Recent beauty and charm 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

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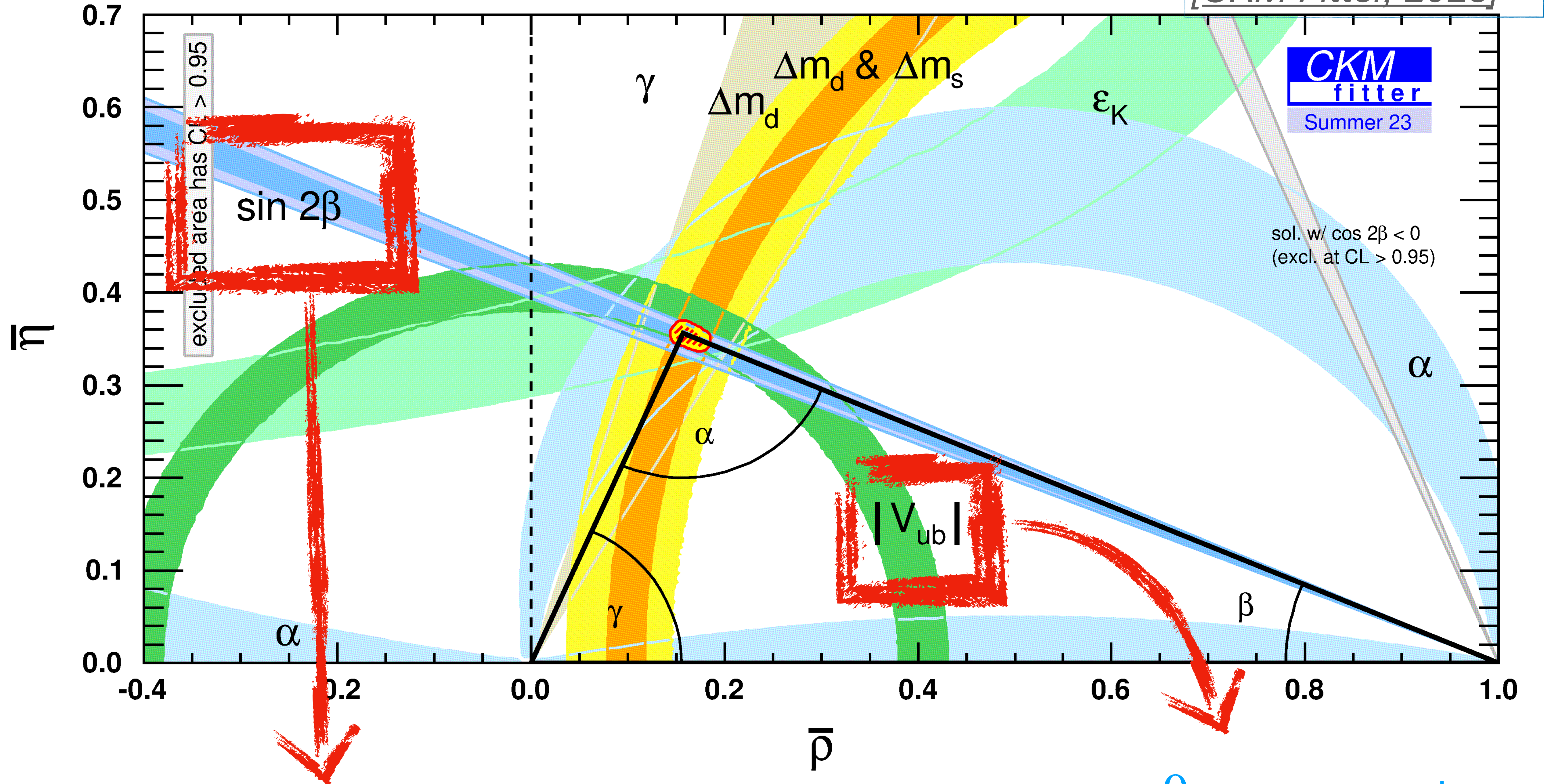
Outline and Motivation

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

They are used to:

- CKM matrix measurement for **SM precision test** in favoured and suppressed B decays
- **Substantially improve** B decays knowledge :
  - $B \to D^0 \rho$
  - $B \to D^{(*)} K^- K^{(*)0}_{(S)}$
  - $B^0 \to \omega\omega$
- **Charm sector** exploration: $\Lambda_c \to p K^0_S \pi^0$
- Access to known rare decays to **investigate New Physics** via Flavor Changing Neutral Current **(FCNC)**
  - $b \to s$: $B \to K^+ \nu \bar{\nu}$
  - $b \to u$: $B \to h \ell^+ \ell^-$
  - radiative: $B \to \rho\gamma, B \to \gamma\gamma$
- **Flavor universality** test: $R(D^*)$ and $R(X_{\tau/\ell})$

[CKM Fitter, 2023]



$B^0 \to J/\psi K^0_S$ with new flavor tagger

$B^0 \to \eta' K^0_S$

$B^0 \to K^0_S \pi^0 \gamma$

$B^0 \to \pi^- \ell^+ \nu$

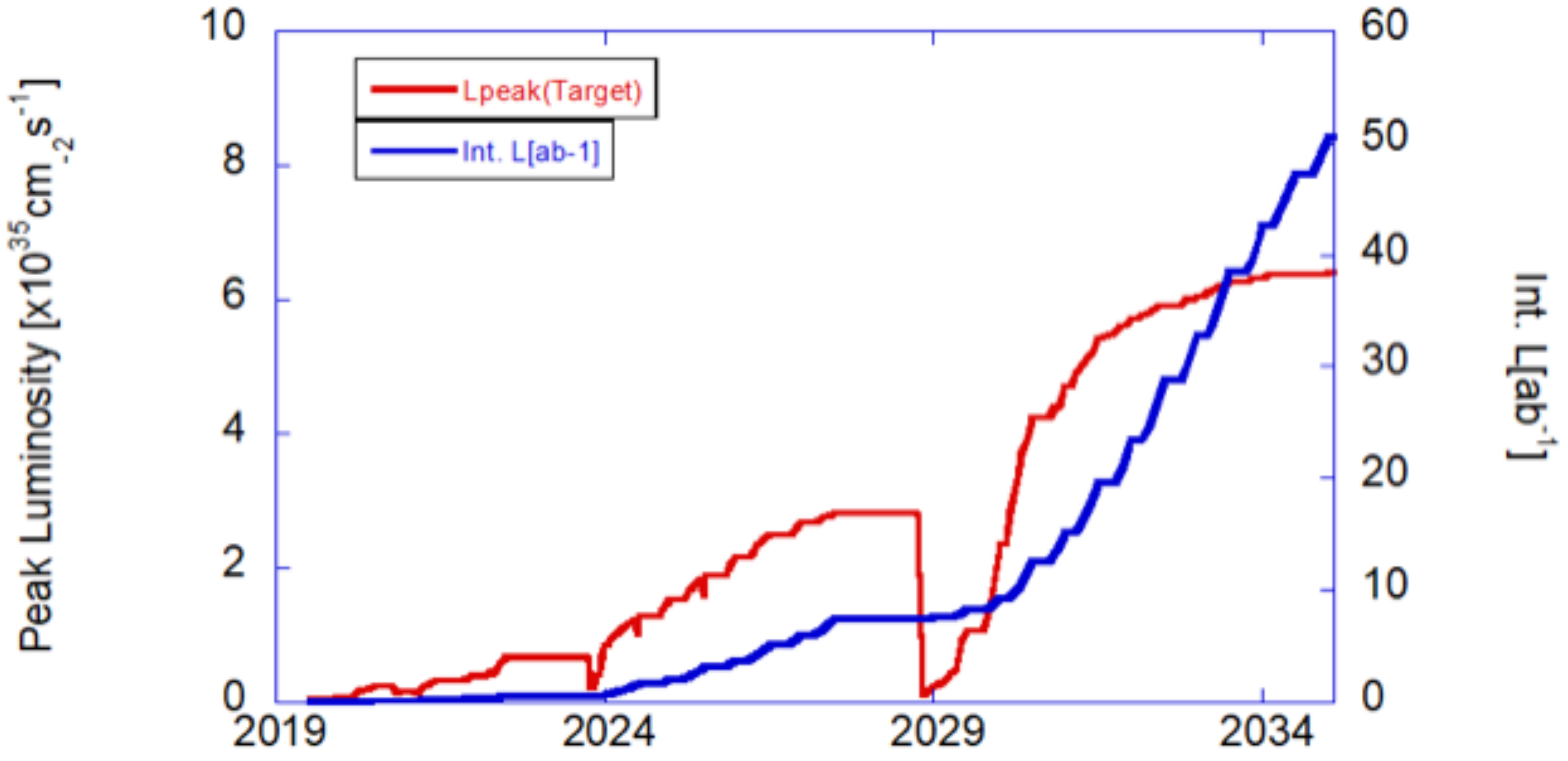
$B^+ \to \rho^0 \ell^+ \nu$

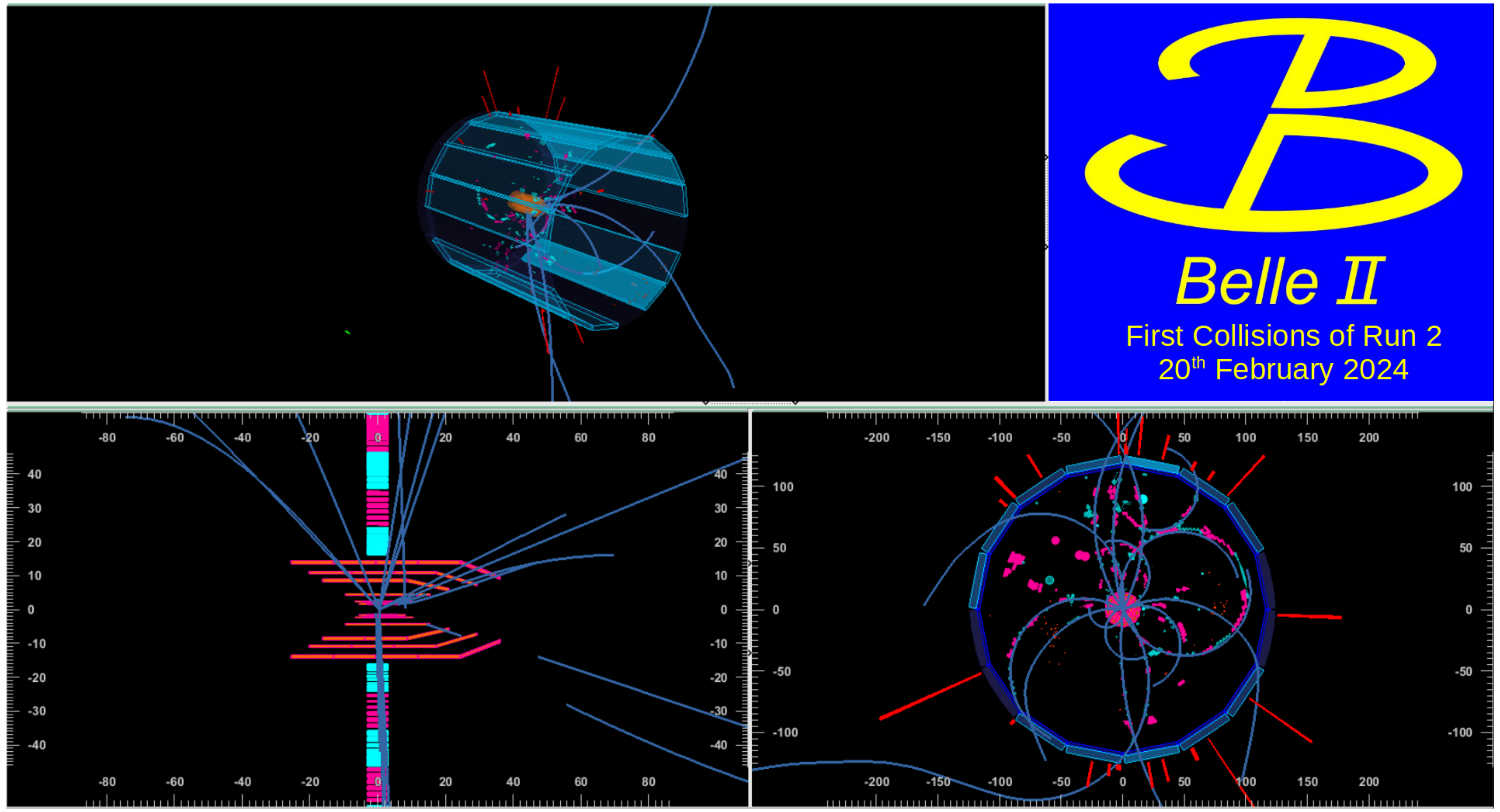
$|V_{cb}|$

$B^0 \to D^* \ell \nu$

Belle II & SuperKEKB status

- Completed detector in 2019
- Run 1 (2019-2022)
  - Peak luminosity $\mathbf{4.7 \cdot 10^{34}\ cm^{-2}s^{-1}}$ (reached the 22/06/2022)
  - Integrated luminosity: $\mathbf{\sim 424\ fb^{-1}}$ (~Babar~0.5 Belle)
- Long Shutdown 1 just finished, **Run 2 restarted the in February 2024**

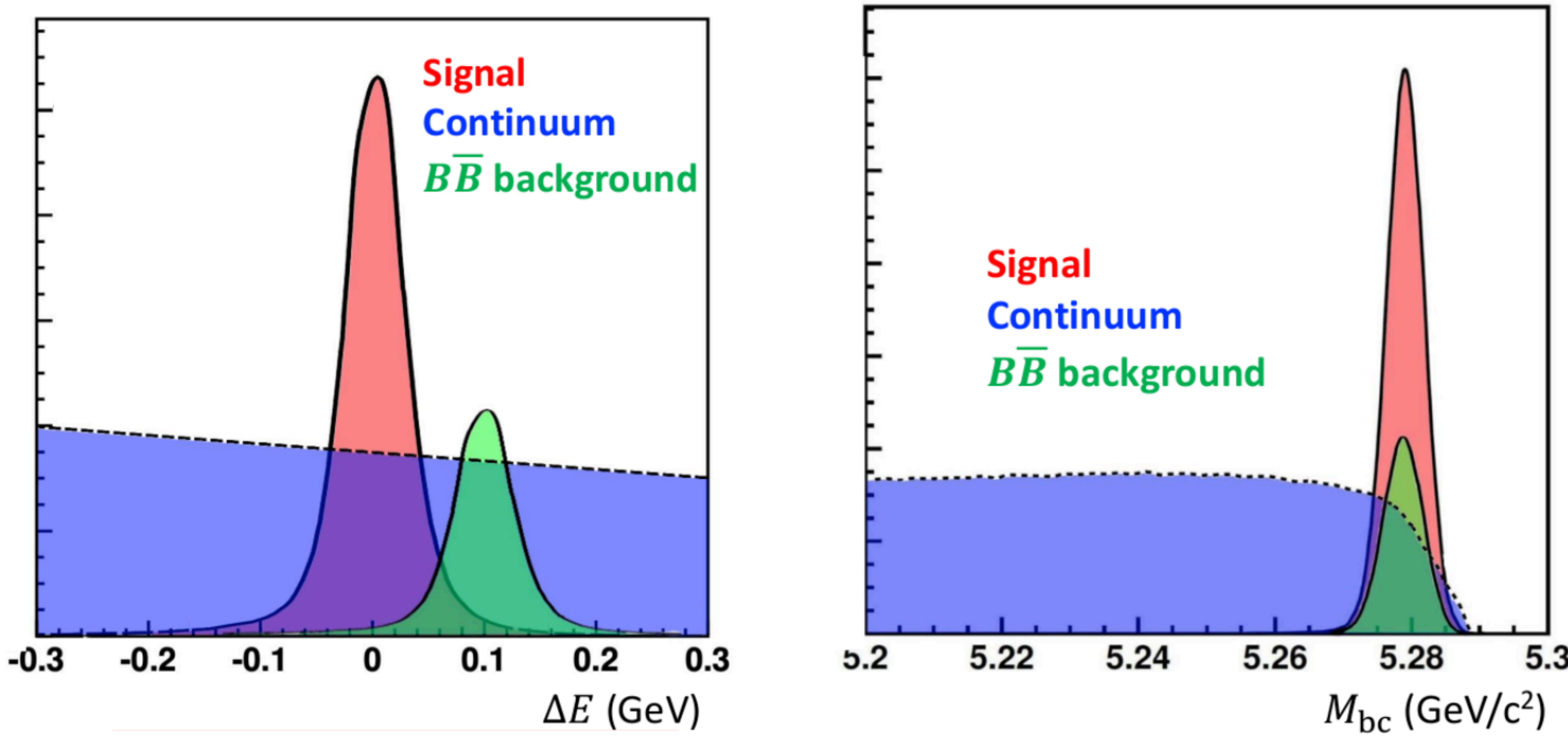




B-Factory basics

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

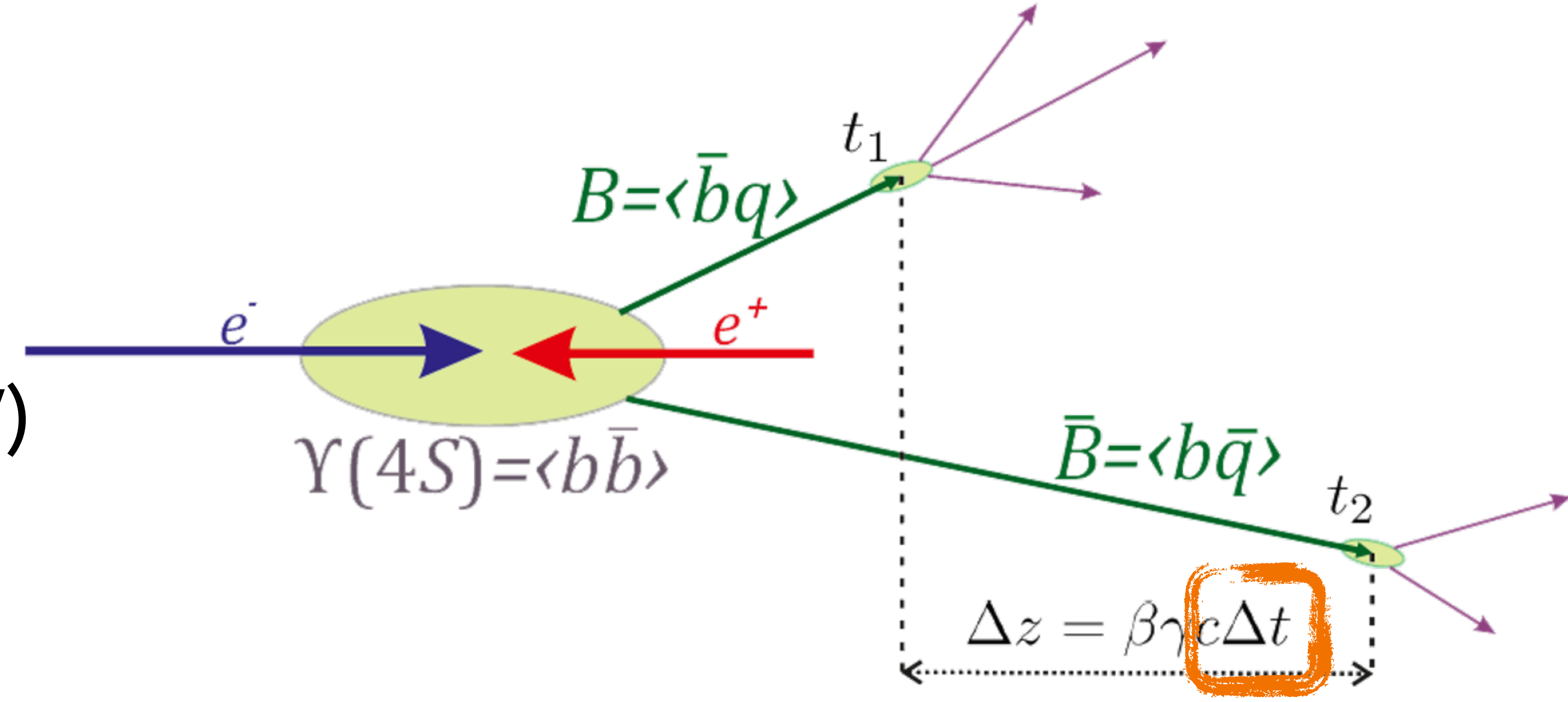
$$\Delta E = E_B^* - \sqrt{s}/2 \qquad M_{bc} = \sqrt{(\sqrt{s}/2)^2 - \vec{p}_B^{*2}}$$



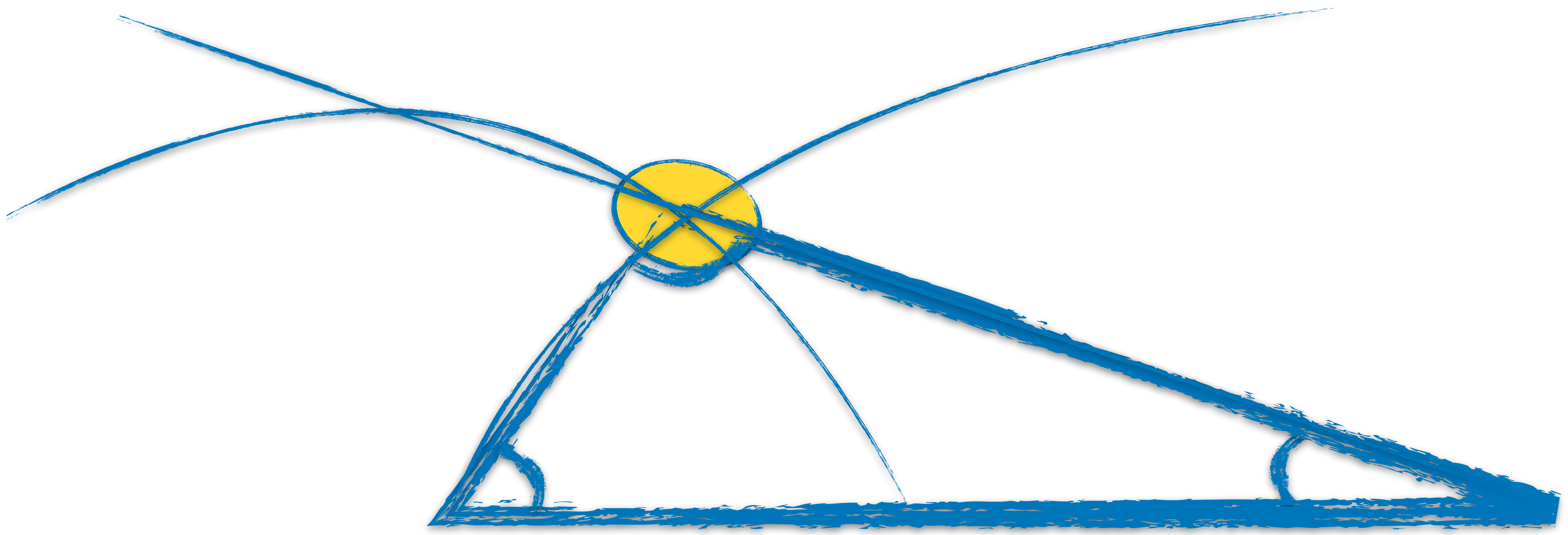
Expected $\Delta E \simeq 0$ Expected $M_{bc} \simeq m_B$

- **Asymmetric** collider $\Rightarrow$ Boost of center-of-mass
- Excellent **vertexing** performance ($\sigma \sim 15\ \mu\text{m}$)
- coherent $B\overline{B}$ pairs production
- Excellent **flavour tagging** performance

$\Rightarrow$ measurement of Δt for time dependent CP violation (TDCPV)



CKM precision measurements



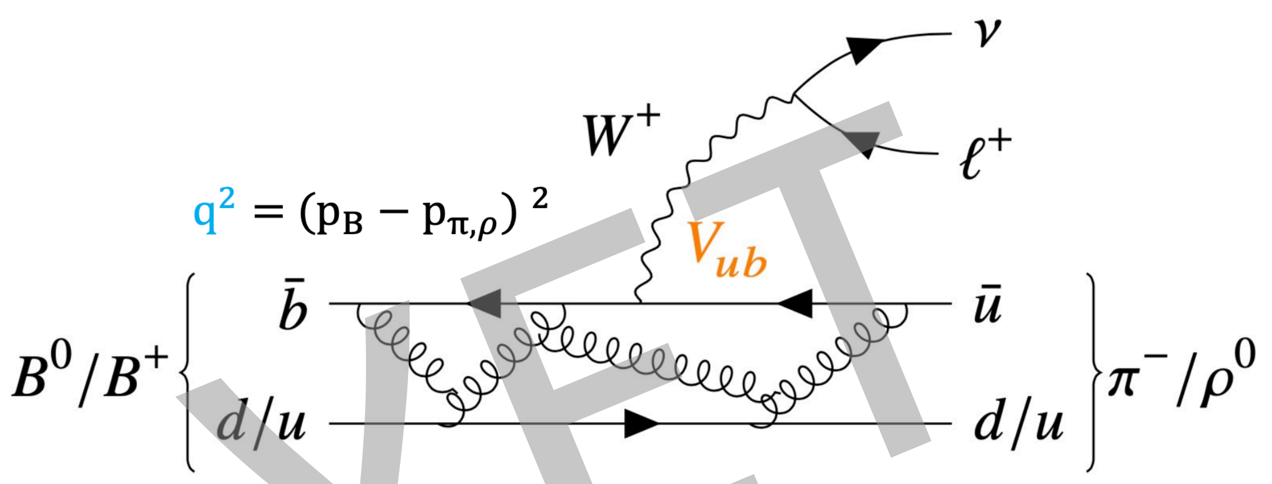
$|V_{ub}|$ from $B^0 \to \pi^- \ell^+ \nu$ and $B^+ \to \rho^0 \ell^+ \nu$

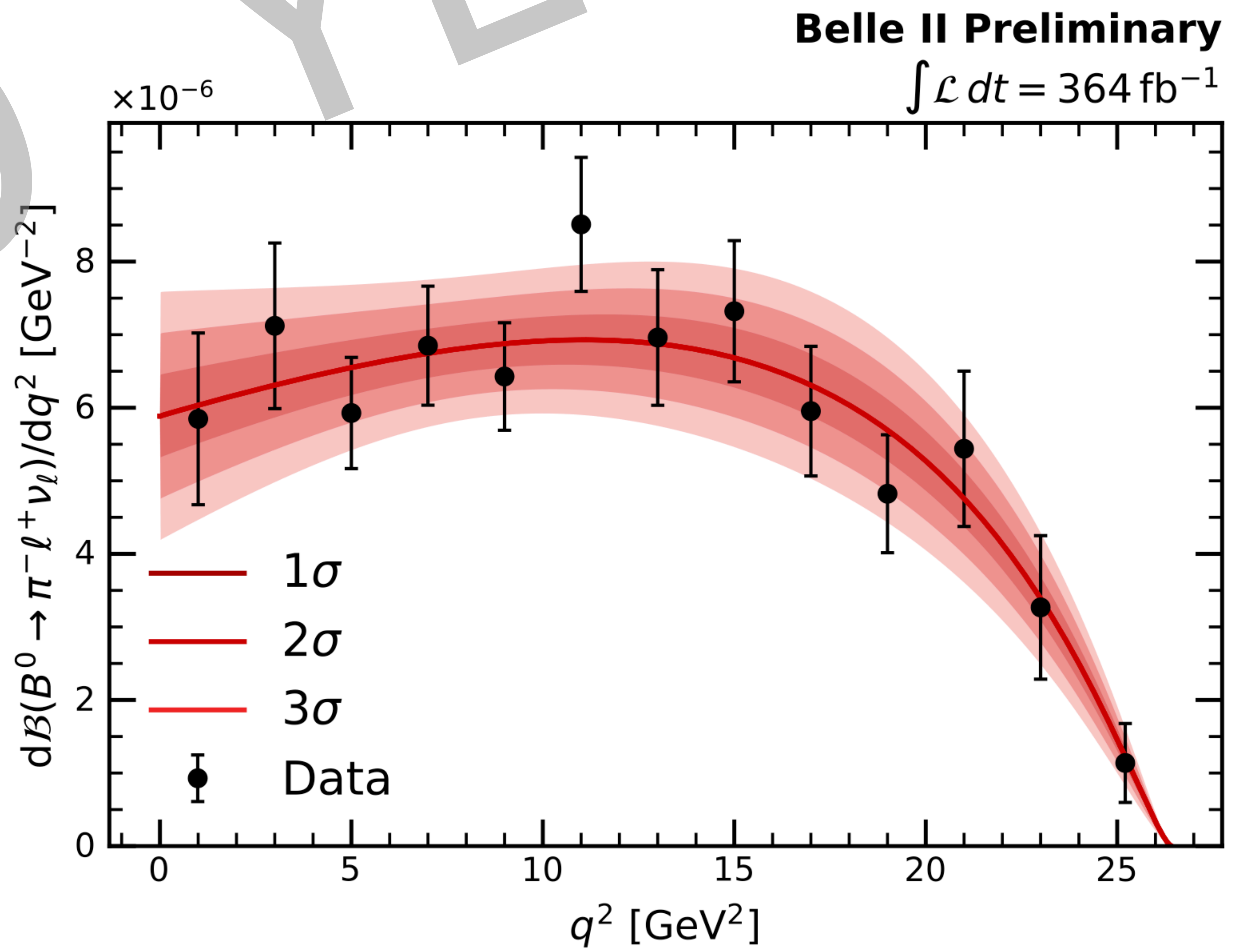
NEW for La Thuile

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

Belle II

- Measurement of **partial branching fractions** (BF) as a function of $q^2 = (p_B - p_h)^2, h = \pi, \rho, \ell = e, \mu$
- Simultaneous fit of the two channels of $(\Delta E, M_{bc})$ in bin of q^2
- $$\frac{d\mathrm{BR}(B \to h\ell\nu)}{dq^2} \propto |V_{ub}|^2 f_+^2(q^2)$$
- Lattice QCD (**LQCD**) at high q^2 and/or light-cone sum rule (**LCSR**) at low q^2 inputs





$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.516 \pm 0.027 \pm 0.037) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \rho^0 \ell^+ \nu_\ell) = (1.625 \pm 0.063 \pm 0.089) \times 10^{-4}$$

world best BF measurements

limited by off-resonance sample size

$$|V_{ub}|_{B\to\pi\ell\nu_\ell} = (3.92 \pm 0.09 \pm 0.13 \pm 0.19) \times 10^{-3}.$$

limited by theory-uncertainty

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

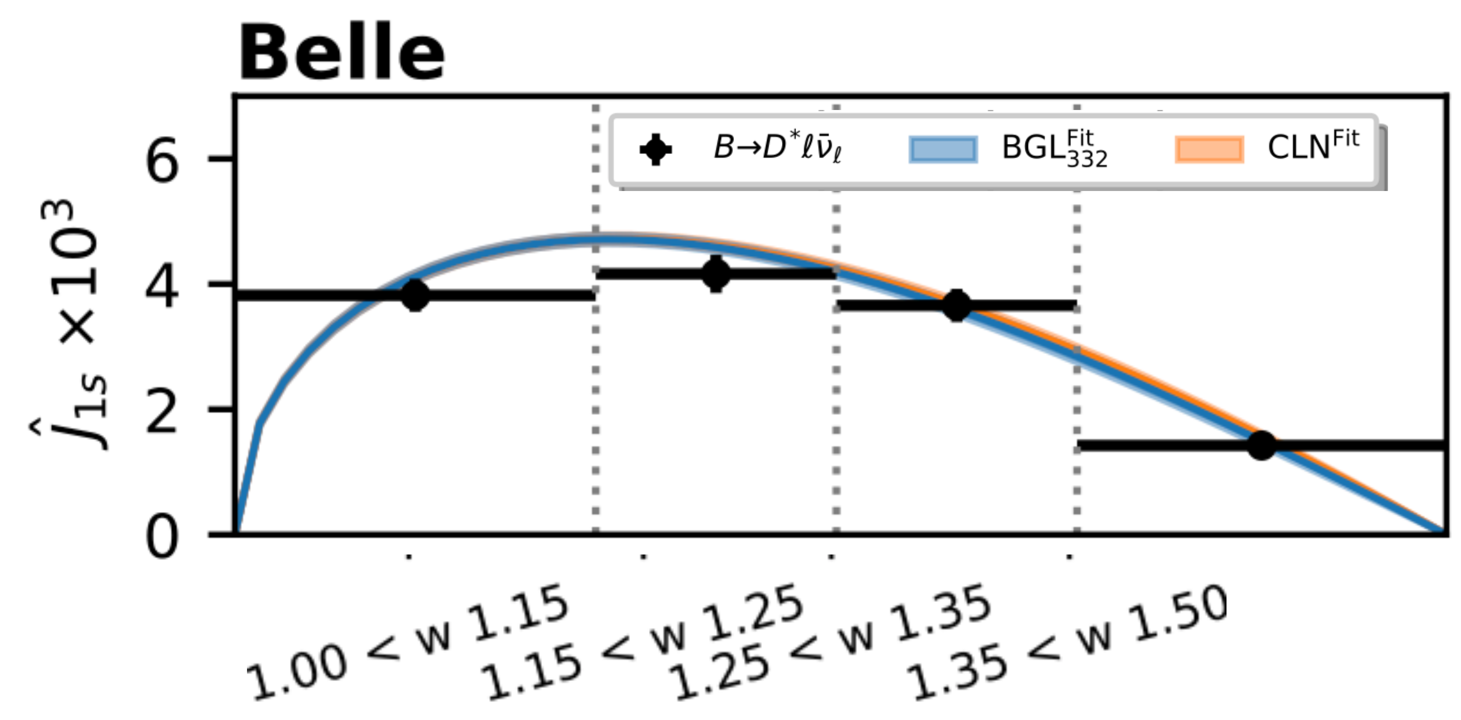
NEW for La Thuile

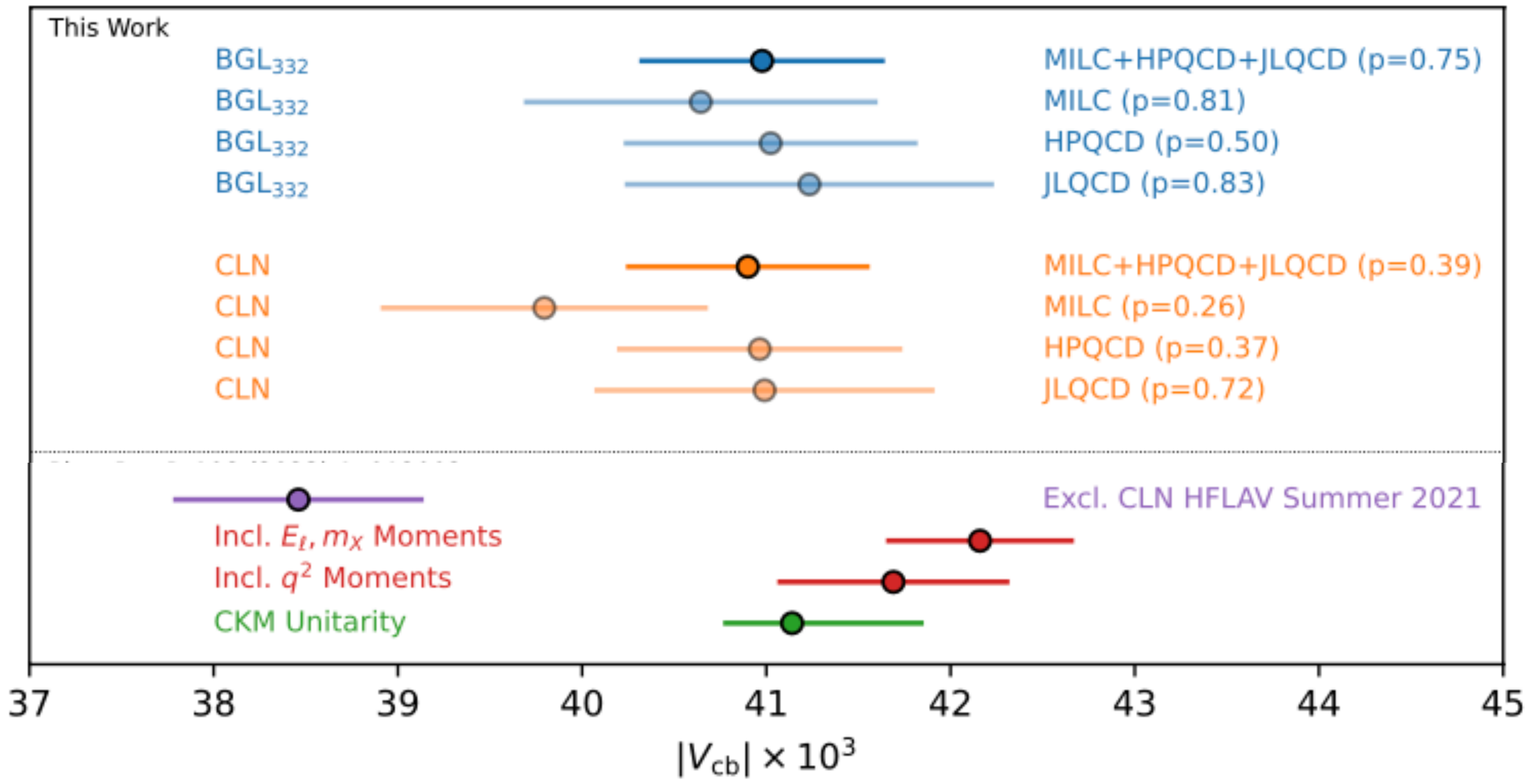
711 fb^{-1}

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)

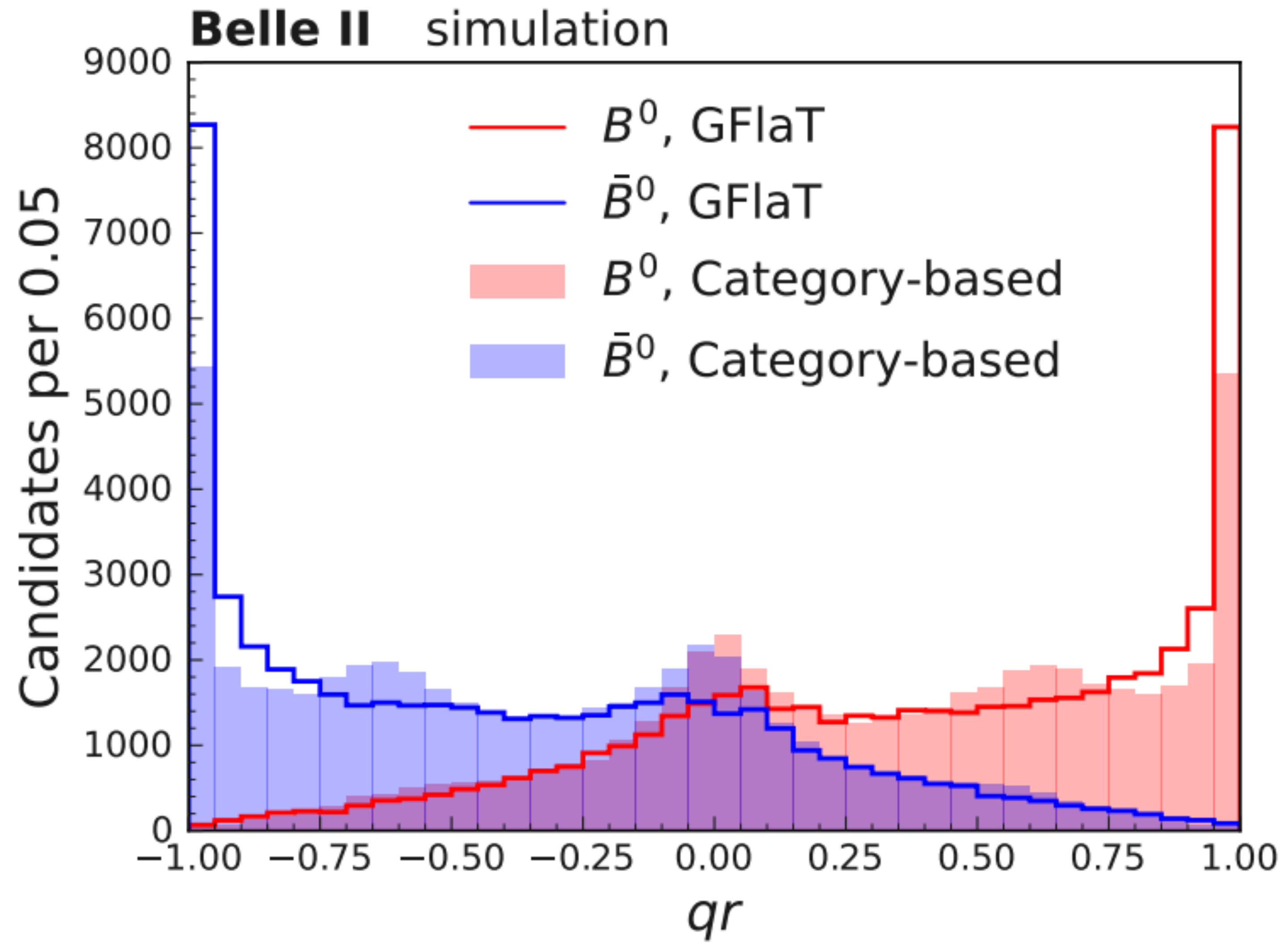
Lepton flavor violation investigated via asymmetries and polarization, but there is no evidence.

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

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

Belle II

- **GFlaT: Graph neural network Flavor 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

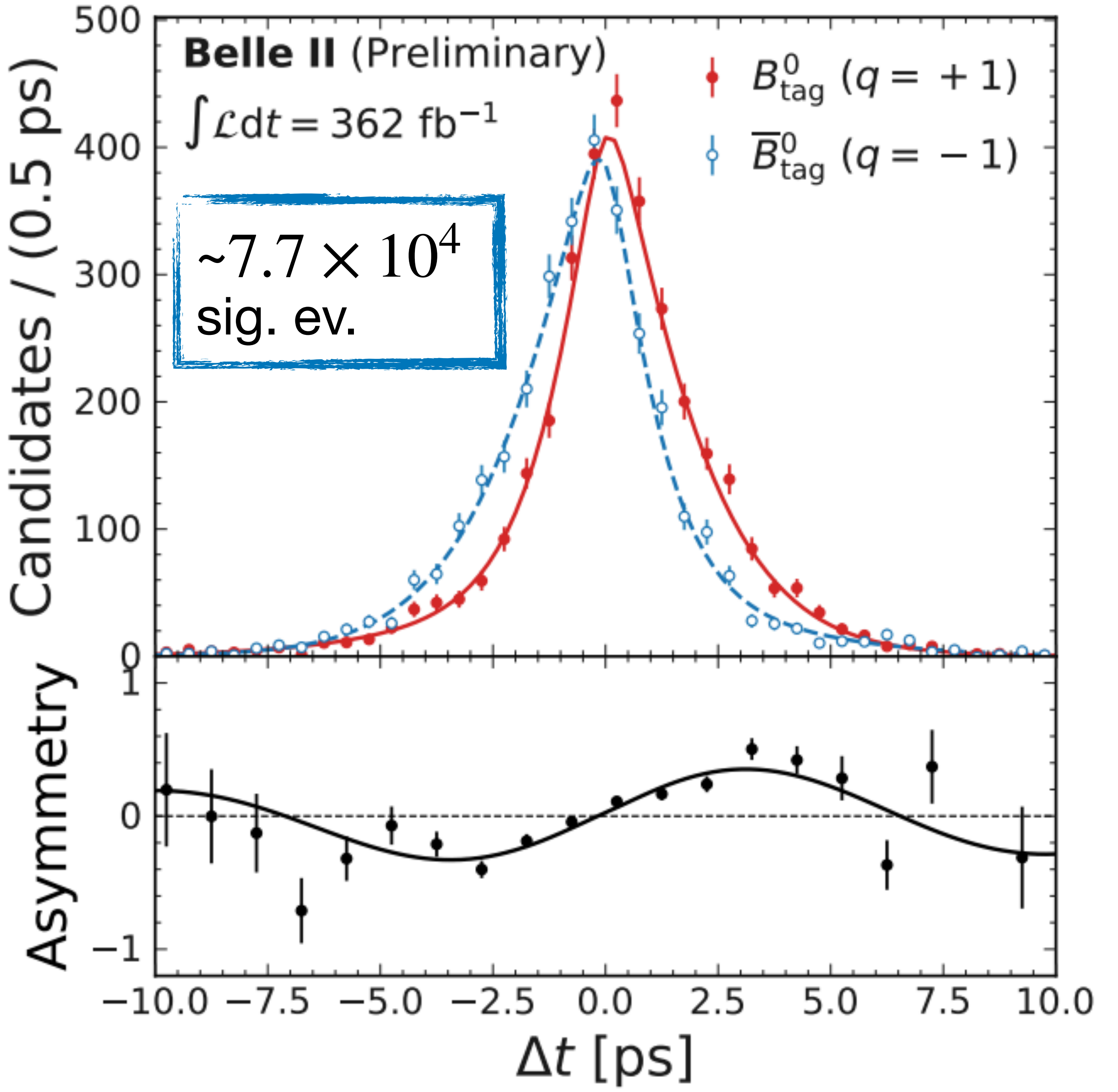


- Time-Dependent Asymmetry from $B^0 \to J/\psi K_S^0$
  - **Reference** for measurement of β with gluonic penguins (next slide)
  - **Clean**, **high yield**, channels to benchmark Belle II analysis performance
  - **Validation** of GFlaT performance $\Rightarrow$ 8% reduction of statistical uncertainty

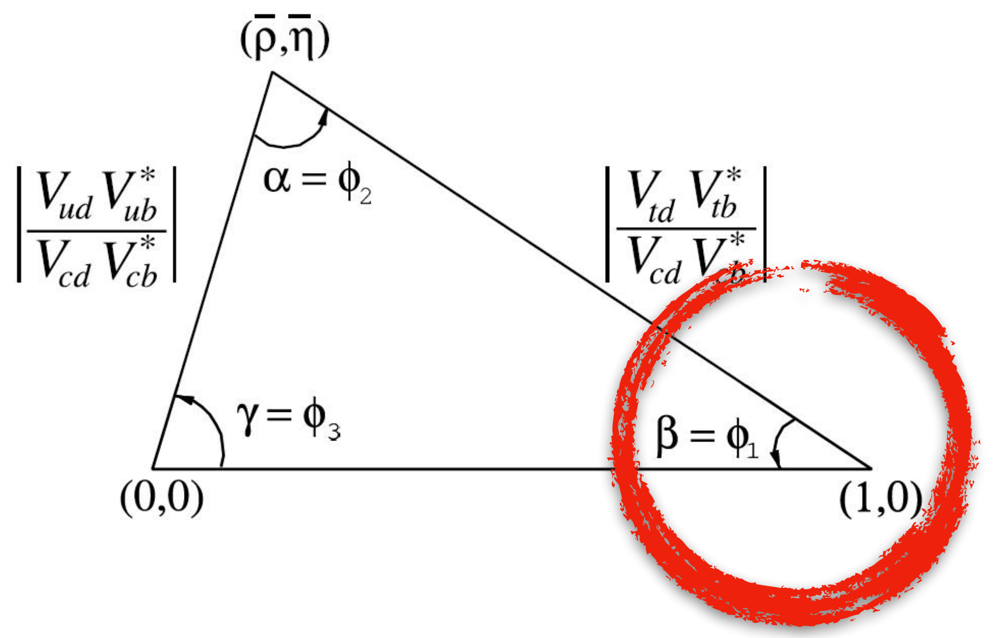
$$S = 0.724 \pm 0.035 \pm 0.014,$$
$$A = -0.035 \pm 0.026 \pm 0.013,$$

Compatible with SM

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



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



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

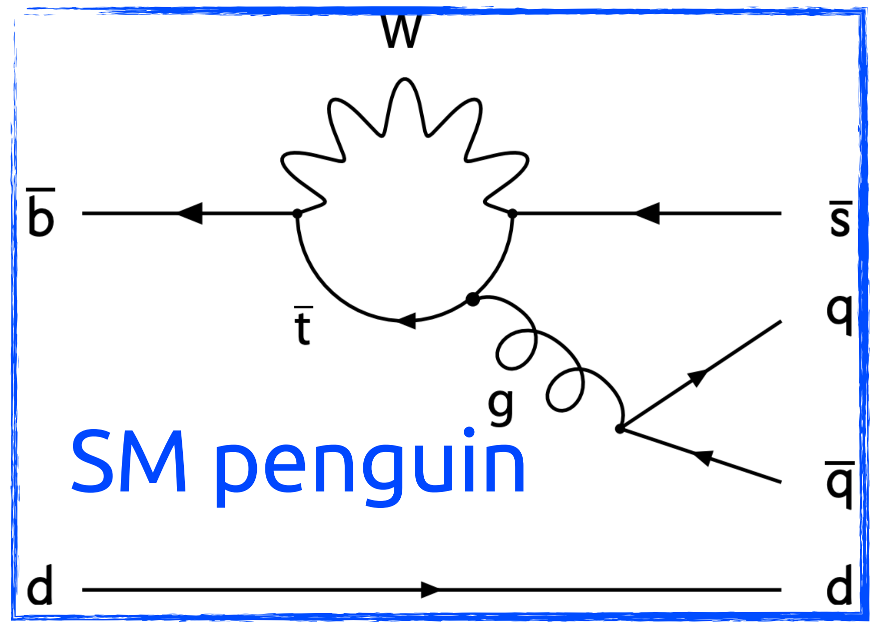
$$A_{\rm CP}(t) = \frac{N(B^0 \to f_{\rm CP}) - N(\overline{B}^0 \to f_{\rm CP})}{N(B^0 \to f_{\rm CP}) + N(\overline{B}^0 \to f_{\rm CP})}(t) = (S_{\rm CP}\sin(\Delta m_d t) + A_{\rm CP}\cos(\Delta m_d t))$$

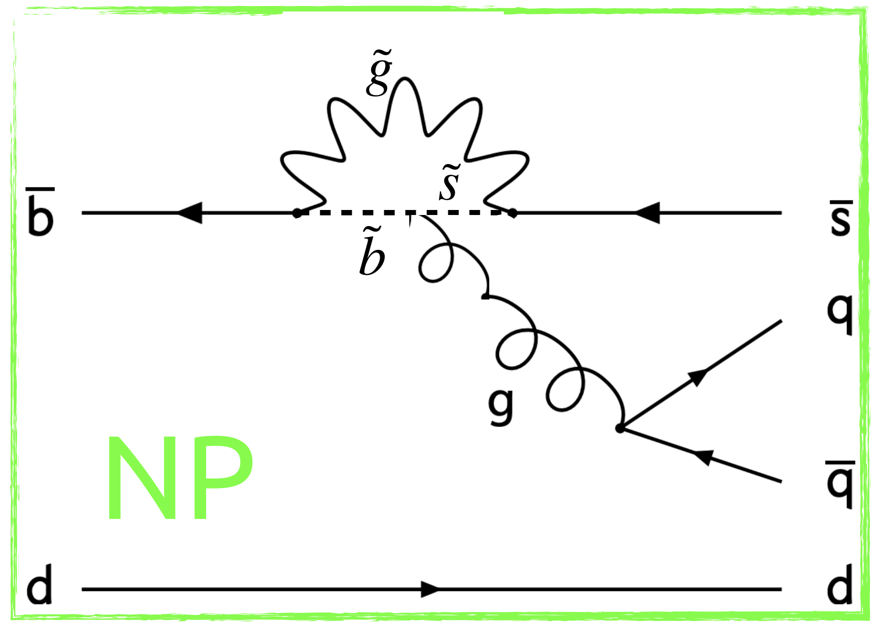
    where $A_{CP} \simeq 0,\ S_{CP} \simeq \pm\sin 2\beta$ in the SM

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

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

$A_{\rm penguin} = \Delta A$

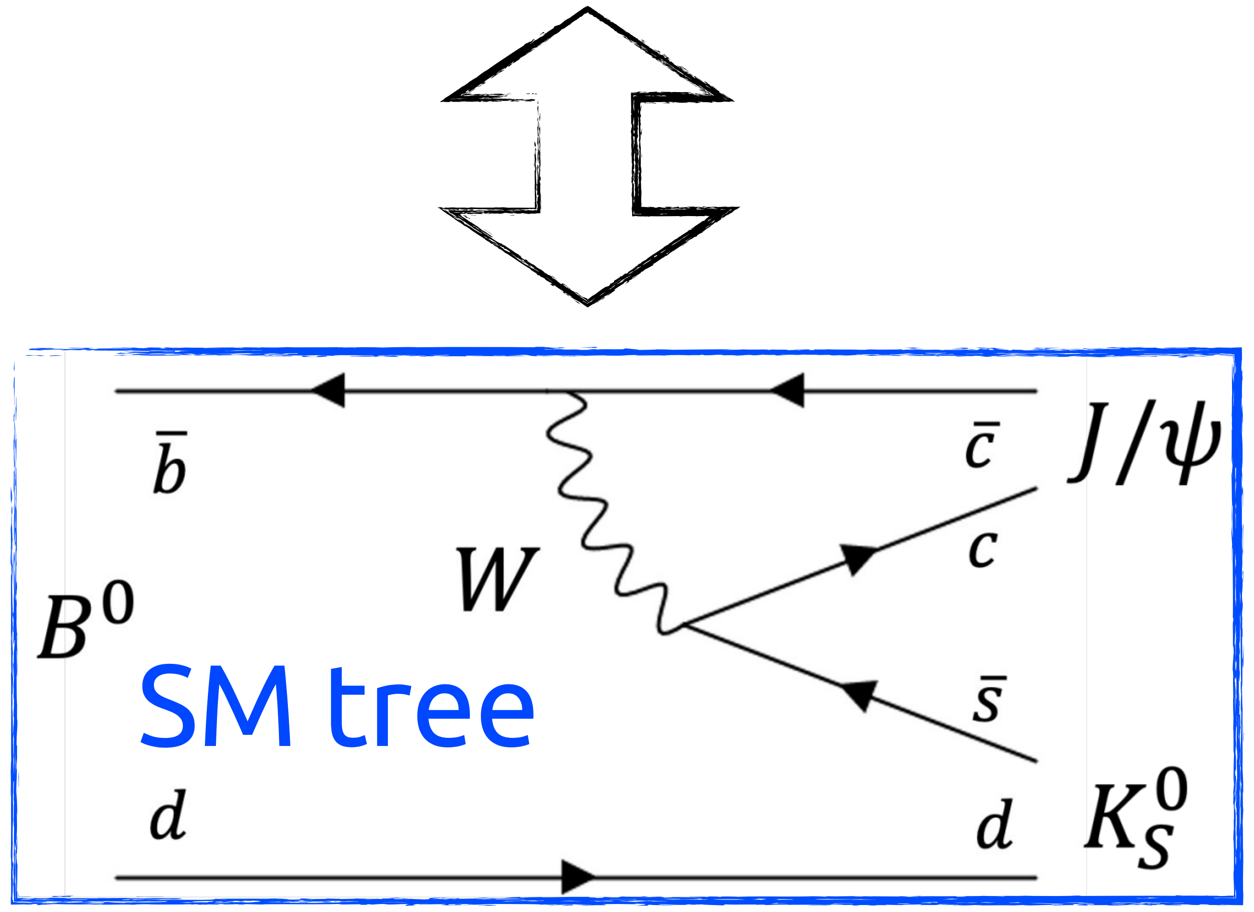




- **Experimentally challenging**:
  - Fully hadronic final state with **neutrals**
  - **Low purity** $\Rightarrow$ dedicated continuum suppression algorithms
  - **Unique** to Belle II

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

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

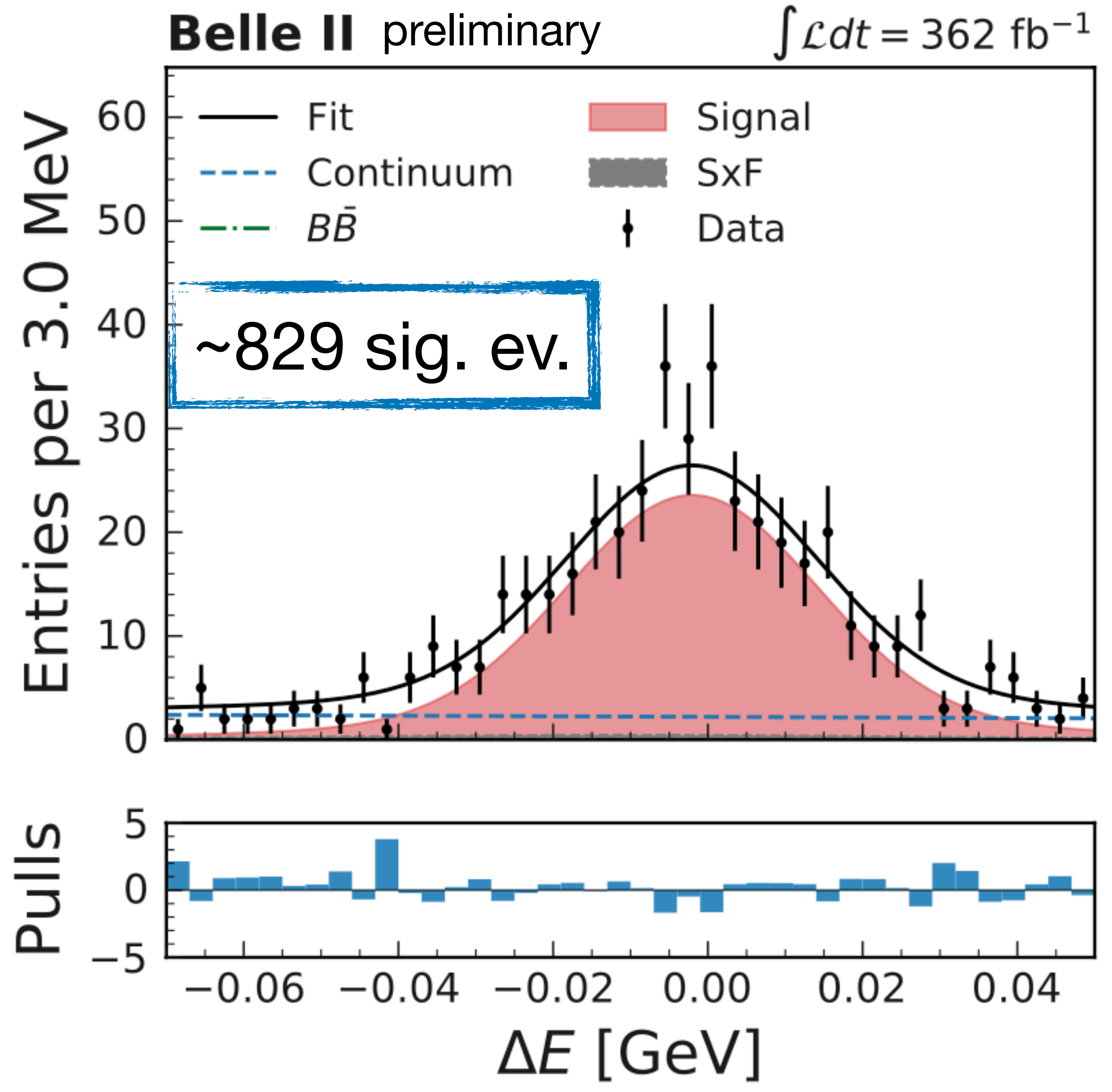


Gluonic penguin: $B^0 \to \eta' K^0_S$

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

Belle II

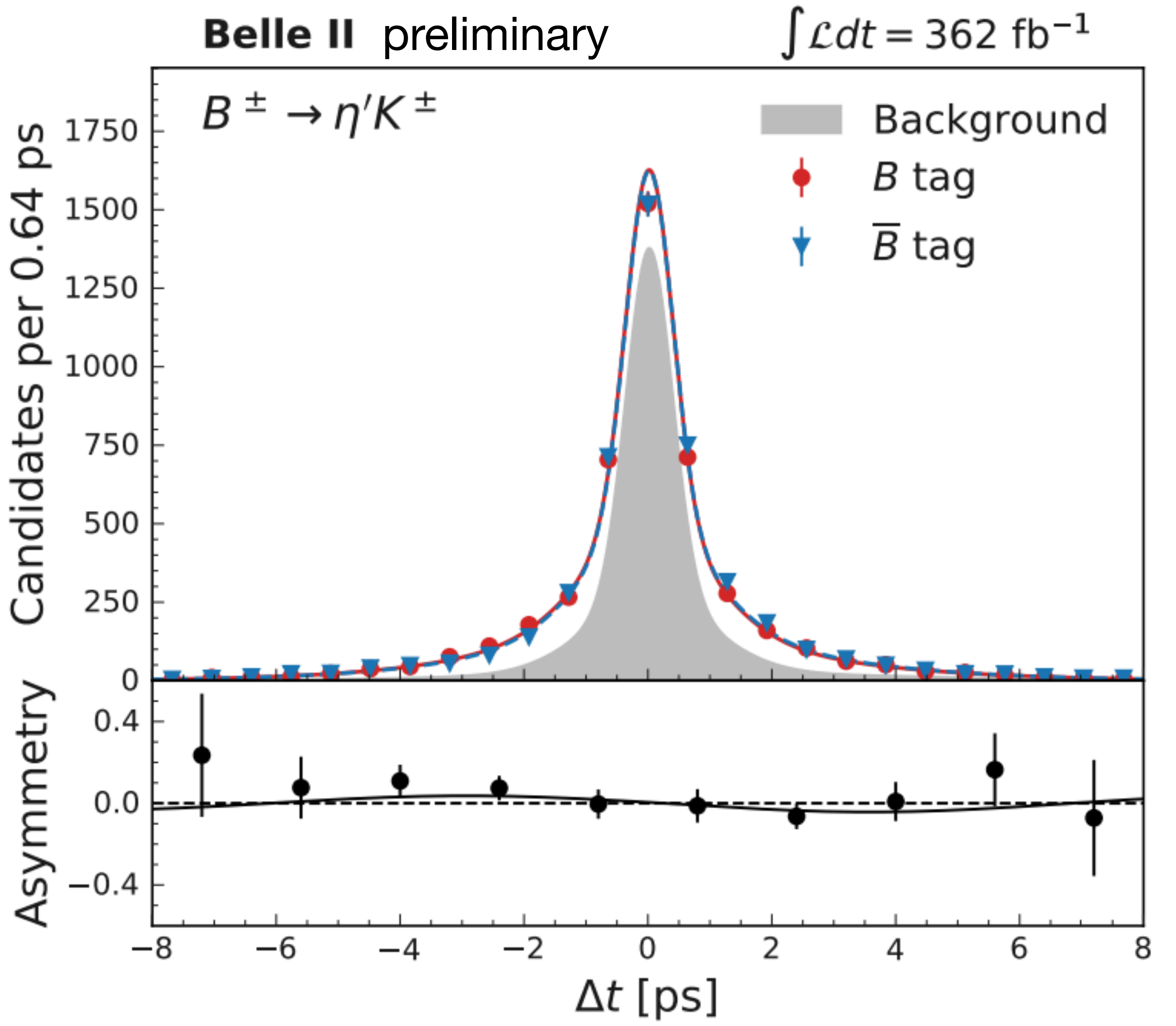
- Two sub-channels:
  - $\eta' \to \eta(\to \gamma\gamma)\pi^+\pi^-$
  - $\eta' \to \rho(\to \pi^+\pi^-)\gamma$
- High bkg from **random tracks** from $q\bar{q}$ events $\Rightarrow$ dedicated BDT
- Fit $(\Delta E, M_{bc}$, BDT output)
  - Bkg Δt shape from sideband
  - Bkg asymmetry included in the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



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

Compatible with SM

Precision compatible with Belle/ Babar



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

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

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

Belle II

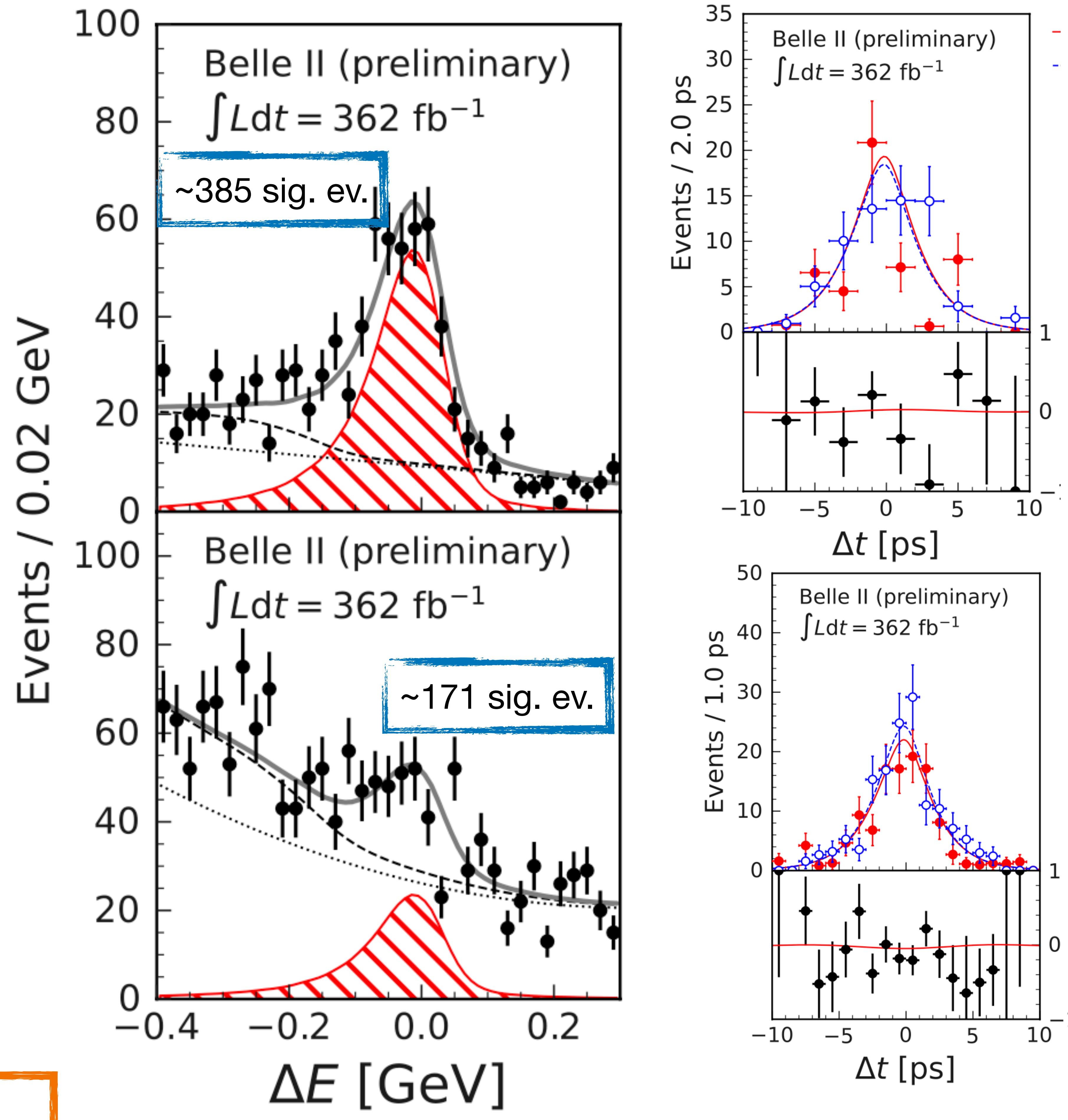
- **Photon polarization** constrained by flavor $\Rightarrow$ interference (i.e. TDCPV) helicity suppressed ($\sim m_s/m_b$) $\Rightarrow S_{CP}$ **sensitive to NP**
- Considered:
  - Exclusive decays $B^0 \to K^{*0}(\to K_S^0 \pi^0)\gamma$
  - Inclusive decays $B^0 \to K_S^0 \pi^0 \gamma$
- Challenge: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

Most precise result and compatible with SM

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

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

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



Top plots: $B^0 \to K^{*0}\gamma$
Bottom plots: $B^0 \to$ non-$K^{*0}\gamma$

Improving B and D decays knowledge

B-tagging at Belle II

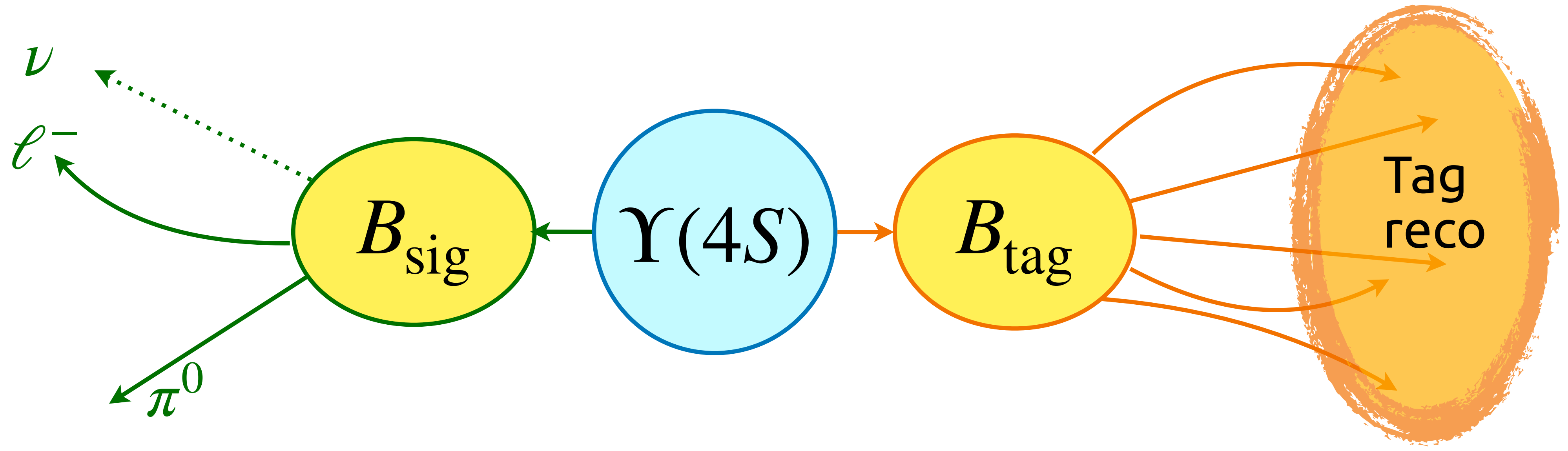
In channels with **missing energy** ⇒ use of the the **Rest of the Event (ROE)** information:

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

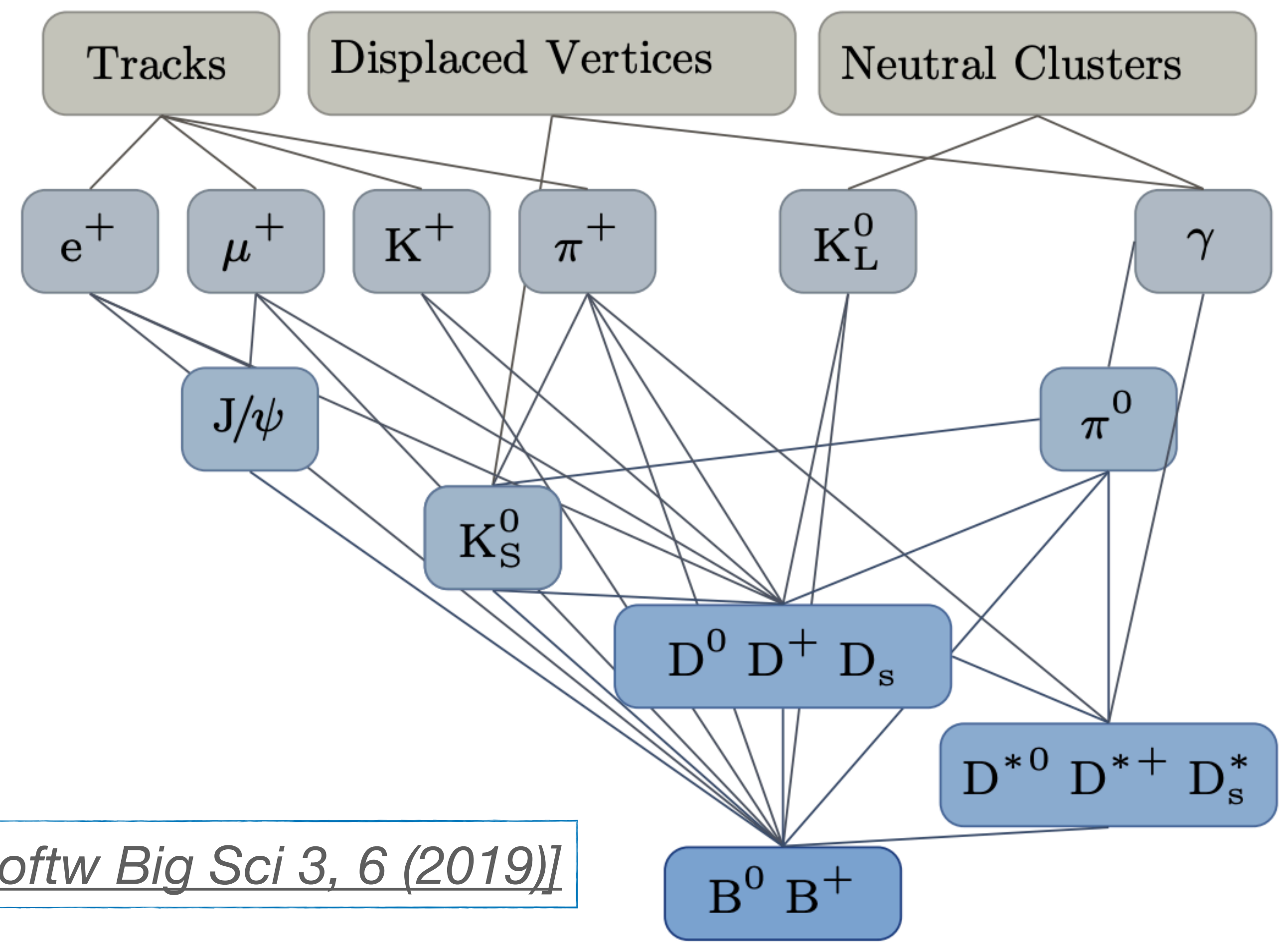
Step 2: Using the $\Upsilon(4S)$ constraint, infer the information on the second B (B_{sig}): **flavour**, **charge** and **kinematic** constraints

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



Full Event Interpretation (FEI)

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



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

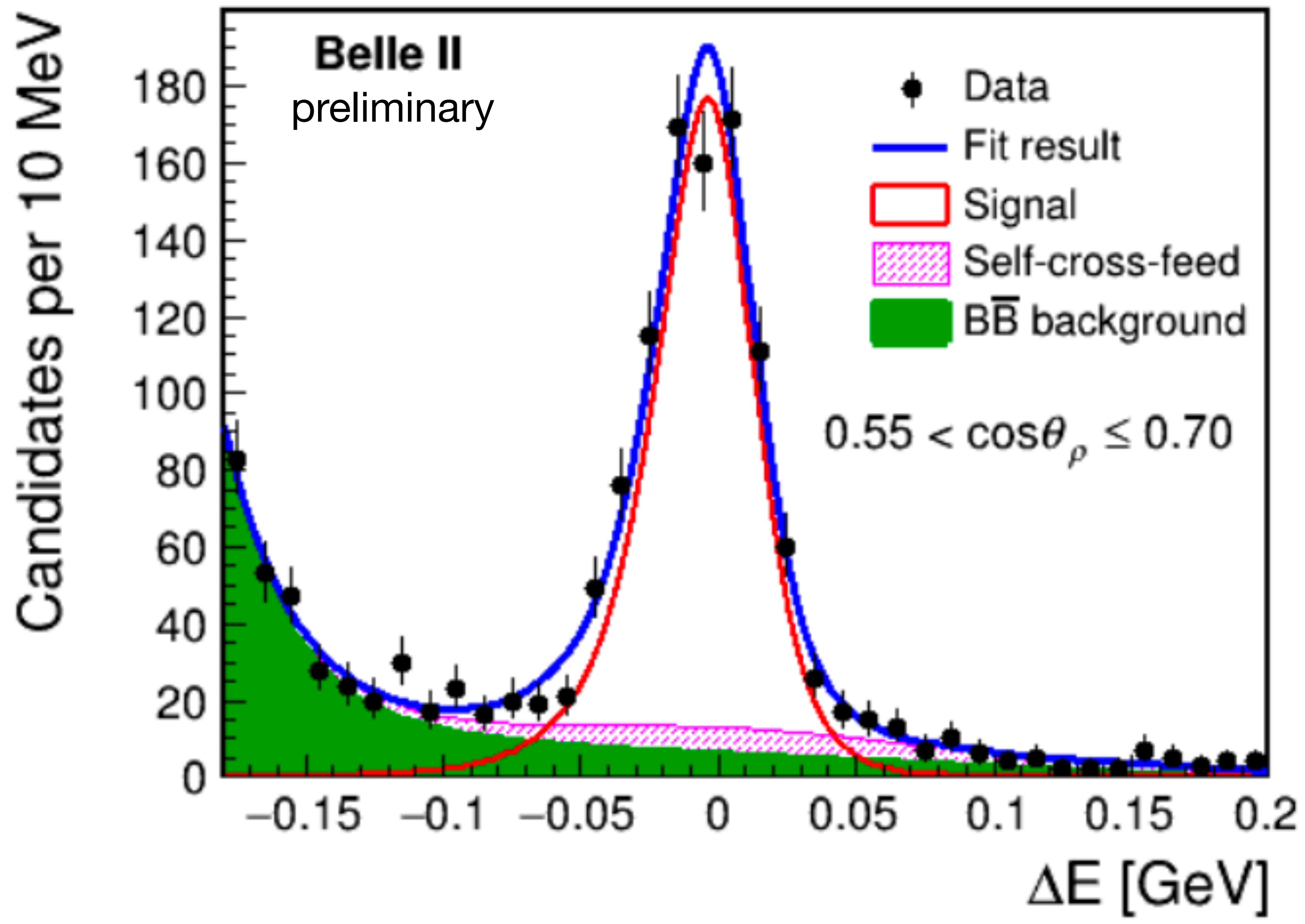
Branching fraction of $B^+ \to D^0\rho(770)^+$

NEW for La Thuile

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

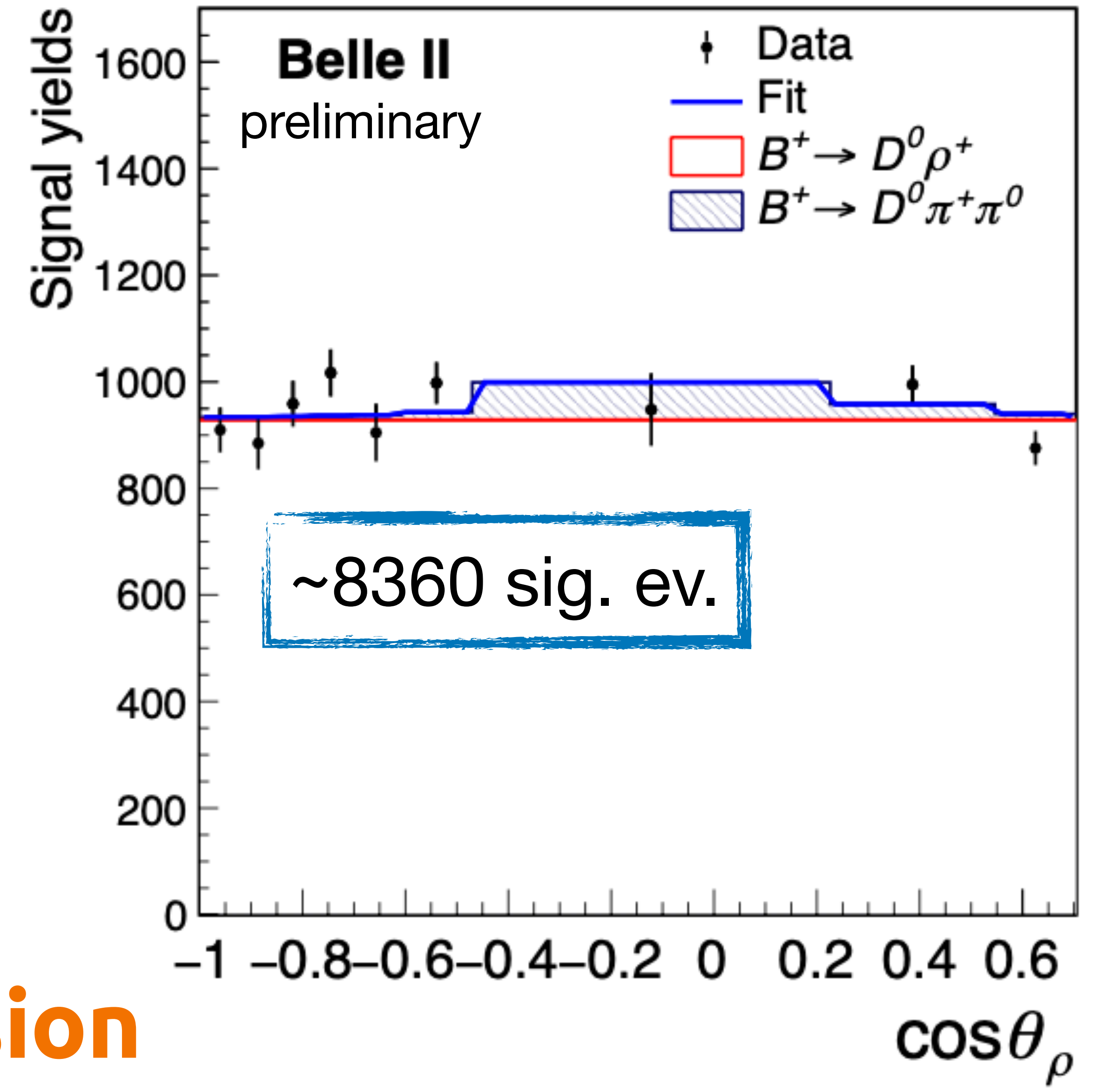
Belle II

- Motivations:
  - $B^+ \to D^0\rho^+$ is one of the main modes of **hadronic B-tagging** $\Rightarrow$ improvement in the BF has a direct impact on large part of Belle II physics program
  - One of the ingredient to test heavy-quark limit and factorization models



- signal extracted from ΔE in bin of **helicity angle**, to separate $B \to D^0\rho(\to \pi^+\pi^0)$ signal from bkg $B \to D^0\pi^+\pi^0$

- Systematically limited, by π^0 efficiency



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

World best result, factor 2 improvement in precision

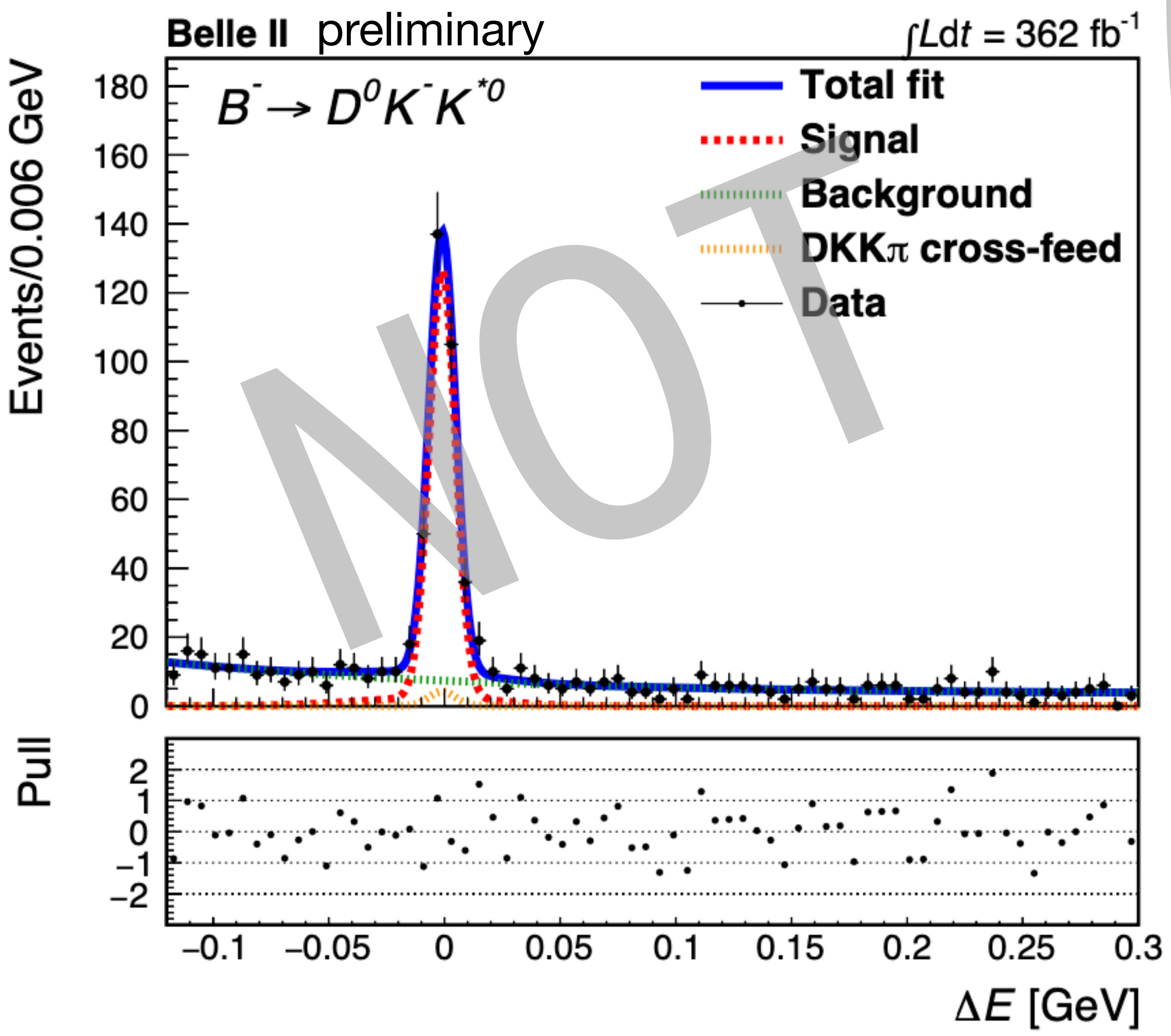
$B \to D^{(*)}K^-K^{(*)0}_{(S)}$ and $B \to D^{(*)}D_s^-$

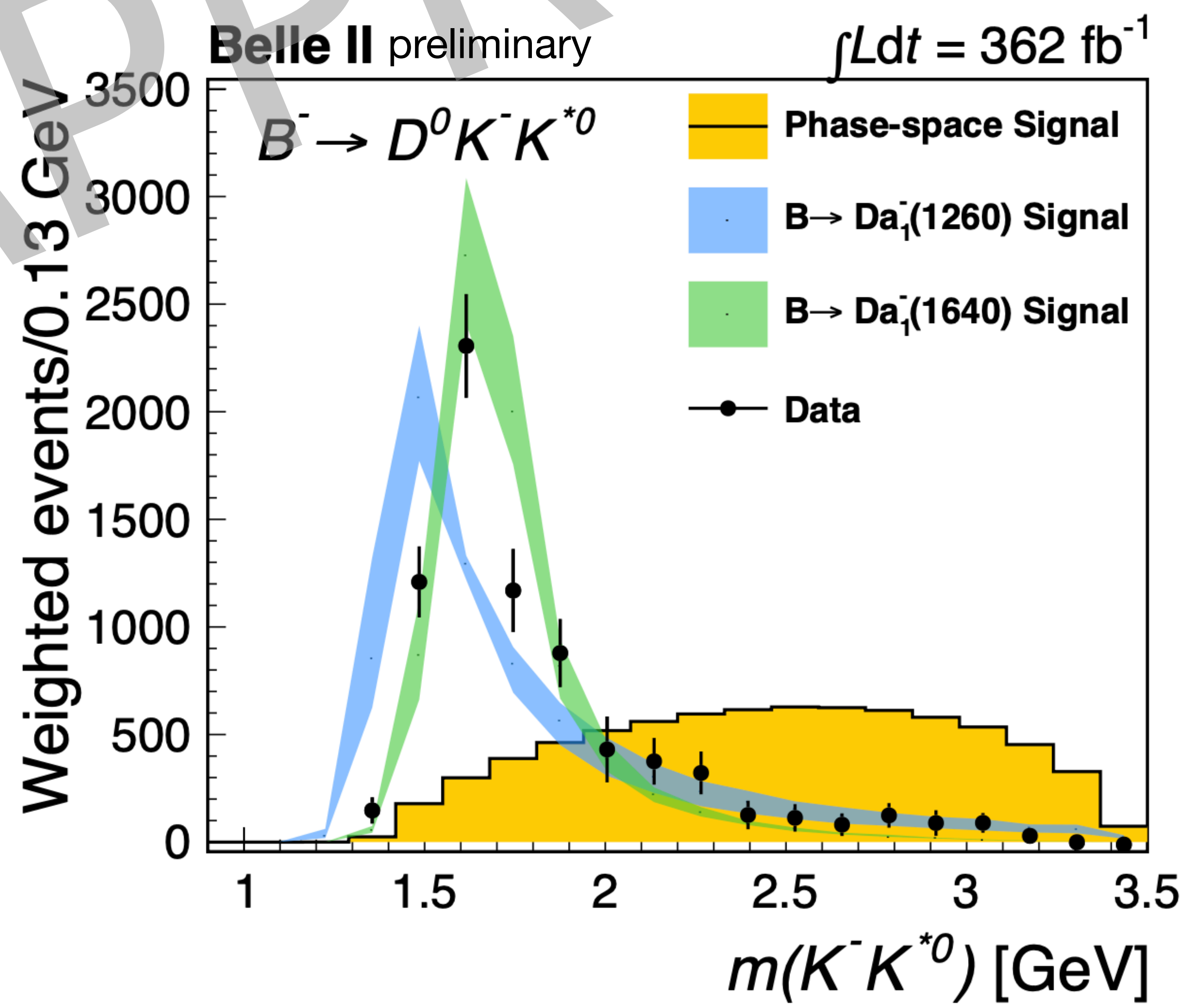
NEW for La Thuile

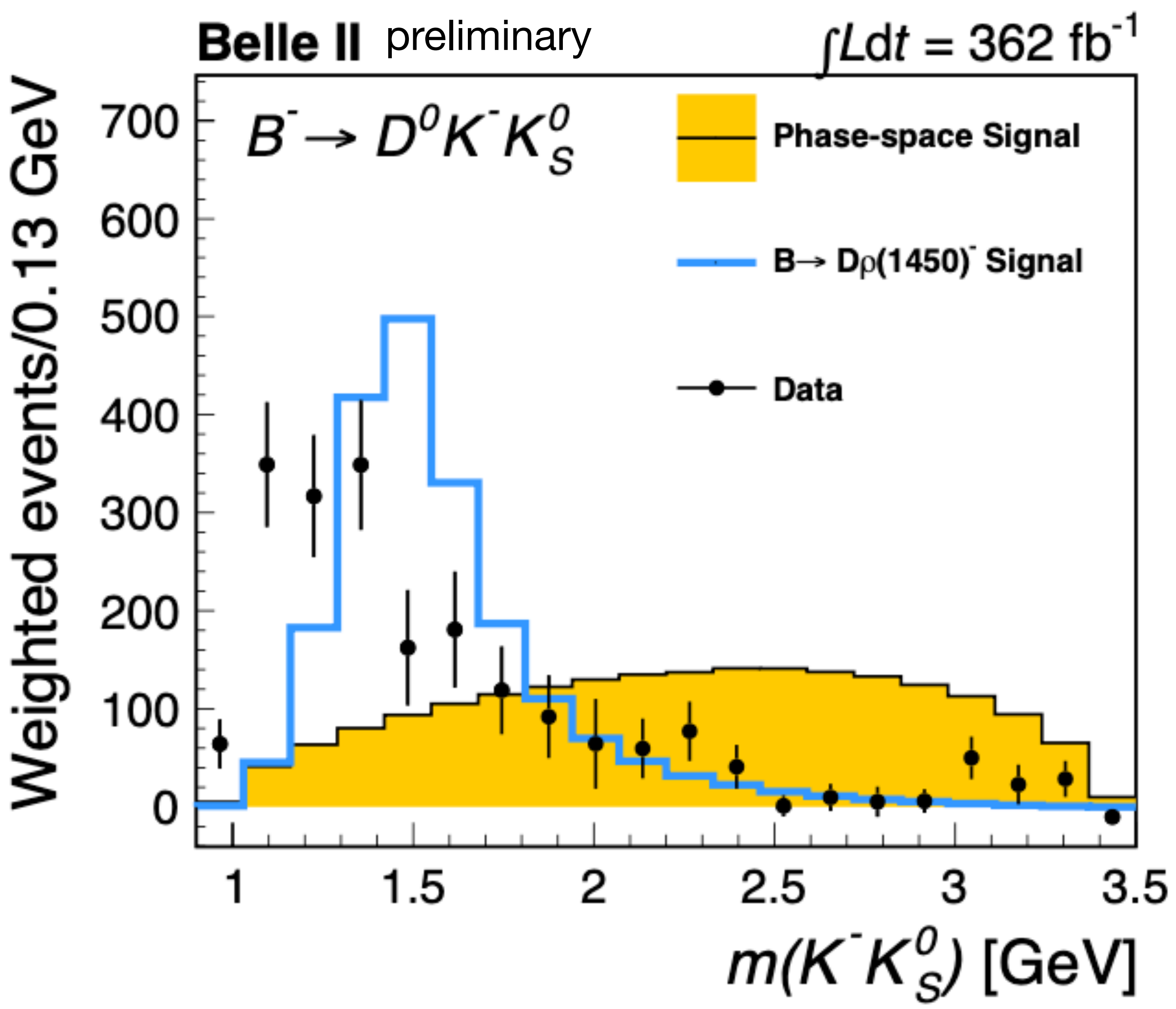
$362\ \text{fb}^{-1}$

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
- **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 *(values in the backup)*
- **World best measurements** for $B \to D^{(*)}D_s^-$, reconstructed in $D_s^- \to K^-K^0_S$ and $D_s^- \to K^-K^{*0}$ *(values in the backup)*
- Low-mass **structures** observed in $m(K^-K^{*0})$ system, compatible with $J^P = 1^+$ transition (one or more a_1 resonances)
- Low-mass **structures** observed in $m(K^-K^0_S)$ system, with a dominant $J^P = 1^-$ transition (one or more ρ' resonances)







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

NEW for La Thuile

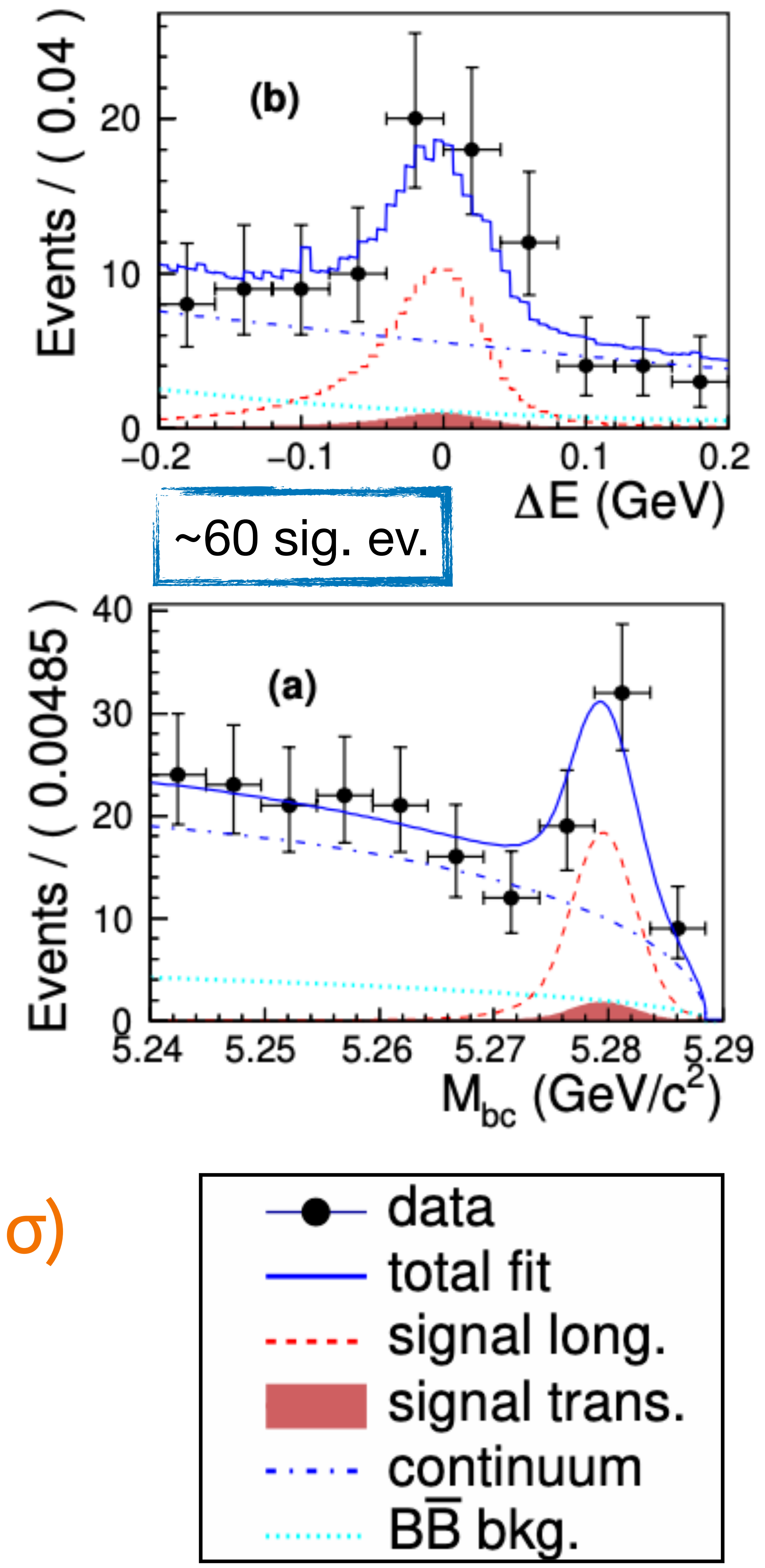
$711\ \text{fb}^{-1}$

BELLE

- It is a rare **never observed** decay

[arXiv:2401.04646]

- 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
- Flavor tagging exploiting Rest-of-Event
- Simultaneous fit for f_L, A_{CP} to 7 kinematic variables



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

First observation of the decay (7.9σ)

f_L as expected, no significant A_{CP}

Branching fraction of $\Lambda_c^+ \to p K_S^0 \pi^0$

NEW for La Thuile

$980\ \mathrm{fb}^{-1}$

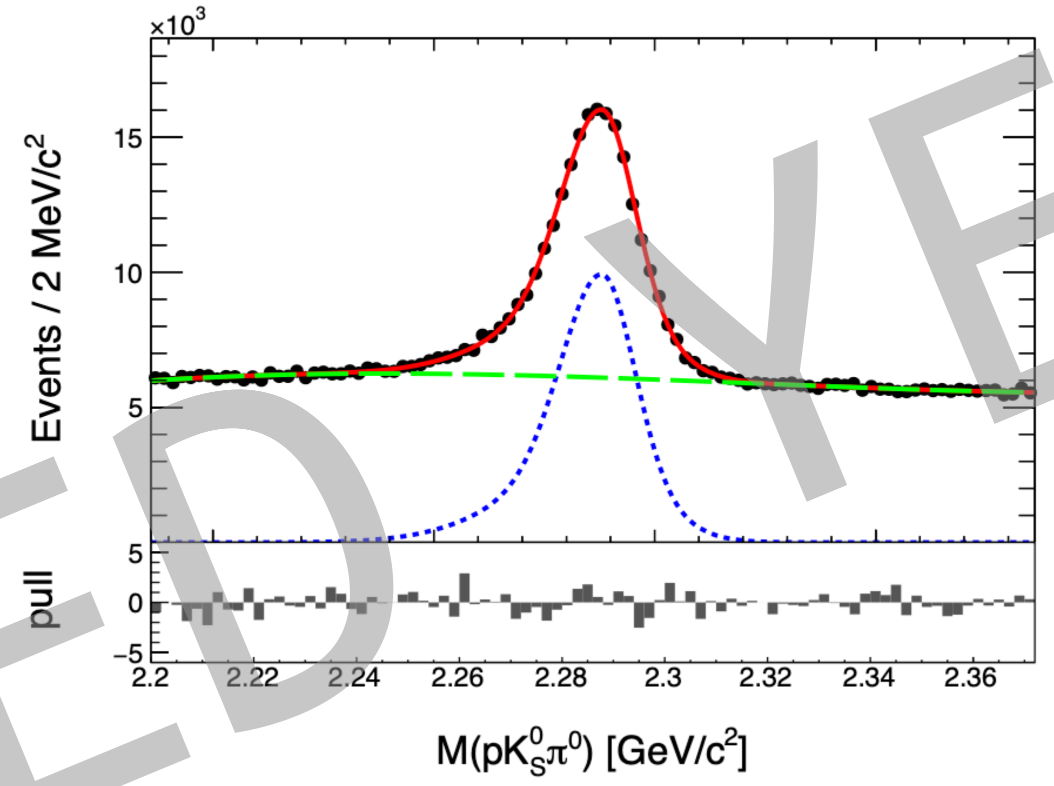
BELLE

- Motivation: important to investigate the isospin properties of the Λ_c and to improve the understanding of this class of decay
- Branching fraction measured relatively to $B(\Lambda_c^+ \to p K^- \pi^+)$
- Signal extraction from $m(pK^-\pi^+)$, $m(pK_S^0\pi^0)$

$$\frac{\mathcal{B}(\Lambda_c^+ \to p K_S^0 \pi^0)}{\mathcal{B}(\Lambda_c^+ \to p K^- \pi^+)} = 0.343 \pm 0.002 \pm 0.009$$

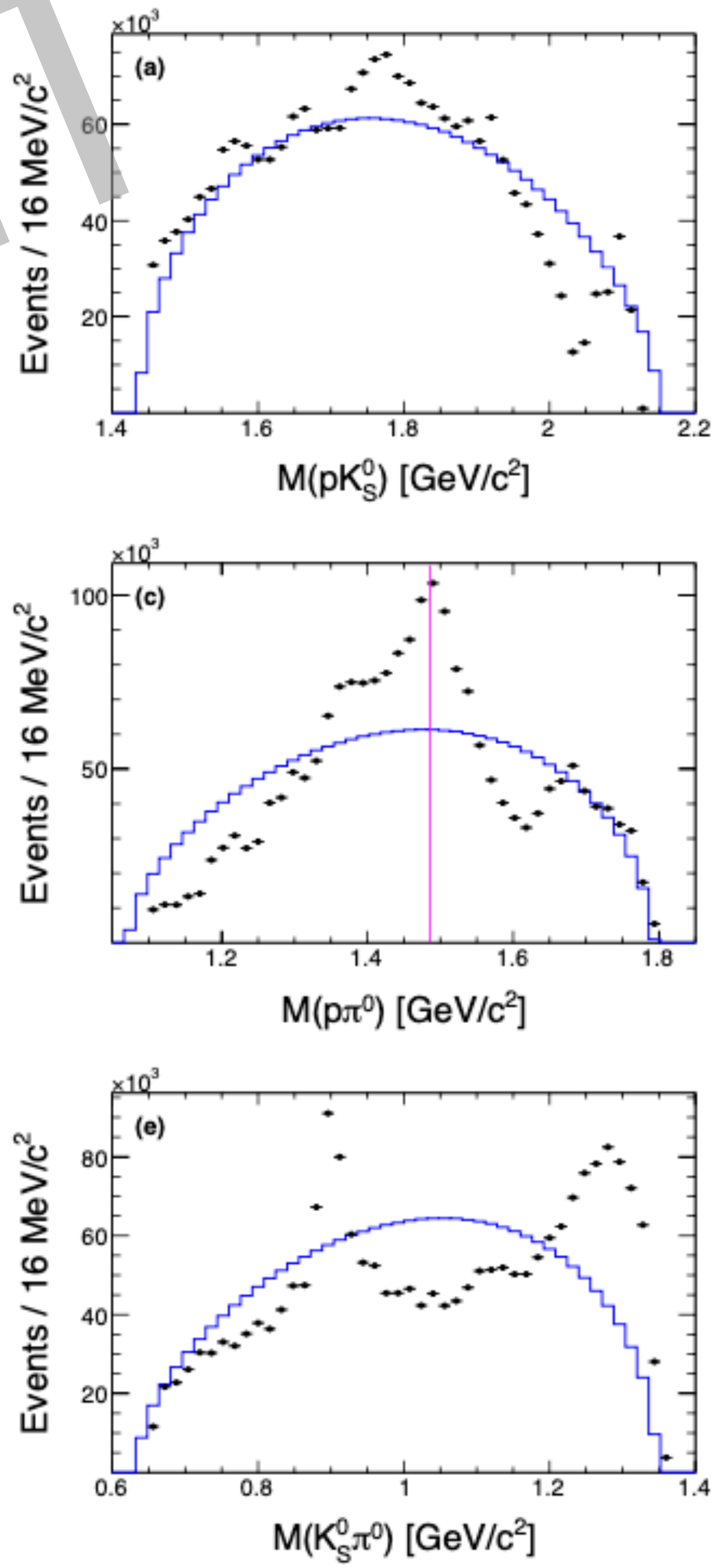
if external is BF assumed

$$\mathcal{B}(\Lambda_c^+ \to p K_S^0 \pi^0) = (2.16 \pm 0.01 \pm 0.05 \pm 0.11)\%$$

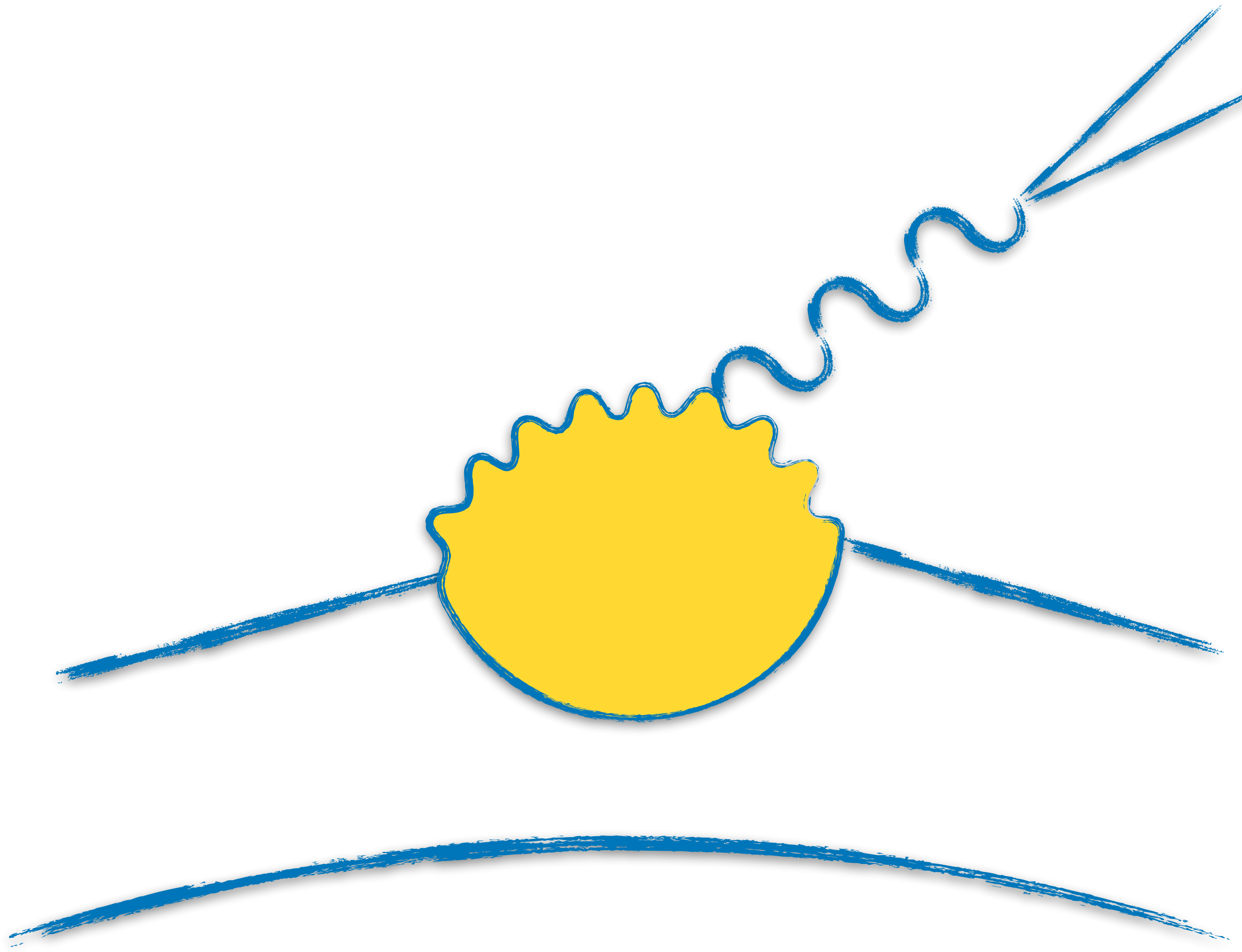


Improvement of a factor 5 compared to previous measurement

Dalitz projections show several structures



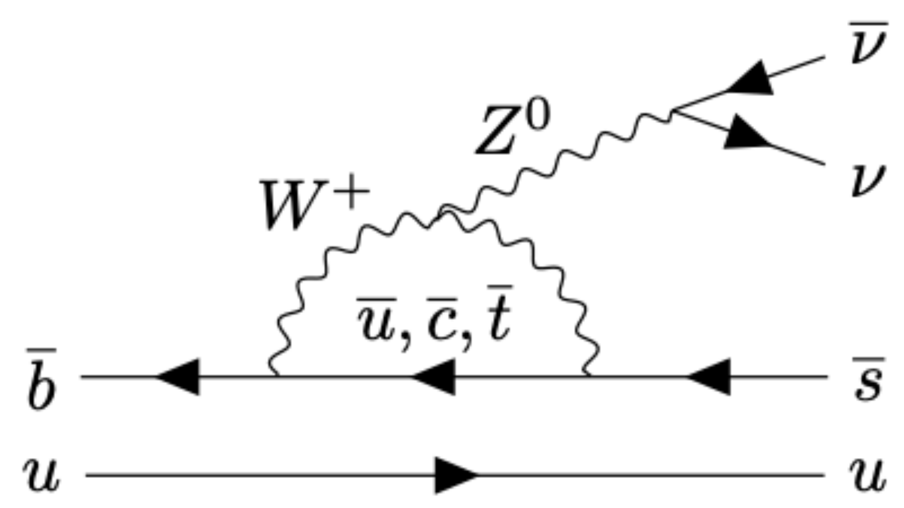
Flavour changing neutral currents
&
lepton flavor universality

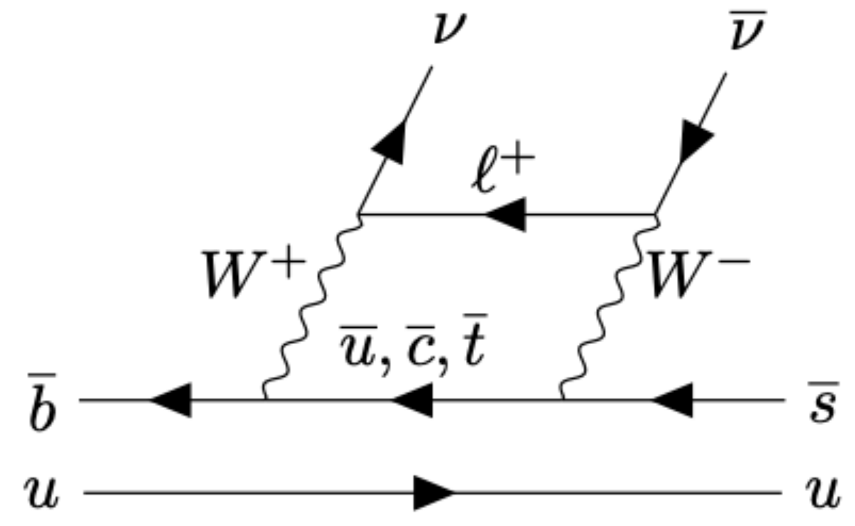


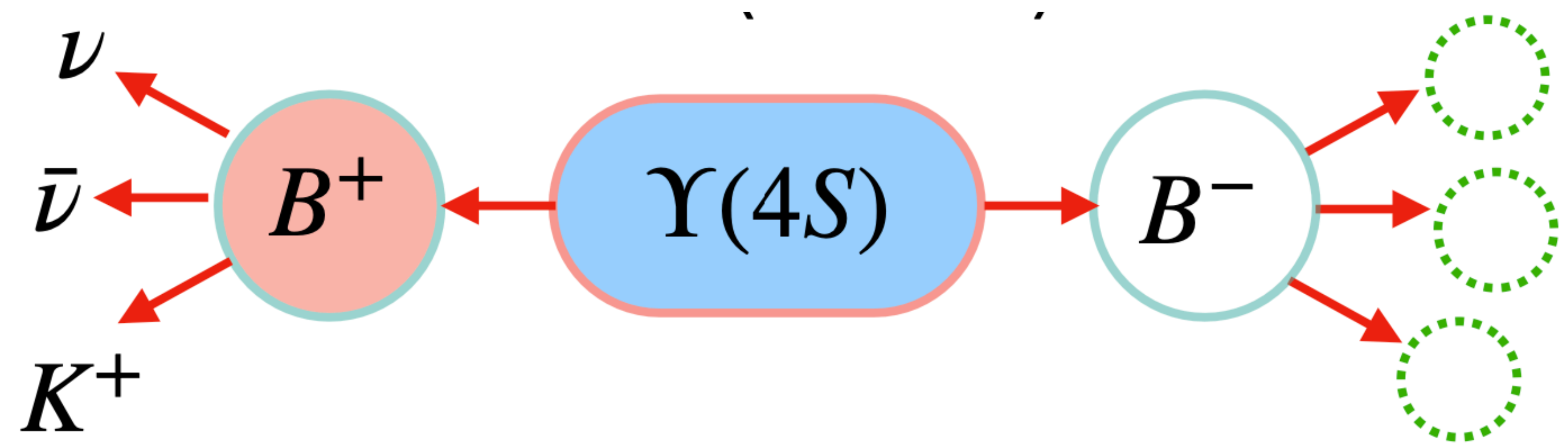
Evidence of $B^+ \to K^+ \nu\bar{\nu}$ (1)

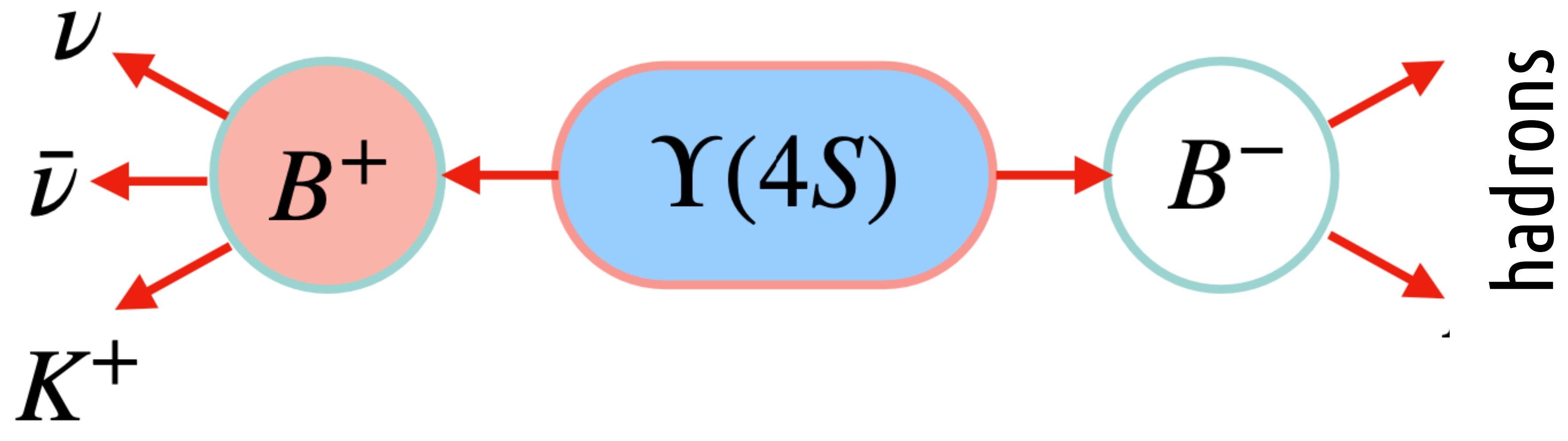
[arXiv:2311.14647] $362\ \mathrm{fb}^{-1}$ Belle II

- 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
- Reconstruction combination of two methods, (almost) statistically indipendent
  - **hadronic-tagging:** higher purity
  - **inclusive tagging:** higher efficiency
- **Bkg suppression and control** is extremely challenging: only one K track, two neutrino in the final state







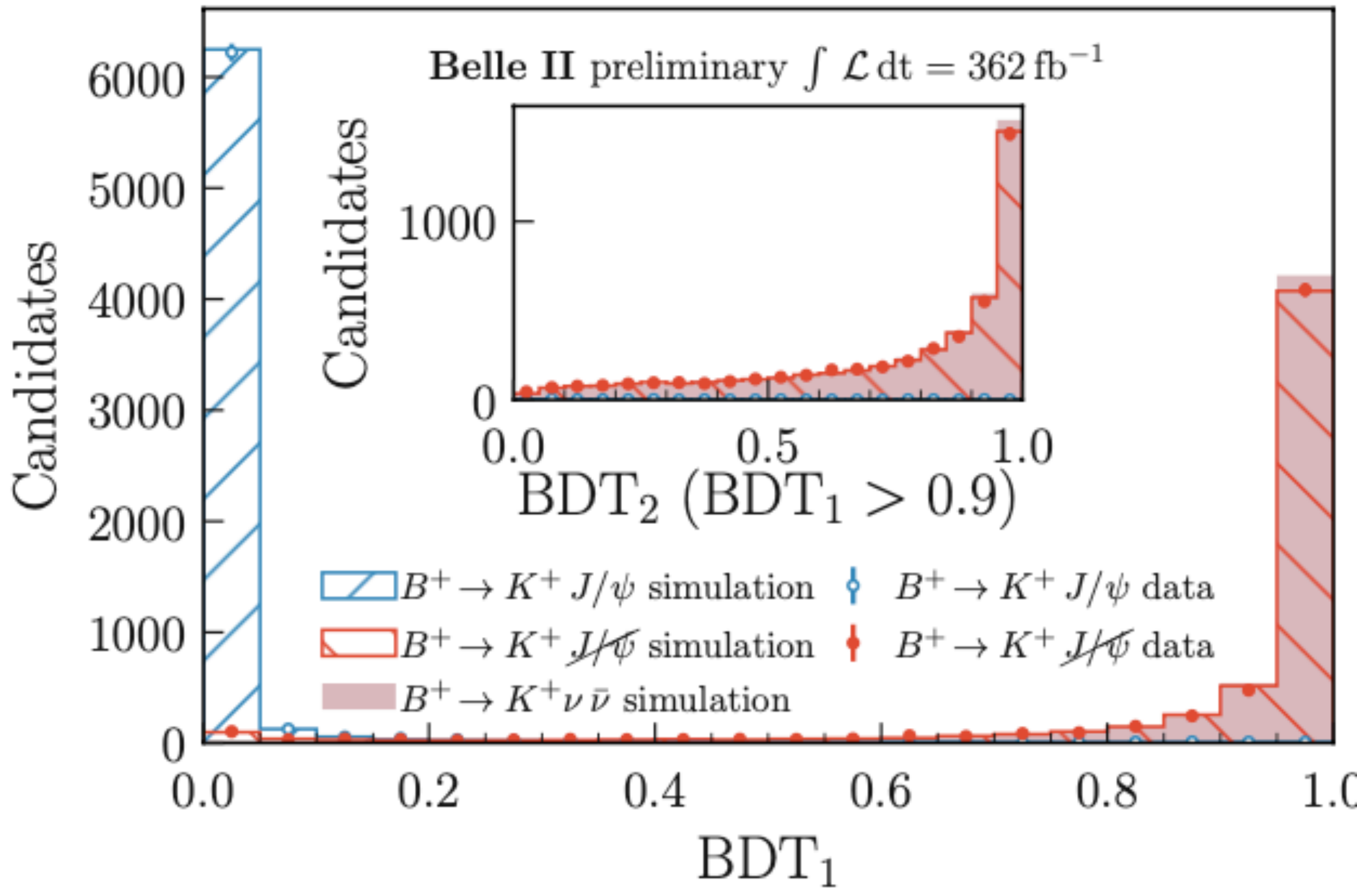


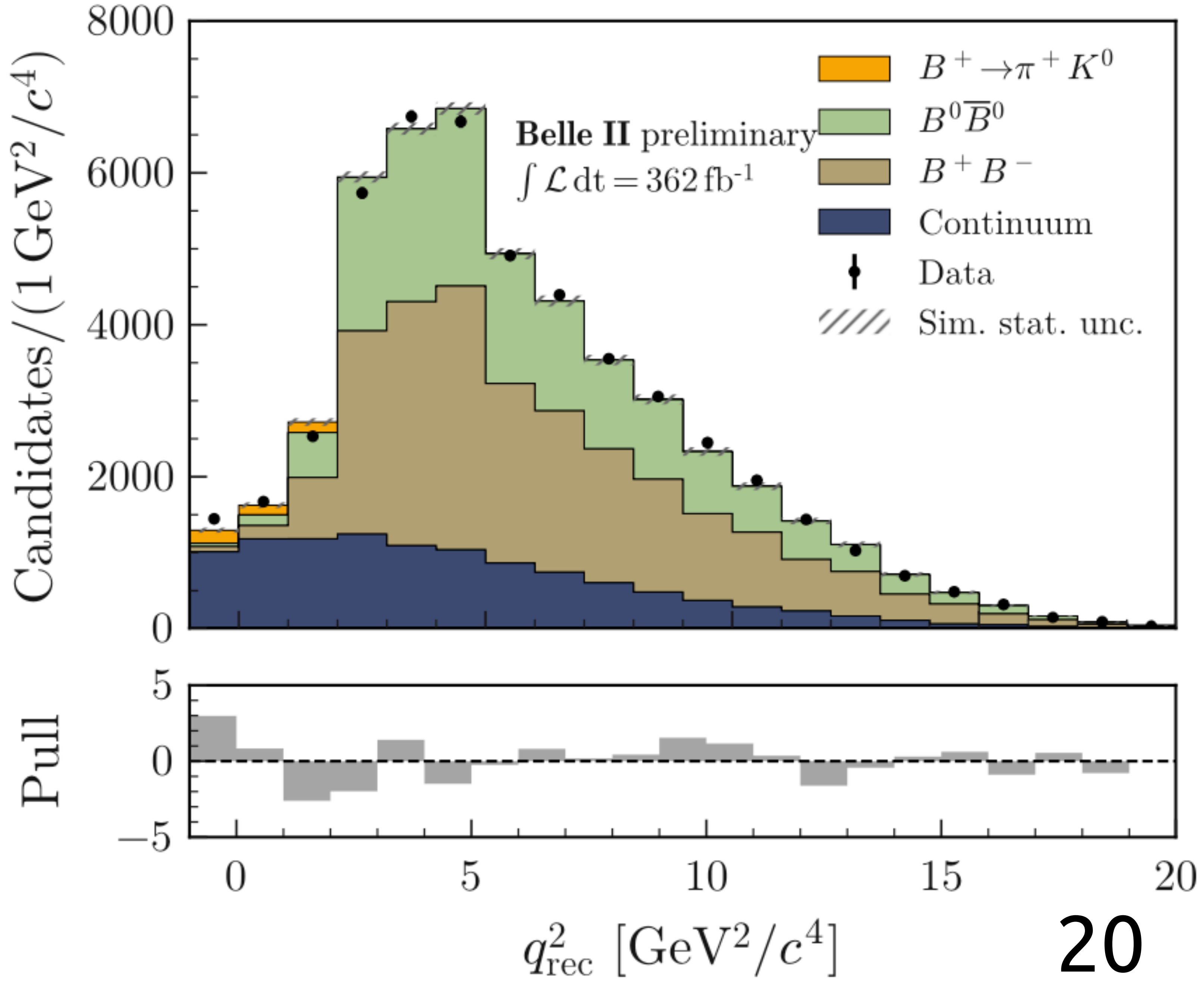
Evidence of $B^+ \to K^+ \nu\bar{\nu}$ (2)

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

Belle II

- Bkg suppressed with **two BDT in cascade** targeting $q\bar{q}$ and other B decays
- **Signal efficiency validated** with $B \to K^+ J/\psi(\to \mu\mu)$, without matching the muons
- **Bkg control validated** with:
  - $ee \to q\bar{q}$ 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 $e^+e^- \to \gamma\phi(\to K_L^0 K_S^0)$
  - $B \to K^+ K^0 K^0$ bkg simulation constrained with previous measurements ($B \to K^+ K_S^0 K_S^0$, $B \to K^+ K^- K_S^0$)
- **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 PDG





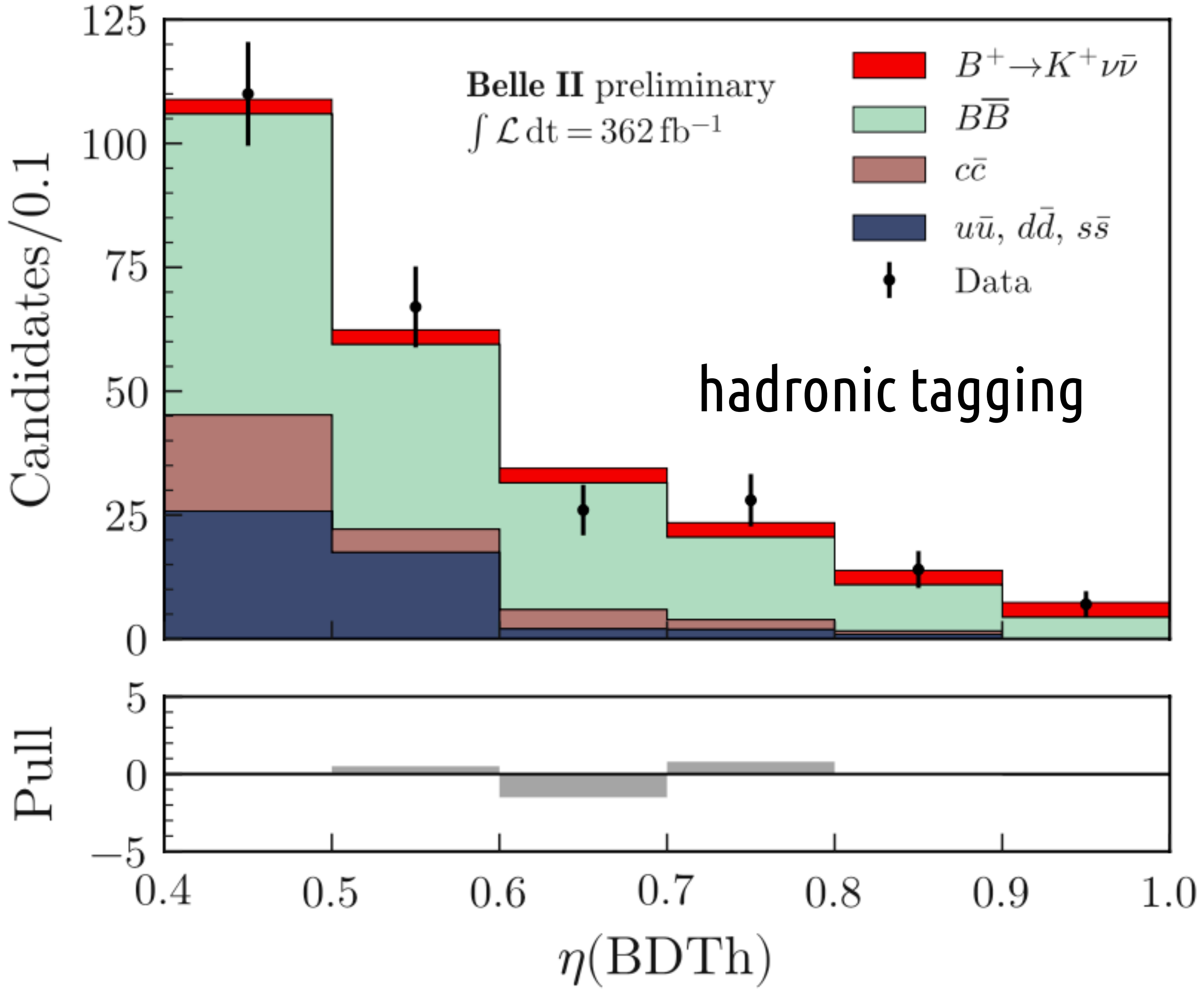
Evidence of $B^+ \to K^+ \nu \bar{\nu}$ (3)

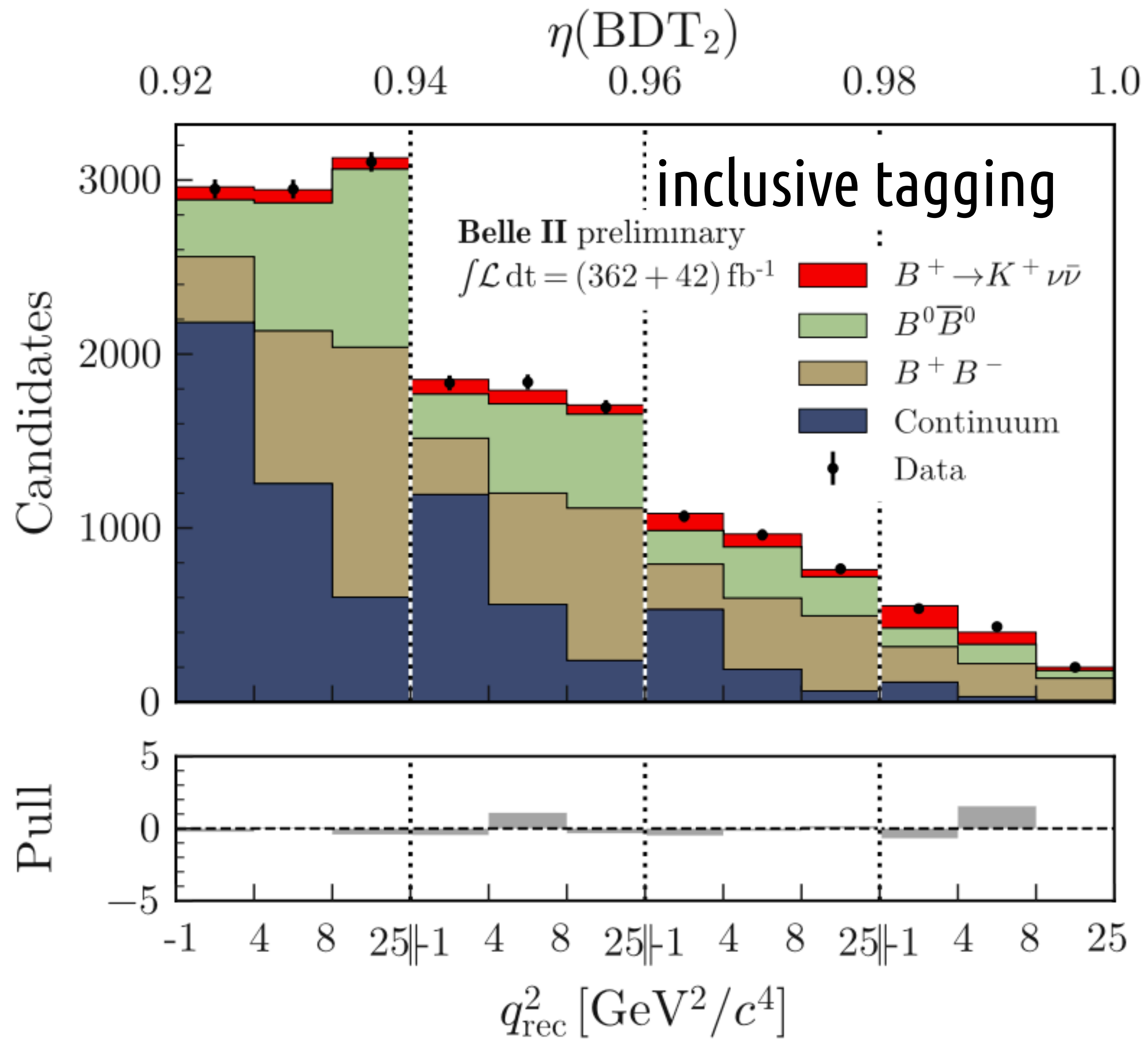
[arXiv:2311.14647] $362\ \mathrm{fb}^{-1}$

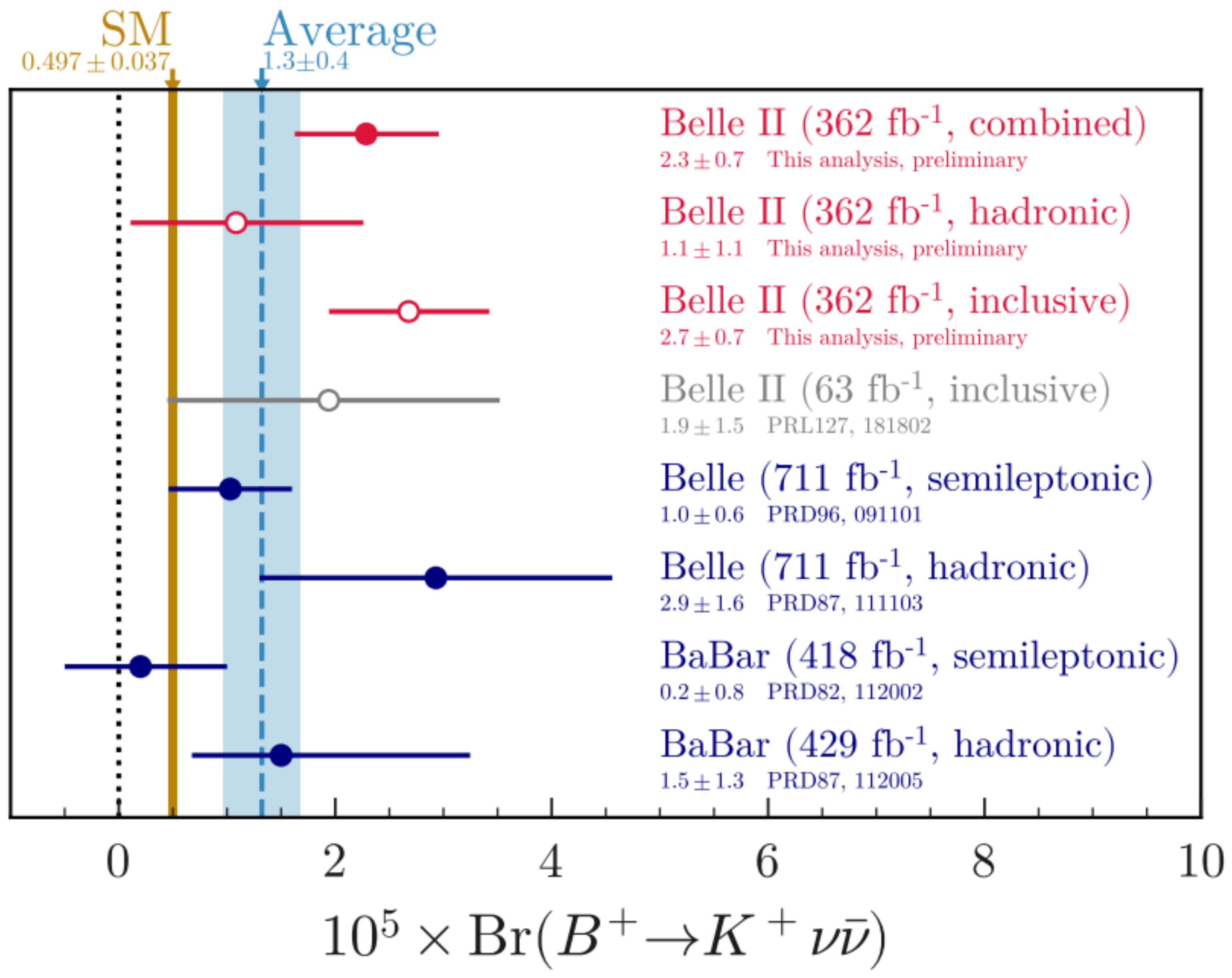
Belle II

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

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







Combined result:

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

$$BR(B^+ \to K^+ \nu\nu) = [2.4 \pm 0.5(\mathrm{stat})^{+0.5}_{-0.4}(\mathrm{syst})] \times 10^{-5}$$

3.5σ above the bkg-only hypothesis

2.7σ above the SM prediction

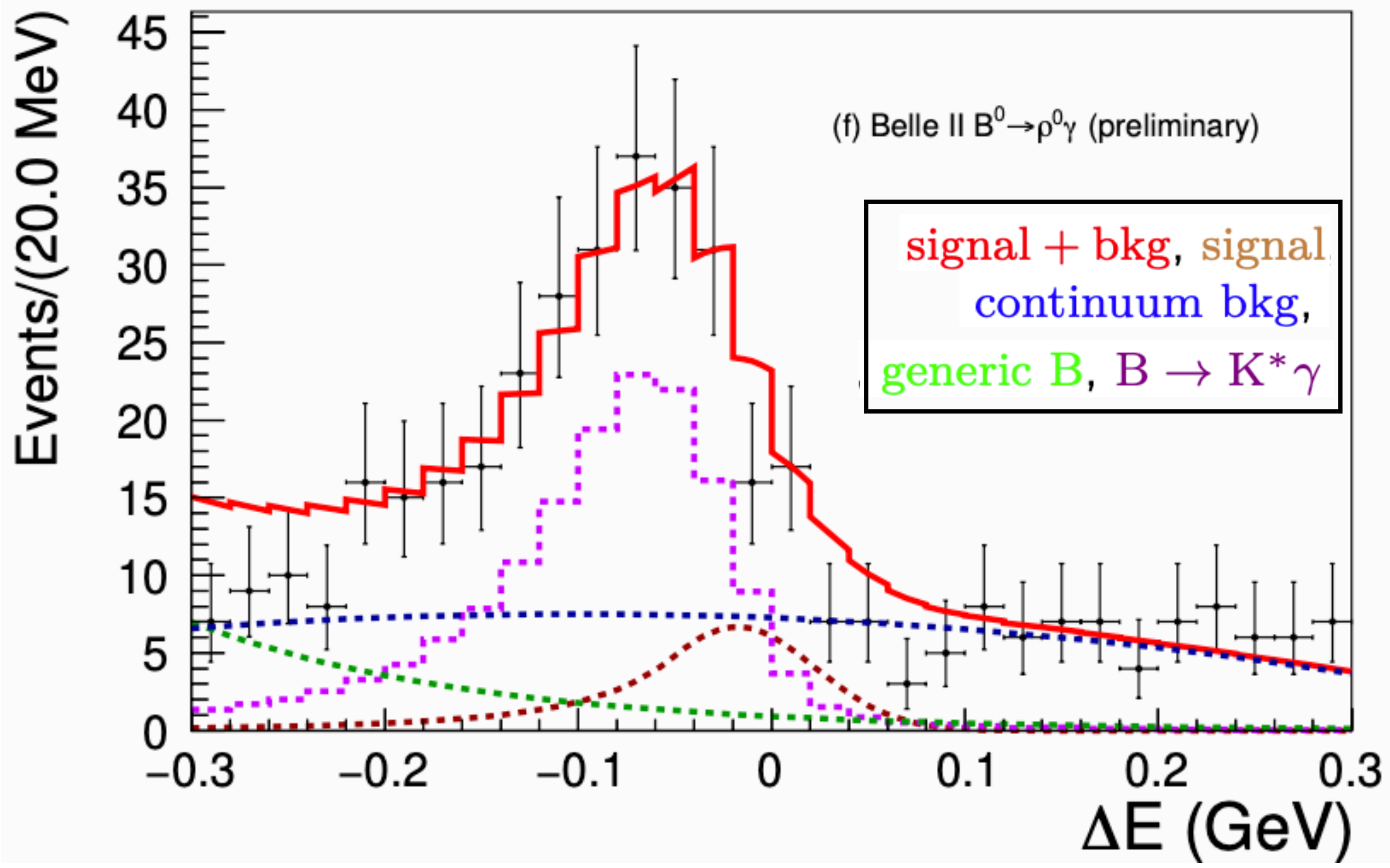
Branching fraction and isospin asymmetries of $B \to \rho\gamma$

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

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

- Motivations:
  - $b \to d\gamma$ **FCNC** $\Rightarrow$ extremely suppressed in the SM, BF are one order of magnitude smaller than $b \to s\gamma$ and possibly **sensitive differently to NP**
  - $B \to \rho\gamma$ has been already observed and the **isospin asymmetry is currently 2σ from the SM**
- $B^+ \to \rho^+(\to \pi^+\pi^0)\gamma$ and $B^0 \to \rho^0(\to \pi^+\pi^-)\gamma$ reconstruction
- Fit to $(\Delta E, M_{bc}, m(\pi\pi))$
- Challenging due to $B \to K^*\gamma$ bkg (when K is misreconstructed)

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



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

World beast measurement for BFs

A_I compatible with SM

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

NEW for La Thuile

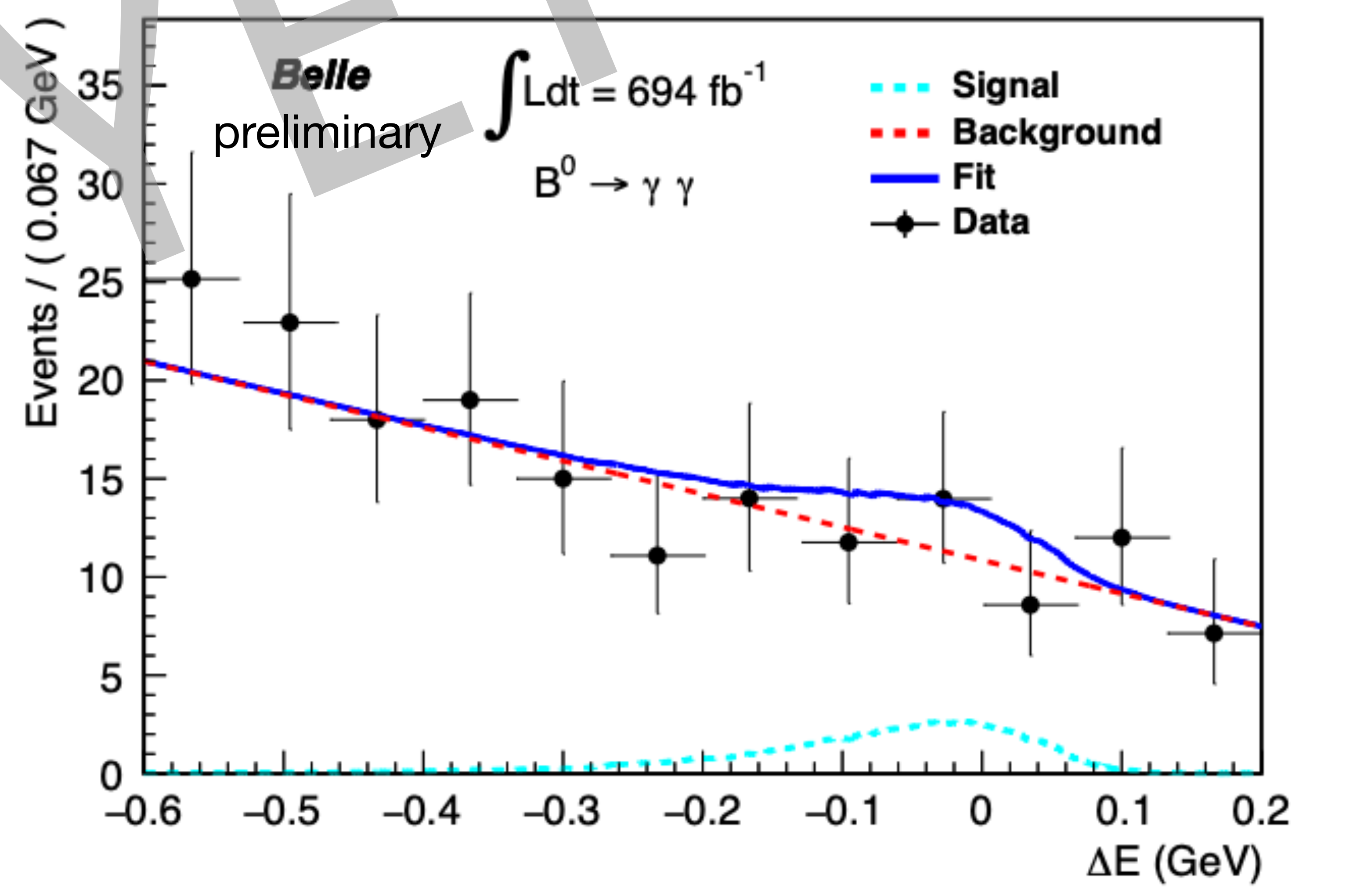
$362\ \text{fb}^{-1}$ Belle II

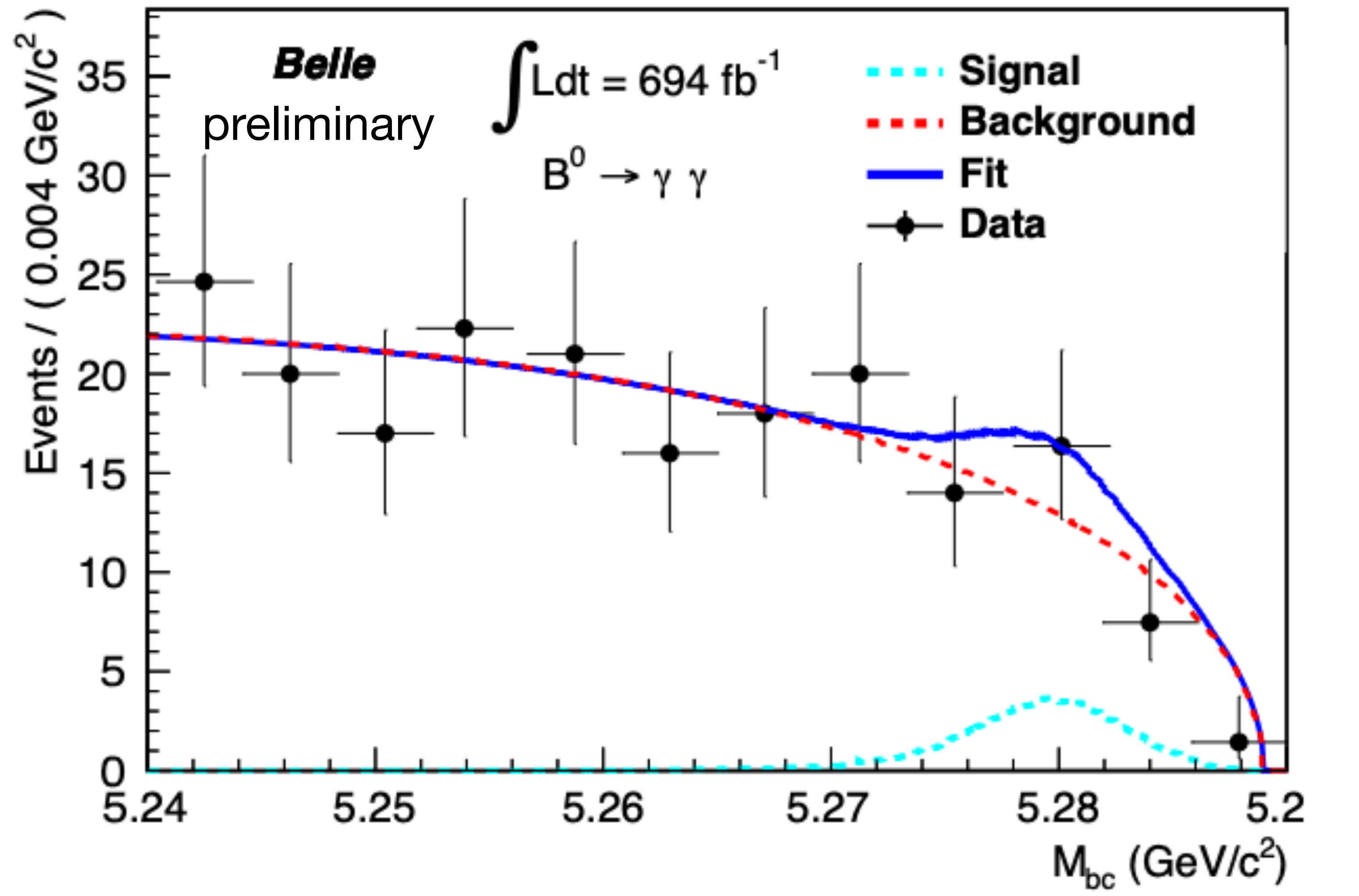
$711\ \text{fb}^{-1}$ BELLE

Dedicated YSF talk later 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 $q\bar{q}$ bkg
- Fit to $(\Delta E, M_{bc}$, BDT output)
- No signal observed (2.5σ significance)
- **world best upper limit: 6.40×10^{-8} 90% CL**

NOT APPROVED YET





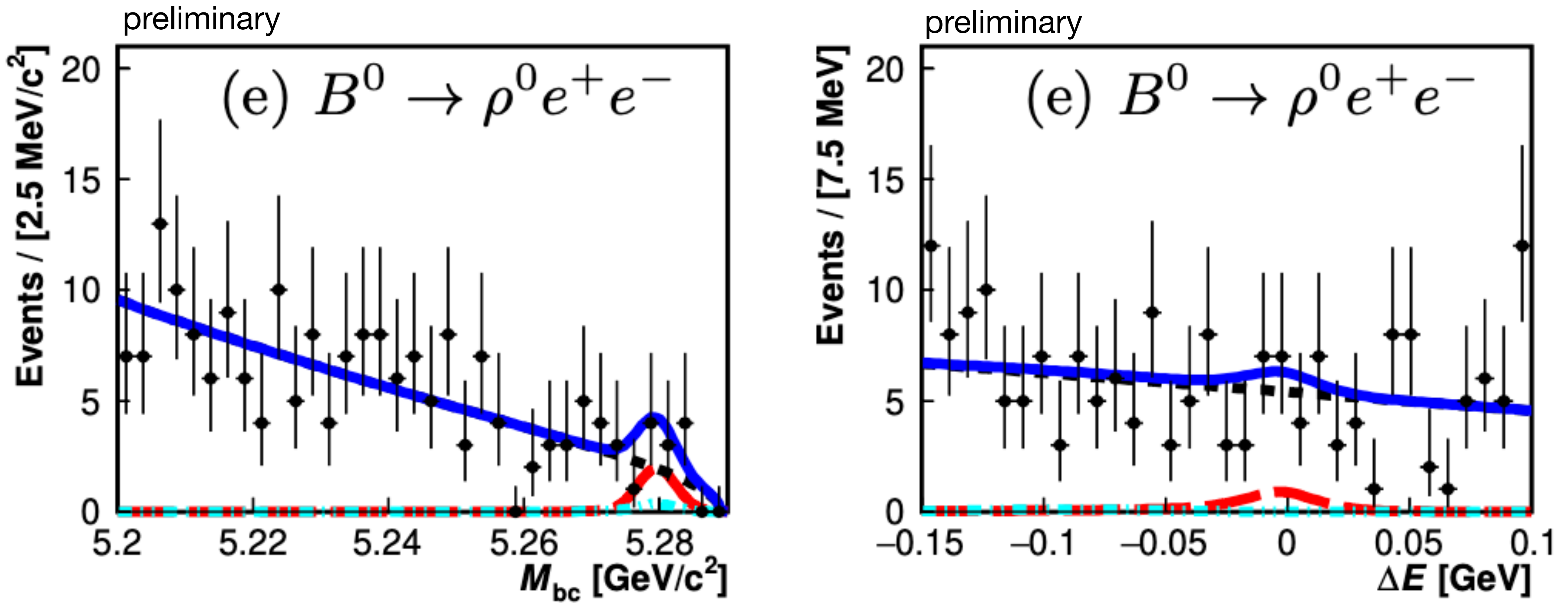
Search for $b \to d\ell^+\ell^-$

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 fitting $(\Delta E, M_{bc})$
- No signal observed $\Rightarrow$ set upper limits: $(3.8 - 4.7) \times 10^{-8}$ 90 CL



Beast UL for all the channels

Fist search for these channels $\longrightarrow$

channel	$\mathcal{B}^{\mathrm{UL}}\ (10^{-8})$	$\mathcal{B}\ (10^{-8})$
$B^0 \to \omega e^+ e^-$	< 30.7	$-2.1^{+26.5}_{-20.8} \pm 0.2$
$B^0 \to \omega \mu^+ \mu^-$	< 24.9	$7.7^{+10.8}_{-7.5} \pm 0.6$
$B^0 \to \omega \ell^+ \ell^-$	< 22.0	$6.4^{+10.7}_{-7.8} \pm 0.5$
$B^0 \to \rho^0 e^+ e^-$	< 45.5	$23.6^{+14.6}_{-11.2} \pm 1.1$
$B^+ \to \rho^+ e^+ e^-$	< 46.7	$-38.2^{+24.5}_{-17.2} \pm 3.4$
$B^+ \to \rho^+ \mu^+ \mu^-$	< 38.1	$13.0^{+17.5}_{-13.3} \pm 1.1$
$B^+ \to \rho^+ \ell^+ \ell^-$	< 18.9	$2.5^{+14.6}_{-11.8} \pm 0.2$

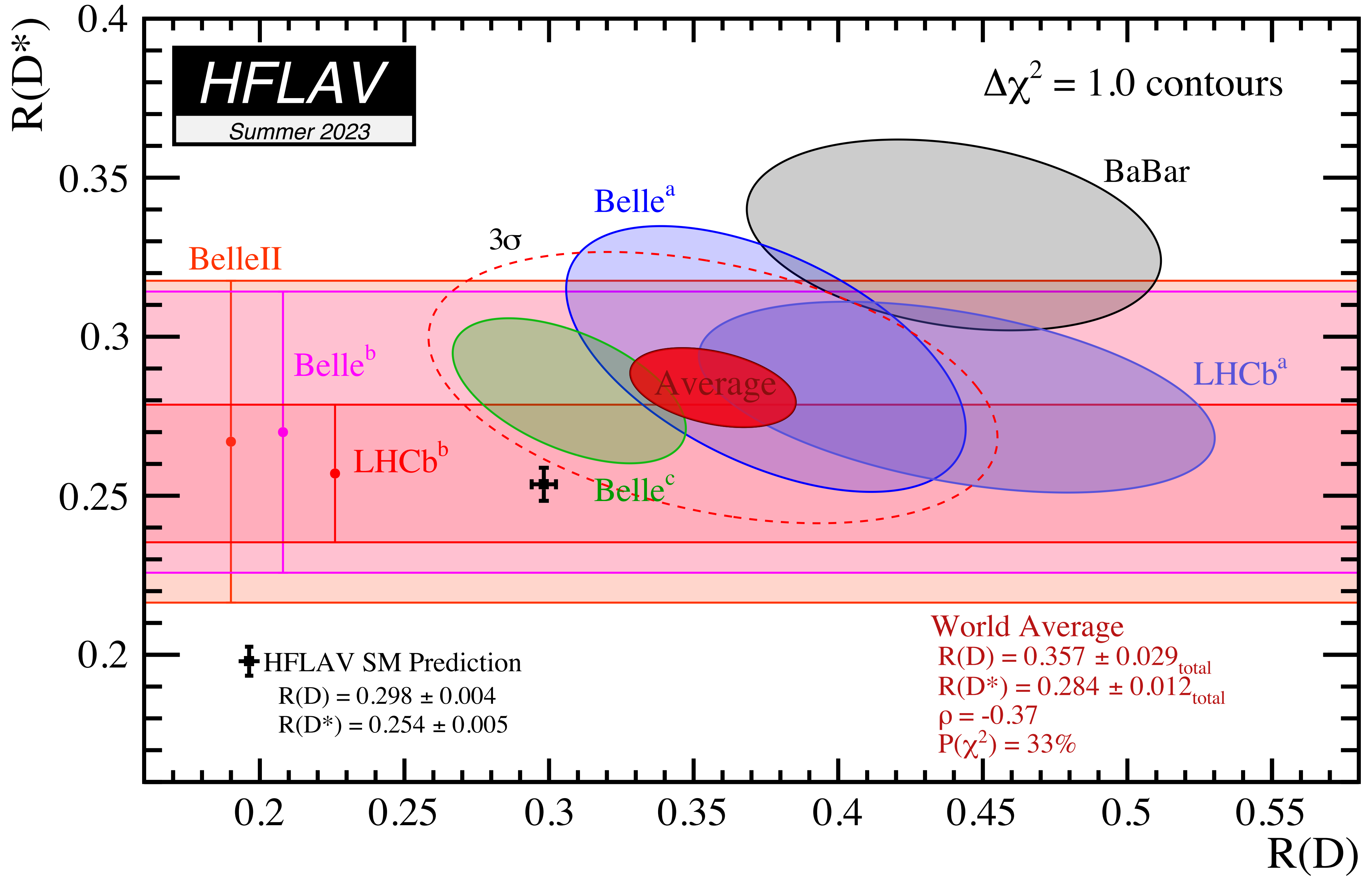
Lepton flavor universality test: $R(D^*)$

189 fb^{-1}

Belle II

[arXiv:2401.02840]

- **First $R(D^*)$ measurement at Belle II** $R(D^{(*)}) = \frac{\mathcal{B}(\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^{(*)}\ell^-\overline{\nu}_\ell)}$,
- **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

Measured also the inclusive:
$R(X_{\tau/\ell}) \equiv \mathcal{B}(B \to X\tau\nu)/\mathcal{B}(B \to X\ell\nu)$
and it is consistent with SM

[arXiv:2311.07248]

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})
- β^{eff} from gluonic and radiative penguins produces competitive results, exploiting Belle II-unique channels ($B^0 \to \eta' K_S^0, B^0 \to K_S^0 \pi^0 \gamma$)
- We are constantly improving our $B \to$ **hadron knowledge**, also **observing new decay** channels ($B \to D\rho$, $B \to D^{(*)}KK^{(*)}, B \to D^{(*)}D_s, B \to \omega\omega$)
- Strong push to investigate **FCNC**s:
  - serval new **world best upper limits** or **BF** in $b \to d(\gamma)$ transition
  - **Evidence** of $B \to K^+ \nu \bar{\nu}$ **2.7σ away from the SM**

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

Thank you for your attention!

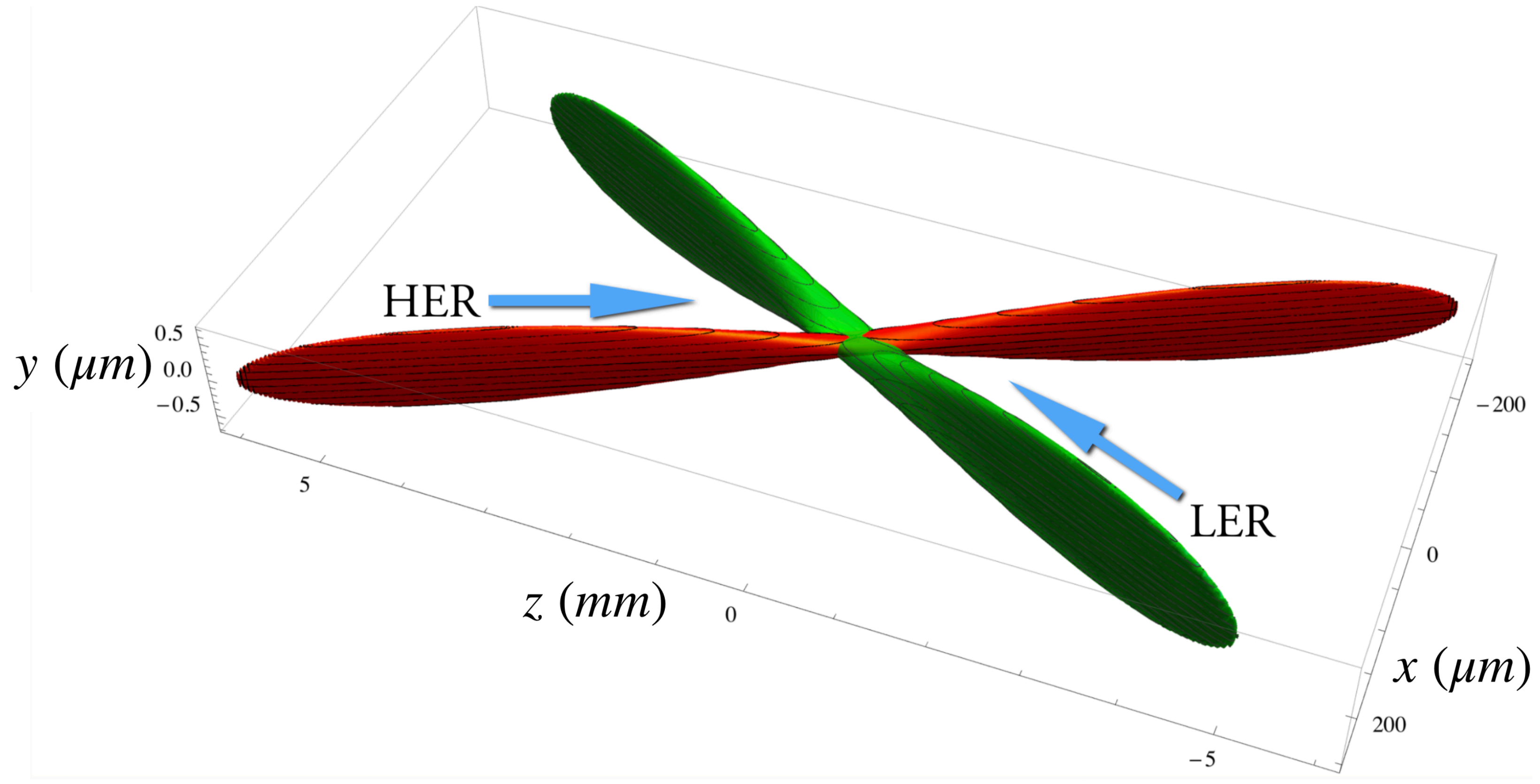
Valerio Bertacchi - bertacchi@cppm.in2p3.fr - Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France

BACKUP SLIDES

Belle II experiment at SuperKEKB collider

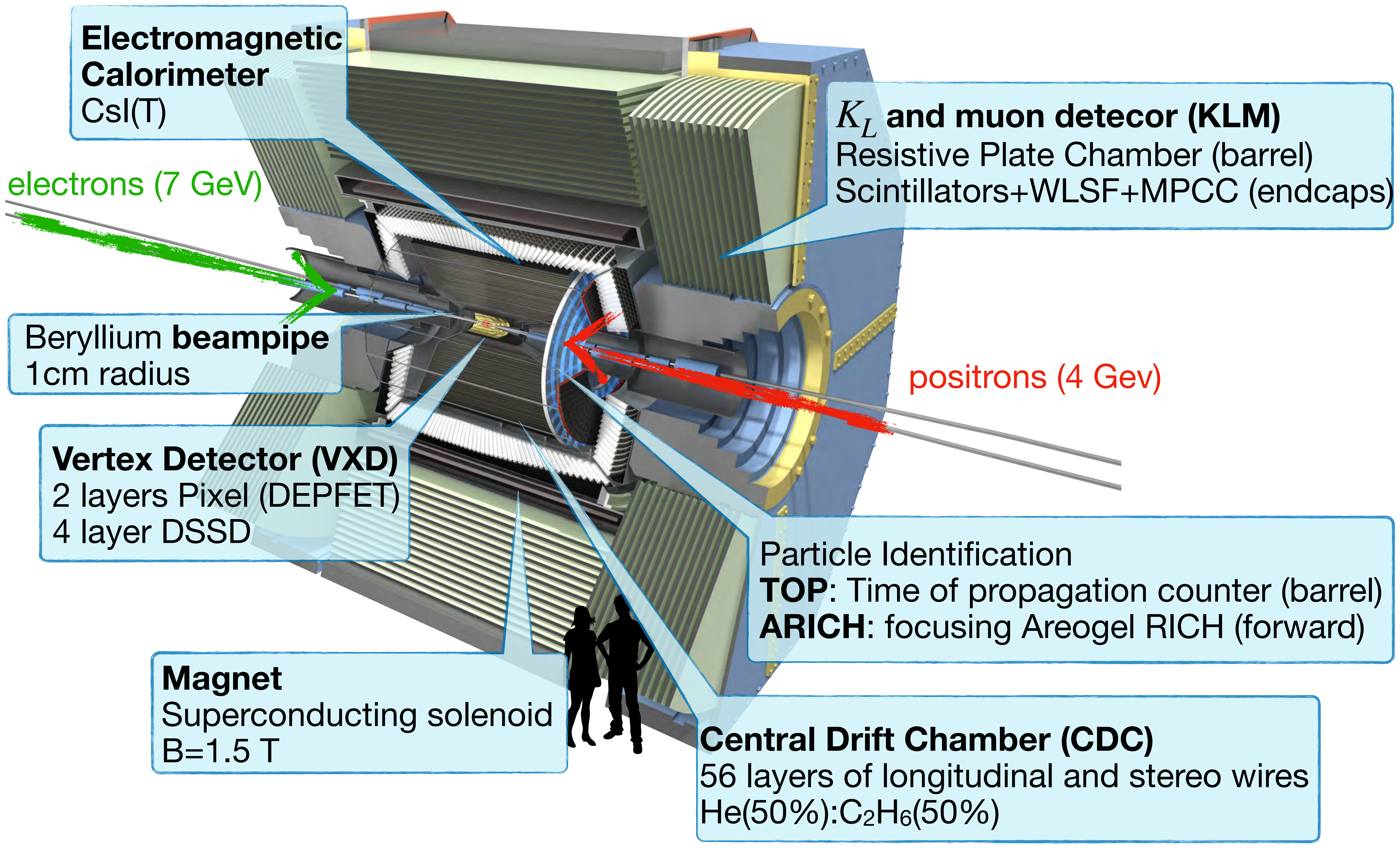
SuperKEKB

- Successor of KEKB (1999-2010, KEK, Japan)
- Target peak luminosity: $6 \cdot 10^{35}\ \mathrm{cm^{-2}s^{-1}}$ (x 30 of KEKB)



Nano-beam scheme:
250 μm (Z) × 10 μm (X) × 50 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

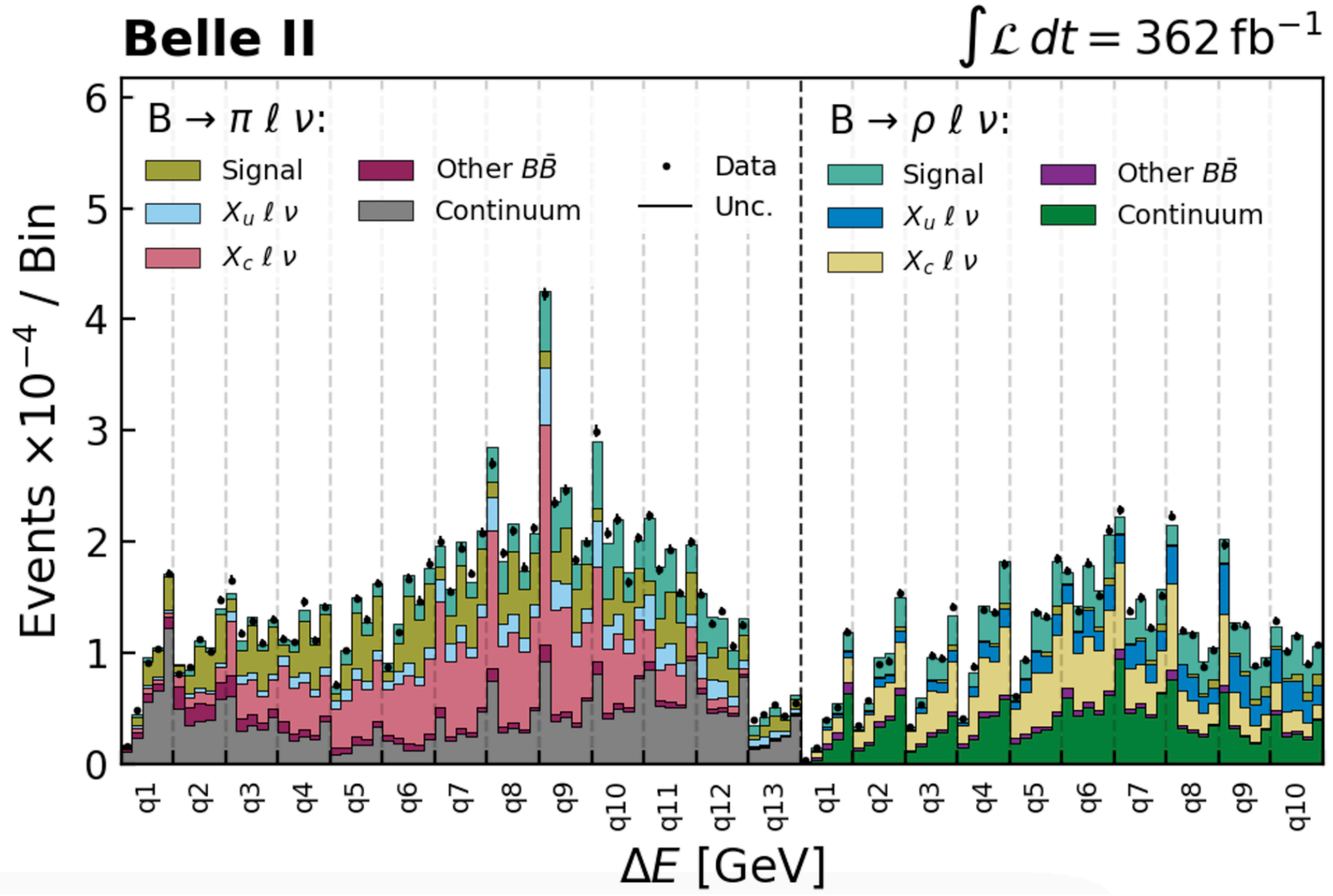
Data taking restated in February 2024!

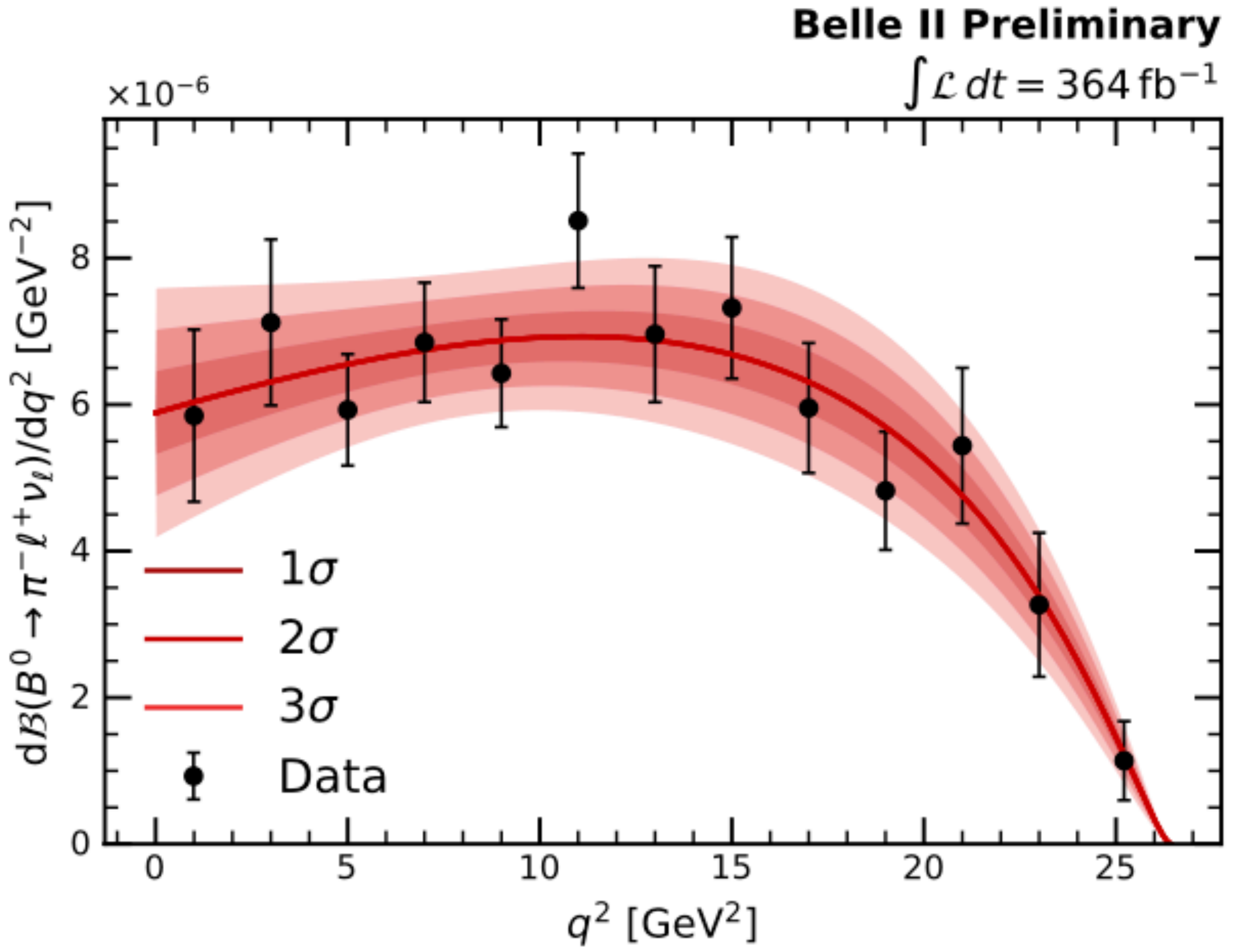
LS1 activities:

- 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

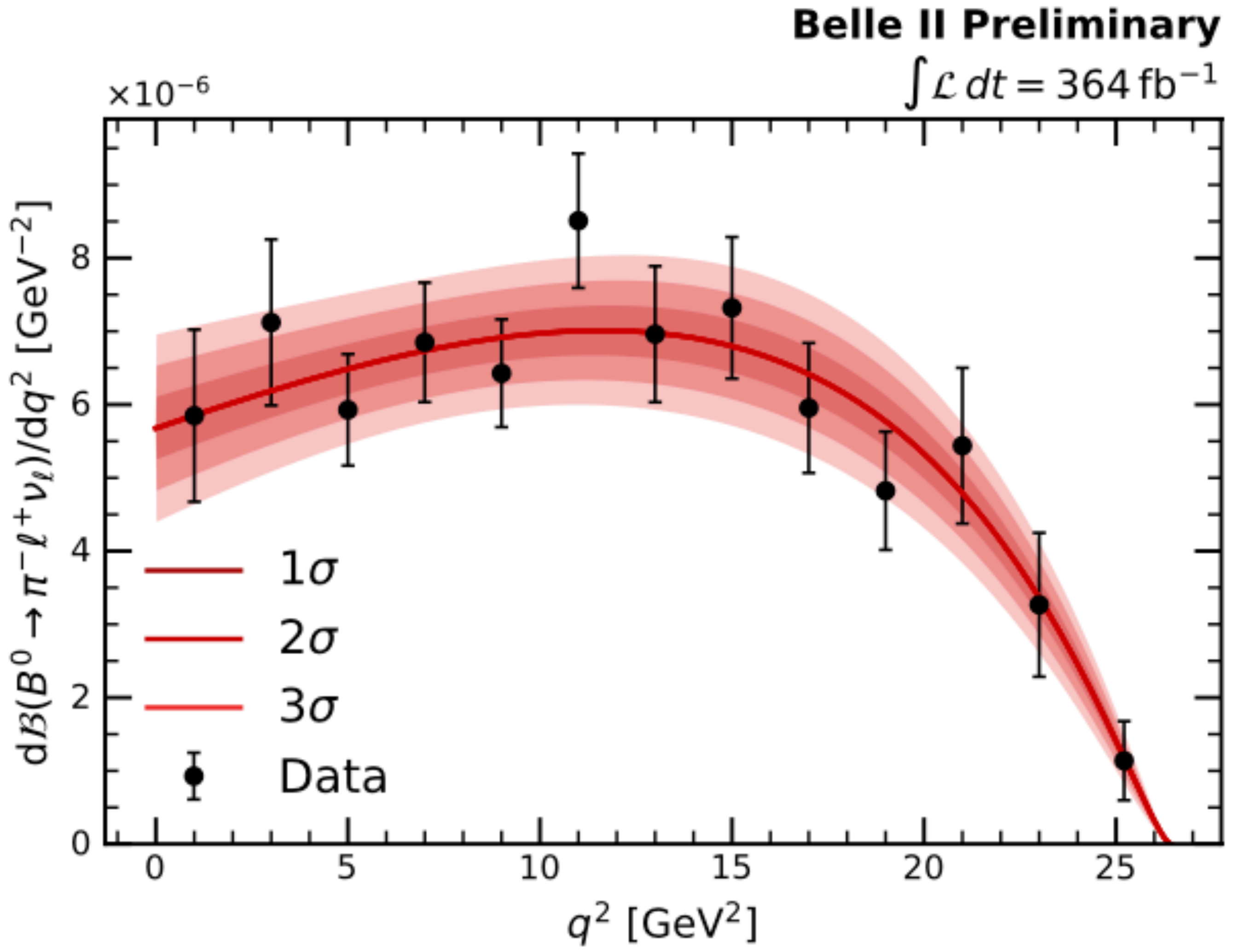
$|V_{ub}|$ $(B \to \pi/\rho\ell^+\nu)$: extra info (1)

- LQCD: $|V_{ub}|_{B\to\pi\ell\nu_\ell} = (3.92 \pm 0.09 \pm 0.13 \pm 0.19) \times 10^{-3}$.
- LQCD+LCSR: $|V_{ub}|_{B\to\pi\ell\nu_\ell} = (3.73 \pm 0.07 \pm 0.07 \pm 0.16) \times 10^{-3}$.
- LCSR: $|V_{ub}|_{B\to\rho\ell\nu_\ell} = (3.20 \pm 0.12 \pm 0.18 \pm 0.26) \times 10^{-3}$,

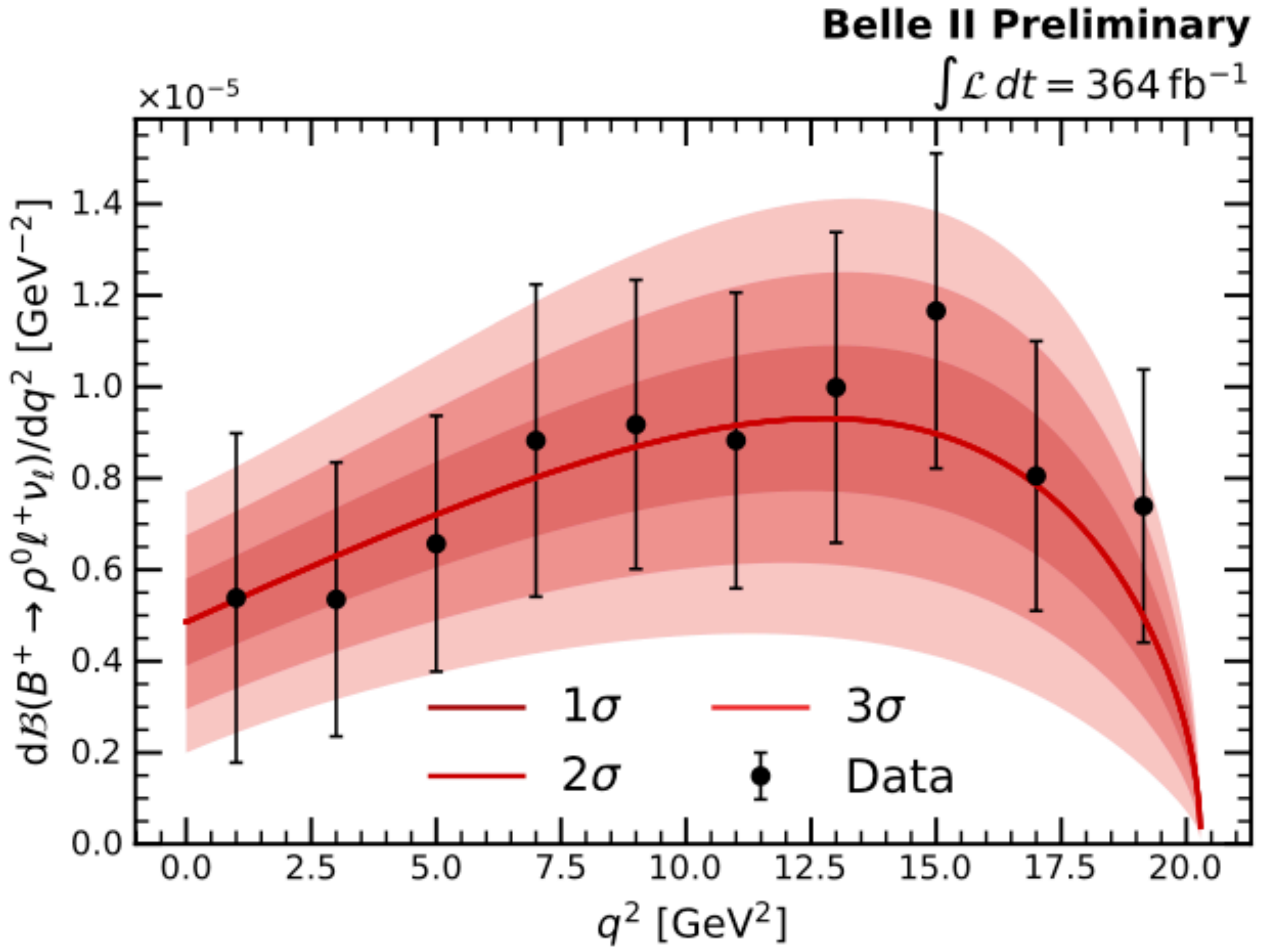




LQCD



LQCD+LCSR



LCSR

$|V_{ub}|$ $(B \to \pi/\rho\ell^+\nu)$: extra info (2)

Systematic uncertainties:

Source	$q1$	$q2$	$q3$	$q4$	$q5$	$q6$	$q7$	$q8$	$q9$	$q10$	$q11$	$q12$	$q13$
Detector effects	2.0	0.9	1.1	1.0	1.0	1.1	1.1	1.0	0.9	1.2	2.3	4.1	5.8
Beam energy	0.6	0.8	0.7	0.8	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.6	0.7
MC sample size	4.7	3.8	3.3	3.2	3.2	2.9	3.8	3.7	4.0	4.5	5.9	8.0	13.6
Physics constraints	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Signal model	0.1	0.1	0.2	0.1	0.0	0.2	0.2	0.4	0.3	0.8	0.9	0.2	4.9
ρ lineshape	0.1	0.1	0.3	0.3	0.2	0.1	0.3	0.1	0.3	0.1	0.2	0.2	0.6
Nonresonant $B \to \pi\pi\ell\nu_\ell$	0.5	0.6	0.4	0.4	0.5	1.0	1.2	1.0	0.8	1.8	1.2	2.3	14.3
DFN parameters	0.8	0.4	1.5	1.6	1.4	1.7	1.2	0.1	0.7	1.2	2.9	3.5	3.7
$B \to X_u\ell\nu_\ell$ model	0.2	0.4	0.3	0.4	0.2	0.9	1.1	1.2	1.0	1.3	1.6	0.7	8.7
$B \to X_c\ell\nu_\ell$ model	1.4	2.0	1.7	1.3	1.3	1.4	1.8	1.6	1.3	1.4	1.1	0.5	1.7
Continuum	15.1	11.3	7.6	7.1	5.8	5.7	8.1	8.3	9.6	10.4	14.5	23.8	34.4
Total syst.	16.8	13.3	10.1	9.6	8.7	8.6	10.7	10.7	11.8	12.8	17.0	26.3	41.8
Stat.	9.8	9.2	7.2	7.3	7.3	7.6	8.4	8.7	9.4	10.1	11.4	14.8	21.2
Total	19.5	16.1	12.4	12.0	11.3	11.5	13.6	13.8	15.1	16.3	20.5	30.2	46.8

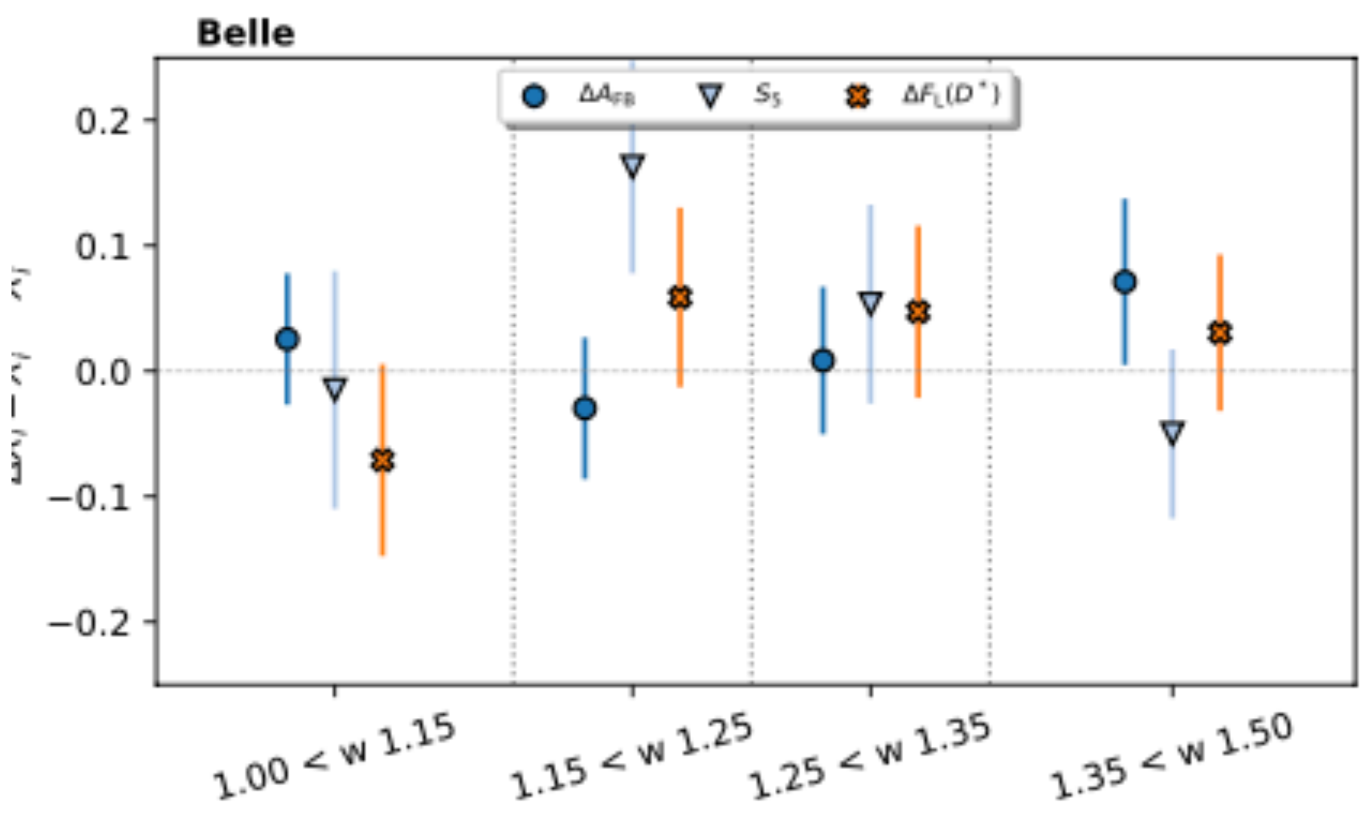
- The limiting factor is the **continuum ($q\overline{q}$) description**, obtained from **off-resonance data** ⇒ only 42 fb^{-1} 60-MeV shifted sample available

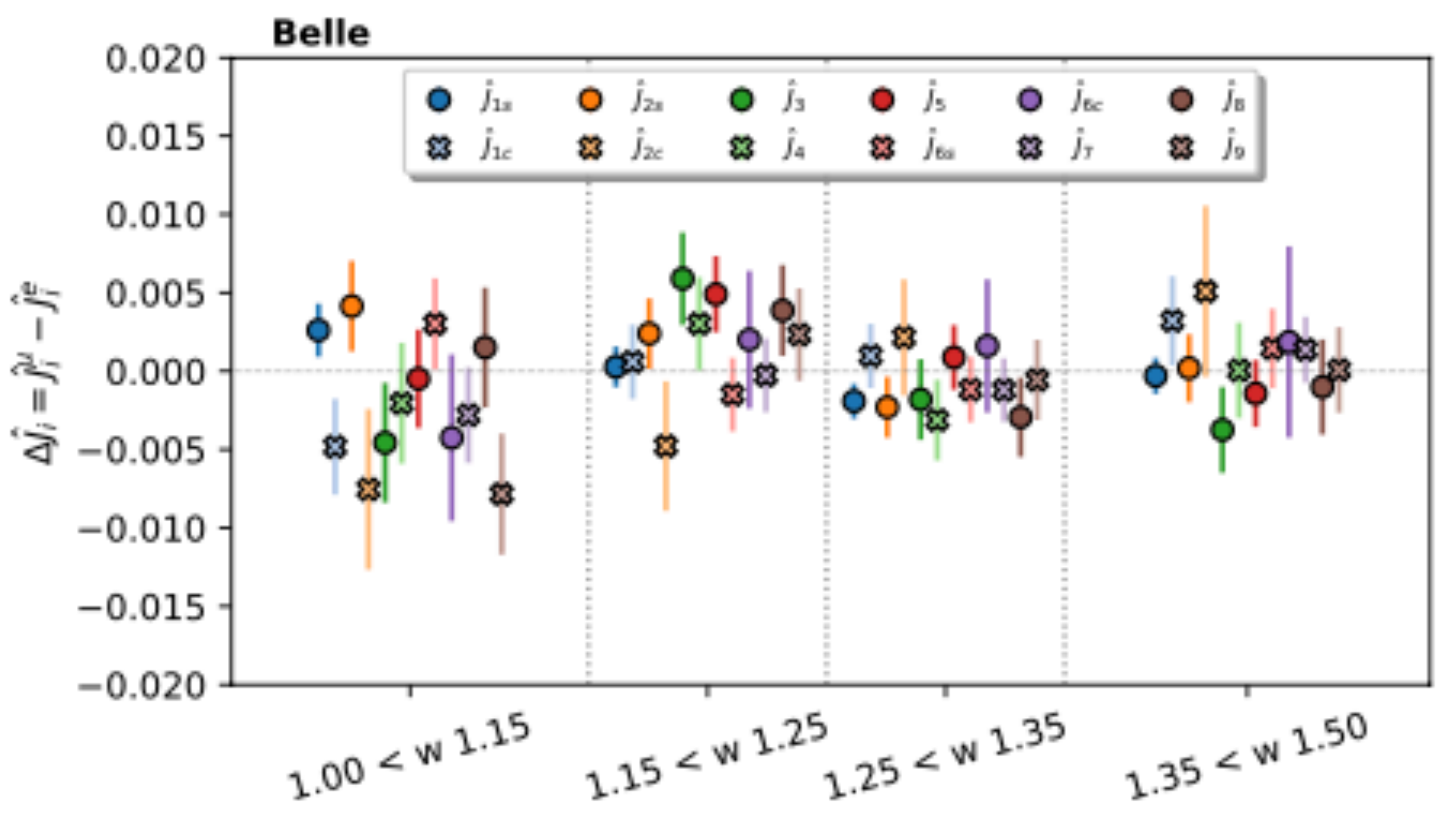
$|V_{cb}|$ (angular coefficients): extra info

- 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.

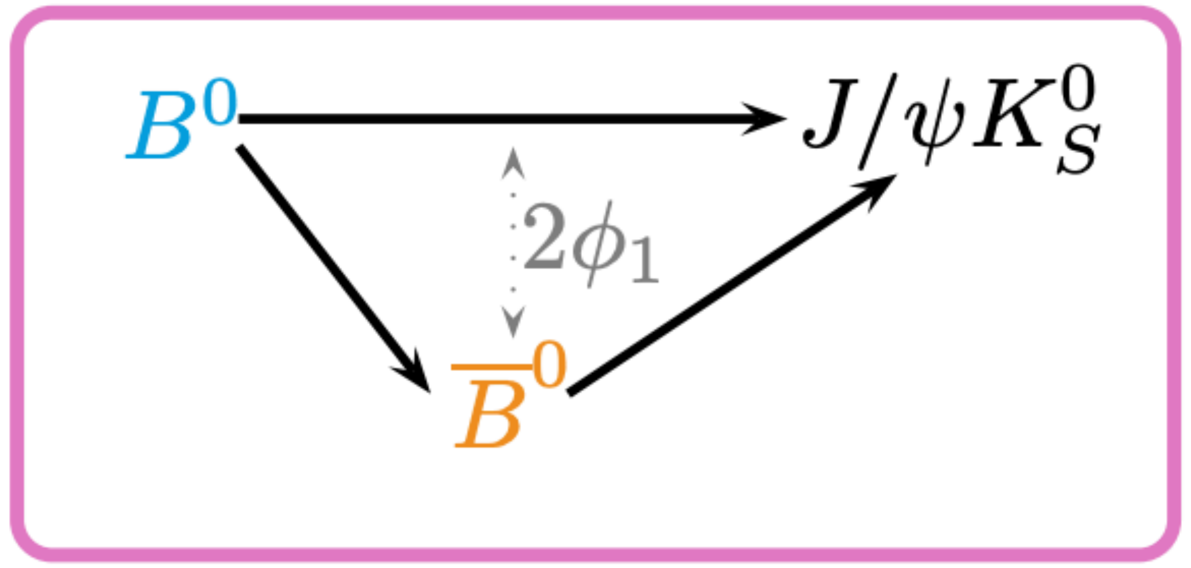
Observable	χ^2 / ndf	p-value
$\Delta A_{\rm FB}$	1.7 / 4	0.79
$\Delta F_{\rm L}(D^*)$	2.3 / 4	0.67
$\Delta \hat{J}_{1s}$	5.3 / 4	0.26
$\Delta \hat{J}_{1c}$	4.2 / 4	0.38
$\Delta \hat{J}_{2s}$	4.6 / 4	0.33
$\Delta \hat{J}_{2c}$	5.0 / 4	0.28
$\Delta \hat{J}_{3}$	7.4 / 4	0.12
$\Delta \hat{J}_{4}$	2.5 / 4	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

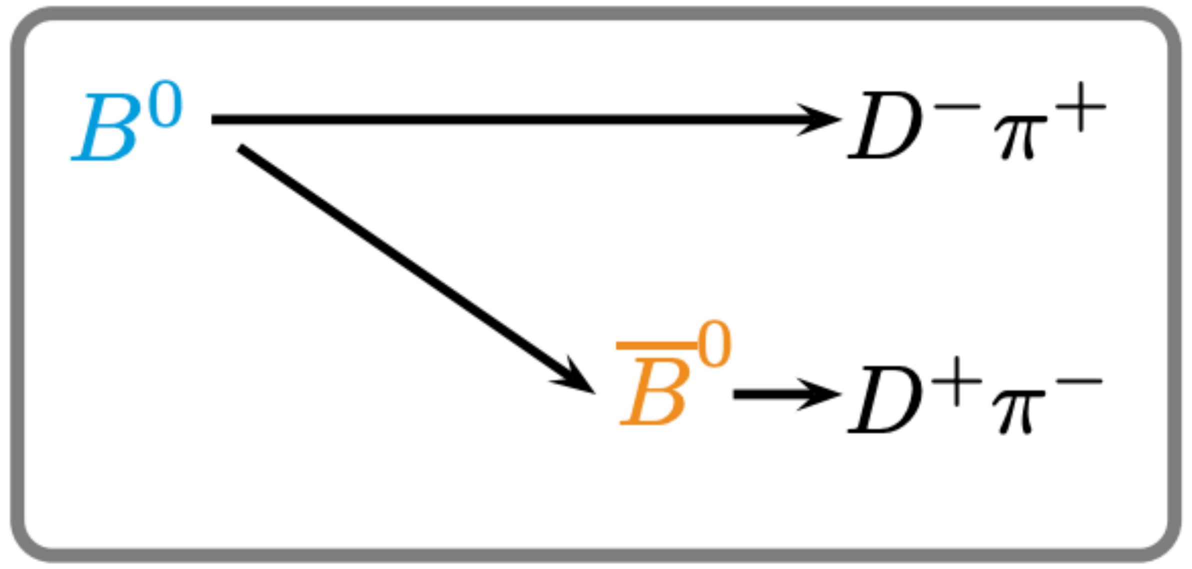




- Systematic uncertainties: dominated by MC sample size

Time-Dependent CPV analysis scheme





***CP*-asymmetry in interference between mixing and decay:**

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

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

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

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

with Δm_d the oscillation frequency.

[From Thibaud Humair, Moriond EW 22]

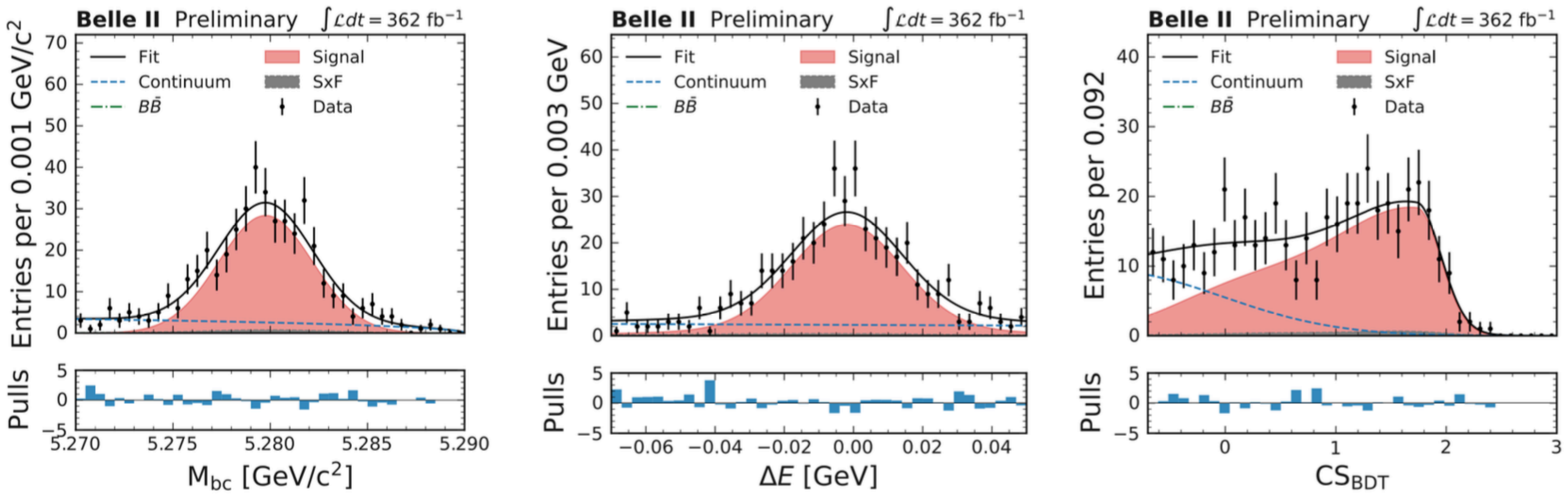
$B^0 \to J/\psi K_S^0$ and GFlaT: extra info

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

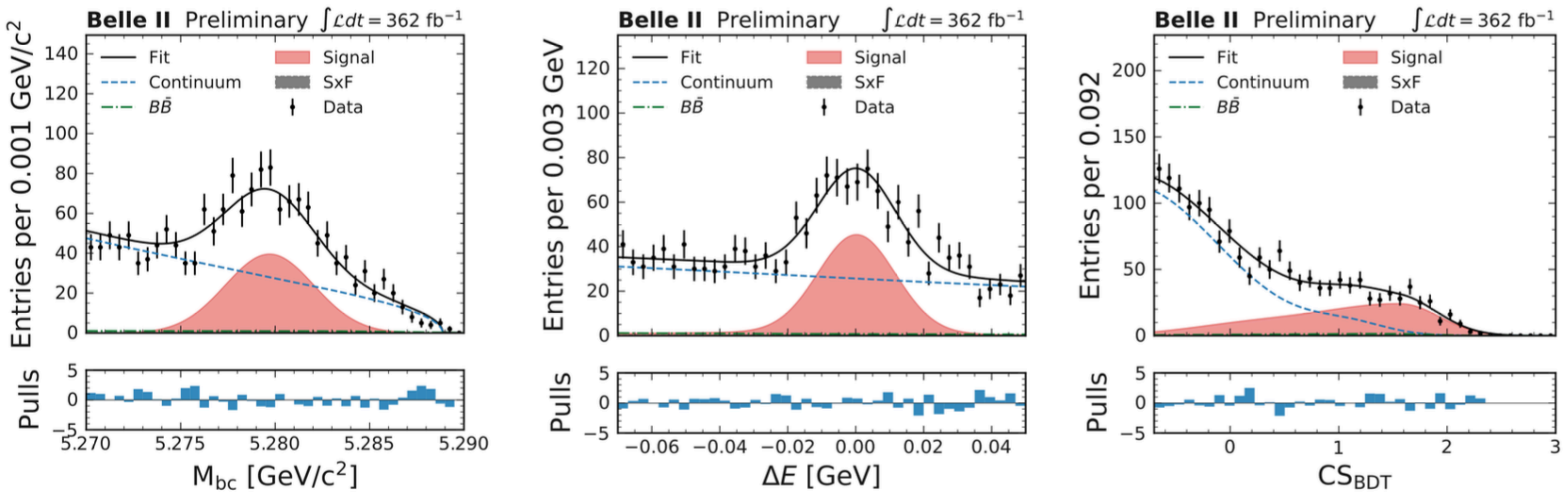
Source	ε_{tag} [%]	S	C
Detector alignment	0.08	0.005	0.003
Interaction region	0.16	0.002	0.002
Beam energy	0.03	$<$ 0.001	0.001
ΔE-fit background model	0.11	0.001	0.001
ΔE-fit signal model	0.08	0.003	0.006
sWeight background subtraction	0.24	0.001	0.001
Fixed resolution-function parameters	0.07	0.004	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_{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

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

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

- Systematic uncertainties

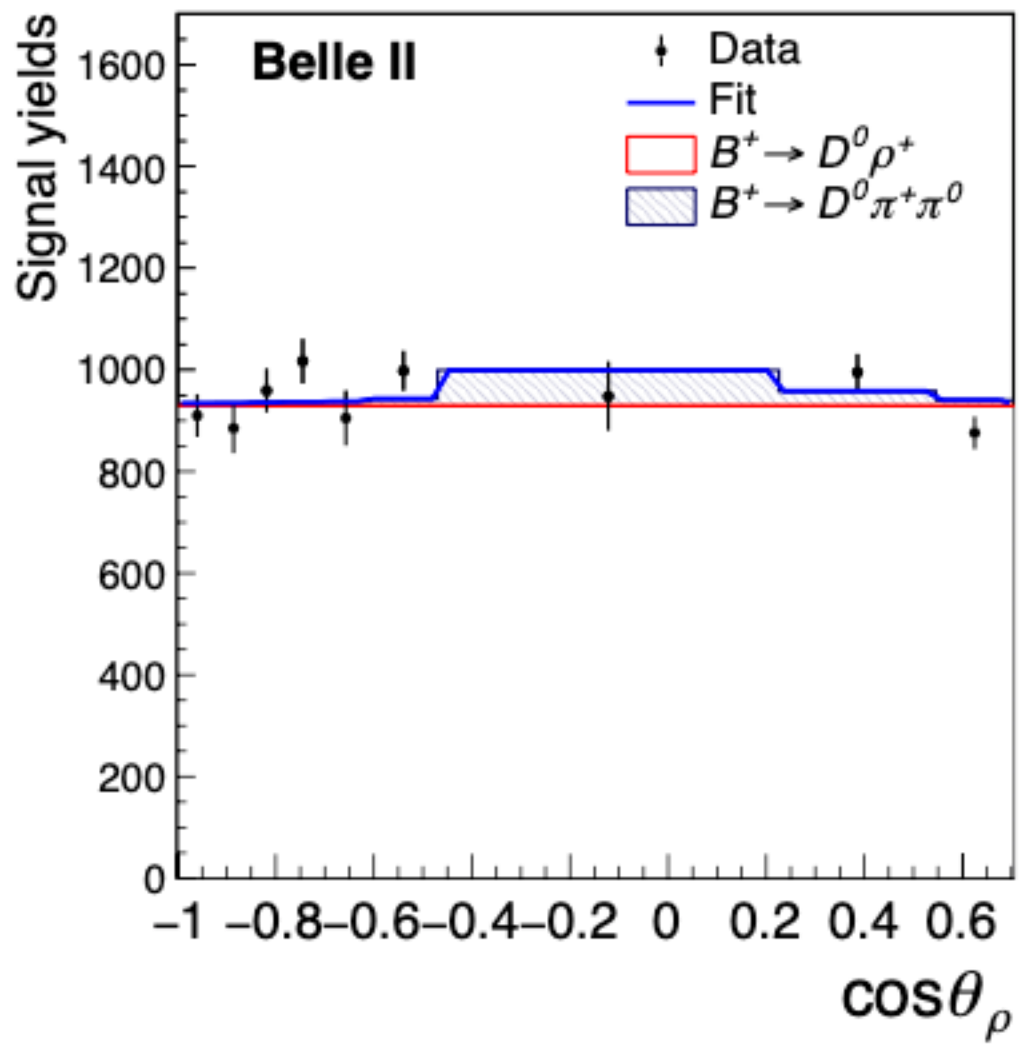
Source	$K^{*0}\gamma$ S	$K^{*0}\gamma$ C	$K_S^0\pi^0\gamma$ S	$K_S^0\pi^0\gamma$ C
E and p scales	± 0.017	± 0.015	± 0.083	± 0.047
Vertex measurement	± 0.021	± 0.009	± 0.023	± 0.036
Flavor tagging	± 0.005	$^{+0.012}_{-0.009}$	± 0.008	$^{+0.013}_{-0.009}$
Event-by-event fractions	± 0.003	$^{+0.004}_{-0.003}$	± 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	$^{+0.033}_{-0.037}$	$^{+0.032}_{-0.031}$	$^{+0.100}_{-0.098}$	$^{+0.071}_{-0.070}$

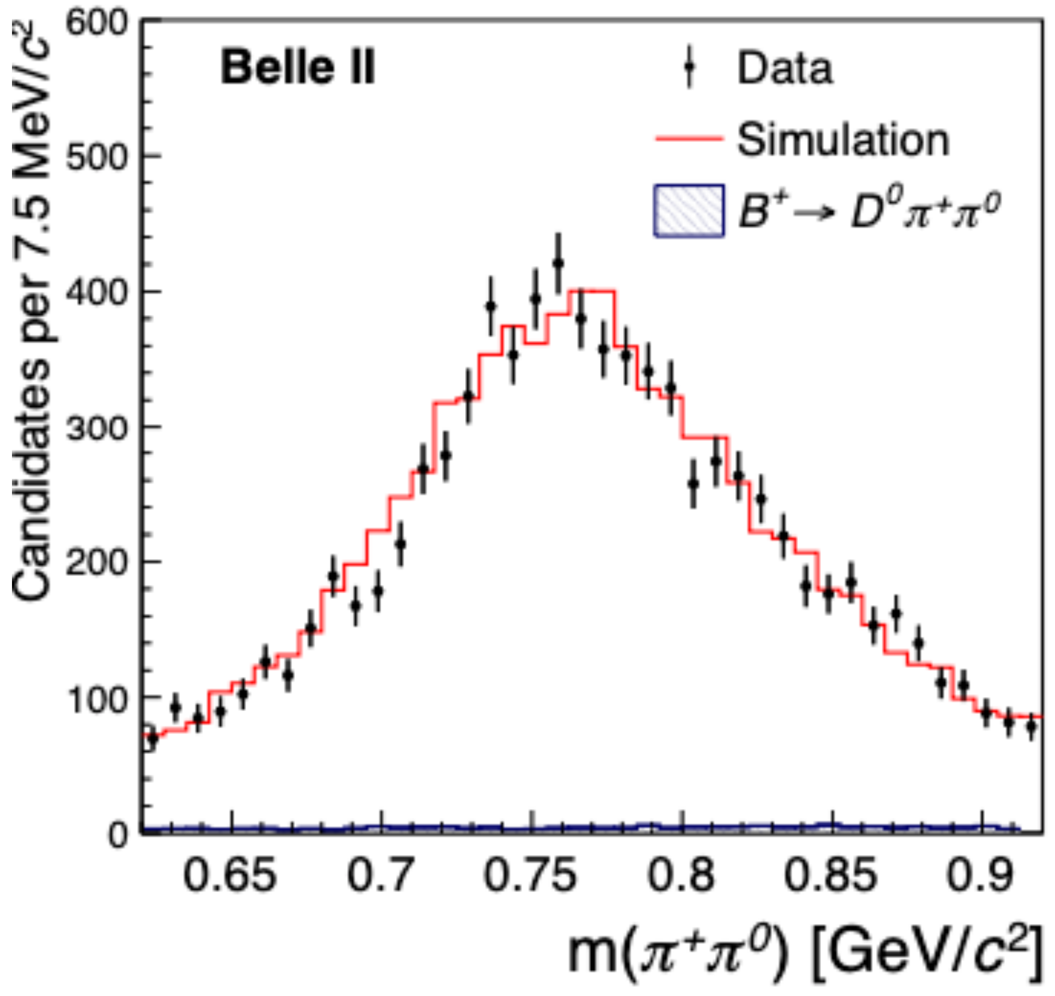
$B^+ \to D^0\rho(770)^+$: extra info

- signal extracted from ΔE in bin of **helicity angle**, to separate $B \to D^0\rho(\to \pi^+\pi^0)$ signal from bkg $B \to D^0\pi^+\pi^0$
- non-uniform binning to have $\cos\theta_{\text{hel}}$ uniform distribution for the signal
- Template fit to the signal and bkg distributions

Systematic uncertainties

Source	Relative uncertainty (%)
$N_{B\bar{B}}$	1.5
f^{+-}	2.4
$\mathcal{B}_{\text{sub}}$	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

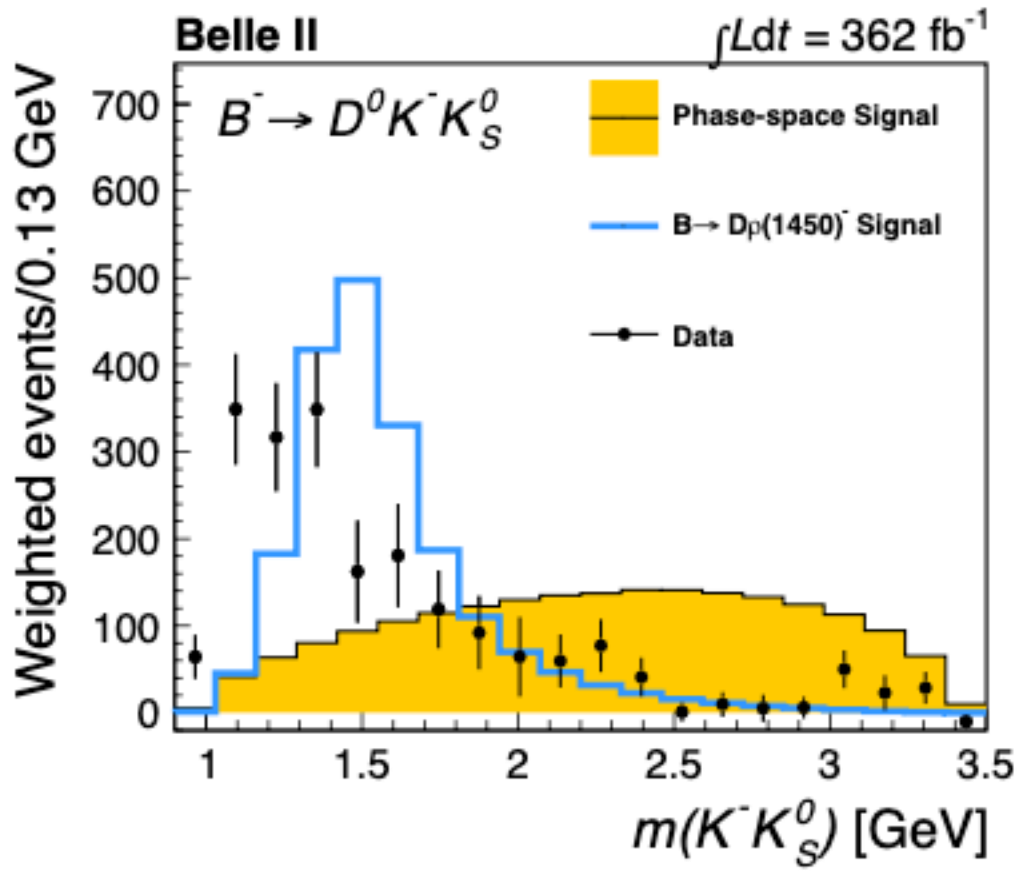


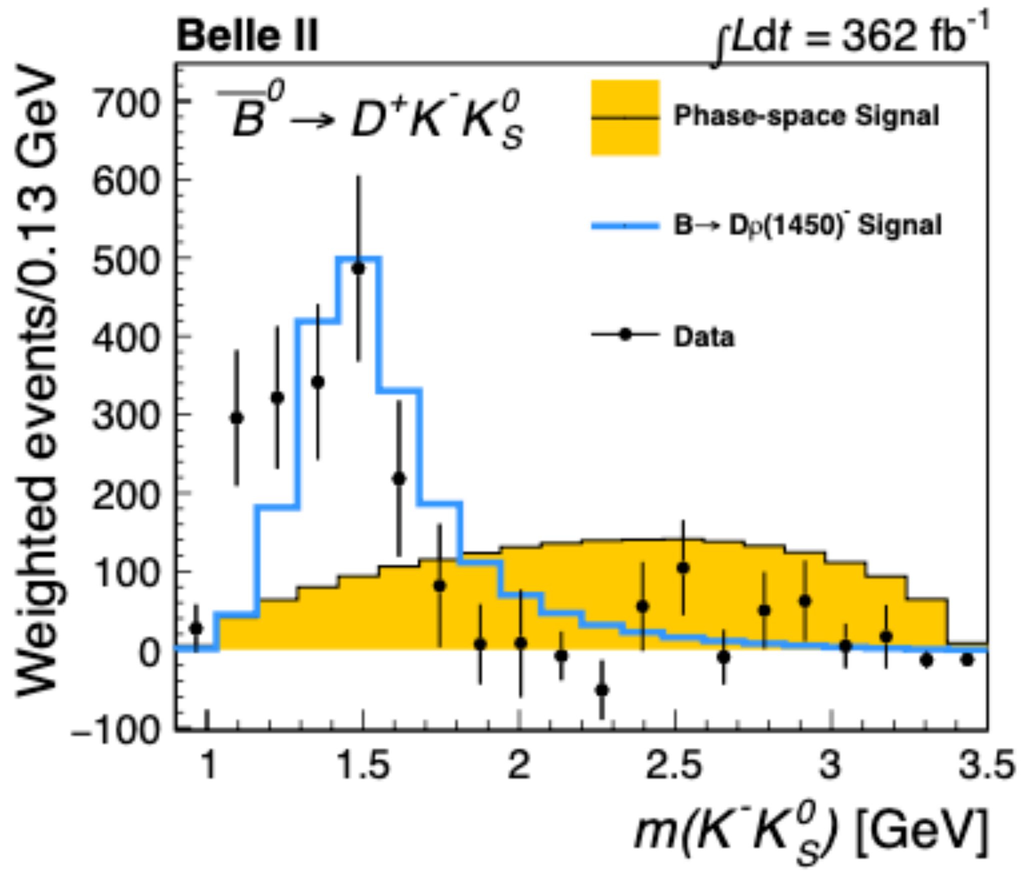


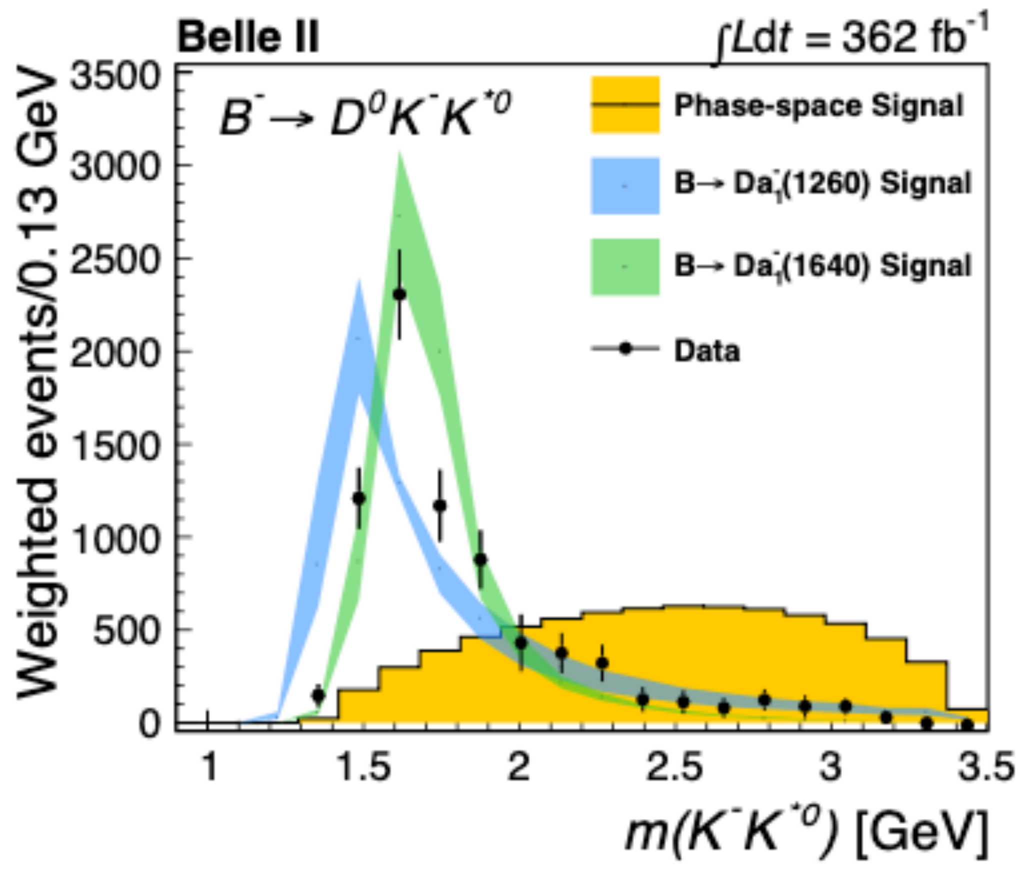
$=(1.9 \pm 1.8)\ \%$ of bkg

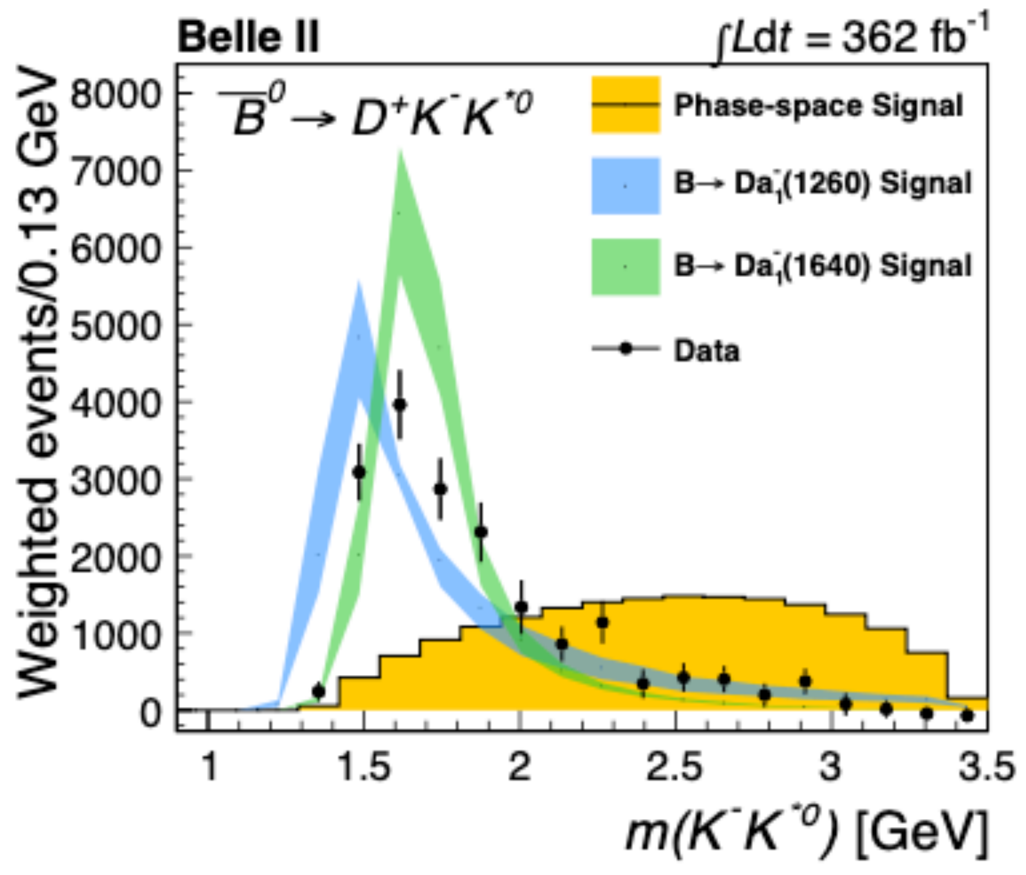
$B \to D^{(*)}K^-K^{(*)0}_{(S)}$ and $B \to D^{(*)}D_s^-$: extra info (1)

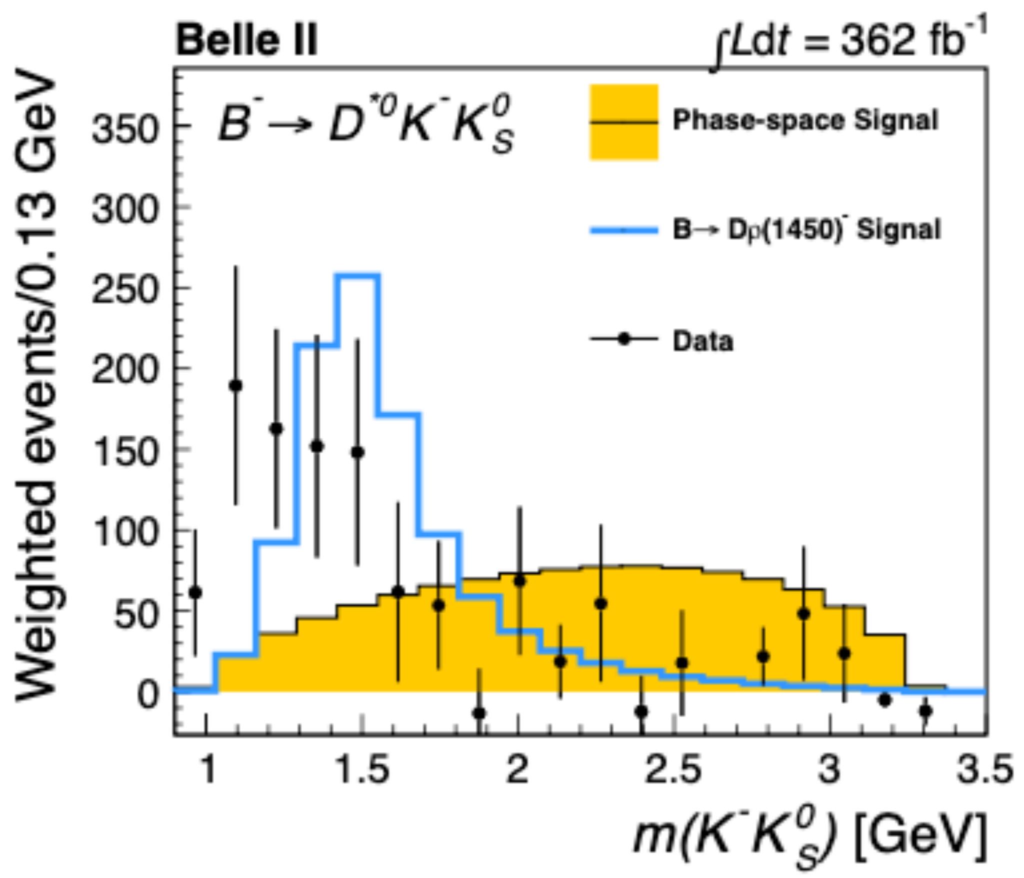
bkg-subtracted and efficiency corrected $m(K^-K)$ distributions

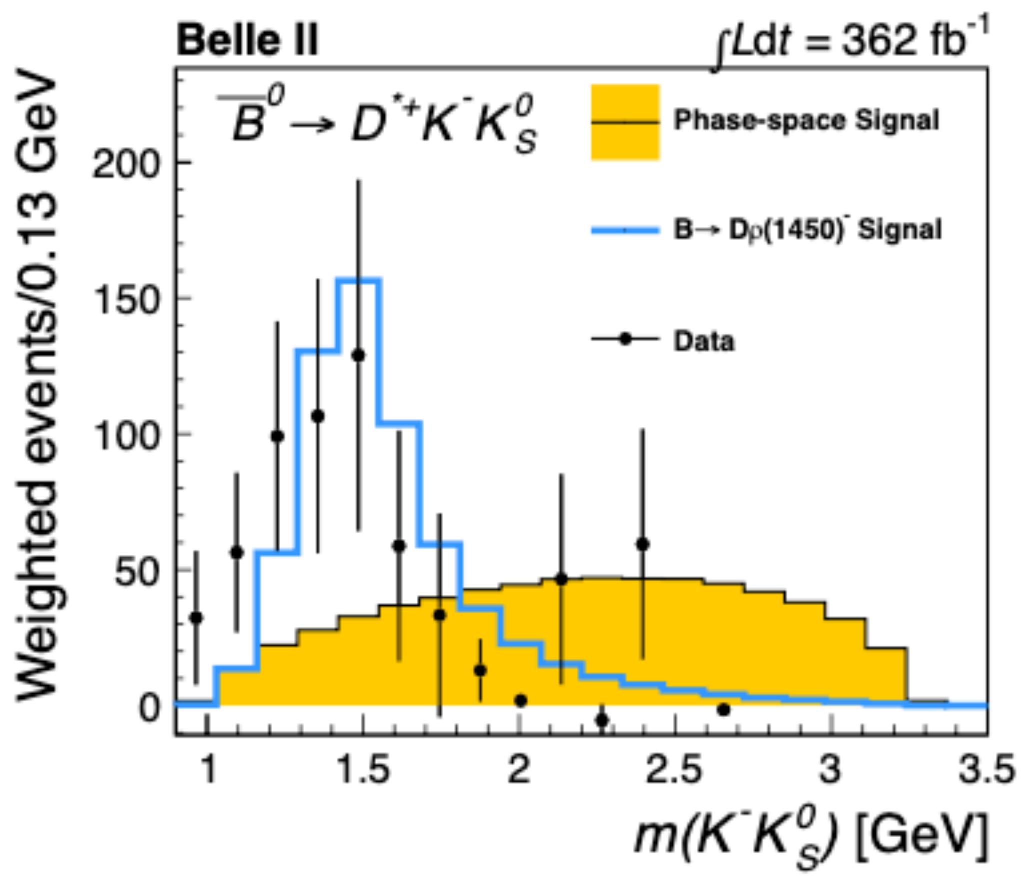


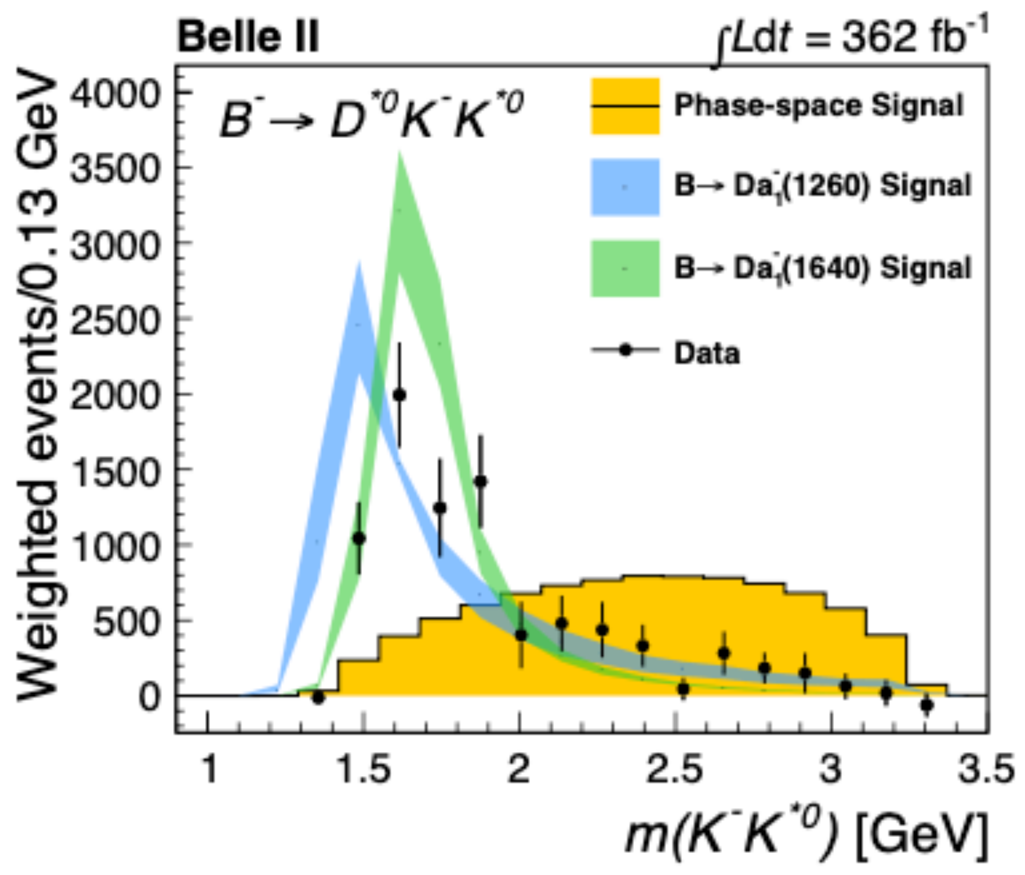


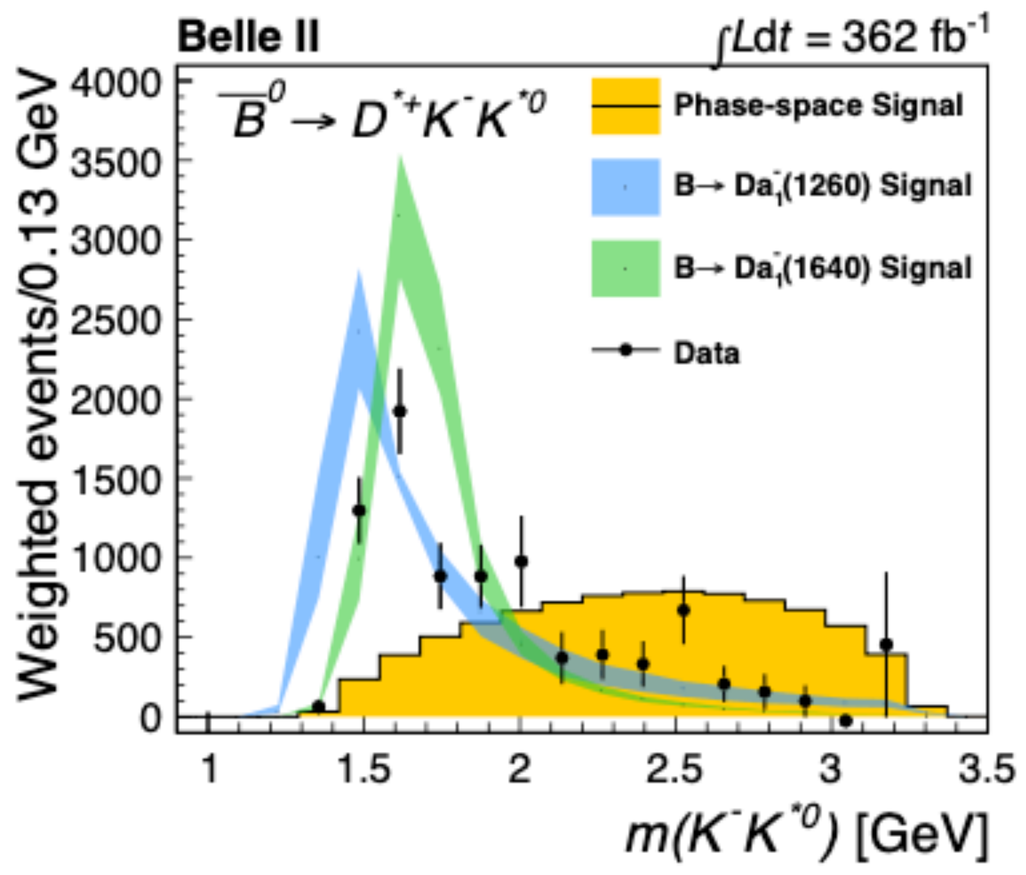












$B \to D^{(*)}K^-K^{(*)0}_{(S)}$ and $B \to D^{(*)}D_s^-$: extra info (2)

Branching fractions:

Channel	Yield (K^0_S / K^{*0})	Average ε (K^0_S / K^{*0})	$\mathcal{B}$ [10^{-4}]
$B^- \to D^0 K^- K^0_S$	209 ± 17	0.098	$1.82 \pm 0.16 \pm 0.08$
$\overline{B}^0 \to D^+ K^- K^0_S$	105 ± 14	0.048	$0.82 \pm 0.12 \pm 0.05$
$B^- \to D^{*0} K^- K^0_S$	51 ± 9	0.044	$1.47 \pm 0.27 \pm 0.10$
$\overline{B}^0 \to D^{*+} K^- K^0_S$	36 ± 7	0.046	$0.91 \pm 0.19 \pm 0.05$
$B^- \to D^0 K^- K^{*0}$	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	$13.12 \pm 1.21 \pm 0.71$
$B^- \to D^0 D_s^-$	144 ± 12 / 153 ± 13	0.04 / 0.09	$95 \pm 6 \pm 5$
$\overline{B}^0 \to D^+ D_s^-$	145 ± 12 / 159 ± 13	0.02 / 0.05	$89 \pm 5 \pm 5$
$B^- \to D^{*0} D_s^-$	30 ± 6 / 29 ± 7	0.02 / 0.04	$65 \pm 10 \pm 6$
$\overline{B}^0 \to D^{*+} D_s^-$	43 ± 7 / 37 ± 7	0.02 / 0.04	$83 \pm 10 \pm 6$

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

Fit variables:

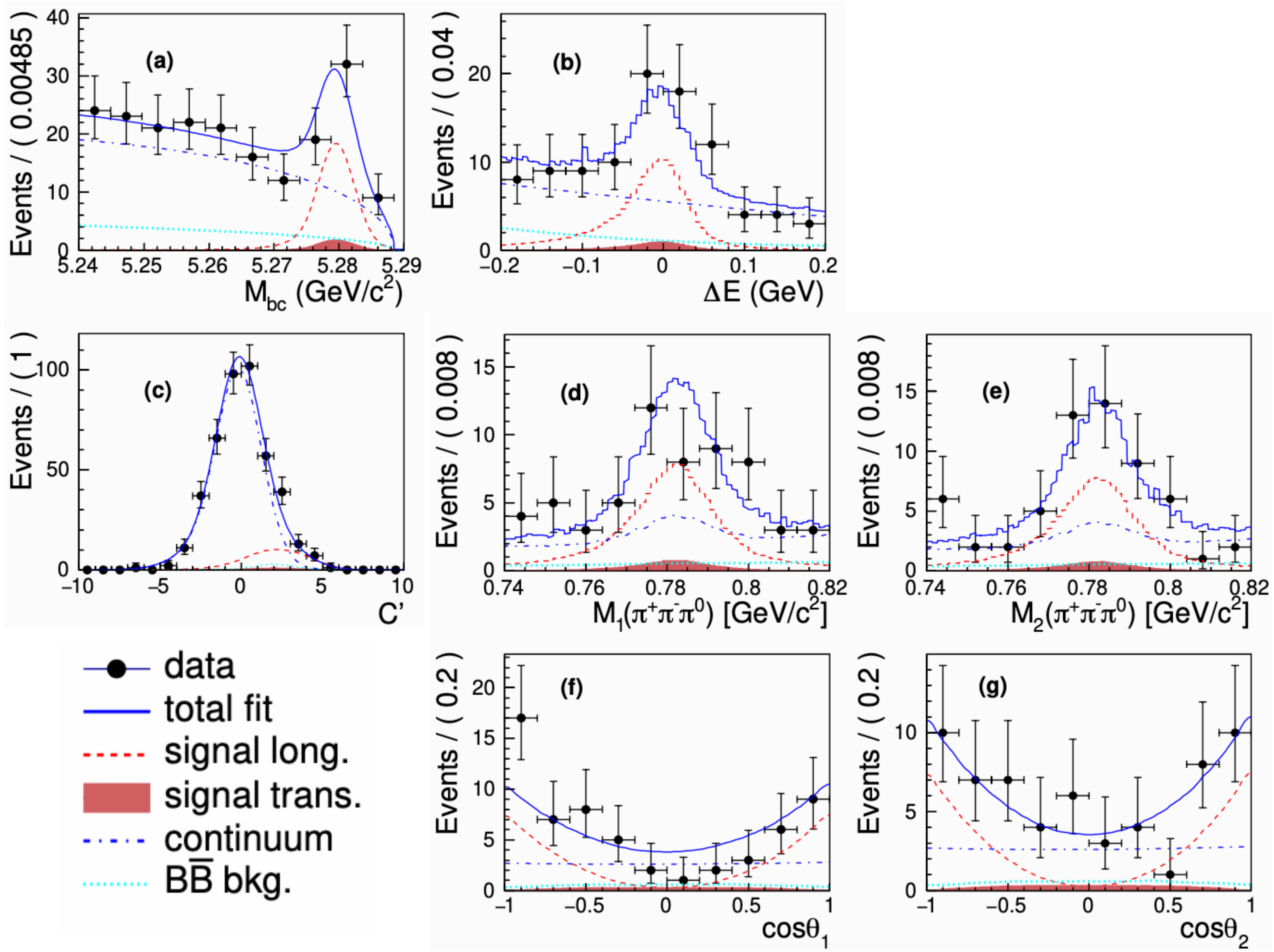


TABLE I. Systematic uncertainties on $\mathcal{B}$, f_L, and A_{CP}. Those listed in the upper part are additive and included in the significance calculation as discussed in the text. Those listed in the lower part are multiplicative.

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

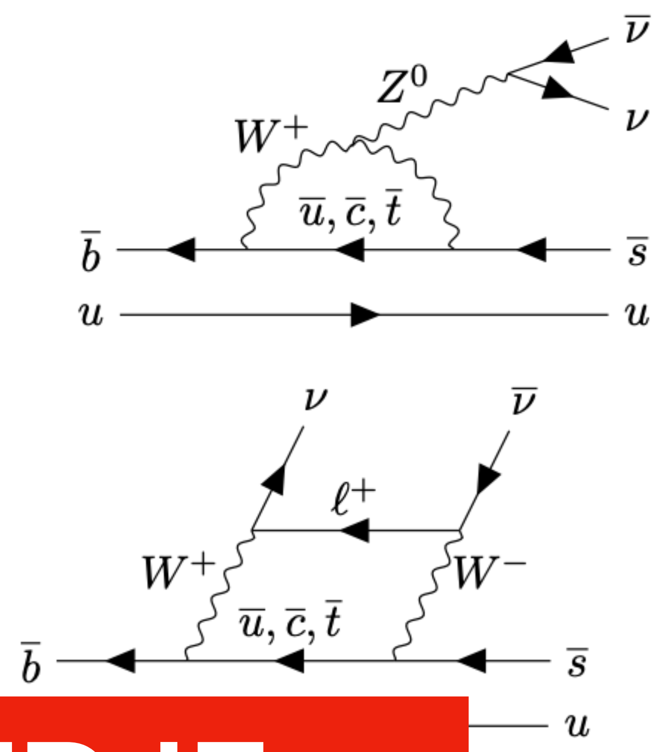
Evidence of $B^+ \to K^+\nu\bar{\nu}$ (1)

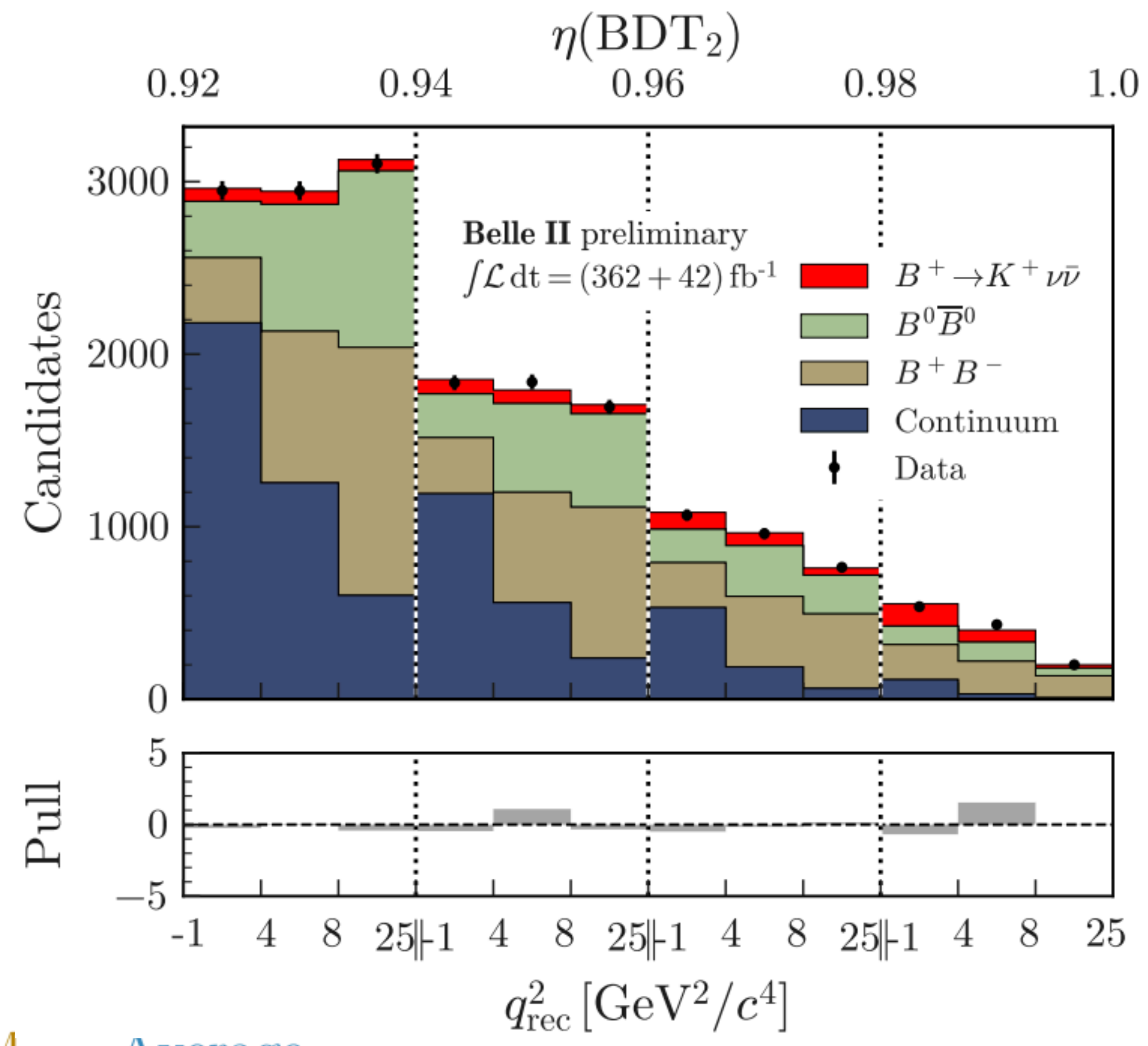
[arXiv:2311.14647] $362\ \mathrm{fb}^{-1}$

Belle II

- Motivations: FCNC, strongly suppressed in the SM: $\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) = (5.58 \pm 0.37) \times 10^{-6}$ [arxiv:2207.13371]
  - NP can enhance the BF
- Reconstruction: co **tagging** and **inclus** **tagging**
- Bkg suppressed with multiple BDT in cascade

SLIDE TO BE REMOVED IF WORKS WITH SPLITTED SLIDES



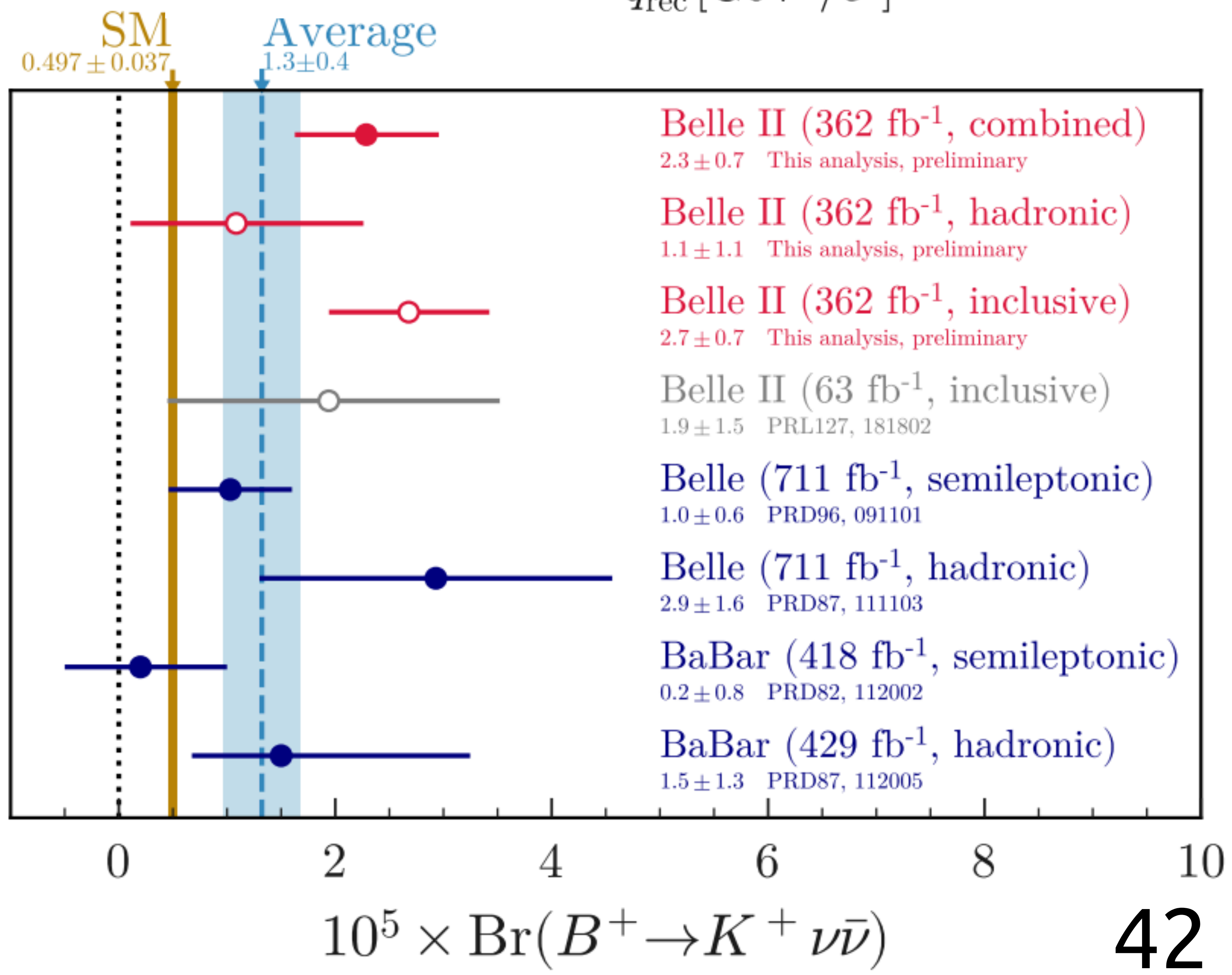


$$\mu = 4.6 \pm 1.0(\mathrm{stat}) \pm 0.9(\mathrm{syst})$$

$$BR(B^+ \to K^+\nu\nu) = [2.4 \pm 0.5(\mathrm{stat})^{+0.5}_{-0.4}(\mathrm{syst})] \times 10^{-5}$$

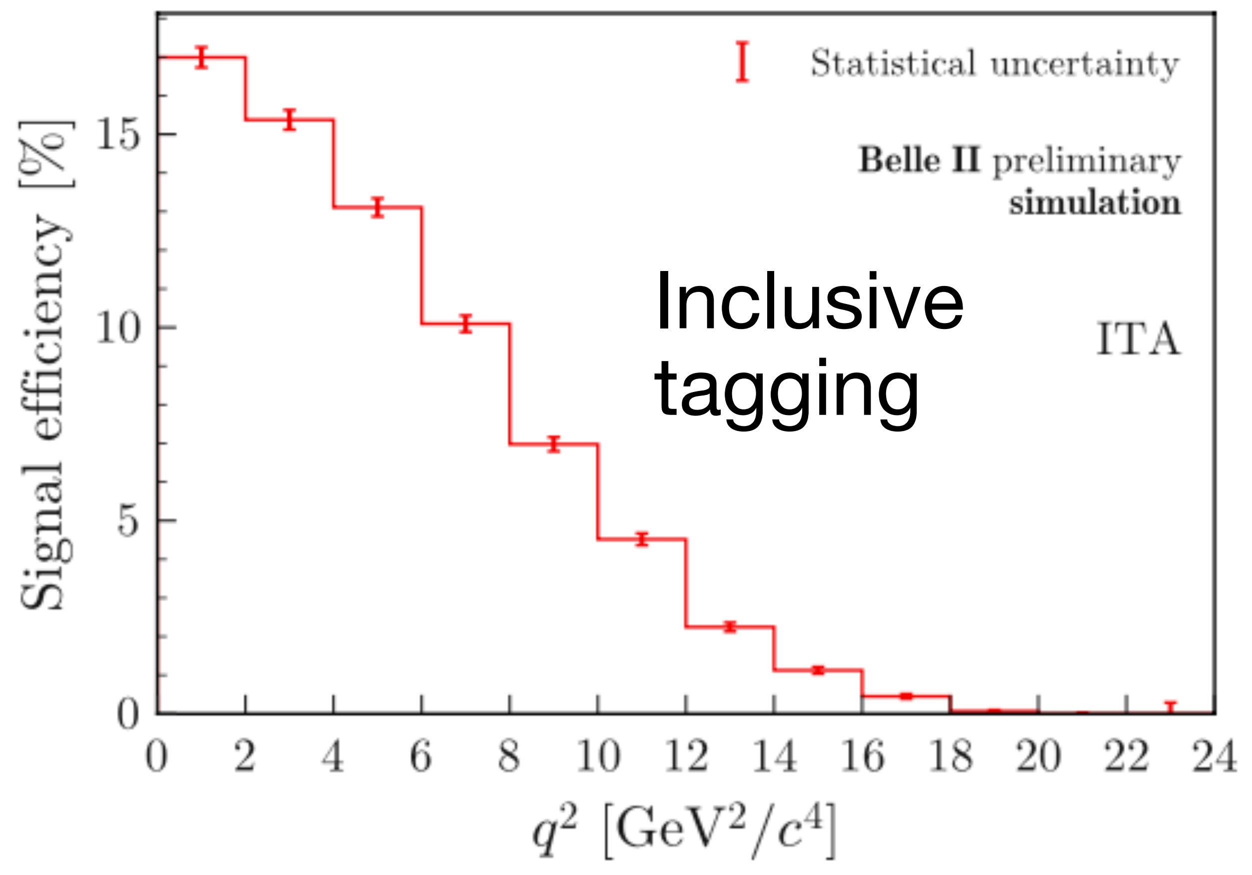
3.5σ above the bkg-only hypothesis

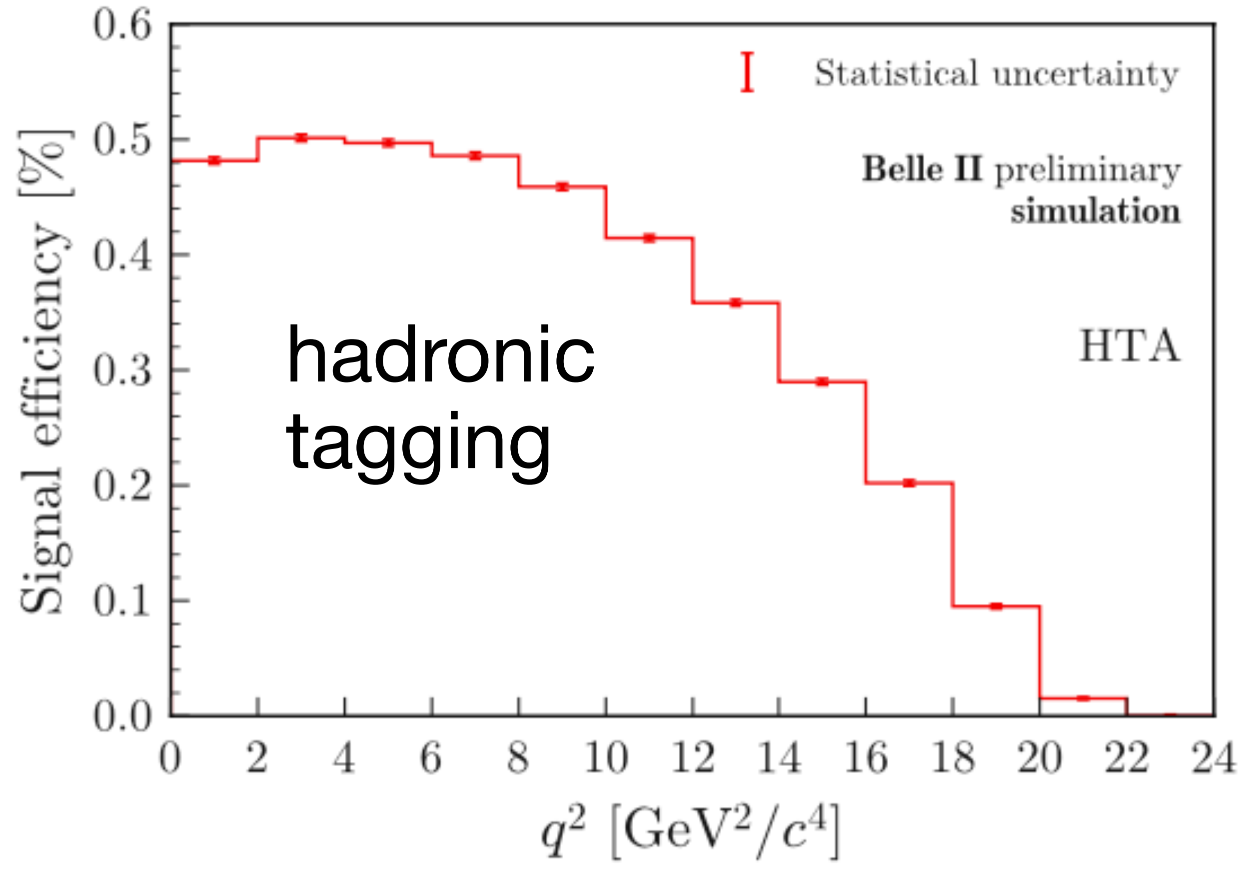
2.7σ above the SM prediction



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

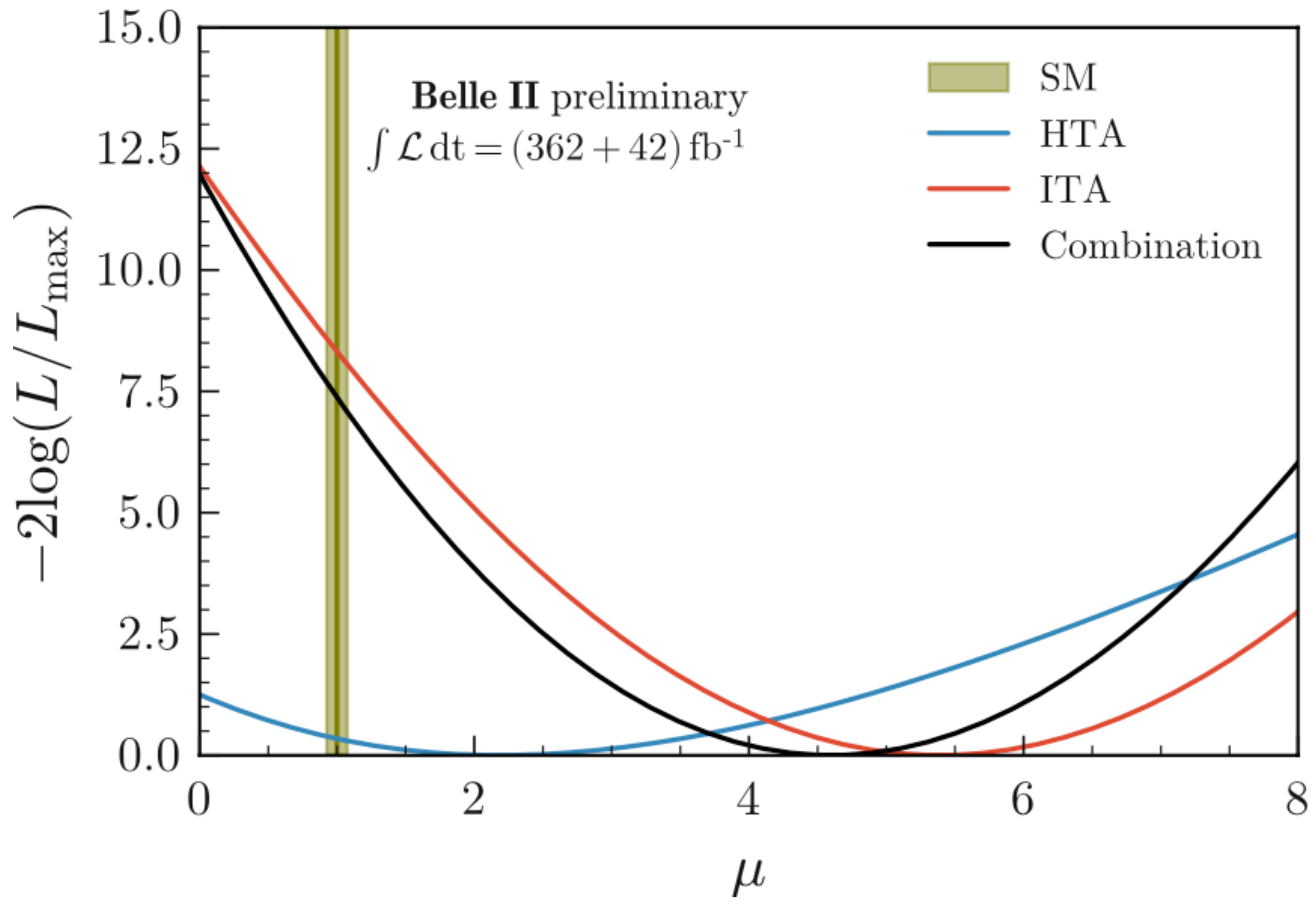
Efficiency:





Combination:

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



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 (2)

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	$n_{\gamma\text{extra}}$ 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

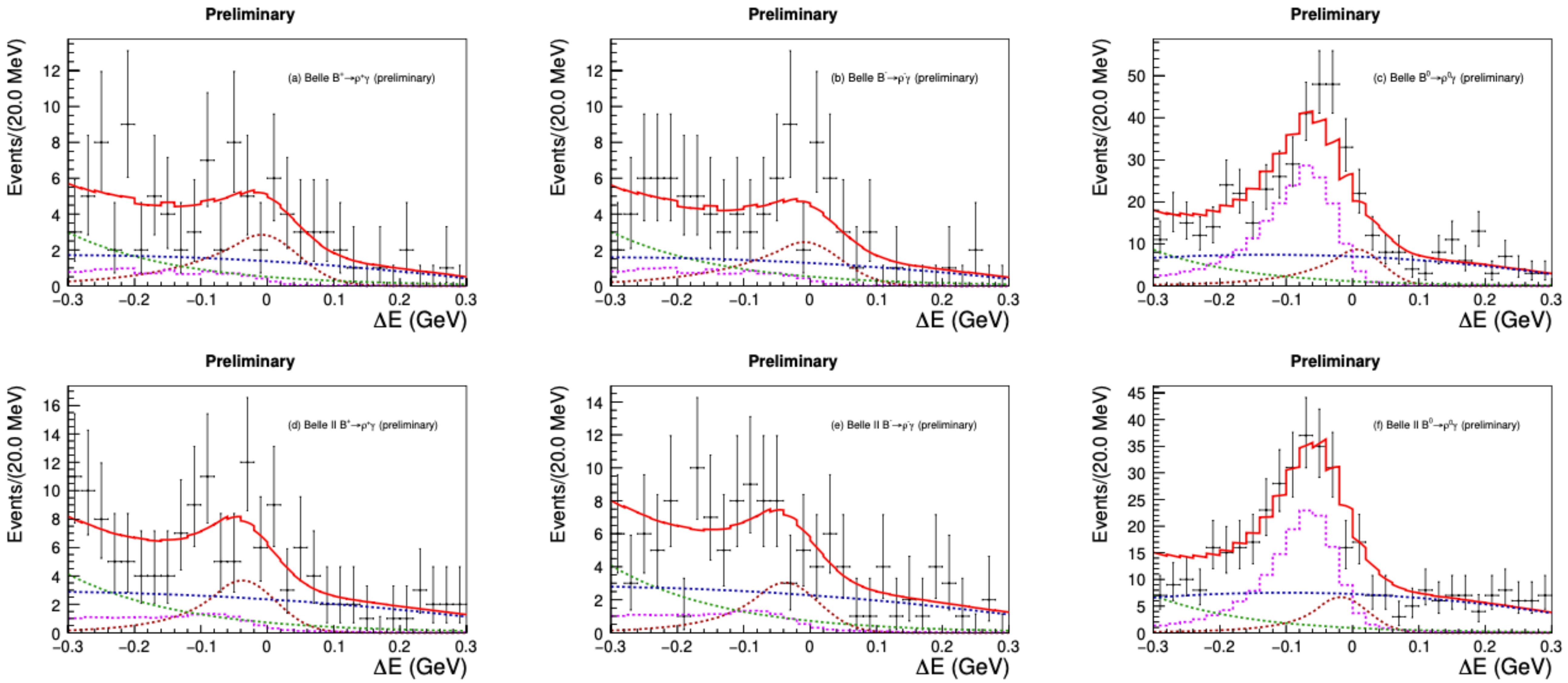
Rare B decays

- $b \to s$ transitions are **FCNC** $\Rightarrow$SM suppressed (forbidden at tree level) $\Rightarrow$ sensitive to NP
- SM BR $\mathcal{O}(10^{-5} - 10^{-7})$ with 10-30% uncertainty, but ratios, asymmetries, angular distributions can be used
- Opportunity to test LFU and LFV (eg. $R_{K^{(*)}}$, $B \to K\ell\ell'$)
  - NB: Belle II has similar (and good) performance **both in electron and muons**
- Most of the channels in Belle II will become **competitive with few ab**$^{-1}$, now Belle II is statistically limited
- Several unique opportunities in Belle II (radiative, multiple neutrinos)

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

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

- Full list of limits

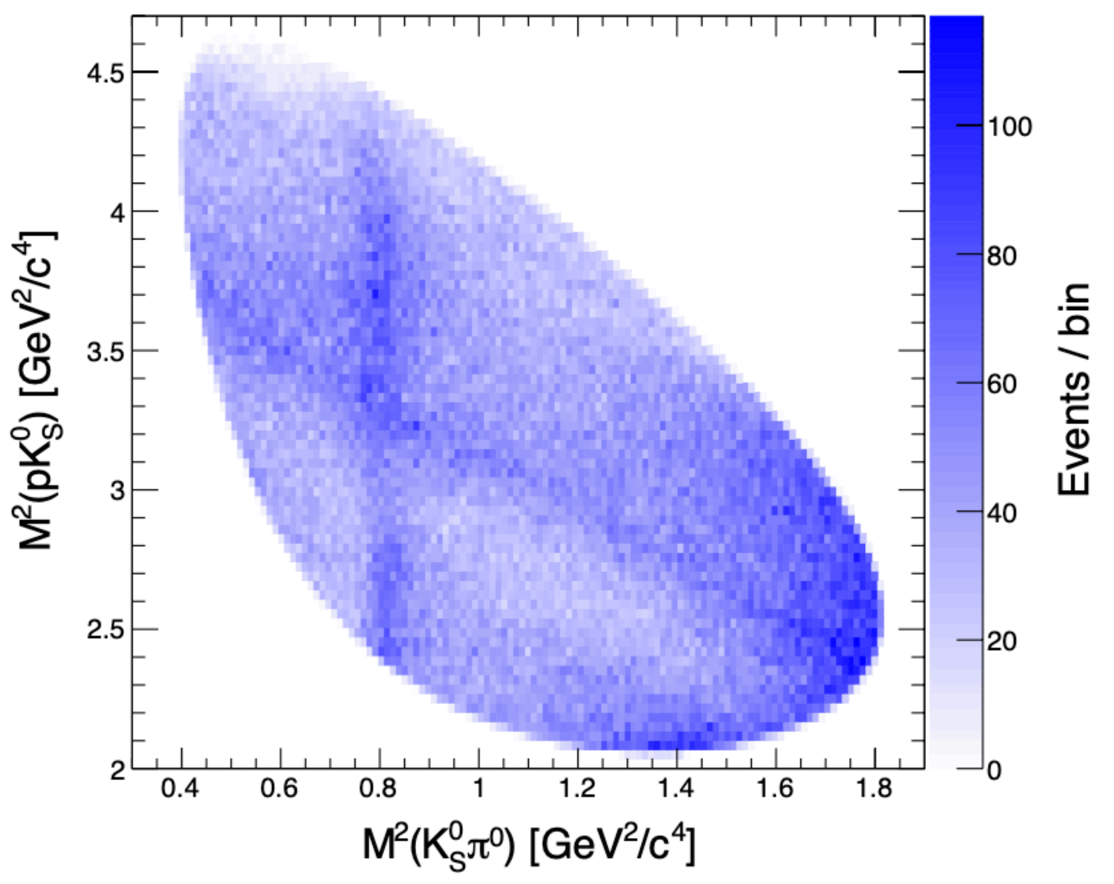
channel	$N_{\rm sig}$	$N_{\rm sig}^{\rm UL}$	ε (%)	$\mathcal{B}^{\rm UL}$ (10^{-8})	$\mathcal{B}$ (10^{-8})
$B^0 \to \eta e^+e^-$	$0.0^{+1.4}_{-1.0}$	3.1	3.9	< 10.5	$0.0^{+4.9}_{-3.4} \pm 0.1$
$B^0 \to \eta\mu^+\mu^-$	$0.8^{+1.5}_{-1.1}$	4.2	5.9	< 9.4	$1.9^{+3.4}_{-2.5} \pm 0.2$
$B^0 \to \eta\ell^+\ell^-$	$0.5^{+1.0}_{-0.8}$	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	$2.5^{+14.6}_{-11.8} \pm 0.2$

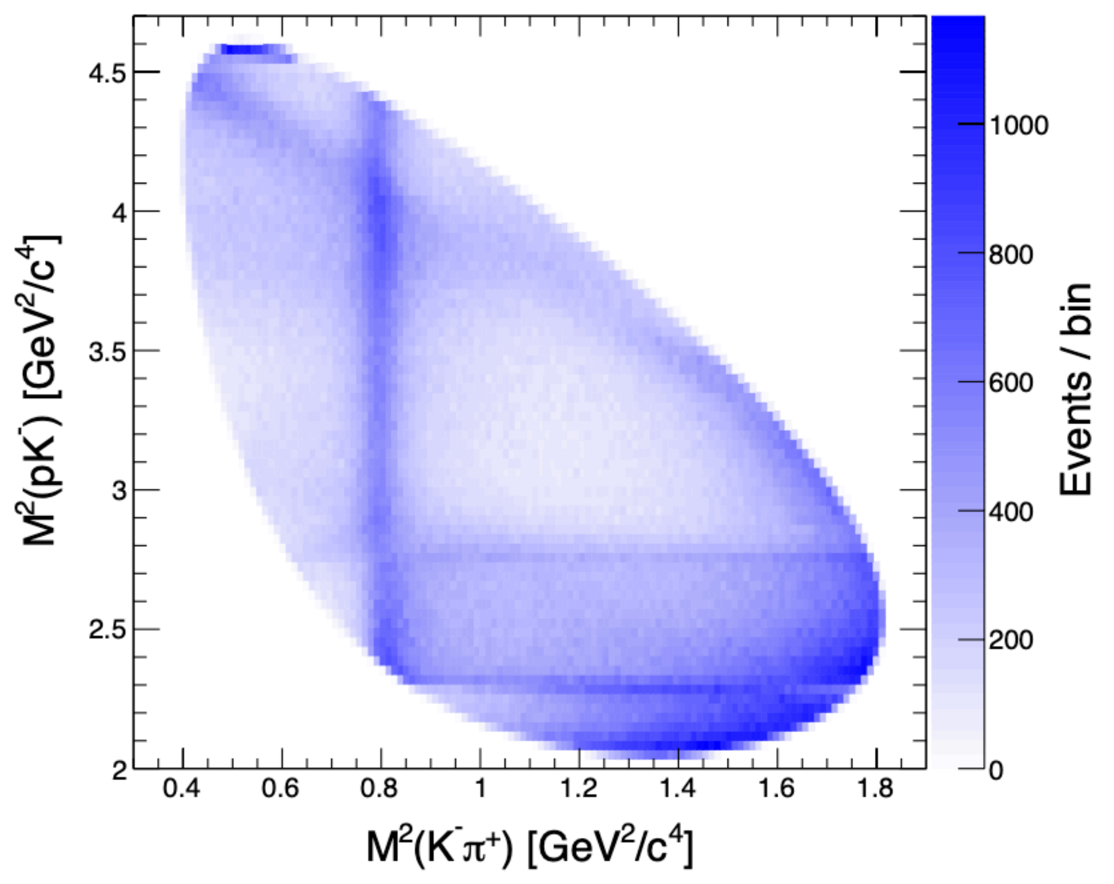
$\Lambda_c^+ \to pK_S^0\pi^0$: extra info

Systematics:

Sources	$\mathcal{B}(\Lambda_c^+ \to pK_S^0\pi^0)$	$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$
K_S^0 reconstruction	1.57	–
π^0 reconstruction	1.54	–
PID of K^- and π^+	–	0.34
Fit procedure	0.71	0.18
MC statistics	0.49	0.31
Dalitz plot binning	0.62	0.15
$\mathcal{B}(\pi^0 \to \gamma\gamma)$ and $\mathcal{B}(K_S^0 \to \pi^+\pi^-)$	0.05	–
Total	2.42	0.64

Dalitz distributions:





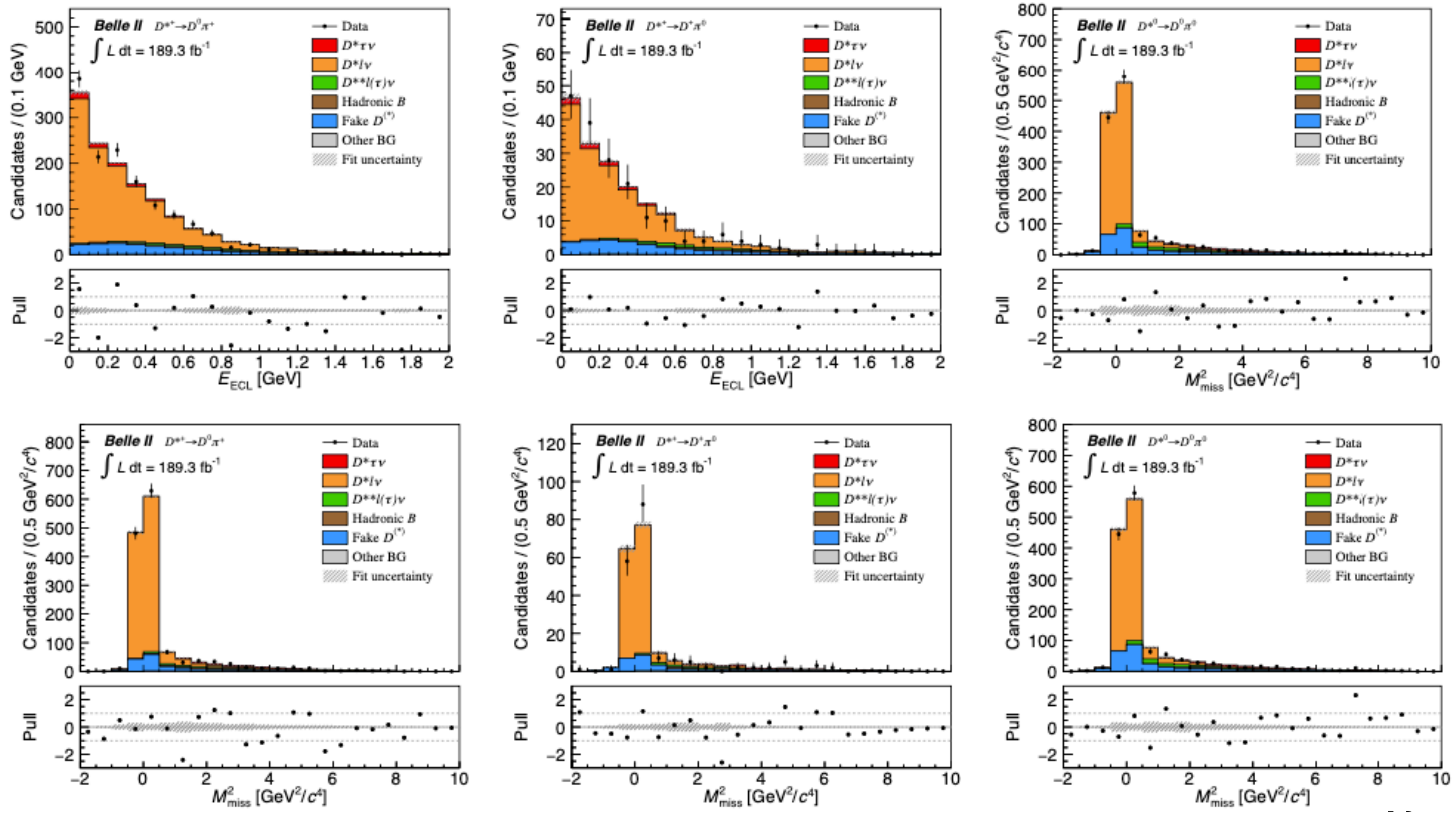
$R(D^*)$: extra info

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	$^{+13.5\%}_{-12.3\%}$

Bkg control studies:

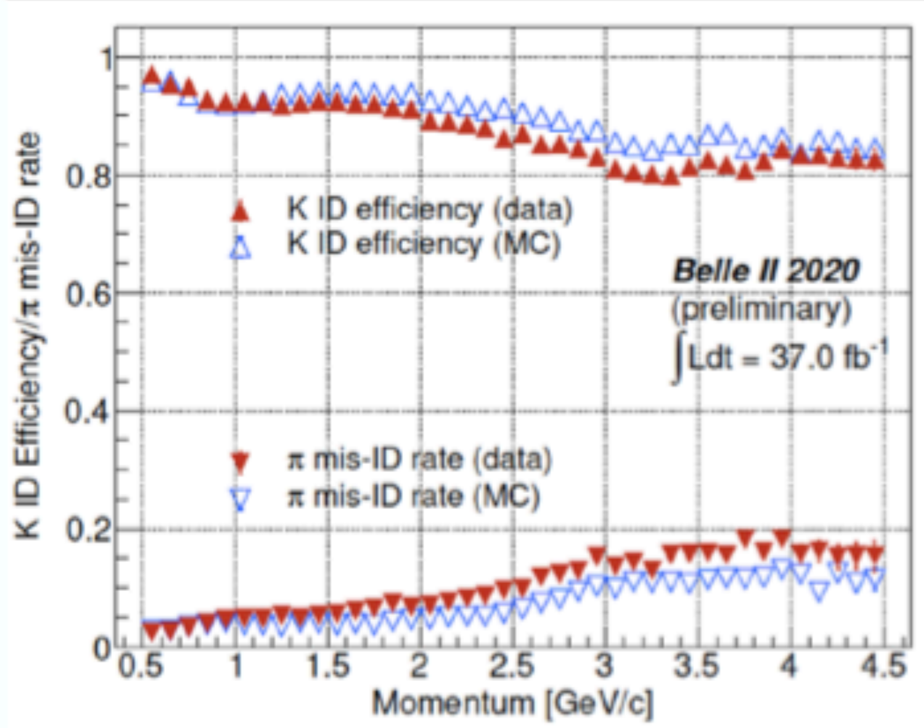
- $B \to D^*\ell\nu$ validated in low q^2 sideband
- $B \to D^{**}\ell\nu$ validated in the extra-π^0 control sample
- Fake D^* bkg validated in $\Delta m = m_{D^*} - m_D$ sideband



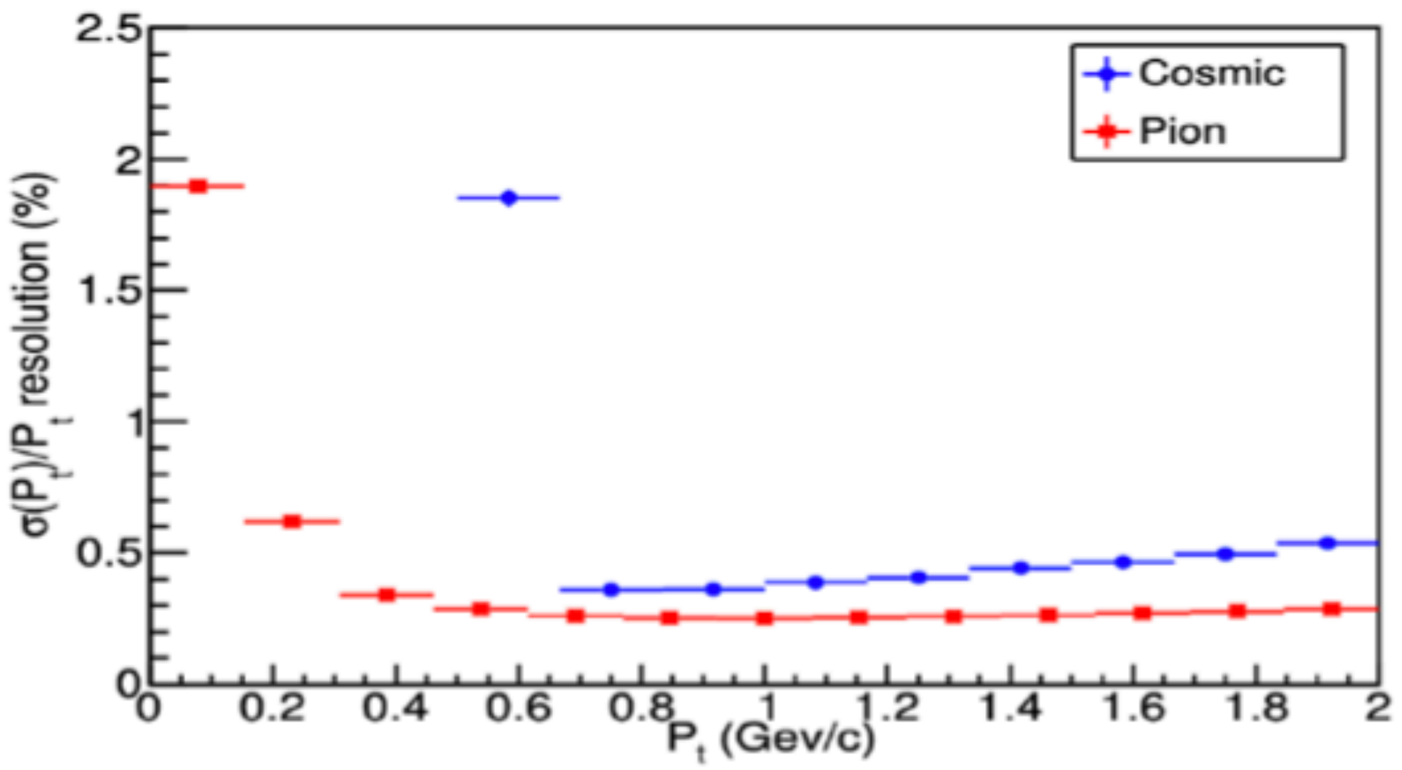
Yields: $B \to D^*\tau\nu$: ~108

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)

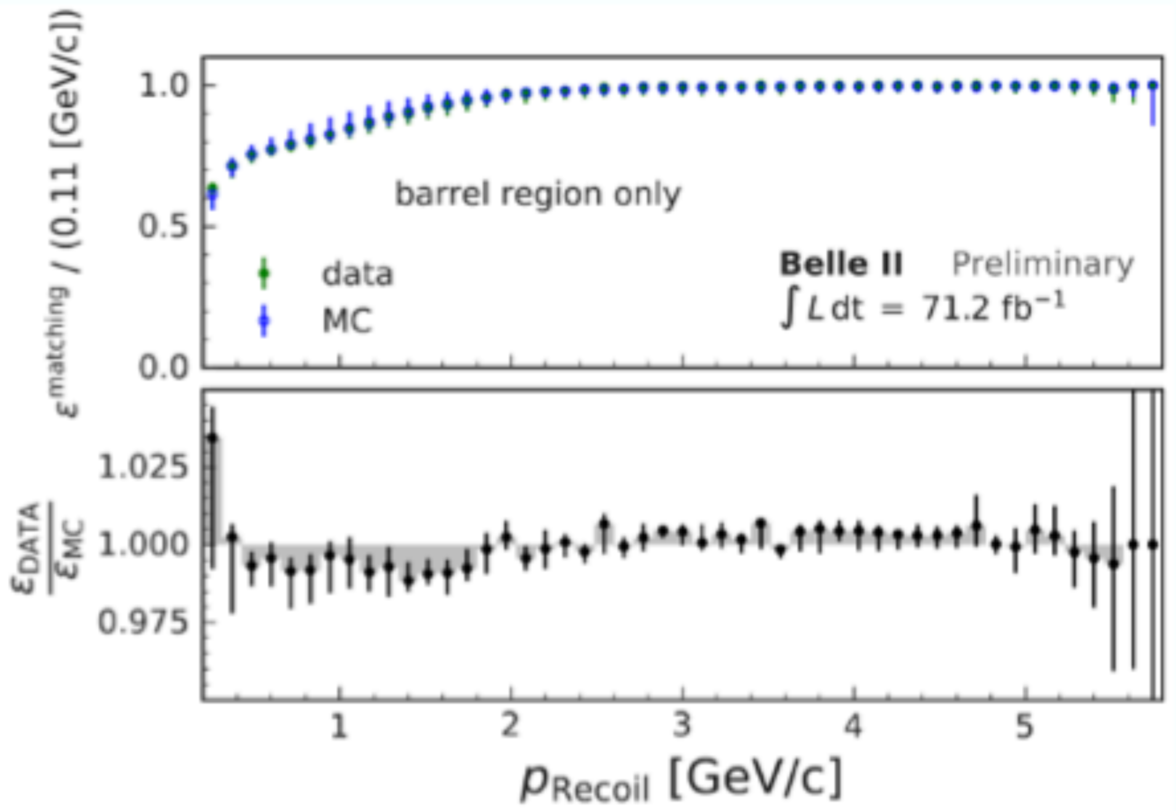
Belle II performance



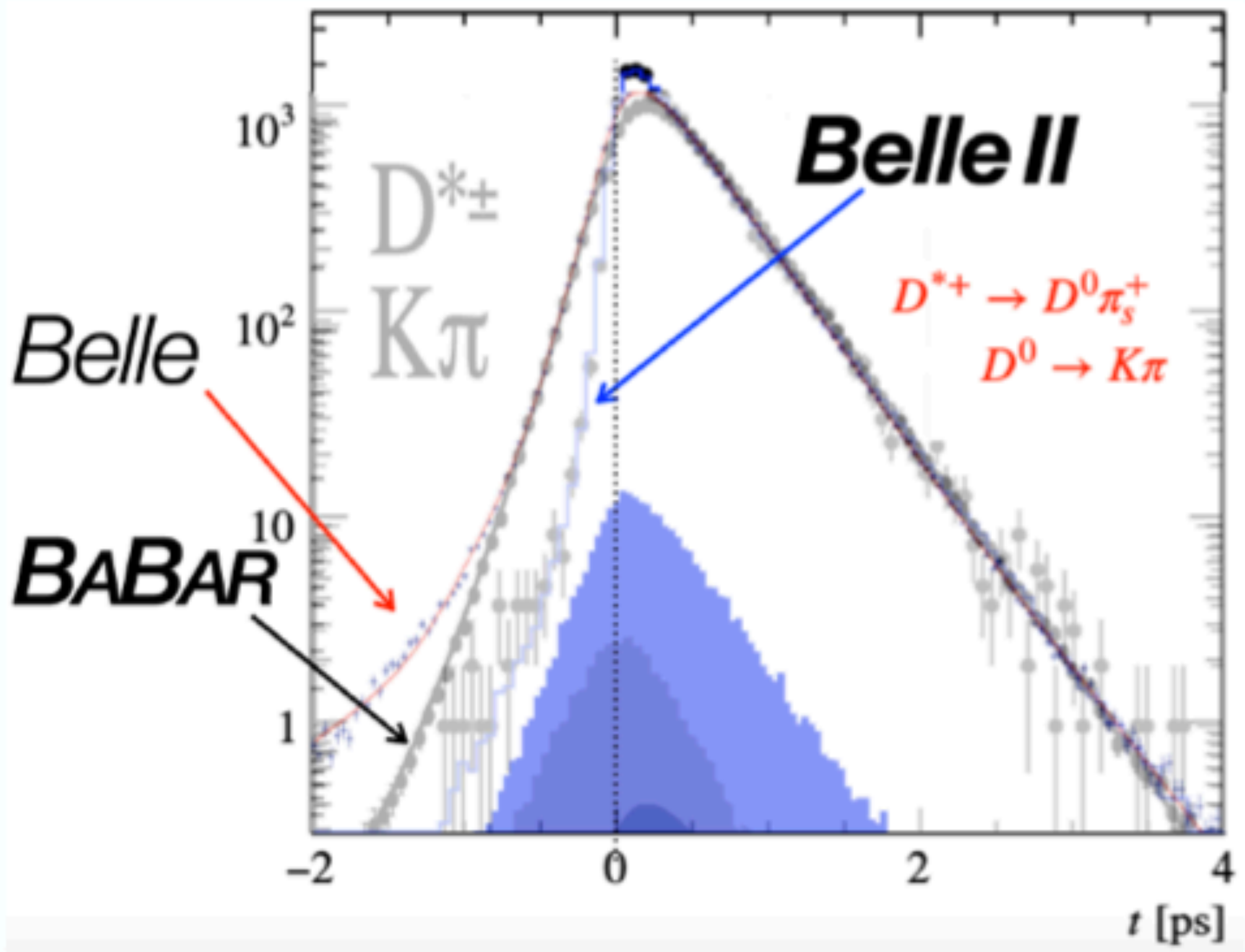
PID still 20% worse than Belle but improving



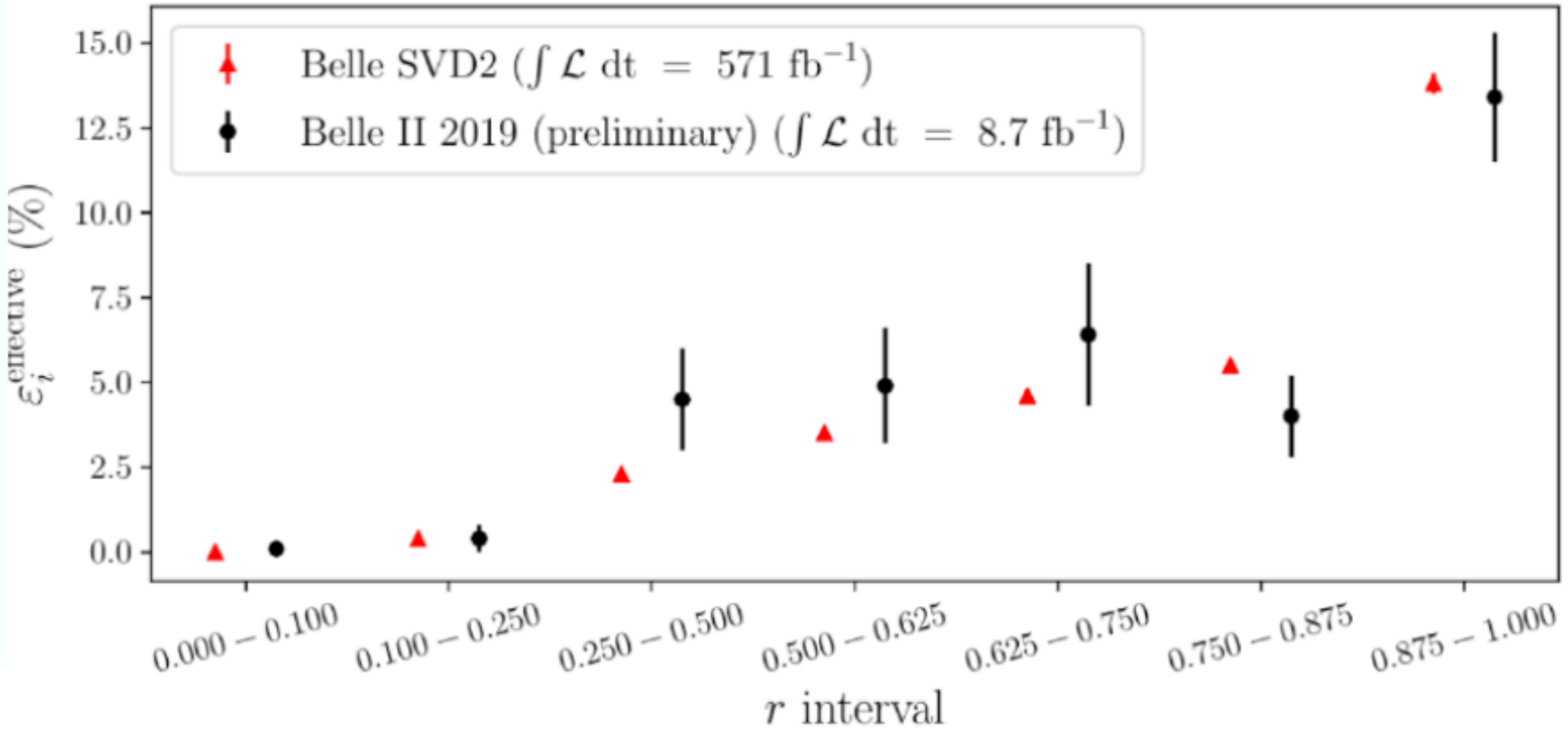
Momentum resolution 20% better than Belle



High photon efficiency,



Nearly 2x better decay-time resolution than Belle



Tagging performance similar to Belle and improving

[From D. Tonelli]