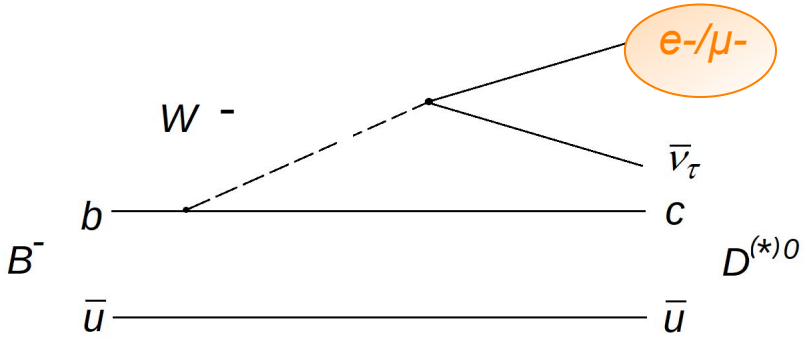
Recent results of **L**epton **F**lavour **U**niversality tests in semileptonic B decays at Belle II

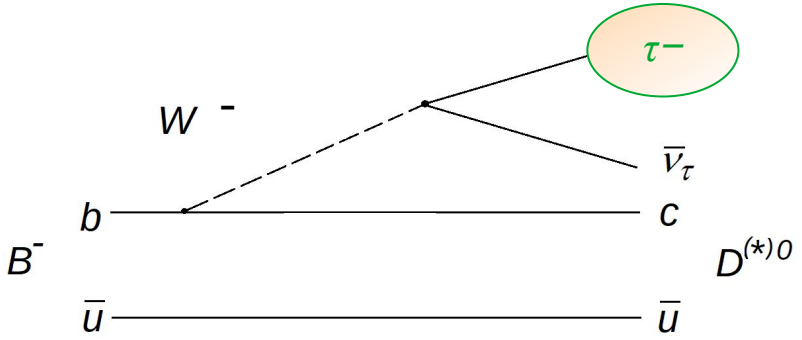
M. Prim for A. Manthei for the Belle II collaboration

42nd International Conference on High Energy Physics
19/07/2024

Motivation
- evidence for lepton flavour universality violation? -

- SL decays allow for probe of LFU
- **SM:** equal coupling strengths for e/μ & τ in interaction with W bosons





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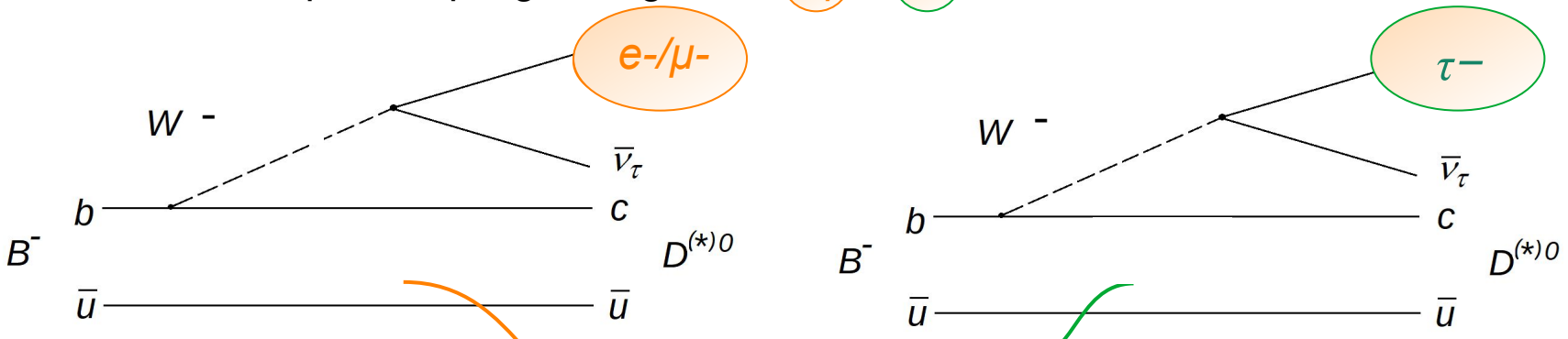

Measurements of the ratio $\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)}$ $(\ell = e, \mu)$ → partial cancellation of uncertainties

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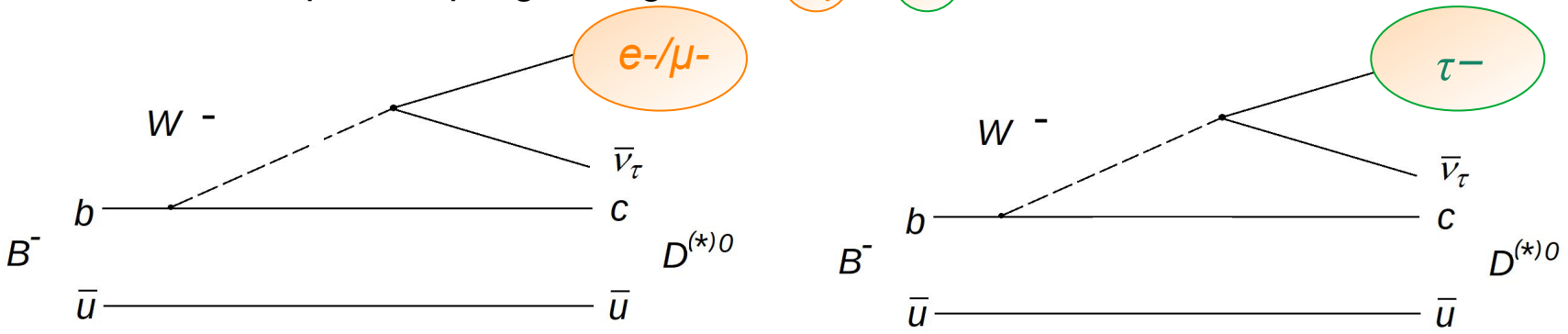

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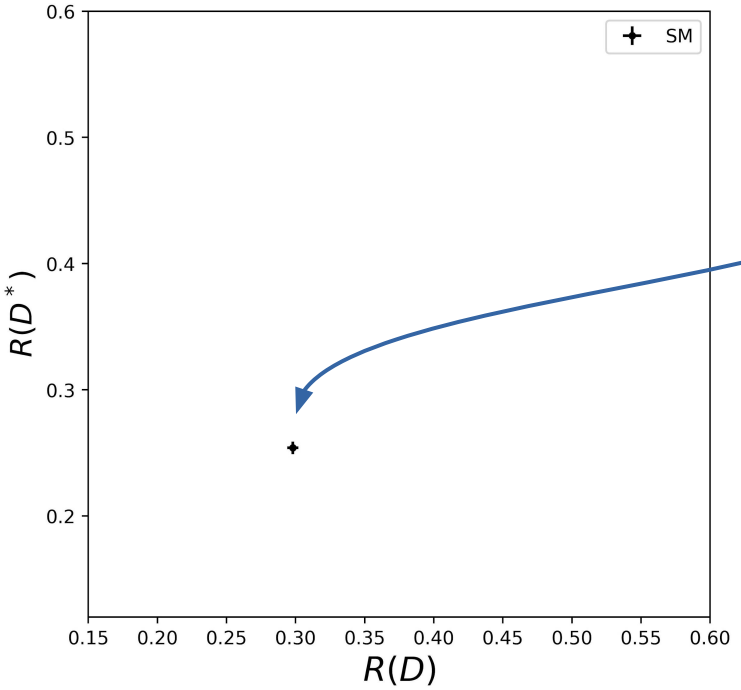

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$R(D^*) = 0.254 \pm 0.005$ [HFLAV 2021]

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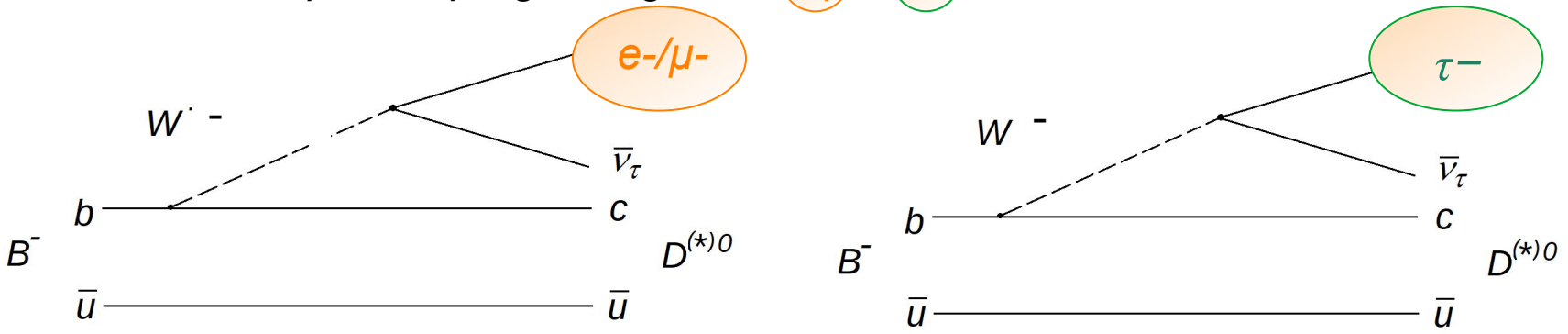

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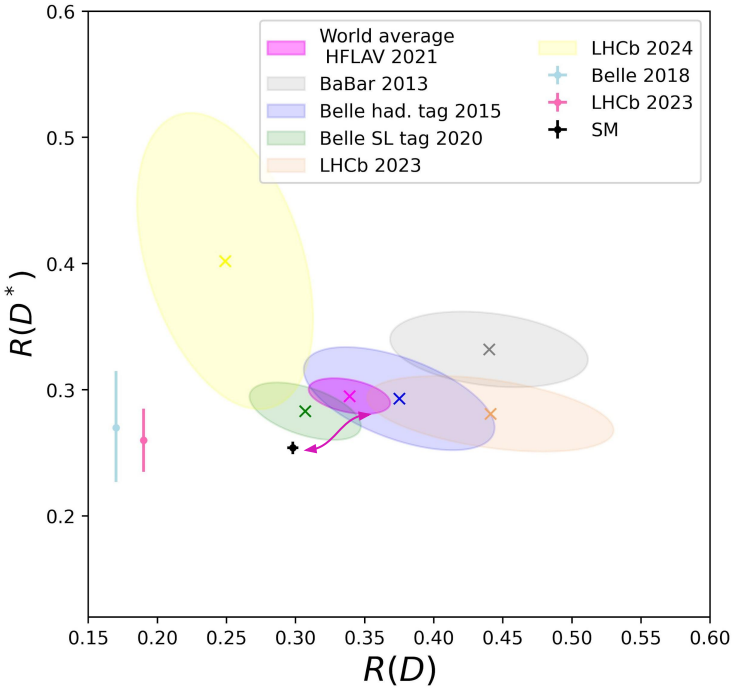

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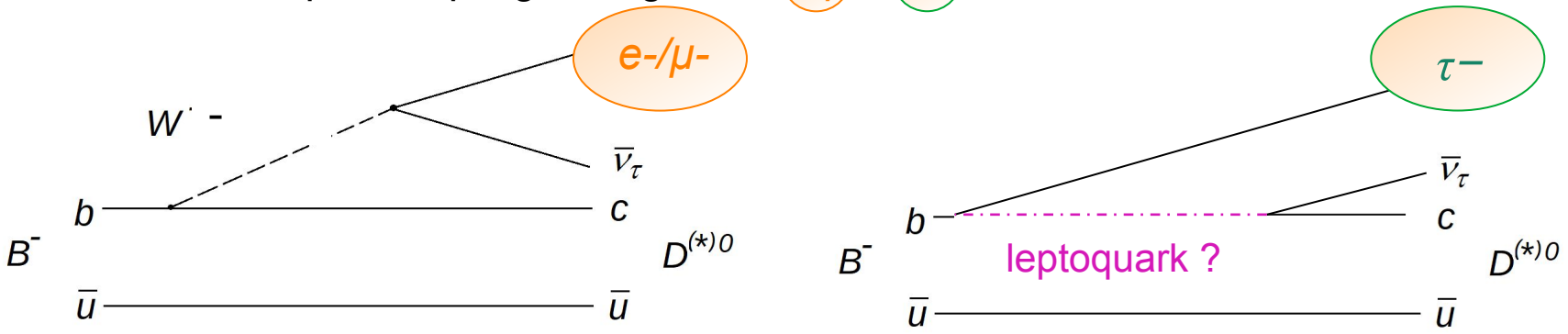

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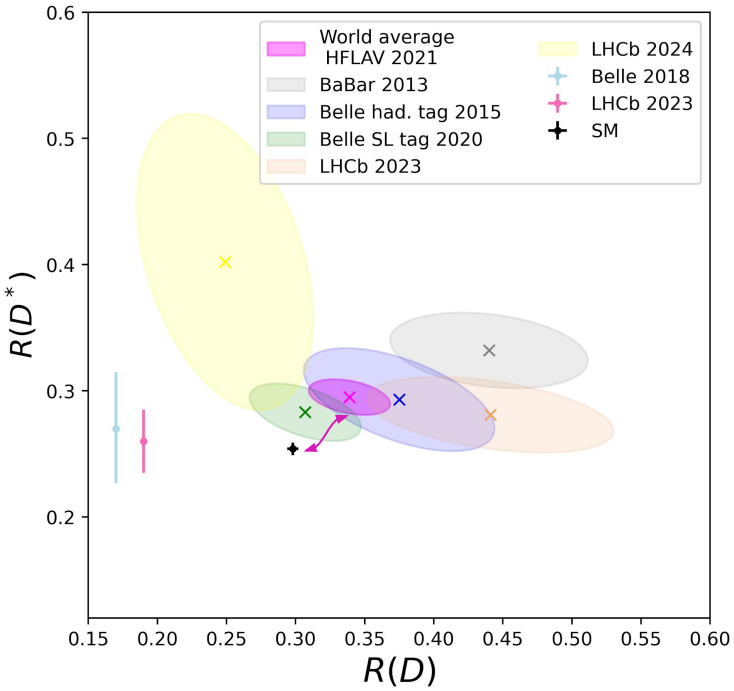

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vs **experiment**: potential violation of LFU?

- → long-standing tension between world average of measurements from LHCb, BaBar & Belle with the SM prediction: **~3.31σ**
- → could be a sign of new physics!

How to test this at Belle II
- SuperKEKB & Belle II detector -

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SuperKEKB:

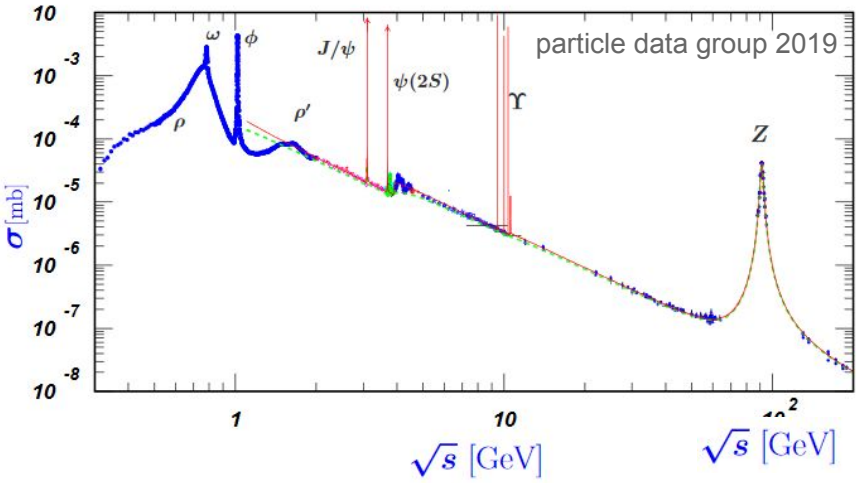
→ electron-positron collider at Y(4S) resonance

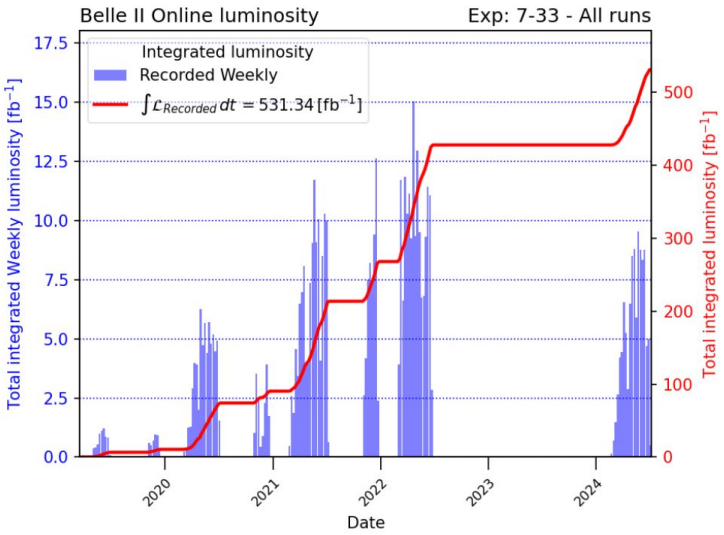
→ upgrade of KEKB: target luminosity: ~6x10^{35}/cm^2s^{-1}

→ production of BB pairs

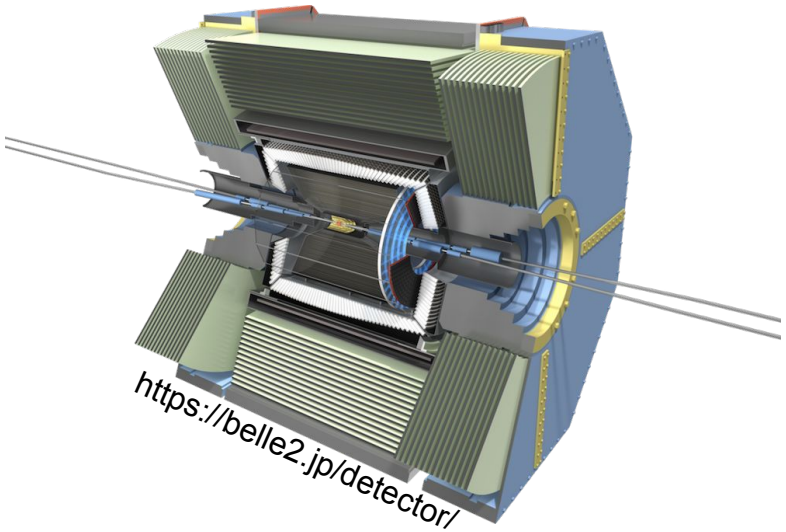
→ measure B decays with Belle II detector

→ total recorded int. luminosity: 531fb^{-1}





www.belle2.org/research/luminosity/ Updated on 2024/07/01 09:43 JST



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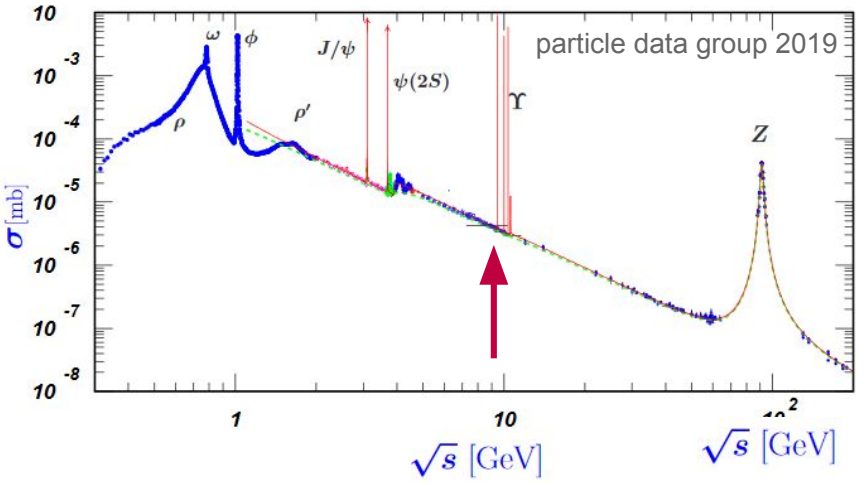

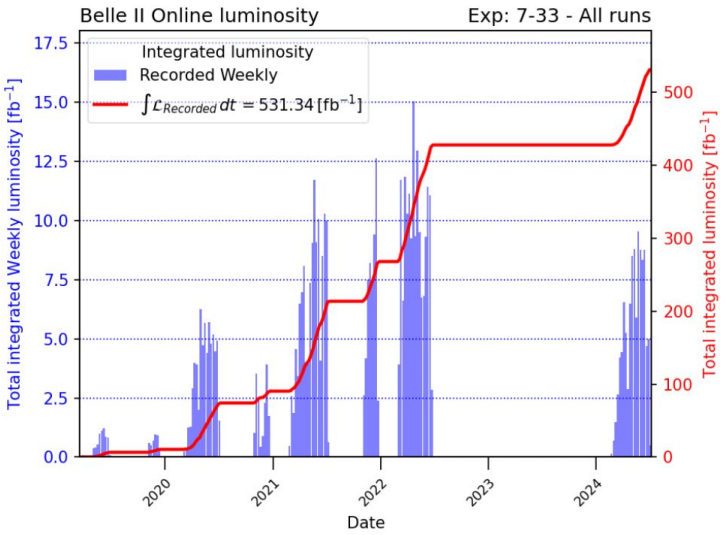

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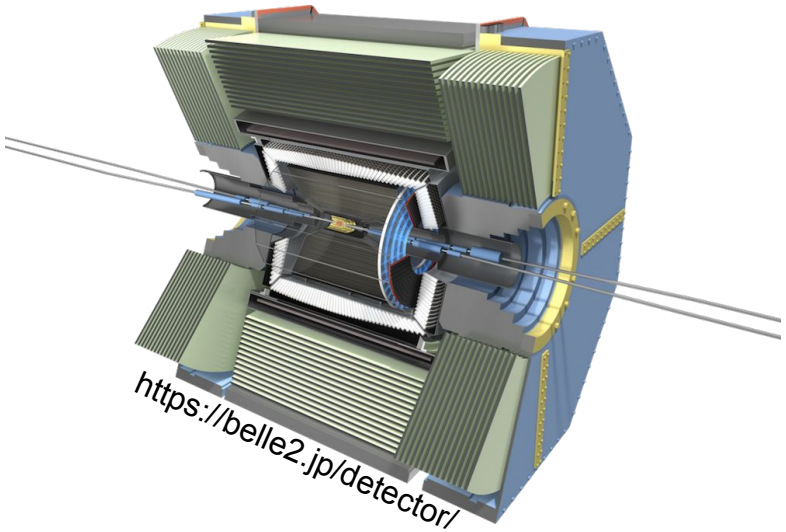

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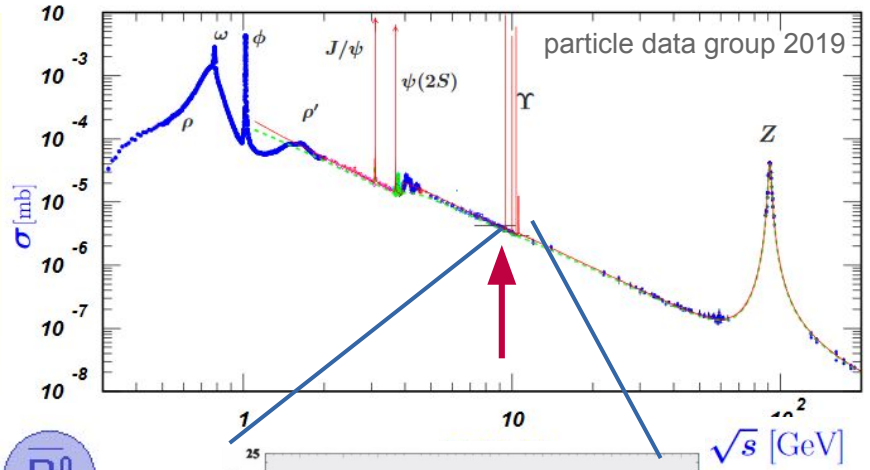
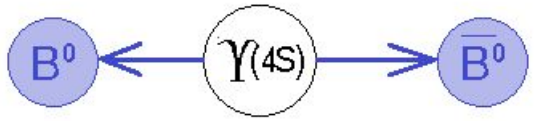
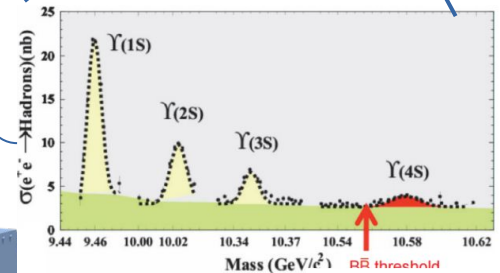
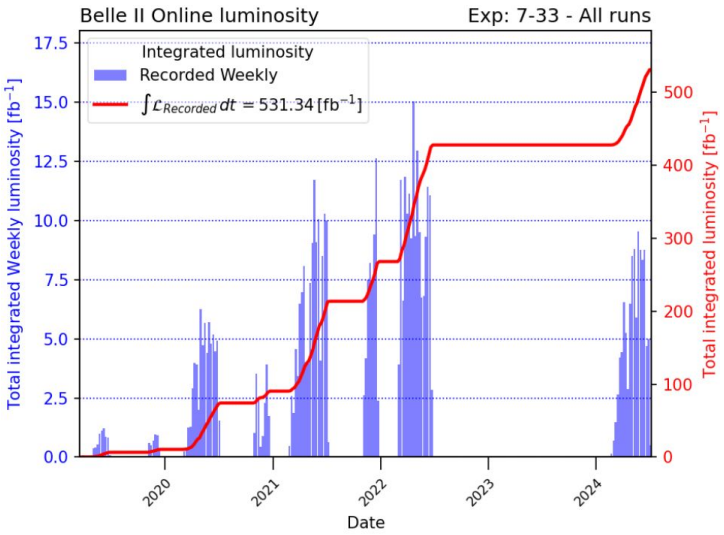






$B\overline{B}$ threshold



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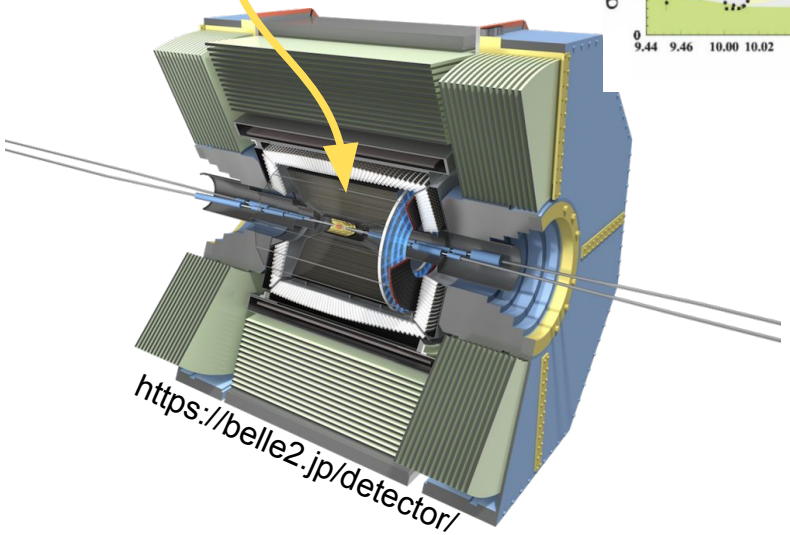

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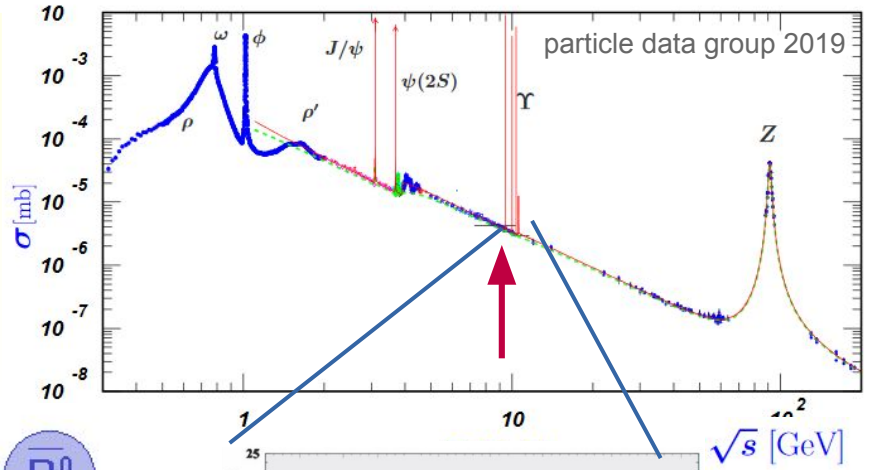
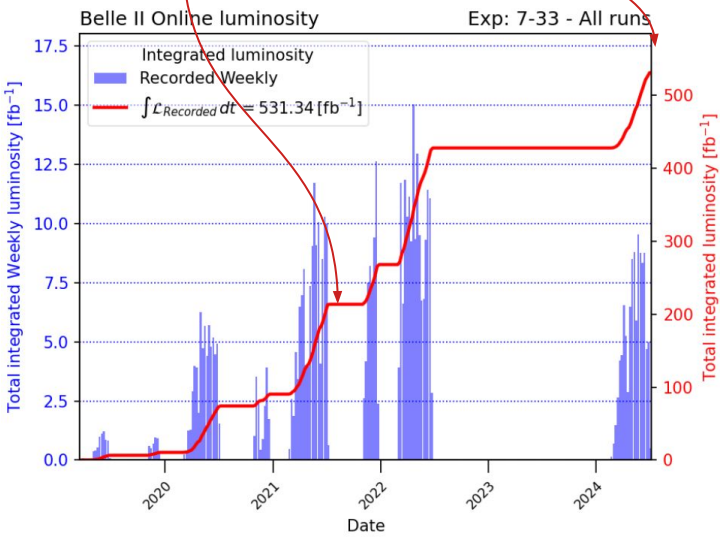


→ **189fb-1 used for *R*(D*) & *R*(X) analyses to be presented here**

→ **531fb-1 up to now**



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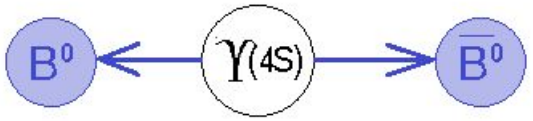

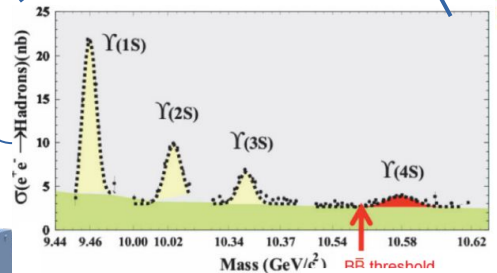

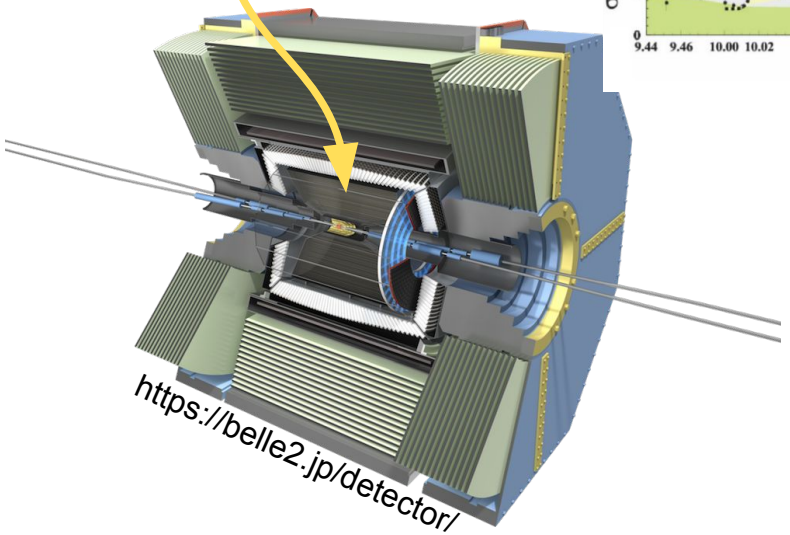

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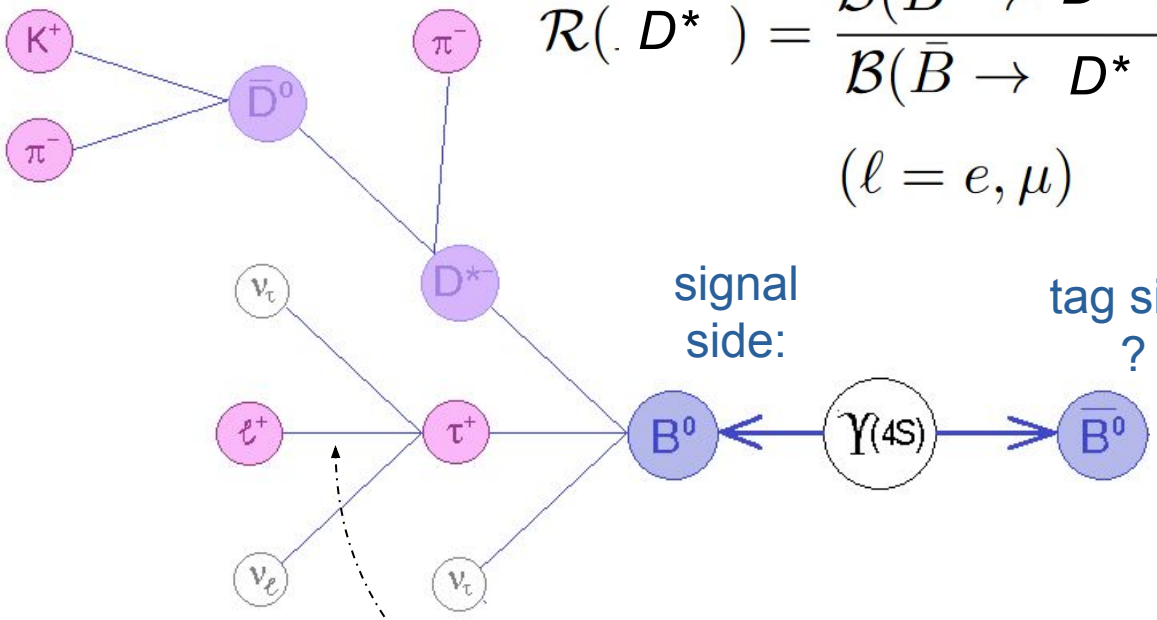
Strategies for reconstruction of SL B decays



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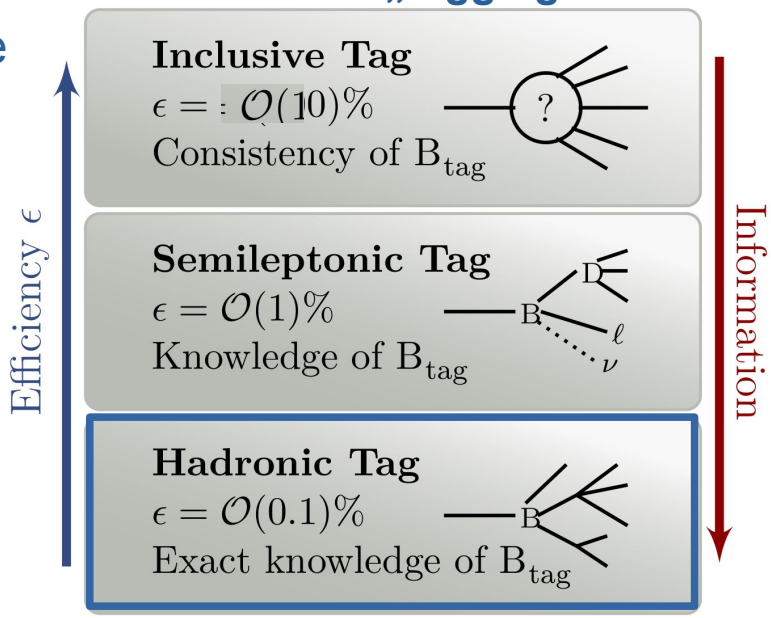
signal side:

tag side ?

possibilities for reconstruction of second B = „tagging“:



***R*(D*) with hadronic tagging:**
arxiv2401.02840

→ all rely on **leptonic τ decays**

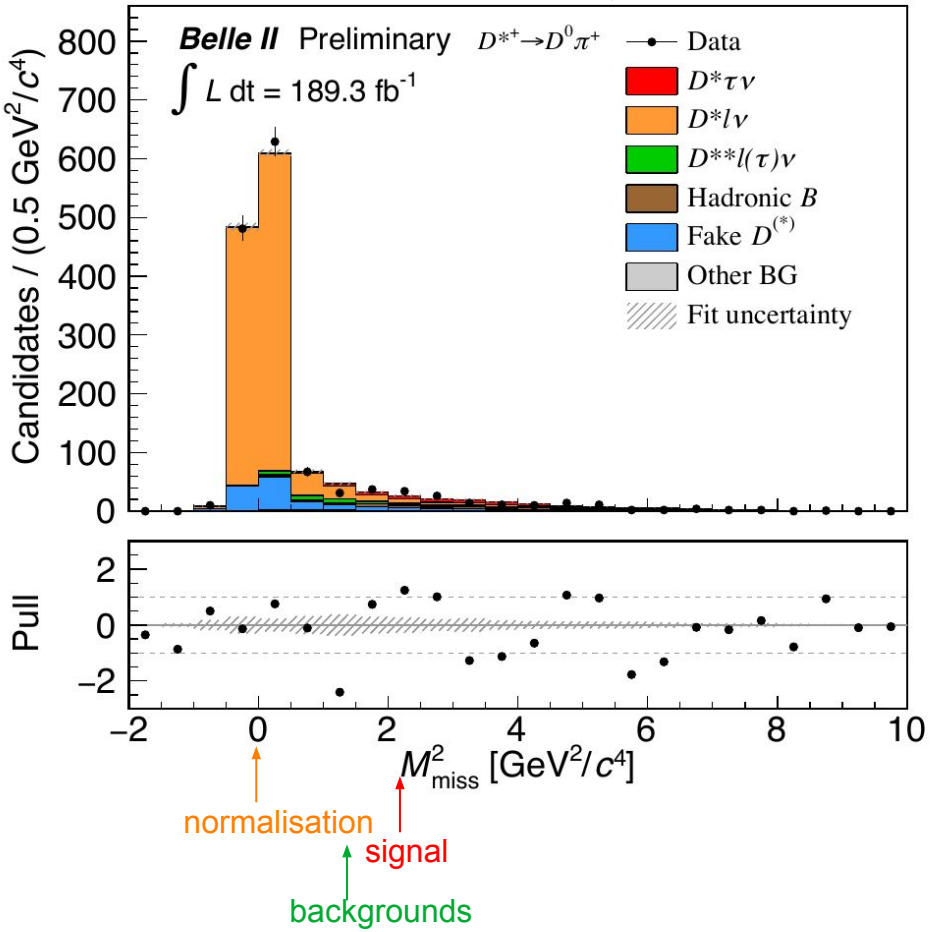
→ same reconstruction for signal & normalisation modes

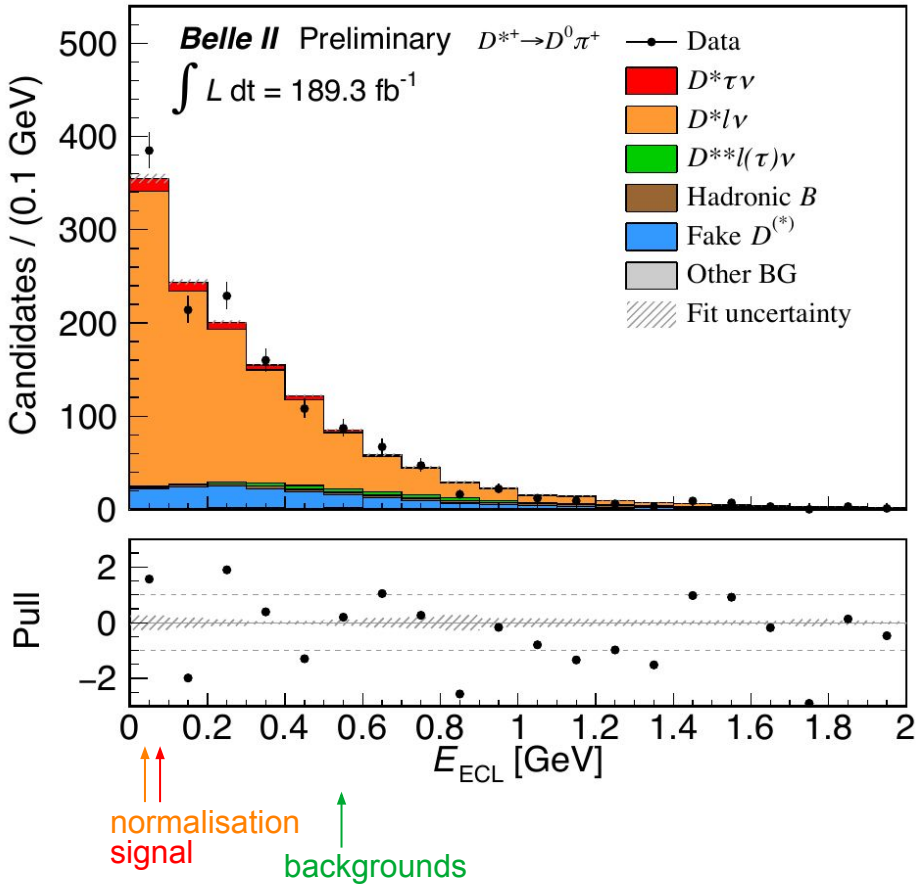
→ *use dedicated tag-side reconstruction algorithm*

Measurement of R(D*) with had. tagging (189fb^{-1})

arxiv2401.02840

- Use **completeness constraint**: no add. charged tracks in the event
- Extract R(D*) in 2D binned template neg. log-likelihood fit
- → fit variables: **missing mass squared** of the event + **additional energy** in the calorimeter





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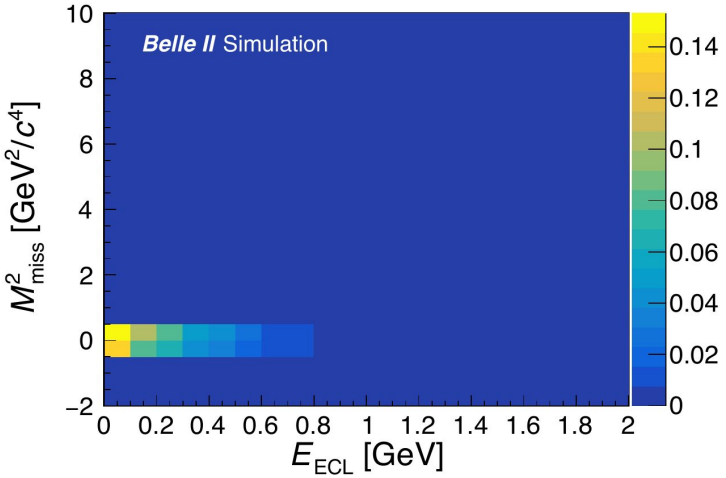

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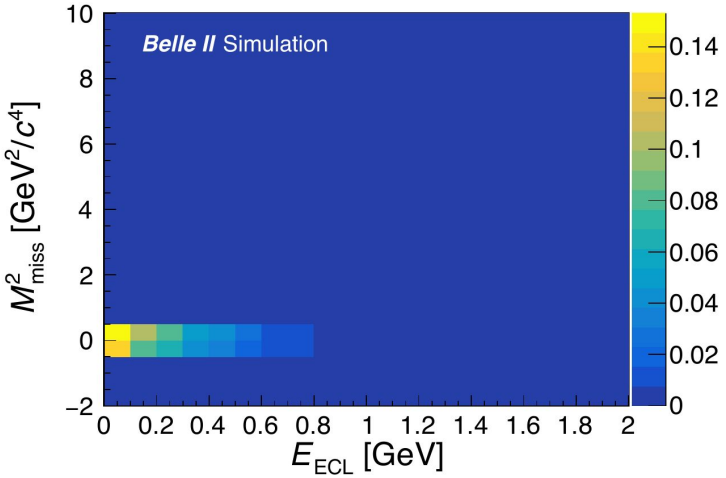

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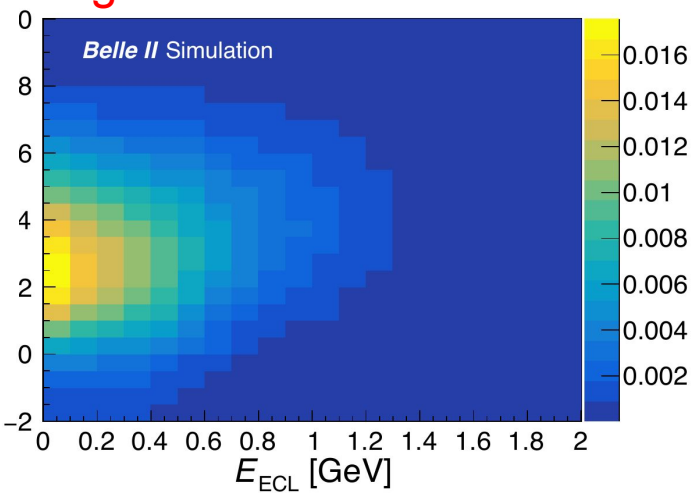

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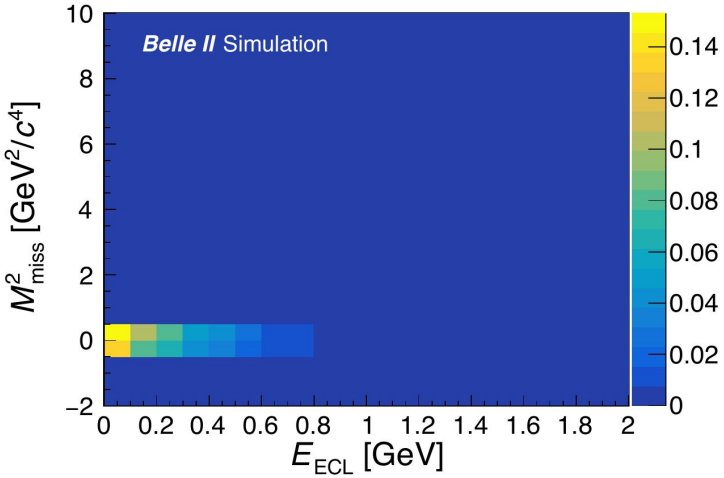

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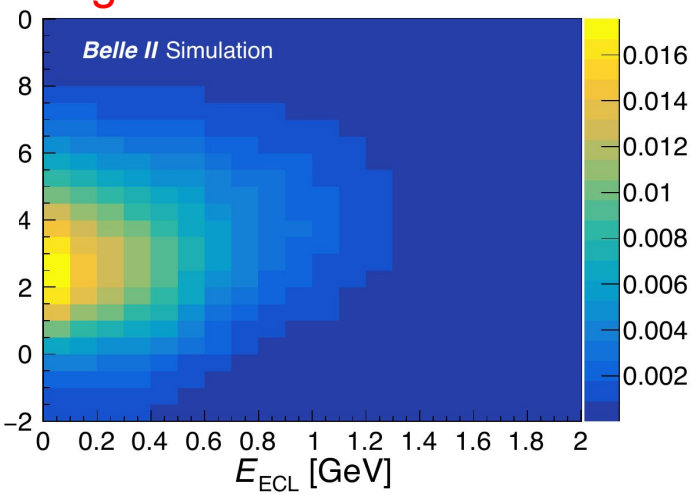

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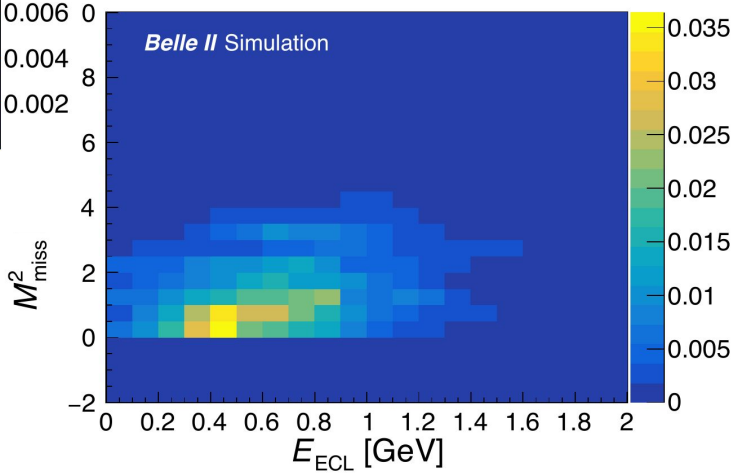

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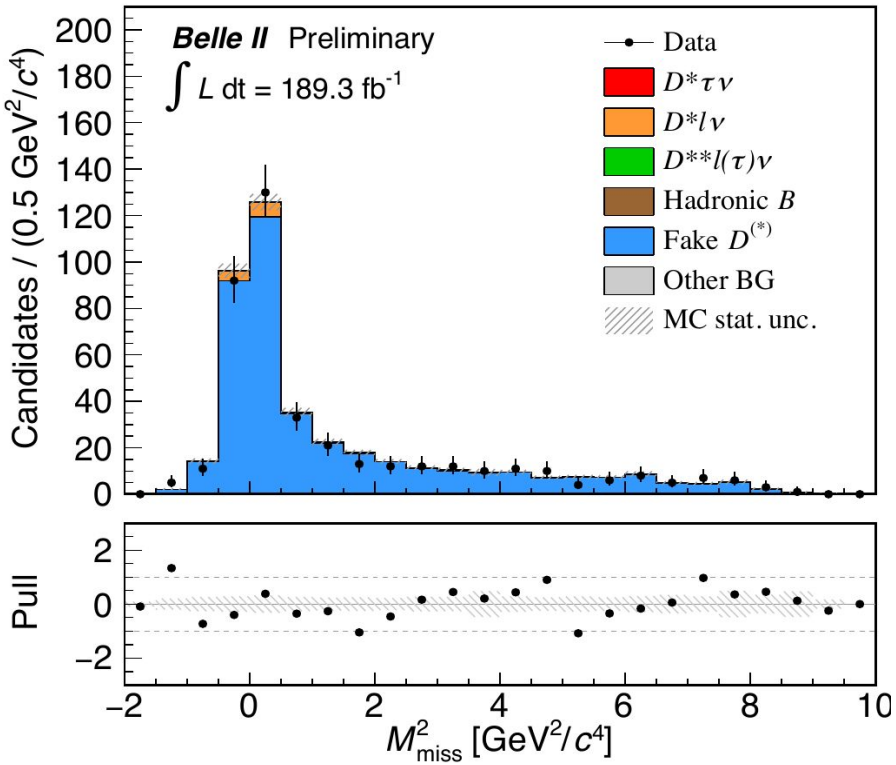

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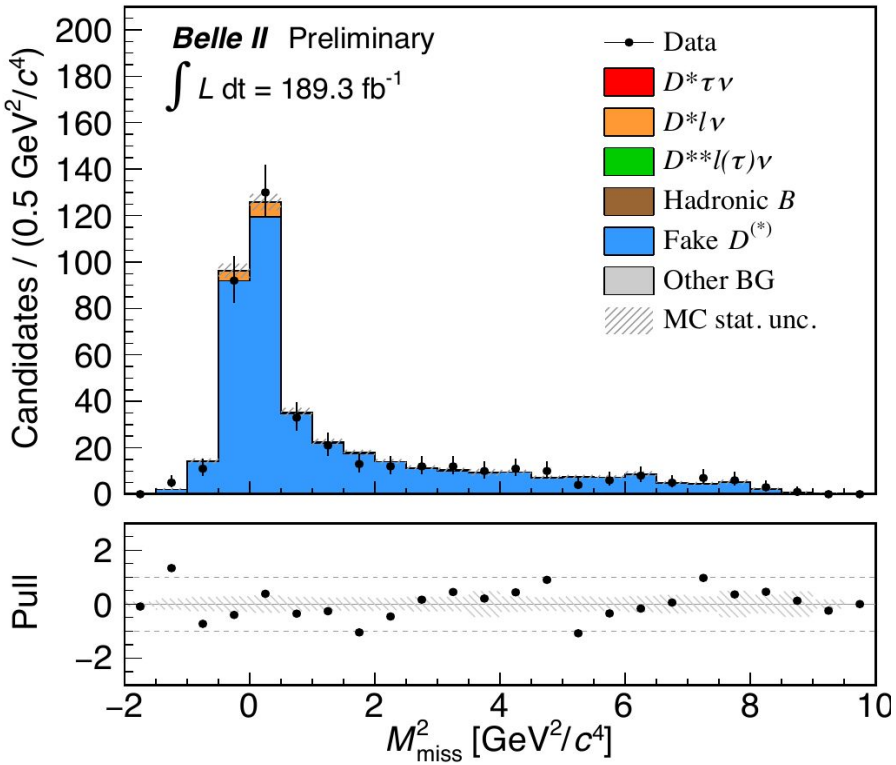
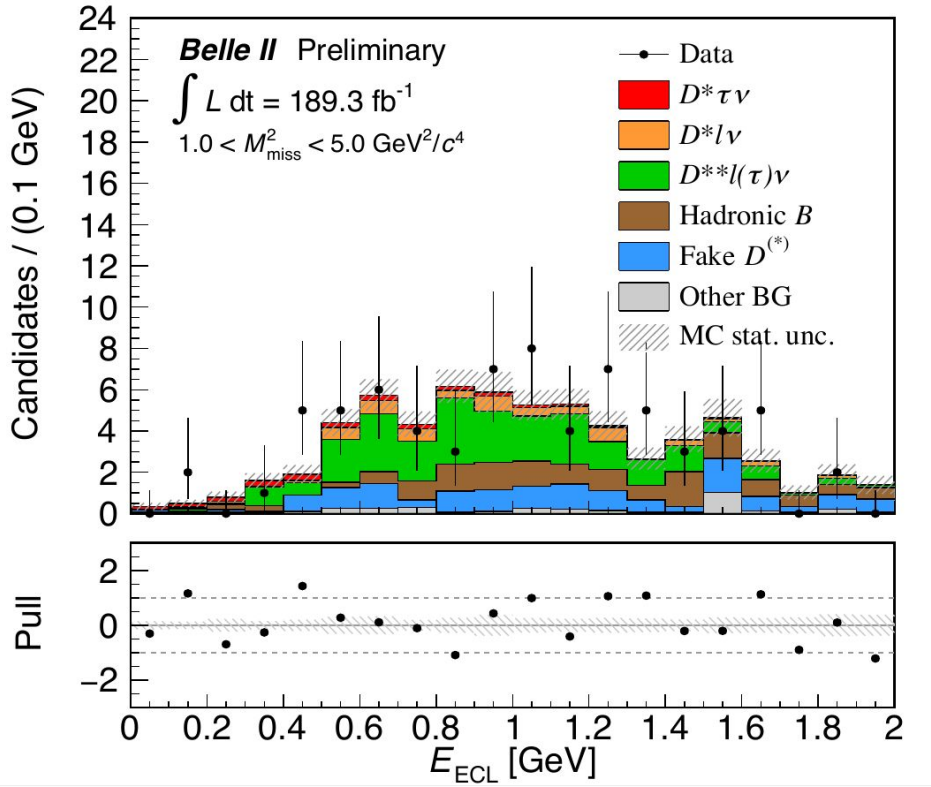
  - → reconstruct B→ D*πlν to test the modelling of the **D**s /„gap“ modes**





„gap“: difference between the inclusive SL B branching fraction & the sum of exclusive semileptonic B decays

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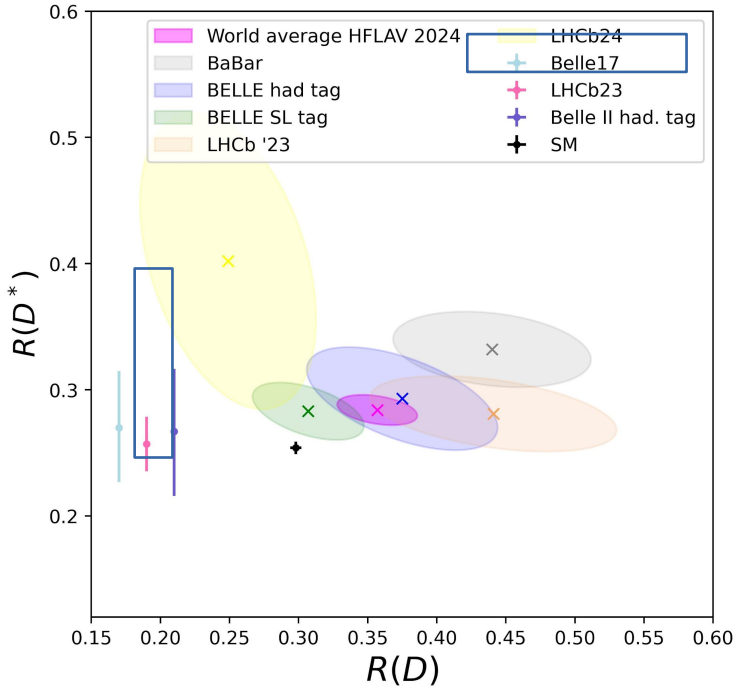
- → result (preliminary)::

$$R(D^*) = 0.262\ ^{+0.041}_{-0.039}(\text{stat})\ ^{+0.035}_{-0.032}(\text{syst})$$

- → **compatibility with world av. & SM:**

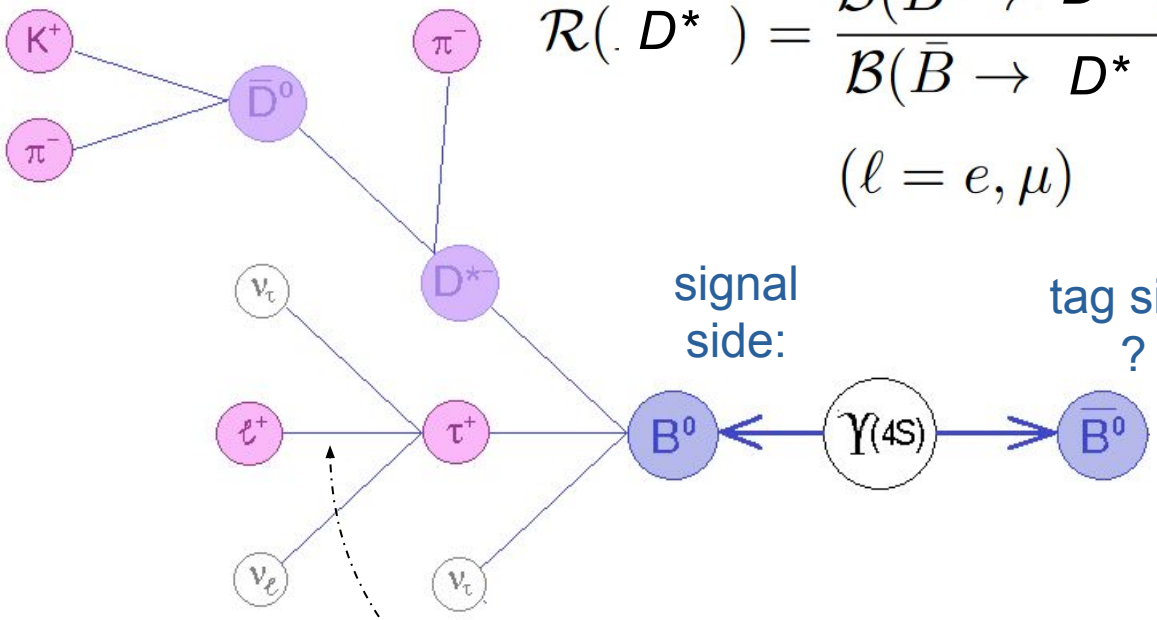


→ leading systematic uncertainties:

Source	Uncertainty
PDF shapes	$^{+9.1\%}_{-8.3\%}$
Simulation sample size	$^{+7.5\%}_{-7.5\%}$
$\overline{B} \to D^{**}\ell^-\overline{\nu}_\ell$ branching fractions	$^{+4.8\%}_{-3.5\%}$

→ ***in agreement*** *with SM & HFLAV av.*

Strategies for reconstruction of SL B decays



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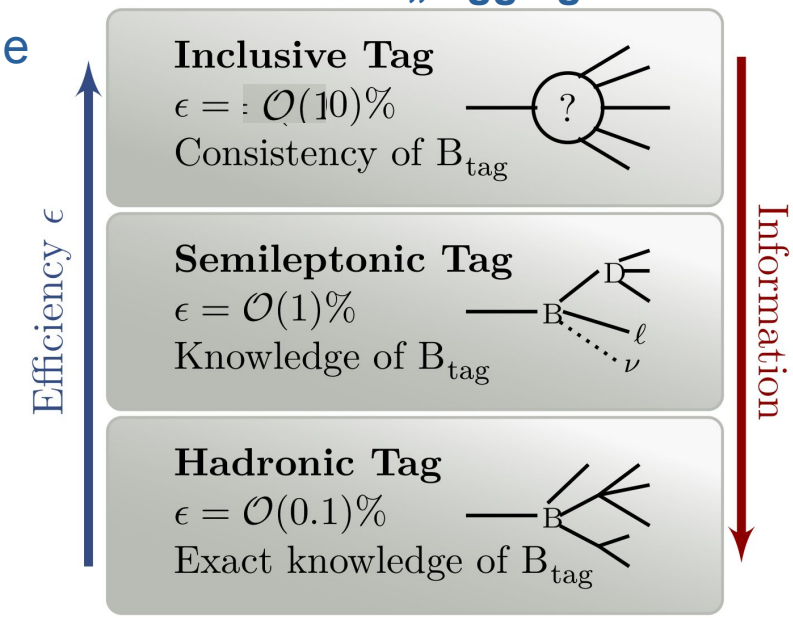

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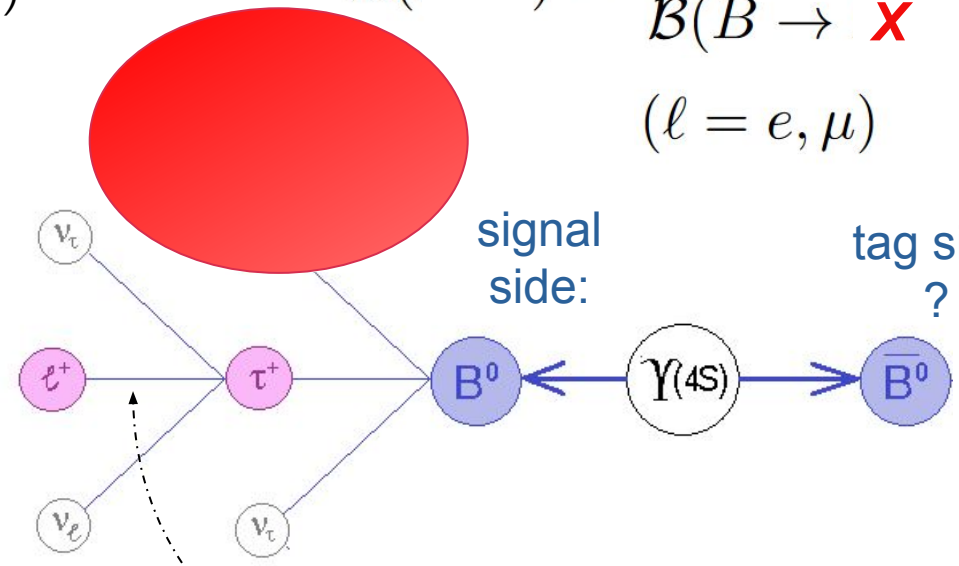
Strategies for reconstruction of SL B decays

*main contributions from B→ D(*) l/τν but **only O(1%) stat. overlap** with exclusive R(D(*))*

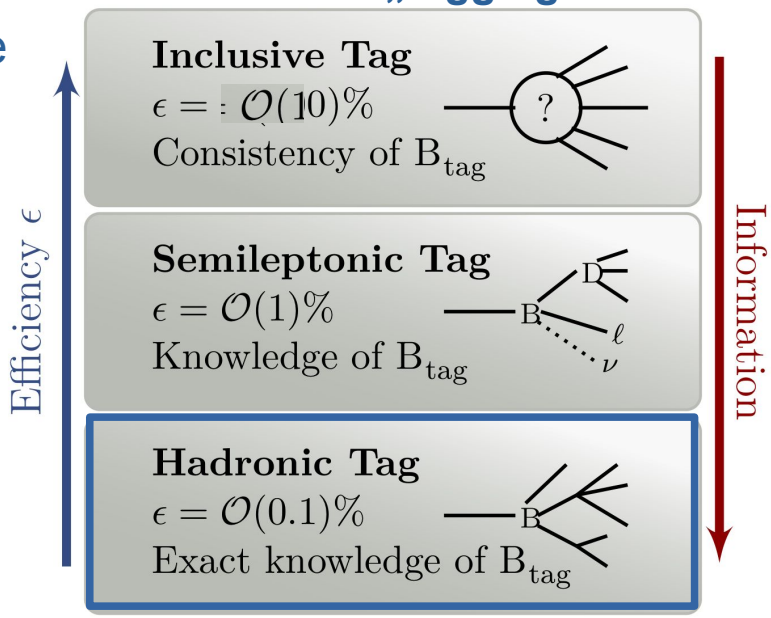
$$\mathcal{R}(\ X\ ) = \frac{\mathcal{B}(\bar{B} \to\ X\ \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to\ X\ \ell^- \bar{\nu}_\ell)} \quad (\ell = e, \mu)$$

← referred to as ``signal mode´´

← referred to as ``normalisation mode´´



possibilities for reconstruction of second B = „tagging“:



R(X) with hadronic tagging
PhysRevLett.132.211804

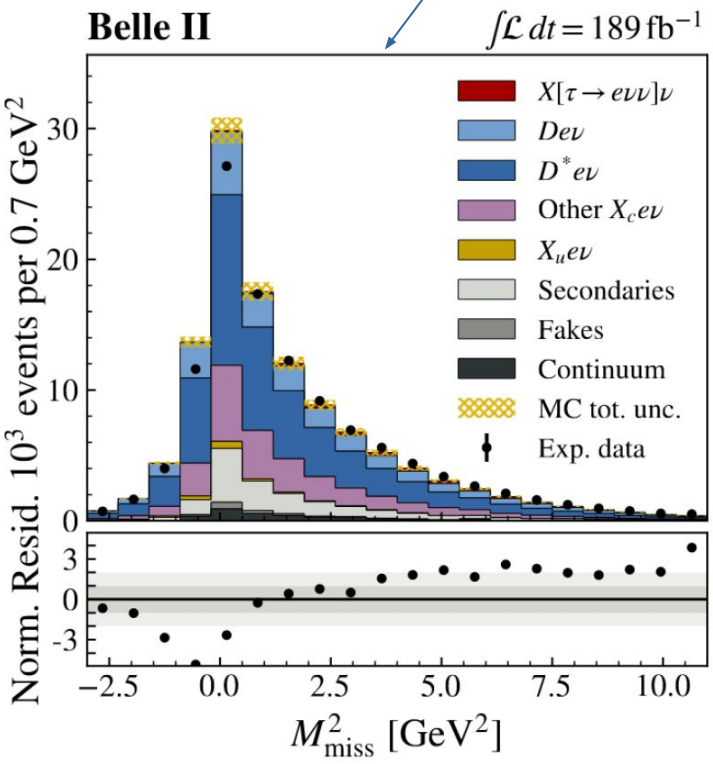
→ all rely on **leptonic τ decays**
→ same reconstruction for signal & normalisation modes

→ *use dedicated tag-side reconstruction algorithm*

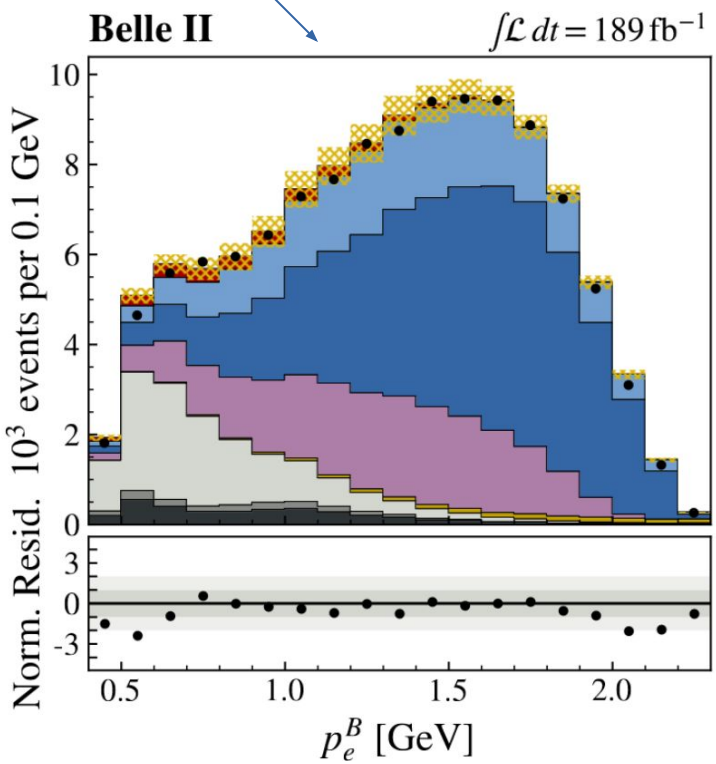
Measurement of R(X) with had. tagging (189fb^{-1})

PhysRevLett.132.211804

- Reconstruct only the lepton; remaining particles = X system
- Extract R(X) in 2D binned neg. log-likelihood fit using bin-wise NPs for systematics
- → fit variables: missing mass squared of the event + lepton momentum



- *main challenge:*
- *disagreement supposedly due to mismodelling in D decays to K^0_L*



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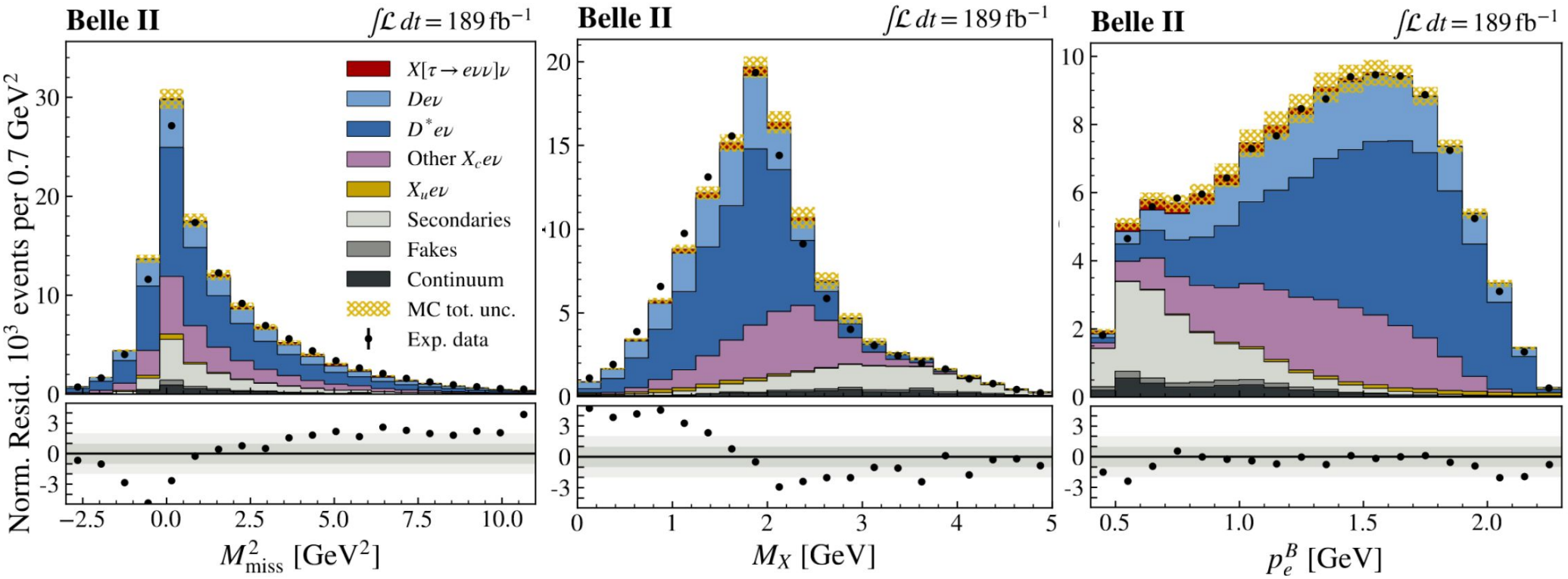
- → fit variables: missing mass squared of the event + lepton momentum
- → **reweight Xlν based on M_X** *(invariant mass of the X system)*



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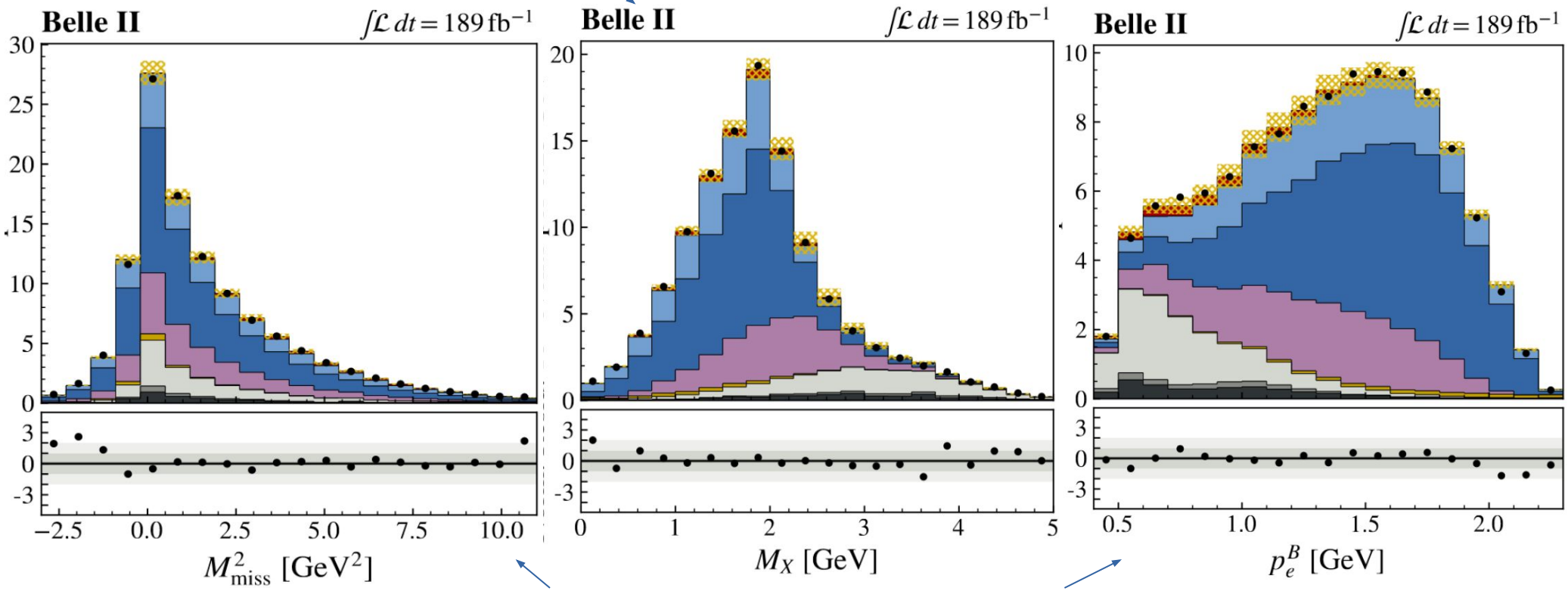

→ fixes mismodelling in all observables

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- → fit variables: missing mass squared of the event + lepton momentum
- → reweight Xlν based on M_X
- → result:

$$R(X_{\tau/\ell}) = 0.228 \pm 0.016\ (\text{stat}) \pm 0.036\ (\text{syst})$$

→ **leading uncertainties:**

- Sample sizes
- M_X shape corrections
- Branching fractions of the „gap modes“
- B→ D* l ν form factors

Source	Uncertainty [%] e	μ	ℓ
Experimental sample size	8.8	12.0	7.1
Simulation sample size	6.7	10.6	5.7
Tracking efficiency	2.9	3.3	3.0
Lepton identification	2.8	5.2	2.4
$X_c\ell\nu$ reweighting	7.3	6.8	7.1
$B\overline{B}$ background reweighting	5.8	11.5	5.7
$X\ell\nu$ branching fractions	7.0	10.0	7.7
$X\tau\nu$ branching fractions	1.0	1.0	1.0
$X_c\tau(\ell)\nu$ form factors	7.4	8.9	7.8
Total	18.1	25.6	17.3

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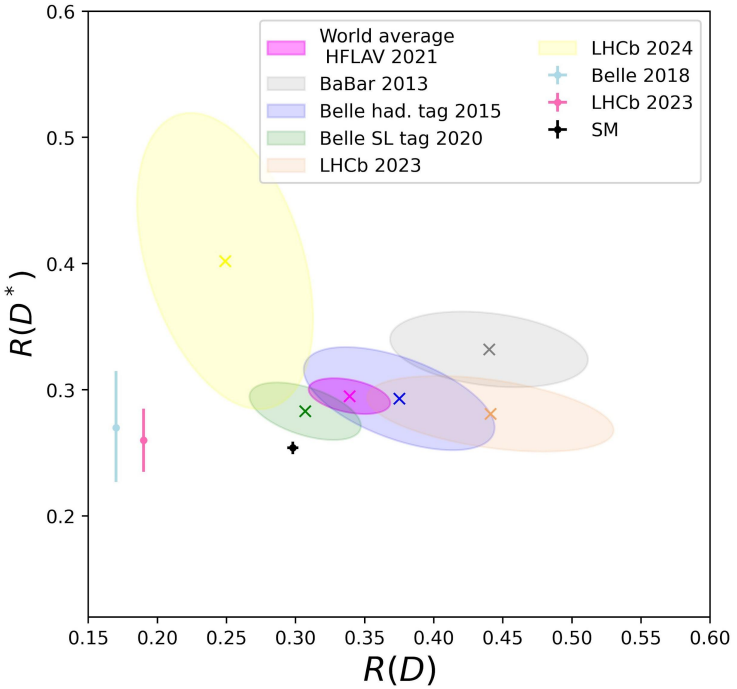
→ **compatibility with world av. & SM:** **(can we fit it in there?)**



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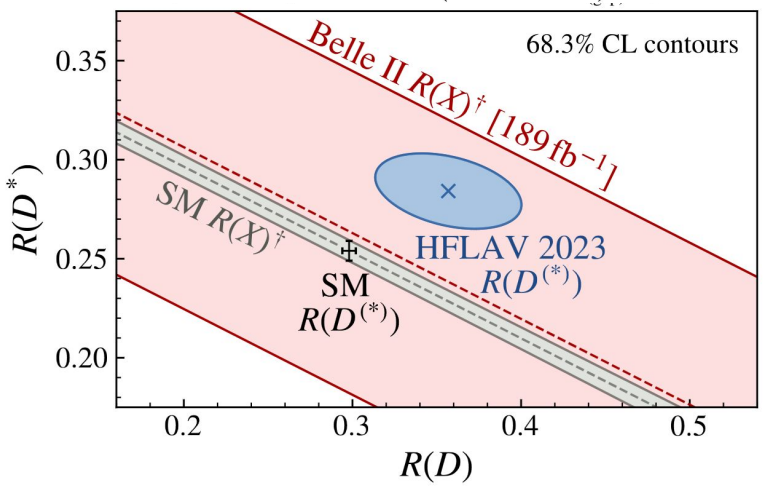
First measurement at the Υ(4S) resonance !

→ **compatibility with world av. & SM:** We can! Exclude SM exp. contributions from D**/gap, Xu

→ leading uncertainties:

$$R(X_{\tau/\ell})^{\dagger} \equiv \frac{\mathcal{B}(B \to X\tau\nu) - \mathcal{B}(B \to D^{**}_{(\text{gap})}/X_u\tau\nu)_{\text{SM}}}{\mathcal{B}(B \to X\ell\nu)}$$



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→ ***in agreement*** *with* **HFLAV av. & SM prediction=0.223 ± 0.005** *within* 1σ

Summary & outlook

- Belle II contributes to LFU tests with several measurements
- Recent results:

$$R(D^*) = 0.262\ ^{+0.041}_{-0.039}(\text{stat})\ ^{+0.035}_{-0.032}(\text{syst})$$

$$R(X_{\tau/\ell}) = 0.228 \pm 0.016\ (\text{stat}) \pm 0.036\ (\text{syst})$$

- *R*(D*) had. & *R*(X) in agreement with SM prediction, all compatible with current world average, results will be more precise with more data to be taken