



Recent Belle II results and status

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第五届重味物理与量子色动力学研讨会

Boosting the reach



Energy-asymmetric e^+e^- collisions at the $\Upsilon(4S)$ from SuperKEKB.
Unprecedented luminosity, $4.7 \times 10^{34} \text{ cm}^{-2} \text{ Hz}$ world record.

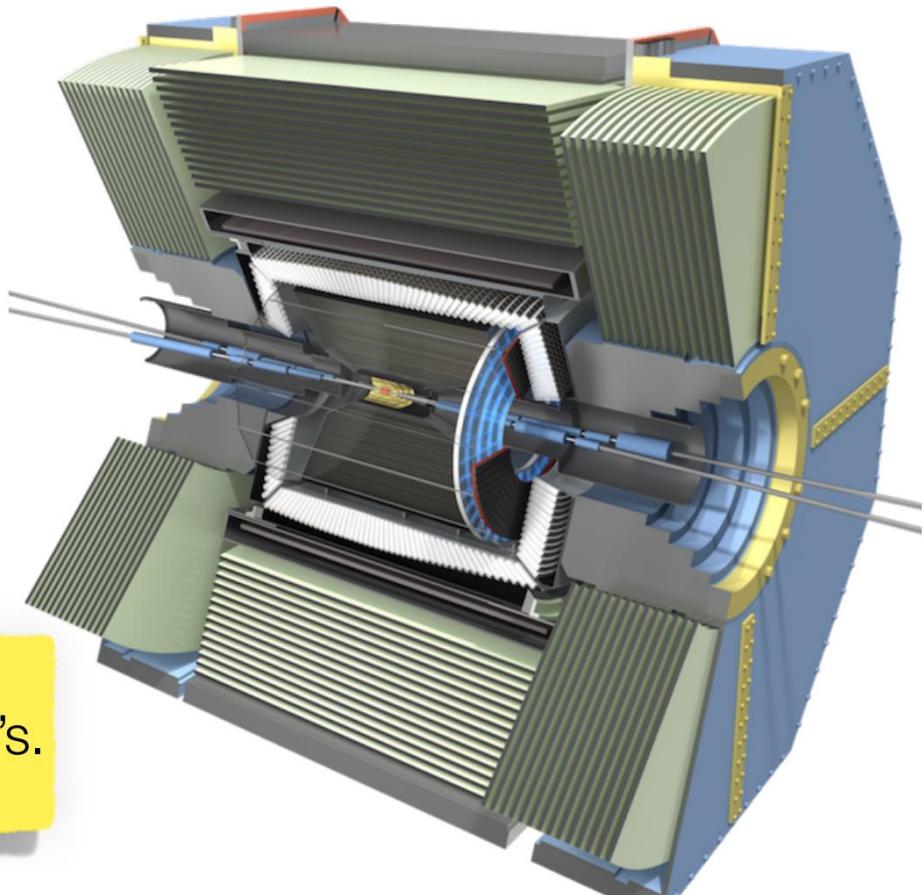


Belle 2 looks like “old” Belle, but effectively a brand new instrument.

Excellent vertexing and tracking.
Good PID and neutrals.

Performance pretty uniform over any final state and kinematic regime.
Efficiency for reconstructing tracks,
 π^0 , K_S are similar across the board.

424 fb^{-1} of data on tape.
Comparable to Babar’s. Half of Belle’s.
Partly unique (energy scan)

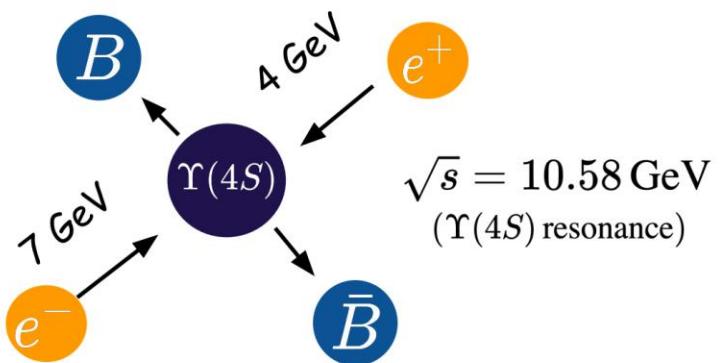


Belle II experiment

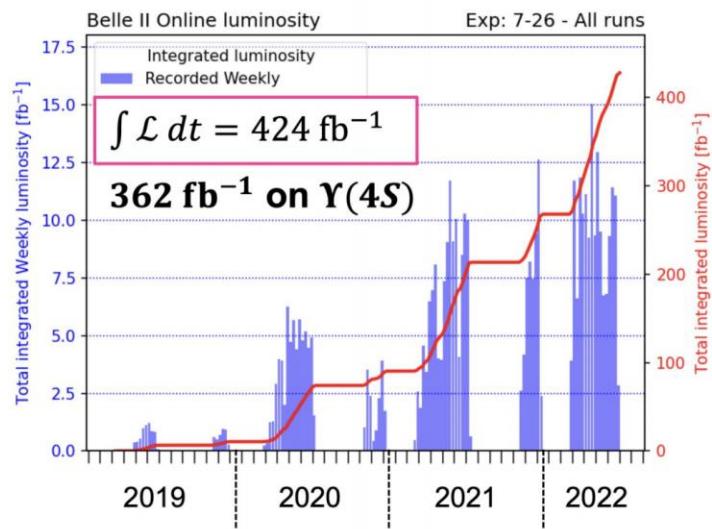


> 1100 active members
124 institutes
27 countries

KEK
Tsukuba, Japan



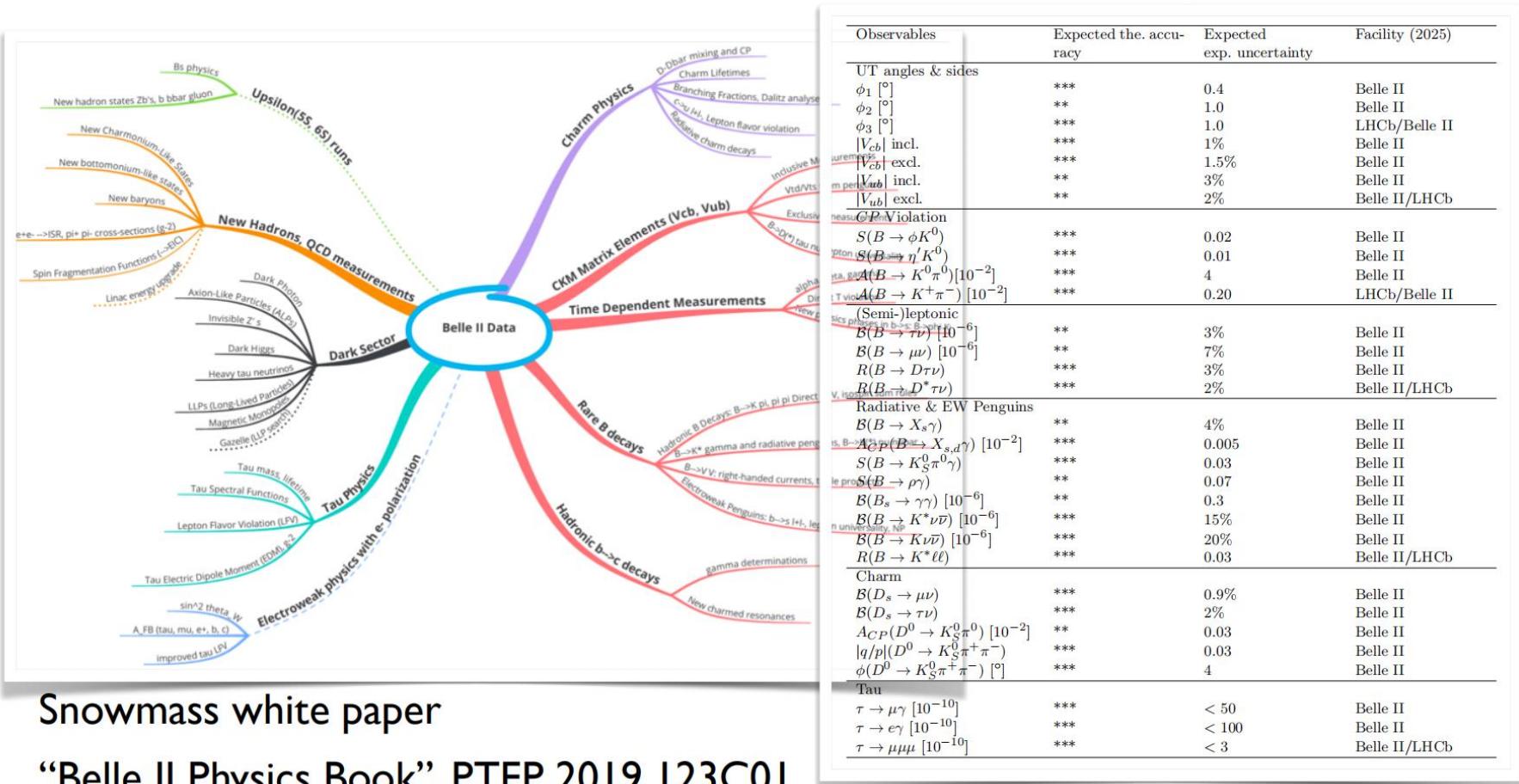
- 362/fb at Y(4S)*
 - 42/fb off-resonance, 60 MeV below Y(4S)
 - 19/fb energy scan between 10.6 to 10.8 GeV for exotic hadron studies



- Max instantaneous luminosity
 $\mathcal{L}=4.7\times10^{34} \text{ cm}^{-2}\text{s}^{-1}$ (world record)
 - LS1 starts from summer 2022 to fully install the PXD detector
 - Operation will be resumed around the end of 2023.

Belle II Physics Program

Belle II contributes in many sectors with many type of analyses and with ultimate precision down to theory errors!



Observables	Expected the. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
$\phi_1 [^\circ]$	***	0.4	Belle II
$\phi_2 [^\circ]$	**	1.0	Belle II
$\phi_3 [^\circ]$	***	1.0	LHCb/Belle II
$ V_{cb} $ incl.	***	1%	Belle II
$ V_{cb} $ excl.	***	1.5%	Belle II
$ V_{ub} $ incl.	**	3%	Belle II
$ V_{ub} $ excl.	**	2%	Belle II/LHCb
measuring CP-Violation			
$S(B \rightarrow \phi K^0)$	***	0.02	Belle II
$S(B \rightarrow \eta' K^0)$	***	0.01	Belle II
$A(B \rightarrow K^0 \pi^0)$ [10^{-2}]	***	4	Belle II
$A(B \rightarrow K^+ \pi^-)$ [10^{-2}]	***	0.20	LHCb/Belle II
(Semi-)leptonic			
$\mathcal{B}(B \rightarrow \tau \nu)^{[10^{-6}]}$	**	3%	Belle II
$\mathcal{B}(B \rightarrow \mu \nu)^{[10^{-6}]}$	**	7%	Belle II
$R(B \rightarrow D \tau \nu)$	***	3%	Belle II
$R(B \rightarrow D^* \tau \nu)$	***	2%	Belle II/LHCb
Radiative & EW Penguins			
$\mathcal{B}(B \rightarrow X_s \gamma)$	**	4%	Belle II
$A_{CP}(B \rightarrow X_{s,d} \gamma)$ [10^{-2}]	***	0.005	Belle II
$S(B \rightarrow K_S^0 \pi^0 \gamma)$	***	0.03	Belle II
$S(B \rightarrow \rho \gamma)$	**	0.07	Belle II
$B(B_s \rightarrow \gamma\gamma)$ [10^{-6}]	**	0.3	Belle II
$\mathcal{B}(B \rightarrow K^* \nu \bar{\nu})$ [10^{-6}]	***	15%	Belle II
$\mathcal{B}(B \rightarrow K \bar{\nu})$ [10^{-6}]	***	20%	Belle II
$R(B \rightarrow K^* \ell \bar{\ell})$	***	0.03	Belle II/LHCb
Charm			
$\mathcal{B}(D_s \rightarrow \mu \nu)$	***	0.9%	Belle II
$\mathcal{B}(D_s \rightarrow \tau \nu)$	***	2%	Belle II
$A_{CP}(D^0 \rightarrow K_S^0 \pi^0)$ [10^{-2}]	**	0.03	Belle II
$ q/p (D^0 \rightarrow K_S^0 \pi^+ \pi^-)$	***	0.03	Belle II
$\phi(D^0 \rightarrow K_S^0 \pi^+ \pi^-)$ [°]	***	4	Belle II
Tau			
$\tau \rightarrow \mu \gamma$ [10^{-10}]	***	< 50	Belle II
$\tau \rightarrow e \gamma$ [10^{-10}]	***	< 100	Belle II
$\tau \rightarrow \mu \mu \mu$ [10^{-10}]	***	< 3	Belle II/LHCb

Snowmass white paper

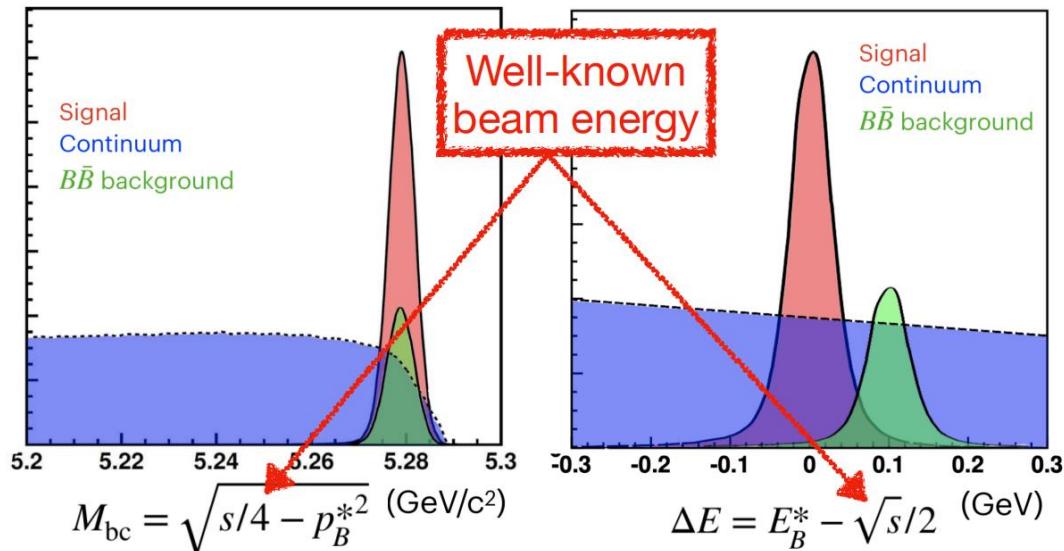
“Belle II Physics Book”, PTEP 2019 I23C01

(Some) B -factory basics

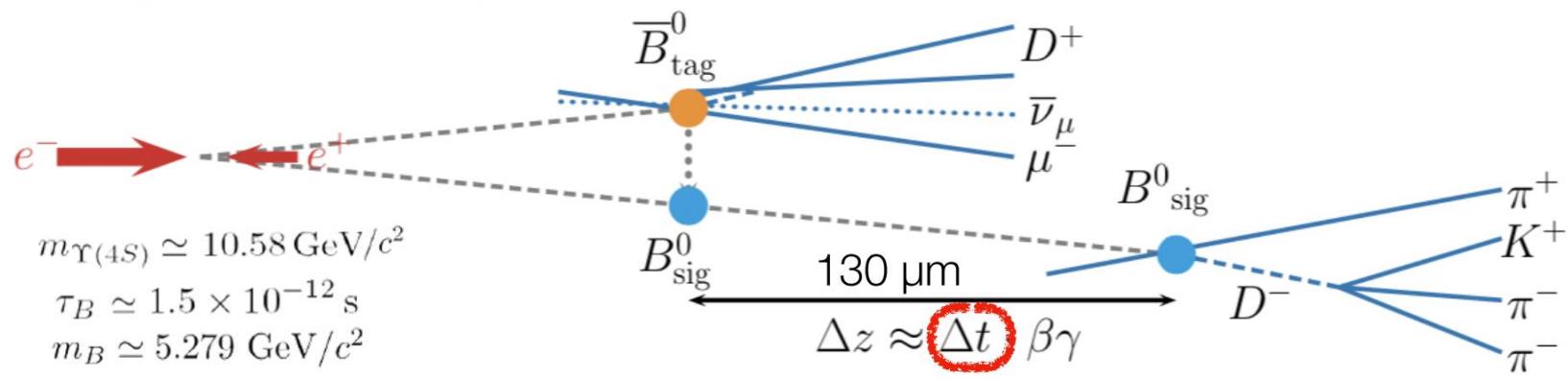
Low-background production of 30 (now)–600 (design) $B\bar{B}$ per second.

Threshold B production from point-like colliding particles, $e^+e^- \rightarrow Y(4S) \rightarrow B\bar{B}$.

Kinematic well constrained..

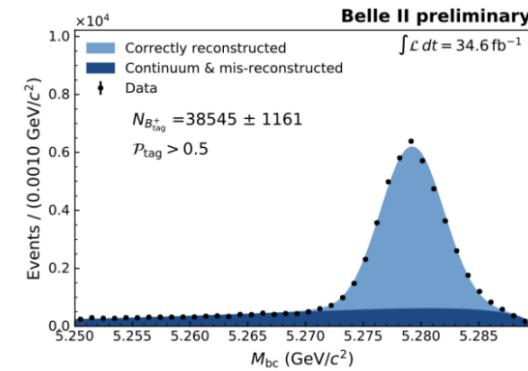
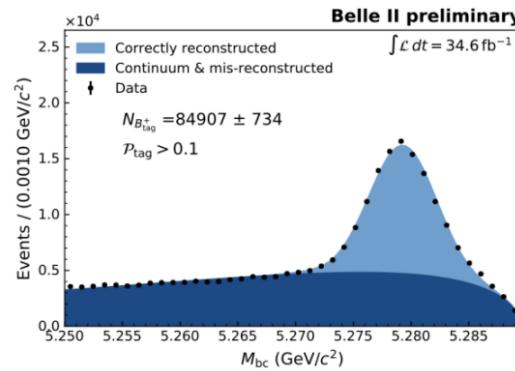
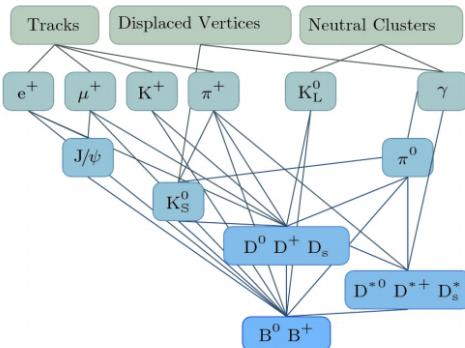


The asymmetric collision gives the boost to measure the displacement.



Full Event Interpretation

- Full Event Interpretation algorithm [Comput Softw Big Sci 3, 6 (2019)] to reconstruct B_{tag}
 - Reconstruct B candidate with all combination of daughters
 - Calculate signal probability with multivariate classifiers



$$M_{bc} = \sqrt{E_{beam}^2/4 - (p_{B_{tag}}^{cm})^2} > 5.27 \text{ GeV}/c^2$$

■ Hadronic FEI

- Over 200 BDTs to reconstruct $\mathcal{O}(10000)$ distinct decay chains
- $\epsilon_{B^+} \approx 0.5\%$, $\epsilon_{B^0} \approx 0.3\%$ at $\sim 15\%$ purity
 - $\sim 50\%$ increase over Belle tag

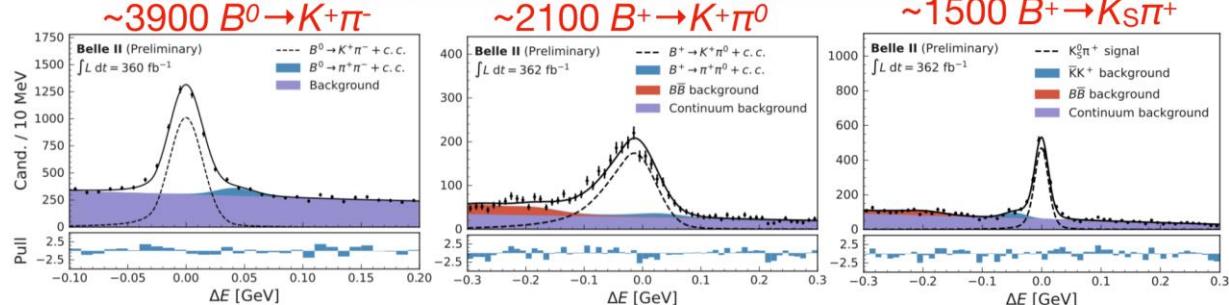
$K\pi$ isospin sum-rule

- Rare decay, but relatively high branching fraction ($\sim 10^{-5}$)
- Tree diagram (with V_{ub}) + penguin diagram
 - ✓ Direct CP violation is possible (observed)
- The sum-rule provides precise prediction of the relation of the branching fractions and A_{CP} .

$$I_{K\pi} = \mathcal{A}_{K^+\pi^-} + \mathcal{A}_{K^0\pi^+} \frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^+\pi^0} \frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^0\pi^0} \frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

Experimentally consistent with zero with 10% precision limited by $K_S\pi^0$.

Belle 2 unique possibility to access all final states



$$\mathcal{B} = (20.67 \pm 0.37 \pm 0.62) \times 10^{-6}$$

$$A_{CP} = (-7.2 \pm 1.9 \pm 0.7) \%$$

$$\mathcal{B} = (14.21 \pm 0.38 \pm 0.85) \times 10^{-6}$$

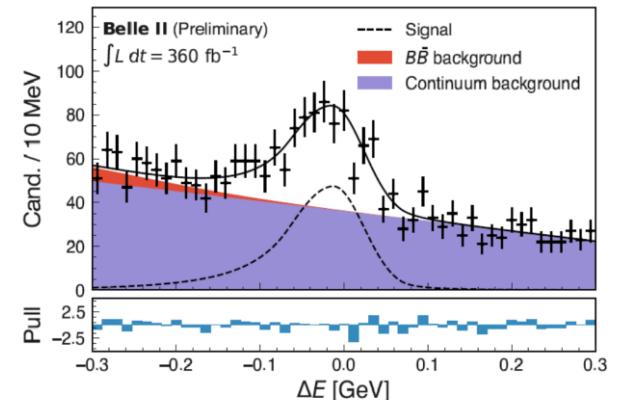
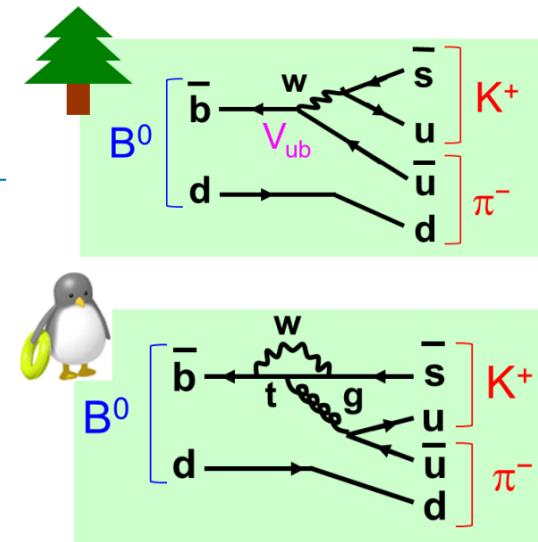
$$A_{CP} = (1.3 \pm 2.7 \pm 0.5) \%$$

$$\mathcal{B} = (24.40 \pm 0.71 \pm 0.86) \times 10^{-6}$$

$$A_{CP} = (4.6 \pm 2.9 \pm 0.7) \%$$

$$I_{K\pi} = -0.03 \pm 0.13 \pm 0.05$$

Agree with SM. Competitive with world average (-0.13 ± 0.11)



$$\mathcal{B}(B^0 \rightarrow K^0\pi^0) = [10.16 \pm 0.65(\text{stat}) \pm 0.65(\text{syst})] \times 10^{-6}$$

$$A_{K^0\pi^0} = -0.06 \pm 0.15(\text{stat}) \pm 0.05(\text{syst})$$

from the time-integrated analysis. This is combined with the time-dependent analysis.

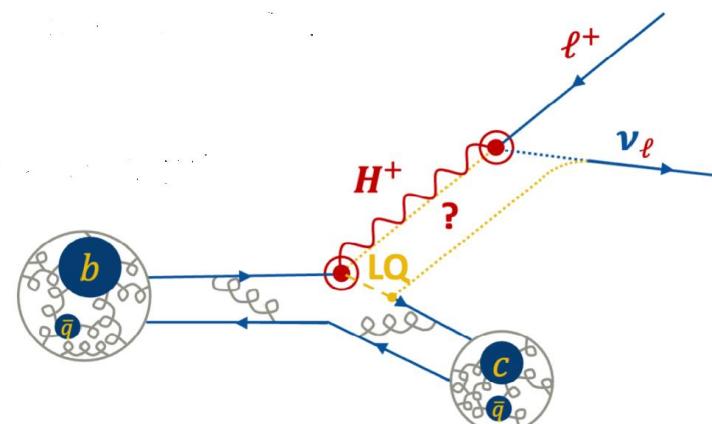
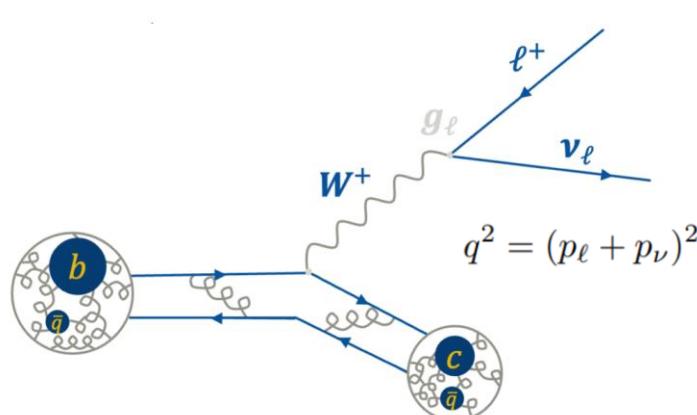
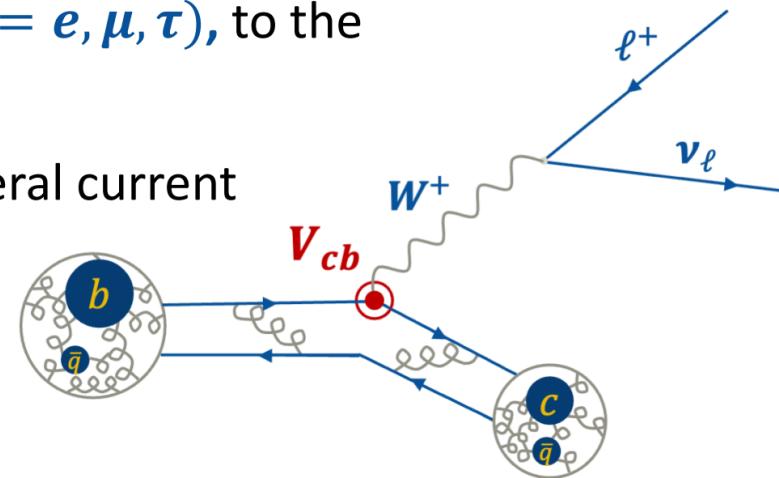
SEMILEPTONIC B -MESON DECAYS

- The **universality of the lepton coupling**, g_ℓ ($\ell = e, \mu, \tau$), to the electroweak gauge bosons **can be probed**

- Lepton universality (LU) is challenged by several current measurements. Deviations would be a clear sign of BSM physics

- SL B decays are studied to **determine the CKM elements $|V_{cb}|$ and $|V_{ub}|$**

- $|V_{cb}|$ are limiting the global constraining power of UT fits
- Important inputs in predictions of the SM rates for ultrarare decays such as $B_s \rightarrow \mu\nu$ and $K \rightarrow \pi\nu\nu$

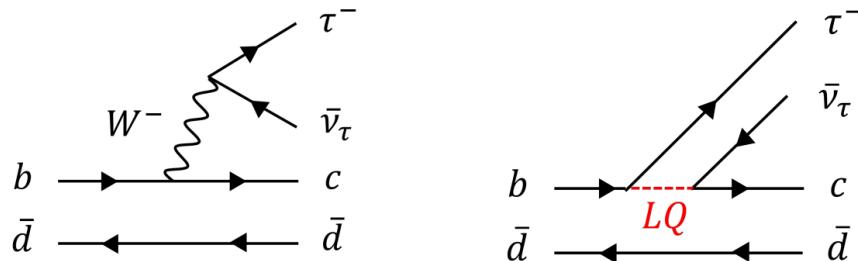


Anomalies in $b \rightarrow c$ decays

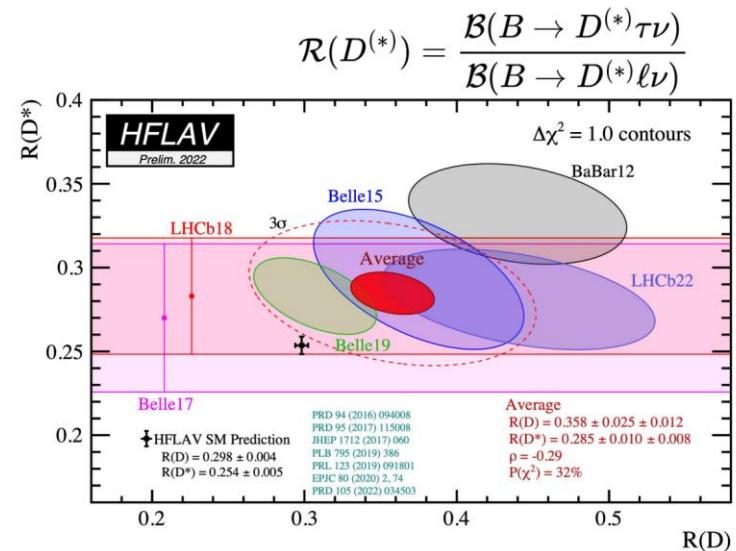
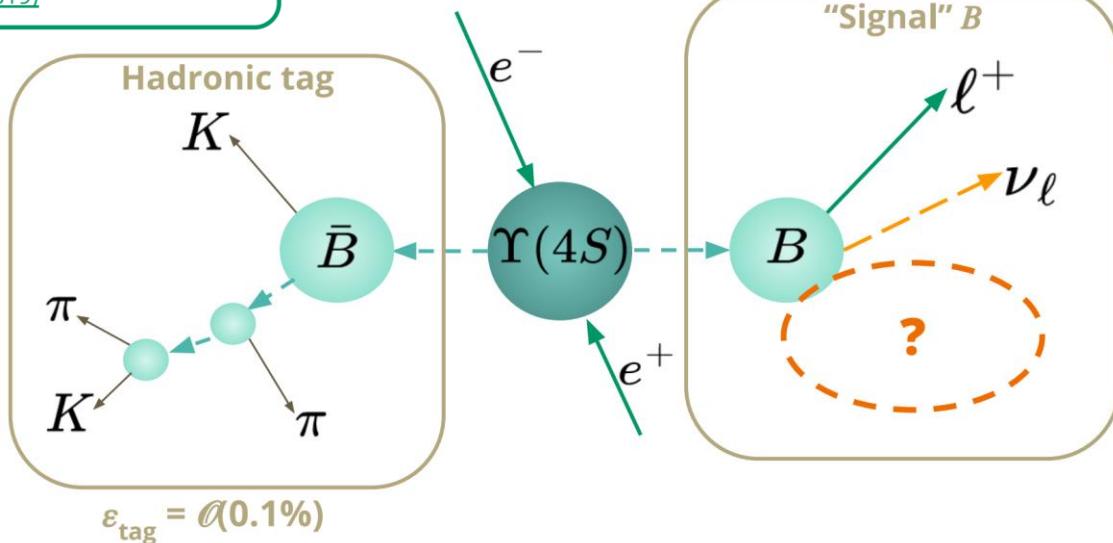
Standard Model assumes **lepton flavor universality**

(LFU): $g_e = g_\mu = g_\tau$

- Observed $\sim 3\sigma$ tension in $R(D^{(*)})$ could hint possible new physics scenarios



BDT-based algorithm: **Full Event Interpretation**
[Comput Softw Big Sci 3, 6 \(2019\)](#)



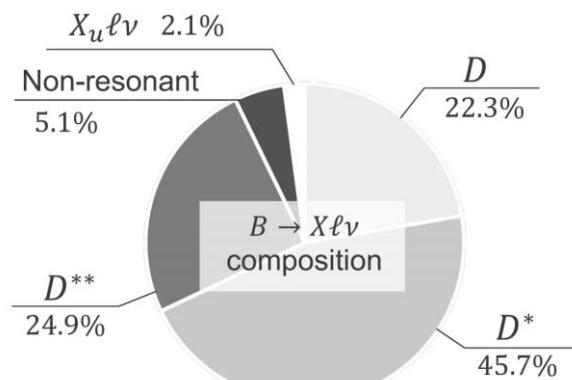
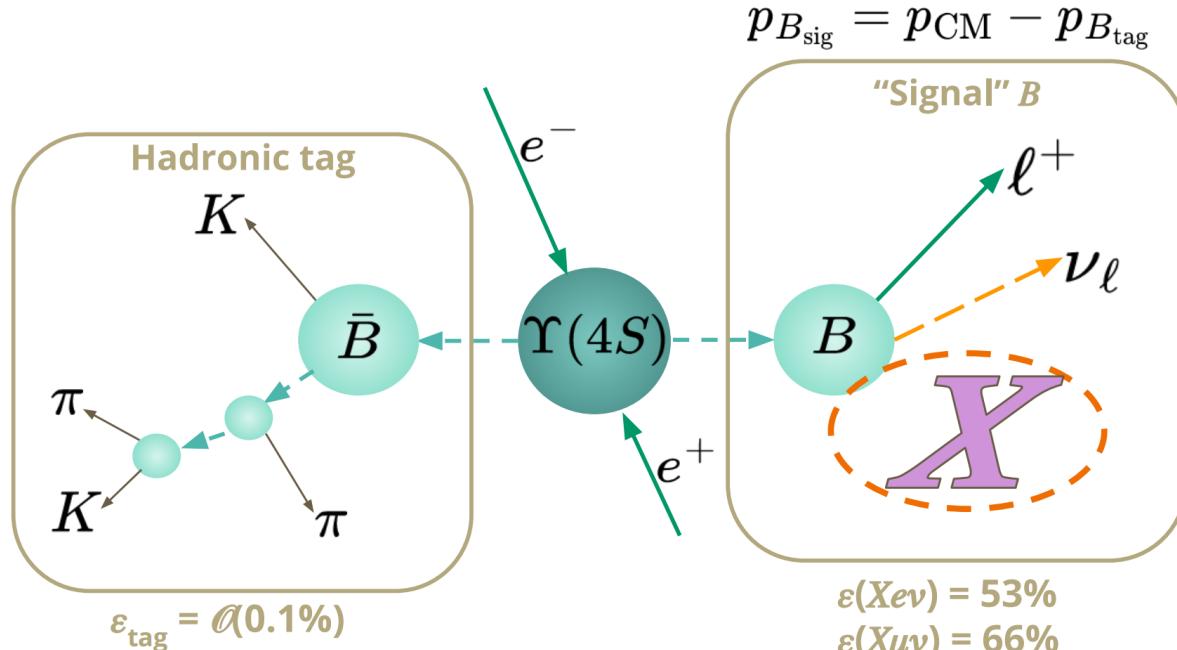
B -mesons are produced in pairs with opposite flavors

- Tag a B -meson (B_{tag}) in fully hadronic decays
 - $\mathcal{O}(0.1\%)$ efficiency of correctly reconstructed B_{tag}
- The other B -meson has well-defined energy and momentum

$R(X_{e/\mu})$

$$R(X_{e/\mu}) = \frac{\text{Br}(B \rightarrow X e \nu)}{\text{Br}(B \rightarrow X \mu \nu)}$$

arXiv:2301.08266
(submitted to PRL)



Signal modelling

- Tag a B -meson (B_{tag}) in **fully hadronic** decays
- Lepton momentum in B_{sig} rest-frame: $p_\ell^B > 1.3 \text{ GeV}/c$
 - reduce fakes and secondaries
 - suppress $B \rightarrow X \tau \nu$
 - if more leptons, keep the one with highest lepton-ID probability
- Rest of the event assigned to fully-inclusive X

$R(X_{e/\mu})$

Extract signal yields N^{meas} by fit in 10 bins of p_ℓ^B (simultaneously for e and μ -channel)

- Maximize binned likelihood, systematics included as nuisance parameters
- 3 model templates (for e, μ separately):
 - $X\ell\nu$ signal
 - continuum background
 - **other backgrounds** (fakes and secondaries)

Obtain N^{meas} by fit on signal-region data and evaluate $R(X)$, reweighting for signal efficiency:

$$R(X_{e/\mu}) = \frac{N_e^{\text{meas}}}{N_\mu^{\text{meas}}} \cdot \frac{\varepsilon_\mu}{\varepsilon_e}$$

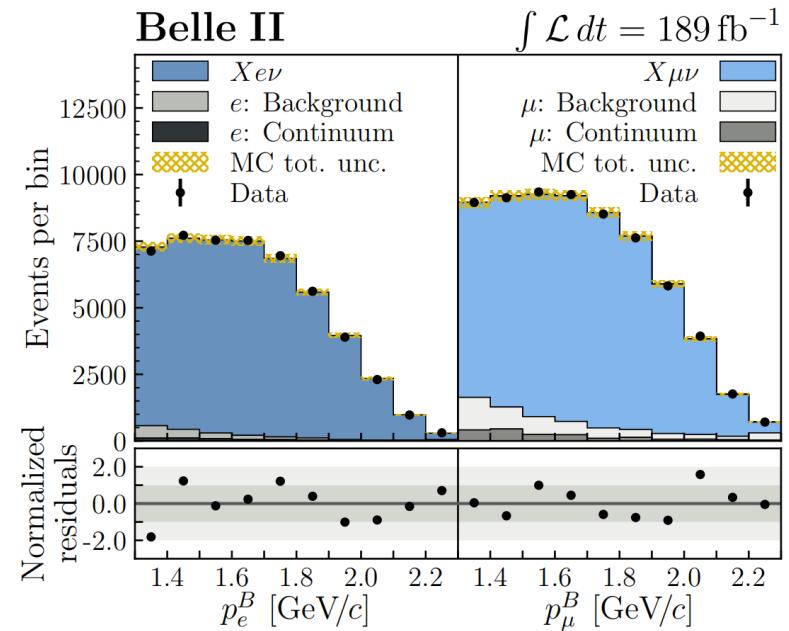
Signal **efficiency** ε for each channel is:

$$\varepsilon_\ell = \frac{N_\ell^{\text{sel}}}{N_\ell^{\text{gen}}} \quad \begin{aligned} \varepsilon_e &= (1.62 \pm 0.03) \times 10^{-3} \\ \varepsilon_\mu &= (2.04 \pm 0.05) \times 10^{-3} \end{aligned}$$

- N^{sel} → signal yield extracted by fit on MC
- N^{gen} → total generated signal events

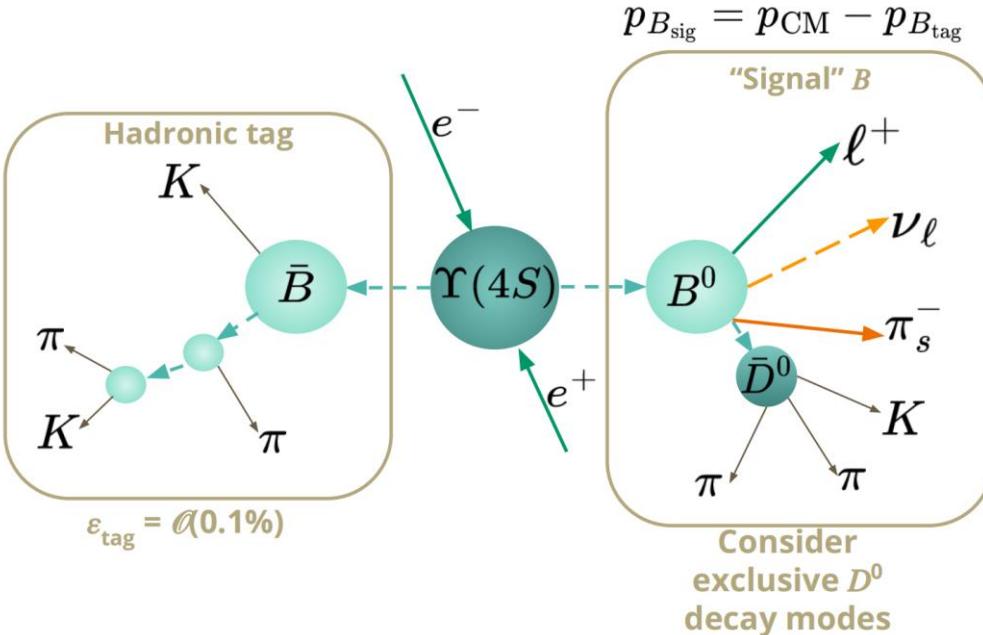
$$R(X_{e/\mu}) = 1.033 \pm 0.010(\text{stat}) \pm 0.019(\text{syst})$$

Most precise BF based lepton universality test in semileptonic decays to date



$R(X_{e/\mu})_{\text{SM}} = 1.006 \pm 0.001$
[JHEP11\(2022\)007](#)

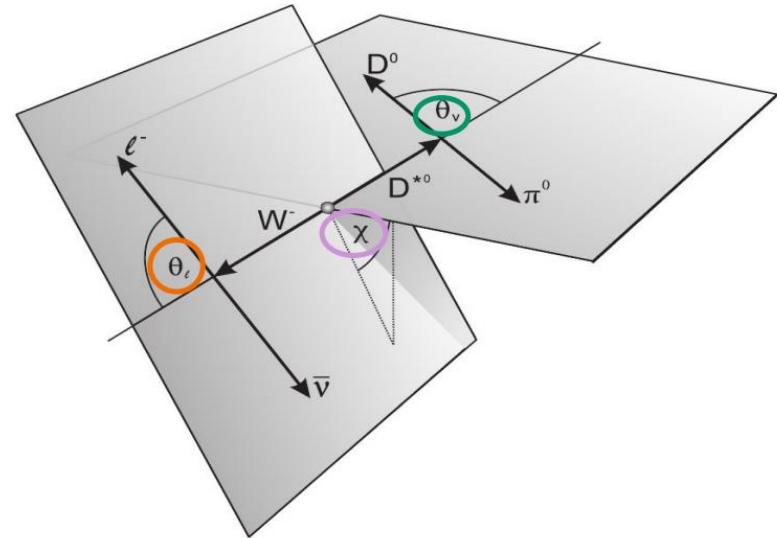
$B^0 \rightarrow D^* \ell \nu$ angular asymmetries



- Fully reconstruct a B -meson (B_{tag}) in **hadronic decay**
- Reconstruct signal-side $D^* \ell \nu$ **exclusively**
 - select one lepton with $p_\ell > 1.0 \text{ GeV}/c$
 - look for clean and abundant D^0 decay modes
 - combine with a charged slow pion: $D^* \rightarrow D^0 \pi_s$

Study semileptonic B decays to D^* vector

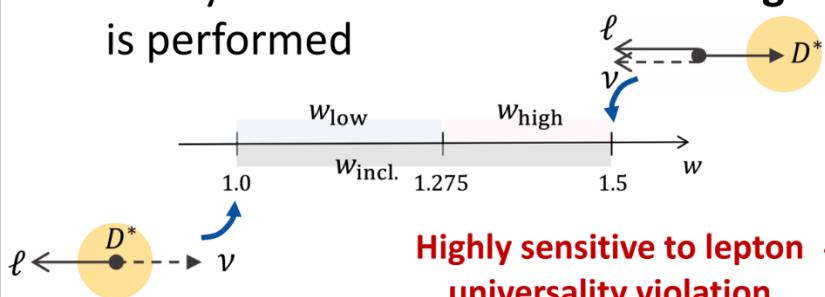
- **4 parameters** to fully describe $B \rightarrow D^* \ell \nu$ decay:
 - $q^2 = (p_B - p_{D^*})^2$
 - 3 helicity angles $\theta_\ell, \theta_V, \chi$



We measure **angular distributions asymmetries** as function of q^2
 World's first experimental measurement of complete set of angular asymmetries

$B^0 \rightarrow D^* \ell \nu$ angular asymmetries

- Light lepton universality tested by comparing **five angular asymmetries** of e and μ , $\Delta A_x = A_x^e - A_x^\mu$ using $B^0 \rightarrow D^{*-} \ell^+ \nu$ decays.
- The simultaneous determination of all asymmetries in **different w ranges** is performed



Less sensitive or insensitive to NP.
Control tests of the analysis method

Define a set of 5 asymmetries for angular observables x

$$A_x(w) = \left(\frac{d\Gamma}{dw} \right)^{-1} \left[\int_0^1 - \int_{-1}^0 \right] dx \frac{d^2\Gamma}{dw dx}$$

w : Recoil parameter $w = \frac{m_B^2 + m_{D^*}^2 - q^2 c^2}{2m_B m_{D^*}}$

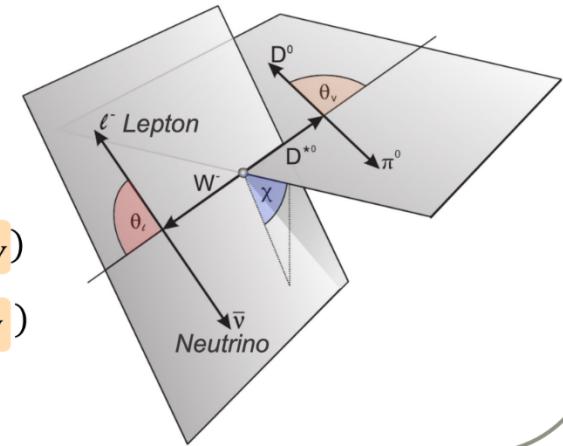
$$A_{FB}(w) : dx = d(\cos \theta_\ell)$$

$$S_3(w) : dx = d(\cos 2\chi)$$

$$S_5(w) : dx = d(\cos \chi \cos \theta_V)$$

$$S_7(w) : dx = d(\sin \chi \cos \theta_V)$$

$$S_9(w) : dx = d(\sin 2\chi)$$



$S_7(w)$ 0 in SM and NP

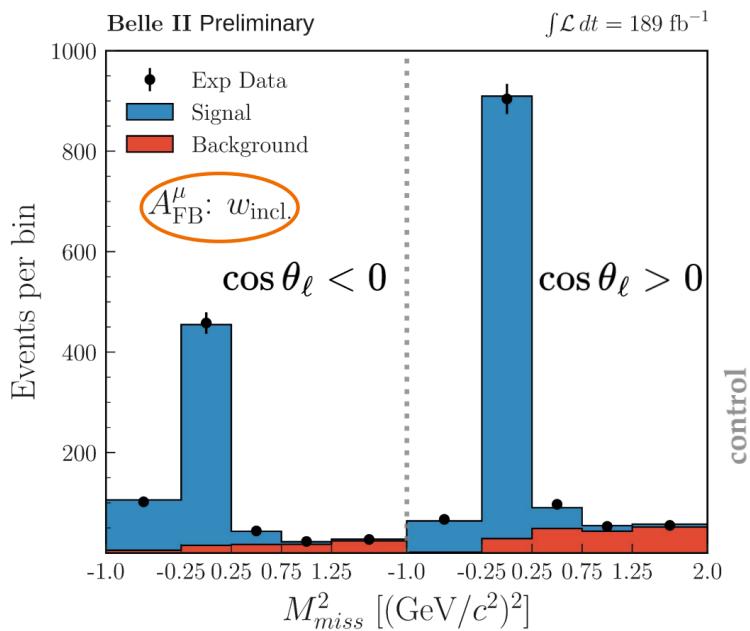
$S_9(w)$ 0 in SM and ~ 0 in NP

- Asymmetries A are **experimentally clean** (most systematics cancel)
- ΔA difference is **theoretically well-known** (form factors uncertainty cancel)

~4 σ deviation in ΔA_{FB} was claimed by theoretical reinterpretation of Belle data [[Eur. Phys. J. C 81, 984 \(2021\)](#), [Phys. Rev. D 103, 079901 \(2021\)](#)]

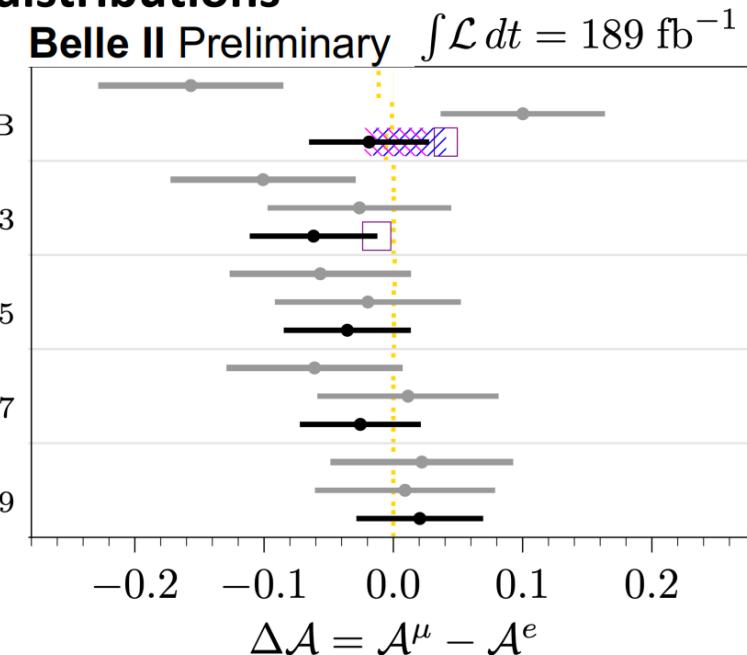
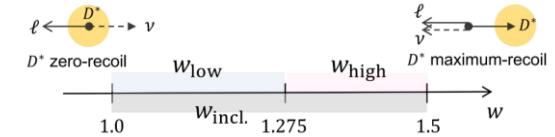
$B^0 \rightarrow D^* \ell \nu$ angular asymmetries

- The signal yields are extracted through a binned maximum-likelihood fit to M_{miss}^2 distributions



Observed overall **agreement** with Standard Model

χ^2/ndof	$w_{\text{incl.}}$	$w_{\text{low}} + w_{\text{high}}$
$\Delta A_{FB}, \Delta S_3, \Delta S_5$	2.1 / 3 ($p=0.56$)	10.2 / 6 ($p=0.12$)
$\Delta S_7, \Delta S_9$	0.6 / 2 ($p=0.32$)	1.1 / 4 ($p=0.89$)



Uncertainties
statistically dominated

- w_{high}
- w_{low}
- $w_{\text{incl.}}$
- SM
- Belle (2023) [\[2301.07529\]](#)
- Belle II (2023) [\[NEW\] arXiv:2301.04716](#)
- Bobeth, et al. [\[arXiv:2301.04716\]](#)

BELLE II'S $|V_{cb}|$ & $|V_{ub}|$ SUMMARIZED

Recent Belle II results on
exclusive decays:

Belle II Preliminary

$$|V_{cb}| \times 10^3$$

WA values (HFLAV 2021):

$$|V_{cb}|_{\text{excl}} = (39.10 \pm 0.50) \times 10^{-3}$$

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

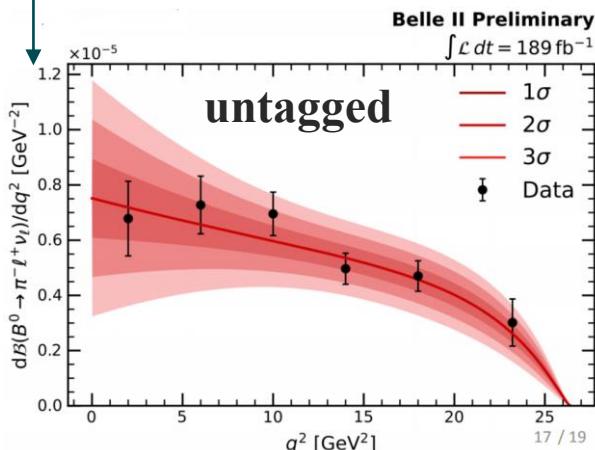
$B^0 \rightarrow D^{*-} \ell^+ \nu$ untagged	40.9 ± 1.2 (BGL) 40.4 ± 1.2 (CLN)	To be submitted to PRD
$B^0 \rightarrow D^{*-} \ell^+ \nu$ had. tagged	37.9 ± 2.7 (CLN)	arXiv:2301.04716
$B \rightarrow D \ell^+ \nu$ untagged	38.28 ± 1.16 (BGL)	arXiv:2210.13143

Belle II Preliminary

$$|V_{ub}| \times 10^3$$

[arXiv:2210.04224](https://arxiv.org/abs/2210.04224)

[arXiv:2206.08102](https://arxiv.org/abs/2206.08102)

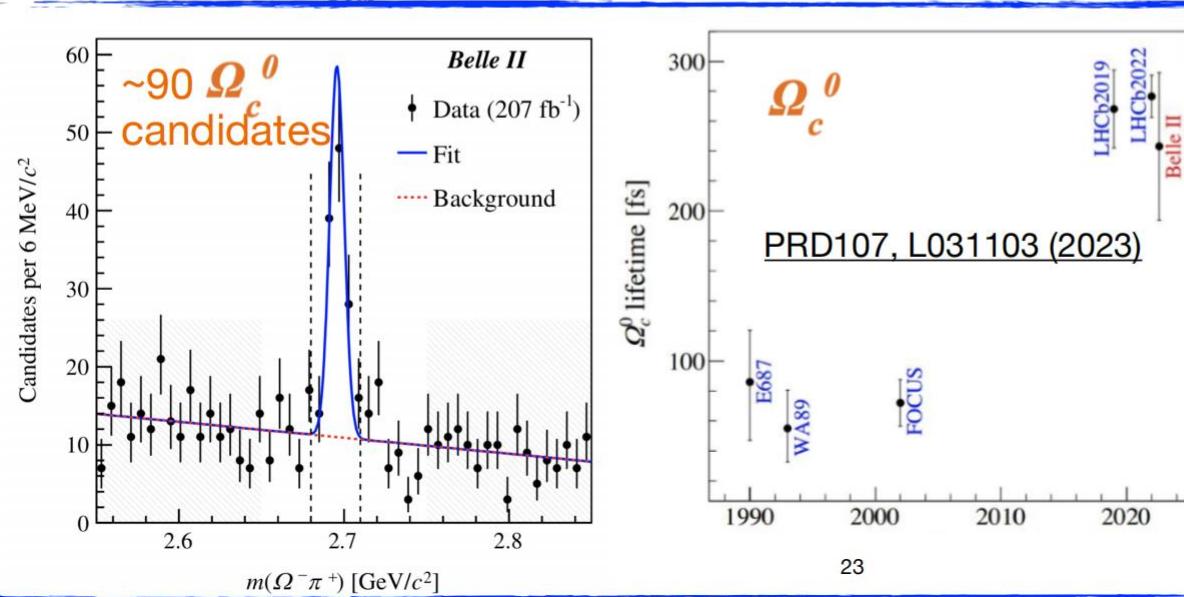
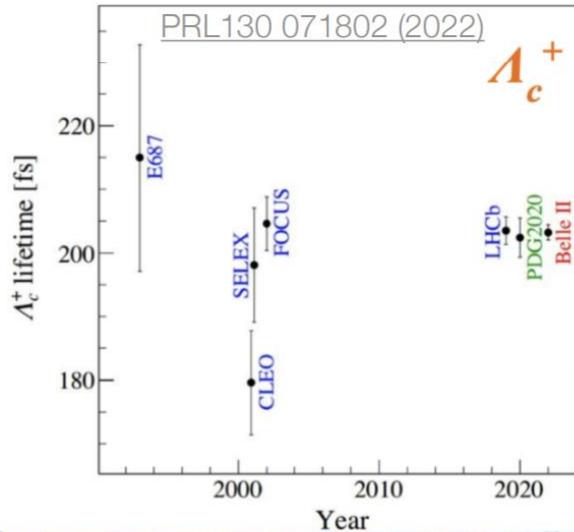
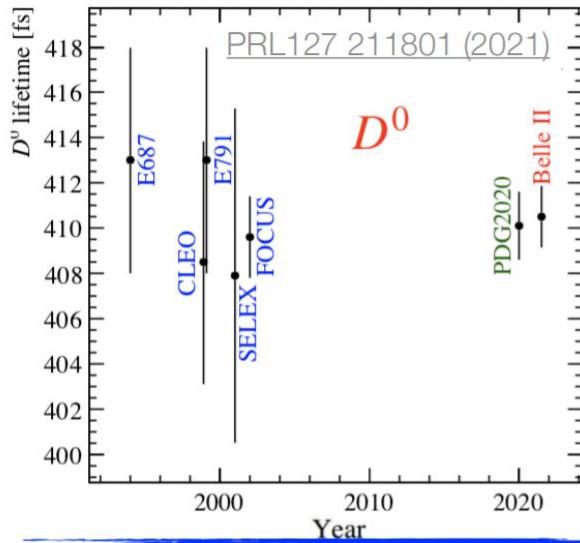


Two form factor
parametrization:

Boyd, Grinstein, Lebed (BGL)
[\[Phys. Rev. D56, 6895 \(1997\)\]](https://doi.org/10.1103/PhysRevD.56.6895)

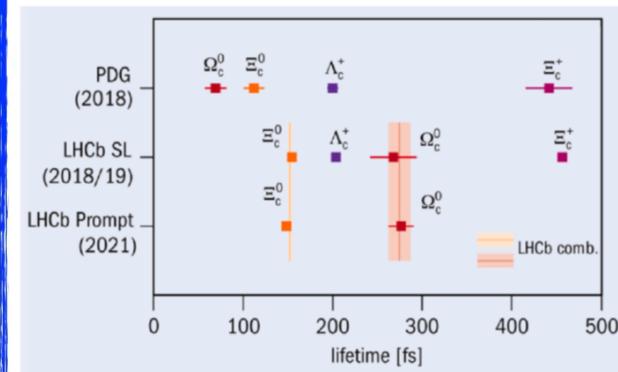
Caprini, Lellouch, Neubert (CLN)
[\[Nucl. Phys. B530, 153 \(1998\)\]](https://doi.org/10.1016/S0550-3213(97)00617-7)

Charm lifetimes benchmark



World's best measurements of D and Λ_c lifetimes, pushing the limit to few per-mill accuracy.

Excellent performance
and alignment of our
vertex detector
established.



What τ decays may tell us

- Tau properties: mass, lifetime, edm, g-2
- Tau polarization \rightarrow e- τ universality, $\sin^2\theta_W$
- Tau decay parameters \rightarrow Lorentz structure of the charged current
- Lepton Universality (e- μ - τ)
- Asymptotic behavior of QCD ($\alpha_s(s)$)
- Strange quark mass (m_s) & CKM matrix element ($|V_{us}|$)
- Test CVC (HVP \rightarrow a_μ and running α)
- Second class currents
- BSM: LFV, LNV, BNV, CPV.....

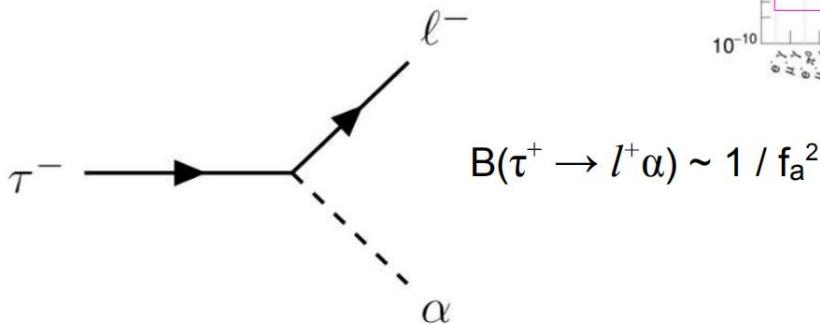
$$\sigma(e^+e^- \rightarrow \tau^+\tau^-) = 0.92 \text{ nb}$$

- ➔ High precision identification of all τ decay modes
- ➔ High precision measurement of τ decay branching fractions (BF) & hadronic spectral functions (SF)

$\tau^+ \rightarrow l^+ \alpha$ (invisible boson)

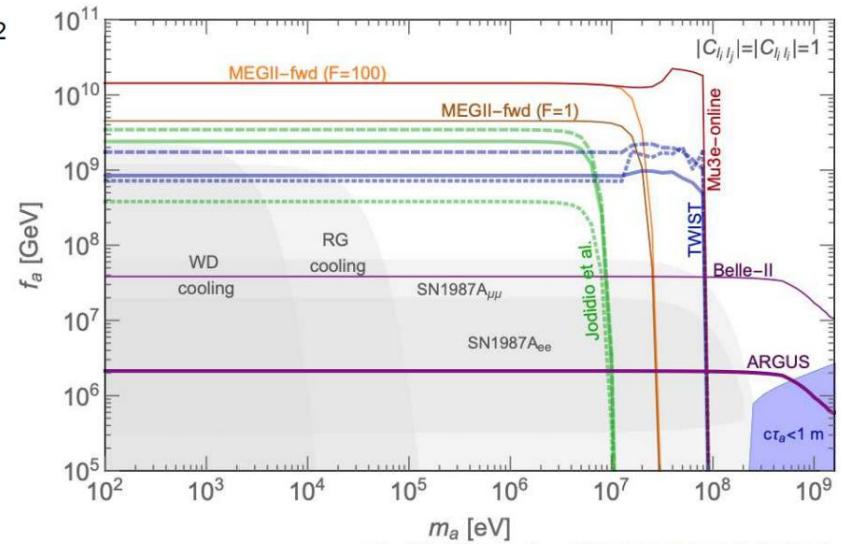
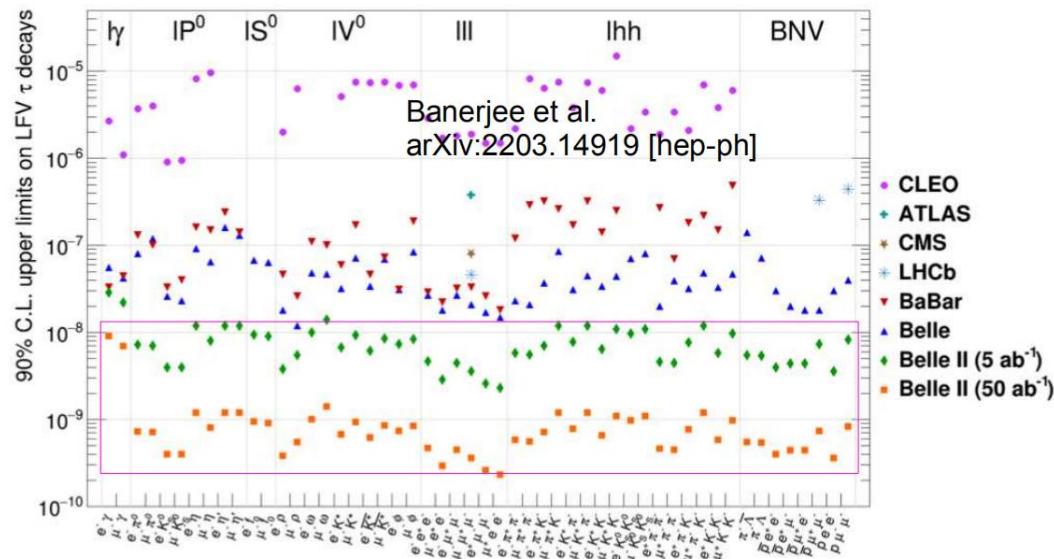
B factories are also tau lepton factories: ~ 1 million $\tau^+\tau^-$ pairs per fb^{-1}

- Dedicated low-multiplicity trigger lines to ensure high efficiency
- Neutrino-less and Lepton Flavour Violating (LFV) tau decays are a sensitive probe of new physics



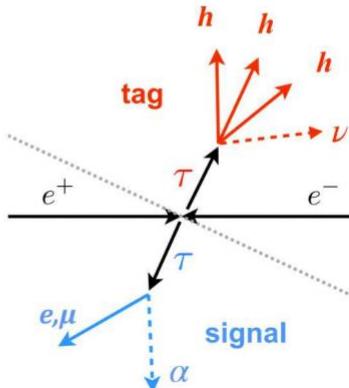
$\tau^+ \rightarrow l^+ \alpha$ can arise in new physics models such as light long-lived ALPs

- Long-lived α does not interact in detector
- Previous results from ARGUS, hence accessible to Belle II with early data

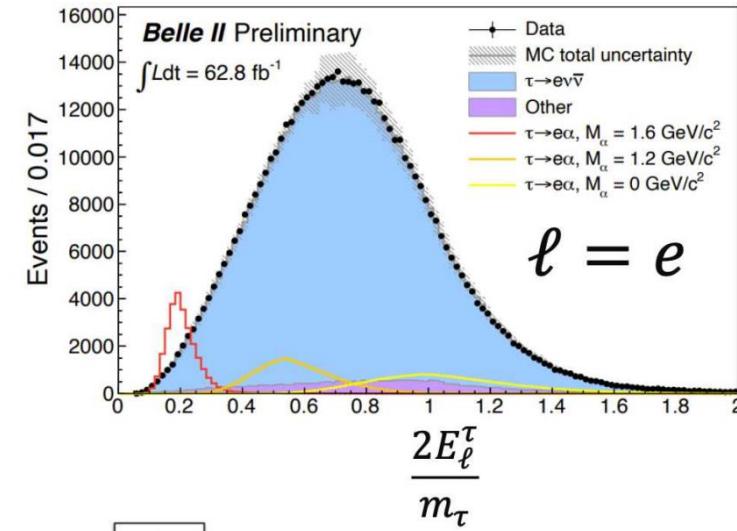


$\tau^+ \rightarrow l^+ \alpha$ (invisible boson)

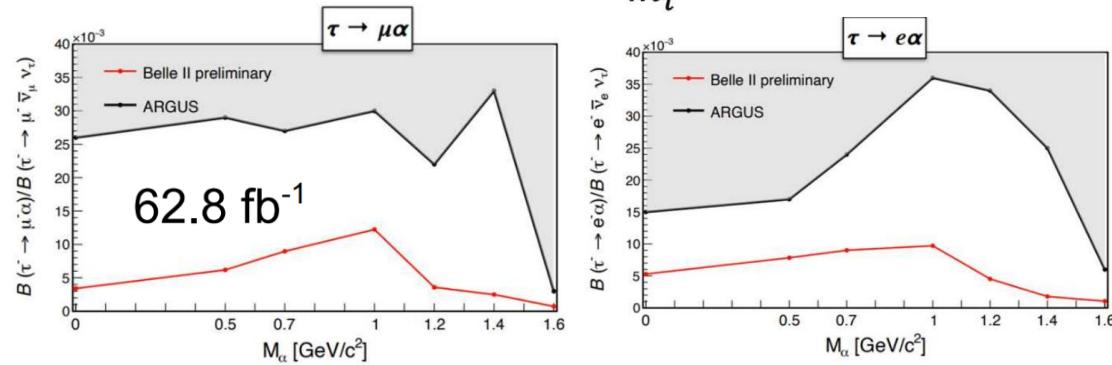
At B factories, $\tau^+\tau^-$ pairs are produced back to back and boosted:



- Signal is similar to $\tau^+ \rightarrow l^+ \nu \bar{\nu}$, except that the lepton is mono-energetic in the τ rest frame
- “Bump hunt” in the lepton energy spectrum
- Signal peak smeared by resolution of τ rest frame determination from $\pi^+\pi^-\pi^+$ system:



- Require a 1 - 3 event topology, i.e. 4 tracks with $\tau^+ \rightarrow \pi^+\pi^-\pi^+\nu$ in one event “hemisphere”
- Veto events with additional neutrals (γ, π^0)
- Backgrounds from continuum $q\bar{q}$, di-lepton and 4-fermion sources

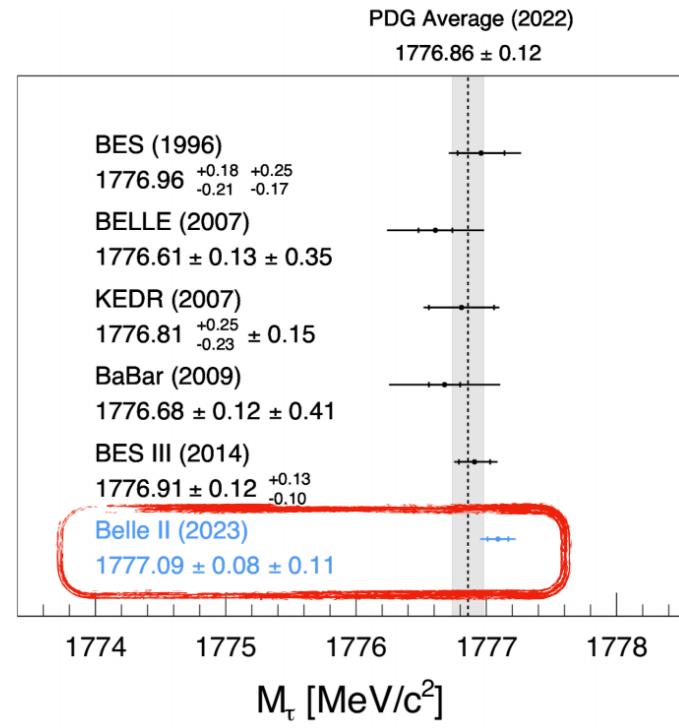
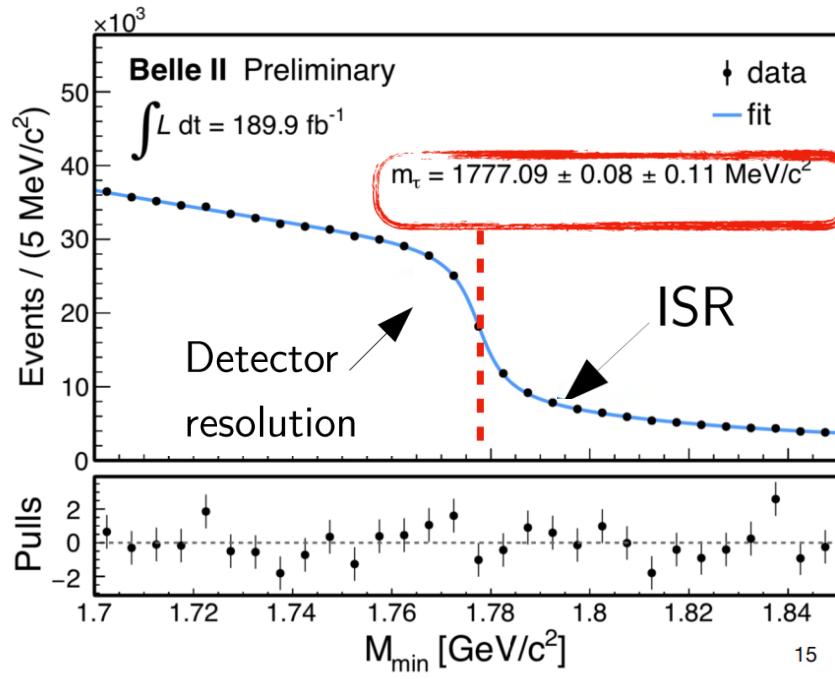


Precision τ physics

High production of $e^+e^- \rightarrow \tau^+\tau^-$ events allow high-precision measurements of τ properties (mass, lifetime, edm...) and search for LFV decays.

Obtain world best τ mass measurement using $\tau^+ \rightarrow \pi^+\pi^-\pi^+\nu$ decays.
Crucial knowledge of beam-energy and its resolution.

$$M_{\min} = \sqrt{M_{3\pi}^2 + 2(\cancel{\sqrt{s}/2} - E_{3\pi}^*)(E_{3\pi}^* - P_{3\pi}^*)} \leq M_\tau.$$



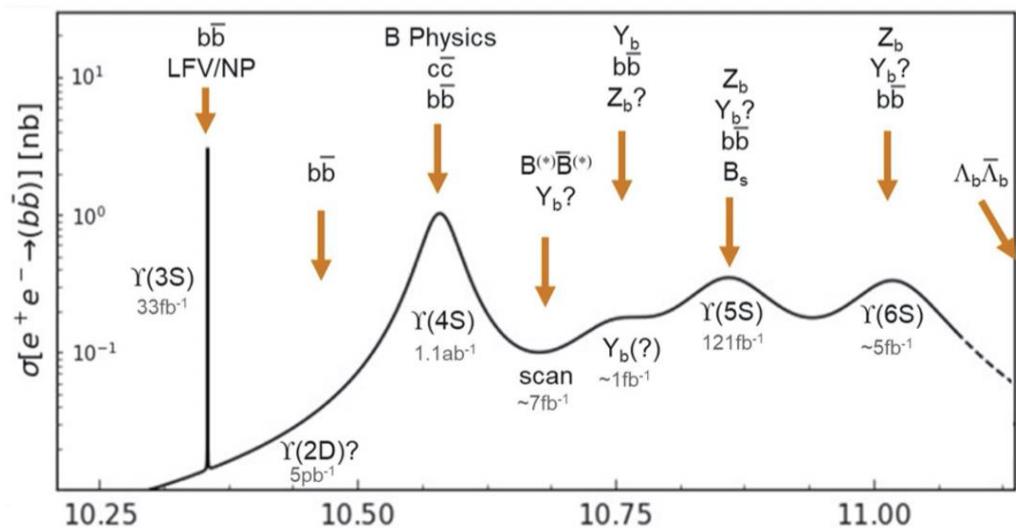
Bottomonium(-like) prospects at Belle II

Run at $\Upsilon(6S)$ and $\Upsilon(5S)$ and high energy scan:

- Search for new missing bottomonia $\eta_b(3S)$, $h_b(3P)$, $\Upsilon(D)$, exotic states Y_b , Z_b , etc
- Improve precision of already known processes and states, e.g., Z_b
- Measure the effect of the coupled channel contribution
- Study $B^{(*)}\bar{B}^{(**)}$ and $B_s^{(*)}\bar{B}_s^{(**)}$ threshold regions (challenging for Super-KEKB)

Run at $\Upsilon(3S)$ and $\Upsilon(2S)$:

- Search for missing $\pi\pi/\eta$ transitions in inclusive decays to constrain further models
- Search for new physics: LFV, LFU, light Higgs, ...



Observation of $e^+e^- \rightarrow \omega\chi_{bJ}$ at \sqrt{s} near 10.75 GeV

- Belle: several $\sim 1\text{ fb}^{-1}$ scan points below $\Upsilon(5S)$
 - New structure observed in $\pi^+\pi^-\Upsilon(nS)$ transitions

	$\Upsilon(10860)$	$\Upsilon(11020)$	New structure
M (MeV/c ²)	$10885.3 \pm 1.5^{+2.2}_{-0.9}$	$11000.0^{+4.0}_{-4.5}{}^{+1.0}_{-1.3}$	$10752.7 \pm 5.9^{+0.7}_{-1.1}$
Γ (MeV)	$36.6^{+4.5}_{-3.9}{}^{+0.5}_{-1.1}$	$23.8^{+8.0}_{-6.8}{}^{+0.7}_{-1.8}$	$35.5^{+17.6}_{-11.3}{}^{+3.9}_{-3.3}$

- Theoretical interpretations

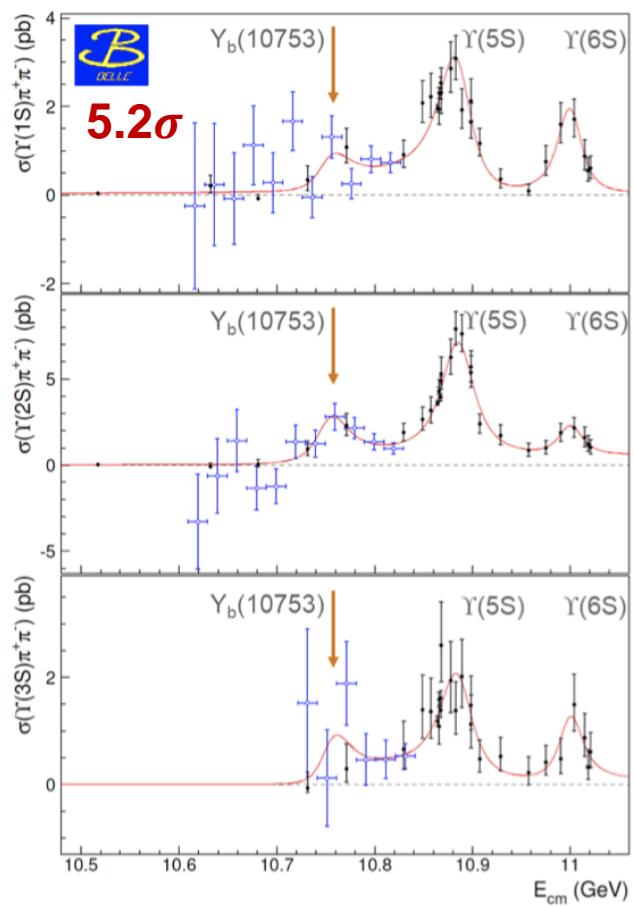
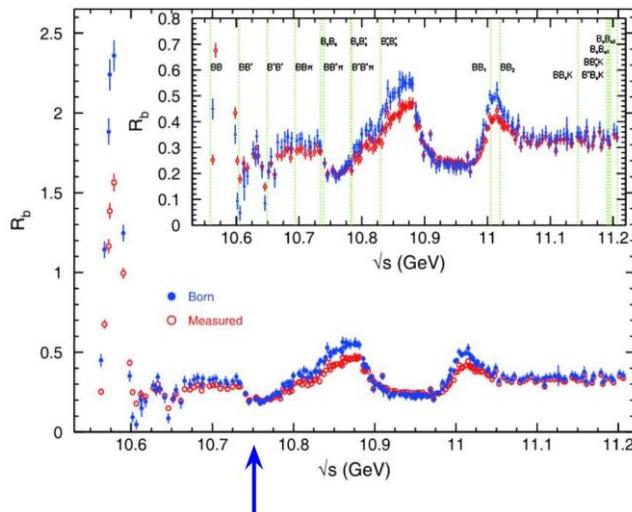
JHEP 10, 220 (2019)

Conventional D- or S-D mixed bottomonium:

PRD 105, 074007 (2022), PRD 104, 034036 (2021)
 EPJC 80, 59 (2020), PRD 101, 397 014020 (2020)
 PRD 102, 014036399 (2020), EPJP 137, 357 (2022)
 PRD 105, 114041 (2022), PLB 803, 135340 (2020)
 arXiv:2204.11915, Prog. Part. Nucl. Phys. 117, 103845 (2021)

A tetraquark:

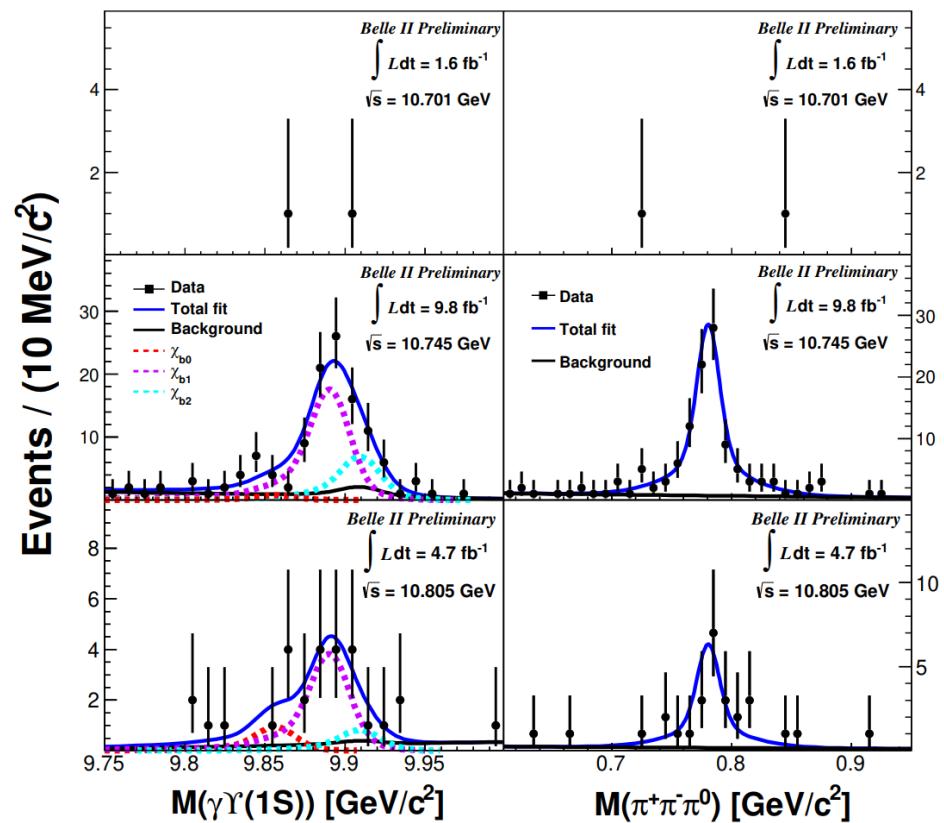
PLB 802, 135217 (2020)
PRD 103, 074507 (2021)
arXiv:2205.11475
Chin. Phys. C 43, 123102 (2019)



- Interpretations as an admixture of the conventional 4S and 3D states predict comparable branching fractions of 10^{-3} for $\Upsilon(10753) \rightarrow \pi^+ \pi^- \Upsilon(nS)$ and $\Upsilon(10753) \rightarrow \omega \chi_{bJ}$ [PRD 104, 034036 (2021), PRD 105, 074007 (2022)].

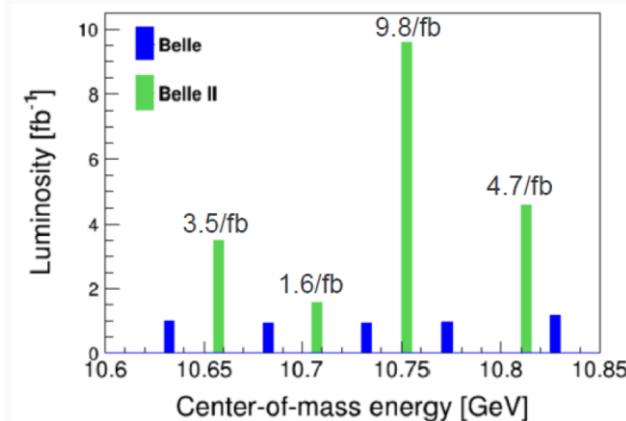
Observation of $e^+e^- \rightarrow \omega\chi_{bJ}$

PRL 130, 091902 (2023)



Two dimensional unbinned maximum likelihood fits to the $M(\gamma\Upsilon(1S))$ and $M(\pi^+\pi^-\pi^0)$ distributions.

Note that the $\sigma_{\text{Born}}(e^+e^- \rightarrow \omega\chi_{b1}/\omega\chi_{b2})$ is only $(0.76 \pm 0.16)/(0.29 \pm 0.14)$ pb at $\sqrt{s} = 10.867$ GeV [PRL 113, 142001(2014)].

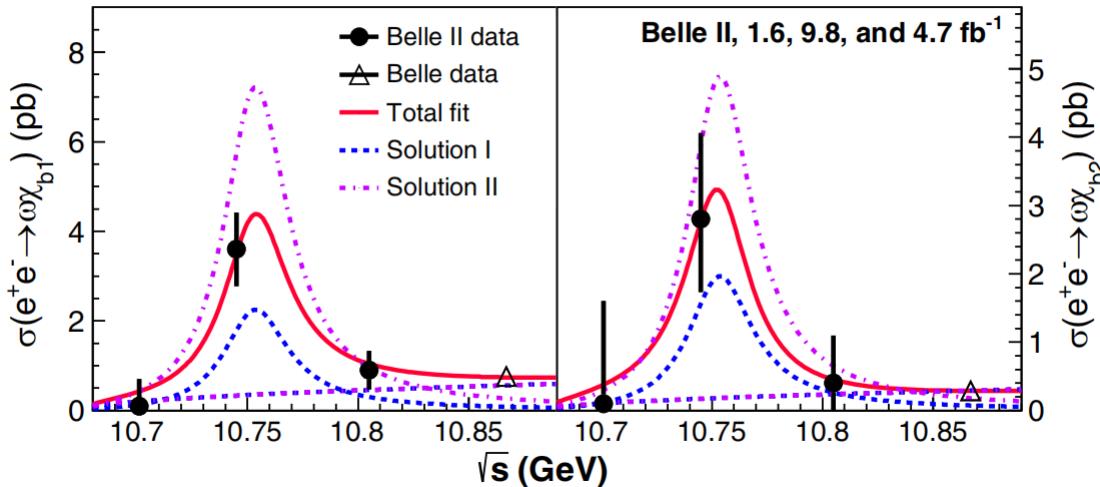


Channel	\sqrt{s} (GeV)	N^{sig}	$\sigma_{\text{Born}}^{(\text{UL})}$ (pb)
$\omega\chi_{b1}$	10.745	$68.9^{+13.7}_{-13.5}$	$3.6^{+0.7}_{-0.7} \pm 0.5$
$\omega\chi_{b2}$		$27.6^{+11.6}_{-10.0}$	$2.8^{+1.2}_{-1.0} \pm 0.4$
$\omega\chi_{b1}$	10.805	$15.0^{+6.8}_{-6.2}$	$1.6 @ 90\% \text{ C.L.}$
$\omega\chi_{b2}$		$3.3^{+5.3}_{-3.8}$	$1.5 @ 90\% \text{ C.L.}$

The total χ_{bJ} signal significances are 11.1σ and 4.5σ at $\sqrt{s} = 10.745$ and 10.805 GeV.

Observation of $\Upsilon(10753) \rightarrow \omega\chi_{bJ}$

PRL 130, 091902 (2023)



The $e^+e^- \rightarrow \omega\chi_{bJ}$ ($J = 1, 2$) cross sections peak at $\Upsilon(10753)$.

Fit cross section with function:

$$\begin{aligned} & \sigma_{e^+e^- \rightarrow \omega\chi_{b1}}(\sqrt{s}) \\ &= | \sqrt{PS_2(\sqrt{s})} \\ &+ BW(\sqrt{s})e^{i\phi}|^2, BW(\sqrt{s}) \\ &= \frac{\sqrt{12\pi\Gamma_{ee}\mathcal{B}_f\Gamma}}{s - M^2 + iM\Gamma} \sqrt{\frac{PS_2(\sqrt{s})}{PS_2(M)}} \end{aligned}$$

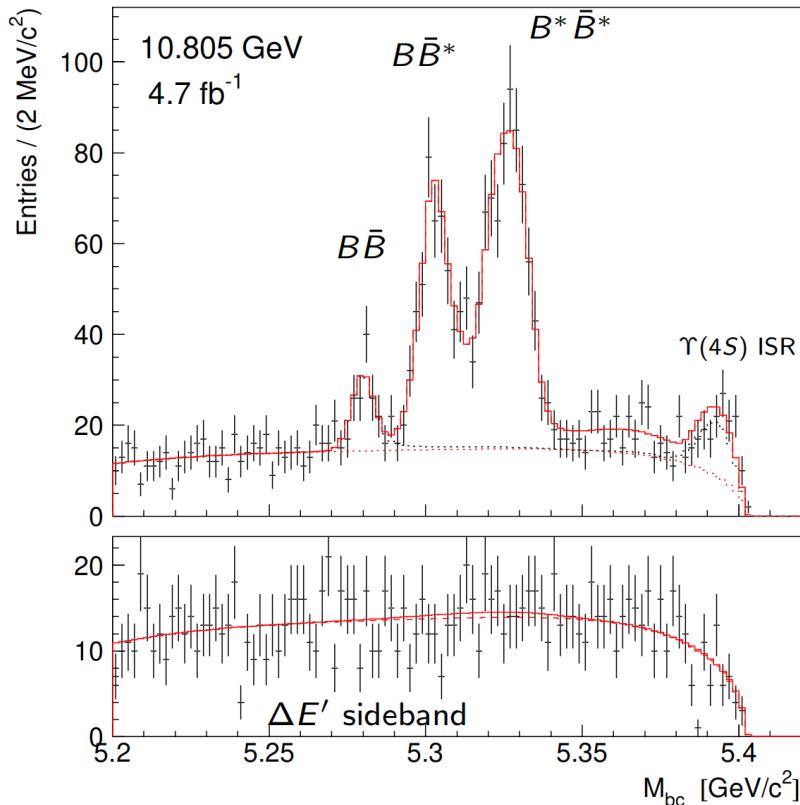
M and Γ of $\Upsilon(10753)$ are fixed according to Ref. [JHEP 10, 220(2019)].

$\Gamma_{ee}\mathcal{B}_f$	Solution I (constructive interference)	Solution II (destructive interference)
$\Gamma_{ee}\mathcal{B}(\Upsilon(10753) \rightarrow \omega\chi_{b1})$	$(0.63 \pm 0.39 \pm 0.20)$ eV	$(2.01 \pm 0.38 \pm 0.76)$ eV
$\Gamma_{ee}\mathcal{B}(\Upsilon(10753) \rightarrow \omega\chi_{b2})$	$(0.53 \pm 0.46 \pm 0.15)$ eV	$(1.32 \pm 0.44 \pm 0.55)$ eV

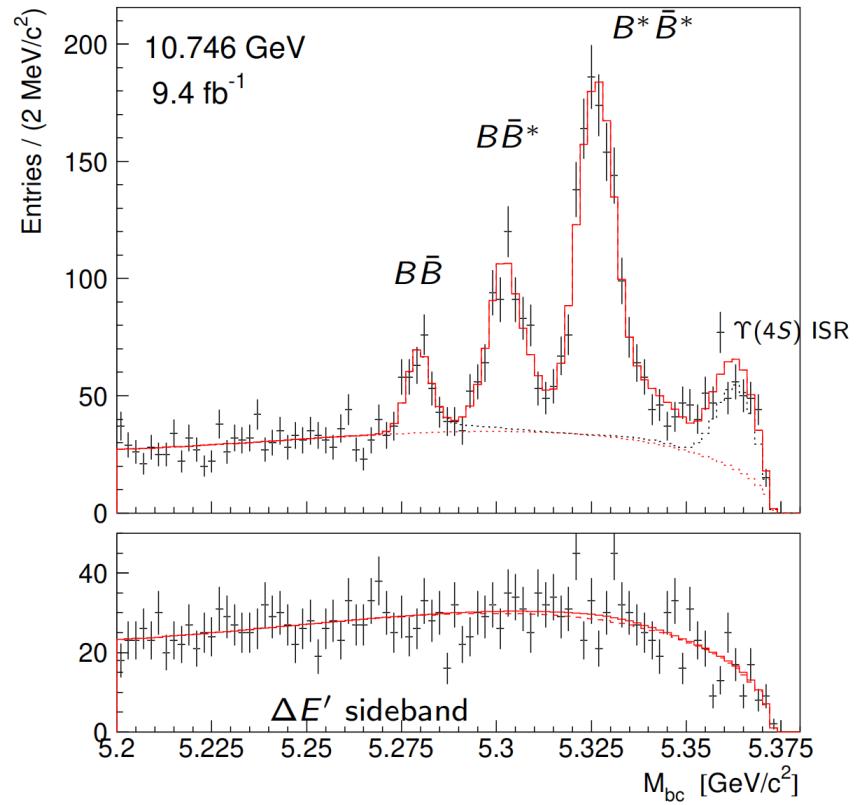
1. $\sigma(e^+e^- \rightarrow \omega\chi_{b1})/\sigma(e^+e^- \rightarrow \omega\chi_{b2}) = 1.3 \pm 0.6$ at 10.745 GeV, contradicts the expectation for a pure D-wave bottomonium state of 15 [PLB 738, 172 (2014)]
2. There is also a 1.8σ difference with the prediction for a S-D-mixed state of 0.2 [PRD 104, 034036 (2021)]

Measurement of the energy dependence of the $e^+e^- \rightarrow B\bar{B}$, $B\bar{B}^*$, $B^*\bar{B}^*$ cross sections

4.7 fb^{-1}

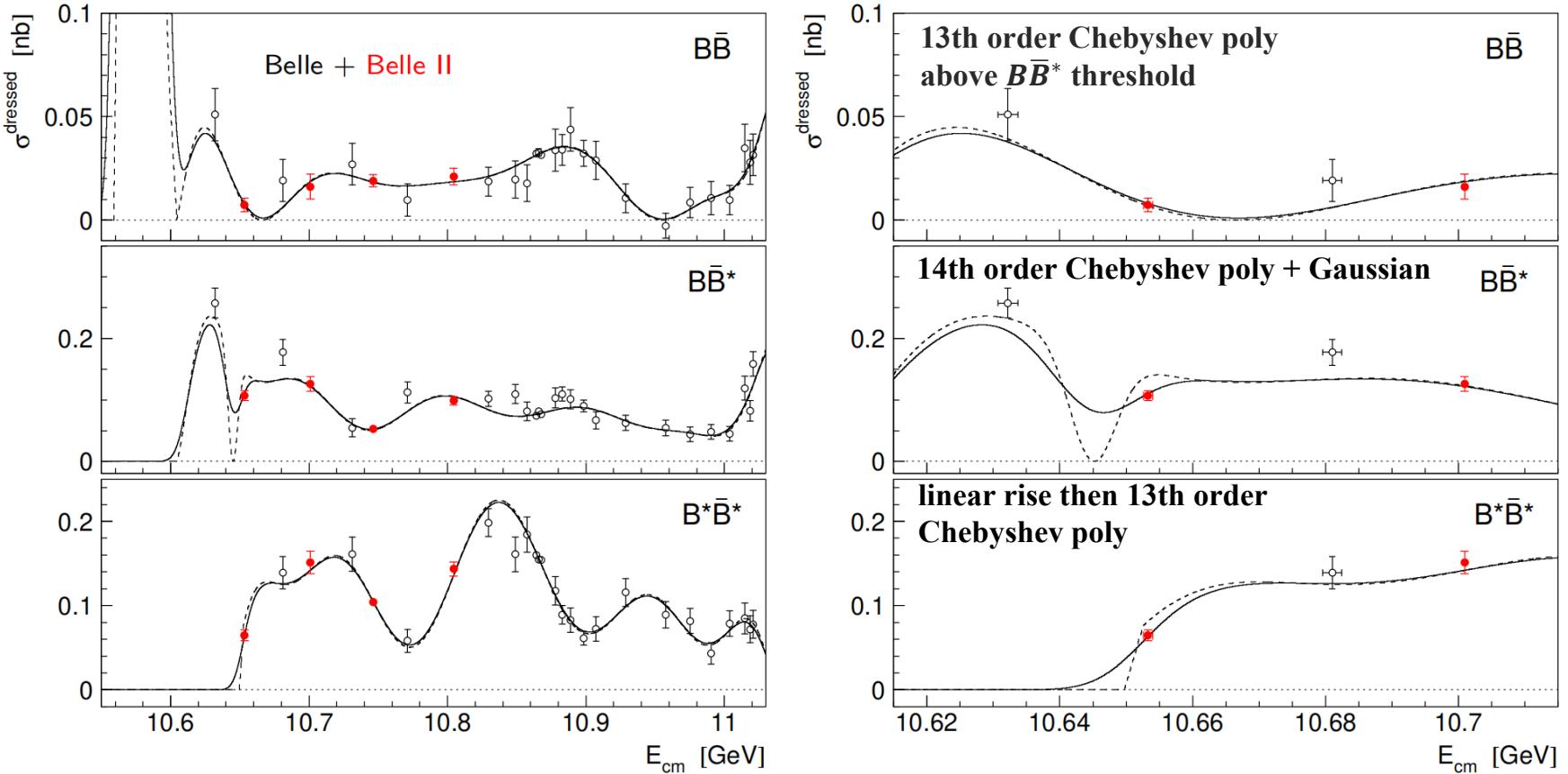


9.8 fb^{-1}



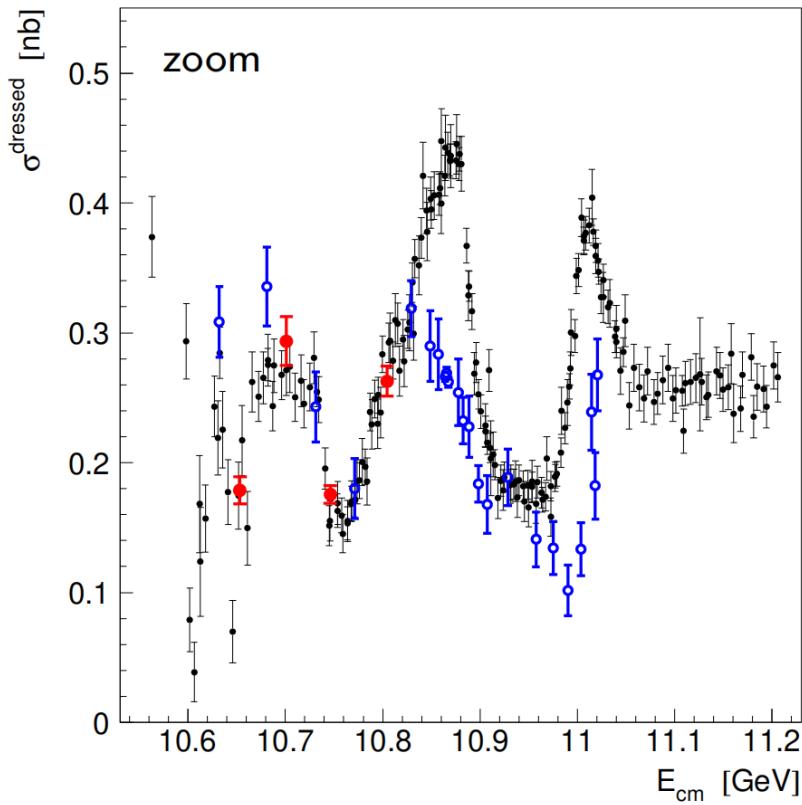
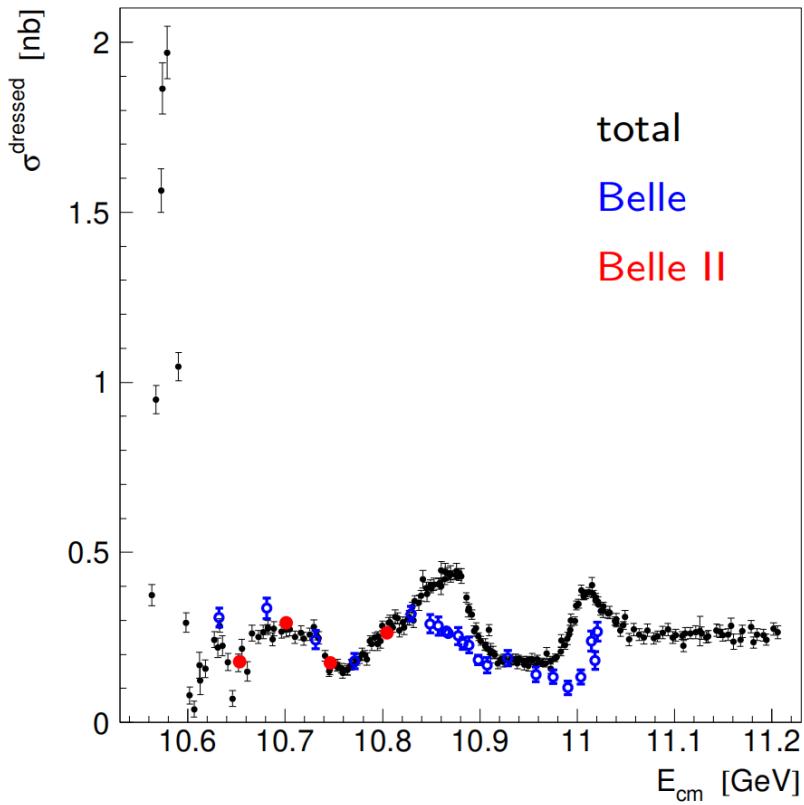
At 4 Belle II energy points, we can see clear signals of $e^+e^- \rightarrow B\bar{B}$, $B\bar{B}^*$, $B^*\bar{B}^*$, where one B meson is reconstructed in hadronic channels, and signals are identified using $M_{bc} = \sqrt{(E_{cm}/2)^2 - P_B^2}$

Energy dependence of the $e^+e^- \rightarrow B\bar{B}, B\bar{B}^*, B^*\bar{B}^*$ cross



- New: rapid increase of $\sigma_{B^*\bar{B}^*}$ above the threshold.
- Together with dip in $\sigma_{B\bar{B}^*}$, could be a signal of a $B^*\bar{B}^*$ bound state.
similar phenomena near the $D^*\bar{D}^*$ threshold – Dubynskiy, Voloshin, MPLA **21**, 2779 (2006).
- Inelastic channels [$\Upsilon(nS)\pi\pi$, $h_b(1P)\eta\dots$] could be enhanced – need more data.

$\sigma_{b\bar{b}}$ vs. $\sigma_{B\bar{B}} + \sigma_{B\bar{B}^*} + \sigma_{B^*\bar{B}^*}$



- Agreement at low energy – cross check.
- Departure above $B_s^* \bar{B}_s^*$ threshold: production of B_s , three body $B^{(*)} \bar{B}^{(*)} \pi$, and bottomonium.

Long-shutdown activity and plans

Belle II stopped taking data in Summer 2022 for a long shutdown for

- replacement of beam-pipe
- replacement of photomultipliers of the central PID detector (TOP)
- installation of 2-layered pixel vertex detector
- improved data-quality monitoring and alarm system
- complete transition to new DAQ boards (PCIe40)
- replacing of ageing components
- additional shielding and increased resilience against beam background

Currently working on pixel detector installation:

- shipping to KEK in mid March
- final test in KEK scheduled in April

On track to resume data taking next Winter with new pixel detector.

Belle II 中国组

- 单位数：高能所，中科大，北大，北航，复旦，辽宁师大，苏大，山大，南京师大，湖南师大，河南师大，郑大，东南大学，南开，吉大共15个。
- 人员：89人
 - 物理分析：奇特态，强子谱，B物理，粲物理， τ 物理。。
 - 硬件：DAQ, trigger, PXD, HLT, KLM, (PXD)…
 - 探测器运行：BelleII, KLM, HLT, 现在主要是remote
 - Performance: luminosity, calibration, ECL, KLM, …
 - Data production.

Country	Amount ↓	Female Members	Male Members
Germany	236	52	182
Japan	171	26	145
U.S.A.	122	15	106
Italy	108	25	82
China	89	28	61
France	65	11	54
India	65	17	48



第五届Belle II中国组研讨会，2023.4.7—4.10，河南师范大学

Summary & prospects

- SuperKEKB/Belle II is the luminosity frontier project to search for physics beyond SM with ultimate sensitivity.
- The project has achieved so far, by Summer 2022;
 - $L_{\text{peak}} = 4.7 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ (the world highest luminosity)
 - $L_{\text{int}} = 428 \text{ fb}^{-1}$ (similar to BaBar, about 1/2 of Belle)
- Many physics results are coming.
 - Benefited by improved detector performance and analysis technique!
 - Some of them are already world-leading!
- Currently, we are in the long shutdown I (LSI). Many components are to be improved.
 - We plan to resume in the coming winter, and will try to achieve higher luminosity.
- LS2 is planned for the major upgrade of the IR region and detector subsystems to further boost the luminosity frontier!





感谢您的批评指正

沈成平

shencp@fudan.edu.cn



B-factory classic

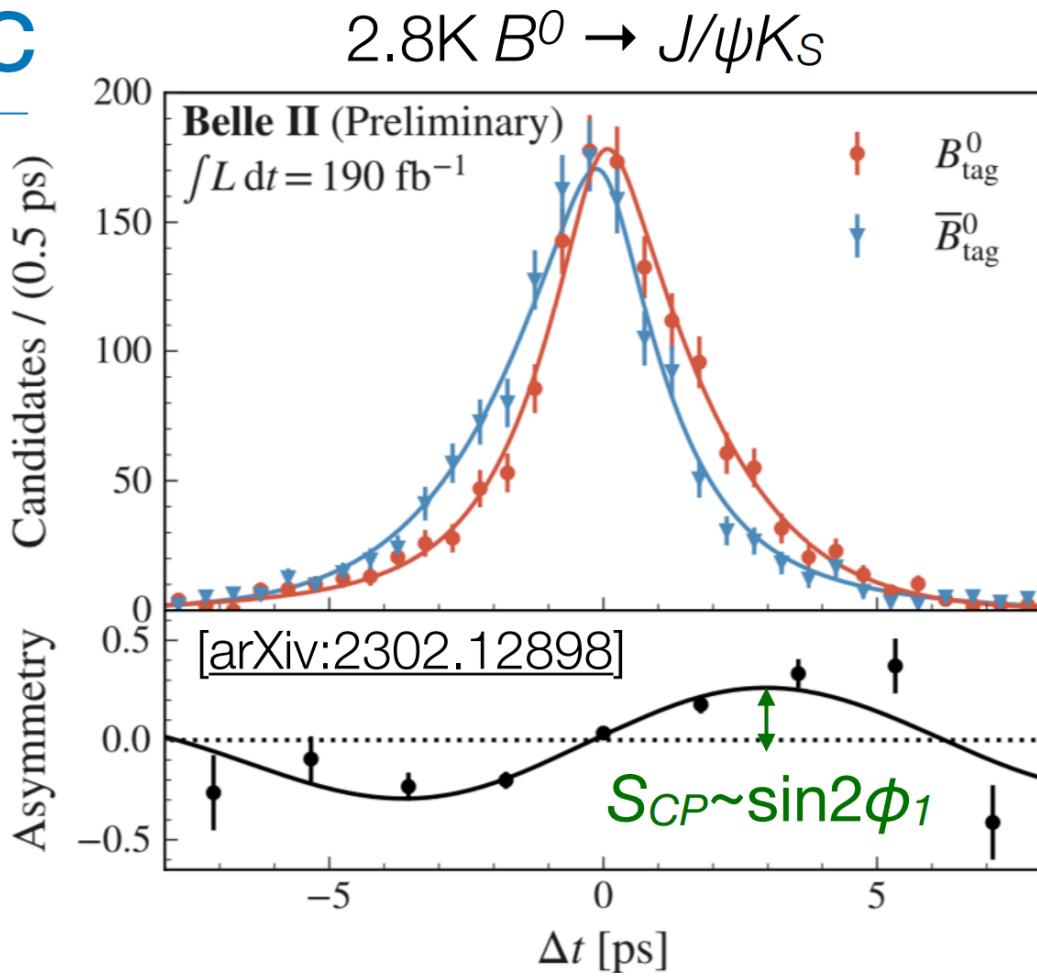
ϕ_1/β best-known angle of the UT with 0.7 degree precision. Provide reference for non-SM searches in gluonic penguin decays.

Nano-beam scheme comes with the price of a reduced boost: B flight only 130 μm on average (200 μm at Belle). PXD to recover decay-time resolution.

$$\begin{aligned} \mathcal{A}^{\text{raw}}(\Delta t) &= \frac{N(\bar{B}^0 \rightarrow f_{CP}) - N(B^0 \rightarrow f_{CP})}{N(\bar{B}^0 \rightarrow f_{CP}) + N(B^0 \rightarrow f_{CP})}(\Delta t) \\ &= A_{CP} \cos(\Delta m_d \Delta t) + S_{CP} \sin(\Delta m_d \Delta t) \end{aligned}$$

$$S_{CP} = 0.720 \pm 0.062(\text{stat}) \pm 0.016(\text{syst}) \quad \text{w.a. } 0.698 \pm 0.017$$

$$A_{CP} = 0.094 \pm 0.044(\text{stat})^{+0.042}_{-0.017}(\text{syst}) \quad \text{w.a. } -0.005 \pm 0.015$$



Not yet competitive with world best,
but crucial testbed

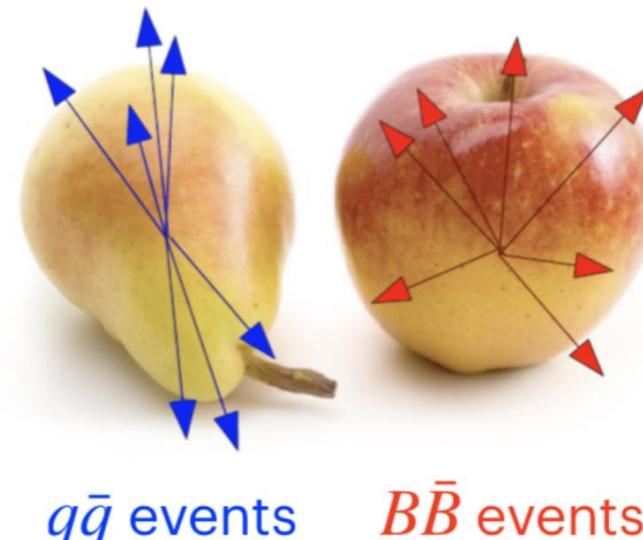
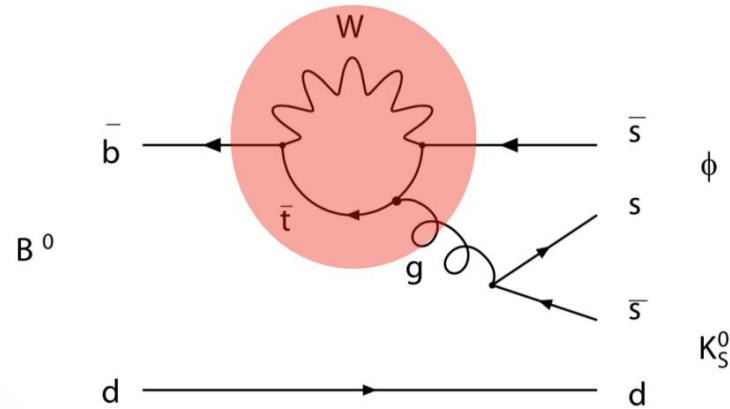
β^{eff} from suppressed decays

Gluonic-penguin mode suppressed in the SM, BR $\sim 10^{-5}$ - 10^{-6} .

Important comparison of $\sin 2\beta^{eff}$ with the reference favored channels to probe new amplitudes in loops.

Experimentally challenging.
Fully-hadronic final state with (many) neutrals. Need to fight against “continuum” light-quark production.
Background $O(10^6)$ larger than signal.

Exploit discriminating event topology:
continuum features a jet-like structure,
while B decays isotropically at rest.
Boost event-classification with machine learning algorithms (BDT, NNet).



$B^0 \rightarrow \varphi K_S$

4D fit to mass, decay-time, continuum-suppression discriminator, helicity angle, to discriminate between signal and background and extract the asymmetry.

Validate the decay-time resolution on

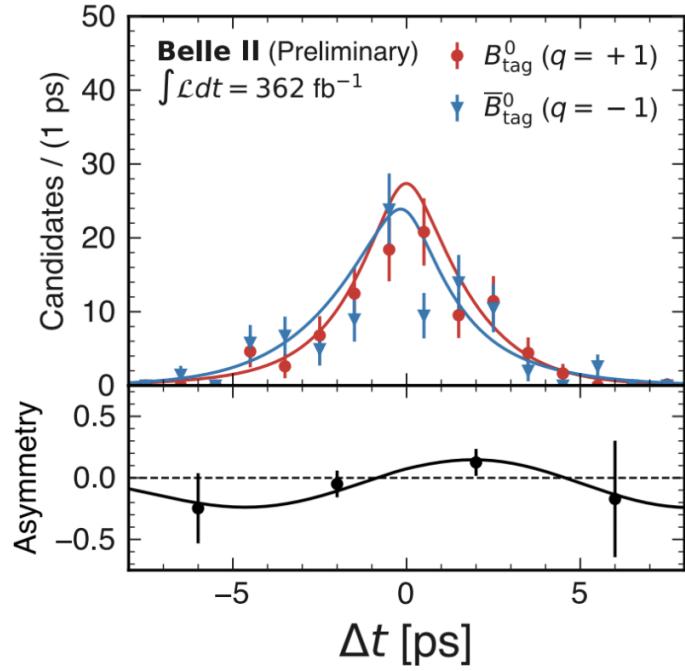
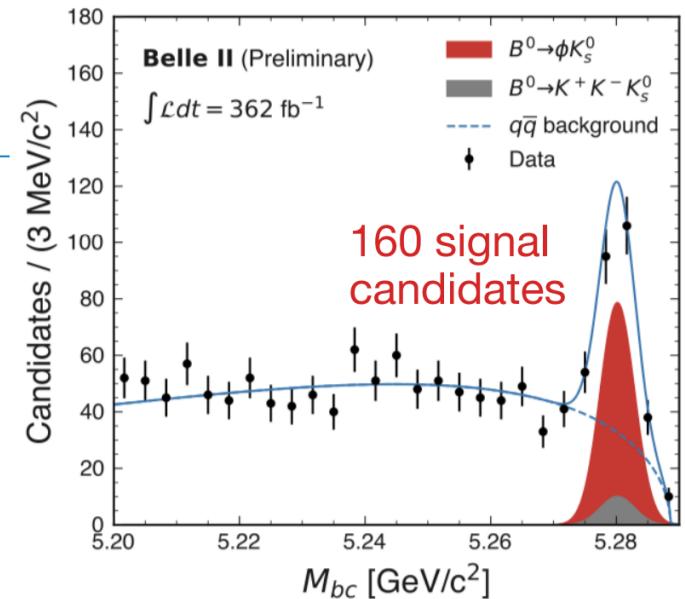
$B^+ \rightarrow \varphi K^+$ control data.

$$A_{CP}^{\phi K_S^0} = -0.01 \pm 0.14, \quad S_{CP}^{\phi K_S^0} = 0.59 \pm 0.14$$

$$A_{CP} = 0.31 \pm 0.20^{+0.05}_{-0.06}$$

$$S_{CP} = 0.54 \pm 0.26^{+0.06}_{-0.08}$$

Consistent with previous determinations.
Paving the way for $B^0 \rightarrow \eta(')K_S$.



TDCPV: $B^0 \rightarrow K_S^0 K_S^0 K_S^0$

362 fb⁻¹

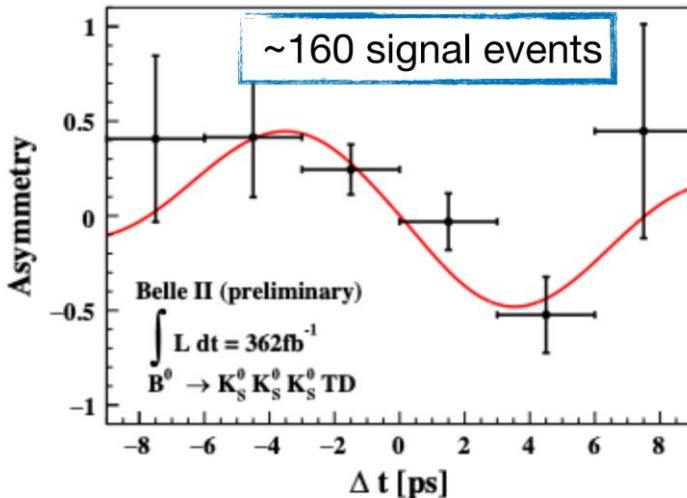
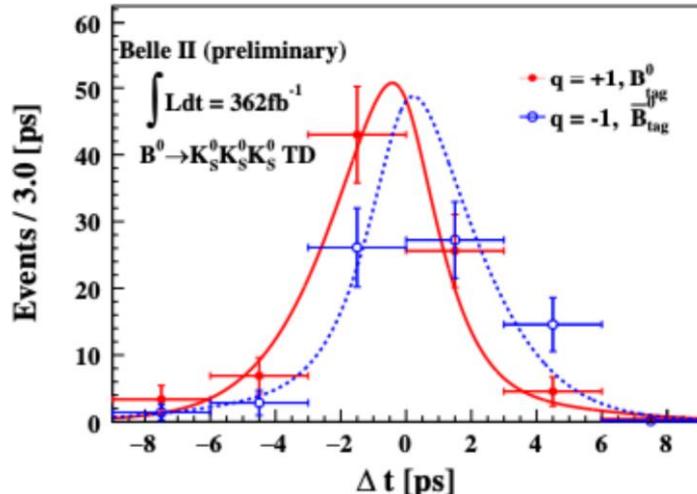
- Challenge: **only displaced tracks!** ($d_{K_S^0} \sim 10
- 3D signal extraction Fit (M_{bc}, M_B, O'_{CS})
 - simultaneous fit on $B^+ \rightarrow K_S^0 K_S^0 K^+$ for bkg and Δt calibration
 - simultaneous fit on $B^0 \rightarrow K_S^0 K_S^0 K_S^0$ events with low Δt quality for A_{CP} constraint
- Fit to $\Delta t$$

**consistent with world average
 A_{CP} on par with best measurements**

$$S = -1.37^{+0.35}_{-0.45} \pm 0.03$$

$$A = 0.07^{+0.15}_{-0.20} \pm 0.02$$

Belle
◦ $S = -0.71 \pm 0.23 \pm 0.05$
◦ $A = +0.12 \pm 0.16 \pm 0.05$
BaBar
◦ $S = -0.94^{+0.24}_{-0.21} \pm 0.06$
◦ $A = +0.17 \pm 0.18 \pm 0.04$



$B^0 \rightarrow K_S \pi^0$

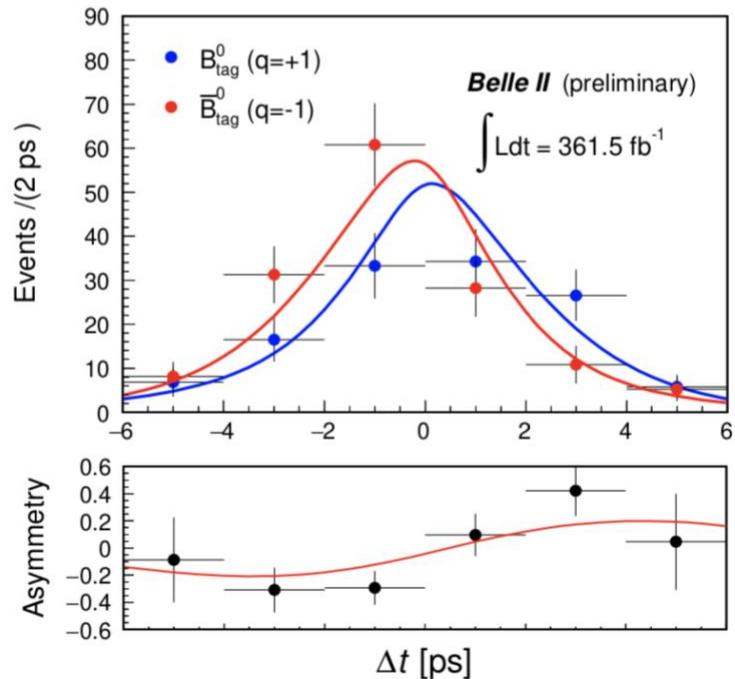
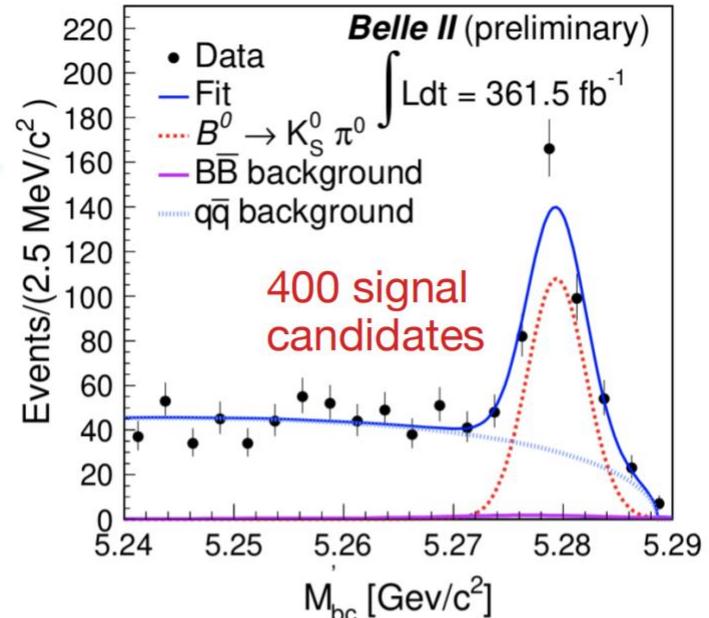
K_S flights 10 cm on average, decays after first silicon layers: challenging B vertex reconstruction, degraded decay-time resolution. Validate on $B^0 \rightarrow J/\psi K_S$ with K_S -only vertexing. Categorise the events according to decay-time uncertainty to measure TD asymmetries

$$A_{CP} = 0.04^{+0.15}_{-0.14} \pm 0.04$$

$$S_{CP} = 0.74^{+0.20}_{-0.23} \pm 0.04$$

Improved π^0 reconstruction and enhanced continuum-suppression yield precision competitive with world best results.

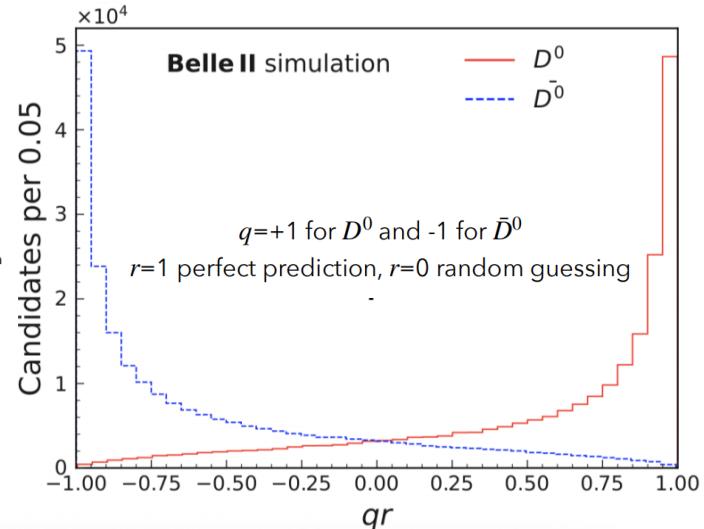
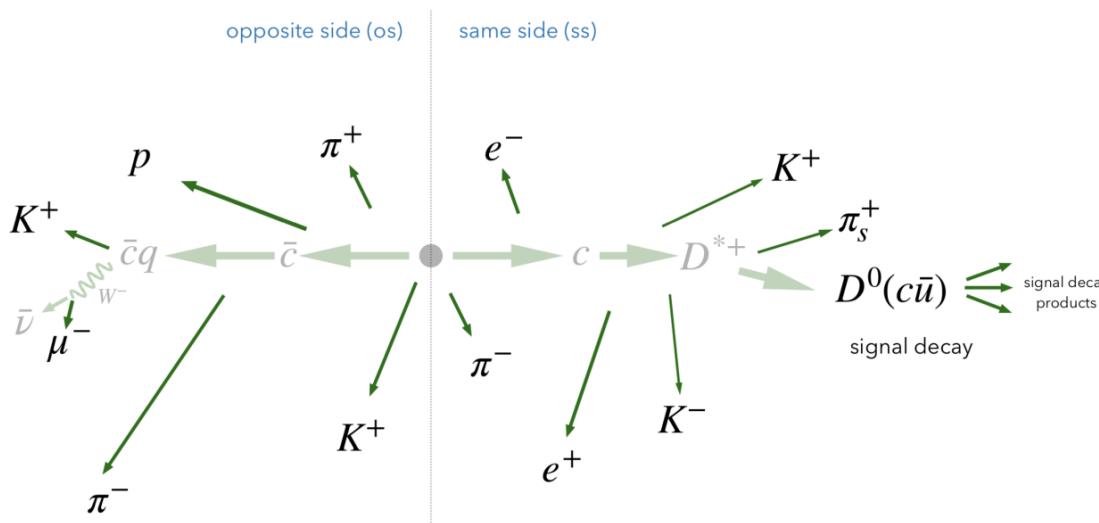
HFLAV: $S = 0.57 \pm 0.17$, $A = -0.01 \pm 0.10$



Enhancing charm reach

Rich program of charm physics with neutrals ($\pi^0\pi^0, \pi^+\pi^0, K_S\pi^0, K_SK_S, \dots$) to complement LHCb CPV observations in $D^0 \rightarrow h^+h^-$.

New flavour-tagging algorithm to recover D^0 candidates not tagged by $D^{*+} \rightarrow D^0\pi^+$ strong decays. Exploit $c\bar{c}$ pair production and charge correlation between signal D flavour and the tracks in the rest of the events.

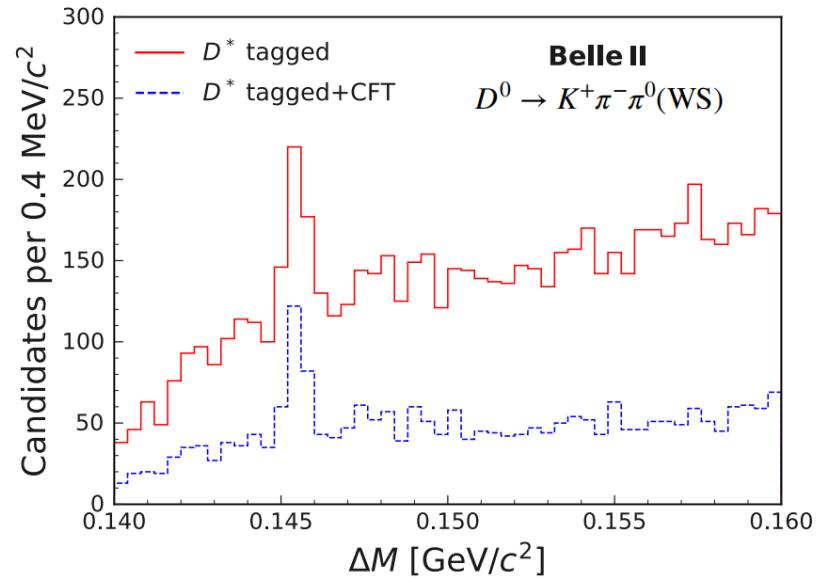
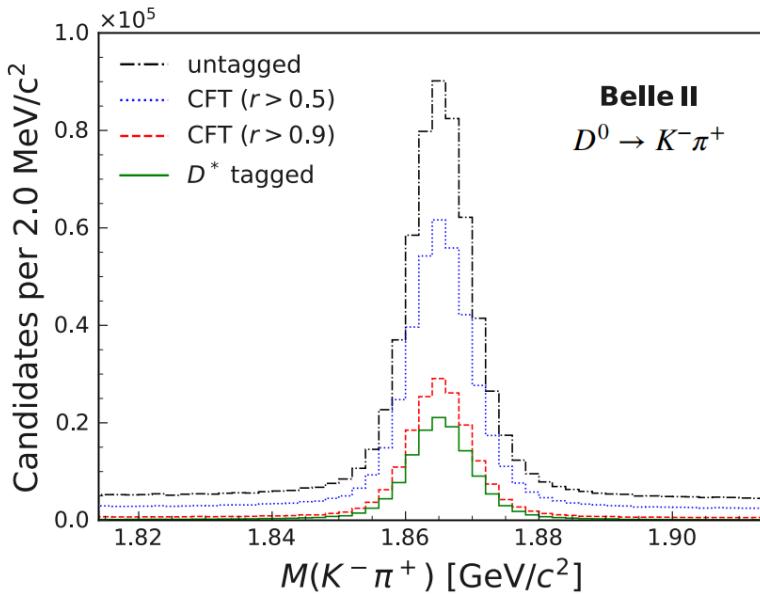


Calibrated with flavour-specific decays, 48% effective efficiency.
Roughly doubling sample of tagged D^0 candidates.

The Charm Flavor Tagger (CFT)

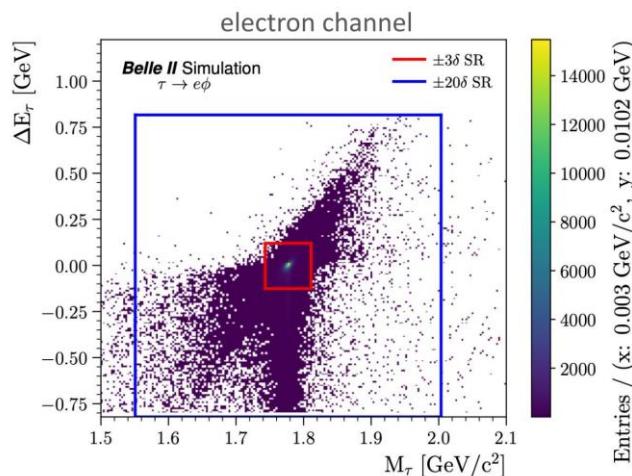
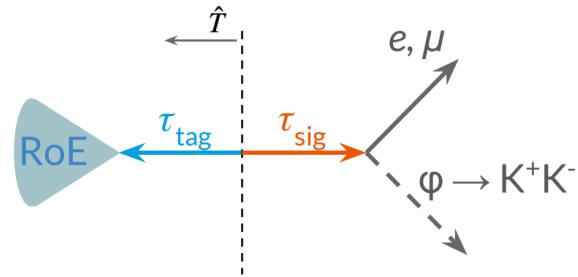
- uses **kinematic features** (ΔR , recoiling mass) and **PID** of tagging particles
- based on BDT, **predicts** qr (tagging decision q and dilution r)
- trained using simulation and calibrated with Belle II data

Novel method for the identification of neutral charmed mesons,
arXiv:2304.02042



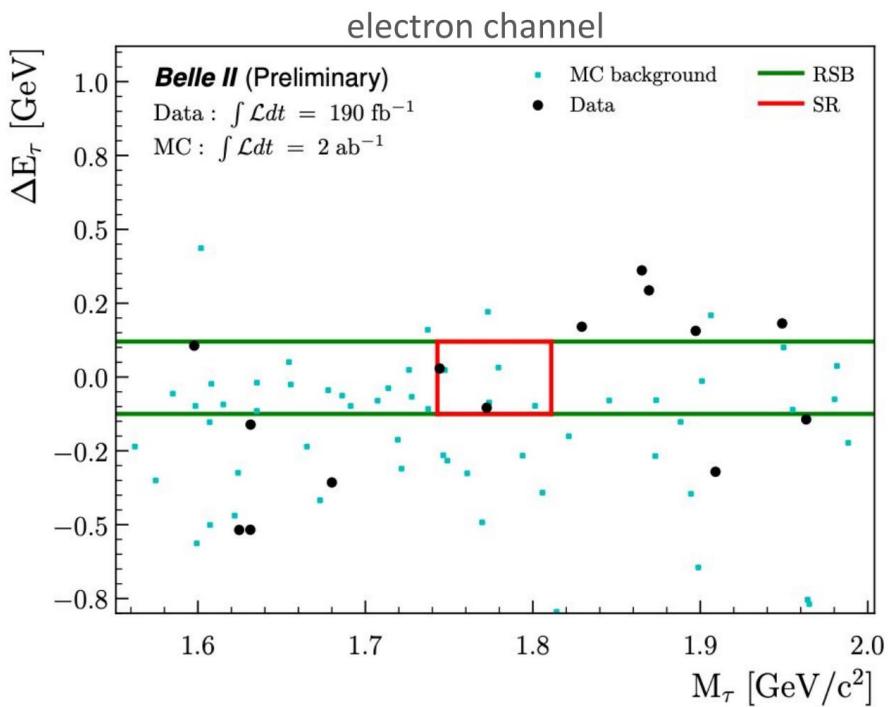
search for LFV decay: $\tau \rightarrow \ell \phi$

- Motivation:
 - observation of LFV would be an indisputable sign of new physics (SM prediction $\sim 10^{-50}$)
 - leptoquark models predict BF of up to 10^{-8} - 10^{-10}
- signal side: $\tau \rightarrow \ell \phi$
 - $\ell = e, \mu$ and $\phi \rightarrow K^+ K^-$ ($\sim 50\%$ BF of ϕ)
- tag side: inclusive
 - everything except for signal is considered as “rest of event” (RoE)
- Challenge: keeping signal efficiency high while discriminate against the backgrounds (mostly $q\bar{q}$)
 - RoE and signal kinematics in BDT classifier
 - signal efficiency of 6.1% (6.5%) for e (μ) channel
- The trick: exploit the signal kinematics (no neutrino in the decay)
 - Inv. mass on the signal side is expected to peak at actual tau mass!
 - $\Delta E = E_{\text{sig}}^* - \sqrt{s}/2$ expected to peak at zero for signal

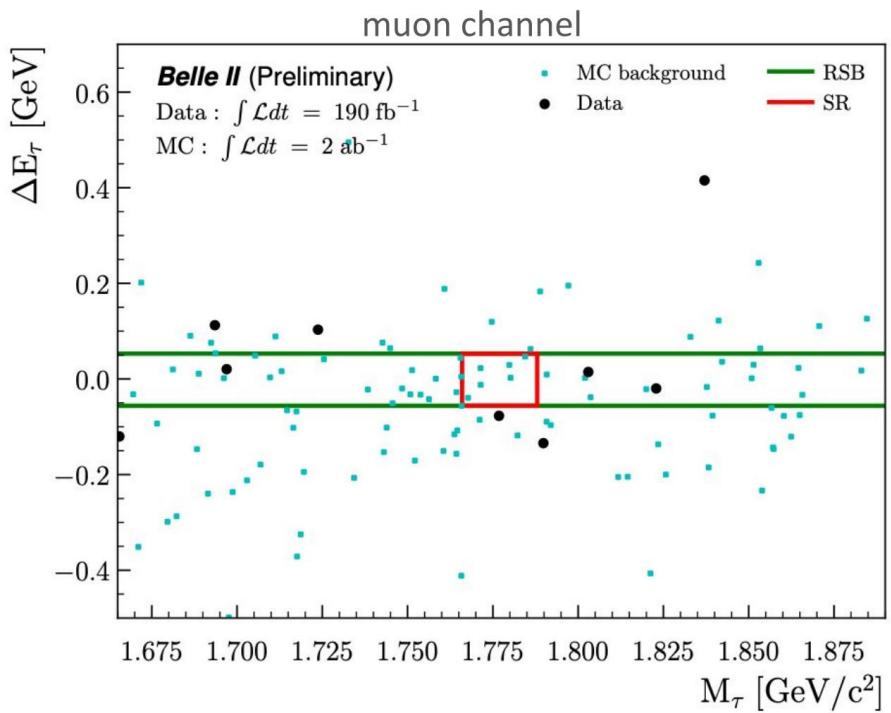


search for LFV decay: $\tau \rightarrow l\phi$

- Background estimation
 - using data in the sidebands
 - obtain transfer factor from simulation



Result	Region	Mode	
		$e\phi$	$\mu\phi$
N_{exp}	SR	$0.23^{+0.55}_{-0.21} \text{ stat}$	$0.36^{+0.39}_{-0.23} \text{ stat}$
N_{obs}	SR	$2.0^{+2.6}_{-1.3} \text{ stat}$	$0.0^{+1.8}_{-0.0} \text{ stat}$



$\tau \rightarrow \ell\phi$: the results

- No significant excess is observed.
 - we set 90% CL upper limits on $\text{BF}(\tau \rightarrow \ell\phi)$

