Beauty and charm physics at Belle and Belle II

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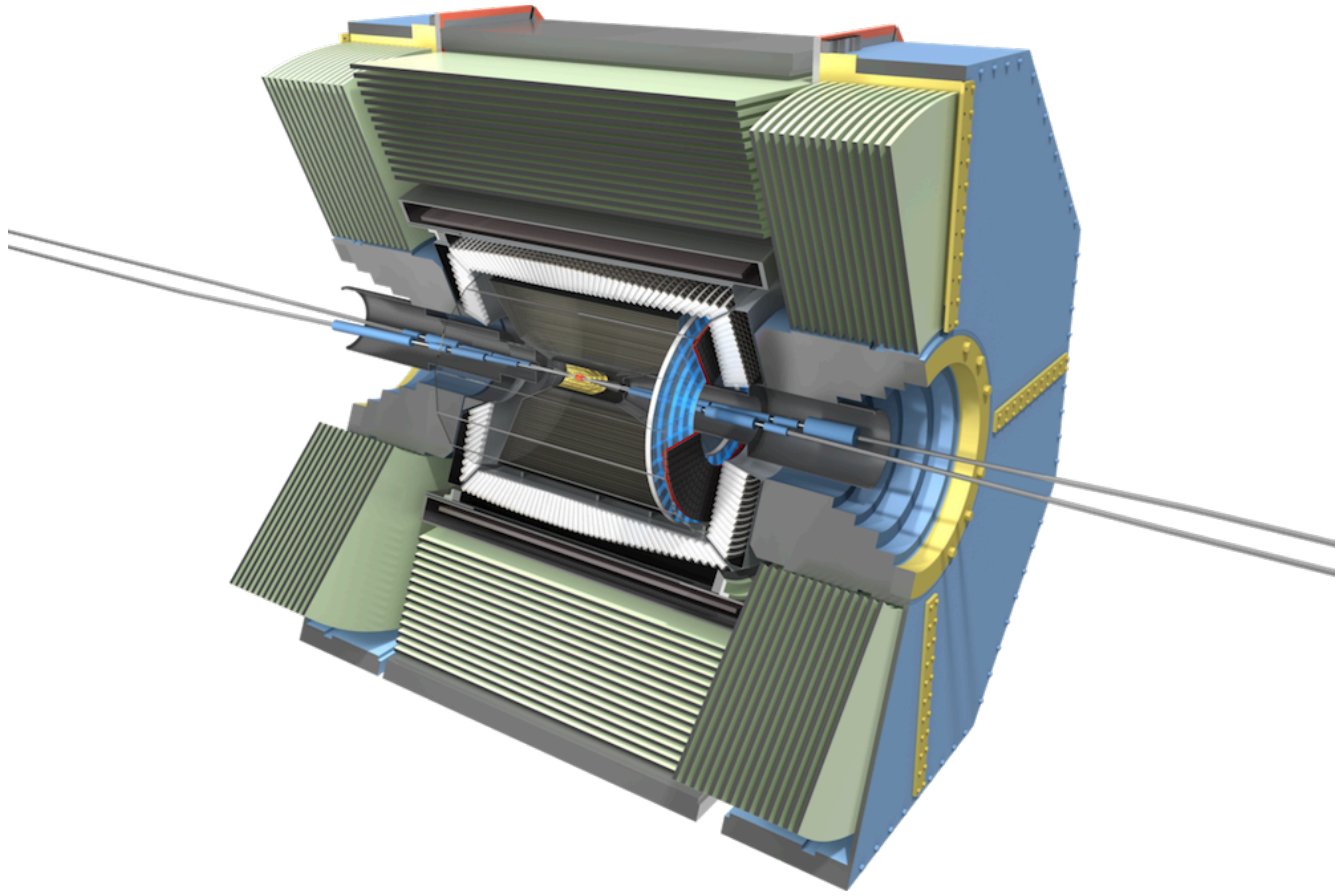
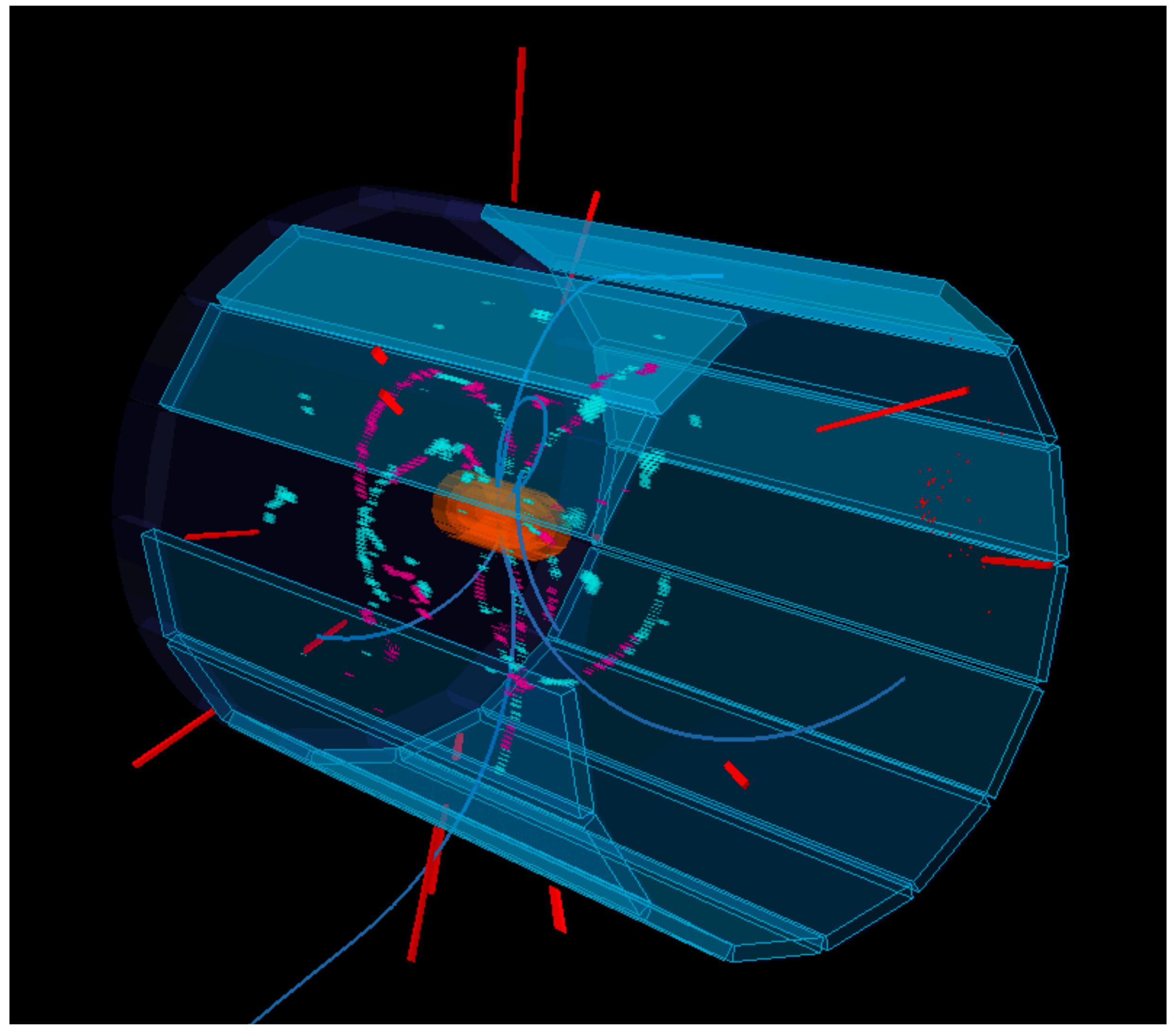
Belle II

Belle (II) at (Super)KEKB

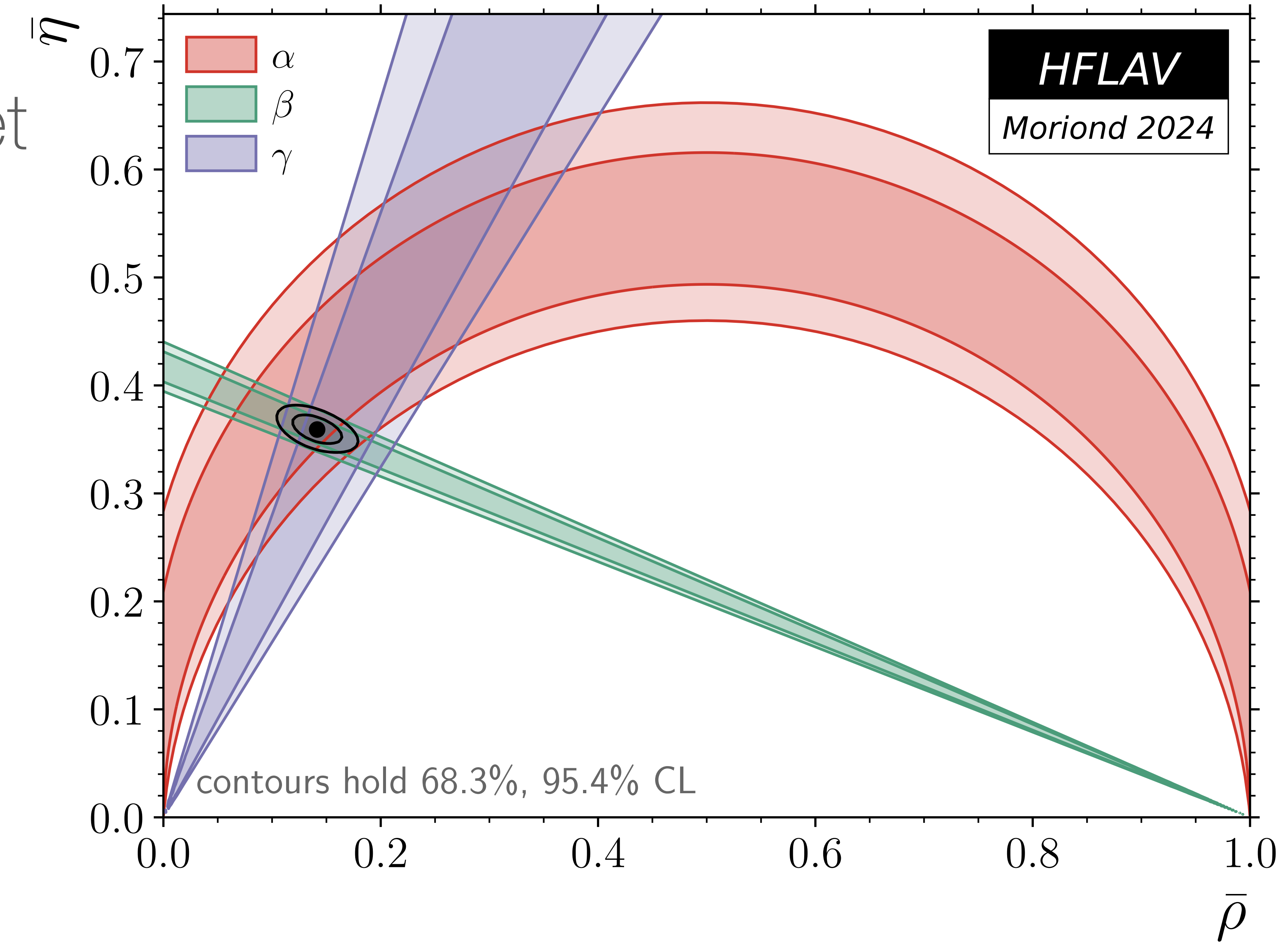
- Asymmetric e^+e^- collider, running at Υ(4s) resonance
  - KEKB (1999-2012) => SuperKEKB (2019-present)
  - Achieved world's record instantaneous luminosity of $5.1\text{x}10^{34}\text{cm}^{-2}\text{s}^{-1}$ (December 2024)
  - Recorded 772M (387M) $B\bar{B}$ pairs at Belle (II), Run 2 data-taking ongoing
- Beauty (and tau/charm) factory experiment
  - Improved performance (vertexing, tracking, neutral particle reconstruction, PID, flavor tagging)
  - Hermetic detector and known initial energy (ideal for decays with missing energy)

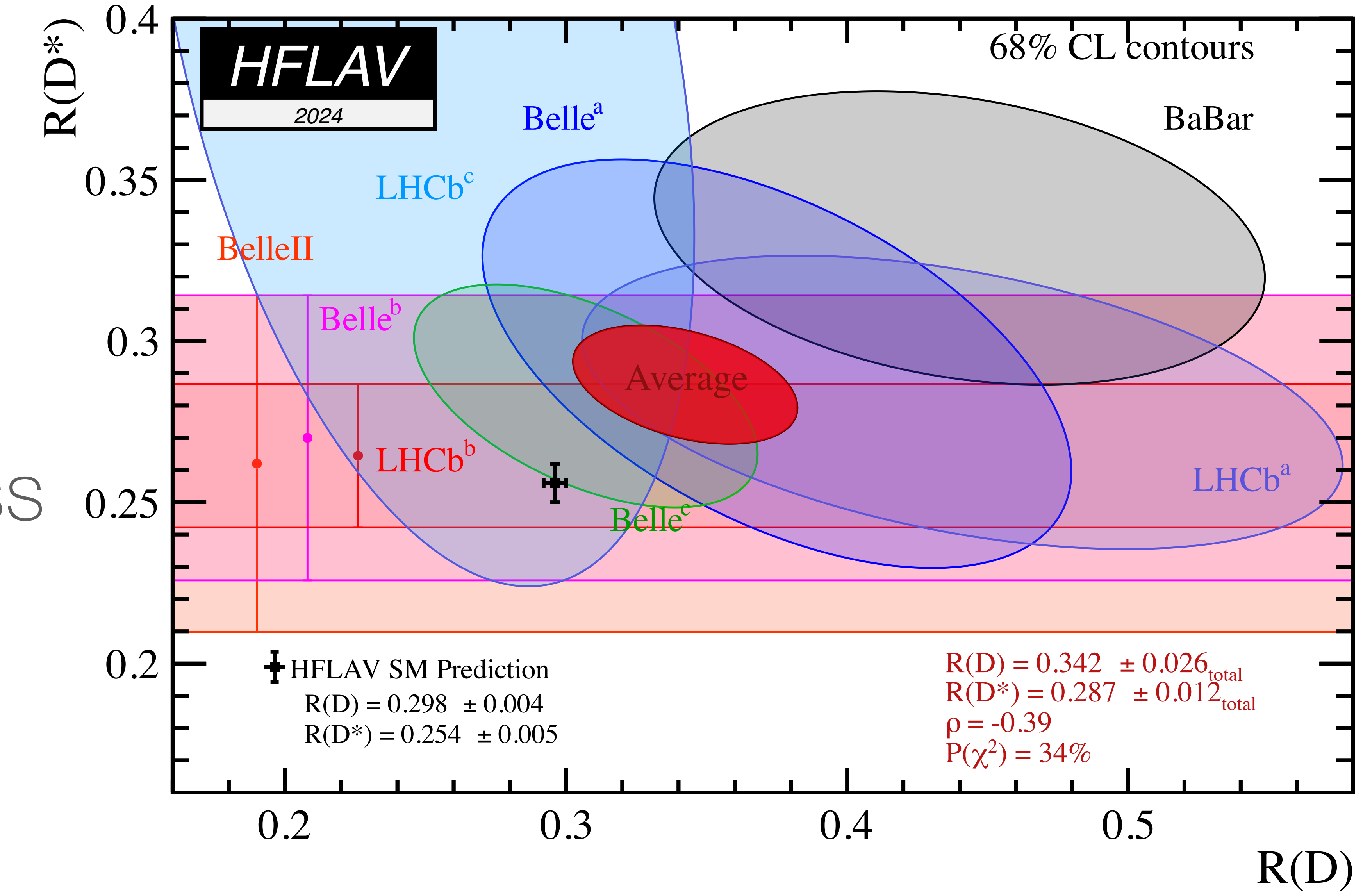




Recent results on beauty and charm*

- **CPV in charm:** nature of CPV observed in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ yet to be fully understood
  - $D^0 \to K^0_S K^0_S$ approaching precision to observe SM-induced CPV, first measurement using opposite-side charm tagging NEW
  - $D^0 \to \pi^0\pi^0$ important ingredient for the $D \to \pi\pi$ isospin sum rule, least known experimentally NEW
- **CPV in beauty:** constrain the angles of the unitarity triangle
  - $\phi_1(\beta)$: measured in $b \to c\bar{c}s$ transitions, precision close to effect of penguin amplitudes, controlled with $B^0 \to J/\psi\pi^0$
  - $\phi_2(\boldsymbol{\alpha})$: least known angle, determined from isospin analysis of $B \to \pi\pi$ and $B \to \rho\rho$
- **(Semi)tauonic and lepton-flavor violating B-decays:** enhancements predicted by models explaining $b \to c\tau\nu$ anomalies and $B \to K\nu\nu$ excess
  - Searches for $B^0 \to K^{*0}\tau\tau$ and $B^0 \to K^0_S\tau l$
  - Measurement of BF of $B^+ \to \tau\nu$ (and V_{ub})





*see talks from F. Trantou and M. Campajola for Belle II results on tau and dark sector

CPV in $D^0 \to K^0_S K^0_S$

- Color and CKM-suppressed transition, interference between $c \to us\bar{s}$ and $c \to ud\bar{d}$ amplitudes, ~O(1%) CPV possible in SM

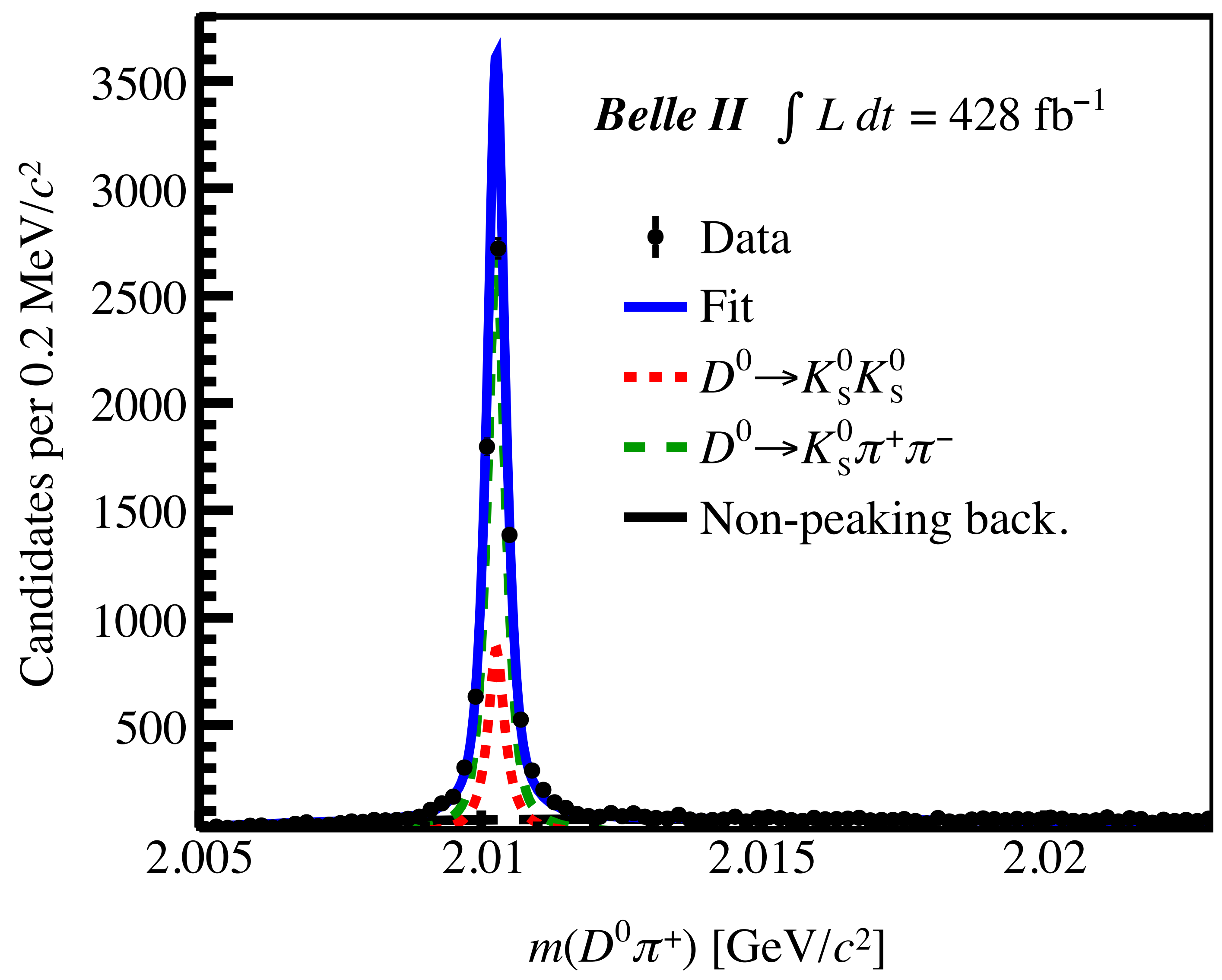
- Using Belle (980fb-1) + Belle II (428fb-1) datasets and combining D^{*+} tag (~7k signal candidates) and opposite-side tag (~20k) samples [PRD 107, 112010 (2023)]

- Combination of two analyses gives most precise determination of the CP asymmetry

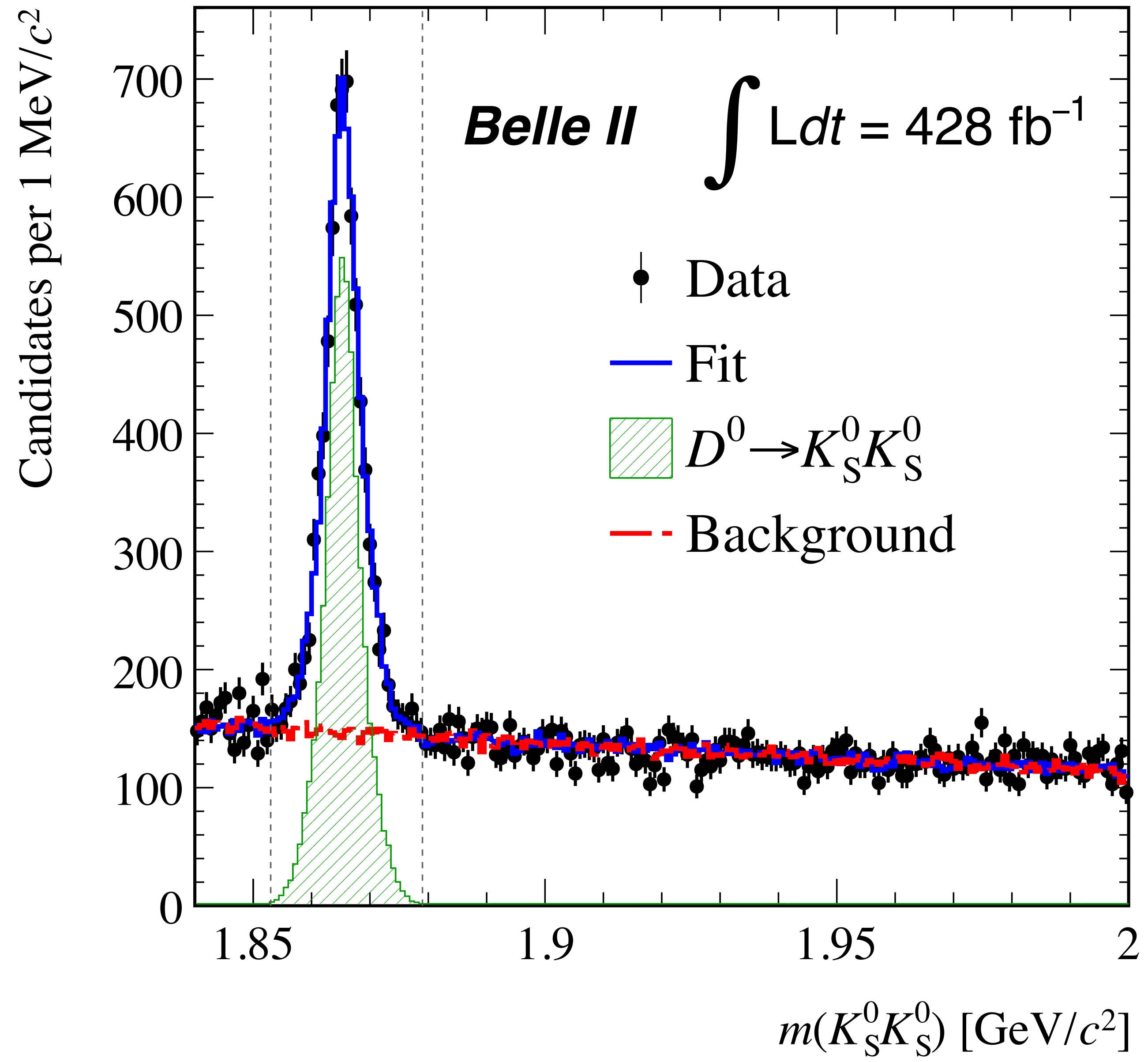
$$A_{CP}(D^0 \to K^0_S K^0_S) = (-0.6 \pm 1.1 \pm 0.1)\%$$

NEW

D^{*+} tag [PRD 111, 012015 (2025)]



Opposite-side tag [paper in preparation]



CPV in $D^0 \to \pi^0\pi^0$

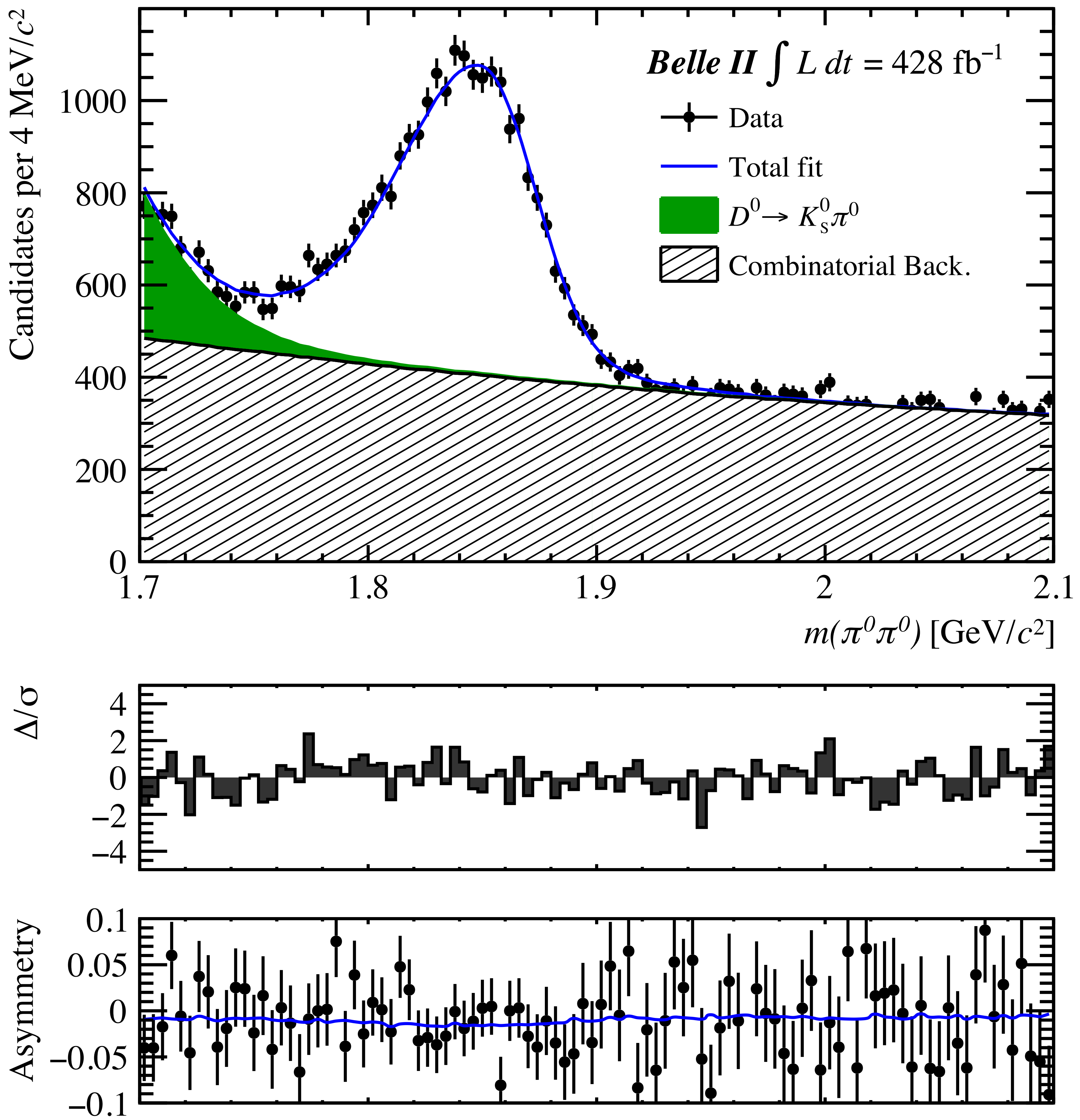
[paper in preparation]

- Non-zero CP asymmetries arise from interference of CKM-suppressed and QCD-penguin amplitudes
  - Current data from $D^0 \to \pi^+\pi^-$ suggest ~O(1%) CPV in $D^0 \to \pi^0\pi^0$ possible in SM
  - Isospin sum rule of $D \to \pi\pi$ modes can help identify the source of charm CPV
- D^{*+} tagged Belle II sample (~16k signal candidates), instrumental asymmetries cancelled with $D^0 \to K^+\pi^-$ control sample (CPV~0)
- Precision comparable to Belle result and 18% improvement on the isospin sum rule

$$A_{CP}(D^0 \to \pi^0\pi^0) = (0.30 \pm 0.72(\text{stat}) \pm 0.20(\text{syst}))\%$$

$$R = (1.5 \pm 2.5) \times 10^{-3}$$

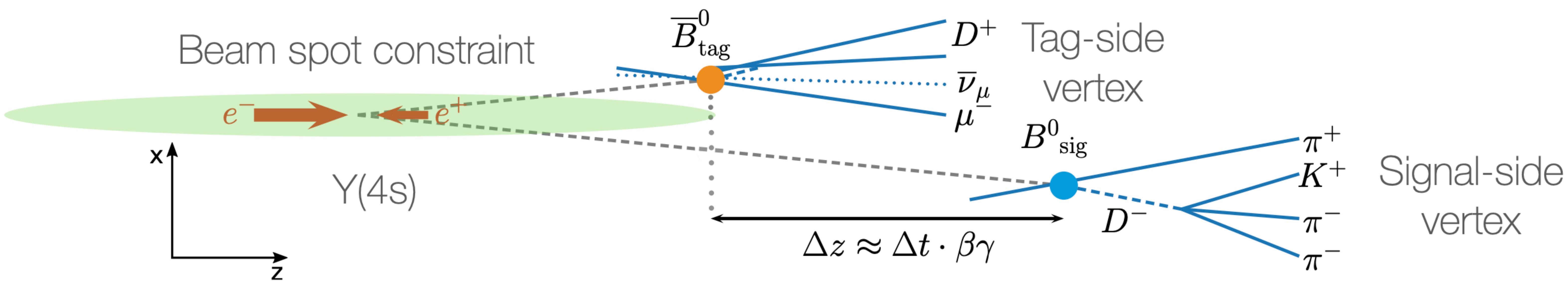
NEW



CPV in B^0 decays

PRD 110, 012001 (2024)

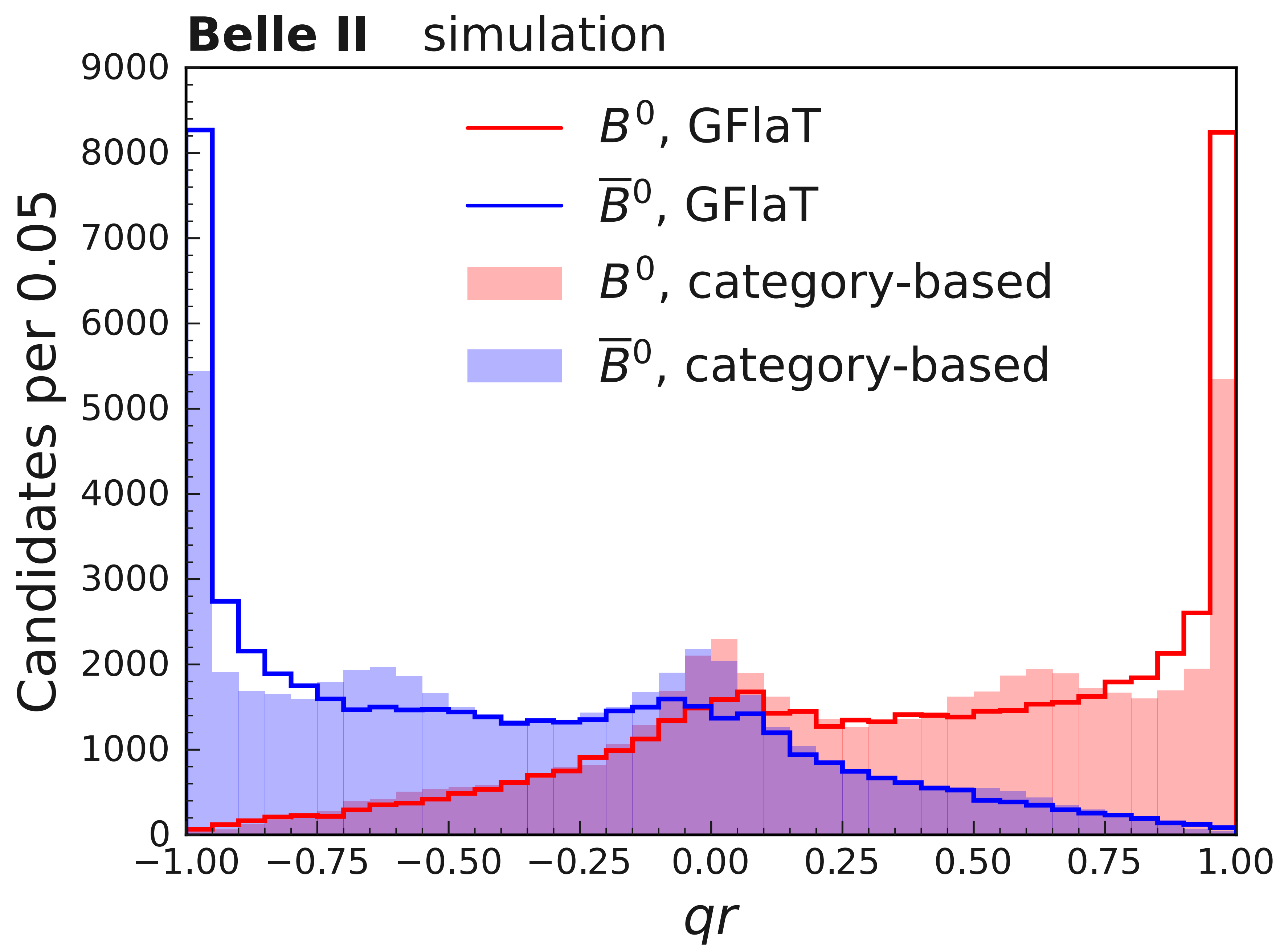
Essential ingredients for (in)direct CPV analysis:



- Tag initial flavor from partially reconstructed tag-side B^0 (efficiency ~ 37%)
- Exploit correlation of $B^0\bar{B}^0$ pairs to measure Δt asymmetries

$$\mathcal{P}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\{1 + q[S_{CP}\sin(\Delta m_d \Delta t) - C_{CP}\cos(\Delta m_d \Delta t)]\}$$

- Suppress non-resonant $ee \rightarrow q\bar{q}$ "continuum" with event shape and rest-of-the event variables
- Model signal and backgrounds distributions in *beam-constrained mass* M_{bc} and *energy difference* ΔE

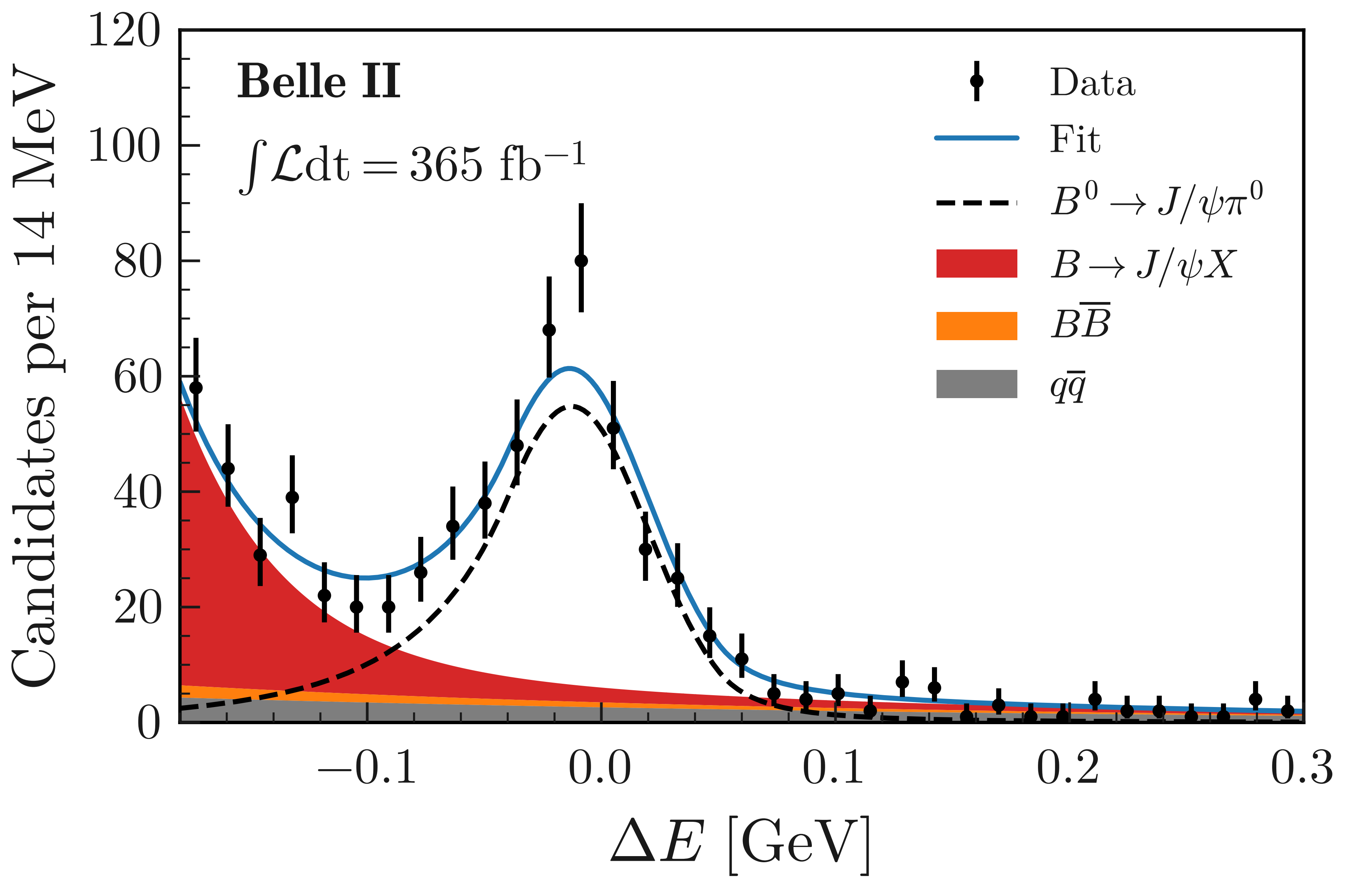


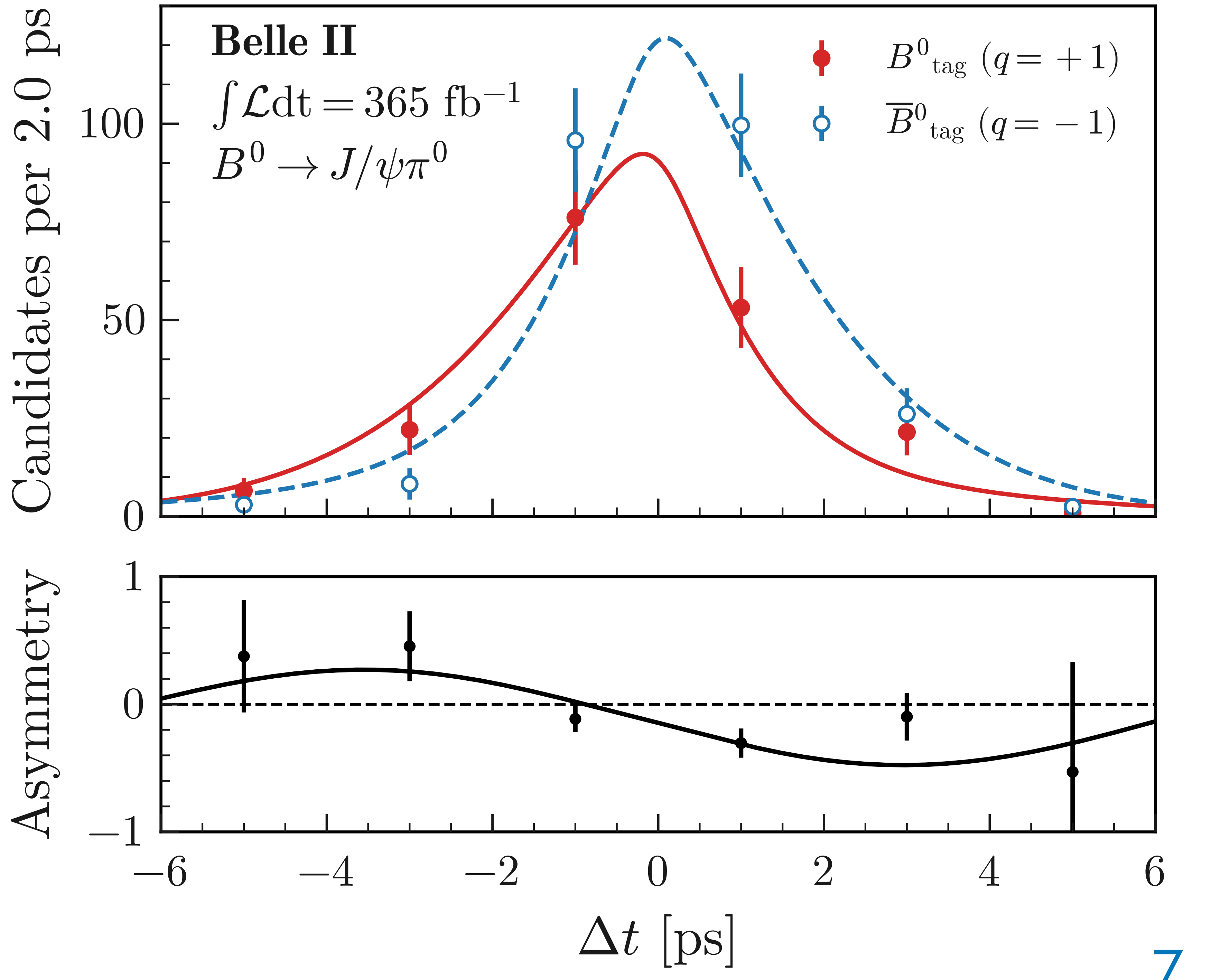
$(\Delta)\phi_1$ in $B^0 \to J/\psi\pi^0$

[PRD 111, 012011 (2025)]

- Doubly-CKM suppressed ("penguin") amplitudes can shift the value of $\phi_d = 2\phi_1$ measured in $B^0 \to J/\psi K^0$ by ~O(0.5°)
  - Current experimental knowledge $\phi_d^{eff} = [45.12 \pm 0.94]°$
  - BF and CP asymmetries in $B^0 \to J/\psi\pi^0$ constrain $\Delta\phi_d$
- First observation of indirect CPV and competitive BF with 392±24 signal candidates in 387M $B\bar{B}$ pairs
  - Experimental error on $\phi_d = [45.6^{+1.1}_{-1.0}(\text{exp}) \pm 0.3(\text{SU(3)})]°$ reduced by ~10% with this result [arxiv:2501.09414]

$$\mathcal{B}(B^0 \to J/\psi\,\pi^0) = (2.00 \pm 0.12 \pm 0.09) \times 10^{-5},$$
$$C_{CP} = 0.13 \pm 0.12 \pm 0.03,\ \ S_{CP} = -0.88 \pm 0.17 \pm 0.03$$



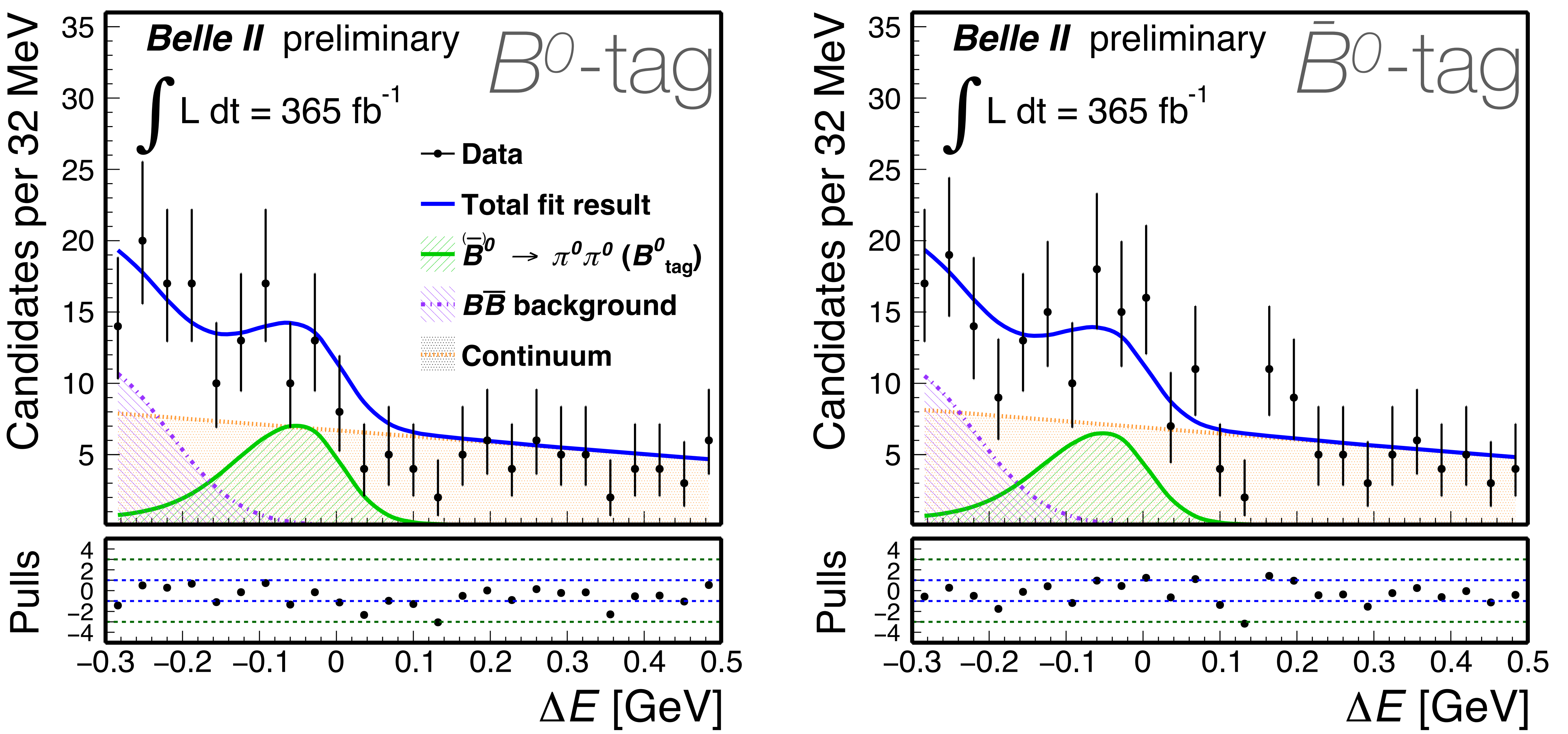


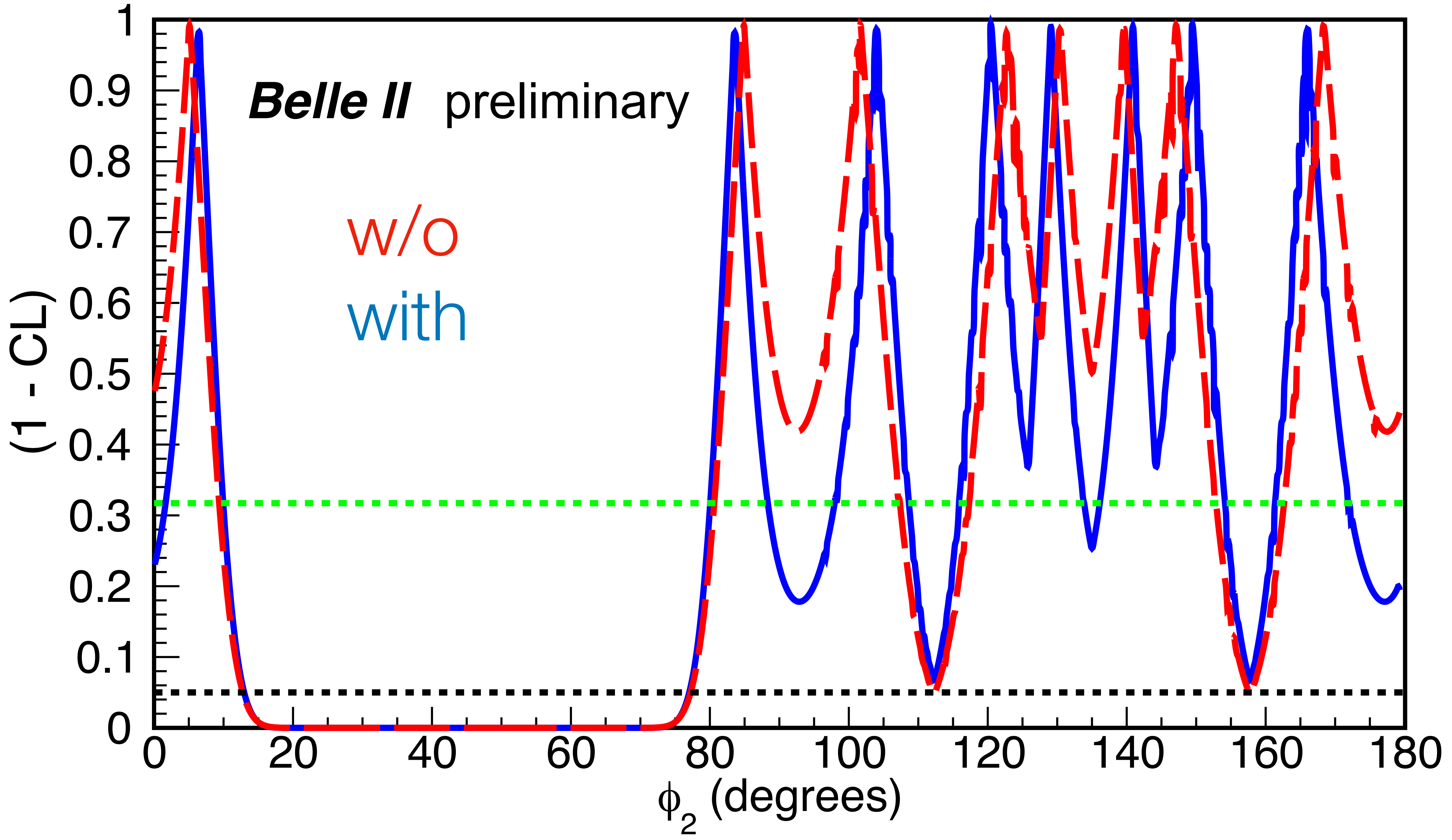
ϕ_2 in $B^0 \to \pi^0\pi^0$

Accepted by PRDL [arxiv:2412.14260]

- Knowledge of BF and CP asymmetries in $B^0 \to \pi^0\pi^0$ limits the precision on ϕ_2 extracted from the $B \to \pi\pi$ system
- Experimentally reconstruct $2\pi^0$'s (i.e. 4 photons and no vertex) among large continuum background
- Found **126±20** signal candidates in 387M $B\bar{B}$ pairs, from which competitive precision on *BF* and A_{CP} is achieved
  - 30% fractional increase in ϕ_2 precision from $B \to \pi\pi$ system including this result

$$\mathcal{B}(B^0 \to \pi^0\pi^0) = (1.25 \pm 0.20 \pm 0.11) \times 10^{-6}$$
$$\mathcal{A}_{CP}(B^0 \to \pi^0\pi^0) = 0.03 \pm 0.30 \pm 0.04$$





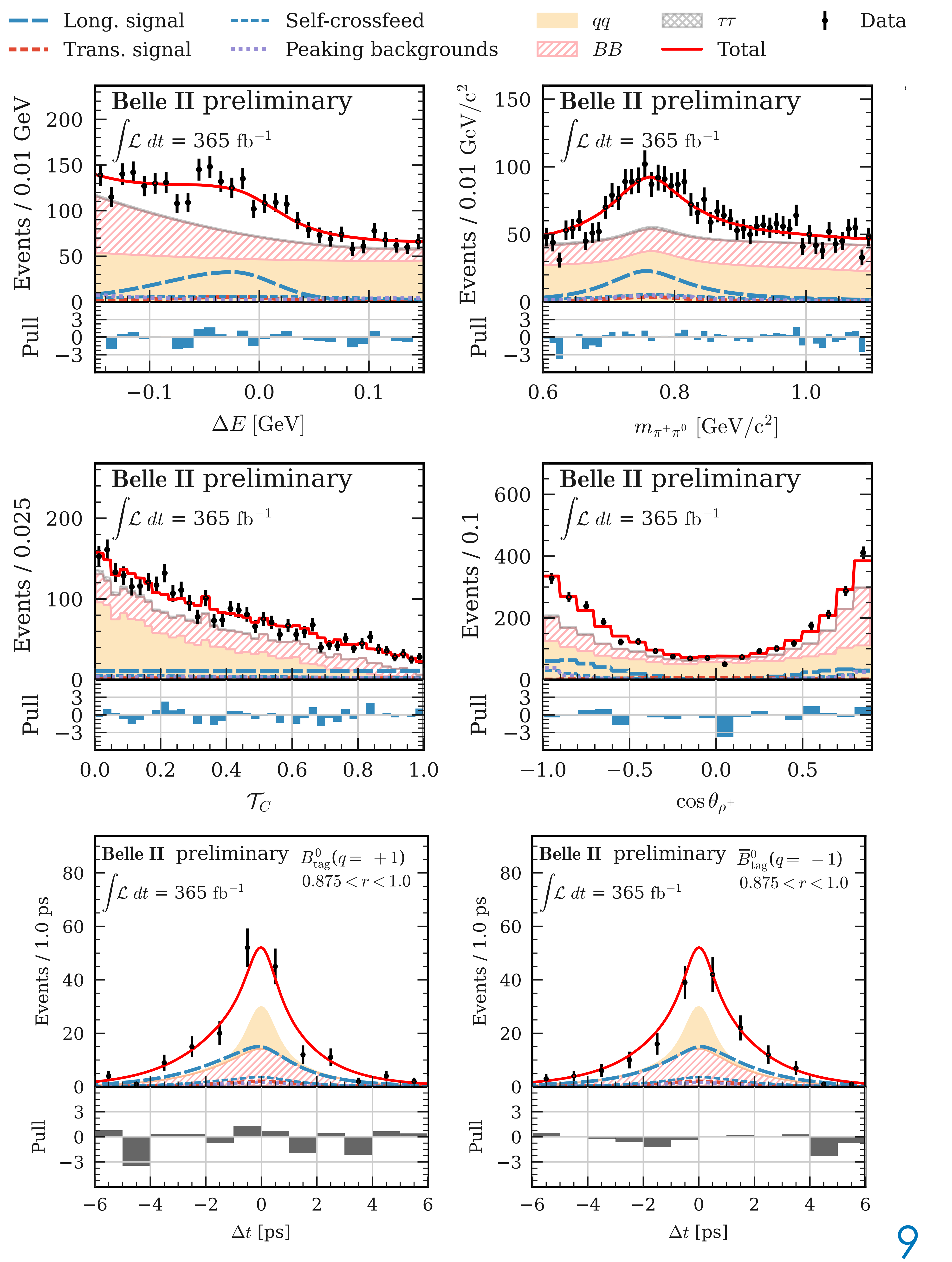
ϕ_2 in $B^0 \to \rho^+\rho^-$

Submitted to PRD [arxiv:2412.19624]

- $B^0 \to \rho^+\rho^-$ dominates precision on ϕ_2 due to small loop contribution
- Experimentally reconstruct $2\pi^0$'s in the final state and angular analysis to separate longitudinal/transverse polarization in P→VV decay
- Found **436±35** longitudinally polarized signal candidates, from which Δt-dependent CP-asymmetries are measured
  - Precision similar to Belle/BaBar and ~8% relative improvement on the precision of ϕ_2 with $B \to \rho\rho$

$$\begin{aligned}
\mathcal{B}(B^0 \to \rho^+\rho^-) &= \left(2.88^{+0.23}_{-0.22}{}^{+0.29}_{-0.27}\right) \times 10^{-5}, \\
f_L &= 0.921^{+0.024}_{-0.025}{}^{+0.017}_{-0.015}, \\
S &= -0.26 \pm 0.19 \pm 0.08, \\
C &= -0.02 \pm 0.12^{+0.06}_{-0.05},
\end{aligned}$$

$$\begin{aligned}
\phi_2 &= (92.6^{+4.5}_{-4.7})^\circ \\
\Delta\phi_2 &= (2.4^{+3.8}_{-3.7})^\circ
\end{aligned}$$

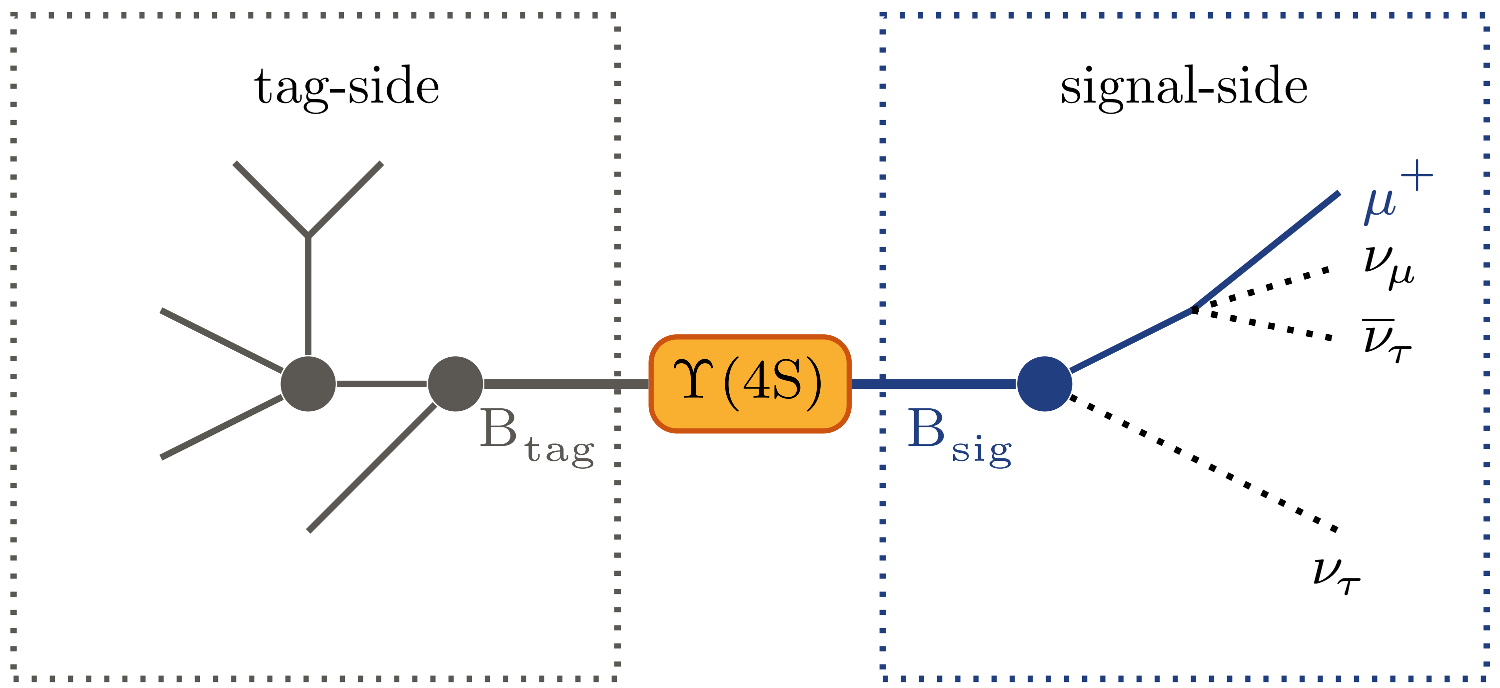


B-tagging

Comput Softw Big Sci 3, 6 (2019)

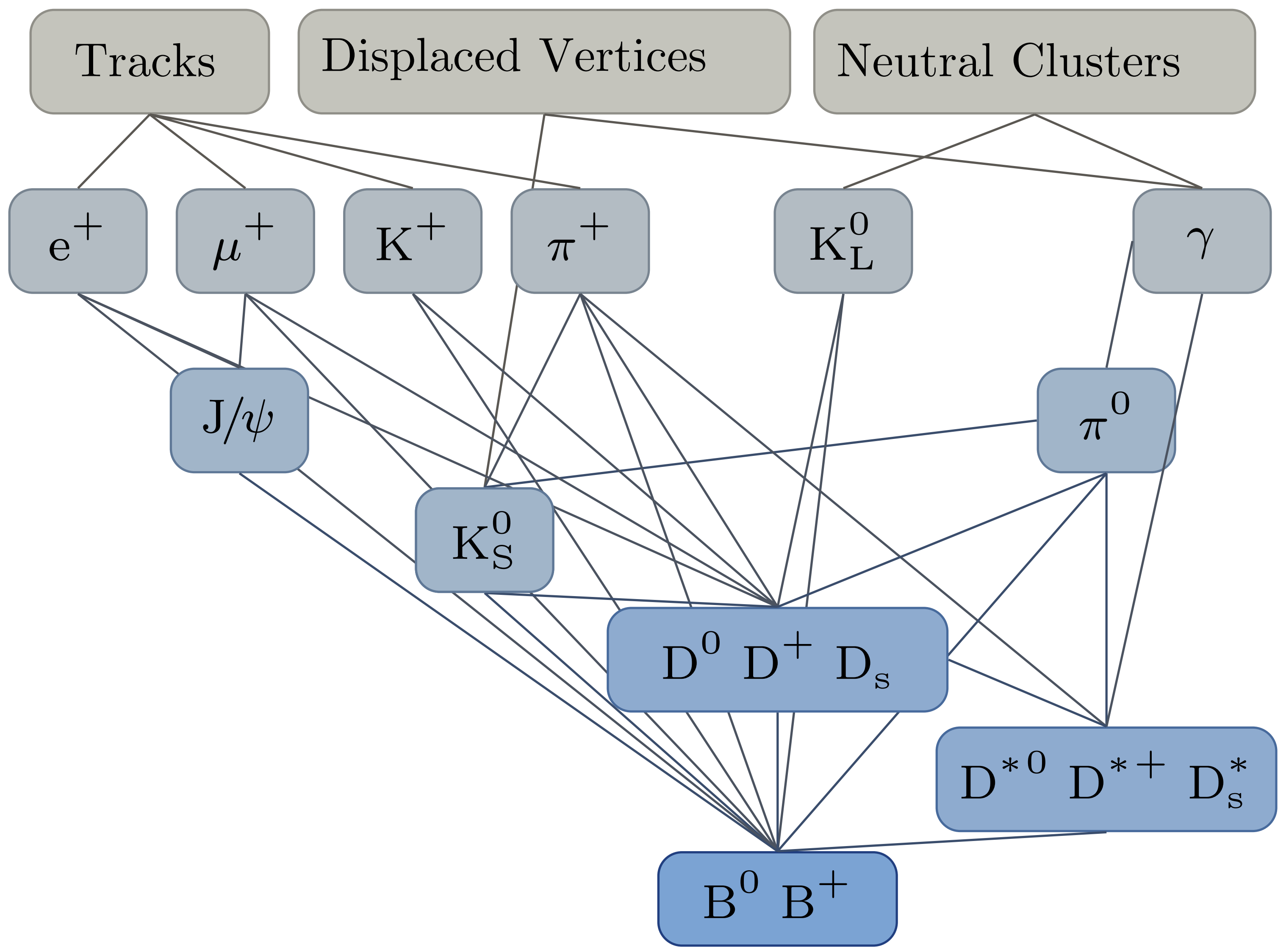
Essential ingredient for analyses with >1ν in the final state

- Fully reconstruct tag-side B-meson with hadronic B-decays (e.g. $B \to D^{(*)} n\pi$)
- Calibrate efficiency (<1%) in data using $B \to X l \nu$ and partially reconstructed $B \to D^{(*)} \pi$ decays



Separate signal and background distributions in

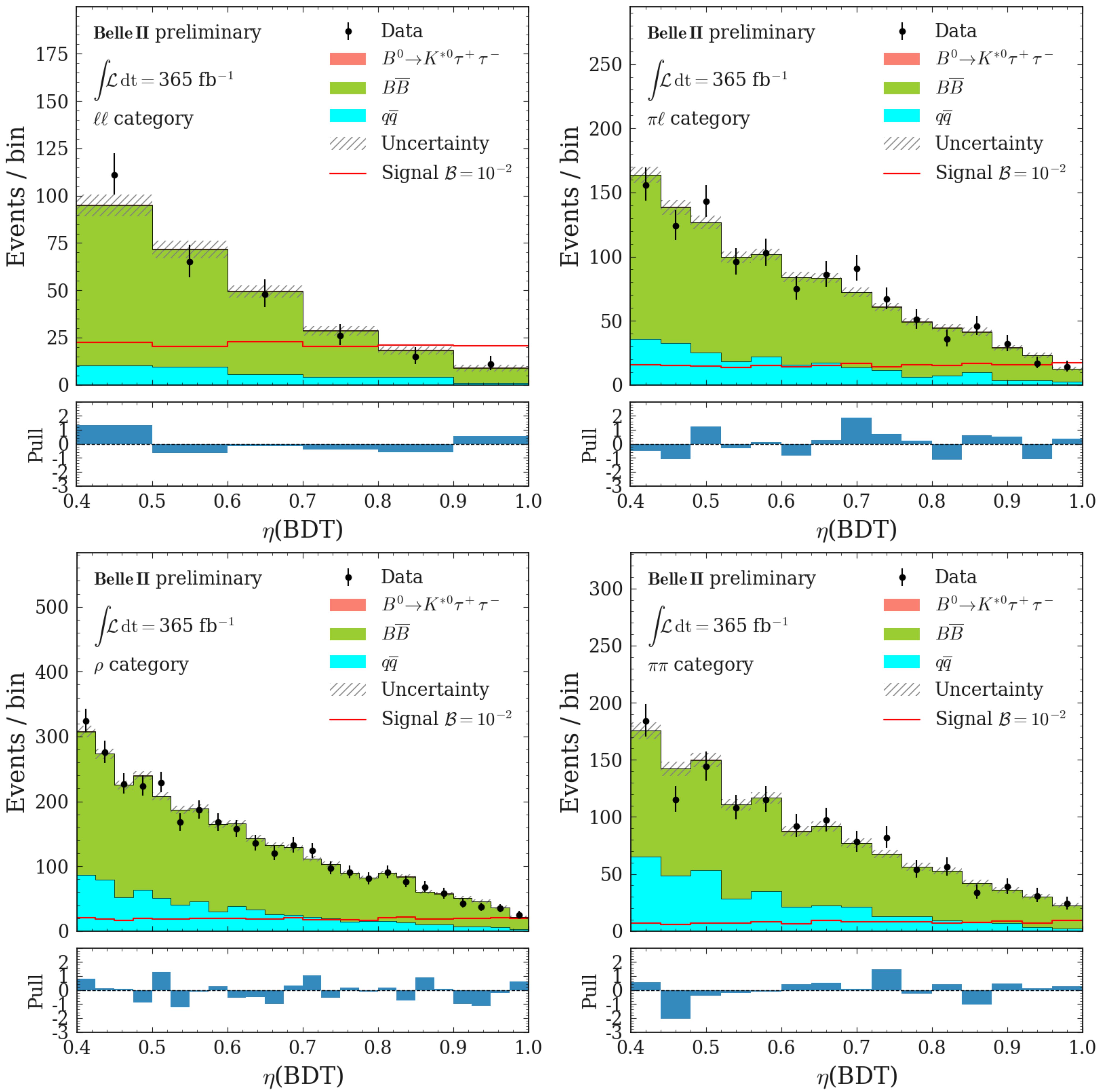
- Sum of the energy deposits in the calorimeter not associated with B_{tag} and B_{sig} (E_{ECL})
- Missing four-momentum of the event from the known beam energies (M_{miss}^2)



$B^0 \to K^{*0}\tau\tau$

- BF~O(10^{-7}) in SM, enhanced up to ~O(10^{-3}) in models explaining $b \to c\tau\nu$ anomalies and $B \to K\nu\nu$ excess, close to experimental sensitivities
- Reconstructing the tag-side with hadronic decays and signal side from combinations of $\tau^+ \to (e^+, \mu^+)\nu\nu$ and $\tau^+ \to (\pi^+, \rho^+)\nu$ (up to 4ν in the final state)
- Signal extracted from fit to BDT classifier combining E_{ECL}, M_{miss}^2, and event shape variables
  - Limit twice improved over Belle (higher B-tagging efficiency and inclusion of $\tau \to \rho\nu$ channel)
  - Most stringent limit on $b \to s\tau\tau$ transitions to date

BF($B^0 \to K^{*0}\tau^+\tau^-$)<1.8 x$10^{-3}$ @90% C.L.

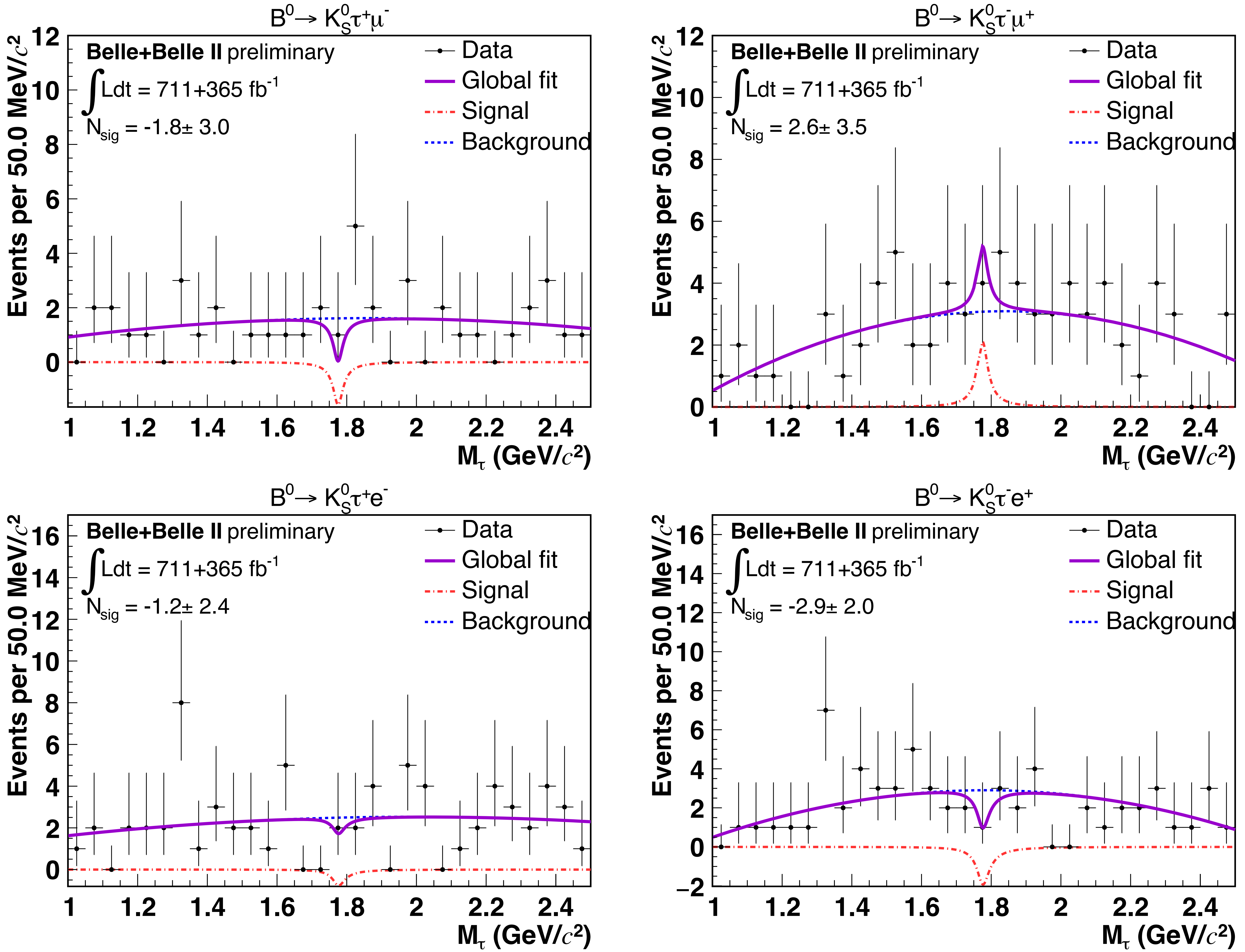


$B^0 \to K^0_S \tau l$

Submitted to PRL [arxiv:2412.16470]

- Lepton-flavor violating $b \to s\tau l$ transitions may similarly arise with BF~$O(10^{-6})$, also close to experimental sensitivities
- First search for $B^0 \to K^0_S \tau l$ using hadronic B-tagging and recoil mass to reconstruct M_τ
  - Clean $K^0_S \to \pi^+\pi^-$ signature, first $B \to K\tau l$ analysis including of $\tau^+ \to \rho^+ \nu$ channel
  - Most stringent ULs on $b \to s\tau e$ transitions

$$\mathcal{B}(B^0 \to K^0_S \tau^+ \mu^-) < 1.1 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to K^0_S \tau^- \mu^+) < 3.6 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to K^0_S \tau^+ e^-) < 1.5 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to K^0_S \tau^- e^+) < 0.8 \times 10^{-5}$$



$B^+ \to \tau^+ \nu$

Submitted to PRD [arxiv:2502.04885]

- Leptonic B decay with largest BF, sensitive to BSM (charged Higgs, 2HDM) and theoretically clean probe for V_{ub}

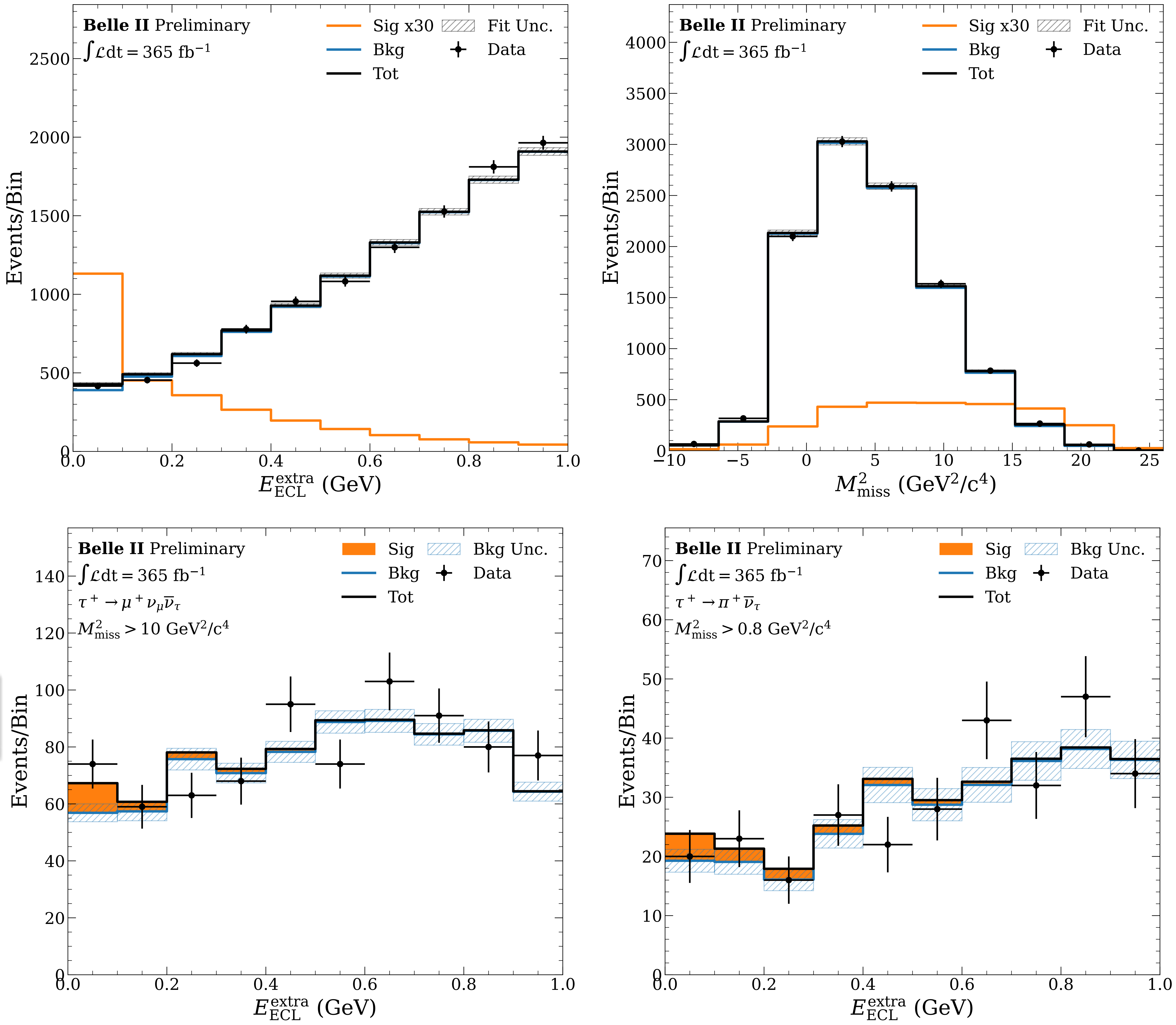
$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = \frac{G_F^2 m_B m_\tau^2}{8\pi} \left[1 - \frac{m_\tau^2}{m_B^2}\right]^2 f_B^2 |V_{ub}|^2 \tau_B$$

- Using hadronic B-tag and $\tau^+ \to (e^+, \mu^+)\nu\nu$ and $\tau^+ \to (\pi^+, \rho^+)\nu$ (~72% of τ decays)

- Observed 94±31 signal candidates from fit to E_{ECL} and M_{miss}^2 (3σ evidence)

$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = [1.24 \pm 0.41(\text{stat.}) \pm 0.19(\text{syst.})] \times 10^{-4}$$

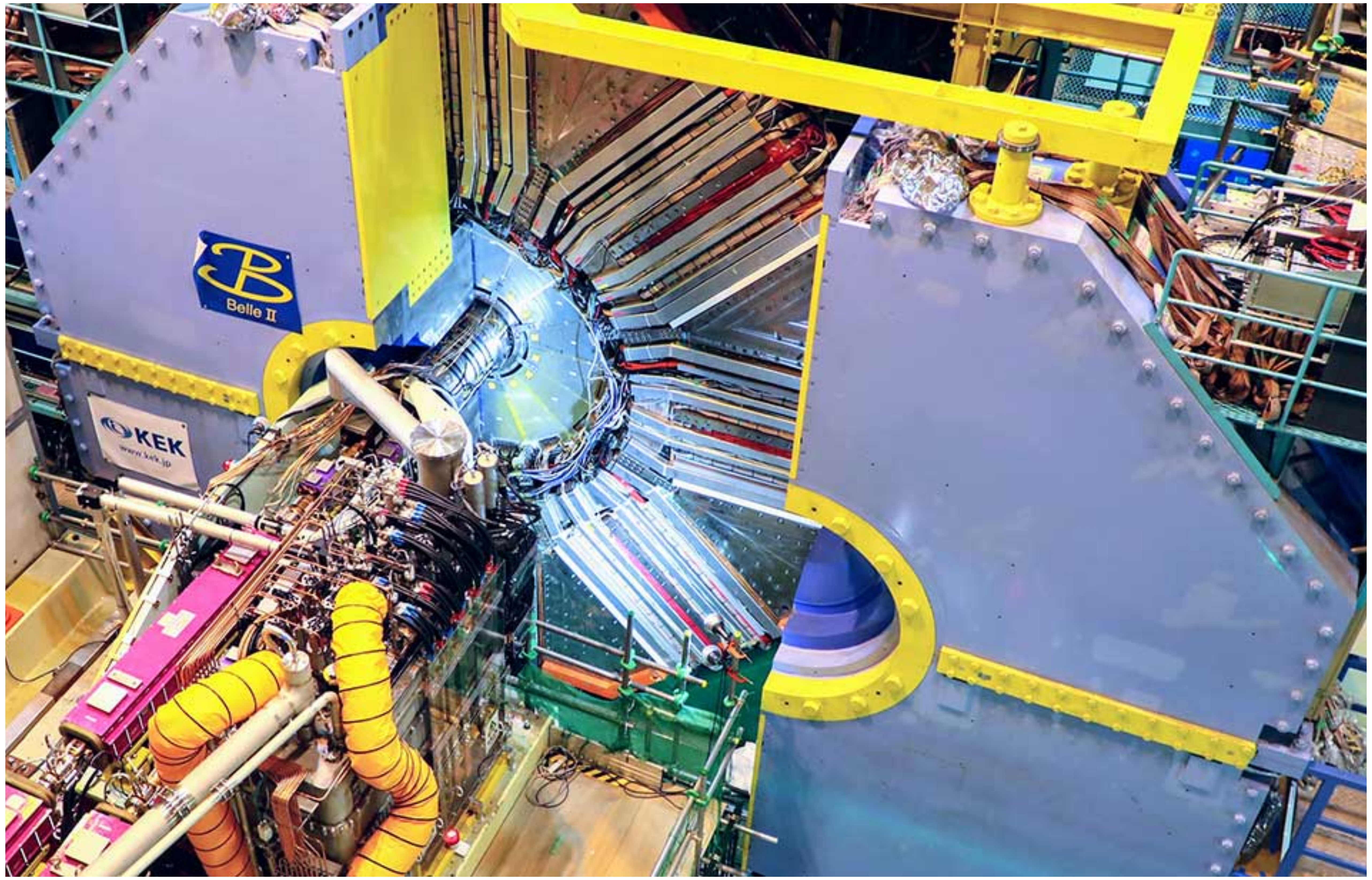
  - Sensitivity comparable to previous had. tagged analyses



Summary and outlook

Belle II continues to provide essential inputs to test the CKM structure of the SM

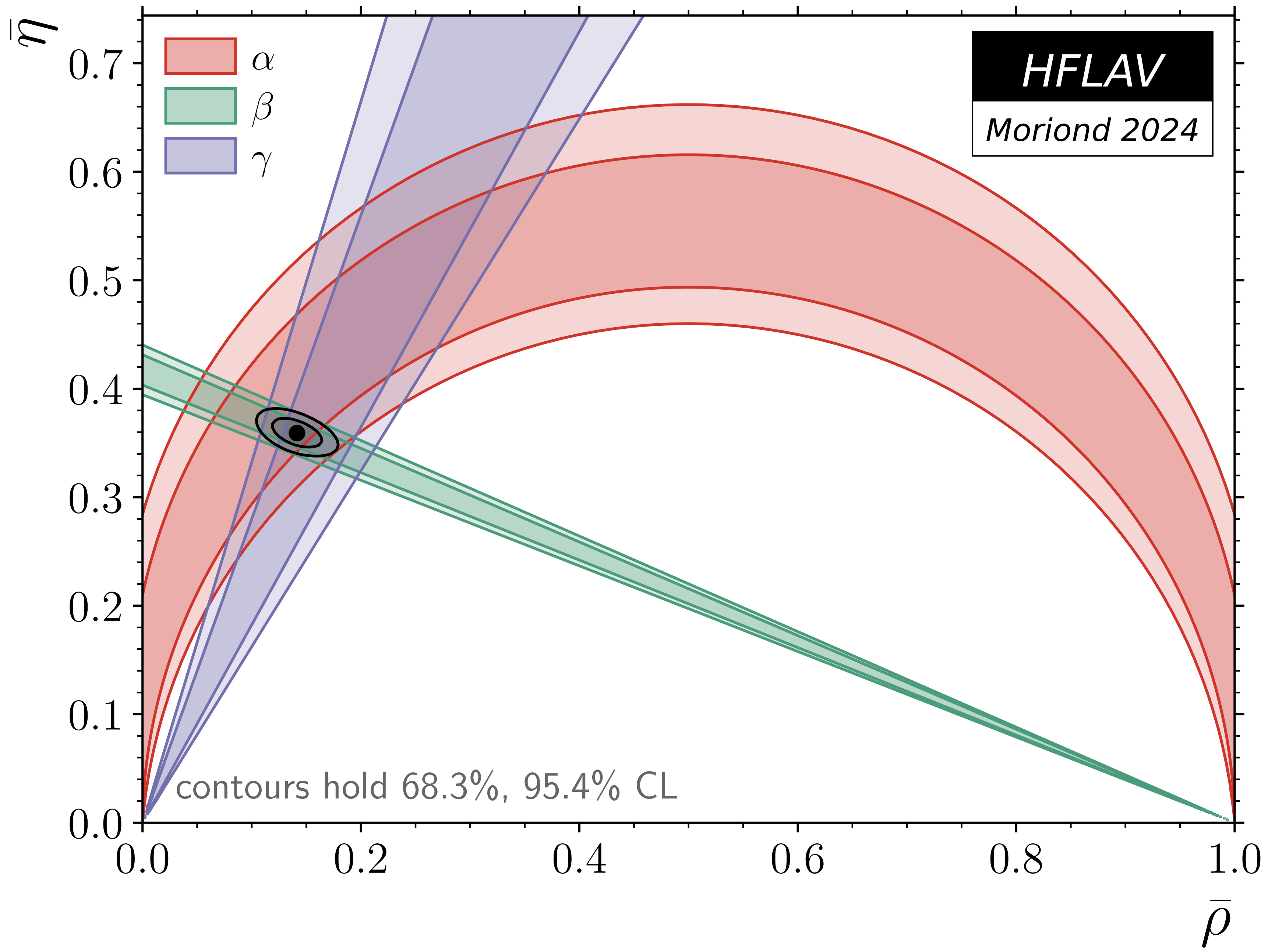
- Several world leading results and mostly unique measurements with neutrals and missing energy
- Improved detector performance and analysis techniques
- Expecting significant increase in sample size with ongoing run

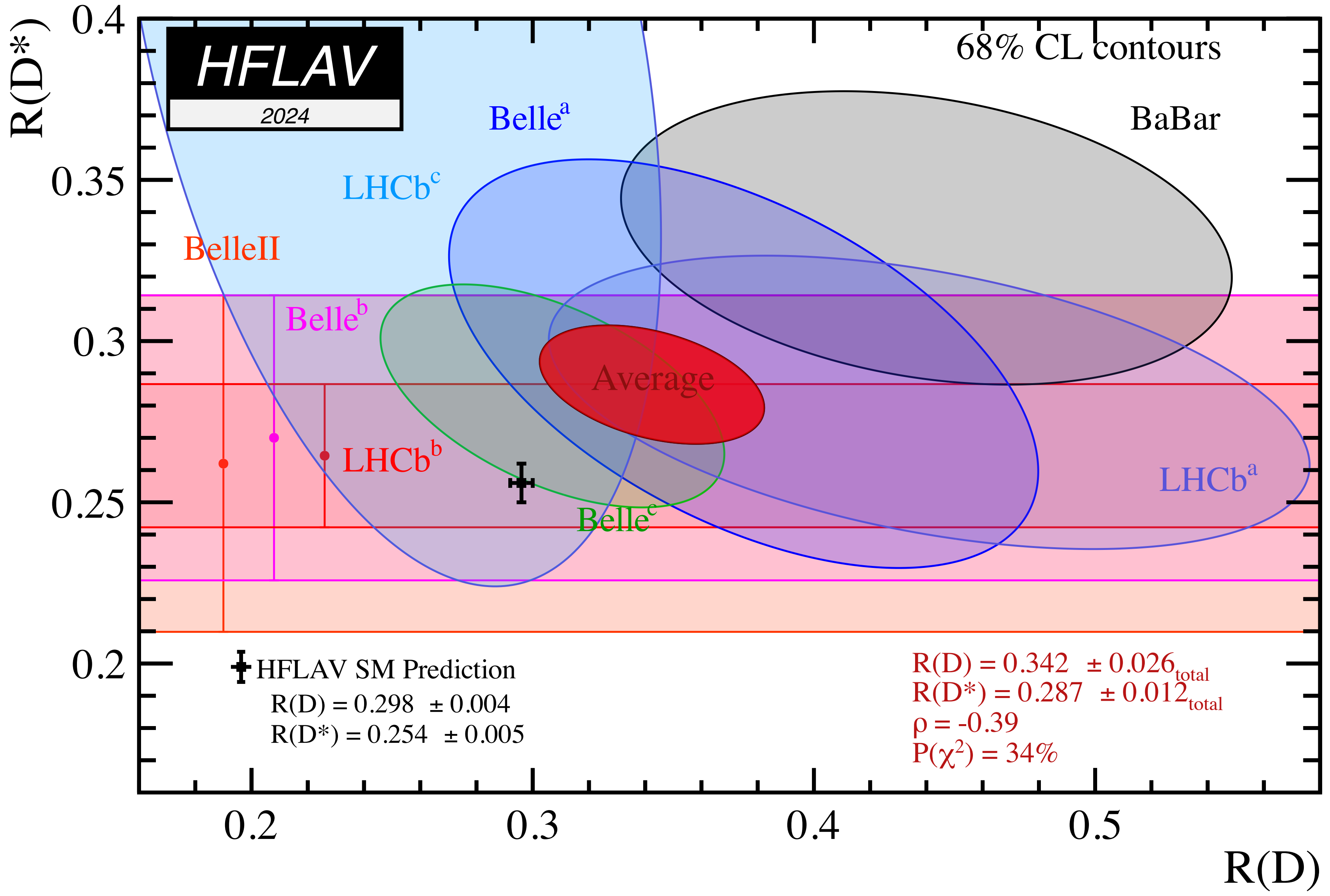


Backup

Recent results on beauty and charm*

- **CPV in charm:** $D^0 \to K^0_S K^0_S$ approaching precision to observe SM-induced CPV, can help understand the origin of CPV observed in $D^0 \to \pi^+\pi^-$
- **CPV in beauty:** constrain the angles of the unitarity triangle
  - $\phi_1(\beta)$: measured in $b \to c\bar{c}s$ transitions, precision close to effect of penguin amplitudes, controlled with $B^0 \to J/\psi\pi^0$
  - $\phi_2(\alpha)$: least known angle, determined from isospin analysis of $B \to \pi\pi$ and $B \to \rho\rho$
- **(Semi)tauonic** and **lepton-flavor violating** B-decays, motivated by anomalies in $b \to c\tau\nu$ and $B \to K\nu\nu$ excess
  - Searches for $B^0 \to K^{*0}\tau\tau$ and $B^0 \to K^0_S\tau l$
  - Measurement of BF of $B^+ \to \tau\nu$ (and V_{ub})





*see talks from F. Trantou and M. Campajola for Belle II results on tau and dark sector

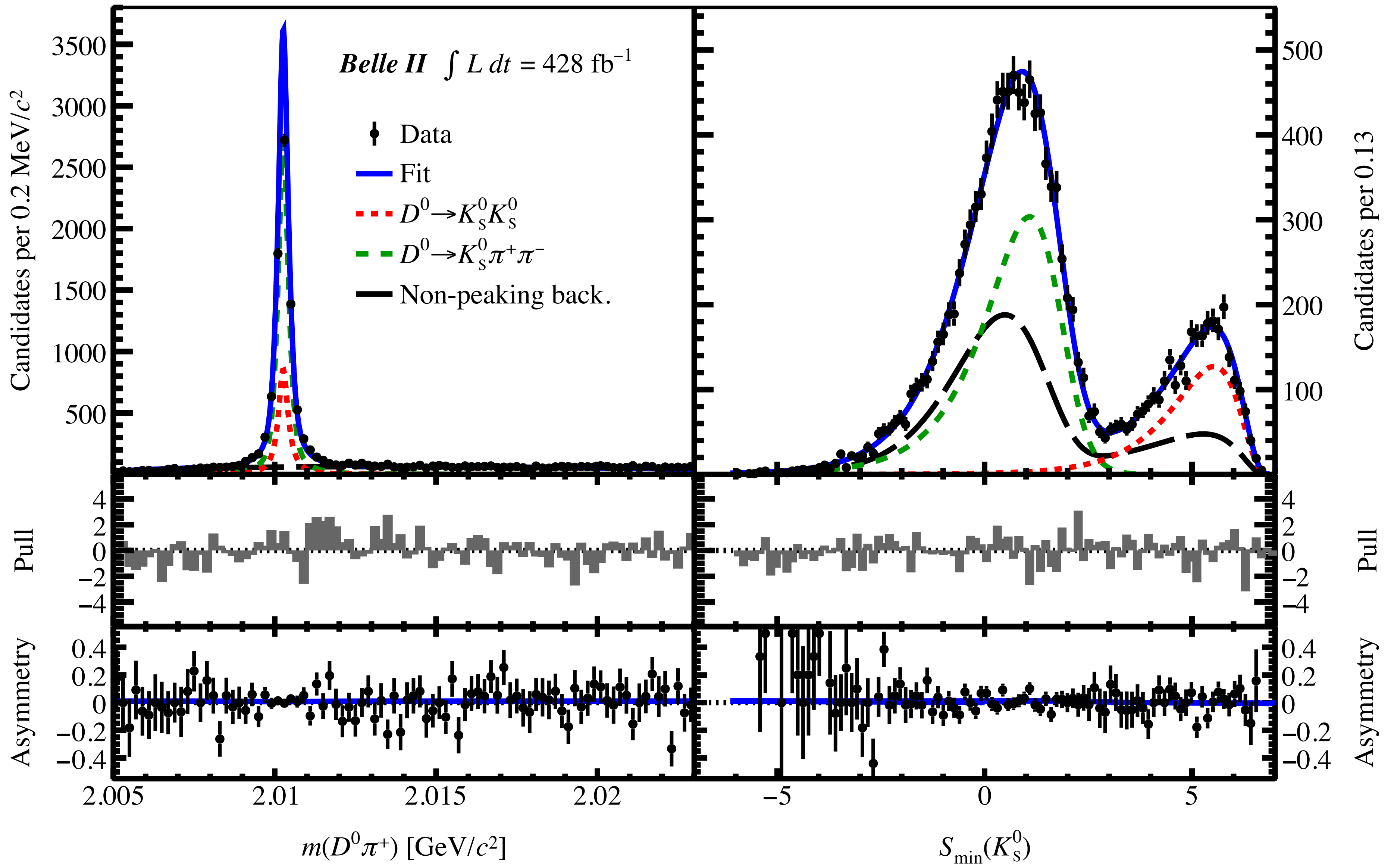
CPV in $D^0 \to K^0_S K^0_S$

[PRD 111, 012015 (2025)]

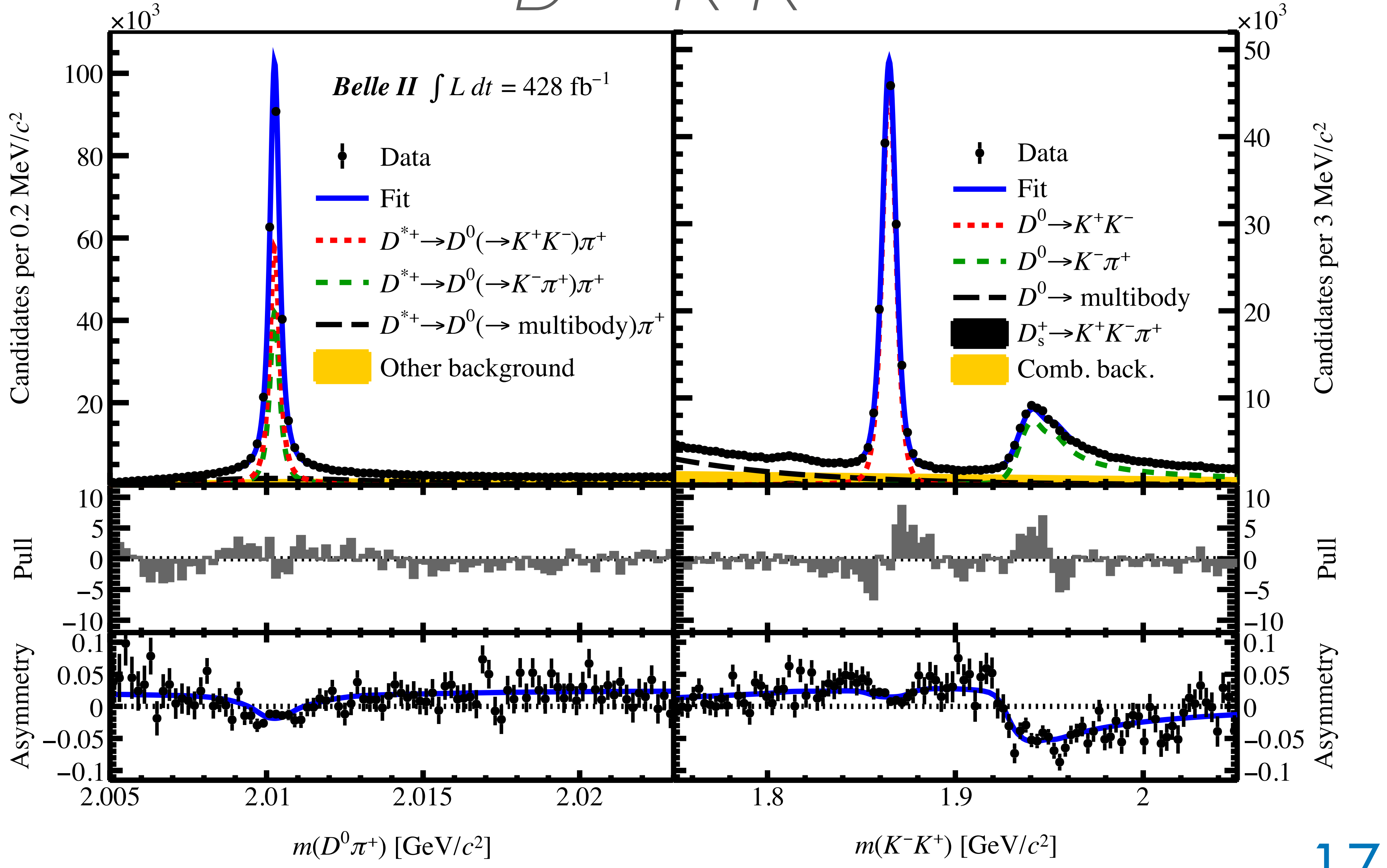
- Color and CKM-suppressed transition, interference between $c \to u s \bar{s}$ and $c \to u d \bar{d}$ amplitudes, ~O(1%) CPV possible in SM
- Using Belle (980fb-1) + Belle II (428fb-1) D^{*+}-tag and $D^0 \to K^+K^-$ control sample
- Statistical precision comparable to LHCb, systematic uncertainties reduced by half wrt. previous Belle analysis, thanks to improved control mode [PRD 104, L031102 (2021)]

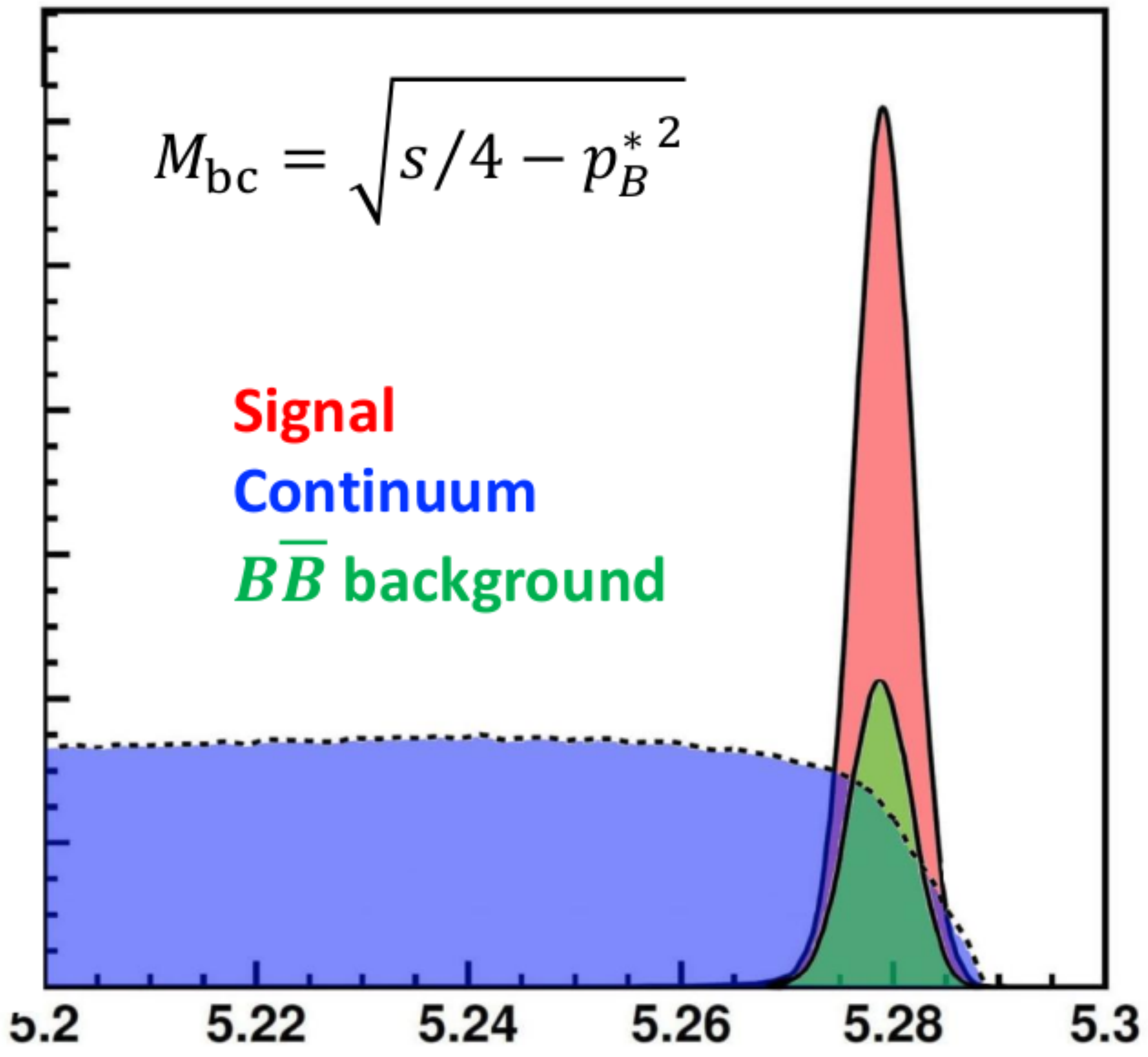
$$A_{CP}(D^0 \to K^0_S K^0_S) = (-1.4 \pm 1.3(\text{stat}) \pm 0.1(\text{syst}))\%$$

$D^0 \to K^0_S K^0_S$

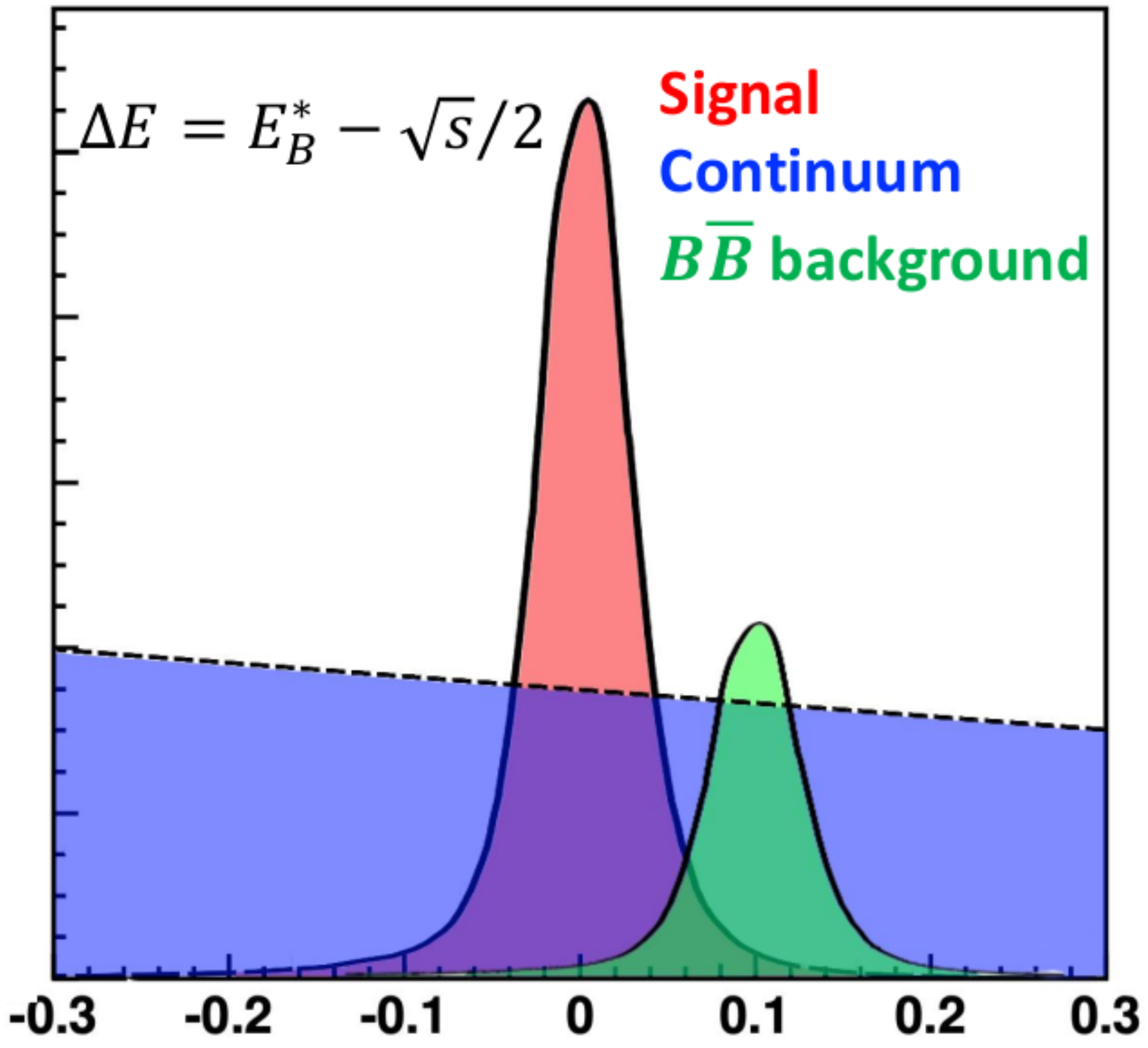


$D^0 \to K^+K^+$

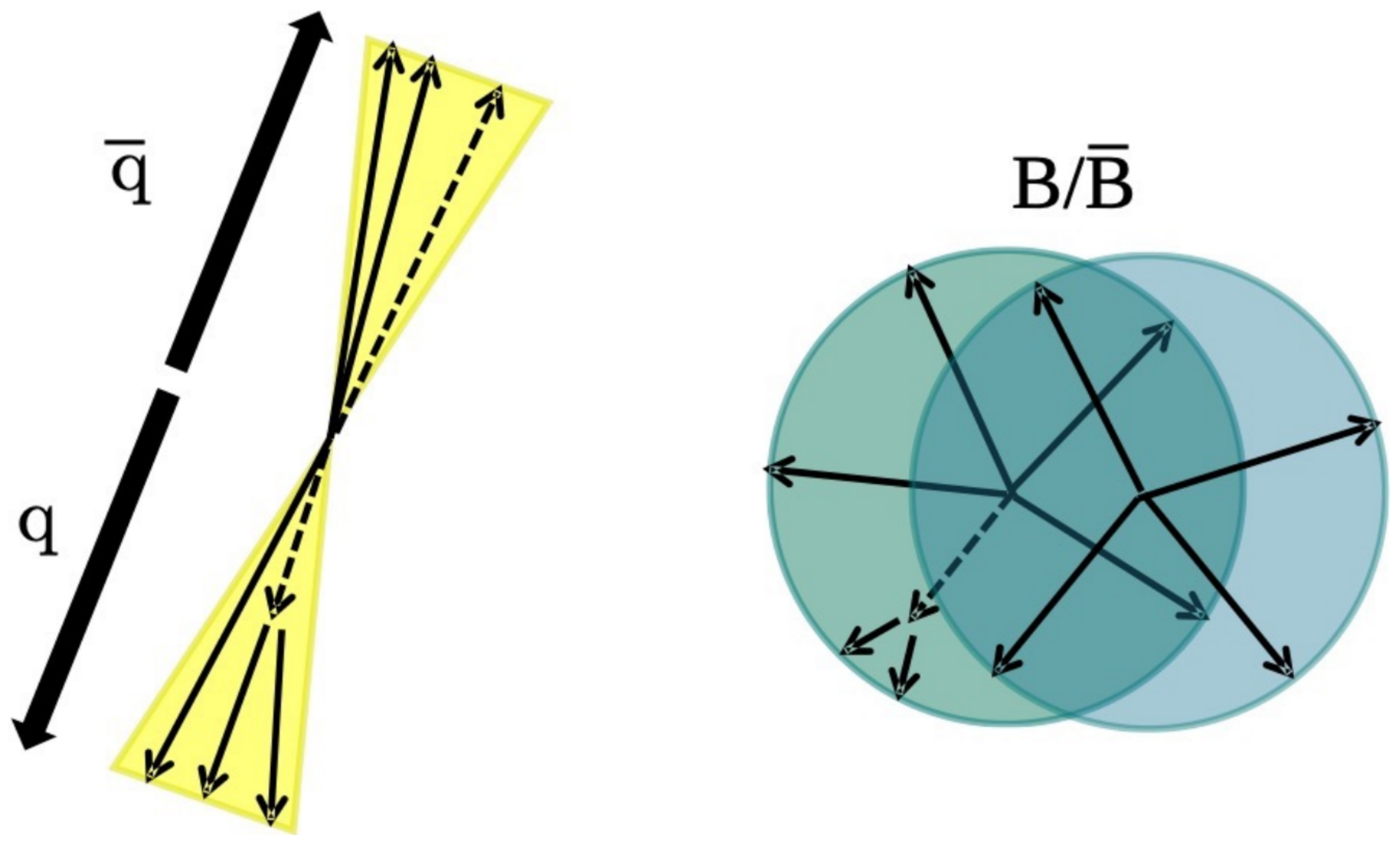




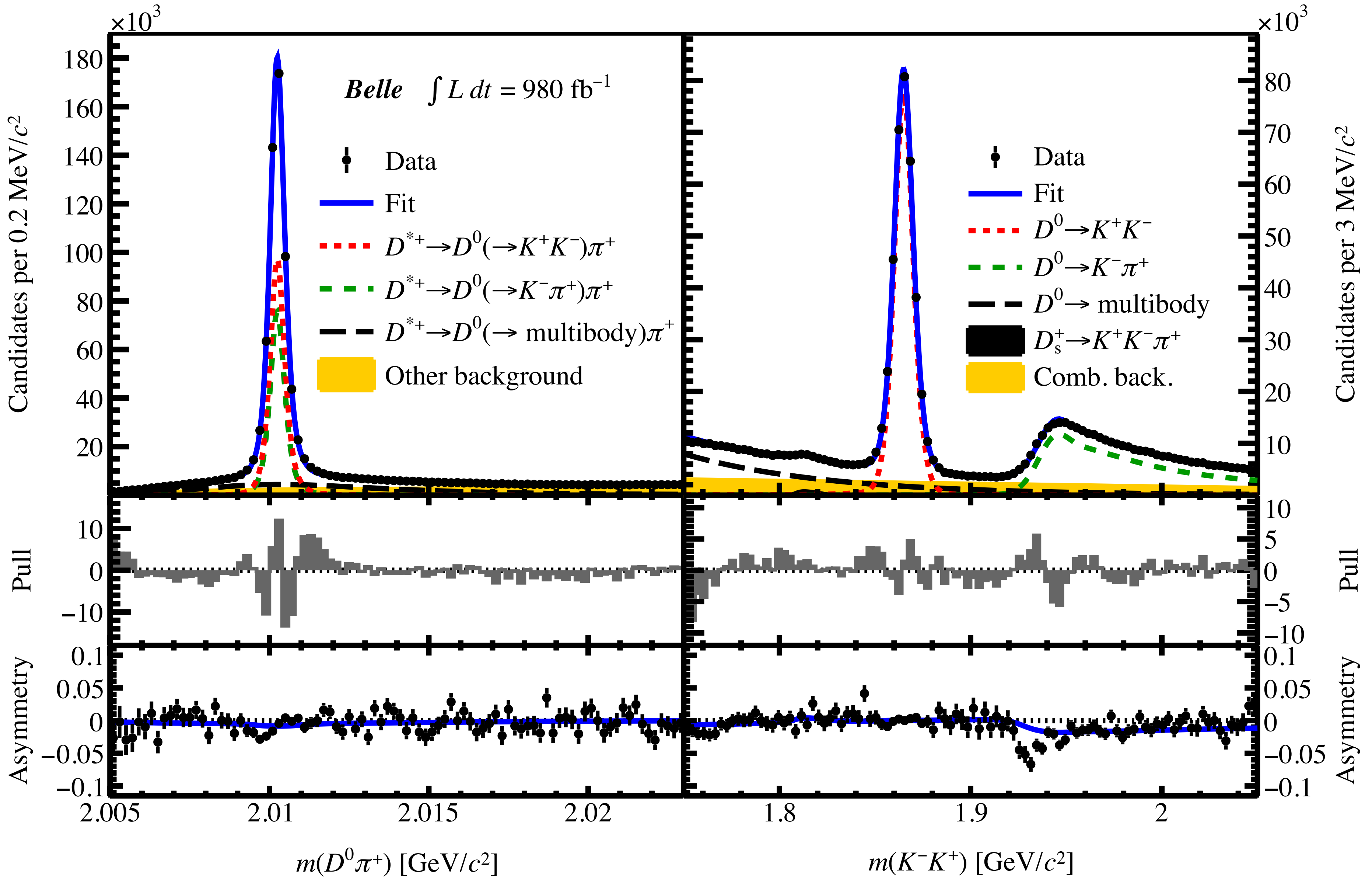
Beam-constrained mass [GeV/c^2]

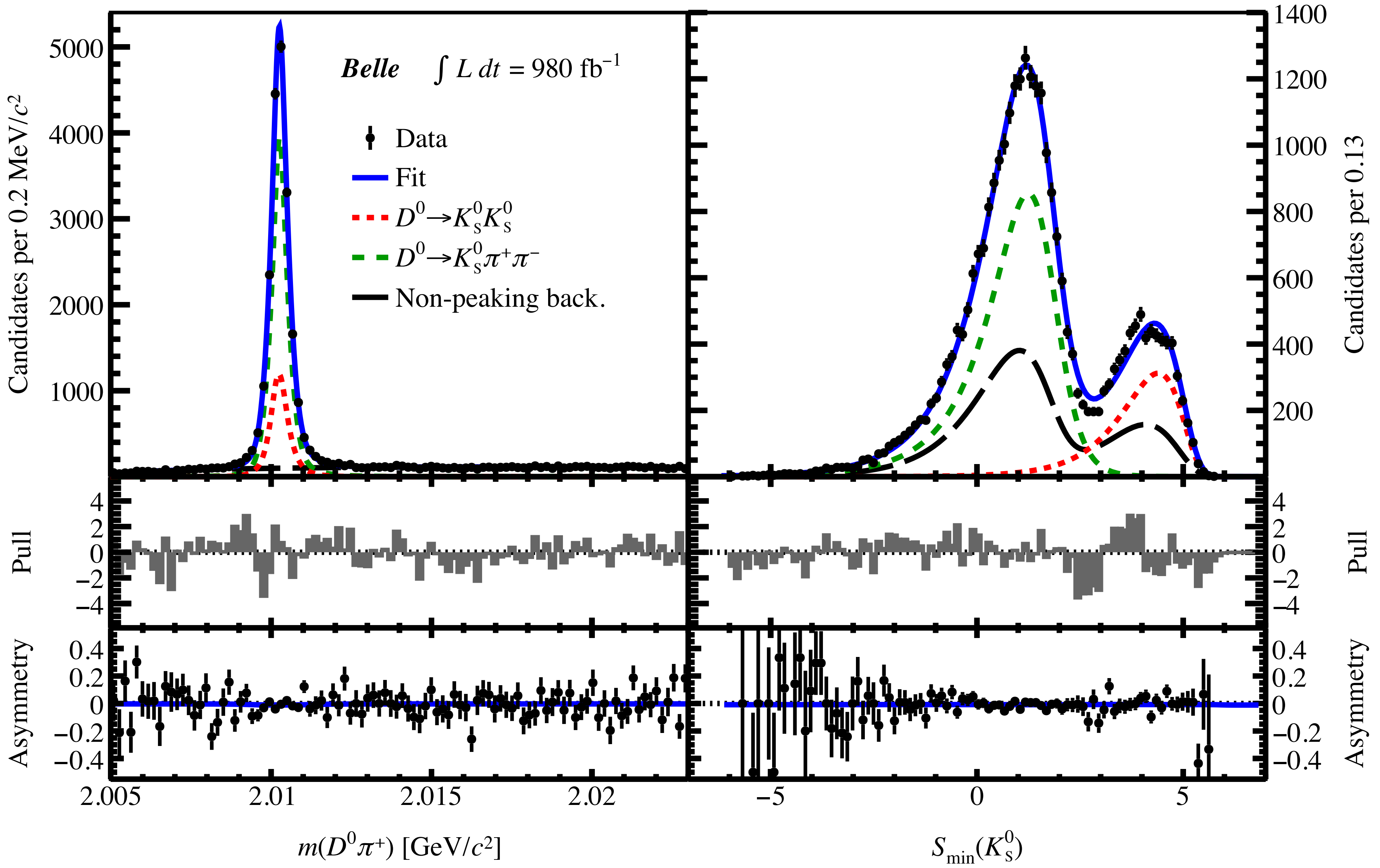


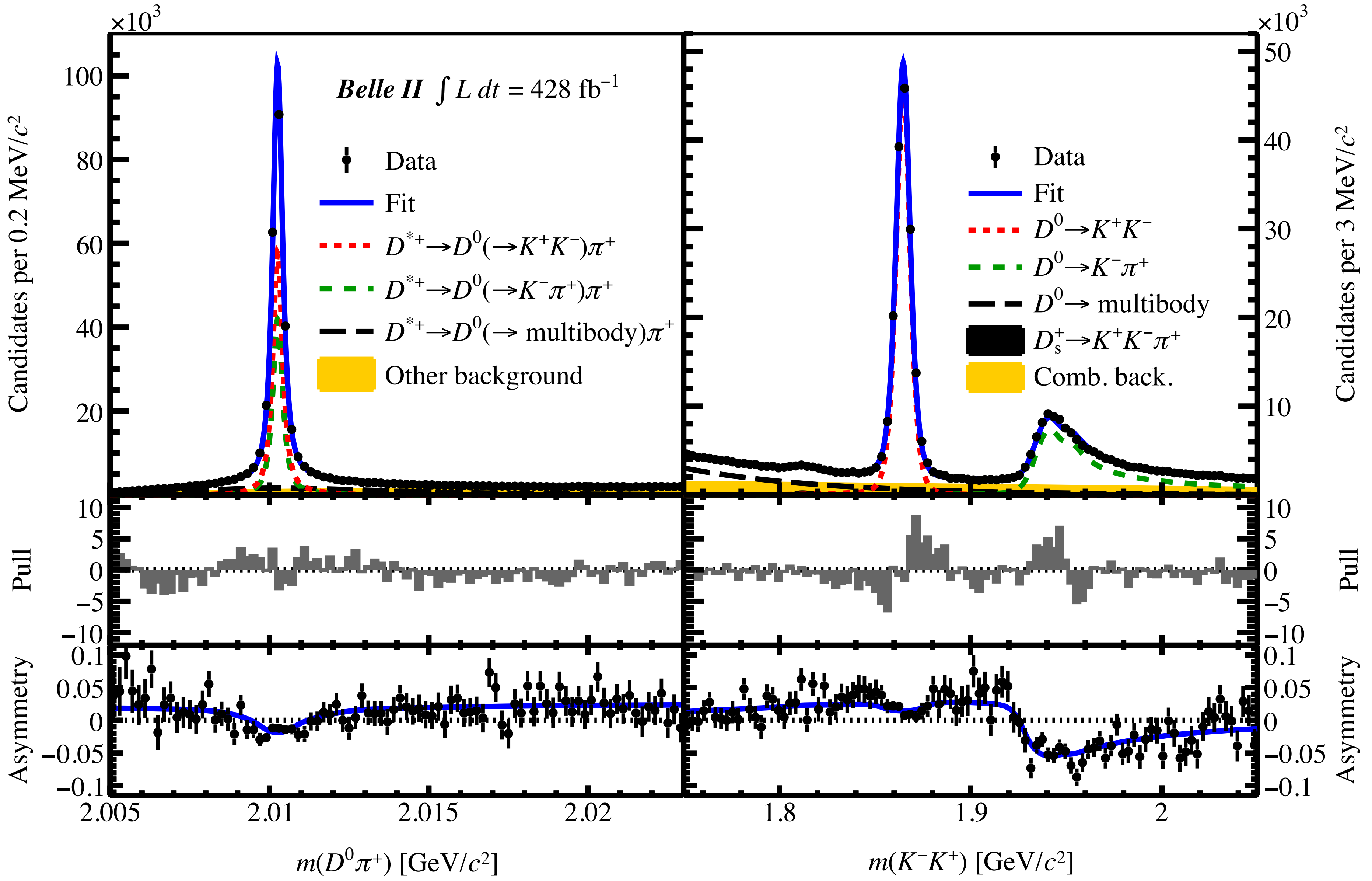
Energy difference [GeV]



Event shape


Belle $\int L\,dt$ = 980 fb^{-1}
Data
Fit
$D^{*+}\to D^0(\to K^+K^-)\pi^+$
$D^{*+}\to D^0(\to K^-\pi^+)\pi^+$
$D^{*+}\to D^0(\to$ multibody$)\pi^+$
Other background
$D^0\to K^+K^-$
$D^0\to K^-\pi^+$
$D^0\to$ multibody
$D_s^+\to K^+K^-\pi^+$
Comb. back.
Candidates per 0.2 MeV/c^2
Candidates per 3 MeV/c^2
Pull
Asymmetry
$m(D^0\pi^+)$ [GeV/c^2]
$m(K^-K^+)$ [GeV/c^2]


Belle $\int L\,dt$ = 980 fb^{-1}
Data
Fit
$D^0\to K_S^0K_S^0$
$D^0\to K_S^0\pi^+\pi^-$
Non-peaking back.
Candidates per 0.2 MeV/c^2
Candidates per 0.13
Pull
Asymmetry
$m(D^0\pi^+)$ [GeV/c^2]
$S_{\min}(K_S^0)$


Belle II $\int L\,dt$ = 428 fb^{-1}
Data
Fit
$D^{*+}\to D^0(\to K^+K^-)\pi^+$
$D^{*+}\to D^0(\to K^-\pi^+)\pi^+$
$D^{*+}\to D^0(\to$ multibody$)\pi^+$
Other background
$D^0\to K^+K^-$
$D^0\to K^-\pi^+$
$D^0\to$ multibody
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Comb. back.
Candidates per 0.2 MeV/c^2
Candidates per 3 MeV/c^2
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$m(D^0\pi^+)$ [GeV/c^2]
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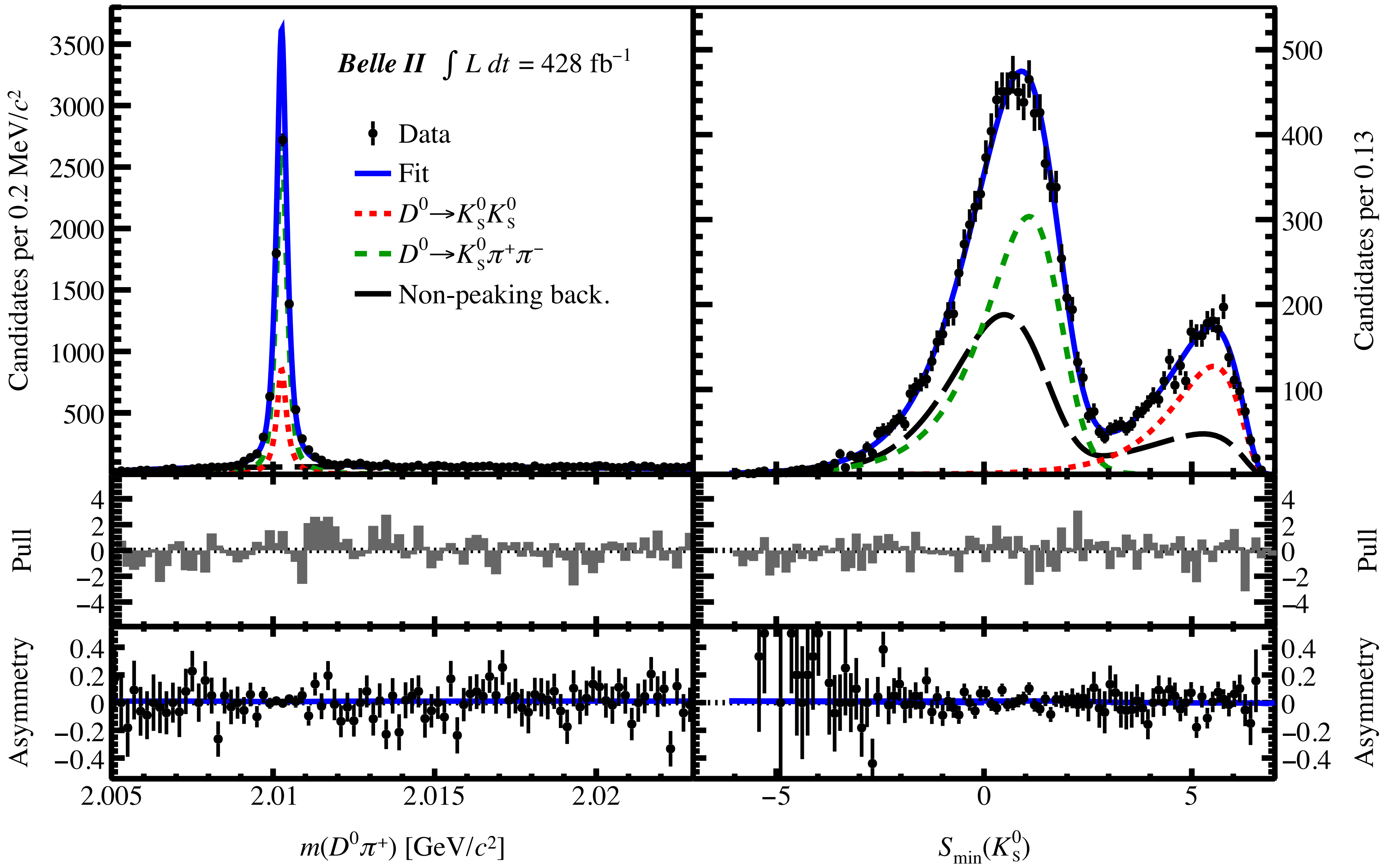
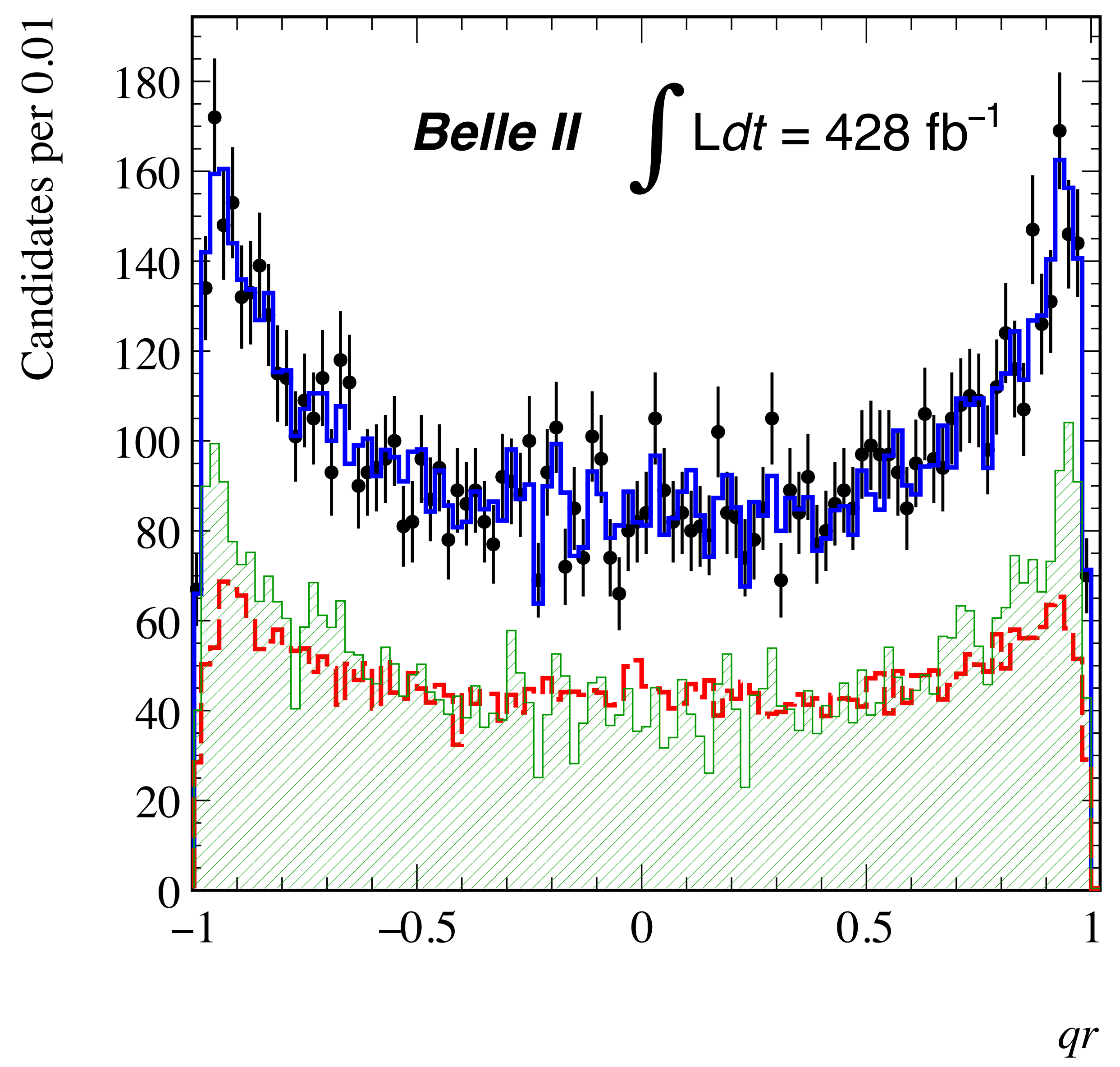

Belle II $\int L\,dt$ = 428 fb^{-1}
Data
Fit
$D^0\to K_S^0K_S^0$
$D^0\to K_S^0\pi^+\pi^-$
Non-peaking back.
Candidates per 0.2 MeV/c^2
Candidates per 0.13
Pull
Asymmetry
$m(D^0\pi^+)$ [GeV/c^2]
$S_{\min}(K_S^0)$

$$A_{CP}(D^0 \to K^0_S K^0_S) = (-1.4 \pm 1.3(\text{stat}) \pm 0.1(\text{syst}))\%$$

D* tag

$$A_{CP}(D^0 \to K^0_\mathrm{S} K^0_\mathrm{S}) = (1.3 \pm 2.0 \pm 0.2)\%$$

Opposite-side tag



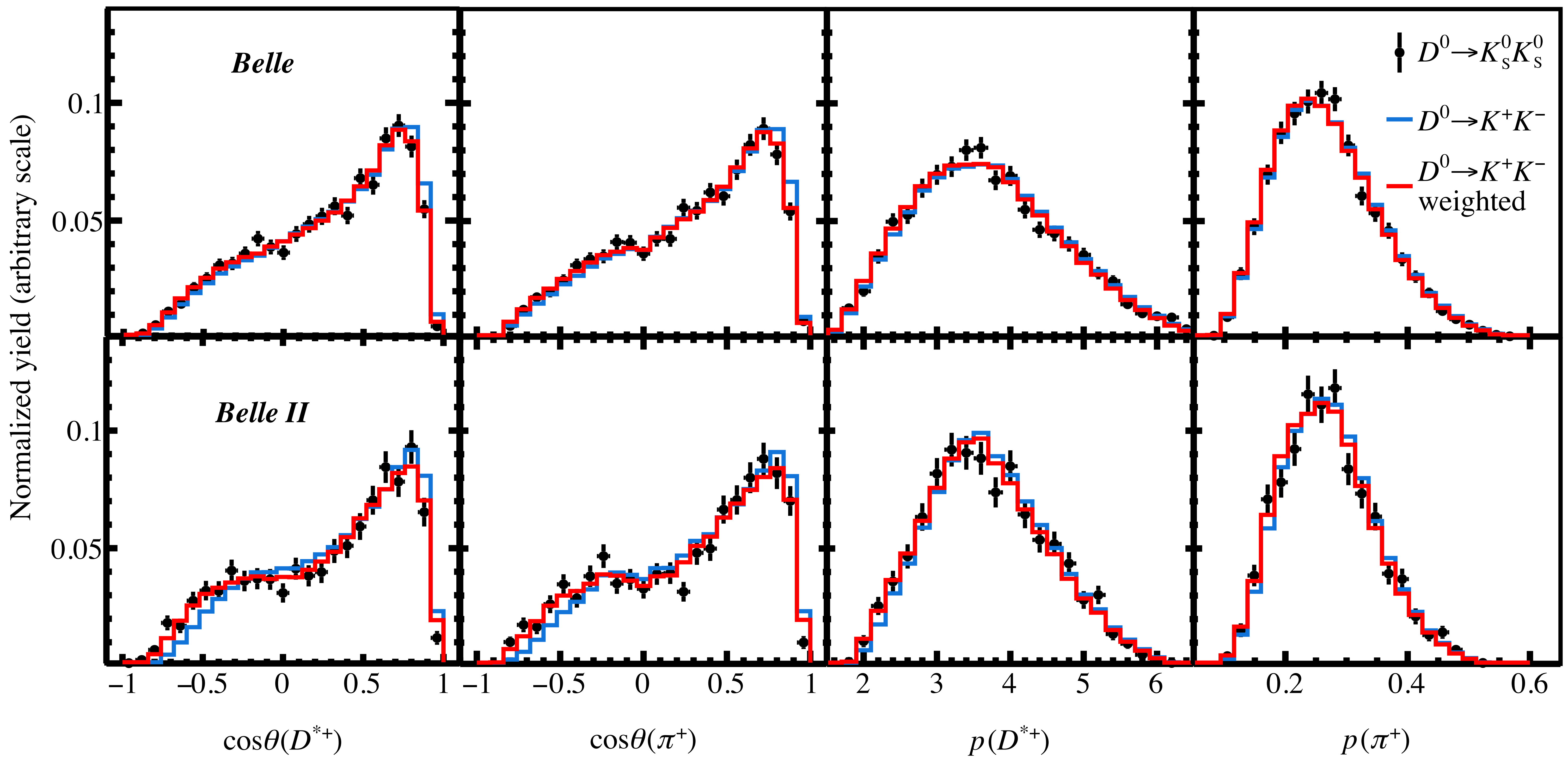


TABLE I. Summary of uncertainties in $A_{CP}(D^0 \to K^0_S K^0_S)$.

Source	Uncertainty (%) Belle	Belle II
Modeling in the $D^0 \to K^0_S K^0_S$ fit	0.04	0.05
Modeling in the $D^0 \to K^+K^-$ fit	0.02	<0.01
Kinematic weighting	0.06	0.07
Input $A_{CP}(D^0 \to K^+K^-)$	0.05	0.05
Total systematic	0.09	0.10
Statistical	1.60	2.30

Belle

$$A_{CP}(D^0 \to K^0_S K^0_S) = (-1.1 \pm 1.6(\text{stat}) \pm 0.1(\text{syst}))\%$$

Belle II

$$A_{CP}(D^0 \to K^0_S K^0_S) = (-2.2 \pm 2.3(\text{stat}) \pm 0.1(\text{syst}))\%$$

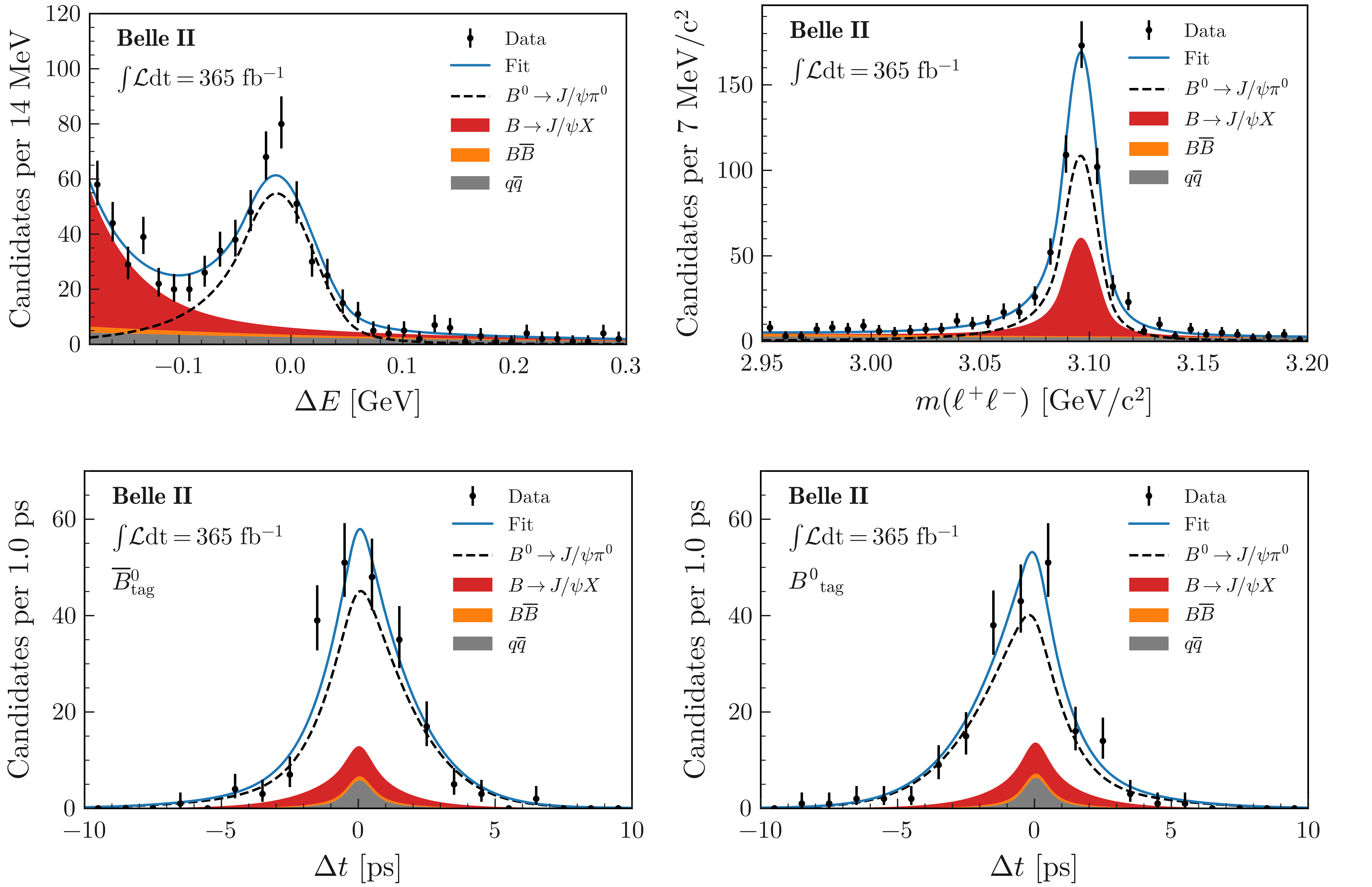

Belle II
∫ℒdt = 365 fb⁻¹
Data
Fit
B⁰ → J/ψπ⁰
B → J/ψX
BB̄
qq̄
Candidates per 14 MeV
ΔE [GeV]
Candidates per 7 MeV/c²
m(ℓ⁺ℓ⁻) [GeV/c²]
B̄⁰tag
B⁰tag
Candidates per 1.0 ps
Δt [ps]

TABLE II. Relative systematic uncertainties on the branching fraction compared with the statistical uncertainties.

Source	Relative uncertainty on BF [%]
π^0 efficiency	3.7
Lepton ID	0.4
BDT	0.3
Tracking efficiencies	0.5
External inputs	0.4
$N(B\bar{B})$	1.4
f^{+-}/f^{00}	1.5
Fixed parameters	0.9
Backgrounds composition	0.4
Multiple candidates	0.5
Total systematic uncertainty	4.5
Statistical uncertainty	6.0

TABLE III. Systematic uncertainties on the CP asymmetries compared with the statistical uncertainties.

Source	C_{CP}	$-\eta_f S_{CP}$
Calibration with $B^0 \to D^{*-}\pi^+$	0.017	0.023
Signal extraction fit	0.003	0.017
Backgrounds composition	0.005	0.009
Backgrounds Δt shapes	<0.001	0.001
Fit bias	0.010	0.010
Multiple candidates	<0.001	0.002
Tracking detector misalignment	0.002	0.002
Tag-side interference	0.027	0.001
τ_{B^0} and Δm_d	<0.001	<0.001
Total systematic uncertainty	0.034	0.032
Statistical uncertainty	0.123	0.171

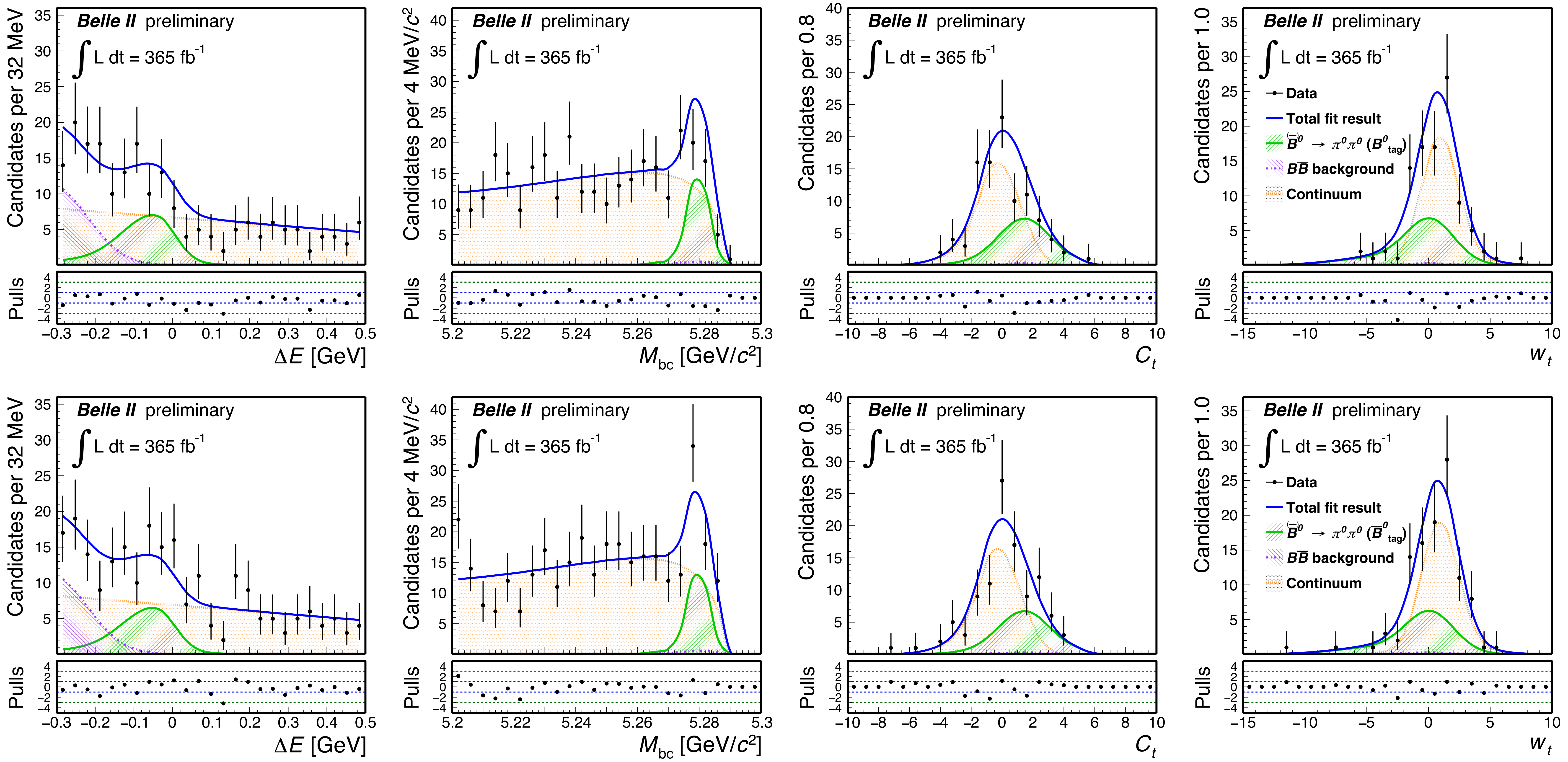


TABLE I. Fractional systematic uncertainties on the branching fraction and absolute systematic uncertainties on the CP asymmetry. Total systematic uncertainties, resulting from their sums in quadrature, are also given and compared with statistical uncertainties.

Source	$\mathcal{B}$	$\mathcal{A}_{CP}$
π^0 efficiency	8.1%	n/a
Continuum-suppression efficiency	1.9%	n/a
$B\overline{B}$-background model	1.7%	0.01
Signal model	1.2%	0.02
Continuum-background model	0.9%	0.03
$\Upsilon(4S)$ branching fractions $(1 + f^{+-}/f^{00})$	1.5 %	n/a
Sample size $N_{B\bar{B}}$	1.5%	n/a
$B^0\overline{B}^0$-oscillation probability	n/a	< 0.01
Wrong-tag probability calibration	n/a	0.01
Total systematic uncertainty	8.9%	0.04
Statistical uncertainty	15.9%	0.30

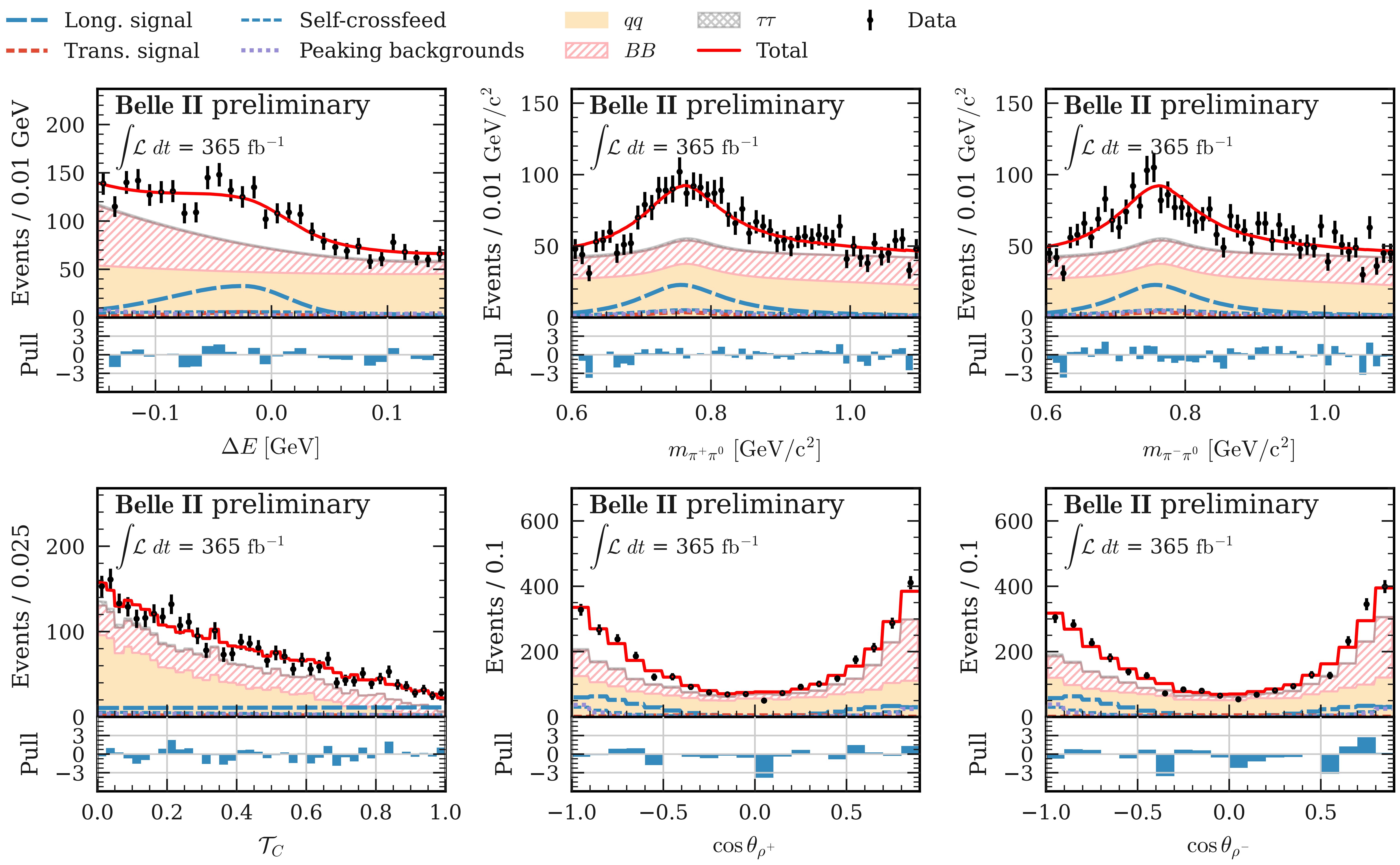


Table VI. Systematic uncertainties for $\mathcal{B}$ and f_L. Relative uncertainties are shown for $\mathcal{B}$.

Source	$\mathcal{B}$ [%]	$f_L[10^{-2}]$
Tracking	±0.54	—
π^0 efficiency	±7.67	—
PID	±0.08	—
$\mathcal{T}_C$	±2.87	—
MC sample size	±0.24	±0.2
Single candidate selection	±0.55	±0.3
SCF ratio	$^{+2.97}_{-2.45}$	$^{+0.2}_{-0.3}$
$\mathcal{B}$'s of peaking backgrounds	$^{+0.94}_{-0.98}$	±0.1
$\tau^+\tau^-$ background yield	$^{+0.65}_{-0.69}$	±0.0
Signal model	$^{+1.14}_{-2.02}$	±0.2
$q\bar{q}$ model	$^{+0.49}_{-0.51}$	$^{+0.1}_{-0.2}$
$B\bar{B}$ model	$^{+1.00}_{-0.40}$	$^{+0.3}_{-0.1}$
$\tau^+\tau^-$ model	$^{+0.17}_{-0.26}$	$^{+0.0}_{-0.1}$
Peaking model	$^{+1.37}_{-1.01}$	$^{+0.3}_{-0.5}$
Interference	±1.20	±0.5
Data-MC mis-modeling	$^{+3.51}_{-1.70}$	$^{+0.8}_{-0.3}$
Fit bias	±1.03	±1.2
f_{+-}/f_{00}	±1.51	—
N_{BB}	±1.45	—
Total systematic uncertainty	$^{+10.07}_{-9.51}$	$^{+1.7}_{-1.5}$
Statistical uncertainty	$^{+7.93}_{-7.58}$	$^{+2.4}_{-2.5}$

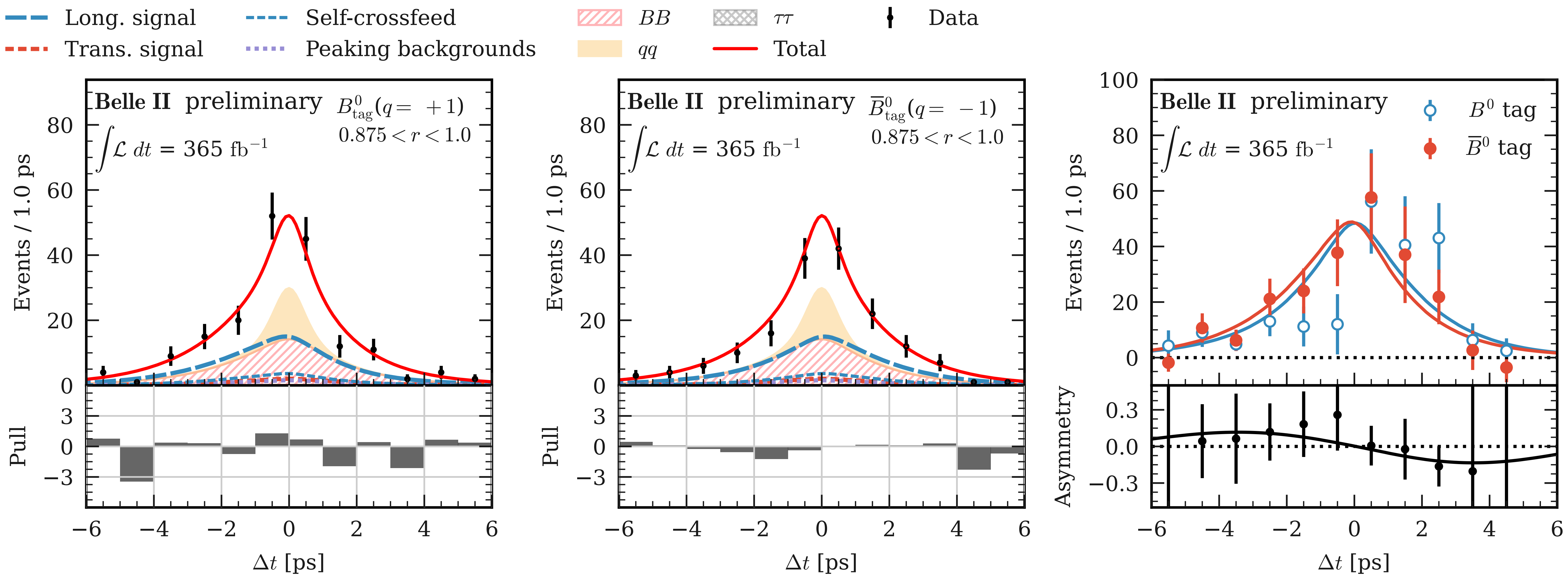
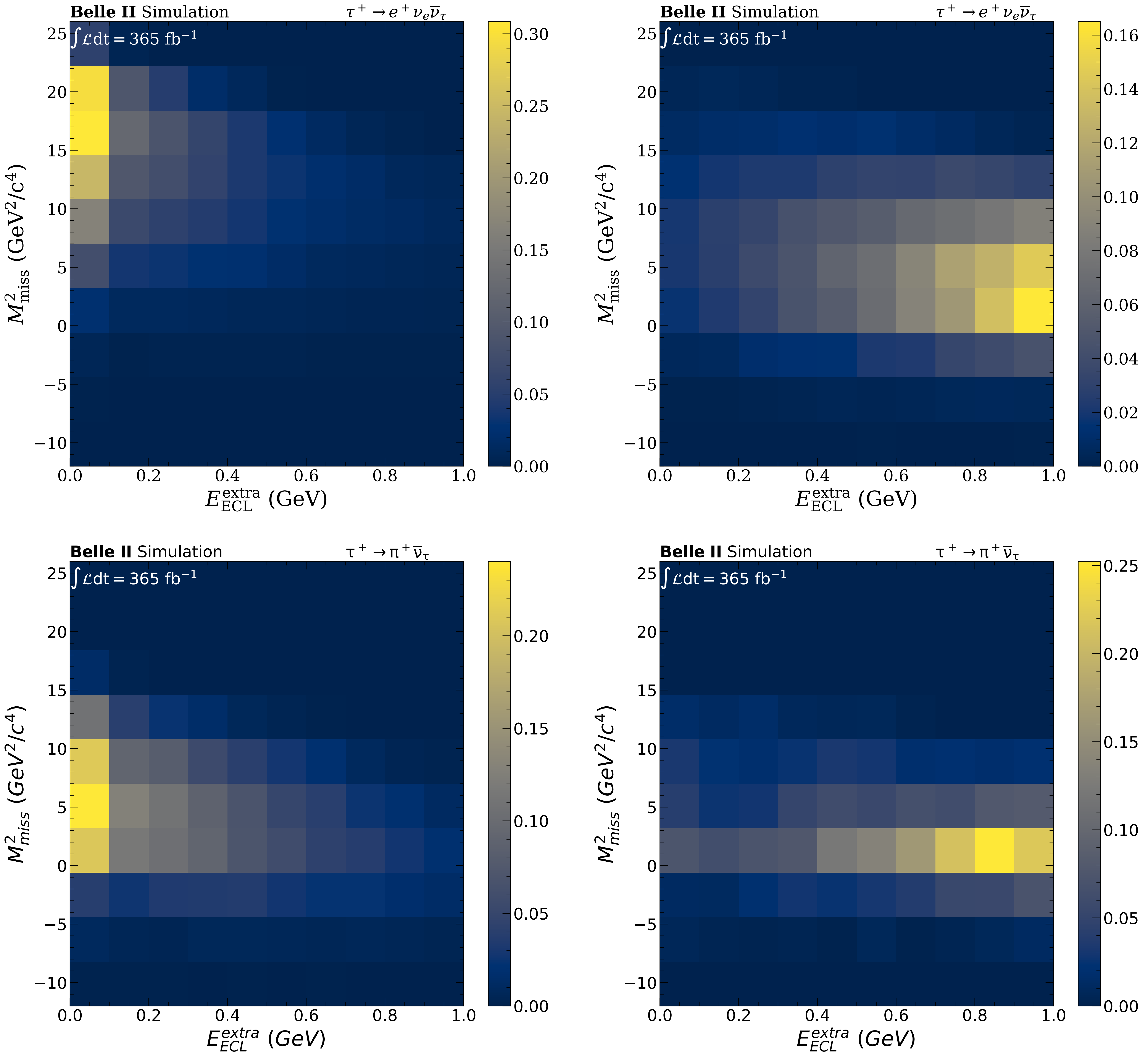


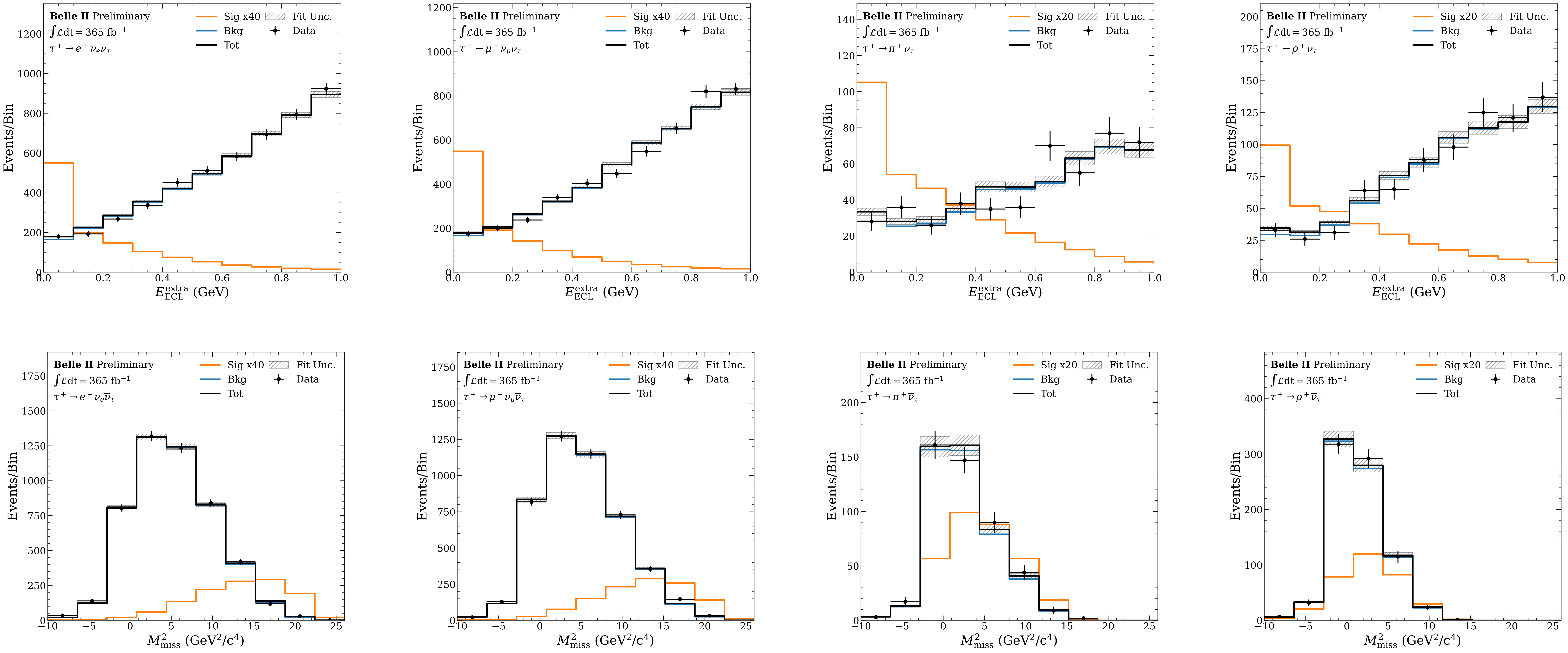
Table VII. Systematic uncertainties for S and C.

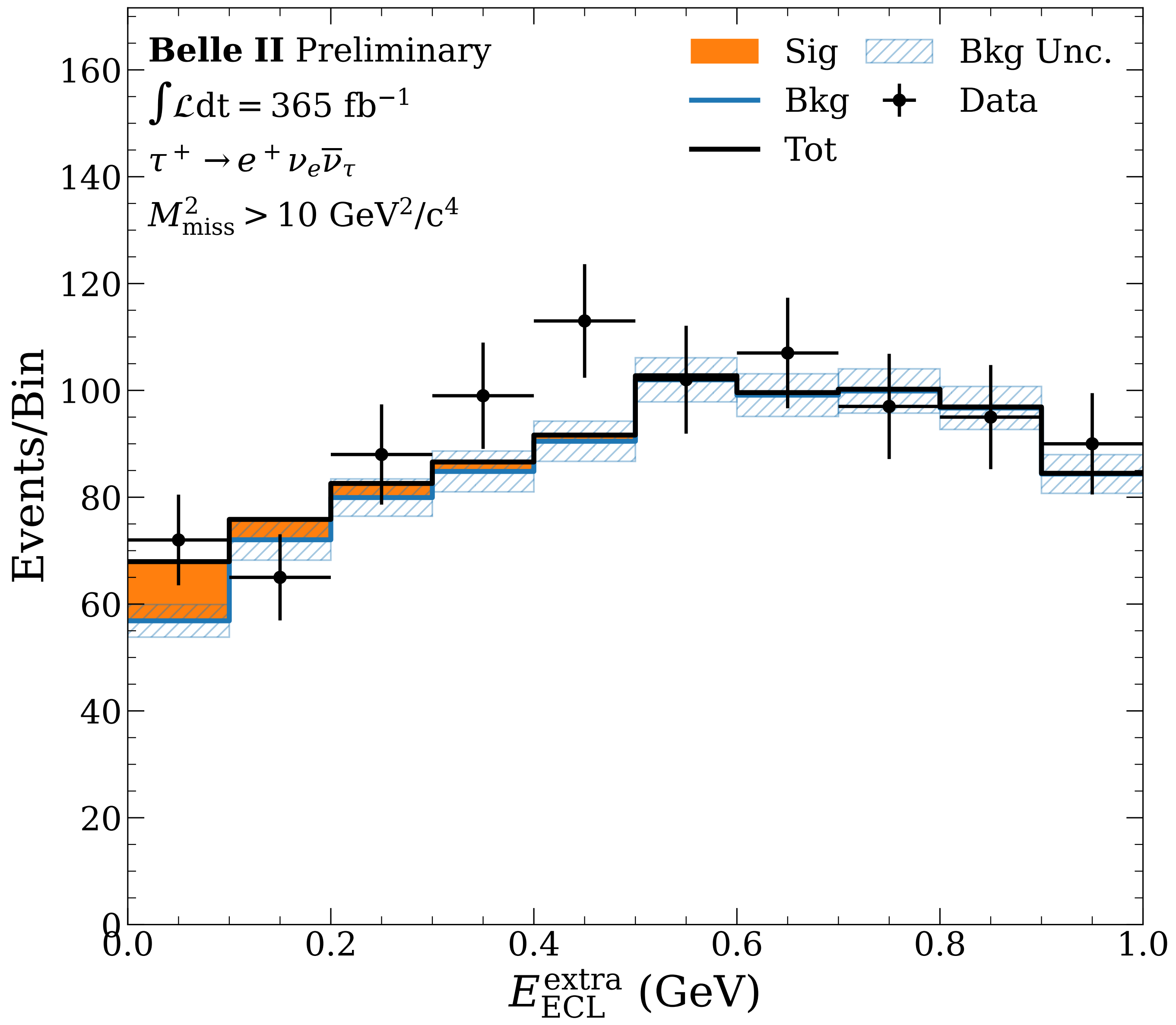
Source	$S[10^{-2}]$	$C[10^{-2}]$
$\mathcal{B}$'s of peaking backgrounds	$^{+0.6}_{-0.5}$	±0.1
$\tau\tau$ background yield	±0.9	$^{+0.0}_{-0.1}$
Data-MC mis-modeling	$^{+0.6}_{-1.1}$	$^{+1.5}_{-0.6}$
Single candidate selection	±1.3	±1.9
SCF ratio	$^{+0.5}_{-0.4}$	$^{+0.7}_{-0.0}$
Signal model	$^{+1.1}_{-1.4}$	$^{+0.3}_{-0.4}$
$q\bar{q}$ model	$^{+2.2}_{-1.0}$	±0.2
$B\bar{B}$ model	±0.9	$^{+0.7}_{-0.5}$
$\tau^+\tau^-$ model	±0.1	±0.0
Peaking model	$^{+0.8}_{-0.4}$	$^{+0.2}_{-0.4}$
Fit bias	±2.0	±0.6
Interference	±2.8	±1.7
Resolution	$^{+3.4}_{-4.4}$	$^{+1.9}_{-1.4}$
Δt PDF for $q\bar{q}$ and $B\bar{B}$	$^{+3.8}_{-1.8}$	$^{+0.7}_{-0.1}$
Tag side interference	±0.5	±2.1
Wrong tag fraction	$^{+0.2}_{-0.3}$	±0.5
Background CP violation	$^{+3.8}_{-3.6}$	$^{+4.2}_{-3.7}$
CP violation in TP signal	$^{+0.8}_{-0.2}$	$^{+0.2}_{-0.4}$
Tracking detector misalignment	±1.4	±0.5
τ_{B^0} and Δm_d	$^{+1.4}_{-1.6}$	±0.3
Total systematic uncertainty	$^{+8.2}_{-7.8}$	$^{+6.1}_{-5.3}$
Statistical uncertainty	±18.8	±12.1

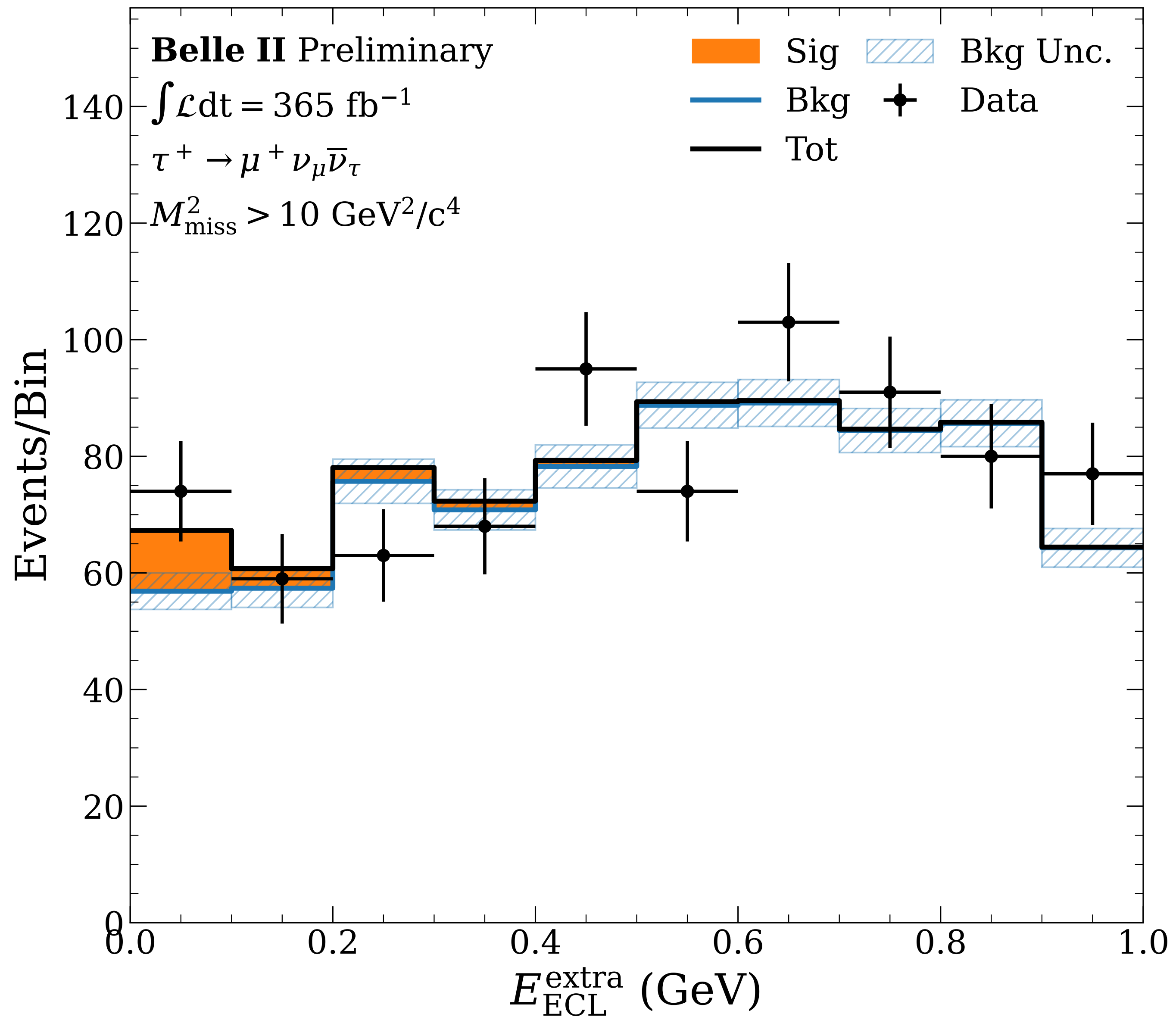
submitted to PRD [arxiv:2502.04885]

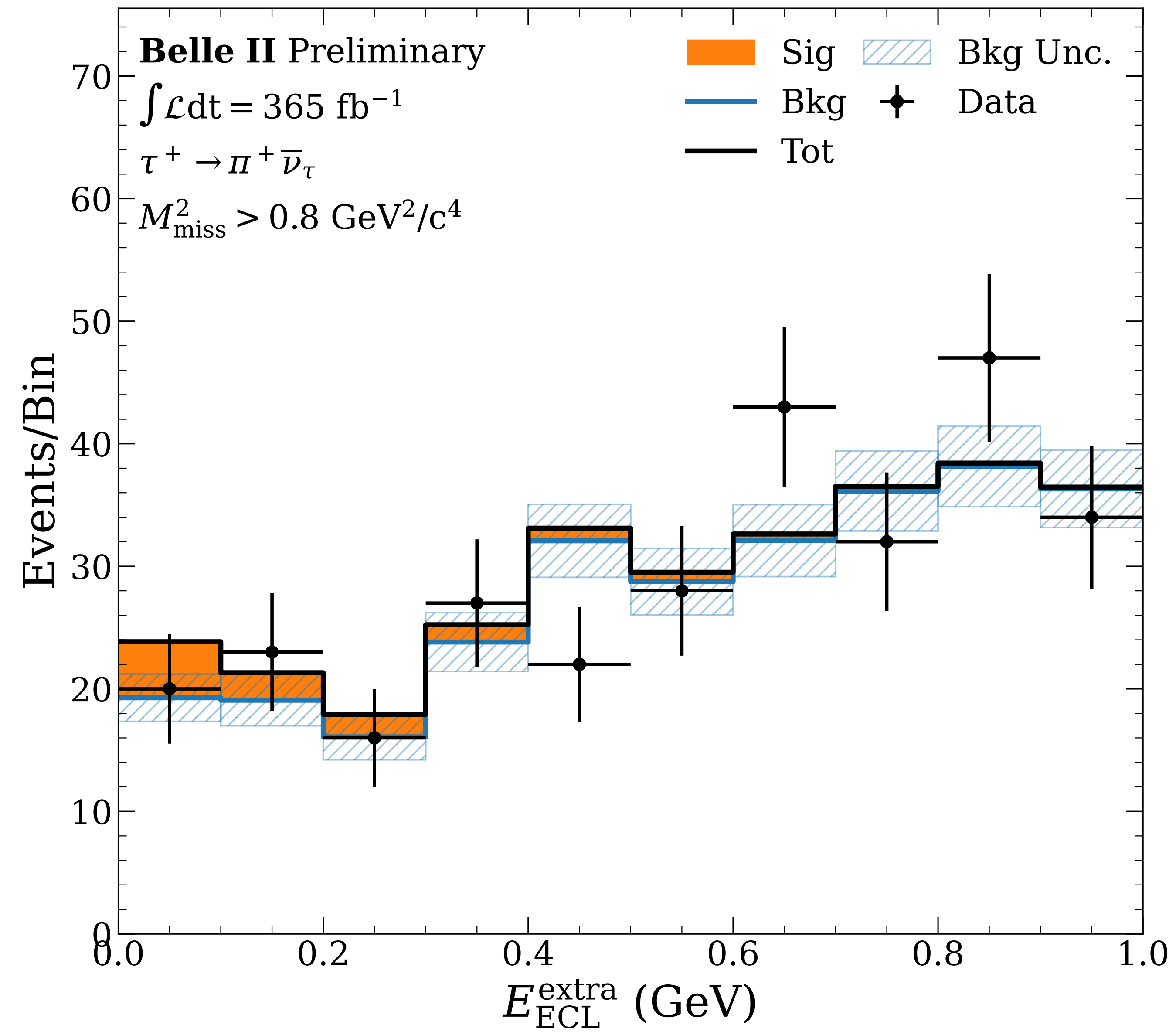
signal | background

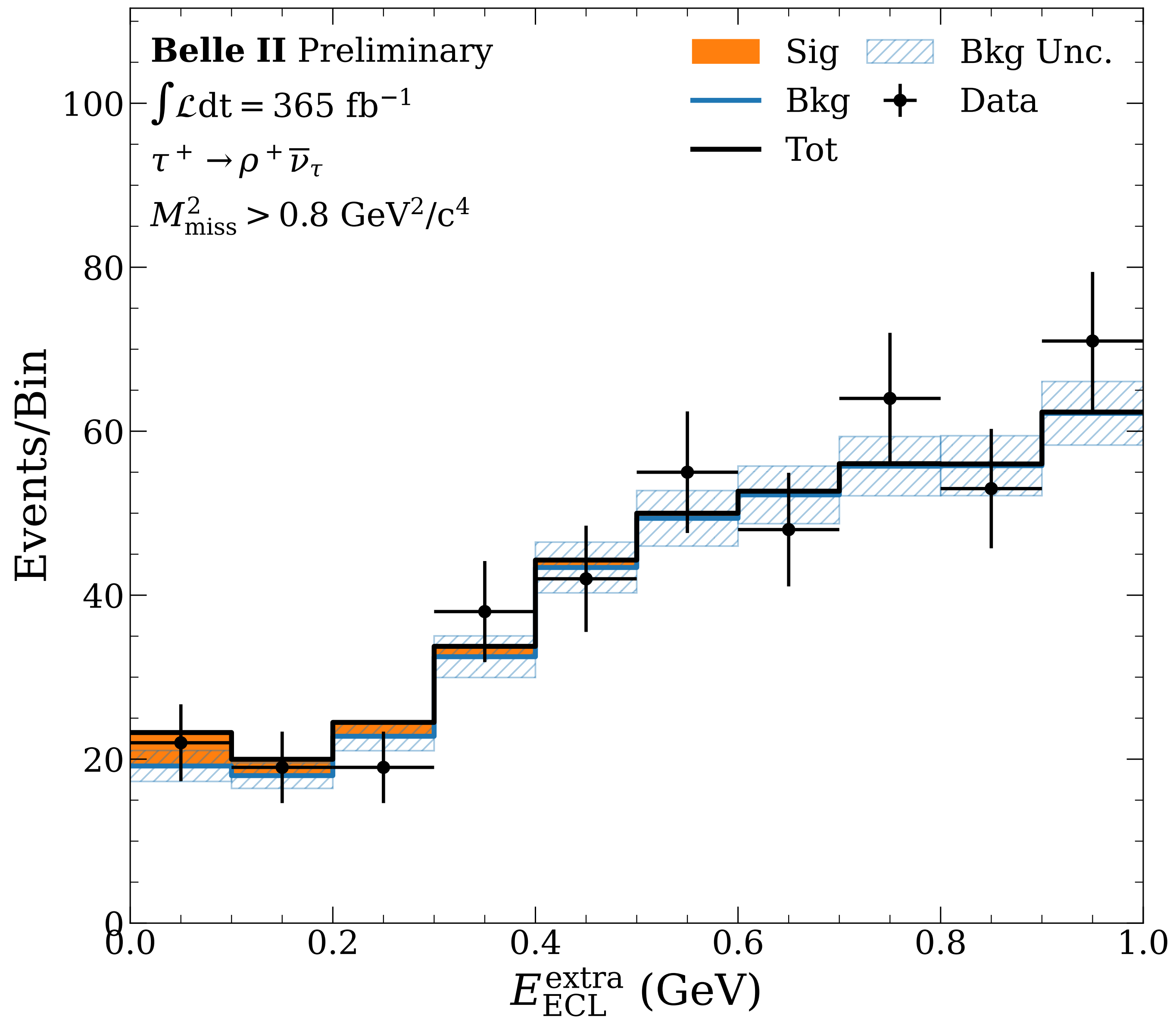



Belle II Preliminary
$\int \mathcal{L}dt = 365$ fb^{-1}
$\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$
Sig x40
Bkg
Tot
Fit Unc.
Data
Events/Bin
E_{ECL}^{extra} (GeV)
Belle II Preliminary
$\int \mathcal{L}dt = 365$ fb^{-1}
$\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$
Sig x40
Bkg
Tot
Fit Unc.
Data
Events/Bin
E_{ECL}^{extra} (GeV)
Belle II Preliminary
$\int \mathcal{L}dt = 365$ fb^{-1}
$\tau^+ \to \pi^+ \bar{\nu}_\tau$
Sig x20
Bkg
Tot
Fit Unc.
Data
Events/Bin
E_{ECL}^{extra} (GeV)
Belle II Preliminary
$\int \mathcal{L}dt = 365$ fb^{-1}
$\tau^+ \to \rho^+ \bar{\nu}_\tau$
Sig x20
Bkg
Tot
Fit Unc.
Data
Events/Bin
E_{ECL}^{extra} (GeV)
Belle II Preliminary
$\int \mathcal{L}dt = 365$ fb^{-1}
$\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$
Sig x40
Bkg
Tot
Fit Unc.
Data
Events/Bin
M_{miss}^2 (GeV^2/c^4)
Belle II Preliminary
$\int \mathcal{L}dt = 365$ fb^{-1}
$\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$
Sig x40
Bkg
Tot
Fit Unc.
Data
Events/Bin
M_{miss}^2 (GeV^2/c^4)
Belle II Preliminary
$\int \mathcal{L}dt = 365$ fb^{-1}
$\tau^+ \to \pi^+ \bar{\nu}_\tau$
Sig x20
Bkg
Tot
Fit Unc.
Data
Events/Bin
M_{miss}^2 (GeV^2/c^4)
Belle II Preliminary
$\int \mathcal{L}dt = 365$ fb^{-1}
$\tau^+ \to \rho^+ \bar{\nu}_\tau$
Sig x20
Bkg
Tot
Fit Unc.
Data
Events/Bin
M_{miss}^2 (GeV^2/c^4)







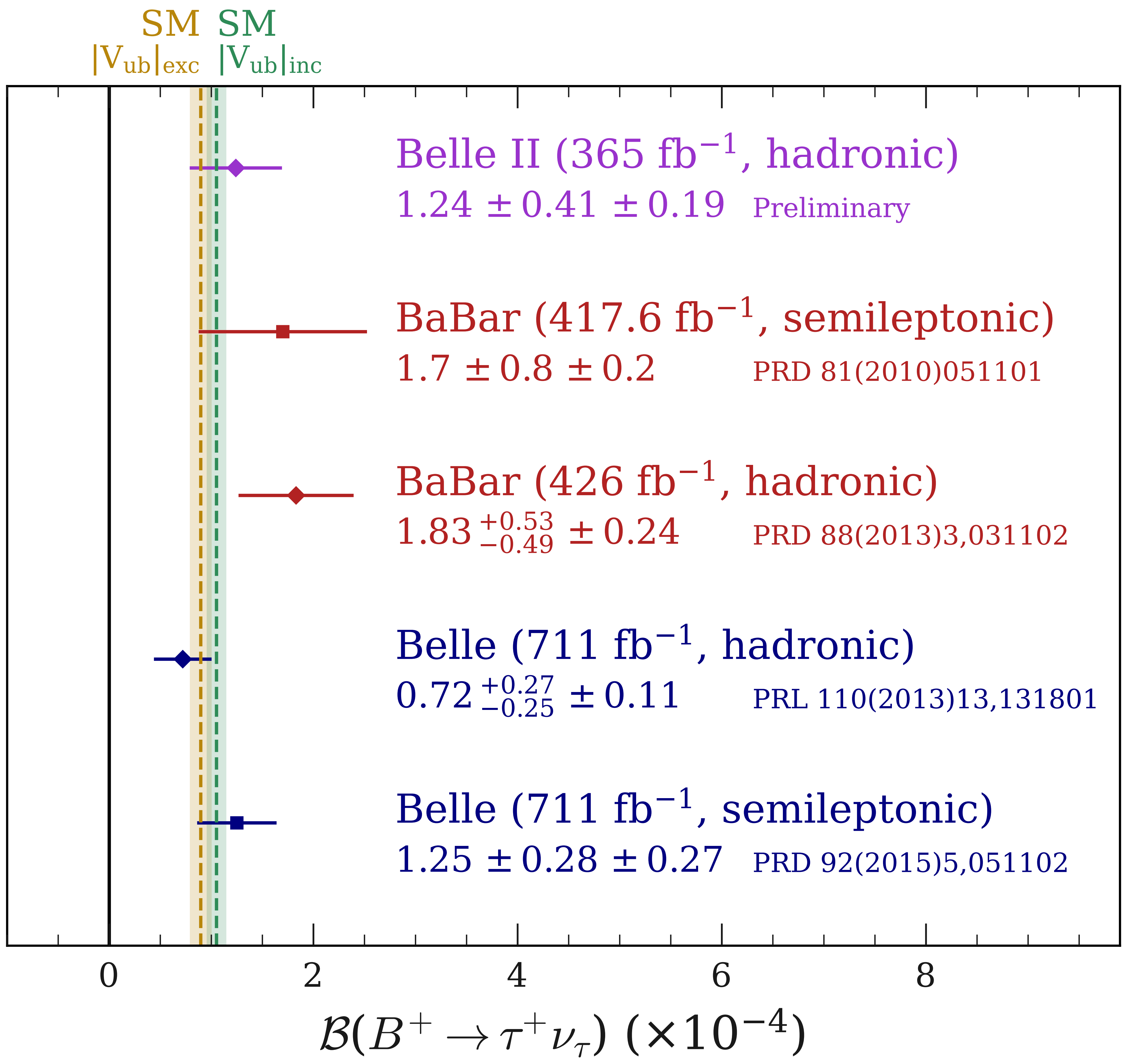


TAB. IV. Observed and expected values of the background yields in the fit. The expected values are estimated from a simulation corresponding to an integrated luminosity of 365 fb^{-1}.

Parameter	Observed value	Expected value
n_{b,e^+}	4907 ± 71	4846 ± 24
n_{b,μ^+}	4620 ± 69	4493 ± 24
n_{b,π^+}	454 ± 22	461 ± 9
n_{b,ρ^+}	772 ± 28	811 ± 11

TAB. V. Observed values of the signal yields and branching fractions, obtained from single fits for each τ^+ decay mode and the simultaneous fit.

Decay mode	n_s	$\mathcal{B}(10^{-4})$
Simultaneous	94 ± 31	1.24 ± 0.41
$e^+ \; \nu_e \; \overline{\nu}_\tau$	13 ± 16	0.51 ± 0.63
$\mu^+ \; \nu_\mu \; \overline{\nu}_\tau$	40 ± 20	1.67 ± 0.83
$\pi^+ \; \overline{\nu}_\tau$	31 ± 13	2.28 ± 0.93
$\rho^+ \; \overline{\nu}_\tau$	6 ± 25	0.42 ± 1.82



TAB. VI. Summary of systematic uncertainties (syst.) on the fitted branching fraction presented as relative uncertainties. The effect of each source is evaluated in the simultaneous fit of the four signal modes. The last three sources do not affect the signal yields.

Source	Syst.
Simulation statistics	13.3%
Fit variables PDF corrections	5.5%
Decays branching fractions in MC	4.1%
Tag B^- reconstruction efficiency	2.2%
Continuum reweighting	1.9%
π^0 reconstruction efficiency	0.9%
Continuum normalization	0.7%
Particle identification	0.6%
Number of produced $\Upsilon(4S)$	1.5%
Fraction of B^+B^- pairs	2.1%
Tracking efficiency	0.2%
Total	15.5%

Table I: Signal efficiencies (ε) and expected background yields, for $\eta(\mathrm{BDT}) > 0.4$. The signal categories are ordered according to the expected sensitivity.

Signal category	$\varepsilon \times 10^5$	$B\overline{B}$	$q\bar{q}$
$\ell\ell$	4.0	275	39
$\pi\ell$	7.6	1058	230
ρ	15.5	3279	845
$\pi\pi$	4.0	1077	424

Table II: The systematic uncertainties for the branching fraction of $B^0 \to K^{*0}\tau^+\tau^-$, which were computed following the procedure in Ref. [38].

Source	Impact on $\mathcal{B} \times 10^{-3}$
$B \to D^{**}\ell/\tau\nu$ branching fractions	0.29
Simulated sample size	0.27
$q\bar{q}$ normalization	0.18
ROE cluster multiplicity	0.17
π and K ID	0.14
B decay branching fraction	0.11
Combinatorial $B\overline{B}$ normalization	0.09
Signal and peaking $B^0\overline{B}^0$ normalization	0.07
Lepton ID	0.04
π^0 efficiency	0.03
f_{00}	0.01
$N_{\Upsilon(4S)}$	0.01
$D \to K_L$ decays	0.01
Signal form factors	0.01
Luminosity	< 0.01
Total systematics	0.52
Statistics	0.86

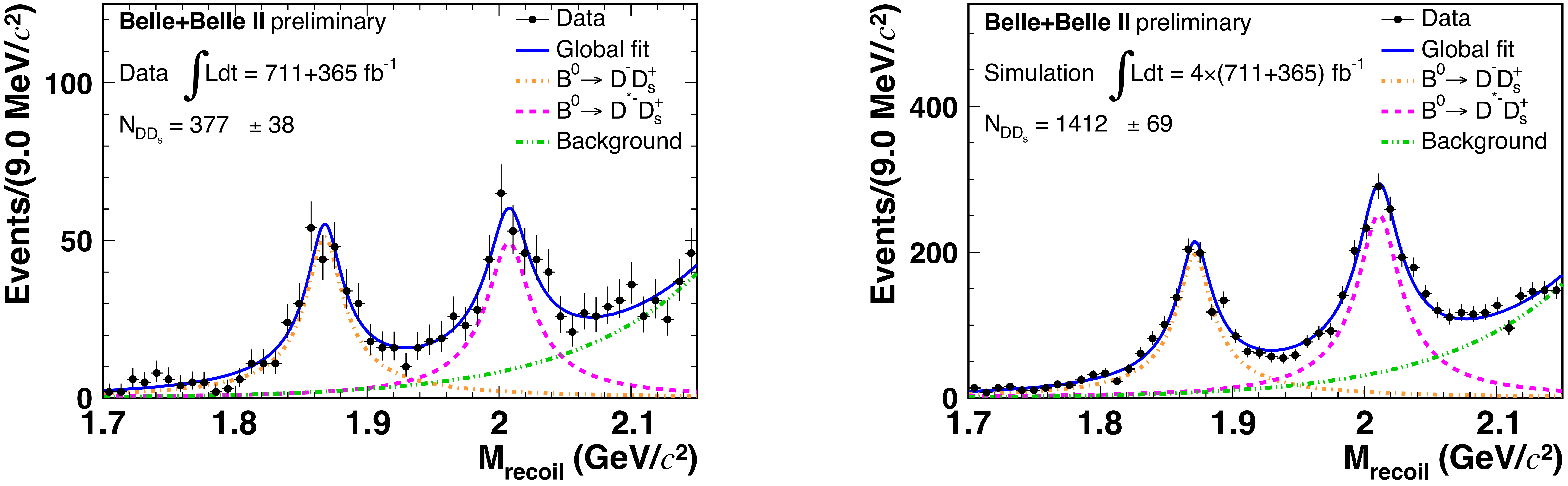


TABLE I. Efficiencies (ϵ), signal yields (N_{sig}) of the data fit, central value of the branching fractions and the observed $\mathcal{B}^{\text{UL}}$ at 90% CL. The first uncertainty of the central value is statistical and the second is systematic.

			$\mathcal{B}(10^{-5})$	
Channels	$\epsilon(10^{-4})$	N_{sig}	Central value	UL
$B^0 \to K_S^0\tau^+\mu^-$	1.7	-1.8 ± 3.0	$-1.0 \pm 1.6 \pm 0.2$	1.1
$B^0 \to K_S^0\tau^-\mu^+$	2.1	2.6 ± 3.5	$1.1 \pm 1.6 \pm 0.3$	3.6
$B^0 \to K_S^0\tau^+e^-$	2.0	-1.2 ± 2.4	$-0.5 \pm 1.1 \pm 0.1$	1.5
$B^0 \to K_S^0\tau^-e^+$	2.1	-2.9 ± 2.0	$-1.2 \pm 0.9 \pm 0.3$	0.8