

# Summary: Physics Analyses and Theory session

Conveners: Thomas Lück, Thibaud Humair, Anshika Bansal

Belle II Germany Meeting 2024 @ DESY

02/10/2024

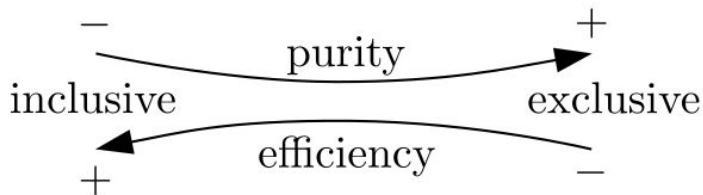
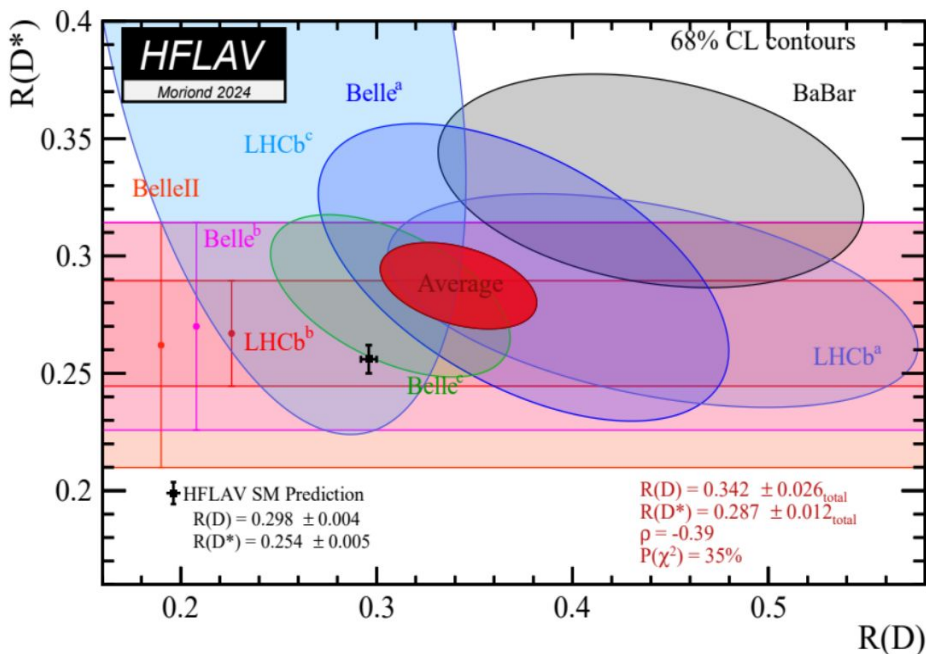
# Overview

- In total we had 13 experimental and 1 theory talk.
- 3 Poster presentations
- A broad range of topics covered:
  - $R(D^*)$  measurements
  - $V_{ub}/V_{cb}$  determinations
  - $B \rightarrow K/\pi \ell \bar{\nu} \nu$  Decays
  - Direct measurements of  $R_{0^+}$
  - Baryon number violation in B decays
  - Study of exotic particles
  - Tau lifetimes
  - Rare charm decays, and
  - ALPs searches

# R(D\*) Measurements

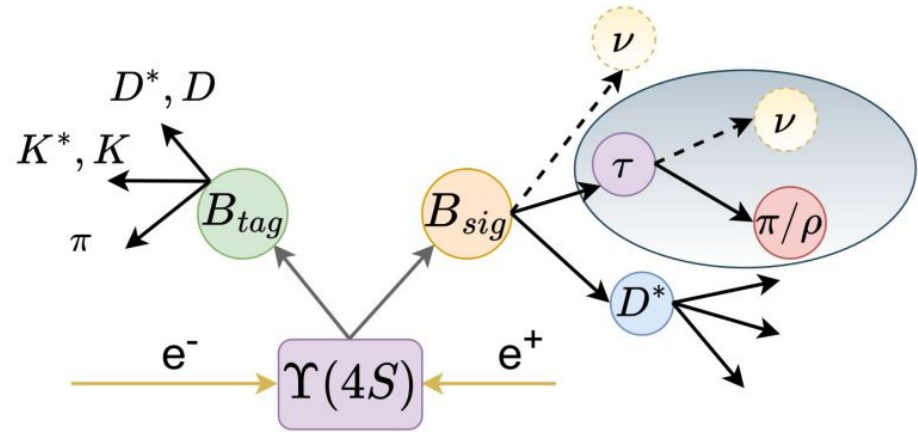
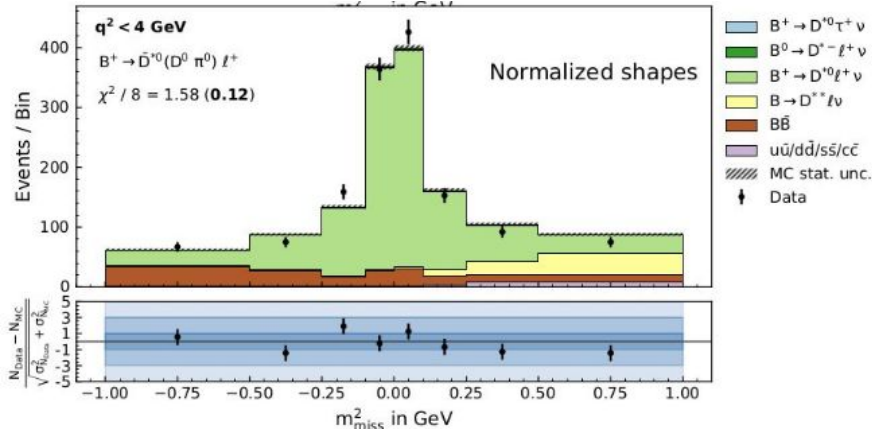
$$R(D^*) = \frac{\mathcal{B}(B \rightarrow D^* \tau \nu_\tau)}{\mathcal{B}(B \rightarrow D^* \ell \nu_\ell)}, \quad (\ell = e, \mu)$$

- test lepton universality in the SM
- currently around R(D\*) exceeds SM prediction by 2.5 sigma
- combined R(D) and R(D\*) exceed SM by 3.3sigma
- different approaches at B-factories
  - tag: hadronic vs. semileptonic vs. inclusive
  - tau decay: leptonic vs. hadronic



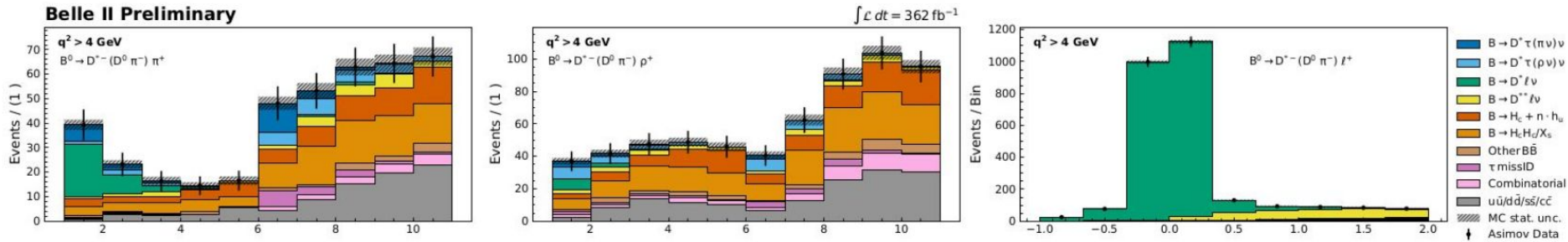
# R(D\*) Measurements in hadronic one prong-tau decays

- Ilias Tsaklidis
- tag one B by fully reconstructing it in hadronic decay mode
- hadronic tau decay
  - tau to rho nu
  - tau to pi nu
- some basic selections
- use  $q^2 < 4\text{GeV}^2$  as calibration



# R(D\*) Measurements in hadronic one prong-tau decays

- extract signal from fit to extra energy and missing mass squared
  - Extra helps to distinguish from bkg
  - missing mass squared to distinguish normalization and signal
- supporting document is prepared (80%)
- aim for publication 2025
- possible extension to also extract tau polarization
- still blinded results on Asimov data:

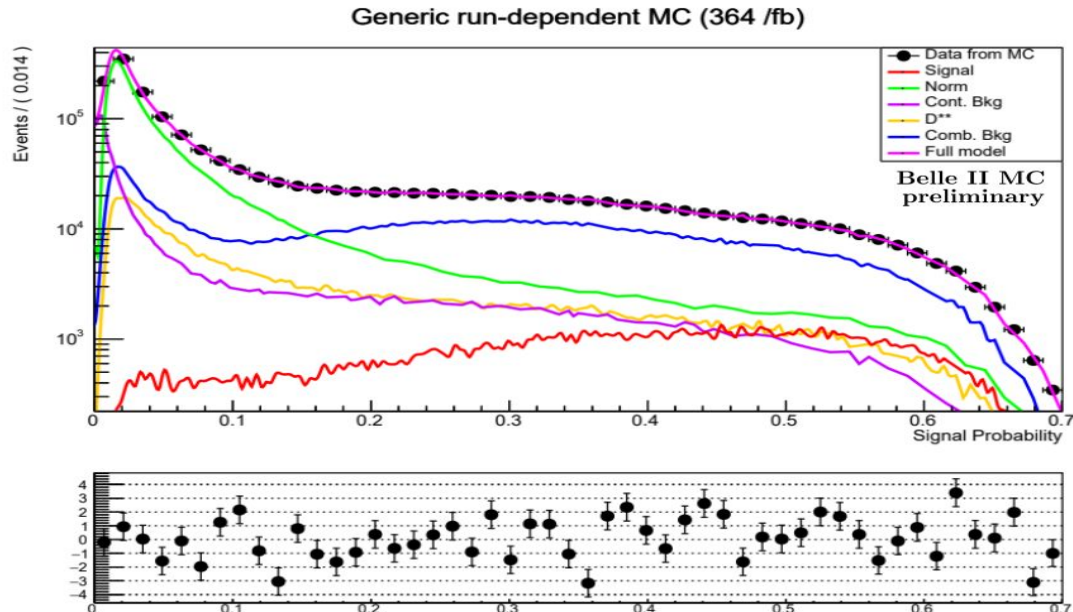


$$R(D^*) = 0.2580 \pm 0.0370 \pm 0.0148$$

$$\text{Belle result : } R(D^*) = 0.270 \pm 0.035(\text{stat})^{+0.028}_{-0.025}(\text{sys}),$$

# R(D\*) Measurement with inclusive tag


- Thomas Ametsbichler
- reconstruct  $B \rightarrow D^* l \nu$
- define rest of event as tag B
- train BDT on 12 input variables to distinguish 5 event classes: signal, normalization,  $D^{**} l \nu$ , other BB, continuum
- 1D fit on BDT output for signal probability
- MC study only



Measurement	Tagging	$\int \mathcal{L} dt [\text{fb}^{-1}]$	$R(D^*)$	$\sigma_{\text{stat.}}$	$\sigma_{\text{syst.}}$	$\sigma_{\text{stat.}}$ rescaled to $364 \text{ fb}^{-1}$
Belle (2020)	semileptonic	737	0.283	0.018	0.014	0.026
Belle II (2024)	hadronic	189	0.262	+0.041 -0.039	+0.035 -0.032	+0.030 -0.029
This analysis	inclusive	364	0.242	0.010	+0.020 -0.014	0.010


# R(D<sup>\*</sup>) Measurements using inclusive tagging

- similar analysis by Tia Crane
- some differences:
  - use 2 MVA to reduce background and classify event
  - measure both R(D) and R(D<sup>\*</sup>)
  - signal extraction binned 2D fit on MVA output x Mmiss2
- possibilities for collaboration between the two analyses are explored



## Precision Measurement of R(D<sup>\*</sup>) via Inclusive Tagging Methods

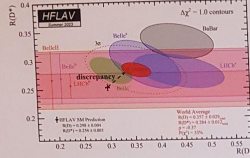
Tia Crane - DESY



### Motivation

➤ The standard model predicts all leptons have the same coupling ( $g_{\ell=e,\mu,\tau}$ ) to charged electroweak boson ( $W^\pm$ )



➤ HFLAV tension: 3.3σ

➤ OUR GOAL: Increase precision of R(D<sup>\*</sup>) measurement with tagging to further test lepton flavour universality

$$R(D^{(*)}) = \frac{N(D^{(*)}\tau\nu) \epsilon(D^{(*)}\tau)}{N(D^{(*)}\nu\nu) \epsilon(D^{(*)}\nu) B(C)}$$

Removes most systematic uncertainties

### Inclusive Tagging

Inclusive Tag  
 $\epsilon \approx O(100\%)$   
 Consistency of  $P_{tag}$

➤

ADVANTAGE: Maximize sensitivity by increasing signal efficiency

Semileptonic Tag  
 $\epsilon \approx O(1\%)$   
 Knowledge of  $P_{tag}$

➤

DISADVANTAGE: Yields lower purity compared to FEI tagging

Hadronic Tag  
 $\epsilon \approx O(10\%)$   
 Exact knowledge of  $P_{tag}$

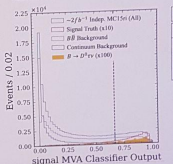
➤

DISADVANTAGE: Yields lower purity compared to FEI tagging

### First Level Filter

➤ Apply first level filter before detailed analysis + corrections

➤ 15 Input Features:  $Mbc_{ROE}$  + KSFV moments + Thrust variables



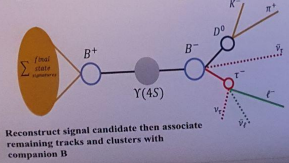
Classification	Relative Efficiency
Signal	70.79
$B\bar{B}$ Background	21.62
$q\bar{q}$ Background	6.78

Selection cut determined by maximizing  $S$   
 $POM = \frac{S}{\sqrt{S+B}}$

### Analysis Overview

- **Signal Reconstruction**
  - Simultaneously reconstruct signal and normalization
- **ROE Mask Optimization**
  - Select good companion B via minimizing  $Mbc_{ROE}$  and  $\Delta E_{ROE}$  widths
- **First Level Filter (MVA 1)**
- **Split Analysis**
  - Create two variations: fully inclusive + hadronically inclusive (lepton veto)
- **Best Candidate Selection**
- **Second Level Filter (MVA 2)**
  - Reduce signal-like background with multiclass BDT
- **Signal Extraction and Validation**
  - Binned fit on MVA 2 output +  $M_{miss}^2$

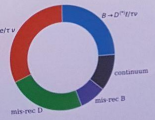


Reconstruct signal candidate then associate remaining tracks and clusters with companion B

### Background Composition

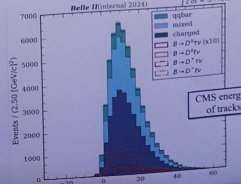
➤ Determine potential features for MVA 2:

- Kinematics +  $\Delta E_{ROE}$
- Cluster shape +  $z(D^0, \ell^\pm)$



### Q<sup>2</sup> Distribution



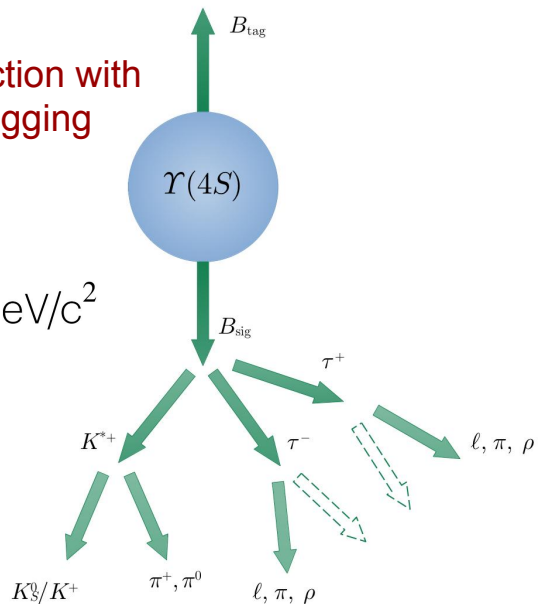
CMS energy + momentum of tracks and clusters



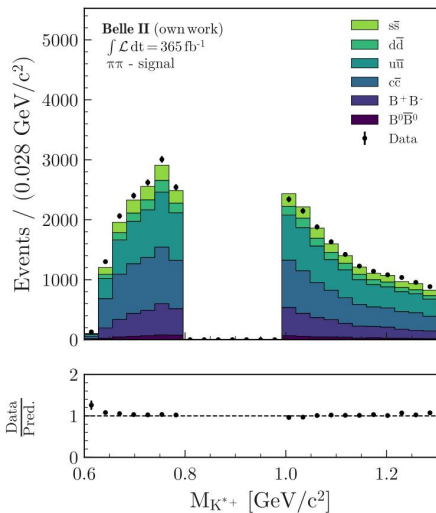
# Study of $B^+ \rightarrow K^{*+} \tau \tau$

- Lennard Damer
- SM:  $BR(B^+ \rightarrow K^{*+} \tau^+ \tau^-) \approx 10^{-7}$ ,  $BR_{NP} \approx 10^{-4}$
- Enforced mass criterion to boost signal sensitivity.
- Tails as the control region :  $M_{K^*} < 0.79 \text{ GeV}/c^2$  and  $M_{K^*} > 0.994 \text{ GeV}/c^2$
- FastBDT for background suppression.
- Most Challenging background: B+B-

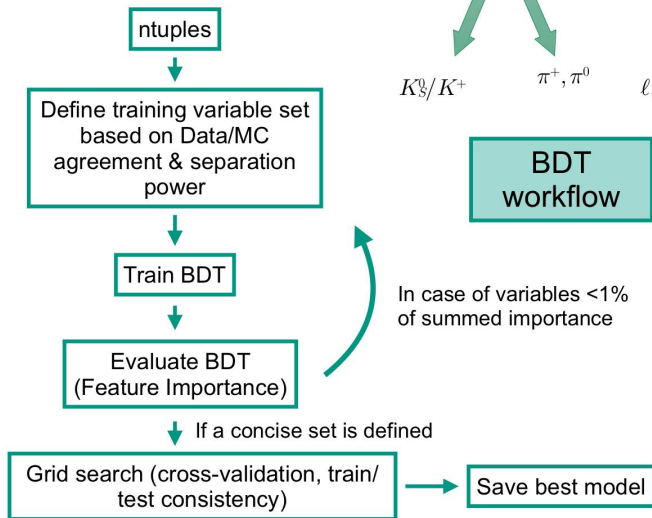
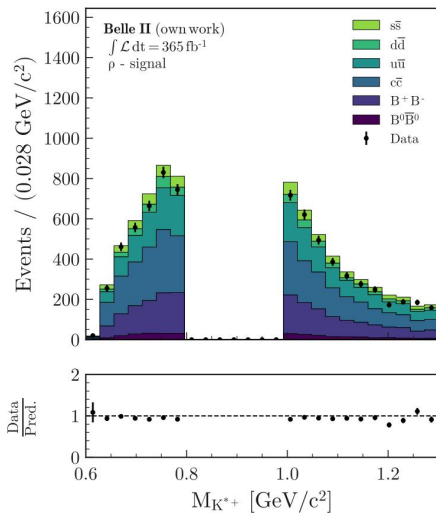
Reconstruction with hadronic tagging



$\pi\pi$ -channel

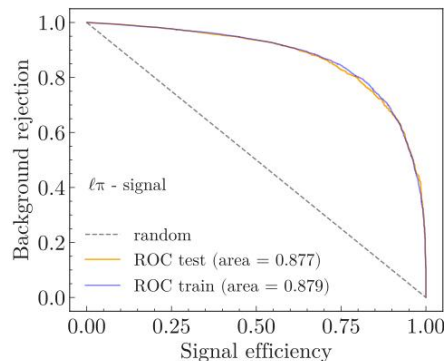
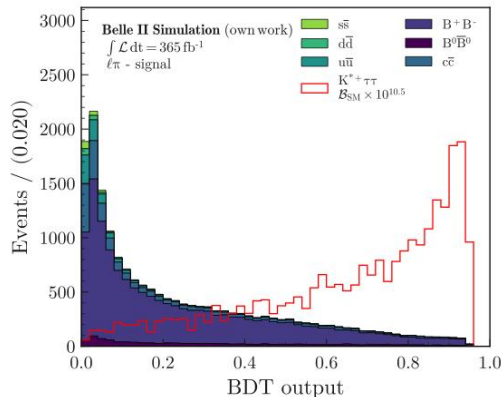


$\rho$ -channel





## $\ell\pi$ -channel

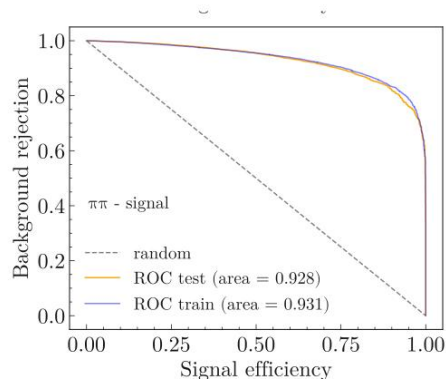
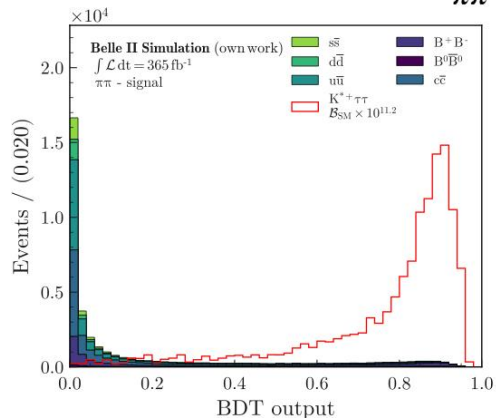


First search for  $B \rightarrow K^* \tau^+ \tau^-$

$$\text{BR}(B^+ \rightarrow K^{*+} \tau^+ \tau^-) < 8.38 \times 10^{-3} \text{ @90\% CL}$$

(Upper limit derived by counting experiment, with corrections, without systematics)

## $\pi\pi$ -channel

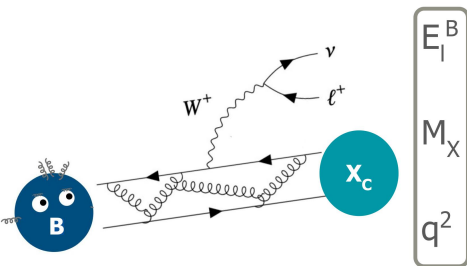


Yet to be done: Full optimization of cuts,  
 Systematic uncertainties estimates,  
 validations, ..

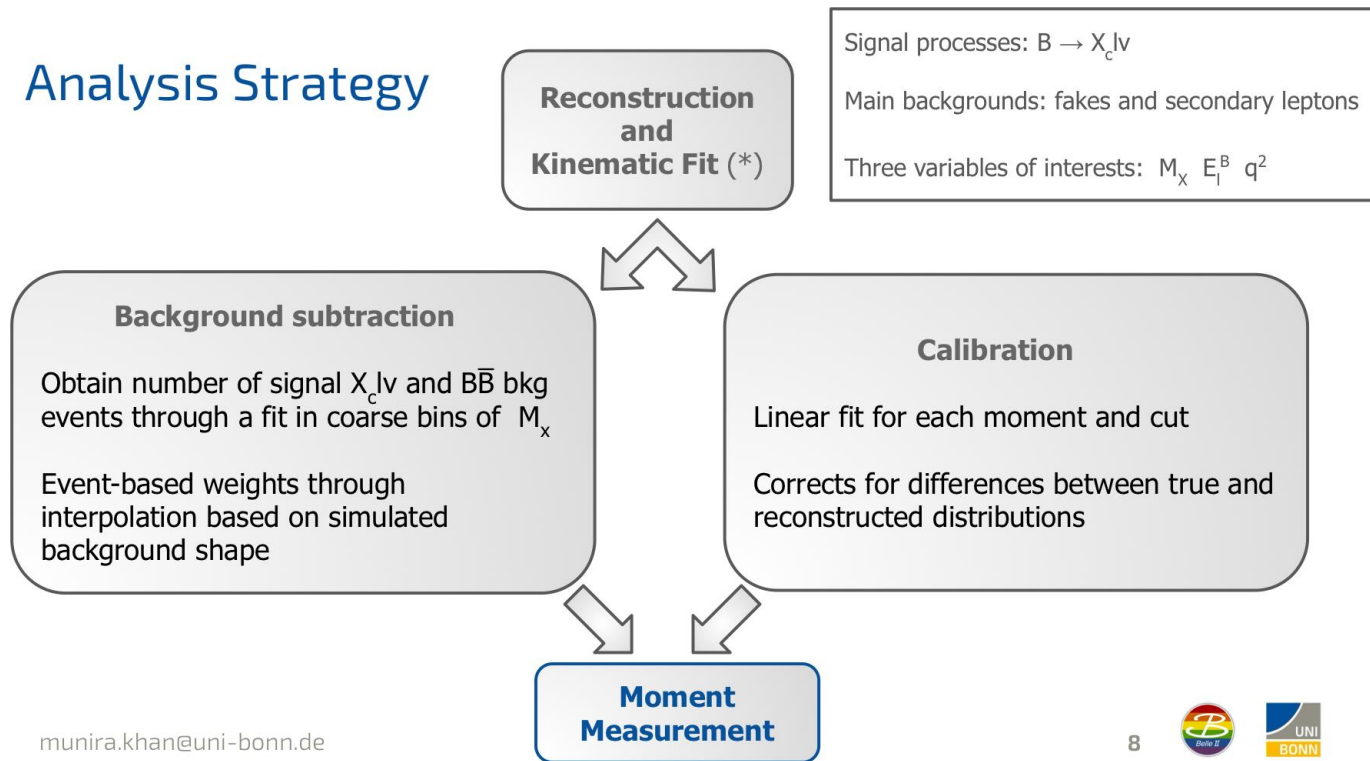
Achieved good separation between signal and background.

# Kinematic Moments in inclusive semileptonic $b \rightarrow c$ decays

- Munira Khan
- Kinematic moments required for determination of  $V_{cb}$ .
- Very challenging theoretically due to non-perturbative QCD dynamics.



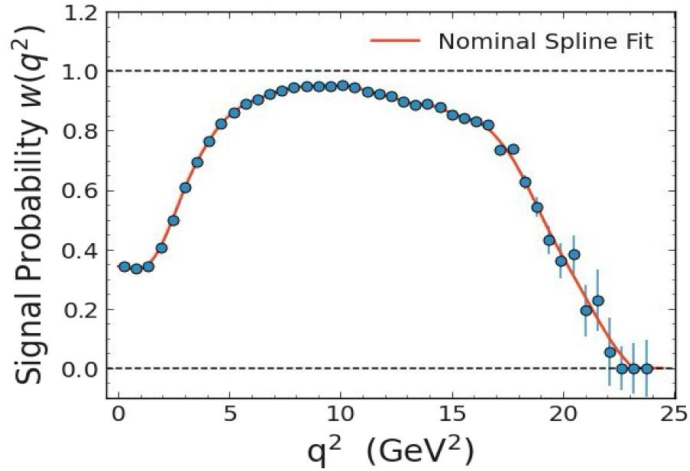
## Analysis Strategy



[munira.khan@uni-bonn.de](mailto:munira.khan@uni-bonn.de)

# Calibration

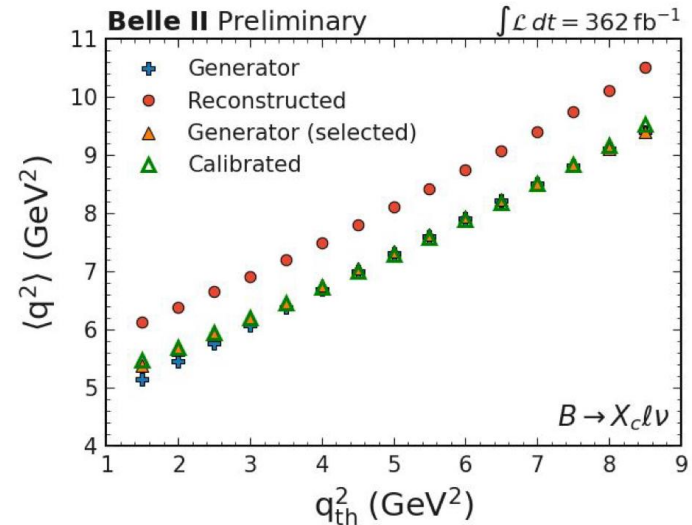
## Background Subtraction



- Bias tests have been performed to make sure that the calibration is unbiased

- Signal-probability
- Linear calibration
- Correct **bias** of linear calibration
- **Reconstruction** effects

$$\langle q^{2n} \rangle = \frac{\sum_i^{N_{\text{data}}} w(q_i^2) \times q_{\text{calib},i}^{2n}}{\sum_j^{N_{\text{data}}} w(q_j^2)} \times C_{\text{calib}} \times C_{\text{gen}}$$



# Inclusive determination of $V_{ub}$

- Tommy Martinov
- Long standing tension between the exclusive and inclusive determination

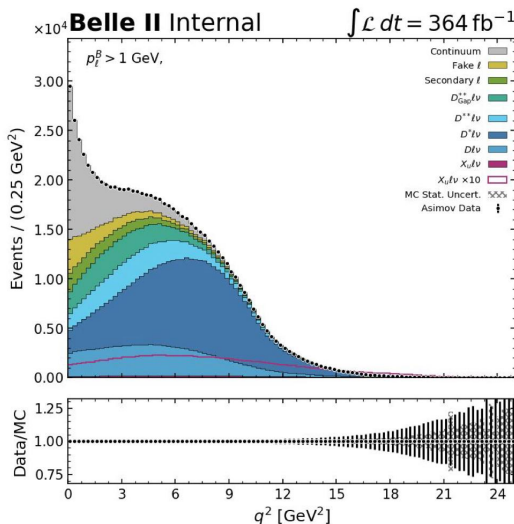
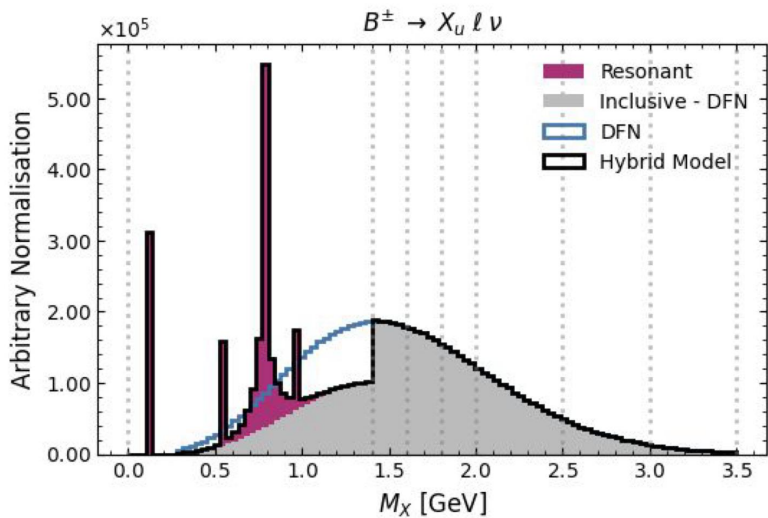
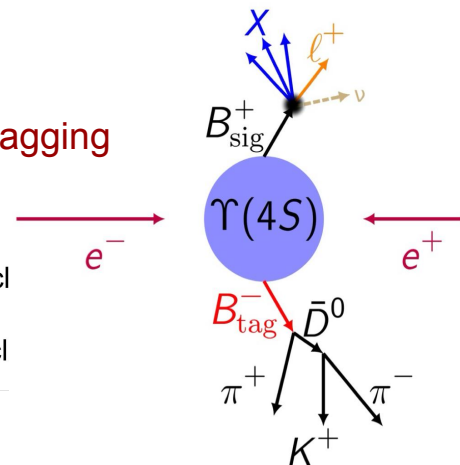
$$|V_{ub}| = (4.13 \pm 0.12^{+0.13}_{-0.14} \pm 0.18) \times 10^{-3} \quad \text{PDG incl}$$

- Based on Heavy Quark Expansion.
- Largest background :  $B \rightarrow X_c \ell \nu$

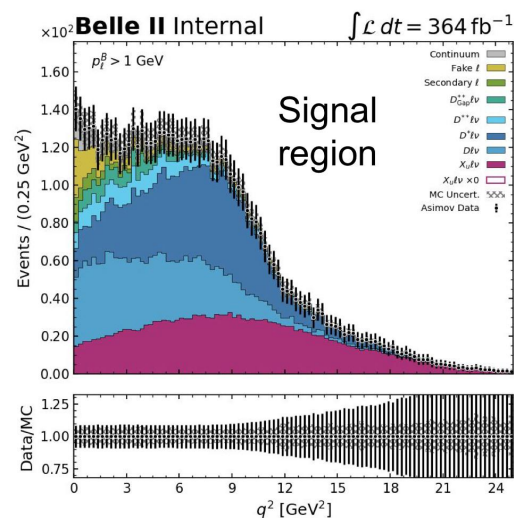
$$|V_{ub}| = (3.70 \pm 0.10 \pm 0.12) \times 10^{-3} \quad \text{PDG excl}$$

- Cuts in phase space leading to break down of HQE.

Hadronic tagging



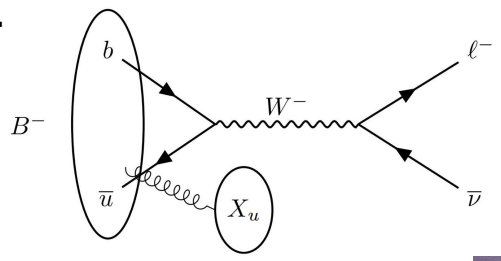
Before selection



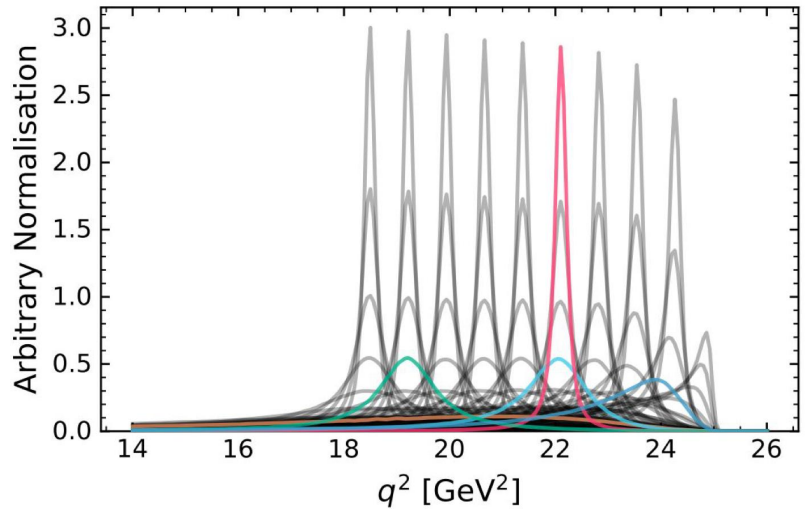
After selection

# Weak Annihilations

- Enter @  $O(1/\text{mb}^{\wedge}3)$
- Not included in most models
- Poor theoretical understanding.
- Subleading but sizable : important with shrinking uncertainties.
- Shape of peak known poorly.
- **Goal:** Extraction of limit on WA contribution.



Belle II Simulation



Belle II

Measurement of  $B \rightarrow X_u \ell \nu$  branching fraction and  $|V_{ub}|$   
via inclusive semi-leptonic  $B$  decays at Belle II

Tommy Martinov, DESY, Hamburg, Germany, tomy.martinov@desy.de

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**Physics Motivation**

- Standard Model precision measurement  $\rightarrow$  measuring a CKM matrix element
- Can be measured using exclusive decays  $\rightarrow$  reconstruct specific  $u$ -meson:  $\pi, \rho, \dots$
- Can be measured using inclusive decays  $\rightarrow$  any hadronic system containing a  $u$  quark
- $|V_{ub}|$  has previously been measured by CLEO, BaBar, Belle, LHCb
- PDG exclusive/inclusive:  $(3.70 \pm 0.16) \times 10^{-3} / (1.13 \pm 0.26) \times 10^{-3}$
- Variables of interest
  - Lepton momentum:  $p_\ell$
  - Leptonic system invariant mass:  $q^2$
  - Hadronic system mass:  $M_X$

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**Experimental setup**

Belle II @ SuperKEKB

- Asymmetric  $e^+e^-$  collider at  $\sqrt{s} = \Upsilon(4S)$  resonance ( $\sim 10.58 \text{ GeV}$ )  $\rightarrow$  B-factory
- World record luminosity:  $4.5 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- Advantages compared to hadron collider: clean event environment and precise knowledge of initial state

**Event reconstruction**

- Inclusive Tag:  $\Gamma \approx O(10)\%$ , Consistency of  $B_{tag}$
- Signal-side:  $\Gamma \approx O(10)\%$ , Knowledge of  $B_{tag}$
- Hadronic Tag:  $\Gamma \approx O(10)\%$ , Exact knowledge of  $B_{tag}$
- Full Event Interpretation: Multi-Variable Analysis algorithm to reconstruct the tag-side  $B$
- Reconstruction steps
  - Detector data
  - Final state particles ( $\ell, \nu, X, \dots$ )
  - Intermediate steps ( $\Upsilon(4S), B$ )
  - $B$  meson
- Challenging calibration: sizable uncertainty for semi-lepton decay

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**$B \rightarrow X_u \ell \nu$  inclusive analysis at Belle II**

Theory and modeling

- Description of inclusive decays is based on Heavy Quark Expansion (HQE)
  - All  $X_u \ell \nu$  ( $X_u = \Upsilon(4S), B, \dots$ ) decays are considered by  $B \rightarrow X_u \ell \nu$  background
  - Cuts in phase space such as  $M_X < M_{\Upsilon(4S)} - 1.50 \text{ GeV}$  help clean from the HQE
  - $B \rightarrow X_u \ell \nu$  decay rate calculation becomes sensitive to the "shape function"  $\rightarrow$  Lepage-Feynman model in B meson
  - Additional inputs to describe  $B \rightarrow X_u \ell \nu$  decays: ANP (PhyMND 22.0306), LFN (HEP99.09991)
- Additional contribution from Weak Annihilation (see box below)
- Modeling strategy for experimental measurement: signal model
  - Add an invariant decay  $B \rightarrow X_u \ell \nu$  on  $q^2$  with non-measurement decay
  - Inclusive contribution is added down such that total decay rate matches inclusive prediction
  - Weighting performed in 80 bins of  $p_\ell$  with  $M_X$  from  $\Upsilon(4S), \Upsilon(4S)^2, \Upsilon(4S)^3$

Measurement

- Measurement strategy
  - Signal modeling: hybrid model (see left box)
  - Modeling of non-background: sum of  $B \rightarrow X_u \ell \nu$  mesons
  - Other backgrounds:  $\Upsilon(4S) \rightarrow B^0 \text{ mesons}$  ( $\Upsilon(4S) \rightarrow X_u \ell \nu$ ), late leptons, baryons coming from secondary decays
  - Multi-variate analysis: classifiers to suppress background
  - One Neural Network to separate  $\Upsilon(4S) \rightarrow B^0$  events from different spatial and kinematical properties compared to  $B \rightarrow X_u \ell \nu$
  - One Neural Network to separate  $B \rightarrow X_u \ell \nu$  using the event missing mass and properties of the reconstructed  $B$  ( $B \rightarrow \Upsilon(4S) \rightarrow B^0 \text{ mesons}$ )
- Systematic uncertainties:
  - Modeling uncertainties: parameterisation of form factor models in exclusive decays, branching fractions, inclusion model approximations, invariant mass differences, logarithmic factorisation, modeling of PDFs
  - Experimental uncertainties: charged particle identification,  $\Upsilon(4S)$  detection efficiency,  $B^0$  tagging efficiency
- Signal extraction in different phase space regions using binned likelihood  $\mathcal{L} \propto \prod_{i=1}^N \mathcal{L}_i(p_\ell, q^2) \cdot \mathcal{L}_{\text{tag}}(p_\ell)$

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**Weak Annihilation**

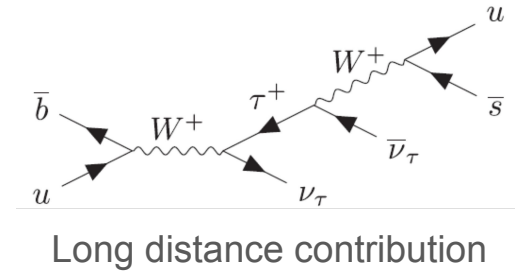
- Weak Annihilation contribution enters inclusive  $B \rightarrow X_u \ell \nu$  modeling at  $O(1/\Lambda^2)$
- Not included in most analysis  $B \rightarrow X_u \ell \nu$  models, purely perturbative, non-leading effects but dominant contribution in  $\Upsilon(4S)$  meson
- One structure at short momentum at CLEO:  $\Upsilon(4S) \rightarrow X_u \ell \nu$  with  $q^2 \approx 0$
- One structure at short momentum at Belle II:  $\Upsilon(4S) \rightarrow X_u \ell \nu$  with  $q^2 \approx 0$

- The shape of the Weak Annihilation peak in  $q^2$  is poorly known
- Span a range of scales from below  $q^2 \approx 0$  to above
- Phase of distribution of different models (see left box)
- The plot is sensitive to both these uncertainties

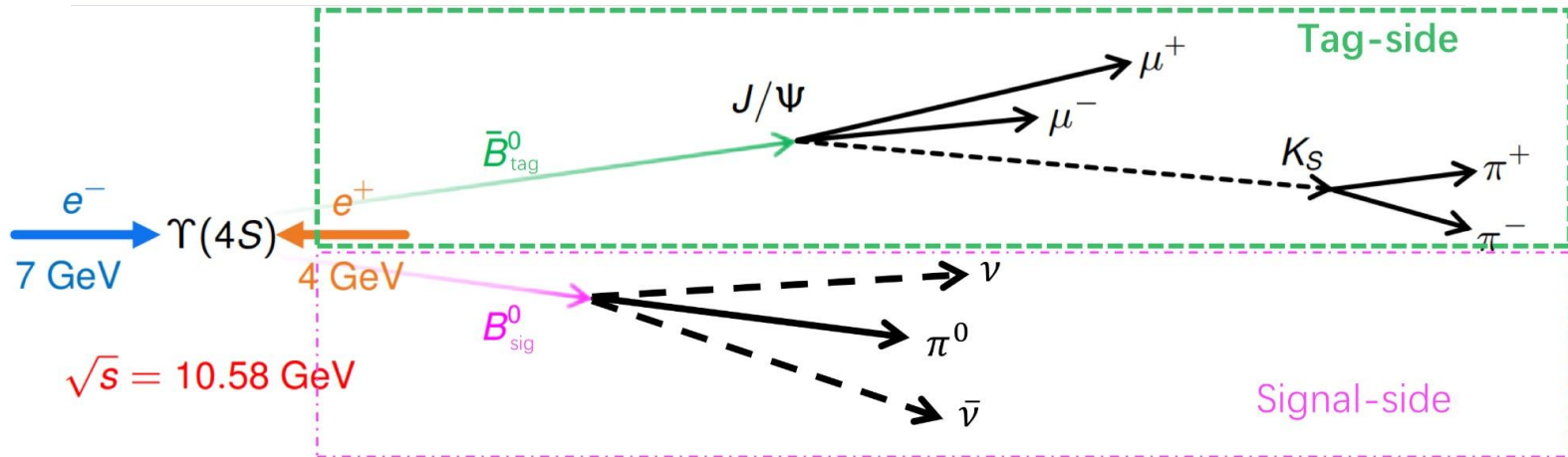


# Study of $B \rightarrow \pi \nu \bar{\nu}$

- Boyang Yu
- SM: Penguin and Box contribution.



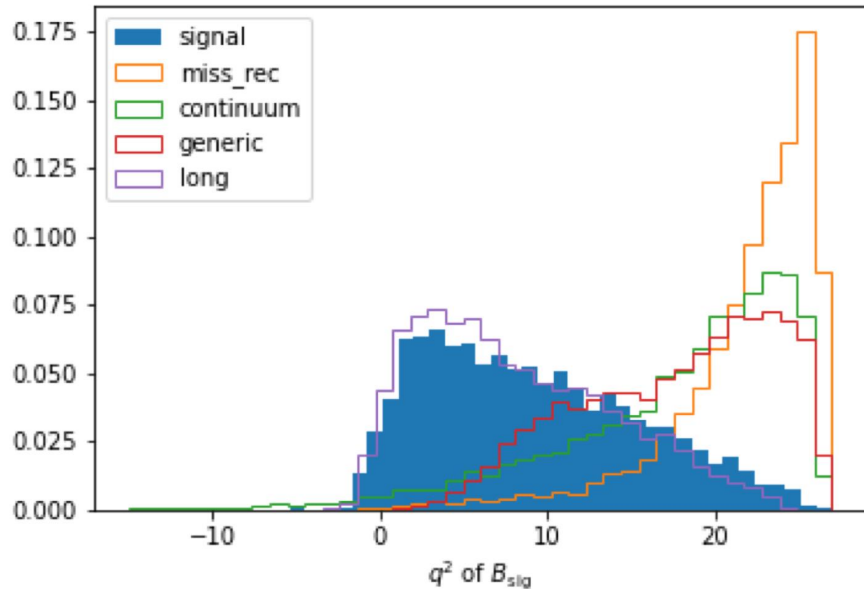
Charged Channel	SM Prediction	Long-distance Channel	SM Prediction
$B^+ \rightarrow \pi^+ \nu \bar{\nu}$	$0.239 \times 10^{-6}$	$B^+ \rightarrow [\tau^+ \rightarrow \pi^+ \bar{\nu}] \nu$	$11.8 \times 10^{-6}$
$B^+ \rightarrow K^+ \nu \bar{\nu}$	$5.58 \times 10^{-6}$	$B^+ \rightarrow [\tau^+ \rightarrow K^+ \bar{\nu}] \nu$	$0.61 \times 10^{-6}$



$$q^2 = \frac{s}{4c^2} + M_\pi^2 - \frac{\sqrt{s}E_\pi^*}{c^4}$$

Dataset	Retention	Efficiency	Multiplicity	nEvents
Signal	0.7388	8.546	8.63	1969
Long	0.7183	8.248	8.36	1957
Miss reconstructed	0.4606	6.620	6.90	1915
Generic charged	0.0407	0.253	2.48	5430
Generic mixed	0.0367	0.236	2.37	4485
uubar	0.0143	0.055	1.63	2189
ddbar	0.0140	0.054	1.60	2359
ccbar	0.0253	0.111	1.89	3587
ssbar	0.0214	0.077	1.58	3298

**After selection**

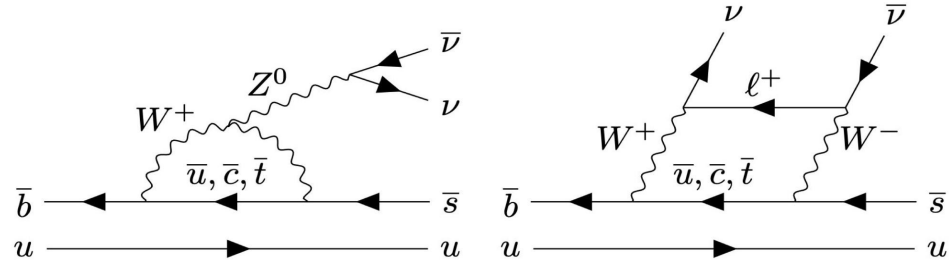


- $B \rightarrow \pi \nu \bar{\nu}$  : Good platform for testing new reconstruction algorithm.
- Expected BR  $\sim O(10^{-7})$
- UL from previous study  $\sim O(10^{-5})$
- Similar study for  $B \rightarrow K \nu \bar{\nu}$  to follow.



# Study of $B \rightarrow K \nu \bar{\nu}$

- Yabo Han
- $b \rightarrow s \nu \bar{\nu}$  transition: Powerful to probe SM.
- Major challenge: Low efficiency of final states with  $K_S^0$  and  $\pi^0$



## Work flow and Analysis status

### 1) Basic selection:

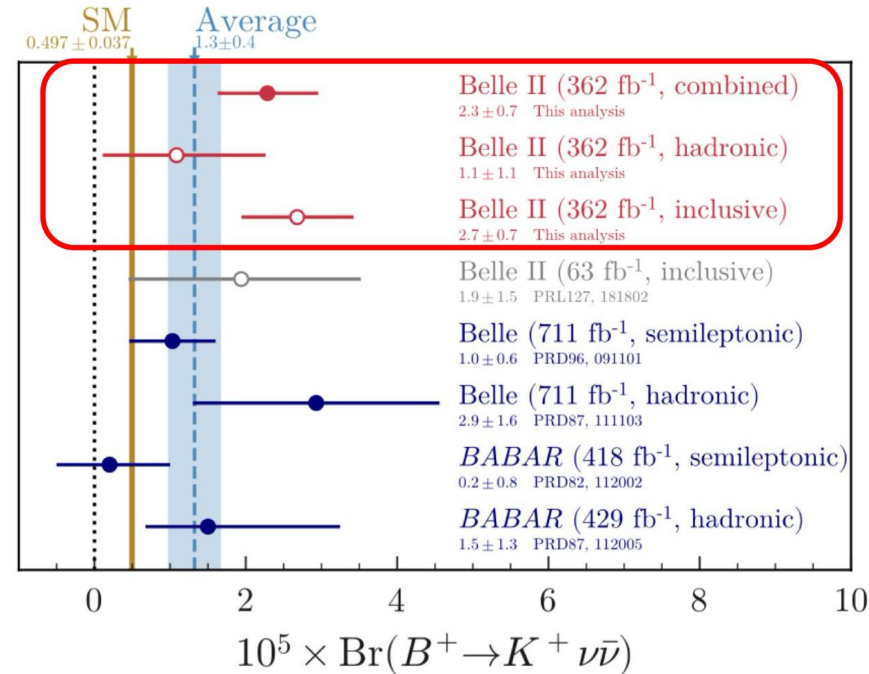
- Object selection and event cleanup
- Signal candidate selection

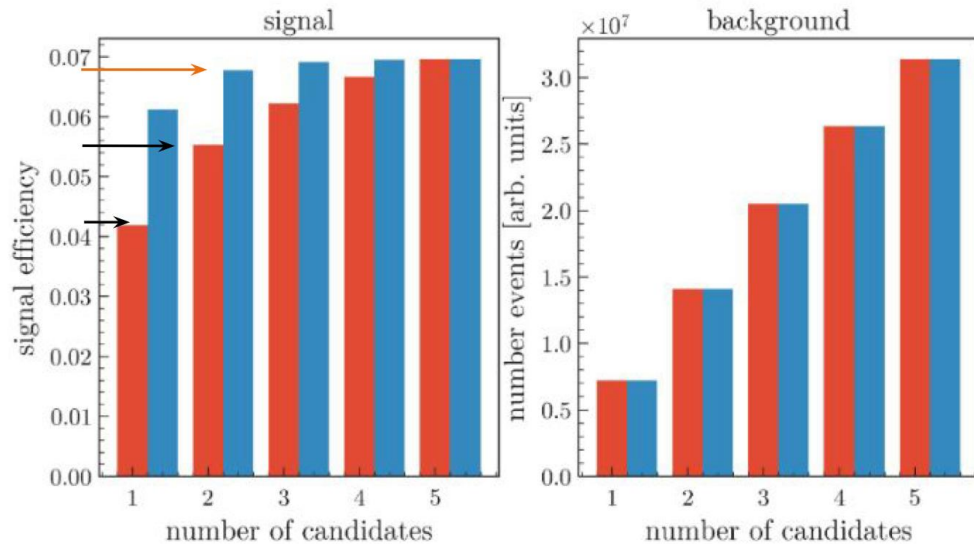
### 2) Main background suppression

- BDT1 for event selection
- Background suppression: e.g from D
- Final selection using BDT2

### 3) Validation with control channels

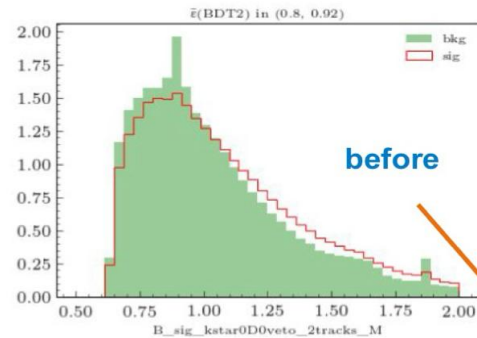
### 4) Statistic interpretation



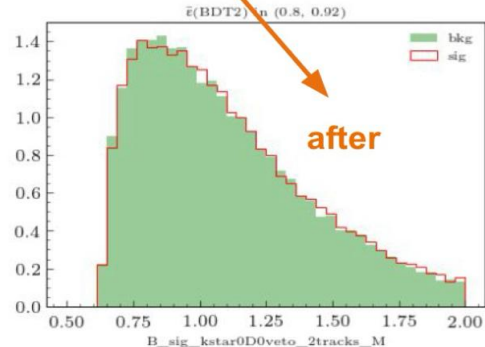


Signal efficiency and background events in  $K^{*+}$  channel as a function of multiple candidates

- Dominant background:
  - $K^+$ ,  $K_s0$  : from D
  - $K^*$ : D  $\rightarrow$   $K^*X$  and Combinatorial background



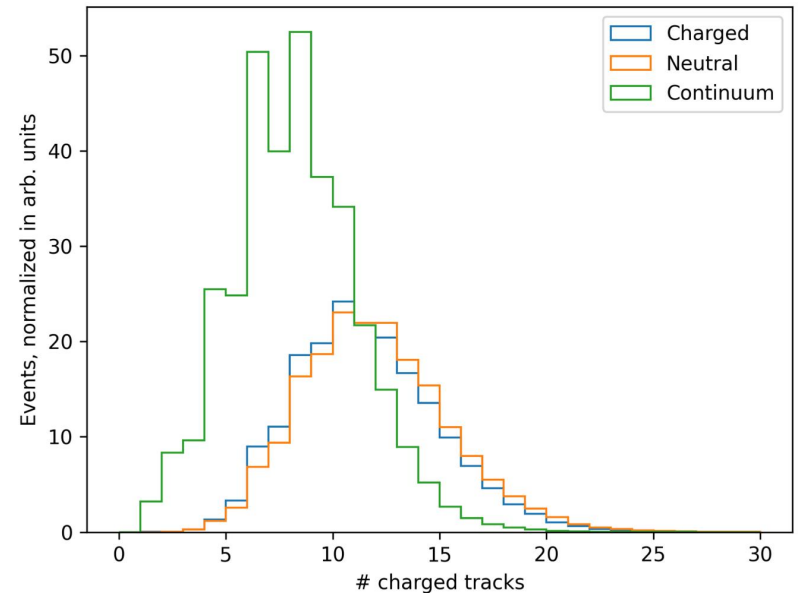
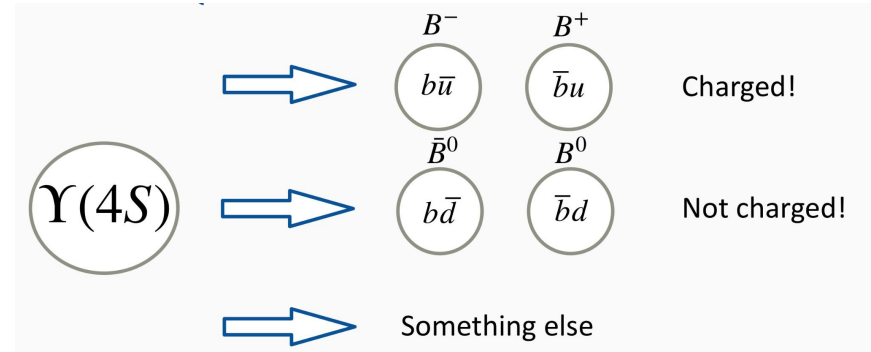
BDT2 retrained



# Direct measurements of $R_0^+$

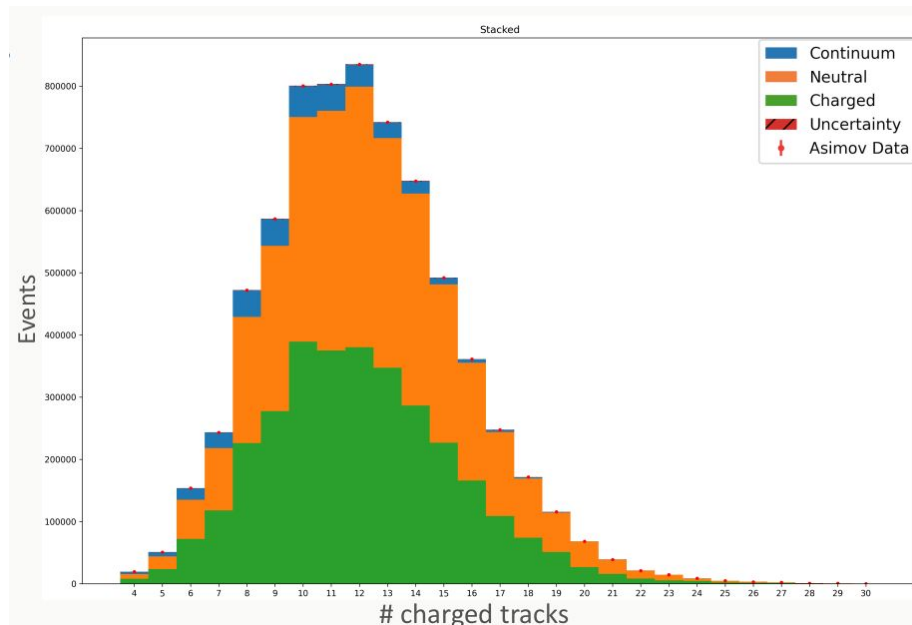
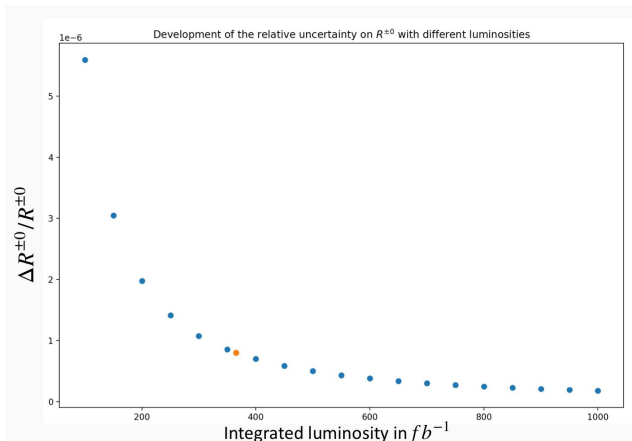
$$R^{\pm 0} = \frac{\Gamma(\Upsilon(4S) \rightarrow B^+ B^-)}{\Gamma(\Upsilon(4S) \rightarrow B^0 \bar{B}^0)}$$

- Anna-Maria Heyn
- Current  $R^{\pm 0} = 1.057^{+0.024}_{-0.025}$  (HFLAV)
- Hard for theory
- count number of tracks in event: slightly different for charged and neutral B
- direct measurement: no reconstruction of intermediate states
- use BDT to suppress continuum events



# Direct measurements of $R_0^+$

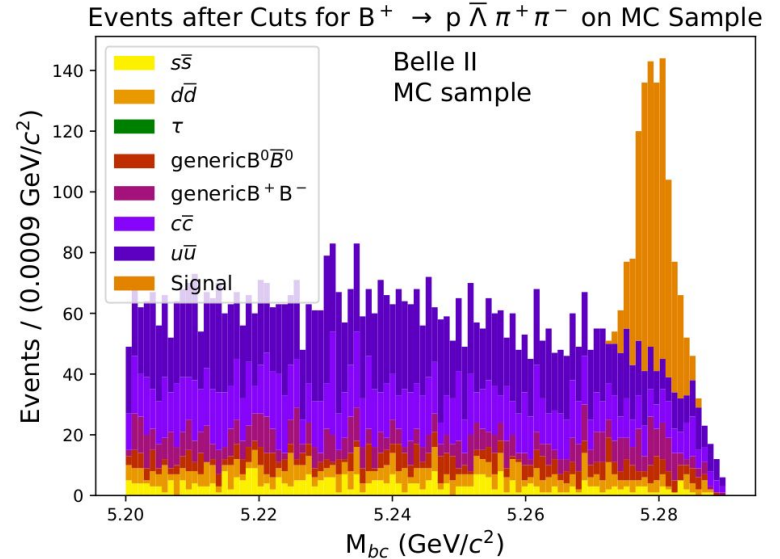
- perform template fit to extract signal yields
- so far only MC studies
- promising results
- very low stat. uncertainty
- use control channel to estimate systematic uncertainties
- would be first measurement of this kind



Future improvement with more statistics

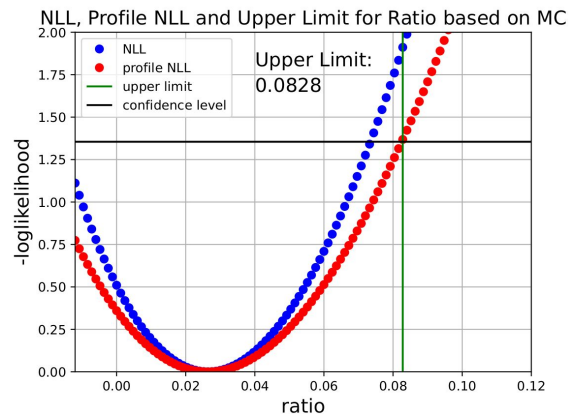
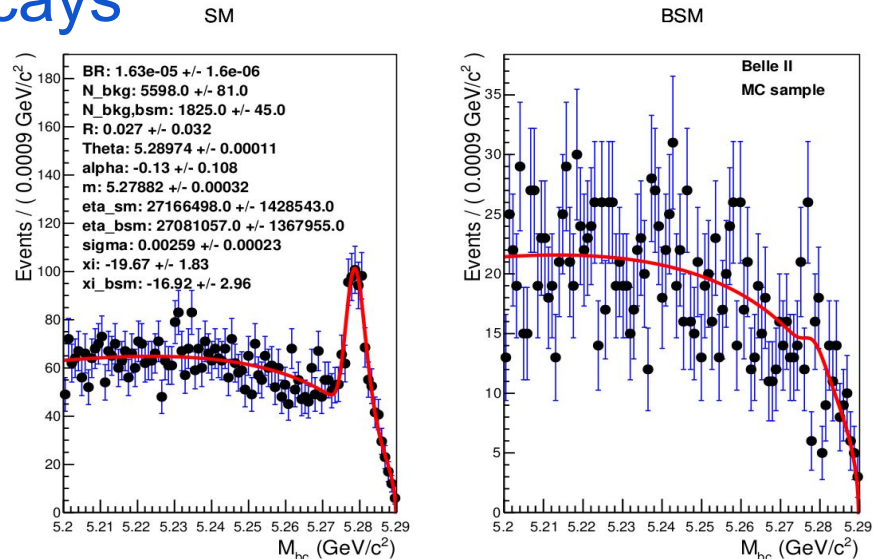
# Baryon Number Violation in B decays

- baryon number violation can explain matter-antimatter asymmetry
- baryon number violation by 1 unit experimentally well constrained, less constraints for change by 2 units
- reconstruct → SM decay:  $B^+ \rightarrow p\bar{\Lambda}(\rightarrow \bar{p}\pi^+)\pi^+\pi^-$   
→ BSM decay:  $B^+ \rightarrow p\Lambda(\rightarrow p\pi^-)\pi^+\pi^-$
- selection:
  - PID and kinematic selections
  - train dedicated BDT to reduce continuum bkg



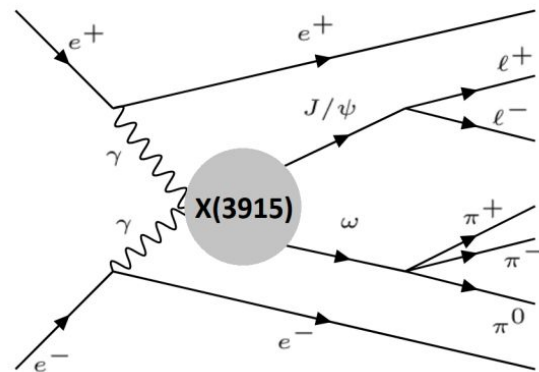
# Baryon Number Violation in B decays

- Melanie Hess
- simultaneous fit to SM and BSM channel:
  - extract SM BR
  - ratio of BSM/SM BR
- uncertainties included as nuisance parameter
- on MC:
  - upper limit on BR ratio 0.082 corresponding to  $BR < 1.35 \times 10^{-6}$  @90%CL

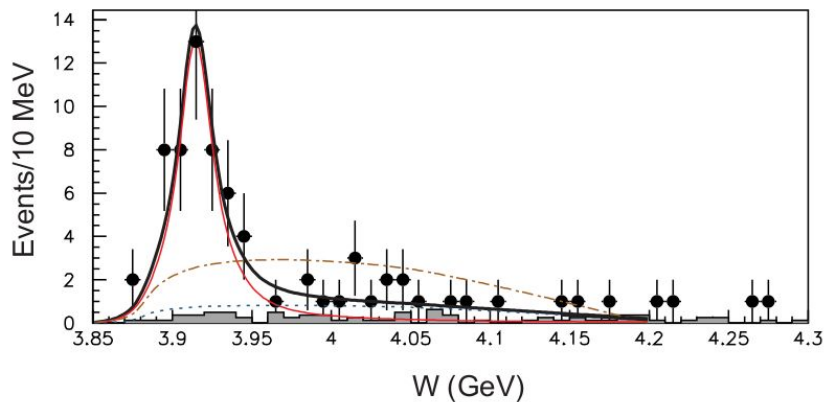


# Study of X(3915)

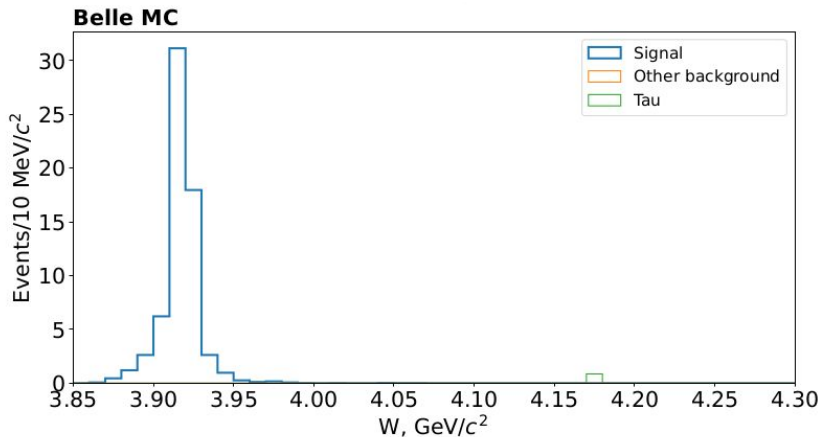
- Yaroslav Kulii
- exotic state X(3915) undetermined quantum numbers
- full Belle data set
- untagged: initial  $e^+e^-$  escape detector



Belle analysis (2010)



This analysis





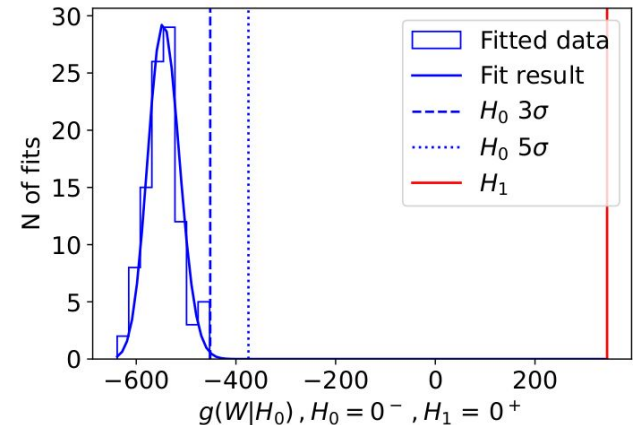
# Study of X(3915)

- do an amplitude analysis to determine  $J^P$  quantum numbers
- measure 5 decay angles and fit hypothesis using theory prediction to fit for up to 9 free parameters (depending on hypothesis)

$$\ln \mathcal{L}(\vec{\theta}; \tau_k) = \underbrace{\sum_{k=1}^N w_k \ln \mathcal{I}(\tau_k; \vec{\theta})}_{\text{Data sample (weighted)}} - \underbrace{N \ln \left[ \frac{1}{N_{MC}} \sum_{j=1}^{N_{MC}^{acc}} \mathcal{I}(\tau_j; \vec{\theta}) \right]}_{\text{Phase space MC}}, \text{ where } \mathcal{I} - \textit{intensity} \text{ is the number density of produced events in the phase space}$$

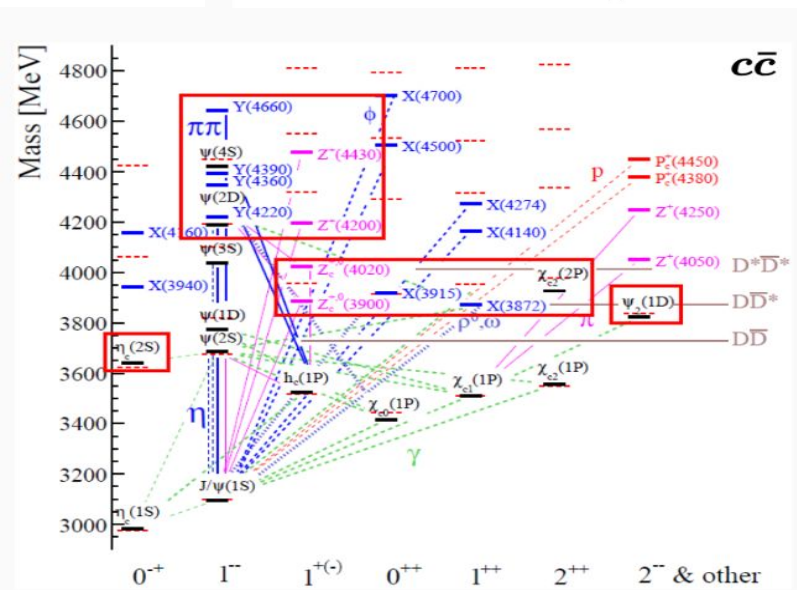
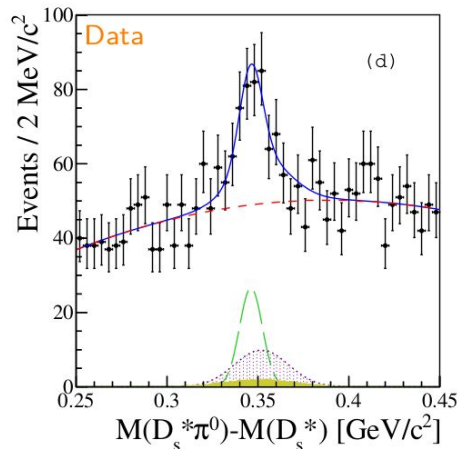
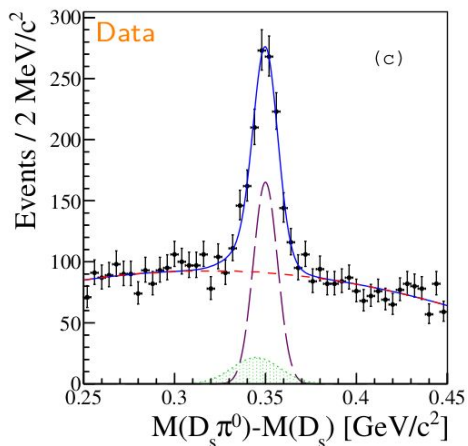
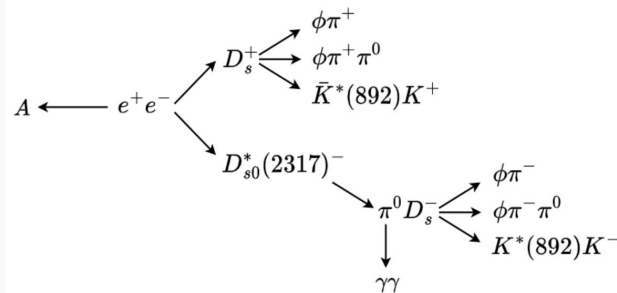
- do hypothesis testing by comparing likelihood differences for different hypothesis

$$W(\vec{x}) = 2[\ln \mathcal{L}(\vec{x}|H_1) - \ln \mathcal{L}(\vec{x}|H_0)]$$



# Exotics searches and chiral symmetry tests

- Dmytro Meleshko
- large Zoo of predicted and/or observed exotic states
- using Belle data to look for resonances in  $ee \rightarrow D_s D_{sJ} A$  ( $J=0,1$ )



# Exotics searches and chiral symmetry tests

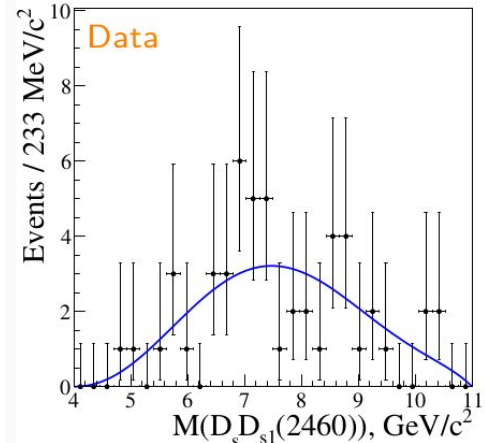
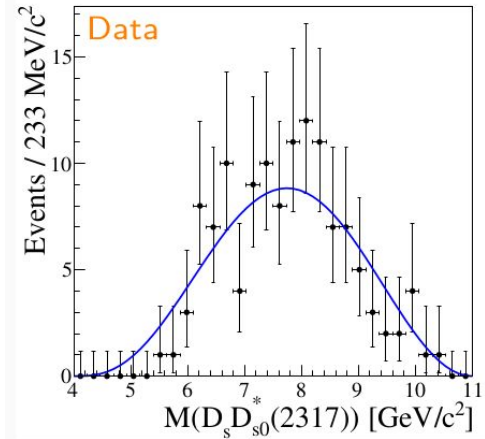
- tested different hypothesis existence of exotic states but no signal found: upper limit set
- determined precise values for masses, width and mass splitting for  $D_{sJ}$  states

$$\frac{Br(D_{s1}(2460) \rightarrow D_s^* \pi^0)}{Br(D_{s0}^*(2317) \rightarrow D_s \pi^0)} \times \frac{\sigma(D_{s1}(2460), \text{MVA})}{\sigma(D_{s0}^*(2317), \text{MVA})} = 0.26 \pm 0.07(\text{stat}) \pm 0.03(\text{syst})$$

\*The value earlier measured by Belle is  $0.29 \pm 0.06 \pm 0.03$

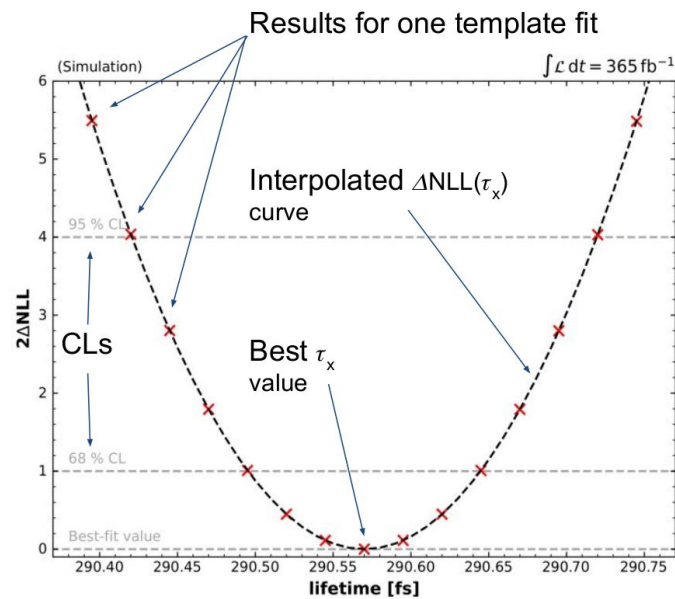
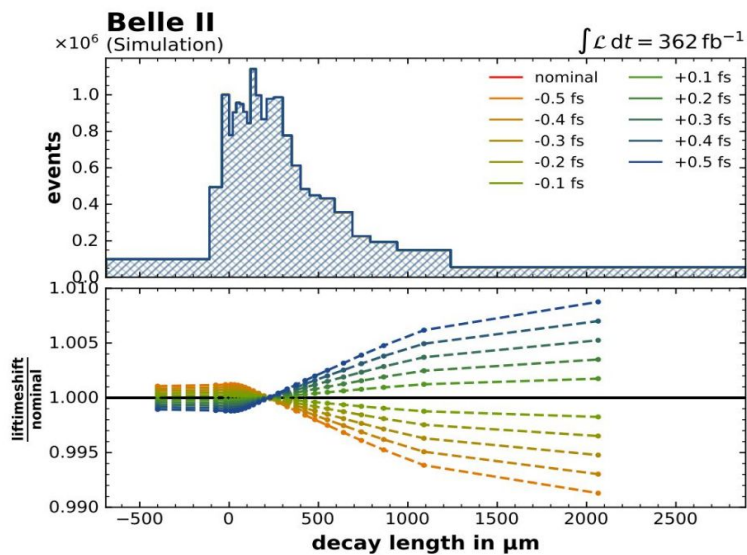
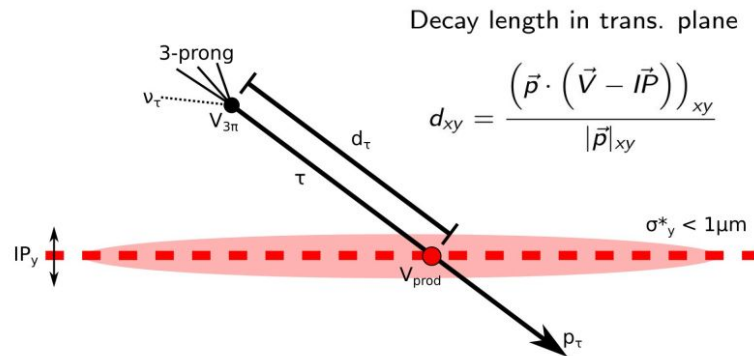
\*\*The value predicted by theory is 3

Decay chain	Total error [%]	Estimated $N_{90}^{UL}$	$\sigma^{UL} \times \mathcal{B}(X \rightarrow D_s D_{sJ}^*)$ [fb]
$e^+ e^- \rightarrow X(4274)A$	13.3	2.45	122.5
$e^+ e^- \rightarrow X(4685)A$	14.1	2.04	101.8
$e^+ e^- \rightarrow X(4630)A$	18.3	2.05	228.1
$e^+ e^- \rightarrow X(4500)A$	18.0	2.34	260.1
$e^+ e^- \rightarrow X(4700)A$	18.7	2.18	241.8



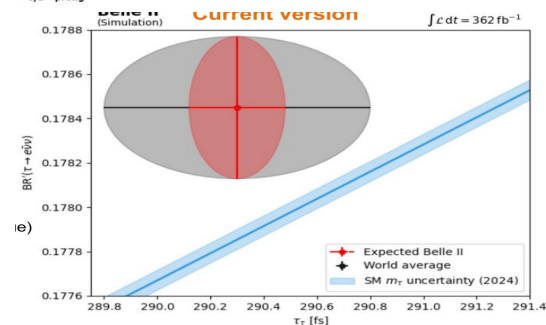
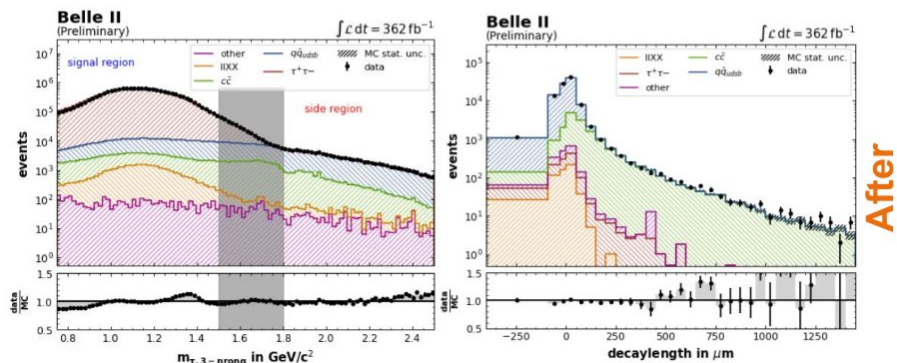
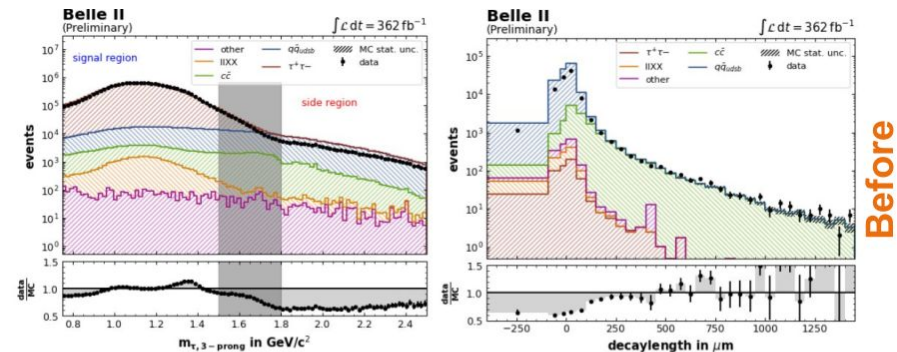
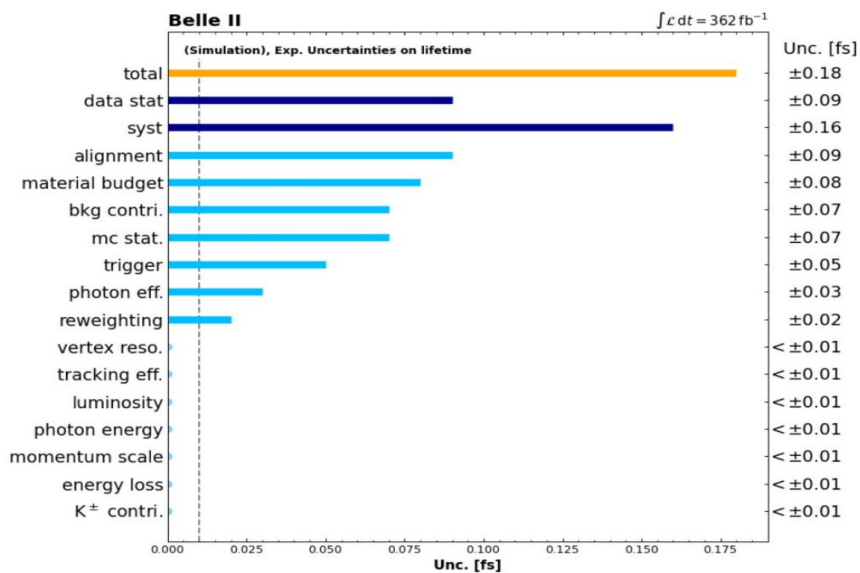
# Measurement of the Tau lifetime

- Anselm Baur
- use current 365fb-1 of Belle II data
- reconstruct tau lifetime from decay length
- perform template fit for different lifetime hypotheses



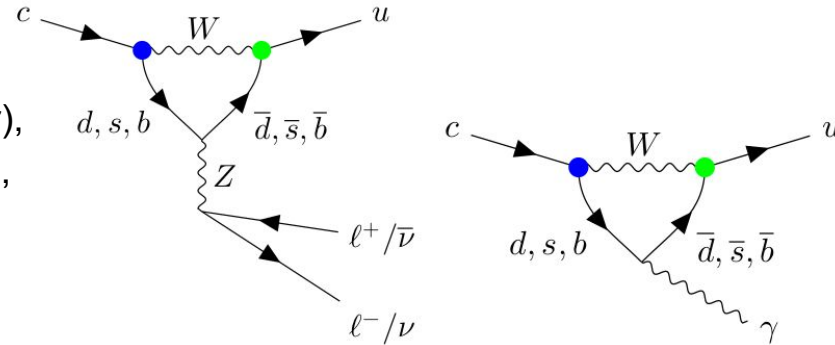
# Measurement of the Tau lifetime

- corrections needed to adjust for data-MC differences
- systematically limited
- perform further tests before unblinding



# Rare charm decays

- Dominik Suelmann
- rare  $c \rightarrow u$  transitions :  $c \rightarrow u + \text{invisible}$  (eg.  $D \rightarrow \pi \nu \bar{\nu}$ ),  $c \rightarrow u \ell \ell$  (eg.  $D \rightarrow \pi \ell \ell$ ),  $c \rightarrow u \gamma$  (eg.  $D^0 \rightarrow \rho^0 \gamma$ ),
- Strong GIM and CKM suppression in SM
- Can help in constraining the NP Wilson Coefficients.



## Experimental status on $c \rightarrow u \ell \ell$

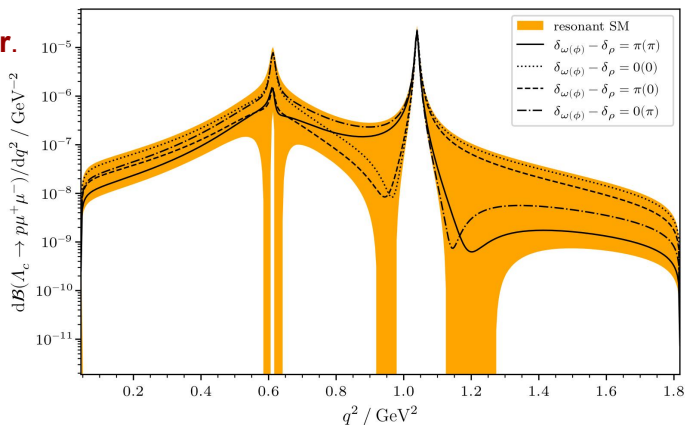
	[CMS-PAS-BPH-23-008]	[LHCb, arXiv:2011.00217]	[LHCb, arXiv:2407.11474]	[LHCb, arXiv:1707.08377, arXiv:2111.03327]
	$D^0 \rightarrow \mu^+ \mu^-$	$D^+ \rightarrow \pi^+ \mu^+ \mu^-$	$\Lambda_c^+ \rightarrow p \mu^+ \mu^-$	$D^0 \rightarrow \pi^+ \pi^- \mu^+ \mu^-$
upper limits BR	✓	full- $q^2$ , (low- $q^2$ , high- $q^2$ )	low- $q^2$ , high- $q^2$ , combined, full- $q^2$	high- $q^2$
resonant BR	$< 4 \cdot 10^{-11}$	$\mathcal{B}_\phi$ , narrow-width approx. (NWA)	$\frac{\mathcal{B}_{\omega\text{-region}}}{\mathcal{B}_{\phi\text{-region}}}, \frac{\mathcal{B}_{\rho\text{-region}}}{\mathcal{B}_{\phi\text{-region}}}$ , NWA	$\mathcal{B}_{\omega/\rho\text{-region}}, \mathcal{B}_{\phi\text{-region}}$ $\left( \frac{d\Gamma}{dm_{\mu^+\mu^-}}, \frac{d\Gamma}{dm_{\pi^+\pi^-}} \right)$
angular obs.	—	not measured	not measured	CP-sym./CP-asym. $\langle S_{2-9} \rangle, \langle A_{2-9} \rangle$

- $c \rightarrow u \ell \ell$  constrain NP models independently in low- $q^2$  and high- $q^2$ .
- Major source of uncertainty : Strong phases
- Best constraints on C10 from  $D^0 \rightarrow \mu \mu$
- Best constraints on C7 from  $\Lambda_c \rightarrow p \mu^+ \mu^-$
- Constraints from  $D \rightarrow \pi \mu \mu$  are weakest: Theoretically more challenging.

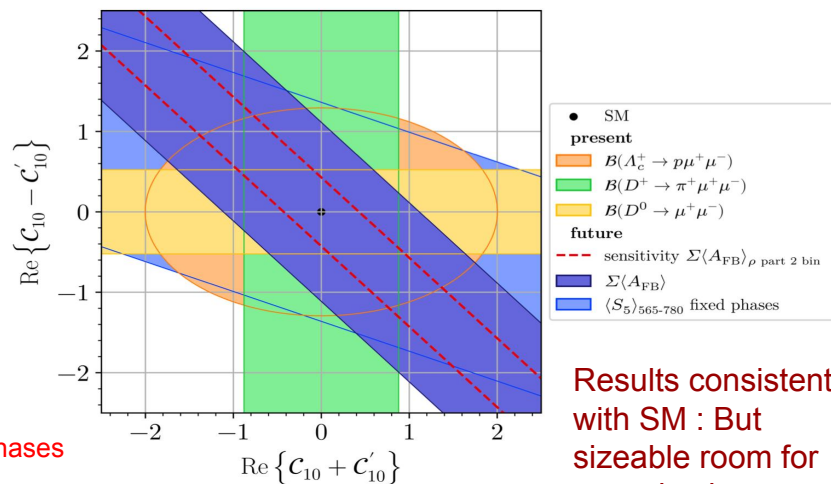


## $\Lambda_c \rightarrow p\mu^+\mu^-$ : The rising star.

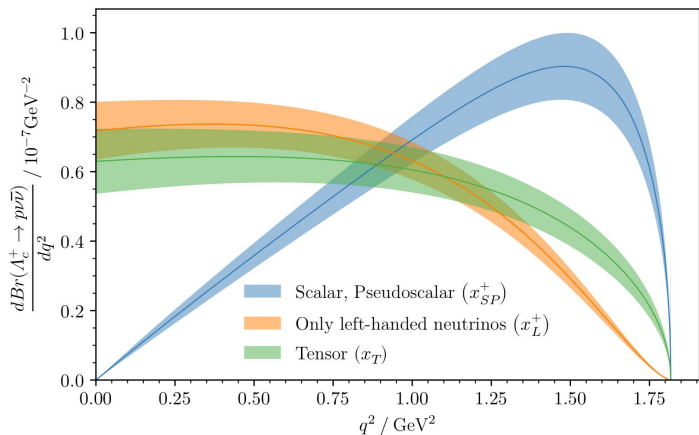
- 3 body decay : Simpler
- Form factors available from Lattice.
- Sensitive to 4 fermion as well as dipole coupling



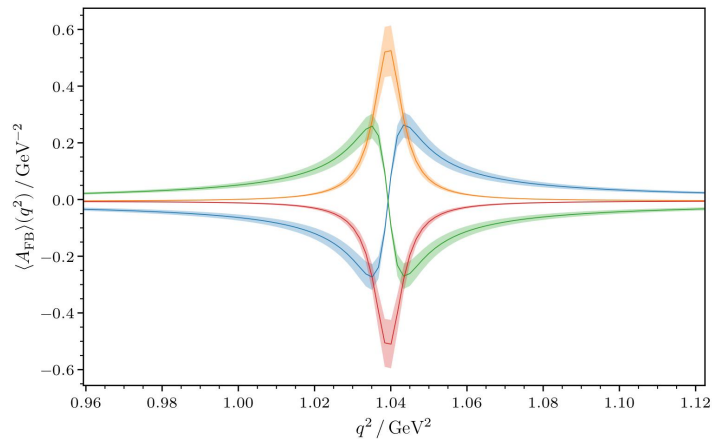
Major sources of uncertainty: Lack of information on strong phases



Results consistent with SM : But sizeable room for new physics.



- Much potential for future.
- Other light NP plausible (like ALPs, Z', Dark Photon)



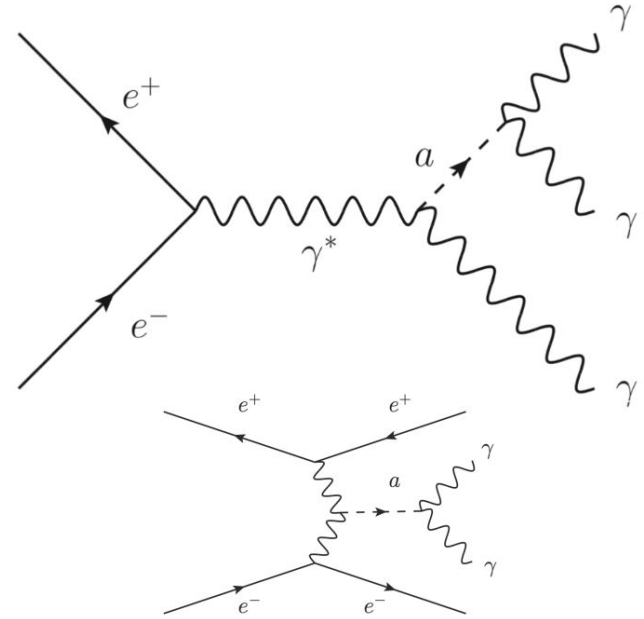
- Future improvements with Null tests.
- Binning around resonances is important for null tests.

Results on arxiv today (<https://arxiv.org/pdf/2410.00115>)



# Searches for $e^+e^- \rightarrow a(-\rightarrow \gamma\gamma) \gamma$

- Alexander Heidelbach
- search for Axion Like Particles
  - ALP Strahlung
- several sources for backgrounds



$e^+e^- \rightarrow \gamma\gamma\gamma$

- Most dominant background
- Approximately constant distribution in  $M_{\gamma\gamma}$

$e^+e^- \rightarrow e^+e^- \gamma$

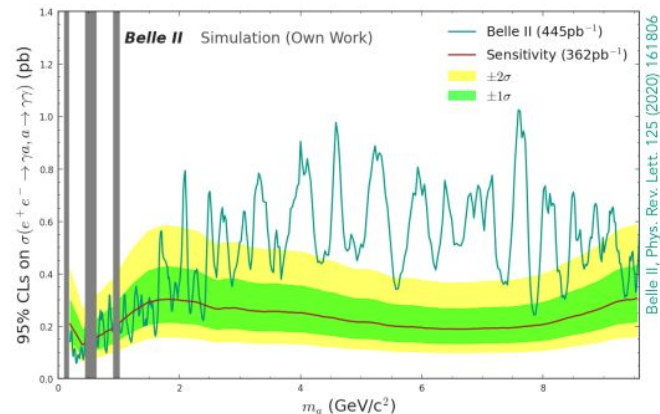
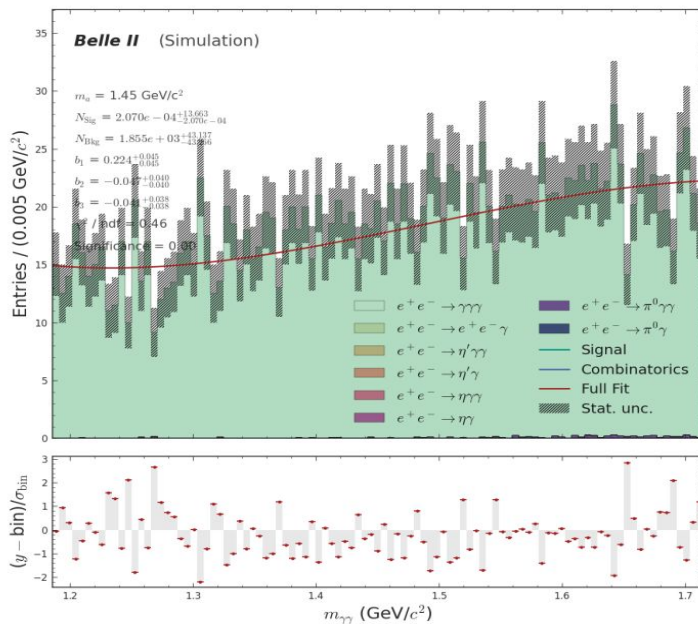
- Most common process
- Need to miss both tracks and reconstructed ECL clusters to be counted as background

$e^+e^- \rightarrow h\gamma(\gamma)$

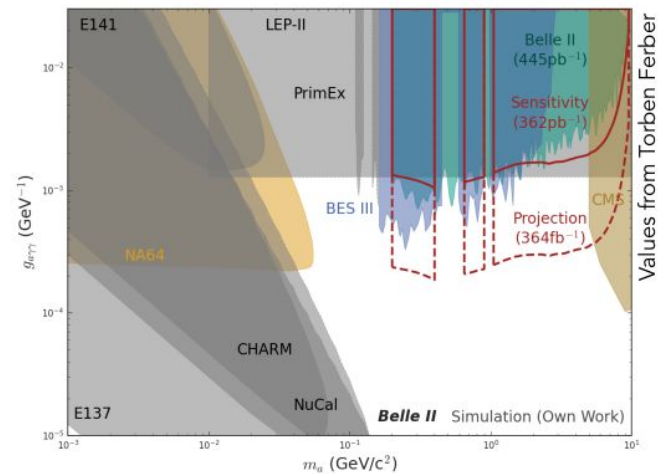
- $h = \pi^0, \eta, \eta', \dots$
- Irreducible background in  $M_{\gamma\gamma}$
- Additional source through next order process  $ee \rightarrow h\gamma\gamma$

# Searches for $e^+e^- \rightarrow a(-\rightarrow \gamma\gamma) \gamma$

- hypothesis testing by fitting the  $m(\gamma\gamma)$
- extract upper limits and put constraints on physics models



Belle II, Phys. Rev. Lett. 125 (2020) 161806



# Inclusive rare radiative decays

- Ana Luisa Carvalho, Christian Wessel, Lu Cao, Kerstin Tackman
- hadronically tag one B meson
- signal side: inclusive  $X_s$  gamma
- only preliminary result for 189fb-1 from Belle II
- update to full Belle II data set
  - full signal side reconstruction
  - use multiclass classifier to reduce backgrounds
  - alternative fit strategy
- sensitive to non-perturbative shape function of B-meson:
  - input to other

## Inclusive rare radiative decays in Belle II

Ana Luisa Carvalho | Christian Wessel | Lu Cao | Kerstin Tackman

1 Motivation and introduction

- Rare, loop induced process in the Standard Model (penguin diagrams)
- Potentially sensitive to beyond the SM physics

Illustrative diagram of  $b \rightarrow \bar{d}$  transition with  $R^2$   $\gamma$  final state

$$\mathcal{L}_{\text{eff}} \propto C_2 \times \left[ \text{Diagram 1} \right] + C_3 \times \left[ \text{Diagram 2} \right] + \sum_{i=1,2,7,8} C_i \times \left[ \text{Diagram 3} \right]$$

- Contributions from operators  $O_{1,2,7,8}$  in heavy flavor effective lagrangian
- Inclusive branching ratio:** sensitive to  $|V_{ts}^* V_{tb}|$
- Photon energy in B meson rest frame:** sensitive to non-perturbative shape function  $\Rightarrow$  Input for  $B \rightarrow X_s \gamma$  theoretical description

2 Methodology

- Inclusive  $X_s$  system:**  $B \rightarrow X_s \gamma$
- BR =  $(3.49 \pm 0.19) \times 10^{-4}$  [PDG average]
- Hadronic tagging**
- Fully reconstructed tag (FEI)  $\Rightarrow$  infer kinematics of signal B-meson
- Better control over backgrounds
- Cross-check with other tagging methods

3 State of the art

- $B \rightarrow X_s \gamma$  with hadronic tagging unexplored in Belle
- Babar:  $(3.90 \pm 0.64 (\text{stat.}) \pm 0.91 (\text{syst.})) \times 10^{-4}$  [1]
- Belle II preliminary result (189 /fb) [2]

BR =  $(3.65 \pm 0.80 (\text{stat.}) \pm 0.86 (\text{syst.})) \times 10^{-4}$

Photon energy  $> 1.5 \text{ GeV}$

Room for improvement: current dataset of 365 /fb and run-dependent Monte Carlo simulation

4 What is new in this round of the analysis?

- Reconstruction improvements: **full signal side reconstruction, p meson rejection**
- Continuum reweighting: further modeling improvement
- Multiclass BDT: continuum and **BB background rejection**
- Alternative template fit strategy (under study)

5 Conclusions and outlook

- Analysis effort restarted:** inclusive and differential measurements of  $B \rightarrow X_s \gamma$  branching fraction with hadronic tagging with 365 /fb of data
- Work ongoing for **potential improvements**
- Increase rejection of BB background
- Control background photons from signal-side
- Reduce systematic uncertainties

References

FEI mode: charged

- $B^+ \rightarrow X_s^+ \gamma$
- $B^0 \rightarrow X_s^0 \gamma$
- $B^+ \rightarrow B^0 \gamma$
- $B^0 \rightarrow B^+ \gamma$
- $B^0 \rightarrow B^0 \gamma$
- $B^+ \rightarrow B^+ \gamma$
- $B^0 \rightarrow B^0 \gamma$
- $B^+ \rightarrow B^+ \gamma$
- $B^0 \rightarrow B^0 \gamma$
- $B^+ \rightarrow X_s^+ \gamma \times 100$
- $B^0 \rightarrow X_s^0 \gamma \times 100$
- Data