Recent beauty measurements from Belle and Belle II

La Thuile 2024
Les Rencontres de Physique de la Vallée d'Aoste

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on behalf of Belle II and Belle collaborations

La Thuile, 6 March 2024

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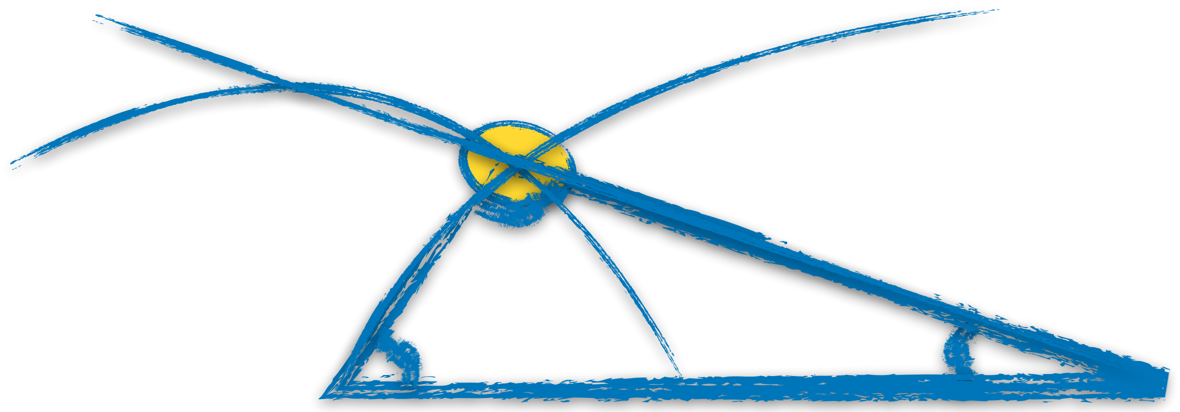
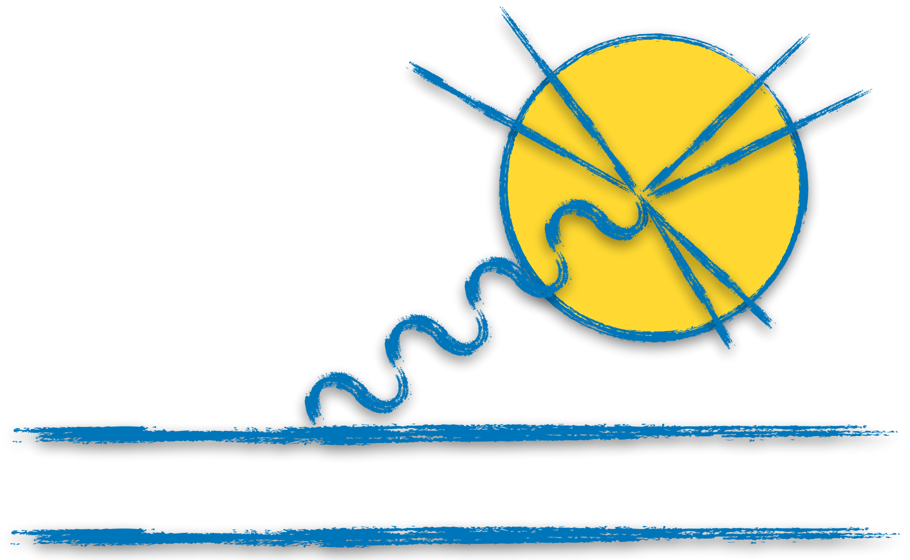
Outline and Motivation

We have the **Belle II Run 1** $\Upsilon(4S)$ **dataset** (362 fb^{-1}) combined to **Belle** $\Upsilon(4S)$ **dataset** (711 fb^{-1})

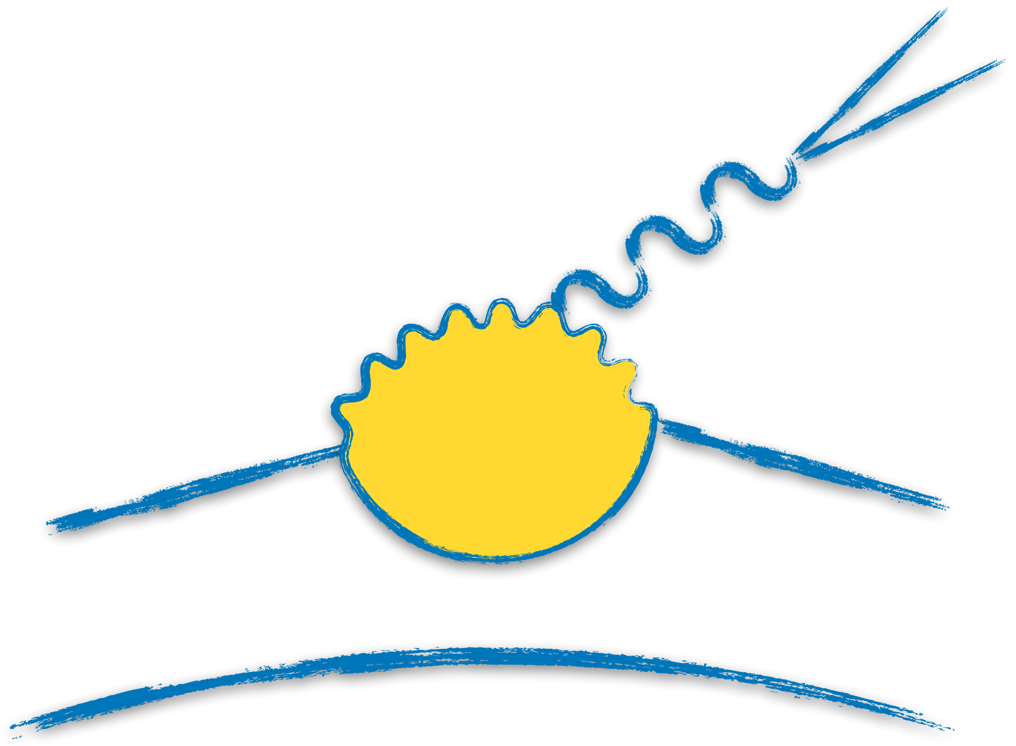
- CKM matrix measurement for **SM precision test** in suppressed B decays: $B^0 \to \eta' K_S^0$, $B^0 \to K_S^0 \pi^0 \gamma$



- Substantially improve B **decays knowledge** :
  - $B^+ \to D^0 \rho$ NEW
  - $B \to D^{(*)} K^- K_{(S)}^{(*)0}$ and $B \to D^{(*)} D_s^-$ NEW
  - $B^0 \to \omega\omega$ NEW



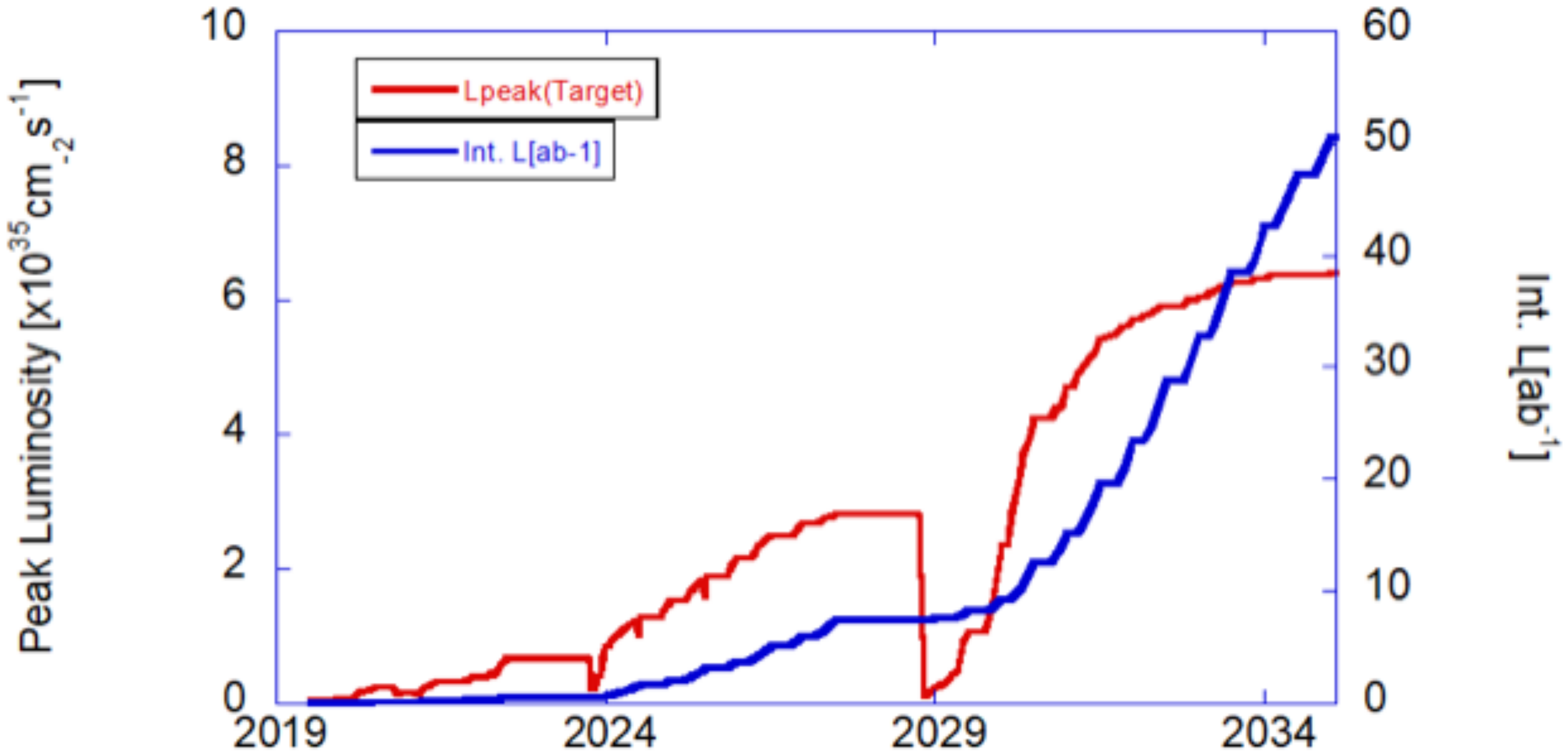
- Access rare decays to **investigate New Physics** via Flavour Changing Neutral Current **(FCNC)**
  - $b \to s$: $B \to K^+ \nu \bar{\nu}$
  - $b \to d$: $B \to h \ell^+ \ell^-$ NEW
  - radiative: $B \to \rho \gamma$

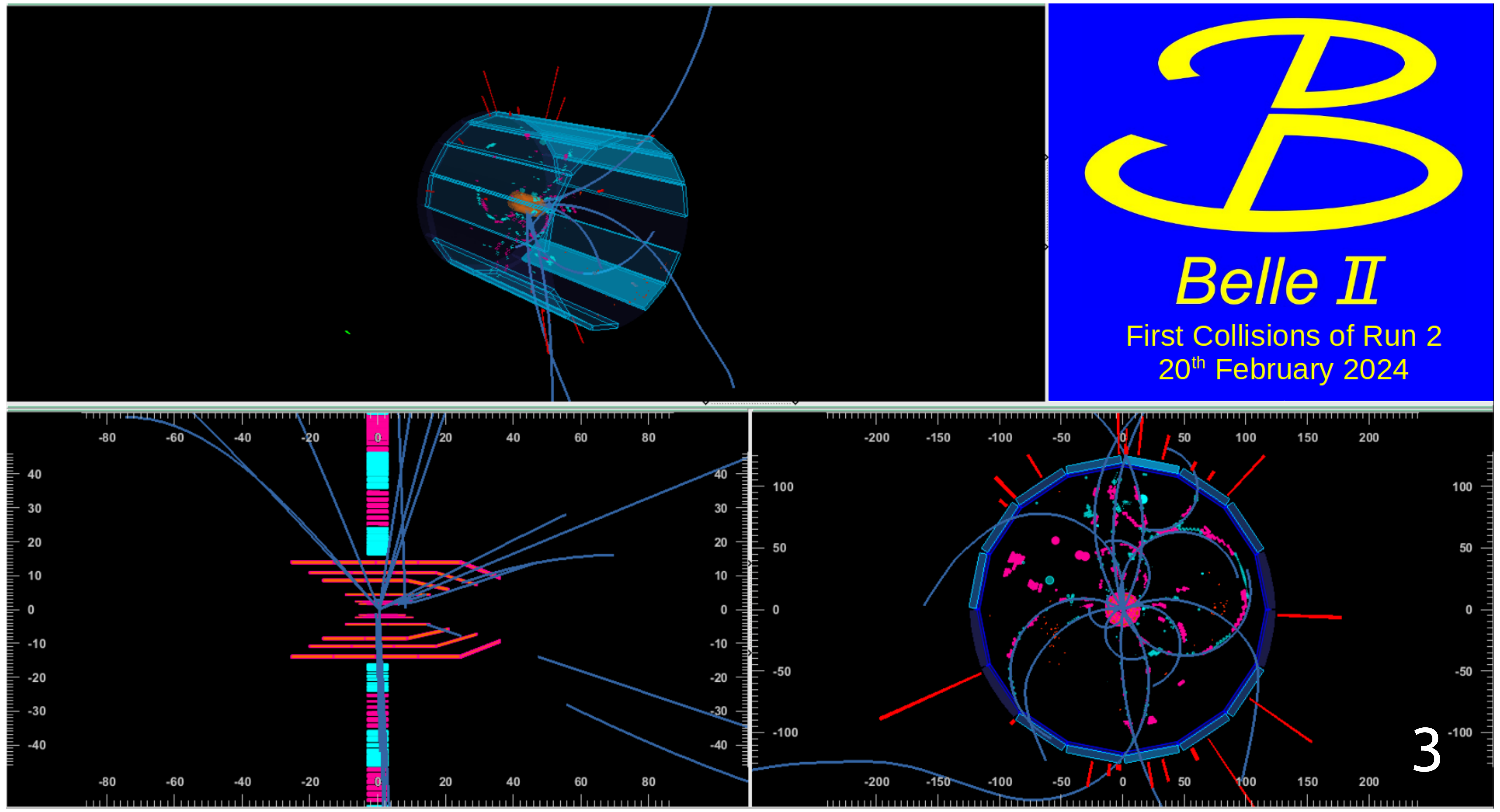


- Lepton Flavour Universality **(LFU)** tests: $R(D^*)$ and $R(X_{\tau/\ell})$

Belle II & SuperKEKB status

- Run 1 (2019-2022)
  - Peak luminosity $\mathbf{4.7 \cdot 10^{34}\ cm^{-2}s^{-1}}$ (reached the 22/06/2022)
  - Integrated luminosity: $\mathbf{424\ fb^{-1}}$ (~Babar, 0.5 Belle)
- Long Shutdown 1 (07/2022-01/2024) for major upgrades
  - new **two-layers pixel detector**
- Run 2: **data taking resumed** in February 2024



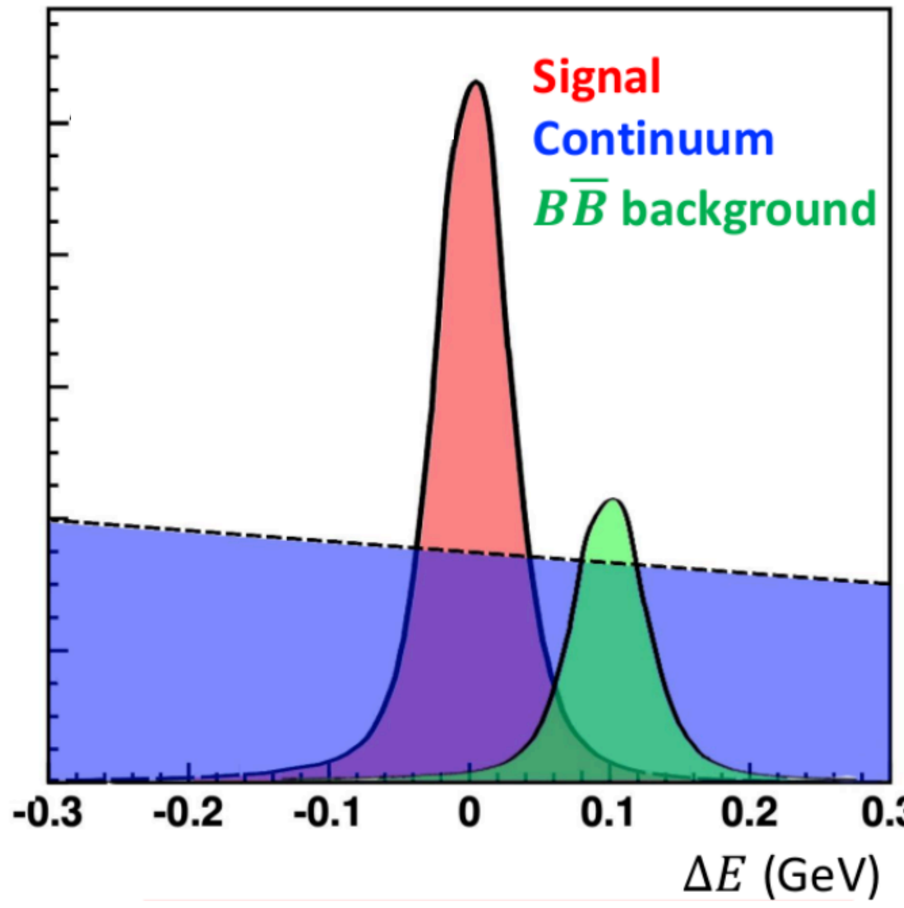


[More information about SuperKEKB and Belle II in the backup]

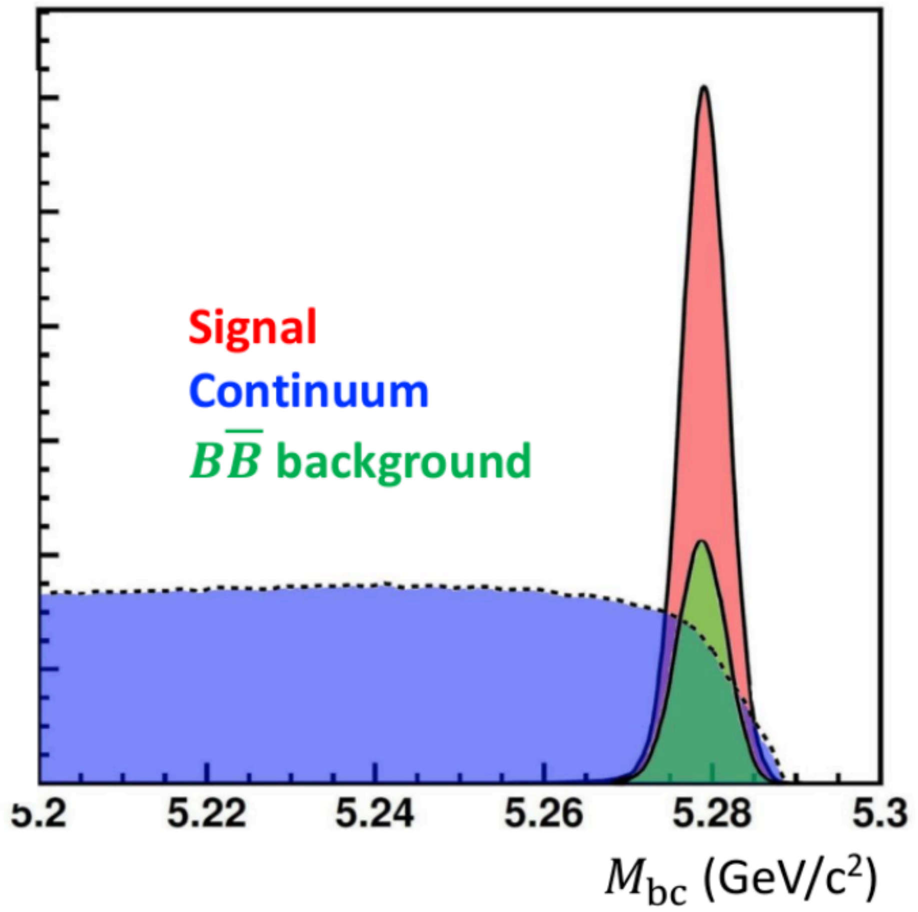
B-Factory basics

- $\sqrt{s} = m(\Upsilon(4S)) = 10.58\ \text{GeV} \simeq 2m_B \Rightarrow$ **constrained kinematics**
- **Hermetic** detector ⇒ complete event reconstruction

$$\Delta E = E_B^* - \sqrt{s}/2 \qquad M_{bc} = \sqrt{(\sqrt{s}/2)^2 - \vec{p}_B^{*2}}$$



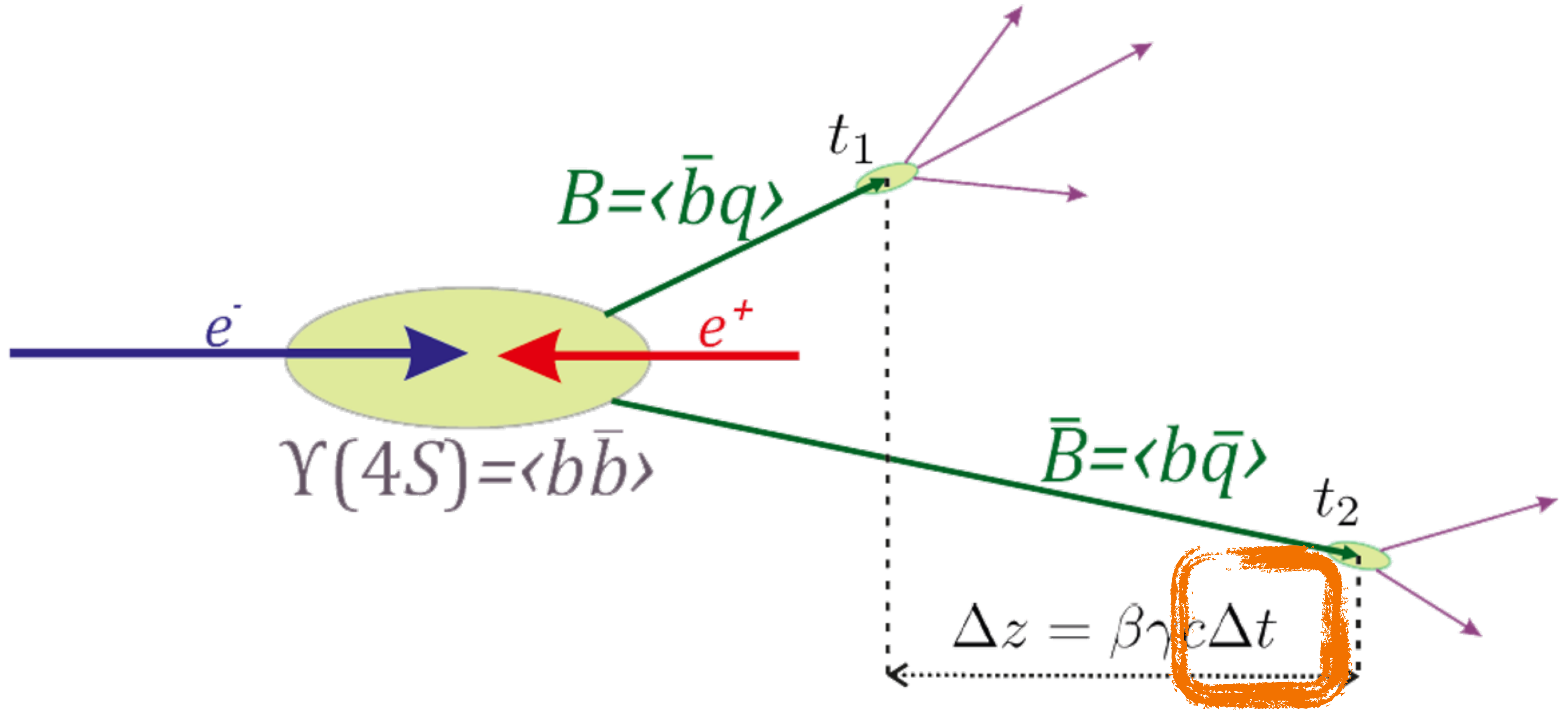
Expected $\Delta E \simeq 0$



Expected $M_{bc} \simeq m_B$

- **Asymmetric** collider ⇒ Boost of center-of-mass
- Excellent **vertexing** performance ($\sigma \sim 15\ \mu$m)

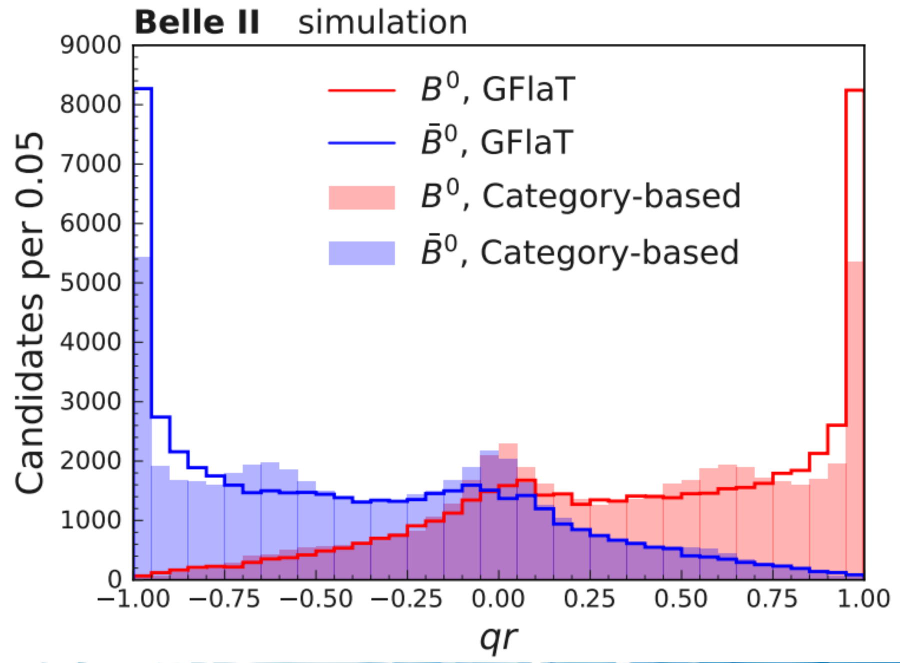
⇒ measurement of Δt for time dependent CP violation (TDCPV)



- coherent $B\bar{B}$ pairs production
- Excellent **flavour tagging** performance

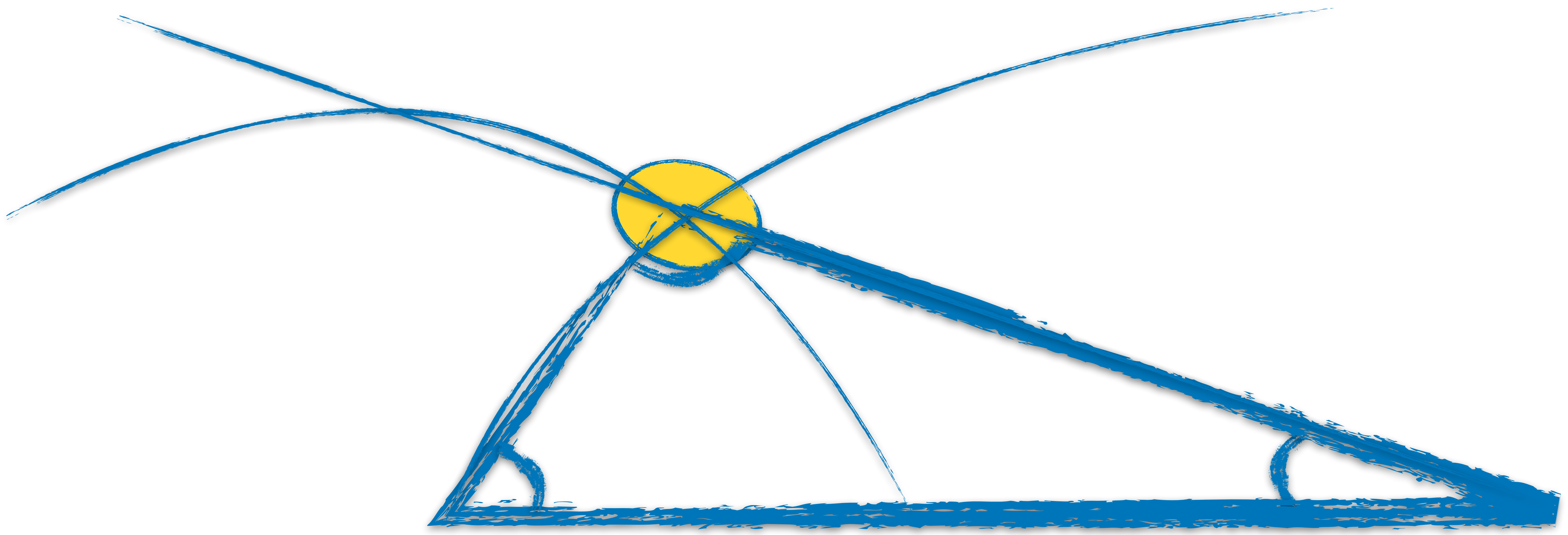
Recently developed a new Graph Neural Network Flavour tagger (**GFlaT**) with $\varepsilon \approx 37\ \%$

(**18% gain** compared to previous tagger)

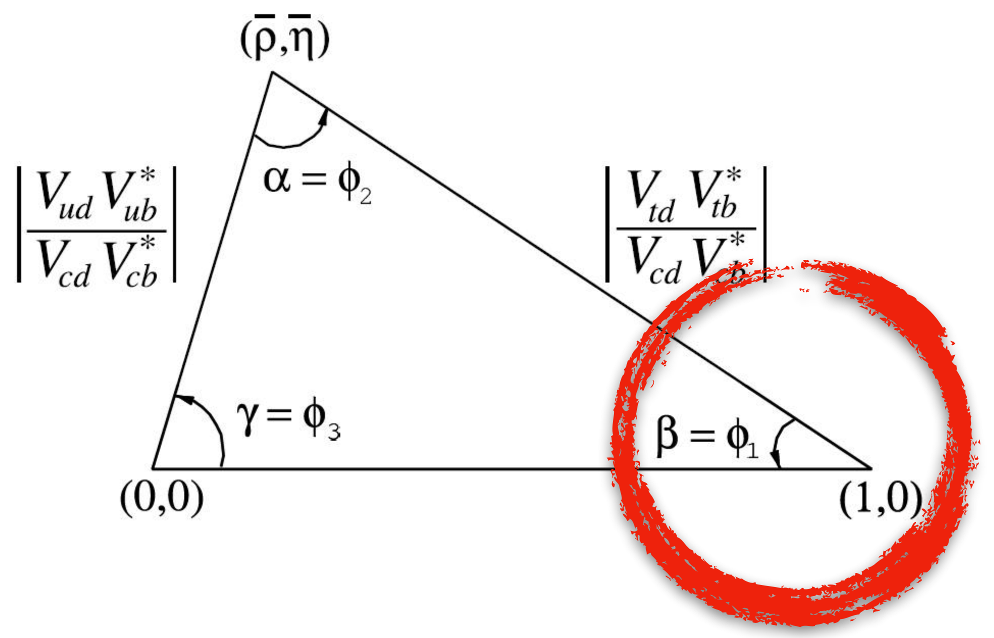


[arxiv:2402.17260]

CKM precision measurements



$\beta^{\text{eff}}/\phi_1^{\text{eff}}$ from suppressed penguins



- $b \to q\bar{q}s$ **gluonic penguins**, suppressed in the SM (BF $\sim 10^{-5} - 10^{-6}$)
  - SM test measuring $\sin 2\beta^{\text{eff}}$:

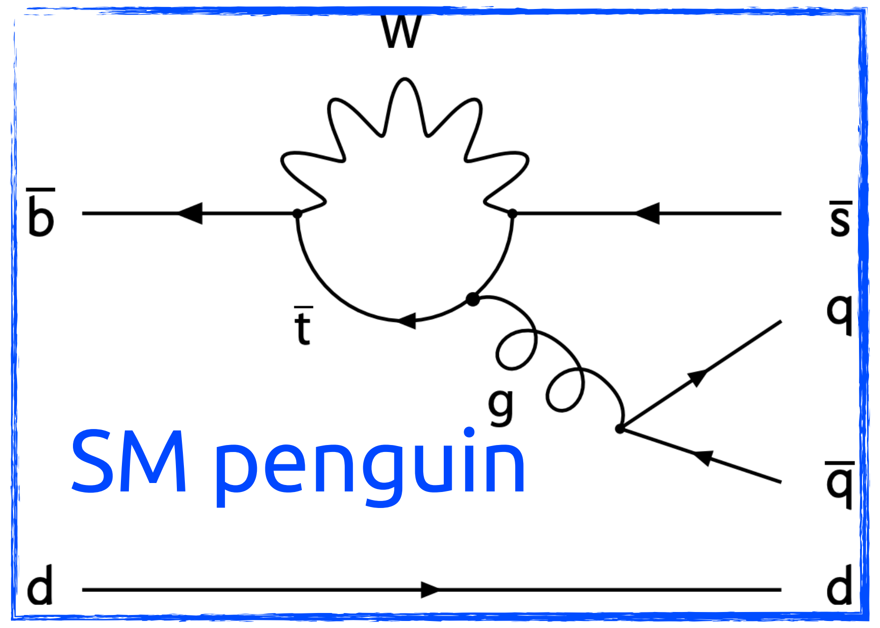
$$\mathscr{A}_{CP}(\Delta t) = \frac{N(B^0 \to f_{CP}) - N(\bar{B}^0 \to f_{CP})}{N(B^0 \to f_{CP}) + N(\bar{B}^0 \to f_{CP})}(\Delta t) = S\sin(\Delta m \Delta t) - C\cos(\Delta m \Delta t)$$

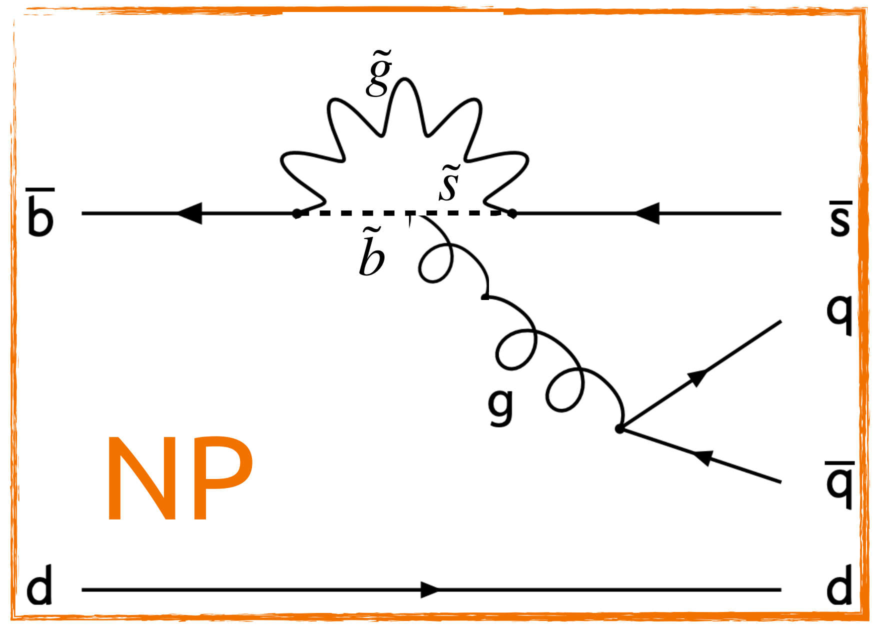
    where $C \simeq 0,\ S \simeq \pm\sin 2\beta$ in the SM

  - Relatively clean theory prediction
  - Access to new physics (NP) amplitudes

$S_{\text{penguin}} = \pm\sin 2\beta + \Delta S$

$C_{\text{penguin}} = \Delta C$

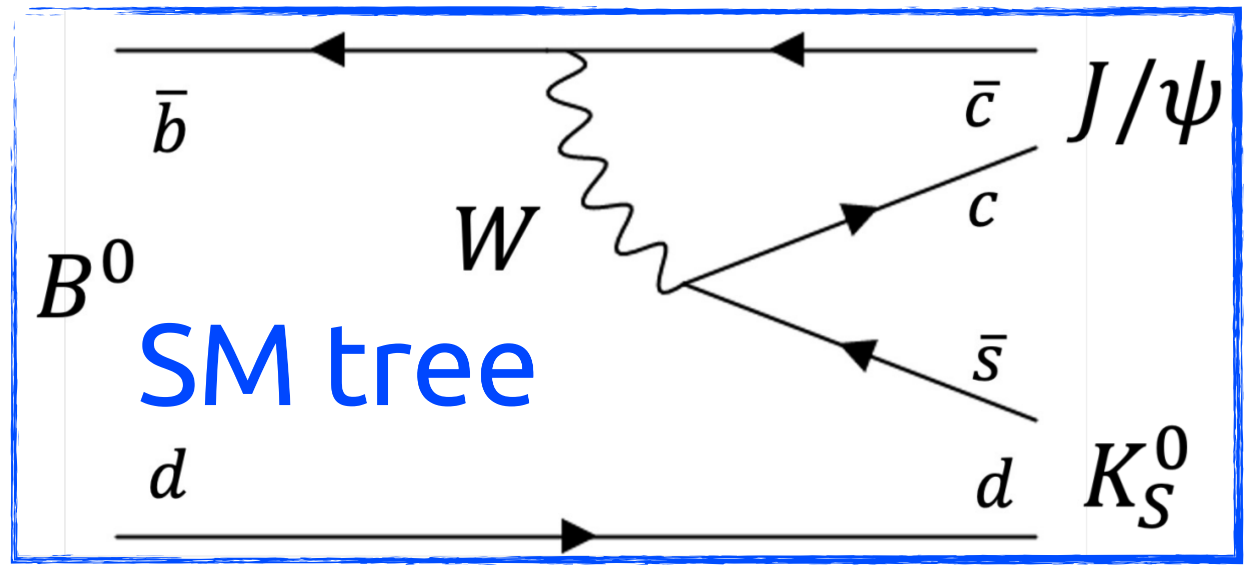




- **Experimentally challenging**:
  - Fully hadronic final state with **neutrals**
  - **Low purity** $\Rightarrow$ dedicated continuum suppression algorithms
  - **Unique** to Belle II

$S_{J/\psi K_S^0} = \pm\sin 2\beta$

$C_{J/\psi K_S^0} = 0$



Gluonic penguin: $B^0 \to \eta' K_S^0$

[arXiv:2402.03713] $362\ \text{fb}^{-1}$

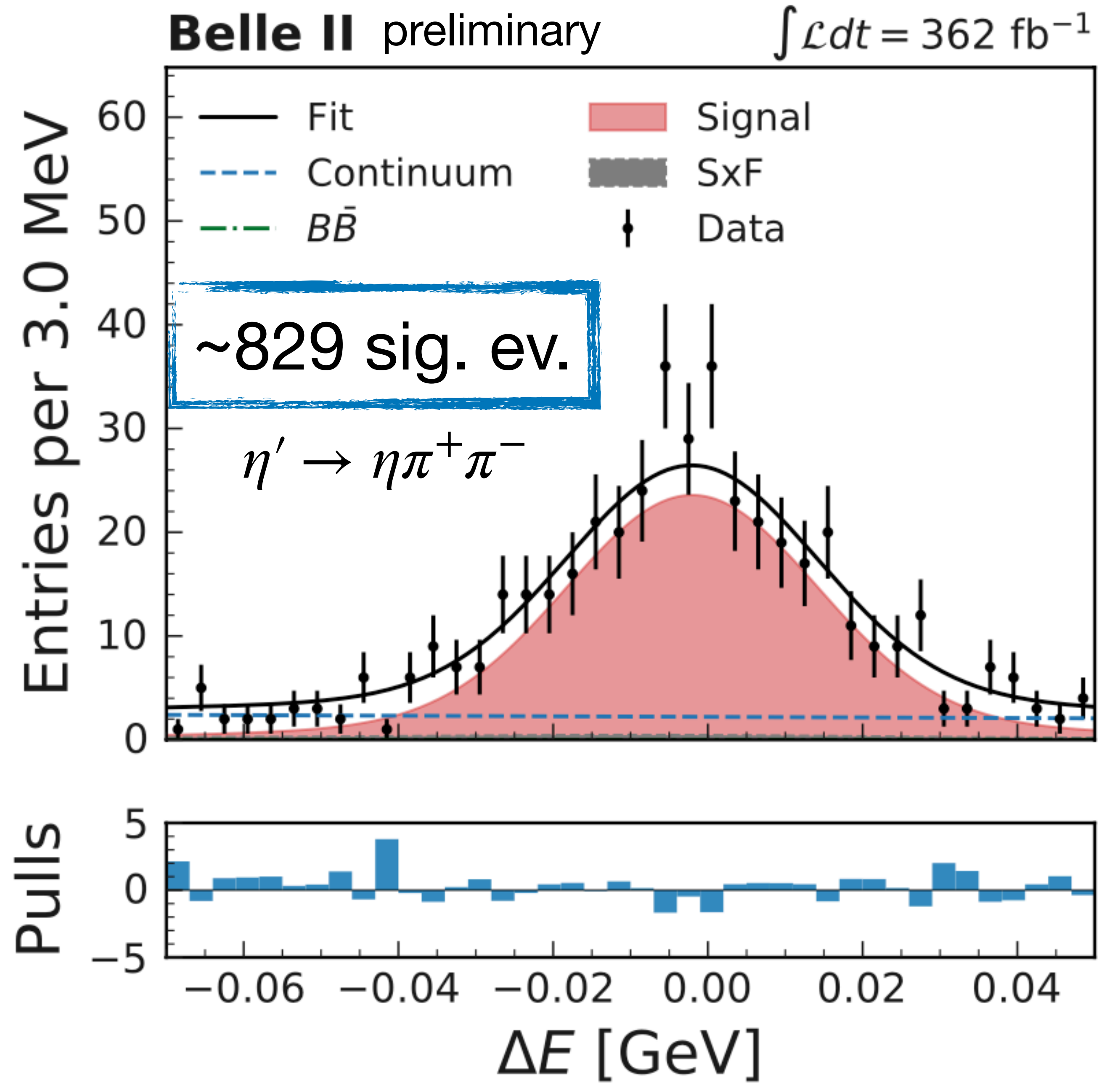
- Two sub-channels:
  - $\eta' \to \eta(\to \gamma\gamma)\pi^+\pi^-$
  - $\eta' \to \rho(\to \pi^+\pi^-)\gamma$
- High bkg from **random tracks** from $q\bar{q}$ events $\Rightarrow$ suppressed with dedicated BDT
- Fit $(\Delta E, M_{bc}$, BDT output)
- S and C parameter extraction:
  - Bkg Δt shape from sideband
  - Bkg asymmetry included in the fit
  - validation on $B^+ \to \eta' K^+$

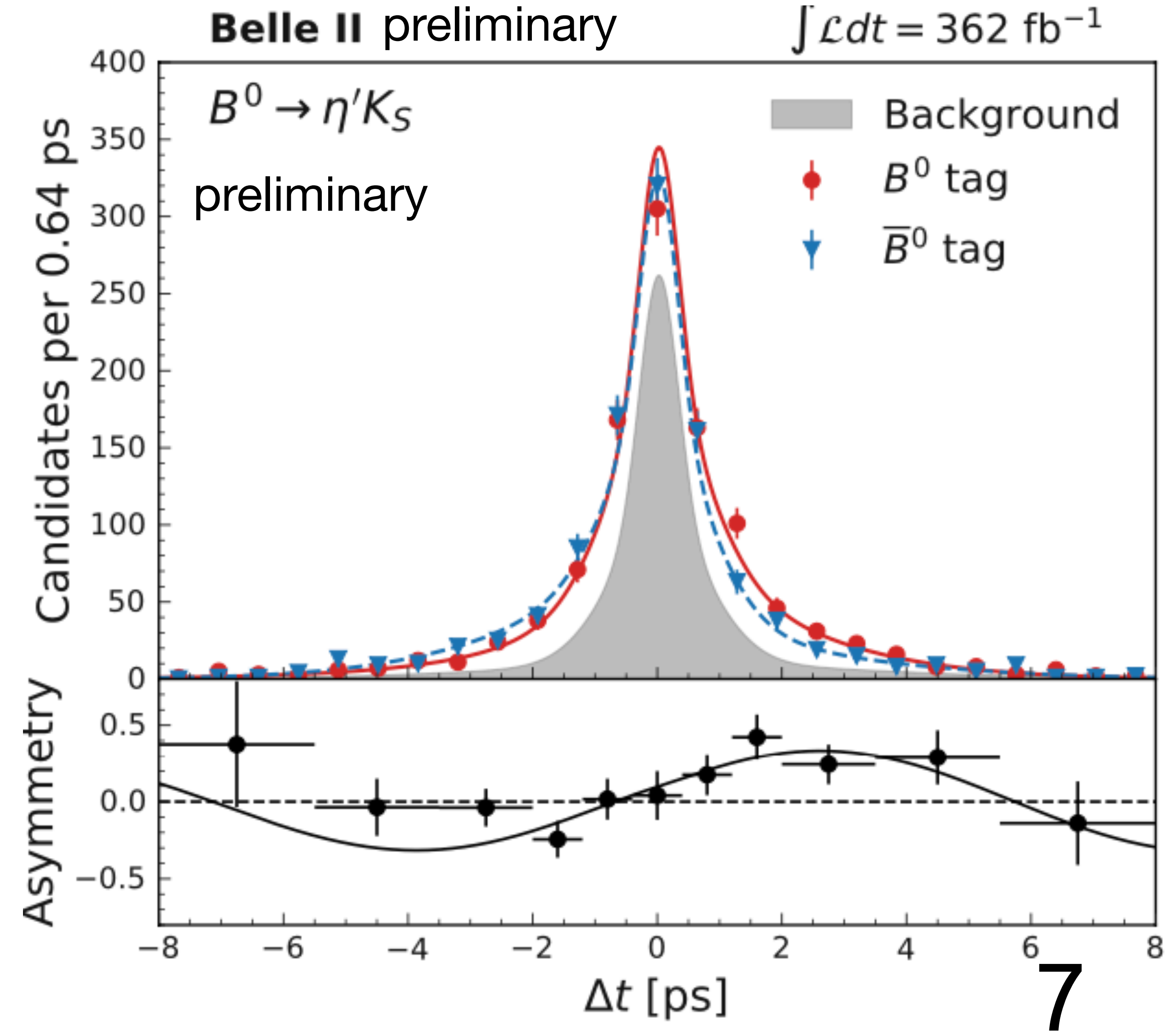
$$S = 0.67 \pm 0.10 \pm 0.04$$
$$C = -0.19 \pm 0.08 \pm 0.03$$

Compatible with SM

Precision compatible with Belle or BaBar despite smaller sample

SM [HFLAV]: $S = 0.63 \pm 0.06$, $C = -0.05 \pm 0.04$





Radiative penguin: $B^0 \to K_S^0 \pi^0 \gamma$

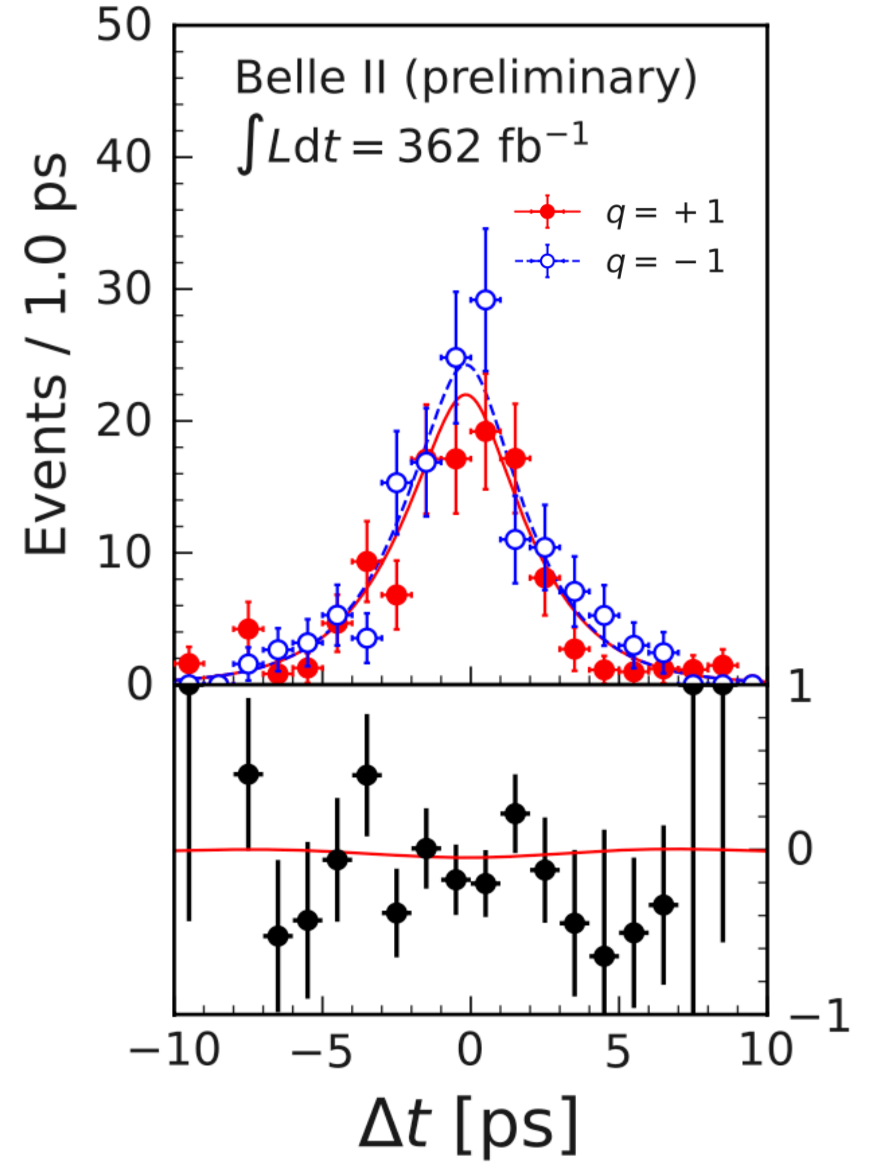
362 fb^{-1}

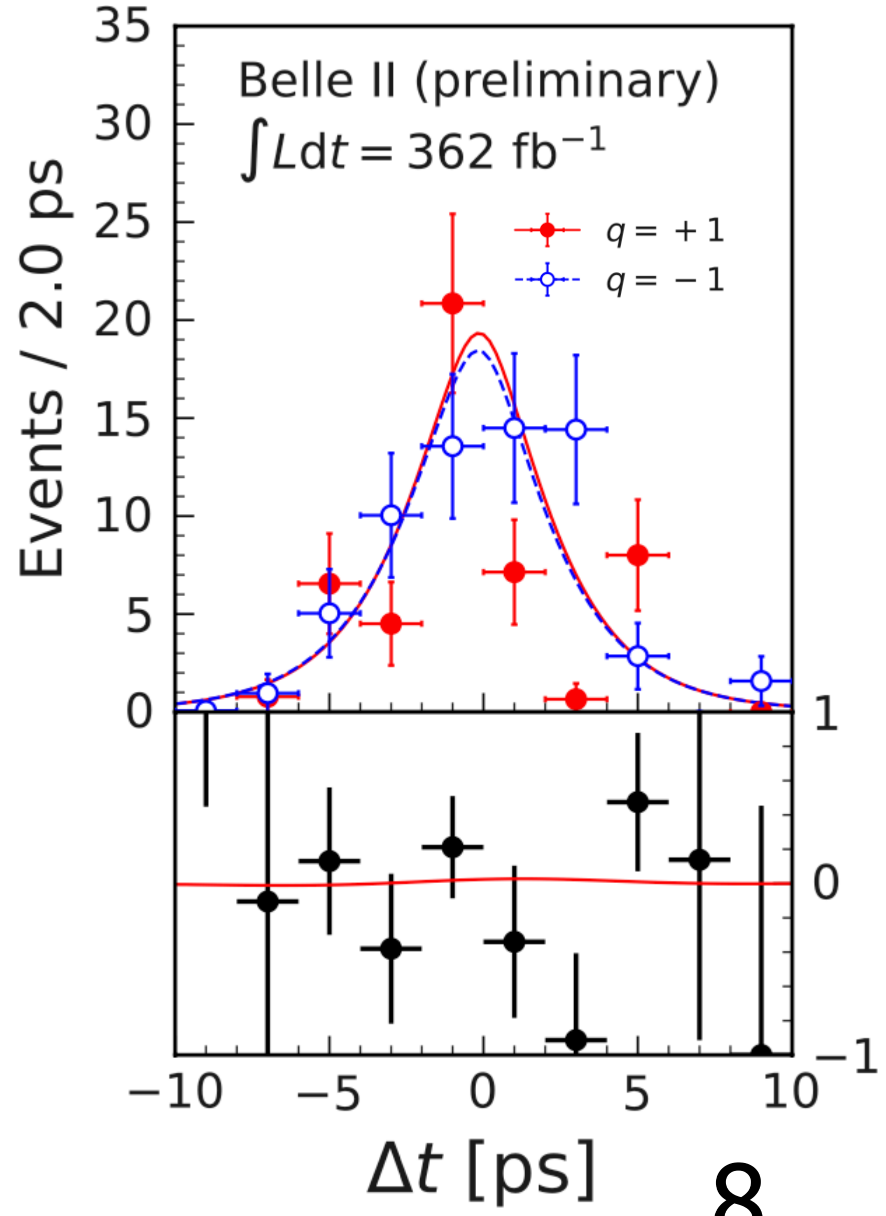
Belle II

- **Photon polarization** constrained by flavour $\Rightarrow$ interference (i.e. TDCPV) helicity suppressed ($\sim m_s/m_b$) $\Rightarrow S_{CP}$ **sensitive to NP**
- Considered:
  - Exclusive decays $B^0 \to K^{*0}(\to K_S^0 \pi^0)\gamma$
  - Inclusive decays $B^0 \to K_S^0 \pi^0 \gamma$
- Challenge: B^0 vertex **without prompt tracks**
  - $K_S^0 \to \pi^+\pi^-$ information + beamspot constraint
  - poor-quality vertex events used for time-integrated fit
- Fit to $(\Delta E, M_{bc})$ to extract the signal, followed by the Δt fit

Top plot: $B^0 \to K^{*0}\gamma$, $0.8\,\mathrm{GeV} < m(K_S^0\pi^0) < 1\,\mathrm{GeV}$

Bottom plot: $B^0 \to$ non-$K^{*0}\gamma$, excluding above mass region





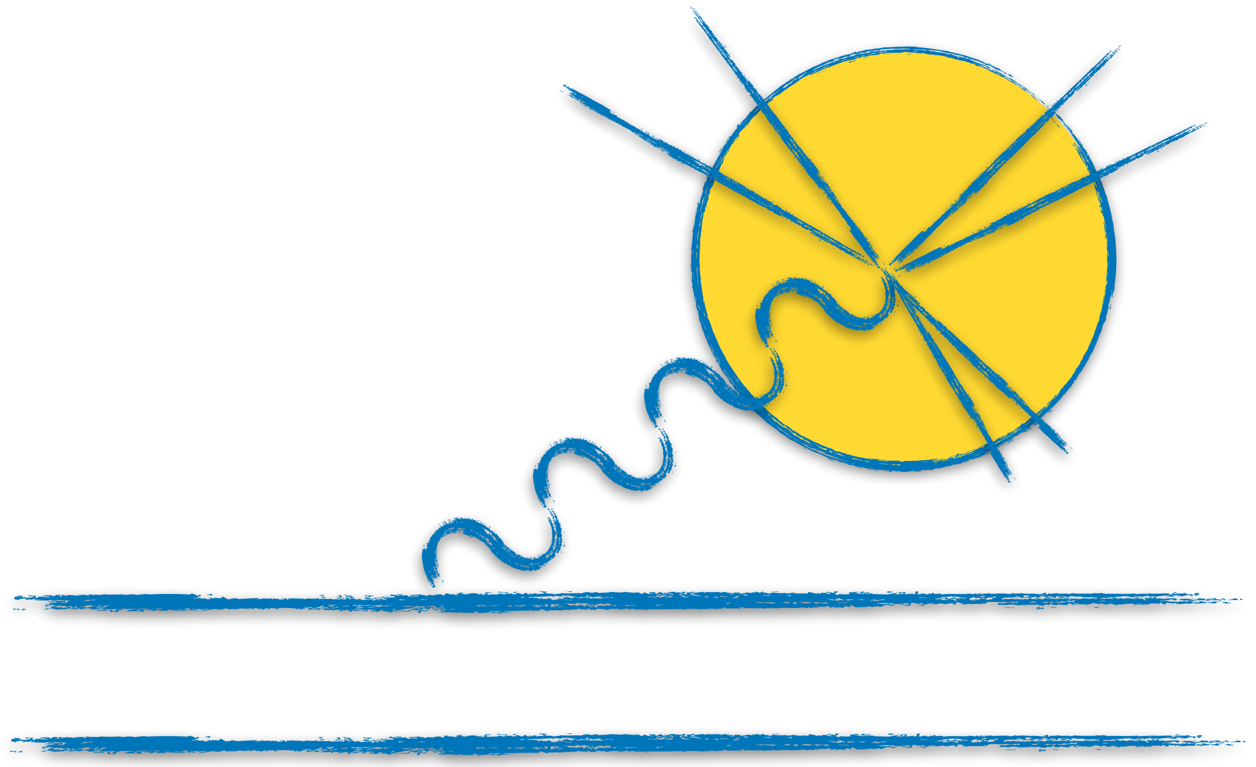
Most precise result and compatible with SM

$$S(K^{*0}\gamma) = 0.00^{+0.27+0.03}_{-0.26-0.04},$$
$$C(K^{*0}\gamma) = 0.10 \pm 0.13 \pm 0.03,$$

$$S(K_S^0\pi^0\gamma) = 0.04^{+0.45}_{-0.44} \pm 0.10,$$
$$C(K_S^0\pi^0\gamma) = -0.06 \pm 0.25 \pm 0.07,$$

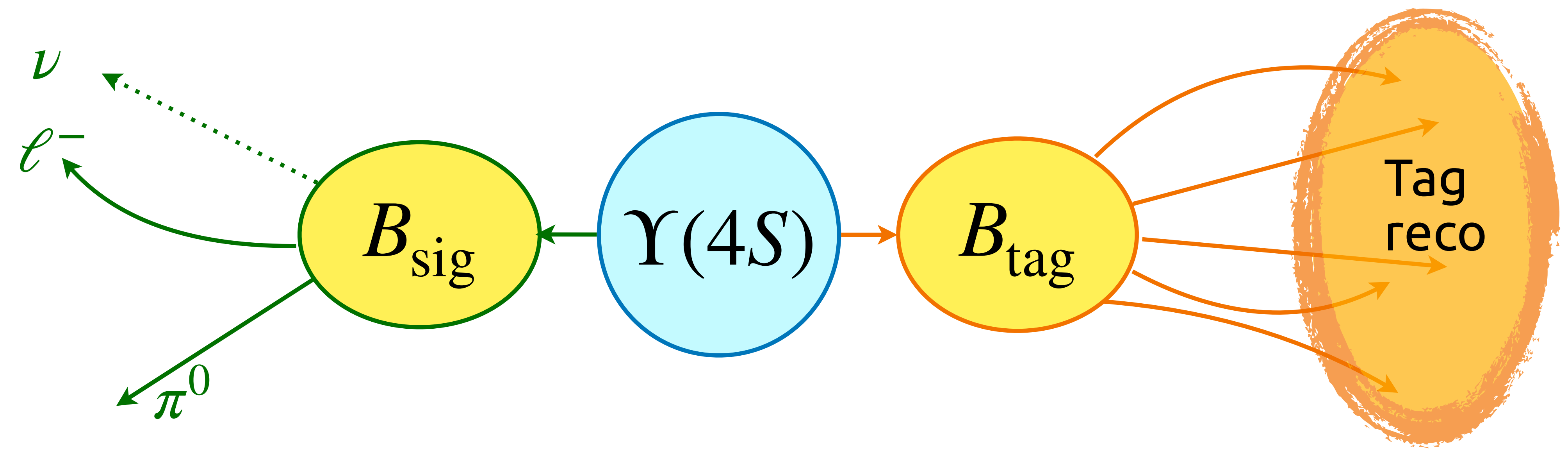
SM [HFLAV]: $S = -0.16 \pm 0.22, A = -0.07 \pm 0.12,$ $S = -0.15 \pm 0.20, A = -0.07 \pm 0.12$

Improving B decays knowledge



B-tagging at Belle II

In channels with **missing energy** ⇒ use of the the **Rest of the Event (ROE)** information:



- Exclusive tagging:

  Step 1: Reconstruction of the partner B (B_{tag}) using **well-known channels**

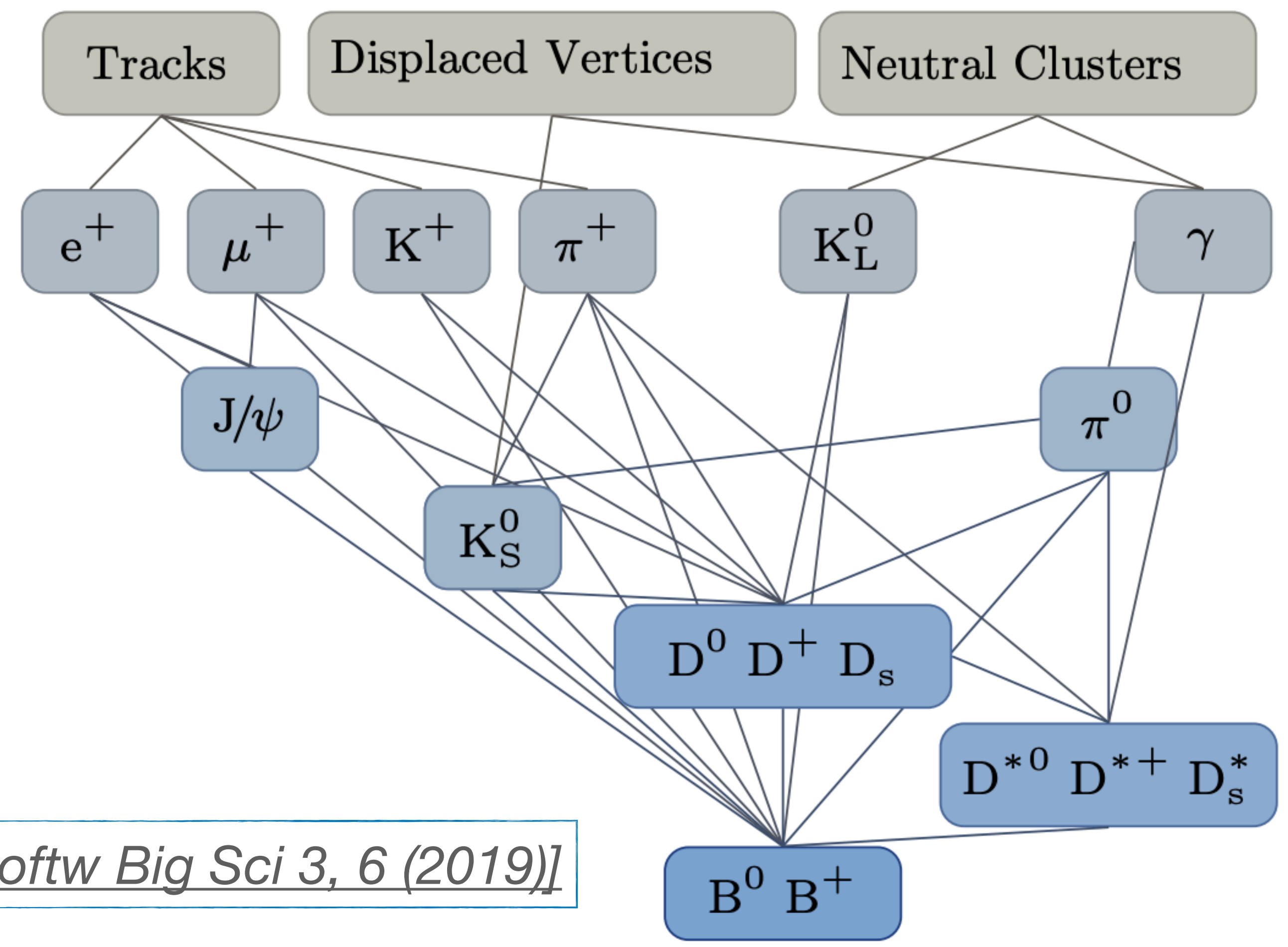
  - **Hadronic tagging:** lower efficiency, but full tag reconstruction
  - **Semileptonic Tagging:** higher efficiency, but lower purity

  Step 2: Using the $\Upsilon(4S)$ constraint, infer the information on the second B (B_{sig}): **flavour**, **charge** and **kinematic** constraints

- **Inclusive Tagging:** signal reconstruction first, and then use of the ROE+$\Upsilon(4S)$ constraint to infer the signal signature

Full Event Interpretation (FEI)

- MVA based B-tagging algorithm
- hierarchical approach to reconstruct $\mathcal{O}(10^4)$ decay chains
- $\varepsilon_{\mathrm{had}} \simeq 0.5\,\%$, $\varepsilon_{\mathrm{SL}} \simeq 2\,\%$



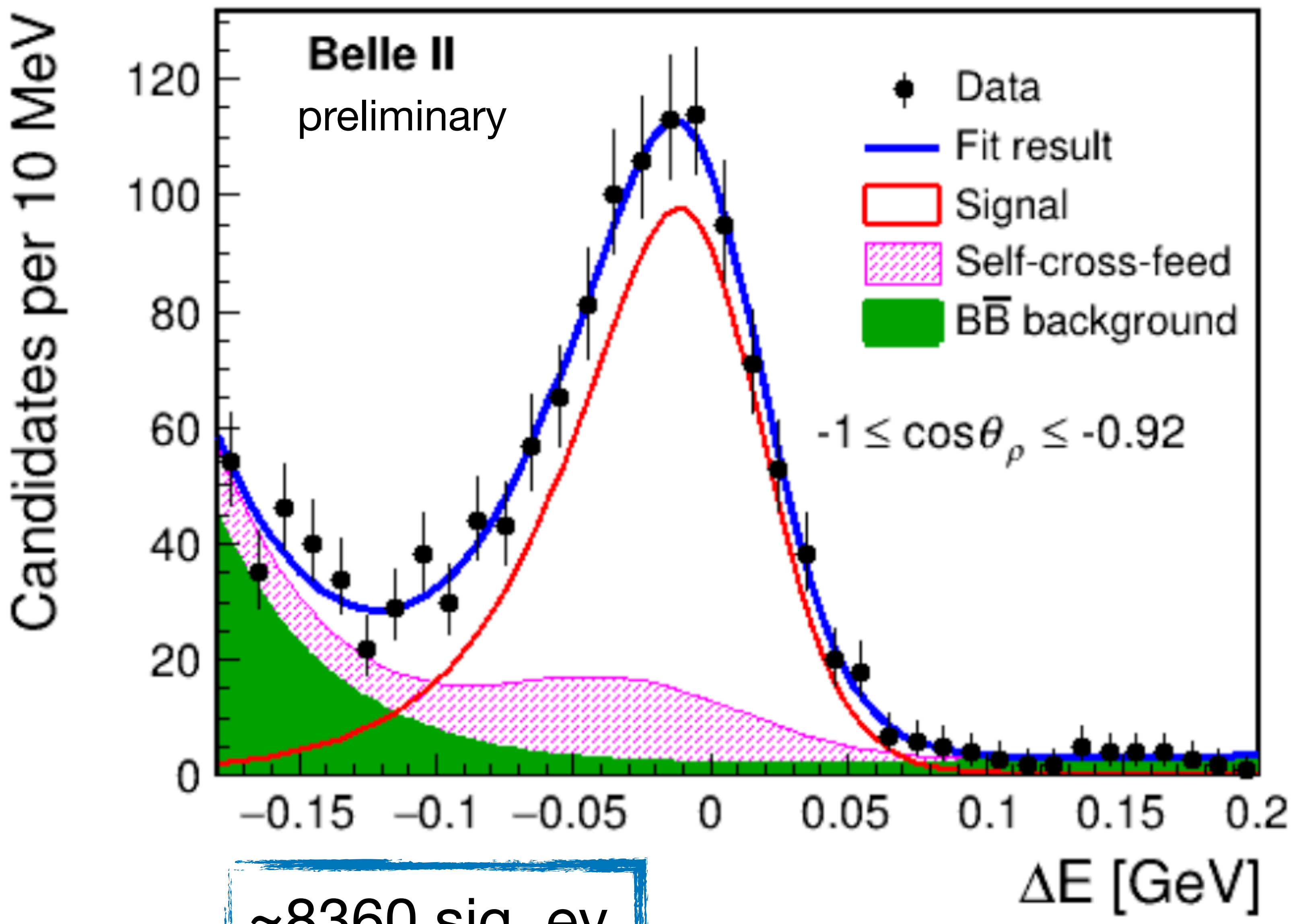
[T. Keck et al, Comput Softw Big Sci 3, 6 (2019)]

Branching fraction of $B^+ \to D^0\rho(770)^+$

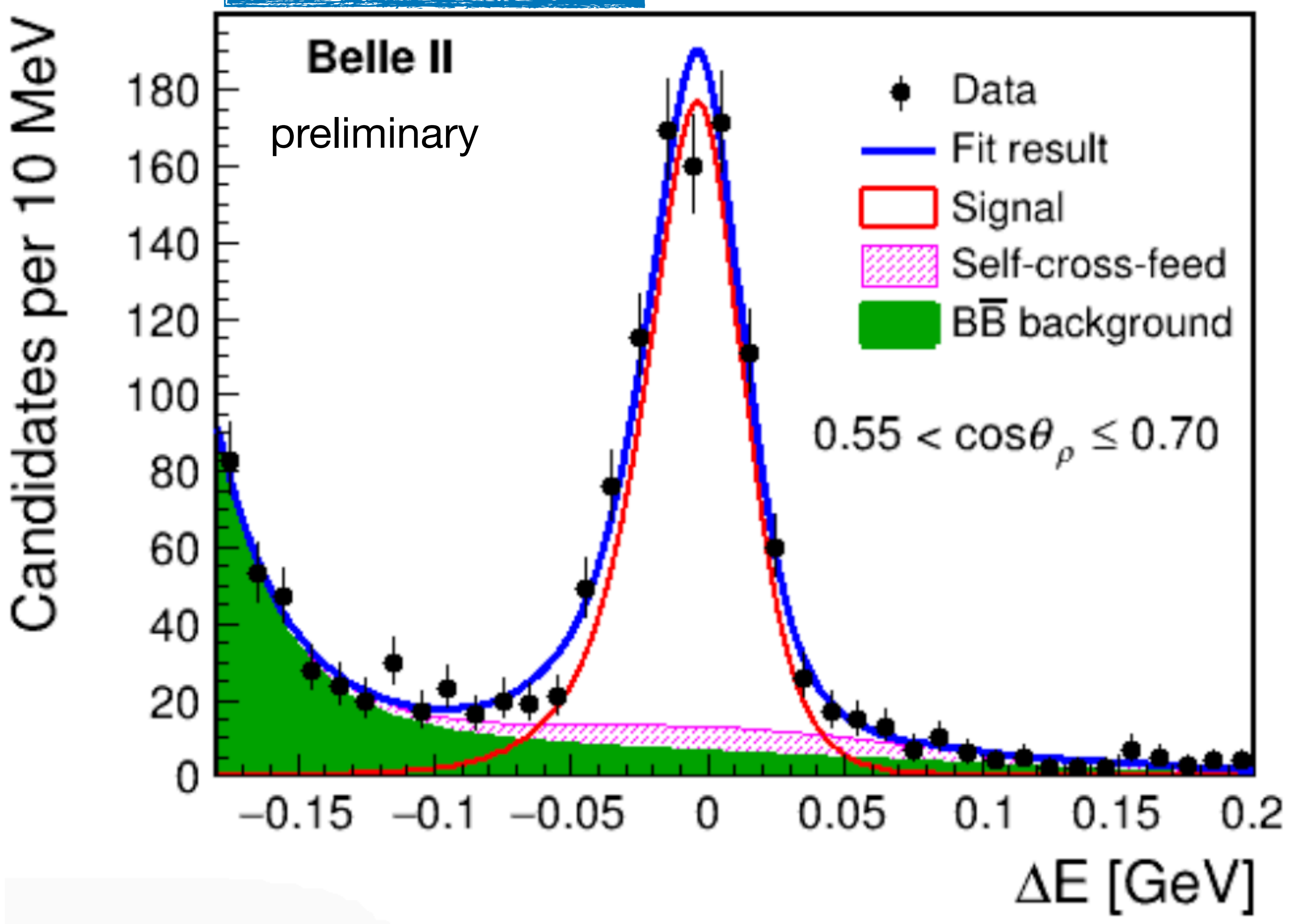
NEW for La Thuile

$362\ \mathrm{fb}^{-1}$

- Motivations:
  - $B^+ \to D^0\rho^+$ is one of the main modes of **hadronic B-tagging**
  - One of the ingredients to test heavy-quark limit and factorization models (see for instance: [Nucl. Phys. B 591, 313 (2000)])
  - World average $B(B^+ \to D^0\rho) = 1.35 \pm 0.18$ is driven by an old measurement [CLEO, PRD 50, 43 (1994)])
- signal extracted from ΔE in bin of **helicity angle**, to separate $B \to D^0\rho(\to \pi^+\pi^0)$ and $B \to D^0\pi^+\pi^0$ components



~8360 sig. ev.



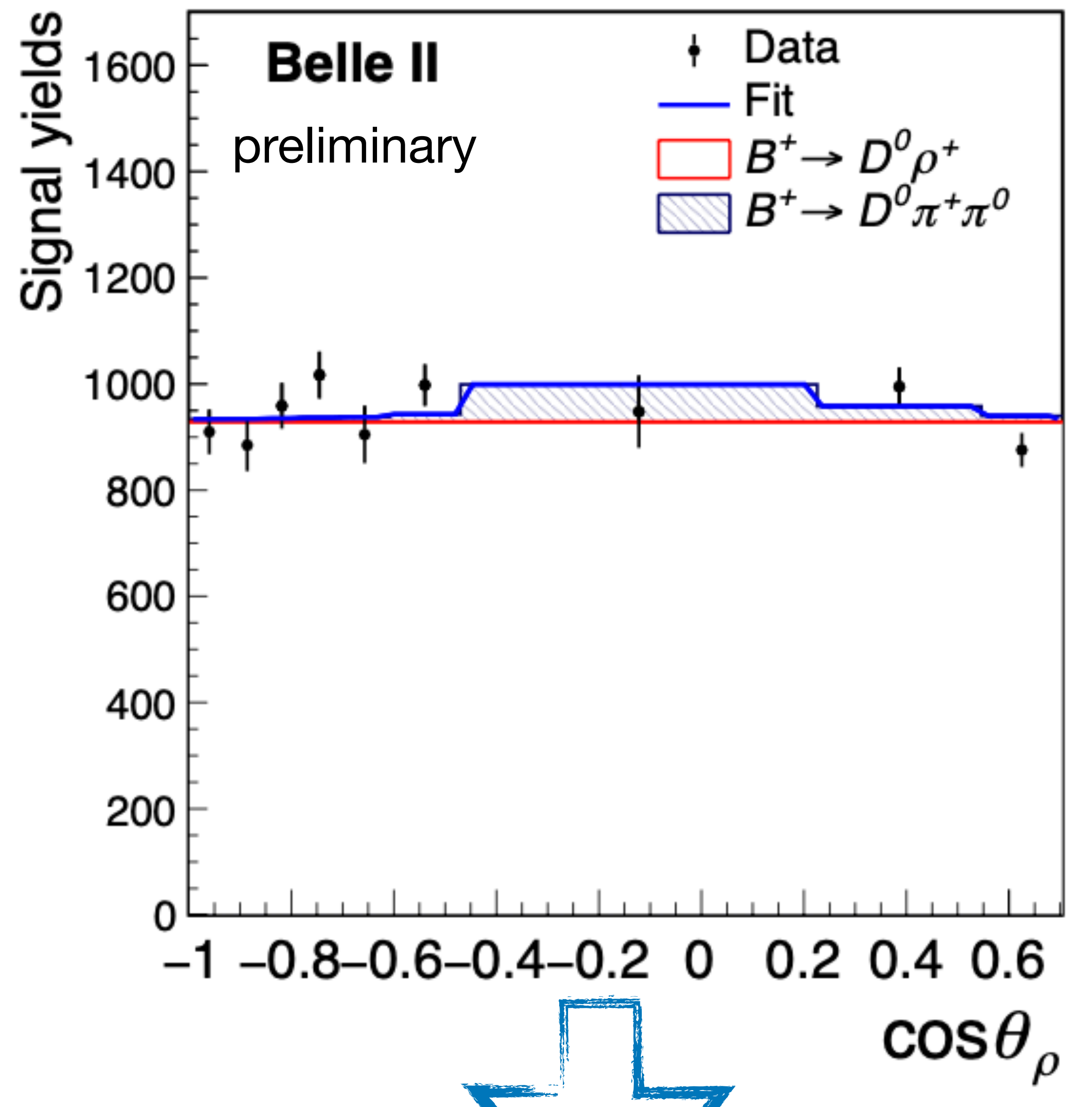
Branching fraction of $B^+ \to D^0\rho(770)^+$

NEW for La Thuile

$362\ \text{fb}^{-1}$

Belle II

- Template fit to $\cos\theta_\rho$ distribution using $B \to D^0\rho$ and $B \to D^0\pi^+\pi^0$ templates
  - Non-uniform binning to have $\cos\theta_\rho$ uniform distribution for the $B \to D^0\rho$
  - found $(1.9 \pm 1.8)\,\%$ of $B \to D^0\pi^+\pi^0$

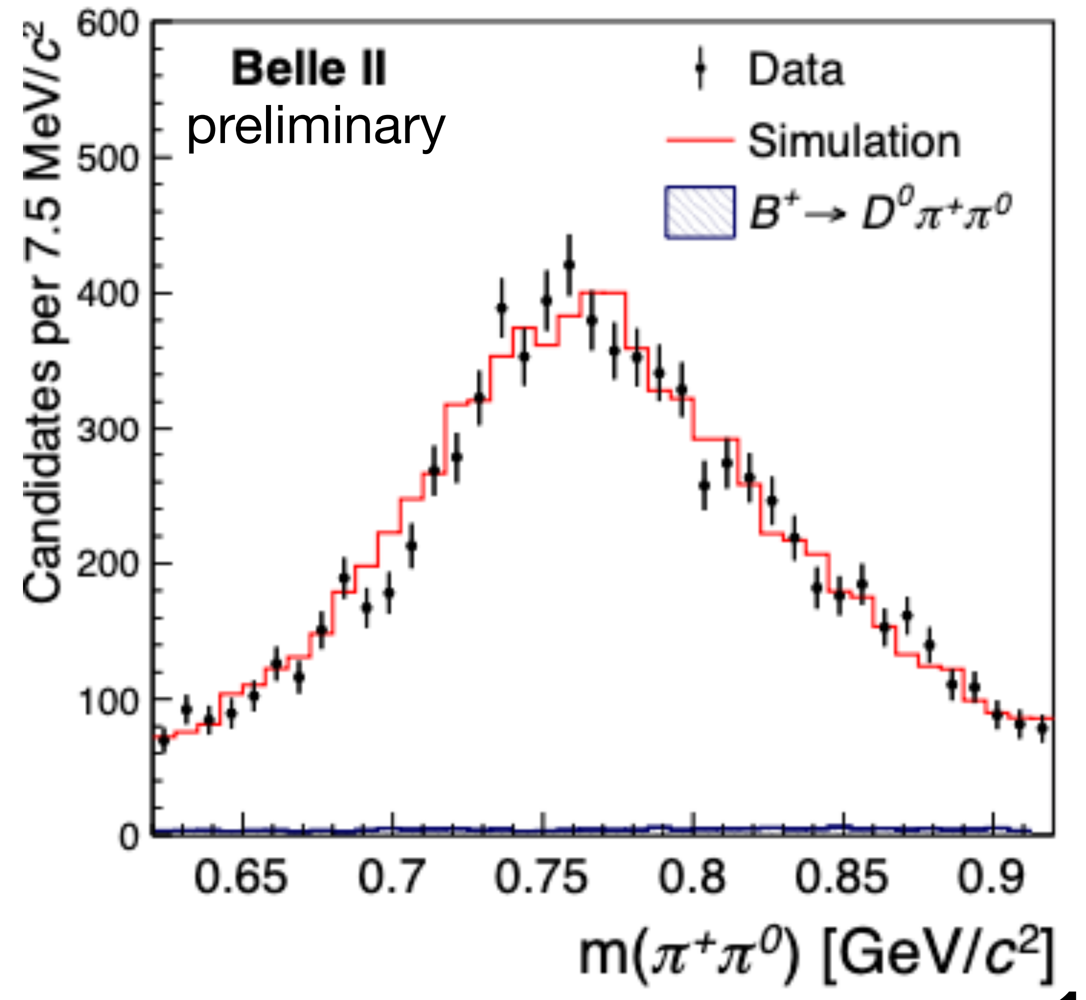


World best result

More than factor 2 improvement in precision

2σ tension with the w.a.

$$\mathcal{B}(B^- \to D^0\rho^-) = (0.939 \pm 0.021 \pm 0.050)\%$$



- **Systematically limited**, by π^0 efficiency calibration

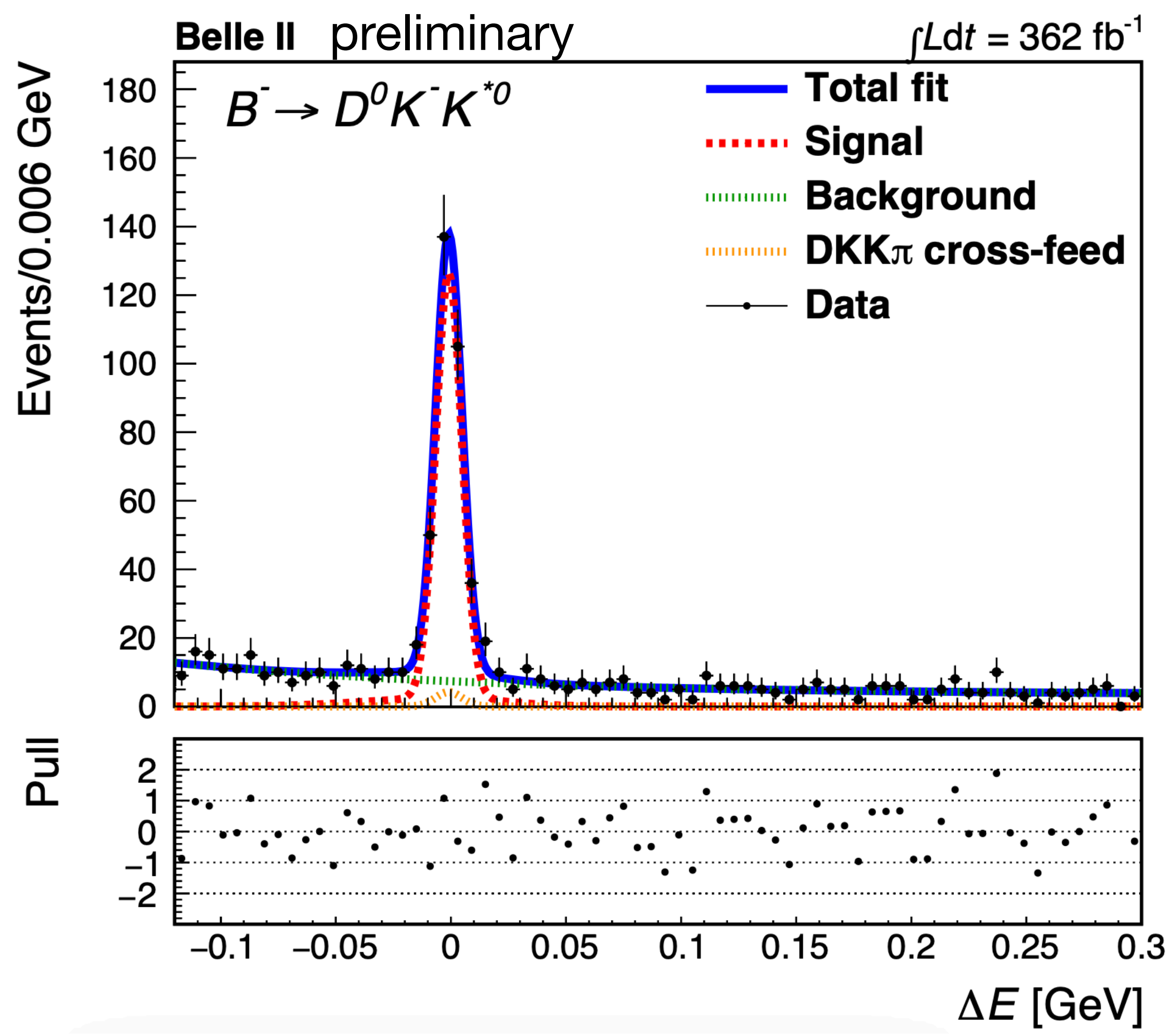
$B \to D^{(*)}K^-K^{(*)0}_{(S)}$ and $B \to D^{(*)}D_s^-$

NEW for La Thuile

$362\ \mathrm{fb}^{-1}$

Belle II

- $B \to DKK$ is a completely unexplored sector, few % of B BF expected, only 0.28% measured
  - **simulation** and **B-tagging** techniques will take advantage from an improvement
- Signal extracted from a fit in ΔE
  - challenging background from $B \to DK^-K^+\pi$ in K^{*0} channels $\Rightarrow$ fit to $m(K^+\pi^-)$ distribution
- BFs extracted applying an efficiency correction differential in the plane $\left(m(D^{(*)}K^{0(*)}_{(S)}), m(K^-K^{0(*)}_{(S)})\right)$



- **Observation** of **3 new decay modes** $(D^+, D^{*0}, D^{*+})K^-K^0_S$
- **x3 precision** on $D^0KK^0_S$ and DKK^{*0} modes
- **World best measurements** for $B \to D^{(*)}D_s^-$, reconstructed in $D_s^- \to K^-K^0_S$ and $D_s^- \to K^-K^{*0}$

Channel	Yield (K^0_S / K^{*0})	Average ε (K^0_S / K^{*0})	$\mathcal{B}$ [10^{-4}]
$B^- \to D^0K^-K^0_S$	209 ± 17	0.098	$1.82 \pm 0.16 \pm 0.08$
$\bar{B}^0 \to D^+K^-K^0_S$	105 ± 14	0.048	$0.82 \pm 0.12 \pm 0.05$
$B^- \to D^{*0}K^-K^0_S$	51 ± 9	0.044	$1.47 \pm 0.27 \pm 0.10$
$\bar{B}^0 \to D^{*+}K^-K^0_S$	36 ± 7	0.046	$0.91 \pm 0.19 \pm 0.05$
$B^- \to D^0K^-K^{*0}$	325 ± 19	0.043	$7.19 \pm 0.45 \pm 0.33$
$\bar{B}^0 \to D^+K^-K^{*0}$	385 ± 22	0.021	$7.56 \pm 0.45 \pm 0.38$
$B^- \to D^{*0}K^-K^{*0}$	160 ± 15	0.019	$11.93 \pm 1.14 \pm 0.93$
$\bar{B}^0 \to D^{*+}K^-K^{*0}$	193 ± 14	0.020	$13.12 \pm 1.21 \pm 0.71$
$B^- \to D^0D_s^-$	144 ± 12 / 153 ± 13	0.09 / 0.04	$95 \pm 6 \pm 5$
$\bar{B}^0 \to D^+D_s^-$	145 ± 12 / 159 ± 13	0.05 / 0.02	$89 \pm 5 \pm 5$
$B^- \to D^{*0}D_s^-$	30 ± 6 / 29 ± 7	0.04 / 0.02	$65 \pm 10 \pm 6$
$\bar{B}^0 \to D^{*+}D_s^-$	43 ± 7 / 37 ± 7	0.04 / 0.02	$83 \pm 10 \pm 6$

first observation (rows $\bar{B}^0 \to D^+K^-K^0_S$, $B^- \to D^{*0}K^-K^0_S$, $\bar{B}^0 \to D^{*+}K^-K^0_S$)

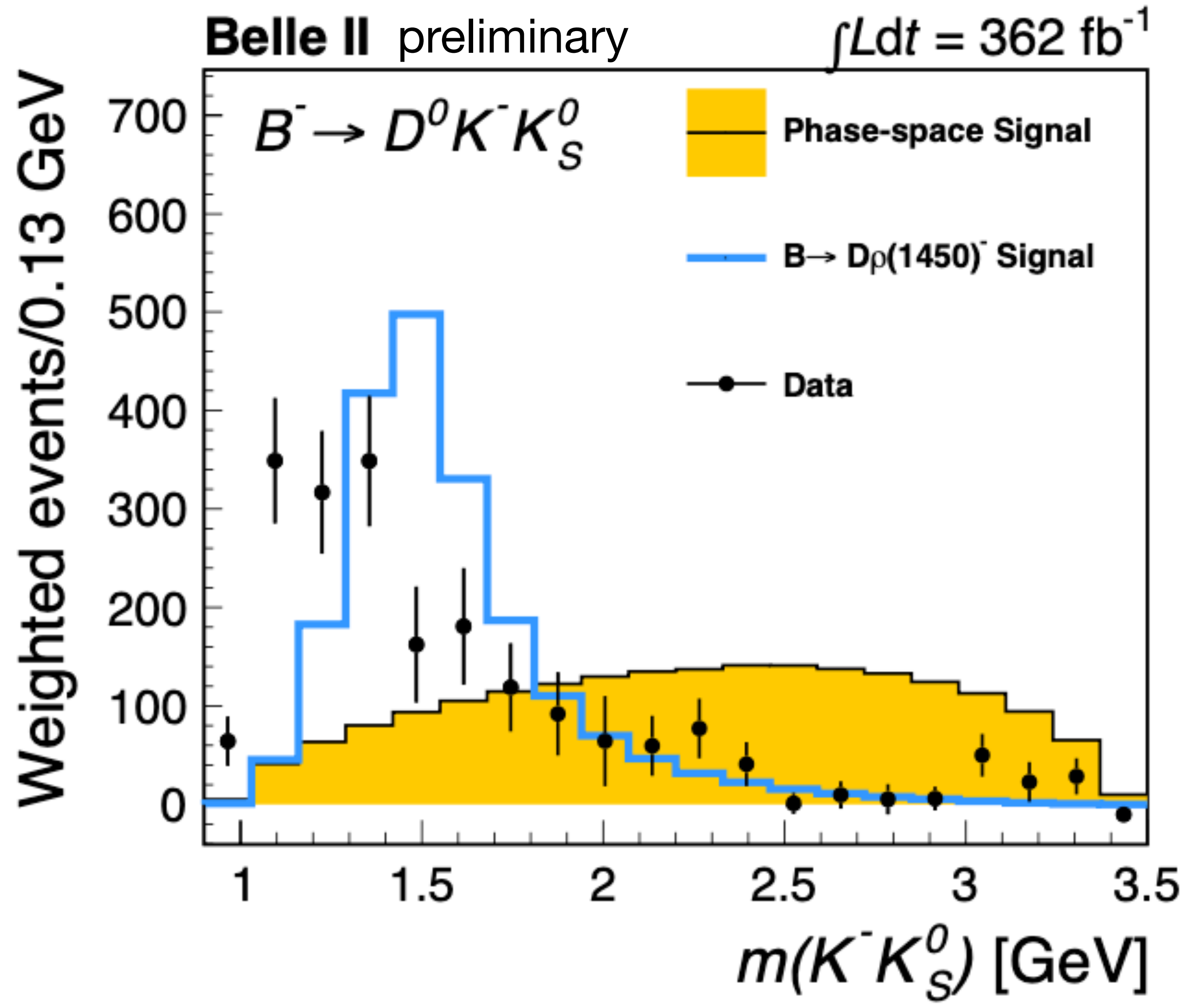
$B \to D^{(*)}K^-K^{(*)0}_{(S)}$ and $B \to D^{(*)}D_s^-$

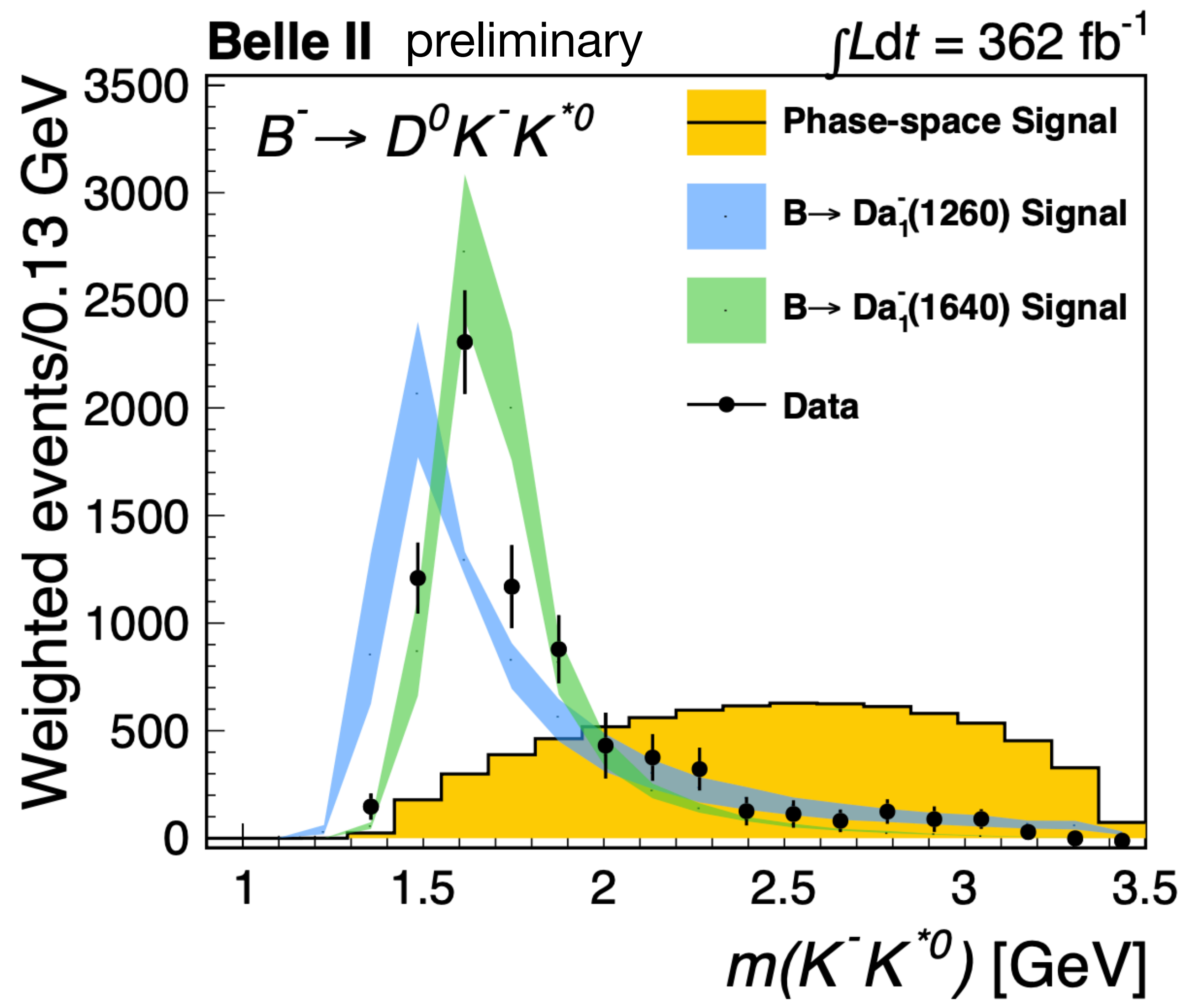
NEW for La Thuile

$362\ \text{fb}^{-1}$

Belle II

- extracted bkg-subracted and efficiency-corrected **invariant mass** and **helicity angles** with an sPlot
- Low-mass **structures** observed in $m(K^-K_S^0)$ system, with a dominant $J^P = 1^-$ transition (one or more ρ' resonances)
- Low-mass **structures** observed in $m(K^-K^{*0})$ system, compatible with $J^P = 1^+$ transition (one or more a_1 resonances)





Branching fraction and polarization of $B^0 \to \omega\omega$

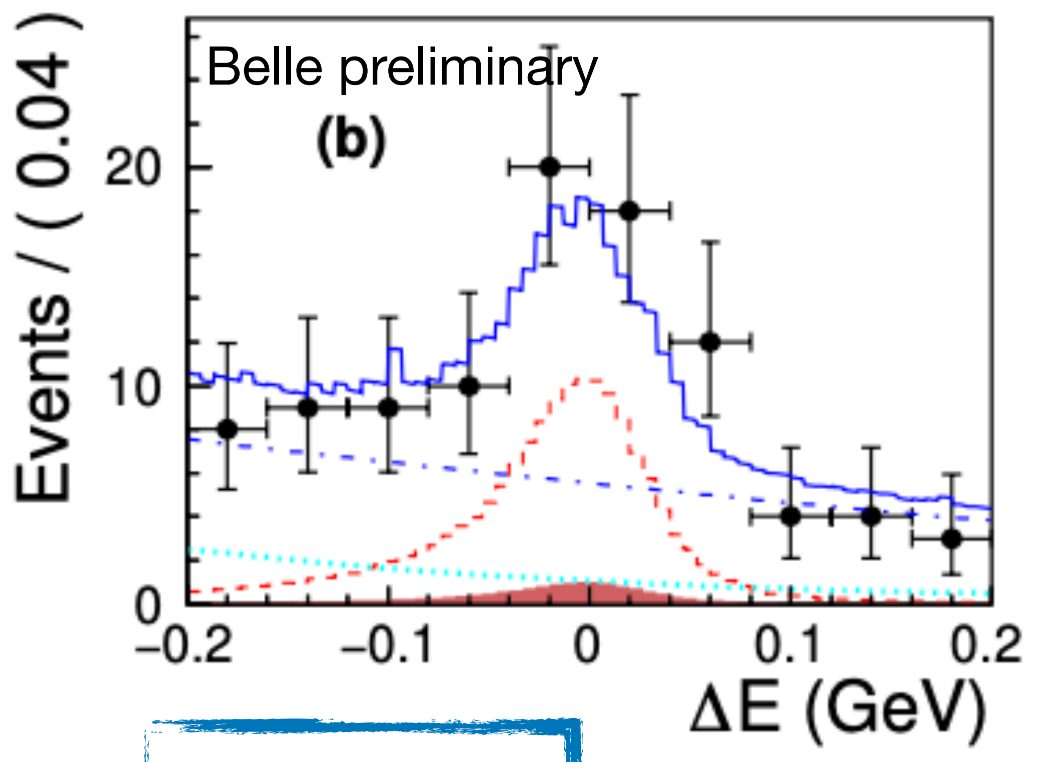
NEW for La Thuile

$711\ \mathrm{fb}^{-1}$

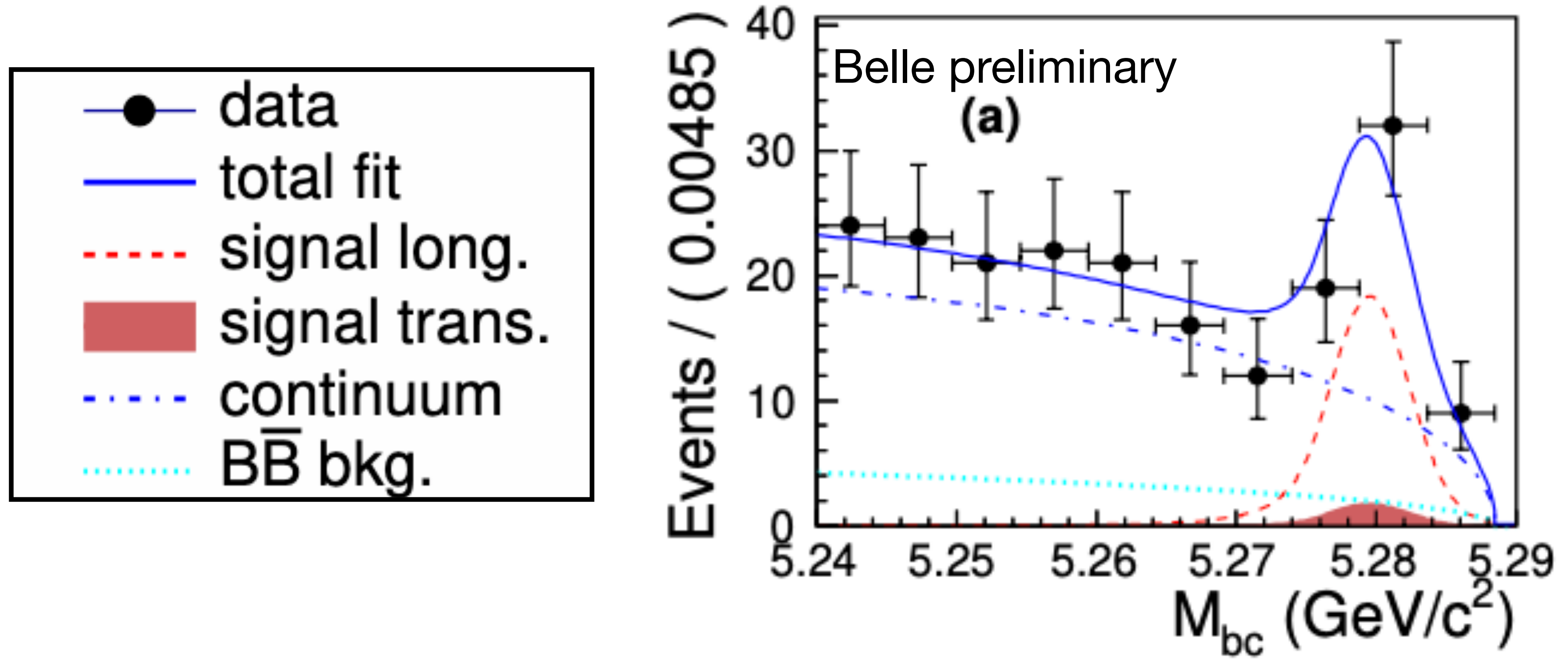
BELLE

[arXiv:2401.04646]

- It is a rare, **never observed** decay
- The **polarization** f_L and the **direct CP violation** parameter A_{CP} will be useful to understand better the $B \to VV$ decays
- Untagged measurement, reconstructed $\omega \to \pi^+\pi^-\pi^0$
- BDT for bkg suppression
- Flavour tagging exploiting Rest-of-Event
- Simultaneous fit for f_L, A_{CP} to 7 kinematic variables



~60 sig. ev.

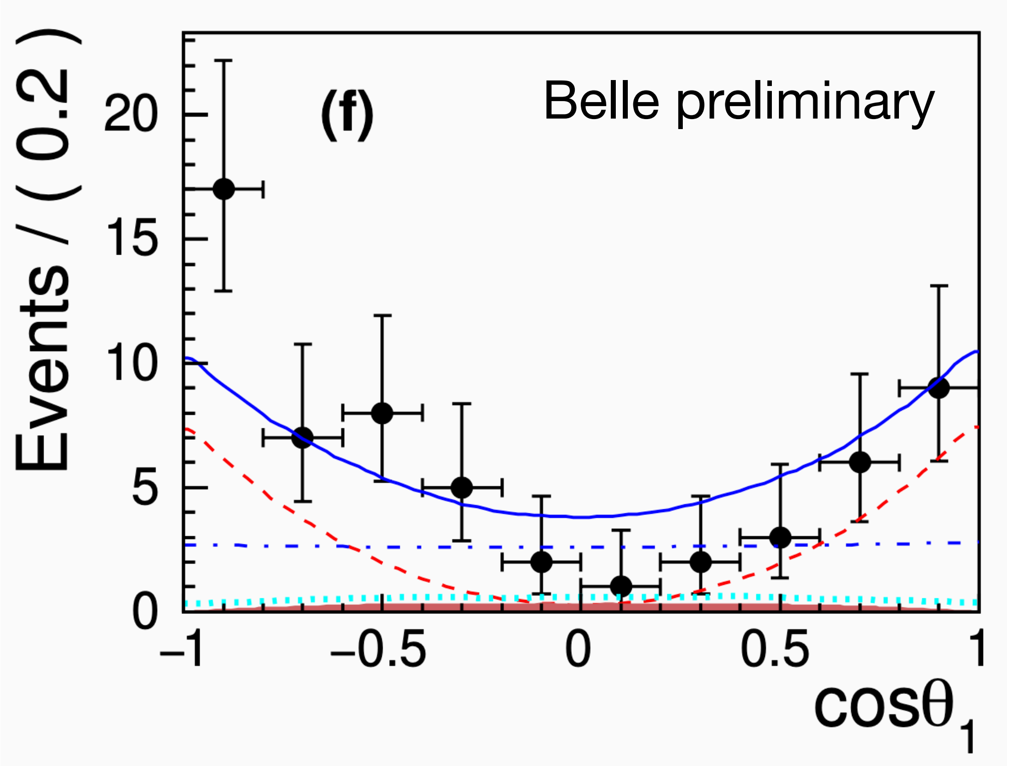


$$\mathcal{B} = (1.53 \pm 0.29 \pm 0.17) \times 10^{-6}$$
$$f_L = 0.87 \pm 0.13 \pm 0.13$$
$$A_{CP} = -0.44 \pm 0.43 \pm 0.11$$

First observation of the decay (7.9σ)

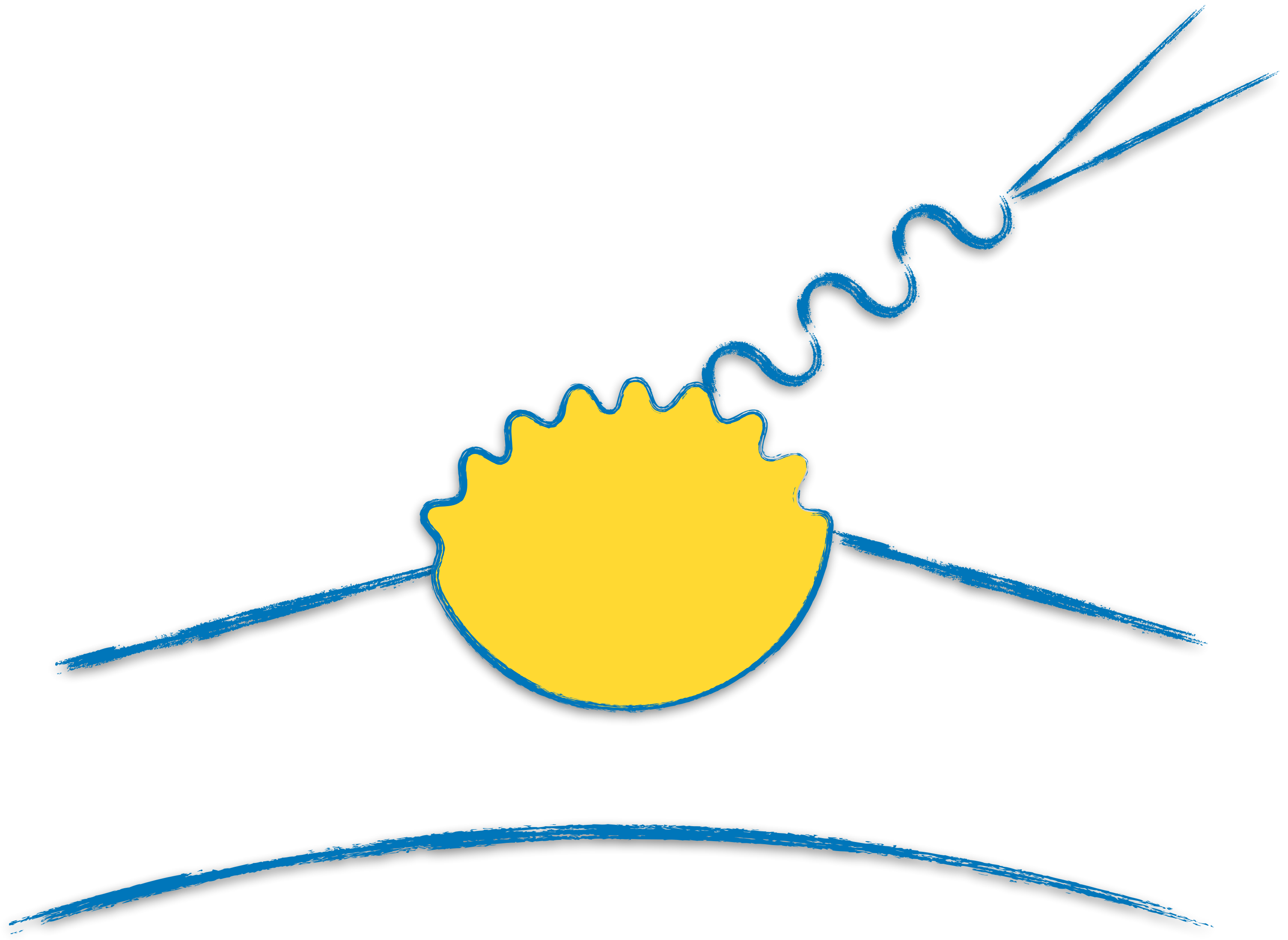
f_L compatible with SM

no significant A_{CP}



SM Expected $f_L \approx 0.9 - 0.95$ [PRD, 77, 095004]

Flavour changing neutral currents
&
Lepton flavour universality



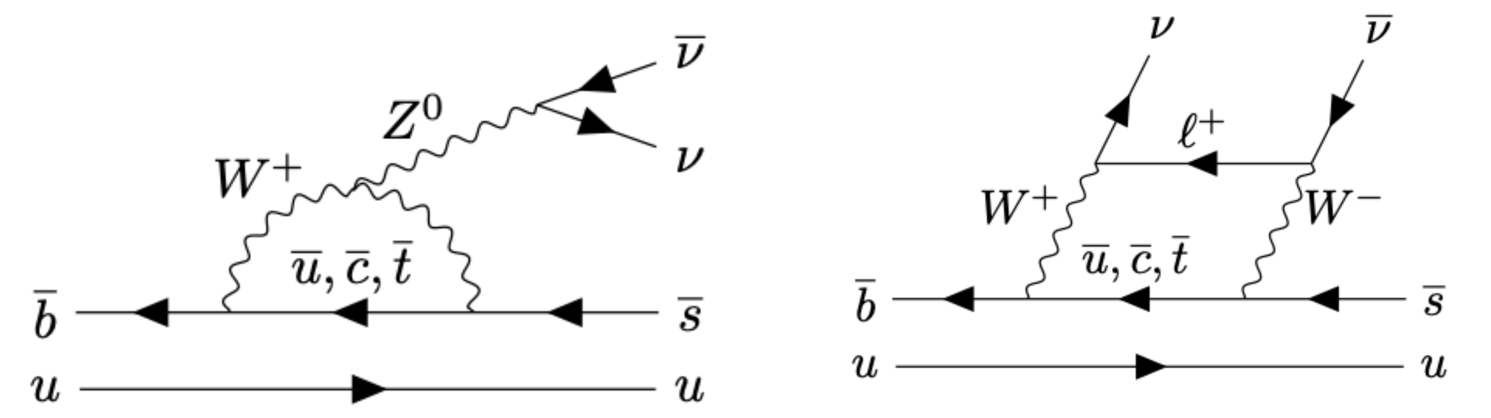
First evidence of $B^+ \to K^+ \nu\bar{\nu}$ (1)

[arXiv:2311.14647] *To appear in PRD*

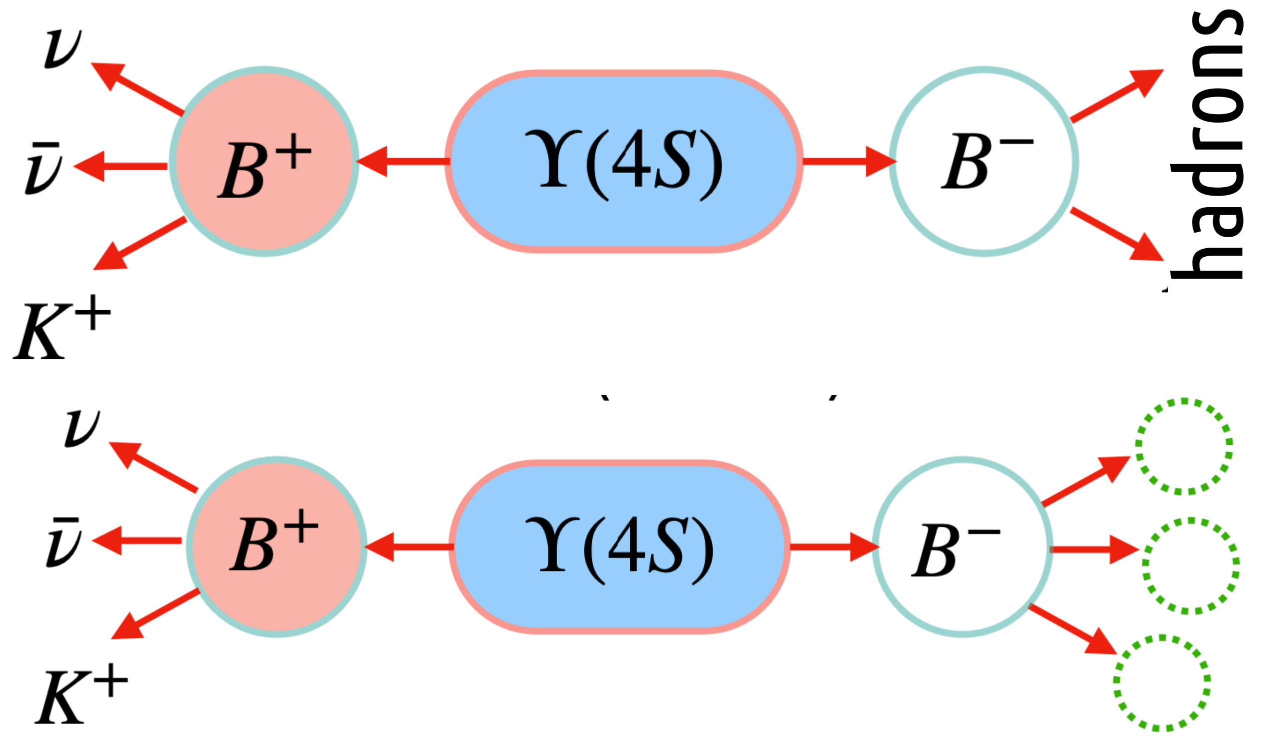
$362\ \text{fb}^{-1}$

Belle II

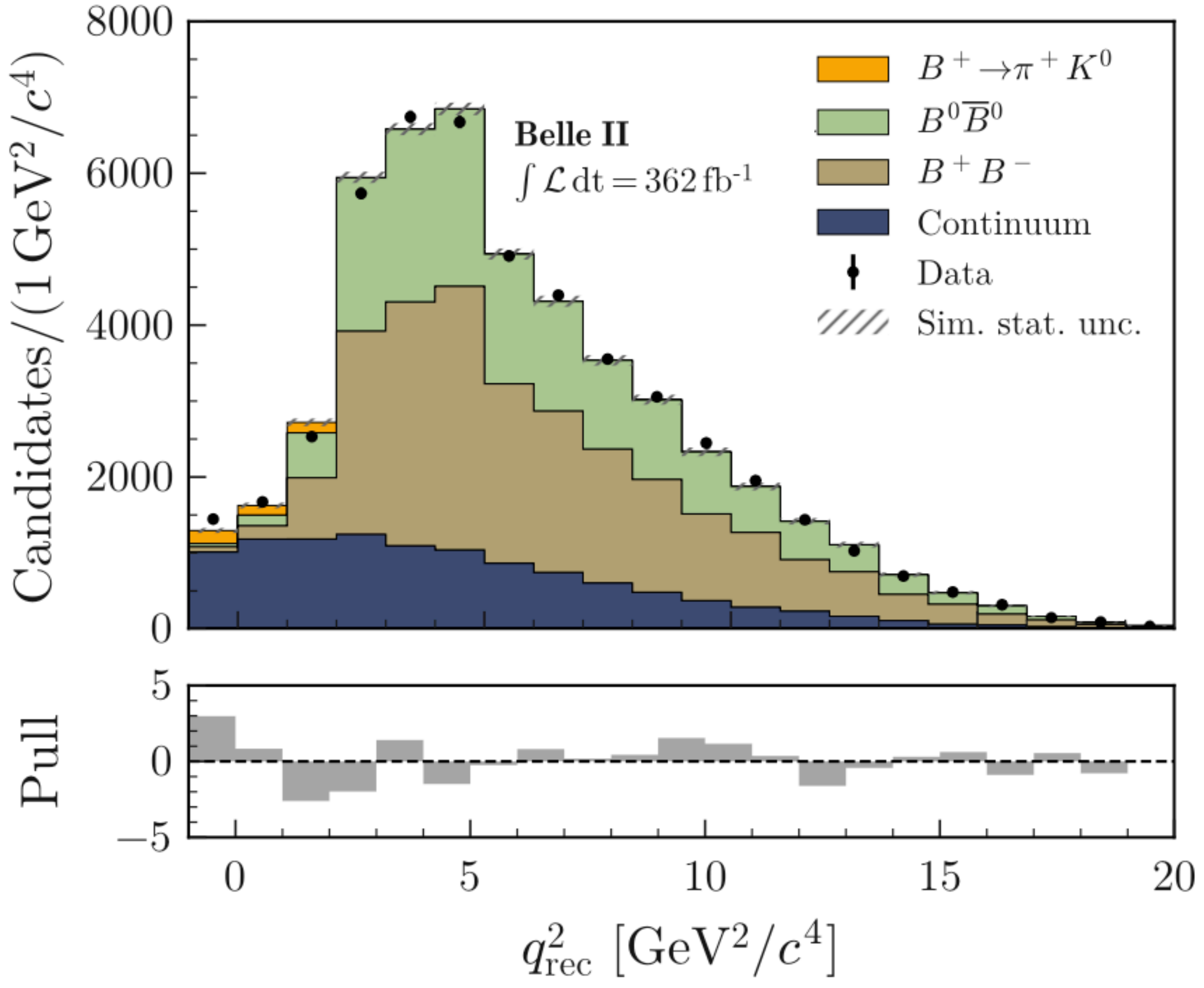
- FCNC, strongly suppressed in the SM:
  $\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) = (5.58 \pm 0.37) \times 10^{-6}$ [PRD 107, 014511 (2023)]
  - NP can enhance the BF (for instance [PRD, 98, 055003 (2018)])



- Tagging: combination of two methods, (almost) statistically independent:
  - **hadronic-tagging:** higher purity (more conventional)
  - **inclusive tagging:** higher efficiency (more sensitive)



- **Bkg suppression and control** is extremely challenging: only one K track, two neutrino in the final state
  - Bkg suppressed with **two BDT in cascade** targeting $q\bar{q}$ and other B decays
  - **Bkg control validated** for each specific source of bkg
  - **Signal efficiency validated** with $B \to K^+ J/\psi(\to \mu\mu)$, without matching the muons
  - **Closure** test: extraction of the BF of $B \to K^0\pi^+$, as a function of $q^2_{rec} = s + M_K^2 - \sqrt{s}E_K^* \Rightarrow$ found consistent with w.a.



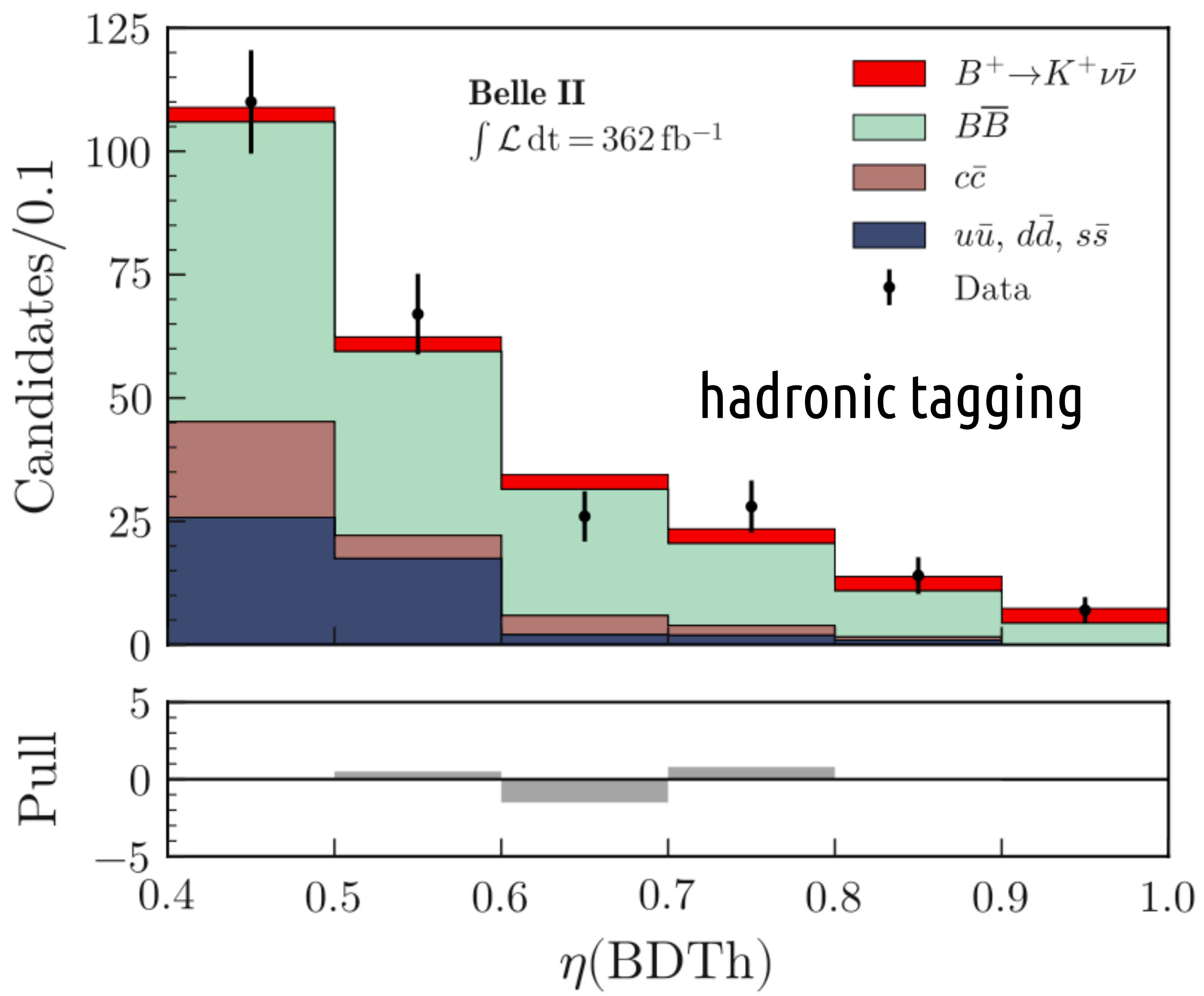
First evidence of $B^+ \to K^+\nu\bar{\nu}$ (2)

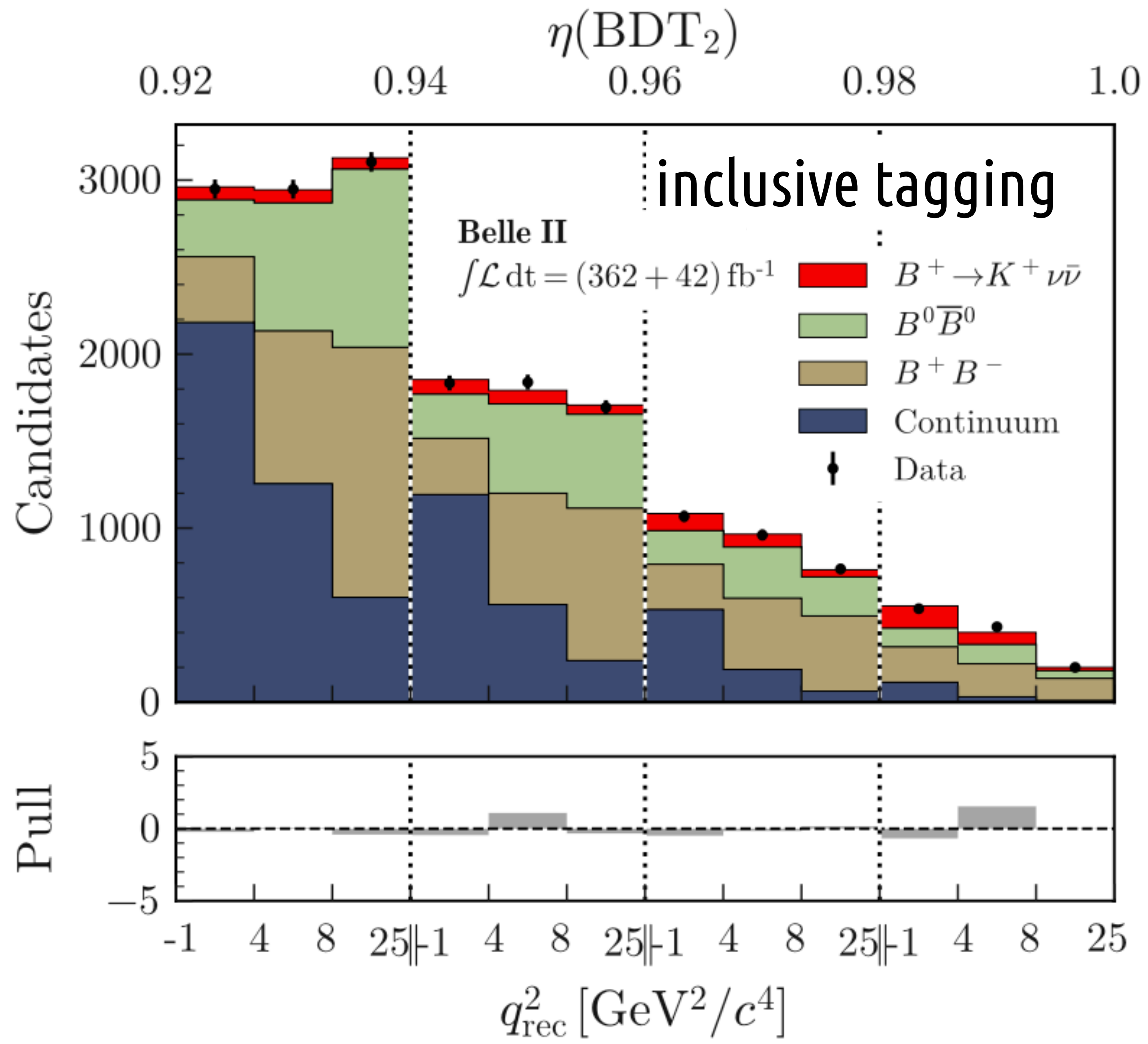
[arXiv:2311.14647]
To appear in PRD

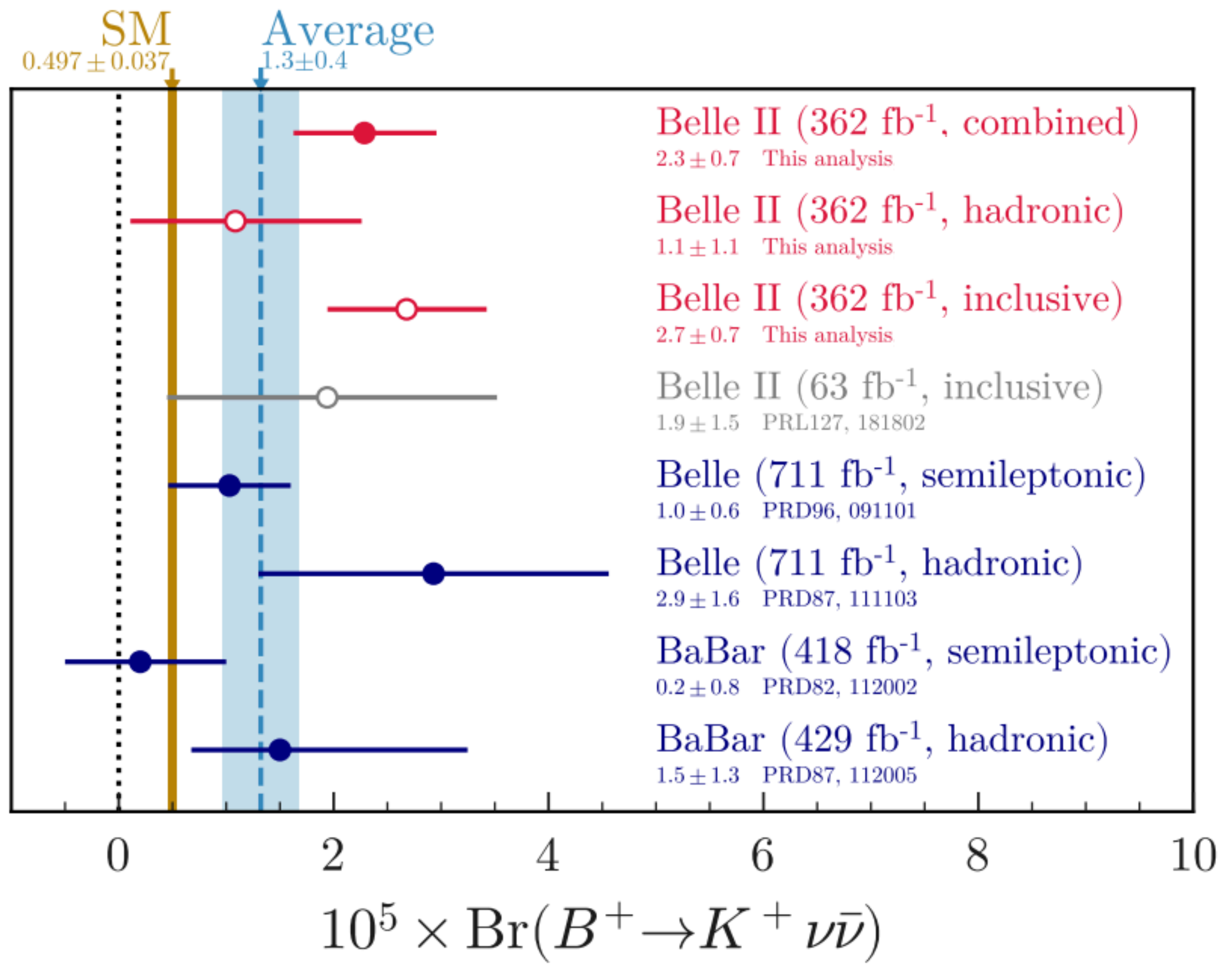
362 fb^{-1}

Hadronic tagging: fit in bin of **BDT output** (η)

Inclusive tagging: fit in bin of **BDT output** (η) and **dineutrino mass** $q^2_{\rm rec}$







Combined result:

$$\mu = 4.6 \pm 1.0(\mathrm{stat}) \pm 0.9(\mathrm{syst})$$

$$BF(B^+ \to K^+\nu\bar{\nu}) = \left[2.3 \pm 0.5(\mathrm{stat})^{+0.5}_{-0.4}(\mathrm{syst})\right]\times 10^{-5}$$

3.5σ above the bkg-only hypothesis

2.7σ above the SM prediction

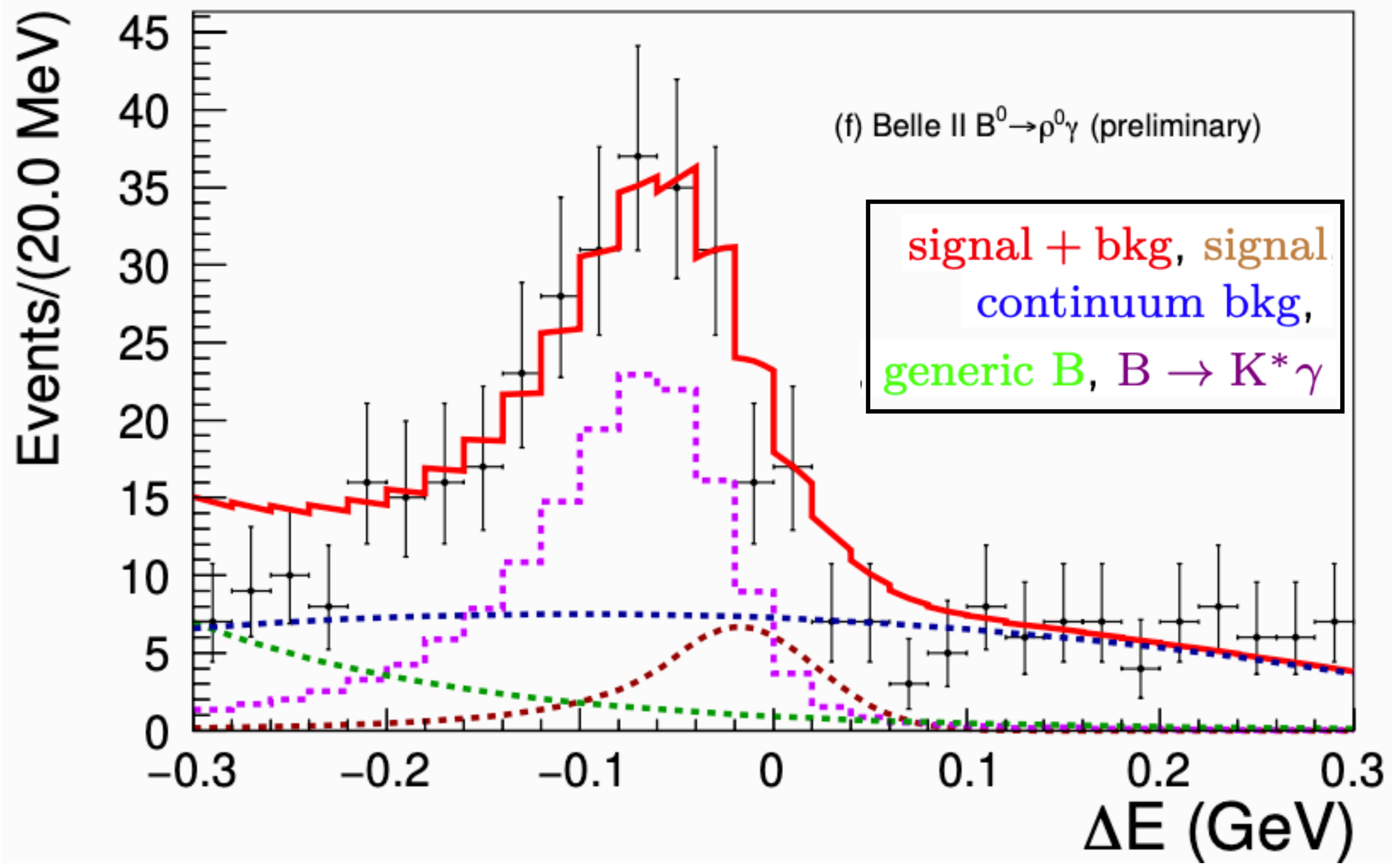
Branching fraction and isospin asymmetries of $B \to \rho\gamma$

$362\ \mathrm{fb}^{-1}$ Belle II

$711\ \mathrm{fb}^{-1}$ BELLE

- Motivations:
  - $b \to d\gamma$ **FCNC** $\Rightarrow$ BFs are one order of magnitude smaller than $b \to s\gamma$ and possibly **sensitive differently to NP**
  - From previous measurements, **isospin asymmetry is currently 2σ from the SM** [Belle, PRD 101,111801 (2008)]
- $B^+ \to \rho^+(\to \pi^+\pi^0)\gamma$ and $B^0 \to \rho^0(\to \pi^+\pi^-)\gamma$ reconstruction
- Challenging due to $B \to K^*\gamma$ bkg (when K is misreconstructed)
- Fit to $(\Delta E, M_{bc}, m(\pi\pi))$

$$A_{\mathrm{I}} = \frac{c_\rho^2\Gamma(\overset{(-)}{B^0} \to \rho^0\gamma) - \Gamma(B^\pm \to \rho^\pm\gamma)}{c_\rho^2\Gamma(\overset{(-)}{B^0} \to \rho^0\gamma) + \Gamma(B^\pm \to \rho^\pm\gamma)}.$$



$$\mathcal{B}(B^+ \to \rho^+\gamma) = (13.1^{+2.0+1.3}_{-1.9-1.2}) \times 10^{-7},$$
$$\mathcal{B}(B^0 \to \rho^0\gamma) = (7.5 \pm 1.3^{+1.0}_{-0.8}) \times 10^{-7},$$
$$A_{\mathrm{CP}}(B^+ \to \rho^+\gamma) = (-8.2 \pm 15.2^{+1.6}_{-1.2})\ \%,$$
$$A_{\mathrm{I}}(B \to \rho\gamma) = (10.9^{+11.2+6.8+3.8}_{-11.7-6.2-3.9})\ \%,$$

World best measurement for BFs

A_I compatible with SM

Search for $b \to d\ell^+\ell^-$

NEW for La Thuile

$711\ \mathrm{fb}^{-1}$

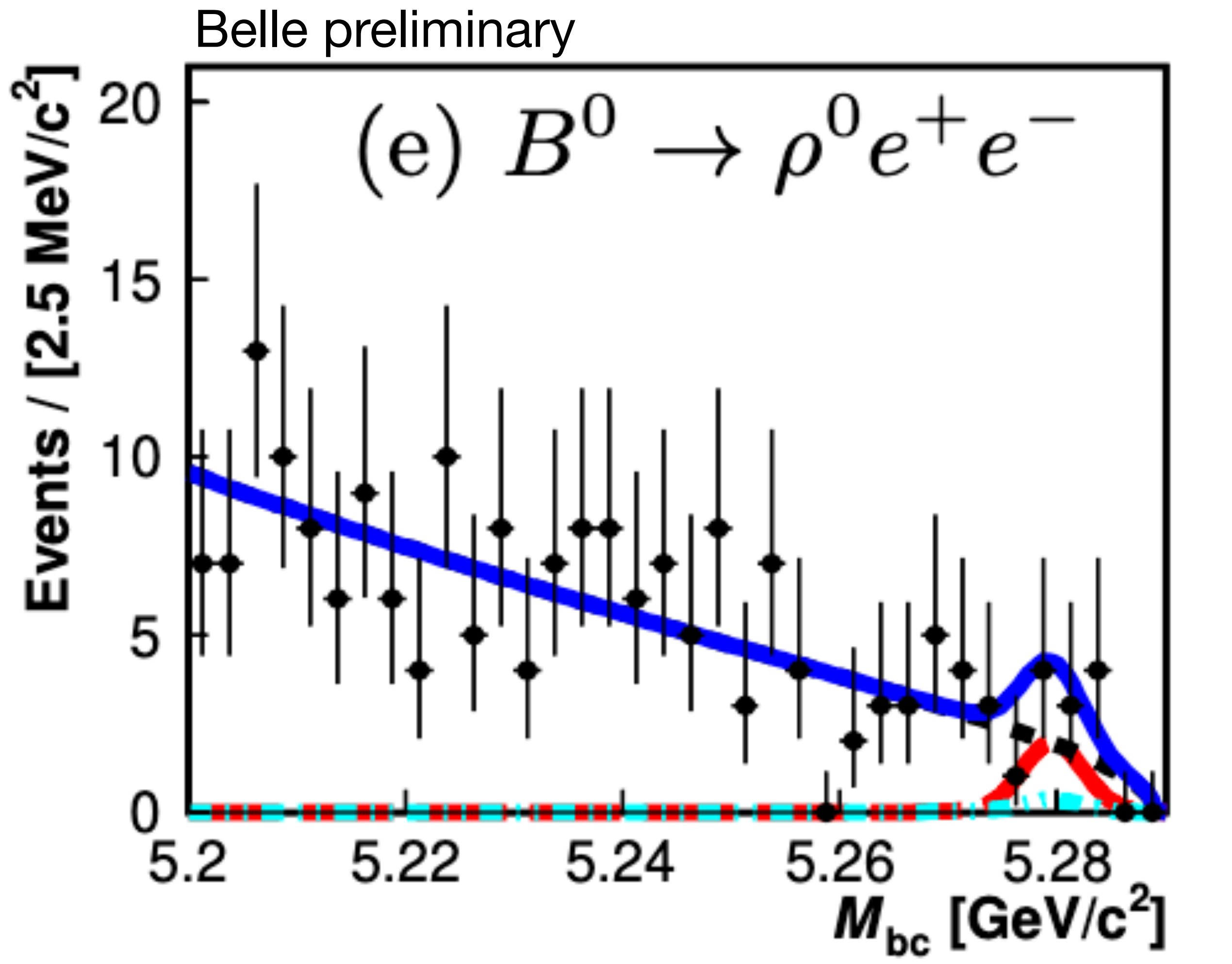
BELLE

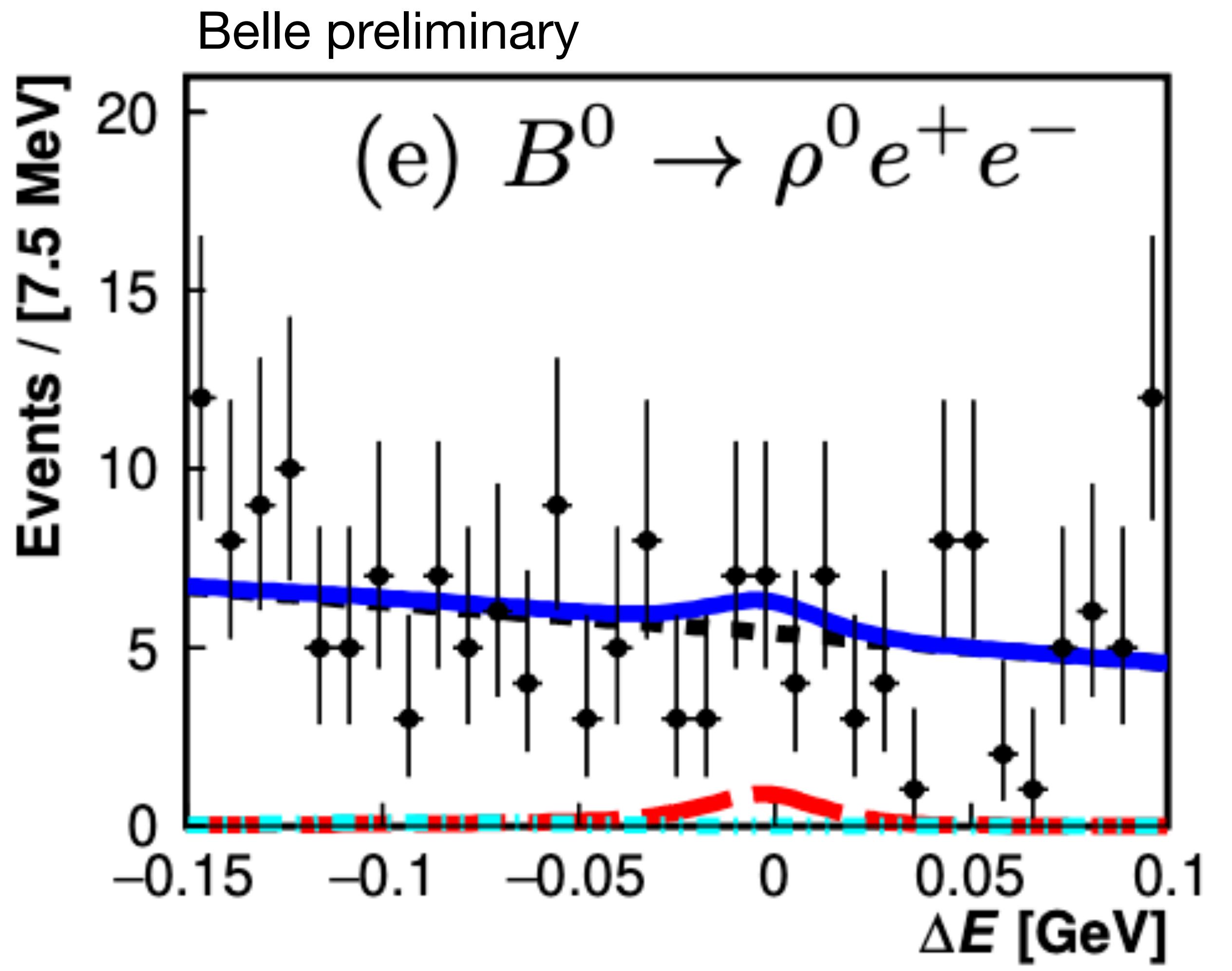
- Search :
  - $B \to (\eta, \omega, \pi^{+,0}, \rho^{+,0})e^+e^-$
  - $B \to (\eta, \omega, \pi^0, \rho^+)\mu^+\mu^-$
- all of these are **never observed** $b \to d$ **FCNCs**
- Bkg suppression via BDT
- Signal extraction by fitting $(\Delta E, M_{bc})$
- No signal observed $\Rightarrow$ set upper limits: $(3.8 - 47) \times 10^{-8}$ at 90 CL
- Complementary with LHCb limits [JHEP 10(2015)034, PLB743(2015)46] on $B \to (\pi^+, \rho^0)\mu^+\mu^-$, and consistent with our $B \to he^+e^-$ modes

Best UL for all the channels

First search for highlighted channels

channel	$\mathcal{B}^{\mathrm{UL}}$ (10^{-8})
$B^0 \to \eta e^+e^-$	< 10.5
$B^0 \to \eta\mu^+\mu^-$	< 9.4
$B^0 \to \eta\ell^+\ell^-$	< 4.8
$B^0 \to \omega e^+e^-$	< 30.7
$B^0 \to \omega\mu^+\mu^-$	< 24.9
$B^0 \to \omega\ell^+\ell^-$	< 22.0
$B^0 \to \pi^0 e^+e^-$	< 7.9
$B^0 \to \pi^0\mu^+\mu^-$	< 5.9
$B^0 \to \pi^0\ell^+\ell^-$	< 3.8
$B^+ \to \pi^+ e^+e^-$	< 5.4
$B^0 \to \rho^0 e^+e^-$	< 45.5
$B^+ \to \rho^+ e^+e^-$	< 46.7
$B^+ \to \rho^+\mu^+\mu^-$	< 38.1
$B^+ \to \rho^+\ell^+\ell^-$	< 18.9



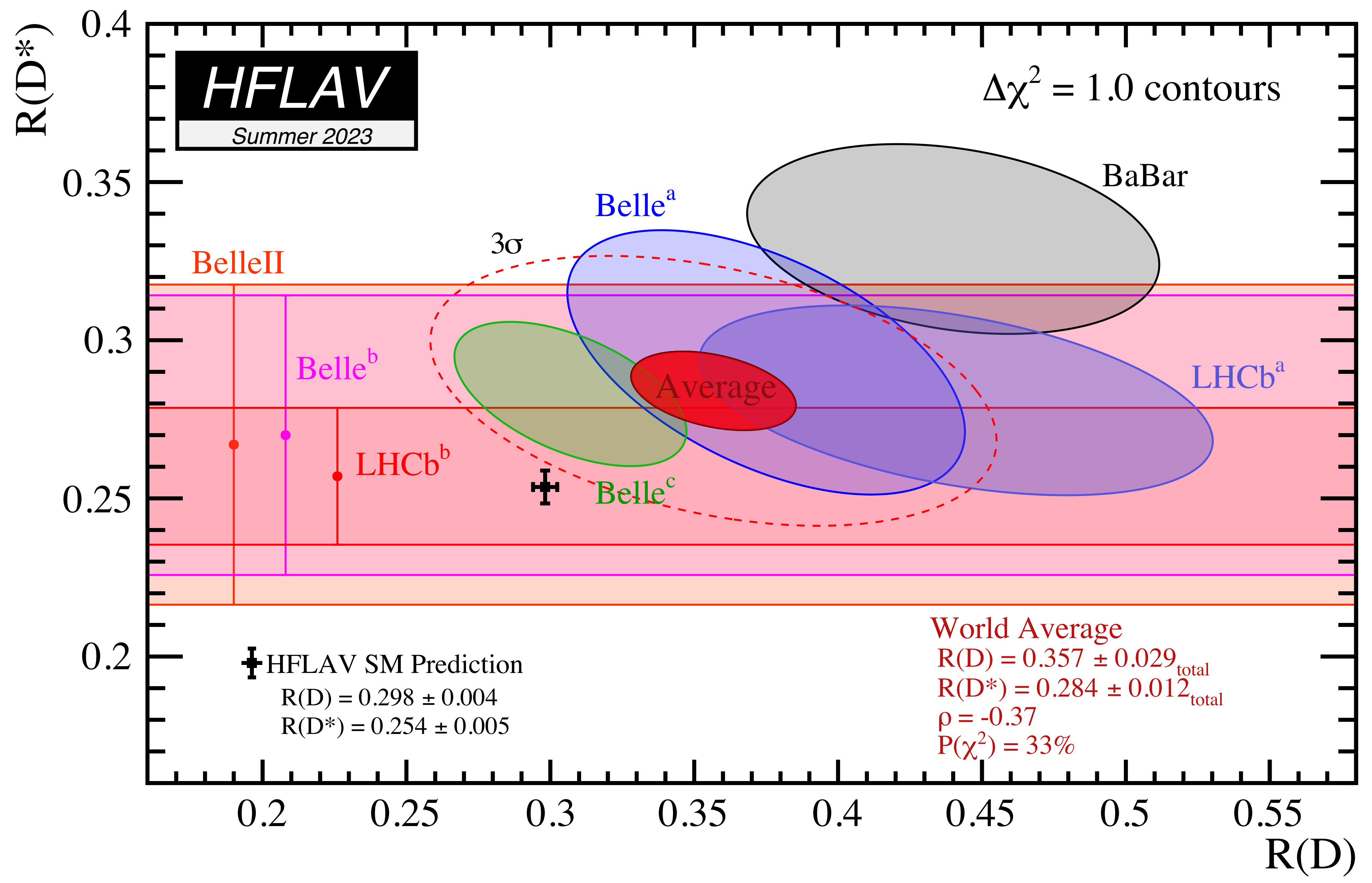


LFU test: $R(D^*)$

[arXiv:2401.02840] $189\ \mathrm{fb}^{-1}$ Belle II

- **First $R(D^*)$ measurement at Belle II** $R(D^{(*)}) = \dfrac{\mathcal{B}(\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^{(*)}\ell^-\overline{\nu}_\ell)}$,
- **Hadronic** B tagging
- Reconstructed only $\tau \to \ell\nu\nu$,
- Signal extraction from 2D fit:
  - Missing mass: $M^2_{\text{miss}} = (p_{e^+e^-} - p_{B_{tag}} - p_{D^*} - p_\ell)^2$
  - Extra energy on calorimeter $E^{\text{extra}}_{\text{ECL}}$
- Bkg validation on on multiple data sidebands

$$R(D^*) = 0.262\ ^{+0.041}_{-0.039}(\text{stat})\ ^{+0.035}_{-0.032}(\text{syst}),$$



40% precision improvement compared to Belle with the same luminosity

Compatible with SM

LFU test: $R(X_{\tau/\ell})$

[arXiv:2311.07248]

189 fb^{-1}

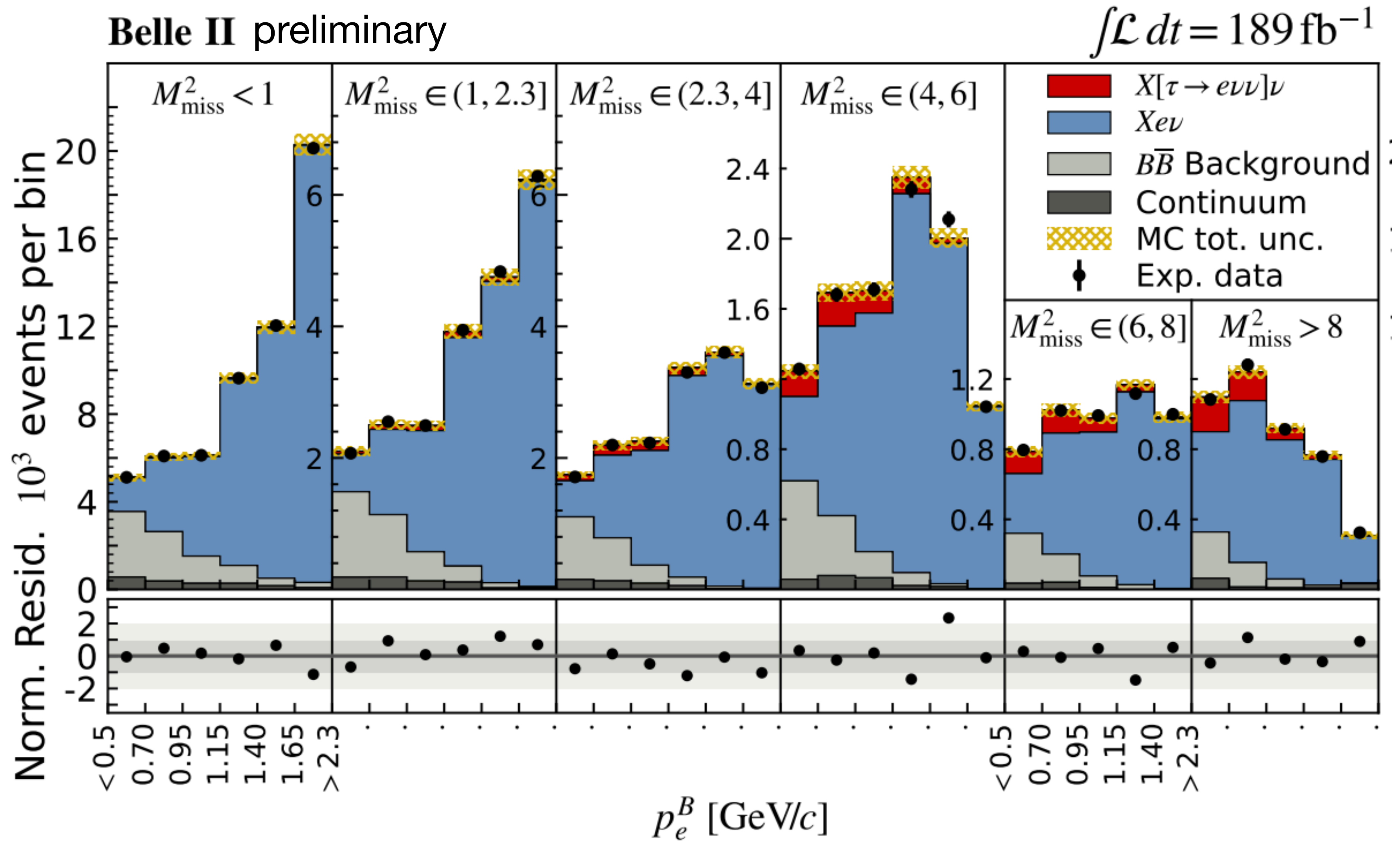
Belle II

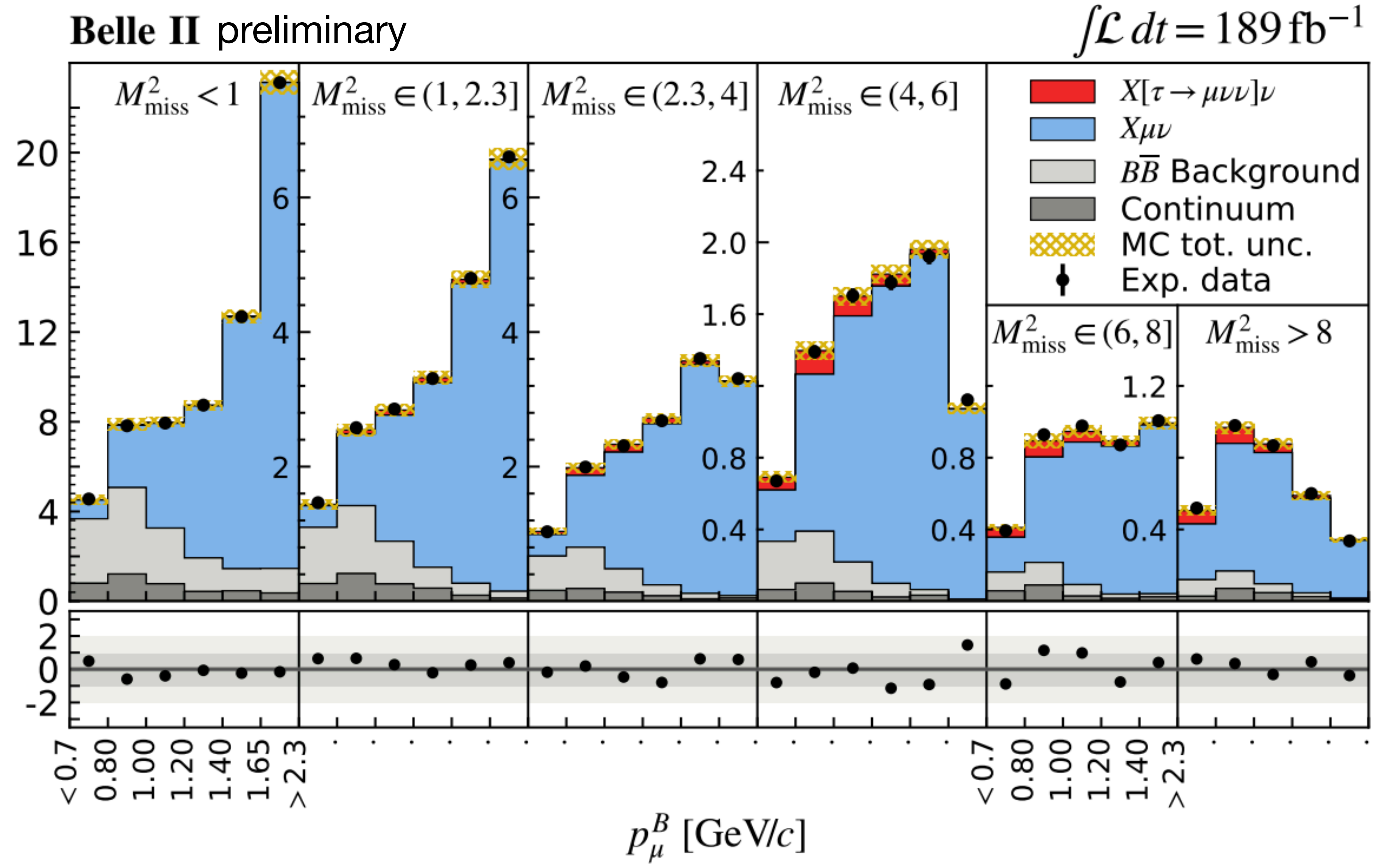
- The measurement of $R(X_{\tau/\ell}) \equiv \mathcal{B}(B \to X\tau\nu)/\mathcal{B}(B \to X\ell\nu)$ is:
  - **complementary** test of flavour universality compared to $R(D^*)$, since is statistically and systematically distinct
  - **unique** to Belle II
- **Hadronic** B-tagging
- Reconstruction of $\tau \to \ell\nu\nu$ and considered X all the other particles in the final states
- Challenging **bkg contamination** ⇒ **data driven** subtraction using sidebands
- Signal extracted from a template fit of $(p_\ell^B, M_{\text{miss}}^2)$ with templates from $X\tau\nu$, $X\ell\nu$, $B\overline{B}$ bkg, $q\overline{q}$ bkg (constrained from off-resonance data)

$$R(X_{\tau/\ell}) = 0.228 \pm 0.016\ (\text{stat}) \pm 0.036\ (\text{syst})$$
$$R(X_{\tau/e}) = 0.232 \pm 0.020\ (\text{stat}) \pm 0.037\ (\text{syst})$$
$$R(X_{\tau/\mu}) = 0.222 \pm 0.027\ (\text{stat}) \pm 0.050\ (\text{syst})$$

Consistent with SM, previous measurement and w.a. $R(D^*)$

[JHEP, 11,7 (2022)]





- Limited by MC sample size, PDF shape and bkg BF systematics

Conclusions

- Shown several analysis which are fully exploiting the available samples before Run 2:
  - **Belle II Run 1 sample** (362 fb^{-1})
  - **Combined Belle+Belle II sample** (~1ab^{-1})
- $\sin 2\beta^{\text{eff}}$ from gluonic and radiative penguins produces competitive results, exploiting Belle II unique channels (like $B^0 \to \eta' K_S^0$, $B^0 \to K_S^0 \pi^0 \gamma$)
- We are constantly improving the B **decay knowledge** (like $B^+ \to D^0 \rho$), also **observing new decay** channels (like $B \to D^{(*)} K^- K_{(S)}^{(*)0}$ and $B \to \omega\omega$)
- Strong push to investigate **FCNC**s:
  - several new **world best upper limits** in $b \to d$ transitions ($B \to h\ell\ell$), or best BFs in $b \to d\gamma$ ($B \to \rho\gamma$)
  - **Evidence** of $B \to K^+ \nu \bar{\nu}$, **2.7σ above the SM**

- **LFU test effort** is ramping up exploiting unique channels ($R(X_{\tau\ell})$) or contributing to the known one $R(D^*)$

Data taking just resumed, with upgraded detector and collider: more luminosity is coming!

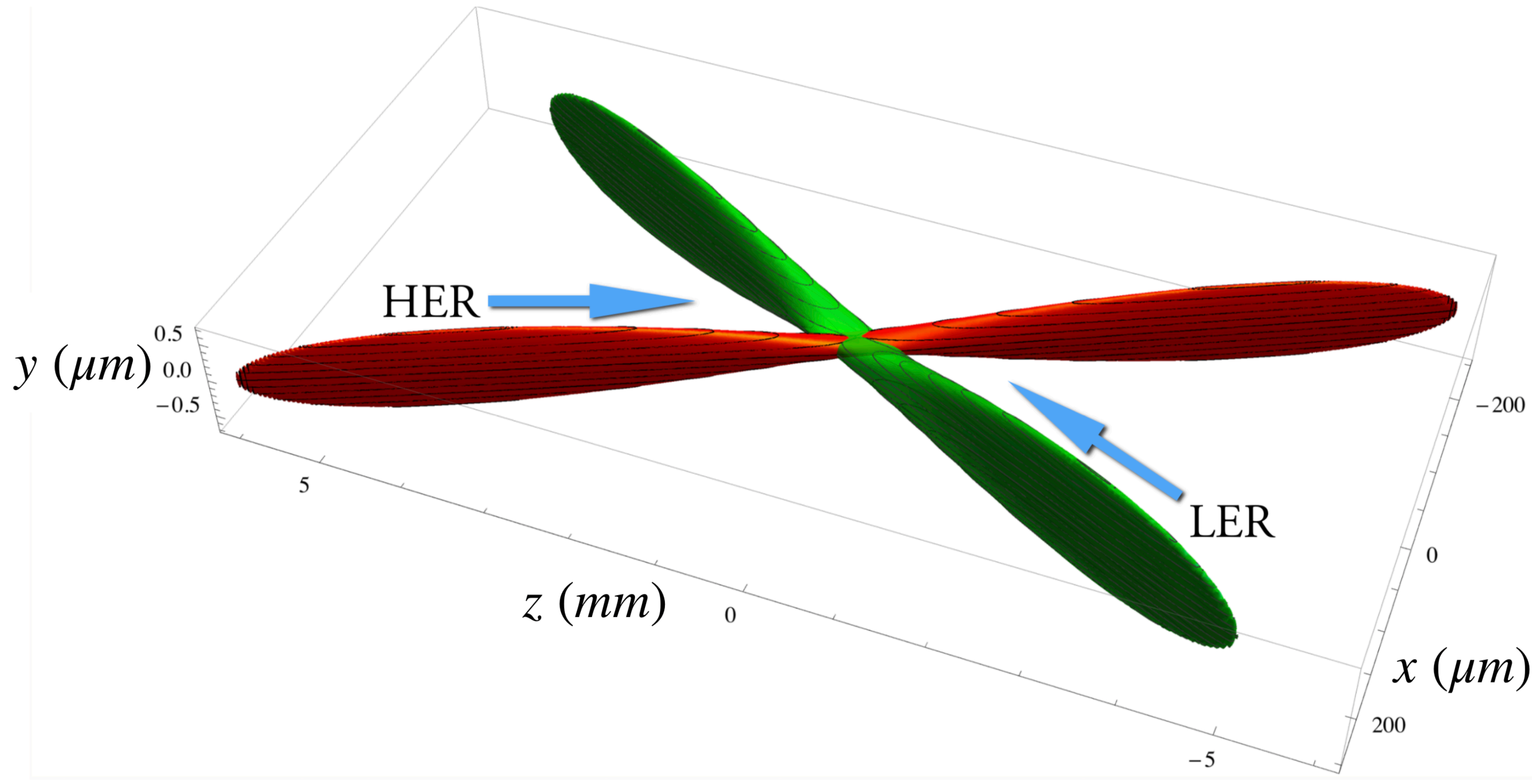
Thank you for your attention!

BACKUP SLIDES

Belle II experiment at SuperKEKB collider

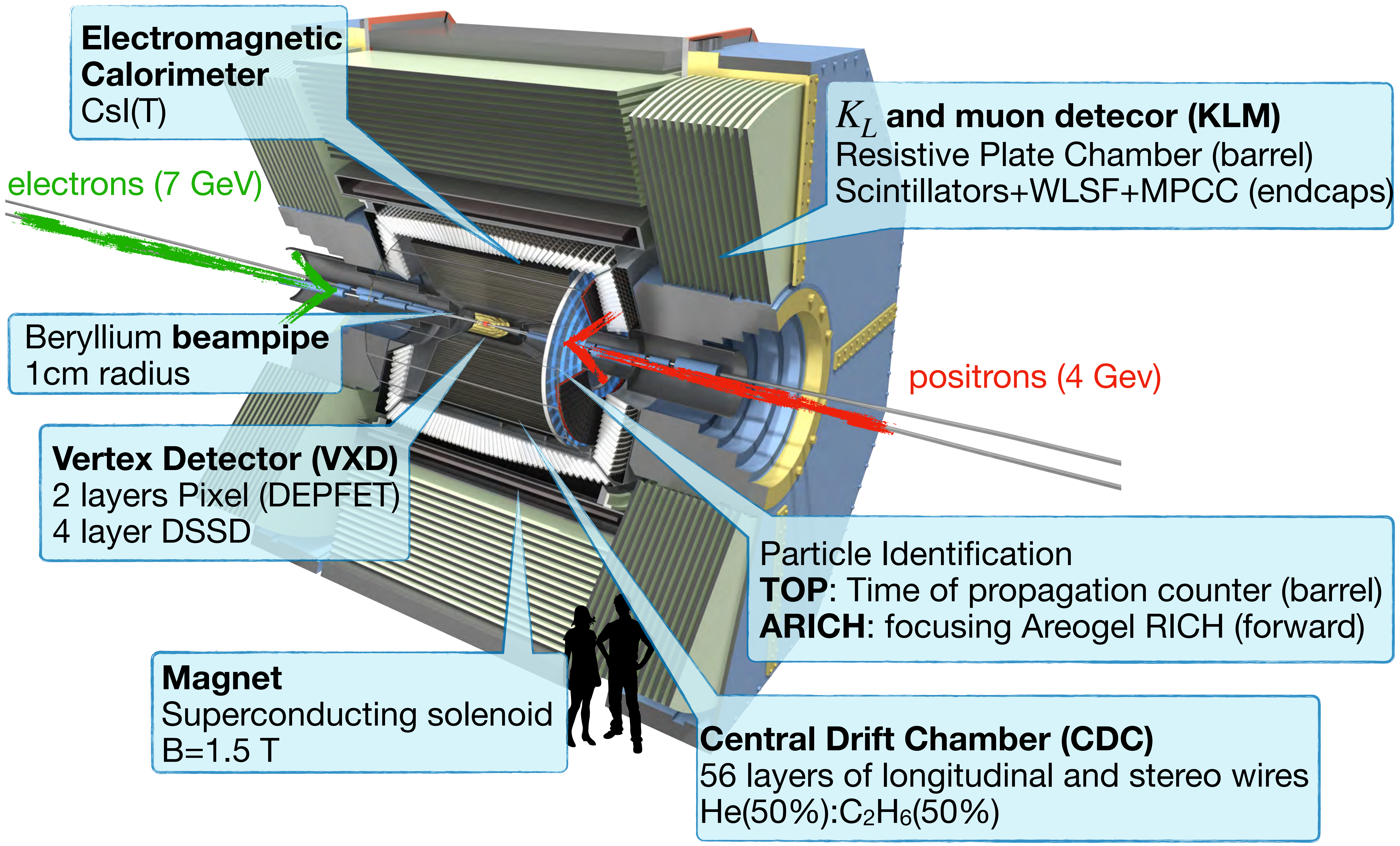
SuperKEKB

- Successor of KEKB (1999-2010, KEK, Japan)
- Asymmetric e^+e^- collider:
  - $\beta\gamma = 0.28\ (\Delta z_B \approx 128\ \mu\mathrm{m})$
  - $\sqrt{s} = m(\Upsilon(4S)) = 10.58\ \mathrm{GeV}$
- Target peak luminosity: $\mathbf{6 \cdot 10^{35}\ cm^{-2}s^{-1}}$ (x 30 of KEKB)



Nano-beam scheme:
$250\,\mu\mathrm{m}\,(Z) \times 10\,\mu\mathrm{m}\,(X) \times 50\,\mathrm{nm}\,(Y)$

Belle II



[Belle II Technical Design Report, arXiv:1011.0352]

Long shutdown 1 plans

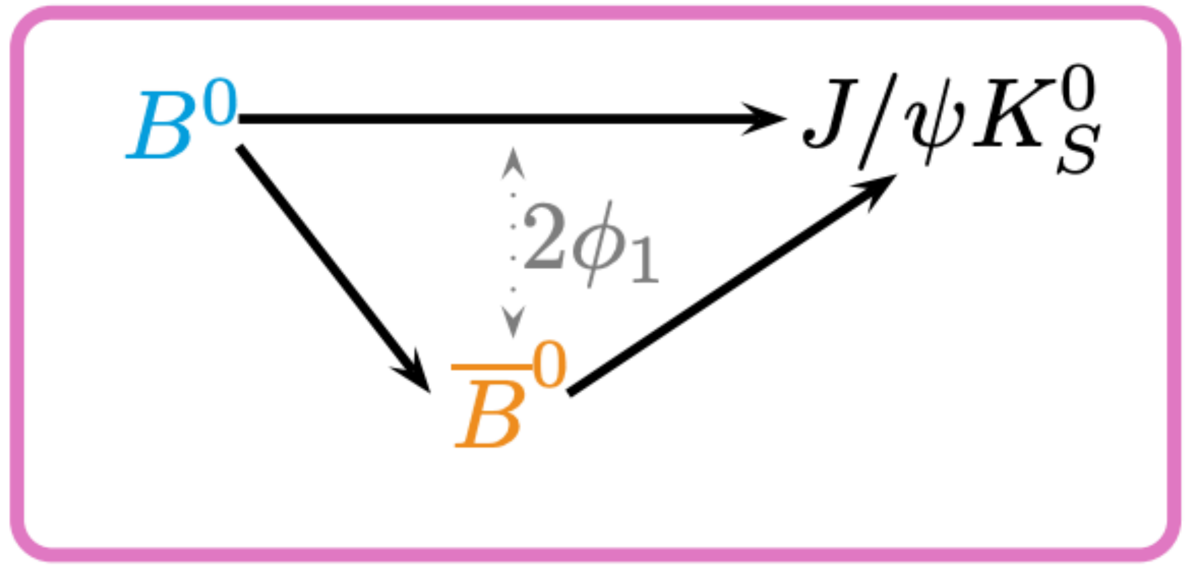
Long shutdown 1 (LS1): data-taking sopped in July 2022

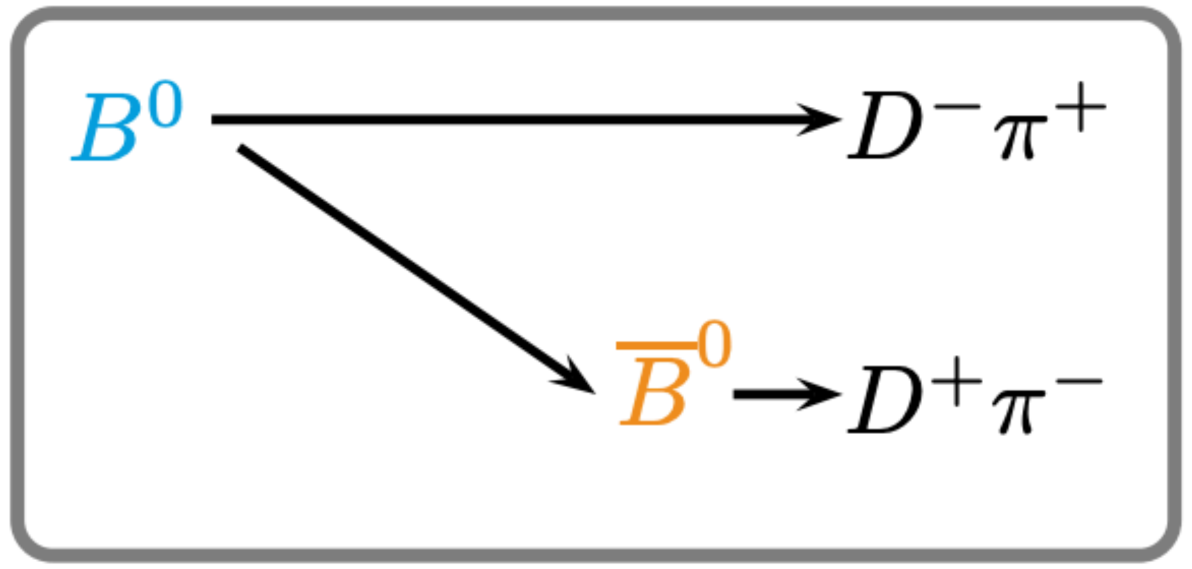
Data taking restated in February 2024!

LS1 activities:

- replacement of the **beam-pipe**
- replacement of PMT of central PID detector (**TOP**)
- installation of 2-layer of **pixel detector**
  - shipped to KEK mid-March
  - final test scheduled in April
- improvement of data-quality monitoring and alarm system
- complete transition to new DAQ boards (PCle40)
- replacement of aging components
- additional shielding against beam backgrounds
- accelerator improvements: injection, non linear-collimators, monitoring

Time-Dependent CPV analysis scheme





CP-asymmetry in interference between mixing and decay:

$$\mathcal{A}_{\rm CP}(t) = \frac{N(B^0 \to f_{\rm CP}) - N(\overline{B}^0 \to f_{\rm CP})}{N(B^0 \to f_{\rm CP}) + N(\overline{B}^0 \to f_{\rm CP})}(t) = (\mathcal{S}_{\rm CP} \sin(\Delta m_d t) + \mathcal{A}_{\rm CP} \cos(\Delta m_d t))$$

with $\mathcal{S}_{\rm CP}$: time-dependent asymmetry and $\mathcal{A}_{\rm CP}$: direct *CP*-asymmetry.

B^0-$\overline{B}^0$ mixing:

$$\text{mix}(t) = \frac{N(B^0 \to B^0) - N(B^0 \to \overline{B}^0)}{N(B^0 \to B^0) + N(B^0 \to \overline{B}^0)}(t) = \cos(\Delta m_d t)$$

with Δm_d the oscillation frequency.

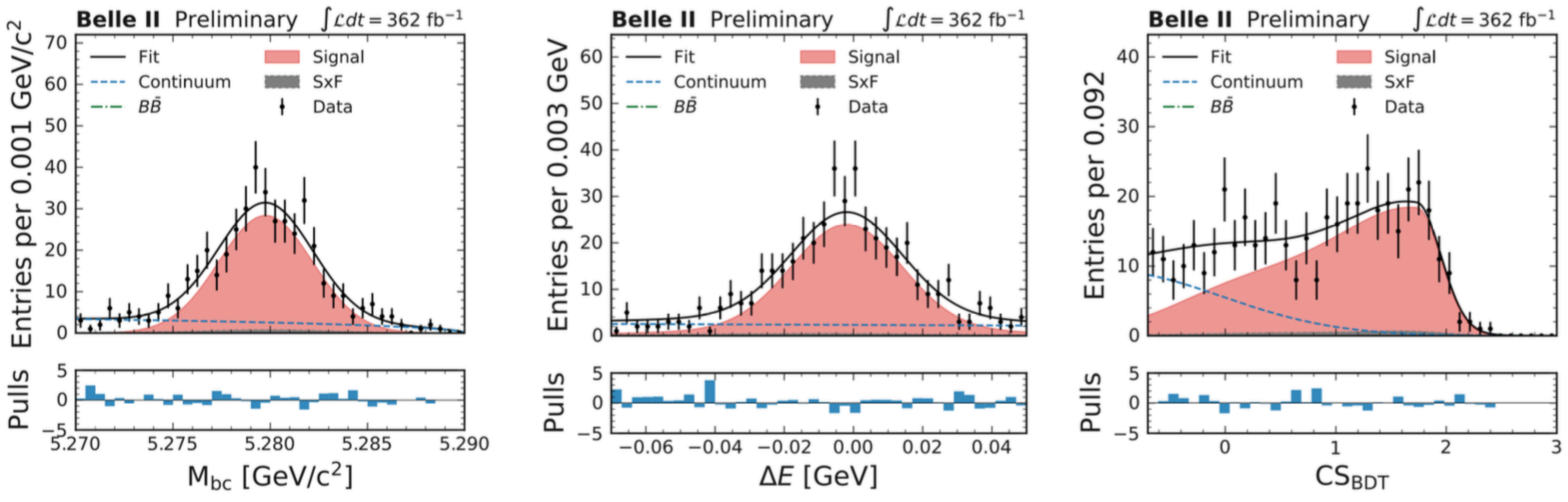
[From Thibaud Humair, Moriond EW 22]

$B^0 \to \eta' K_S^0$: extra info

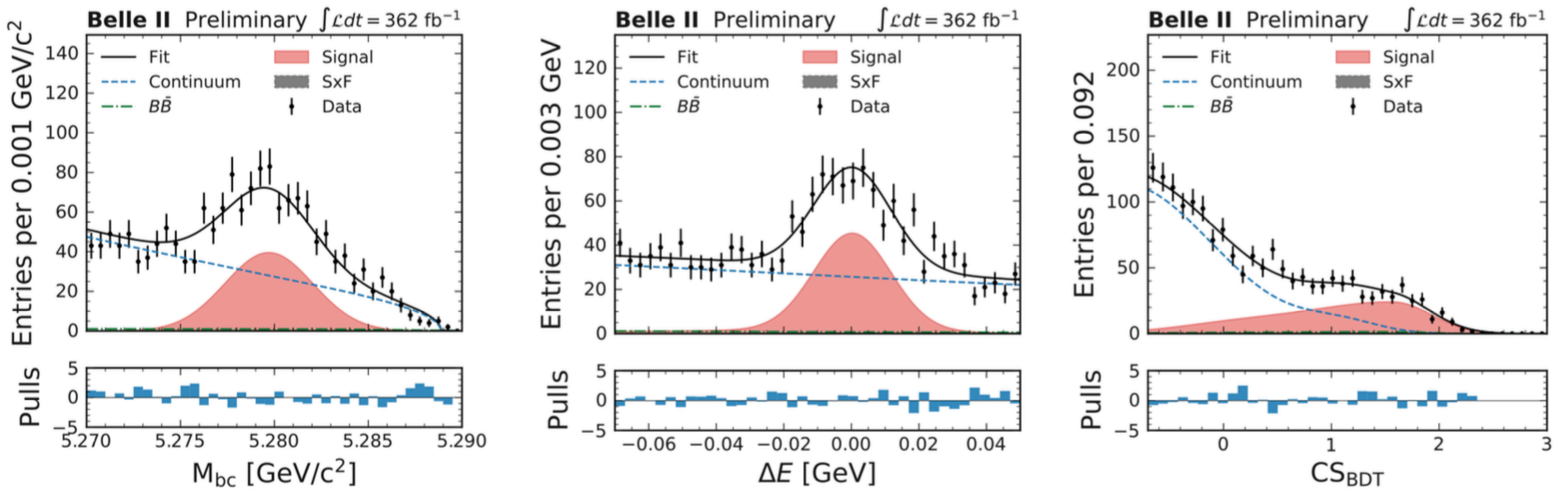
[arXiv:2402.03713] $362\ \text{fb}^{-1}$

Belle II

$\eta' \to \eta(\to \gamma\gamma)\pi^+\pi^-$ (358 events)



$\eta' \to \rho(\to \pi^+\pi^-)\gamma$ (471 events)

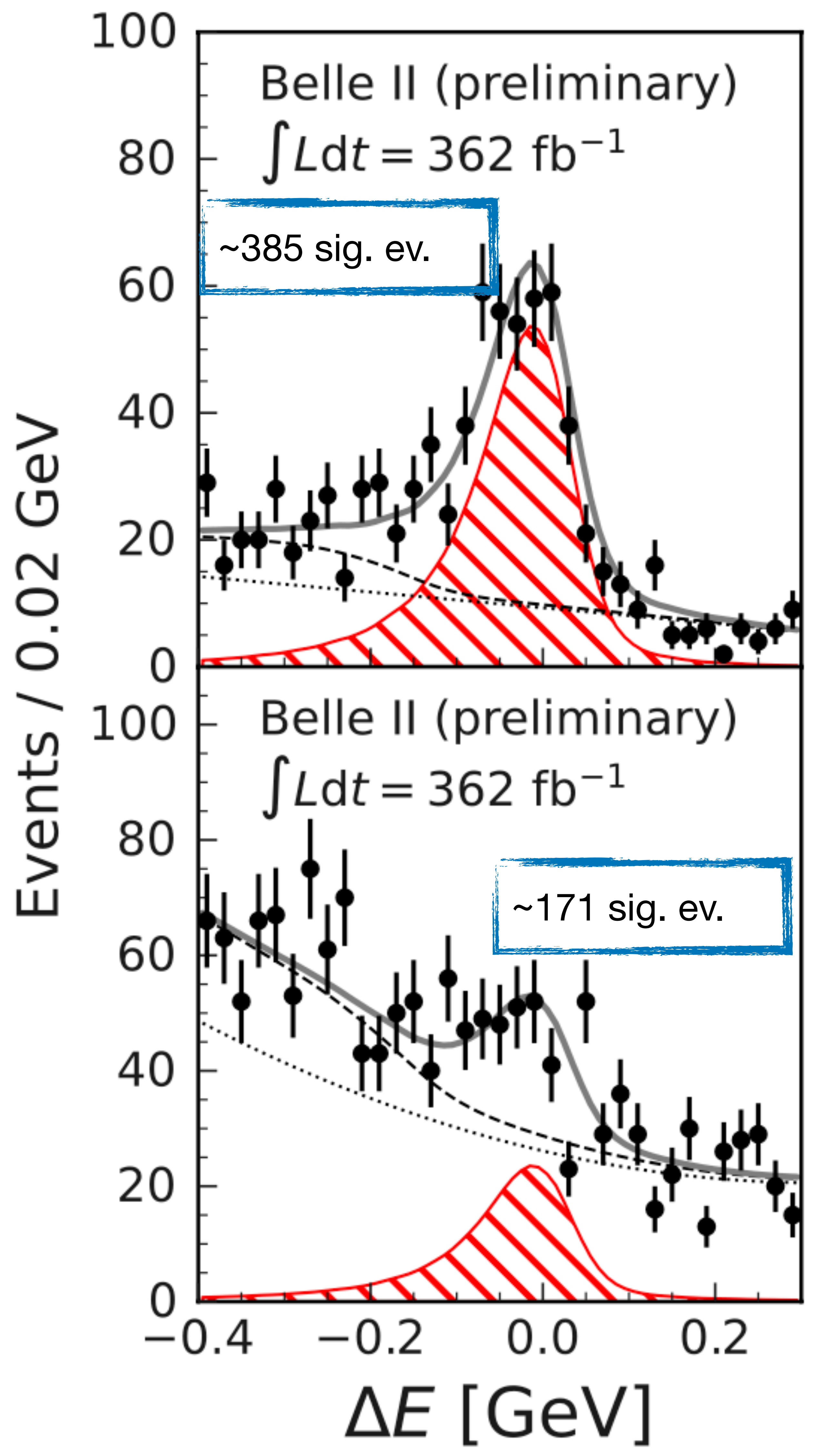


- Systematic uncertainties:

Source	$C_{\eta' K_S^0}$	$S_{\eta' K_S^0}$
Signal and continuum yields	< 0.001	0.002
SxF and $B\bar{B}$ yields	< 0.001	0.006
C_{BDT} mismodeling	0.004	0.010
Signal and background modeling	0.020	0.014
Observable correlations	0.008	0.001
Δt resolution fixed parameters	0.005	0.009
Δt resolution model	0.004	0.019
Flavor tagging	0.007	0.004
τ_{B^0} and Δm_d	< 0.001	0.002
Fit bias	0.003	0.002
Tracker misalignment	0.004	0.006
Momentum scale	0.001	0.001
Beam spot	0.002	0.002
B-meson motion in the $\Upsilon(4S)$ frame	< 0.001	0.017
Tag-side interference	0.005	0.011
$B\bar{B}$ background asymmetry	0.008	0.006
Candidate selection	0.007	0.009
Total	0.027	0.037

$B^0 \to K_S^0\pi^0\gamma$: extra info

362 fb^{-1} Belle II



Systematic uncertainties

	$K^{*0}\gamma$		$K_S^0\pi^0\gamma$	
Source	S	C	S	C
E and p scales	±0.017	±0.015	±0.083	±0.047
Vertex measurement	±0.021	±0.009	±0.023	±0.036
Flavor tagging	±0.005	$^{+0.012}_{-0.009}$	±0.008	$^{+0.013}_{-0.009}$
Event-by-event fractions	±0.003	$^{+0.004}_{-0.003}$	±0.032	±0.013
Resolution functions	±0.014	±0.009	±0.032	±0.013
Physics parameters	< 0.001	< 0.001	±0.003	< 0.001
$B\bar{B}$ asymmetries	$^{+0.010}_{-0.021}$	±0.022	$^{+0.023}_{-0.015}$	$^{+0.032}_{-0.033}$
Tag-side interference	< 0.001	-0.002	$+0.001$	$+0.001$
Total	$^{+0.033}_{-0.037}$	$^{+0.032}_{-0.031}$	$^{+0.100}_{-0.098}$	$^{+0.071}_{-0.070}$

Top plots: $B^0 \to K^{*0}\gamma,\ 0.8\,\text{GeV} < m(K_S^0\pi^0) < 1\,\text{GeV}$
Bottom plots: $B^0 \to$ non-$K^{*0}\gamma$, excluding above mass region

$B^+ \to D^0\rho(770)^+$: extra info

$362\ \mathrm{fb}^{-1}$ Belle II

Systematic uncertainties

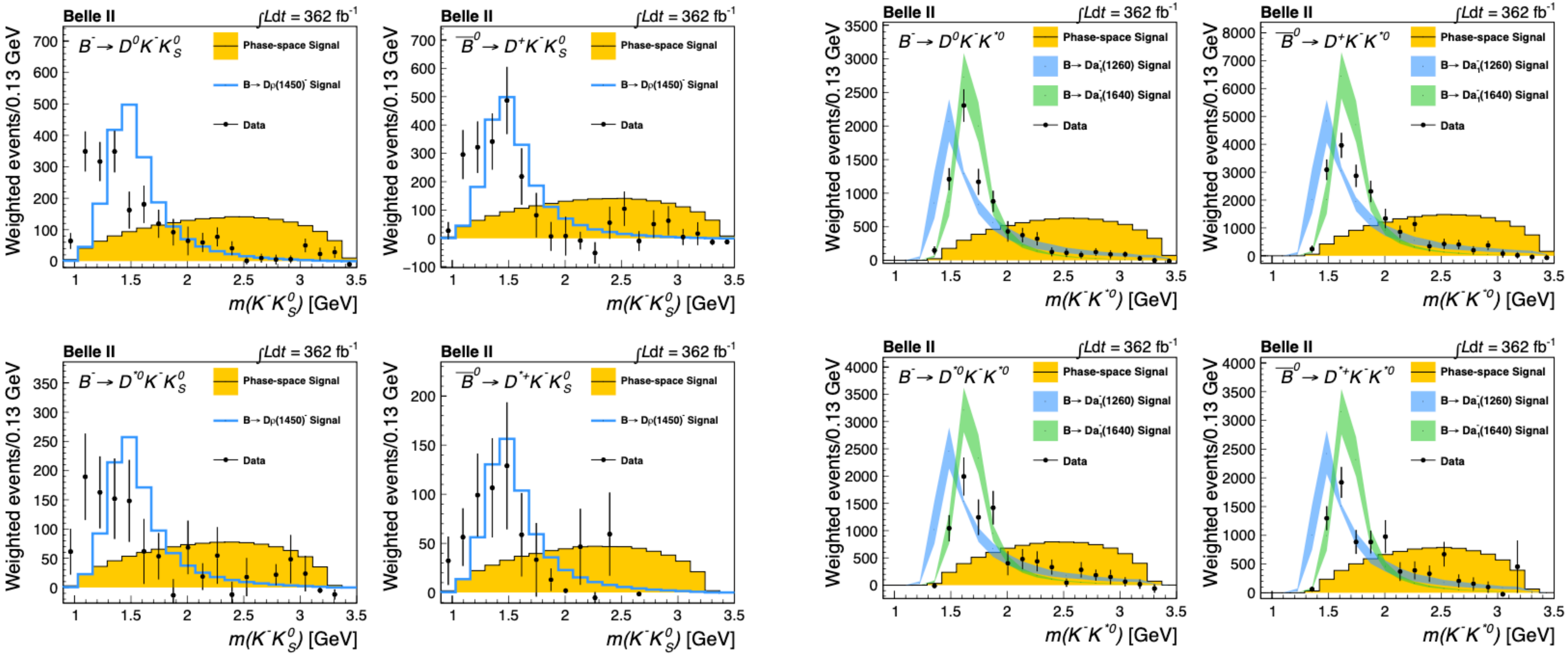
Source	Relative uncertainty (%)
$N_{B\bar{B}}$	1.5
f^{+-}	2.4
$\mathcal{B}_{\mathrm{sub}}$	0.8
Fit modelling	1.7
π^0 efficiency	3.7
Particle-identification efficiency	0.6
Continuum-suppression efficiency	1.5
Tracking efficiency	0.7
Total	5.3

- data/MC ratio correction
- $D^{*+} \to D^0(\to K^-\pi^+\pi^0)\pi^+$ and $D^{*+} \to D^0(\to K^-\pi^+)\pi^+$
- as a function of momentum and polar angle of π^0

$B \to D^{(*)}K^-K^{(*)0}_{(S)}$ and $B \to D^{(*)}D_s^-$: extra info (1)

$362\ \text{fb}^{-1}$

bkg-subtracted and efficiency corrected $m(K^-K)$ distributions



$B \to D^{(*)}K^- K^{(*)0}_{(S)}$ and $B \to D^{(*)}D_s^-$: extra info (2)

$362\ \text{fb}^{-1}$

Belle II

Example of all the derived results for a single channel ($\bar{B}^0 \to D^+ K^- K^0_S$)

$B^0 \to \omega\omega$: extra info

711 fb^{-1}

BELLE

Fit variables:

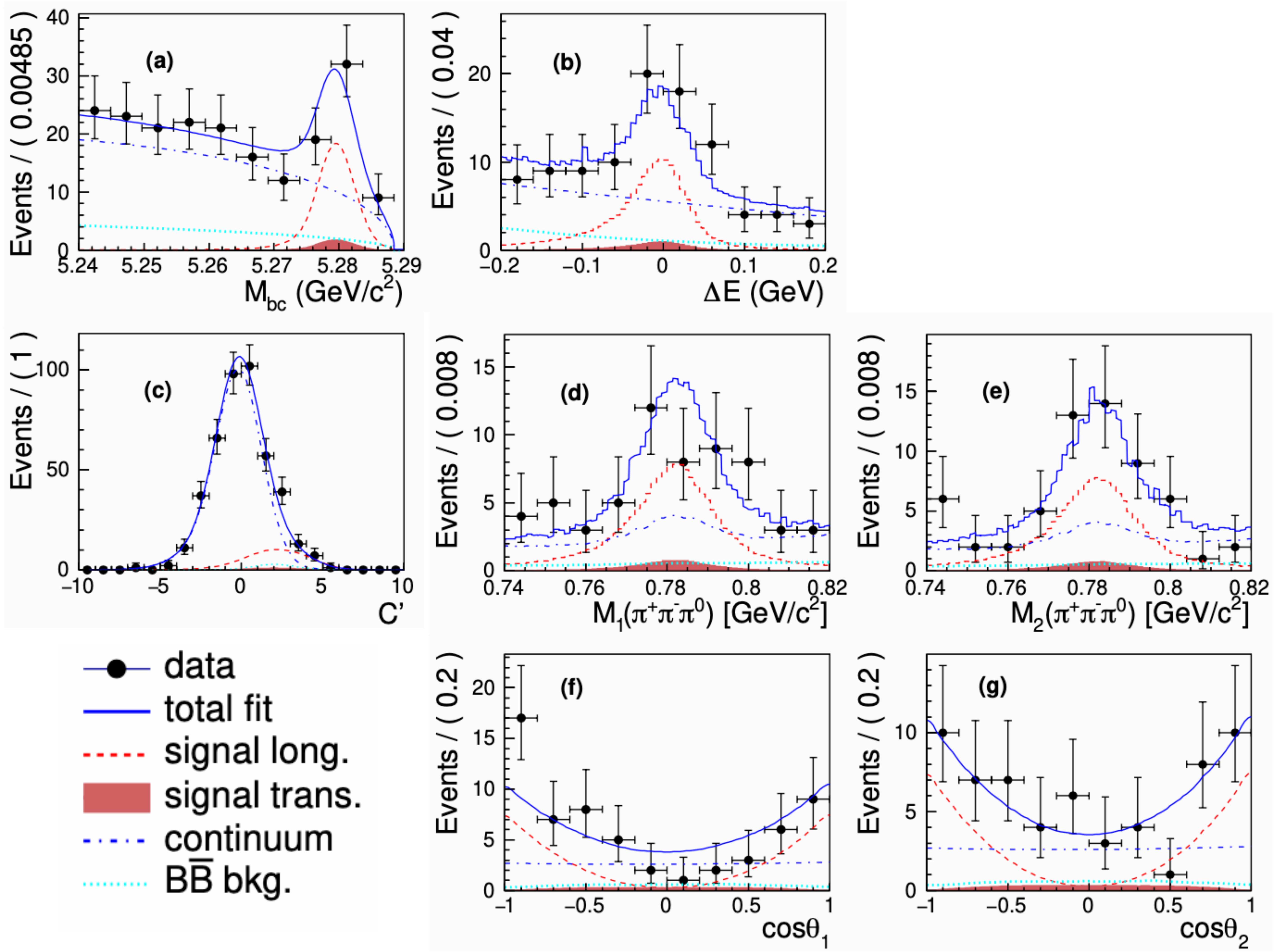


TABLE I. Systematic uncertainties on $\mathcal{B}$, f_L, and A_{CP}. Those listed in the upper part are additive and included in the significance calculation as discussed in the text. Those listed in the lower part are multiplicative.

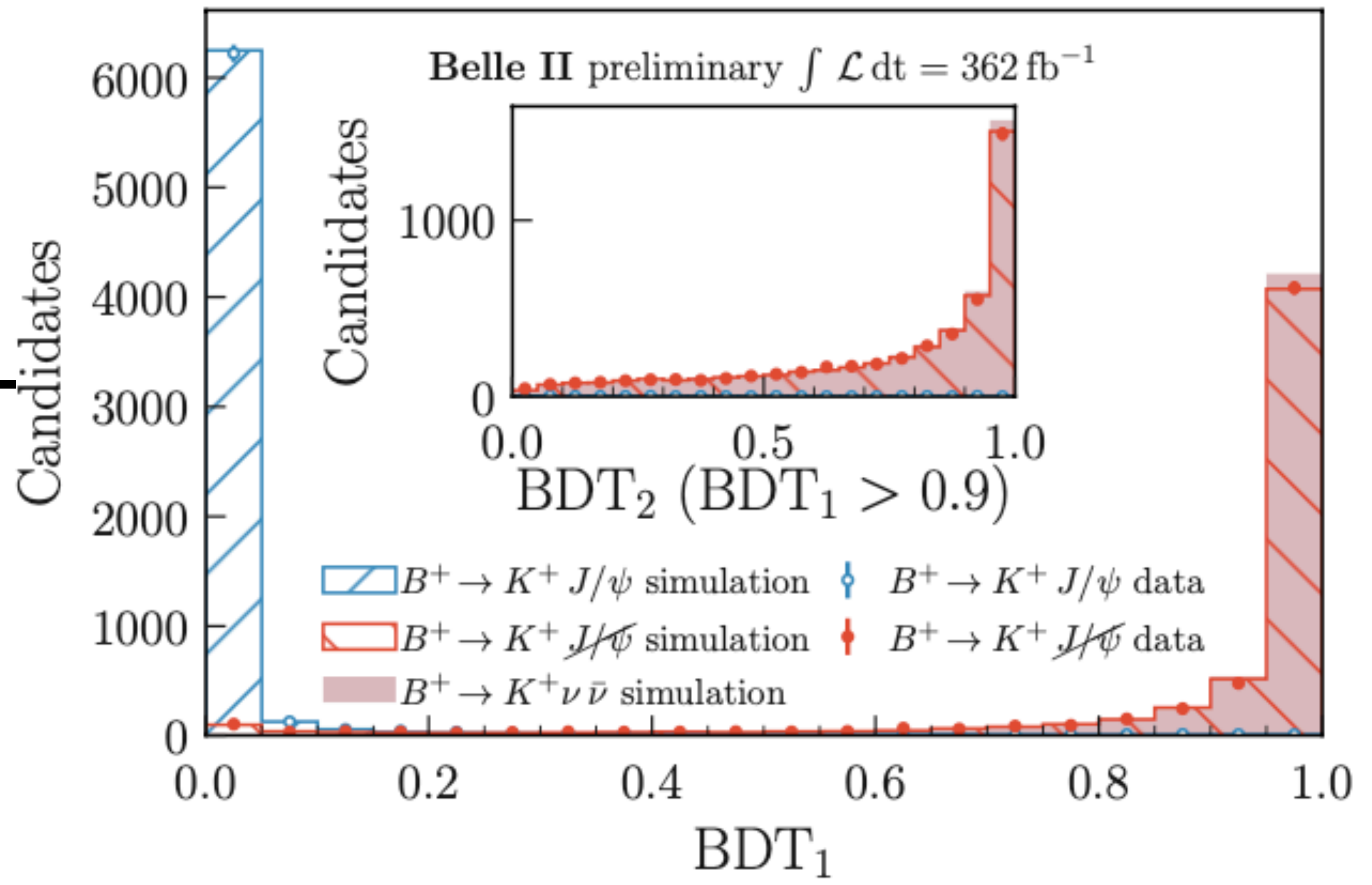
Source	$\mathcal{B}$ (%)	f_L	A_{CP}
Best candidate selection	3.0	0.07	0.04
Signal PDF	7.7	0.10	0.10
Fit bias	3.0	0.01	0.01
Background PDF	0.7	0.00	0.01
Tracking efficiency	1.4	0.00	0.00
π^0 efficiency	4.0	0.00	0.00
PID efficiency	3.5	0.00	0.00
Continuum suppression	2.4	–	–
Flavor mistagging	–	–	0.02
Detection asymmetry	–	–	0.01
$N_{B^0\overline{B}^0}$	2.8	–	–
$\mathcal{B}(\omega \to \pi^+\pi^-\pi^0) \times \mathcal{B}(\pi^0 \to \gamma\gamma)$	1.6	–	–
Total	11.4	0.13	0.11

$B^+ \to K^+\nu\bar{\nu}$: extra info (1)

[arXiv:2311.14647] 362 fb^{-1} Belle II

Dedicated bkg validations:

- $ee \to q\bar{q}$ bkg simulation validated with off-resonance (60 MeV below $\Upsilon(4S)$) data
- $B \to X_c(\to K_L^0 X)$ bkg validated with lepton- and pion-enriched control sidebands
- Undetected K_L^0 validated with $e^+e^- \to \gamma\phi(\to K_L^0 K_S^0)$
- $B \to K^+K^0K^0$ bkg simulation constrained with previous measurements ($B \to K^+K_S^0K_S^0$, $B \to K^+K^-K_S^0$)

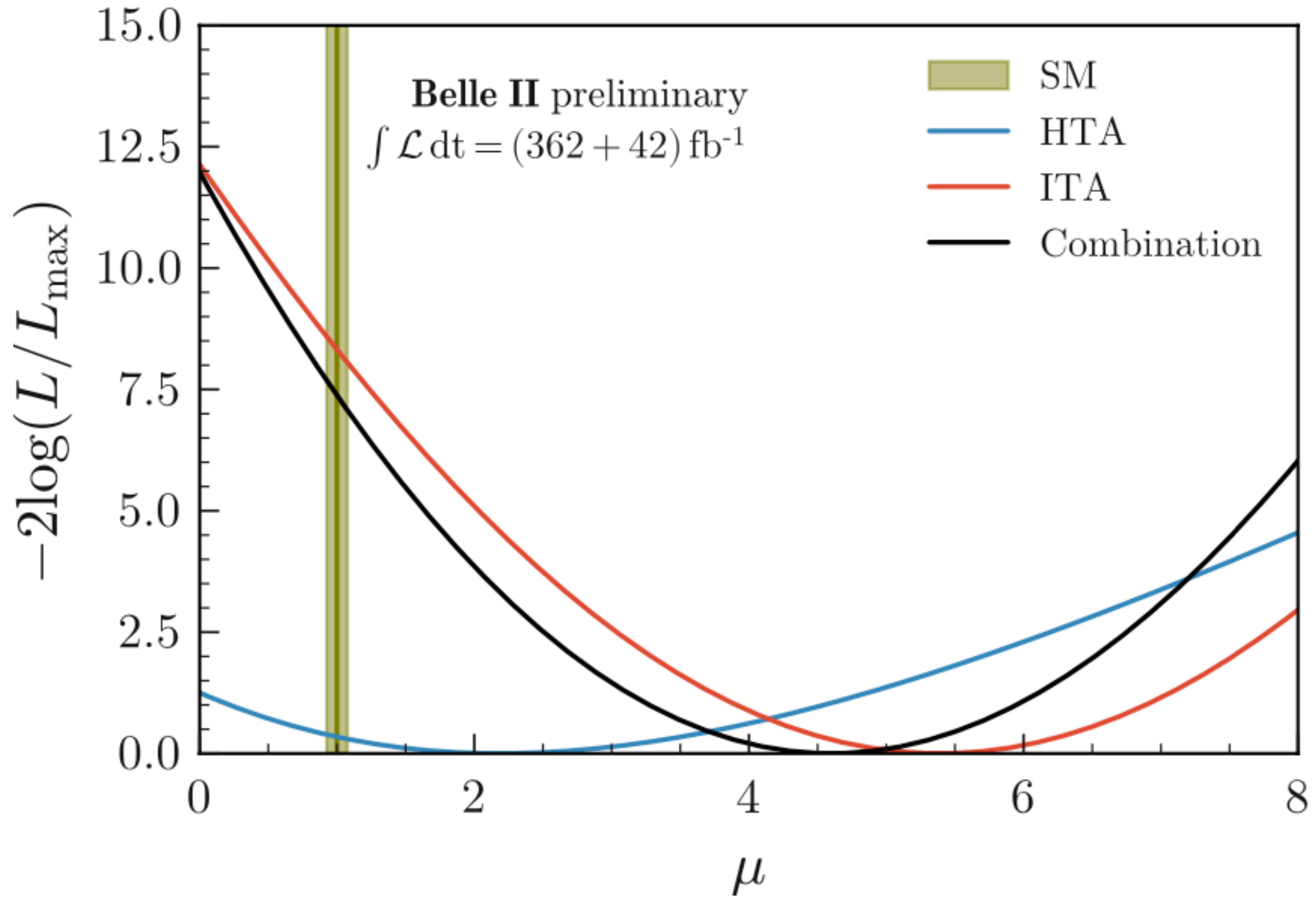


$B^+ \to K^+ \nu\bar{\nu}$: extra info (2)

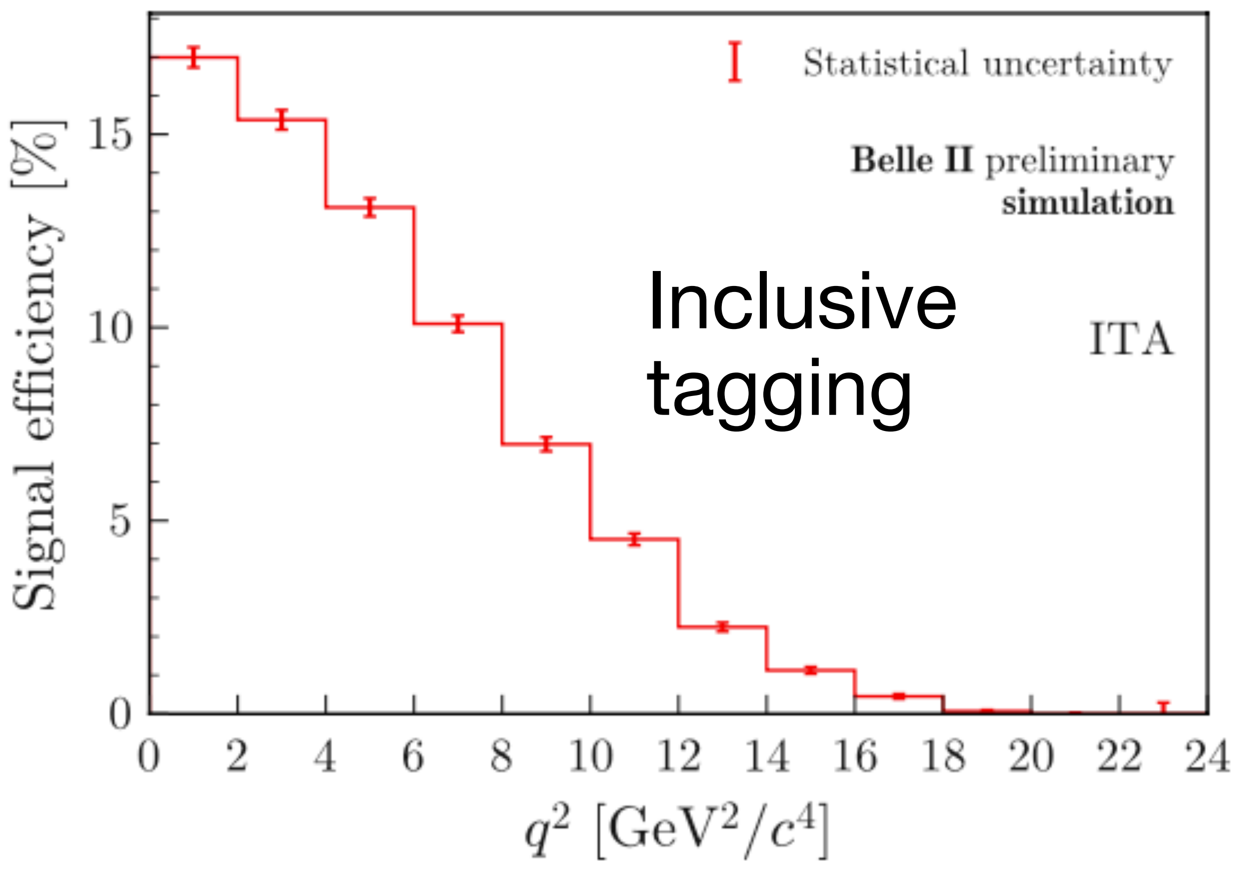
[arXiv:2311.14647] $362\ \text{fb}^{-1}$

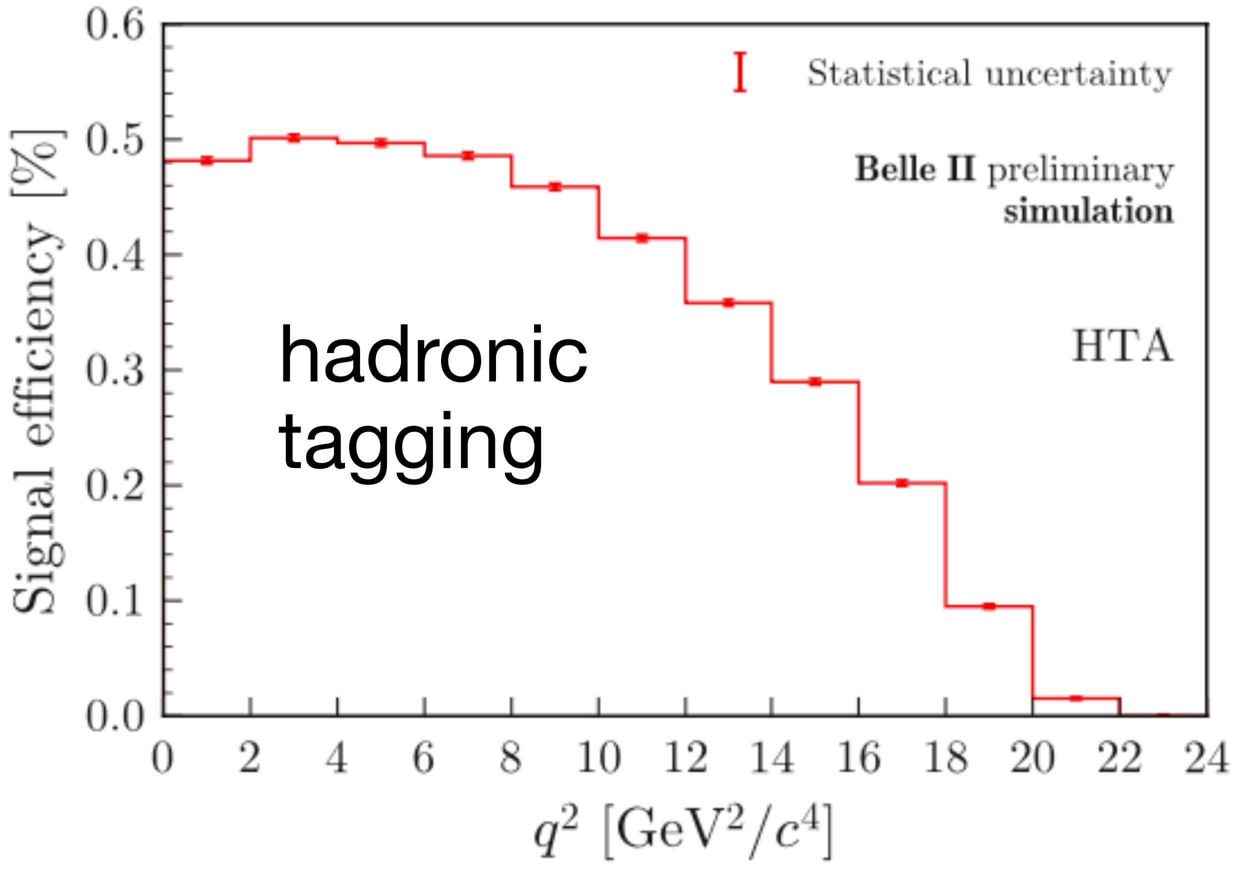
Combination:

- profile likelihood fit
- including correlation in syst
- Excluding common events from inclusive tagging fit



Efficiency:





Results separated in the two tagging approaches:

- **Hadronic tag:** $\mu = 2.2^{+1.8}_{-1.7}\,{}^{+1.6}_{-1.1}$, $\text{BF} = (1.1^{+0.9}_{-0.8}\,{}^{+0.8}_{-0.5}) \times 10^{-5}$ 1.1σ above bkg only, 0.6σ above SM
- **Inclusive tag:** $\mu = 5.4 \pm 1.0 \pm 1.1$, $\text{BF} = (2.7 \pm 0.5 \pm 0.5) \times 10^{-5}$, 3.5σ above bkg only, 2.9σ above SM

$B^+ \to K^+\nu\bar{\nu}$: extra info (3)

[arXiv:2311.14647] 362 fb^{-1} Belle II

Systematics inclusive tagging

Source	Correction	Uncertainty type, parameters	Uncertainty size	Impact on σ_μ
Normalization of $B\bar{B}$ background	—	Global, 2	50%	0.90
Normalization of continuum background	—	Global, 5	50%	0.10
Leading B-decay branching fractions	—	Shape, 5	$O(1\%)$	0.22
Branching fraction for $B^+ \to K^+K^0_L K^0_L$	q^2 dependent $O(100\%)$	Shape, 1	20%	0.49
p-wave component for $B^+ \to K^+K^0_S K^0_L$	q^2 dependent $O(100\%)$	Shape, 1	30%	0.02
Branching fraction for $B \to D^{**}$	—	Shape, 1	50%	0.42
Branching fraction for $B^+ \to K^+n\bar{n}$	q^2 dependent $O(100\%)$	Shape, 1	100%	0.20
Branching fraction for $D \to K^0_L X$	+30%	Shape, 1	10%	0.14
Continuum-background modeling, BDT$_c$	Multivariate $O(10\%)$	Shape, 1	100% of correction	0.01
Integrated luminosity	—	Global, 1	1%	< 0.01
Number of $B\bar{B}$	—	Global, 1	1.5%	0.02
Off-resonance sample normalization	—	Global, 1	5%	0.05
Track-finding efficiency	—	Shape, 1	0.3%	0.20
Signal-kaon PID	p, θ dependent $O(10-100\%)$	Shape, 7	$O(1\%)$	0.07
Photon energy	—	Shape, 1	0.5%	0.08
Hadronic energy	−10%	Shape, 1	10%	0.37
K^0_L efficiency in ECL	−17%	Shape, 1	8%	0.22
Signal SM form-factors	q^2 dependent $O(1\%)$	Shape, 3	$O(1\%)$	0.02
Global signal efficiency	—	Global, 1	3%	0.03
Simulated-sample size	—	Shape, 156	$O(1\%)$	0.52

Systematics hadronic tagging

Source	Correction	Uncertainty type, parameters	Uncertainty size	Impact on σ_μ
Normalization of $B\bar{B}$ background	—	Global, 1	30%	0.91
Normalization of continuum background	—	Global, 2	50%	0.58
Leading B-decay branching fractions	—	Shape, 3	$O(1\%)$	0.10
Branching fraction for $B^+ \to K^+K^0_L K^0_L$	q^2 dependent $O(100\%)$	Shape, 1	20%	0.20
Branching fraction for $B \to D^{**}$	—	Shape, 1	50%	< 0.01
Branching fraction for $B^+ \to K^+n\bar{n}$	q^2 dependent $O(100\%)$	Shape, 1	100%	0.05
Branching fraction for $D \to K^0_L X$	+30%	Shape, 1	10%	0.03
Continuum-background modeling, BDT$_c$	Multivariate $O(10\%)$	Shape, 1	100% of correction	0.29
Number of $B\bar{B}$	—	Global, 1	1.5%	0.07
Track finding efficiency	—	Global, 1	0.3%	0.01
Signal-kaon PID	p, θ dependent $O(10-100\%)$	Shape, 3	$O(1\%)$	< 0.01
Extra-photon multiplicity	$n_{\gamma\mathrm{extra}}$ dependent $O(20\%)$	Shape, 1	$O(20\%)$	0.61
K^0_L efficiency	—	Shape, 1	17%	0.31
Signal SM form-factors	q^2 dependent $O(1\%)$	Shape, 3	$O(1\%)$	0.06
Signal efficiency	—	Shape, 6	16%	0.42
Simulated-sample size	—	Shape, 18	$O(1\%)$	0.60

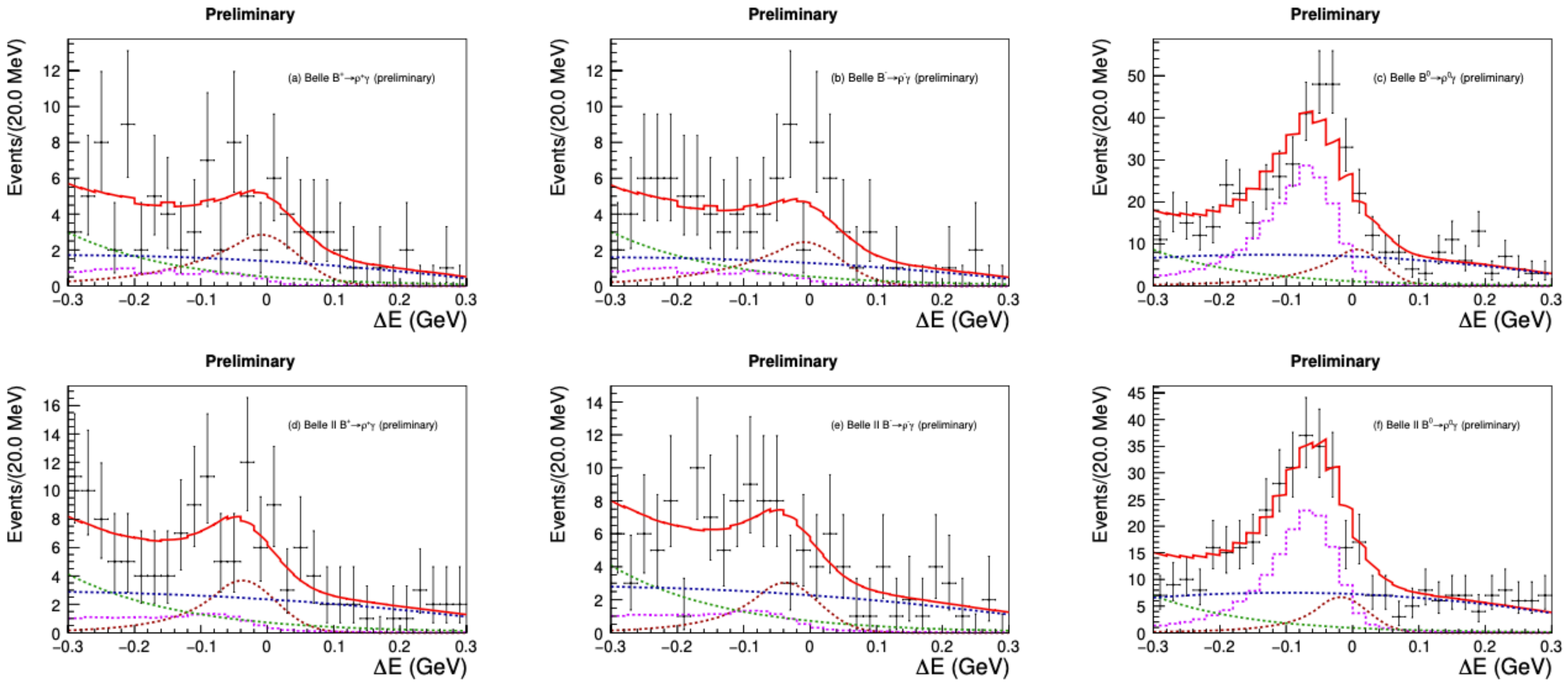
$B \to \rho\gamma$: extra info

$362\ \text{fb}^{-1}$ Belle II

$711\ \text{fb}^{-1}$ BELLE

Yields and efficiencies

Mode	ϵ [%]	N_S	$N_{q\bar{q}}$
Belle $B^+ \to \rho^+\gamma$	5.5 ± 0.5	19.7 ± 4.0	14.0 ± 0.7
Belle $B^- \to \rho^-\gamma$	5.5 ± 0.5	16.7 ± 3.8	12.9 ± 0.7
Belle $B^0 \to \rho^0\gamma$	10.3 ± 0.4	41.7 ± 7.2	53.8 ± 1.6
Belle II $B^+ \to \rho^+\gamma$	11.0 ± 1.1	20.7 ± 4.2	23.3 ± 1.1
Belle II $B^- \to \rho^-\gamma$	11.0 ± 1.1	17.6 ± 4.0	23.1 ± 1.1
Belle II $B^0 \to \rho^0\gamma$	14.9 ± 0.5	31.1 ± 5.4	55.9 ± 1.8



Systematics

Source	$\mathcal{B}_{\rho^+\gamma} \times 10^8$	$\mathcal{B}_{\rho^0\gamma} \times 10^8$	A_I	A_{CP}
Reconstruction	4.1	1.3	1.4%	0.5%
Selection	9.0	3.4	4.0%	0.5%
Fixed PDF	1.1	2.7	1.8%	0.2%
Signal shape	4.7	3.0	3.1%	0.5%
Histogram PDF	1.0	0.6	0.5%	0.1%
$K^*\gamma$ yield	3.4	5.4	3.1%	0.1%
$B\overline{B}$ peaking yield	2.2	0.8	0.9%	0.2%
$B\overline{B}$ peaking A_{CP}	0.1	0.0	0.1%	1.0%
Number of $B\overline{B}$'s	1.7	1.4	0.3%	0.1%
Other parameters	4.0	3.6	3.9%	0.0%
Total	12.5	8.6	7.5%	1.4%

$b \to d\ell^+\ell^-$: extra info

$711\ \text{fb}^{-1}$

BELLE

- Full list of limits

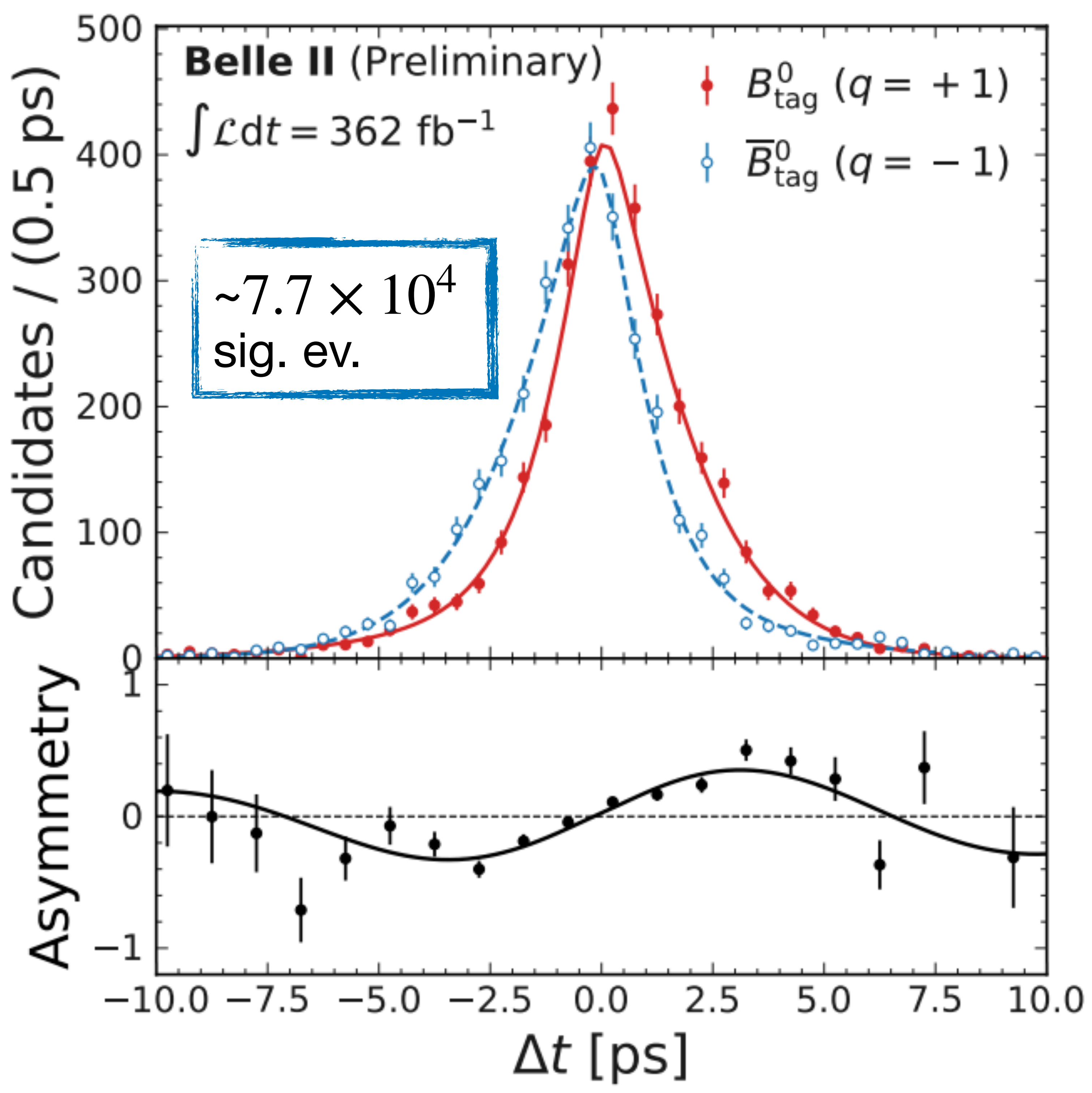
channel	N_{sig}	$N_{\text{sig}}^{\text{UL}}$	ε (%)	$\mathcal{B}^{\text{UL}}$ (10^{-8})	$\mathcal{B}$ (10^{-8})
$B^0 \to \eta e^+ e^-$	$0.0^{+1.4}_{-1.0}$	3.1	3.9	< 10.5	$0.0^{+4.9}_{-3.4} \pm 0.1$
$B^0 \to \eta \mu^+ \mu^-$	$0.8^{+1.5}_{-1.1}$	4.2	5.9	< 9.4	$1.9^{+3.4}_{-2.5} \pm 0.2$
$B^0 \to \eta \ell^+ \ell^-$	$0.5^{+1.0}_{-0.8}$	1.8	4.9	< 4.8	$1.3^{+2.8}_{-2.2} \pm 0.1$
$B^0 \to \omega e^+ e^-$	$-0.3^{+3.2}_{-2.5}$	3.7	1.6	< 30.7	$-2.1^{+26.5}_{-20.8} \pm 0.2$
$B^0 \to \omega \mu^+ \mu^-$	$1.7^{+2.3}_{-1.6}$	5.5	2.9	< 24.9	$7.7^{+10.8}_{-7.5} \pm 0.6$
$B^0 \to \omega \ell^+ \ell^-$	$1.0^{+1.8}_{-1.3}$	3.6	2.2	< 22.0	$6.4^{+10.7}_{-7.8} \pm 0.5$
$B^0 \to \pi^0 e^+ e^-$	$-2.9^{+1.8}_{-1.4}$	4.0	6.7	< 7.9	$-5.8^{+3.6}_{-2.8} \pm 0.5$
$B^0 \to \pi^0 \mu^+ \mu^-$	$-0.5^{+3.6}_{-2.7}$	6.1	13.7	< 5.9	$-0.4^{+3.5}_{-2.6} \pm 0.1$
$B^0 \to \pi^0 \ell^+ \ell^-$	$-1.8^{+1.6}_{-1.1}$	2.9	10.2	< 3.8	$-2.3^{+2.1}_{-1.5} \pm 0.2$
$B^+ \to \pi^+ e^+ e^-$	$0.1^{+2.5}_{-1.6}$	5.0	11.5	< 5.4	$0.1^{+2.7}_{-1.8} \pm 0.1$
$B^0 \to \rho^0 e^+ e^-$	$5.6^{+3.5}_{-2.7}$	10.8	3.2	< 45.5	$23.6^{+14.6}_{-11.2} \pm 1.1$
$B^+ \to \rho^+ e^+ e^-$	$-4.4^{+2.3}_{-2.0}$	5.3	1.4	< 46.7	$-38.2^{+24.5}_{-17.2} \pm 3.4$
$B^+ \to \rho^+ \mu^+ \mu^-$	$3.0^{+4.0}_{-3.0}$	8.7	2.9	< 38.1	$13.0^{+17.5}_{-13.3} \pm 1.1$
$B^+ \to \rho^+ \ell^+ \ell^-$	$0.4^{+2.3}_{-1.8}$	3.0	2.0	< 18.9	$2.5^{+14.6}_{-11.8} \pm 0.2$

$\sin 2\beta$ from $B^0 \to J/\psi K_S^0$ with GFlaT

[arxiv:2402.17260] $362\ \mathrm{fb}^{-1}$

Belle II

- **Reference** for measurement of β with gluonic penguins (next slide)
- **Clean**, **high yield**, channels to benchmark Belle II analysis performance
- **Validation** of GFlaT performance $\Rightarrow$ 8% reduction of statistical uncertainty



$$S = \quad 0.724 \pm 0.035 \pm 0.014,$$
$$C = -0.035 \pm 0.026 \pm 0.013,$$

Compatible with SM

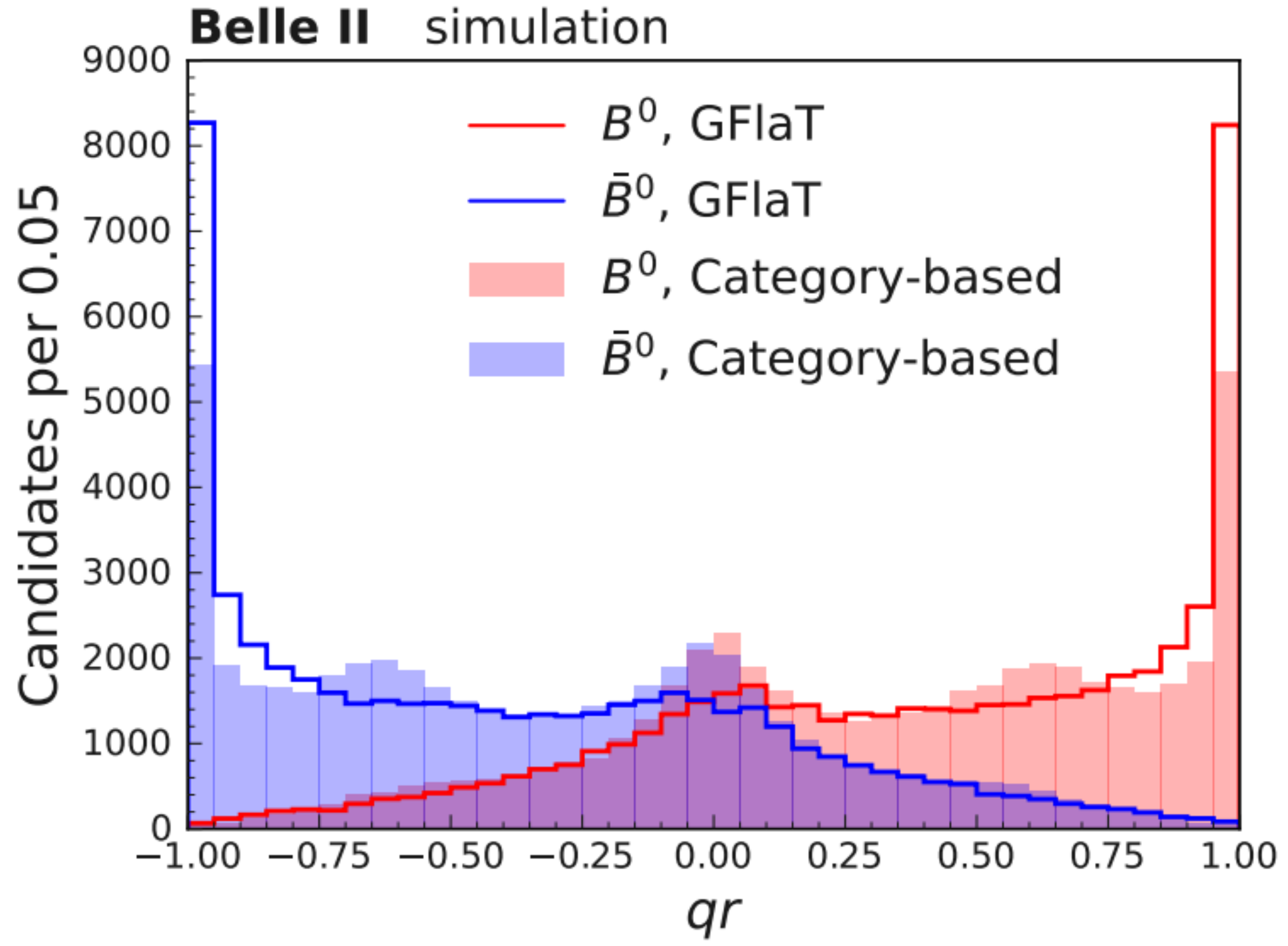
SM [HFLAV]: $S = 0.695 \pm 0.019$, $A = -0.000 \pm 0.020$

$\sin 2\beta$ from $B^0 \to J/\psi K_S^0$ with GFlaT: extra info [arxiv:2402.17260]

$362\ \text{fb}^{-1}$

Belle II

- **GFlaT: Graph neural network Flavour Tagger**
  - Use of particle relations to improve separation B^0-$\overline{B}^0$
  - Cat. FT: $\varepsilon = (31.68 \pm 0.45)\,\%$
  - GFlaT: $\varepsilon = (37.40 \pm 0.43 \pm 0.36)\,\%$ $\Rightarrow$ 18% of gain



- GFlat performance evaluated on $B^0_{\rm sig} \to D^{*-}\pi^+$ sample
- Systematic uncertainties

Source	$\varepsilon_{\rm tag}$ [%]	S	C
Detector alignment	0.08	0.005	0.003
Interaction region	0.16	0.002	0.002
Beam energy	0.03	< 0.001	0.001
ΔE-fit background model	0.11	0.001	0.001
ΔE-fit signal model	0.08	0.003	0.006
sWeight background subtraction	0.24	0.001	0.001
Fixed resolution-function parameters	0.07	0.004	0.004
τ and Δm_d	0.06	0.001	< 0.001
$\sigma_{\Delta t}$ binning	0.04	< 0.001	< 0.001
Δt-fit bias	0.09	0.002	0.005
CP violation in $B_{\rm tag}$ decay		0.011	0.006
$B^0 \to D^{(*)-}\pi^+$ sample size		0.004	0.007
Total systematic uncertainty	0.36	0.014	0.013
Statistical uncertainty	0.43	0.035	0.026

$R(D^*)$: extra info

[arXiv:2401.02840] $189\ \text{fb}^{-1}$ Belle II

Systematics

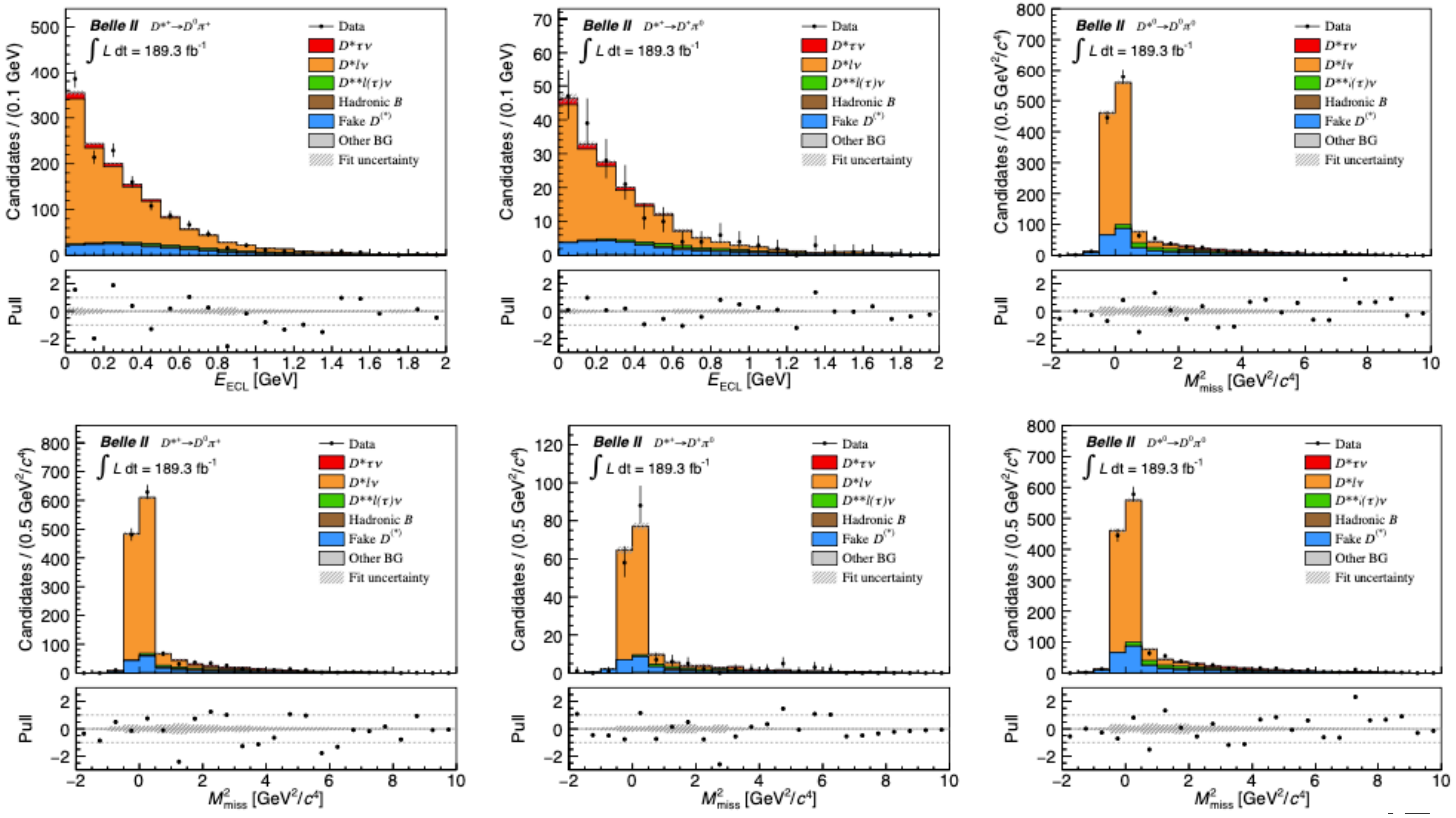
Source	Uncertainty
PDF shapes	$^{+9.1\%}_{-8.3\%}$
Simulation sample size	$^{+7.5\%}_{-7.5\%}$
$\overline{B} \to D^{**}\ell^-\overline{\nu}_\ell$ branching fractions	$^{+4.8\%}_{-3.5\%}$
Fixed backgrounds	$^{+2.7\%}_{-2.3\%}$
Hadronic B decay branching fractions	$^{+2.1\%}_{-2.1\%}$
Reconstruction efficiency	$^{+2.0\%}_{-2.0\%}$
Kernel density estimation	$^{+2.0\%}_{-0.8\%}$
Form factors	$^{+0.5\%}_{-0.1\%}$
Peaking background in ΔM_{D^*}	$^{+0.4\%}_{-0.4\%}$
$\tau^- \to \ell^-\nu_\tau\bar{\nu}_\ell$ branching fractions	$^{+0.2\%}_{-0.2\%}$
$R(D^*)$ fit method	$^{+0.1\%}_{-0.1\%}$
Total systematic uncertainty	$^{+13.5\%}_{-12.3\%}$

Yields: $B \to D^*\tau\nu$: ~108

Parameter	Observed (expected) yield		
	$D^{*+} \to D^0\pi^+$	$D^{*+} \to D^+\pi^0$	$D^{*0} \to D^0\pi^0$
$N^i_{D^*\tau\nu} + N^i_{D^*\tau\nu,\ell\text{-misID}}$	50.9 ± 7.8	7.8 ± 1.2	49.2 ± 7.5
$N^i_{D^*\ell\nu}$	1084.6 ± 36.7 (1041.0 ± 11.2)	137.9 ± 6.6 (133.2 ± 4.3)	940.9 ± 36.0 (927.2 ± 10.7)

Bkg control studies:

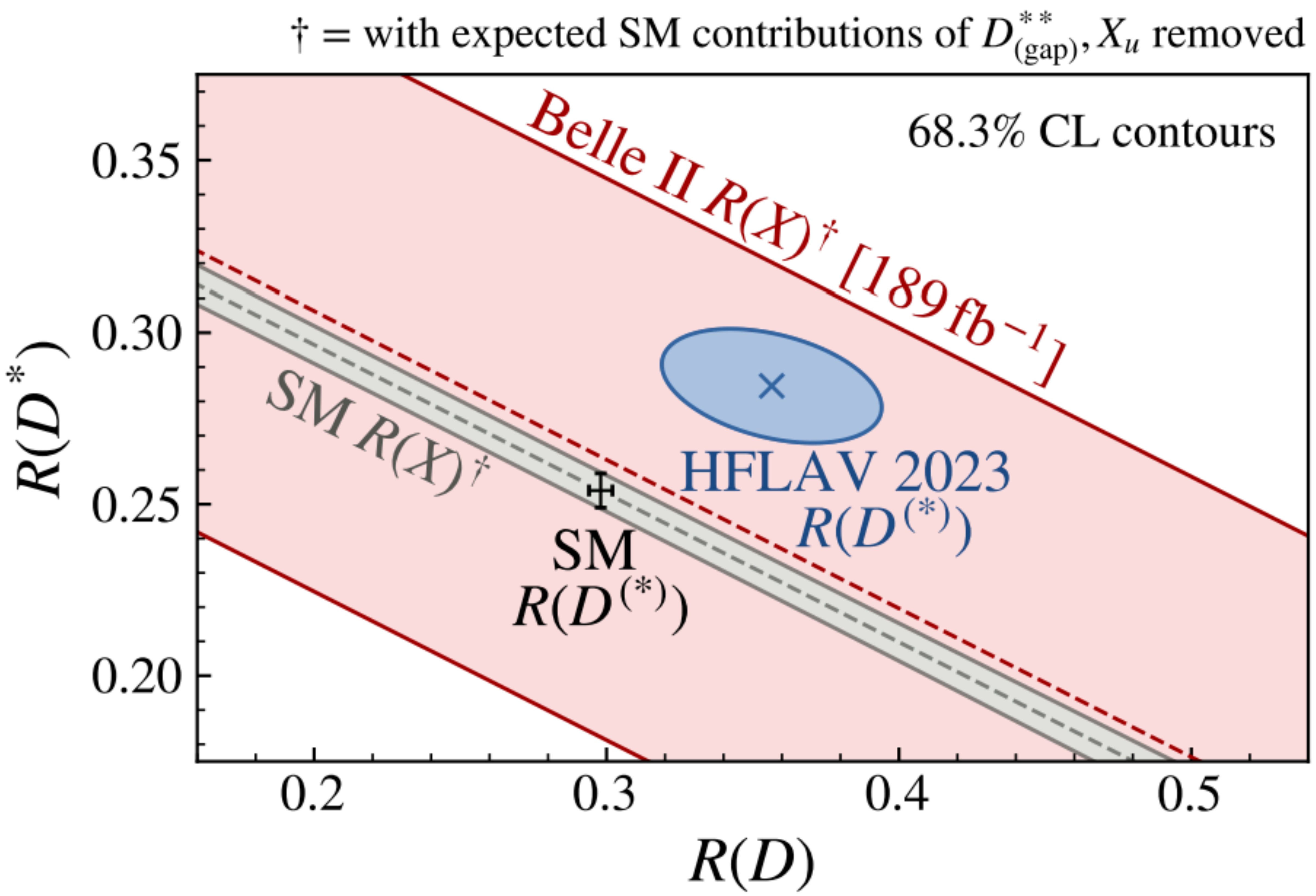
- $B \to D^*\ell\nu$ validated in low q^2 sideband
- $B \to D^{**}\ell\nu$ validated in the extra-π^0 control sample
- Fake D^* bkg validated in $\Delta m = m_{D^*} - m_D$ sideband



$R(X_{\tau/\ell})$: extra info

[arXiv:2311.07248] $189\ \text{fb}^{-1}$ Belle II

Constraint on $R(D^*)$



Systematic uncertainties

Source	Uncertainty [%] e	μ	ℓ
Experimental sample size	8.8	12.0	7.1
Simulation sample size	6.7	10.6	5.7
Tracking efficiency	2.9	3.3	3.0
Lepton identification	2.8	5.2	2.4
$X_c\ell\nu$ M_X shape	7.3	6.8	7.1
Background (p_ℓ, M_X) shape	5.8	11.5	5.7
$X\ell\nu$ branching fractions	7.0	10.0	7.7
$X\tau\nu$ branching fractions	1.0	1.0	1.0
$X_c\tau(\ell)\nu$ form factors	7.4	8.9	7.8
Total	18.1	25.6	17.3

Bkg details:

- continuum constrained using off-resonant data
- $p_\ell > 1.4$ GeV for normalization
- same-B-flavour sample for BB and fakes bkg

Modelling details:

- $B \to D^{**}\tau(\ell)\nu$: BLR model [PRD 97, 075011 (2018)]
- Gap modes (discrepancy between sum and total semileptonic widths): $B \to D^*\pi\pi\tau(\ell)\nu$ and $B \to D^*\eta\tau(\ell)\nu$

Search for $B^0 \to \gamma\gamma$

NEW for La Thuile

$362\ \mathrm{fb}^{-1}$ Belle II

$694\ \mathrm{fb}^{-1}$ BELLE

Dedicated YSF talk by S. Maurya this afternoon!

- $b \to d\gamma$ **FCNC**, particularly sensitive to heavy NP
- Bkg suppression using:
  - high quality, energetic photon requirements
  - rejection of photon from π^0 and η
  - BDT targeting $q\overline{q}$ bkg
- Fit to $(\Delta E, M_{bc},$ transformed BDT output$)$
- Result not approved yet

Previous world best: $< 3.2 \times 10^{-7}$ [Belle, PRD, 83, 032006]   SM prediction: $B(B^0 \to \gamma\gamma) = 1.434^{+1.251}_{-0.795} \times 10^{-8}$ [JHEP, 169 (2020)]

$|V_{cb}|$ from $B \to D^* \ell \nu$ angular coefficients

711 fb^{-1}

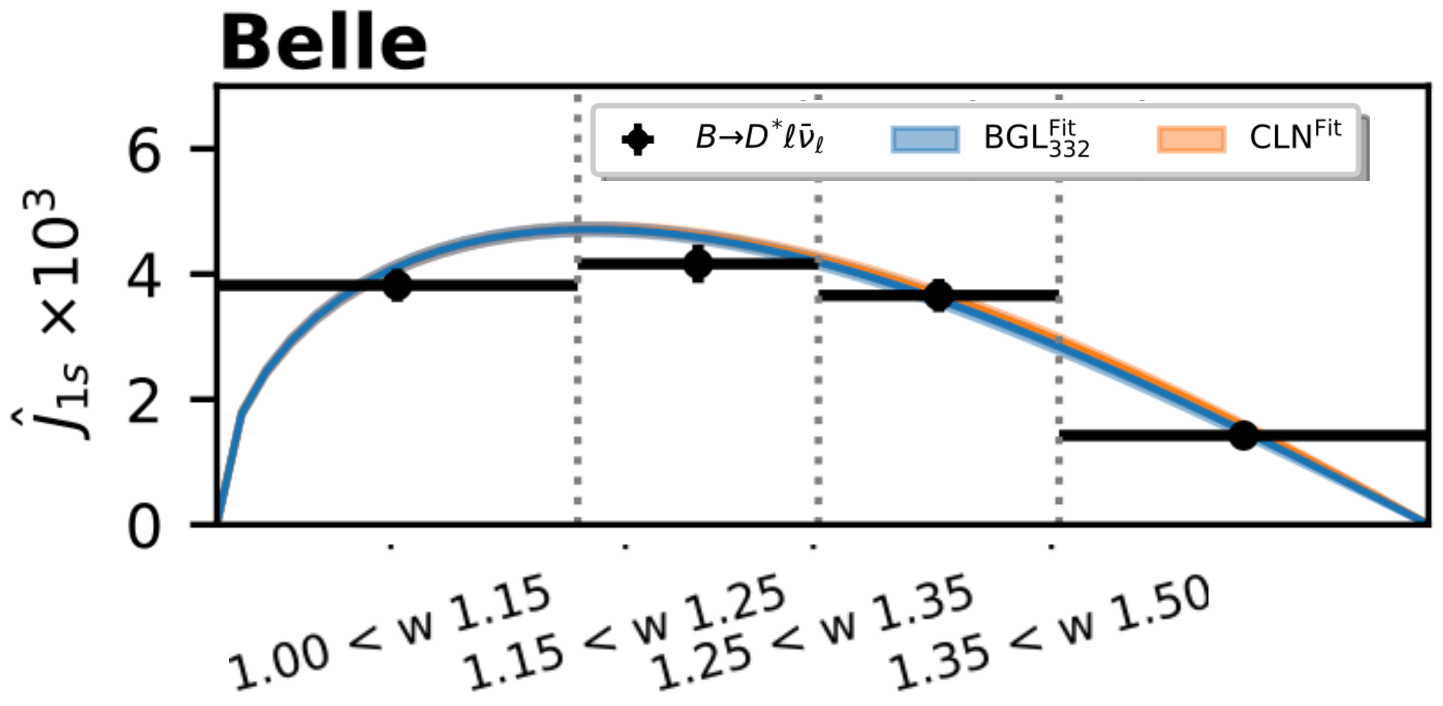
BELLE

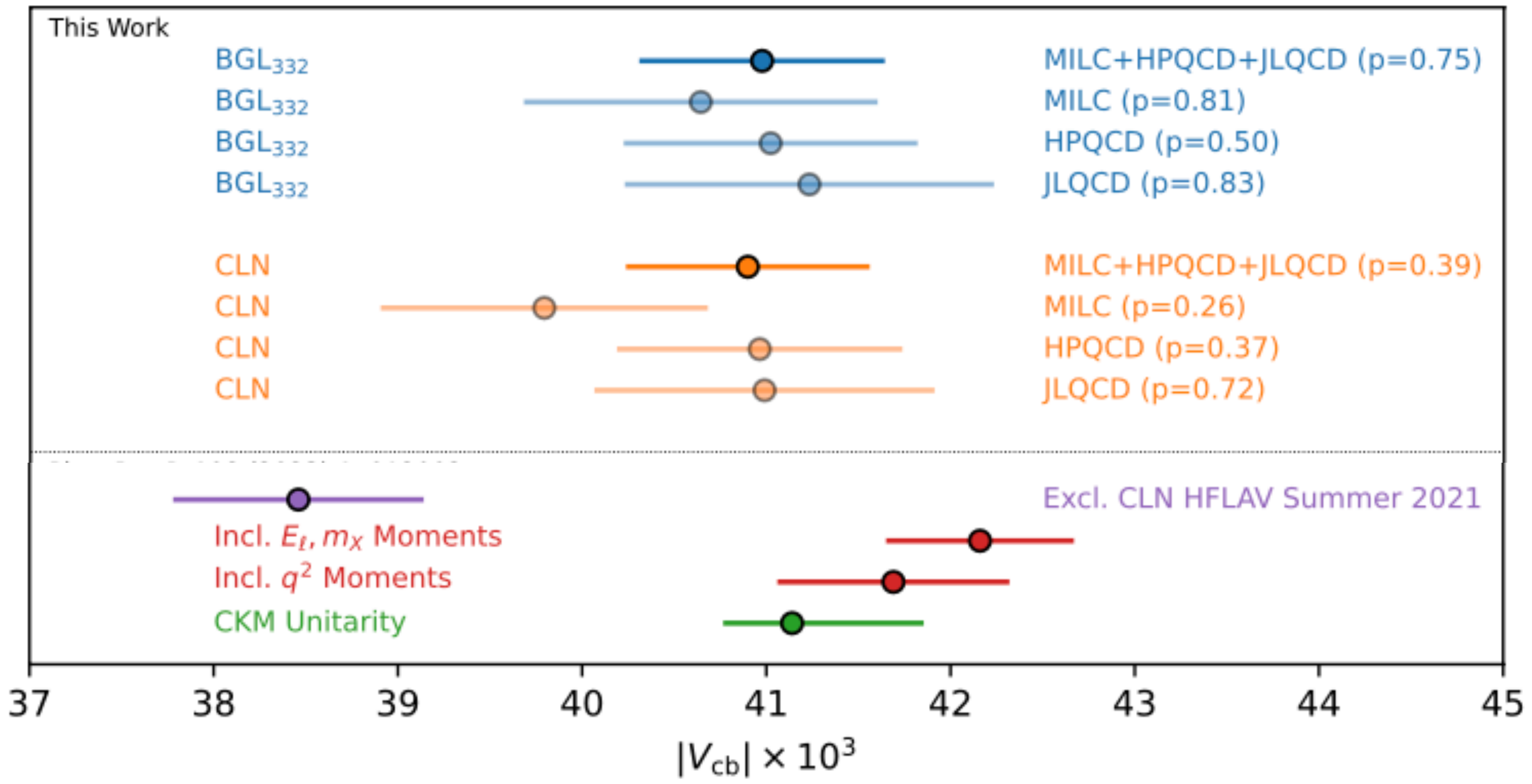
[arXiv:2310.20286]

- Extraction of **partial branching fraction** as a function of **hadronic recoil** $w = \frac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$ and angles.
- Measurement of $B \to D^* \ell \nu$ **angular coefficients**
- Conversion in non-perturbative **form factors** of the $B \to D^*$ transition (two parameterizations used)
- adding **Lattice QCD** input (beyond zero-recoil lattice), and external BF, $|V_{cb}|$ can be extracted

$$|V_{cb}| = (41.0 \pm 0.3 \pm 0.4 \pm 0.5) \times 10^{-3}\ (\mathrm{BGL}_{332}),$$
$$|V_{cb}| = (40.9 \pm 0.3 \pm 0.4 \pm 0.4) \times 10^{-3}\ (\mathrm{CLN}),$$

stat+syst external BF theory





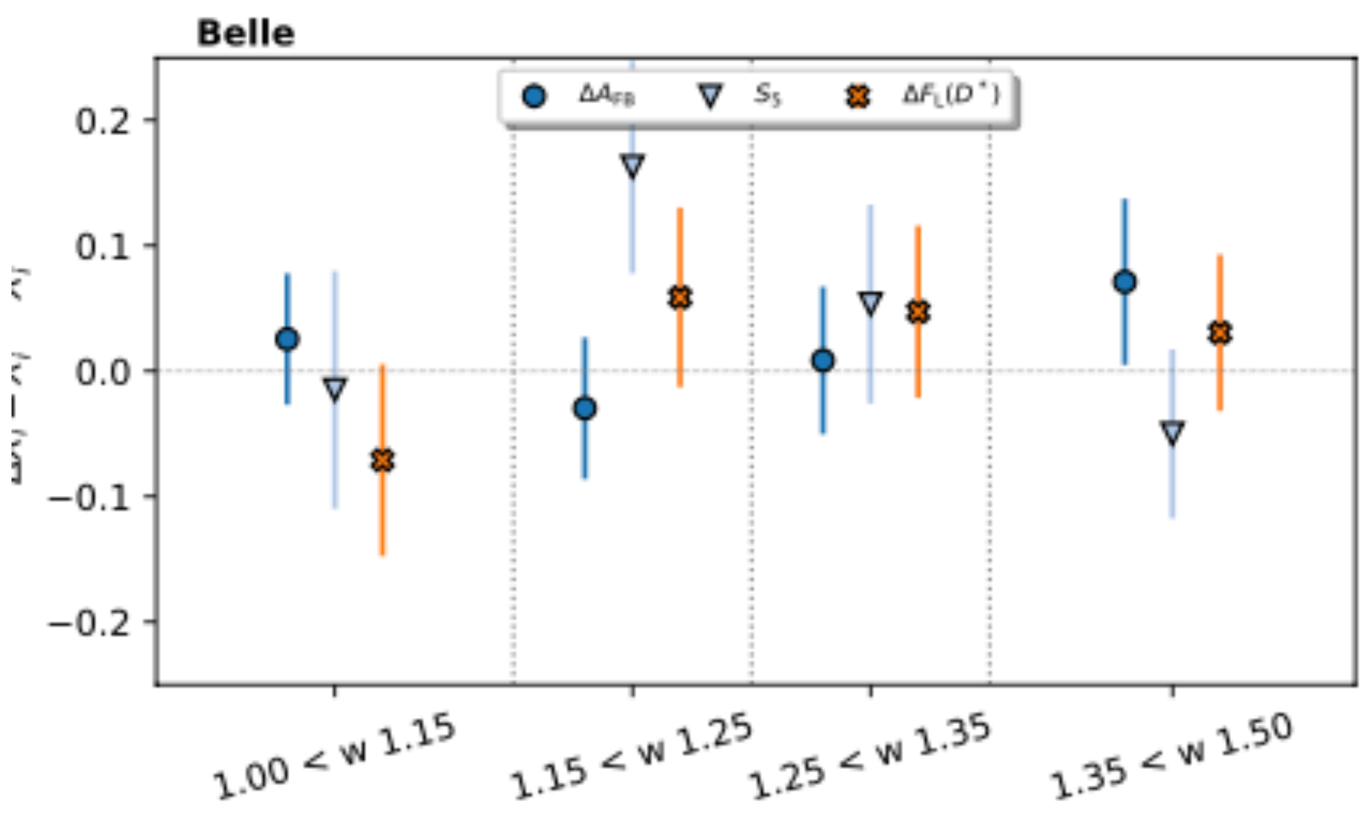
Compatible with previous results (inclusive or exclusive HFLAV average)

Lepton flavour violation investigated via asymmetries and polarization, but there is no evidence.

$|V_{cb}|$ (angular coefficients): extra info

711 fb^{-1}

- Reconstruction: **Hadronic** tagging
- Tested FLV-sensitive parameters:
  - Lepton forward-backwoard asymmetry
  - D^* logitudinal polarization
  - $S_i \propto J_i$ parameters from [EPJC 81, 984 (2021)]



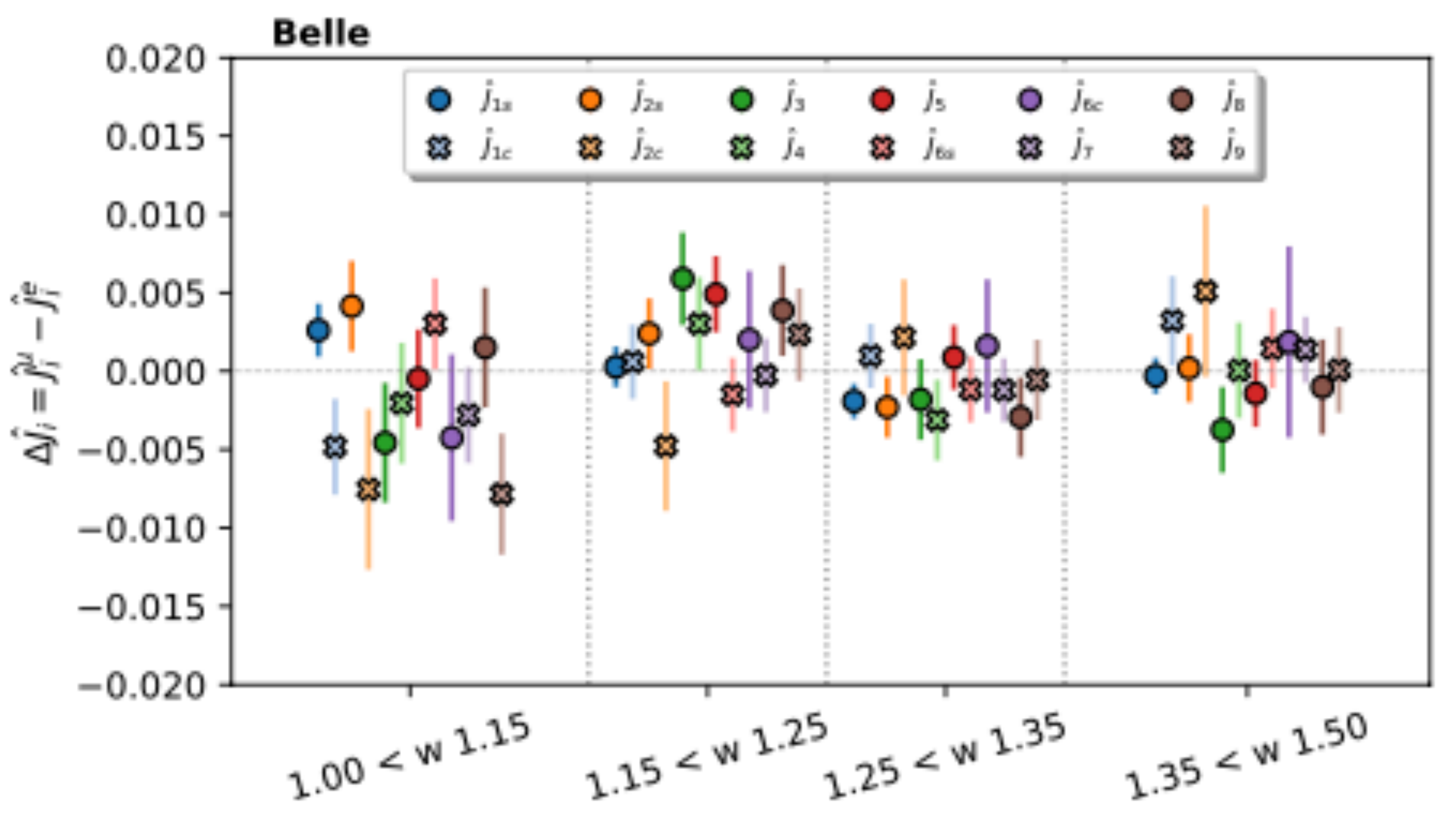
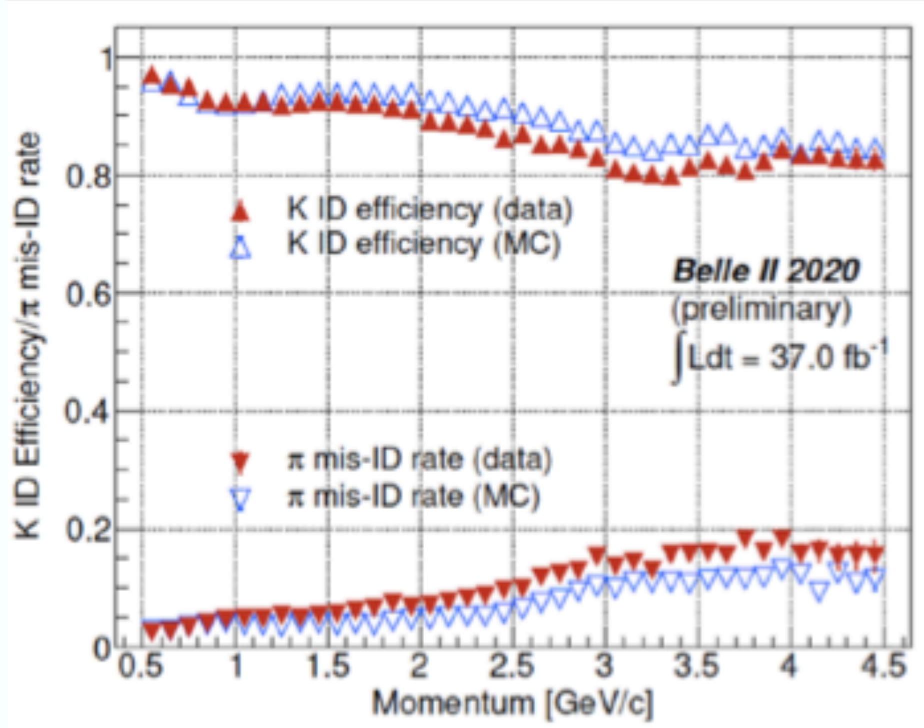


TABLE I. Compatibility of the lepton flavor universality observables with the SM expectation. The $\Delta X = X^\mu - X^e$ are the observables testing the lepton flavor universal by calculating the difference between the decays with muons and electrons.

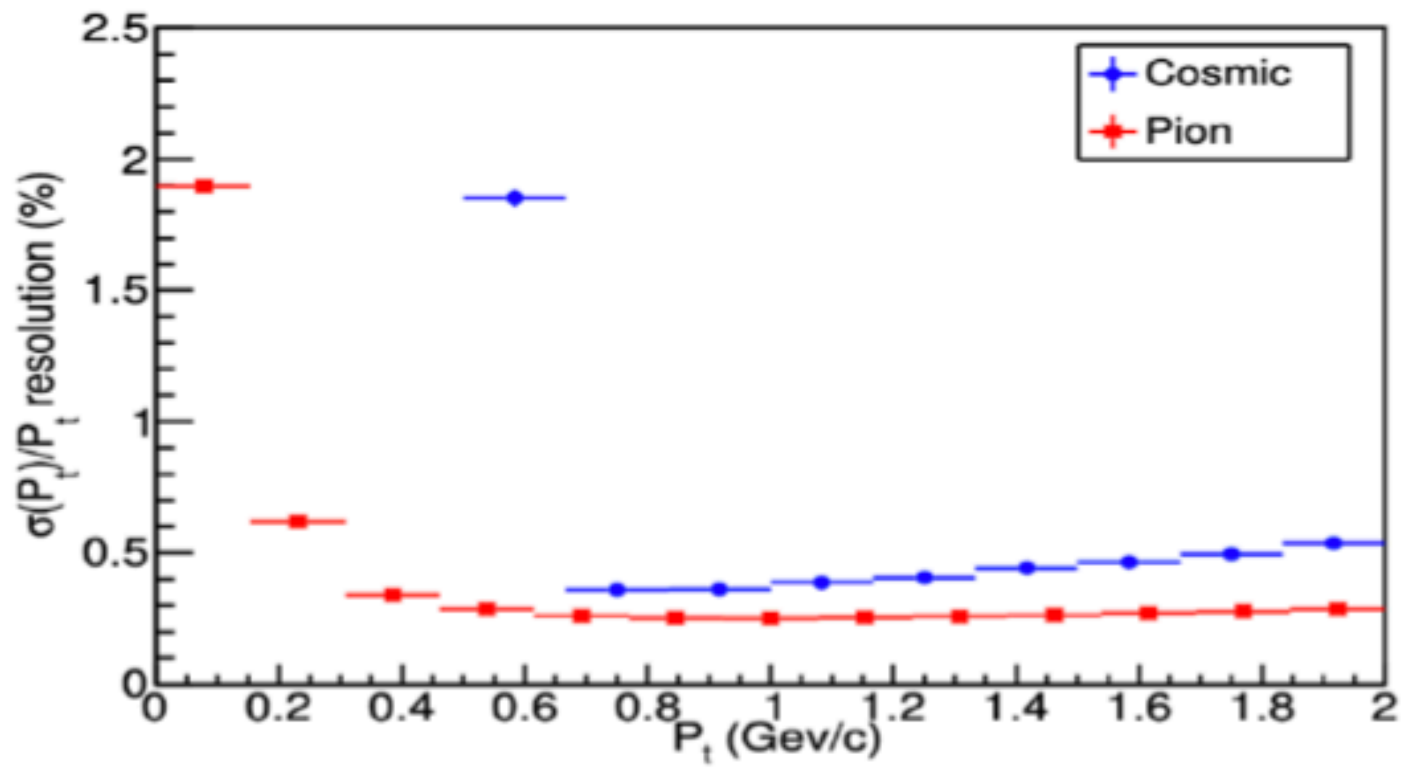
Observable	χ^2 / ndf	p-value
$\Delta A_{\rm FB}$	1.7 / 4	0.79
$\Delta F_{\rm L}(D^*)$	2.3 / 4	0.67
$\Delta\hat{J}_{1s}$	5.3 / 4	0.26
$\Delta\hat{J}_{1c}$	4.2 / 4	0.38
$\Delta\hat{J}_{2s}$	4.6 / 4	0.33
$\Delta\hat{J}_{2c}$	5.0 / 4	0.28
$\Delta\hat{J}_{3}$	7.4 / 4	0.12
$\Delta\hat{J}_{4}$	2.5 / 4	0.64
$\Delta\hat{J}_{5}$	4.8 / 4	0.31
$\Delta\hat{J}_{6s}$	2.1 / 4	0.72
$\Delta\hat{J}_{6c}$	1.1 / 4	0.89
$\Delta\hat{J}_{7}$	1.6 / 4	0.81
$\Delta\hat{J}_{8}$	3.3 / 4	0.51
$\Delta\hat{J}_{9}$	4.6 / 4	0.33
$\Delta\hat{J}_{i}$	41 / 48	0.76

- Systematic uncertainties: dominated by MC sample size

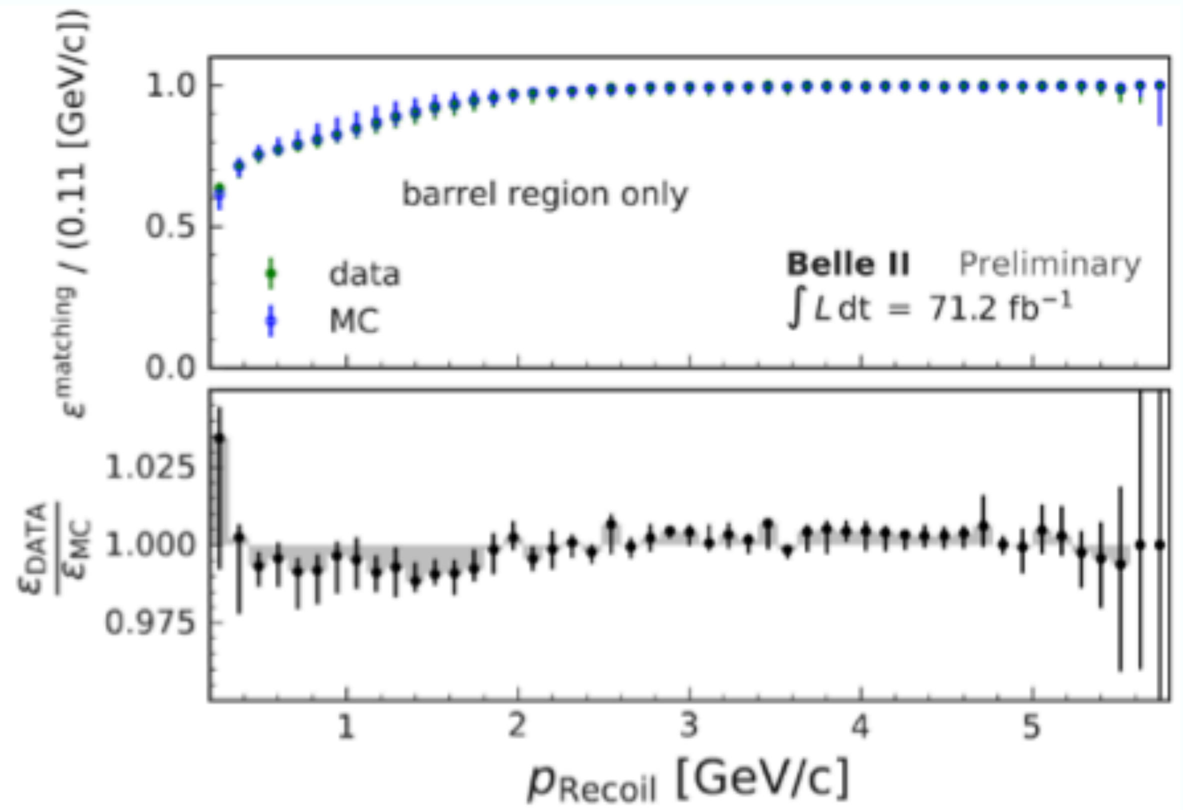
Belle II performance



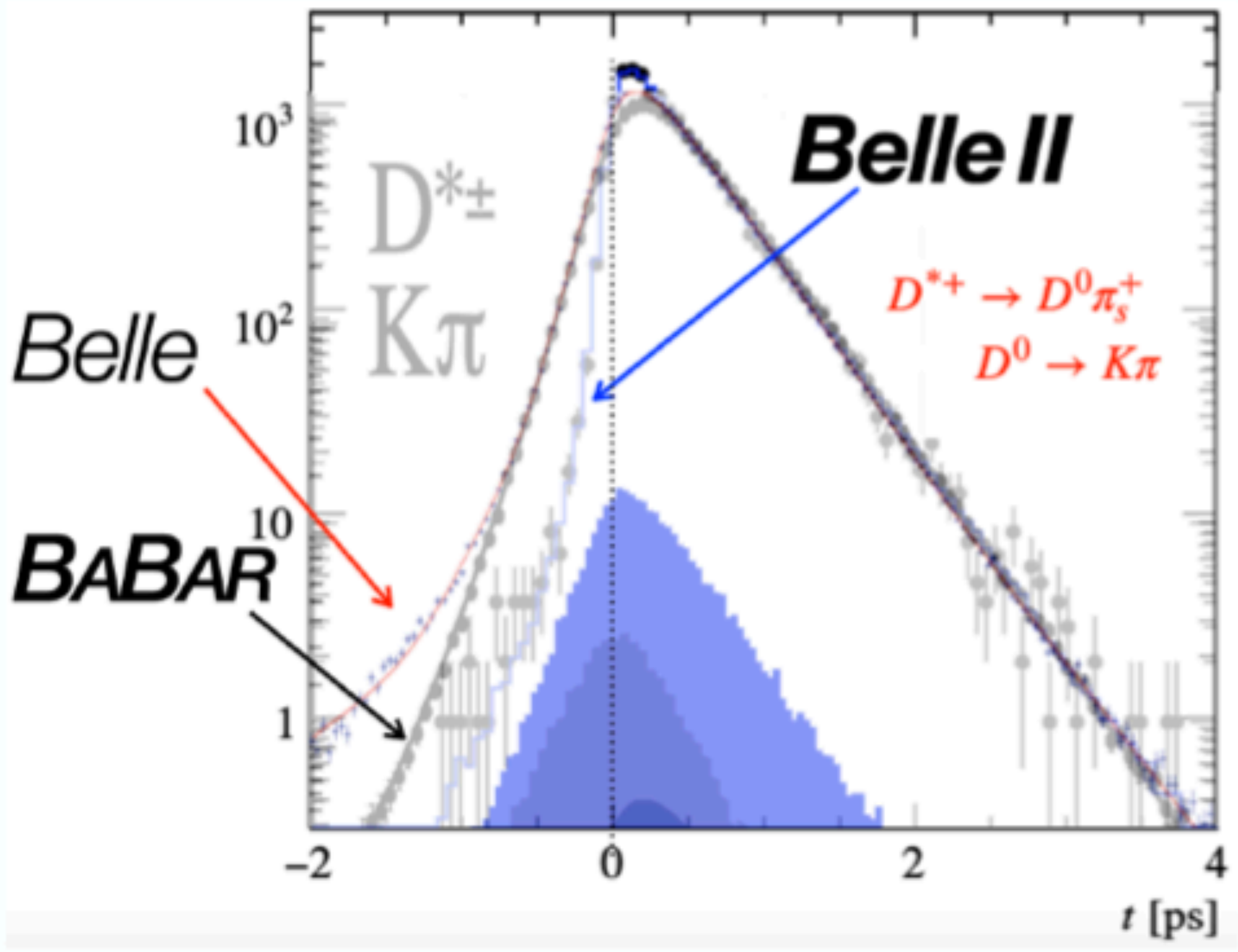
PID still 20% worse than Belle but improving



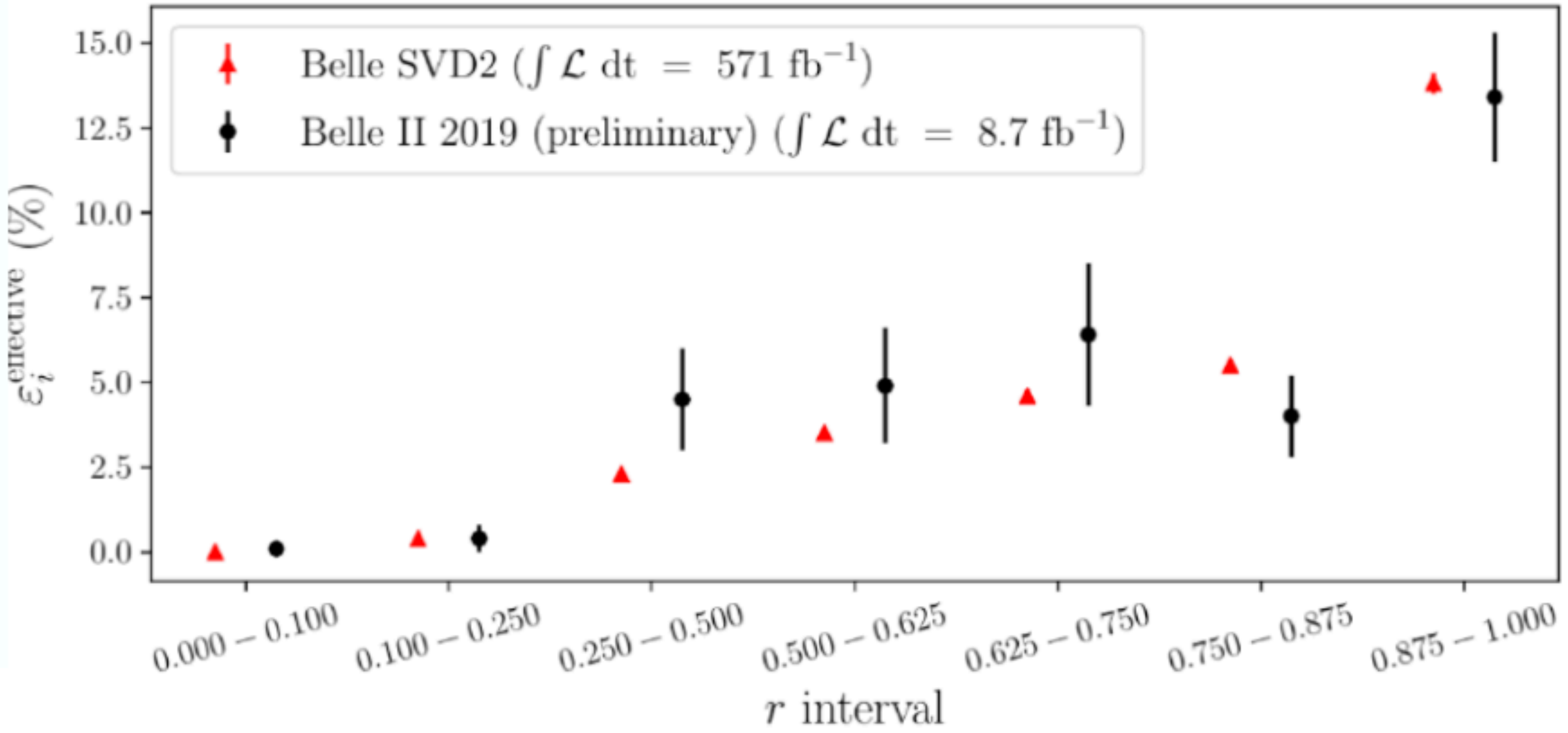
Momentum resolution 20% better than Belle



High photon efficiency,



Nearly 2x better decay-time resolution than Belle



Tagging performance similar to Belle and improving

[From D. Tonelli]