CKM & CPV

(Quark Flavour)

Phillip Urquijo

ICHEP Plenary, Seoul

July 2018

On behalf of the Belle II collaboration

Results from Babar, Belle(II), BESIII, LHCb, KLOE(2)

Belle II

POSTERA CRESCAM LAUDE
THE UNIVERSITY OF MELBOURNE

Flavour motivations

- **Matter antimatter asymmetry**
  → <u>New sources of CP Violation</u>
- Quark and Lepton flavour & mass hierarchy
  →extended gauge sector coupling to third generation ($H^{\pm}$, W', Z')
  →restored L-R symmetry
- **Finite neutrino masses**
  → <u>LFV and LFUV.</u>
- 19 free parameters
  → GUTs, **<u>leptoquarks</u>**
- Hidden and dark sectors at the GeV scale, may have flavour properties.

Kimchi (SPICY)

Gochujang (HOT)

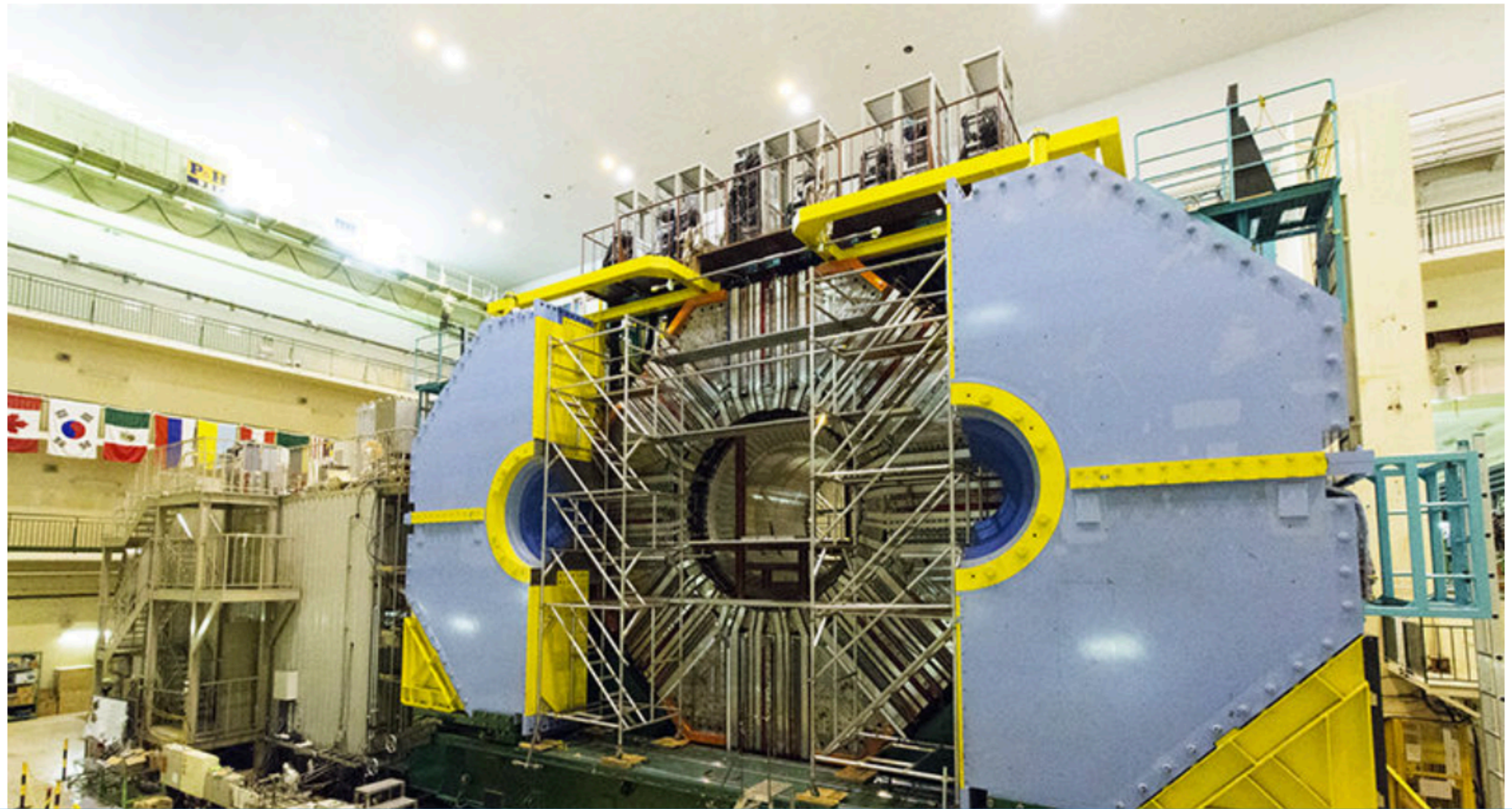
- **Leptonic and Semileptonic decays**
  - CKM matrix element magnitudes
  - Violations of lepton flavour universality
- **Direct and indirect CP violation**
  - SM Weak CP phase
  - New sources of CP violation

NEWS · 12 JANUARY 2018

Revamped collider hunts for cracks in the fundamental theory of physics

Experiment smashes electrons into positrons to search for unseen particles and problems with overarching physics framework.

Elizabeth Gibney



PDF

RELATED

Rare pa
physics

Physicis
anomaly

LHC sig
standar

PHYSICS

Lawbreaking Particles May Point to a Previously Unknown Force in the Universe

Scientists aren't yet certain that electrons and their relatives are violating the Standar Model of particle physics, but the evidence is mounting

By Jesse Dunietz on July 17, 2017

FEATURE 27 April 2016

That's odd: Unruly penguins hint where all the antimatter went

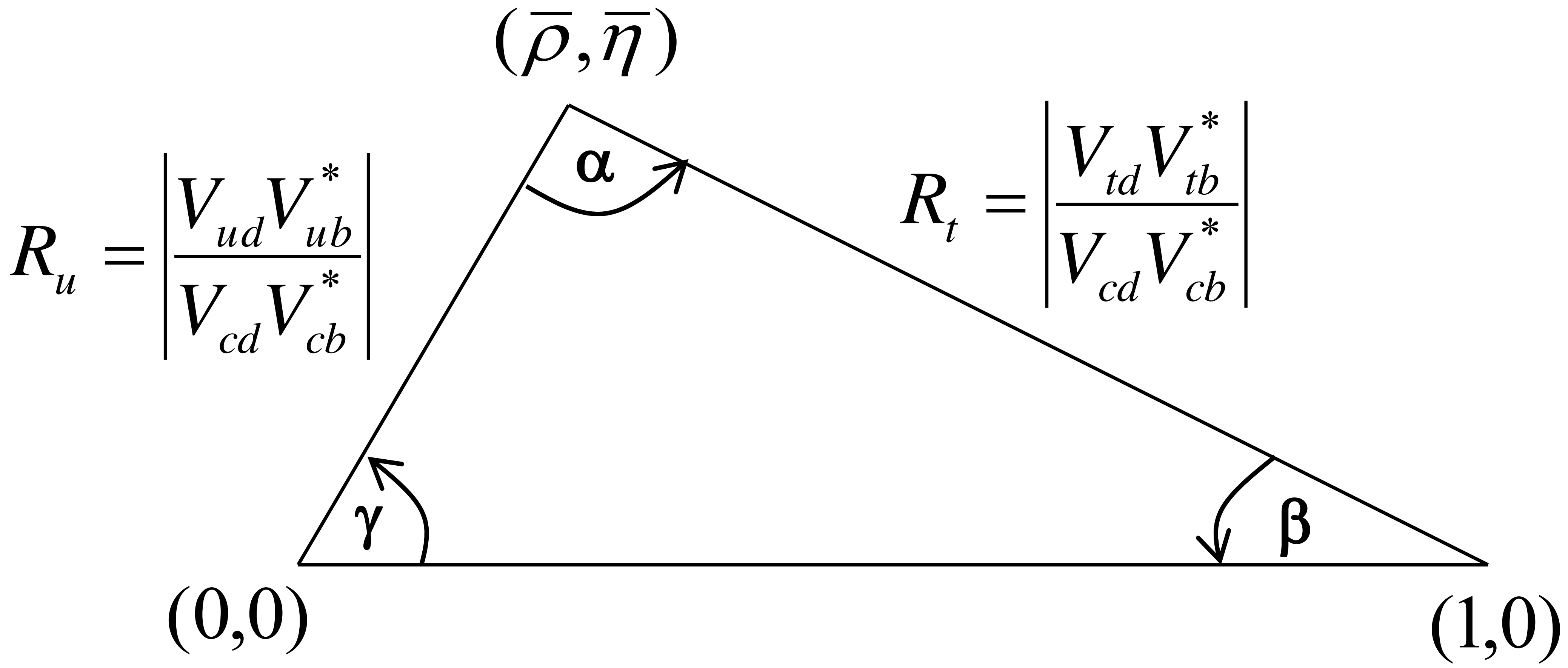
Rare "penguin" particle decays should all happen at the same rate. They don't – perhaps providing a clue to why we live in a universe made of matter

CP violation in the SM

- The SM describes the mixing of quarks of different generations through the weak force.

$$V_{\mathrm{CKM}} \propto \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|\, e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|\, e^{-i\beta} & -|V_{ts}|\, e^{-i\beta_s} & |V_{tb}| \end{pmatrix}$$

3 Generations, 1 Phase: single source of CPV in the SM.

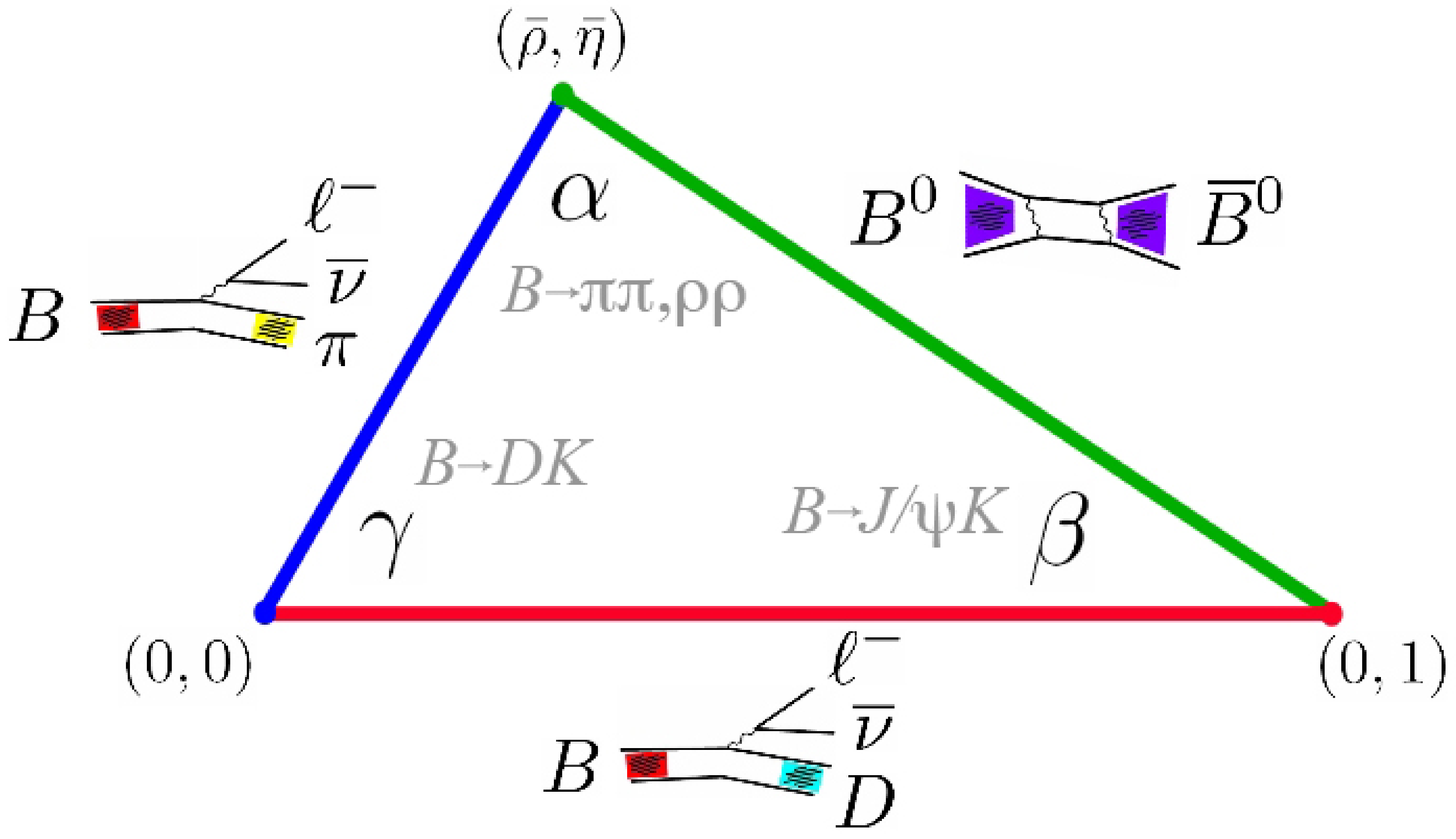


Wolfenstein parameterisation: Phase invariant, conserving CKM matrix unitarity at any order in λ.

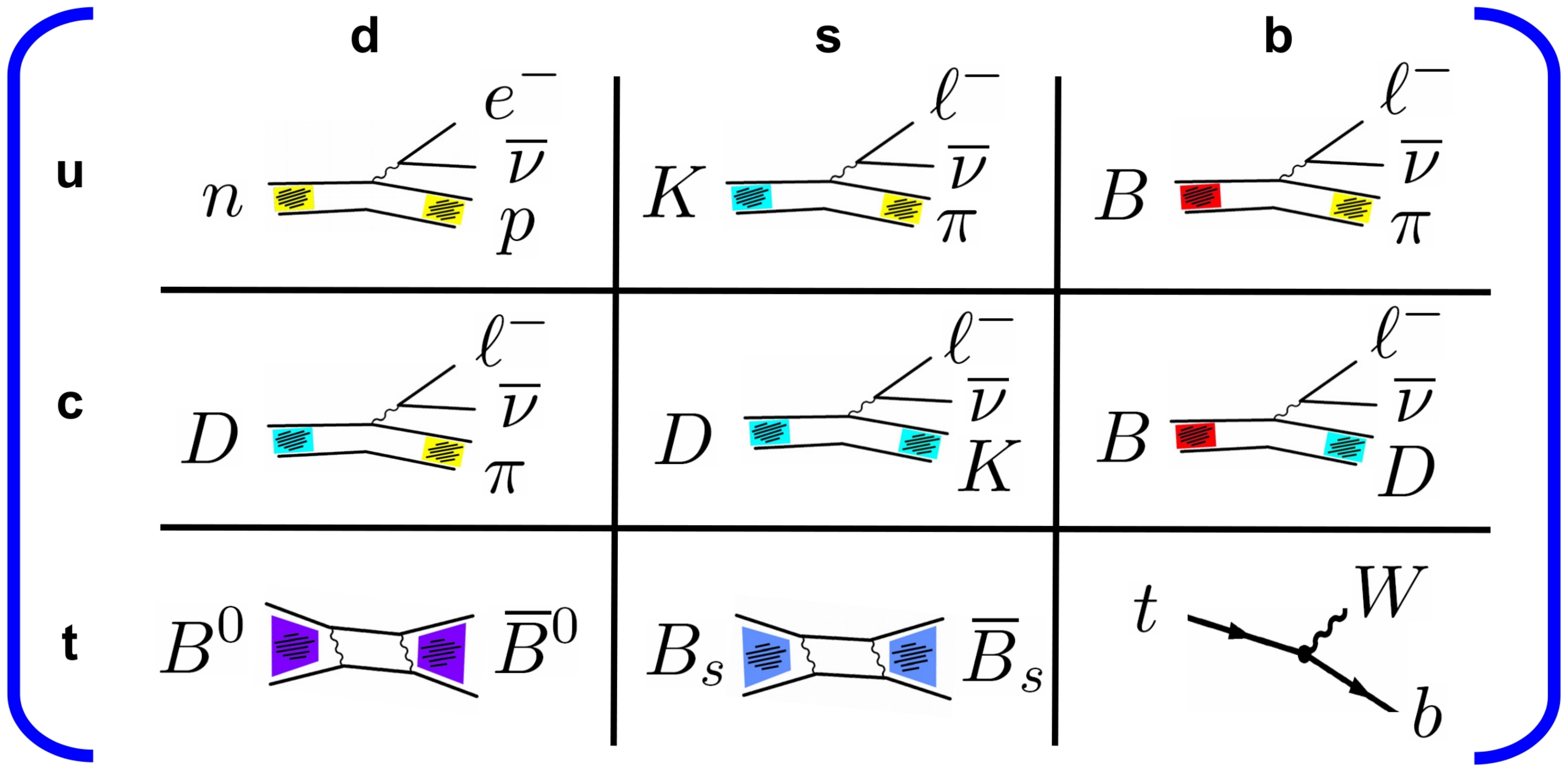
$$\lambda^2 \equiv \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad A^2\lambda^4 \equiv \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad \bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

CKM and CPV SM Metrology

- How do we measure the CKM parameters?



V =



$B \to \pi\pi, \rho\rho$	α / Φ_2	$B \to D^* l \nu$ / $b \to c l \nu$	$\lvert V_{cb} \rvert$ via Form factor / OPE
$B \to D^{(*)} K^{(*)}$	γ / Φ_3	$B \to \pi l \nu$ / $b \to u l \nu$	$\lvert V_{ub} \rvert$ via Form factor / OPE
$B \to J/\psi K_S$	β / Φ_1	$M \to l \nu (\gamma)$	$\lvert V_{UD} \rvert$ via Decay constant f_M
$B_s \to J/\psi \Phi$	β_s	ε_K	(ρ, η) via B_K
$K \to \pi \nu$ anti-ν	ρ, η	$\Delta m_d, \Delta m_s$	$\lvert V_{tb} V_{t\{d,s\}} \rvert$ via Bag factor B_B
		$B_{(s)} \to \mu^+ \mu^-$	$\lvert V_{t\{d,s\}} \rvert$ via Decay constant f_B

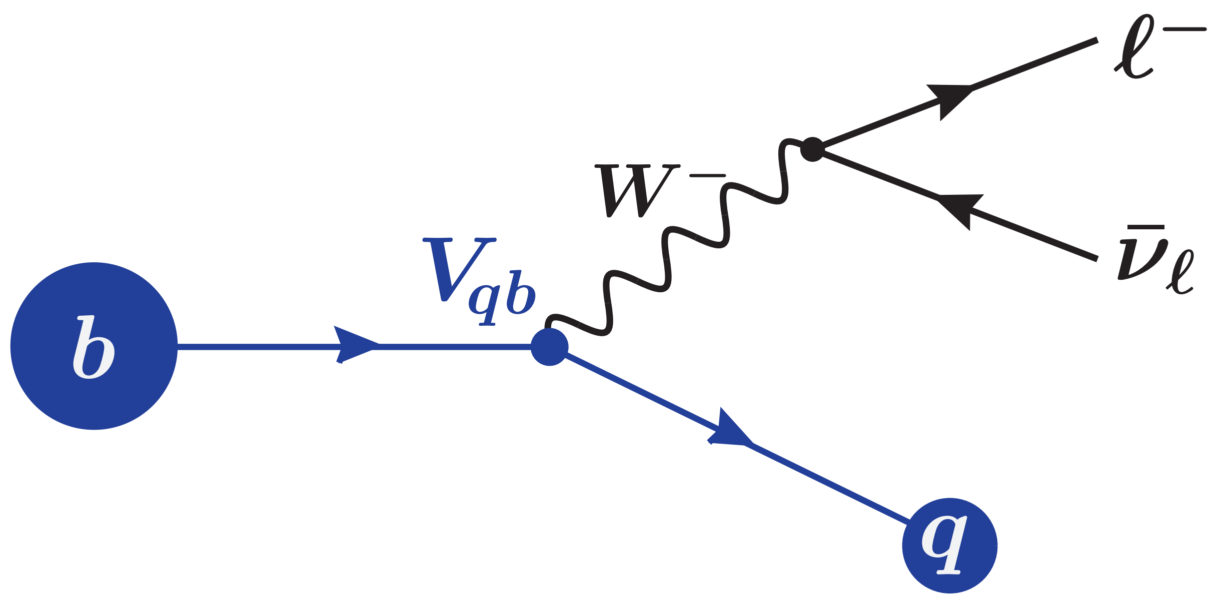
Flavour data sets from colliders

- Several experiments at different machines contributing to the field with new results in 2018.
- **SuperKEKB is the first new collider since the LHC.**

Experiment	$\int L\,dt$	σ(bb)	σ(cc)	σ(ss)	Operation
Babar	530 fb^{-1}	1.1 nb	1.6 nb	0.4 nb	1999-2008
Belle	1040 fb^{-1}	1.1 nb	1.6 nb	0.4 nb	1999-2010
Belle II	**>0.5 fb^{-1} (50 ab^{-1})**	**1.1 nb**	**1.6 nb**	**0.4 nb**	**2018-**
BESIII	~16 fb^{-1}	-	6 nb (3770 MeV)	-	2008-
KLOE-2	5.5 fb^{-1}	-		~3 μb (1020 MeV)	2014-2018
ATLAS	> 100 fb^{-1}	250-500 μb	-	-	2009-
CMS	> 100 fb^{-1}	250-500 μb	-	-	2009-
LHCb	1 + 2 + >5 fb^{-1}	250-500 μb	1200- 2400 μb	(~10^{13} K_S / fb^{-1})	2009-

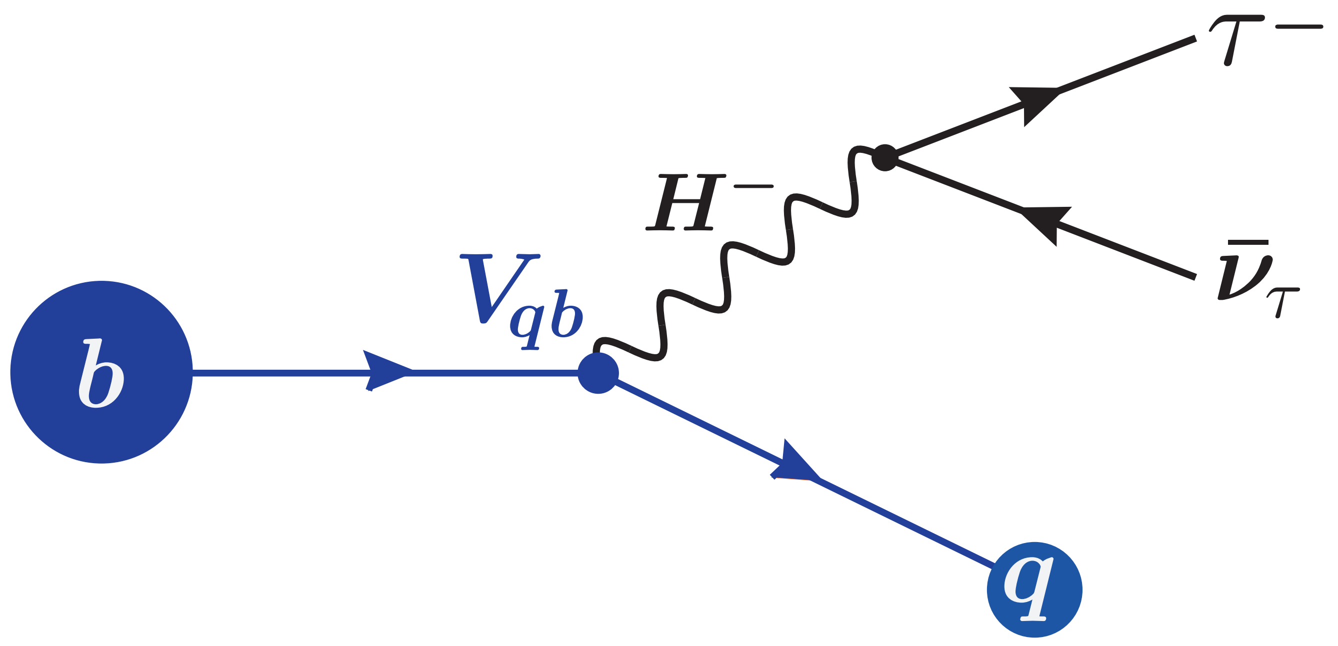
Leptonic and Semileptonic Decay

- 3-ways to measure $|V_{CKM}|$ with leptonic and semileptonic decays



- **Leptonic**: decay constant from LQCD

$$\Gamma(B \to \ell_1 \ell_2) = \frac{M_B}{4\pi} |G|^2 f_B^2 \zeta_{12} \frac{\lambda_{12}^{1/2}}{M_B^2} \qquad G = \frac{G_F}{\sqrt{2}} V_{ub}, \quad (m_{\nu_\ell} \to 0)$$



- **Exclusive semileptonic**: form factor parameterisation with normalisation from LQCD or Light Cone Sum Rules

$$\frac{d\Gamma}{dq^2} = C_q |\eta_{\rm EW}|^2 \frac{G_F^2 |V_{qb}|^2}{(2\pi)^3} \frac{\lambda^{1/2}}{4M_B^3} \frac{\lambda_{12}^{1/2}}{q^2} \left\{ q^2 \beta_{12} \left[|H_+|^2 + |H_-|^2 + |H_0|^2 \right] + \zeta_{12} |H_s|^2 \right\}$$

- **Inclusive semileptonic**: Heavy quark symmetry if you measure the full rate, described by heavy quark expansion

$$\Gamma(B \to X_c \ell \nu) = \frac{G_{\rm F}^2 m_b^5}{192\pi^3} |V_{cb}|^2 [[1 + A_{\rm ew}] A_{\rm nonpert} A_{\rm pert}]$$

$$\lambda_{12} = (M_B^2 - m_1^2 - m_2^2)^2 - 4m_1^2 m_2^2,$$

$$\zeta_{12} = m_1^2 + m_2^2 - \frac{(m_1^2 - m_2^2)^2}{M_B^2},$$

$$\beta_{12} = 1 - \frac{m_1^2 + m_2^2}{q^2} - \frac{\lambda_{12}}{q^{2\,2}}$$

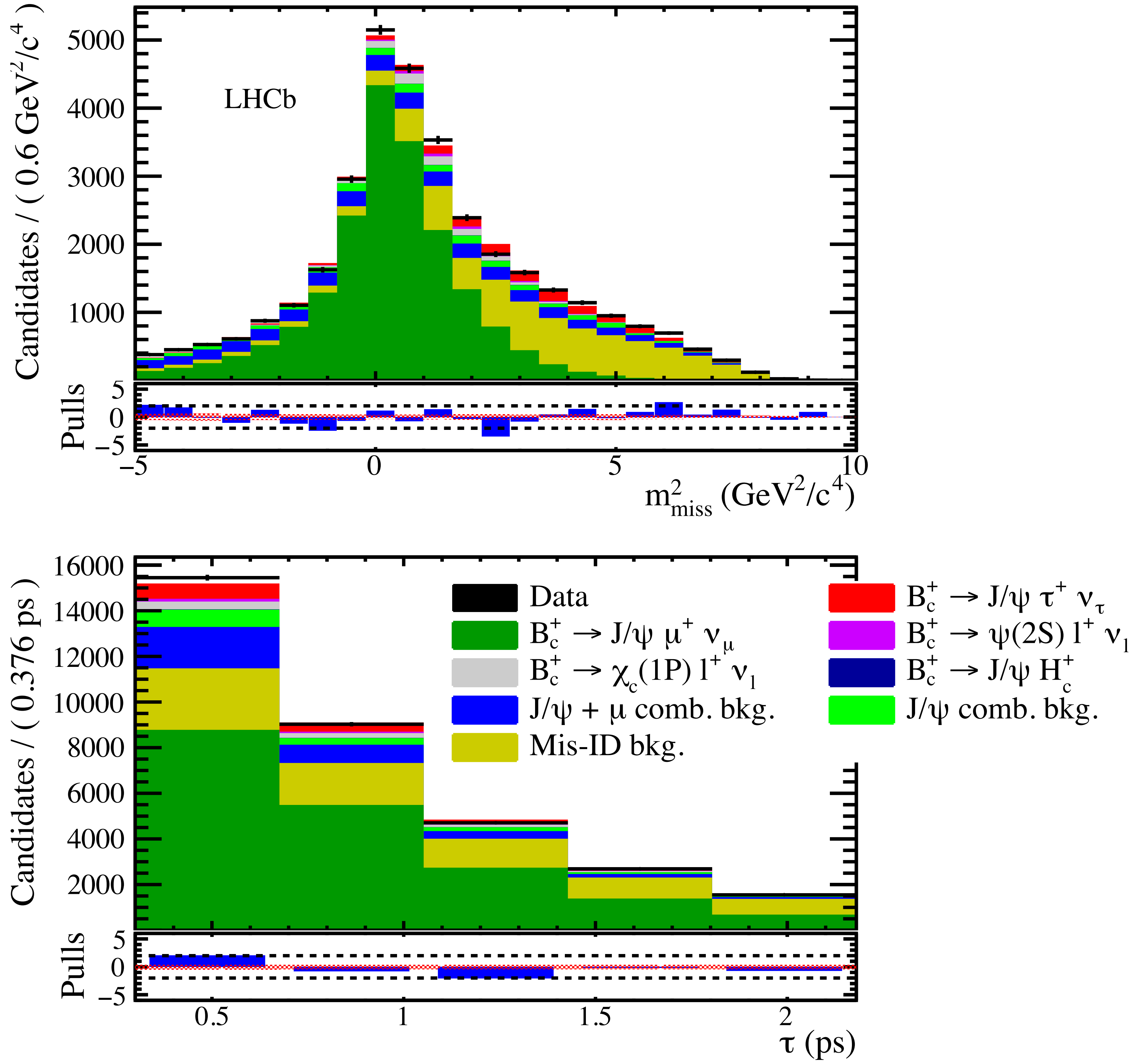
$B \to D^{(*)} \tau \nu$, $B_c \to J/\psi \tau \nu$

O. Leroy
K. Matsuoka

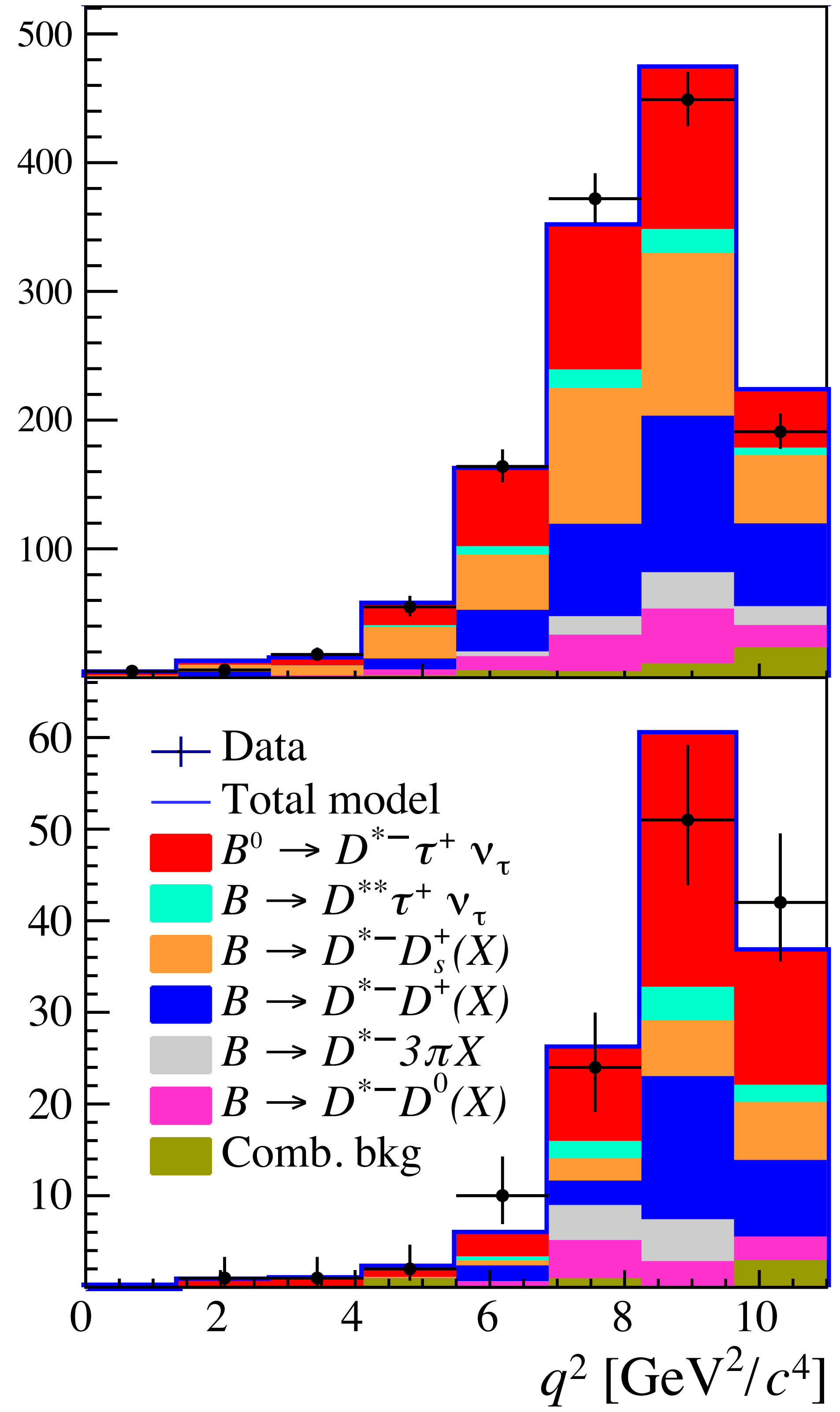
LHCb PRL 120, 121801 (2018)
LHCb PRD97 7, 072013 (2018)
Belle PRD97 1, 012004 (2018)

- → Large anomaly (first seen by Belle), now numerous measurements. Do we understand the background?
  Only Belle(II) has high hermetic coverage (for τ reco.)

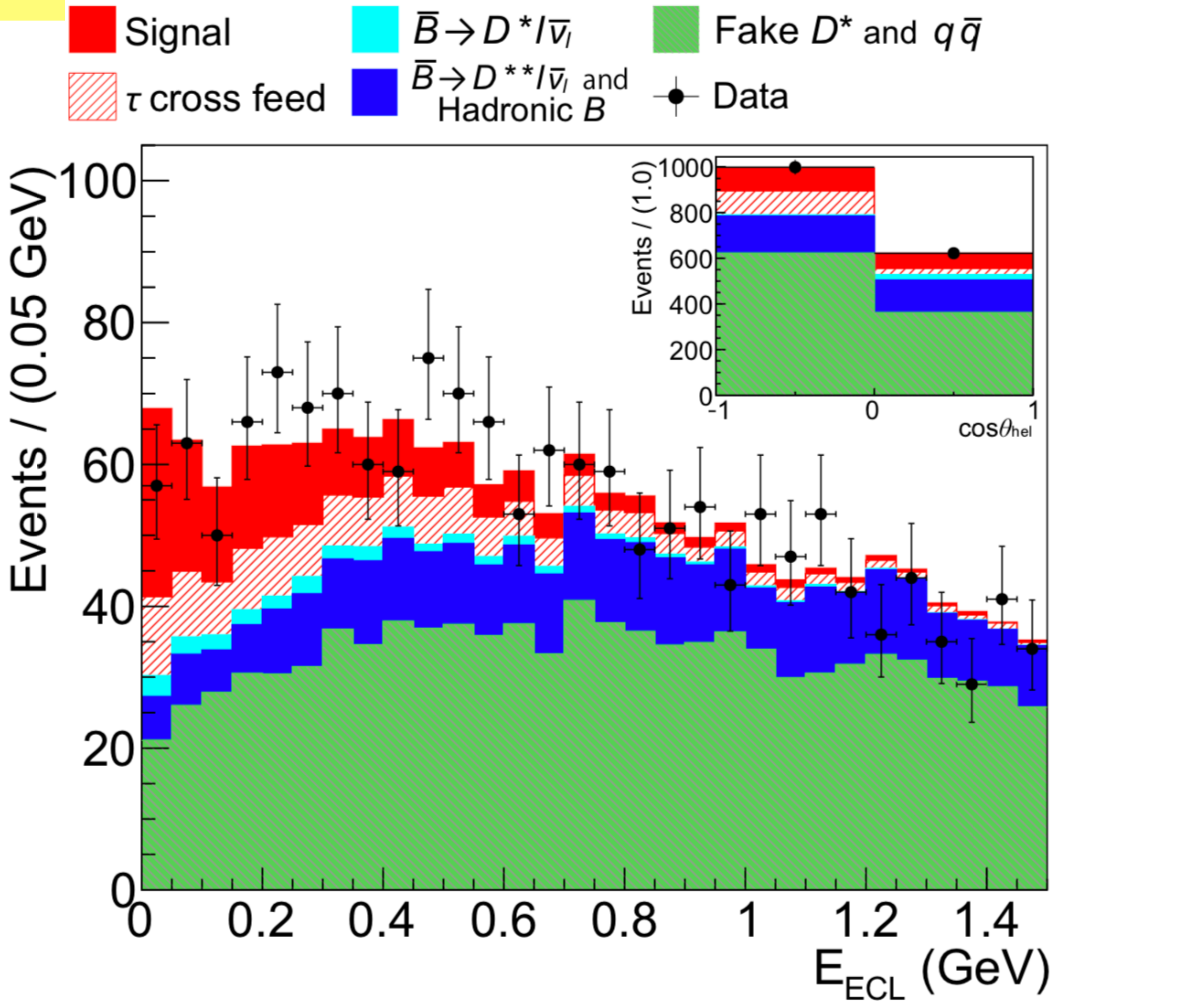
Belle and Babar still yet to release full semileptonic tagged R(D)+R(D*)



Measurement of the Ratio of Branching Fractions $\mathcal{B}(B^+_c \to J/\psi \tau^+ \nu_\tau)/\mathcal{B}(B^+_c \to J/\psi \mu^+ \nu_\mu)$



Test of LFU in $B^0 \to D^{*-} \tau^+ \nu_\tau$ branching fraction using 3-prong τ decays

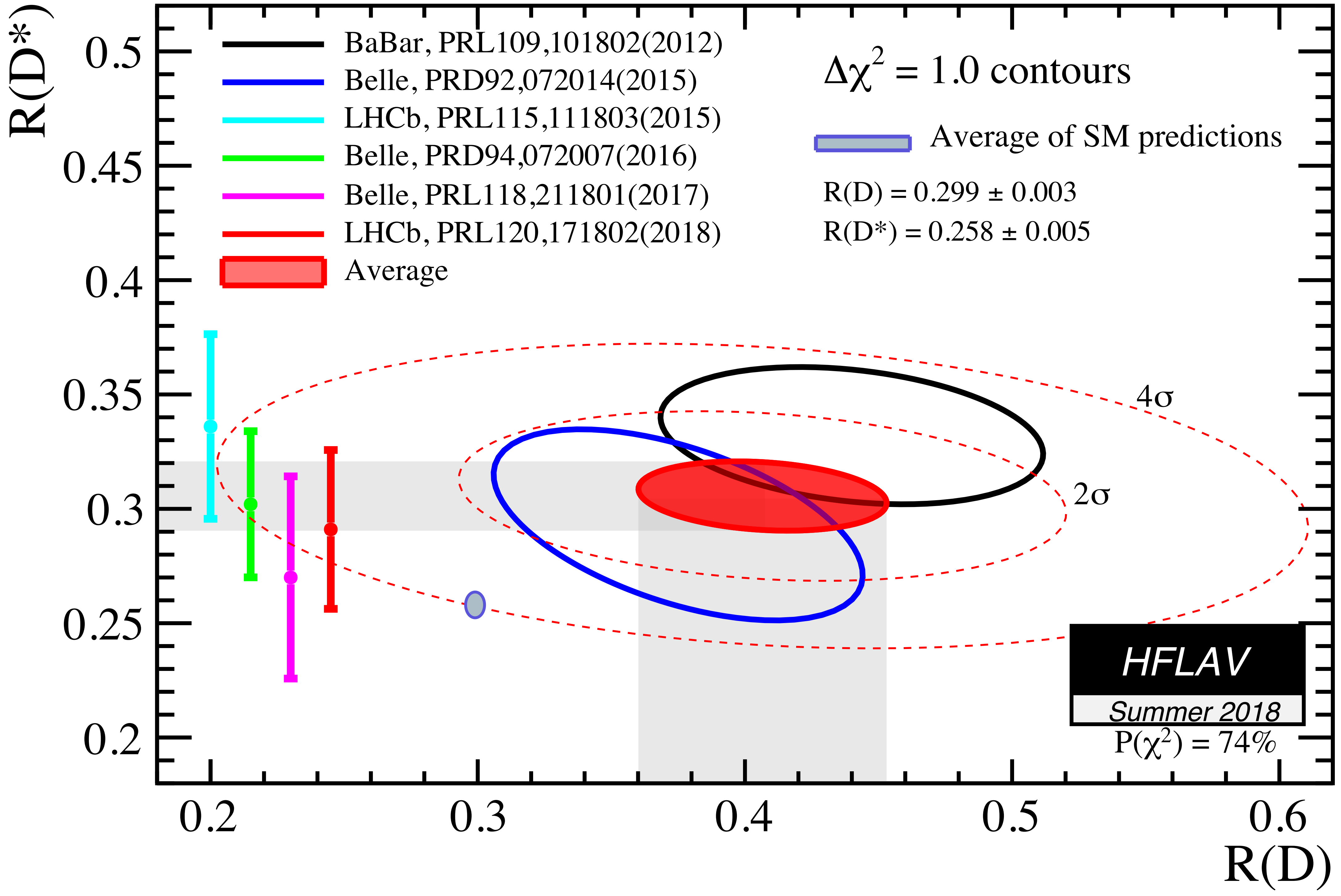


Measurement of τ lepton polarisation and $R(D^*)$ in the decay $B \to D^* \tau^- \nu_\tau$ with 1-prong hadronic τ decays at Belle

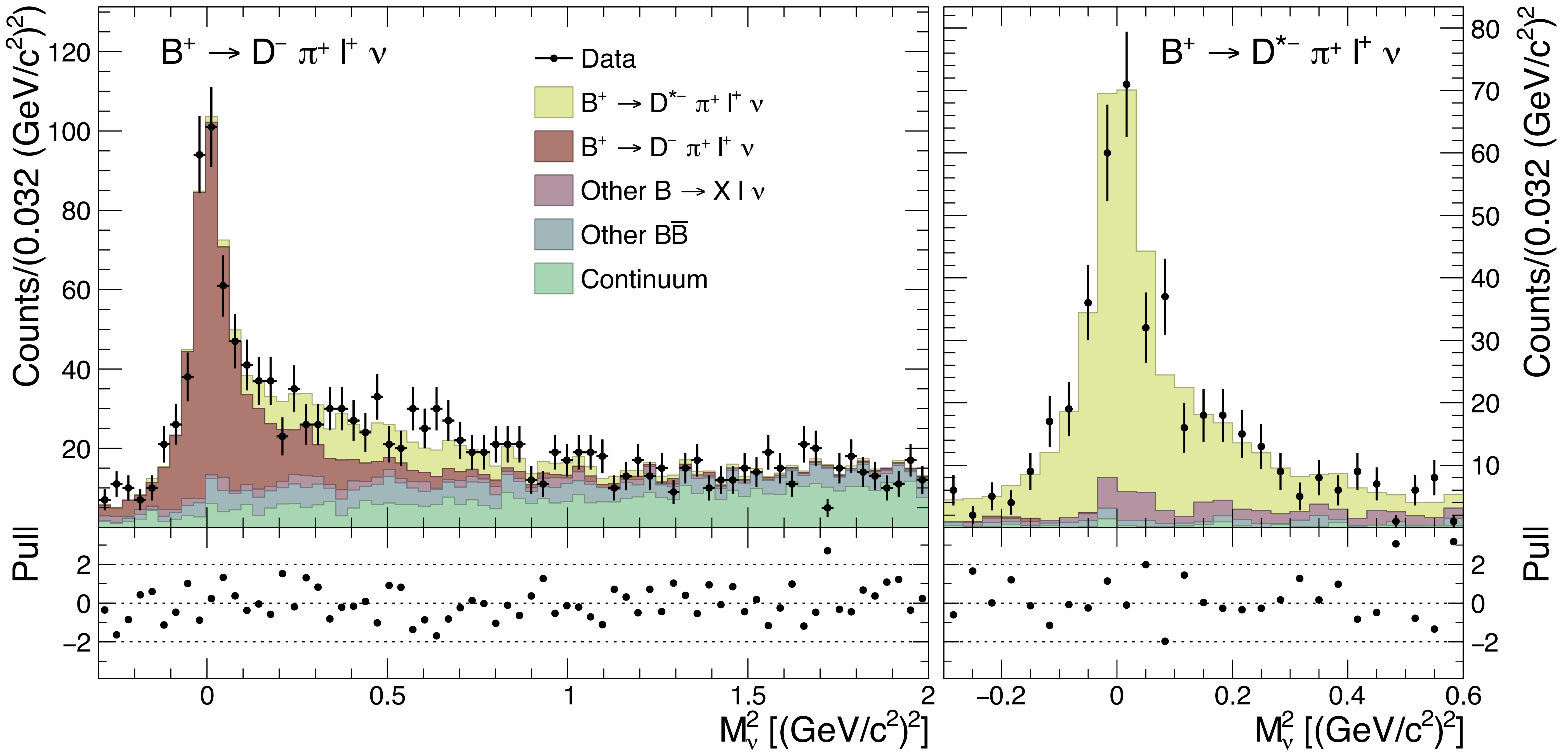
B → D(*) τ ν & B → D(*) π l ν

HFLAV ICHEP 2018
Belle arXiv:1803.06444

- **World average near 3.9 σ from SM expectation**
  - R(D*) with hadronic modes are 1σ consistent with SM
  - Belle R(D*) combination < 2 σ from SM.
  - τ are mimicked by background → enhancement. More studies of B→D** (→ Dnπ) lν necessary



HFlav Combination



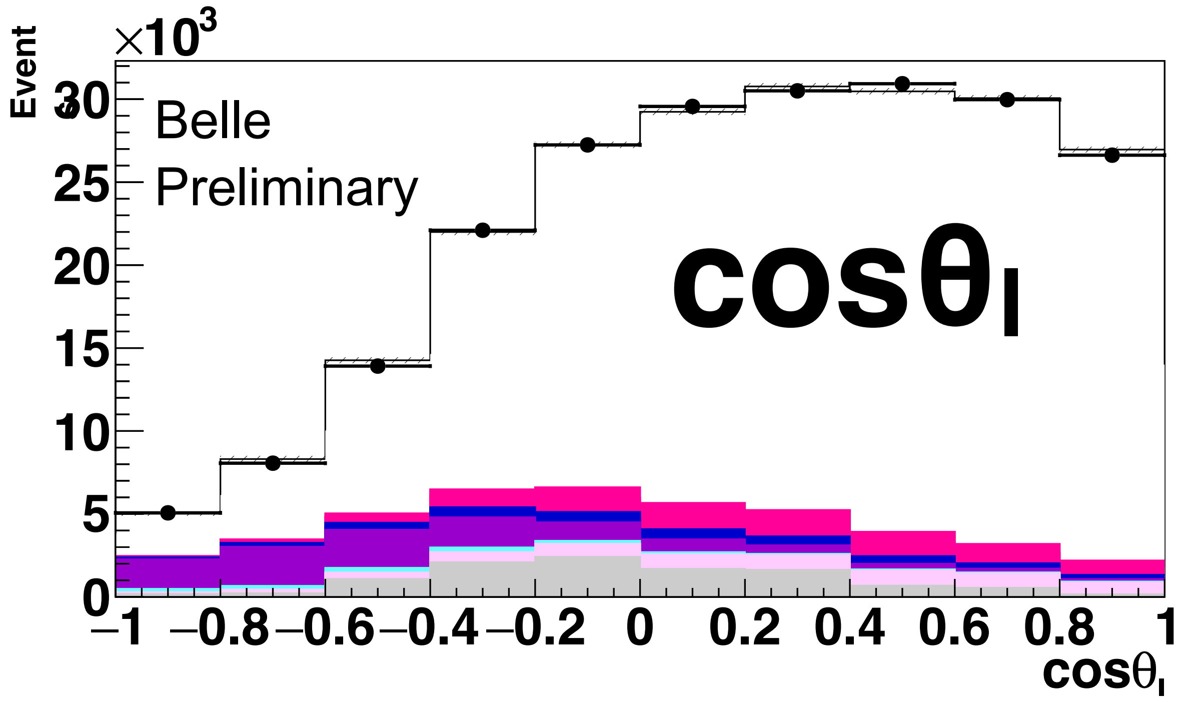
Measurement of the branching fraction of B→D(*)πℓν at Belle using hadronic tagging in fully reconstructed events

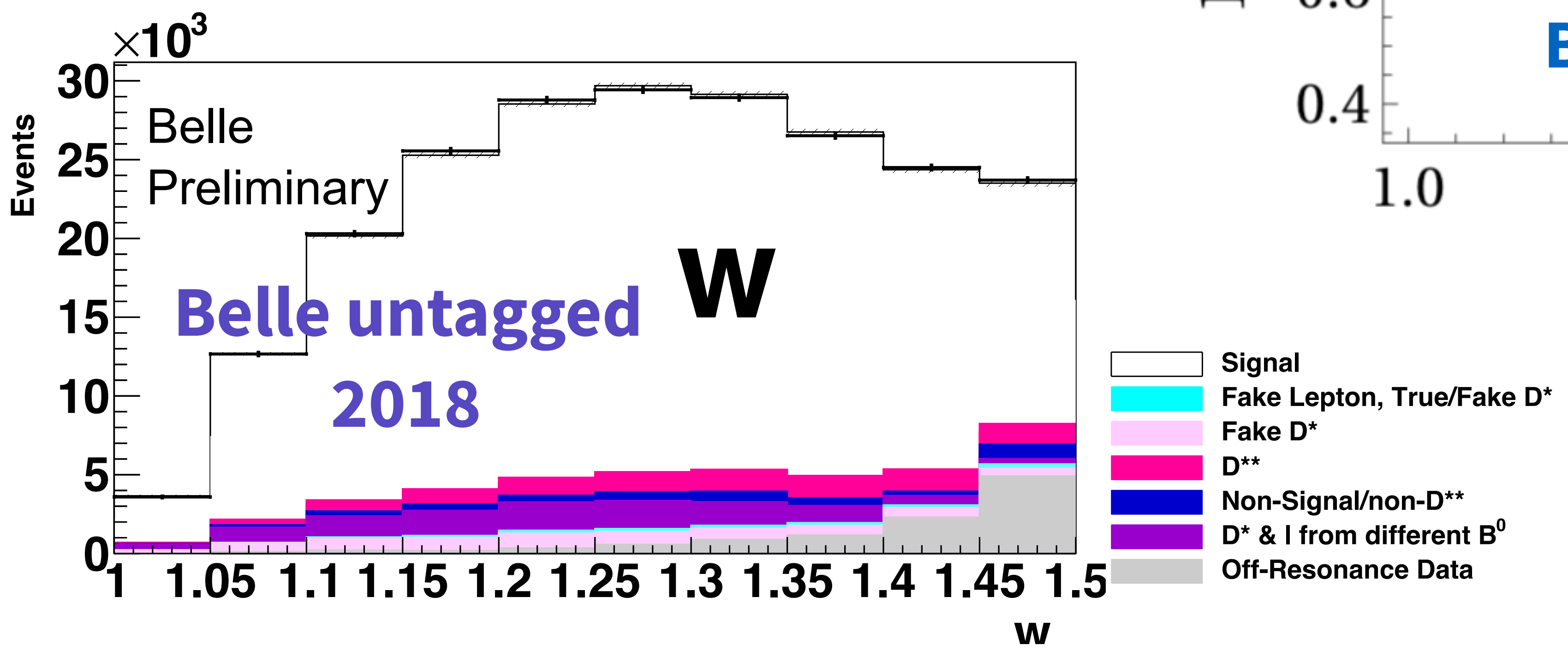
$|V_{cb}|$

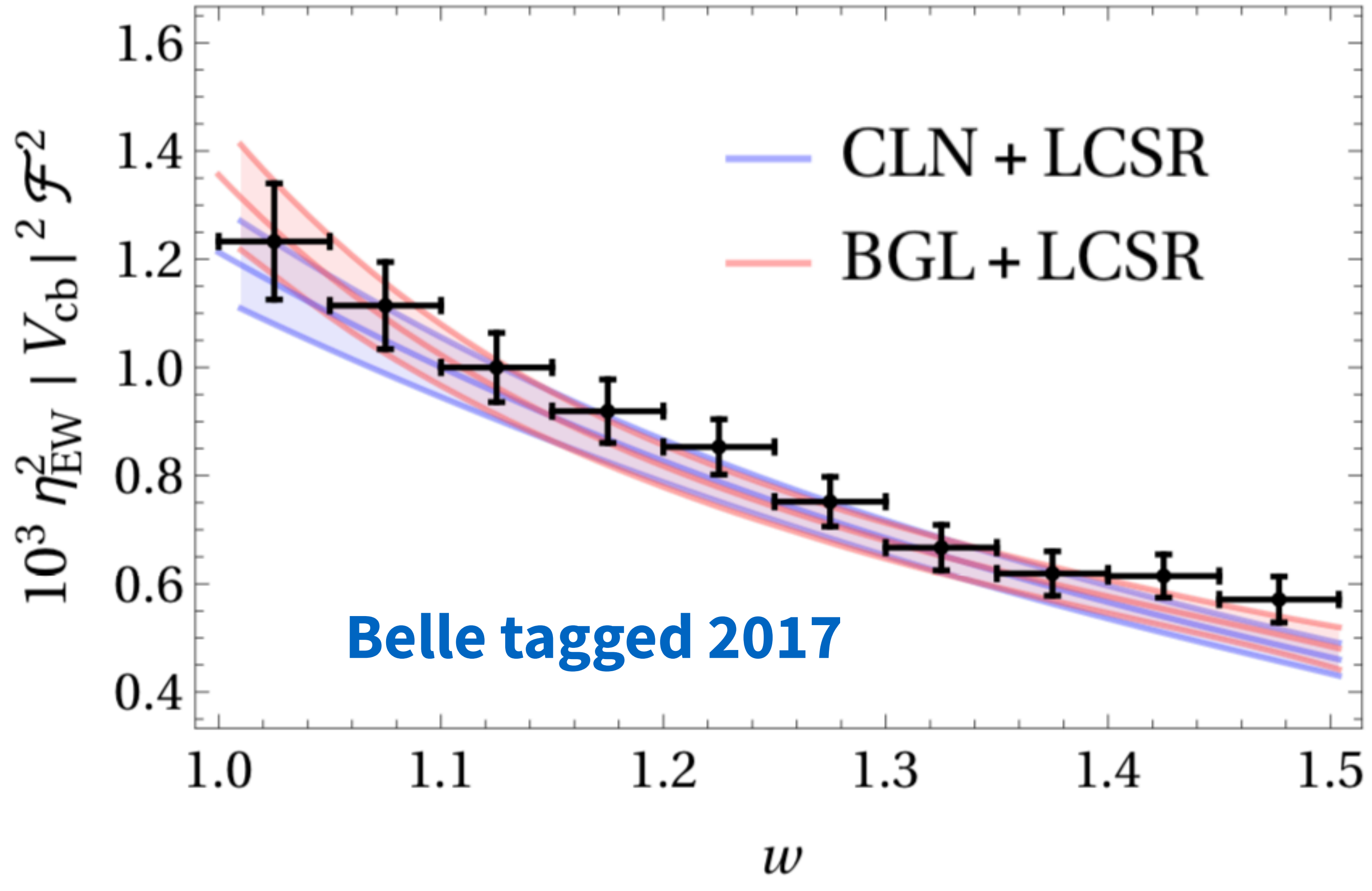
E. Waheed

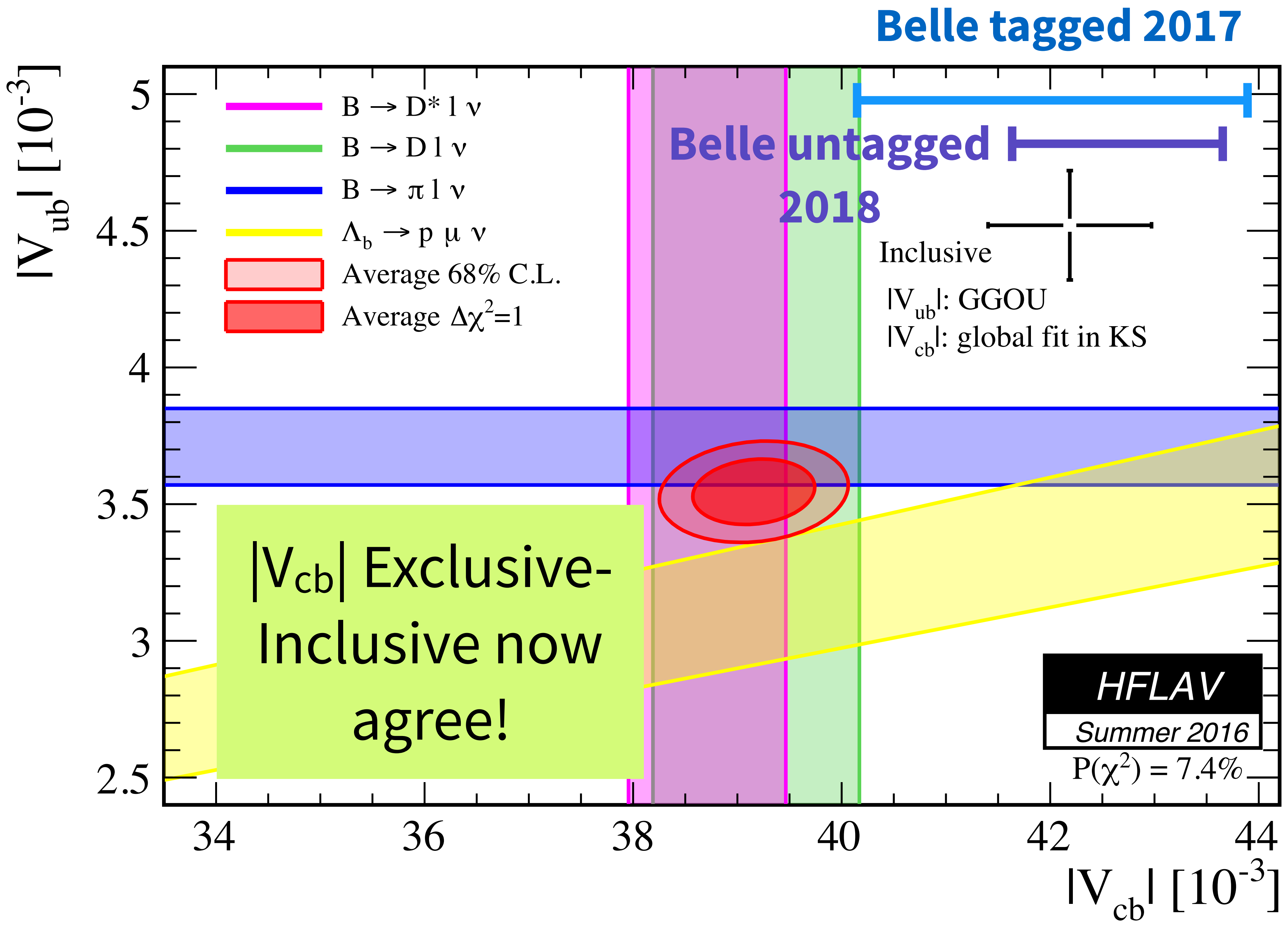
Belle ICHEP Preliminary

- Persistent difference in inclusive and exclusive $|V_{cb}|$ and $|V_{ub}|$. What is the cause?
- New Belle $B \to D^* l \nu$, BF, $|V_{cb}|$ and form factor measurements
  - BGL z-expansion: $|V_{cb}| = (42.5 \pm 0.3_{stat} \pm 0.7_{sys} \pm 0.6_{LQCD}) \times 10^{-3}$ NEW
  - CLN model: $|V_{cb}| = (38.4 \pm 0.2_{stat} \pm 0.6_{sys} \pm 0.6_{LQCD}) \times 10^{-3}$
  - Inclusive: $|V_{cb}| = (42.2 \pm 0.8) \times 10^{-3}$







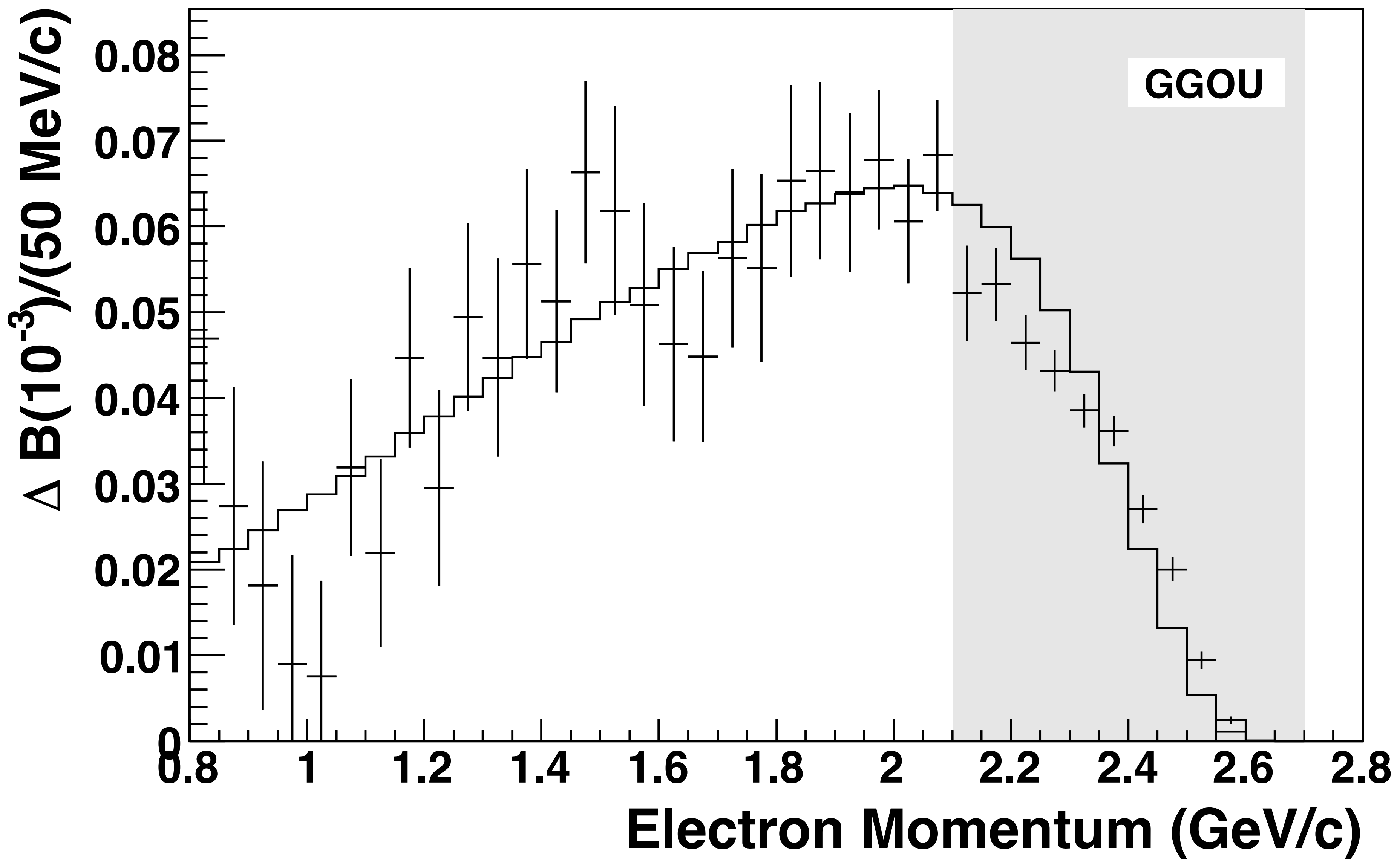


Measurement of the branching fraction of $B \to D^* \ell \nu$, determination of $|V_{cb}|$, and tests of lepton flavour universality at Belle

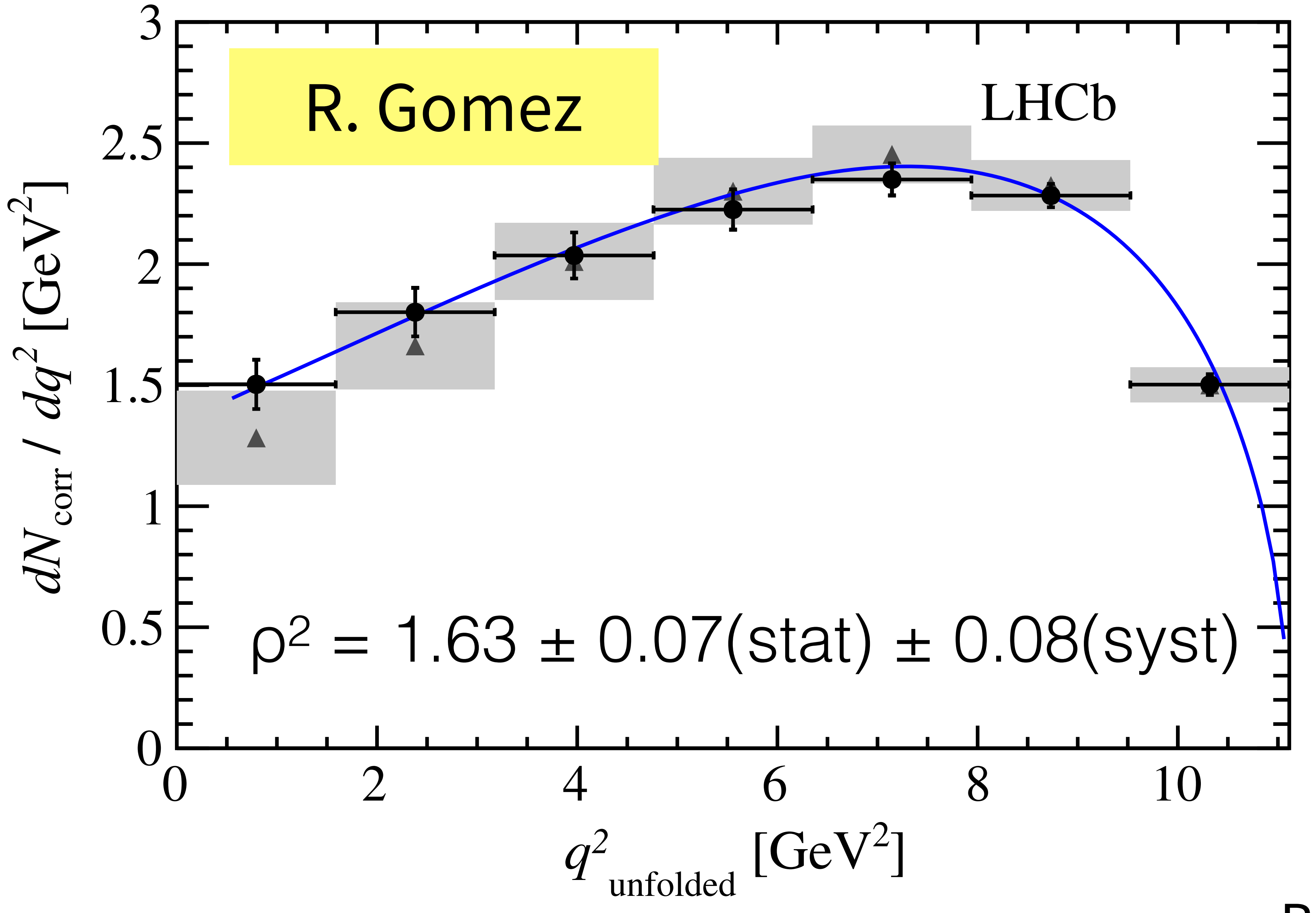
$|V_{ub}|$ & $|V_{ub}|/|V_{cb}|$

Belle arXiv: 1712.04123
Babar PRD95 7, 072001 (2017)
Belle PRD96 9, 091102 (2017)
LHCb PRD96 11, 112005 (2017)

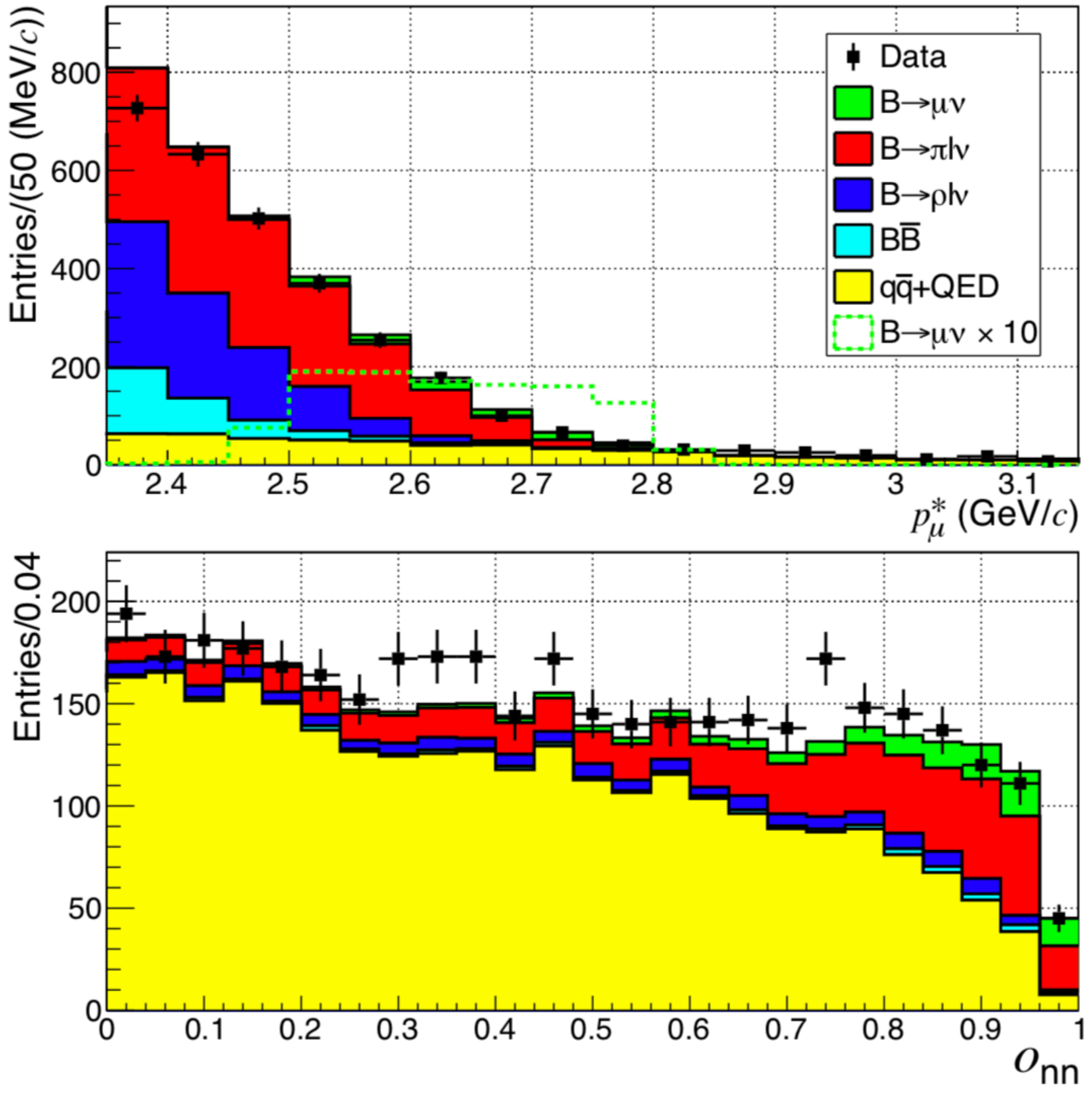
- $|V_{ub}|$ - exclusive inclusive difference is still ~20%. 2017 Babar study shows b→ulν and b→clν modelling affects endpoint analyses.
- LHCb precisely compared LQCD and predictions in $\Lambda_b \to \Lambda_c$ l ν.
- Belle found a first hint of B→μν: a BSM probe or clean $|V_{ub}|$ at Belle II



Measurement of B→X_u l ν from and determination of $|V_{ub}|$ at Babar



Measurement of the shape of the $\Lambda^0_b \to \Lambda^+_c \mu^- \nu_\mu$ differential decay rate



Belle $\mathcal{B}(B^+ \to \mu^+\nu_\mu) = (6.46 \pm 2.22 \pm 1.60) \times 10^{-7}$

SM $\mathcal{B}(B^+ \to \mu^+\nu_\mu) = (3.80 \pm 0.31) \times 10^{-7}$

Search for B→μν at Belle

$|V_{cd}|$ - Cabbibo angle

BESIII PRD 96 (2017) 1, 012002
BESIII PRD97 (2018) 9, 092009
BESIII arXiv:1803.02166
BESIII ICHEP Preliminary

J-C. Chen

Other recent results on $D \to a_0(980)^- e^+ \nu_e$ and $D^+ \to \eta^{(\prime)} e^+ \nu_e$ at BESIII

- New semileptonic V_{cd} results from $D \to \pi e \nu$, $D_s \to K e \nu$, tests of $D^+ \to \tau \nu$ LFUV (no signs of NP)

Leptonic: $0.2210 \pm 0.0058 \pm 0.0047$

Semileptonic: $0.2155 \pm 0.0027 \pm 0.0014 \pm 0.0094$

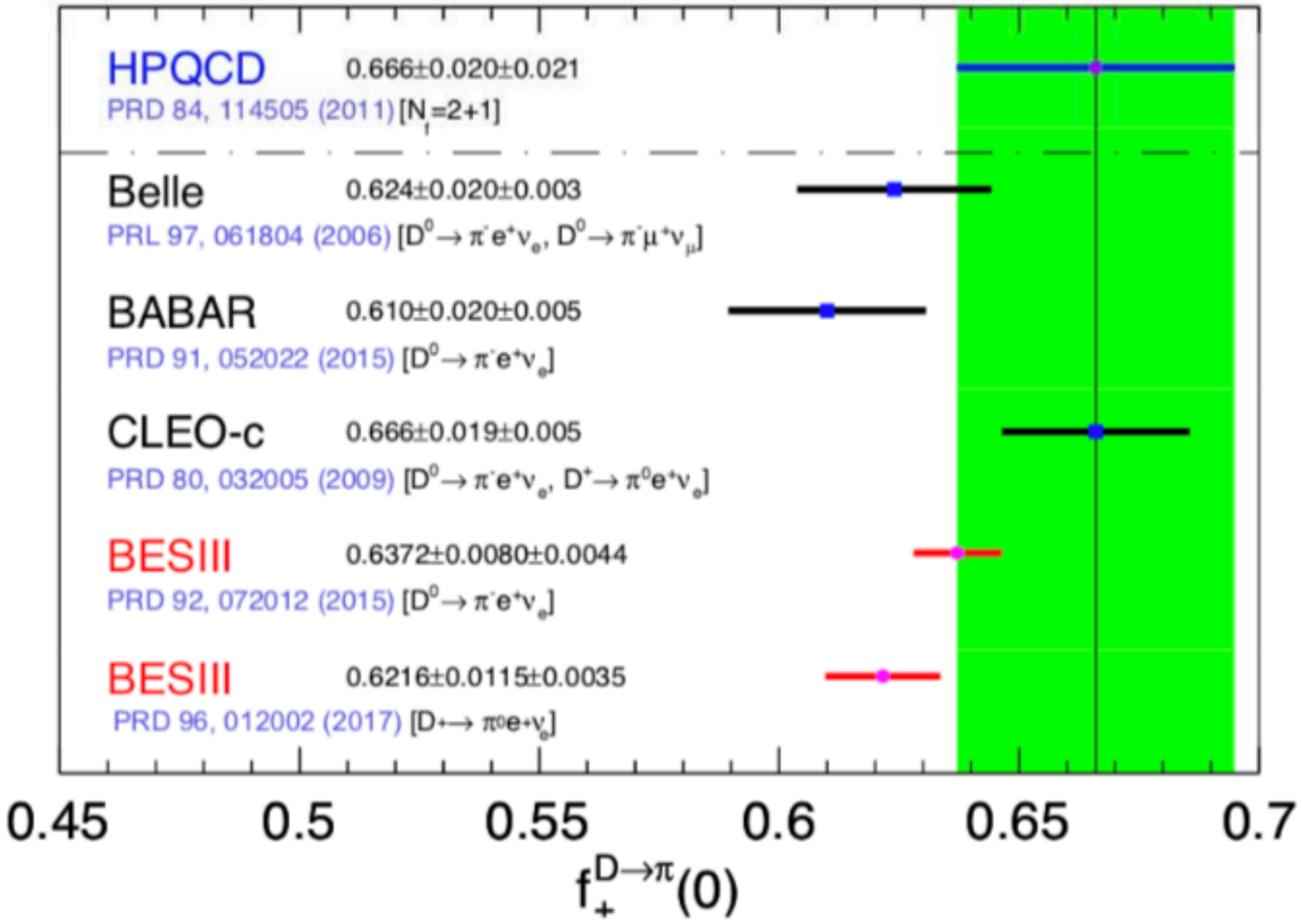
CKMfitter: $0.22494\ ^{+0.00029}_{-0.00028}$

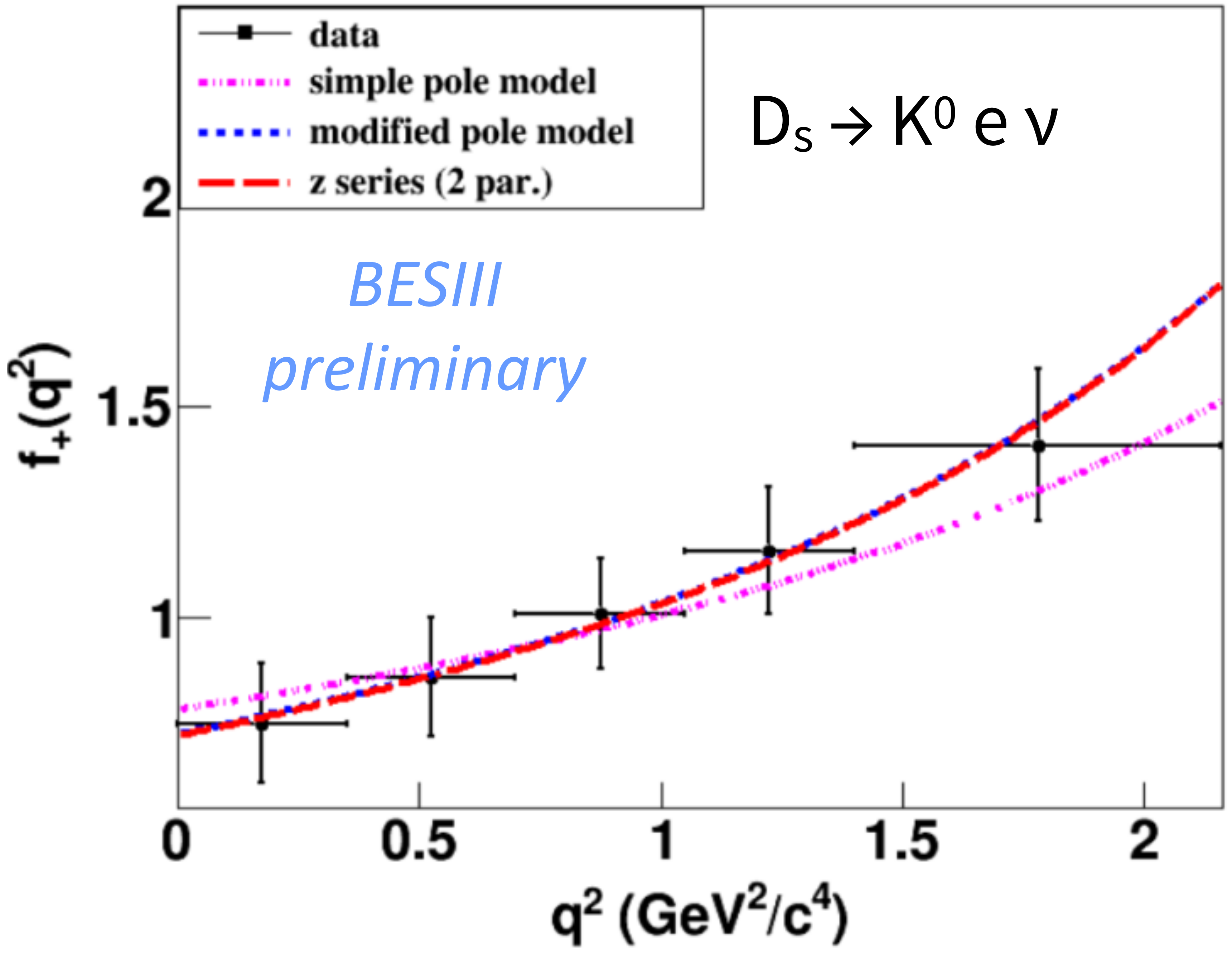
BES III [MeV]

$f_{D+} = (203.2 \pm 5.3 \pm 1.8)$

LQCD [MeV]

$f_{D+} = (211.9 \pm 1.0)$





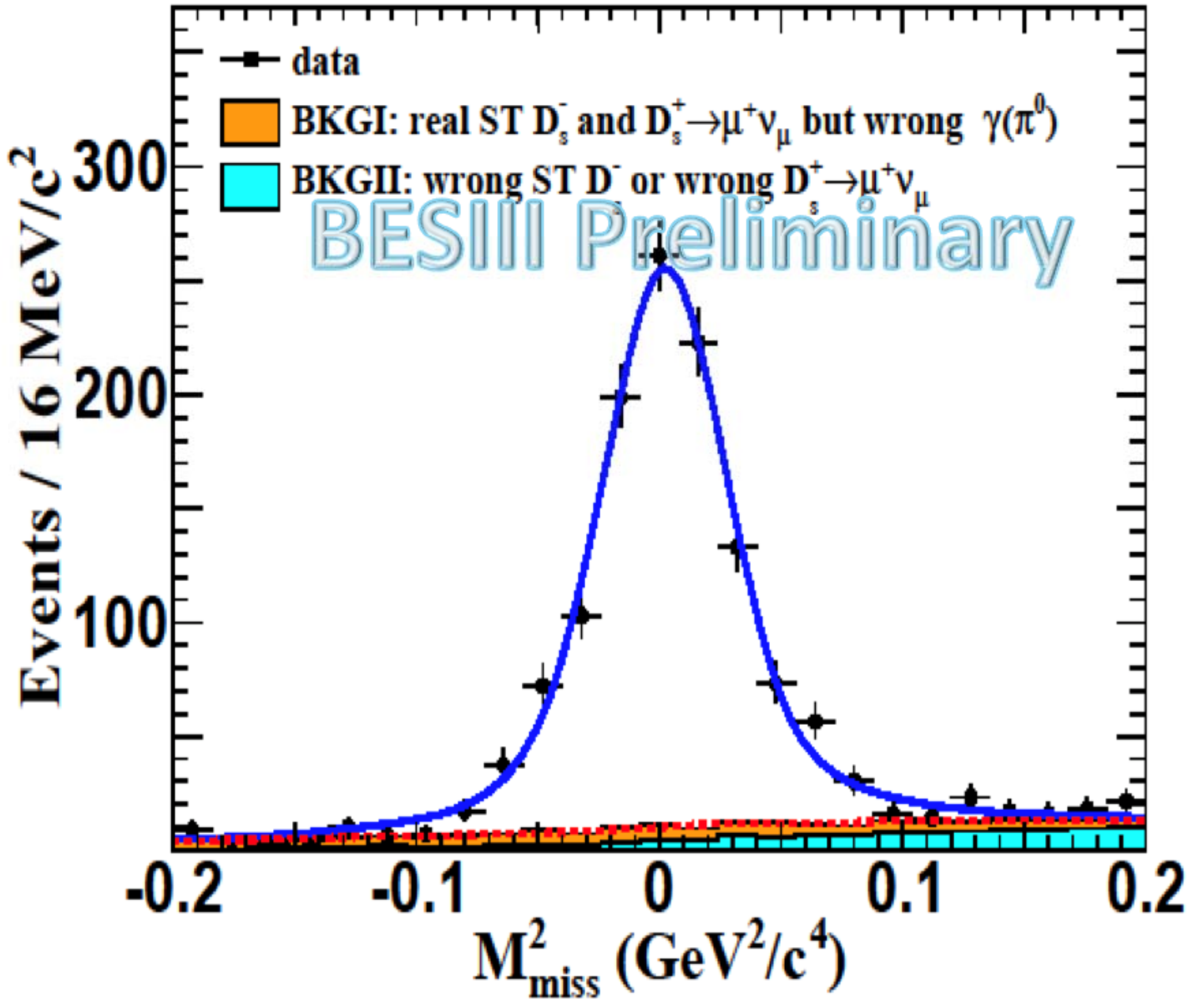
$|V_{cs}|$

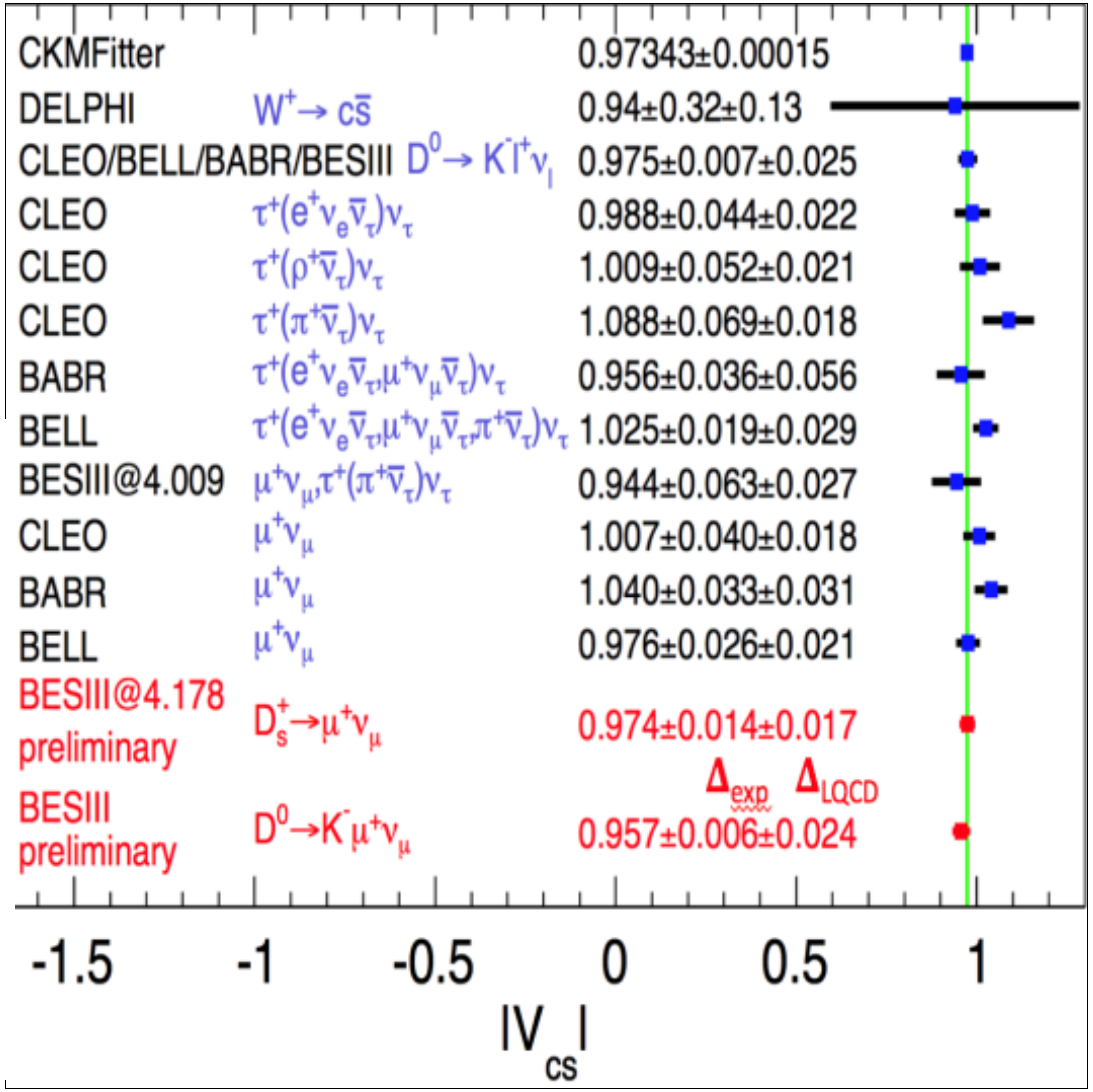
- New leptonic and semileptonic results from BESIII
- Impressive agreement with LQCD!

BESIII PRD97 1, 012006 (2018)
BESIII Preliminary

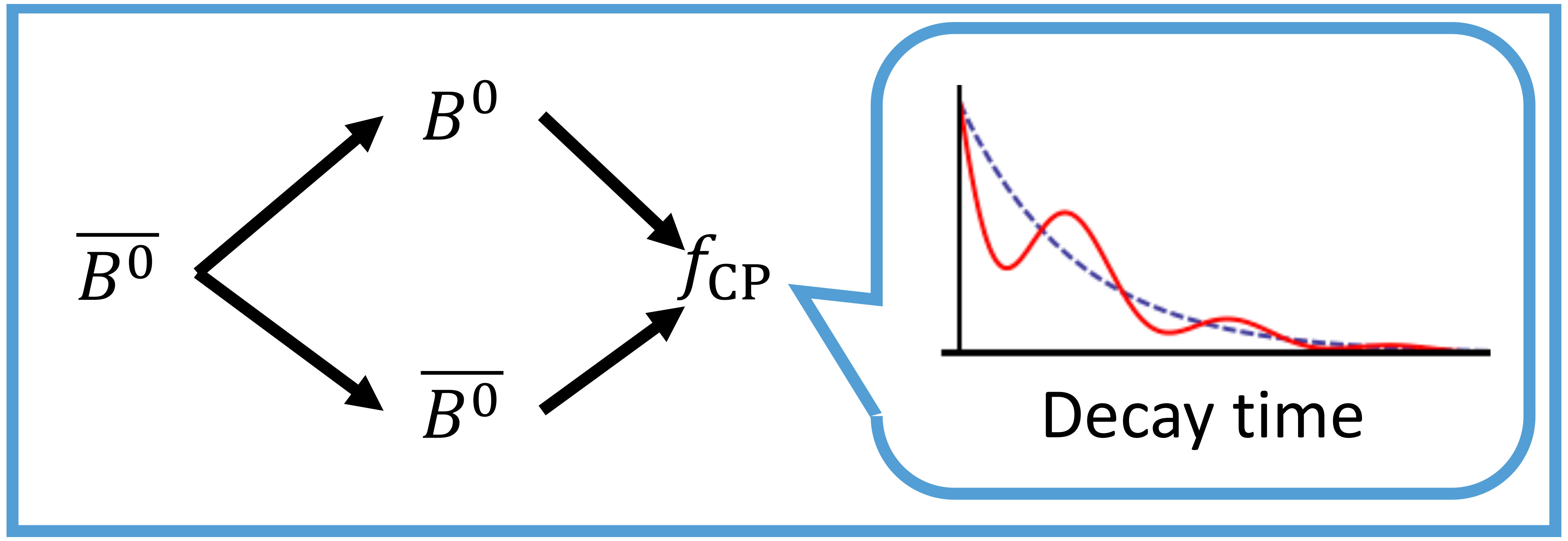
Leptonic: $0.974 \pm 0.014 \pm 0.016$
Semileptonic: $0.9601 \pm 0.0033 \pm 0.0047 \pm 0.0239$
CKMFitter (indirect): 0.9743 ± 0.00015

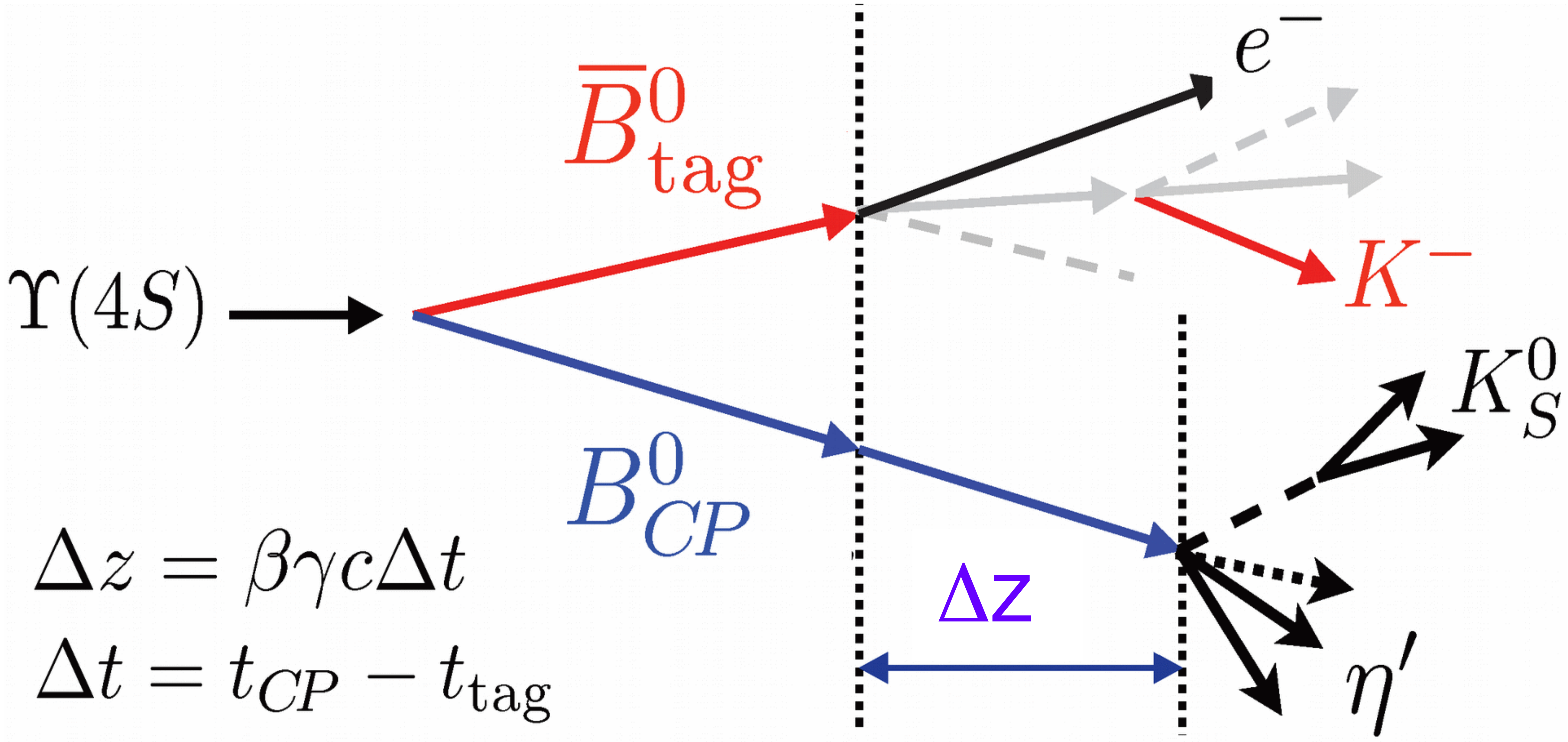
BES III [MeV]
$f_{Ds+} = (249.1 \pm 3.6 \pm 3.8)$
LQCD [MeV]
$f_{Ds+} = (249.0 \pm 0.3 \pm 1.5)$





Time dependent CP Violation (mixing+decay)





$$\mathcal{A}_{CP}(t) = \frac{\Gamma\left(\overline{B}^0_q(t) \to f\right) - \Gamma\left(B^0_q(t) \to f\right)}{\Gamma\left(\overline{B}^0_q(t) \to f\right) + \Gamma\left(B^0_q(t) \to f\right)}$$

$$= \frac{\mathcal{S}_f \sin(\Delta m t) - \mathcal{C}_f \cos(\Delta m t)}{\cosh\left(\frac{\Delta\Gamma t}{2}\right) + \mathcal{A}_{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma t}{2}\right)}$$

- Vertex fitting and flavour tagging: Boost, IP resolution, hermetic coverage
- Hadron identification: K / π / proton separation
- Kaons (K_L, K_S) from CP eigenstate b→c anti-c s and b→s penguin decays

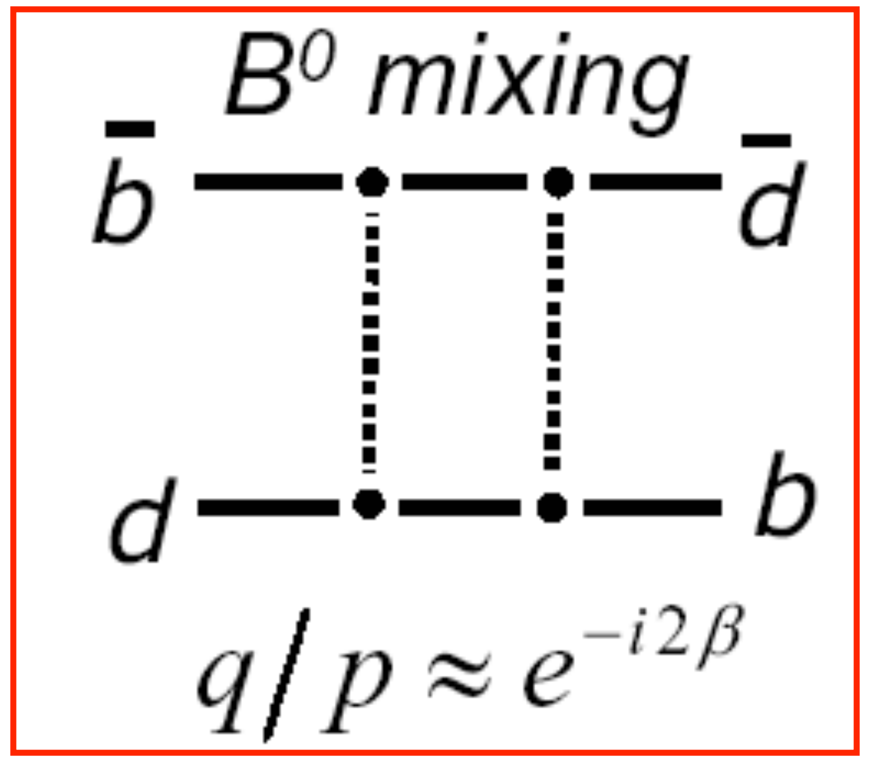
Flavour tagging eff.

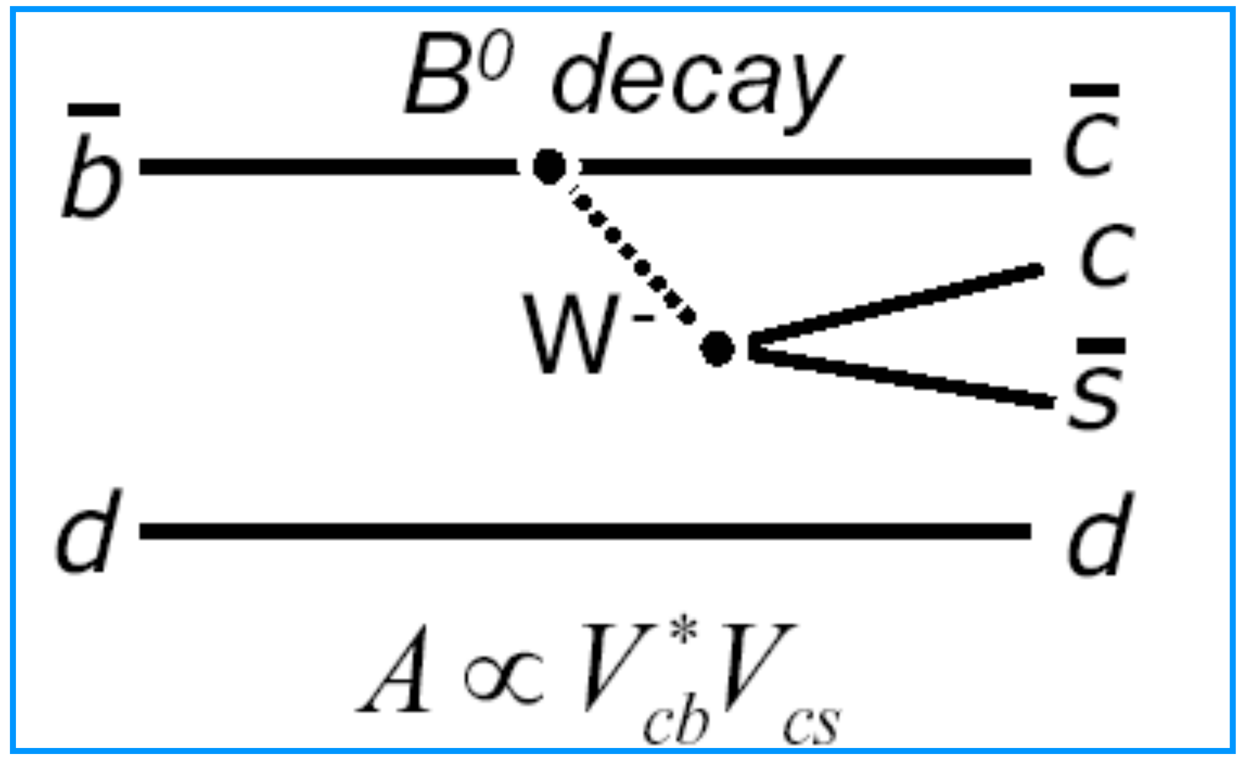
3-5% LHCb

30% Belle

35% Belle II

Φ_1/β (phase of V_{td})

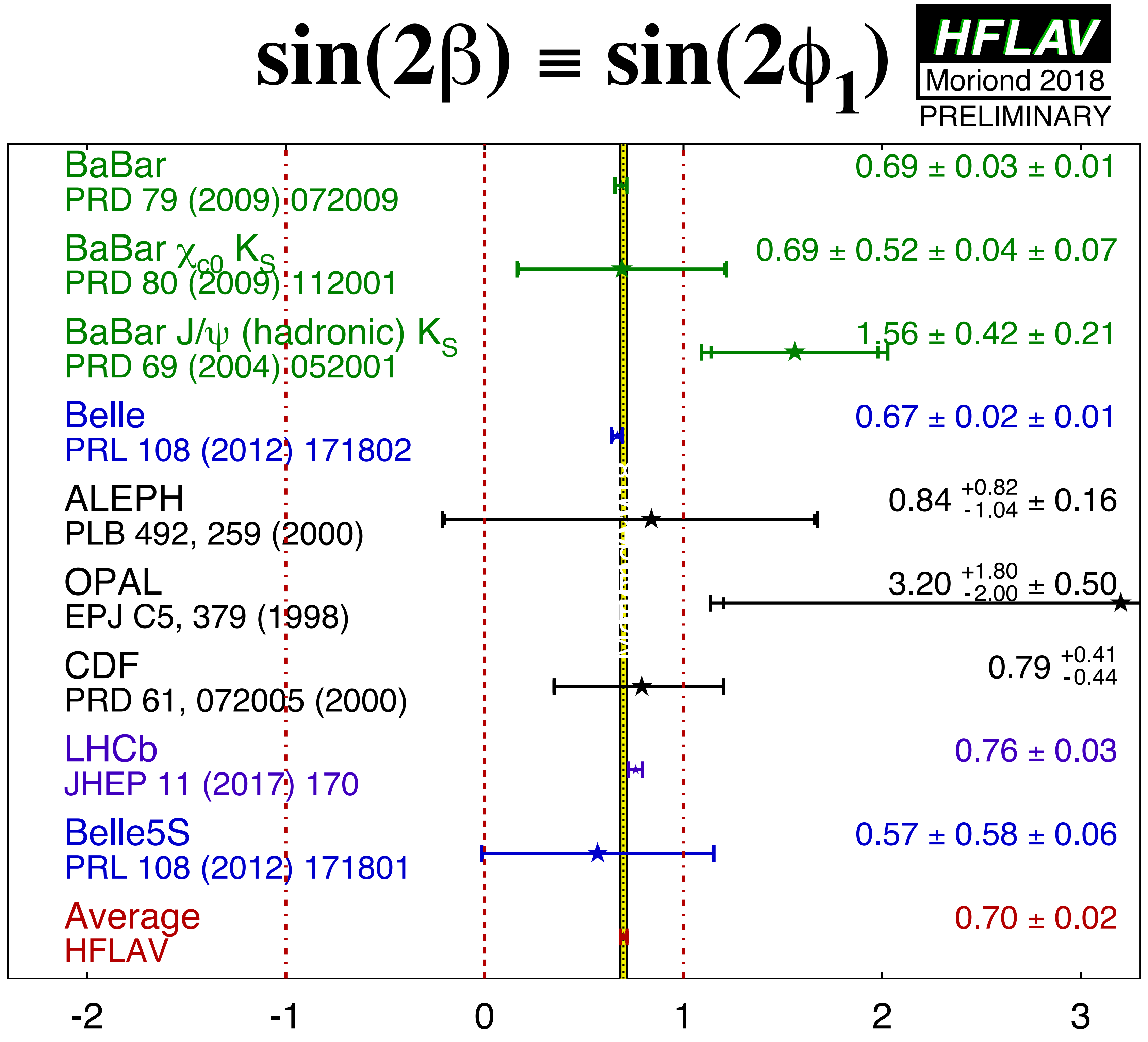


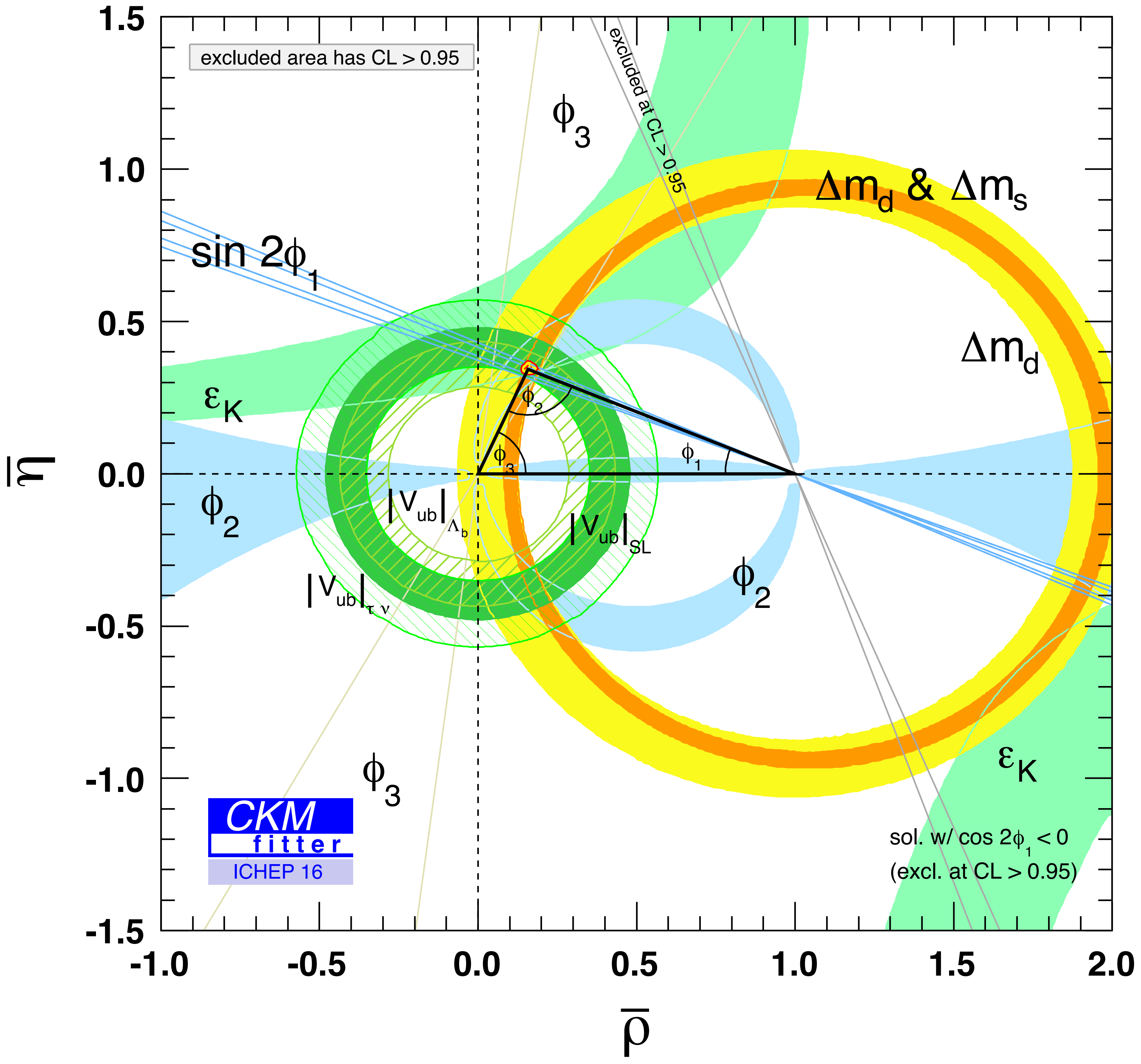


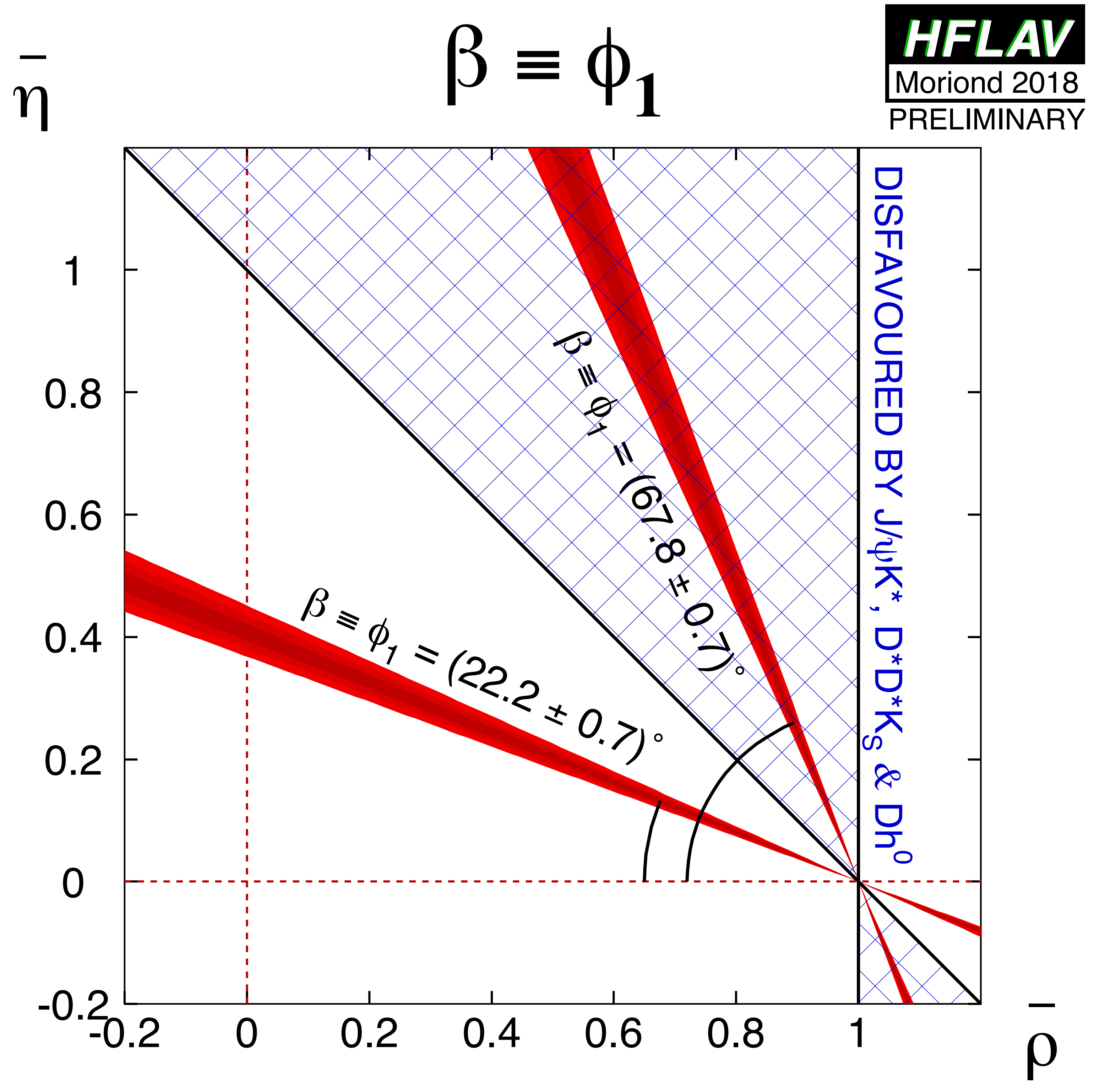
S_{CP}

0.70±0.02 WA HFLAV

$0.740\ ^{+0.020}_{-0.025}$ Indirect CKMFitter





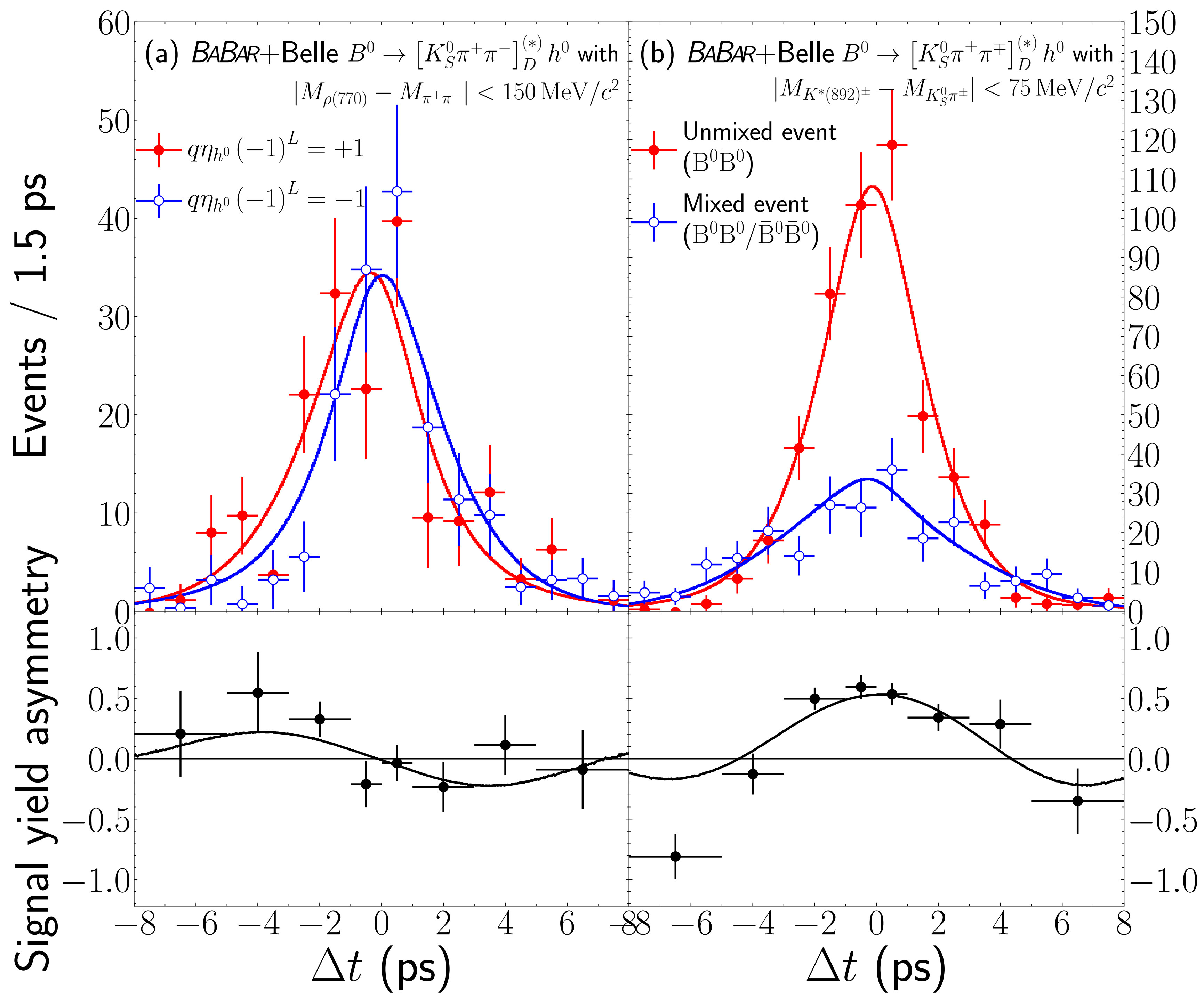


Φ_1 challenges

V. Vorobyev
J. Grabowski

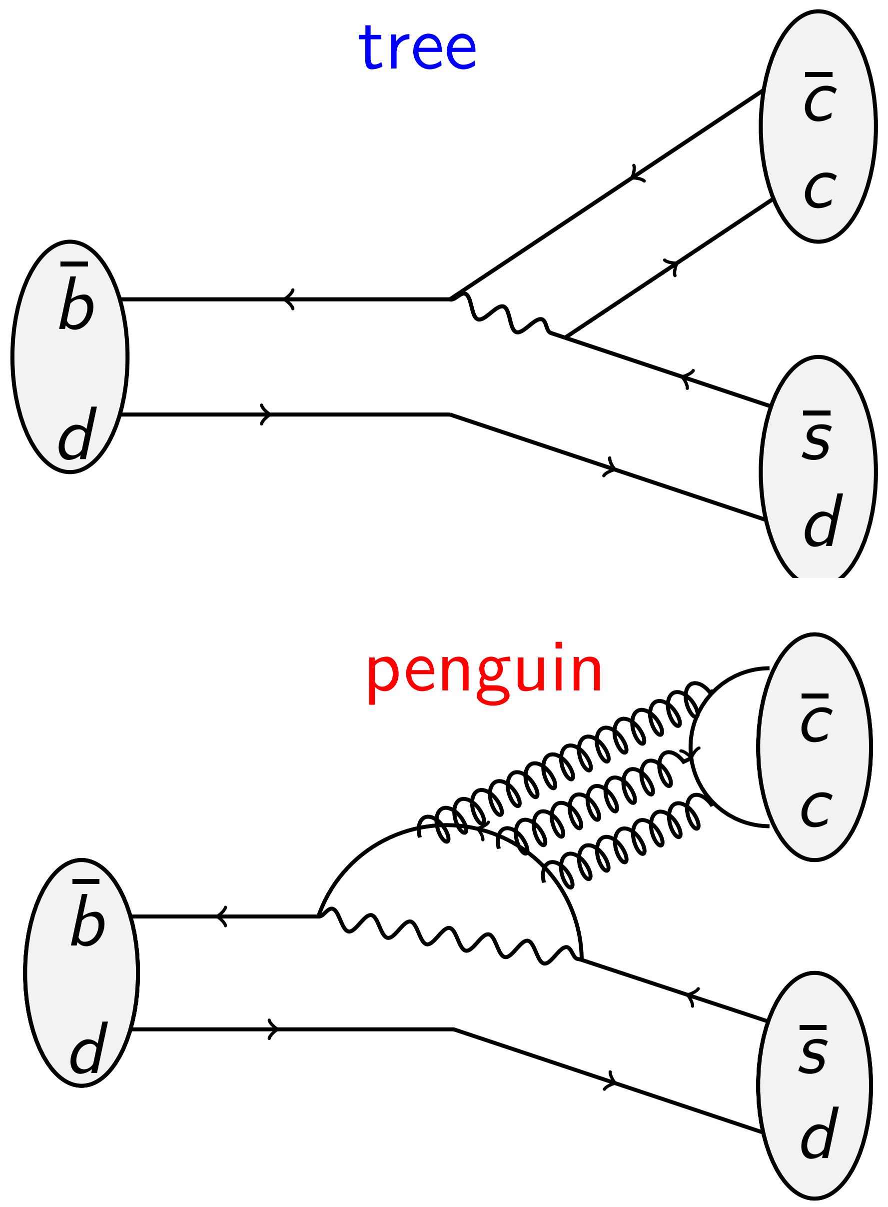
Belle+Babar arXiv: 1804.06153
Belle+Babar arXiv: 1804.06152
LHCb JHEP 1711 (2017) 170
LHCb PRD95 5, 052005 (2017)

- What is the sign of $\cos 2\Phi_1$? (2 fold ambiguity) **Positive!**
- Can we control theory errors to < 1° (penguin pollution)?



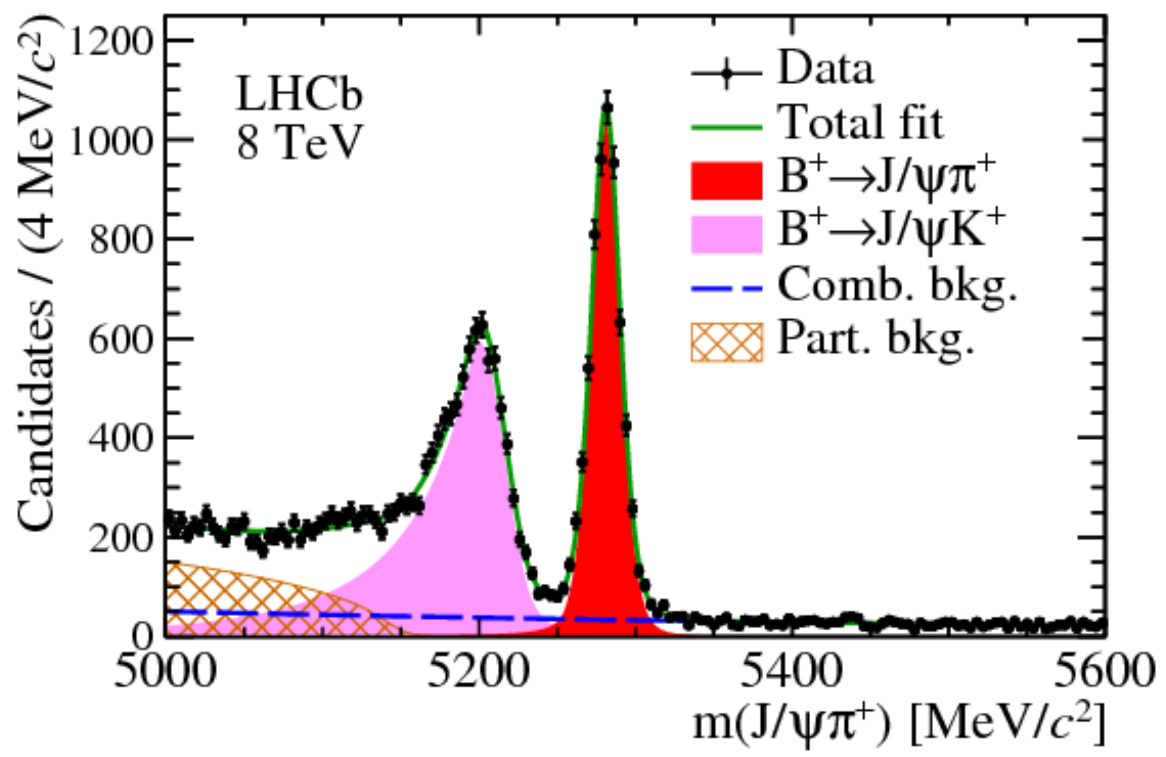
Belle+Babar: 7σ evidence for cos2β>0 and resolution of the CKM Unitarity Triangle ambiguity by a time-dependent Dalitz plot analysis of $B^0 \to D^{(*)}h^0$ with $D \to K^0_S\pi^+\pi^-$ decays

$\phi^{obs} = \phi^{tree} + \Delta\phi^{peng} + \phi^{NP}$

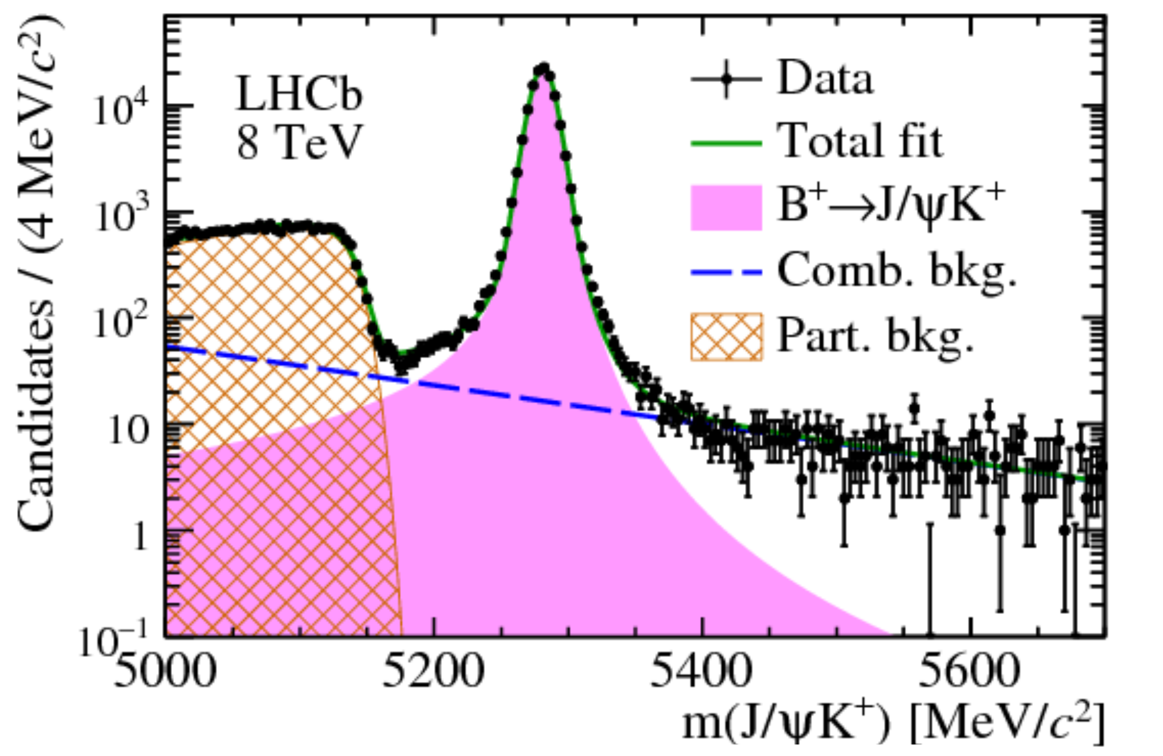


Measurement of the $B^\pm$ production asymmetry and the CP asymmetry in $B^\pm \to J/\psi K^\pm$ decays

$B^+ \to J/\psi\,\pi^+$



$B^+ \to J/\psi\,K^+$

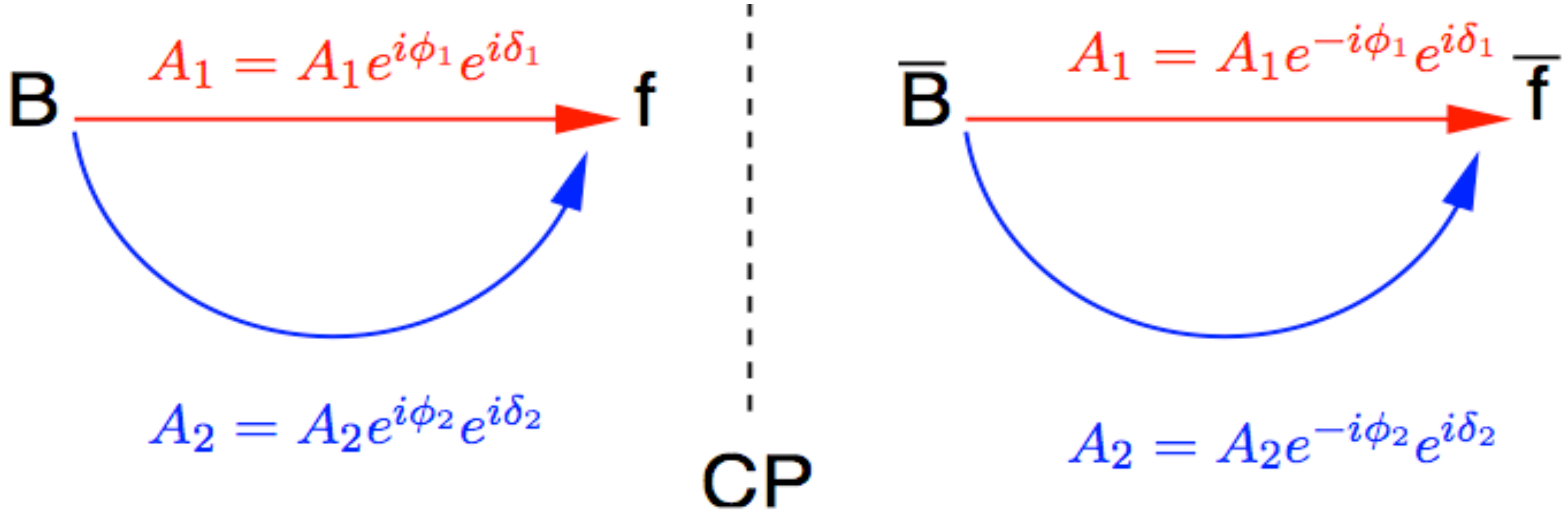


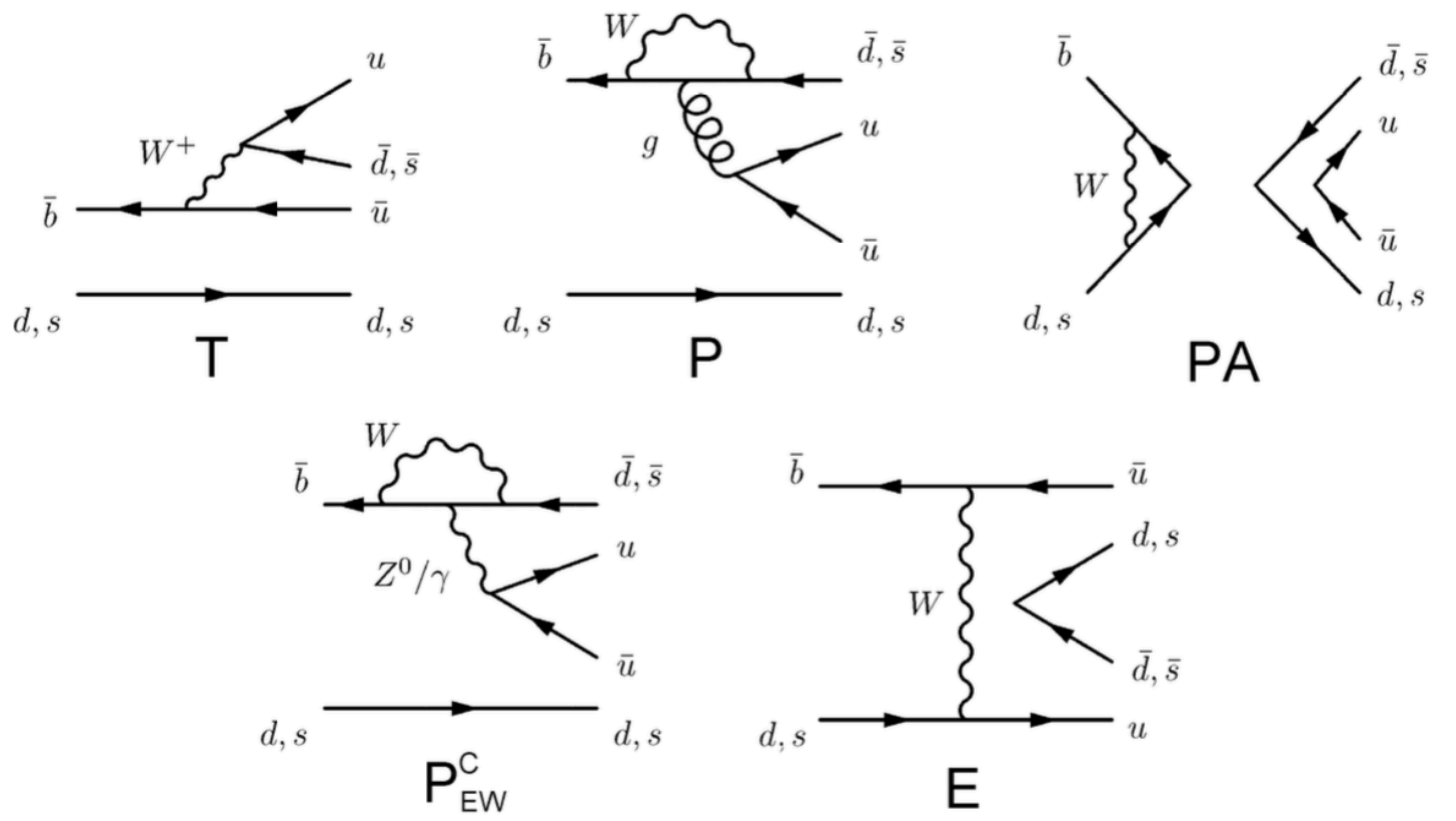
$\Delta\phi_{peng} = (-1.10^{+0.70}_{-0.85})^\circ$

$\sigma(\Delta\phi_{obs}) = 1.6^\circ$

Direct CP Violation

Φ_1 relies on $\Delta F=2$ (mixing+decay), but we can also use $\Delta F=1$ (direct) as a precise probe





$$\text{CPV: } |A_f|^2 \neq |\bar{A}_{\bar{f}}|^2 \Rightarrow \Delta\phi \text{ and } \Delta\delta \neq 0$$

For CPV A_1 and A_2 need to have **different weak phases Φ** and different **CP invariant (e.g. strong) phases δ.**

To measure Φ you need to know δ, and ratio of amplitudes -

e.g. in γ/Φ_3 measurements the relative strength of V_{ub} and V_{cb} processes and colour suppression.

Φ_3 (phase of V_{ub}), CPV in B→Charm

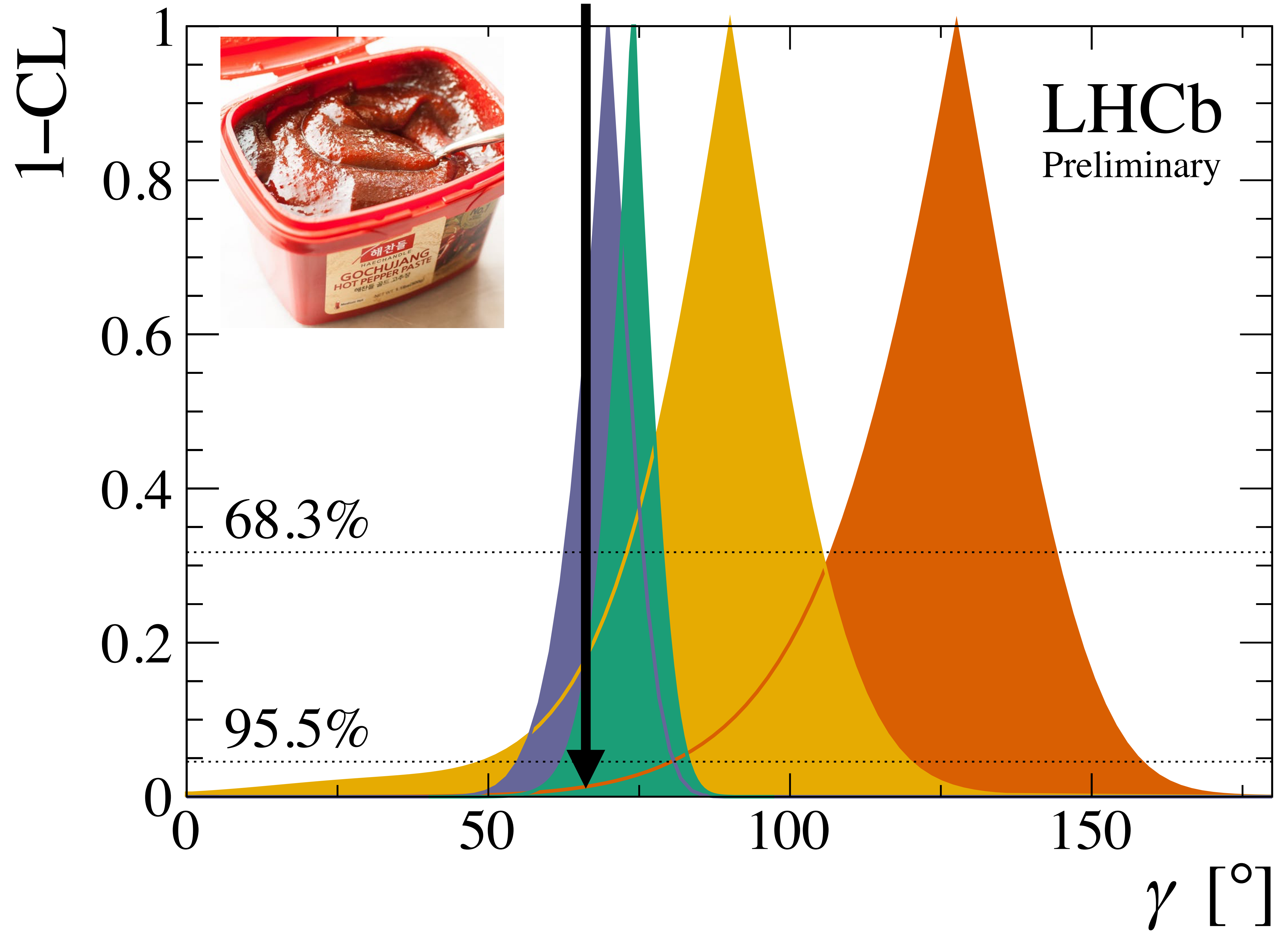
LHCb arXiv:1806.01202
LHCb JHEP 1803 (2018) 059
LHCb PLB777 (2018) 16-30
LHCb JHEP 1806 (2018) 084

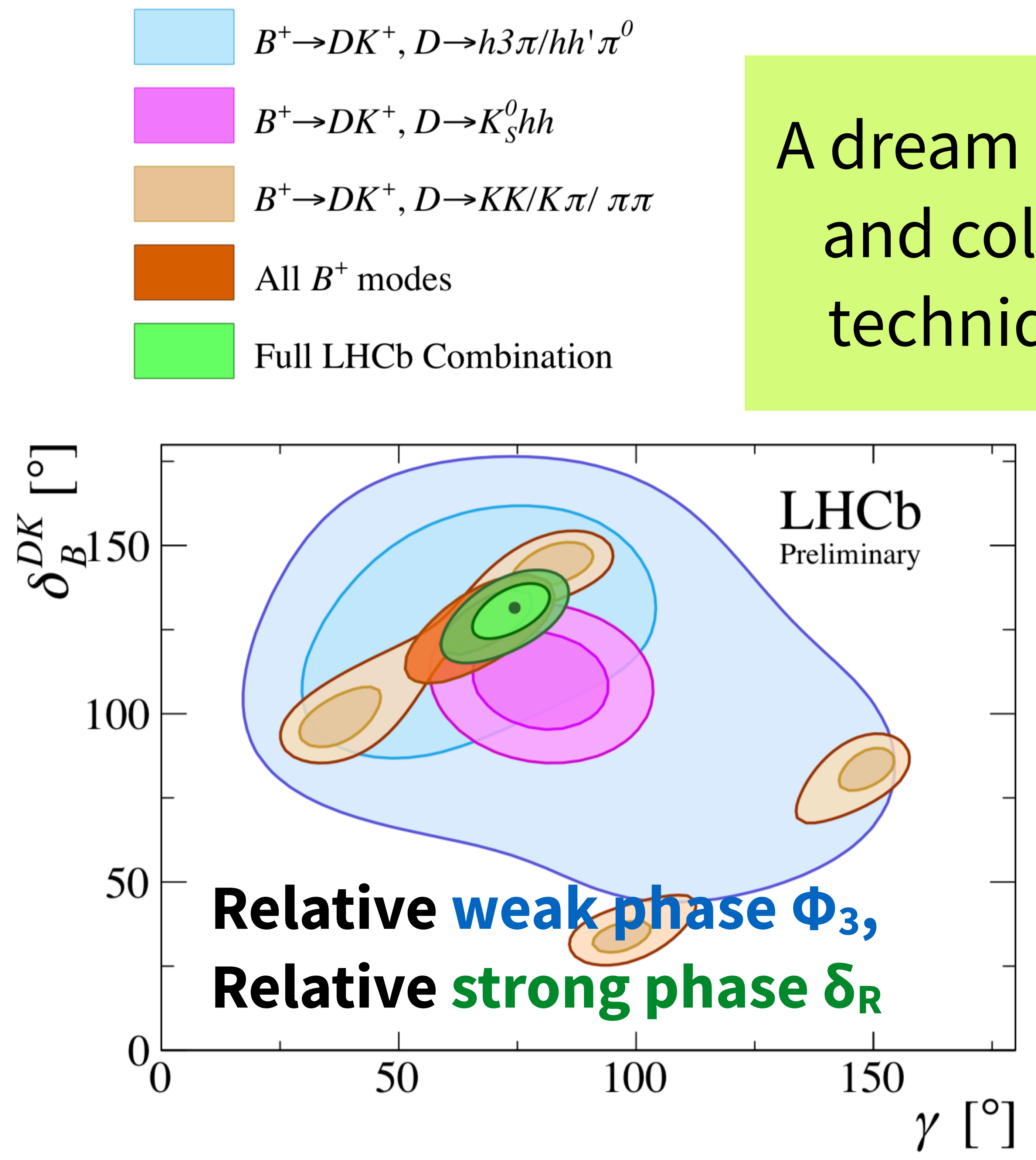
- Theory is "pristine" in these approaches, << 1% on Φ_3
- LHCb triumph $B^{\pm}$, B^0, B_s combination w/ D phase input from CLEO (BES III data coming)

M. Whitehead
A. Birnkraut

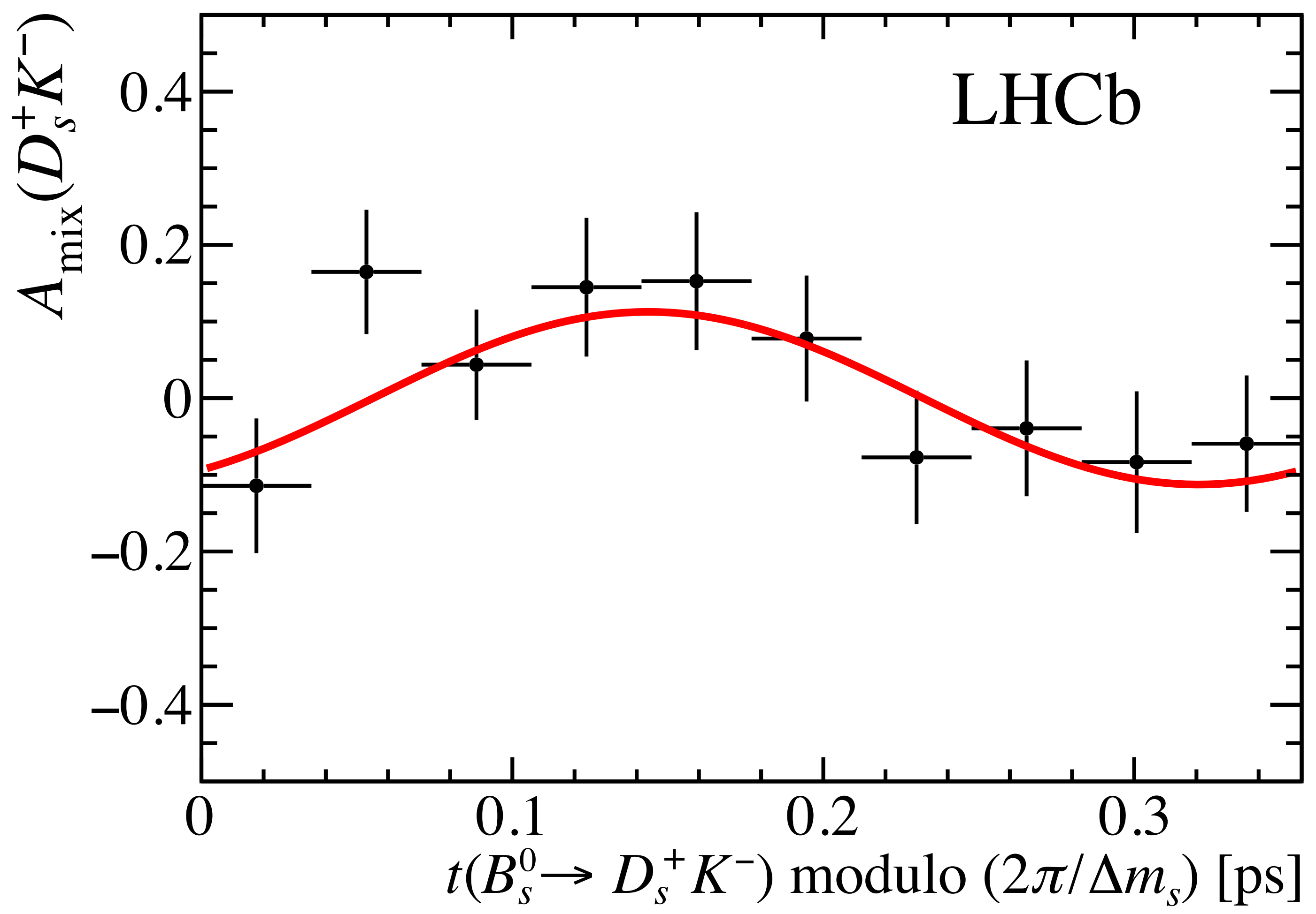
$(73.5^{+4.2}_{-5.1})^o$ WA HFLAV
$(73.5^{+5.1}_{-5.7})^o$ LHCb
$(65.3^{+1.0}_{-2.5})^o$ Indirect CKMFitter

A dream of Belle & Babar: difficult due to V_{ub} and colour suppression. Many Direct CPV techniques developed at the B-factories.





Measurement of the CKM angle γ using $B^{\pm}\to DK^{\pm}$ with $D\to K^0_S\pi^+\pi^-$, $K^0_S K^+K^-$ decays



New time-dependent measurements in $B\to D\pi$ ($2\Phi_1 + \Phi_3$) and $B_s\to D_sK$ (Φ_s-Φ_3)

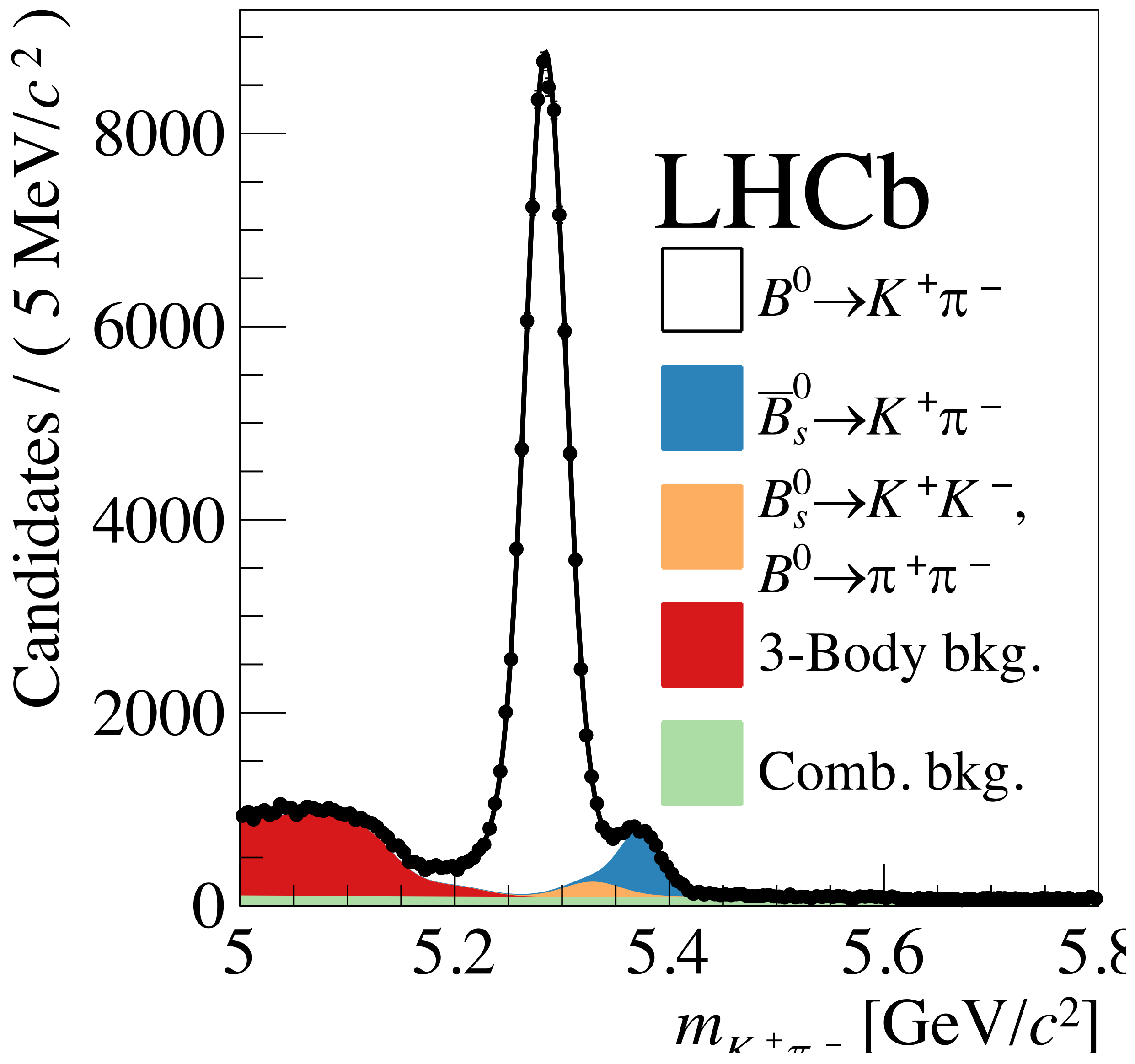
Φ_2 & CPV in B→2-body charmless

LHCb arXiv: 1805.06759
Belle PRD96 (2017) 3, 032007
EPJ C77 (2017) no.8, 574

- Extremely precise tests of B→Kπ, and B→ππ.
- Isospin sum rules exploited to control strong phase, but need neutral modes.

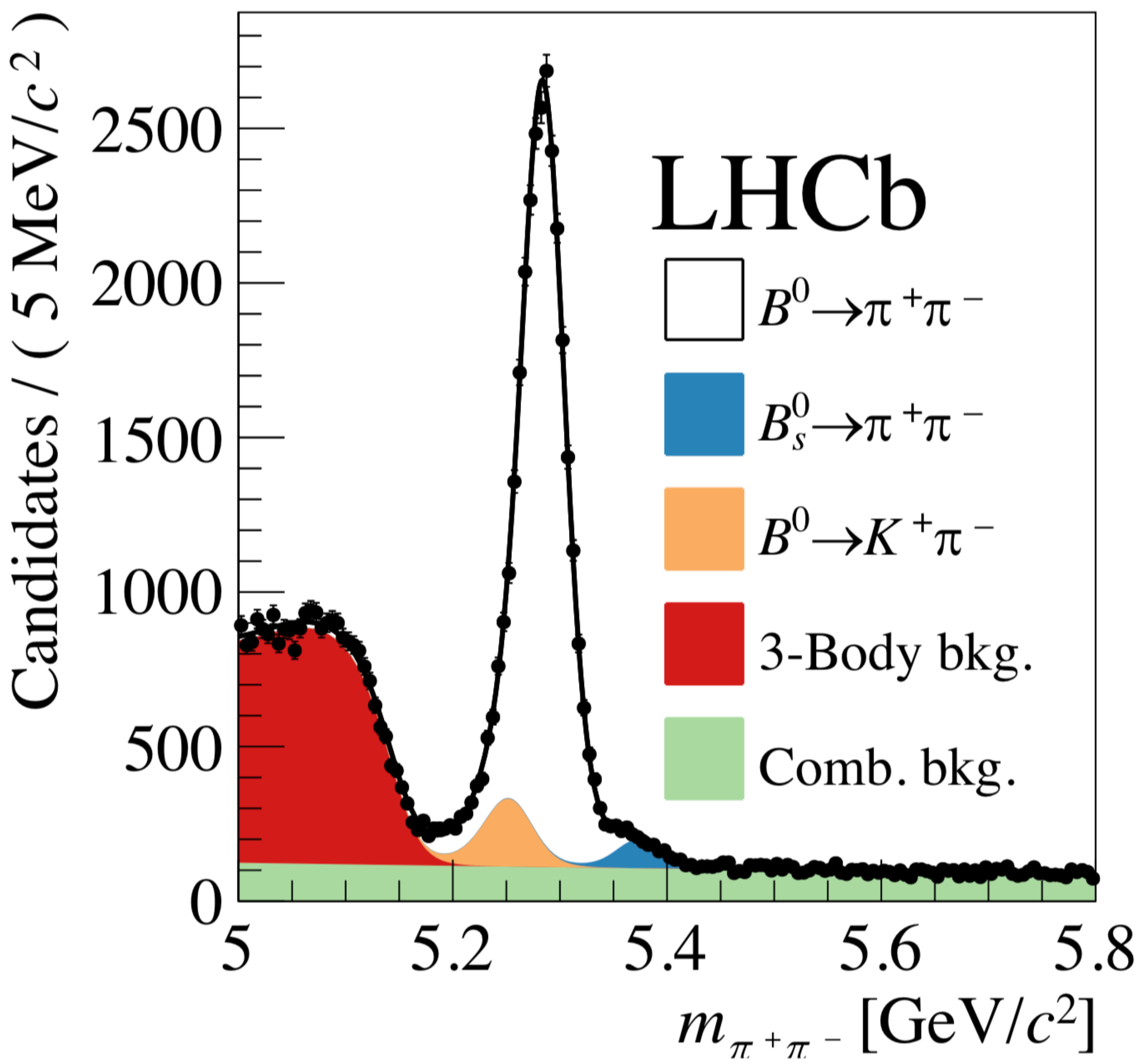
$(84.9\ ^{+5.1}_{-4.5})^\circ$ HFLAV 2018
$(86.2\ ^{+4.4}_{-4.0})^\circ$ CKMFitter Direct 2017
$(92.5\ ^{+1.5}_{-1.1})^\circ$ CKMFitter Indirect 2016

C-L. Hsu
S. Perazzini



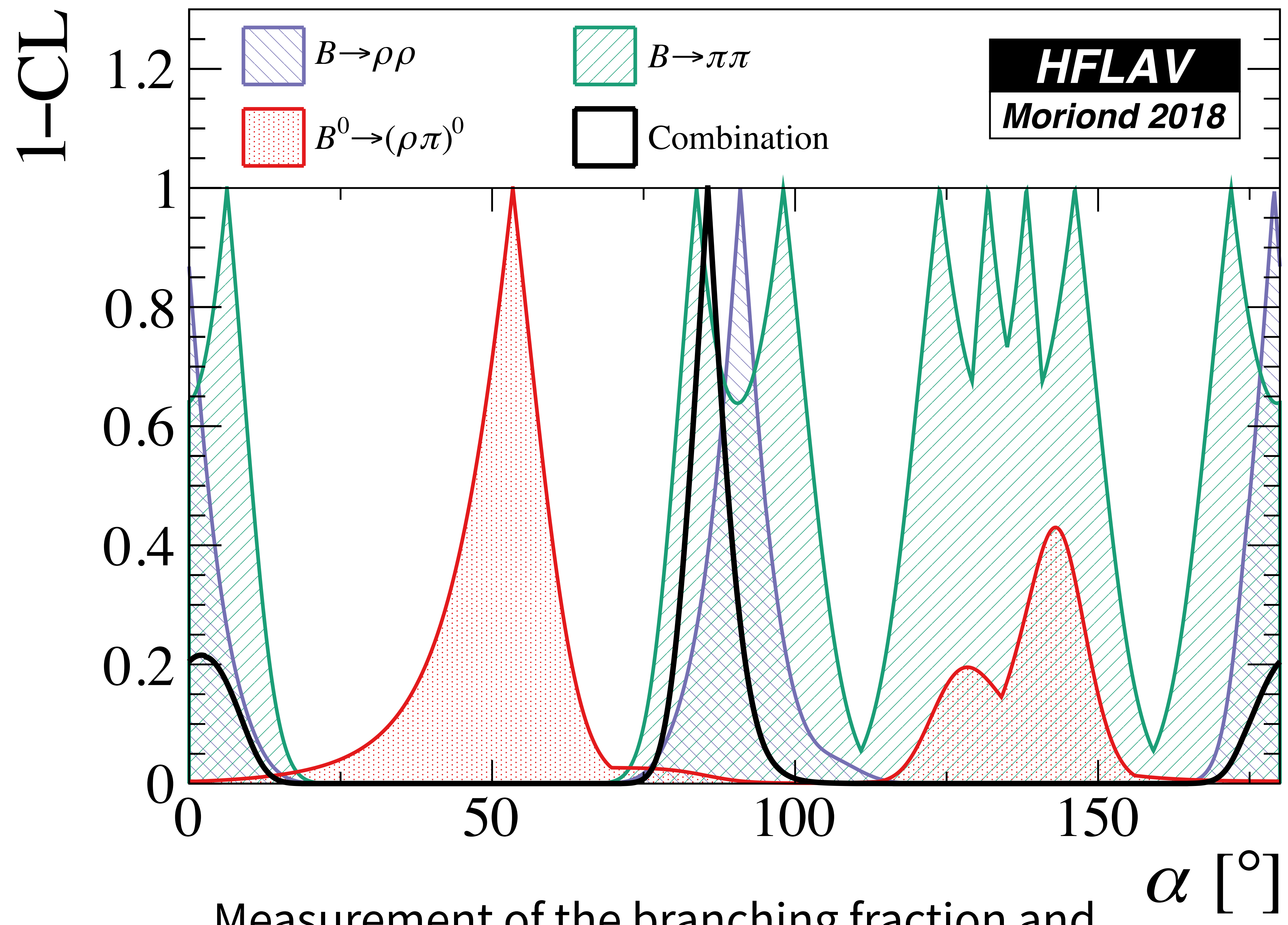
$$A_{CP}^{B^0} = -0.084 \pm 0.004 \pm 0.003$$
$$A_{CP}^{B_s^0} = 0.213 \pm 0.015 \pm 0.007$$

Original Direct CPV signature of the B-factories.



$$C_{\pi^+\pi^-} = -0.34 \pm 0.06 \pm 0.01$$
$$S_{\pi^+\pi^-} = -0.63 \pm 0.05 \pm 0.01$$

Measurement of CP asymmetries in two-body $B^0_{(s)}$-meson decays to charged pions and kaons



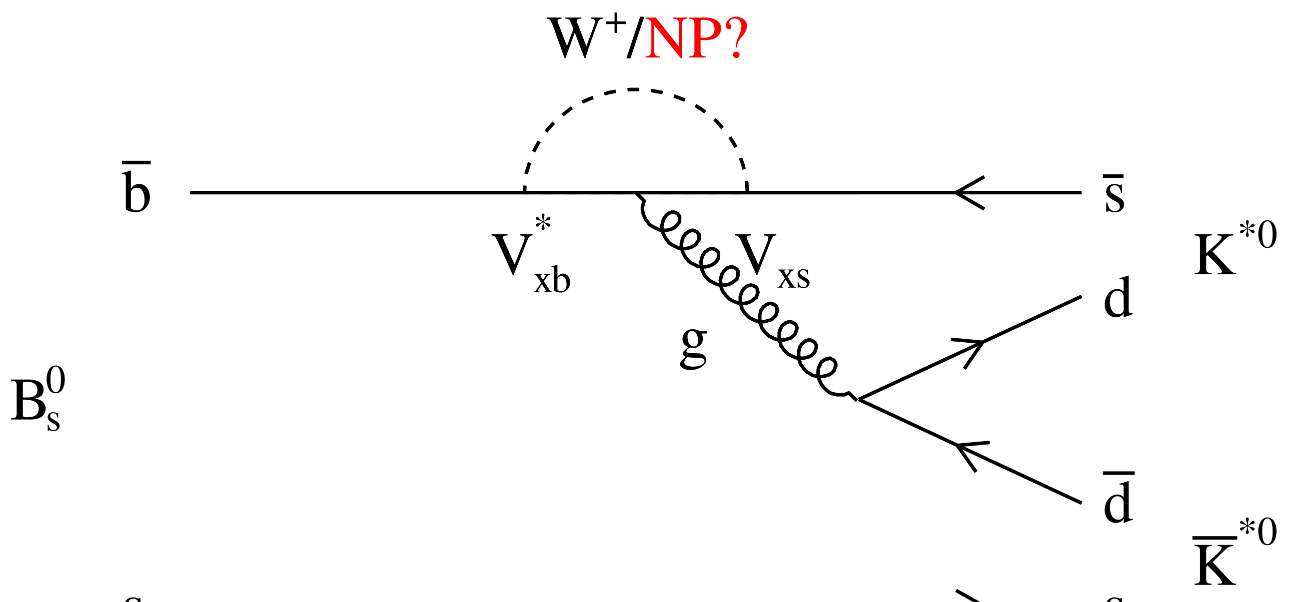
Measurement of the branching fraction and CP asymmetry in $B^0 \to \pi^0\pi^0$ decays, and an improved constraint on φ_2

Large CPV in B→3- and 4-body

LHCb PRL 120 (2018) 26, 261801
LHCb JHEP 1803 (2018) 140
Belle PRD96 (2017) 3, 031101
Belle ICHEP Prelminary

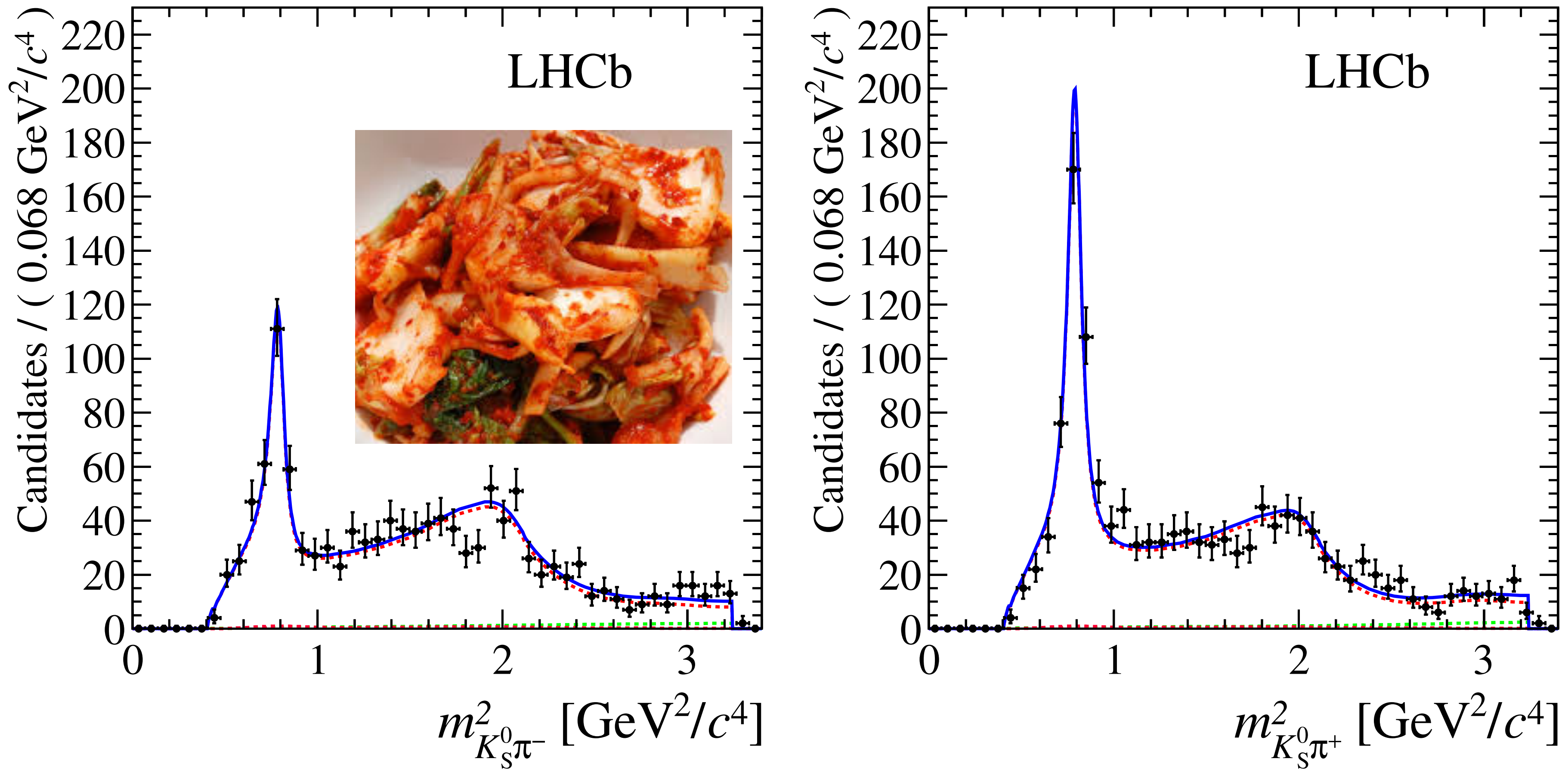
J. Dalseno
D. O'Hanlon

- Very large CP asymmetries in localised Dalitz space.
- Experiments switched gear to amplitude analyses!
- New triple product studies in 4-body as a tool to probe new CPV.

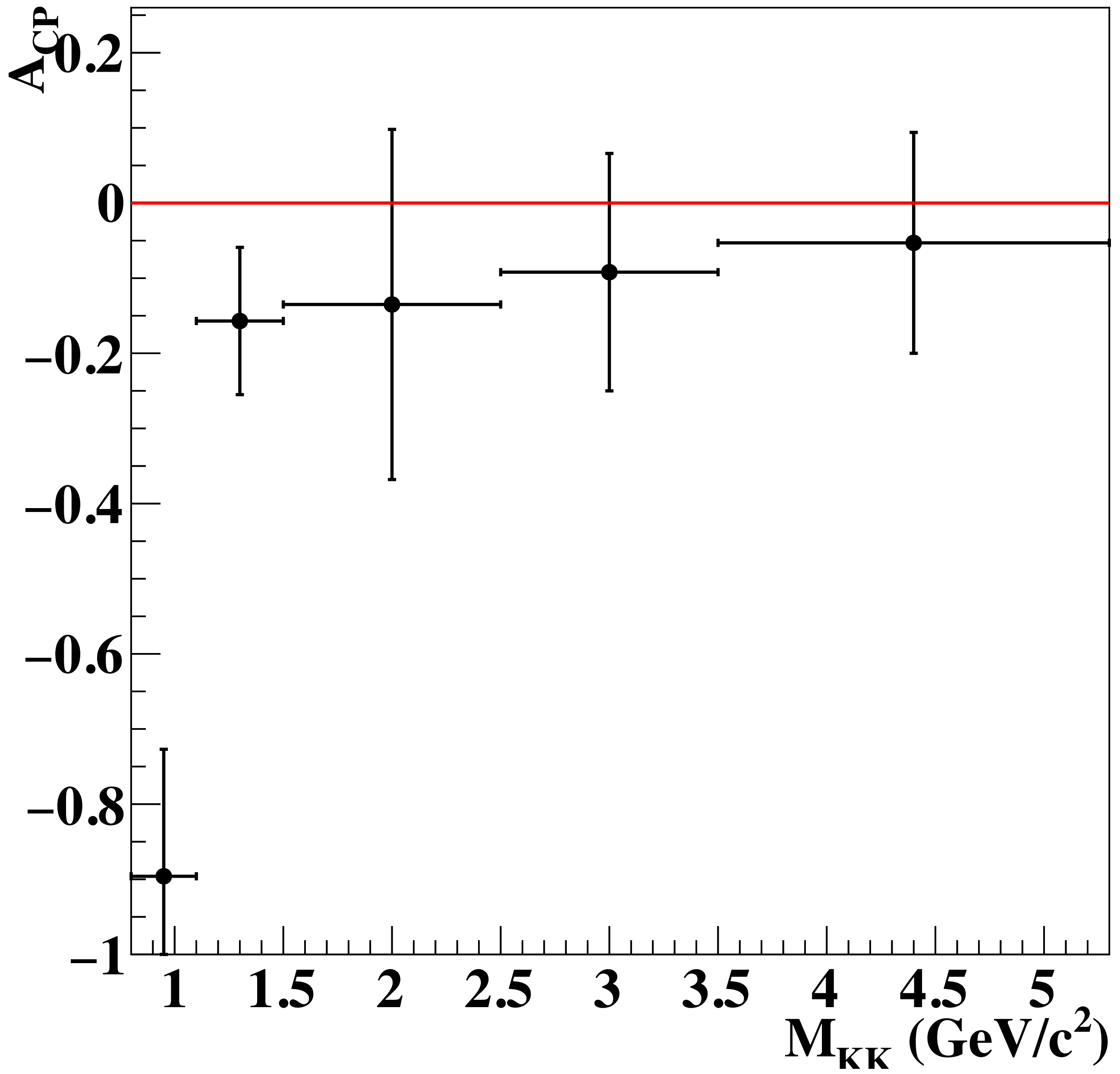


CPV > 6 σ significance, due to B→ K* π

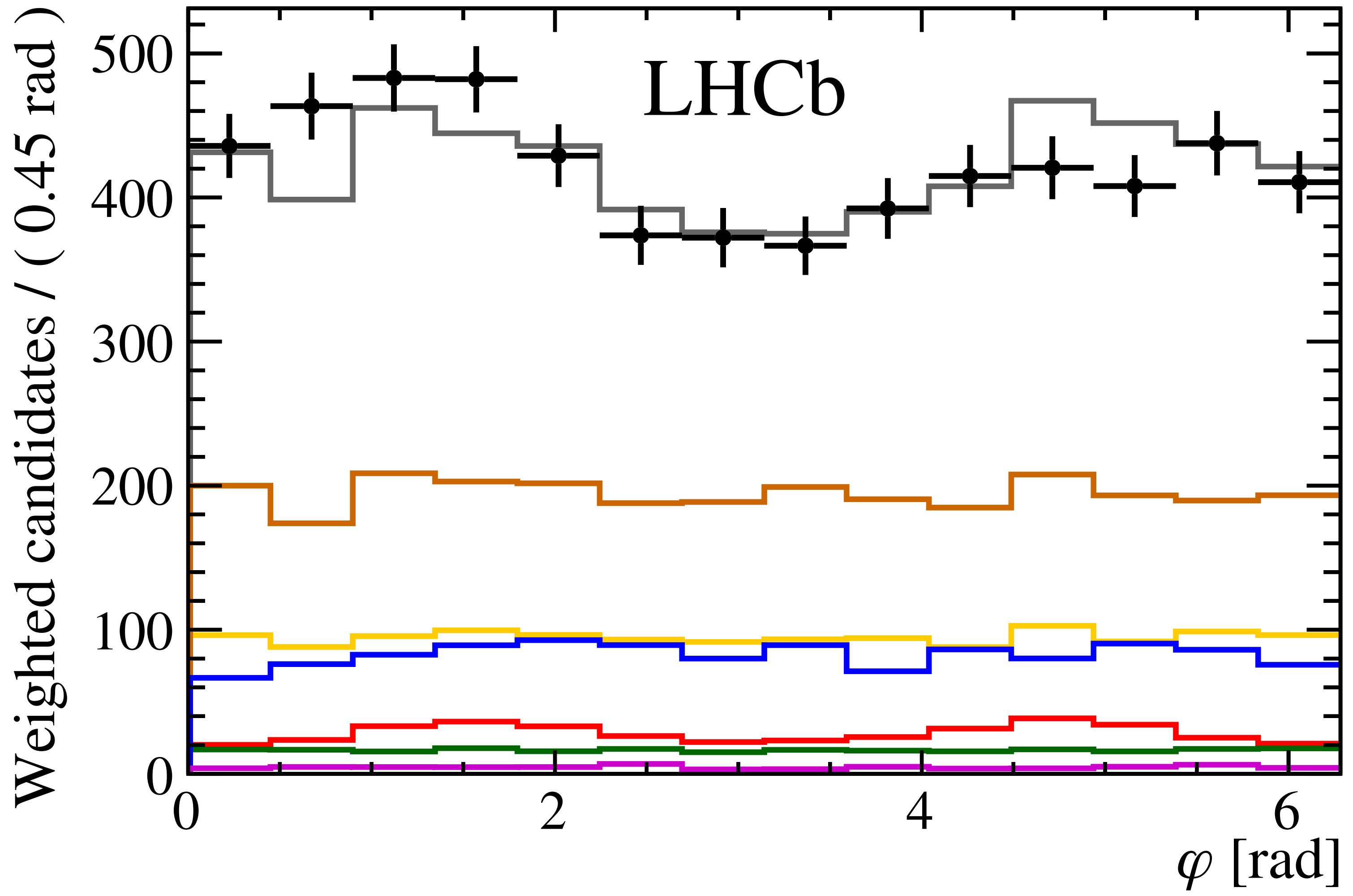
$A_{CP}(B^0 \to K^* \pi) = -0.308 \pm 0.060_{stat} \pm 0.011_{sys} \pm 0.012_{model}$



Amplitude Analysis of the Decay **B⁰→K⁰ₛπ+π−** and First Observation of the CP Asymmetry in **B⁰→K*(892)⁻π⁺**



Measurement of branching fraction and direct CP asymmetry in charmless **B⁺→K⁺K⁻π⁺ and B⁰→KₛK⁻π⁺** decays at Belle



$\phi_s^{s\bar{d}d} = -0.10 \pm 0.13\ \mathrm{(stat)} \pm 0.14\ \mathrm{(syst)}\ \mathrm{rad}$

First measurement of the CP-violating phase φ_s^{dd} in $B^0_s \to (K^+\pi^-)(K^-\pi^+)$ decays

Charm CP Violation

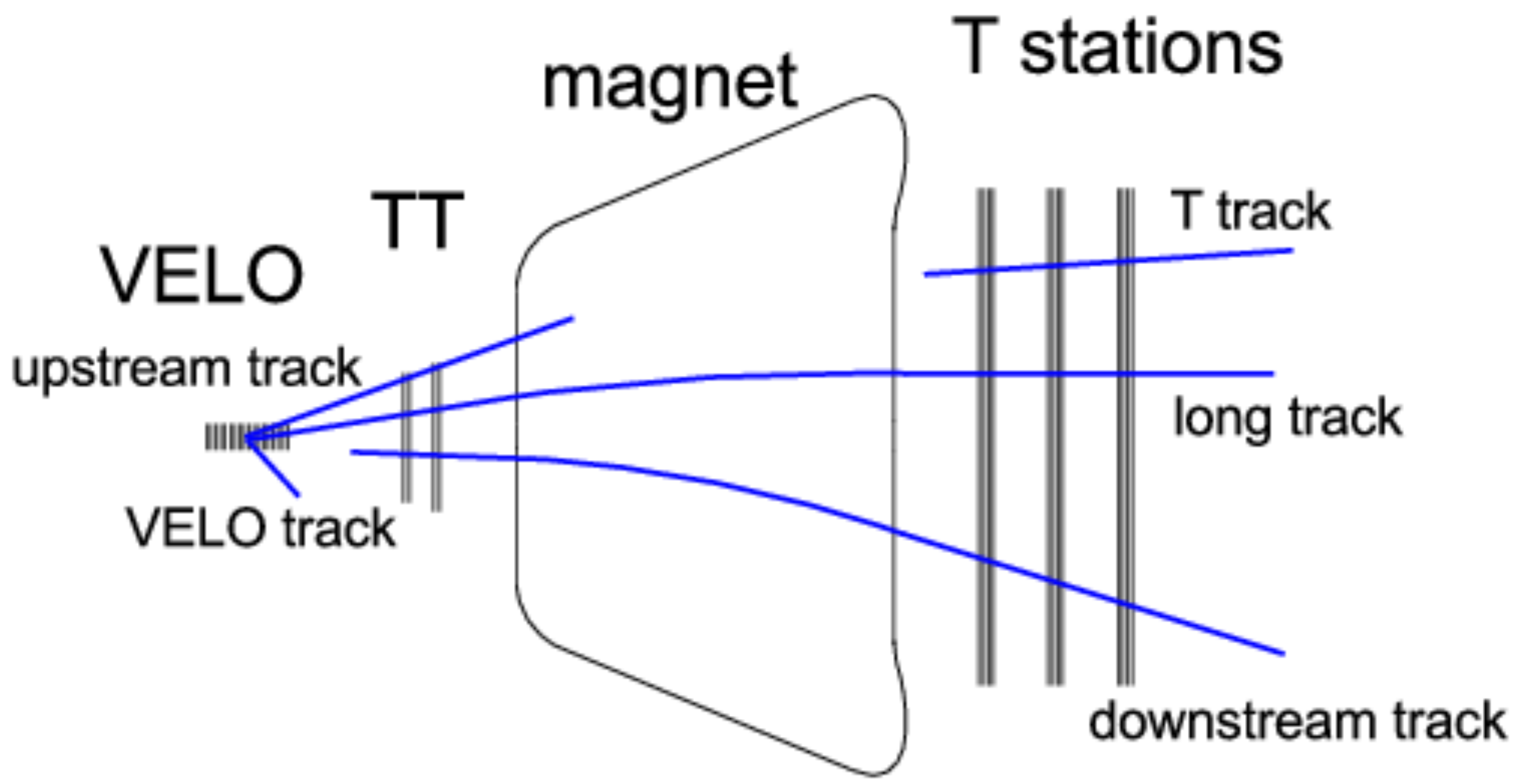
Non-zero CPV in charm is a New physics smoking gun.

LHCb arXiv: 1806.01642
Belle PRD97 (2018) 1, 011101
Belle PRL 119 (2017) 17, 171801
LHCb PRL 118, 261803 (2017)
LHCb PRD97, 031101 (2018)

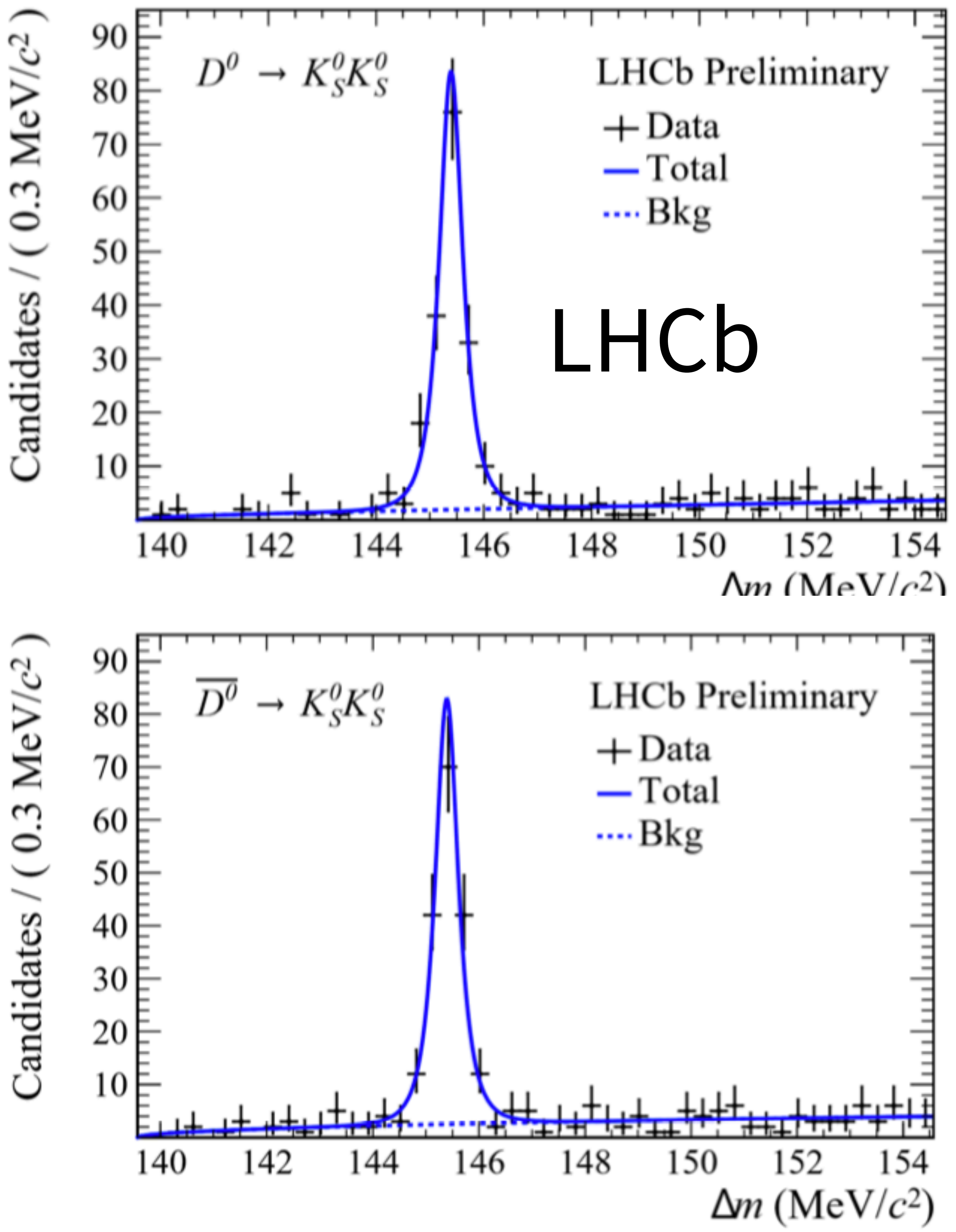
Y-T. Lai
L-Y. Dong
M. Martinelli

Other recent results on Search for CP violation in the $D^+ \to \pi^+ \pi^0$ decay at Belle

- Recent work on CPV in modes with neutrals at Belle and LHCb
  - Need neutrals to constrain strong phases if CP observed.
  - No sign of CPV direct or indirect

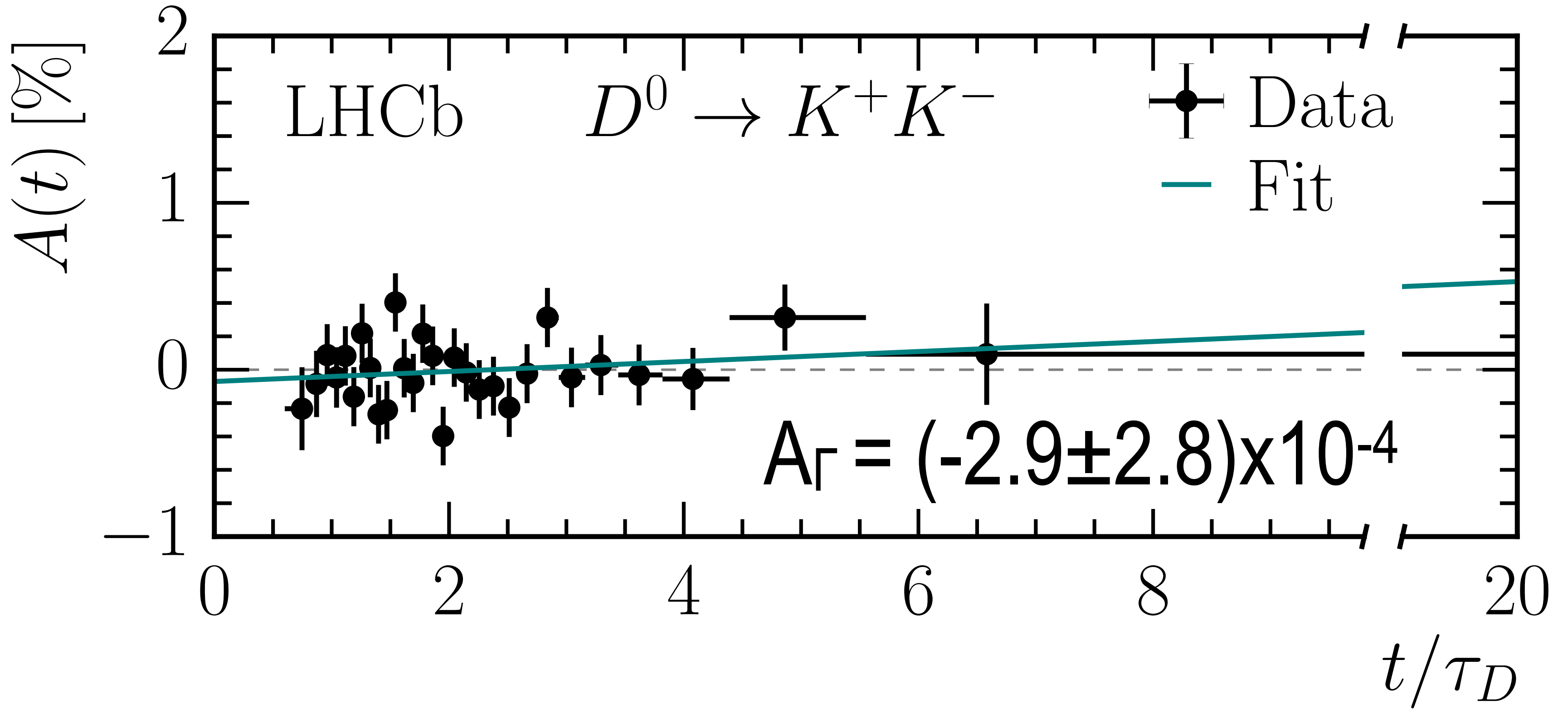


$A_{CP}^{LHCb} = (2.0 \pm 2.9 \pm 1.0)\%$
$A_{CP}^{Belle} = (-0.02 \pm 1.53 \pm 0.18)\%$



Measurements of the time-integrated
CP asymmetry (and branching fraction) in $D^0 \to K^0_S K^0_S$ decays at Belle / and LHCb

$$A_\Gamma \equiv \frac{\hat{\Gamma}(D^0 \to f) - \hat{\Gamma}(\overline{D}^0 \to f)}{\hat{\Gamma}(D^0 \to f) + \hat{\Gamma}(\overline{D}^0 \to f)}$$



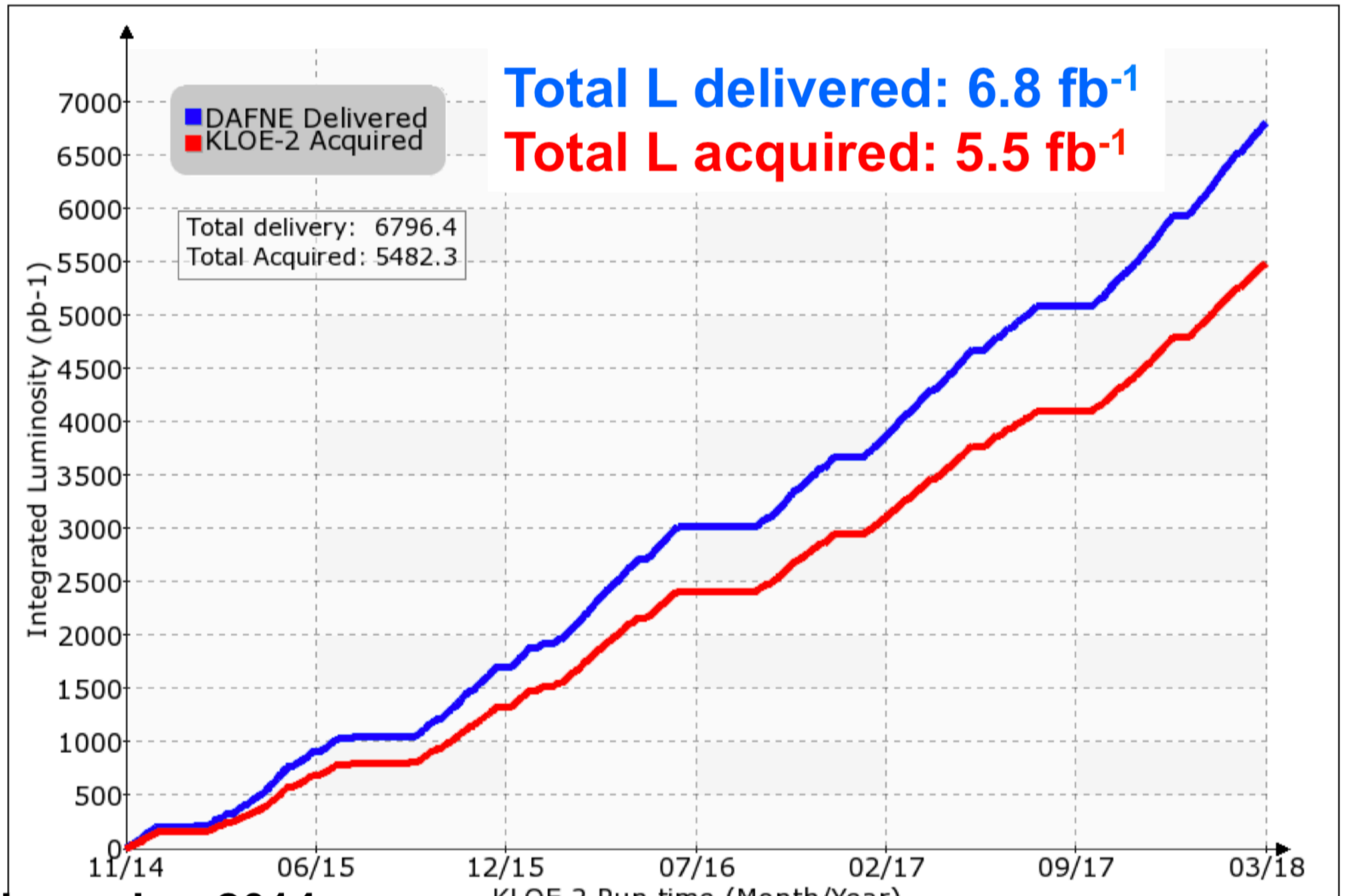
Updated determination of D^0 mixing and CP violation parameters with $D^0 \to K^+\pi^-$ decays

CPT tests in Kaon decays

A. Di Domenico

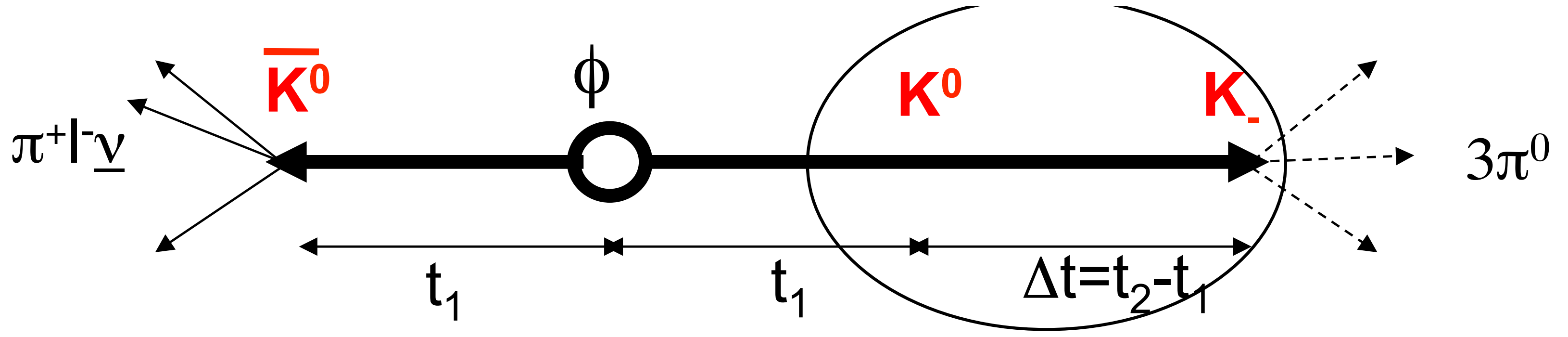
KLOE ICHEP Preliminary
KLOE arXiv:1806.08654

- Final KLOE-2 dataset collected on 30 March 2018 - we await their CPV and CKM analyses.
  - CPT and QM tests with kaon interferometry
  - Direct T and CPT tests using QM entanglement
  - CP violation and CPT test: $K_S \to 3\pi^0$, Im(ε'/ε)
  - CKM V_{us}: K_S semileptonic, Kμ3, Kl3



November 2014 — 30 March 2018

Orthogonal "CP states" K_+ and K_-

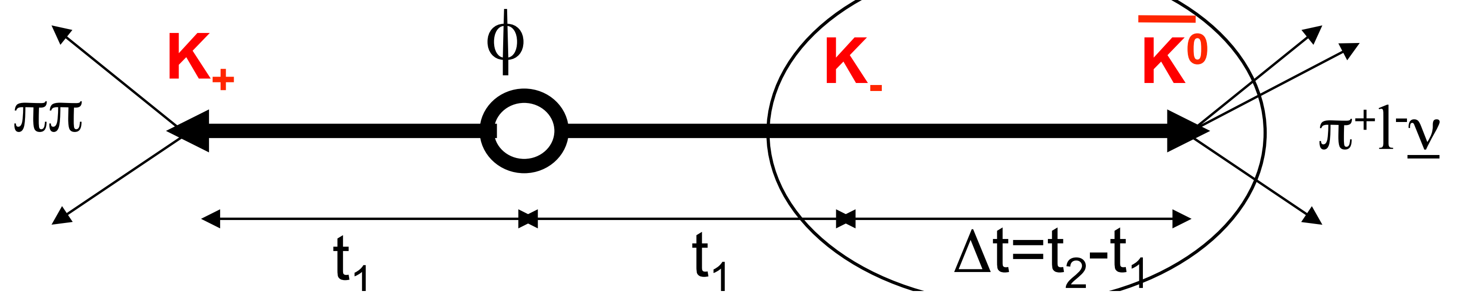


$K^0 \to K_-$ reference process

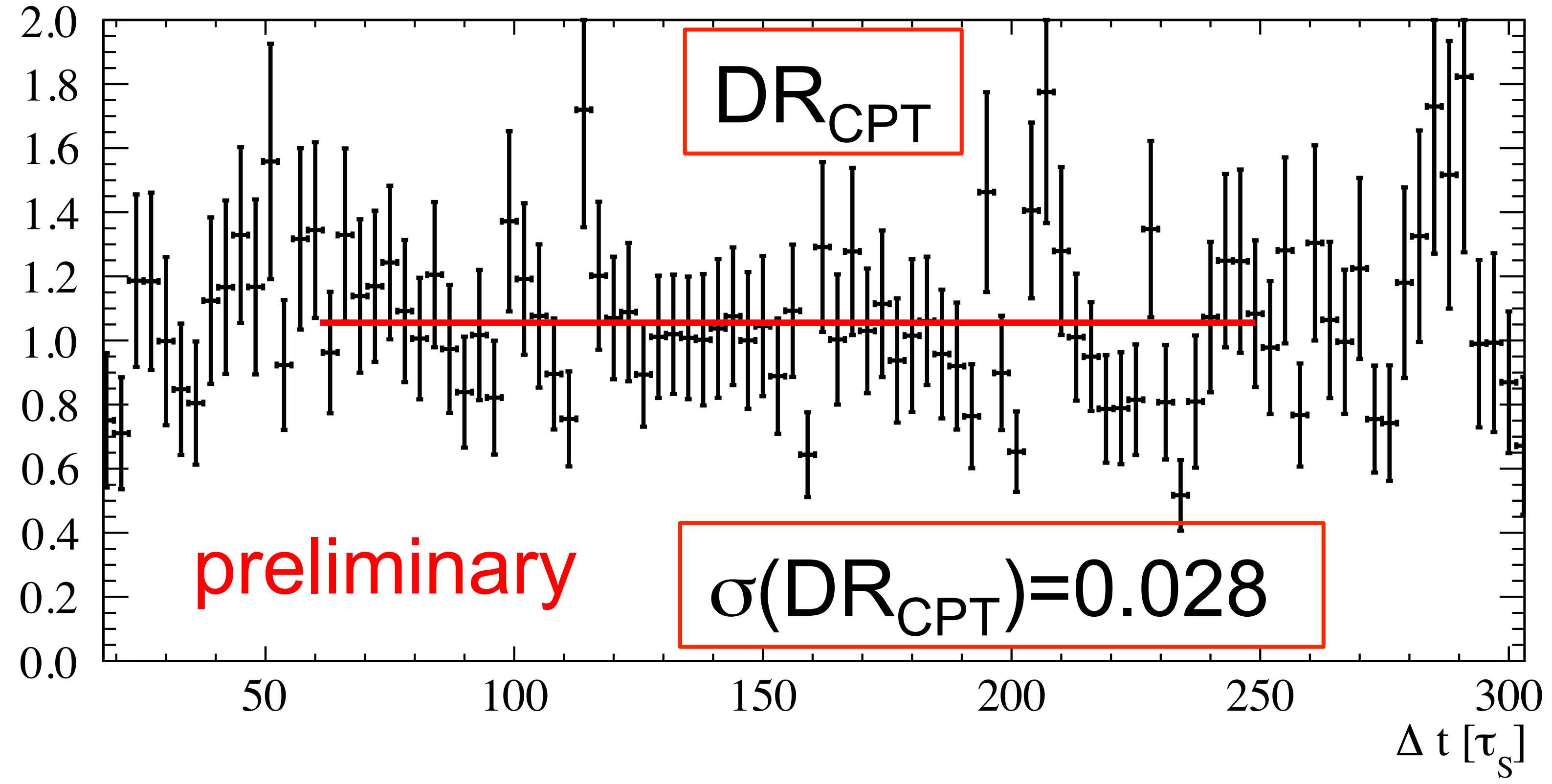
$K_- \to \overline{K}^0$ CPT-conjugated process

$$R_{2,CPT}(\Delta t) = \frac{P\left[K^0(0) \to K_-(\Delta t)\right]}{P\left[K_-(0) \to \overline{K}^0(\Delta t)\right]}$$

$$R_{4,CPT}(\Delta t) = \frac{P\left[\overline{K}^0(0) \to K_-(\Delta t)\right]}{P\left[K_-(0) \to K^0(\Delta t)\right]}$$



$$DR_{CPT} = \frac{R_{2,CPT}(\Delta t >> \tau_S)}{R_{4,CPT}(\Delta t >> \tau_S)}$$



Relation to SL asymmetries

$$DR_{CPT} = 1 + 2(A_L - A_S)$$

Combination KLOE(2006)+KLOE (2018)

$A_S = (-3.8 \pm 5.0 \pm 2.6) \times 10^{-3}$

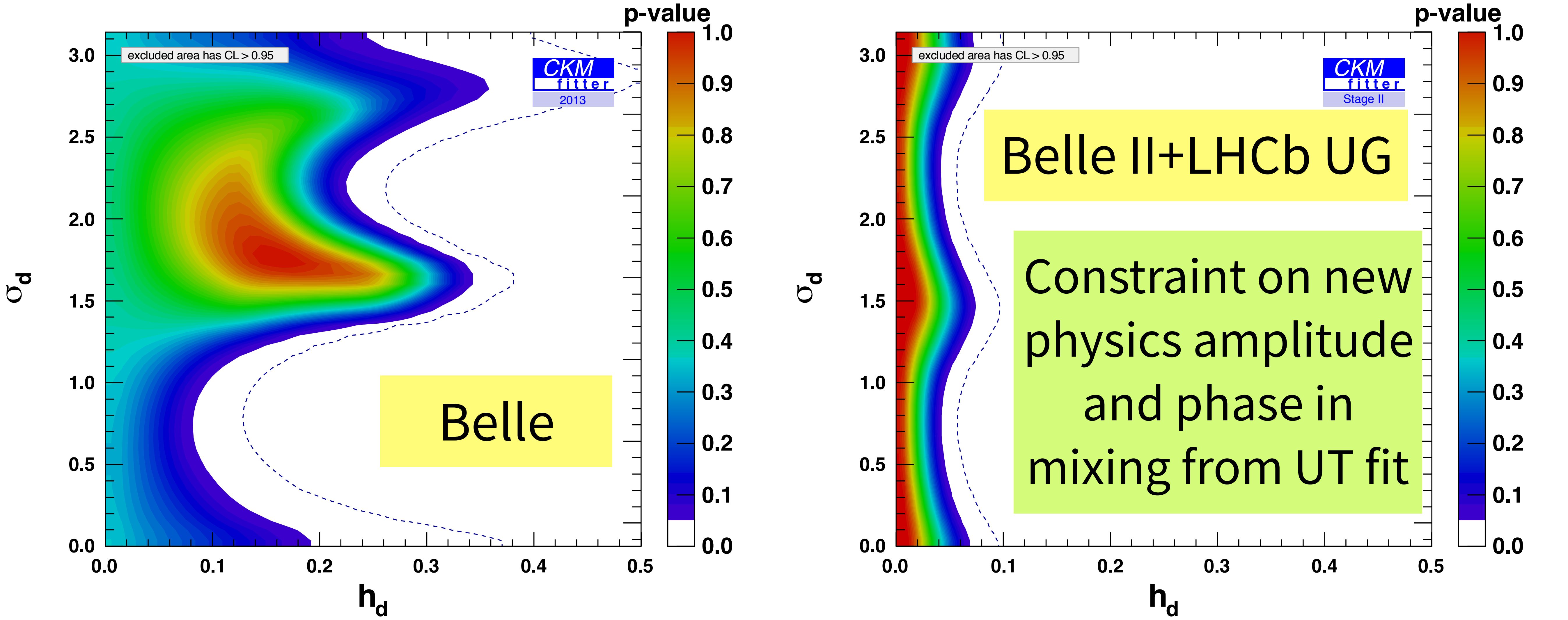
Should be 1 to conserve CPT

Using KTeV result on A_L and KLOE on A_S: **$DR_{CPT} = 1.016 \pm 0.011$** (preliminary)

V_{CKM} - Summary

- **$|V_{cb}|$ puzzle addressed by Belle**
  - **$B \to D^{(*)} \tau \nu$ anomaly needs new $B \to D^{**} l \nu$ background studies**
- **$|V_{ub}|/|V_{cb}|$** at LHCb has **better understood form factors!**
- **$|V_{ub}|$ inclusive-exclusive puzzle** - final B-factory results awaited.
- **$|V_{cd}|$ & $|V_{cs}|$** direct constraints from BES III are world best. **Outstanding test of LQCD! No LFUV found.**

- **CPV for SM phase measurements (WA HFLAV)**
  - $\sin 2\Phi_1 = 0.70 \pm 0.02$
  - $\Phi_2 = (84.9^{+5.1}_{-4.5})°$
  - **$\Phi_3 = (73.5^{+4.2}_{-5.1})°$**
  - All measurements are statistics limited.
- **CPV for new physics searches:**
  - Large local asymmetries. Switching gear to amplitude analyses.
  - Baryon decays a new window to CPV (see backup)
  - $\Phi_s = -0.021 \pm 0.031$ WA HFLAV 2018 (see backup)

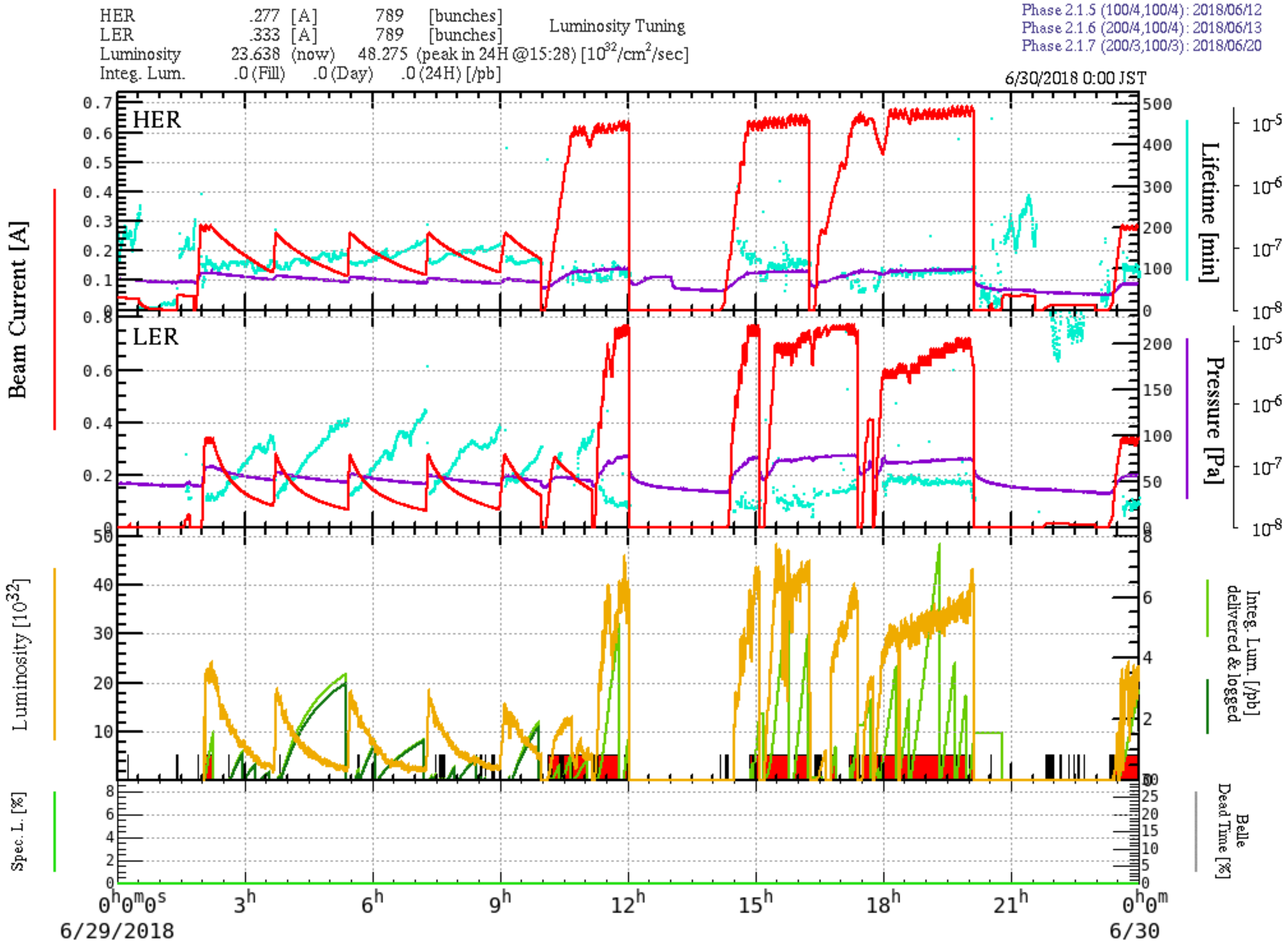


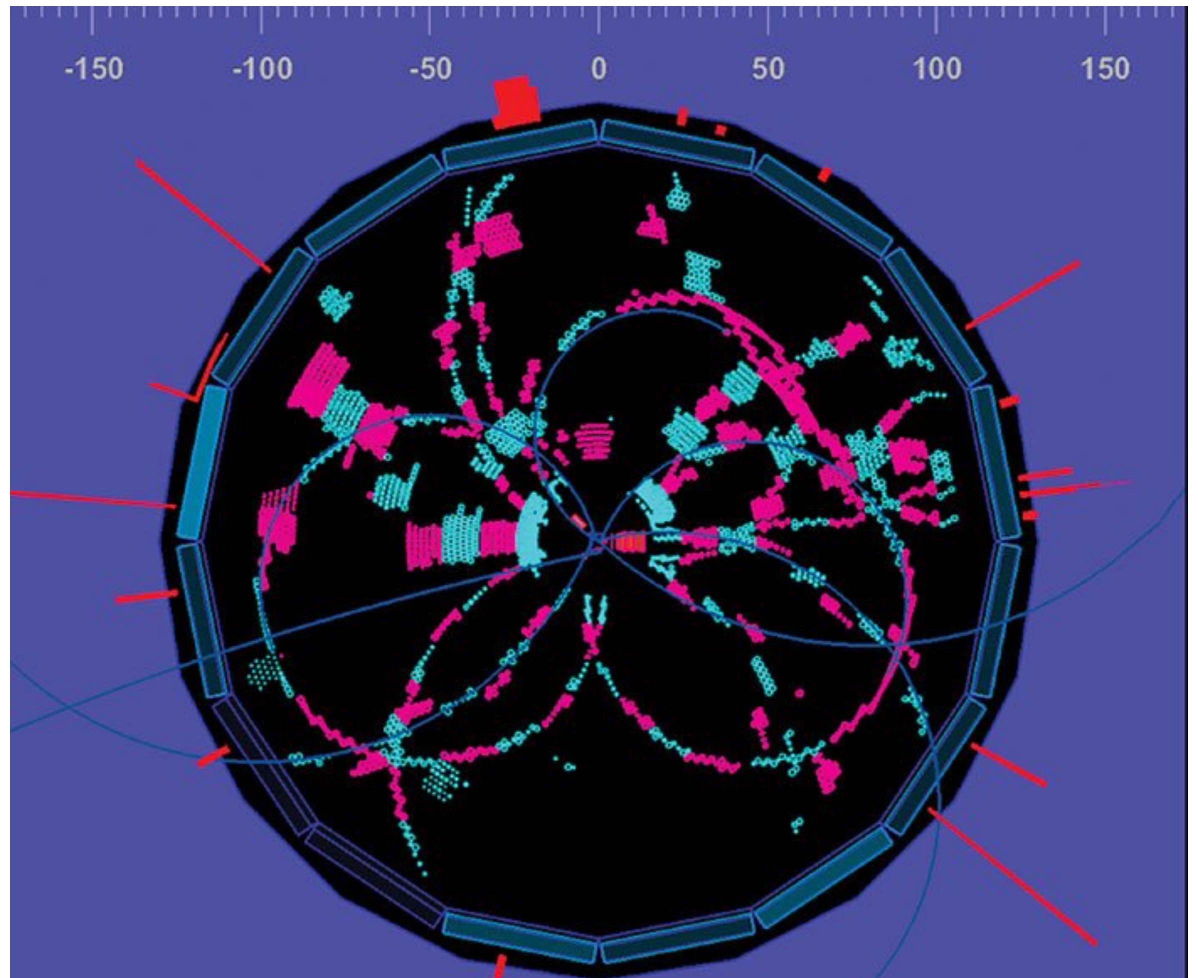
$$M_{12}^{d,s} = (M_{12}^{d,s})_{SM} \times \left(1 + h_{d,s} e^{2i\sigma_{d,s}}\right)$$

- **LHCb upgrade & Belle II will push 1 order of magnitude further on searches for CPV sources. 20-30% NP amplitude still allowed in CKM ΔB=2.**

Belle II & SuperKEKB online

- Nano-beam scheme in action
  - 5.5×10^{33} cm^{-2} s^{-1} achieved
  - > 0.5 fb^{-1} collected to date.
- Belle II first studies shown at ICHEP



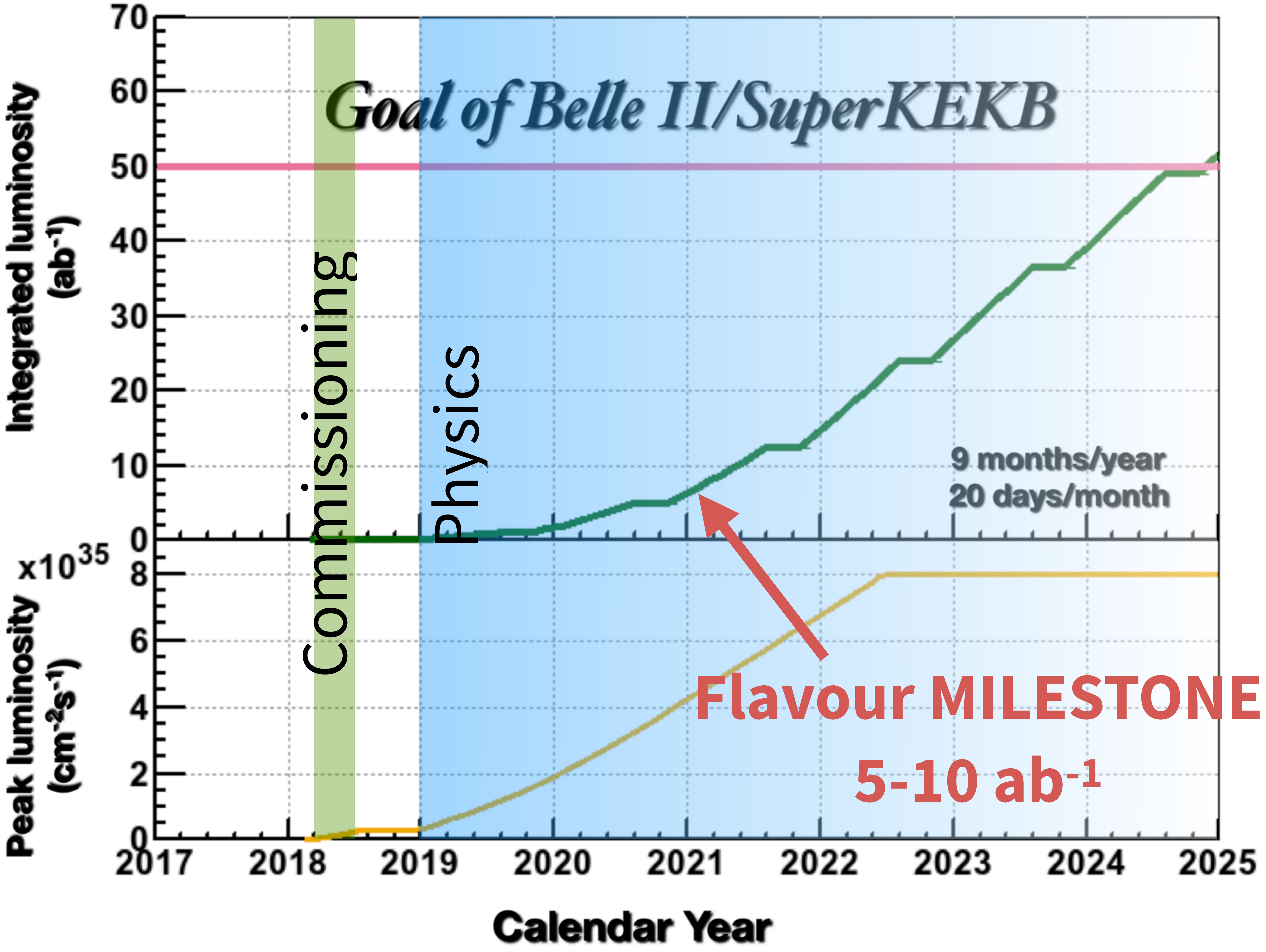


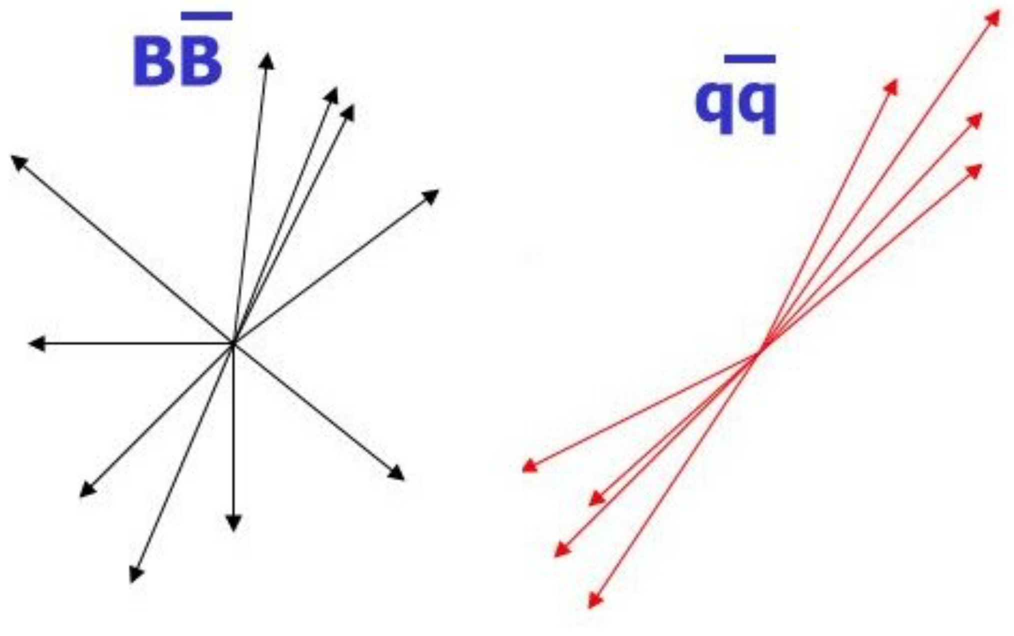
First hadronic event, April 26 2018

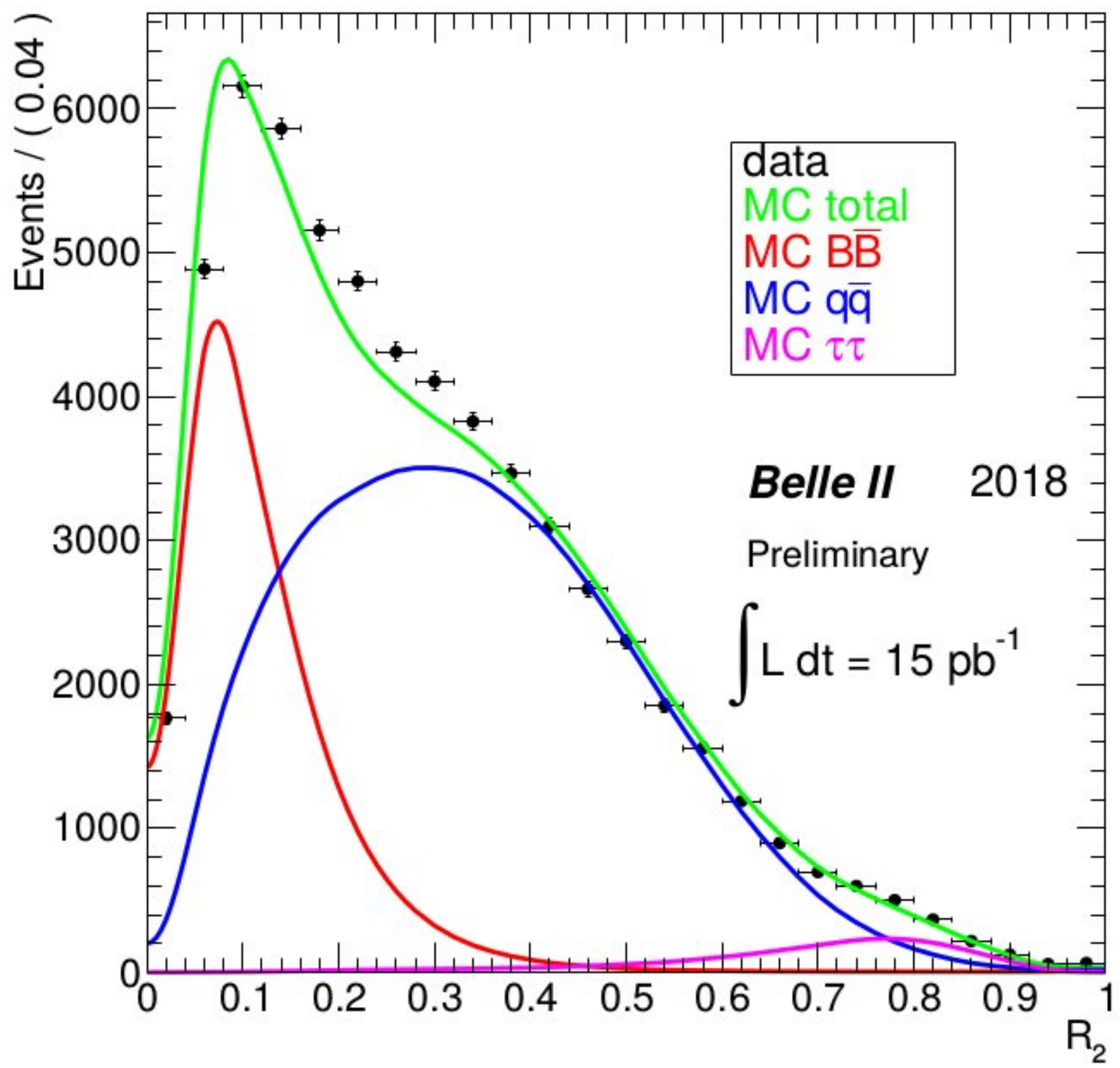
Kobayashi @ First collisions ceremony

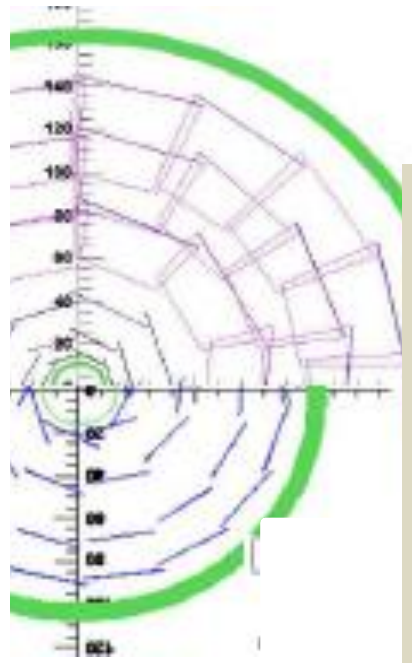
Belle II and SuperKEKB

- >800 Collaborators from 110 institutions and 25 countries.
- **Belle II Korea (45 members) makes high-impact contributions to the calorimeter, trigger, DAQ and computing.**
- **The foreign co-spokesperson of Belle is Youngjoon Kwon.**

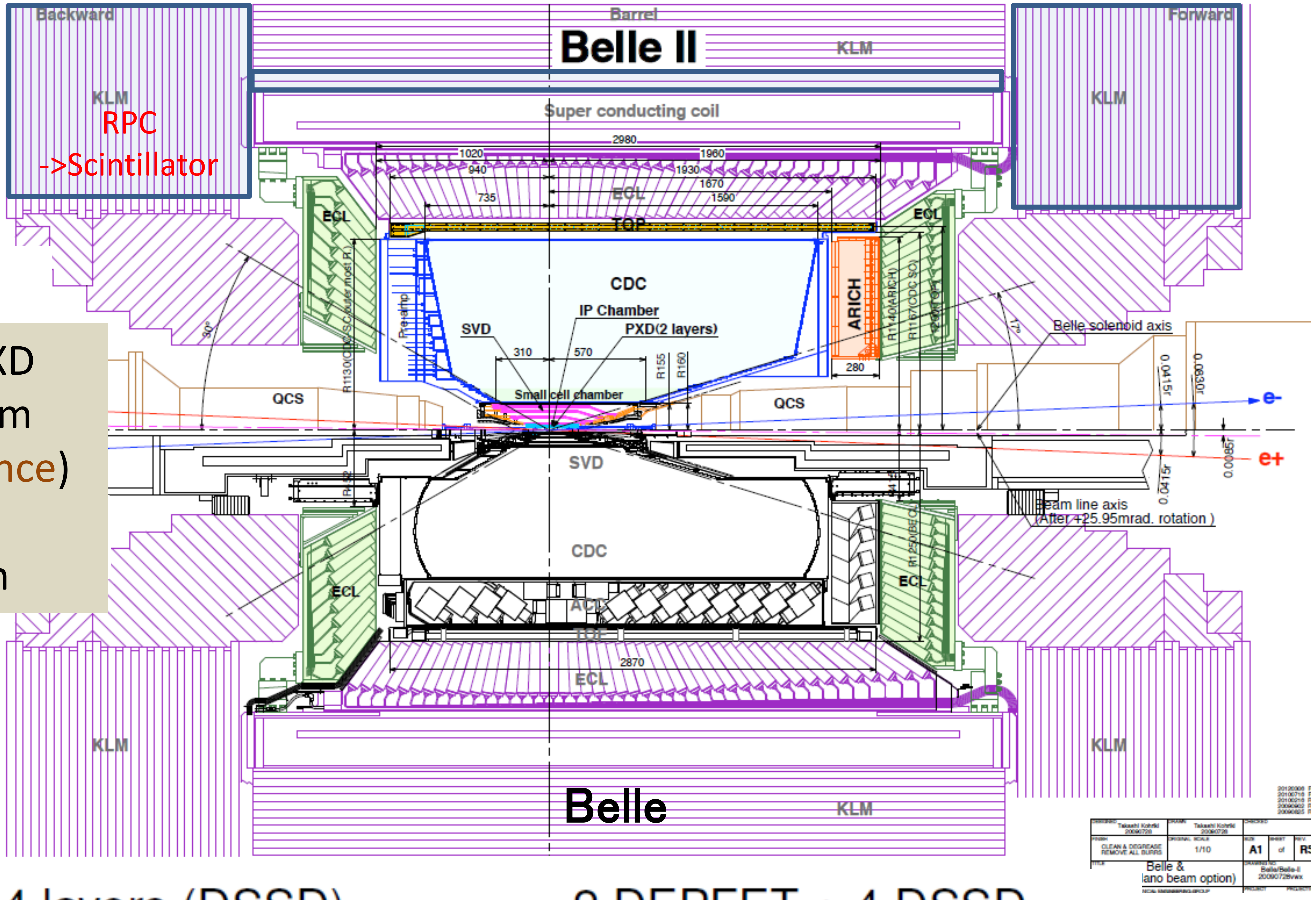


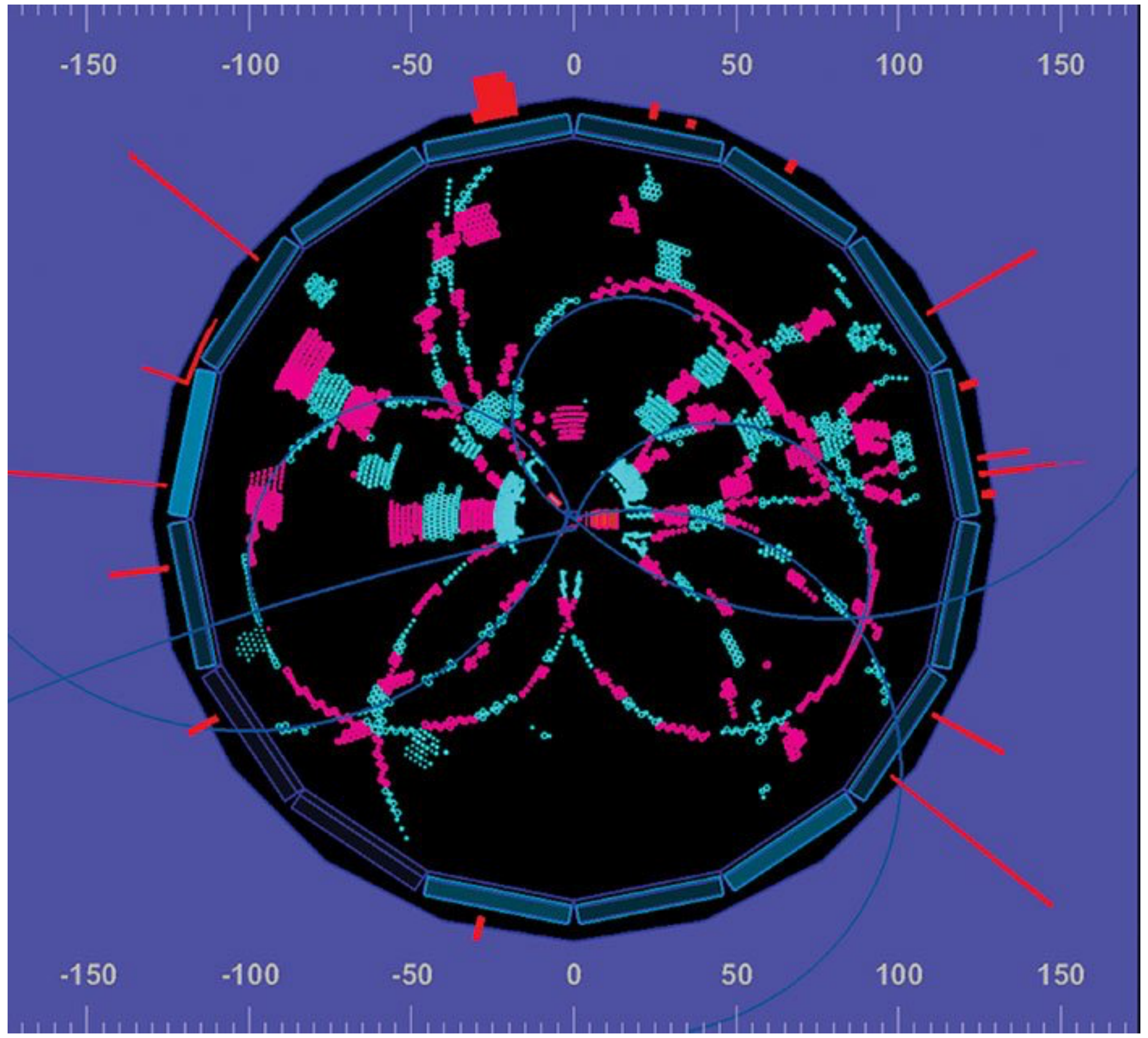


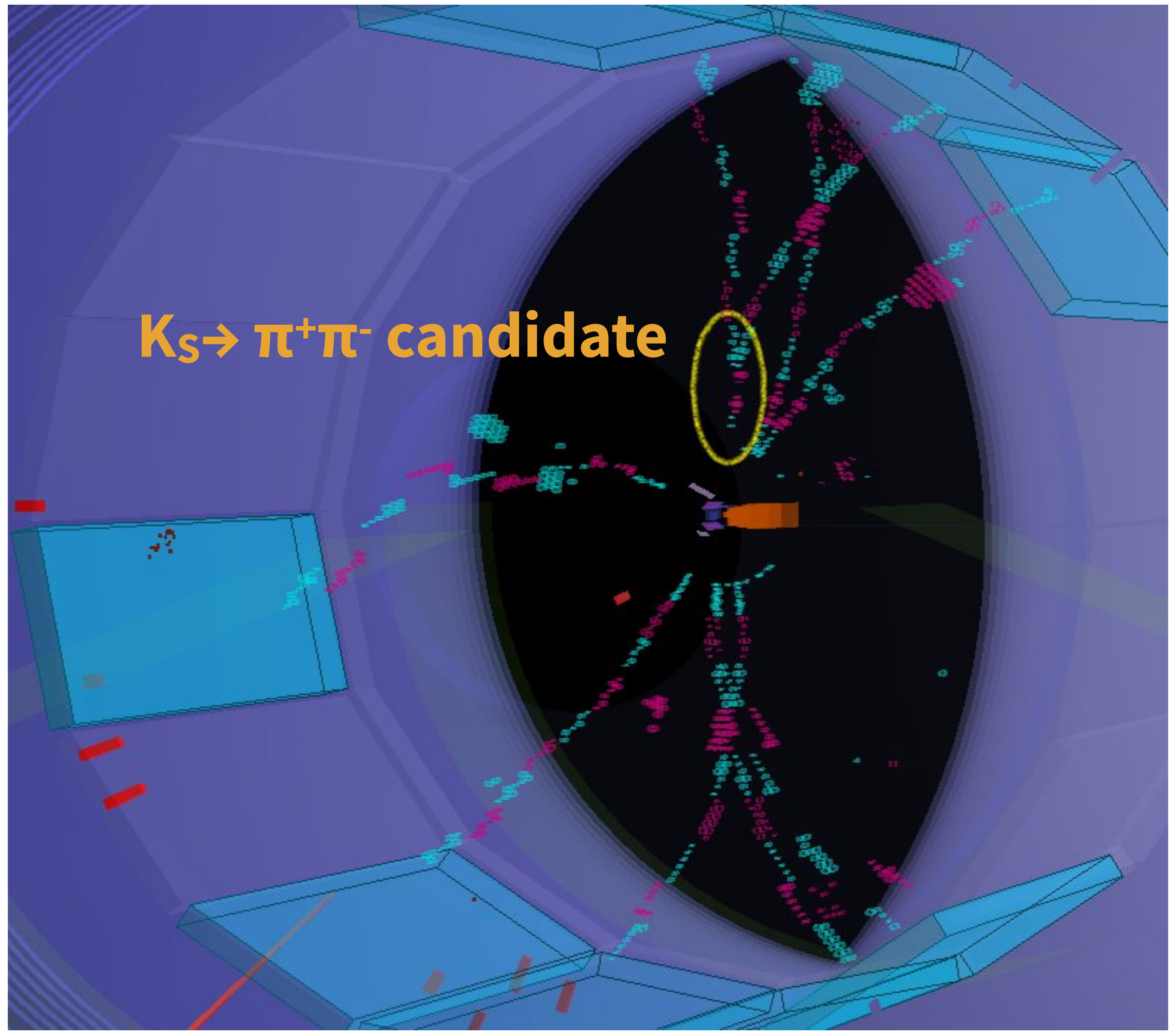




Belle II VXD
R=14-140mm
(Ks acceptance)
Belle SVD
R=20-88mm







SVD 4 layers (DSSD)	→	2 DEPFET + 4 DSSD
CDC:		small cell, long lever arm
ACC+TOF	→	TOP+ARICH (Better K/p separation)
ECL:		waveform sampling
KLM: RPC	→	Scintillator+SiPM

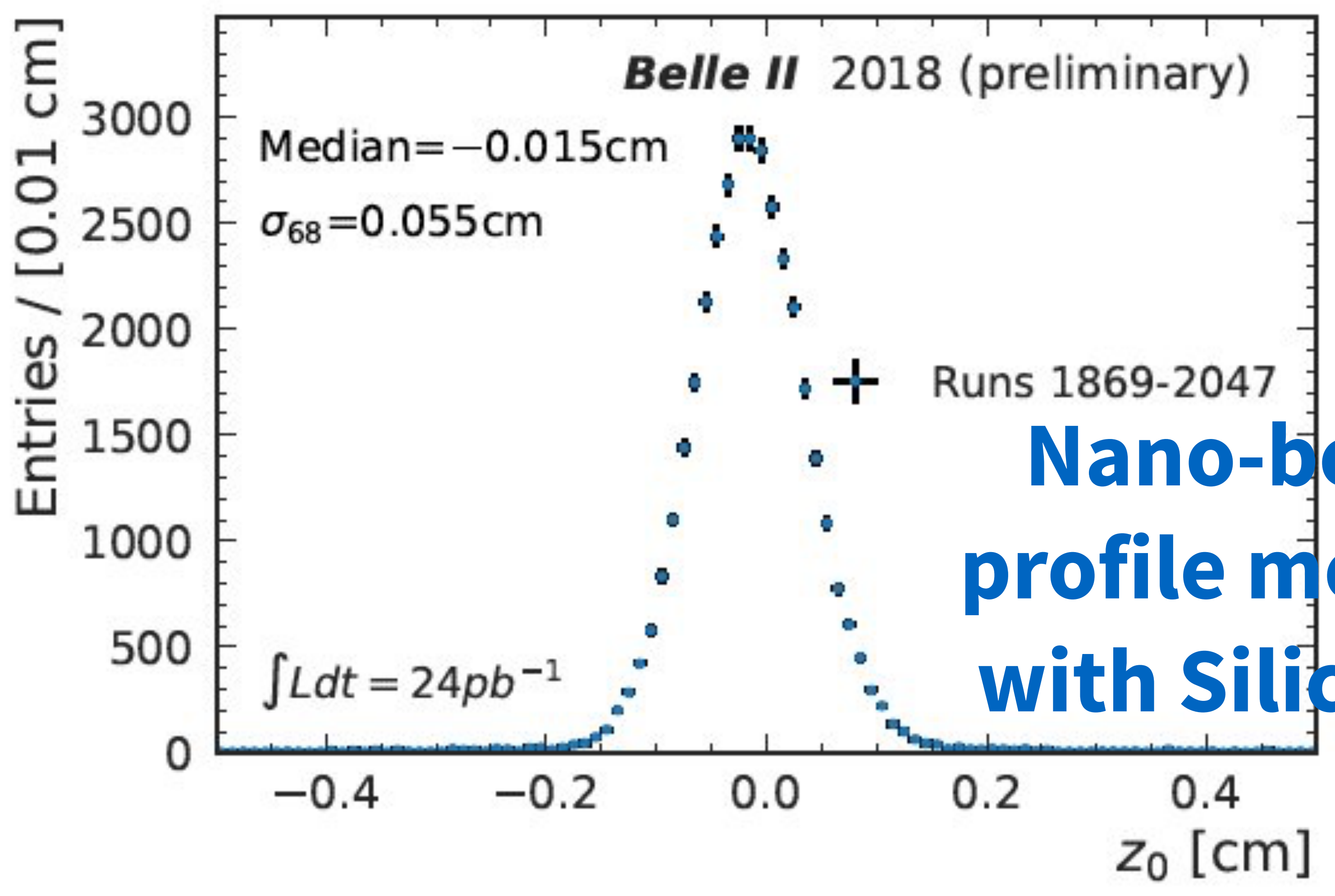
(Endcap and inner two layer of Barrel for neutron BG)

- **Silicon vertex detectors (Layers 1, 3-6) to be installed for 2019 operation**

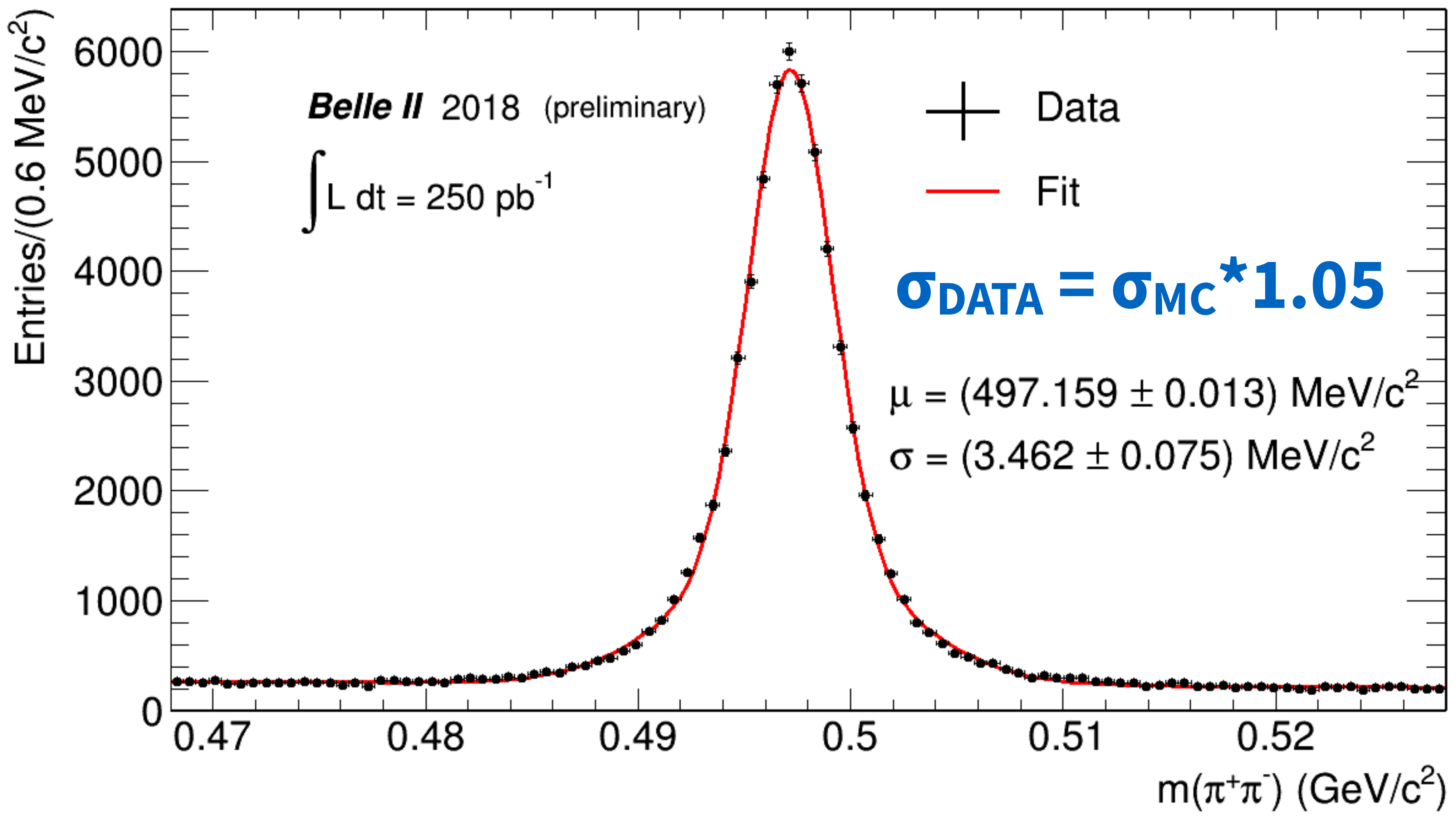
Performance / Calibration modes

S. Tanaka

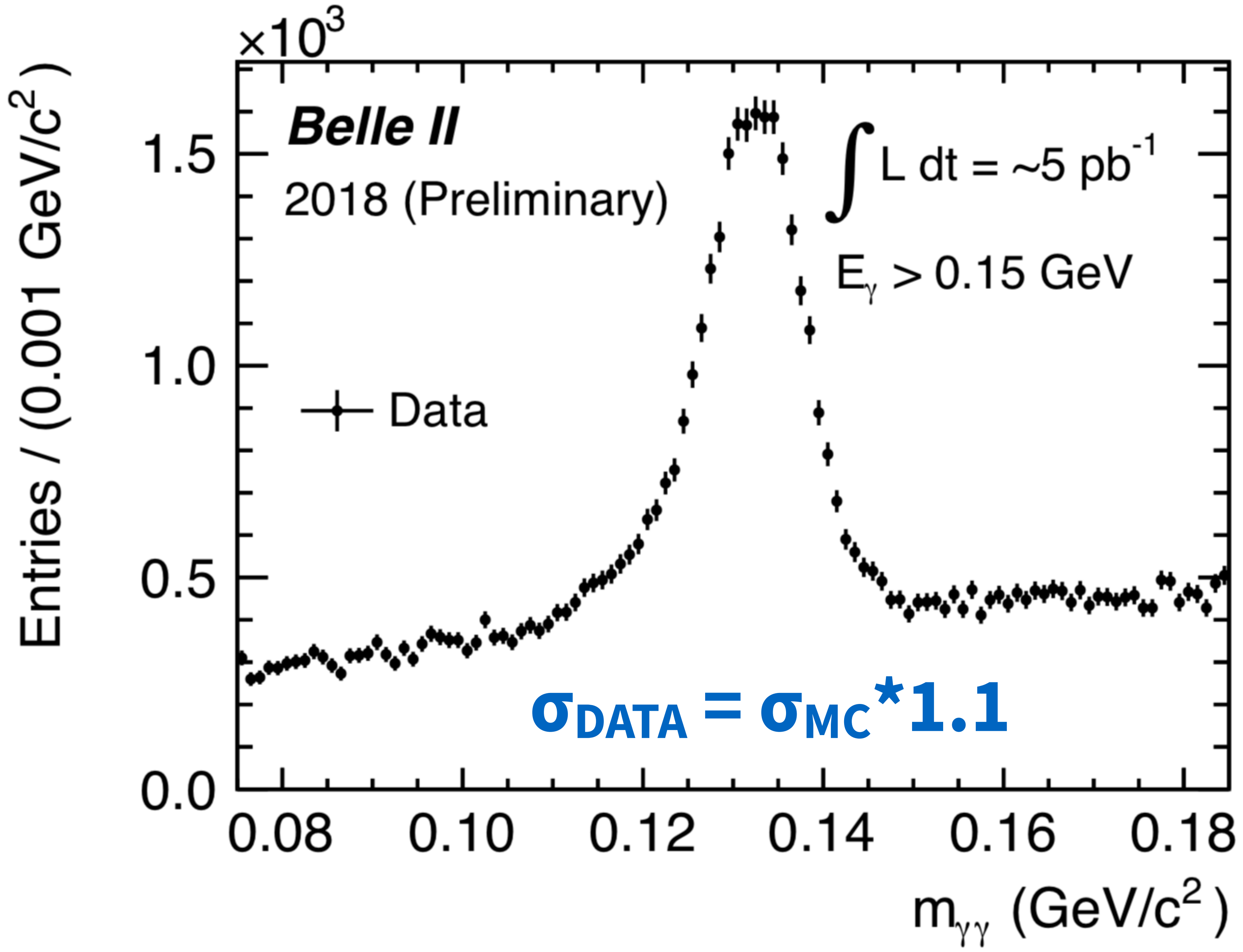
- Spatial resolution of the new vertex detector a factor ~2x better than Belle, ~30% larger acceptance for K_S
- K/π separation → 2x lower misidentification rates
- After first calibration: spectacular performance (mid-commissioning run). Invariant masses spot-on!



Nano-beam z-profile measured with Silicon VXD



$\sigma_{DATA} = \sigma_{MC}$*1.05

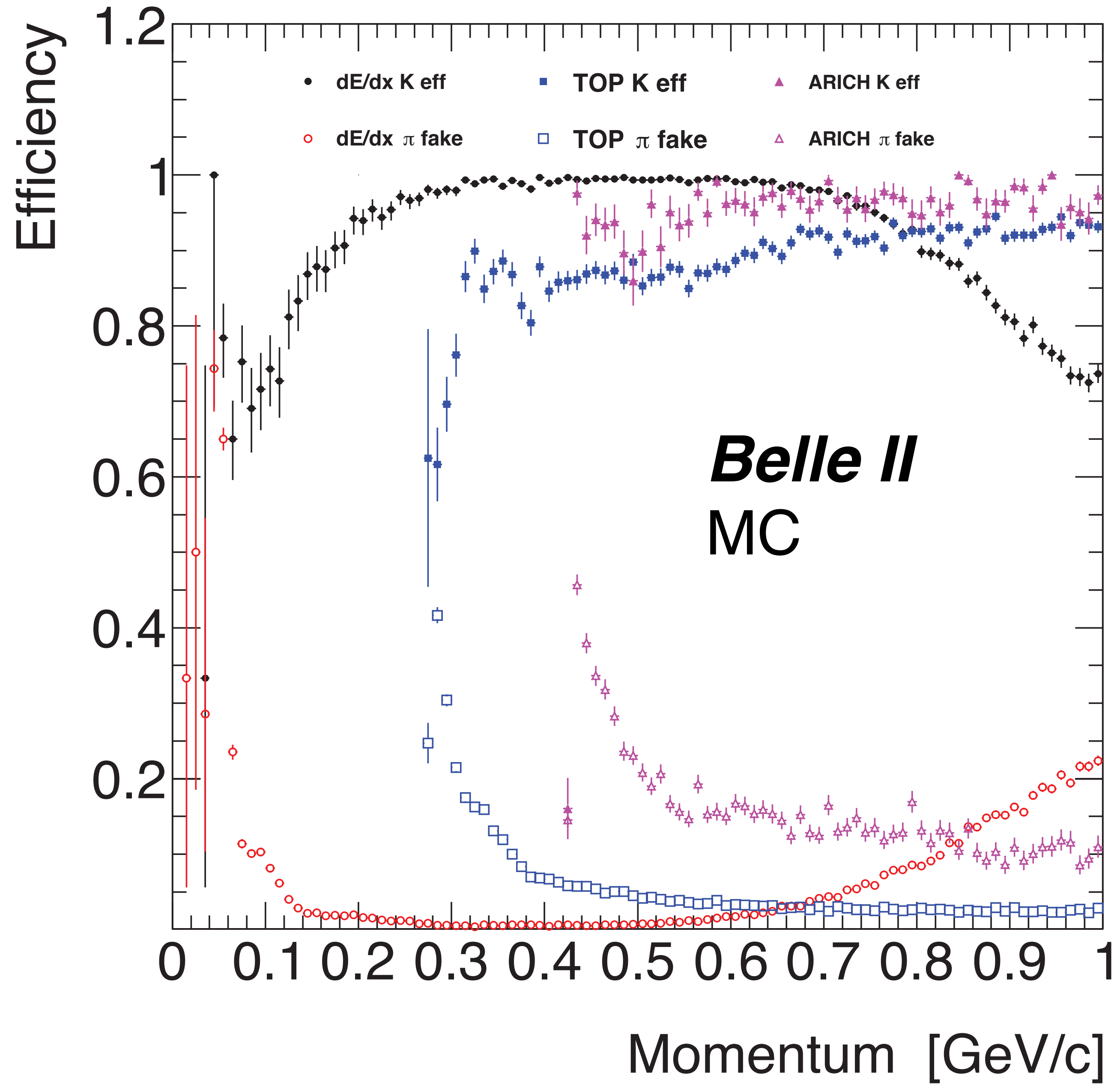


$\sigma_{DATA} = \sigma_{MC}$*1.1

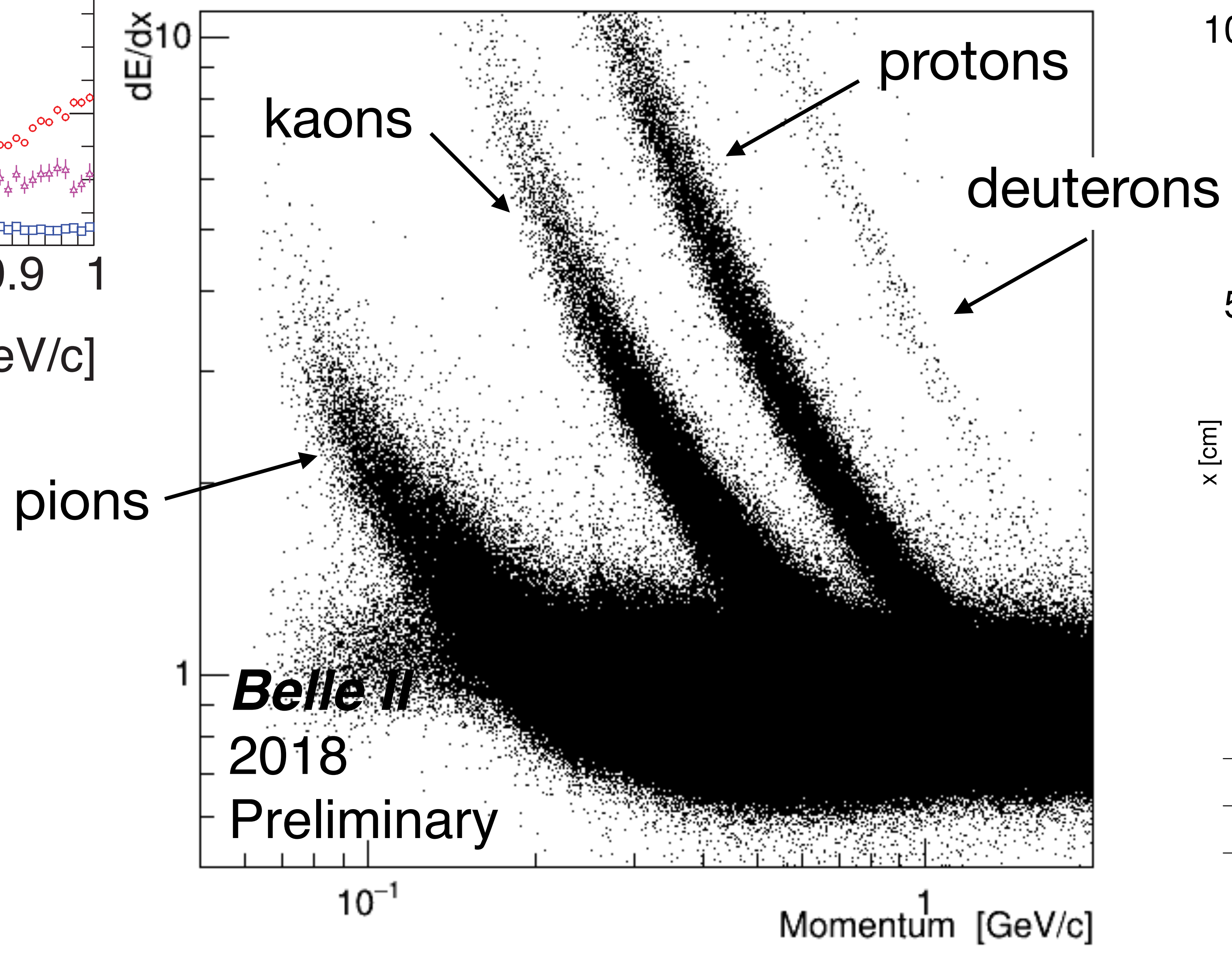
Particle identification

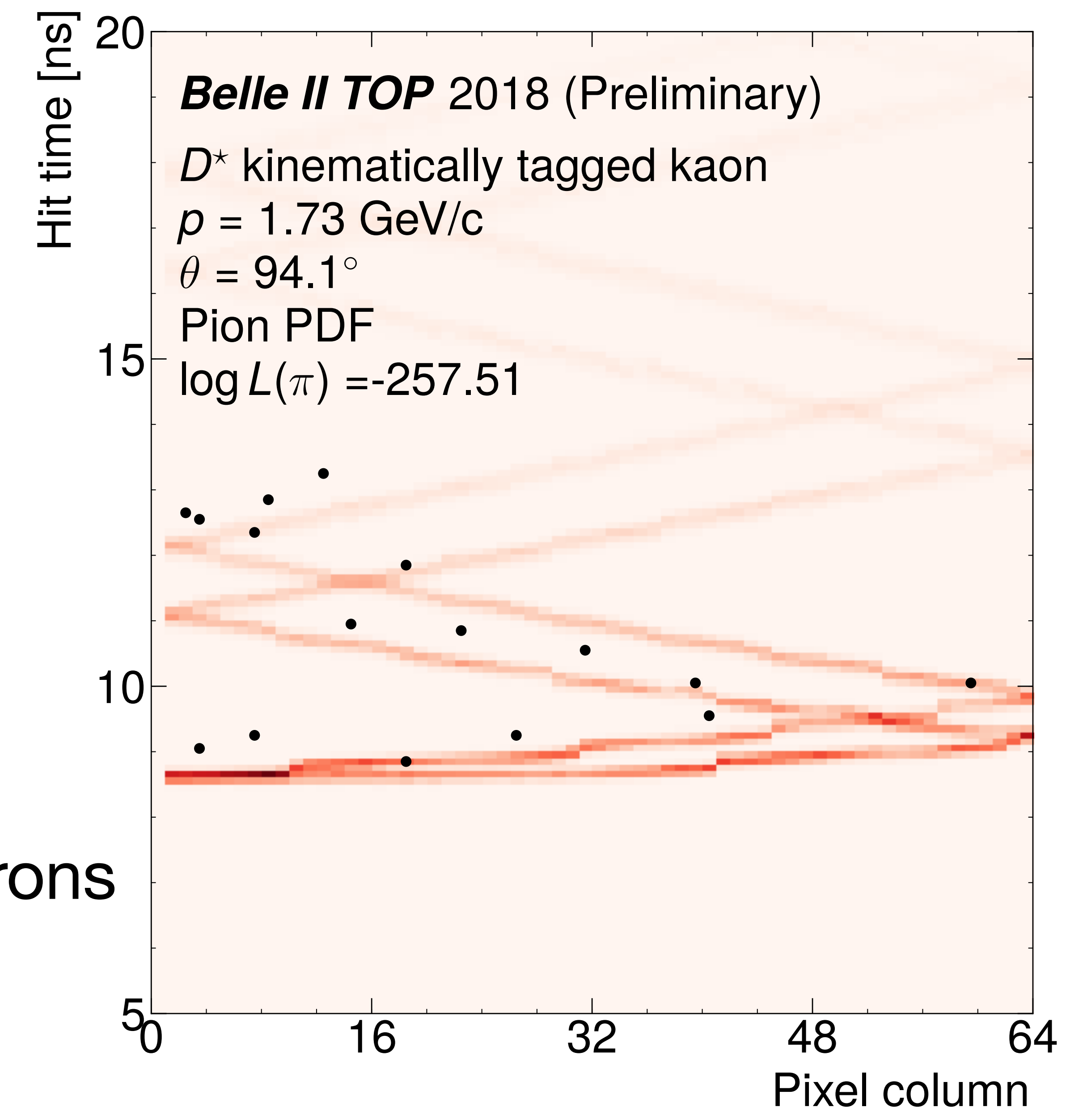
- Central Drift Chamber dE/dx & Time of propagation Cherenkov patterns - 2018 data
- New detector technology (TOP) working well!

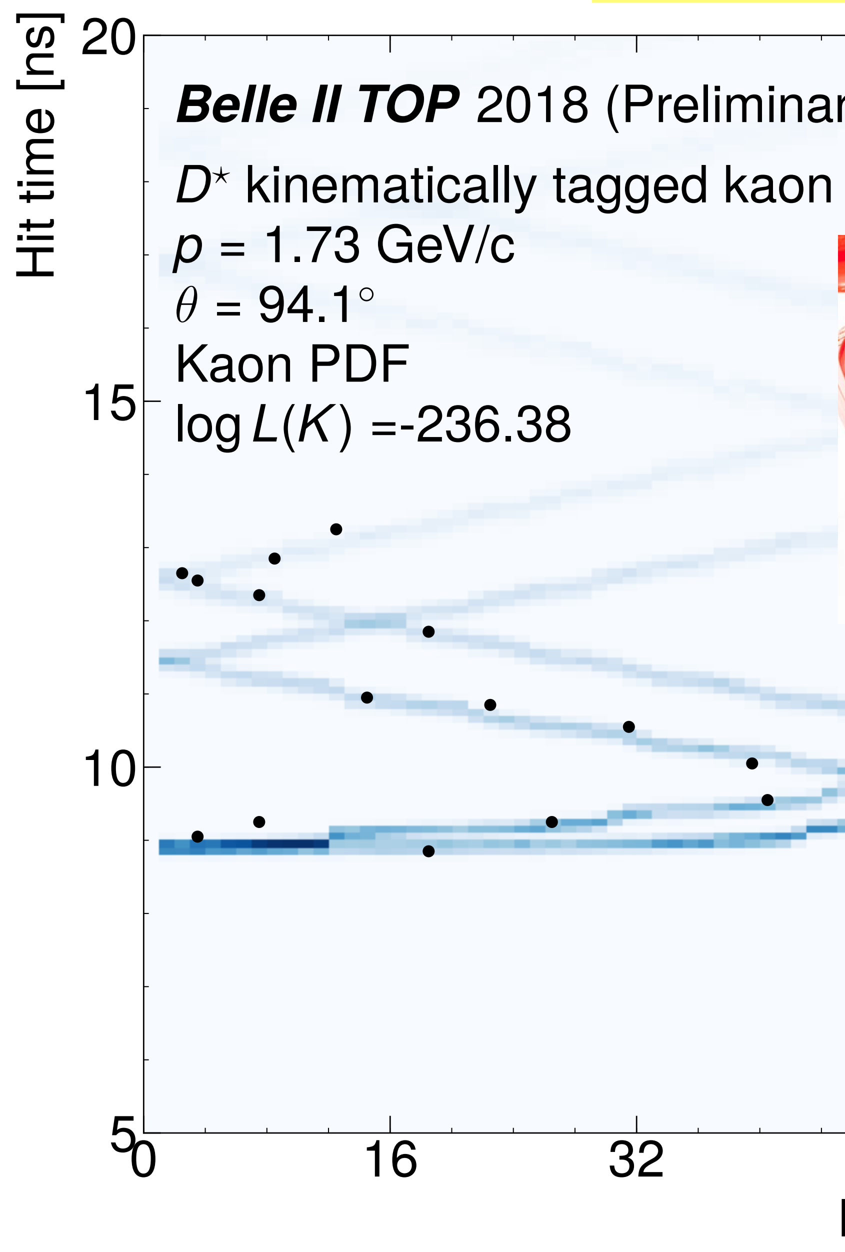
H. Atmacan

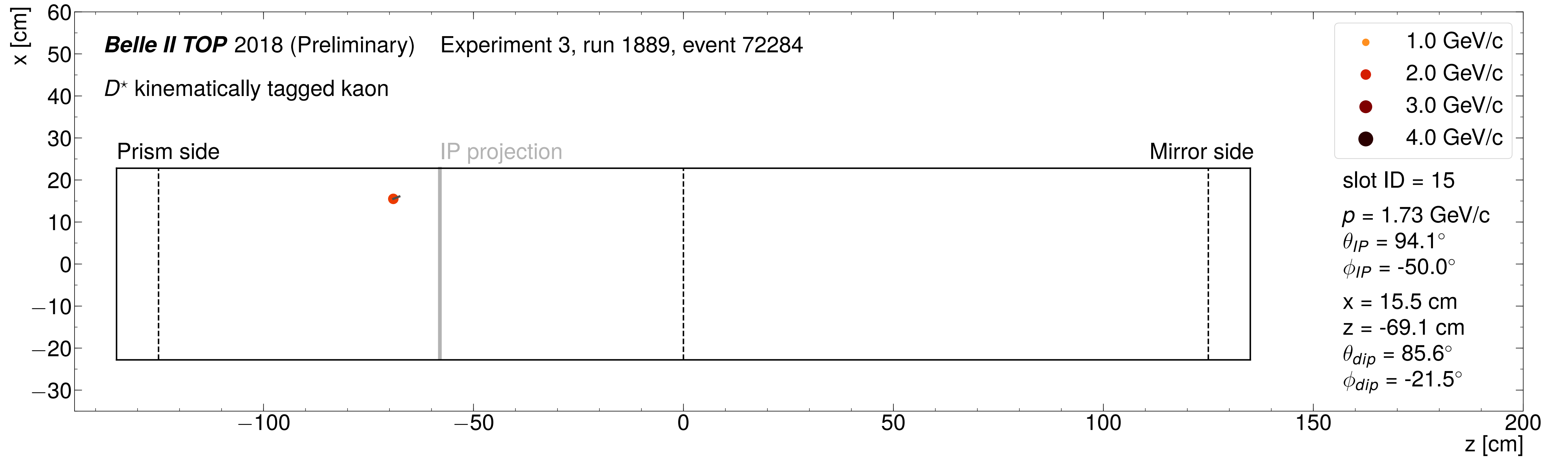


CDC dE/dx



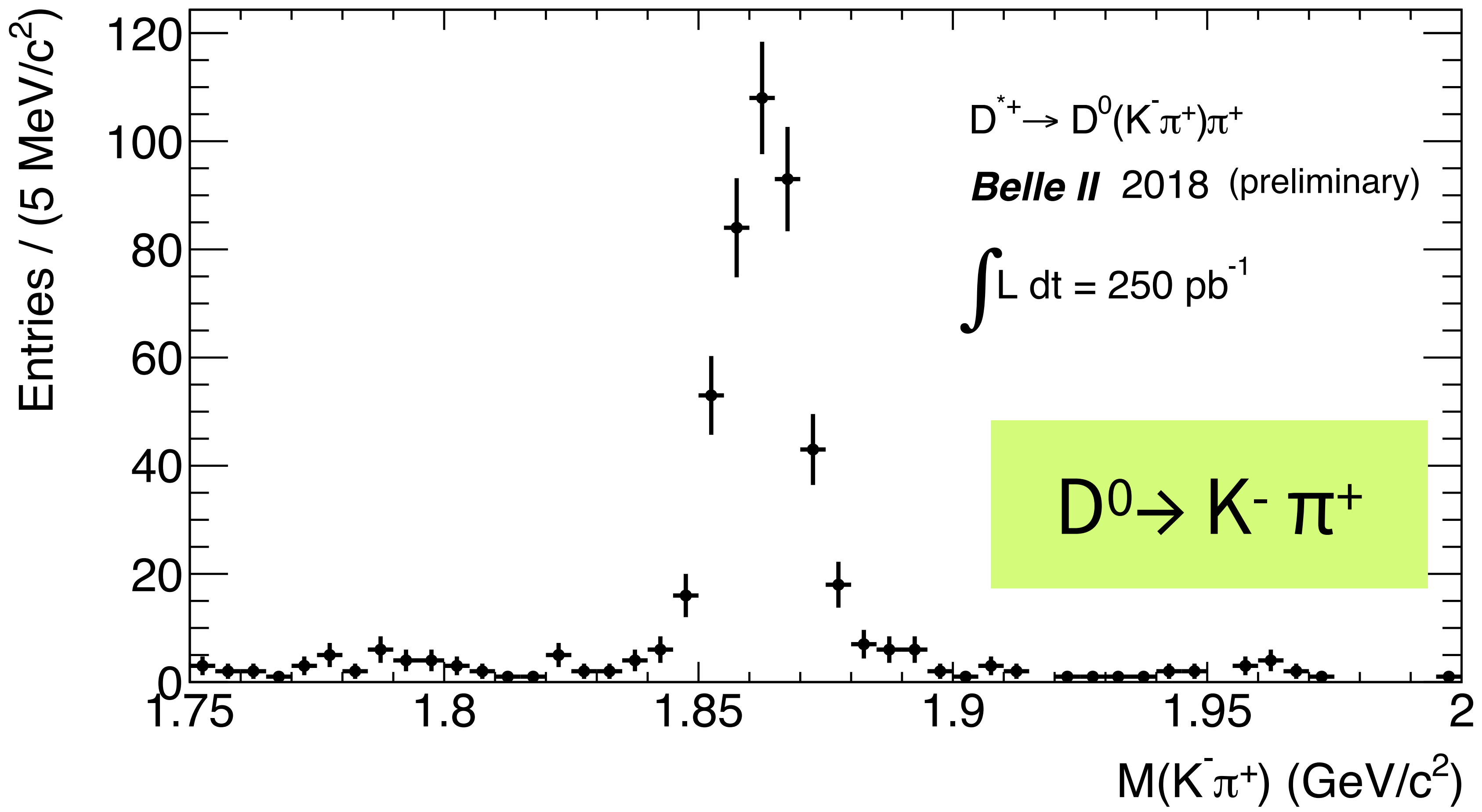


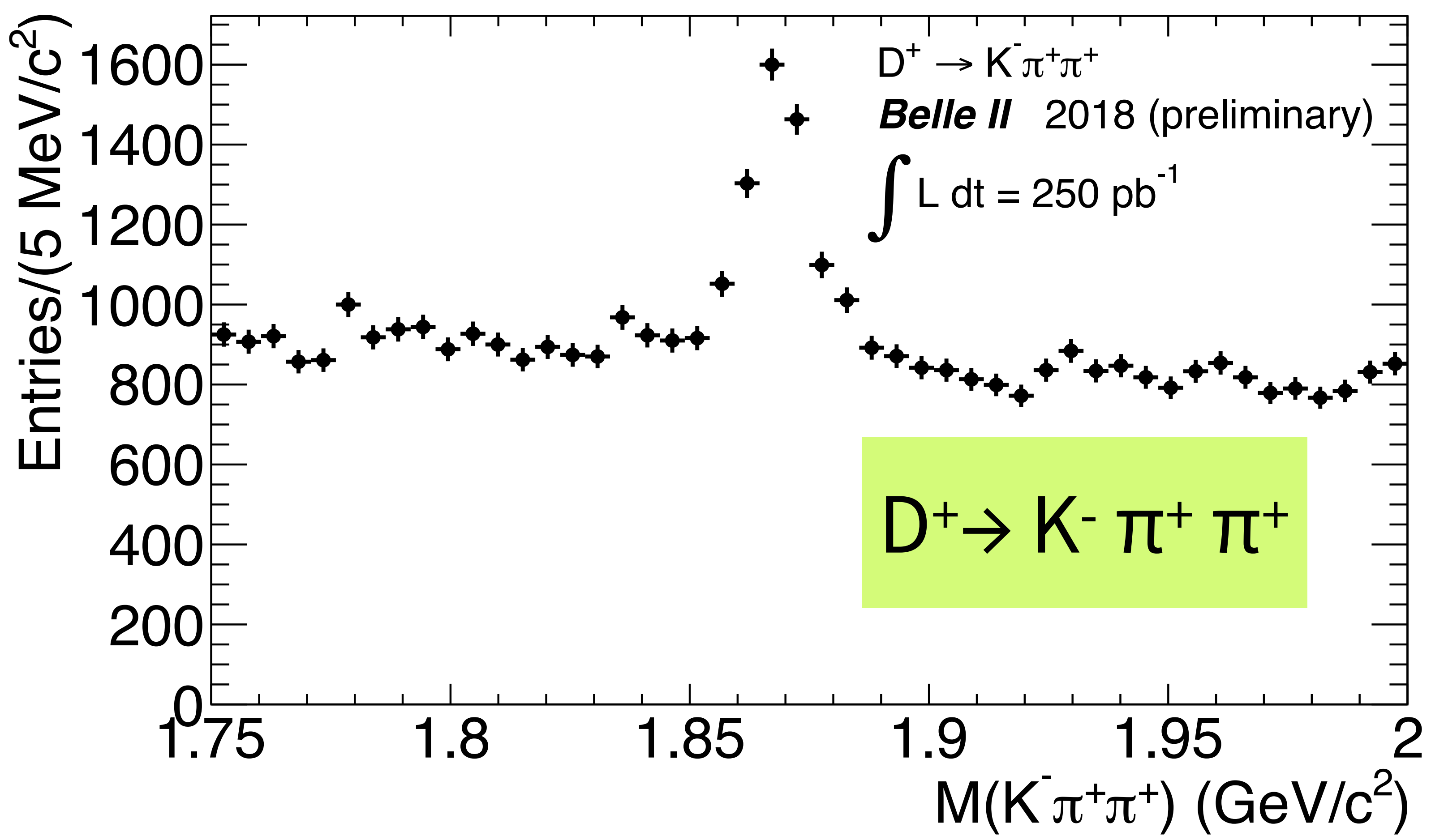


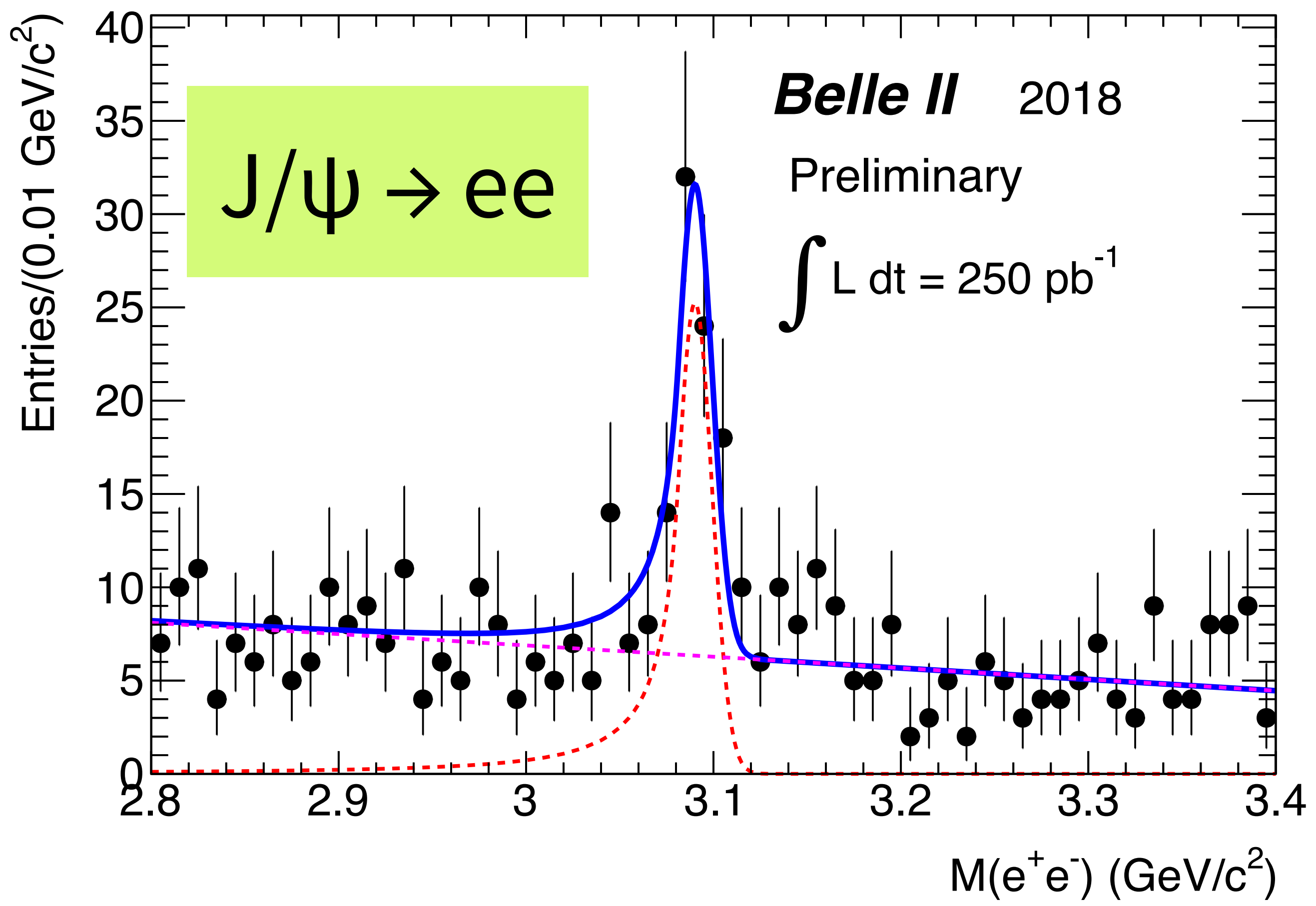


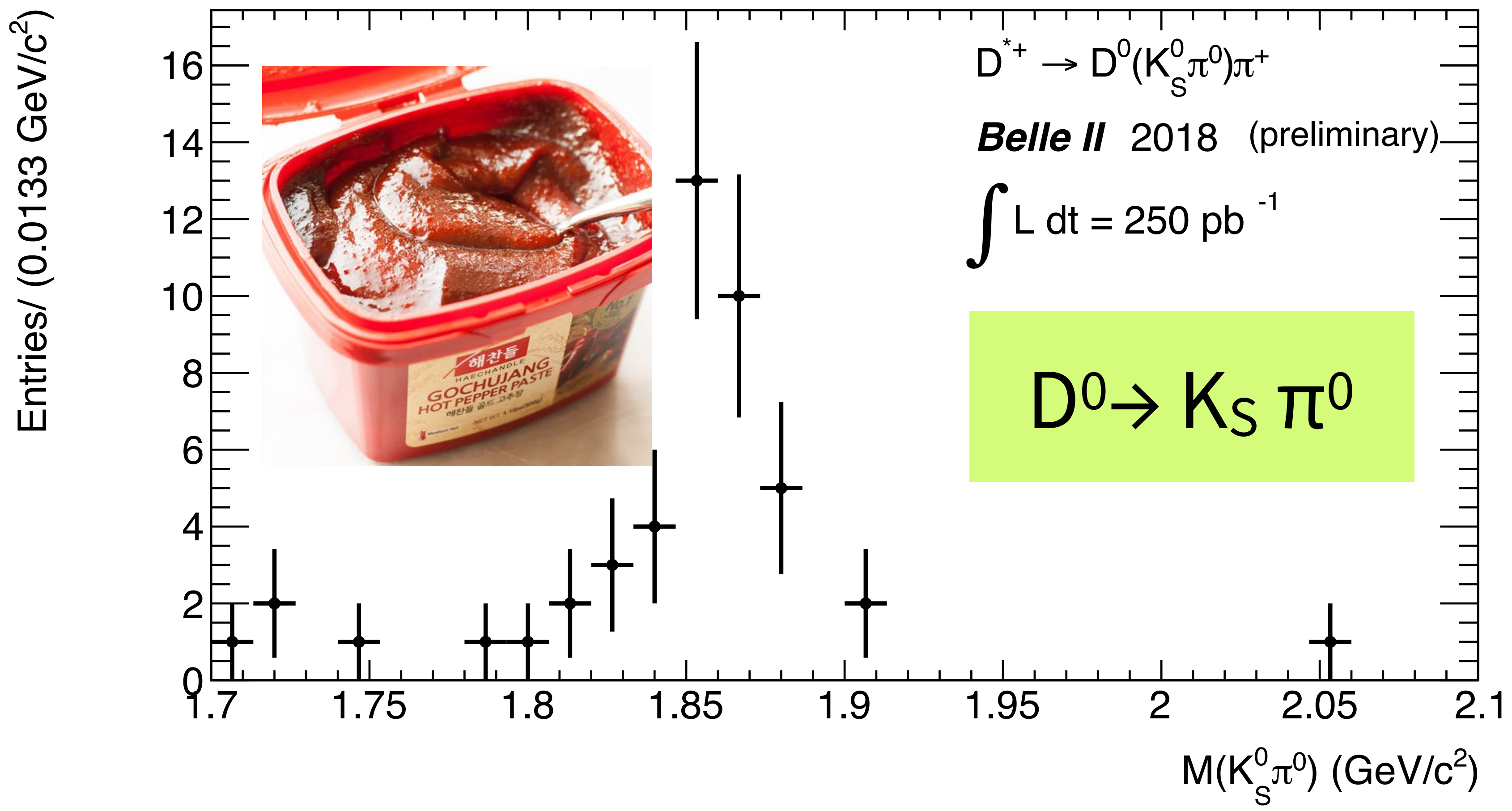
Charm "rediscovery"

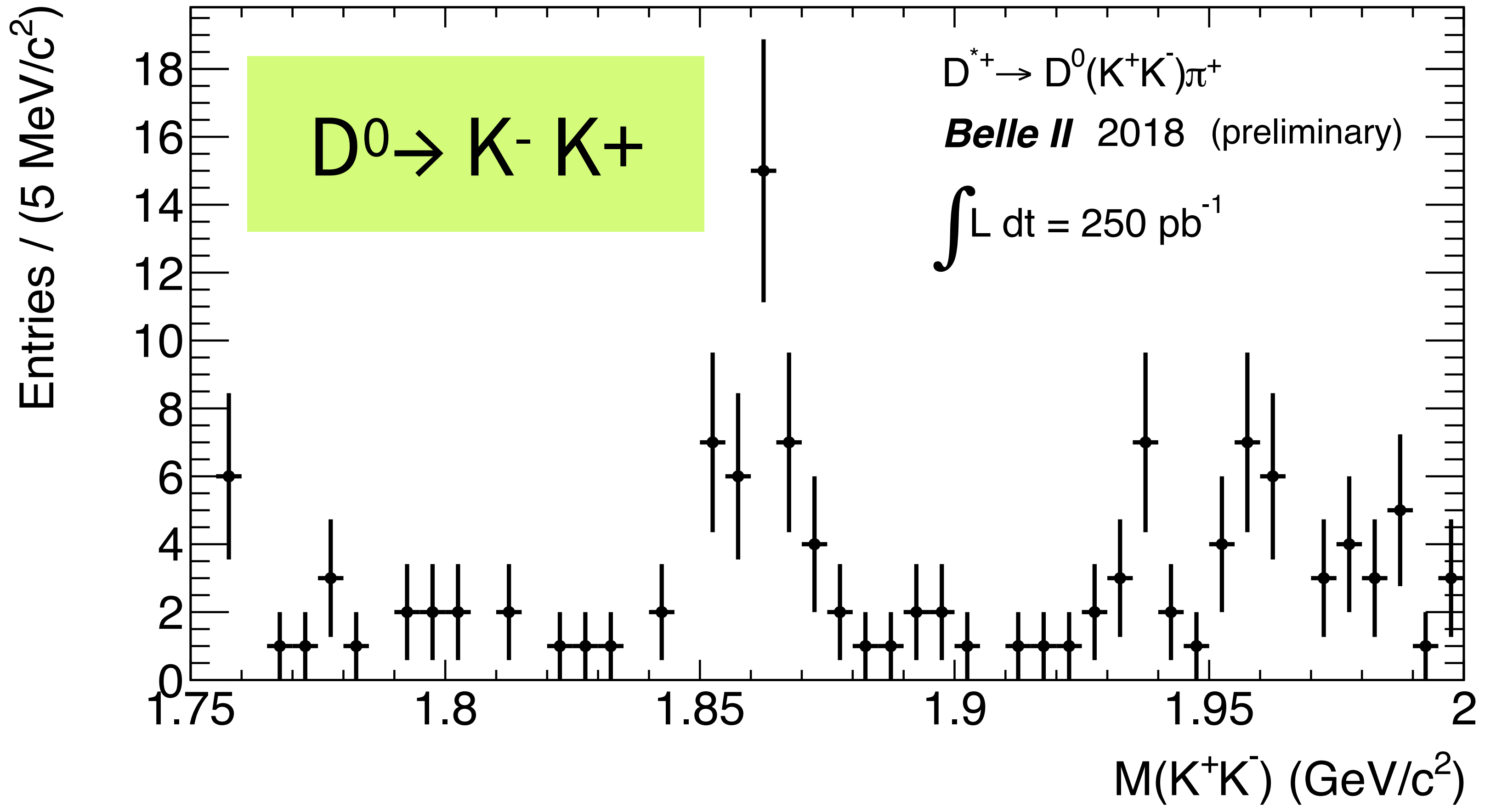
- Open charm, D^0, D^+, D_s^+, D^{*+}, D^{*0} and Charmonium J/ψ. Found the difficult to see $D^0 \to K_S \pi^0$.

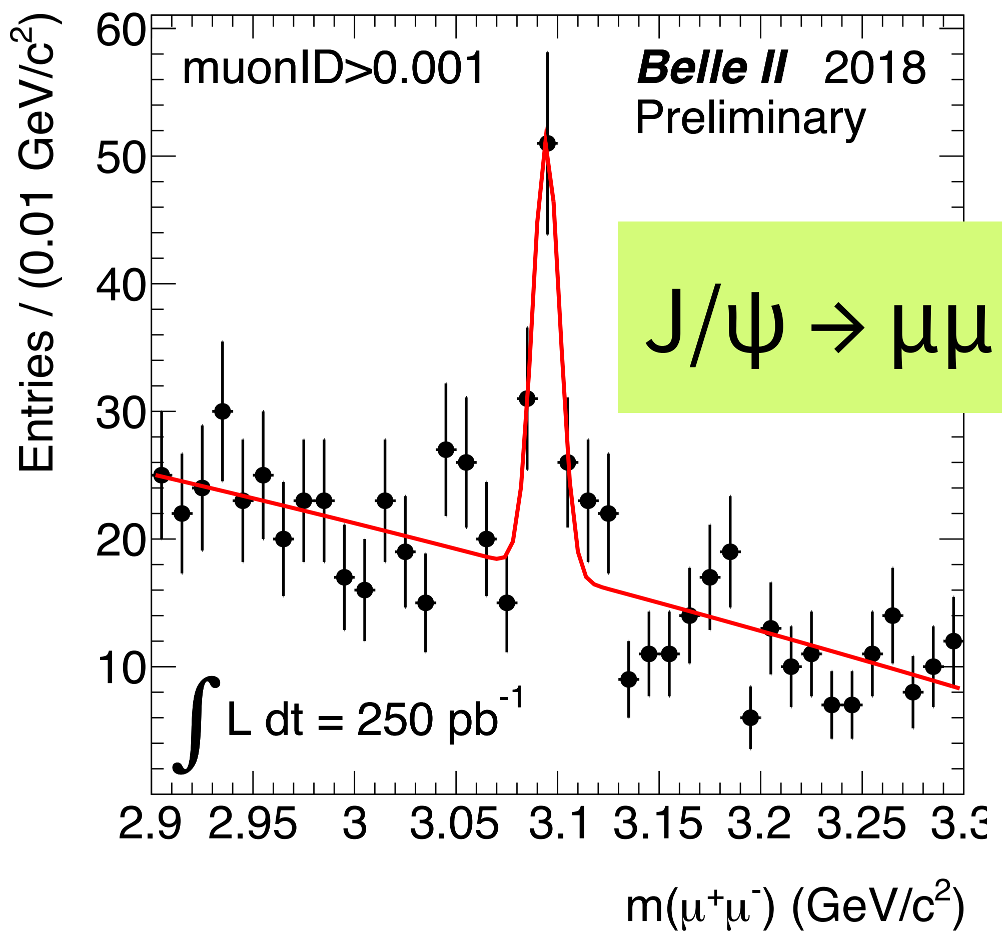






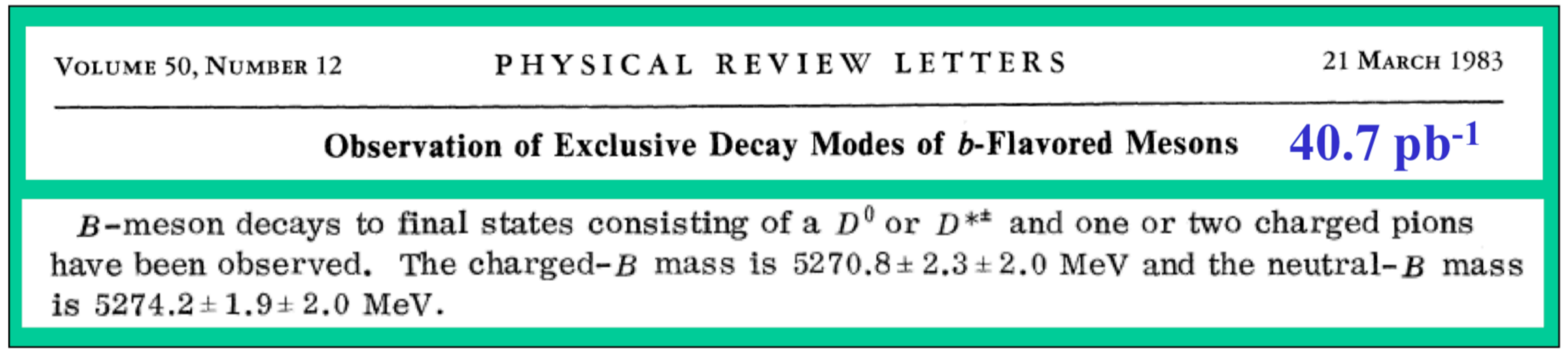






Beauty "Rediscovery"

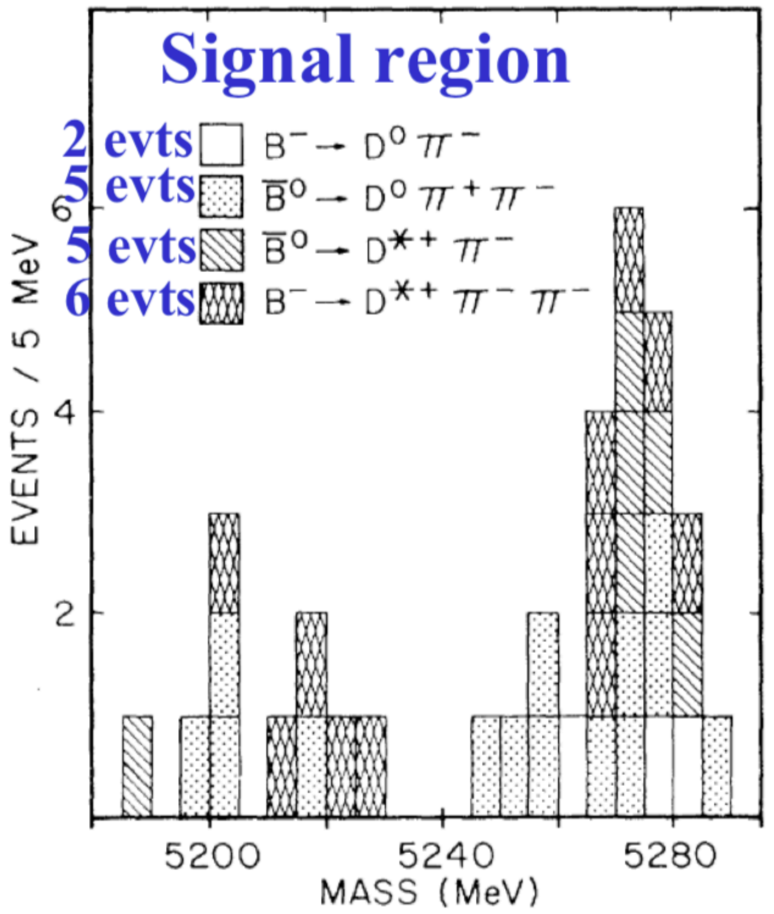
- Recreating CLEO & ARGUS
  - ~100 B candidates in hadronic modes
  - ~14 B → D* e ν found

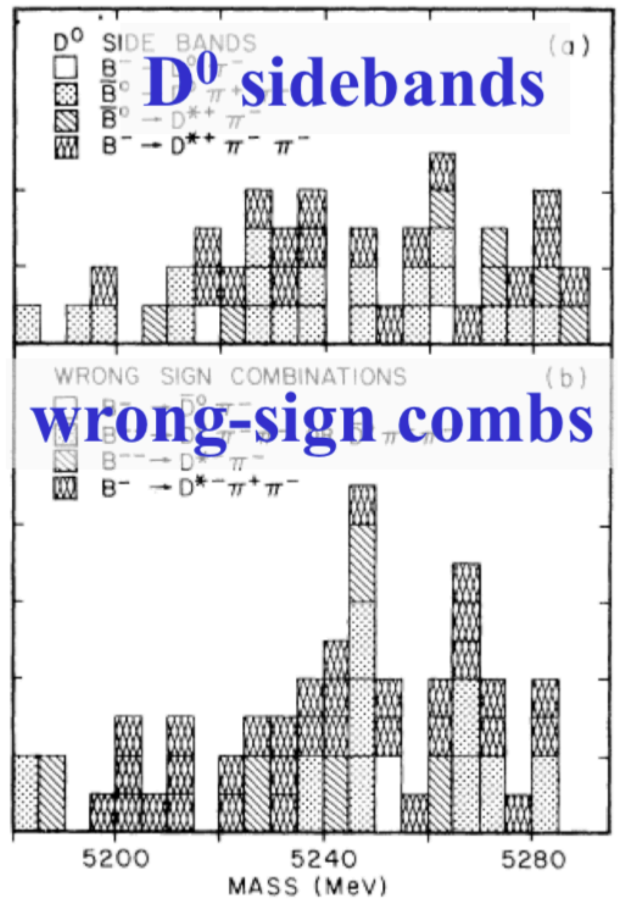


VOLUME 50, NUMBER 12 — PHYSICAL REVIEW LETTERS — 21 MARCH 1983

Observation of Exclusive Decay Modes of b-Flavored Mesons 40.7 pb^{-1}

B-meson decays to final states consisting of a D^0 or $D^{*\pm}$ and one or two charged pions have been observed. The charged-B mass is 5270.8 ± 2.3 ± 2.0 MeV and the neutral-B mass is 5274.2 ± 1.9 ± 2.0 MeV.

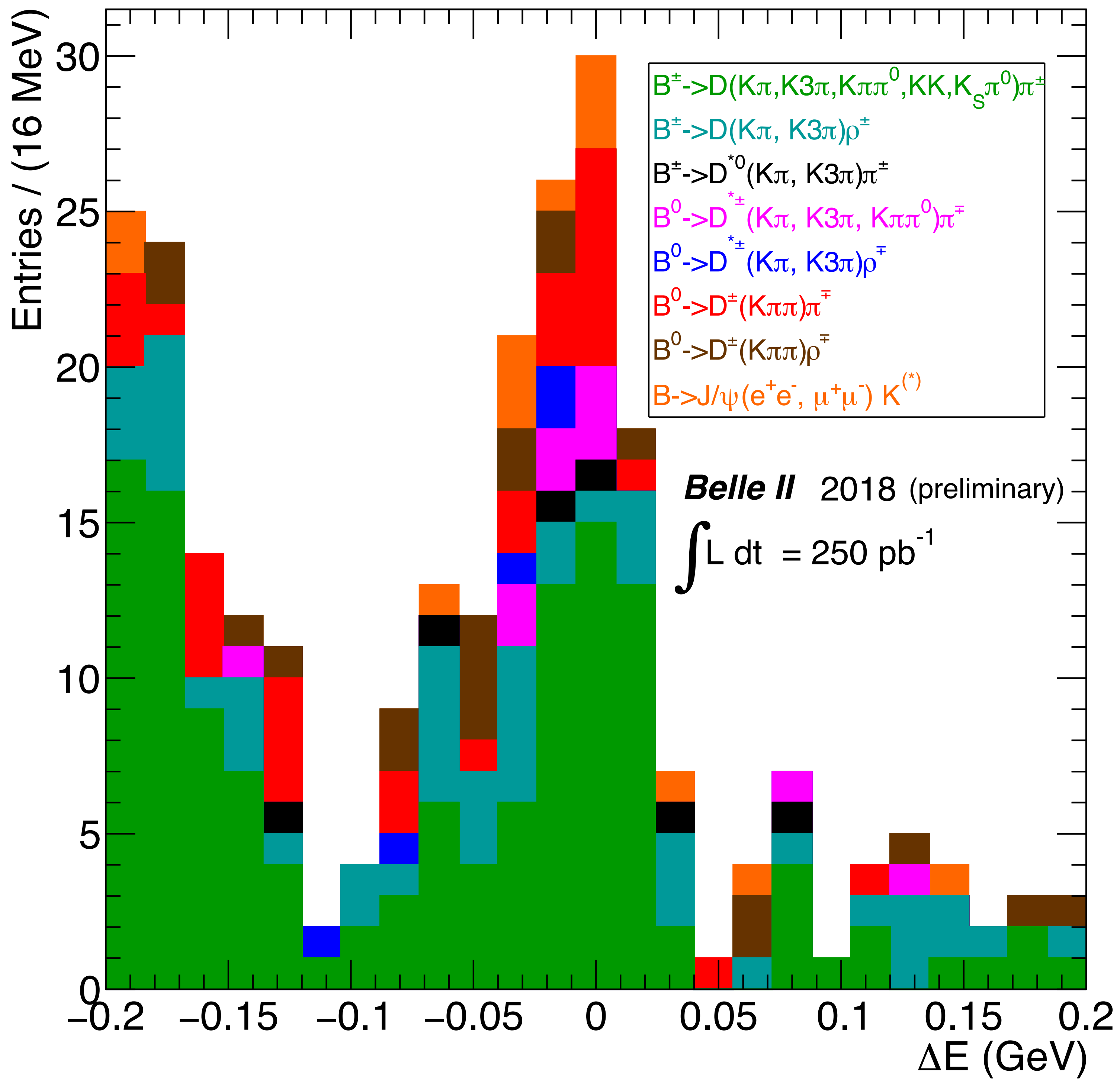


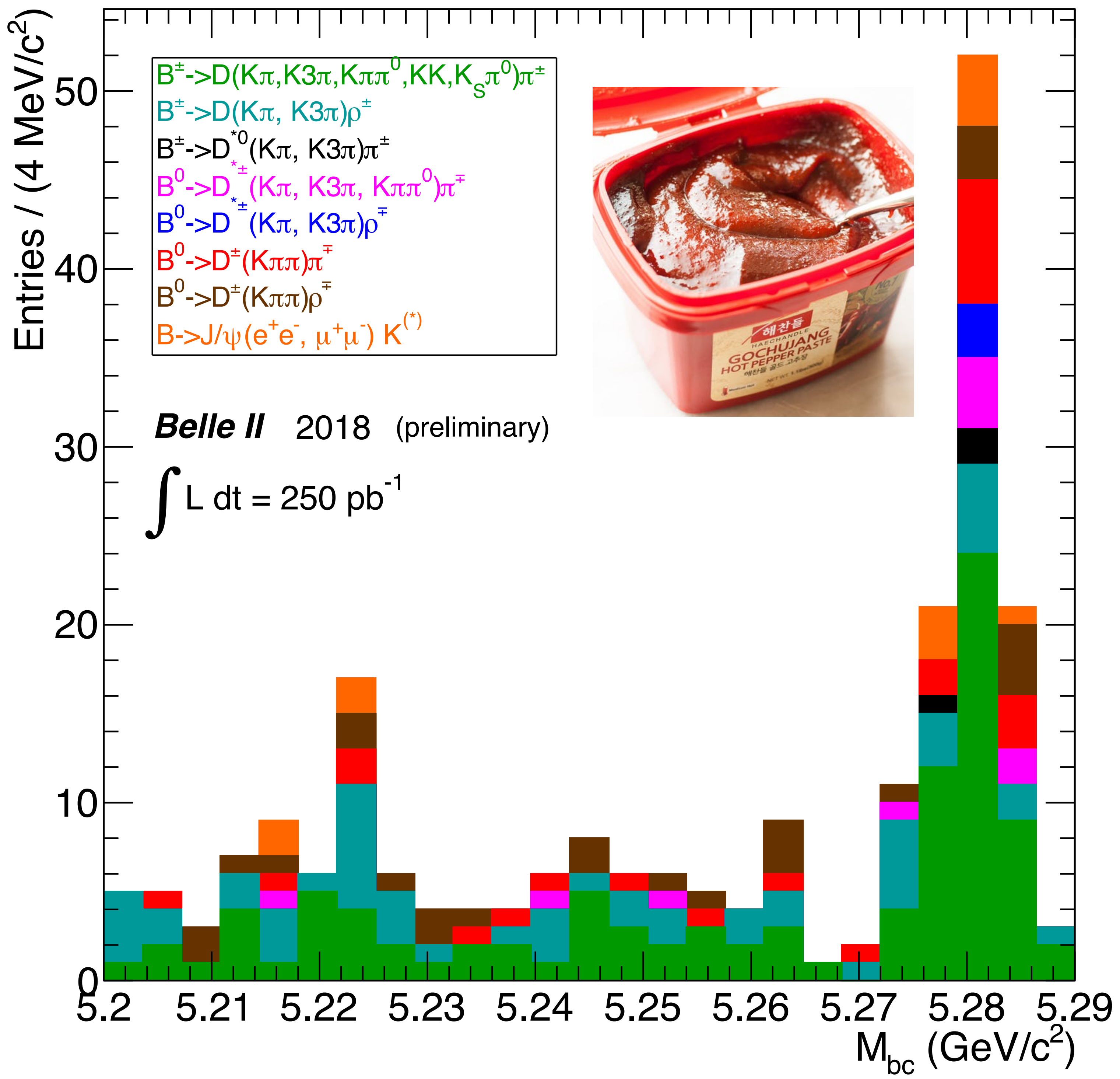


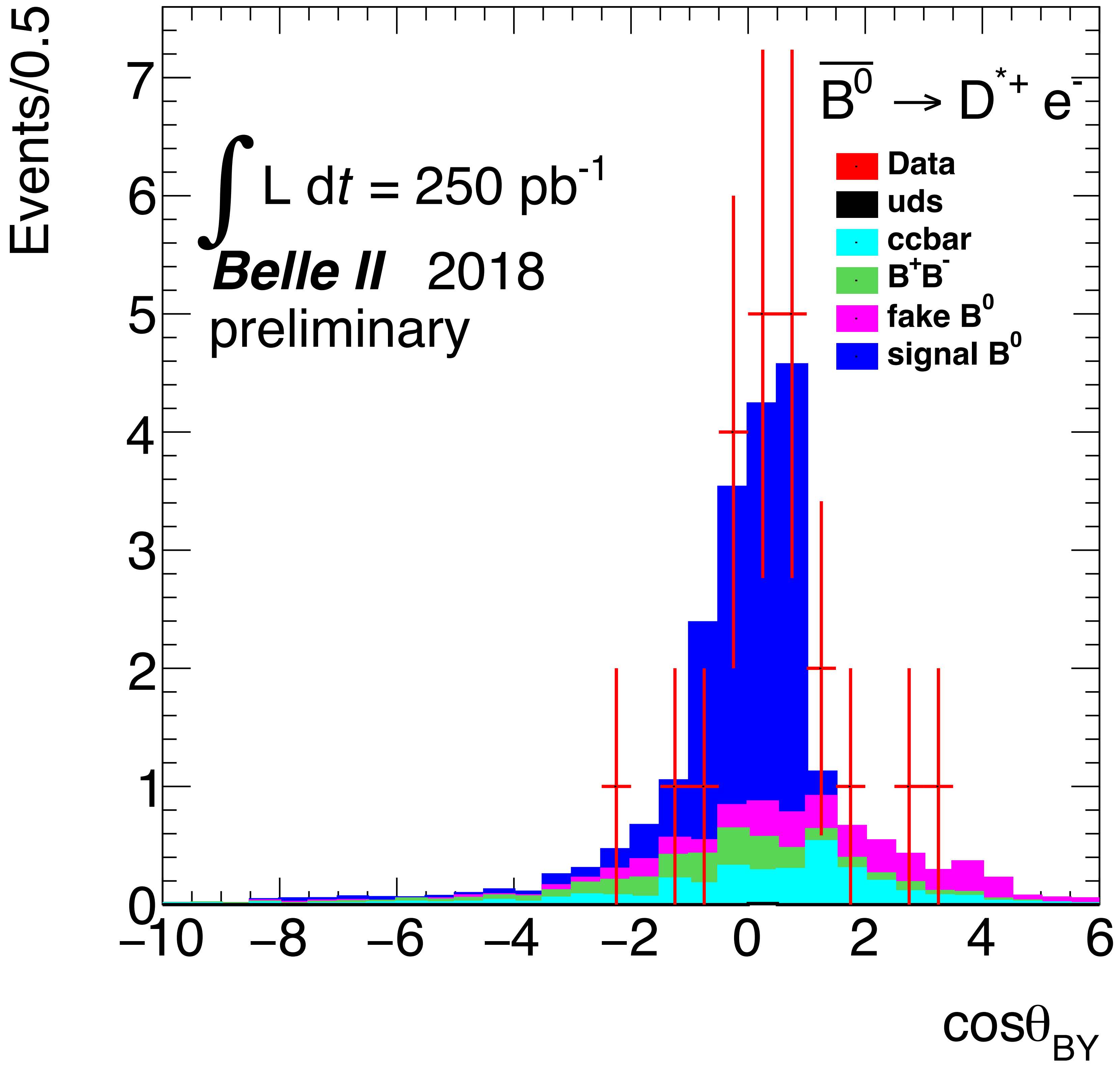
B → D$^{(*)}$ h, J/ψK$^{(*)}$

B→D* e ν

T. Lück





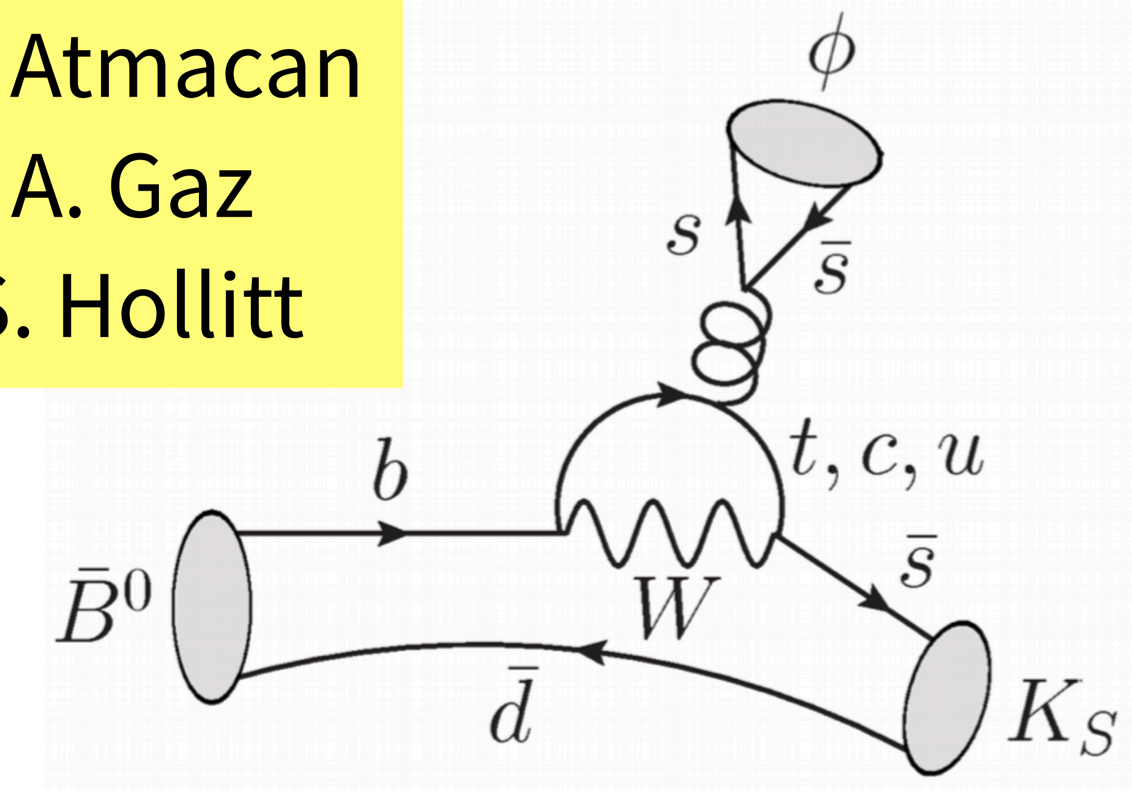


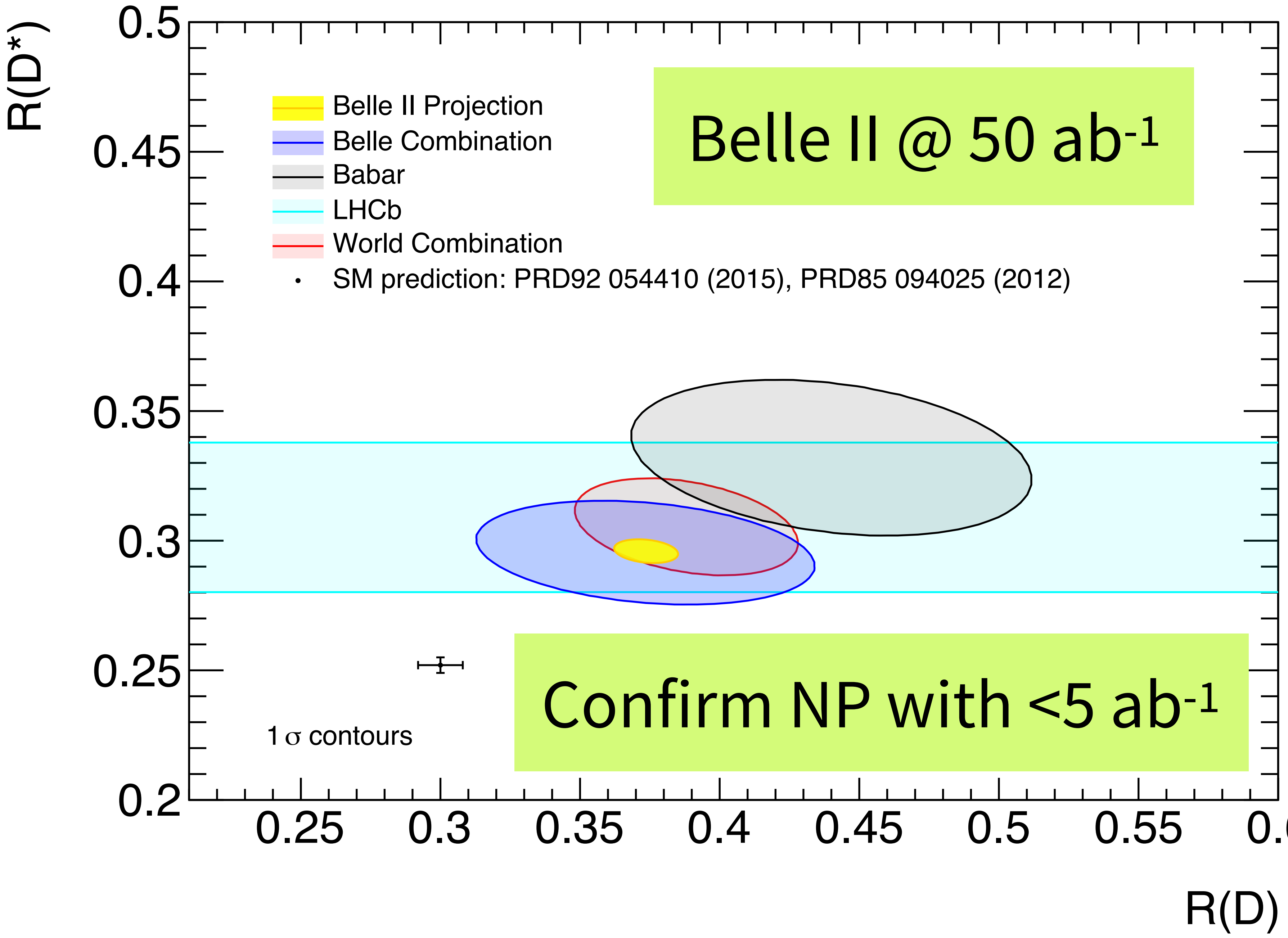
Belle II prospects CKM & CPV

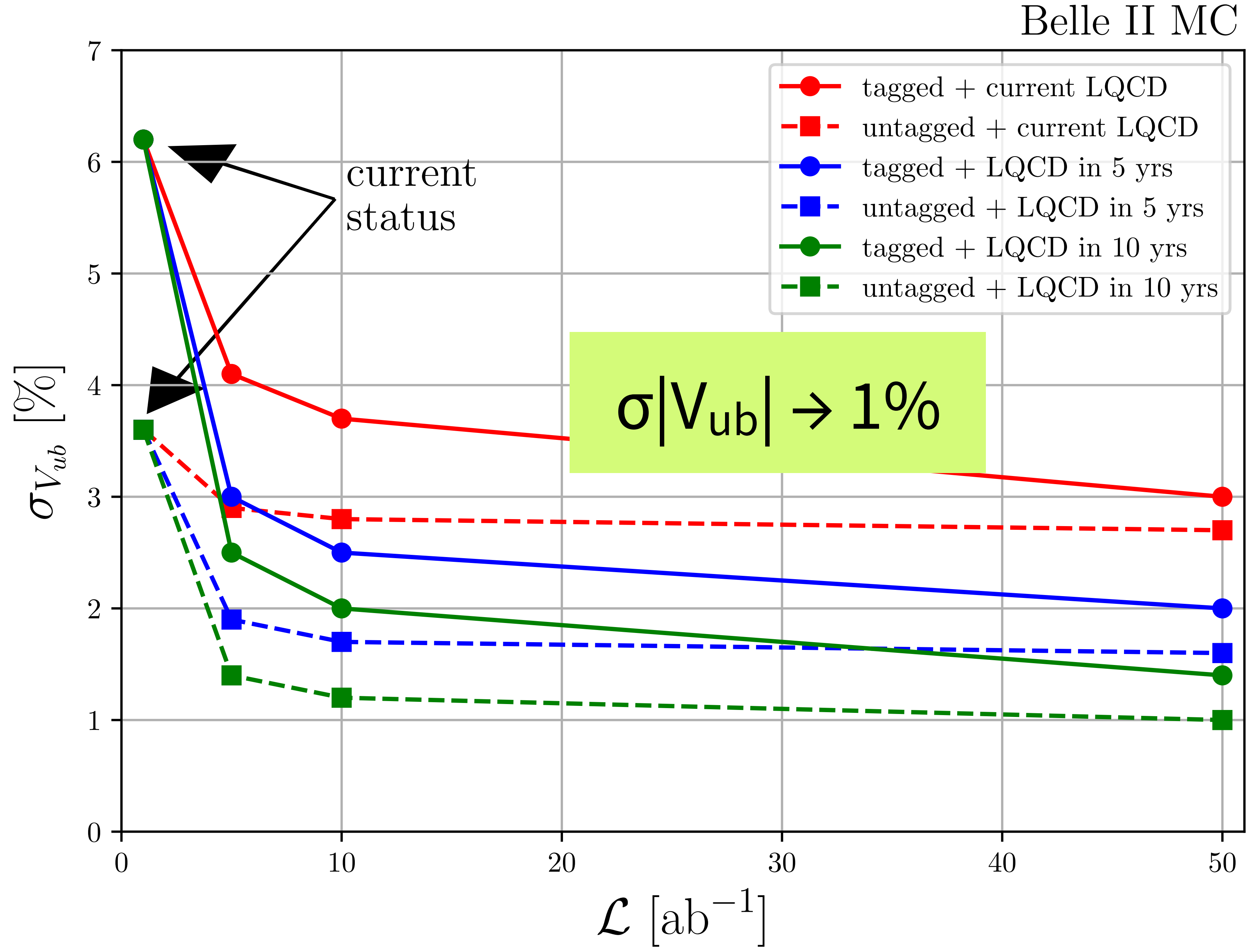
Belle II Physics Book Eds. E. Kou, P.U. + Belle II & B2TiP Theory community (to be submitted to PTEP this week)

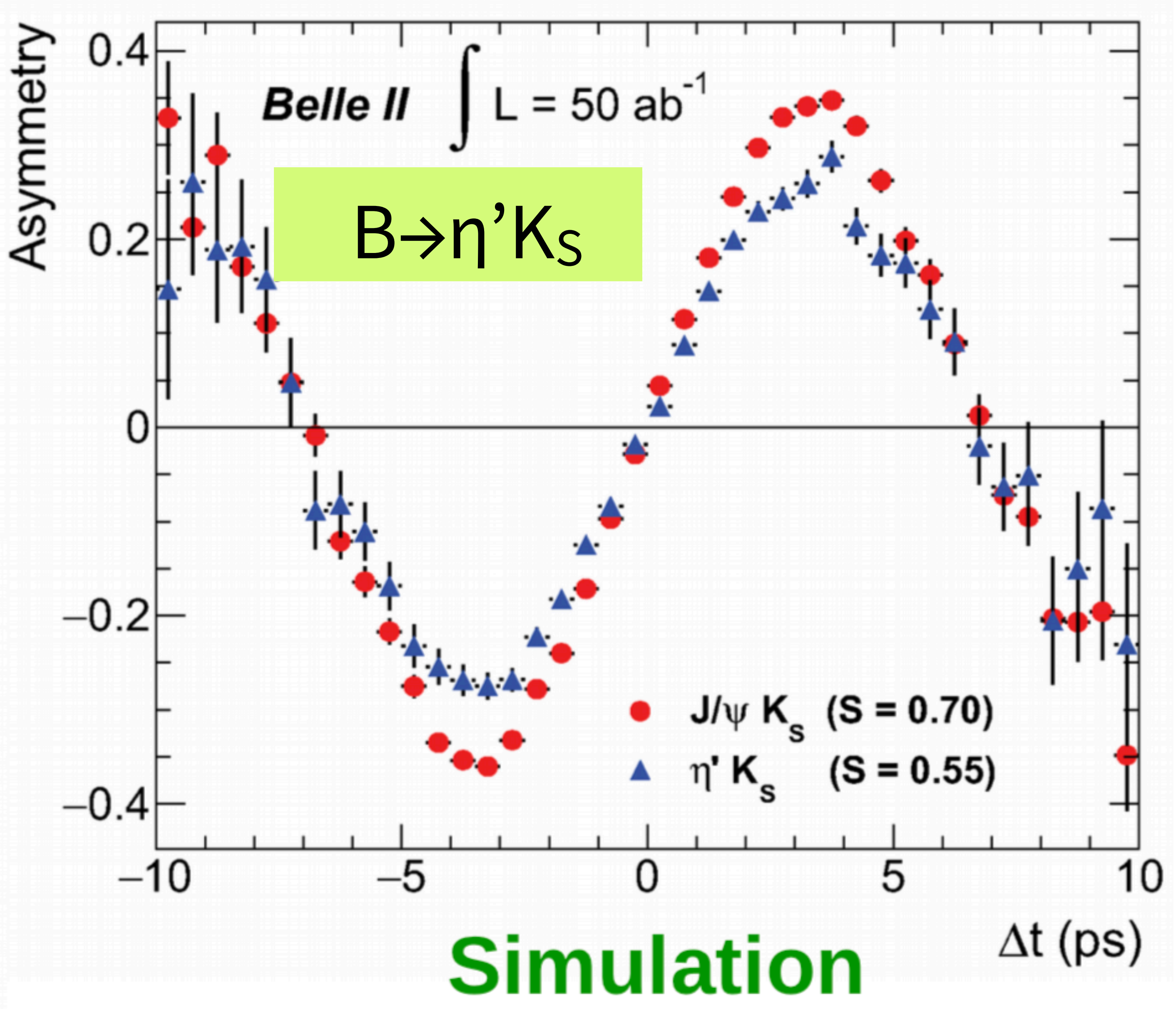
- **$|V_{ub}|$ @ 1% from semileptonic, 2% from leptonic**
  - Excellent detection universality for e and μ - strong on τ.
- **Φ_1 @ 0.7%, Φ_2 <1°, Φ_3~1°**
- **Attack new phases and right handed currents in TDCPV in B_d decays**
- Excellent prospects for amplitude analysis of multi-body decays
  - flat efficiency in Dalitz plane.

H. Atmacan
A. Gaz
S. Hollitt



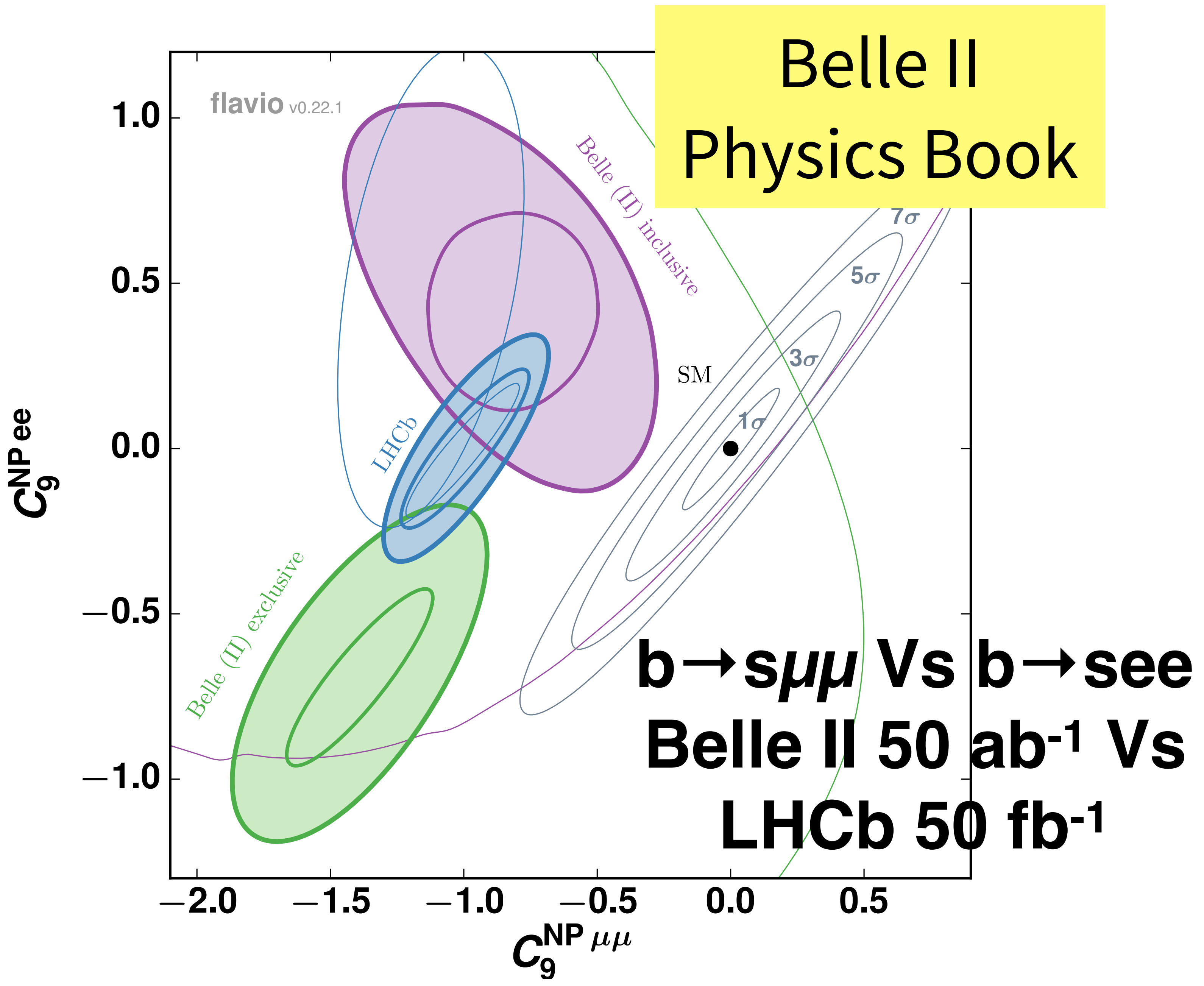


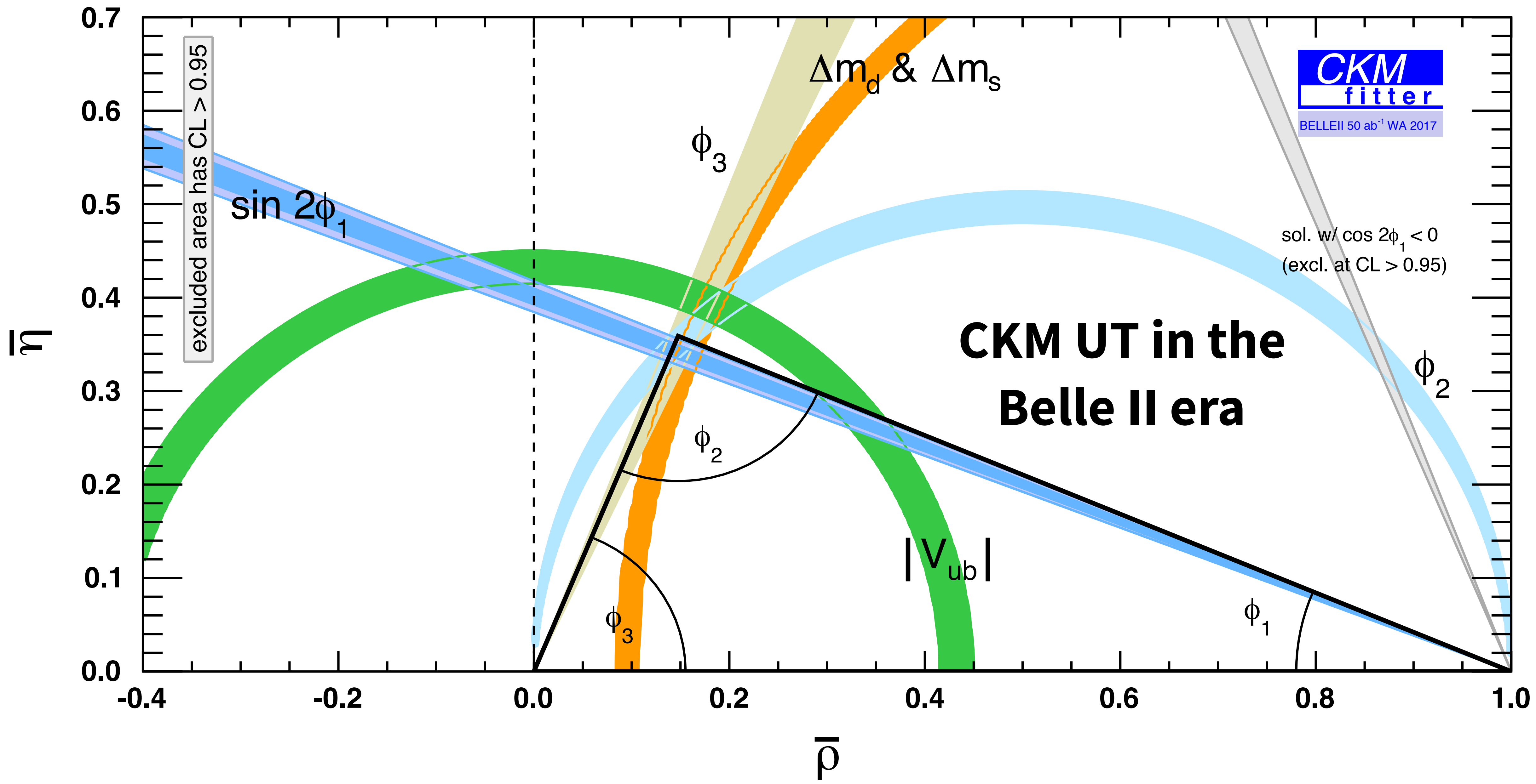




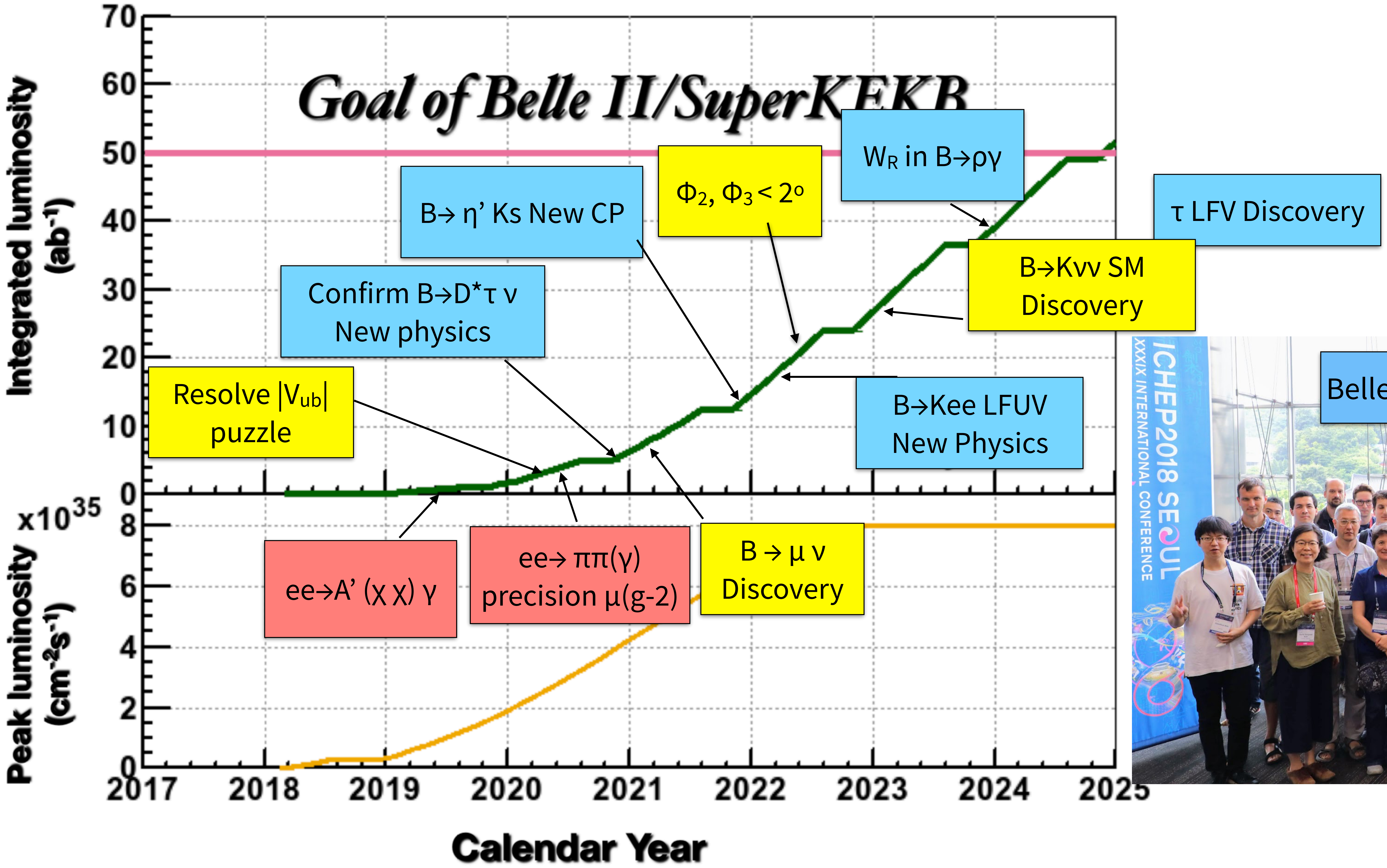
Conclusion

- Many new, constraining CKM and CPV measurements.
  - Our most powerful tests will continue to be statistics limited, clean theoretically and systematically.
  - LFUV in leptonic and semileptonic theoretically clean but NOT always experimentally clean. Material mapping, hermetic coverage, and lepton universality in DETECTION is critical.
- Belle II is having a very successful commissioning run, and has big ambitions for ICHEP 2020.





Belle II Wishlist / Roadmap



Sookyung Choi
discoverer of X, Y, Z mesons on Belle,
recipient of 2017 Ho-Am Science Prize

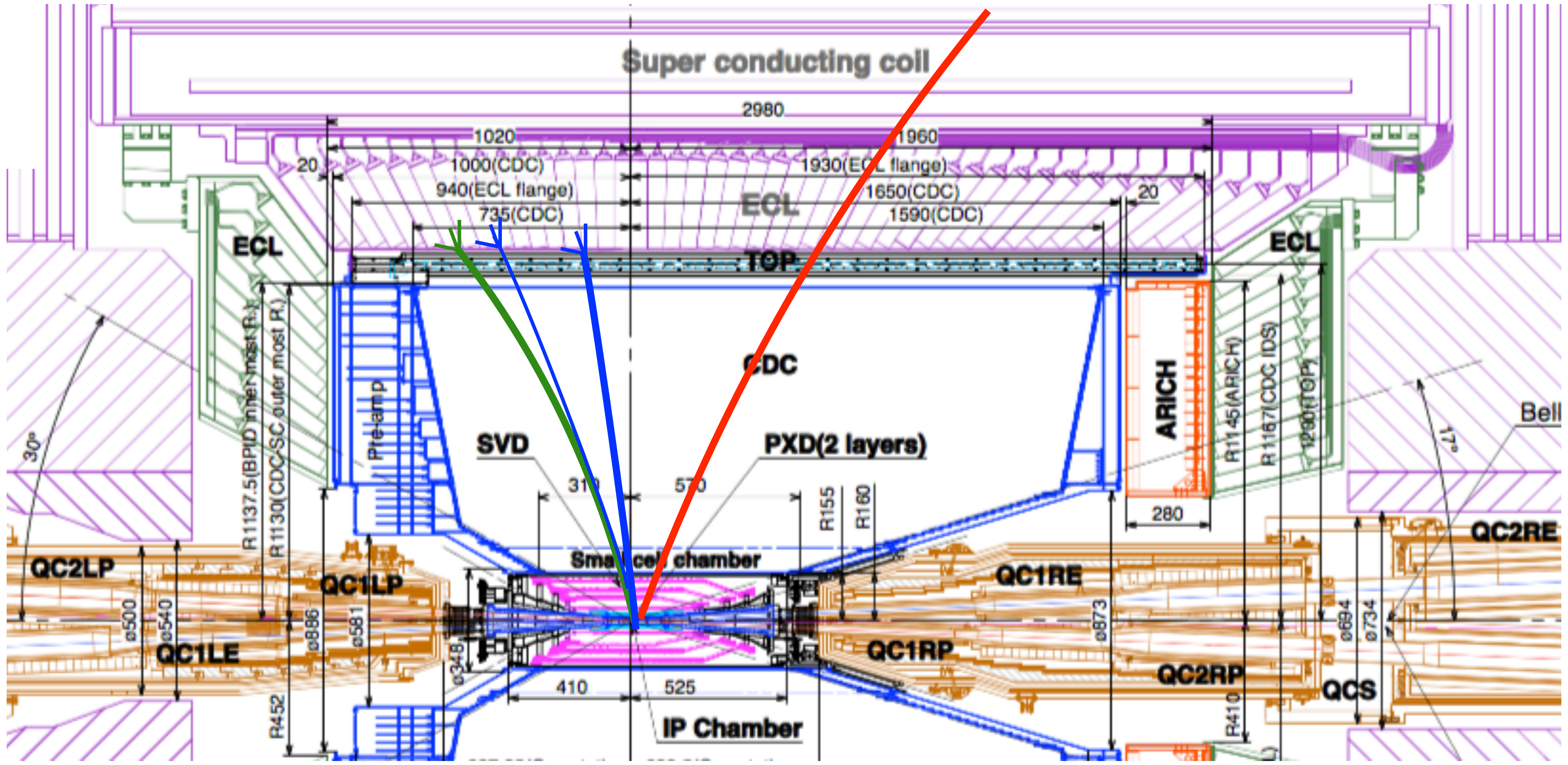

ICHEP2018 SEOUL
ICHEP2018 SEOUL
XXXIX INTERNATIONAL CONFERENCE
ON high Energy PHYSICS
JULY 4 - 11, 2018
COEX, SEOUL
International Advisory Committee
Abramowicz, Halina (Israel)
Antinori, Federico (Italy)
Barberio, Elisabetta (Australia)
Bediaga, Ignácio (Brazil)
Bentvelsen, Stan (Netherlands)
Blucher, Edward (USA)
Browder, Thomas (USA)
Butler, Joel (USA)
Campana, Pierluigi (Italy)
Chao, Kuang-Ta (China)
Chomaz, Philippe (France)
Dighe, Amol (India)
Doležal, Zdeněk (Czech Republic)
Fuster, Juan (Spain)
Gianotti, Fabiola (Switzerland)
Giudice, Gian (Switzerland)
Heinemann, Beate (Germany)
Henderson, Stuart (USA)
Hewett, JoAnne (USA)
Jakobs, Karl (Germany)
Kajita, Takaaki (Japan)
Kim, Soo-Bong (Korea)
Kim, Young-Kee (USA)
Kirch, Klaus (Switzerland)
Konstantinidis, Nikos (U.K.)
Matveev, Victor (Russia)
Mnich, Joachim (Germany)
Murayama, Hitoshi (Japan)
Muronga, Azwinndini (South Africa)
Passaleva, Giovanni (Italy)
Quevedo, Fernando (Italy)
Roe, Natalie (USA)
Schellman, Heidi (USA)
Seo, Eunsook (USA)
Son, Dongchul (Korea)
Tyurin, Nikolai (Russia)
Van, Tran Thanh (Vietnam)
Volkas, Raymond (Australia)
Wang, Yifang (China)
Wark, David (U.K.)
Yamauchi, Masanori (Japan)
Local Organizing Committee
Chang Rim Ahn (Ewha WU), ByungGu Cheon (Hanyang U), Kihyeon Cho (KISTI), Kiwoon Choi (C Theo Phys Universe, IBS), Seong Youl Choi (Chonbuk NU), Seonho Choi (SNU), Soo Kyung Choi (Gyeongsang NU),
Suyong Choi (Korea U), Young-Il Choi (SKKU), Byungsik Hong (Korea U), Deog Ki Hong (Pusan NU), Jai-chan Hwang (Kyungpook NU), Sin Kyu Kang (Seoul Tech), Choong Sun Kim (Yonsei U),
Donghee Kim (Kyungpook NU), Doris Yangsoo Kim (Soongsil U), Do-Won Kim (Gangneung-Wonju NU), Jihn E Kim (Kyung Hee U, Chair), Nakwoo Kim (APCTP), Sang Pyo Kim (Kunsan NU), Seyong Kim (Sejong U),
Siyeon Kim (Chung-Ang U), Sun Kee Kim (SNU), Yeongduk Kim (C Underground Phys, IBS, Co-chair), Pyungwon Ko (KIAS), Youngjoon Kwon (Yonsei U), Bum-Hoon Lee (Sogang U), Hyun Min Lee (Chung-Ang U),
Hyun Su Lee (C Underground Phys, IBS), Jungil Lee (Korea U), Kang Seog Lee (Chonnam NU), Su Houng Lee (Yonsei U), Jae Sik Lee (Chonnam NU), Soonkeon Nam (Kyung Hee U), Sun Kun Oh (Konkuk U),
Stephen Olsen (C Underground Phys, IBS), Il Hung Park (SKKU), Inkyu Park (U of Seoul), Carsten Rott (SKKU), Stefano Scopel (Sogang U), Yannis Semertzidis (C Axion Precision Phys, IBS and KAIST),
Sang-Jin Sin (Hanyang U), Jeonghyeon Song (Konkuk U), Eunil Won (Korea U), Jong-Kwan Woo (Jeju NU), Un-ki Yang (SNU, Co-chair), Piljin Yi (KIAS), Hwidong Yoo (SNU), In-Kwon Yoo (Pusan NU),
Jonghee Yoo (C Axion Precision Phys, IBS and KAIST), Jin-Hee Yoon (Inha U), Intae Yu (SKKU)
Organized by IUPAP / C11
Hosted by IBS and KPS
ICHEP2018 Secretariat ichep2018@insession.co.kr
Website www.ichep2018.org

Backup

Belle II Collaboration Map 2018

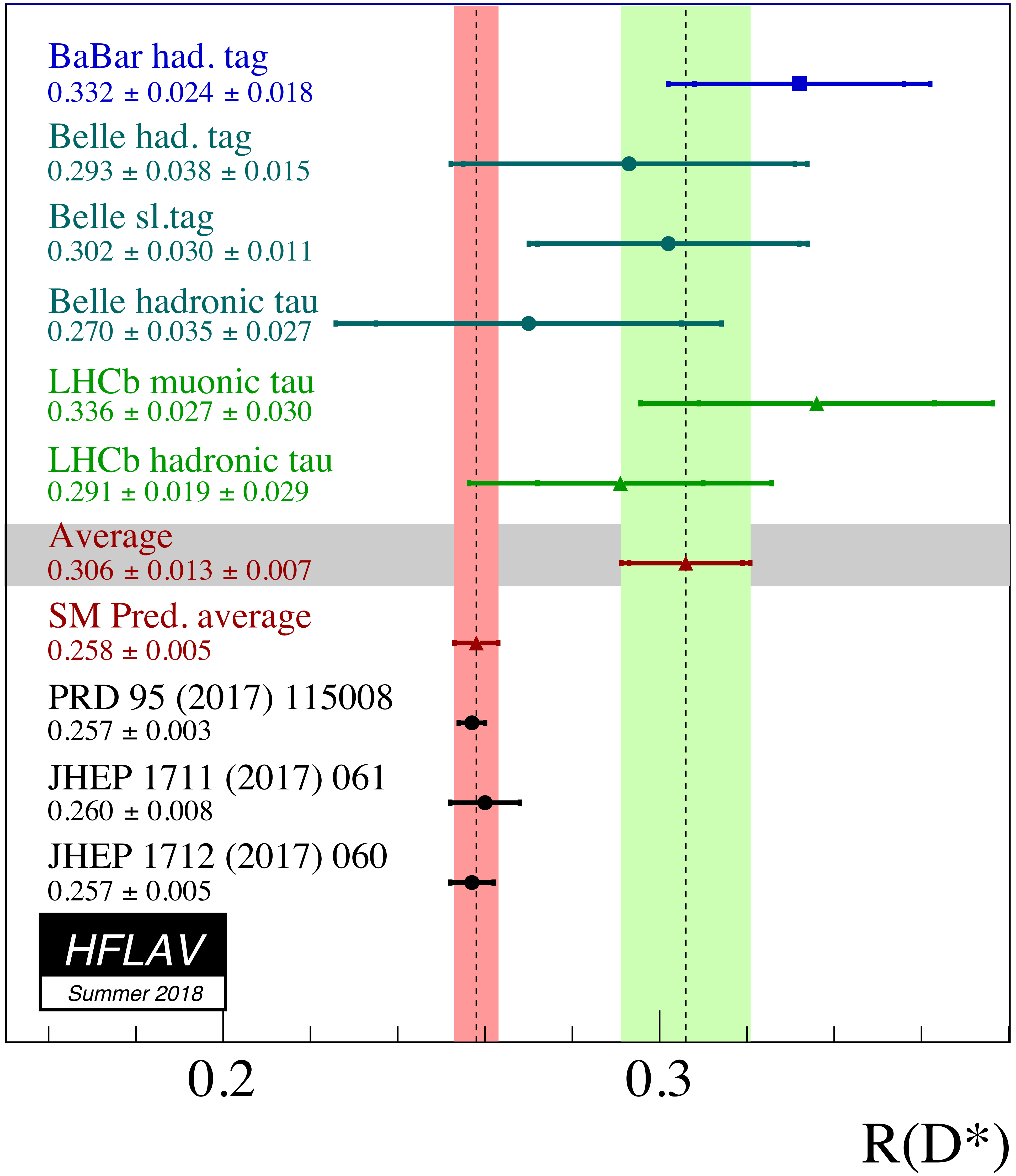
Lepton reconstruction and identification

- Lepton reconstruction (**efficiency** and **resolution**) is crucial for $\mathbf{V_{CKM}}$ measurements.
- Decays with electrons, muons and taus should all be identical, correcting for phase space
- Discovery of **lepton flavour non-universality** is a key signature of New physics e.g. Leptoquarks, W', Z', H±
  - **Identification / reconstruction of leptons is not universal**

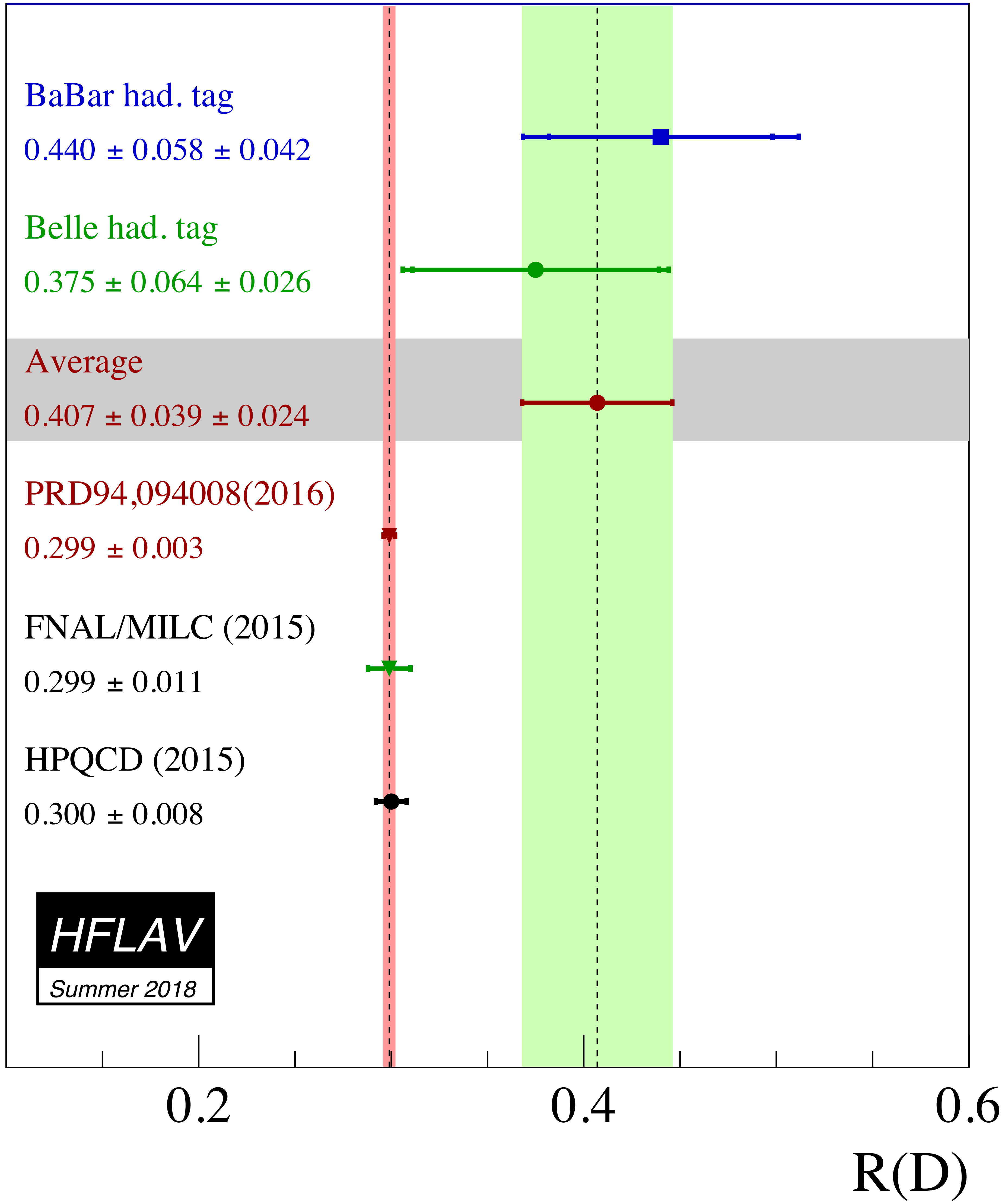


- Muons: Little to **no radiation** (heavy), **Stable** within particle detectors, no strong interactions
- Electrons are light: Final state radiation, Bremsstrahlung in material is likely,
- Taus have a lifetime of 10^{-12} s: background mimics the the signal where some daughters are lost e.g. K_L, π^0

R(D) and R(D*)



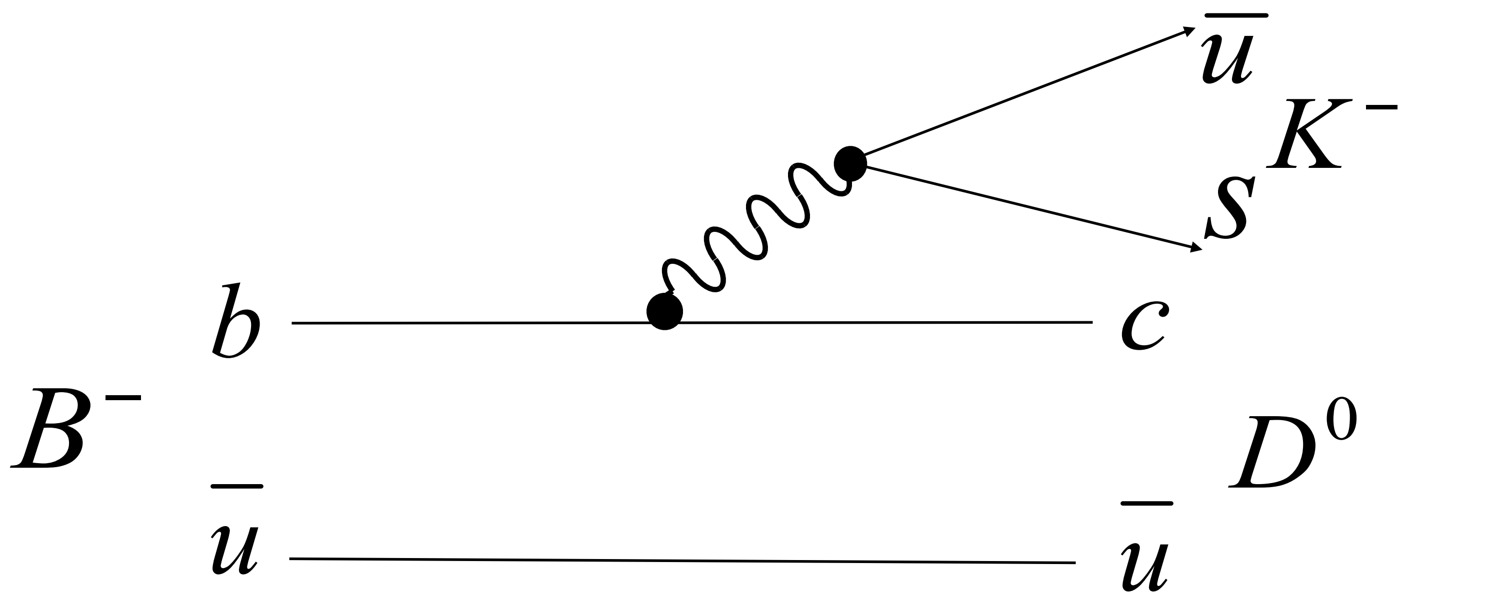
BaBar had. tag
0.332 ± 0.024 ± 0.018
Belle had. tag
0.293 ± 0.038 ± 0.015
Belle sl.tag
0.302 ± 0.030 ± 0.011
Belle hadronic tau
0.270 ± 0.035 ± 0.027
LHCb muonic tau
0.336 ± 0.027 ± 0.030
LHCb hadronic tau
0.291 ± 0.019 ± 0.029
Average
0.306 ± 0.013 ± 0.007
SM Pred. average
0.258 ± 0.005
PRD 95 (2017) 115008
0.257 ± 0.003
JHEP 1711 (2017) 061
0.260 ± 0.008
JHEP 1712 (2017) 060
0.257 ± 0.005
HFLAV
Summer 2018
0.2
0.3
R(D*)



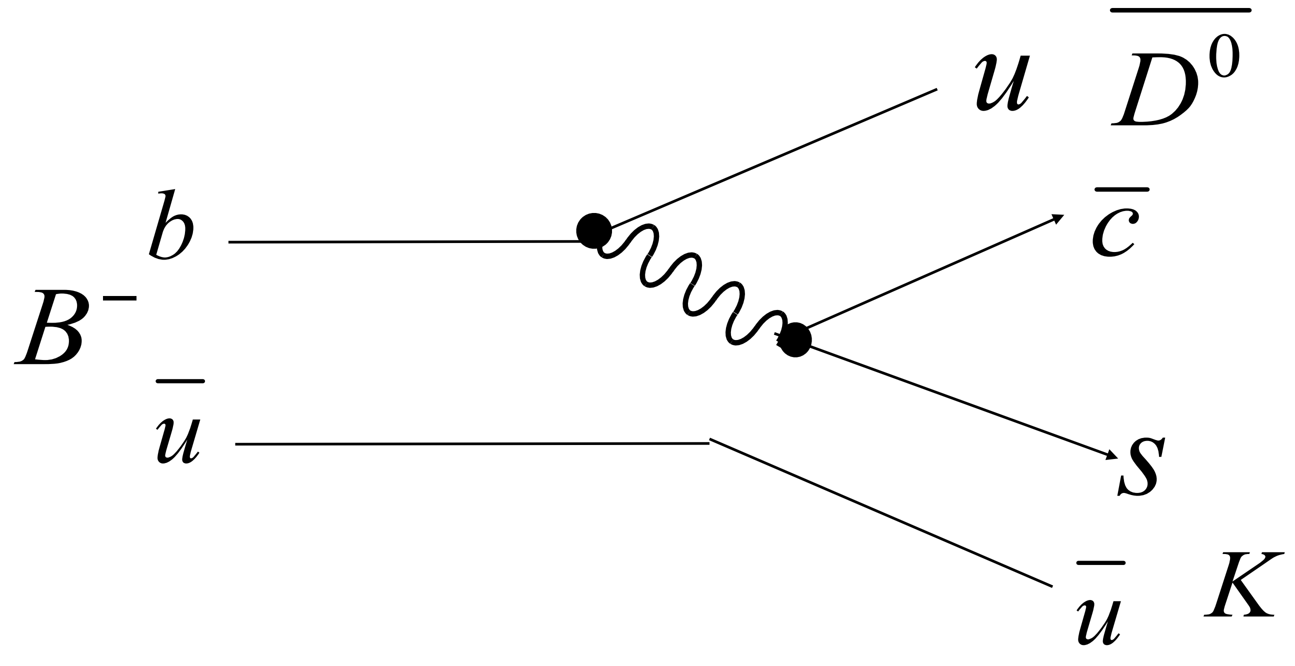
BaBar had. tag
0.440 ± 0.058 ± 0.042
Belle had. tag
0.375 ± 0.064 ± 0.026
Average
0.407 ± 0.039 ± 0.024
PRD94,094008(2016)
0.299 ± 0.003
FNAL/MILC (2015)
0.299 ± 0.011
HPQCD (2015)
0.300 ± 0.008
HFLAV
Summer 2018
0.2
0.4
0.6
R(D)

Φ_3/γ (phase of V_{ub}) Determination

- Theory is "pristine" in these approaches, << 1% on Φ_3



Favoured



Suppressed

$$r_B = \frac{|A_{\text{suppressed}}|}{|A_{\text{favoured}}|} \approx \frac{V_{ub}V_{cs}^*}{V_{cb}V_{us}^*} \times [\text{colour supp.}] = 0.1 - 0.2$$

Relative weak phase is Φ_3, Relative strong phase is δ_R

A dream of Belle & Babar: difficult due to V_{ub} and colour suppression. Many Direct CPV techniques developed at the B-factories.

3 D^0 mode categories:

- D_{CP}, CP eigenstates [GLW]
- D_{sup}, Doubly cabibbo suppressed [ADS]
- 3-Body [GGSZ]

- LHCb Φ_3 from 98 observables

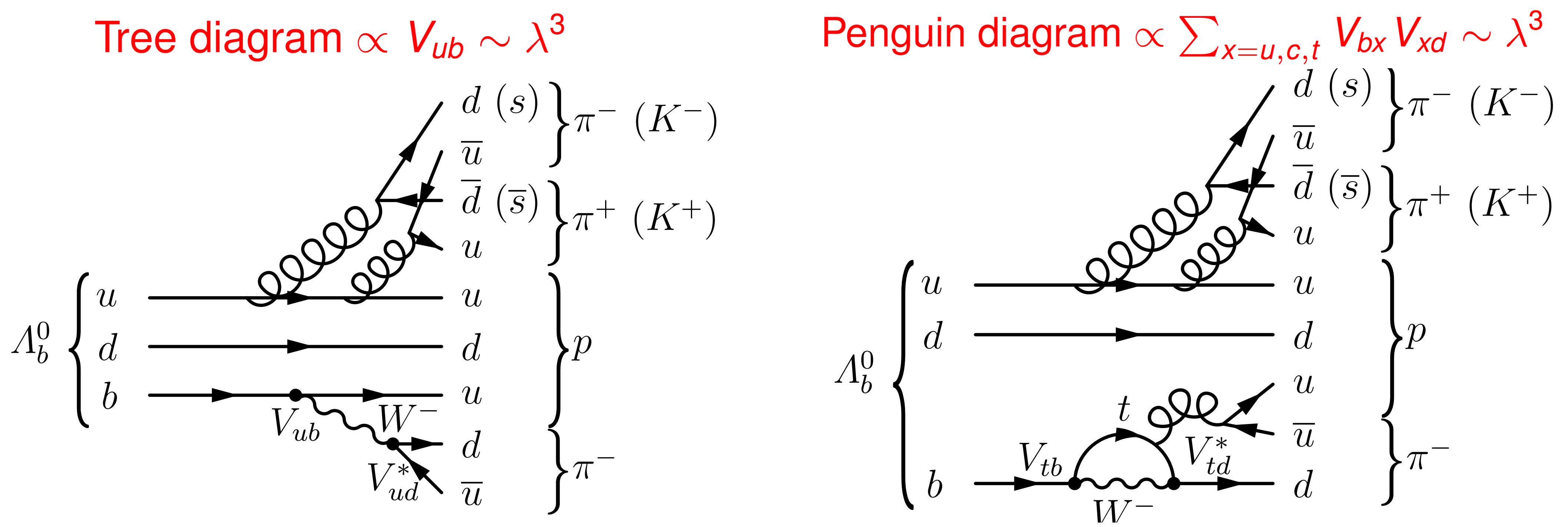
B decay	D decay	Method
$B^+ \to DK^+$	$D \to h^+h^-$	GLW
$B^+ \to DK^+$	$D \to h^+h^-$	ADS
$B^+ \to DK^+$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS
$B^+ \to DK^+$	$D \to h^+h^-\pi^0$	GLW/ADS
$B^+ \to DK^+$	$D \to K^0_S h^+h^-$	GGSZ
$B^+ \to DK^+$	$D \to K^0_S h^+h^-$	GGSZ
$B^+ \to DK^+$	$D \to K^0_S K^+\pi^-$	GLS
$B^+ \to D^*K^+$	$D \to h^+h^-$	GLW
$B^+ \to DK^{*+}$	$D \to h^+h^-$	GLW/ADS
$B^+ \to DK^{*+}$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS
$B^+ \to DK^+\pi^+\pi^-$	$D \to h^+h^-$	GLW/ADS
$B^0 \to DK^{*0}$	$D \to K^+\pi^-$	ADS
$B^0 \to DK^+\pi^-$	$D \to h^+h^-$	GLW-Dalitz
$B^0 \to DK^{*0}$	$D \to K^0_S\pi^+\pi^-$	GGSZ
$B^0_s \to D_s^\mp K^\pm$	$D_s^+ \to h^+h^-\pi^+$	TD
$B^0 \to D^\mp\pi^\pm$	$D^+ \to K^+\pi^-\pi^+$	TD

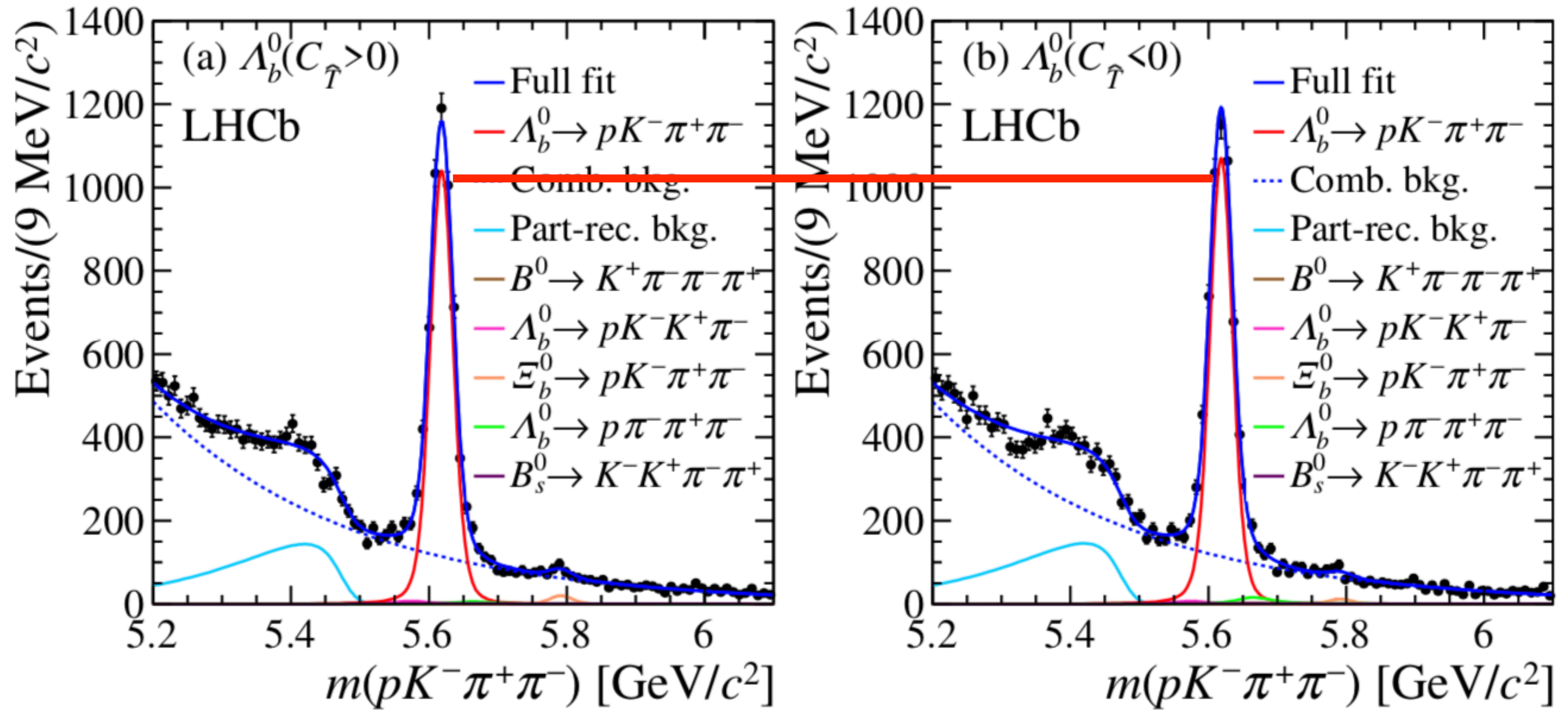
CPV in Baryon Decays

M. Schubiger
J-L. Fu

LHCb arXiv: 1805.03941
LHCb JHEP 1803 (2018) 182
Nature Phys. 13 (2017) 391-396

- New window on CPV using baryon decay.
- 3.3 σ CPV evidence for the first time in $\Lambda_b \to p\pi\pi\pi$ (2017)

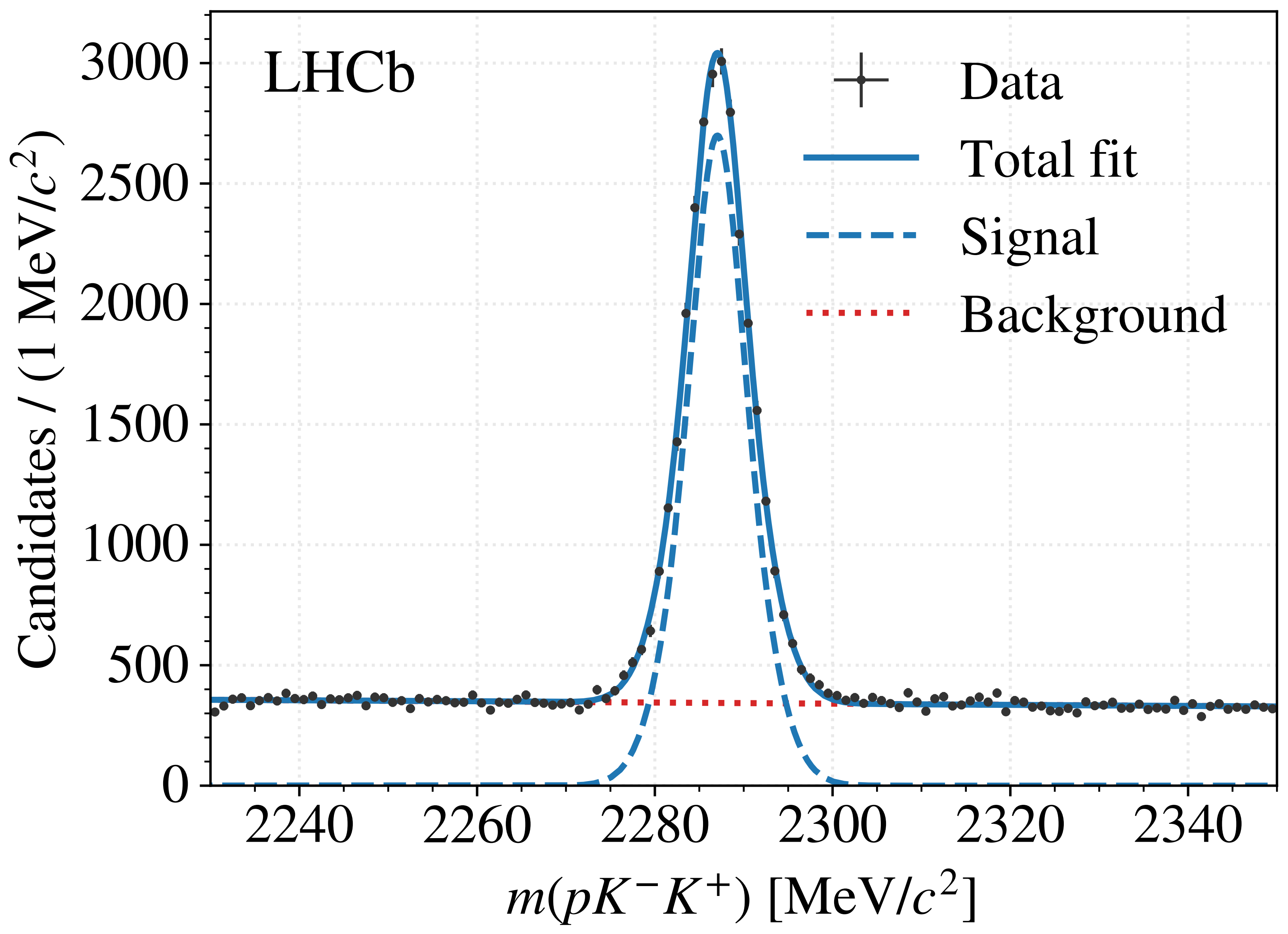




Search for CP violation using triple product asymmetries in $\Lambda^0_b \to pK^-\pi^+\pi^-$, $\Lambda^0_b \to pK^-K^+K^-$ and $\Xi_b^0 \to pK^-K^-\pi^+$ decays

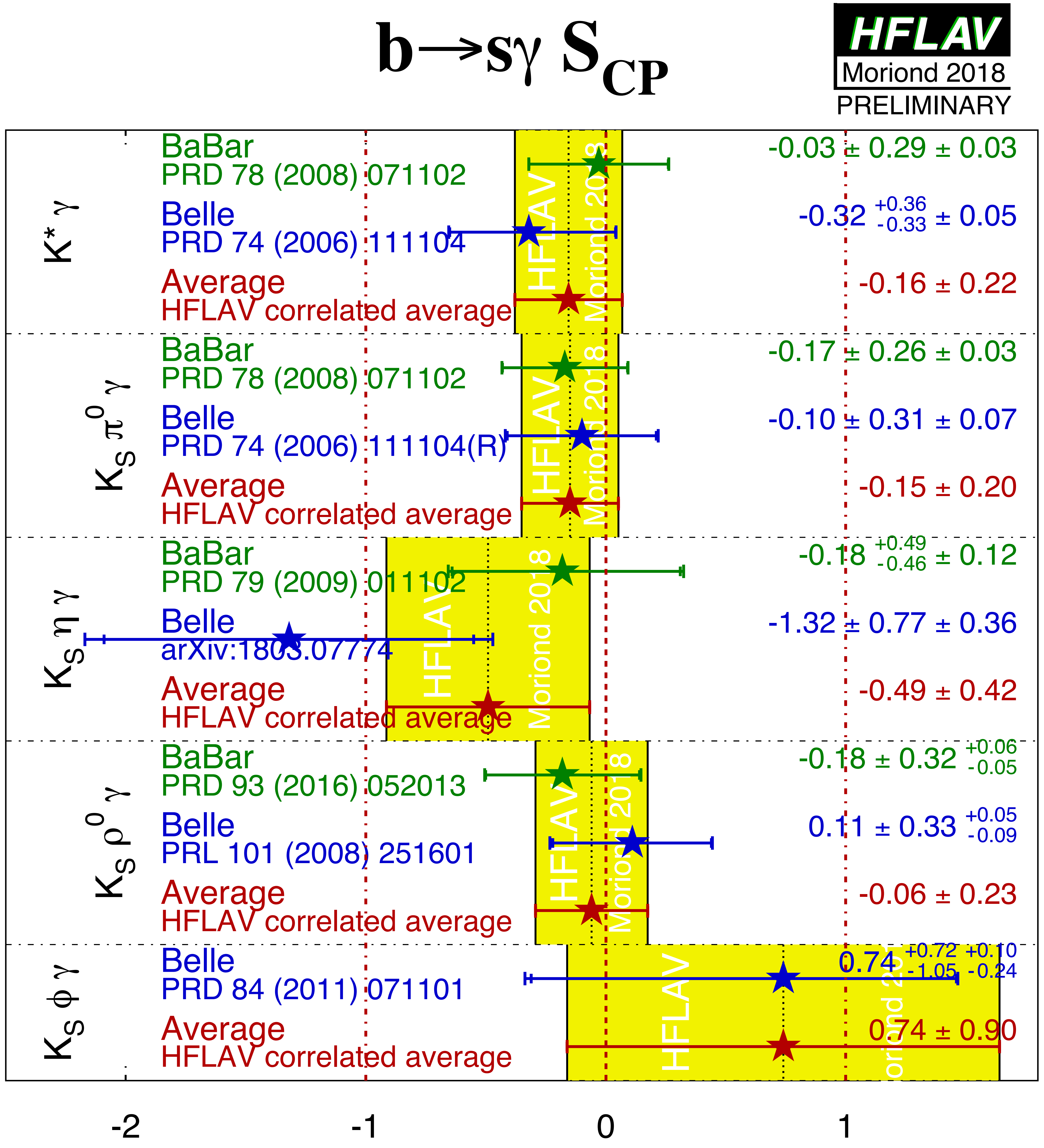
- No sign in charm, $\Lambda_c \to pKK$, $p\pi\pi$

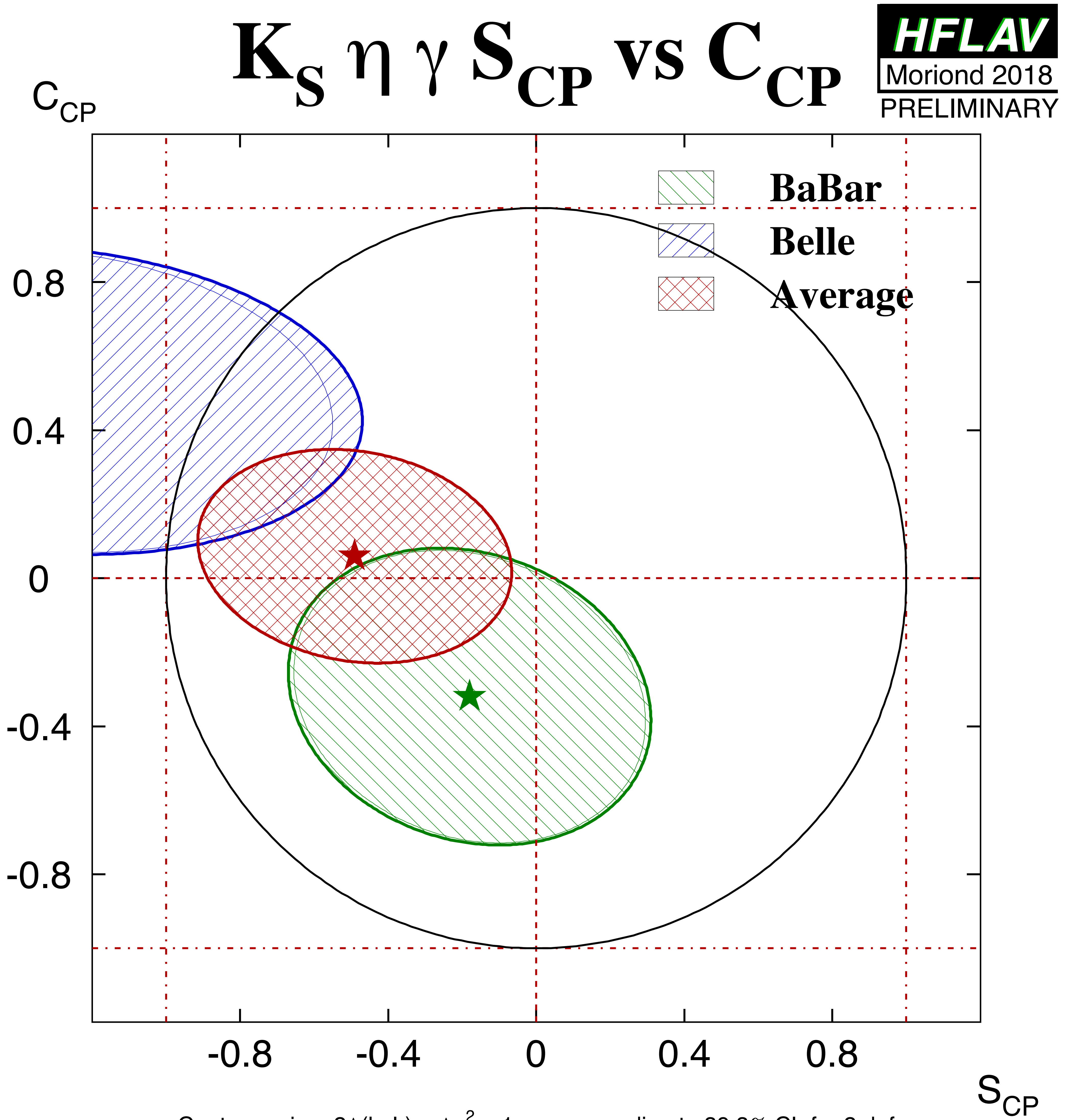
$$\Delta A_{CP}^{\text{wgt}} = A_{\text{raw}}^{\text{wgt}}(pK^+K^-) - A_{\text{raw}}^{\text{wgt}}(p\pi^+\pi^-)$$
$$= (3.0 \pm 9.1 \pm 6.1) \times 10^{-3}$$



A measurement of the CP asymmetry difference between $\Lambda^+_c \to pK^-K^+$ and $p\pi^-\pi^+$ decays

Time dependent CP violation in b→s γ

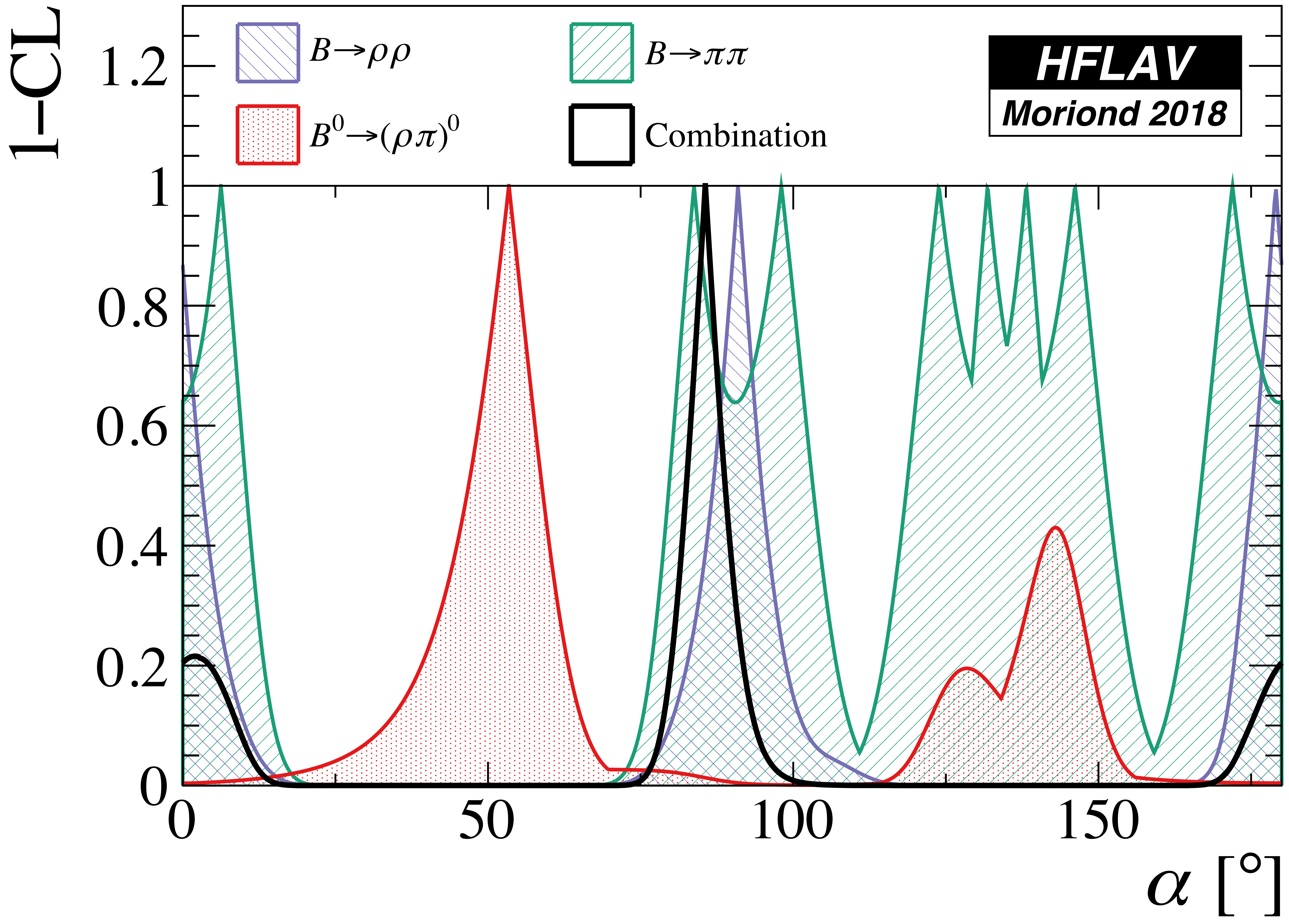


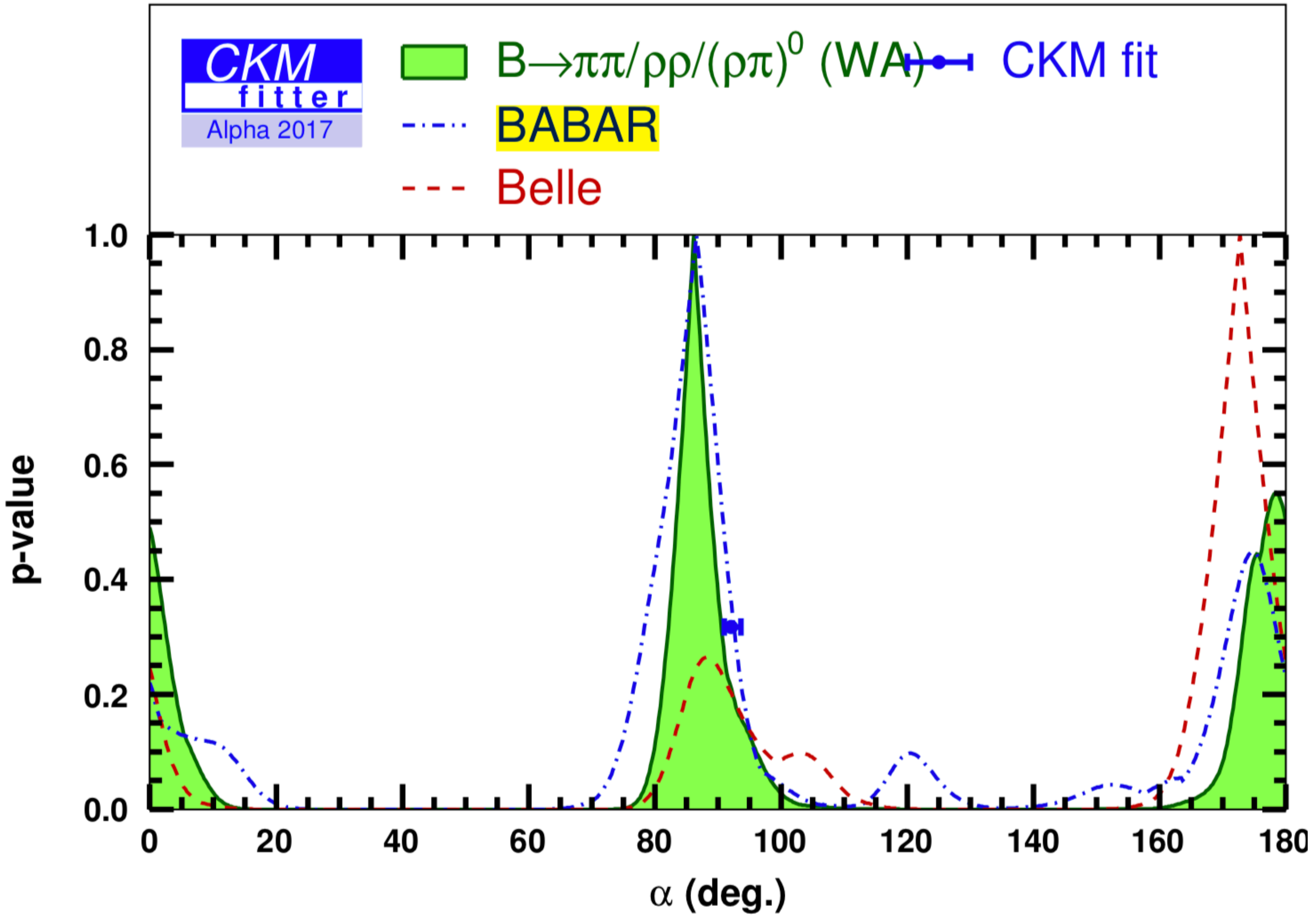


Contours give $-2\Delta(\ln L) = \Delta\chi^2 = 1$, corresponding to 39.3% CL for 2 dof

Φ_2 from b→ u anti-u d

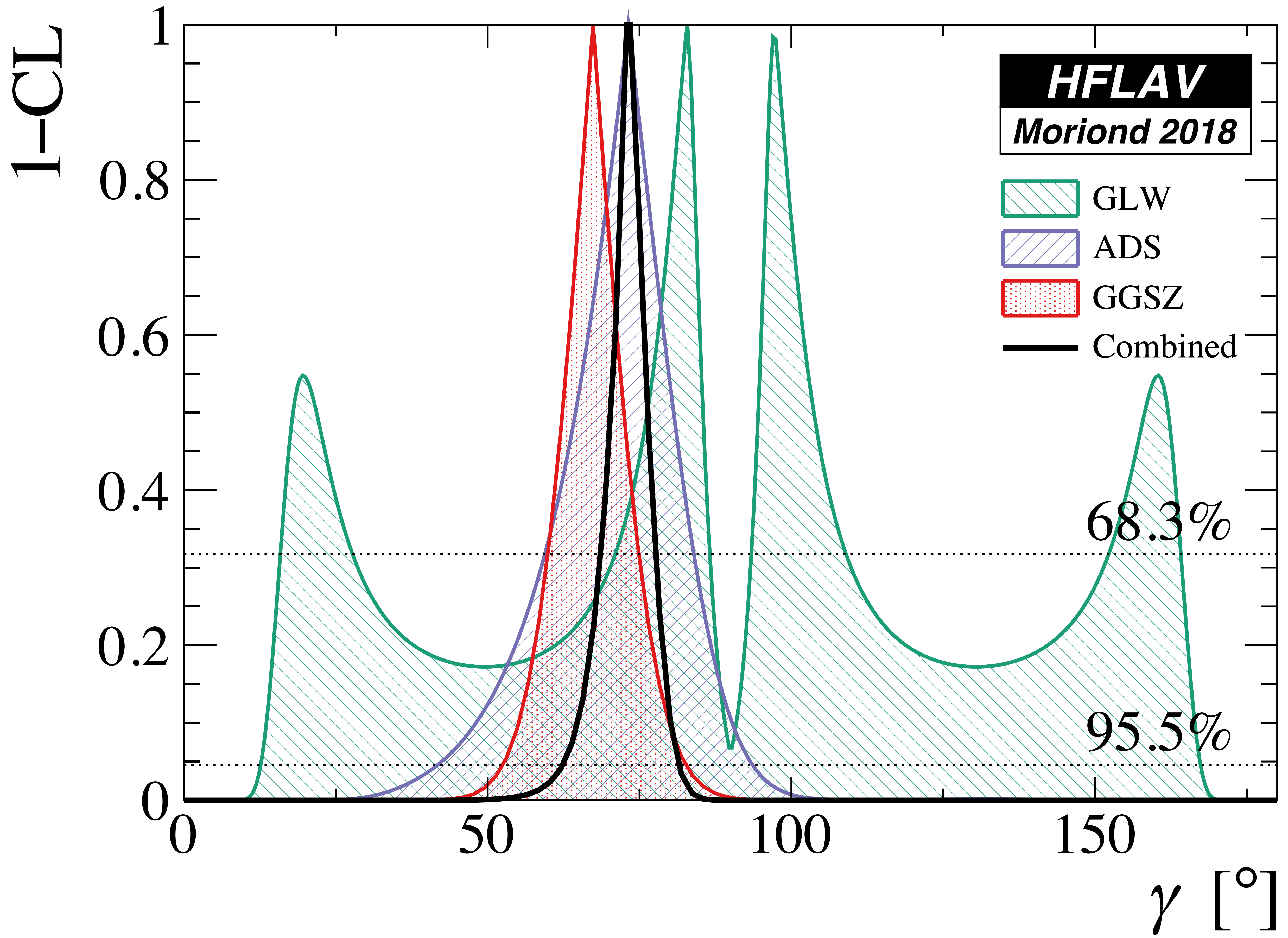
- $\Phi_2 = (84.9\ ^{+5.1}_{-4.5})°$ HFLAV 2018
- $\Phi_2 = (86.2\ ^{+4.4}_{-4.0})°$ CKMFitter 2017

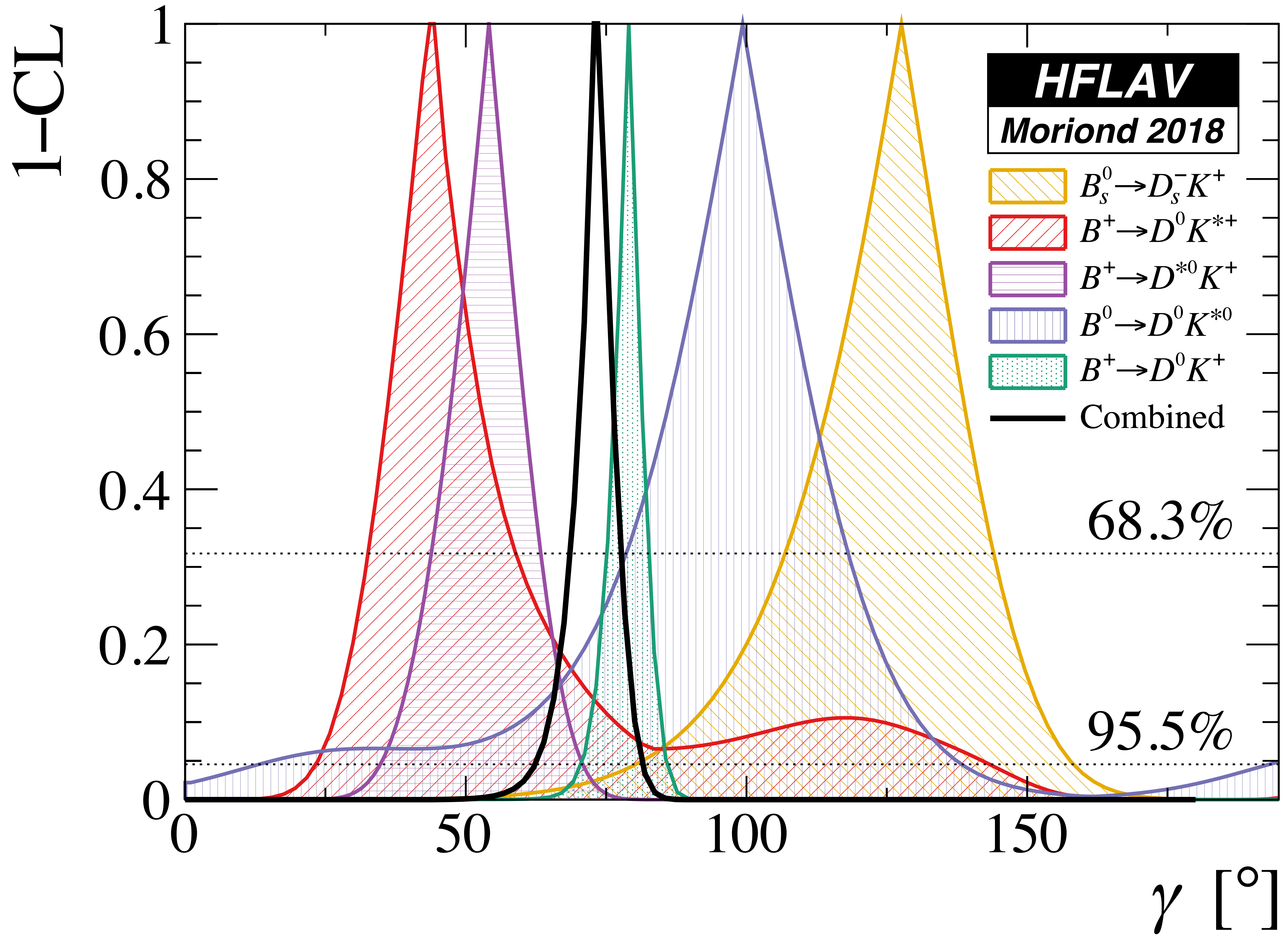




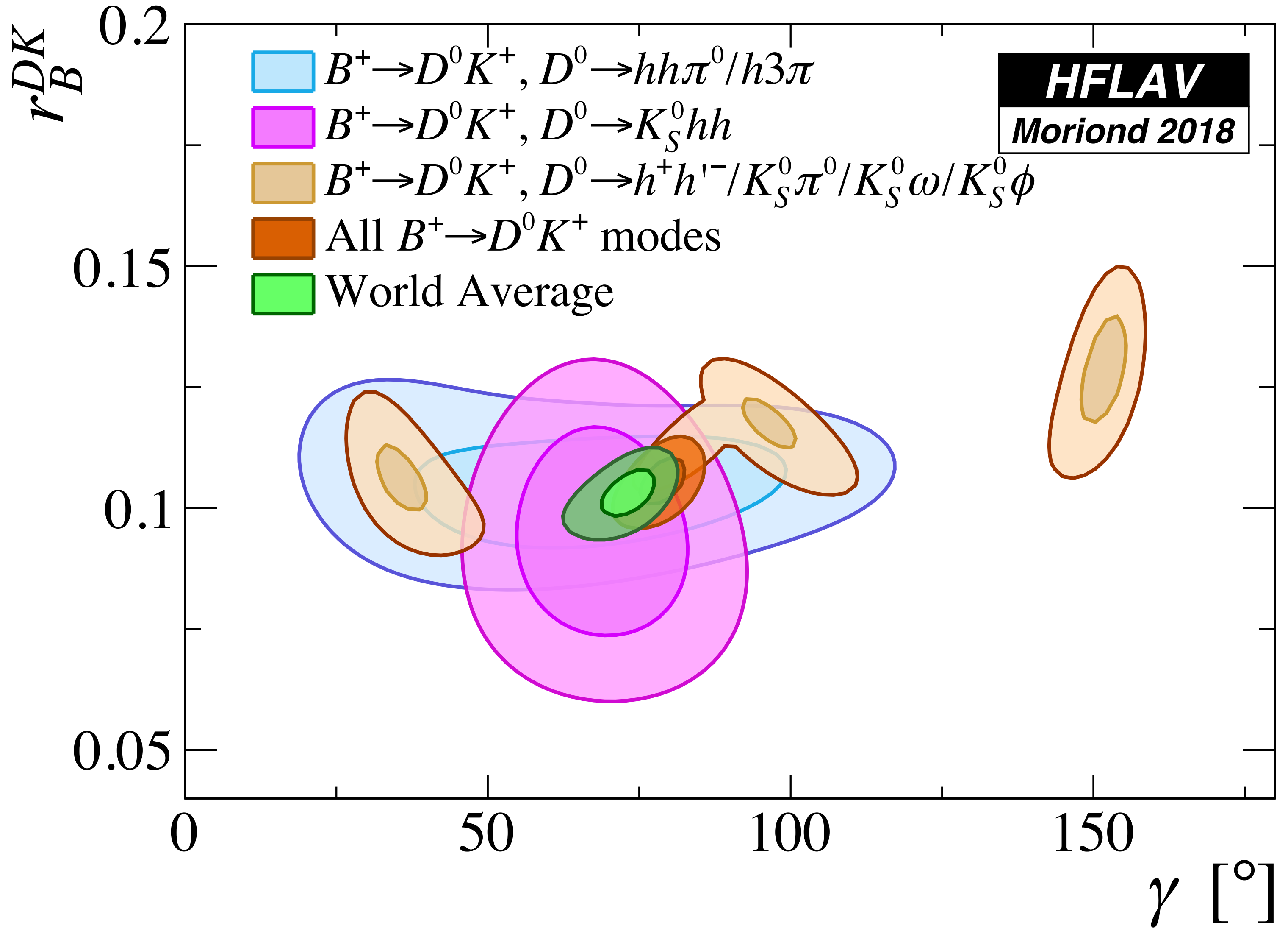
Φ_3

- HFLAV 2018 combinations

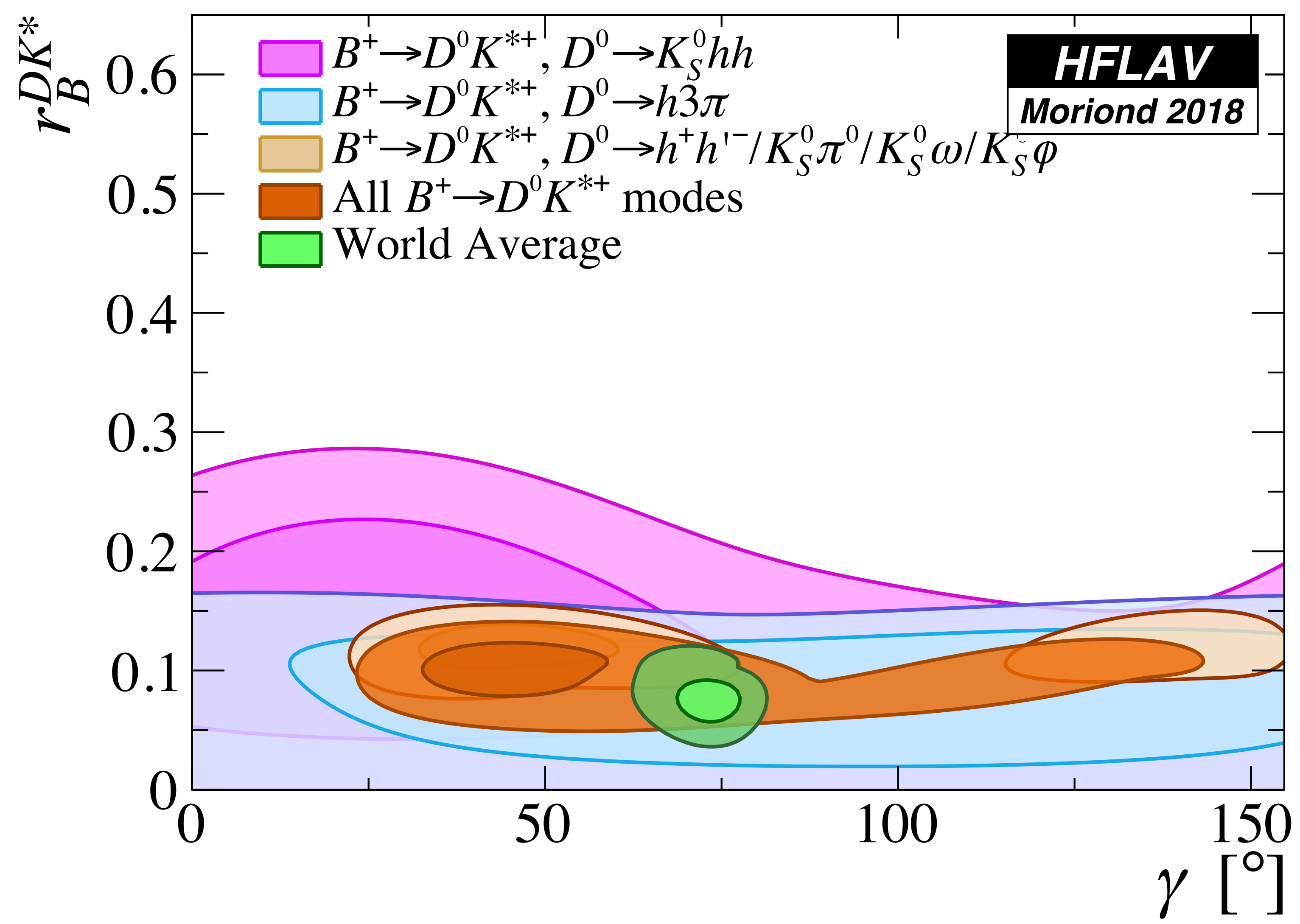




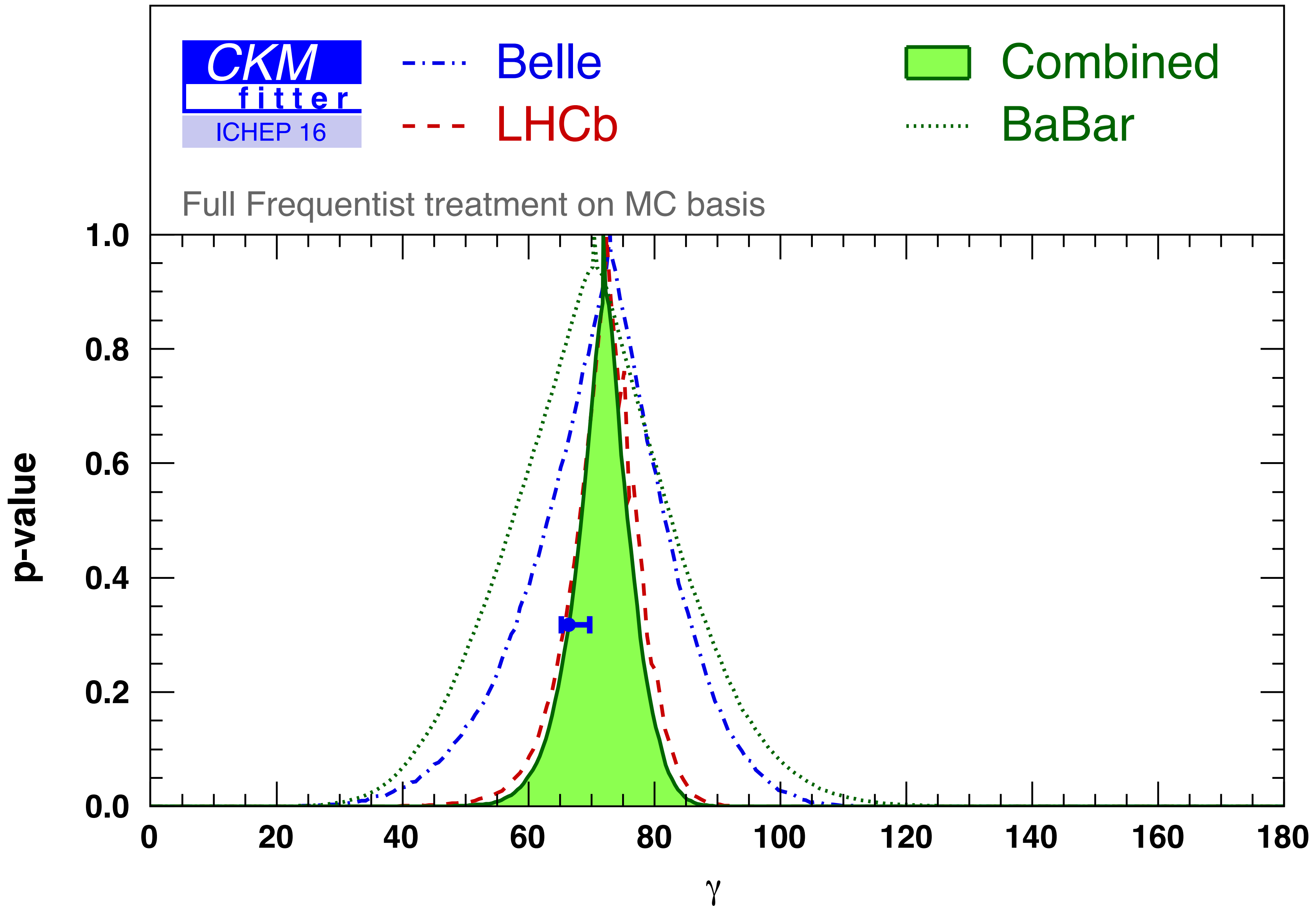
$r_B^{D(*)K(*)}$ Vs Φ_3



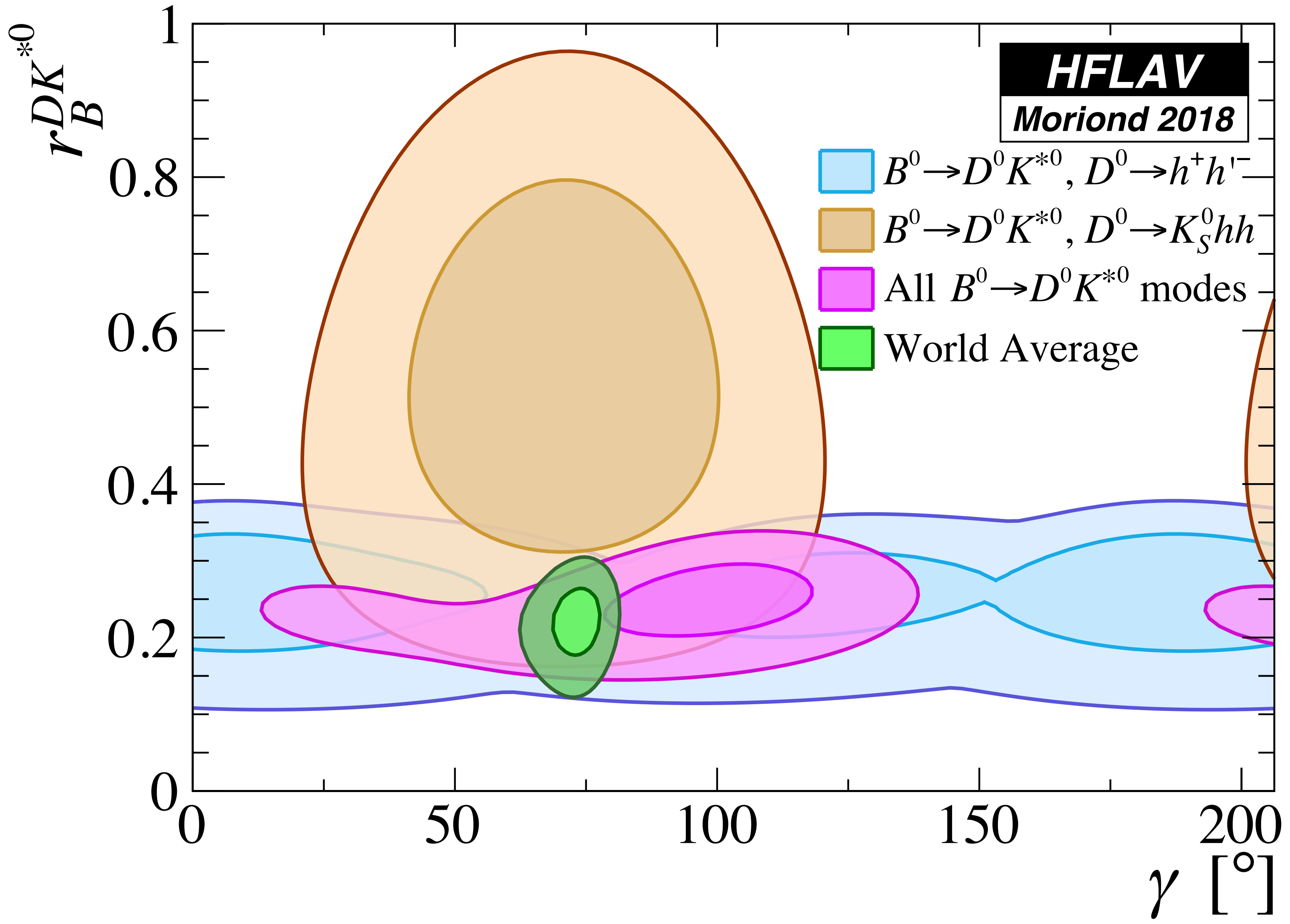
r_B^{DK}
$B^+ \to D^0K^+$, $D^0 \to hh\pi^0/h3\pi$
$B^+ \to D^0K^+$, $D^0 \to K_S^0hh$
$B^+ \to D^0K^+$, $D^0 \to h^+h'^-/K_S^0\pi^0/K_S^0\omega/K_S^0\phi$
All $B^+ \to D^0K^+$ modes
World Average
HFLAV
Moriond 2018
γ [°]



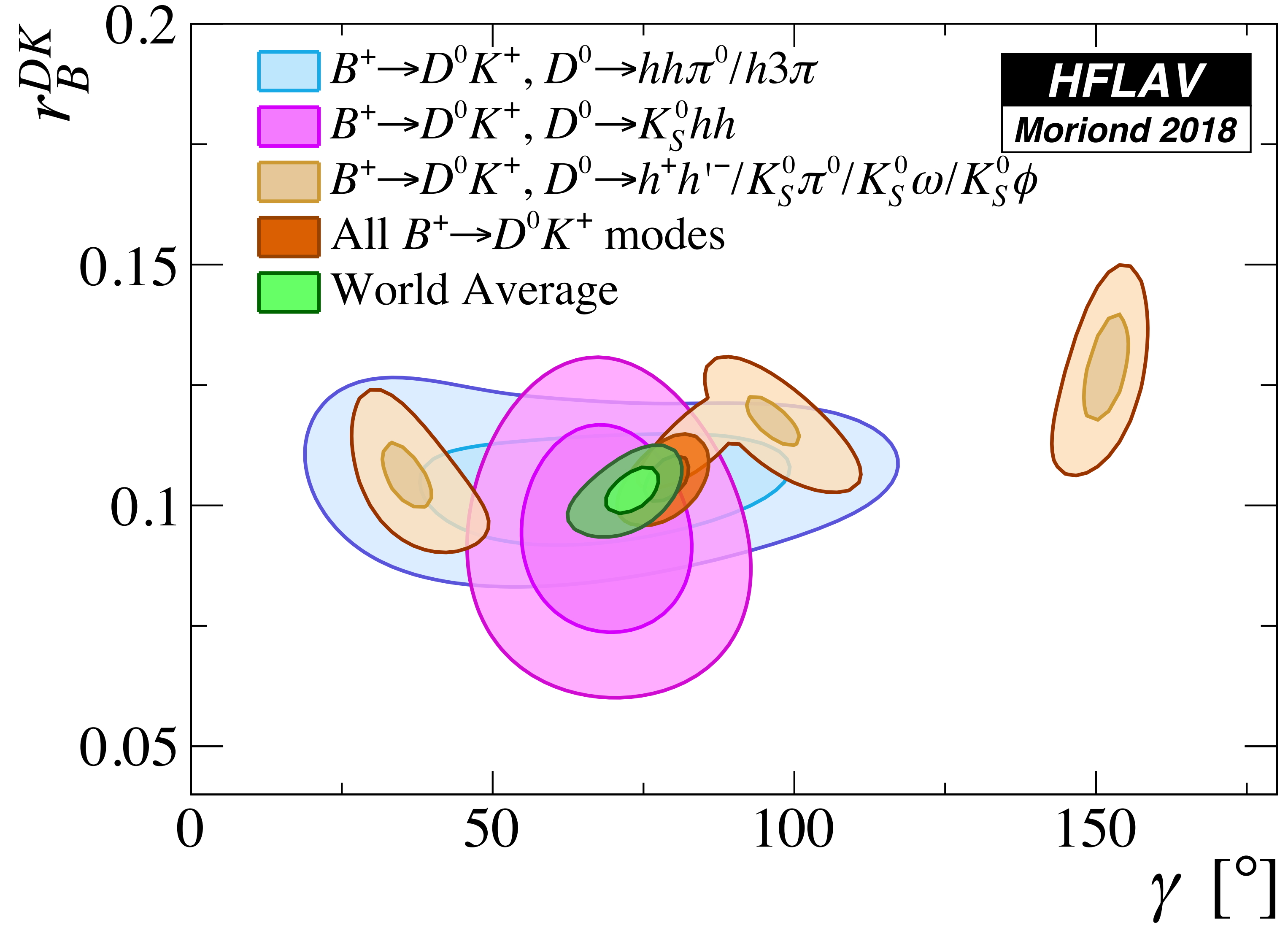
$r_B^{DK^*}$
$B^+ \to D^0K^{*+}$, $D^0 \to K_S^0hh$
$B^+ \to D^0K^{*+}$, $D^0 \to h3\pi$
$B^+ \to D^0K^{*+}$, $D^0 \to h^+h'^-/K_S^0\pi^0/K_S^0\omega/K_S^0\varphi$
All $B^+ \to D^0K^{*+}$ modes
World Average
HFLAV
Moriond 2018
γ [°]



CKM fitter
ICHEP 16
Belle
LHCb
Combined
BaBar
Full Frequentist treatment on MC basis
p-value
γ

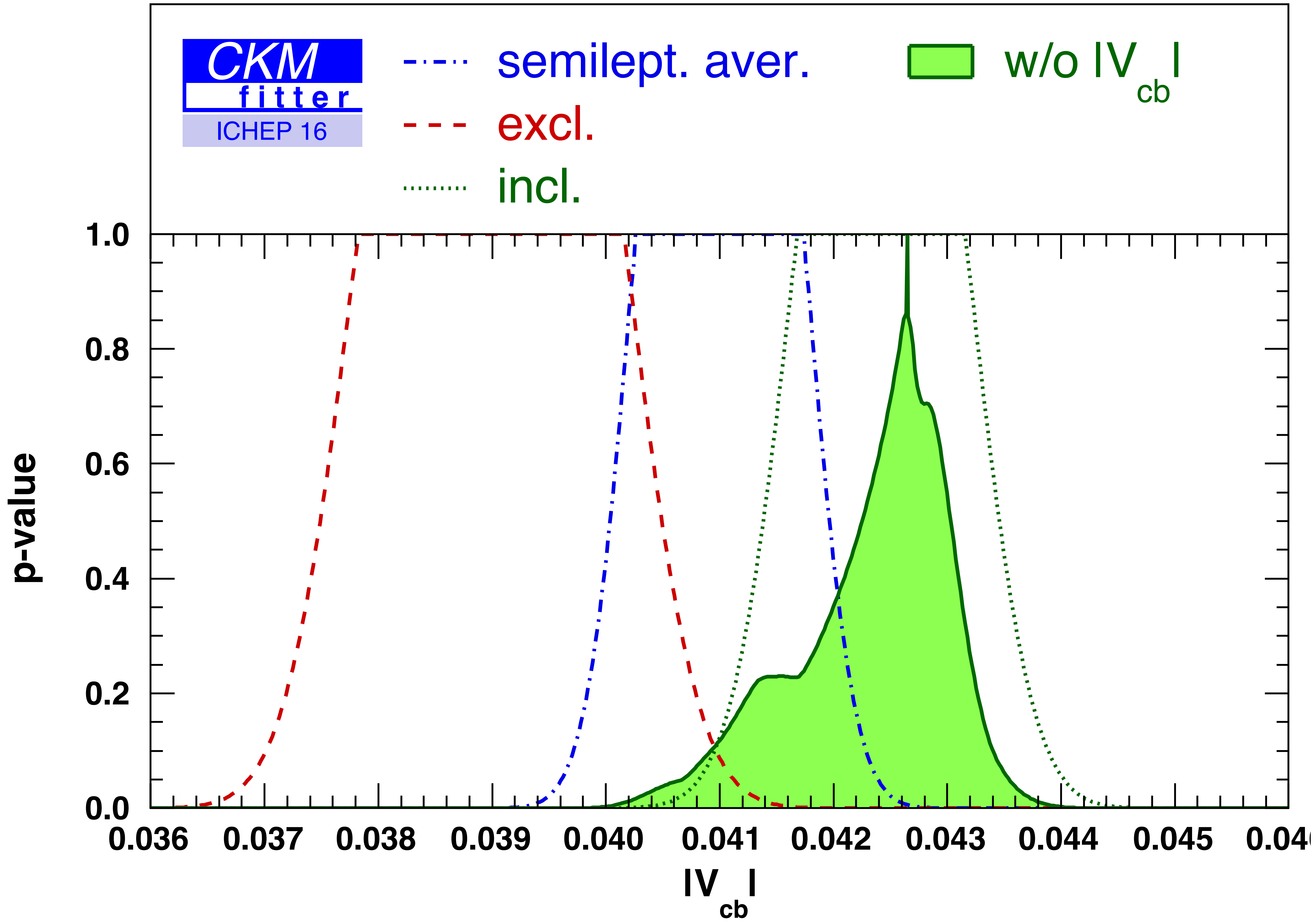


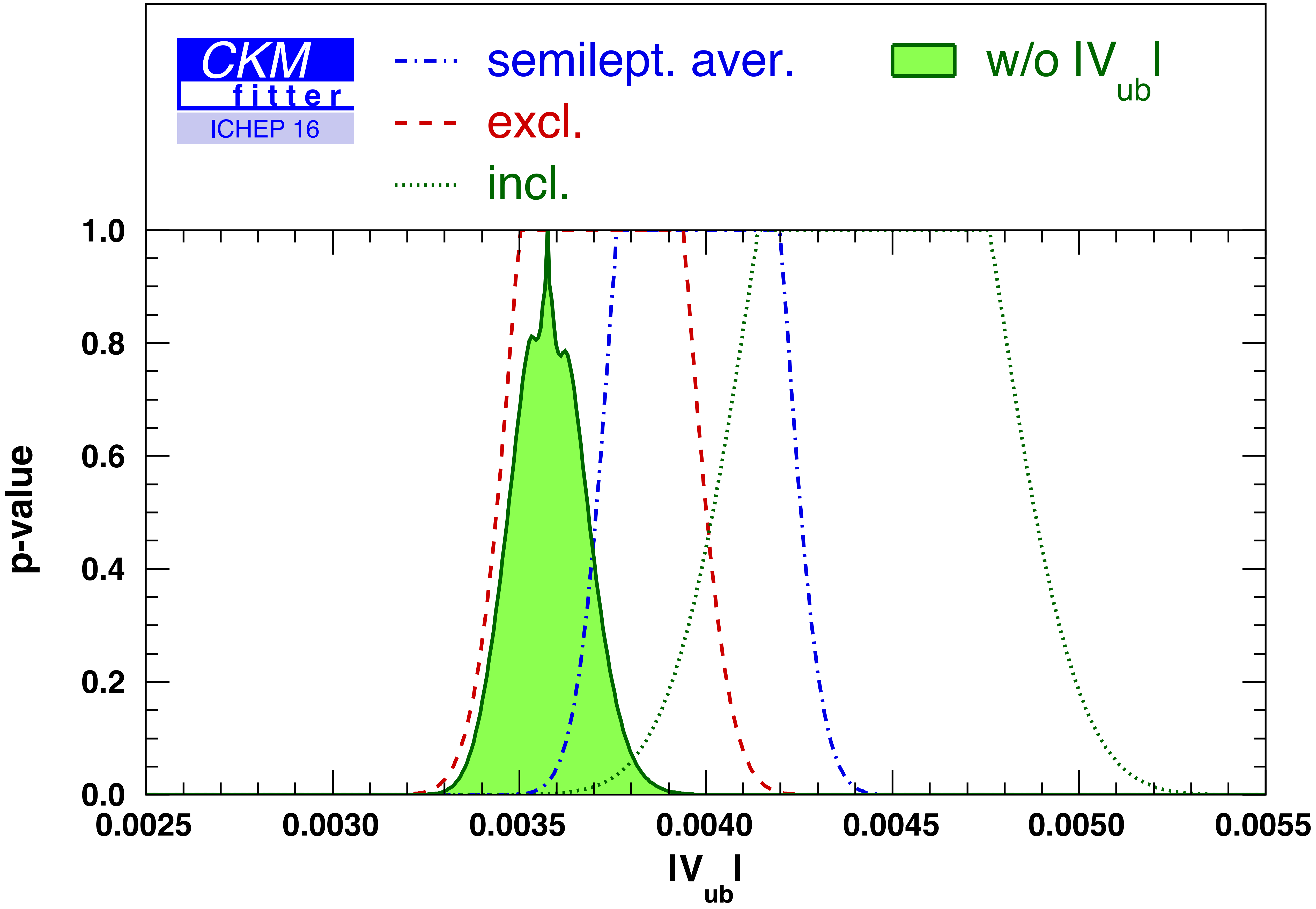
$r_B^{DK^{*0}}$
$B^0 \to D^0K^{*0}$, $D^0 \to h^+h'^-$
$B^0 \to D^0K^{*0}$, $D^0 \to K_S^0hh$
All $B^0 \to D^0K^{*0}$ modes
World Average
HFLAV
Moriond 2018
γ [°]



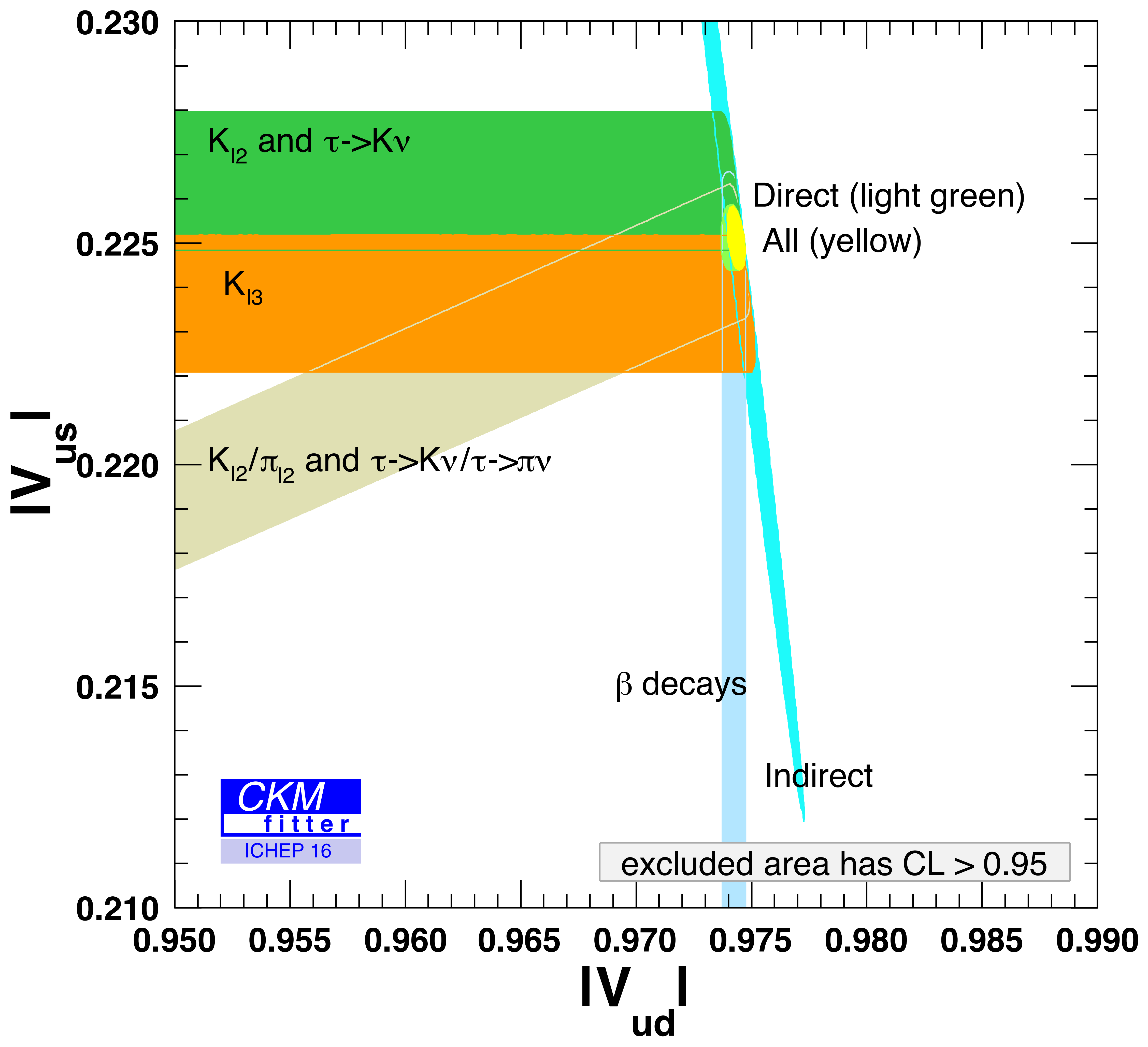
r_B^{DK}
$B^+ \to D^0K^+$, $D^0 \to hh\pi^0/h3\pi$
$B^+ \to D^0K^+$, $D^0 \to K_S^0hh$
$B^+ \to D^0K^+$, $D^0 \to h^+h'^-/K_S^0\pi^0/K_S^0\omega/K_S^0\phi$
All $B^+ \to D^0K^+$ modes
World Average
HFLAV
Moriond 2018
γ [°]

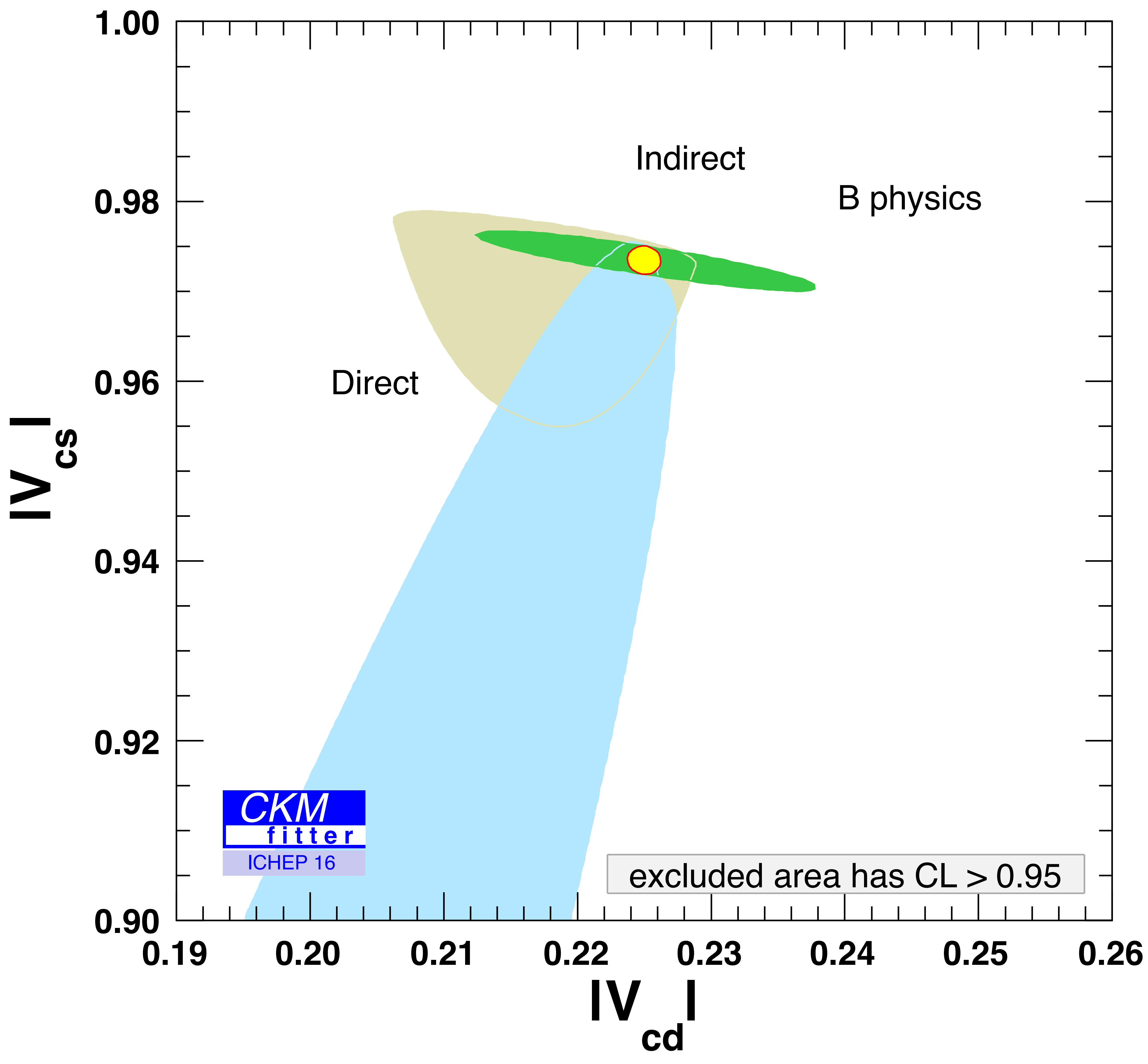
$|V_{cb}|$ and $|V_{ub}|$ Vs CKM expectation



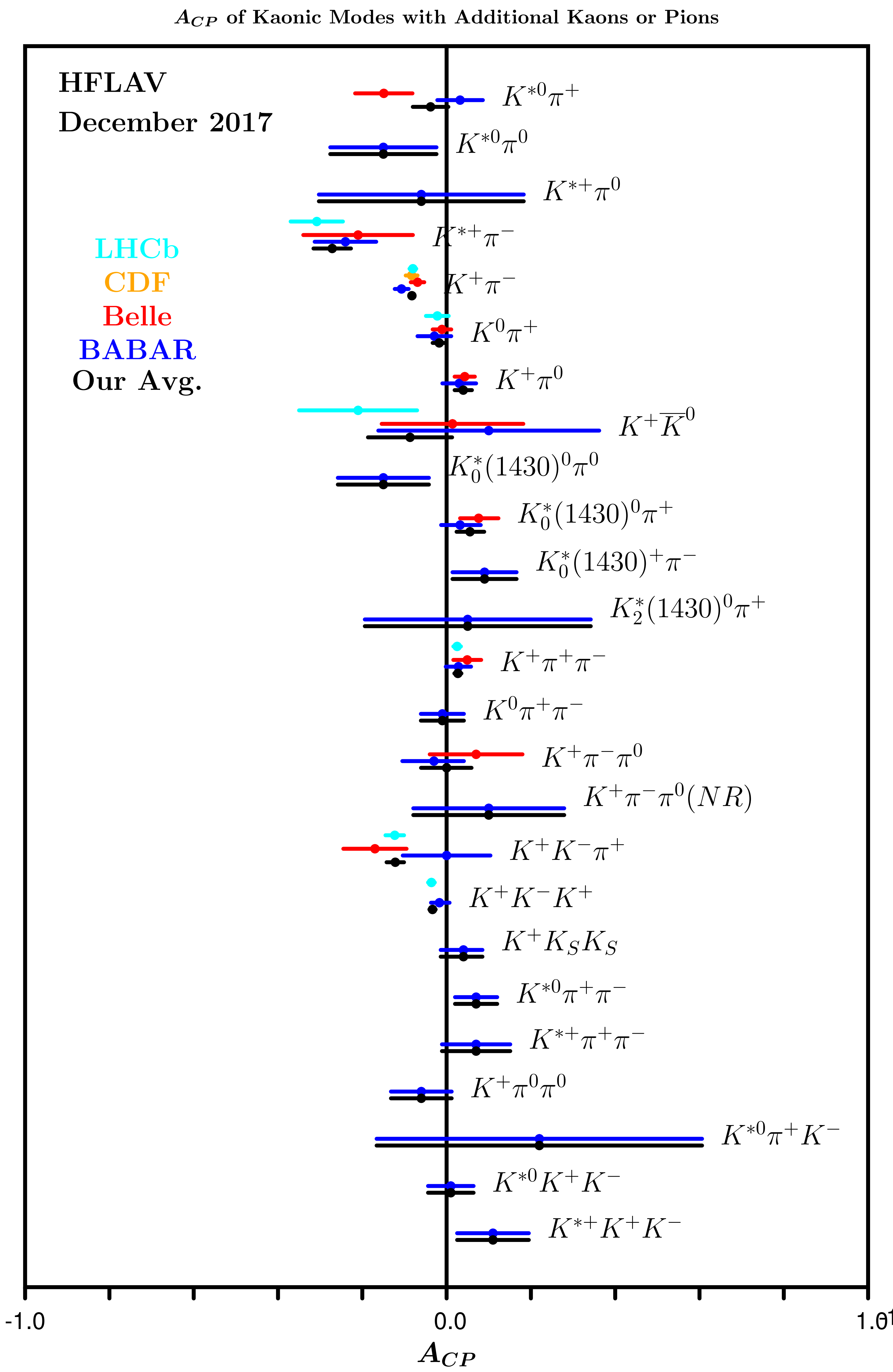


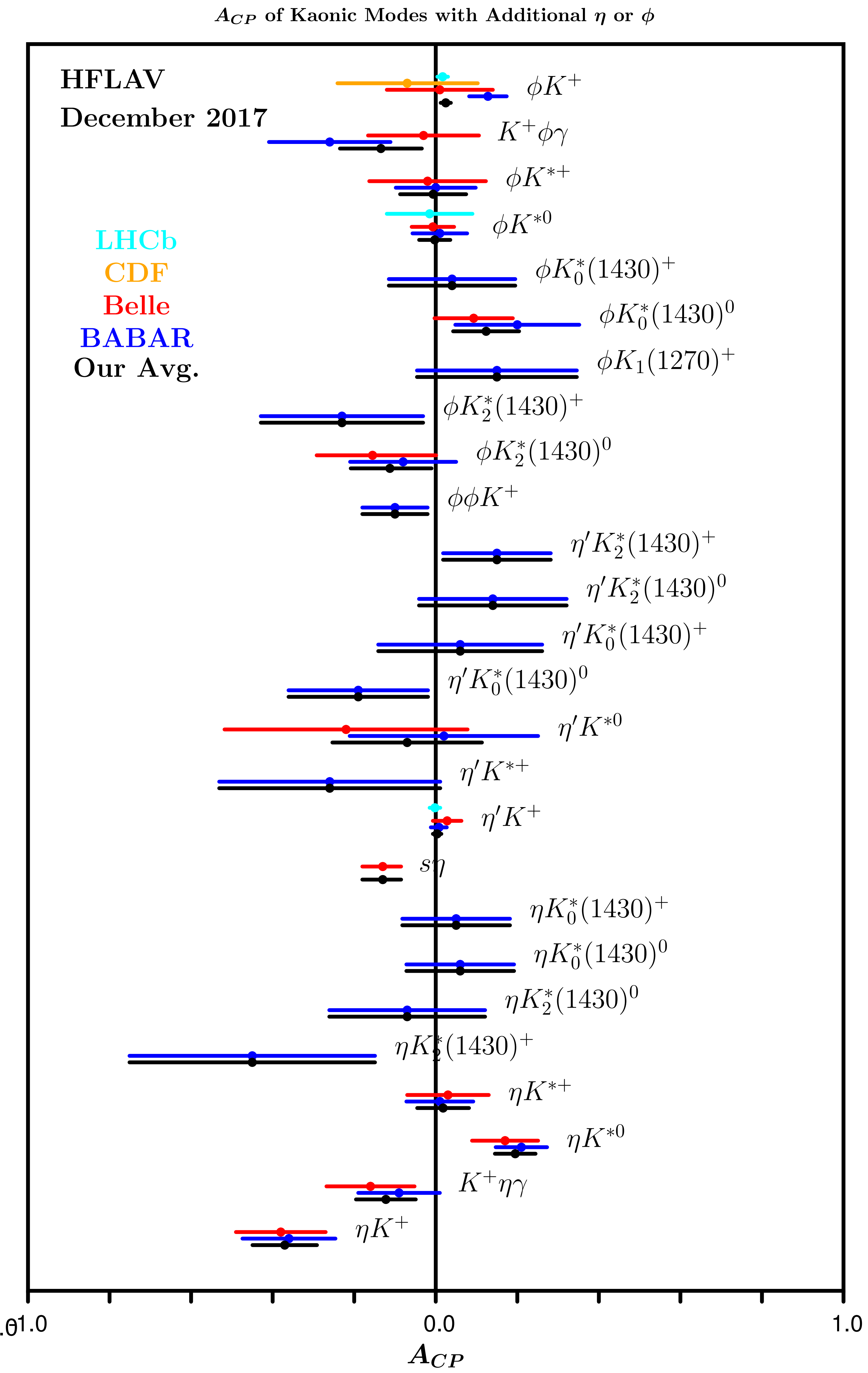
$|V_{ud}|$ Vs $|V_{us}|$, $|V_{cs}|$ vs $|V_{cd}|$

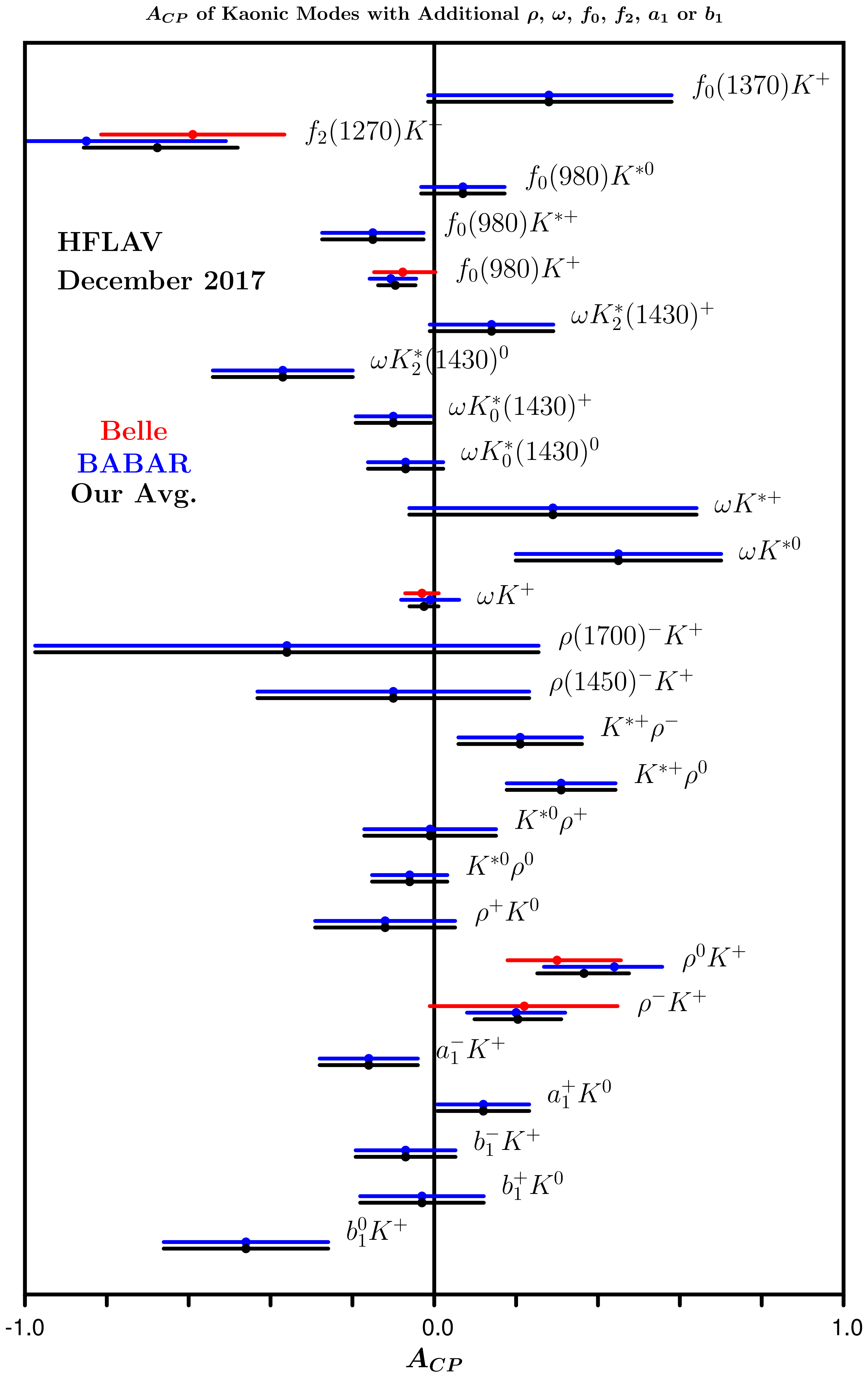




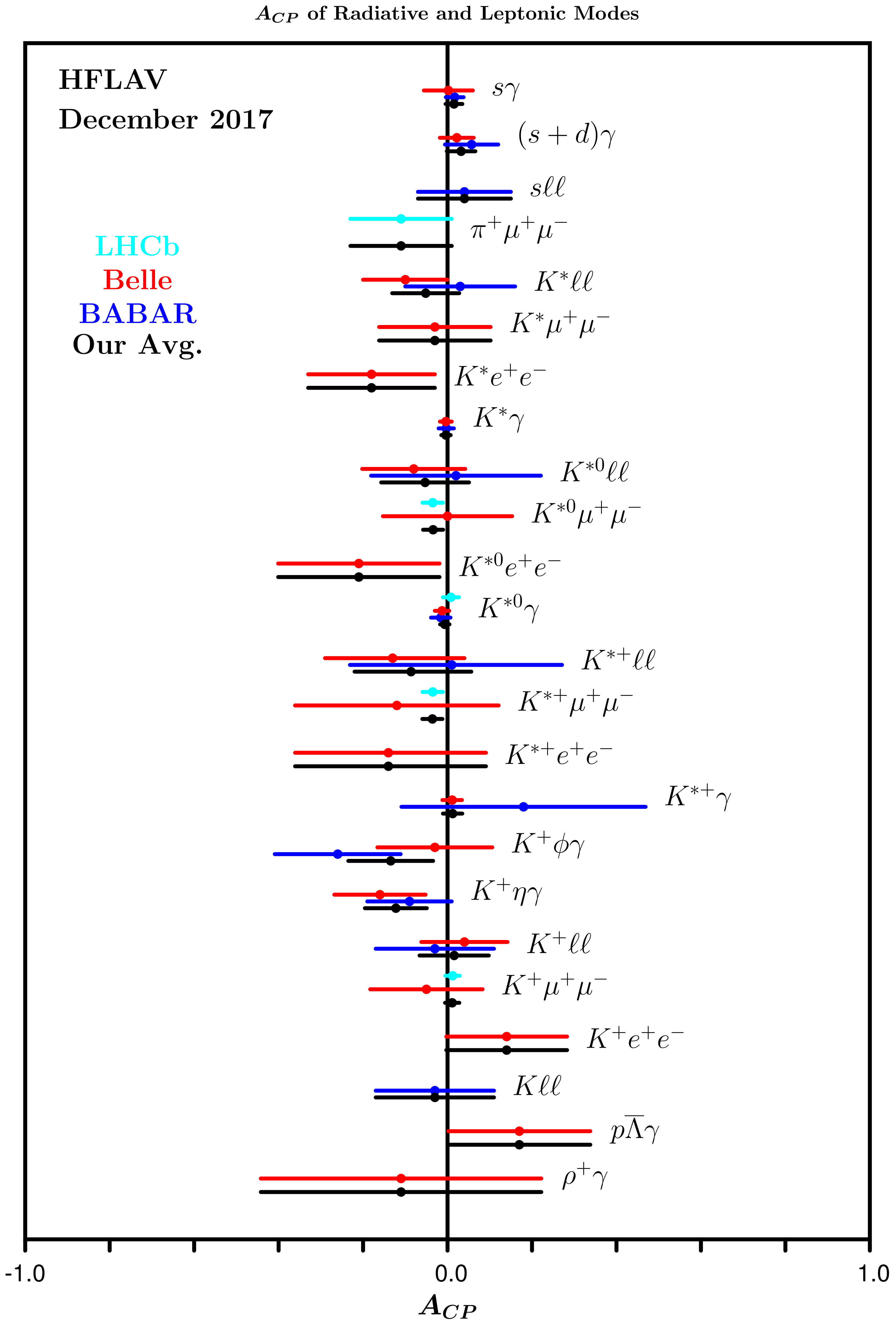
Direct CP Asymmetry in hadronic B decays

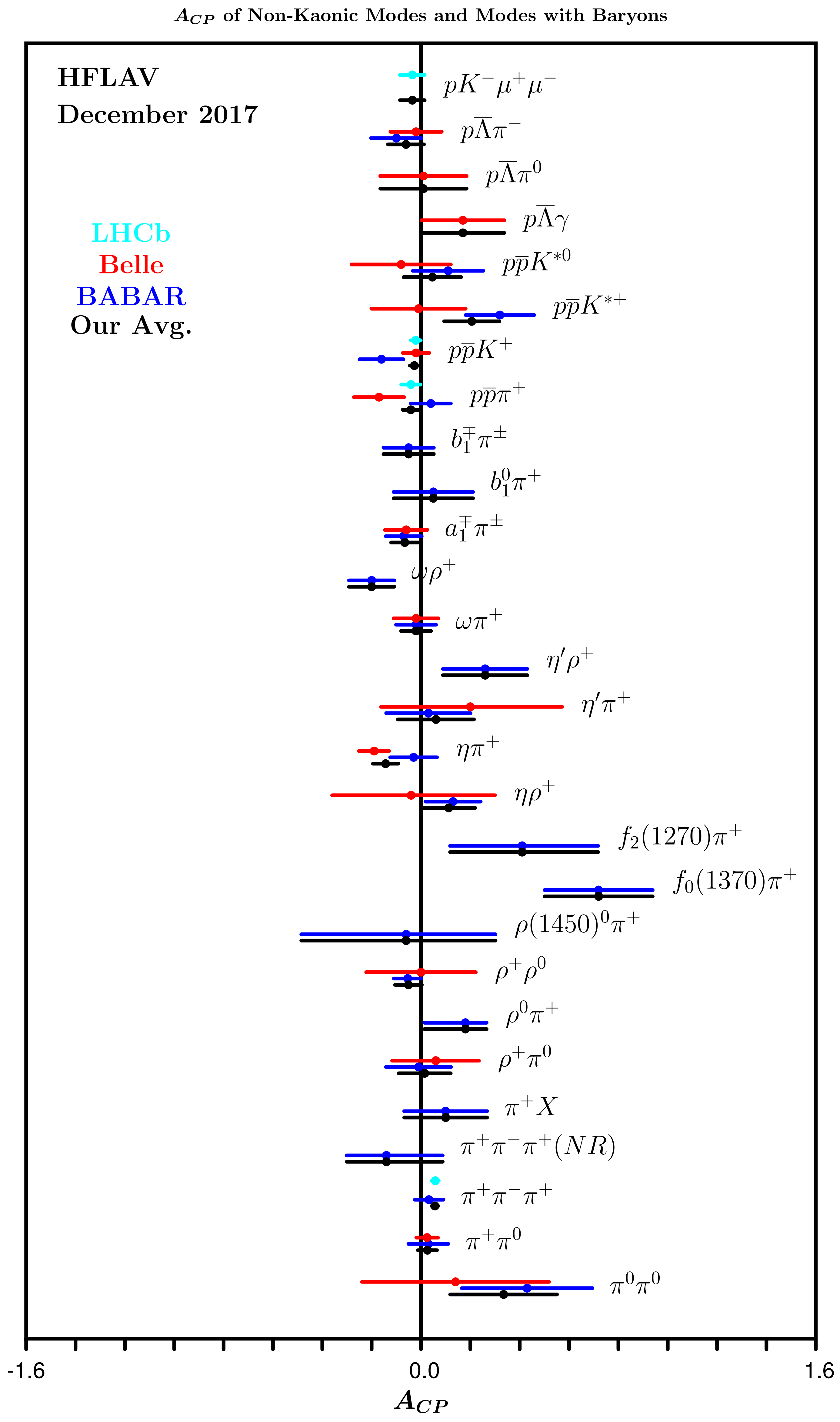






Direct CP Asymmetry in rare B decays





Φ_s (phase of V_{ts}) and Φ_1 NP (EWP)

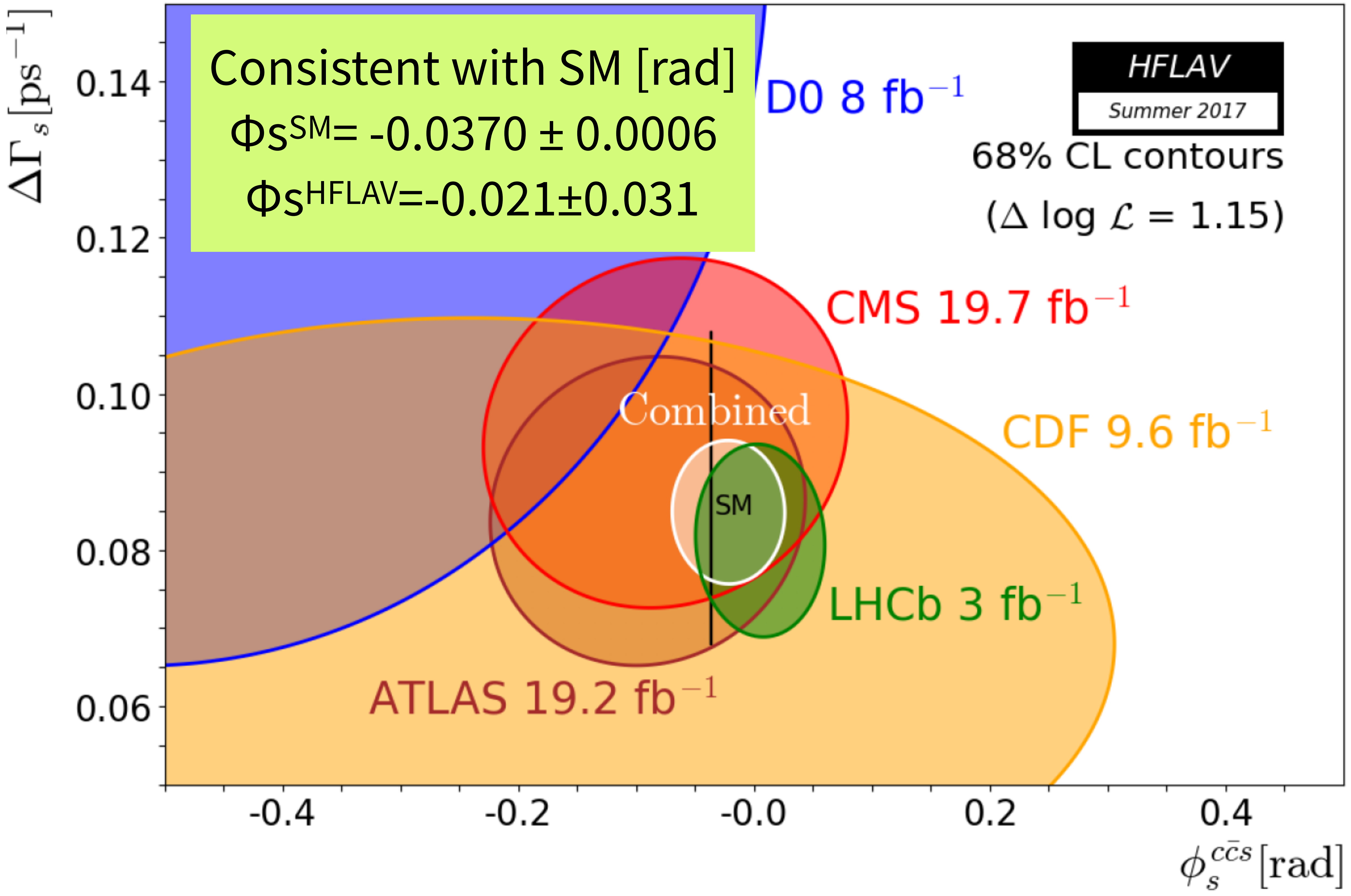
I. Lee
F. Dordei

Belle PRD97 9, 092003 (2018)
Belle PRL 119 19, 191802 (2017)
LHCb JHEP 1708 (2017) 037

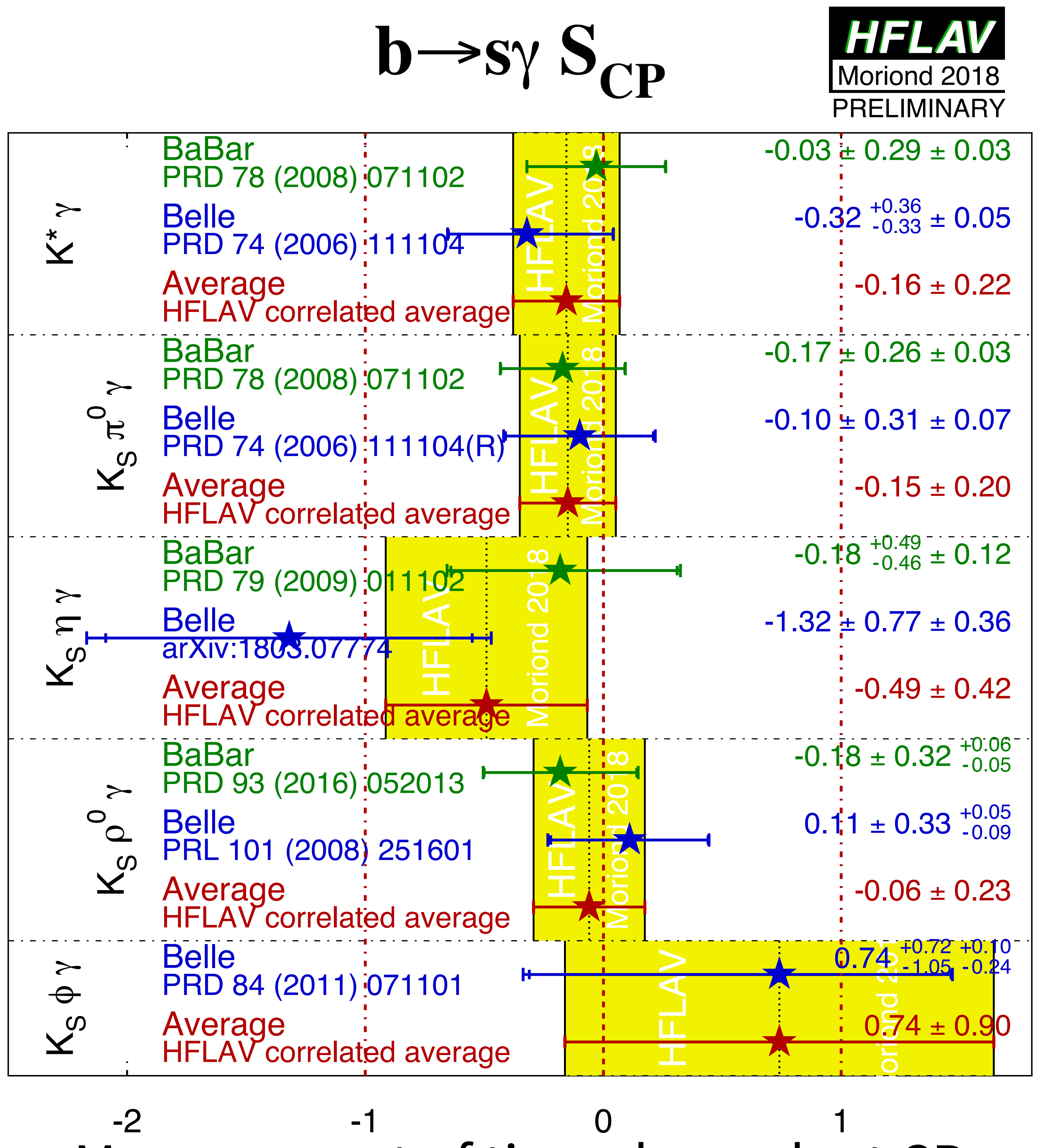
- Φ_s is a well predicted NP null test with B_s TDCPV
- Belle search for right handed currents in $B \to K_S^0 \eta \gamma$ (Belle II needed)

Other recent results: Evidence for Isospin Violation and Measurement of CP Asymmetries in B→K(892) γ*

Consistent with SM [rad]
$\Phi_s^{SM} = -0.0370 \pm 0.0006$
$\Phi_s^{HFLAV} = -0.021 \pm 0.031$

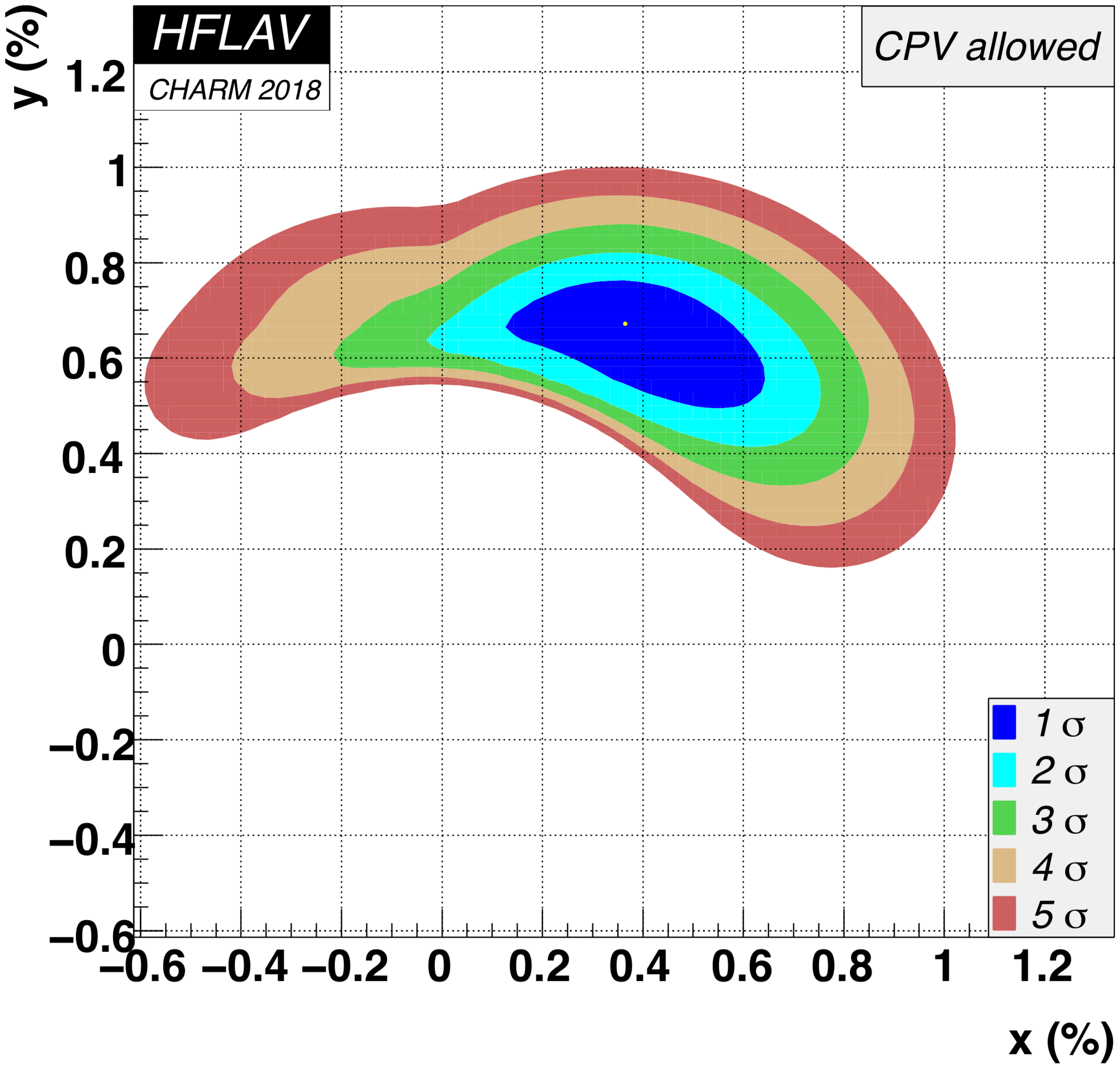


Resonances and CP violation in B^0_s and $B^0_s \to J/\psi K^+K^-$ decays in the mass region above the $\Phi(1020)$ at LHCb



Measurement of time-dependent CP asymmetries in $B0 \to K^0_S \eta \gamma$ decays at Belle

Charm mixing

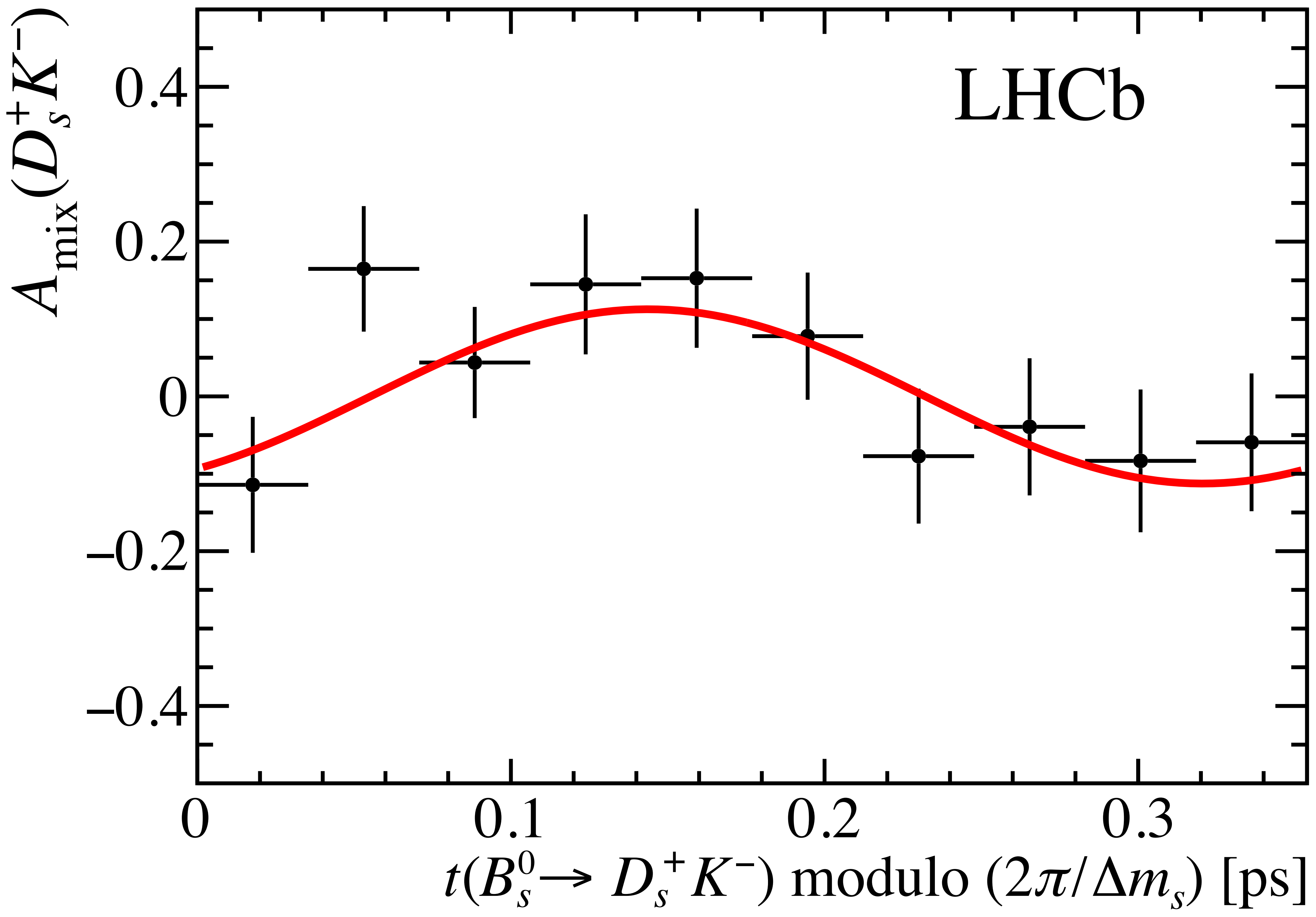


Parameter	No CPV	No direct CPV in DCS decays	CPV-allowed	CPV-allowed 95% CL Interval
x (%)	$0.50^{+0.13}_{-0.14}$	$0.46^{+0.12}_{-0.13}$	$0.36^{+0.21}_{-0.16}$	[0.06, 0.70]
y (%)	0.63 ± 0.08	0.62 ± 0.07	$0.67^{+0.06}_{-0.13}$	[0.46, 0.79]
$\delta_{K\pi}$ (°)	$9.9^{+8.9}_{-9.7}$	$8.6^{+9.1}_{-9.7}$	$14.7^{+8.4}_{-17.6}$	[−16.8, 30.7]
R_D (%)	0.345 ± 0.002	0.344 ± 0.002	0.344 ± 0.002	[0.339, 0.348]
A_D (%)	–	–	$-0.73^{+0.84}_{-0.67}$	[−2.0, 0.7]
$\|q/p\|$	–	$0.998^{+0.007}_{-0.008}$	$0.94^{+0.17}_{-0.07}$	[0.81, 1.20]
ϕ (°)	–	$0.09^{+0.33}_{-0.32}$	$-7.2^{+14.7}_{-9.6}$	[−26.6, 15.8]
$\delta_{K\pi\pi}$ (°)	$19.1^{+22.8}_{-23.5}$	$20.2^{+23.1}_{-23.8}$	$28.4^{+24.3}_{-28.8}$	[−26.3, 75.6]
A_π(%)	–	0.02 ± 0.13	$0.03^{+0.13}_{-0.14}$	[−0.24, 0.29]
A_K(%)	–	-0.11 ± 0.12	-0.10 ± 0.13	[−0.37, 0.15]
x_{12} (%)	–	$0.46^{+0.12}_{-0.13}$		[0.19, 0.69]
y_{12} (%)	–	0.62 ± 0.07		[0.47, 0.76]
ϕ_{12}(°)	–	$-0.25^{+0.90}_{-0.94}$		[−2.5, 1.7]

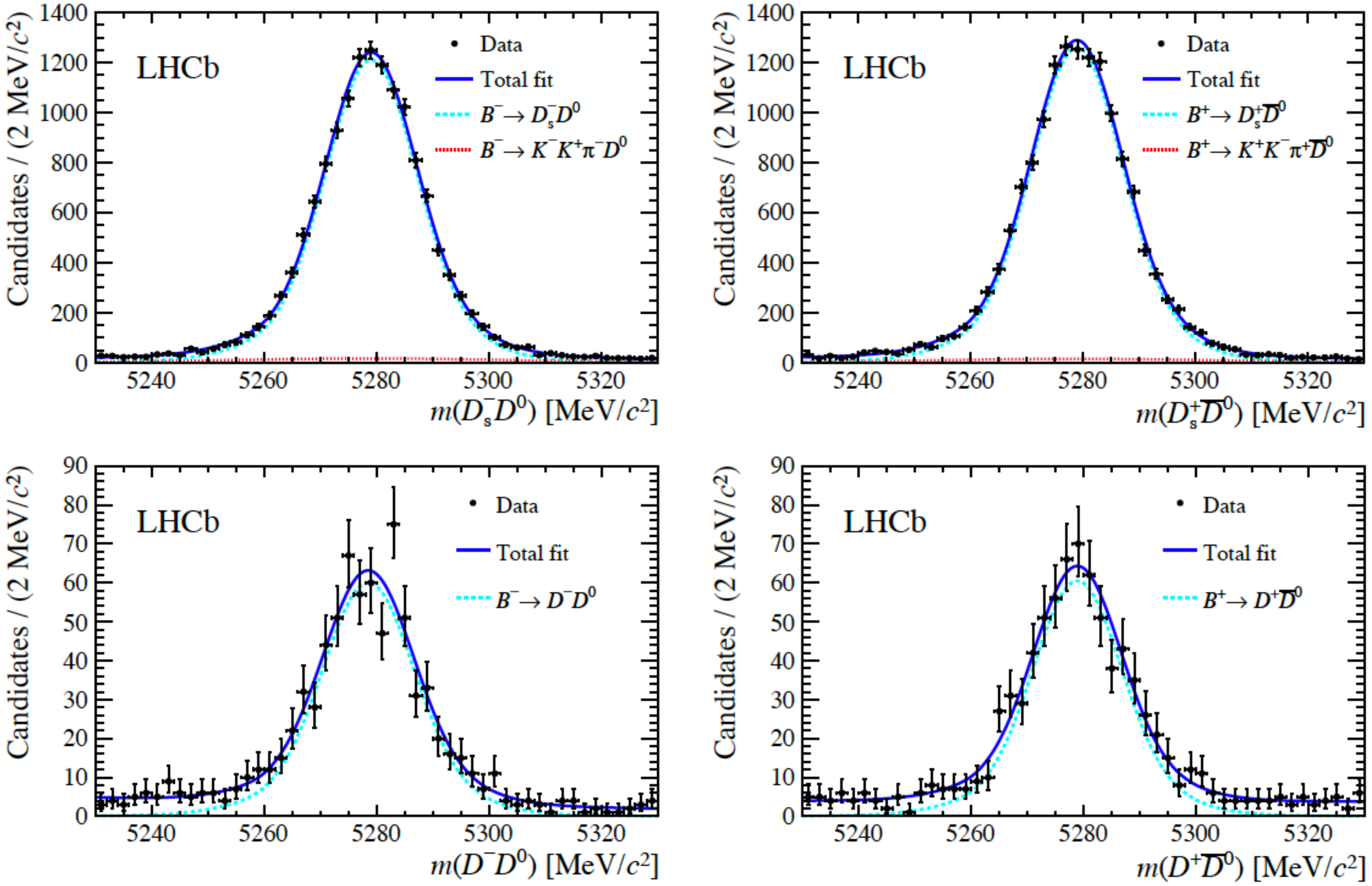
CPV in B→Charm

LHCb JHEP 1806 (2018) 084
LHCb JHEP 1805 (2018) 160

- LHCb exploring new methods for Φ_3 determination.
- New time-dependent measurements in $B \to D\pi$ $(2\Phi_1 + \Phi_3)$ and $B_s \to D_s K$ $(\Phi_s - \Phi_3)$ respectively



Measurement of CP violation in $B^0 \to D^{\mp}\pi^{\pm}$ decays



$$\mathcal{A}^{CP}(B^- \to D_s^- D^0) = (-0.4 \pm 0.5 \pm 0.5)\%$$
$$\mathcal{A}^{CP}(B^- \to D^- D^0) = (\ \ 2.3 \pm 2.7 \pm 0.4)\%$$

Measurement of the CP asymmetry in $B^- \to D_s^- D^0$ and $B^- \to D^- D^0$ decays