ASPEN CENTER FOR PHYSICS

Prospecting for New Physics through Flavor, Dark Matter, and Machine Learning
Aspen Winter Conference
26–31 March 2023

Heavy Flavors at Belle II:
Prospecting for New Physics with b & c quarks and τ leptons

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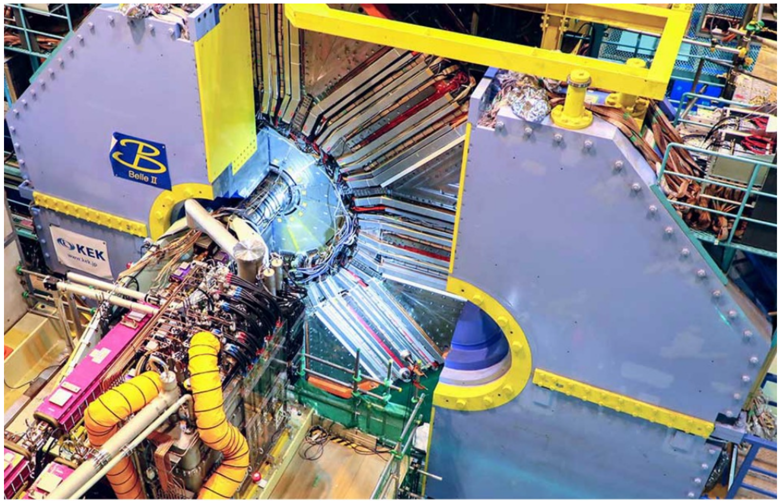
31 March 2023
On behalf of the Belle II Collaboration

Belle II

University of Victoria

Belle II Physics Program ‘Snapshot’

Goal: Prospect for new physics beyond the SM
in e+e- collisions at or near Υ(4S) 10.58GeV



New Physics searches via:

- Improved precision on SM physics:
  - CP Violation measurements
  - Lepton flavour violation (LFV) searches
  - Lepton flavour universality (LFU) measurements
  - …
- Direct searches
  - Unique searches in Dark Sector

We use various approaches, including
- time-dependent searches
- missing energy and missing mass
- Dalitz plot (multi-body) studies

Some are unique to Belle II
- inclusive decays and absolute branching fraction
  measurements that may be impractical at hadron machines

- benefits of precisely known initial state

SuperKEKB and Belle II

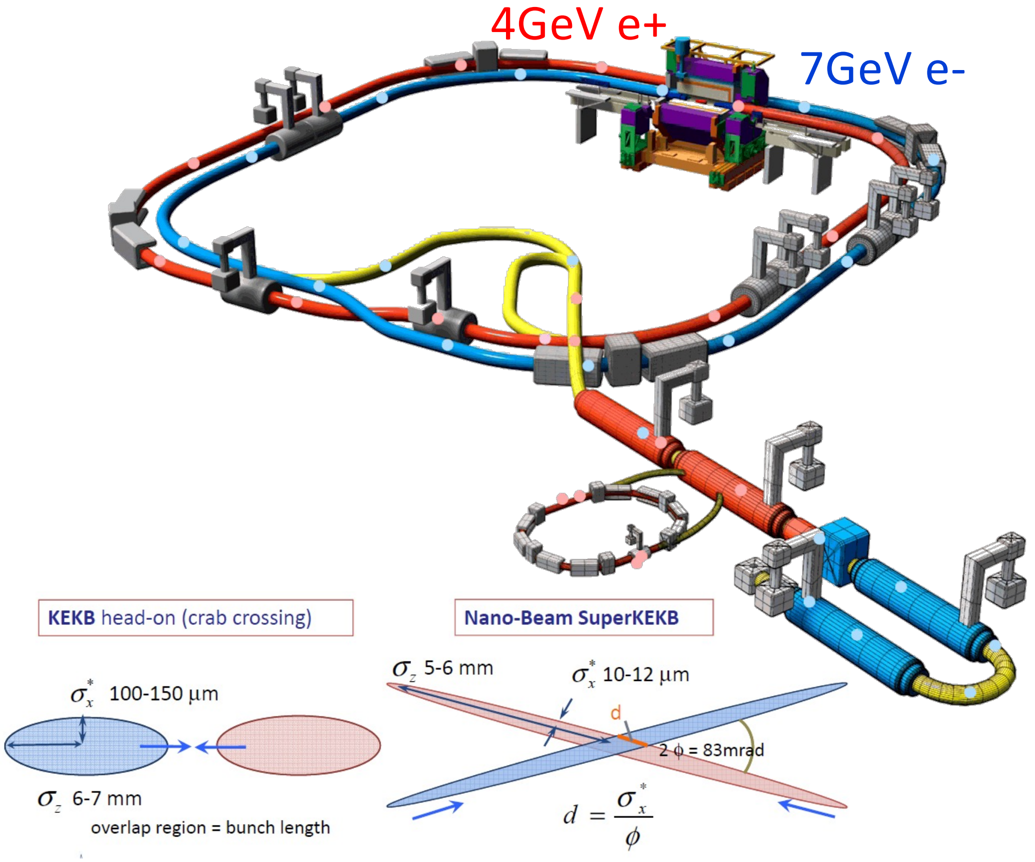
- SuperKEKB asymmetric e^+e^- collider operating at KEK in Tsukuba, Japan – since 2019 with Belle II vertex detector
- Belle II detector instruments the single interaction point
- $\int\mathcal{L}$ of 424 fb^{-1} by June 2022
- Peak $\mathcal{L}^{inst}$ of $4.7\text{x}10^{34}$ $cm^{-2}s^{-1}$ World Record (8 June 2022)

Higher than any other collider!

Targets:

$\int\mathcal{L}$: $50ab^{-1}$

Peak $\mathcal{L}^{inst}$: $6\text{x}10^{35}$ $cm^{-2}s^{-1}$

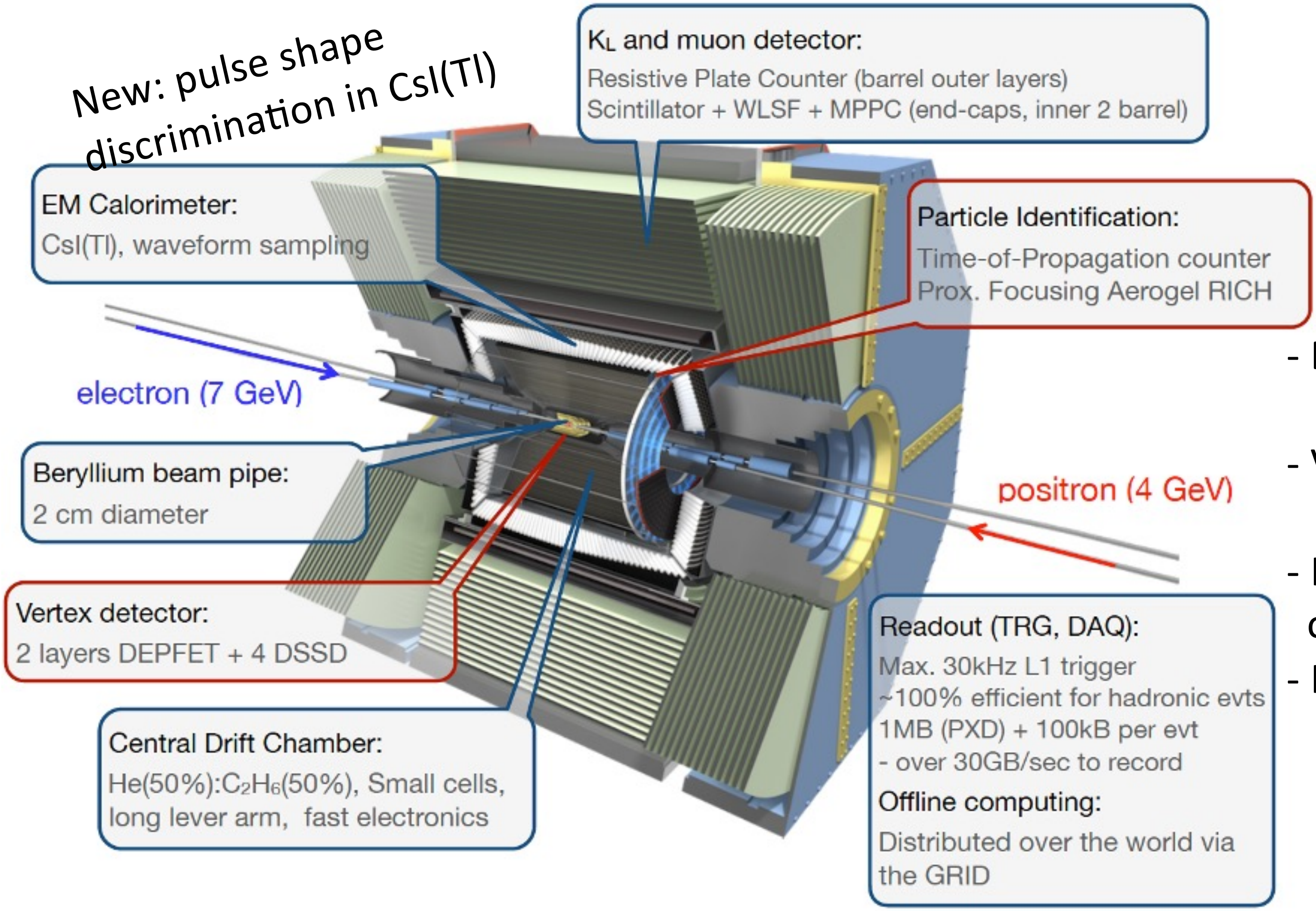


Nano-beam scheme:

- Increase beam current, squeeze beams at reduce beam energy asymmetry
- Target beam height: 50nm;
  currently: 300nm

SuperKEKB and Belle II

New: pulse shape discrimination in CsI(Tl)



K_L and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps, inner 2 barrel)

EM Calorimeter:
CsI(Tl), waveform sampling

Particle Identification:
Time-of-Propagation counter
Prox. Focusing Aerogel RICH

Beryllium beam pipe:
2 cm diameter

Vertex detector:
2 layers DEPFET + 4 DSSD

Central Drift Chamber:
$He(50\%):C_2H_6(50\%)$, Small cells, long lever arm, fast electronics

Readout (TRG, DAQ):
Max. 30kHz L1 trigger
~100% efficient for hadronic evts
1MB (PXD) + 100kB per evt
- over 30GB/sec to record

Offline computing:
Distributed over the world via the GRID

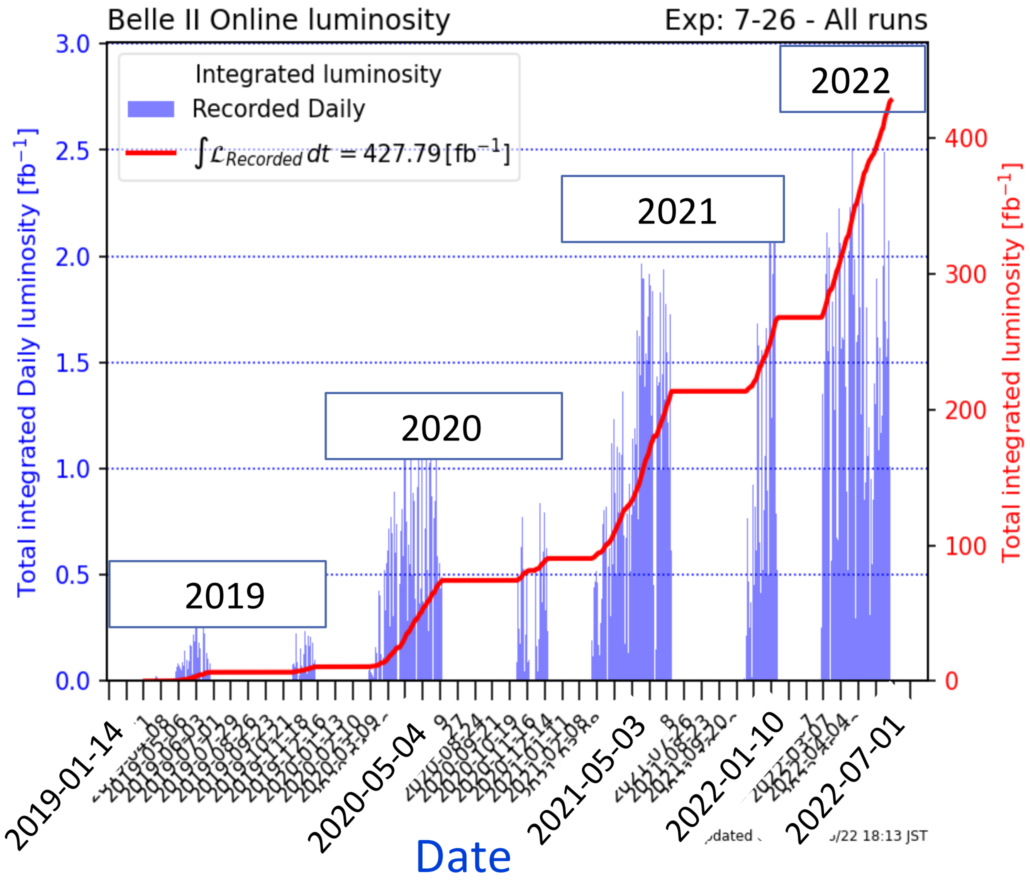
- Excellent particle ID (barrel and forward)
- Vertex resolutions x2 better than Belle&BaBar
- High detection efficiency of neutrals (γ, π^0, $\eta\ldots$)
- High trigger efficiency, Low multiplicity special triggers (not in Belle only last year of BaBar)

$$c\bar{c},\ s\bar{s},\ d\bar{d},\ u\bar{u},\ \tau^+\tau^- \leftarrow e^+e^- \rightarrow \Upsilon(nS) \rightarrow B^{(*)}\bar{B}^{(*)}$$

SuperKEKB and Belle II

$\int\mathcal{L}$ for physics:
424 fb^{-1} 2019-22

363 fb^{-1} at $\Upsilon(4S)$ 387M $B\bar{B}$
42.3fb^{-1} off $\Upsilon(4S)$ resonance
78 pb^{-1} $\Upsilon(4S)$ scan
19.7fb^{-1} "5S" energy scan



SuperKEKB and Belle II

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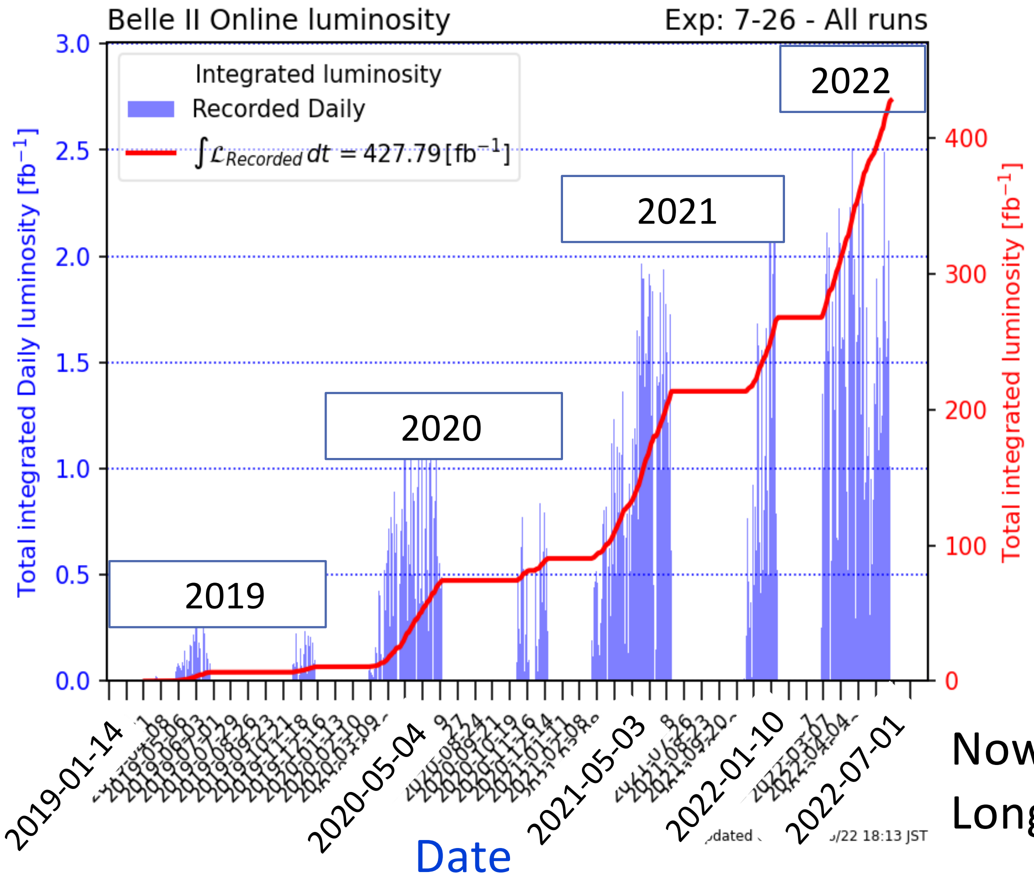


Belle II collected ~*BABAR*-sized dataset but in ¼ of time AND during the pandemic!

Now in Long Shutdown 1

This is just the start!

Much more to come with increasing instantaneous luminosity

Many new Belle II analyses…

DARK SECTOR DIRECT SEARCHES:

Belle II's high luminosity dataset with new trigger lines provides unique opportunities to **search for evidence of a dark sector in** e^+e^- collisions

- see Ezio Torassa's talk from yesterday:

  - Axion-like → $\gamma\gamma$
  - Z' → invisible
  - Dark Higgsstrahlung
  - Z', S → $\tau^+\tau^-$
  - Long-lived scalar in b → s *

* New for Winter 2023 Conferences

Many new Belle II analyses…

New results for Winter 2023 Conferences

- Long-lived (pseudo)scalar in b → s from B [world first model indep limits]
- **$|V_{cb}|$ in untagged D* [competitive with world best]***
- **A_{FB} asymmetries sensitive to LFU anomalies [world first, unique to Belle II] ***
- **time-dep CPV in $K^0\pi^0$ [NP:penguins, unique to us and competitive w/ world best]***
- **time-dep CPV in ϕK_s [NP in penguins, unique to Belle II]***
- **time-dep CPV in $K_sK_sK_s$ [NP in penguins, unique to Belle II] ***
- **$K\pi$ isospin sum rule [NP generic, unique to us, competitive w/ world best results] ***
- **tau mass [world best] ***
- Belle + Belle II GLW analysis for CKM angle gamma
- Belle + Belle II GLS analysis for CKM angle gamma
- **Charm flavor tagger [doubles our size of tagged D^0 samples] ***
- **Search for $\tau \rightarrow \ell\phi$ ***
- e+e- → $B^{(*)}B^{(*)}$ cross section in energy scan
- $\mathcal{B}(B\rightarrow D^{(*)}K^-K^0_s)$ [1st observations: $B \rightarrow D^*K^-K^0_s$, $B^0 \rightarrow D^+K^-K^0_s$ and most precise for $\mathcal{B}(B^0\rightarrow D^0K^-K^0_s)$]

*** will present these today in a focus on 'Prospecting for New Physics' in b, c and τ**

Belle II ICHEP 2022 results

- |Vcb| from untagged $B \to D \ell \nu$ decays
- |Vub| from untagged $B \to \pi \ell \nu$ decays
- BF($B \to \rho \ell \nu$) from tagged decays
- **LFU test in semileptonic *B* decays**
- Inclusive $B \to X_s \gamma$ using hadronic tagging
- B^0 mixing phase ϕ_1/β from $B^0 \to J/\psi K^0_S$
- *CP* violation in $B^0 \to K^0_S K^0_S K^0_S$ decays
- BF and f_L in $B^0 \to \rho^+\rho^-$
- BF and A_{CP} in $B^+ \to h^+\pi^0$
- BF and A_{CP} in $B^0 \to \pi^0\pi^0$
- Measurement of R(K) in resonant decays
- Measurement of the Ωc lifetime
- Observation of $e^+e^- \to \omega\chi b$ and search for X_b at a and near 10.75 GeV
- **Search for $\tau \to \ell \alpha$ (invisible)**
- Search for *Z'*, *S*, *ALP* → *ττ* in *μμττ* final states
- Search for an invisible *Z'* in *μμ* + missing energy

Lepton Flavour Universality test in inclusive semileptonic B⟶ X ℓν decays

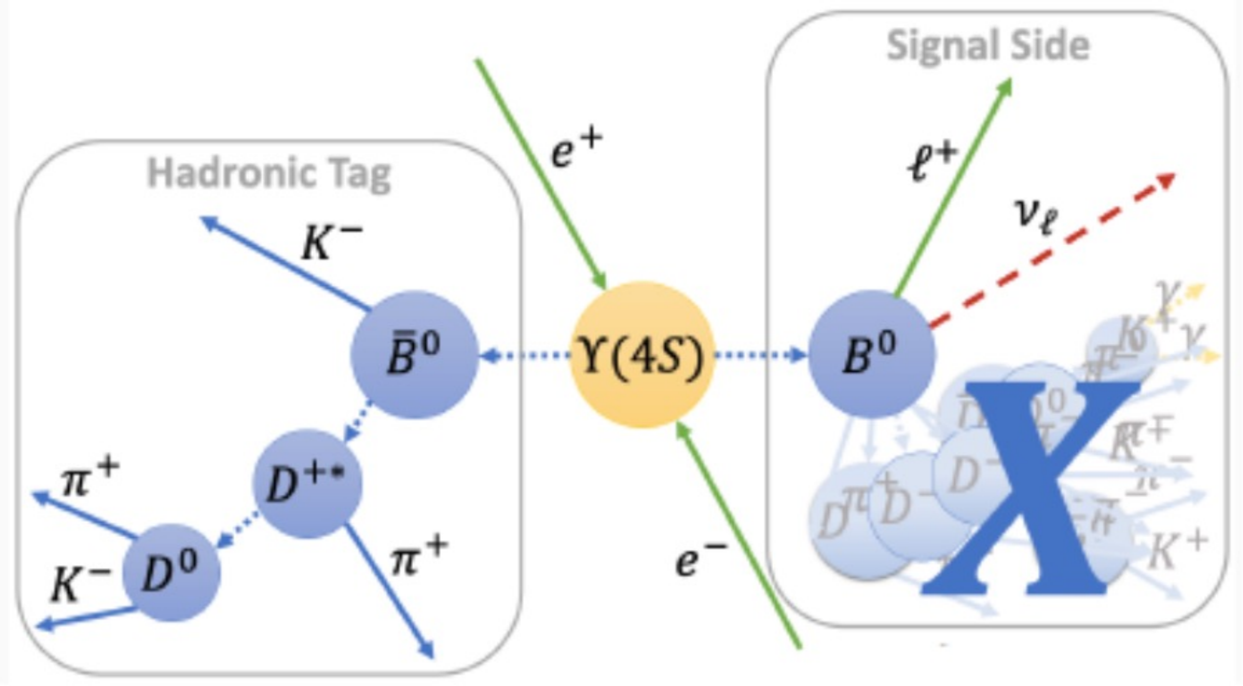
ℓ = e or μ

$R(X_{e/\mu}) = \mathcal{B}(B\rightarrow Xe\nu)/\mathcal{B}(B\rightarrow X\mu\nu)$ probes e-μ LFU in inclusive semileptonic B decays at high momentum : **p^*_ℓ > 1.3 GeV**

Critical cross-check paving the way to

$R(X_{\tau/\ell}) = \mathcal{B}(B\rightarrow X\tau\nu)/\mathcal{B}(B\rightarrow X\ell\nu)$

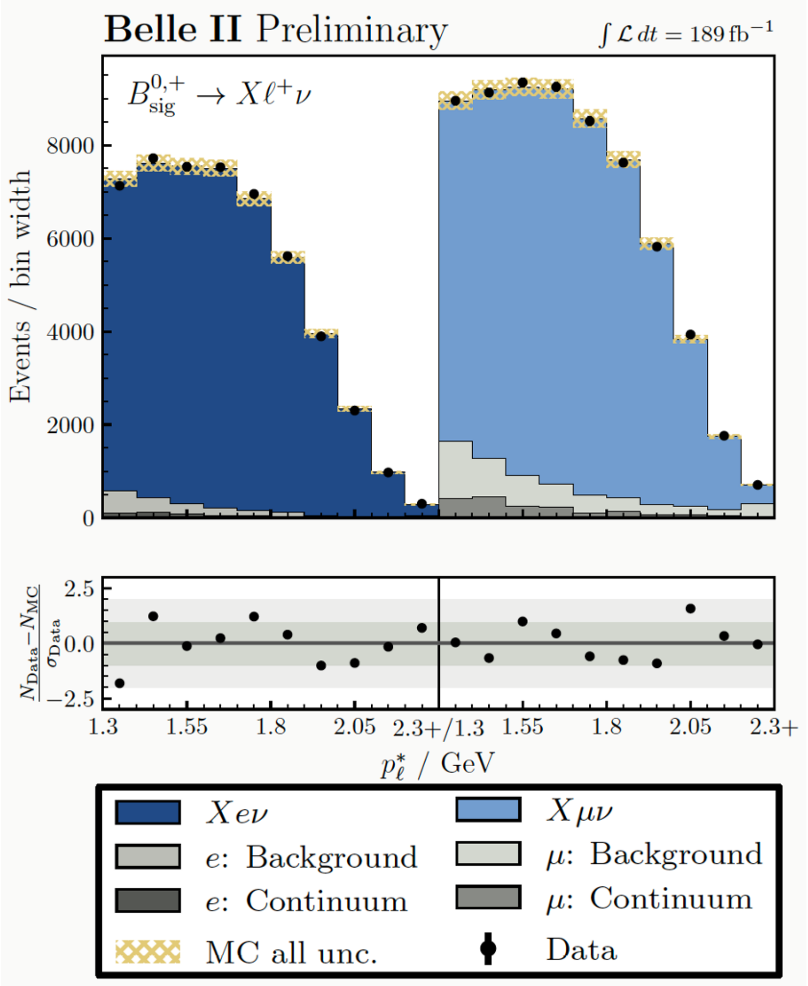
Analysis of 189fb^{-1} using a hadronic tag:



Lepton Flavour Universality test in inclusive semileptonic B⟶ X ℓν decays

Signal extraction from a binned log-likelihood fit in p^*_ℓ with backgrounds constrained in the incorrect charge sideband

Source	Uncertainty [%]
Sample size	1.0
Lepton identification	1.9
$X_c \ell \nu$ branching fractions	0.1
$X_c \ell \nu$ form factors	0.2
Total	2.2



$$R(X_{e/\mu}) = \mathcal{B}(B\to Xe\nu)/\mathcal{B}(B\to X\mu\nu)$$
$$= 1.033 \pm 0.010^{\mathrm{stat}} \pm 0.019^{\mathrm{syst}}$$

Most precise LFU test in semileptonic B decays to date

Consistent with SM value of $1 + \mathcal{O}(10^{-3})$

https://arxiv.org/abs/2301.08266, submitted to PRL

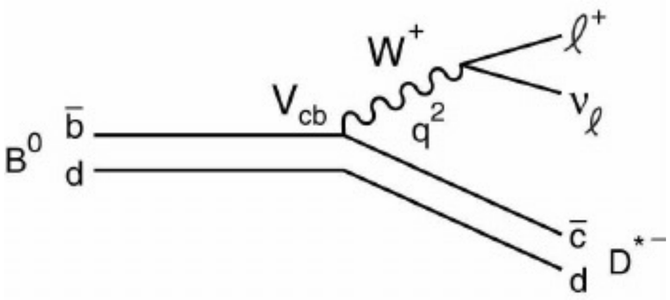
A couple of b → c anomalies…

1. Evidence for lepton-universality violation (LUV) in the $\mathcal{B}(B\rightarrow D^{(*)}\tau\nu) / \mathcal{B}(B\rightarrow D^{(*)}\ell\nu)$ has been observed in the combination of results from the *BABAR*, Belle, and LHCb

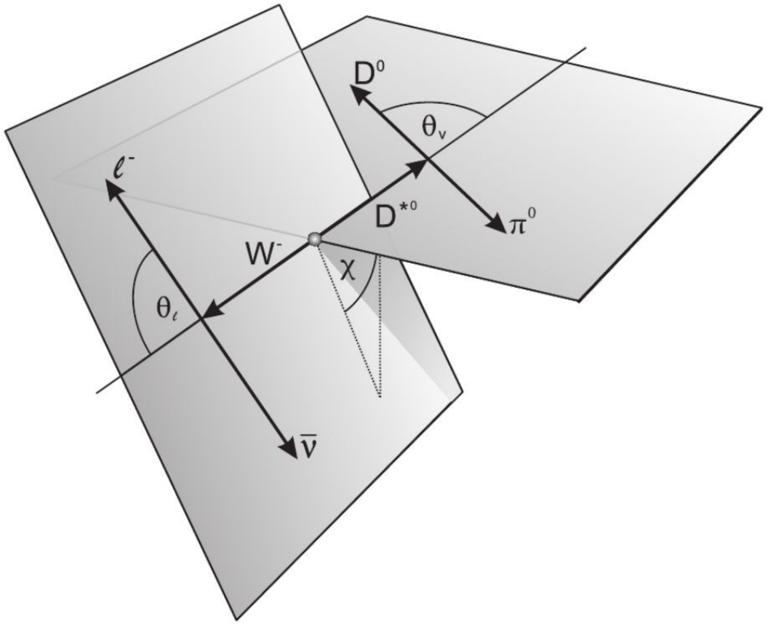
2. C. Bobeth *et al* *[Eur. Phys. J. C 81, 984 (2021)]* report 4σ evidence of e-μ LUV from e-μ differences in $B\rightarrow D^{*}\ell\nu$ angular distributions by reinterpreting published Belle data *[PRD 100, 052007 (2019)]* using available 1D projections of the angular distributions that characterize these semileptonic decays

e-μ universality in angular observables of $B\to D^*\ell\nu$ decays

- In SM, D* meson spin → much of the information of V-A coupling and the spin of the virtual W is encoded in angular distributions of the final state particles.



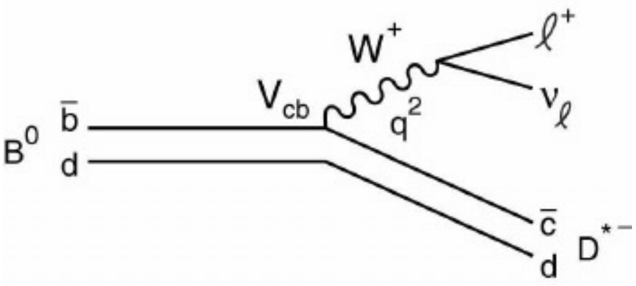
- These can be fully characterized in terms of recoil parameter, *w*, and three helicity angles, where



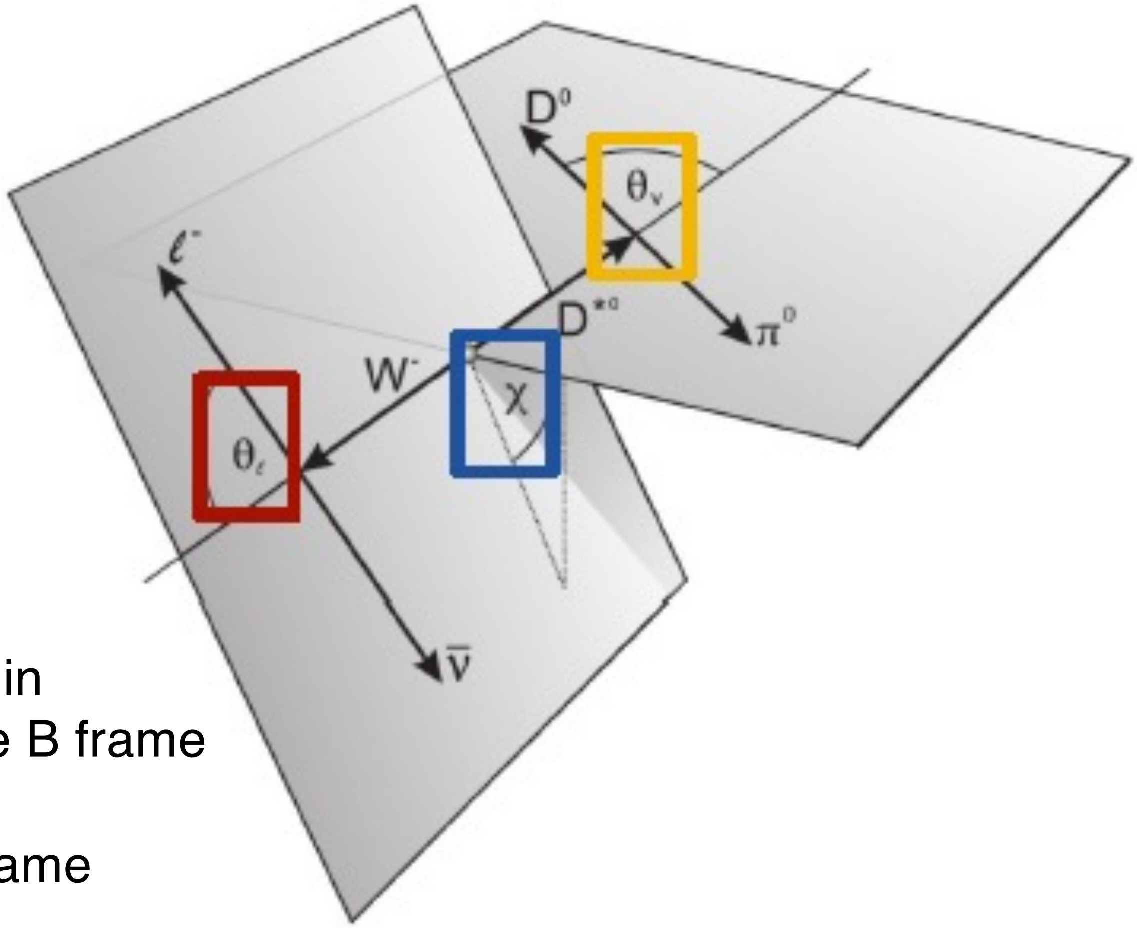
$$w = \frac{m_B^2 + m_{D^*}^2 - q^2c^2}{2m_B m_{D^*}}$$

$q^2 = (\boldsymbol{p}_B - \boldsymbol{p}_{D^*})^2$ is (momentum transfer)^2

e-μ universality in angular observables of B→D*ℓν decays



…and the three helicity angles are:



$\boxed{\theta_\ell}$ angle between the direction of ℓ in virtual W frame and the W in the B frame

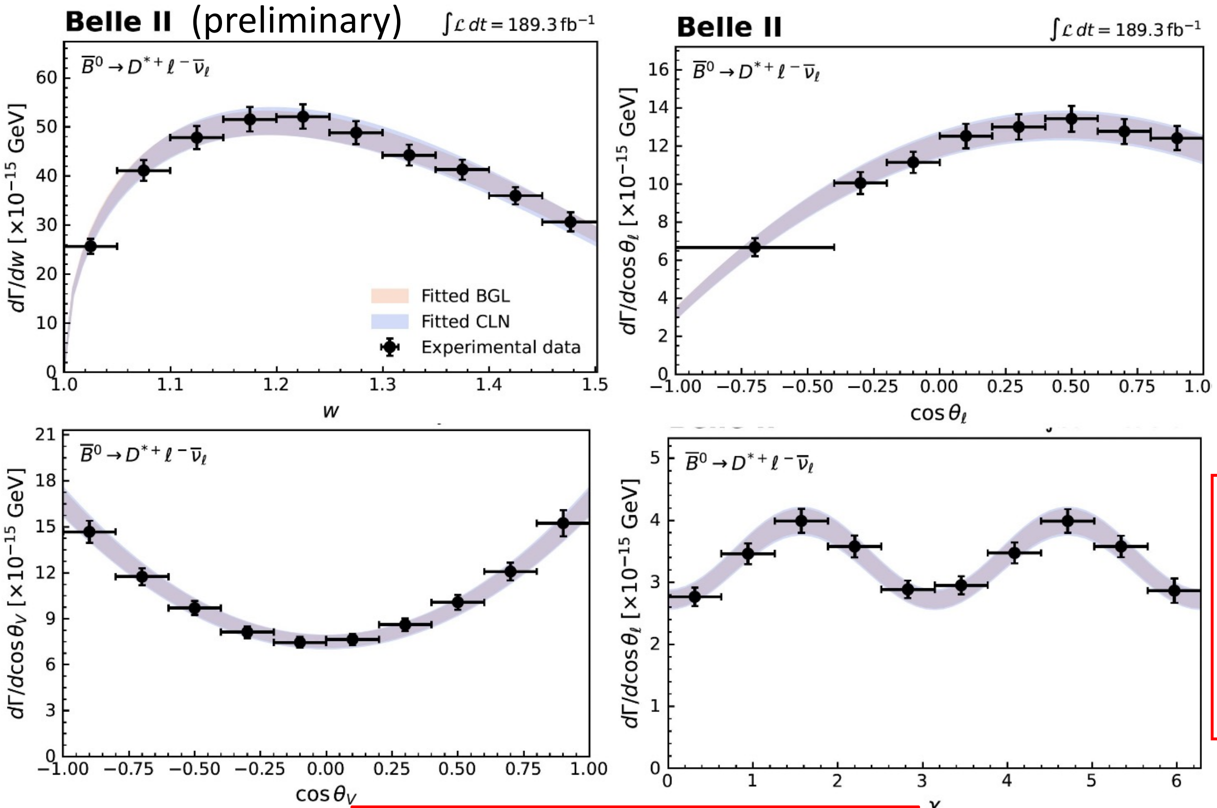
$\boxed{\theta_V}$ angle between the D in the D* frame and the D* in the B frame

$\boxed{\chi}$ angle between the decay planes formed by virtual W and the D in the B frame

e-μ universality in angular observables of B→D*ℓν decays

analysis #1: untagged sample of B→D*ℓν decays in 189fb^{-1}

Determine |V$_{cb}$| with 2 form factor parametrizations: Caprini-Lellouch-Neubert (CLN) and Boyd-Grinstein-Lebed (BGL).



Recall |V$_{cb}$ | discrepancy

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

HFLAV:
B → D ℓ$\bar{\nu}_\ell$, B → D*ℓ$\bar{\nu}_\ell$ and B$_s$ → D$^{(*)}_s$ ℓ$\bar{\nu}_\ell$)

$$|V_{cb}| = (42.16 \pm 0.51) \times 10^{-3} \quad \text{(inclusive)}$$

(Bordone et al, PhysLett 2021, arX2107.00604)

BELLE II Preliminary results:

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

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

$$\begin{aligned} \mathcal{A}_{\text{FB}}^{e} &= 0.219 \pm 0.011 \pm 0.020\,, \\ \mathcal{A}_{\text{FB}}^{\mu} &= 0.215 \pm 0.011 \pm 0.022\,, \\ \Delta\mathcal{A}_{\text{FB}} &= (-4 \pm 16 \pm 18) \times 10^{-3} \end{aligned}$$

LFU: Ratio of branching fractions:

$$R_{e/\mu} = 1.001 \pm 0.009 \pm 0.021$$

e-μ universality in angular observables of B→D*ℓν decays

analysis #2: Using **hadronically** tagged sample of B→D*ℓν decays, in 189fb^{-1} of data we report the first dedicated e-μ LU **study using a complete set of angular asymmetry observables** designed to cancel most theoretical and experimental uncertainties and are maximally sensitive to LUV [B. Bhattacharya et al., A new tool to search for physics beyond the Standard Model in $\bar{B}^0 \to D^{*+} \ell^- \nu$, in 2022 Snowmass Summer Study (2022) arXiv:2203.07189]

- The 4D SM differential rate can be represented as 8 helicity amplitudes & as a function of w, θ_ℓ , θ_V & χ
- Construct integrals of these differential rates to isolate LUV-sensitive angular asymmetries: A_{FB}, S_3 , S_5 , S_7 and S_9

$$\mathcal{A}_x(w) \equiv \left(\frac{\mathrm{d}\Gamma}{\mathrm{d}w}\right)^{-1} \left[\int_0^1 - \int_{-1}^0\right] \mathrm{d}x \frac{\mathrm{d}^2\Gamma}{\mathrm{d}w\mathrm{d}x}$$

$\mathcal{A}_x$ (x) = (F-B)/(F+B)

$\mathcal{A}_x \to A_{FB}$, S_3 , S_5 , S_7 and S_9

A_{FB} : dx = d(cos θ_ℓ)

S_3 : dx = d(cos2χ)

S_5 : dx = d(cosχ cosθ_V)

S_7 : dx = d(sinχ cosθ_V)

S_9 : dx = d(sin2χ)

e-μ universality in angular observables of B→D*ℓν decays

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

e-μ universality measurement parameters $\mathcal{A}_x$ → A_{FB} , S_3 , S_5 , S_7 and S_9

- Most experimental systematic uncertainties cancel in $\mathcal{A}_x$
- SM contributions, e.g. hadronic uncertainties in form factors, largely cancel in $\Delta\mathcal{A}_x$, apart from lepton mass effects

→ Simultaneous determination of all asymmetries with correlations in different *w* ranges provides a powerful test of LU, while also providing a way to help understand the nature of any new interactions

We measure them integrated over 3 *w* ranges:

$1.000 \leq w_{low} \leq 1.275$

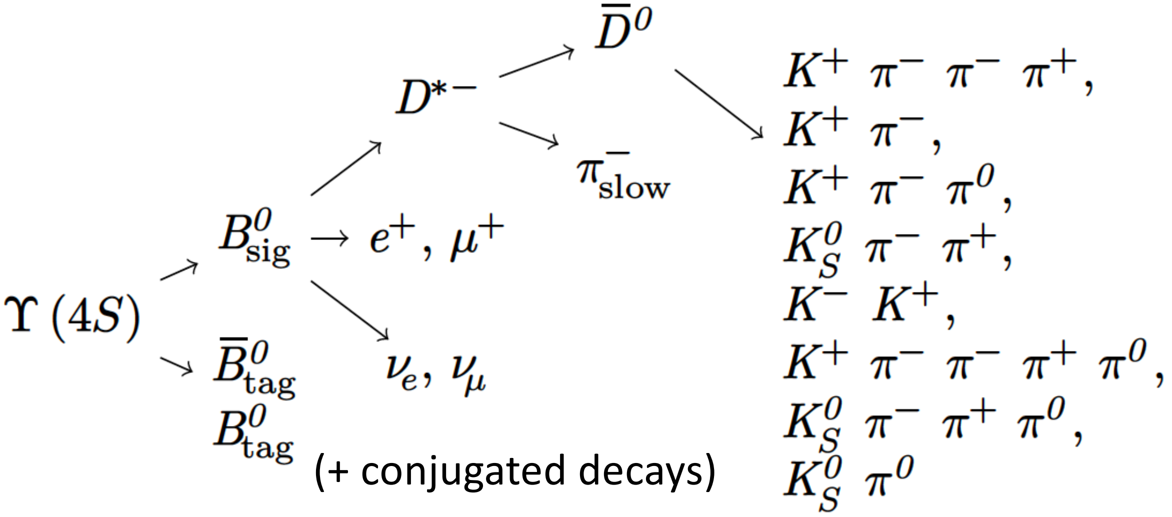
$1.275 \leq w_{high} \leq 1.650$ *(kinematic end-point)*

$1.000 \leq w_{inclusive} \leq 1.650$

- New Physics can be expected to change $\Delta\mathcal{A}_x$ by a few % [arxiv:2206.11283]

e-μ universality in angular observables of B→D*ℓν decays

We use the Full Event Interpretation (FEI) algorithm *[T. Keck et al., Comput. Softw. Big Sci. 3, 6 (2019)]* to reconstruct B_{tag} in a fully hadronic decay



(+ conjugated decays)

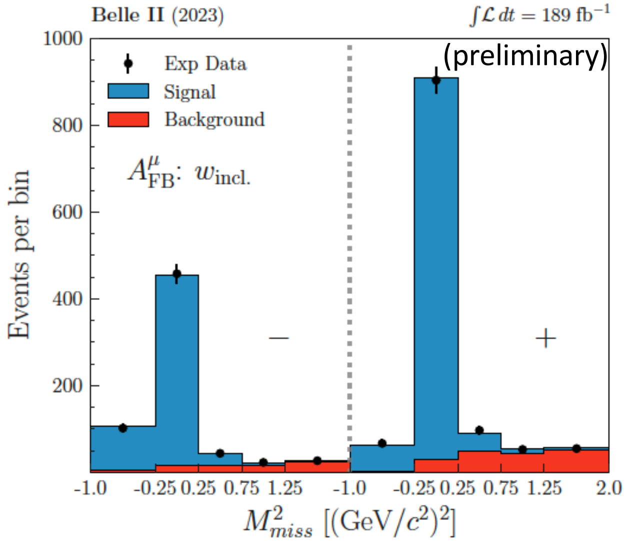


Figure 1: Muon-mode M^2_{miss} distributions and fit results for − (left) and + (right) categories of $\cos\theta_\ell$, corresponding to A^μ_{FB}, in the full w range ($w_{incl.}$).

Steps:

Reconstruct clean ***D*ℓ*** sample → **Reconstruction** of angular observables in bins of w → **Background subtraction** → experimental resolution

Use **hadronically tagged** events and abundant/clean ***D*** **decay modes**

Ignore **1D** projections; reconstruct 4x1D **angular asymmetry** variables vs. *w*

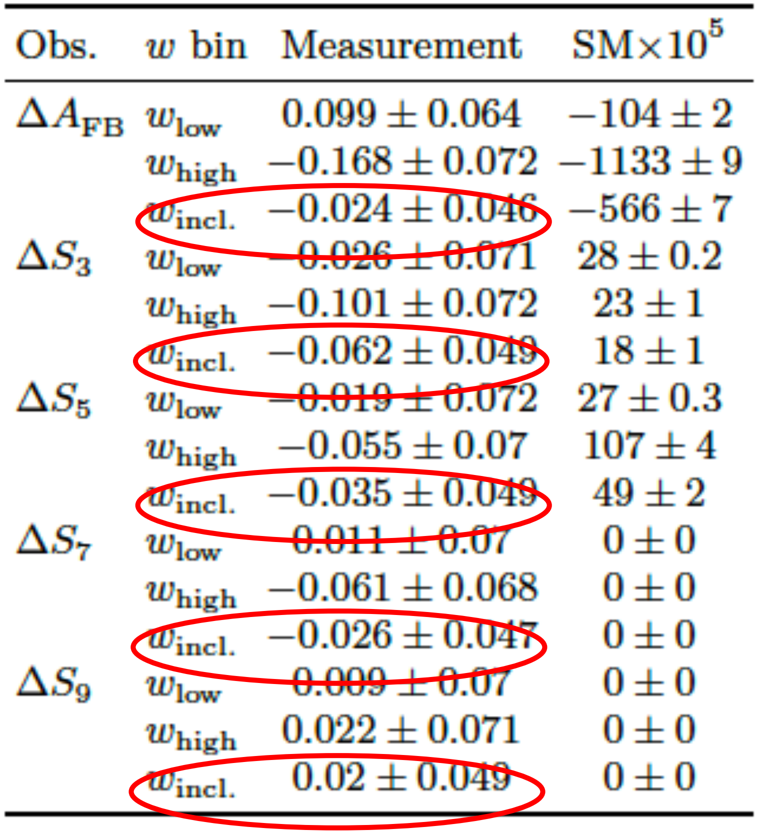
Independent **fits in M_{miss}^2** to separate signal from background in 2x2 (+/- and *w*) bins

Use **matrix inversion**

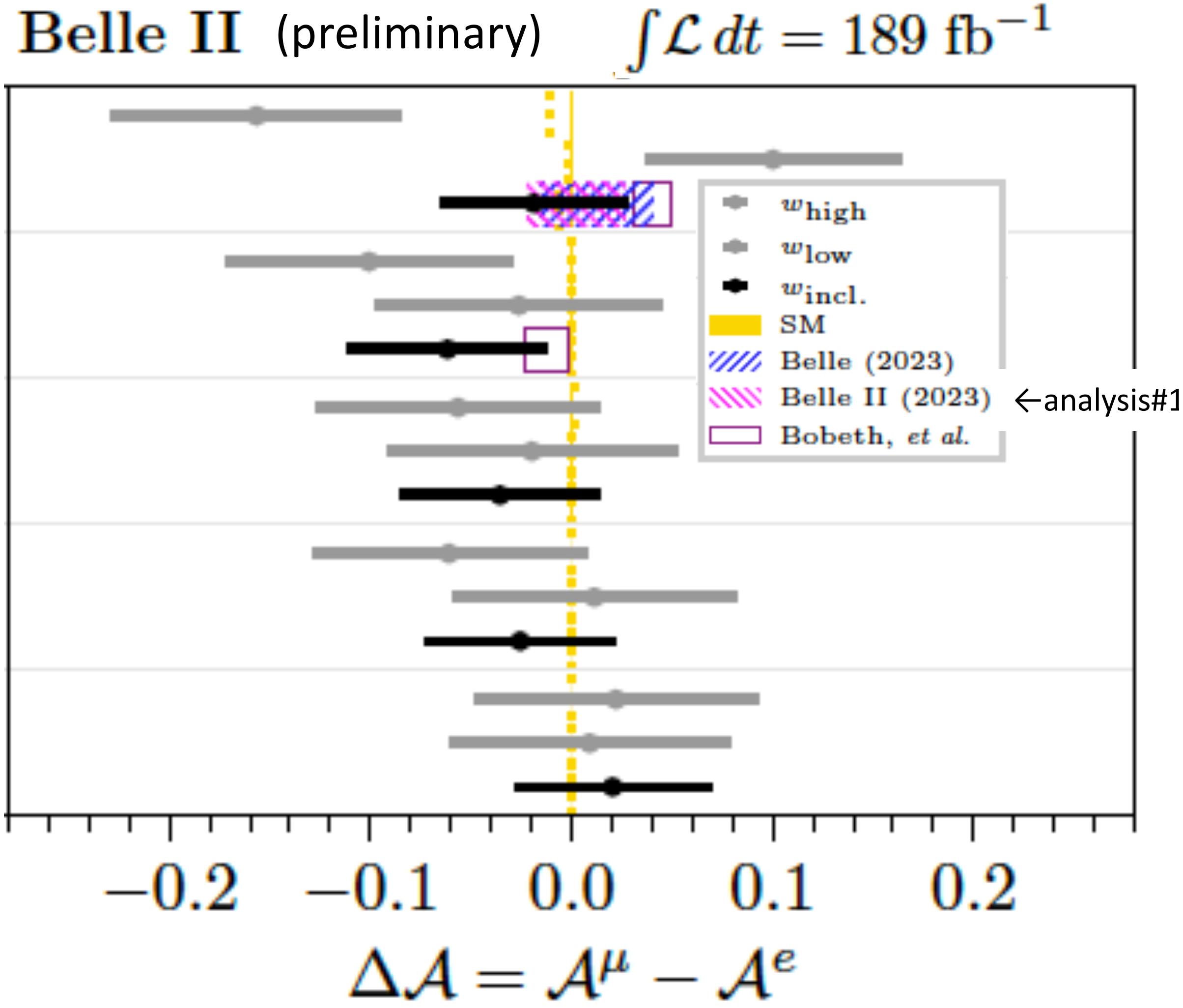
e-μ universality in angular observables of B→D*ℓν decays

Measured e–μ asymmetries differences for each *w* region

(preliminary)



Obs.	w bin	Measurement	SM$\times10^5$
ΔA_{FB}	w_{low}	0.099 ± 0.064	-104 ± 2
	w_{high}	-0.168 ± 0.072	-1133 ± 9
	$w_{incl.}$	-0.024 ± 0.046	-566 ± 7
ΔS_3	w_{low}	-0.026 ± 0.071	28 ± 0.2
	w_{high}	-0.101 ± 0.072	23 ± 1
	$w_{incl.}$	-0.062 ± 0.049	18 ± 1
ΔS_5	w_{low}	-0.019 ± 0.072	27 ± 0.3
	w_{high}	-0.055 ± 0.07	107 ± 4
	$w_{incl.}$	-0.035 ± 0.049	49 ± 2
ΔS_7	w_{low}	0.011 ± 0.07	0 ± 0
	w_{high}	-0.061 ± 0.068	0 ± 0
	$w_{incl.}$	-0.026 ± 0.047	0 ± 0
ΔS_9	w_{low}	0.009 ± 0.07	0 ± 0
	w_{high}	0.022 ± 0.071	0 ± 0
	$w_{incl.}$	0.02 ± 0.049	0 ± 0



←analysis#1

Uncertainties for w_{incl} all < 0.05 for 189fb^{-1} & are statistics dominated

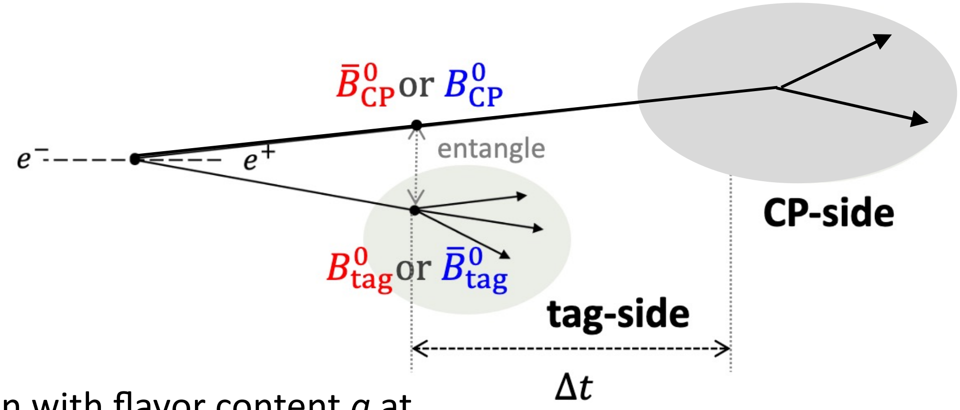
Time-dependent CP asymmetries

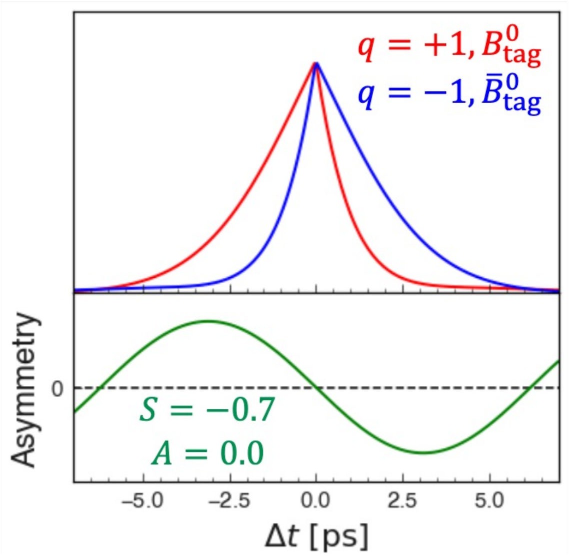
Recall: CP Violation - Original *raison d'etre* of B-factories

Time-dependent CP asymmetry is normalized difference between the decay rate involving a b quark and that involving a $\bar{b}$ quark:

We measure

- Δt : proper decay time difference of B_{CP} & B_{tag}
- $q = +1$ / -1 : flavor of B_{tag} (B^0_{tag}/ $\bar{B}^0_{\mathrm{tag}}$)





Probability of B meson with flavor content q at some time decays to a CP eigenstate f after a time Δt:

$$P(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{2\tau_{B^0}}\{1 + q[S_{CP}\sin(\Delta m_d \Delta t) + A_{CP}\cos(\Delta m_d \Delta t)]\}$$

$$\mathrm{asym}(\Delta t) = \frac{P(\Delta t, +1) - P(\Delta t, -1)}{P(\Delta t, +1) + P(\Delta t, -1)} = S_{CP}\sin(\Delta m \Delta t) + A_{CP}\cos(\Delta m \Delta t)$$

What we extract
S_{CP} is mixing-induced CP parameter
A_{CP} is direct CP parameter

Δm_d is the B^0-$\bar{B}^0$ oscillation frequency

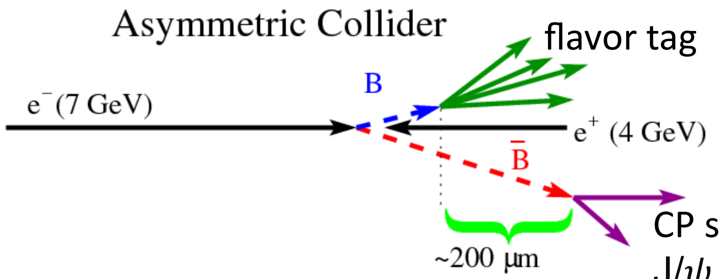
Time-dependent CP asymmetries: B → $J/\psi\ K^0_s$

Measure the asymmetry:

$$\mathcal{A}_f(\Delta t) \equiv \frac{\Gamma_{\overline{B}^0\to f}(\Delta t) - \Gamma_{B^0\to f}(\Delta t)}{\Gamma_{\overline{B}^0\to f}(\Delta t) + \Gamma_{B^0\to f}(\Delta t)}$$

$= S_{CP}\sin(\Delta m \Delta t) + A_{CP}\cos(\Delta m \Delta t)$

(Not to scale)



CP state:
$J/\psi\ K_s$ (CP odd)

SM predicts:

$A_{CP}=0$

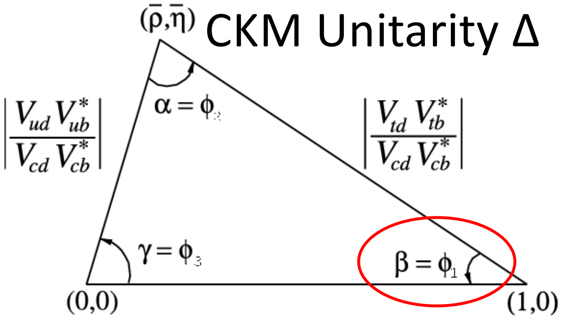
$S_{CP} = -\eta\sin 2\phi_1$

$\eta = +1$ for CP-odd

$= -1$ for CP-even

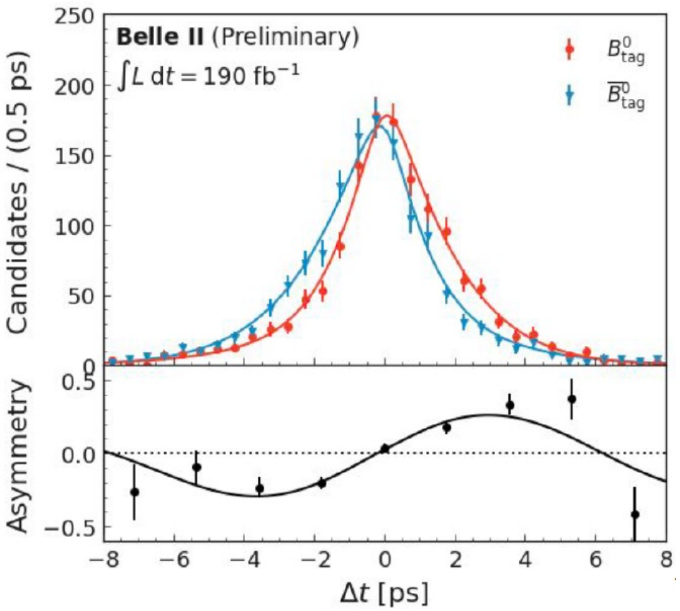
J/ψ Ks is CP odd

CKM Unitarity Δ

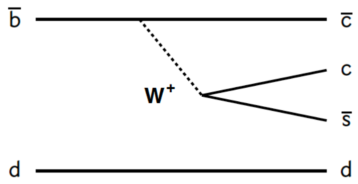


25μm vertex resolution
flavour tagging ε_{eff} ~ 30%

~ 2.8k B → $J/\psi\ K_s$



"Tree" b → $c\bar{c}s$
e.g. B->$J/\psi K_s$



B → $J/\psi\ K_s$ 190fb^{-1} (preliminary)

$$S_{CP} = 0.720 \pm 0.062(\text{stat}) \pm 0.016(\text{syst})$$

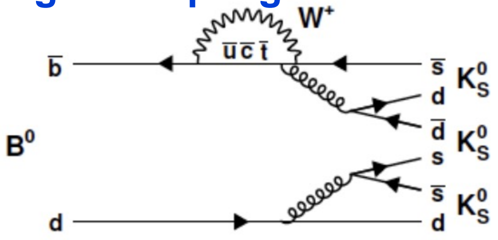
$$A_{CP} = 0.094 \pm 0.044(\text{stat})\,{}^{+0.042}_{-0.017}(\text{syst})$$

arXiv:2302.12898

Time-dependent CP asymmetries in B → $K^0_S K^0_S K^0_S$

(preliminary for winter 2023 conferences)

gluonic penguins



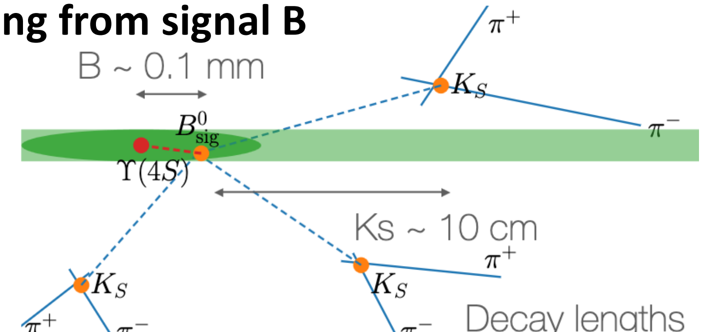
$K^0_S K^0_S K^0_S$ is CP even

In SM:

$S_{CP} \approx -\sin(2\varphi_1)$ and $A_{CP} = 0$

$[\, S_{CP} - \sin(2\varphi_1) \,] = 0.02 \pm <.01$

No track coming from signal B



Decay lengths (not to scale)

Channels

- $B^0 \to K^0_S K^0_S K^0_S$ Time Differential (TD) 158^{+14}_{-13} events
- $B^0 \to K^0_S K^0_S K^0_S$ Time Integrated (TI, no use of Δt information) 62±9 events
- $B^+ \to K^0_S K^0_S K^+$ (control channel)

1. Event reconstruction

- K^0_S selection, vertex fits, continuum suppression, TD/TI classification

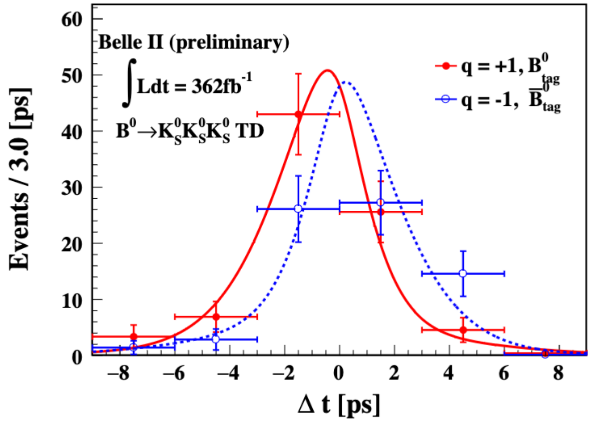
2 BDTs to suppress fake K_S (kinematic/hits $\pi^\pm$ tracks) and continuum (event shape variables)

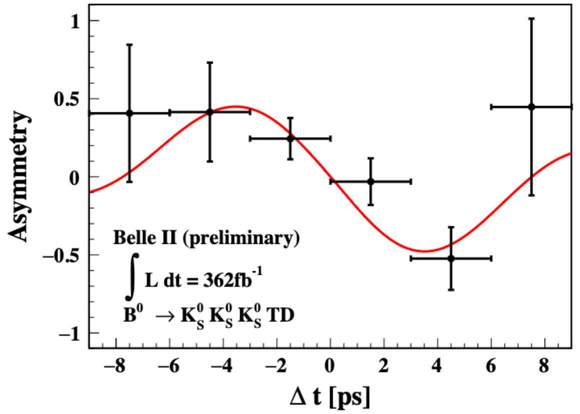
2. Signal extraction fit

- determine signal yields & background shape
- 3D fit to $(M_{bc}, M, \mathcal{O}'_{CS})$, simultaneous over three channels
  - M: invariant mass of B_{CP}, $\mathcal{O}'_{CS}$: modified continuum suppression FastBDT classifier

3. Δt fit

- determine CP asymmetries (S,A) & resolution scale factor
- 2D fit to (Δt, q), simul. over three channel





362 fb^{-1} (preliminary)

B → $K^0_S K^0_S K^0_S$

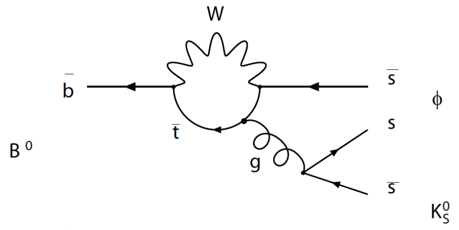
$$S_{CP} = -1.37^{+0.35}_{-0.45}(\text{stat}) \pm 0.03(\text{syst})$$

$$A_{CP} = 0.07^{+0.15}_{-0.20}(\text{stat}) \pm 0.02(\text{syst})$$

HFLAV: S = -0.83±0.17, A = 0.15±0.12

Time-dependent CP asymmetries in B → ϕ K^0_S

(preliminary for winter 2023 conferences)

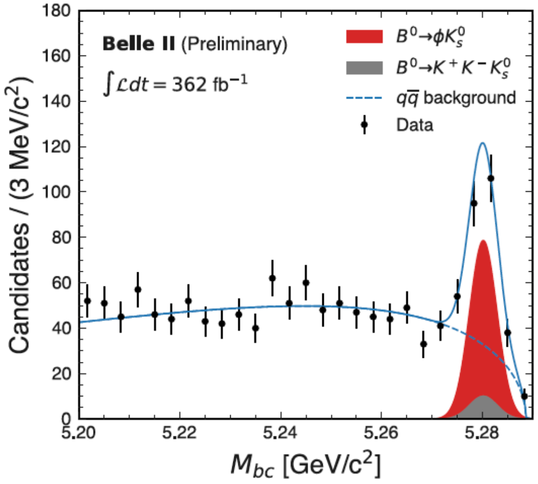


Penguin dominated
b → $q\bar{q}s$ transition

Pre-Belle II:

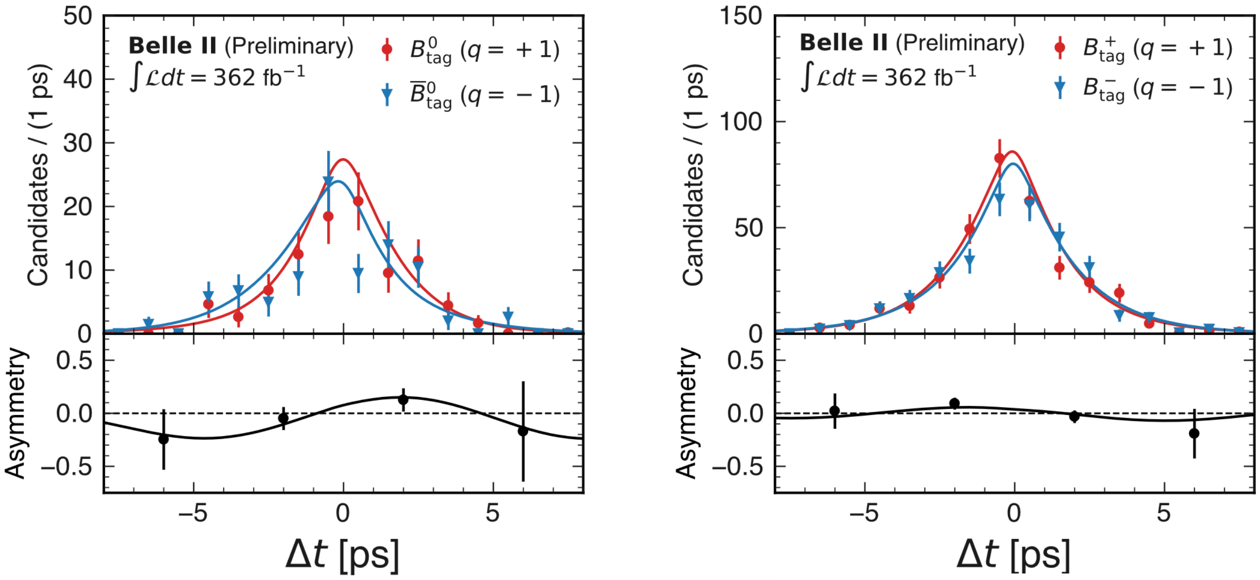
	A_{CP}	S_{CP}
Belle (2010)	$-0.04 \pm 0.20 \pm 0.10 \pm 0.02$	$0.90^{+0.09}_{-0.19}$
BABAR (2012)	$-0.05 \pm 0.18 \pm 0.05$	$0.66 \pm 0.17 \pm 0.07$
HFLAV	-0.01 ± 0.14	$0.74^{+0.11}_{-0.13}$

Main background from non-resonant B → K^+K^- K^0_S with opposite CP
Fixed from HFLAV



CP even $B^0 \to \phi K^0_S$

$B^+ \to \phi K^+$ control



$$A_{CP} = 0.12 \pm 0.10 \text{ (stat.)}$$
$$S_{CP} = -0.09 \pm 0.12 \text{ (stat.)}$$

Non-resonant B → K^+K^- K^0_S component disentangled in cosθ

With 362 fb^{-1} dataset:
(preliminary)

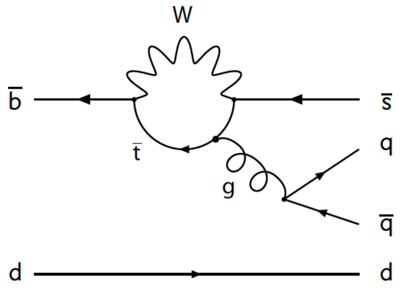
$$A_{CP} = 0.31 \pm 0.20^{+0.05}_{-0.06}$$
$$S_{CP} = 0.54 \pm 0.26^{+0.06}_{-0.08}$$

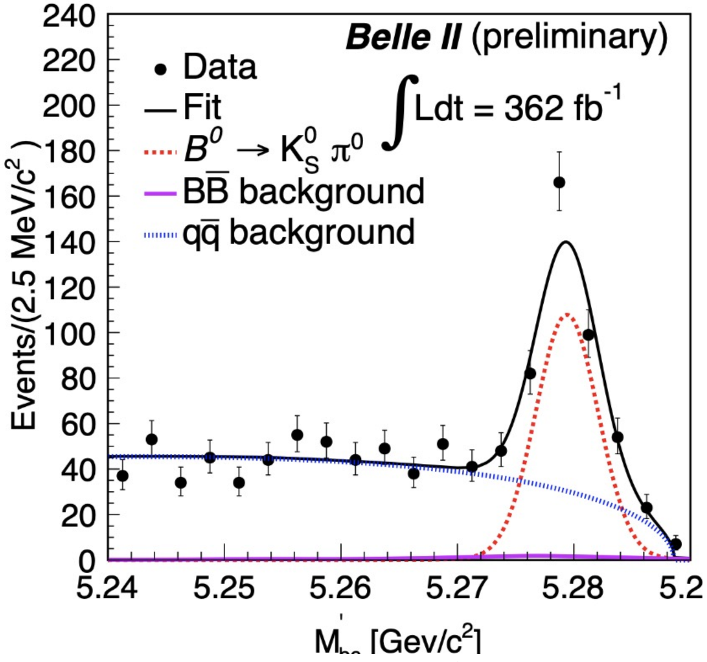
10-20% improvement on S_{CP} for the same signal yield wrt Belle/BaBar determinations

Time-dependent CP asymmetries in B → $K^0_S\ \pi^0$

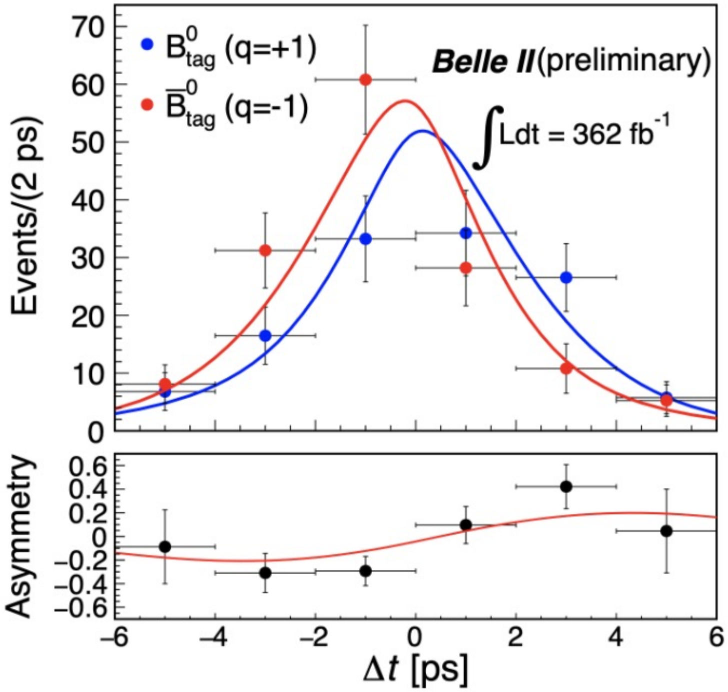
(preliminary for winter 2023 conferences)

Sensitive to New Physics in penguins:





$$M_{\rm bc} = \sqrt{(E^*_{\rm beam})^2 - (\mathbf{p}^*_B)^2}$$



B → $K^0_S\ \pi^0$ a challenge:

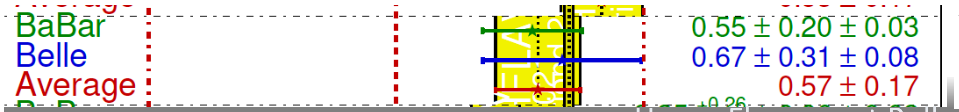
- BF ~10^{-6}
- Neutrals in final state
  → unique to e^+e^-

$$A_{CP} = 0.04 \pm 0.15 \pm 0.05$$

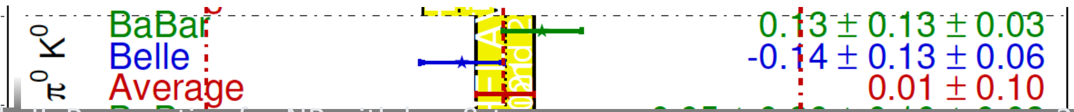
$$S_{CP} = 0.75^{+0.20}_{-0.23} \pm 0.04$$

Competitive with world's best results with much lower luminosity

$\sin(2\beta^{\rm eff}) \equiv \sin(2\phi_1^{\rm eff})$ HFLAV 2021



$C_f = -A_f$ HFLAV 2021



Kπ isospin sum rule

(preliminary for winter 2023 conferences)

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

Where

$$\mathcal{A}_{CP} = \frac{\Gamma(\bar{B}\to\bar{X}) - \Gamma(B\to X)}{\Gamma(\bar{B}\to\bar{X}) + \Gamma(B\to X)}$$

is direct CP asymmetry for final state *X*

Summing over isospin combinations overcomes theoretical uncertainties in SM determination of the individual $A^{K\pi}_{CP}$ values

In SM: $I_{K\pi} = 0$ (± $\lesssim$1%); before Belle II : $I_{K\pi} = -0.13 \pm 0.11$

(preliminary)

Decay	$\mathcal{B}\ [10^{-6}]$	$\mathcal{A}_{CP}$
$B^0 \to K^+\pi^-$	$20.67 \pm 0.37 \pm 0.62$	$-0.072 \pm 0.019 \pm 0.007$
$B^0 \to \pi^+\pi^-$	$5.83 \pm 0.22 \pm 0.17$	–
$B^+ \to K^+\pi^0$	$14.21 \pm 0.38 \pm 0.85$	$0.013 \pm 0.027 \pm 0.005$
$B^+ \to \pi^+\pi^0$	$5.02 \pm 0.28 \pm 0.31$	$-0.082 \pm 0.054 \pm 0.008$
$B^+ \to K^0\pi^+$	$24.4 \pm 0.71 \pm 0.86$	$0.046 \pm 0.029 \pm 0.007$
$B^0 \to K^0\pi^0$	$10.16 \pm 0.65 \pm 0.65$	$-0.06 \pm 0.15 \pm 0.05$
$*B^0 \to K^0\pi^0$	$10.50 \pm 0.62 \pm 0.65$	$-0.01 \pm 0.12 \pm 0.05$

*combined with our Time Dependent $K^0\pi^0$ result of previous page

$$\tau_{B^0}/\tau_{B^+} = 0.9273 \pm 0.0033$$

Modes	Ratio
$\mathcal{B}_{K^0\pi^+}/\mathcal{B}_{K^+\pi^-}$	$1.180 \pm 0.040 \pm 0.027$
$\mathcal{B}_{K^+\pi^0}/\mathcal{B}_{K^+\pi^-}$	$0.687 \pm 0.022 \pm 0.040$
$\mathcal{B}_{K^0\pi^0}/\mathcal{B}_{K^+\pi^-}$	$0.508 \pm 0.031 \pm 0.030$

Belle II *w/* 362 fb^{-1} : $\boxed{I_{K\pi} = -0.03 \pm 0.13 \pm 0.05}$

(preliminary)

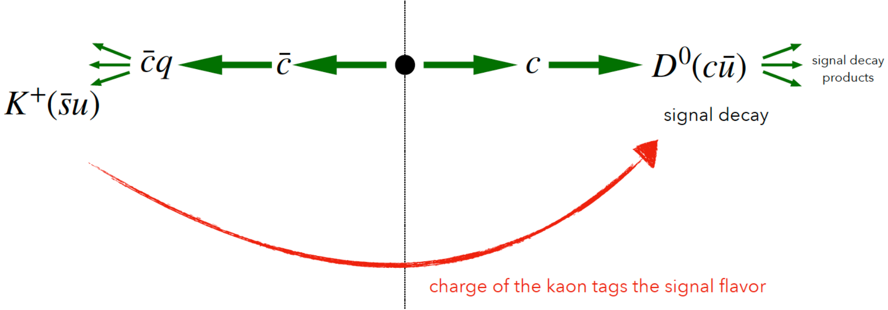
Charm: D-tagging improvement at Belle II

(preliminary for winter 2023 conferences)

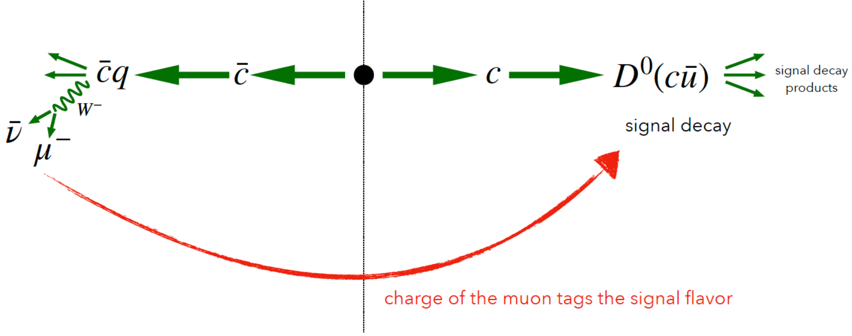
- CP Violation and charm-mixing measurements so far rely on neutral D mesons from $D^{*\pm}$ decays in $e^+e^- \rightarrow c\,\bar{c}$
- These measurements need to ID the charm flavour content at production, i.e. tag if neutral D meson is produced as a D^0 or a $\bar{D}^0$
- Current $D^{*\pm}$ approach only tags ~25% of neutral D mesons

New approach use opposite-side charge or slow pion on signal side

Rest Of Event info input to histogram-based gradient-boosting decision tree (HBDT)

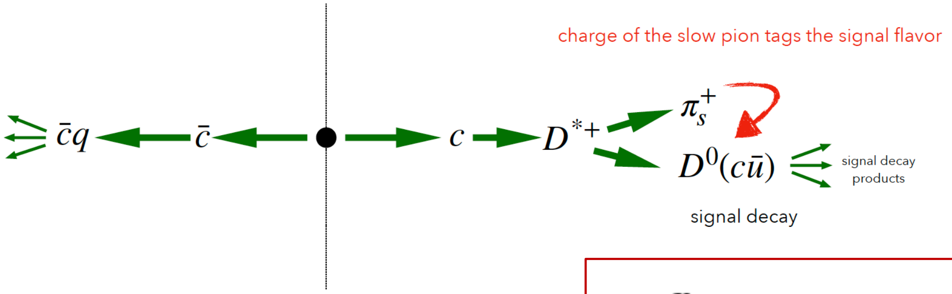


charge of the kaon tags the signal flavor



charge of the muon tags the signal flavor

charge of the slow pion tags the signal flavor



tagging power for $D^0 \rightarrow K^-\pi^+$ decays

$$\varepsilon_{\rm tag}^{\rm eff} = \varepsilon_{\rm tag}(1-2\omega)^2$$

(ω is mis-tag rate)

Measured *w/* 362fb^{-1} sample: $\boxed{\varepsilon_{\rm tag}^{\rm eff} = (47.91 \pm 0.07({\rm stat}) \pm 0.51({\rm syst}))\%}$

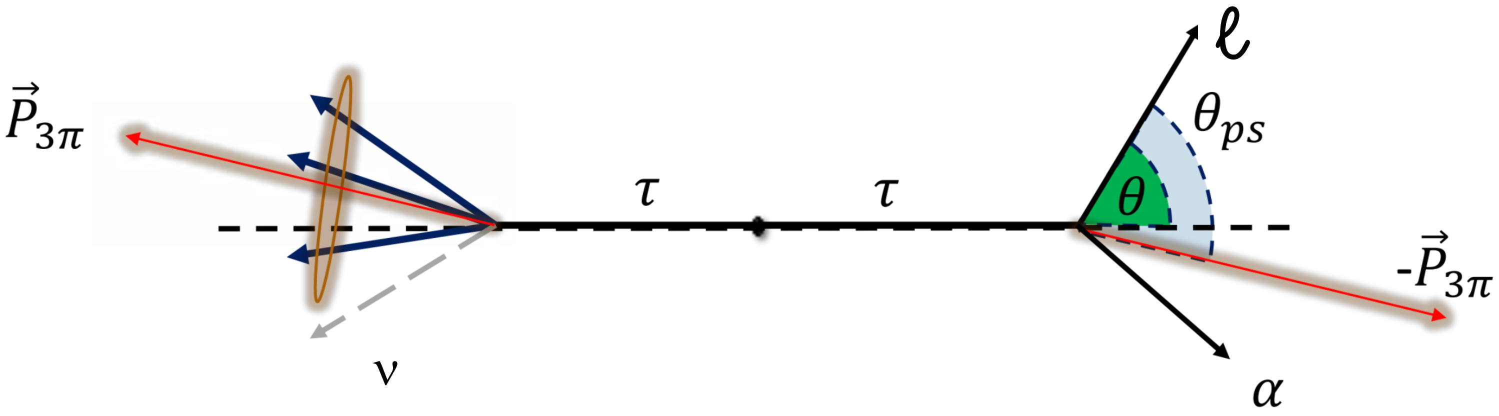
Doubles Sample size!

Search for $\tau^{\pm} \rightarrow \ell^{\pm} \alpha$
(ℓ = μ or e; α=invisible scalar)

Models with axion-like particles predict such τ decays

- *Z. G. Berezhiani and M. Y. Khlopov, Z. Phys. C 49, 73 (1991).*
- *L. Calibbi, D. Redigolo, R. Ziegler, and J. Zupan, J. HEP 09, 173 (2021).*
- *M. Bauer, M. Neubert, S. Renner, M. Schnubel, and A. Thamm, PRL 124, 211803 (2020).*
- *C. Cornella, P. Paradisi, and O. Sumensari, J. HEP ys 01, 158 (2020)*

Search for $e^+e^- \rightarrow \tau^{\pm}_{sig}\, \tau^{\mp}_{tag}$ with $\tau^{\mp}_{tag} \rightarrow 3h^{\mp}\overset{(-)}{\nu}$, h = π or K



2-body decay of the signal peaks in ℓ momentum distribution in τ rest frame

Search for $\tau^{\pm} \to \ell^{\pm} \alpha$

(ℓ = μ or e; α=invisible scalar)

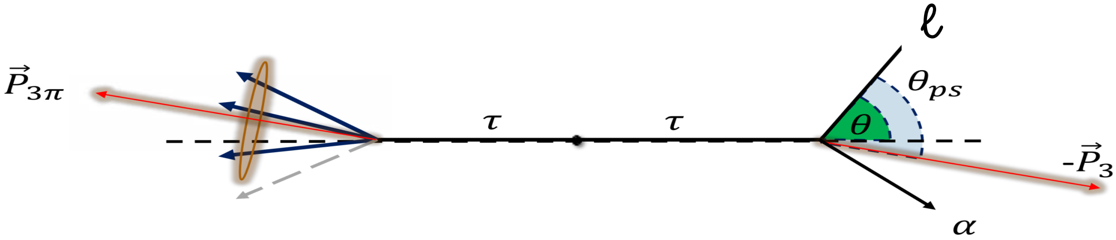
arXiv:2212.03634

“τ pseudo rest frame”:

- $\tau^{\pm}_{sig}$ direction approximated as opposite 3h $^{\mp}$ momentum:

$$\hat{p}_{\tau} \approx -\vec{p}_{3h}/|\vec{p}_{3h}|$$

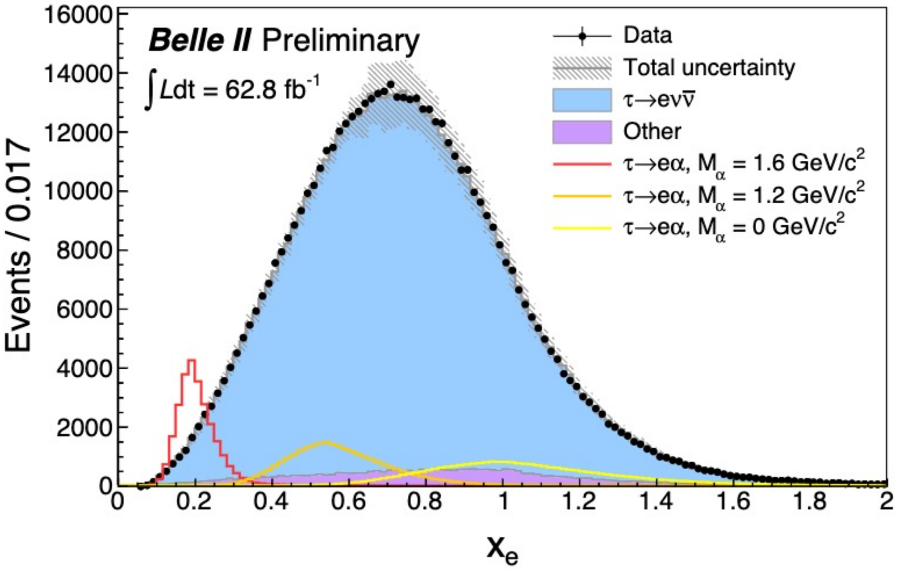
- $E_{\tau} \approx E_{cm}/2$

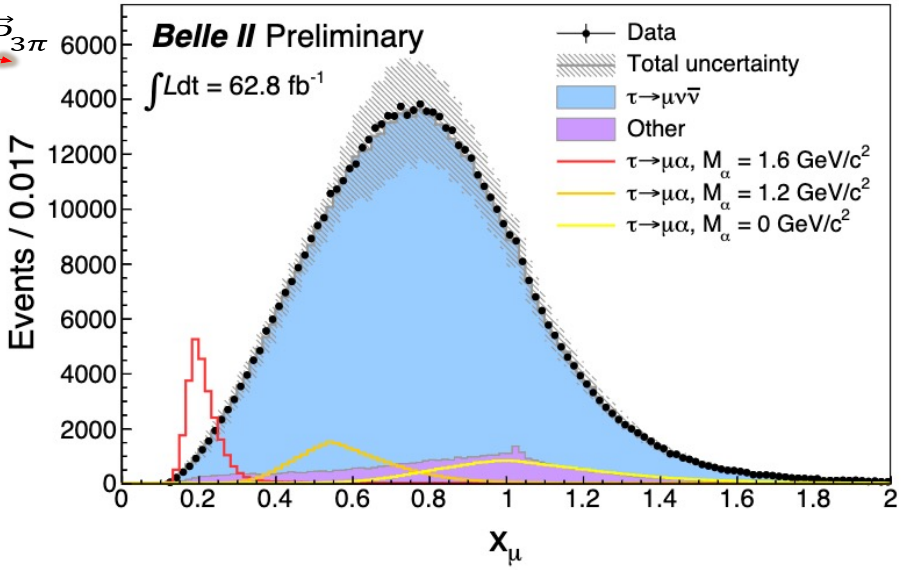


$X_{\ell} = E^{*}_{\ell} / (m_{\tau} c^2/2)$

(E^{*}_{ℓ} : ℓ energy in τ pseudo rest frame)

Search for bump in X_{ℓ} on top of $\tau \to \ell \nu \bar{\nu}$





Search for $\tau^{\pm} \to \ell^{\pm}\alpha$

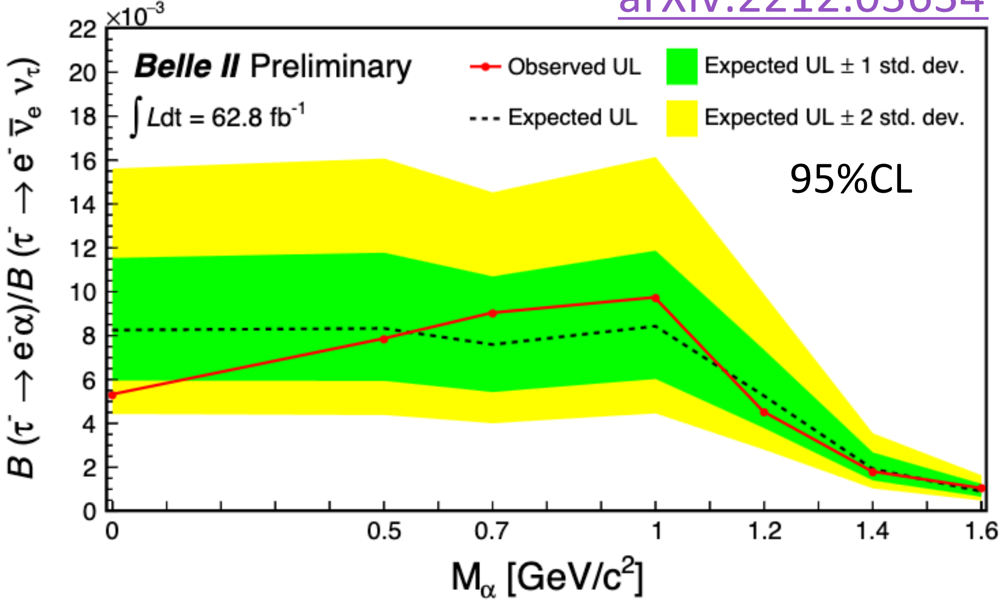
(ℓ = μ or e; α=invisible scalar)

arXiv:2212.03634

Using early Belle II dataset of 62.8fb^{-1} collected in 2019 & 2020 we set limits on

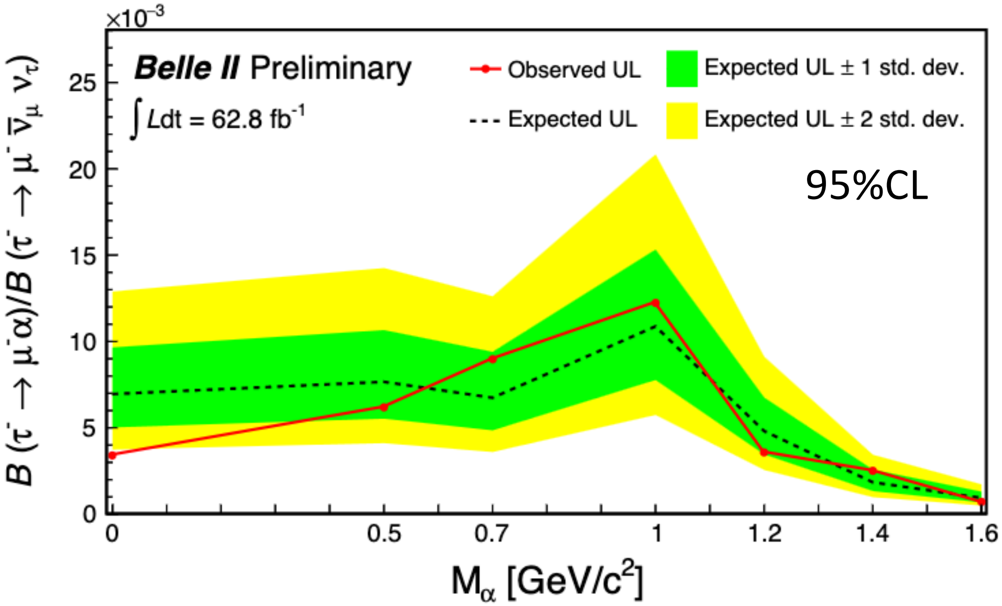
$$B(\tau \to \ell\alpha)/B(\tau \to \ell\nu\bar{\nu})$$

as function of α mass



Depending on M_α ,these 95%CL limits are 2.2 to 14 times more stringent that best previous limits set by ARGUS

ARGUS Collaboration, Z. Phys. C 68, 25 (1995)



Search for $\tau^{\pm} \to \ell^{\pm}\alpha$

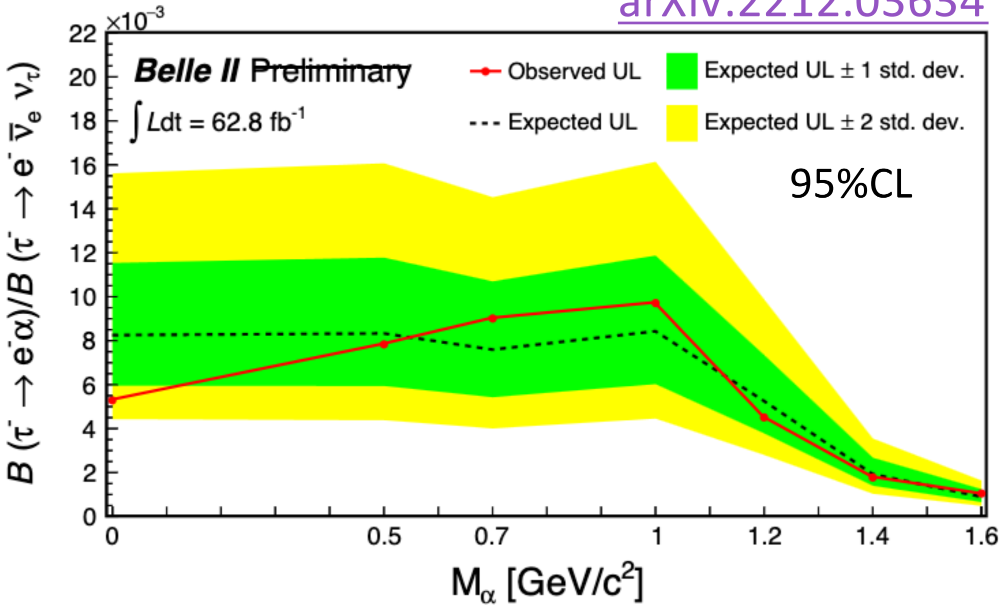
($\ell = \mu$ or e; α=invisible scalar)

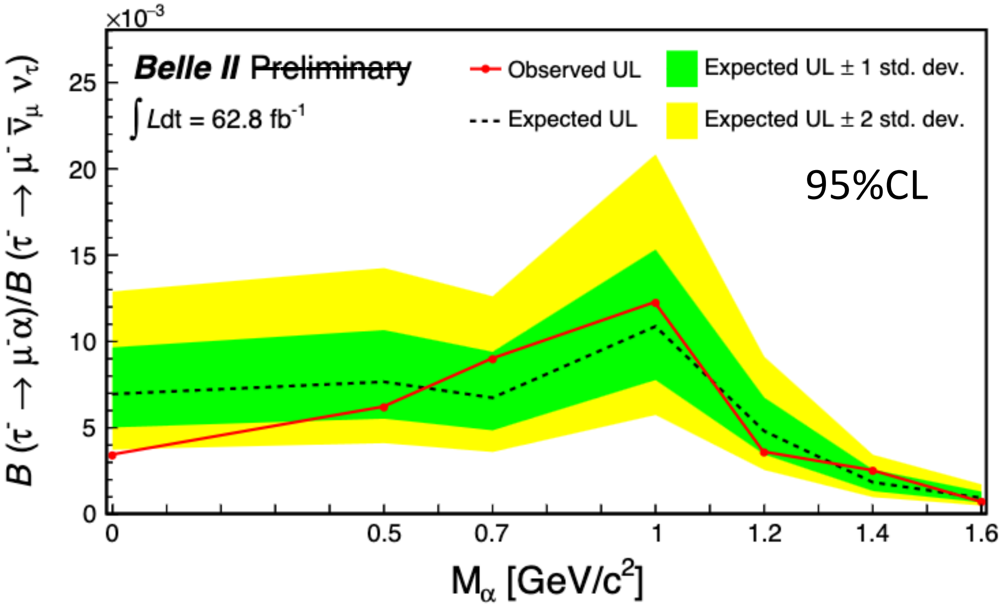
arXiv:2212.03634

Using early Belle II dataset of $62.8\mathrm{fb}^{-1}$ collected in 2019 & 2020 we set limits on

$$B(\tau \to \ell\alpha)/B(\tau \to \ell\nu\bar{\nu})$$

as function of α mass





Depending on M_α ,these 95%CL limits are 2.2 to 14 times more stringent that best previous limits set by ARGUS

ARGUS Collaboration, Z. Phys. C 68, 25 (1995)

ACCEPTED FOR PUBLICATION IN Physical Review Letters this month

Search for $\tau^{\pm} \to \ell^{\pm} \phi$

(preliminary for winter 2023 conferences)

Leptoquark models predict BF of up to 10^{-8} - 10^{-10}

BF ~ 10^{-50} in SM (via ν mixing)

PDG 90%CL: $B(\tau\to e\varphi) < 3.1\times10^{-8}$; $B(\tau\to\mu\varphi) < 8.4\times10^{-8}$

Belle II data size : 190fb^{-1} (<< datasets of Belle & BaBar input to PDG)

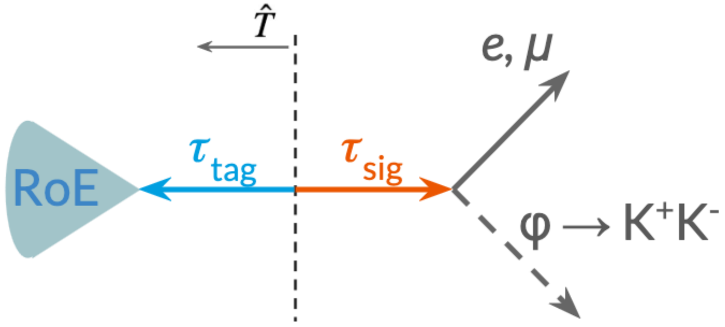
Methodology

Signal side: $\tau\to\ell\varphi$

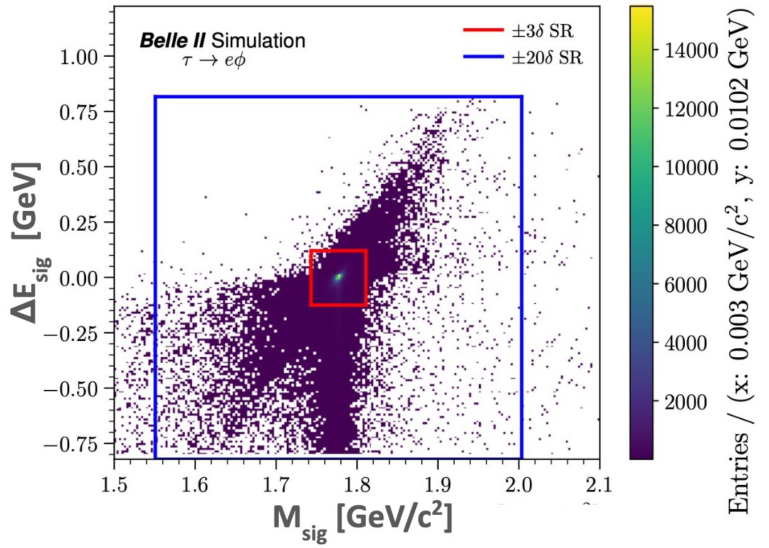
- ℓ=e, μ and $\varphi\to K^+K^-$ (~50% BF of φ)
- Tag side: inclusive (***novel approach)***
  everything except for signal: "Rest of Event" (RoE)
  RoE and signal kinematics in BDT classifier
  suppresses continuum backgrounds

Signal efficiency= 6.1% (6.5%) for e (μ) channel

- Inv. mass on the signal side (M_{sig}) peaks at $M\tau$
- $\Delta E_{sig} = E^*_{sig} - \sqrt{s}/2$ peaks at zero



electron channel



Backgrounds determined using sidebands

(preliminary)

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

90%CL upper limits on BF($\tau\to\ell\varphi$)
(preliminary for winter 2023 conferences)

BF($\tau\to e\varphi$)< 2.3×10^{-7} (expected: 1.5×10^{-7})
BF($\tau\to\mu\varphi$)< 9.7×10^{-8} (expected: 9.9×10^{-8})

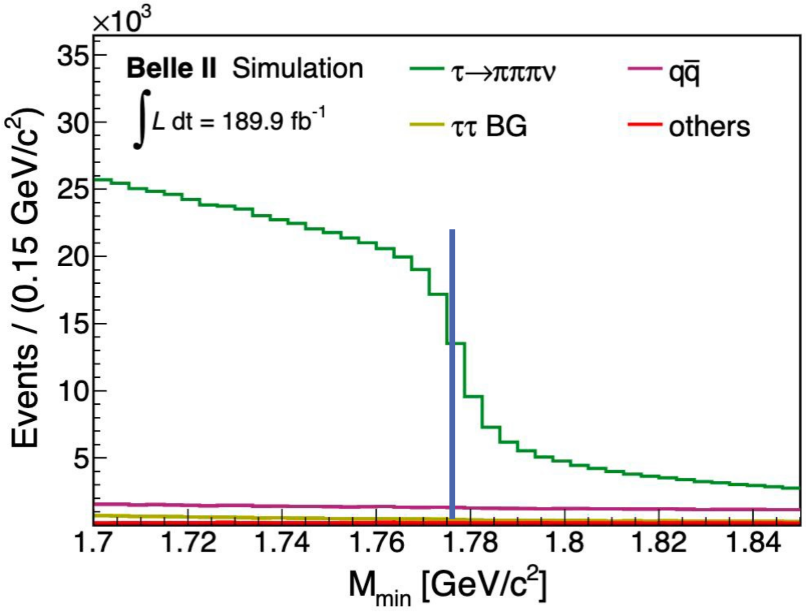
Precision Measurement of τ Mass

(preliminary for winter 2023 conferences)

Use $\tau^{\pm}_{sig} \to 3\,\pi^{\mp}\overset{(-)}{\nu}$ decays and ARGUS approach, which gives a sharp edge at M_{τ} in the distribution of the pseudo-mass, M_{min} :

$$M_{min} = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})} \leq m_{\tau}$$

(E_{beam}, $E_{3\pi}$ and $P_{3\pi}$ in e^+e^- centre-of-mass frame)



Monte Carlo Simulation

Assumes:

- $E_{\tau} = E_{beam}$
- $M_{\nu} = 0$
- ν collinear with 3π in tau frame

Upper tail caused by

- Initial State Radiation
- Detector resolution

Precision Measurement of τ Mass

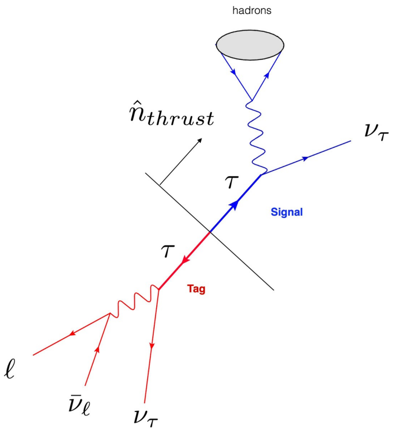
(preliminary for winter 2023 conferences)

In 189.9 fb^{-1} of data we reconstruct:

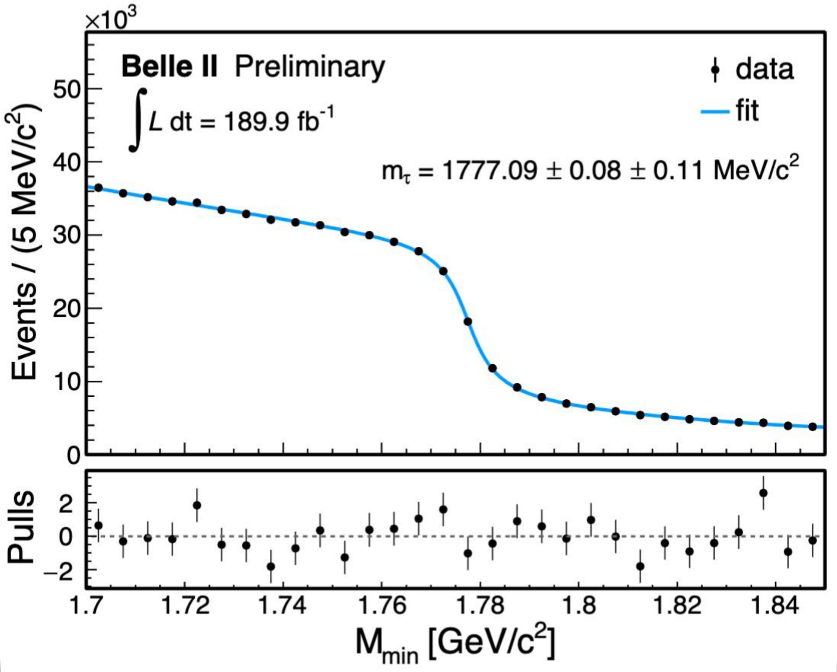
$e^+e^- \rightarrow \tau^{\pm}_{sig}\,\tau^{\mp}_{tag}$ with

$\tau^{\pm}_{sig} \rightarrow 3\,\pi^{\mp}\overset{(-)}{\nu}$

$\tau^{\mp}_{tag} \rightarrow h^{\mp}(\pi^0)\overset{(-)}{\nu}$, or $\tau \rightarrow \ell\,\nu\,\bar{\nu}$



Select events with 4 charged particle tracks and no photons >200MeV apart from tag-side $\pi^0 \rightarrow \gamma\gamma$



Fit the distribution in 1.7 < M_{min} <1.85 window with the edge function:

$$F(x) = -P_3 tan^{-1}\left(\frac{x-P_1}{P_2}\right) + P_7(x-P_1)^2 + P_5(x-P_1) + 1$$

P_1 is a biased estimator of the mass with bias from PDF, selection, ISR/FSR:

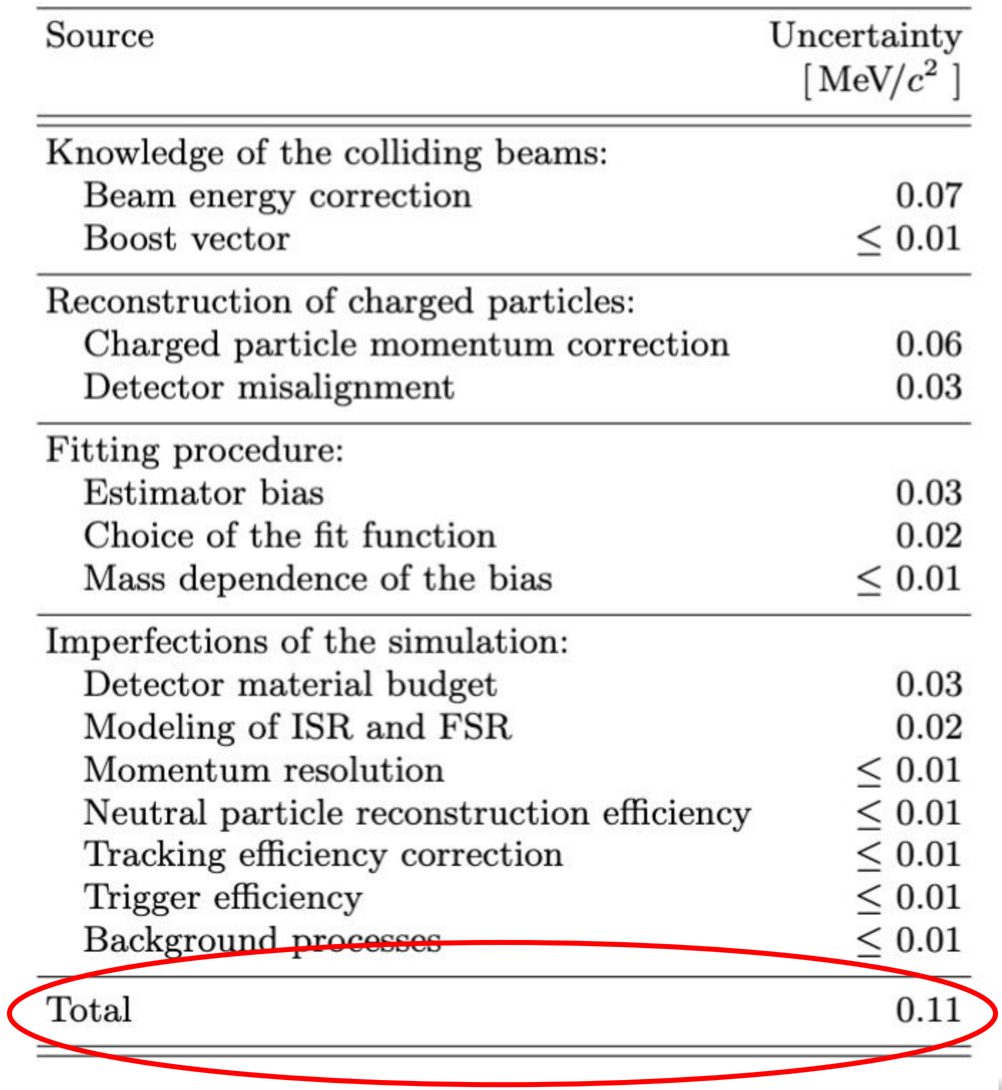
$\Delta m = m^{fit}_{\tau} - m^{gen}_{\tau} = 0.40 \pm 0.04$ MeV

(*cf* Belle and BaBar bias of 1-1.5MeV)

Precision Measurement of τ Mass

(preliminary for winter 2023 conferences)

Systematic Uncertainties (preliminary)



Source	Uncertainty [MeV/c^2]
Knowledge of the colliding beams:	
Beam energy correction	0.07
Boost vector	$\lesssim 0.01$
Reconstruction of charged particles:	
Charged particle momentum correction	0.06
Detector misalignment	0.03
Fitting procedure:	
Estimator bias	0.03
Choice of the fit function	0.02
Mass dependence of the bias	$\lesssim 0.01$
Imperfections of the simulation:	
Detector material budget	0.03
Modeling of ISR and FSR	0.02
Momentum resolution	$\lesssim 0.01$
Neutral particle reconstruction efficiency	$\lesssim 0.01$
Tracking efficiency correction	$\lesssim 0.01$
Trigger efficiency	$\lesssim 0.01$
Background processes	$\lesssim 0.01$
Total	0.11

Uncertainty on m_τ :

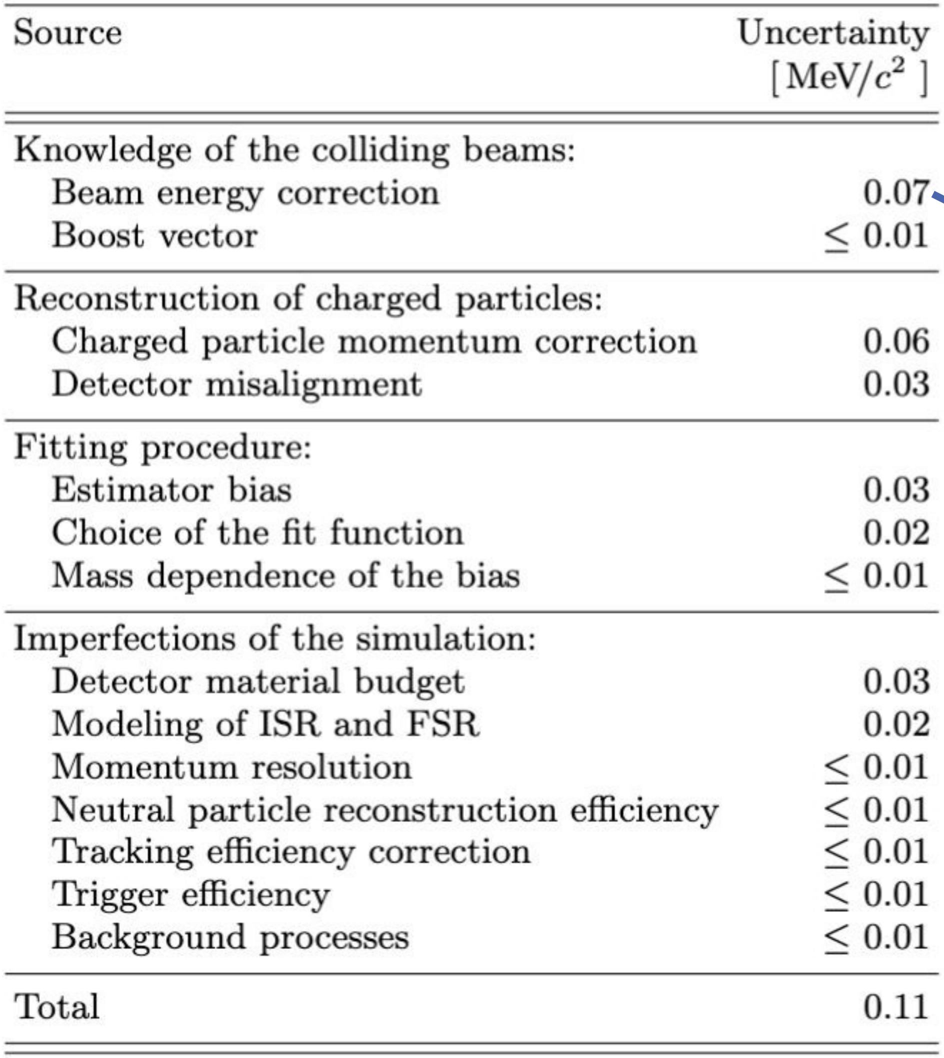
± 0.08(stat) ± 0.11(syst) MeV

(*cf* PDG: ± 0.12(syst) MeV)

Precision Measurement of τ Mass

(preliminary for winter 2023 conferences)

Systematic Uncertainties (preliminary)



Source	Uncertainty [MeV/c^2]
Knowledge of the colliding beams:	
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Estimator bias	0.03
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Imperfections of the simulation:	
Detector material budget	0.03
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Momentum resolution	$\lesssim 0.01$
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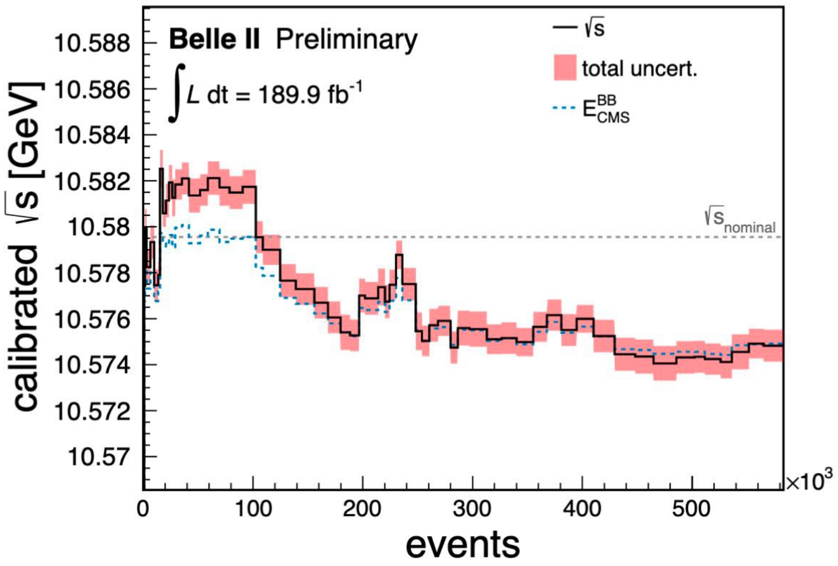
Tracking efficiency correction	$\lesssim 0.01$
Trigger efficiency	$\lesssim 0.01$
Background processes	$\lesssim 0.01$
Total	0.11

Uncertainty on m_τ :
± 0.08(stat) ± 0.11(syst) MeV

(*cf* PDG: ± 0.12(syst) MeV)

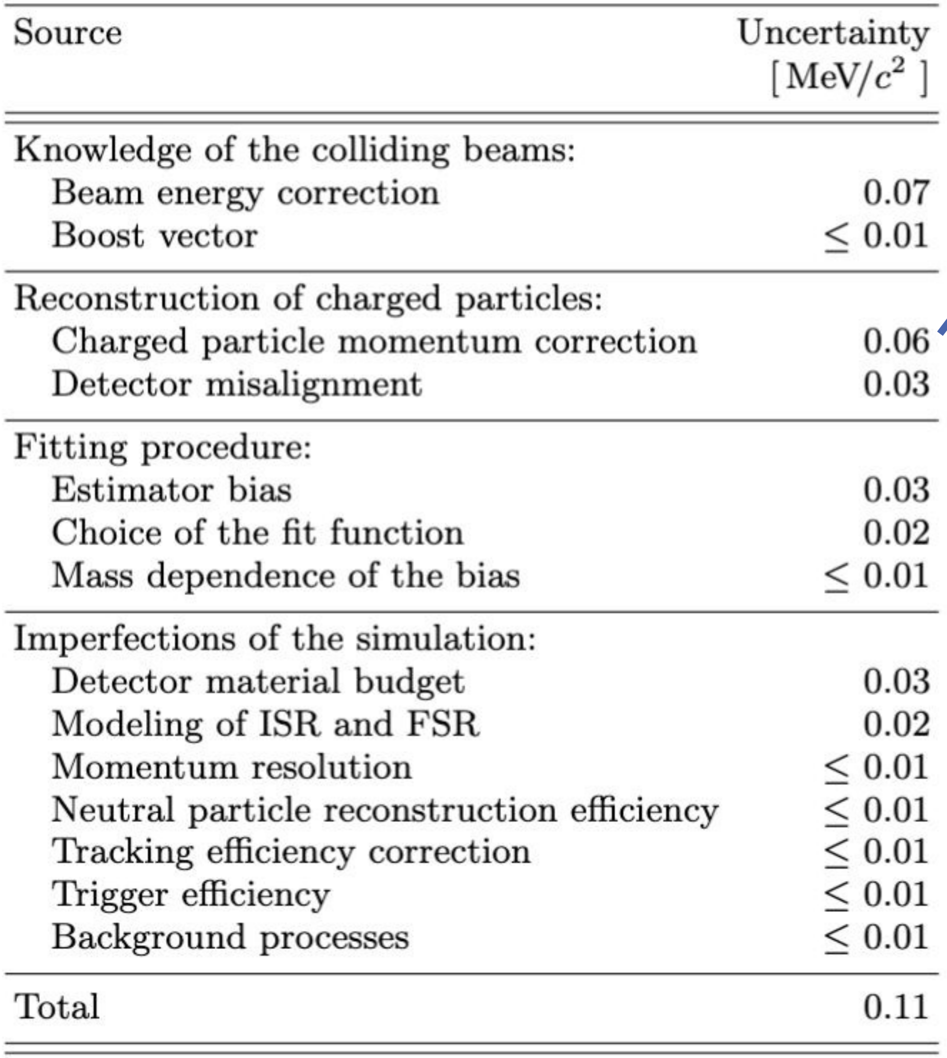
Correction to CM Energy from counting reconstructed B decays, which depend on CM energy. Include corrections for ISR, beam energy spread, Υ(4S) shape:



Precision Measurement of τ Mass

(preliminary for winter 2023 conferences)

Systematic Uncertainties (preliminary)



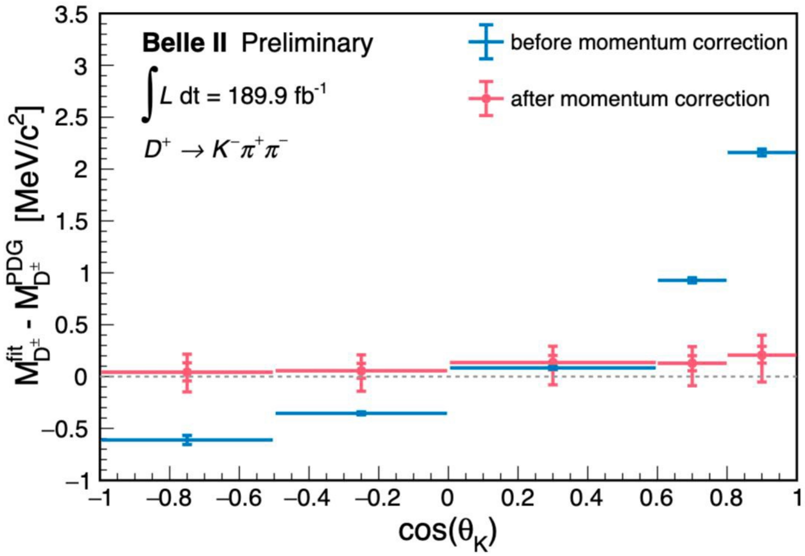
Source	Uncertainty [MeV/c^2]
Knowledge of the colliding beams:	
Beam energy correction	0.07
Boost vector	≤ 0.01
Reconstruction of charged particles:	
Charged particle momentum correction	0.06
Detector misalignment	0.03
Fitting procedure:	
Estimator bias	0.03
Choice of the fit function	0.02
Mass dependence of the bias	≤ 0.01
Imperfections of the simulation:	
Detector material budget	0.03
Modeling of ISR and FSR	0.02
Momentum resolution	≤ 0.01
Neutral particle reconstruction efficiency	≤ 0.01
Tracking efficiency correction	≤ 0.01
Trigger efficiency	≤ 0.01
Background processes	≤ 0.01
Total	0.11

Uncertainty on m_τ :
$\pm$ 0.08(stat) $\pm$ 0.11(syst) MeV

(*cf* PDG value: ± 0.12 MeV)

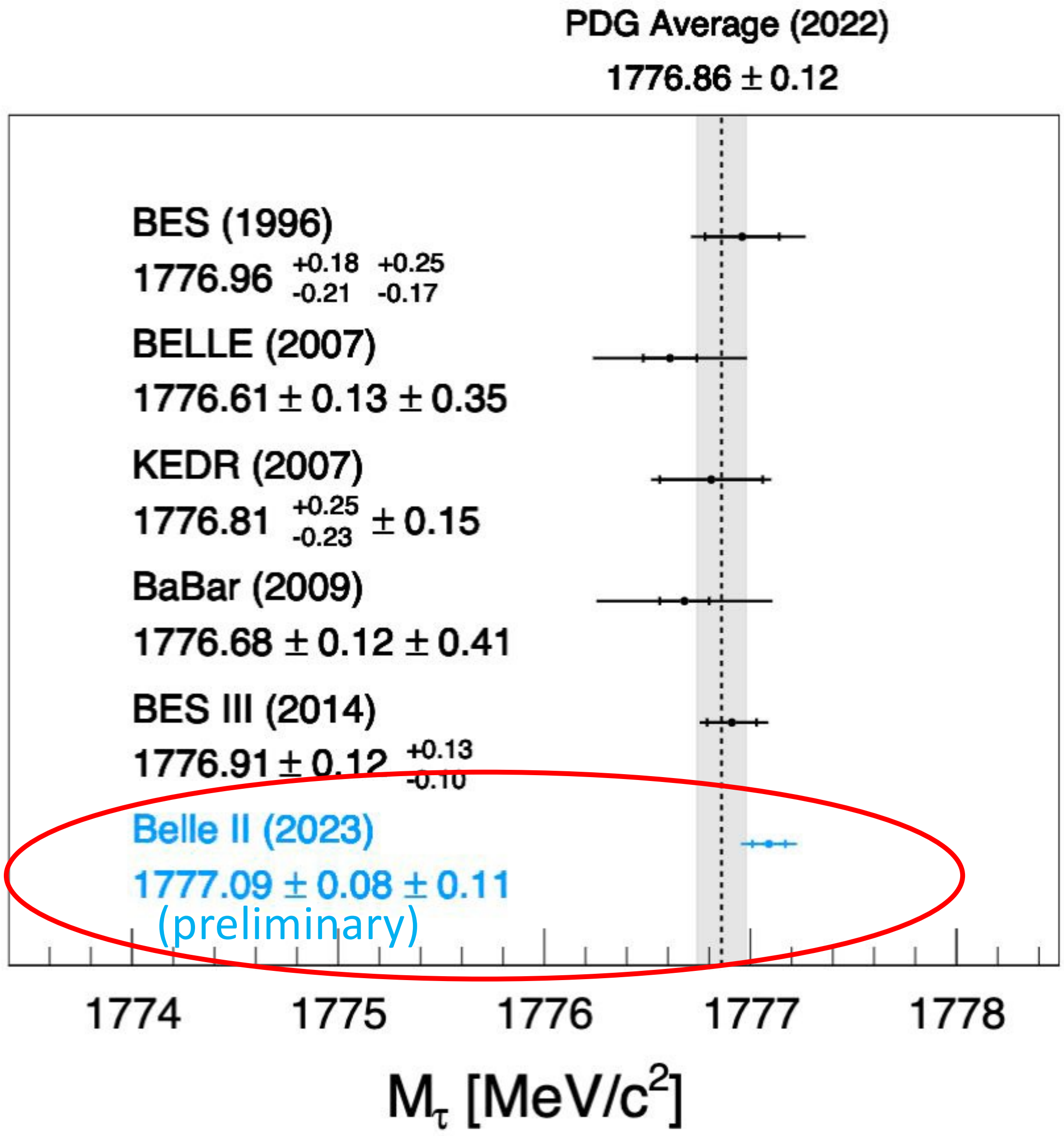
Correction to momentum scale obtained from shifts of D^0 mass peak in $D^0 \rightarrow K\pi$ *cf* PDG D^0 mass

Closure test with $D^+ \rightarrow K^-\pi^+\pi^-$:



Precision Measurement of τ Mass

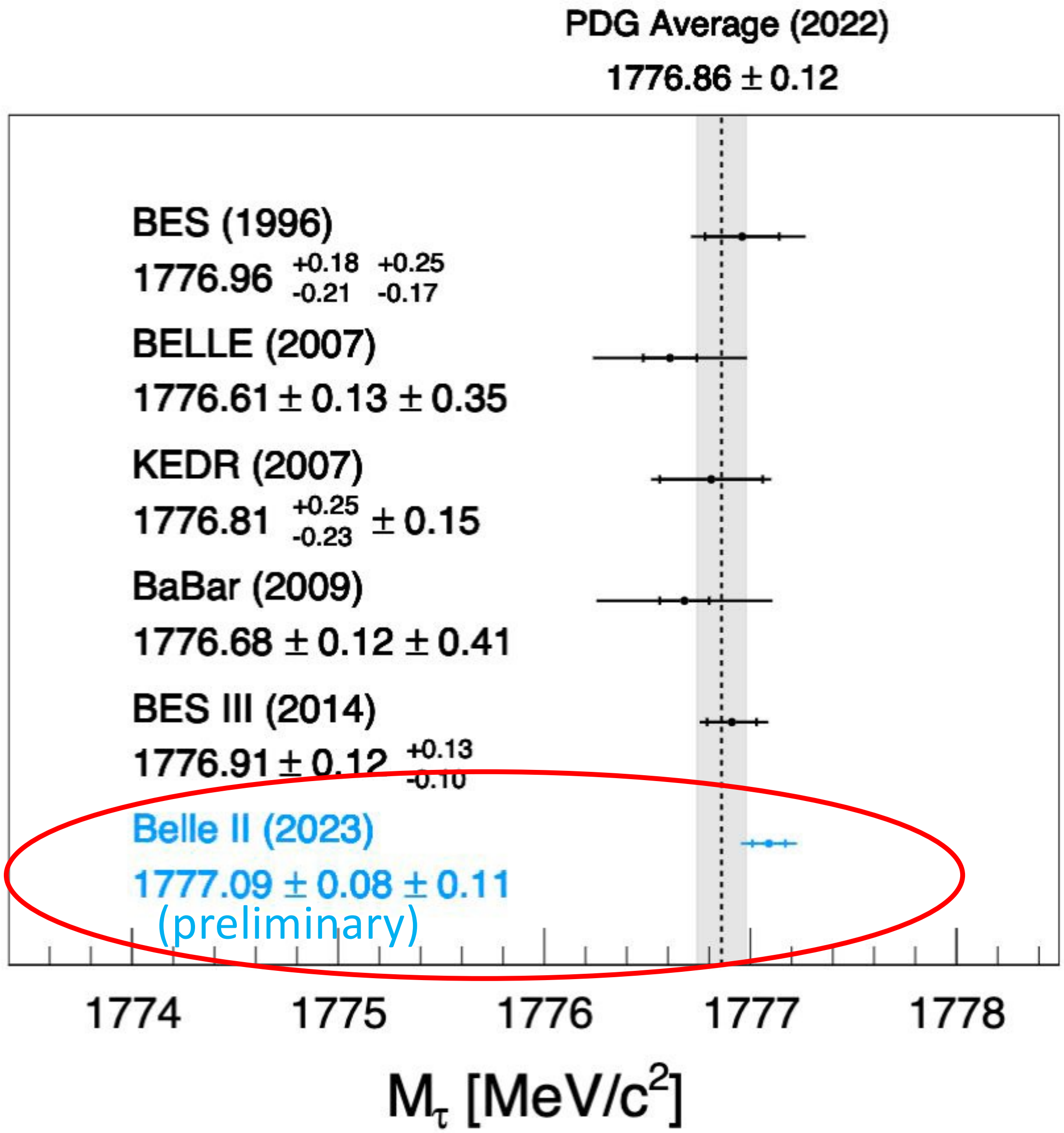
(preliminary for winter 2023 conferences)



World leading measurement
Consistent with PDG 2022 Average

Precision Measurement of τ Mass

(preliminary for winter 2023 conferences)



World leading measurement
Consistent with PDG 2022 Average

New WA would be
(ignoring correlations)
m_τ = 1776.96 ± 0.09 MeV

Overall 25% decrease in WA uncertainty

Prospecting for NP with τ Mass

μ and τ masses & lifetimes required in precision $\mu-\tau$ lepton universality ratio that uses $B(\tau \to e\,\nu\,\nu)/B(\mu \to e\,\nu\,\nu)$

$$\left(\frac{g_\tau}{g_\mu}\right)^2_T = B_e \frac{\tau_\mu}{\tau_\tau} \frac{f_\mu(x_e)}{f_\tau(x_e)} \left(\frac{m_\mu}{m_\tau}\right)^5 \delta_{cor}$$

δ_{cor} *higher order EW corrections*

$f_{\mu/\tau}$ *phase space correction;* $x_e=m_e/m_\mu$ *or* m_e/m_τ

Currently precision primarily limited by τ lifetime and $B(\tau \to e\,\nu\,\bar{\nu})$ and then by τ mass

Prospecting for NP with τ Mass

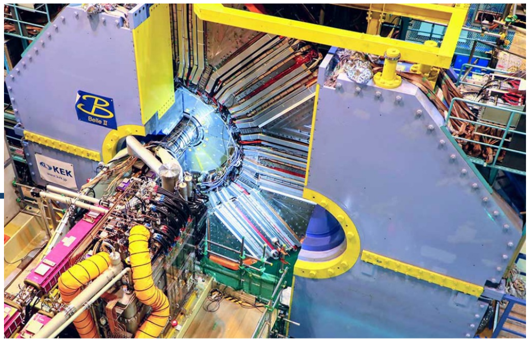
Precision τ mass also needed in future high precision τ g-2 measurements with polarized e^- beams in e^+e^- at 10GeV to get towards $\mathcal{O}(10^{-6})$ precision –

Chance to see if μ g-2 tension persists in 3rd generation

Required to get precision cancellation of F_1 in experimental measurement of asymmetries yielding Re{F_2} (i.e. g-2 form factor)

(D.M. Asner et al. [US Belle II Group and Belle II/SuperKEKB e- Polarization Upgrade Working Group], ``Snowmass 2021 White Paper on Upgrading SuperKEKB with a Polarized Electron Beam: Discovery Potential and Proposed Implementation,'' [arXiv:2205.12847 [physics.acc-ph]] and *A. Crivellin et al, Phys.Rev.D 106 (2022) 9, 093007. 2111.10378 [hep-ph])*

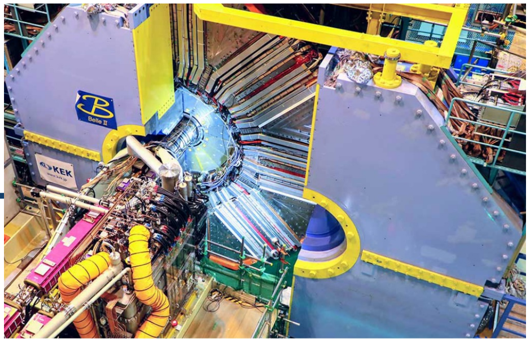
Summary



- SuperKEKB producing world record luminosities
- Belle II now producing world-leading precision measurements and novel searches
- Presented small sample of new world leading Belle II results
  - LFU in semileptonic B decays and
    in asymmetries of in angular distributions of B→D*ℓν decays
  - TD CPV in $K^0\pi^0$ & Isospin Sum Rule test
  - Search for LFV in $\tau \rightarrow \ell\, \alpha$
  - Precision τ mass
- Though no evidence of new physics yet -
  this is an excellent 'mountain' on which
  to 'prospect for new physics'
- Stay tuned as we collect 100 times more data!

Mount Tsukuba

Summary



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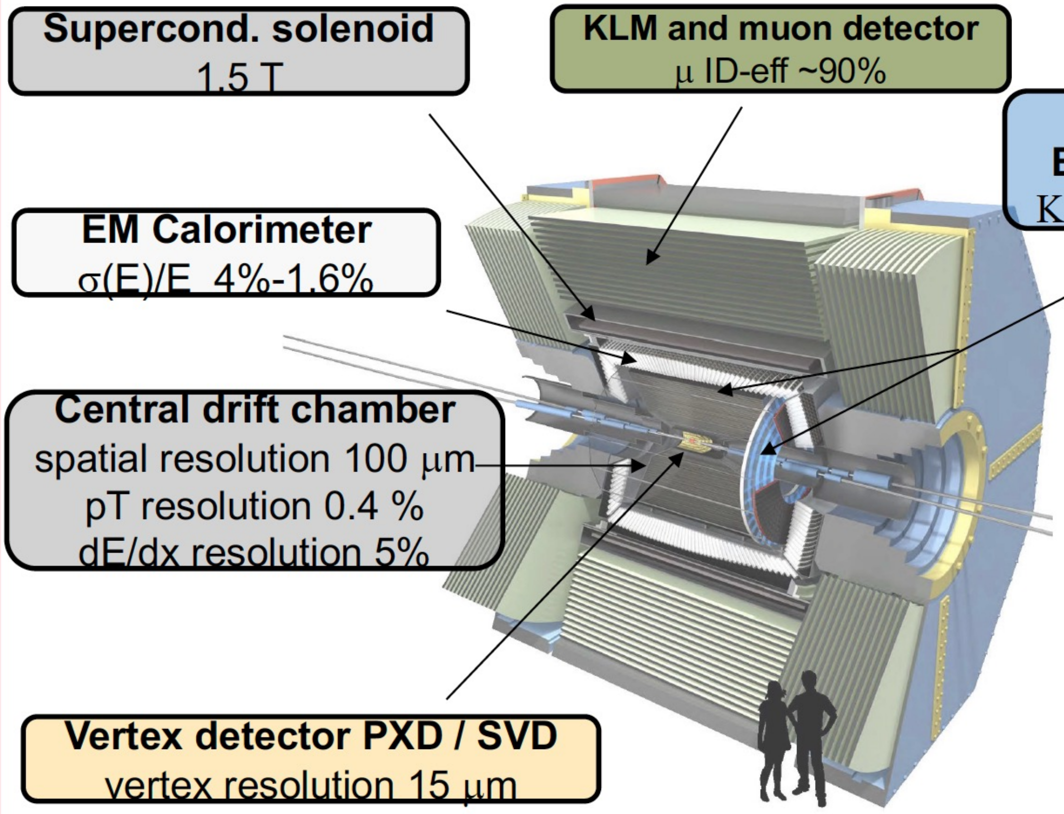
  - TD CPV in $K^0\pi^0$ & Isospin Sum Rule test
  - Search for LFV in $\tau \to \ell\, \alpha$
  - Precision τ mass
- Though no evidence of new physics yet - this is an excellent 'mountain' on which to 'prospect for new physics'

- Stay tuned as we collect 100 times more data!

Additional background information

SuperKEKB and Belle II

Belle II collecting collision data with its vertex detector since 2019



Supercond. solenoid
1.5 T

KLM and muon detector
μ ID-eff ~90%

Particle Identification
Barrel TOP / Forward ARICH
K ID-eff ~90% , π fake rate 10%

EM Calorimeter
$\sigma(E)/E$ 4%-1.6%

Central drift chamber
spatial resolution 100 μm
pT resolution 0.4 %
dE/dx resolution 5%

Vertex detector PXD / SVD
vertex resolution 15 μm

Accelerator and detector upgrade in LS1

- **Beam pipe** replacement
- **PXD** full installation
- **TOP** photodetectors with short lifetime replacement
- **Beam abort & monitoring** additional diamonds
- **ALL** repair of not working electronics channels
- etc.

$$c\bar{c},\ s\bar{s},\ d\bar{d},\ u\bar{u},\ \tau^+\tau^- \leftarrow e^+e^- \rightarrow \Upsilon(nS) \rightarrow B^{(*)}\bar{B}^{(*)}$$

For untagged D* analysis:

Reconstruction of kinematic variables

- What do we know about B?

$$E_B^{CM} = E_{Beam}^{CM}/2 \qquad |\vec{p}_B^{\,CM}| = \sqrt{(E_{Beam}^{CM}/2)^2 - m_{B^0}^2}$$

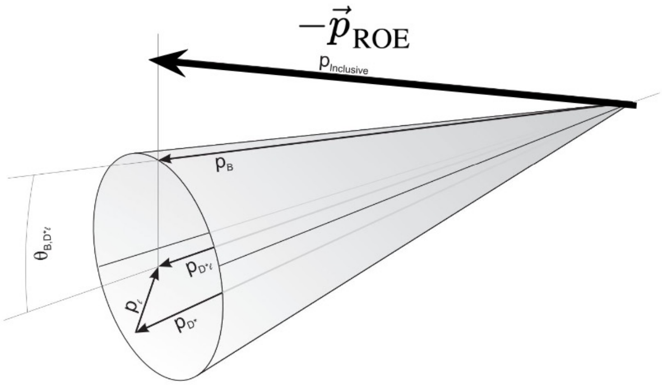
(magnitude of B momentum)

θ_{BY}: the angle between B and D*ℓ system (denoted by Y) determined by

$$\cos\theta_{BY} = \frac{2E_B^* E_Y^* - M_B^2 - m_Y^2}{2p_B^* p_Y^*}$$

where all energy and momenta are in the CM frame.

- How we guess its exact **direction**?



➢ Pick up the direction on the cone closest to $-\vec{p}_{\mathrm{ROE}}$

➢ Consider also the B^0 angular distribution with respect to the beam axis

Novel approach

Weighted average of kinematic variables determined using 10 equal-spacing directions on the cone, where the weight is

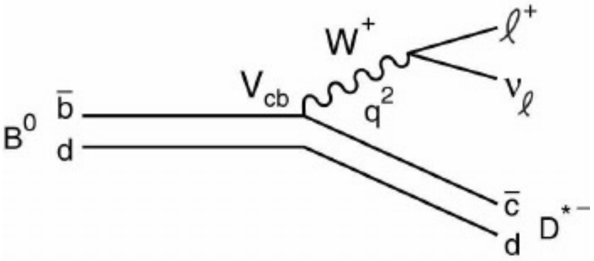
$$\alpha = (1 - \hat{p}_{\mathrm{ROE}} \cdot \hat{p}_B)\sin^2\theta_B$$

Variable	Bias	Resolution
w	0.001	0.04
$\cos\theta_\ell$	−0.005	0.10
$\cos\theta_V$	0.004	0.13
χ [rad]	0.0004	0.58

$\}$ Reconstructed using novel approach

Reconstructed using ROE information only

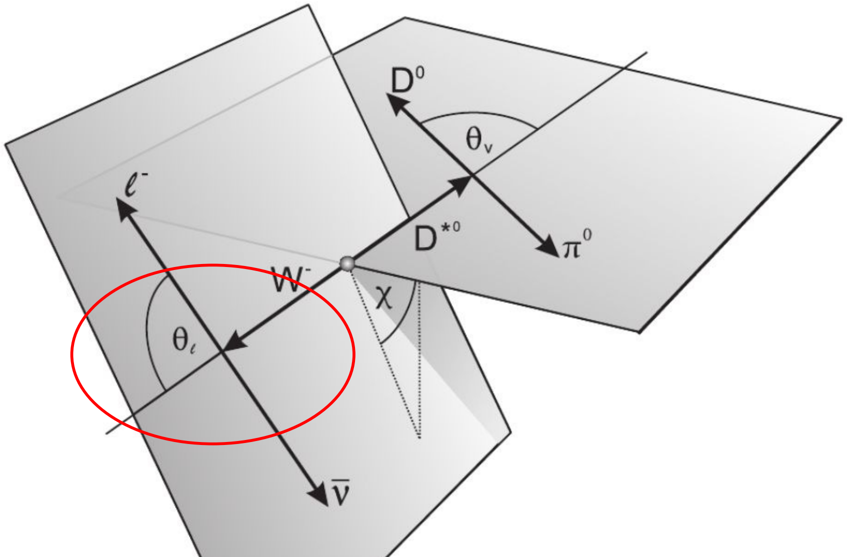
e-μ universality in angular observables of B→D*ℓν decays



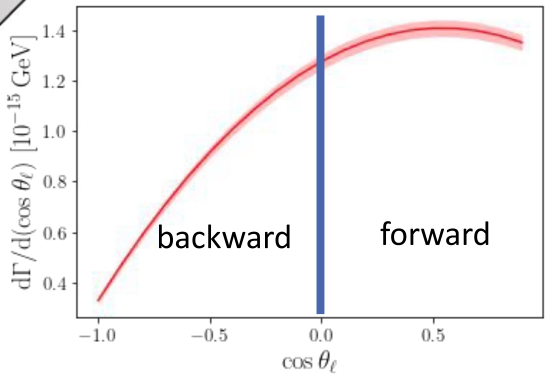
$$A_{\rm FB} = \frac{\int_0^1 {\rm d}\cos\theta_\ell \frac{{\rm d}\Gamma(\bar{B}\to D^*\ell\bar{\nu})}{{\rm d}\cos\theta_\ell} - \int_{-1}^0 {\rm d}\cos\theta_\ell \frac{{\rm d}\Gamma(\bar{B}\to D^*\ell\bar{\nu})}{{\rm d}\cos\theta_\ell}}{\int_{-1}^1 {\rm d}\cos\theta_\ell \frac{{\rm d}\Gamma(\bar{B}\to D^*\ell\bar{\nu})}{{\rm d}\cos\theta_\ell}}$$

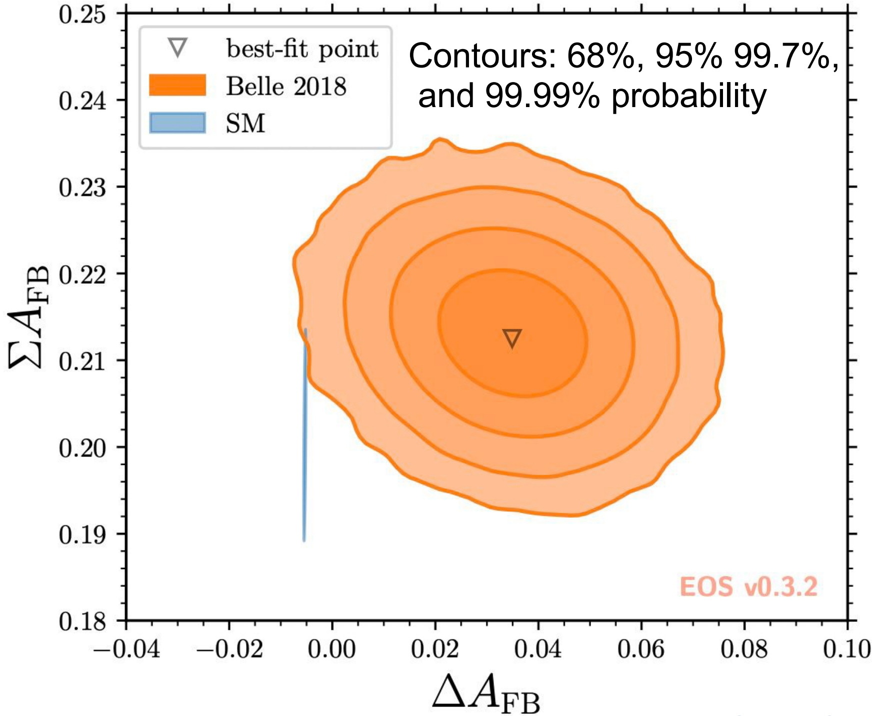
$$\Delta A_{\rm FB} = A_{\rm FB}(m_\ell = m_\mu) - A_{\rm FB}(m_\ell = m_e)\,,$$

$$\sum A_{\rm FB} = A_{\rm FB}(m_\ell = m_\mu) + A_{\rm FB}(m_\ell = m_e)$$



SM expectation →

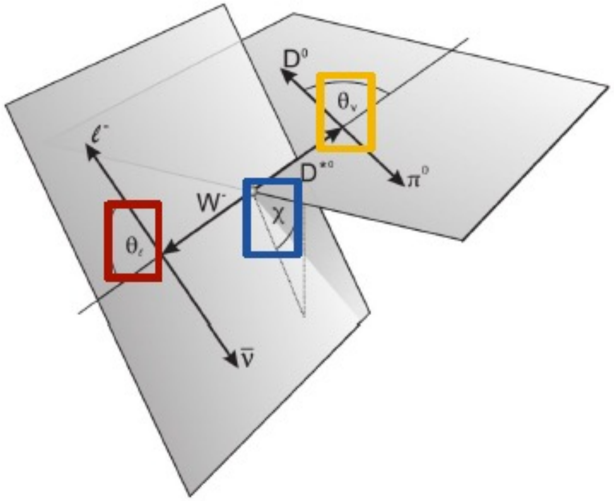




C. Bobeth *et al Eur. Phys. J. C 81, 984 (2021)*

e-μ universality in angular observables of B→D*ℓν decays

- A_{FB} measures the propensity ℓ travel in same direction as virtual W
- S_3 and S_9 sensitive to propensities in alignment of ℓ and D* systems
- S_5 and S_7 measure coupled propensities in such alignment with the orientation of the D meson with respect to the D*



$$\mathcal{A}_x(w) \equiv \left(\frac{d\Gamma}{dw}\right)^{-1}\left[\int_0^1 - \int_{-1}^0\right] dx \frac{d^2\Gamma}{dw\,dx}$$

$$\mathcal{A}_x \rightarrow \begin{cases} A_{FB}: & dx = d(\cos\theta_\ell) \\ S_3: & dx = d(\cos 2\chi) \\ S_5: & dx = d(\cos\chi\cos\theta_V) \\ S_7: & dx = d(\sin\chi\cos\theta_V) \\ S_9: & dx = d(\sin 2\chi) \end{cases}$$

N_x^+ is # events with $0 \leq x \leq 1$

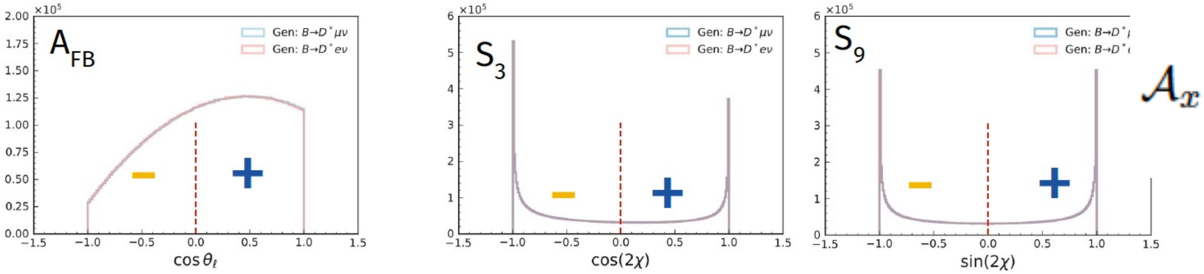
N_x^- is # events with $-1 \leq x \leq 0$

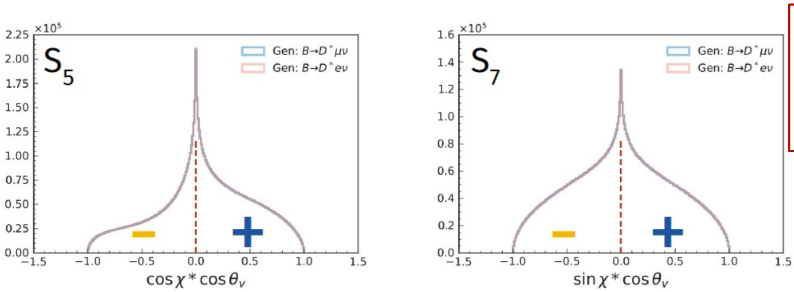
corrected for acceptance & resolution

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

e-μ universality in angular observables of B→D*ℓν decays

SM Monte Carlo:





$$\mathcal{A}_x(w) \equiv \left(\frac{d\Gamma}{dw}\right)^{-1}\left[\int_0^1 - \int_{-1}^0\right] dx \frac{d^2\Gamma}{dw\,dx}$$

$\mathcal{A}_x$ (x) = (F-B)/(F+B)

$\mathcal{A}_x$ → A_{FB} , S_3 , S_5 , S_7 and S_9

corrected for acceptance & resolution

A_{FB} : dx = d(cos θ_ℓ)
S_3 : dx = d(cos2χ)
S_5 : dx = d(cosχ cosθ_V)
S_7 : dx = d(sinχ cosθ_V)
S_9 : dx = d(sin2χ)

- Only A_{FB} and S_3 have been measured, but not differentially in *w*
- S_3 and S_5 are highly sensitive to LUV
- S_9 = 0 in SM & its extensions and S_7 = SM & reduced sensitivity in SM extensions
  → S_7 & S_9 useful as experimental controls

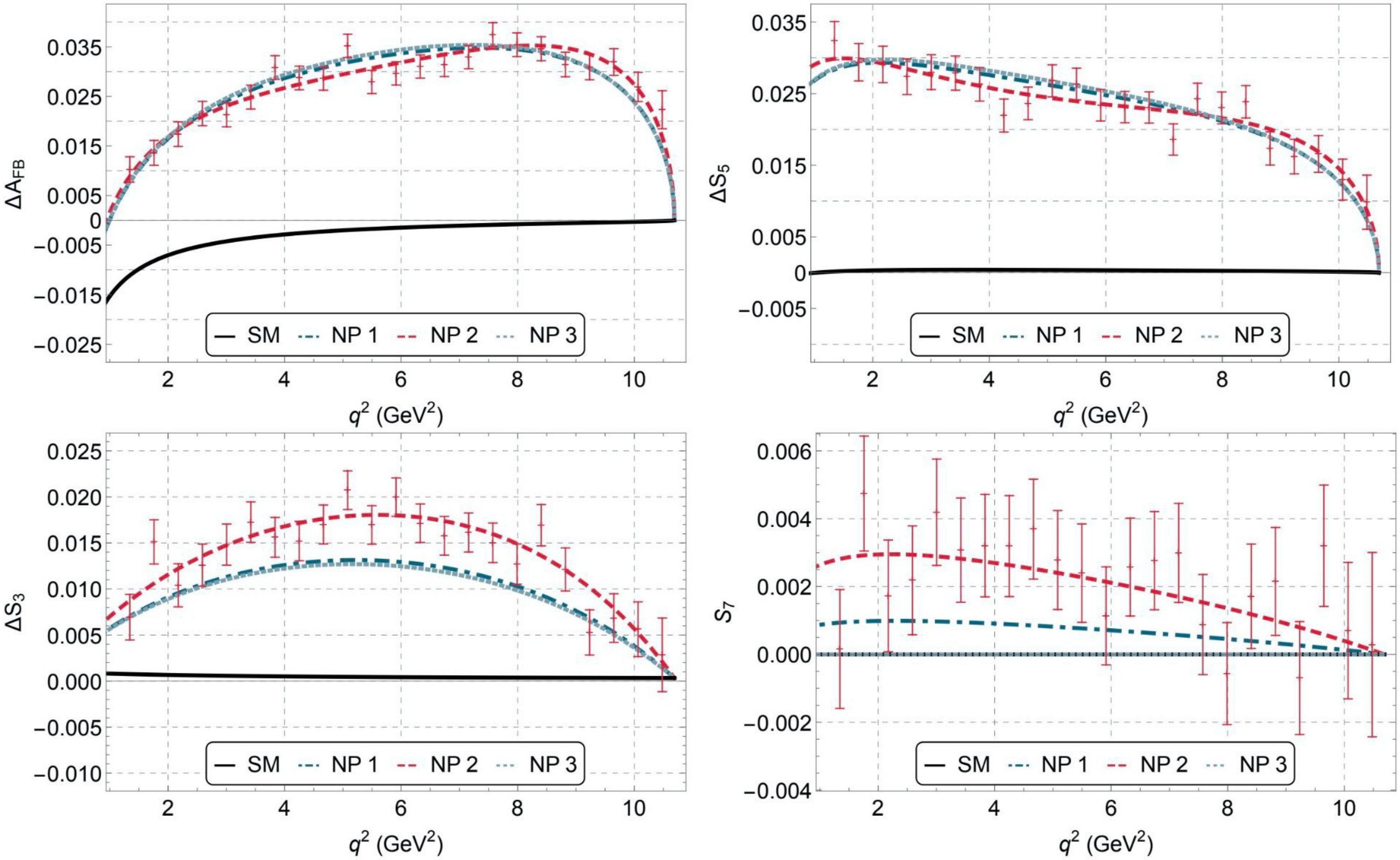
- Correlated LUV signatures between the different asymmetries can help to probe the nature of any new interactions

→ **Simultaneous determination of all asymmetries with correlations in different *w* ranges provides a powerful test of LU, while also providing a way to help understand the nature of any new interactions**

e-μ universality in angular observables of $B\to D^*\ell\nu$ decays

[arxiv:2206.11283]

How $\Delta\mathcal{A}_x$ vs q^2 looks for SM and some NP scenarios and how combined analyses can differentiate NP scenarios



MC stat. errors shown: projected for 50 ab^{-1} equivalent data sample

NP

	g_L	g_R	g_P
Scenario 1:	0.06	0.075	$0.2i$
Scenario 2:	0.08	0.090	$0.6i$
Scenario 3:	0.07	0.075	0

e-μ universality in angular observables of B→D*ℓν decays

Experimental uncertainties by source:

data stat, MC stat, lepton ID & slow pion efficiency

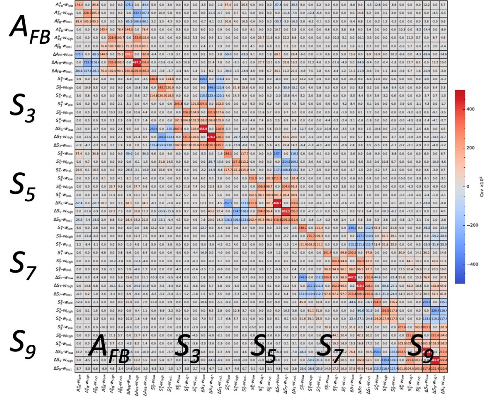
(preliminary)

Obs.	w bin	Total	Stat.	MC stat.	LID	π_{slow}
A_{FB}^{e}	w_{low}	0.047	0.044	0.015	0.004	0.001
	w_{high}	0.052	0.049	0.017	0.004	0.001
	$w_{\text{incl.}}$	0.034	0.032	0.011	0.004	0.001
A_{FB}^{μ}	w_{low}	0.043	0.041	0.013	0.001	0.001
	w_{high}	0.050	0.047	0.016	0.002	0.001
	$w_{\text{incl.}}$	0.032	0.030	0.010	0.001	0.001
ΔA_{FB}	w_{low}	0.064	0.060	0.020	0.004	0.001
	w_{high}	0.072	0.067	0.024	0.004	0.001
	$w_{\text{incl.}}$	0.046	0.044	0.015	0.004	0.001
S_3^{e}	w_{low}	0.053	0.050	0.018	0.000	0.001
	w_{high}	0.051	0.048	0.018	0.000	0.000
	$w_{\text{incl.}}$	0.036	0.034	0.012	0.000	0.000
S_3^{μ}	w_{low}	0.048	0.045	0.016	0.001	0.000
	w_{high}	0.050	0.047	0.016	0.000	0.000
	$w_{\text{incl.}}$	0.034	0.032	0.011	0.001	0.000
ΔS_3	w_{low}	0.071	0.067	0.024	0.001	0.000
	w_{high}	0.072	0.067	0.025	0.001	0.000
	$w_{\text{incl.}}$	0.049	0.046	0.017	0.001	0.000
S_5^{e}	w_{low}	0.053	0.050	0.018	0.001	0.000
	w_{high}	0.051	0.048	0.017	0.001	0.000
	$w_{\text{incl.}}$	0.036	0.034	0.012	0.001	0.000
S_5^{μ}	w_{low}	0.048	0.045	0.016	0.001	0.000
	w_{high}	0.049	0.046	0.016	0.000	0.000
	$w_{\text{incl.}}$	0.034	0.032	0.011	0.000	0.000
ΔS_5	w_{low}	0.072	0.068	0.024	0.001	0.000
	w_{high}	0.070	0.066	0.023	0.001	0.000
	$w_{\text{incl.}}$	0.049	0.046	0.016	0.001	0.000

Obs.	w bin	Total	Stat.	MC stat.	LID	π_{slow}
S_7^{e}	w_{low}	0.052	0.049	0.018	0.001	0.000
	w_{high}	0.049	0.046	0.017	0.000	0.000
	$w_{\text{incl.}}$	0.034	0.032	0.012	0.000	0.000
S_7^{μ}	w_{low}	0.047	0.044	0.015	0.000	0.000
	w_{high}	0.047	0.045	0.015	0.000	0.000
	$w_{\text{incl.}}$	0.032	0.031	0.011	0.000	0.000
ΔS_7	w_{low}	0.070	0.066	0.023	0.001	0.001
	w_{high}	0.068	0.064	0.022	0.000	0.000
	$w_{\text{incl.}}$	0.047	0.044	0.016	0.000	0.000
S_9^{e}	w_{low}	0.052	0.048	0.018	0.000	0.000
	w_{high}	0.051	0.048	0.018	0.000	0.000
	$w_{\text{incl.}}$	0.036	0.034	0.012	0.000	0.000
S_9^{μ}	w_{low}	0.047	0.044	0.016	0.000	0.000
	w_{high}	0.049	0.047	0.016	0.000	0.001
	$w_{\text{incl.}}$	0.033	0.032	0.011	0.000	0.000
ΔS_9	w_{low}	0.070	0.065	0.024	0.000	0.000
	w_{high}	0.071	0.067	0.024	0.001	0.001
	$w_{\text{incl.}}$	0.049	0.046	0.017	0.000	0.000

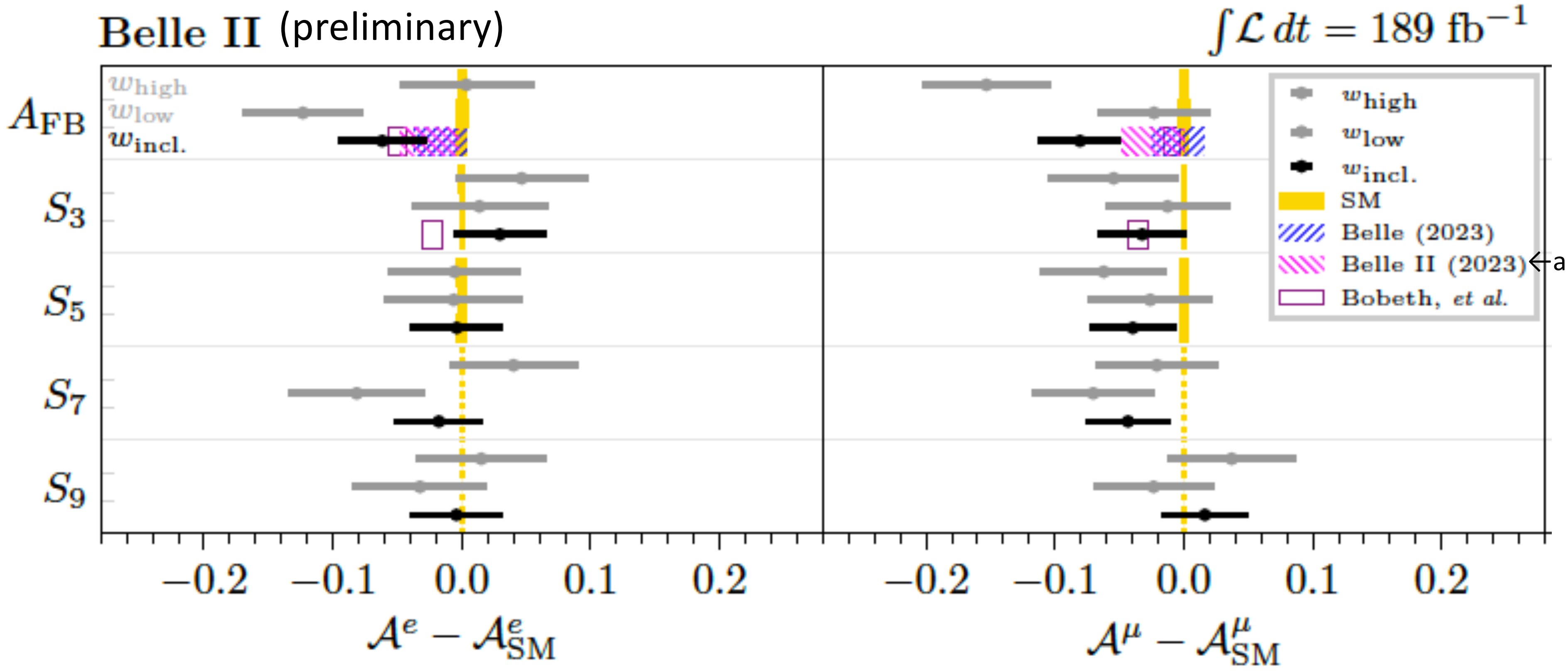
Statistical covariance matrix

(preliminary)



e-μ universality in angular observables of B→D*ℓν decays

Measured asymmetries differences from SM for each *w* region

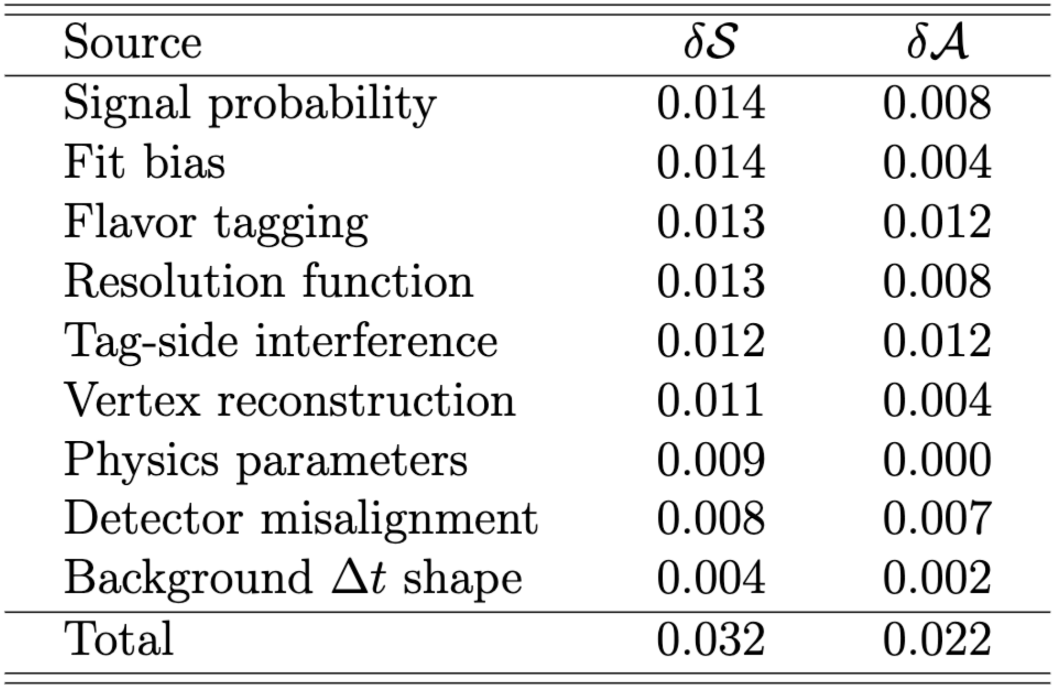


←analysis#1

Experimental uncertainties from:
data stat, MC stat, lepton ID & slow π efficiency

Time-dependent CP asymmetries in B → $K^0_s K^0_s K^0_s$

Systematic Uncertainties:



Source	$\delta\mathcal{S}$	$\delta\mathcal{A}$
Signal probability	0.014	0.008
Fit bias	0.014	0.004
Flavor tagging	0.013	0.012
Resolution function	0.013	0.008
Tag-side interference	0.012	0.012
Vertex reconstruction	0.011	0.004
Physics parameters	0.009	0.000
Detector misalignment	0.008	0.007
Background Δt shape	0.004	0.002
Total	0.032	0.022

Time-dependent CP asymmetries in B → $J/\psi\ K^0_s$

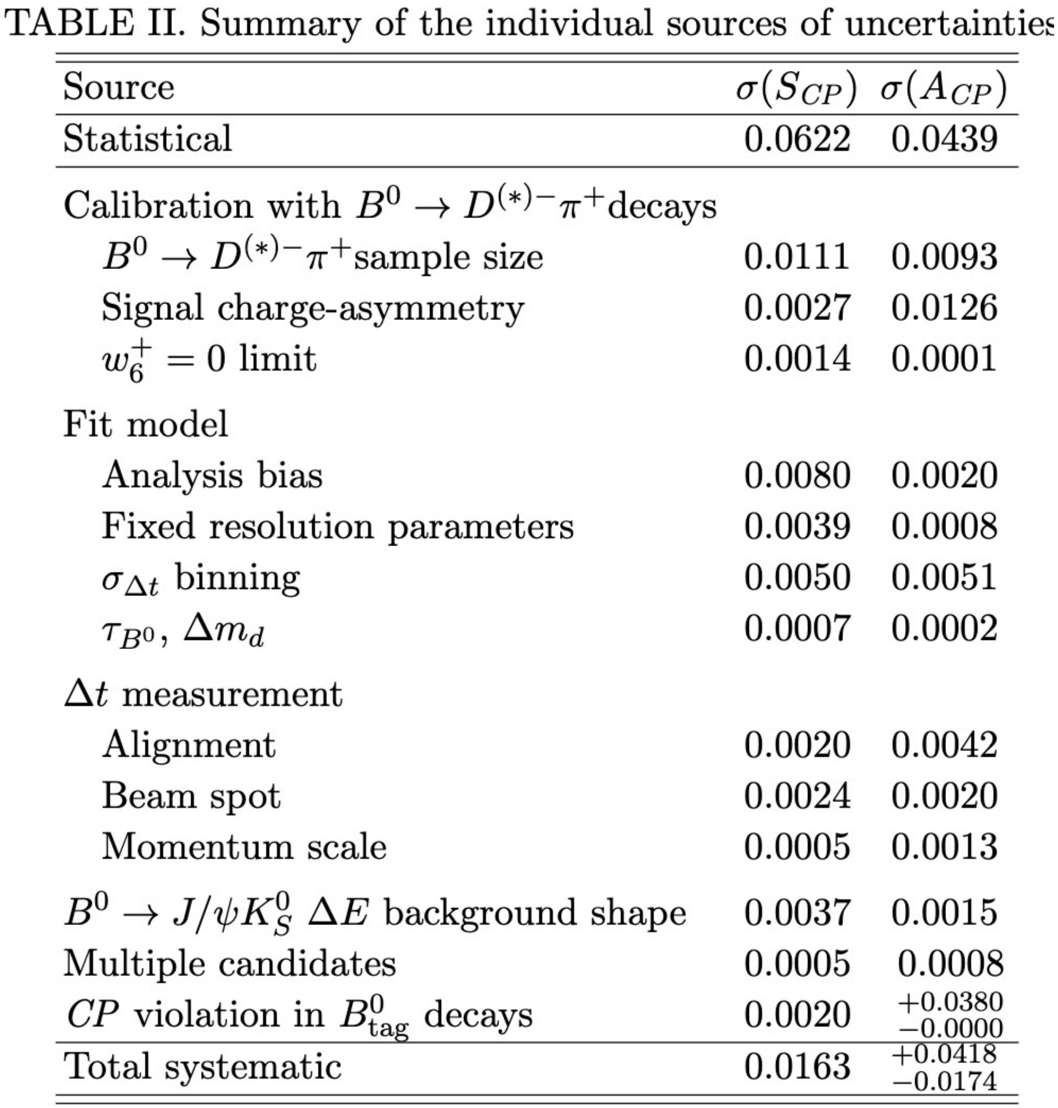


TABLE II. Summary of the individual sources of uncertaintie

Source	$\sigma(S_{CP})$	$\sigma(A_{CP})$
Statistical	0.0622	0.0439
Calibration with $B^0 \to D^{(*)-}\pi^+$ decays		
$B^0 \to D^{(*)-}\pi^+$ sample size	0.0111	0.0093
Signal charge-asymmetry	0.0027	0.0126
$w_6^+ = 0$ limit	0.0014	0.0001
Fit model		
Analysis bias	0.0080	0.0020
Fixed resolution parameters	0.0039	0.0008
$\sigma_{\Delta t}$ binning	0.0050	0.0051
τ_{B^0}, Δm_d	0.0007	0.0002
Δt measurement		
Alignment	0.0020	0.0042
Beam spot	0.0024	0.0020
Momentum scale	0.0005	0.0013
$B^0 \to J/\psi K^0_S$ ΔE background shape	0.0037	0.0015
Multiple candidates	0.0005	0.0008
CP violation in $B^0_{\rm tag}$ decays	0.0020	$^{+0.0380}_{-0.0000}$
Total systematic	0.0163	$^{+0.0418}_{-0.0174}$

Signal:

Control sample:

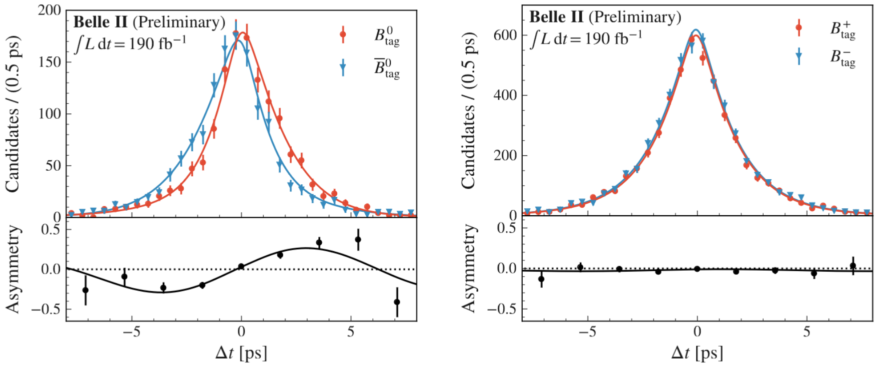


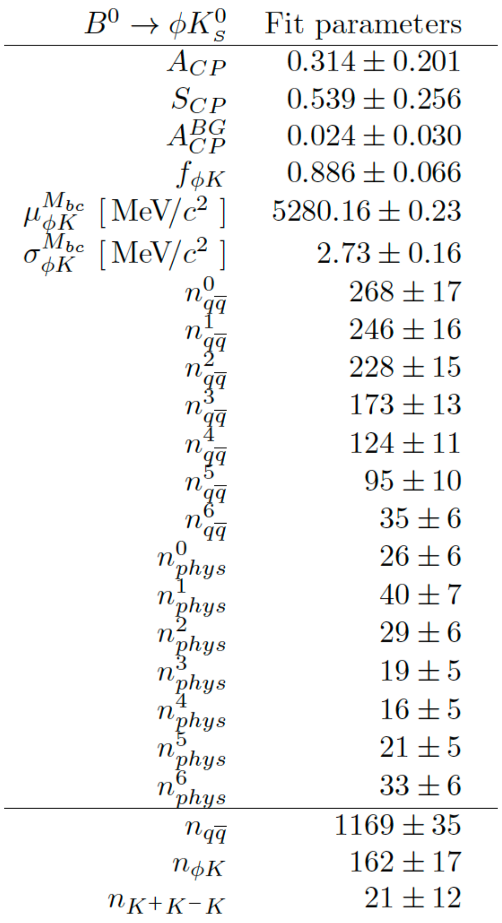
FIG. 2. sWeighted Δt distributions of $B^0 \to J/\psi K^0_S$ (left) and $B^+ \to J/\psi K^+$ (right) decays, separated by $B_{\rm tag}$ flavor. The fit projections are shown by solid curves and the asymmetry, defined as $(N(B^0_{\rm tag}) - N(\bar{B}^0_{\rm tag}))/(N(B^0_{\rm tag}) + N(\bar{B}^0_{\rm tag}))$ for the neutral $B_{\rm tag}$ or $(N(B^+_{\rm tag}) - N(B^-_{\rm tag}))/(N(B^+_{\rm tag}) + N(B^-_{\rm tag}))$ for the charged $B_{\rm tag}$, is displayed underneath.

Time-dependent CP asymmetries in B $\longrightarrow$ ϕ K^0_S

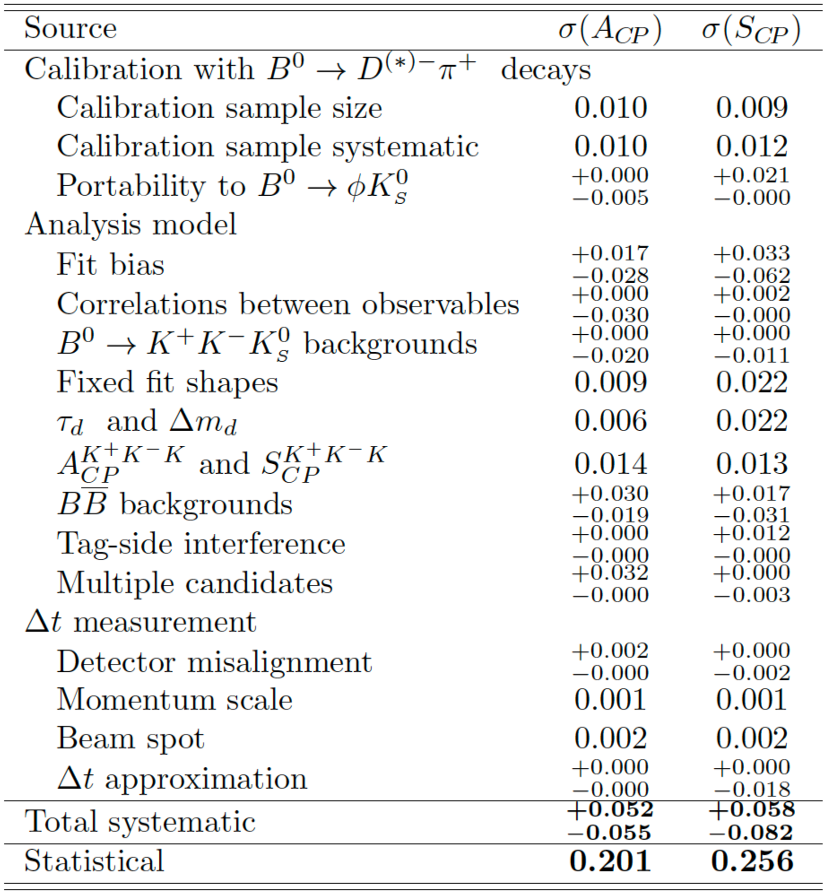
Systematic uncertainties

Free parameters

Total yields



$B^0 \to \phi K^0_S$	Fit parameters
A_{CP}	0.314 ± 0.201
S_{CP}	0.539 ± 0.256
A^{BG}_{CP}	0.024 ± 0.030
$f_{\phi K}$	0.886 ± 0.066
$\mu^{M_{bc}}_{\phi K}$ [MeV/c^2]	5280.16 ± 0.23
$\sigma^{M_{bc}}_{\phi K}$ [MeV/c^2]	2.73 ± 0.16
$n^0_{q\bar{q}}$	268 ± 17
$n^1_{q\bar{q}}$	246 ± 16
$n^2_{q\bar{q}}$	228 ± 15
$n^3_{q\bar{q}}$	173 ± 13
$n^4_{q\bar{q}}$	124 ± 11
$n^5_{q\bar{q}}$	95 ± 10
$n^6_{q\bar{q}}$	35 ± 6
n^0_{phys}	26 ± 6
n^1_{phys}	40 ± 7
n^2_{phys}	29 ± 6
n^3_{phys}	19 ± 5
n^4_{phys}	16 ± 5
n^5_{phys}	21 ± 5
n^6_{phys}	33 ± 6
$n_{q\bar{q}}$	1169 ± 35
$n_{\phi K}$	162 ± 17
$n_{K^+K^-K}$	21 ± 12



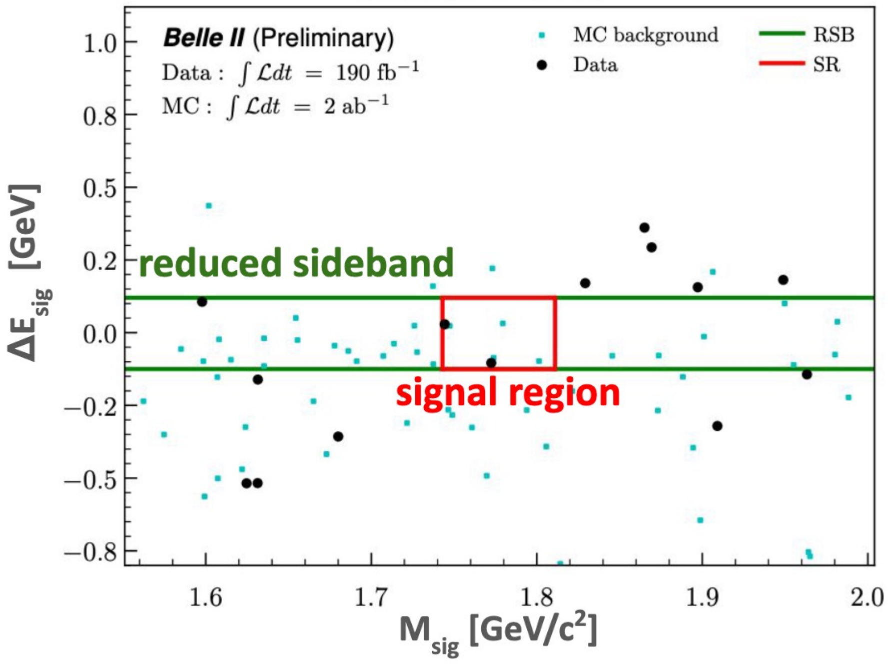
Source	$\sigma(A_{CP})$	$\sigma(S_{CP})$
Calibration with $B^0 \to D^{(*)-}\pi^+$ decays		
Calibration sample size	0.010	0.009
Calibration sample systematic	0.010	0.012
Portability to $B^0 \to \phi K^0_S$	$^{+0.000}_{-0.005}$	$^{+0.021}_{-0.000}$
Analysis model		
Fit bias	$^{+0.017}_{-0.028}$	$^{+0.033}_{-0.062}$
Correlations between observables	$^{+0.000}_{-0.030}$	$^{+0.002}_{-0.000}$
$B^0 \to K^+K^-K^0_S$ backgrounds	$^{+0.000}_{-0.020}$	$^{+0.000}_{-0.011}$
Fixed fit shapes	0.009	0.022
τ_d and Δm_d	0.006	0.022
$A^{K^+K^-K}_{CP}$ and $S^{K^+K^-K}_{CP}$	0.014	0.013
$B\overline{B}$ backgrounds	$^{+0.030}_{-0.019}$	$^{+0.017}_{-0.031}$
Tag-side interference	$^{+0.000}_{-0.000}$	$^{+0.012}_{-0.000}$
Multiple candidates	$^{+0.032}_{-0.000}$	$^{+0.000}_{-0.003}$
Δt measurement		
Detector misalignment	$^{+0.002}_{-0.000}$	$^{+0.000}_{-0.002}$
Momentum scale	0.001	0.001
Beam spot	0.002	0.002
Δt approximation	$^{+0.000}_{-0.000}$	$^{+0.000}_{-0.018}$
Total systematic	$\mathbf{^{+0.052}_{-0.055}}$	$\mathbf{^{+0.058}_{-0.082}}$
Statistical	**0.201**	**0.256**

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

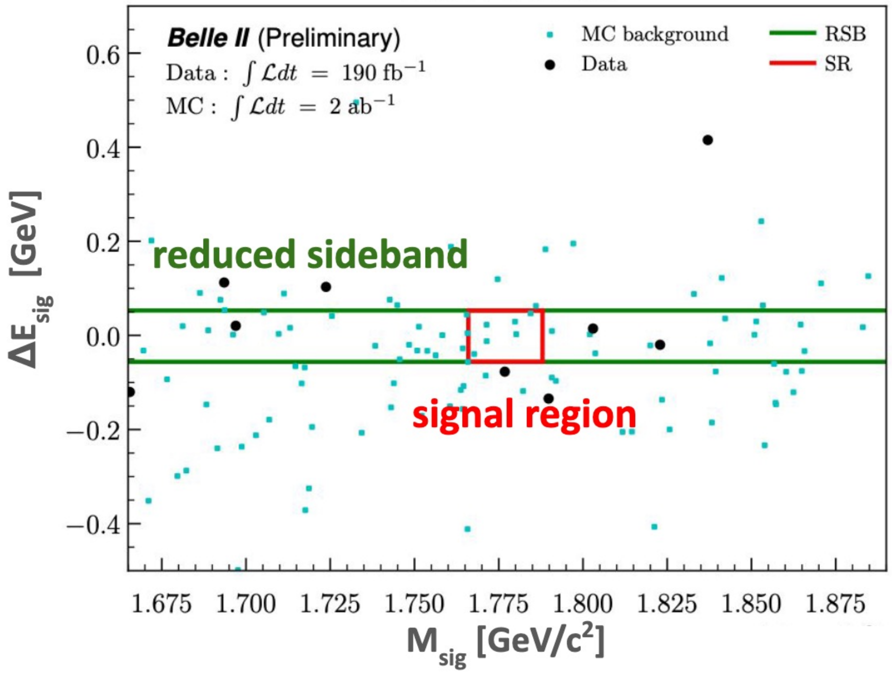
- Background estimation
  - using data in the reduced sidebands
  - obtain transfer factor from simulation

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

electron channel



muon channel



Outlook for Belle II and SuperKEKB

From 1 July 2022 – end of 2023 we have been in Long Shutdown 1 (LS1) - upgrading the inner vertex (pixel) detector to provide full angular for all layers with next generation pixel detector: PXD2

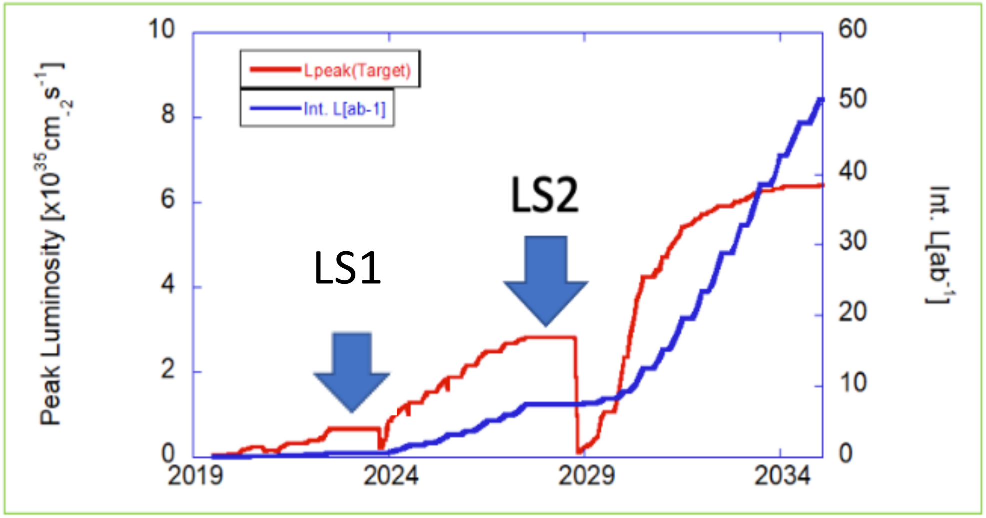
In addition to maintenance of accelerator and other detector subsystems

We need another long shutdown (LS2) to improve the machine performance beyond $2.4\times10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ and toward the target peak luminosity of $6\times10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

It probably requires a modification of

- the IR and,
- an upgrade of the injection complex.

→ more than 1 year long shutdown.



The modifications must be effective enough that the integrated luminosity lost during LS2 is recovered quickly afterwards.

- Proposing upgrade ideas is one of the tasks of accelerator International Task Force (ITF)

Upgrading SuperKEB with Polarized Electron Beams: “Chiral Belle” uses Belle II with L-R polarized SuperKEKB

- Goal is ~70% polarization with 80% polarized source (SLC had 75% polarization at the experiment)
- Electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode (similar to SLC source)
- Inject vertically polarized electrons into the High Energy Ring (HER) - needs low enough emittance source to be able to inject.
- Rotate spin to longitudinal before IP, and then back to vertical after IP using solenoidal and dipole fields – recent studies have demonstrated feasibility
- Use Compton polarimeter to monitor longitudinal polarization with <1% absolute precision, higher for relative measurements (arXiv:1009.6178) - needed for real time polarimetry – similar to HERA and EIC technologies.
- Use tau decays to obtain absolute average polarization at IP – *BABAR* analysis demonstrates 0.5% precision (see C. Miller, Lake Louise Winter Institute 2022)

“Chiral Belle II” -> Left-Right Asymmetries

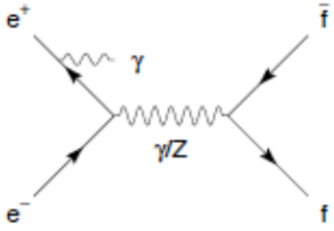
- Measure *difference* between cross-sections with left-handed beam electrons and right-handed beam electrons
- Same technique as SLD A_{LR} measurement at the Z-pole giving single most precise measurement of :

$$\sin^2\theta_{\mathrm{eff}}^{\mathrm{lepton}} = 0.23098 \pm 0.00026$$

- At 10.58 GeV, polarized e^- beam yields product of the neutral axial-vector coupling of the electron and vector coupling of the final-state fermion via Z-γ interference:

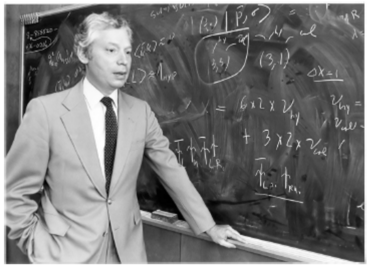
$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}}\left(\frac{G_F s}{4\pi\alpha Q_f}\right)\boxed{g_A^e g_V^f}\langle Pol\rangle$$

$$\propto T_3^f - 2Q_f \sin^2\theta_W$$

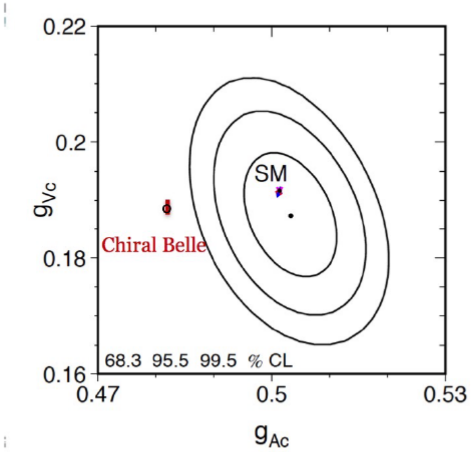

(for s-channel Born)

A New Path for Belle II Discovery in a *Precision Neutral Current Electroweak Program* with Heavy Quarks

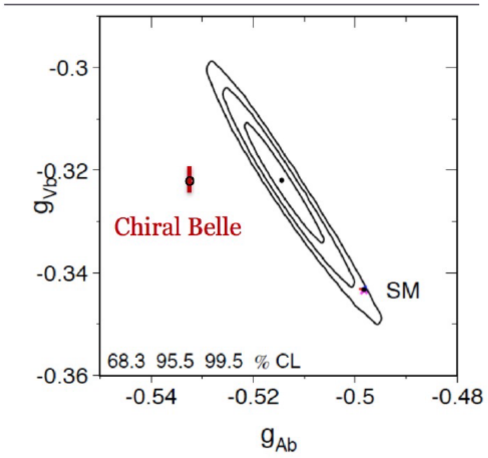
- Left-Right Asymmetries (A_{LR}) yield high precision measurements of the *neutral current vector couplings* (g_V) to each of accessible fermion flavor, *f* :
  - beauty (D-type) (as well as for 3 charged leptons and light quarks)
  - charm (U-type)


Steve Weinberg

c-quark:
Chiral Belle ~7 times more precise



b-quark:
Chiral Belle ~4 times more precise
with 20 ab^{-1}



$$\text{Recall: } g_V^f \text{ gives } \theta_W \text{ in SM} \begin{cases} g_A^f = T_3^f \\ g_V^f = T_3^f - 2Q_f \sin^2\theta_W \end{cases}$$

T_3 = -0.5 for charged leptons and D-type quarks
+0.5 for neutrinos and U-type quarks

Unique Access to New Physics in bottom-to-charm Neutral Current Vector Coupling Universality Ratio via A_{LR} (b-bbar)/ A_{LR} (c-cbar)

Projections of b-quark and c-quark Neutral Current Vector Coupling Sensitivities with 70% polarized e^- beam

UNPRECEDENTED PRECISION

bottom-to-charm UNIVERSALITY RATIO Beam Polarization (dominant systematic) cancels in the ratio

Final State Fermion	SM	World Average[1]	Chiral Belle 20 ab^{-1}	Chiral Belle 50 ab^{-1}	Chiral Belle 250 ab^{-1}
	g_V^f (Mz)	g_V^f (Mz)	σ (g_V^f) or σ(g_V^b/ g_V^c)	σ (g_V^f) or σ(g_V^b/ g_V^c)	σ (g_V^f) or σ(g_V^b/ g_V^c)
b-quark	-0.3437	-0.322	±0.0003(stat) ±0.0017(sys)	±0.0002(stat) ±0.0017(sys)	±0.00009(stat) ±0.0017(sys)
(eff.=0.3)	± .00049	±0.0077	±0.0017(total)	±0.0017(total)	±0.0017(total)
		2.8σ tension	Improves x 4	Improves x 4	Improves x 4
c-quark	0.192	0.1873	±0.0006(stat) ±0.0009(sys)	±0.00035(stat) ±0.0009(sys)	±0.00016(stat) ±0.0009(sys)
(eff.=0.3)	± .0002	±0.0070	±0.0011(total)	±0.0010(total)	±0.0009(total)
			Improves x 7	Improves x 7	Improves x 8
g_V^b /g_V^c	**-1.7901**	**-1.719**	**±0.0058 (stat ~ total)**	**±0.0034 (stat ~ total)**	**±0.00015 (stat ~ total)**
Ratio	± .0005	± .082	**Improve x 14**	**Improve x 24**	**Improve x 53**
Relative error:	0.18%	4.8%	**0.32%**	**0.19%**	**0.09%**

Get stuck at ~20 ab^{-1}

Use the ratio

$\sin^2\Theta_W$ - all LEP+SLD measurements combined WA = 0.23153 ± 0.00016

$\sin^2\Theta_W$ - Chiral Belle combined leptons with 40 ab^{-1} have error ~current WA