Electroweak and Radiative Penguin Decays at Belle II

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Belle II

Karlsruher Institut für Technologie

DESY.

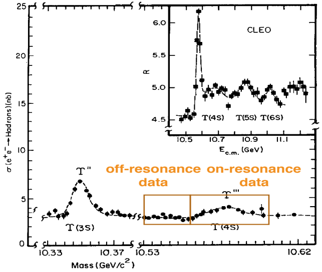
SuperKEKB

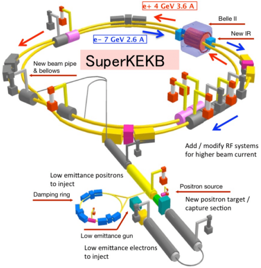
Energy asymmetric e^+e^- collider @ $\sqrt{s} = 10.58$ GeV:

- $\sqrt{s} = 10.58$ GeV $\leftrightarrow \Upsilon(4S)$ resonance $\rightarrow$
  $\Upsilon(4S) \rightarrow B\bar{B}$ + nothing else with $\mathcal{B} > 96\%$
  $\rightarrow$ clean B sample (on-resonance)
- @ 60 MeV below $\Upsilon(4S)$ resonance
  $\rightarrow$ control sample to constrain continuum backgrounds
  ($e^+e^- \rightarrow q\bar{q}$, where $q = (u, d, s, c)$) (off-resonance)

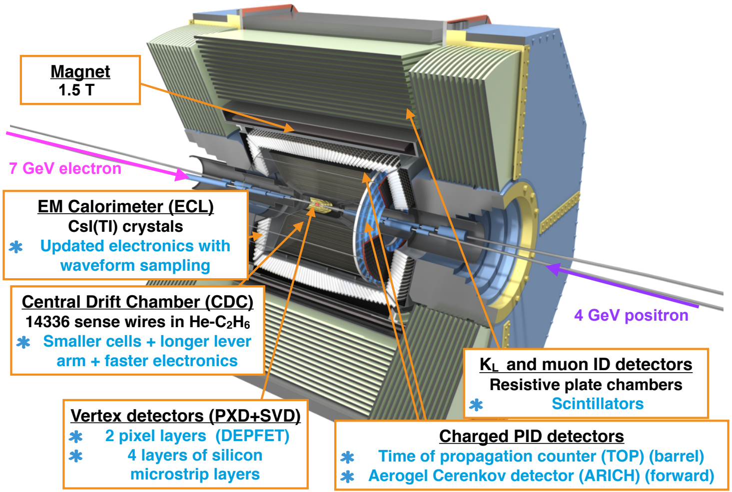
With nanobeam scheme and upgraded rings SuperKEKB aims to reach $30\times$ higher $\mathcal{L}_{inst}$ than KEKB at cost of $\mathcal{O}(10)\times$ higher backgrounds:

- x 1.5 currents
- x 1/20 vertical beam size





Belle II Detector

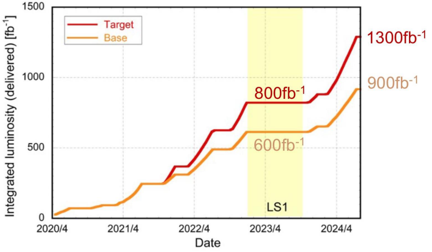


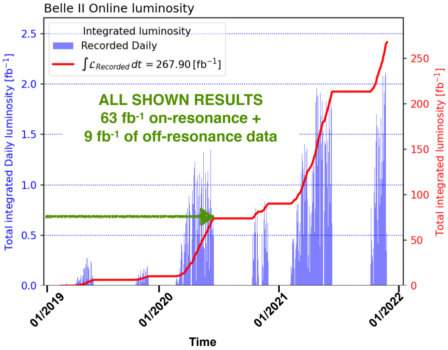
- ▷ Belle II was designed to give **similar or better performance** than Belle even under $\mathcal{O}(10)\times$ higher backgrounds
- ▷ **DAQ and trigger** systems were also upgraded (higher readout frequency + low multiplicity channels)!

Luminosity

Status:

- Collected $\sim$ **268 fb^{-1}** since April 2019
- Slower luminosity accumulation than initially planned, but with $\sim$90% data-taking efficiency
- **Record-breaking instantaneous luminosity: 3.8×10^{34}cm^{-2}s^{-1}**
- **Highest daily integrated luminosity: 2.2 fb^{-1}**





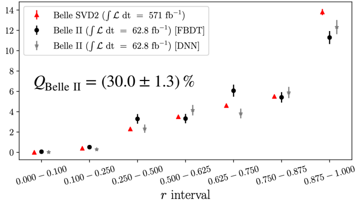
Plans:

- **Short-term plan:** shutdown in 2023:
  - full PXD installation $\rightarrow$ important to maintain good vertex resolution at high luminosity
  - Replacement of 50% of barrel TOP PMTs
- **Goal: 50 ab^{-1}**

Performance Highlights

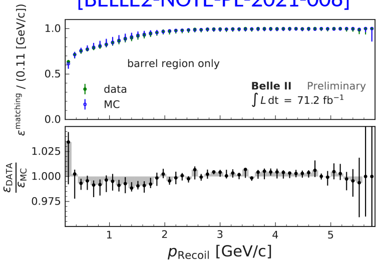
Good flavour tagger performance

[arxiv:2110.00790]



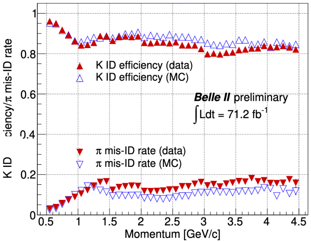
High photon matching efficiency

[BELLE2-NOTE-PL-2021-008]



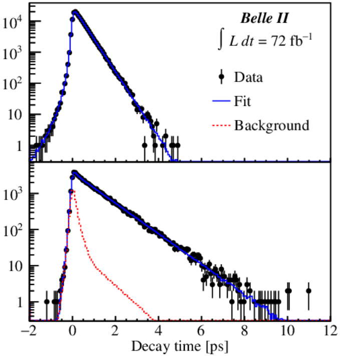
Good particle identification

[BELLE2-NOTE-PL-2020-024]



Factor 2 improvement in proper time resolution

[PRL 127, 211801 (2021)]



Electroweak and Radiative Penguin Decays

Flavour changing neutral current (FCNC) transitions occurring at loop level only $\rightarrow$ **highly suppressed**

- In this this talk concentrate mostly on $b \rightarrow s$ transitions:

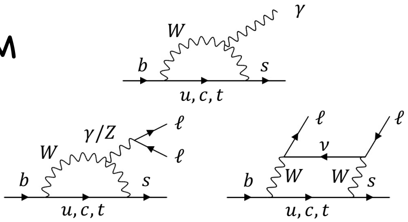
Radiative penguin decays:

- Measurement of $\mathcal{B}(B \rightarrow K^{*}\gamma)$ (exclusive)
- Observation of $B \rightarrow X_s\gamma$ (inclusive)

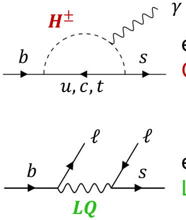
Electroweak penguin decays:

- Study of $B^{+} \rightarrow K^{+}l^{+}l^{-}$ (exclusive)
- Search for $B^{+} \rightarrow K^{+}\nu\bar{\nu}$ (exclusive)

SM



NP



e.g.
Charged Higgs

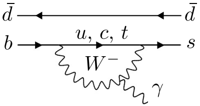
e.g.
Leptoquark

Interesting as NP can appear either in a loop or mediate FCNC at the tree level, recently tensions wrt SM

Measurement of $\mathcal{B}(B \to K^*\gamma)$

arxiv:2110.08219

- SM $\mathcal{B}(B \to K^*\gamma) = \mathcal{O}(10^{-5})$ with large uncertainties due to FF
- **First step before measurement of theoretically cleaner observables** such as CP violation asymmetry A_{CP} and isospin asymmetry Δ_{0+}:



$$A_{CP} = \frac{\Gamma(\bar{B} \to \bar{K}^*\gamma) - \Gamma(B \to K^*\gamma)}{\Gamma(\bar{B} \to \bar{K}^*\gamma) + \Gamma(B \to K^*\gamma)},$$

$$\Delta_{0+} = \frac{\Gamma(B^0 \to K^{*0}\gamma) - \Gamma(B^+ \to K^{*+}\gamma)}{\Gamma(B^0 \to K^{*0}\gamma) + \Gamma(B^+ \to K^{*+}\gamma)},$$

which are then more sensitive to NP

- Latest measurement from Belle with 772×10^6 $B\bar{B}$ pairs $\to$ 3.1σ evidence for the isospin asymmetry violation

Observable	Belle [PRL 119, 191802 (2017)]	SM [JHEP 04,027 (2017)][PRD D88, 094004 (2013)]
$\mathcal{B}(B^0 \to K^{*0}\gamma)$	$(3.96 \pm 0.07 \pm 0.14) \times 10^{-5}$	$(3.48 \pm 0.81) \times 10^{-5}$
$\mathcal{B}(B^+ \to K^{*+}\gamma)$	$(3.76 \pm 0.10 \pm 0.12) \times 10^{-5}$	$(3.43 \pm 0.84) \times 10^{-5}$
$A_{CP}(B^0 \to K^{*0}\gamma)$	$(-1.3 \pm 1.7 \pm 0.4)\%$	$(0.3 \pm 0.1)\%$
Δ_{0+}	$(+6.2 \pm 1.5 \pm 0.6 \pm 1.2)\%$	$(4.9 \pm 2.6)\%$

- **Challenge:** in future Δ_{0+} will be dominated by f_{+-}/f_{00}, A_{CP} will be statistically limited

Measurement of $\mathcal{B}(B \to K^*\gamma)$

arxiv:2110.08219

Full decay chain reconstruction:

- K^* : $K^{*0}(K^+\pi^-, K_s^0\pi^0), K^{*+}(K^+\pi^0, K_s^0\pi^+)$; $K_s^0 \to \pi^+\pi^-, \pi^0 \to \gamma\gamma$
- γ : $(2.25 < E_\gamma^{CMS} < 2.85$ GeV)

Main backgrounds:

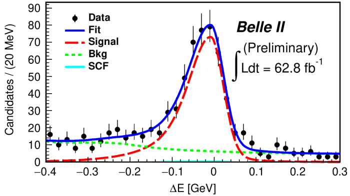
- Continuum events with γs coming from $\pi^0, \eta \to$ veto events consistent with (π^0, η) kinematics + BDT suppression with event-based variables
- Misreconstructed events
- Combinatorial background

Signal extraction with unbinned ML fit to $\Delta E = E_B^* - E_{beam}^*$

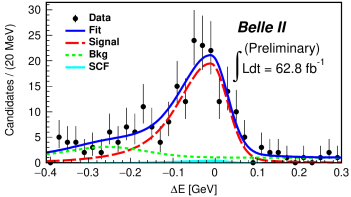
Mode	$\mathcal{B}_{\rm meas}$ $[10^{-5}]$	$\mathcal{B}_{\rm PDG}$ $[10^{-5}]$
$B^0 \to K^{*0}\gamma$	$4.5 \pm 0.3 \pm 0.2$	4.18 ± 0.25
$B^+ \to K^{*+}\gamma$	$5.2 \pm 0.4 \pm 0.3$	3.92 ± 0.22

Consistent with world average within $1\sigma(2\sigma)$ for neutral (charged) mode

$B^0 \to K^{*0}(\to K^+\pi^-)\gamma$



$B^+ \to K^{*+}(\to K_s^0\pi^+)\gamma$

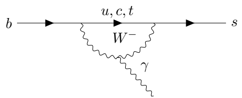


Observation of $B \to X_s\gamma$

BELLE2-NOTE-PL-2021-004

First step towards the inclusive measurement of $\mathcal{B}(B \to X_s\gamma)$

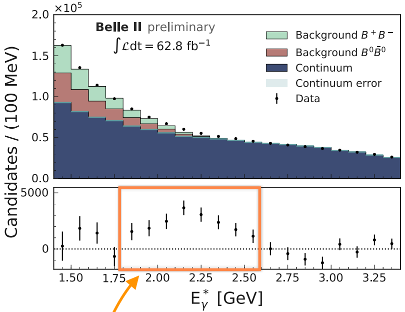
- Sensitive to NP: charged Higgs [EPJC 78 8, 675 (2018)]



Analysis strategy:

- Untagged approach (reconstruct high energy γ on signal side)
- Basic selection includes π^0 and η veto
- Suppression of the continuum backgrounds using BDT trained with event shape variables
- Expected continuum backgrounds obtained from off-resonance data; charged B backgrounds and neutral B backgrounds obtained from simulation

Signal extraction from inclusive photon energy spectrum by looking at the excess wrt total expected background



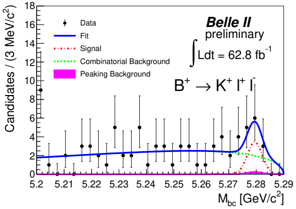
Excess compatible with $B \to X_s\gamma$ signal

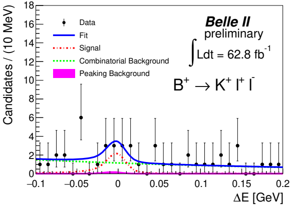
Study of $B^+ \to K^+ l^+ l^-$

BELLE2-NOTE-PL-2021-005

First look at the rare $B^+ \to K^+ l^+ l^-$ in Belle II:

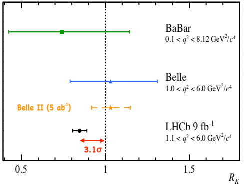
- Both muon and electron modes are reconstructed
- Background suppression with BDT using event shape, vertex information
- Signal extraction with simultaneous ML fit to $M_{bc} = \sqrt{E^{*2}_{beam} - p^{*2}_{B}}$ and ΔE
- Peaking background from $B^+ \to K^+ \pi^+ \pi^-$
- $\mathrm{N_{sig}} = 8.6^{+4.3}_{-3.9}(\mathrm{stat}) \pm 0.4(\mathrm{syst}) \to$ **hint for $B^+ \to K^+ l^+ l^-$ signal**

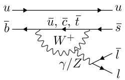




3.1 σ evidence for LFU violation in $b \to s l^+ l^-$ transitions by LHCb!
[arxiv:2103.11769]

$$R(K) = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to K^+ e^+ e^-)}$$





$R(K)$ @ Belle II statistically limited for foreseeable future, future challenge: lepton ID

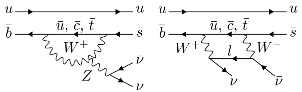
Belle II with > 5 ab^{-1} to provide significant independent information on $R(K)$

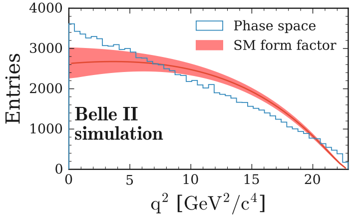
Search for $B^+ \to K^+\nu\bar{\nu}$

PRL 127, 181802 (2021)

SM Theory:

- Does not suffer from charm-loop contributions
  $\to$ **clean SM computation**
- $\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) = (4.6 \pm 0.5) \times 10^{-6}$ [arxiv:1606.00916]
- SM $q^2(\nu\bar{\nu})$ distribution [arXiv:1409.4557]



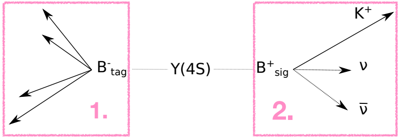


BSM:

- Complementary channel to $b \to sll$ transitions where tensions with the SM have been observed
- NP scenarios: Leptoquarks [PRD 98, 055003 (2018)], Axions [PRD 102, 015023 (2020)], and Dark Matter candidates [PRD 101, 095006 (2020)]

This decay has not been observed yet:

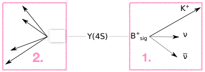
- So far best upper limit of 1.6×10^{-5} @ 90% C.L. set by BaBar [PRD 87, 112005 (2013)] using an exclusive reconstruction ($\epsilon_{sig}^{max} = 0.2\%$)



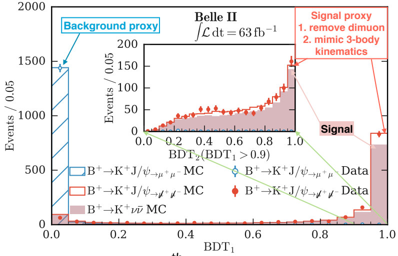
Search for $B^+ \to K^+\nu\bar{\nu}$

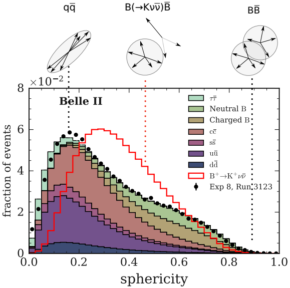
PRL 127, 181802 (2021)

With only 1/10 $\mathcal{L}$ new inclusive tag exploits **very distinct signal kinematics**:



- 1. Reconstruct signal: highest-p_T track in the event with at least 1 PXD hit ($\epsilon_{sig} = 78\%$)
- 2. Reconstruct remaining tracks and clusters in the event
- Minimise the background contamination with two nested BDTs (variables: event topology, missing energy, vertex separation, signal kinematics)
- **20 $\times$ higher signal efficiency ($\epsilon_{sig} = 4.3\%$) wrt exclusive reconstruction but also higher background contamination**
- **Validation with control channel: $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$**





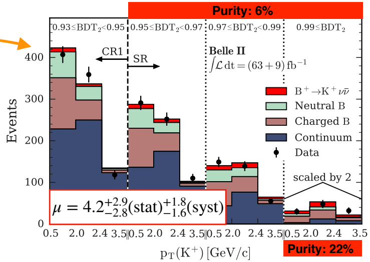
Search for $B^+ \to K^+ \nu\bar{\nu}$

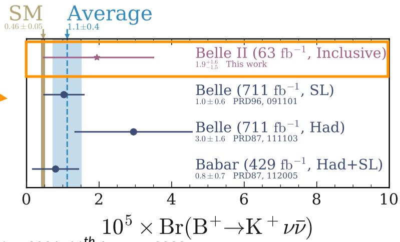
PRL 127, 181802 (2021)

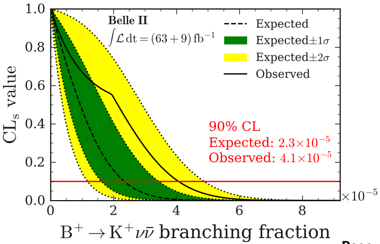
Results and prospects:

- Binned simultaneous ML fit to $p_T(K^+) \times \text{BDT}_2$ to extract signal strength μ (1 μ = SM $\mathcal{B} = 4.6 \times 10^{-6}$)
- No significant signal is observed, limit of $\mathbf{4.1 \times 10^{-5}}$ @ 90 C.L. is set $\to$ **competitive with "*only*" 63 fb^{-1}**
- Inclusive tag shows the best performance, can be used in similar channels
- For next iteration, leading systematics can be reduced
- Combined analysis of inclusive + exclusive tagged events can lead to faster observation

On-resonance data





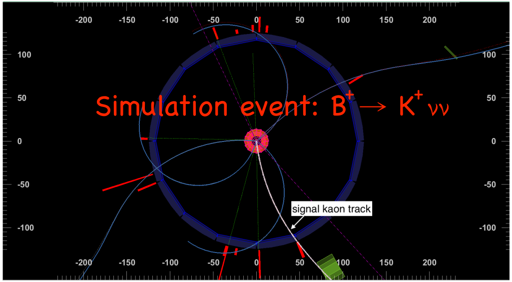


Summary

In conclusion:

- **Belle II** is accumulating **high-quality data** $\to$ the **first** electroweak and radiative **penguin signals** have been seen
- Search for $B^+ \to K^+\nu\bar{\nu} \to$ **first published Belle II *B*-physics paper** employing **novel inclusive tagging approach** yielding highly **competitive limit** with "*only*" 1/10 of previous *B*-factory dataset
- Expect improved measurements soon ($4\times$ bigger dataset on tape, improved analysis techniques)
- Belle II is going to become crucial player in **understanding the flavour anomalies**

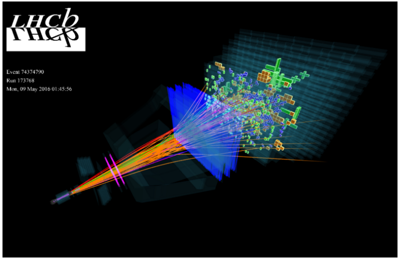
Thank you!

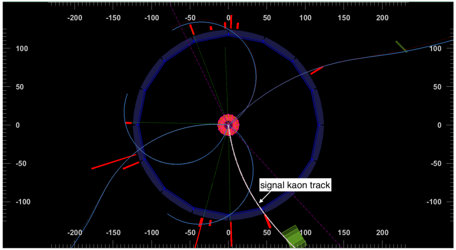


BACKUP

LHCb vs Belle II

LHCb	Belle II
single-arm detector longitudinal momentum of B not known	hermetic detector known initial state kinematics pro @ neutral object reconstruction (photon, K_L)



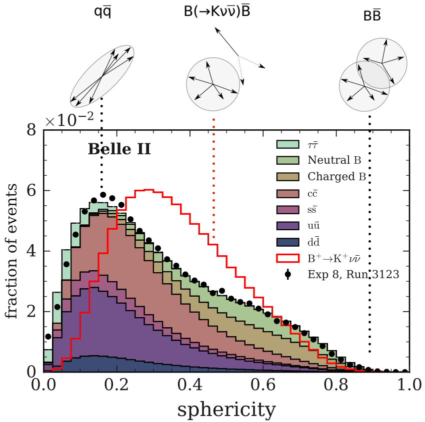


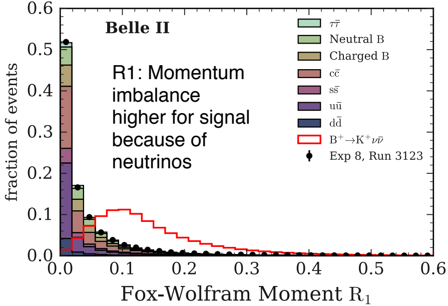
- $B^+ \to K^+ \nu \bar{\nu}$ **is a golden channel @ Belle II:** clean environment and well defined initial state but still **challenging** as two neutrinos in the final state leave no signature

BDT parameters I

To suppress the backgrounds list of potential features (>100) such as:

- variables related to event-shape,



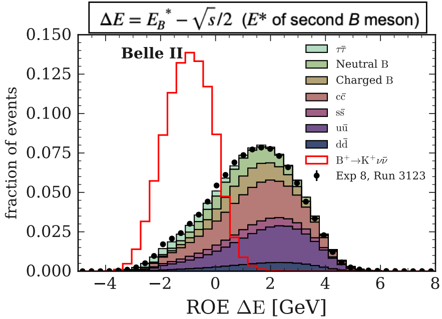


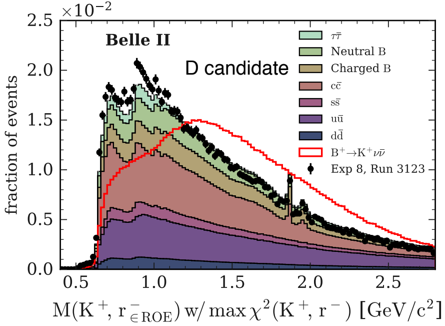
BDT parameters II

To suppress the backgrounds list of potential features (>100) such as:

- variables related to event-shape, ROE-related variables, variables related to the distance wrt to beam spot and tag-vertex, variables related to 2/3-track vertex fits, missing mass …

51 most discriminating variables w/o loss of performace are chosen as an input to BDTs

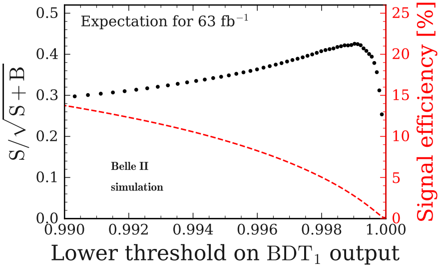


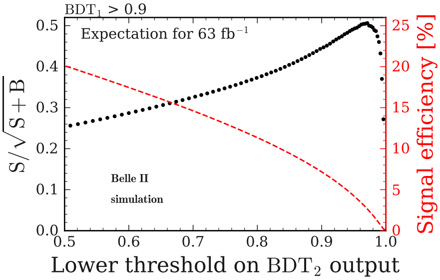


Two-stage BDT

Two consecutive BDTs (BDT_1 and BDT_2) have been trained on simulated subsamples to suppress the backgrounds:

- BDT_1 trained on the chosen 51 variables on $\sim 10^6$ events for all types of backgrounds and signal
- BDT_2 is trained with the same set of variables but only on events with $BDT_1 > 0.9$ ($\sim 28\%\ \epsilon_{sig}$)
- **Boosting of statistics in signal region $\rightarrow$ improvement of signal purity of 35% @ 4% ϵ_{sig}**
- No overtraining is observed





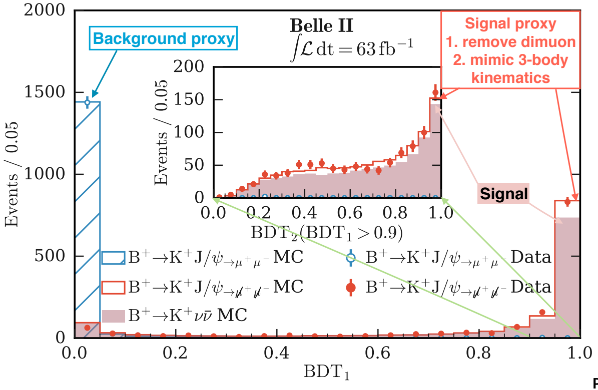
Validation I: $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$

BDT_1 and BDT_2 validated with data/MC comparison using $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$

- ▷ Used because of high BF and clean signature
- ▷ Validation for both signal and *B*-backgrounds !
- ▷ **Excellent agreement** $\to$ for $\text{BDT}_2 > 0.95$, data/MC = 1.06 ± 0.10

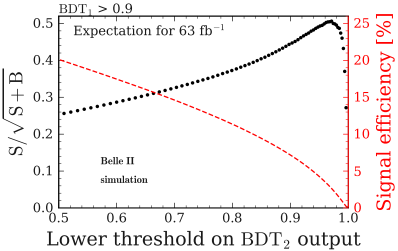
Signal-like $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$

- ▷ 0. Reconstruct $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$
- ▷ 1. Ignore dimuon from J/ψ to mimic missing energy
- ▷ 2. Replace four-momenta of K^+ by that of the signal to mimic 3-body kinematics

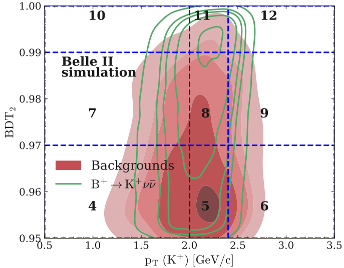


Fit Region Definition

- Signal region: maximum sensitivity → $\mathrm{BDT}_2 > 0.95$ → **4.3%** ϵ_{sig}
- In SR, kaon PID > 0.9 → keep 62% kaons, remove 97% pions
- **24 bins in $p_T \times \mathrm{BDT}_2$ space**
  (12 bins on-resonance + 12 bins off-resonance)
- Bin boundaries determined from 2D grid optimisation



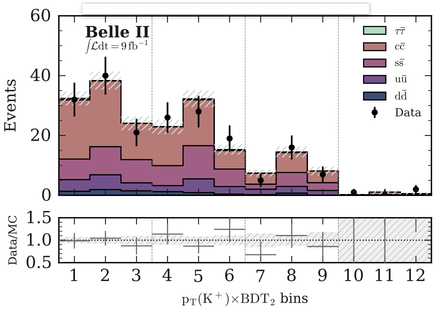
Region	2D Bin Boundary Definition	Physics Processes	$\sqrt{s}$
Signal Region (SR)	$p_T(K^+) \in [0.5, 2.0, 2.4, 3.5]$ GeV/c $\mathrm{BDT}_2 \in [0.95, 0.97, 0.99, 1.0]$	signal + all backgrounds	$\Upsilon(4S)$
Control Region 1 (CR1)	$p_T(K^+) \in [0.5, 2.0, 2.4, 3.5]$ GeV/c $\mathrm{BDT}_2 \in [0.93, 0.95]$	signal + all backgrounds	$\Upsilon(4S)$
Control Region 2 (CR2)	$p_T(K^+) \in [0.5, 2.0, 2.4, 3.5]$ GeV/c $\mathrm{BDT}_2 \in [0.95, 0.97, 0.99, 1.0]$	continuum backgrounds	off-resonance (-60 MeV/c^2)
Control Region 3 (CR3)	$p_T(K^+) \in [0.5, 2.0, 2.4, 3.5]$ GeV/c $\mathrm{BDT}_2 \in [0.93, 0.95]$	continuum backgrounds	off-resonance (-60 MeV/c^2)

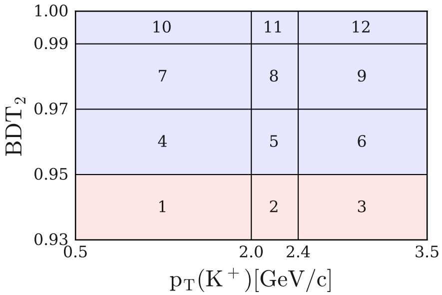


Validation II: Continuum

Data/MC comparison between off-resonance data and continuum simulation in $p_T \times \text{BDT}_2$ bins

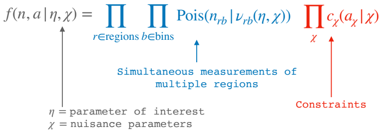
- **Very good agreement in shape**
- **Discrepancy in scale:** Data/MC factor = 1.40 $\pm$0.12
- Introduction of normalisation uncertainty of 50% to all the backgrounds (conservative)

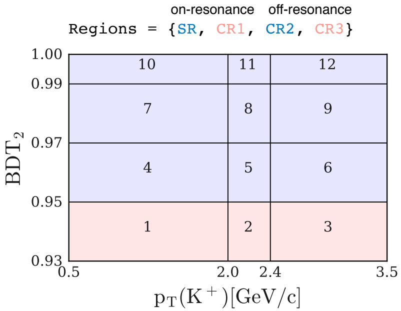




Statistical Model

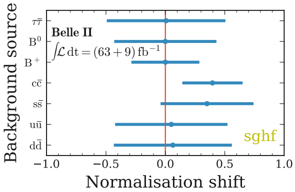
- Likelihood implemented within `pyhf` package
- Cross-check with `sghf`: simplified Gaussian model
- **Inclusion of systematics in the model via nuisance parameters:** background normalisation uncertainty, tracking inefficiency, neutral energy miscalibration for photons, neutral energy miscalibration for unmatched photons, uncertainty on PID correction due to limited statistics, uncertainty on branching fractions of leading bkg processes, uncertainty on SM form factor
- All 7 background samples considered separately: mixed B, charged B, $c\bar{c}$, $u\bar{u}$, $s\bar{s}$, $d\bar{d}$, $\tau^+\tau^-$
- Total number of fit parameters: 175 nuisance parameters ($\vec{\phi}$) and 1 parameter of interest (signal strength=μ)
- **1 μ = SM BF = $(4.6 \pm 0.5) \times 10^{-6}$**



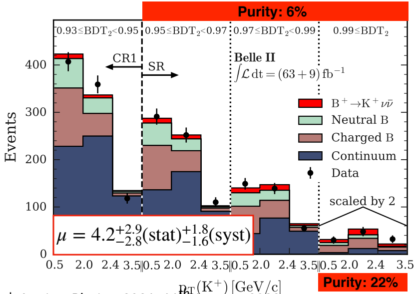


Fit To Data

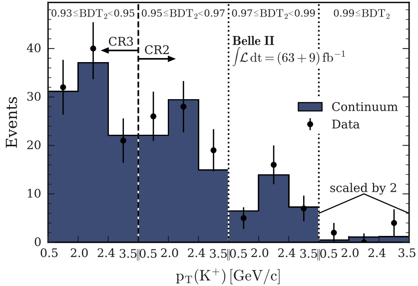
- Binned simultaneous ML fit to data to extract signal strength μ
- **Result:** $\mu = 4.2^{+2.9}_{-2.8}(\text{stat})^{+1.8}_{-1.6}(\text{syst}) = 4.2^{+3.4}_{-3.2}$
- Continuum bkgs pulled up by up to 40%, *B*-bkgs stay the same



On-resonance data

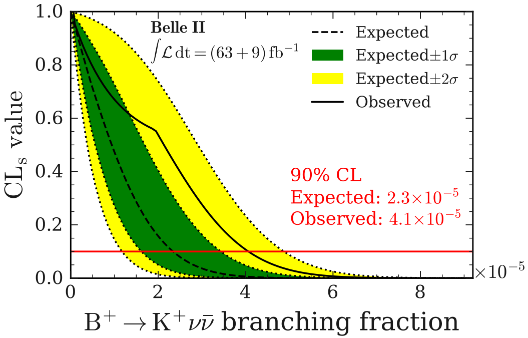


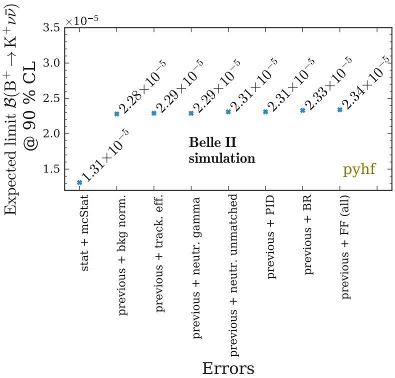
Off-resonance data



Limit Setting

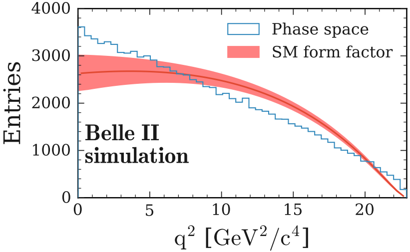
- As no significant signal is observed → limit setting
- Use both `pyhf` and `sghf` to compute a limit → consistent results
- **Result: $\mathcal{B}(B^+ \to K^+\nu\bar{\nu}) < 4.1 \times 10^{-5}$ @ 90 CL**
- Leading systematic: background normalisation

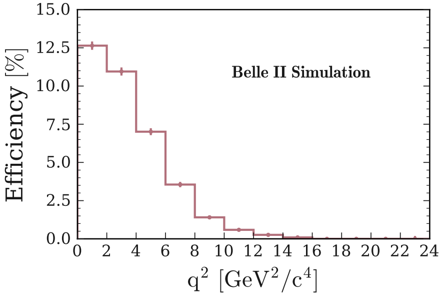




Reinterpretation

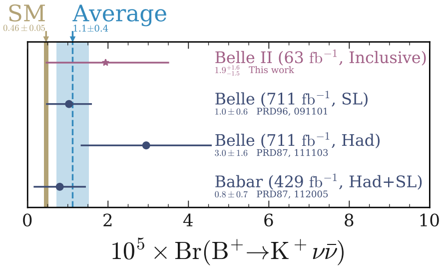
- Publish ϵ_{sig} as a function of $q^2(\nu\bar{\nu})$
- Reminder: default signal model $\rightarrow$ PHSP model with SM form factor reweighting [arXiv:1409.4557]
- **At low q^2 maximum signal efficiency of $\sim$ 13%, but no sensitivity for $q^2 > 16$ GeV^2/c^2**





Comparison with Other Measurements

- **Competitive limit**
- **Comparison with other experiments** via σ_{BR} assuming same luminosity $\rightarrow$ the performance of inclusive tag:
  - 3.5 better than hadronic tag
  - 20% better than semileptonic tag
  - 10% better than combined hadronic and semileptonic tag



Experiment	Year	Observed limit on $BR(B^+ \to K^+\nu\bar{\nu})$	Approach	Data [fb^{-1}]
BABAR	**2013**	$< 1.6 \times 10^{-5}$ **[Phys.Rev.D87,112005]**	**SL + Had tagging**	429
Belle	**2013**	$< 5.5 \times 10^{-5}$ **[Phys.Rev.D87,111103(R)]**	**Had tagging**	711
Belle	**2017**	$< 1.9 \times 10^{-5}$ **[Phys.Rev.D96,091101(R)]**	**SL tagging**	711
Belle II	**2021**	$< 4.1 \times 10^{-5}$	**Inclusive tagging**	63

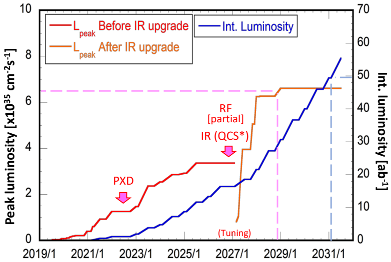
Conclusion and Prospects

- **Bigger dataset** (+ possible combination with Belle dataset)
- **Attacking biggest systematic** (background normalisations, e.g continuum modelling)
- **More channels** (K^*, K_s^0, K^{*+}...)
- **Possible improvement in background suppression** (use of NN architecture, discriminating vars)
- **Combined analysis of inclusive and exclusive tagged events**

$10^5 \times \sigma_{\rm BR}$ uncertainty for next analyses, assuming 25% improvement + 40% K_S^0

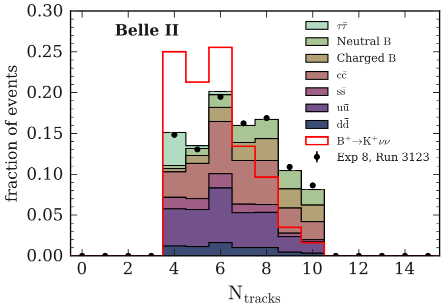
	$63\ \mathrm{fb}^{-1}$ (arXiv:2104.12624)	$197\ \mathrm{fb}^{-1}$ (Summer 2021 – current lumi)	$450\ \mathrm{fb}^{-1}$ (Summer 2022 – expected)	$(450 + 700)\ \mathrm{fb}^{-1}$ (+ Belle I sample)
$\sigma_{BR}(K^+)$	1.55	0.78	0.52	**0.32**
$\sigma_{BR}(K^+ + K_S^0)$	–	0.68	0.45	**0.28**

Preliminary



Basic Event Selection

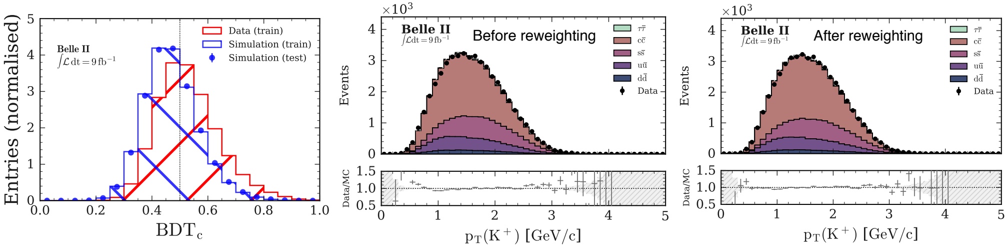
- Track cleanup: $p_T > 0.1\text{GeV}/c$, $\theta \in$ CDC, $|dr| < 0.5$cm, $|dz| < 3.0$cm, E < 5.5 GeV
- Photon cleanup: E > 0.1 GeV, $\in$ CDC, E < 5.5 GeV
- Other loose preselection to reject low-multiplicity background:
  - $4 \leq \texttt{nTracksCleaned} \leq 10$
  - $0.3 < \theta(\mathbf{p}_{\text{miss}}) < 2.8$ rad
  - Visible E in CMS frame> 4GeV



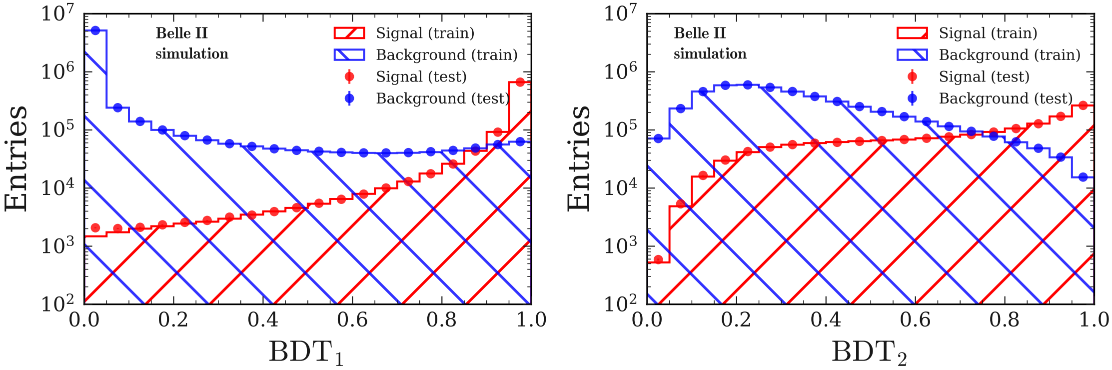
Continuum Modelling Improvement

Additional BDT$_c$ is trained on events with BDT$_1 > 0.9$ in order to correct mismodeling of continuum simulation:

- Signal = off-resonance data , background = continuum simulation
- Continuum simulation events are reweighted with $\frac{p}{1-p}$, where p = BDT$_c$ output
- Method taken from here: J. Phys.: Conf. Ser. 368 012028

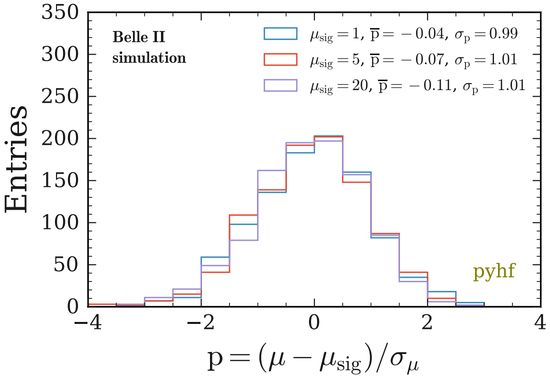


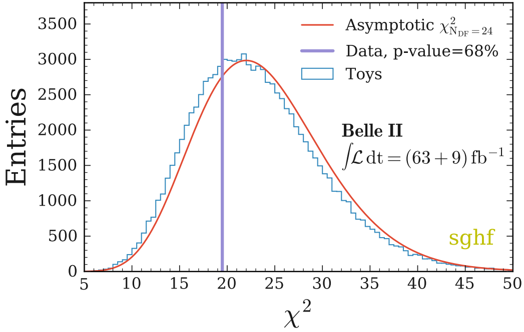
Overtraining



Fit Validation

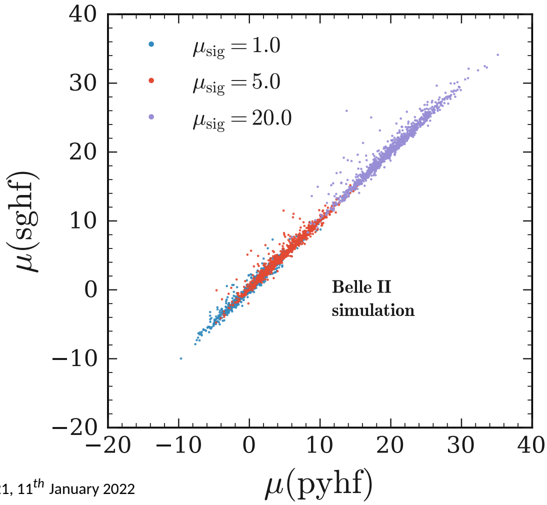
- Test with injected signal $\rightarrow$ check pulls = $\frac{\mu_{fit} - \mu_{inj}}{\sigma_\mu}$ for 1, 5, 20 $\times$ signal
- Test the fit quality $\rightarrow$ high *p*-value, good agreement with χ^2 distribution





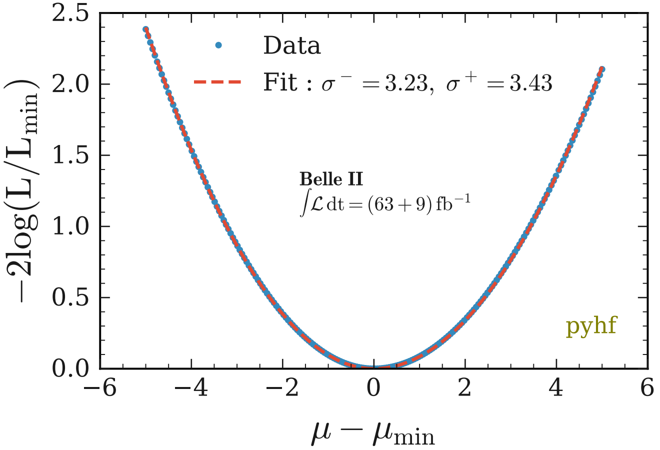
pyhf versus sghf

- Check correlation between pyhf and sghf fitted μ for 1, 5, 20 $\times$ signal $\rightarrow$ very good correlation



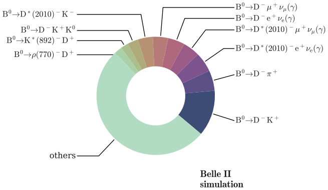
Profile Likelihood Scan

- Assymetric uncertainty on signal strength μ estimated by fitting of parabola of the points from profile likelihood scan

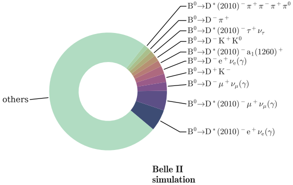


Background Composition in the Fit Region

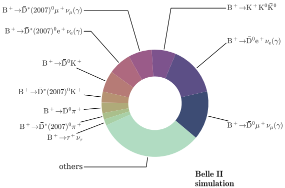
- $B^0\bar{B}^0$ signal side:



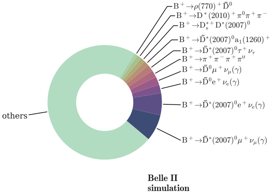
- $B^0\bar{B}^0$ tag side:



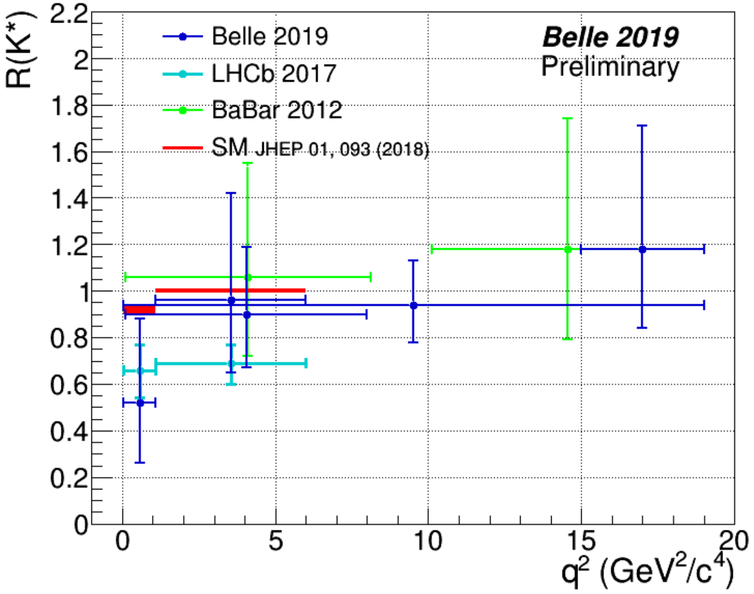
- B^+B^- signal side:



- $B^+\bar{B}^-$ tag side:



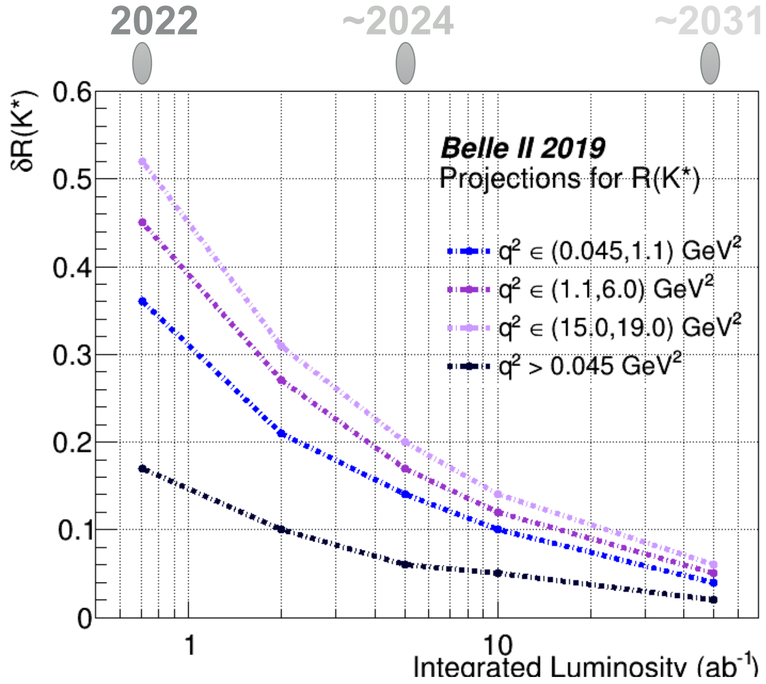
Belle II Prospects (R(K*), angular)



[Belle arXiv: 1904.02440]

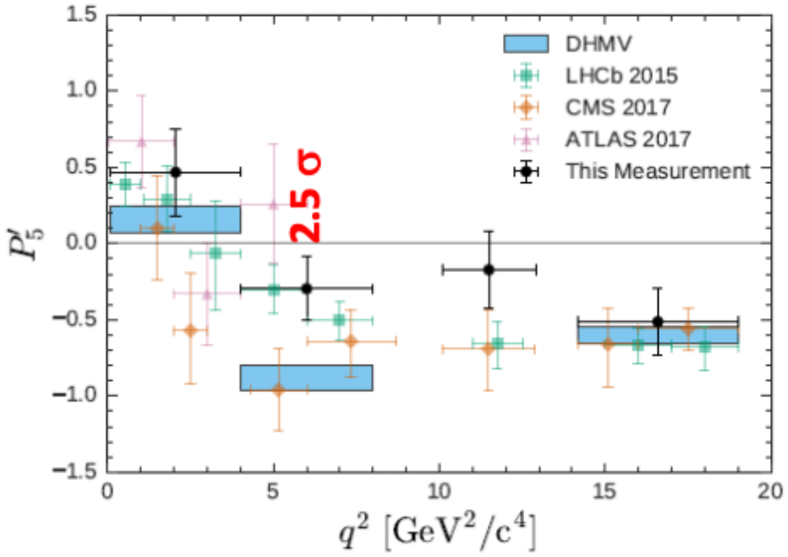
Belle (R(K*))

- Largest deviation in the low q^2 bin

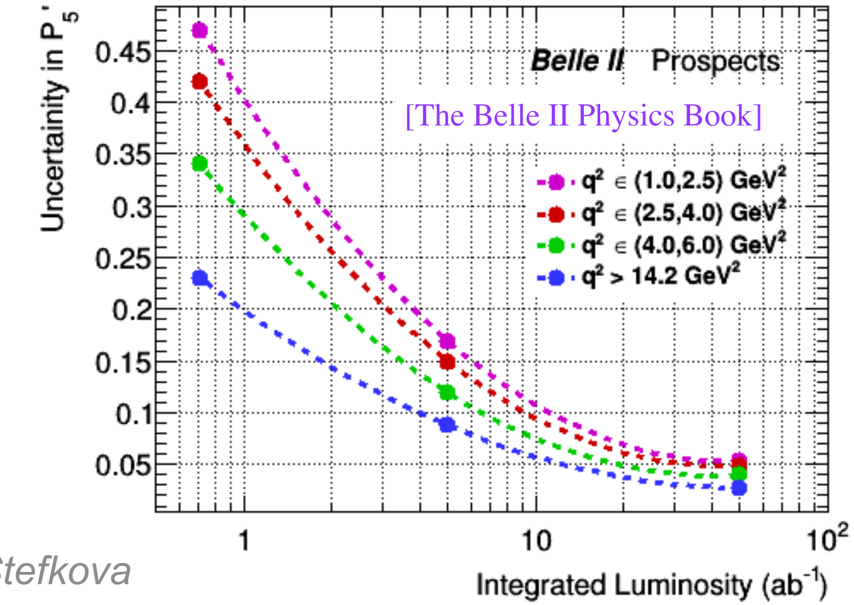


[Belle Phys. Rev. Lett. 118, 111801]

Belle P'$_5$

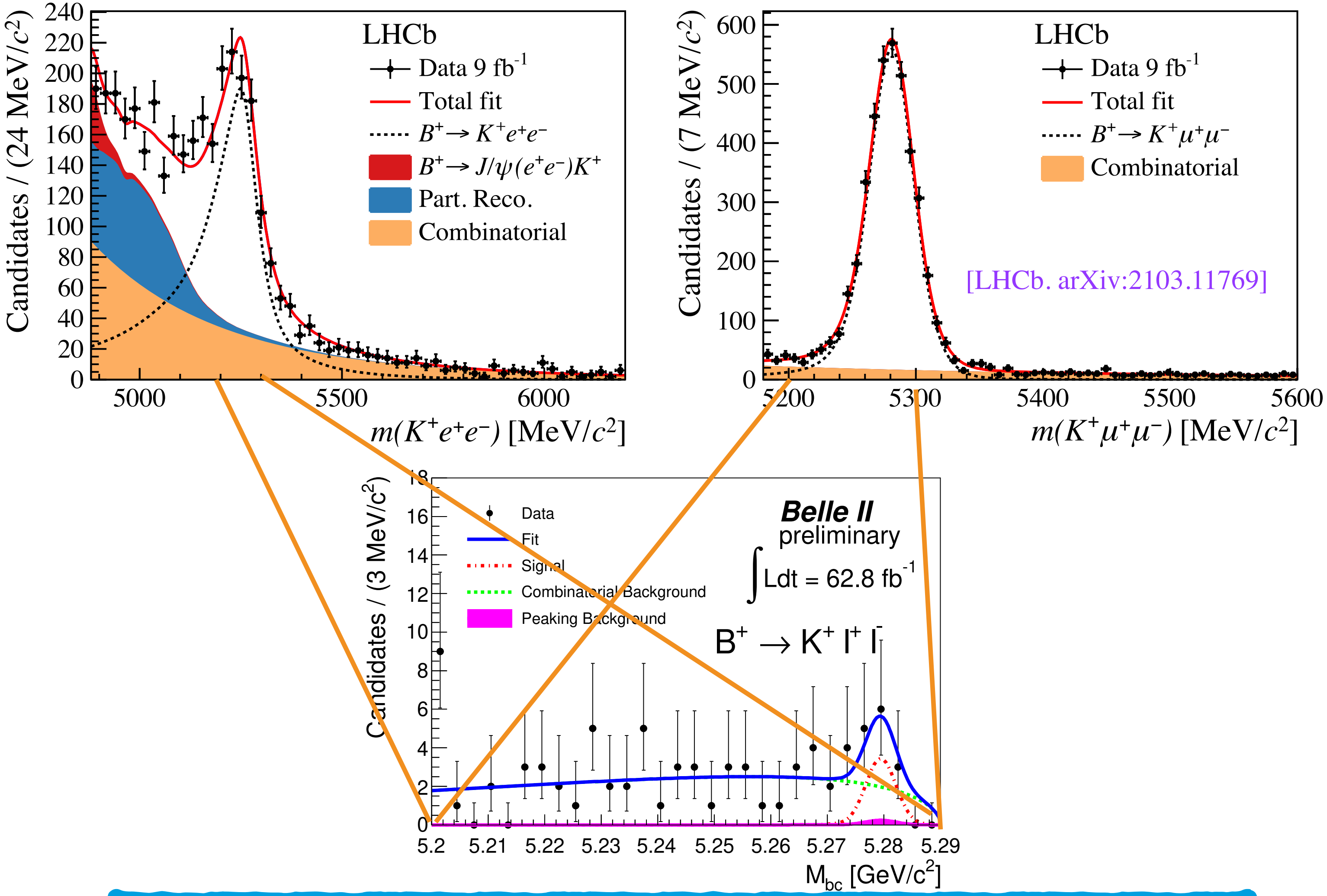


- The largest deviation with 2.6 sigma observed in muon channel
- Electron channel is deviating with 1.1 sigma
- With 2.8 ab^{-1} the uncertainty on P'$_5$ (both e & mu) will be comparable to LHCb 3 fb^{-1} (mu only)



R(K) Belle II vs LHCb

Moriond 2021:63 fb^{-1}



In comparison to LHCb, 3 differing aspects to consider: efficiency, statistics and resolution

	Belle II	LHCb
Signal	K^+, K_S	K^+
Same K e e Statistics	1 ab^{-1}	1 fb^{-1}
B->K mu mu Efficiency	30 %	~5 %
B->K e e Efficiency	30 %	<5% Lower due to tracking and trigger
B->K e e Resolution	Better thanks to M_{bc}	Worse because of Brems
High q^2 bin	Accessible	Hard

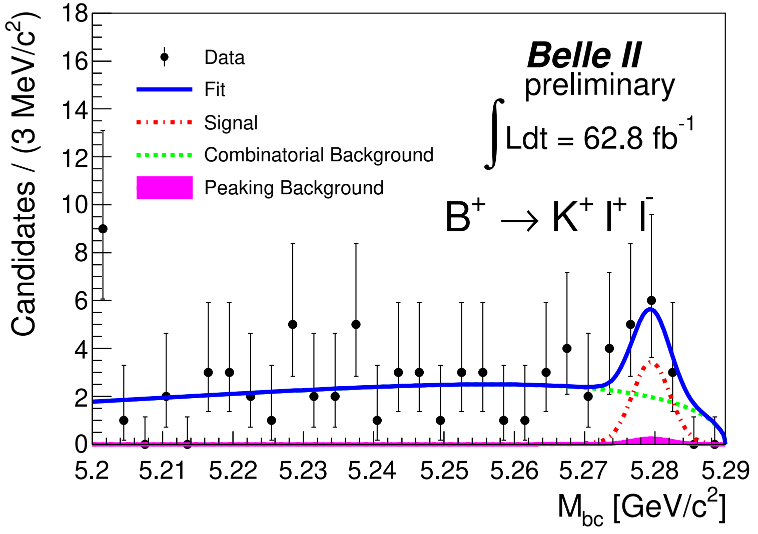
Electrons (and muons) in Belle II have better resolution thanks to M_{bc}

Towards R(K) in Belle II

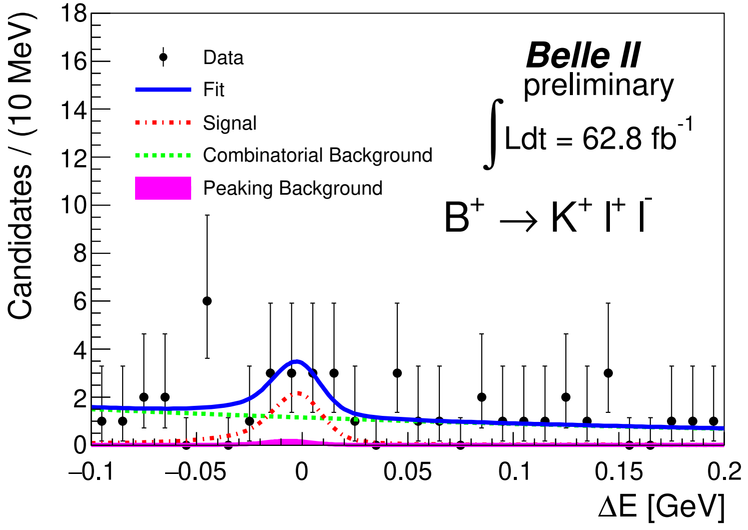
Moriond 2021:63 fb^{-1}

First Belle II measurement of $B^+ \to K^+ l^+ l^-$

- Signal yield extracted with 2D ML
  fit to M_{bc} and ΔE: $8.6^{+4.3}_{-3.9}(\text{stat}) \pm 0.4(\text{syst})$
- Significance: 2.7 sigma
- Peaking background from $B^+ \to K^+ \pi^+ \pi^-$



$$M_{bc} = \sqrt{E^2_{beam} - |\overrightarrow{p_B}|^2}$$



$$\Delta E = E_B - E_{beam}$$

Prospects for R(K)

- Measurement is going to be statistically limited for foreseeable future with leading systematics due to lepton ID~0.4%
- In order to confirm LHCb's R(K) anomaly (5 sigma) need at least 20 ab^{-1}

~2028

[The Belle II Physics Book]