Summary: Physics Analyses and Theory session

Conveners: Thomas Lück, Thibaud Humair, Anshika Bansal

Belle II Germany Meeting 2024 @ DESY

02/10/2024

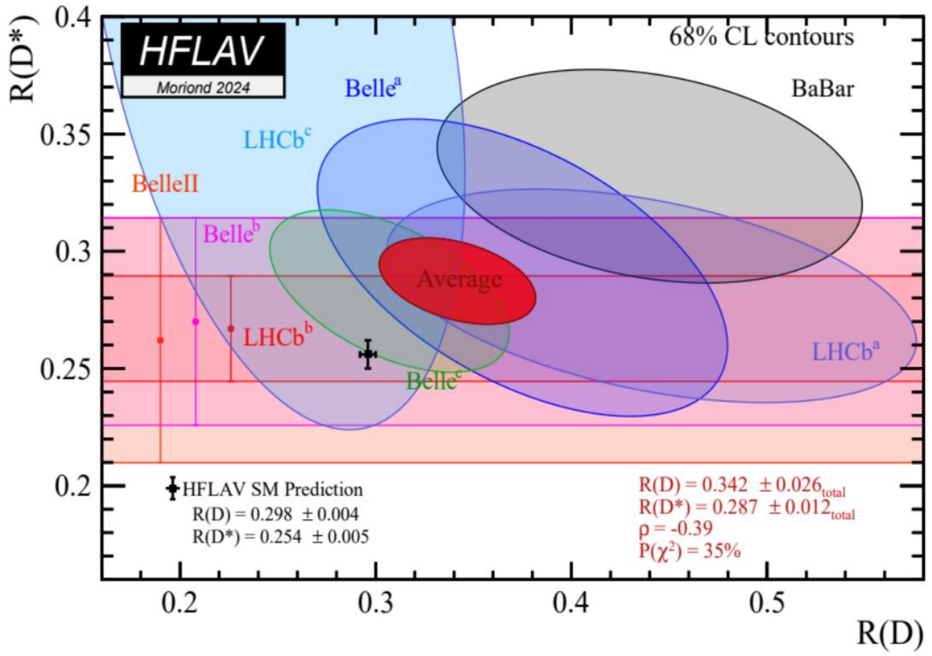
Overview

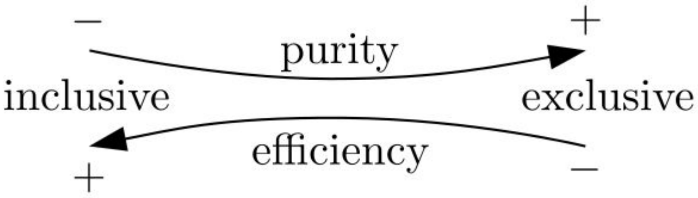
- In total we had 13 experimental and 1 theory talk.
- 3 Poster presentations
- A broad range of topics covered:
    - R(D*) measurements
    - V_{ub}/V_{cb} determinations
    - B->K/pi \nu \bar \nu Decays
    - Direct measurements of R_0^+
    - Baryon number violation in B decays
    - Study of exotic particles
    - Tau lifetimes
    - Rare charm decays, and
    - ALPs searches

R(D*) Measurements

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

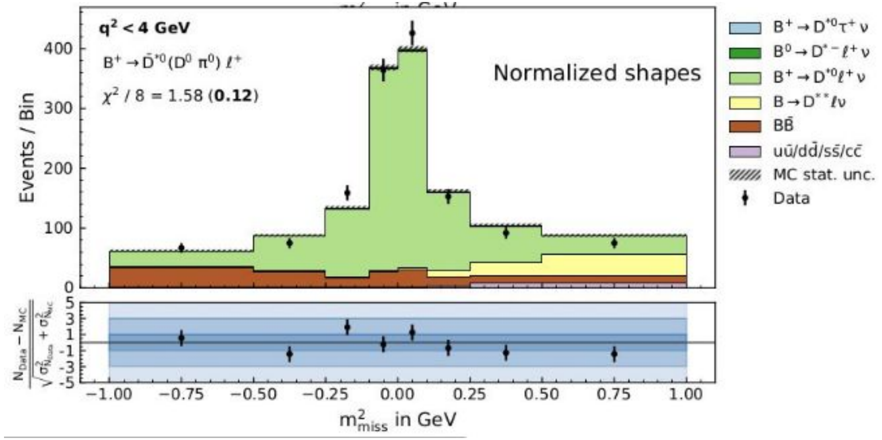
- test lepton universality in the SM
- currently around R(D*) exceeds SM prediction by 2.5 sigma
- combined R(D) and R(D*) exceed SM by 3.3sigma
- different approaches at B-factories
    - tag: hadronic vs. semileptonic vs. inclusive
    - tau decay: leptonic vs. hadronic

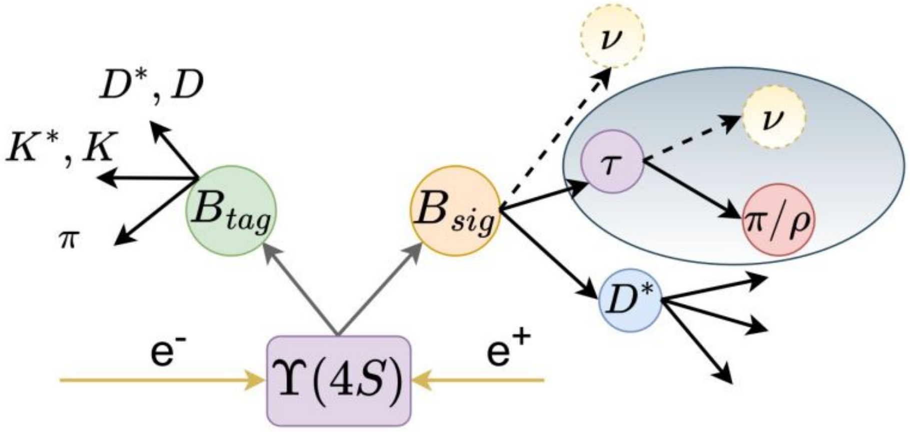




R(D*) Measurements in hadronic one prong-tau decays

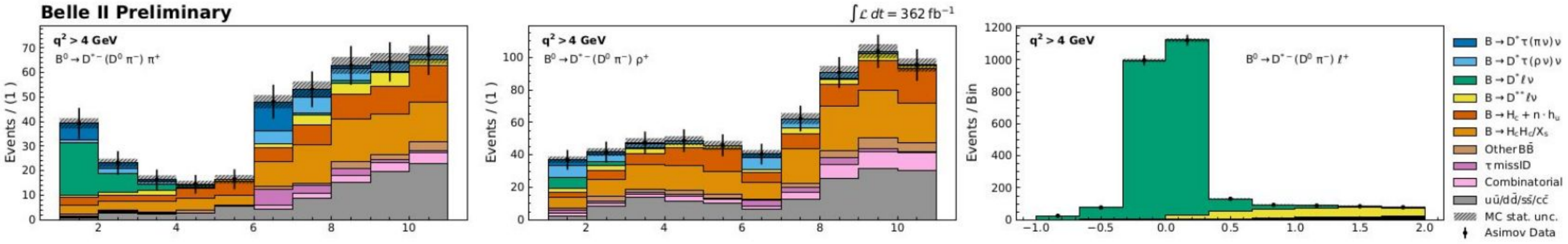
- Ilias Tsaklidis
- tag one B by fully reconstructing it in hadronic decay mode
- hadronic tau decay
  - tau to rho nu
  - tau to pi nu
- some basic selections
- use q2 < 4GeV2 as calibration





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:

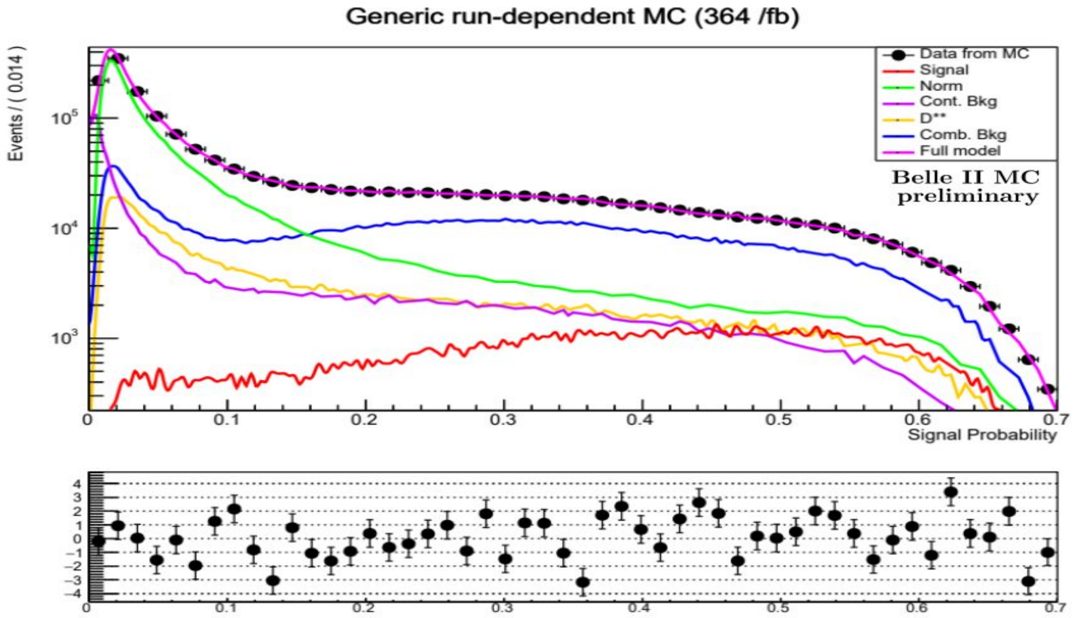


R(D*) = 0.2580 ± 0.0370 ± 0.0148

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

R(D*) Measurement with inclusive tag

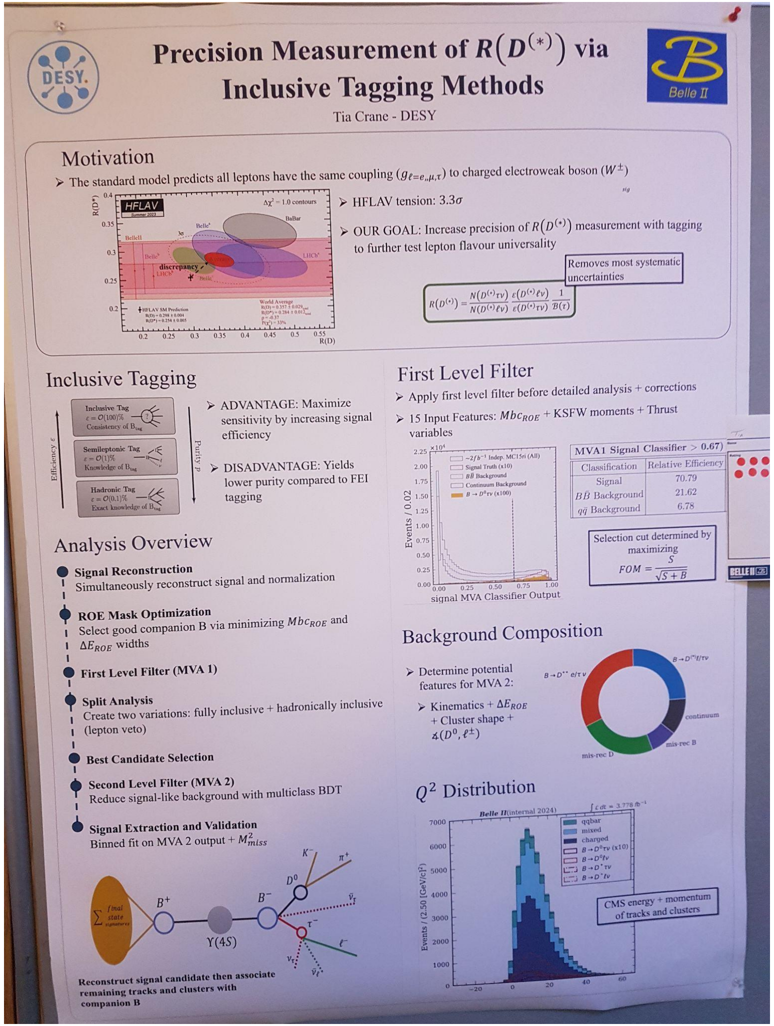
- Thomas Ametsbichler
- reconstruct B->D*l nu
- define rest of event as tag B
- train BDT on 12 input variables to distinguish 5 event classes: signal, normalization, D**lnu, other BB, continuum
- 1D fit on BDT output for signal probability
- MC study only



Measurement	Tagging	$\int \mathcal{L}\,dt$ [fb^{-1}]	$R(D^*)$	$\sigma_{stat.}$	$\sigma_{syst.}$	$\sigma_{stat.}$ rescaled to 364 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

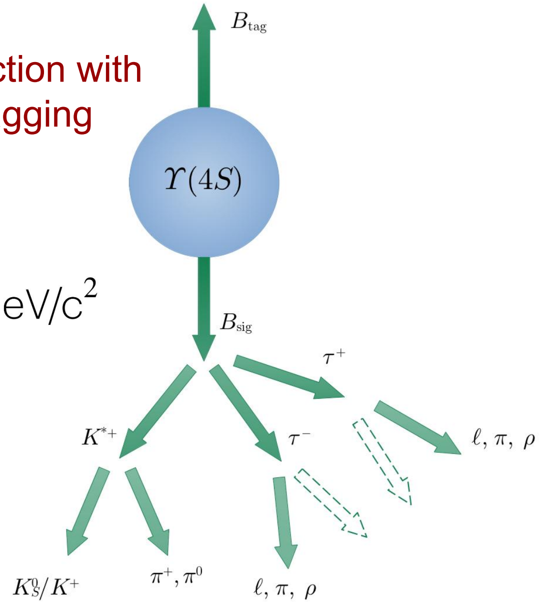
R(D(*)) Measurements using inclusive tagging

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



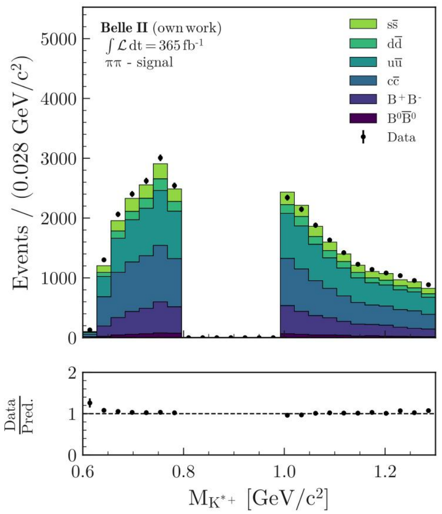
Study of $B^+ \to K^{*+}\tau\tau$

Reconstruction with hadronic tagging

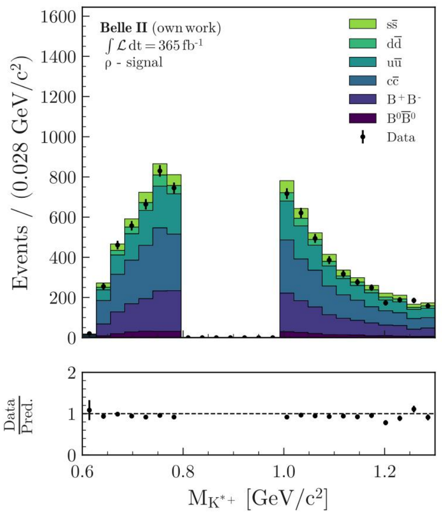


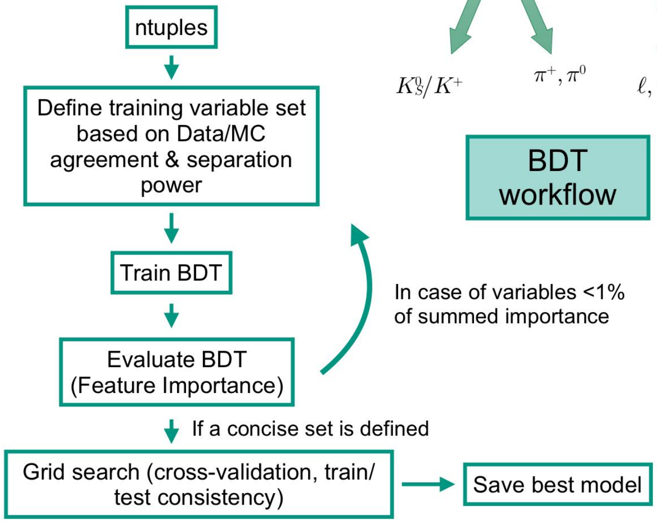
- Lennard Damer
- SM: $BR(B^+ \to K^{*+}\tau^+\tau^-) \approx 10^{-7}, BR_{NP} \approx 10^{-4}$
- Enforced mass criterion to boost signal sensitivity.
- Tails as the control region : $M_{K^*} < 0.79$ GeV/c^2 and $M_{K^*} > 0.994$ GeV/c^2
- FastBDT for background suppression.
- Most Challenging background: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

$\pi\pi$-channel

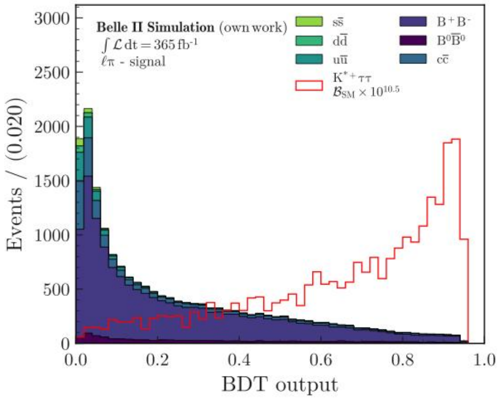


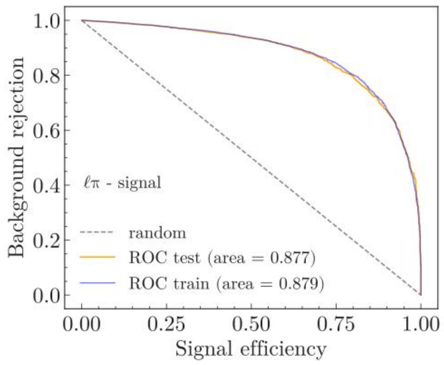
ρ-channel



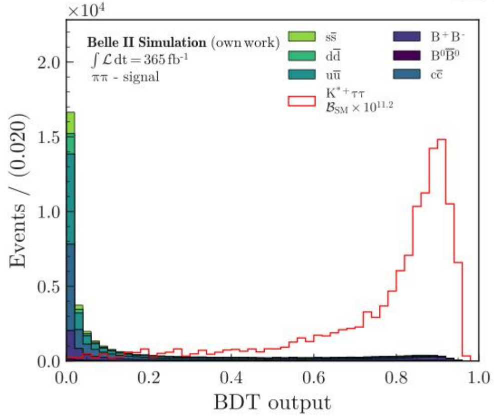


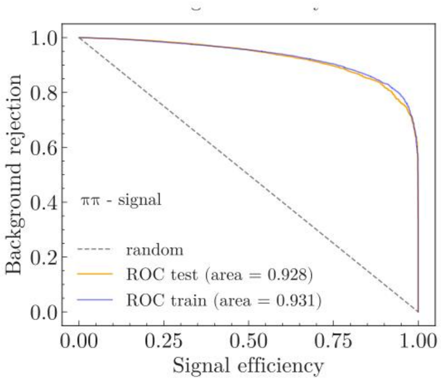
$\ell\pi$-channel





$\pi\pi$-channel





Achieved good separation between signal and background.

First search for B->K* \tau^+ \tau^-

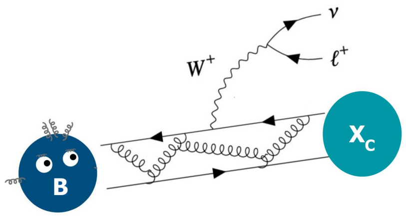
BR $(B^+ \rightarrow K^{*+}\tau^+\tau^-) < 8.38 \times 10^{-3}$ @90% CL

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

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

Kinematic Moments in inclusive semileptonic b->c decays

- Munira Khan
- Kinematic moments required for determination of Vcb.
- Very challenging theoretically due to non-perturbative QCD dynamics.

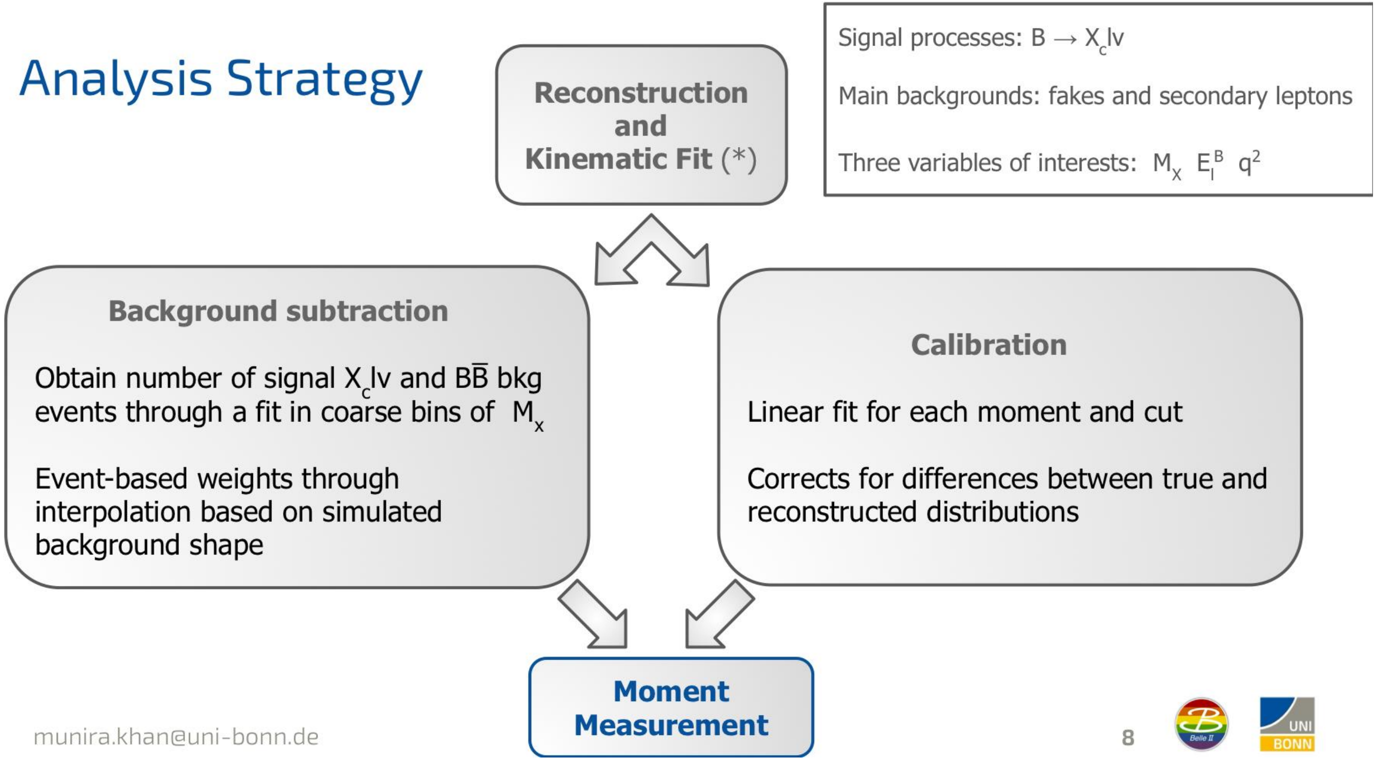


E_l^B

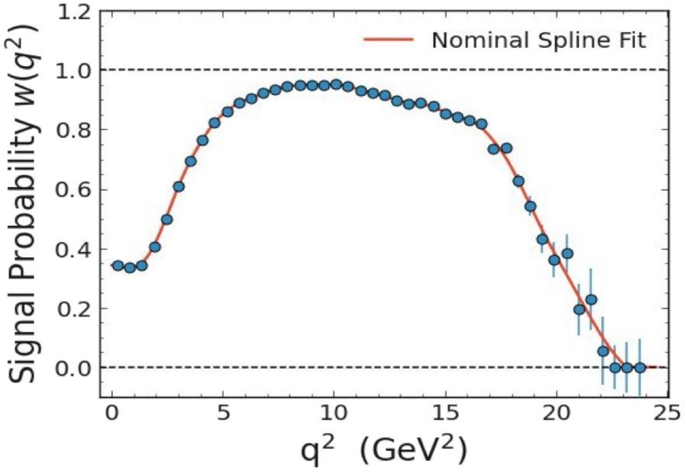
M_X

q^2

Analysis Strategy



Background Subtraction

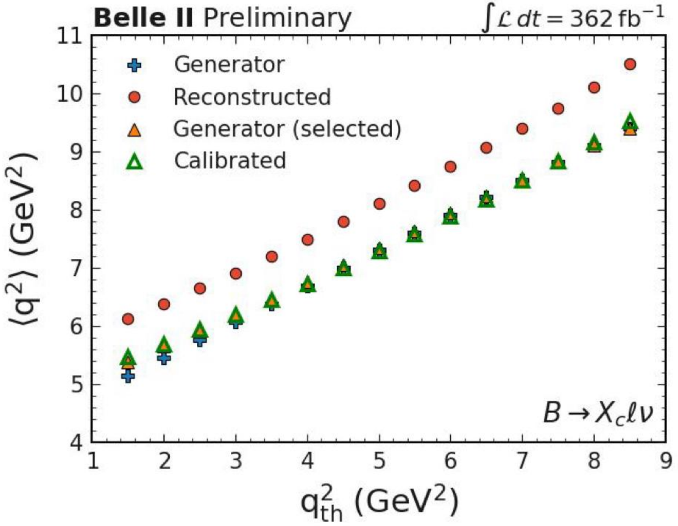


- Bias tests have been performed to make sure that the calibration is unbiased

Calibration

- 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 Vub

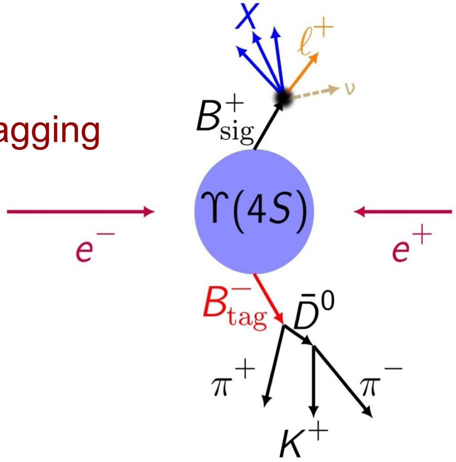
- Tommy Martinov
- Long standing tension between the exclusive and inclusive determination

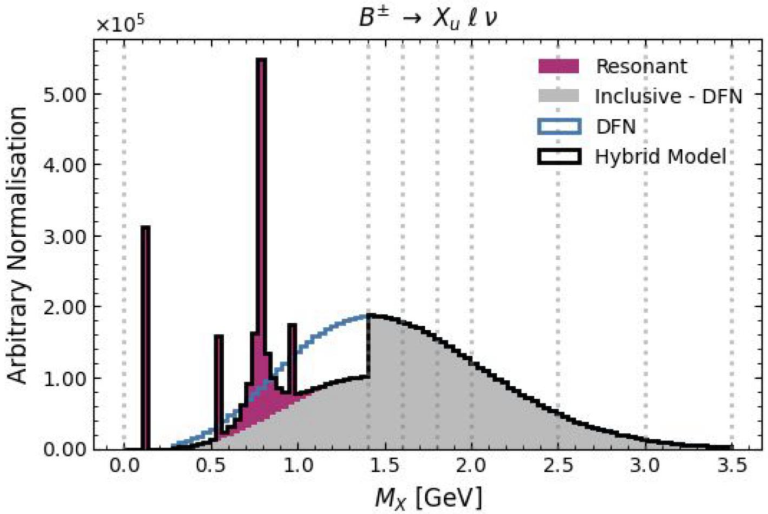
$$|V_{ub}| = (4.13 \pm 0.12^{+0.13}_{-0.14} \pm 0.18) \times 10^{-3}$$ PDG incl

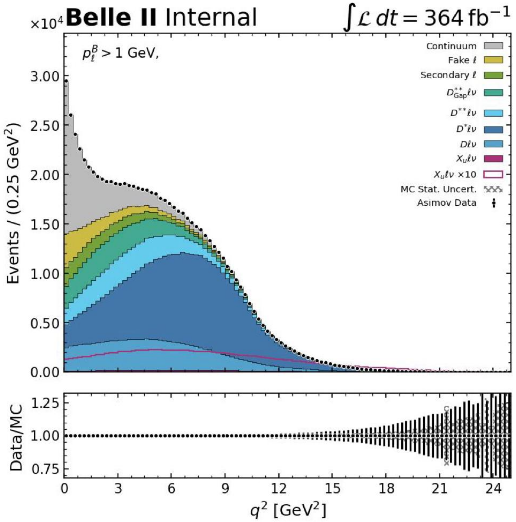
$$|V_{ub}| = (3.70 \pm 0.10 \pm 0.12) \times 10^{-3}$$ PDG excl

- Based on Heavy Quark Expansion.
- Largest background : B -> Xc l nu
  - Cuts in phase space leading to break down of HQE.

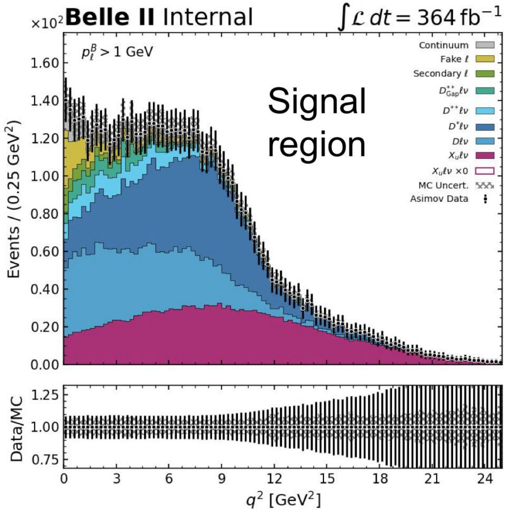
Hadronic tagging







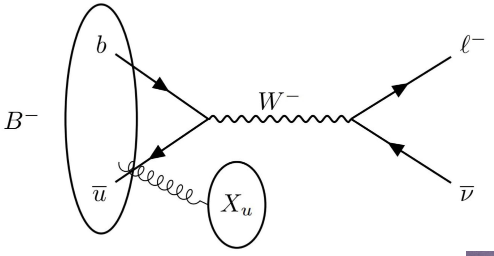
Before selection

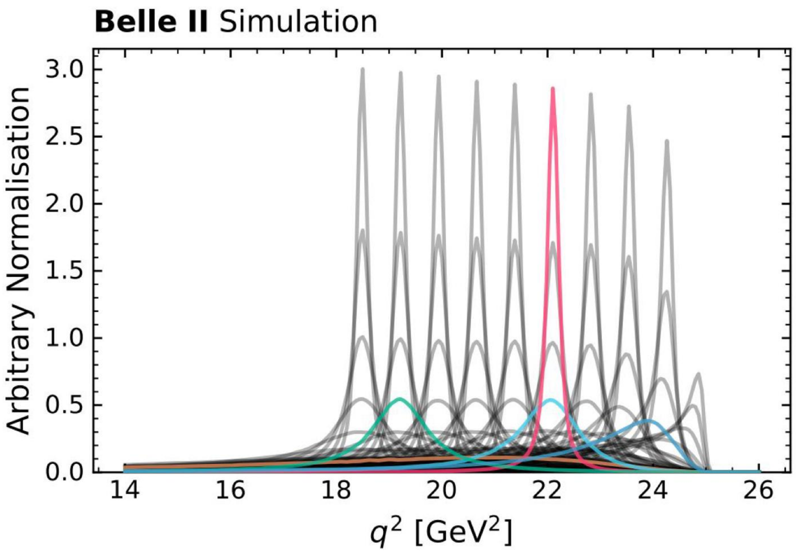


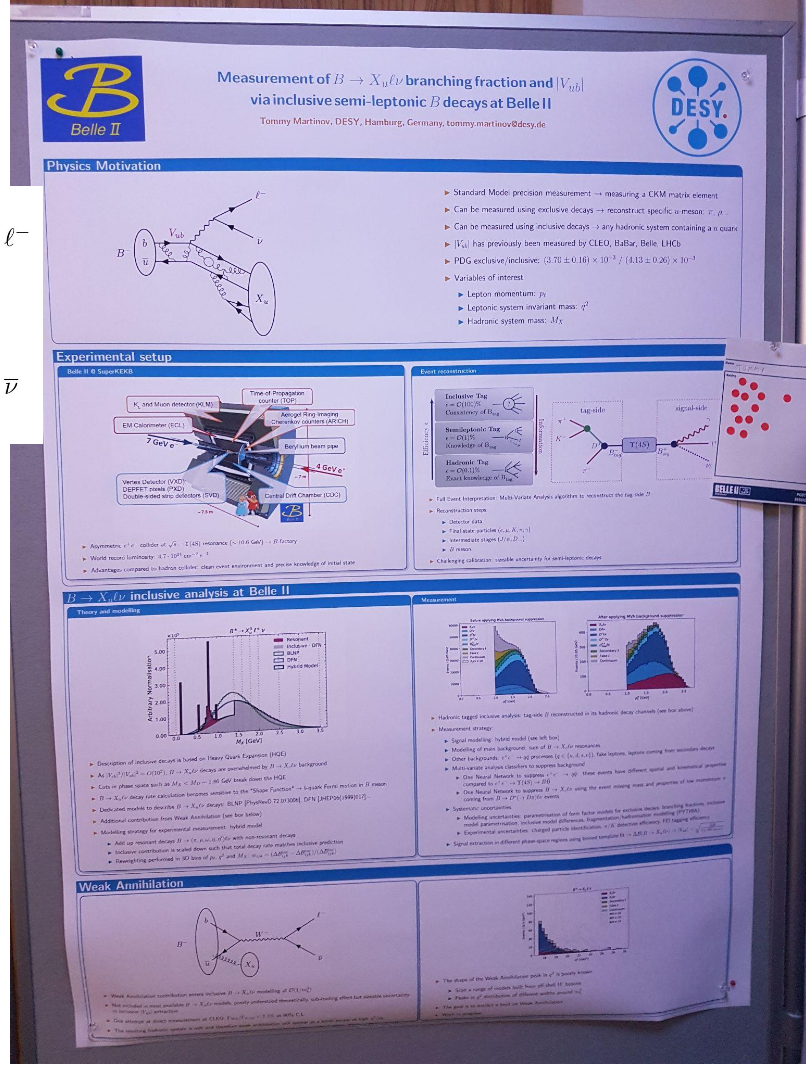
After selection

Weak Annihilations

- Enter @ O(1/mb^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.

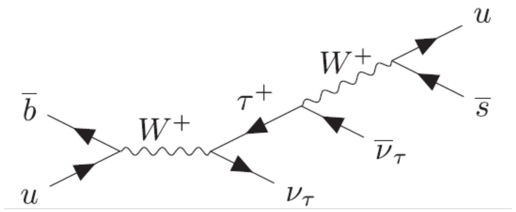






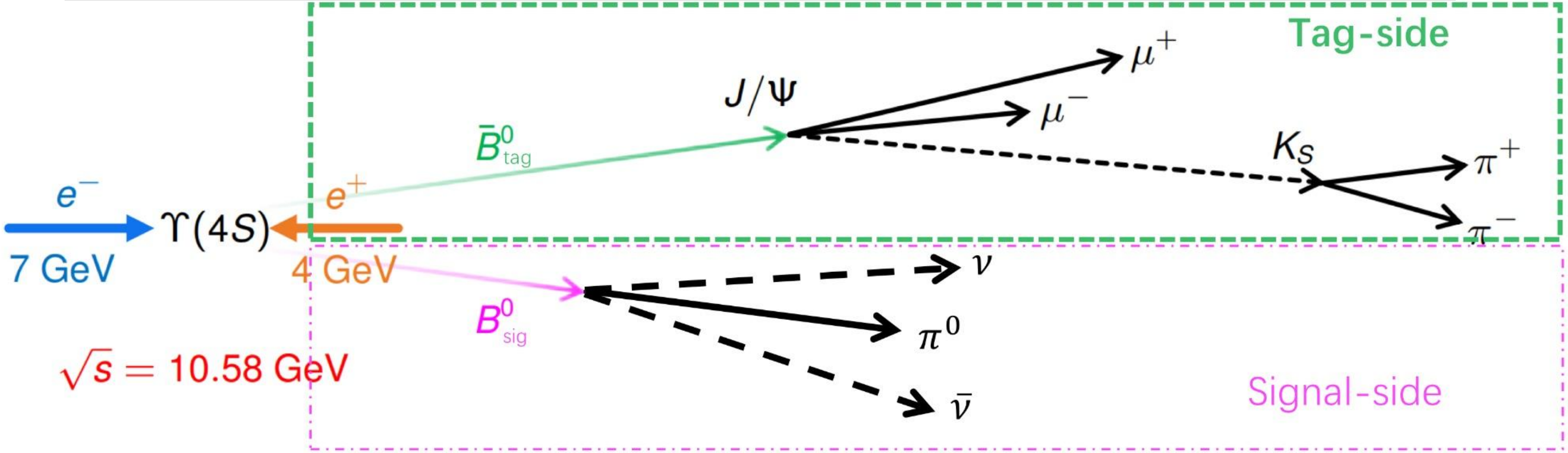
Study of B->\pi \nu \bar\nu

- Boyang Yu
- SM: Penguin and Box contribution.



Long distance contribution

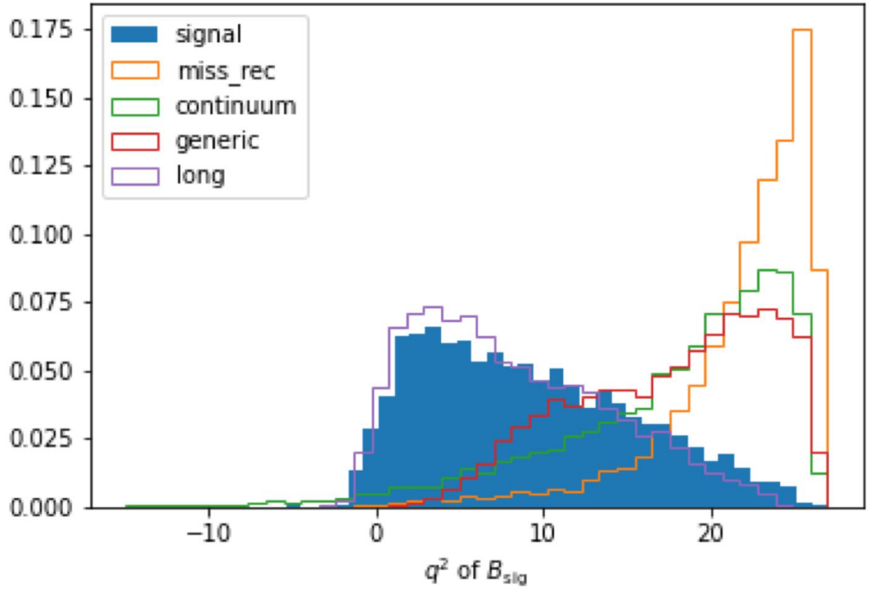
Charged Channel	SM Prediction	Long-distance Channel	SM Prediction
$B^+ \to \pi^+ \nu\bar{\nu}$	0.239×10^{-6}	$B^+ \to [\tau^+ \to \pi^+ \bar{\nu}]\nu$	11.8×10^{-6}
$B^+ \to K^+ \nu\bar{\nu}$	5.58×10^{-6}	$B^+ \to [\tau^+ \to K^+ \bar{\nu}]\nu$	0.61×10^{-6}



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

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

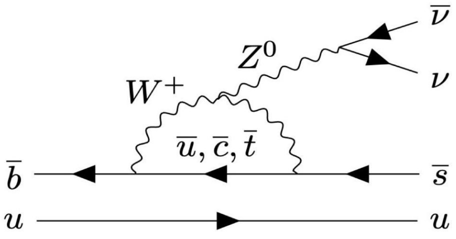
After selection

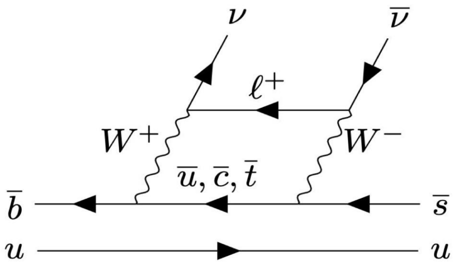


- B->\pi \nu\bar\nu : Good platform for testing new reconstruction algorithm.
- Expected BR ~ O(10^{-7})
- UL from previous study ~ O(10^{-5})
- Similar study for B->K\nu\bar\nu to follow.

Study of B->K \nu \bar\nu

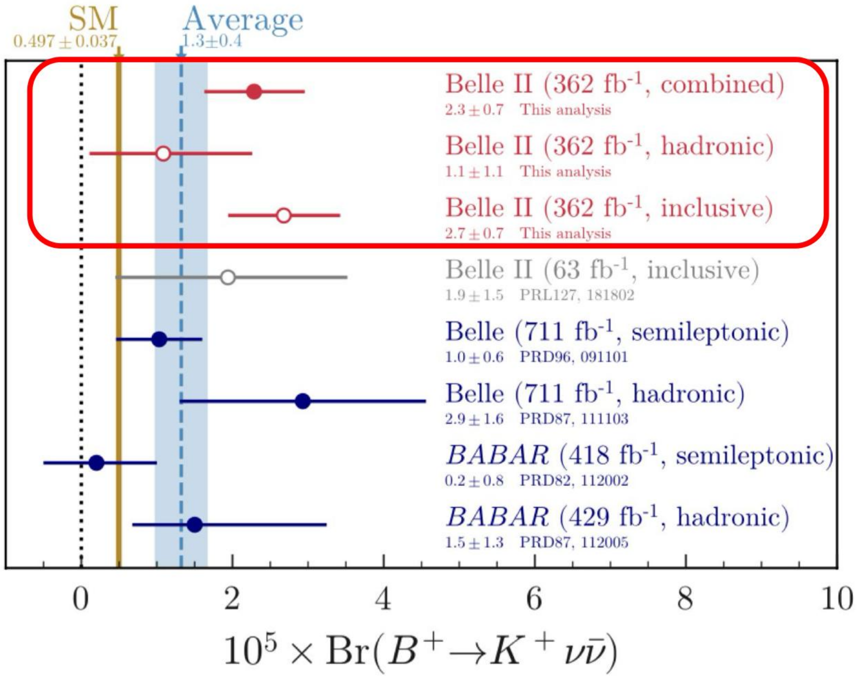
- Yabo Han
- b->s\nu\bar\nu transition: Powerful to probe SM.
- Major challenge: Low efficiency of final states with Ks0 and pi0

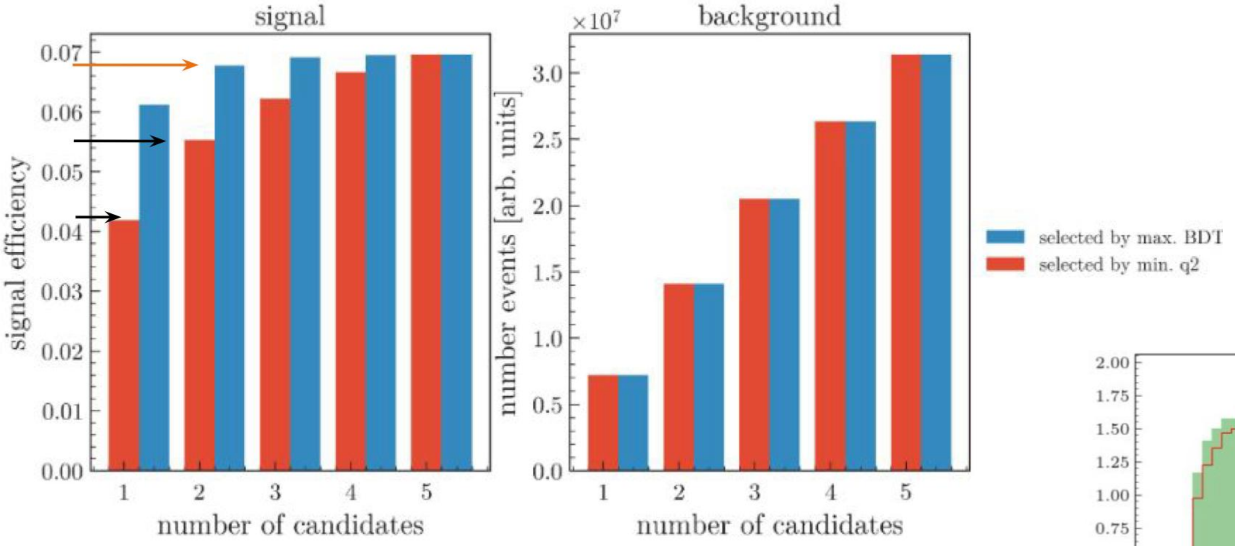




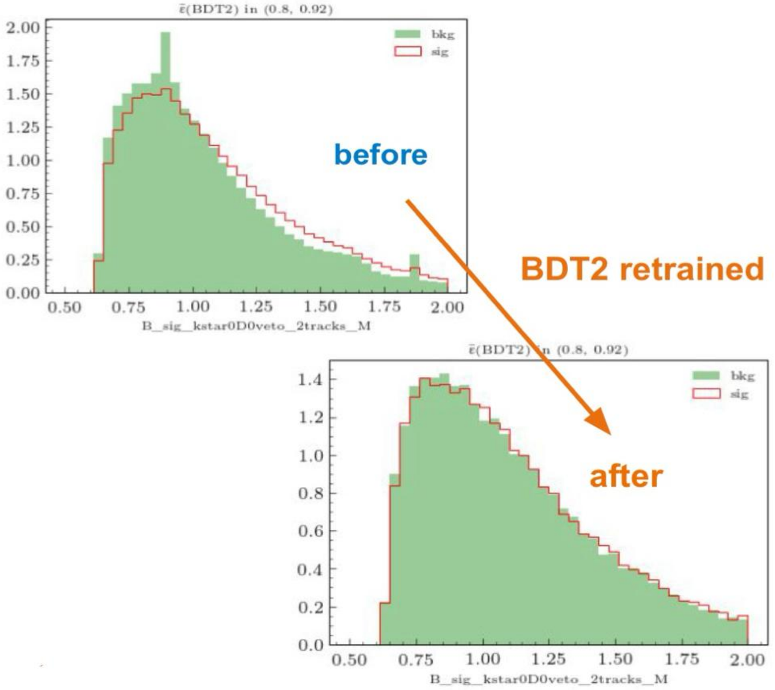
Work flow and Analysis status

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

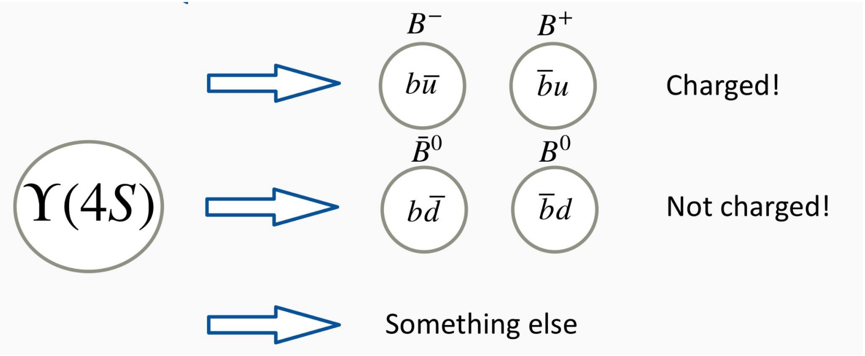


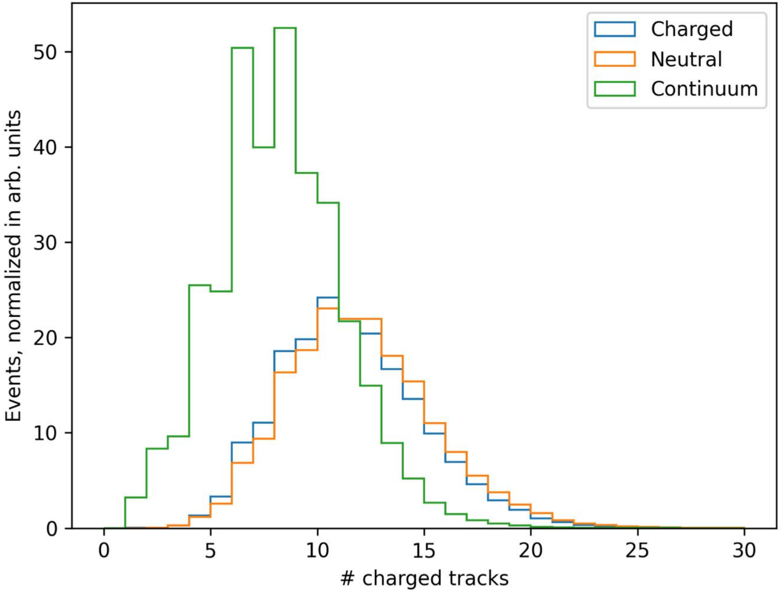
- Dominant background:
  - K+, Ks0 : from D
  - K*: D -> K*X and Combinatorial background

Direct measurements of R_0^+

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

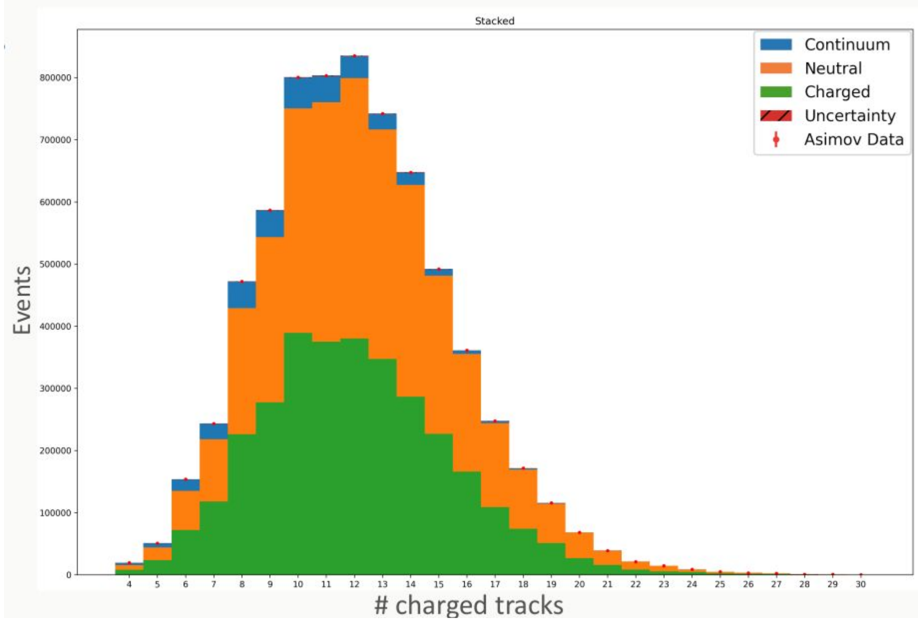
- Anna-Maria Heyn
- Current $R^{\pm 0} = 1.057^{+0.024}_{-0.025}$ (HFLAV)
- Hard for theory
- count number of tracks in event: slightly different for charged and neutral B
- direct measurement: no reconstruction of intermediate states
- use BDT to suppress continuum events

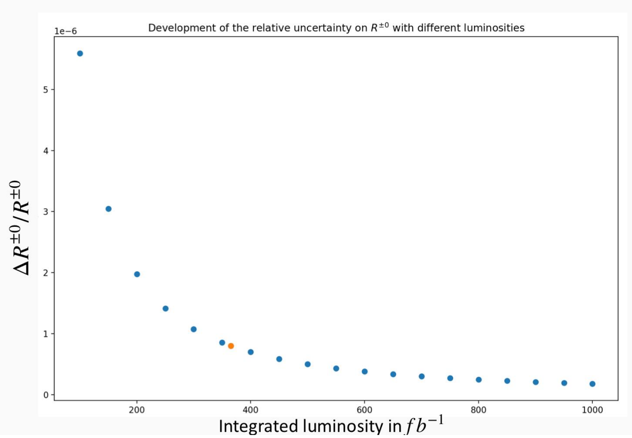




Direct measurements of R_0^+

- 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

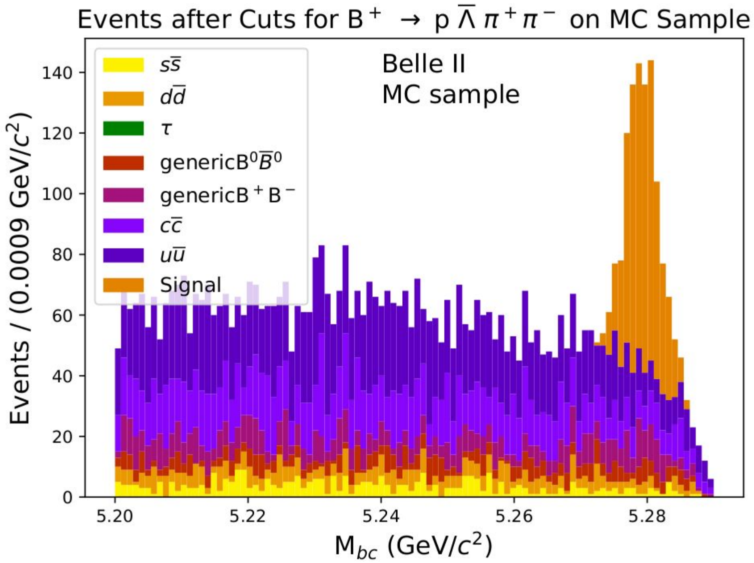
Baryon Number Violation in B decays

- 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

$\rightarrow$ SM decay: $B^+ \rightarrow p\overline{\Lambda}(\rightarrow \overline{p}\pi^+)\pi^+\pi^-$

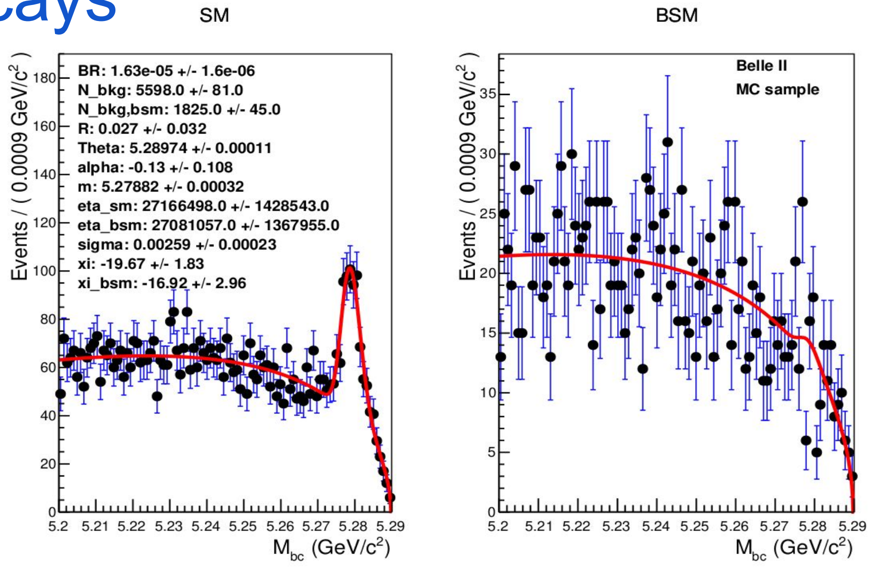
$\rightarrow$ BSM decay: $B^+ \rightarrow p\Lambda(\rightarrow p\pi^-)\pi^+\pi^-$

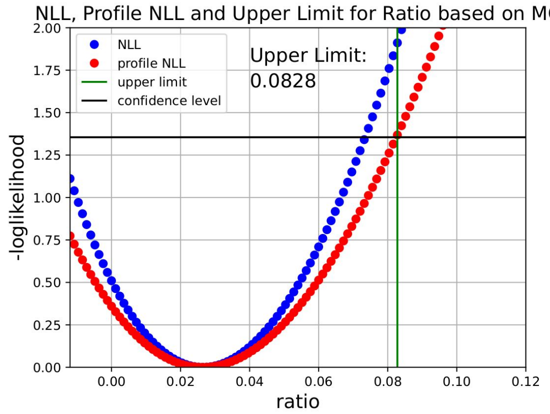
- selection:
  - PID and kinematic selections
  - train dedicated BDT to reduce continuum bkg



Baryon Number Violation in B decays

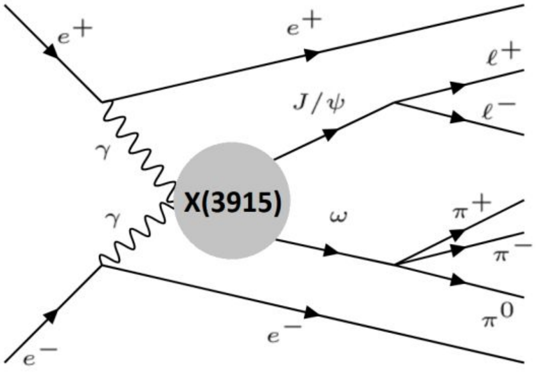
- Melanie Hess
- simultaneous fit to SM and BSM channel:
  - extract SM BR
  - ratio of BSM/SM BR
- uncertainties included as nuisance parameter
- on MC:
  - upper limit on BR ratio 0.082 corresponding to BR < 1.35 x 10-6 @90%CL



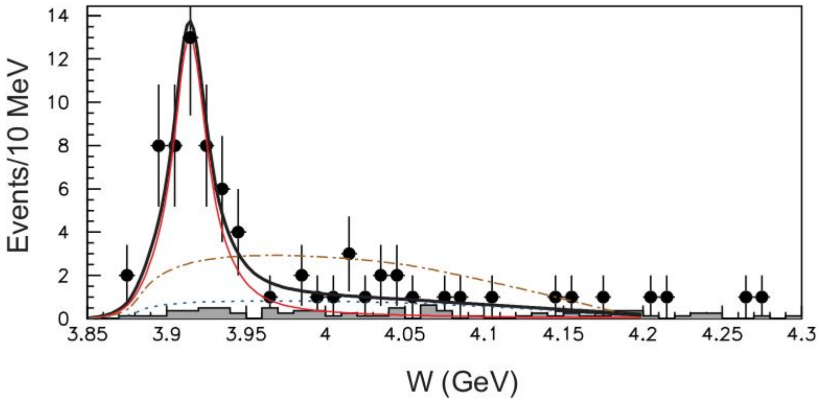


Study of X(3915)

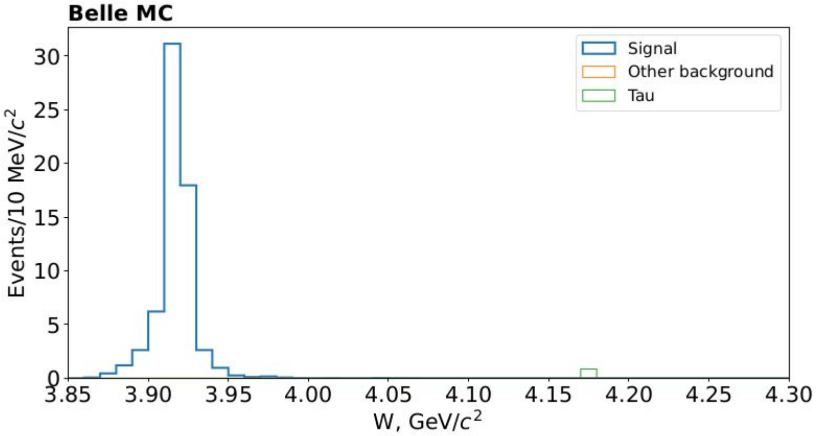
- Yaroslav Kulii
- exotic state X(3915) undetermined quantum numbers
- full Belle data set
- untagged: initial e+e- escape detector



Belle analysis (2010)



This analysis



Study of X(3915)

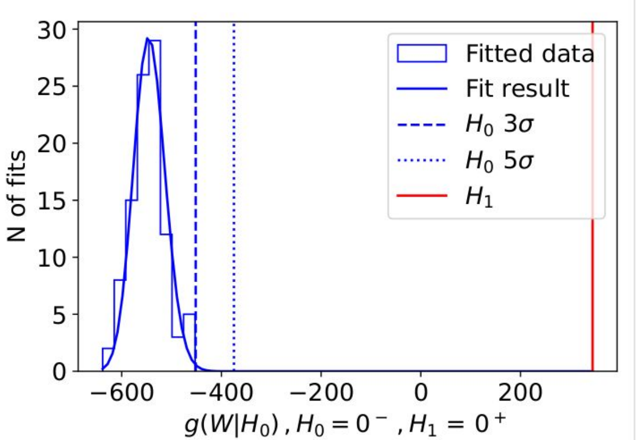
- do an amplitude analysis to determine J^P quantum numbers
- measure 5 decay angles and fit hypothesis using theory prediction to fit for up to 9 free parameters (depending on hypothesis)

$$\ln \mathcal{L}(\vec{\theta};\tau_k) = \underbrace{\sum_{k=1}^{N} w_k \ln \mathcal{I}(\tau_k;\vec{\theta})}_{\text{Data sample (weighted)}} - \underbrace{N \ln[\frac{1}{N_{MC}} \sum_{j=1}^{N_{\mathrm{MC}}^{\mathrm{acc}}} \mathcal{I}(\tau_j;\vec{\theta})]}_{\text{Phase space MC}},$$

where $\mathcal{I}$ - *intensity* is the number density of produced events in the phase space

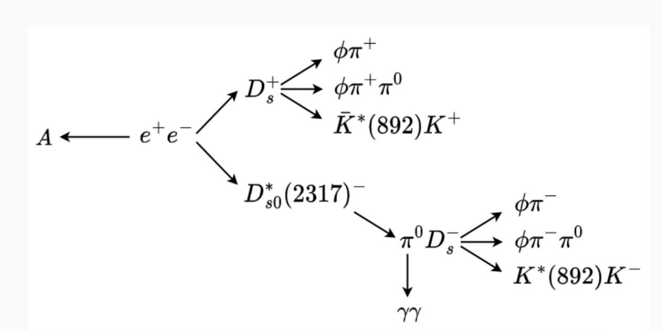
- do hypothesis testing by comparing likelihood differences for different hypotheis

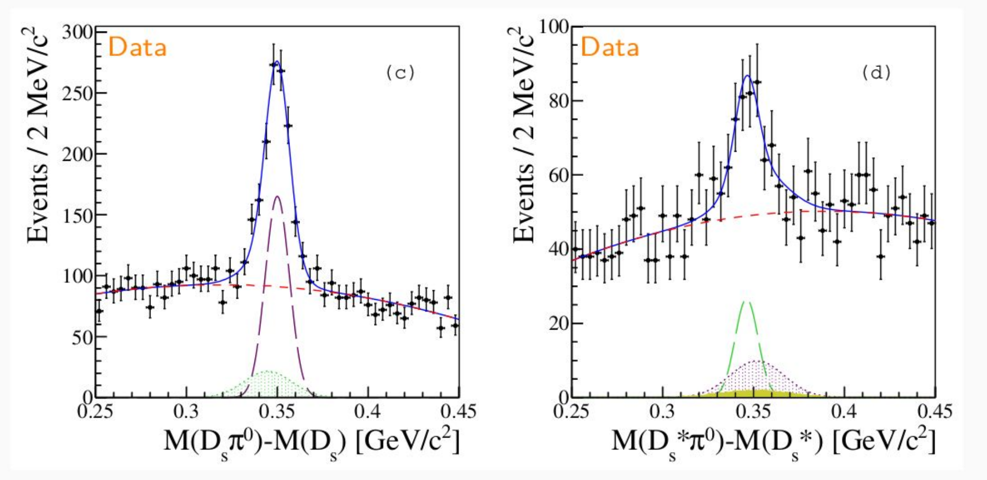
$$W(\vec{x}) = 2[\ln \mathcal{L}(\vec{x}|H_1) - \ln \mathcal{L}(\vec{x}|H_0)]$$

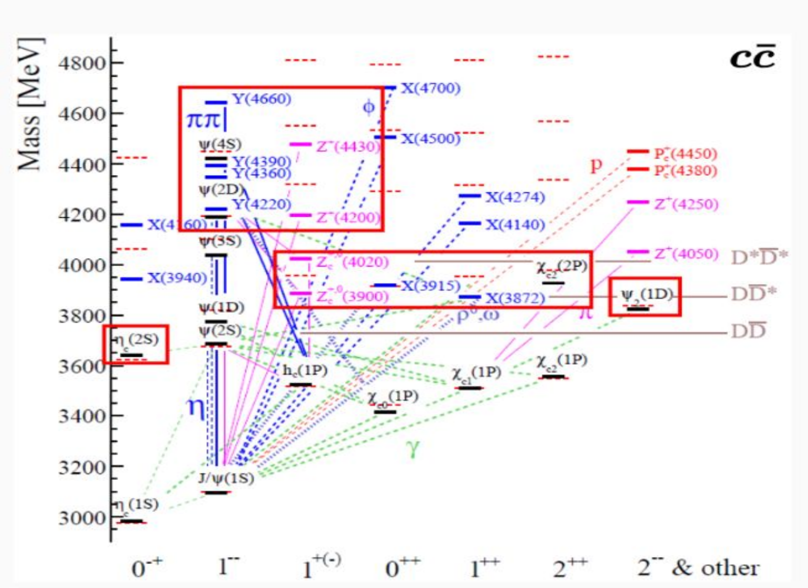


Exotics searches and chiral symmetry tests

- Dmytro Meleshko
- large Zoo of predicted and/or observed exotic states
- using Belle data to look for resonances in ee->D_s D_sJ A   (J=0,1)







Exotics searches and chiral symmetry tests

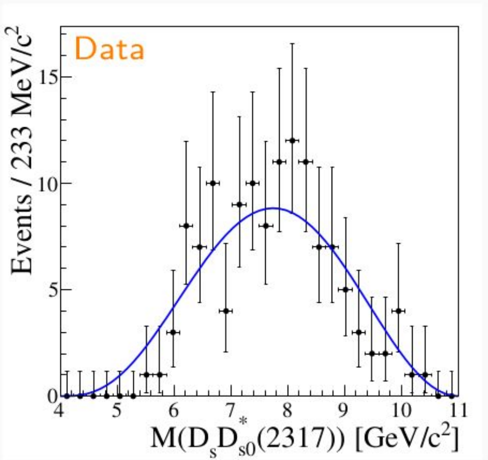
- tested different hypothesis existence of exotic states but no signal found: upper limit set
- determined precise values for masses, width and mass splitting for D_sJ states

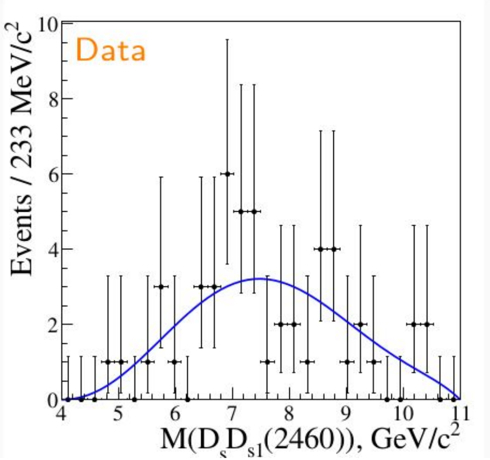
$$\frac{Br(D_{s1}(2460) \to D_s^* \pi^0)}{Br(D_{s0}^*(2317) \to D_s \pi^0)} \times \frac{\sigma(D_{s1}(2460), \mathrm{MVA})}{\sigma(D_{s0}^*(2317), \mathrm{MVA})} = 0.26 \pm 0.07(\mathrm{stat}) \pm 0.03(\mathrm{syst})$$

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

**The value predicted by theory is 3

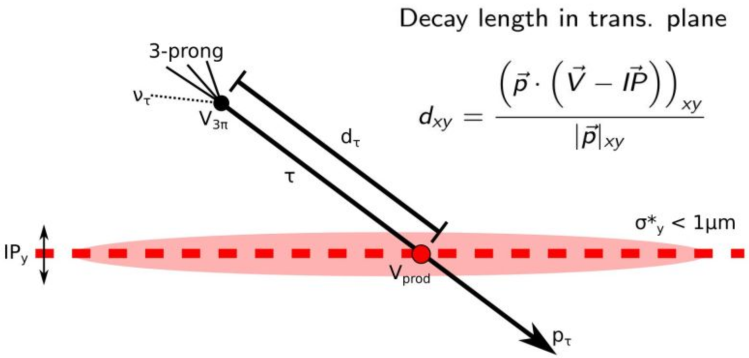
Decay chain	Total error [%]	Estimated N_{90}^{UL}	$\sigma^{UL} \times \mathcal{B}(X \to D_s D_{sJ}^*)$ [fb]
$e^+e^- \to X(4274)A$	13.3	2.45	122.5
$e^+e^- \to X(4685)A$	14.1	2.04	101.8
$e^+e^- \to X(4630)A$	18.3	2.05	228.1
$e^+e^- \to X(4500)A$	18.0	2.34	260.1
$e^+e^- \to X(4700)A$	18.7	2.18	241.8

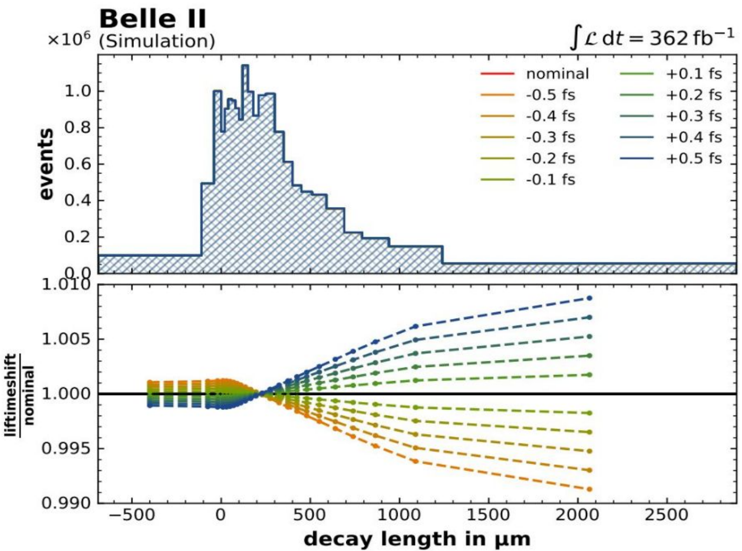


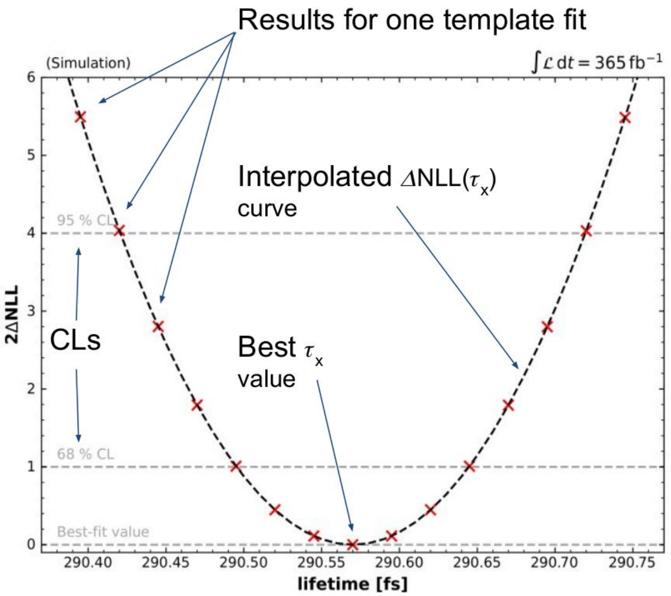


Measurement of the Tau lifetime

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

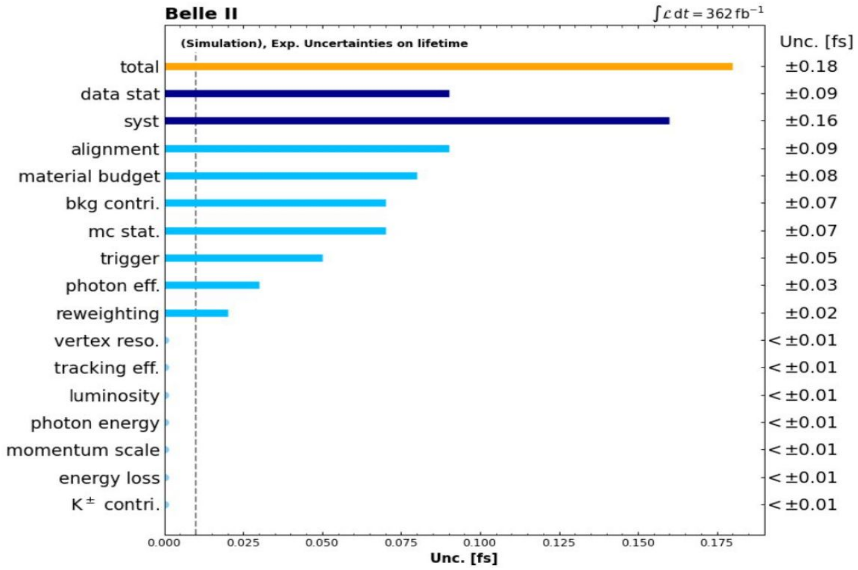


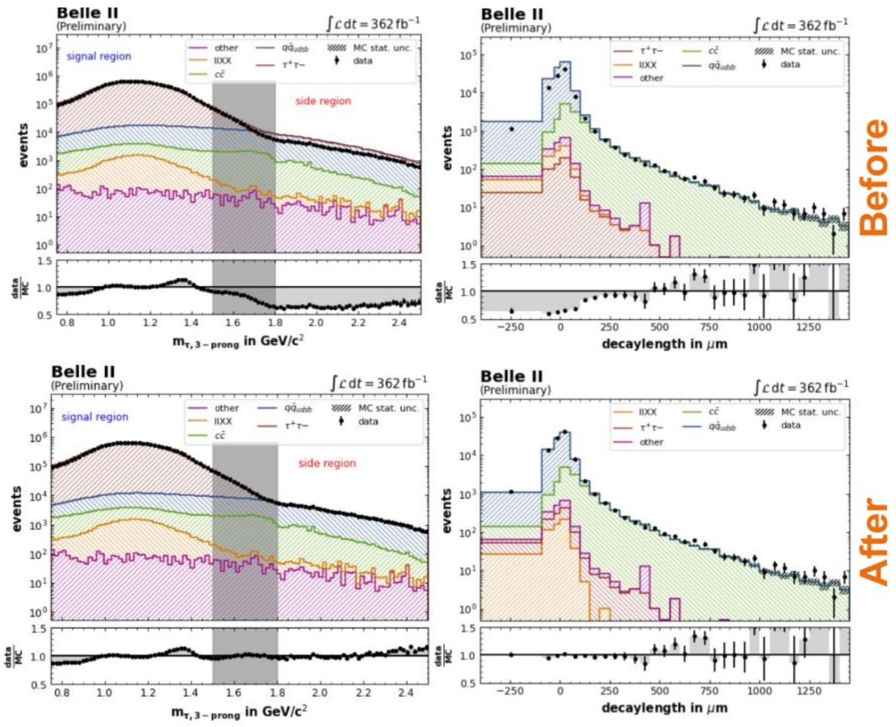


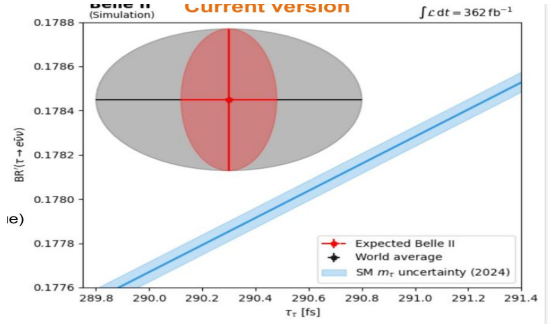


Measurement of the Tau lifetime

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

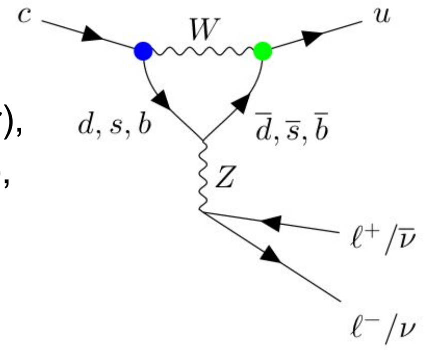


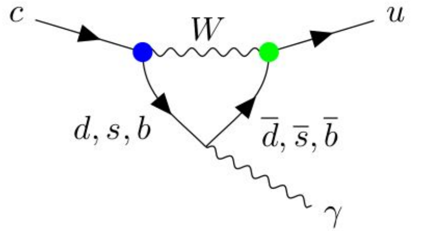




Rare charm decays

- Dominik Suelmann
- rare c->u transitions : c->u+invisible (eg. D->pinunubar), c->ull (eg. D->pill), c->ugamma (eg. D0->rho0 gamma),
- Strong GIM and CKM suppression in SM
- Can help in constraining the NP Wilson Coefficients.





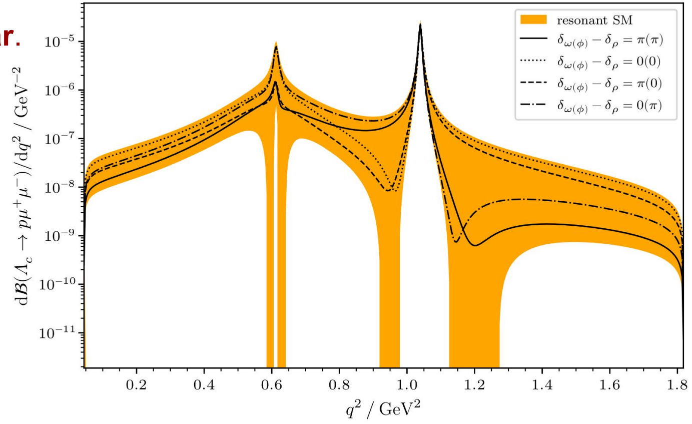
Experimental status on c->ull

	[CMS-PAS-BPH-23-008] $D^0 \to \mu^+\mu^-$	[LHCb, arXiv:2011.00217] $D^+ \to \pi^+\mu^+\mu^-$	[LHCb, arXiv:2407.11474] $\Lambda_c^+ \to p\mu^+\mu^-$	[LHCb, arXiv:1707.08377, arXiv:2111.03327] $D^0 \to \pi^+\pi^-\mu^+\mu^-$
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. $\langle S_{2-9}\rangle$,$\langle A_{2-9}\rangle$

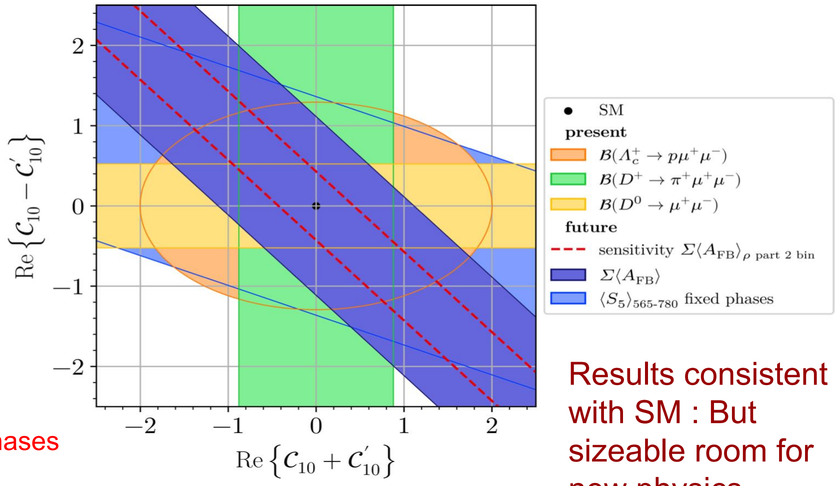
- c->ull constrain NP models independently in low-q2 and high-q2.
- Major source of uncertainty : Strong phases
- Best constraints on C10 from D0->mumu
- Best constraints on C7 from $\Lambda_c \to p\mu^+\mu^-$
- Constraints from D->pipimumu are weakest: Theoretically more challenging.

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

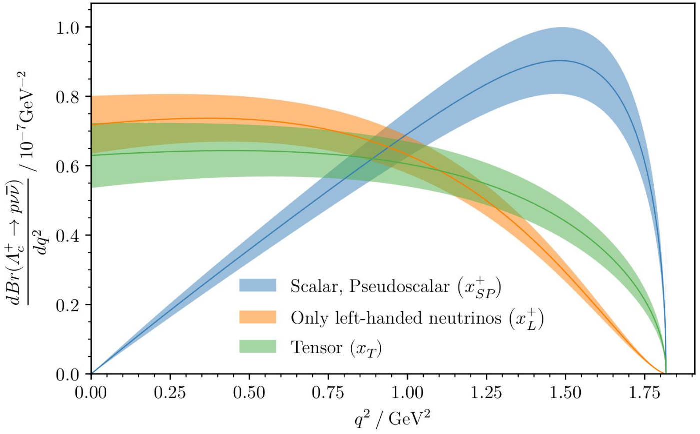
- 3 body decay : Simpler
- Form factors available from Lattice.
- Sensitive to 4 fermion as well as dipole coupling

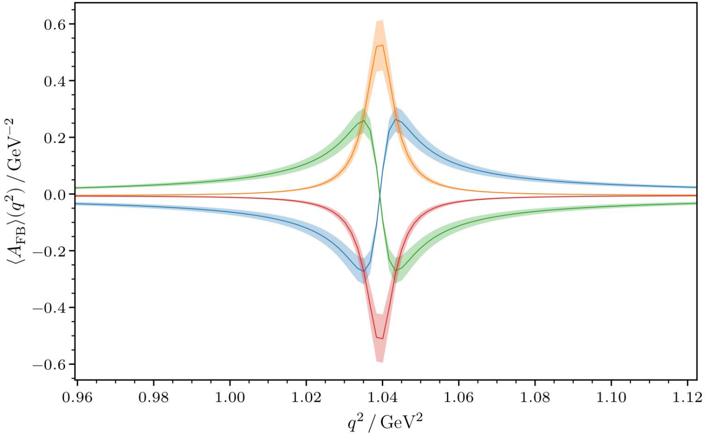


Major sources of uncertainty: Lack of information on strong phases



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





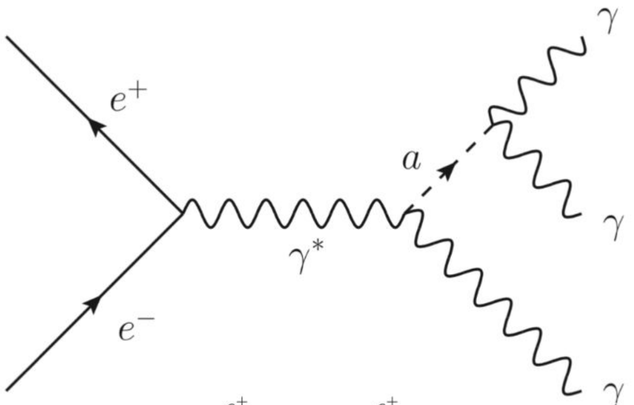
- Future improvements with Null tests.
- Binning around resonances is important for null tests.

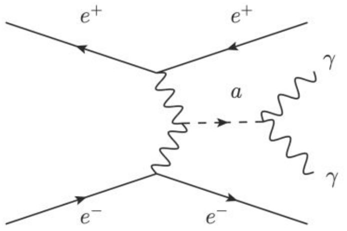
- Much potential for future.
- Other light NP plausible (like ALPs, Z', Dark Photon)

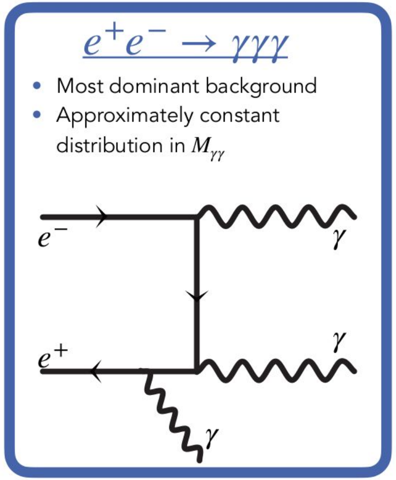
Results on arxiv today (https://arxiv.org/pdf/2410.00115)

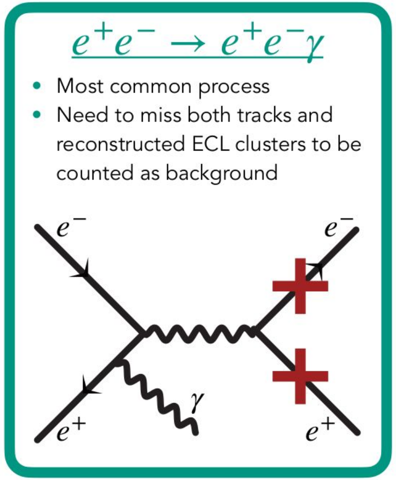
Searches for e^+e^-->a(->\gamma\gamma) \gamma

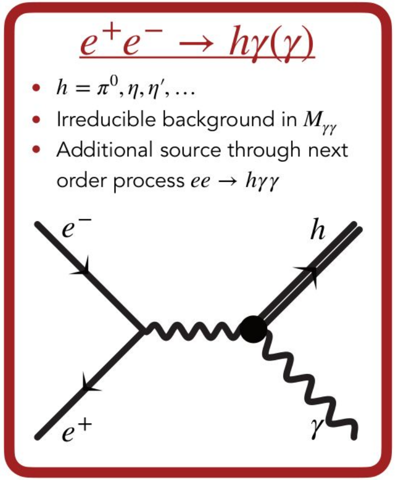
- Alexander Heidelbach
- search for Axion Like Particles
  - ALP Strahlung
- several sources for backgrounds





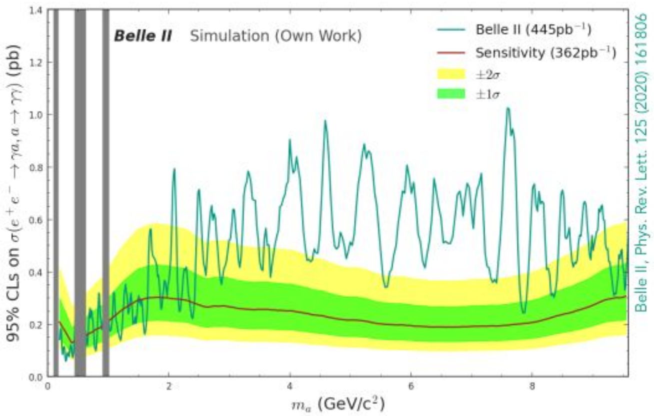


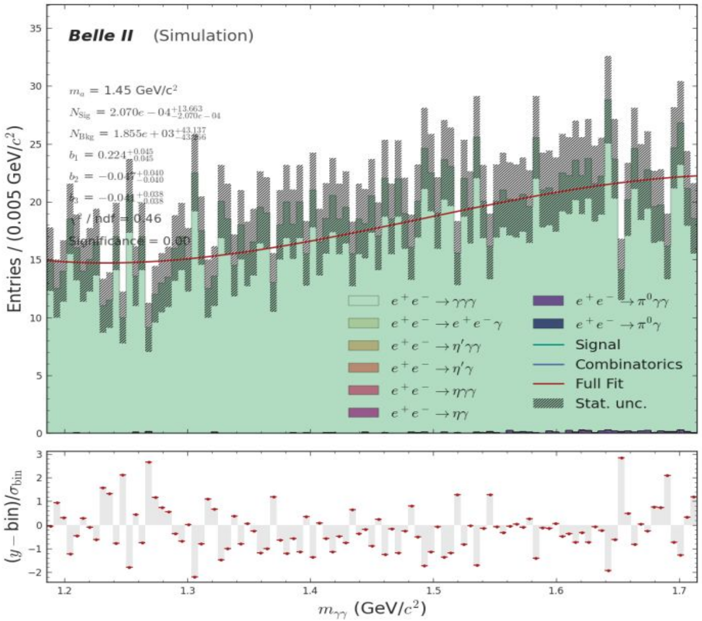


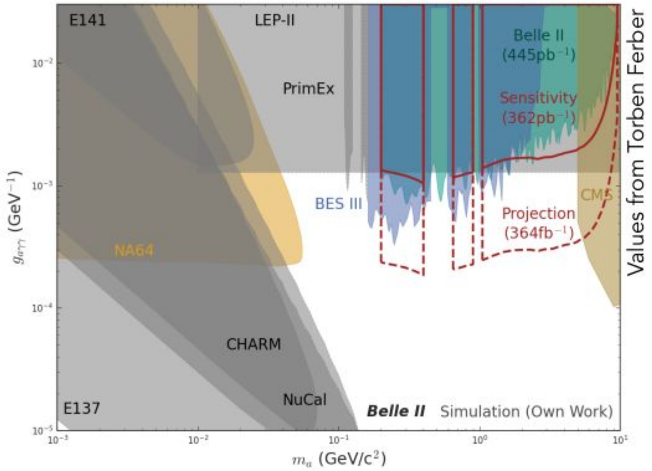


Searches for e^+e^-->a(->\gamma\gamma) \gamma

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







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