Time-dependent, hadronic B decays and electroweak penguins at Belle II

QCD and High Energy Interaction 2023

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on behalf of Belle II collaboration

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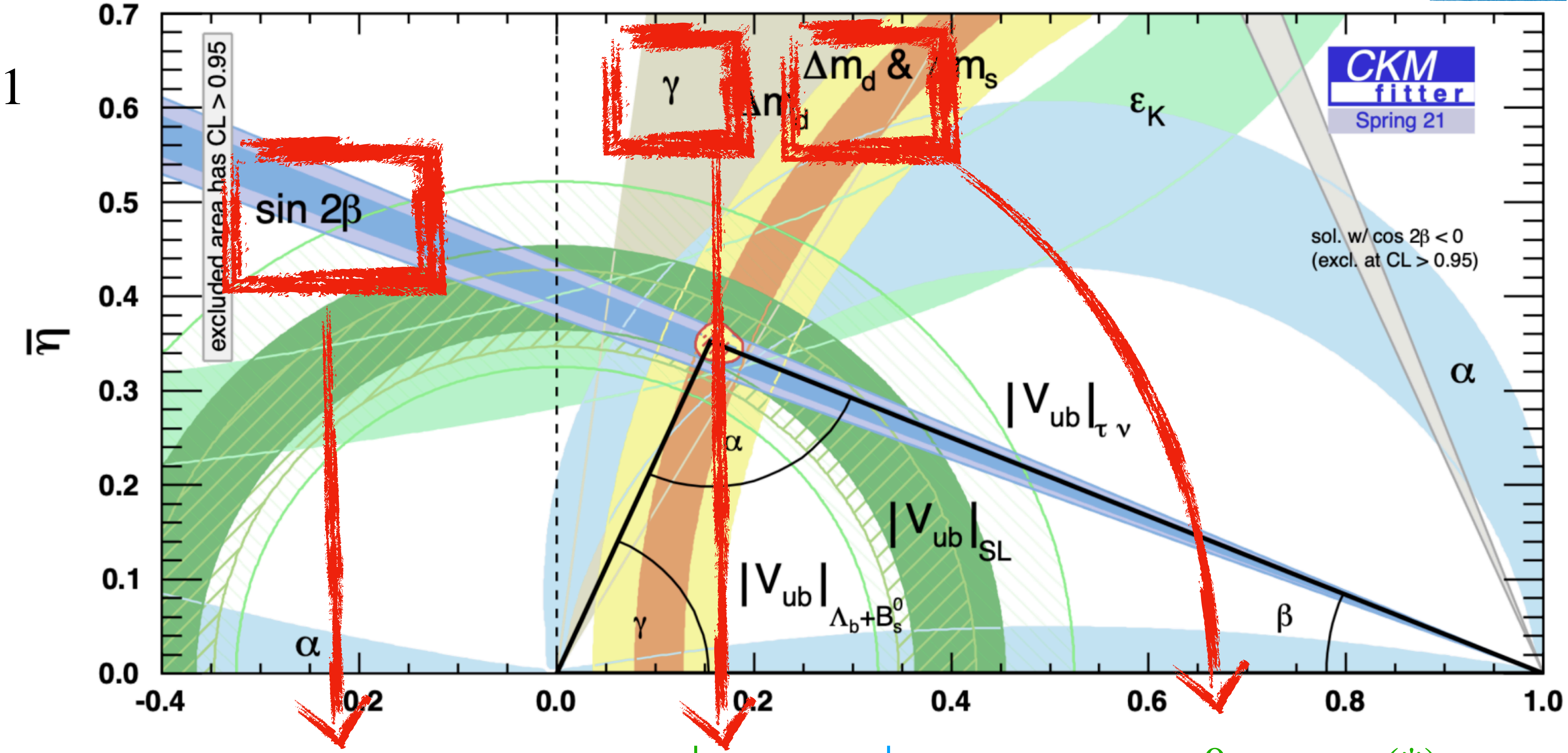
Outline and Motivation

[CKM Fitter, 2021]

Belle II Run 1 $\Upsilon(4S)$ dataset: 362 fb^{-1}
It is used to:

- CKM matrix measurement for **SM precision test** in favoured and suppressed B decays
- **Observe** new decay channels: $B \to D^{(*)} K^- K_S^0$
- Access to known rare decays to **investigate New Physics:** $B \to X_s \gamma$



$B^0 \to J/\psi K_S^0$

$B^{\pm} \to DK^{\pm}$

$B^0 \to D^{(*)-}\pi^+$

$B^0 \to \phi K_S^0$

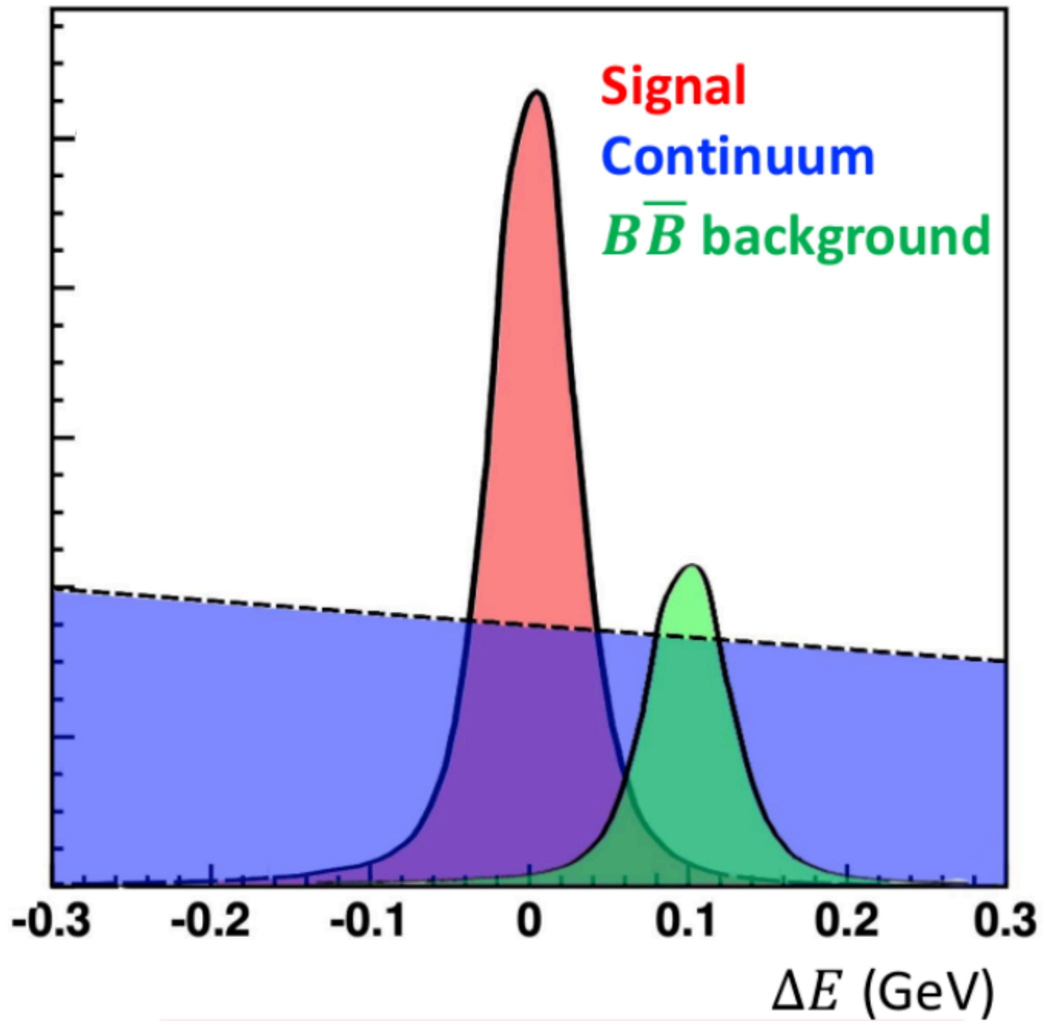
$B^0 \to K_S^0 K_S^0 K_S^0$

$B^0 \to K_S^0 \pi^0$

B-Factory basics

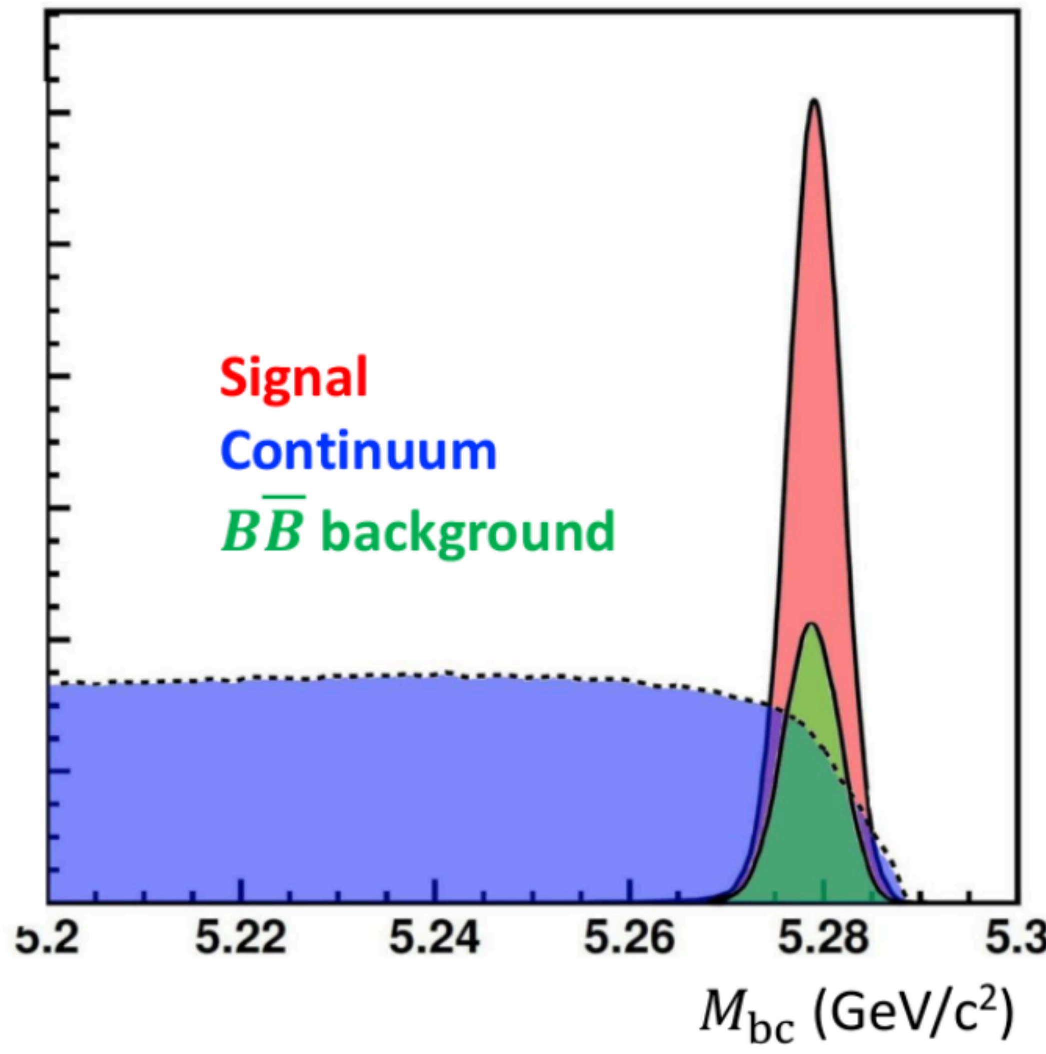
- $\sqrt{s} = m(\Upsilon(4S)) = 10.58\ \text{GeV} \simeq 2m_B \Rightarrow$ constrained kinematics
- Hermetic detector $\Rightarrow$ complete event reconstruction

$\Delta E = E_B^* - \sqrt{s}/2$



Expected $\Delta E \simeq 0$

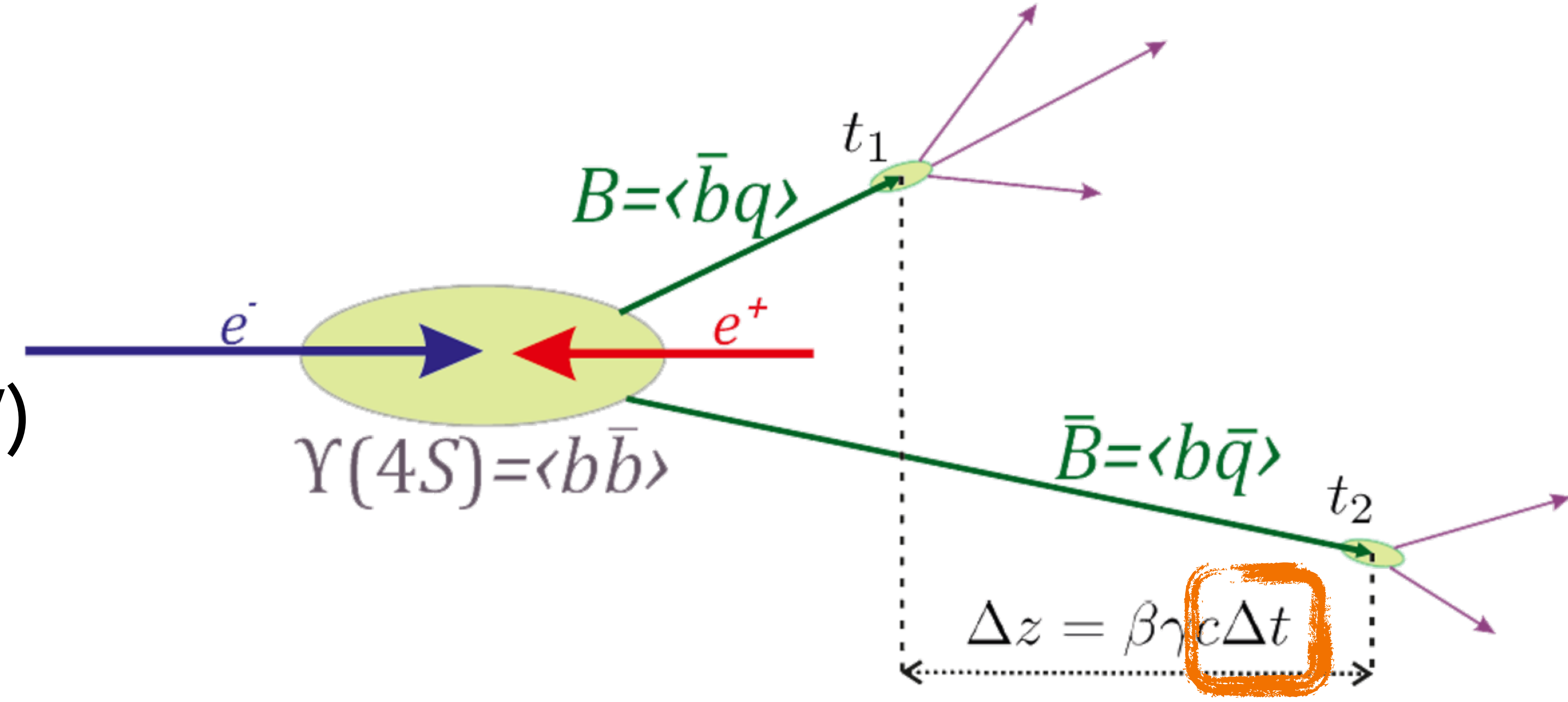
$M_{bc} = \sqrt{(\sqrt{s}/2)^2 - \vec{p}_B^{*2}}$



Expected $M_{bc} \simeq m_B$

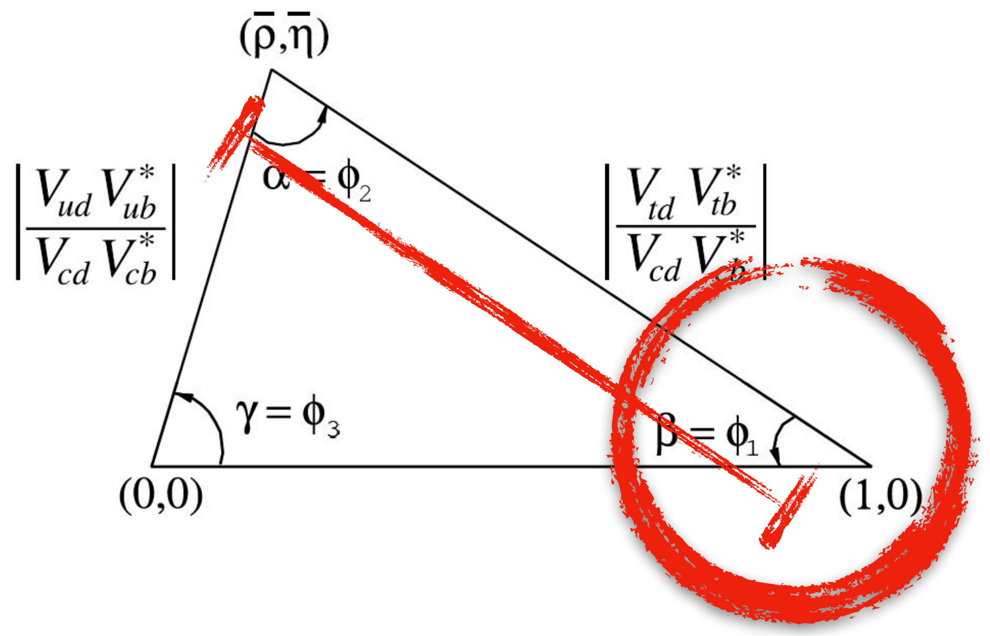
- Asymmetric collider $\Rightarrow$ Boost of center-of-mass
- Excellent vertexing performance ($\sigma \sim 15\ \mu$m)
- coherent $B\bar{B}$ pairs production
- Excellent flavour tagging performance

measurement of Δt for time dependent CP violation (TDCPV)



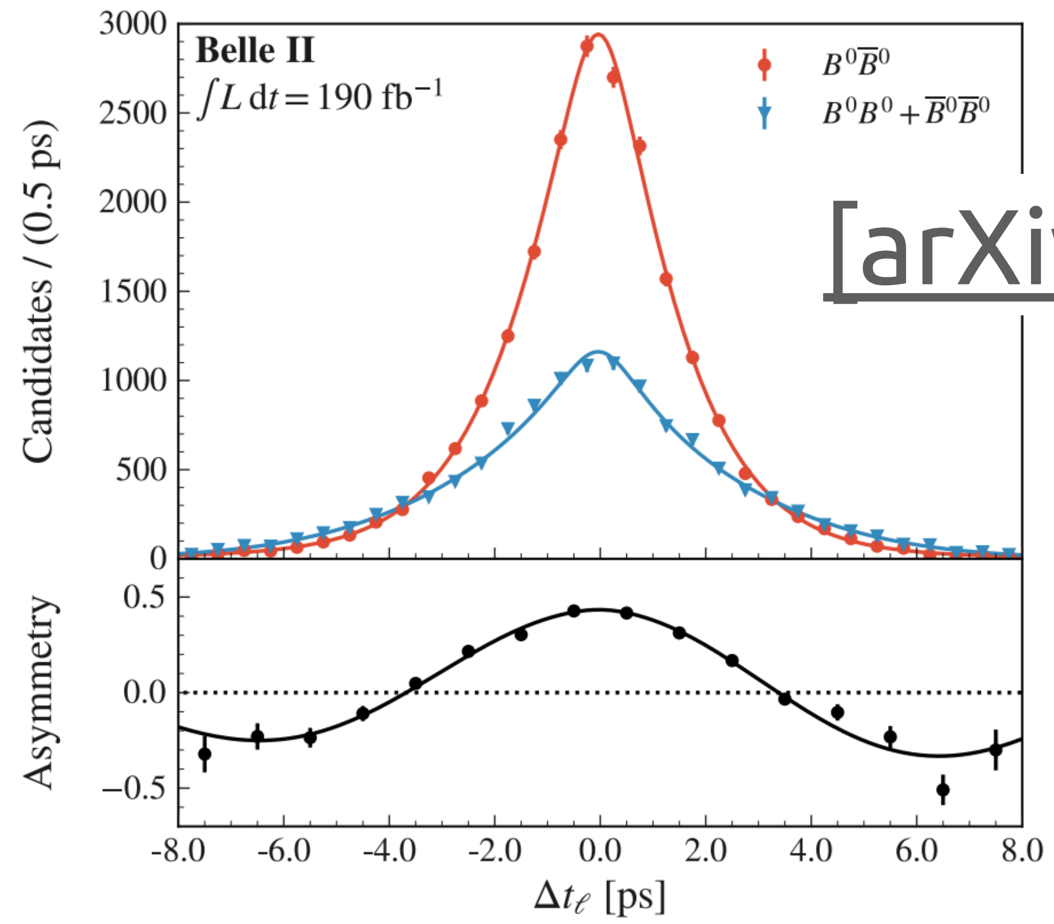
B-factory benchmark: mixing frequency and $\sin 2\beta$

$190\ \mathrm{fb}^{-1}$



- Essential step to validate Δt **resolution** (~1 ps) and **flavour tagger** performance ($\varepsilon_{\mathrm{tag}} \sim 30\,\%$) for TDCPV analyses
- **Reference** for measurement of β with gluonic penguins (next slide)
- **Clean**, **high yield**, channels to benchmark Belle II analysis performance, but:
  - Only half of the dataset has been used
  - Not yet competitive with world-best

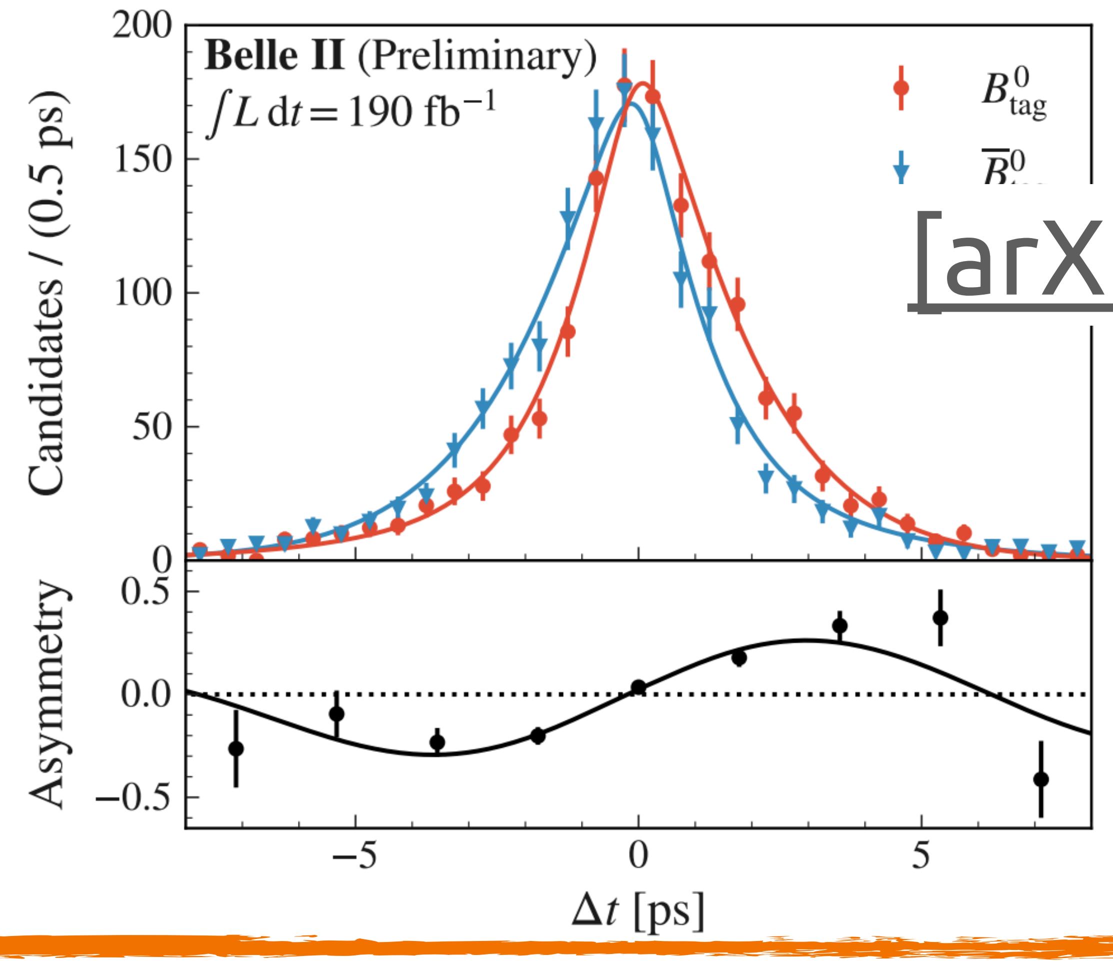
33K events from $B^0 \to D^{(*)-}\pi^+$



[arXiv:2302.12791]

$\tau_{B^0} = 1.499 \pm 0.013 \pm 0.008$ ps w.a. 1.519 ± 0.004 ps
$\Delta m_d = 0.516 \pm 0.008 \pm 0.005\ \mathrm{ps}^{-1}$ w.a. $0.5065 \pm 0.0019\ \mathrm{ps}^{-1}$

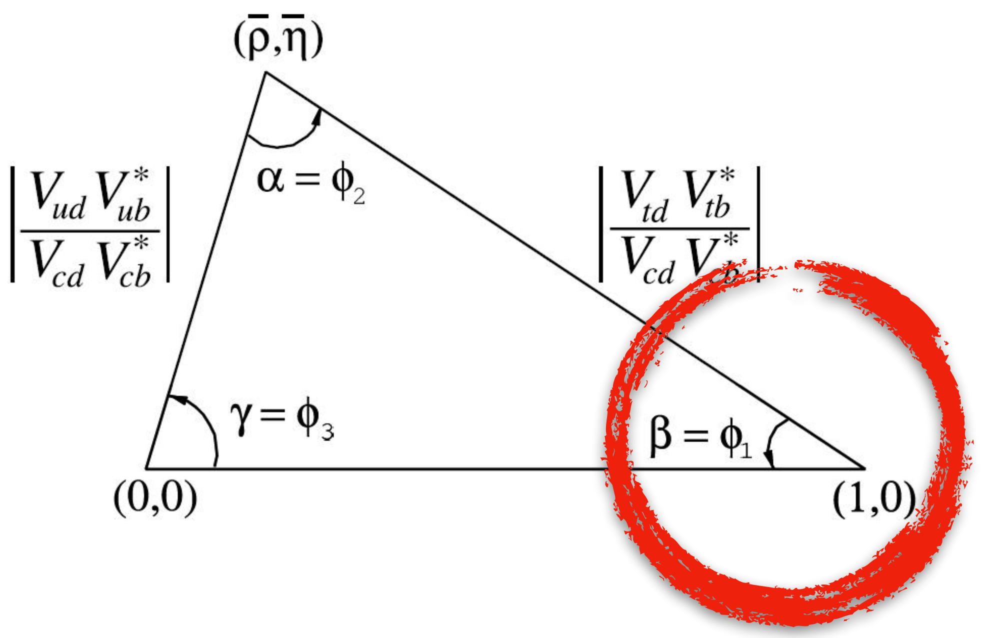
2.8K events from $B^0 \to J/\psi K_S^0$



[arXiv:2302.12898]

$S_{CP} = 0.720 \pm 0.062(\mathrm{stat}) \pm 0.016(\mathrm{syst})$ w.a. 0.698 ± 0.017
$A_{CP} = 0.094 \pm 0.044(\mathrm{stat})^{+0.042}_{-0.017}(\mathrm{syst})$ w.a. -0.005 ± 0.015

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



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

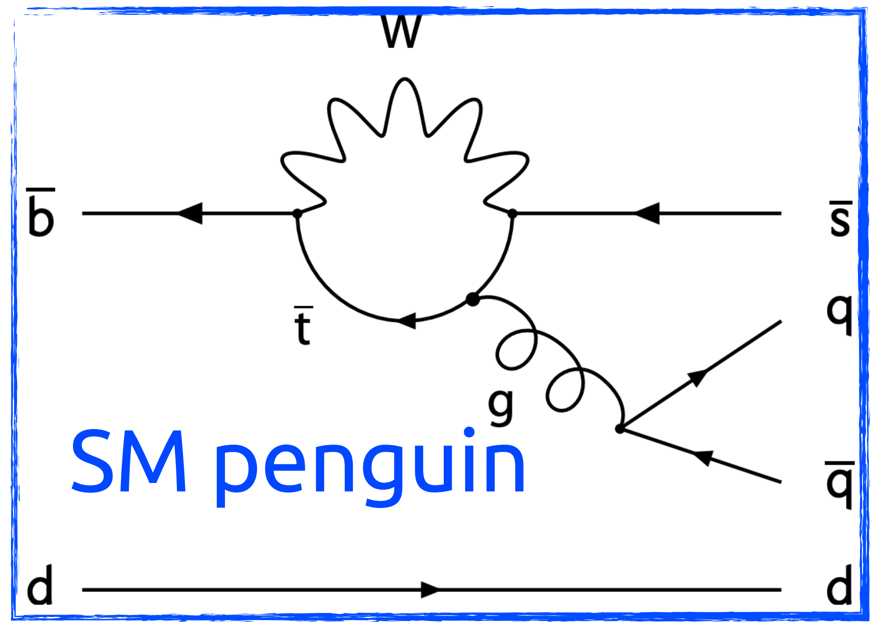
$$\mathcal{P}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_d}}{4\tau_d}\left\{1 + q\left[A_{CP}\cos(\Delta m_d \Delta t) + S_{CP}\sin(\Delta m_d \Delta t)\right]\right\}$$

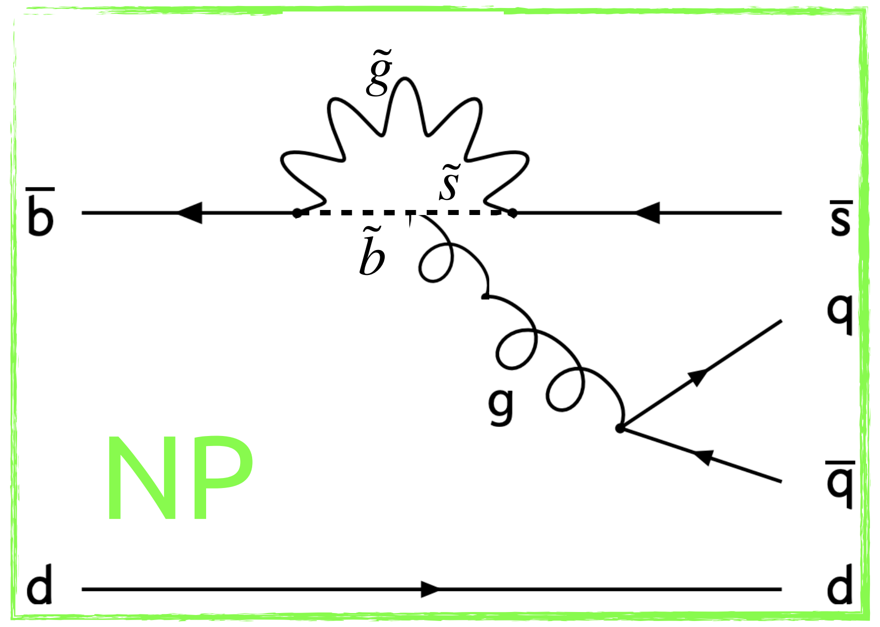
where $A_{CP} \simeq 0,\ S_{CP} \simeq \sin 2\beta$ in the SM

  - Relatively clean theory prediction
  - Access to BSM amplitudes

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

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

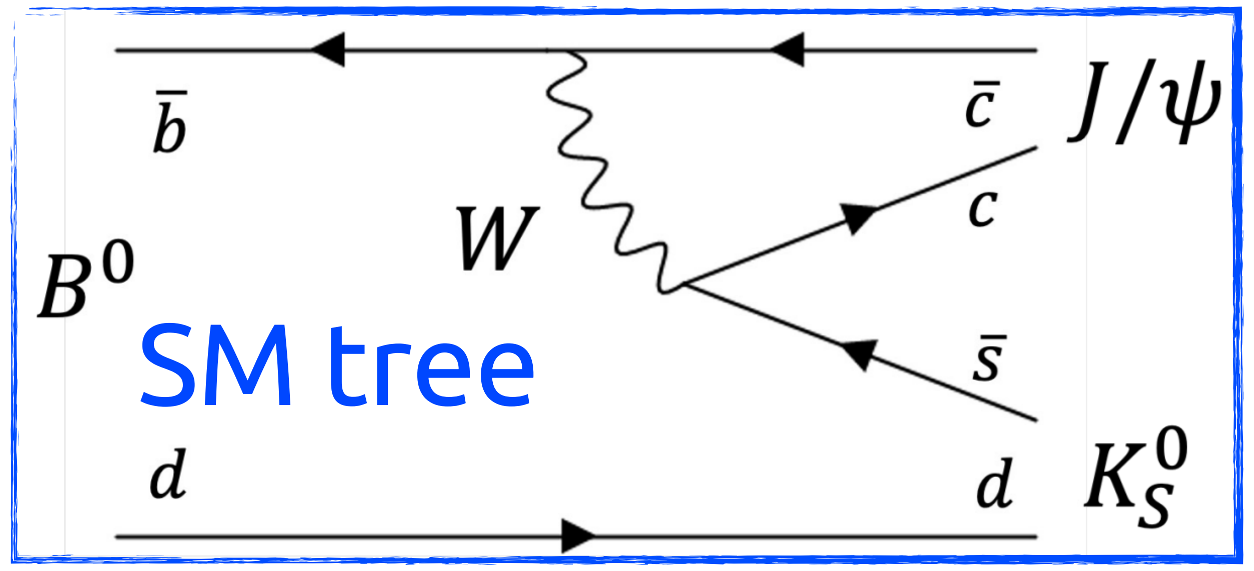




- **Experimentally challenging**:
  - Fully hadronic final state with **neutrals**
  - **Low purity** $\Rightarrow$ dedicated continuum suppression algorithms
  - **Unique** to Belle II

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

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



Gluonic penguins: $B^0 \to \phi K_S^0$

NEW for Moriond

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

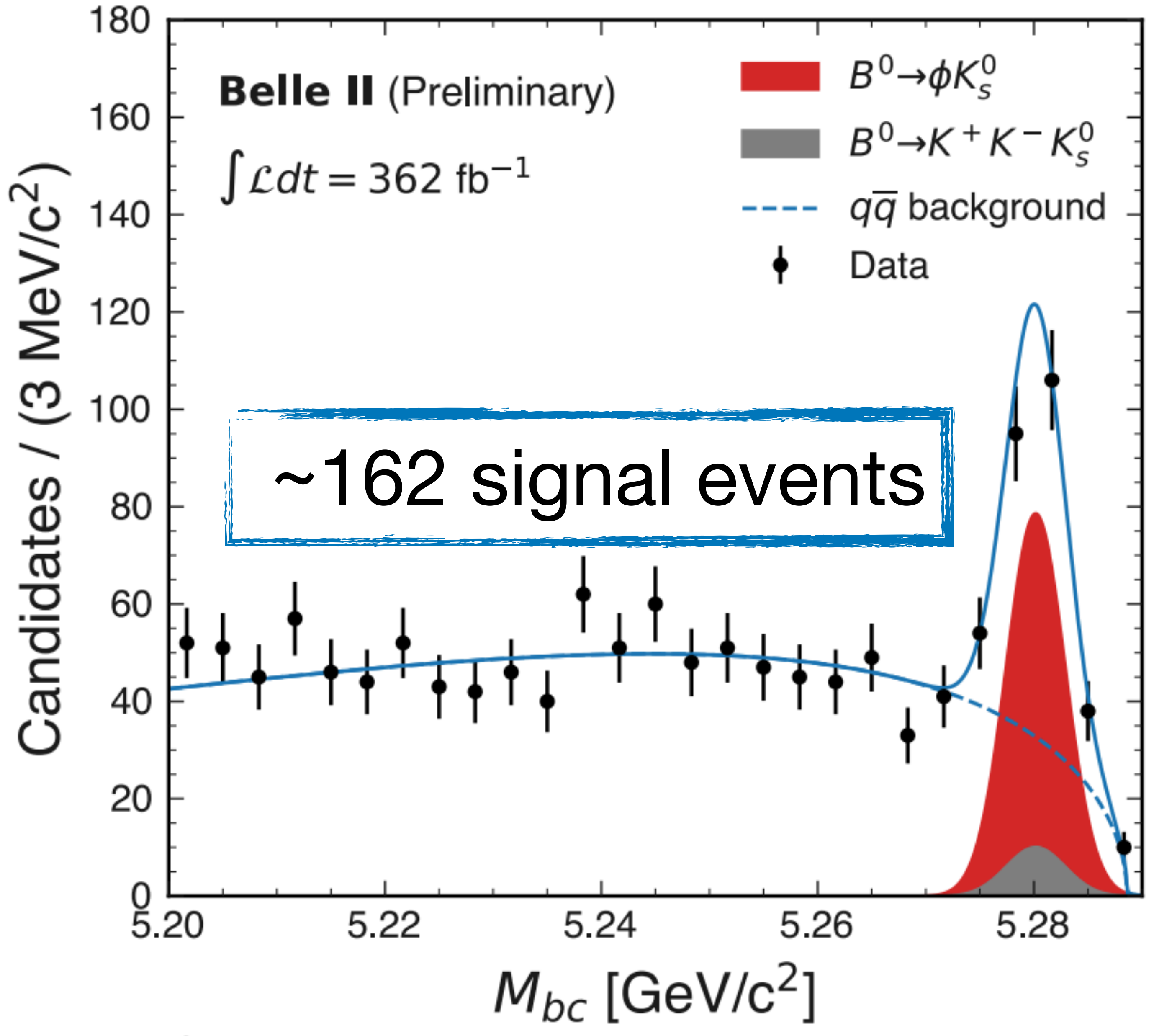
- **Quasi-2 body decay**: $\phi \to K^+K^-, K_S^0 \to \pi^+\pi^-$
  - Challenge: non-resonant $B^0 \to K^+K^-K_S^0$ bkg ⇒ discriminated with **helicity angle fit**
- 4D fit: $(M_{\mathrm{bc}}, O'_{CS}, \cos\theta, \Delta t)$, with O'_{CS}=cont. suppression BDT
  - Control channel $B \to D^*\pi$ for calibration of resolution & tagging
  - Control channel $B^+ \to \phi K^+$ to validation (null asymmetry test)

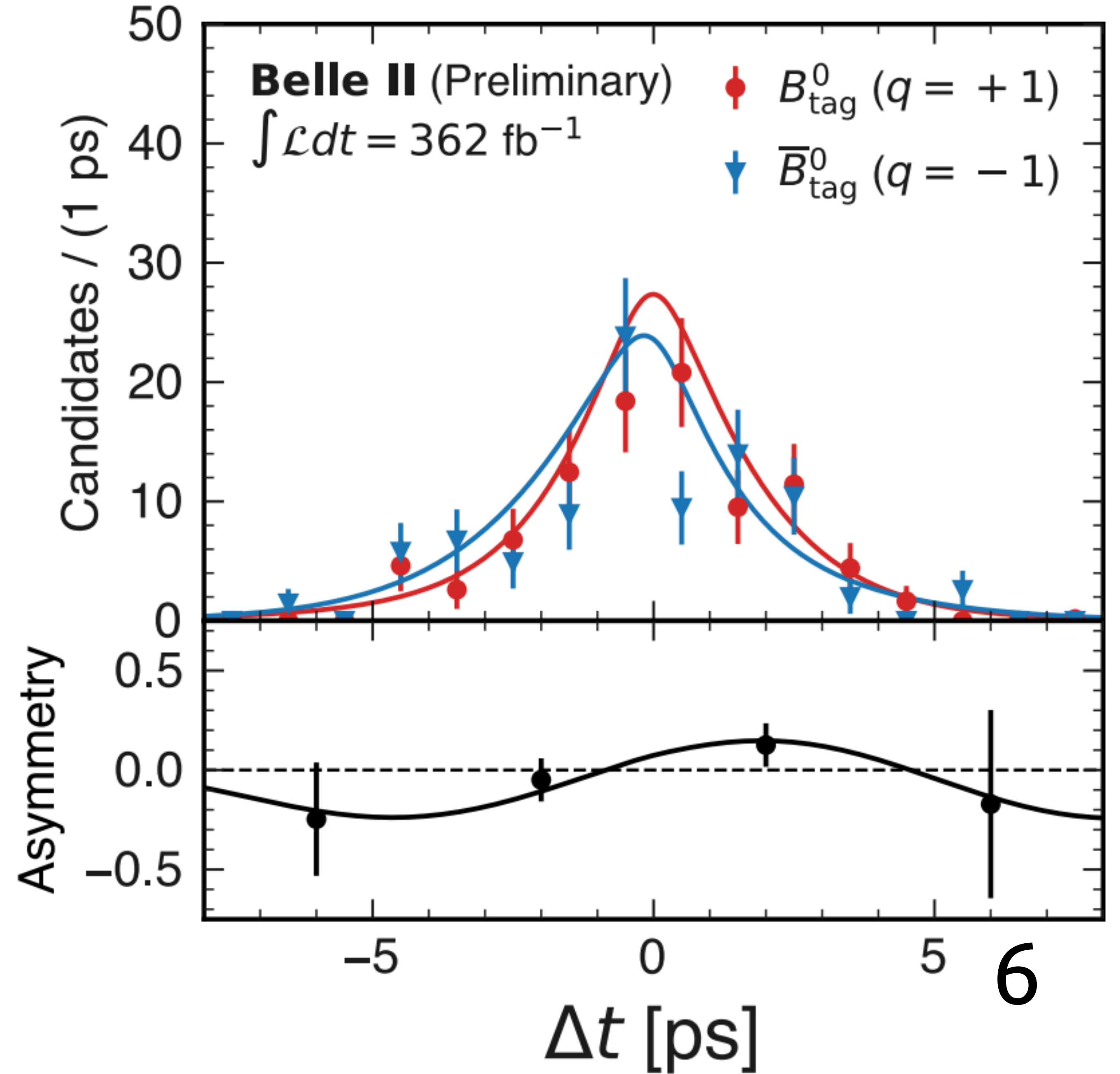
A_{CP} on par with best measurements

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

w.a. $A_{CP}^{\phi K_S^0} = -0.01 \pm 0.14,$

w.a. $S_{CP}^{\phi K_S^0} = 0.59 \pm 0.14$



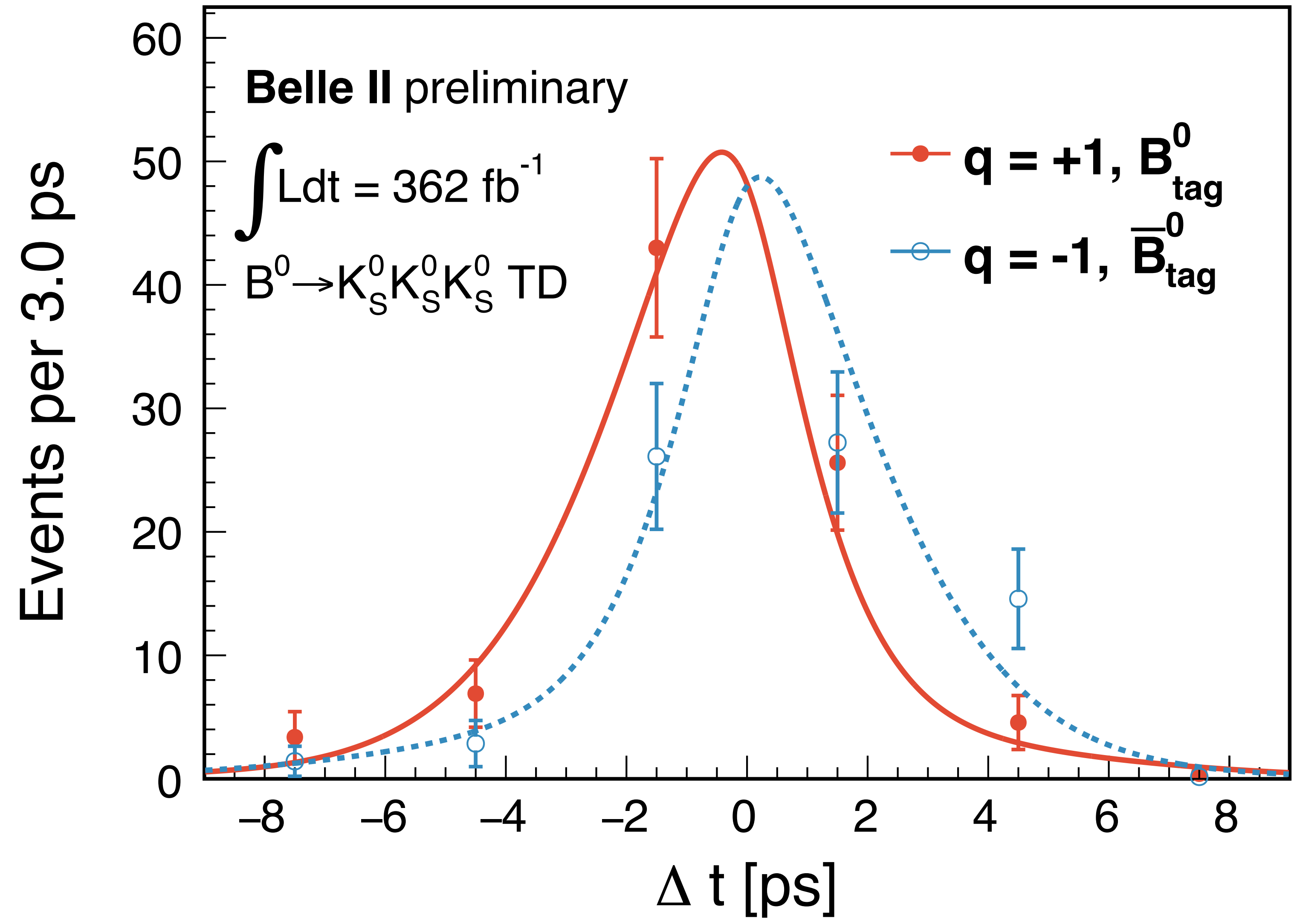


Gluonic penguins: $B^0 \to K_S^0 K_S^0 K_S^0$

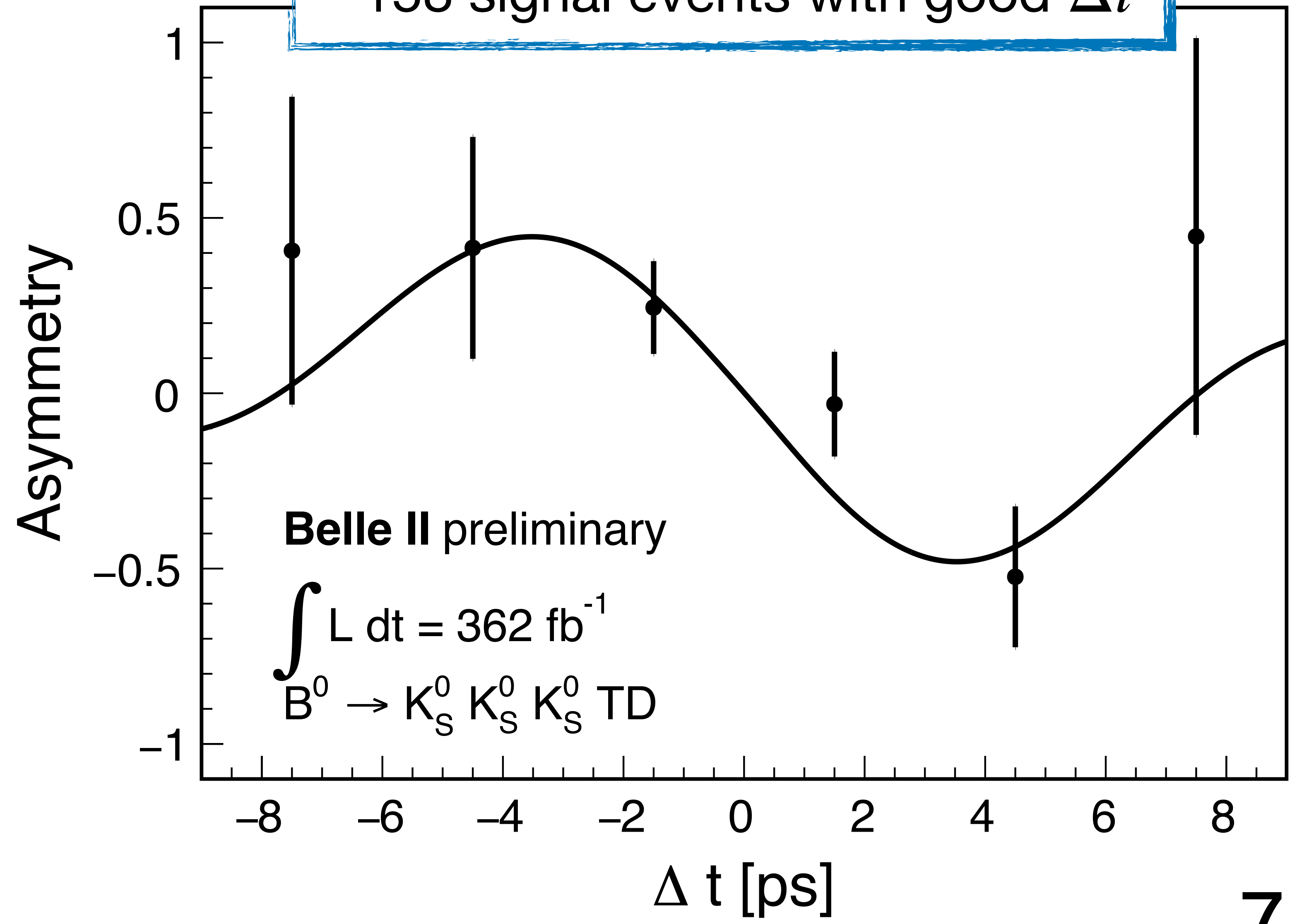
NEW for Moriond

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

- Challenge: **only displaced tracks**! (K_S^0 flight distance ~10 cm)
- 3D signal extraction Fit $(M_{\mathrm{bc}}, M_B, O'_{CS})$
  - simultaneous fit on $B^+ \to K_S^0 K_S^0 K^+$ for bkg and Δt calibration
  - simultaneous fit on $B^0 \to K_S^0 K_S^0 K_S^0$ events with low Δt quality for A_{CP} constraint
- Fit to Δt



~158 signal events with good Δt



A_{CP} on par with best measurements

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

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

w.a. $S^{K_S^0 K_S^0 K_S^0} = -0.83 \pm 0.17$

w.a. $A^{K_S^0 K_S^0 K_S^0} = 0.15 \pm 0.12$

Gluonic penguins: $B^0 \to K_S^0 \pi^0$

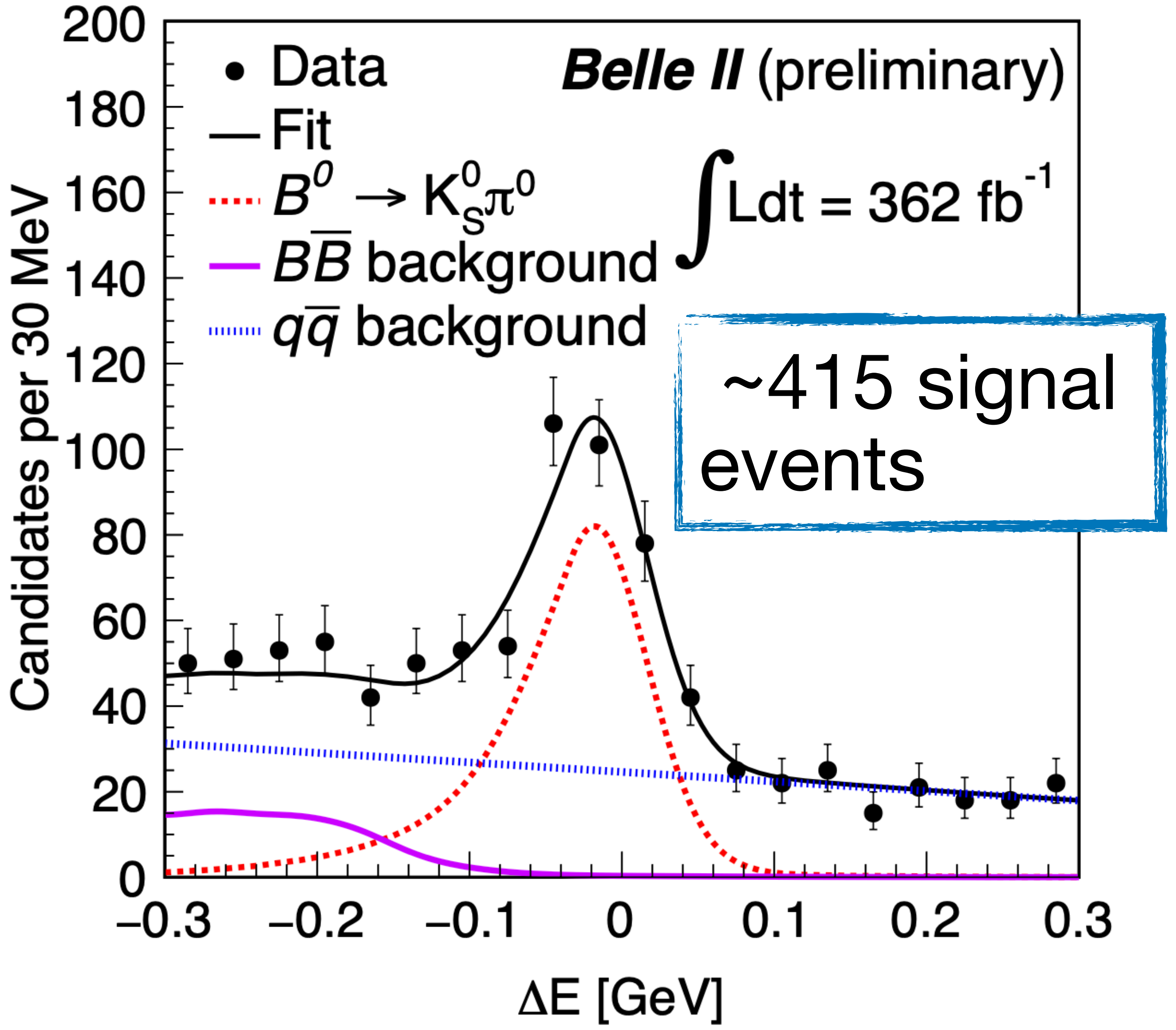
NEW for Moriond

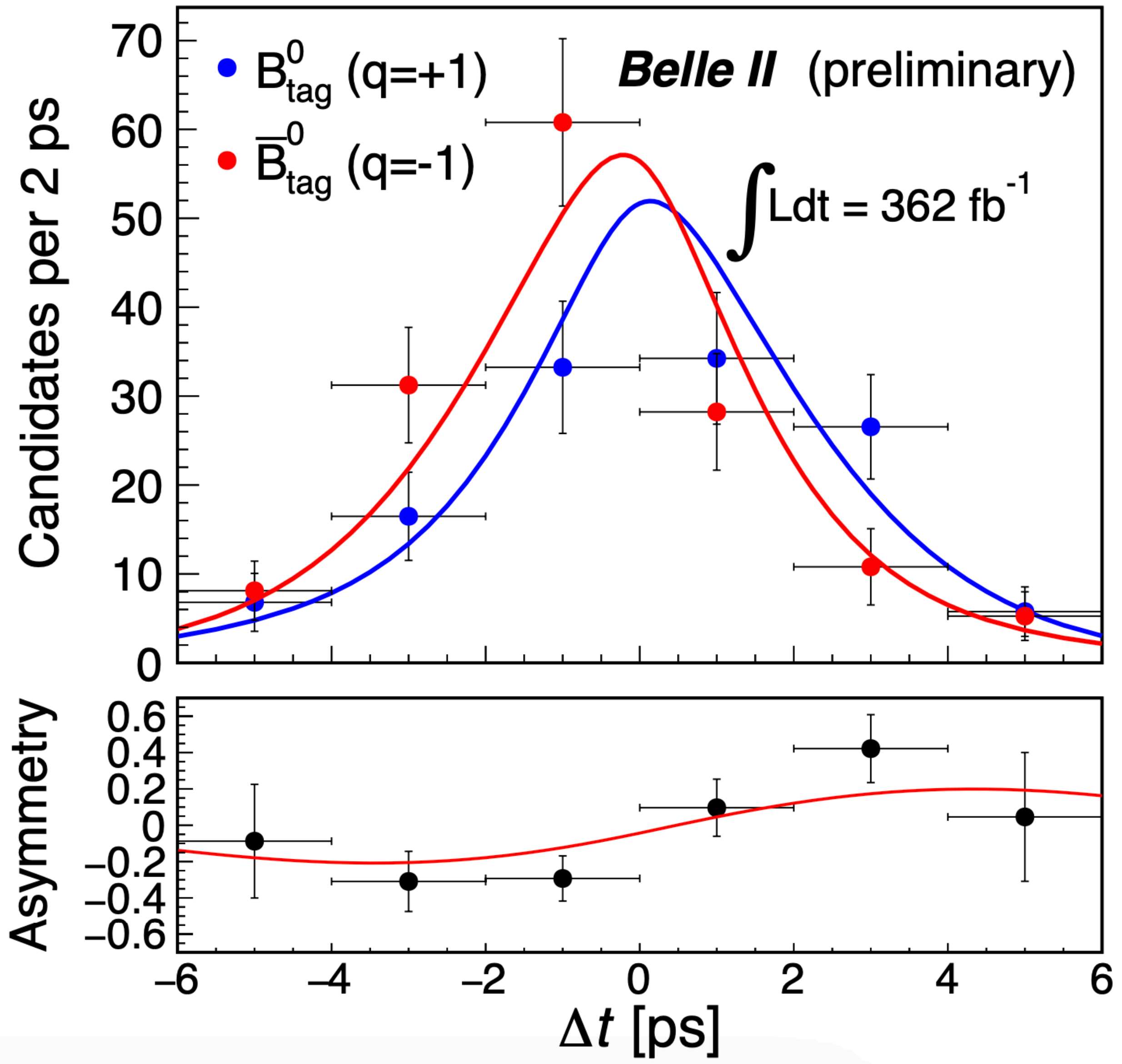
$362\ \mathrm{fb}^{-1}$

- Challenge: B vertex with K_S^0 **displaced tracks only**
- 4D Fit $(\boldsymbol{\Delta E, M_{\mathrm{bc}}, \Delta t, O_{CS}})$
  - Ancillary fit to B lifetime
  - Control sample fit to $B^0 \to J/\psi K_S^0$ with only K_S^0 vertexing, for validation and Δt calibration
  - Control sample fit to $B^+ \to \overline{D}^0(\to K_S^0\pi^0)\pi^+$ for other fit variables calibration
  - Events with low-Δt quality used to constrain better A_{CP}
- A_{CP} input crucial for Isospin sum rule (see next slide)

already competitive with world average

parameter	Belle II(@387 M)	PDG value
$\mathcal{A}_{CP}$	$0.04^{+0.15}_{-0.14}(stat.) \pm 0.04(syst.)$	0.00 ± 0.13
$\mathcal{S}_{CP}$	$0.74^{+0.20}_{-0.23}(stat.) \pm 0.04(syst.)$	0.58 ± 0.17



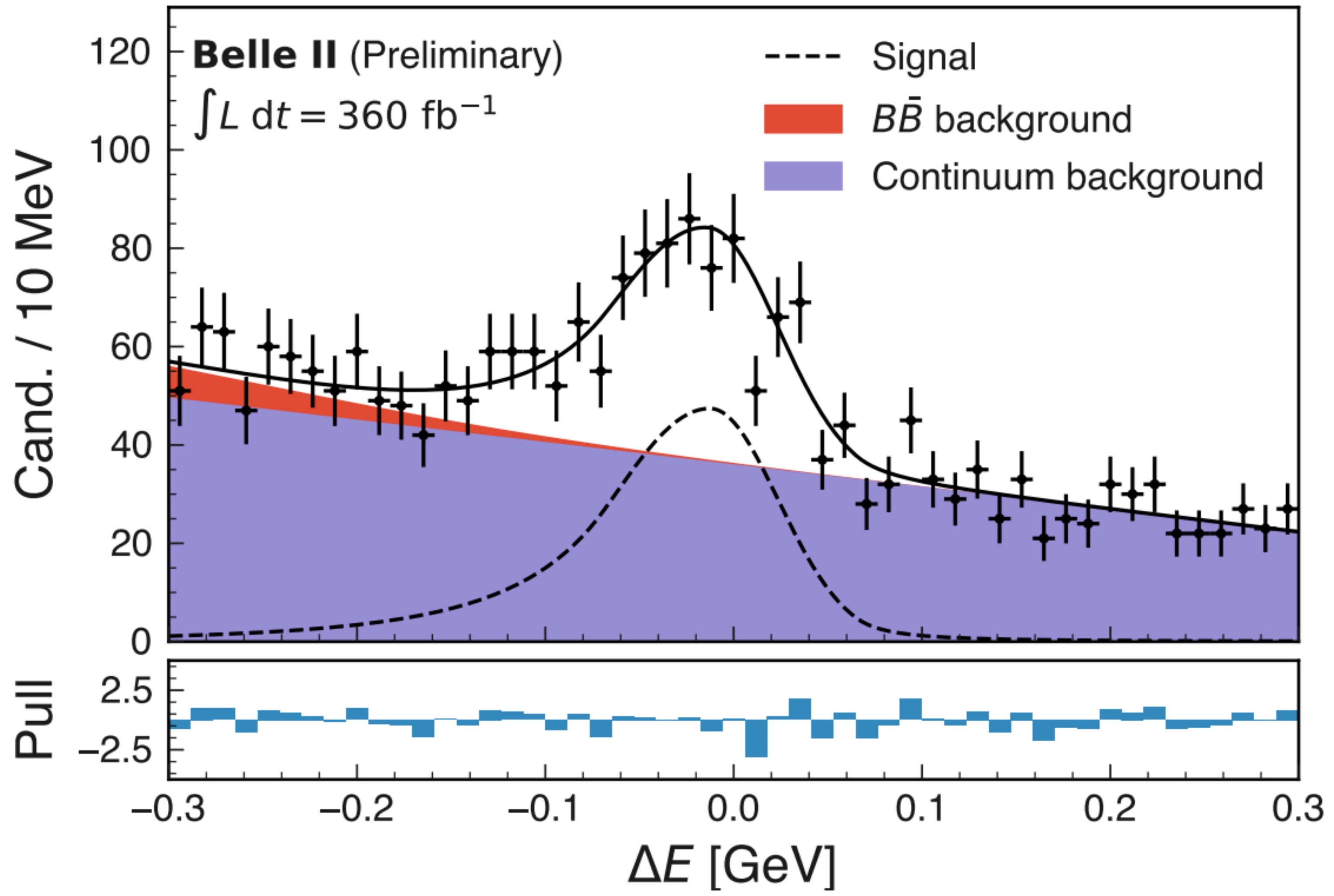


Isospin sum rule

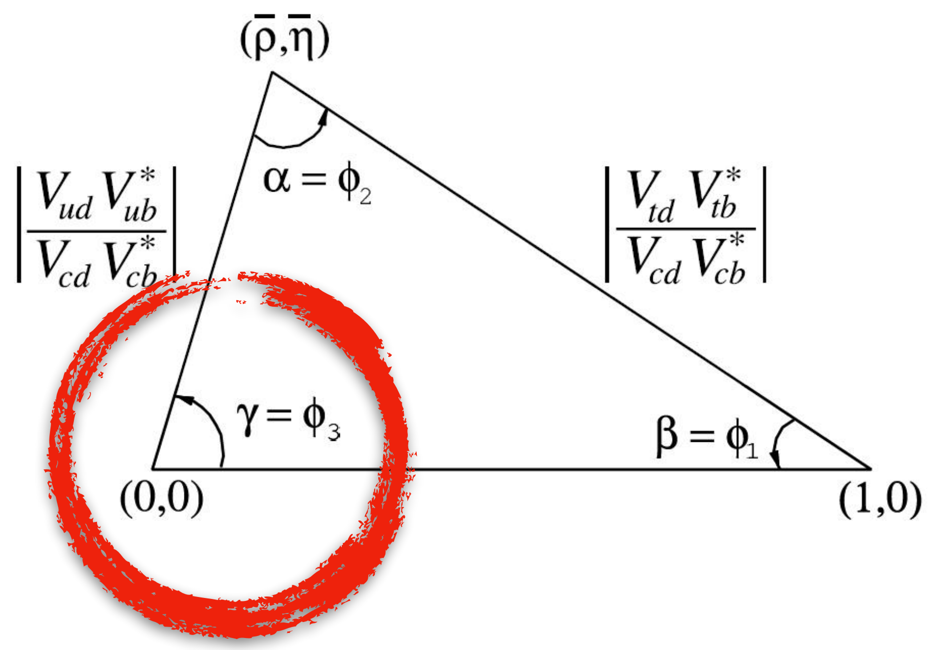
NEW for Moriond

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

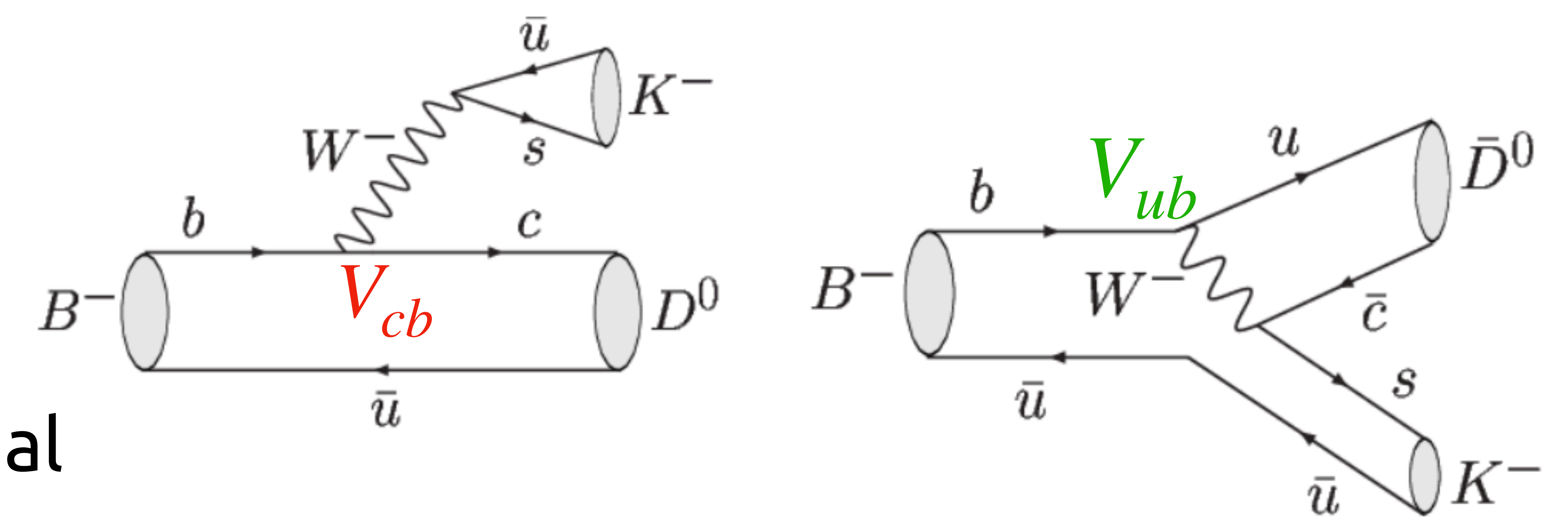
- Isospin sum rule: $I_{K\pi} = \mathscr{A}_{K^+\pi^-} + \mathscr{A}_{K^0\pi^+} \cdot \frac{\mathscr{B}_{K^0\pi^+}}{\mathscr{B}_{K^+\pi^-}} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathscr{A}_{K^+\pi^0} \cdot \frac{\mathscr{B}_{K^+\pi^0}}{\mathscr{B}_{K^+\pi^-}} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathscr{A}_{K^0\pi^0} \cdot \frac{\mathscr{B}_{K^0\pi^0}}{\mathscr{B}_{K^+\pi^-}} \approx 0$
  - Exactly 0 in the limit of isospin symmetry and no EW penguins
  - Theoretical precision below 1% *[Phys.Lett. B627 (2005) 82-88]*, experimental precision O(10%), driven by $A_{K^0\pi^0}$
- We measure **all** final states: $B^0 \to K^+\pi^-, \quad B^+ \to K^0_S\pi^+, \quad B^+ \to K^+\pi^0, \quad B^0 \to K^0_S\pi^0$
- Fit: 2D $(\Delta E, C')$
- **BRs** and A_{CP} results in agreements with world averages and **competitive with world best**
- In particular, $B \to K^0_S\pi^0$ is **combined with time-dependent** analysis, to obtain:
  - **world best**: $A_{K^0\pi^0} = -0.01 \pm 0.12 \pm 0.05$ (w.a. 0.0 ± 0.13)
- Combining all the $B \to K\pi$ final states measured by Belle II:
  - $I_{K\pi} = -0.03 \pm 0.13 \pm 0.05$ (w.a: 0.13 ± 0.11)

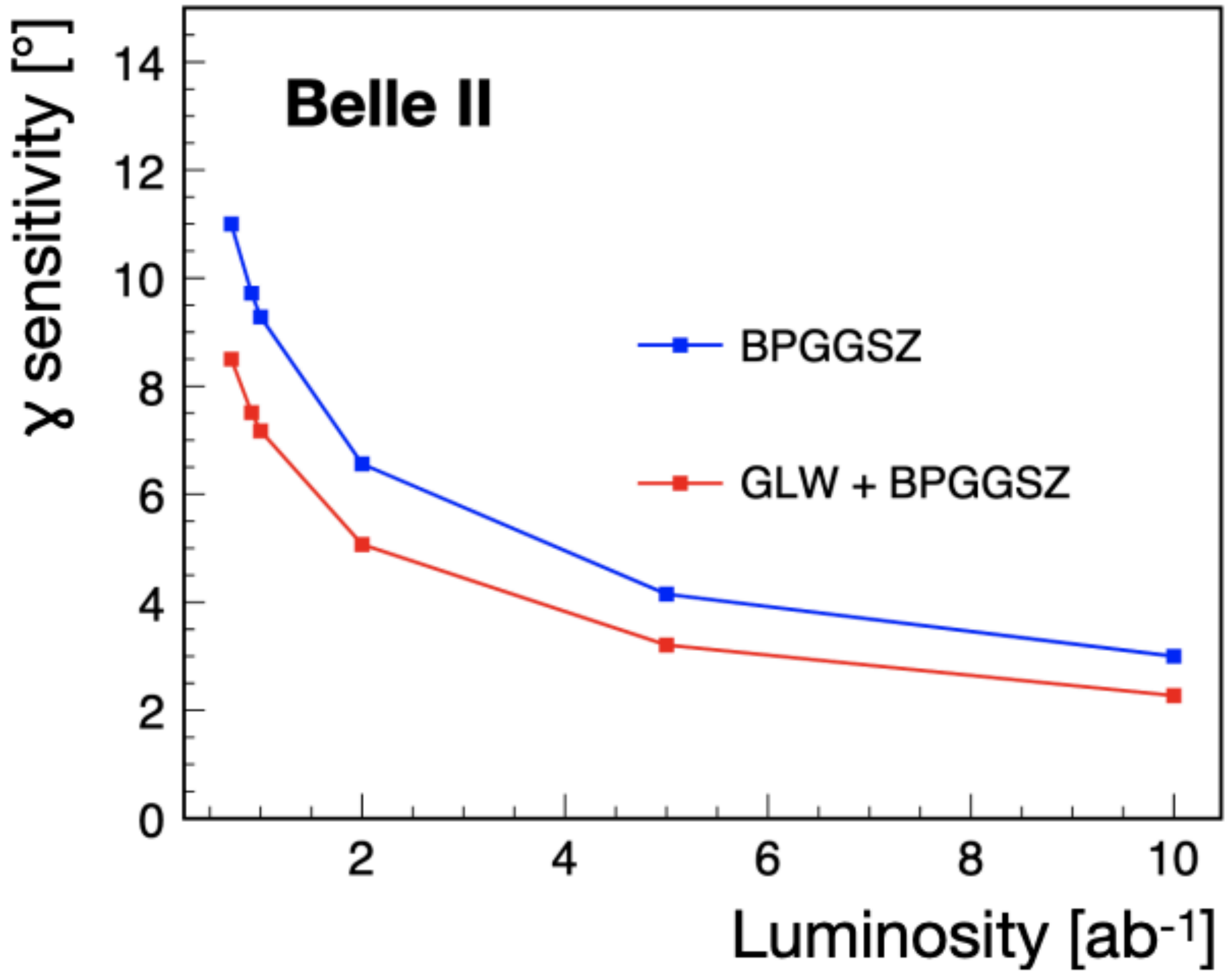


Measurement of CKM matrix γ/ϕ_3 angle



- Motivation:
  - CPV in the interference $b \to c\bar{u}s$ and $b \to u\bar{c}s$
    $$\frac{A_{\text{sup}}(B^- \to \overline{D^0}K^-)}{A_{\text{fav}}(B^- \to D^0K^-)} = r_B e^{i(\delta_B - \phi_3)} \Rightarrow \gamma$$
  - Tree-dominated $\Rightarrow \boldsymbol{\Delta\gamma_{\text{theory}}/\gamma \sim 10^{-7}}$
- **Multiple approaches**, according to the chosen D decay final state:
  - **BPGGSZ**: self-conjugate final state $D \to K_S^0\pi^+\pi^-, K_S^0K^+K^-$ [JHEP 02 2022, 063 (2022)]
  - **GLS**: cabibbo-suppressed decays $D \to K_S^0K^{\pm}\pi^{\mp}$
  - **GLW**: CP eigenstates $D \to K^+K^-, \pi^+\pi^-, K_S^0\pi^0$
- Challenge: **statistical** limitation
- Current world **average experimental precision** $\boldsymbol{\Delta\gamma \sim 4°}$



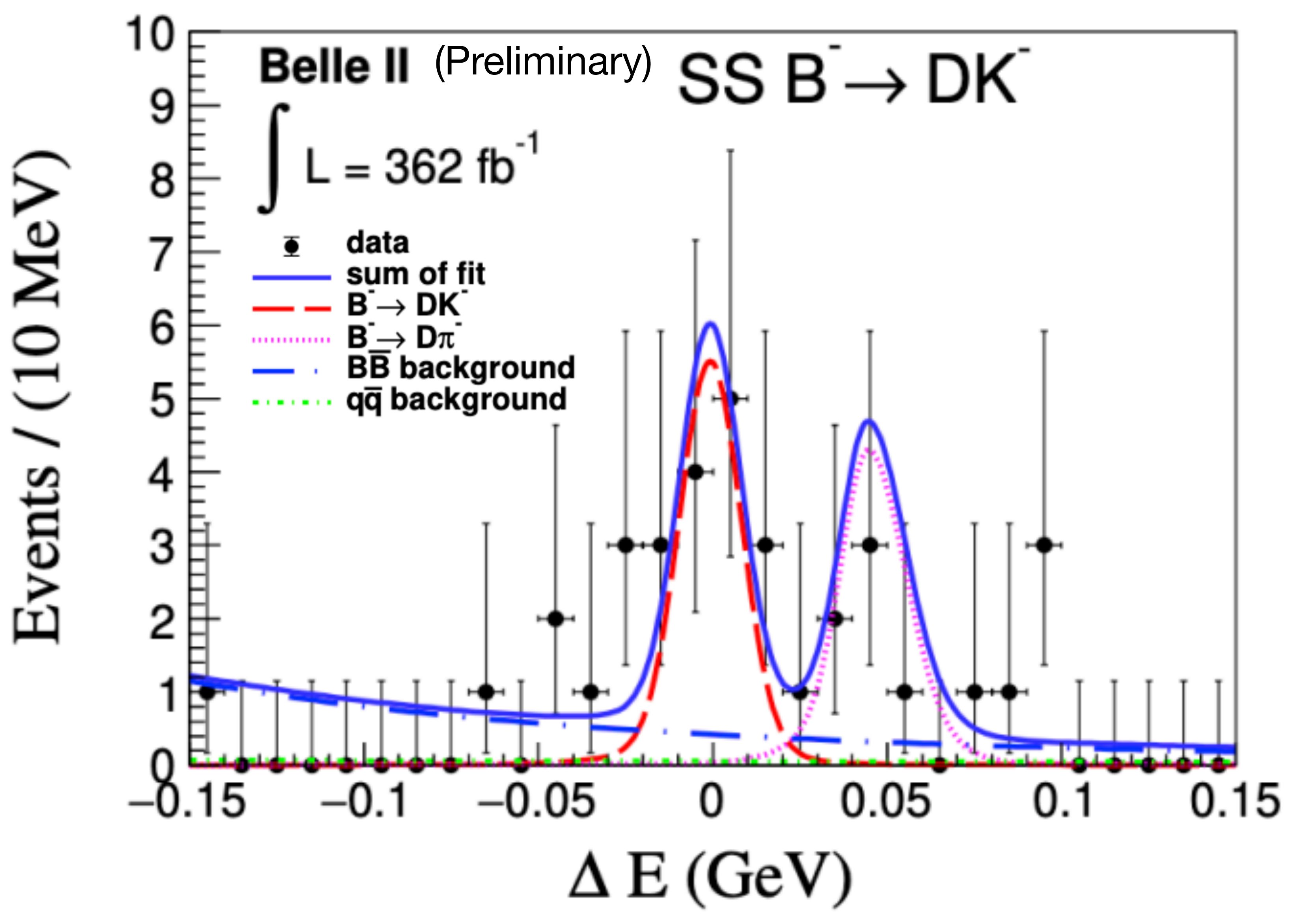


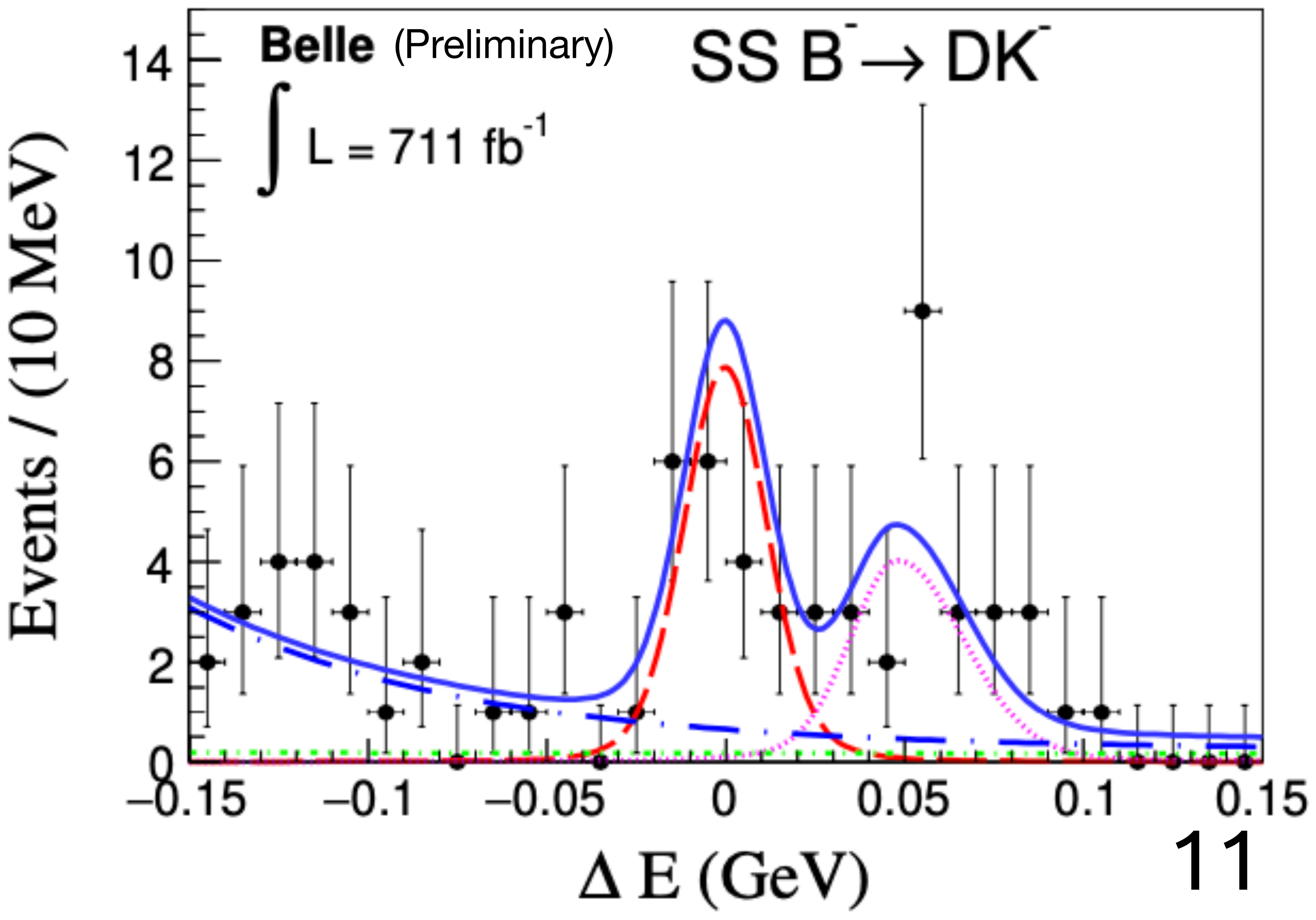
CKM γ angle with GLS method

NEW for Moriond

Belle II + Belle: $362\ \text{fb}^{-1} + 711\ \text{fb}^{-1}$

- $B^{\pm} \to DK^{\pm}, D\pi^{\pm}, \quad D \to K_S^0 K^{\pm}\pi^{\mp}$
- 7 CP observables: 4 asymmetries, 3 BRs ratios
- Measurement performed in full D phase space and in the enhanced-interference $D \to K^*K$ region
- 2D Fit $(\Delta E, C')$ of 8 categories: (SS,OS) x (DK,Dπ) x (+,-)
  - SS=K from D and B have the same charge, OS=opposite
- **external inputs from CLEO** are needed (D decay parameters [Phys. Rev. D 94, 099905 (2016)]) to extract γ
- The results are not competitive, but combining Belle and Belle II data sample, they are **the best constraint we can provide with this approach**





CKM γ angle with GLW method

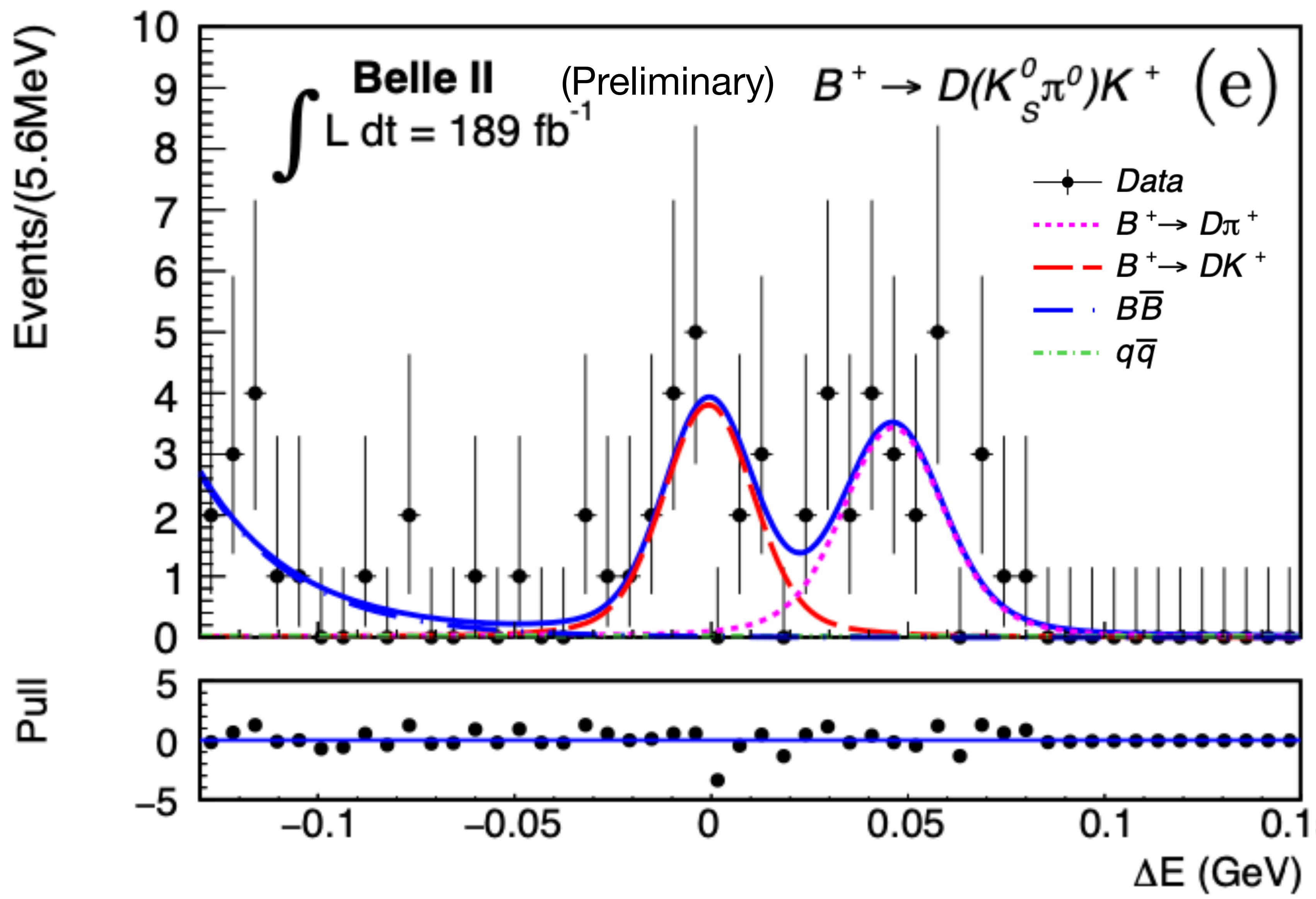
NEW for Moriond

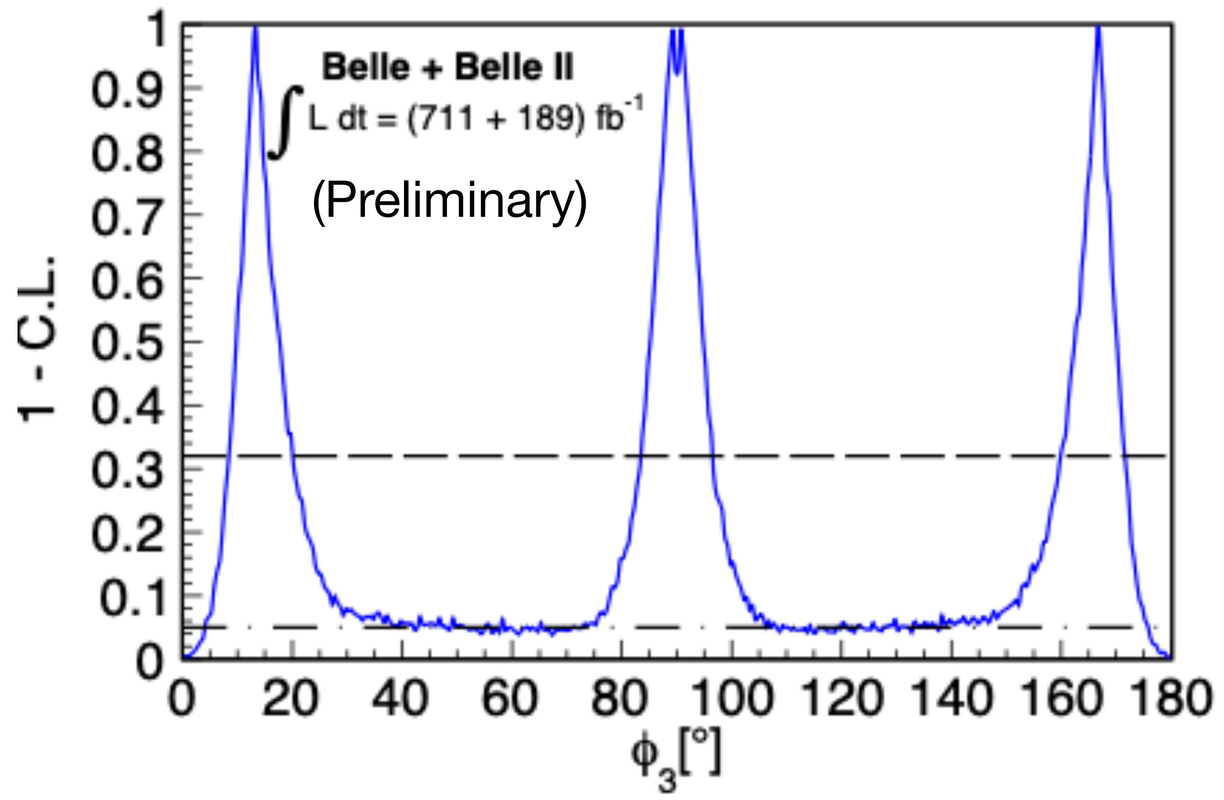
Belle II + Belle: $189\ \text{fb}^{-1} + 711\ \text{fb}^{-1}$

- $B^{\pm} \to DK^{\pm}$ with $D \to K^+K^-$ (CP-even) or $D \to K_S^0\pi^0$ (CP-odd)
  - **CP-odd only accessible at B-factory**
- Interference between the to CP eigenstates:

$$\mathcal{R}_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\phi_3,$$
$$\mathcal{A}_{CP\pm} = \pm 2r_B \sin\delta_B \sin\phi_3 \,/\, \mathcal{R}_{CP\pm}.$$

- Control sample $B^{\pm} \to D(\to K^+\pi^-)h$ to access to D decay information
- 2D Fit $(\Delta E, C')$ of 6 categories ($D\pi$,DK,)x (K^+K^-,$K_S^0\pi^0$, $K^+\pi^-$)



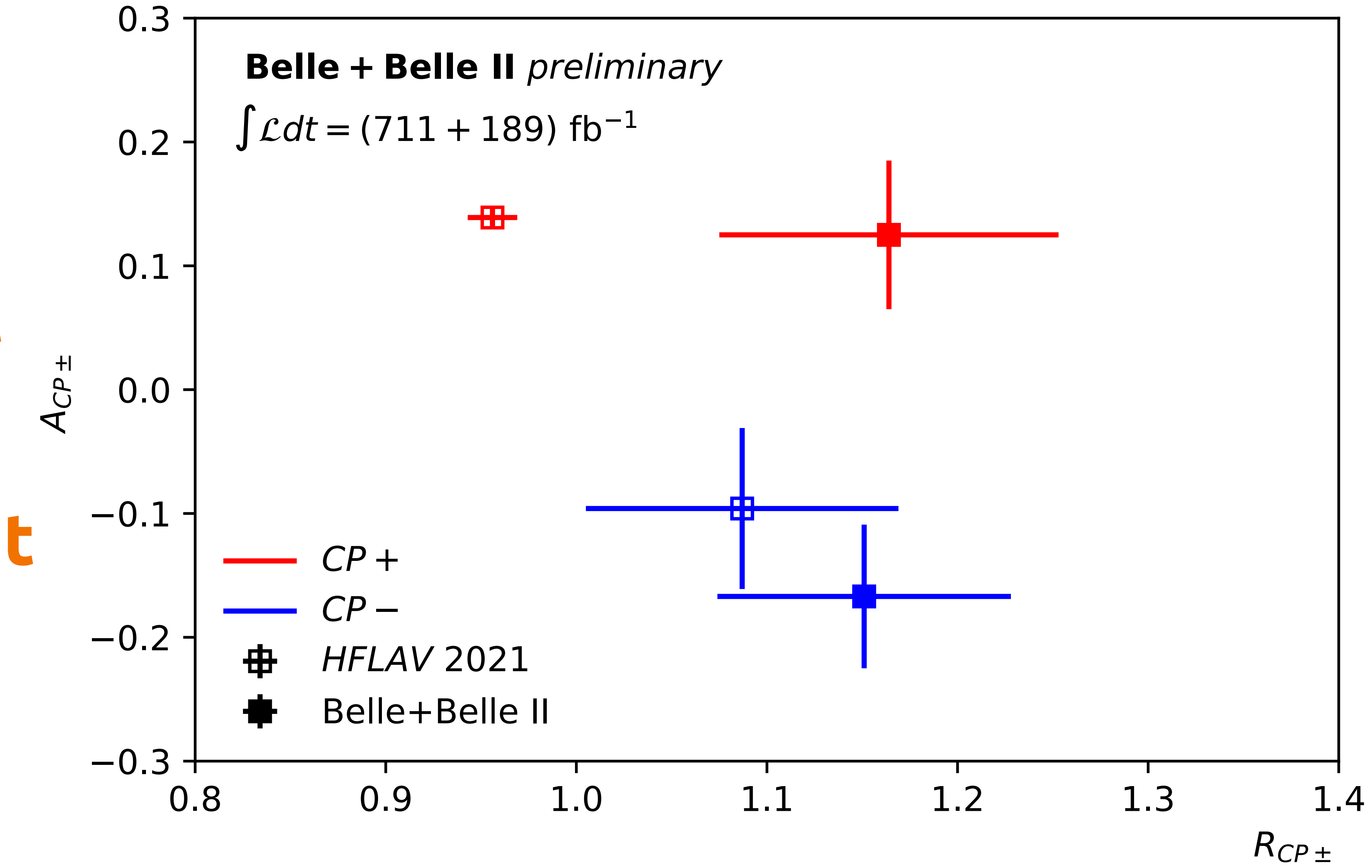


$$\mathcal{R}_{CP+} = 1.164 \pm 0.081 \pm 0.036,$$
$$\mathcal{R}_{CP-} = 1.151 \pm 0.074 \pm 0.019,$$
$$\mathcal{A}_{CP+} = (+12.5 \pm 5.8 \pm 1.4)\%,$$
$$\mathcal{A}_{CP-} = (-16.7 \pm 5.7 \pm 0.6)\%.$$

Best A_{CP-} measurement

3.5σ

In agreement with SM prediction



world average: $\phi_3\,(\circ) = 66.2^{+3.4}_{-3.6}$ $\quad r_B = 0.0996 \pm 0.0026$

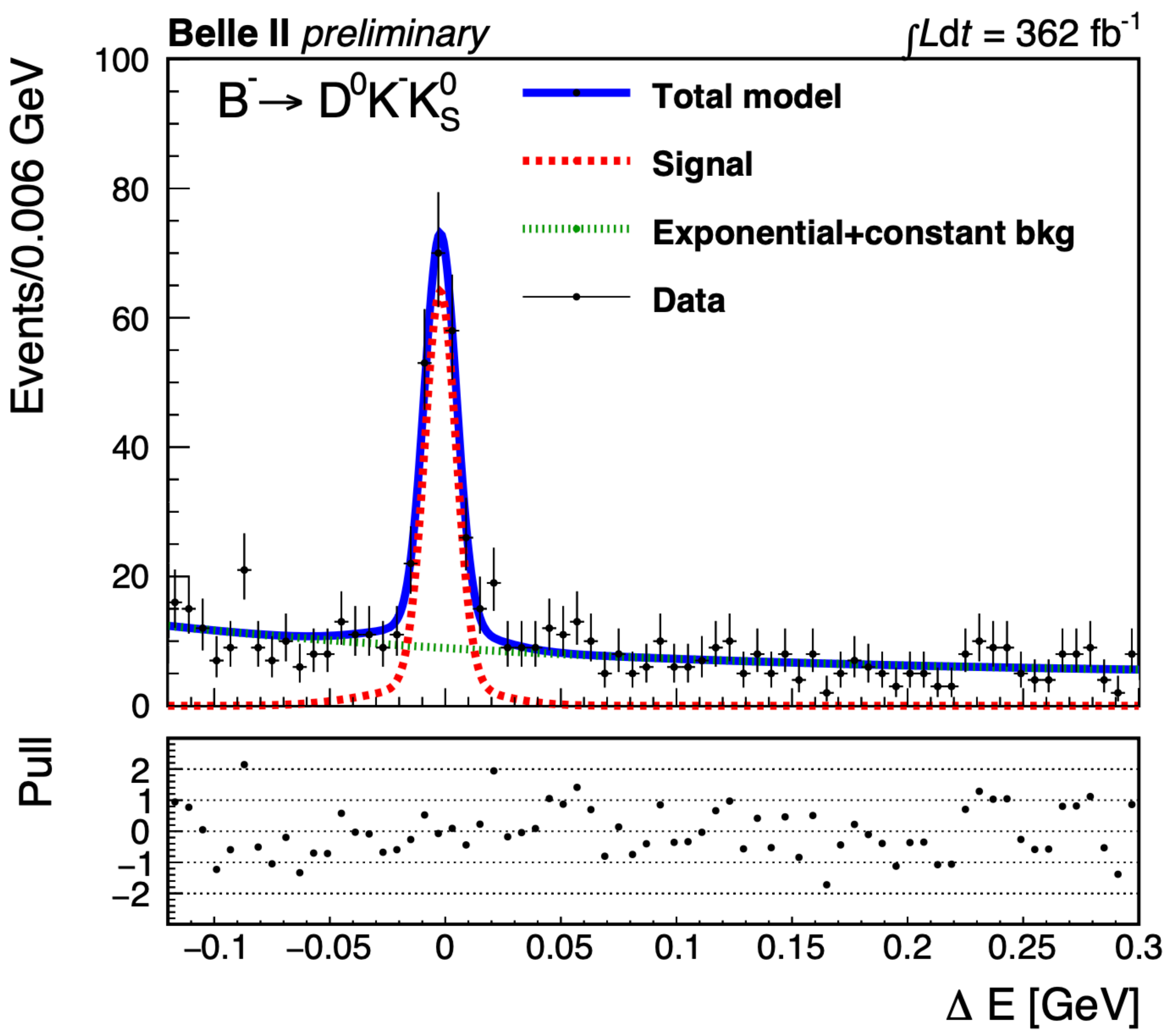
$B \to D^{(*)}K^-K^0_S$

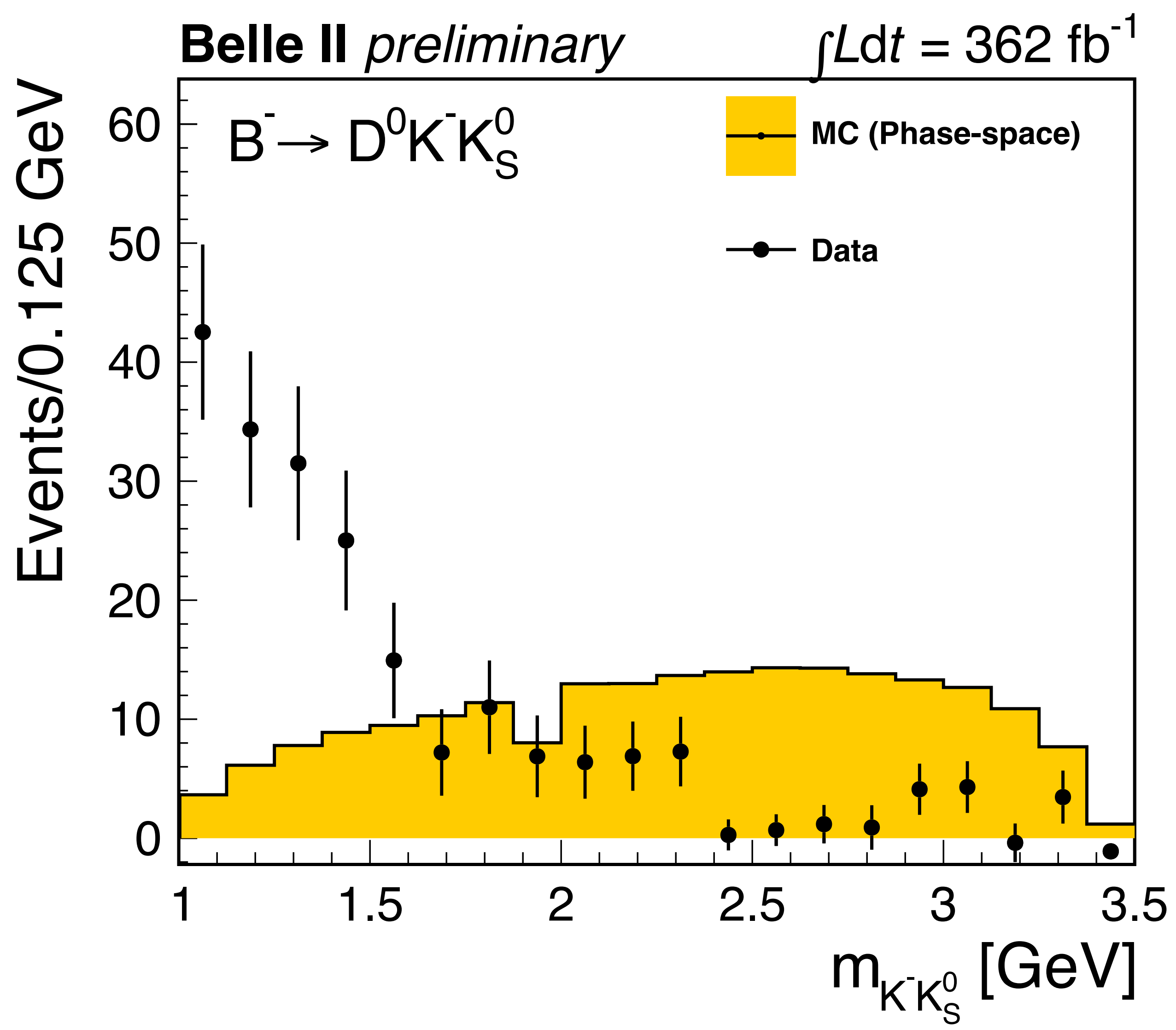
NEW for Moriond QCD!

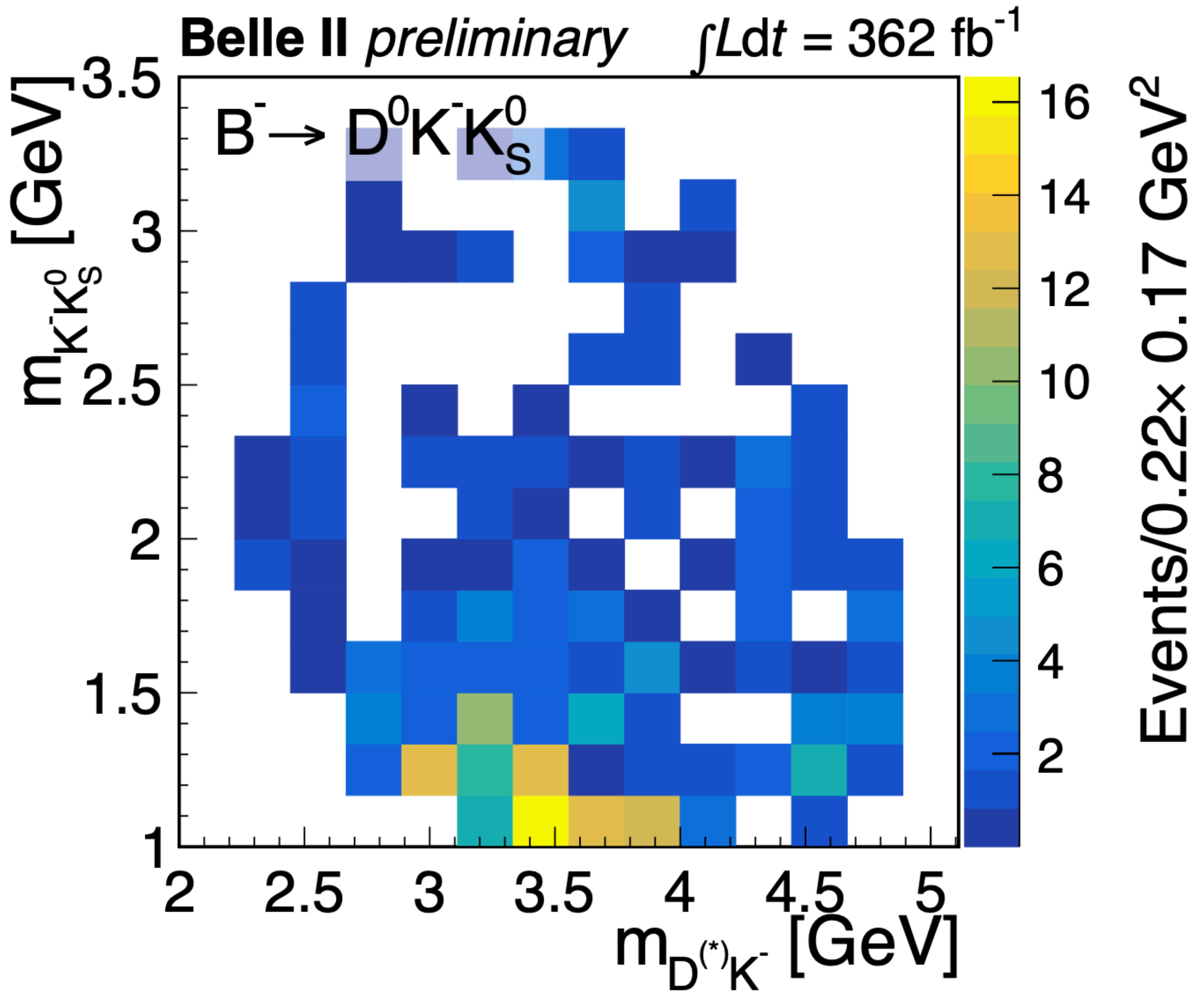
$362\ \text{fb}^{-1}$

- $B \to DKK$ is a completely unexplored sector, few % of B BR, only 0.28% measured
  - simulation and tagging techniques will take advantage from that
- **Observation** of **3 new decay modes** (D^+, D^{*0}, D^{*+}), x3 precision on D^0
- Low-mass **structure** observed in $m_{K^-K^0_S}$ system
- Multiple structures observed in the **Dalitz plane**

Channel	$\mathcal{B}\ [10^{-4}]$
$B^- \to D^0K^-K^0_S$	$1.89 \pm 0.16 \pm 0.10$
$\overline{B}^0 \to D^+K^-K^0_S$	$0.85 \pm 0.11 \pm 0.05$
$B^- \to D^{*0}K^-K^0_S$	$1.57 \pm 0.27 \pm 0.12$
$\overline{B}^0 \to D^{*+}K^-K^0_S$	$0.96 \pm 0.18 \pm 0.06$

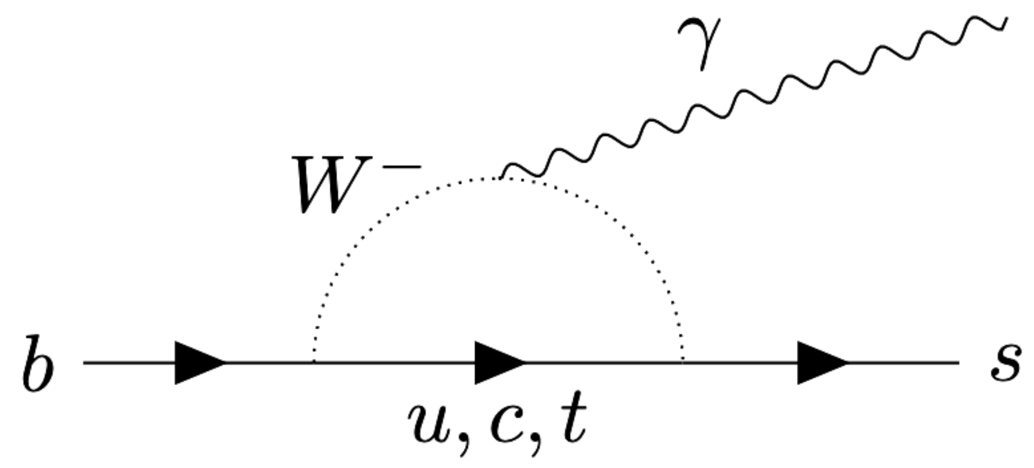




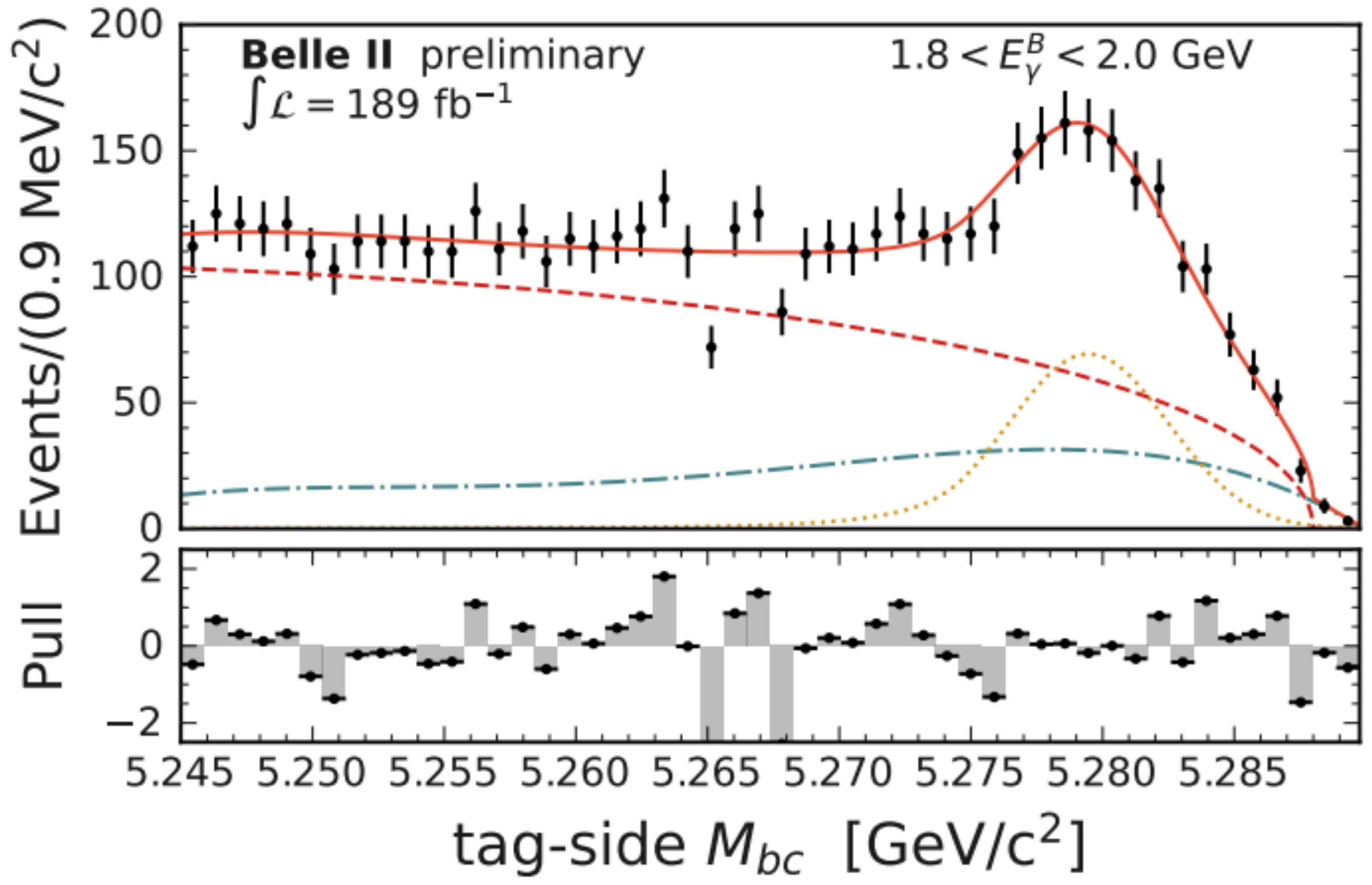


Fully inclusive $B \to X_s\gamma$

[arXiv:2210.10220] $189\ \text{fb}^{-1}$

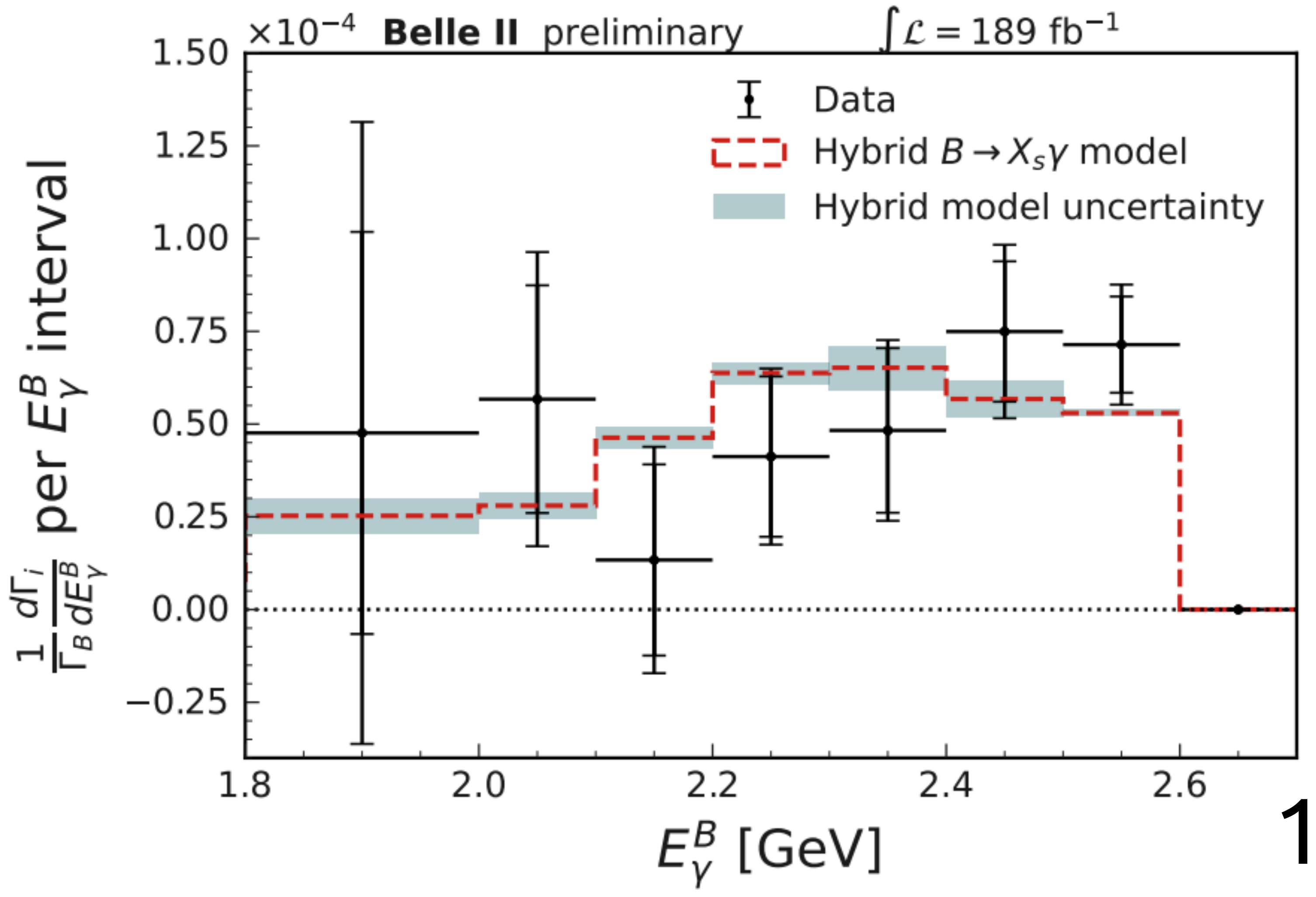


- $b \to s$ **radiative FCNC transition** ⇒SM suppressed and particularly sensitive to New Physics
- Hadronic B tagging
- Bkg suppression via BDT+ MC information (X_d)
- Fit of M_{bc} in bin of E_γ



E_γ^B threshold [GeV]	$\mathcal{B}(B \to X_s\gamma)$ $[10^{-4}]$	Experiment
1.8	$\mathbf{3.54 \pm 0.78 \pm 0.83}$	Belle II
2.0	$\mathbf{3.06 \pm 0.56 \pm 0.47}$	Belle II
1.9	$3.66 \pm 0.85 \pm 0.60$	BaBar

Competitive with had. tag. measurement



Summary

Shown the fist analyses that use the **full Belle II sample** (362 fb^{-1})~ BaBar size

- β^{eff} from gluonic penguins ($B^0 \to \phi K_S^0$, $B^0 \to K_S^0 K_S^0 K_S^0$) and γ (GLS, GLW) measurements are getting competitive with world best
- $B^0 \to K_S^0 \pi^0$ produced the **world-best input** for the **Isospin sum rule**
- **Observed 3 new channels** in $B \to DKK$, with unexpected structures
- Photon energy spectrum in $B \to X_s \gamma$, **competitive** with hadronic tagged results

Data taking **will resume next winter**, with an upgraded detector and improved collider, aiming for more luminosity!

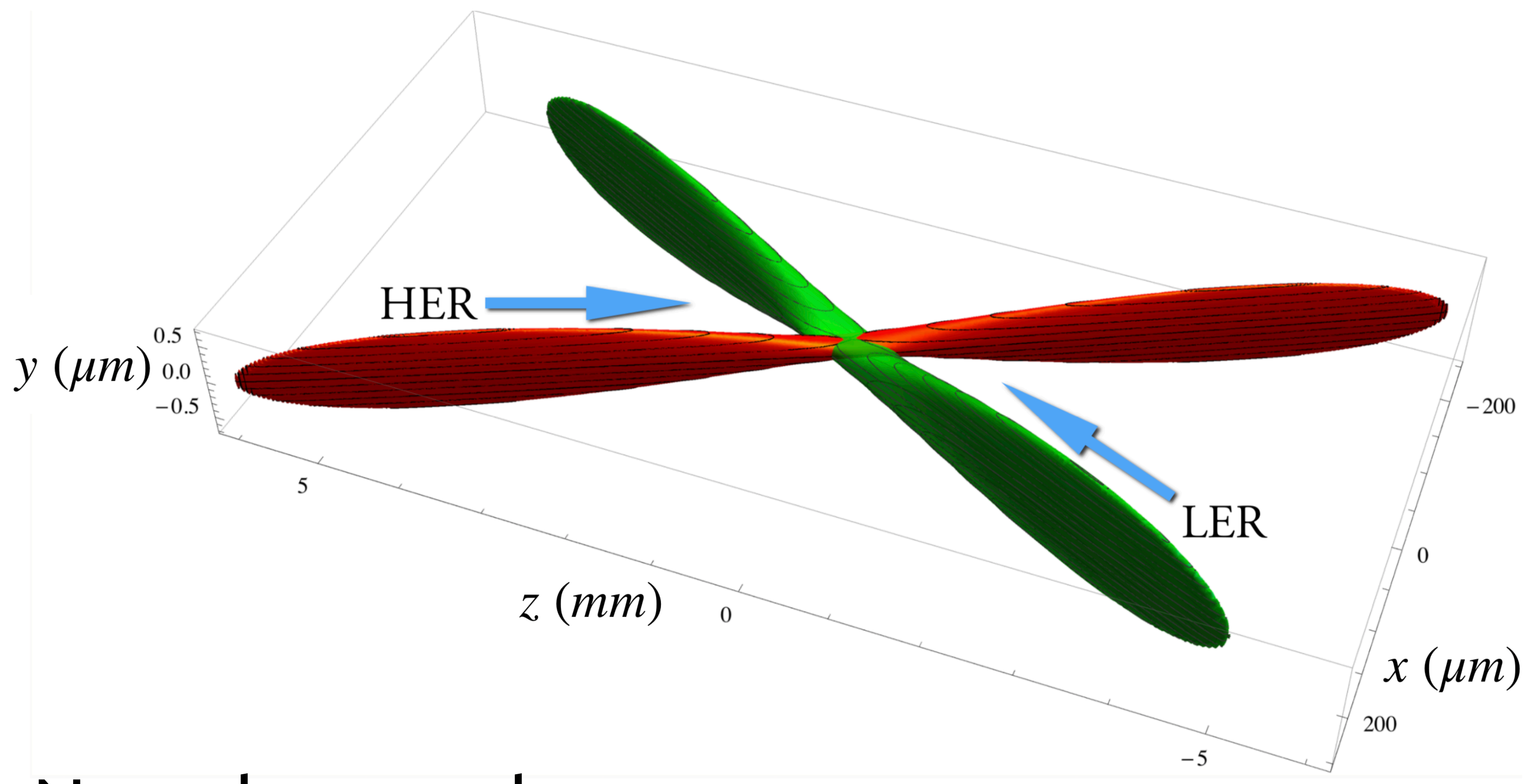
Thank you for your attention!

BACKUP SLIDES

Belle II experiment at SuperKEKB collider

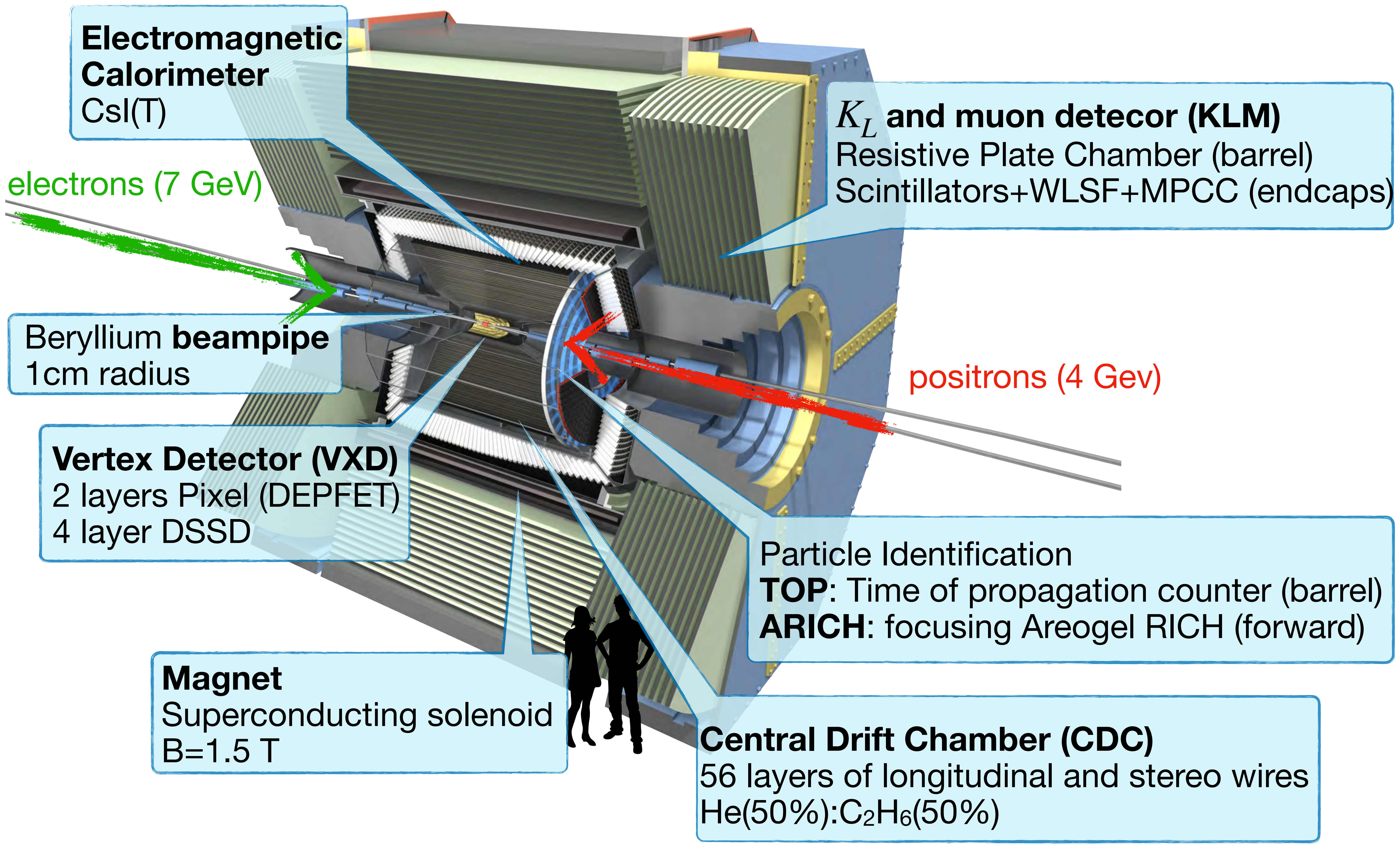
SuperKEKB

- Successor of KEKB (1999-2010, KEK, Japan)
- Target peak luminosity: $6 \cdot 10^{35}$ $\mathrm{cm^{-2}s^{-1}}$ (x 30 of KEKB)
- Target integrated luminosity: 50 $\mathrm{ab^{-1}}$ (x 70 Belle at $\Upsilon(4S)$)



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

Belle II



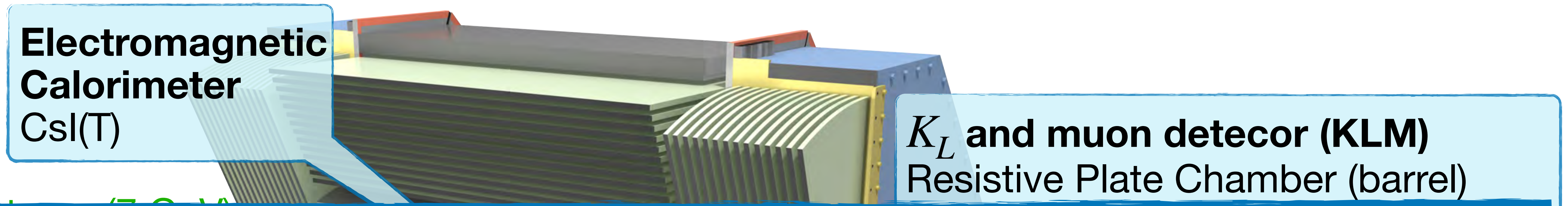
[Belle II Technical Design Report, arXiv:1011.0352]

Belle II experiment at SuperKEKB collider

SuperKEKB

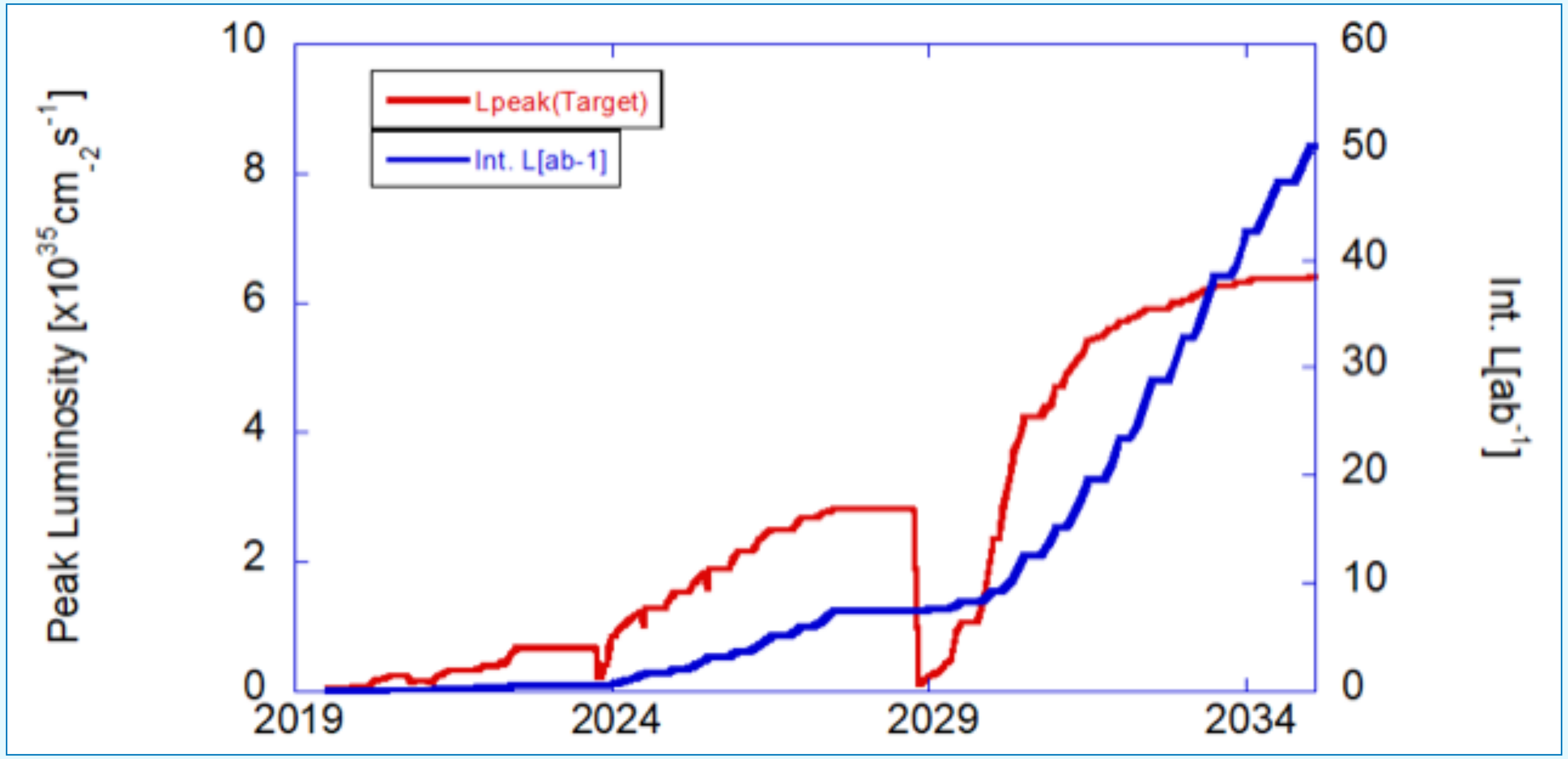
- Successor of KEKB (1999-2010, KEK, Japan)

Belle II



Current Status

- complete detector data taking started in 2019
- Current peak luminosity $4.7 \cdot 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (reached the 22/06/2022)
- current integrated luminosity: $\sim 424\ \mathrm{fb}^{-1}$ (~Babar~0.5 Belle)
- Long Shutdown 1 (LS1) is starting now for several upgrades (beam pipe, pixel, TOP PMT)



Long shutdown 1 plans

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

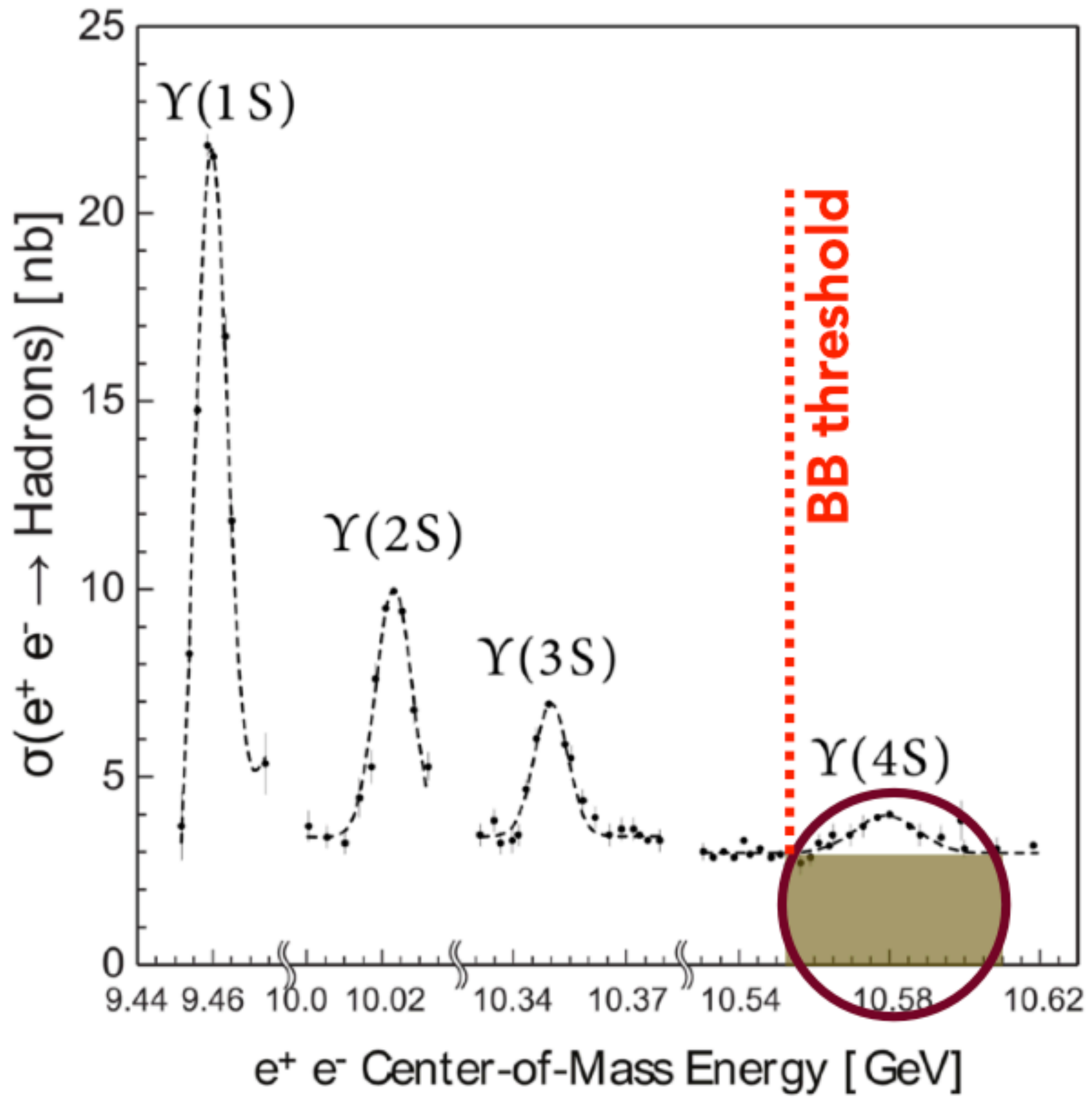
On track to resume data taking in winter!

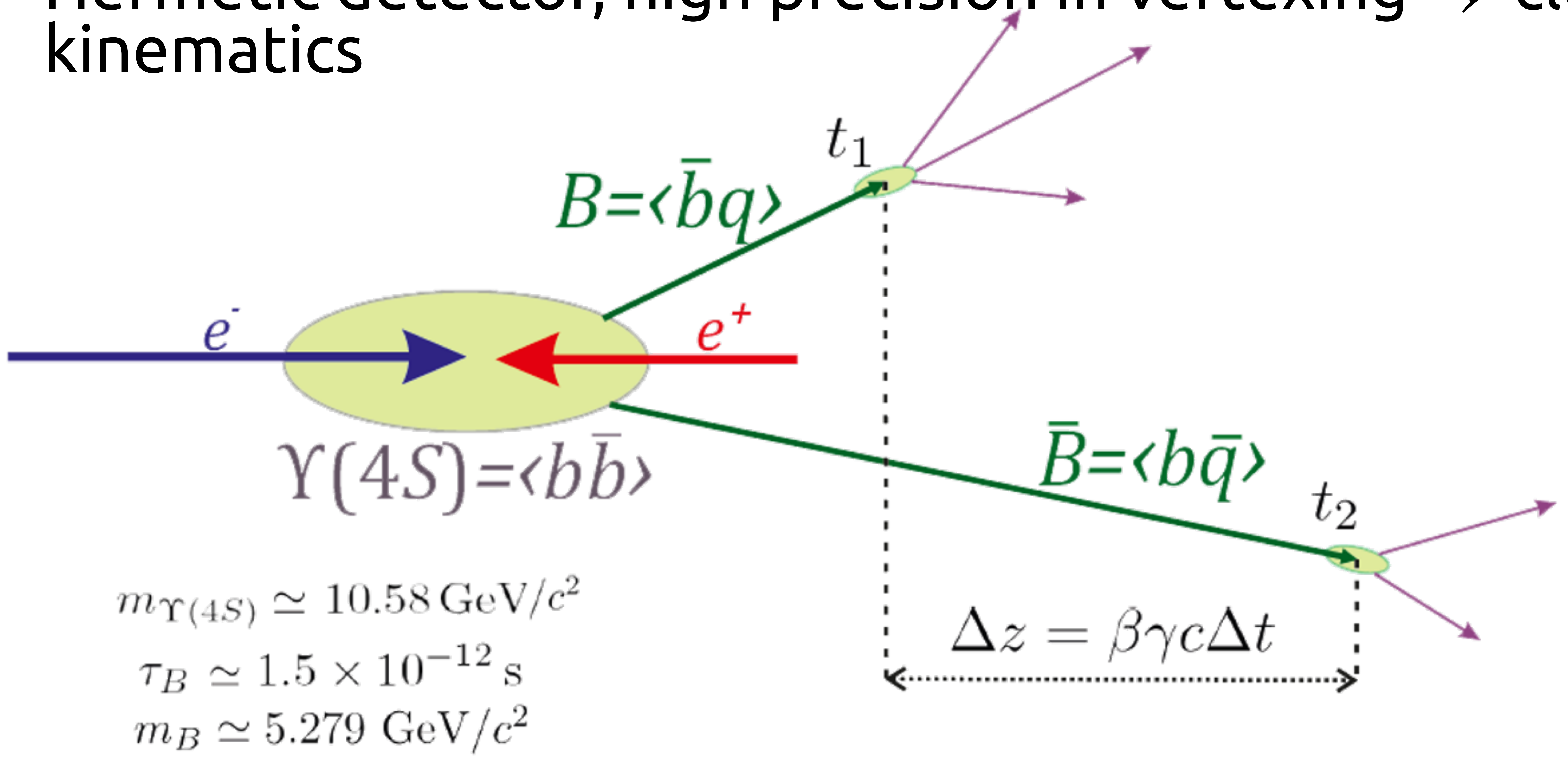
LS1 activities:

- 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

B-Factory idea

- Asymmetric collider e^+e^-, $E_{cm} = m(\Upsilon(4S)) = 10.58\ \text{GeV}$ $\Rightarrow$ coherent $B\overline{B}$ pairs
- Boost of center-of-mass ($\beta\gamma = 0.28$)$\Rightarrow$ measure of Δz
- High luminosity $\Rightarrow$ precision measurements
- Hermetic detector, high precision in vertexing $\Rightarrow$ closed kinematics





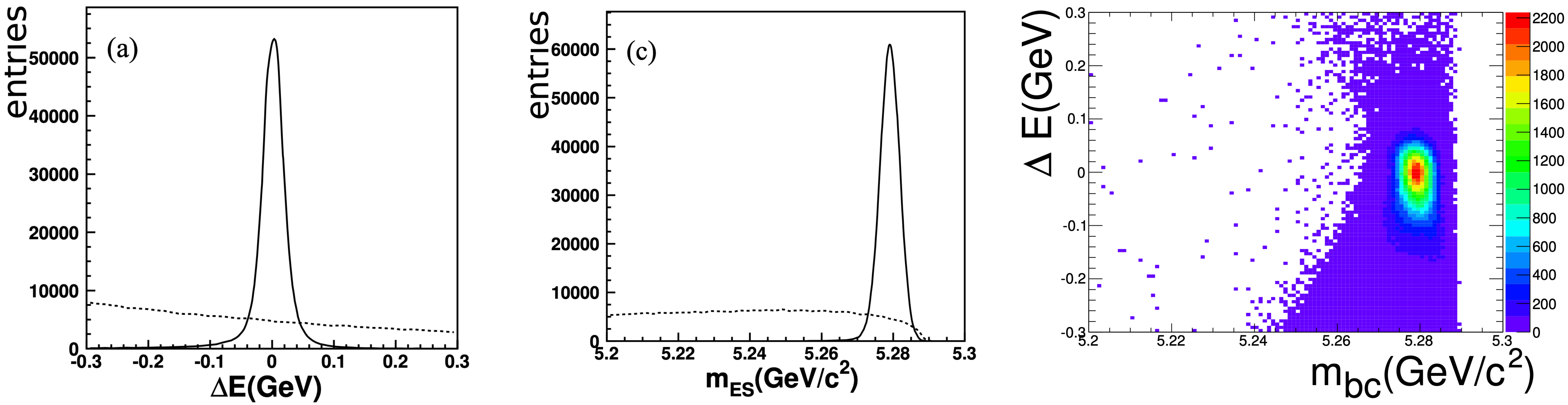
$e^+e^- \to$	Cross section [nb]
$\Upsilon(4S)$	1.05 ± 0.10
$c\bar{c}$	1.30
$s\bar{s}$	0.38
$u\bar{u}$	1.61
$d\bar{d}$	0.40
$\tau^+\tau^-(\gamma)$	0.919
$\mu^+\mu^-(\gamma)$	1.148
$e^+e^-(\gamma)$	300 ± 3

B factory variables

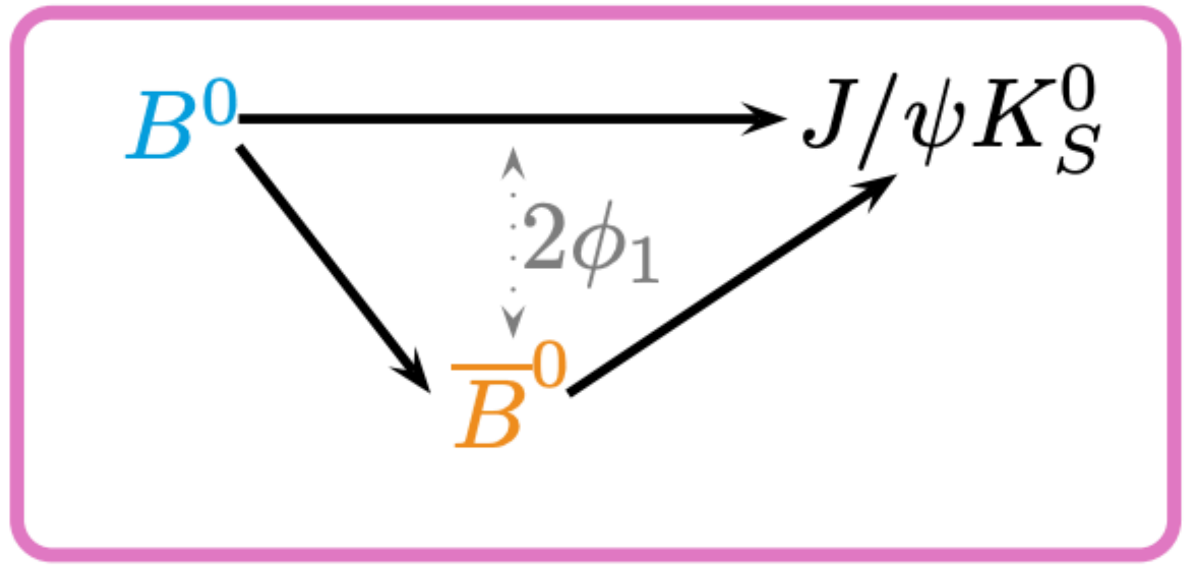
- $\Delta E = E^*_B - E^*_{\text{beam}}$
- Expected $\Delta E \simeq 0$ for properly reconstructed signal

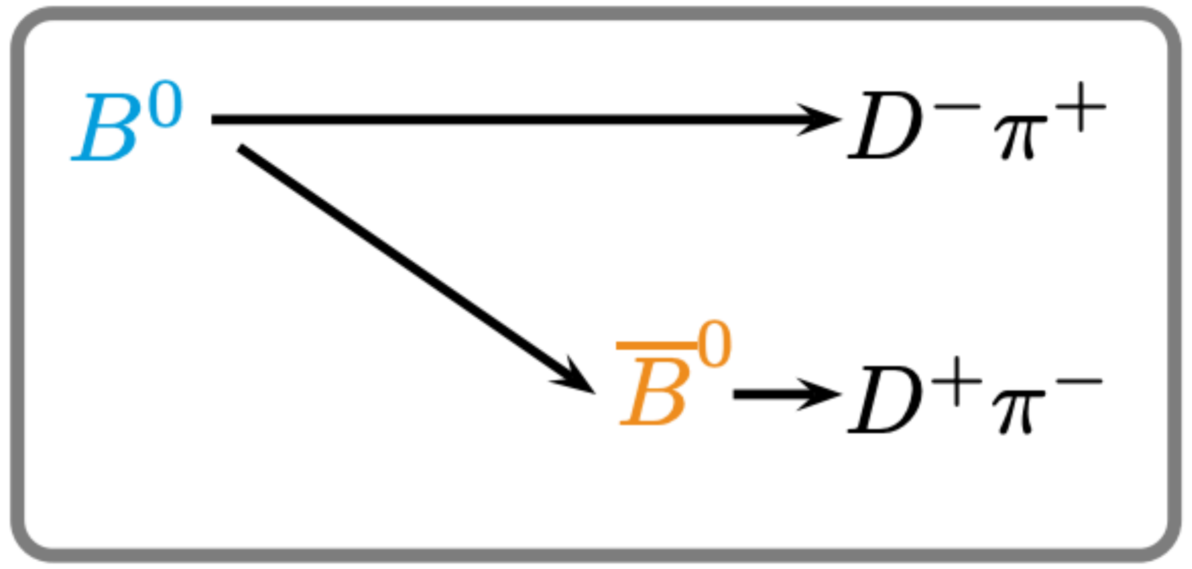
- $m_{ES} = M_{bc} = \sqrt{E^{*2}_{\text{beam}} - \vec{p}^{*2}_B}$
- Expected $M_{bc} \simeq m_B$ for properly reconstructed signal

- 2 variable mostly uncorrelated
- tag-signal relation:
  - $E^*_{B_{\text{tag}}} = E^*_{B_{\text{sig}}} = \sqrt{s}/2,$
  - $\vec{p}^*_{B_{\text{tag}}} = -\vec{p}^*_{B_{\text{sig}}}$



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.

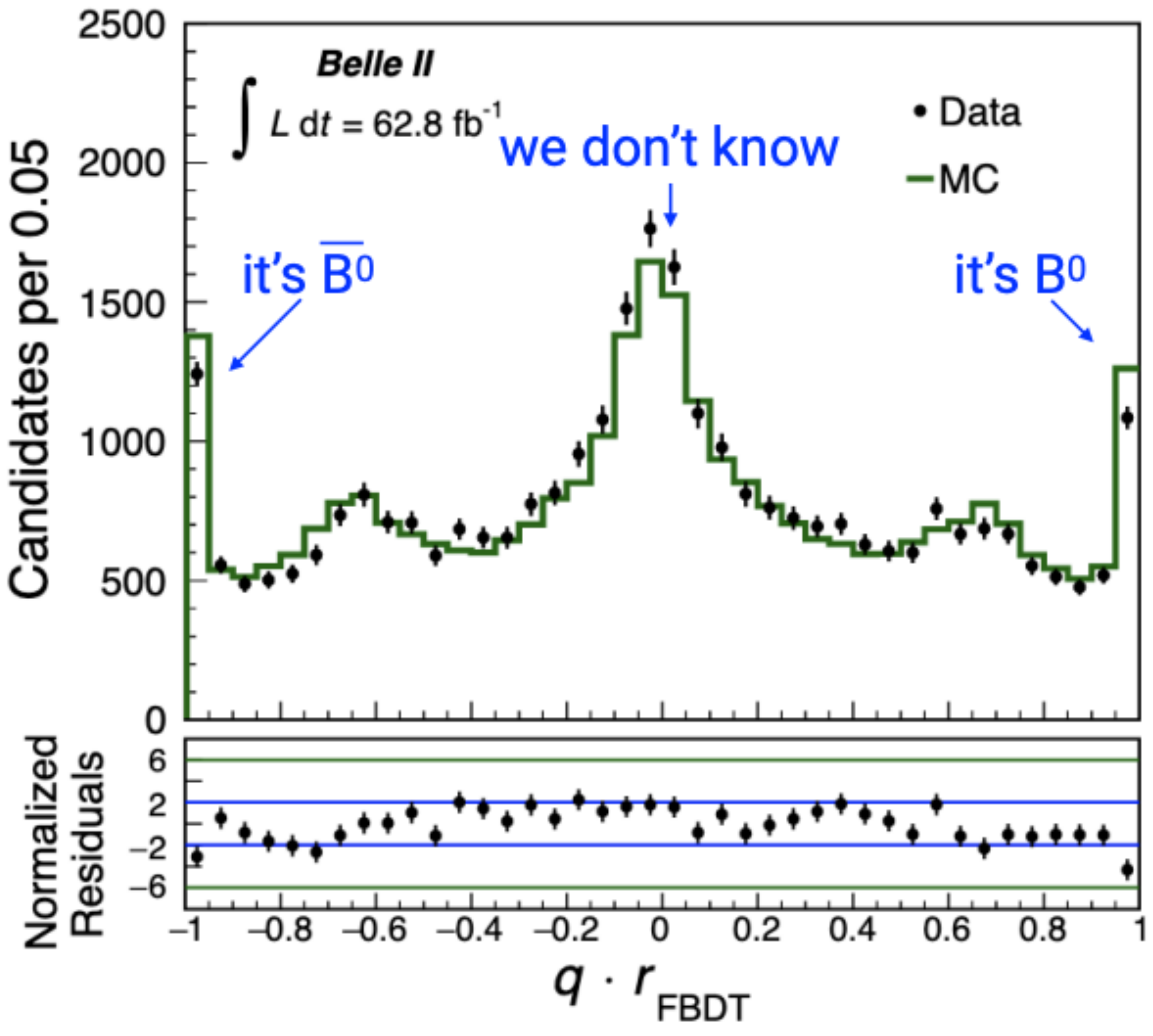
[From Thibaud Humair, Moriond EW 22]

Belle II flavour tagger

[Eur. Phys. J. C 82, 283(2022)]

- Crucial step for all the TDCPV analysis
- MVA to flag the flavour of the B_{tag} using the information of intermediate and final state particles
- Performance: wrong tag fraction (w) and efficiency of taggable events (ε)

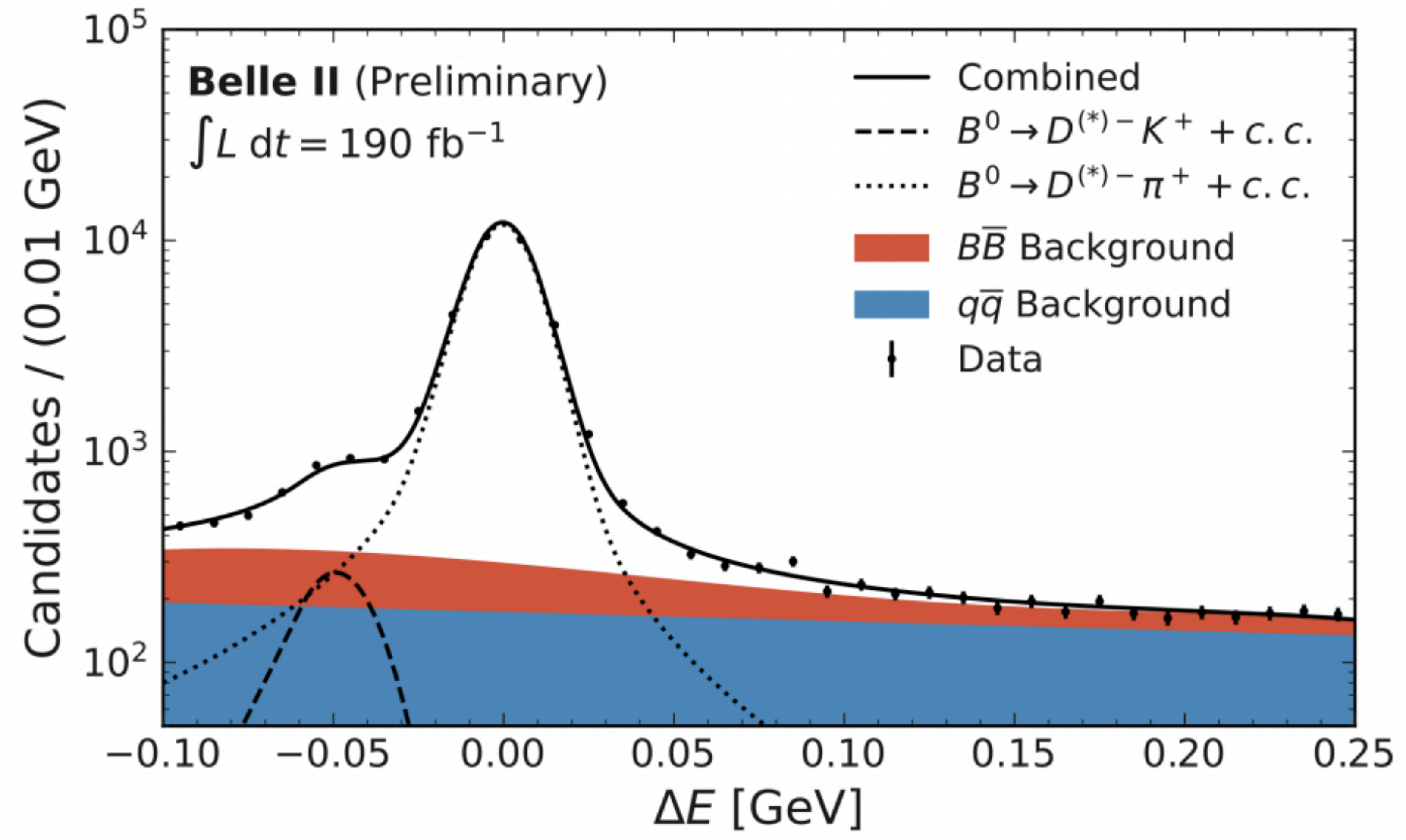
$$\Rightarrow \varepsilon_{eff} = \varepsilon(1-2w)^2 = \mathbf{(30.0 \pm 1.2 \pm 0.4)}\ \%$$

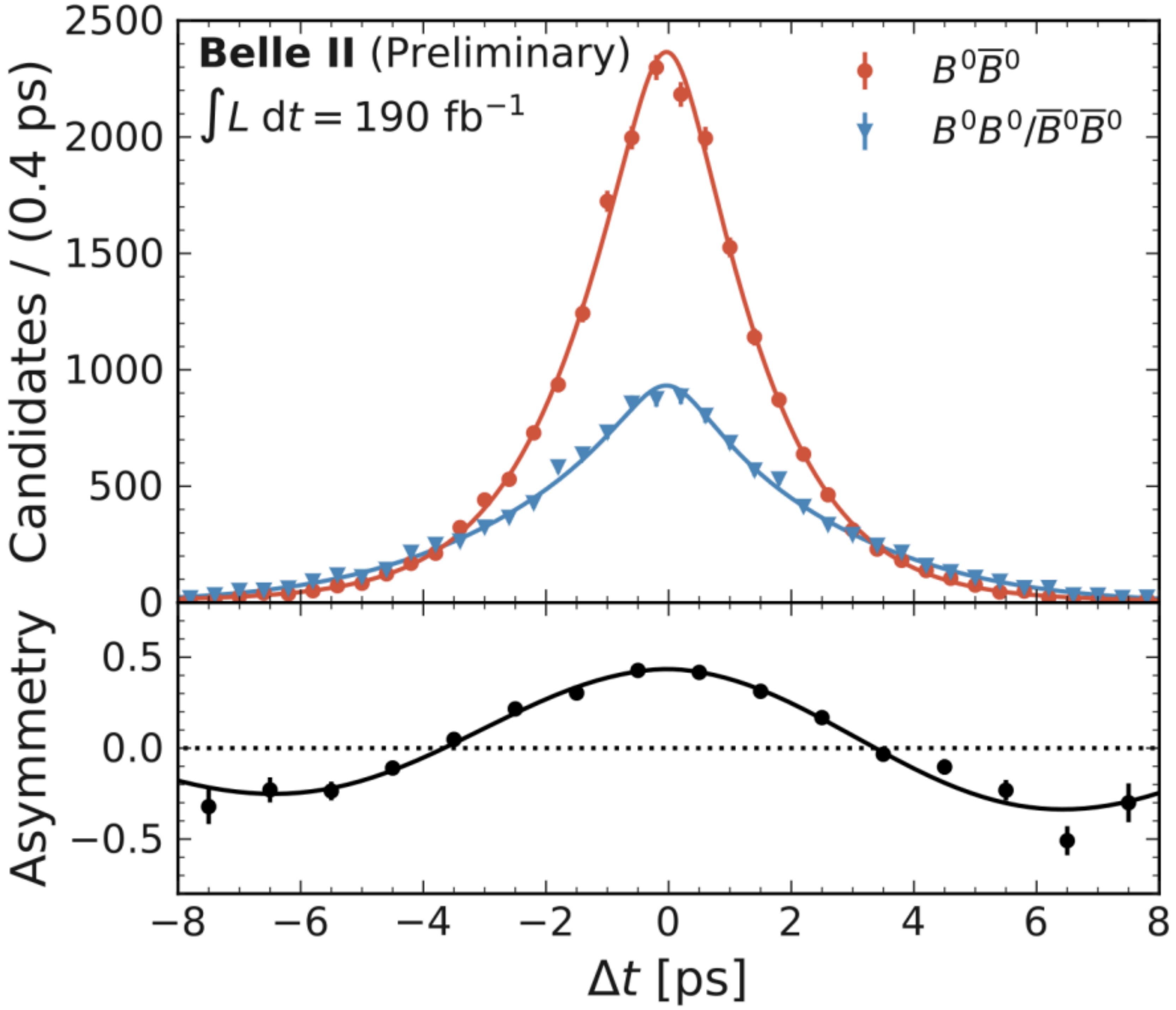


TDCPV: B^0 lifetime - extra info

$190\ \mathrm{fb}^{-1}$

- Δt and Δm_d are central ingredients for **TDCPV** analysis
- Reconstruction:
  - B^0_{sig} reconstruction in specific $D^{(*)}\pi^+/K^+$ modes
  - B_{tag} reconstruction from the Rest Of the Event tracks
  - Flavour tagging ⇒ Same Flavour / Opposite Flavour categories
- Bkg: $ee \to q\bar{q}, B\bar{B}$ suppressed with ΔE+BDT
- Fit: Δt using a model including **wrong-tagging** and **vertex resolution** effects
- Results: Not competitive, but syst. reduced compared to Belle
- Next steps: add **semileptonic**, $\sin 2\beta$, increase **statistic** (Belle measurement is only 150 fb^{-1}, but included semileptonic)





TDCPV: B^0 lifetime extra info (2)

- Δt obtained projecting the two vertices in the direction of $\Upsilon(4S)$ momentum:

$$\Delta t^{\mathrm{MC}} = \frac{\Delta\ell^{\mathrm{MC}}}{\beta\gamma\gamma^*}. \qquad \Delta t = \frac{\Delta\ell}{\beta\gamma\gamma^*}.$$

$$f^i_{\mathrm{phys}}(\Delta\tau, q) = n_i \frac{1}{4\tau} \exp\left(\frac{-|\Delta t^{\mathrm{MC}}|}{\tau}\right) \cdot (1 + q(1-2w_i)\cos(\Delta m_d \Delta t^{\mathrm{MC}})).$$

- Previous measurements:

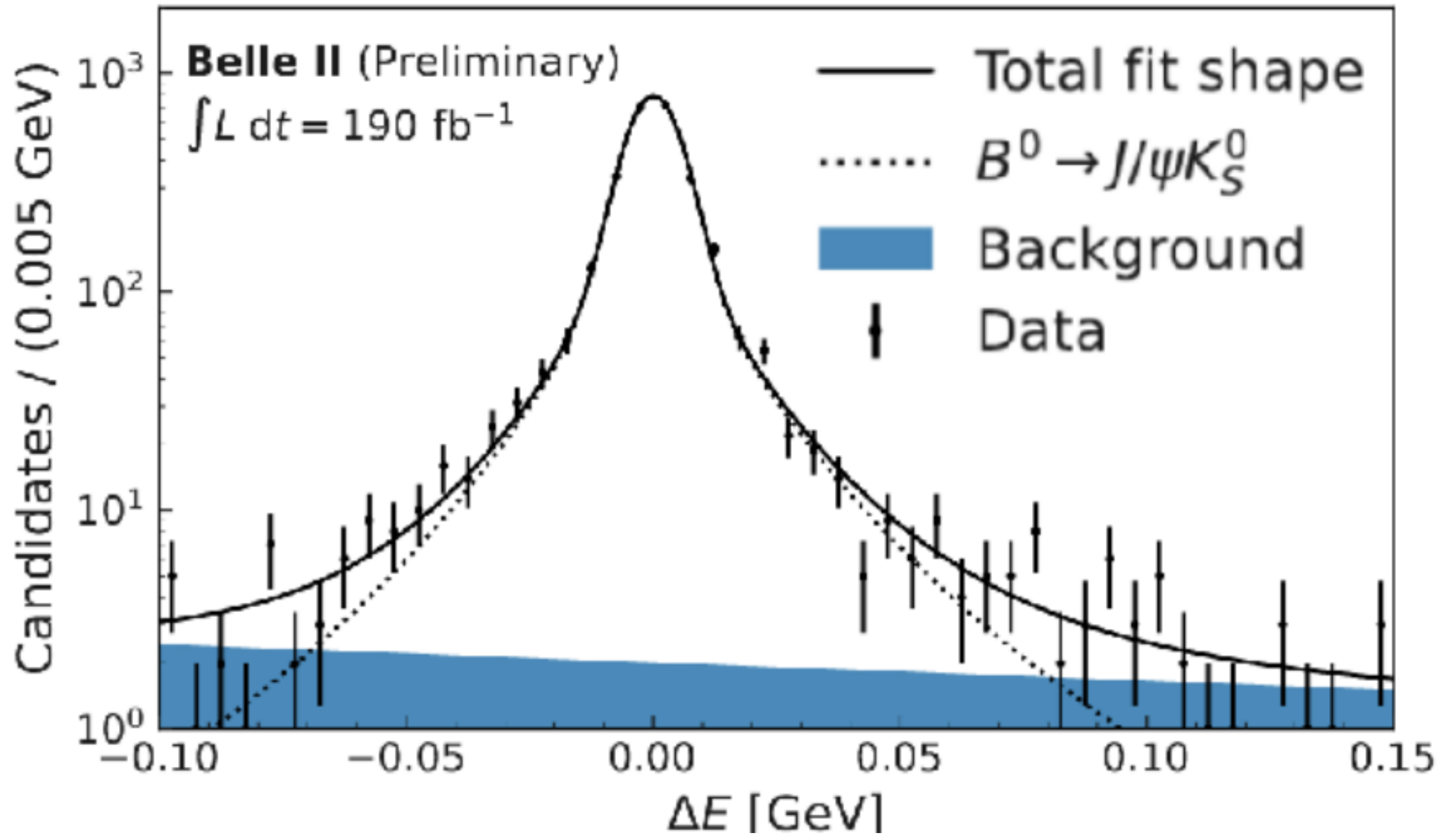
Collaboration+year	τ_B [ps]	Δm_d [ps^{-1}]
BaBar 2005 [3]	$1.504 \pm 0.013 \pm 0.016$	$0.511 \pm 0.007 \pm 0.007$
Belle 2005 [2]	$1.534 \pm 0.008 \pm 0.010$	$0.511 \pm 0.005 \pm 0.006$
LHCb 2016 [5]	-	$0.505 \pm 0.002 \pm 0.001$
LHCb 2014 [6]	$1.524 \pm 0.006 \pm 0.004$	-
Belle II 2020 [1]	-	$0.531 \pm 0.046 \pm 0.013$
PDG [4]	1.519 ± 0.004	0.5065 ± 0.0019

systematic uncertainties

Uncertainty	τ[ps]	Δm_d[ps^{-1}]
Statistical	**0.0130**	**0.0079**
Analysis bias	0.0003	0.0011
Alignment	0.0027	0.0024
Resolution function	0.0063	0.0028
Momentum scale	0.0002	0.0008
Multiple candidates	0.0024	0.0009
Binning of $\sigma_{\Delta t}$	0.0005	0.0010
$B^0 \to D^{(*)+}\pi^-$ fraction	0.0007	0.0003
ΔE; LTBDT shapes		
$\to b\bar{b}$ ΔE shapes	0.0004	0.0001
$\to q\bar{q}$ ΔE shapes	0.0006	0.0000
$\to$ LTBDT shapes	0.0004	0.0014
Beam		
$\to$ Beam spot	0.0021	0.0014
$\to$ Boost vector	0.0003	0.0001
$\to$ CoM energy	0.0007	0.0002
Total systematic	**0.0077**	**0.0046**

TDCPV: $B^0 \to J/\psi K_S^0$ - extra info

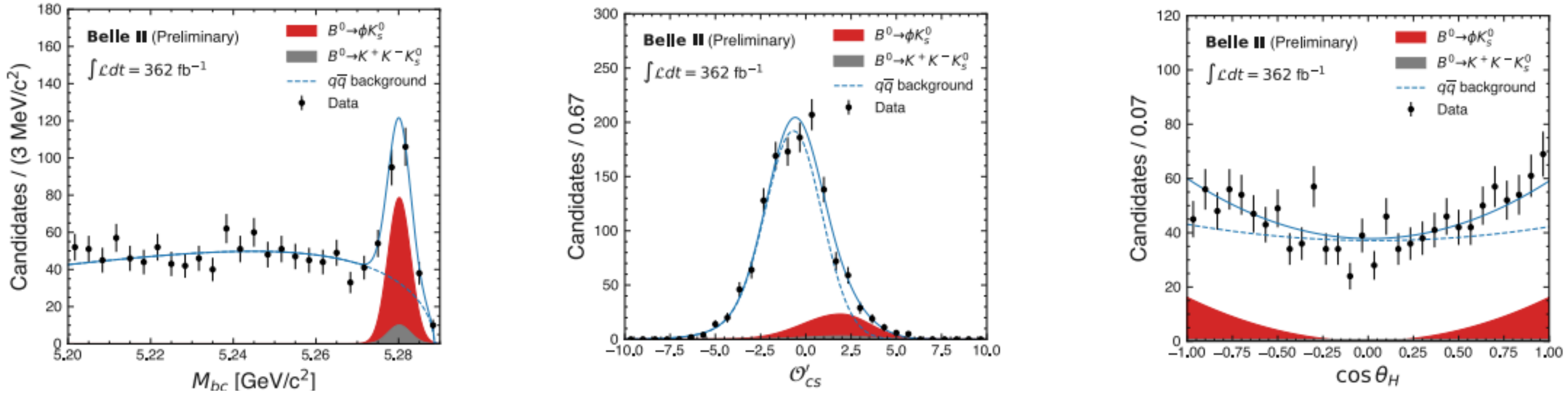
- high yield, tree dominated, small penguin amplitude (1%)
- $B^0 \to D^{(*)-}\pi^+$ control channel for **calibration of flavour tagger and resolution**
- signal extraction from ΔE **fit**
- $B^+ \to J/\psi K^+$ control sample as **null asymmetry cross check**
- **Limited by sample size**
- adding $B^0 \to J/\psi K_L^0$ will reduce systematics

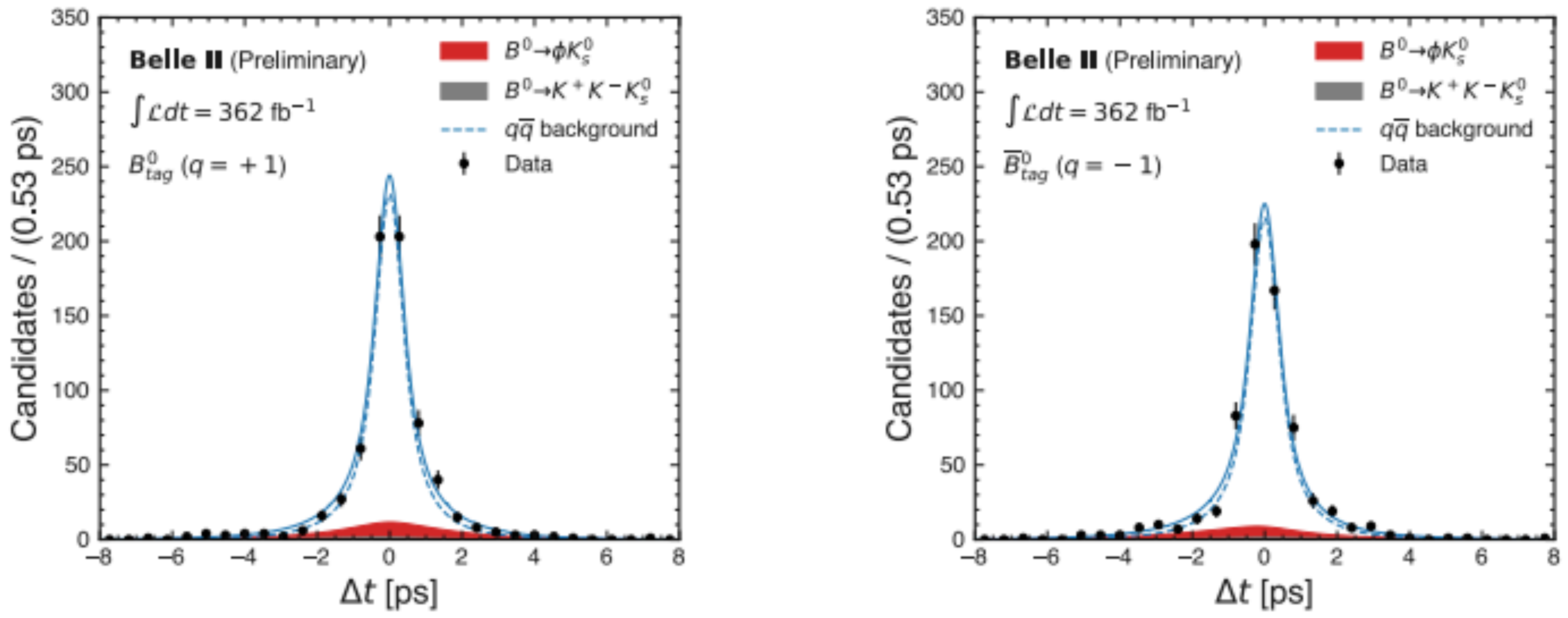


systematic uncertainties

Source	$\sigma(S_{CP})$	$\sigma(A_{CP})$
Statistical	0.0622	0.0439
$B^0 \to D^{(*)-}\pi^+$ sample size	0.0111	0.0093
Analysis bias	0.0080	0.0020
Signal charge asymmetry	0.0027	0.0126
$w_6^+ = 0$ limit	0.0014	0.0001
Resolution function parametrization	0.0039	0.0008
τ_{B^0}, Δm_d	0.0007	0.0002
Alignment	0.0020	0.0042
Beam spot	0.0024	0.0020
Momentum scale	0.0005	0.0013
$\sigma_{\Delta t}$ binning	0.0050	0.0051
Multiple candidates	0.0005	0.0008
Tag-side interference	0.0020	$^{+0.0380}_{-0.000}$
Total systematic	0.0159	$^{+0.0418}_{-0.0173}$

TDCPV: $B^0 \to \phi K_S^0$ - extra info





Systematics

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

NR bkg:

- Cut on m_ϕ: 10 MeV
- syst for neglecting interference

Continuum suppression: $O'_{CS} = \log \frac{O_{CS} - 0.2}{1 - O_{CS}}$

- main variables: Thrust, CosTBTO, FWR1...
- Training: signal MC

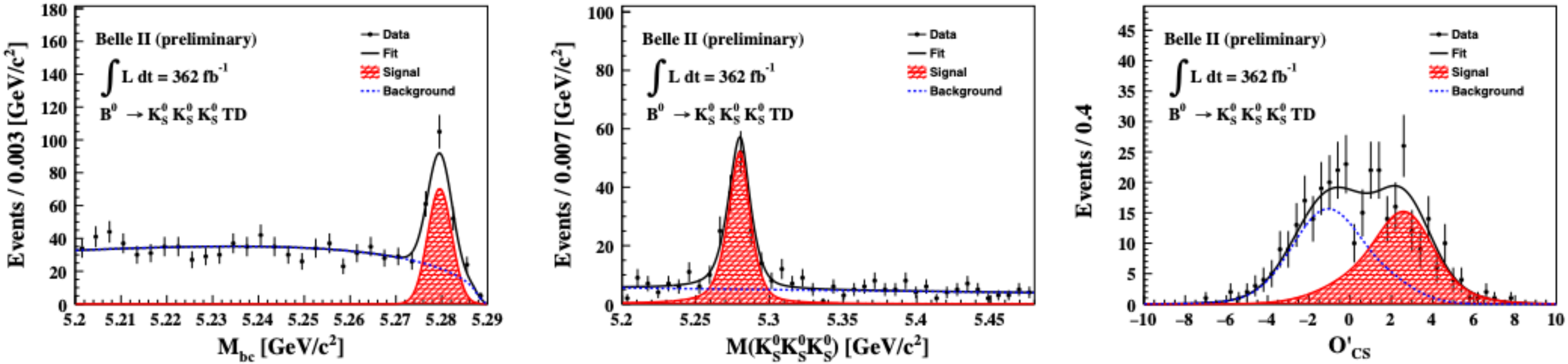
Δt fit: flavour tagging and resolution calibration from $D^{*-}\pi^+$

TDCPV: $B^0 \to K_S^0 K_S^0 K_S^0$ - extra info

- BDT to suppress fake K (kinematics, hits, pion tracks) and continuum (event shape)
- Signal extraction fit:

Systematics

Source	$\delta\mathcal{S}$	$\delta\mathcal{A}$
Signal probability	0.014	0.008
Fit bias	0.014	0.004
Flavor tagging	0.013	0.012
Resolution function	0.013	0.008
Tag-side interference	0.011	0.006
Vertex reconstruction	0.011	0.004
Physics parameters	0.009	0.000
Detector misalignment	0.008	0.007
Background Δt shape	0.004	0.002
Total	0.032	0.020



TDCPV: $B^0 \to K_S^0 K_S^0 K_S^0$ - extra info (2)

- Δt fit

$$P(\Delta t, q; \tau_B, S, A, s_{\rm det}) = f_{\rm sig} \int d\Delta t' P_{\rm sig}(\Delta t', q) R(\Delta t - \Delta t'; s_{\rm det}) + (1 - f_{\rm sig}) P_{\rm bkg}(\Delta t)$$

$$P_{\rm sig}(\Delta t, q; \tau_B, S, A) = \frac{1}{4\tau_B} e^{-\frac{|\Delta t|}{\tau_B}} [1 - q\Delta w + q(1 - 2w)(S \sin(\Delta m_d \Delta t) + A \cos(\Delta m_d \Delta t))]$$

μ neglected → systematic uncertainty
(flavor asymmetry in flavor tag efficiency)

- Signal fraction (signal probability)
- Resolution function (Δt response function)
- Background Δt PDF
- mis-tag probability

$f_{\rm sig}$, R, $P_{\rm bkg}$, w, Δw are changed per event

composed of 4 functions: $R = R_{\rm k} \otimes R_{\rm rec} \otimes R_{\rm asc} \otimes R_{\rm np}$

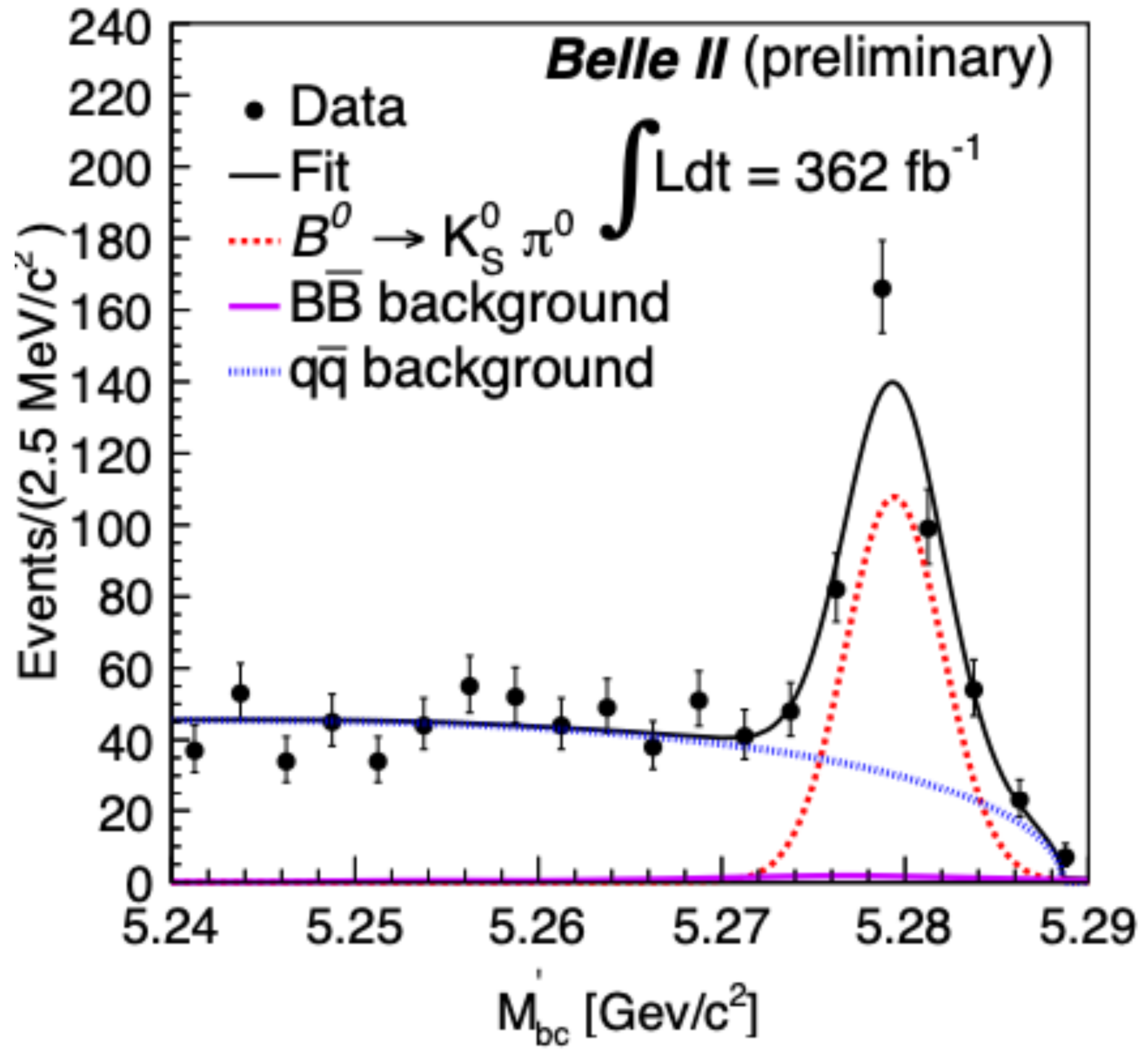
- $R_{\rm k}$: corrects approximation of boost factor
- $R_{\rm rec}$: CP-side detector resolution
- $R_{\rm asc}$: tag-side detector resolution
- $R_{\rm np}$: tag-side bias due to non-primary tracks

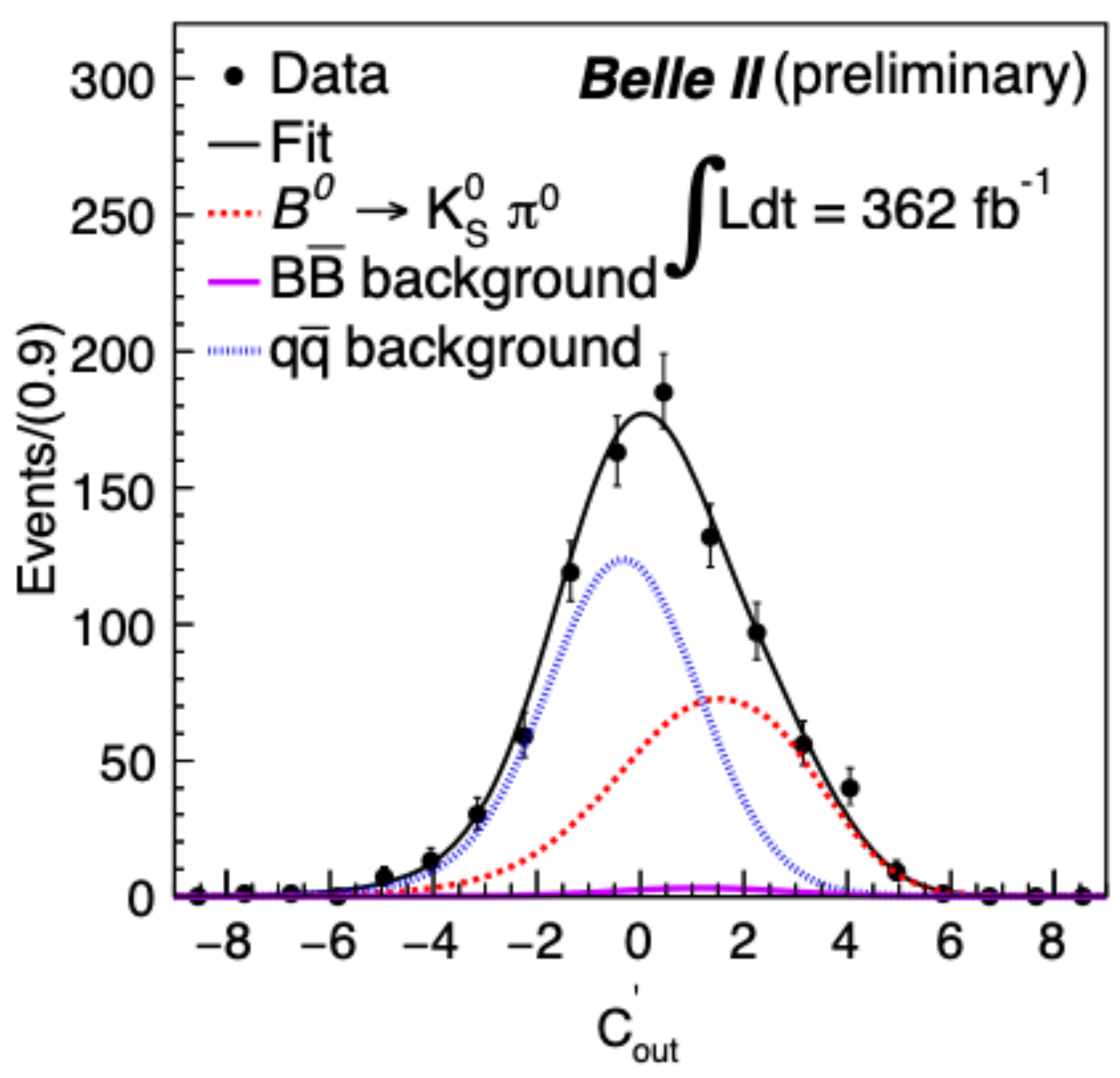
TDCPV: $B^0 \to K_S^0 \pi^0$ - extra info

- results from B lifetime:

Parameter	Fitted value	PDG value
Lifetime (ps)	1.46 ± 0.05	1.519 ± 0.004

-





Systematics

Source	δA_{CP}	δS_{CP}
Flavor tagging	0.013	0.011
Resolution function	0.014	0.022
$B\bar{B}$ background asymmetry	0.030	0.018
$q\bar{q}$ background asymmetry	0.028	< 0.001
Signal modelling	0.004	0.003
Background modelling	0.006	0.018
Possible fit bias	0.005	0.011
External inputs	< 0.001	< 0.001
Tag-side interference	0.008	0.010
VXD misalignment	0.004	0.005
Total	0.045	0.039

Gluonic penguins summary measuements

Experiment		$N(B\overline{B})$	$-\eta S_{b\to q\bar{q}s}$	$C_{b\to q\bar{q}s}$
			ϕK^0	
BABAR	[262]	470M	$0.66 \pm 0.17 \pm 0.07$	$0.05 \pm 0.18 \pm 0.05$
Belle	[261]	657M	$0.90\,^{+0.09}_{-0.19}$	$-0.04 \pm 0.20 \pm 0.10 \pm 0.02$
Belle II (362M BB pairs)			$0.54 \pm 0.26^{+0.06}_{-0.08}$	$-0.31 \pm 0.20^{+0.05}_{-0.06}$
			$K^0_S K^0_S K^0_S$	
BABAR	[383]	468M	$0.94\,^{+0.21}_{-0.24} \pm 0.06$	$-0.17 \pm 0.18 \pm 0.04$
Belle	[384]	722M	$0.71 \pm 0.23 \pm 0.05$	$-0.12 \pm 0.16 \pm 0.05$
Belle II (362M BB pairs)			$-1.37^{+0.35}_{-0.45} \pm 0.03$	$-0.07^{+0.15}_{-0.20} \pm 0.02$
			$\pi^0 K^0$	
BABAR	[381]	467M	$0.55 \pm 0.20 \pm 0.03$	$0.13 \pm 0.13 \pm 0.03$
Belle	[378]	657M	$0.67 \pm 0.31 \pm 0.08$	$-0.14 \pm 0.13 \pm 0.06$
Belle II (362M BB pairs)			$0.74^{+0.20}_{-0.23} \pm 0.04$	$-0.04 \pm 0.15 \pm 0.05$

$B \to K\pi$ puzzle

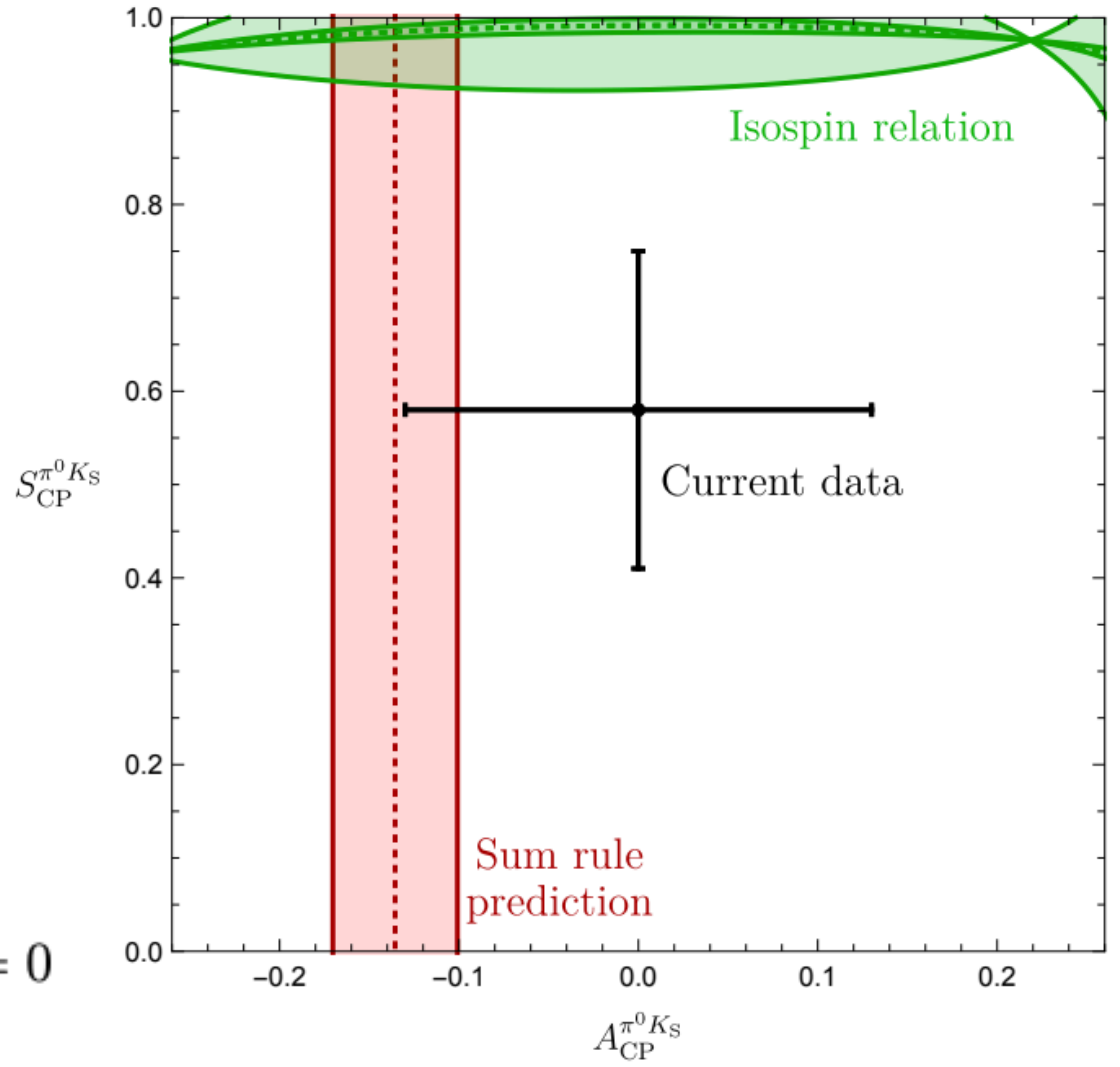
$$\frac{\Gamma(\overline{B}^0_d(t) \to \pi^0 K_S) - \Gamma(B^0_d(t) \to \pi^0 K_S)}{\Gamma(\overline{B}^0_d(t) \to \pi^0 K_S) + \Gamma(B^0_d(t) \to \pi^0 K_S)} = A_{\rm CP}^{\pi^0 K_S} \cos(\Delta M_d t) + S_{\rm CP}^{\pi^0 K_S} \sin(\Delta M_d t),$$

- where $A_{\rm CP}(B \to f) \equiv \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)}.$
- Expected **equal asymmetries** between $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$ at LO
- Isospin sum rule:

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

in the limit or isospin symmetry and no EW penguins

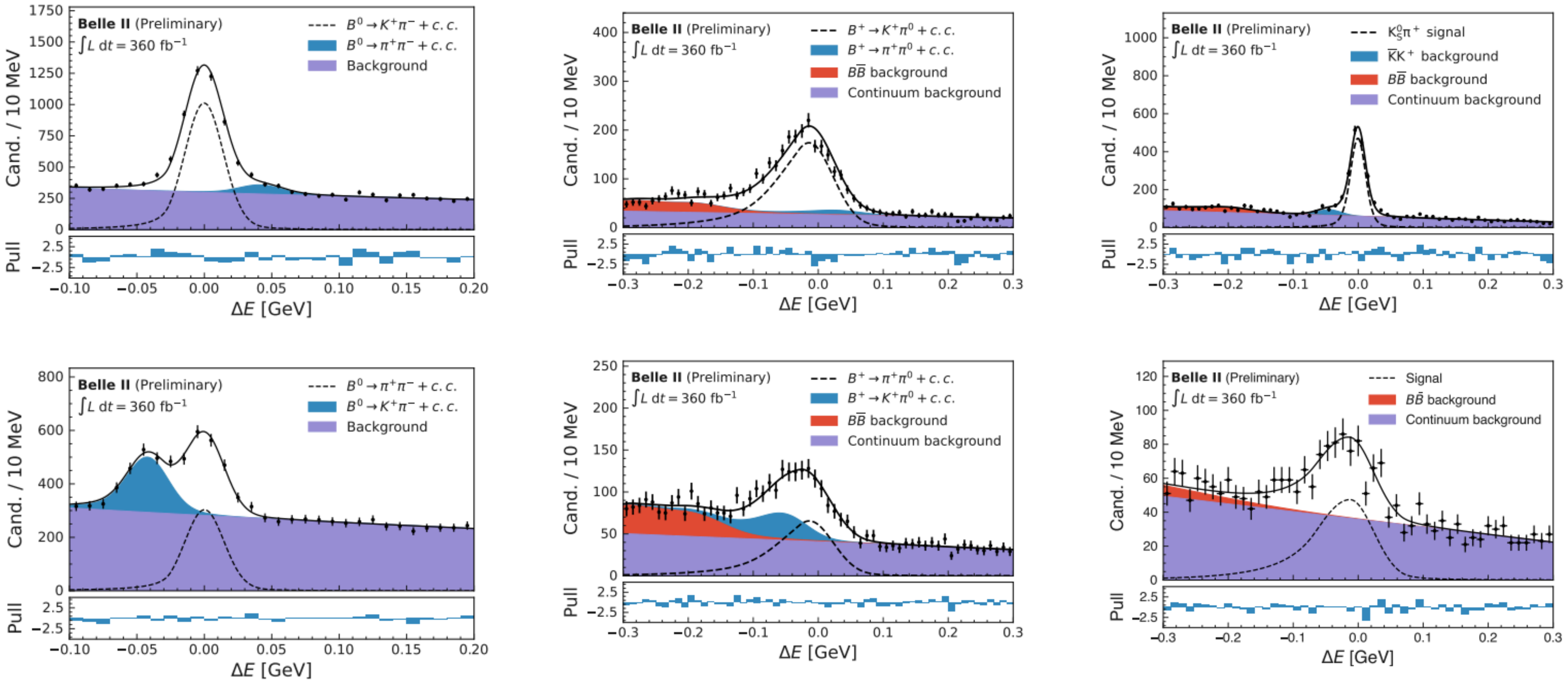
- if EWP are considered, **still precision below 1%** with largest uncertainties from $B \to K^0\pi^0$
- Deviation can be NP or enhancement of color suppressed tree



[Eur. Phys. J. C 78, 943 (2018)]

Isospin sum rule - extra info

$362\ fb^{-1}$



Isospin sum rule - extra info (2)

362 fb^{-1}

Decay	Signal yield	$\mathcal{B}$ $[10^{-6}]$	$\mathcal{A}_{CP}$
$B^0 \to K^+\pi^-$	3868 ± 71	$20.67 \pm 0.37 \pm 0.62$	$-0.072 \pm 0.019 \pm 0.007$
$B^0 \to \pi^+\pi^-$	1187 ± 43	$5.83 \pm 0.22 \pm 0.17$	–
$B^+ \to K^+\pi^0$	2070 ± 57	$14.21 \pm 0.38 \pm 0.85$	$0.013 \pm 0.027 \pm 0.005$
$B^+ \to \pi^+\pi^0$	786 ± 44	$5.02 \pm 0.28 \pm 0.31$	$-0.082 \pm 0.054 \pm 0.008$
$B^+ \to K^0\pi^+$	1547 ± 45	$24.4 \pm 0.71 \pm 0.86$	$0.046 \pm 0.029 \pm 0.007$
$B^0 \to K^0\pi^0$ (this analysis)	502 ± 32	$10.16 \pm 0.65 \pm 0.65$	$-0.06 \pm 0.15 \pm 0.05$
$B^0 \to K^0\pi^0$ (combination with Ref. [9])	–	$10.50 \pm 0.62 \pm 0.65$	$-0.01 \pm 0.12 \pm 0.05$

TABLE III. Summary of the fractional systematic uncertainties (%) on the branching ratios.

Source	$B^0 \to K^+\pi^-$	$B^0 \to \pi^+\pi^-$	$B^+ \to K^+\pi^0$	$B^+ \to \pi^+\pi^0$	$B^+ \to K_S^0\pi^+$	$B^0 \to K_S^0\pi$
Tracking	0.5	0.5	0.2	0.2	0.7	0.5
$N_{B\bar{B}}$	1.5	1.5	1.5	1.5	1.5	1.5
f^{+0}	2.5	2.5	2.4	2.4	2.4	2.5
π^0 efficiency	-	-	5.0	5.0	-	5.0
K_S^0 efficiency	-	-	-	-	2.0	2.0
CS efficiency	0.2	0.2	0.7	0.7	0.5	1.7
PID correction	0.1	0.1	0.1	0.2	-	-
ΔE shift and scale	0.1	0.2	1.2	2.0	0.3	0.2
$K\pi$ signal model	0.1	0.2	0.1	<0.1	<0.1	0.1
$\pi\pi$ signal model	<0.1	0.1	<0.1	<0.1	-	-
$K\pi$ CF model	<0.1	0.1	<0.1	0.1	-	-
$\pi\pi$ CF model	0.1	0.2	<0.1	0.1	-	-
$K_S^0 K^+$ model	-	-	-	-	0.1	-
$B\bar{B}$ model	-	-	0.3	0.5	<0.1	0.3
Multiple candidates	<0.1	<0.1	1.0	0.3	0.1	0.3
Total	3.0	3.0	6.0	6.2	3.6	6.4

TABLE IV. Summary of the absolute systematic uncertainties on the *CP* asymmetry.

Source	$B^+ \to K^+\pi^-$	$B^+ \to K^+\pi^0$	$B^+ \to \pi^+\pi^0$	$B^+ \to K_S^0\pi^+$	$B^0 \to K_S^0\pi^0$
ΔE shift and scale	<0.001	0.001	0.002	0.001	0.003
$K_S^0 K^+$ model	-	-	-	0.001	-
$B\bar{B}$ background asymmetry	-	-	-	-	0.046
$q\bar{q}$ background asymmetry	-	-	-	-	0.024
Fitting bias	-	-	0.007	0.006	-
Instrumental asymmetry	0.007	0.005	0.004	0.004	-
Total	0.007	0.005	0.008	0.007	0.052

γ GLS - extra info

- 2 Acp for DK: (plus 2 similar Acp for Dpi)

$$A_{SS}^{DK} \equiv \frac{N_{SS}^{-} - N_{SS}^{+}}{N_{SS}^{-} + N_{SS}^{+}}, \quad A_{OS}^{DK} \equiv \frac{N_{OS}^{-} - N_{OS}^{+}}{N_{OS}^{-} + N_{OS}^{+}},$$

Physics meanings →

$$A_{SS}^{DK} = \frac{2r_B r_D \kappa \sin(\delta_B - \delta_D) \sin\phi_3}{1 + r_B^2 r_D^2 + 2r_B r_D \kappa \cos(\delta_B - \delta_D)\cos\phi_3},$$

$$A_{OS}^{DK} = \frac{2r_B r_D \kappa \sin(\delta_B + \delta_D) \sin\phi_3}{r_B^2 + r_D^2 + 2r_B r_D \kappa \cos(\delta_B + \delta_D)\cos\phi_3},$$

- 3 Ratios:

$$R_{SS}^{DK/D\pi} \equiv \frac{N_{SS}^{-} + N_{SS}^{+}}{N_{SS}^{\prime -} + N_{SS}^{\prime +}}, \quad R_{OS}^{DK/D\pi} \equiv \frac{N_{OS}^{-} + N_{OS}^{+}}{N_{OS}^{\prime -} + N_{OS}^{\prime +}}, \quad R_{SS/OS}^{D\pi} \equiv \frac{N_{SS}^{\prime -} + N_{SS}^{\prime +}}{N_{OS}^{\prime -} + N_{OS}^{\prime +}},$$

Physics meanings →

$$R_{SS}^{DK/D\pi} = R\frac{1 + r_B^2 r_D^2 + 2r_B r_D \kappa \cos(\delta_B - \delta_D)\cos\phi_3}{1 + r_B^{\prime 2} r_D^2 + 2r_B' r_D \kappa \cos(\delta_B' - \delta_D)\cos\phi_3},$$

$$R_{OS}^{DK/D\pi} = R\frac{r_B^2 + r_D^2 + 2r_B r_D \kappa \cos(\delta_B + \delta_D)\cos\phi_3}{r_B^{\prime 2} + r_D^2 + 2r_B' r_D \kappa \cos(\delta_B' + \delta_D)\cos\phi_3},$$

$$R_{SS/OS}^{D\pi} = \frac{1 + r_B^{\prime 2} r_D^2 + 2r_B' r_D \kappa \cos(\delta_B' - \delta_D)\cos\phi_3}{r_B^{\prime 2} + r_D^2 + 2r_B' r_D \kappa \cos(\delta_B' + \delta_D)\cos\phi_3},$$

γ GLS - extra info (2)

Numerical results

Full D:

$$A_{\rm SS}^{DK} = -0.089 \pm 0.091 \pm 0.011,$$
$$A_{\rm OS}^{DK} = 0.109 \pm 0.133 \pm 0.013,$$
$$A_{\rm SS}^{D\pi} = 0.018 \pm 0.026 \pm 0.009,$$
$$A_{\rm OS}^{D\pi} = -0.028 \pm 0.031 \pm 0.009,$$
$$R_{\rm SS}^{DK/D\pi} = 0.122 \pm 0.012 \pm 0.004,$$
$$R_{\rm OS}^{DK/D\pi} = 0.093 \pm 0.013 \pm 0.003,$$
$$R_{\rm SS/OS}^{D\pi} = 1.428 \pm 0.057 \pm 0.002.$$

K* region:

$$A_{\rm SS}^{DK} = 0.055 \pm 0.119 \pm 0.020,$$
$$A_{\rm OS}^{DK} = 0.231 \pm 0.184 \pm 0.014,$$
$$A_{\rm SS}^{D\Pi} = 0.046 \pm 0.029 \pm 0.016,$$
$$A_{\rm OS}^{D\Pi} = 0.009 \pm 0.046 \pm 0.009,$$
$$R_{\rm SS}^{DK/D\pi} = 0.093 \pm 0.012 \pm 0.005,$$
$$R_{\rm OS}^{DK/D\pi} = 0.103 \pm 0.020 \pm 0.006,$$
$$R_{\rm SS/OS}^{D\pi} = 2.412 \pm 0.132 \pm 0.019.$$

Systematic uncertainties (relative)

	$A_{\rm SS}^{DK}$	$A_{\rm OS}^{DK}$	$A_{\rm SS}^{D\pi}$	$A_{\rm OS}^{D\pi}$	$R_{\rm SS}^{DK/D\pi}$	$R_{\rm OS}^{DK/D\pi}$	$R_{\rm SS/OS}^{D\pi}$
full D phase space							
PID	0.38	0.56	0.19	0.14	0.05	0.06	0.09
$\epsilon_{DK}/\epsilon_{D\pi}$	0.00	0.03	0.00	0.00	0.04	0.03	0.02
Model	0.62	0.78	0.02	0.02	0.30	0.22	0.07
$\epsilon_{K_S^0 K^- \pi^+}/\epsilon_{K_S^0 K^+ \pi^-}$	0.82	0.83	0.82	0.83	0.01	0.01	0.02
Total syst. unc.	1.10	1.30	0.90	0.90	0.40	0.30	0.20
Stat. unc.	9.10	13.30	2.60	3.10	1.20	1.30	5.70
K^* region							
PID	0.37	0.61	0.17	0.15	0.03	0.08	0.13
$\epsilon_{DK}/\epsilon_{D\pi}$	0.02	0.02	0.01	0.01	0.03	0.04	0.04
Model	1.04	0.97	0.20	0.03	0.46	0.49	0.61
$\epsilon_{K_S^0 K^- \pi^+}/\epsilon_{K_S^0 K^+ \pi^-}$	1.60	0.80	1.60	0.80	0.10	0.10	1.70
Total syst. unc.	2.00	1.40	1.60	0.90	0.50	0.60	1.90
Stat. unc.	11.90	18.40	2.90	4.60	1.20	2.00	13.20

γ GLW - extra info

- $$A_{CP\pm} = \frac{\Gamma[B^- \to D_{CP}K^-] - \Gamma[B^+ \to D_{CP}K^+]}{\Gamma[B^- \to D_{CP}K^-] + \Gamma[B^+ \to D_{CP}K^+]} = \pm\frac{2r_B sin\delta_B sin\phi_3}{1 + r_B^2 \pm 2r_B cos\delta_B cos\phi_3}$$

- $$\mathcal{R}_{CP\pm} \equiv \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D_{\text{flav}}K^-) + \mathcal{B}(B^+ \to D_{\text{flav}}K^+)} \approx \frac{R_{CP\pm}}{R_{\text{flav}}}$$ with $$R_X \equiv \frac{\mathcal{B}(B^- \to D_X K^-) + \mathcal{B}(B^+ \to D_X K^+)}{\mathcal{B}(B^- \to D_X \pi^-) + \mathcal{B}(B^+ \to D_X \pi^+)}$$

$\Rightarrow \mathcal{R}_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos\delta_B \cos\phi_3$ (with the assumption of CP conservation in $B^\pm \to D\pi^\pm$)

Channels:

- signal: $B \to D(\to KK, K_S^0\pi^0)K$
- R_{flav} control channel: $B \to D(\to K\pi)K$
- Rx control channel: $B \to D\pi$

Yields

		$N(B \to DK)$	$N(B \to D\pi)$
$D \to K^\pm\pi^\mp$	Belle	4238(94)	59 481(267)
	Belle II	1084(44)	14 229(126)
$D \to K^+K^-$	Belle	476(36)	5559(85)
	Belle II	107(15)	1336(40)
$D \to K_S^0\pi^0$	Belle	541(42)	6484(95)
	Belle II	145(16)	1763(46)

γ GLW - extra info (2)

Yield extraction

$$Y_h(B^\pm \to D_X K^\pm) = \tfrac{1}{2}[1 \mp A(B^\pm \to D_X K^\pm)]\, N(B \to D_X K)\, R_X\, \varepsilon^h_\pm\, \delta,$$

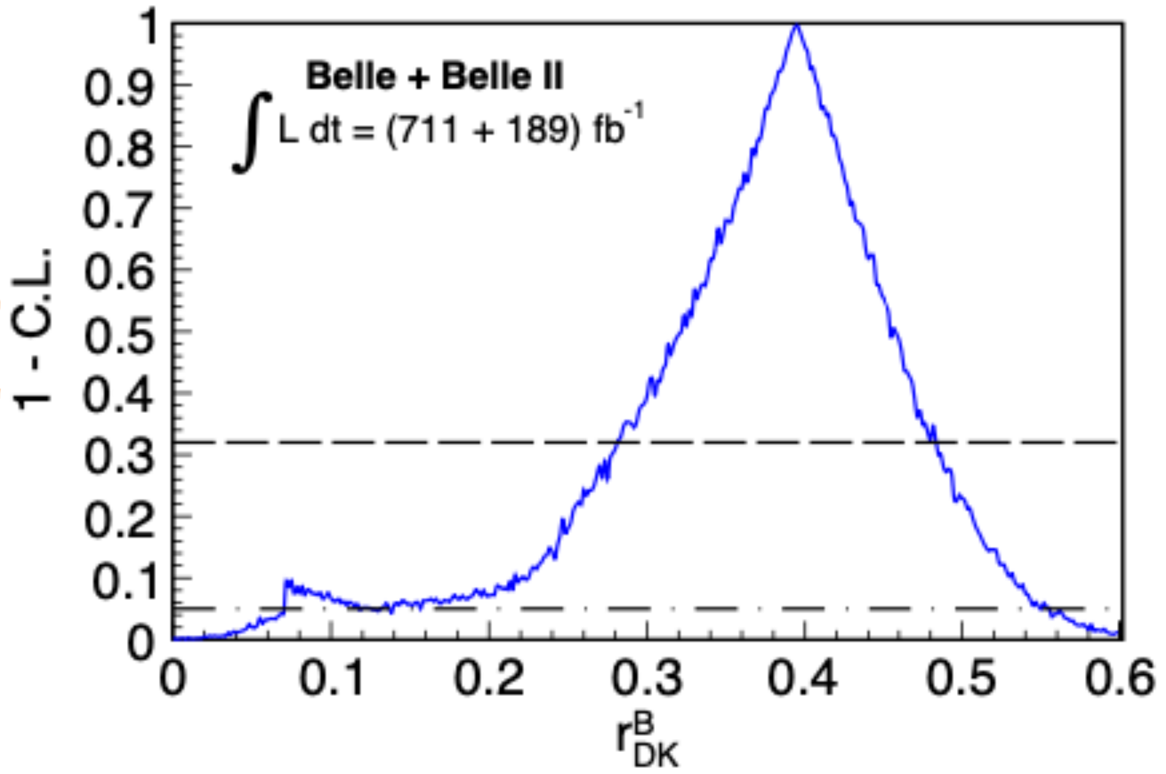
$$Y_h(B^\pm \to D_X \pi^\pm) = \tfrac{1}{2}[1 \mp A(B^\pm \to D_X \pi^\pm)]\, N(B \to D_X \pi)\, \kappa^h_\pm$$

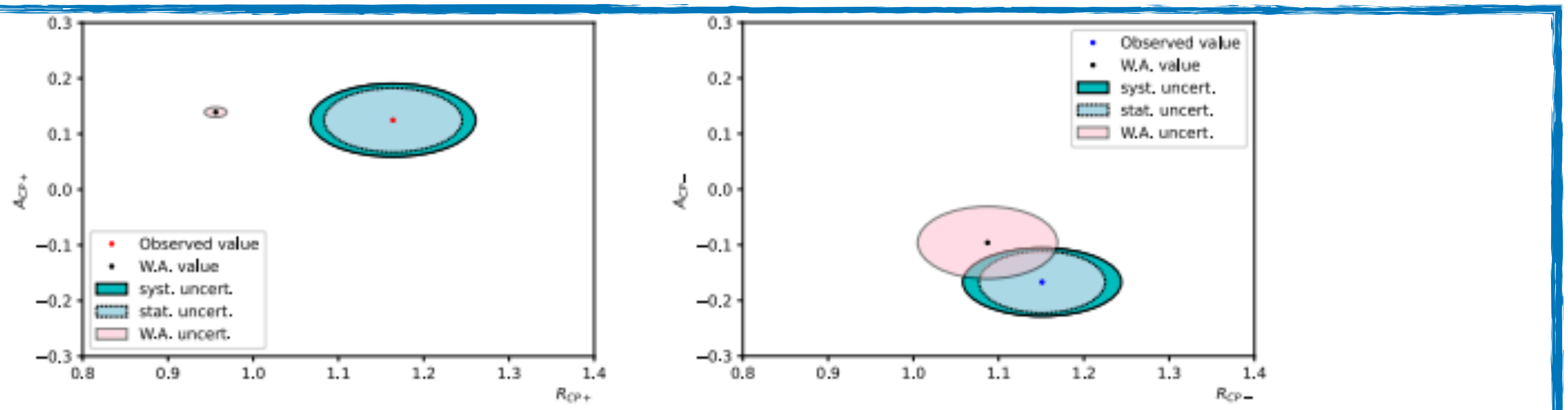
Systematics

	$\mathcal{R}_{CP+}$	$\mathcal{R}_{CP-}$	$\mathcal{A}_{CP+}$	$\mathcal{A}_{CP-}$
PDF parameters	0.012	0.014	0.002	0.002
PID parameters	0.009	0.010	0.003	0.005
$B\bar{B}$-background yields	0.033	0.002	0.013	—
Efficiency ratio	0.001	0.001	0.000	0.000
commonality of ΔE modes	−0.005	−0.006	0.000	0.000
Total systematic uncertainty	0.036	0.019	0.014	0.006
Statistical uncertainty	0.081	0.074	0.058	0.057

CL of the final result

	68.3% CL	95.4% CL
ϕ_3 (°)	[8.7, 20.5] [83.8, 96.1] [163.4, 173.1]	[4.7, 175.8]
r_B	[0.282, 0.489]	[0.069, 0.560]





$A_{CP+} = (+12.5 \pm 5.8(stat.) \pm 1.4(syst.))\%$

$A_{CP-} = (-16.7 \pm 5.7(stat.) \pm 0.6(syst.))\%$

$R_{CP+} = 1.164 \pm 0.081(stat.) \pm 0.036\,(syst.)$

$R_{CP-} = 1.151 \pm 0.074(stat.) \pm 0.019\,(syst.)$

ΔA_{CP} ~ 30%;

Opposite signs of A_{CP} are as expected with 3.5σ significance

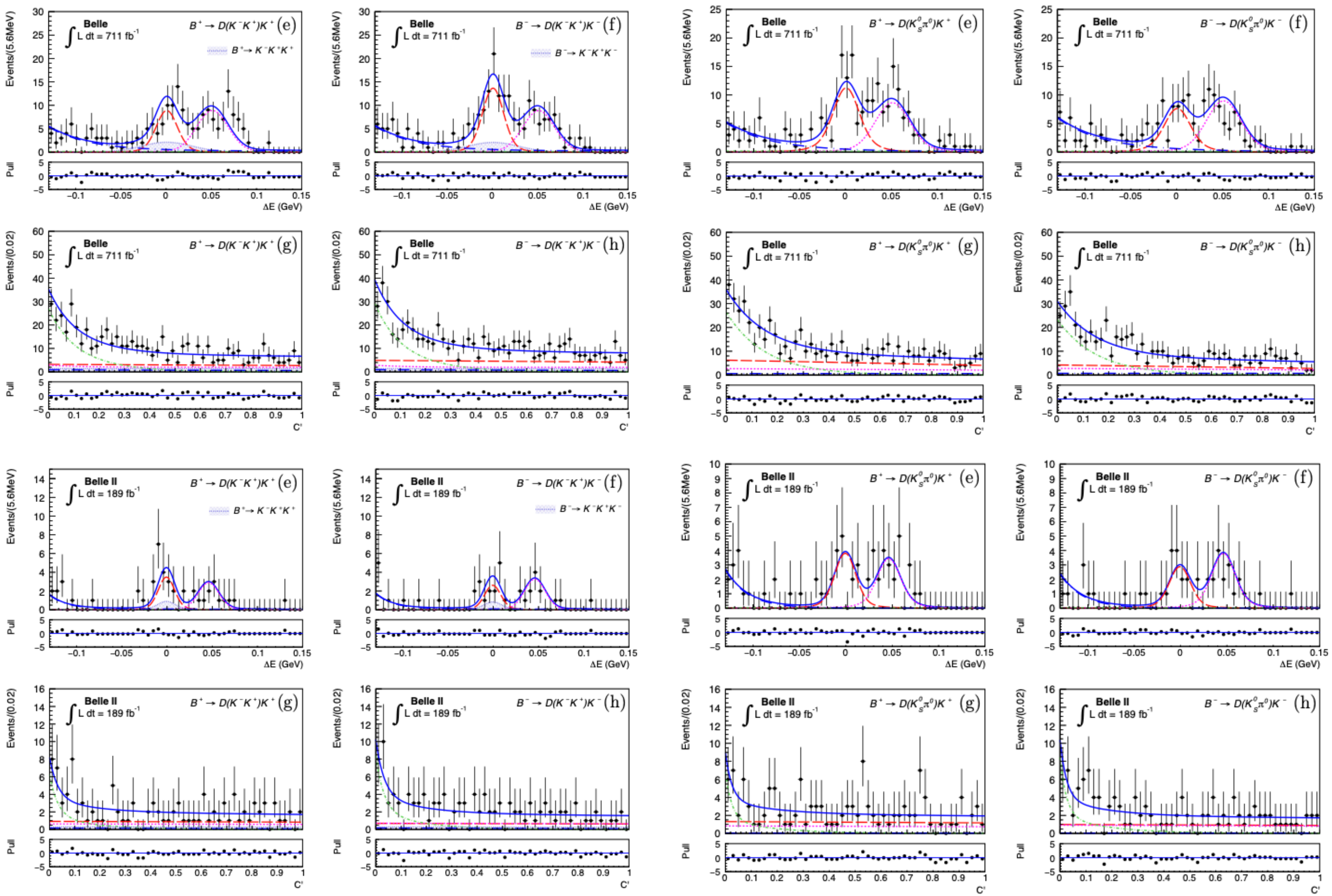
significance of CP violation:

$$\sqrt{-2\ln(\mathcal{L}_0/\mathcal{L}_{\max})}\,\sigma_{\rm stat}/\sqrt{\sigma^2_{\rm stat}+\sigma^2_{\rm syst}}$$

→ 2.0 σ for CP+ mode

→ 2.8 σ for CP− mode

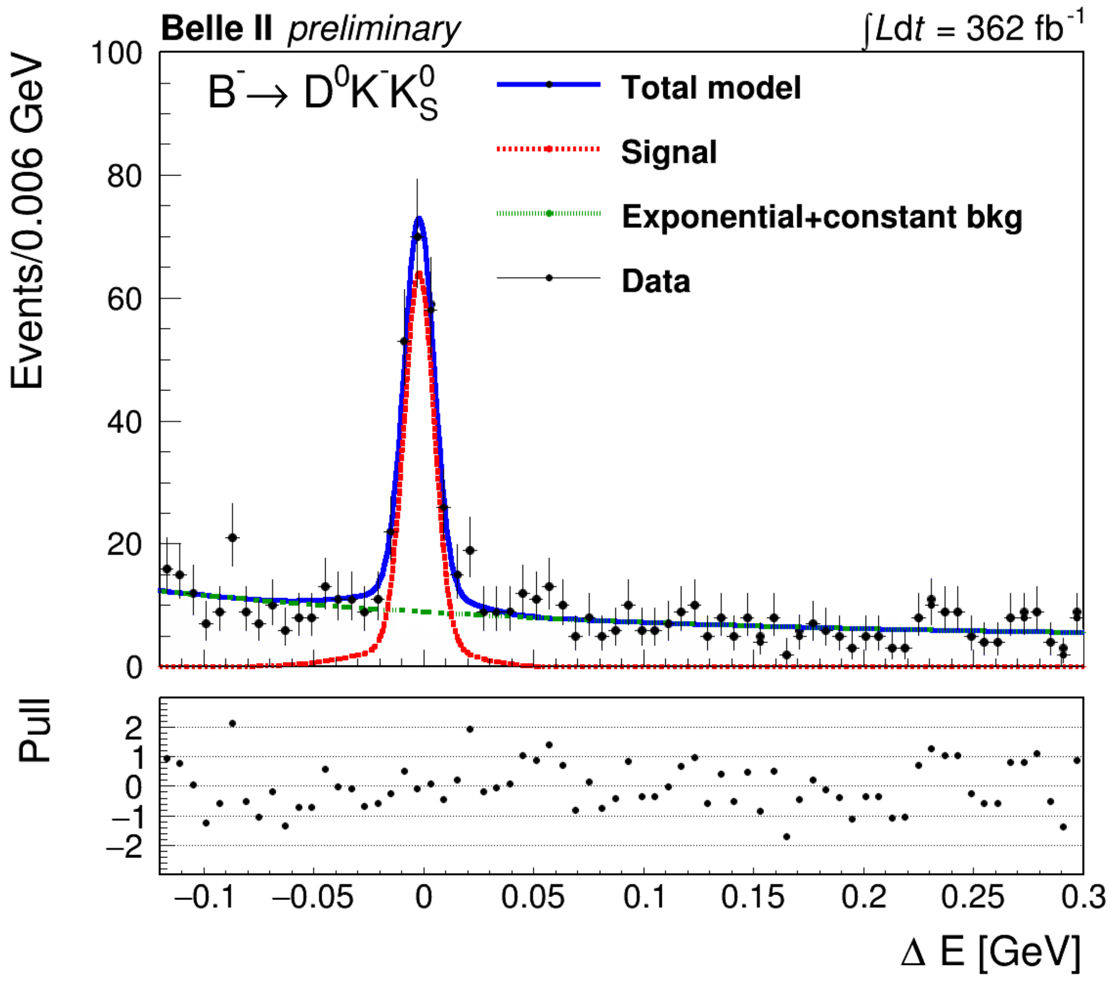
γ GLW - extra info (3)

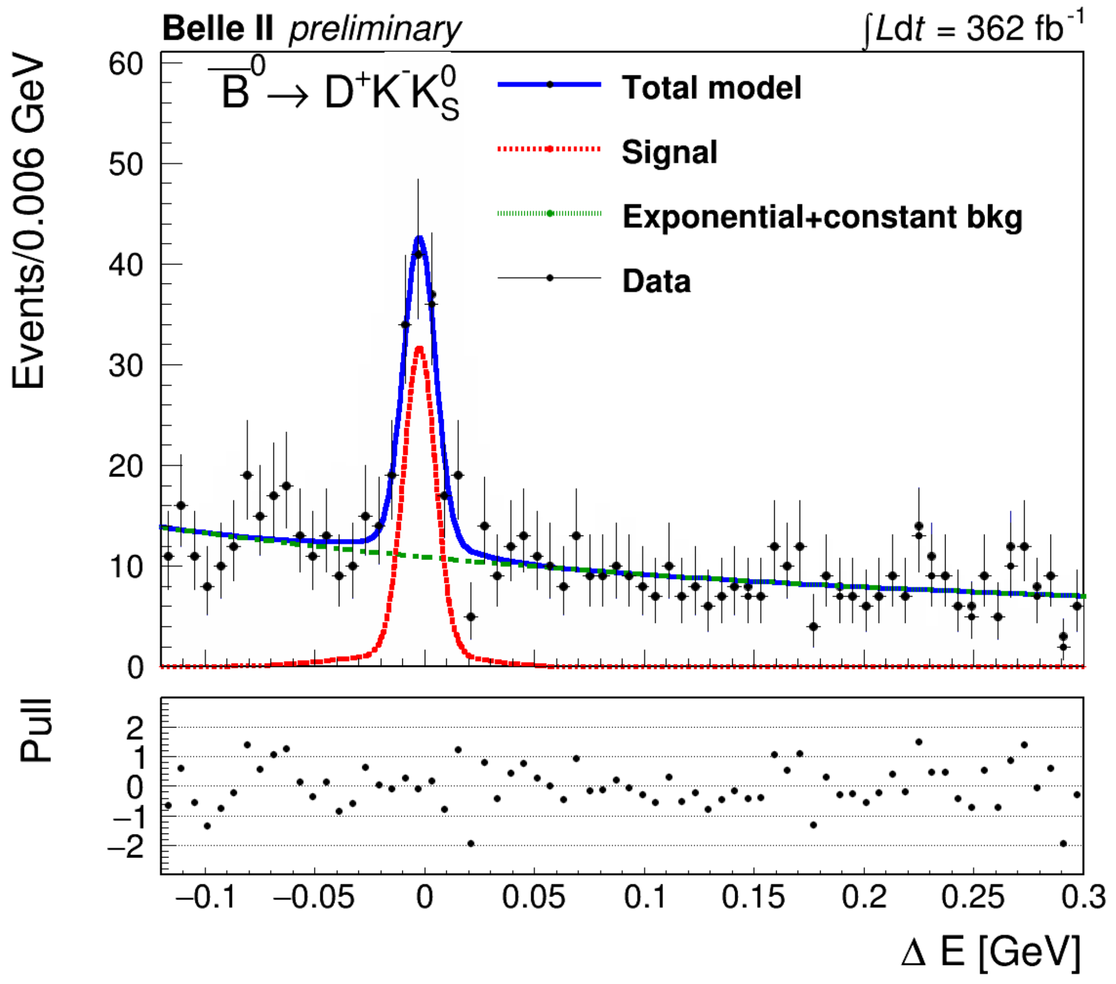


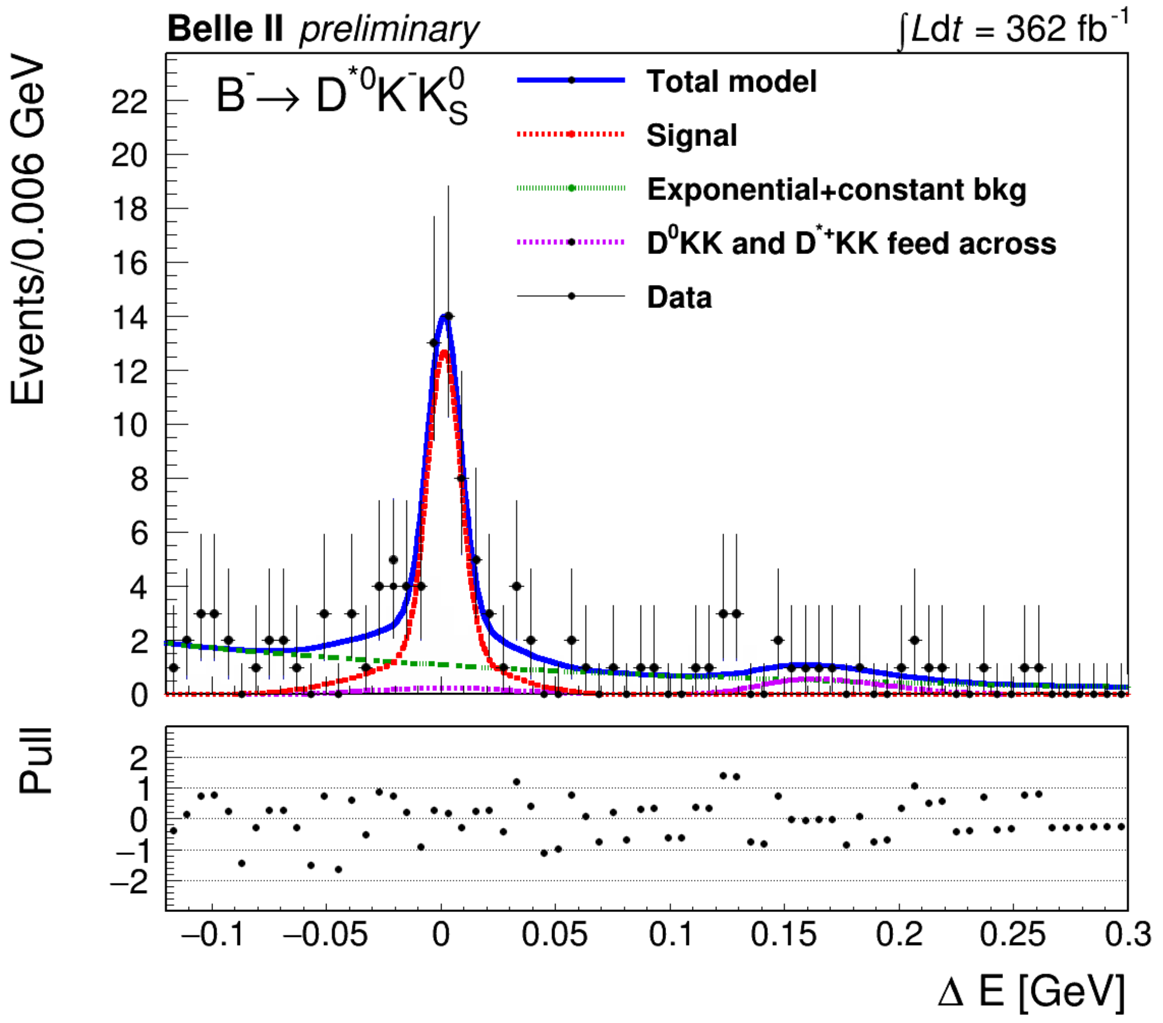
Belle

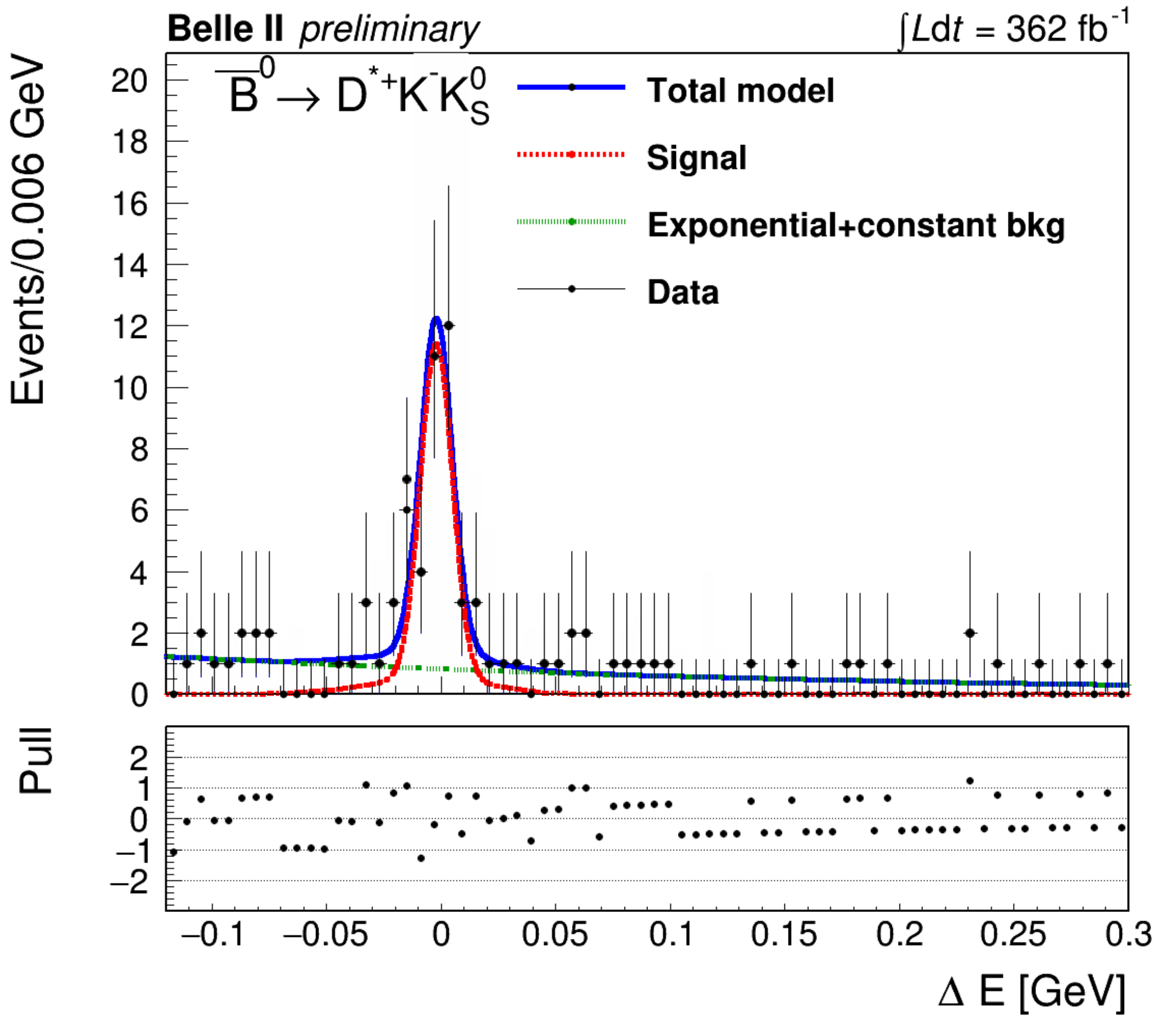
Belle II

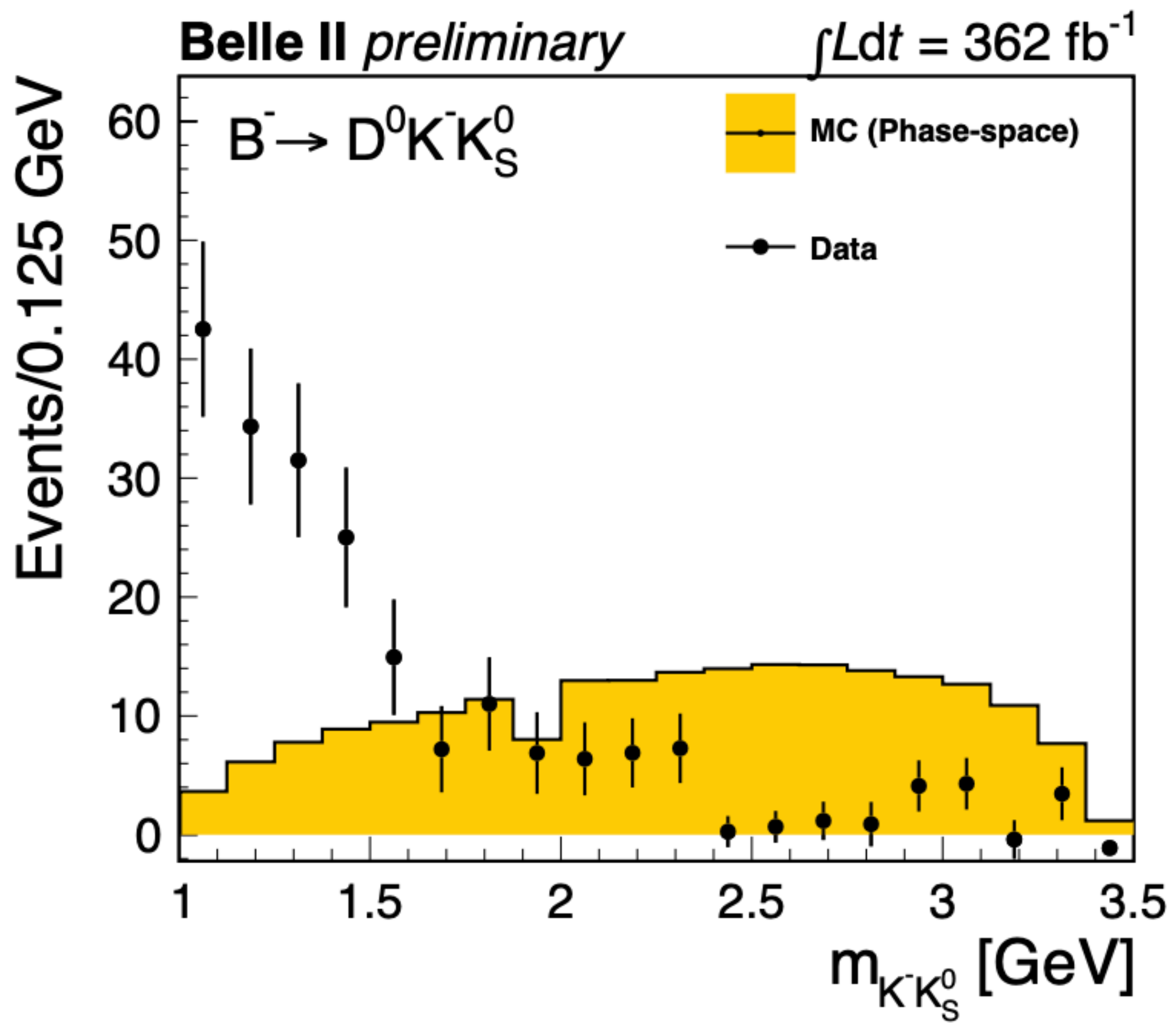
$B \to D^{(*)}K^-K_S^0$ - extra info

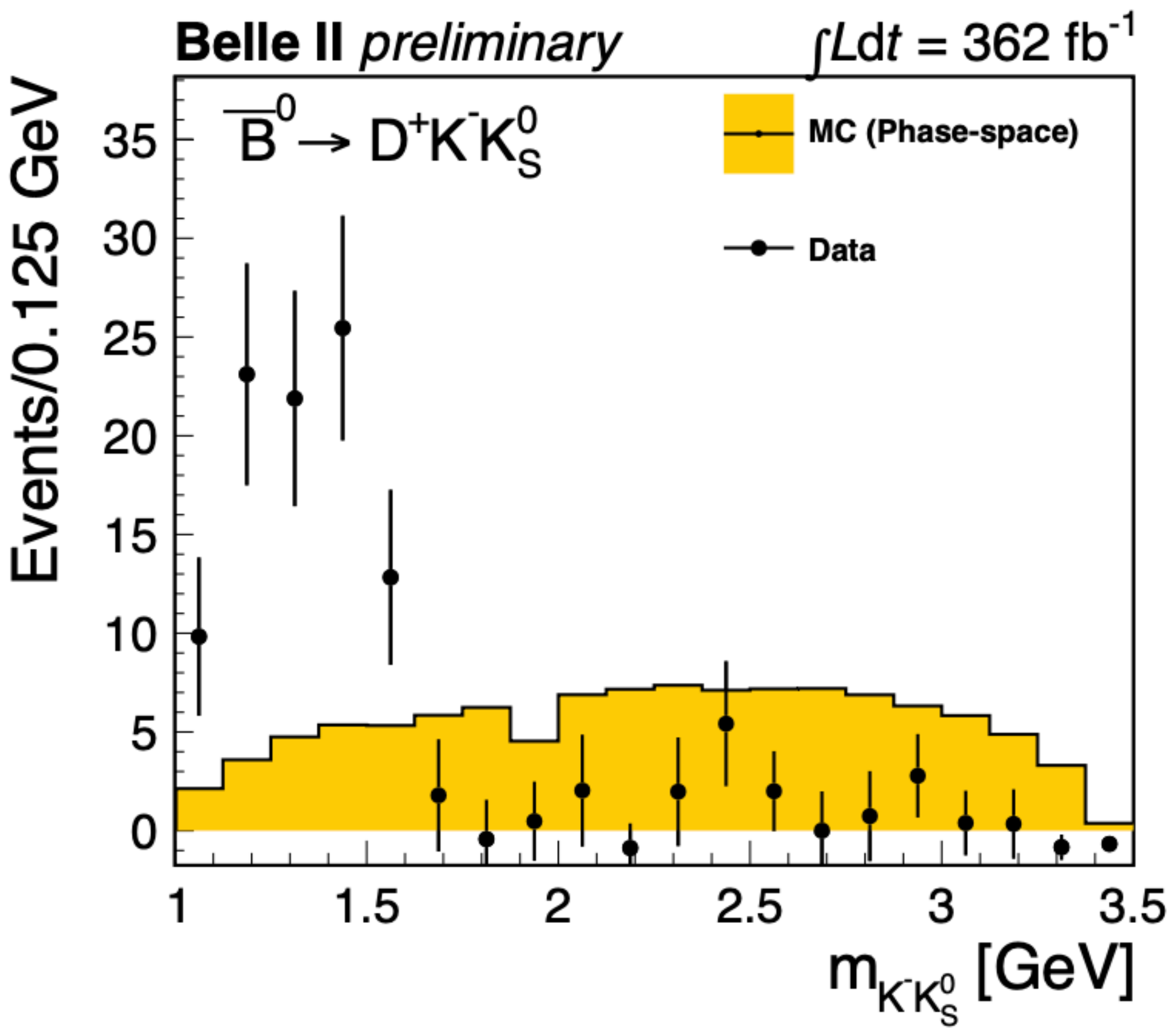


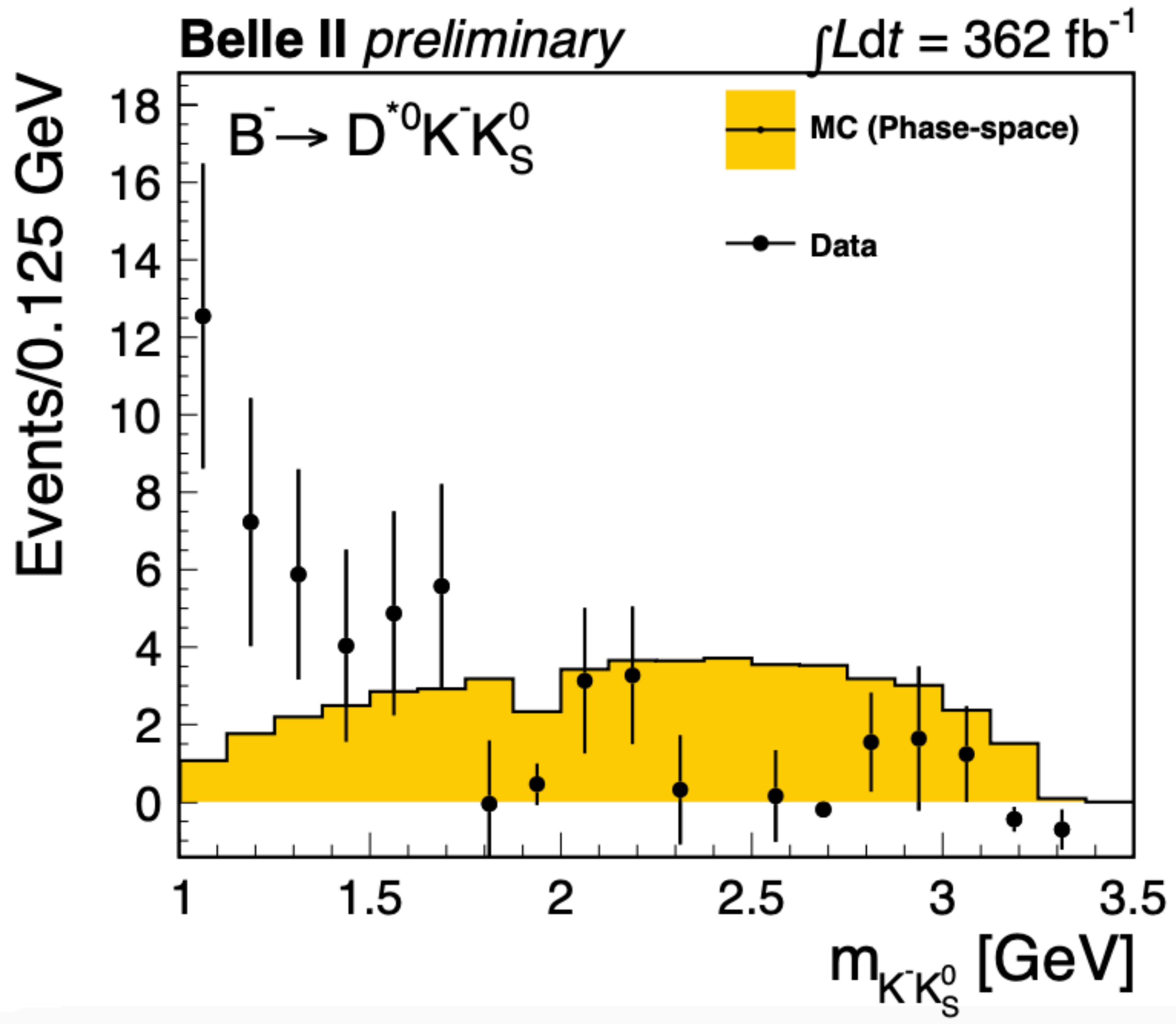


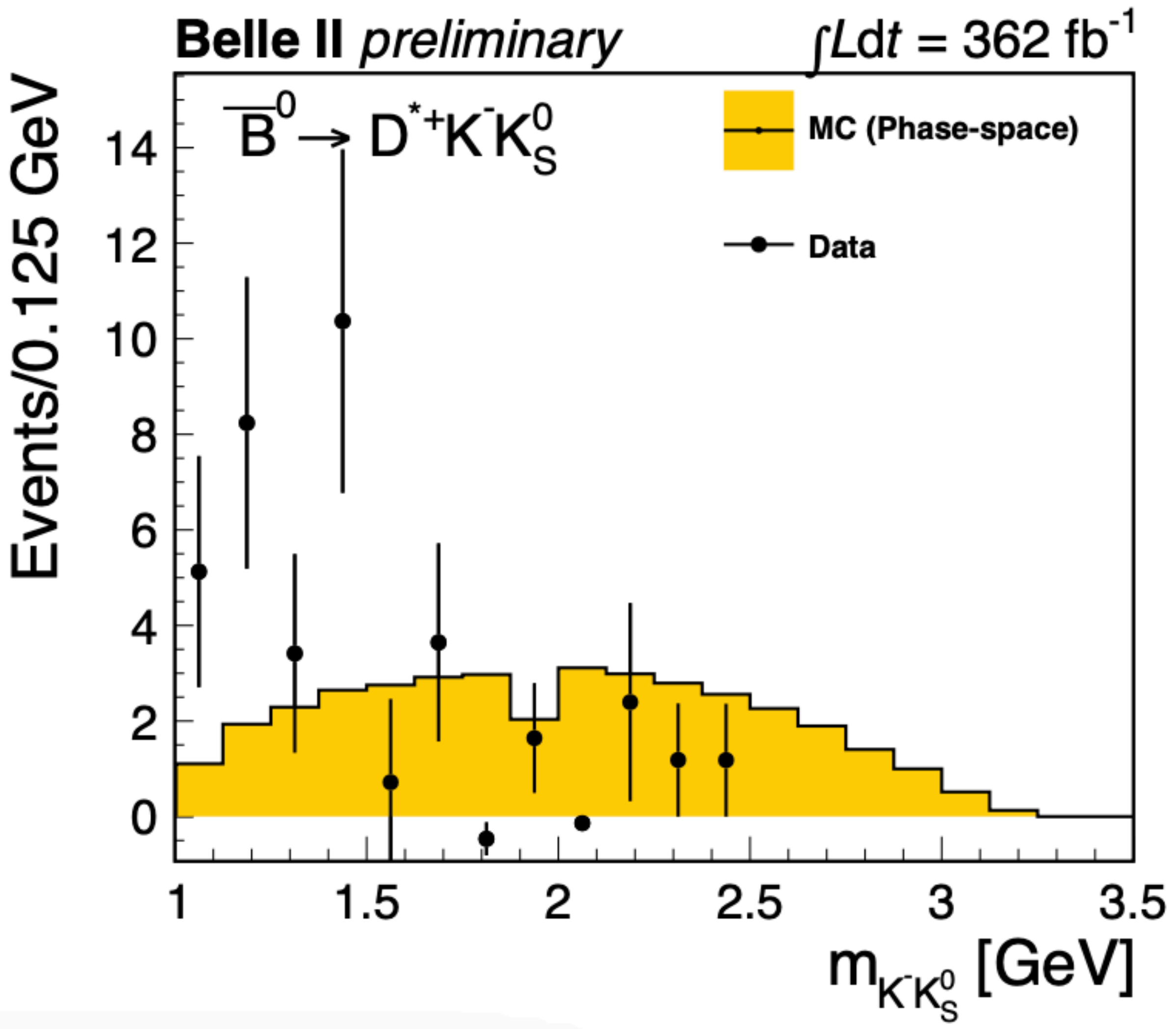












$B \to D^{(*)} K^- K_S^0$ - extra info (2)

$B \to D^{(*)}K^-K^0_S$ - extra info (3)

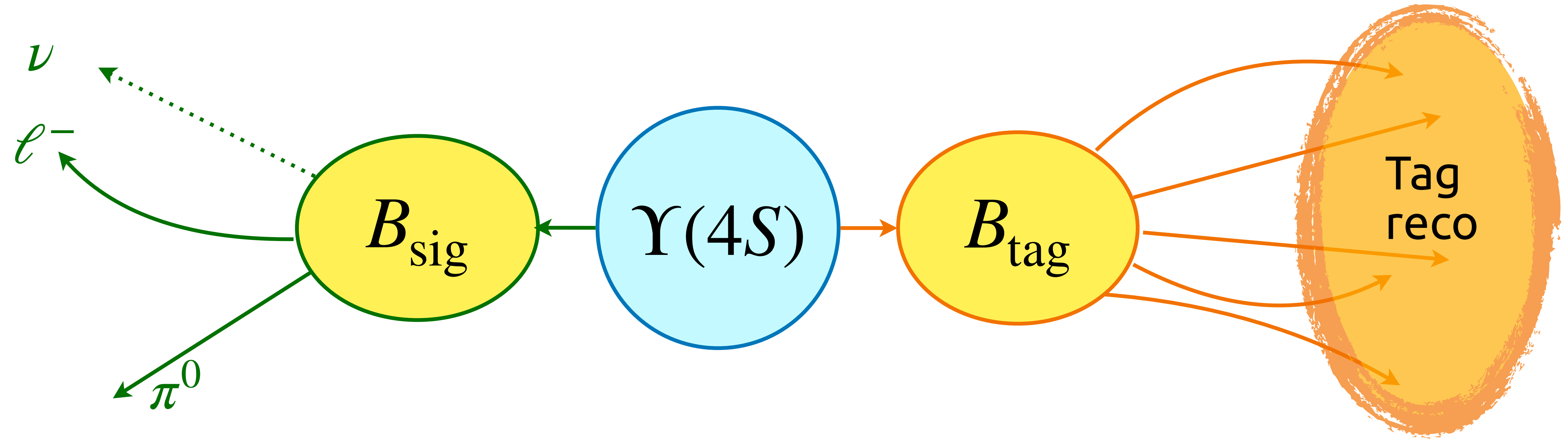
Systematics (relative)

Source	$B^- \to D^0K^-K^0_S$	$\overline{B}^0 \to D^+K^-K^0_S$	$B^- \to D^{*0}K^-K^0_S$	$\overline{B}^0 \to D^{*+}K^-K^0_S$
Eff. - MC stat.	0.62	0.90	0.97	0.79
Eff. - tracking	0.72	0.96	0.72	0.96
Eff. - slow π^+	-	-	-	2.73
Eff. - K^0_S :	3.44	3.41	3.39	3.26
Eff. - PID	1.28	1.41	0.48	0.60
Eff. - π^0	-	-	5.11	-
Signal model	0.58	1.10	0.40	1.07
Bkg model	1.06	0.85	0.09	0.13
Fit model	1.79	3.12	-	2.88
Self-cross-feed	-	-	2.72	-
D^{*0} peaking bkg	-	-	0.38	-
$N_{B\overline{B}}$, $f_{+-,00}$	2.66	2.78	2.66	2.78
Intermediate $\mathcal{B}$s	0.76	1.71	1.59	1.06
Total systematic	5.16	6.14	7.52	6.18
Statistical	8.31	13.50	17.09	19.01

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-tagging at Belle II



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

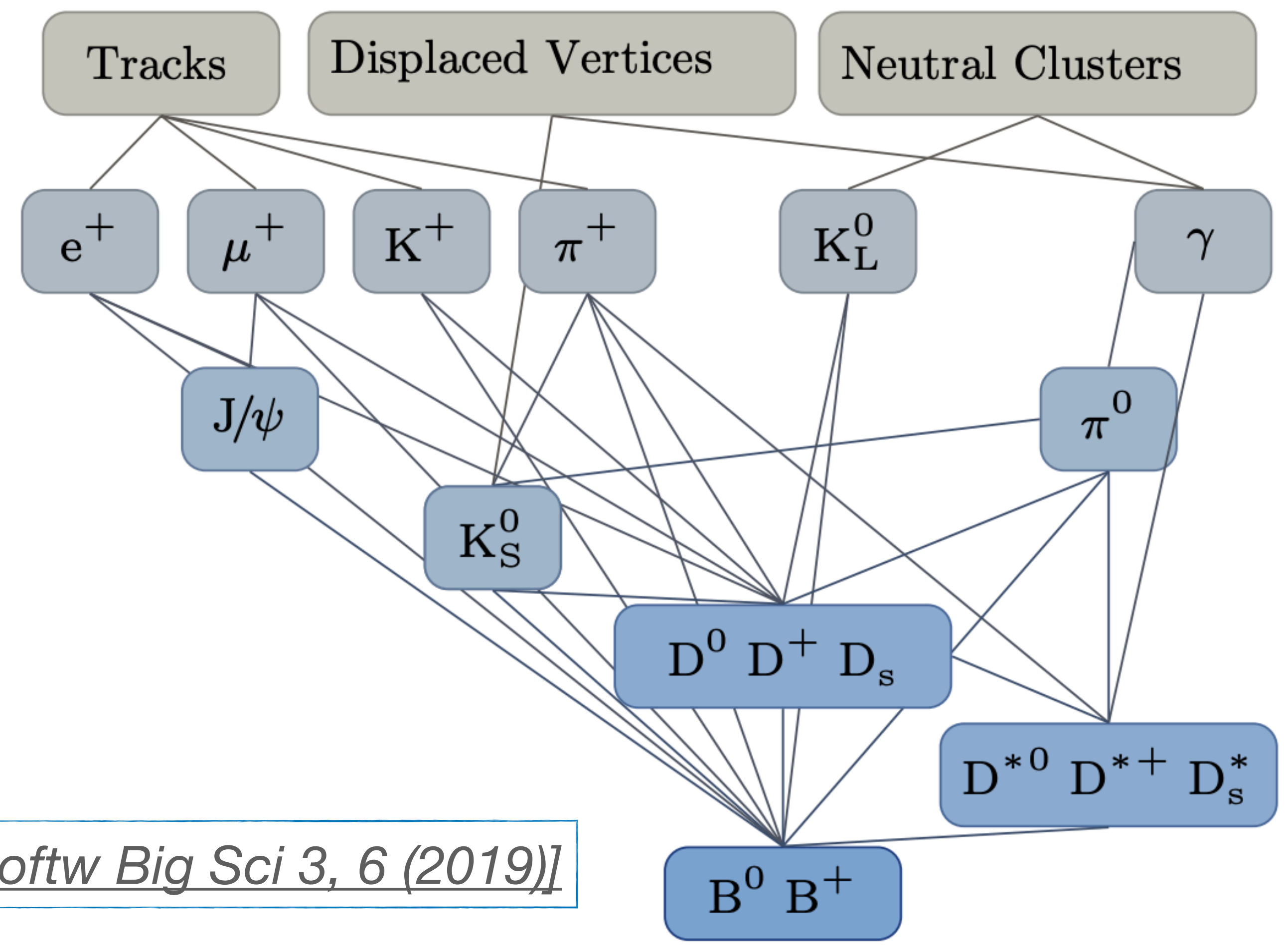
1. Reconstruction of one B (B_{tag}) using **well-known channels**

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

- **Hadronic tagging:** lower efficiency, but full tag reconstruction
- **Semileptonic Tagging:** higher efficiency, but lower purity
- **Inclusive Tagging:** signal reconstruction first, and then use of the ROE 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
- $\varepsilon_{had} \simeq 0.5\,\%\,,\quad \varepsilon_{SL} \simeq 2\,\%$



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

Fully inclusive $B \to X_s\gamma$ - extra info

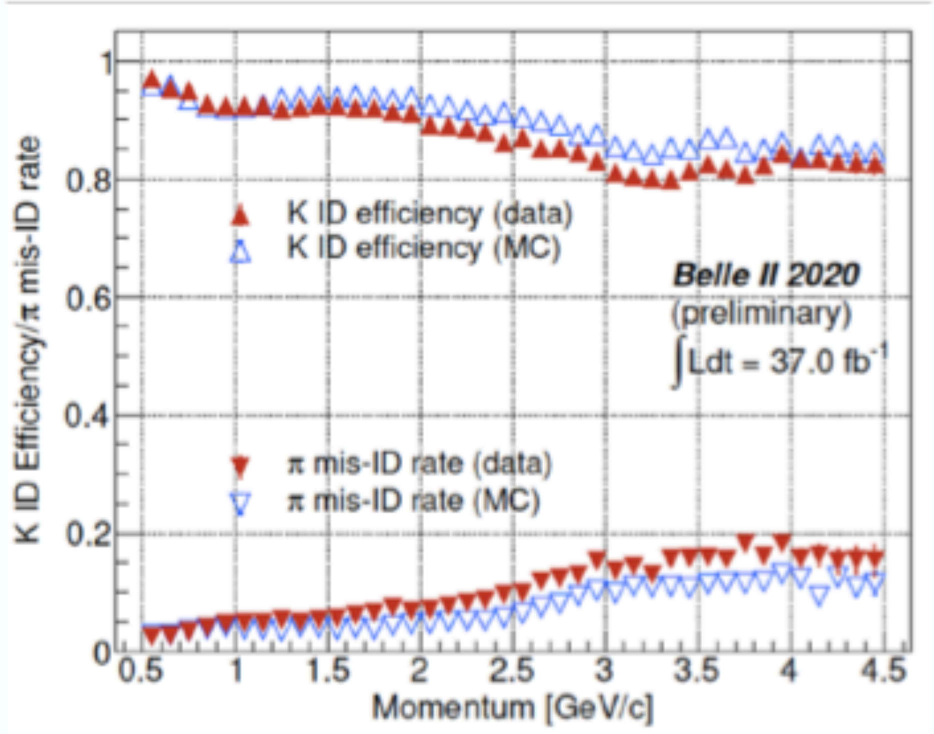
- Bkg suppression:
  - veto of $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ decays, associating lower-energy photons, basing the veto on an MVA
  - BDT for continuum
  - FEI probability for tag-side
  - MC for residual bkg from X_d
- Unfolding: bin-by-bin multiplicative factor based on signal model (Nexp/Ngen)

$$\frac{1}{\Gamma_B}\frac{d\Gamma_i}{dE_\gamma^B} = \frac{\mathcal{U}_i \times (N_i^{\mathrm{DATA}} - N_i^{\mathrm{BKG,\ MC}} - N_i^{B\to X_d\gamma})}{\varepsilon_i \times N_B},$$

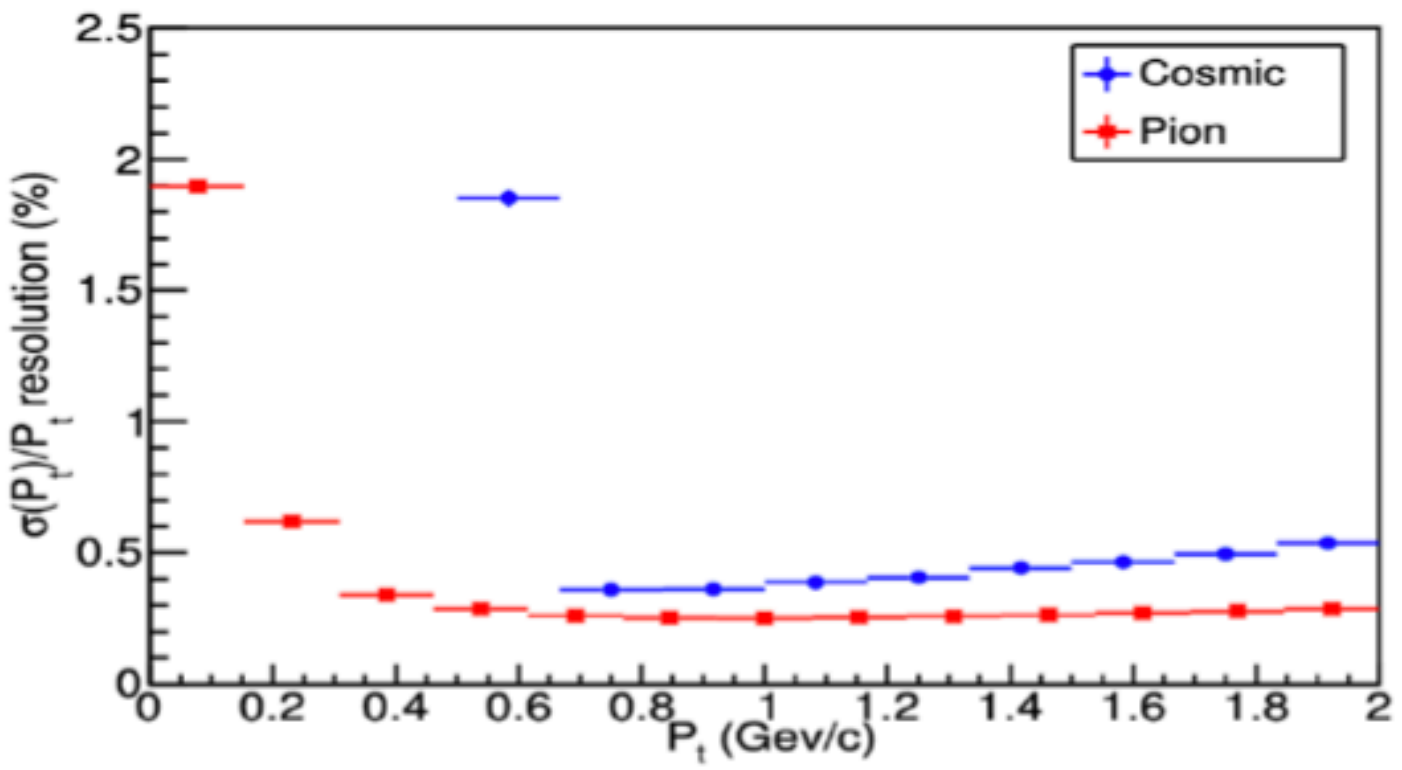
- Signal MC: BTOXGAMMA with the addition of $B \to K^*\gamma$

E_γ^B [GeV]	$\frac{1}{\Gamma_B}\frac{d\Gamma_i}{dE_\gamma^B}(10^{-4})$	Statistical	Systematic	Fit procedure	Signal efficiency	Background modelling	Other
$1.8-2.0$	0.48	0.54	0.64	0.42	0.03	0.49	0.09
$2.0-2.1$	0.57	0.31	0.25	0.17	0.06	0.17	0.07
$2.1-2.2$	0.13	0.26	0.16	0.13	0.01	0.11	0.01
$2.2-2.3$	0.41	0.22	0.10	0.07	0.05	0.04	0.02
$2.3-2.4$	0.48	0.22	0.10	0.06	0.06	0.02	0.05
$2.4-2.5$	0.75	0.19	0.14	0.04	0.09	0.02	0.09
$2.5-2.6$	0.71	0.13	0.10	0.02	0.09	0.00	0.04

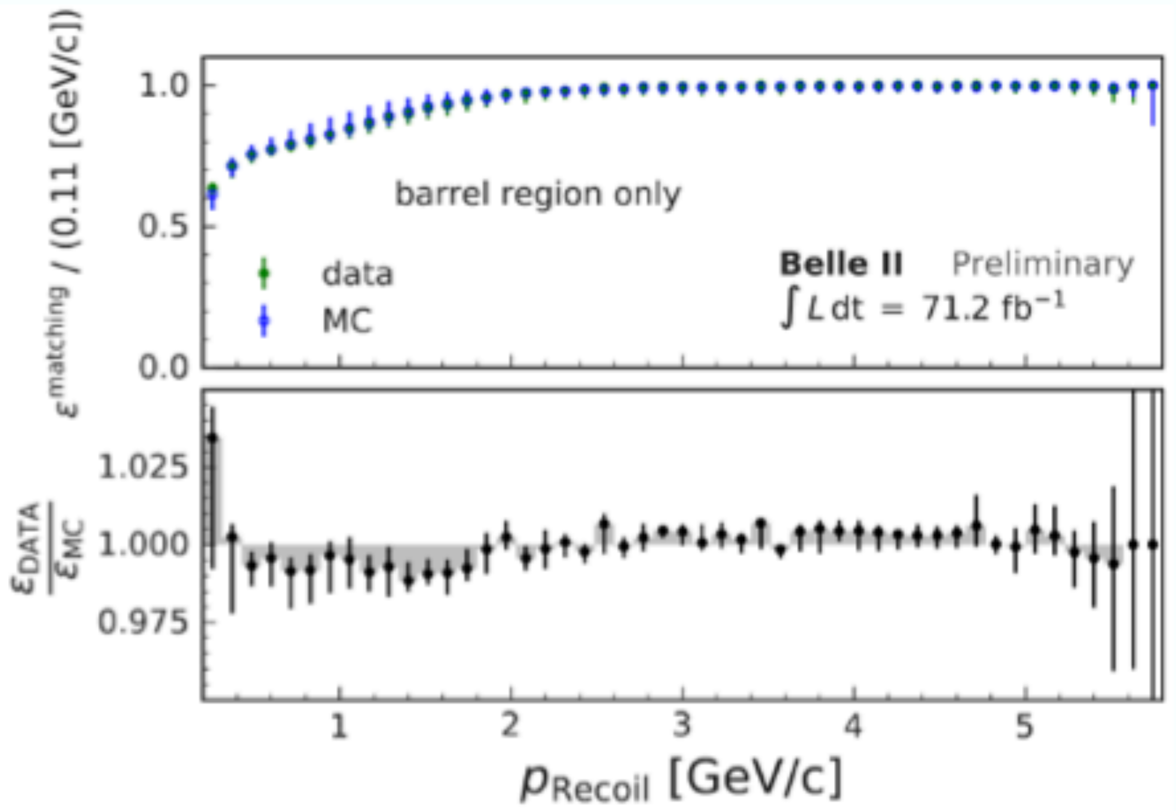
Belle II performance



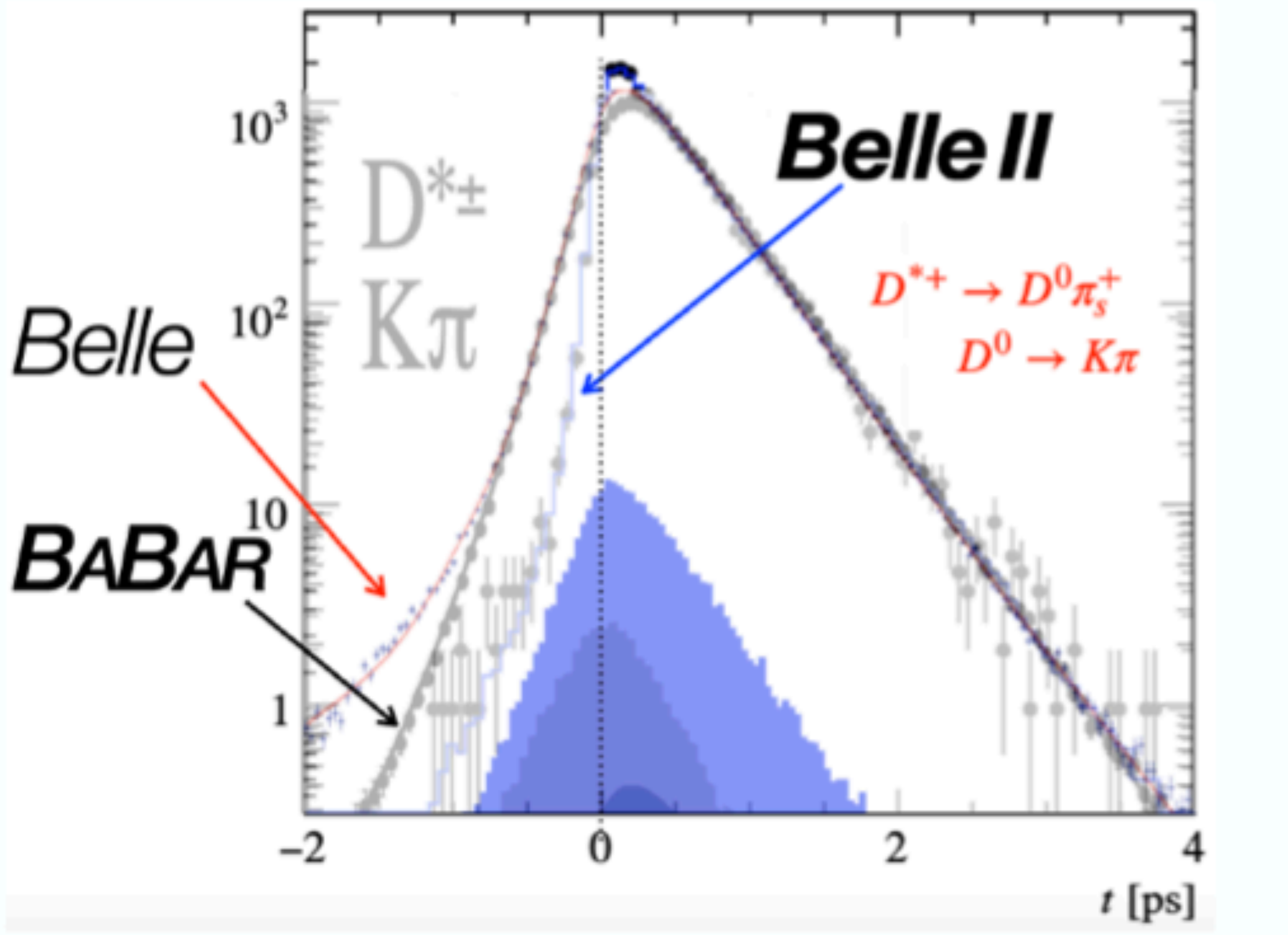
PID still 20% worse than Belle but improving



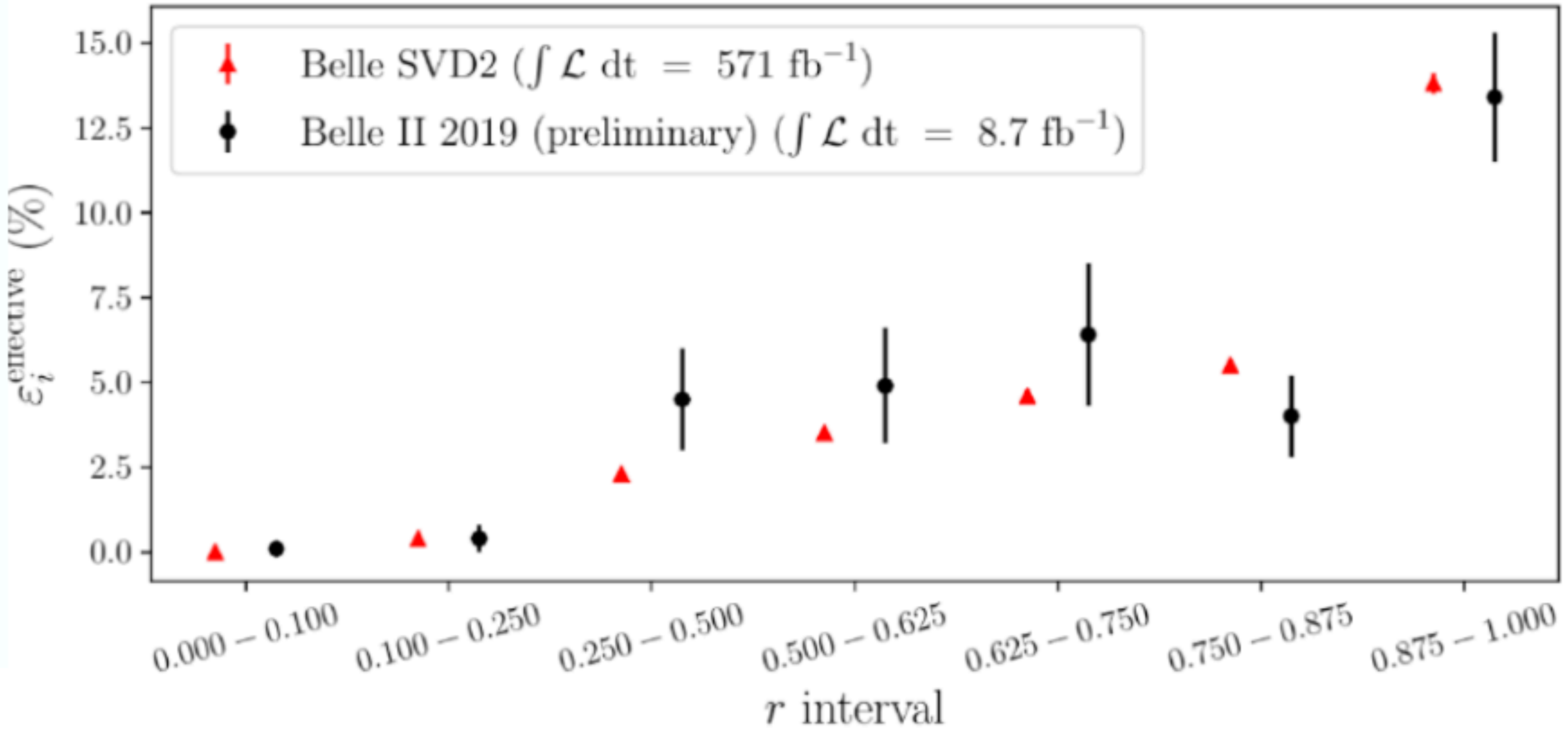
Momentum resolution 20% better than Belle



High photon efficiency,



Nearly 2x better decay-time resolution than Belle



Tagging performance similar to Belle and improving

[From D. Tonelli]