Charmless Decays at Belle II

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Hadronic Charmless B-Decays

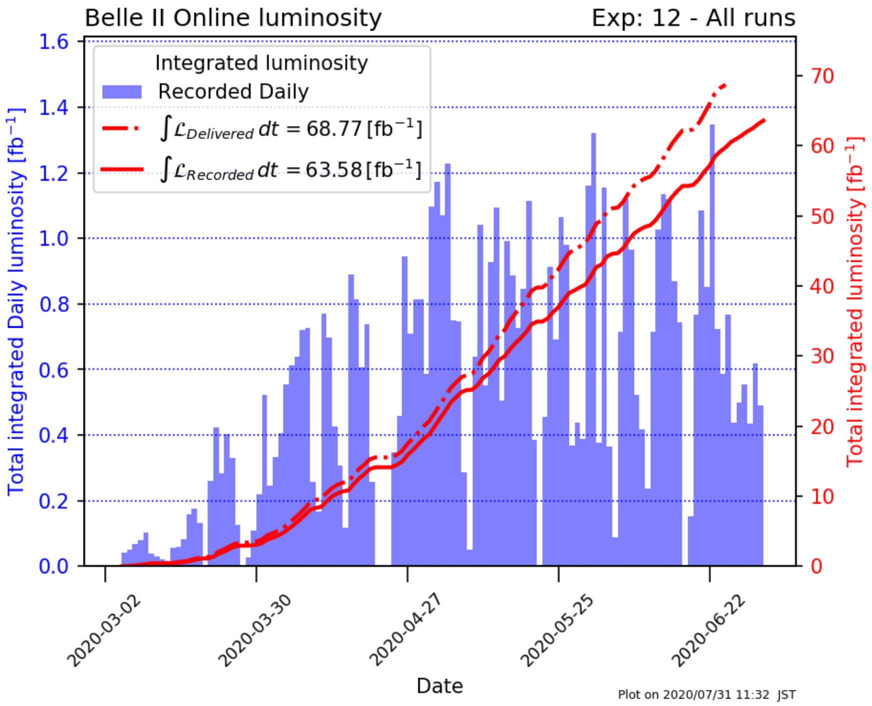
- mediated through Cabibbo-suppressed b→u and/or loop-suppressed b→d/s transitions
- for transitions governed by penguin diagrams → room for new physics contributions in loops
- theory calculations prone to hadronic uncertainties → test of QCD factorization approach and SU(3) breaking effects
- investigate long-standing $K\pi$ −puzzle
- isospin-related modes can be combined to cancel experimental and theoretical uncertainties

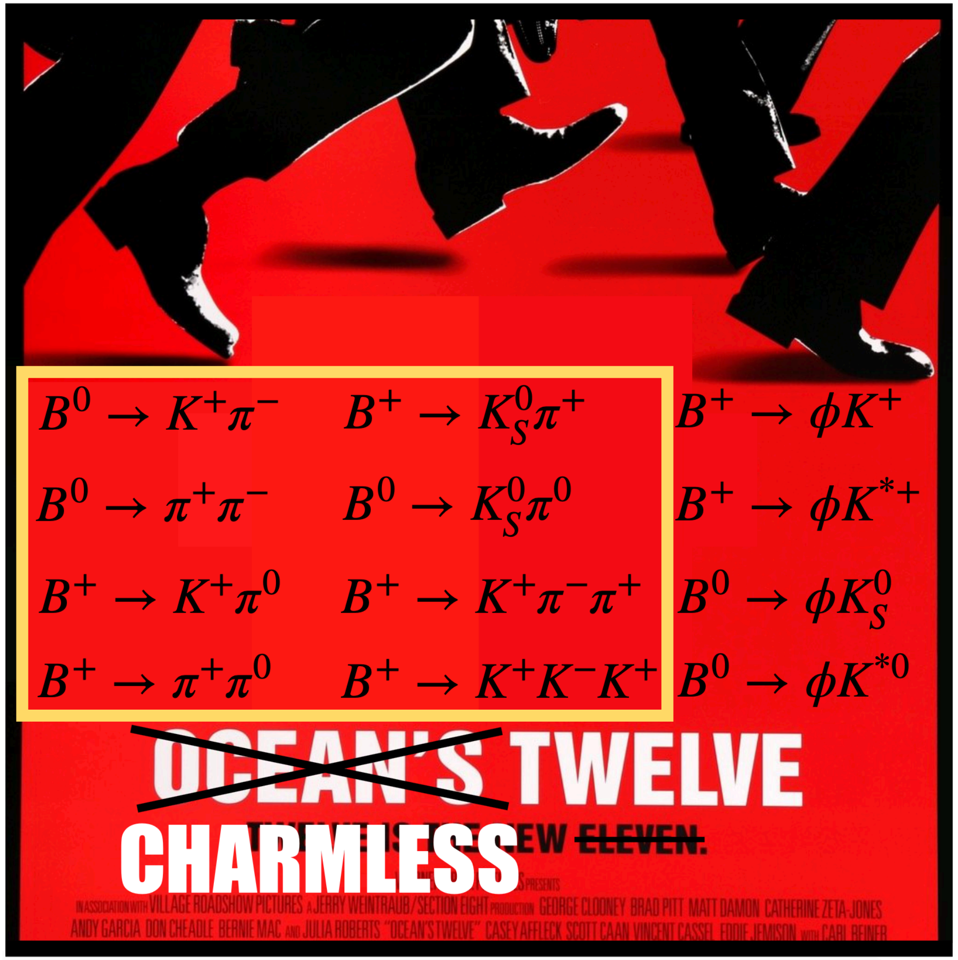
$$\mathcal{A}_{CP}(K^+\pi^-)+\mathcal{A}_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+}=\mathcal{A}_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+}+\mathcal{A}_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

- low branching ratios (order < 10^{-5})
- usually strongly dominated by continuum background

recently in the Belle II charmless group …

- first **BR and direct CPV** measurements in a number of modes
- using all 2019–2020 Υ(4S) good-quality runs collected until May 14, 2020 corresponding to an integrated luminosity of **34.6 fb^{-1}**





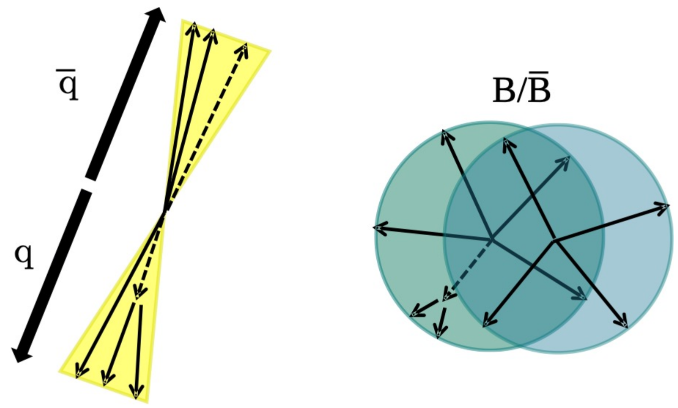
Eldar Ganiev: ICHEP 2020 talk

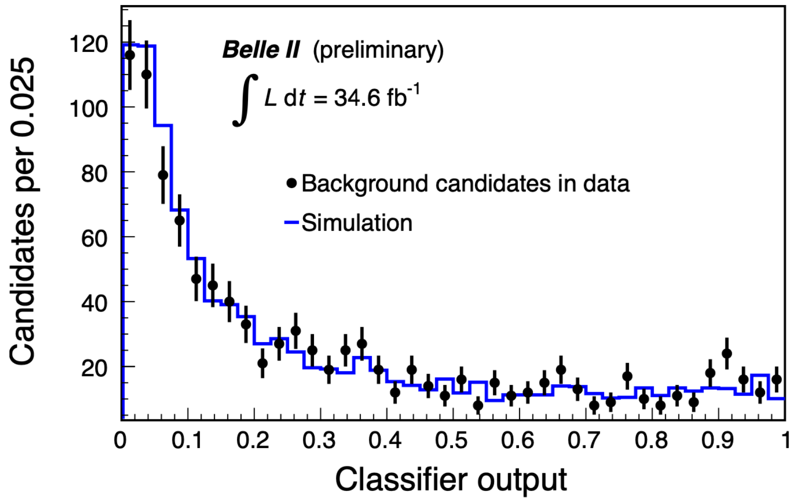
Analysis Workflow / Strategy

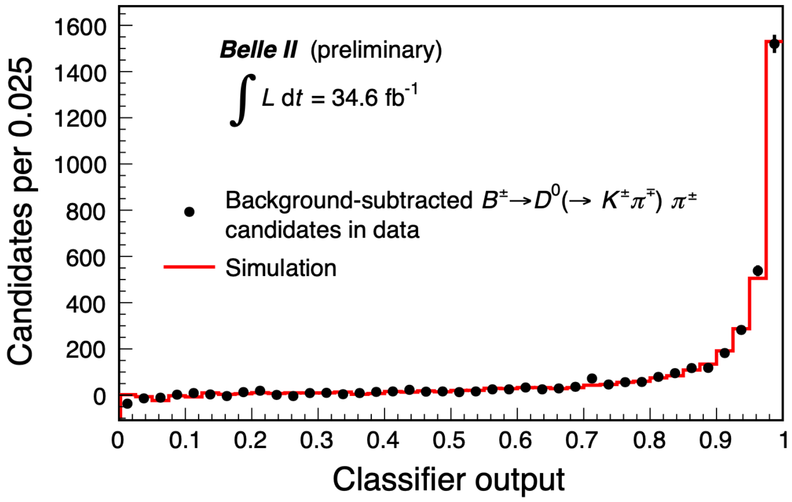
1. **Reconstruction**
   - combine candidates in kinematic fits to fill list of B-meson candidates
2. **Selection**
   - now: loose baseline selection followed by optimized continuum suppression and particle identification cuts
3. **Modelling**
   - use simulated data (MC) to model relevant features in $\Delta E \equiv E_B^* - \sqrt{s}/2$
   - determine selection efficiencies for BR calculations
4. **Fit to data & calculate physics quantities**
5. **Assess systematic uncertainties**

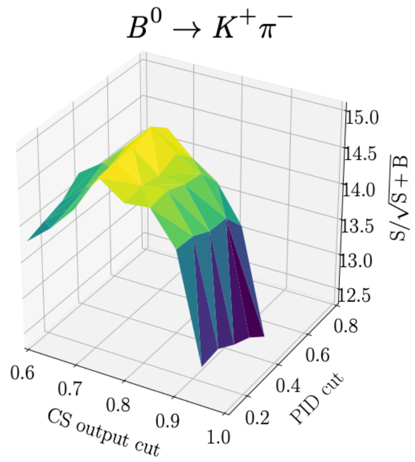
Continuum Suppression

- 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 39 variables
- optimize simultaneously cut on classifier and PID to maximize FOM = S/sqrt(S+B)



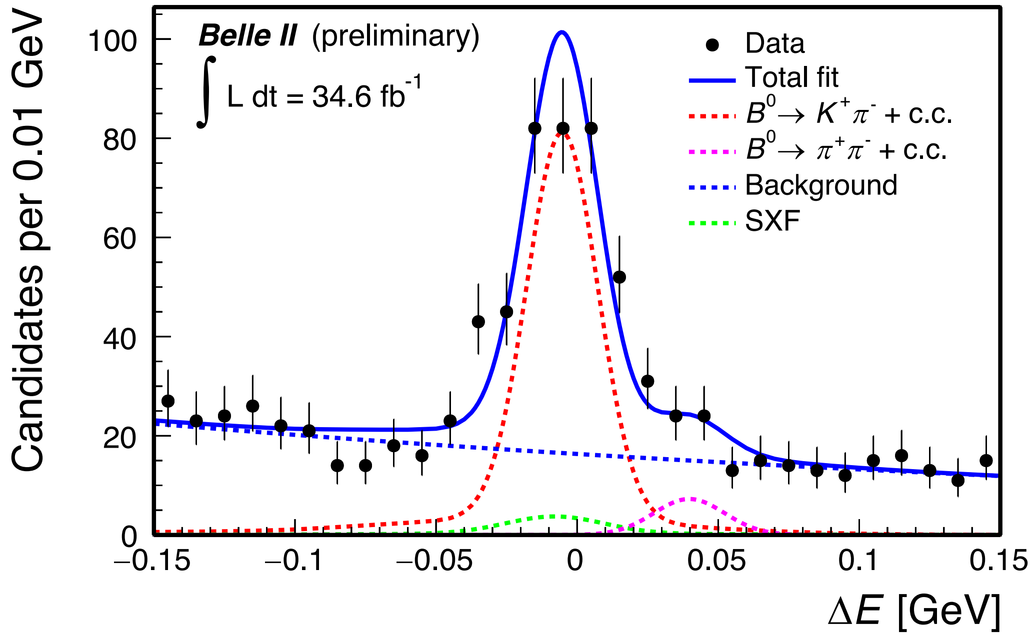






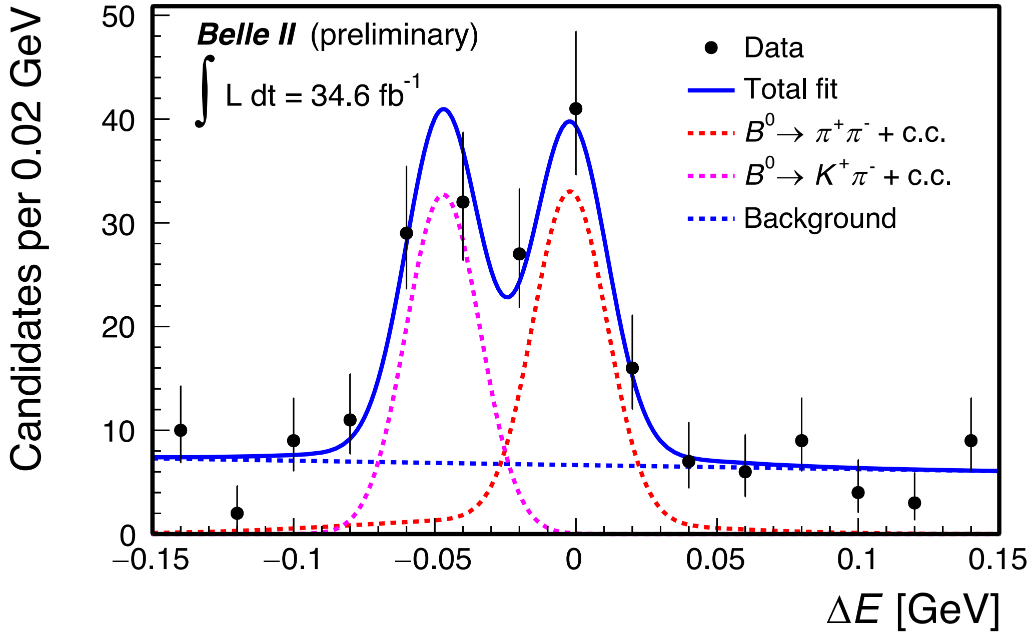
2-Body: $B^0 \to K^+\pi^-$, $B^0 \to \pi^+\pi^-$

$K^+\pi^-$



signal yield	289^{+22}_{-21}
BR Fit [x 10^{-6}]	**$18.9^{+1.4}_{-1.4}$ (stat) ± 0.7 (sys)**
BR PDG [x 10^{-6}]	**19.6 ± 0.5**

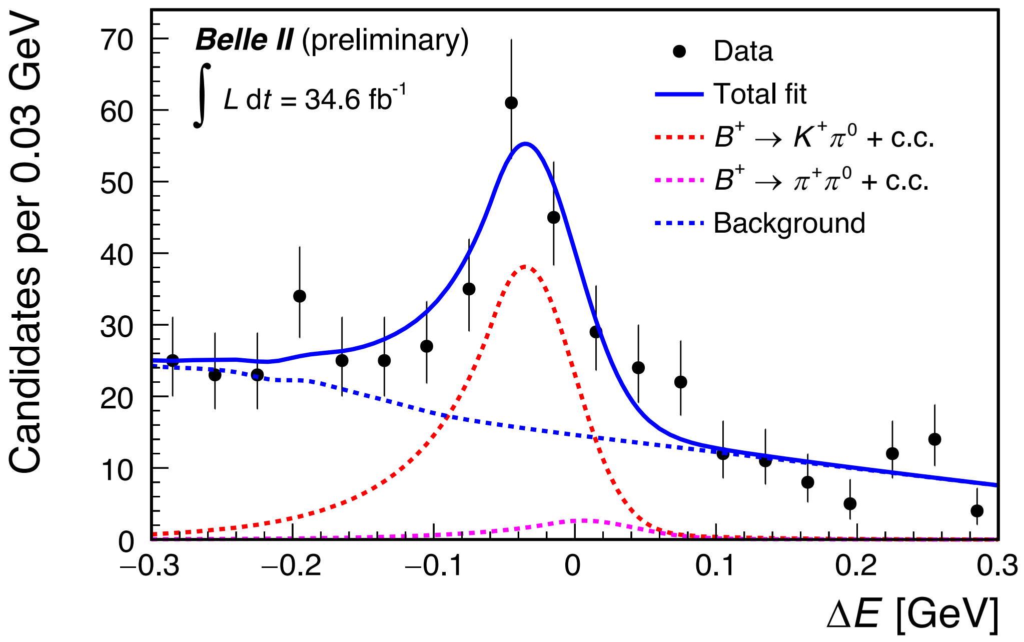
$\pi^+\pi^-$



signal yield	61^{+11}_{-10}
BR Fit [x 10^{-6}]	**$5.6^{+1.0}_{-0.9}$ (stat) ± 0.3 (sys)**
BR PDG [x 10^{-6}]	**5.12 ± 0.19**

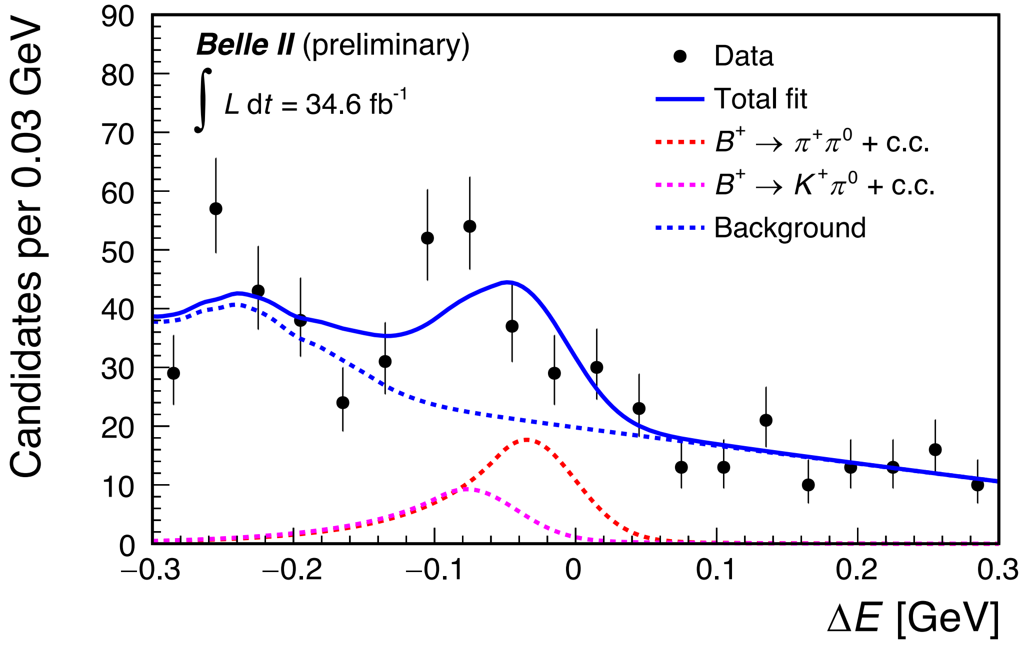
2-Body: $B^+ \to K^+\pi^0$, $B^+ \to \pi^+\pi^0$

$K^+\pi^0$



signal yield	144^{+25}_{-24}
BR Fit [x 10^{-6}]	**$12.7^{+2.2}_{-2.1}$ (stat) ± 1.1 (sys)**
BR PDG [x 10^{-6}]	**12.9 ± 0.5**

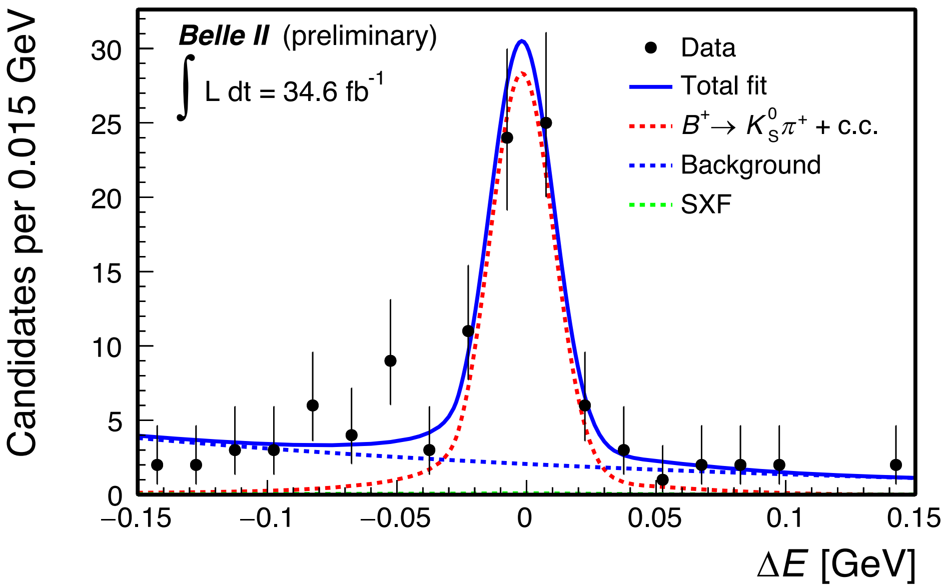
$\pi^+\pi^0$



signal yield	68^{+27}_{-27}
BR Fit [x 10^{-6}]	**$5.7^{+2.3}_{-2.3}$ (stat) ± 0.5 (sys)**
BR PDG [x 10^{-6}]	**5.5 ± 0.4**

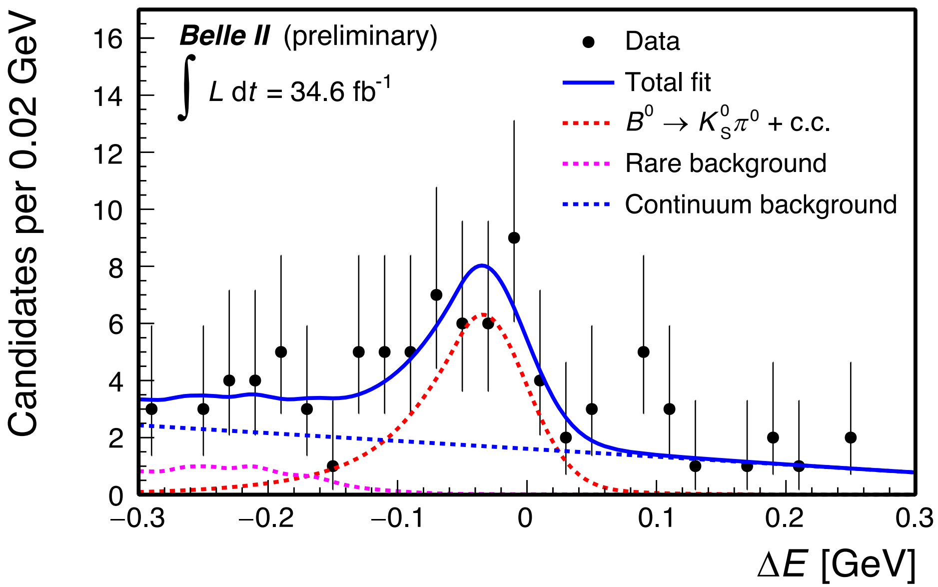
2-Body: $B^+ \to K_S{}^0\pi^+$, $B^0 \to K_S{}^0\pi^0$

$K_S{}^0\pi^+$



signal yield	65^{+10}_{-9}
BR Fit [x 10^-6]	$21.8\ ^{+3.3}_{-3.0}$ (stat) ± 2.9 (sys)
BR PDG [x 10^-6]	**23.7 ± 0.8**

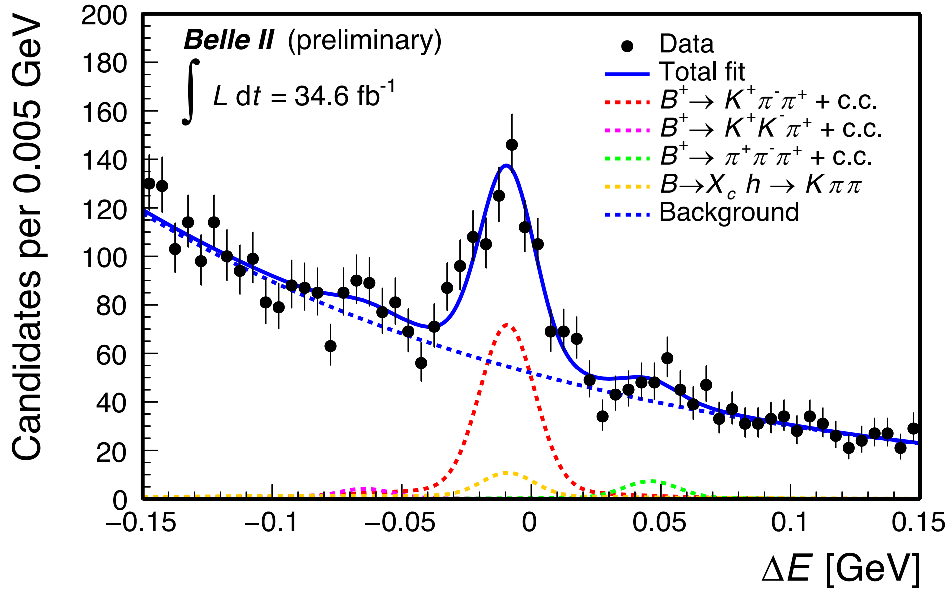
$K_S{}^0\pi^0$



signal yield	35^{+9}_{-9}
BR Fit [x 10^-6]	$10.9\ ^{+2.9}_{-2.6}$ (stat) ± 1.6 (sys)
BR PDG [x 10^-6]	**9.9 ± 0.5**

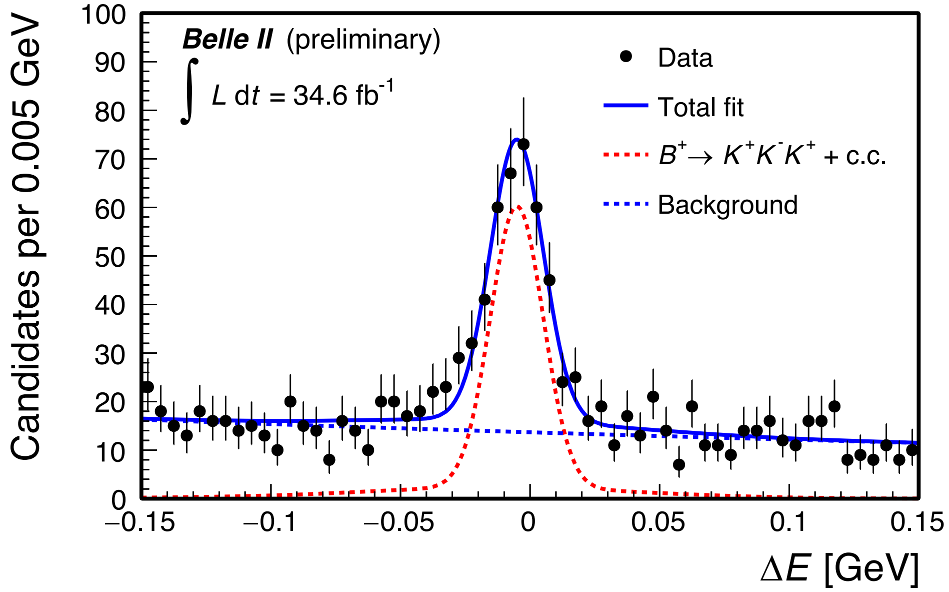
3-Body: $B^+ \to K^+\pi^-\pi^+$, $B^+ \to K^+K^-K^+$

$K^+\pi^-\pi^+$



signal yield	449^{+37}_{-37}
BR Fit [x 10-6]	$48.0\ ^{+3.8}_{-3.8}$ (stat) ± 3.3 (sys)
BR PDG [x 10-6]	**51.0 ± 2.9**

$K^+K^-K^+$



signal yield	359^{+25}_{-25}
BR Fit [x 10-6]	$32.0\ ^{+2.2}_{-2.2}$ (stat) ± 1.4 (sys)
BR PDG [x 10-6]	**34.0 ± 1.4**

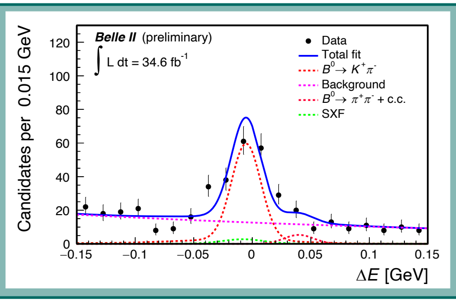
2-Body: direct CPV

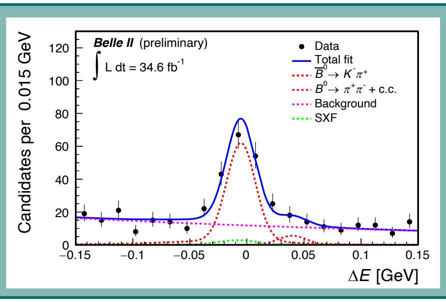
$$\mathcal{A} = \frac{N(b) - N(\bar{b})}{N(b) + N(\bar{b})}$$

$K^+\pi^-$

$A_{CP} = 0.030 \pm 0.064(\text{stat.}) \pm 0.008(\text{sys.})$

PDG: $A_{CP} = -0.083 \pm 0.004$

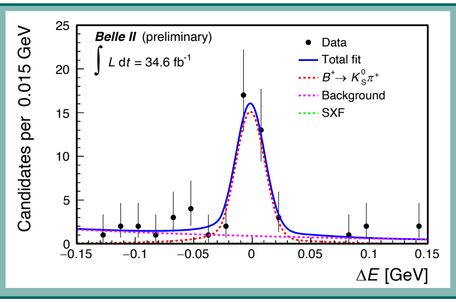


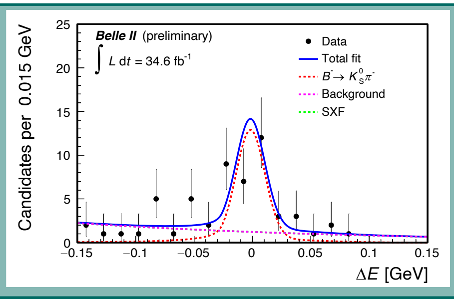


$K_S^0\pi^+$

$A_{CP} = -0.072\ ^{+0.109}_{-0.114}\ (\text{stat.}) \pm 0.024\ (\text{sys.})$

PDG: $A_{CP} = -0.017 \pm 0.016$

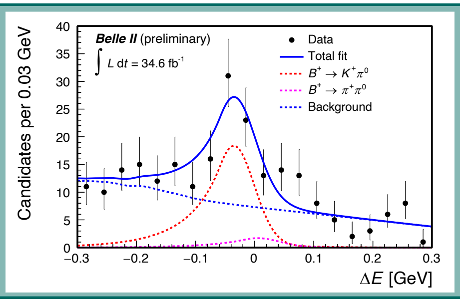


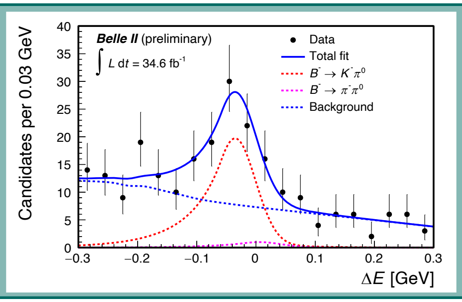


$K^+\pi^0$

$A_{CP} = 0.052\ ^{+0.121}_{-0.119}\ (\text{stat.}) \pm 0.022\ (\text{sys.})$

PDG: $A_{CP} = 0.037 \pm 0.021$

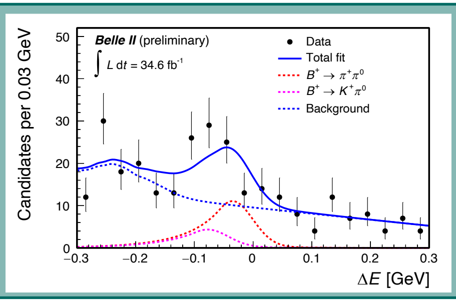


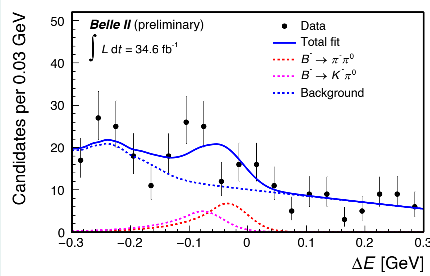


$\pi^+\pi^0$

$A_{CP} = -0.268\ ^{+0.249}_{-0.322}\ (\text{stat.}) \pm 0.123\ (\text{sys.})$

PDG: $A_{CP} = 0.03 \pm 0.04$



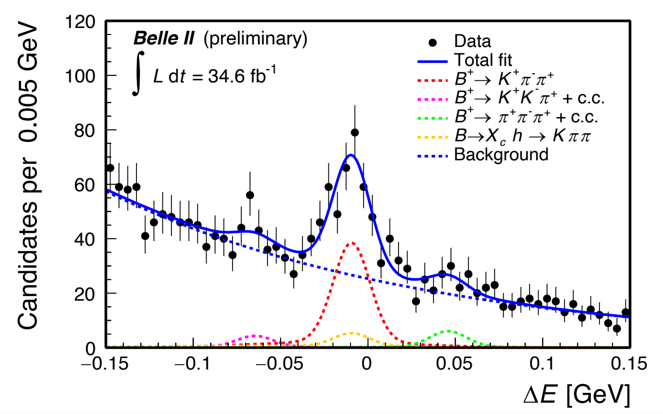


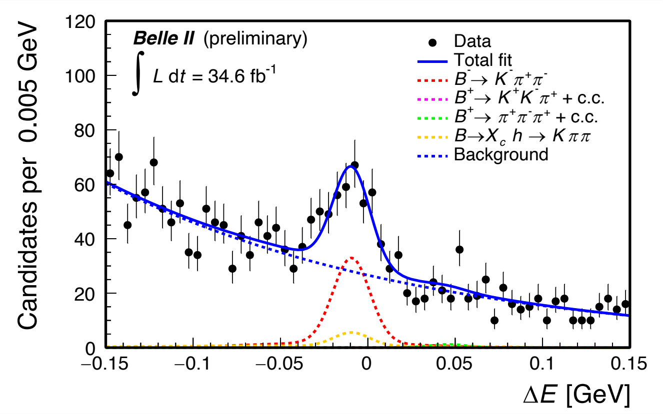
3-Body: direct CPV

$K^+\pi^-\pi^+$

$A_{CP} = -0.063 \pm 0.081(\text{stat.}) \pm 0.023(\text{syst.})$

PDG: $A_{CP} = 0.027 \pm 0.008$

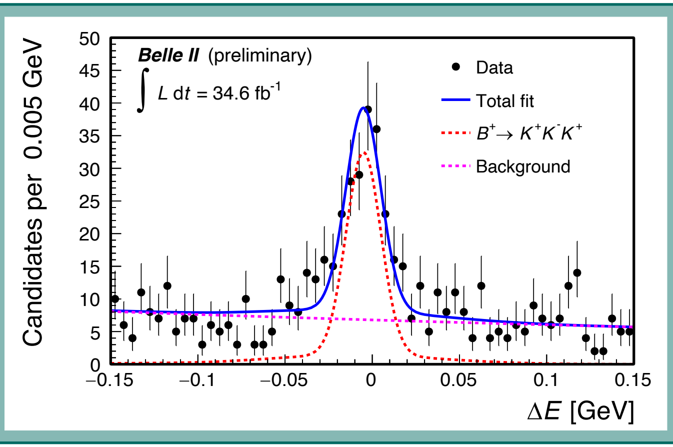


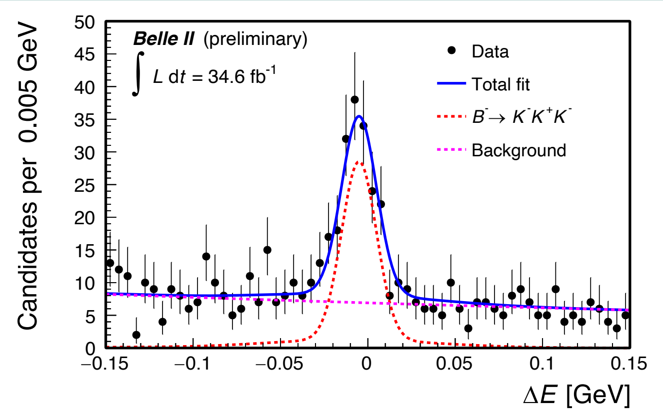


$K^+K^-K^+$

$A_{CP} = -0.049 \pm 0.063(\text{stat.}) \pm 0.022(\text{syst.})$

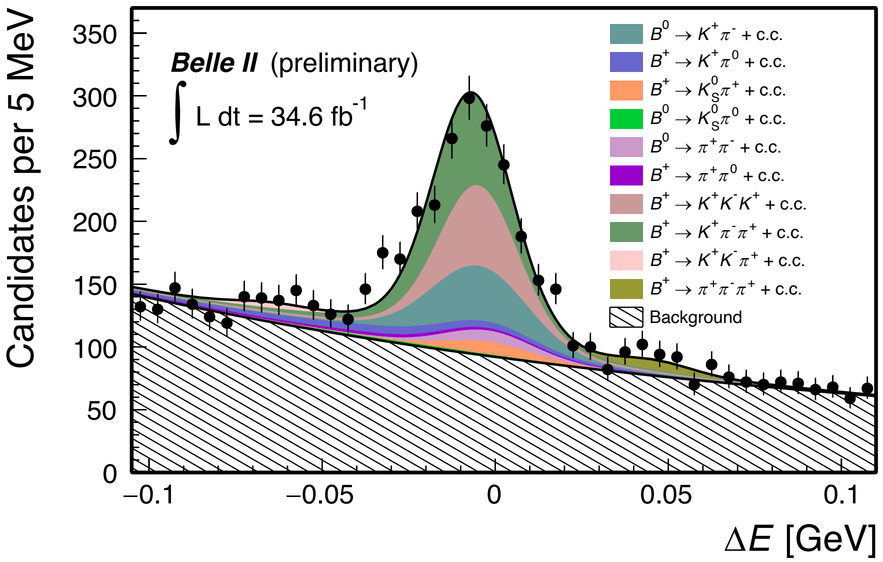
PDG: $A_{CP} = -\,0.033 \pm 0.008$





Conclusion

- observed ~1500 charmless decays in 35 fb^{-1} of Υ(4S) data
- first measurements of branching fractions and direct CPV of charmless *B* decays at Belle II
- results show good agreement with world averages!
- plenty of room for improvement (multidimensional fits, selection, …)



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

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

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

$$\mathcal{B}(B^0 \to K^0\pi^0) = [10.9^{+2.9}_{-2.6}(\text{stat}) \pm 1.6(\text{syst})] \times 10^{-6},$$

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

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

$$\mathcal{B}(B^+ \to K^+K^-K^+) = [32.0 \pm 2.2(\text{stat.}) \pm 1.4(\text{syst})] \times 10^{-6},$$

$$\mathcal{B}(B^+ \to K^+\pi^-\pi^+) = [48.0 \pm 3.8(\text{stat}) \pm 3.3(\text{syst})] \times 10^{-6},$$

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

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

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

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

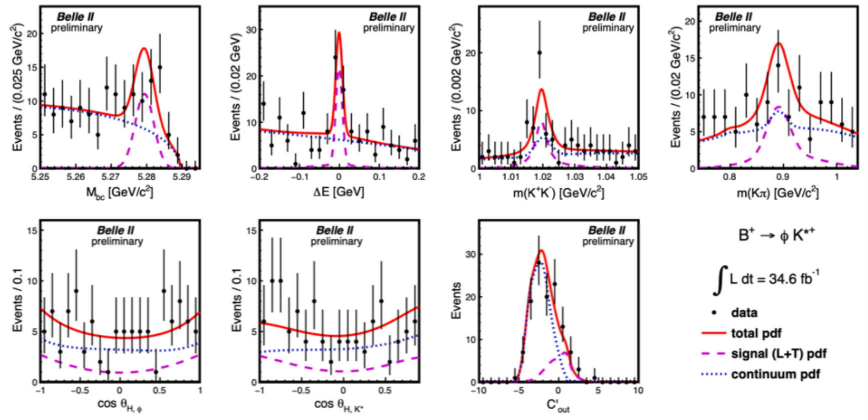
$$\mathcal{A}_{\text{CP}}(B^+ \to K^+K^-K^+) = -0.049 \pm 0.063(\text{stat}) \pm 0.022(\text{syst}), \text{ and}$$

$$\mathcal{A}_{\text{CP}}(B^+ \to K^+\pi^-\pi^+) = -0.063 \pm 0.081(\text{stat}) \pm 0.023(\text{syst}).$$

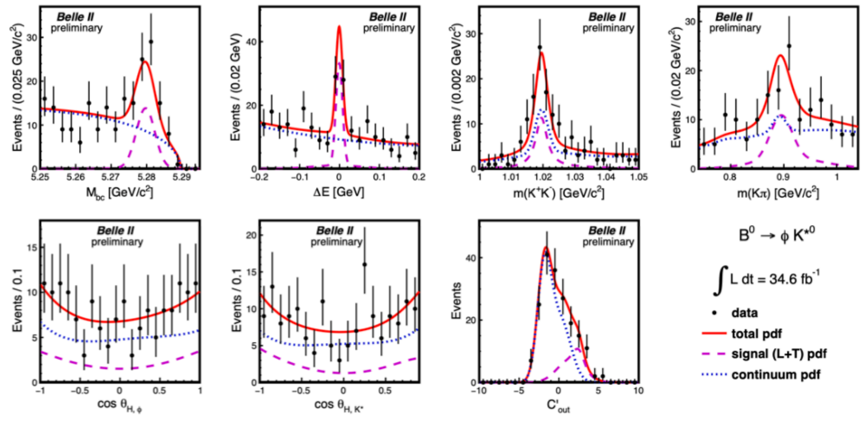
Backup

$B \to VV$: $B^+ \to \phi K^{*+}$, $B^0 \to \phi K^{*0}$

Require full angular analysis.



$B^+ \to \phi K^{*+}$	
N_{sig}	33 ± 8
First reconstruction in Belle II data!	
$\mathcal{B}$ [10^{-6}]	21.7 ± 4.6(stat.) ± 1.9(syst.)
f_L	0.58 ± 0.23(stat.) ± 0.02(syst.)
PDG	
$\mathcal{B}$ [10^{-6}]	10 ± 2
f_L	0.50 ± 0.05



$B^0 \to \phi K^{*0}$	
N_{sig}	48 ± 10
First reconstruction in Belle II data!	
$\mathcal{B}$ [10^{-6}]	11.0 ± 2.1(stat.) ± 1.1(syst.)
f_L	0.57 ± 0.20(stat.) ± 0.04(syst.)
PDG	
$\mathcal{B}$ [10^{-6}]	10.0 ± 0.5
f_L	0.497 ± 0.017

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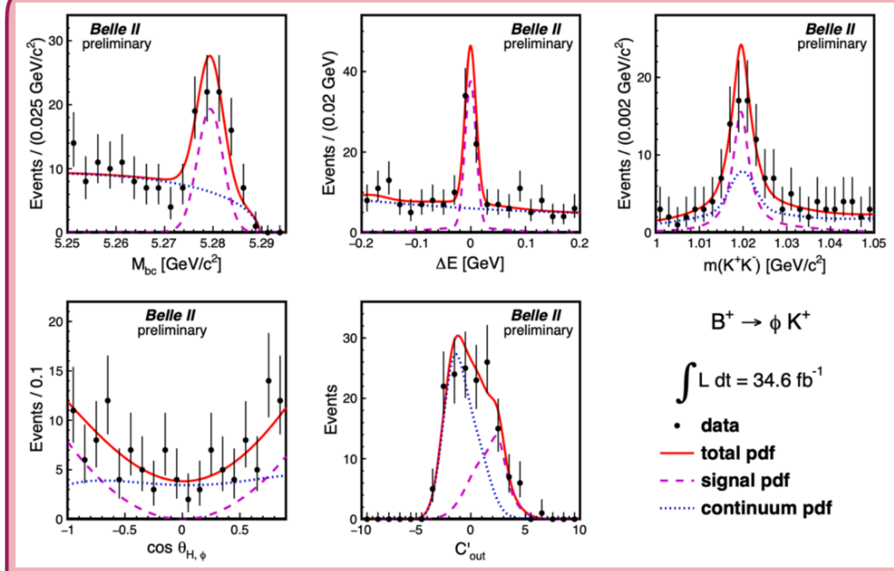
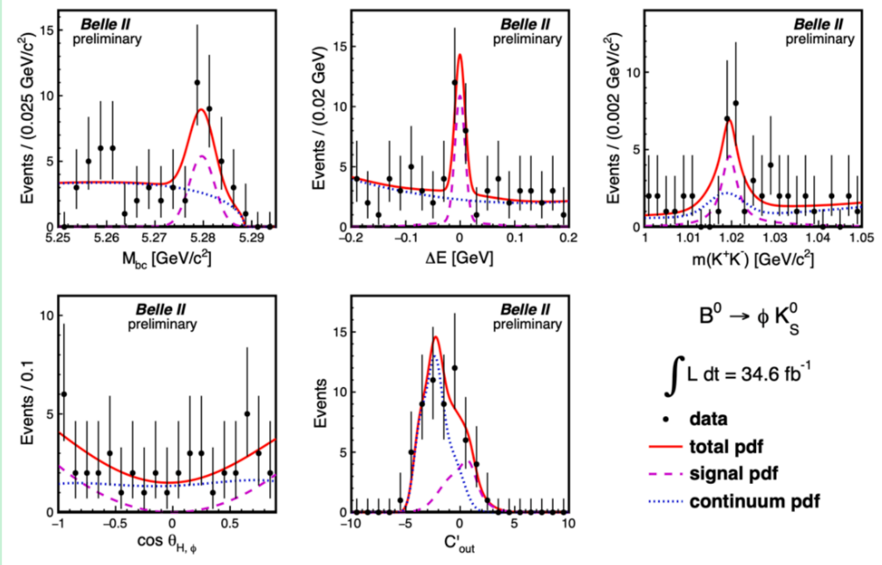
$B \to VP$: $B^+ \to \phi K^+, B^0 \to \phi K^0$

Require advanced analysis techniques.



$B^+ \to \phi K^+$

$N_{sig}(B^+ \to \phi K^+)$	55 ± 9
First reconstruction in Belle II data!	
$\mathcal{B}$ [10^{-6}]	6.7 ± 1.1(stat.) ± 0.5(syst.)
PDG	
$\mathcal{B}$ [10^{-6}]	$8.8^{+0.7}_{-0.6}$



$B^0 \to \phi K^0$

$N_{sig}(B^0 \to \phi K^0_S)$	16 ± 5
First reconstruction in Belle II data!	
$\mathcal{B}$ [10^{-6}]	5.9 ± 1.8(stat.) ± 0.7(syst.)
PDG	
$\mathcal{B}$ [10^{-6}]	7.3 ± 0.7

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Systematic Uncertainties

Source	$K^+\pi^-$	$K^+\pi^0$	$K^0\pi^+$	$K^0\pi^0$	$\pi^+\pi^-$	$\pi^+\pi^0$	$K^+K^-K^+$	$K^+\pi^-\pi^+$
Tracking	1.8%	0.9%	2.7%	1.8%	1.8%	0.9%	2.7%	2.7%
K_S^0 efficiency	-	-	12.5%	11.6%	-	-	-	-
π^0 efficiency	-	6.5%	-	6.5%	-	6.5%	-	-
PID and continuum-supp. eff.	1.1%	2.6%	0.9%	1.4%	1.3%	2.7%	2.3%	1.0%
$N_{B\bar{B}}$	2.7 %	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%
Signal model	1.1%	2.3%	$< 0.1\%$	$< 0.1\%$	4.5%	0.5%	0.6%	3.5%
Continuum bkg. model	4.2%	3.1%	1.5%	4.8%	$< 0.1\%$	3.6%	0.3%	4.6%
$B\overline{B}$ bkg. model	0.4%	$< 0.1\%$	-	-	1.6%	0.4%	-	0.2%
Total	5.5%	8.5%	13.2%	14.6%	5.9%	8.4%	4.5%	7.0%

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 $\mathcal{L}$, $\sigma(\Upsilon(4S))$, 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

syst. uncertainties: 2) charge-asymmtry

- **Signal+SxF modeling**: allow for independent mean shifts for both charges, difference as systematic
- **Background modeling**: allow for independent background shapes for both charges, difference as systematic
- **Instrumental correction**: use stat. uncertainty of asymmetry measurement in control channel as sys. uncertainty