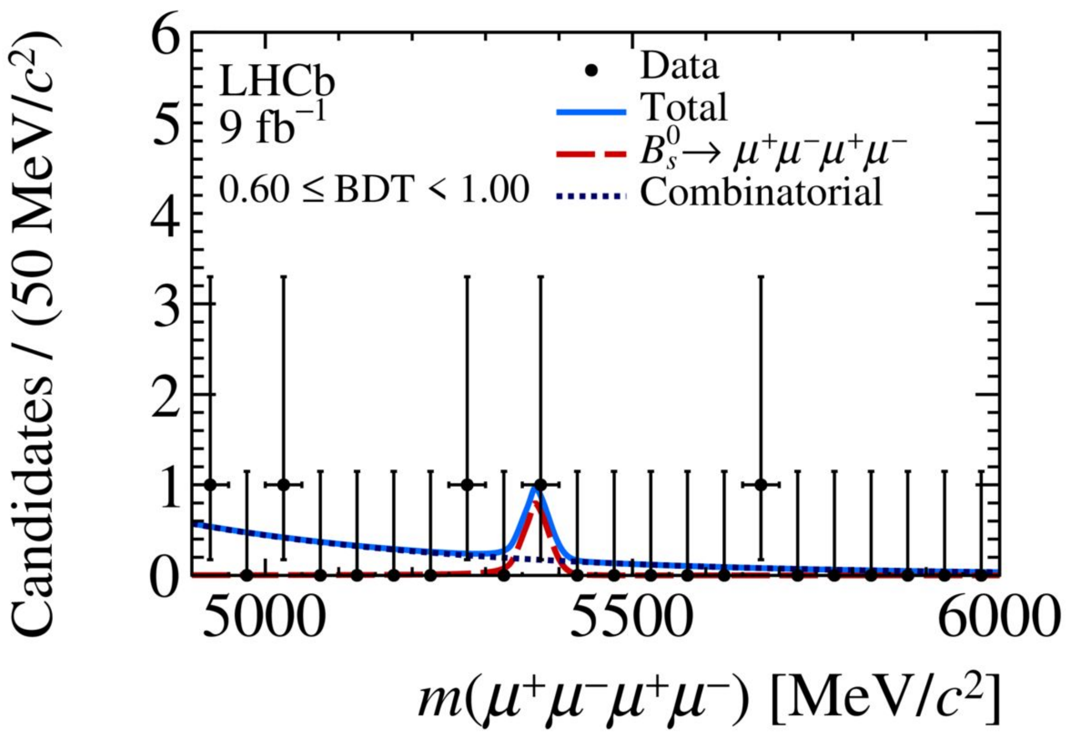
Kookhyun Kang @ ICHEP 2022



Phys.Rev.Lett.118(2017):251802



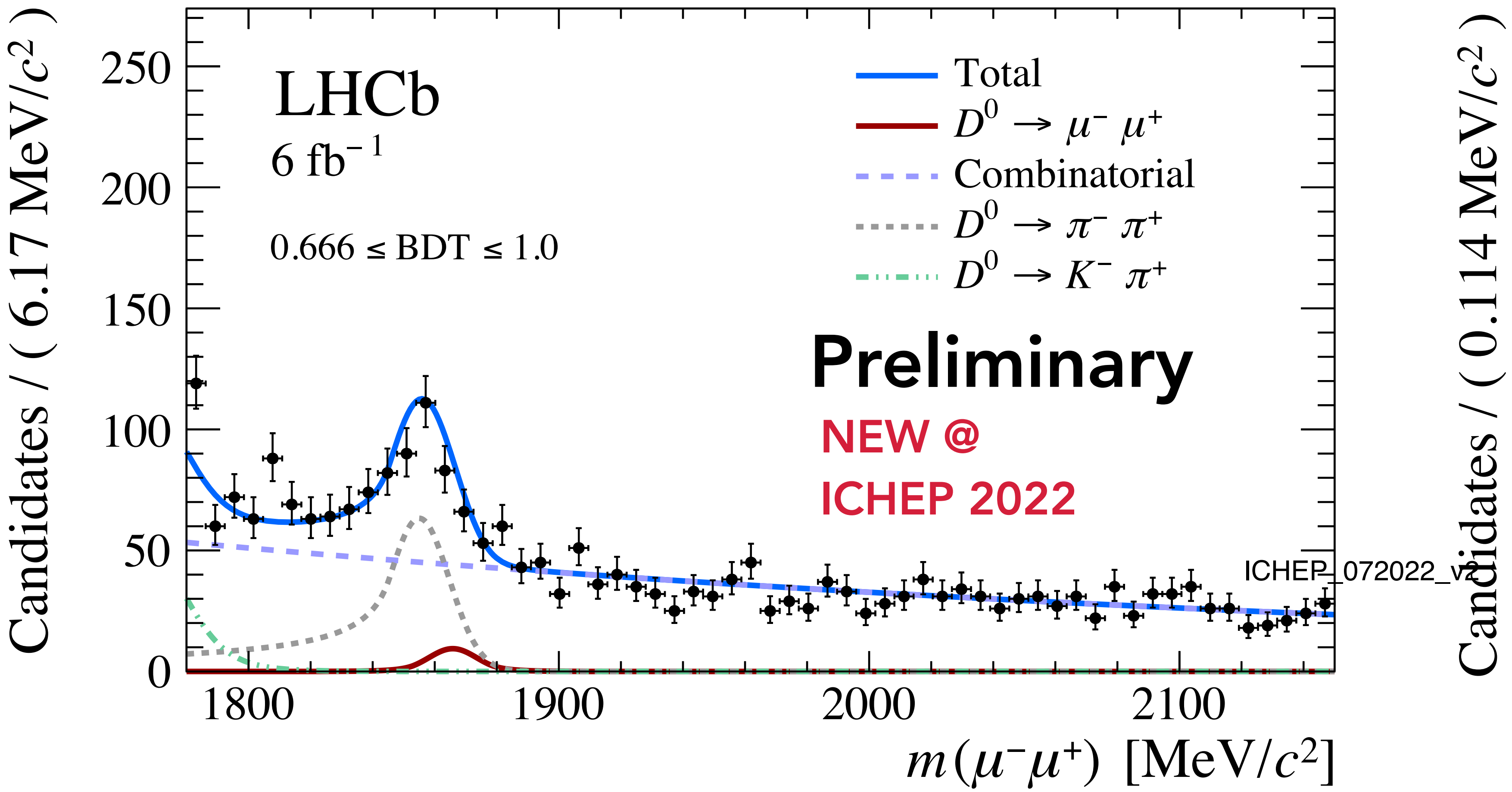
Phys.Rev.Lett.124(2020):211802

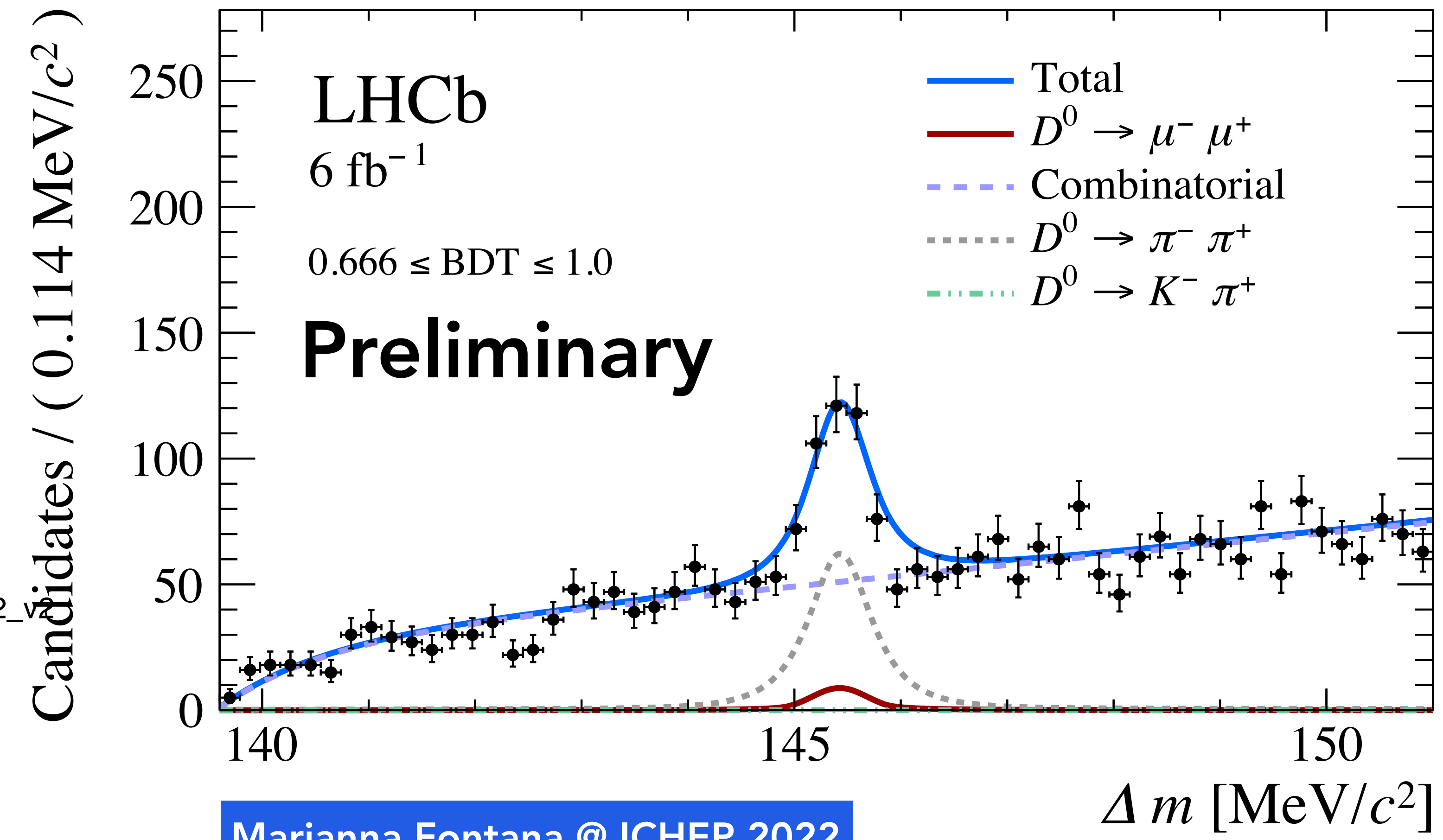


JHEP 03 (2022) 109

Phenomenologically complementary but in many cases far more experimentally challenging.

LHC, ultimate charm factory: $D^0 \to \mu\mu$





Marianna Fontana @ ICHEP 2022

Extremely challenging due to overwhelming backgrounds e.g. $D^0 \to \pi\pi$.

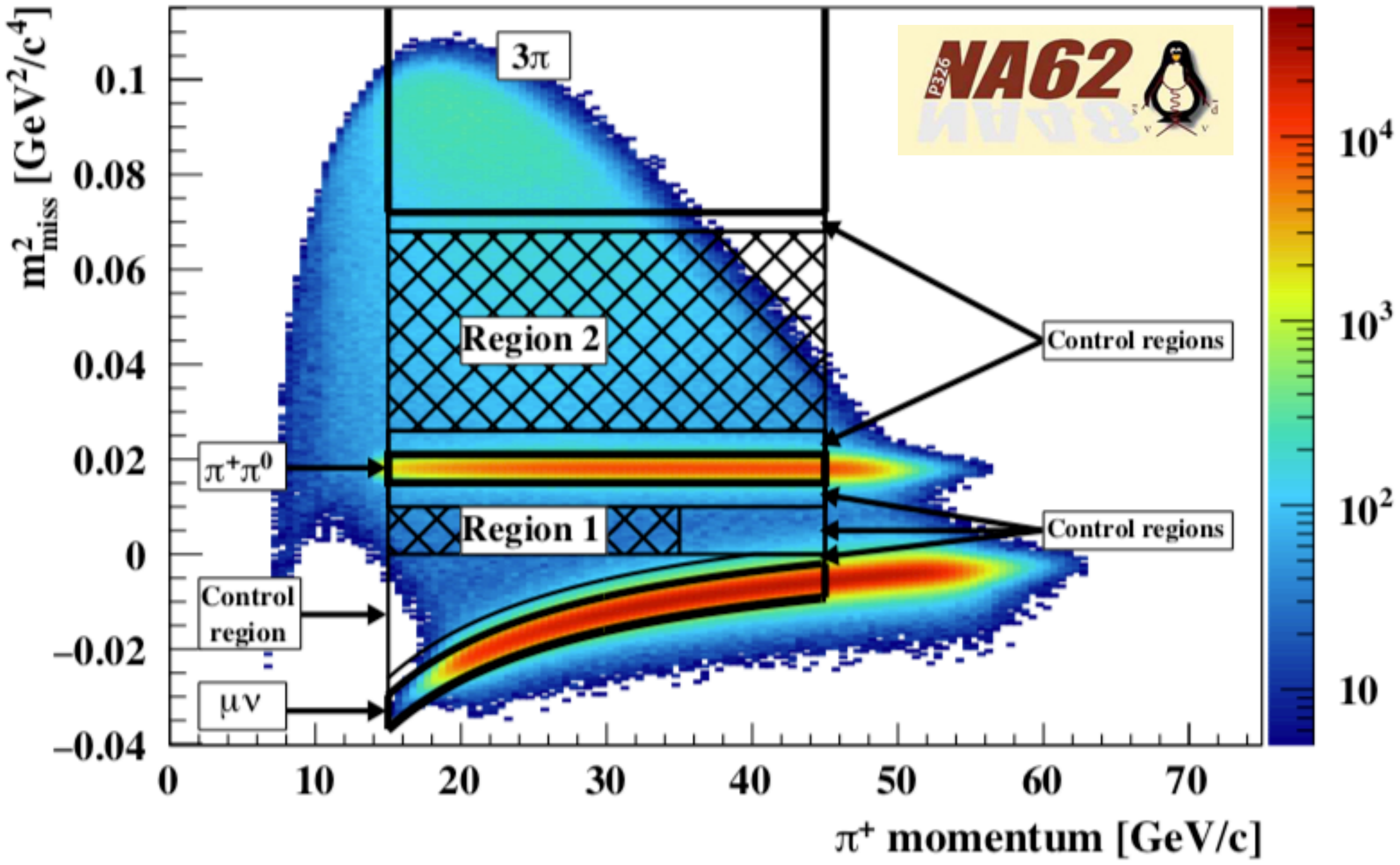
Stringent validation of LHCb's muon identification!

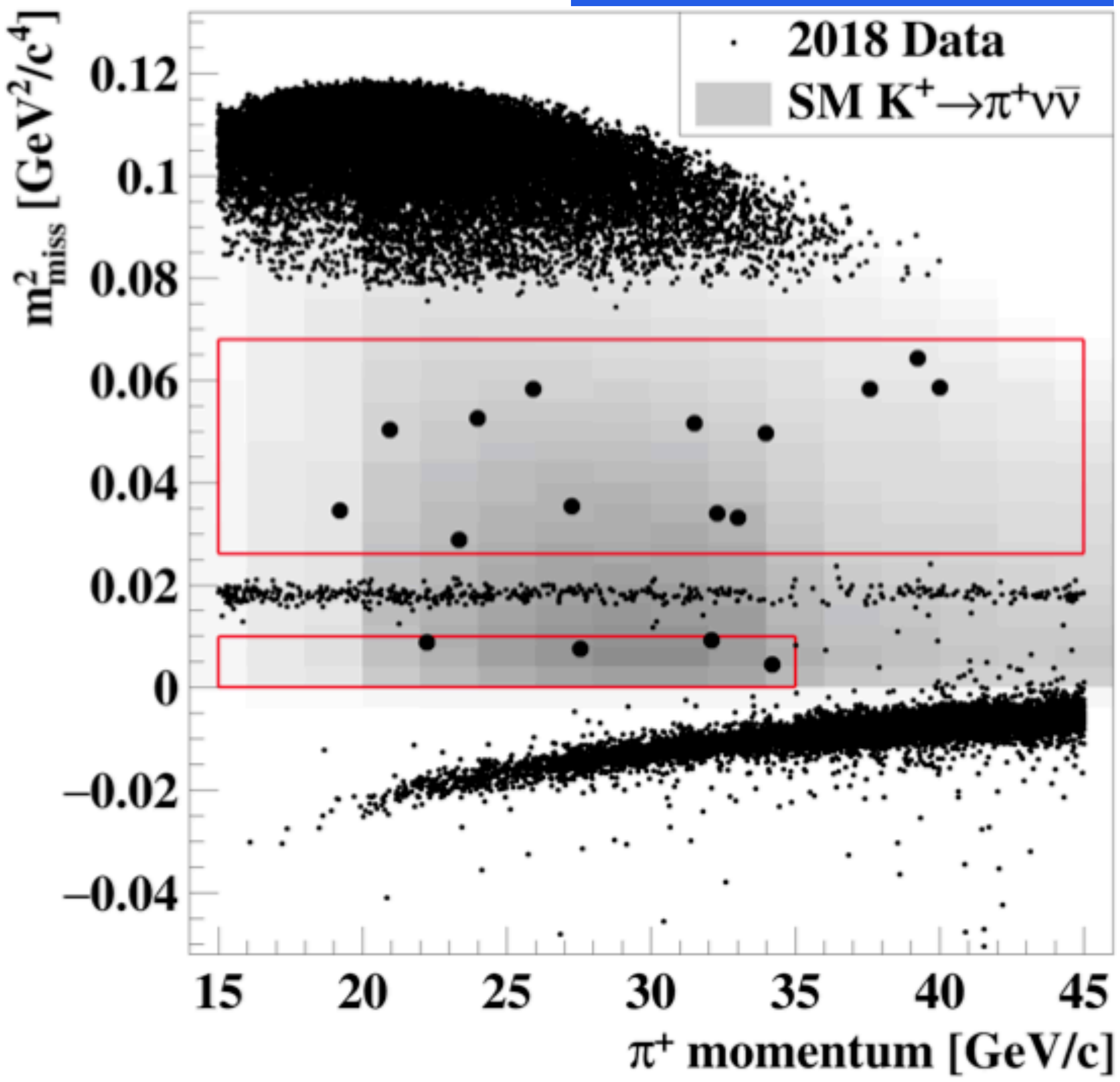
$$\mathcal{B}(D^0 \to \mu^+\mu^-) < 2.94\ (3.25) \times 10^{-9} \text{ @ } 90\ (95)\%\ \text{CL}$$

Most stringent limit on charm FCNC transitions to date with full legacy LHCb Run 1+2 dataset!

s→νν̄d steps towards discovery

JHEP 06 (2021) 093



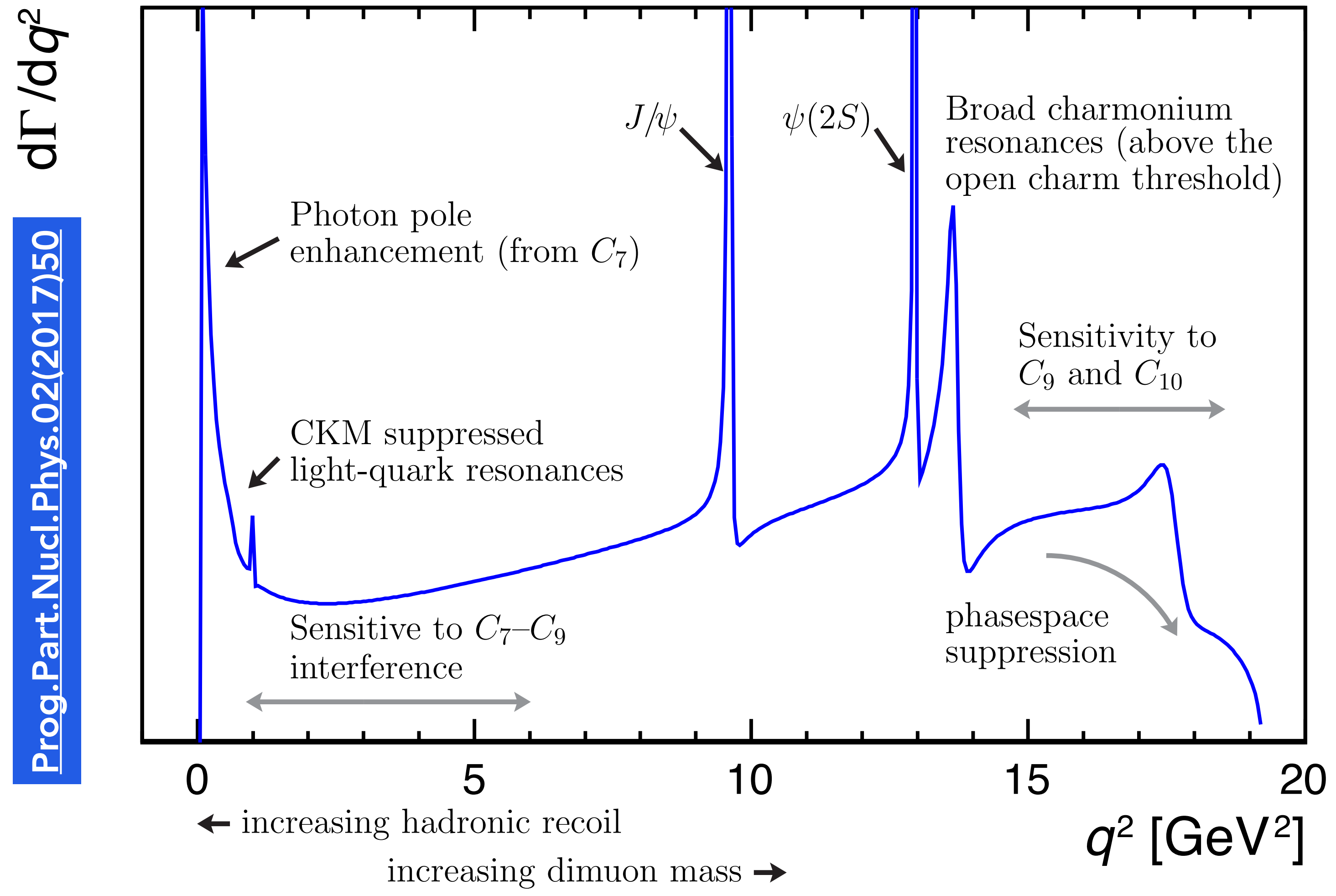


$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = (10.6^{+4.0}_{-3.4}|_{\rm stat} \pm 0.9_{\rm syst}) \times 10^{-11}$$

Evidence of the decay and good agreement with the SM. A tremendous achievement for NA62!

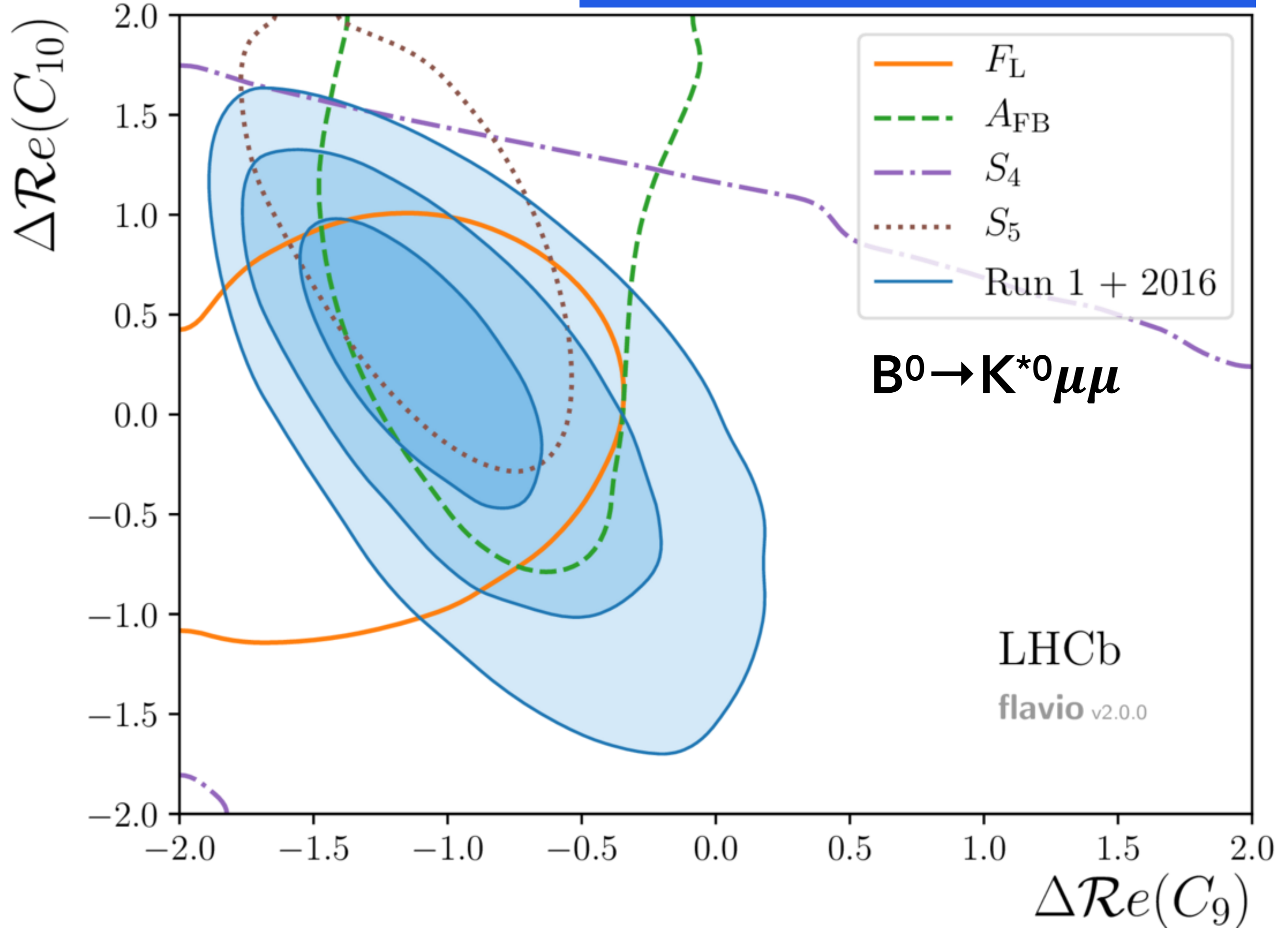
A future observation of $K^0 \to \pi^0 \nu\nu$ opens a fifth way to constrain the apex of the CKM Unitarity Triangle

Angular tests in b→$s\mu\mu$ decays



Prog.Part.Nucl.Phys.02(2017)50

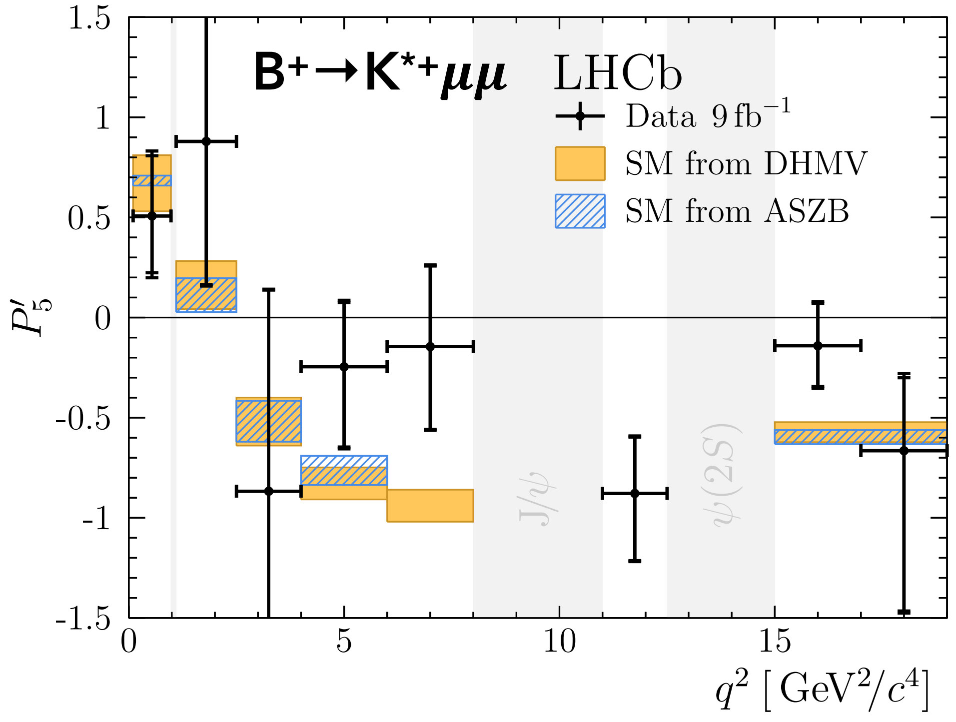
Phys. Rev. Lett. 125 (2020) 011802



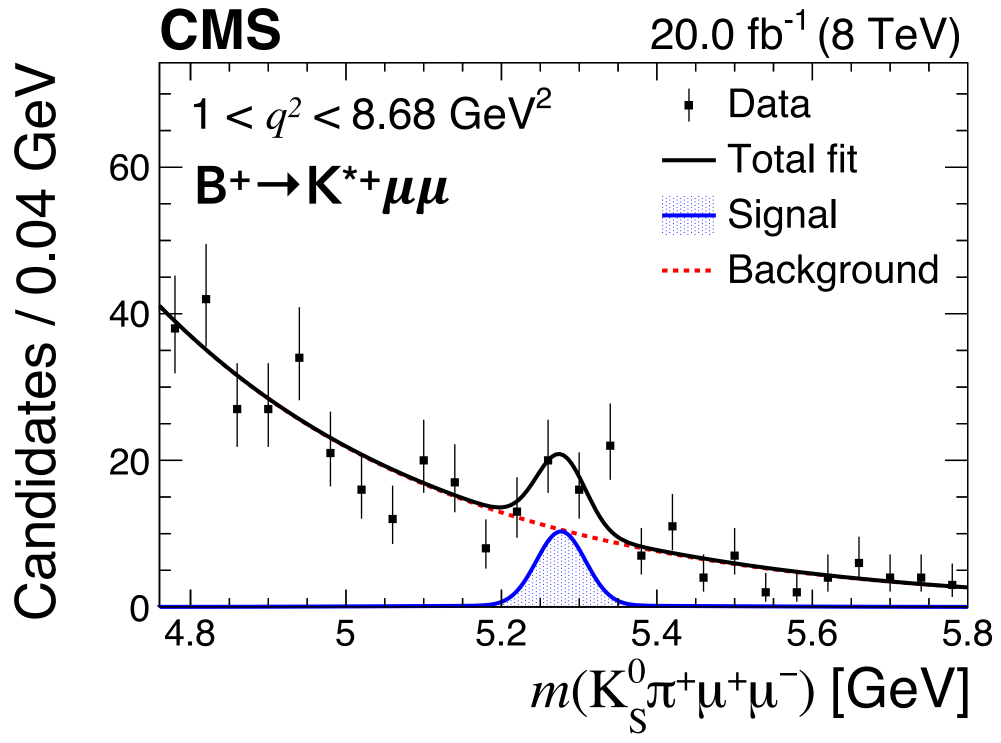
Rich laboratory for SM tests: the angular structure of these decays leads to many phenomenologically complementary observables

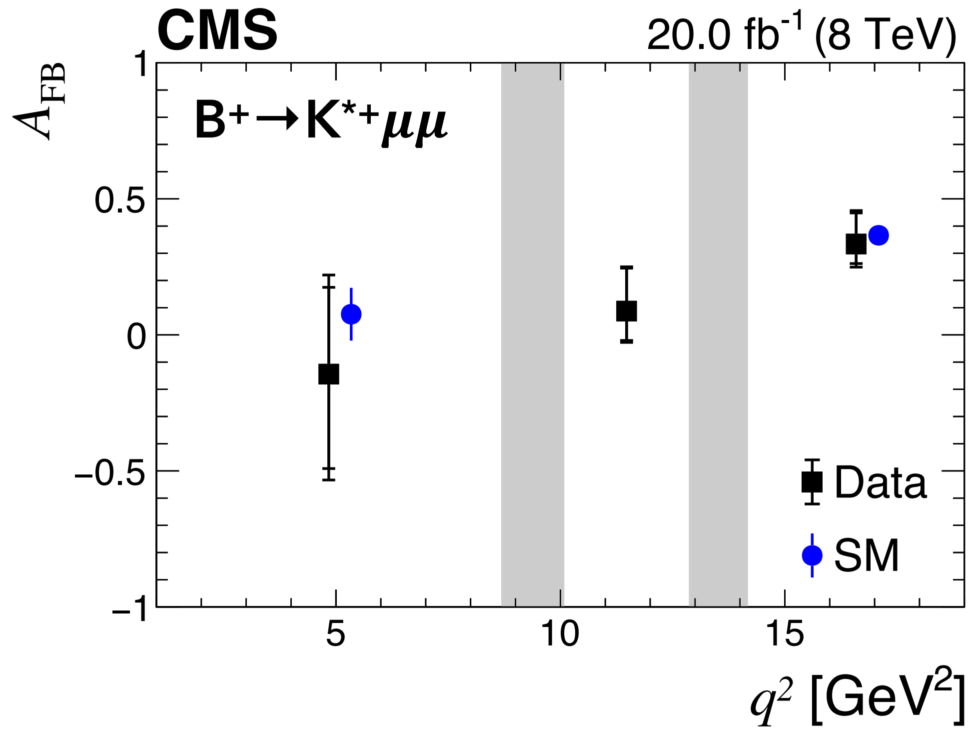
A clear pattern of deviations from the SM has been observed in the last years, however there is ongoing debate over its cause (e.g. charm loops)

Recent experimental progress



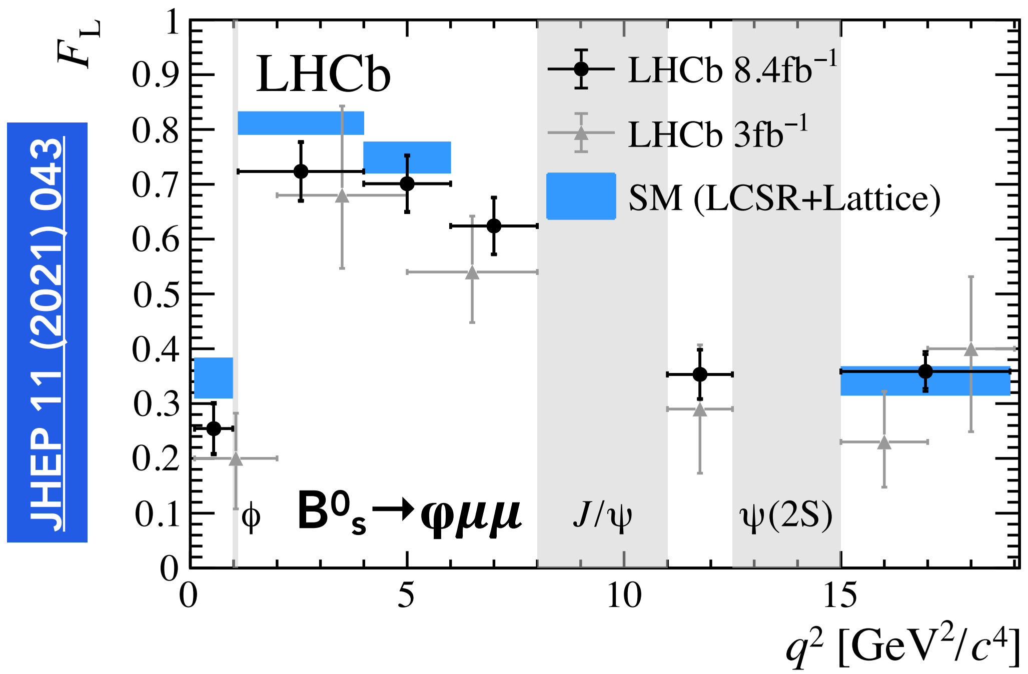
Phys.Rev.Lett.126(2021):161802





JHEP 04 (2021) 124

JHEP 11 (2021) 043



Impressive progress towards the legacy Run 1+2 results across LHC collaborations, and eagerly awaiting Belle 2!

Lepton universality tests in b→sll decays

Theoretically pristine observables!

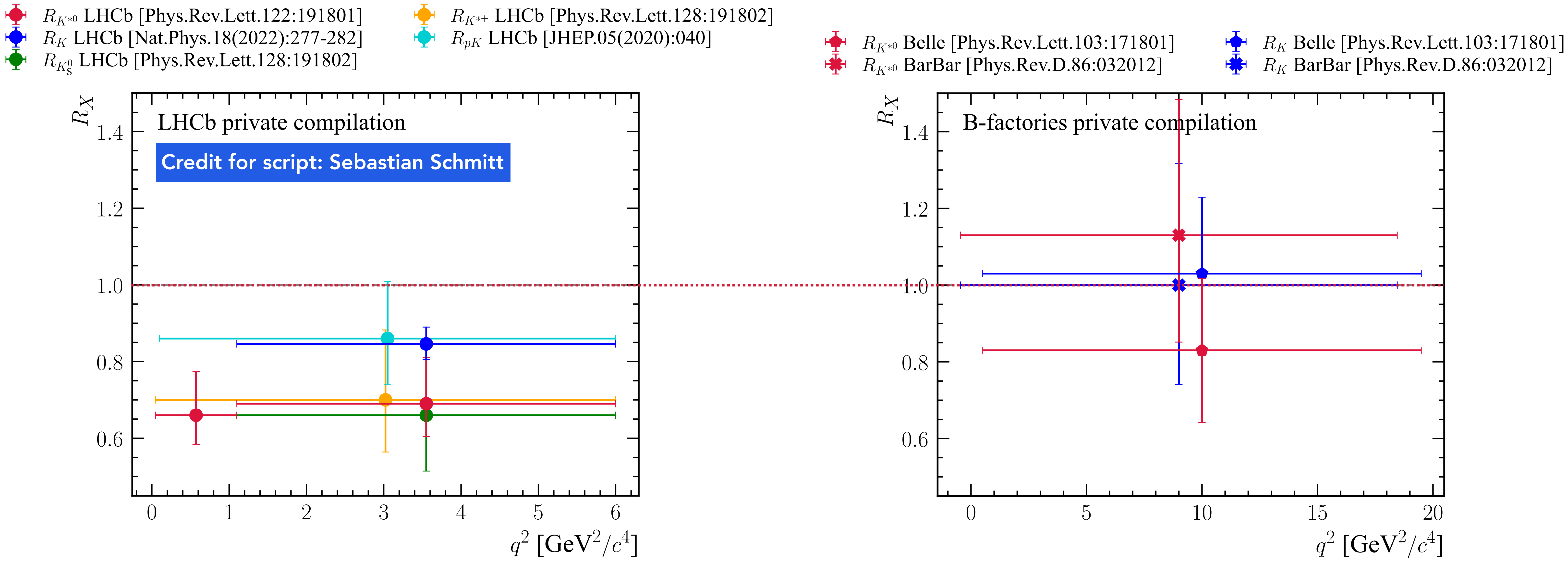
Even the percent level "theory" uncertainties we quote are driven by modelling of radiative effects in electron reconstruction rather than any QCD effects.

Experimentally challenging because of electron reconstruction and resolution.

b→$s\tau\tau$ even more so due to missing energy

Effective LHCb legacy Run 1+2 statistical sensitivity to e-μ lepton universality in branching ratios is ~2-3%

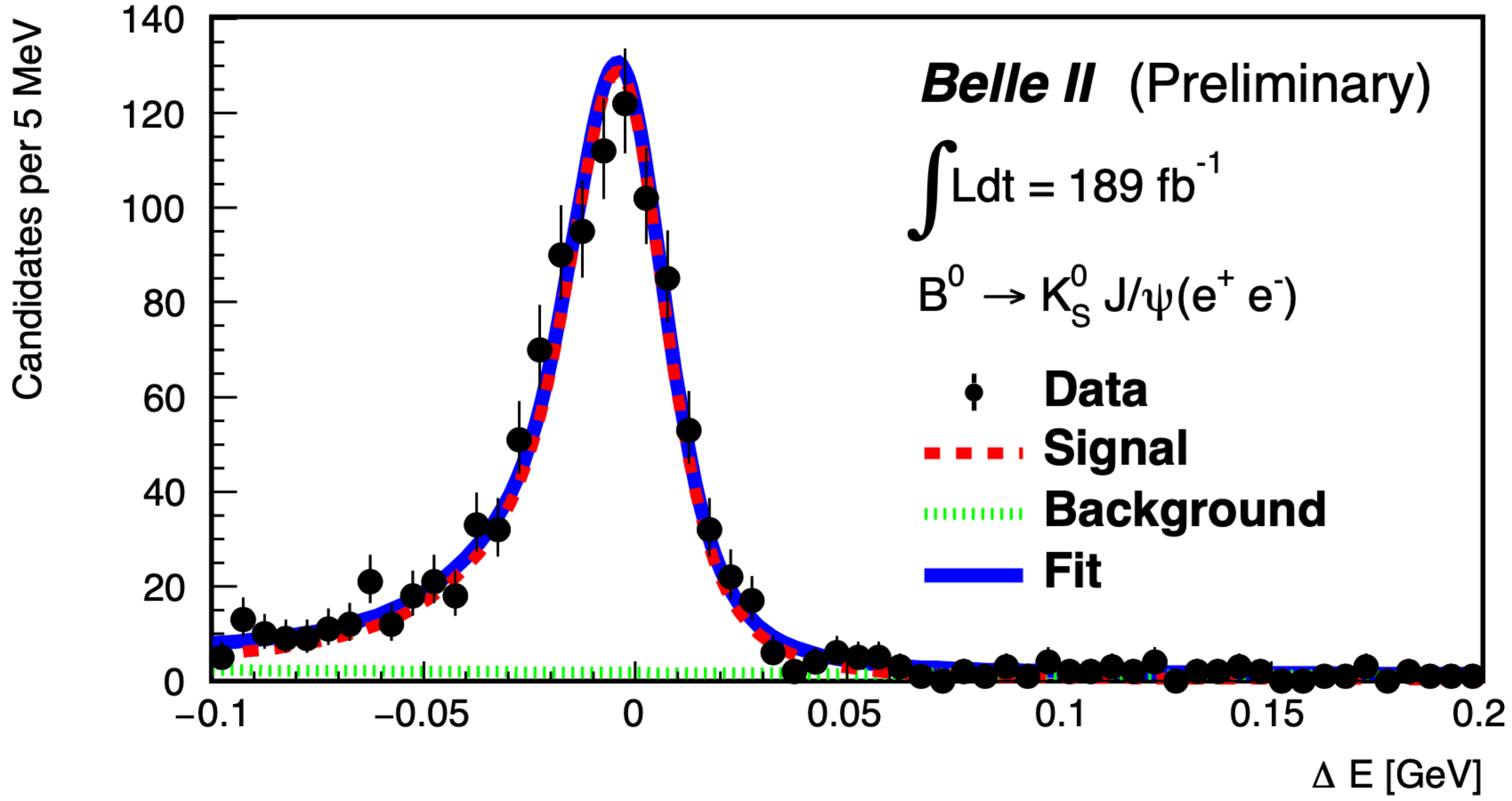
Exp status of b→see/b→s$\mu\mu$ LU tests



Precision dominated by LHCb, Belle 2 will be able to independently verify with ~10ab^{-1}.
Will be interesting to see the eventual impact of the parked CMS dataset.

LHCb is focused on completing a combined analysis of RK & RK* with the Run 1+2 legacy dataset
This work has led to a deeper understanding of systematics which will be reflected in the final result
While RK+RK* gives bulk of sensitivity, tests in $B^{0,\pm}\to\phi ll$, $K\pi\pi ll$, and $K\pi ll$ at high $K\pi$ mass also progressing.

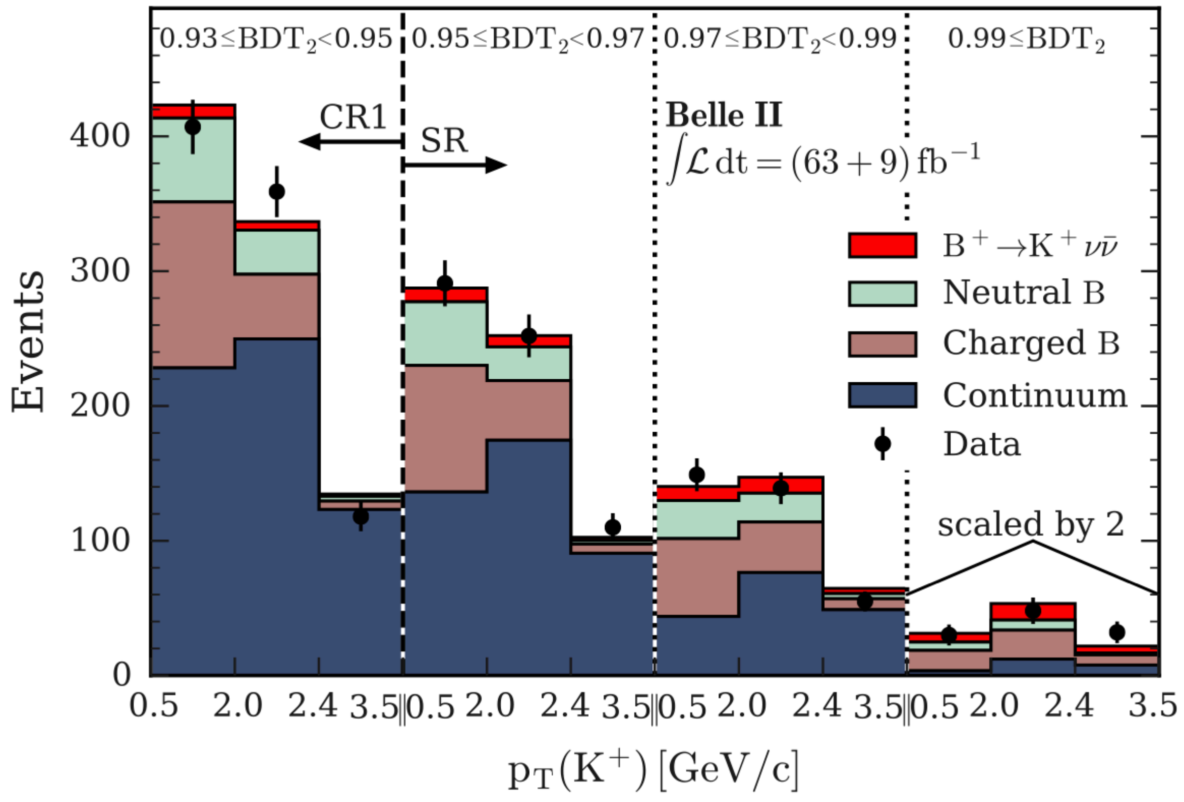
Complementary progress from Belle II



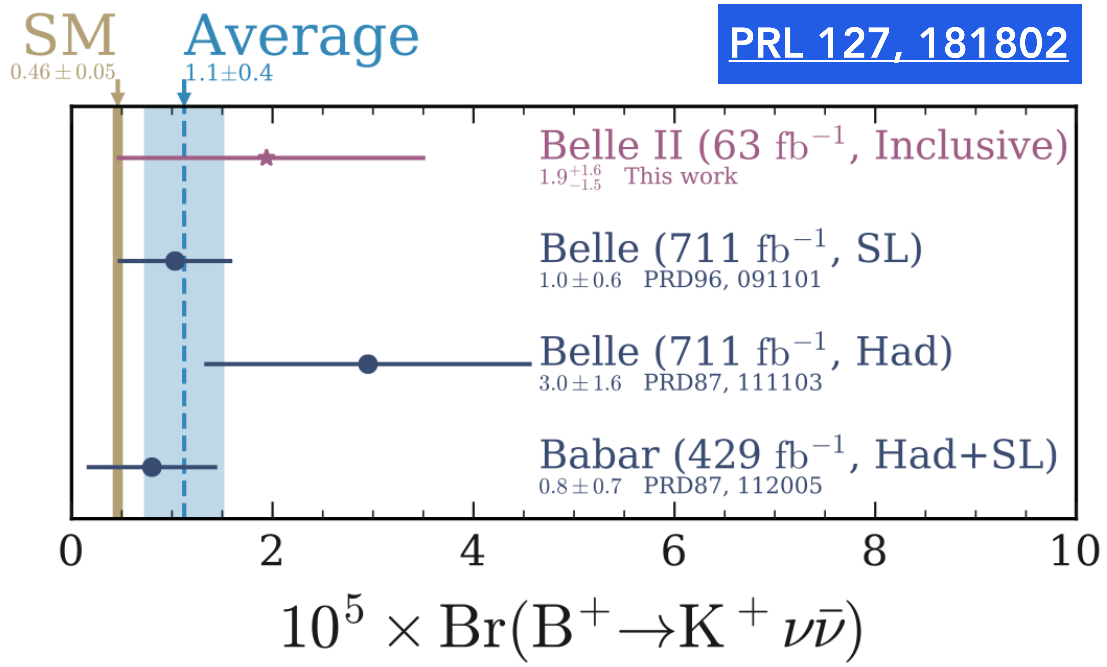
Observable	Belle II	Belle (2021)
$R_{K^+}(J/\psi)$	$1.009 \pm 0.022 \pm 0.008$	$0.994 \pm 0.011 \pm 0.010$
$R_{K^0_S}(J/\psi)$	$1.042 \pm 0.042 \pm 0.008$	$0.993 \pm 0.015 \pm 0.010$

Eldar Ganiev @ ICHEP 2022

NEW @ ICHEP 2022



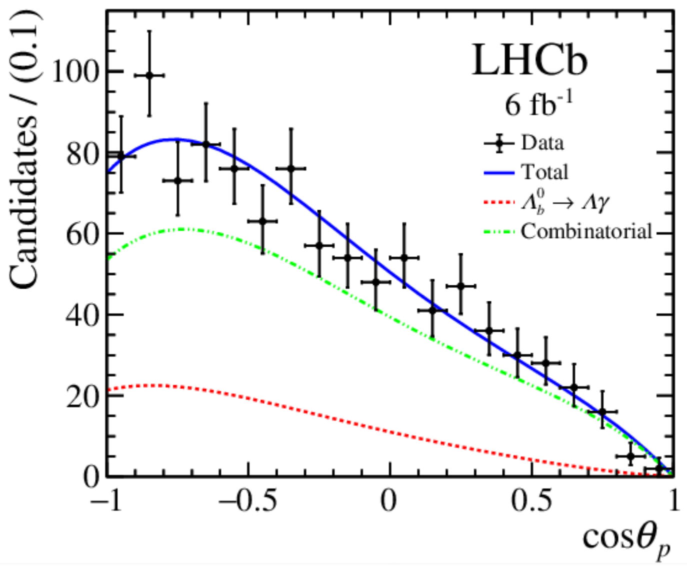
PRL 127, 181802



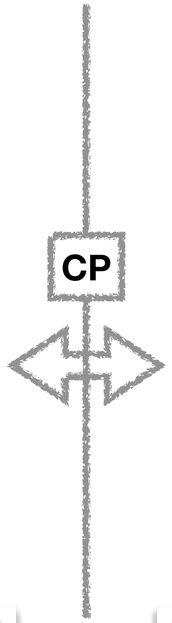
Tests with radiative decays

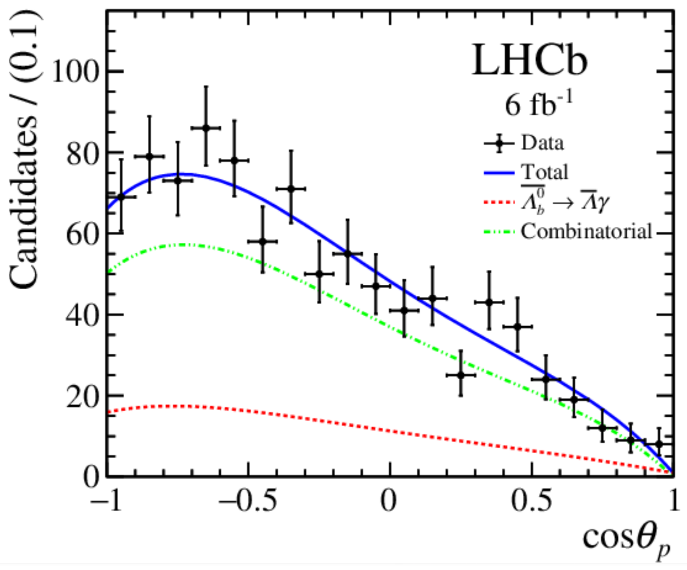
[Phys.Rev.D105(2022):L051104]

[Eldar Ganiev @ ICHEP 2022]

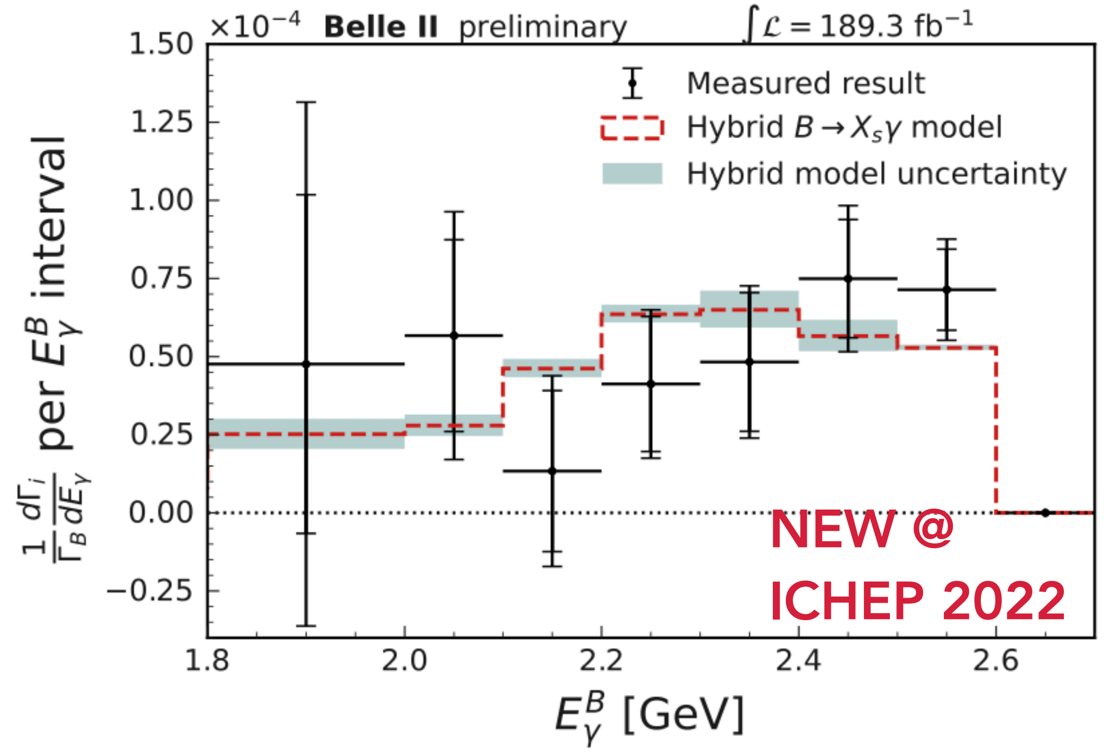


$\alpha_\gamma^- > 0.56\ (0.44)$ at 90% (95%) CL





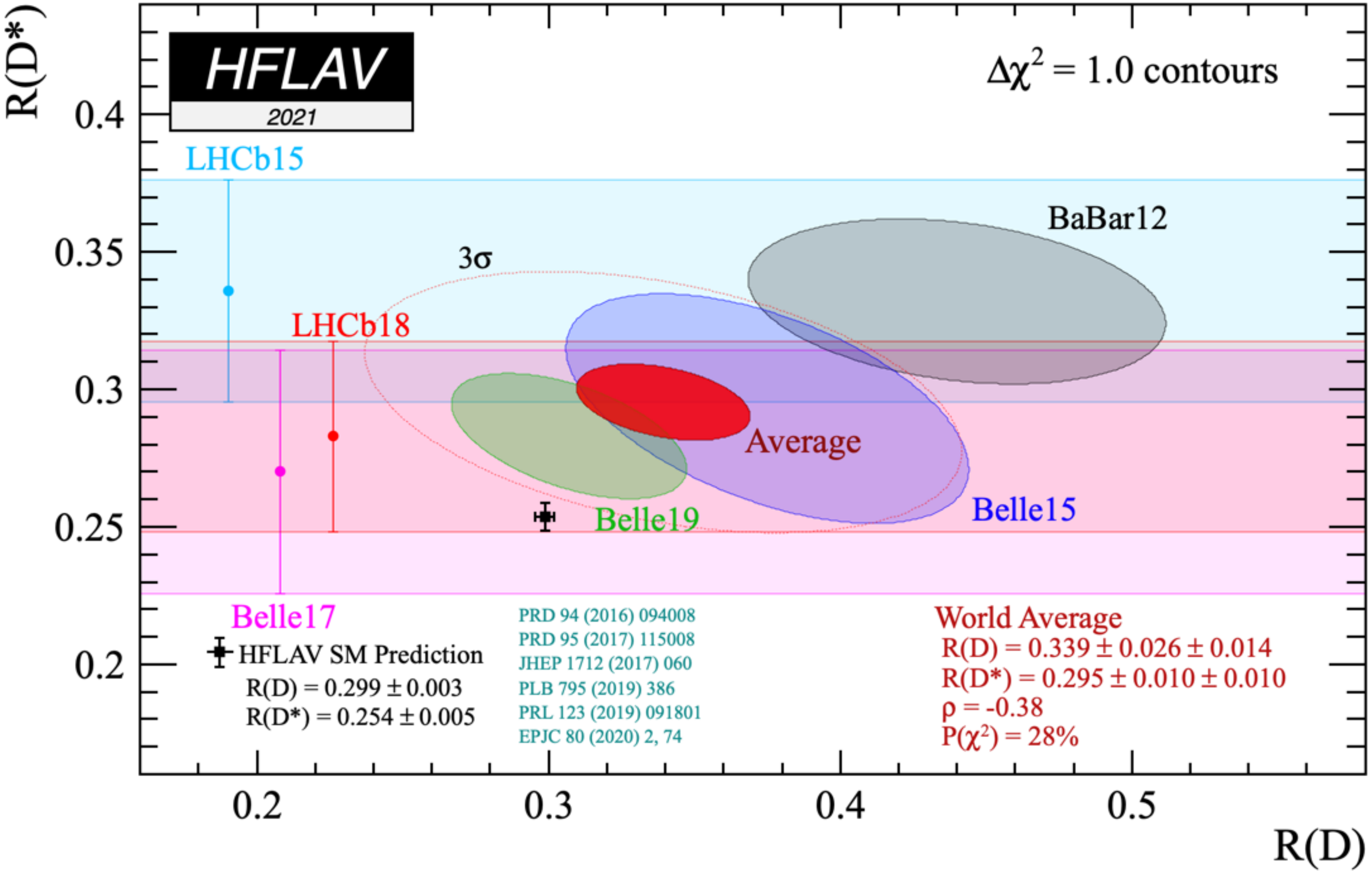
$\alpha_\gamma^+ = -0.56^{+0.36}_{-0.33}\,(stat.)^{+0.16}_{-0.09}\,(syst.)$



Phenomenologically complementary tests with b→s penguins which probe a different set of operators to the leptonic modes.

Rich complementarity between LHCb's statistical power & unique reach for baryon decays and Belle II's clean environment & unique reach for inclusive decays.

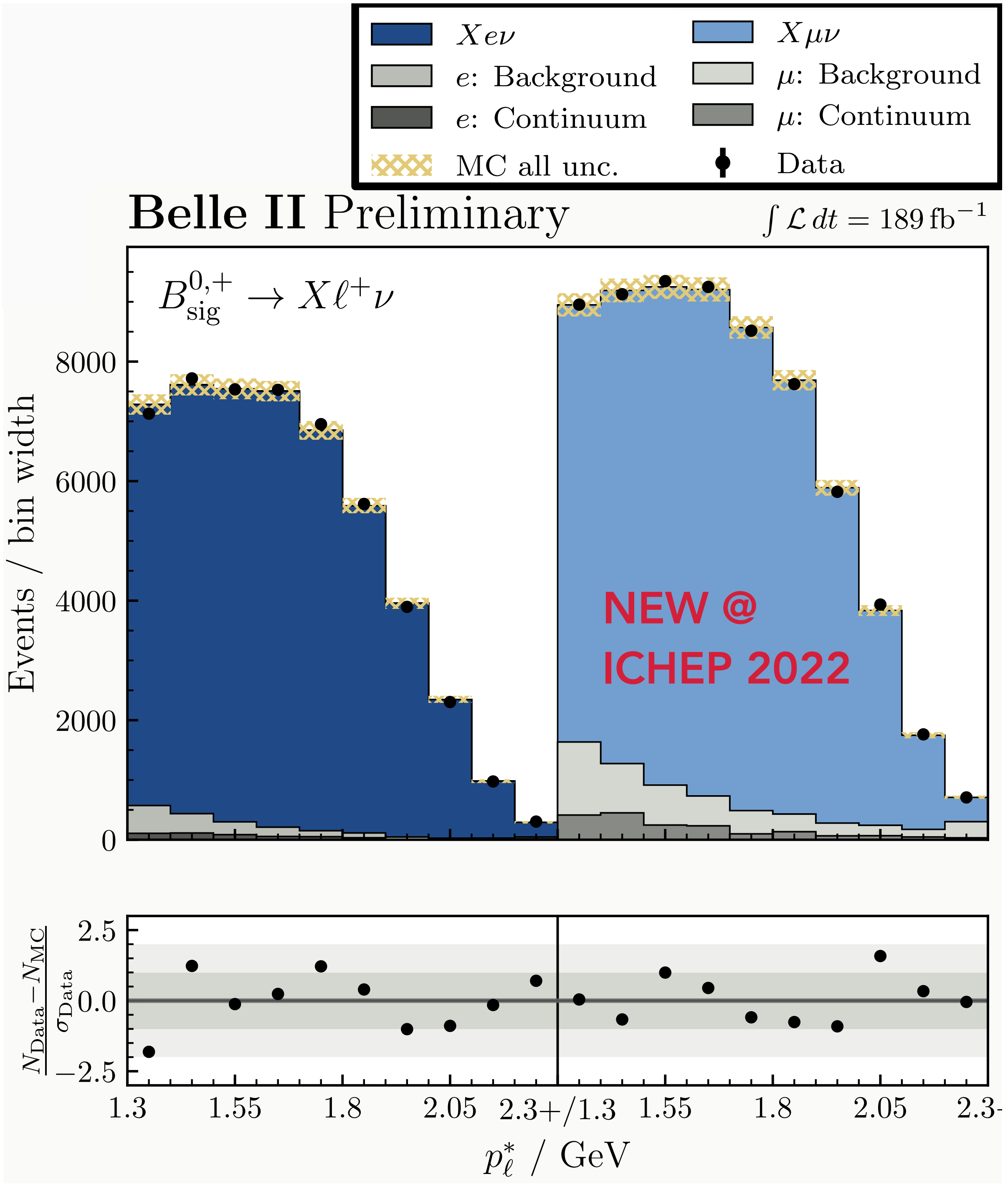
LU tests in $b \to c\tau\nu / b \to c(\mu,e)\nu$ decays



Sadly no "headline" new results in this 2D plane for ICHEP 2022…

See Robin's and Admir's talks for connections of anomaly models to high-PT searches!

LU tests in b→ceν/b→cμν decays



Henrik Junkerkalefeld @ ICHEP 2022

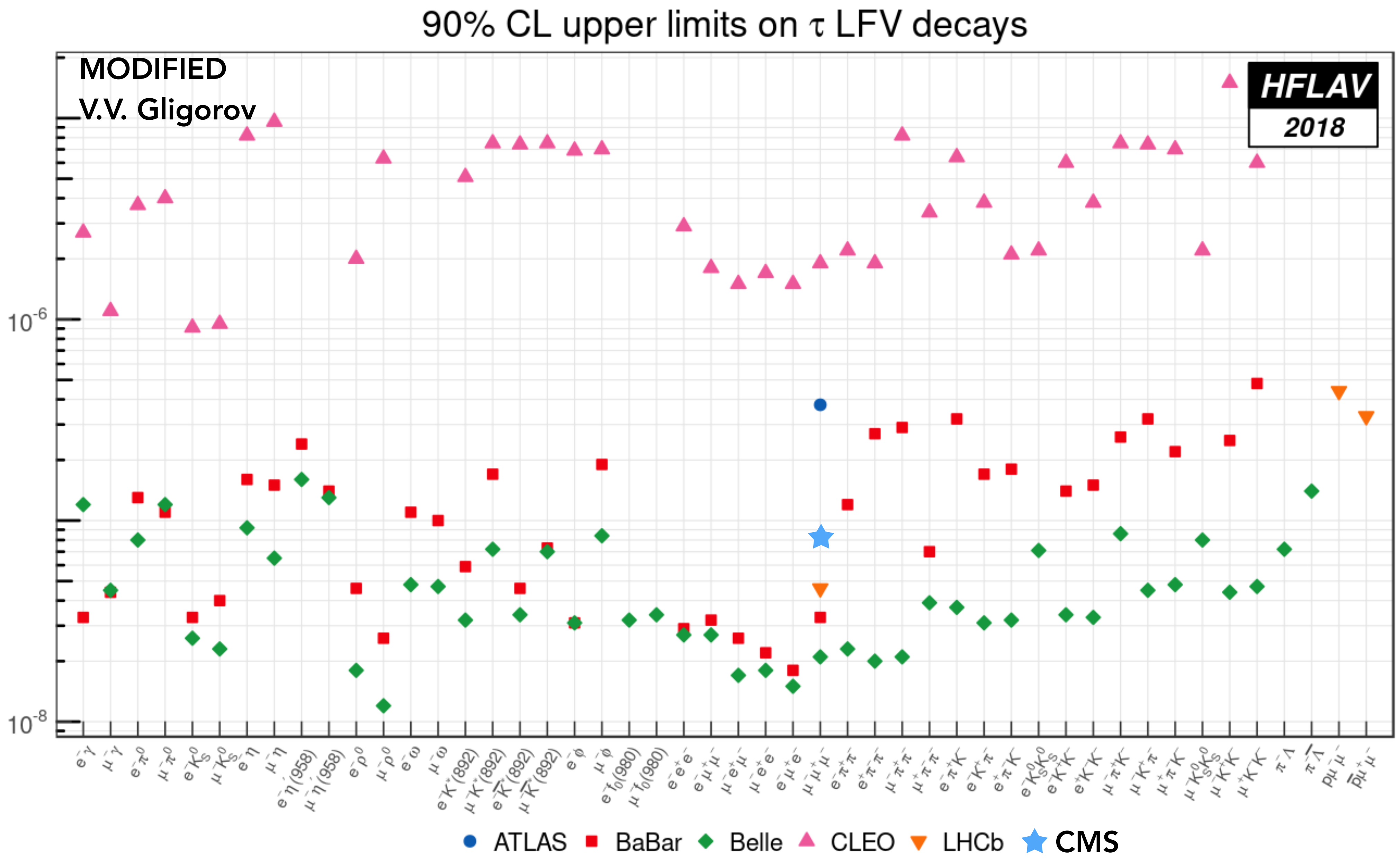
Almost fully inclusive test of electron-muon lepton universality in b→clν transitions

Paves the way for the first such inclusive test of tau-muon and tau-electron universality

Powerful demonstration of complementary capabilities of Belle II in semileptonic decays

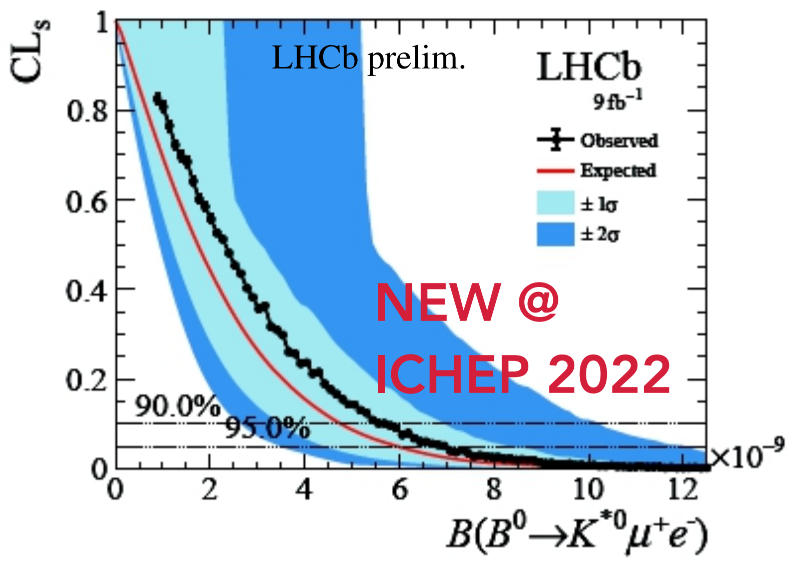
$$R(X_{e/\mu})^{p^{*}_{\ell}>1.3\mathrm{GeV}} = 1.033 \pm 0.010^{\mathrm{stat}} \pm 0.020^{\mathrm{syst}}$$

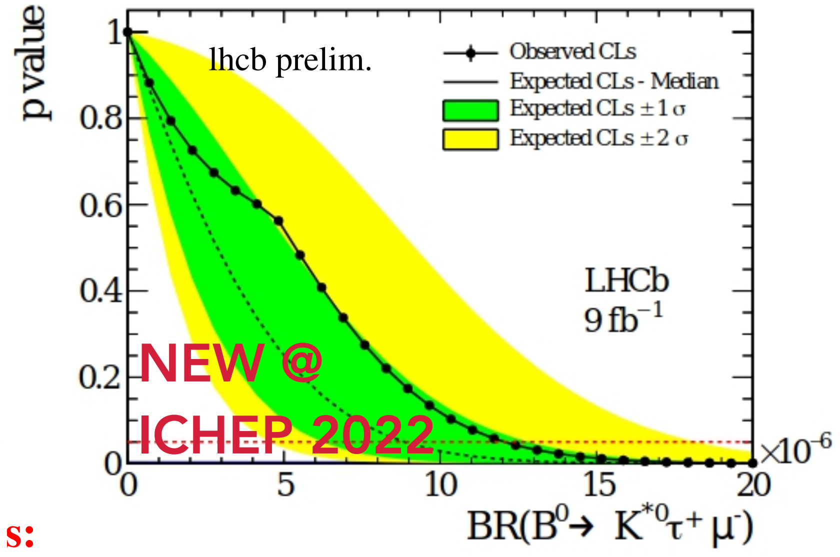
Direct LFV/LNV/BNV searches



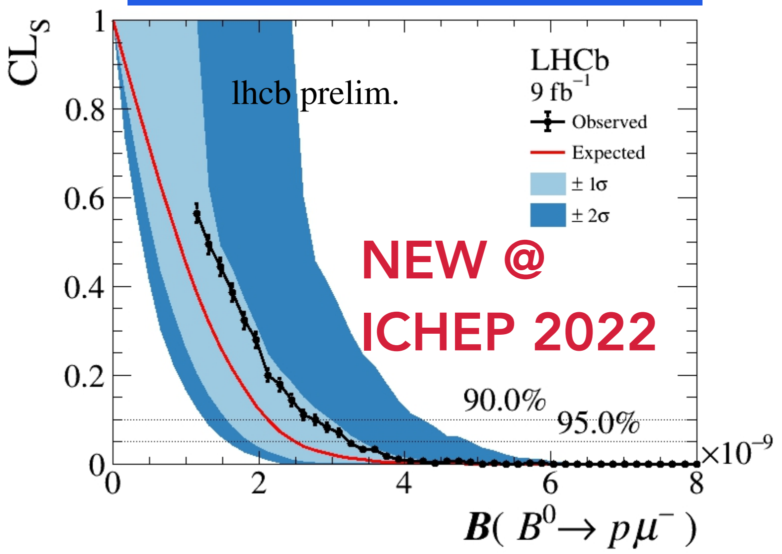
LFV/LNV go naturally together with LUV — most models which explain the LUV anomalies predict LFV/LNV effects, often near current reach!

LFV/LNV/BNV searches in b,c,s decays





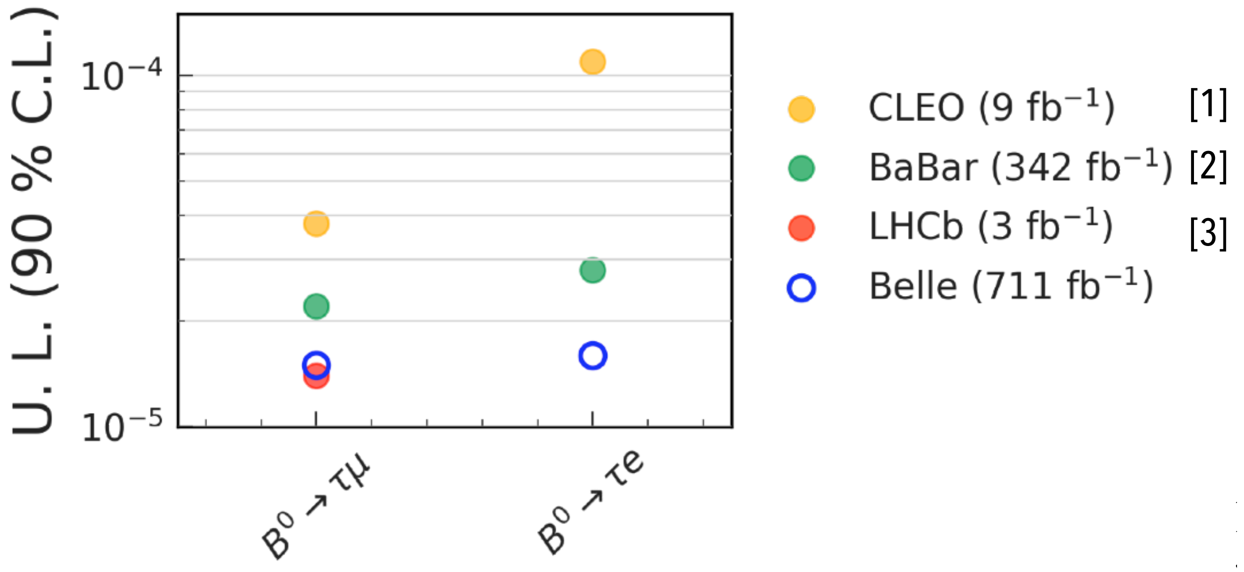
[Lingzhu Bian @ ICHEP 2022]



[Viacheslav Duk @ ICHEP 2022]

Decay mode	NA62 UL on BR (90% CL)
$K^+ \to \pi^- \mu^+ \mu^+$	4.2×10^{-11}
$K^+ \to \pi^- e^+ e^+$	5.3×10^{-11}
$K^+ \to \pi^- \mu^+ e^+$	4.2×10^{-11}
$K^+ \to \pi^+ \mu^- e^+$	6.6×10^{-11}
$\pi^0 \to \mu^- e^+$	3.2×10^{-10}
$K^+ \to \pi^- \pi^0 e^+ e^+$	8.5×10^{-10}
$K^+ \to \mu^- \nu e^+ e^+$	8.1×10^{-11}

NEW @ ICHEP 2022

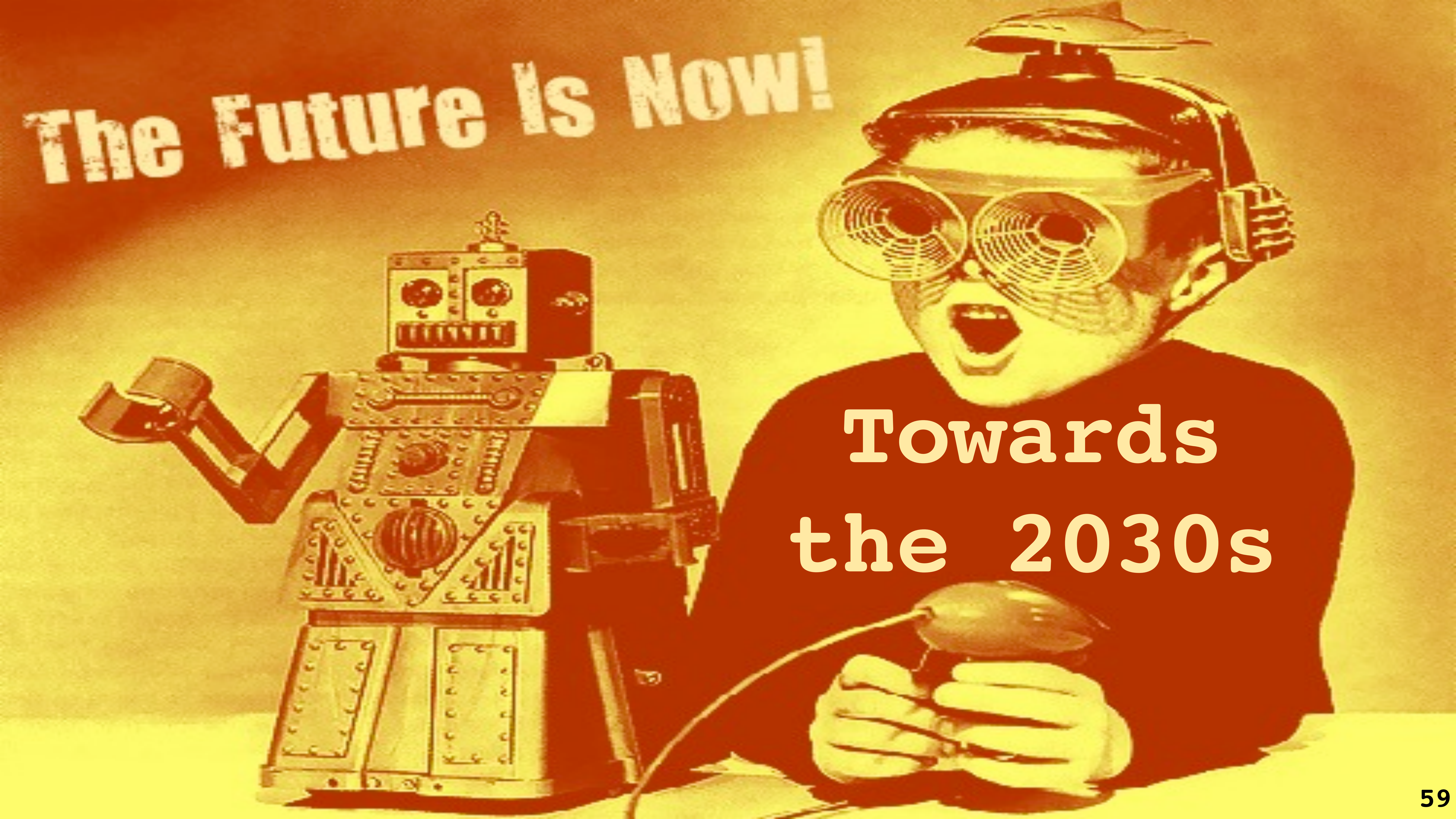


Decay mode	BES III UL on BR (90% CL)	Decay mode	BES III UL on BR (90% CL)
$D^0 \to \bar{p}e^+$	1.2×10^{-6}	$D^+ \to \Sigma^0 e^+$	1.7×10^{-6}
$D^0 \to pe^-$	2.2×10^{-6}	$D^+ \to \Sigma^0 e^+$	1.3×10^{-6}
$D^+ \to \Lambda e^+$	1.1×10^{-6}	$J/\Psi \to \Lambda_c e^-$	6.9×10^{-8}
$D^+ \to \bar{\Lambda} e^+$	6.5×10^{-7}	$J/\Psi \to pK^-\Lambda$ / $J/\Psi \to pK^-\bar{\Lambda}$	4.4×10^{-6}

NEW @ ICHEP 2022, preliminary

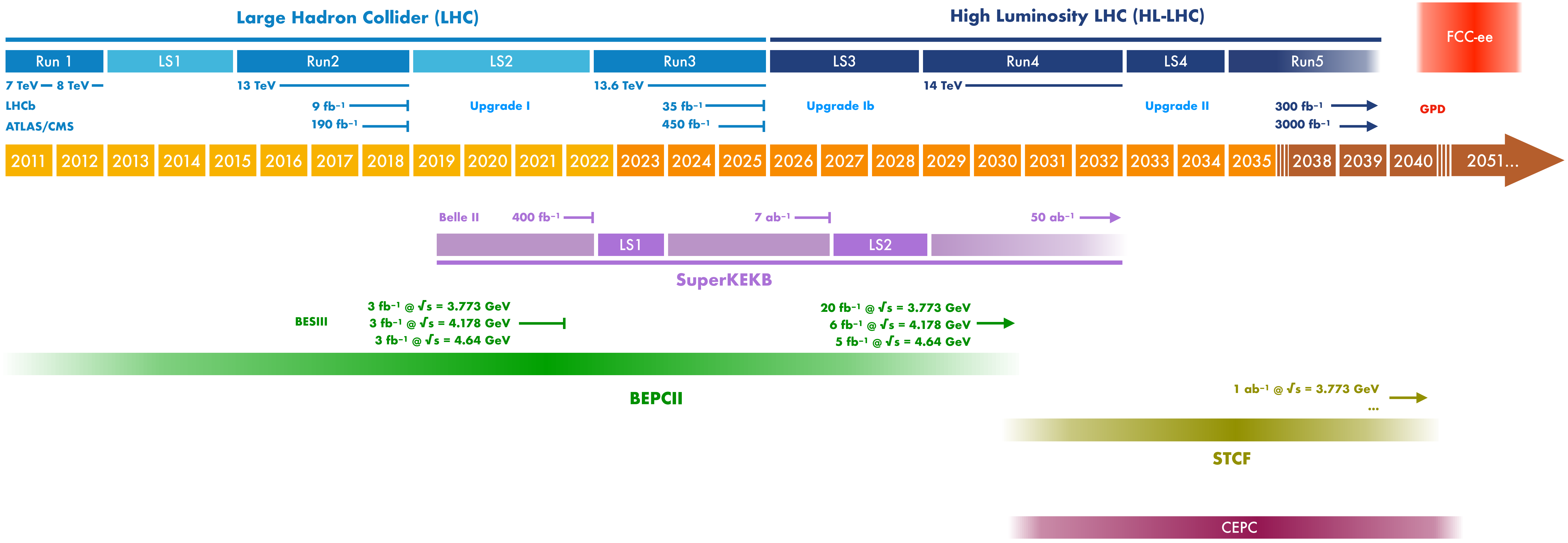
[Tengjiao Wang @ ICHEP 2022]

Many new or improved limits are being set in last years: probing 10^{-5} to 10^{-9} in beauty decays (worse limits when τ leptons are involved in the decay), 10^{-6} to 10^{-8} in charm decays, 10^{-10} to 10^{-11} in strange decays



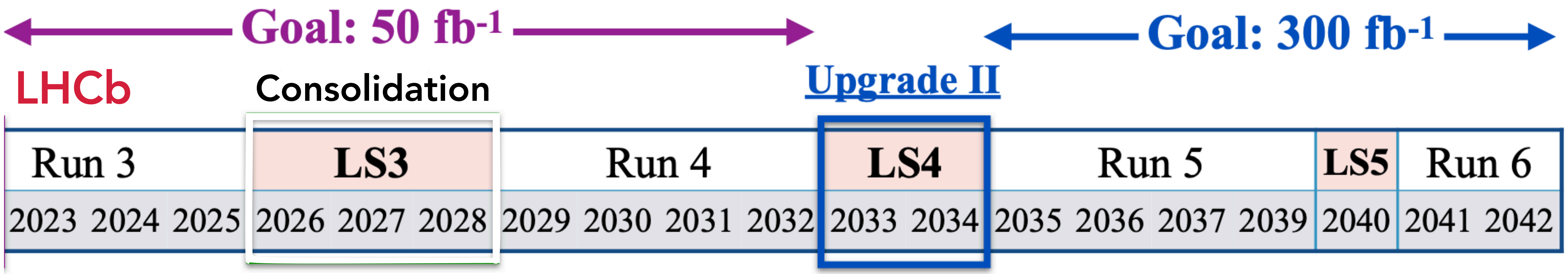
Towards the 2030s

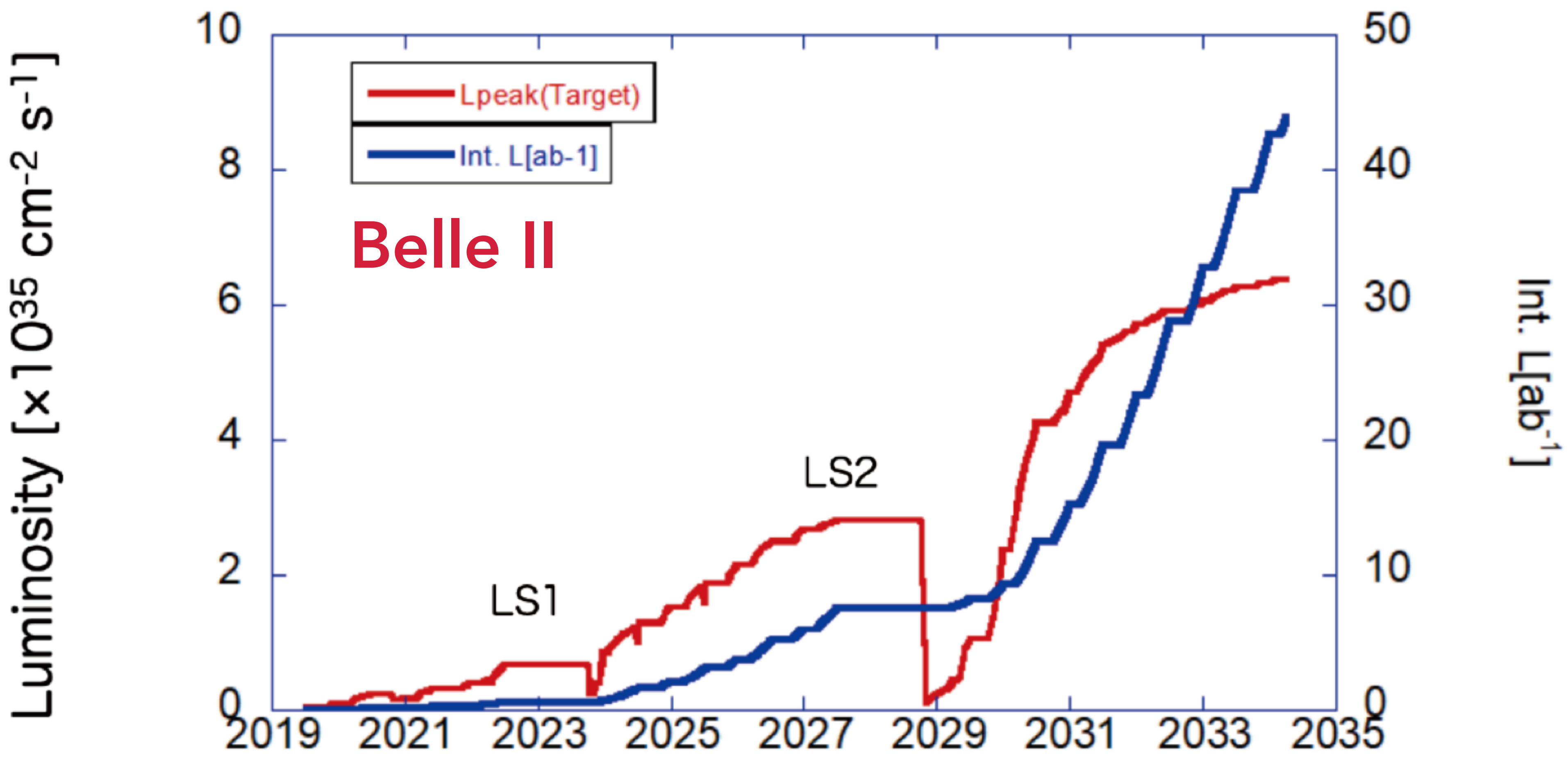
Exploring the next decades of flavour



Numbers are indicative, for official projections from collaborations see next slides.

Latest Belle II and LHCb plans





Belle II reaches 50 ab^{-1} at around the same time as LHCb's second upgrade is scheduled to start datataking

Key LHCb/Belle II sensitivity projections

Belle II (Upgrade snowmass whitepaper)

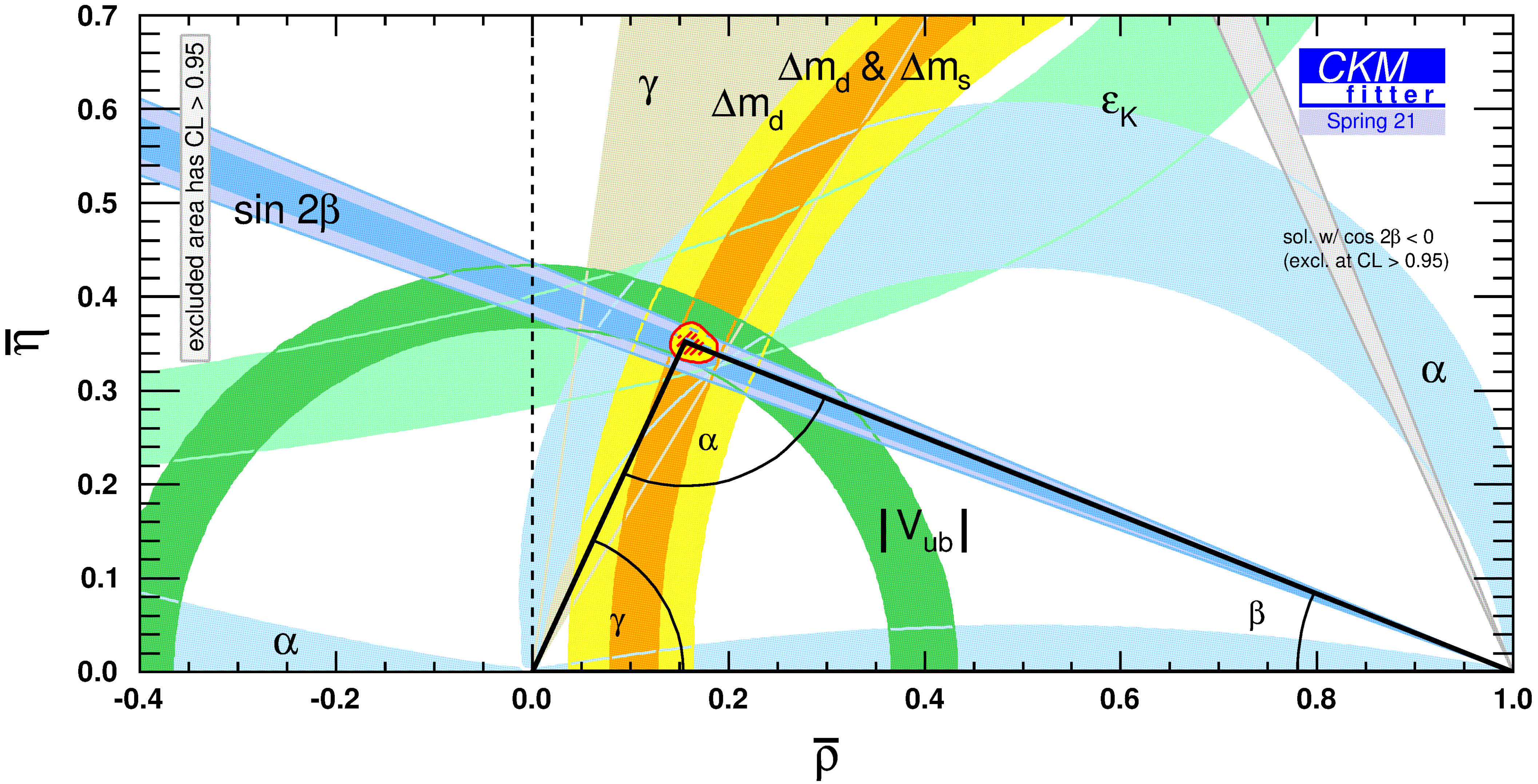
Observable	2022 Belle(II), BaBar	Belle-II 5 ab^{-1}	Belle-II 50 ab^{-1}
$\sin 2\beta/\phi_1$	0.03	0.012	0.005
γ/ϕ_3 (Belle+BelleII)	$11°$	$4.7°$	$1.5°$
α/ϕ_2 (WA)	$4°$	$2°$	$0.6°$
$\lvert V_{ub}\rvert$ (Exclusive)	4.5%	2%	1%
$S_{CP}(B \to \eta' K^0_S)$	0.08	0.03	0.015
$A_{CP}(B \to \pi^0 K^0_S)$	0.15	0.07	0.025
$S_{CP}(B \to K^{*0}\gamma)$	0.32	0.11	0.035
$R(B \to K^* \ell^+ \ell^-)^\dagger$	0.26	0.09	0.03
$R(B \to D^* \tau \nu)$	0.018	0.009	0.0045
$R(B \to D \tau \nu)$	0.034	0.016	0.008
$\mathcal{B}(B \to \tau \nu)$	24%	9%	4%
$B(B \to K^* \nu \bar{\nu})$	–	25%	9%
$\mathcal{B}(\tau \to \mu \gamma)$ UL	42×10^{-9}	22×10^{-9}	6.9×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$ UL	21×10^{-9}	3.6×10^{-9}	0.36×10^{-9}

LHCb and upgrades (Framework TDR)

Observable	Current LHCb (up to 9 fb^{-1})		Upgrade I (23 fb^{-1})	Upgrade I (50 fb^{-1})	Upgrade II (300 fb^{-1})
CKM tests					
γ ($B \to DK$, *etc.*)	$4°$	[9, 10]	$1.5°$	$1°$	$0.35°$
ϕ_s ($B^0_s \to J/\psi\phi$)	32 mrad	[8]	14 mrad	10 mrad	4 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda^0_b \to p\mu^-\bar{\nu}_\mu$, *etc.*)	6%	[29, 30]	3%	2%	1%
a^d_{sl} ($B^0 \to D^-\mu^+\nu_\mu$)	36×10^{-4}	[34]	8×10^{-4}	5×10^{-4}	2×10^{-4}
a^s_{sl} ($B^0_s \to D^-_s\mu^+\nu_\mu$)	33×10^{-4}	[35]	10×10^{-4}	7×10^{-4}	3×10^{-4}
Charm					
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5}	[5]	13×10^{-5}	8×10^{-5}	3.3×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5}	[38]	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}
Δx ($D^0 \to K^0_s\pi^+\pi^-$)	18×10^{-5}	[37]	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}
Rare Decays					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B^0_s \to \mu^+\mu^-)$	69%	[40, 41]	41%	27%	11%
$S_{\mu\mu}$ ($B^0_s \to \mu^+\mu^-$)	—		—	—	0.2
$A^{(2)}_T$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
A^{Im}_T ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$\mathcal{A}^{\Delta\Gamma}_{\phi\gamma}(B^0_s \to \phi\gamma)$	$^{+0.41}_{-0.44}$	[51]	0.124	0.083	0.033
$S_{\phi\gamma}(B^0_s \to \phi\gamma)$	0.32	[51]	0.093	0.062	0.025
$\alpha_\gamma(\Lambda^0_b \to \Lambda\gamma)$	$^{+0.17}_{-0.29}$	[53]	0.148	0.097	0.038
Lepton Universality Tests					
R_K ($B^+ \to K^+\ell^+\ell^-$)	0.044	[12]	0.025	0.017	0.007
R_{K^*} ($B^0 \to K^{*0}\ell^+\ell^-$)	0.12	[61]	0.034	0.022	0.009
$R(D^*)$ ($B^0 \to D^{*-}\ell^+\nu_\ell$)	0.026	[62, 64]	0.007	0.005	0.002

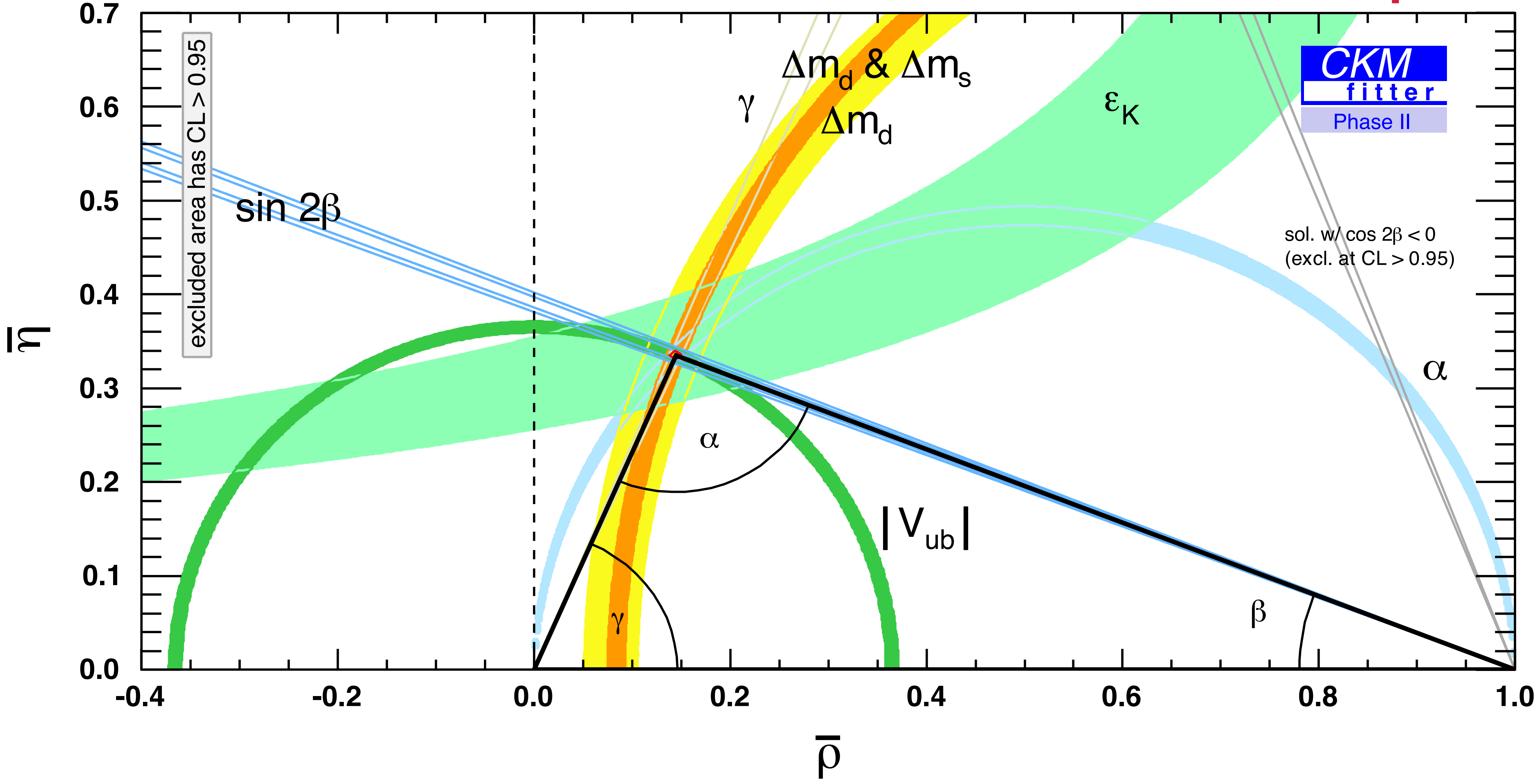
Vital to underline that LHCb and Belle II primarily complement each other!
They will also check each other across key observables — rare processes, spectroscopy & CKM metrology.
LHCb's unique reach in charm reminds that LHC is the biggest ever charm factory — essential to exploit it.

CKM metrology: today



CKM metrology: LHCb U2 + Belle II

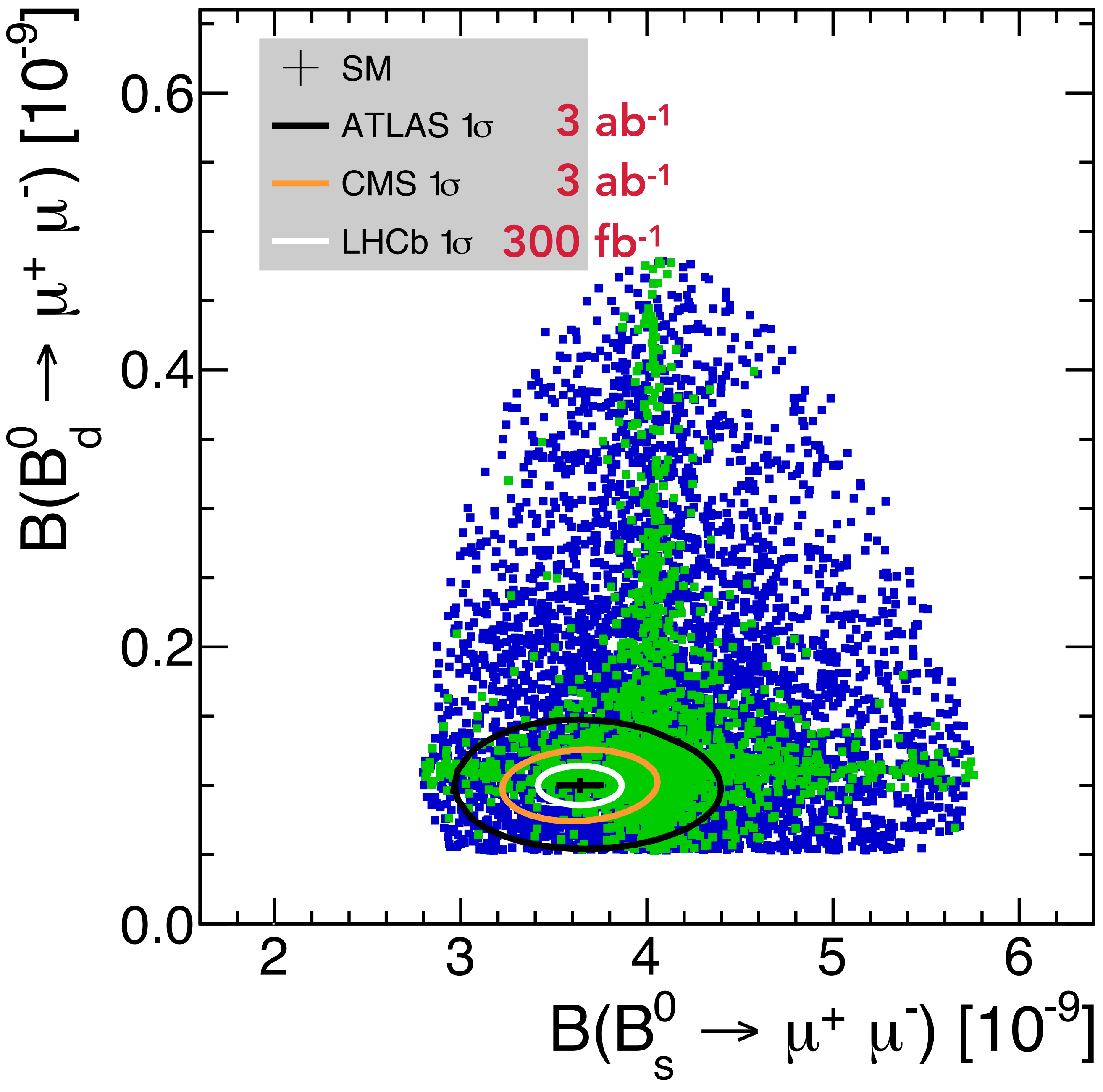
HL-LHC Yellow Report



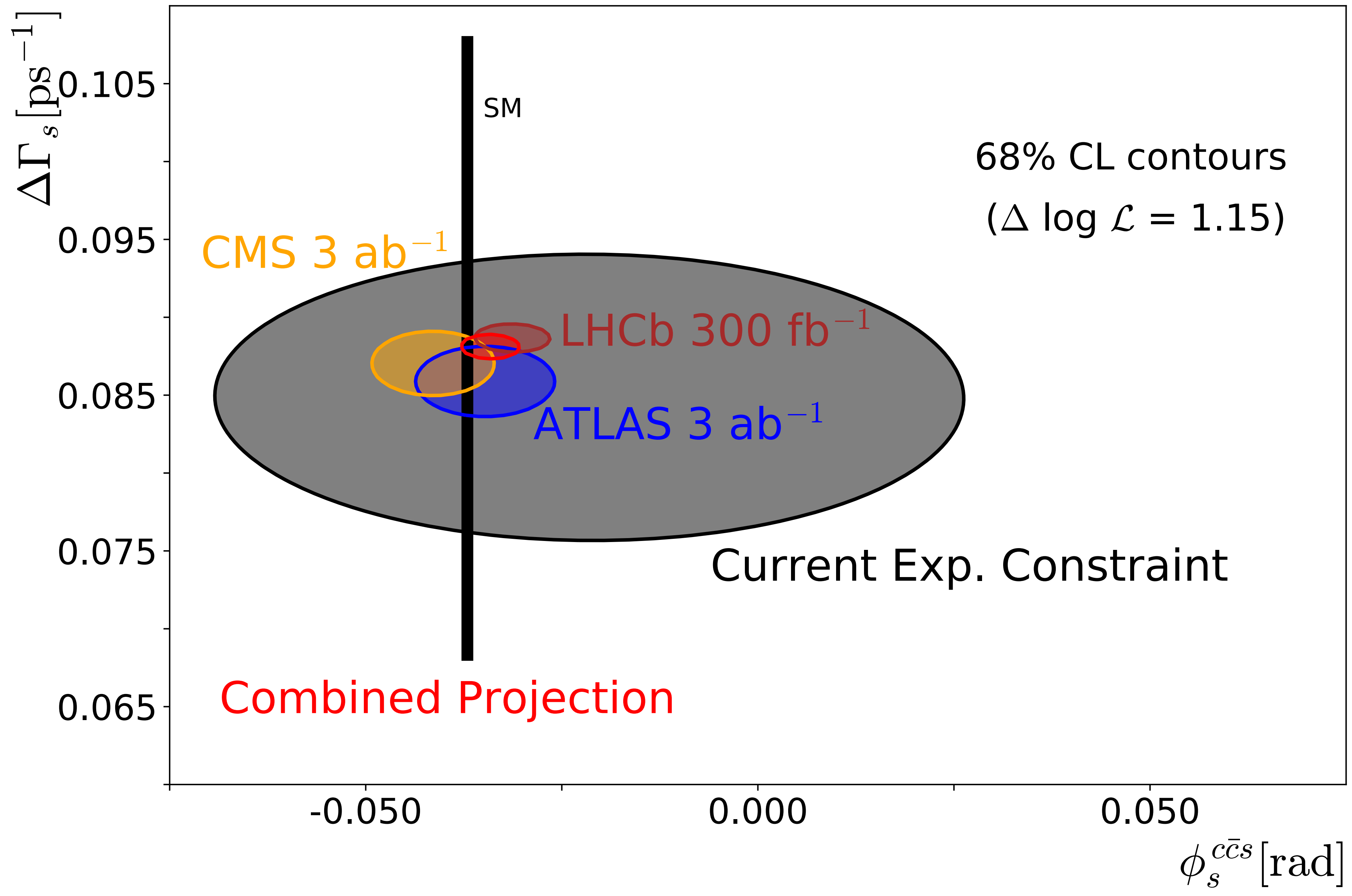
A permille understanding of the Unitarity triangle apex is fundamental and worth the next decades of our lives to achieve!

Complementarity with HL-LHC GPDs

HL-LHC Yellow Report



HL-LHC Yellow Report



Can independently measure multiple key observables — vital that HL-LHC GPD triggers give full impact

Diversity is the strength of flavour

Flavour physics has a vibrant present and a future worth our efforts!

Underpinned by a rich phenomenology and the complementarity of flavour experiments and facilities.

In addition to the flavour factories (LHCb and Belle II) and the LHC's general purpose detectors, dedicated experiments and facilities like BESIII, NA62, KOTO, will be crucial in mapping the fundamental properties of how quarks mix and combine for the next generations!

See Admir's talk for the crucial role theory will play in this effort.

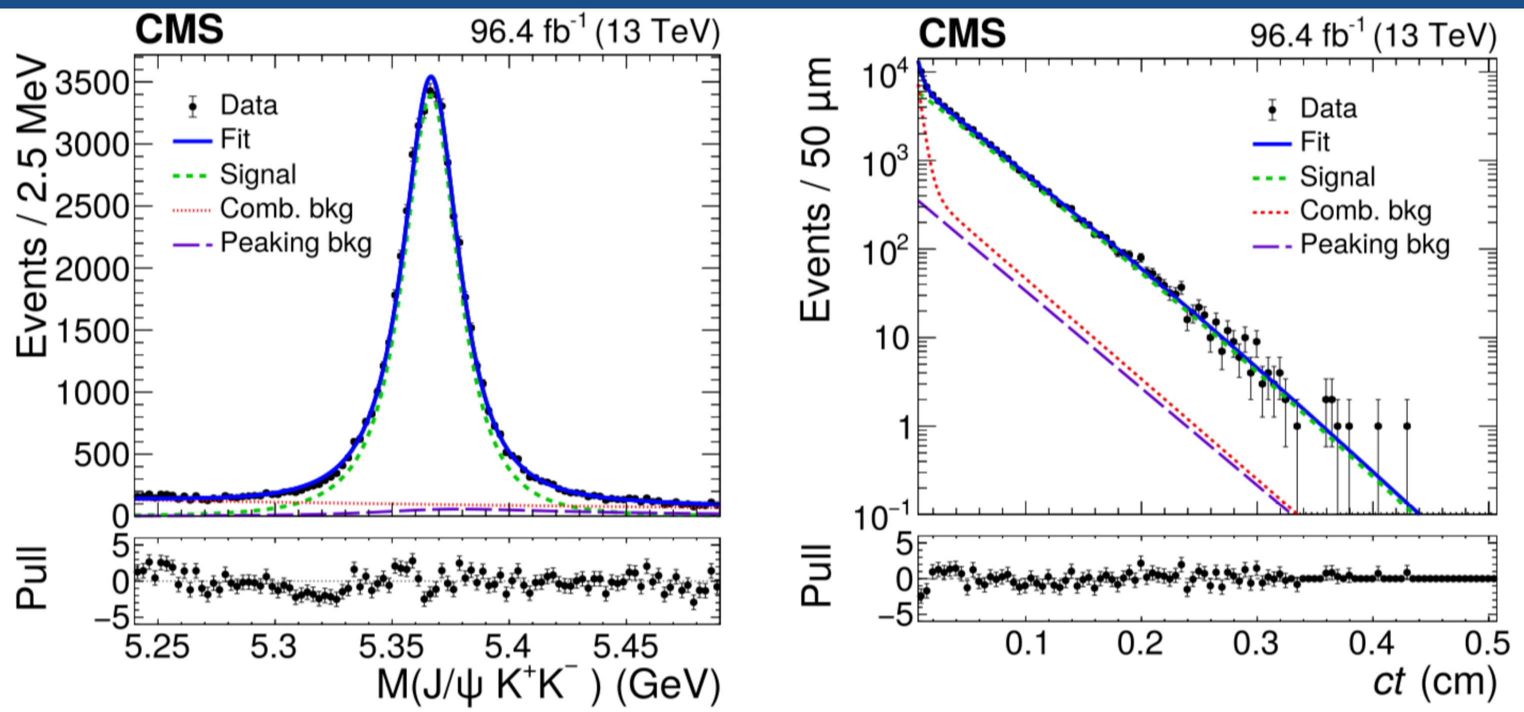
FCC-ee may carry the torch into the second half of this century, with complementary insights into the flavourful nature of fundamental particles from the Z pole. I hope to see many of you along this road!

A huge thank you to the organisers for the invitation and wonderful conference!

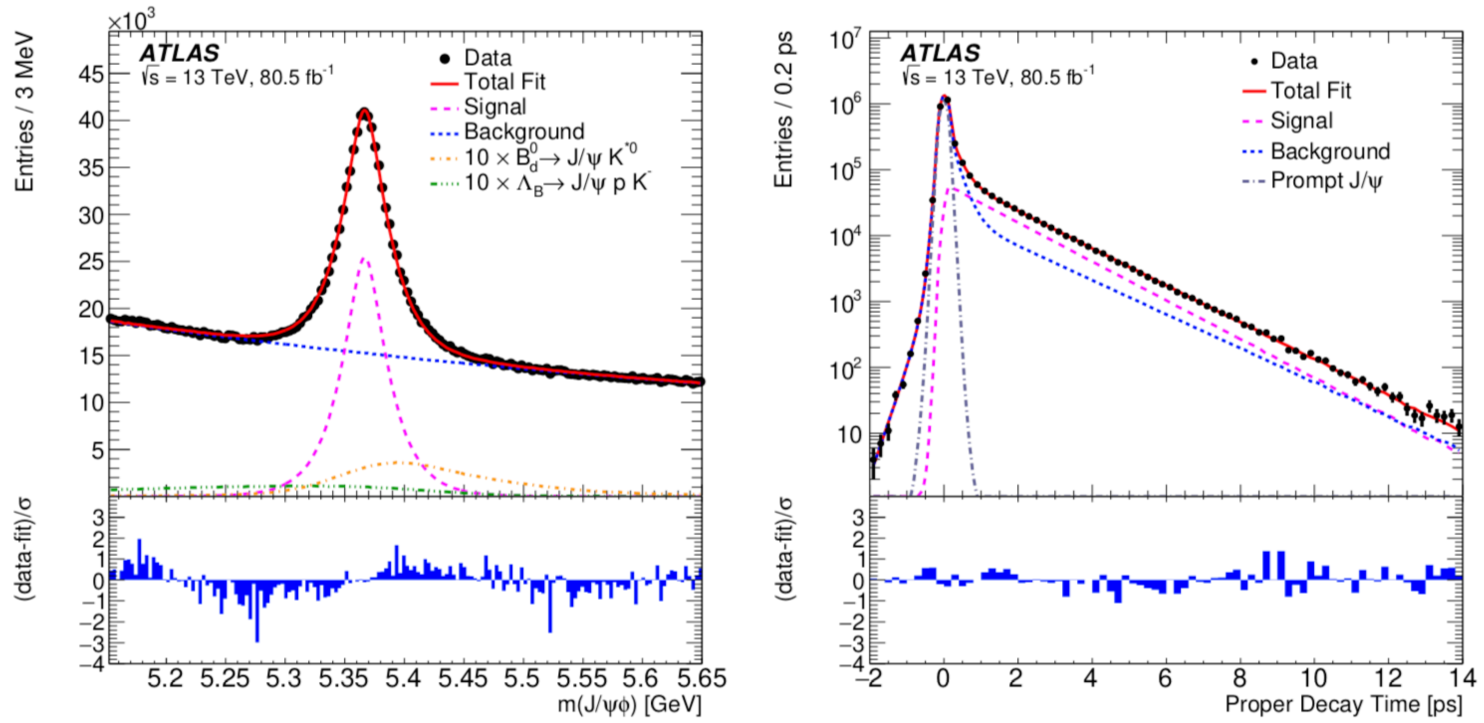
Backup

Time-dependent analyses of B_s decays

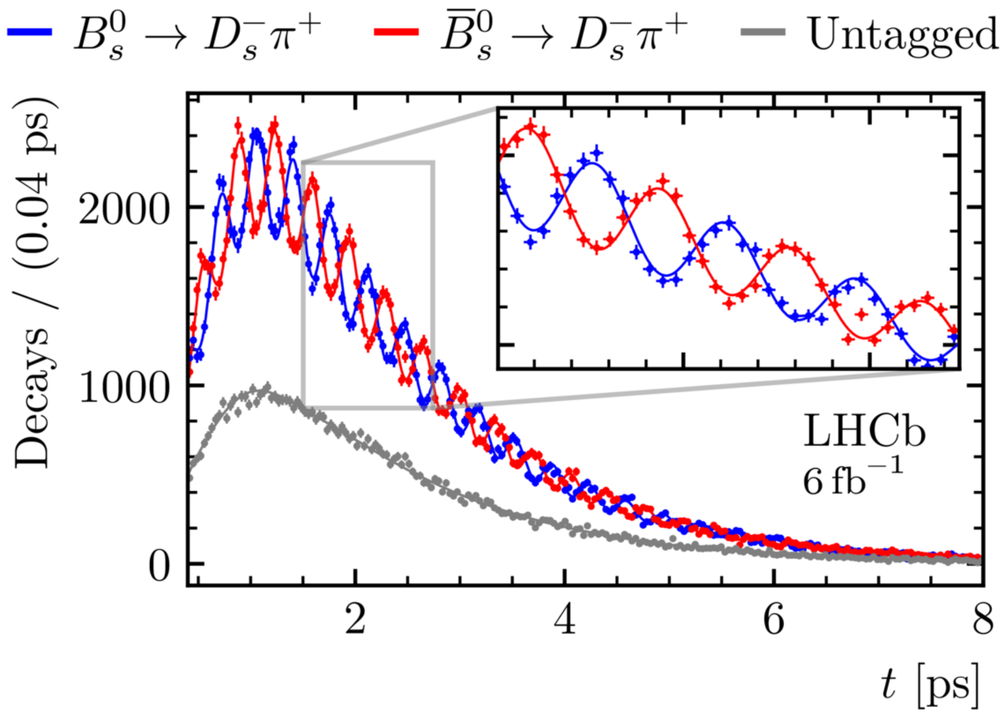
Phys. Lett. B 816 (2021) 136188

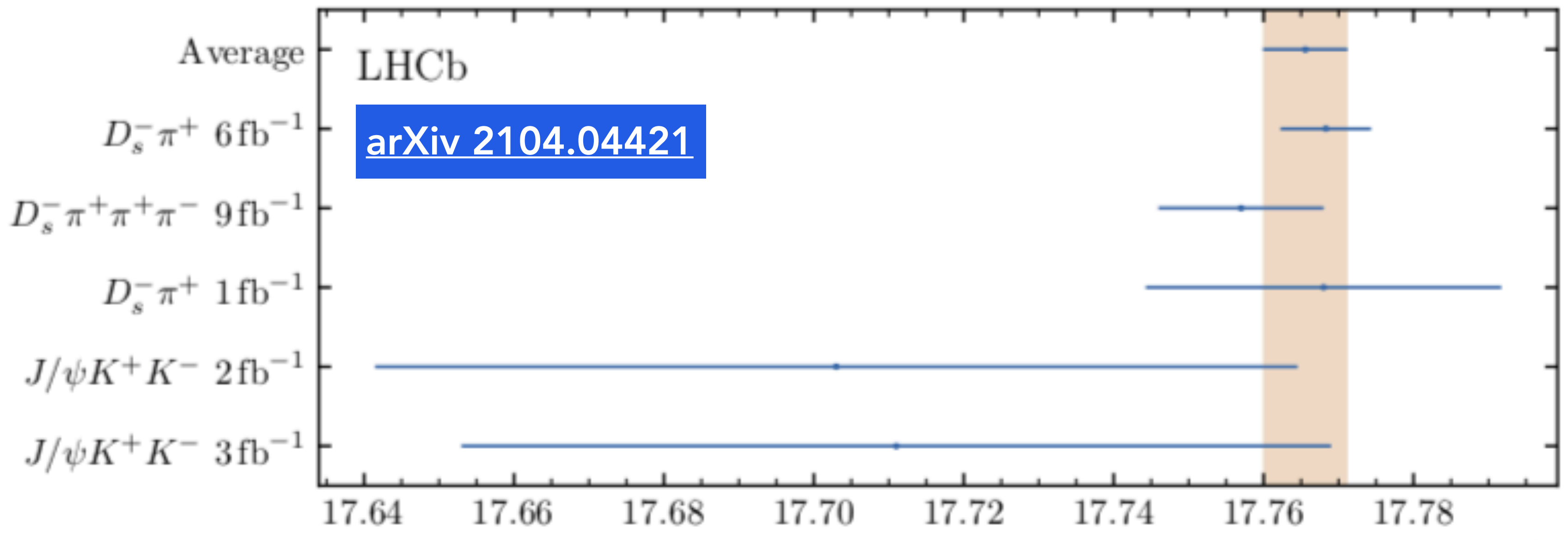


Eur. Phys. J. C 81 (2021) 342



arXiv 2104.04421





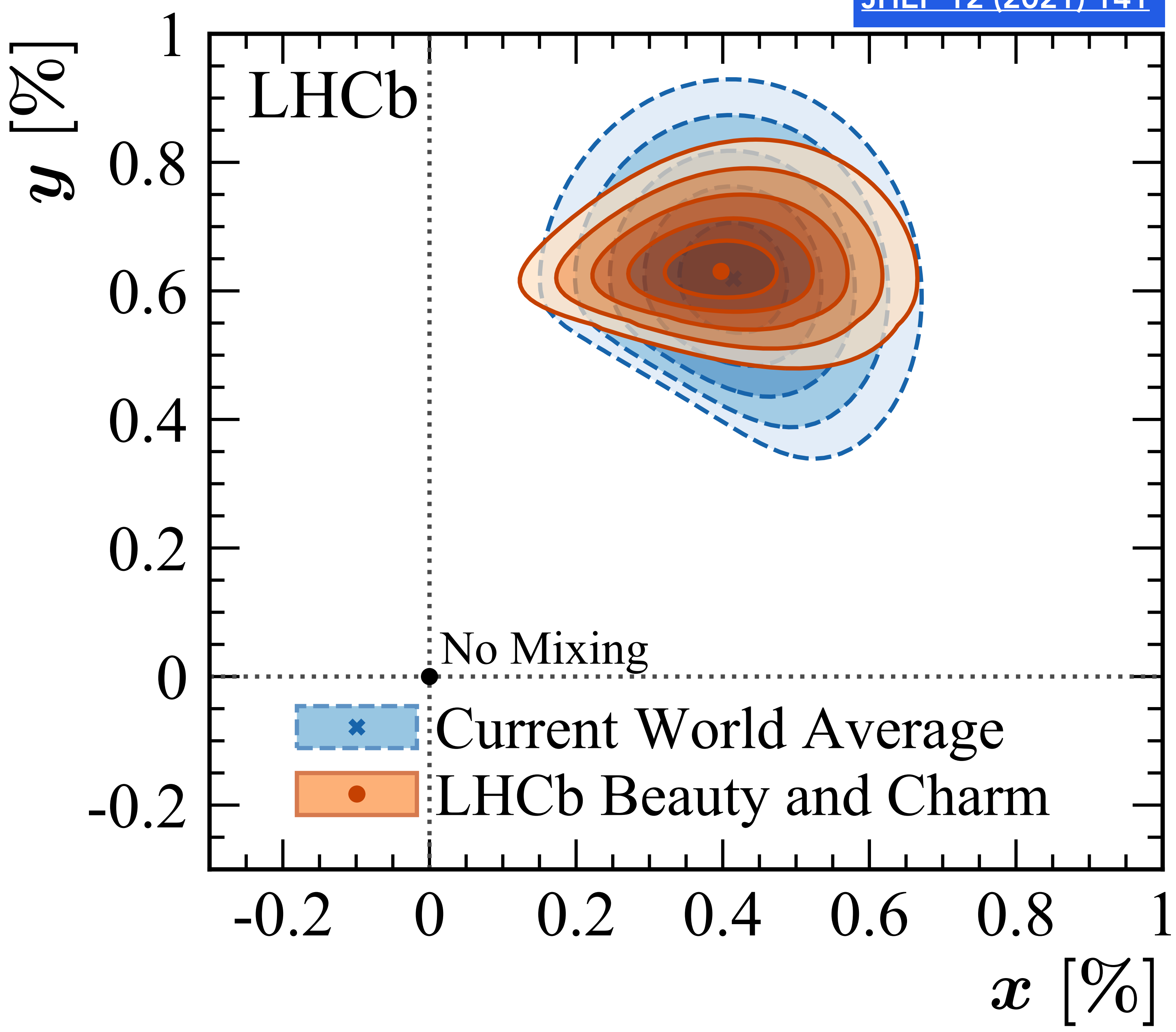
LHCb combined → $17.7683 \pm 0.0051\,(\mathrm{stat}) \pm 0.0032\,(\mathrm{syst})\,\mathrm{ps}^{-1}$ Δm_s [ps^{-1}]

b→ccs and b→sss processes provide many complementary null tests of the Standard Model!

LHCb, ATLAS, CMS can all make these measurements — critical for long-term confidence in results.

Exploiting synergies of beauty & charm

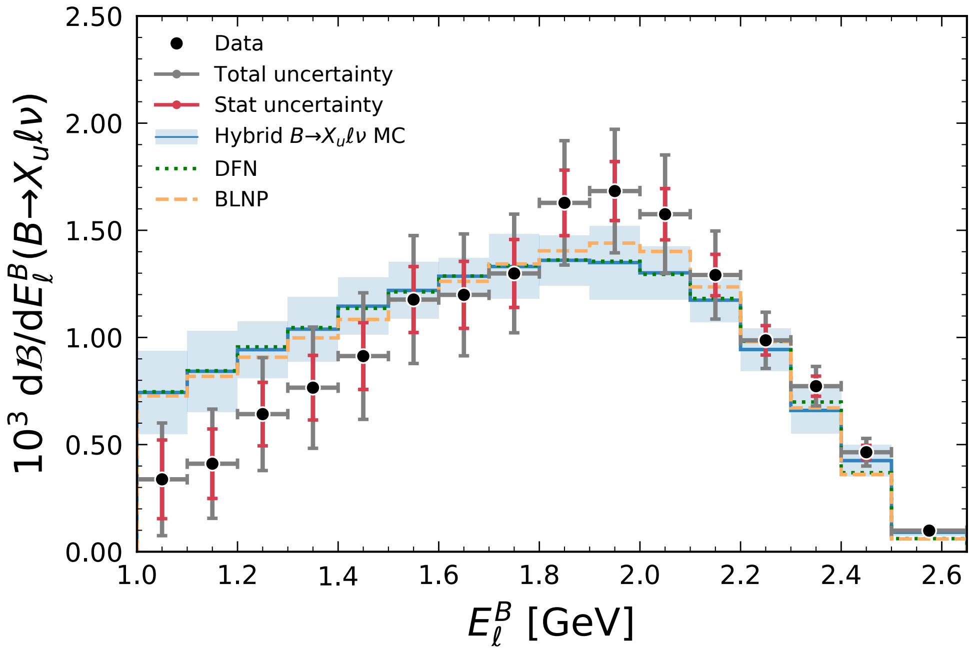
JHEP 12 (2021) 141



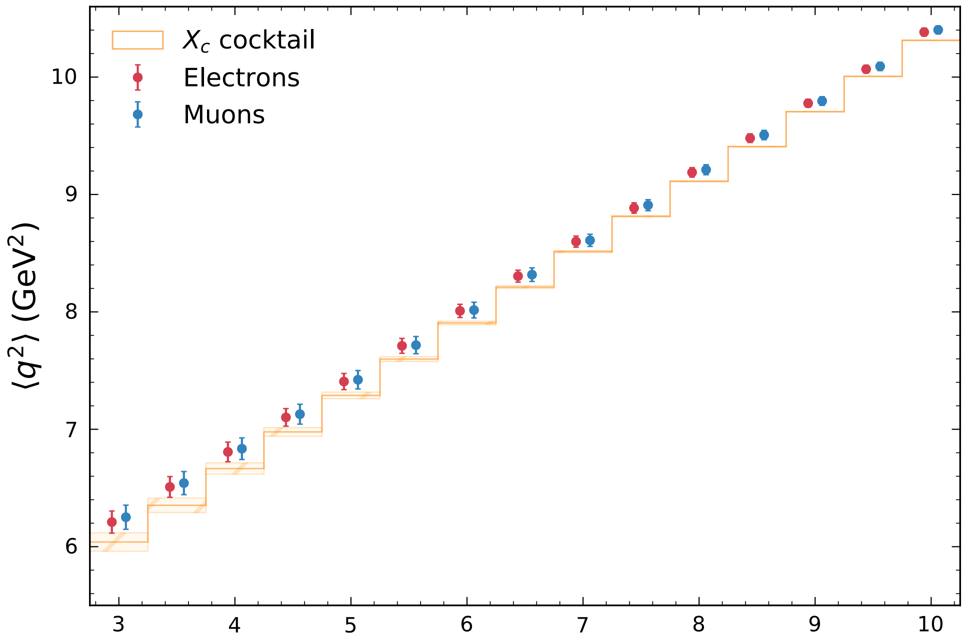
Full power comes from global fits to all sectors & experiments — an organisational and scientific challenge!

The quest for V_{ub} & V_{cb}

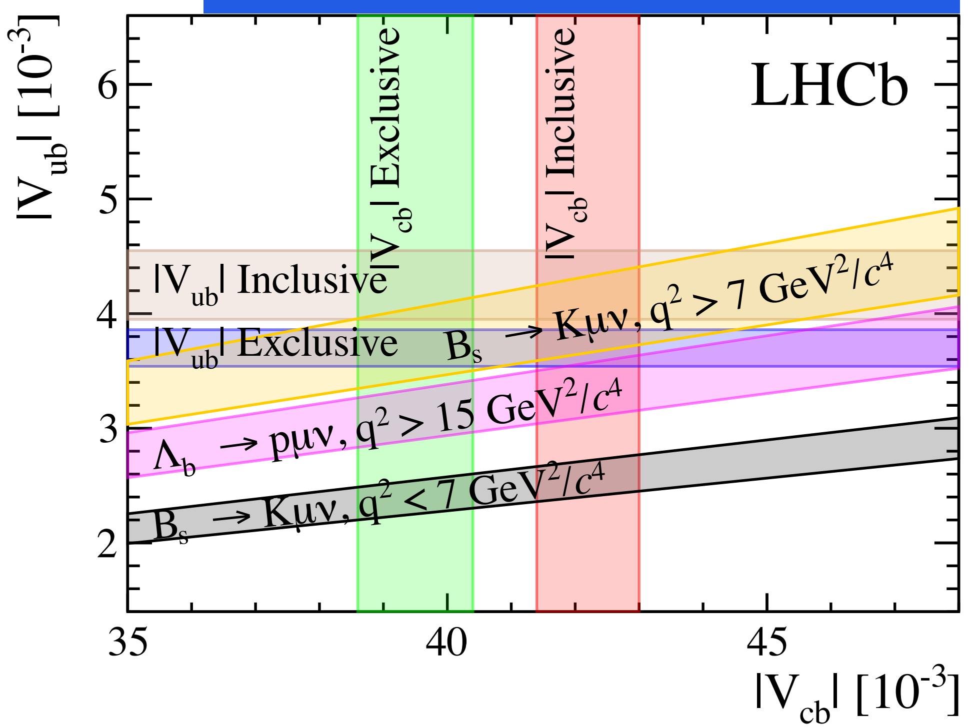
Belle Preprint 2021-015



Belle Preprint 2021-018



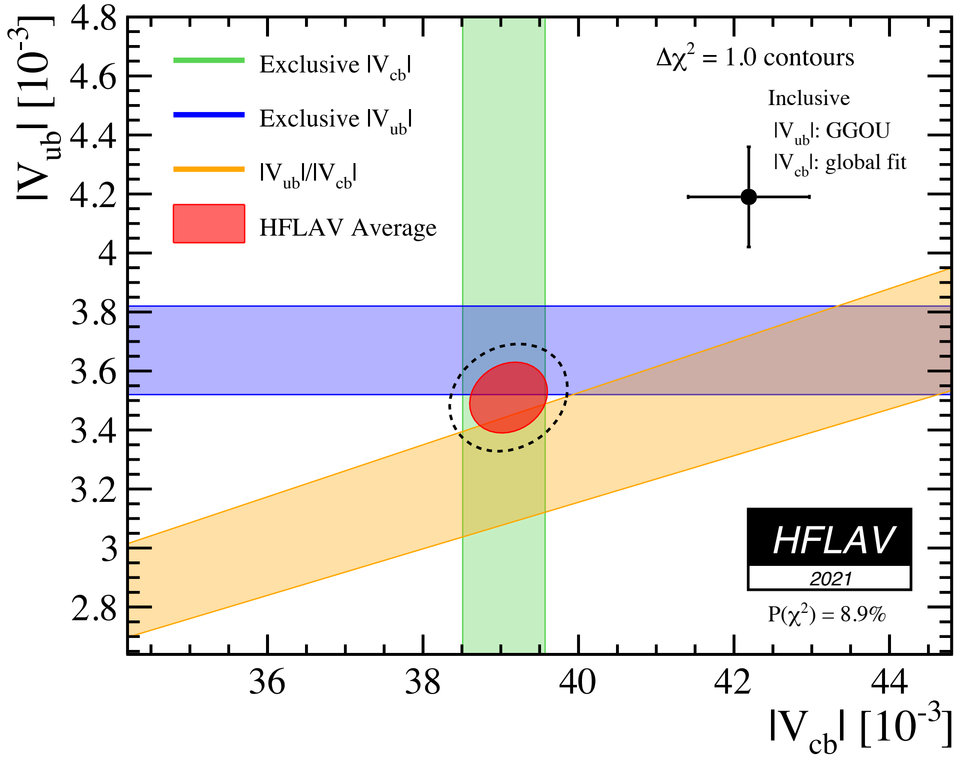
PHYS. REV. LETT. 126 (2021) 081804



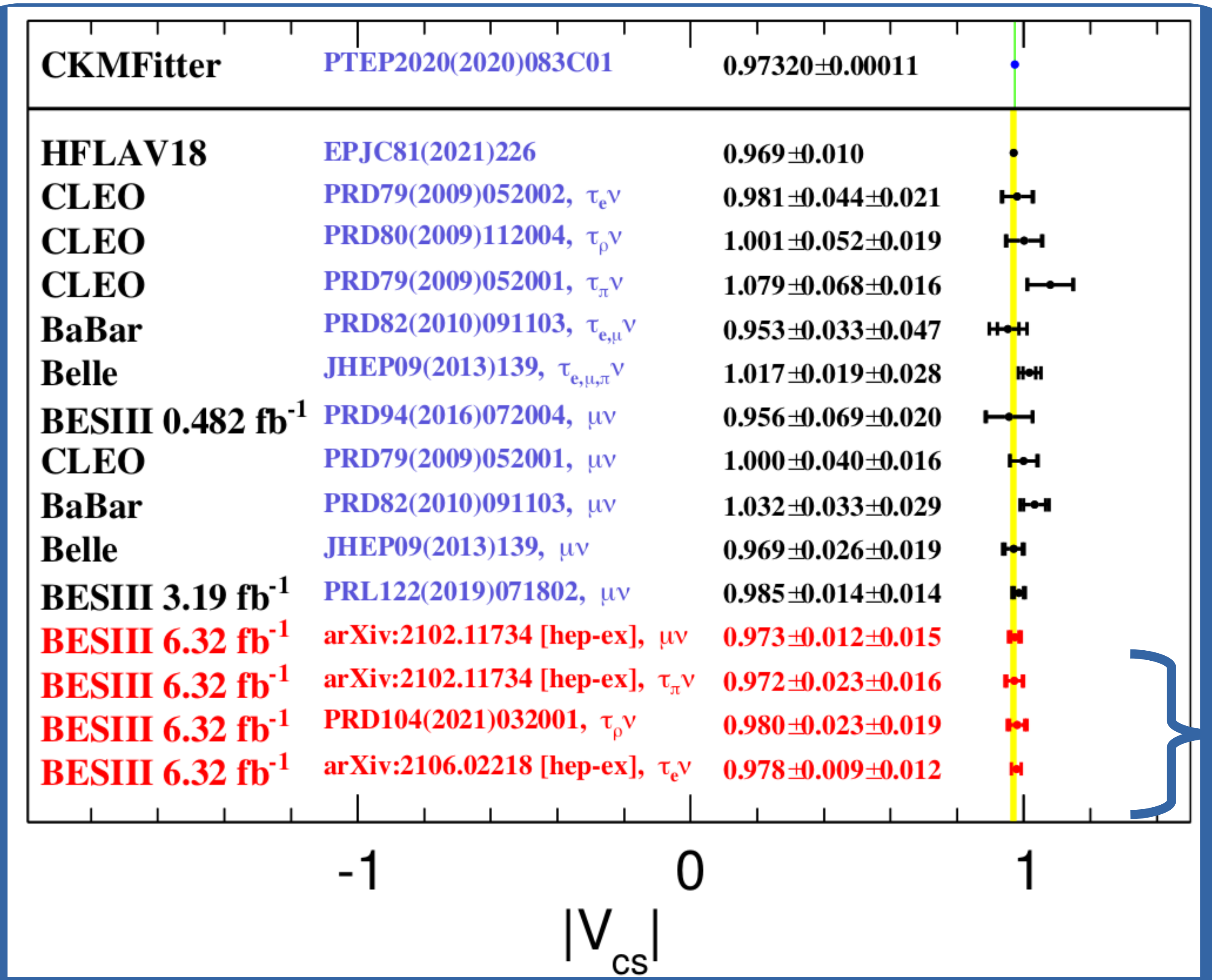
Measurements by Belle shed light on V_{ub} & V_{cb}

Inclusive-exclusive tensions remain in V_{cb}, are reduced in V_{ub}
Tension in Vub from 2-3 sigma depending on inputs
V_{cb} remains at 3 sigma, further experimental input must be matched by progress in theory/lattice calculations

Discrepancy in V_{ub}/V_{cb} from $B \to K\mu\nu$ at low/high q^2 needs to be understood better, implication for calculation of form-factors



BESIII results impact on V_{cs}



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

From LQCD calculations

(FLAVG19)

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

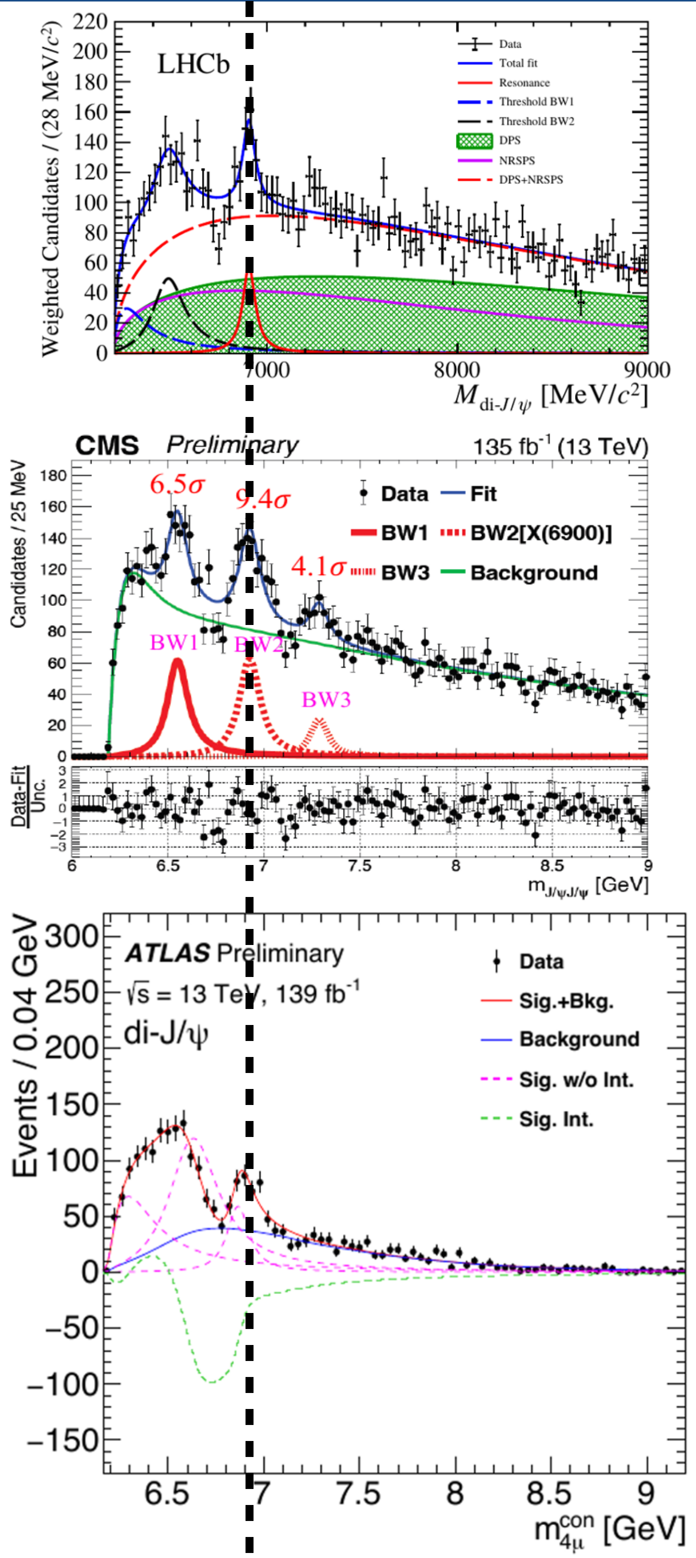
Combined → 0.979 ± 0.007 ± 0.008

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

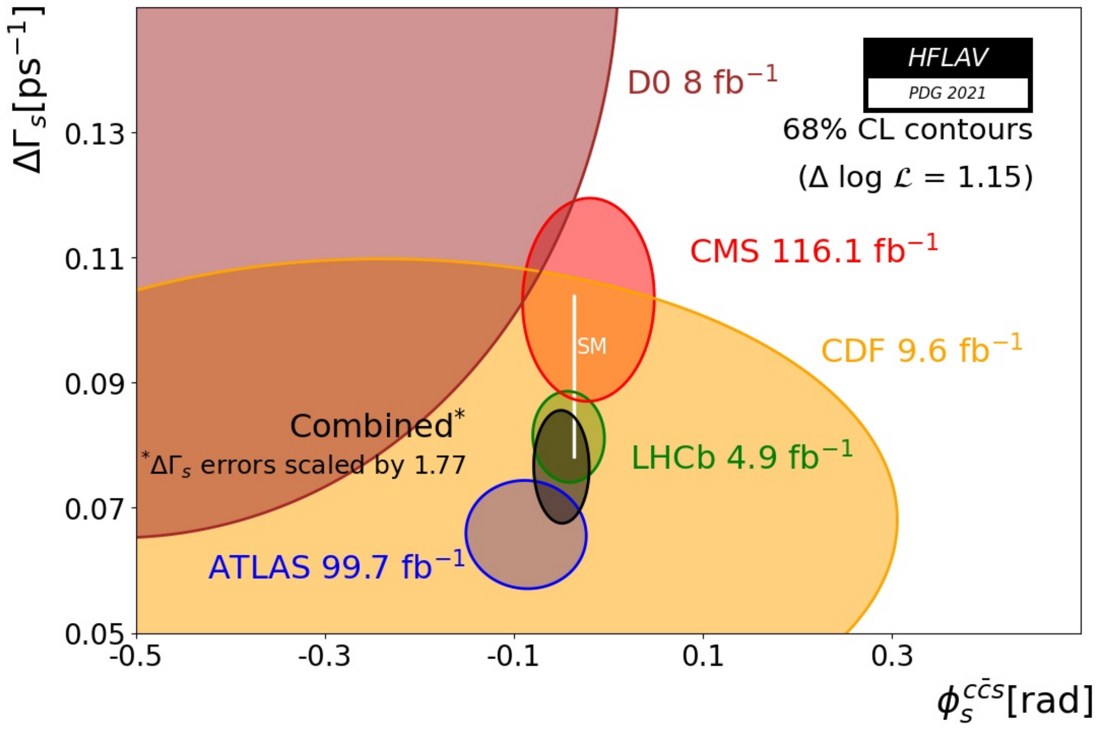
1% precision!

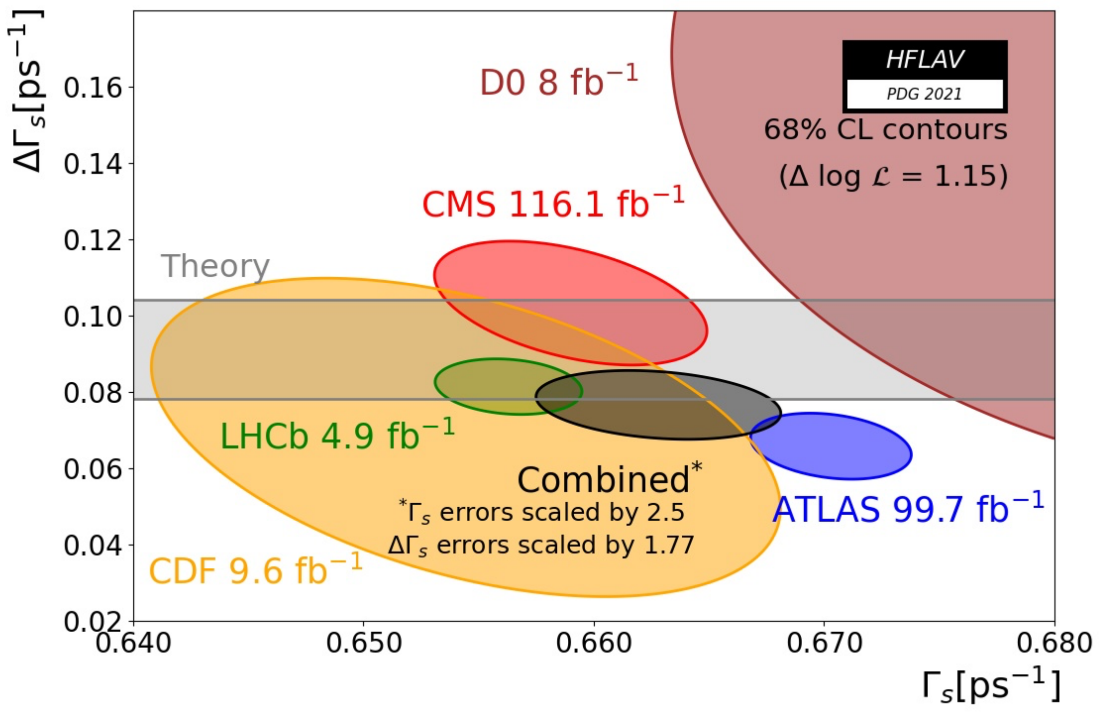
10

One slide show of di-J/ψ 4-quark states

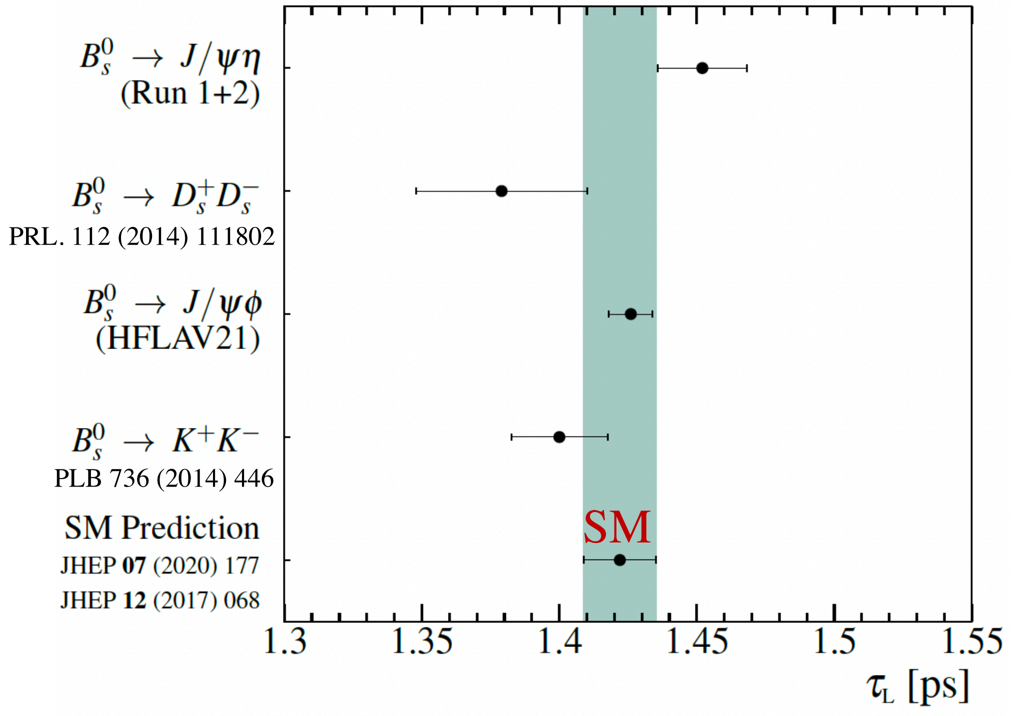


Time-dependent analyses of B_s decays





LHCb-PAPER-2022-010 (Submitted to EPJC)



Important to resolve the ongoing tension in measurements of the B_s lifetime and width difference of the light and heavy eigenstates!

Must improve all measurements: not only φ_s but also individual lifetimes.

Cross-experiment work on common experimental assumptions seems vital.

Latest 4-quark states from BESIII

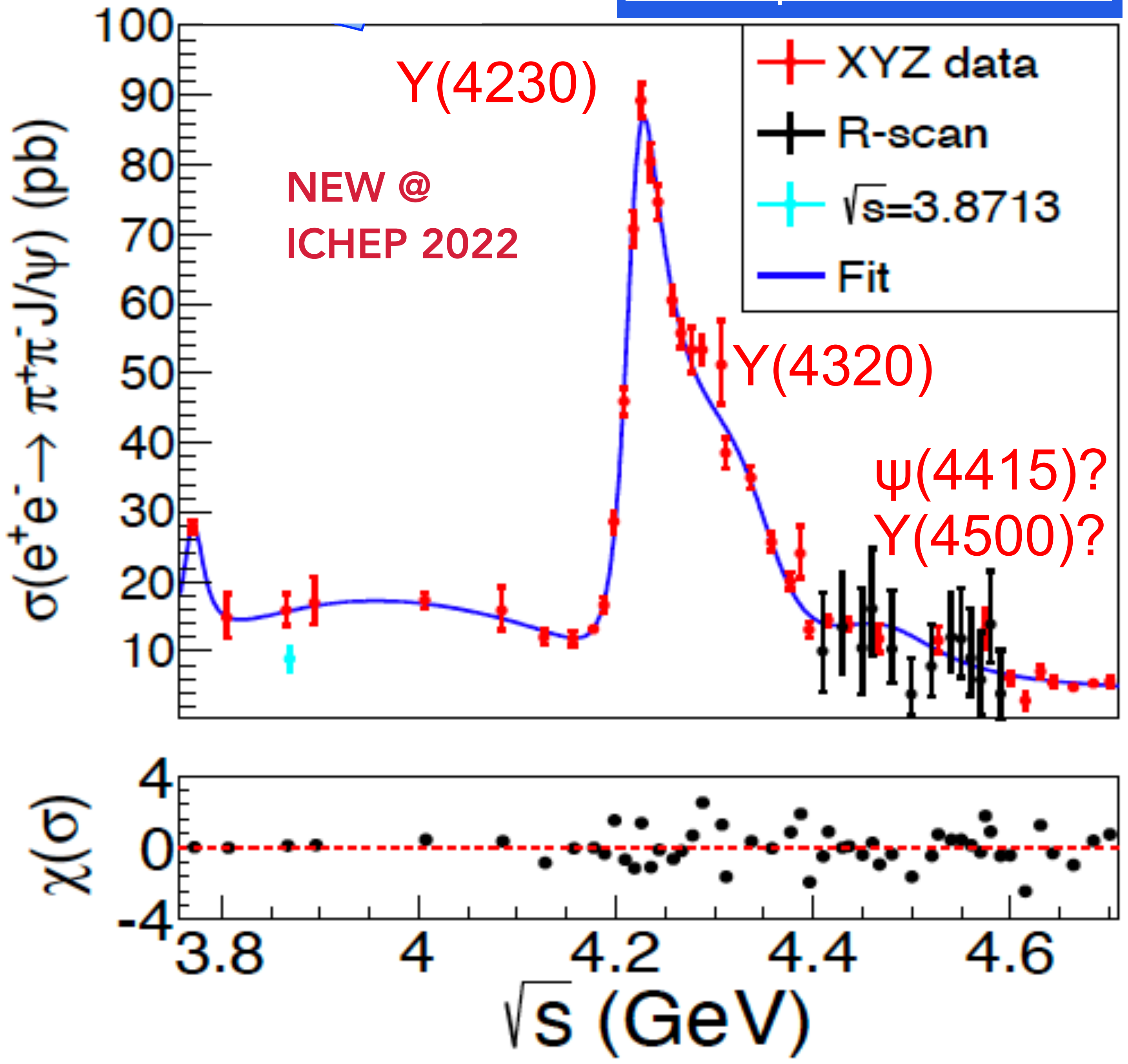
Too many results to truly do them justice — a cornerstone of the BESIII programme

Pick here the characterisation of Y(4230) and Y(4320) states in $J/\Psi\pi\pi$ decays

$M_{Y(4230)}$	=	$4221.4 \pm 1.5 \pm 2.0$ MeV/c^2
$\Gamma_{Y(4230)}$	=	$41.8 \pm 2.9 \pm 2.7$MeV

$M_{Y(4320)}$	=	$4298 \pm 12 \pm 26$ MeV/c^2
$\Gamma_{Y(4320)}$	=	$127 \pm 17 \pm 10$ MeV

Stefano Spataro @ ICHEP 2022



LU tests in LHCb, challenges