Belle II news on charm and *B* to charm

56th Rencontres de Moriond 2022

Electroweak Interactions & Unified Theories

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on behalf of the Belle II collaboration

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Belle II

Beauty and charm factory

Energy-asymmetric e^+e^- collisions at the $\Upsilon(4S)$.
CM boosted with βγ ~ 0.28.
Final focus magnets to
- squeeze vertical size to ~50 nm
- large crossing angle of ~83 mrad

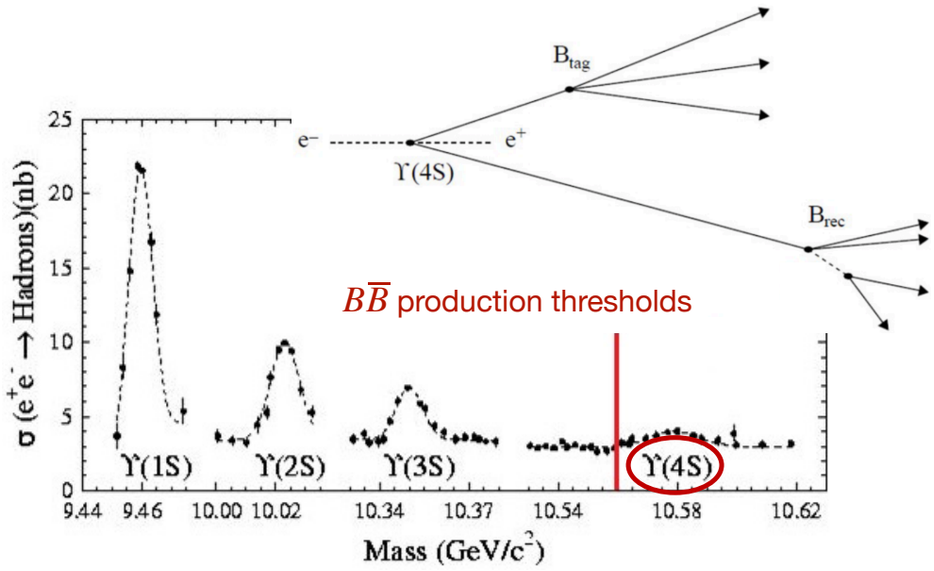
⇒ design 30x intensity wrt previous *B*-factories

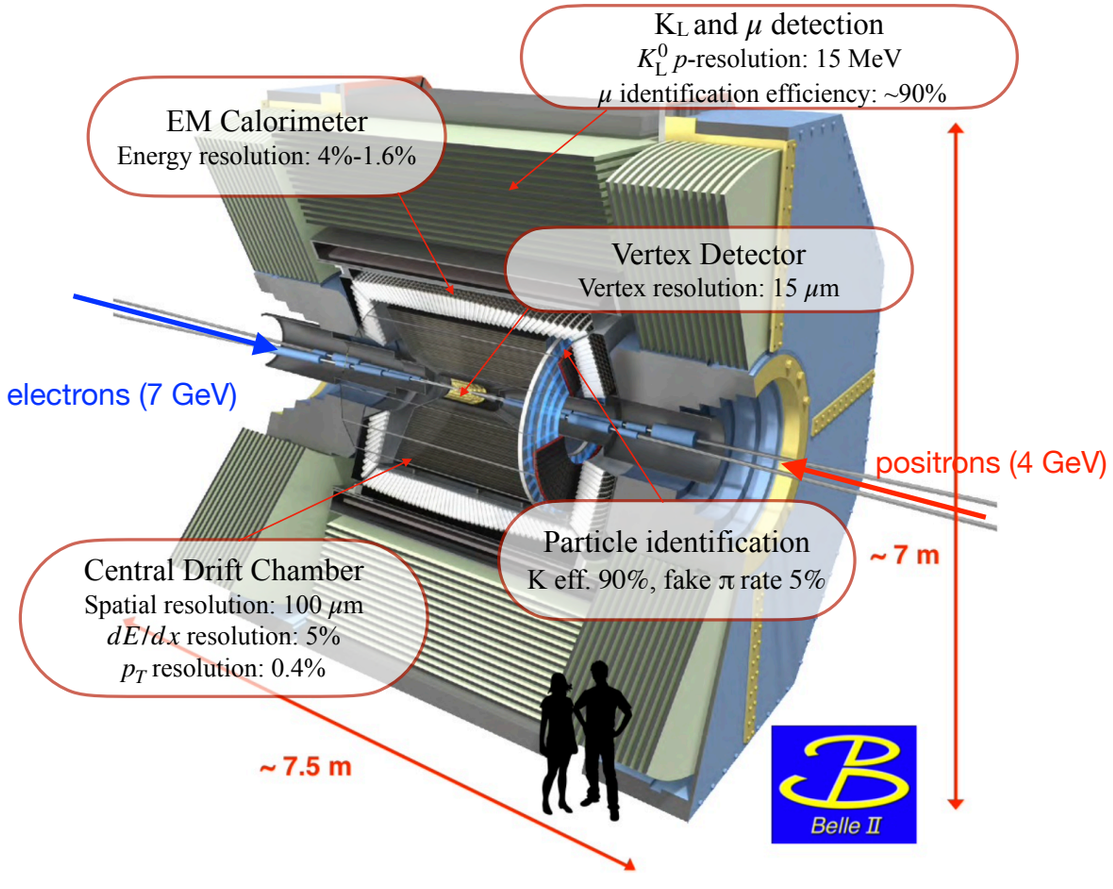
Compared to Belle
- much improved vertexing
- greater acceptance

⇒ similar performance with expected 20x bkg

Large clean samples of *B* and *D* mesons.
Current dataset of ~265 fb^{-1}.

Today:
- Λ_c^+ (new for Moriond), D^0, D^+ lifetimes
- CKM γ from Belle + Belle II combined data (first combined measurement)

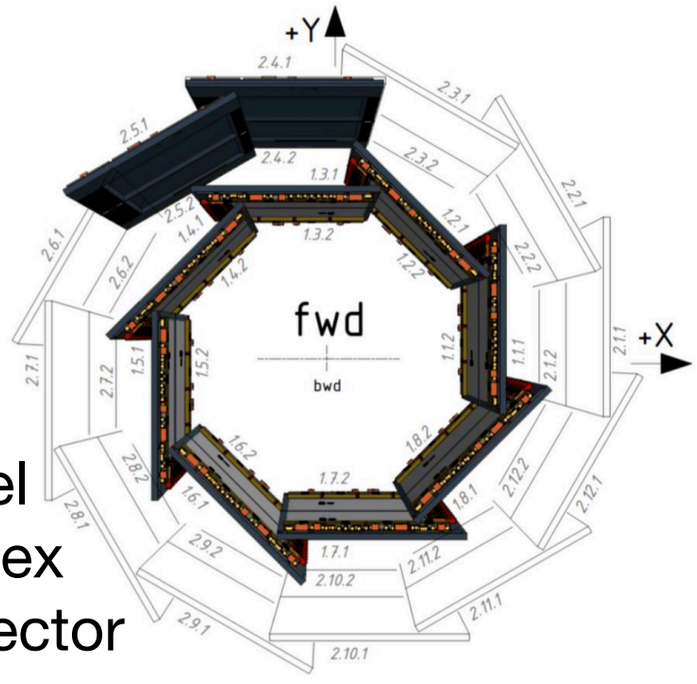




Charm physics at Belle II

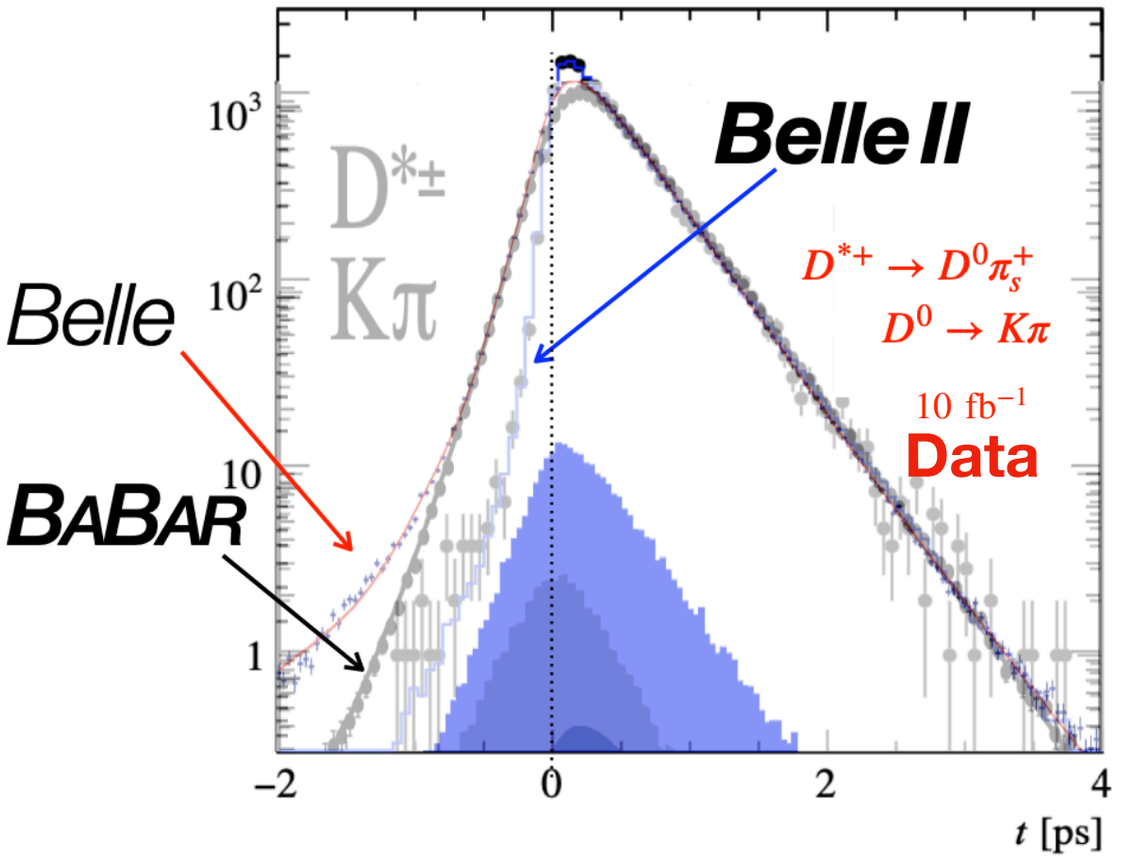
Program: CPV measurements, searches for rare and forbidden decays. Focus on final states with neutrals or missing *E*.

Lifetimes: high-precision measurements probe vertexing capabilities and give insight of systematic effects for future time-dependent analyses.



Pixel vertex detector

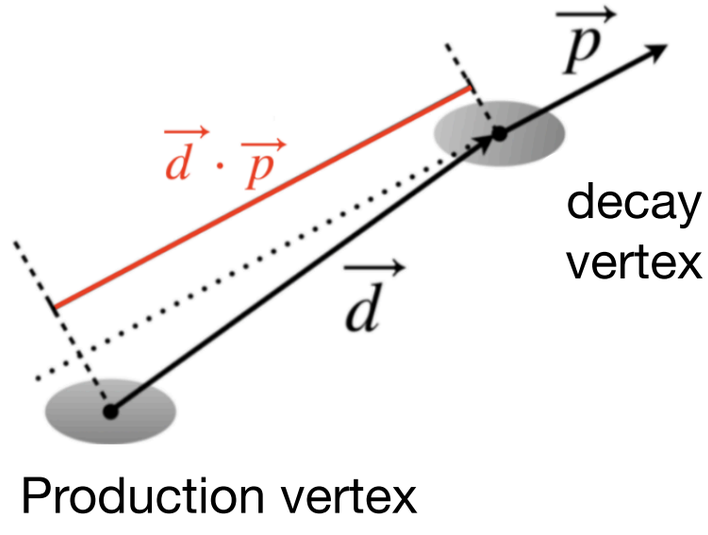
Belle II/SuperKEKB
- small interaction region allows stringent constraints on production vertex position
- new vertex detector improves 2x resolution wrt Belle and BaBar



Measuring decay time

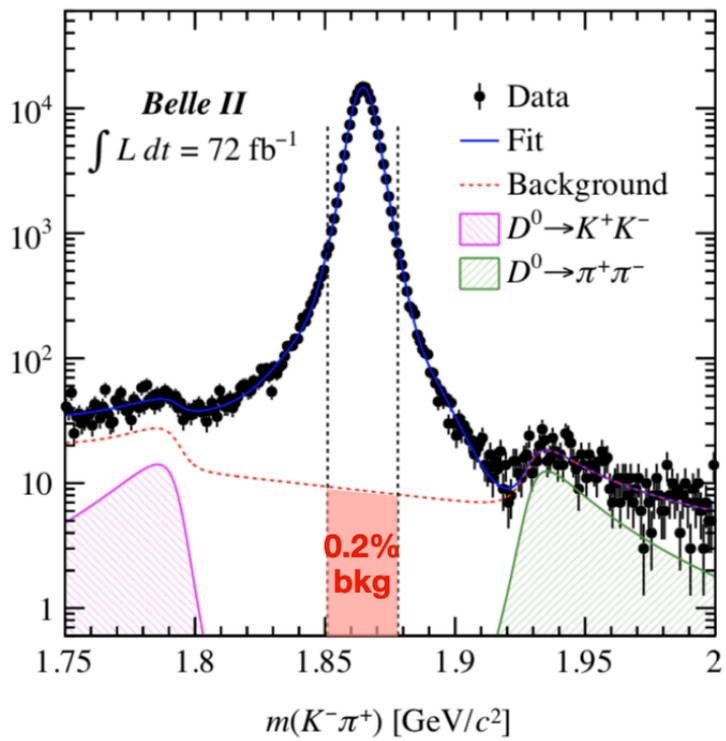
Compute decay time t and its uncertainty σ_t from the production and decay vertices and momentum:

$$t = m\frac{\vec{d}\cdot\vec{p}}{p^2\cdot c}$$

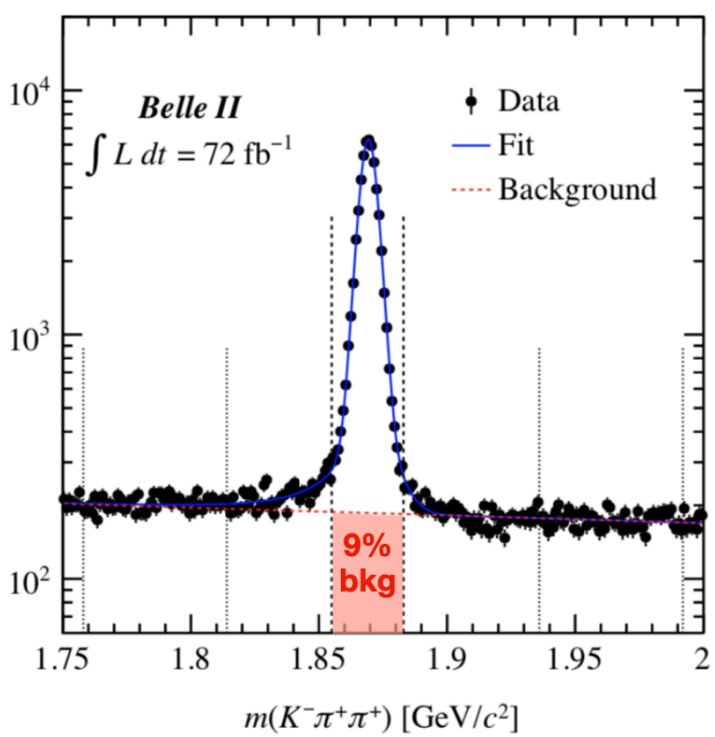


Selection explicitly checked to be unbiased.
Controlling systematics is crucial.

~171k $D^{*+}\to(D^0\to K^-\pi^+)\pi^+$

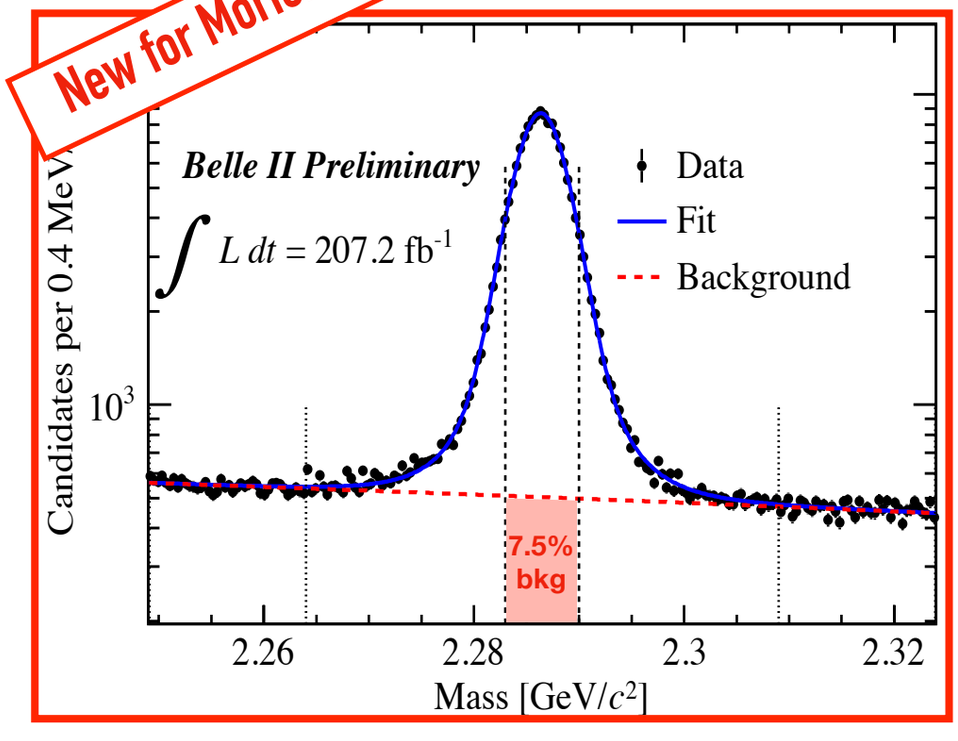


~59k $D^{*+}\to(D^+\to K^-\pi^+\pi^+)\pi^0$



~152k $\Lambda_c^+\to pK^-\pi^+$

New for Moriond



Decay-time fits

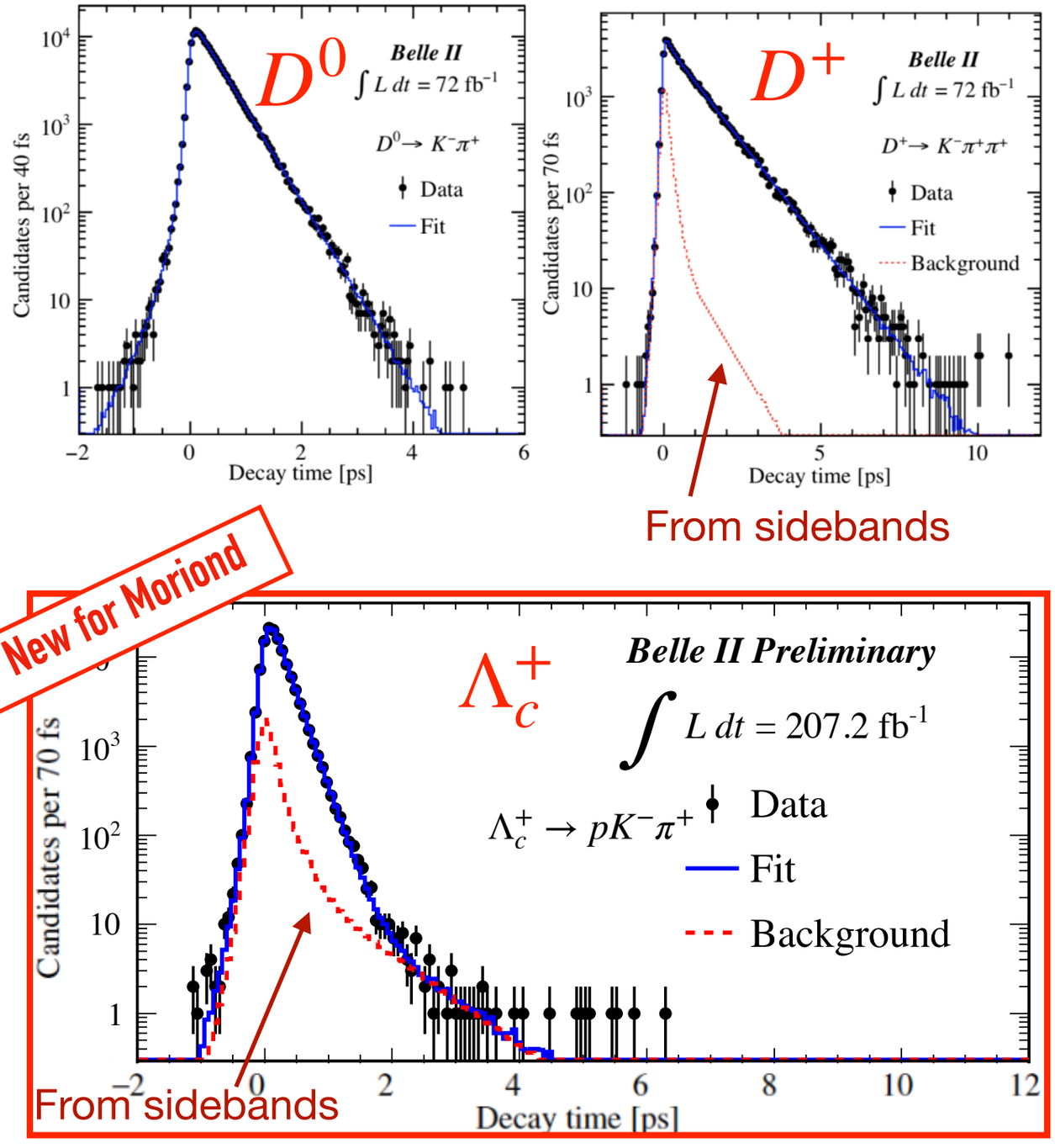
2D fit of unbinned t - σ_t distributions.

Signal: exponential convoluted with resolution (single or double Gaussian) determined directly in data.

Background: fit sidebands simultaneously.

All shape parameters free.

Blind analyses.



The name of the game

Misalignment: affects decay-length scale. Estimated using simulations of various misaligned configurations.

Background: account for simulation not well reproducing decay-time distributions.

Resolution: account for neglected correlations between t and σ_t.

$\Xi_c \to \Lambda_c \pi$ background can introduce biases. Unaccounted for in previous measurement. Significant uncertainty based on pheno expectations of Ξ_c rate. May reduce with dedicated data-driven studies.

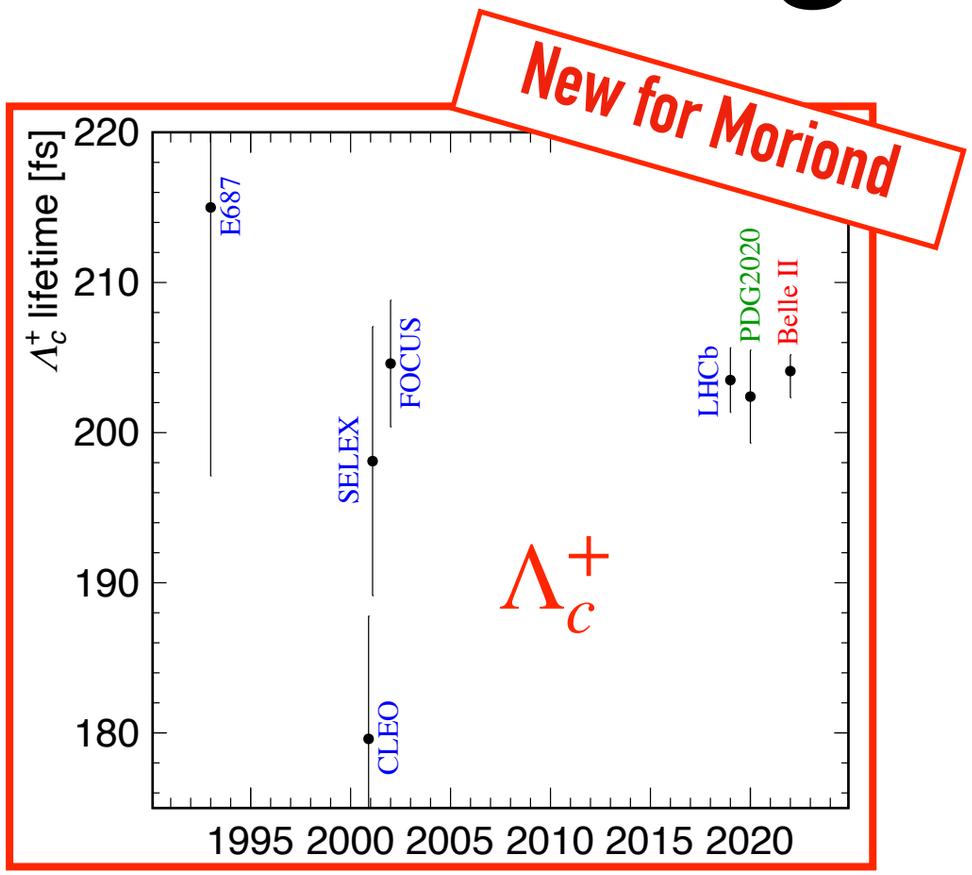
Source	Uncertainty (fs)	
	$D^0 \to K^-\pi^+$	$D^+ \to K^-\pi^+\pi^+$
Statistical	1.1	4.7
Resolution model	0.16	0.39
Backgrounds	0.24	2.52
Detector alignment	0.72	1.70
Momentum scale	0.19	0.48
Total systematic	0.8	3.1

New for Moriond

$\Lambda_c^+ \to pK^-\pi^+$ (preliminary)

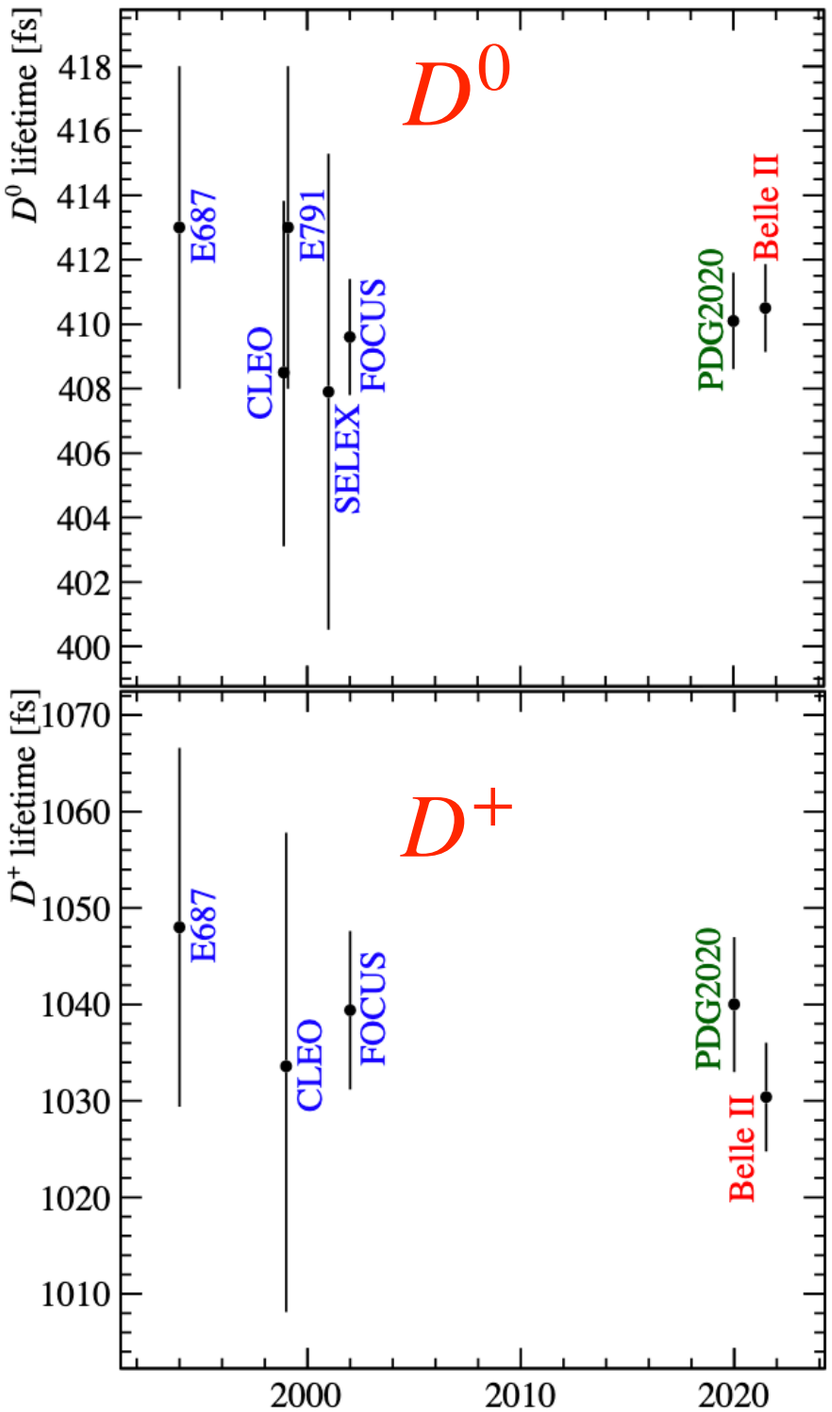
Source	uncertainty (fs)
Resolution model	0.46
Background contamination	0.20
Imperfect alignments	0.46
Momentum scale correction	0.09
Input charm masses	0.01
Total systematic uncertainty	0.69
Contamination from $\Xi_c \to \Lambda_c \pi$	- 1.4

World-leading charm lifetimes



Belle II	World average
$\tau(D^0)$ = **(410.5 ± 1.1 ± 0.8) fs**	(410.1 ± 1.5) fs
$\tau(D^+)$ = **(1030.4 ± 4.7 ± 3.1) fs**	(1040 ± 7) fs
$\tau(\Lambda_c^+)$ = **(204.1 ± 0.8 ± 0.7 - 1.4) fs**	(202.4 ± 3.1) fs

World's best. Establish excellent detector performances (see Thibaud's talk for more on vertexing).
Λ_c benchmarks future baryon lifetime measurements.



PRL 127, 211801 (2021)

Measurement of γ

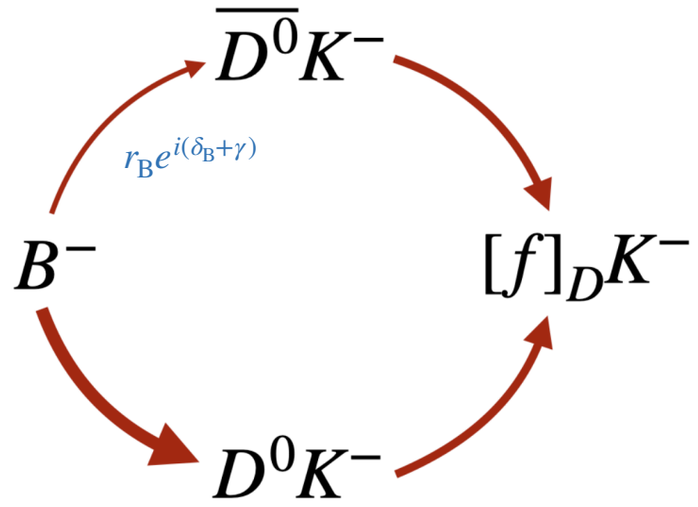
γ from $B \to DK$ decays

Phase between $b \to c$ and $b \to u$.
Tree-dominated: precise SM reference.

Access with interfering decays to same final states. Direct determination WA:
HFLAV

$$\gamma[^\circ] = 65.9\ ^{+\ 3.3}_{-\ 3.5}$$

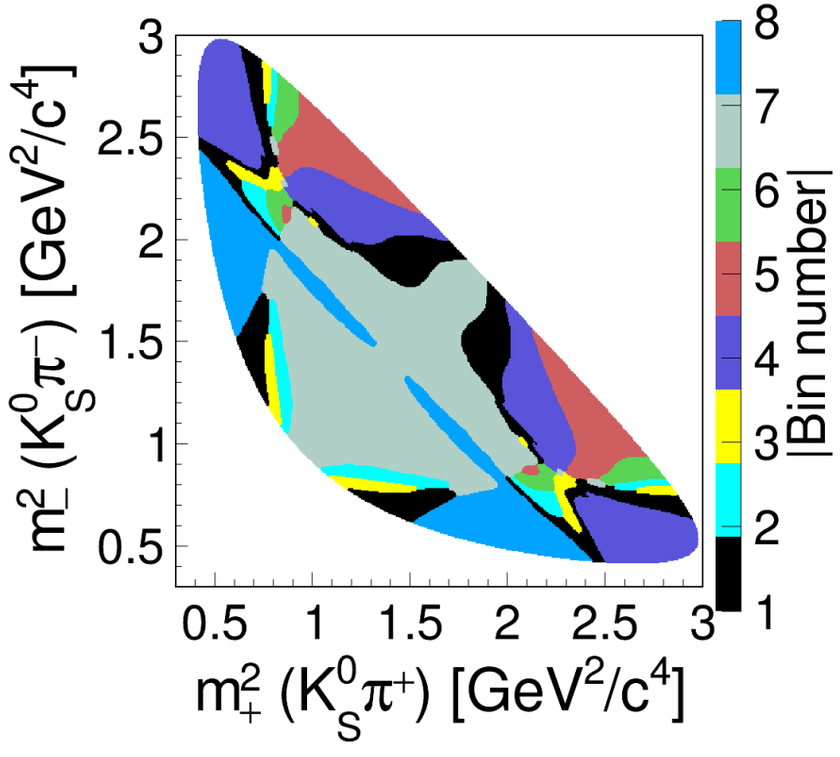
Self-conj. D^0 final states $K_S^0\pi\pi$, K_S^0KK.
D Dalitz plot binning eliminates amplitude-model uncertainties.



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

$$N_i^{\pm} = h_B^{\pm}\left[F_i + r_B{}^2\overline{F}_i + 2\sqrt{F_i\overline{F}_i}(c_i x_{\pm} + s_i y_{\pm})\right]$$

$(x_{\pm}, y_{\pm}) = r_B\left(\cos(\gamma+\delta_B),\ \sin(\gamma+\delta_B)\right)$
c_i, s_i: D^0-$\overline{D}^0$ strong phase differences (inputs from BES III/CLEO)
F_i: fraction of D decays to i-th bin



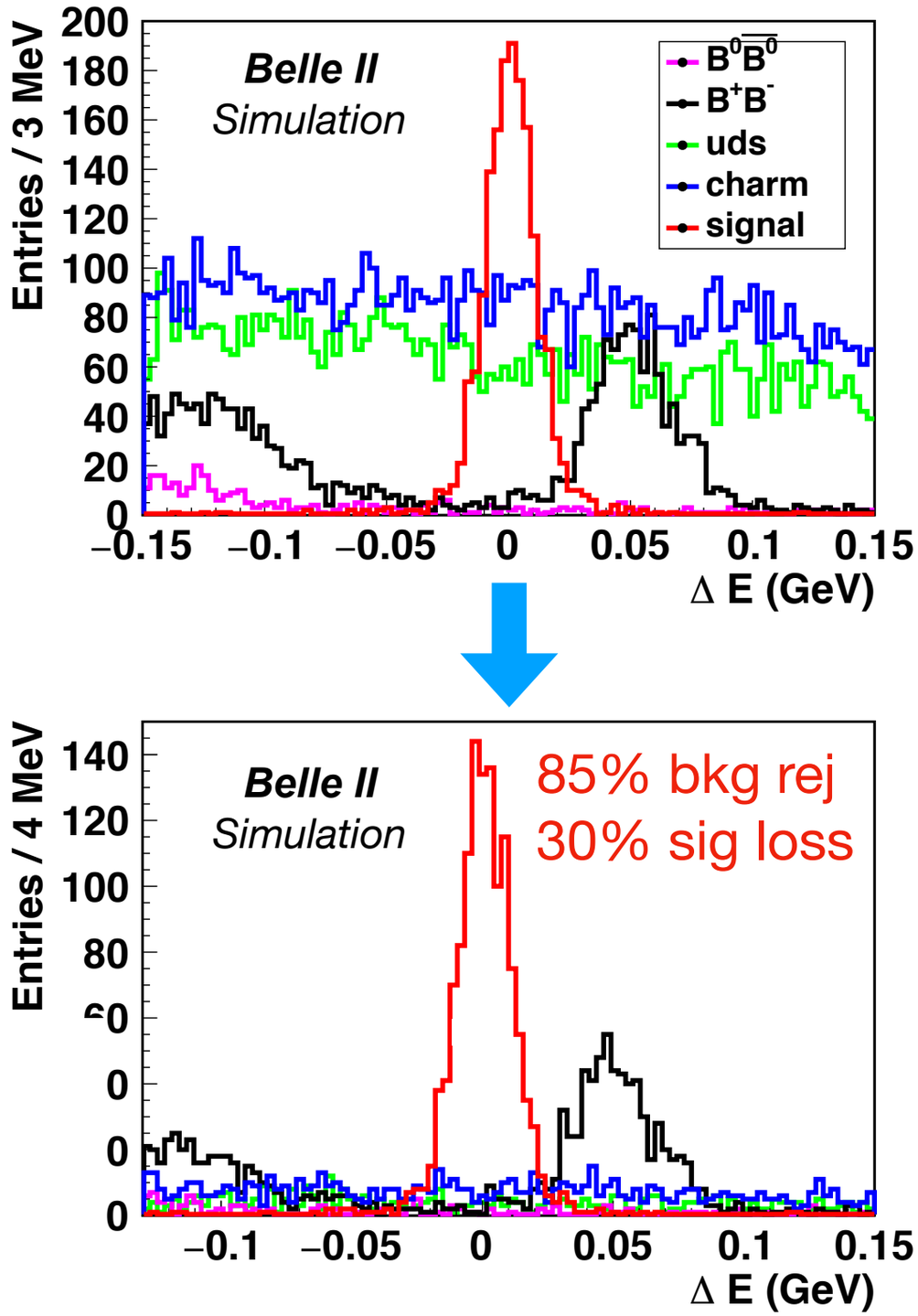
Sample selection

128 fb^{-1} Belle II + 711 fb^{-1} Belle.

Improvements wrt previous Belle:
- K_S^0 selection
- background suppression
- signal determination
- more statistics from $D^0 \to K_S^0 KK$
- new inputs from BESIII

Suppress "continuum" ($e^+e^- \to q\bar{q}$):
input event shape, angular distributions,
B vertex and flavor tagging in MVA.

Additional discriminating variable for 2D
ΔE—MVA signal fit



Signal yield determination

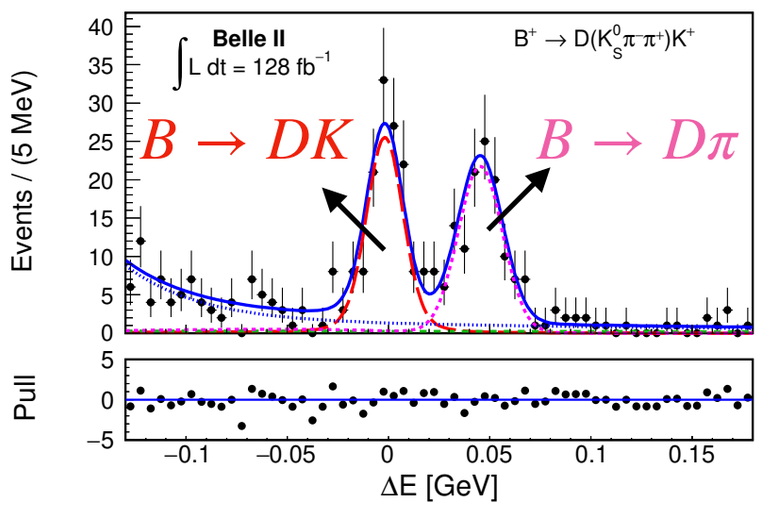
PID cut isolates $B \to DK$ candidates: ~8% mis-ID $B \to D\pi$ contamination.

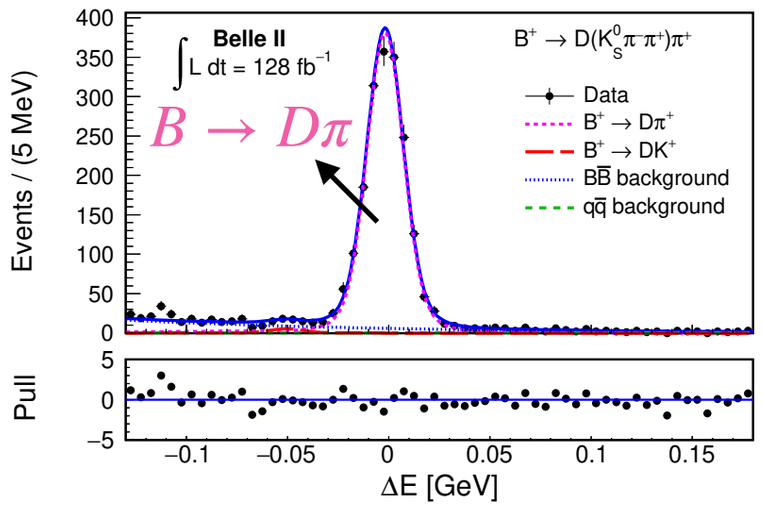
K-π efficiencies and mis-ID rates directly from data with simultaneous fit of disjoint $B \to DK$ and $B \to D\pi$ samples.

Belle:
$K_S^0\pi\pi$: 1467 ± 53
K_S^0KK: 194 ± 17

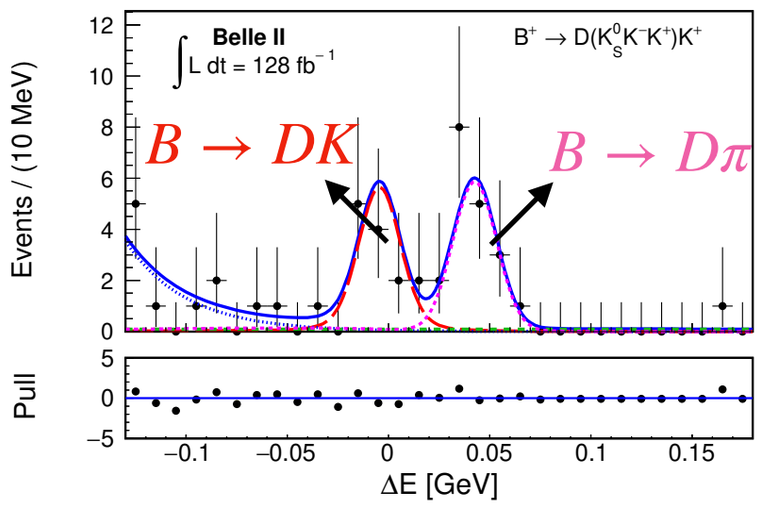
Belle II :
$K_S^0\pi\pi$: 280 ± 21
K_S^0KK: 34 ± 7

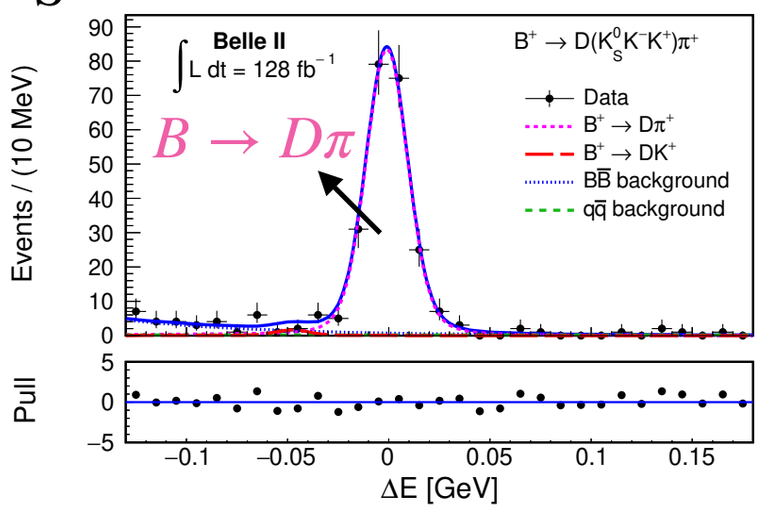
$D^0 \to K_S^0\pi^+\pi^-$





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



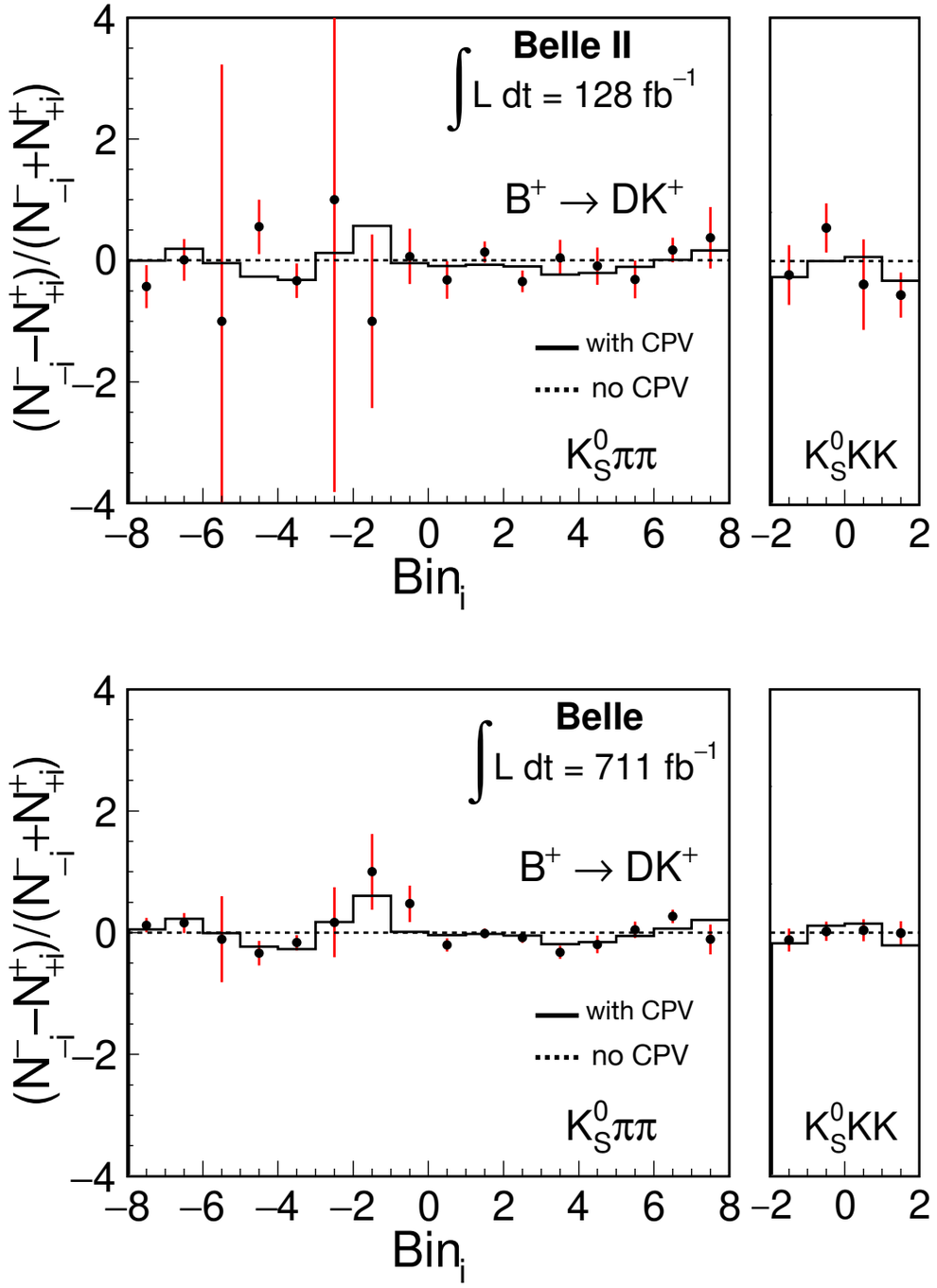


Determination of CPV parameters

Simultaneous fit in each Dalitz bin to extract CP observables $(x_{\pm}, y_{\pm})$. Mis-ID rate fixed from previous unbinned fit.

Extract F_i parameters directly in data to cancel the associated systematics and reduce reliance on simulation.

$$x_{+}^{DK} = -0.113 \pm 0.032$$
$$y_{+}^{DK} = -0.046 \pm 0.042$$
$$x_{-}^{DK} = +0.092 \pm 0.033$$
$$y_{-}^{DK} = +0.100 \pm 0.042$$



Results

$$\delta_B[^\circ] = 124.8 \pm 12.9\ (\text{stat}) \pm 0.5\ (\text{syst}) \pm 1.7\ (\text{ext})$$

$$r_B^{DK} = 0.129 \pm 0.024\ (\text{stat}) \pm 0.001\ (\text{syst}) \pm 0.002\ (\text{ext})$$

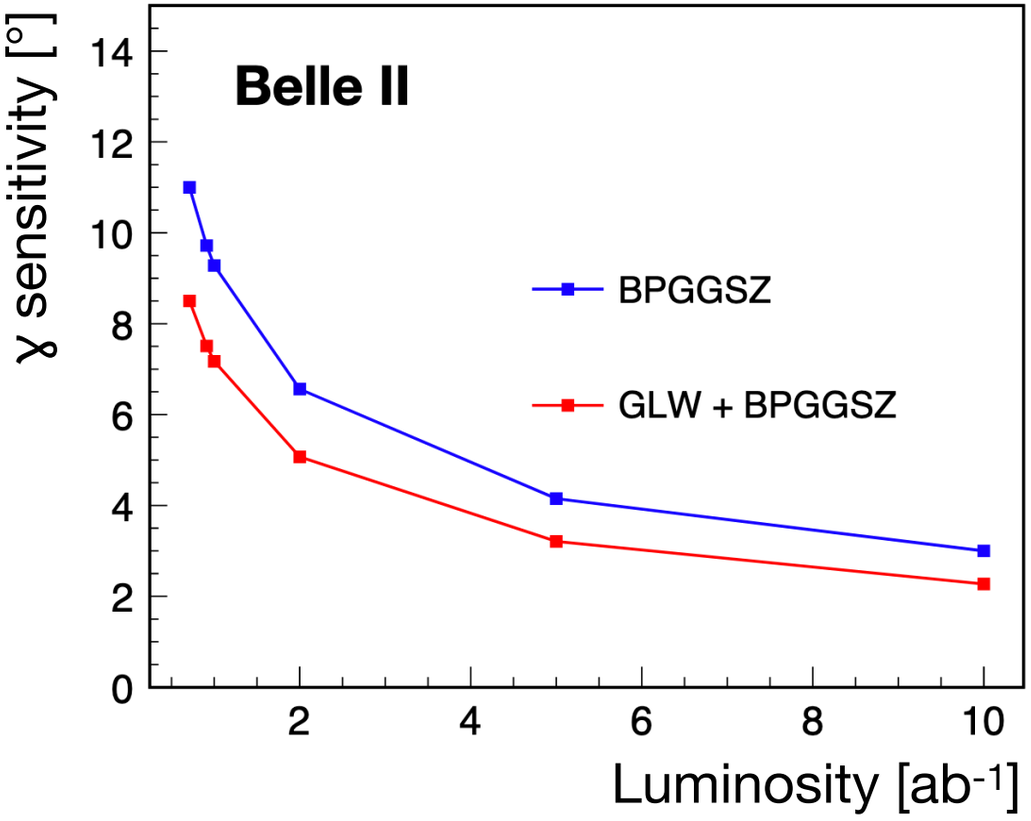
$$\gamma[^\circ] = 78.4 \pm 11.4\ (\text{stat}) \pm 0.5\ (\text{syst}) \pm 1.0\ (\text{ext})$$

JHEP 02, 063 (2022)

Improvements wrt previous Belle equivalent to doubling statistics.

Latest inputs on strong-phase from BESIIII highly reduces systematics.

Expect < 3° uncertainty with 10 ab^{-1}, including also more *D* final state. Uncertainty will still be dominated by the size of the data sample.



Summary

Exploit new improved detector: first high-precision ($O(10^{-3})$) results

- world's best D lifetimes, establishes excellent vertexing
- world's best Λ_c lifetime, benchmark for future baryon lifetimes (first Belle II)

Combine with Belle data to be impactful on flavor measurements with early data. Sensitivity improved in addition to larger data set:

- most precise CKM γ determination from B-factories (first B + BII)

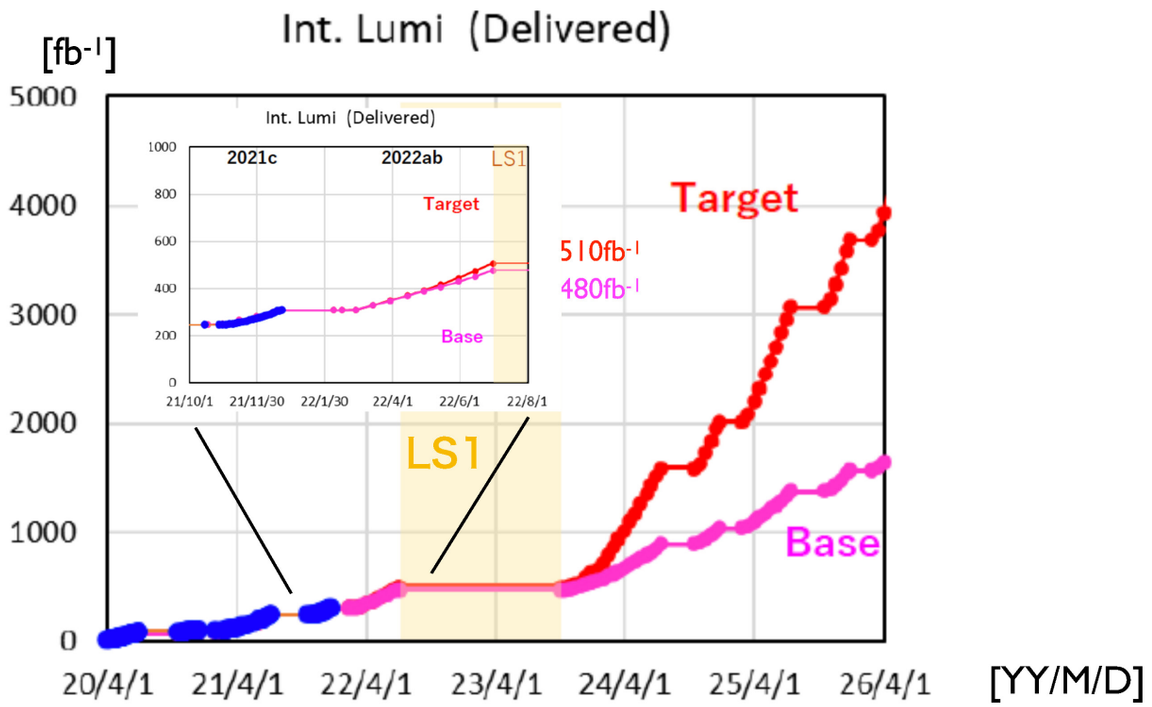
Competitive physics results even with initial data sets!

backup

Projections of integrated luminosity delivered by SuperKEKB to Belle II

Target scenario: extrapolation from 2021 run including expected improvements.

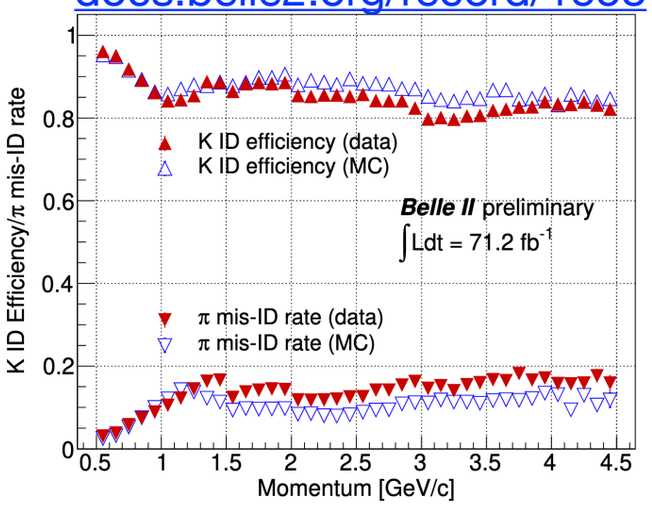
Base scenario: conservative extrapolation of SuperKEKB parameters from 2021 run.



- We start long shutdown I (LS I) from summer 2022 for 15 months to replace VXD. There will be other maintenance/improvements works of machine and detector.
- We resume physics running from Fall 2023.
- A SuperKEKB International Taskforce (aiming to conclude in summer 2022) is discussing additional improvements.
- An LS2 for machine improvements could happen on the time frame of 2026-2027.

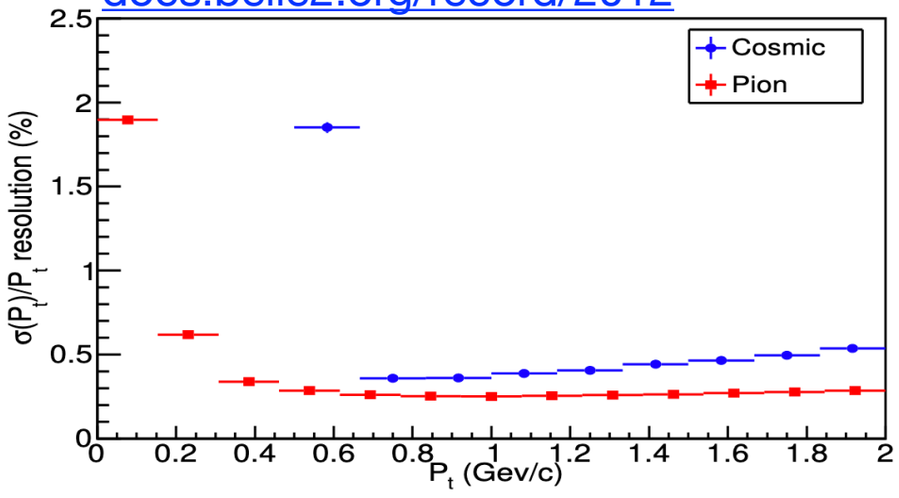
Performance overview

docs.belle2.org/record/1558



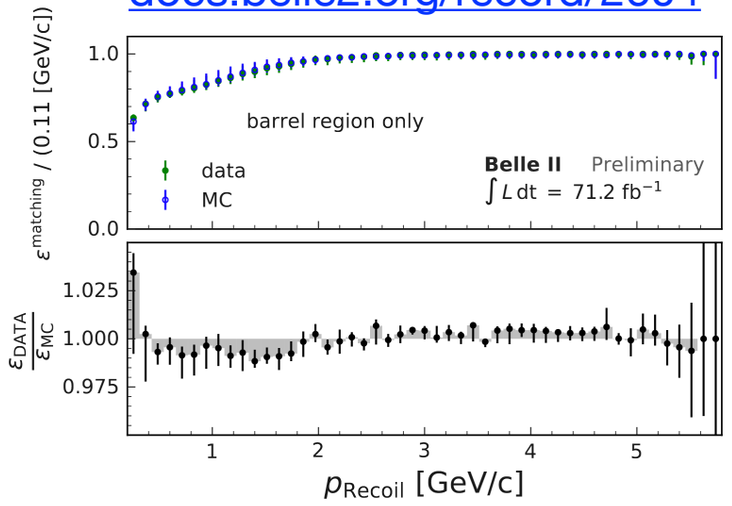
Strong charged particle identification.

docs.belle2.org/record/2012



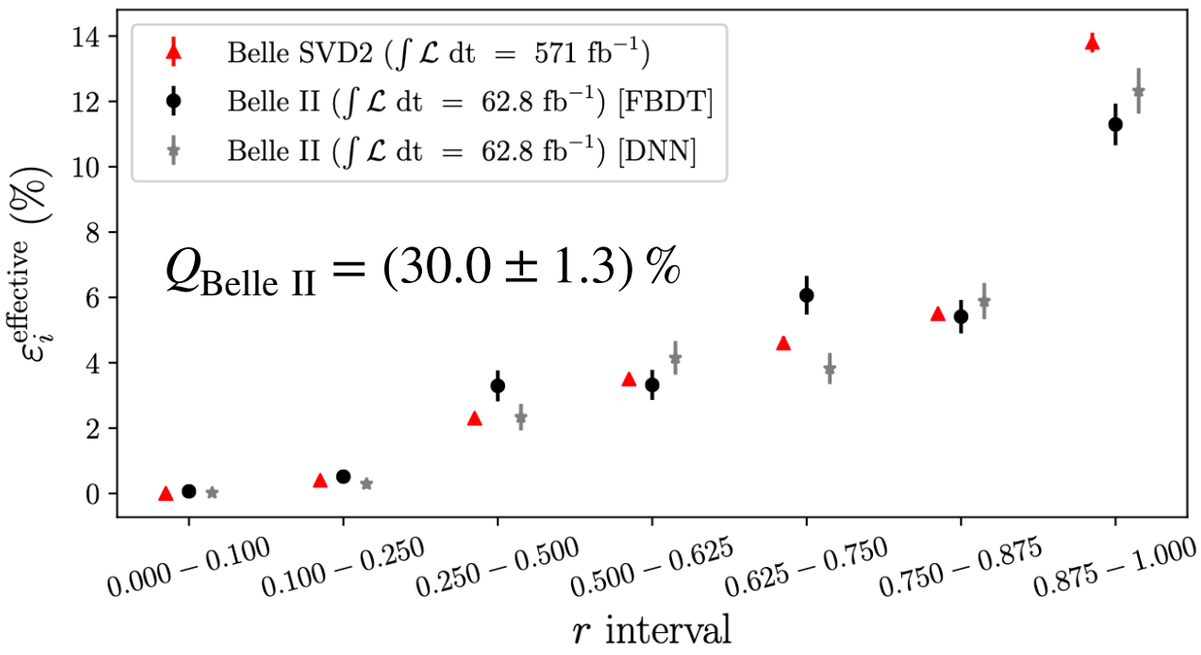
Good momentum resolution.

docs.belle2.org/record/2604



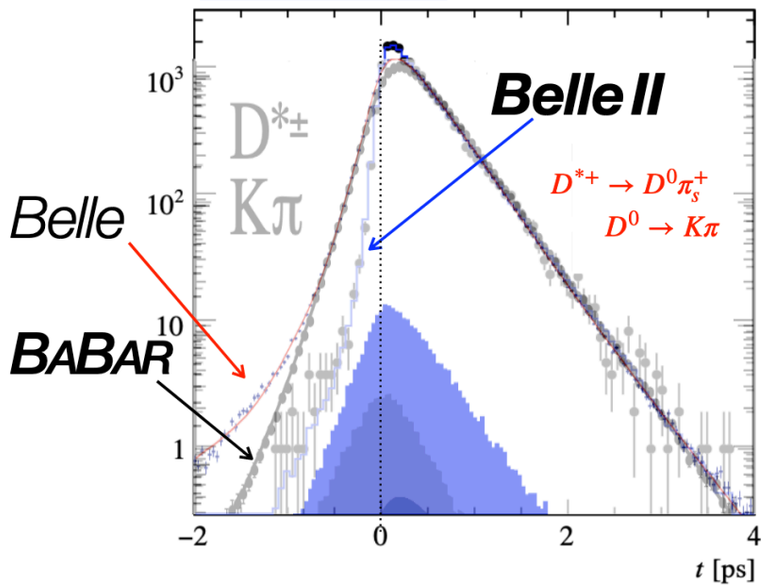
High ɣ efficiency.

To be submitted to EPJC



Flavor tagging efficiency comparable to Belle.

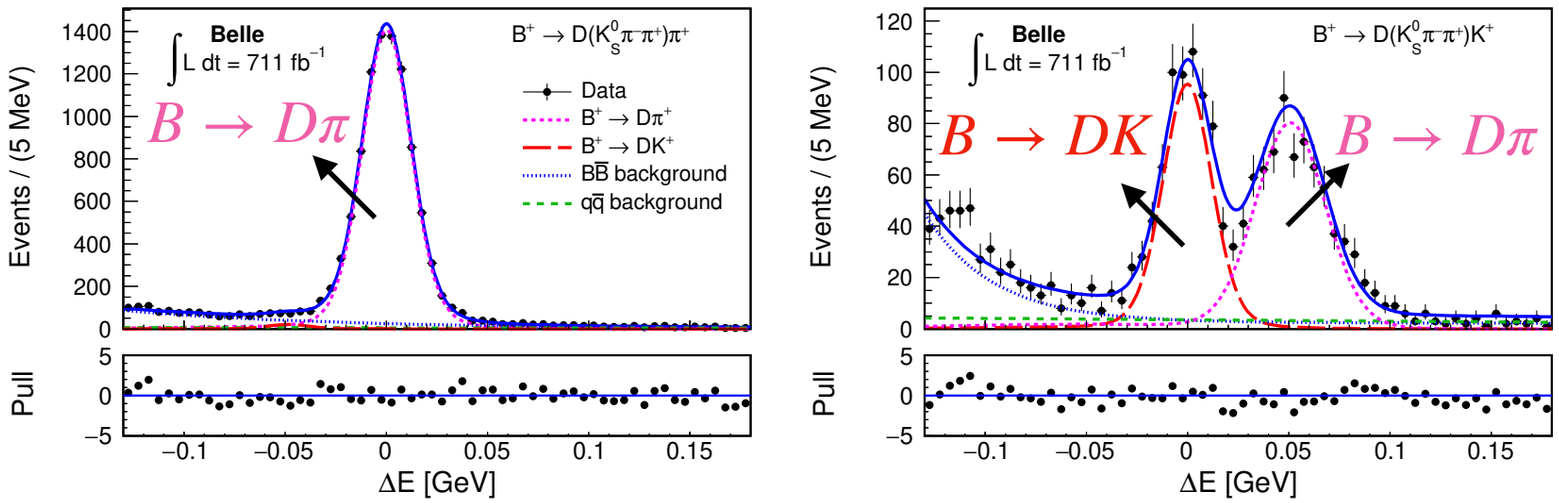
ICHEP 2020



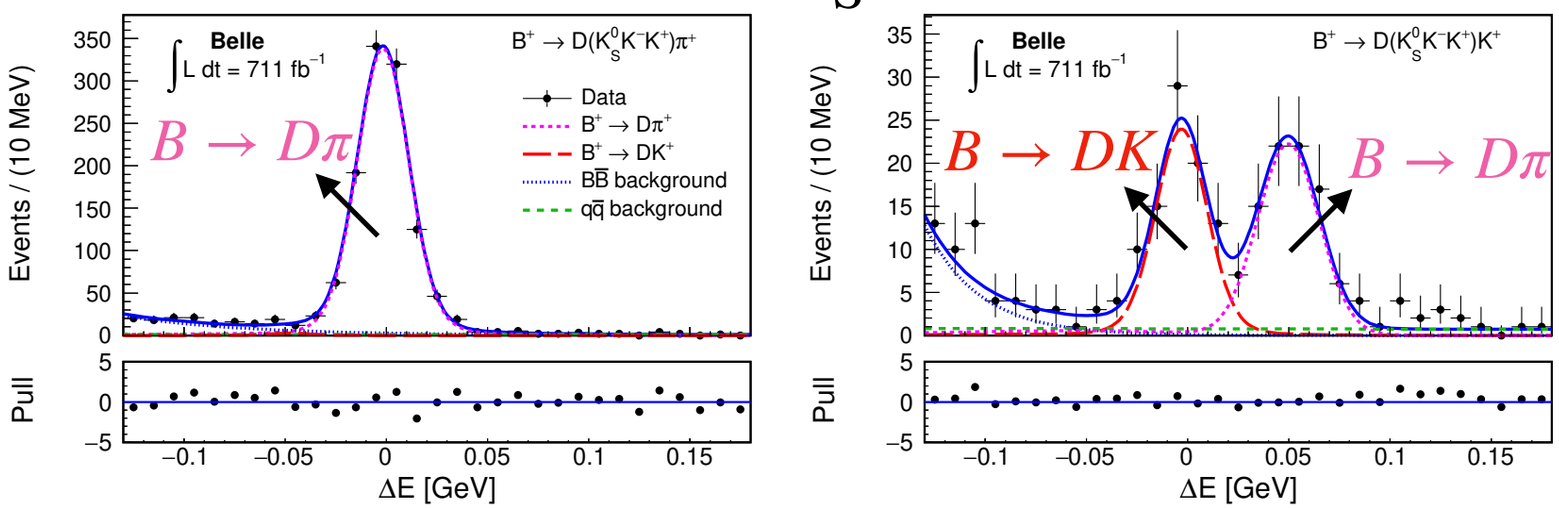
Greatly improved time resolution compared to previous *B*-factories.

Fit of Belle data

$$D^0 \to K^0_S \pi^+ \pi^-$$



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



CPV in $B \to D\pi$ decays