西安交通大學
XI'AN JIAOTONG UNIVERSITY

Review of
Belle and Belle II results

BELLE

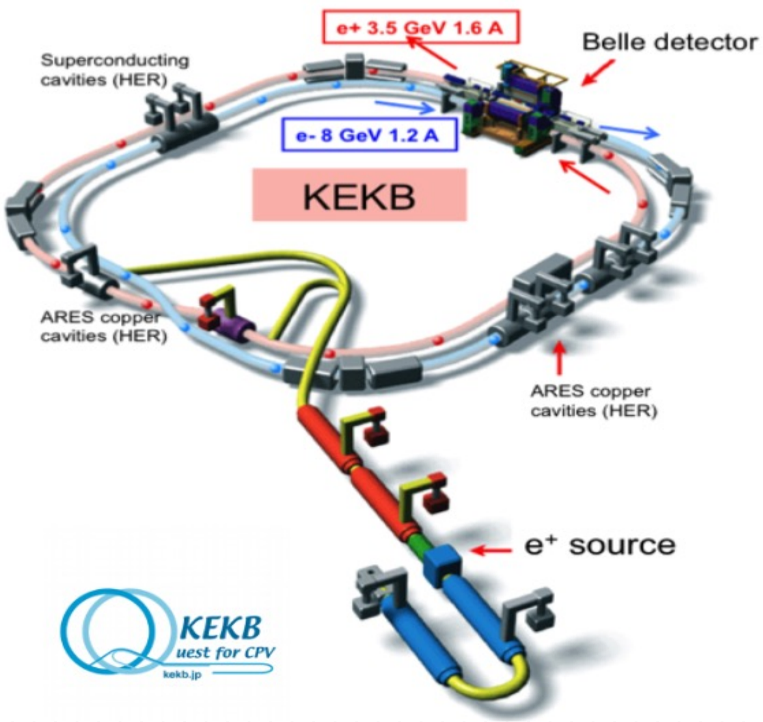
Belle II

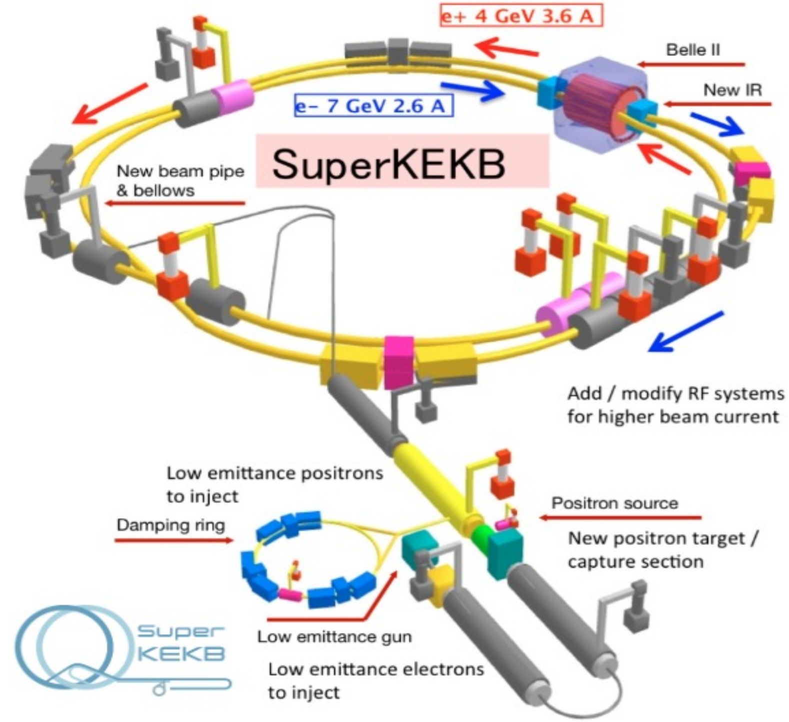
Yubo Li （李郁博）

全国第二十届重味物理和CP破坏研讨会

2023年12月16日

Update of accelerator





	$E_{\pm}$ (GeV) LER/HER	Cross Angle (mrad)	$I_{\pm}$ (A) LER/HER	β^*_y (mm) LER/HER	$\mathcal{L}$ $(cm^{-2}s^{-1})$
KEKB	3.5/8.0	22	1.64/1.19	5.9/5.9	2.1×10^{34}
SuperKEKB	4.0/7.0	83	3.60/2.60	0.27/0.31	80×10^{34}
	$\beta\gamma \sim 2/3$		$\times 2$	$\times 20$	$\times 40$

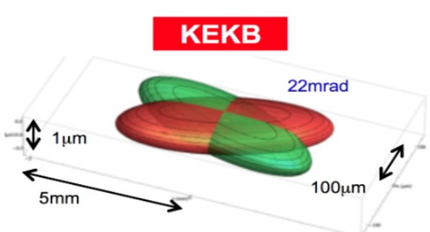
luminosity

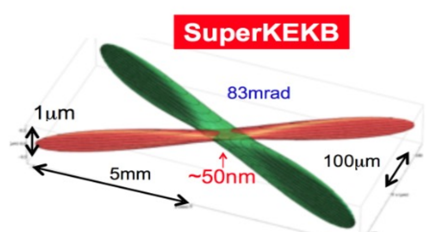
$$\mathcal{L} = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma^*_y}{\sigma^*_x}\right)\frac{I_{\pm}\xi_{y\pm}}{\beta^*_{y\pm}}\left(\frac{R_L}{R_{\xi_y}}\right)$$

beam size: σ^*, beam-beam par.: $\xi_{\pm}$,
beam current: $I_{\pm}$, beta function: β^*

$$\mathcal{L}_{\rm II}^{\rm peak} \approx 30 \times \mathcal{L}_{\rm I}^{\rm peak}$$

$$\int^{\rm goal} \mathcal{L}_{\rm II}\, dt = 50 \text{ ab}^{-1} \approx 50 \int \mathcal{L}_{\rm I}\, dt$$

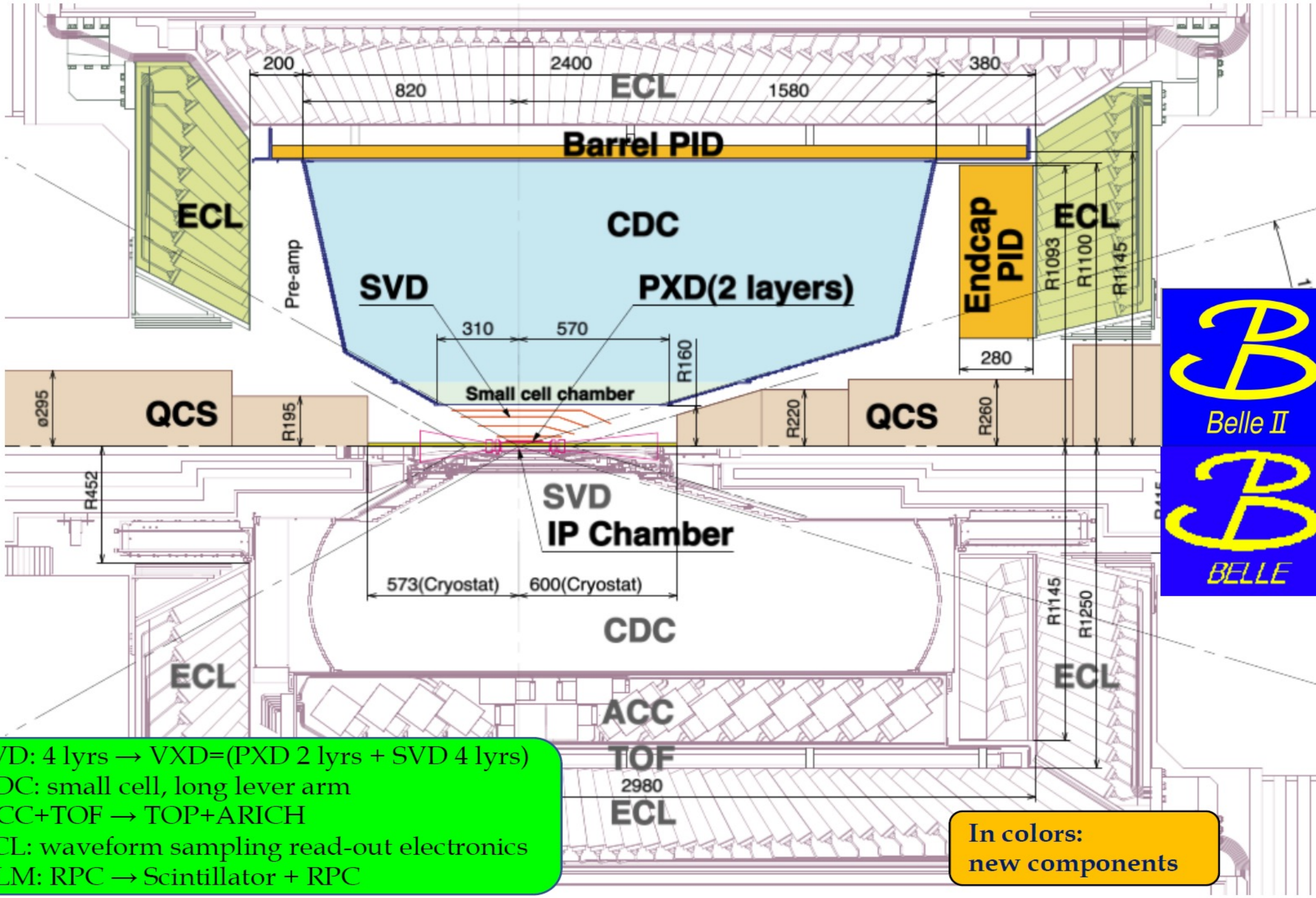




Nano beam: small beamspot

Update of detector

Belle II : ~424 fb^{-1}

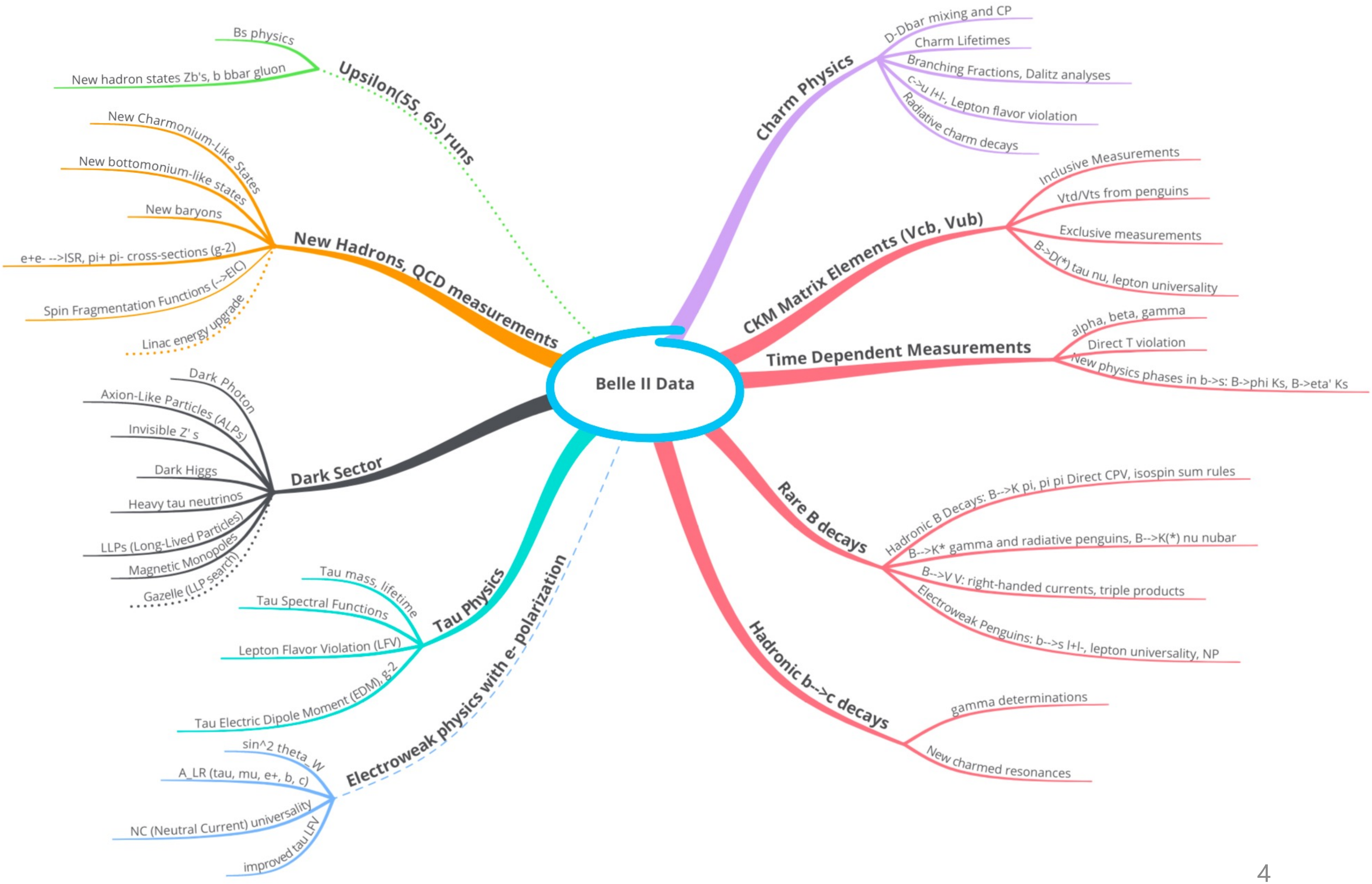


SVD: 4 lyrs → VXD=(PXD 2 lyrs + SVD 4 lyrs)
CDC: small cell, long lever arm
ACC+TOF → TOP+ARICH
ECL: waveform sampling read-out electronics
KLM: RPC → Scintillator + RPC

In colors:
new components

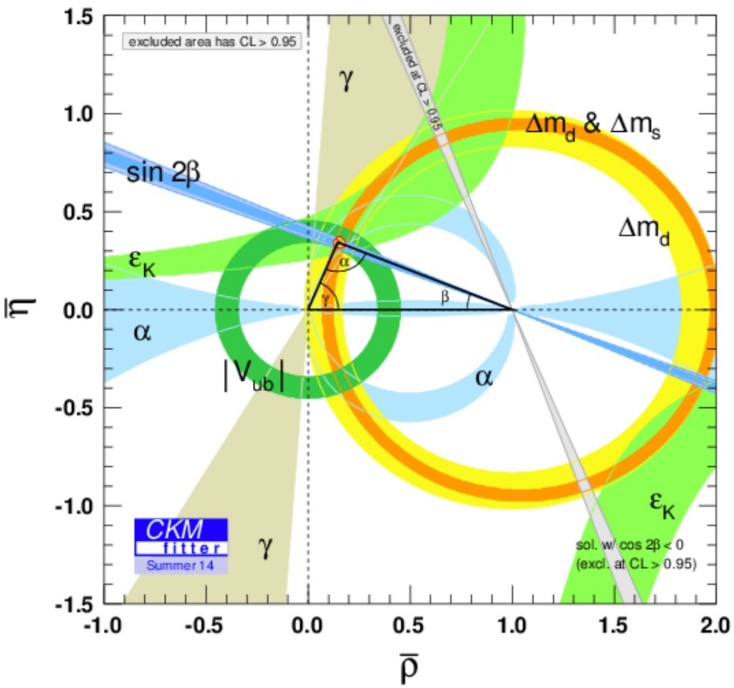
Belle : ~980 fb^{-1}

What are Belle and Belle II can do?

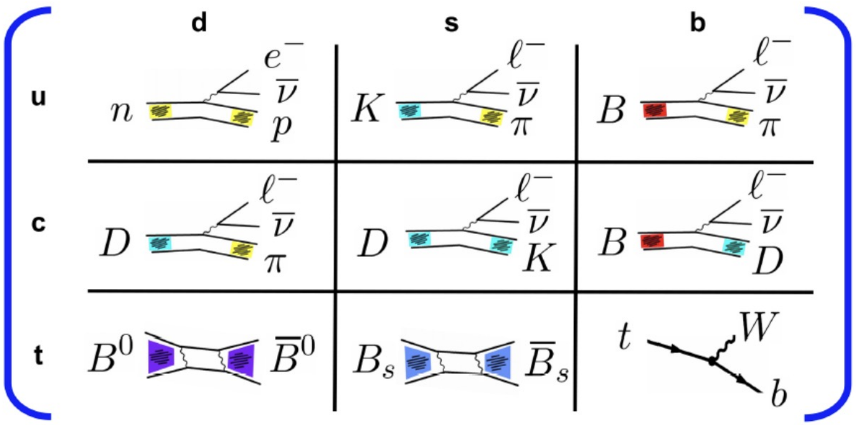


CKM

How do quarks participate in weak decays? -> CKM matrix



$V =$



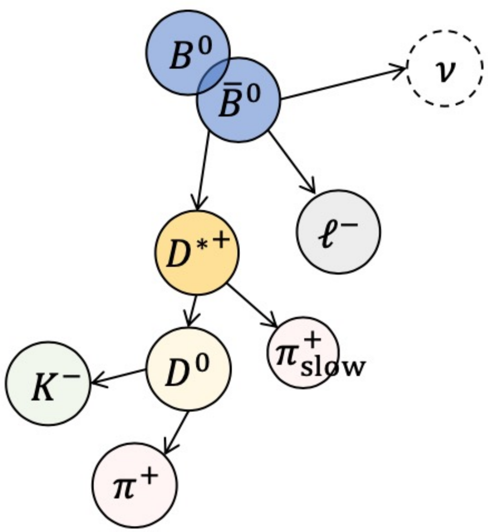
$$\alpha = \phi_2 \qquad \beta = \phi_1 \qquad \gamma = \phi_3$$

- ❖ d → u: Nuclear physics (superallowed β decays)
- ❖ s → u: Kaon physics (KLOE, KTeV, NA62)
- ❖ **c → d, s: Charm physics (CLEO-c, Babar, Belle, BESIII)**
- ❖ **b → u, c and t → d, s: B physics (Babar, Belle, CDF, DØ, LHCb)**
- ❖ t → b: Top physics (CDF/DØ, ATLAS, CMS)

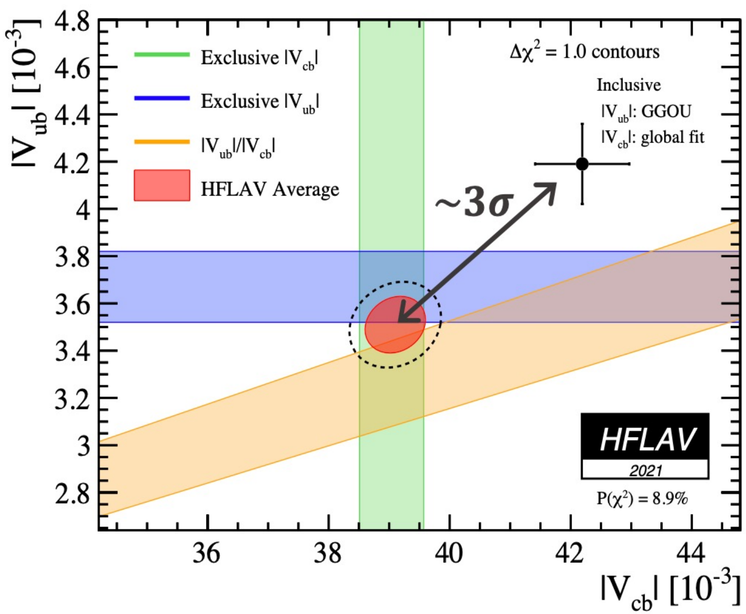
Semileptonic B Decays

- determine the CKM elements $|V_{cb}|$ and $|V_{ub}|$
- Tests of lepton universality, $R(D^{(*)}), R(K^{(*)})$
- ...

Exclusive

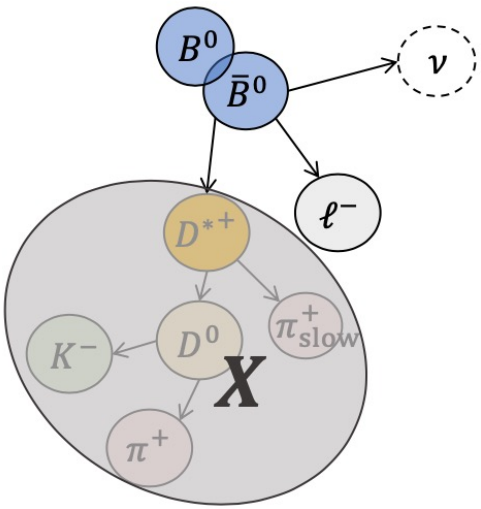


Reconstruct all daughters through specific channels exclusively.



The current experimental focus is on understanding the origin of this discrepancy.

Inclusive



Reconstruct a lepton and assign other tracks and clusters as an inclusive daughter X.

Measurement of $|V_{cb}|$ and $|V_{ub}|$

Status of |Vxb| measurments at Belle (II)

4:20 PM - 4:40 PM

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Presenter 璐 曹

Vxb-puzzle:

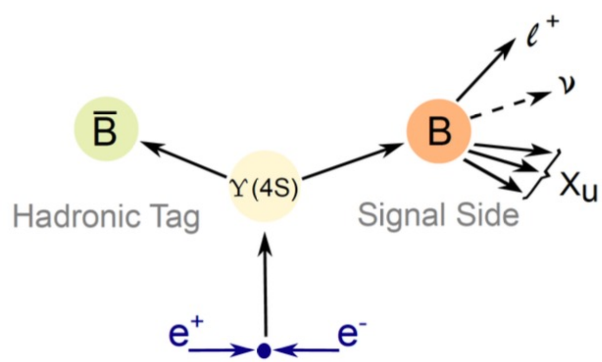
$$|V_{ub}^{\text{excl.}}| = (3.51 \pm 0.12) \times 10^{-3}$$
$$|V_{ub}^{\text{incl.}}| = (4.19 \pm 0.16) \times 10^{-3}$$

Ratio = 0.84 ± 0.04

3.7σ from unity!!

Inclusive measurement of. $|V_{ub}|$

PRD 104 , 012008 (2021)

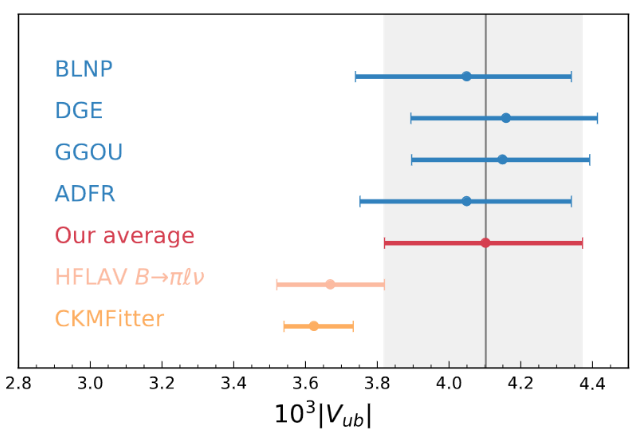


$$B \to X_u \ell \nu$$

$$X_u = \pi, \rho, \omega, \eta^{(\prime)}, \text{non-resonant contribution}$$

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u \ell \nu)}{\tau_B \cdot \Delta\Gamma(B \to X_u \ell \nu)}}$$

Theoretical predictions of incl. decay rates (model-dependent!!)



Average:

$$(4.10 \pm 0.09_{stat} \pm 0.22_{sys} \pm 0.15_{theo}) \times 10^{-3}$$

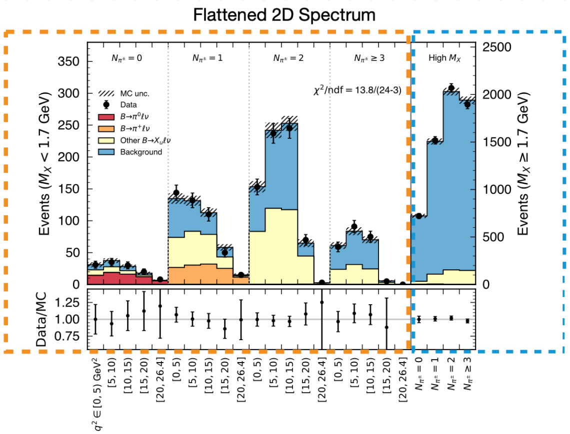
Exclusive $\leftrightarrow 1.3\sigma$

CKMfit $\leftrightarrow 1.6\sigma$

First Simultaneous Determination of Inclusive and Exclusive $|V_{ub}|$

PRL131.211801(2023)

Low M_X



High M_X

Excl. $(3.78 \pm 0.23_{\rm stat} \pm 0.16_{\rm syst} \pm 0.14_{\rm theo}) \times 10^{-3}$

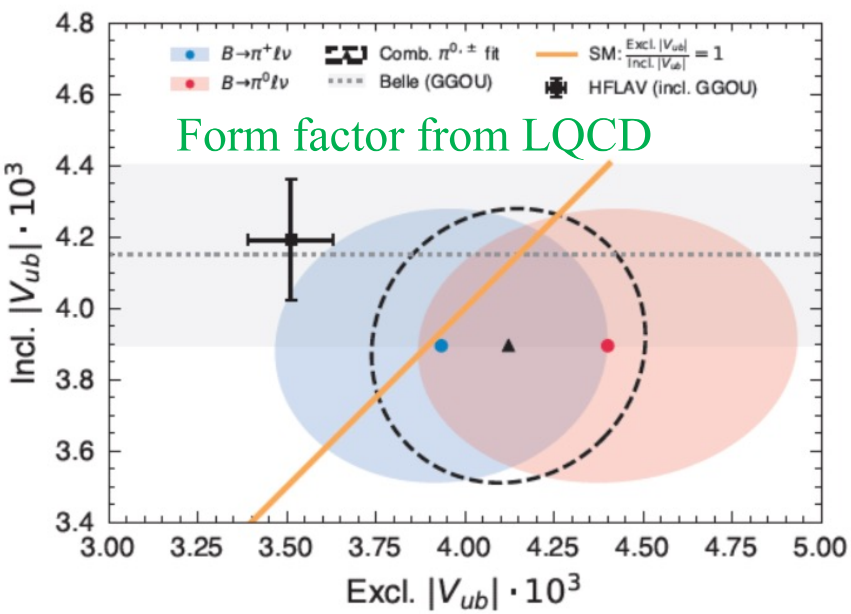
Incl. $(3.88 \pm 0.20_{\rm stat} \pm 0.31_{\rm syst} \pm 0.09_{\rm theo}) \times 10^{-3}$

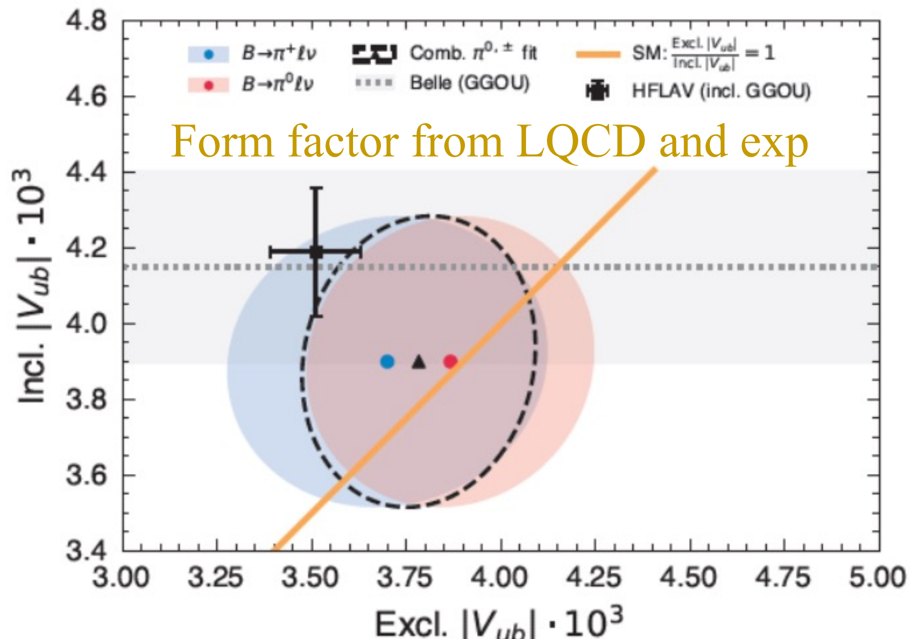
Ratio $0.97 \pm 0.12 \quad (\rho = 0.11)$ compatible with the world average within 1.2σ

$|V_{ub}| = (3.84 \pm 0.26) \times 10^{-3}$ (LQCD + exp.) $1.2\,\sigma$

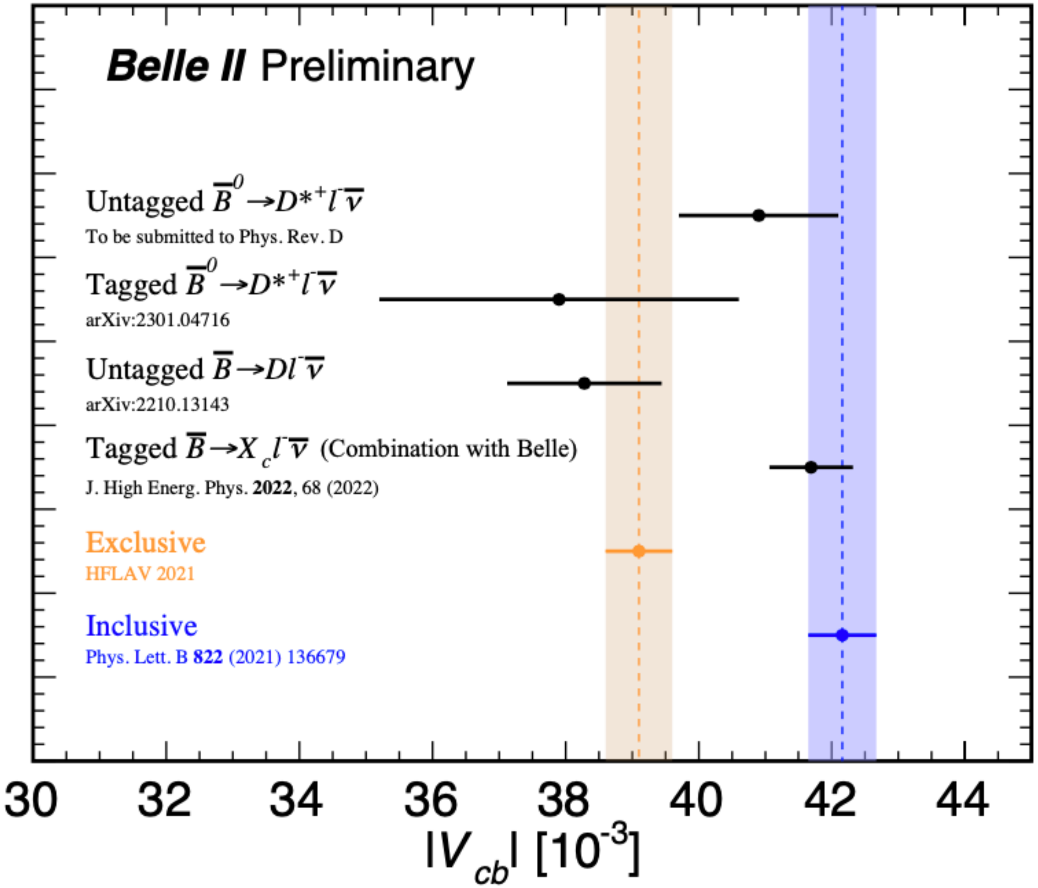
$|V_{ub}| = (3.96 \pm 0.27) \times 10^{-3}$ (LQCD) $0.8\,\sigma$

$|V_{ub}^{CKM}|$: $(3.6 \pm 0.07)\times 10^3$





measurement of $|V_{cb}|$



PRD 108 092013 (2023)

$$|V_{cb}|\eta_{\rm EW}\mathcal{F}(1) = \frac{1}{\sqrt{m_B m_{D^*}}}\left(\frac{|\tilde{b}_0|}{P_f(0)\phi_f(0)}\right)$$

$$|V_{cb}|_{\rm BGL} = (40.9 \pm 0.3 \pm 1.0 \pm 0.6) \times 10^{-3}$$

$$|V_{cb}|_{\rm CLN} = (40.4 \pm 0.3 \pm 1.0 \pm 0.6) \times 10^{-3}$$

Slow pion eff. plays leading role in syst.

Input from LQCD at zero-recoil F(1)

ϕ_3: most Imprecision among ϕ_i

$$\phi_3 = \arg\left[\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$$

- World average:
  - Direct: $(66.2^{+3.4}_{-3.6})^\circ$, PRD 107 (2023) 052008]
  - Indirect: $(66.29^{+0.72}_{-1.86})^\circ$, [JHEP03(2020)112]

$$\frac{A^{suppr.}[B^-\to\overline{D^0}K^-]}{A^{favor.}[B^-\to D^0K^-]} = r_B e^{i(\delta_B-\phi_3)}$$

Recent phi3 measurement at Belle II

4:40 PM - 5:00 PM

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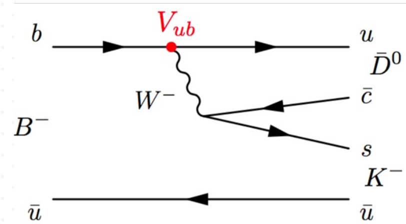
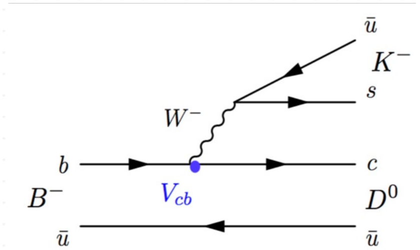
Presenter Xiaodong Shi

$$R_t = \left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right| = \frac{1}{|V_{us}|}\left|\frac{V_{td}}{V_{ts}}\right| + \mathcal{O}(\lambda^2)$$



color allowed

$B^-\to D^0K^-\sim V_{cb}V_{us}^*$

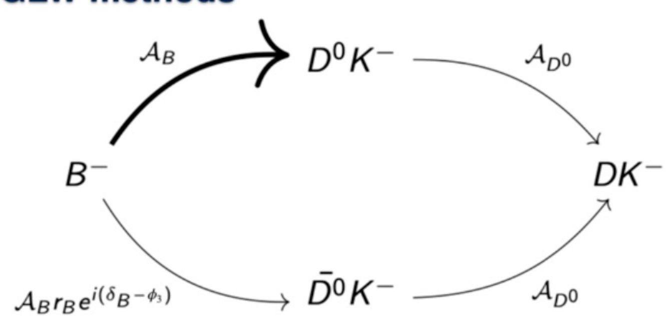


color suppressed

$B^-\to\bar{D}^0K^-\sim V_{ub}V_{cs}^*$

- Methods depending on different D final states:
  - **BPGGSZ**: self conjugated multi-body decays, e.g. $K_S^0\pi^+\pi^-$, $K_S^0\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^+\pi^-$
  - **GLW**: CP eigenstates, e.g. $K_S^0\pi^0$, K^+K^-
  - **ADS**: CF and DCS decays, e.g. $K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^\pm\pi^\mp$
  - **GLS**: SCS decays, e.g. $K_S^0K^\mp\pi^\pm$

GLW methods



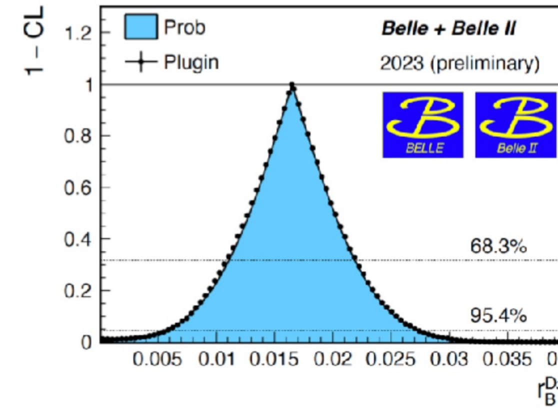
Combined measurement of ϕ_3 with Belle & Belle II

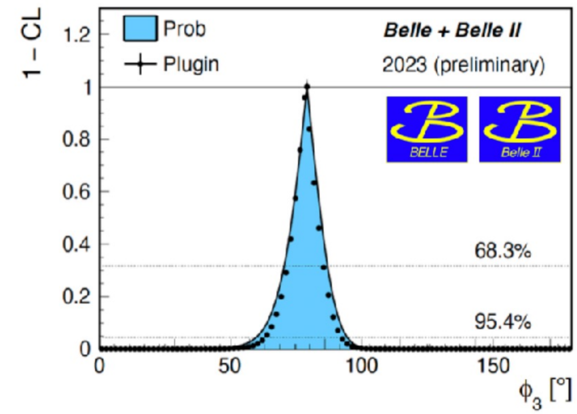
Preliminary

- Four different methods using 17 different final states
- Inputs on D decays dynamics from other experiments
  - r_D (amplitude ratio), δ_D (strong-phase difference), κ_D (coherence factor), etc.

B decay	D decay	Method	Data set (Belle + Belle II) [fb^{-1}]	
$B^+ \to Dh^+$	$D \to K_S^0 h^- h^+$	BPGGSZ	$711 + 128$	[JHEP 02 063 (2022)]
$B^+ \to Dh^+$	$D \to K_S^0 \pi^- \pi^+ \pi^0$	BPGGSZ	$711 + 0$	[JHEP 10 178 (2019)]
$B^+ \to Dh^+$	$D \to K_S^0 \pi^0, K^- K^+$	GLW	$711 + 189$	[arxiv:2308.05048]
$B^+ \to Dh^+$	$D \to K^+ \pi^-, K^+ \pi^- \pi^0$	ADS	$711 + 0$	[PRL 106 231803 (2011)]
$B^+ \to Dh^+$	$D \to K_S^0 K^- \pi^+$	GLS	$711 + 362$	[JHEP 09 (2023) 146]
$B^+ \to D^* K^+$	$D \to K_S^0 \pi^- \pi^+$	BPGGSZ	$605 + 0$	[PRD 81 112002 (2010)]
$B^+ \to D^* K^+$	$D \to K_S^0 \pi^0, K_S^0 \phi, K_S^0 \omega, K^- K^+, \pi^- \pi^+$	GLW	$210+0$	[PRD 73 051106 (2006)]

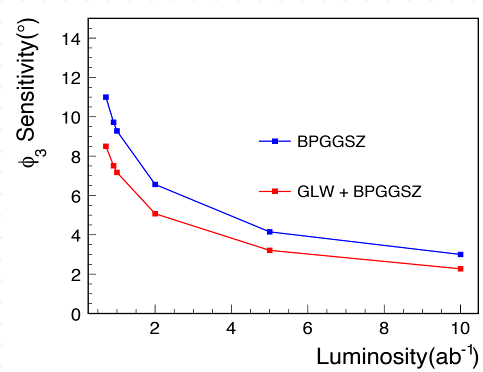
Parameters	$\phi_3 (^\circ)$	r_B^{DK}	$\delta_B^{DK} (^\circ)$	$r_B^{D\pi}$	$\delta_B^{D\pi} (^\circ)$	$r_B^{D^*K}$	$\delta_B^{D^*K} (^\circ)$
			PLUGIN method				
Best fit value	78.6	0.117	138.4	0.0165	347.0	0.234	341
68.3% interval	[71.4, 85.4]	[0.105, 0.130]	[129.1, 146.5]	[0.0109, 0.0220]	[337.4, 355.7]	[0.165, 0.303]	[327,355]
95.5% interval	[63, 92]	[0.092, 0.141]	[118, 154]	[0.006, 0.027]	[322, 366]	[0.10, 0.37]	[307, 369]





$\phi_3 = (78.6 \pm 7.3)^\circ$, consistent with WA, $\phi_3 = (66.2^{+3.2}_{-3.6})^\circ$, within 2σ

Foreseen precision of ϕ_3 is expected with the future Belle II dataset
(current world-average $\delta\phi \sim 4^\circ$)



B anomalies

Test of the lepton flavor universality at Belle II

2:30 PM - 2:50 PM
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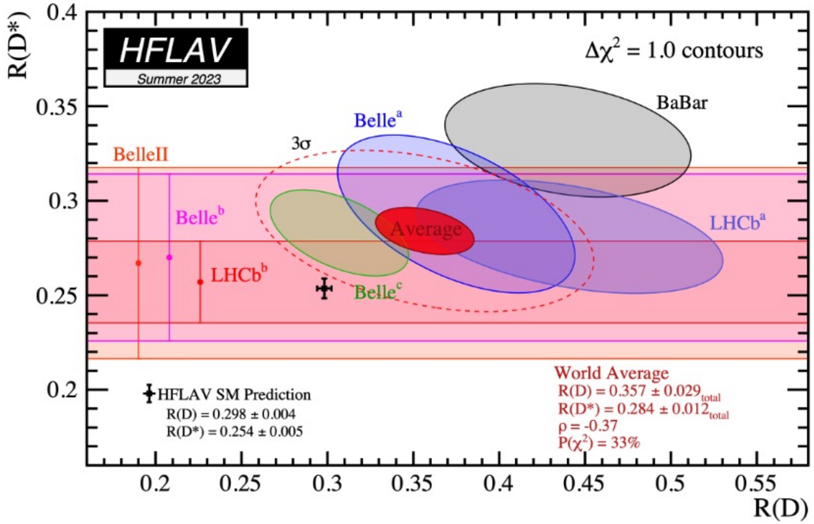
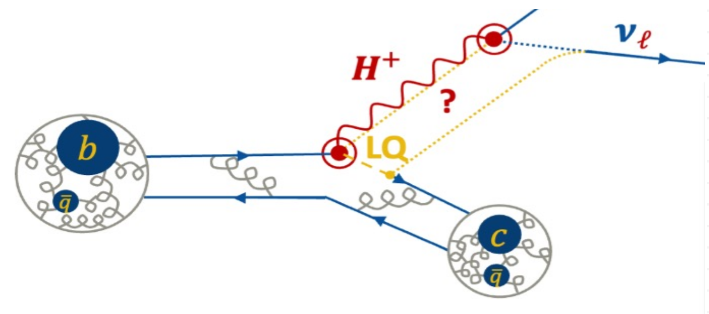
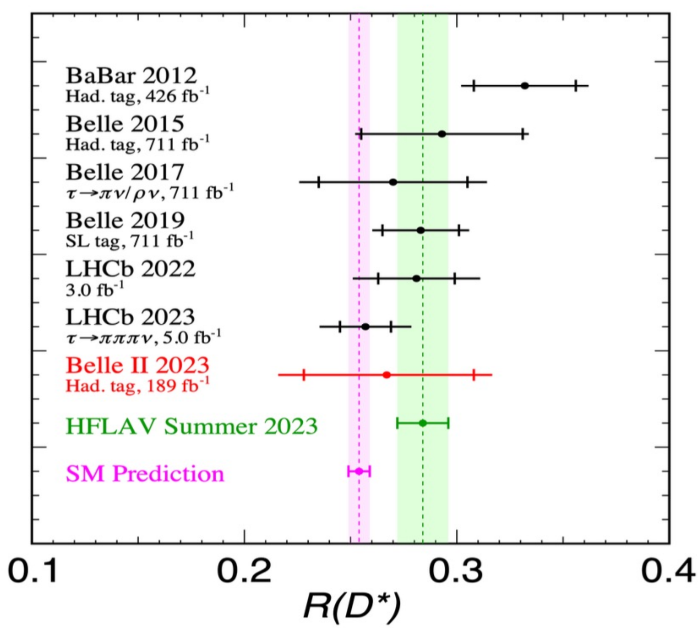
Presenter 启东/Qidong 周/Zhou

❖ Tests of lepton universality, $R\left(D^{(*)}\right), R(K^{(*)})$



$$R\left(D^{(*)}\right) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)}, (\ell = e \text{ or } \mu)$$





- LHCb: PRD 108 012018 (2023)
  - => reduce tension $2.49\sigma \to 2.15\sigma$
- Belle II: PRL 131 181801 (2023)
  - => 40% improvement in statistical precision over Belle at the same sample size

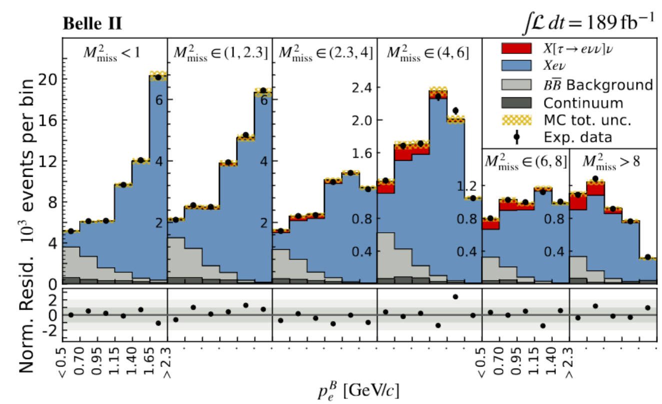
LHCb: arXiv 2302.02886
=> simultaneous measurement of $R(D)$ and $R(D^*)$, 1.9σ tension

First measurement of $R(X_{\tau/\ell})$ arXiv:2311.07248

- $R(X_{\tau/\ell}) = \dfrac{\mathcal{B}(B \to X\tau\nu_\tau)}{\mathcal{B}(B \to X\ell\nu_\ell)}$, measure inclusively. First measurement at B factories

- X reconstructed from remaining tracks and neutral clusters.

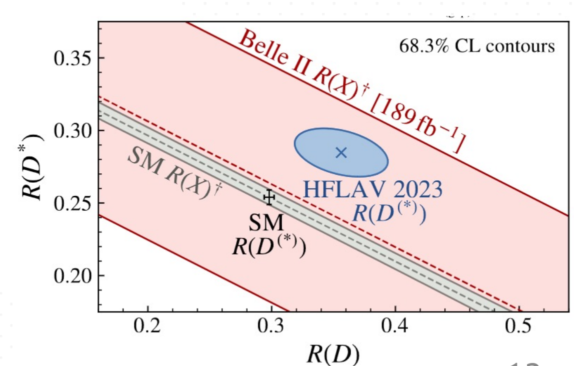
- Variables for yield extraction, 2D-fit to M^2_{miss} and p^B_ℓ



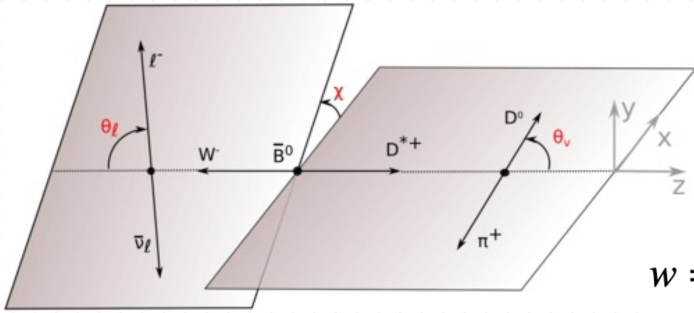
- Results:
  - $R(X_{\tau/e}) = 0.232 \pm 0.020(\text{stat.}) \pm 0.037(\text{syst.})$
  - $R(X_{\tau/\mu}) = 0.222 \pm 0.027(\text{stat.}) \pm 0.050(\text{syst.})$

- Combining:
  - $R(X_{\tau/\mu}) = 0.228 \pm 0.016(\text{stat.}) \pm 0.036(\text{syst.})$

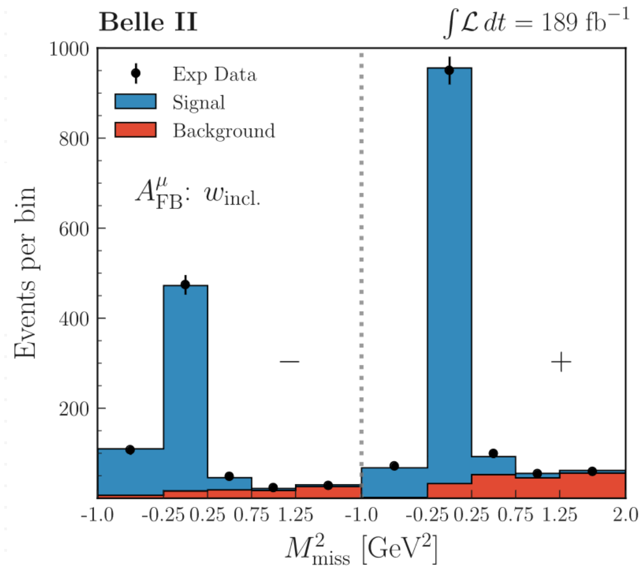
In agreement with SM prediction and $R(D^{(*)})$ measurements



Angular asymmetries using $B^0 \to D^{*-}\ell^+\nu$ arXiv:2311.07248



$$w = \frac{m_{B^0}^2 + m_{D^*}^2 - q^2}{2m_{B^0}m_{D^*}}$$



$\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell$ is parameterized by the recoil parameter (w) and three decay angles (θ_l, χ, θ_V)

Agree well with the standard-mode

$$\mathcal{A}_x(w) = \frac{N_x^+(w) - N_x^-(w)}{N_x^+(w) + N_x^-(w)}$$

$$\Delta\mathcal{A}_x(w) \equiv \mathcal{A}_x^\mu(w) - \mathcal{A}_x^e(w)$$

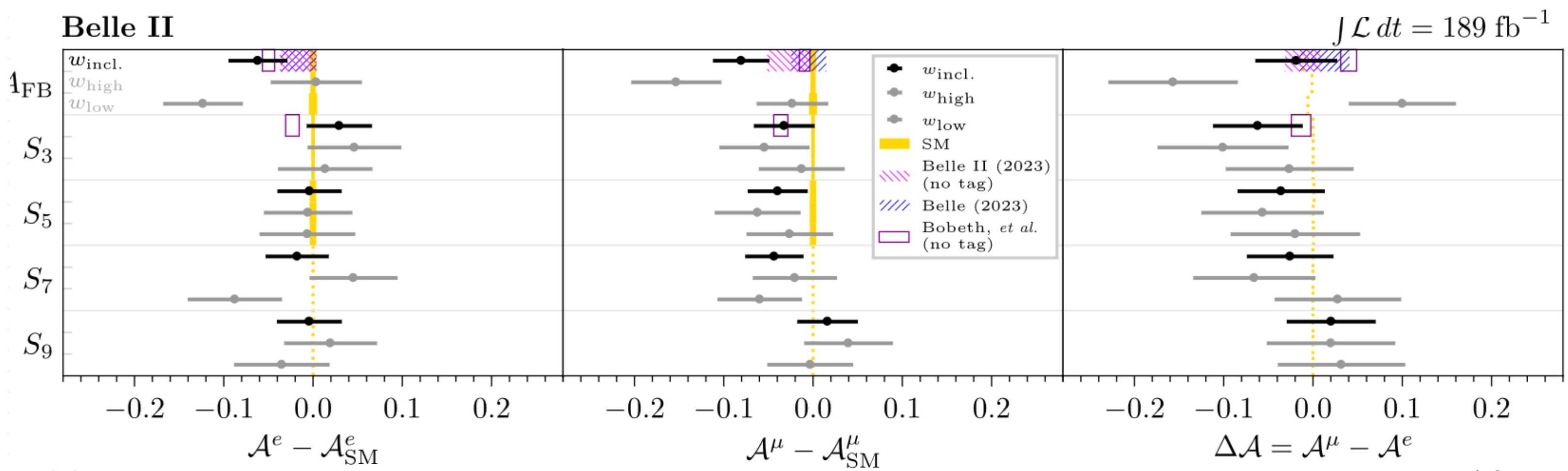
w

$\cos 2\chi$

$\cos\chi\cos\theta_V$

$\sin\chi\cos\theta_V$

$\sin 2\chi$



PRD 107 015011 (2023)

Search for $B^+ \to K^+\nu\nu$

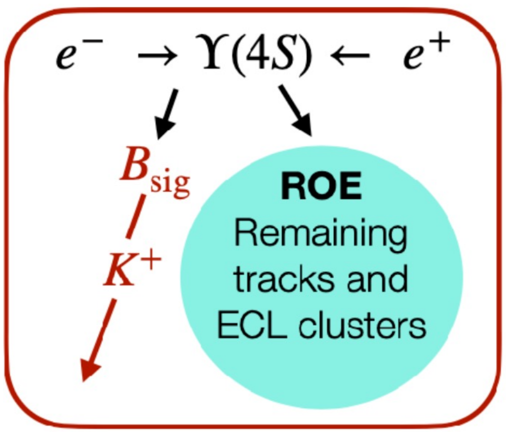
arXiv:2311.14647

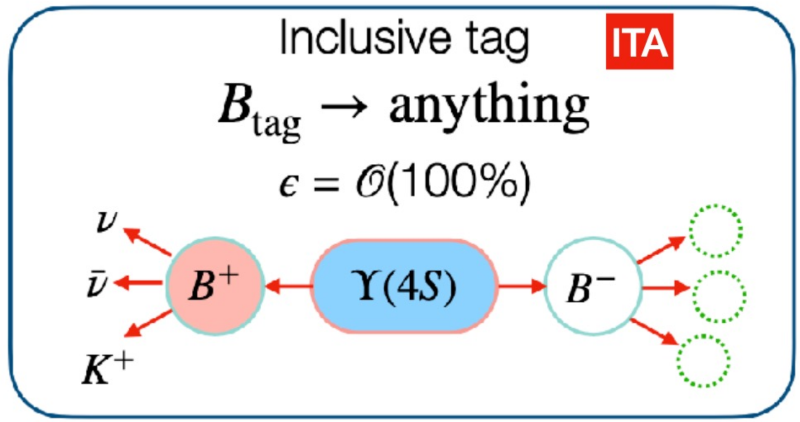
The process is known with high accuracy in the SM:

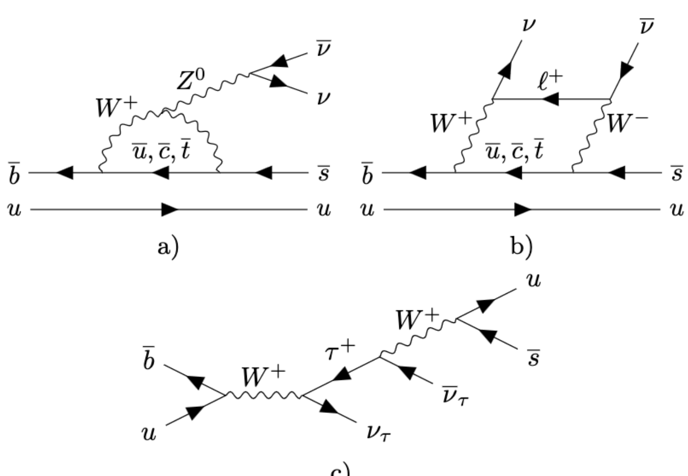
$$\mathcal{B}(B^+ \to K^+\nu\nu) = (5.6 \pm 0.4)\times 10^{-6} \text{ (arXiv:2207.13371)}$$

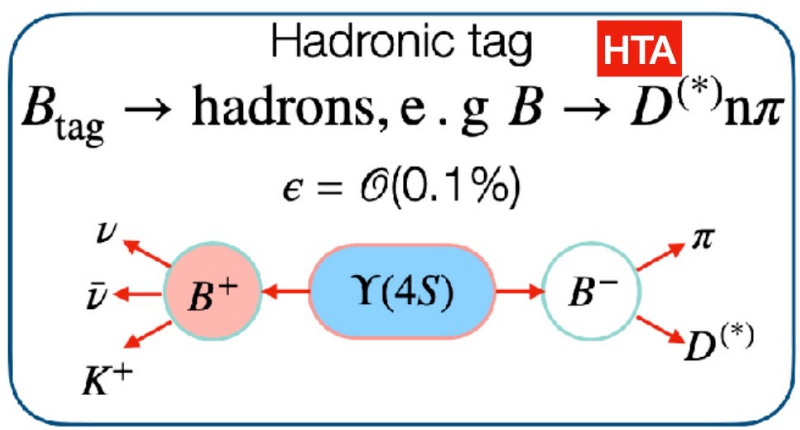
$$= 4.96\times 10^{-6} \text{ with } B^+ \to \tau^+(K^+\nu)\nu \text{ removed.}$$

Extensions beyond SM may lead to significant rate increase









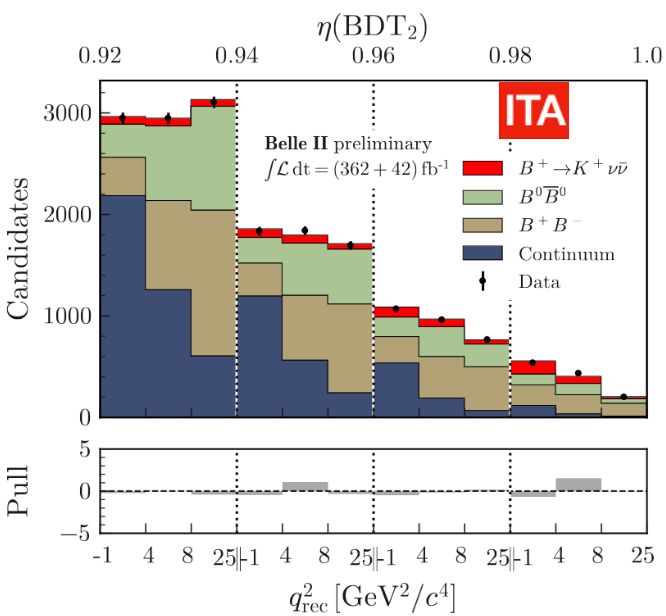
Search for $B^+ \to K^+\nu\nu$

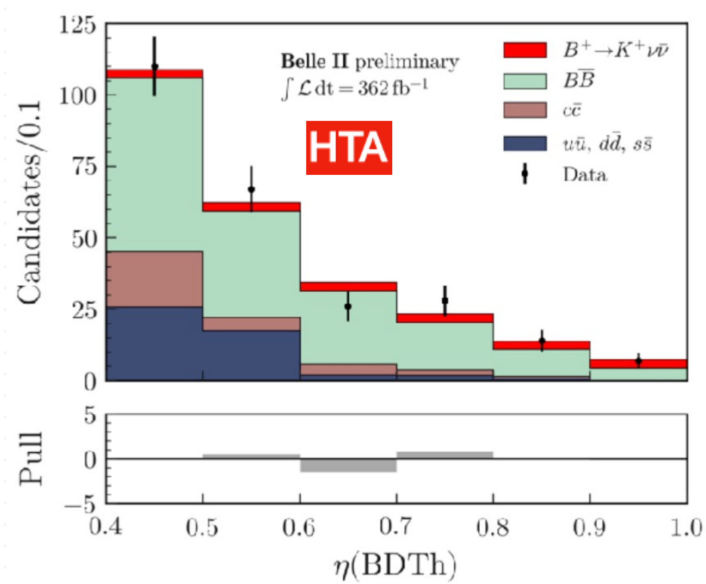
arXiv:2311.14647

- Signal is extracted in terms of signal strength μ

  signal relative to SM expectation

  - Inclusive tag: $\mu = 5.4 \pm 1.0(\text{stat}) \pm 1.1(\text{syst})$ $\mathscr{B} = 2.7 \pm 0.5(\text{stat}) \pm 0.5(\text{syst})$
  - Hadronic tag: $\mu = 2.2^{+1.8}_{-1.7}(\text{stat})^{+1.6}_{-1.1}(\text{syst})$ $\mathscr{B} = 1.1^{+0.9}_{-0.8}(\text{stat})^{+0.8}_{-0.5}(\text{syst})$
  - Combined: $\mu = 4.6 \pm 1.0(\text{stat}) \pm 0.9(\text{syst})$ $\mathscr{B} = 2.3 \pm 0.5(\text{stat})^{+0.5}_{-0.4}(\text{syst})$





Search for $B^+ \to K^+ \nu\nu$

arXiv:2311.14647

For the inclusive tag, significance of the result

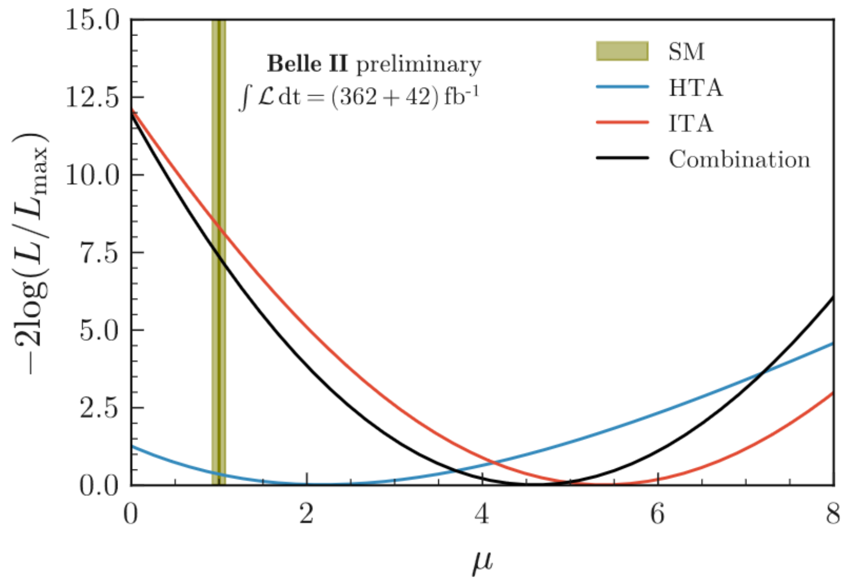
- wrt null hypothesis is 3.5σ
- wrt SM is 2.9σ

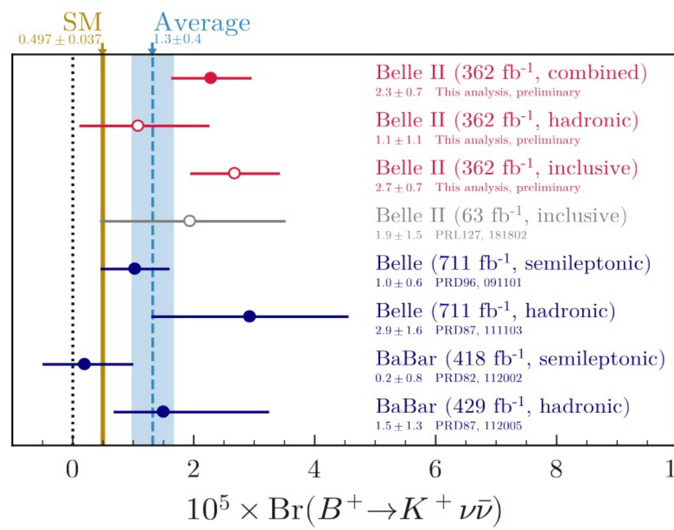
For the hadronic tag, significance of the result

- wrt null hypothesis is 1.1σ
- wrt SM is 0.6σ

For the combination, significance of the result

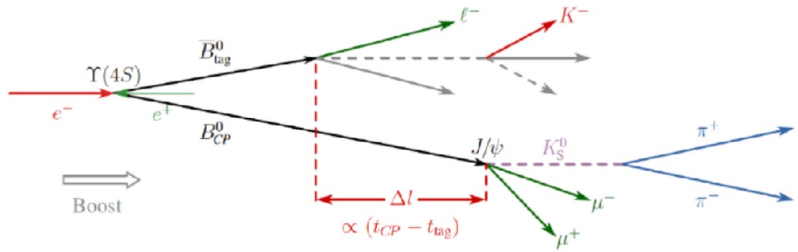
- wrt null hypothesis is 3.5σ
- wrt SM is 2.7σ





First evidence for $B^+ \to K^+ \nu\nu$ decay

Measurements of $sin2\phi_1$



- Sensitive to BSM physics

- Fit Δt to extract S_{CP} and C_{CP}:

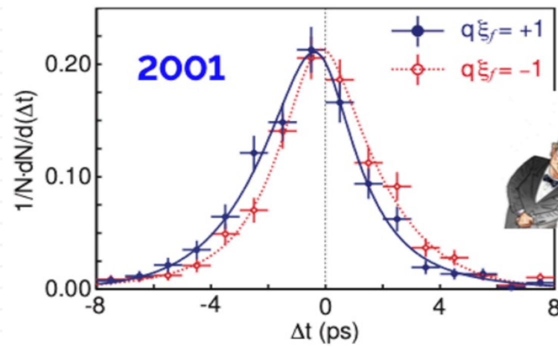
$$f_{CP}^{\text{true}} = \frac{1}{4\tau_B^0} e^{-|\Delta t|/\tau_B^0}(1 + q[S_{CP}\sin(\Delta m \Delta t) - C_{CP}\cos(\Delta m \Delta t)])$$

- SM expectation: $S_{CP} = \sin 2\phi_1$, and $C_{CP} = 0$

- Deviation from $\sin 2\phi_1$would suggest BSM physics

$sin2\phi_1 = 0.99 \pm 0.14 \pm 0.06$

PRL 87, 091802 (2001)



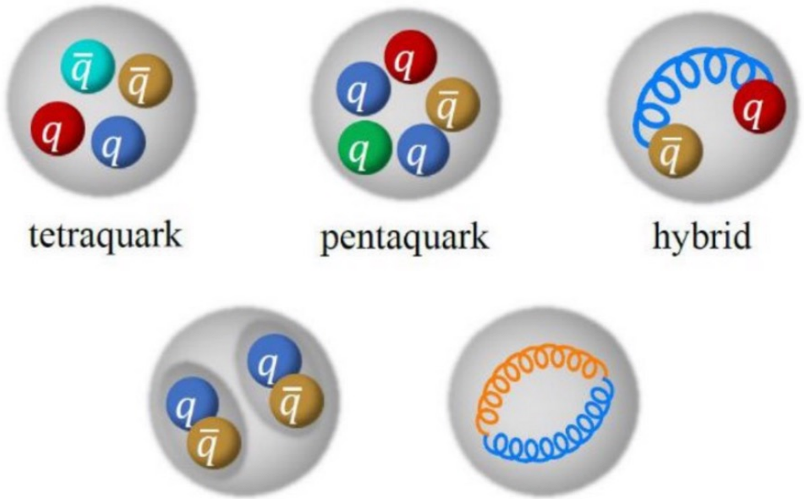
channel	S_meas	C_meas	
$B^0 \to K_S^0 J/\psi$	$0.724 \pm 0.035 \pm 0.014$	$-0.035 \pm 0.026 \pm 0.012$	preliminary
$B^0 \to K_S^0 \pi^0 \gamma$	$0.04^{+0.45}_{-0.44} \pm 0.10$	$-0.06 \pm 0.25 \pm 0.07$	preliminary
$B^0 \to \eta' K_S^0$	$0.67 \pm 0.10 \pm 0.04$	$-0.19 \pm 0.08 \pm 0.03$	preliminary
$B^0 \to \pi^0 K_S^0$	$0.75^{+0.20}_{-0.23} \pm 0.04$	$-0.04^{+0.14}_{-0.15} \pm 0.05$	PRL 131, 111803 (2023)
$B^0 \to \phi K_S^0$	$0.54 \pm 0.26^{+0.06}_{-0.08}$	$-0.31 \pm 0.20 \pm 0.05$	PRD 108, 072012 (2023)

Quarkonium & Exotic states

What are they?

Bottomonium?

Or:



tetraquark pentaquark hybrid

hadronic molecule glueball

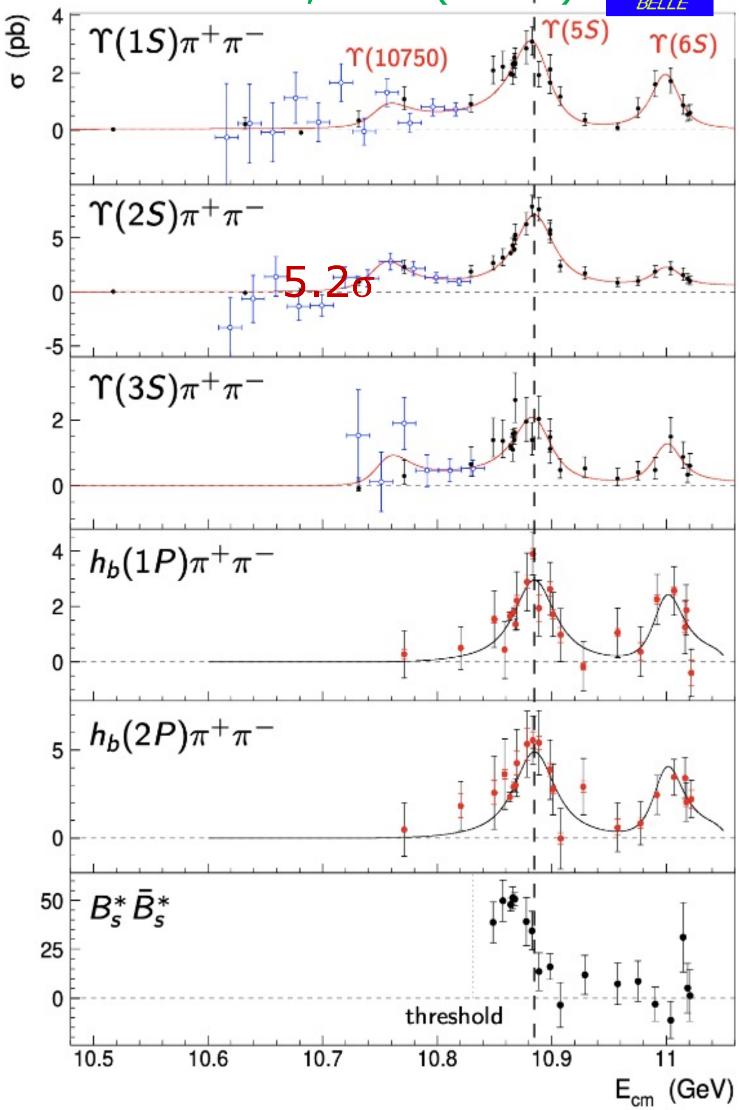
Bottom:

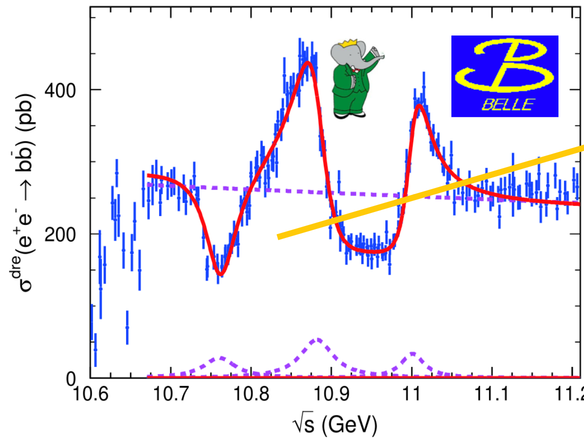
- $e^+e^- \to \omega\chi_{bJ}$ and $X_b \to \omega\Upsilon(1S)$
- $e^+e^- \to \omega\eta_b(1S)$
- $e^+e^- \to \pi\pi\Upsilon(nS)$
- $e^+e^- \to B^{(*)}\bar{B}^{(*)}$
- $e^+e^- \to B_s^0\bar{B}_s^0X$

$\Upsilon(10750)$ state

observed in $e^+e^- \to \pi^+\pi^-\Upsilon(nS)$

JHEP 10, 220 (2019)

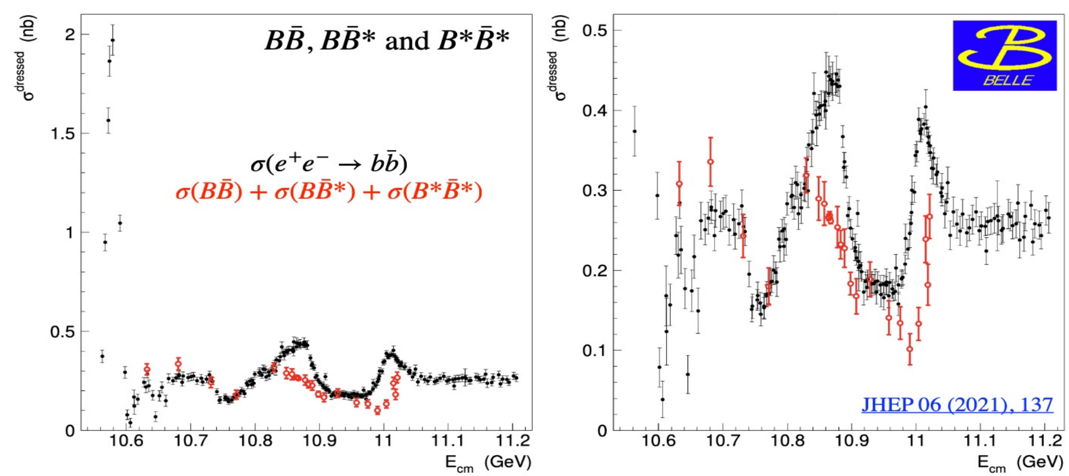




CPC 44 (2020) 8, 083001

A dip at 10.75 GeV may correspond to $\Upsilon(10753)$.

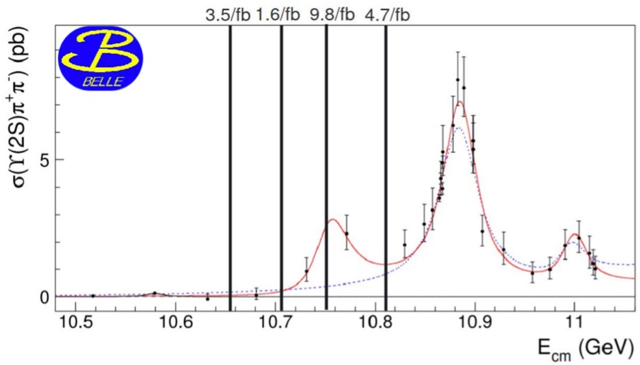
The individual cross sections contain more information than sum

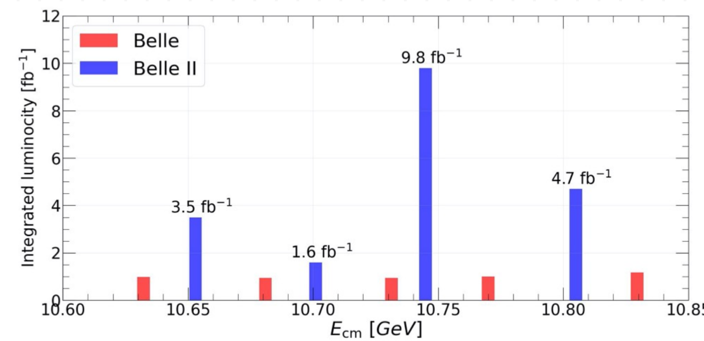


$\Upsilon(10753) \to \omega\chi_{bJ}$ and $X_b \to \omega\Upsilon(1S)$ PRL 130, 091902 (2023)

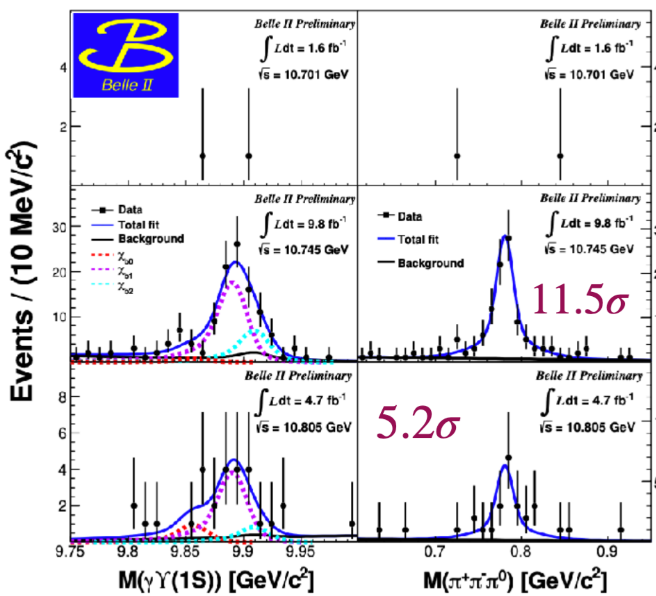
Theory: $\mathcal{B}(\Upsilon(10753) \to \omega\chi_{bJ})$ and $\mathcal{B}(\Upsilon(10753) \to \pi^+\pi^-\Upsilon(nS))$ are $\sim 10^{-3}$

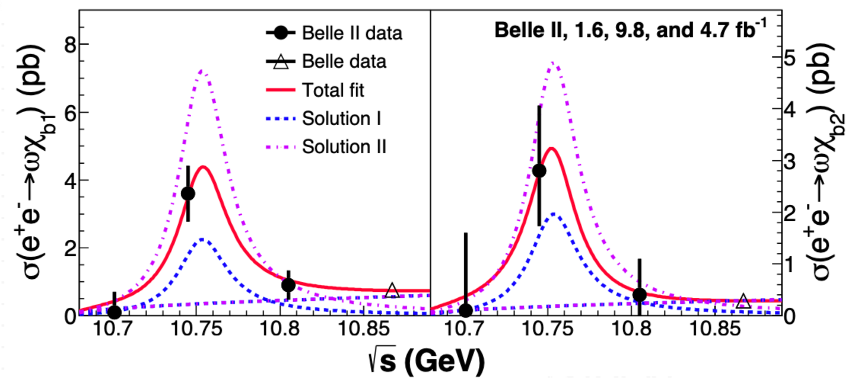
if Υ(10753) is Υ(4S) - Υ(3D) mixing state [PRD 104, 034036] [PRD 105, 074007]





Clear $\omega\chi_{bJ}$ signals at $\sqrt{s} = 10.745$ and 10.805 GeV



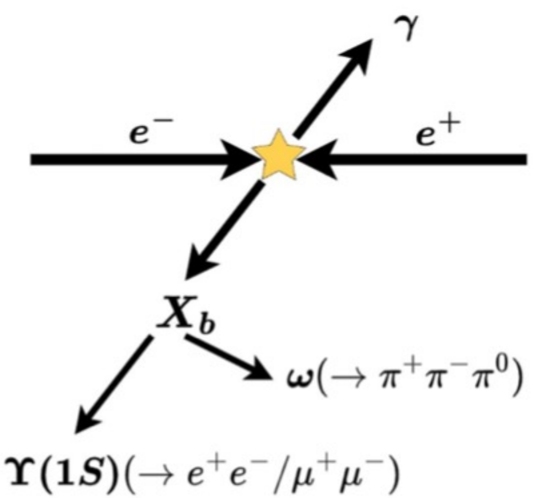


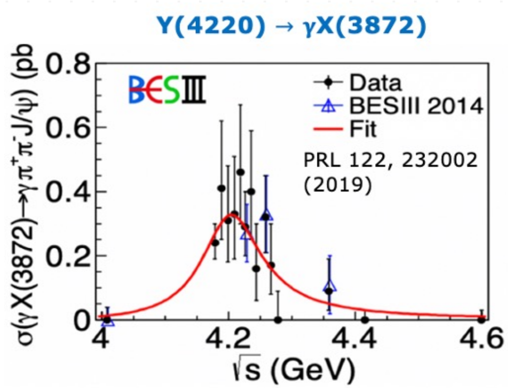
$$\frac{\sigma(e^+e^-\to\chi_{b1}\omega)}{\sigma(e^+e^-\to\chi_{b2}\omega)} \sim 1\text{: consistent with HQFT}$$

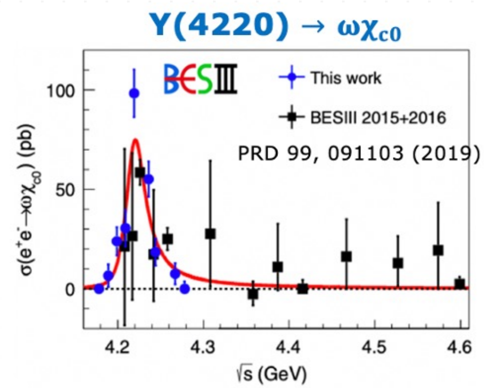
$$\frac{\sigma(e^+e^-\to\chi_{b1}\omega)}{\sigma(e^+e^-\to\pi\pi\Upsilon(2S))} \begin{cases} \sim 1.5 \ @\Upsilon(10753) \\ \sim 0.1 \quad @\Upsilon(5S) \end{cases}:$$

difference in the internal structures Υ(5S) and Υ(10753)

$\Upsilon(10753) \to \omega\chi_{bJ}$ and $X_b \to \omega\Upsilon(1S)$ PRL 130, 091902 (2023)

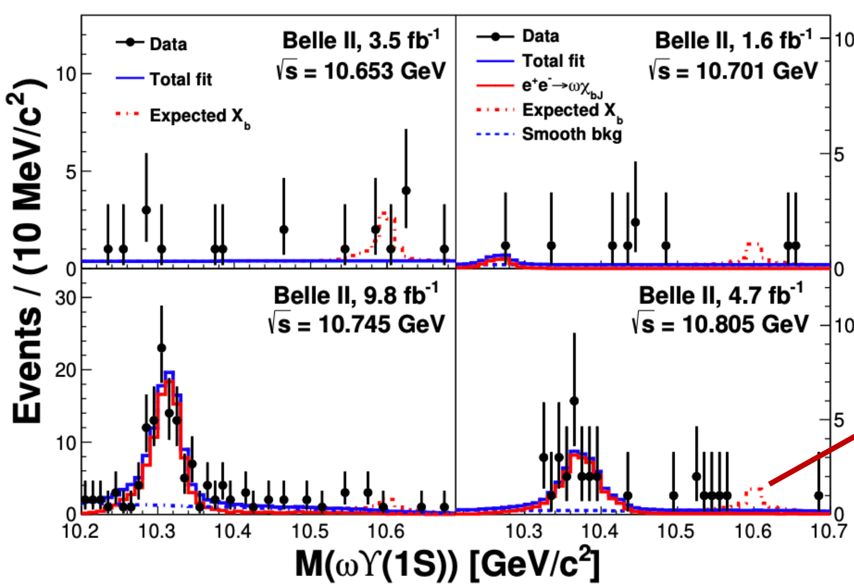






Y(4220) → $\gamma X(3872)$ and $\omega\chi_{c0}$ observed by BESIII.

So we expect the observations of $\Upsilon(10753) \to \gamma X_b$ and $\omega\chi_{bJ}$.



- **No significant X_b signal is observed.**
- The peaks are the reflections of $e^+e^- \to \omega\chi_{bJ}$.

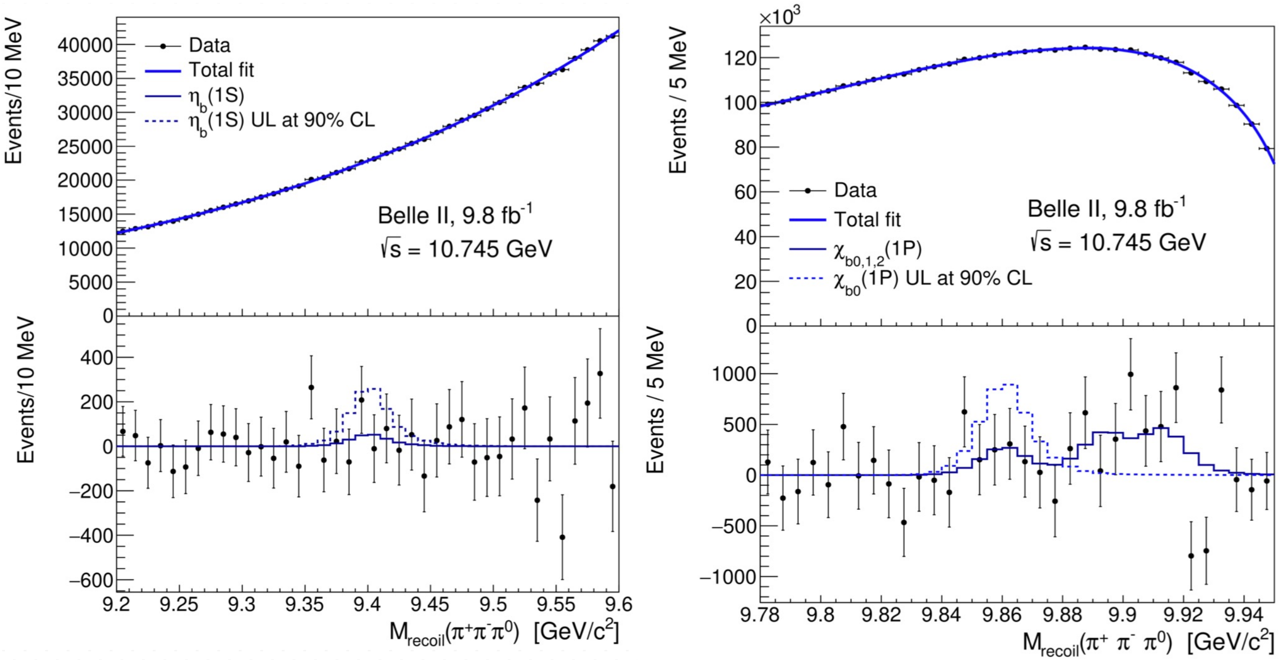
From simulated events with $m(X_b)$ = 10.6 GeV/c^2
The yield is fixed at the upper limit at 90% C.L.

Search for $e^+e^- \to \omega\eta_b(1S)$ and $e^+e^- \to \omega\chi_{b0}(1P)$ preliminary

- Tetraquark (diquark-antidiquark) interpretation
  enhancement of $\Upsilon(10753) \to \omega\eta_b(1S)$ transition

$$\frac{\Gamma(\eta_b\ \omega)}{\Gamma(\Upsilon\ \pi^+\pi^-)} \sim 30$$

[Chin. Phys. C 43, 123102 (2019)].



Recoiling the ω

The yields for $\chi_{b1}(1P)$ and $\chi_{b2}(1P)$ are fixed [PRL 130, 091902 (2023)].

Tetraquark model in Ref. [CPC 43, 123102]:

$$\Gamma(\Upsilon(10753) \to \eta_b(1S)\omega) = 2.64^{+4.70}_{-1.69}\ \text{MeV}$$
$$\Gamma(\Upsilon(10753) \to \Upsilon\pi^+\pi^-) = 0.08^{+0.20}_{-0.06}\ \text{MeV}$$

This measurement and JHEP 10, 220 (2019):

$$\sigma^B(\Upsilon(10753) \to \eta_b(1S)\omega) < 2.5\ \text{pb}$$
$$\sigma^B(\Upsilon(10753) \to \Upsilon(2S)\pi^+\pi^-) \approx (3 \pm 1)\ \text{pb}$$

No clear $\eta_b(1S)$ and $\chi_{b0}(1P)$ signals are observed.
not support the prediction

Update of the cross section of $e^+e^- \to \pi\pi\Upsilon(nS)$

preliminary

Fit with three coherent BW, convoluting a Gaussian modeling energy spread:

$$\sigma \propto \left|\sum_i^3 \frac{\sqrt{12\pi\Gamma_i\mathcal{B}_i}}{s - M_i + iM_i\Gamma_i} \cdot \sqrt{\frac{f(\sqrt{s})}{f(M_i)}} e^{i\phi_i}\right|^2 \otimes G(0, \delta E)$$

All parameters are free, except $\delta E = 0.0056$ GeV

Parameters of $\Upsilon(10753)$:

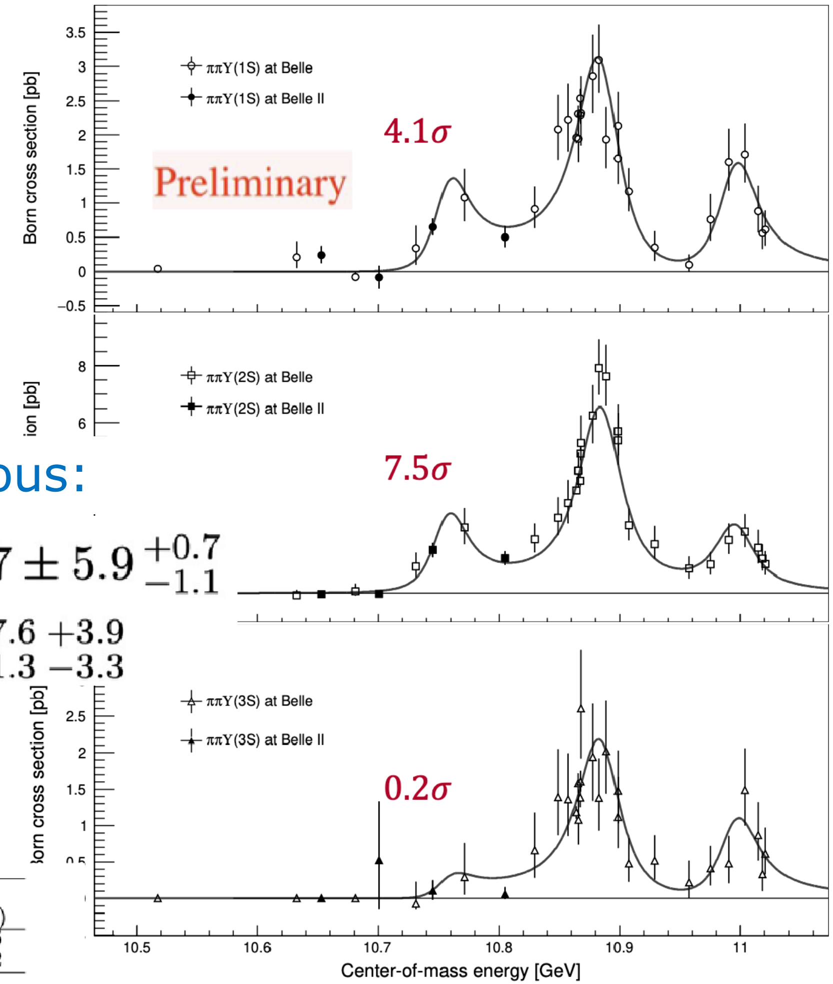
$M = 10756.3 \pm 2.7_{(stat.)} \pm 0.6_{(syst.)}\,\mathrm{MeV}/c^2$

$\Gamma = 29.7 \pm 8.5_{(stat.)} \pm 1.1_{(syst.)}\,\mathrm{MeV}$

Previous:

$10752.7 \pm 5.9^{+0.7}_{-1.1}$

$35.5^{+17.6}_{-11.3}{}^{+3.9}_{-3.3}$

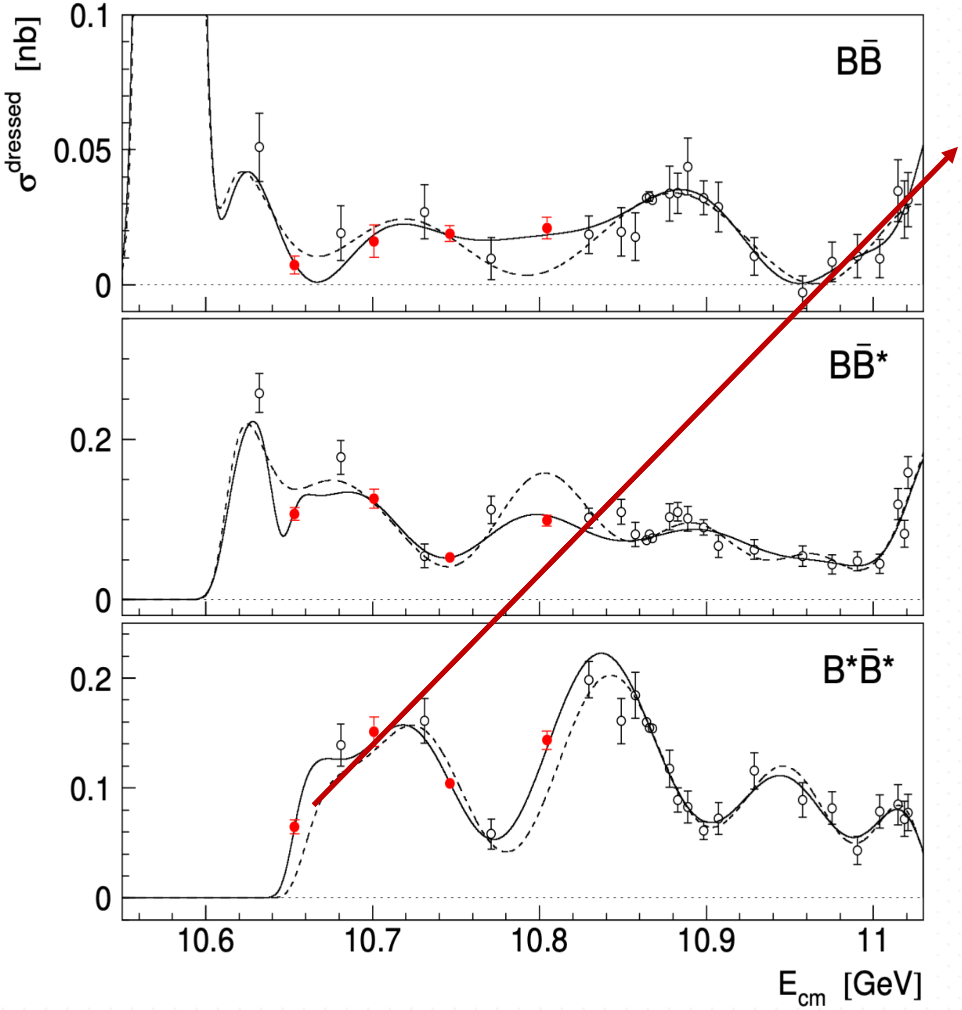


Relative ratios of cross section at different resonance peaks

	$\mathcal{R}^{\Upsilon(10753)}_{\sigma(1S/2S)}$	$\mathcal{R}^{\Upsilon(10753)}_{\sigma(3S/2S)}$	$\mathcal{R}^{\Upsilon(5S)}_{\sigma(1S/2S)}$	$\mathcal{R}^{\Upsilon(5S)}_{\sigma(3S/2S)}$	$\mathcal{R}^{\Upsilon(6S)}_{\sigma(1S/2S)}$	$\mathcal{R}^{\Upsilon(6S)}_{\sigma(3S/2S)}$
Ratios	$0.46^{+0.15}_{-0.12}$	$0.10^{+0.05}_{-0.04}$	$0.45^{+0.04}_{-0.04}$	$0.32^{+0.04}_{-0.03}$	$0.64^{+0.23}_{-0.13}$	$0.41^{+0.16}_{-0.12}$

The $e^+e^- \to B\bar{B}$, $B\bar{B}^*$ and $B^*\bar{B}^*$ cross sections

preliminary



Solid curve: fit to Belle + Belle II data
Dashed curve: fit to Belle data fit only

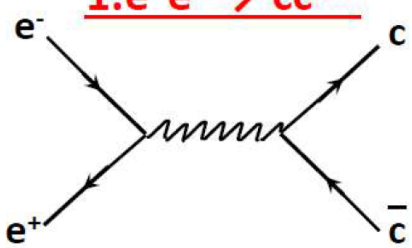
New: rapid increase of $\sigma_{B^*\bar{B}^*}$ above the threshold

- Similar behaviour was seen for $D^*\bar{D}^*$ cross section (PRD 97, 012002 (2018))
- Possible interpretation: resonance or bound state ($B^*\bar{B}^*$ or $b\bar{b}$) near threshold (MPL A 21, 2779 (2006))
- Also explains a narrow dip in $\sigma(e^+e^- \to B\bar{B}^*)$ near $B^*\bar{B}^*$ threshold by destructive interference between $e^+e^- \to B\bar{B}^*$ and $e^+e^- \to B^*\bar{B}^* \to B\bar{B}^*$
- Inelastic channels [$\pi^+\pi^-\Upsilon(nS)$ and $h_b(1P)\eta$] could also be enhanced (PRD 87, 094033 (2013))

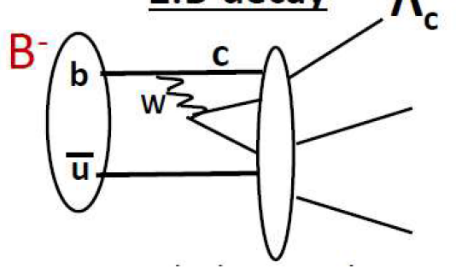
Normal Charm

Charmed Baryon: new states;
parameters;
decays..

1.$e^+e^- \rightarrow c c^{bar}$



2.B-decay



Baryons produced via fragmentation

- Charmed baryons – rather direct
- Hyperons – later stage of fragmentation

Huge statistics

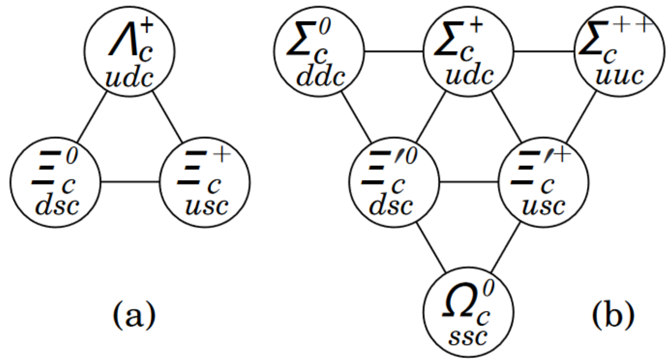
B is efficiently produced via $\Upsilon(4s)$

Once bottom is produced, it favorably decays into charm.

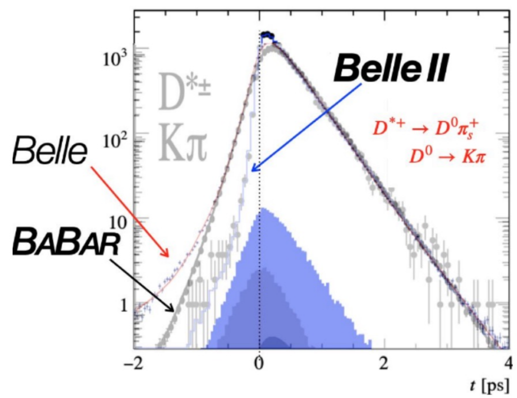
Analysis of heavy baryon lifetimes

4:50 PM - 5:10 PM
信业悦你酒店 (上海)
上海市嘉定区环城路762弄3号

Presenter Hai-Yang Cheng

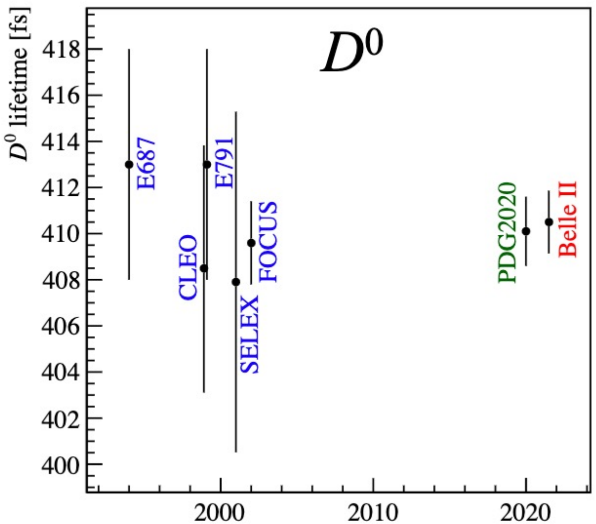


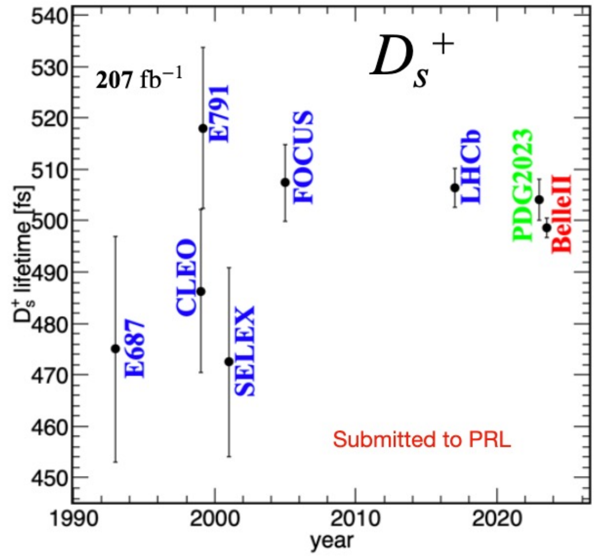
Charm mesons: lifetimes
good vertex

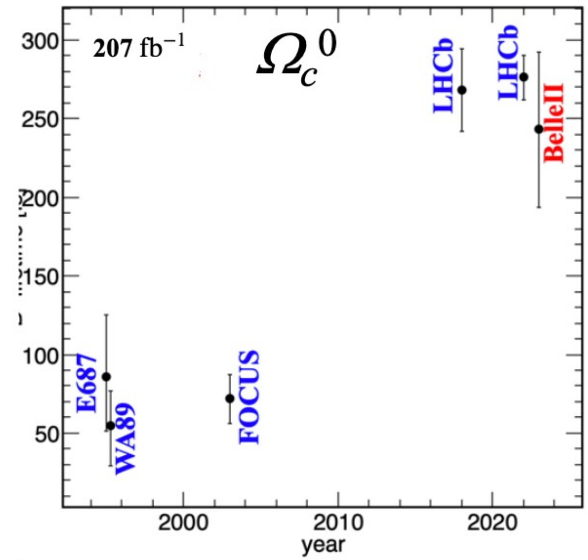


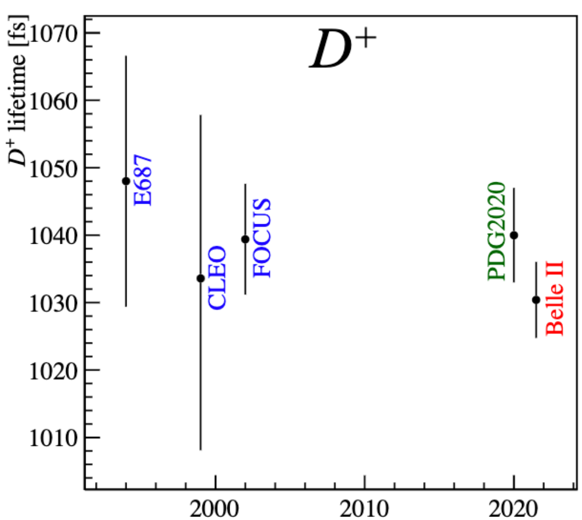
Belle II

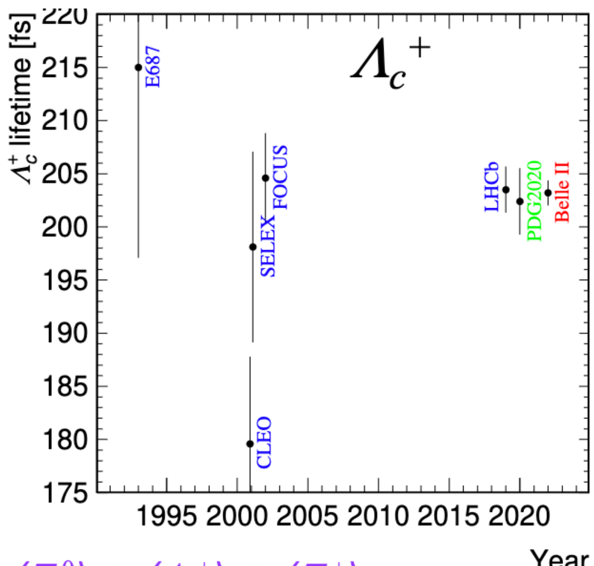
Lifetime measurements











In all cases except for Ω_c^0, Belle II has made the world's highest precision measurement

Theory expectation: $\tau(\Omega_c) < \tau(\Xi_c^0) < \tau(\Lambda_c^+) < \tau(\Xi_c^+)$

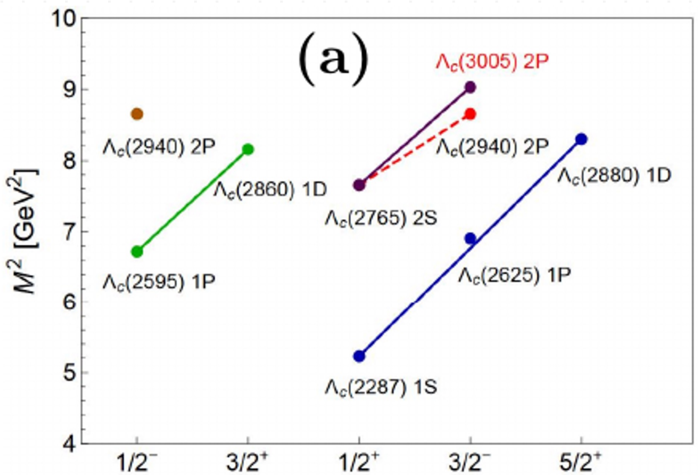
(& E687, WA89)

LHCb measurement: $\tau(\Xi_c^0) < \tau(\Lambda_c^+) < \tau(\Omega_c) < \tau(\Xi_c^+)$

(2018, 2022)

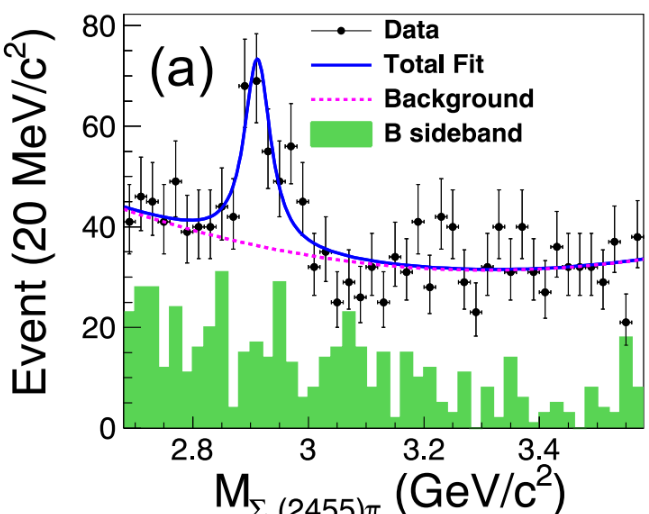
Evidence of $\Lambda_c(2910)^+$

PRL 130, 031901 (2023)



Theoretical interpretation:

- $\Lambda_c(2940)$: $J^P = \frac{1}{2}^-$ state, lies in other Regge trajectories
  - ➢ search for $\Lambda_c(3005)$?
- Like $\Lambda(1405), D_s(2317), X(3872)$, D^*N contribute in $\Lambda_c(2940)$
  - ➢Mass of $\Lambda_c\left(\frac{1}{2}^-, 2P\right)$ invese, and larger than $\Lambda_c\left(\frac{3}{2}^-, 2P\right)$



- **A new structure in $M_{\Sigma_c\pi}$ spectrum is seen**

$$m = (2913.8 \pm 5.6 + 3.7)\ \mathrm{MeV/c^2}$$
$$\Gamma = (51.8 \pm 20.0 \pm 18.8)\ \mathrm{MeV}$$

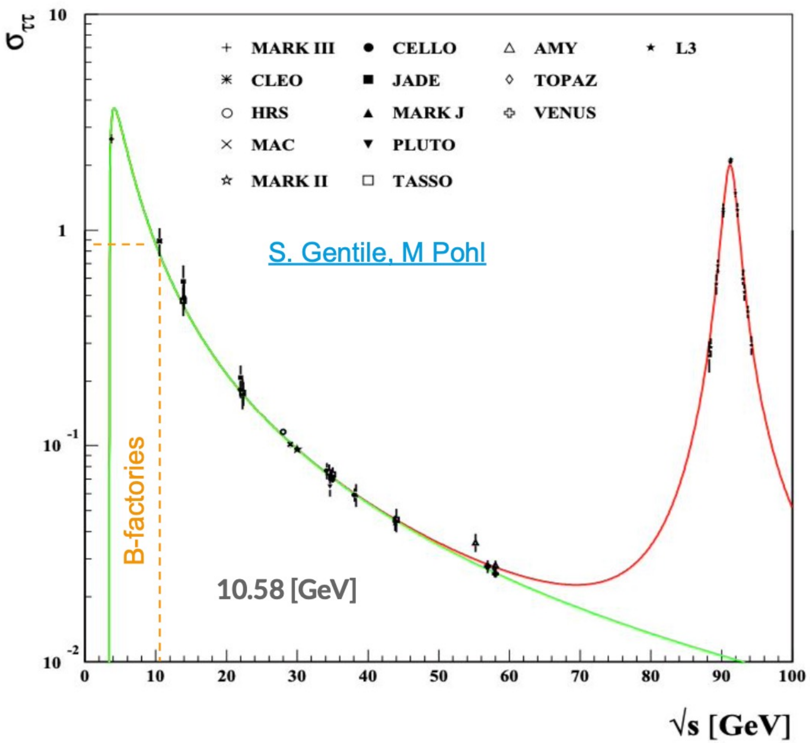
- Statistic significance: 6.1σ
- most conservative significance include syst. err: 4.2σ
- Possible $J^P = \frac{1}{2}^-$, agrees with $\Lambda_c\left(\frac{1}{2}^-, 2P\right)$
- Need more study to confirm its nature

See talk from 岳自力 tomorrow

17:10—17:30 Strong decays of the $\Lambda_c(2910)$ and $\Lambda_c(2940)$ in $D^{(*)}N$ molecular picture 岳自力

τ physics

$\sigma(e^+e^- \rightarrow \tau^+\tau^-)$



@10.58 GeV:

$$\sigma(e^+e^- \rightarrow \tau^+\tau^-) = 0.92\,nb$$

$$\sigma(e^+e^- \rightarrow \Upsilon(4S)) = 1.11\,nb$$

Features of a B-Factory (super τ-charm Factory):

- High luminosity.
- Well-defined initial state.
- High vertex resolution.
- Excellent calorimetry.
- Sophisticated particle ID.
- Ability to trigger low-multiplicity event

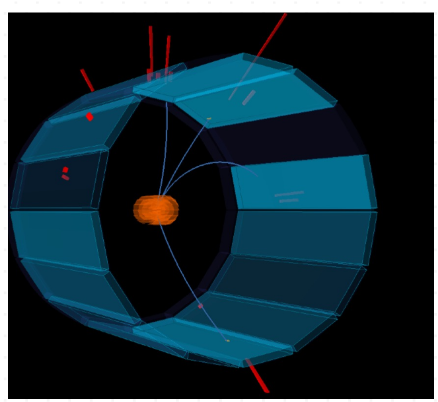
tau physics at Belle II

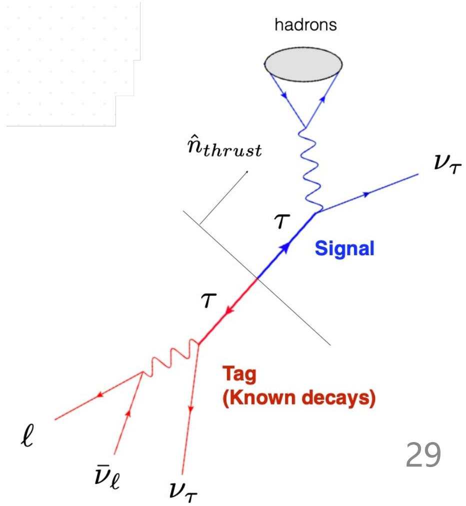
4:30 PM - 4:50 PM

嘉定喜来登酒店 (上海)

上海市嘉定区菊园新区嘉唐公路66号

Presenter Chunhua Li





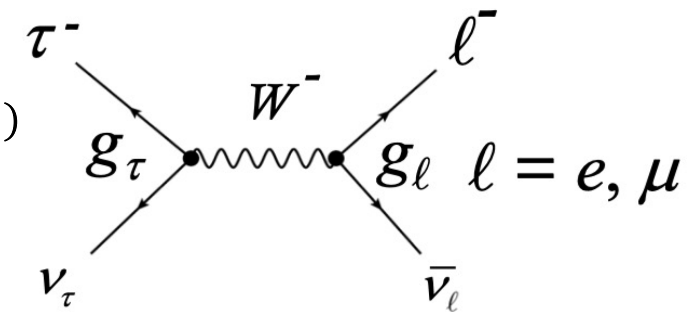
τ physics

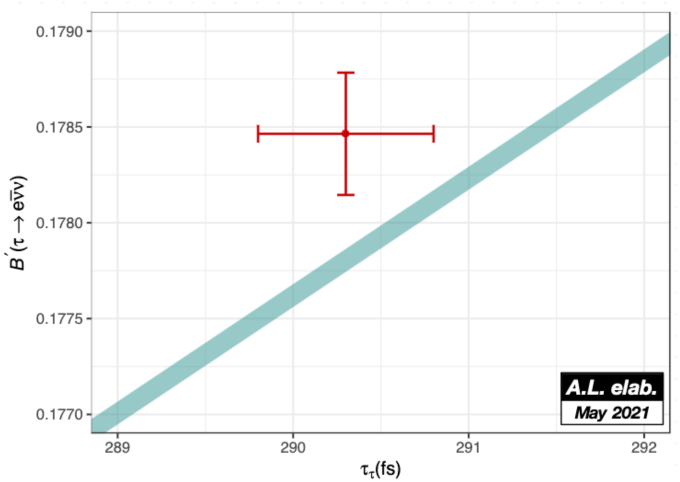
$$\Gamma\left(L^- \to \ell^- \,\bar{\nu}_\ell\, \nu_L(\gamma)\right) = \frac{\mathcal{B}(L^- \to \ell^- \,\bar{\nu}_\ell\, \nu_L(\gamma))}{\tau_L} = \frac{g_L^2 g_\ell^2}{32 M_W^4} \frac{m_L^5}{192\pi^3} f\left(\frac{m_\ell^2}{m_L^2}\right) F_{corr}\,(m_L, M_\ell)$$

$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln(x)$$

$$F_{corr}\,(m_L, M_\ell) = f\left(\frac{m_\ell}{m_L}\right)\left(1 + \frac{3m_\ell^2}{5M_W^2}\right)\left(1 + \frac{\alpha(m_L)}{2\pi}\left(\frac{25}{4} - \pi^2\right)\right)$$

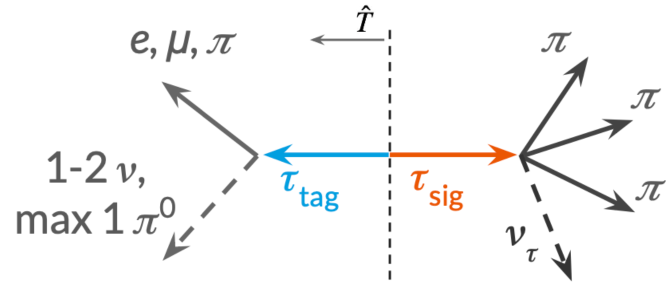
W. Marciano and A. Sirlin PRL. **61, 1815 (1988)**





input	Uncertainty (%)	Best Measurement
$\mathcal{B}(\tau^- \to \ell^- \,\bar{\nu}_\ell\, \nu_\tau(\gamma))$	0.180	ALEPH
τ_τ	0.172	Belle
m_τ	0.007	BES III

Measurement of τ mass



Pseudomass method:

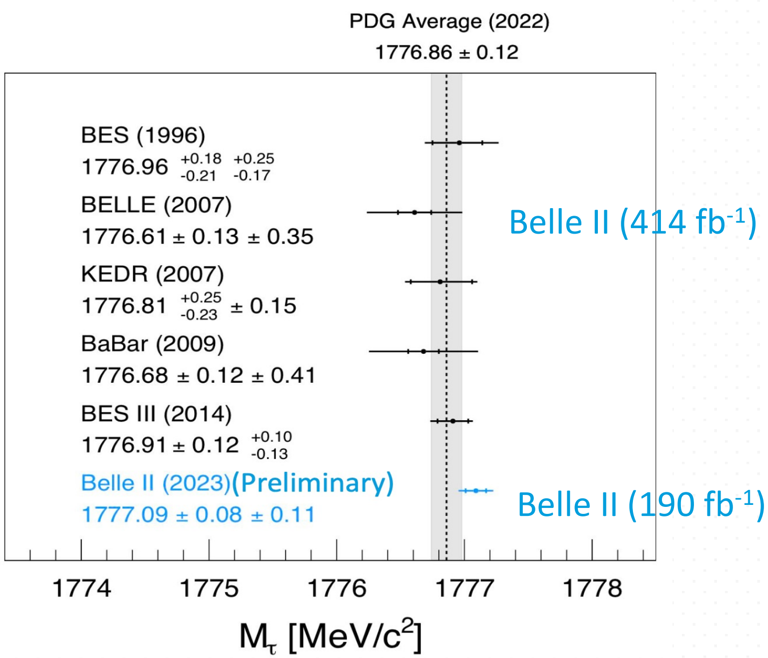
$$m_\tau^2 = (p_h + p_\nu)^2$$

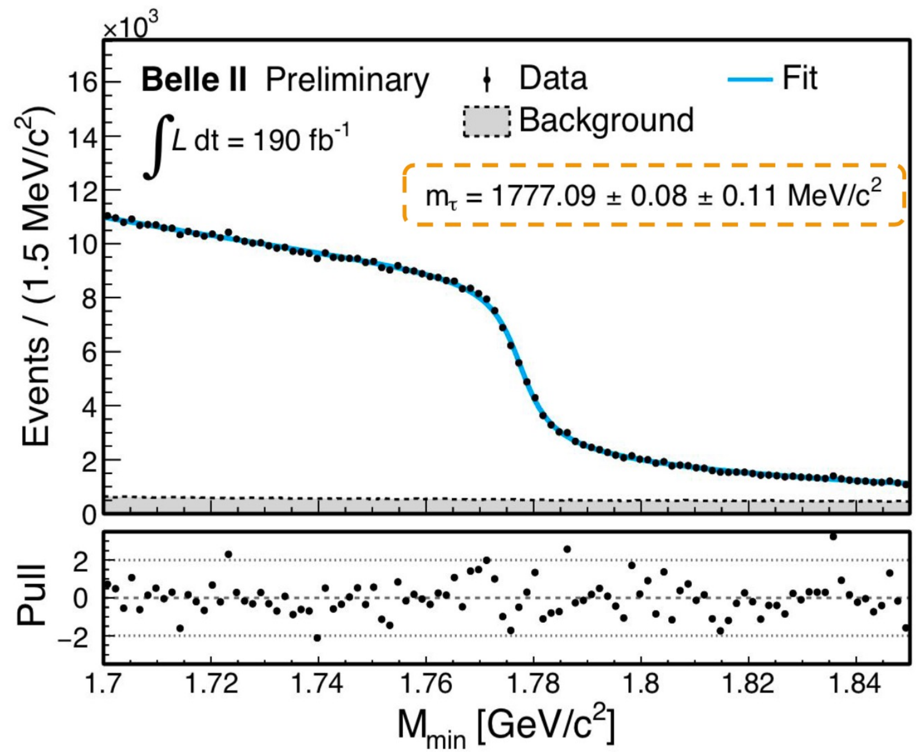
$$= 2\,E_h\,(E_\tau - E_h) + m_h^2 - 2|\vec{p}_h|(E_\tau - E_h)\cos(\vec{p}_h, \vec{p}_\nu)$$

PRD 108, 032006 (2023)

The direction of the neutrino is not known, since $\cos(\vec{p}_h, \vec{p}_\nu) \leq 1$ **Pseudomass:**

$$\sqrt{2\,E_h\,(E_\tau - E_h) + m_h^2 - 2|\vec{p}_h|(E_\tau - E_h)} \leq m_\tau$$





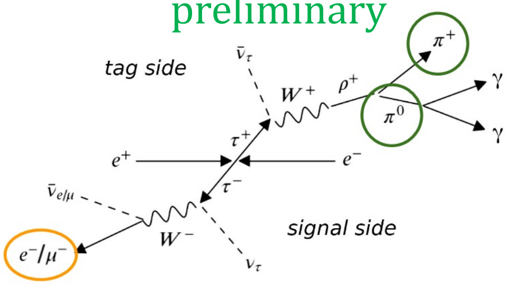
World's best measurement of the τ mass!

Lepton Flavor Universality Violation

preliminary

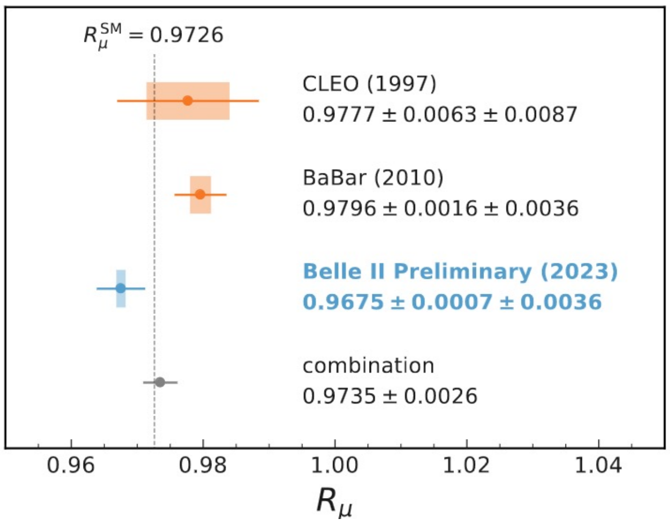
$$\left(\frac{g_\mu}{g_e}\right)_\tau = \sqrt{\frac{BF\left[\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau\right]}{BF\left[\tau^- \to e^- \bar{\nu}_e \nu_\tau\right]} \frac{f\left(m_e^2/m_\tau^2\right)}{f\left(m_\mu^2/m_\tau^2\right)}}$$

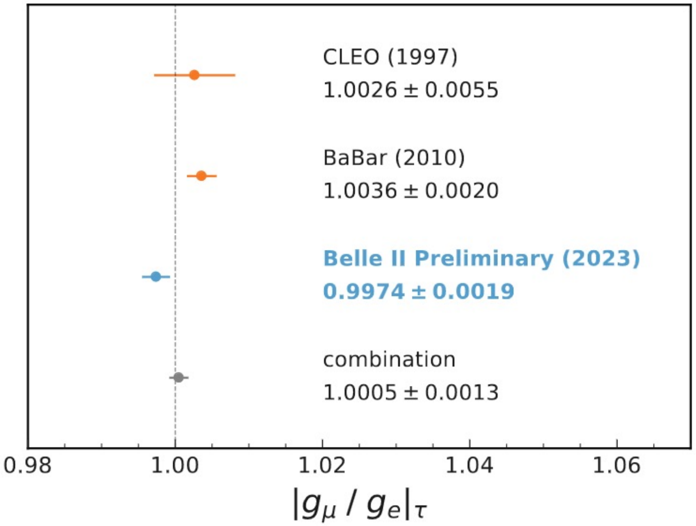
In the SM: $\left(\frac{g_\mu}{g_e}\right)_\tau = 1$



Tag side: 1 hadron prong

362 fb^{-1} date @ 10.58 GeV





$$R_\mu = \frac{\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau)} = 0.9675 \pm 0.0007 \pm 0.0036$$

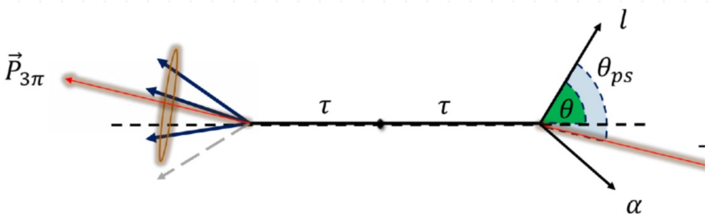
- Pid uncertainty dominant
- consistent with previous measurements
- **most precise to date**

Source	Uncertainty [%]
Charged-particle identification:	
Electron identification	0.22
Muon misidentification	0.19
Electron misidentification	0.12
Muon identification	0.05
Trigger	0.10

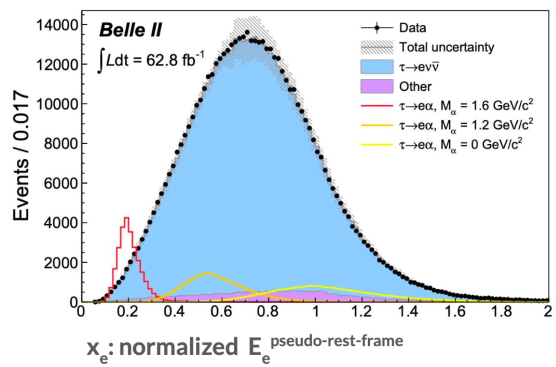
$\tau^- \to \ell^- \alpha$

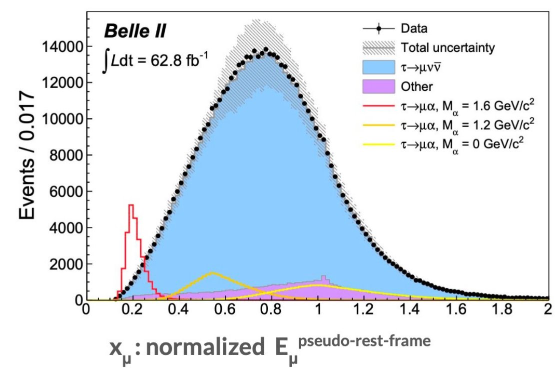
It probes the existence of a **long-lived invisible gauge boson boson** α.

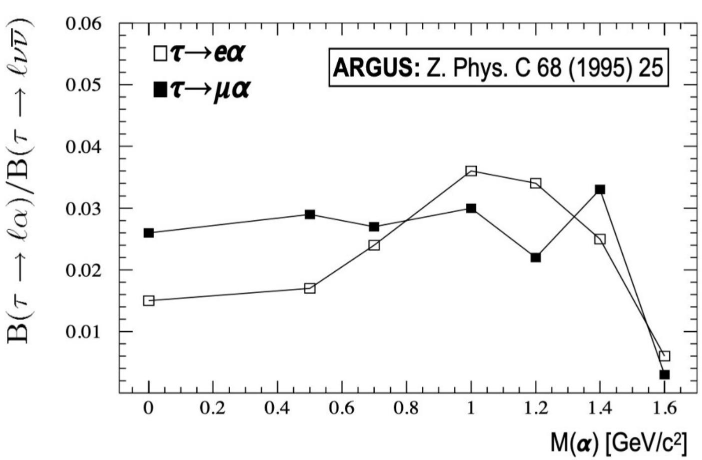
- Possible DM candidate.

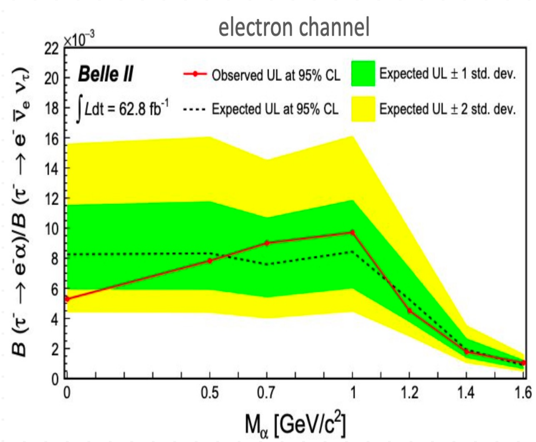


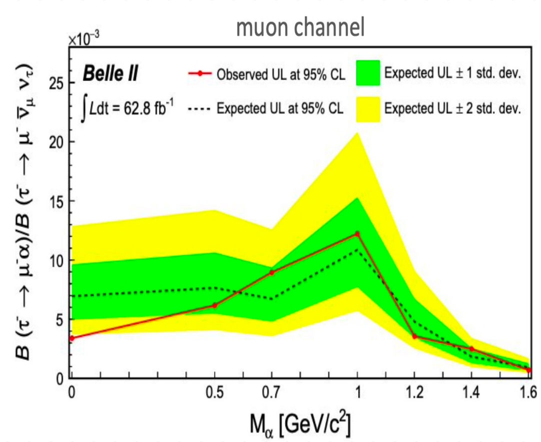
$$E_\tau = E_{\mathrm{cms}}/2, \quad \hat{p}_\tau \approx \overrightarrow{p}_{\mathrm{tag}}/|\overrightarrow{p}_{\mathrm{tag}}|$$











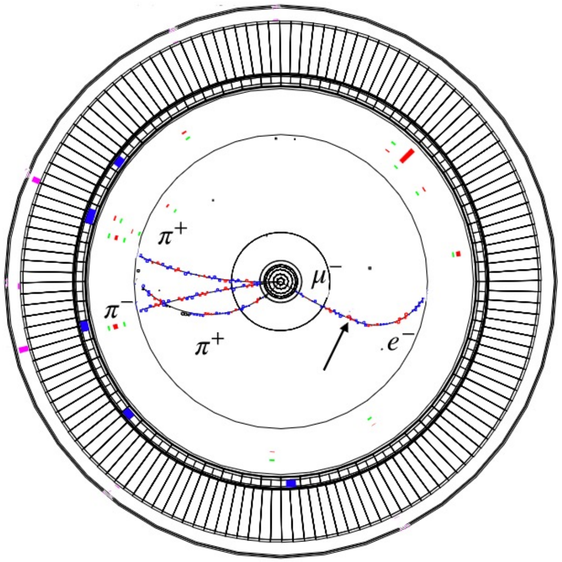
Most stringent limits in these channels to date!
(2-14 times more constraining than Argus)

PRL 130, 181803 (2023)

Michel Parameter ξ' via $\tau \to \mu(\to e\,\nu\nu)\,\nu\nu$

$$\frac{d^3\Gamma}{dx\,dy\,d\cos\theta'_e} = \mathcal{B}(\mu \to e\nu\nu)\frac{12\Gamma_{\tau\to\mu\nu\nu}}{1-3x_0^2}y^2\sqrt{x^2-x_0^2}\,\Big[(3-2y)(3x-2x^2-x_0^2)$$

$$+\xi'(2y-1)\sqrt{x^2-x_0^2}\left(2x-3+\frac{x_0^2}{2}\right)\cos\theta'_e\Big].$$



$$\sum_{\varepsilon,\omega=L,R}\left(\frac{1}{4}|g^S_{\varepsilon\omega}|^2+|g^V_{\varepsilon\omega}|^2+3|g^T_{\varepsilon\omega}|^2\right)\equiv 1$$

PRL 131, 021801 (2023)
PRD 108, 012003 (2023)

$$\xi' = 1-2\sum_{\omega=L,R}\left(\frac{1}{4}|g^S_{R\omega}|^2+|g^V_{R\omega}|^2+3|g^T_{R\omega}|^2\right)$$

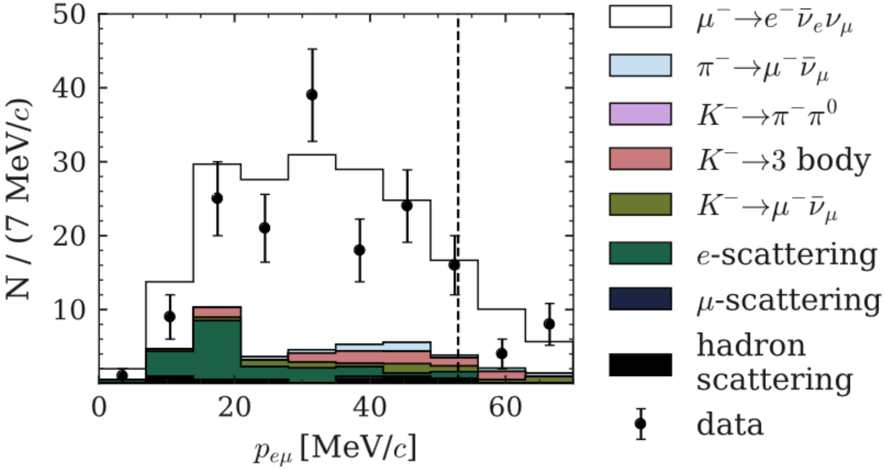
Probability of an unpolarized τ lepton to decay to a right-handed muon: (1- ξ')/2

$\xi' = 1$ in SM

MP (SM)	$\mu \to e\nu_e\nu_\mu$	$\tau \to e\nu_e\nu_\tau$	$\tau \to \mu\nu_\mu\nu_\tau$	MP (SM)	$\mu \to e\nu_e\nu_\mu$	$\tau \to e\nu_e\nu_\tau$	$\tau \to \mu\nu_\mu\nu_\tau$
$\rho\,(0.75)$	0.74979 ± 0.00026	0.747 ± 0.010	0.763 ± 0.020	$\alpha'/A\,(0)$	-0.010 ± 0.020		
$\xi\,(1)$		0.994 ± 0.040	1.030 ± 0.059	$\beta/A\,(0)$	0.004 ± 0.006		
$\eta\,(0)$	0.057 ± 0.034	0.013 ± 0.020	0.094 ± 0.073	$\beta'/A\,(0)$	0.002 ± 0.007		
$\xi\cdot\delta\,(0.75)$		0.734 ± 0.028	0.778 ± 0.037	$a/A\,(0)$			
$\delta\,(0.75)$	0.75047 ± 0.00034			$a'/A\,(0)$			
$\xi\cdot\delta/\rho\,(1)$	$1.0018^{+0.0016}_{-0.0007}$			$(b'+b)/A(0)$		LEGACY	
$\xi'\,(1)$	1.00 ± 0.04		Target	$c/A\,(0)$			

Michel Parameter ξ' via $\tau \to \mu(\to e\,\nu\nu)\,\nu\nu$

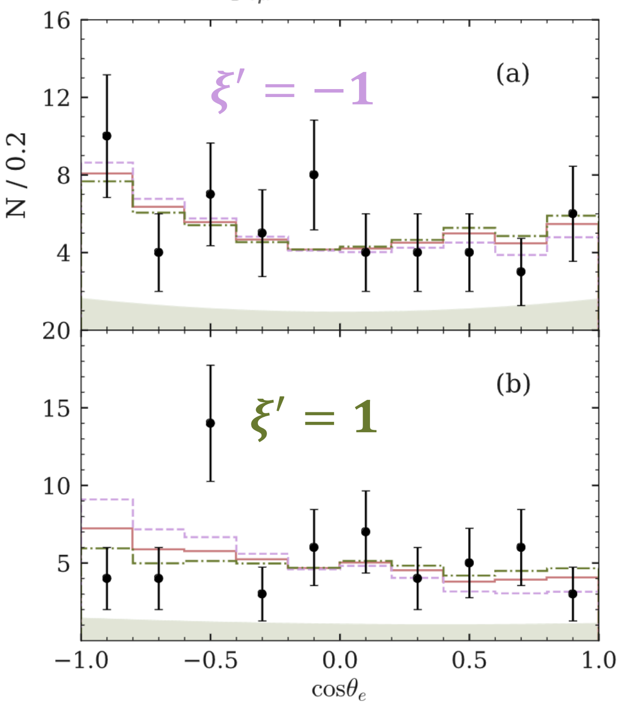
PRL 131, 021801 (2023)
PRD 108, 012003 (2023)



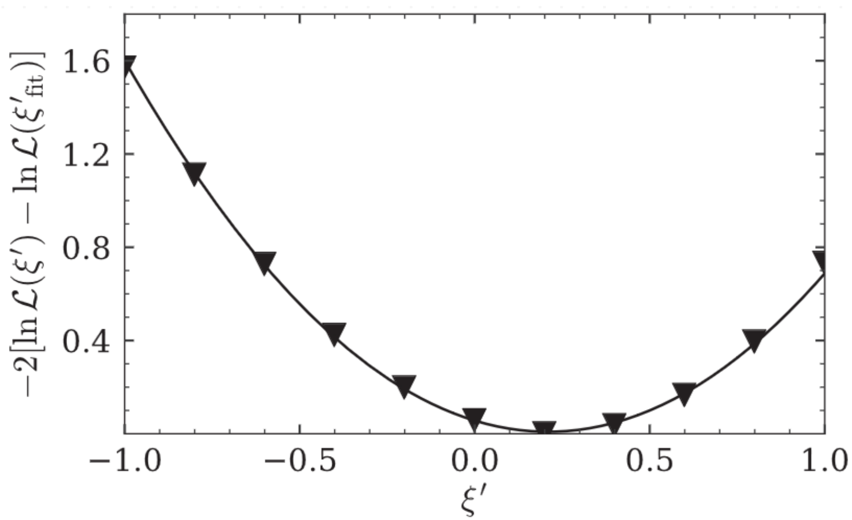
$$\mathcal{P}(y, c; \xi') = p\mathcal{P}_{\text{sig}}(y, c; \xi') + (1 - p)\mathcal{P}_{\text{bckg}}(y, c).$$

y: electron energy in the muon rest frame divided by $m_\mu/2$,

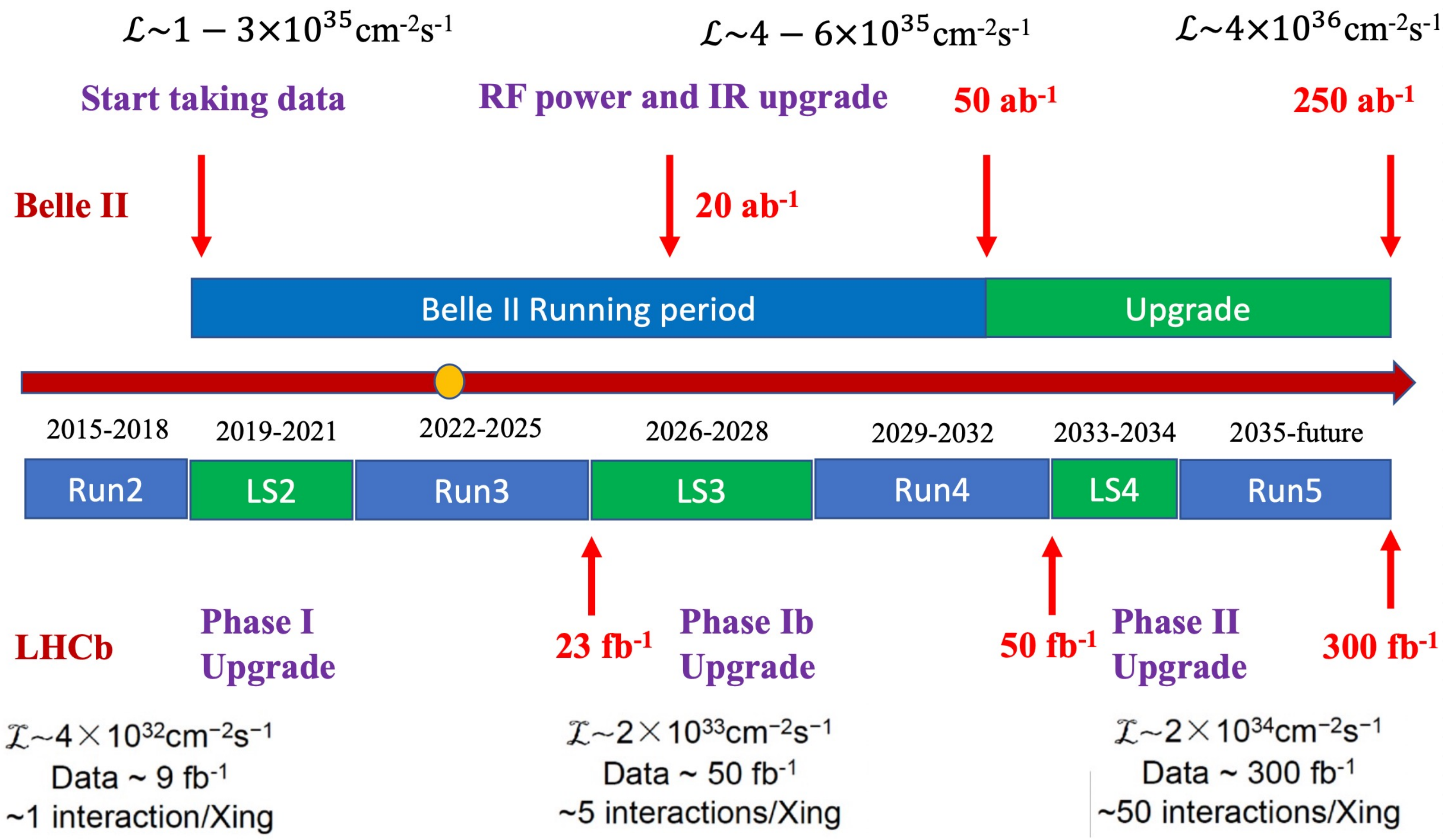
c: $\cos\theta_e$, angle of the electron direction in the muon rest frame.



$\boldsymbol{\xi' = 0.22 \pm 0.94 \pm 0.42}$



Future



The more we know, the more we do not know!

西安交通大學
XI'AN JIAOTONG UNIVERSITY

谢谢大家

Decay mode	Paper	comment
$\Lambda_c^+ \to \Lambda\pi^+\pi^-\pi^+$	Belle: PRL 130, 151903 (2023)	Peaks at 1434 MeV $M_{\Lambda\pi^\pm}$
$\Lambda_c^+ \to \Lambda\eta^{(\prime)}$	Belle: PRD 107, 032003 (2023)	
$\Lambda_c^+ \to \Lambda h, \Sigma^0 h$	Belle: 科学通报 68 583 (2023) BESIII: PRD 106,L111101(2022) PRD106,052003(2022)	CPV measurement for Belle
$\Lambda_c^+ \to pK_sK_s, pK_s\eta$	Belle: PRD 107, 032004 (2023)	
$\Lambda_c^+ \to \Sigma^+\gamma, \Xi_c^0 \to \Xi^0\gamma$	Belle: PRD 107, 032001 (2023) BESIII: arXiv 2212.07214	no evident signal
$\Lambda_c^+ \to pK^+\pi^-$	Belle: PRD 108 3 (2023) LHCb: PRD 108 012023 (2023)	Amplitude analysis from LHCb, observe $\Lambda(2000)$
$\Lambda_c^+ \to p\eta, p\omega$ $\Lambda_c^+ \to p\pi^0$	Belle: PRD 104, 072008 (2021) Belle: PRD 103, 072004 (2021)	
$\Lambda_c^+ \to p\eta'$	Belle: JHEP 03 2022, 090 (2022)	
$\Xi_c^+ \to \Lambda K_S, \Sigma^0 K_S, \Sigma^+ K^-$	Belle: PRD 105, L011102 (2022)	
$\Omega_c^0 \to \Xi^-\pi^+, \Xi K^+, \Omega^- K^+$	Belle: JHEP 01 055 (2023) LHCb: arXiv 2308.08512	No evidence of CS decay from Belle CS decay observed by LHCb

Charm Decays

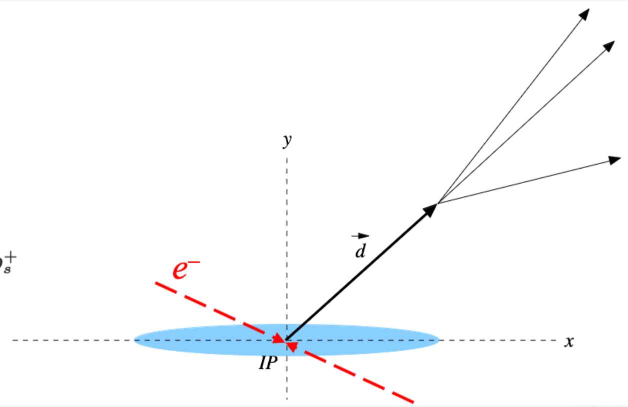
Other recent search for CPV in Charm sector: **not see CPV in all cases**

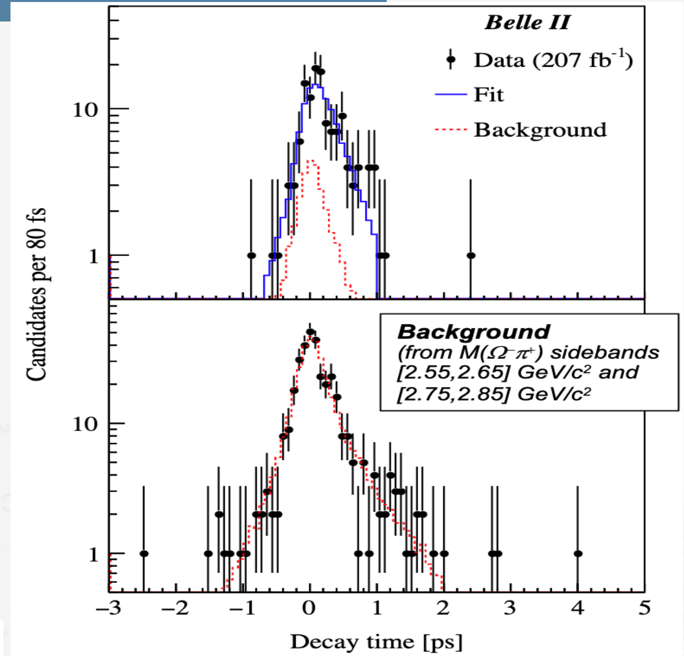
Decay mode	Paper
$D^+_{(s)} \to K^+K^-\pi^+\pi^0$, $\to K^+\pi^-\pi^+\pi^0$ $D^+ \to K^-\pi^+\pi^+\pi^0$	Belle: arXiv 2305.12806
$D^0 \to K^0_S K^0_S \pi^+\pi^-$	Belle: PRD 107, 052001 (2023)
$D^+_{(s)} \to K^+K^0_S h^+h^-$ $D^+_s \to K^+K^-K^0_S\pi^+$	Belle: arXiv 2305.11405

Background

Determine lifetime by measuring vertex displacement and momentum:

$$t = \left(\frac{\vec{d}\cdot\vec{p}}{p^2}\right) m_{D_s^+}$$

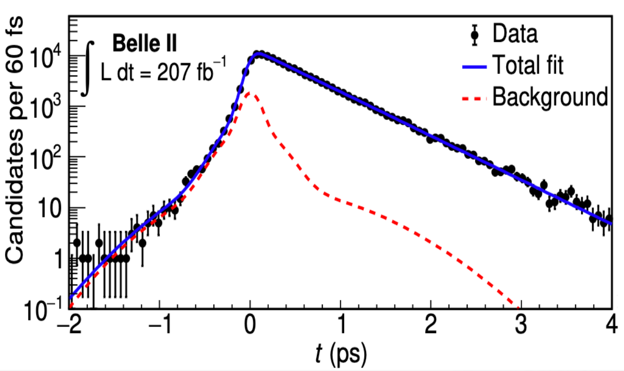


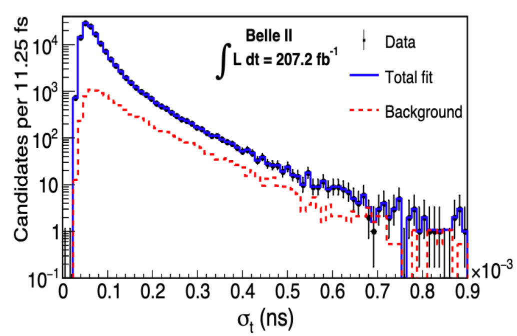


- *lifetime determined from unbinned ML fit to t.*
  Likelihood function for event i:

$$\mathcal{L}(\tau|t^i,\sigma_t^i) = f_{\rm sig}\, P_{\rm sig}(t^i|\tau,\sigma_t^i)\, P_{\rm sig}(\sigma_t^i) + (1-f_{\rm sig})\, P_{\rm bkg}(t^i|\tau,\sigma_t^i)\, P_{\rm bkg}(\sigma_t^i)$$

(to avoid bias: Punzi, arXiv:physics/0401045)





Source	Uncertainty (fs)
Fit bias	**3.4**
Resolution model	**6.2**
Background model	**8.3**
Detector alignment	**1.6**
Momentum scale	**0.2**
Input Ω_c^0 mass	**0.2**
Total	11.0

Background

Theoretical function

- The complete form of the theoretical function to measure MP ξ'

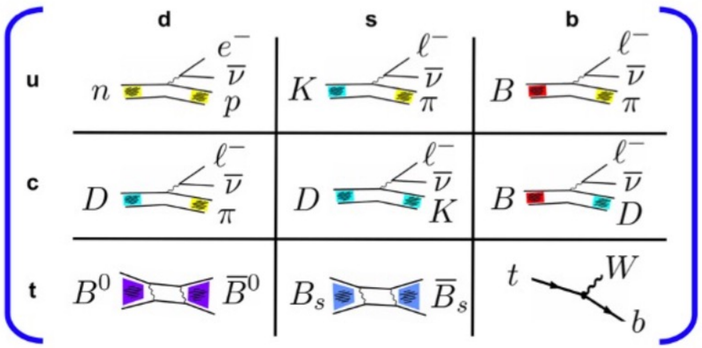
$$\frac{d\sigma(e^+e^- \to [\tau^- \to (\mu^- \to e^-\bar{\nu}_e\nu_\mu)\bar{\nu}_\mu\nu_\tau]\tau^+)}{d\Omega_\tau dxdyd\cos\theta'_e dt} = \frac{\Gamma_{\tau\to\mu}}{\Gamma_\tau}\frac{2}{\tau_\mu}\frac{\alpha^2\beta}{16E^2}A_0 y^2\sqrt{x^2 - x_0^2} \times$$
$$\Big((3-2y)F_{IS}(x) - (1-2y)F_{IP}(x)\cos\theta'_e)\Big)$$

- Here $\cos\theta'_e = (\overrightarrow{n}^{\mu\prime}, \overrightarrow{n}^{e})$, where $n^{\mu\prime}_i = M_{ij}n^\mu_j$ and n^μ_j is muon direction in τ-lepton rest frame at the muon production vertex, n^e_i is electron direction in the muon rest frame. M_{ij} is a rotation matrix. The transition to the angle between electron and τ-lepton momenta in the muon rest frame is done through Jacobian
- The publication with the theoretical calculation of this function will be released soon at arxiv (hope by the end of 2021)
- The important thing to understand — now we have a theoretical calculation of the dependence in the rotation angle

CKM	Process	Observables			Theoretical inputs		
$\lvert V_{ud}\rvert$	$0^+ \to 0^+\ \beta$	$\lvert V_{ud}\rvert_{\mathrm{nucl}}$	$=$	$0.97420 \pm 0 \pm 0.00021$	Nuclear matrix elements		
$\lvert V_{us}\rvert$	$K \to \pi\ell\nu$	$\lvert V_{us}\rvert_{\mathrm{SL}} f_+^{K\to\pi}(0)$	$=$	0.2165 ± 0.0004	$f_+^{K\to\pi}(0)$	$=$	$0.9681 \pm 0.0014 \pm 0.0022$
	$K \to e\nu$	$\mathcal{B}(K \to e\nu)$	$=$	$(1.582 \pm 0.007)\cdot 10^{-5}$	f_K	$=$	$155.6 \pm 0.2 \pm 0.6$ MeV
	$K \to \mu\nu$	$\mathcal{B}(K \to \mu\nu)$	$=$	0.6356 ± 0.0011			
	$\tau \to K\nu$	$\mathcal{B}(\tau \to K\nu)$	$=$	$(0.6960 \pm 0.0096)\cdot 10^{-2}$			
$\frac{\lvert V_{us}\rvert}{\lvert V_{ud}\rvert}$	$K \to \mu\nu / \pi \to \mu\nu$	$\frac{\mathcal{B}(K \to \mu\nu)}{\mathcal{B}(\pi \to \mu\nu)}$	$=$	1.3367 ± 0.0029	f_K/f_π	$=$	$1.1959 \pm 0.0007 \pm 0.0029$
	$\tau \to K\nu / \tau \to \pi\nu$	$\frac{\mathcal{B}(\tau \to K\nu)}{\mathcal{B}(\tau \to \pi\nu)}$	$=$	$(6.438 \pm 0.094)\cdot 10^{-2}$			
$\lvert V_{cd}\rvert$	νN	$\lvert V_{cd}\rvert_{\text{not lattice}}$	$=$	0.230 ± 0.011			
	$D \to \mu\nu$	$\mathcal{B}(D \to \mu\nu)$	$=$	$(3.74 \pm 0.17)\cdot 10^{-4}$	f_{D_s}/f_D	$=$	$1.175 \pm 0.001 \pm 0.004$
	$D \to \pi\ell\nu$	$\lvert V_{cd}\rvert f_+^{D\to\pi}(0)$	$=$	0.1426 ± 0.0019	$f_+^{D\to\pi}(0)$	$=$	$0.621 \pm 0.016 \pm 0.012$
$\lvert V_{cs}\rvert$	$W \to c\bar{s}$	$\lvert V_{cs}\rvert_{\text{not lattice}}$	$=$	$0.94^{+0.32}_{-0.26} \pm 0.13$			
	$D_s \to \tau\nu$	$\mathcal{B}(D_s \to \tau\nu)$	$=$	$(5.55 \pm 0.24)\cdot 10^{-2}$	f_{D_s}	$=$	$247.8 \pm 0.3 \pm 2.0$ MeV
	$D_s \to \mu\nu$	$\mathcal{B}(D_s \to \mu\nu)$	$=$	$(5.39 \pm 0.16)\cdot 10^{-3}$			
	$D \to K\ell\nu$	$\lvert V_{cs}\rvert f_+^{D\to K}(0)$	$=$	0.7226 ± 0.0034	$f_+^{D\to K}(0)$	$=$	$0.741 \pm 0.010 \pm 0.012$
$\lvert V_{ub}\rvert$	semileptonic B	$\lvert V_{ub}\rvert_{\mathrm{SL}}$	$=$	$(3.98 \pm 0.08 \pm 0.22)\cdot 10^{-3}$	form factors, shape functions		
	$B \to \tau\nu$	$\mathcal{B}(B \to \tau\nu)$	$=$	$(1.08 \pm 0.21)\cdot 10^{-4}$	f_{B_s}/f_B	$=$	$1.205 \pm 0.004 \pm 0.006$
$\lvert V_{cb}\rvert$	semileptonic B	$\lvert V_{cb}\rvert_{\mathrm{SL}}$	$=$	$(41.8 \pm 0.4 \pm 0.6)\cdot 10^{-3}$	form factors, OPE matrix elements		
$\lvert V_{ub}/V_{cb}\rvert$	semileptonic Λ_b	$\frac{\mathcal{B}(\Lambda_p \to p\mu^-\bar{\nu})_{q^2>15}}{\mathcal{B}(\Lambda_p \to \Lambda_c\mu^-\bar{\nu})_{q^2>7}}$	$=$	$(0.947 \pm 0.081)\cdot 10^{-2}$	$\frac{\zeta(\Lambda_p \to p\mu^-\bar{\nu})_{q^2>15}}{\zeta(\Lambda_p \to \Lambda_c\mu^-\bar{\nu})_{q^2>7}}$	$=$	$1.471 \pm 0.096 \pm 0.290$
α	$B \to \pi\pi,\ \rho\pi,\ \rho\rho$	branching ratios, CP asymmetries			isospin symmetry		
β	$B \to (c\bar{c})K$	$\sin(2\beta)_{[c\bar{c}]}$	$=$	0.699 ± 0.017	subleading penguins neglected		
$\cos(2\beta)$	$B^0 \to D^{(*)}h^0$	$\cos(2\beta)$	$=$	0.91 ± 0.25			
γ	$B \to D^{(*)}K^{(*)}$	inputs for the 3 methods			GGSZ, GLW, ADS methods		
ϕ_s	$B_s \to J/\psi(KK, \pi\pi)$	$(\phi_s)_{b\to c\bar{c}s}$	$=$	-0.021 ± 0.031			
$V_{tq}^* V_{tq'}$	Δm_d	Δm_d	$=$	$0.5065 \pm 0.0019\ \mathrm{ps}^{-1}$	$\hat{B}_{B_s}/\hat{B}_{B_d}$	$=$	$1.007 \pm 0.013 \pm 0.014$
	Δm_s	Δm_s	$=$	$17.757 \pm 0.021\ \mathrm{ps}^{-1}$	$\hat{B}_{B_s}$	$=$	$1.327 \pm 0.016 \pm 0.030$
	$B_s \to \mu\mu$	$\mathcal{B}(B_s \to \mu\mu)$	$=$	$(2.8^{+0.7}_{-0.6})\cdot 10^{-9}[\times(1-0.063)]$	f_{B_s}	$=$	$226.0 \pm 1.3 \pm 2.0$ MeV
$V_{td}^* V_{ts}$ and $V_{cd}^* V_{cs}$	ε_K	$\lvert\varepsilon_K\rvert$	$=$	$(2.228 \pm 0.011)\cdot 10^{-3}$	$\hat{B}_K$	$=$	$0.7567 \pm 0.0021 \pm 0.0123$
					κ_ε	$=$	$0.940 \pm 0.013 \pm 0.023$

https://indico.cern.ch/event/684284/contributions/2952455/attachments/1719296/2774804/Vale_Silva_3.pdf

Charm Decays

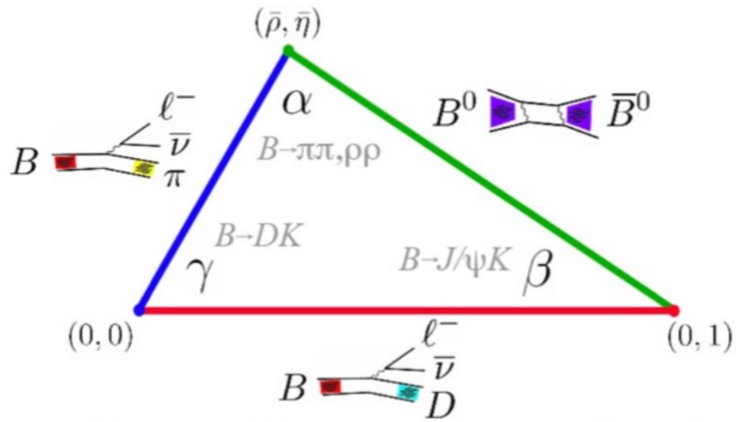


From S. Descotes-Genon

$|V_{cs}|, |V_{cd}|$: (semi-)leptonic charm decays (can be done and should be done, but none has done anything yet)

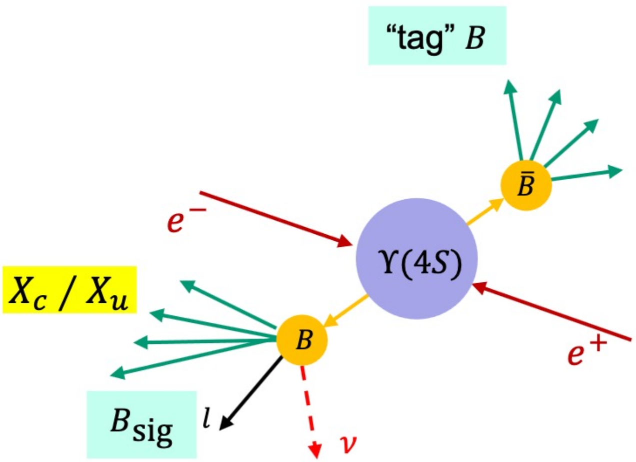
$|V_{ub}|, |V_{cb}|$: (semi-)leptonic B decays

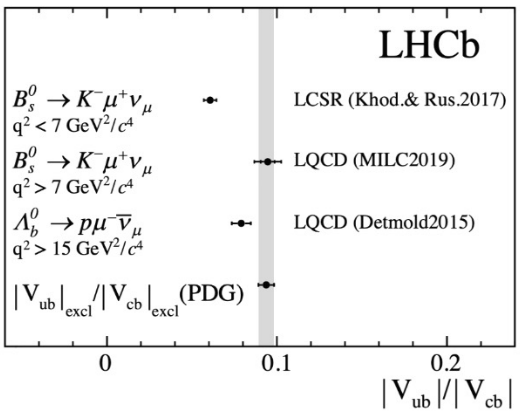
$|V_{td}|, |V_{ts}|$: $\Delta m_d, \Delta m_s$



- α: $B \to \pi\pi, B \to \rho\pi, B \to \rho\rho$, isospin analyses
- β: $B \to (\bar{c}c)K, B \to Dh^0$, time-dependent CP violation
- γ: $B \to DK$, ADS/GLW/GGSZ
- ϕ_s: $B_s^0 \to (c\bar{c})(KK, \pi\pi)$, time-dependent CP violation
- $-2\beta_s + \gamma$: $B_s \to D_s K$

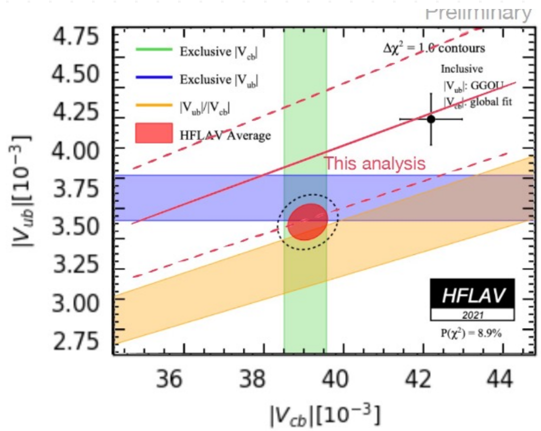
$$\phi_s^{s\bar{s}s} = -0.042 \pm 0.075 \pm 0.009 \text{ rad},$$





$$|V_{ub}|/|V_{cb}|(\text{low}) = 0.0607 \pm 0.0015(\text{stat}) \pm 0.0013(\text{syst}) \pm 0.0008\,(D_s) \pm 0.0030\,(\text{FF}),$$

$$|V_{ub}|/|V_{cb}|(\text{high}) = 0.0946 \pm 0.0030(\text{stat})^{+0.0024}_{-0.0025}(\text{syst}) \pm 0.0013\,(D_s) \pm 0.0068\,(\text{FF}),$$



Belle Preliminary
711 fb^{-1}

- Belle: inclusive $|V_{ub}|$ measurement complicated
  - ✓ Large “bg” contribution from $B \to X_c l\nu$
- Treat $B \to X_c l\nu$ as part of signal
  - ✓ Simultaneously measure $|V_{ub}|$ & $|V_{ub}|$
  - ✓ $B \to X_u l\nu$ dominate (>86%) in high p_l^B bins

- LHCb: 2 fb^{-1}data at 8 pp collisions
- Observation of $B_s^0 \to K^-\mu^+\nu_\mu l$
  - ✓ Branching fraction measurement

$$R_{\rm BF} = \frac{\mathcal{B}(B_s^0 \to K^-\mu^+\nu_\mu)}{\mathcal{B}(B_s^0 \to D_s^-\mu^+\nu_\mu}$$

  - ✓ Determination of $|V_{ub}|$ / $|V_{ub}|$ in low/high q^2 bins

LHCb, PRL126.081804(2021), [arXiv: 2303.17309]

- A few selected recent measurements from Belle(II) and LHCb experiments
  - ✓ Measurements of $|V_{cb}|$ & $|V_{ub}|$
  - ✓ Tests of lepton universality

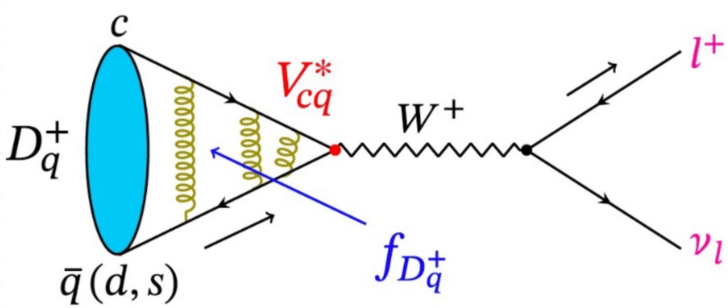
- Discrepancies ($> 3\sigma$) of measured $|V_{cb}|$ and $|V_{ub}|$ between inclusive and exclusive final states remains
  - ✓ Measurements not limited by statistical precision
  - ✓ Better design analysis choice to reduce systematic uncertainties
  - ✓ Many systematic uncertainties can be reduced with more data
  - ✓ Important to improve precision of theoretical calculations

- Deviation of measured $R_{D^{(*)}}$ from the SM prediction remains ($> 3\sigma$)
  - ✓ More precise measurement expected with more coming data
  - ✓ Measurements as a function of q^2 and angular distributions

- Test muon and electron universality: inclusive and angular distributions
  - ✓ Systematic uncertainties that will further be reduced with more data

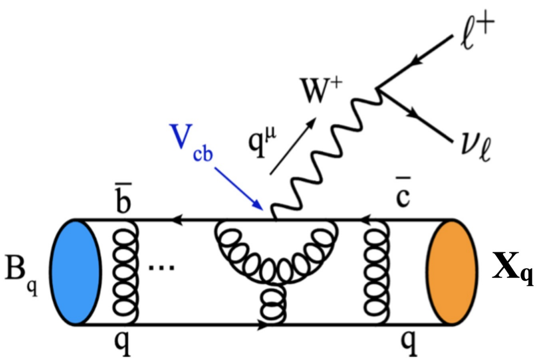
- **Semileptonic *b*-hadron offer reach opportunities to look for NP, expect new results soon**

Why weak decay?



Leptonic decay

$$B[M \to l\nu_l]_{SM} = \frac{G_F^2 m_M m_l^2}{8\pi}\left(1-\frac{m_l^2}{m_M^2}\right)^2 \left|V_{q_i q_j}\right|^2 f_M^2 \tau_M \left(1+\delta_{em}^{Ml2}\right)$$

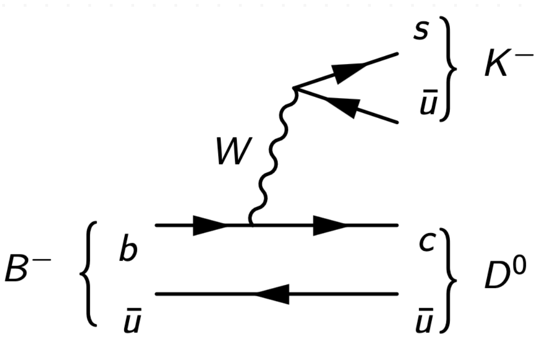


Semi-leptonic decay

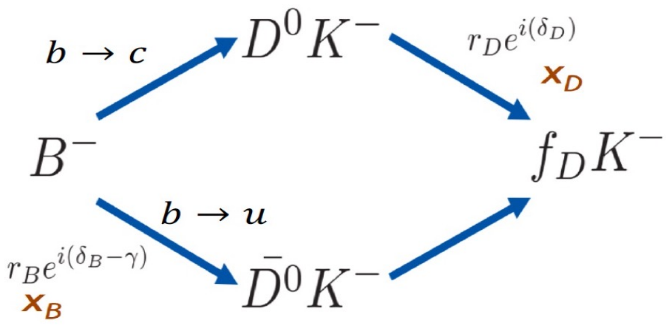
$$\frac{d\Gamma(M\to P l\nu)}{dq^2} = \frac{G_F^2\left|V_{q_u q_d}\right|^2}{24\pi^3}\frac{(q^2-m_l^2)^2\sqrt{E_P^2-m_P^2}}{q^4 m_H^2} \times\left[\left(1+\frac{m_l^2}{2q^2}\right)m_M^2(E_P^2-m_P^2)\left|f_+(q^2)\right|^2+\frac{3m_l^2}{8q^2}(m_M^2-m_P^2)^2\left|f_0(q^2)\right|^2 \ldots\right]$$

	0^+	0^-	1^-	1^+	2^+
$B_{(l)} \to X\ell\bar{\nu}$	f_0	–	f_+	–	f_T
$B_{(l)} \to X^*\ell\bar{\nu}$	–	A_0	V_0	A_1, A_2	T_1, T_2, T_3

hadronic decay



- ❖ **Extract CKM Matrix parameters: $|V_{qq'}|$, ϕ_i (test unitarity)**
- ❖ **CPV** ❖ **FCNC** ❖ **LFU (new physics)**
- ❖ **Decay constants and hadronic Form factor (LQCD)**
- ❖ **Decay parameters, Branching fraction, PWA (QCD, other hadrons)**
- ❖ ……



D^0 and $\bar{D}^0$ decay to same final states to interference

GLW: D = CP eigenstates, e.g. KK, ππ — PLB 253 (1991) 483, PLB 265 (1991) 172

ADS: D = quasi-flavour-specific states e.g. Kπ — PRL 78 (1997) 3257

GGSZ: D = self-conjugate multi(3)-body states e.g. $K_s\pi\pi$ — PRD 68 (2003) 054018

GLS: ADS variant with singly Cabbibo-suppressed decay $D \to K_s K\pi$ — PRD 67 (2003) 071301

time-dependent $B_s \to D_s K$, $B^0 \to D\pi$ etc — Nucl. phys. B 672 (2003) 459

Dalitz (GW) method: $B^0 \to DK\pi$ — PRD 79 (2009) 051301

Sensitivities of γ from many channels, important to measure as many as possible

GLS result (Belle+BelleII!)

- $B^\pm \to DK^\pm$ with $D \to K_S^0 K^+ \pi^-$ (SS) or $D \to K_S^0 K^- \pi^+$ (OS)
- Measure 4 Acp and 3 BR ratios.
- Get results in full D phase space and in the K*K region (large δ_D).

$$A_{SS}^{DK} = \frac{2r_B^{DK} r_D \kappa_D \sin(\delta_B^{DK} - \delta_D)\sin\phi_3}{1 + (r_B^{DK})^2 r_D^2 + 2r_B^{DK} r_D \kappa_D \cos(\delta_B^{DK} - \delta_D)\cos\phi_3},$$

$$A_{OS}^{DK} = \frac{2r_B^{DK} r_D \kappa_D \sin(\delta_B^{DK} + \delta_D)\sin\phi_3}{(r_B^{DK})^2 + r_D^2 + 2r_B^{DK} r_D \kappa_D \cos(\delta_B^{DK} + \delta_D)\cos\phi_3},$$

$$A_{SS}^{D\pi} = \frac{2r_B^{D\pi} r_D \kappa_D \sin(\delta_B^{D\pi} - \delta_D)\sin\phi_3}{1 + (r_B^{D\pi})^2 r_D^2 + 2r_B^{D\pi} r_D \kappa_D \cos(\delta_B^{D\pi} - \delta_D)\cos\phi_3},$$

$$A_{OS}^{D\pi} = \frac{2r_B^{D\pi} r_D \kappa_D \sin(\delta_B^{D\pi} + \delta_D)\sin\phi_3}{(r_B^{D\pi})^2 + r_D^2 + 2r_B^{D\pi} r_D \kappa_D \cos(\delta_B^{D\pi} + \delta_D)\cos\phi_3}.$$

$$R_{SS}^{DK/D\pi} = R\frac{1 + (r_B^{DK})^2 r_D^2 + 2r_B^{DK} r_D \kappa_D \cos(\delta_B^{DK} - \delta_D)\cos\phi_3}{1 + (r_B^{D\pi})^2 r_D^2 + 2r_B^{D\pi} r_D \kappa_D \cos(\delta_B^{D\pi} - \delta_D)\cos\phi_3},$$

$$R_{OS}^{DK/D\pi} = R\frac{(r_B^{DK})^2 + r_D^2 + 2r_B^{DK} r_D \kappa_D \cos(\delta_B^{DK} + \delta_D)\cos\phi_3}{(r_B^{D\pi})^2 + r_D^2 + 2r_B^{D\pi} r_D \kappa_D \cos(\delta_B^{D\pi} + \delta_D)\cos\phi_3},$$

$$R_{SS/OS}^{D\pi} = \frac{1 + (r_B^{D\pi})^2 r_D^2 + 2r_B^{D\pi} r_D \kappa_D \cos(\delta_B^{D\pi} - \delta_D)\cos\phi_3}{(r_B^{D\pi})^2 + r_D^2 + 2r_B^{D\pi} r_D \kappa_D \cos(\delta_B^{D\pi} + \delta_D)\cos\phi_3}.$$

- 2D Fit ($\Delta E, C'$) of 8 categories ($DK, D\pi$)x(SS, OS)x(+,-)

GLS result (Belle+BelleII!)

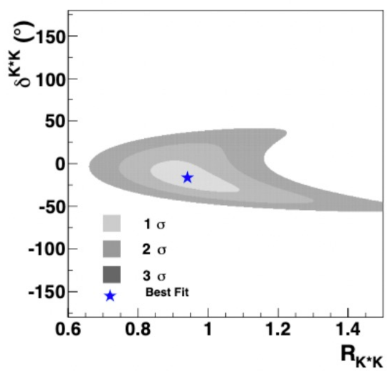
- $B^{\pm} \to DK^{\pm}$ with $D \to K_S^0 K^+ \pi^-$ (SS) or $D \to K_S^0 K^- \pi^+$ (OS)
- Measure 4 Acp and 3 BR ratios.
- Get results in full D phase space and in the K*K region (large δ_D).

In K*K region:

$$A_{\rm SS}^{DK} = 0.055 \pm 0.119 \pm 0.020,$$
$$A_{\rm OS}^{DK} = 0.231 \pm 0.184 \pm 0.014,$$
$$A_{\rm SS}^{D\pi} = 0.046 \pm 0.029 \pm 0.016,$$
$$A_{\rm OS}^{D\pi} = 0.009 \pm 0.046 \pm 0.009,$$
$$R_{\rm SS}^{DK/D\pi} = 0.093 \pm 0.012 \pm 0.005,$$
$$R_{\rm OS}^{DK/D\pi} = 0.103 \pm 0.020 \pm 0.006,$$
$$R_{\rm SS/OS}^{D\pi} = 2.412 \pm 0.132 \pm 0.019,$$

arXiv:2306.02940

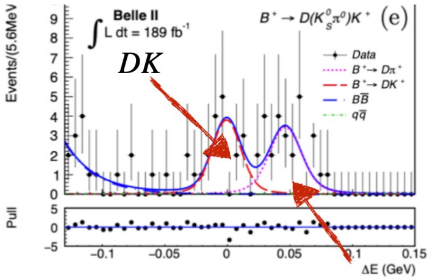
- First Belle/Belle II result from this channel.
- The precision is worse than LCHb's🙁[arXiv:2002.08858]
- With the D information from CLEO-c, will contributed in a combined ϕ_3 from Belle/BelleII. (May get out this summer)



- Model-independent result from CLEO-c.[arXiv:1203.3804]

GLW result (Belle+BelleII!)

- $B^{\pm} \to DK^{\pm}$ with $D \to K^0_S\pi^0$ (CP-odd) or $D \to K^+K^-$ (CP-even)



$$
\begin{aligned}
R_{CP\pm} &= \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D^0K^-) + \mathcal{B}(B^+ \to \bar{D}^0K^+)}, \\
&= 1 + r_B^2 + 2\eta_{CP} r_B \cos(\delta_B)\cos(\phi_3), \\
A_{CP\pm} &= \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) - \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}, \\
&= 2\eta_{CP} r_B \sin(\delta_B)\sin(\phi_3)/R_{CP\pm}.
\end{aligned}
$$

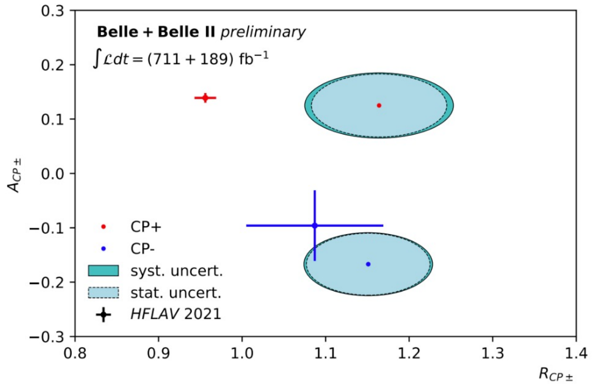
- 2D Fit ($\Delta E, C'$) of 6 categories ($DK, D\pi$)x($K^0_S\pi^0, K^+K^-, K^-\pi^+$)

Large Rcp+ than W.A.
Competitive Rcp- and Acp- with W.A.

	68.3% CL	95.4% CL
ϕ_3 (°)	[8.5, 16.5]	[5.0, 22.0]
	[84.5, 95.5]	[80.0, 100.0]
	[163.3, 171.5]	[157.5, 175.0]
r_B	[0.321, 0.465]	[0.241, 0.522]

$$
\begin{aligned}
\mathcal{R}_{CP+} &= 1.164 \pm 0.081 \pm 0.036, \\
\mathcal{R}_{CP-} &= 1.151 \pm 0.074 \pm 0.019, \\
\mathcal{A}_{CP+} &= (+12.5 \pm 5.8 \pm 1.4)\%, \\
\mathcal{A}_{CP-} &= (-16.7 \pm 5.7 \pm 0.6)\%.
\end{aligned}
$$

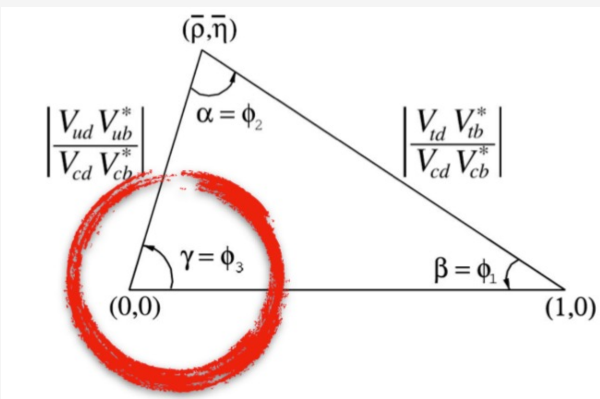
3.5σ



world average: ϕ_3 (°) = $66.2^{+3.4}_{-3.6}$ $r_B = 0.0996 \pm 0.0026$

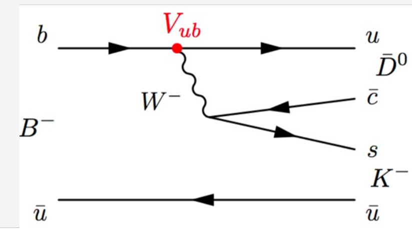
Measurement of CKM angle ϕ_3

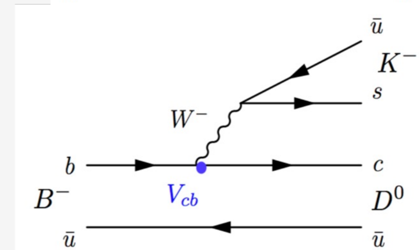
- Theoretical uncertainty on measurement is $\frac{\delta\phi_3}{\phi_3} \sim 10^{-7}$ arxiv:1308.5663
- Test physics beyond SM
- CPV in the interference $b \rightarrow c\bar{u}s$ and $b \rightarrow u\bar{c}s$:



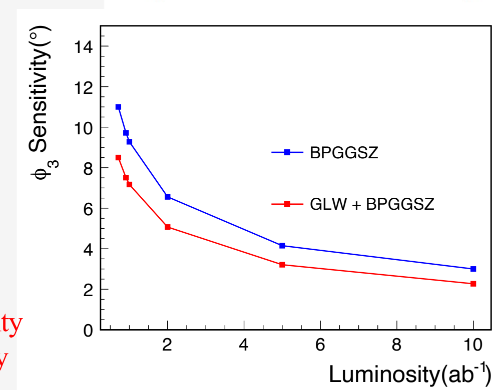
$$\frac{A^{suppr.}[B^- \rightarrow \overline{D^0}K^-]}{A^{favor.}[B^- \rightarrow D^0 K^-]} = r_B e^{i(\delta_B - \phi_3)}$$

$$\phi_3 = \arg\left[\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$$





- Foreseen precision of ϕ_3 is expected (current world-average $\delta\phi \sim 4°$) with the future Belle II dataset



The expected uncertainty of ϕ_3 versus luminosity

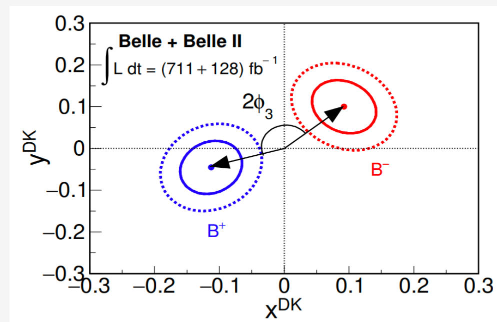
Belle II Measurements of CKM angle ϕ_3

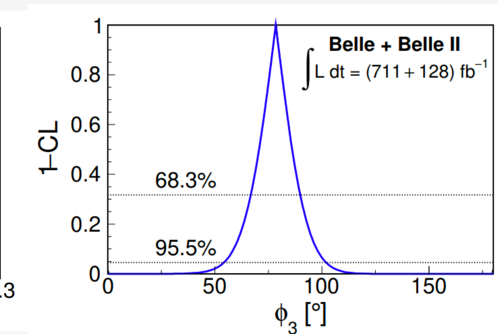
- (ΔE, C′) 2D simultaneous fit for all methods
- GGSZ method with $B^- \to D(\to K_S h^+ h^-)h^-$ decays

JHEP02(2022)063

-- The CP observables of interests

$$x_- = +(9.24 \pm 3.27 \pm 0.17 \pm 0.23)\times 10^{-2}$$
$$x_+ = -(11.28 \pm 3.15 \pm 0.18 \pm 0.22)\times 10^{-2}$$
$$y_- = +(10.00 \pm 4.20 \pm 0.23 \pm 0.67)\times 10^{-2}$$
$$y_+ = -(4.55 \pm 4.20 \pm 0.11 \pm 0.55)\times 10^{-2}$$



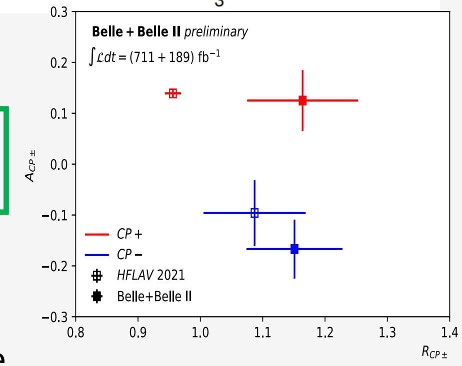


$$\phi_3 = (78.4 \pm 11.4 \pm 0.5 \pm 1.0)^\circ$$

- GLW method $A_{CP\pm} = \pm 2r_B \sin\delta_B \sin\phi_3 / R_{CP\pm}$ $\quad R_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\phi_3$

arXiv:2308.05048

$$A_{CP+} = (+12.5 \pm 5.8(stat.) \pm 1.4(syst.))\% \quad R_{CP+} = 1.164 \pm 0.081(stat.) \pm 0.036\,(syst.)$$
$$A_{CP-} = (-16.7 \pm 5.7(stat.) \pm 0.6(syst.))\% \quad R_{CP-} = 1.151 \pm 0.074(stat.) \pm 0.019\,(syst.)$$



- GLS method with $B^- \to D(\to K_S K^\pm \pi^\mp)h^-$ decays arXiv:2306.02940
  - 7 CP observables: 4 asymmetries, 3 BRs ratios
  - Measurement performed in full D phase space and in the enhanced-interference $D \to K^* K$ region
  - These results can provide constraint on ϕ_3

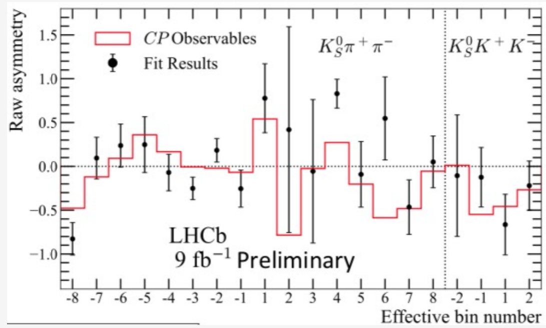
LHCb Measurements of CKM angle ϕ_3

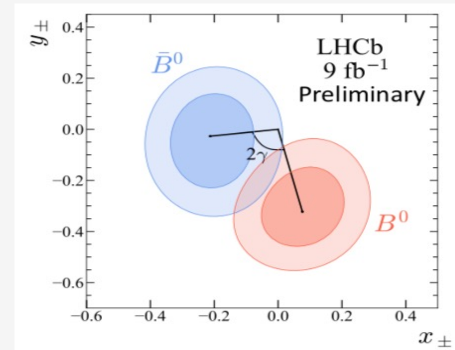
- GGSZ method

  -- $B^0 \to D(\to K_S h^+ h^-) K^{*0}$

  - Limited statistics,
  - CPV still observed in some bins

  $\phi_3 = (49^{+23}_{-18})^\circ$

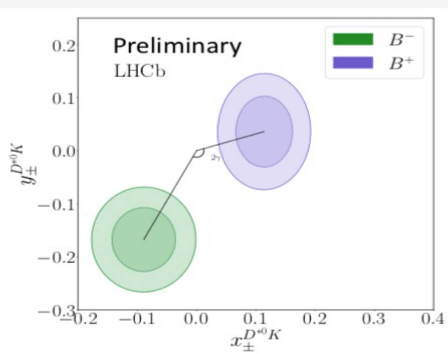




LHCb-PAPER-2023-009

-- $B^- \to D^*(\to D(\to K_S h^+ h^-)\pi^0/\gamma) h^-$

LHCb-PAPER-2023-012



- Opposite CPV between $D^{*0} \to D\pi$ and $D^{*0} \to D\gamma$
- Irreducible bkg
- 2D invariant mass fit

$\phi_3 = (69 \pm 14)^\circ$

-- $B^- \to D(\to K^+K^-\pi^+\pi^-)) h^-$

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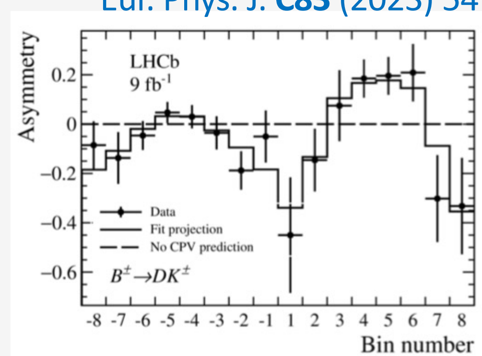

- Measured firstly
- Complicated binning scheme

$\phi_3 = (116^{+12}_{-14})^\circ$