Measurements of $B \to D(*)h$ and charmless B-decays at Belle II

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Charmed and *Charmless B*-decays

B→D(*)h

- mediated through favoured $b \to c$ tree transition with high branching fractions of ~ 0.5%
→ serve as important **control modes**

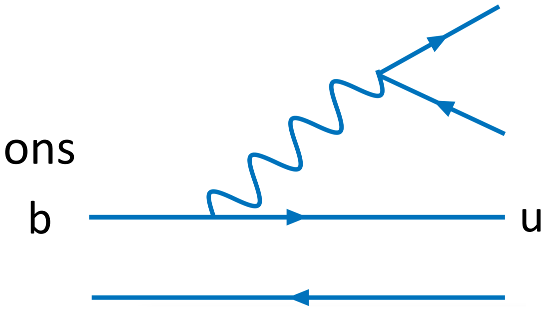
- *B→D(*)**K*** modes are theoretically clean modes to **precisely determine $\boldsymbol{\gamma/\varphi_3}$**

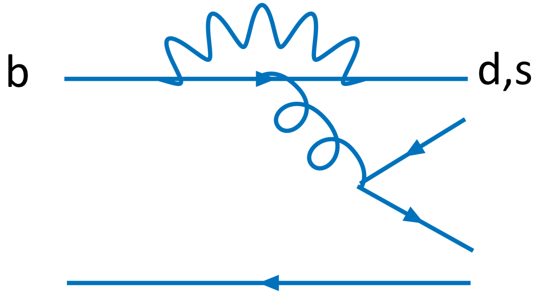
Charmless decays:

- mediated through Cabibbo-suppressed b → u and/or loop-suppressed b → d/s transitions

- highly sensitive to **non-SM loop contributions**

- probe SM and non-SM dynamics in **all three CKM angles (today: $\boldsymbol{\alpha/\varphi_2}$)**





Challenges:

- **low BF**s of order <= 10^{-5}

- $e^+e^- \to$ **$q\bar{q}$ background** dominated

SuperKEKB and Belle II Detector

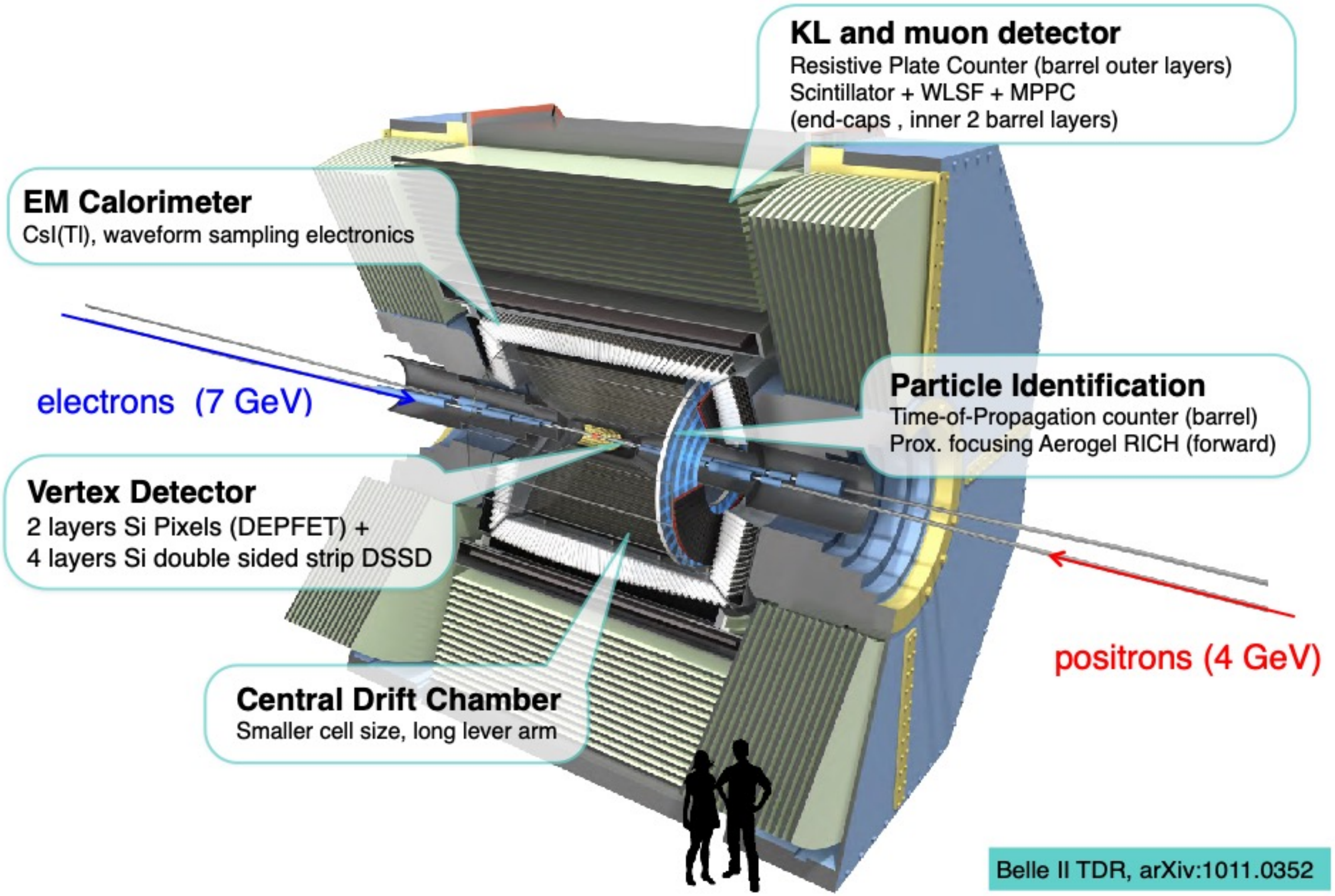
- SuperKEKB: energy-asymmetric $e^+ e^-$ collider running at Υ(4S) resonance (10.58 GeV)

→ clean experimental environment

- world record peak luminosity: 3.1×10^{34} cm^{-2} s^{-1}
- Goal: 50 ab^{-1} by mid 2030s
- so far 213 fb^{-1} of data collected

- unique reach on final states with multiple neutrinos and π^0/photons

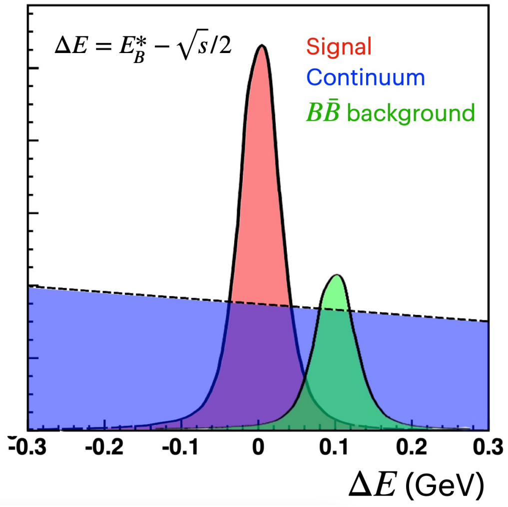
- Today: results on ~**63 fb^{-1}**

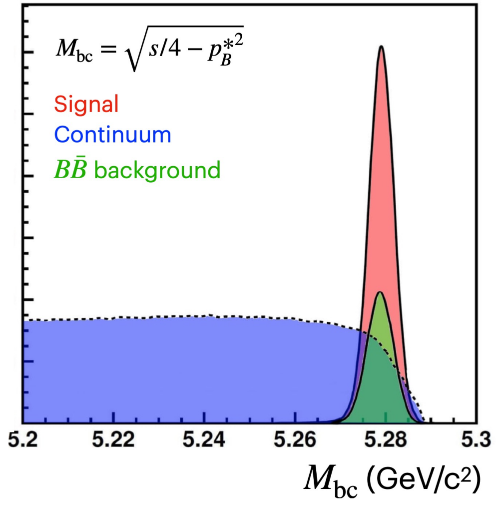


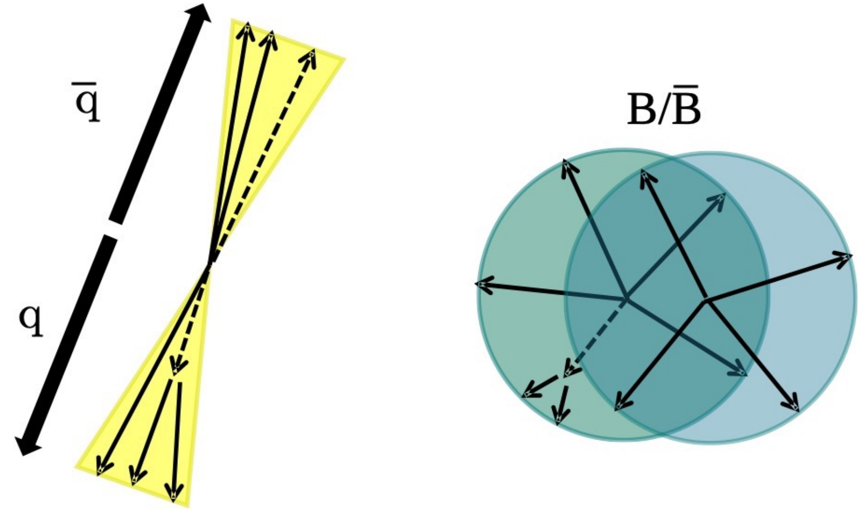
Belle II TDR, arXiv:1011.0352

Analysis Overview

1. **Reconstruction**
   - combine candidates in kinematic fits to fill list of B-meson candidates from low-level observables
2. **Selection**
   - mostly loose baseline selection cuts followed by optimized continuum suppression and particle identification cuts
3. **Modelling**
   - extract models from simulated data (+ calibrate on data)
   - determine selection efficiencies for BR calculations
4. **Fit** to data & calculate physics quantities
   - fit using usually one to three fit variables (ΔE, M_{bc} and **continuum suppression** variable)
5. **Systematic Uncertainties**
   - toy studies and control mode analyses







momenta distribution in CMS frame

$B \to D^0 h^-$

- important observable: ratio of decay rates

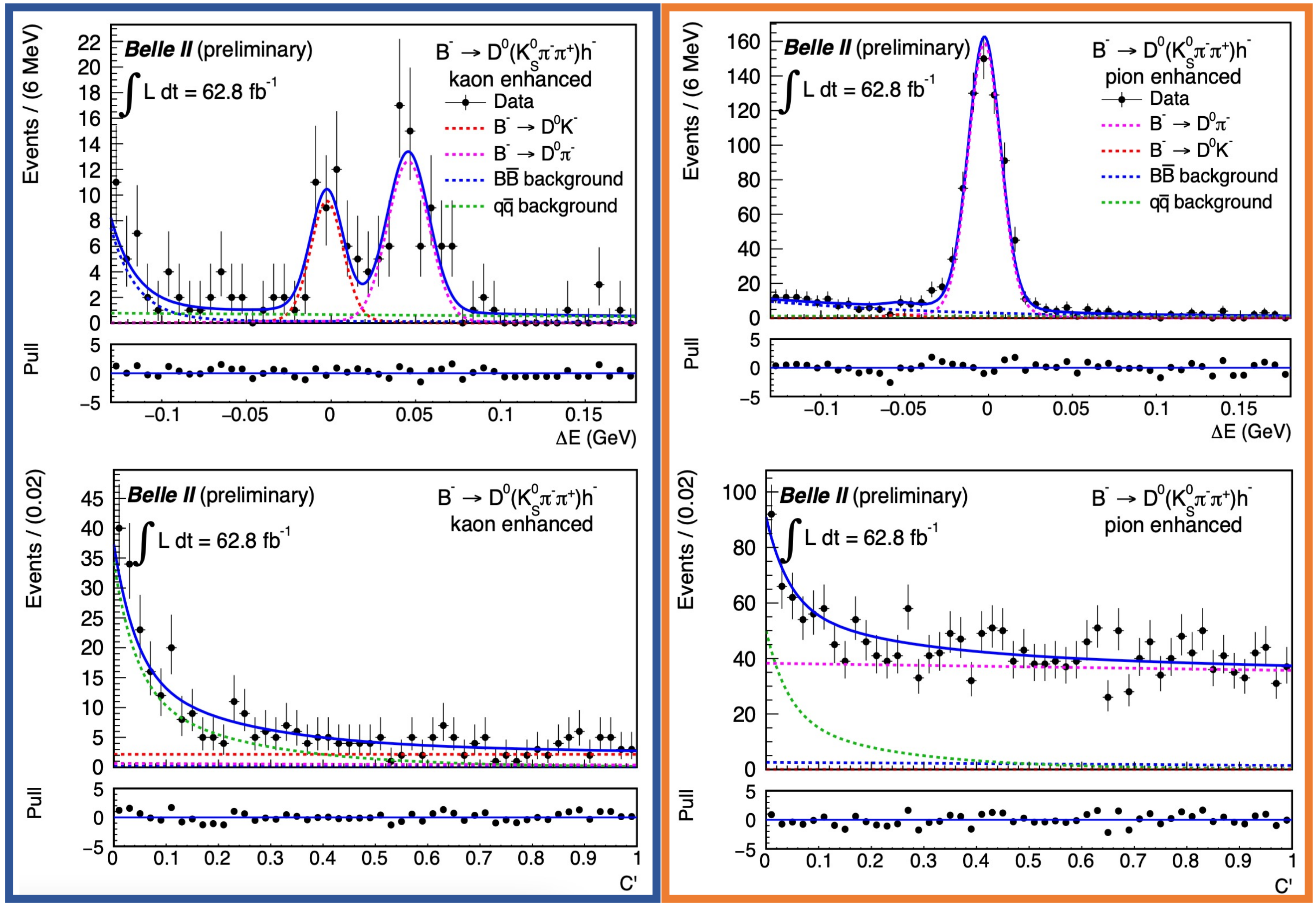
$$R^0 = \frac{\Gamma(B^- \to D^0 K^-)}{\Gamma(B^- \to D^0 \pi^-)}$$

- allows for **cancellation of many systematic uncertainties**

→ clean approach to test theory predictions of factorization and SU(3) symmetry breaking in QCD

- simultaneous 2D-fit in ΔE and CS classifier of kaon/pion-enhanced samples

kaon-enhanced $\mathfrak{L}(K/\pi) > 0.6$ pion-enhanced $\mathfrak{L}(K/\pi) < 0.6$



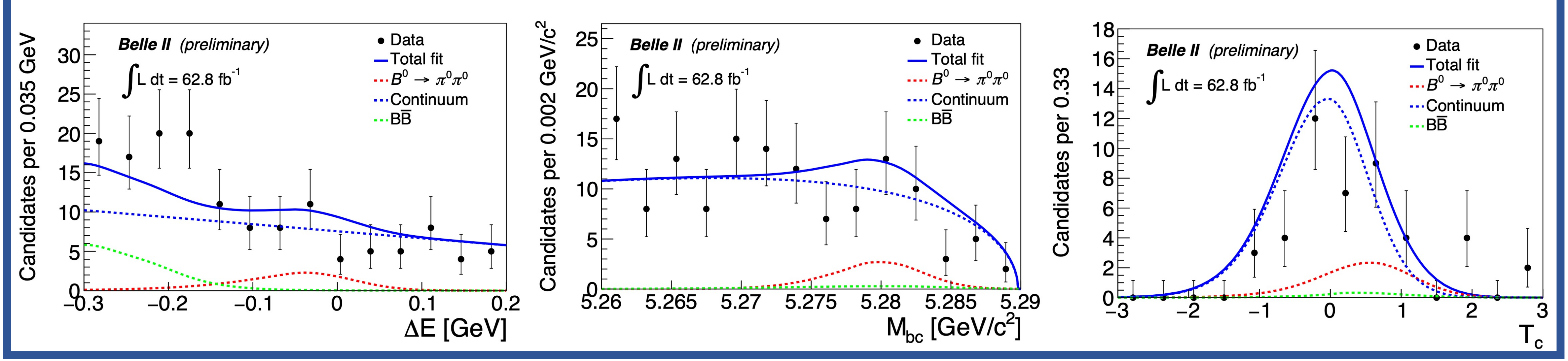
https://arxiv.org/pdf/2104.03628

	$B^- \to D^0(K^-\pi^+)h^-$	$B^- \to D^0(K^0_S\pi^+\pi^-)h^-$	$\bar{B}^0 \to D^+h^-$	$B^- \to D^{*0}h^-$	$\bar{B}^0 \to D^{*+}h^-$
Belle II $R^{+/0}$ $(\times 10^{-2})$	$7.66 \pm 0.55\ ^{+0.11}_{-0.08}$	$6.32 \pm 0.81\ ^{+0.09}_{-0.11}$	$9.22 \pm 0.58 \pm 0.09$	$6.80 \pm 1.01 \pm 0.07$	$5.99 \pm 0.82\ ^{+0.17}_{-0.08}$
LHCb $R^{+/0}$ $(\times 10^{-2})$	$7.77 \pm 0.04 \pm 0.07$ [24]	$7.77 \pm 0.04 \pm 0.07$ [24]	$8.22 \pm 0.11 \pm 0.25$	$7.93 \pm 0.11 \pm 0.56$ [24]	$7.76 \pm 0.34 \pm 0.26$

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

- unique Belle II capability to study all $B \to \pi\pi$ channels in consistent manner to extract α/φ_2
- **most challenging mode**:
  - two π^0's in final state (i.e. photons only)
  - low $\mathfrak{B}$ (10^{-6})
- **optimized π^0 selection**: combine 20 ECL variables using multivariate technique to suppress background photons
- **3D-fit** in ΔE, M_{bc} and transformed continuum suppression variable T_c

https://arxiv.org/pdf/2107.02373.pdf



$N_{fit}(B^0 \to \pi^0\pi^0) = 14^{+6.8}_{-5.6}$ with 3.4σ

$\mathfrak{B}_{fit}(B^0 \to \pi^0\pi^0) = [1.09^{+0.50}_{-0.41}$ (stat) ± 0.27 (sys)] x 10^{-6}

First measurement in Belle II data!

$B^+ \to \rho^+ \rho^0$

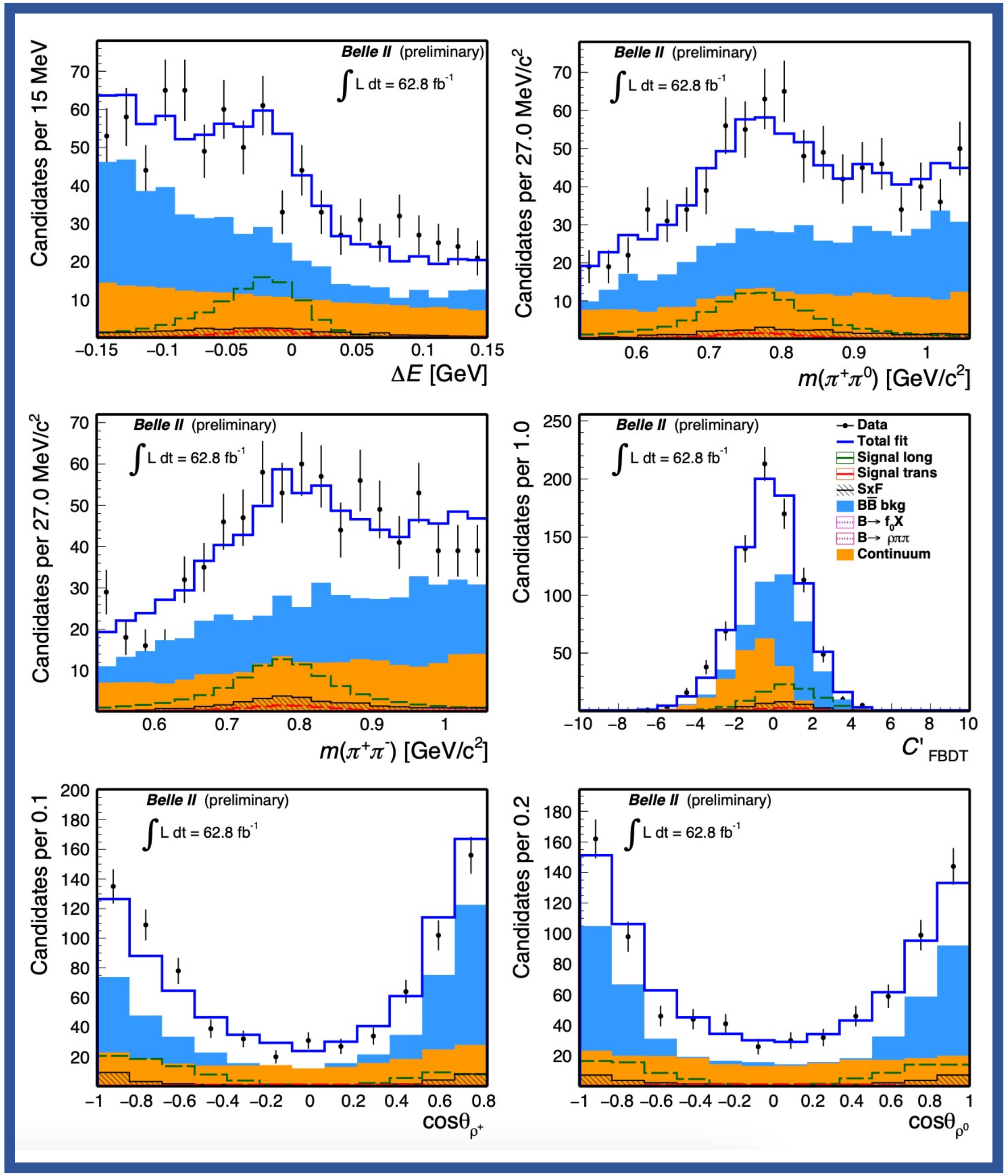
- pion-only final state and broad ρ-peak → large backgrounds
- Spin-0 → Spin+1 + Spin-1 → **angular analysis**
- **6D-fit** including ΔE, T_c , and ρ masses to extract signal; and helicity angles to measure fraction f_L of decays with longitudinal polarization
- syst. uncertainty dominated by data driven π^0 efficiency → will decrease with time

$N_{fit} = 104 \pm 16$

$\mathfrak{B}_{fit} = [20.6 \pm 3.2(stat) \pm 4.0\ (sys)] \times 10^{-6}$

$f_l = 0.936^{+0.049}_{-0.041}(stat) \pm 0.021\ (sys)$

First reconstruction in Belle II data, surpassing early Belle performance!
(20% better precision than Belle using 78 fb-1)
(PRL 91, 221801 (2003))



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

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

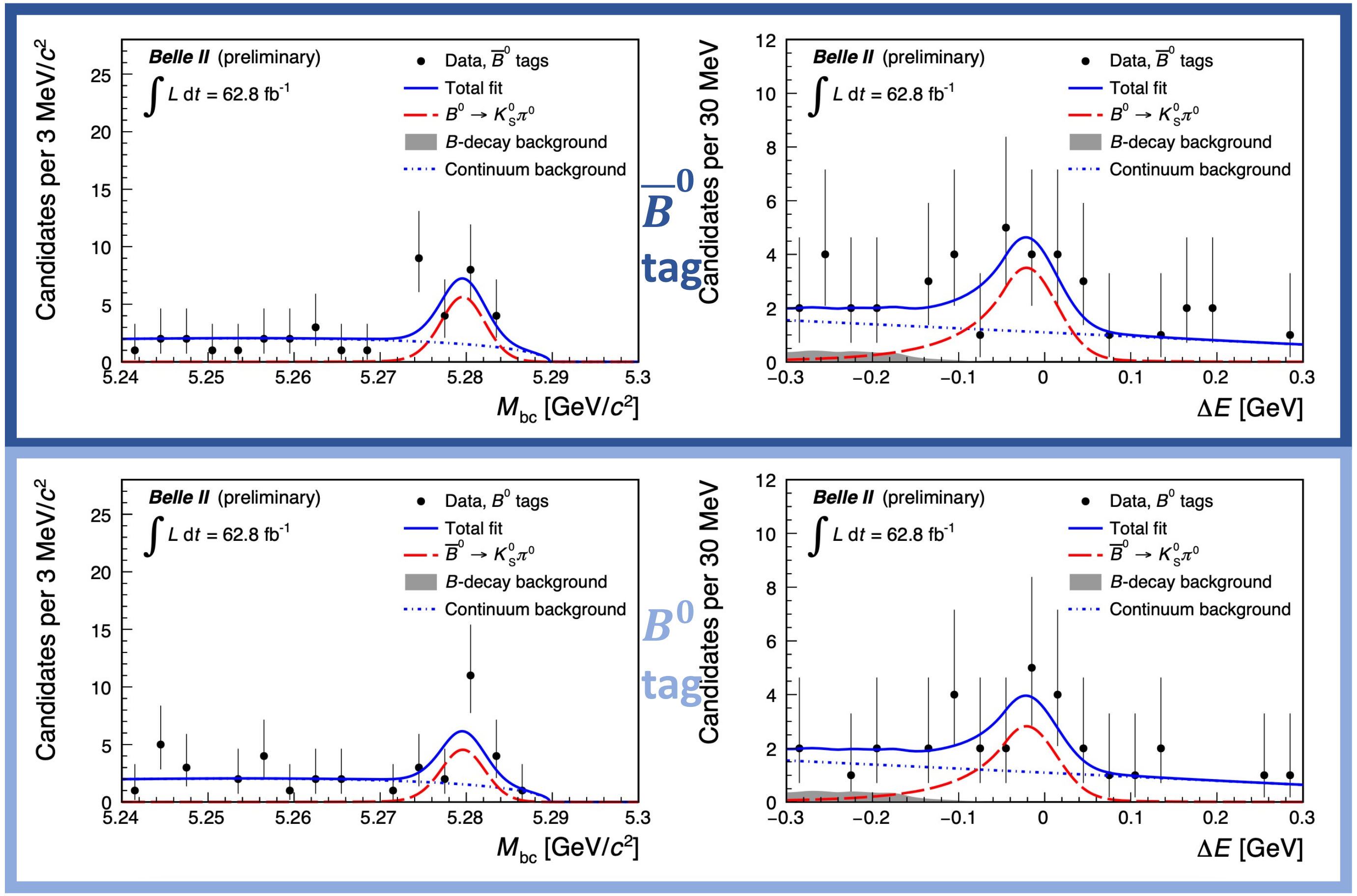
https://arxiv.org/abs/2104.14871

Isospin sum rule: stringent null test of SM, sensitive to presence of non-SM dynamics
in Belle II: unique, consistent access to all channels

BF: challenging as it requires $K_S{}^0$ and π^0 reconstruction
$\mathcal{A}_{CP}$: requires flavor tagging: fit of ΔE-M_{bc}-flavor of the B-meson (q) (see Stephan Duell's talk this morning)

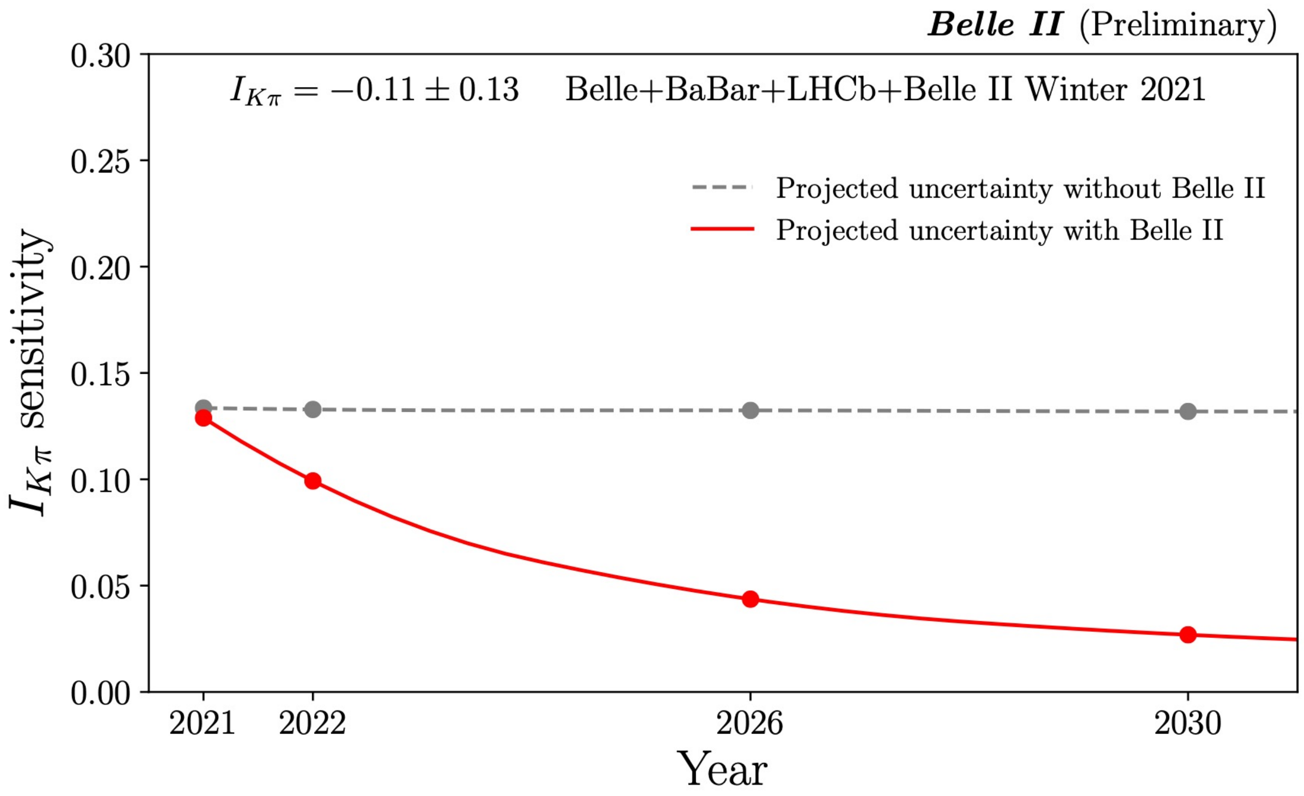
$N_{fit}(B^0 \to K_S{}^0\pi^0) = 45^{+9}_{-8}$
$\mathcal{B}_{fit}(B^0 \to K^0\pi^0) = [8.5^{+1.7}_{-1.6}$ (stat) ± 1.2 (sys)] x 10^{-6}
$\mathcal{A}_{CP}(B^0 \to K^0\pi^0) = 0.40\ ^{+0.46}_{-0.44}$ (stat) ± 0.04 (sys)

First measurement in Belle II data and last missing piece to sum rule!



Isospin sum rule – uncertainty projection

- extrapolate the uncertainty on $I_{K\pi}$ into next decade (assuming stat. ≈ syst.)
- future projections with Belle II and LHCb expected luminosities
- dominant uncertainty coming from $\mathcal{A}_{K0\pi0}$ → **Belle II will play crucial role in pinning down $I_{K\pi}$**



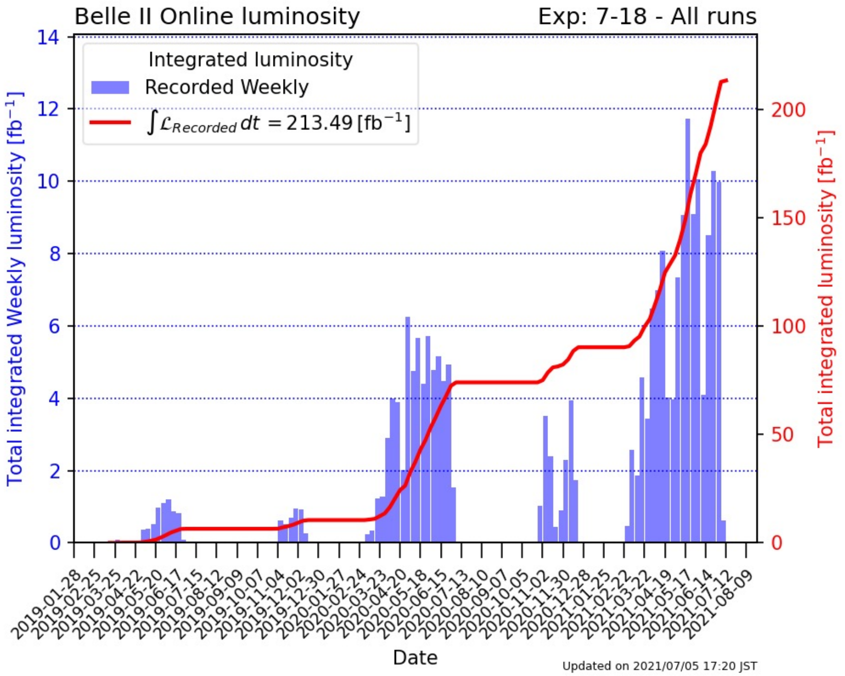
using only updates on $\mathcal{A}_{K+\pi-}$, $\mathcal{A}_{K+\pi0}$ and $\mathcal{A}_{K0\pi+}$

considering updates on complete $K\pi$ set possible with Belle II

https://arxiv.org/abs/2104.14871

Summary

- Belle II train has picked up pace for a leading role in testing **isospin sum rule** and precise determinations of $\boldsymbol{\alpha}$ and $\boldsymbol{\gamma}$
- First/improved measurements of charmless decays in 63 fb^{-1} of early data and a number of vital control modes
- First Belle II measurement of $\mathcal{A}_{K0\pi0}$ completes the ingredients for the isospin sum rule
- All results agree with known values within uncertainties, still dominated by small sample size
- but already 213 fb^{-1} on tape, ready to be analysed!



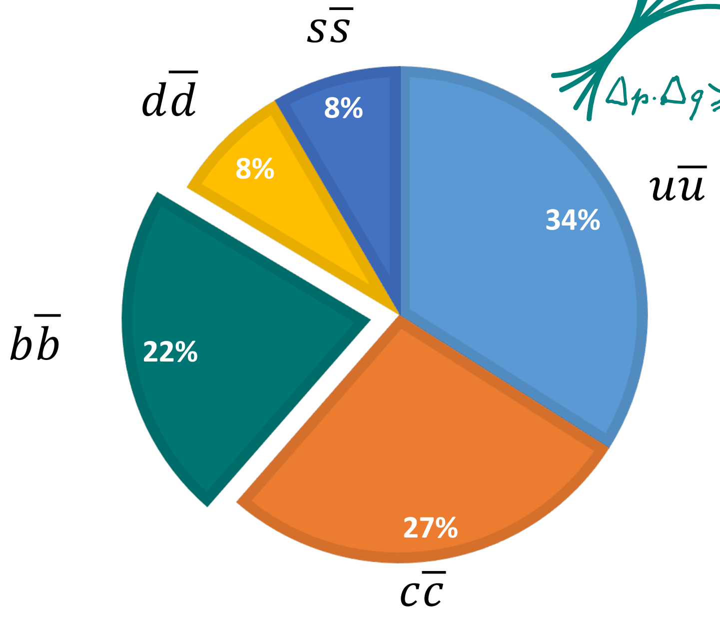
A lot of done and ongoing work not presented today: expect many more new/updated results in the future!

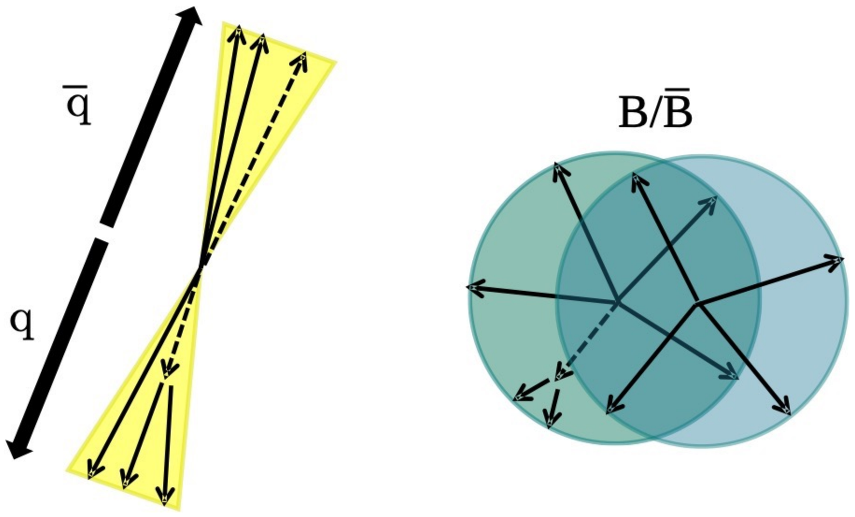
$B \rightarrow D(*)h$ https://arxiv.org/abs/2104.03628
$B \rightarrow K^+\pi^-$, $K^0\pi^-$, $\pi^+\pi^-$: https://arxiv.org/abs/2106.03766
$B \rightarrow K^+\pi^0$, $\pi^+\pi^0$: https://arxiv.org/abs/2105.04111
$B \rightarrow K^0\pi^0$: https://arxiv.org/abs/2104.14871
$B \rightarrow \pi^0\pi^0$: https://arxiv.org/pdf/2107.02373.pdf

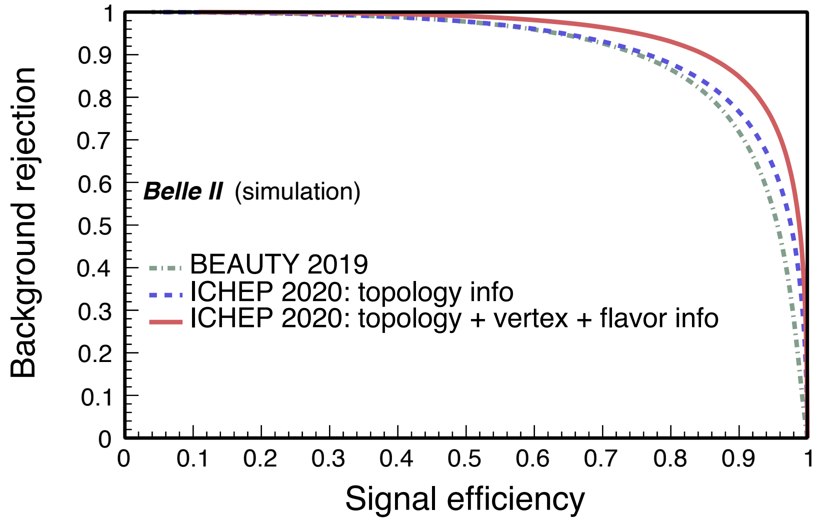
Backup

Continuum Suppression

- continuum background strongly dominating
- exploit kinematic, topological differences between $B\bar{B}$ and $q\bar{q}$
- employ binary boosted decision tree (FastBDT) to create classifier variable from up to ~40 variables
- cut and/or fit this CS classifier







$B \to Dh^-$

- simultaneous 1D-fit of pion- and kaon-enriched samples in ΔE [(1)] to determine $\boldsymbol{R}$

- kaon(pion)-enriched sample: $\mathfrak{L}(K/\pi)$ **> (<) 0.6**

	$B^- \to D^0(K^-\pi^+)h^-$	$B^- \to D^0(K^0_S\pi^+\pi^-)h^-$	$\bar{B}^0 \to D^+h^-$
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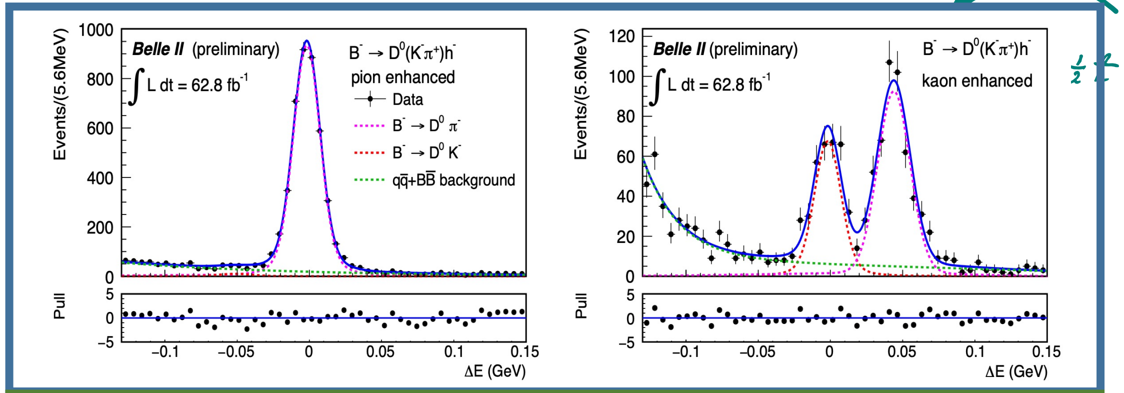

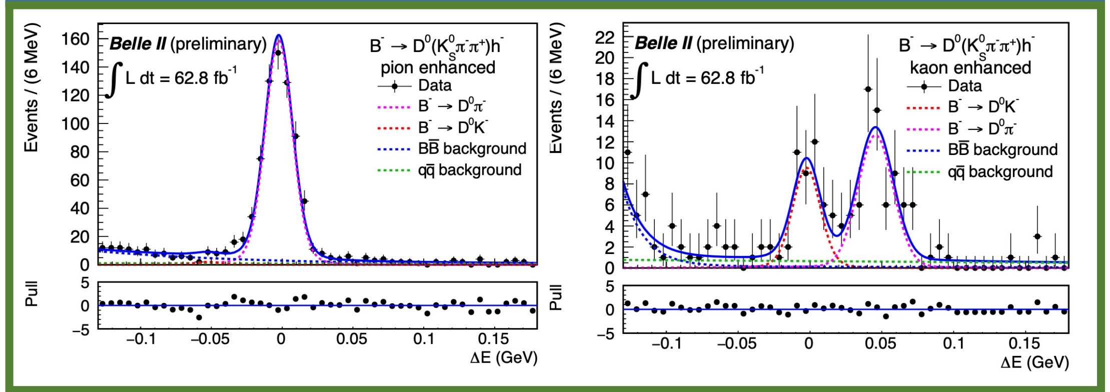

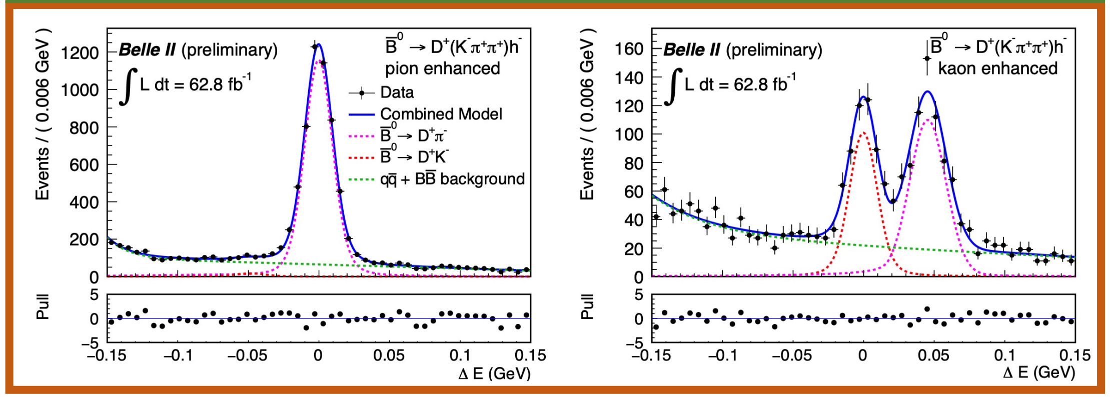

Results compatible with world average values!

(1) : 2D-fit in ΔE and CS classifier for $B^- \to D^0(K_S{}^0\pi^+\pi^-)K^-$

$B \to D^* h^-$

- simultaneous fit of pion- and kaon-enriched samples in ΔE to determine ***R****
- kaon(pion)-enriched sample: $\mathfrak{L}(\boldsymbol{K}/\boldsymbol{\pi})$ **> (<) 0.6**

	$B^- \to D^{*0}h^-$	$\bar{B}^0 \to D^{*+}h^-$
Belle II $R^{*+/0}$ $(\times 10^{-2})$	$6.80 \pm 1.01 \pm 0.07$	$5.99 \pm 0.82 \, ^{+0.17}_{-0.08}$
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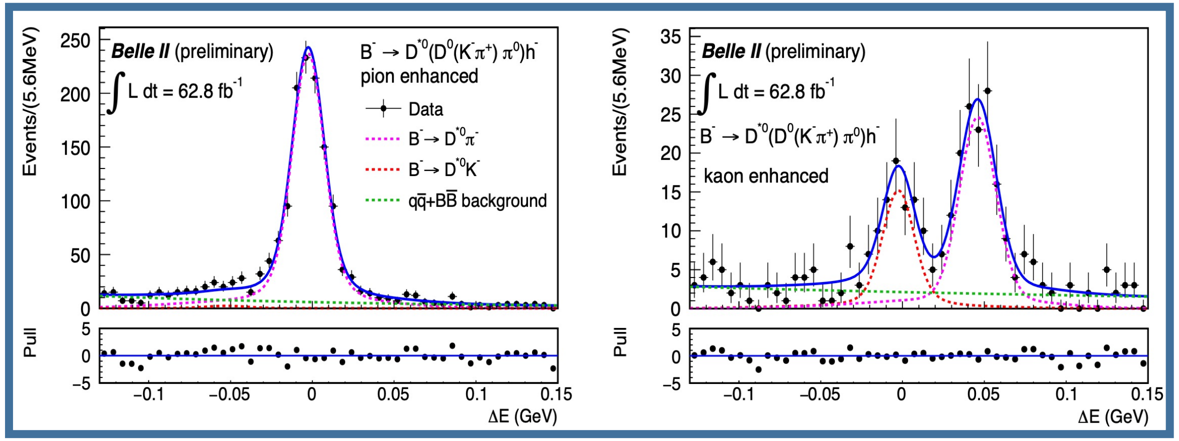
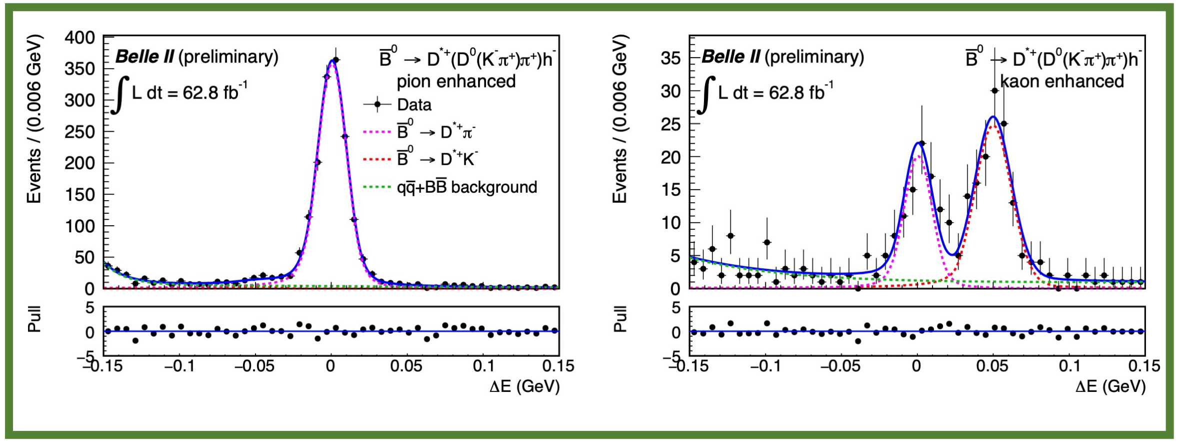


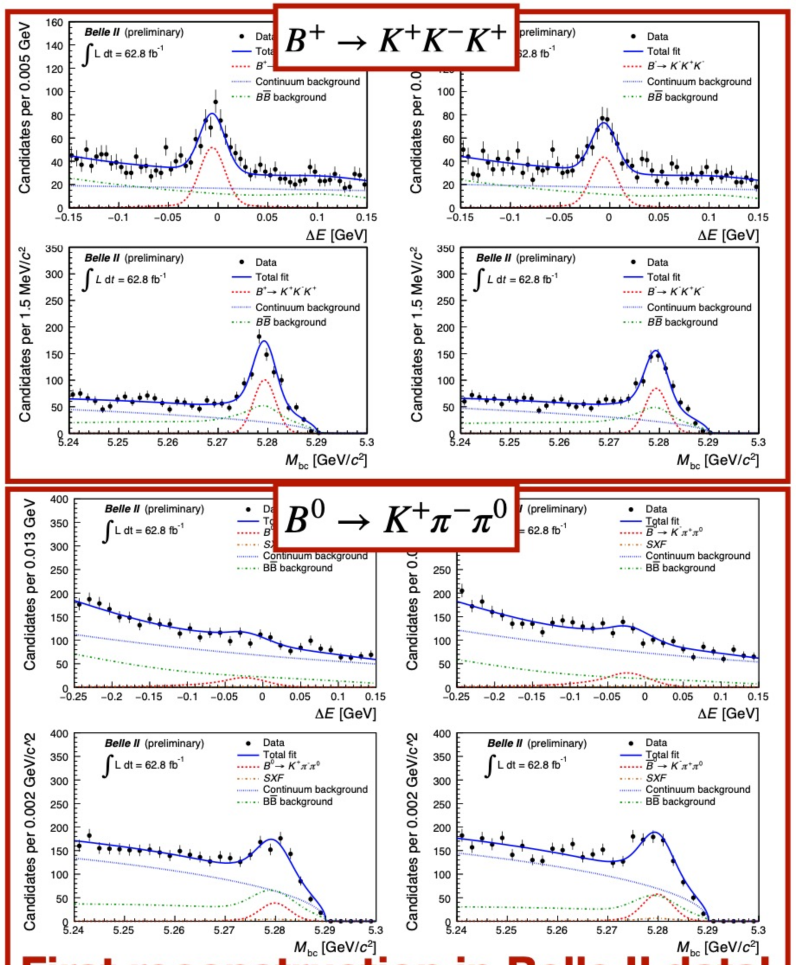


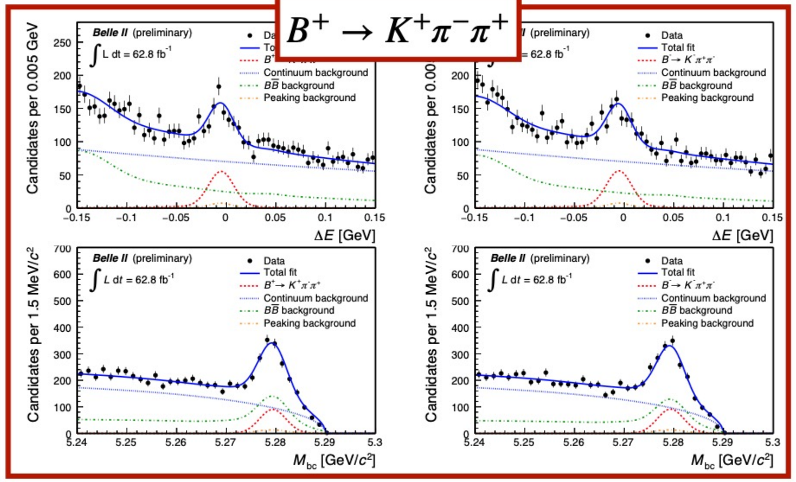
Results compatible with world average values!

stolen from Sebastiano Raiz's talk at PHENO21

CPV in multibody decays

First step towards search of local CPV in Dalitz plots: investigates relative contributions of tree and penguins, and probes non-SM physics.





$$\mathcal{B}(B^+ \to K^+K^-K^+) = [35.8 \pm 1.6(\text{stat}) \pm 1.4(\text{syst})] \times 10^{-6}$$

$$A_{CP}(B^+ \to K^+K^-K^+) = -0.103 \pm 0.042(\text{stat}) \pm 0.020(\text{syst})$$

$$\mathcal{B}(B^+ \to K^+\pi^-\pi^+) = [67.0 \pm 3.3(\text{stat}) \pm 2.3(\text{syst})] \times 10^{-6}$$

$$A_{CP}(B^+ \to K^+\pi^-\pi^+) = -0.010 \pm 0.050(\text{stat}) \pm 0.021(\text{syst})$$

$$\mathcal{B}(B^0 \to K^+\pi^-\pi^0) = [38.1 \pm 3.5(\text{stat}) \pm 3.9(\text{syst})] \times 10^{-6}$$

$$A_{CP}(B^0 \to K^+\pi^-\pi^0) = 0.207 \pm 0.088(\text{stat}) \pm 0.011(\text{syst})$$

Belle II accesses consistently all channels

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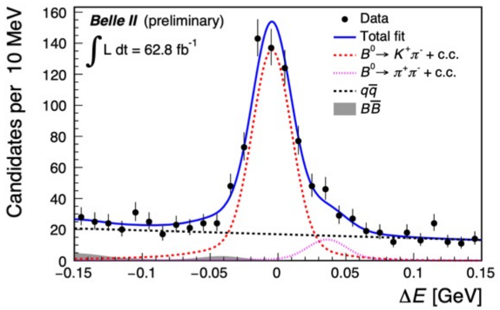
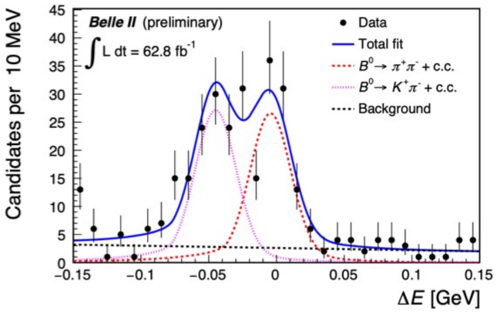
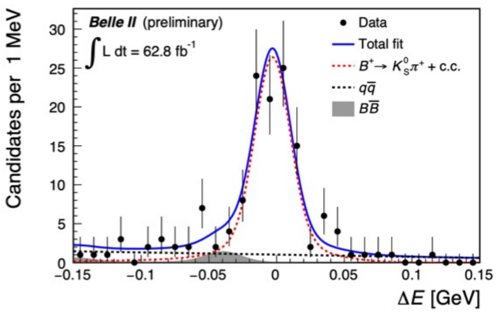
stolen from Sebastiano Raiz's talk at PHENO21

Two-body: $B^{+,0} \to h^+\pi^-,\ h^+\pi^0,\ K_S^0\pi^+$

Unique Belle II capability to study all the $B \to K\pi$ decays to investigate isospin sum-rules.







Probe of tracking and PID performances.

Benchmark of K_S^0 reconstruction

N($B^0 \to K^+\pi^-$): $568\ ^{+29}_{-28}$

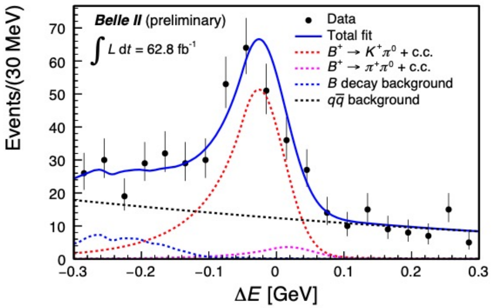
N($B^0 \to \pi^+\pi^-$): $115\ ^{+14}_{-13}$

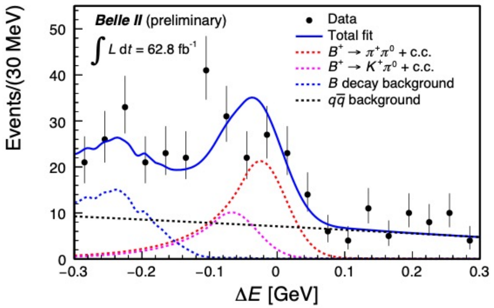
N($B^+ \to K_S^0\pi^+$): $103\ ^{+11}_{-10}$

$\mathscr{B}\ [10^{-6}]$: 18.0 ± 0.9(stat) $\pm\ 0.9$(syst)

5.8 ± 0.7(stat) $\pm\ 0.3$(syst)

$21.4^{+2.3}_{-2.2}$(stat) $\pm\ 1.6$(syst)





Challenge of π^0 reconstruction performances, require good PID.

N($B^+ \to K^+\pi^0$): $211\ ^{+18.8}_{-18}$

N($B^+ \to \pi^+\pi^0$): $83.9\ ^{+14.7}_{-13.9}$

$\mathscr{B}\ [10^{-6}]$: $11.9^{+1.1}_{-1.0}$(stat) $\pm\ 1.6$(syst)

$5.5^{+1.0}_{-0.9}$(stat) $\pm\ 0.7$(syst)

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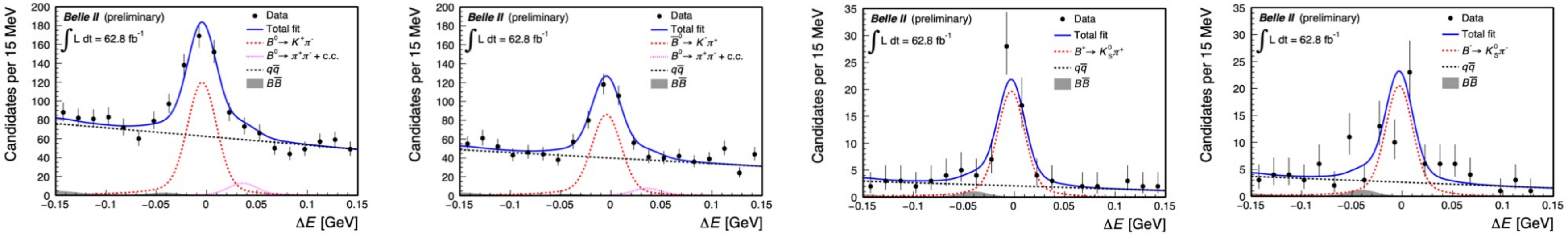
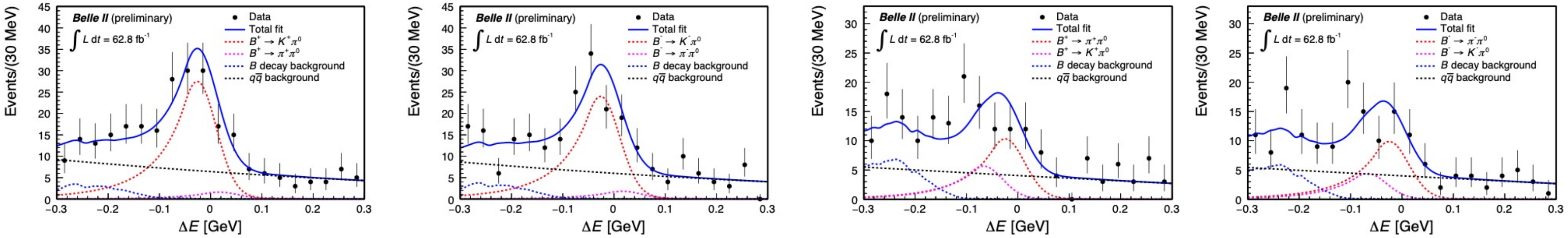
stolen from Sebastiano Raiz's talk at PHENO21

CP asymmetries in two-body decays



$A_{CP}(B^0 \to K^+\pi^-) = -0.16 \pm 0.05(\text{stat}) \pm 0.01(\text{syst})$

$A_{CP}(B^+ \to K^0\pi^+) = -0.01 \pm 0.08(\text{stat}) \pm 0.05(\text{syst})$



$A_{CP}(B^+ \to K^+\pi^0) = -0.09 \pm 0.09(\text{stat}) \pm 0.03(\text{syst})$

$A_{CP}(B^+ \to \pi^+\pi^0) = -0.04 \pm 0.17(\text{stat}) \pm 0.06(\text{syst})$

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syst. uncertainties: 1) branching ratios

- **Tracking efficiency**: 0.91% per charged track as suggested by TG
- **K_S rec. efficiency**: 1% per cm average flight length
- **PID/CS efficiency**: stat. uncert. of selection efficiency using control channel $B^{-} \rightarrow D^{0} (\rightarrow K^{+}\pi^{-})\, \pi^{-}$
- **N_{BB} :** combination of uncertainties in $\mathcal{L}$, $\sigma\big(\Upsilon(4S)\big)$, f_{00} (f_{+-}) and beam energy spread → 2.7 %
- **Signal modeling:**
  a. **shape**: fit with 2 Gaussians instead, difference as systematic
  b. **nCDCHits mismodeling:** require > 4 hits in CDC for each track, difference as systematic
- **Background modeling**: fit with first order poly. instead, difference as systematic
- **Peaking background**: fix peak. bkg. ratio instead of floating, difference as systematic

stolen from Sebastiano Raiz's talk at PHENO21

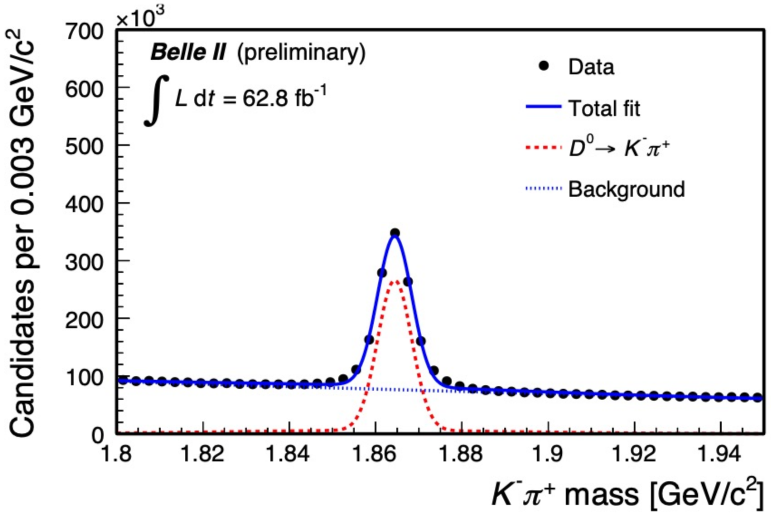
Instrumental asymmetries

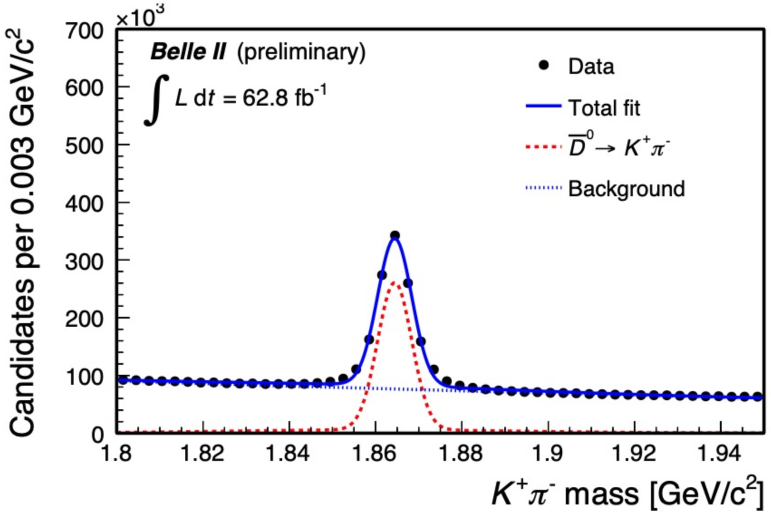
Observed charge-dependent signal yields depend on CP violation but also on charge-dependent instrumental reconstruction asymmetries (K_+/K_- ecc) that need be corrected for CP violation measurements

$$\mathscr{A} = \mathscr{A}_{CP} + \mathscr{A}_{det}$$

Tree-dominated hadronic D decays $D^+ \to K_S \pi^+$ and $D^0 \to K^- \pi^+$ restricted to charmless-like kinematics to determine instrumental asymmetries on data. CPV in charm tree decays assumed inexistent or irrelevant.

$\mathcal{A}_{\rm det}(K^+\pi^-)$	-0.010 ± 0.001
$\mathcal{A}_{\rm det}(K^0_{\rm S}\pi^+)$	$+0.026 \pm 0.019$
$\mathcal{A}_{\rm det}(K^+)$	$+0.017 \pm 0.019$
$\mathcal{A}_{\rm det}(\pi^+)$	$+0.026 \pm 0.019$





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