Charm and beauty hadron decays at Belle and Belle II

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QCD & High Energy Interactions
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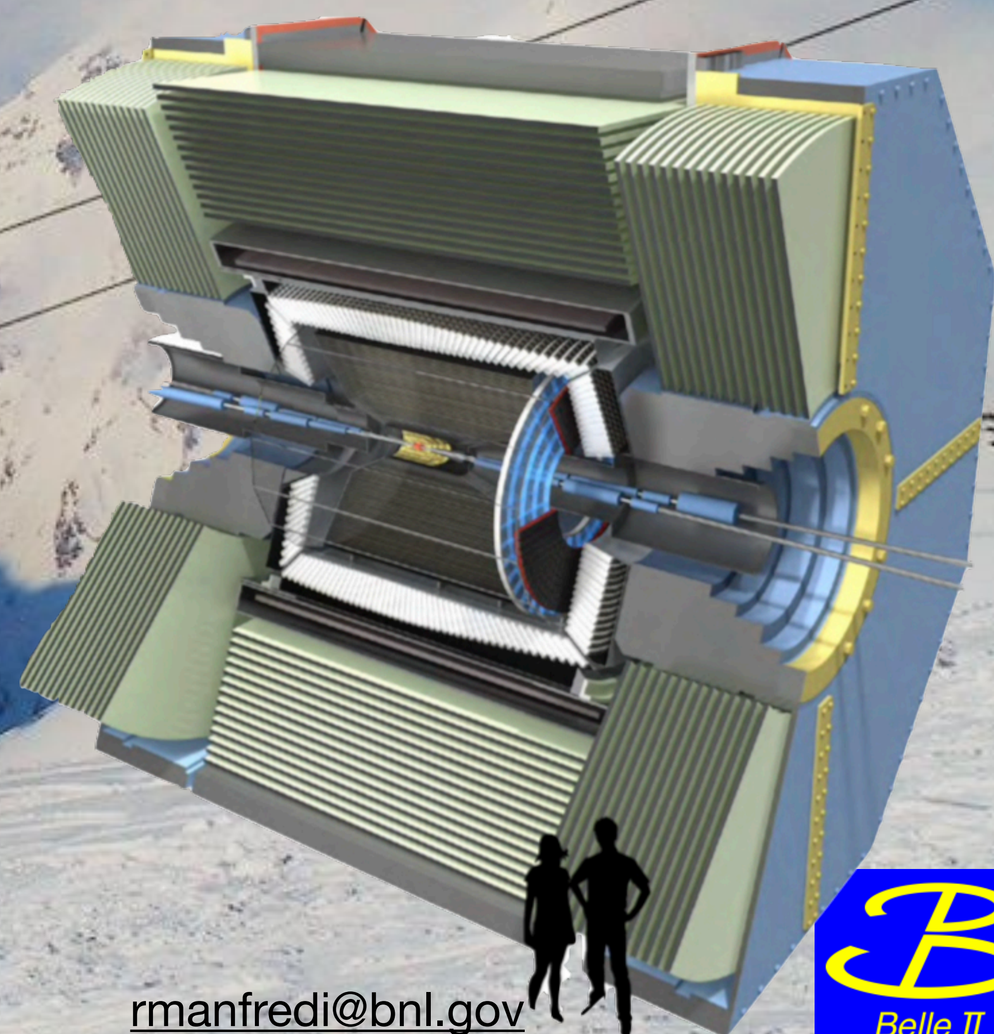
on behalf of the Belle II collaboration



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Beauty and charm factories

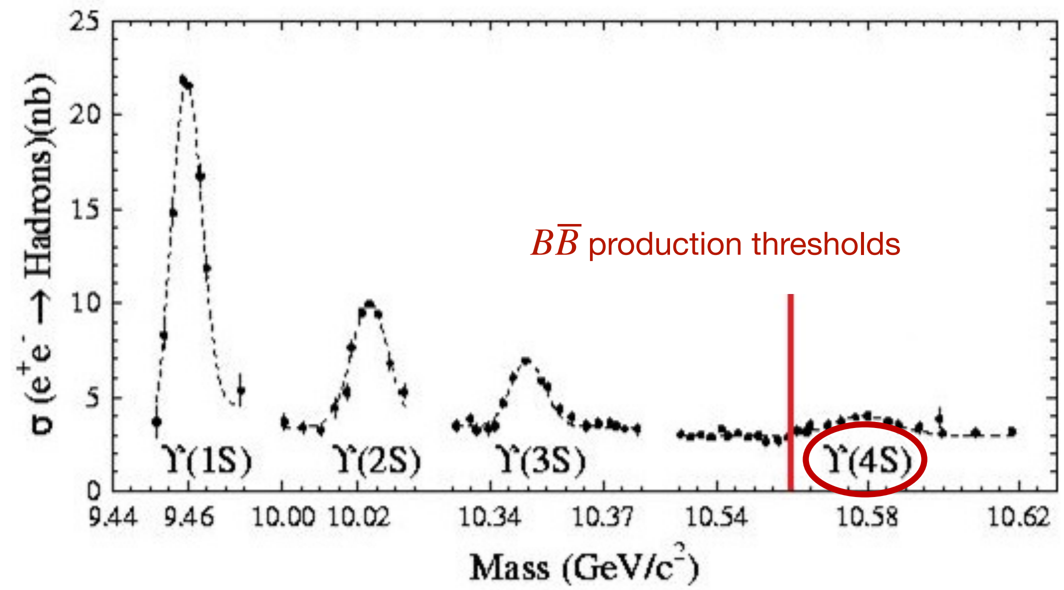
Energy-asymmetric e^+e^- collisions at the $\Upsilon(4S)$, clean $B\overline{B}$ production
+ large $q\bar{q}$ production, $c\bar{c}$ significant fraction

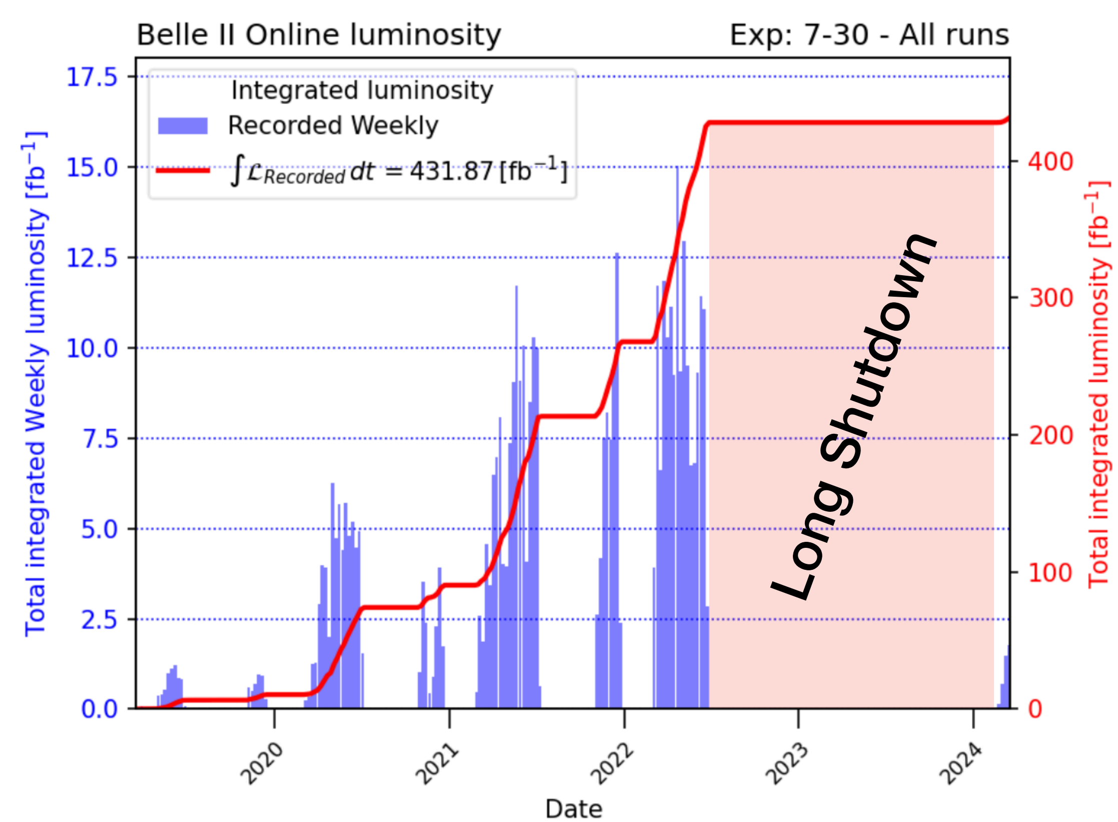
Belle II: ~390M $B\overline{B}$ + ~560M charmed hadron pairs. Data-taking resumed on Feb 15
Belle: additional ~770M $B\overline{B}$ + ~1.3B charmed hadron pairs (data taking ended in 2010)

Belle II compared to Belle
- much improved vertexing
- greater acceptance
- design 30x instantaneous luminosity

⇒ similar performance with 20x machine bkg

Exploit Belle + Belle II dataset combination



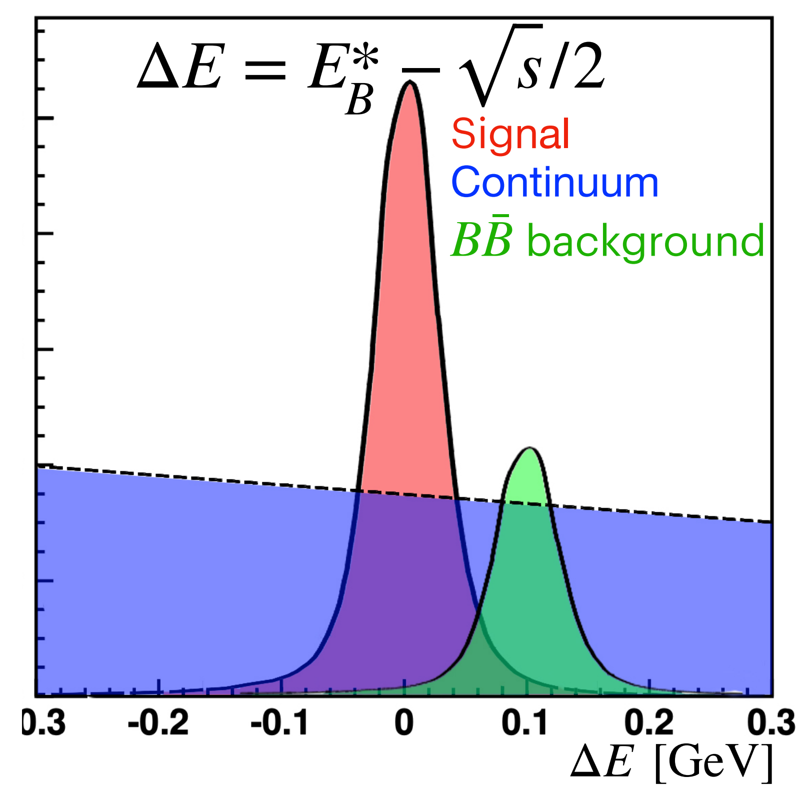


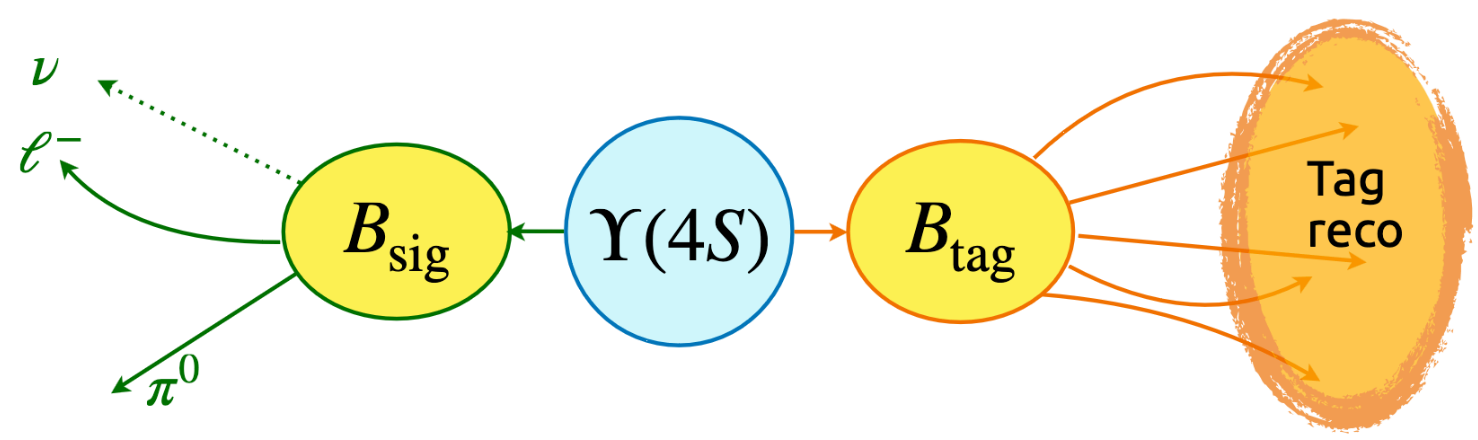
B physics at Belle (II)

Threshold and coherent production of $B\overline{B}$ meson pairs + precise knowledge of collision energy → specific observables

Infer flavor of signal B meson from features of the "other" one (tagging)

Reconstruct the decay of the tag B to constrain kinematics of the signal





New for Moriond

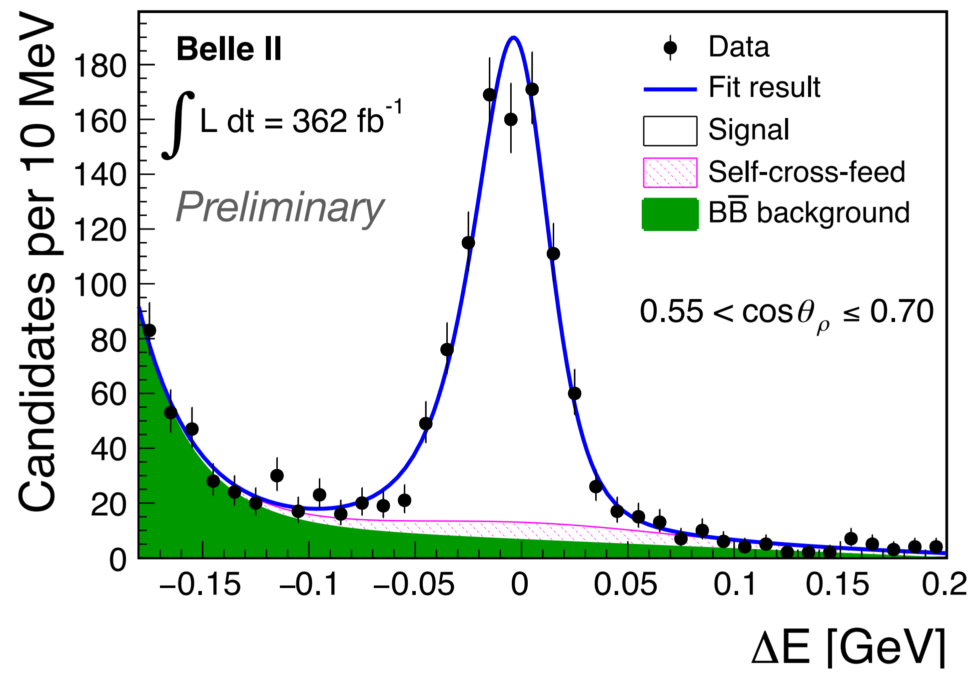
Branching fraction of $B^- \to D^0\rho^-$

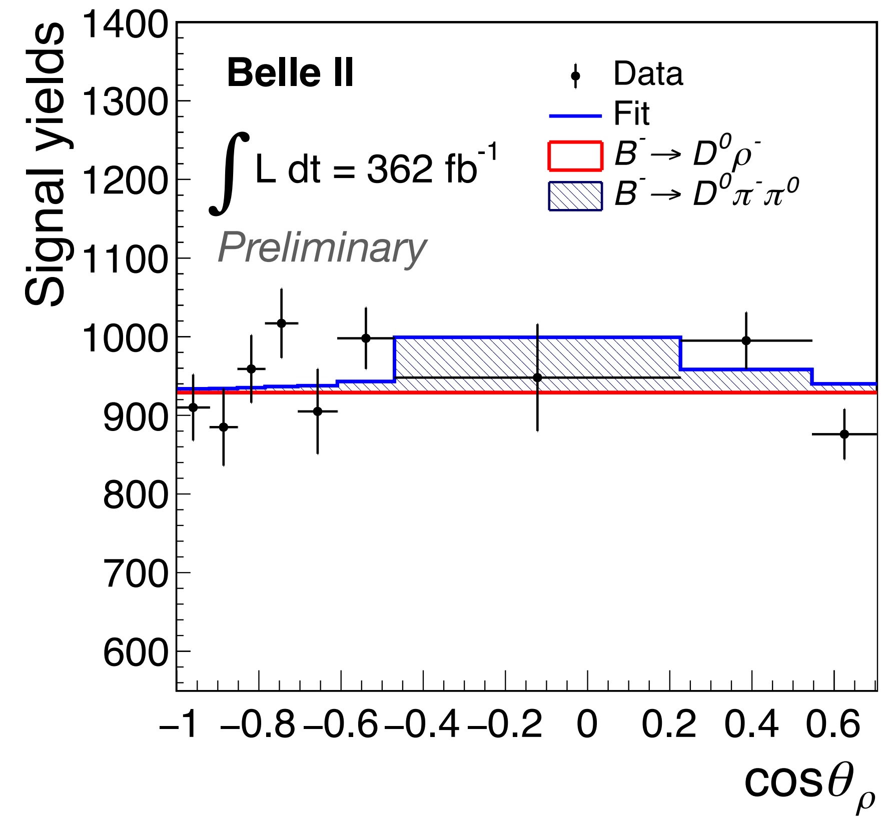
One of the dominant hadronic B decays + test of QCD factorization models.
WA dominated by 1994 measurement

Fit ΔE to subtract background, then fit ρ angular distribution ($\cos\theta_\rho$) to separate signal and non-resonant $B^- \to D^0\pi^-\pi^0$

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

World best result, more than a factor 2 precision improvement





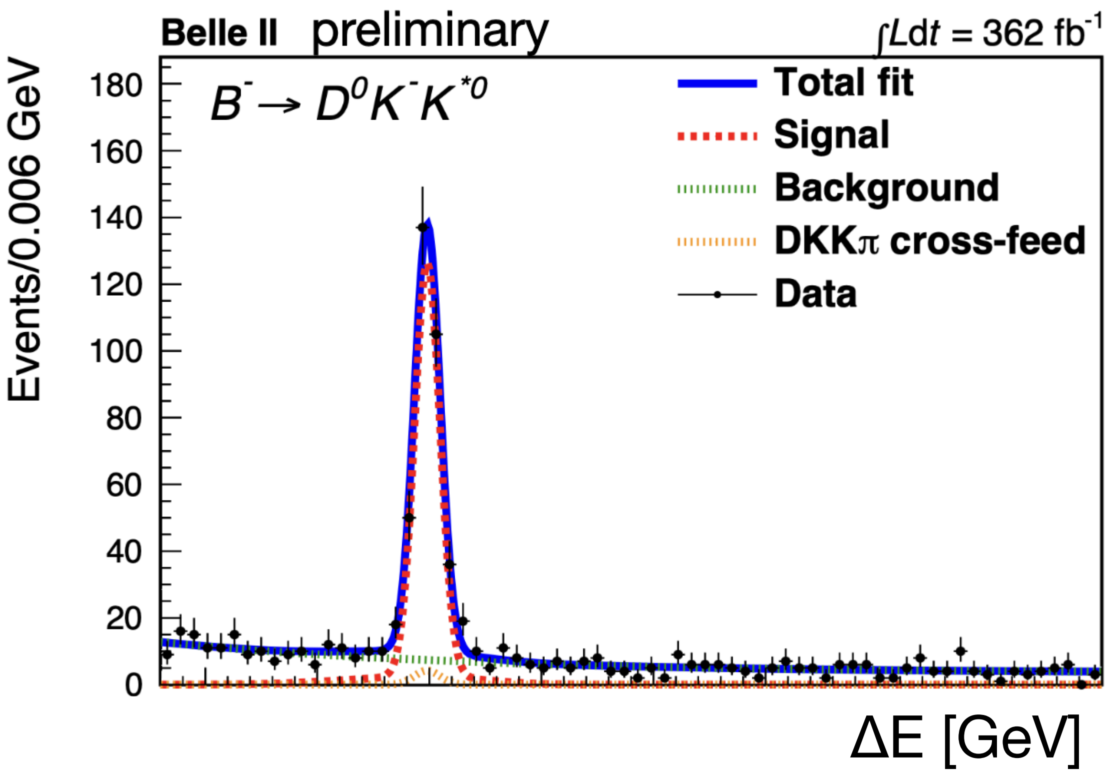
New for Moriond

Branching fractions of $B \to D^{(*)}K^- K^{(*)0}$

DKK mostly unexplored sector: expect few % of BF, measured only 0.28%

Measure signals in ΔE fits, for final states with a K^* fit $m(K\pi)$ distribution to constrain non-resonant fraction

Observed 3 new DKK_S^0 decay modes, improved precision by a factor 3 in the other DKK modes



$\mathcal{B}(B^- \to D^0 K^- K_S^0) = (1.82 \pm 0.16 \pm 0.08) \times 10^{-4}$

$\mathcal{B}(\overline{B}^0 \to D^+ K^- K_S^0) = (0.82 \pm 0.12 \pm 0.05) \times 10^{-4}$

$\mathcal{B}(B^- \to D^{*0} K^- K_S^0) = (1.47 \pm 0.27 \pm 0.10) \times 10^{-4}$

$\mathcal{B}(\overline{B}^0 \to D^{*+} K^- K_S^0) = (0.91 \pm 0.19 \pm 0.05) \times 10^{-4}$

$\mathcal{B}(B^- \to D^0 K^- K^{*0}) = (7.19 \pm 0.45 \pm 0.33) \times 10^{-4}$

$\mathcal{B}(\overline{B}^0 \to D^+ K^- K^{*0}) = (7.56 \pm 0.45 \pm 0.38) \times 10^{-4}$

$\mathcal{B}(B^- \to D^{*0} K^- K^{*0}) = (11.93 \pm 1.14 \pm 0.93) \times 10^{-4}$

$\mathcal{B}(\overline{B}^0 \to D^{*+} K^- K^{*0}) = (13.12 \pm 1.21 \pm 0.71) \times 10^{-4}$

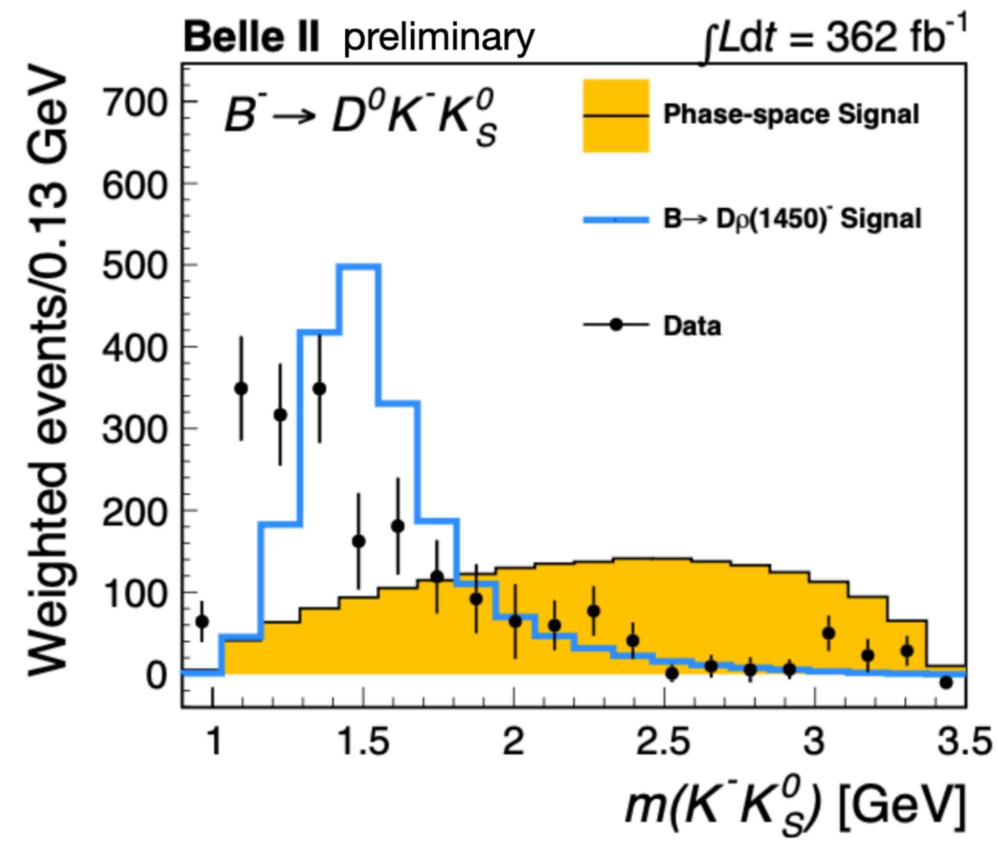
New for Moriond

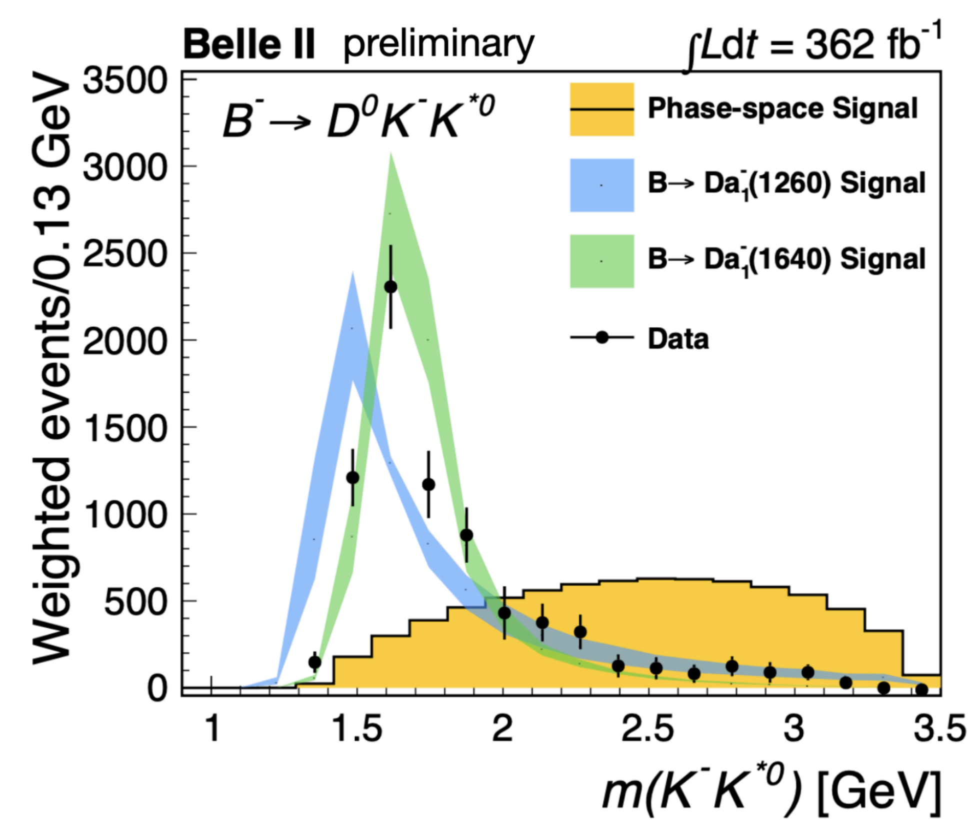
Branching fractions of $B \to D^{(*)}K^-K^{(*)0}$

Extracted background-subracted and efficiency-corrected invariant mass and angular distributions

Low-mass structures in $m(K^-K^0_S)$ and $m(K^-K^{*0})$ qualitatively compatible with ρ or a_1 intermediate resonances

Recent calculations validate that low-mass region is dominated by $\rho(770,1450)$ [arxiv:2403.07499]





Charmed hadron decays

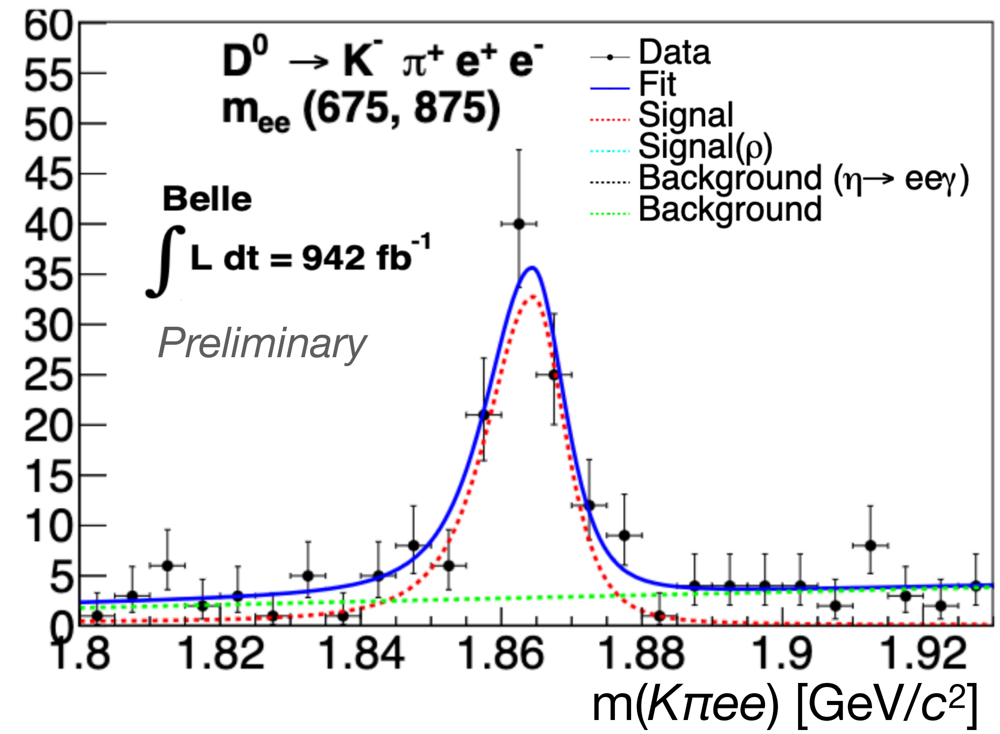
Search for rare $D^0 \to h^- h^{(\prime)+} e^+ e^-$ decays

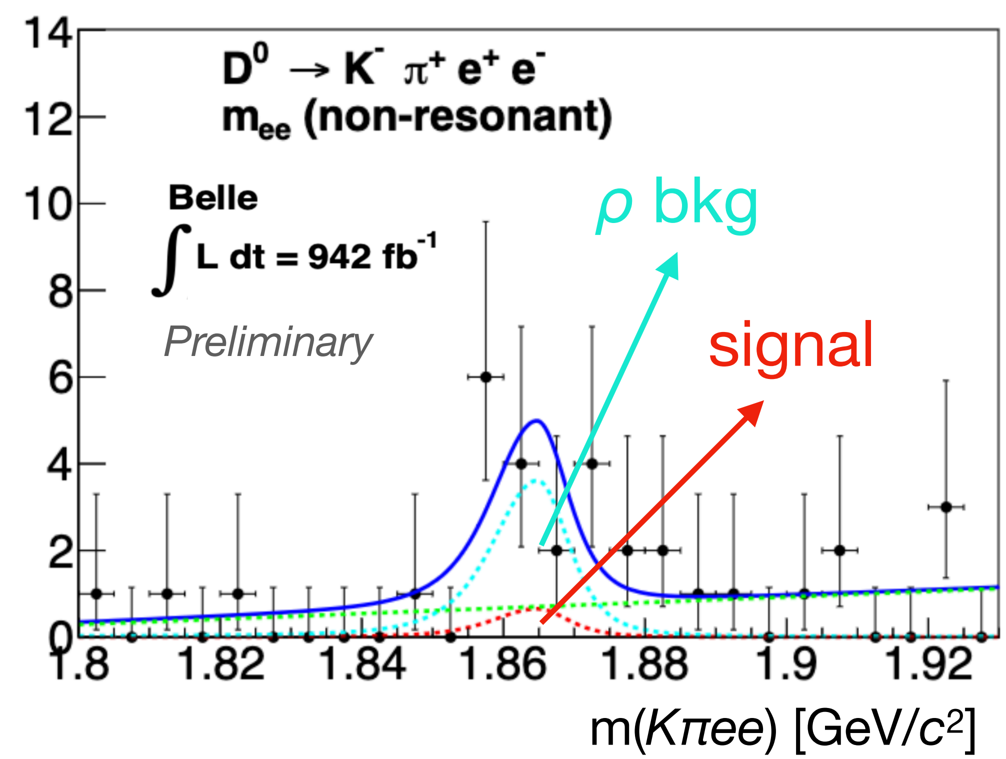
Belle-only data.
Sensitive to FCNC in the non-resonant $m(e^+e^-)$ regions

Reconstruct decays with $h^{(\prime)} = K, \pi$ in different $m(e^+e^-)$ regions, each with optimized selection

$\mathscr{B}(D^0 \to K^- \pi^+ e^+ e^-) = (39.6 \pm 4.5 \pm 2.9) \times 10^{-7}$
in $m_{ee}(675{,}875)$ MeV

Precision comparable with WA.
World's best upper limits on all other regions and on other channels





New for Moriond

Measurements of $\Xi_c^0 \to \Xi^0\pi^0, \Xi^0\eta, \Xi^0\eta'$

Belle + Belle II combined analysis

Reconstruct as $\Xi^{+,0} \to \Lambda(\to p\pi)\pi^{+,0}$, $\eta' \to \eta\pi\pi$ and $\pi^0/\eta \to \gamma\gamma$, extract signals fitting the $m(\Xi\pi)$ distributions

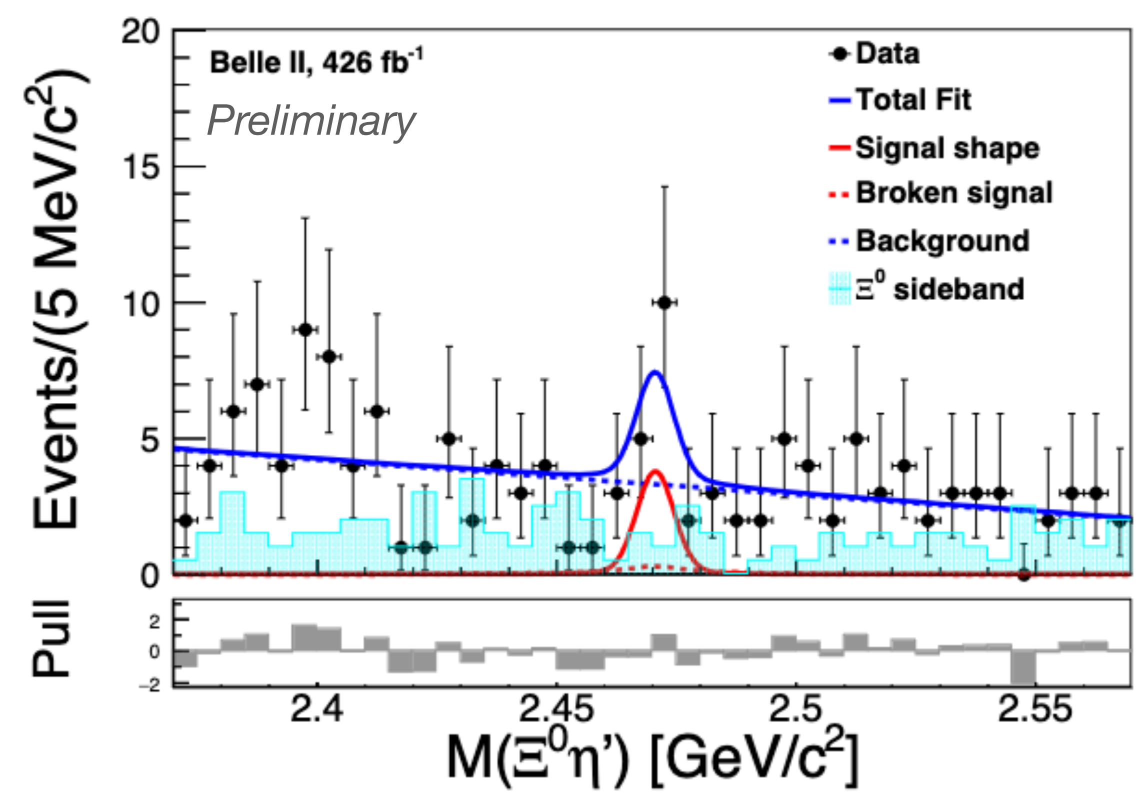
$$\mathscr{B}(\Xi_c^0 \to \Xi^0\pi^0) = (7.2 \pm 0.3 \pm 0.5 \pm 1.6) \times 10^{-3}$$

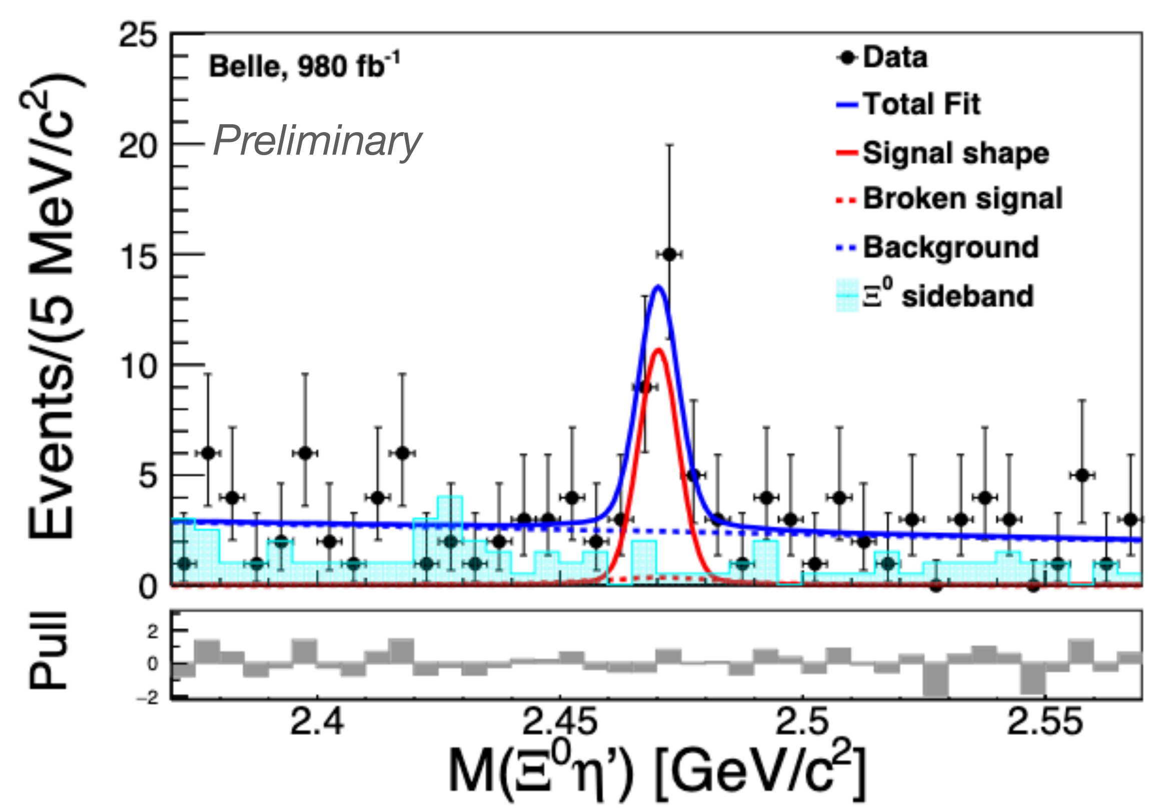
$$\mathscr{B}(\Xi_c^0 \to \Xi^0\eta) = (1.7 \pm 0.2 \pm 0.2 \pm 0.4) \times 10^{-3}$$

$$\mathscr{B}(\Xi_c^0 \to \Xi^0\eta') = (1.3 \pm 0.3 \pm 0.1 \pm 0.3) \times 10^{-3}$$

First measurements for all these decays

Comparable with only one of the three theoretical prediction [JHEP 02 (2023) 235]





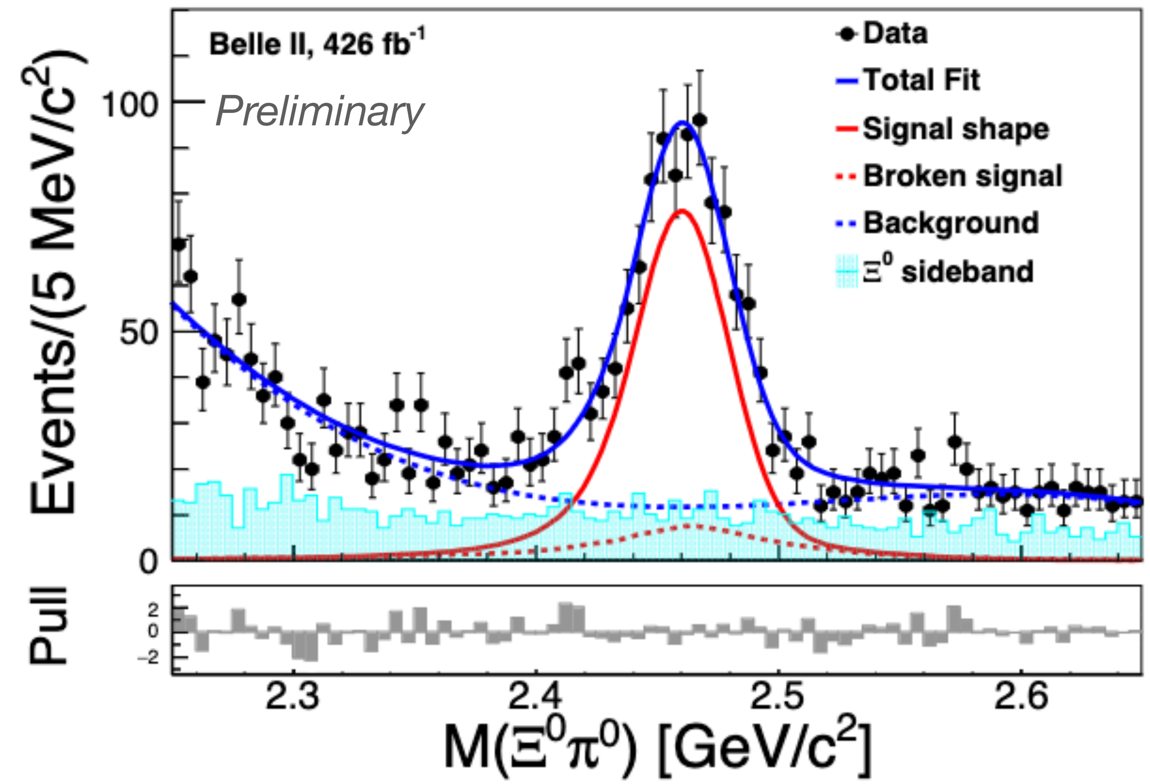
New for Moriond

Measurements of $\Xi_c^0 \to \Xi^0\pi^0, \Xi^0\eta, \Xi^0\eta'$

Differential decay rate is

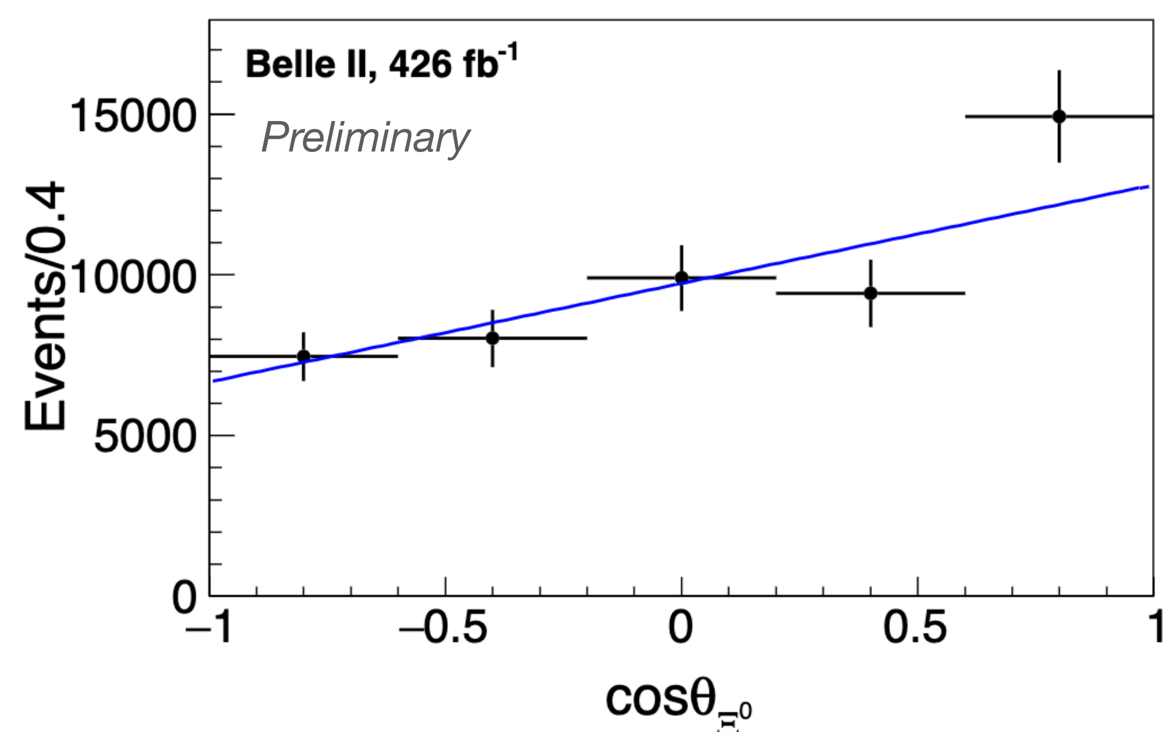
$$\frac{dN}{d\cos\theta_{\Xi^0}} = 1 + \alpha(\Xi^0\pi^0)\alpha(\Lambda\pi^0)cos\theta_{\Xi^0}$$

with $\alpha(\Xi^0\pi^0)$ asymmetry parameter related to P-violation



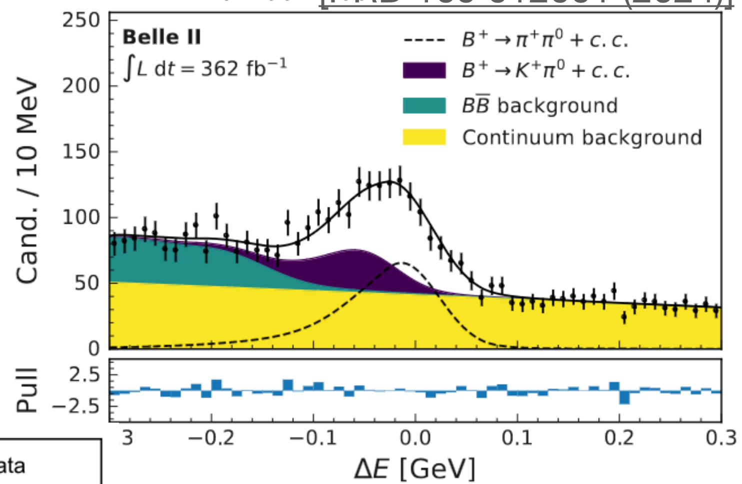
Measure signal yield in bins of helicity angle, extract asymmetry from linear fit simultaneous to Belle and Belle II

$$\alpha(\Xi^0\pi^0) = -0.91 \pm 0.15 \pm 0.23$$

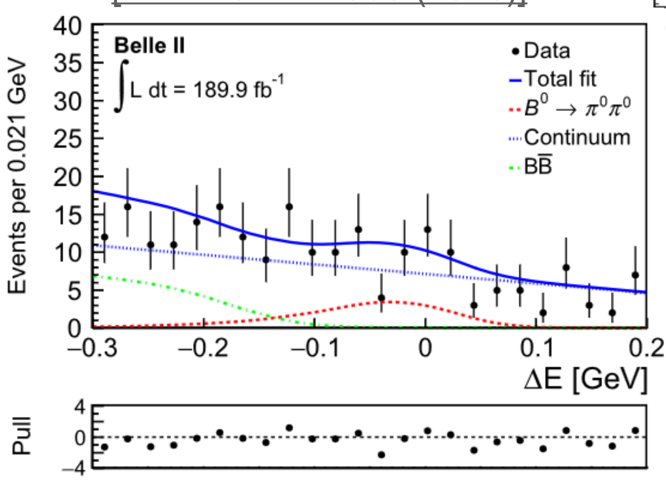


Testing the Standard Model

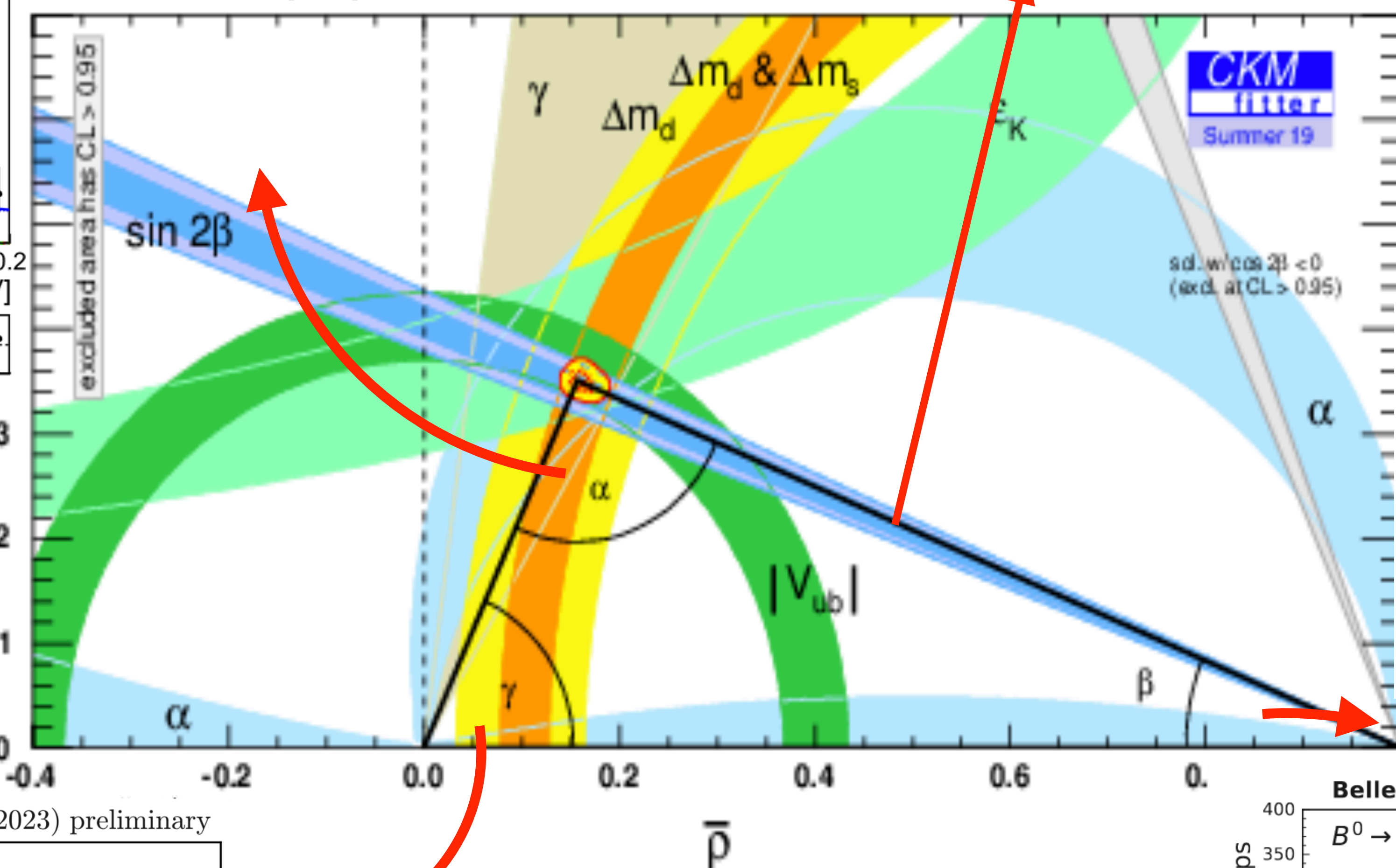
[PRD 109 012001 (2024)]



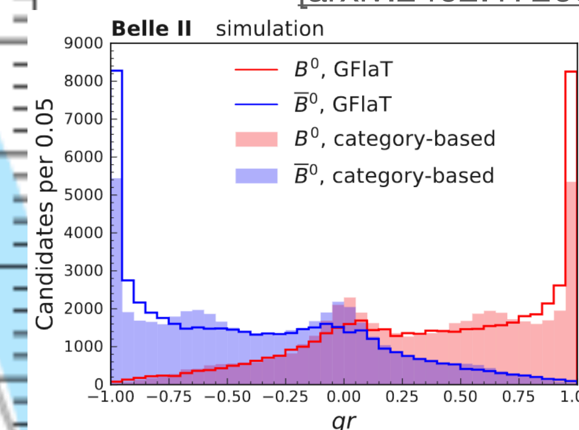
[PRD 107 112009 (2023)]

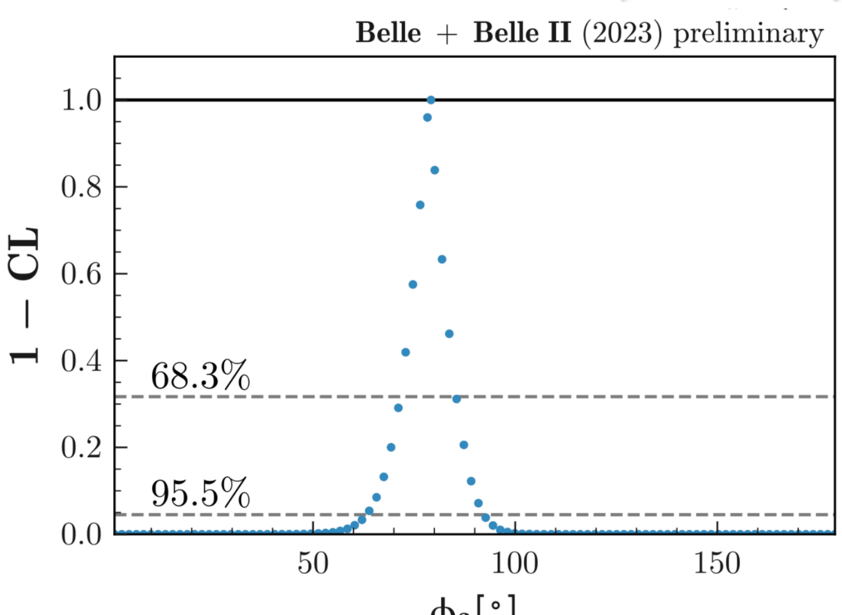


Sides: see Svenja's talk later today

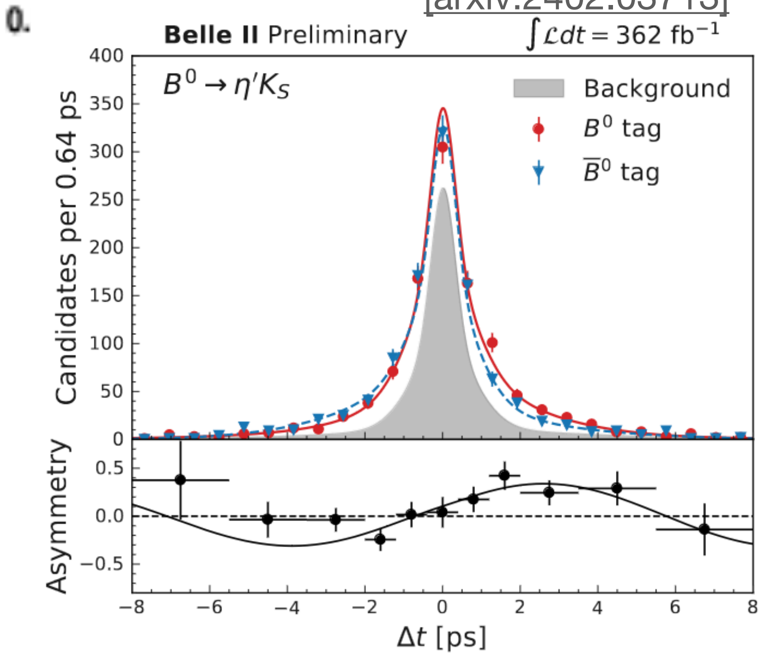


[arxiv:2402.17260]





[arxiv:2402.03713]



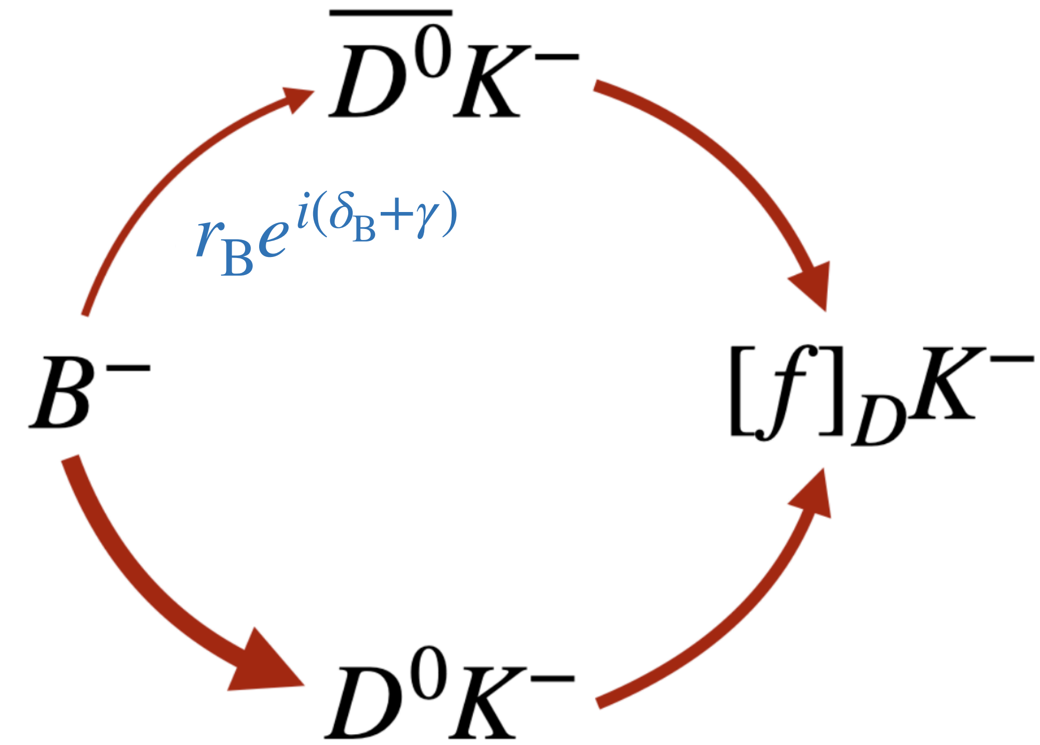
Belle + Belle II determination of γ

Preliminary

Phase between *b*→*c* and *b*→*u*.
Tree-dominated: precise SM reference
HFLAV: $\left(66.2^{+3.4}_{-3.6}\right)^{\circ}$

Access with interfering decays to same final states. Many Belle + Belle II results:

- $D \to K_S hh$ [JHEP 02 063 (2022)]
- $D \to K_S K\pi$ [JHEP 09 146] (2023)]
- $D \to K_S \pi^0, KK$ [arxiv:2308.05048]



$$\frac{\mathscr{A}^{\text{suppr.}}\left(B^- \to \overline{D}^0 K^-\right)}{\mathscr{A}^{\text{favor.}}\left(B^- \to D^0 K^-\right)} = r_B e^{i(\delta_B+\gamma)}$$

First γ determination using only Belle and Belle II results

$$\gamma = (78.6 \pm 7.3)^{\circ}$$

Towards β determination

Measurement in penguin-dominated decays, sensitive to BSM physics.
$B^0 \to \eta' K_S^0$ final state unique to Belle II.

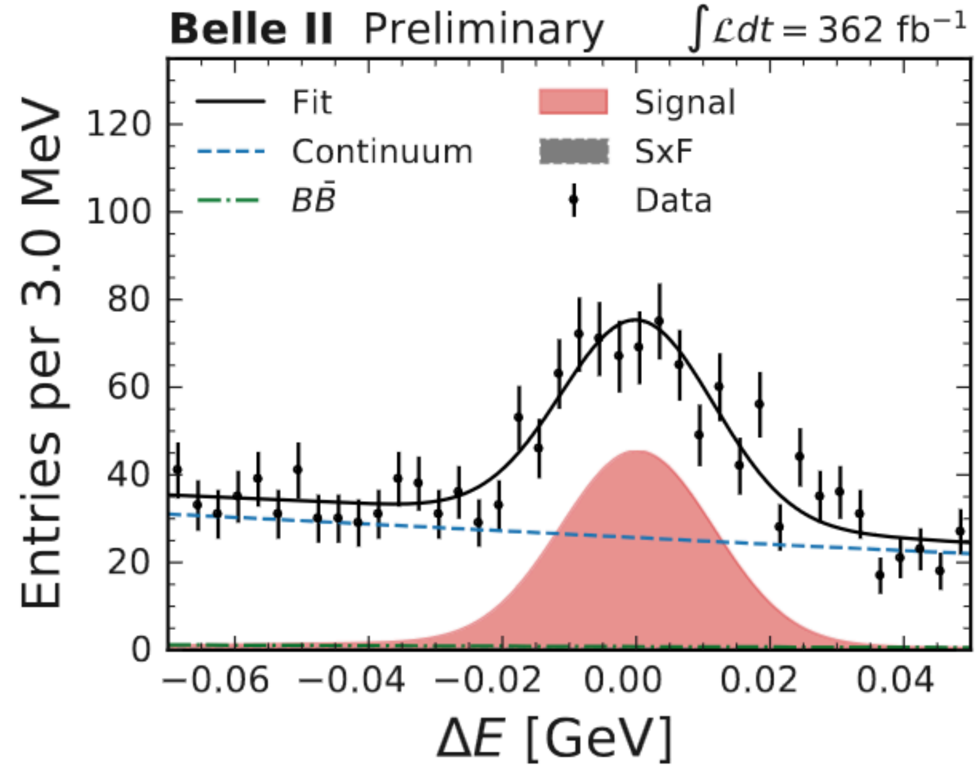
Two sub-channels $\eta' \to \eta_{\gamma\gamma}\pi\pi, \rho\gamma$.
Dominant bkg from track combinations, dedicated suppression BDT

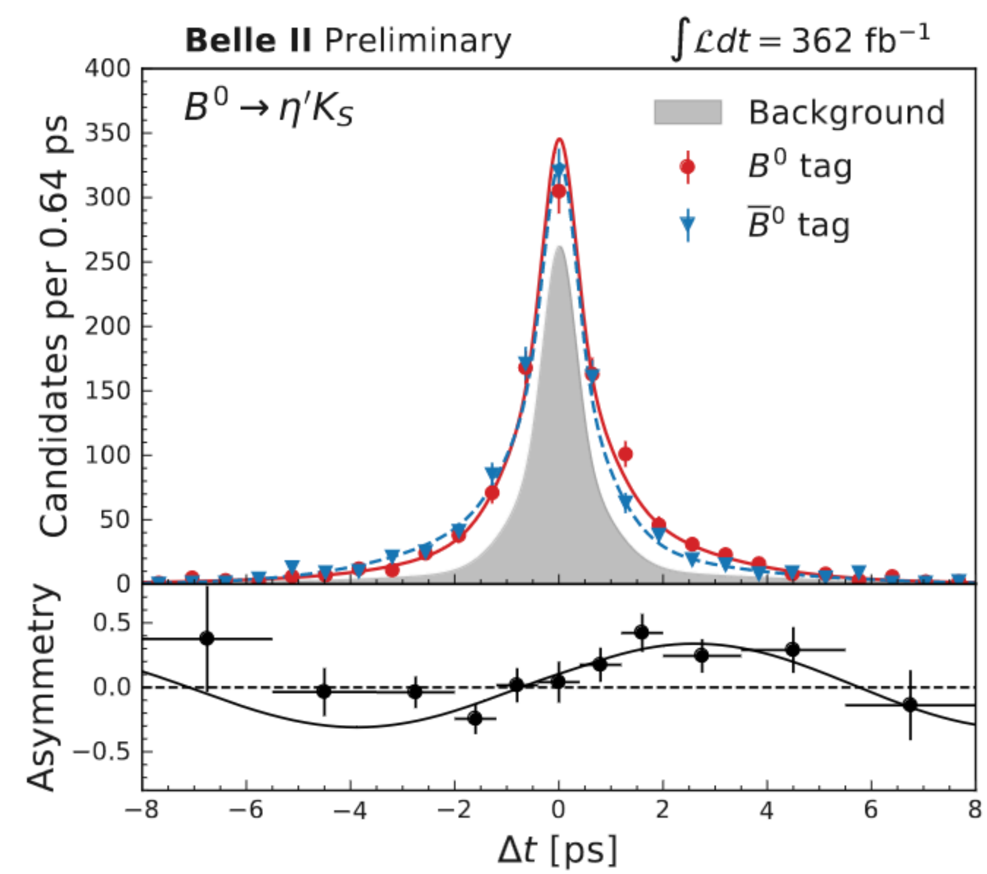
Measure signal with ΔE fit, and then fit the decay time to measure CPV

$$C_{\eta' K_S^0} = -0.19 \pm 0.08 \pm 0.03$$

$$S_{\eta' K_S^0} = +0.67 \pm 0.10 \pm 0.04$$

Competitive with current bests even with smaller sample





[arxiv:2402.03713] *preliminary*

Summary

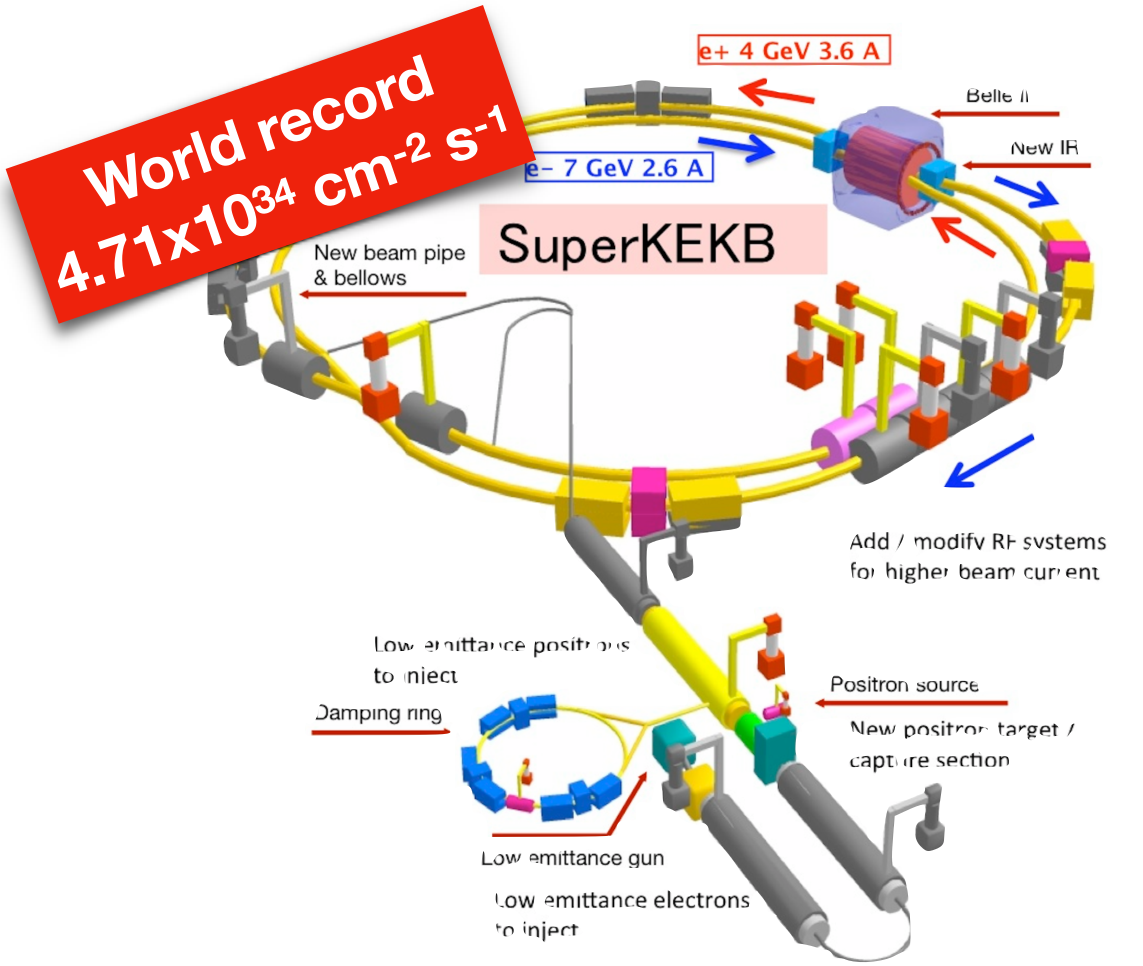
Belle II aims at testing the Standard Model and improving the precision on flavor-physics parameters

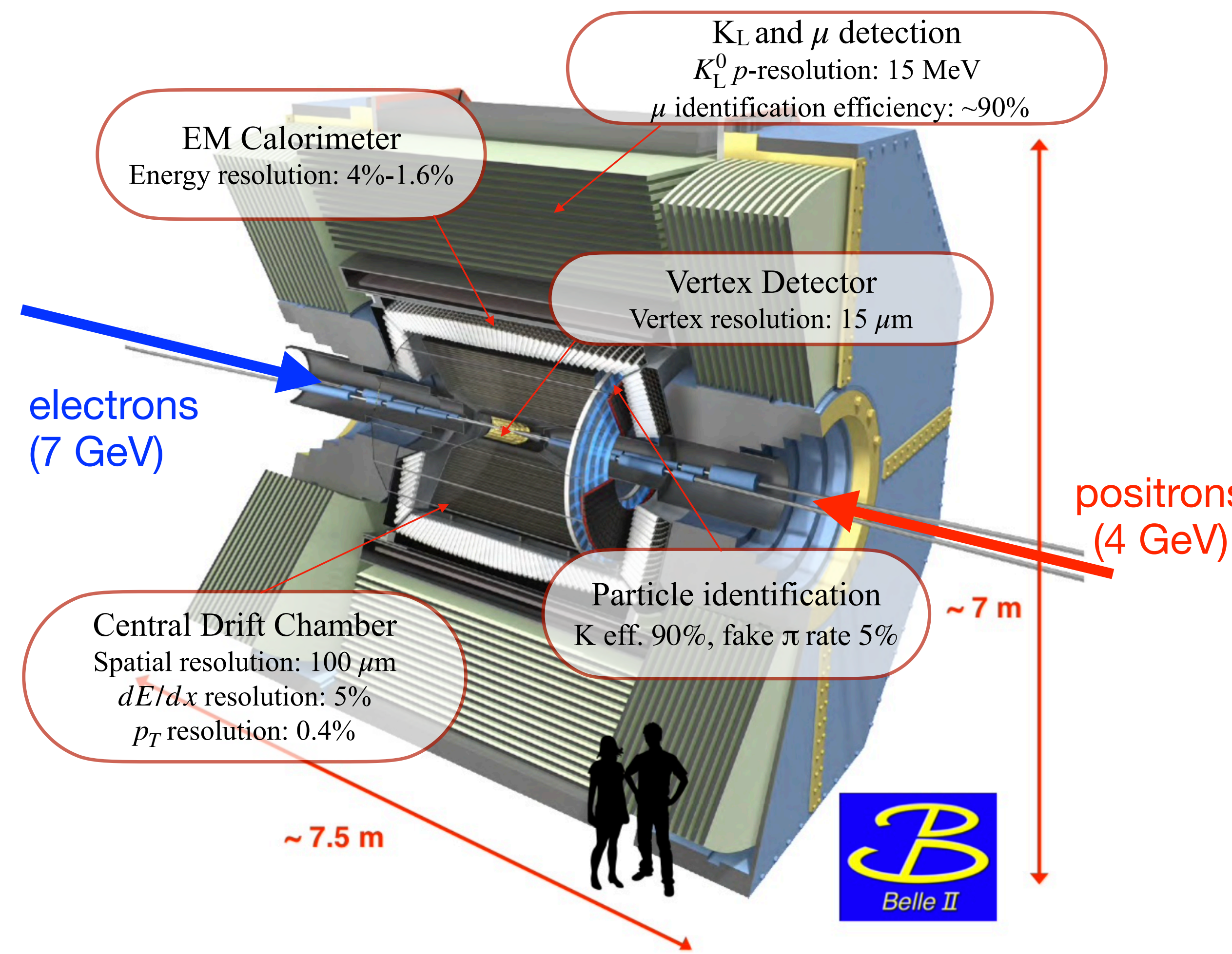
Today showed new branching fraction measurements, competitive with current best even with less statistics. Additional precision by exploiting also the Belle dataset

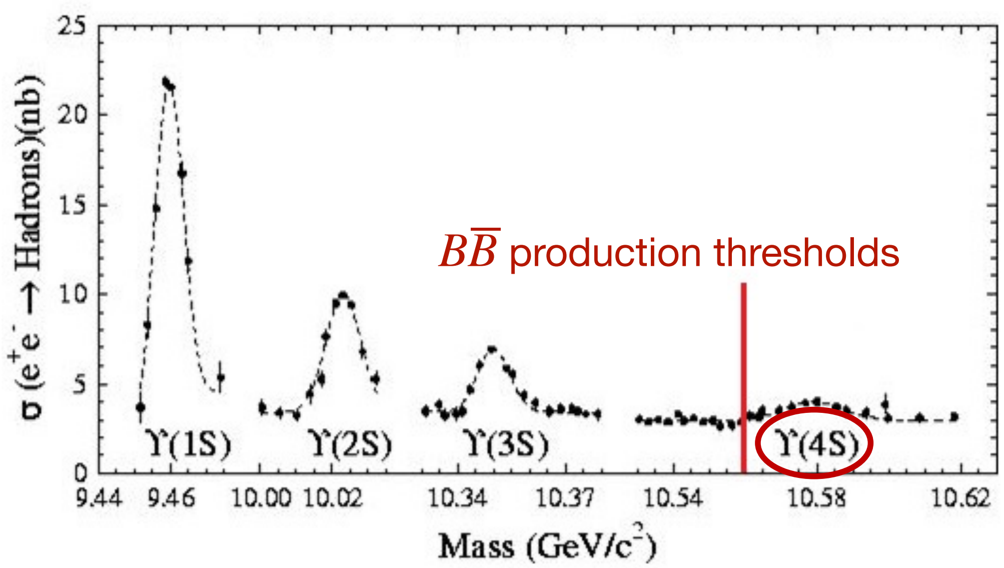
Data-taking just resumed, aim to reach 1 ab^{-1} of integrated luminosity by 2024 and test the Standard Model with competitive data sample

backup

Belle II at SuperKEKB



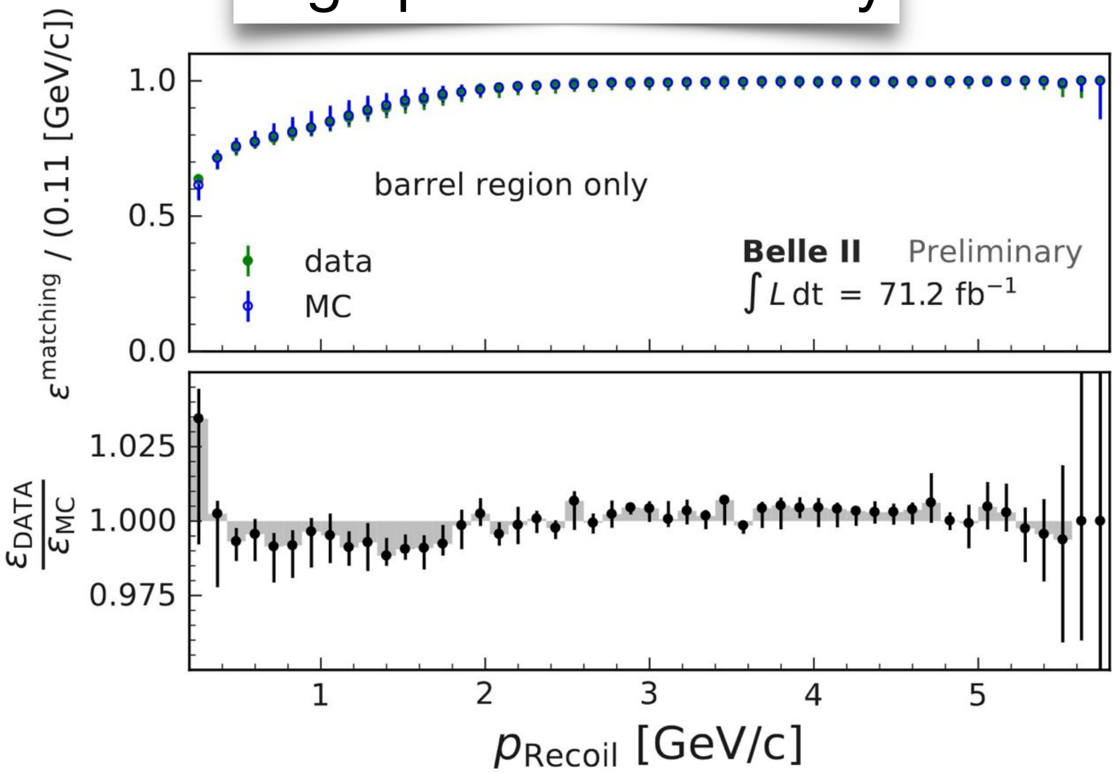


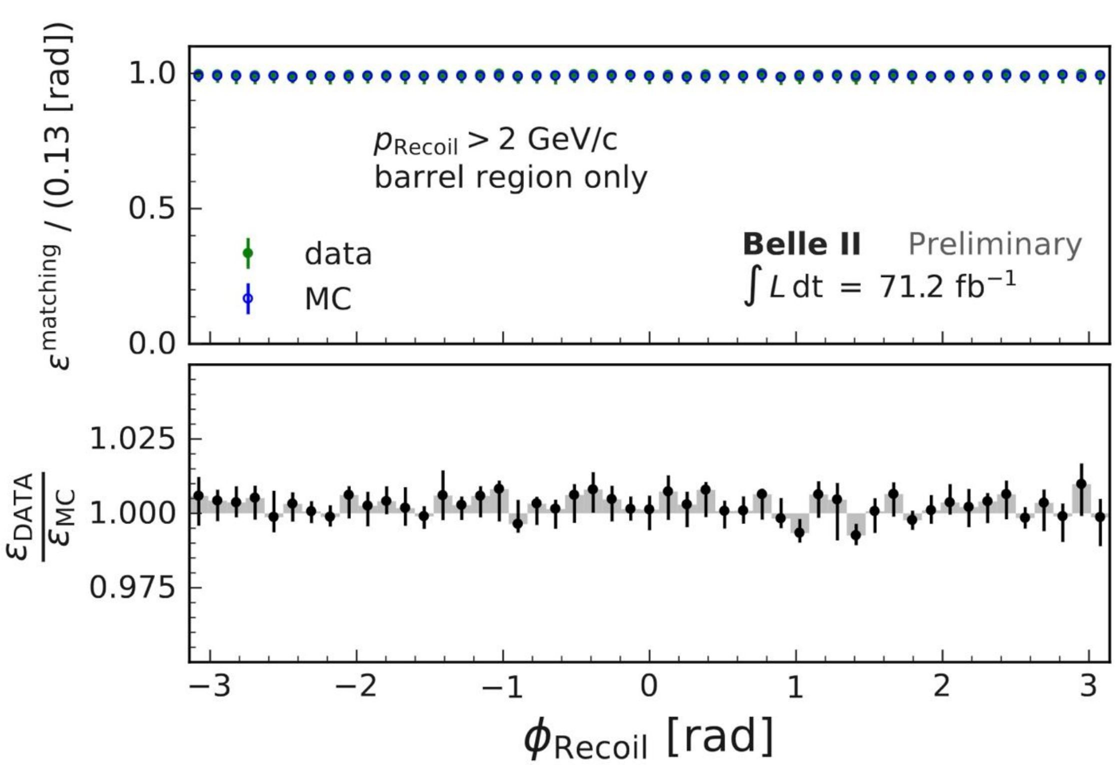


~100% of $\Upsilon(4S)$ decay to $B\overline{B}$ pairs
- Low-background production of ~30 pairs/s
- Precisely known collision energy
- Coherent evolution of B and $\overline{B}$
- **Currently ~390 M pairs**

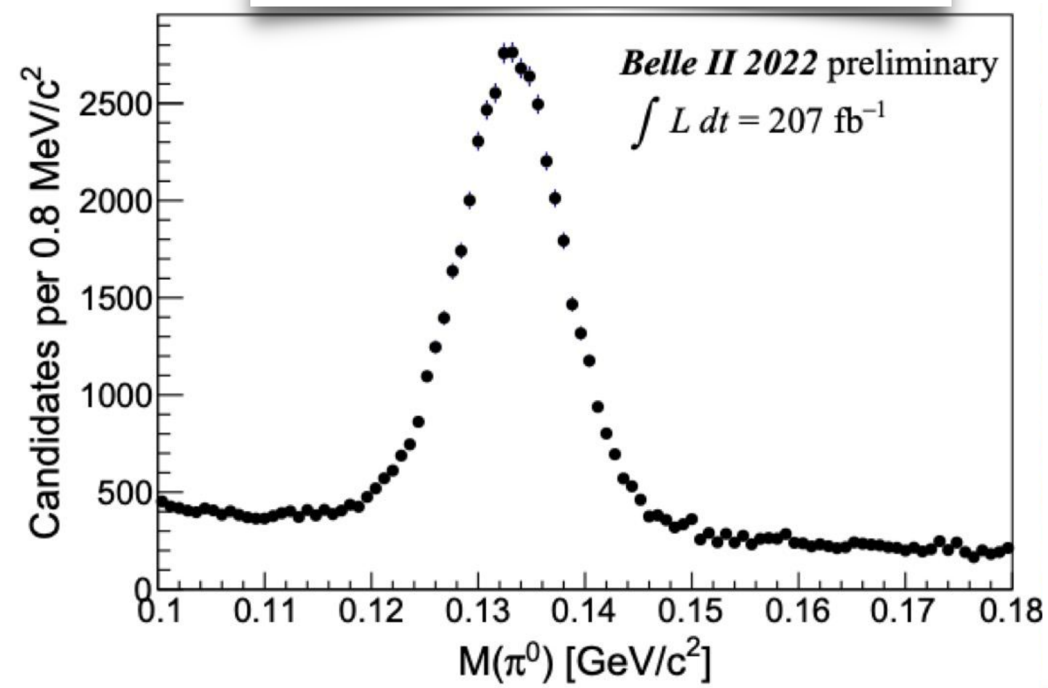
Performance overview

High photon efficiency

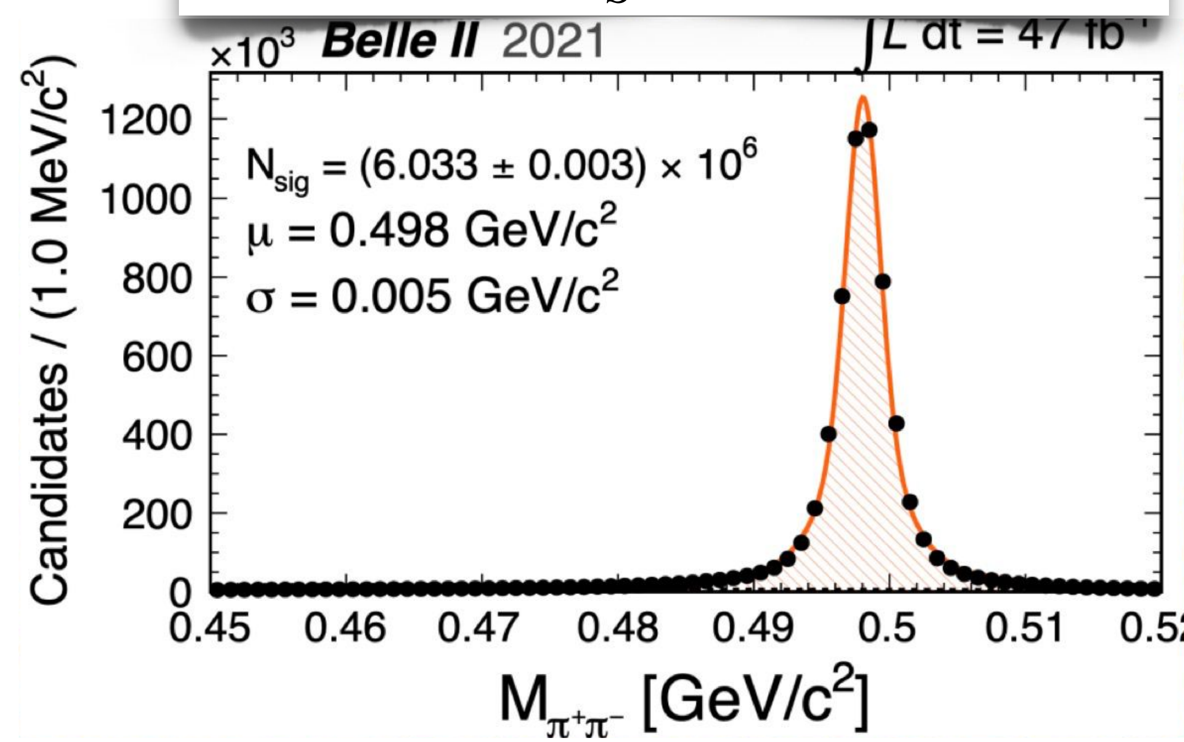




Good π^0 reconstruction



Excellent K_S^0 reconstruction



New for Moriond

Isospin test in $B^- \to D^0\rho^-$

Branching fraction measurements on $\overline{B}^0 \to D^0\rho^0, D^+\rho^-$ and $B^- \to D^0\rho^-$ provide tests of calculations of hadronic decay rates based on heavy-quark limit and factorization models. The ratio *R* and strong-phase difference δ between those amplitudes are related to the branching fractions of the three decays and the ratio of the *B*+ and *B*- lifetimes

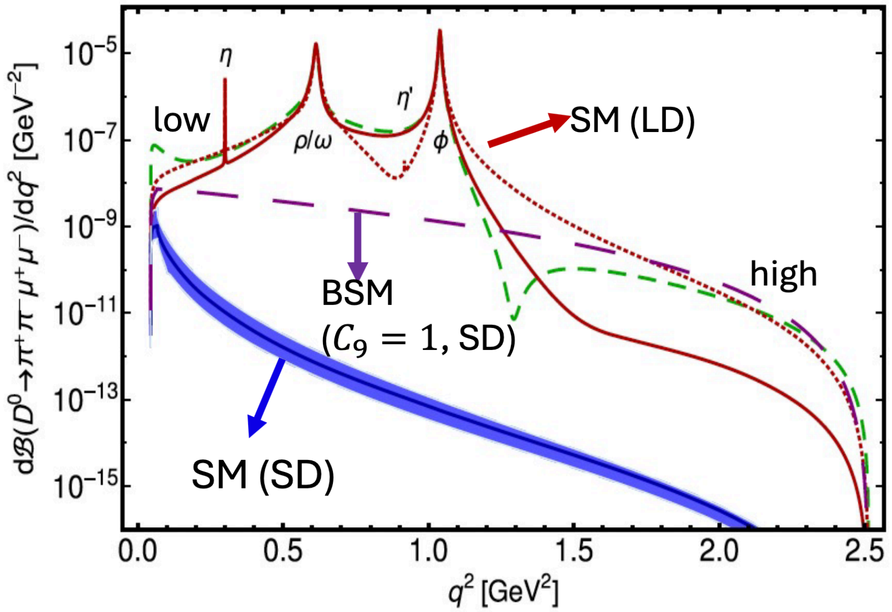
$$R = \left(\frac{3}{2} \frac{\tau_+}{\tau_0} \frac{\mathscr{B}(D^0\rho^0) + \mathscr{B}(D^+\rho^-)}{\mathscr{B}(D^0\rho^-)} - \frac{1}{2} \right)^{\frac{1}{2}} \qquad \cos\delta = \frac{1}{2R} \left(\frac{3}{2} \frac{\tau_+}{\tau_0} \frac{\mathscr{B}(D^0\rho^0) - 2\mathscr{B}(D^+\rho^-)}{\mathscr{B}(D^0\rho^-)} + \frac{1}{2} \right)$$

Results reported by LHCb: $R = 0.69 \pm 0.15$ and $\cos\delta = 0.984^{+0.113}_{-0.048}$
[PRD 92 032002 (2015)]

Update with Belle II $D^0\rho^-$ result : $R = 0.93^{+0.11}_{-0.12}$ and $\cos\delta = 0.919^{+0.012}_{-0.009}$

New for Moriond

Search for rare $D^0 \to h^- h^{(')+} e^+ e^-$ decays



[PRD 98 035041 (2018)]

m_{ee} region	[MeV/c^2]	Yield	Significance	$\mathcal{B}$	UL @ 90% CL
$K^-K^+e^+e^-$					
η	520-560	-	$< 0.1\sigma$	-	< 2.3
ρ^0/ω	> 675	2.6 ± 1.8	2.0σ	$1.2 \pm 0.9 \pm 0.1$	< 3.0
non-resonant	> 200 [a]	3.5 ± 3.3	1.5σ	$3.1 \pm 3.0 \pm 0.4$	< 7.7
$\pi^-\pi^+e^+e^-$					
η	520-560	0.6 ± 2.3	0.3σ	$0.4 \pm 1.4 \pm 0.2$	< 3.2
ρ^0/ω	675-875	3.7 ± 4.1	0.9σ	$2.0 \pm 2.2 \pm 0.8$	< 6.1
ϕ	995-1035	3.6 ± 3.2	1.1σ	$1.1 \pm 1.1 \pm 0.2$	< 3.1
non-resonant	> 200	-0.2 ± 4.1	$< 0.1\sigma$	$-0.2 \pm 3.4 \pm 0.9$	< 7.2
$K^-\pi^+e^+e^-$					
η	520-560	4.0 ± 2.7	1.6σ	$2.2 \pm 1.5 \pm 0.5$	< 5.6
ρ^0/ω	675-875	110 ± 13	11.8σ	$39.6 \pm 4.5 \pm 2.9$	-
ϕ	990-1034	4.6 ± 2.4	2.5σ	$1.4 \pm 0.8 \pm 0.3$	< 2.9
non-resonant	> 560	2.2 ± 4.2	0.4σ	$1.3 \pm 2.4 \pm 0.6$	< 6.5

[a] Excluding resonance regions, which is same for all three modes.