Measurements of charmless *B* decays at Belle II

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on behalf of the Belle II collaboration

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Belle II

Charmless *B* decays

Hadronic *B* decays not mediated by $b \to c$.
Cabibbo-suppressed $\boldsymbol{b \to u}$ trees and $\boldsymbol{b \to d, s}$ penguins.

➡ Highly sensitive to non-SM loops.

➡ Probe non-SM dynamics in all the three CKM angles.

Account for ~15% of experimental flavor physics papers.

Pheno challenges: predictions limited by complicated calculation of hadronic matrix elements.

Exp. challenges: $O(10^{-5})$ branching fractions, same final states of the dominant background ("continuum" $e^+e^- \to q\bar{q}$ at Belle II).

Belle II goals

◉ Test SM using isospin sum rules;

◉ Investigate localized CP asymmetries in Dalitz plot of three-body decays;

◉ Improve precision on ϕ_2/α angle.

Today: results on 35 fb^{-1} and 63 fb^{-1} (new for La Thuile).

In-depth validation of detector early operation and analysis tools.

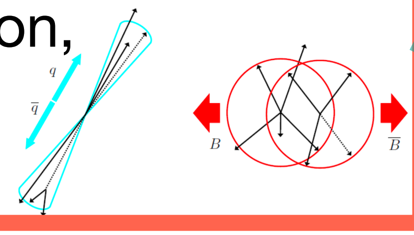
See details on the detector on today's talk by E. Torassa

Analysis overview

Goal: blind measurements of branching fractions, CP asymmetries and polarizations.

Selection

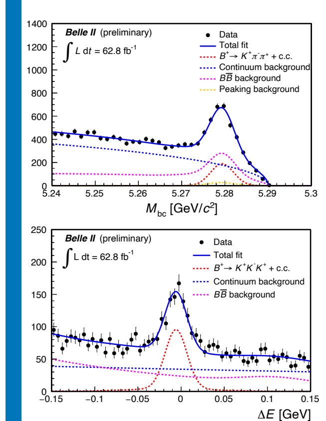
Continuum suppression, optimize on simulation and data.



Efficiencies and corrections

Efficiencies from simulation, validated on data. Instrumental asymmetries from data.

Signal extraction



$$\Delta E = E^*_B - E^*_{\mathrm{beam}}$$

$$M_{\mathrm{bc}} = \sqrt{{E^*_{\mathrm{beam}}}^2 - p^{*2}_B}$$

Models from simulation, adjusted on control modes.

Combine yields, efficiencies and instrumental asymmetries to extract final results.

Systematic uncertainties

Toy studies or control modes in data.

Validation

Validation of the full analysis on more abundant control modes on signal data.

Unblinding

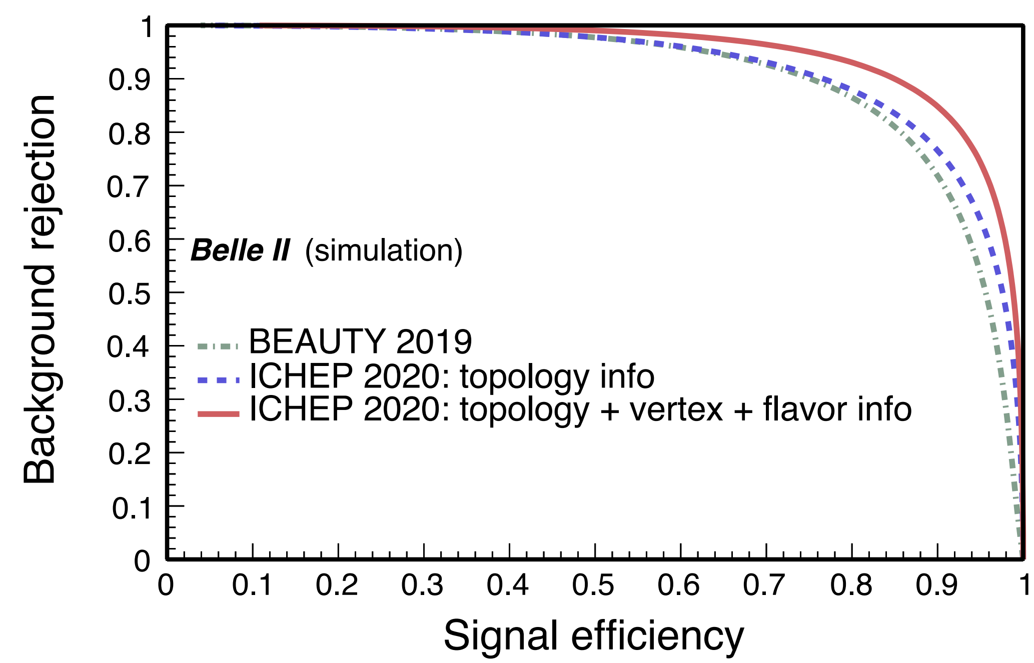
Apply full analysis to data.

All results compatible with the known value within ~6% to ~25% precision, dominated by statistical component.

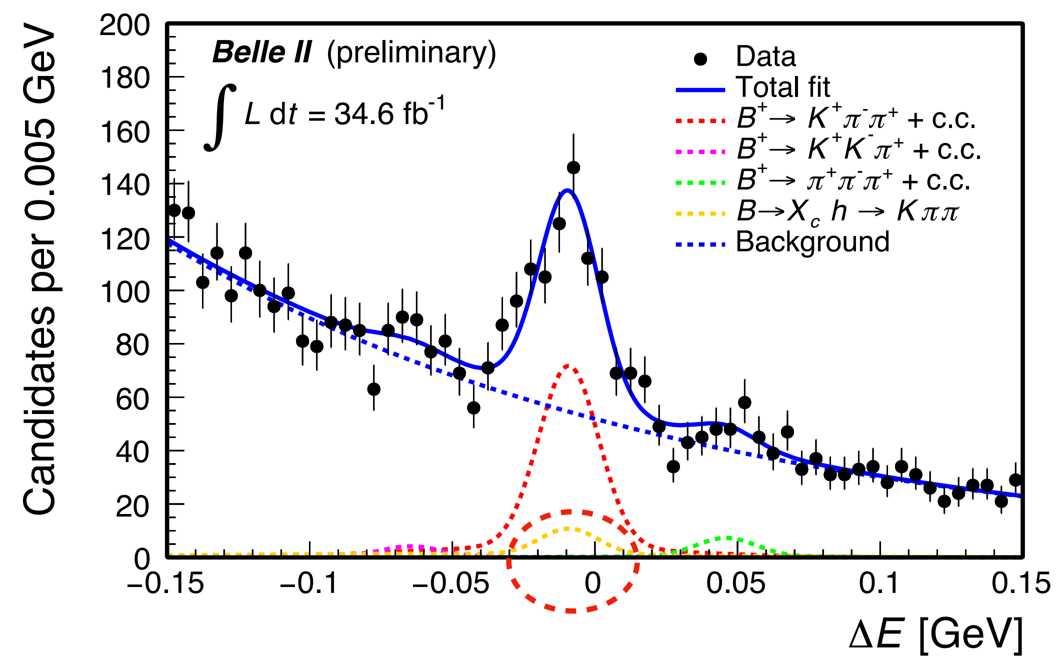
Challenges

Continuum suppression: exploit topological differences, combine 30+ kinematic, decay-time and topological variables in multivariate techniques.

$q\bar{q}$ background rejection: ~99 %



Peaking backgrounds: study vetoes from simulation to exclude them and add fit components to account for survivors.



Multidimensional fits: fit simultaneously more variables to improve fit precision.

Results

Isospin sum rule: $K^+\pi^-$, $K^+\pi^0$, $K^0\pi^+$

Stringent null test of SM, sensitive to presence of non-SM dynamics.

$$I_{K\pi} = A_{\rm CP}^{K^+\pi^-} + A_{\rm CP}^{K^0\pi^+}\frac{\mathscr{B}(K^0\pi^+)}{\mathscr{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{\rm CP}^{K^+\pi^0}\frac{\mathscr{B}(K^+\pi^0)}{\mathscr{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{\rm CP}^{K^0\pi^0}\frac{\mathscr{B}(K^0\pi^0)}{\mathscr{B}(K^+\pi^-)}$$

Unique Belle II capability to study consistently all the $B \to K\pi$ decays.

$\mathscr{B}(B^0 \to K^+\pi^-) = [18.9 \pm 1.4(\text{stat}) \pm 1.0(\text{syst})] \times 10^{-6}$

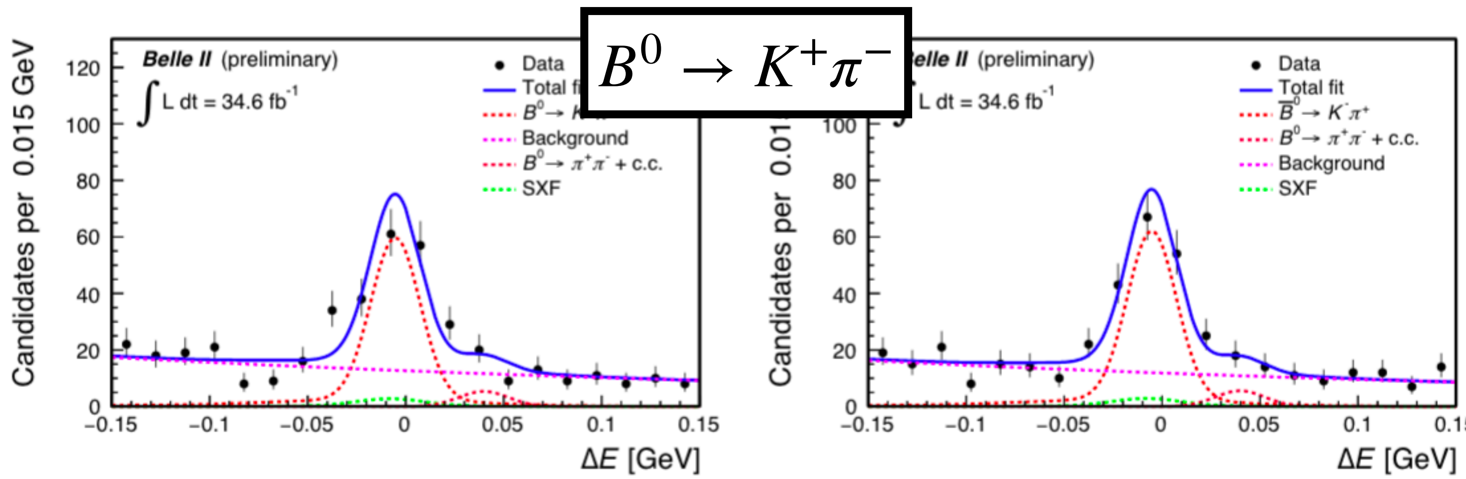
$A_{CP}(B^0 \to K^+\pi^-) = 0.030 \pm 0.064(\text{stat}) \pm 0.008(\text{syst})$

$\mathscr{B}(B^+ \to K^0\pi^+) = [21.8^{+3.3}_{-3.0}(\text{stat}) \pm 2.9(\text{syst})] \times 10^{-6}$

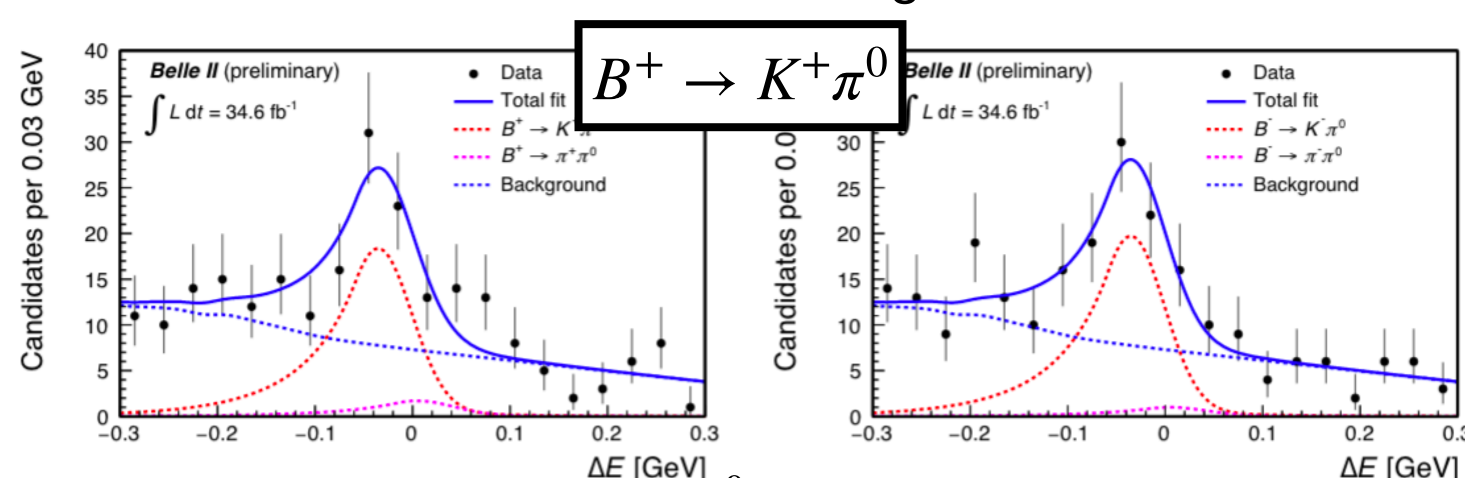
$A_{CP}(B^+ \to K^0\pi^+) = -0.072^{+0.109}_{-0.114}(\text{stat}) \pm 0.024(\text{syst})$

$\mathscr{B}(B^+ \to K^+\pi^0) = [12.7^{+2.2}_{-2.1}(\text{stat}) \pm 1.1(\text{syst})] \times 10^{-6}$

$A_{CP}(B^+ \to K^+\pi^0) = 0.052^{+0.121}_{-0.119}(\text{stat}) \pm 0.022(\text{syst})$



Probes tracking.



Probes π^0 reconstruction.

https://arxiv.org/pdf/2009.09452.pdf (34.6 fb-1)

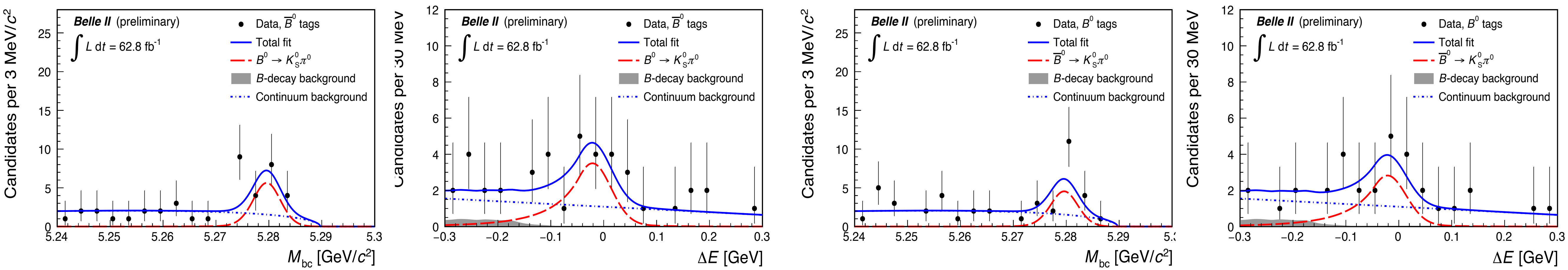
Isospin sum rule: $K^0\pi^0$

62.8 fb^{-1}: new for La Thuile

BF: challenging as it requires K_S^0 and π^0 reconstruction.
A$_{CP}$: requires also flavor tagging. Fit of ΔE-M$_{bc}$-flavor of the B meson (q), simultaneously in 7 ranges of wrong-tag fraction (output from flavor tagger).

$$P_{\text{sig}}(q) = \frac{1}{2}\left(1 + q \cdot (1 - 2w_r) \cdot (1 - 2\chi_d) \cdot \mathcal{A}_{\text{CP}}(K^0\pi^0)\right)$$

$B^0 \to K^0\pi^0$ $\qquad\qquad$ $\overline{B^0} \to K^0\pi^0$



N($B^0 \to K_S^0\pi^0$): $45\ ^{+9}_{-8}$

First measurement in Belle II data!

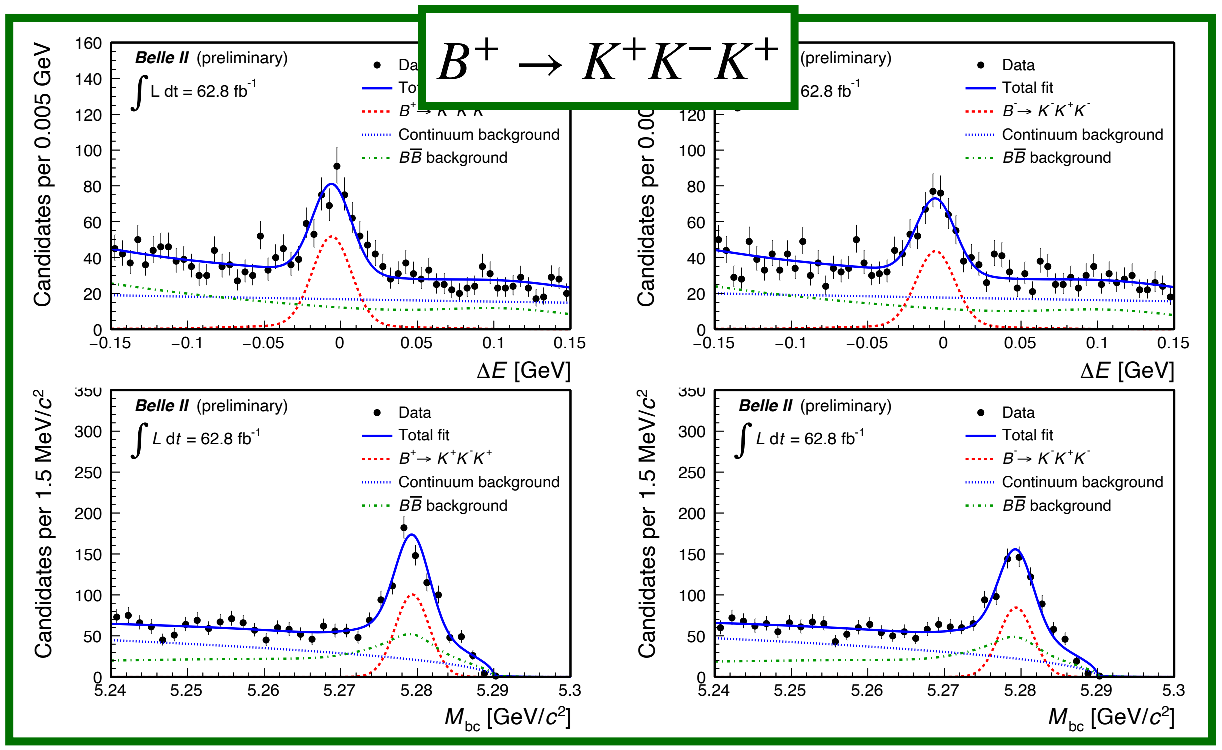
$\mathcal{B}(B^0 \to K^0\pi^0) = [8.5^{+1.7}_{-1.6}(\text{stat}) \pm 1.2(\text{syst})] \times 10^{-6}$

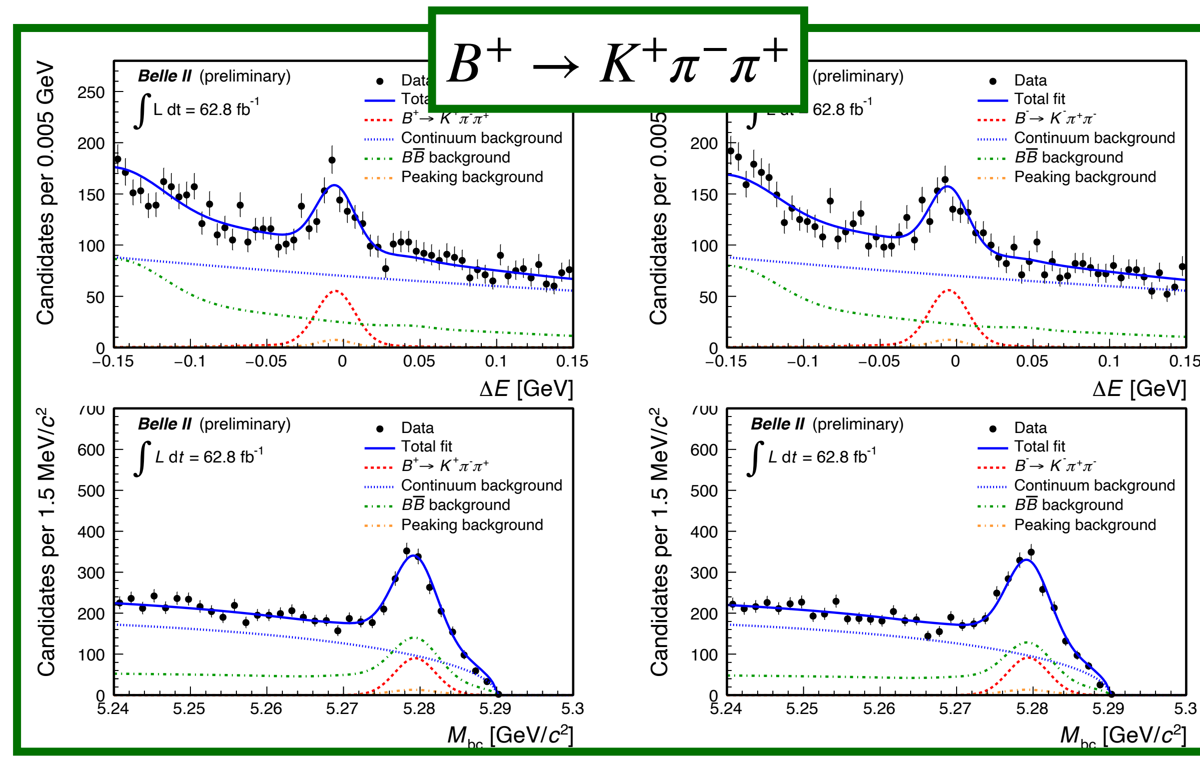
$A_{CP}(B^0 \to K^0\pi^0) = -0.40^{+0.46}_{-0.44}(\text{stat}) \pm 0.04(\text{syst})$

62.8 fb^{-1}: new for La Thuile

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.





Rich Dalitz structure poses the additional challenge of many peaking backgrounds.

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

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

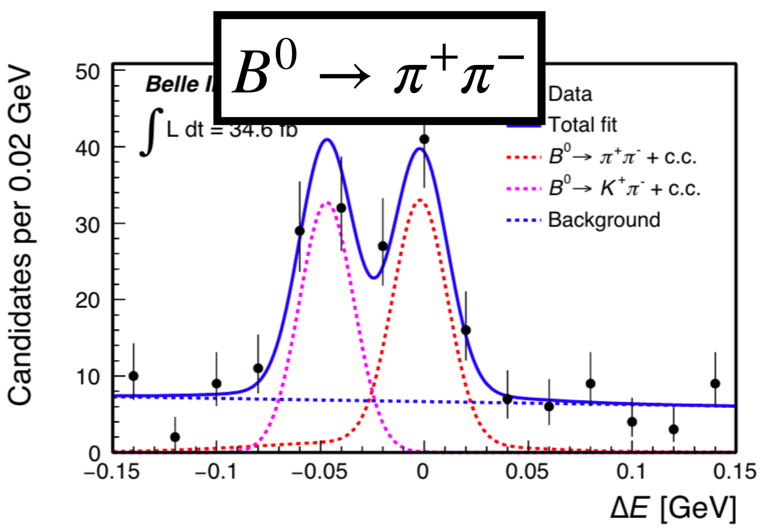
$\mathcal{B}(B^+ \to K^+\pi^-\pi^+) = [67.0 \pm 3.3(\text{stat}) \pm 2.3(\text{syst})] \times 10^{-6}$

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

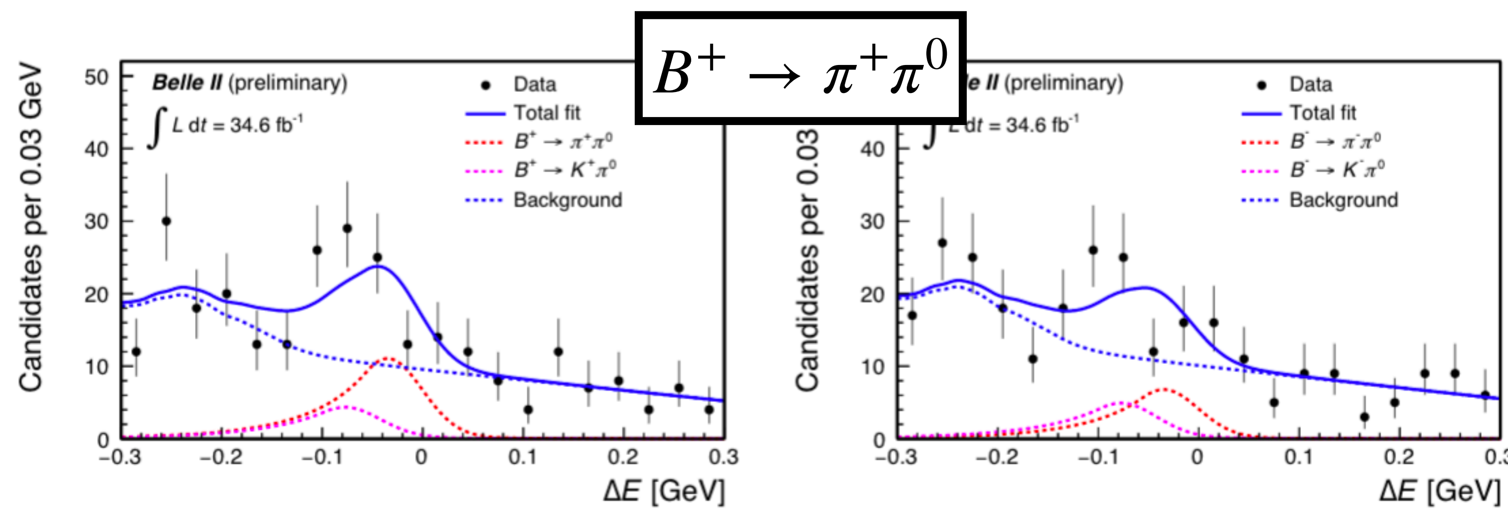
Determination of α/ϕ_2

Unique Belle II capability to study all the $B \to \pi\pi,\ \rho\rho$ decays to determine the CKM angle $\alpha = arg\left[-V_{td}V_{tb}^{*}/V_{ud}V_{ub}^{*}\right]$. Comparing α from penguins or trees offers non-SM sensitivity.

Currently known with 6% uncertainty.



Benchmarks PID and ΔE resolution.



Probes π^0 reconstruction and PID.

$$\mathscr{B}(B^0 \to \pi^+\pi^-) = [5.6^{+1.0}_{-0.9}(\text{stat}) \pm 0.3(\text{syst})] \times 10^{-6}$$

$$\mathscr{B}(B^+ \to \pi^+\pi^0) = [5.7 \pm 2.3(\text{stat}) \pm 0.5(\text{syst})] \times 10^{-6}$$

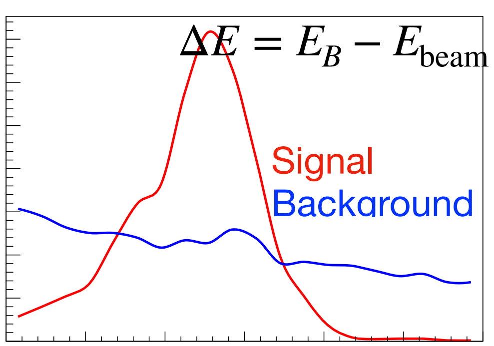
$$A_{CP}(B^+ \to \pi^+\pi^0) = -0.268^{+0.249}_{-0.322}(\text{stat}) \pm 0.123(\text{syst})$$

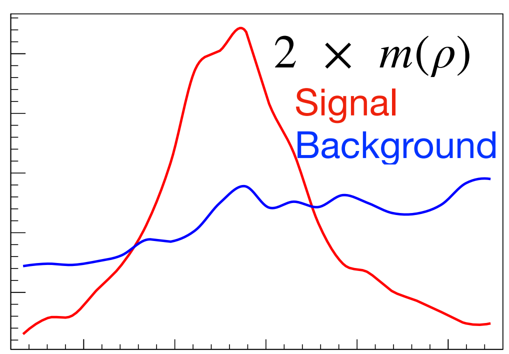
https://arxiv.org/pdf/2009.09452.pdf (34.6 fb^{-1})

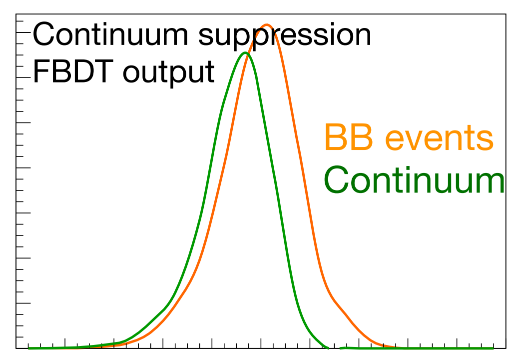
Determination of α/ϕ_2: $B^+ \to \rho^+\rho^0$

$B \to \rho\rho$: the most promising probe of α. Current best result from BaBar on 424 fb^{-1} (PRL 102, 141802 (2009)): $\mathscr{B} = [23.7 \pm 2.0] \times 10^{-6}$, $f_L = 0.950 \pm 0.016$

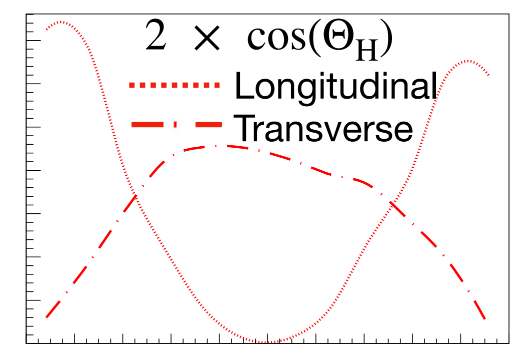
Reconstruct the final state $(\pi^+\pi^0)(\pi^+\pi^-)$ → challenge of π^0.
Intermediate ρ states have spin = 1 → need to fit also angular distributions to determine fraction of longitudinal polarization.
Broad mass peak of ρ meson → accepts lots of background, need to fit.
⇒ 6D fit including ρ masses and helicity angles.







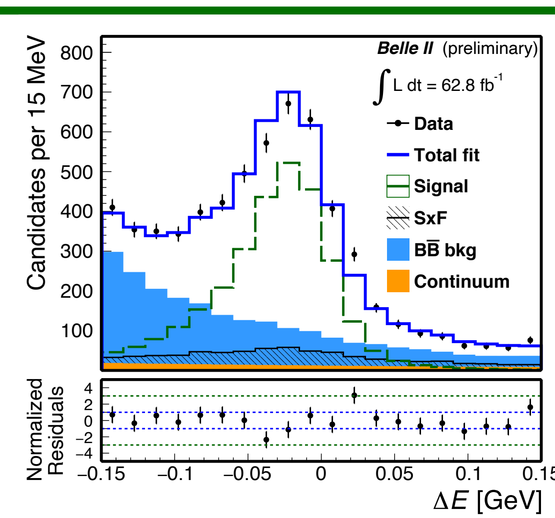
Separate signal from backgrounds.

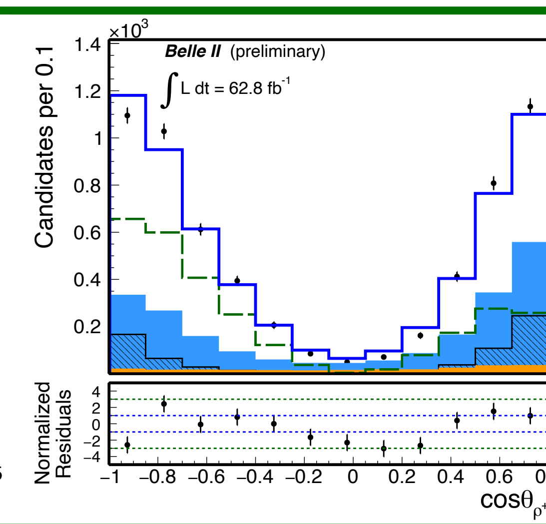


Distinguish the two signal polarizations.

Full angular analysis validated on $B^+ \to \overline{D^0}(\to K^+\pi^-)\rho^+(\to \pi^+\pi^0)$ in data.

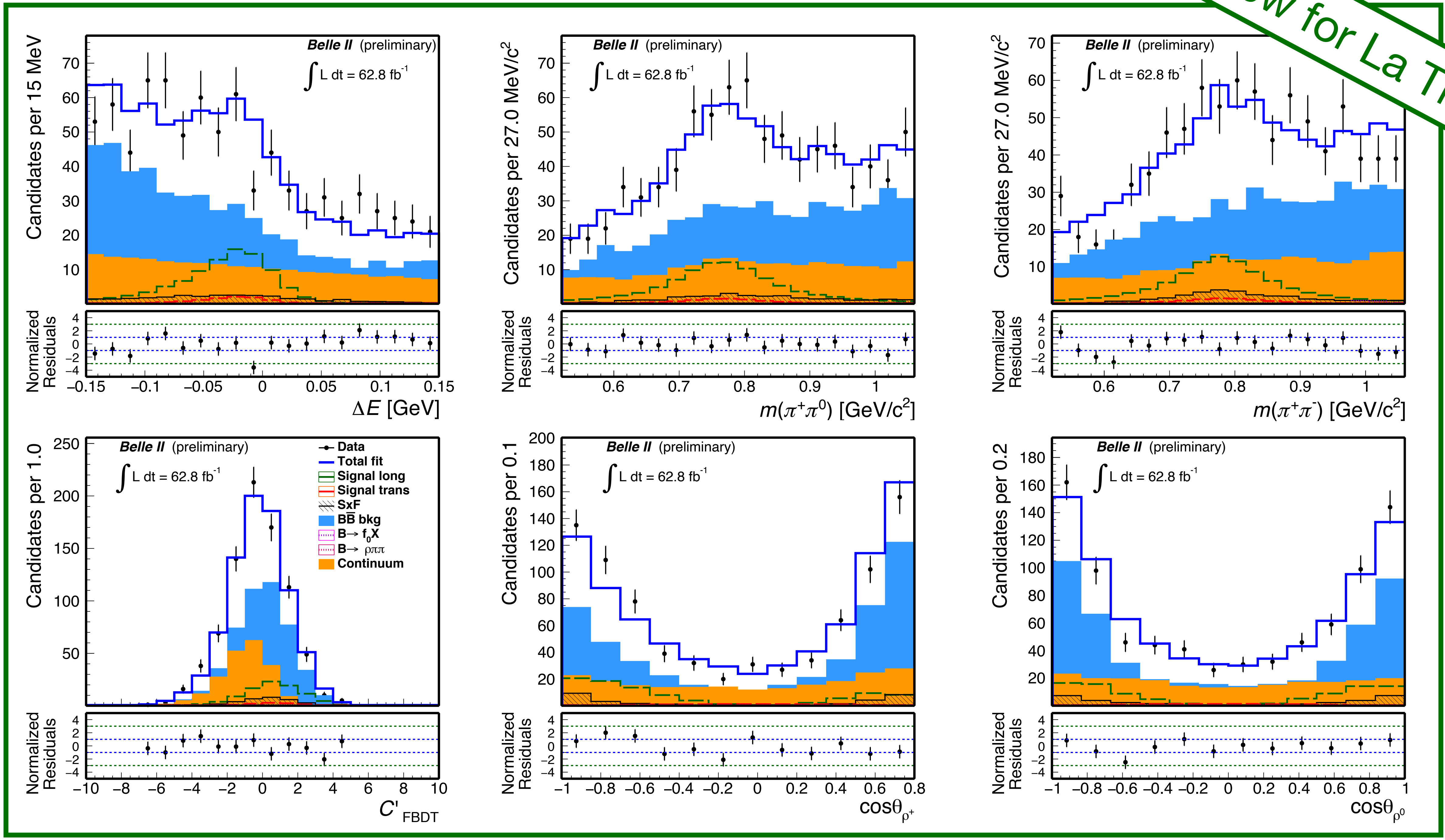
$$N_{sig} = 2877 \pm 79$$





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

62.8 fb-1: new for La Thuile



First reconstruction in Belle II data!

$\mathcal{B} = [20.6 \pm 3.2(\text{stat}) \pm 4.0(\text{syst})] \times 10^{-6}$

$f_L = 0.936^{+0.049}_{-0.041}(\text{stat}) \pm 0.021(\text{syst})$

N: 104 ± 16

Belle on 78 fb-1 (PRL 91, 221801 (2003)):

$\mathcal{B} = [31.7 \pm 7.1(\text{stat})^{+3.8}_{-6.7}(\text{syst})] \times 10^{-6}$

$f_L = 0.948 \pm 0.106(\text{stat}) \pm 0.021(\text{syst})$

N: 59 ± 13

Summary

Charmless *B* physics plays an important role in sharpening our flavor picture.

Belle II preparing for a leading role in: α, local CPVs, isospin sum rules.

First/improved measurements of charmless decays in 35-63 fb^{-1} of early data.

New for La Thuile: first Belle II measurement of $A_{CP}(K^0\pi^0)$ completes the ingredients for the isospin sum rule; ρρ analysis surpasses early Belle's.

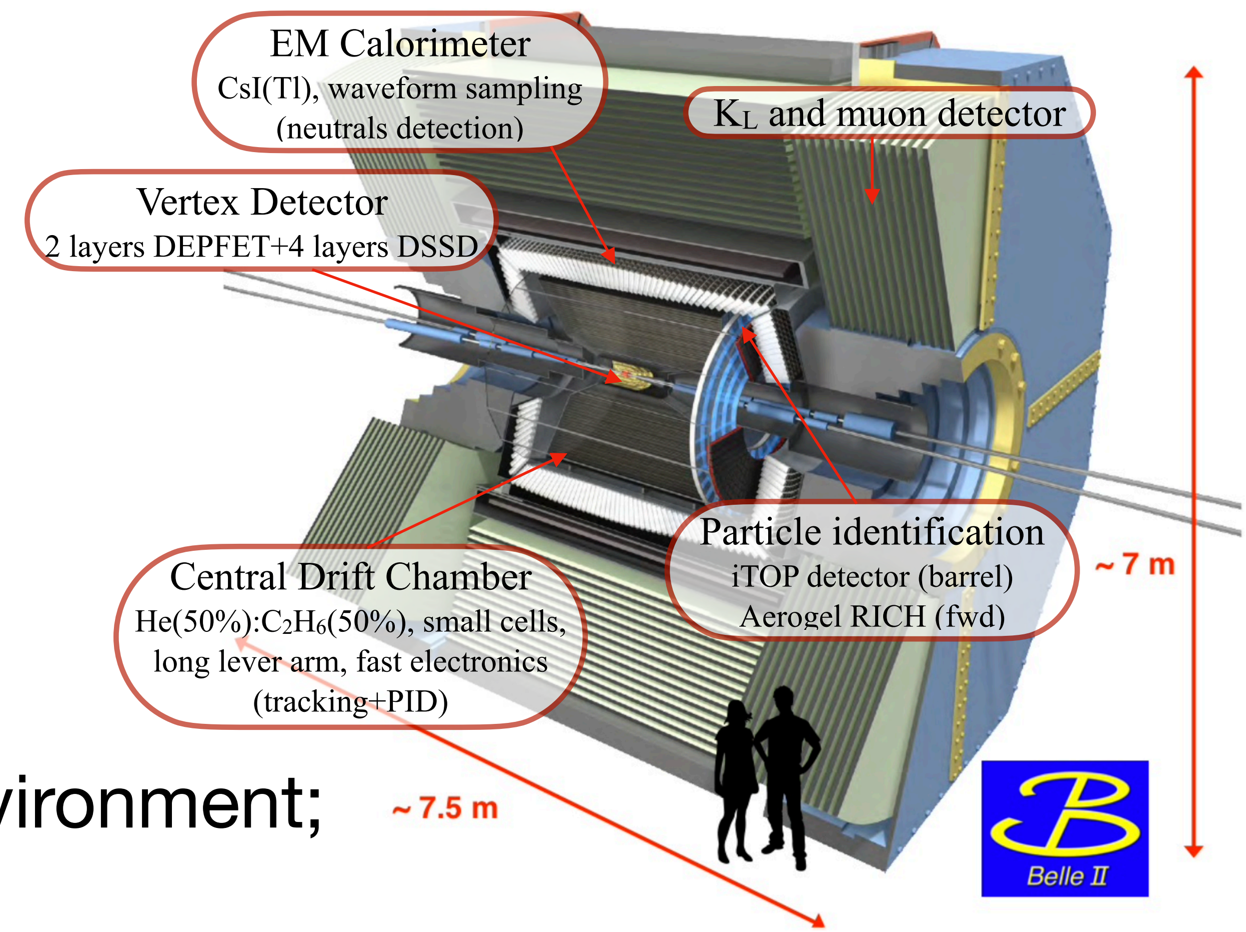
All results agree with known values within uncertainties dominated by small sample size. Performance comparable/better than at Belle demonstrates advanced understanding of detector/analysis tools.

backup

Charmless physics at Belle II

Goals

- Improve precision on ϕ_2/α angle;
- Test SM using isospin sum rules;
- Investigate localized CP asymmetries in three-body *B* decays;
- Study time-dependent CP violations.



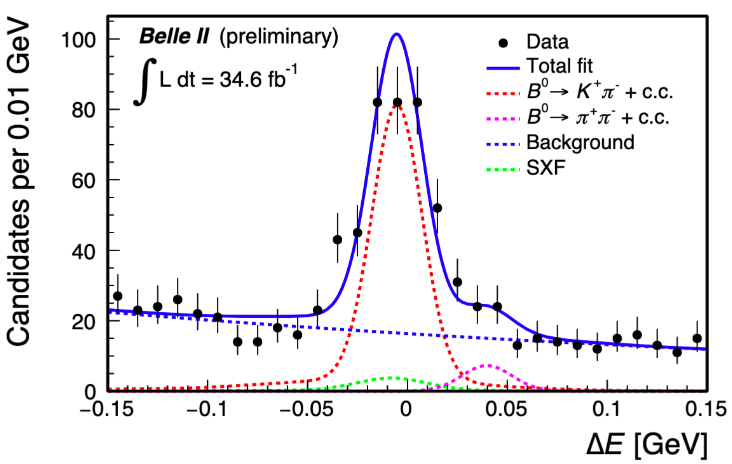
Belle II

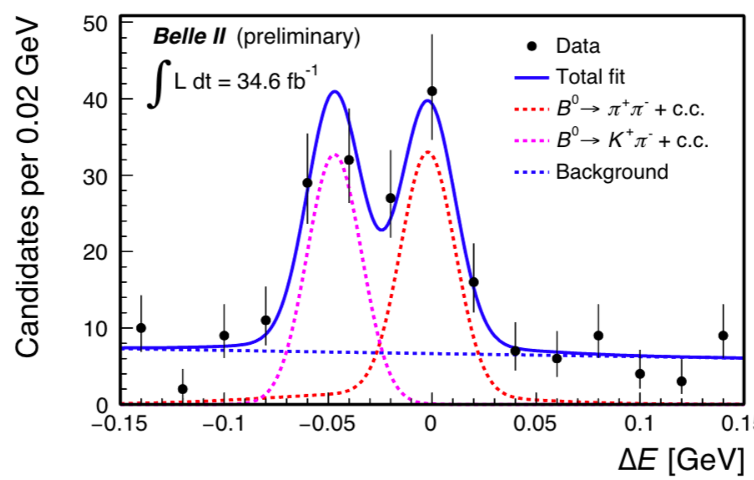
- ~900 BB pairs/second in low-bkg environment;
- xxx fb^{-1} of data collected;
- World record peak luminosity in June 2020: 2.4x10^{34} cm^{-2} s^{-1}
- Complementary to LHCb (final states with neutrals and V0s).

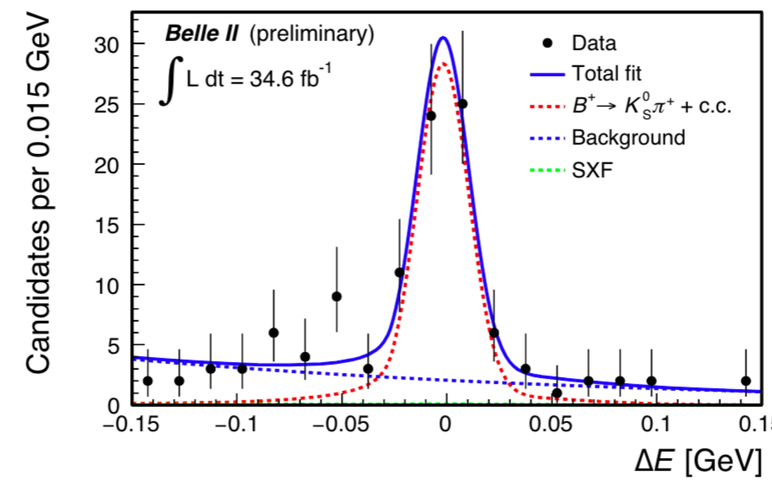
Today: measurements of branching fractions, CP asymmetries and polarizations for various charmless B decays using 35 or 62 fb^{-1}

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($B^0 \to K^+\pi^-$): $289\ ^{+22}_{-21}$

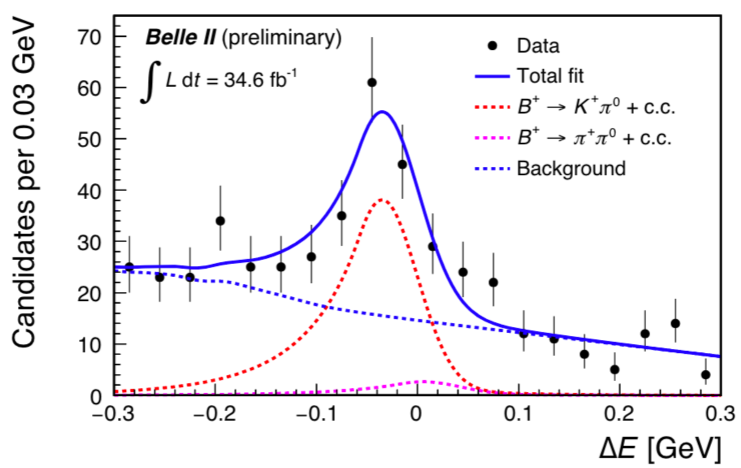
N($B^0 \to \pi^+\pi^-$) $62\ ^{+10}_{-11}$

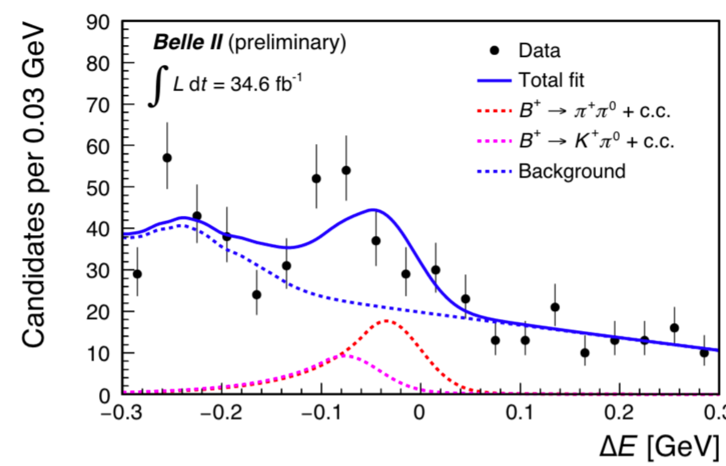
N($B^+ \to K_S^0\pi^+$): $65\ ^{+10}_{-\ 9}$

$\mathscr{B}\ [10^{-6}]$: 35.8 ± 1.6(stat) $\pm\ 1.4$(syst)

$5.6^{+1.0}_{-0.9}$(stat) $\pm\ 0.3$(syst)

$21.8^{+3.3}_{-3.0}$(stat) $\pm\ 2.9$(syst)





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

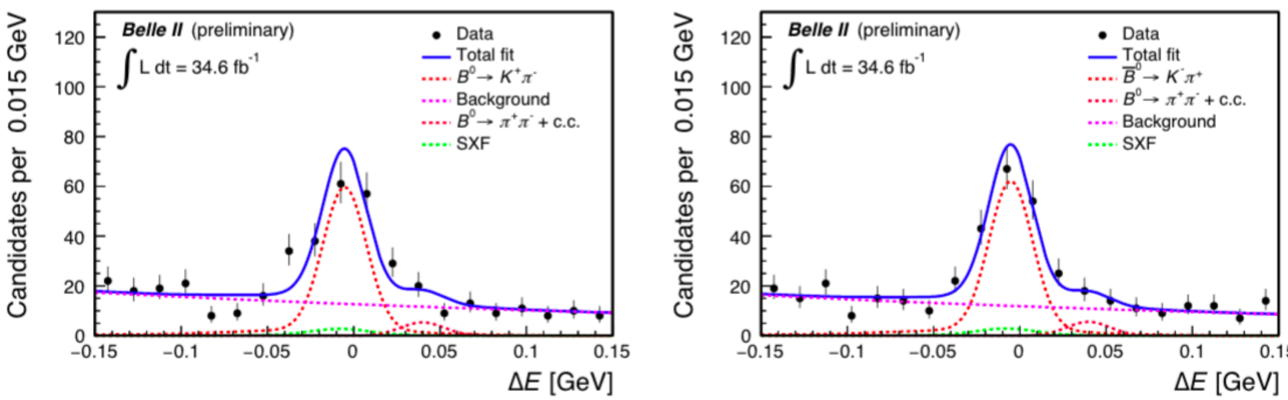
N($B^+ \to K^+\pi^0$): $289\ ^{+22}_{-21}$

N($B^+ \to \pi^+\pi^0$): $62\ ^{+10}_{-11}$

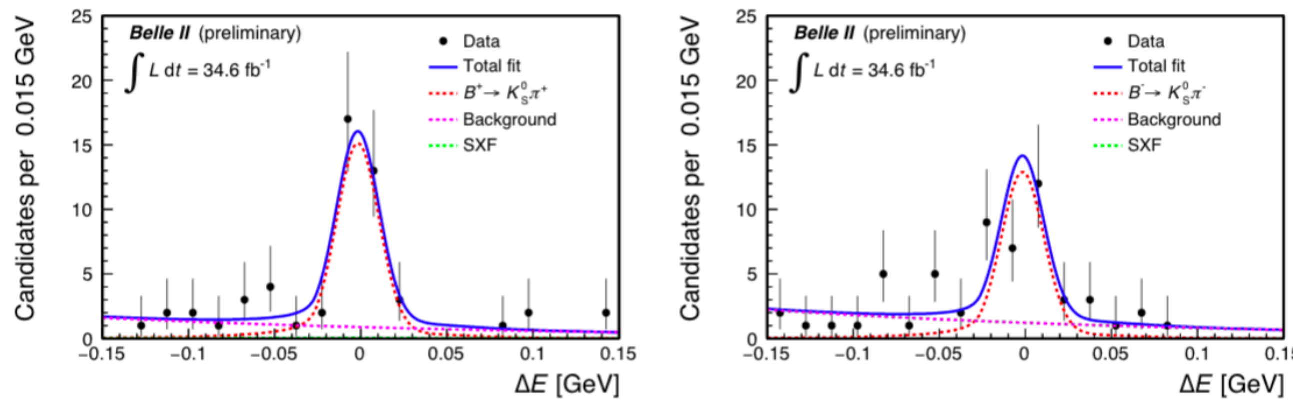
$\mathscr{B}\ [10^{-6}]$: $12.7^{+2.2}_{-2.1}$(stat) $\pm\ 1.1$(syst)

5.7 ± 2.3(stat) $\pm\ 0.5$(syst)

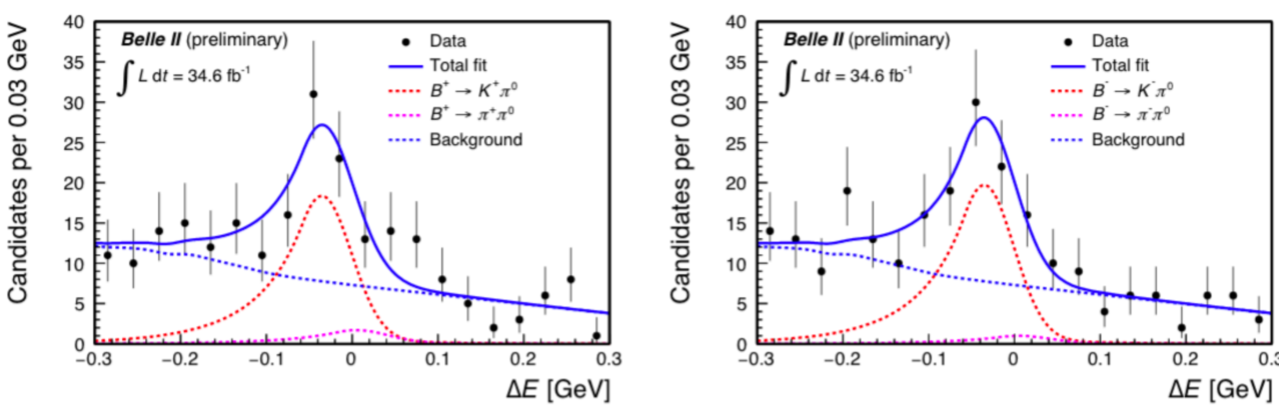
CP asymmetries in two-body decays



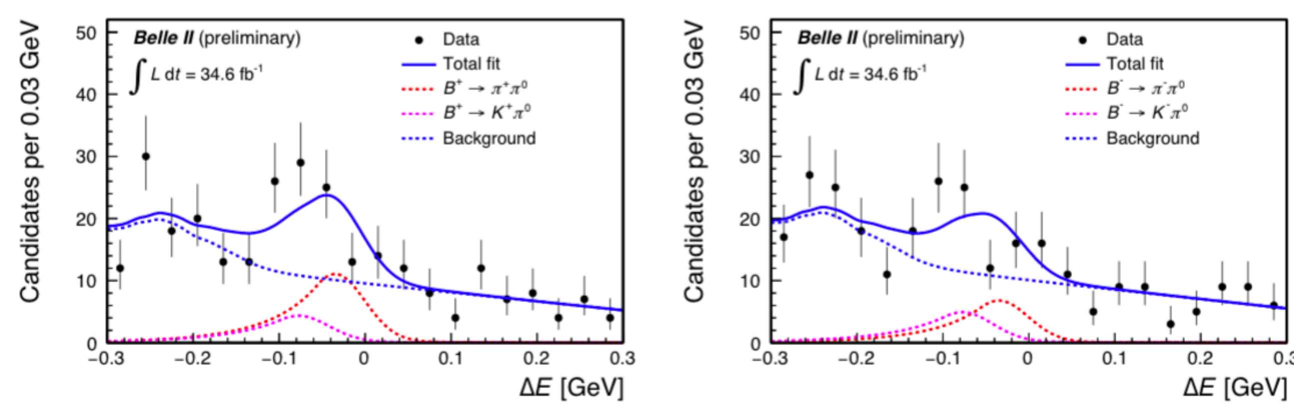
$A_{CP}(B^0 \to K^+\pi^-) = 0.030 \pm 0.064(\text{stat}) \pm 0.008(\text{syst})$



$A_{CP}(B^+ \to K^0\pi^+) = -0.072^{+0.109}_{-0.114}(\text{stat}) \pm 0.024(\text{syst})$



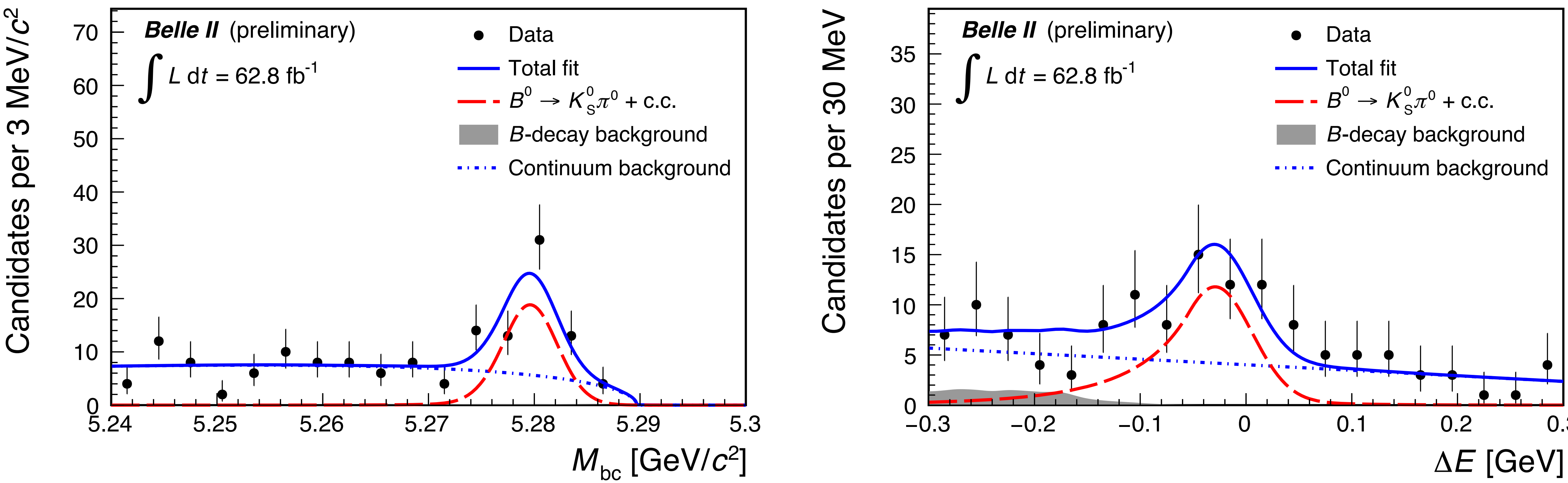
$A_{CP}(B^+ \to K^+\pi^0) = 0.052^{+0.121}_{-0.119}(\text{stat}) \pm 0.022(\text{syst})$



$A_{CP}(B^+ \to \pi^+\pi^0) = -0.268^{+0.249}_{-0.322}(\text{stat}) \pm 0.123(\text{syst})$

$B^0 \to K^0\pi^0$: branching fraction

62.8 fb-1: new for La Thuile



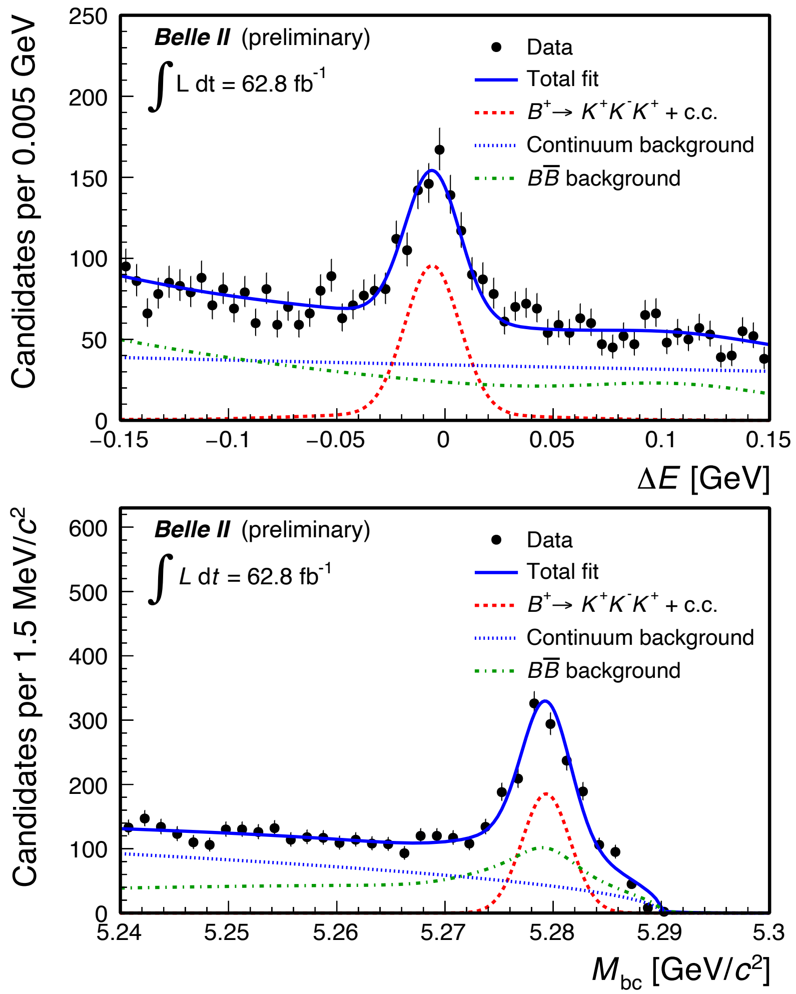
N($B^0 \to K_S^0\pi^0$): $45\ ^{+9}_{-8}$

$\mathscr{B}(B^0 \to K^0\pi^0) = [8.5^{+1.7}_{-1.6}(\text{stat}) \pm 1.2(\text{syst})] \times 10^{-6}$

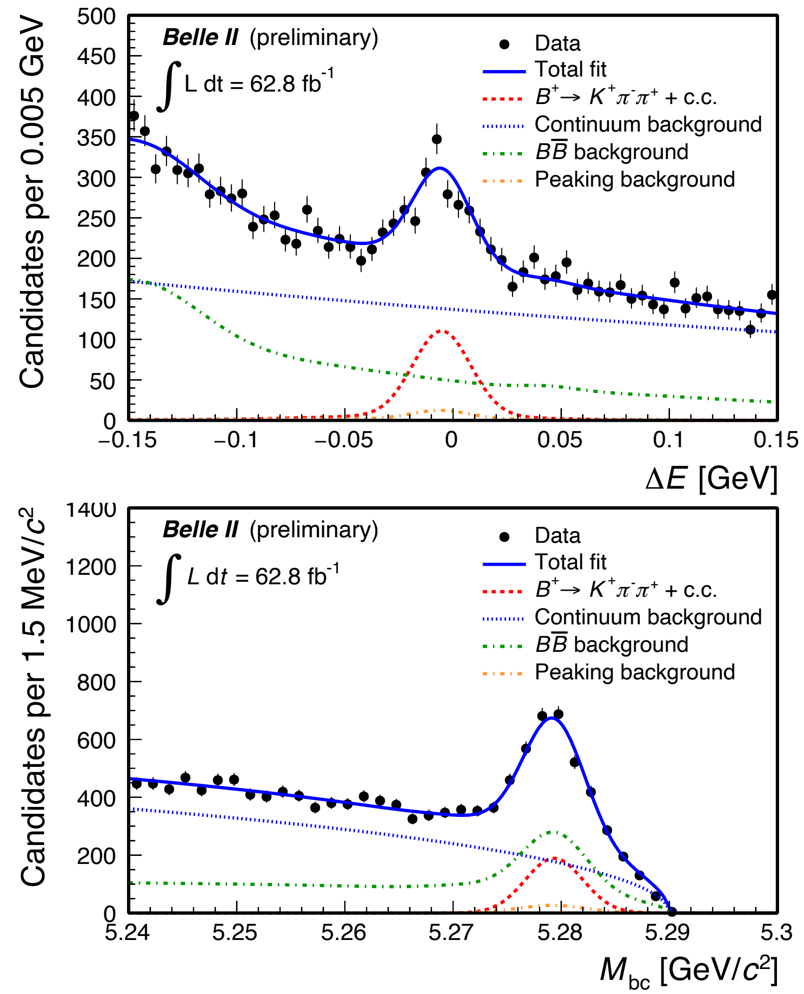
Multibody: branching fractions

62.8 fb-1: new for La Thuile

$B^+ \to K^+K^-K^+$



$B^+ \to K^+\pi^-\pi^+$



$B^+ \to K^+K^-K^+$: N_{Sig}: 690 ± 30

$\mathscr{B}\ [10^{-6}]$: $35.8 \pm 1.6(\text{stat}) \pm 1.4(\text{syst})$

$B^+ \to K^+\pi^-\pi^+$: N_{Sig}: 843 ± 42

$\mathscr{B}\ [10^{-6}]$: $67.0 \pm 3.3(\text{stat}) \pm 2.3(\text{syst})$

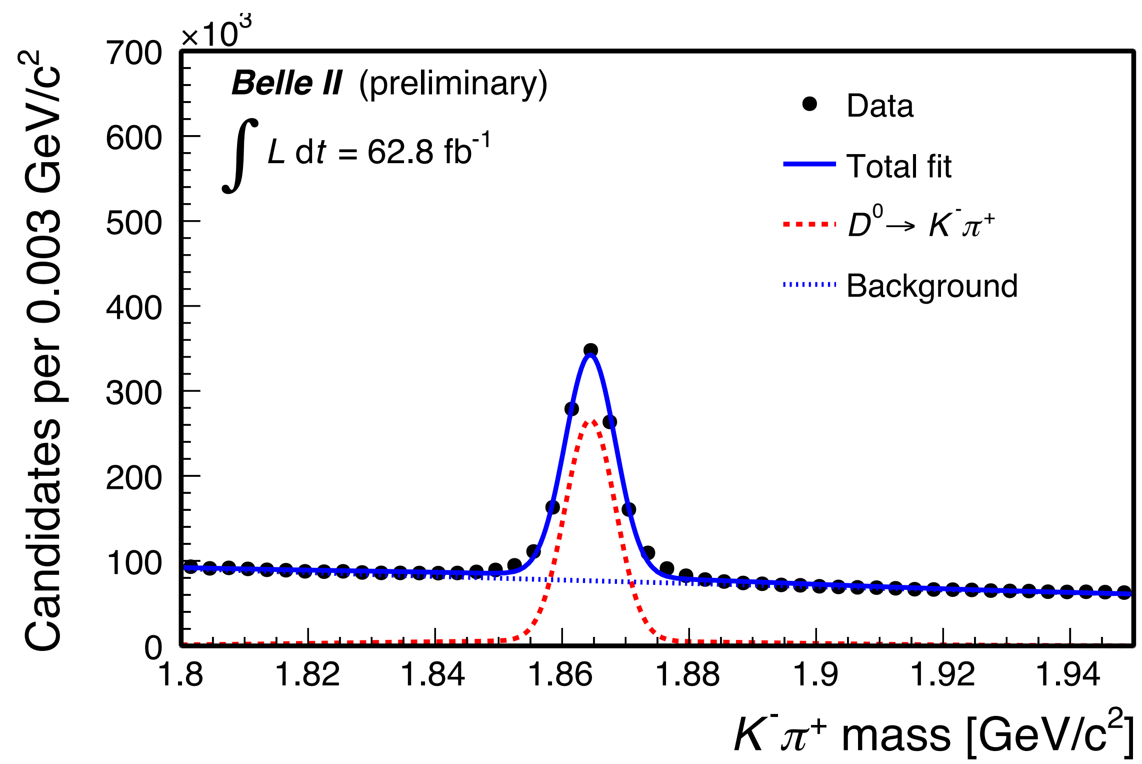
Instrumental asymmetries

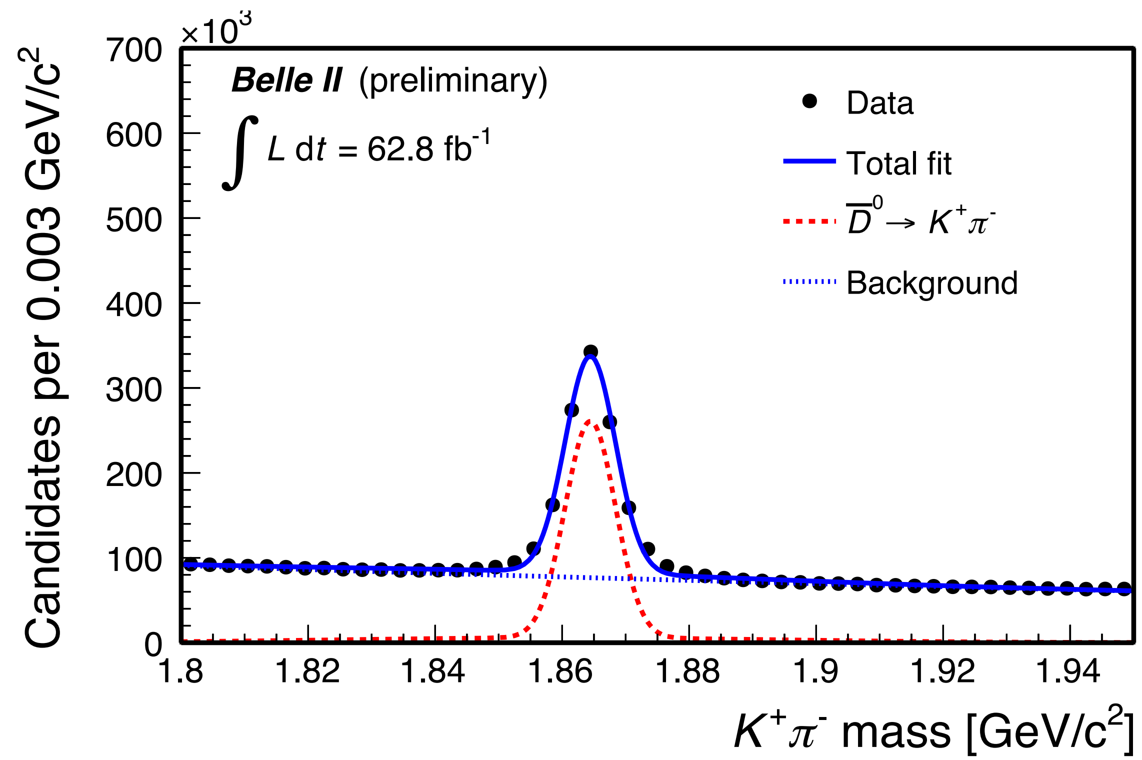
Observed charge-dependent signal yields depend on CP violation but also on charge-dependent instrumental reconstruction asymmetries (K_+/K_- ecc) that need be corrected for CP violation measurements

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

Tree-dominated hadronic D decays $D^+ \rightarrow K_S \pi^+$ and $D^0 \rightarrow K^-\pi^+$ 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
$\mathcal{A}_{\rm det}(K^0_{\rm S}\pi^+)$	$+0.026 \pm 0.019$
$\mathcal{A}_{\rm det}(K^+)$	$+0.017 \pm 0.019$
$\mathcal{A}_{\rm det}(\pi^+)$	$+0.026 \pm 0.019$





Efficiencies validation

Validate the efficiencies by applying the same selection on data and simulation for abundant and signal-rich control channels.

Here, as example the π^0 reconstruction efficiency.

$$\varepsilon(\pi^0) = \frac{\text{Yield}(B^0 \to D^{*-}[\to \overline{D^0}[\to K^+\pi^-\pi^0]\pi^-]\pi^+)}{\text{Yield}(B^0 \to D^{*-}[\to \overline{D^0}[\to K^+\pi^-]\pi^-]\pi^+)} \cdot \frac{\mathcal{B}(\overline{D^0} \to K^+\pi^-)}{\mathcal{B}(\overline{D^0} \to K^+\pi^-\pi^0) \cdot \mathcal{B}(\pi^0 \to \gamma\gamma)}$$

Similar strategy adopted for continuum suppression and PID selections.

Results generally compatible within $O(1)\%$ uncertainties, which propagate as systematics.