The re-discovery of the decays for the CP violation measurements

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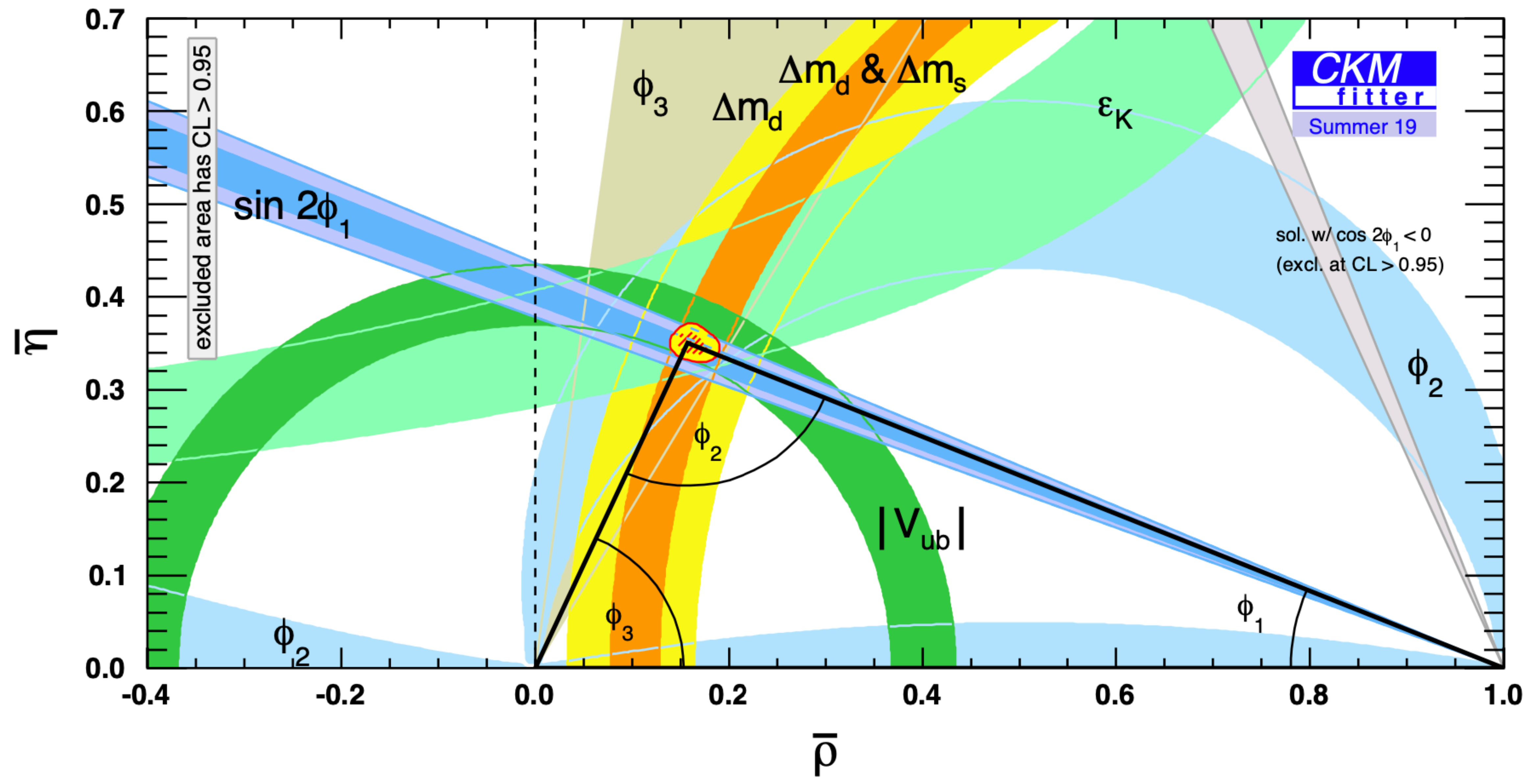
Legacy from B Factories

B factories lead to significant understanding of the flavor dynamics in the Standard Model [arxiv1406.6311]

- Discovery of CP violation in B meson transitions and confirmation of the CKM description of flavor physics
- Precision measurement of the CKM matrix elements and the angles of the unitarity triangle

What we know today about CKM triangle:



$\phi_1 = \beta, \phi_2 = \alpha, \phi_3 = \gamma$

Precision measurements of the CKM triangle sides and angles will provide test of the Standard Model.
The existing constraints do not exclude the possibility of contributions from NP

- World average: $\sin2\phi_1 = 0.699 \pm 0.017$
- Our aim: perform a measurement of $\sin2\phi_1$ using decay modes that are more sensitive to NP effects

SuperKEKB - high luminosity

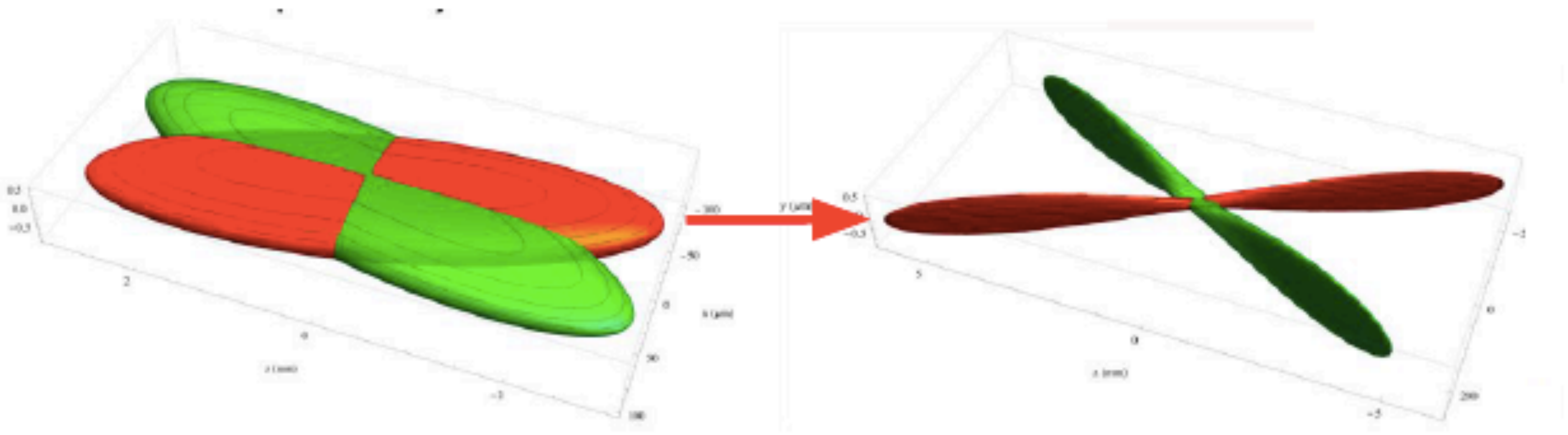
Our target:

L_{peak} = 6.5 x 10^{35} cm^{-2} s^{-1}

L_{Int} = 50 ab^{-1} (50 x KEKB)

How to increase luminosity:

- Increase current: x1.5
- Reduced beam spot size (nano beam scheme): x20



KEKB **Nano-beam scheme** **SuperKEKB**

Consequences:

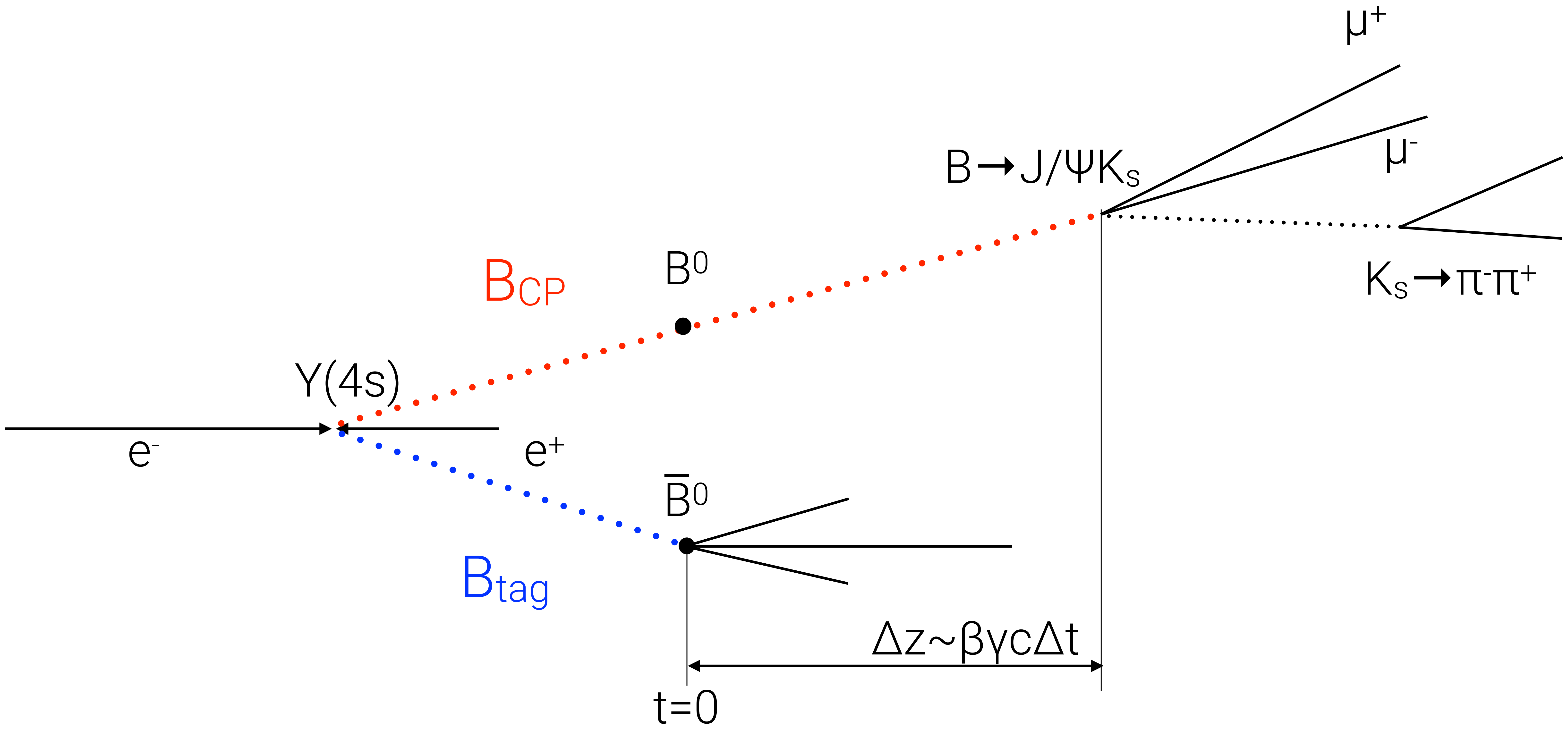
- Deal with more severe background conditions
- Boost factor is reduced ($\beta\gamma$ = 0.43 -> 0.28)

=> Many upgrades for Belle II detector to increase the performance and cope with much more severe background conditions

$\sin 2\phi_1$ - measurement strategy

CPV in the interference between $B \to J/\Psi K_S$ and $B \to \bar{B}^0 \to J/\Psi K_S$ can be measured through the raw asymmetry:

$$A_{CP}^{raw} = \frac{\Gamma(\bar{B}^0_{t=0} \to J/\Psi K_S) - \Gamma(B^0_{t=0} \to J/\Psi K_S)}{\Gamma(\bar{B}^0_{t=0} \to J/\Psi K_S) + \Gamma(B^0_{t=0} \to J/\Psi K_S)} = sin(\Delta m_d \Delta t) sin(2\phi_1)$$



Key aspects:

- measurement of Δt
- flavor of B_{tag}

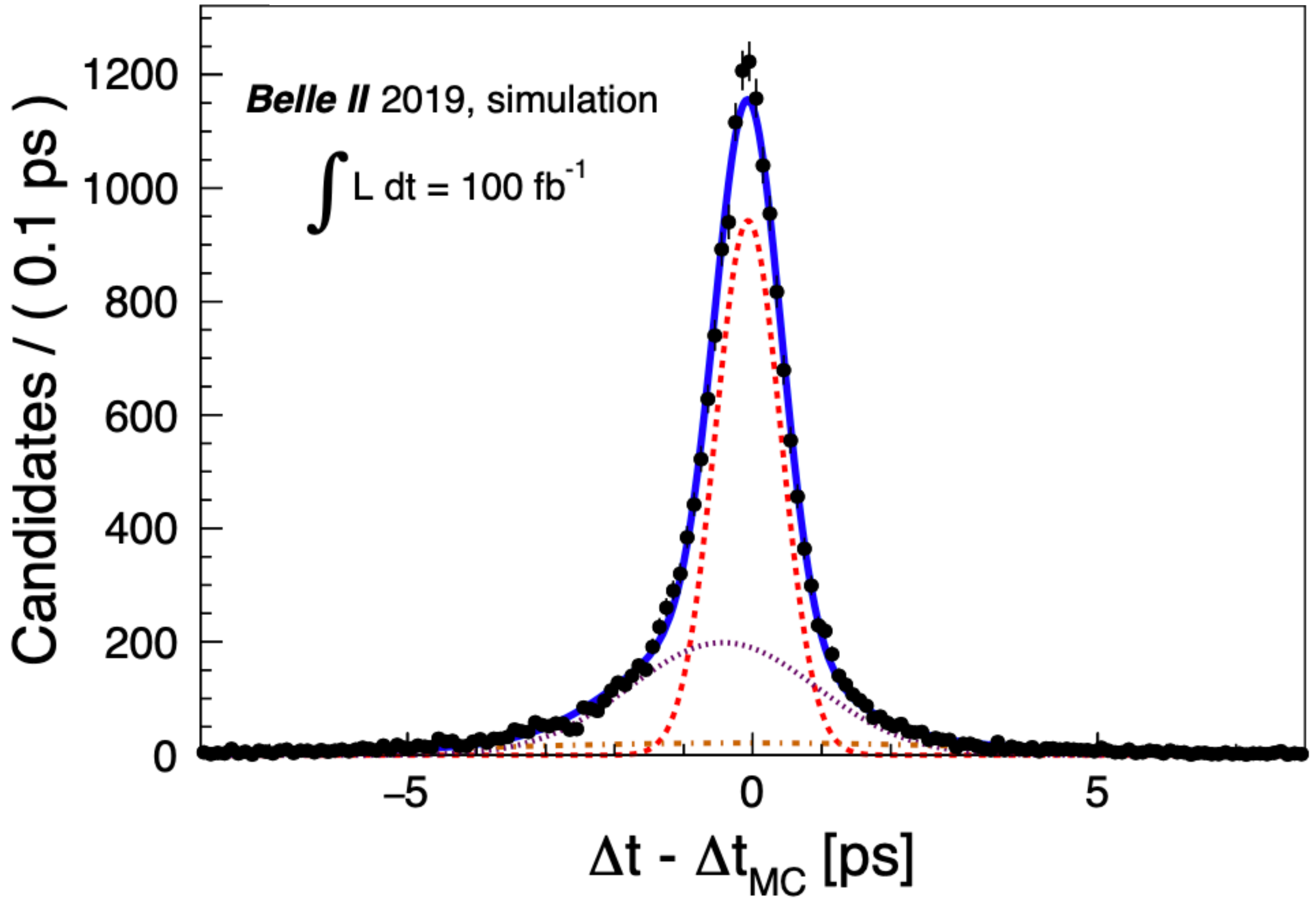
Key aspect - Δt measurement

- Δt measured from the distance Δz between B_{CP} and B_{tag} => Δt~Δz/βγc
- Υ(4s) is boosted along the beam axis with a smaller βγ wrt Belle:
  βγ=0.43 ➞ βγ=0.28 => Δz=200μm ➞ Δz=130μm
  => two new layers of pixel detectors have been added to improve precision in Δt

- We need to consider also the effect of Δt resolution function

$$A_{CP} = A_{CP}^{raw} \otimes R(\Delta t) = sin(\Delta m_d \Delta t) sin(2\phi_1) \otimes R(\Delta t)$$

A_{CP}^{raw} defined in slide 4

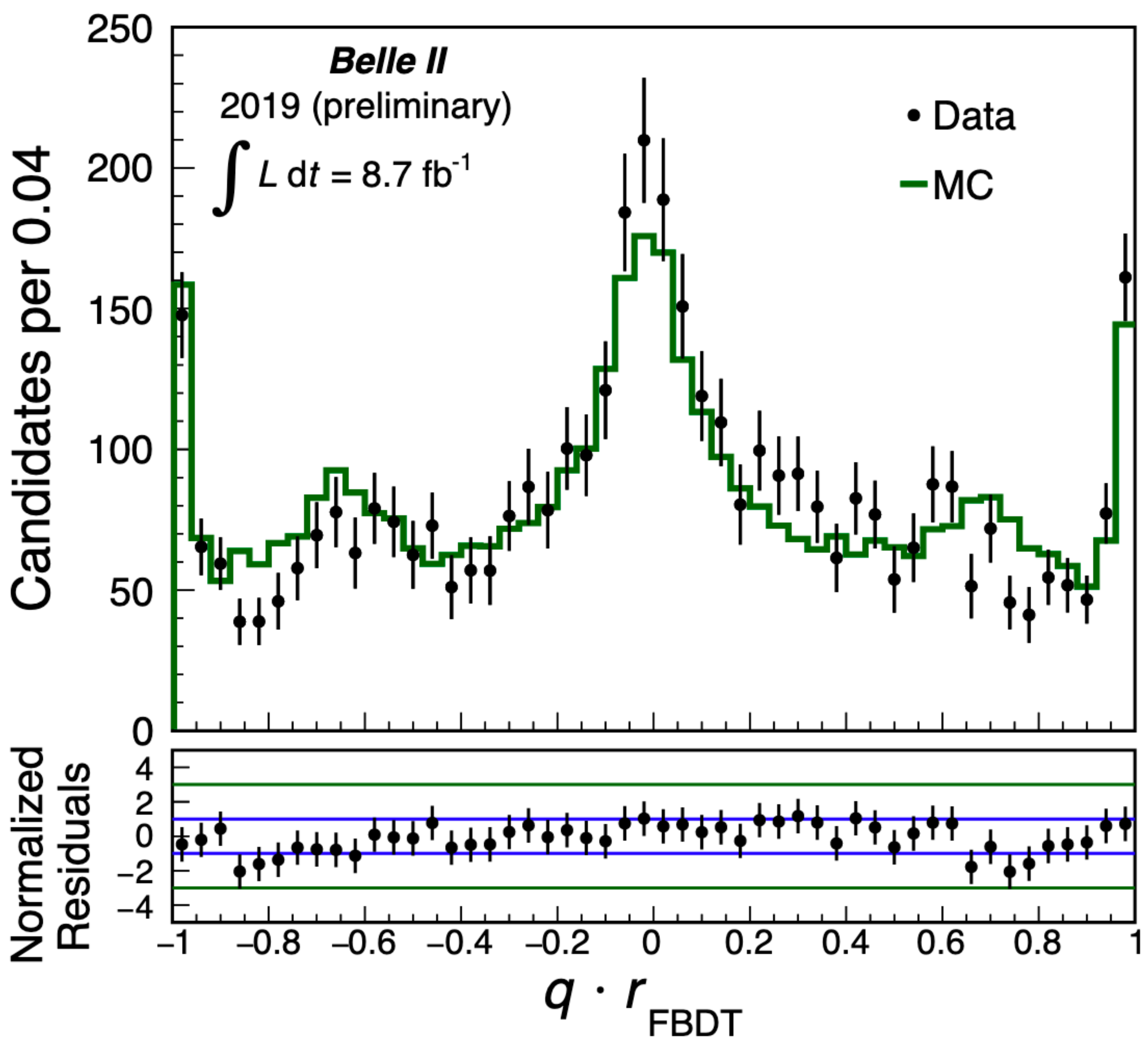


- simple 1D model assumed for R(Δt) so far
- more refined model needed for precision measurement of sin2φ_1

Key aspect - flavor tagger

- We need to determine the quark-flavor content of B_{tag}

- Many B decay channels provide unambiguous flavor signatures through a flavor-specific final state but it is unfeasible to fully reconstruct a large number of flavor-specific B_{tag} decays
- Instead of a full reconstruction, the flavor tagger applies a complex multivariate algorithm



Performance of flavor tagger is evaluated looking at:

- wrong tag fraction w
- efficiency = $\varepsilon = N_{tag}/N$ => dilution effect of w =>
  effective efficiency $\varepsilon_{eff} = \varepsilon\,(1-2w)^2$

ε_{eff}(Belle II) = (33.8 ± 3.6)%

ε_{eff}(Belle) = (30.1 ± 0.4)%

$$A_{CP} = A_{CP}^{raw} \cdot (1-2w) \otimes R(\Delta t) =$$

$$= sin(\Delta m_d \Delta t) sin(2\phi_1) \cdot (1-2w) \otimes R(\Delta t)$$

Δm_d measurement

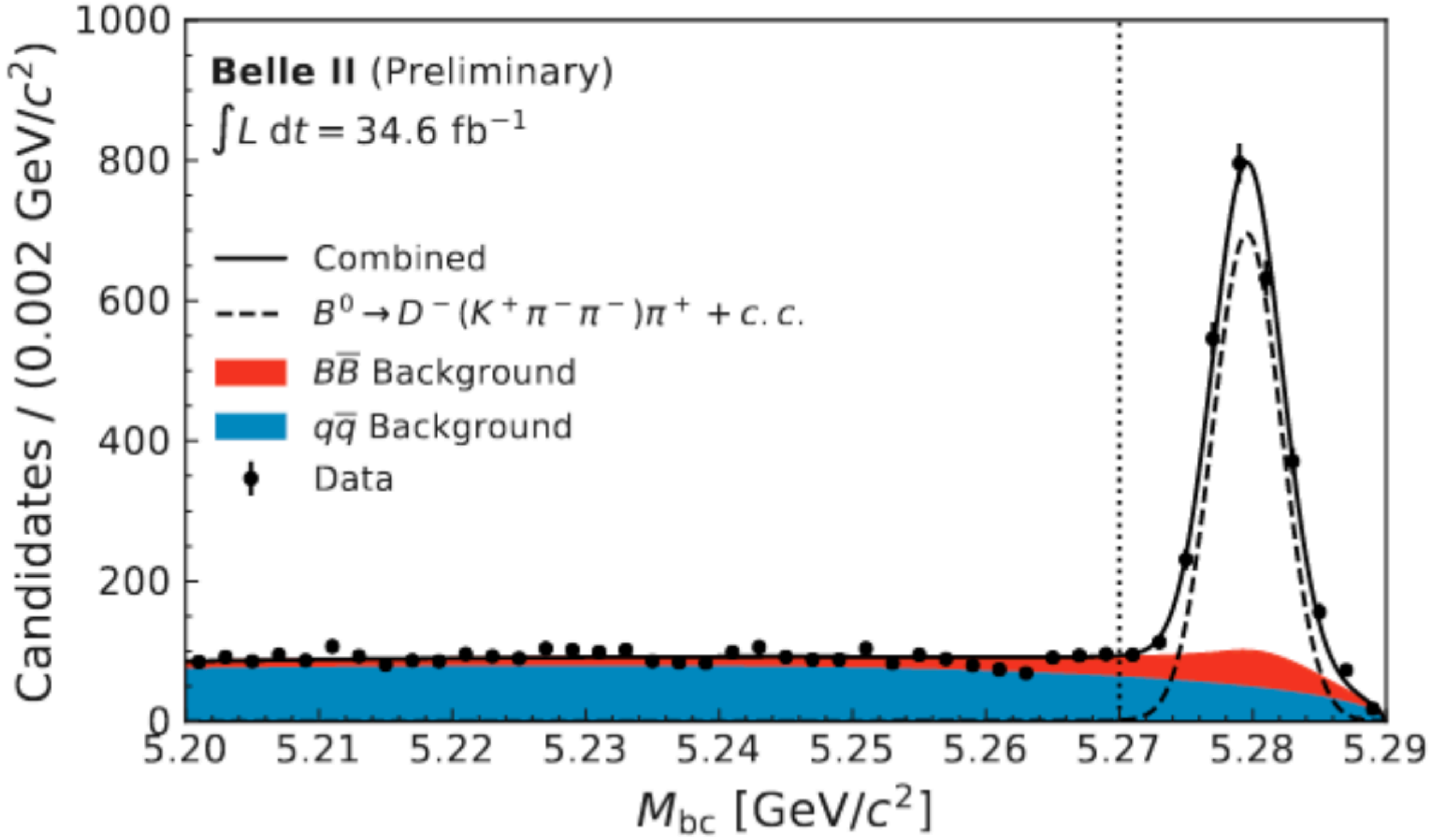
Δm_d can be determined from the asymmetry:

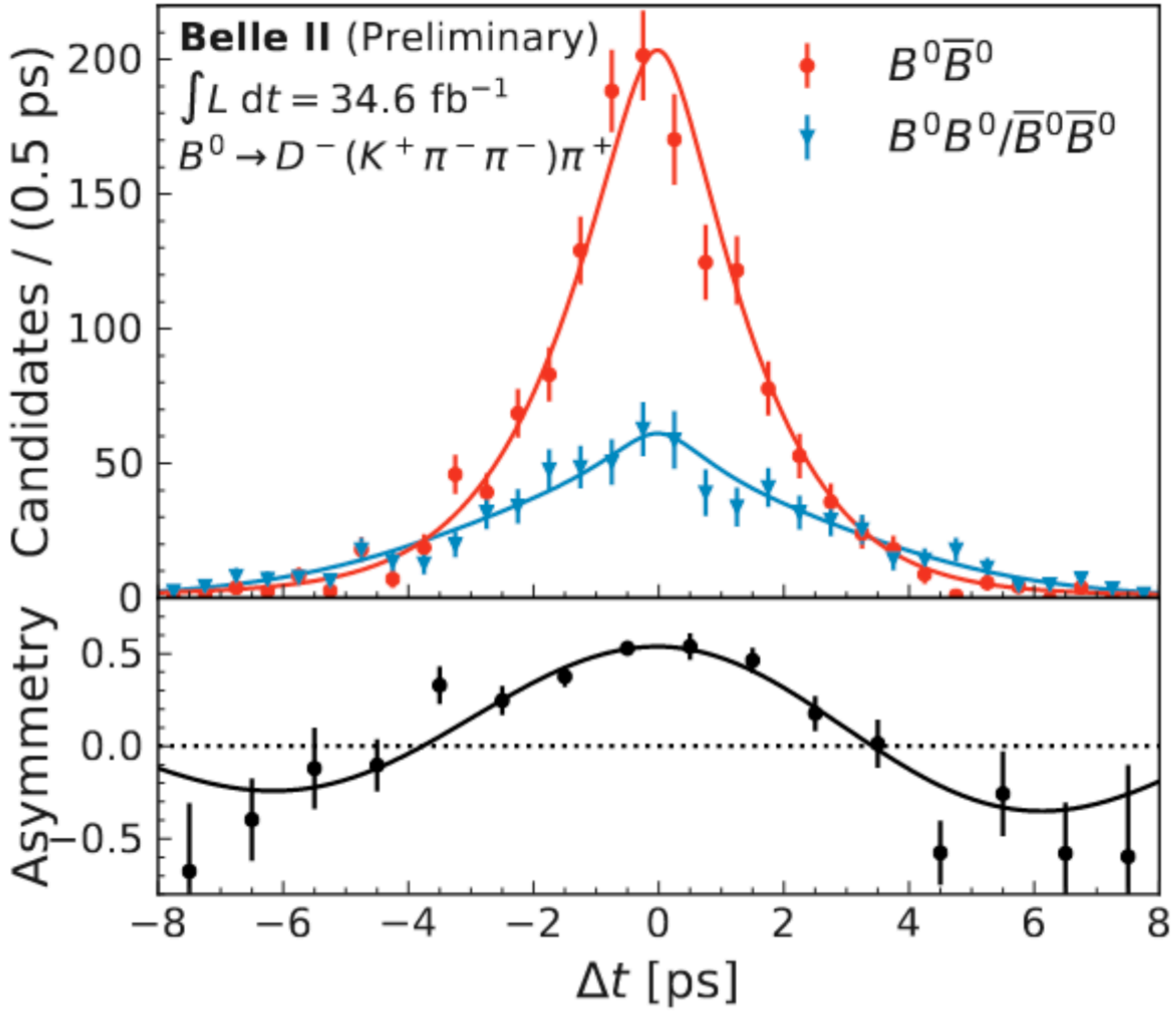
$$A(\Delta t) = \frac{N_{OF} - N_{SF}}{N_{OF} + N_{SF}} = cos(\Delta m_d \Delta t)(1 - 2w) \otimes R(\Delta t)$$

N_{OF}= # opposite flavor

N_{SF}= # same flavor

We performed a time-dependent measurement of Δm_d using the $B^0 \rightarrow D^-(K^+\pi^-\pi^-)\pi^+$ mode.





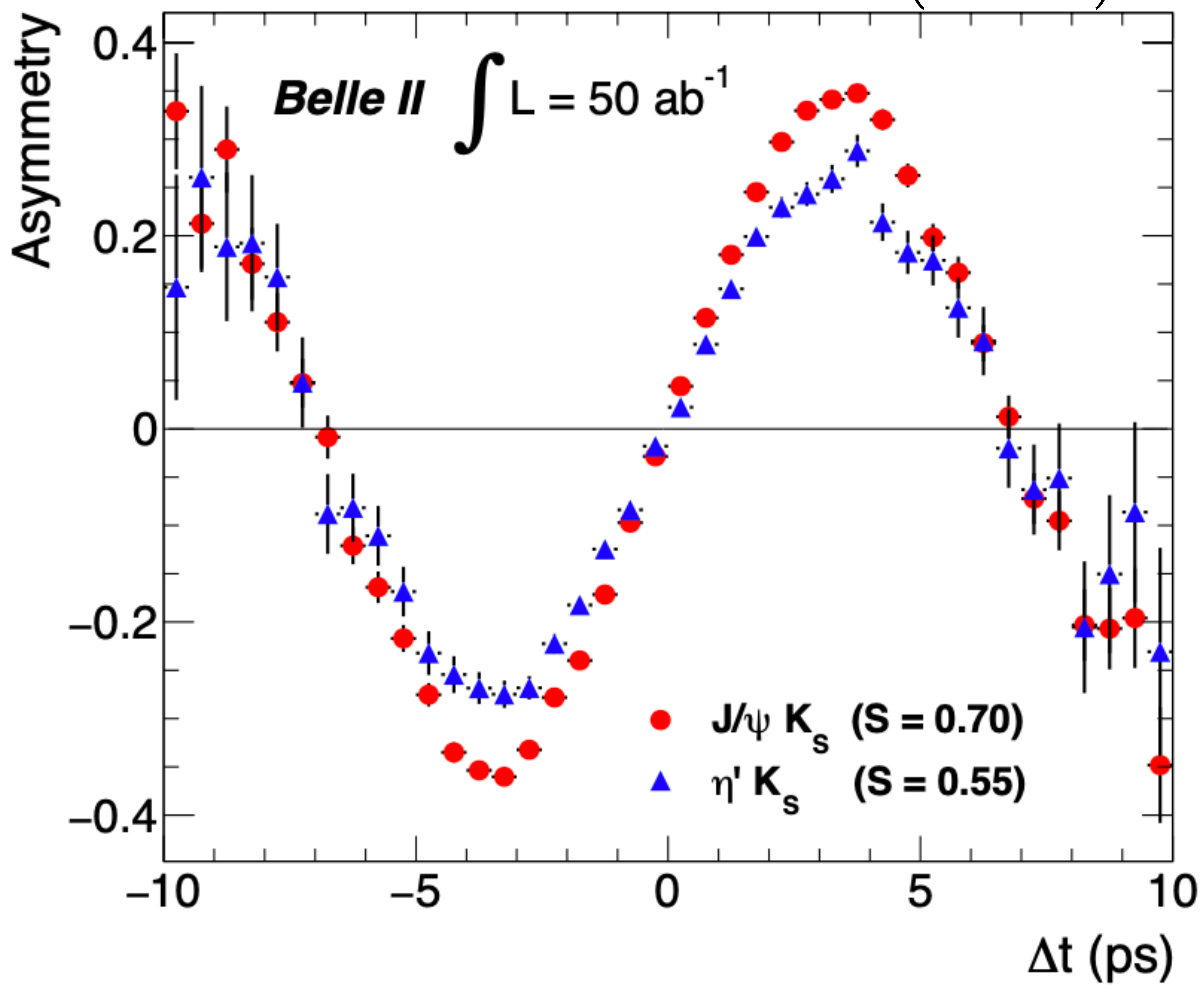
Δm_d = (0.531 ± 0.046 (stat) ± 0.013 (syst)) ps^{-1}

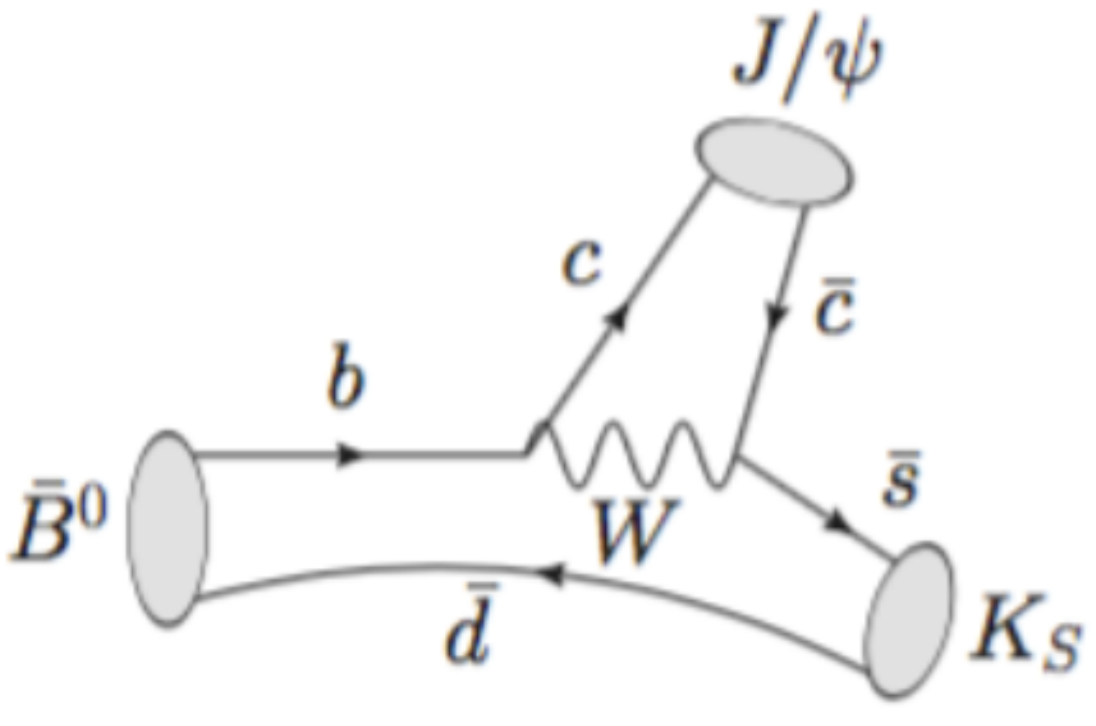
PDG: Δm_d = (0.5065 ± 0.0019) ps^{-1}

Decays for sin2ϕ_1 measurement

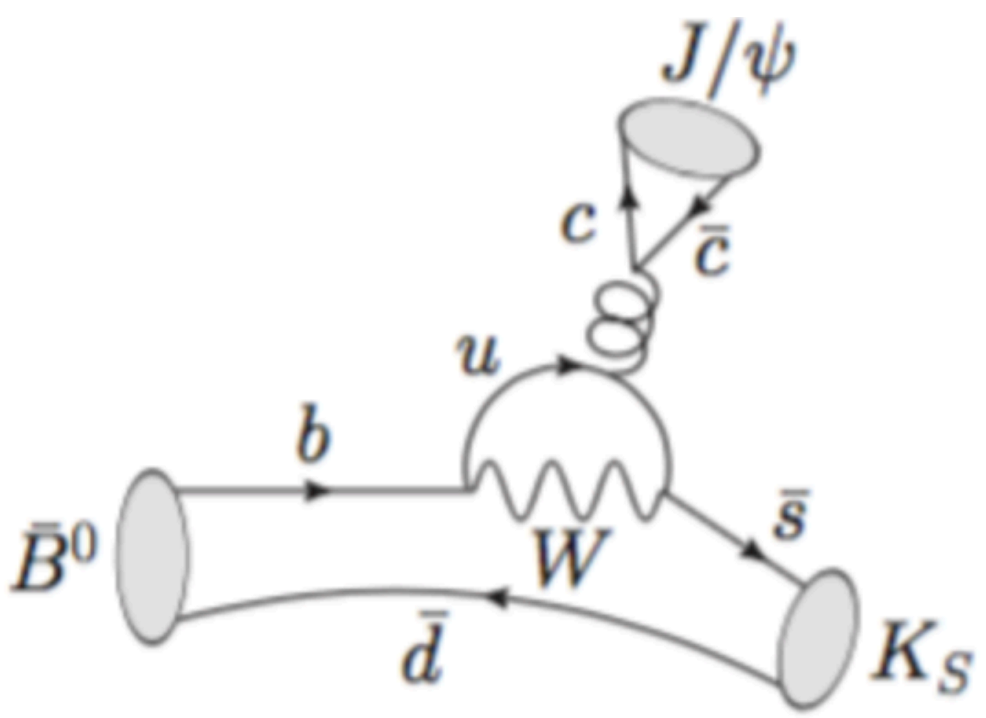
- The angle ϕ_1 can be measured in processes with a tree dominant interaction ($B \to J/\psi K^0$) or with penguin quark transitions ($B \to \eta' K^0_S$).
- Penguin-dominated modes are potentially very sensitive to NP effects
- We performed the first measurement at Belle II of Br for $B \to \eta' K^0_S$ decay but we are still limited by statistics for now
- Meantime we are developing all the tools and performed the first CPV measurement using $B^0 \to J/\psi K^0_S$

Based on simulation ($50 ab^{-1}$)





Tree-level



Penguin pollution

$B^0 \to J/\psi K^0_S$

- clean signature
- contribution from penguin diagram less than 1%

$B \rightarrow \eta' K_S$ decay mode

- $B \rightarrow \eta' K$ is a charmless decay dominated by penguin transition so measurement of CP violation sensitive to new physics in the penguin loop.
- no competition with LHCb expected in this mode due to neutrals in the final state

- Only rediscovery and BR measurement (CP measurement not done yet)

  $B^{\pm} \rightarrow \eta' K^{\pm}$ with $\eta' \rightarrow \eta\pi^{+}\pi^{-}$ or $\eta' \rightarrow \rho\gamma$

  $B^{0} \rightarrow \eta' K_S$ with $\eta' \rightarrow \eta\pi^{+}\pi^{-}$ or $\eta' \rightarrow \rho\gamma$

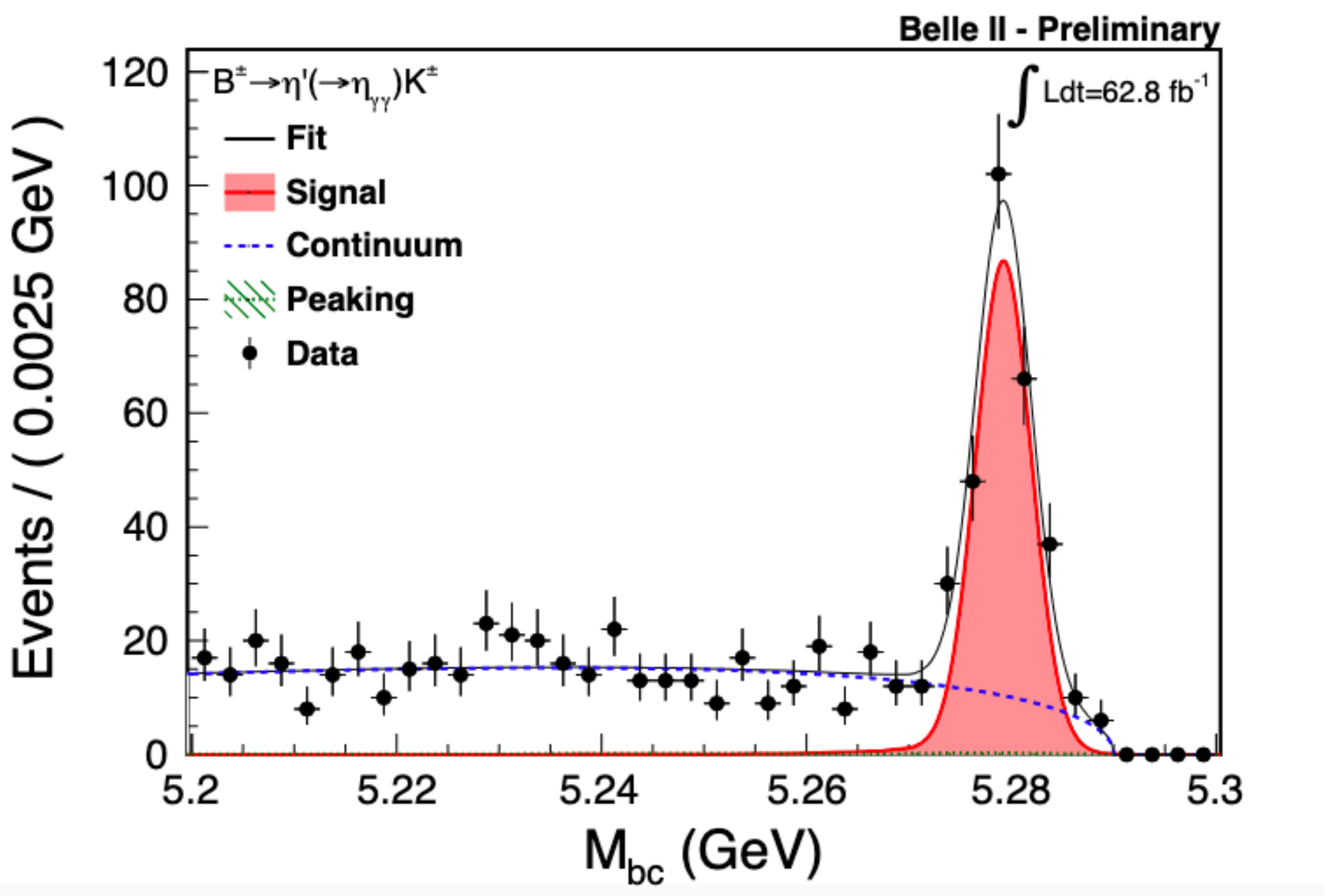
AVERAGE values from
BaBar (467M BB) and Belle(386M BB):

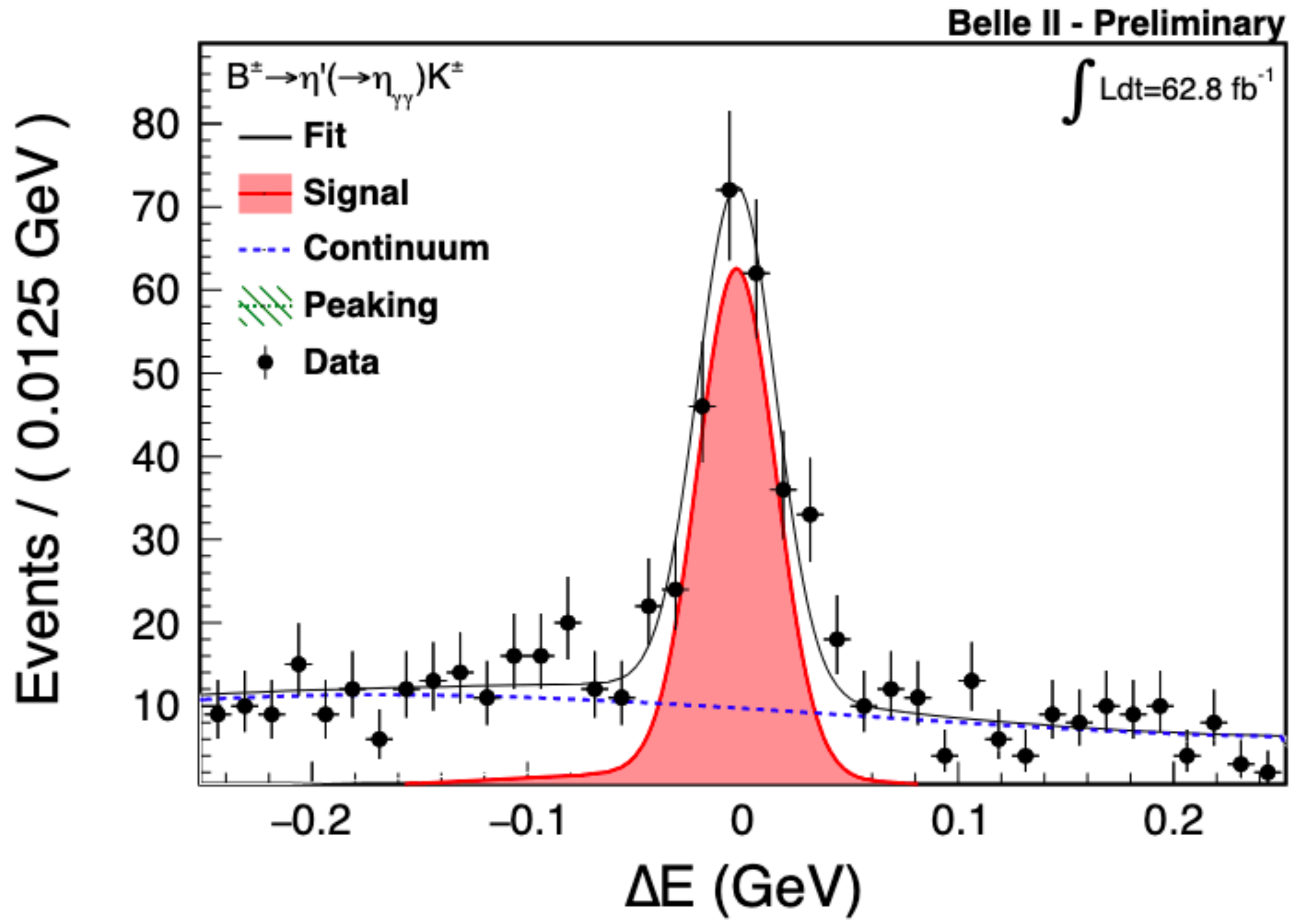
	$B^{\pm} \rightarrow \eta' K^{\pm}$	$B^{0} \rightarrow \eta' K_S$
$B(10^{-6})$	70.4 ± 2.5	66 ± 4

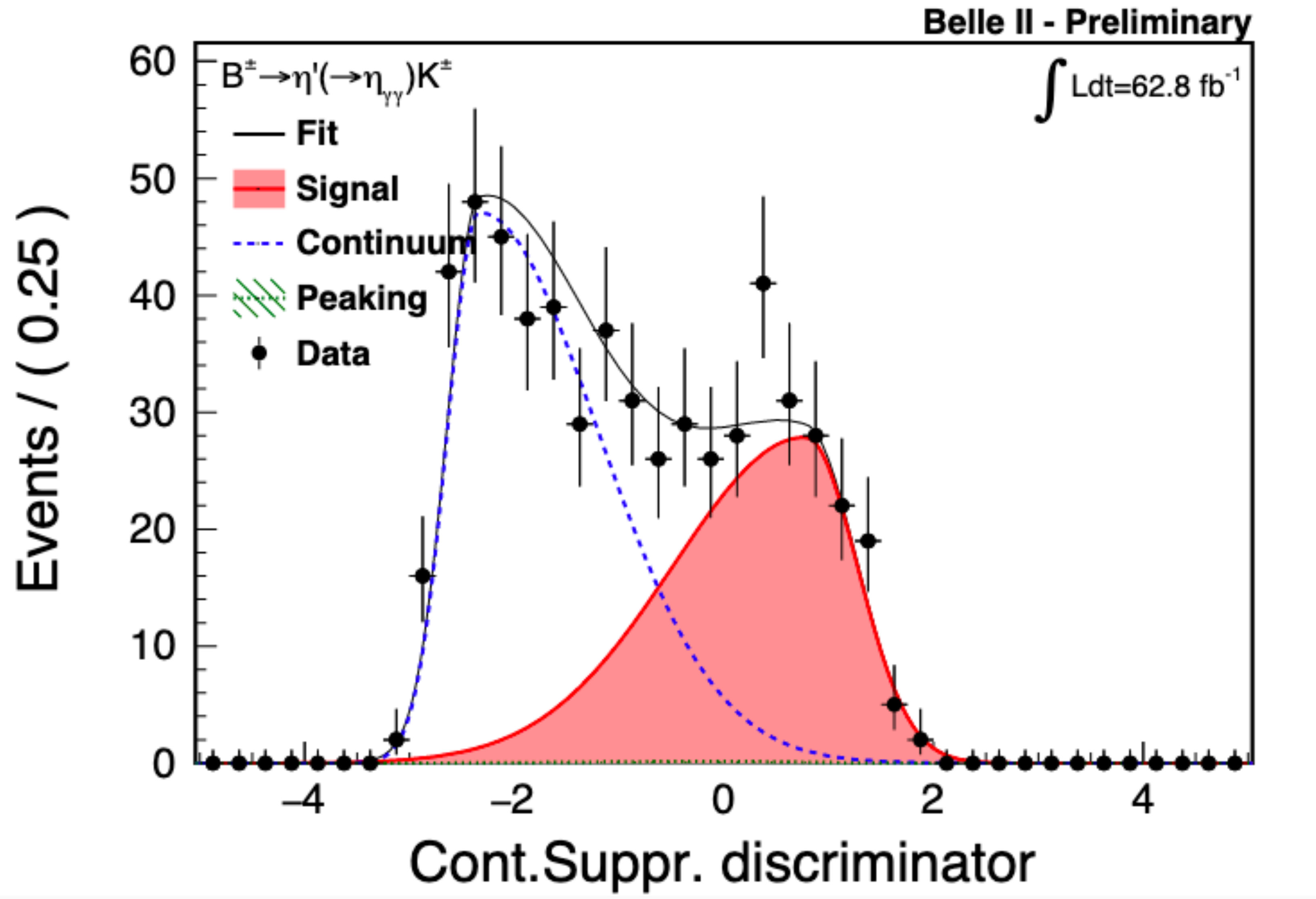
Considering the available luminosity (62.8 fb^{-1}) this measurement is not competitive yet.

First measurement of $B \to \eta' K_S$ at Belle II

$B^{\pm} \to \eta' K^{\pm}$ with $\eta' \to \eta \pi^+ \pi^-$





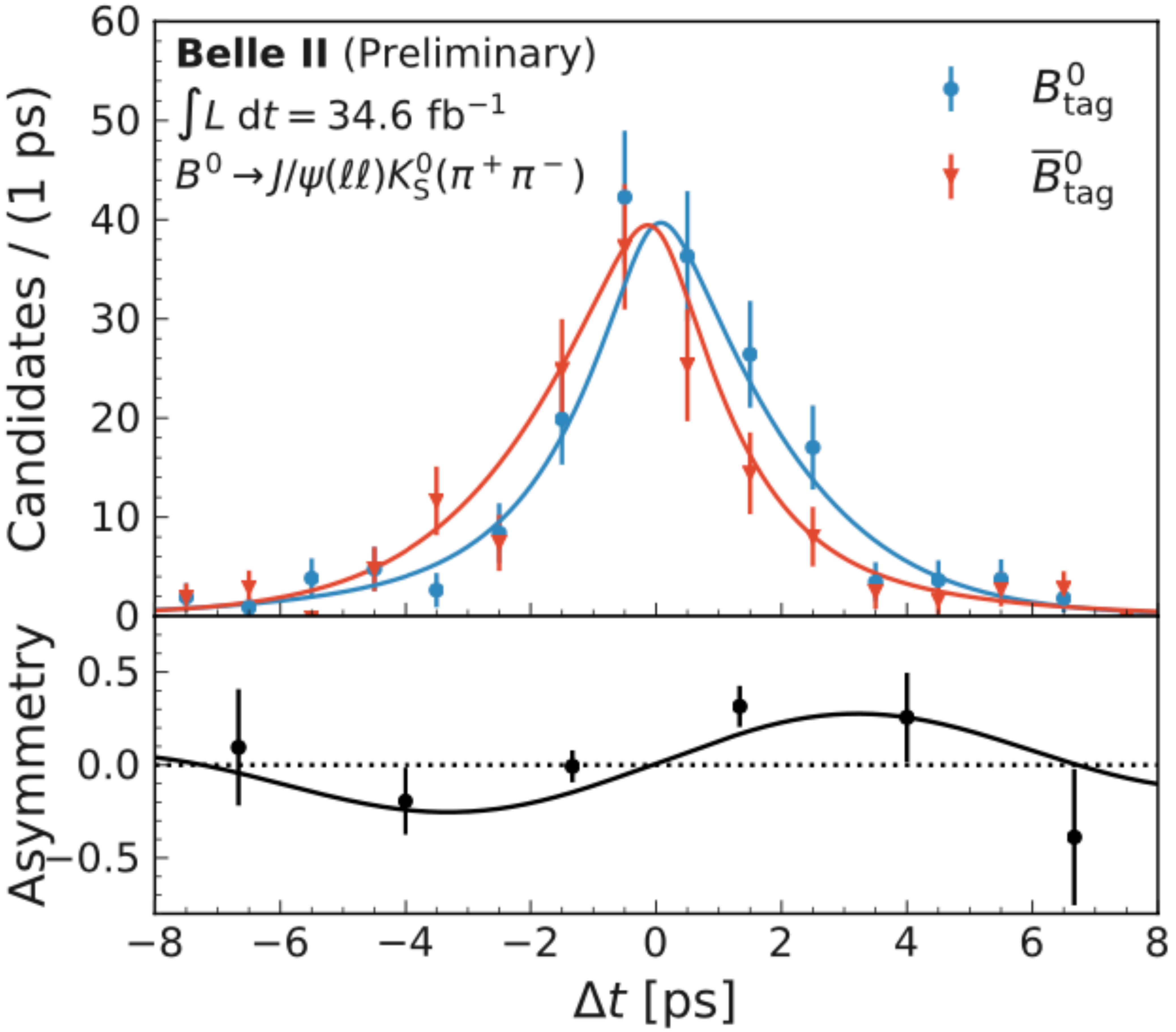


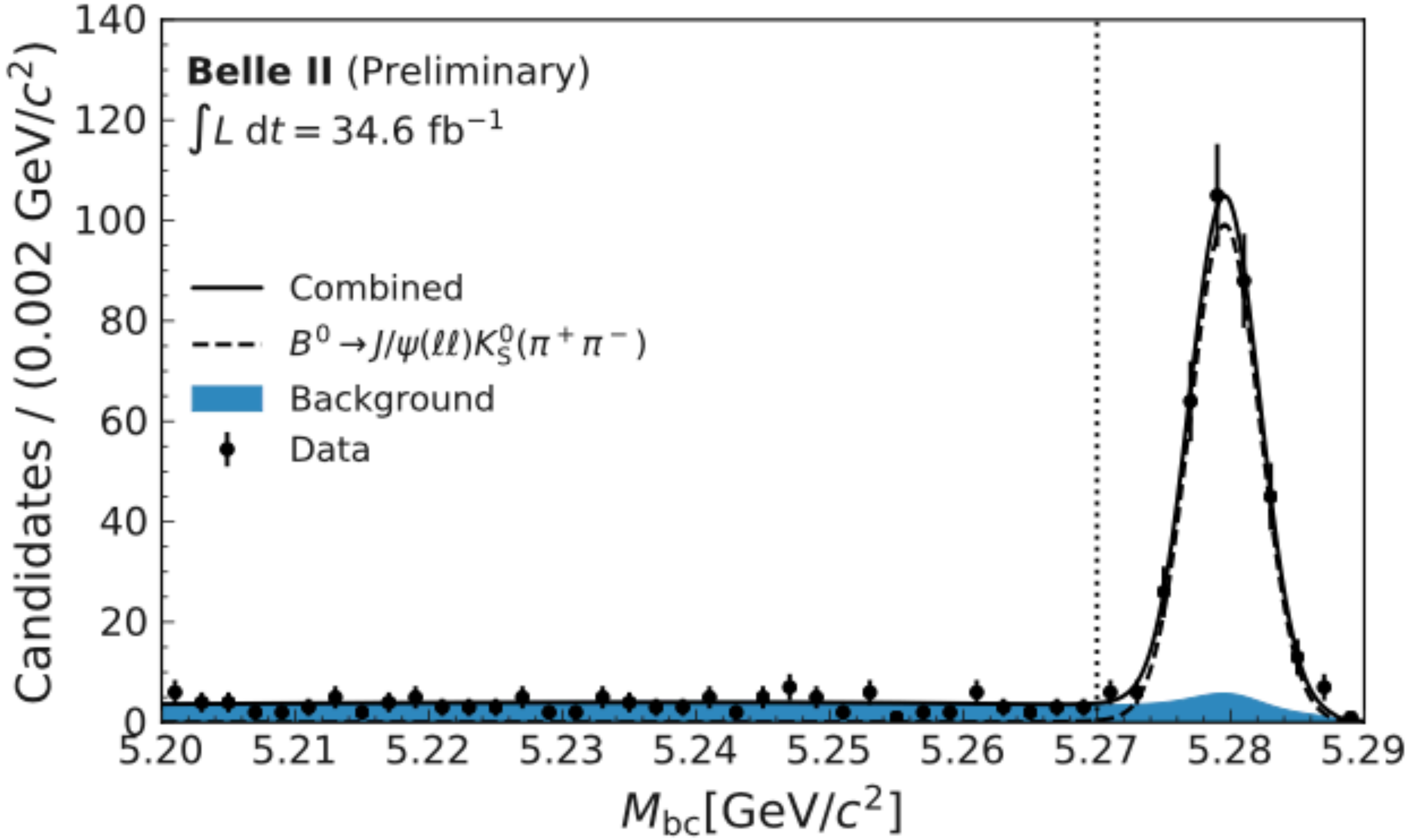
Mode	$\mathcal{B}(10^{-6})$
$B^{\pm} \to \eta'(\to \eta(\to \gamma\gamma)\pi^+\pi^-)K^{\pm}$	$63.9^{+4.6}_{-4.4} \pm 4.0$
$B^{\pm} \to \eta'(\to \eta(\to \pi^+\pi^-)\gamma)K^{\pm}$	$62.9^{+4.8}_{-4.8} \pm 5.5$
$B^0 \to \eta'(\to \eta(\to \gamma\gamma)\pi^+\pi^-)K^0_S$	$61.6^{+8.6}_{-8.0} \pm 3.9$
$B^0 \to \eta'(\to \eta(\to \gamma\gamma)\pi^+\pi^-)K^0_S$	$58.5^{+7.9}_{-7.4} \pm 4.4$

Fit in different η' decays are independent
good agreement between Br

$\sin 2\phi_1$ measurement

- First time-dependent CP violation measurement at Belle II
- Performed with 34.6 fb^{-1}
- Decay mode: $B^0 \rightarrow J/\psi K_S$ with $J/\psi \rightarrow \mu\mu$ or $J/\psi \rightarrow ee$





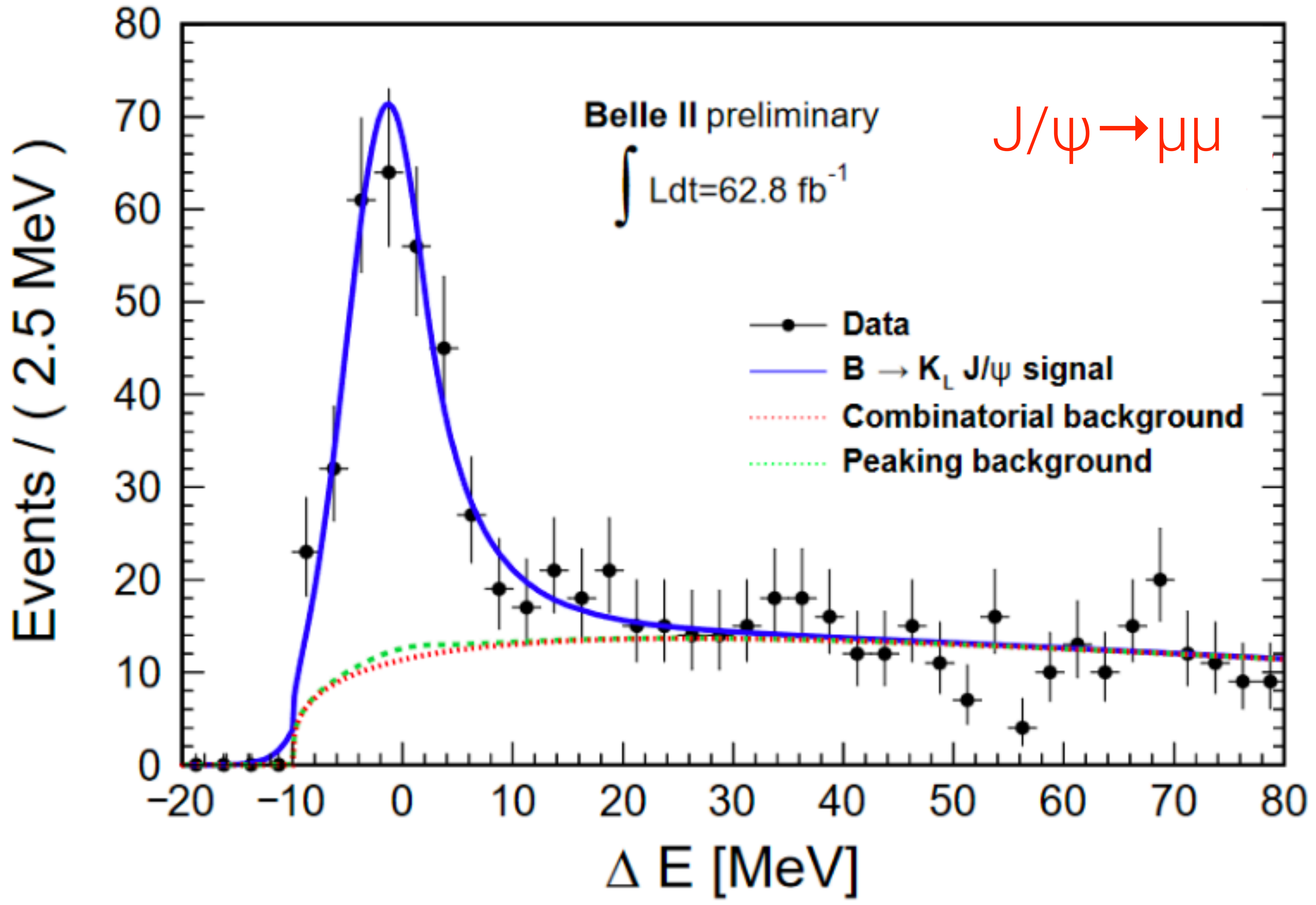
$\sin 2\phi_1 = (0.55 \pm 0.21\ \text{(stat)} \pm 0.04\ \text{(syst)})\ \text{ps}^{-1}$

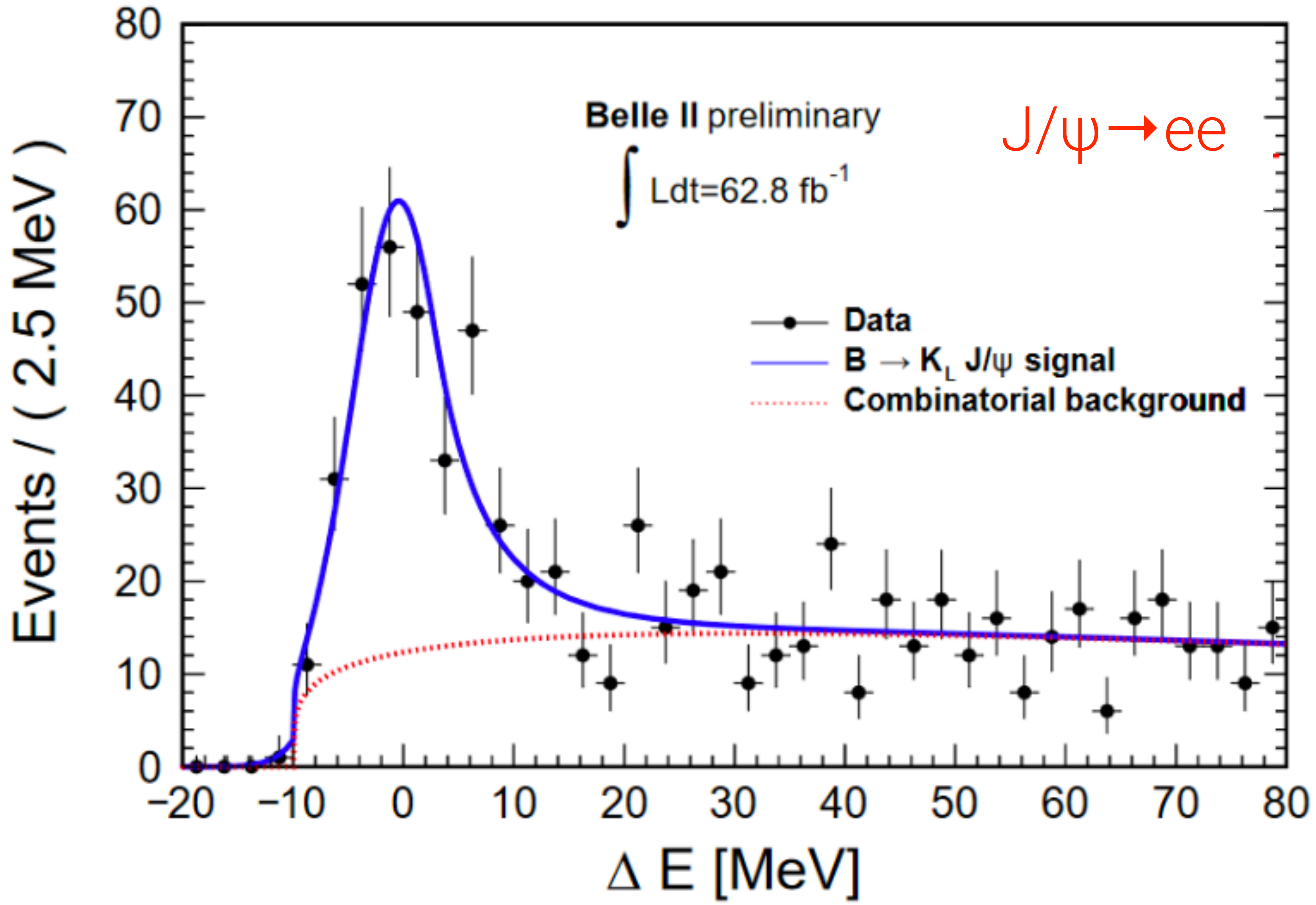
significance ~2.7σ

First measurement of $B^0 \to J/\psi K_L$ at Belle II

Rediscovery of $J/\psi K_L$ with 62.8 fb^{-1}

- $B^0 \to J/\psi K^0$ provides the most precise determination of $\sin(2\phi_1)$
- $B^0 \to J/\psi K^0_L$ provides a measurement of $\sin(2\phi_1)$ independent from $J/\psi K^0_S$ with $\eta_{KL} = -\eta_{KS}$





- The event yield of $(7.3 \pm 0.4)/fb^{-1}$, consistent with Belle
- Next: time-dependent analysis for CPV measurement

Summary

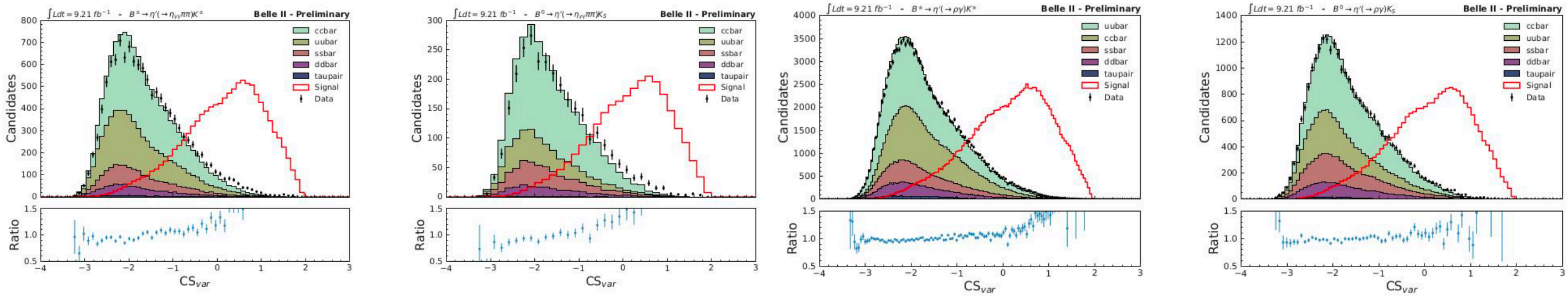
- The existing constraints of CKM triangle angles and sides do not exclude the possibility of contributions from NP
- $\sin 2\phi_1$ measured in loop-dominated modes can provide a powerful way to find evidence of NP
- No competition with LHCb expected in $B \to \eta' K$ mode (first measurement at Belle II)
- First measurement of $\sin 2\phi_1$ from the early Belle II data done using $J/\psi K^0_S$ => 2.7 σ hint for time-dependent CPV
- Towards precision measurements using tree-dominated modes:
    - collect more statistics
    - add more decay modes: first measurement of $B^0 \to J/\psi K^0_L$ at Belle II
    - improved model for the resolution function

So far Belle II has demonstrated good vertex reconstruction capabilities and flavor tagging performance.
This is a good starting point towards the measurement of $\sin 2\phi_1$ with penguin-dominated modes

Backup

Continuum suppression in $B \to \eta' K_S$ measurement

- Dominant background from random combination of particles in continuum events
- A set of variables which are sensitive to the event shape is used in a multivariate approach
  - Kakuno-Super-Fox- Wolfram momenta, Cleo cones, angles of the thrust axis of signal B with respect the rest of event and the beam axis
- All variables which exhibit a correlation greater than 10% with M_{bc} and ΔE are excluded
- The classifier used is based on FastBDT algorithm
- FastBDT Validated on off-resonance data:



Background components in $B^0 \to J/\psi K_L$

- Background is essentially due to $B^0 \bar{B}^0$ and B^+B^- decays (in same amount)
- Due to strong J/ψ signature, no events from the $q\bar{q}$ continuum survive the selection cuts
- Background classification:
    - events with a wrong combination of a real J/ψ and a real K^0_L
    - events with a fake J/ψ
    - events with a true J/ψ and a fake K^0_L (dominant background)

- The fraction of peaking background is determined from fits to the ΔE distributions of generic Montecarlo events
    - $f_{peak} = (0.4 \pm 3.1)\%$ in $\mu\mu$ final state
    - $f_{peak} = (0.0 \pm 3.1)\%$ in ee final state