Belle II Highlights and Prospects

With emphasis on measurements connected to recent B-anomalies

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on behalf of the Belle II collaboration

Beyond the Flavour Anomalies II workshop
22.04.2021
Online

Belle II

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Outline

SuperKEKB

Belle II Detector

Current Luminosity +Prospects

Reconstruction with missing energy

$\mathcal{B}(B^+ \to K^+ \nu \bar{\nu})$

$\mathcal{B}(B^+ \to K^+ \tau^+ \mu^-)$

Channels with missing energy

Reconstruction with leptons

R(K,K*)

Angular $\mathrm{B} \to \mathrm{K}^* \mu^+ \mu^-$

Fully reconstructed channels

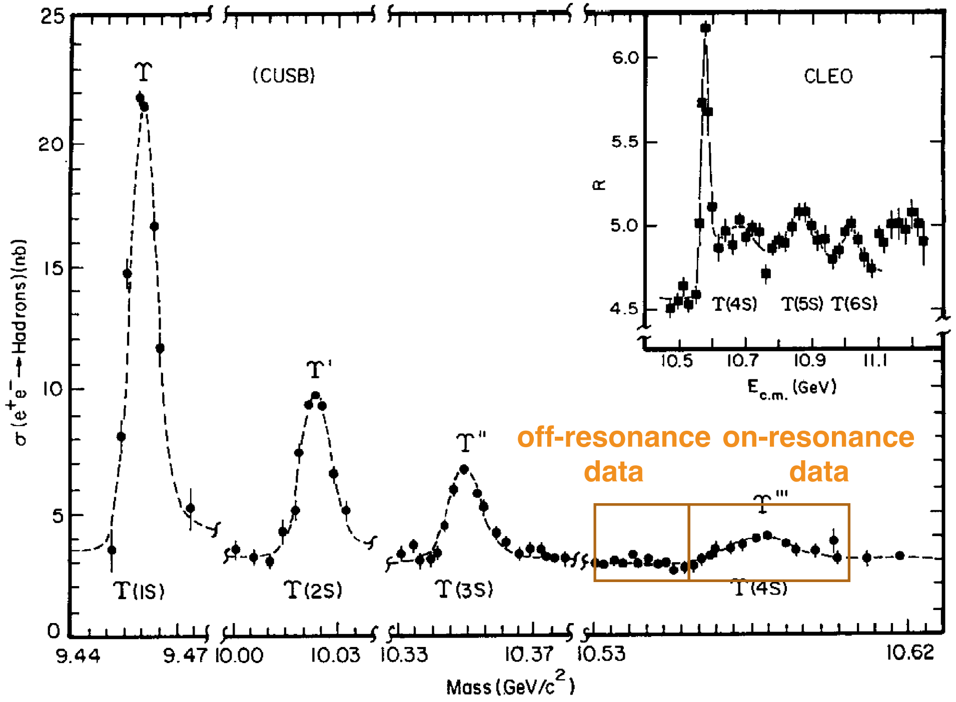
SuperKEKB Accelerator

SuperKEKB is an asymmetric-energy e^+e^- collider in Tsukuba, Japan:

- @Y(4S) resonance (√s = 10.58 GeV): **on-resonance data**

$$\Upsilon(4S) \to B^+B^-, B^0\bar{B}^0 \text{ with } \mathscr{B} > 96\,\%$$

- @ 60 MeV below Y(4S): **off-resonance data**
- @ Y(5S) resonance: B_s physics (future)



With nano-beam scheme and upgraded rings plan to achieve 30 x higher inst. lumi than KEKB:

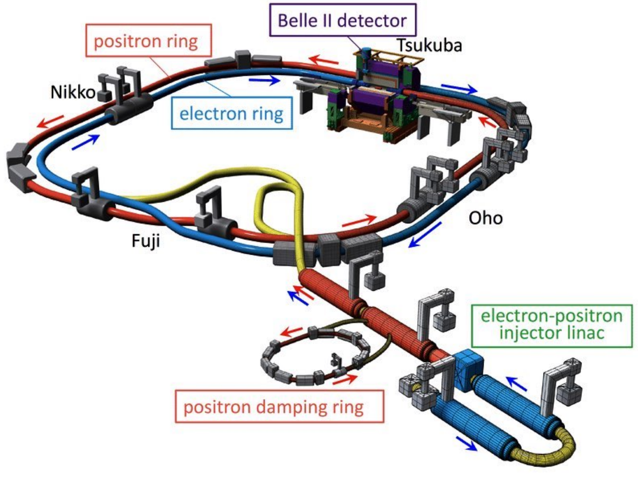
- x 1.5 higher currents
- x 20 smaller β^*_y

beam current

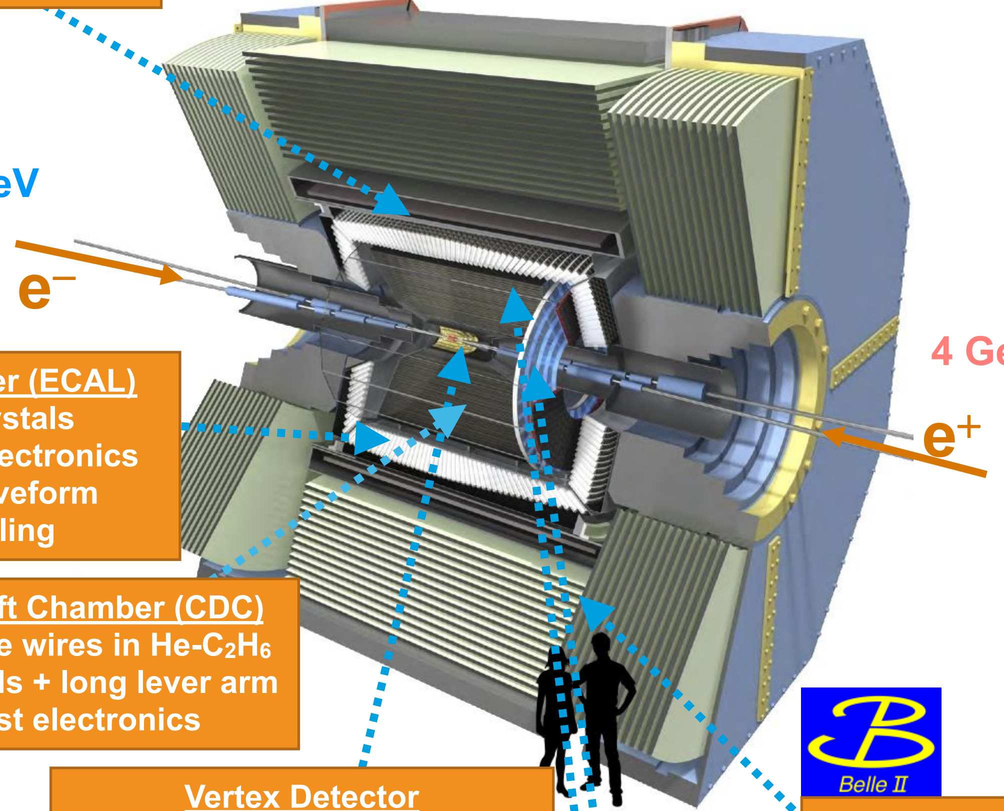
$$L = \frac{\gamma_\pm}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}}\frac{R_L}{R_{\xi_y}}$$

vertical beta function at IP

In Belle II expect O(~15) higher backgrounds than Belle



Belle II Detector



Magnet
1.5 T

EM Calorimeter (ECAL)
CsI(Tl) crystals
✳ Updated Electronics with Waveform sampling

Central Drift Chamber (CDC)
14336 sense wires in He-C_2H_6
✳ small cells + long lever arm + fast electronics

Vertex Detector
✳ 2 pixel layers (PXD)
✳ 4 layers of silicon microstrip layers (SVD)

PID
✳ Time of propagation counter (TOP) (barrel)
Aerogel Cerenkov Detector (ARICH) (forward)

K_L and muon PID
Resistive plate chambers+
✳ Scintillators

Belle II detector was built to give similar or better performance even under mentioned O(~15) backgrounds

- **DAQ+Trigger**: Dark-matter searches
- **VXD**: Better K_s efficiency and improved vertex resolution
- **CDC**: Very good momentum resolution for charged tracks
- **PID**: Achieve very good K/π separation

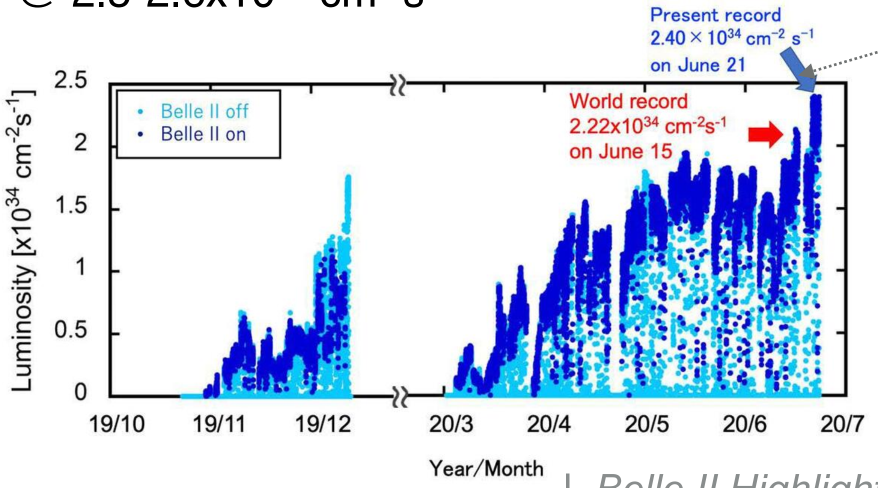
Luminosity Status

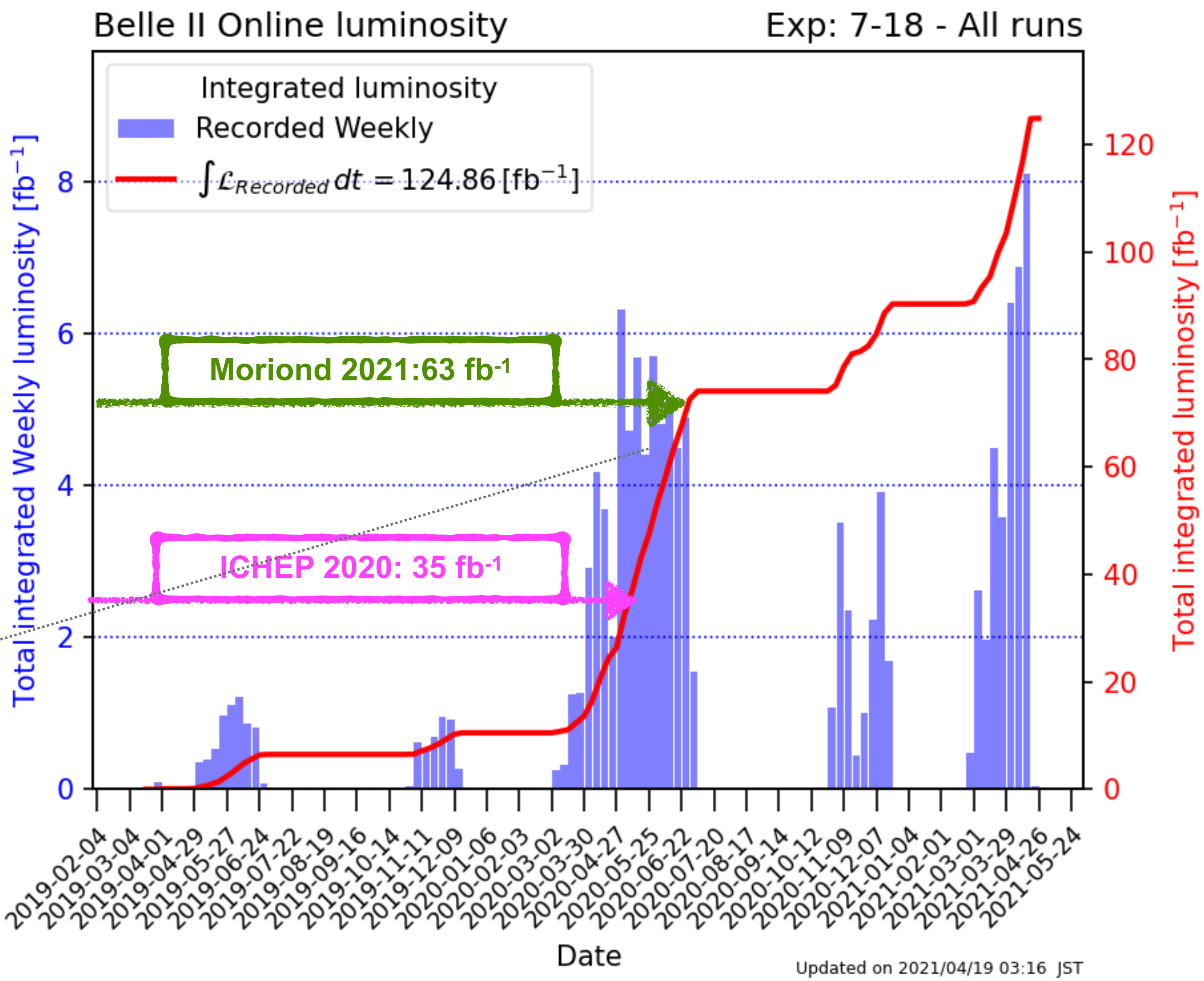
Status:

- Regular data-taking with 20 ladders of PXD from April 2019
- Despite Covid-19, collected 130 fb^{-1} of on-resonance and 9 fb^{-1} of off-resonance data
- Slower luminosity accumulation than initially planned
- In this talk, results are based on **ICHEP 2020** and **Moriond 2021** dataset

Important Milestone:

- Record-breaking instantaneous luminosity of 2.4×10^{34} $cm^{-2}s^{-1}$, now running @ $2.5\text{-}2.6 \times 10^{34}$ $cm^{-2}s^{-1}$





Luminosity Prospects

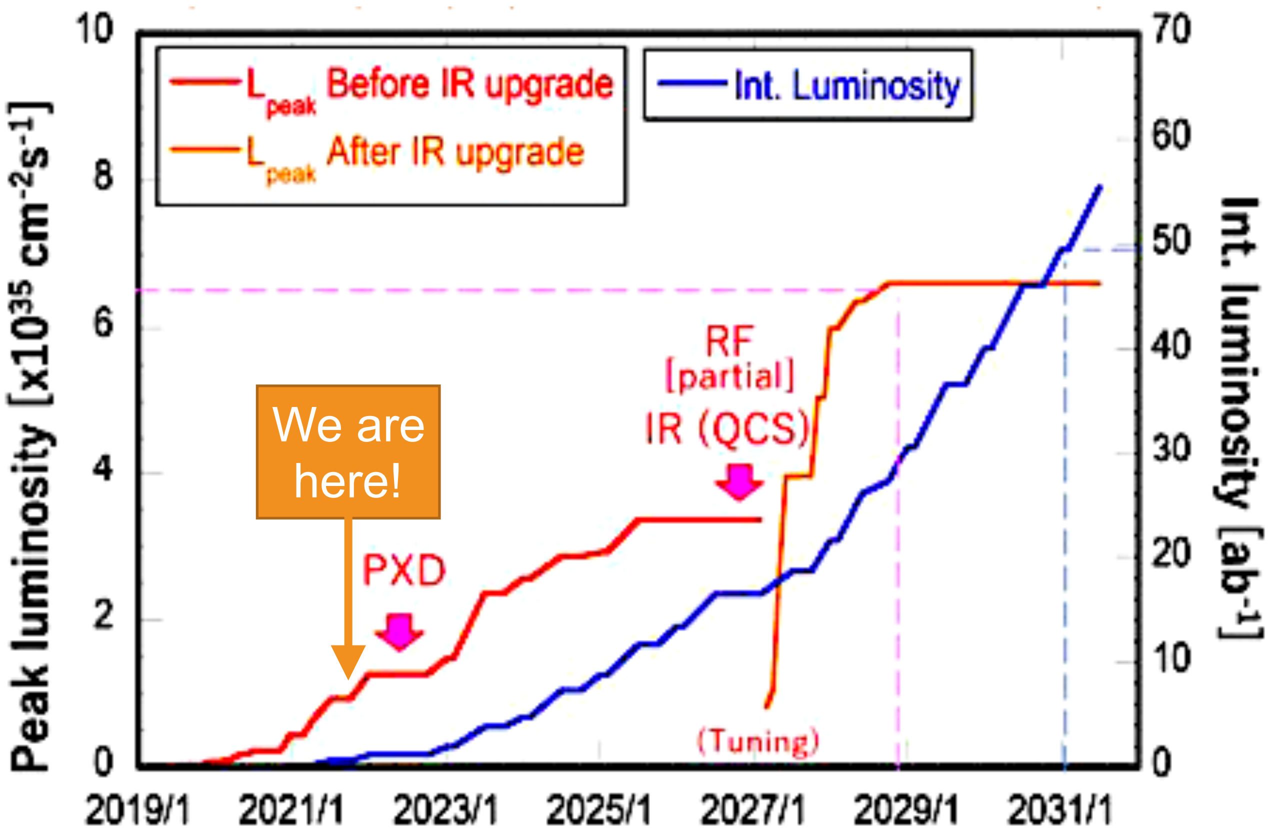
Goal: 50 ab^{-1} by 2031

Short-term plan:

- By summer 2022: 720 fb^{-1} (~ Belle dataset)
- Summer 2022-spring 2023: full new PXD installation → important to maintain good vertex resolution at high luminosity

Long-term plan:

- By 2026: ~15 ab^{-1} (~ 20 x Belle dataset)
- 2026: QCS/IR modification **necessary** to reach design luminosity
- Detailed proposals are currently under discussion, but no exact plan is established yet!



Warning: this luminosity roadmap is tentative, especially after LS1 in 2022

Channels with missing energy

Reconstruction

ICHEP 2020: 35 fb^{-1}

Traditional approach for channels with missing energy:

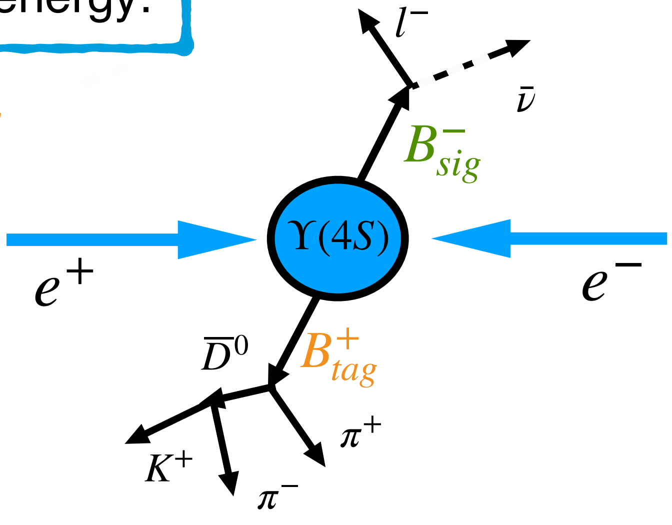
Tagged approach := reconstruction algorithm for B_{tag}

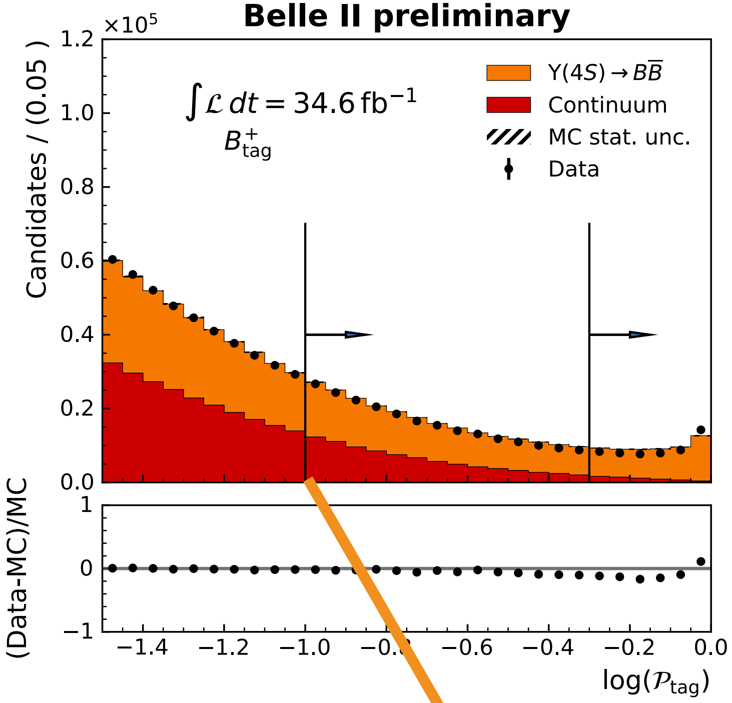
1. step: B_{tag} reconstruction via Full Event Interpretation := MVA tagging algorithm

- ☐ B_{tag} reconstructed in **semileptonic** or **hadronic** channels: efficiency penalty due to BR and ϵ_{rec}, data/MC calibration systematics

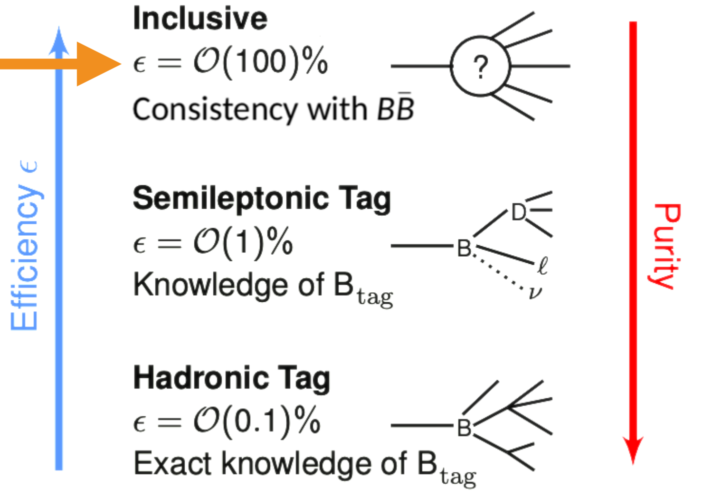
2. step: Look for your signal (B_{sig})

- ☑ Flavour constraint: $B^+_{tag} \rightarrow B^-_{sig}$
- ☑ Kinematically constrained system with hadronically tagged event: $\vec{p}_{\nu} + \vec{p}_{l} = \vec{p}_{e^+e^-} - \vec{p}_{B_{tag}}$

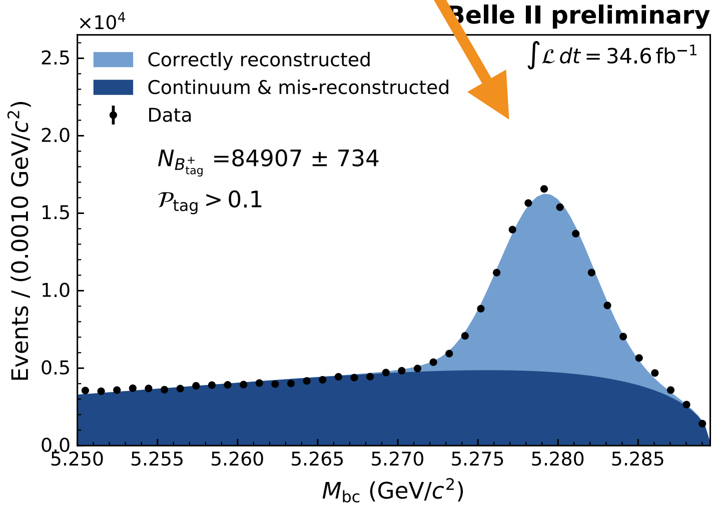




Up x2 ϵ_{rec} improvement compared to Belle B_{tag} algorithm



Schematic by F. Berlochner



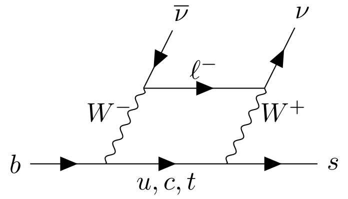
$$M_{bc} = \sqrt{E^2_{beam} - |\vec{p_B}|^2}$$

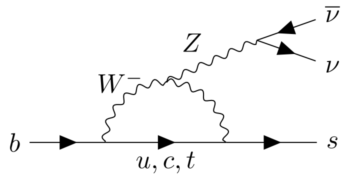
Novel approach implemented for $\mathbf{B^+ \rightarrow K^+ \nu \bar{\nu}}$

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

Moriond 2021:63 fb^{-1}

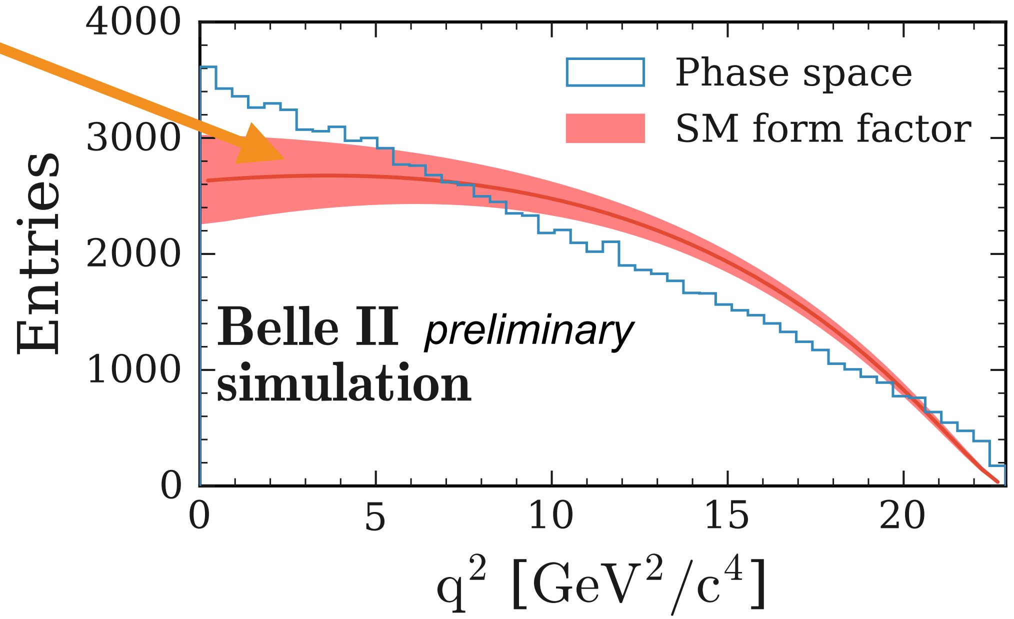
First Belle II B-physics paper about to be submitted to PRL





- Rare decay belonging to $b \to sll$ family with SM $\mathscr{B}(B^+ \to K^+\nu\bar{\nu}) = (4.6 \pm 0.5) \times 10^{-6}$
- Sensitive to BSM physics
- **Not observed yet!** Published limits set by other B-factories use either SL or Hadronic tag reconstruction
- This measurement uses **novel inclusive tag approach** (see next slide)
- SM reference taken from Buras et al: https://arxiv.org/abs/1409.4557

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 tag**	429
Belle	**2013**	$< 5.5 \times 10^{-5}$ **[Phys.Rev.D87,111103(R)]**	**Had tag**	711
Belle	**2017**	$< 1.9 \times 10^{-5}$ **[Phys.Rev.D96,091101(R)]**	**SL tag**	711

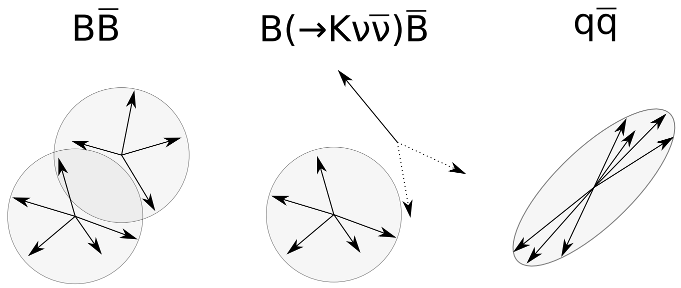


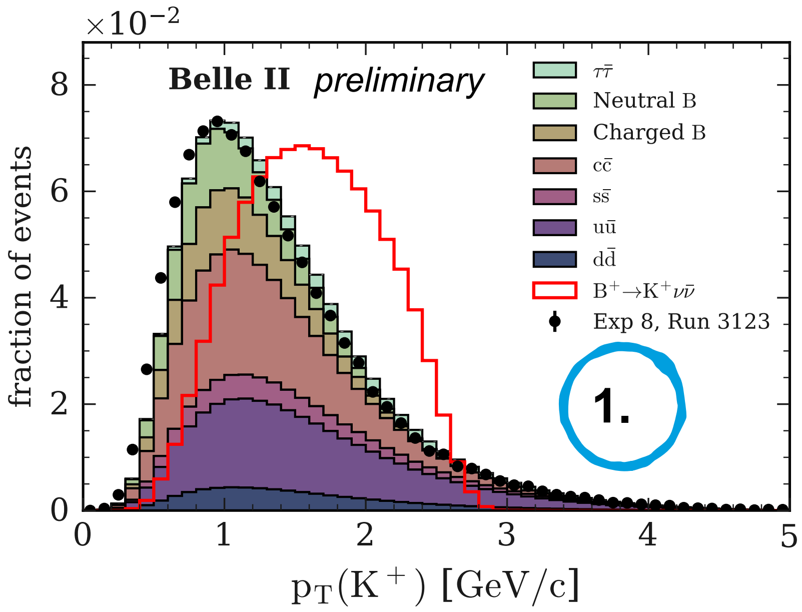
Novel Search for $B^+ \to K^+\nu\bar{\nu}$

Moriond 2021:63 fb^{-1}

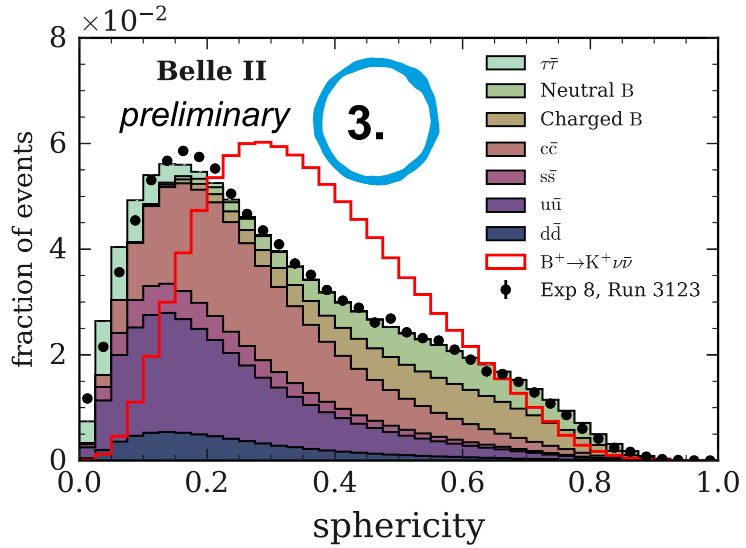
Basic Reconstruction (inclusive tag approach := LHCb-like):

1. Reconstruct signal = the highest p_T track with at least 1 PXD hit (~80% ϵ_{sig})
2. All other tracks and clusters reconstructed as rest-of-event (ROE) object
3. Discriminating variables are identified and used later as an input to BDTs:
   - Event-shape, ROE dynamics, Kinematics of signal B, Vertexing variables





In comparison with tagged approaches this inclusive tag approach leads to **higher signal efficiency but also larger background contributions** from *B*-decays (Neutral/Charged *B*) and continuum production ($e^+e^- \to$ *cc*, *ss*, *uu*, *dd*, τ pair)



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

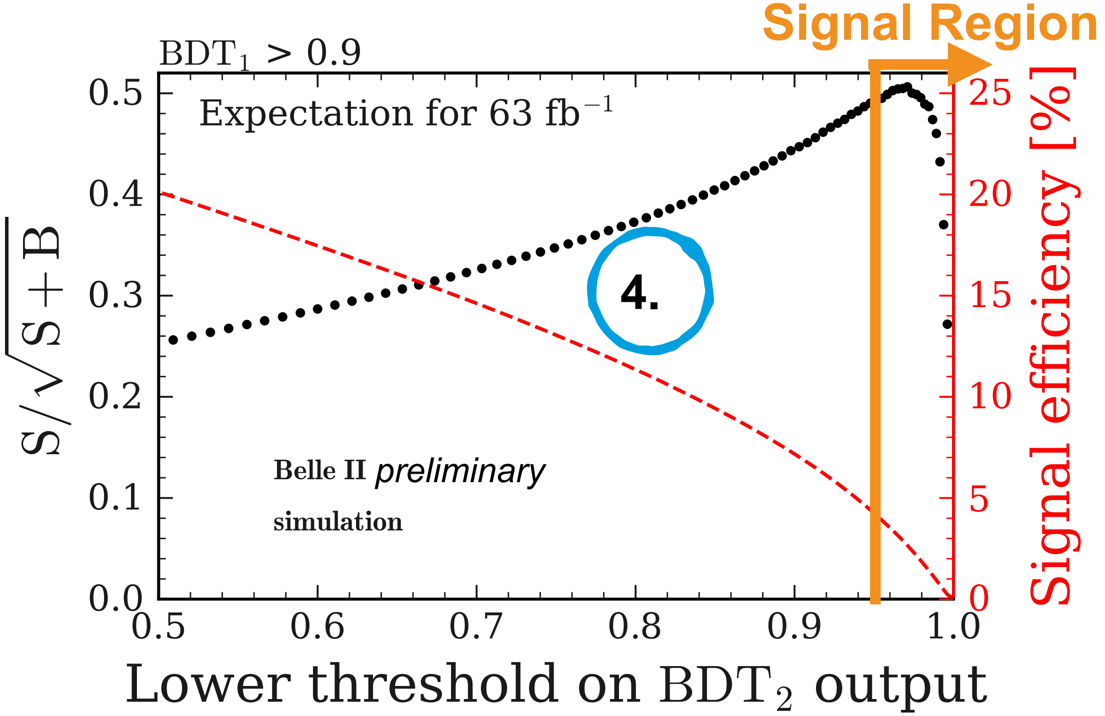
Moriond 2021:63 fb^{-1}

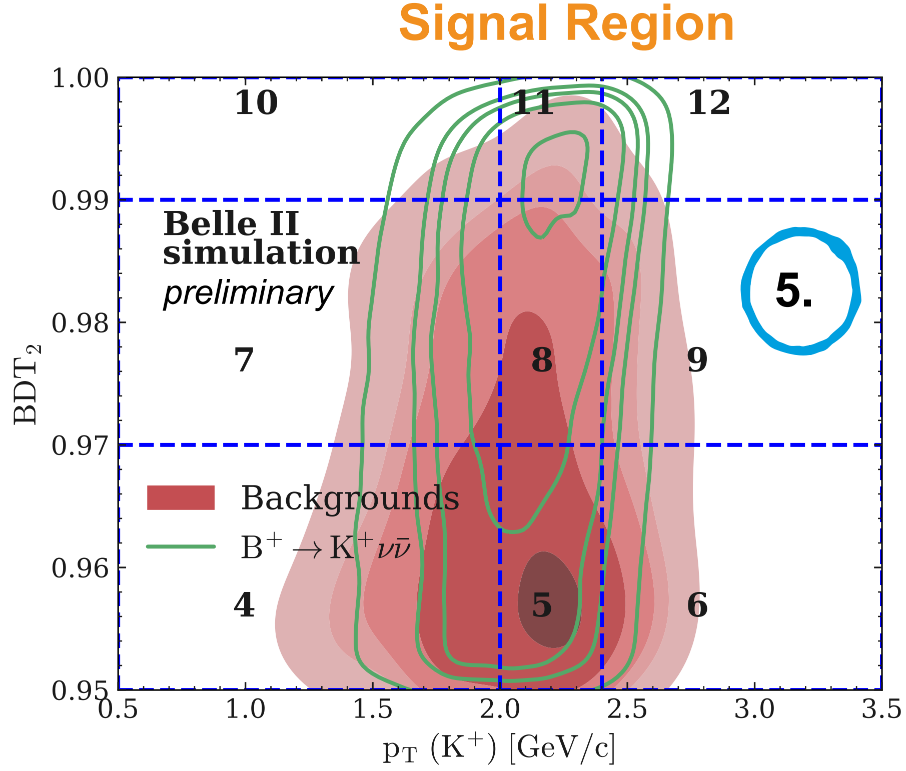
MVA Selection and Measurement Region Definition:

4. Two consecutive BDTs are trained and applied to suppress the backgrounds

   (signal: $B^+ \to K^+\nu\bar{\nu}$, background: generic B decays + continuum)

5. Identify **signal region (SR)** with BDT_2 output and bin further in 2D: BDT_2 x $p_T(K^+)$ to maximise sensitivity





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

Moriond 2021:63 fb^{-1}

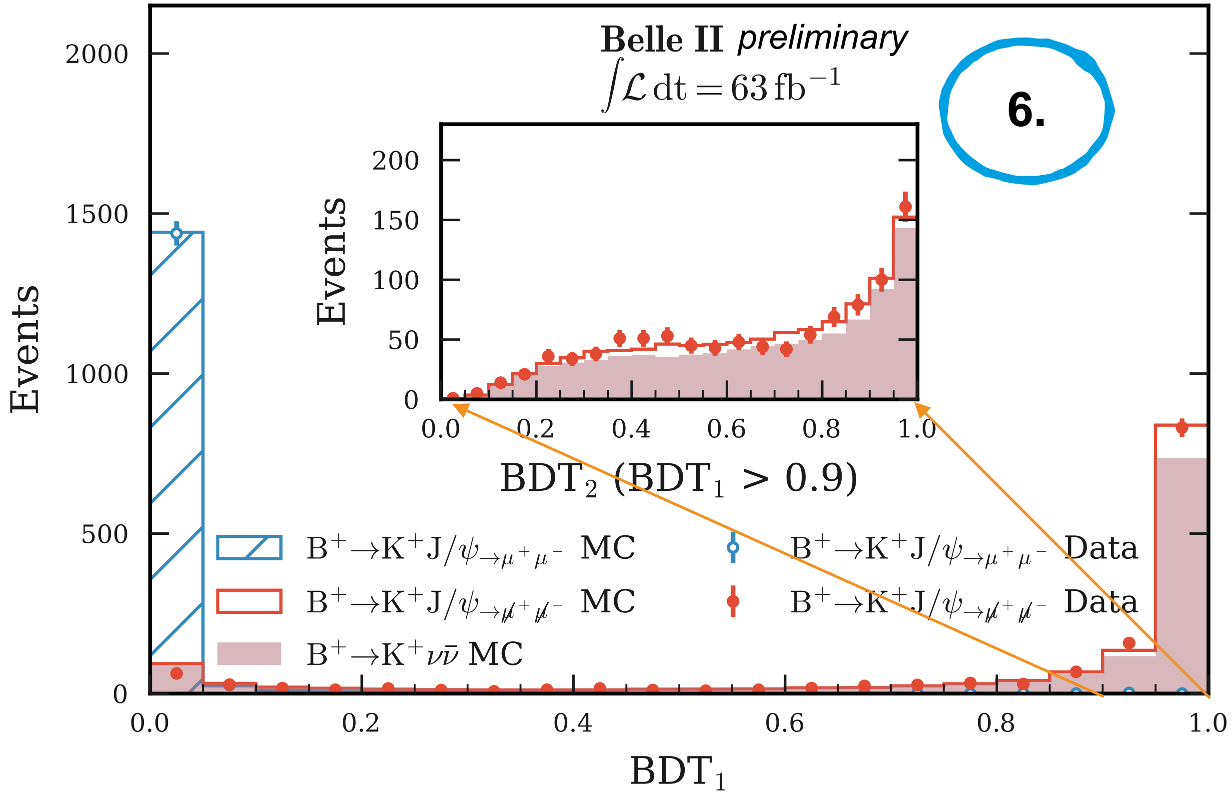
Validation with control channels:

6. Check BDTs output with both $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$ (background-like), $B^+ \to J/\psi(\to \not\mu^+ \not\mu^-)K^+$ (signal-like*) reconstruction:

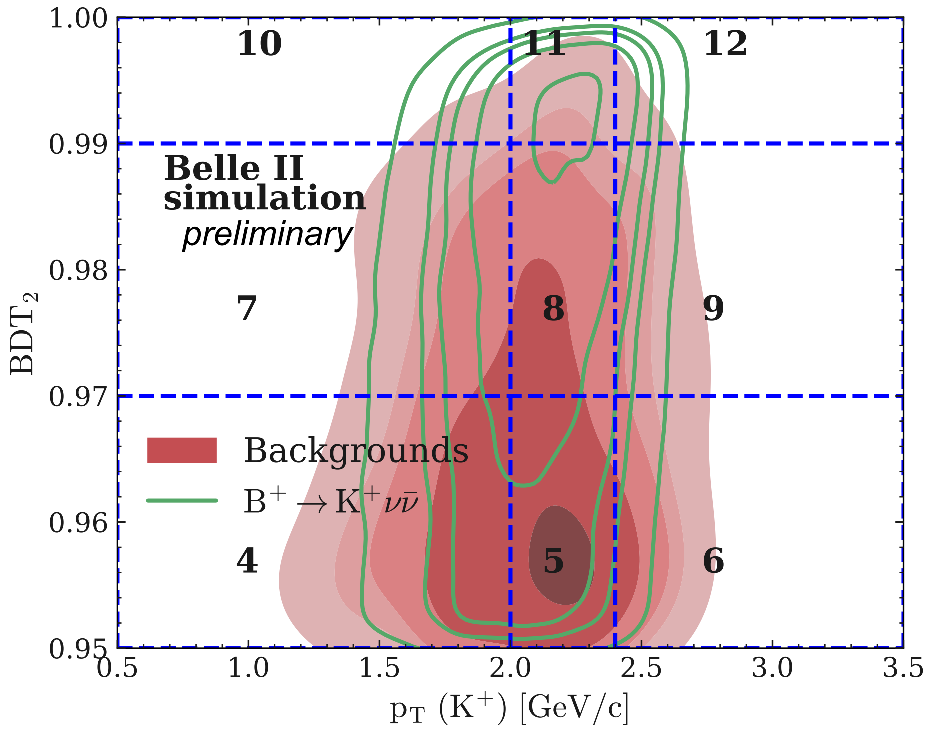
*signal-like: 1. Ignore dimuon from J/ψ to mimic missing energy

2. Replace four-momenta of K+ by that of the signal to mimic 3-body kinematics

7. Check Data/MC agreement in off-resonance data



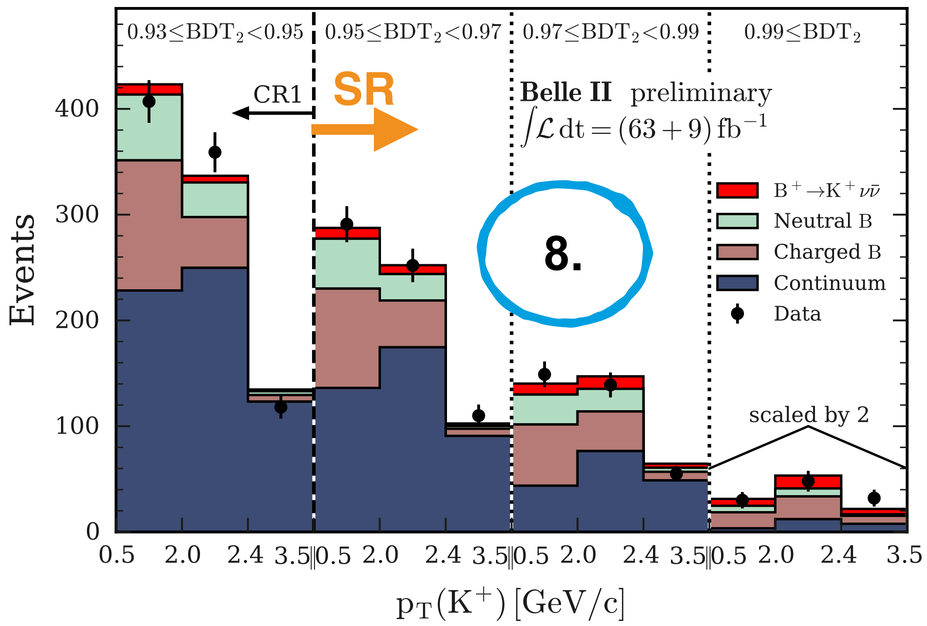
Signal Region



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

Moriond 2021:63 fb^{-1}

on-resonance fit



Signal Extraction:

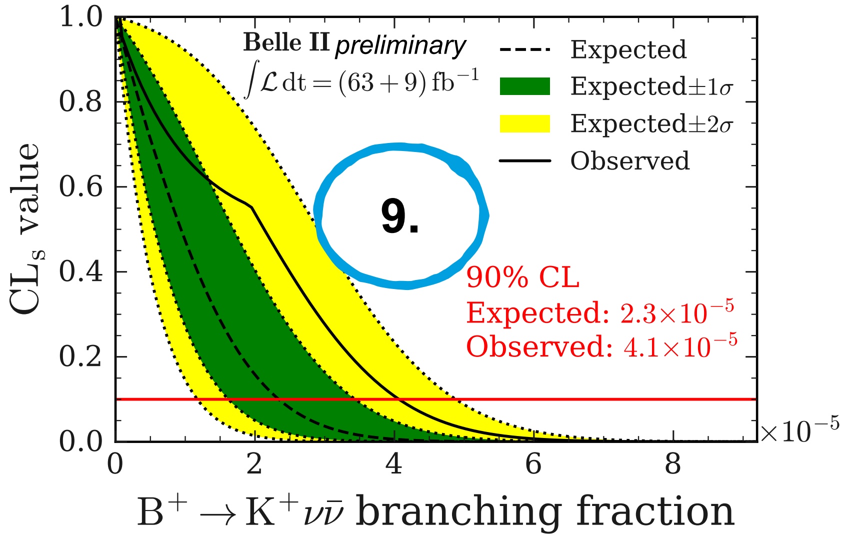
8. Binned simultaneous ML fit to on-resonance + off-resonance data is performed:

- pdf includes 175 nuisance parameters + 1 parameter of interest: signal strength μ (1 μ= SM BF = 4.6×10^{-6})
- nuisance parameters = systematic uncertainties

Measured signal strength $\mu = 4.2^{+2.9}_{-2.8}(\text{stat})^{+1.8}_{-1.6}(\text{syst})$

$$\mathscr{B}(B^+ \to K^+\nu\bar{\nu}) = 1.9^{+1.6}_{-1.5} \times 10^{-5}$$

9. No significant signal is observed so limit on BF is set with CL_s method: 4.1×10^{-5} @90 % CL



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

Moriond 2021:63 fb^{-1}

Summary:

- Set a competitive limit with only 63 fb^{-1}
- Central value of BF show enhancement wrt SM consistent with other results
- Comparison with other experiments shows at least matching performance (*see backup for more details*)

Prospects:

- This novel method can be used in other channels (pi, rho, Ks)
- Improving signal-background separation with other MVA methods seems promising
- Leading systematics: background normalisation uncertainty can be also reduced with increasing statistics (*see backup for more details*)
- Combined analysis using both tagged and inclusive tag approaches could lead to faster observation → under consideration

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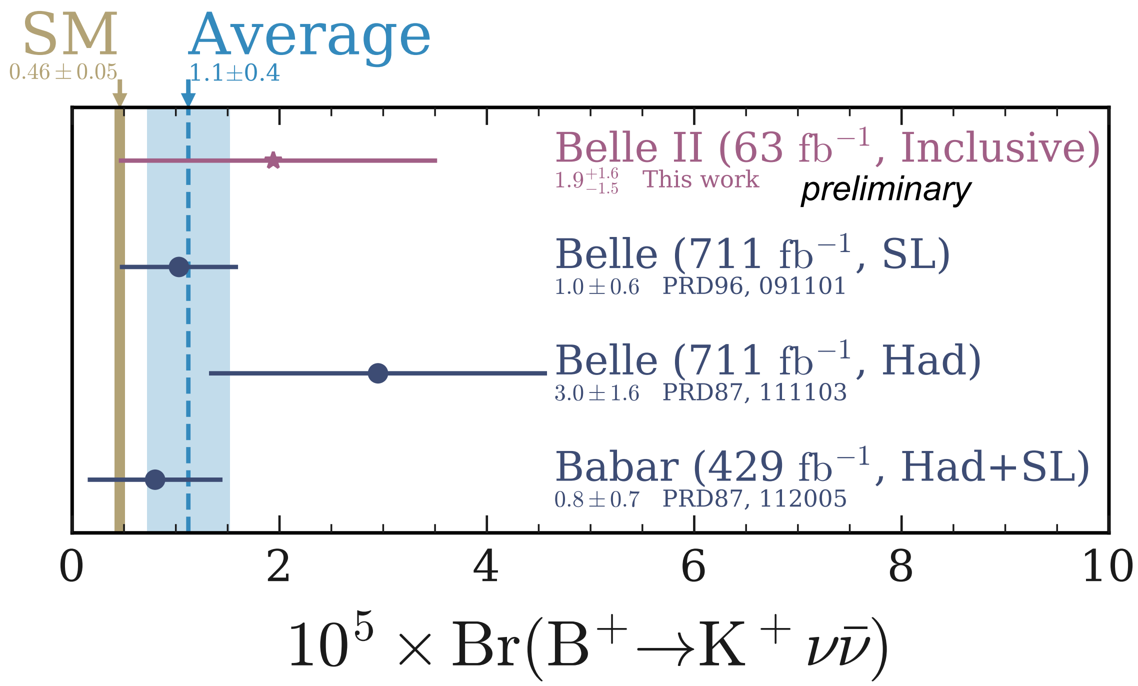
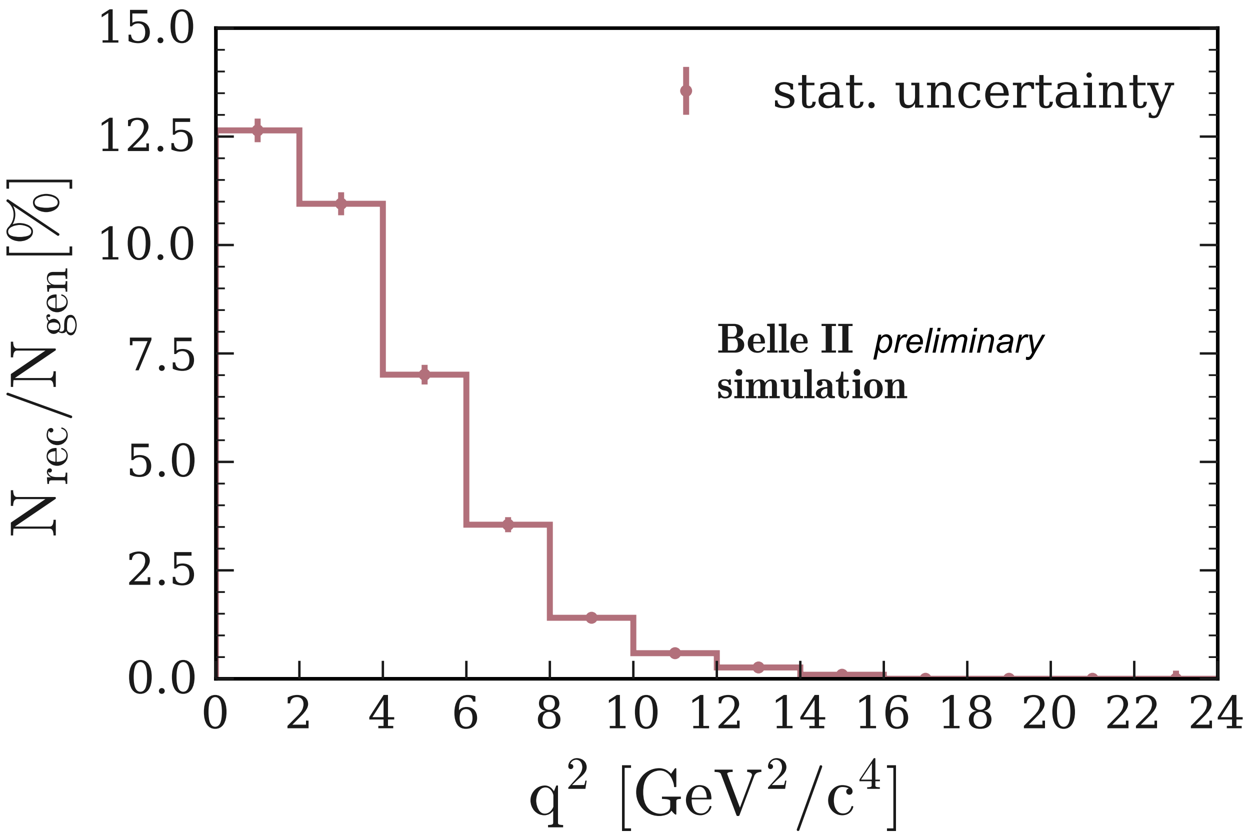
Belle	**2017**	$< 1.9 \times 10^{-5}$ [Phys.Rev.D96,091101(R)]	SL tag	711
Belle II *preliminary*	**2021**	$< 4.1 \times 10^{-5}$	Inclusive tag	63



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

Moriond 2021:63 fb^{-1}

- We are also publishing the selection efficiency as a q^2 ($\nu\bar{\nu}$) spectrum: total integrated selection efficiency is 4.3%
- We plan to upload the json file of the pdf as adapted for pyhf to HEPdata
- **Can you think of other useful quantity/ object that we could provide?**



Search For $B^+ \to K^+\tau l$: Belle II Prospects

LFU violation could be accompanied by LFV

Many recent NP models predict prominent effect in BF in transitions with 3rd lepton generation

New idea to measure $\mathcal{B}(B^+ \to K^+\tau l)$ **:**

- Exploit semi-inclusive tagging because of high BF of

$$B^- \to \overline{D}^0 X = 79 \pm 4\,\%$$

1. Reconstruct B_{tag} D^0
2. Reconstruct signal's K and l, and τ
3. D^0X provides the tag-side

Higher signal efficiency but also higher backgrounds → need to reach ~ 1x10^{-5}

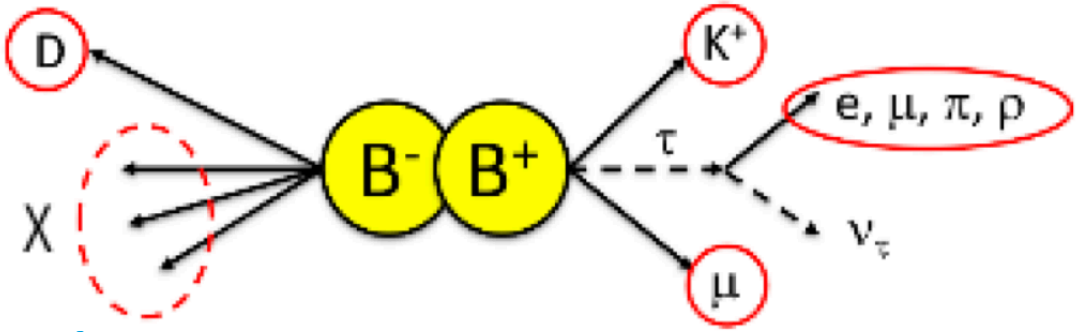
- Fit m_τ: $m_\tau^2 = m_B^2 + m_{Kl}^2 - 2(E_B^* E_{Kl}^* - |\vec{p}^*_{B_{sig}}||\vec{p}^*_{Kl}|\cos\theta)$

  $E_B^* = E^*_{beam}$, $|\vec{p}^*_{B_{sig}}| = \sqrt{(E^*_{beam})^2 - m_B^2}$

  θ angle between $\vec{p}^*_{B_{sig}}$ $(= -\vec{p}^*_{B_{tag}})$ and $\vec{p}^*_K$

- In Belle II this search is also under-way with hadronic tag

Schematic by G. de Marino



LHCb: [JHEP 06 (2020) 129]

$$\mathcal{B}(B^+ \to K^+\tau\mu) < 3.9 \times 10^{-5}$$

BaBar: [Phys.Rev.D 86 (2012) 012004]

Mode	$\mathcal{B}(B \to h\tau\ell)(\times 10^{-5})$ Central value	90% C.L. UL
$B^+ \to K^+\tau\mu$	$0.0^{+2.7}_{-1.4}$	<4.8
$B^+ \to K^+\tau e$	$-0.6^{+1.7}_{-1.4}$	<3.0
$B^+ \to \pi^+\tau\mu$	$0.5^{+3.8}_{-3.2}$	<7.2
$B^+ \to \pi^+\tau e$	$2.3^{+2.8}_{-1.7}$	<7.5

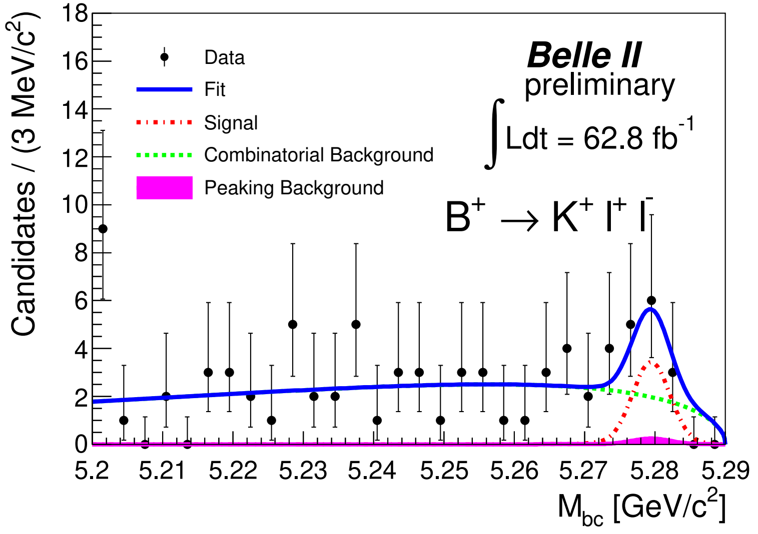
Fully reconstructed channels

Towards R(K) in Belle II

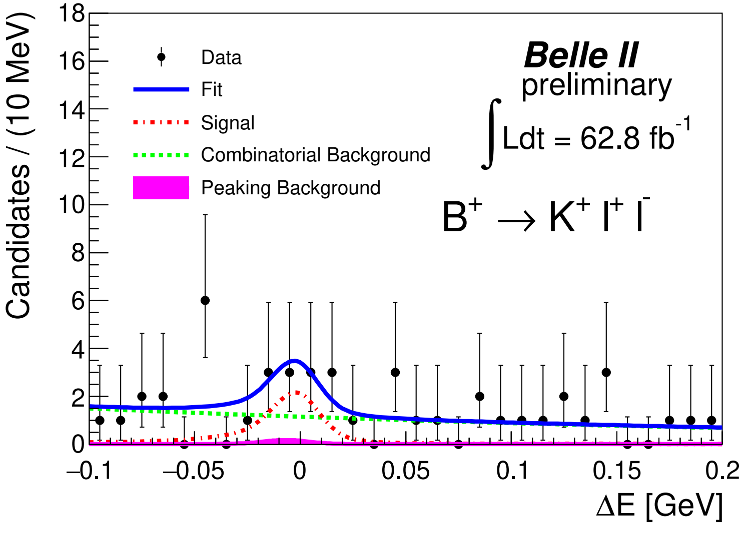
Moriond 2021:63 fb^{-1}

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



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



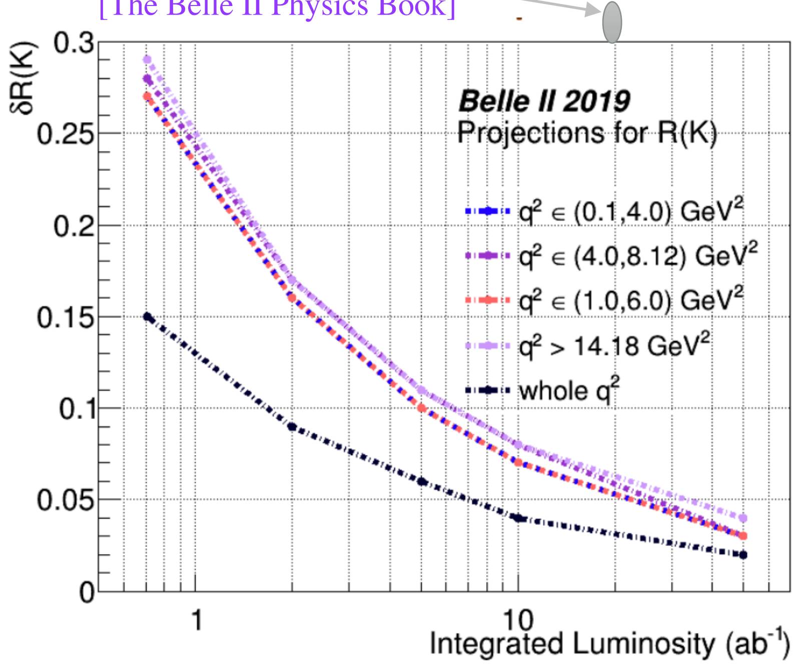
$$\Delta E = E_B - E_{beam}$$

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

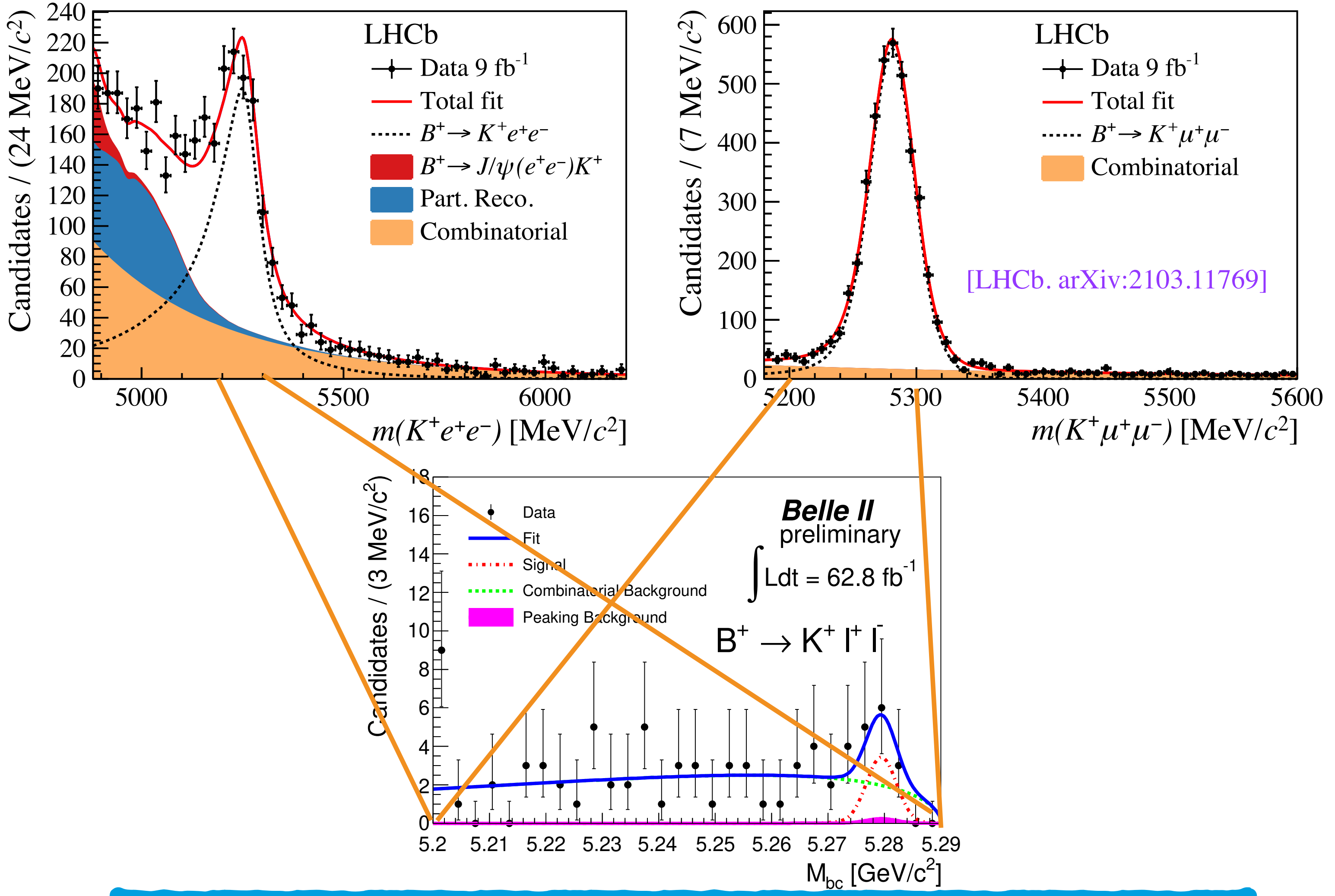
[The Belle II Physics Book]



R(K) Belle II vs LHCb

Moriond 2021:63 fb^{-1}

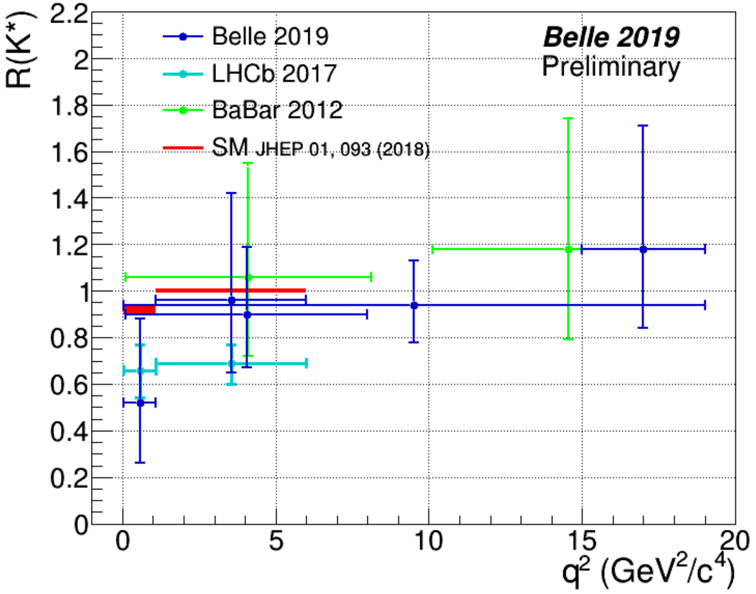
In comparison to LHCb, 3 differing aspects to consider: efficiency, statistics and resolution



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

	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

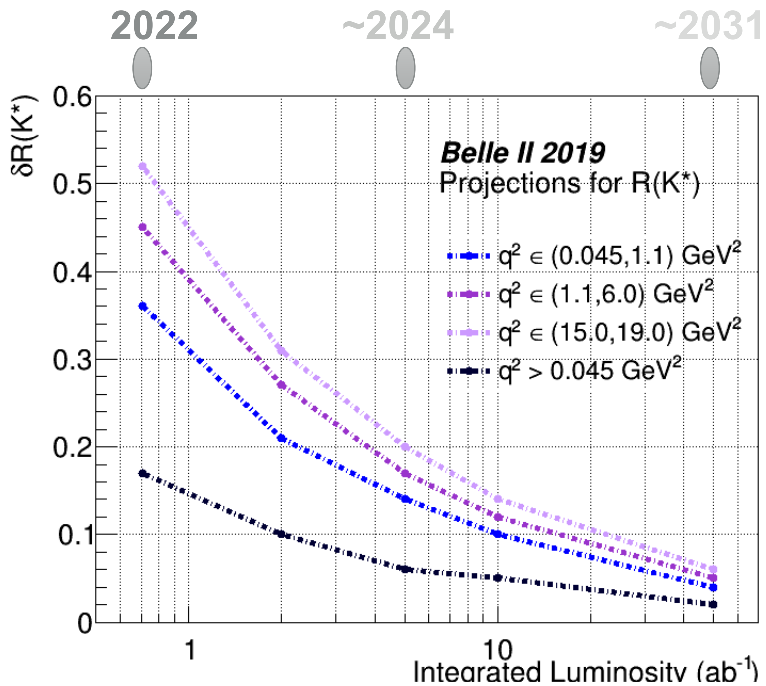
Belle II Prospects (R(K*), angular)

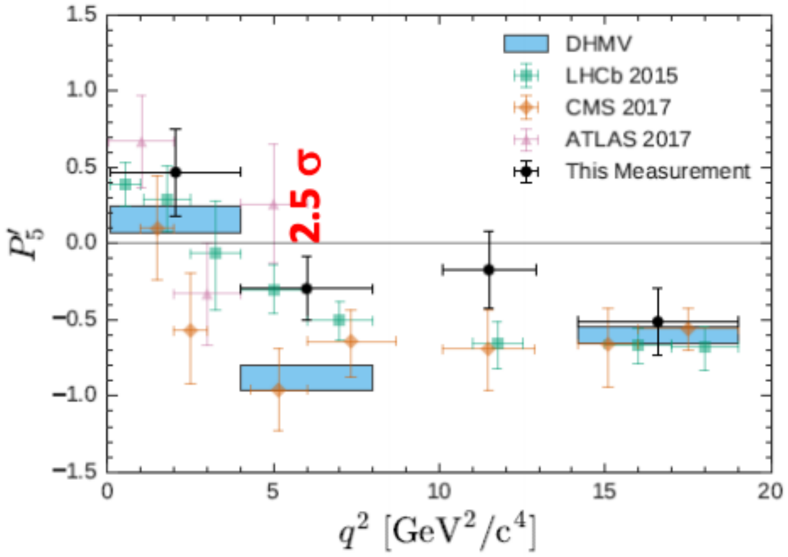


[Belle arXiv: 1904.02440]

Belle (R(K*))

- Largest deviation in the low q² bin

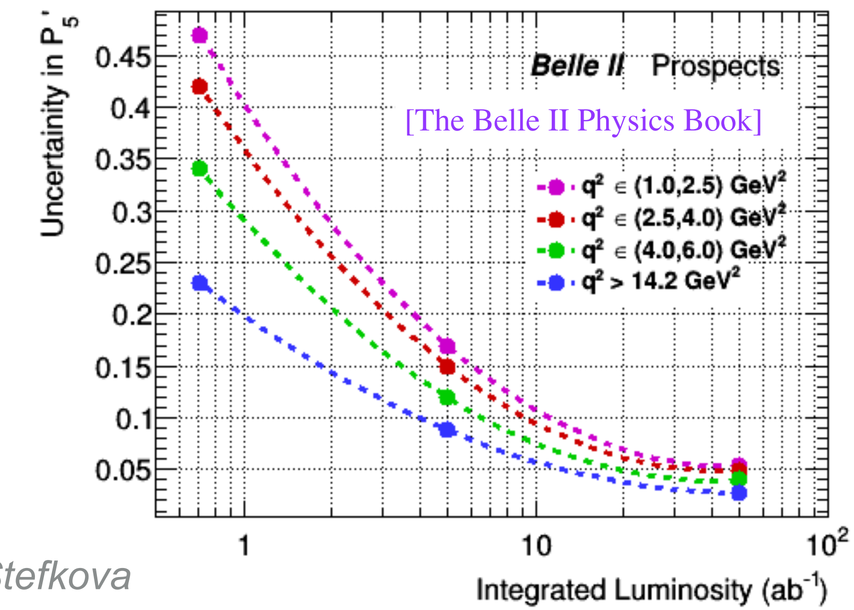




[Belle Phys. Rev. Lett. 118, 111801]

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)

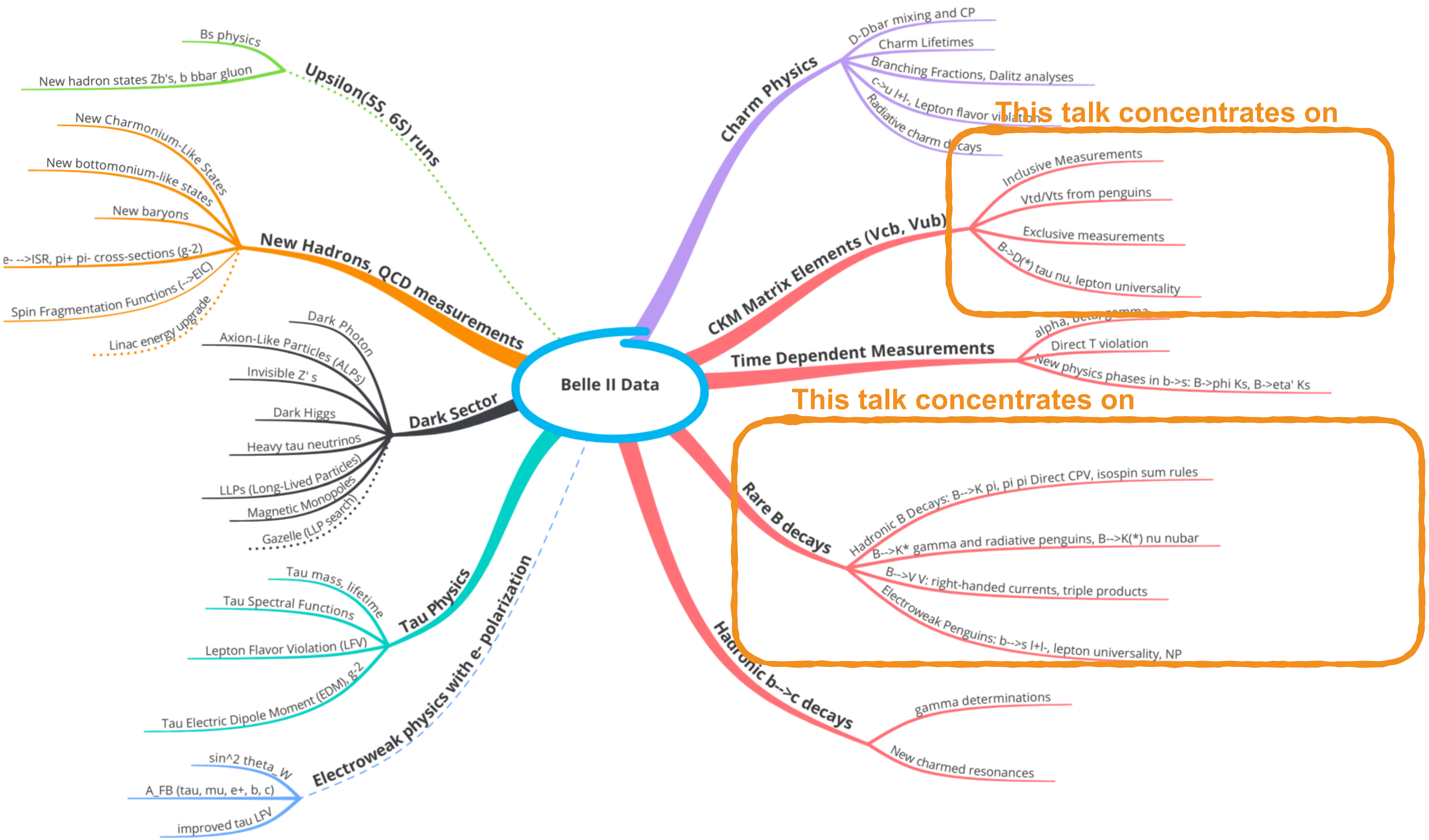


Summary

- Belle II is stably accumulating data
- Only (biased) subset of Belle II measurements and/or their prospects were shown
- New reconstruction approaches are being implemented in channels with missing energy, resulting already in competitive limit for $\mathbf{B}^+ \to \mathbf{K}^+\nu\bar{\nu}$
- With more data we hope to not only reduce statistical errors of the measurements but also find ways to improve on the systematics

Thank you

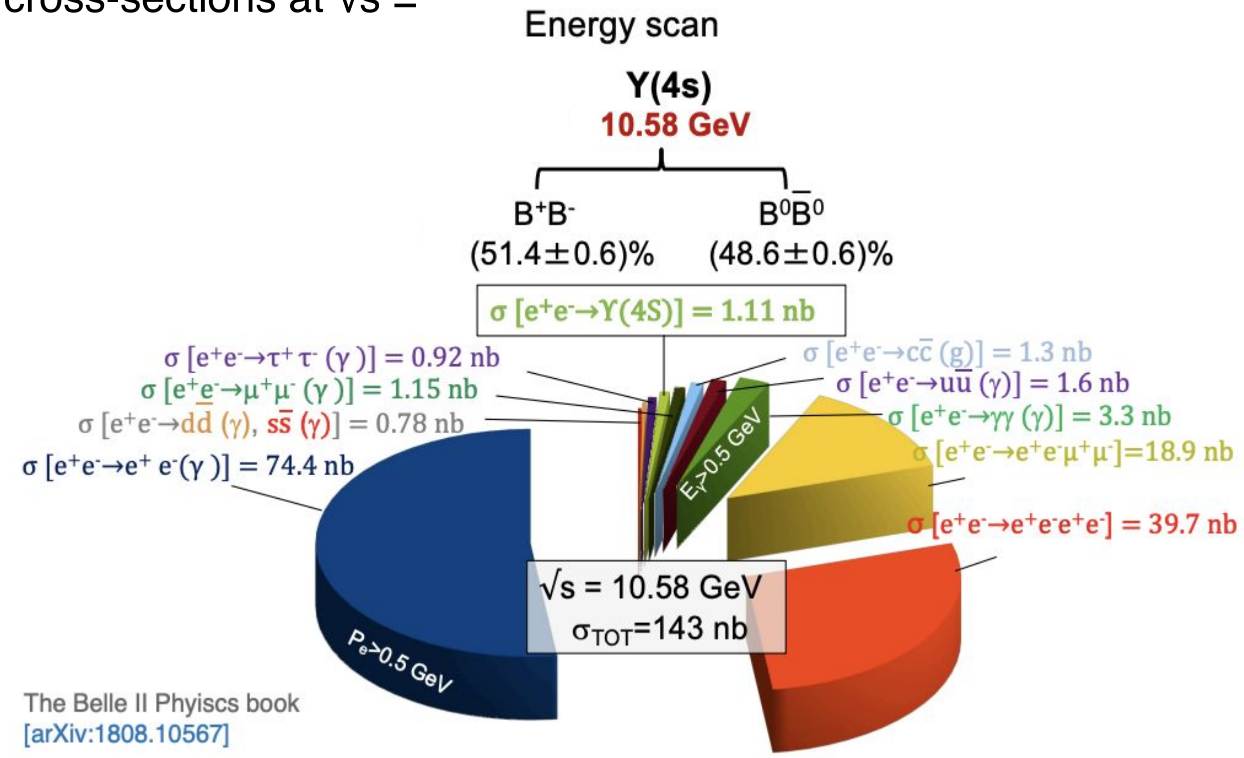
Belle II Physics Program



Upsilon(4S)

SuperKEKB is not only B-factory:

- τ and c pairs have similar cross-sections at $\sqrt{s}$ = 10.58 GeV

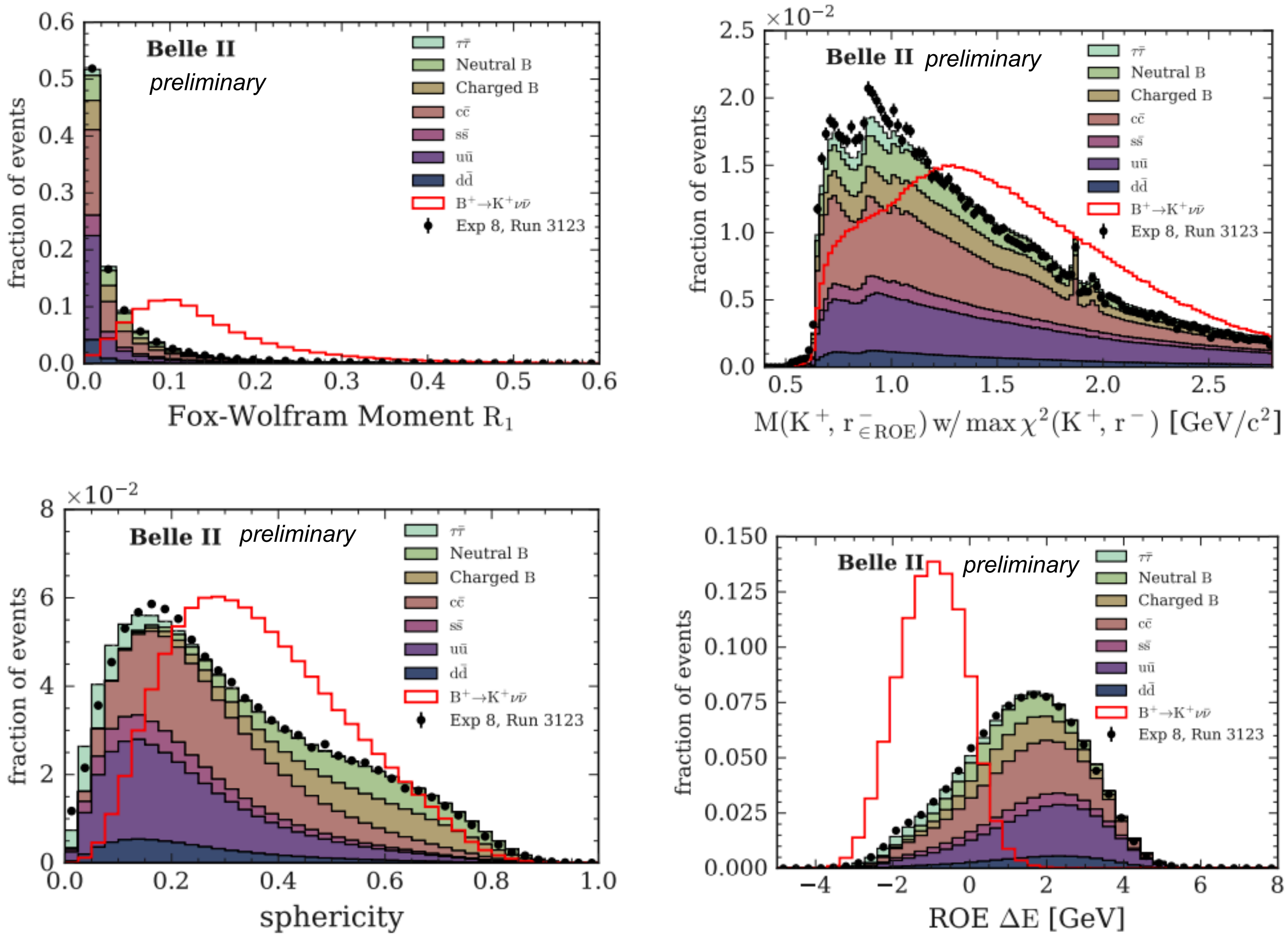


The Belle II Phyiscs book
[arXiv:1808.10567]

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

Moriond 2021:63 fb^{-1}

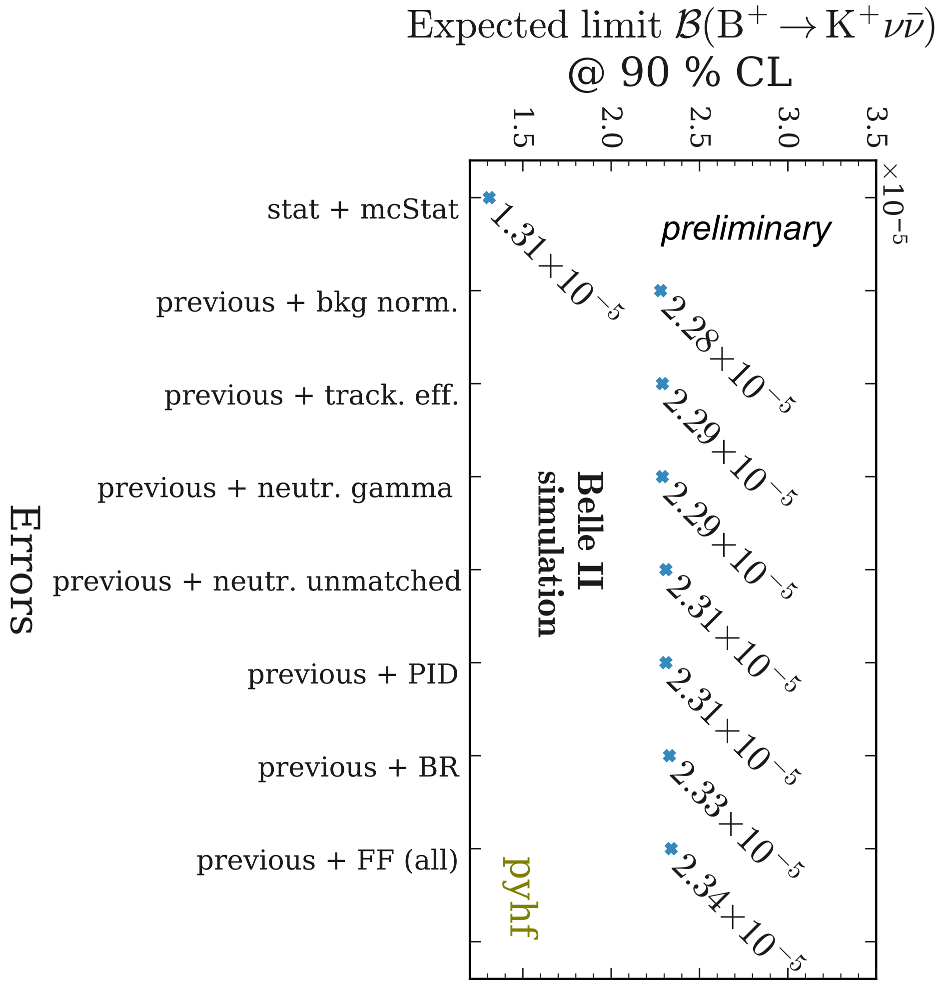
Discriminating variables used in BDT



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

Moriond 2021:63 fb^{-1}

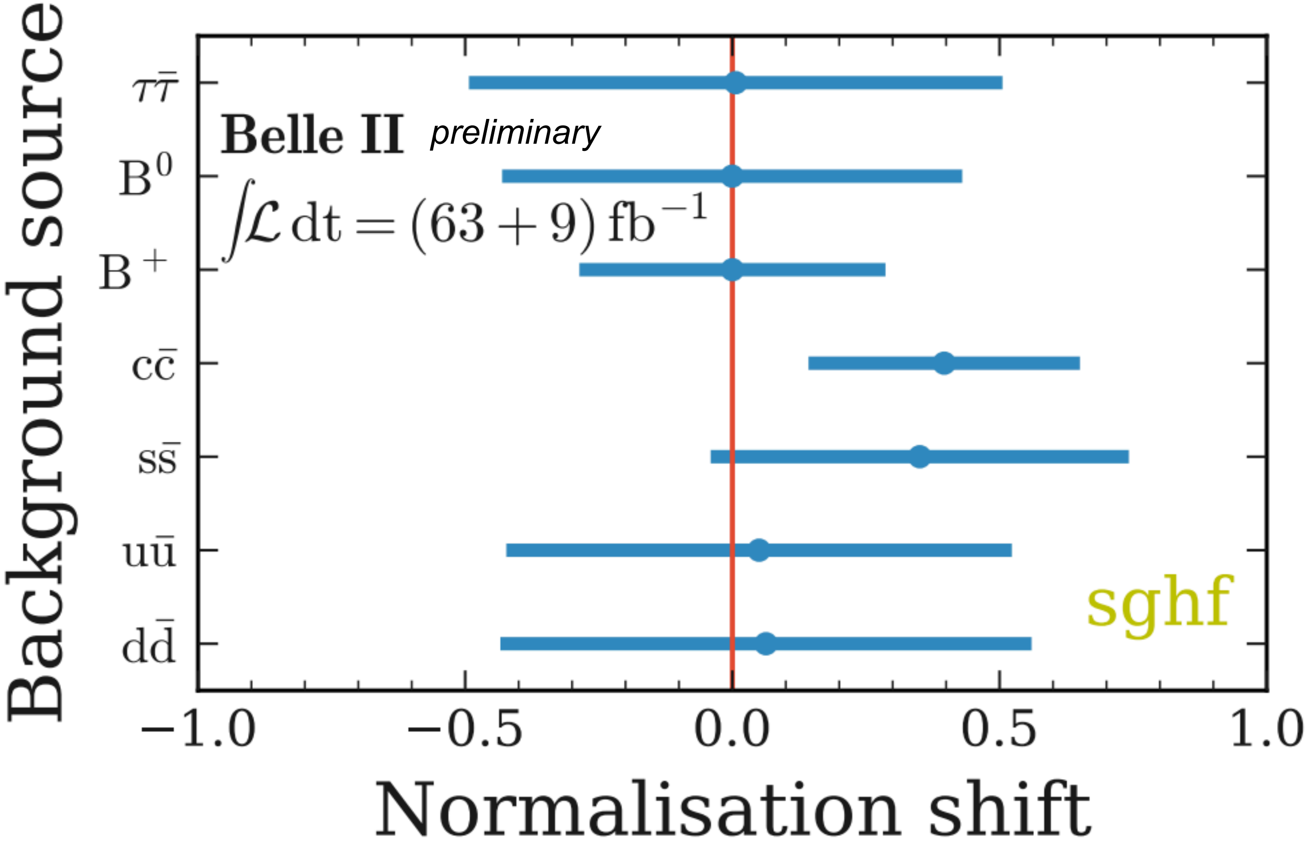
Impact of systematics on the limit



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

Moriond 2021:63 fb^{-1}

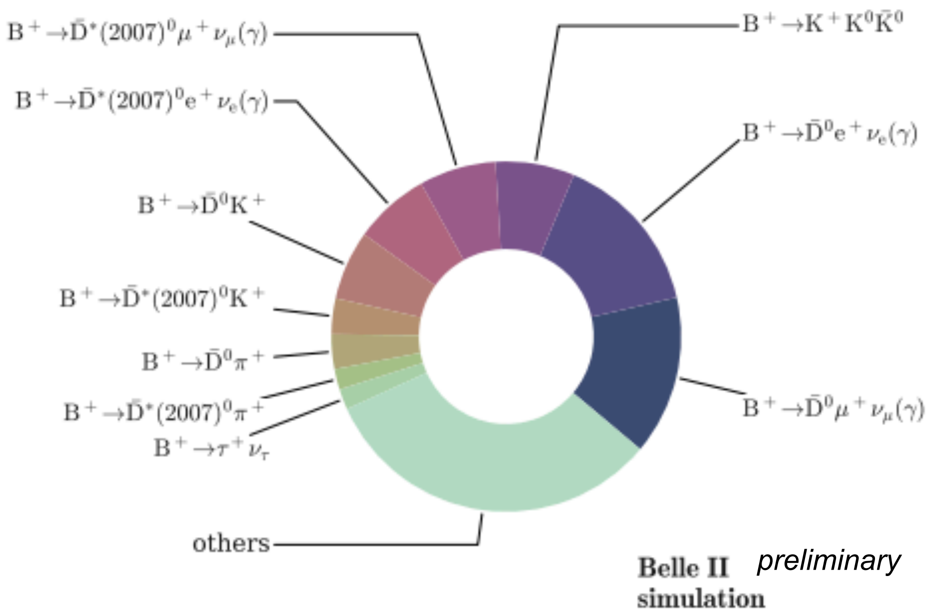
Background shifts

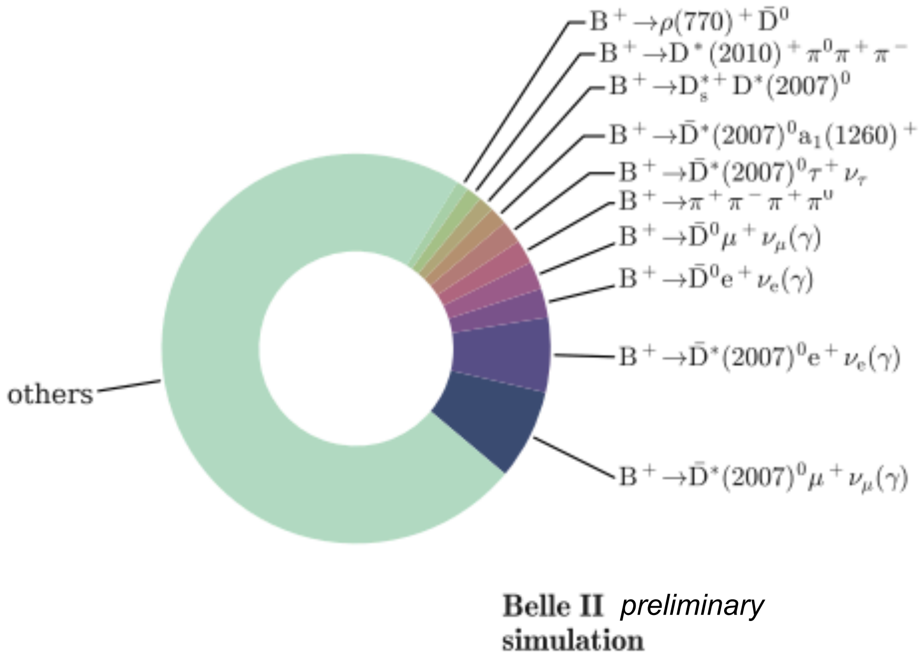


Novel Search for $B^+ \to K^+\nu\bar{\nu}$

Moriond 2021:63 fb^{-1}

Background composition of B-decays in measurement region: BDT_1>0.9 & BDT_2>0.93



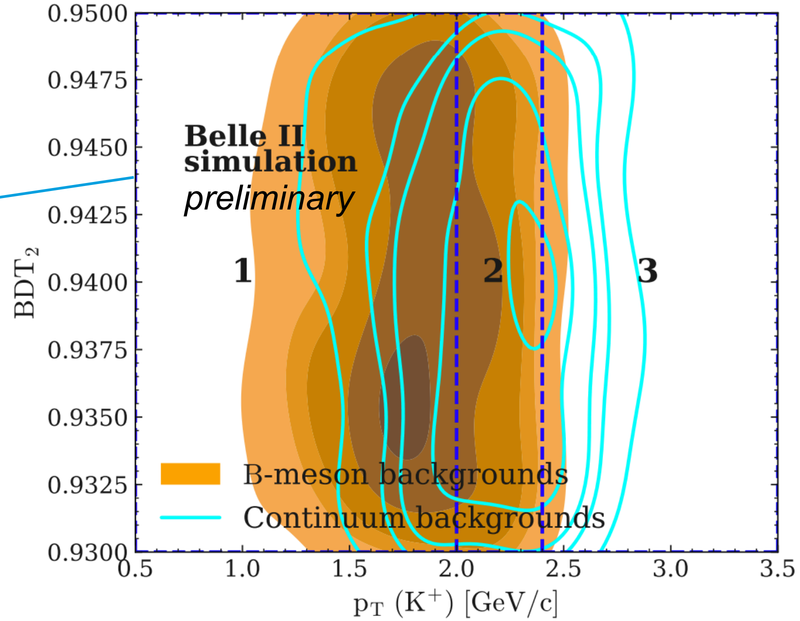


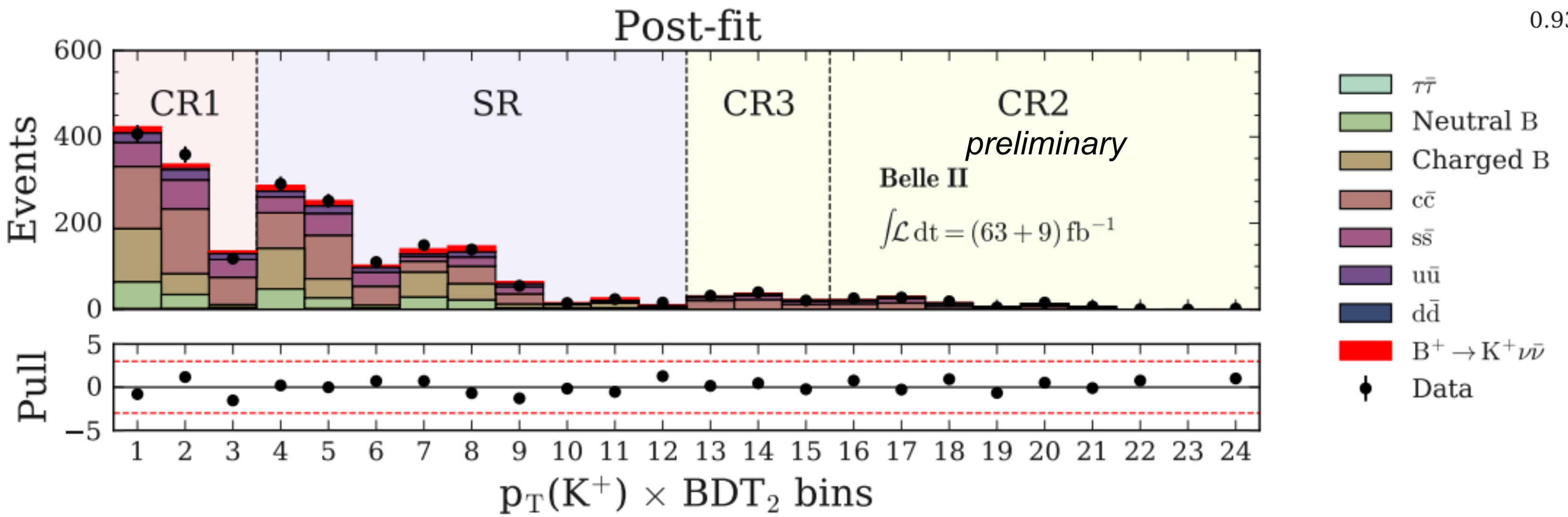
Novel Search for $B^+ \to K^+\nu\bar{\nu}$

Moriond 2021:63 fb[-1]

Measurement Setup

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 $BDT_2 \in [0.95, 0.97, 0.99, 1.0]$	signal + all backgrounds	$\Upsilon(4S)$
Control Region 1 (CR1)	$p_T(K^+) \in [0.5, 2.0, 2.4, 3.5]$ GeV/c $BDT_2 \in [0.93, 0.95]$	signal + all backgrounds	$\Upsilon(4S)$
Control Region 2 (CR2)	$p_T(K^+) \in [0.5, 2.0, 2.4, 3.5]$ GeV/c $BDT_2 \in [0.95, 0.97, 0.99, 1.0]$	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 $BDT_2 \in [0.93, 0.95]$	continuum backgrounds	off-resonance (-60 MeV/c^2)





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

Moriond 2021:63 fb^{-1}

Comparison with other experiments

Experiment	Year	Approach	$L[fb^{-1}]$	$BR[\times 10^{-5}]$	$\sigma[\times 10^{-5}]$	$\sigma\sqrt{\frac{L}{L_{Belle2}}}[\times 10^{-5}]$
BABAR(*)	**2013**	**SL + Had tag**	429	0.8	0.6	1.7
Belle(**)	**2013**	**Had tag**	711	3.0	1.6	5.5
Belle(**)	**2017**	**SL tag**	711	1.0	0.6	1.9
Belle II *preliminary*	**2021**	**Inclusive tag**	63	1.9	1.6	1.6

(*) Combined central value of $B^+ \to K^+ \nu \bar{\nu}$ / $B^0 \to K^0 \nu \bar{\nu}$

(**) Computed from $N_{sig}/(\epsilon_{sig} \cdot N_{B\bar{B}})$.

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

Moriond 2021:63 fb^{-1}

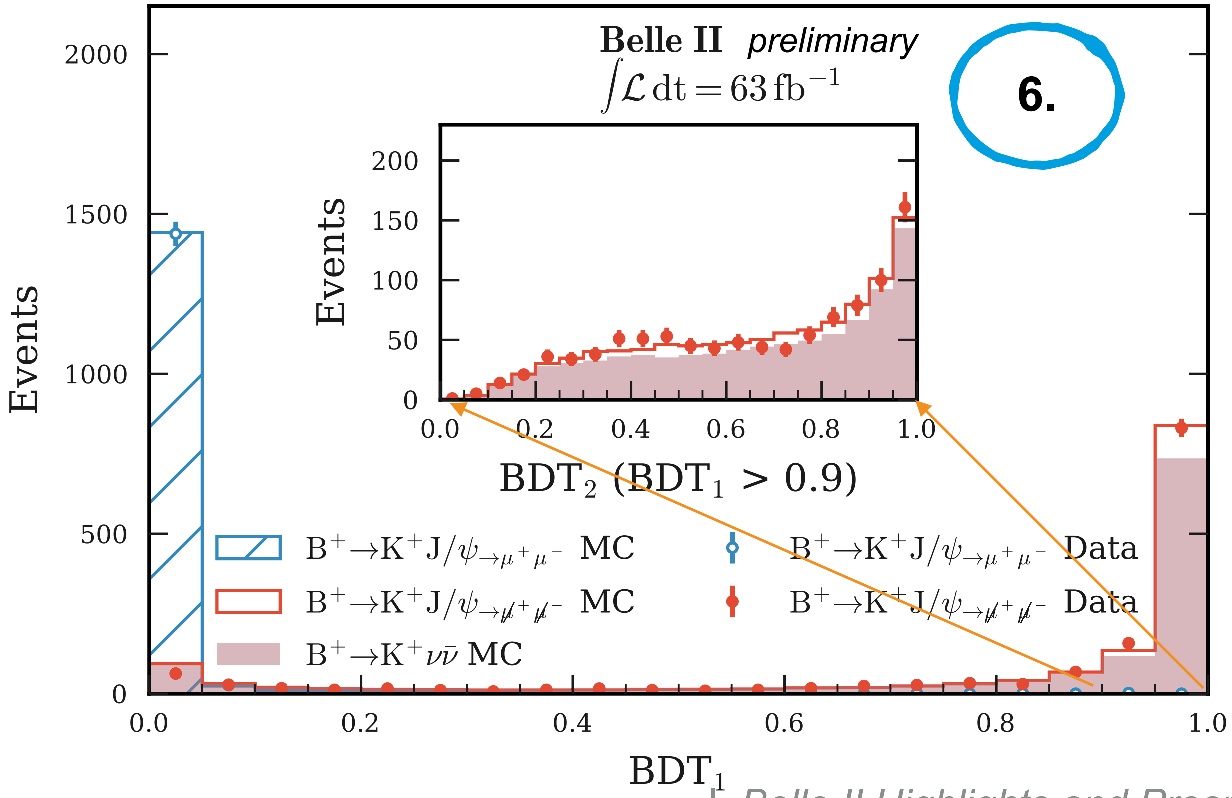
Validation with control channels:

6. Check BDTs output with both $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$ (background-like), $B^+ \to J/\psi(\to \not{\mu}^+\not{\mu}^-)K^+$ (signal-like*) reconstruction:

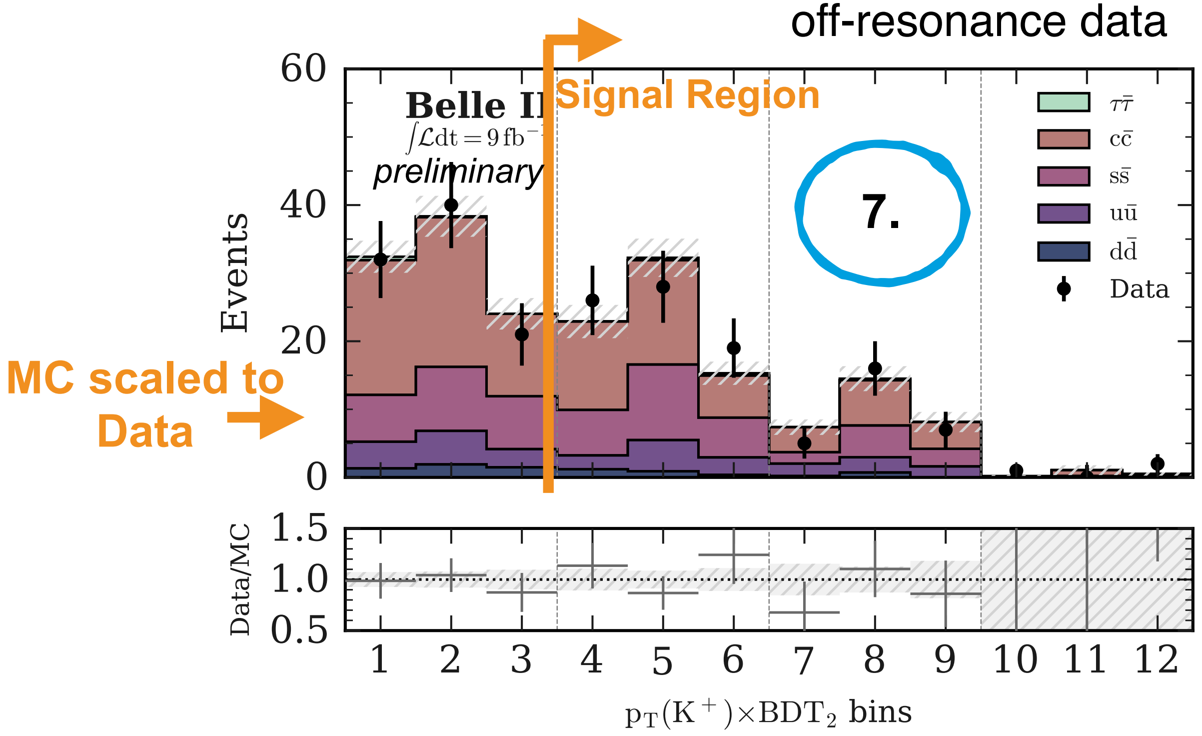
*signal-like: 1. Ignore dimuon from J/ψ to mimic missing energy

2. Replace four-momenta of K+ by that of the signal to mimic 3-body kinematics

7. Check Data/MC agreement in off-resonance data



off-resonance data



Normalisation : K(Data/MC) =1.40+-0.12
Shape: very good agreement

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

Moriond 2021:63 fb^{-1}

2 BDTs:

4. Choose 51 most discriminating variables for BDT_1 training (signal: B->Knunu, background: generic B decays + continuum)

5. Apply BDT_1 on signal and background and select events with $BDT_1 > 0.9$

6. Train BDT_2 with the same set of 51 most discriminating variables on the same samples

   - 2-step BDT leads to significant :=[10%,50%] of the sensitivity in the high purity region

7. Identify signal region (SR) and bin 2D: BDT_2 x pT(K) further to maximise sensitivity

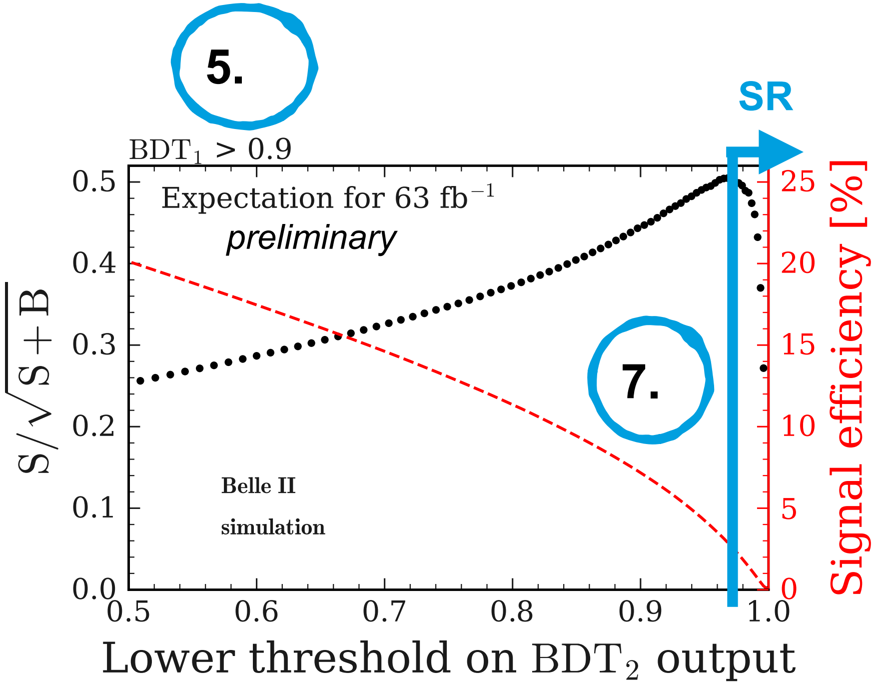
<u>Variables related to the kaon candidate</u>

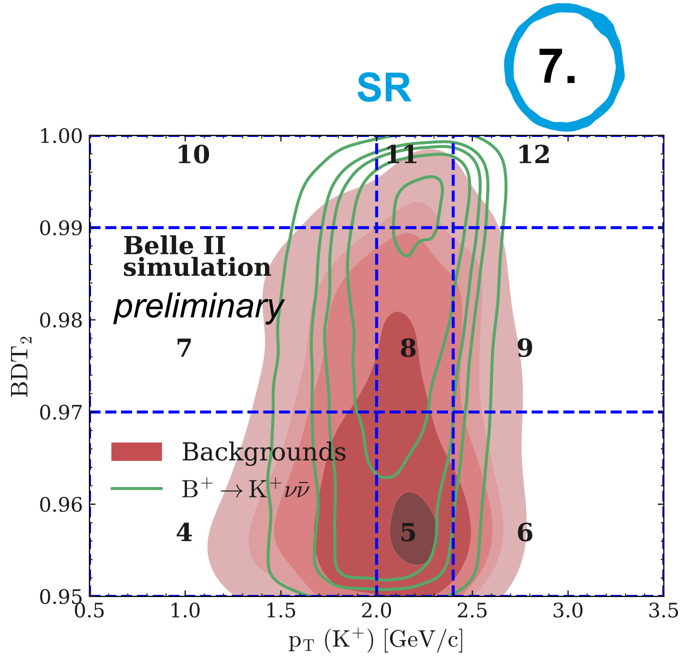
- Azimuthal angle of the kaon momentum at the POCA
- d_r and d_z of the kaon track
- Cosine of the polar angle of the kaon 3-momentum at the POCA

<u>Variables related to the ROE</u>

- Three variables corresponding to the x, y, z components of the vector from the average interaction point to the ROE vertex
- d_r and d_z of the kaon track with respect to the ROE vertex
- Invariant mass of the ROE
- χ^2 of the ROE vertex fit
- p-value of the ROE vertex fit
- Variance of the transverse momentum of the ROE tracks

4.+6.



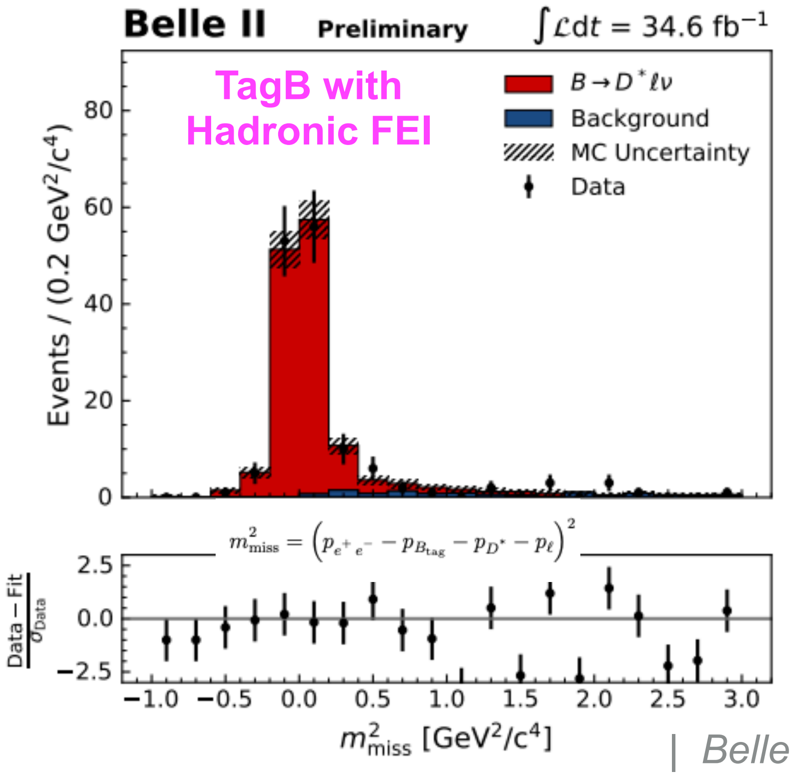


Towards R(D(*)) in Belle II

ICHEP 2020: 35 fb^{-1}

- b → clnu tree level process
- Current tension with SM: 3.1 sigma
- Belle II measured BF of B → D*lnu with hadronic FEI

$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_l) = \left(4.51 \pm 0.41_{\rm stat} \pm 0.27_{\rm syst} \pm 0.45_{\pi_s}\right)\%$$



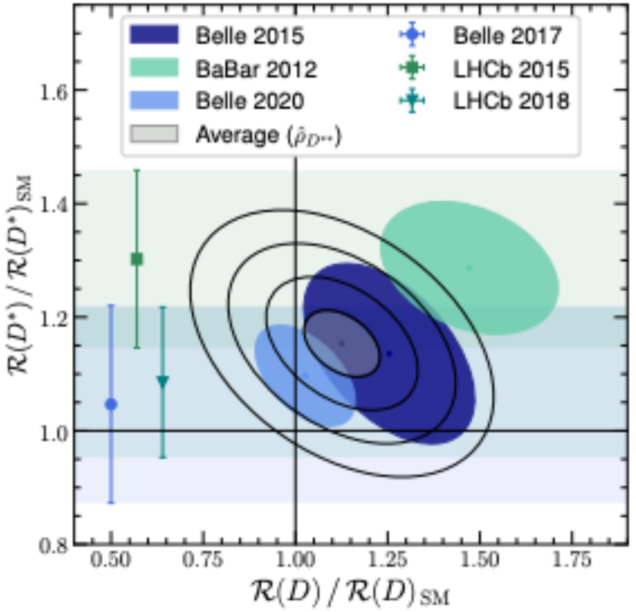
$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)} l\nu)}{\mathcal{B}(B \to D^{(*)}\tau\nu)}$$

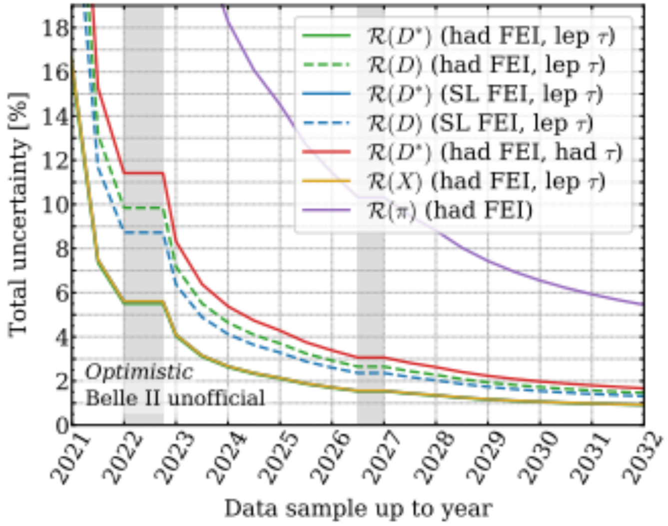
- R(D(*)) usually measured with SL or hadronic tag in Belle with simultaneous fit to O_{sig}(MVA output), E_{ECL}
- In Belle measurement, leading systematics → insufficient MC statistics for both pdf modelling and training of MVA

Prospects:

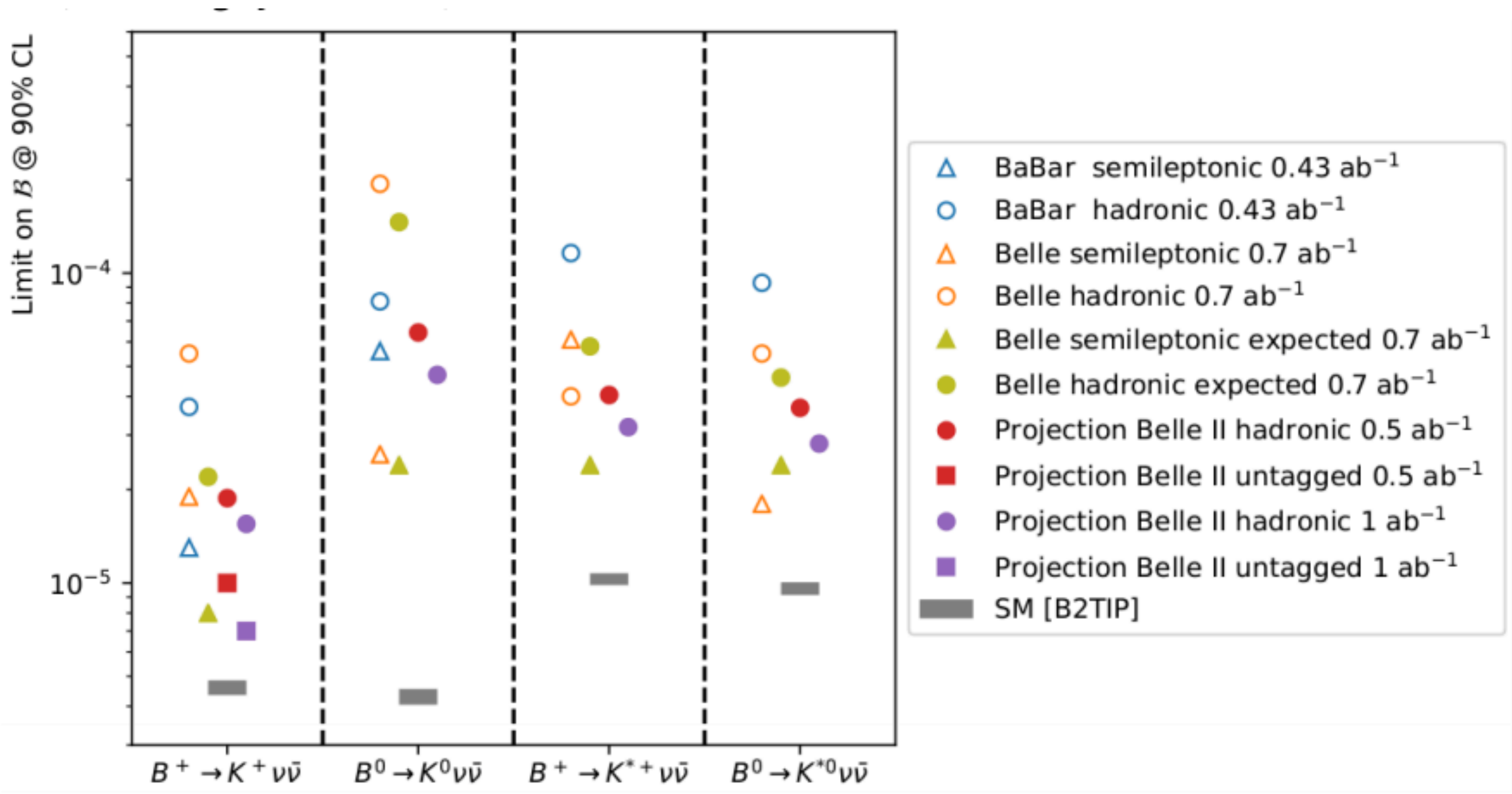
- Optimistic = 50% improvement in reconstruction efficiency in SL or Had tagged analyses
- Other orthogonal measurements could come via semi-inclusive tagging

https://arxiv.org/pdf/2101.08326.pdf

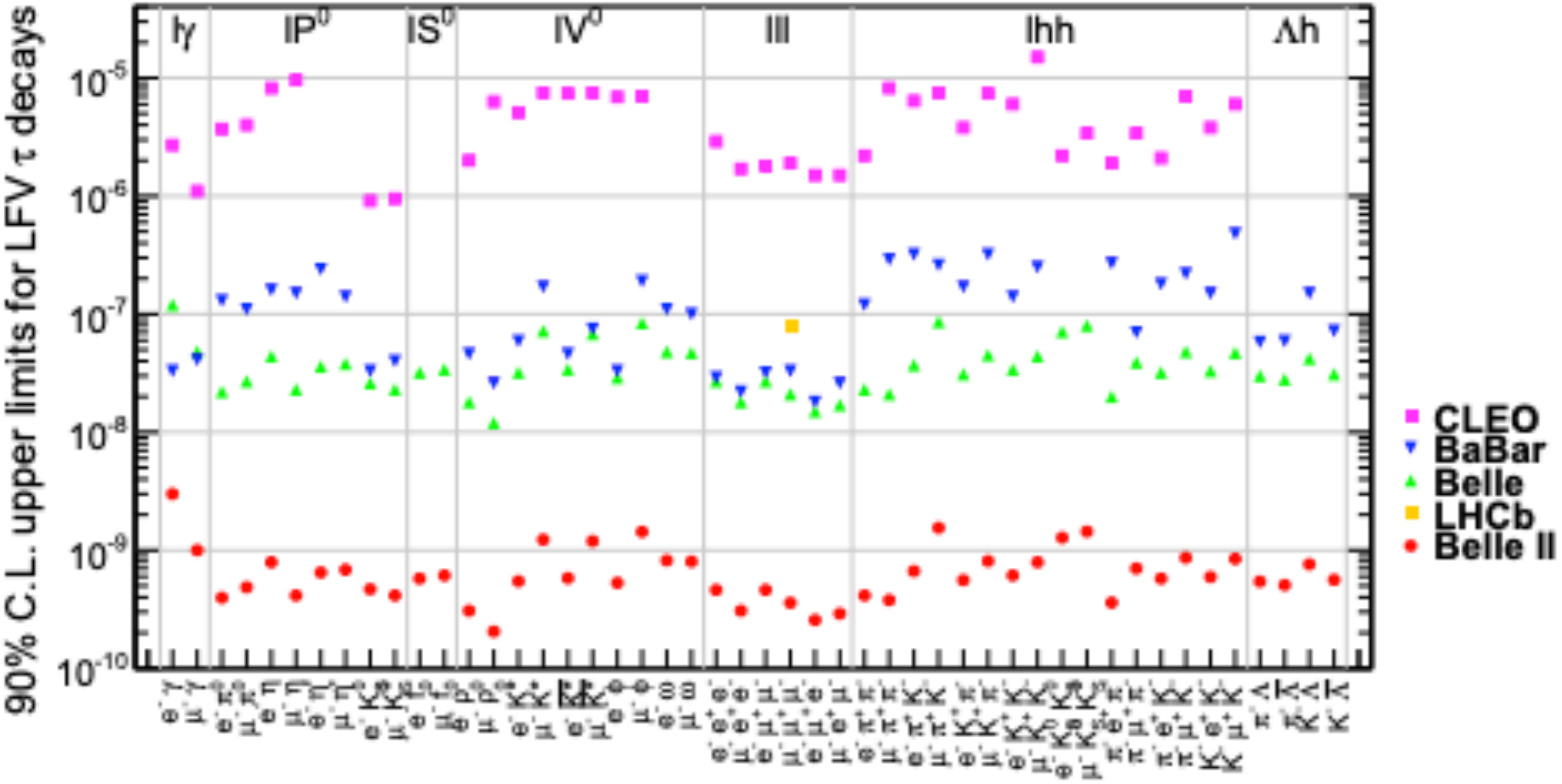




B->Knunu tagged vs untagged: naive



LFV Tau decays



B-> Ktautau + LFV B->tau+X

Observables	Belle $0.71\,\mathrm{ab}^{-1}$ $(0.12\,\mathrm{ab}^{-1})$	Belle II $5\,\mathrm{ab}^{-1}$	Belle II $50\,\mathrm{ab}^{-1}$
$\mathrm{Br}(B^+ \to K^+\tau^+\tau^-)\cdot 10^5$	< 32	< 6.5	< 2.0
$\mathrm{Br}(B^0 \to \tau^+\tau^-)\cdot 10^5$	< 140	< 30	< 9.6
$\mathrm{Br}(B_s^0 \to \tau^+\tau^-)\cdot 10^4$	< 70	< 8.1	–
$\mathrm{Br}(B^+ \to K^+\tau^\pm e^\mp)\cdot 10^6$	–	–	< 2.1
$\mathrm{Br}(B^+ \to K^+\tau^\pm \mu^\mp)\cdot 10^6$	–	–	< 3.3
$\mathrm{Br}(B^0 \to \tau^\pm e^\mp)\cdot 10^5$	–	–	< 1.6
$\mathrm{Br}(B^0 \to \tau^\pm \mu^\mp)\cdot 10^5$	–	–	< 1.3

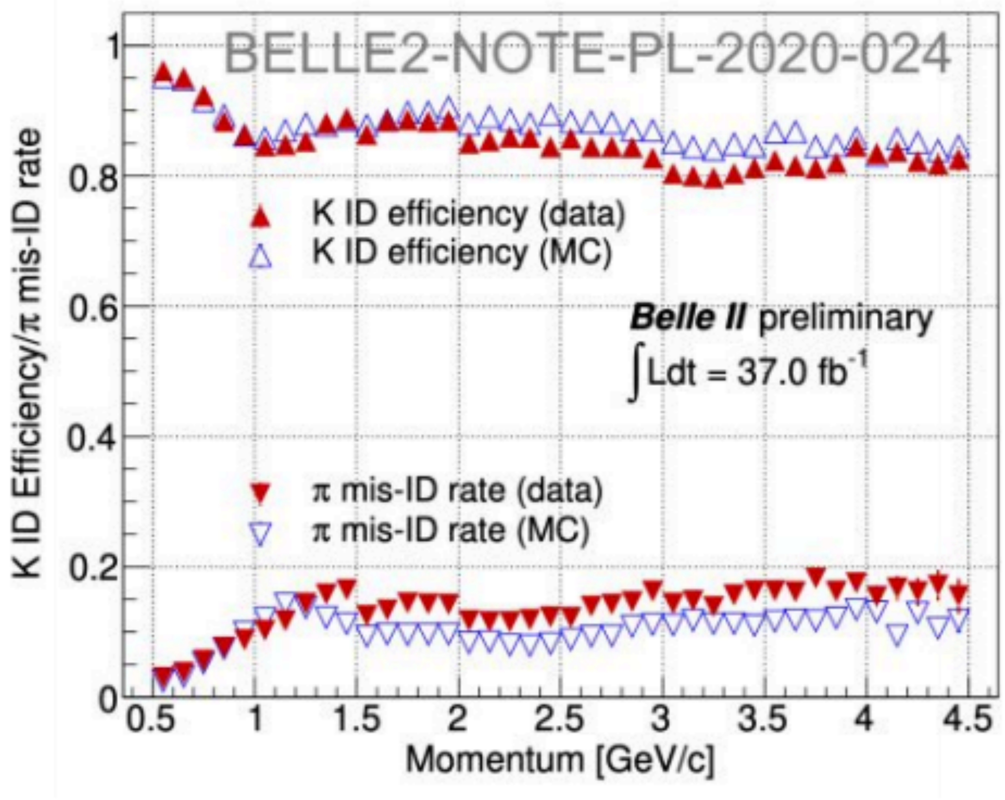
[Babar, PRL.118.031802]

$$\mathscr{B}(B \to K\tau\tau) < 2 \times 10^{-3}$$

Belle II Charged PID Performance

ICHEP 2020: 35 fb^{-1}

Particle Identification (K/π Separation)

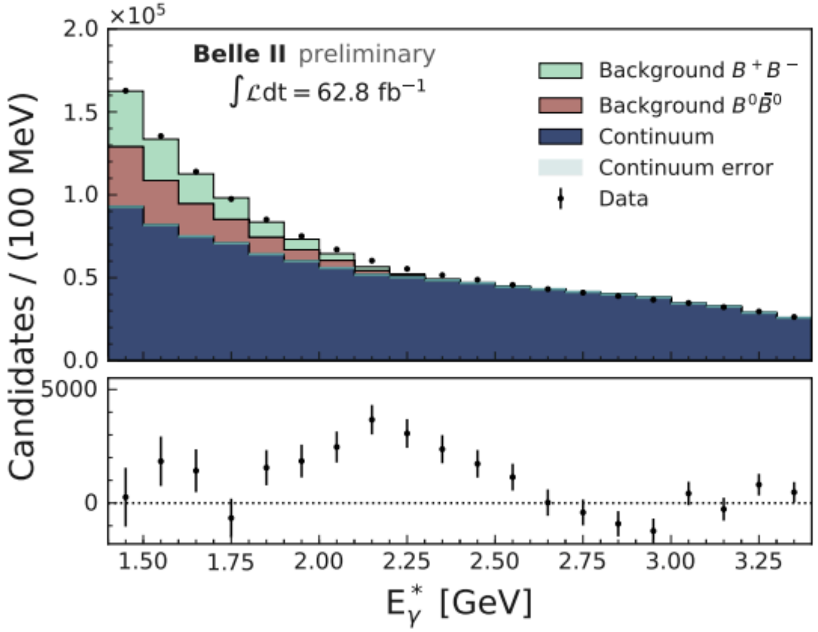


Gamma Spectrum from B->s\gamma

Important step towards inclusive measurement of B->sgamma:

- Decay rate sensitive to BSM physics, decay rate does not depend on SM FF
- Radiative penguin sensitive to Willson coefficient |C7|
- Evidence found also using untagged analysis strategy with 63 inv fb^{-1}
- Main background (gammas from pi0 and eta)
- E\gamma expected at smeared mb_{2} with smearing due to perturbative gluon brews and non-perturbative Fermi motion

Moriond 2021:63 fb^{-1}

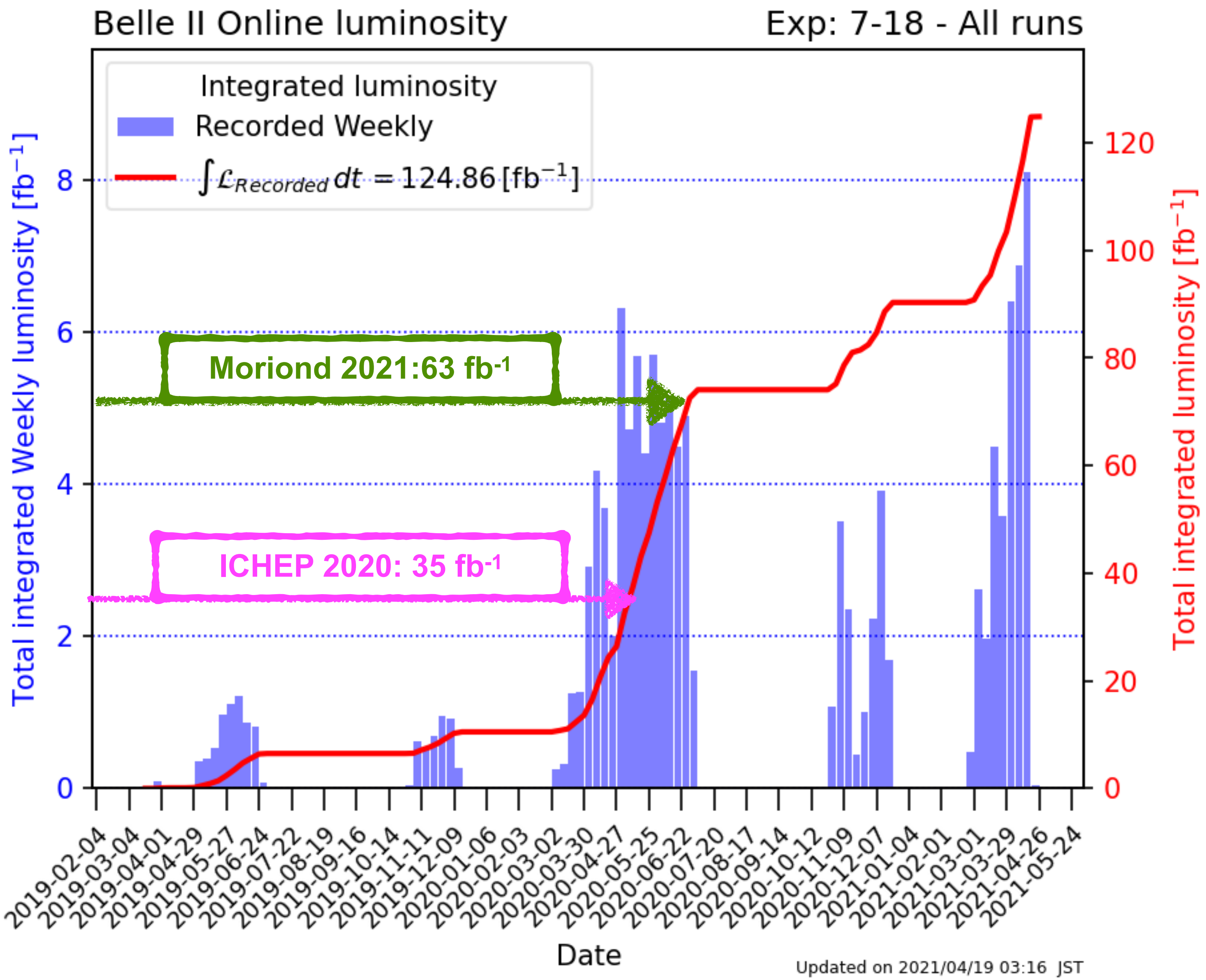


Prospects

- Implementing SL and Hadronic tagging techniques for this measurement
- Developing pi0 and eta object identification and suppression

Theoretical interpretation

- Measured gamma spectrum can be fitted |C incl 7 |^{2} and F(k)
- Model-Independent extraction consistent with SM



Belle II Online luminosity
Exp: 7-18 - All runs
Integrated luminosity
Recorded Weekly
$\int \mathcal{L}_{Recorded}\, dt = 124.86\,[\mathrm{fb}^{-1}]$
Moriond 2021:63 fb-1
ICHEP 2020: 35 fb-1
Total integrated Weekly luminosity [fb−1]
Total integrated luminosity [fb−1]
0
2
4
6
8
20
40
60
80
100
120
2019-02-04
2019-03-04
2019-04-01
2019-04-29
2019-05-27
2019-06-24
2019-07-22
2019-08-19
2019-09-16
2019-10-14
2019-11-11
2019-12-09
2020-01-06
2020-02-03
2020-03-02
2020-03-30
2020-04-27
2020-05-25
2020-06-22
2020-07-20
2020-08-17
2020-09-14
2020-10-12
2020-11-09
2020-12-07
2021-01-04
2021-02-01
2021-03-01
2021-03-29
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