Summary and Vision for Flavour Physics

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Beauty 2020 Online
Kavli IPMU, The University of Tokyo

Experiments @ Beauty 2020

ATLAS EXPERIMENT

LHCb

Belle II

BESIII

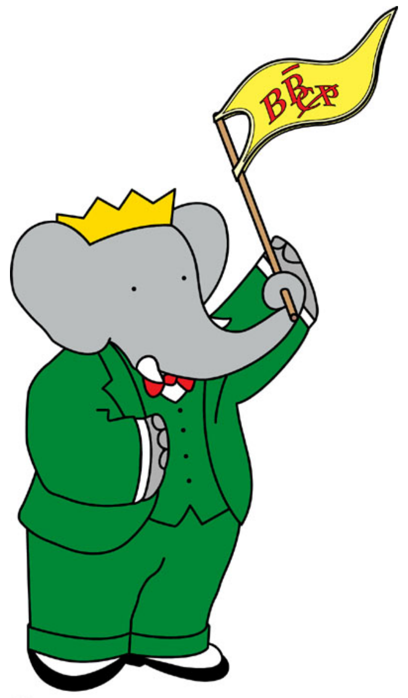
KOTO

CMS

Belle

NA62

ALICE



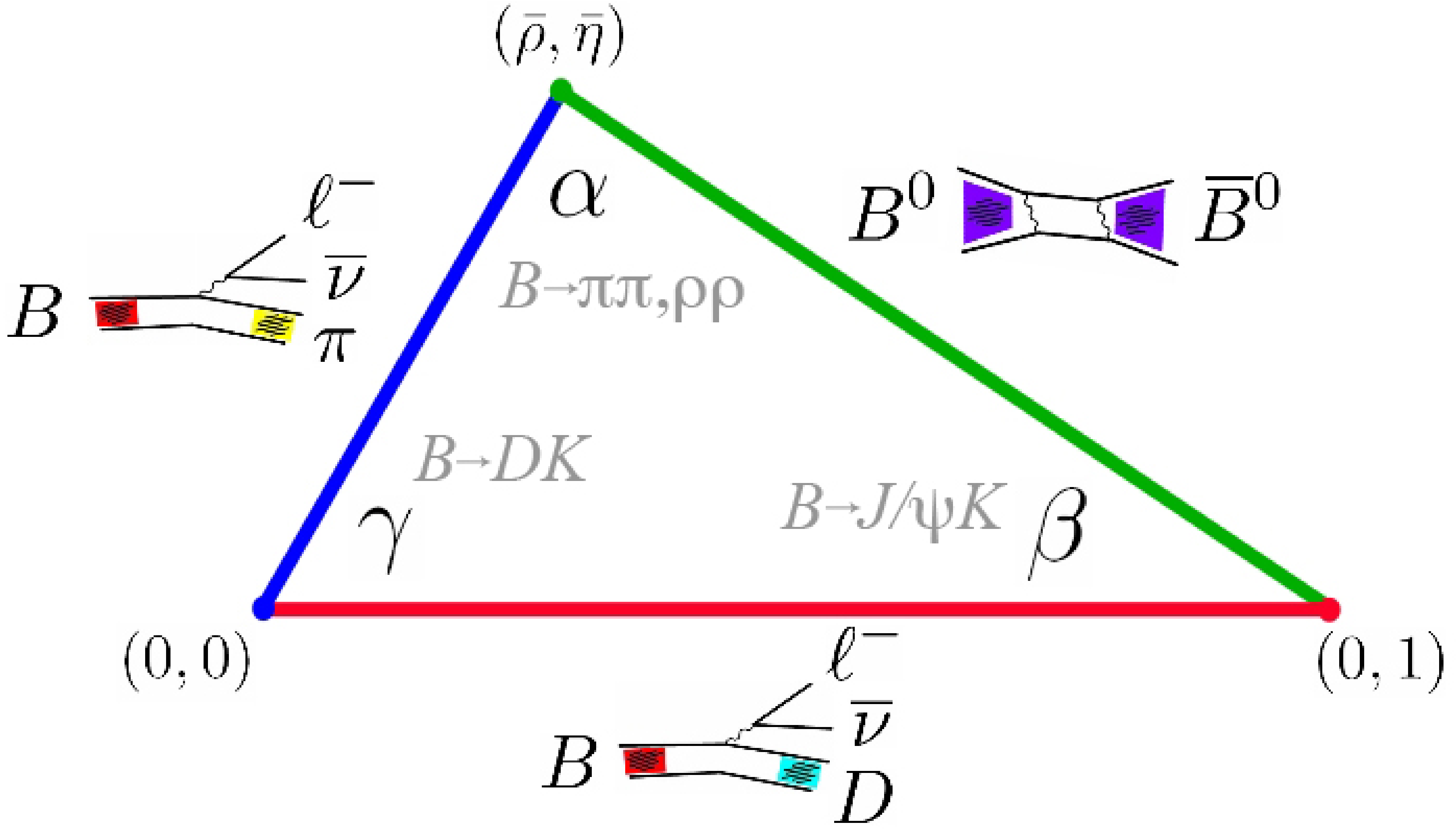
Flavour Programs

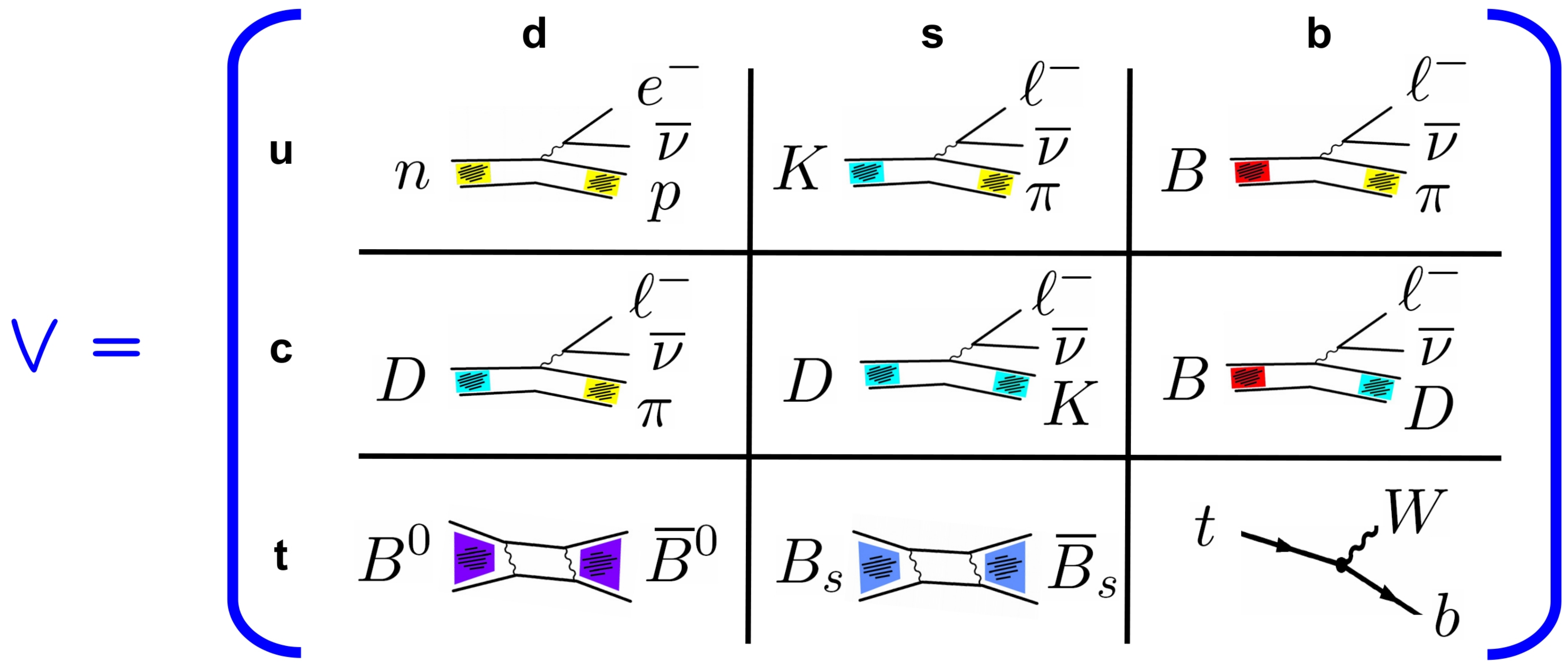
- **Are there new CP-violating phases in the quark sector? (Why is the Universe missing all its antimatter?).**
  - *Quark mixing in B decays, searches for new sources of CP violation, CKM precision metrology.*
  - *Need to disentangle strong phases.*
- **Does nature have multiple Higgs bosons? (Why is there a mass hierarchy in fermions)**
  - *Semileptonic and Leptonic B decays, lepton flavour universality violation.*
  - *Good "detection universality" (e.g. leptons) to tackle anomalies.*
- **Does nature have a L–R symmetry?**
  - *Radiative and Semileptonic rare B decays.*
- **Is there a dark sector of particle physics at the same mass scale as ordinary matter?**
  - *Dark photons, axion like particles, and dark matter, via flavour transitions.*
- **Strong interaction dynamics**
  - *(Exotic) Hadron spectroscopy, flavour production processes.*

Presentation Outline

1. CP Violation
2. CKM elements
3. Rare decays
4. Dark Sector
5. Spectroscopy and exotic states
6. Outlook

CKM and CPV SM Metrology: B core program





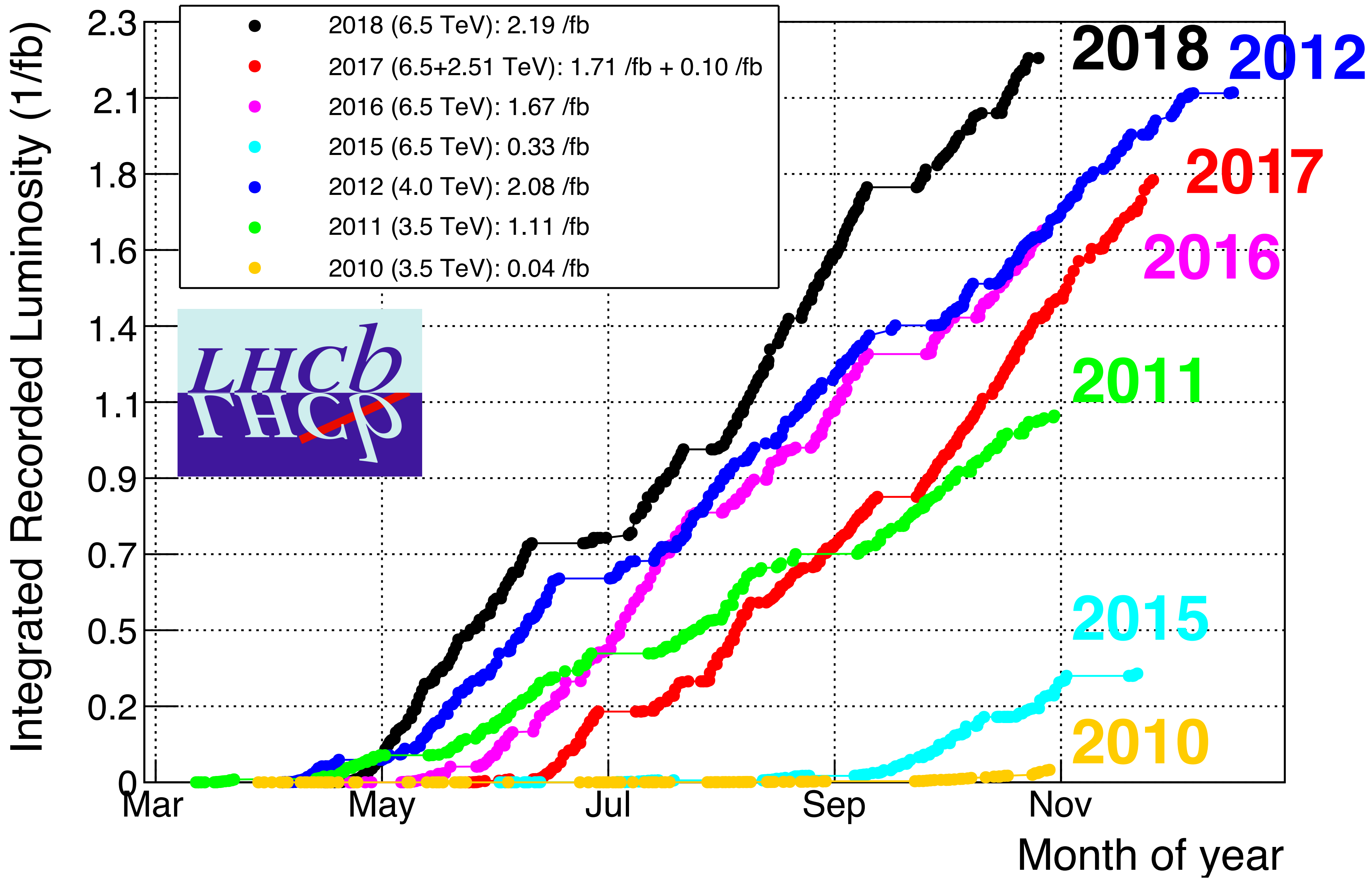
$B \to \pi\pi, \rho\rho$	**Φ_2**	$B \to D\, l\, \nu$ / $b \to c\, l\, \nu$	$|\mathbf{V_{cb}}|$ via Form factor / OPE
$B \to D^{(*)} K^{(*)}$	**Φ_3**	$B \to \pi\, l\, \nu$ / $b \to u\, l\, \nu$	$|\mathbf{V_{ub}}|$ via Form factor / OPE
$B \to J/\psi K_s$	**Φ_1**	$M \to l\, \nu\, (\gamma)$	$|\mathbf{V_{UD}}|$ 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**	$\Delta m_d, \Delta m_s$	$|\mathbf{V_{tb}\, V_{t\{d,s\}}}|$ via Bag factor B_B
		$B_{(s)} \to \mu^+ \mu^-$	$|\mathbf{V_{t\{d,s\}}}|$ via Decay constant f_B

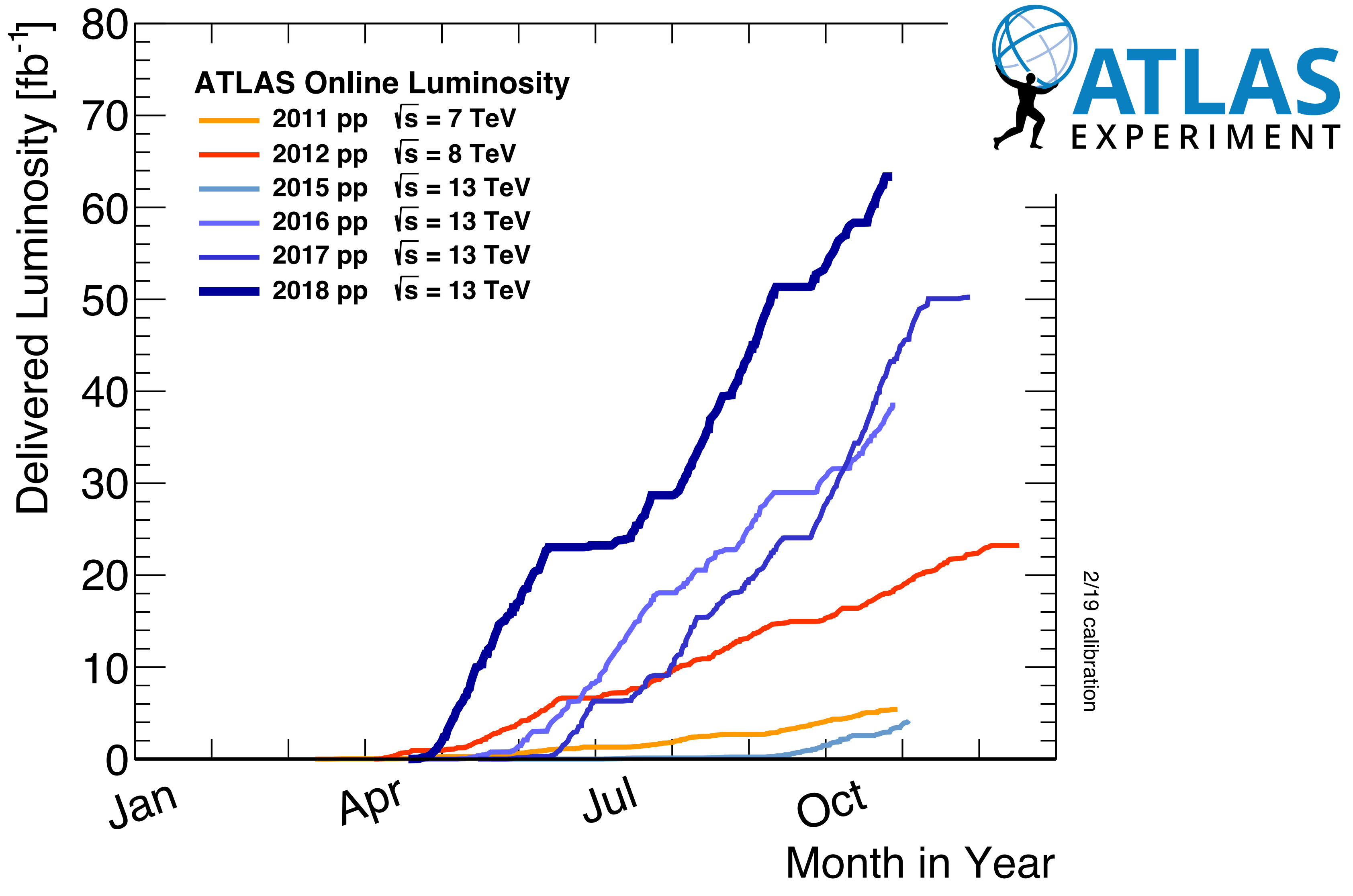
Observables with very different properties

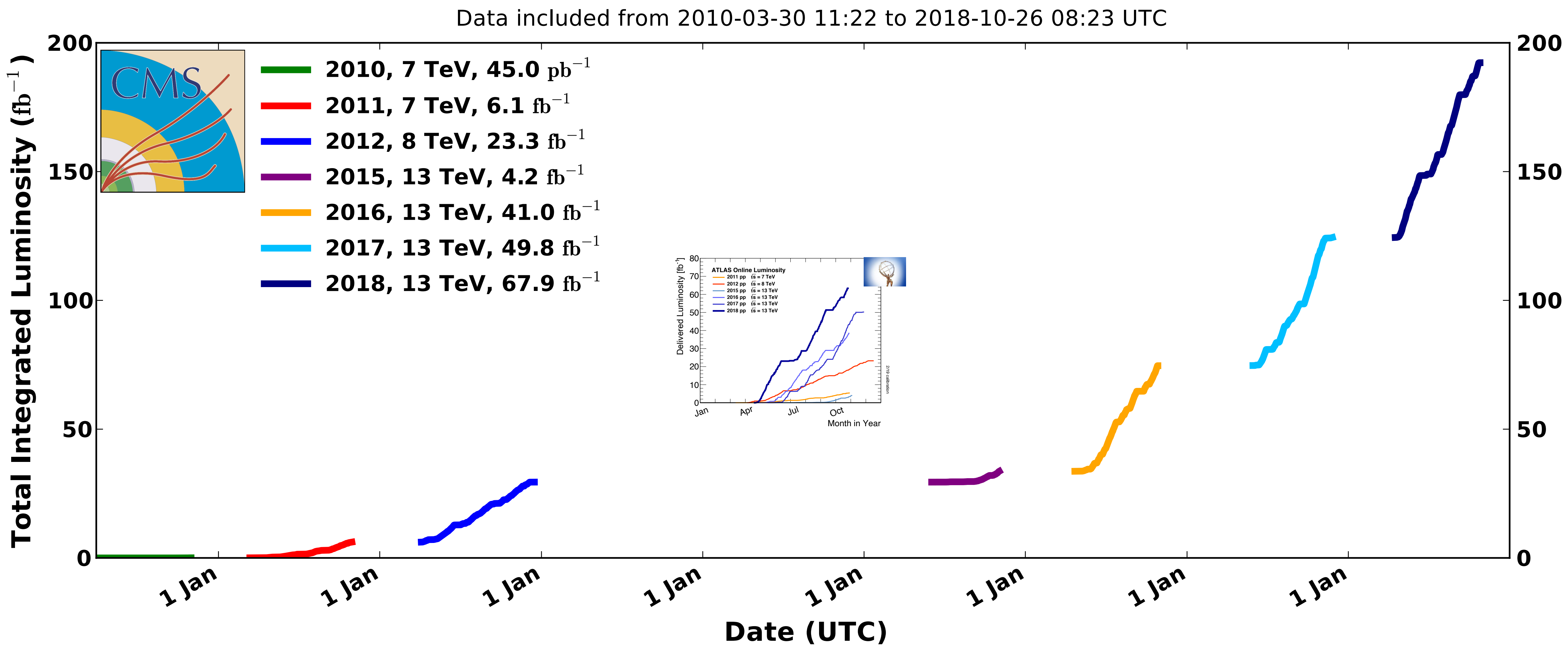
Tree: e.g., $|V_{ub}|/|V_{cb}|$, Φ_3
Loop: e.g., Δm_d , Δm_s , ε_K , $\sin(2\Phi_1)$
CP-conserving: e.g., $|V_{ub}|$, Δm_d, Δm_s
CP-violating: e.g., γ, ε_K , $\sin(2\Phi_1)$

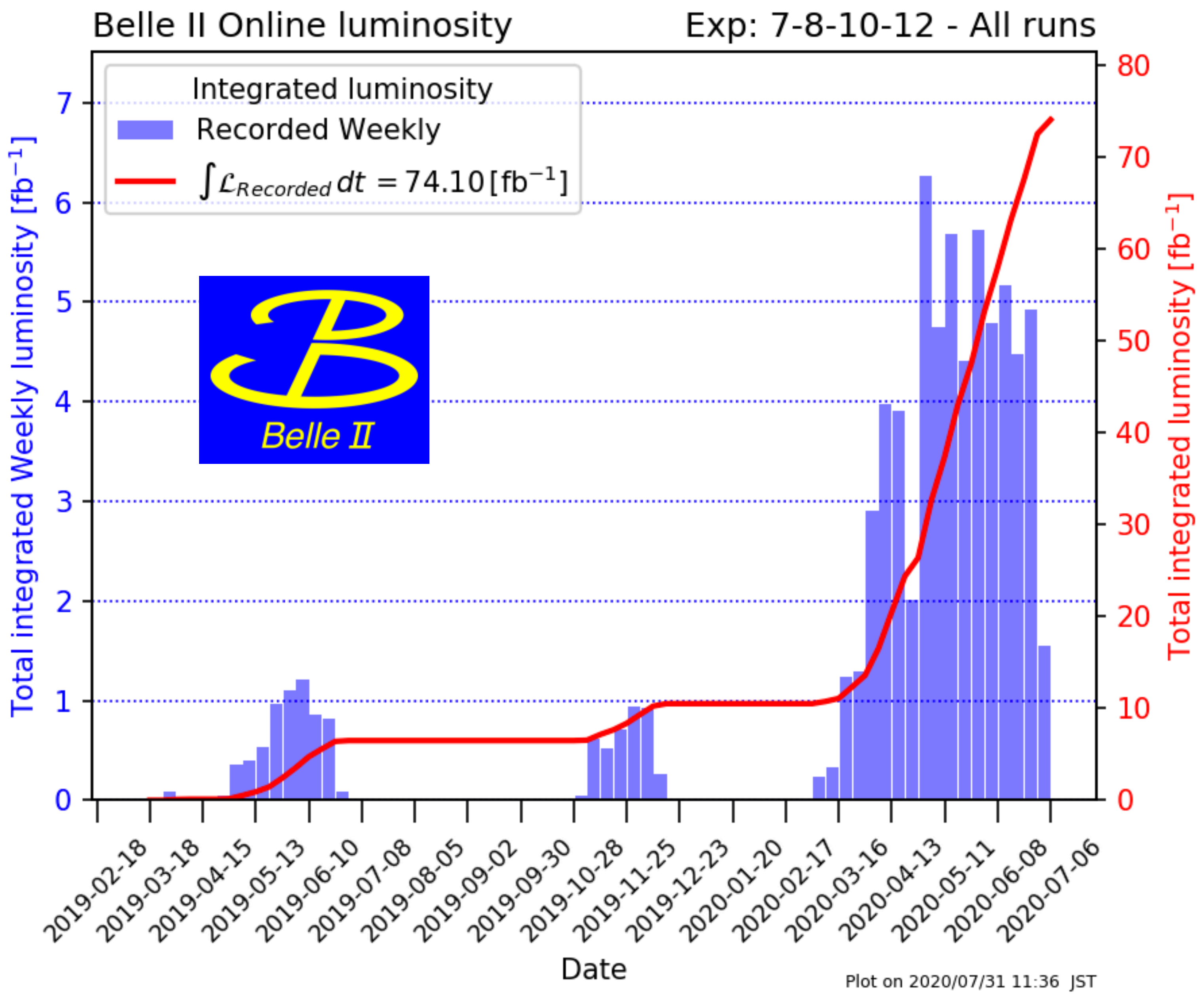
Exp. uncs.: e.g., α, $\sin(2\Phi_1)$, Φ_3
Syst. uncs.: e.g., $|V_{ub}|$, $|V_{cb}|$, ε_K, Δm_d, Δm_s

Integrated Luminosity - B machines









Flavour data sets from colliders

Experiment	**$\int L$ dt: Now**	**$\int L$ dt: 5 years**	**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	**>10 fb^{-1} (50 ab^{-1})**	**15-20 ab^{-1}**	**1.1 nb**	**1.6 nb**	**0.4 nb**	**2018-**
BESIII	~16 fb^{-1}	~30 fb^{-1}	-	6 nb (3770 MeV)	-	2008-
KLOE-2	5.5 fb^{-1}	-	-	-	~3 μb (1020 MeV)	2014-2018
ATLAS	140 fb^{-1}	~300 fb^{-1}	250-500 μb	-	-	2009-
CMS	140 fb^{-1}	~300 fb^{-1}	250-500 μb	-	-	2009-
LHCb	~10 fb^{-1}	23 fb^{-1}	250-500 μb	1200- 2400 μb	(~10^{13} K_S / fb^{-1})	2009-

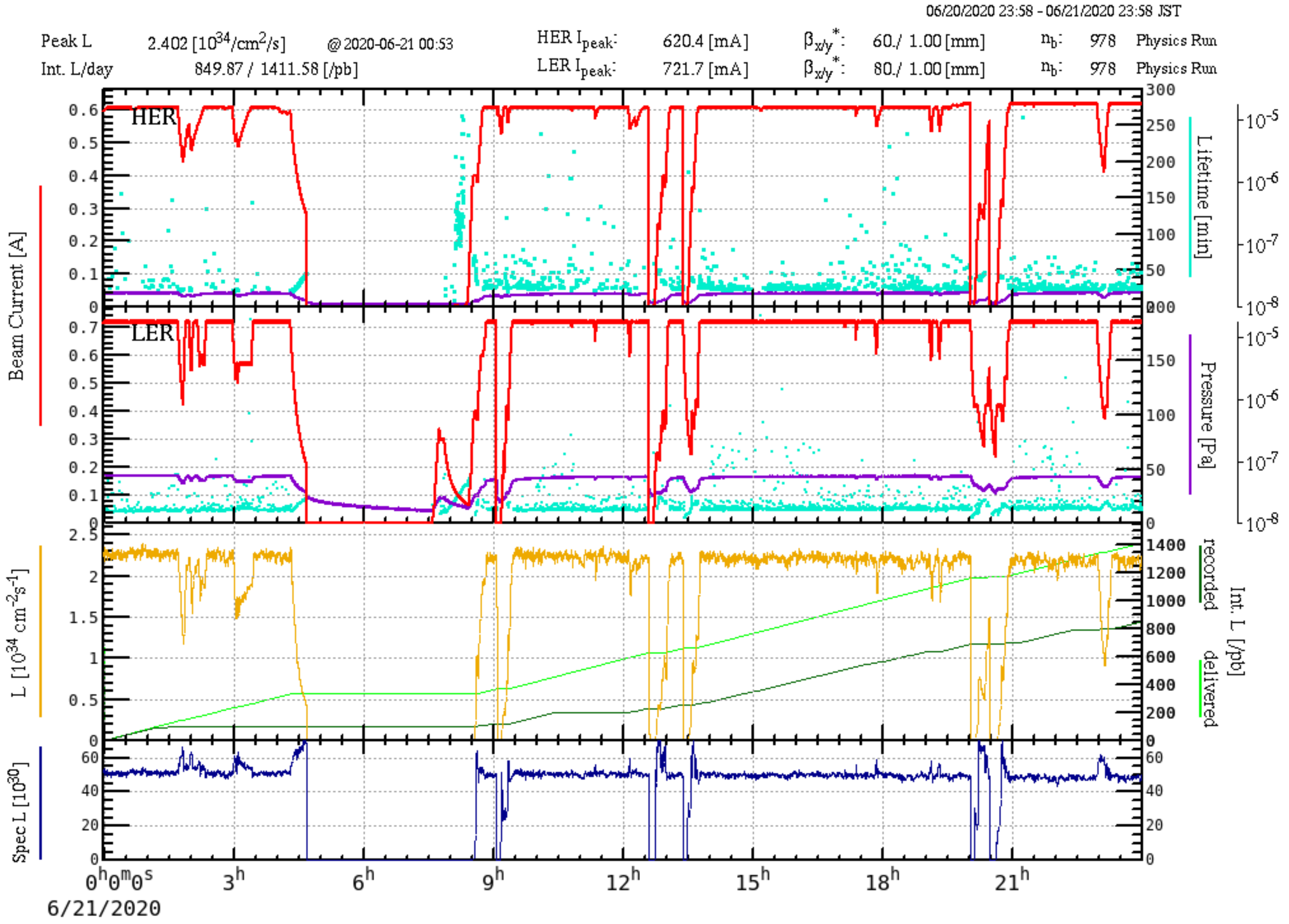
- **Order of magnitude increase in e+e- Υ(4S) dataset.**
- Concurrent advances in lattice QCD will also be crucial for improved precision tests of the SM.
- Also new results from NA62 and KOTO at this conference.

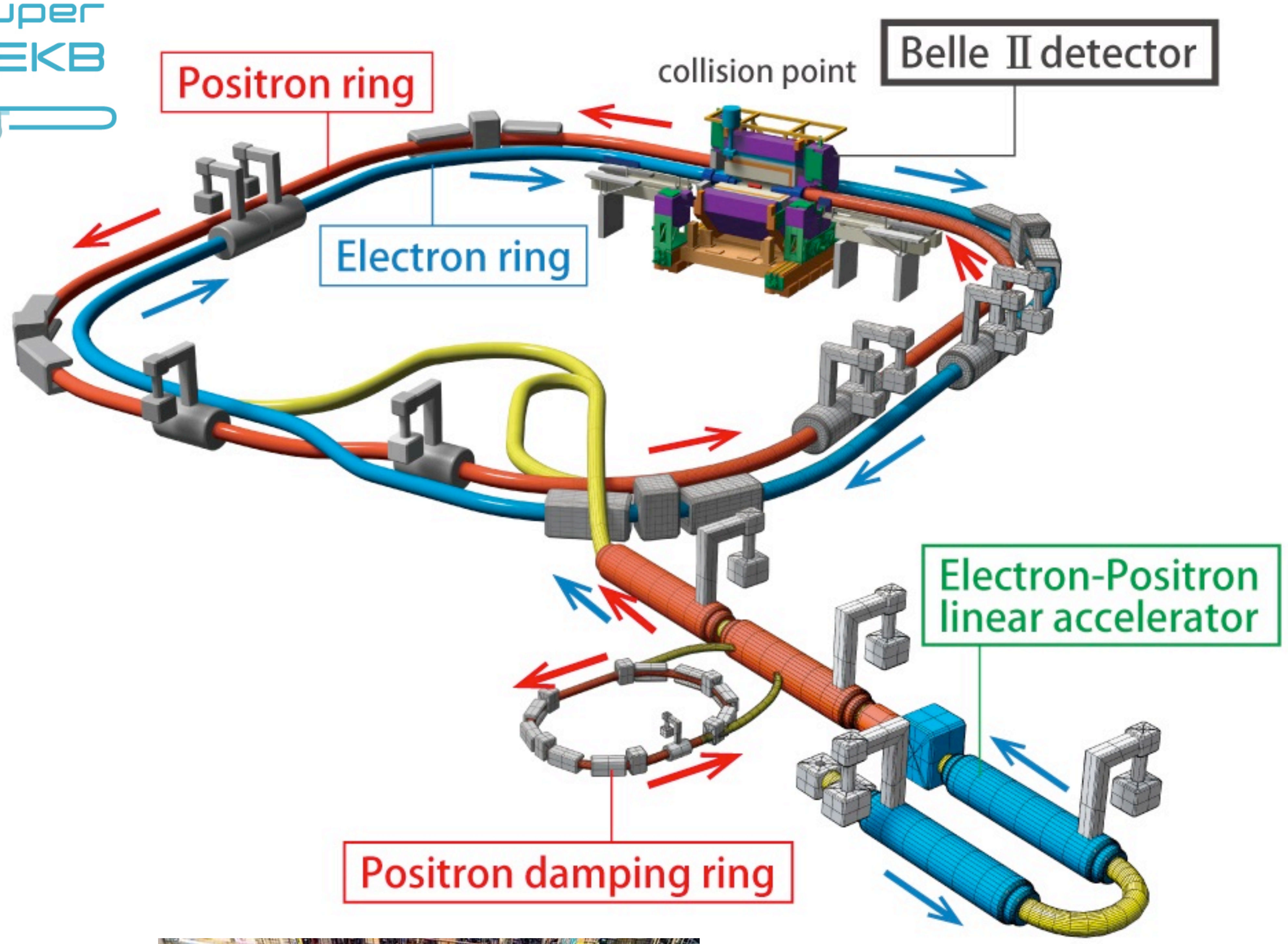
SuperKEKB

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \zeta_{\pm y}}{\beta_y^*}\frac{R_L}{R_y}$$

	KEKB	SuperKEKB	**Achievements**
β^*_y(mm)	5.9/5.9	0.3/0.27	**1/1**
I_{beam}(A)	1.19/1.65	2.6/3.6	**0.7/0.9 ****
L($cm^{-2}s^{-1}$)	2.11x10^{34}	80x10^{34}	**2.4x10^{34}**

SuperKEKB, 21/6/2020





20× smaller beam spot (σ_y=50 nm) but *generally higher beam background*

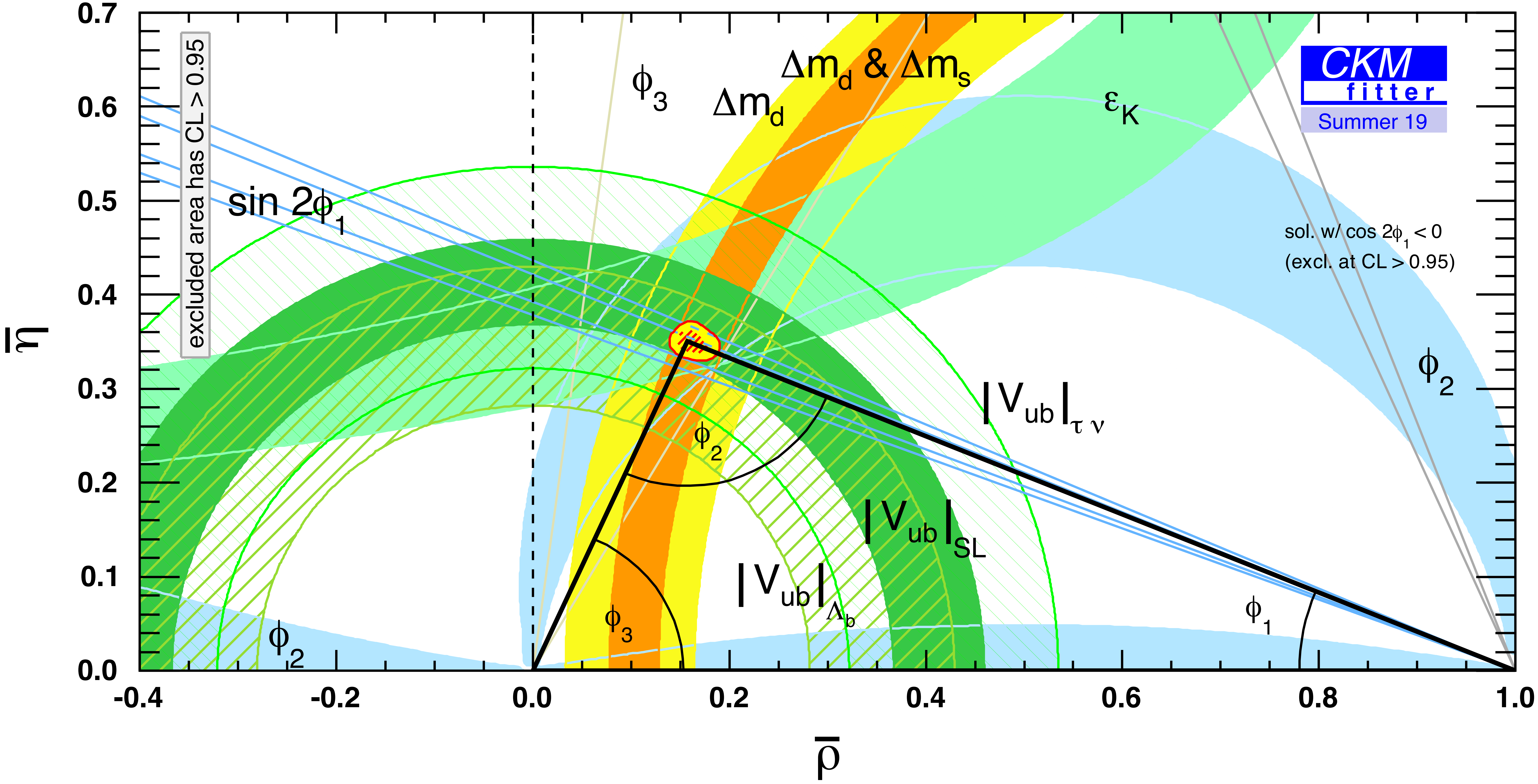
CP Violation

Unitarity triangle angles

B Amplitude analyses

Charm

Current Challenges

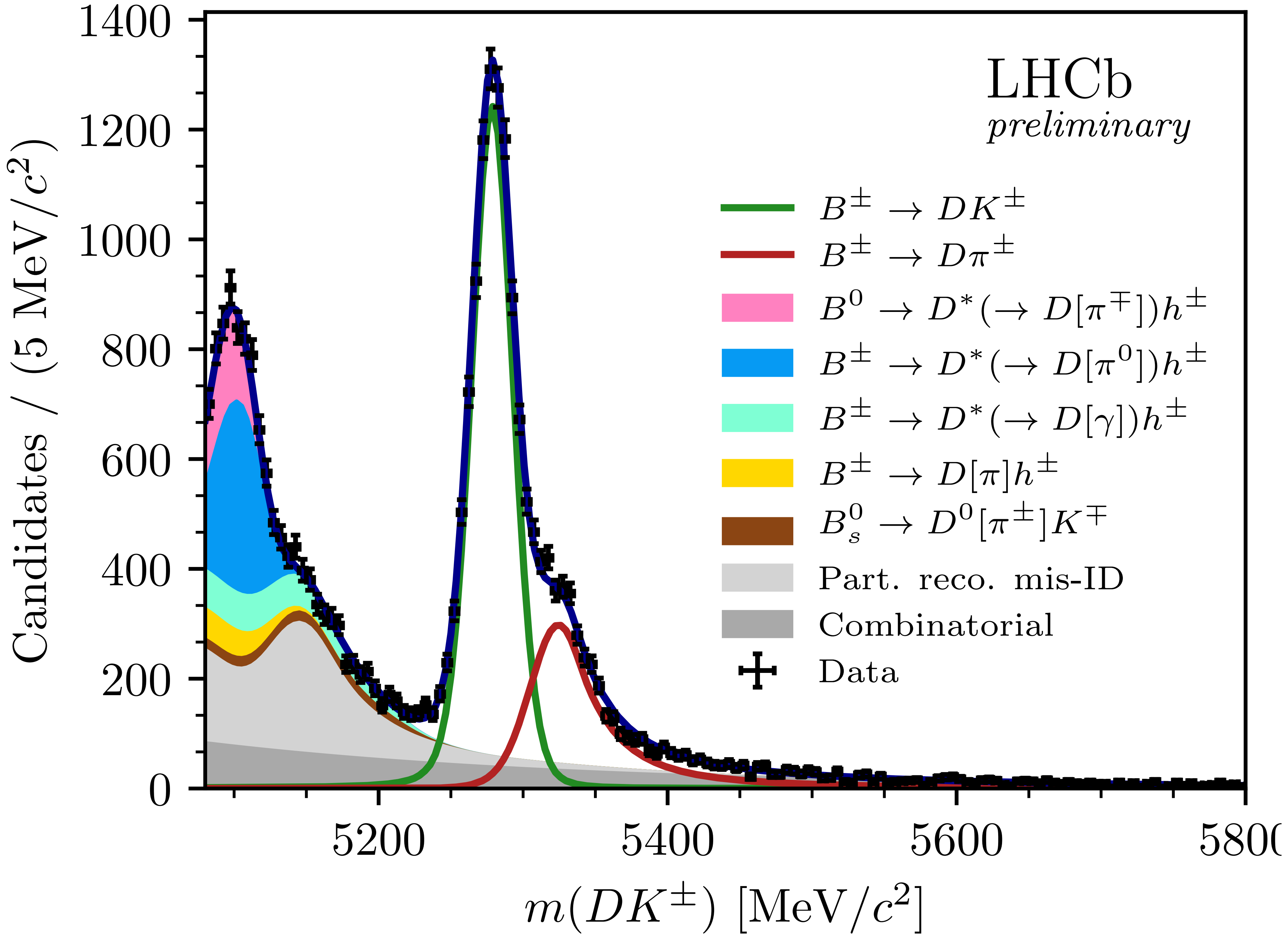


Φ_3 (γ) in BP - GGSZ

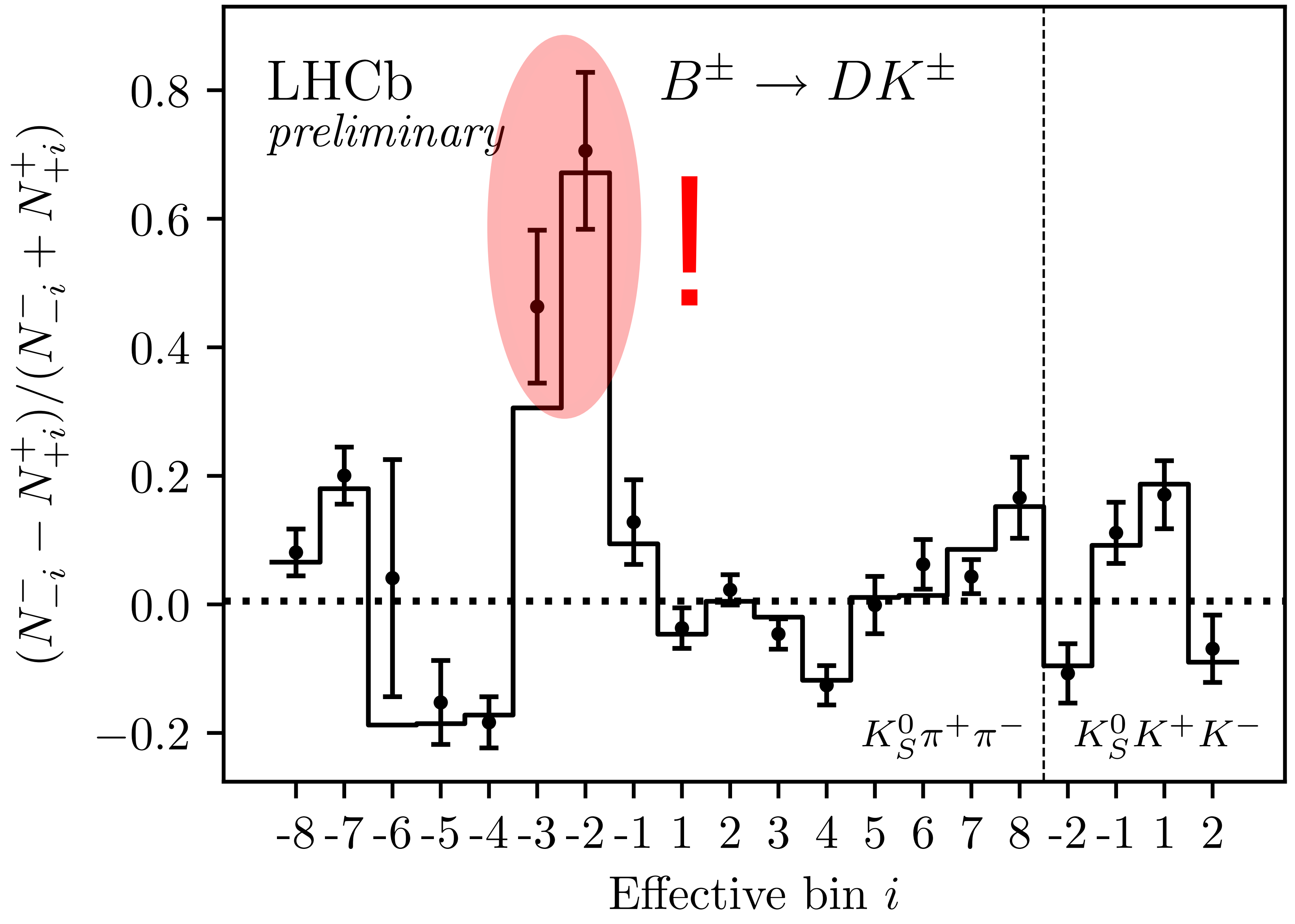
Talk by A. Poluektev

JHEP 06, 40 (2020)
LHCb-CONF-2020-001

$B \to DK,\ D \to K_S^0\pi^+\pi^-$



Dalitz Bins



$$\gamma = (69 \pm 5)^\circ,$$
$$r_B^{DK} = 0.089^{+0.008}_{-0.007},$$
$$\delta_B^{DK} = (118 \pm 6)^\circ,$$
$$r_B^{D\pi} = 0.0048^{+0.0017}_{-0.0016},$$
$$\delta_B^{D\pi} = (287^{+26}_{-27})^\circ.$$

- **Dalitz** plot analysis of D → K_S^0hh from B → Dh (h = K,π) .
- The most precise single measurement. Large local CPV observed.
- LHCb combination of Φ_3 measurements will be updated soon, expect $\sigma(\Phi_3)$ ~ 4○.

Charm inputs to Φ_3

Talk by J. Libby

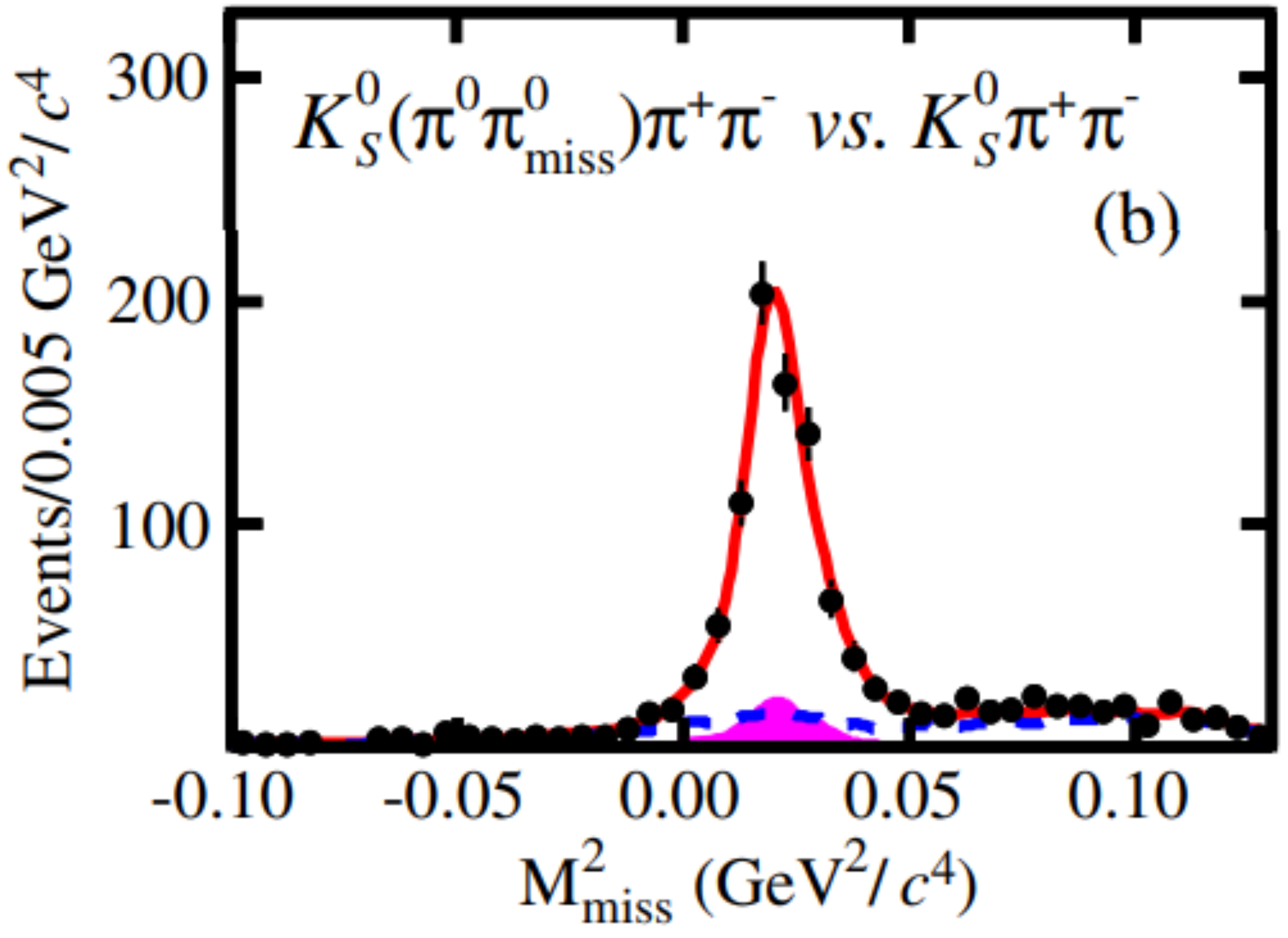
PRL 124, 241802 (2020)
PRD 101, 112002 (2020)

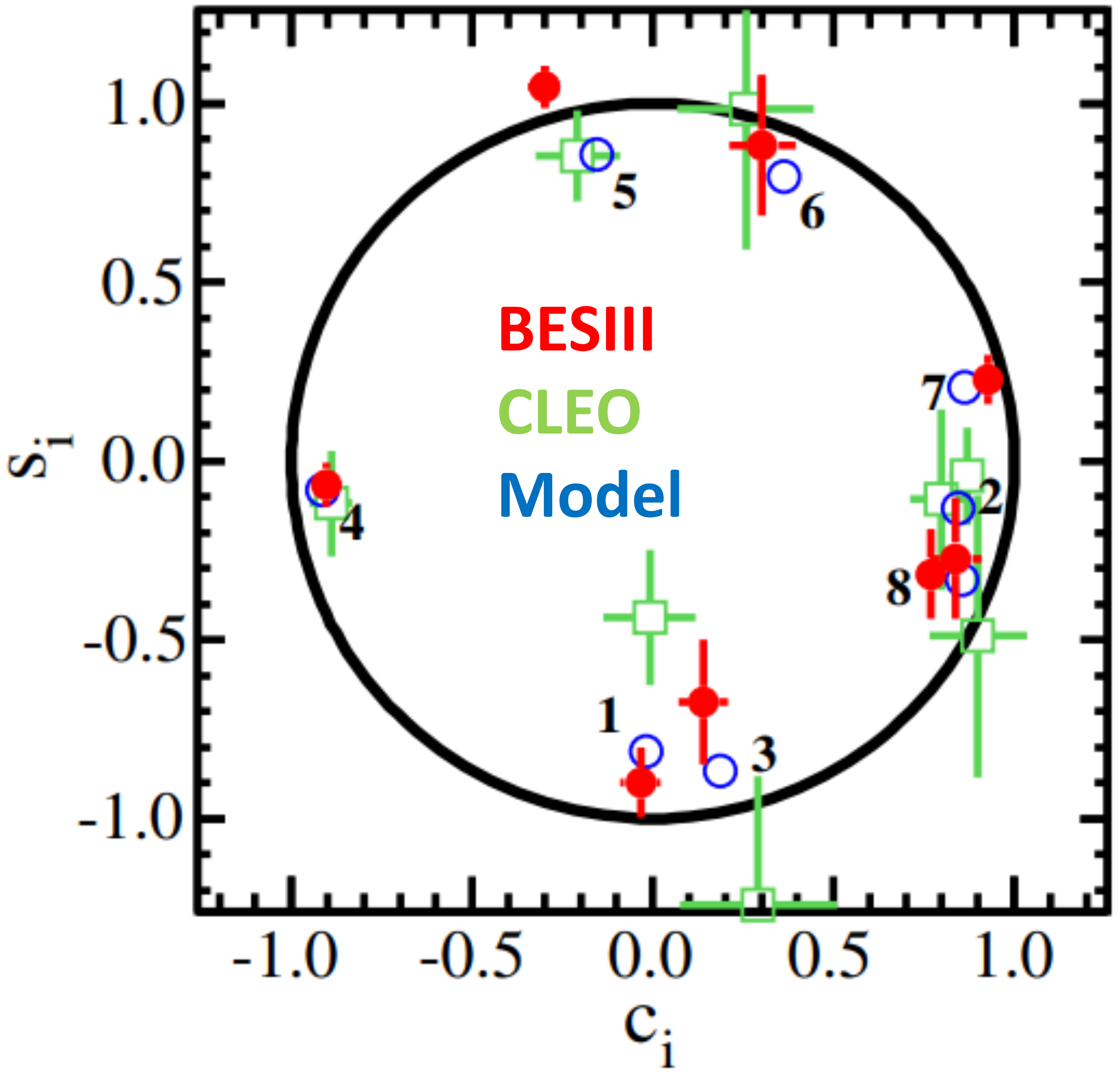
$$N_i^{\pm} = h_{\pm}\left[F_i + (x_{\pm}^2 + y_{\pm}^2)F_{-i} + 2\sqrt{F_i F_{-i}}(x_{\pm}c_i + y_{\pm}s_i)\right]$$

Physics parameters: $x_\pm = r_B \cos(\delta_B \pm \gamma)$, $y_\pm = r_B \sin(\delta_B \pm \gamma)$,
Strong phase parameters: c_i, s_i
Flavour-specific bin yield fractions: F_i , shared between B → DK and B → Dπ

$$
\begin{aligned}
x_-^{DK} &= (5.6 \pm 1.0 \pm 0.2 \pm 0.3) \times 10^{-2},\\
y_-^{DK} &= (6.5 \pm 1.1 \pm 0.3 \pm 0.4) \times 10^{-2},\\
x_+^{DK} &= (-9.2 \pm 1.0 \pm 0.2 \pm 0.2) \times 10^{-2},\\
y_+^{DK} &= (-1.2 \pm 1.2 \pm 0.3 \pm 0.3) \times 10^{-2},\\
x_\xi^{D\pi} &= (-5.3 \pm 2.0 \pm 0.3 \pm 0.2) \times 10^{-2},\\
y_\xi^{D\pi} &= (1.0 \pm 2.3 \pm 0.5 \pm 0.3) \times 10^{-2},
\end{aligned}
$$

exp. syst CLEO, BES-III



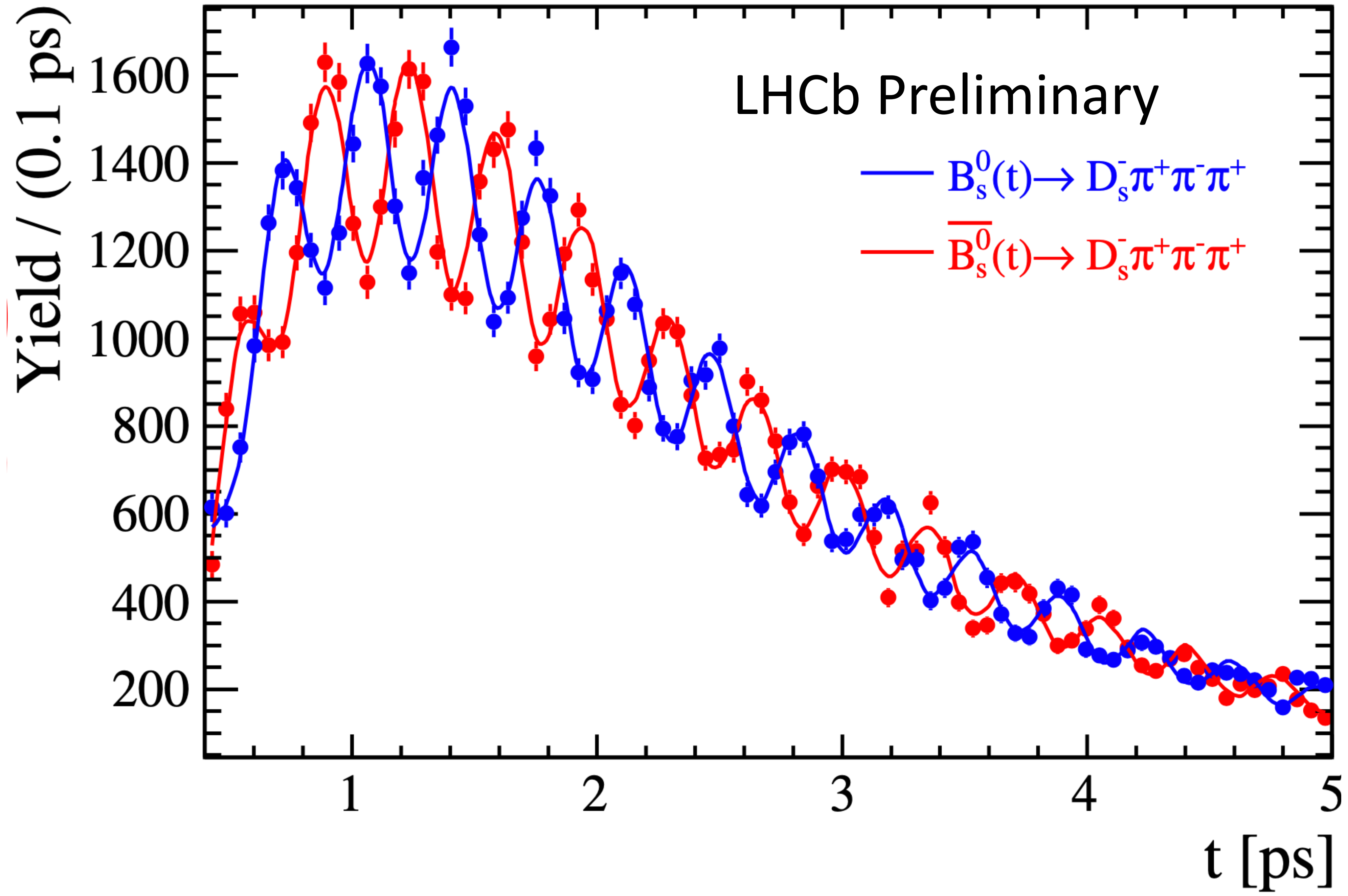


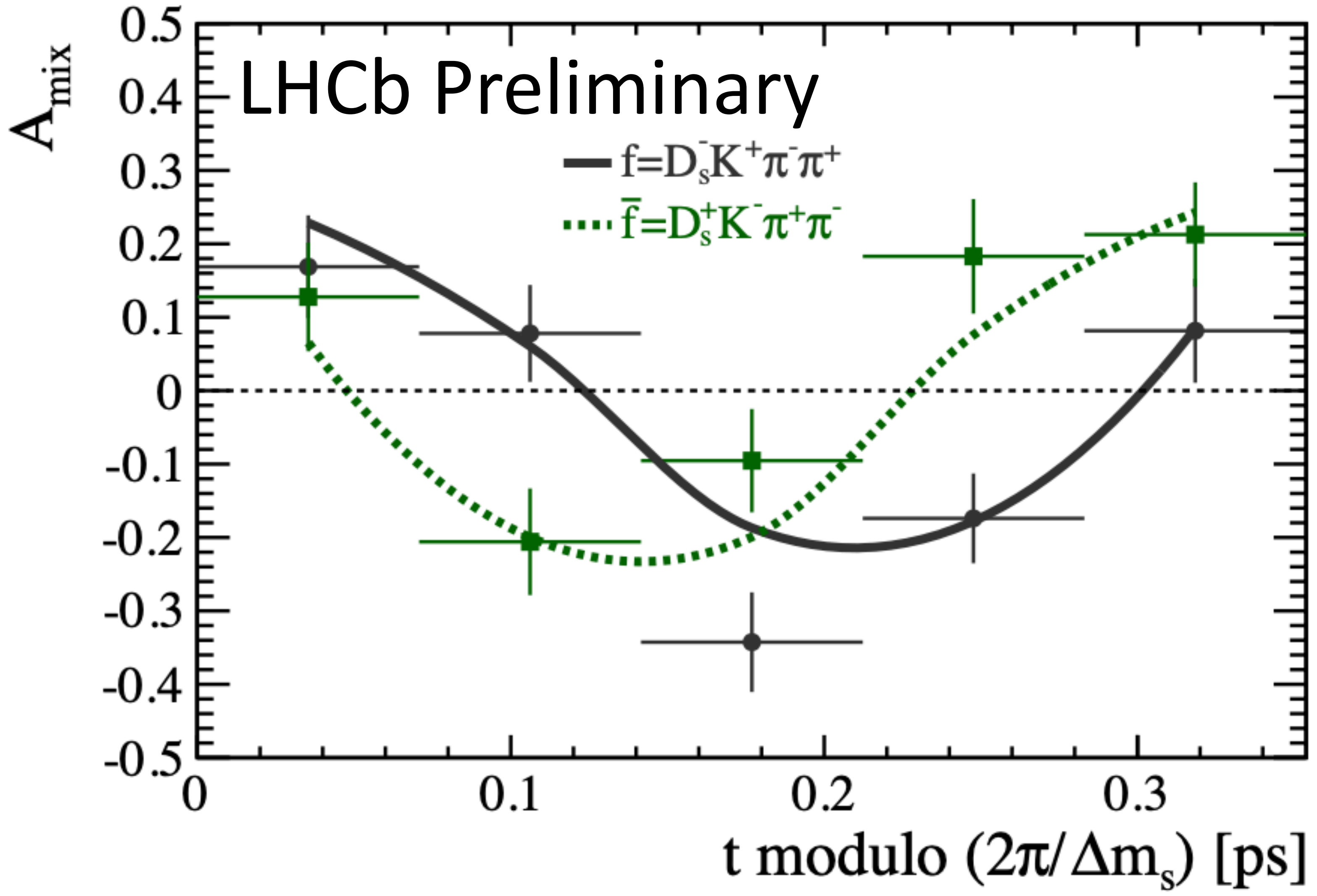
- New generation of c_i and s_i measurements from quantum correlated D decays that result in Φ_3 systematic of 1°.

Φ_3 (γ) from B_s time dependent

Talk by S. Perazzini

LHCb-PAPER-2020-030





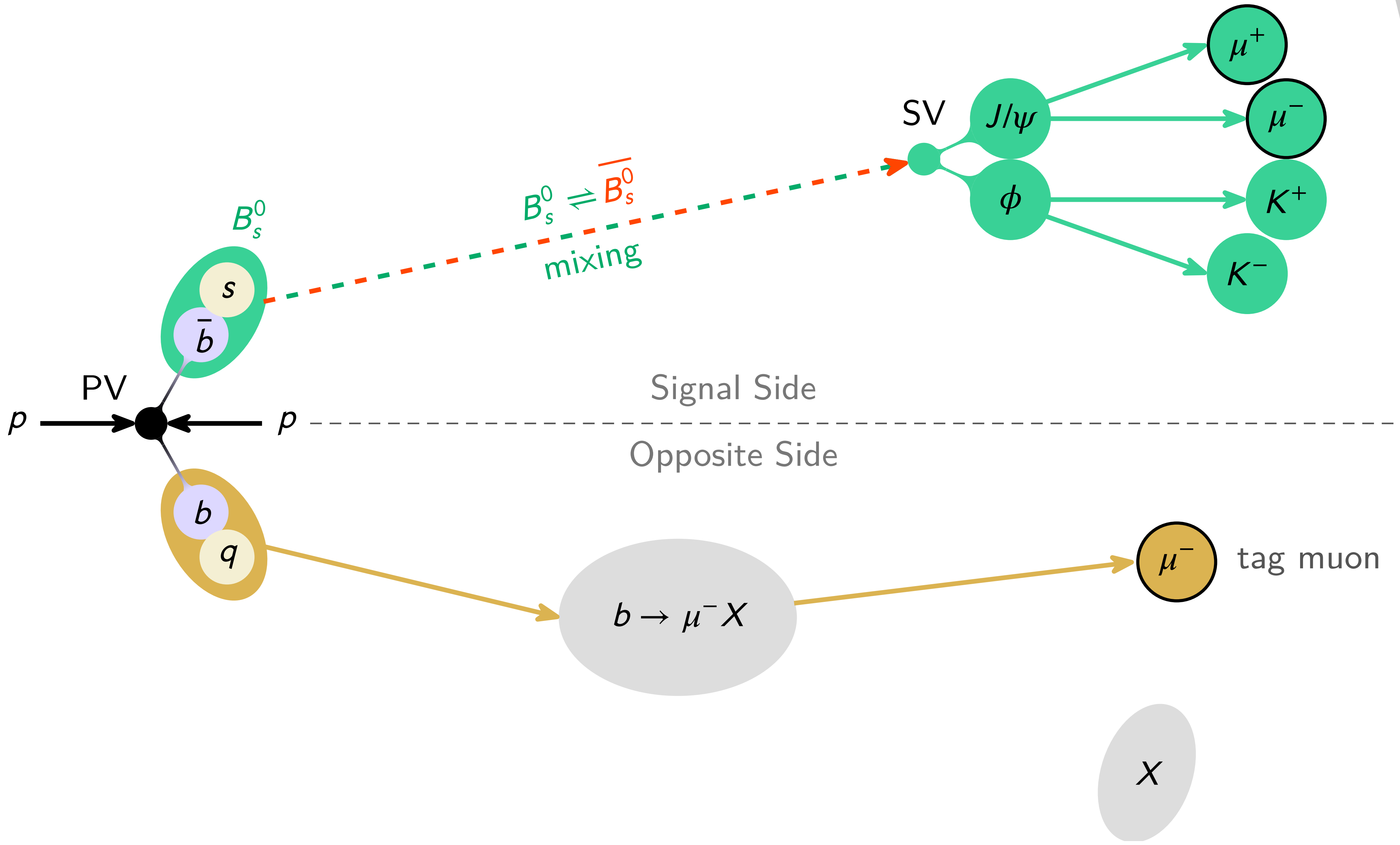
- Measurement of CKM angle Φ_3 from time-dependent amplitude analysis of $B_s \to D_s K\pi\pi$.
- Agrees with WA.

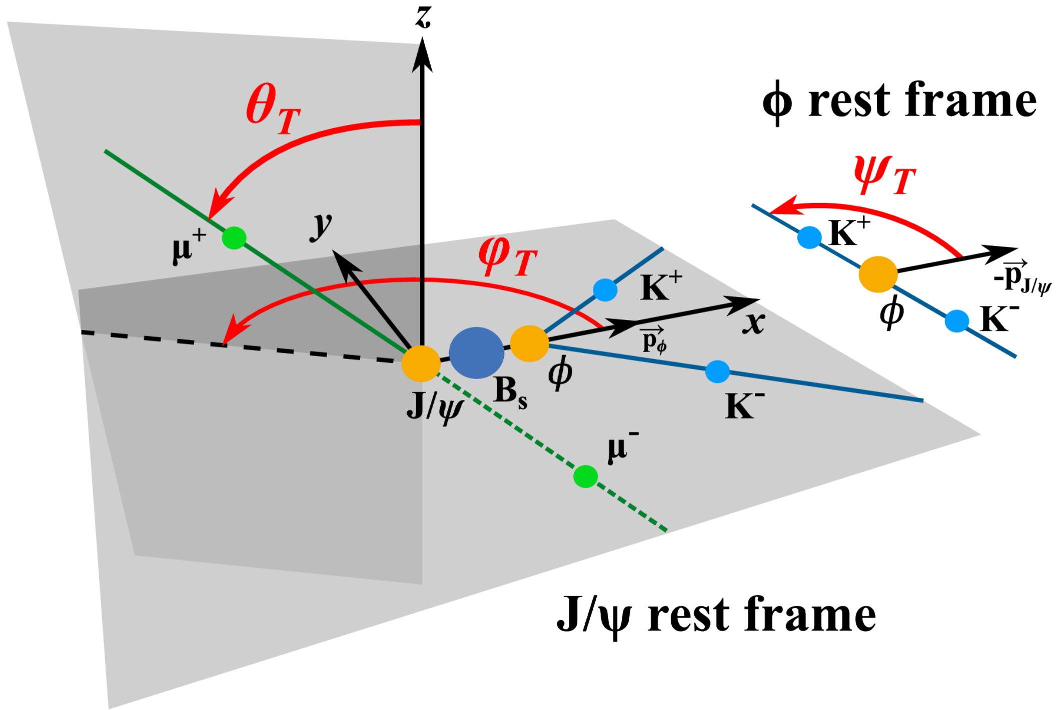
Parameter	Model-independent
r	$0.47^{+0.08}_{-0.08}$
κ	$0.88^{+0.12}_{-0.20}$
δ [°]	-6^{+10}_{-13}
$\gamma - 2\beta_s$ [°]	42^{+20}_{-13}

Φ_s vs $\Delta\Gamma_s$ with $B \to J/\psi\Phi$

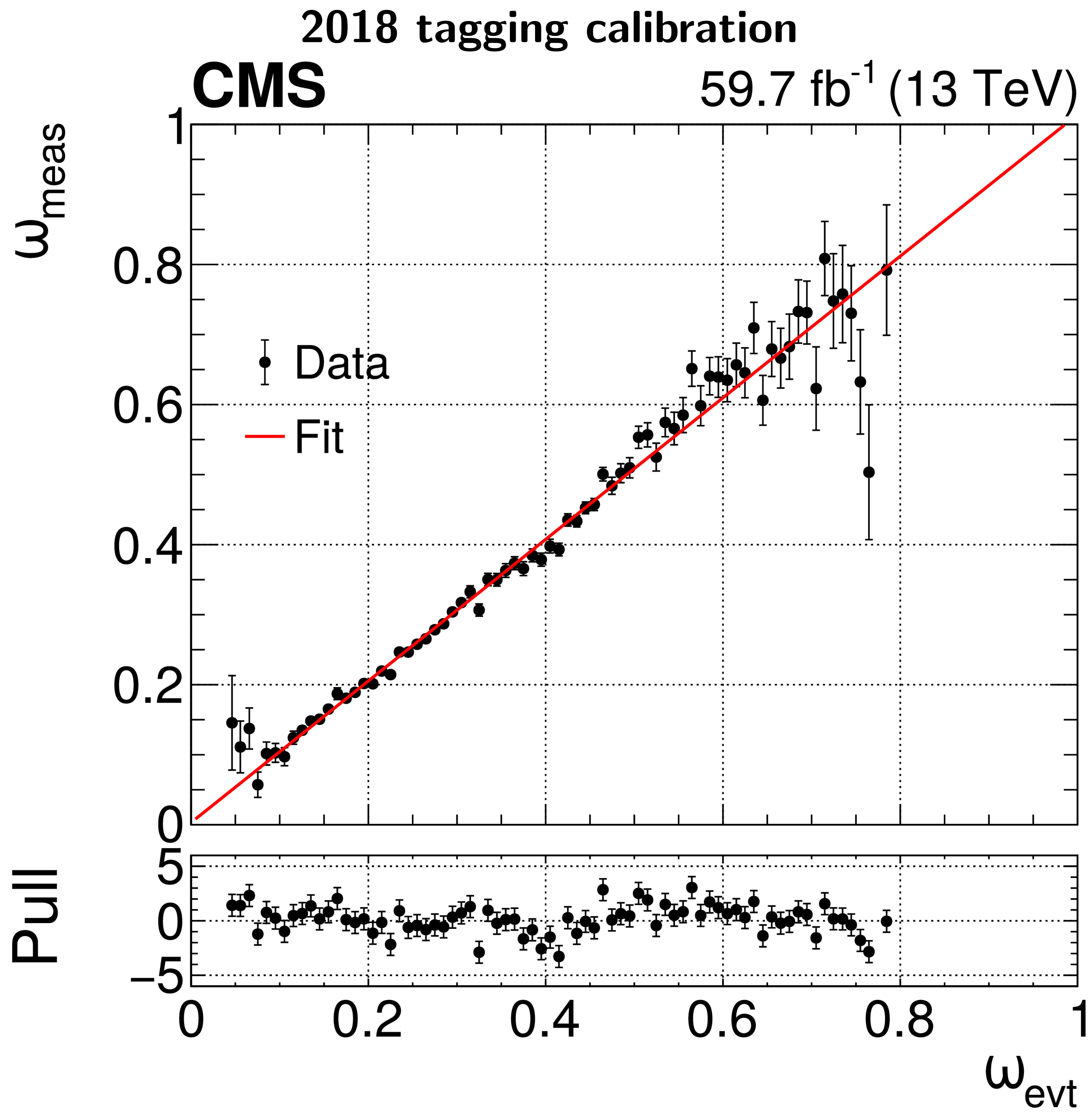
Talks by G. Fedi, S. Simsek

CMS arXiv:2007.02434
ATLAS Preliminary





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

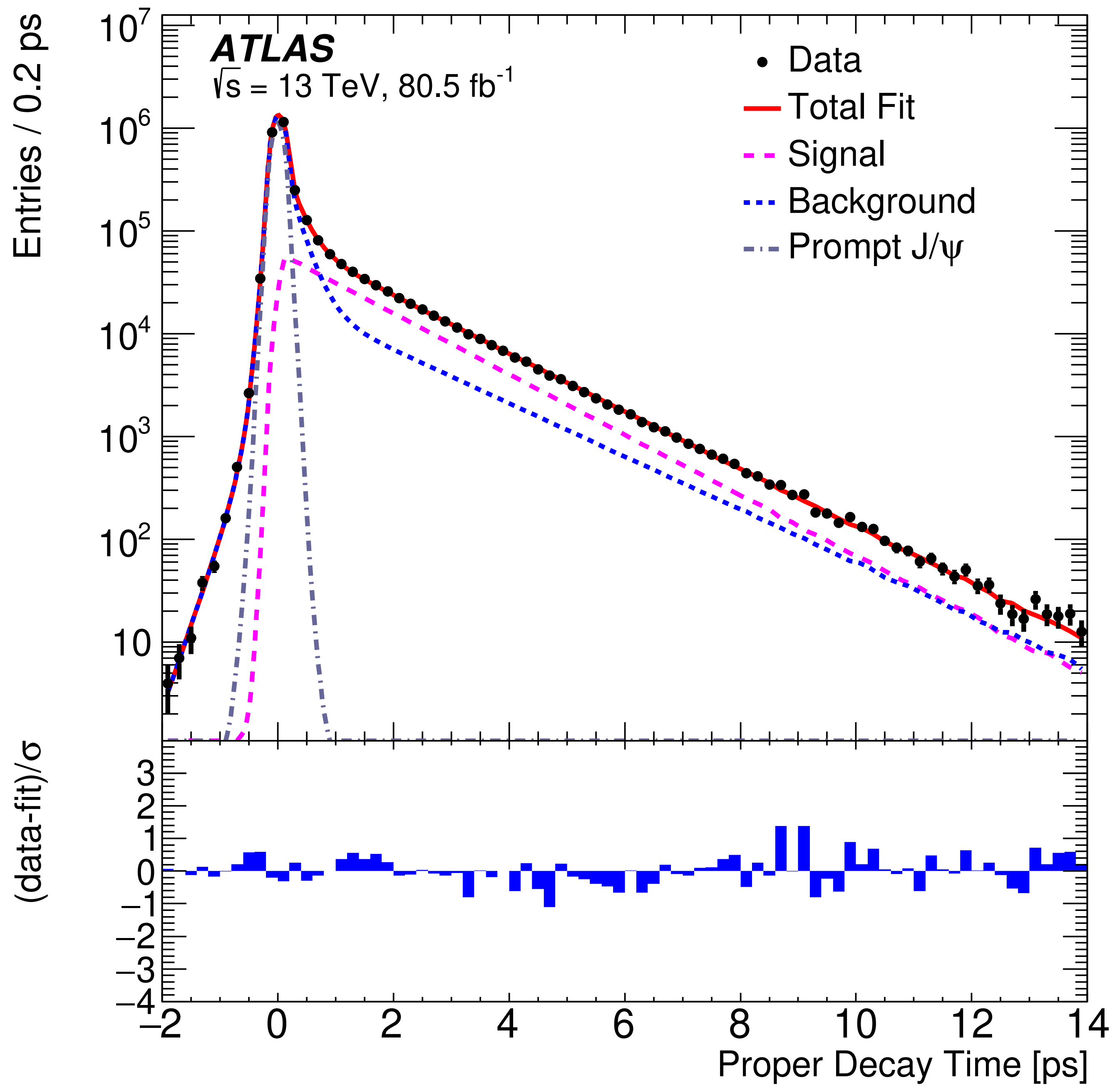


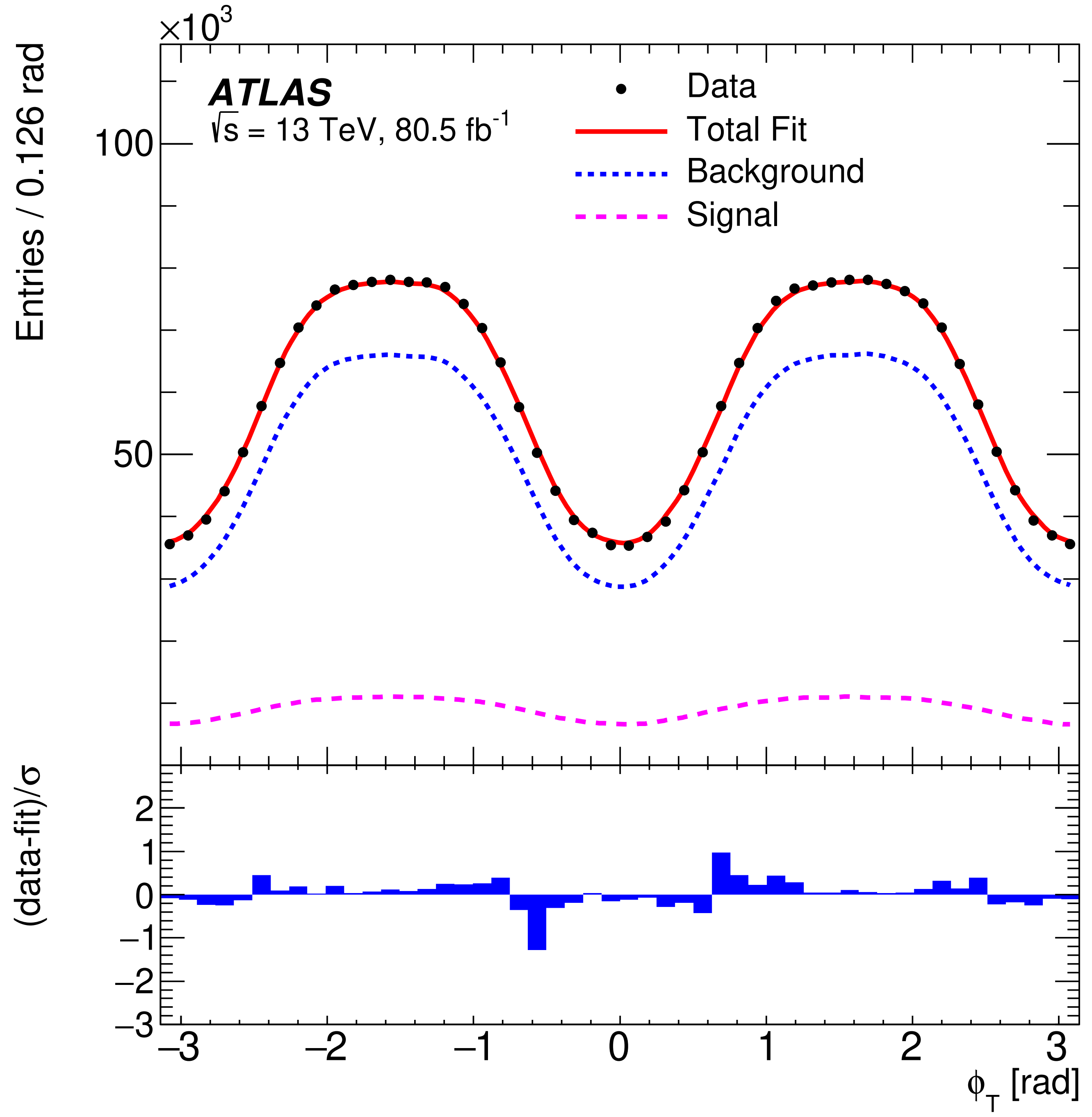
- New studies by ATLAS and CMS with 13 TeV data.
- Angular analyses to disentangle 2 CP eigenstates.
- Small systematics on flavour tagging.

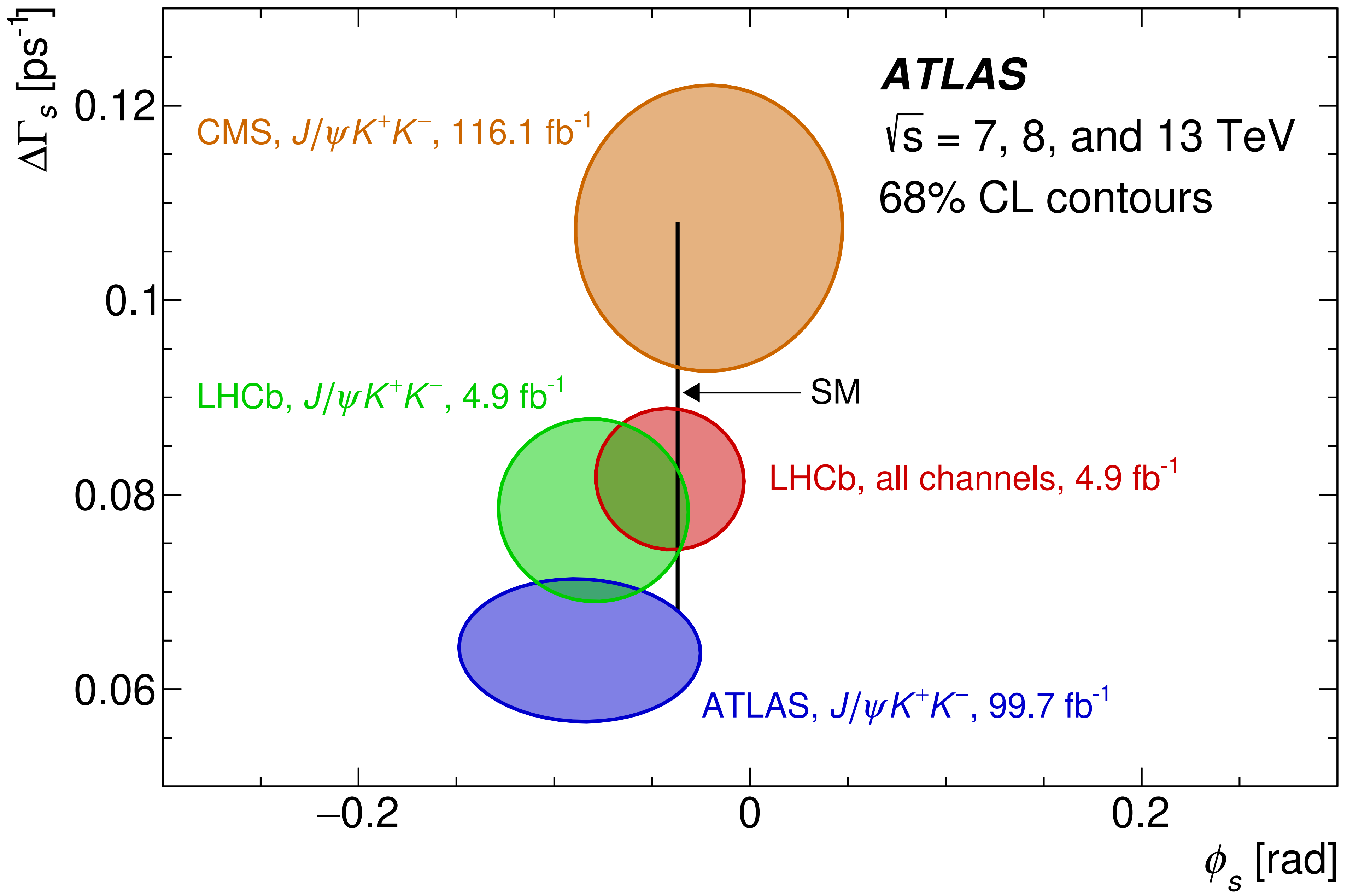
Φ_s vs $\Delta\Gamma_s$ with $B \to J/\psi\Phi$

Talks by G. Fedi, S. Simsek

CMS arXiv:2007.02434
ATLAS Preliminary





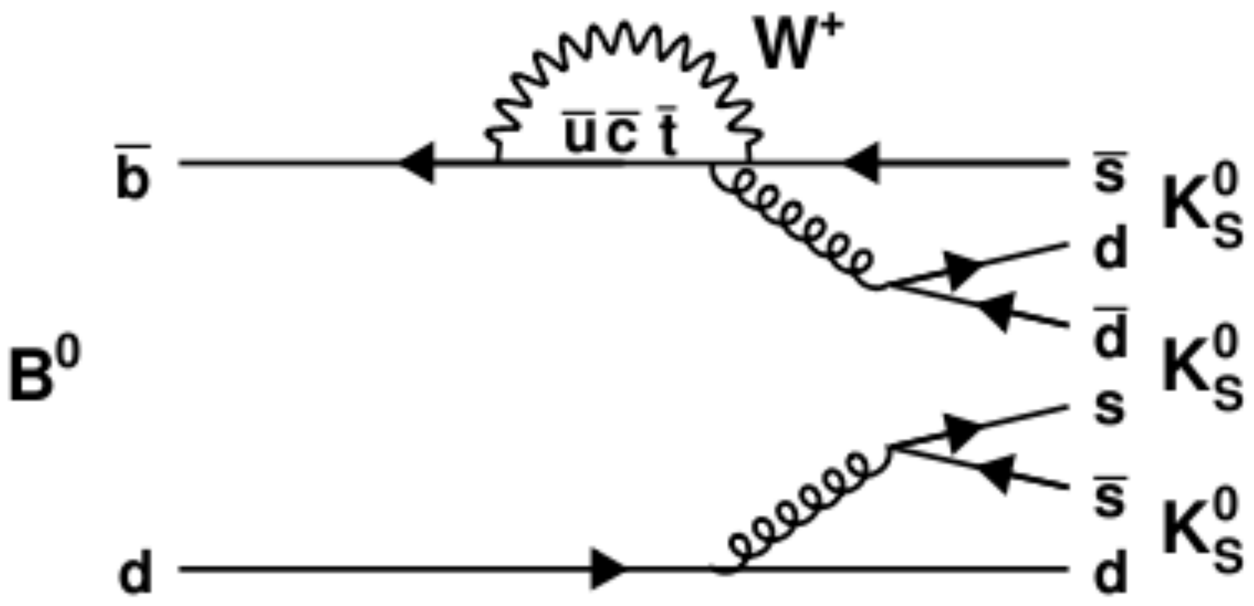


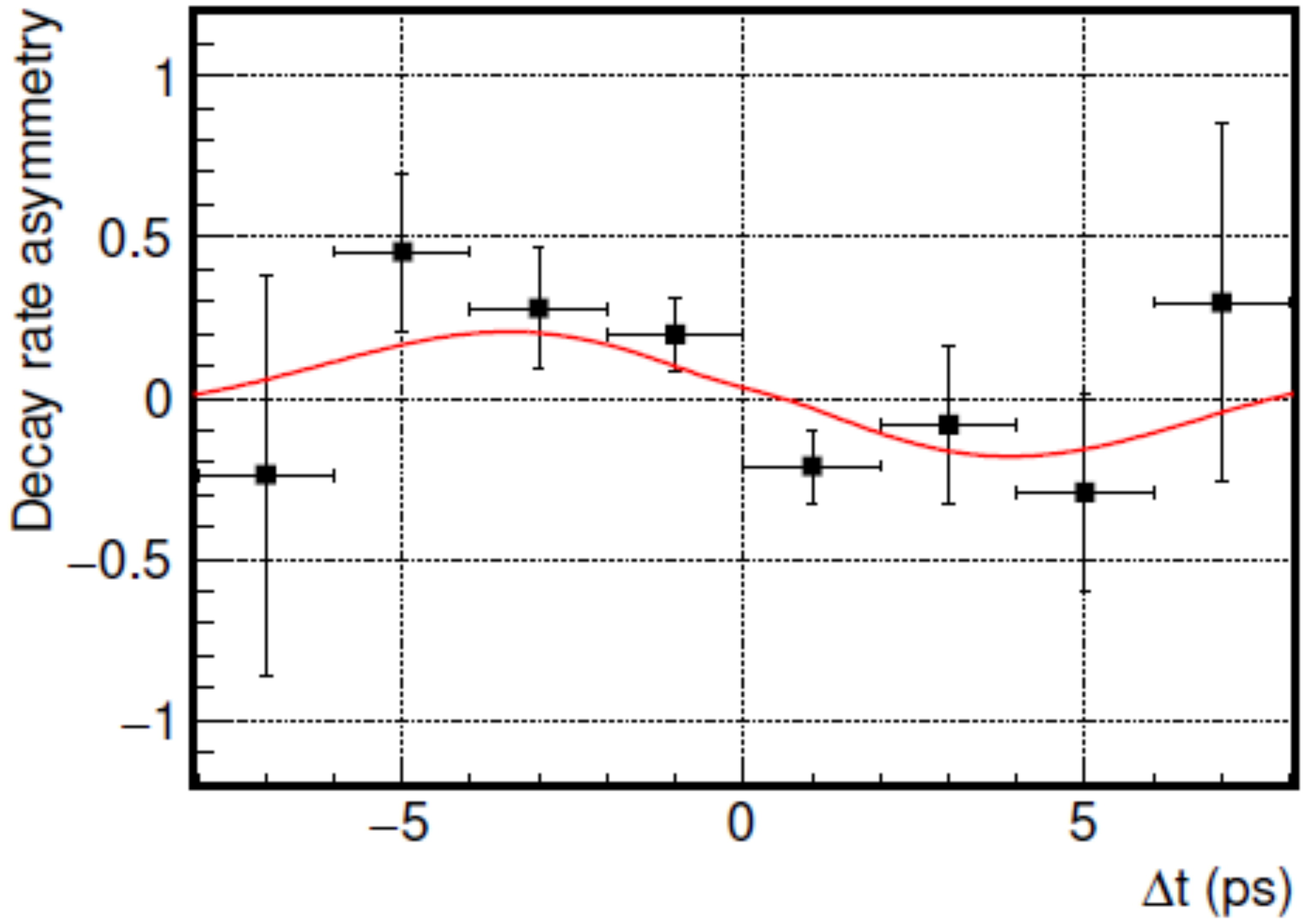
	ϕ_s [rad]
LHC Combined Run 1	-0.021 ± 0.031 (stat)
LHCb 4.9 fb^{-1} EUR. PHYS. J. C 79 (2019)	-0.0042 ± 0.025 (stat)
ATLAS Run 1 JHEP08, 147	-0.090 ± 0.078 (stat) $\pm$ 0.041 (syst)
CMS 96.4 fb^{-1} CMS-PAS-BPH-20-001	-0.021 ± 0.045
ATLAS 2015/16/17 (80.5 fb^{-1}) $\oplus$ Run 1 (19.2 fb^{-1})	-0.087 ± 0.037 (stat) $\pm$ 0.019 (syst)

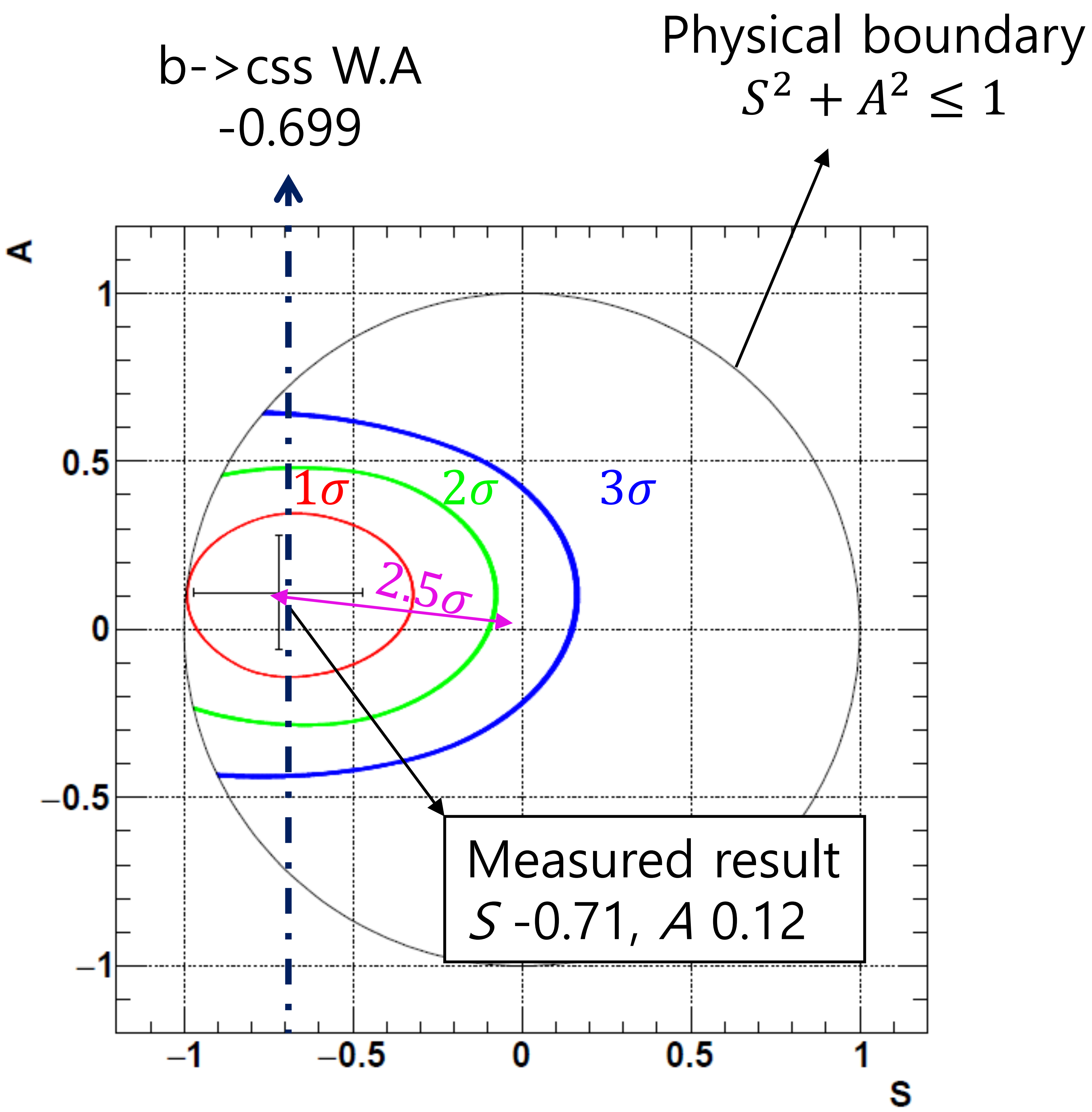
Belle Time Dependent Studies

Talk by K. Kang

Belle Preliminary

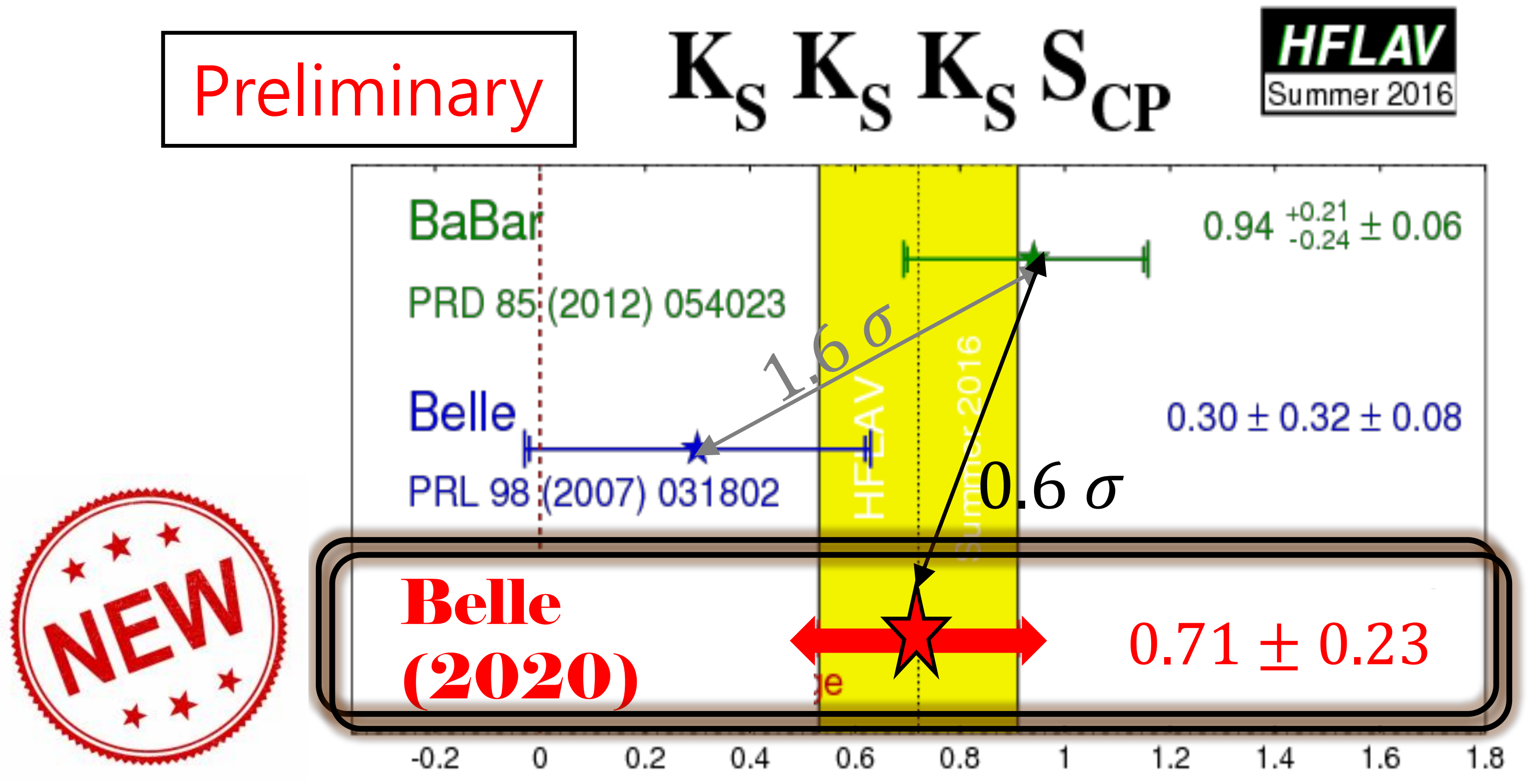






Measured result
S -0.71, A 0.12

Confidence region for S and A

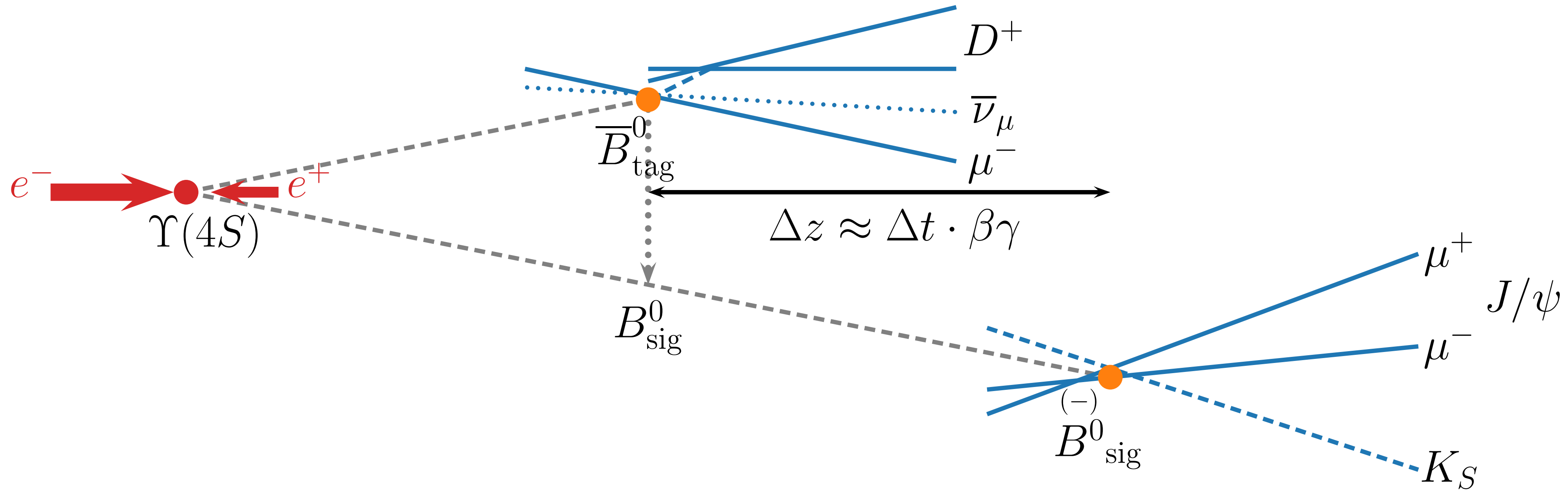


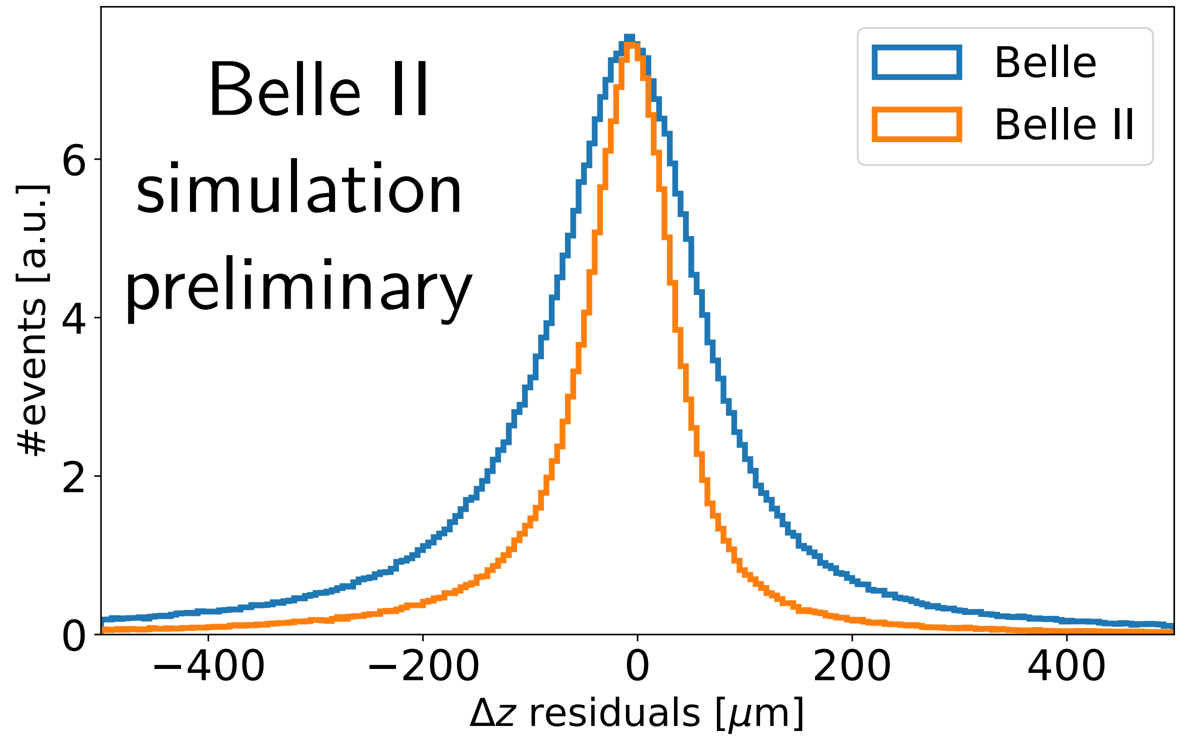
- New B→K$_S$K$_S$K$_S$ result (b→sqq good for NP), S = −0.71 ± 0.23 (stat) ± 0.05 (sys).
- Recent Belle result on B→J/ψπ^0 - key input to strong penguin pollution in B→J/ψ K$_S$.

Belle II Time Dependent Studies

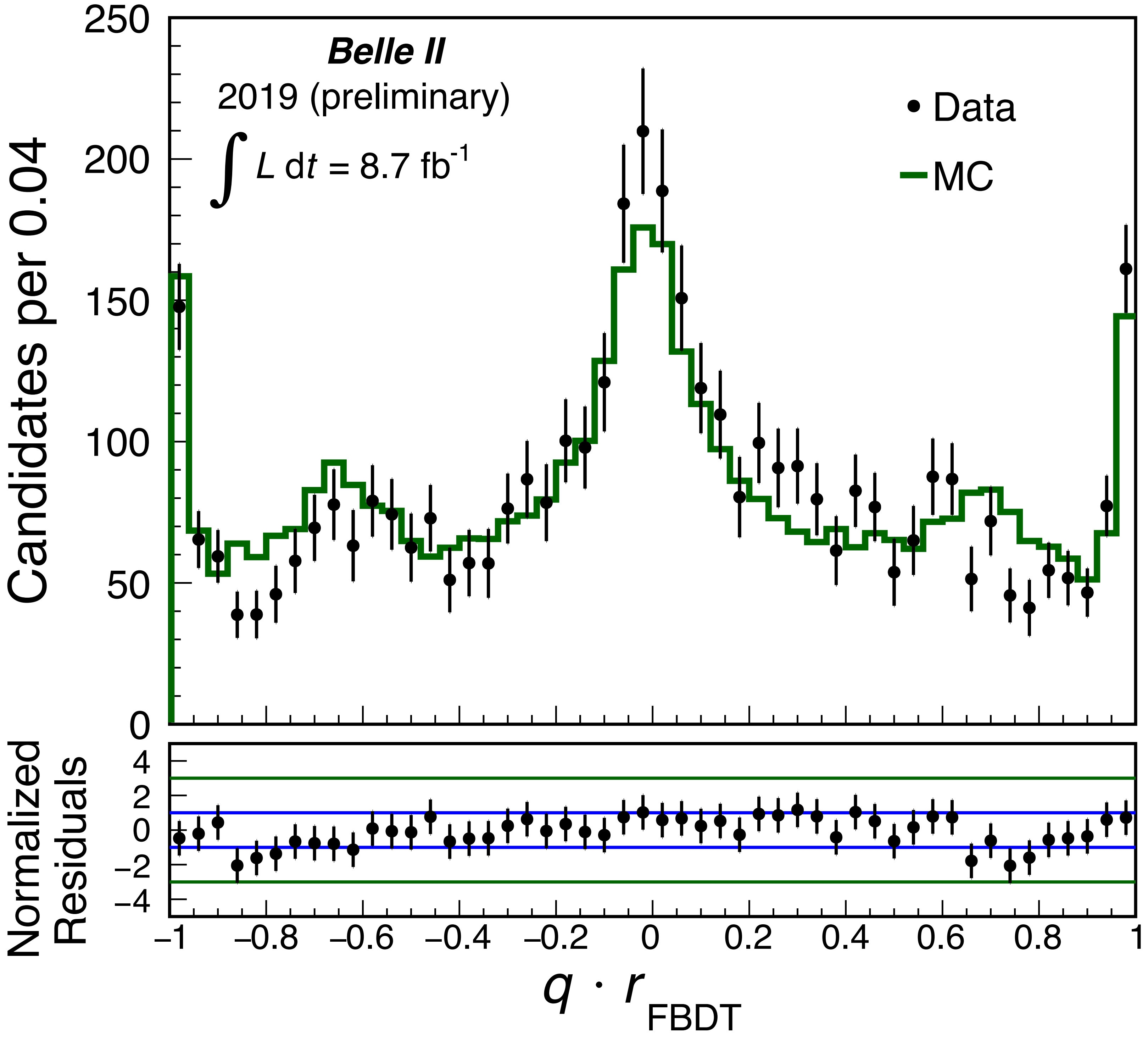
Talk by T. Humair

arXiv:2008.03873

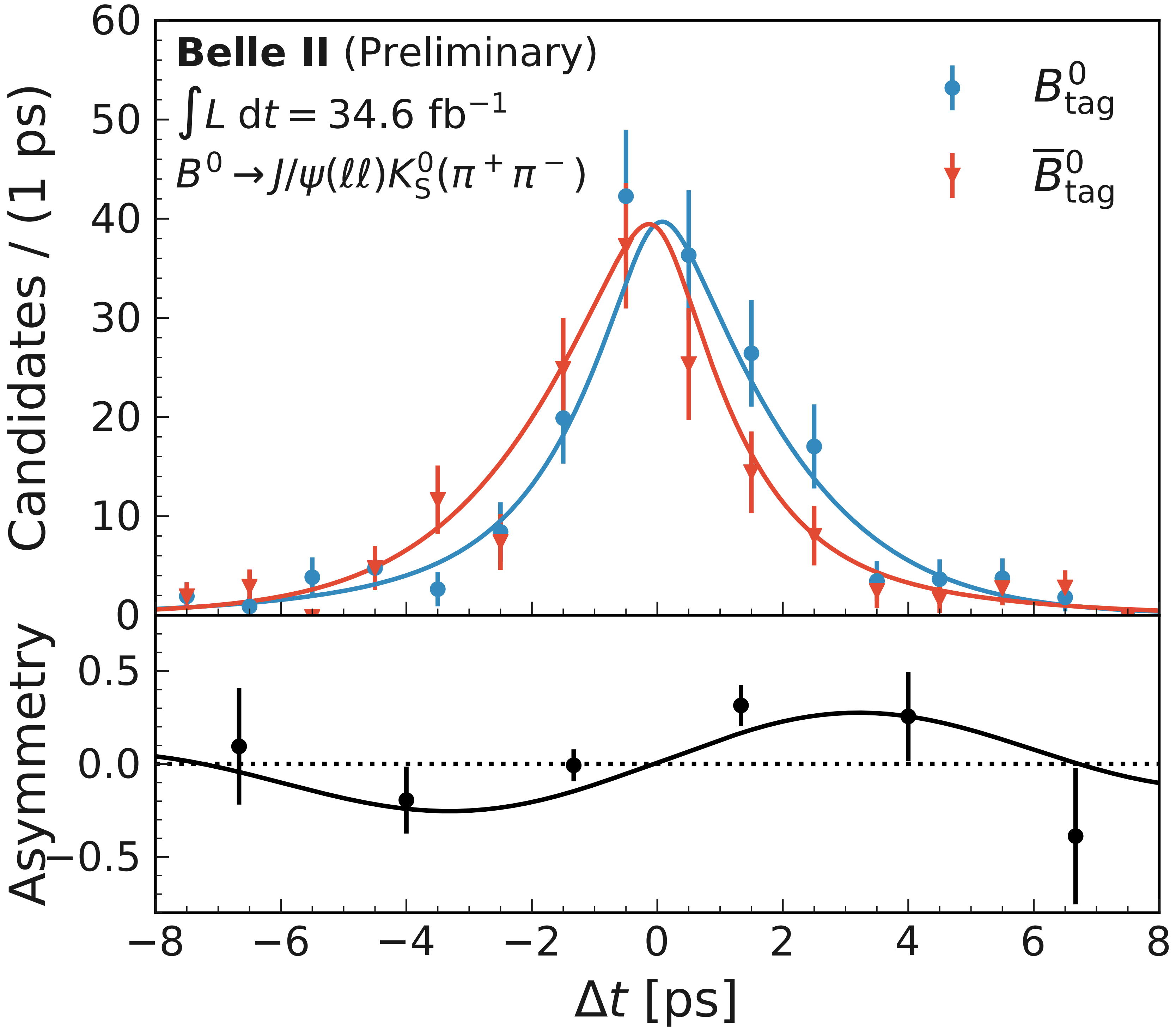




- Good vertex resolution - ability to measure B lifetime.
- Flavour tagging
  Belle: $\varepsilon_{\rm eff}$ = (30.1±0.4)%
  Belle II: $\varepsilon_{\rm eff}$ = (33.8±3.9)%
- $\sin(2\varphi_1)$
  =0.55±0.21(stat)±0.04(sys)
- Δm_d
  =(0.531±0.046(stat)±0.013 (syst)) ps^{-1}



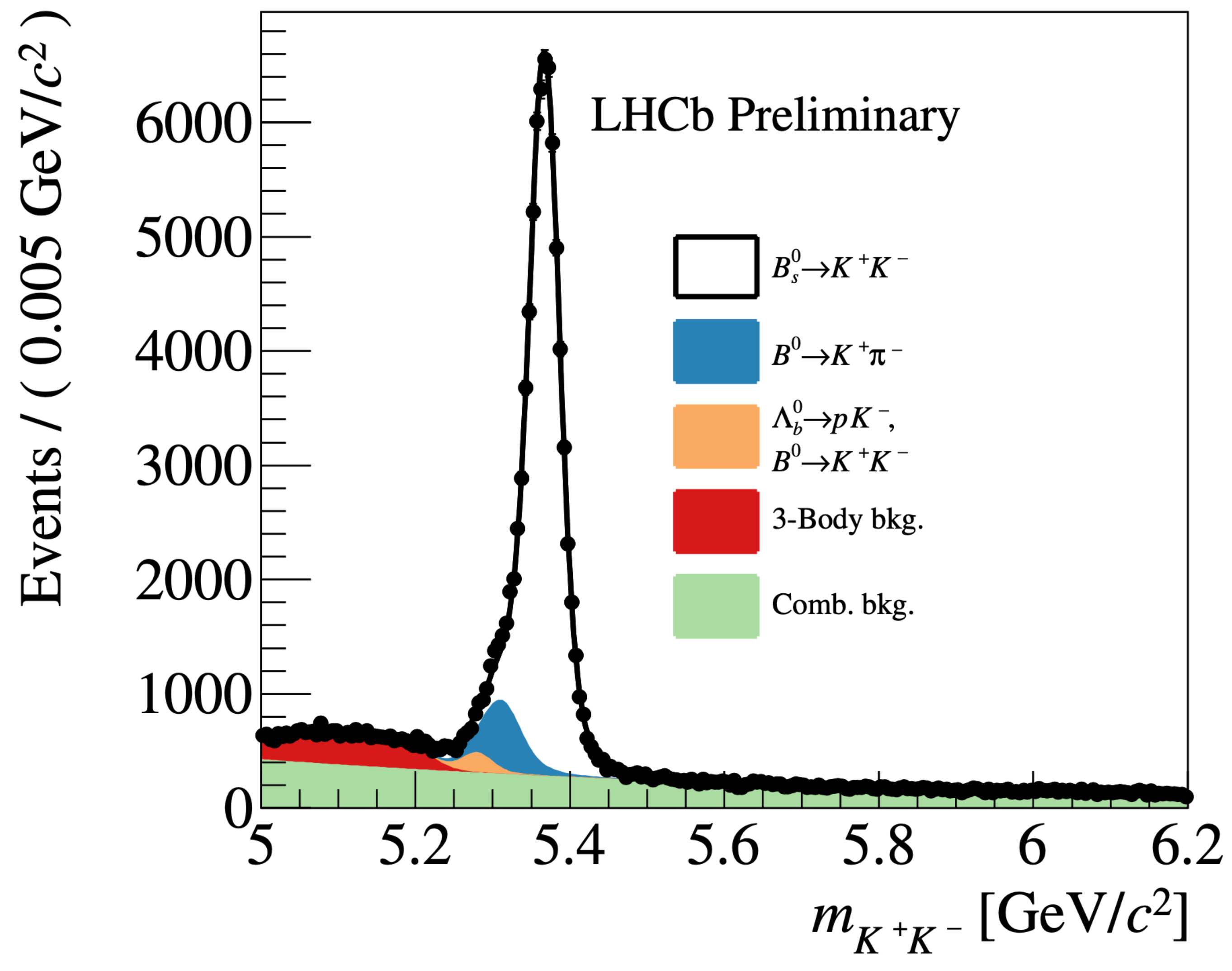
$(r_{\rm FBDT} \approx 1 - 2w)$

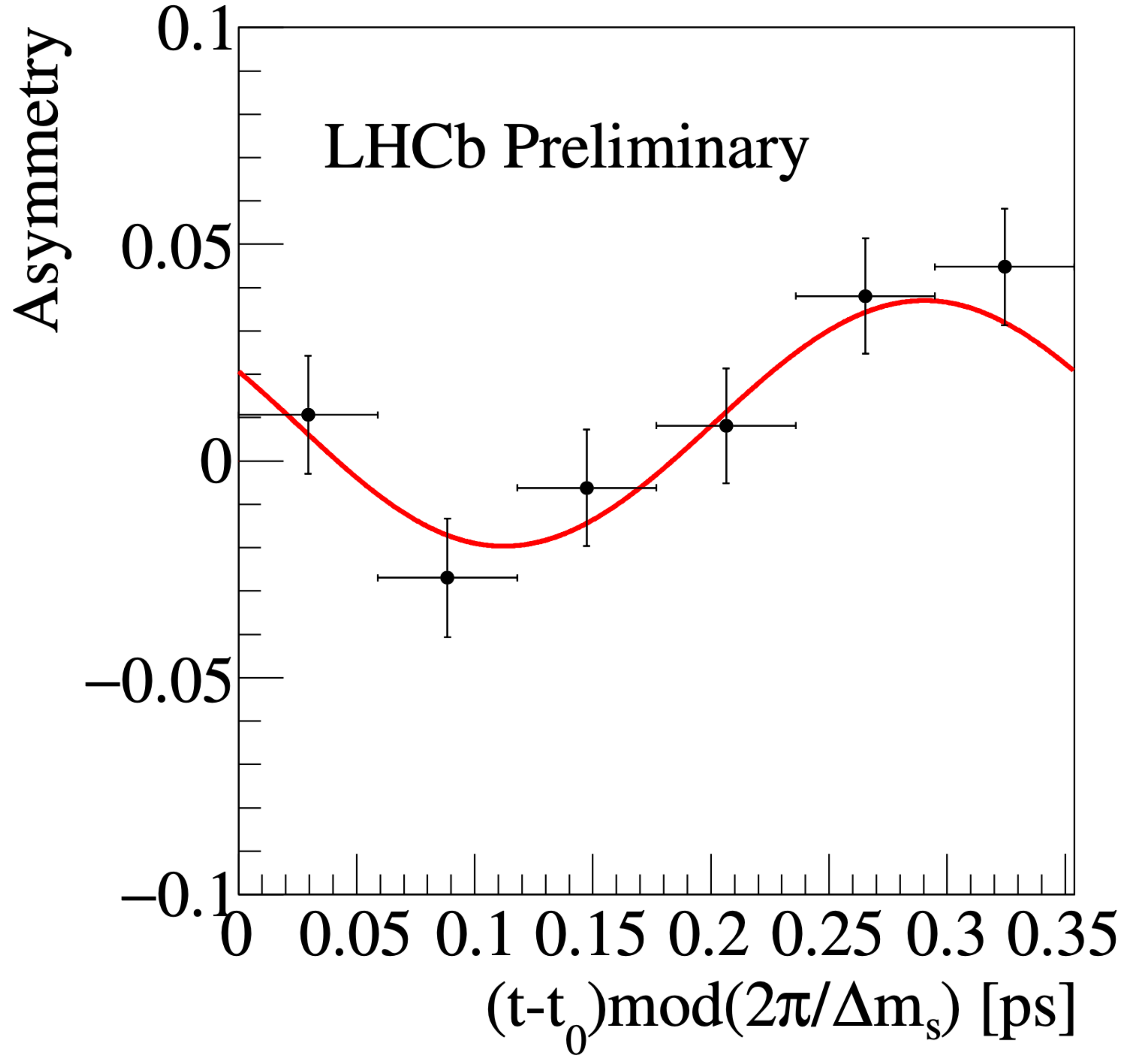


TDCPV in $B_{(s)} \rightarrow h^+h^{-\prime}$

Talk by S. Perazzini

LHCb-PAPER-2020-029





From simultaneous method

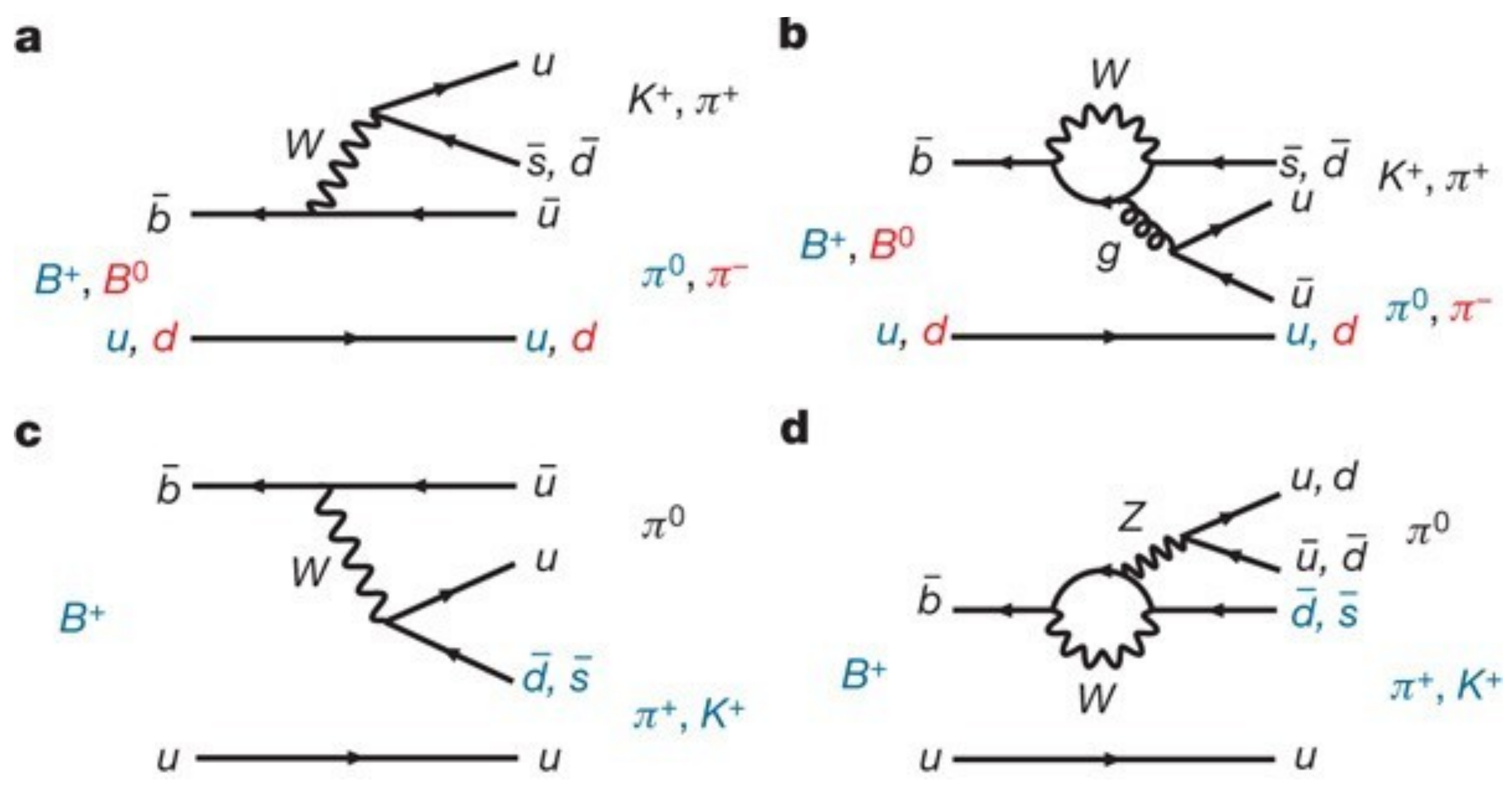
LHCb Preliminary

$$\begin{aligned}
C_{\pi\pi} &= -0.311 \pm 0.045 \pm 0.015, \\
S_{\pi\pi} &= -0.706 \pm 0.042 \pm 0.013, \\
A_{CP}^{B^0} &= -0.0824 \pm 0.0033 \pm 0.0033, \\
A_{CP}^{B_s^0} &= 0.236 \pm 0.013 \pm 0.011, \\
C_{KK} &= 0.164 \pm 0.034 \pm 0.014, \\
S_{KK} &= 0.123 \pm 0.034 \pm 0.015, \\
\mathcal{A}_{KK}^{\Delta\Gamma} &= -0.833 \pm 0.054 \pm 0.094,
\end{aligned}$$

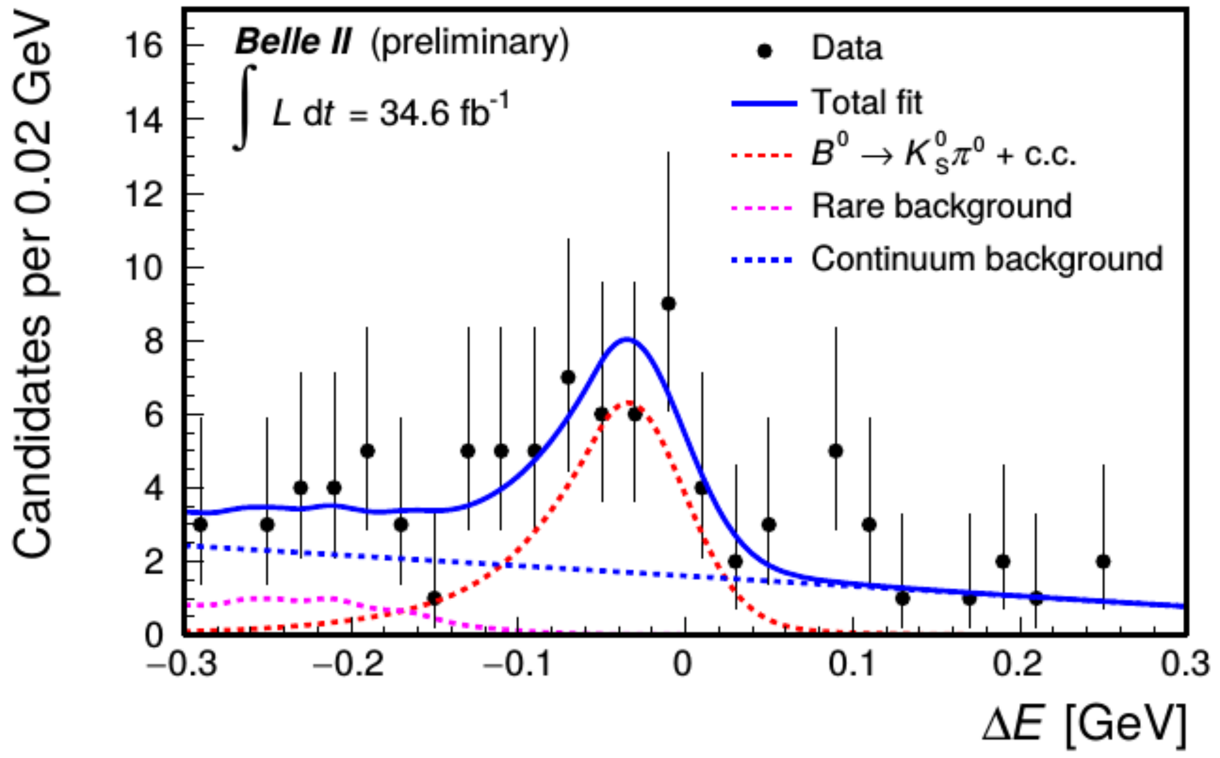
LHCb-PAPER-2020-029

- Measurement of time-dependent and time-integrated CP asymmetries in B(s)→ hh′.
- Combined with Run-1: First observation of time-dependent CP violation in $B_s \rightarrow hh$ decays with 6.7 σ significance .

Belle II Charmless Hadronic Studies



$B^0 \rightarrow K^0\pi^0$



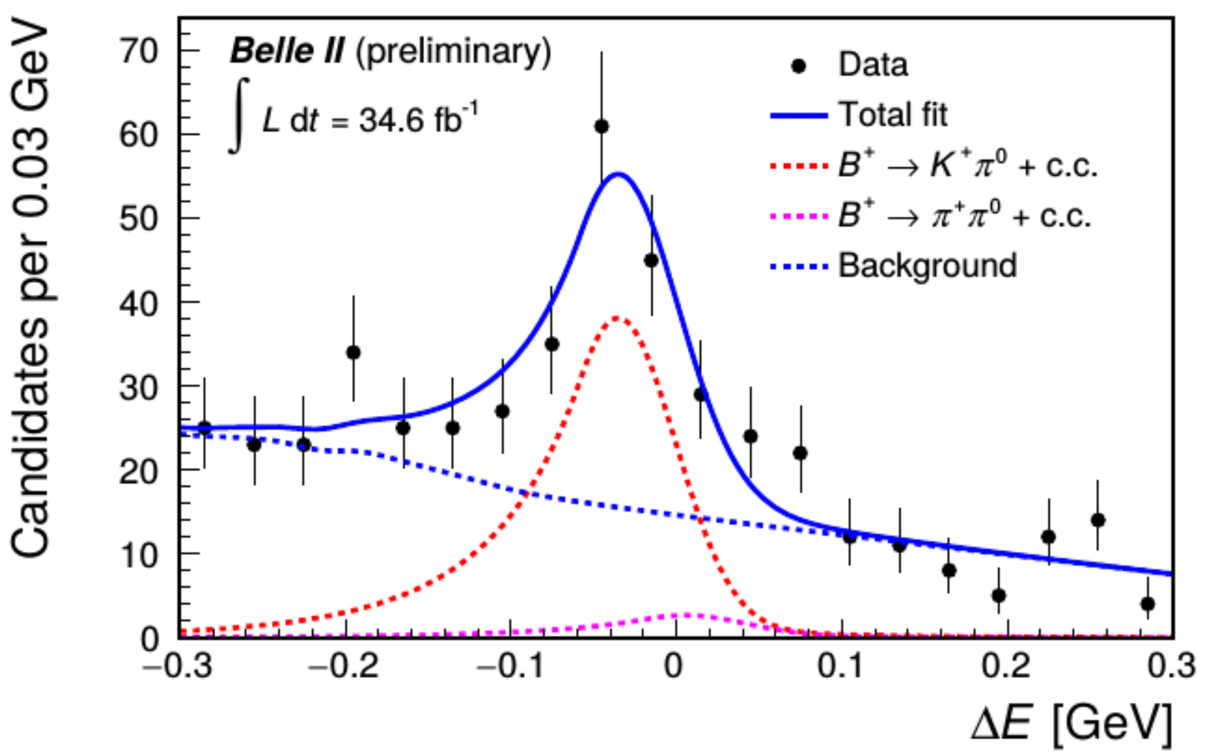
Signal Yield	35±9
Measured $\mathcal{B}$ (10⁻⁶)	$10.9^{+2.9}_{-2.6}(stat.)\pm1.6(syst.)$
PDG (10⁻⁶)	9.9 ± 0.5

Talk by Y-T. Lai

arXiv:2009.09452
arXiv:2008.03873

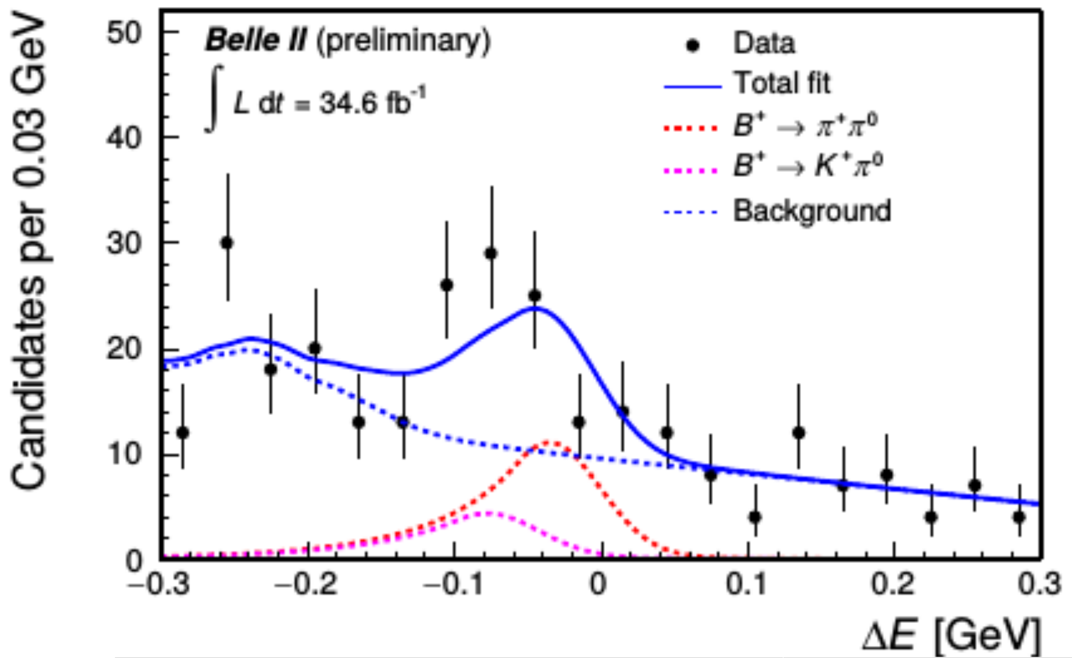
- First Belle II measurement of BFs, CP asymmetries, and Polarisation in
  - B→Kπ
  - B→Khh
  - B→ΦK*
- Critical for neutral mode inputs - to understand strong interaction effects.

$B^+ \rightarrow K^+\pi^0$

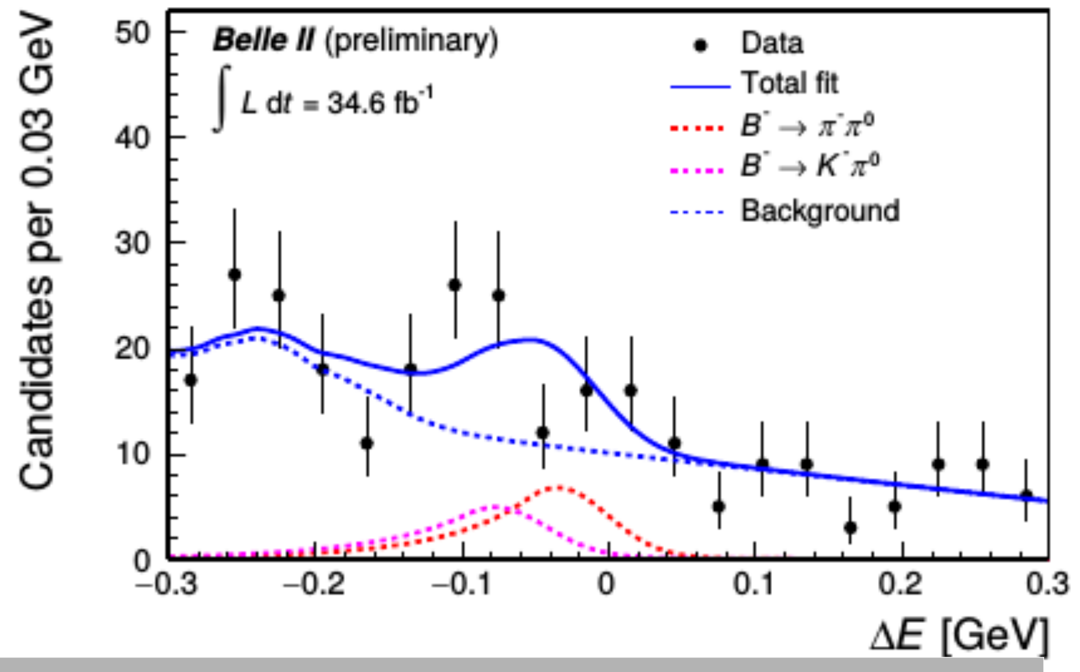


Signal Yield	144^{+25}_{-24}
Measured $\mathcal{B}$ (10⁻⁶)	$12.7^{+2.2}_{-2.1}(stat.)\pm1.1(syst.)$
PDG (10⁻⁶)	12.9 ± 0.5

$B^+ \rightarrow \pi^+\pi^0$ 43^{+19}_{-20}



$B^- \rightarrow \pi^-\pi^0$ 24^{+13}_{-14}

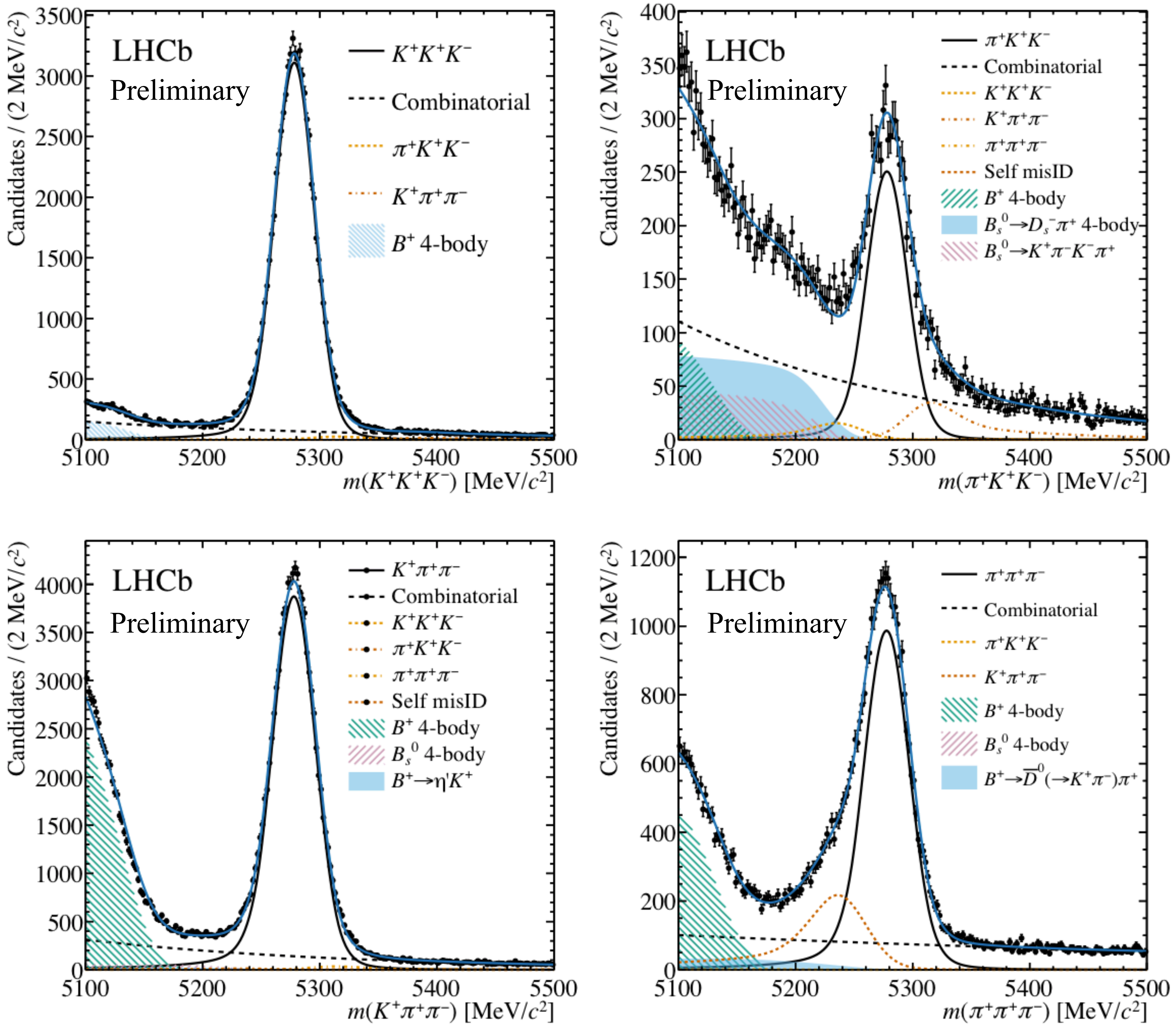


Measured $\mathcal{A}_{CP}$	$-0.268^{+0.249}_{-0.322}(stat.)\pm0.123(syst.)$
PDG	0.03 ± 0.04

B→h+h+'h-'

Talk by T. Latham

LHCb-PAPER-2020-031
PRL 124 (2020) 031801
PRD 101 (2020) 012006
PRD 102 (2020) 012011



$$\mathcal{B}(B^+\to\pi^+K^+K^-)/\mathcal{B}(B^+\to K^+K^+K^-) = 0.151 \pm 0.004\,(\text{stat}) \pm 0.008\,(\text{syst})$$
$$\mathcal{B}(B^+\to K^+\pi^+\pi^-)/\mathcal{B}(B^+\to K^+K^+K^-) = 1.703 \pm 0.011\,(\text{stat}) \pm 0.022\,(\text{syst})$$
$$\mathcal{B}(B^+\to\pi^+\pi^+\pi^-)/\mathcal{B}(B^+\to K^+K^+K^-) = 0.488 \pm 0.005\,(\text{stat}) \pm 0.009\,(\text{syst})$$

- Measurement of the relative branching fractions of B+ → h+h′+h′- decays - big improvement over WA.
- Recent amplitude analyses in B+ → h+h′+h′- with large CP asymmetries observed in several amplitudes.

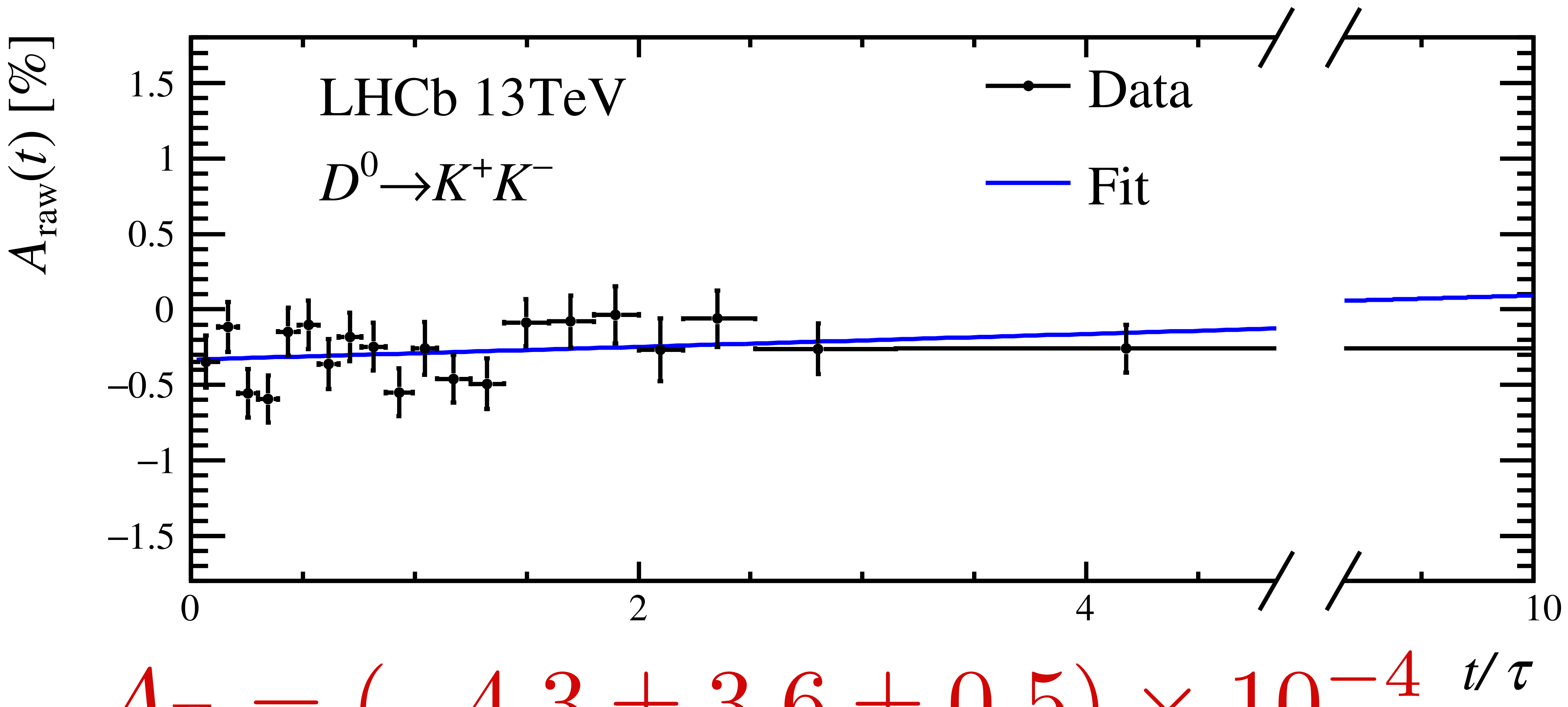
Charm CPV Indirect

Talk by A. Reis

PRD 101, 012005 (2020)

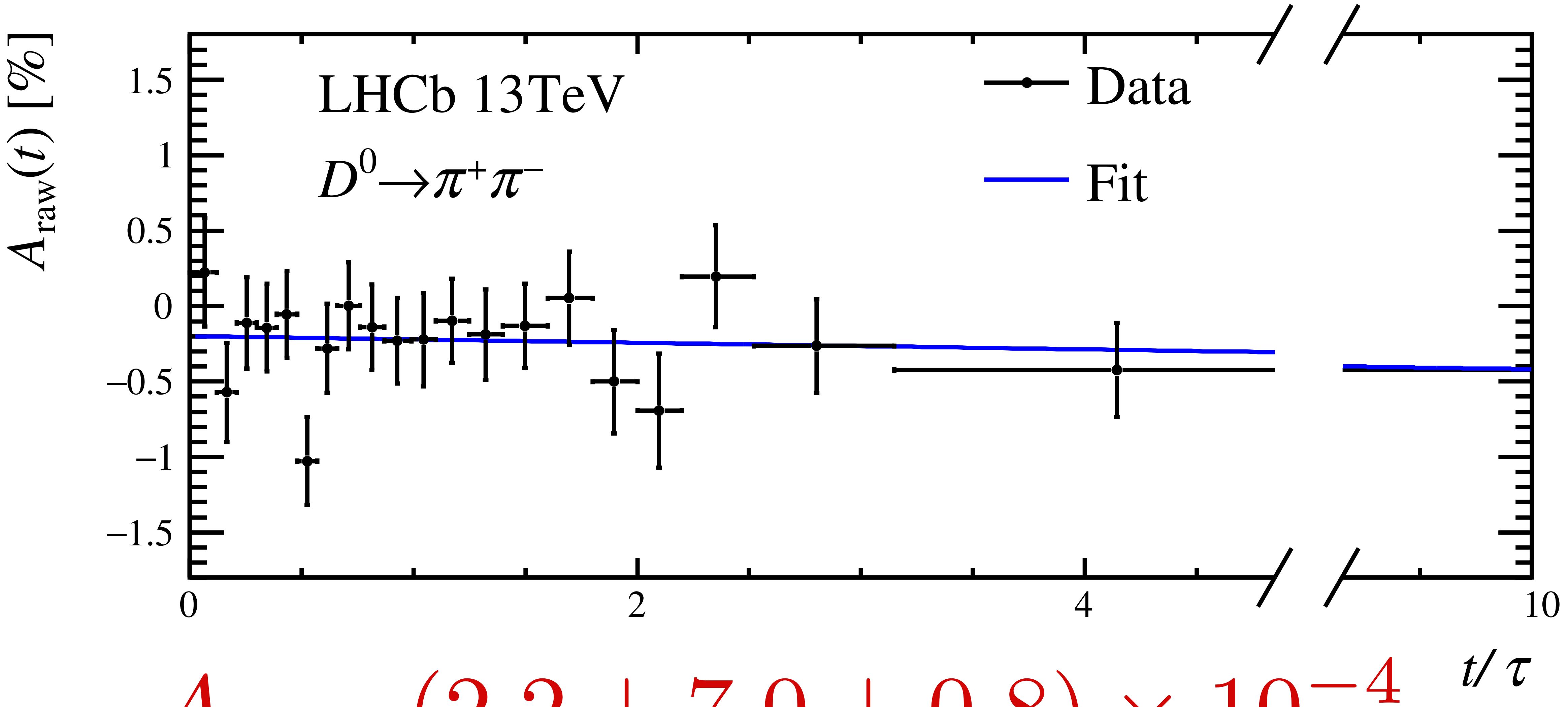
$$A_{\mathrm{raw}}(t) = A_{\mathrm{raw}}(0) + A_{\Gamma}\frac{\langle t\rangle_i}{\tau}$$

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



$$A_{\Gamma} = (-4.3 \pm 3.6 \pm 0.5) \times 10^{-4}$$

$D^0 \to \pi^+\pi^-$

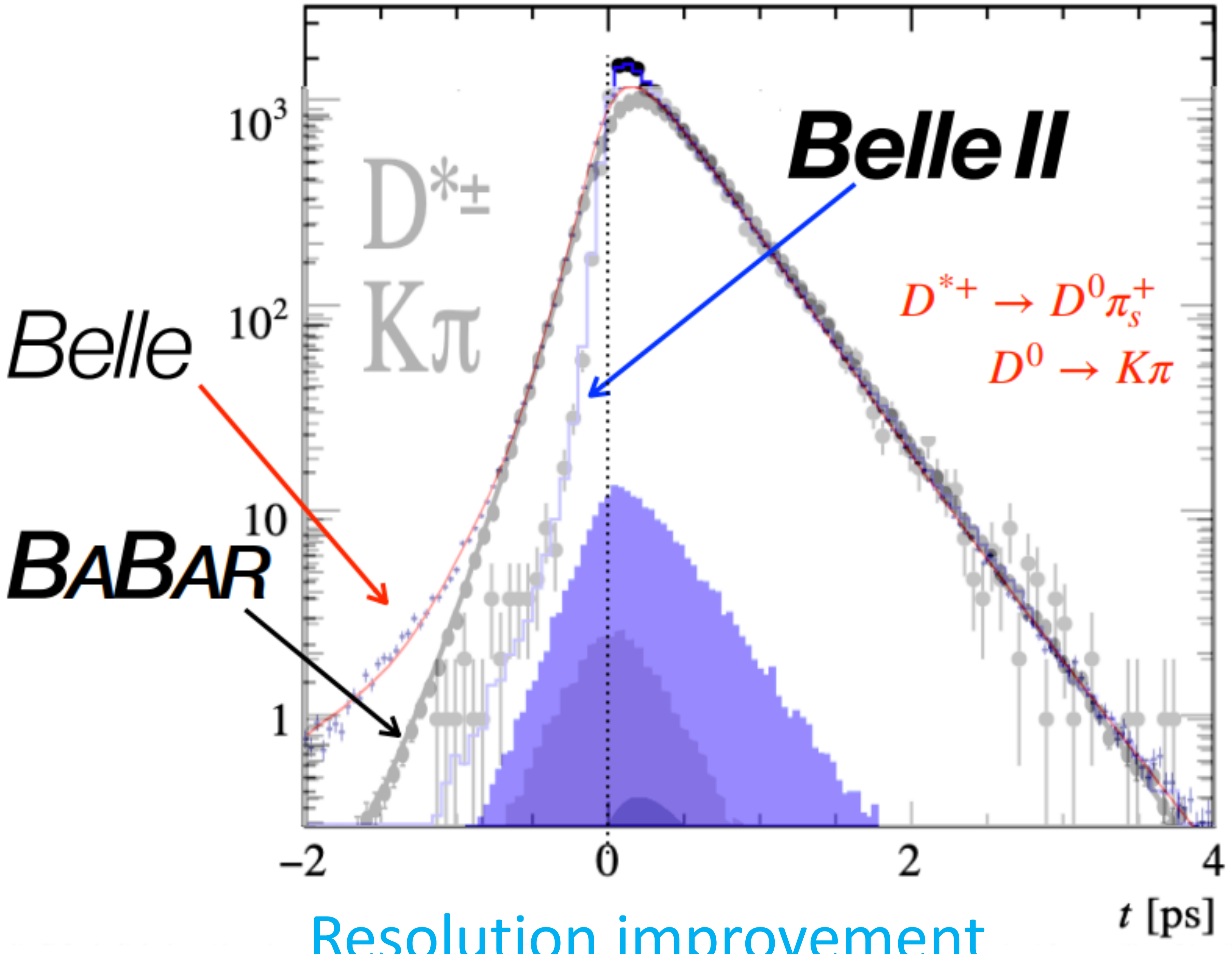


$$A_{\Gamma} = (2.2 \pm 7.0 \pm 0.8) \times 10^{-4}$$

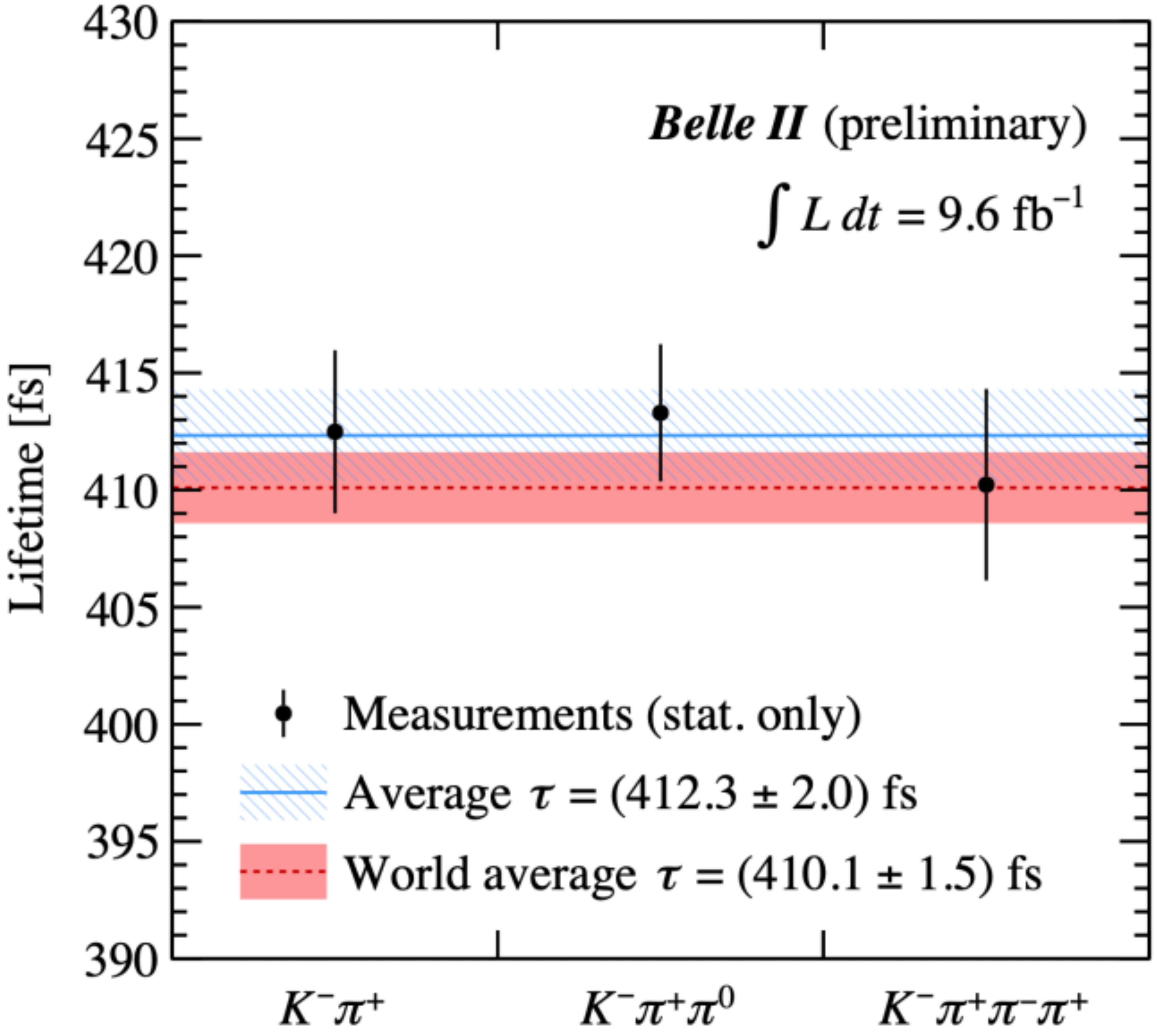
- 2020 Measurement based on charm from B decays at sqrt(s)=13 TeV.
- No indication of mixing-induced CP violation in charm.

Charm at Belle II

Talk by G. Gong



Resolution improvement visible at $t < 0$



estimated **error** on	current HFLAV	Belle scaled to 50/ab	Toy MC 50/ab, CPV
x' (%)	–	(*) 0.45 ➡	0.15
x'^2 (%)	–	0.009	–
y' (%)	–	0.16 ➡	0.10
$\|q/p\|$	~ 0.09	–	0.051
ϕ (°)	~ 9	–	5.7

- Proper time resolution at Belle II is a factor 2 better than Belle & BaBar. Implications for mixing parameter measurements.
- Q-resolution 2x better, good for time dependent amplitude analysis in $D^0 \to K_S\pi\pi$.

THE UNIVERSITY OF
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CKM Matrix Elements & Tree Decays

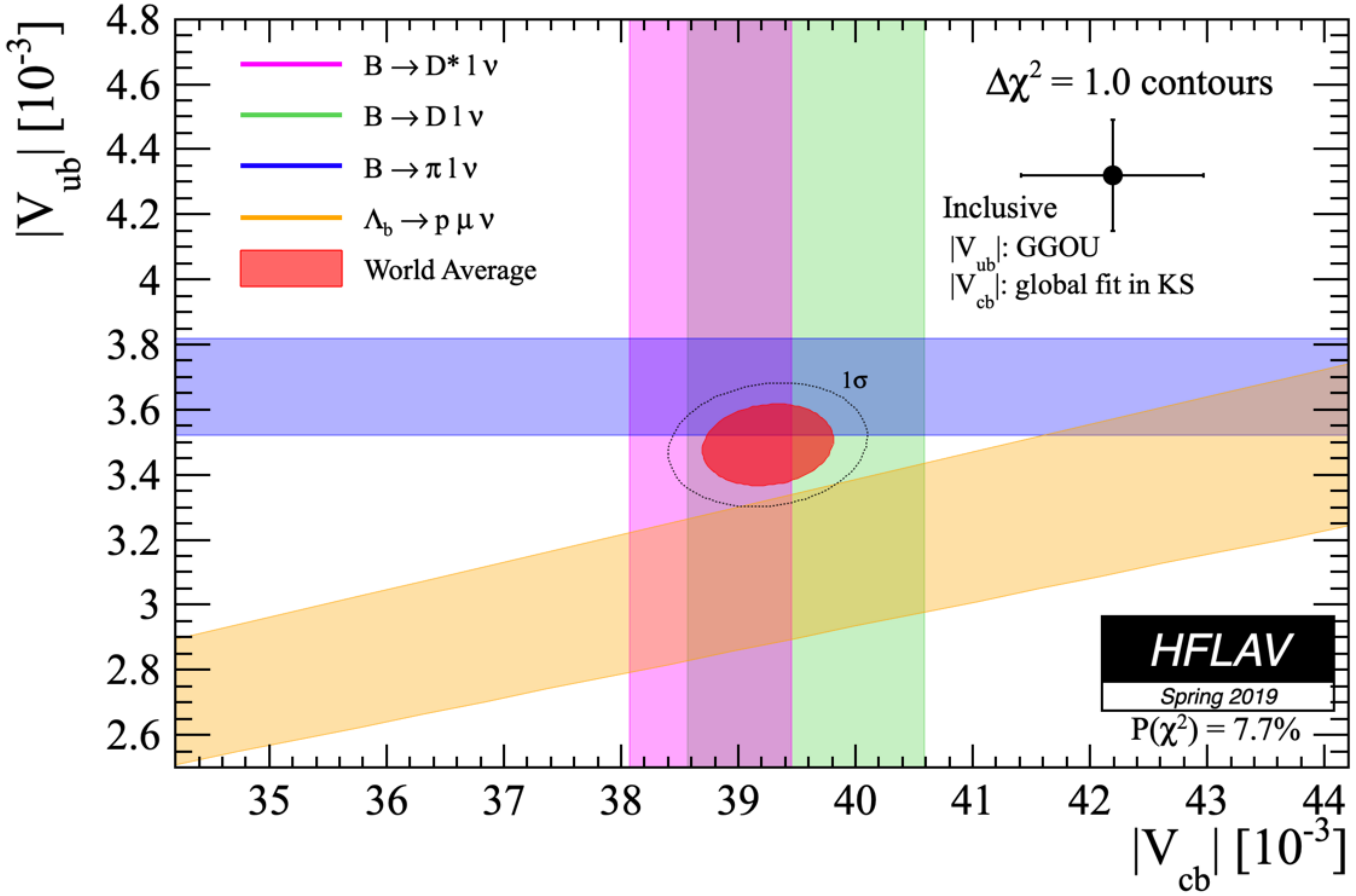
Semileptonic decays

Leptonic decays

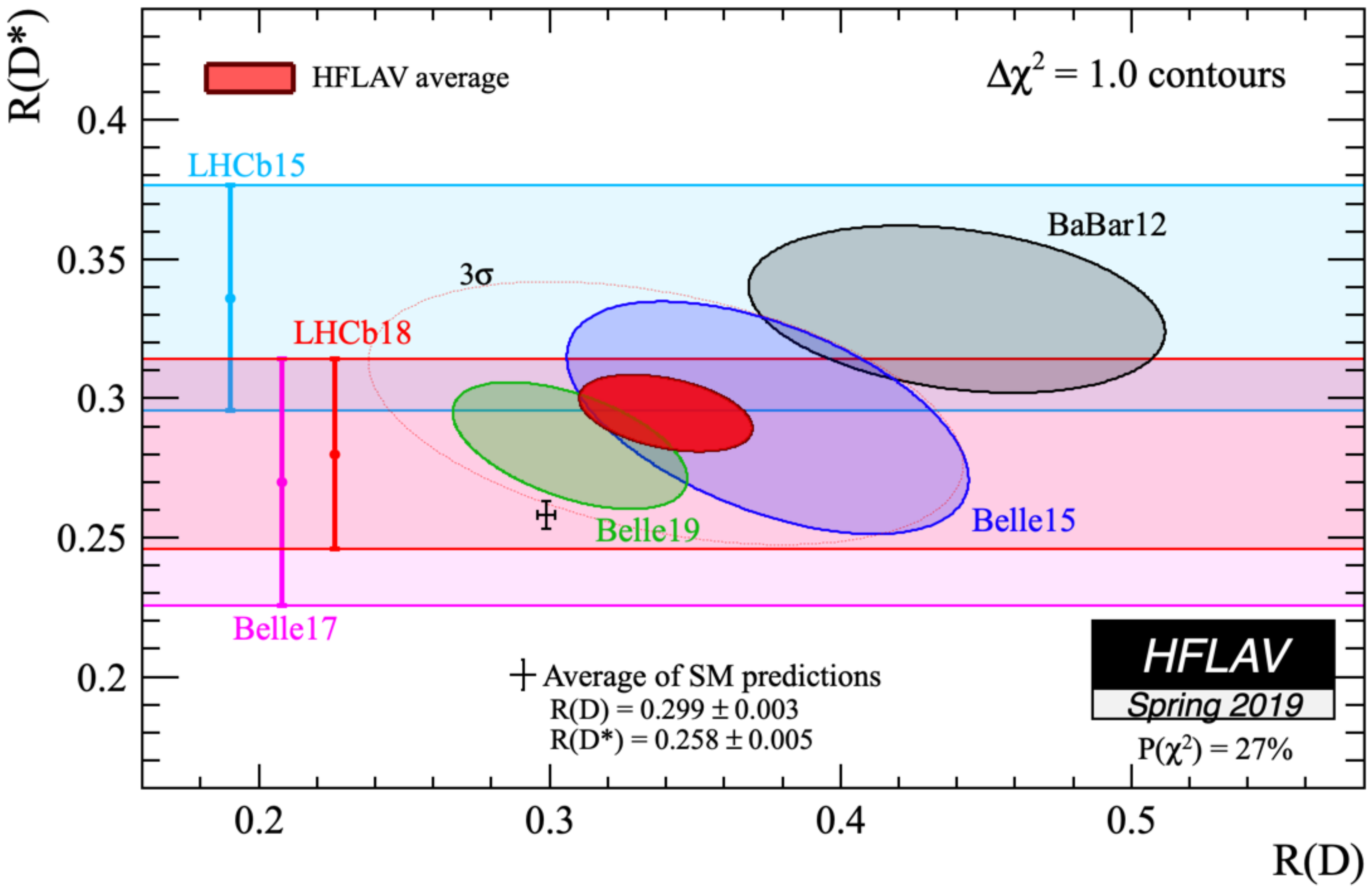
Lepton flavour universality

Current Challenges

1



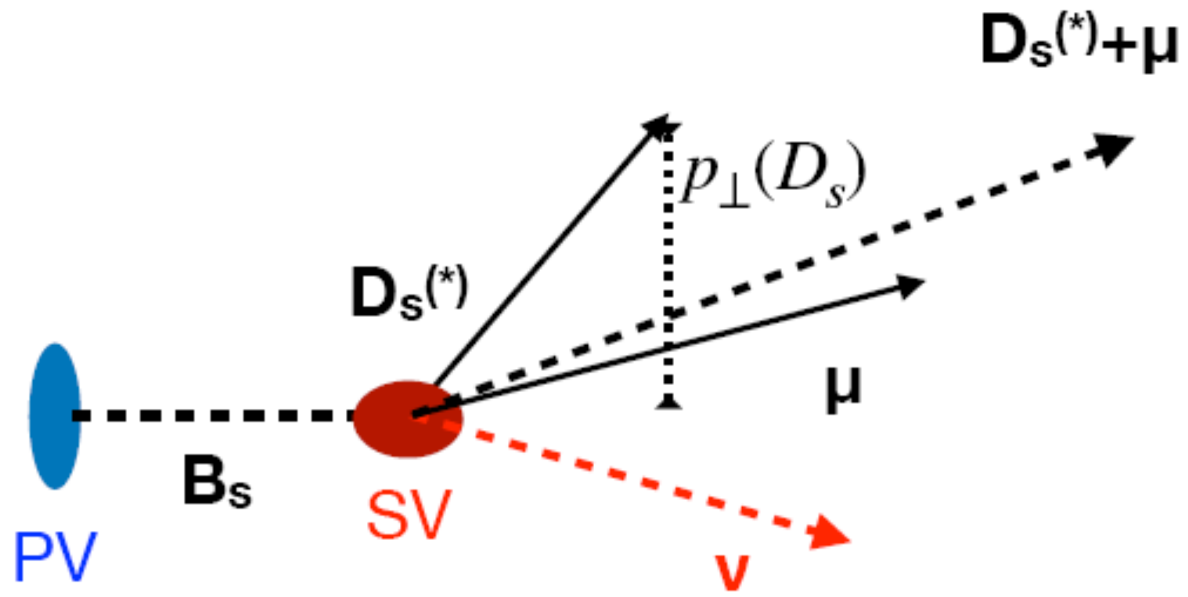
2



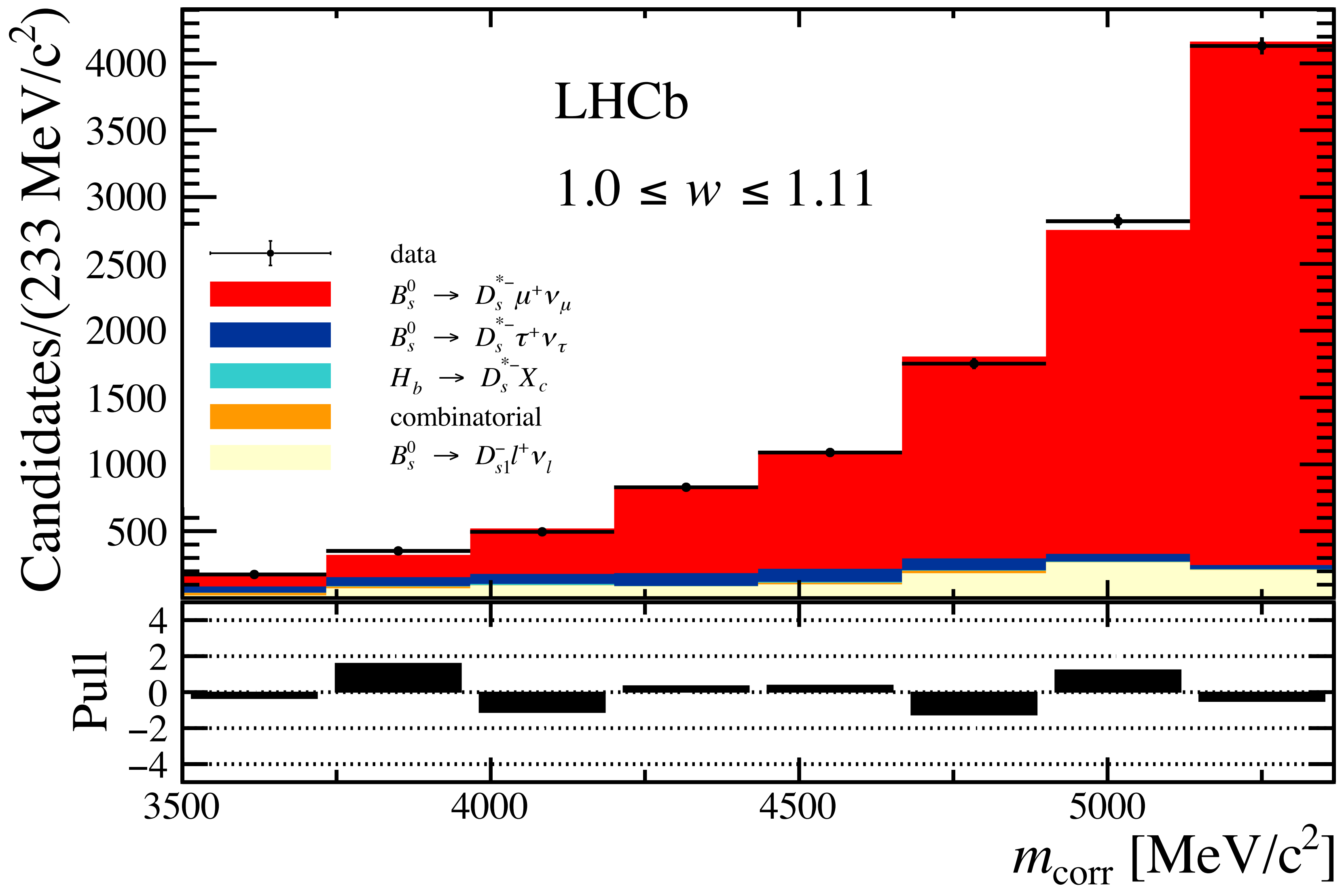
$B_s \rightarrow D_s^* \mu \nu$ Form Factors

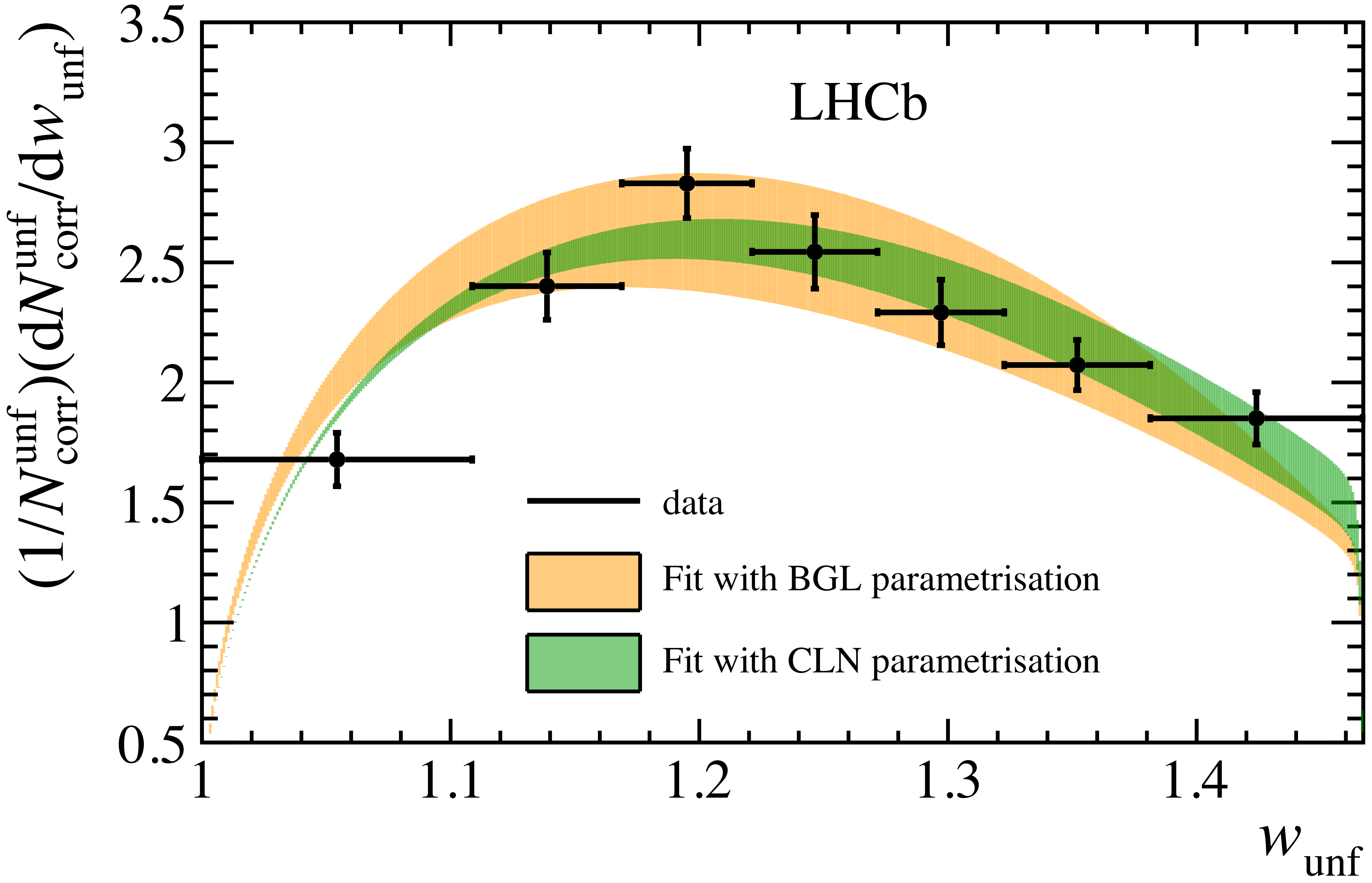
Talk by S. Braun

PRD 101, 072004 (2020)
arXiv: 2003.08453



$$m_{corr} = \sqrt{m^2(D_s\mu) + p_\perp^2(D_s\mu)} + p_\perp(D_s\mu)$$





CLN:
$\rho^2 = 1.16 \pm 0.05(stat) \pm 0.07(syst)$
BGL:
$a_1^f = -0.002 \pm 0.034(stat) \pm 0.046(syst)$
$a_2^f = 0.93^{+0.05}_{-0.20}(stat)^{+0.06}_{-0.38}(syst)$

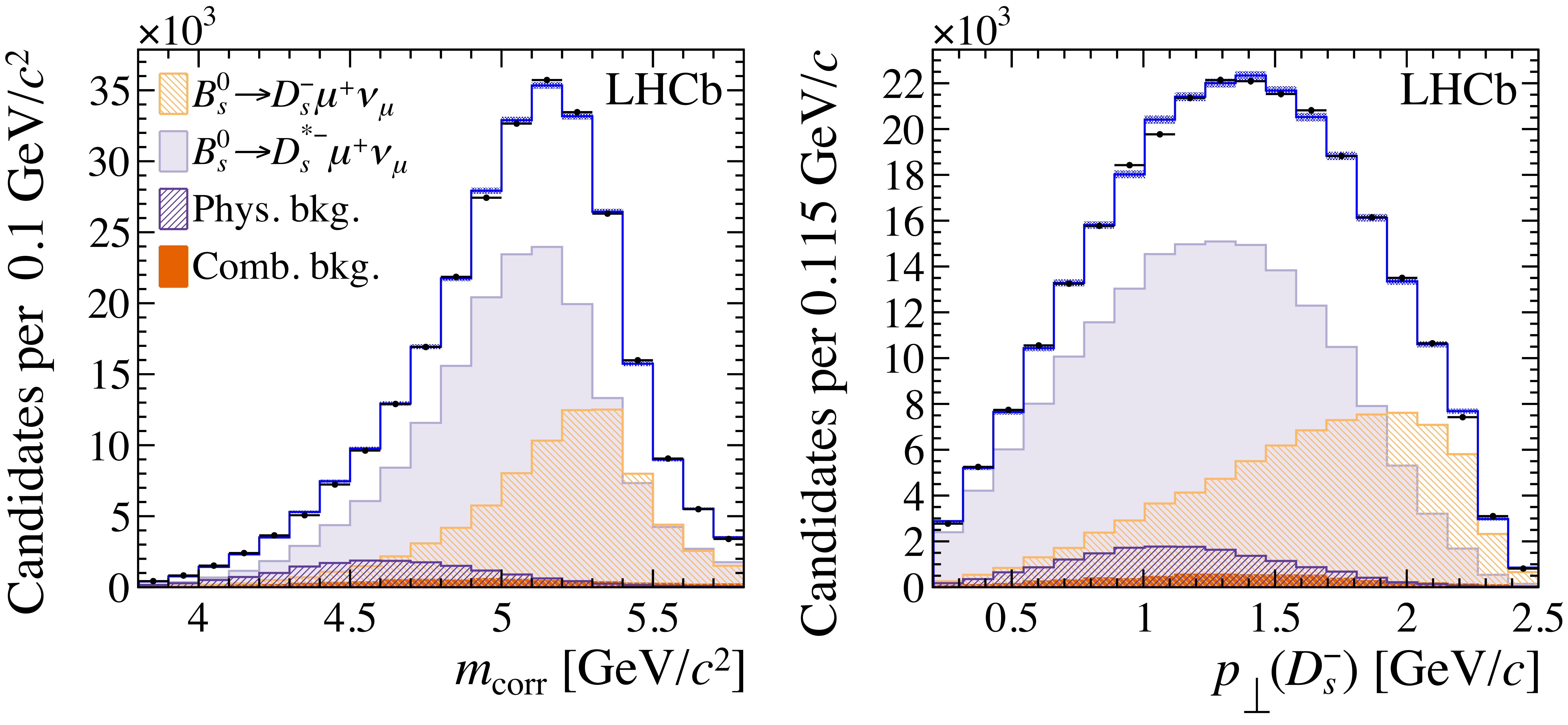
- First unfolded normalised differential decay rate for $B_s^0 \rightarrow D_s^* \mu\nu$.
- Values agree with HFLAV world average from $B^0 \rightarrow D^* \mu\nu$.

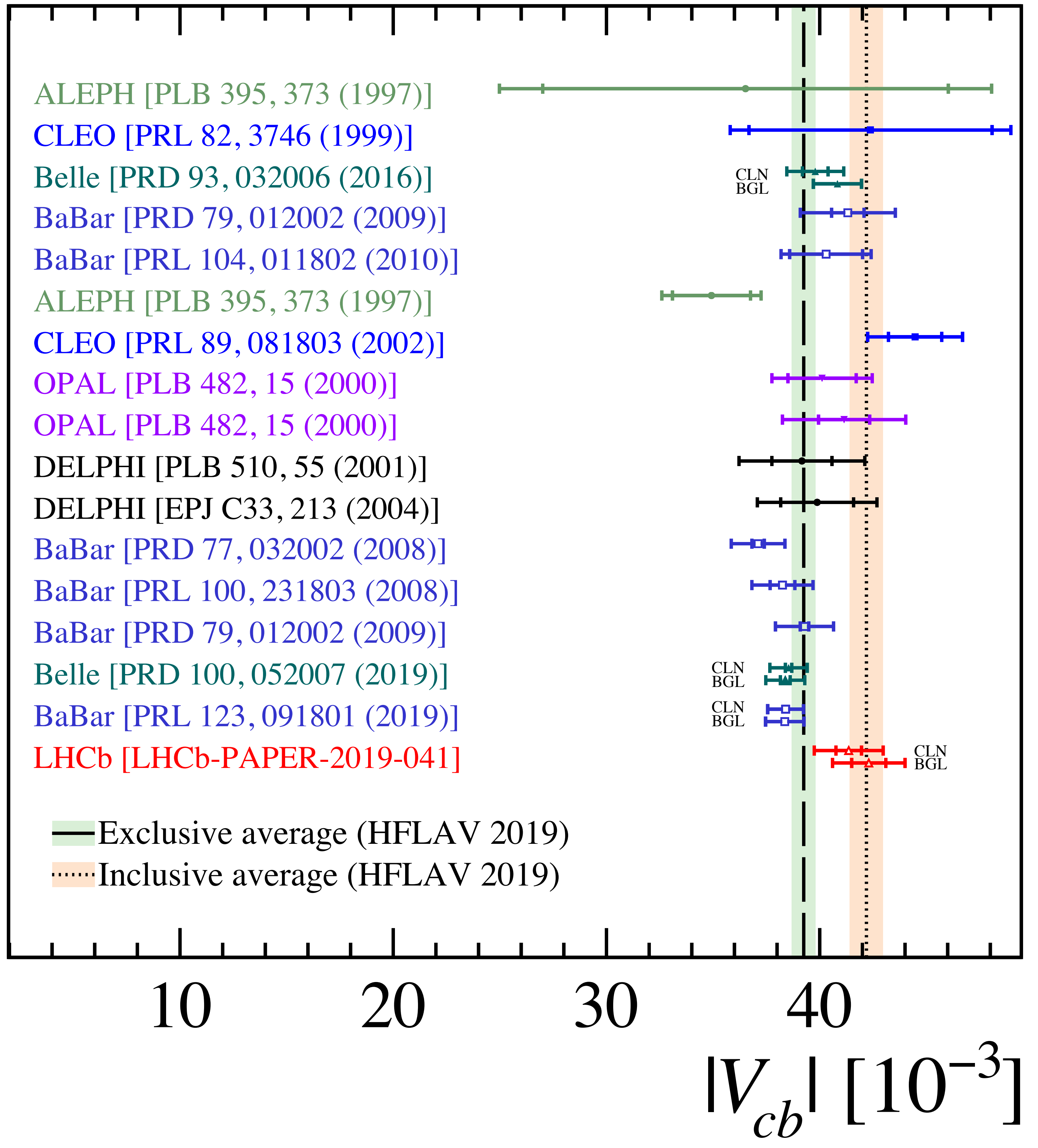
$|V_{cb}|$ with $B_s \to D_s^{(*)} \mu \nu$

Talk by S. Braun

PRD 101, 072004 (2020)
arXiv: 2003.08453

- First exclusive $|V_{cb}|$ measurement at hadron collider and using Bs mesons
  $|V_{cb}| = (42.3 \pm 0.8(\text{stat}) \pm 0.9(\text{syst}) \pm 1.2(\text{ext})) \times 10^{-3}$





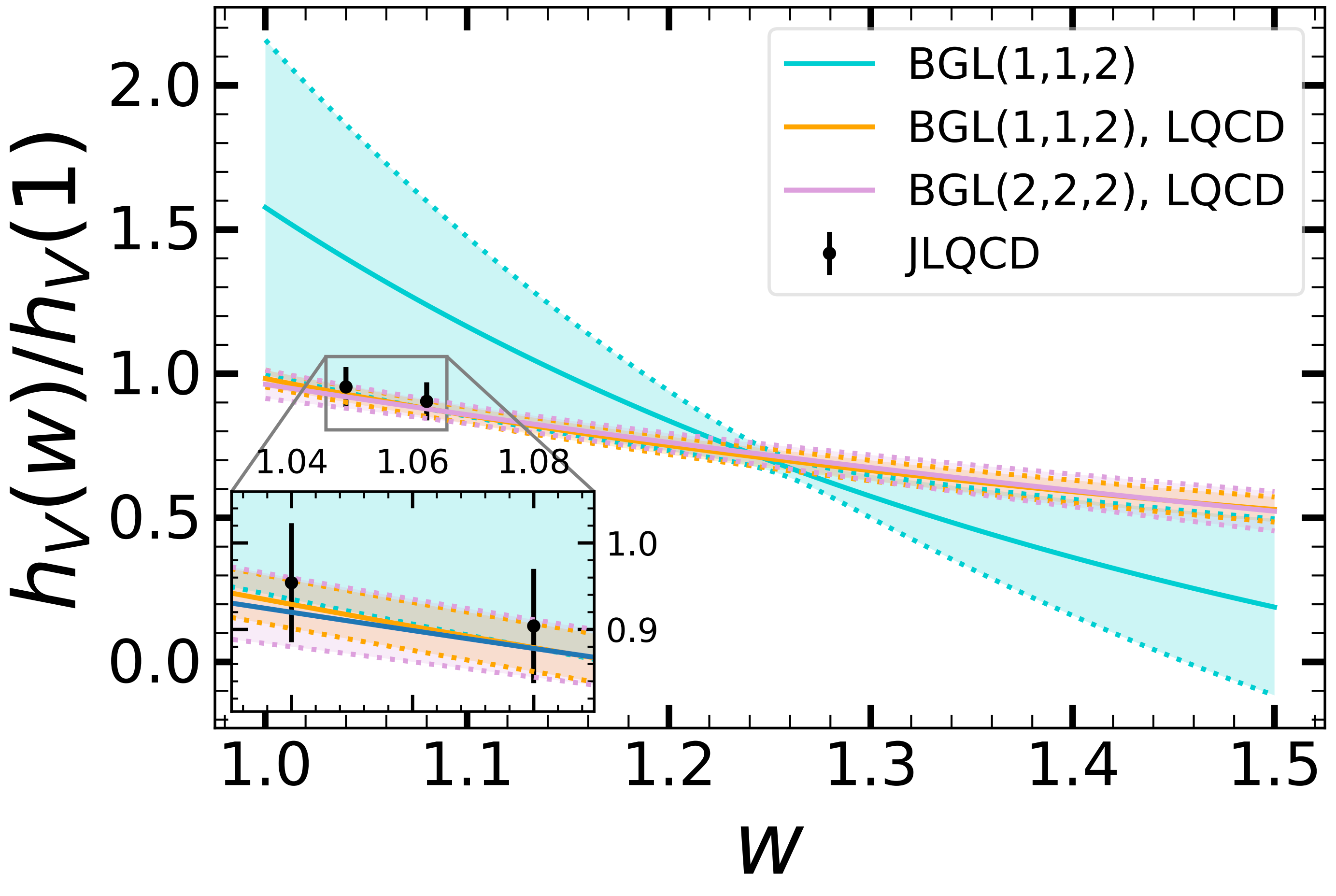
B→D* l ν with non-zero recoil LQCD

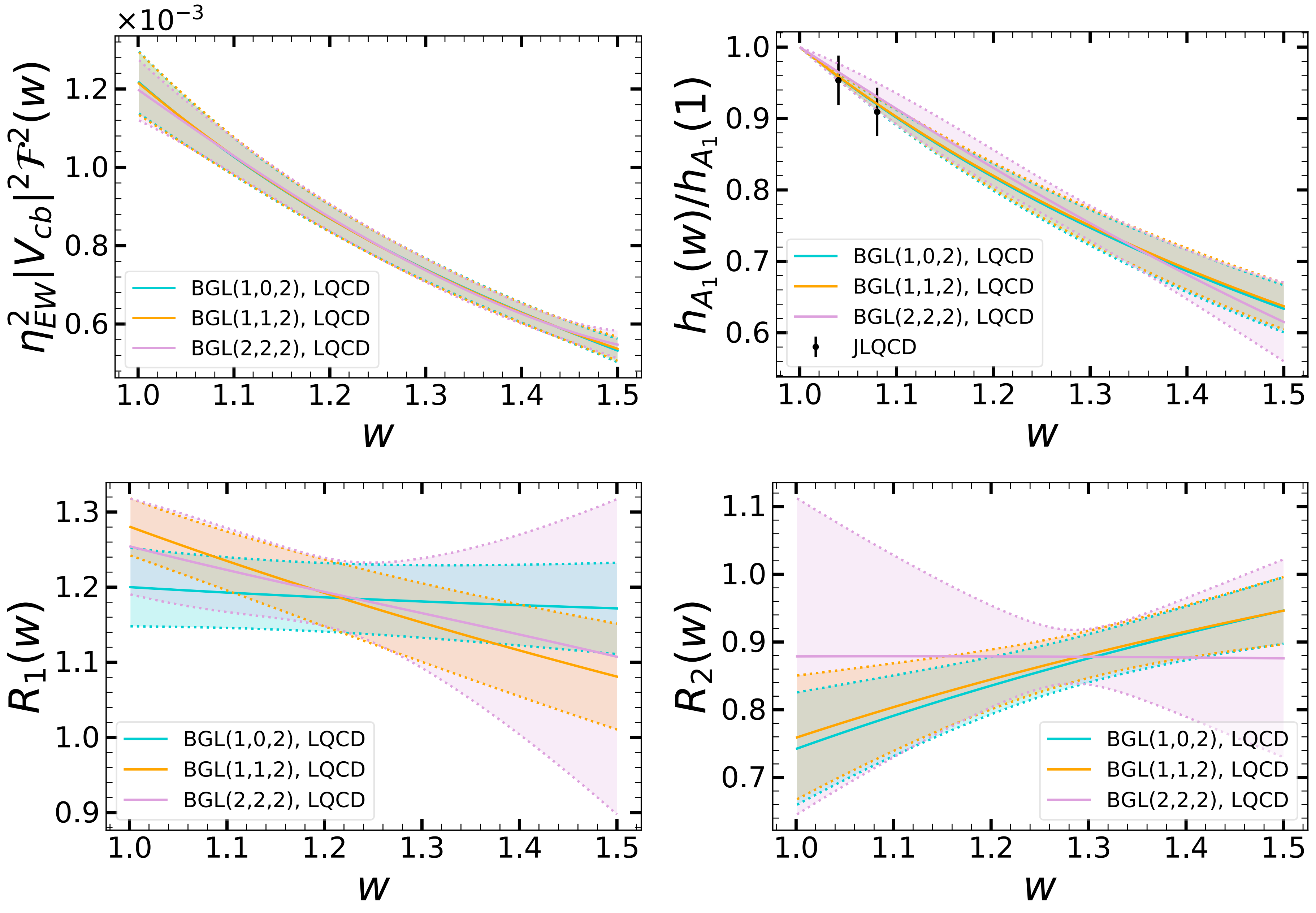
D. Ferlewicz, PU, E. Waheed
arXiv: 2008.09341

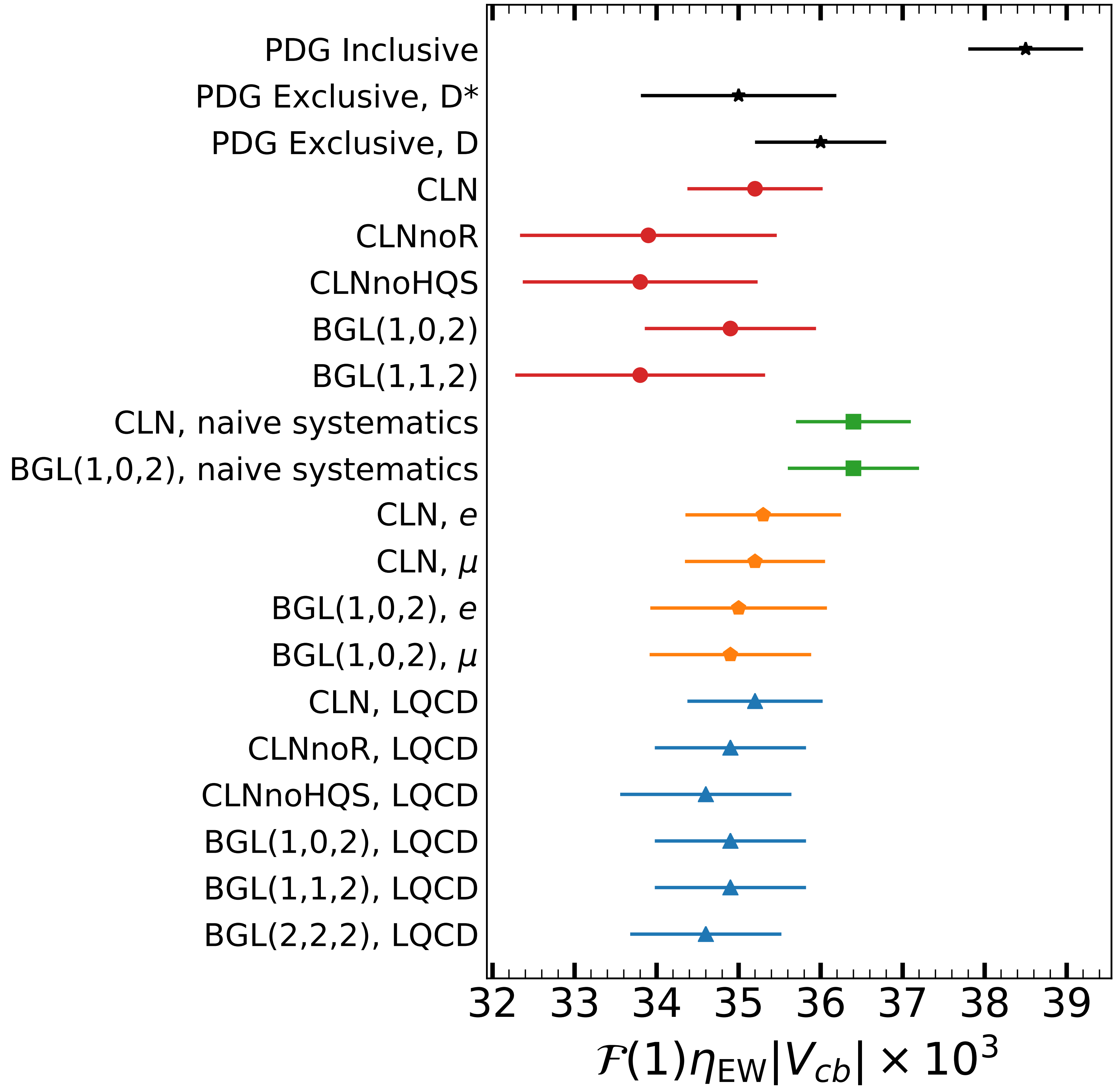
- Analysis of Belle untagged data with *preliminary* LQCD data points (JLQCD) at **non-zero recoil** (normalised to zero recoil).

See Talk by C. Davies on LQCD results

- Constrains high order BGL expansion and form factors, but does not result in different central values for $|V_{cb}|$.







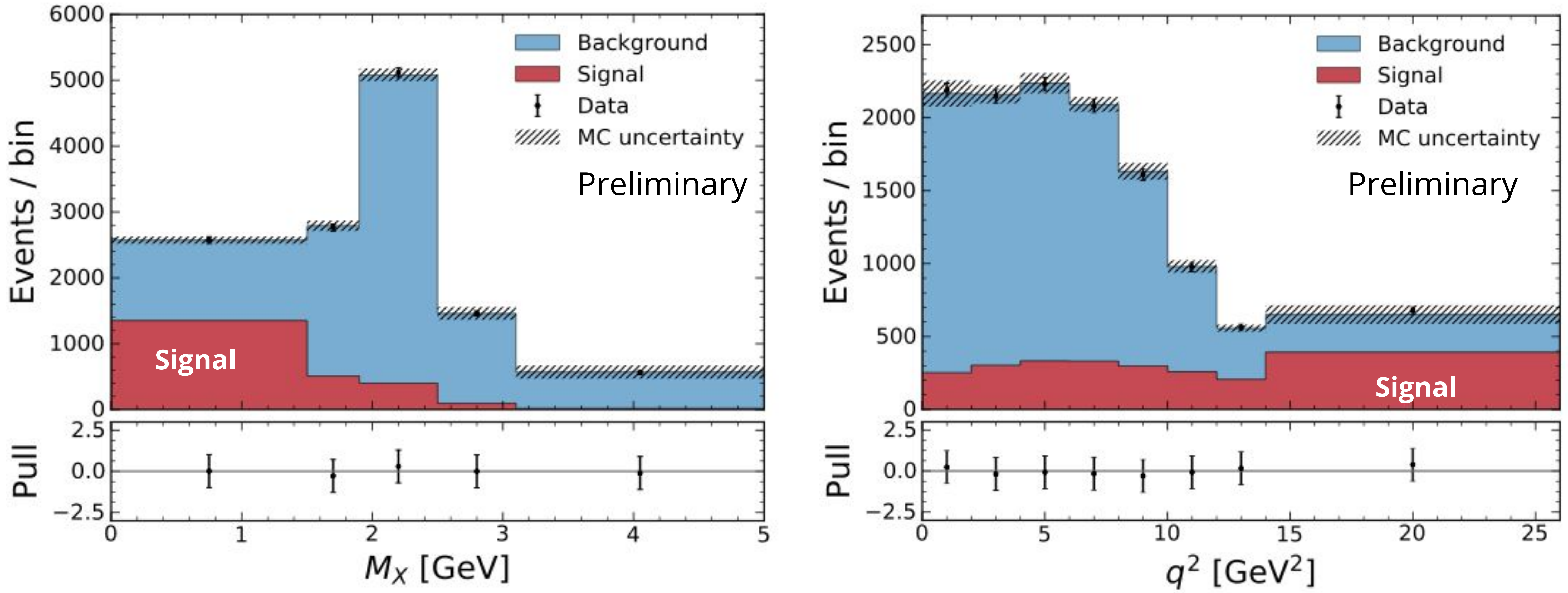
Inclusive $|V_{ub}|$

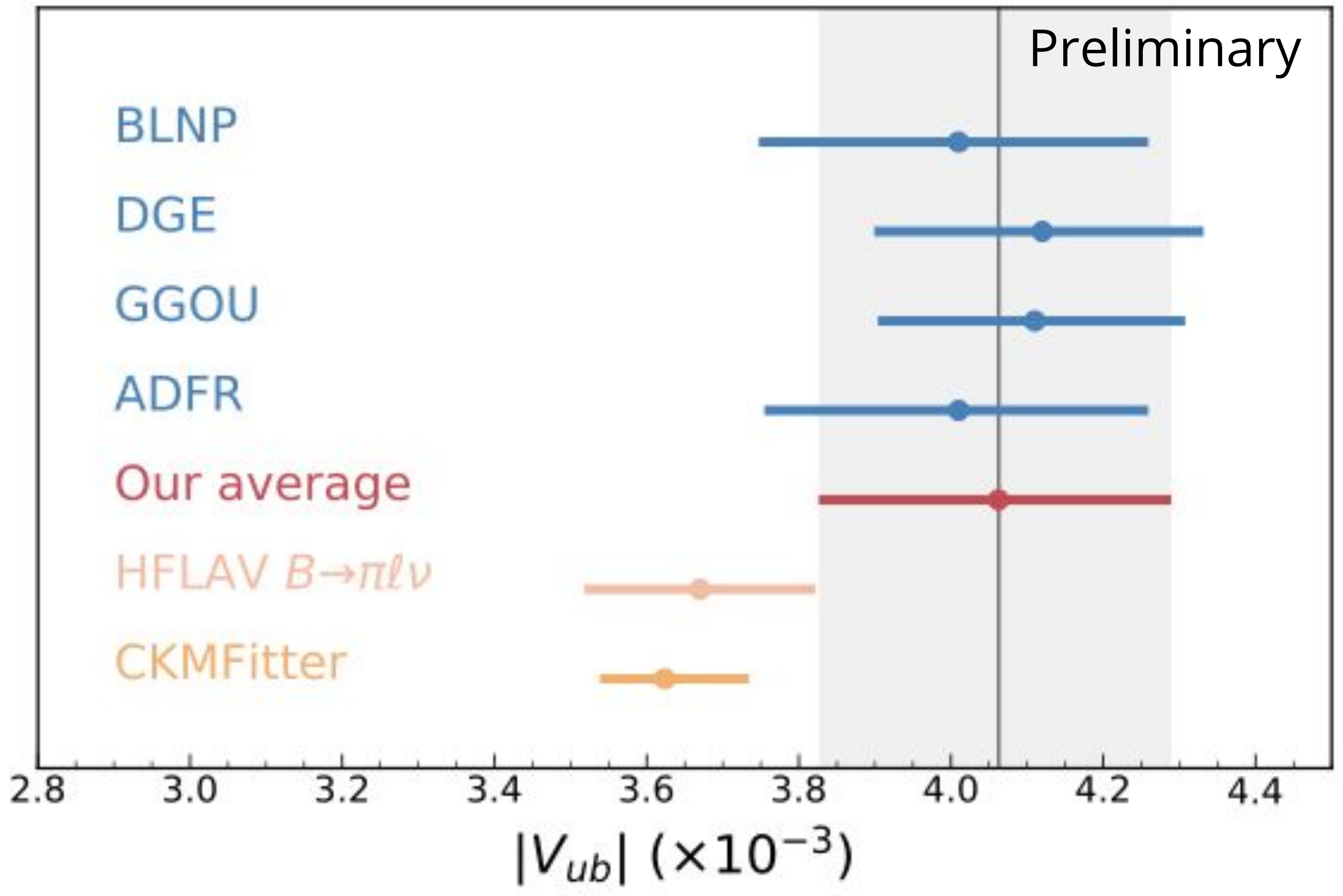
Talk by G. Ricciardi (Theory)

ICHEP Belle Preliminary

- Preliminary Belle analysis of $B \rightarrow X_u\, l\, \nu$ (ICHEP 2020)
  - B-full reconstruction tag
  - Fit to M_X-q^2
  - BDT background suppression
- $|V_{ub}|$ (avg) = $(4.06 \pm 0.09_{stat} \pm 0.16_{sys} \pm 0.15_{theo})\ 10^{-3}$
- Reduced tension with exclusive measurement: 1.4 σ.

Projections of 2D fit resut:



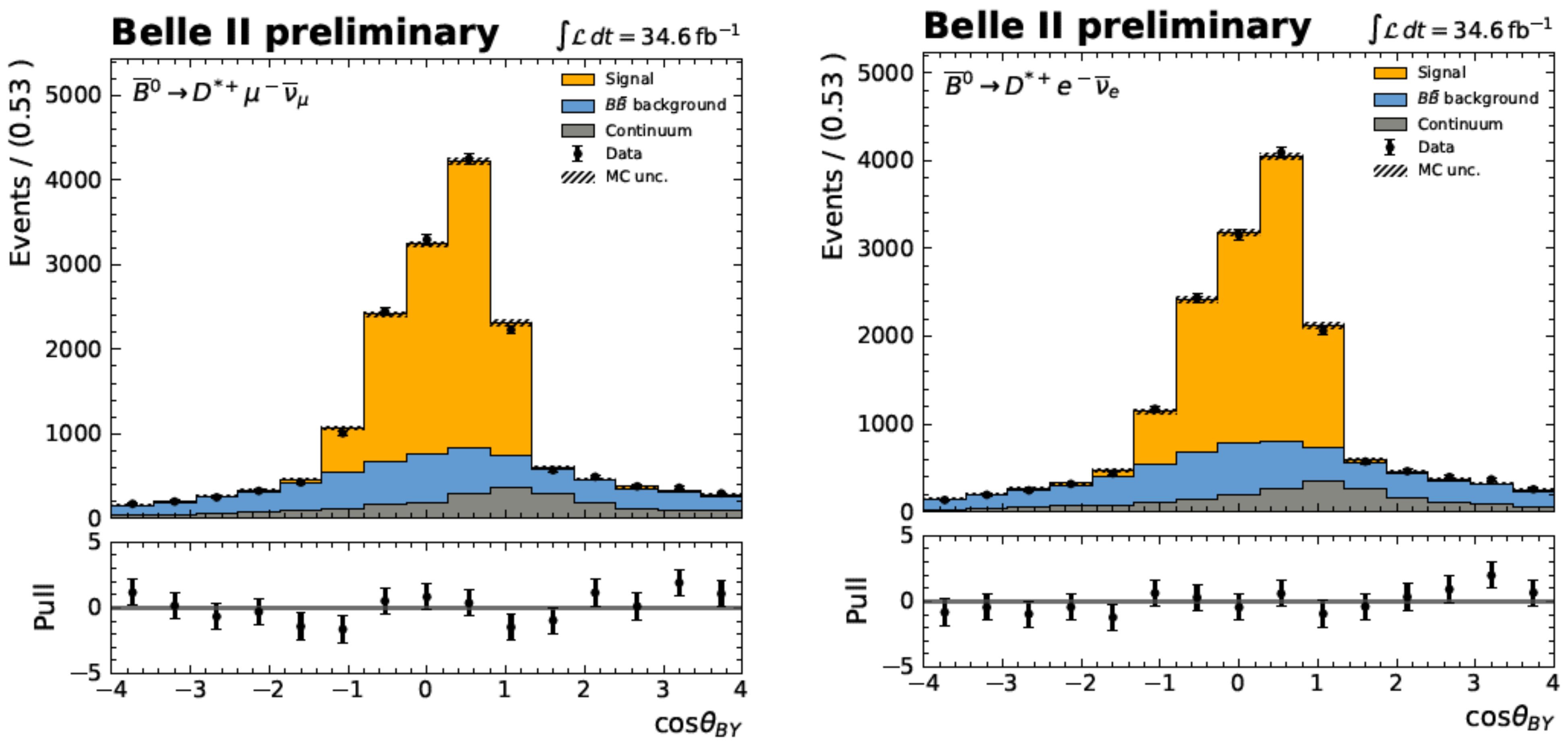


Towards B→D(*) τ ν @ Belle II

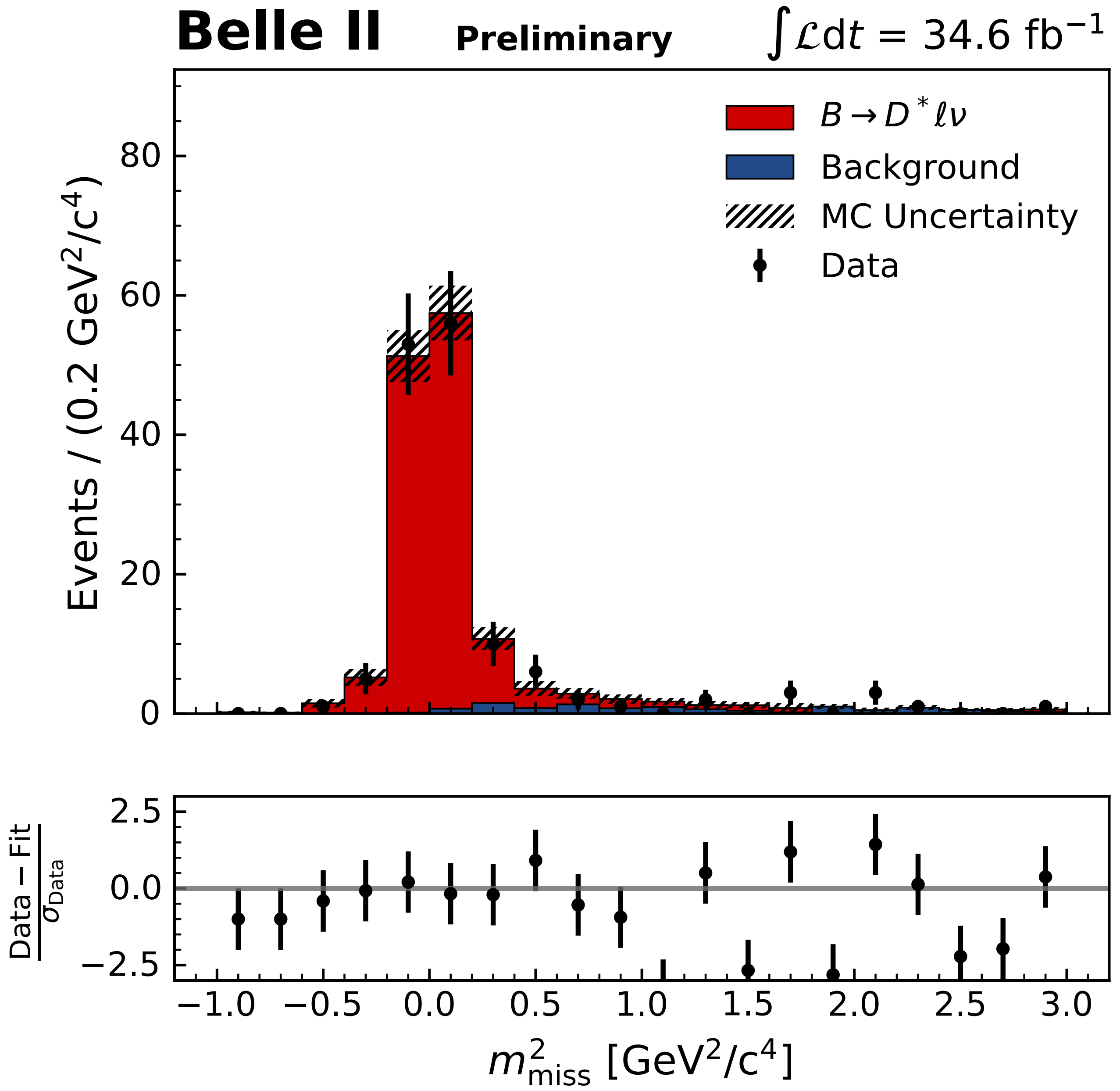
Talk by H. Atmacan

arXiv: 2008.10299

arXiv: 2008.07198

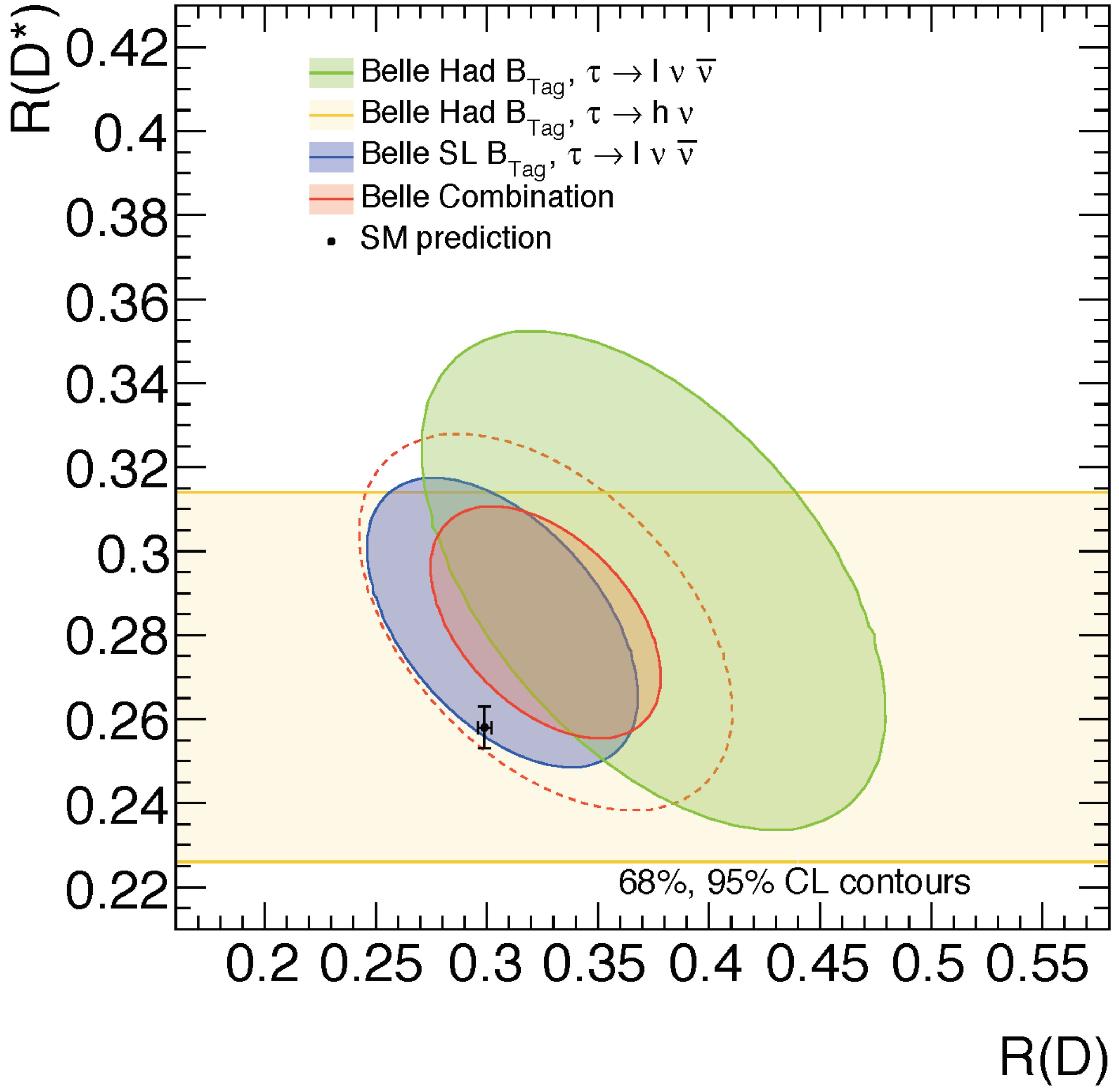


$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_l) = (4.60 \pm 0.05_{\text{stat}} \pm 0.17_{\text{syst}} \pm 0.45_{\pi_s})\ \%$$



$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_l) = (4.51 \pm 0.41_{\text{stat}} \pm 0.27_{\text{syst}} \pm 0.45_{\pi_s})\ \%$$

- Measurements of BR(B→D* l ν) tagged (15% precision), and untagged (12% precision, systematics dominated by control mode). Good e/μ detection universality.
- On track for competitive measurements soon - work on lepton ID at low momentum.

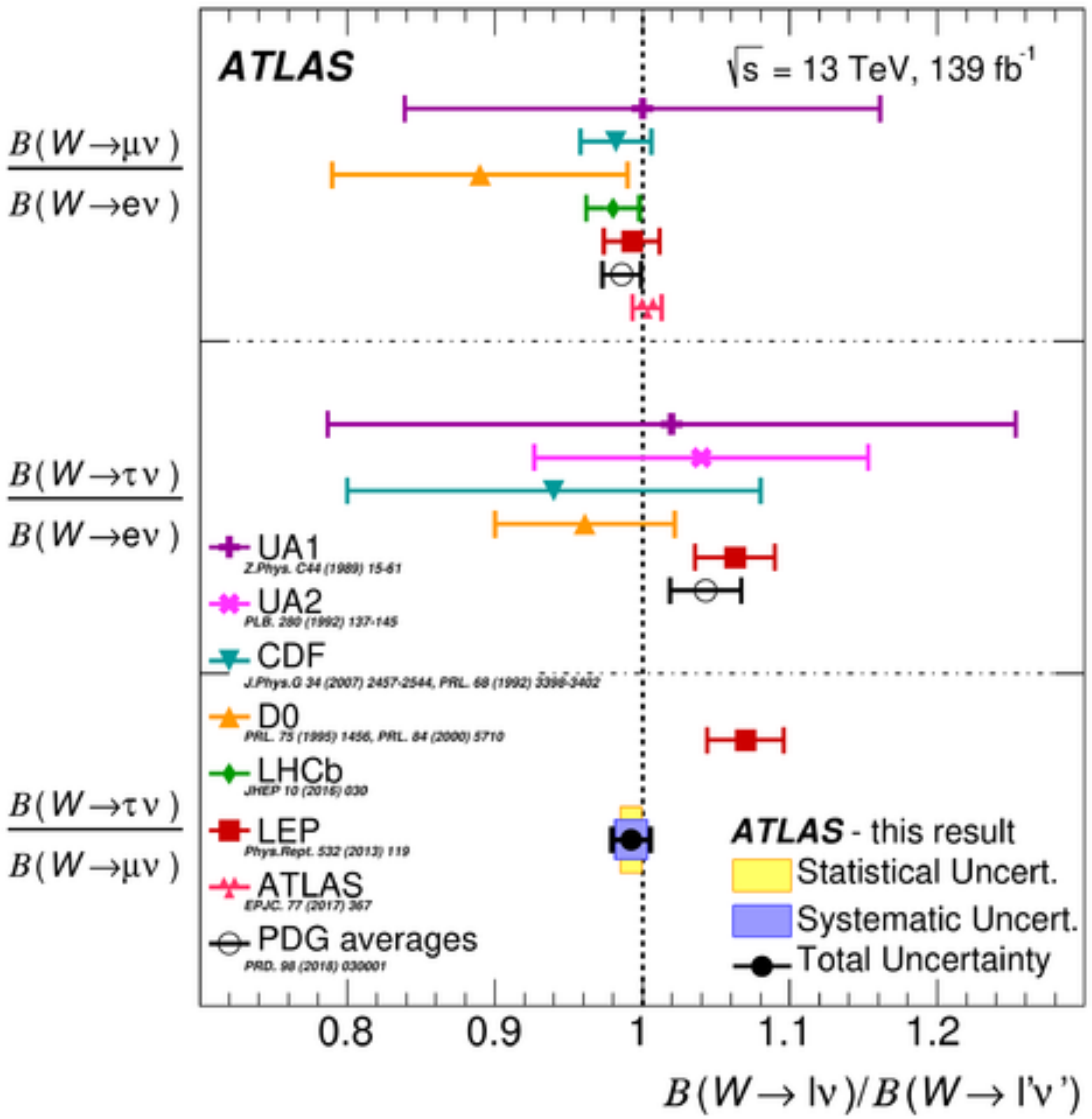


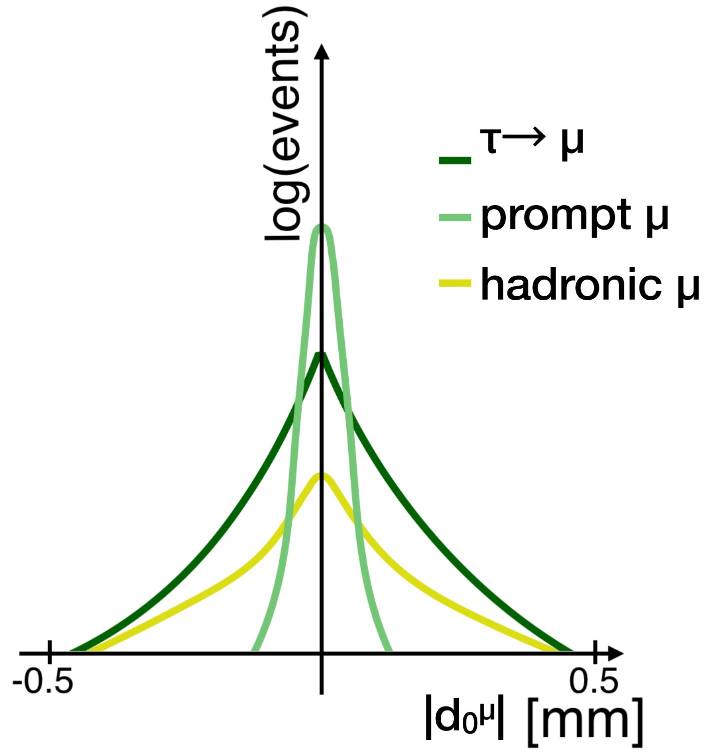
Remark: Not an anomaly at Belle

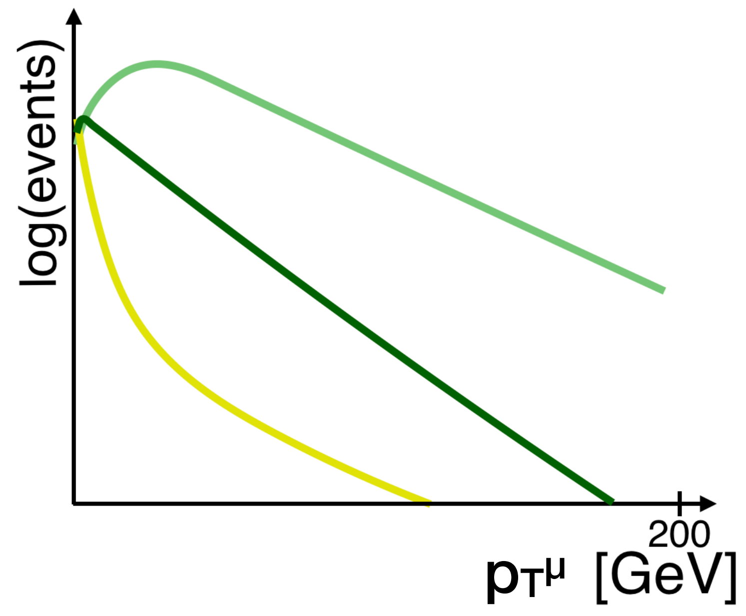
LFU in tt → W → l ν

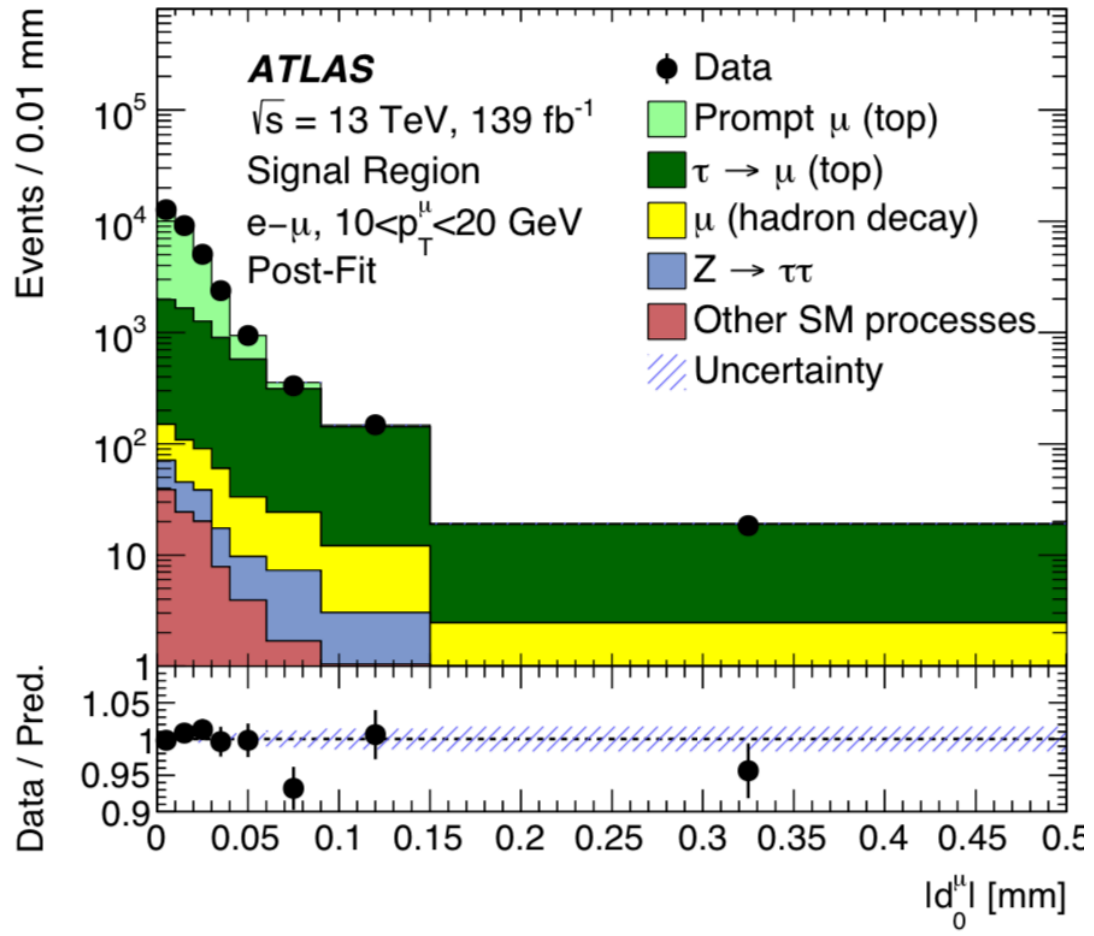
Talk by I. Sanderswood

arXiv:2007.14040









- R(τ/μ)=0.992 ± 0.013 [± 0.007 (stat) ± 0.011 (syst)]
- A new technique making use of ATLAS's huge Run-2 dataset and excellent muon reconstruction shines new light on an old LEP discrepancy

Rare & FCNC Decays

Semileptonic decays

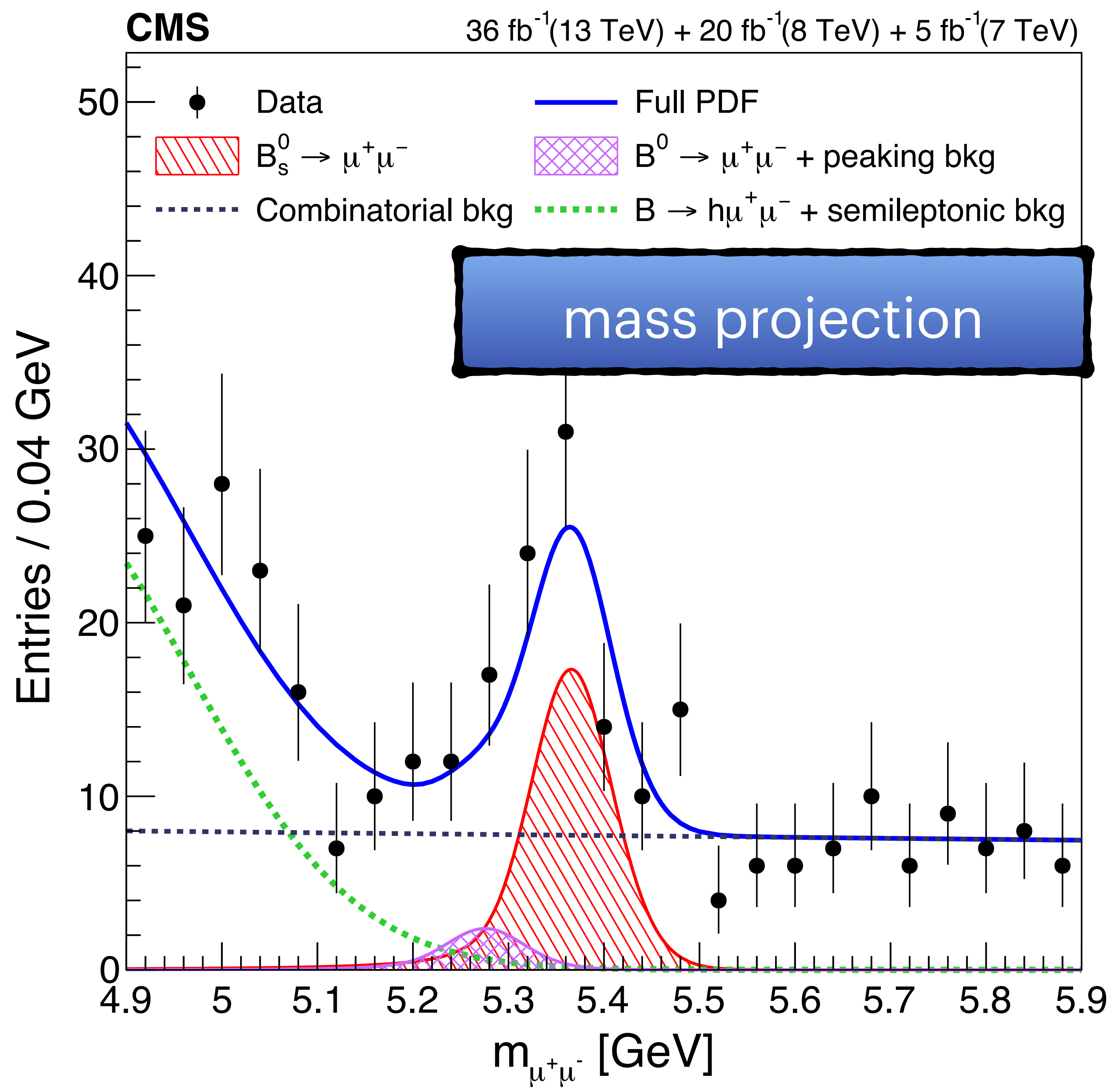
Leptonic decays

LFV and LFUV

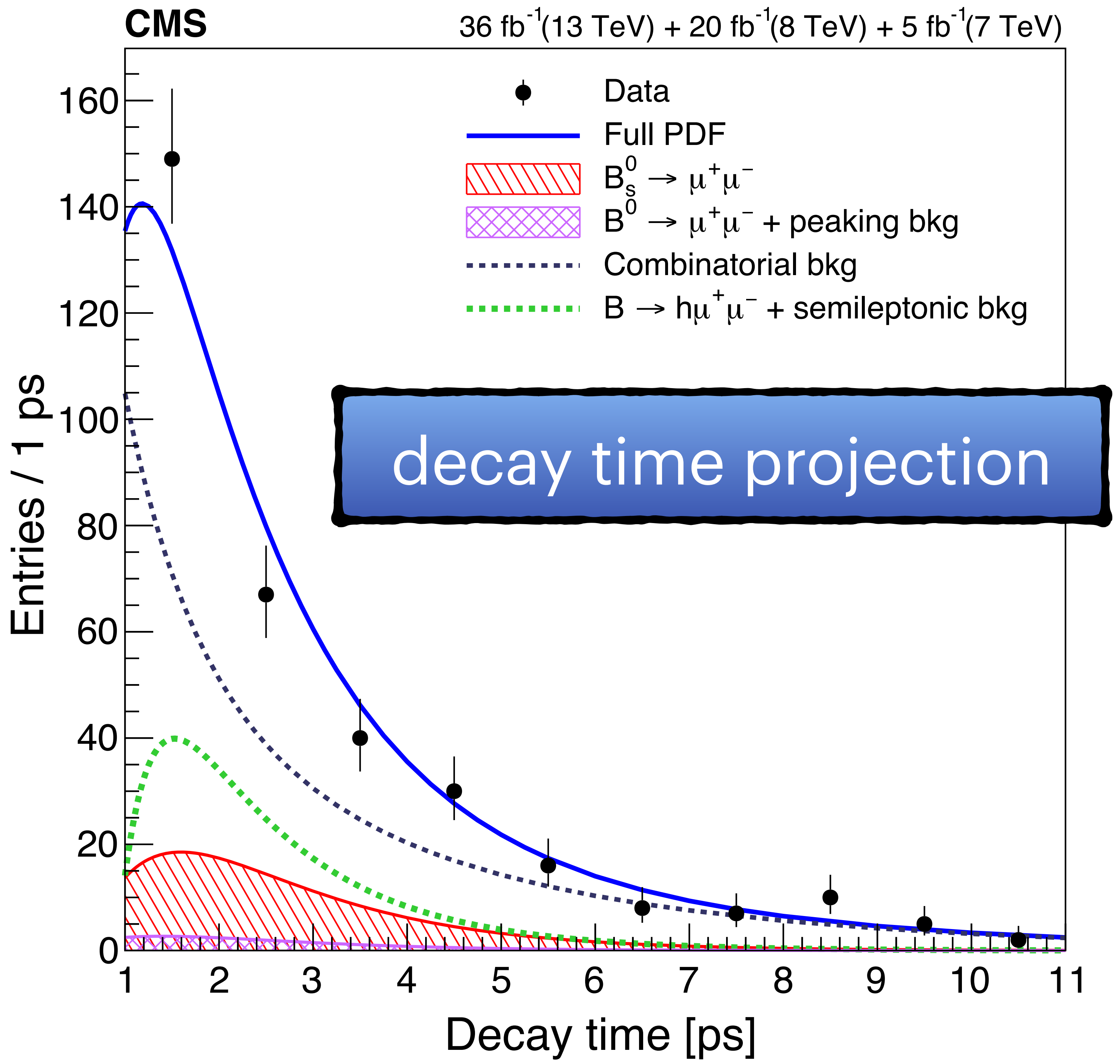
$B_{s,d} \rightarrow \mu\mu$

Talks by C. Kar, A. Perrevoort

CMS JHEP 04 (2020) 188
CMS-PAS-BPH-20-003
LHCb-CONF-2020-002
ATLAS-CONF-2020-049



mass projection



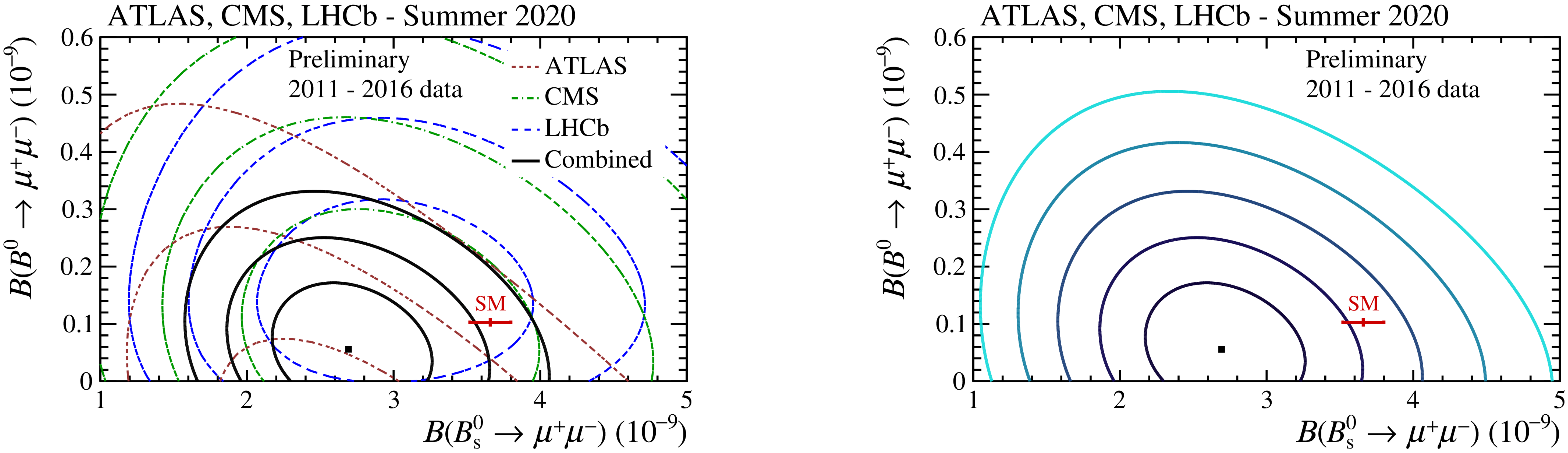
decay time projection

	$\tau_{\mu^+\mu^-}$ (ps)
2D UML	$1.70 + 0.61 / - 0.44$
sPlot	$1.55 + 0.52 / - 0.33$

Channel	Branching fraction	Sign. (Obs)
$B^0_s \rightarrow \mu^+\mu^-$	$(2.9^{+0.7}_{-0.6}(\mathrm{exp}) \pm 0.2(f_s/f_u)) \times 10^{-9}$	5.6 σ
$B^0 \rightarrow \mu^+\mu^-$	$(0.8^{+1.4}_{-1.3}) \times 10^{-10}$	0.6 σ

- $B^0_s \rightarrow \mu^+\mu^-$ has exceeded 5 σ at CMS.
- Lifetime consistent with SM, (1.609 ± 0.010) ps.

$B_{s,d} \rightarrow \mu\mu$



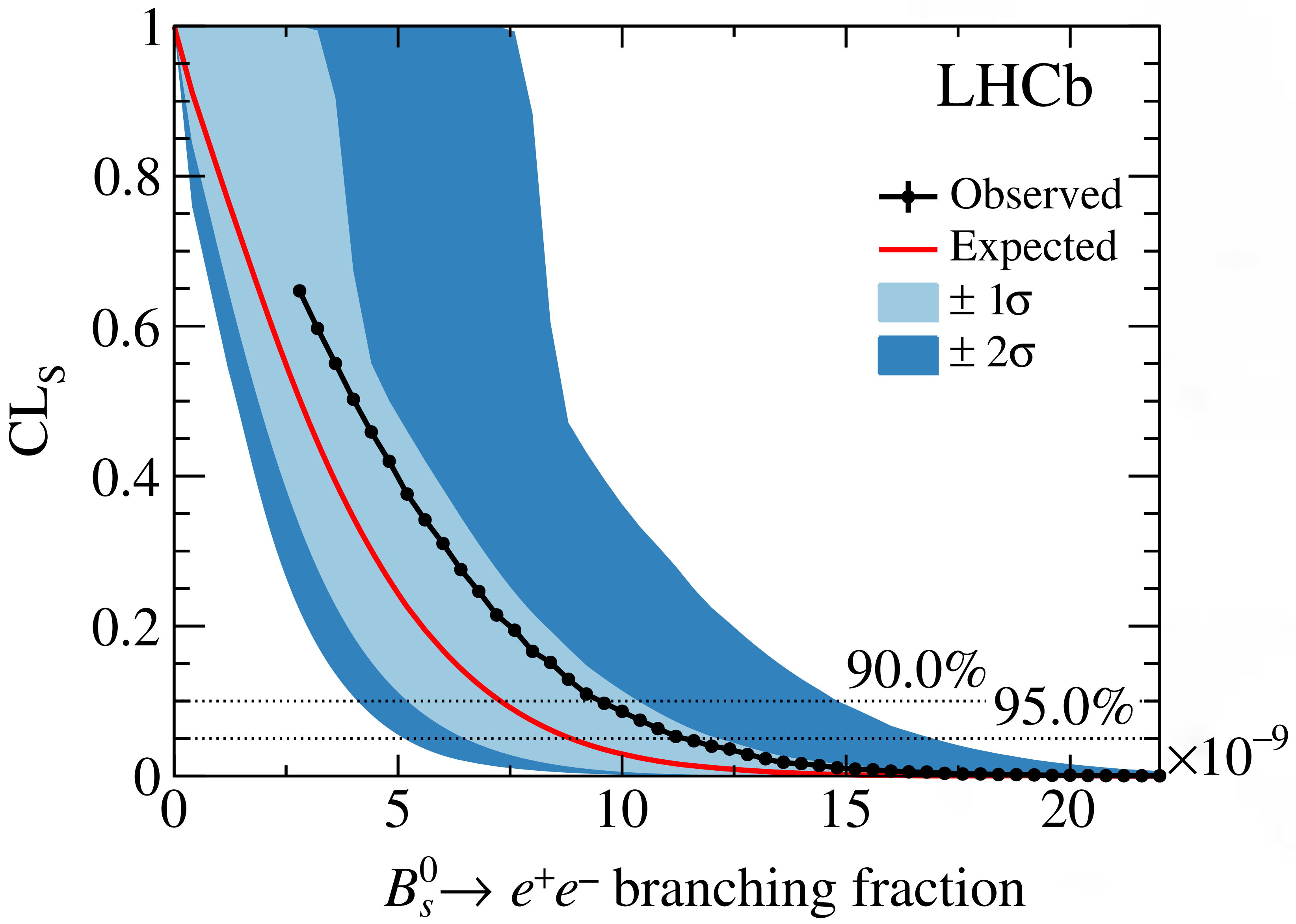
- Combination ATLAS, CMS, LHCb for Run 1 + Run 2 ((2015 +) 2016). 2.1 σ from the SM.

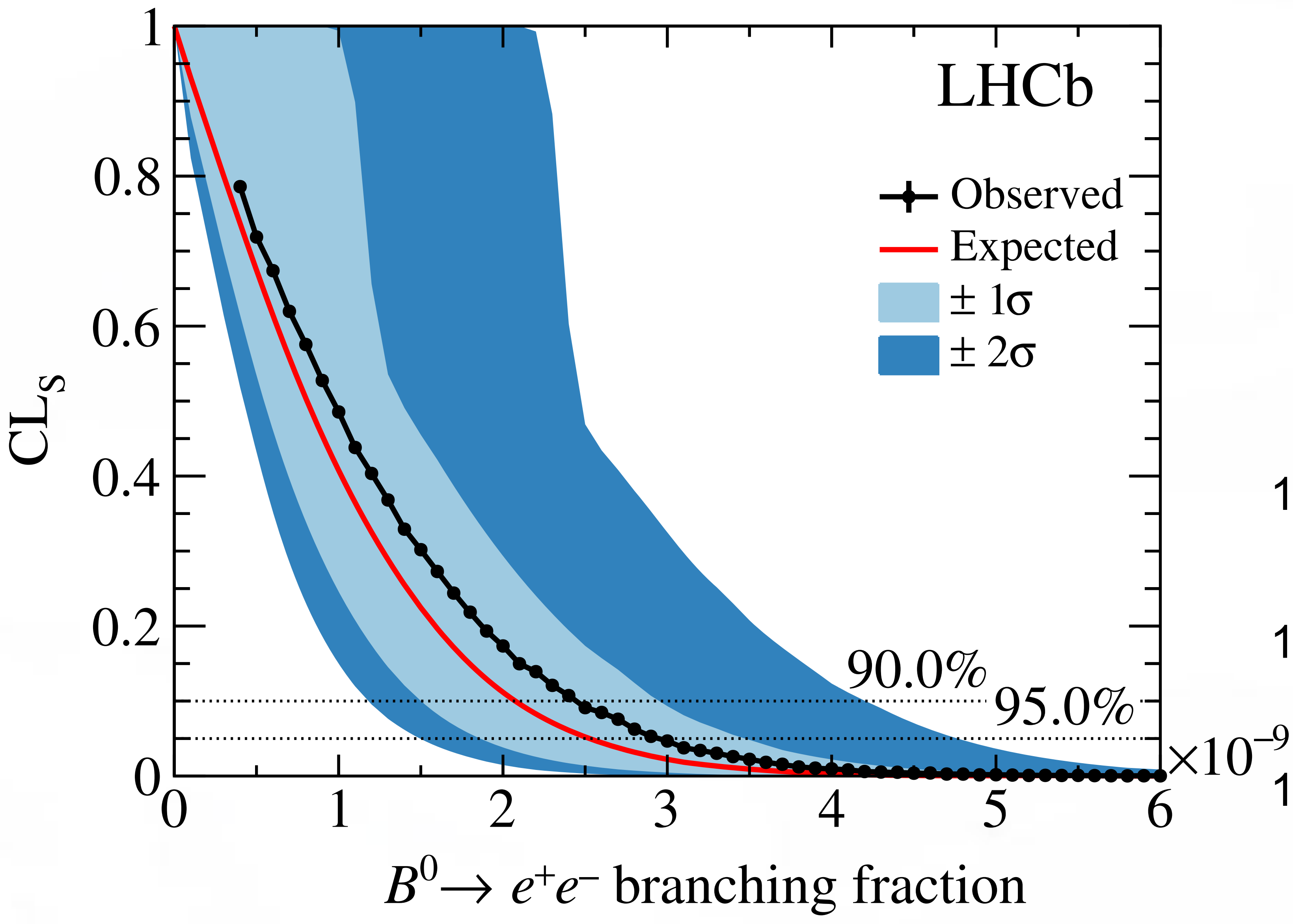
$$\mathcal{B}(B_s^0 \rightarrow \mu\mu) = (2.69^{+0.37}_{-0.35}) \times 10^{-9}$$
$$\mathcal{B}(B^0 \rightarrow \mu\mu) < 1.9 \times 10^{-10} \text{ at 95\% CL}$$

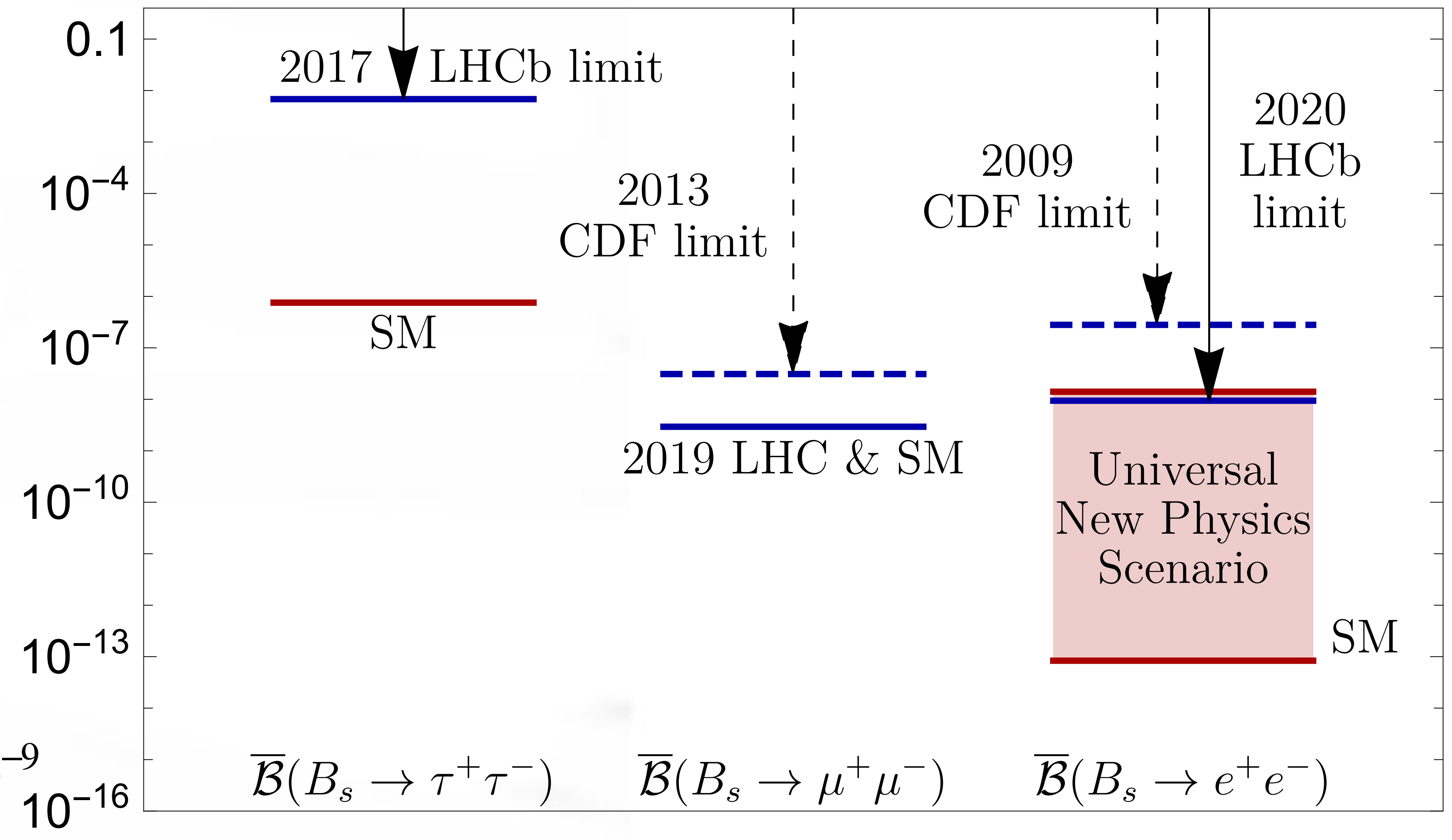
$B_{(s,d)} \rightarrow ee$

Talk by I. Williams

CERN-LHCb-CONF-2020-002
PRL 124 (2020) 211802







$$\mathcal{B}(B_s^0 \to e^+e^-) < 9.4\ (11.2) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to e^+e^-) < 2.5\ (3.0) \times 10^{-9}$$
at 90% (95%) CL

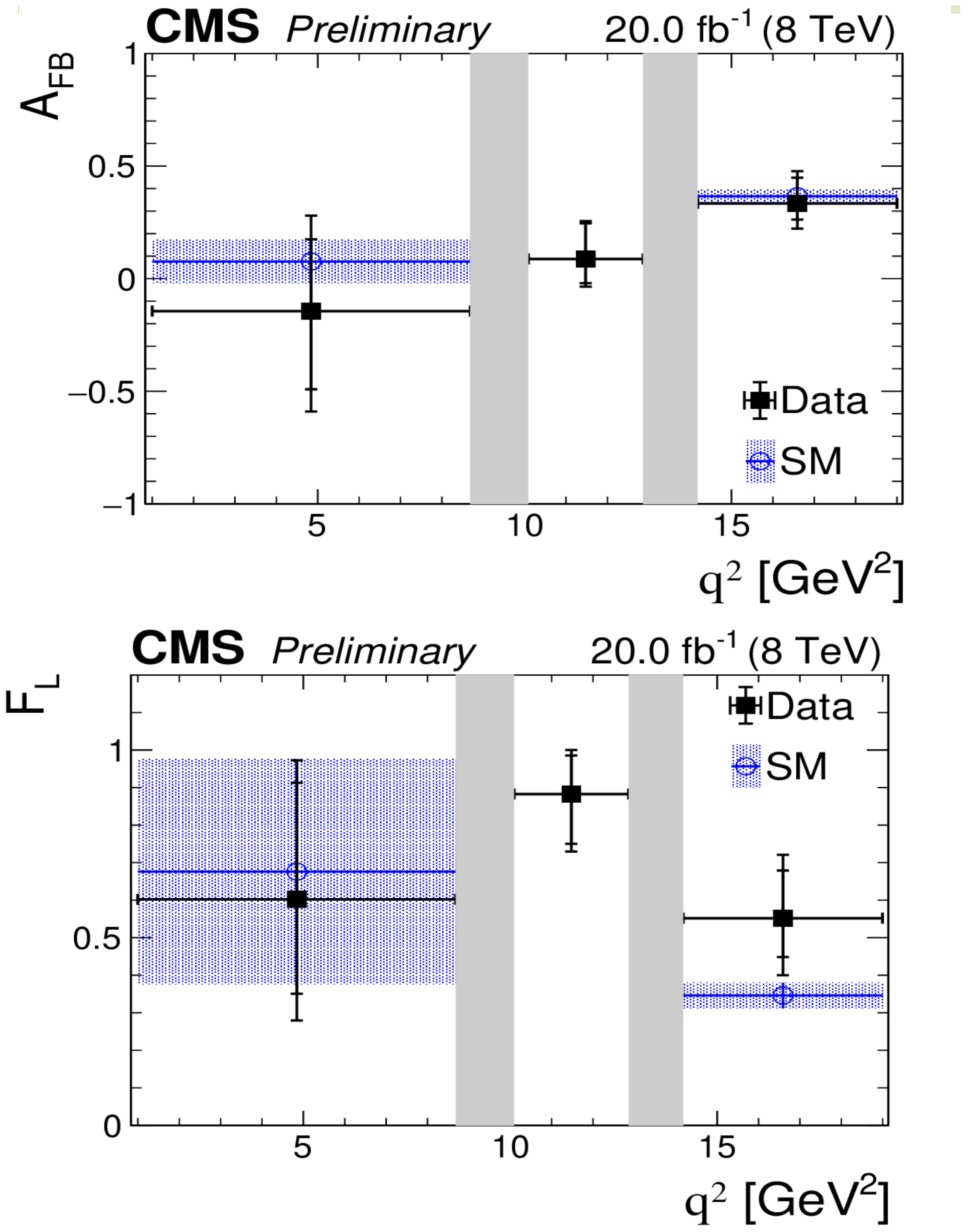
- Helicity suppressed by 10^{-4} below μμ channel - NP effects are therefore potentially large.
- Big improvement over previous CDF limit.

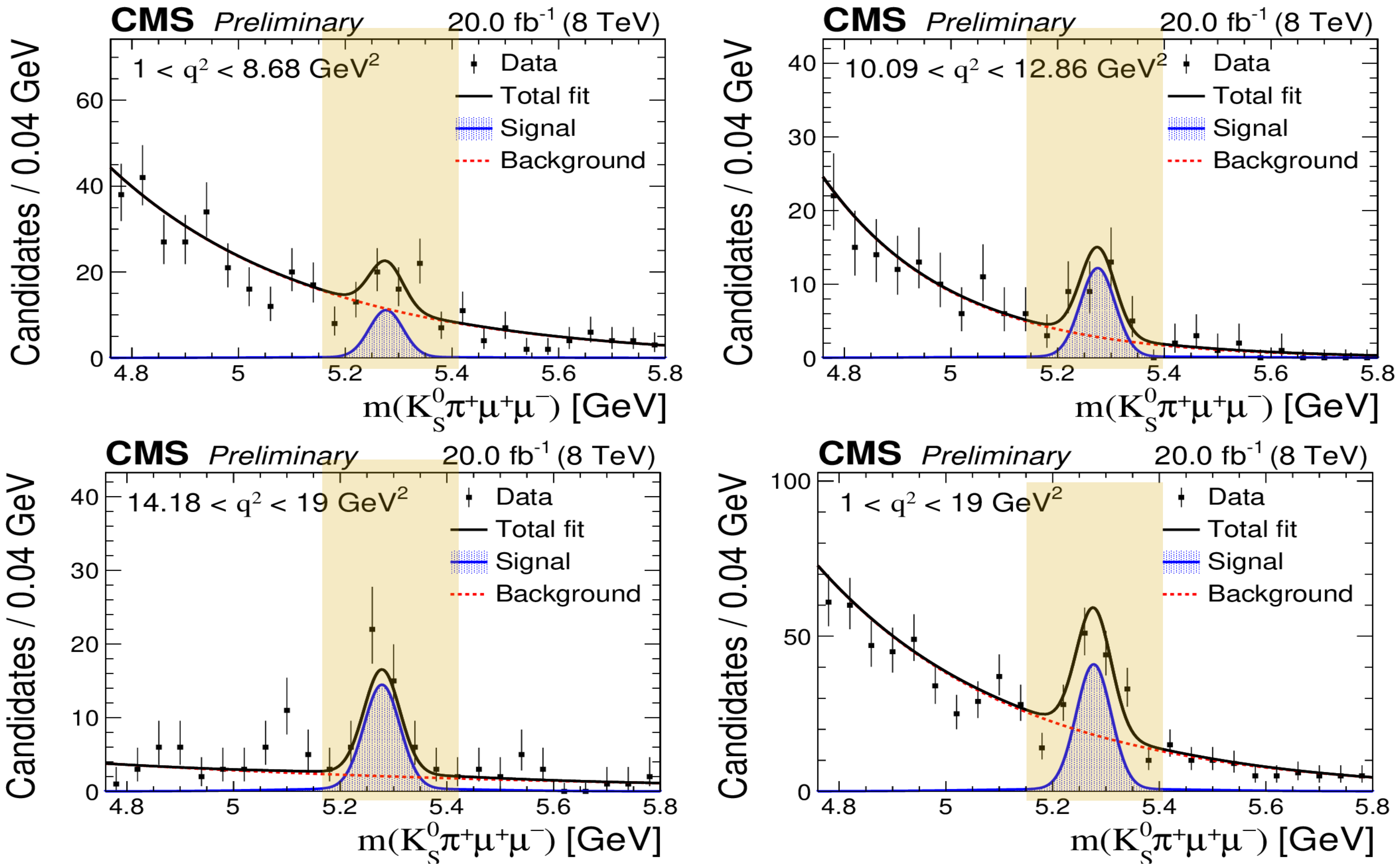
$B^+ \to K^*(K_S\pi^+)\,\mu\mu$ Angular Analysis

- New. $B^+ \to K^{*+}\mu^+\mu^-$ where $K^{*+} \to K^0_S\,\pi^+$.

Talk by S. Swain

CMS Preliminary

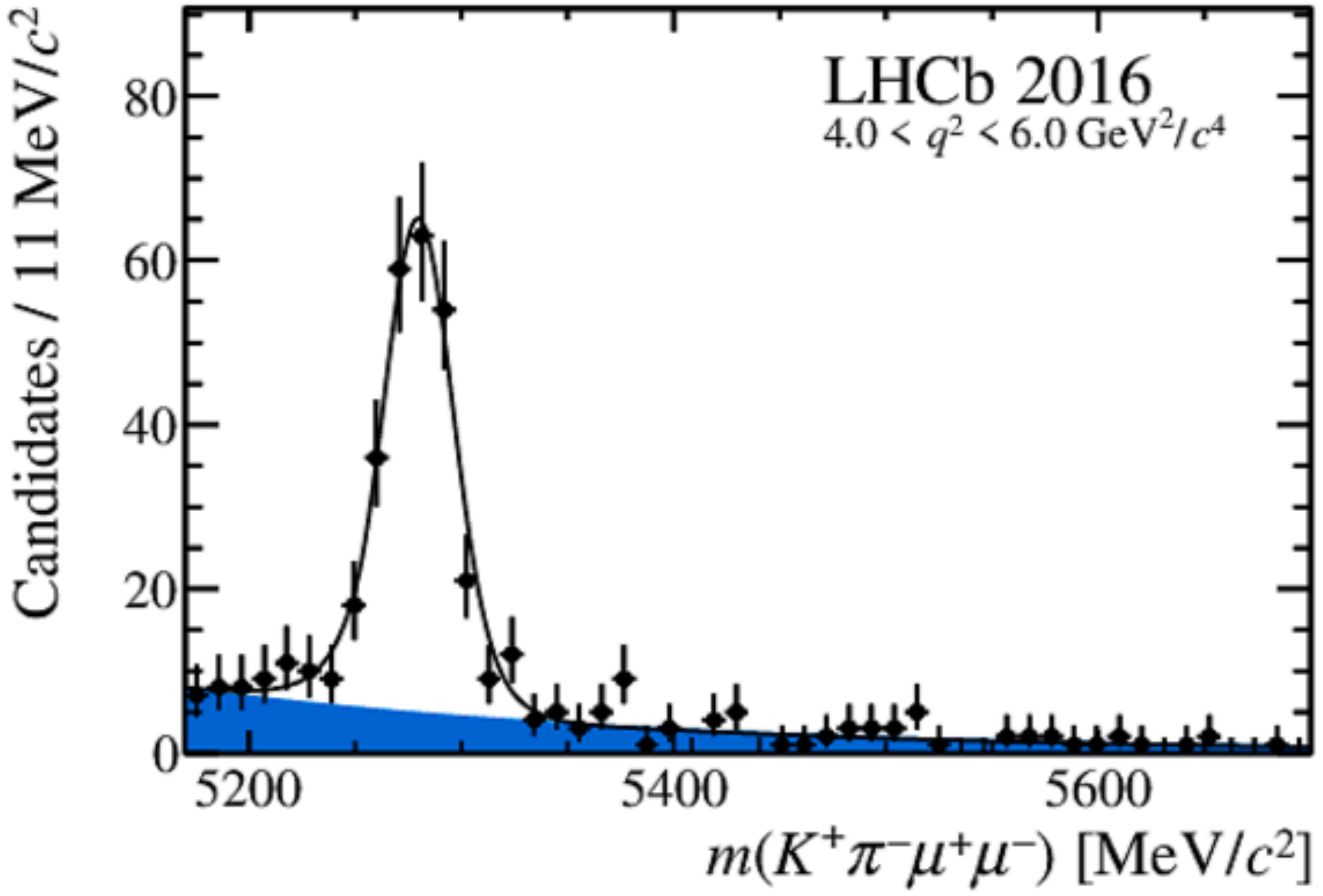


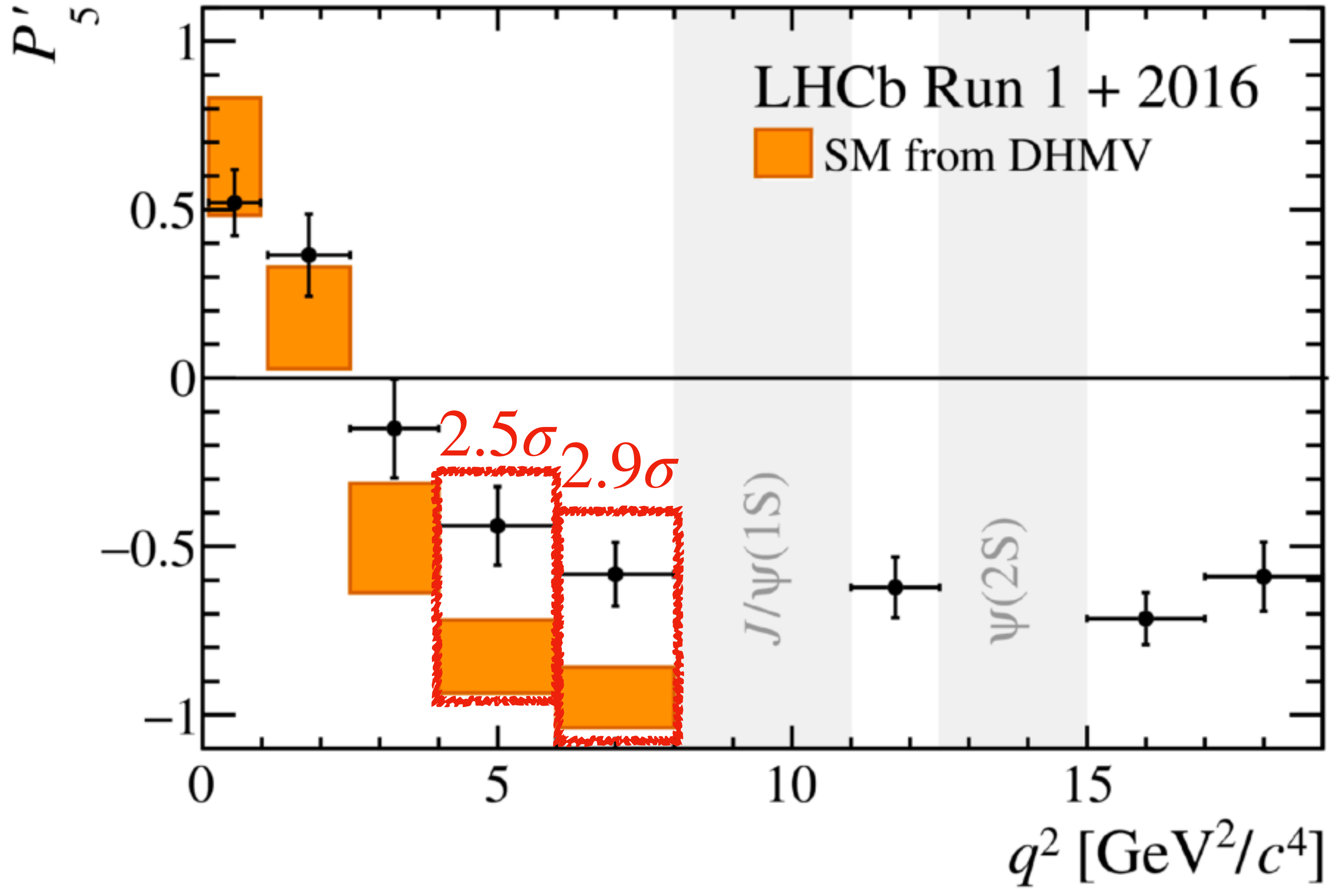


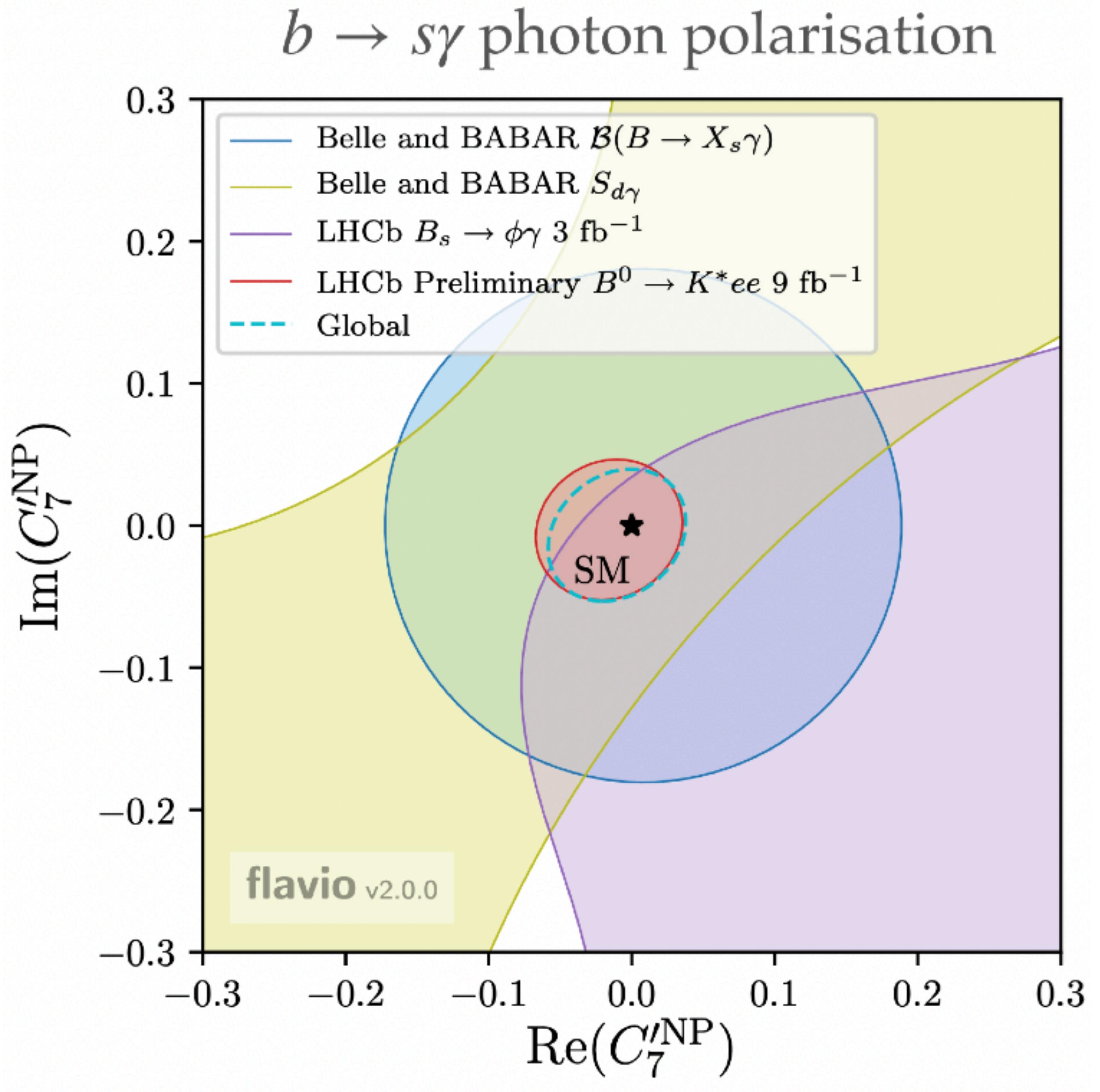
B→K* ll Angular Analysis

Talk by D. Y. Tou

LHCb PRL 125, 011802 (2020)





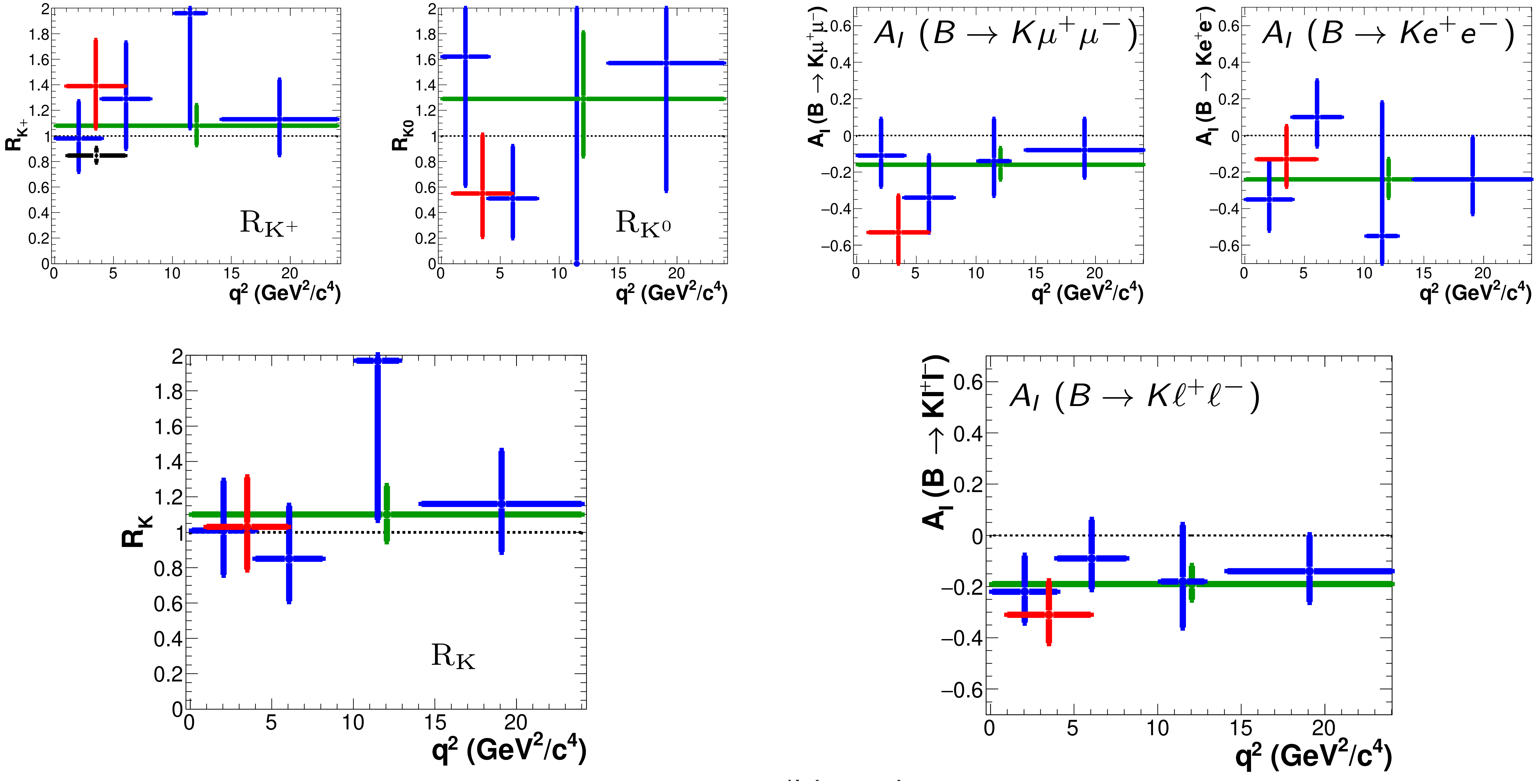


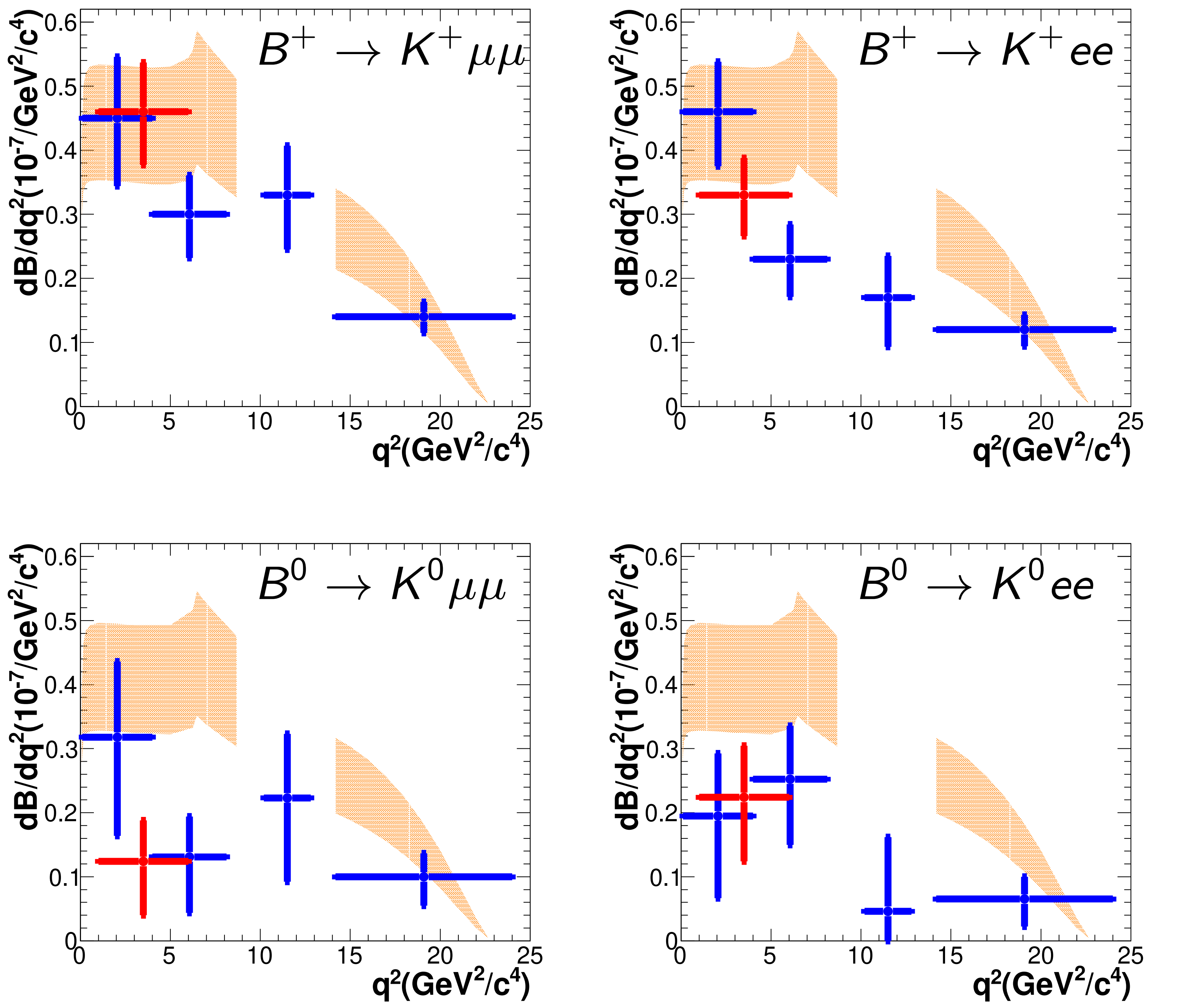
- Fit ΔRe(C_9) using *flavio* package and other parameters assuming their SM value: 3.3σ tension with SM.
- Recent preliminary K*ee analysis (shown at ICHEP) - 4D fit (m, cos θ_l, cos θ_V, φ~). C_7 is SM preferred.

B→Kll LFUV, LFV

Talk by S. Choudhury

Belle arXiv:1908.01848v2





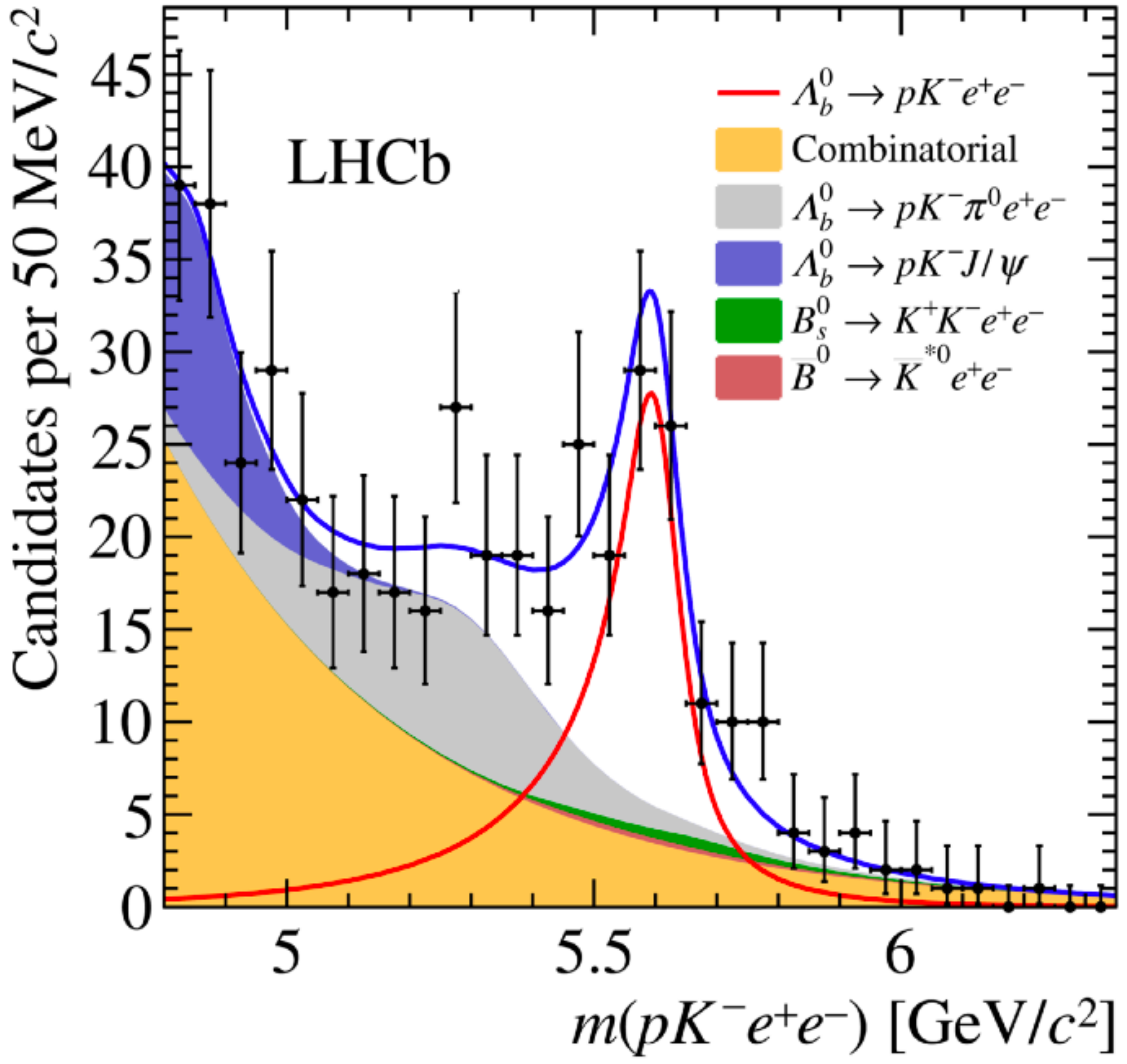
- Most precise B→J/ψ K BRs.
- R_K consistent with SM. A_I shows offset.
- dB/dq² consistent with SM but a bit low like LHCb.
- Best upper limit for B→K^0μe.

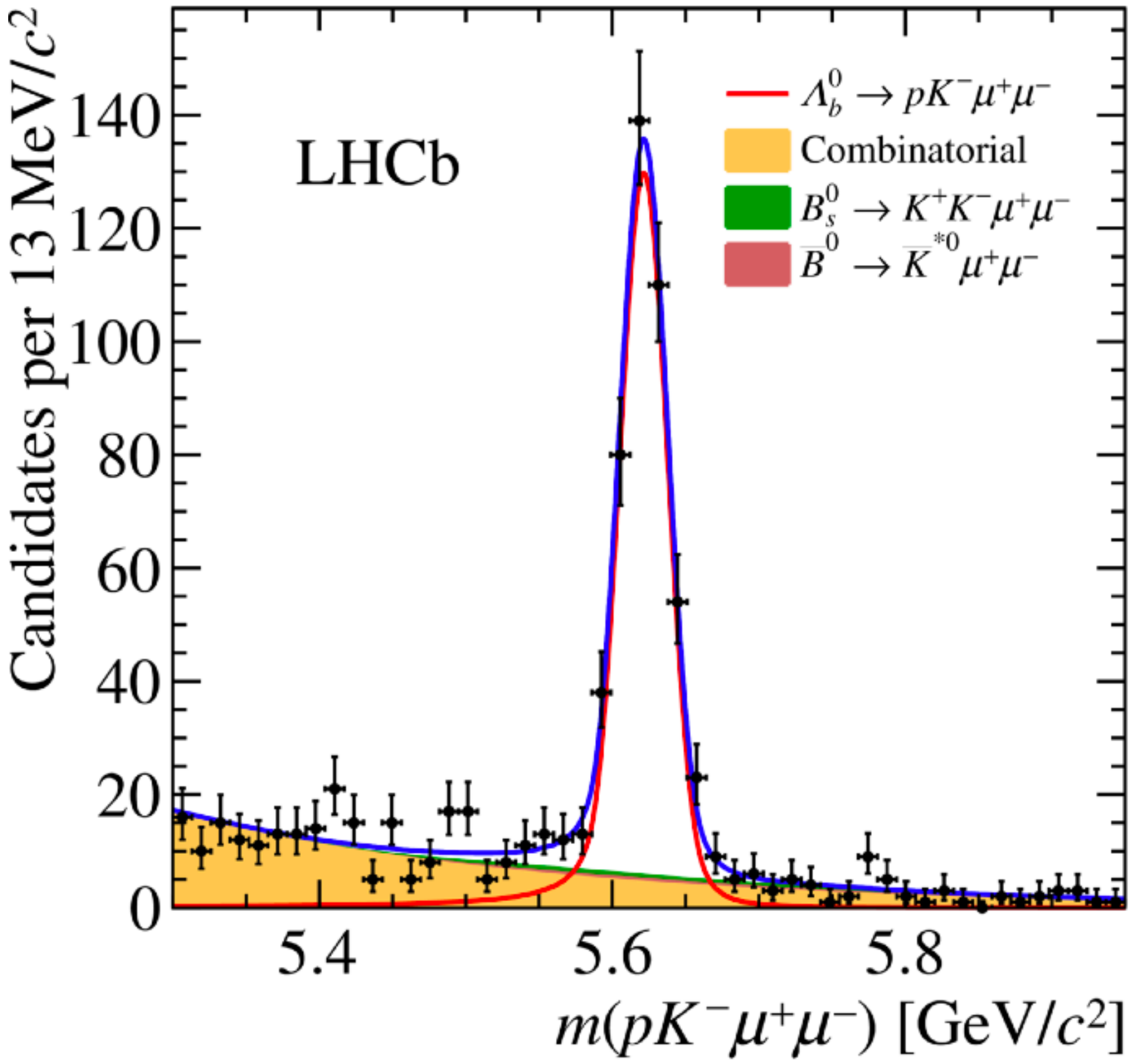
Mode	ε (%)	$N_{\rm sig}$	$N_{\rm sig}^{\rm UL}$	$\mathcal{B}^{\rm (UL)}$ (10^{-8})
$B^+ \to K^+\mu^+e^-$	29.4	$11.6^{+6.1}_{-5.5}$	19.9	8.5
$B^+ \to K^+\mu^-e^+$	31.2	$1.7^{+3.6}_{-2.2}$	7.5	3.0
$B^0 \to K^0\mu^\pm e^\mp$	20.9	$-3.3^{+4.0}_{-2.8}$	3.0	3.8

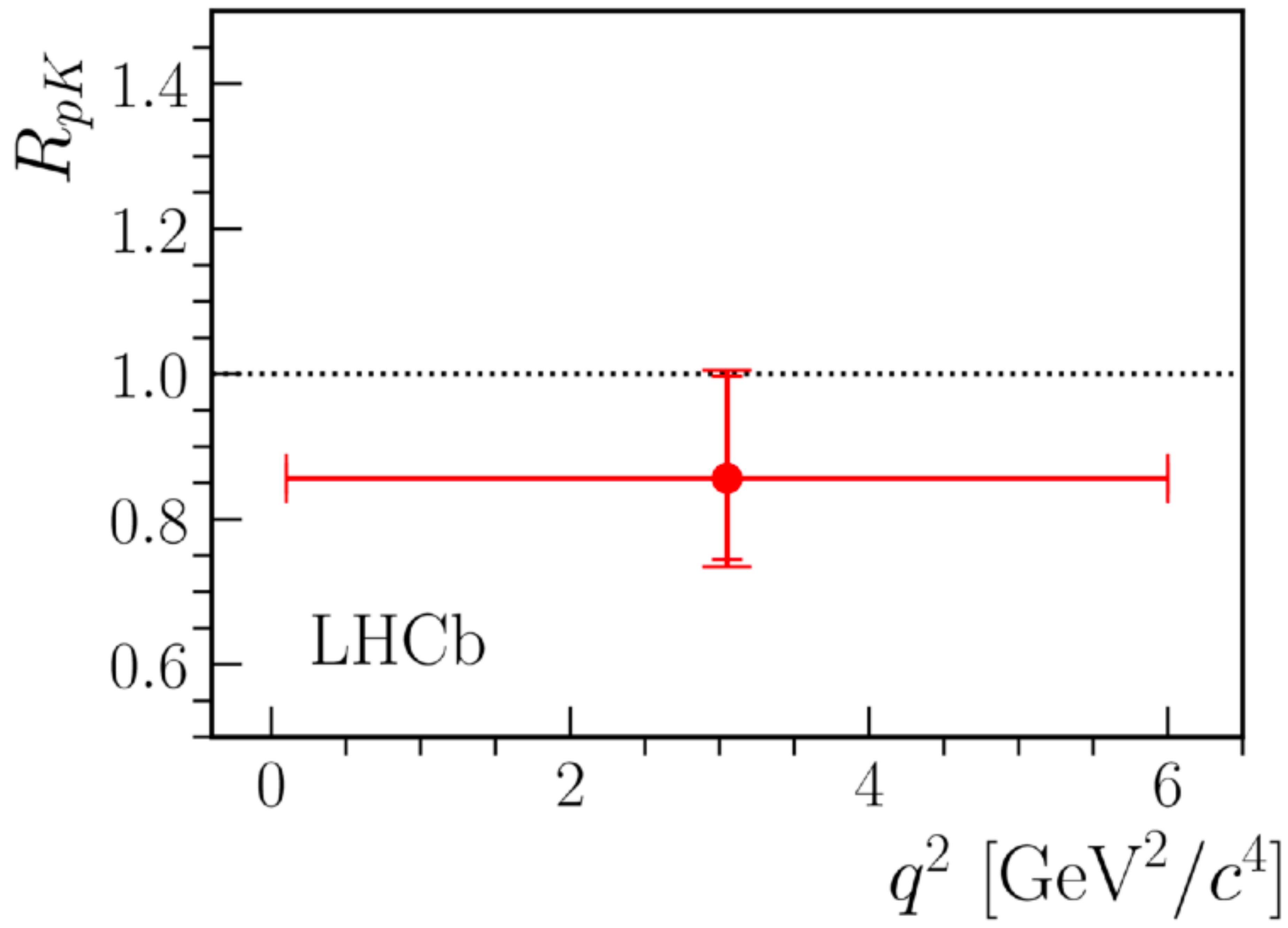
Λ→pKll LFUV

Talk by D. Y. Tou

JHEP 2020, 40 (2020)







- First measurement of B(Λ$_b$→pK$^-$μ$^+$μ$^-$), first observation of B(Λ$_b$→pK$^-$e$^+$e$^-$).

Uncertainty on $\mathscr{B}(\Lambda_b \to pK^-J/\psi)$

Statistical

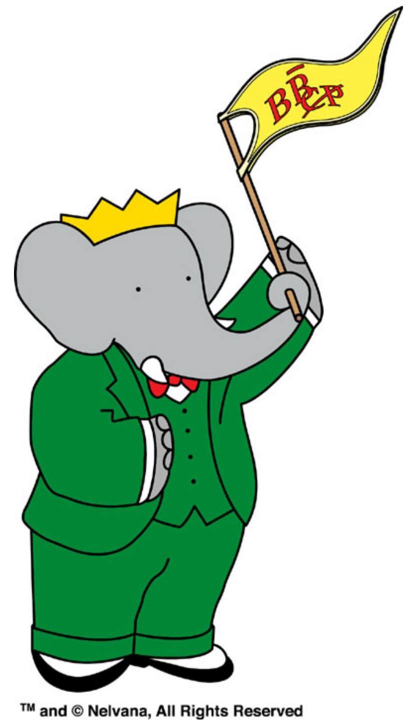
$$\mathscr{B}(\Lambda_b \to pK^-\mu^+\mu^-)|_{0.1<q^2<6.0\ GeV^2/c^4} = (2.65 \pm \boxed{0.14} \pm \boxed{0.12} \pm \boxed{0.29^{+0.38}_{-0.23}}) \times 10^{-7}.$$

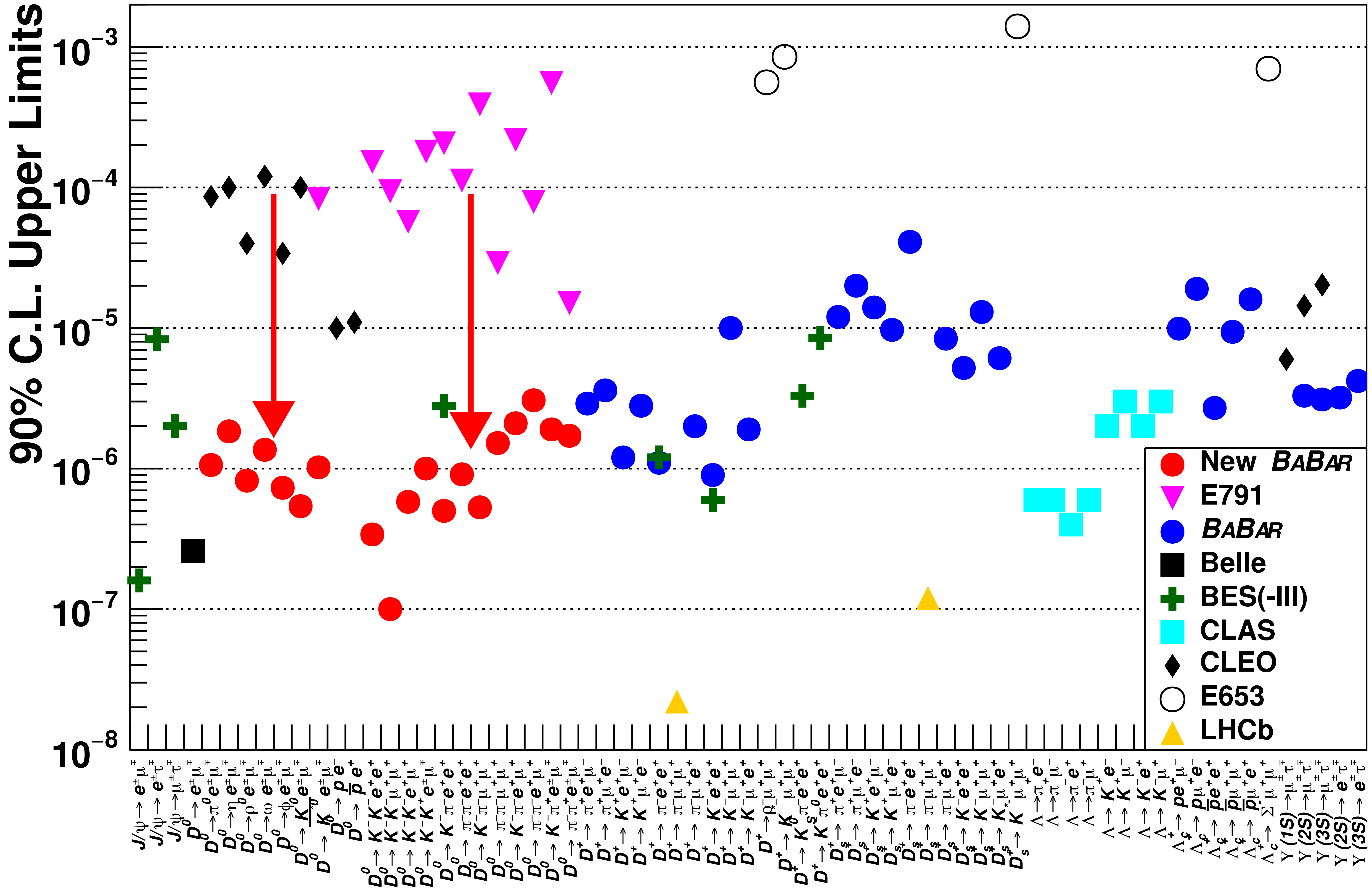
Systematic

D Rare and Forbidden

Talk by A. Lusiani

PRL 124 (2020) 7, 07182
PRD 101 (2020) 11, 112003





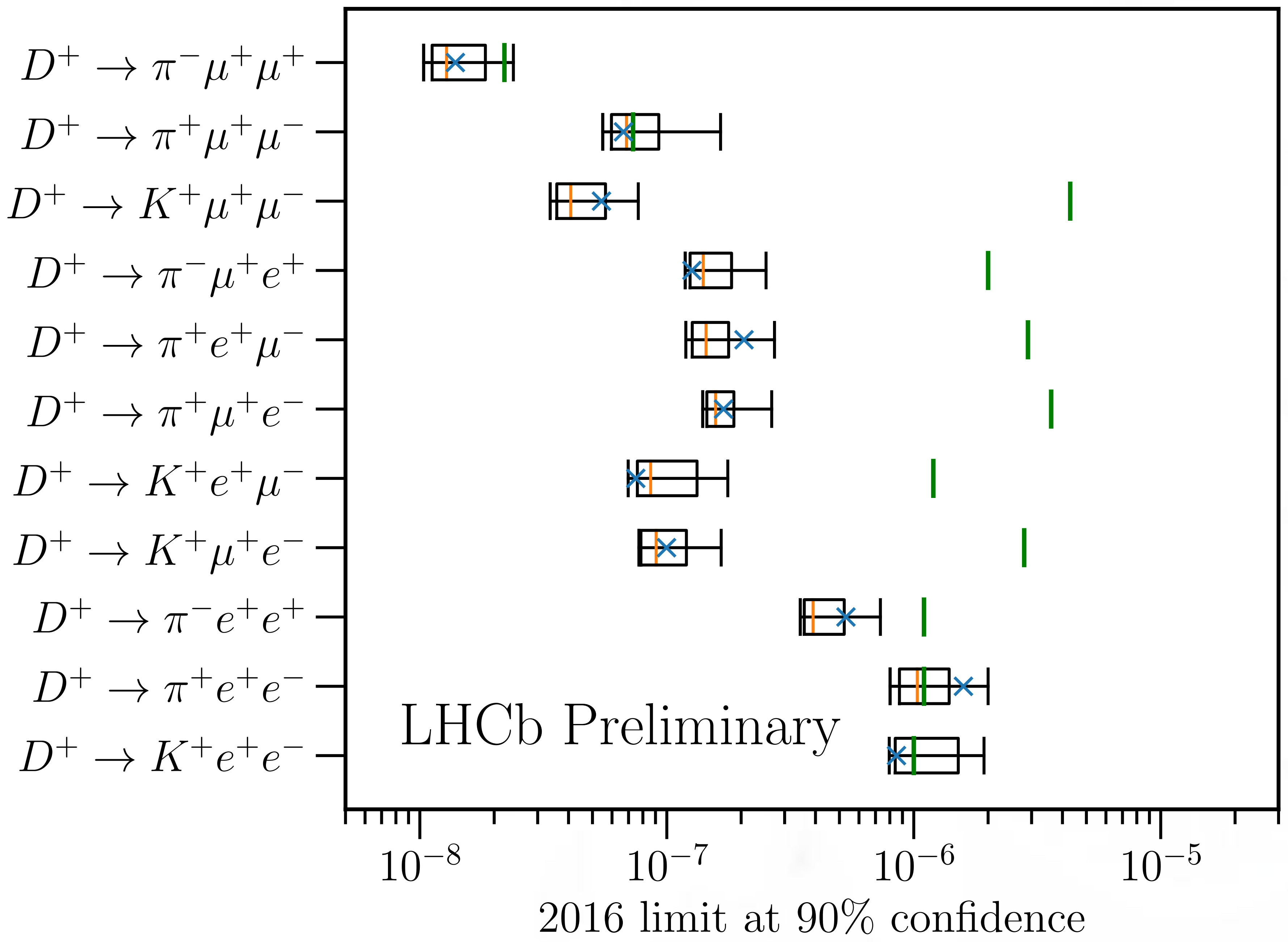
- $D^0 \to h'^- h^+ l^{\pm\prime} l^{\mp}$, and $D^0 \to h'^- h^- l^{+\prime} l^+$,
  - 12 new upper limits in the range (1 - 30) x 10^{-7}
- $D^0 \to X^0 e^{\pm} \mu^{\mp}$
  - 7 new upper limits in the range (5 - 30) x 10^{-7}
- Order 100× more stringent upper limits than previous results.

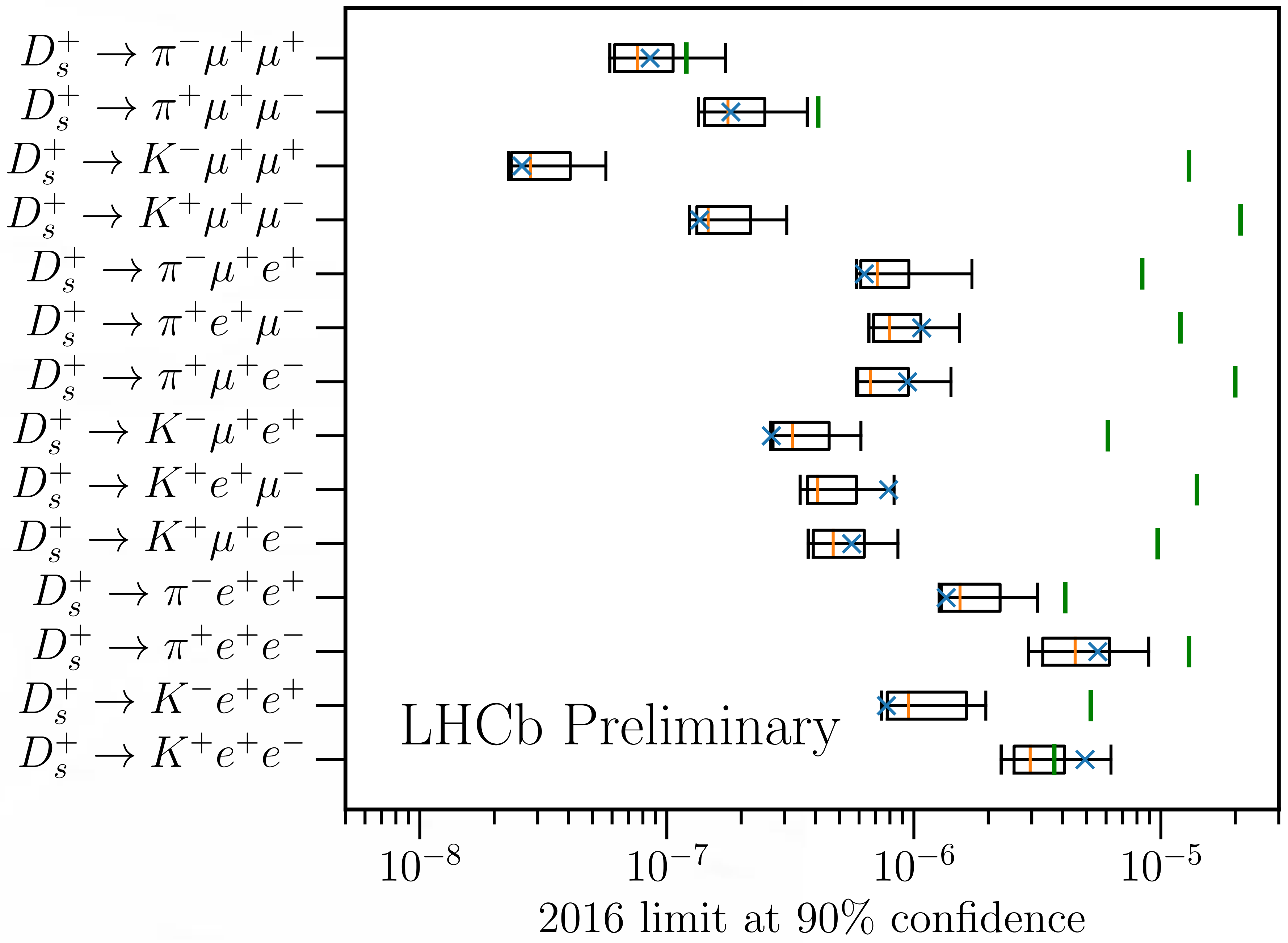
D Rare and Forbidden

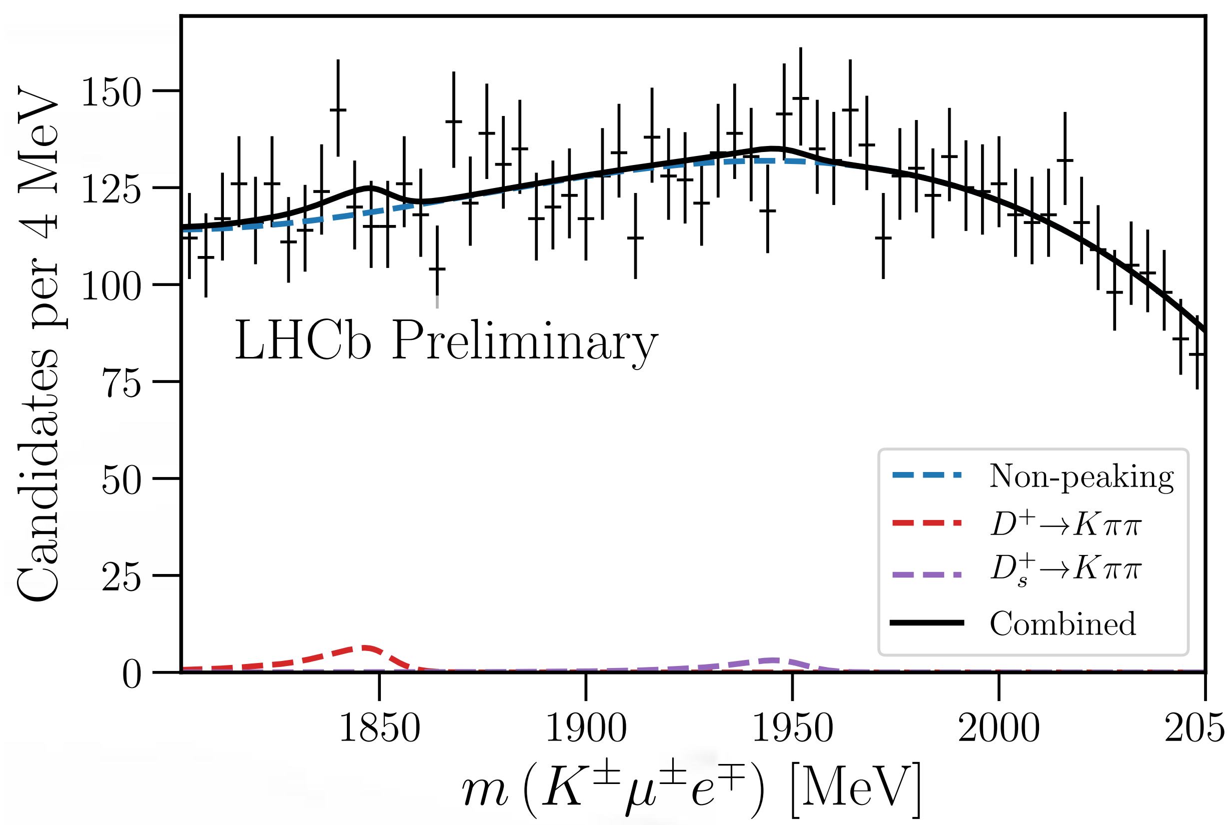
Talk by I. Williams

LHCB-PAPER-2020-007

|- expected median X - observed limit | - previous world’s best limit (BaBar, CLEO, LHCb)





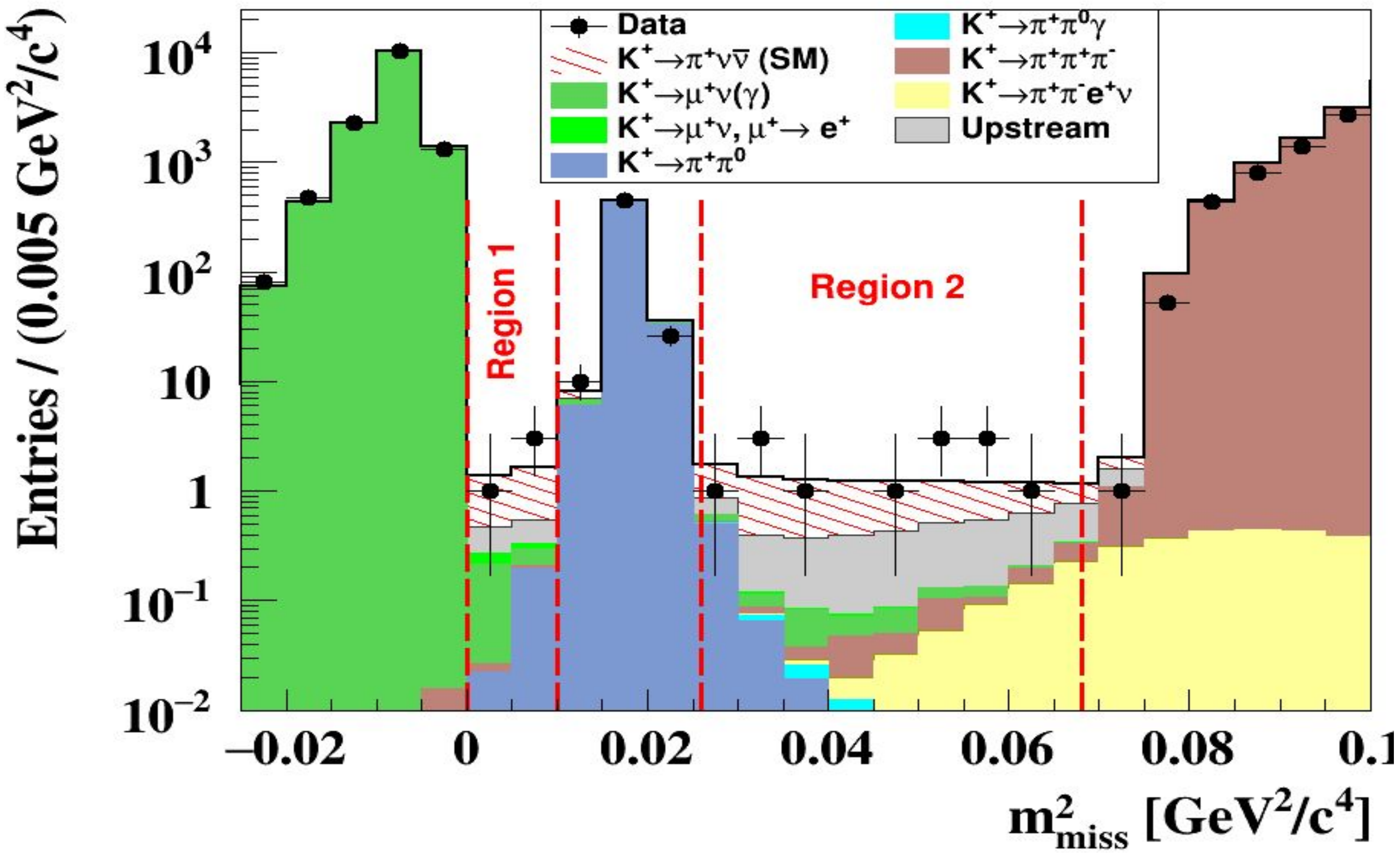


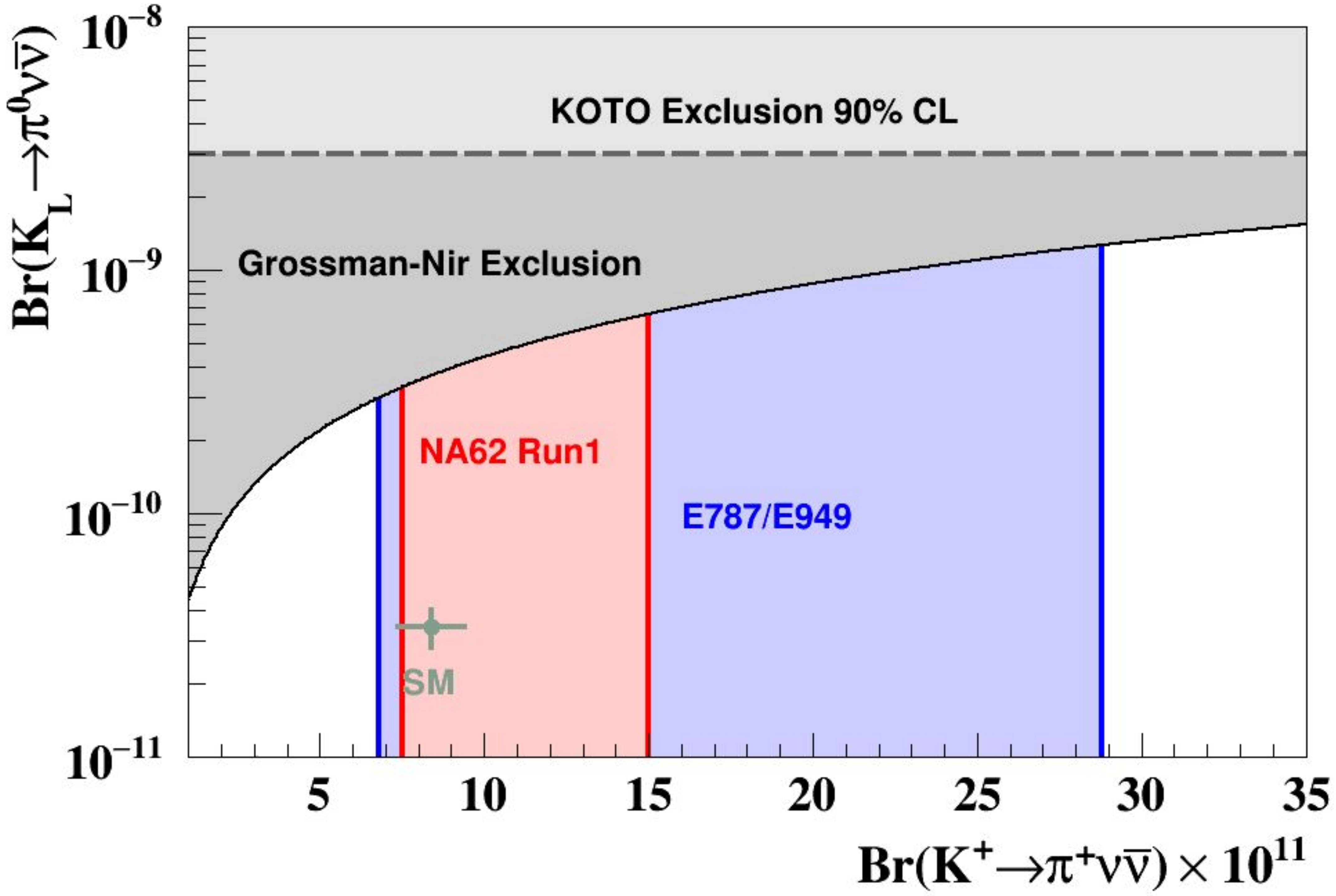
- Search for 25 rare and forbidden modes.
- Limits improve on the previous world best results by up to a factor of 500! 10^{-8} level.

$K^+ \to \pi^+ \nu\nu$

Talks by E. Minucci, K. Shiomi

arXiv: 2007.08218
NA62 Preliminary





Run 1(2016+2017+2018 data) preliminary result

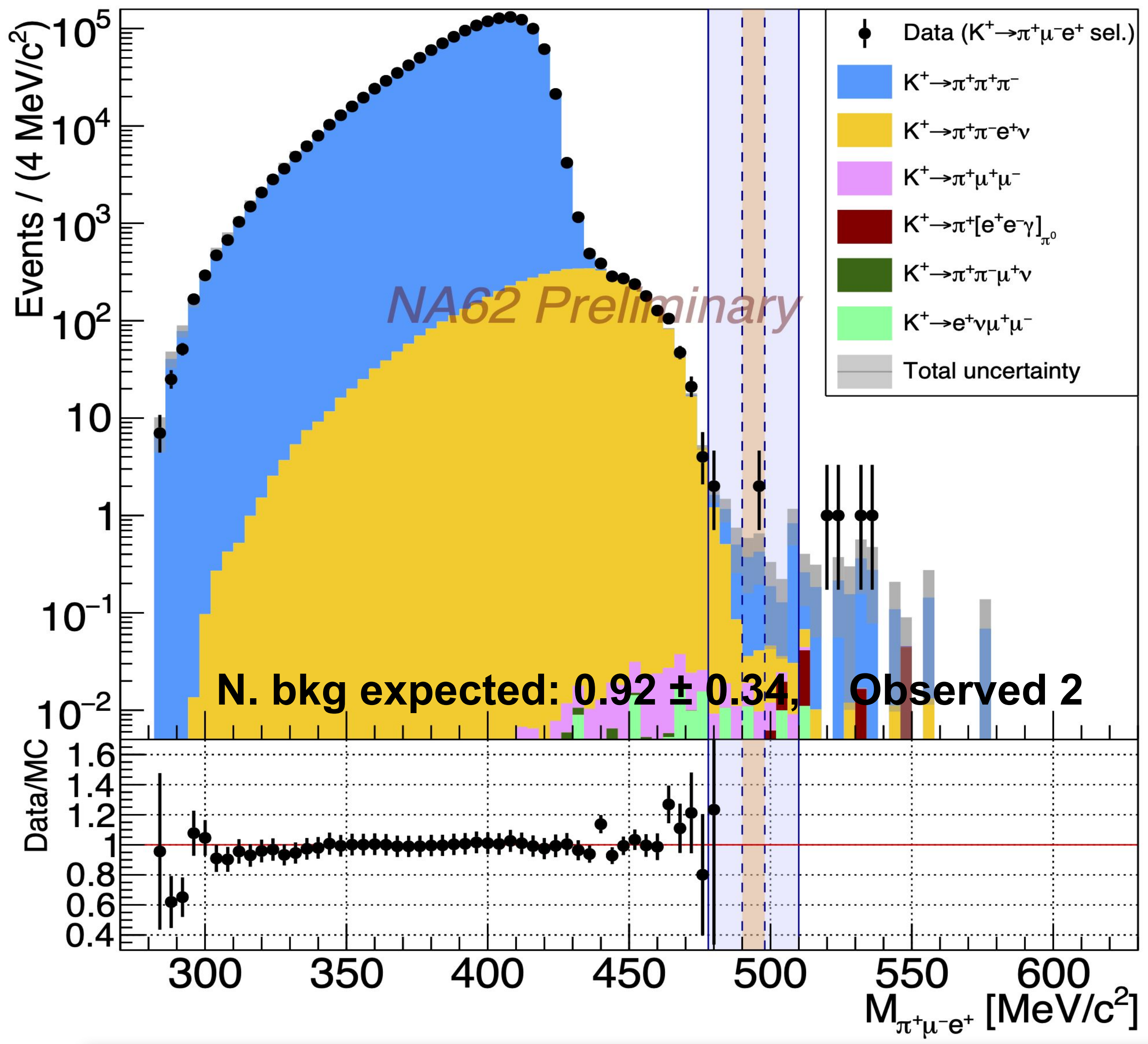
$$Br(K^+ \to \pi^+ \nu\bar{\nu}) = (11.0^{+4.0}_{-3.5stat} \pm 0.3_{syst}) \times 10^{-11} (3.5\sigma\ significance)$$

Maximum Likelihood Fit using signal and background expectation in each category

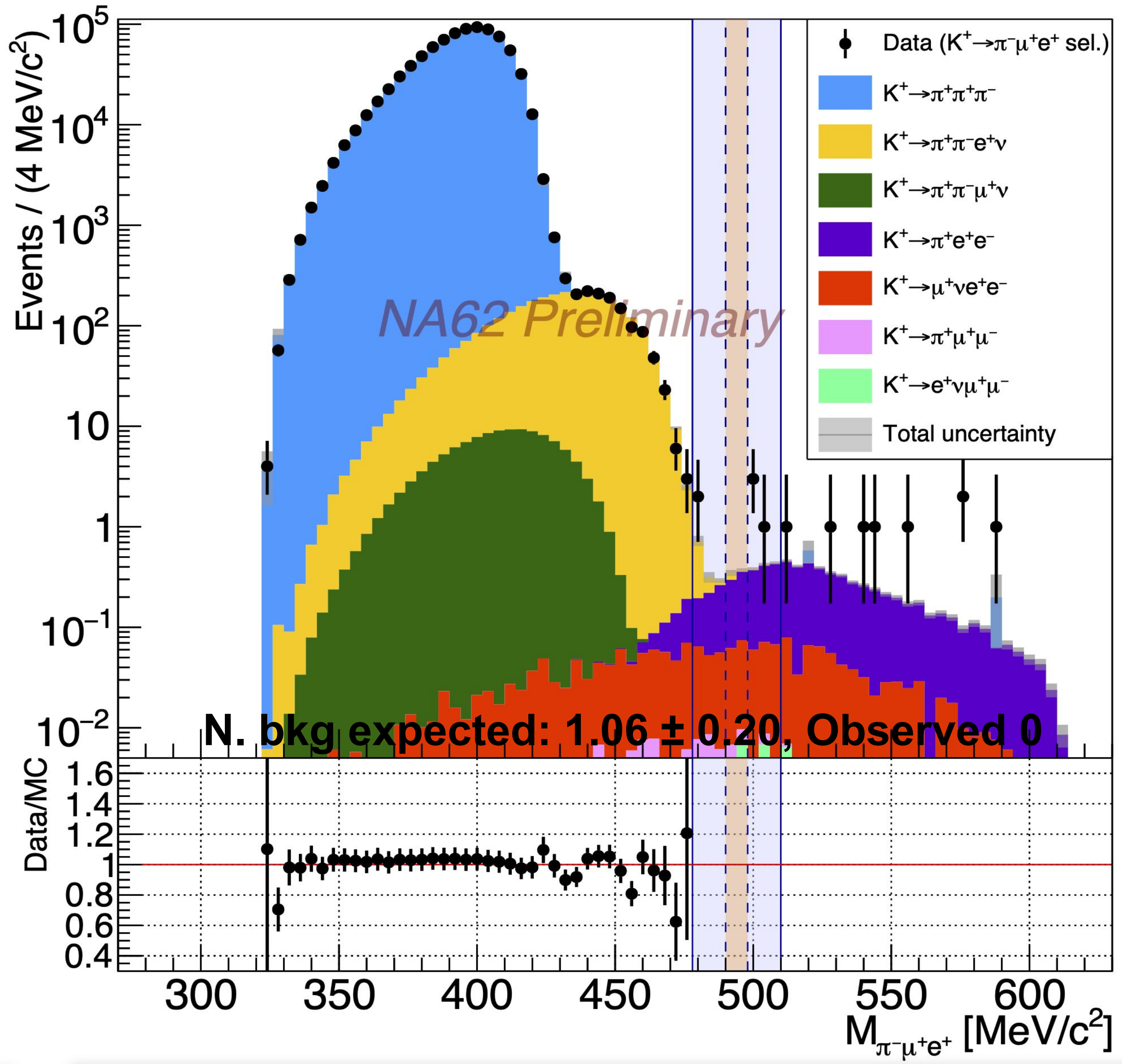
New results from KOTO expected later in the year.

K+ LFV, LFUV, FFs

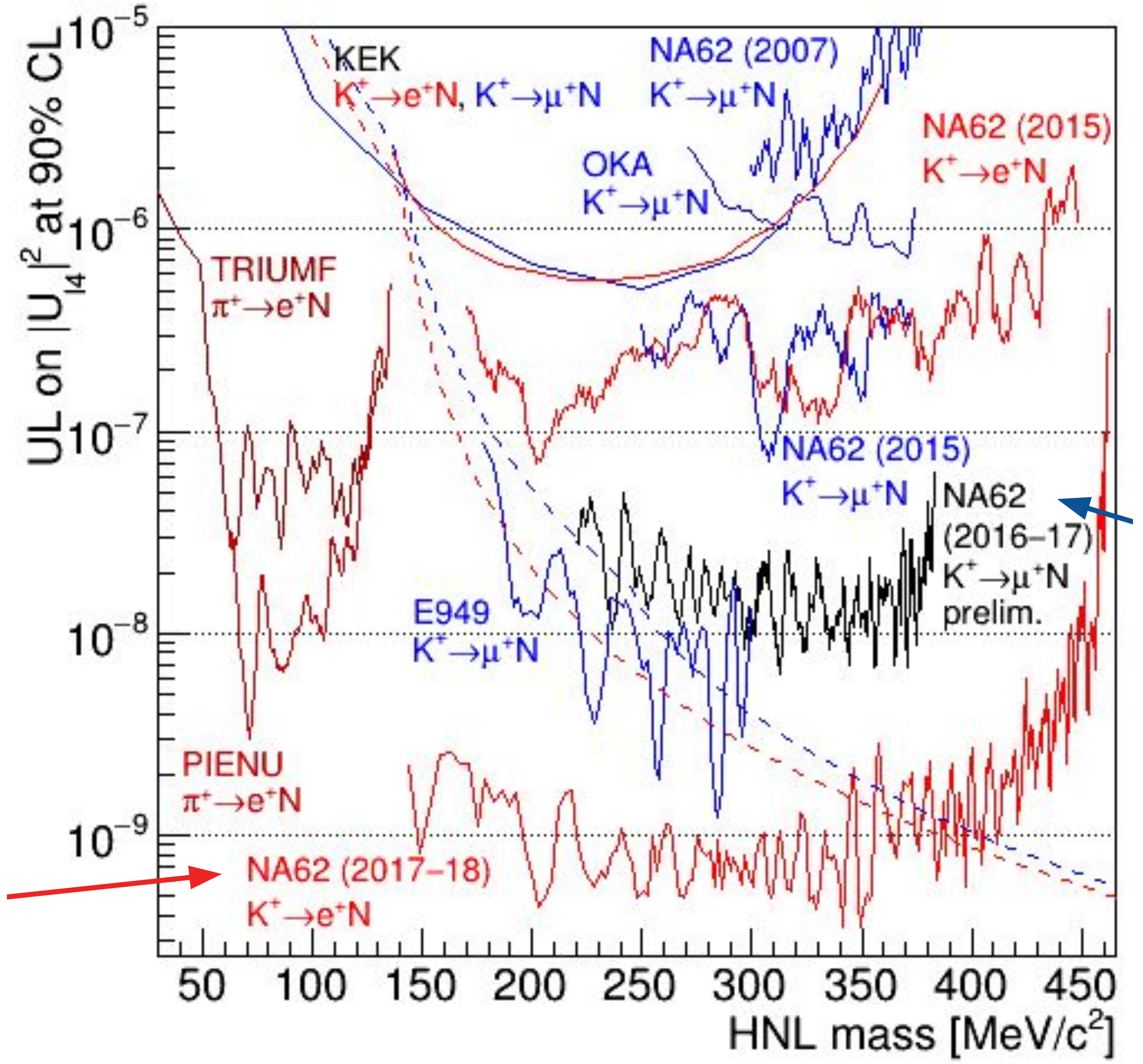
Talk by E. Minucci



$Br(K^+ \rightarrow \pi^+\mu^-e^+) < 6.6 \times 10^{-11}$ @ 90% C.L



$Br(K^+ \rightarrow \pi^-\mu^+e^+) < 4.2 \times 10^{-11}$ @ 90% C.L



- New results from analyses on rare and forbidden kaon decays.
- Tight constraints on heavy neutral leptons in 50 - 450 MeV/c² range.

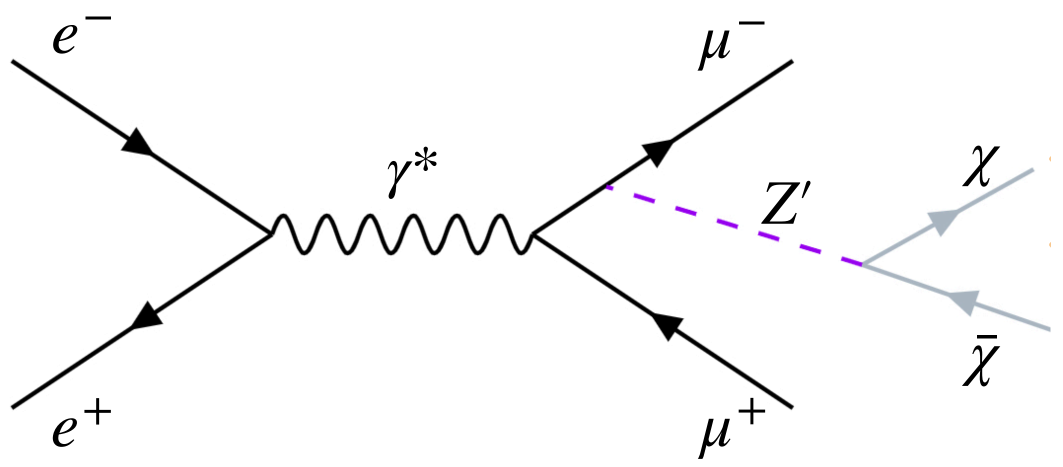
Dark Sector

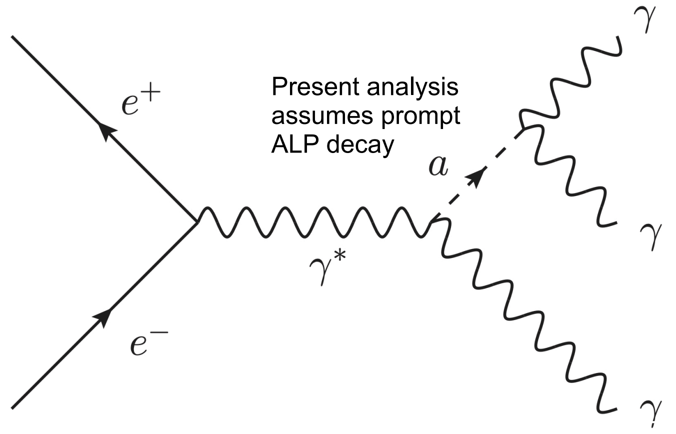
ALPs

Dark Photons

Long lived particles

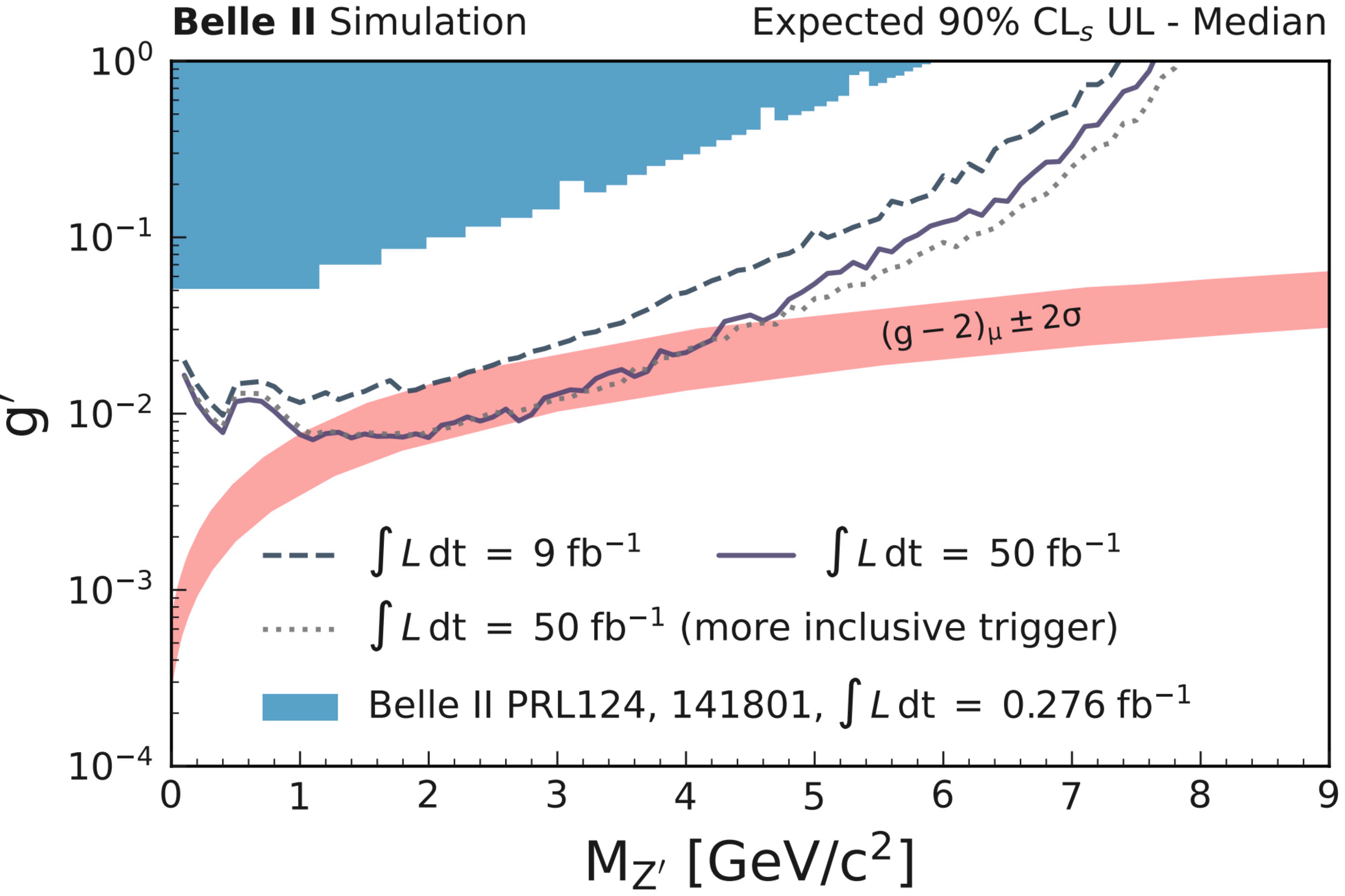
ALPs, Dark Z’

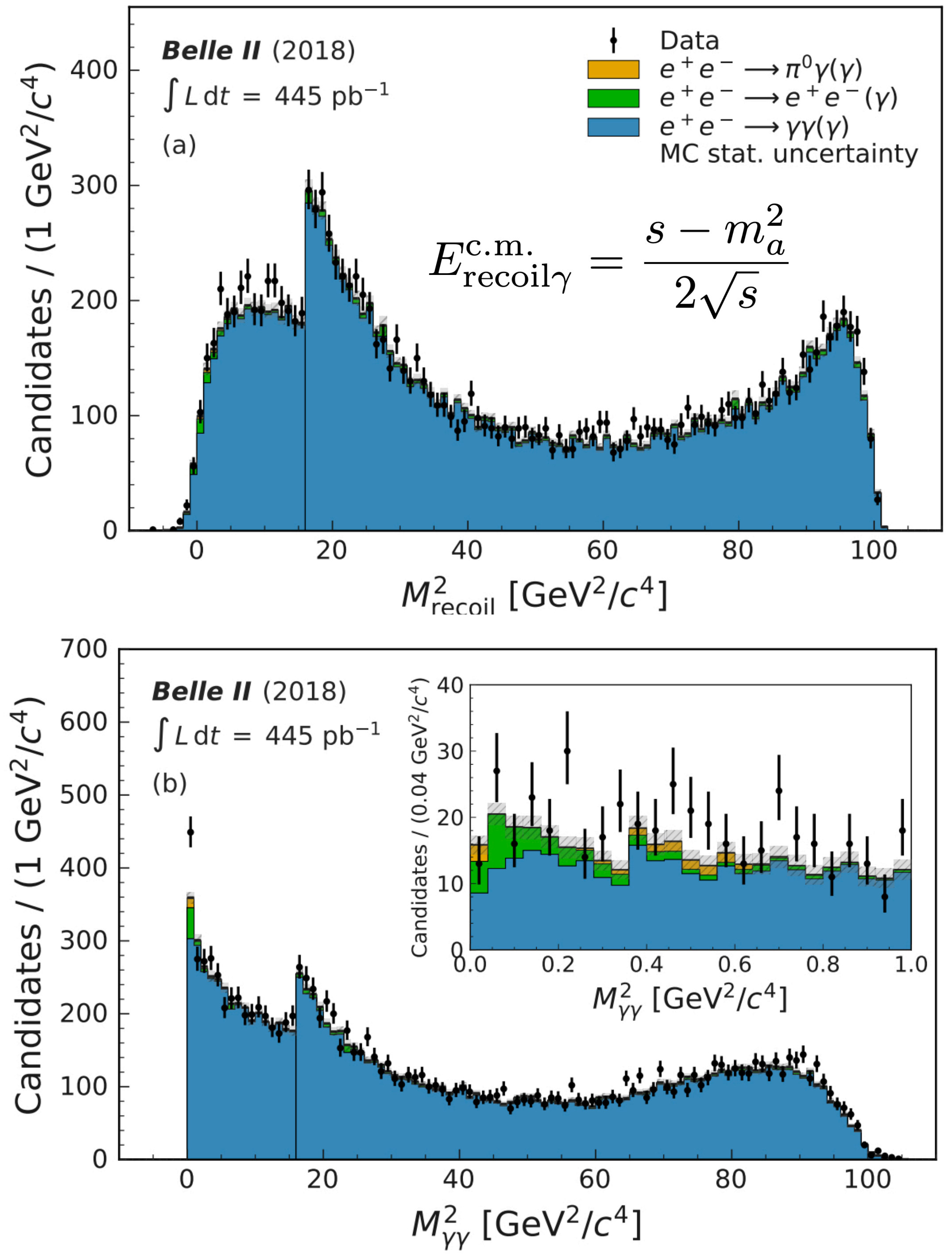


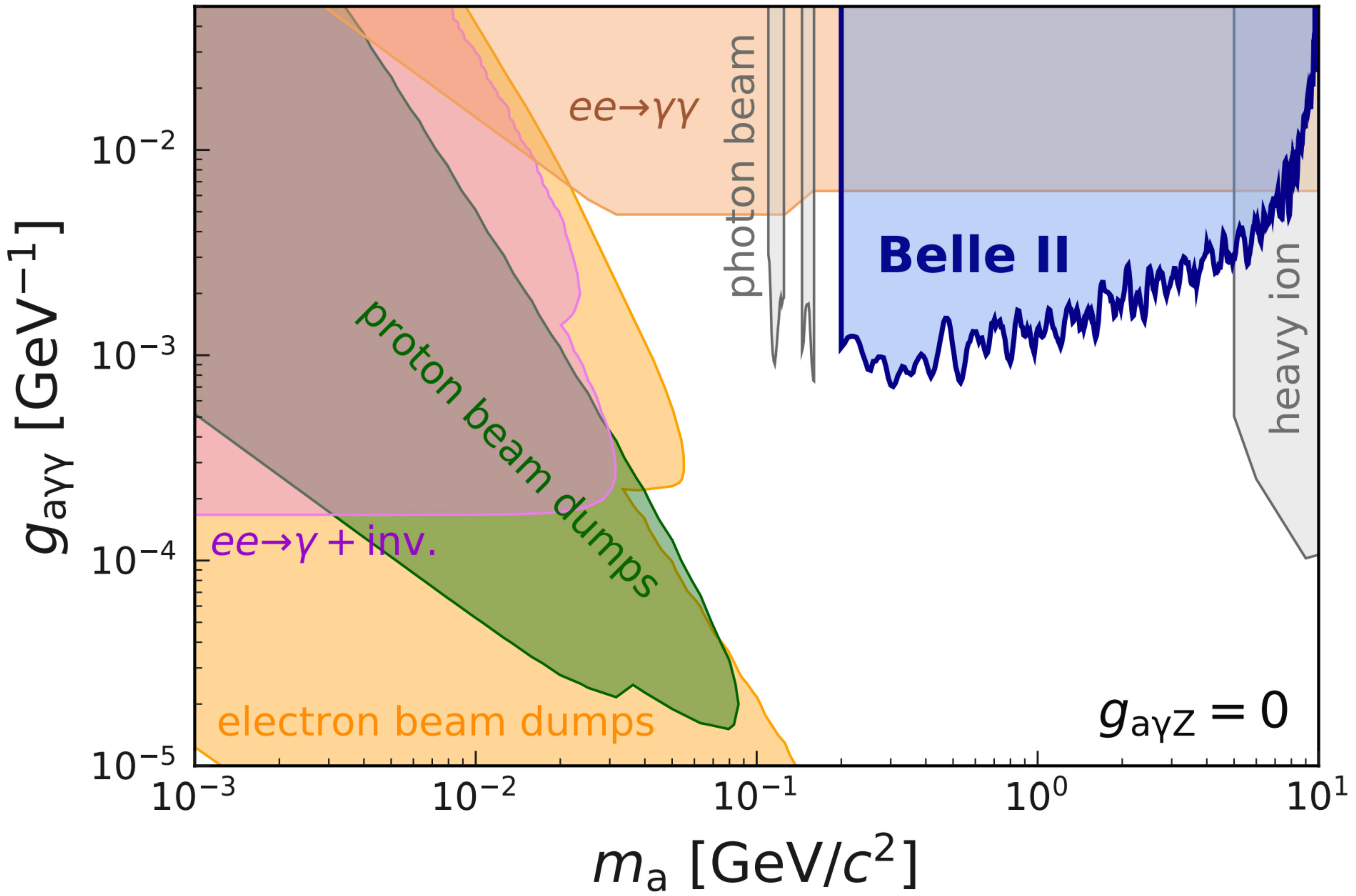


Talk by S. Longo

Phys.Rev.Lett.124,141801(2020)
arXiv: 2007.13071



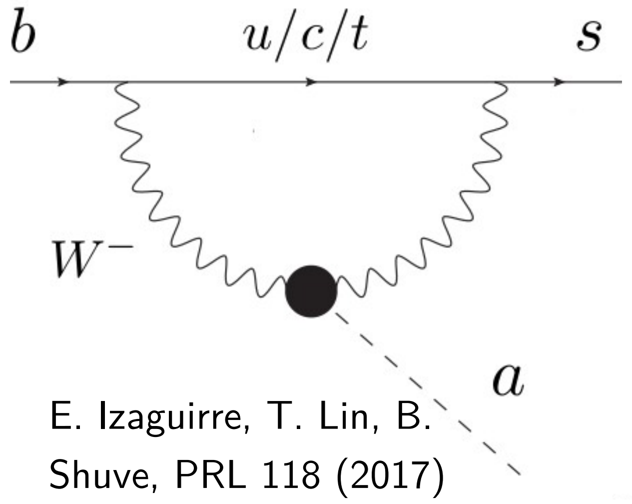




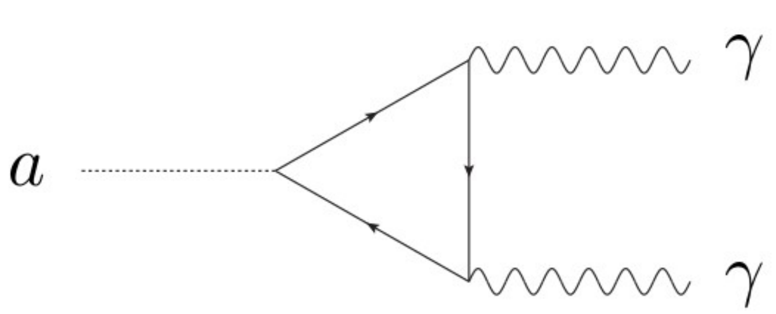
- Z′ and axion-like particle searches using only < 0.5fb^{-1}.
- Single photon search is in progress. L1 trigger efficiency measured to be ~100% above 1 GeV.

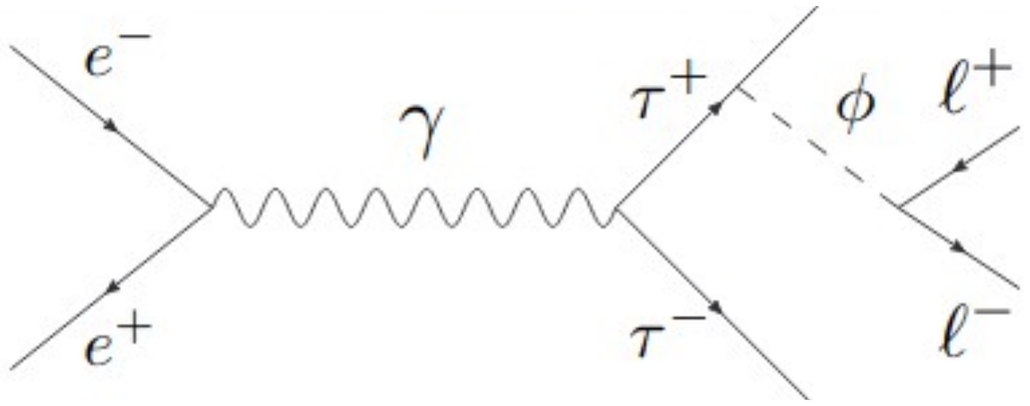
ALPs in meson decays & Dark scalars

Talk by L. Zani

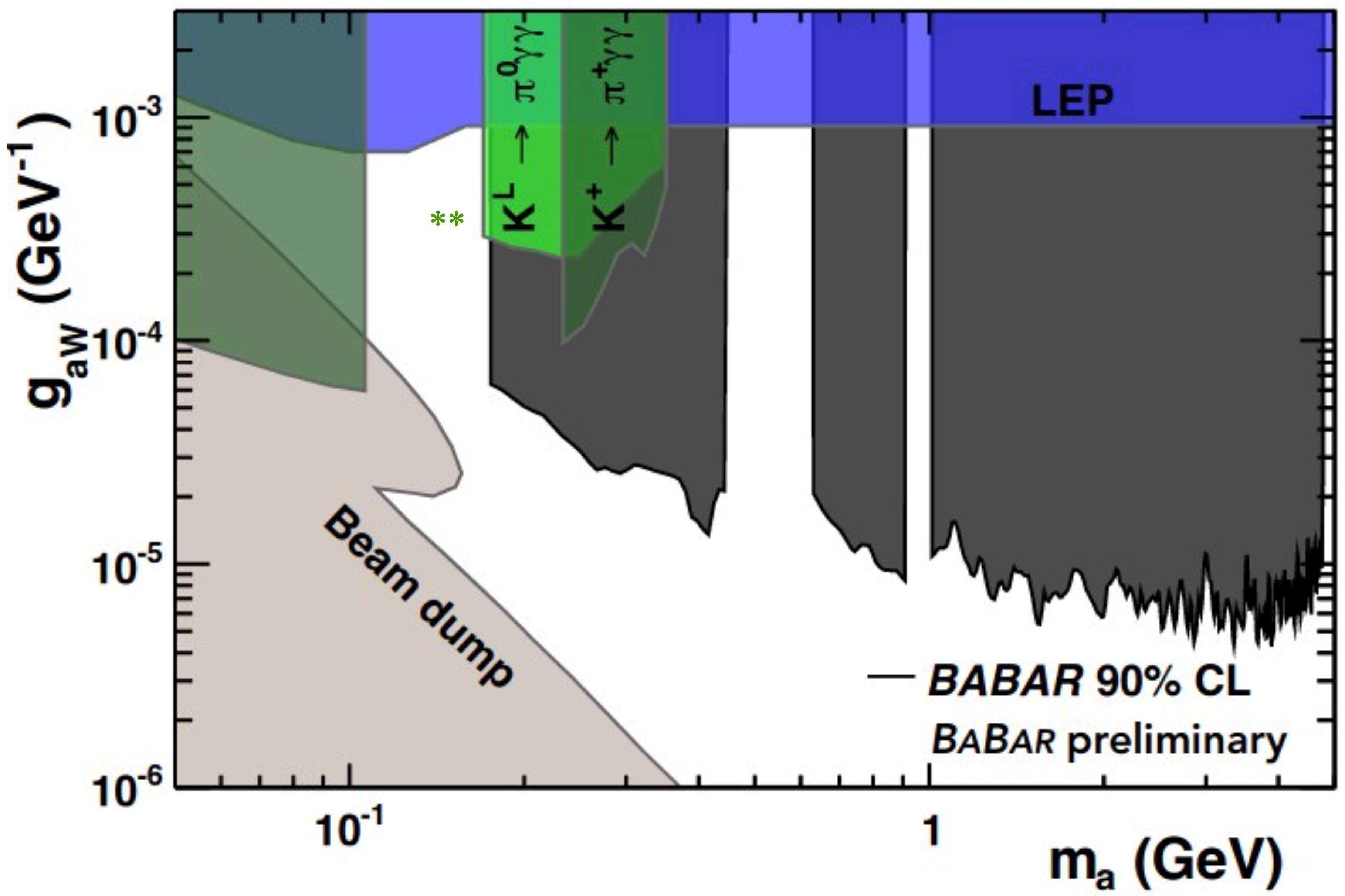


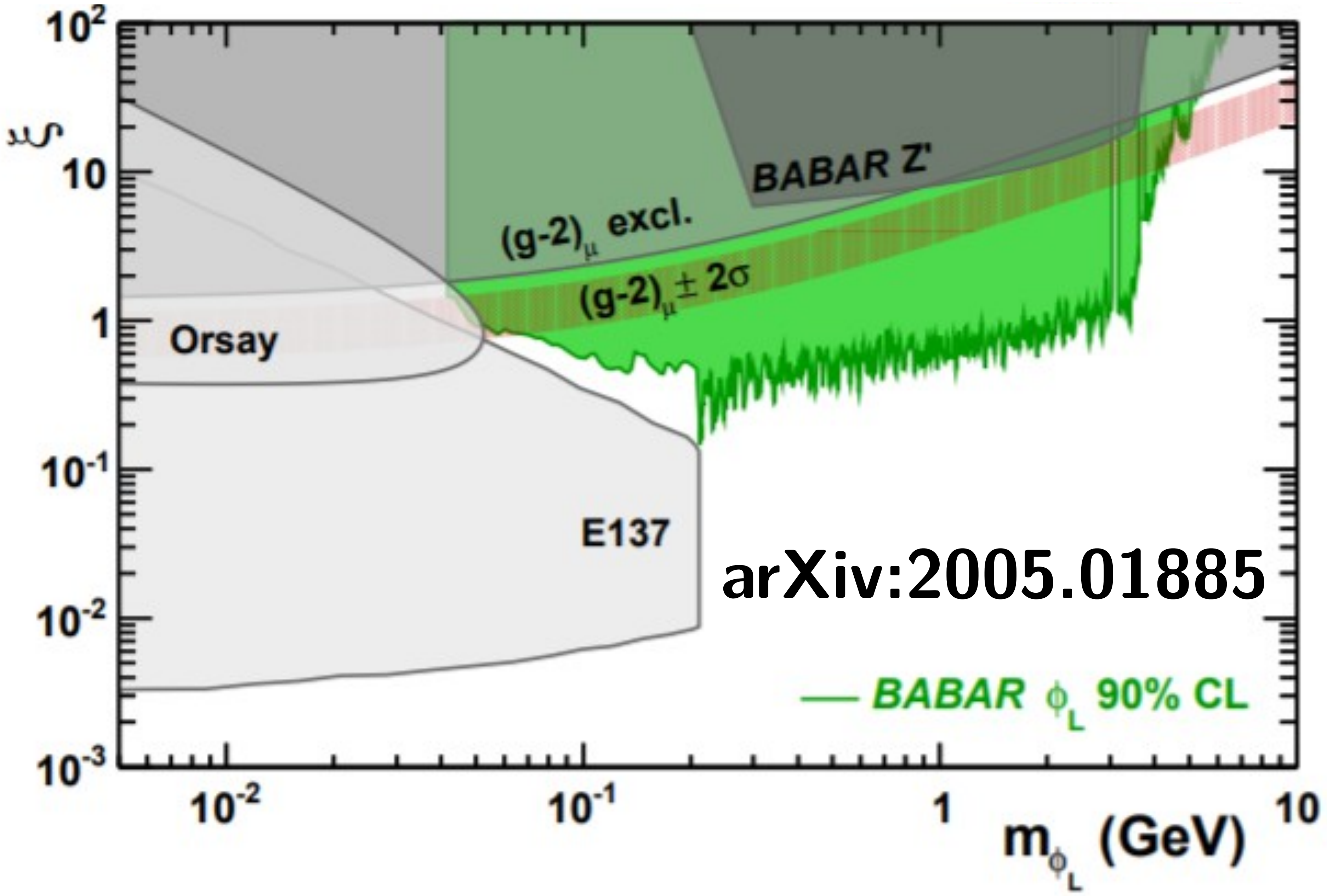
E. Izaguirre, T. Lin, B. Shuve, PRL 118 (2017)





Babar Preliminary + arxiv:2005.01885





arXiv:2005.01885

- First ALPs search in flavour changing B decays ($B^\pm \to K^\pm a$, $a \to \gamma\gamma$) - improves on existing limits on ALP — W-boson coupling by 2 orders of magnitude below 5 GeV/c^2.
- First search for a new dark leptophilic scalar produced in τ--pair events

Spectroscopy & Exotica

Baryons

Quarkonia

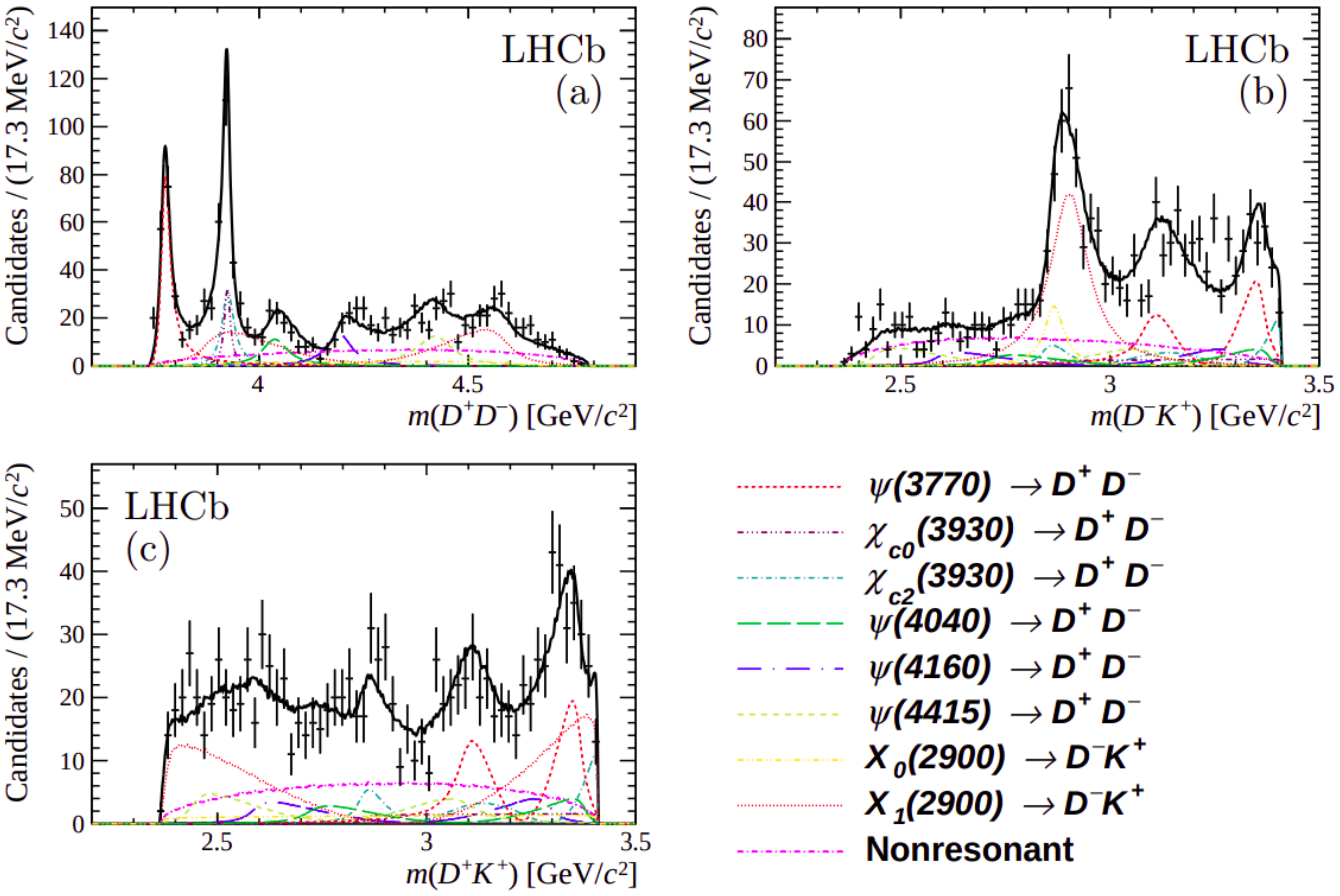
Spectroscopy

4-Quark States

X(2900) Amplitude analysis of $B^+ \to D^+D^-K^+$

Talk by L. Capriotti

arXiv:2009.00025

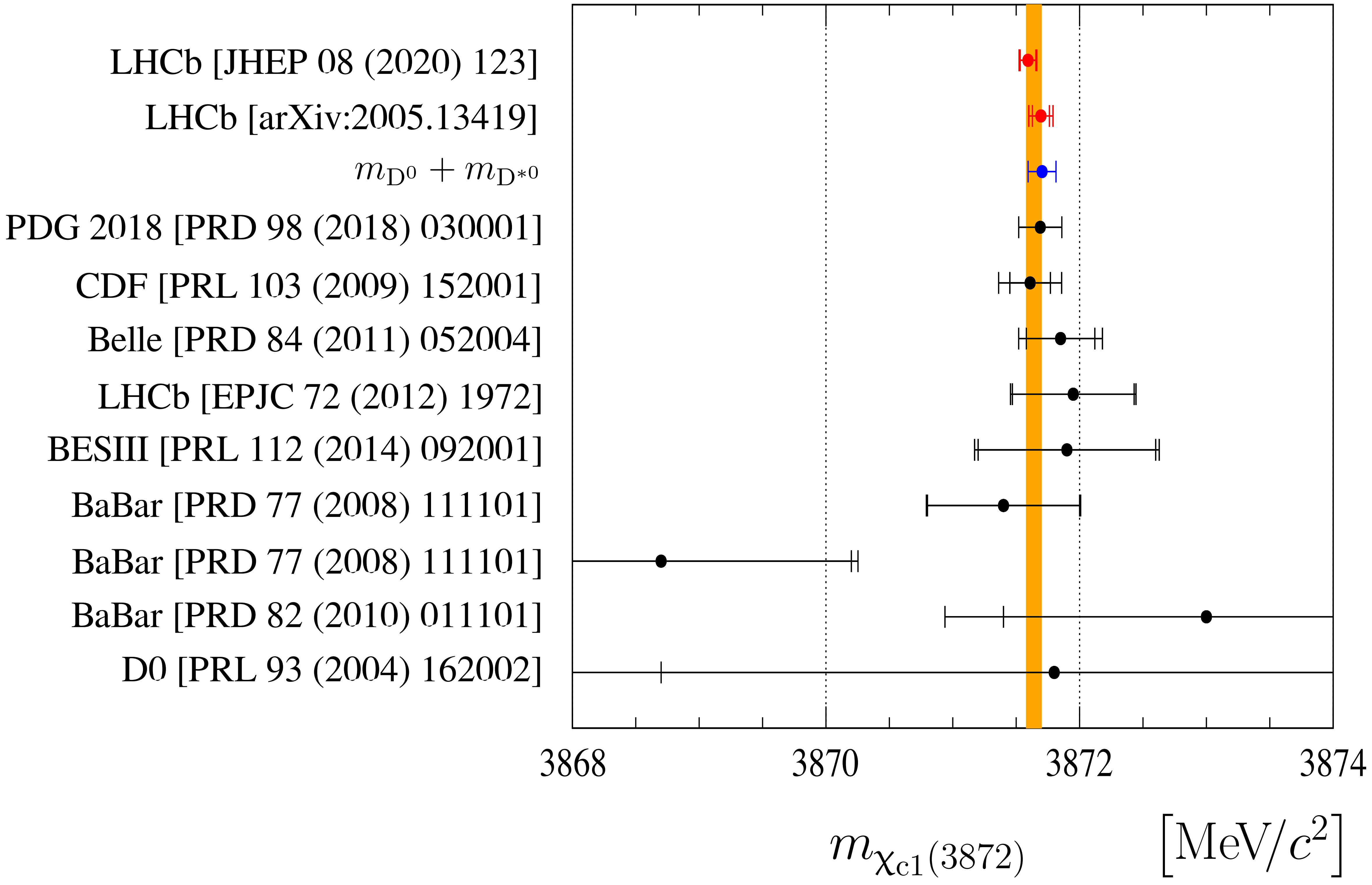


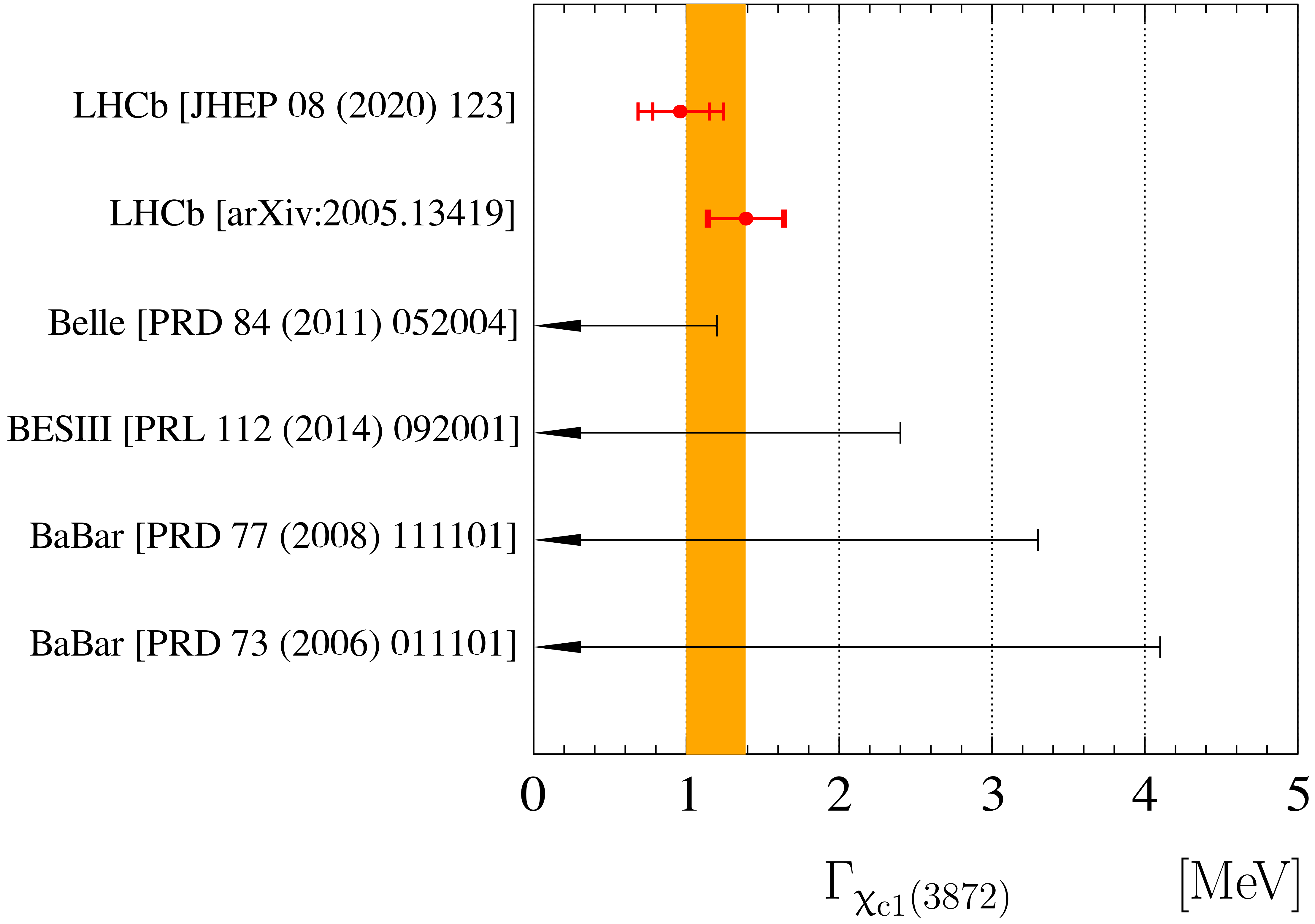
- Reasonable agreement with data when including 2 D^-K^+ Breit-Wigners
  $m_{X0}(2900) = 2886 \pm 7 \pm 2$ MeV,
  $\Gamma_{X0}(2900) = 57 \pm 12 \pm 4$ MeV
  $m_{X1}(2900) = 2904 \pm 5 \pm 1$ MeV,
  $\Gamma_{X1}(2900) = 110 \pm 11 \pm 4$ MeV
  However, other models (i.e. res-cattering) may also explain the discrepancy
- If interpreted as resonances: first clear observation of exotic hadrons with open flavour, and without a heavy quark-antiquark pair.

$X/\chi_{c1}(3872)$

Talks by D. Fasanella. S. Zhentian, L. Capriotti

arXiv:2005.13419
JHEP 08 (2020) 123





$$m^{BW}_{\chi_{c1}(3872)} = 3871.64 \pm 0.06 \text{ MeV}$$

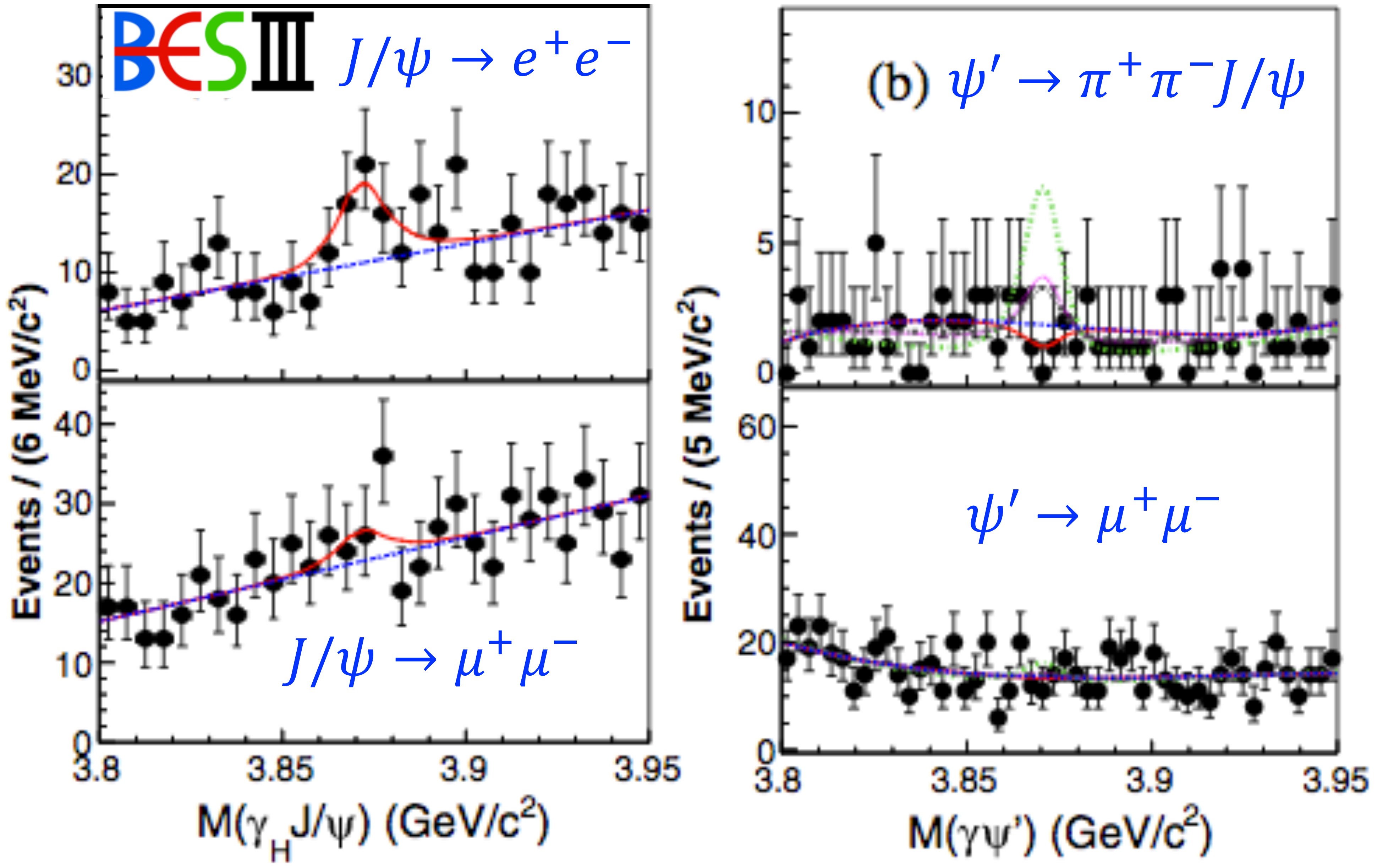
$$\Gamma^{BW}_{\chi_{c1}(3872)} = 1.19 \pm 0.19 \text{ MeV}$$

XYZ States from BESIII

Talk by S. Zhentian

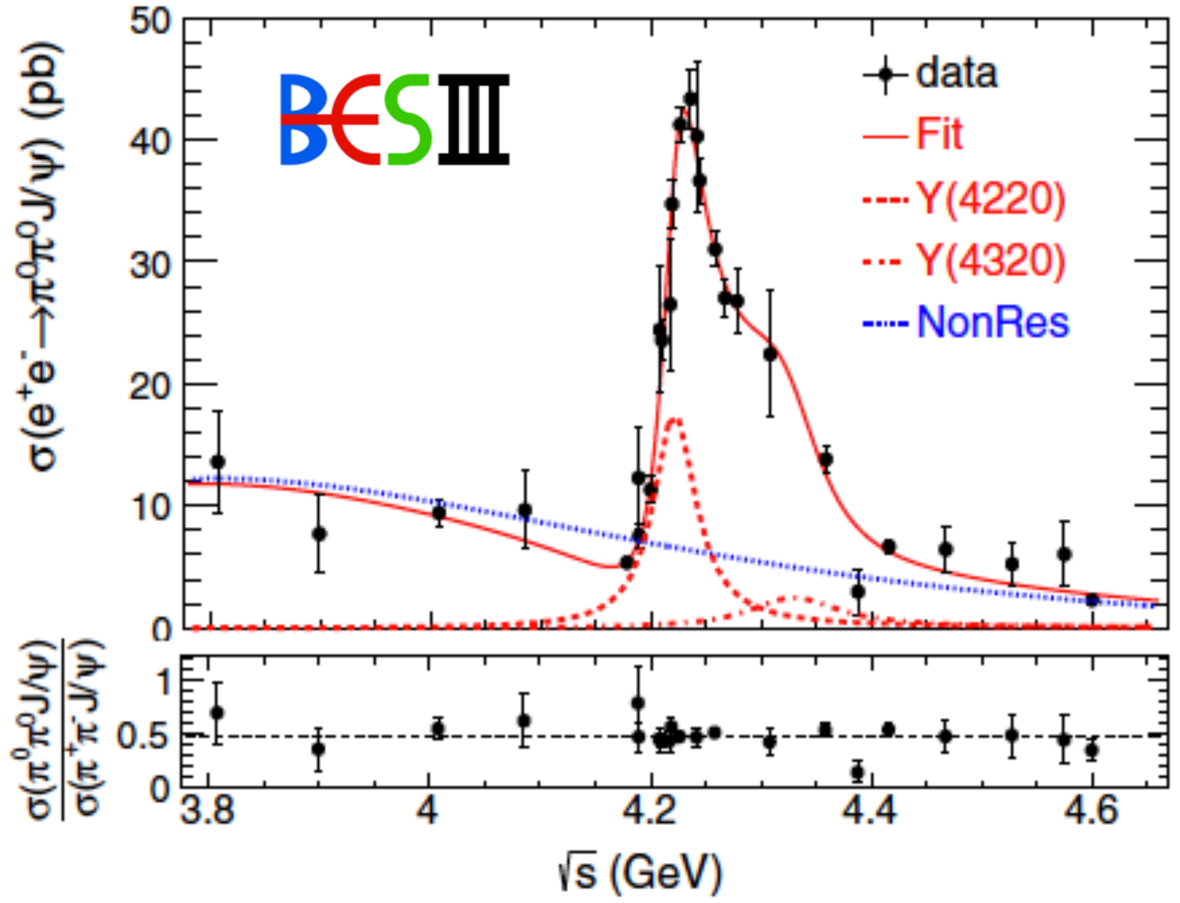
PRD 102, 031101 (2020)
PRD 102, 012009 (2020)

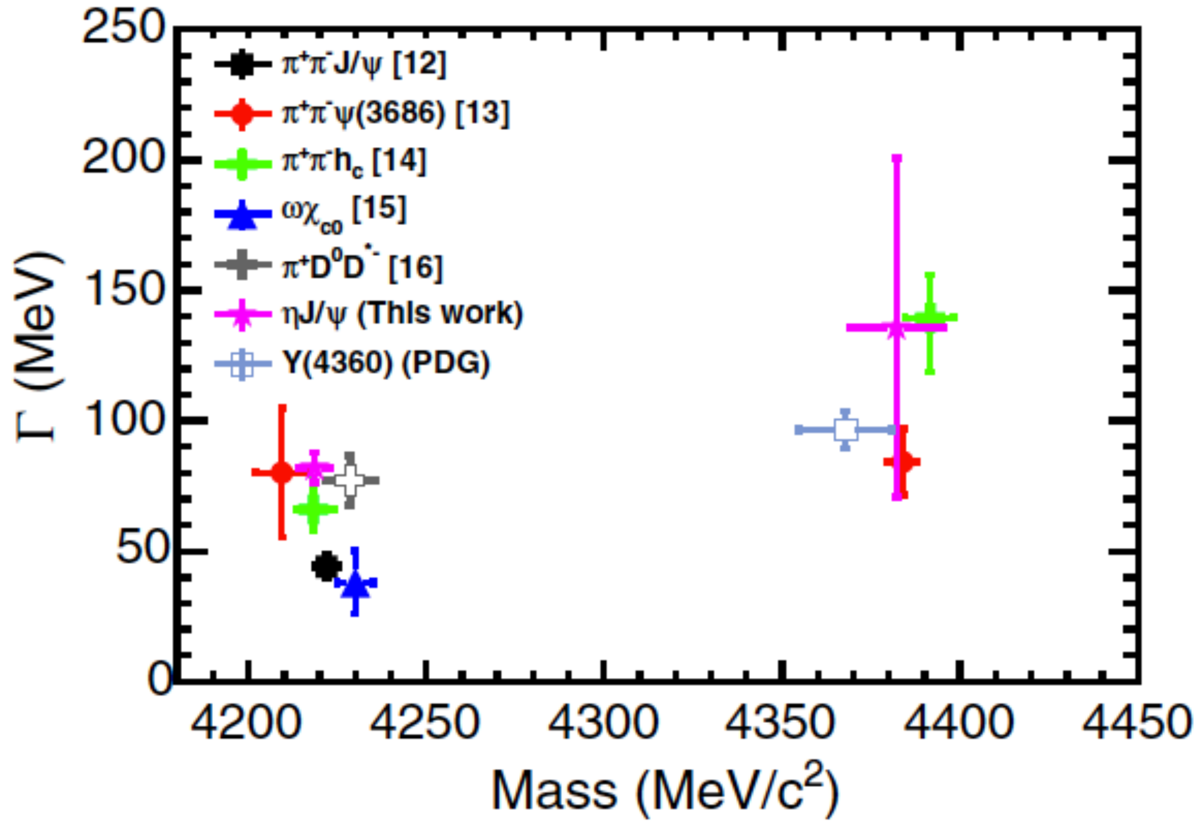
$X(3872) \to \gamma J/\psi$



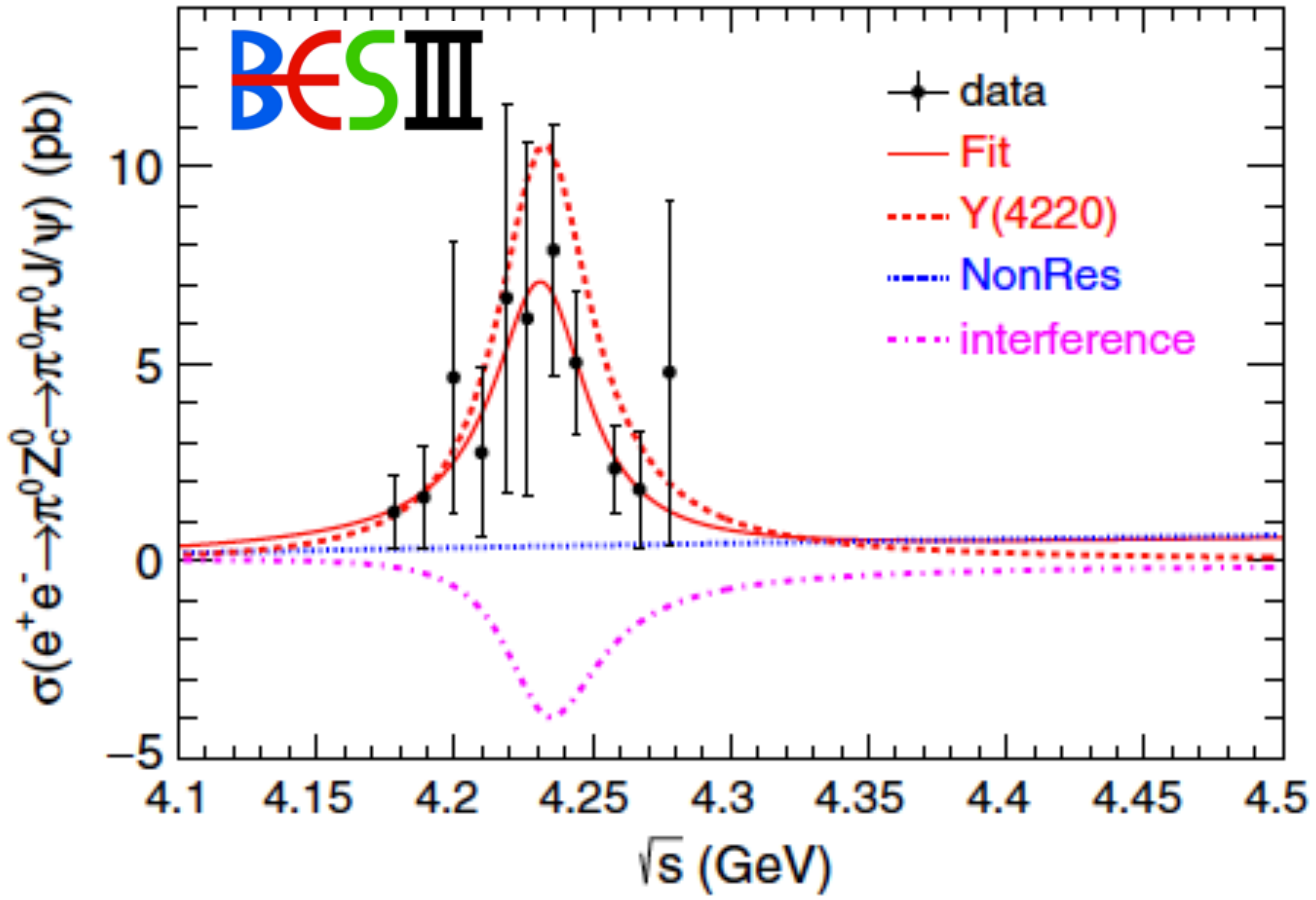
$$R_\psi = \frac{B[X(3872) \to \gamma\psi']}{B[X(3872) \to \gamma J/\psi]} < 0.59 \text{ (CL. 90\%)}$$

$e^+e^- \to \pi^0\pi^0 J/\psi$





$\sigma(e^+e^- \to \pi^0 Z_c^0 \to \pi^0\pi^0 J/\psi)$



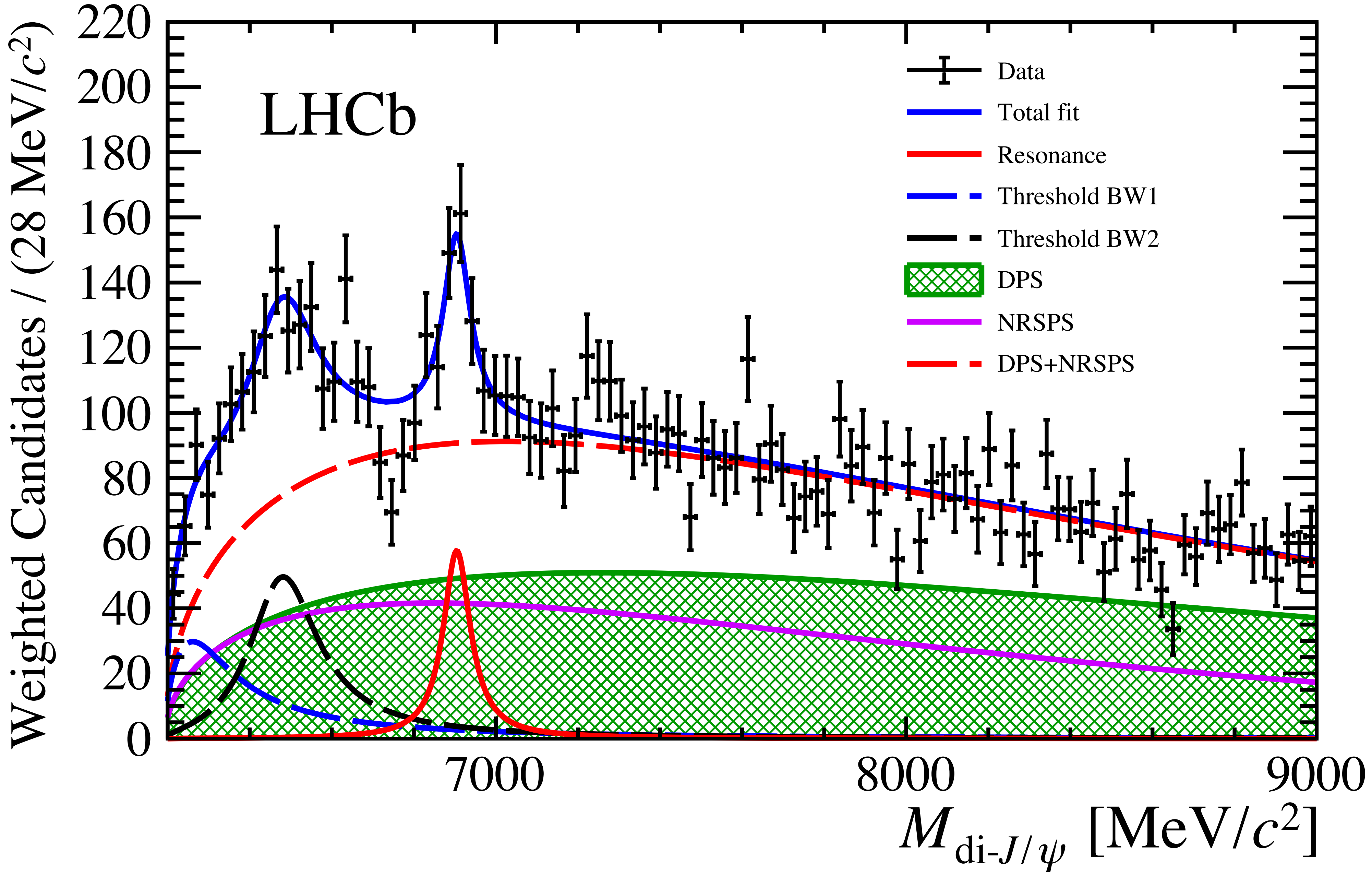
Parameters	Solution I	Solution II
$p_0 (c^2/\text{MeV})$	0.0 ± 11.3	
p_1	$(1.8 \pm 1.9) \times 10^{-2}$	
$M(R)$ (MeV/c^2)	4231.9 ± 5.3	
$\Gamma_{\text{tot}}(R))$ (MeV)	41.2 ± 16.0	
$\Gamma_{ee}\mathcal{B}_{R\to\pi^0 Z_c(3900)^0}$ (eV)	0.53 ± 0.15	0.22 ± 0.25
$\phi(R)$	$(-103.9 \pm 33.9)^\circ$	$(112.7 \pm 43.0)^\circ$

Observation of X(6900)→J/ψ J/ψ

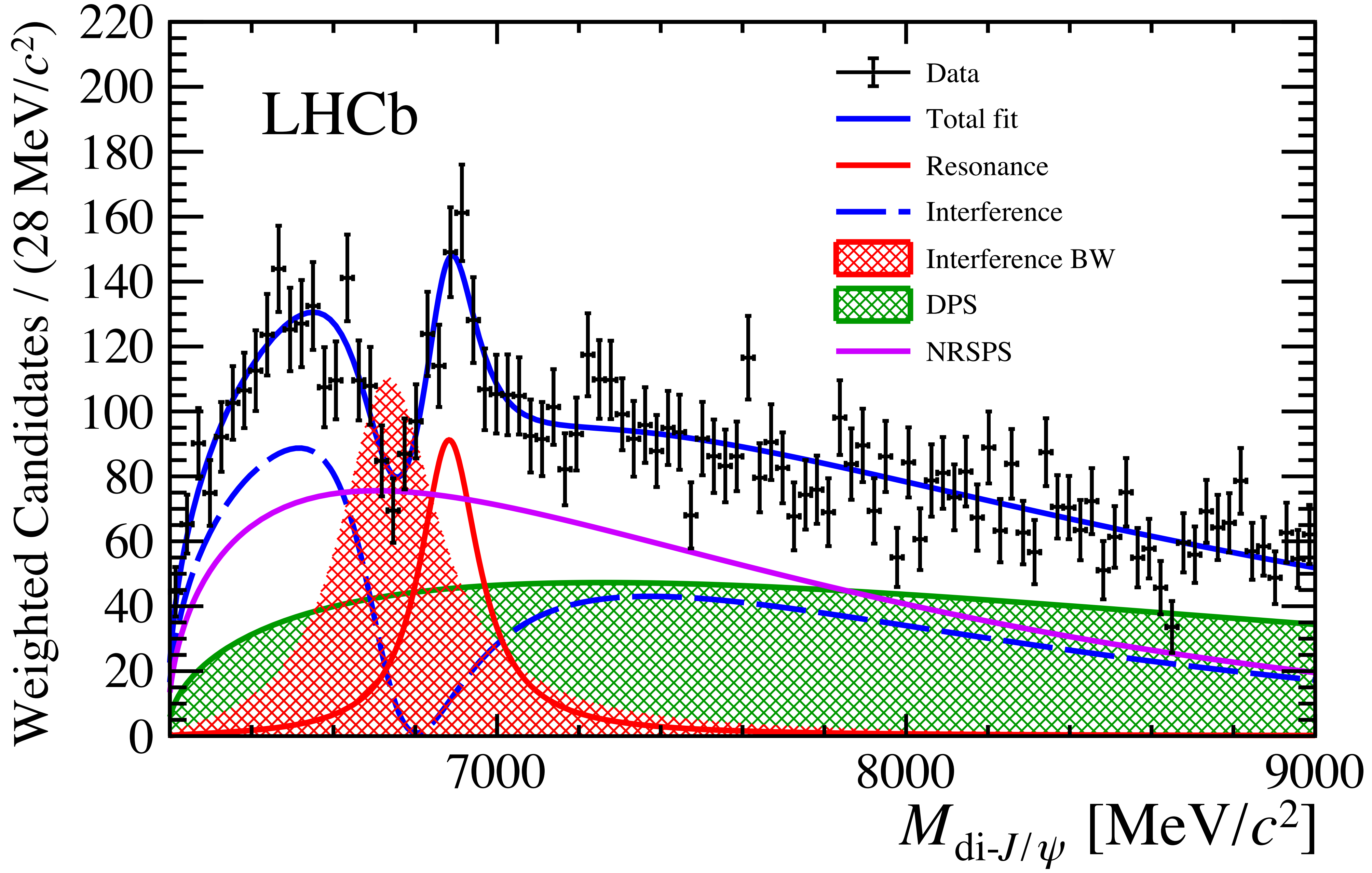
Talk by L. Capriotti

arXiv:2006.16957

No interference



SPS-BW interference

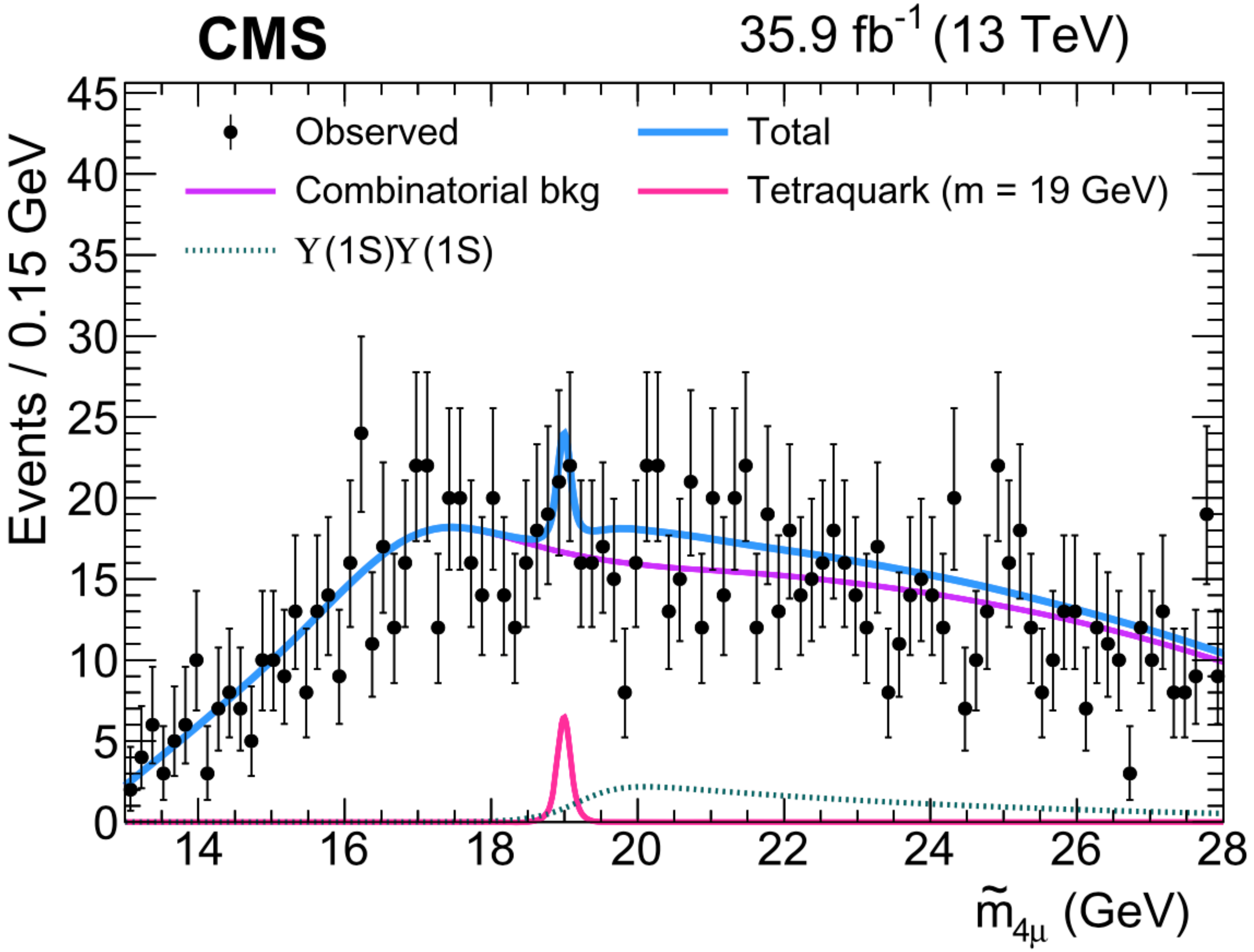


- Predictions for the masses of a 4-charm state: 5.8 - 7.4 GeV
- Further studies are required to investigate the nature of X(6900).
  If confirmed: first observation of an exotic hadron made of 4 heavy quarks of same flavour

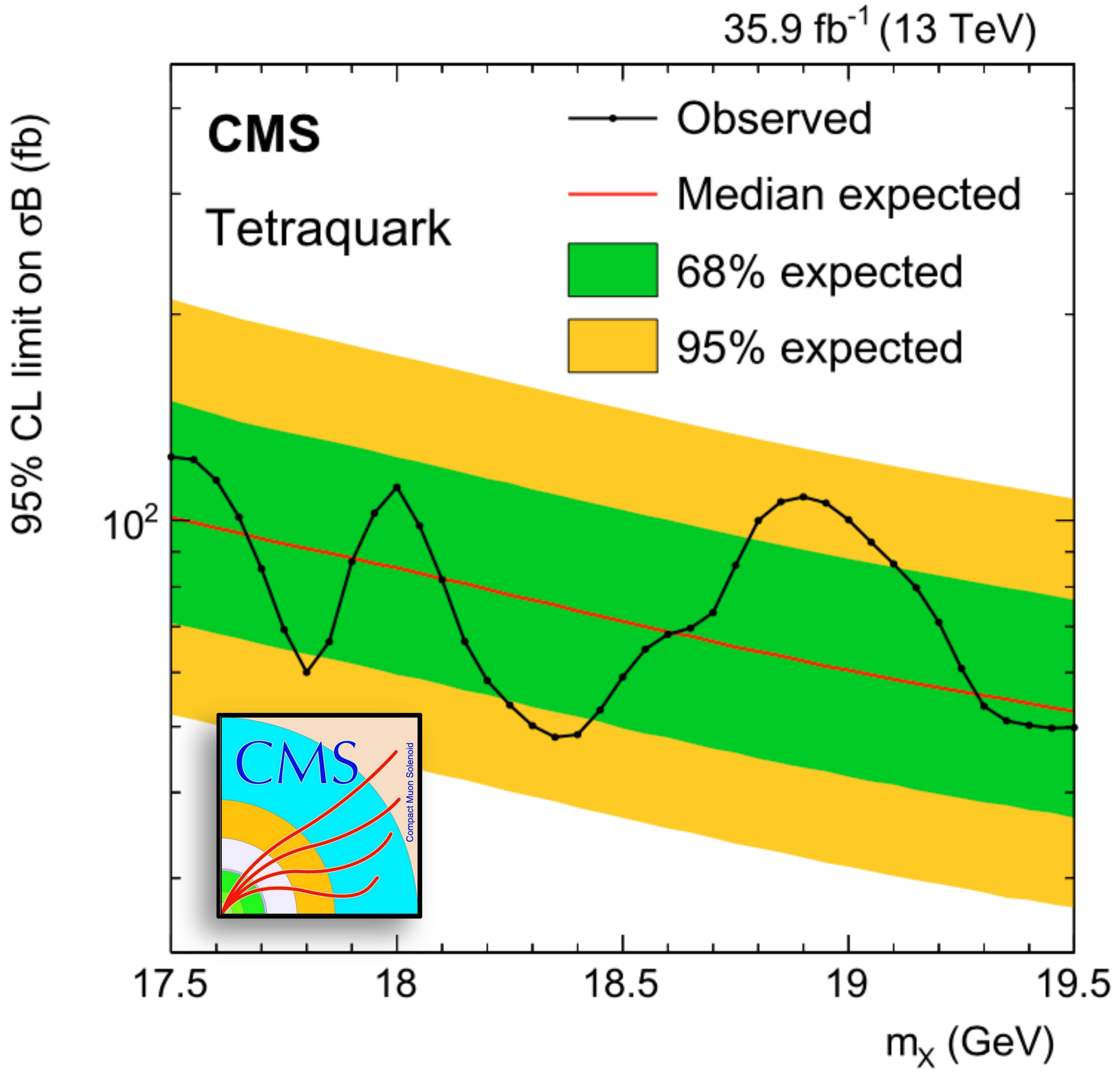
Search for bbbb via $\Upsilon(1S)\mu\mu$

Talk by A. Di Florio

PLB 808 (2020) 135578



$\sigma_{pp\to X}\times\mathcal{B}(X\to\Upsilon(1S)\mu\mu\to 4\mu)$



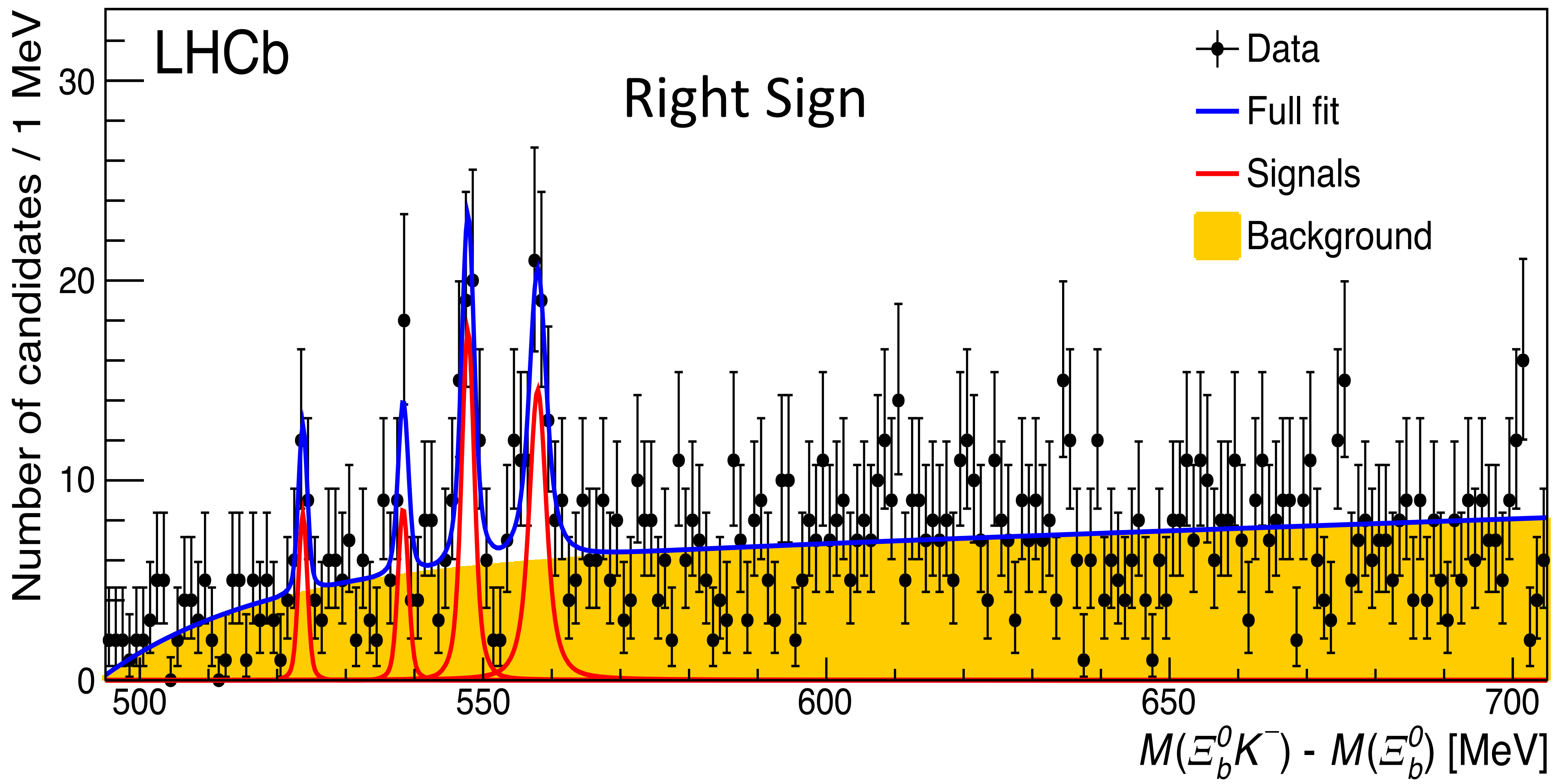
- No significant excess of events compatible with a narrow resonance has been observed in the window between 16.5 and 27 GeV within the $\Upsilon(1S)\mu\mu$ mass spectrum. To be performed with full Run-2 data.

+ more results on Λ_b spectroscopy

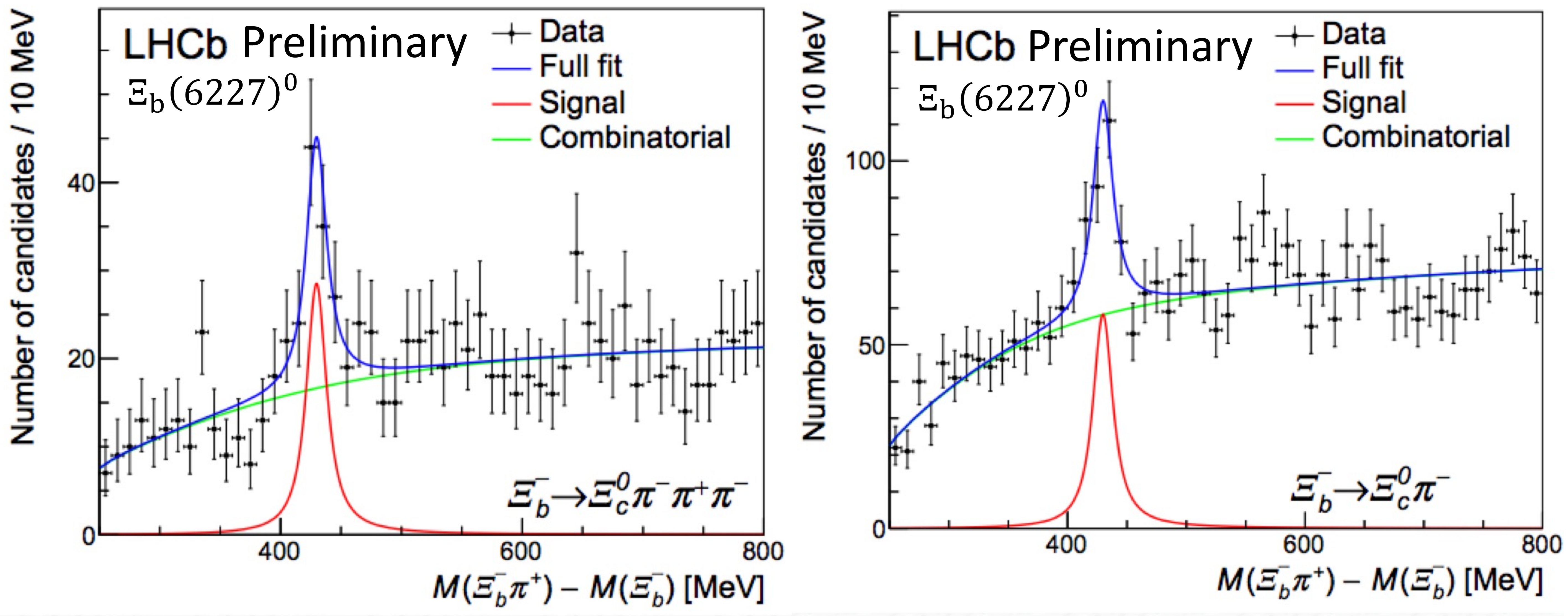
b hadron Spectroscopy

Talk by A. Venkat

PRL 124, 111802 (2020)
arxiv:2007.12096
PRL:124, 082002 (2020)



State	Signal Yield	Mass [MeV]	Width [MeV] (90% CL)
$\Omega_b(6316)^-$	15^{+6}_{-5}	$6315.64 \pm 0.31 \pm 0.07 \pm 0.50$	< 2.8
$\Omega_b(6330)^-$	18^{+6}_{-5}	$6330.30 \pm 0.28 \pm 0.07 \pm 0.50$	< 3.1
$\Omega_b(6340)^-$	47^{+11}_{-10}	$6339.71 \pm 0.26 \pm 0.05 \pm 0.50$	< 1.5
$\Omega_b(6350)^-$	57^{+14}_{-13}	$6349.88 \pm 0.35 \pm 0.05 \pm 0.50$	< 2.8

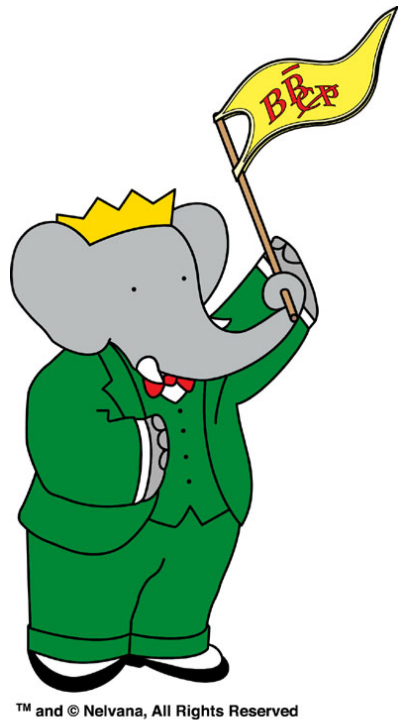


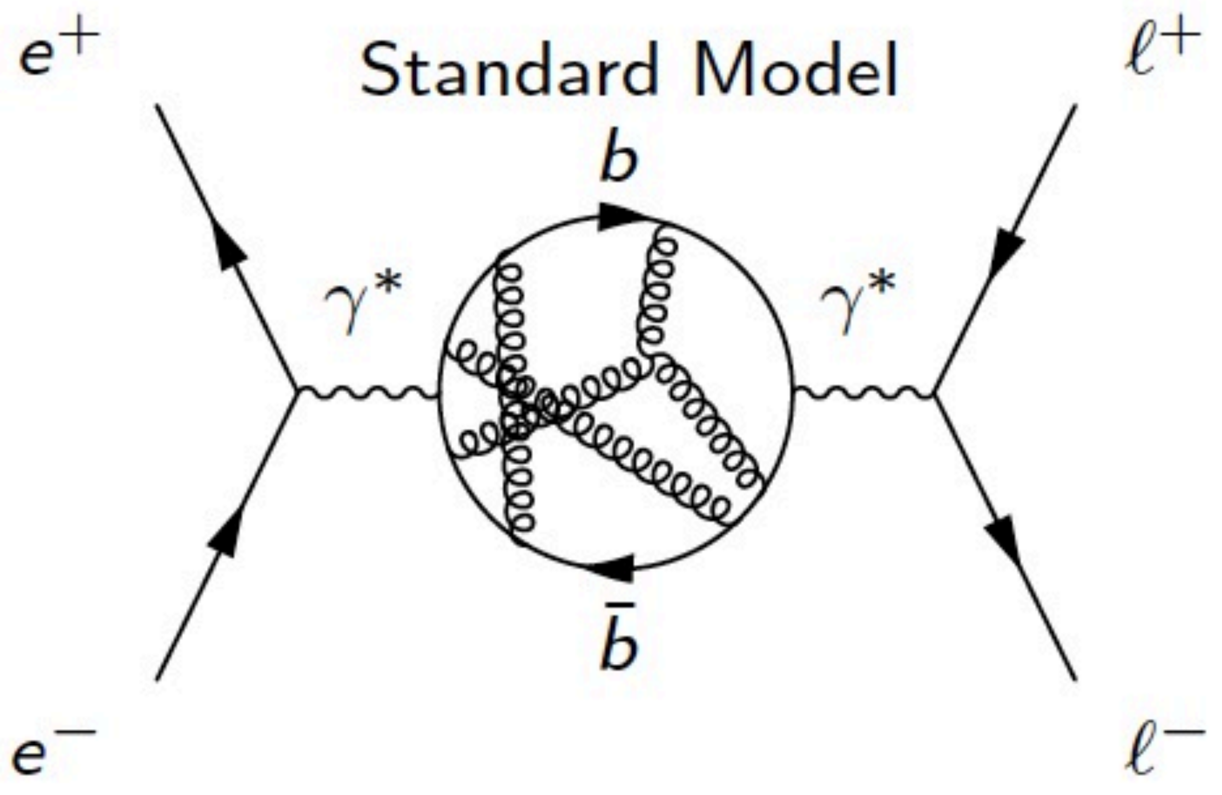
- Various new results: first observation of Ω_b^- states, new Xi$_b$(6227)^0 state, Upper limit on $\Gamma(\Lambda_b \to J/\psi\Sigma^0)/\Gamma(\Lambda_b \to J/\psi\Lambda)$ and first measurement of $\Gamma(\Xi_b \to J/\psi\Sigma^0)/\Gamma(\Xi_b \to J/\psi\Lambda)$.
- New insights into spectroscopy.

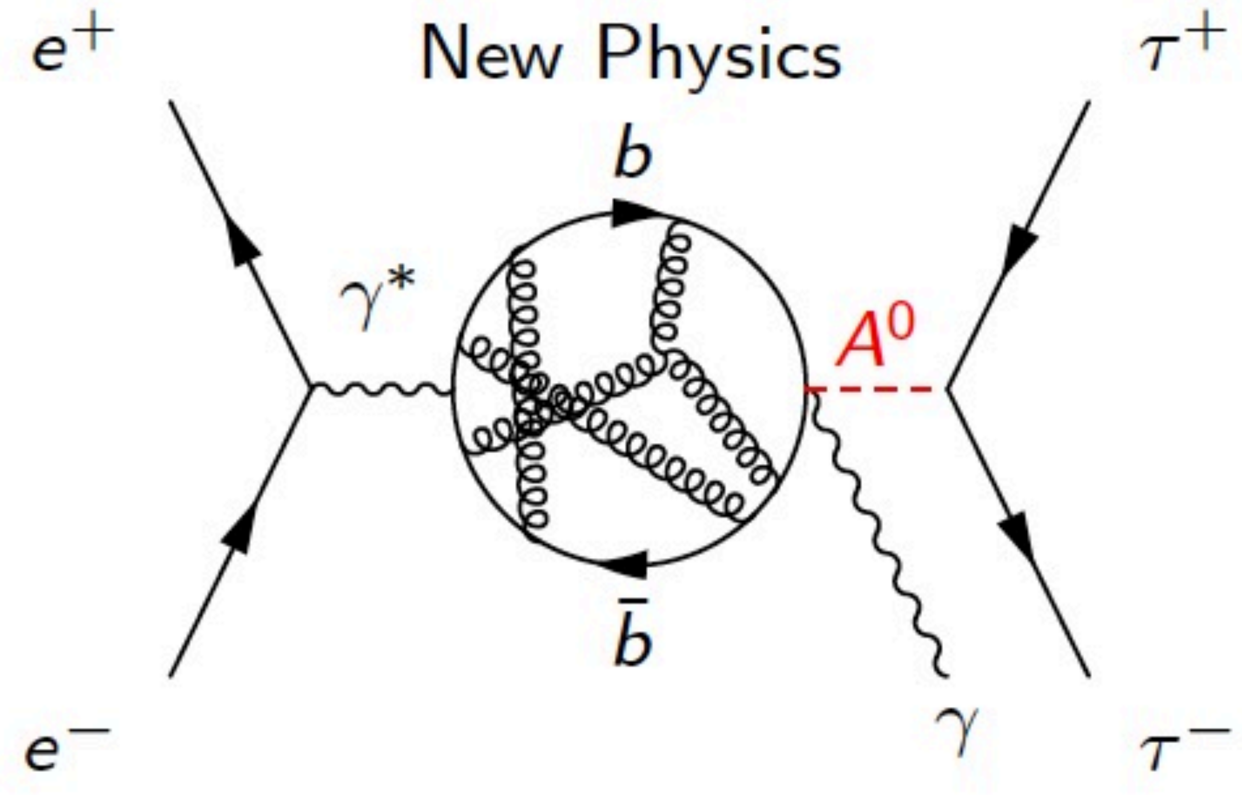
Υ(3S) LFU τ/μ

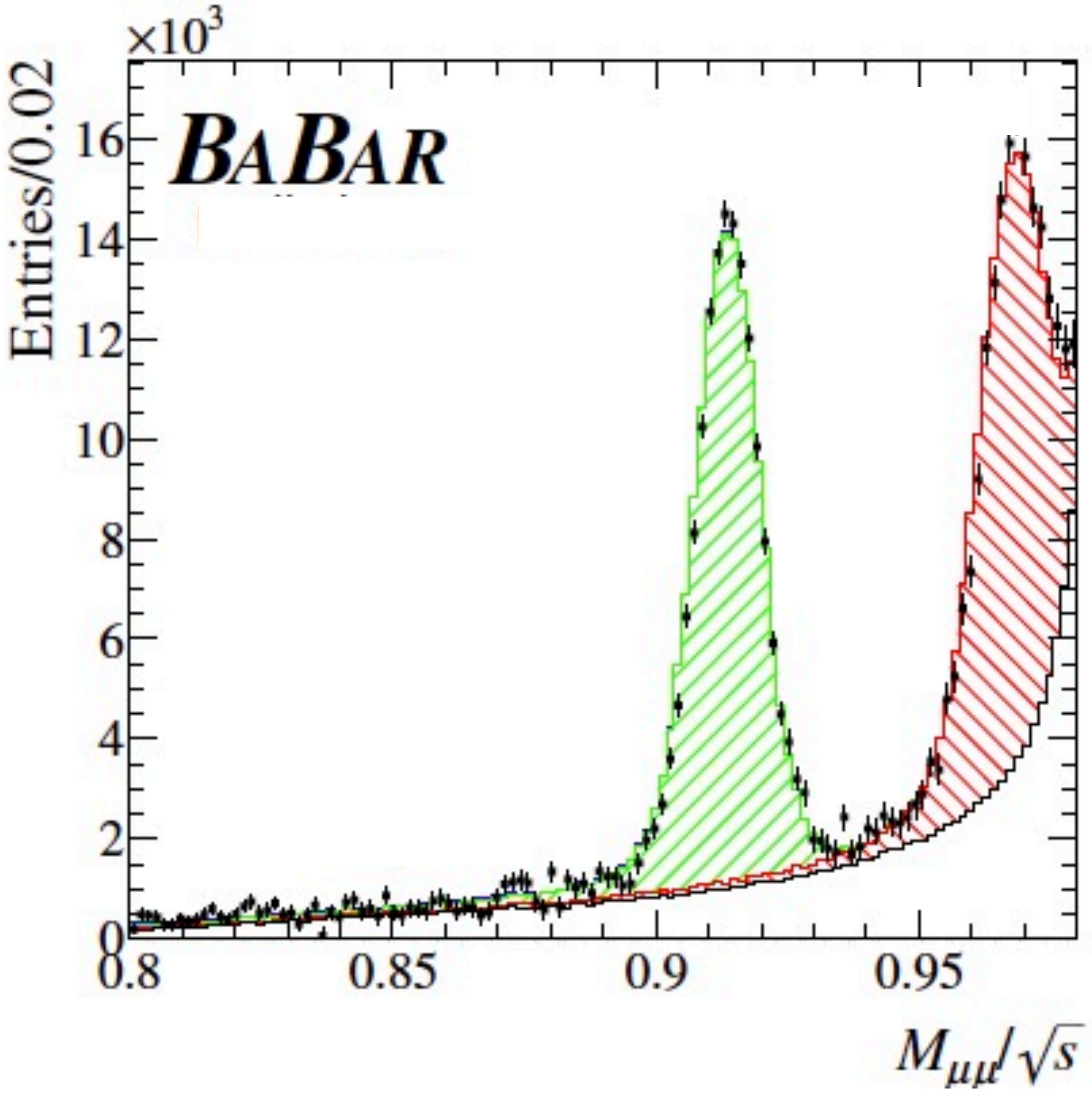
Talk by M. Roney

arXiv:2005.01230









$$R_{\tau\mu} = \frac{\mathcal{B}(\Upsilon(3S)\to\tau^+\tau^-)}{\mathcal{B}(\Upsilon(3S)\to\mu^+\mu^-)} = 0.9662 \pm 0.0084_{stat} \pm 0.014_{syst}$$

$$= 0.9662 \pm 0.016\mathrm{tot}$$

SM = 0.9948
Δ < 2 σ

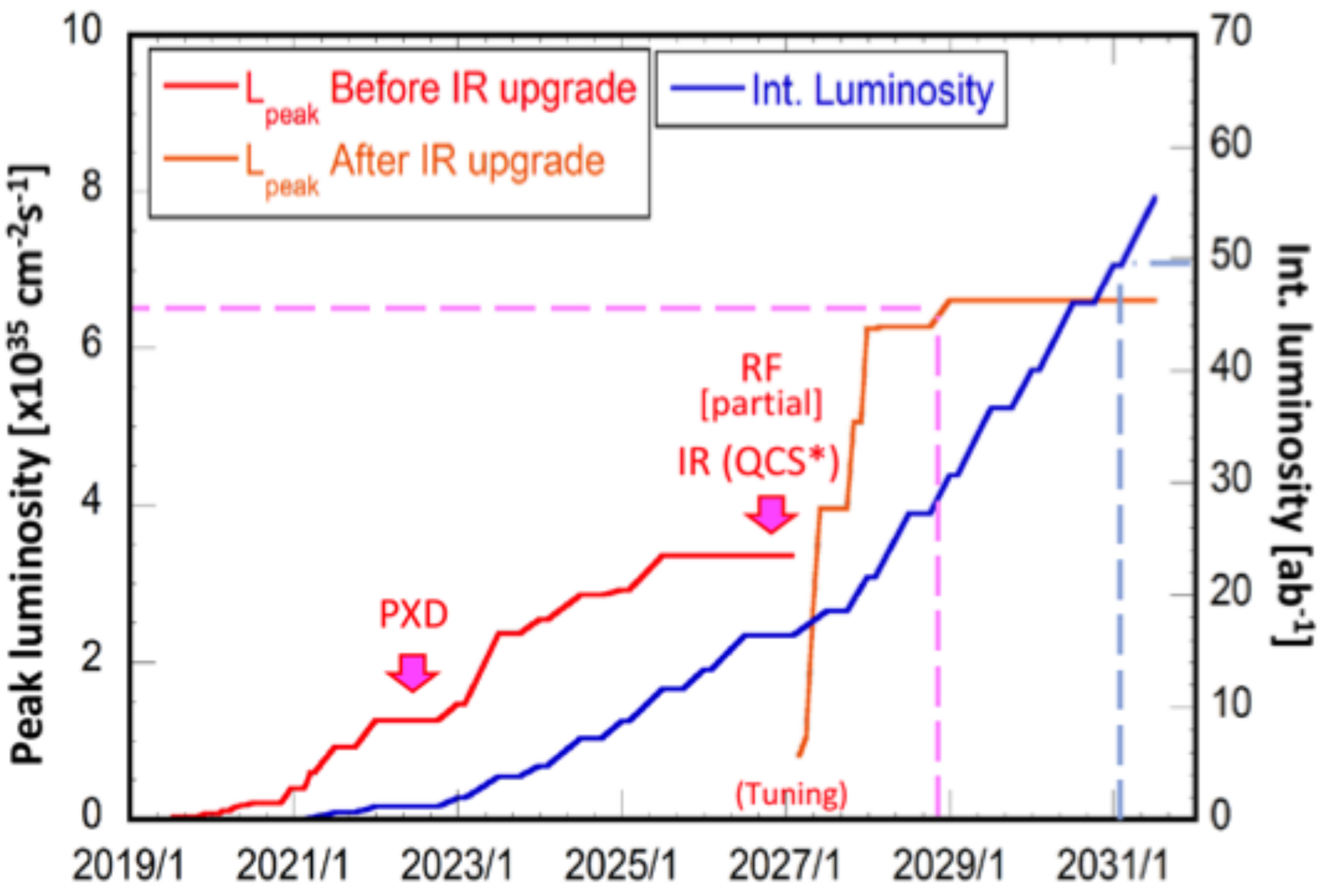
- Using a 26.9 fb^{-1} data sample collected at the Υ (3S) and 78.3 fb^{-1} data sample at the Υ(4S) to describe the continuum. Measurement *O*(10x) improvement on previous result.

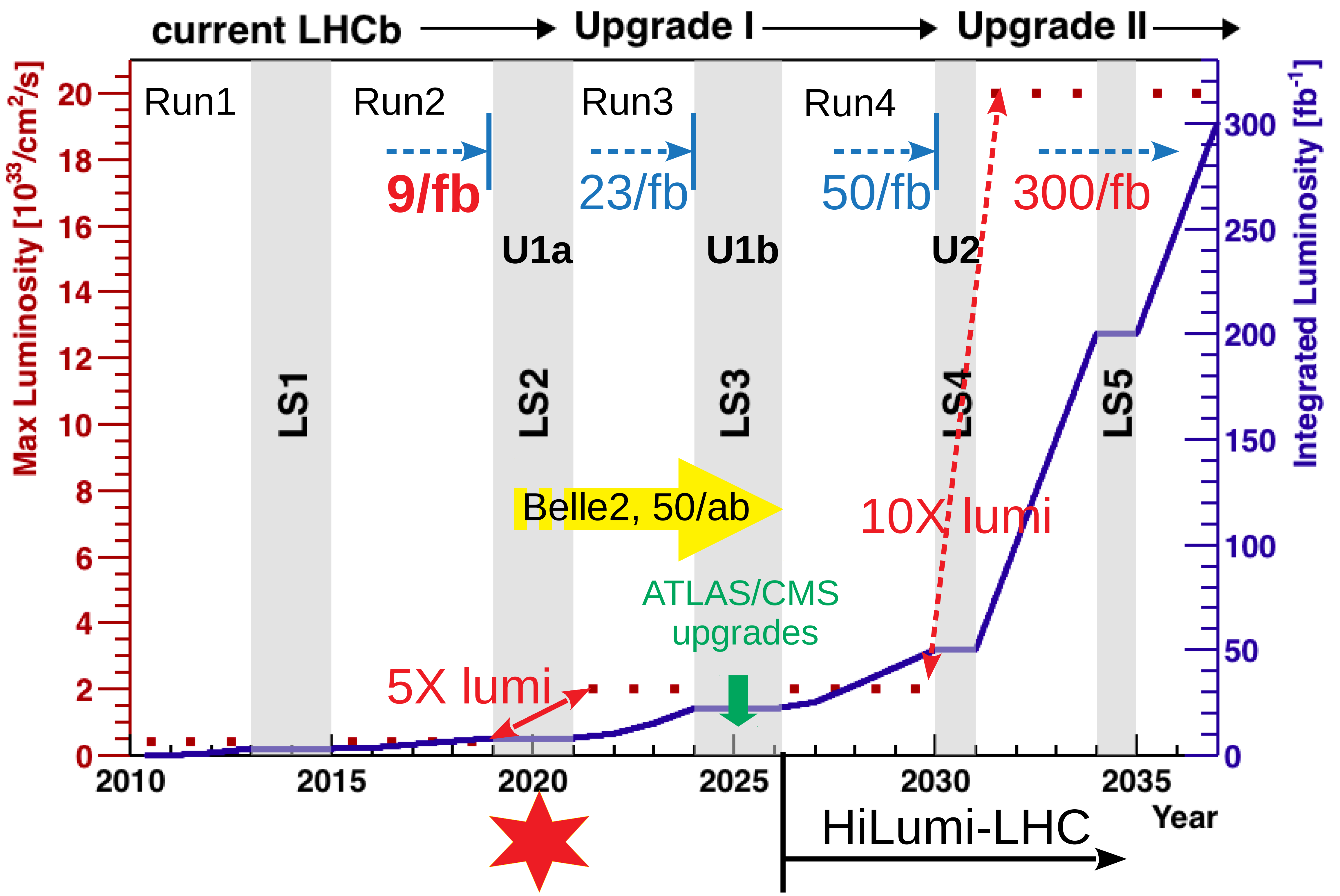
Outlook

LHC & SuperKEKB

Physics Cases

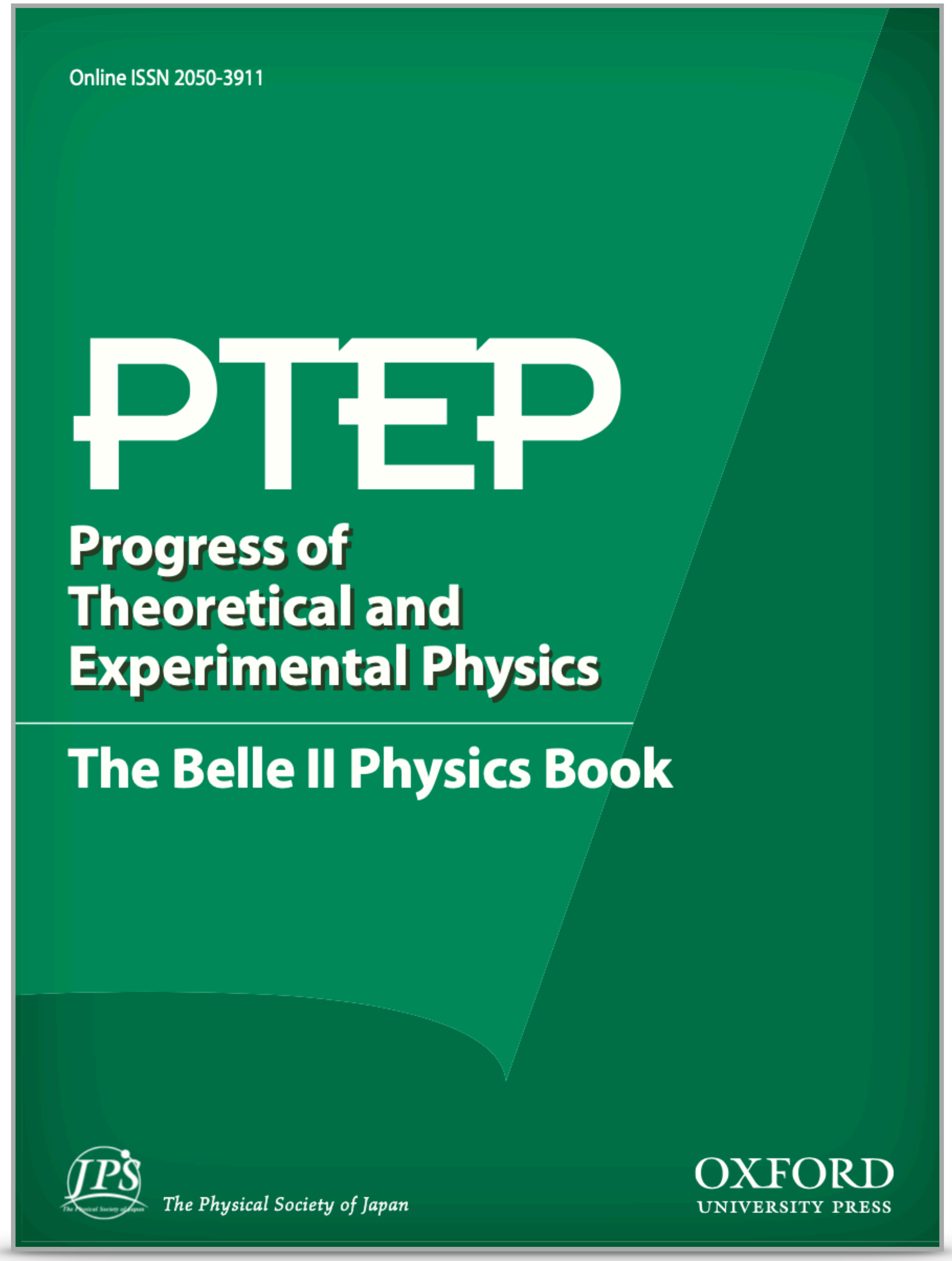
Expected (Integrated) Luminosity @ B machines





Four steps: *Intermediate luminosity* (1-2 x 10^{35} /cm^2/sec, 5ab^{-1});
High Luminosity (6.5 x 10^{35}/cm^2/sec, 50 ab^{-1}) with a detector upgrade
Polarization Upgrade, Advanced R&D
Ultra high luminosity (4 x 10^{36}/cm^2/sec, 250 ab^{-1}), R&D Project

Physics Cases



Online ISSN 2050-3911

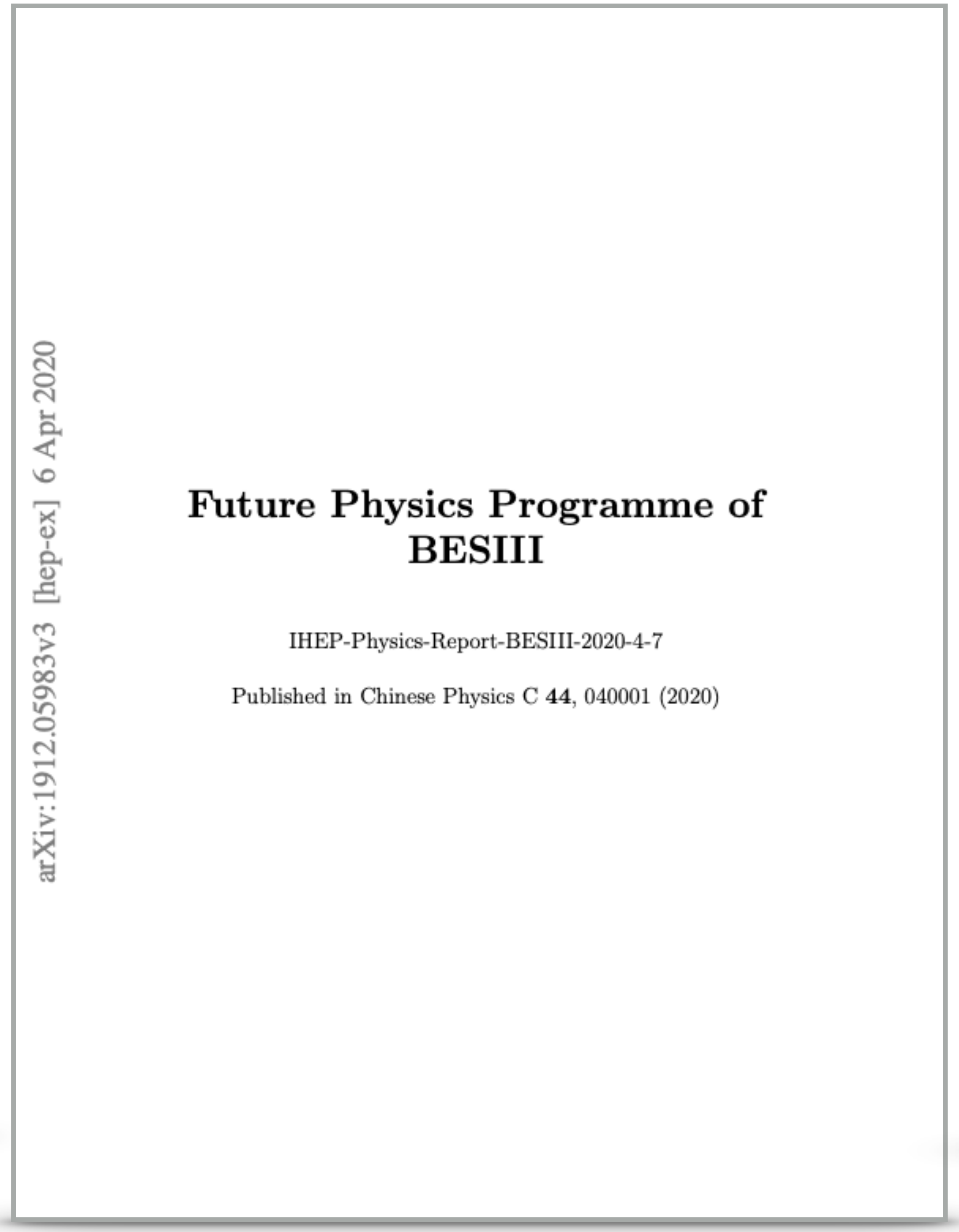
PTEP

Progress of Theoretical and Experimental Physics

The Belle II Physics Book

The Physical Society of Japan

OXFORD UNIVERSITY PRESS

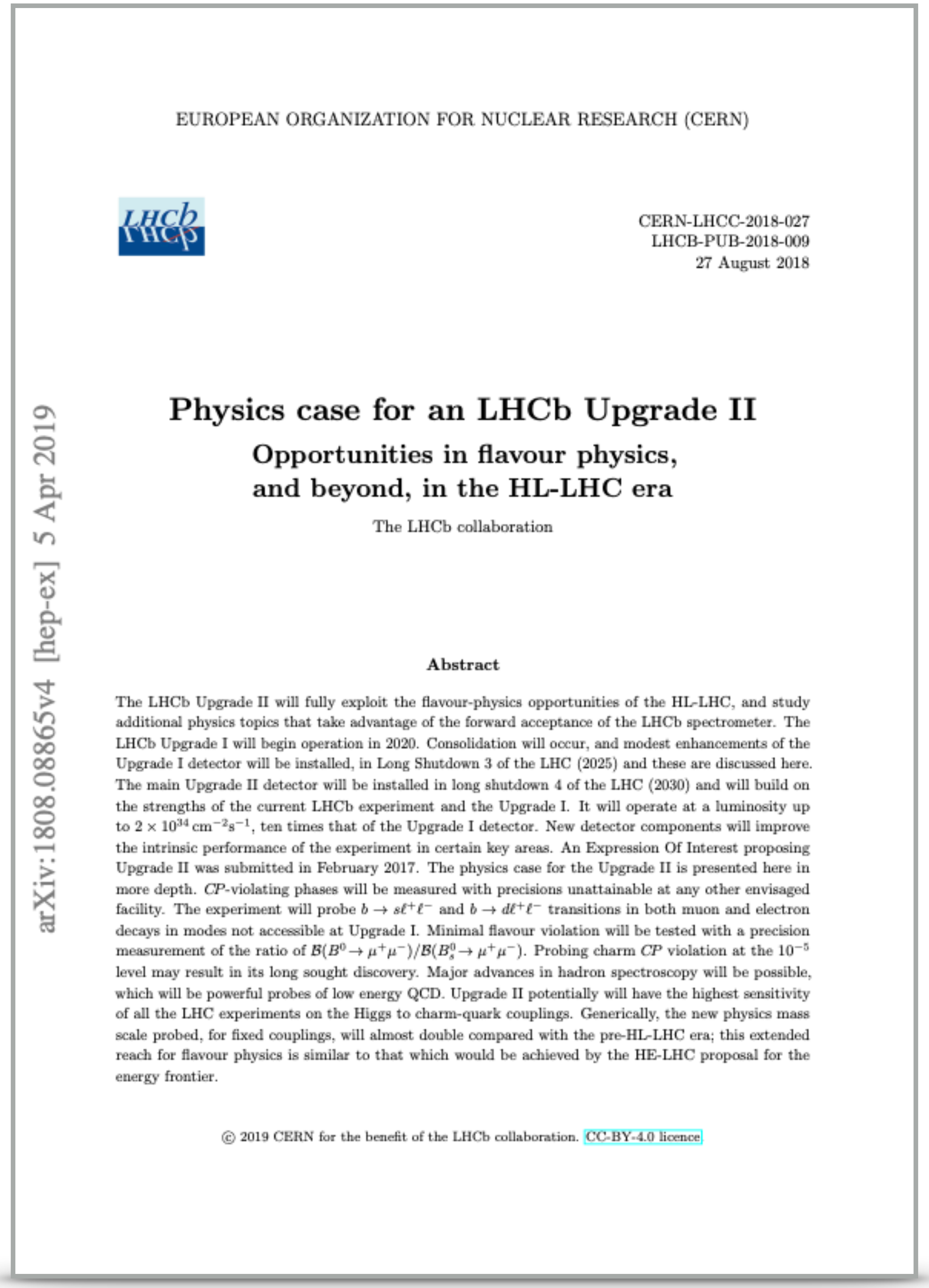


arXiv:1912.05983v3 [hep-ex] 6 Apr 2020

Future Physics Programme of BESIII

IHEP-Physics-Report-BESIII-2020-4-7

Published in Chinese Physics C **44**, 040001 (2020)



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-LHCC-2018-027
LHCB-PUB-2018-009
27 August 2018

arXiv:1808.08865v4 [hep-ex] 5 Apr 2019

Physics case for an LHCb Upgrade II

Opportunities in flavour physics, and beyond, in the HL-LHC era

The LHCb collaboration

Abstract

The LHCb Upgrade II will fully exploit the flavour-physics opportunities of the HL-LHC, and study additional physics topics that take advantage of the forward acceptance of the LHCb spectrometer. The LHCb Upgrade I will begin operation in 2020. Consolidation will occur, and modest enhancements of the Upgrade I detector will be installed, in Long Shutdown 3 of the LHC (2025) and these are discussed here. The main Upgrade II detector will be installed in long shutdown 4 of the LHC (2030) and will build on the strengths of the current LHCb experiment and the Upgrade I. It will operate at a luminosity up to $2 \times 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$, ten times that of the Upgrade I detector. New detector components will improve the intrinsic performance of the experiment in certain key areas. An Expression Of Interest proposing Upgrade II was submitted in February 2017. The physics case for the Upgrade II is presented here in more depth. *CP*-violating phases will be measured with precisions unattainable at any other envisaged facility. The experiment will probe $b \to s\ell^+\ell^-$ and $b \to d\ell^+\ell^-$ transitions in both muon and electron decays in modes not accessible at Upgrade I. Minimal flavour violation will be tested with a precision measurement of the ratio of $\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$. Probing charm *CP* violation at the 10^{-5} level may result in its long sought discovery. Major advances in hadron spectroscopy will be possible, which will be powerful probes of low energy QCD. Upgrade II potentially will have the highest sensitivity of all the LHC experiments on the Higgs to charm-quark couplings. Generically, the new physics mass scale probed, for fixed couplings, will almost double compared with the pre-HL-LHC era; this extended reach for flavour physics is similar to that which would be achieved by the HE-LHC proposal for the energy frontier.

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New perspective on anomalies: Belle II Radiative and EWP B decays

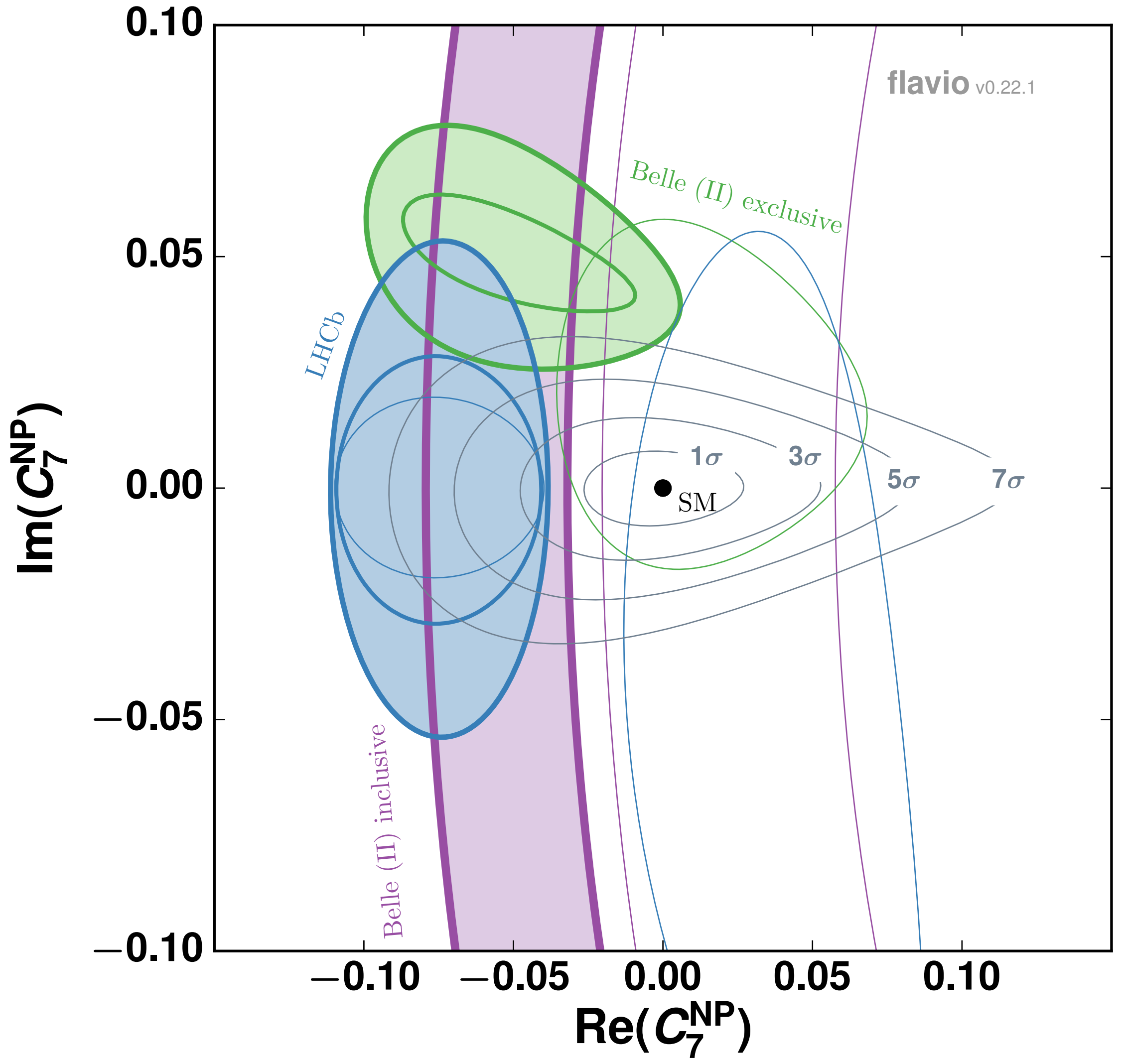
Talk by K. Yoshihara

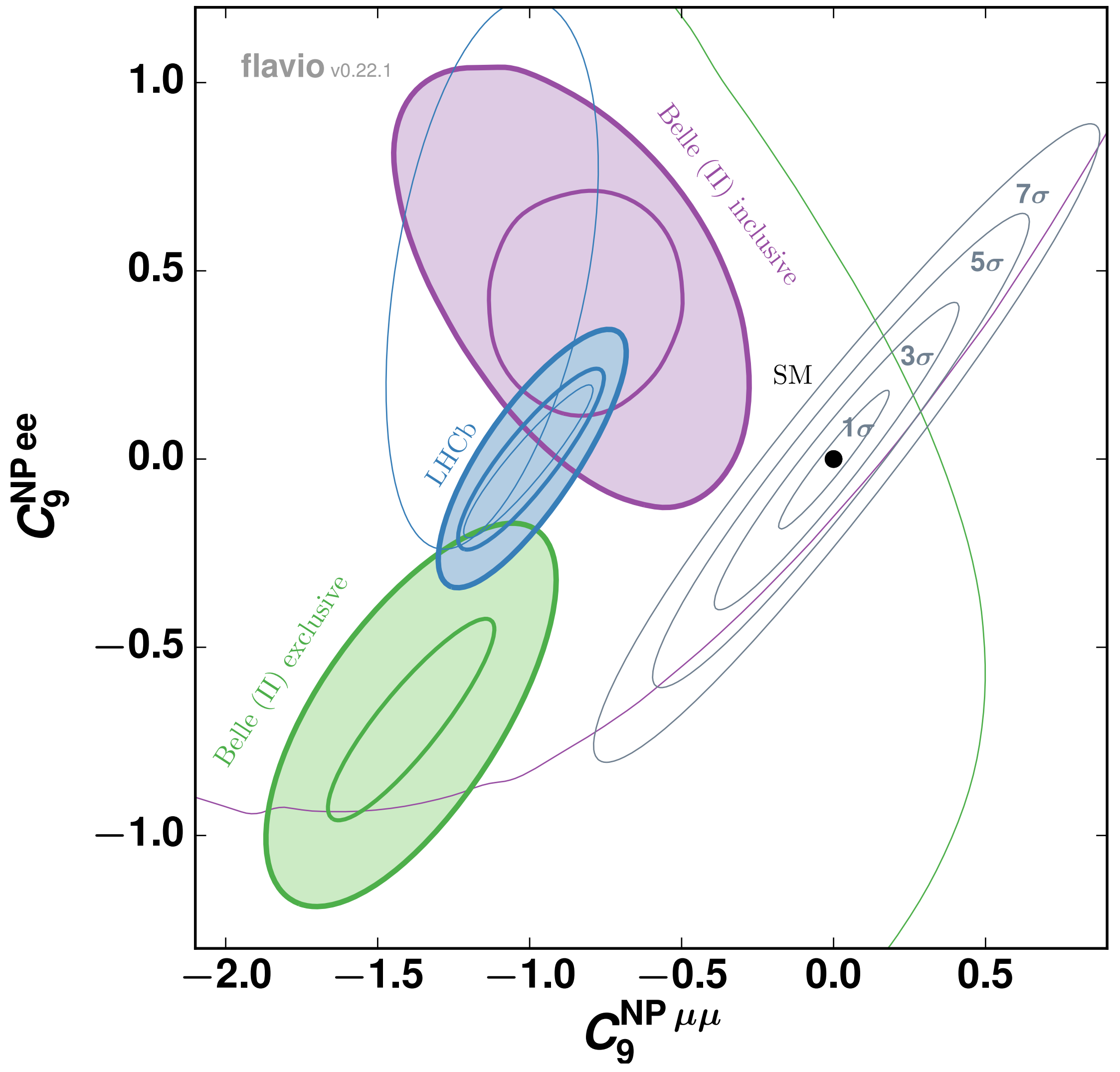
- Except for B→X_{s+d} γ inclusive, all channels are highly statistics limited.
  - Expect systematics to be subdominant beyond 50 ab^{-1}
  - Key to understand beam **background induced efficiency loss and E_{ECL} degradation** in B→Kνν.
- SM level (5σ) in B→Xνν. Novel ALPs/Scalars/LLPs searches in B decays.

$$\mathcal{H}_{\rm eff} = -\frac{4\,G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i (C_i O_i + C_i' O_i') + \text{h.c.}$$

PTEP 2019 (2019) 12, 123C01

Observables	Belle (2017)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathcal{B}(B \to K^{*+}\nu\bar{\nu})$	$< 40 \times 10^{-6}$	25%	9%
$\mathcal{B}(B \to K^{+}\nu\bar{\nu})$	$< 19 \times 10^{-6}$	30%	11%
✸ $A_{CP}(B \to X_{s+d}\gamma)$ $[10^{-2}]$	$2.2 \pm 4.0 \pm 0.8$	1.5	0.5
✸ $S(B \to K_S^0\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	0.11	0.035
✸ $S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	0.23	0.07
✸ $A_{FB}(B \to X_s\ell^+\ell^-)$ $(1 < q^2 < 3.5\ \mathrm{GeV}^2/c^4)$	26%	10%	3%
✸ $Br(B \to K^+\mu^+\mu^-)/Br(B \to K^+e^+e^-)$ $(1 < q^2 < 6\ \mathrm{GeV}^2/c^4)$	28%	11%	4%
✸ $Br(B \to K^{*+}(892)\mu^+\mu^-)/Br(B \to K^{*+}(892)e^+e^-)$ $(1 < q^2 < 6\ \mathrm{GeV}^2/c^4)$	24%	9%	3%
$\mathcal{B}(B_s \to \gamma\gamma)$	$< 8.7 \times 10^{-6}$	23%	–
$\mathcal{B}(B_s \to \tau\tau)$ $[10^{-3}]$	–	< 0.8	–





Belle II - LHCb Comparison

+ Important contributions on B and D flavour physics from ATLAS, CMS, BESIII.

Belle II
Higher sensitivity to decays with photons and neutrinos (e.g. $B\to K\nu\nu$, $\mu\nu$), inclusive decays, time dependent CPV in B_d, τ physics.

LHCb
Higher production rates for ultra rare B, D, & K decays, access to all b-hadron flavours (e.g. Λ_b), high boost for fast B_s oscillations.

Overlap in various key areas to verify discoveries.

Upgrades
Most key channels will be stats. limited (not theory or syst.).
LHCb scheduled major upgrades during LS3 and LS4.
Belle II formulating a 250 ab^{-1} upgrade program post 2028.

	Observable	Current Belle/ Babar	2019 LHCb	Belle II (5 ab^{-1})	Belle II (50 ab^{-1})	LHCb (23 fb^{-1})	Belle II Upgrade (250 ab^{-1})	LHCb upgrade II (300 fb^{-1})
	CKM precision, new physics in CP Violation							
✸	$\sin 2\beta/\varphi_1$ ($B\to J/\psi K_S$)	0.03	0.04	0.012	0.005	0.011	0.002	0.003
✸	γ/φ_3	13°	5.4°	4.7°	1.5°	1.5°	0.4°	0.4°
✸	α/φ_2	4°	–	2	0.6°	–	0.3°	–
✸	$\lvert V_{ub}\rvert$ (Belle) or $\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ (LHCb)	4.5%	6%	2%	1%	3%	<1%	1%
	φ_s	–	49 mrad	–	–	14 mrad	–	4 mrad
✸	$S_{CP}(B\to\eta' K_S$, gluonic penguin)	0.08	○	0.03	0.015	○	0.007	○
✸	$A_{CP}(B\to K_S\pi^0)$	0.15	–	0.07	0.04	–	0.02	–
	New physics in radiative & EW Penguins, LFUV							
✸	$S_{CP}(B_d\to K^*\gamma)$	0.32	○	0.11	0.035	○	0.015	○
✸	$R(B\to K^* l^+l^-)$ ($1<q^2<6$ GeV$^2/c^2$)	0.24	0.1	0.09	0.03	0.03	0.01	0.01
✸	$R(B\to D^*\tau\nu)$	6%	10%	3%	1.5%	3%	<1%	1%
	$Br(B\to\tau\nu)$, $Br(B\to K^*\nu\nu)$	24%, –	–	9%, 25%	4%, 9%	–	1.7%, 4%	–
	$Br(B_d\to\mu\mu)$	–	90%	–	–	34%	–	10%
	Charm and τ							
✸	$\Delta A_{CP}(KK-\pi\pi)$	–	8.5×10^{-4}	–	5.4×10^{-4}	1.7×10^{-4}	2×10^{-4}	0.3×10^{-4}
✸	$A_{CP}(D\to\pi^+\pi^0)$	1.2%	–	0.5%	0.2%	–	0.1%	–
	$Br(\tau\to e\gamma)$	<120×10^{-9}	–	<40×10^{-9}	<12×10^{-9}	–	<5×10^{-9}	–
	$Br(\tau\to\mu\mu\mu)$	<21×10^{-9}	<46×10^{-9}	<3×10^{-9}	<3×10^{-9}	<16×10^{-9}	<0.3×10^{-9}	<5×10^{-9}

Results on other D & τ modes expected

○ Possible in similar channels, lower precision
– Not competitive.

arXiv: 1808.08865 (Physics case for LHCb upgrade II), PTEP 2019 (2019) 12, 123C01 (Belle II Physics Book)

Remarks on research plans

- The B-factories (inc. LHCb) were built to be very good for flavour, but have weaknesses. **Continued upgrade plans and technique development will serve us well**.
    - e.g. LFU **Anomalies**: there's often neutrinos, often a bremsstrahlung tail. Needs 1) improved/ evolving calorimetry techniques, and ideally reduced material, improved mapping; 2) faster, better particle ID and robust tracking with maximal phase space coverage: all things we strive for.
- **Theory errors** are substantial in SM precision measurements. We need sufficient emphasis on measurements of theory control modes, QCD effects in precision SM analyses and precise tests of FCNC NP, and tests of LQCD.
- **New ideas**.
    - The physics plans (Belle II, BESIII, LHCb etc.) were written to benchmark the experiment prospects and develop ideas. Newcomers - *read the physics plans but then put them down and* ***innovate***.
- **Collaboration** and competition.
    - Collaborative work between flavour machines to address outstanding problems are an important area: LHC B→μμ/ee, BESIII+LHCb Φ_3, HFLAV activities, BFs for normalisation.

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Conclusion

Thanks to IMPU Tokyo for hosting the conference.

There were lots of new and exciting results and ideas shared.