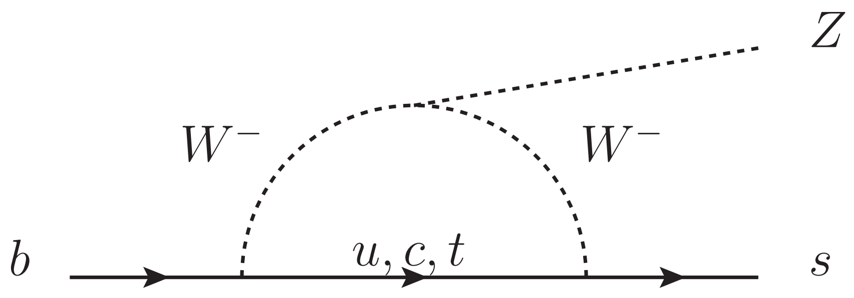
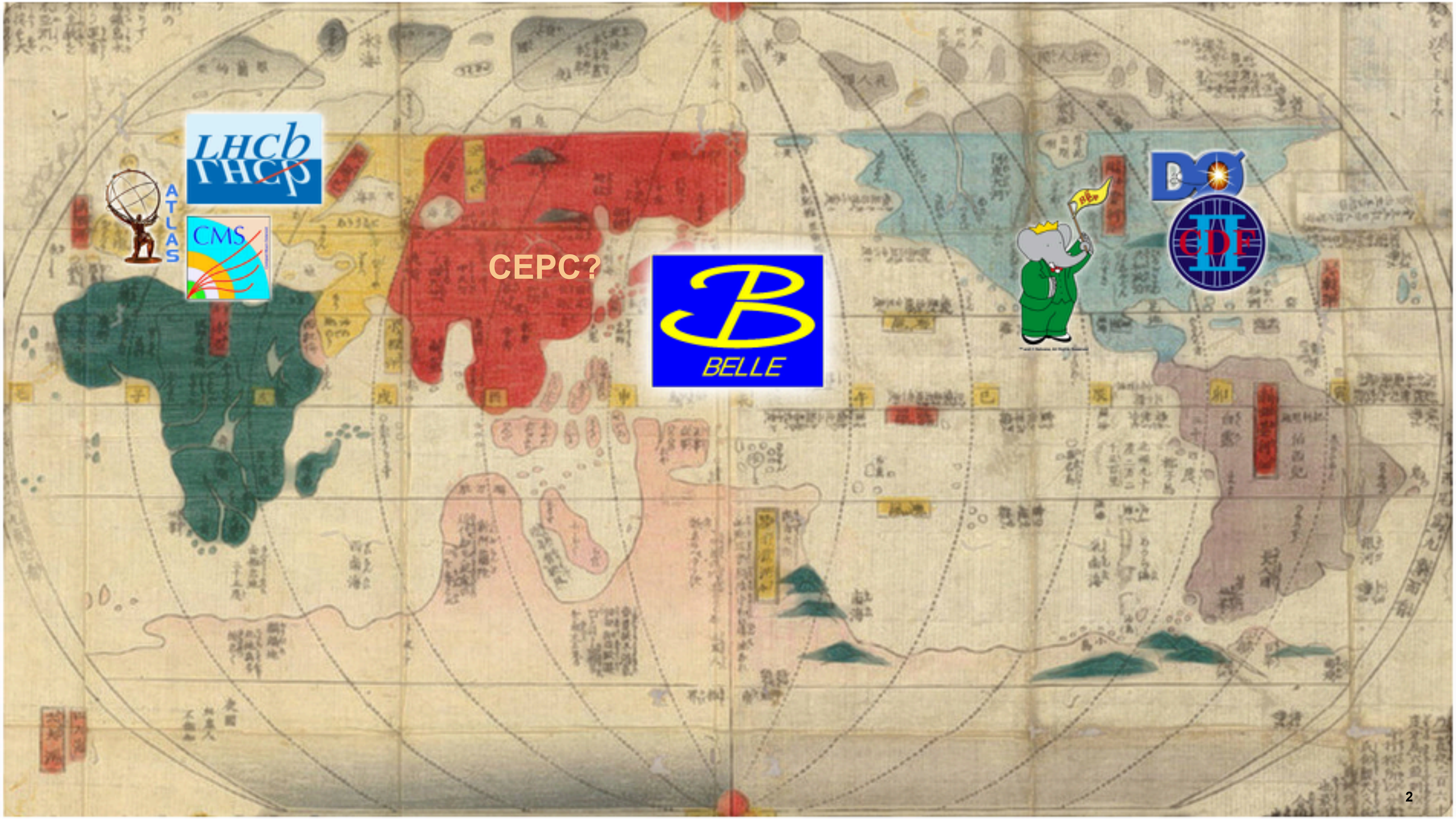
Motivation for analysing b→sll decays at CEPC

CEPC Workshop 2018

Simon Wehle
IHEP, Beijing, 23.11.2018



HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

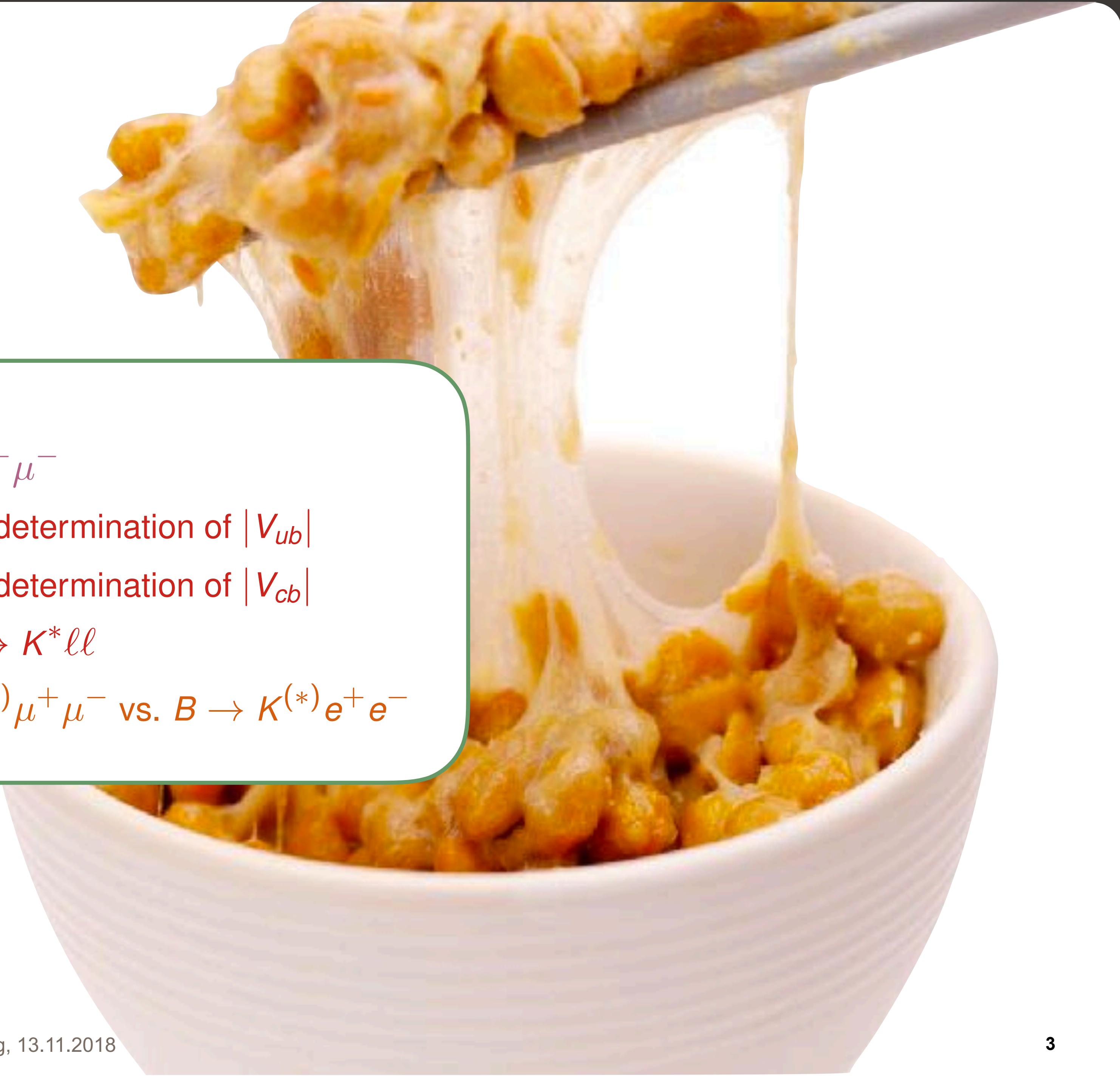

LHCb
ATLAS
CMS
CEPC?
BELLE
DØ
CDF

The Flavour Anomalies

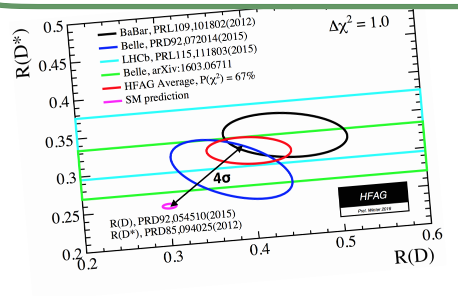
(maybe only “local” anomalies…)

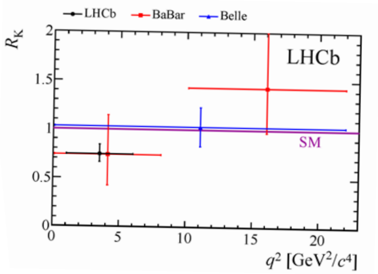
The Flavour Anomalies

(maybe only “local” anomalies…)



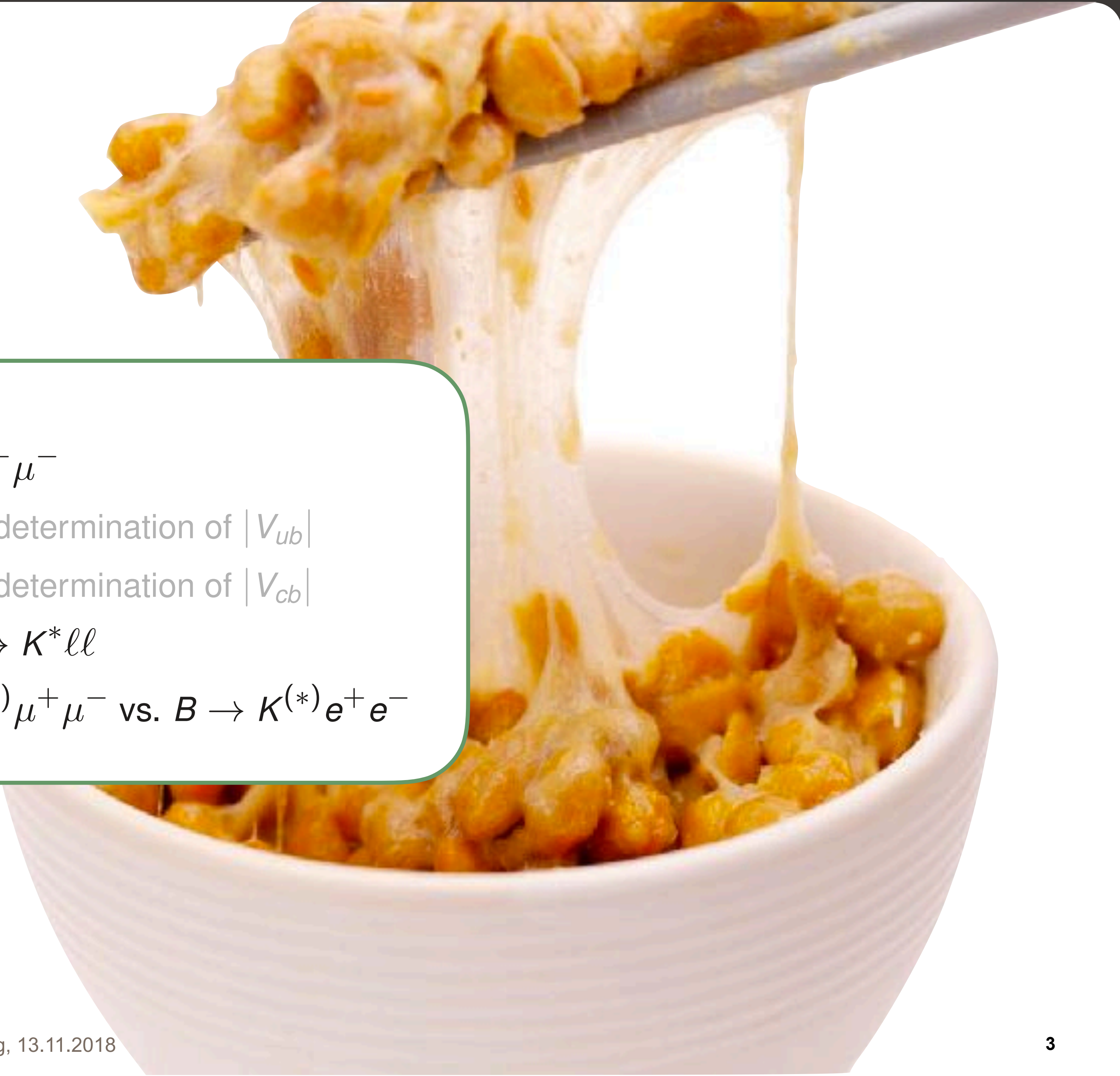
- $> 3.5\sigma$ enhanced $B \to D^{(*)}\tau\nu$ rates
- 3.3σ suppressed branching ratio of $B_s \to \phi\mu^+\mu^-$
- $\sim 3\sigma$ tension between inclusive and exclusive determination of $|V_{ub}|$
- $\sim 3\sigma$ tension between inclusive and exclusive determination of $|V_{cb}|$
- $> 3\sigma$ anomalies in angular distributions of $B \to K^*\ell\ell$
- 2.6σ lepton flavor non-universality in $B \to K^{(*)}\mu^+\mu^-$ vs. $B \to K^{(*)}e^+e^-$



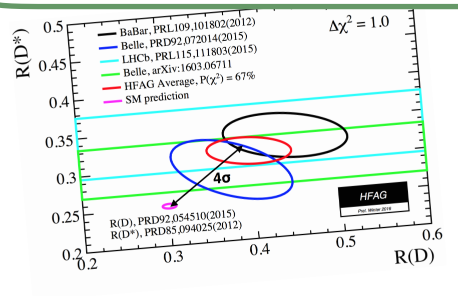


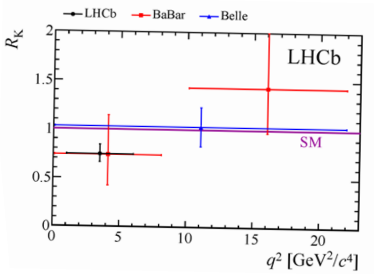
The Flavour Anomalies

(maybe only “local” anomalies…)



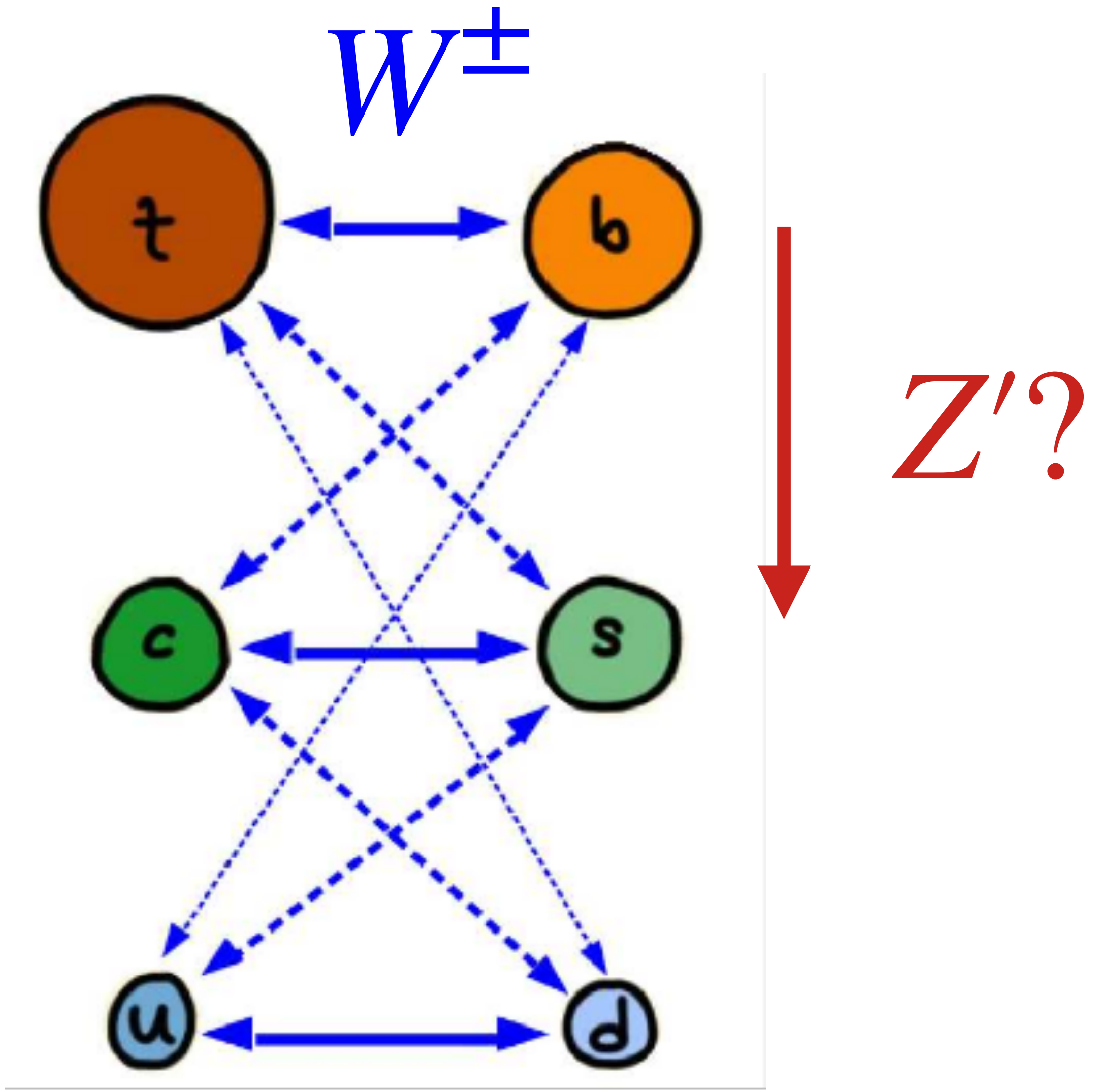
- $> 3.5\sigma$ enhanced $B \to D^{(*)}\tau\nu$ rates
- 3.3σ suppressed branching ratio of $B_s \to \phi\mu^+\mu^-$
- $\sim 3\sigma$ tension between inclusive and exclusive determination of $|V_{ub}|$
- $\sim 3\sigma$ tension between inclusive and exclusive determination of $|V_{cb}|$
- $> 3\sigma$ anomalies in angular distributions of $B \to K^*\ell\ell$
- 2.6σ lepton flavor non-universality in $B \to K^{(*)}\mu^+\mu^-$ vs. $B \to K^{(*)}e^+e^-$



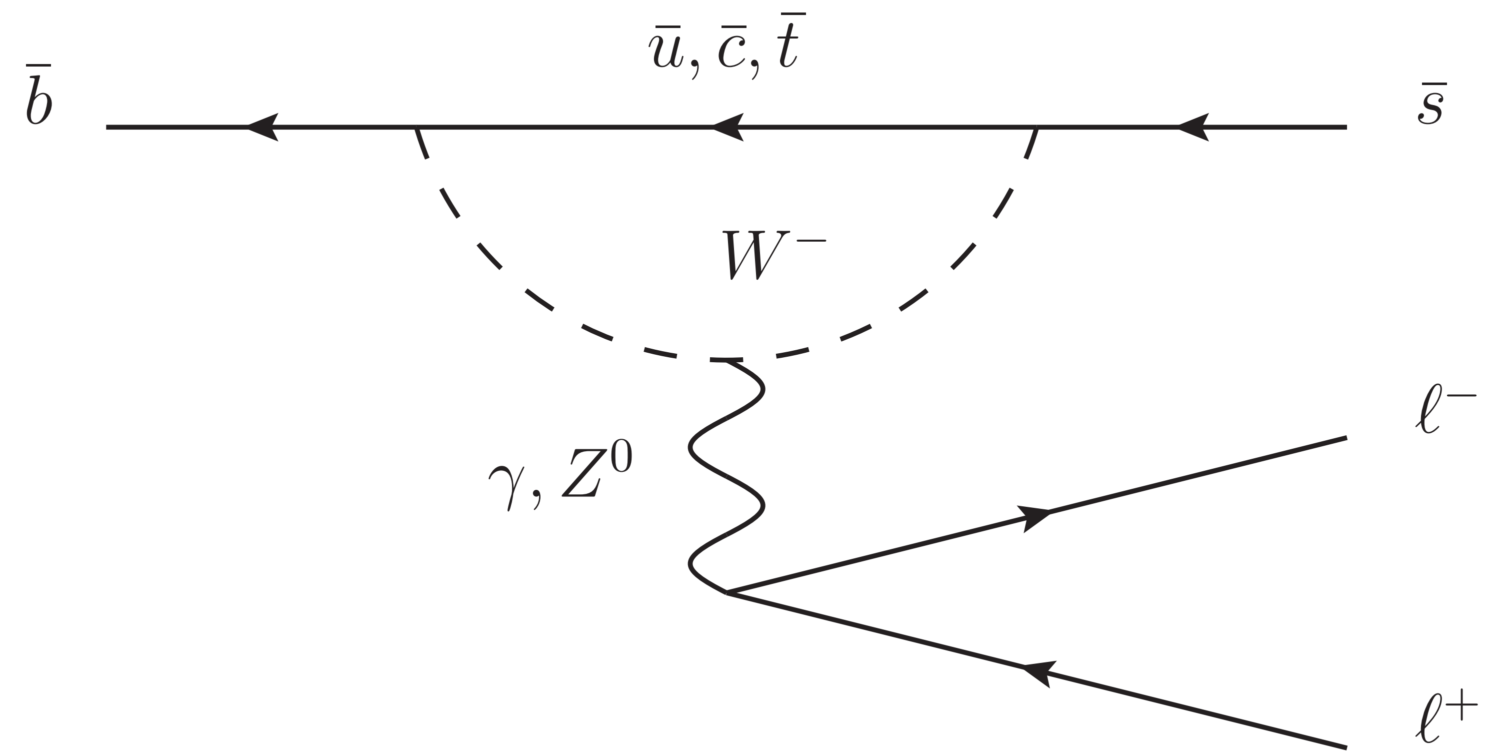


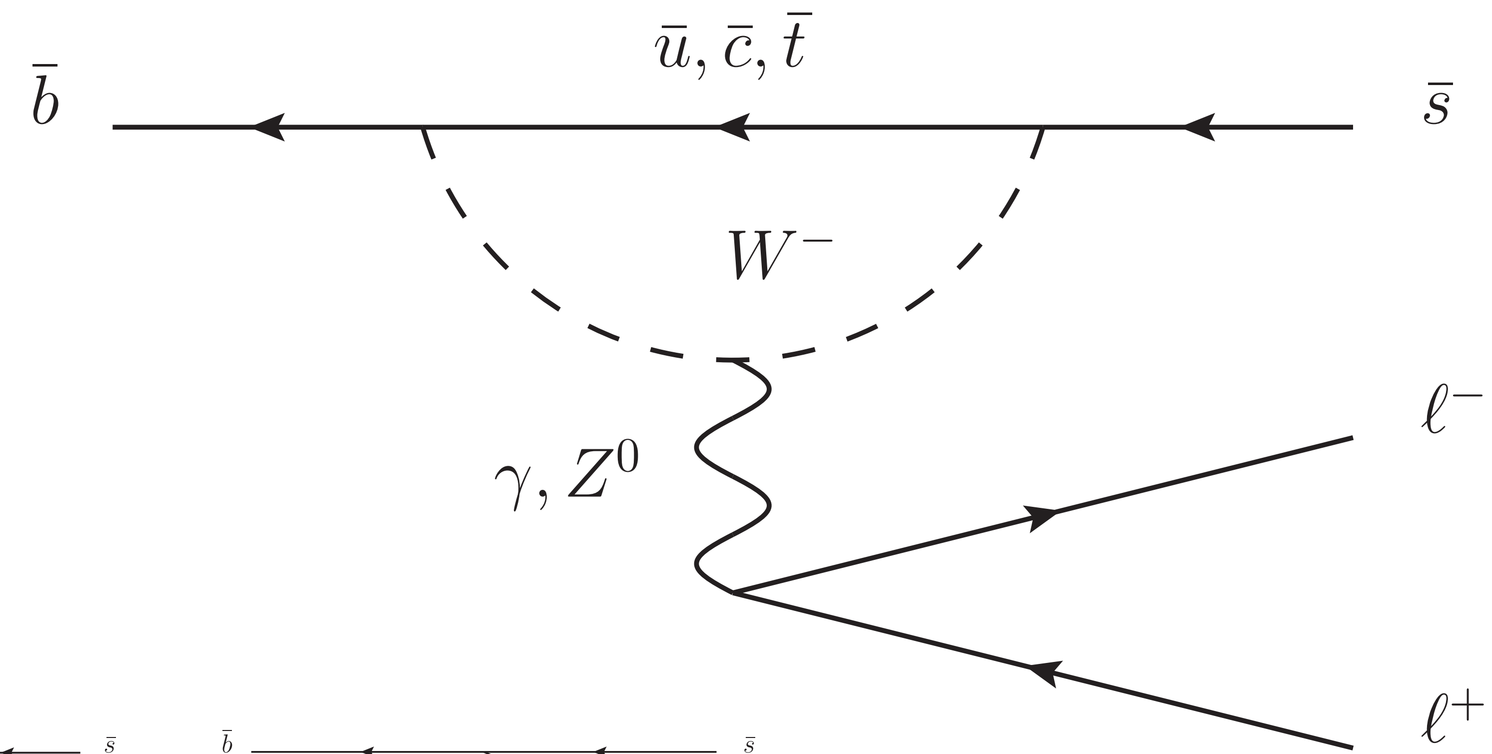
The b→s transition

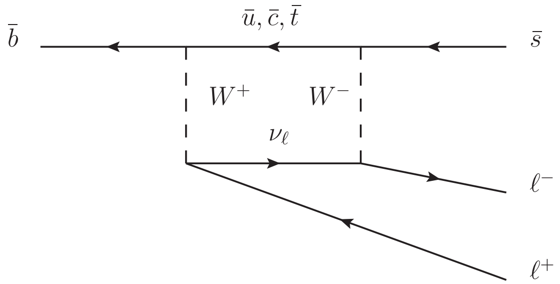
Probe the SM with FCNC



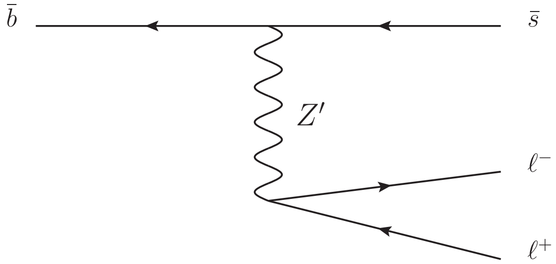
Credit: W. Altmannshofer, The Flavor Puzzle


$\bar{b}$
$\bar{u}, \bar{c}, \bar{t}$
$\bar{s}$
W^-
γ, Z^0
ℓ^-
ℓ^+

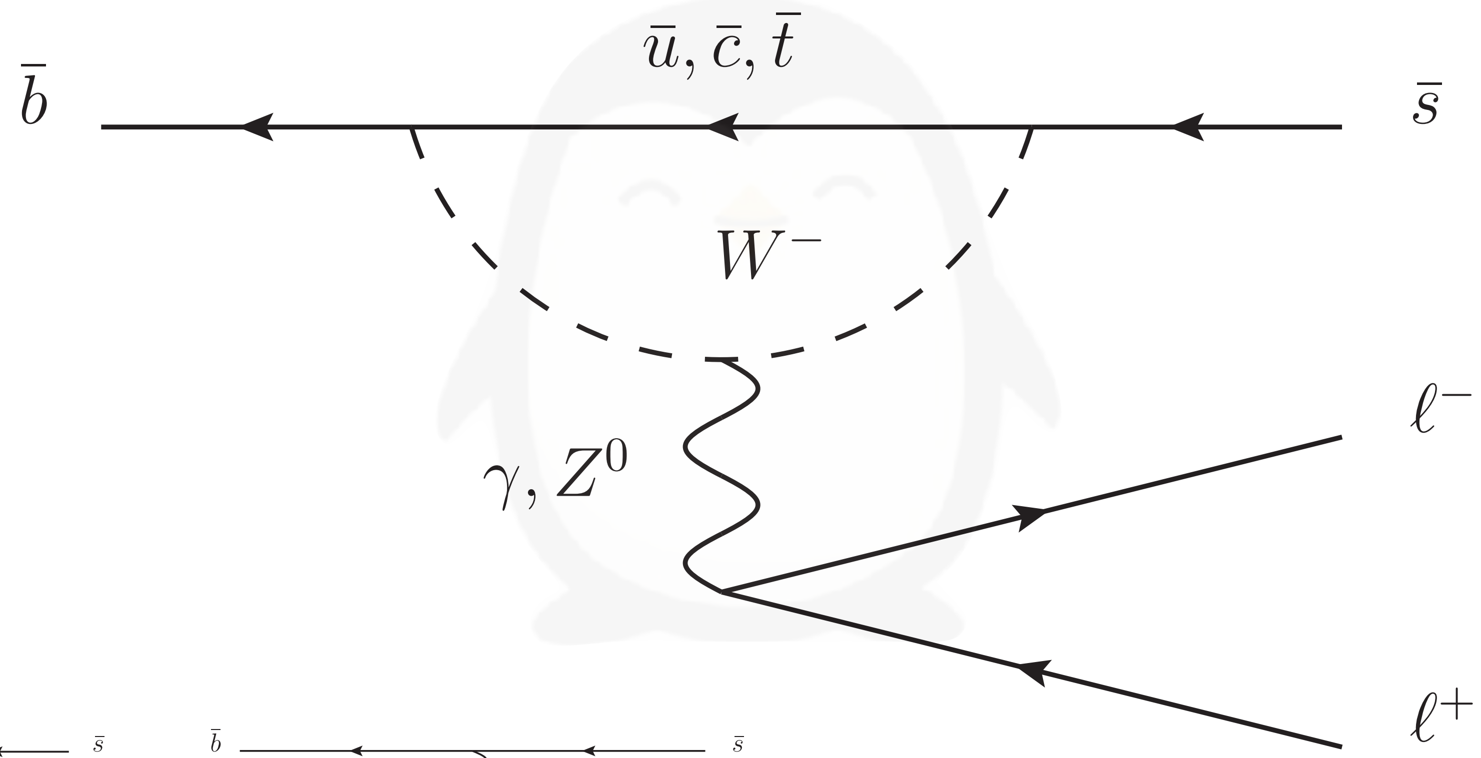


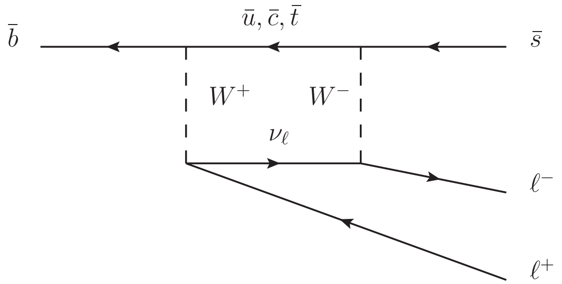


(c) SM example

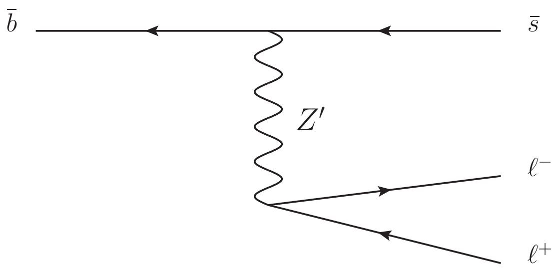


(d) NP example





(c) SM example



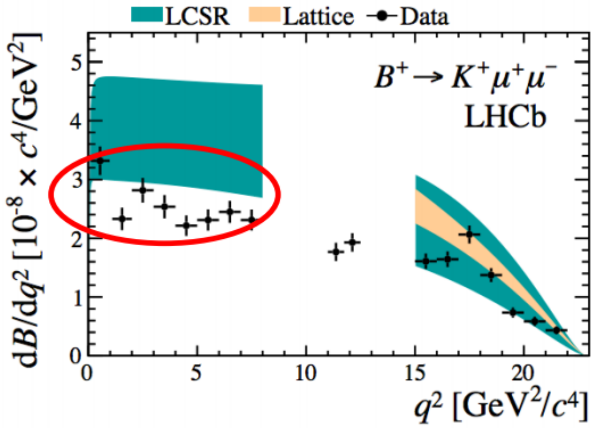
(d) NP example

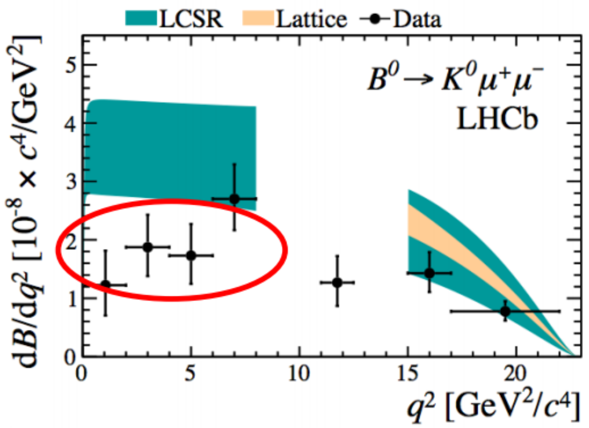
$$\mathscr{B}_{SM}(b \to s\ell\ell) = \mathcal{O}(10^{-6})$$

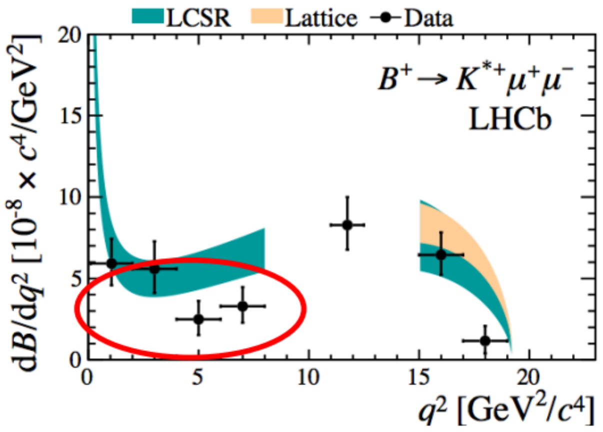
An overview of the flavour anomalies

Branching Ratio Measurement - Overview LHCb

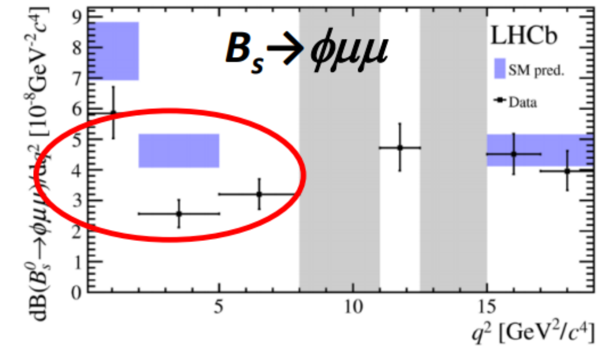
New Physics or systematic problem?



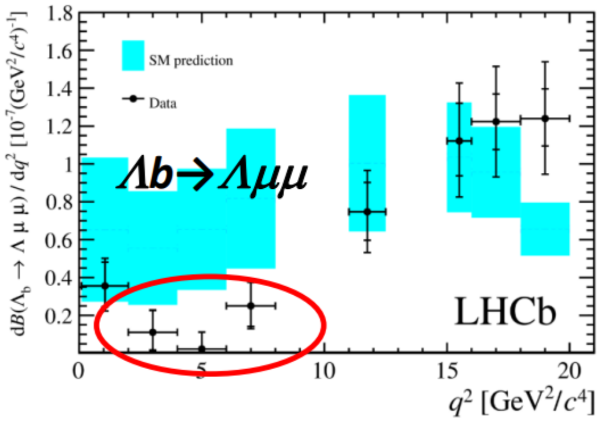




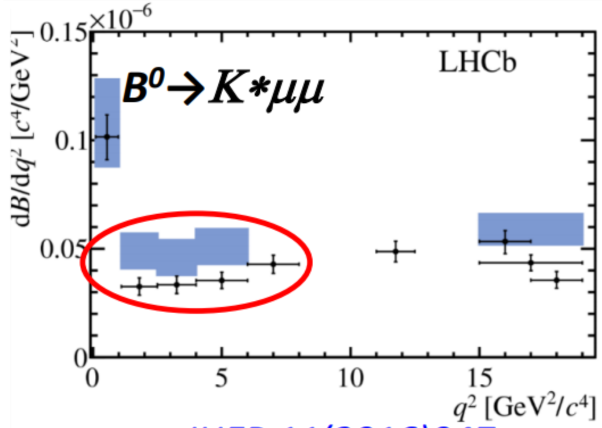
JHEP 06 (2014)133



JHEP 09 (2015)179



JHEP 06 (2015) 115

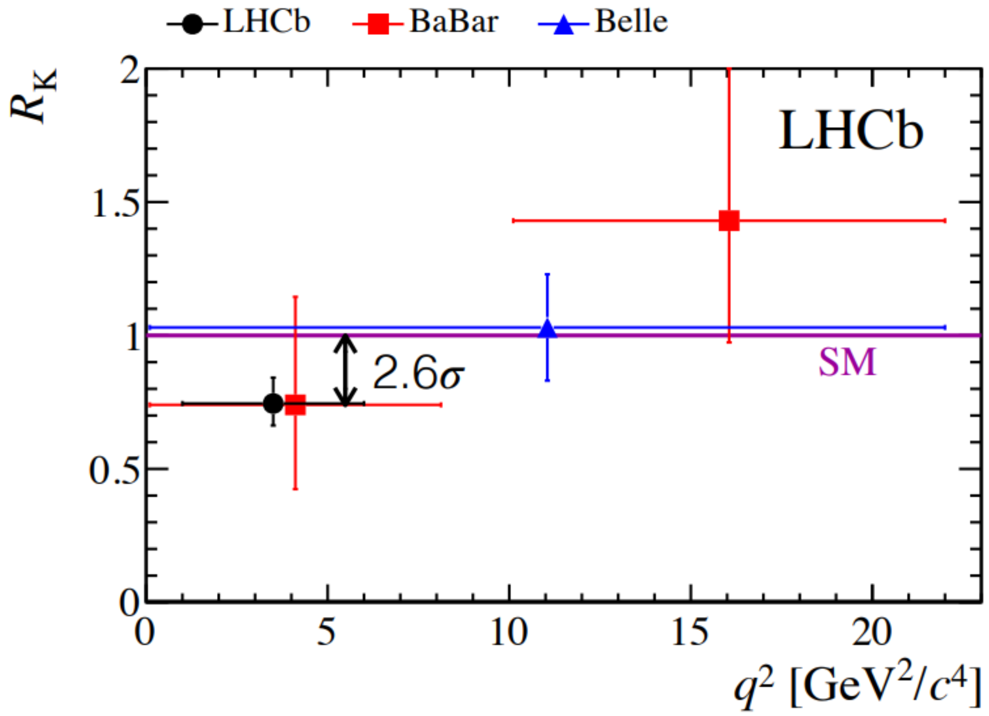


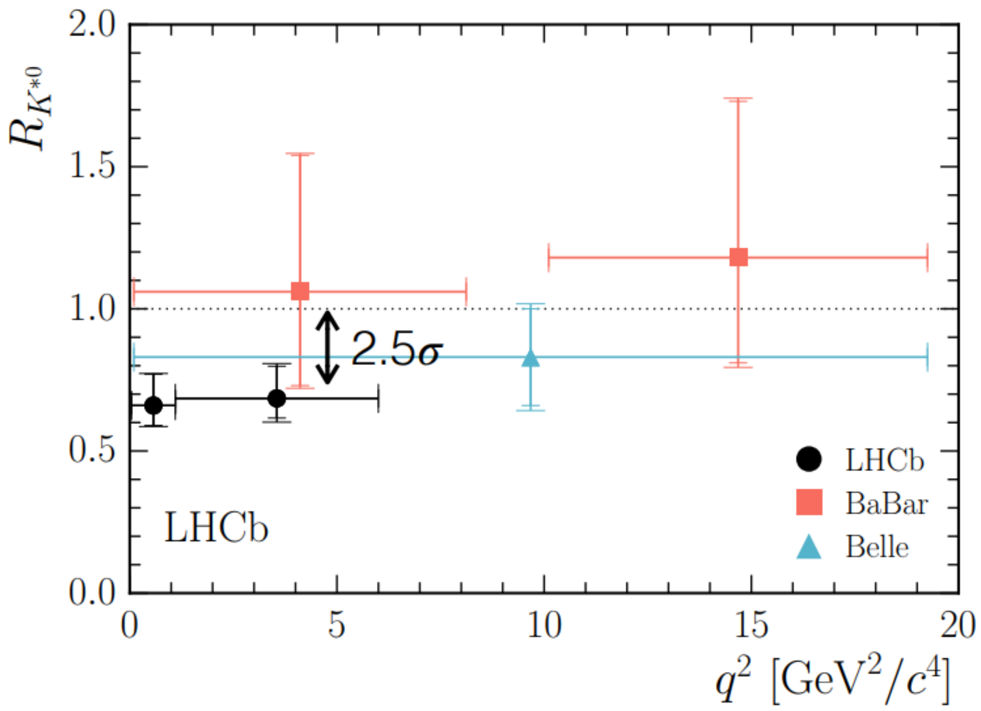
JHEP 11(2016)047
JHEP 04(2017)142

Most simple approach: Ratio of Branching Ratios

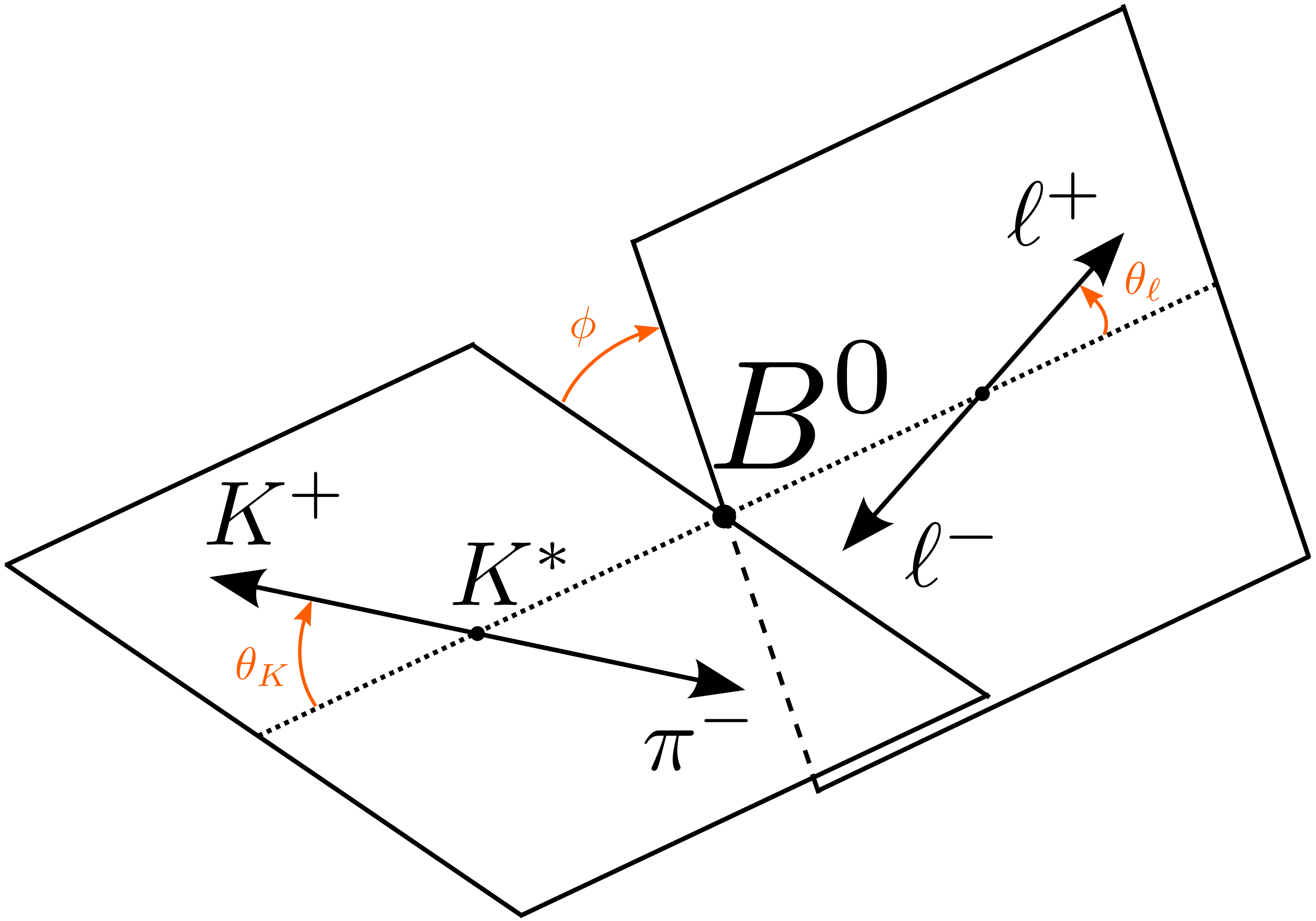
Clean observables

$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)} \qquad R_K^* = \frac{\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{*0}e^+e^-)}$$

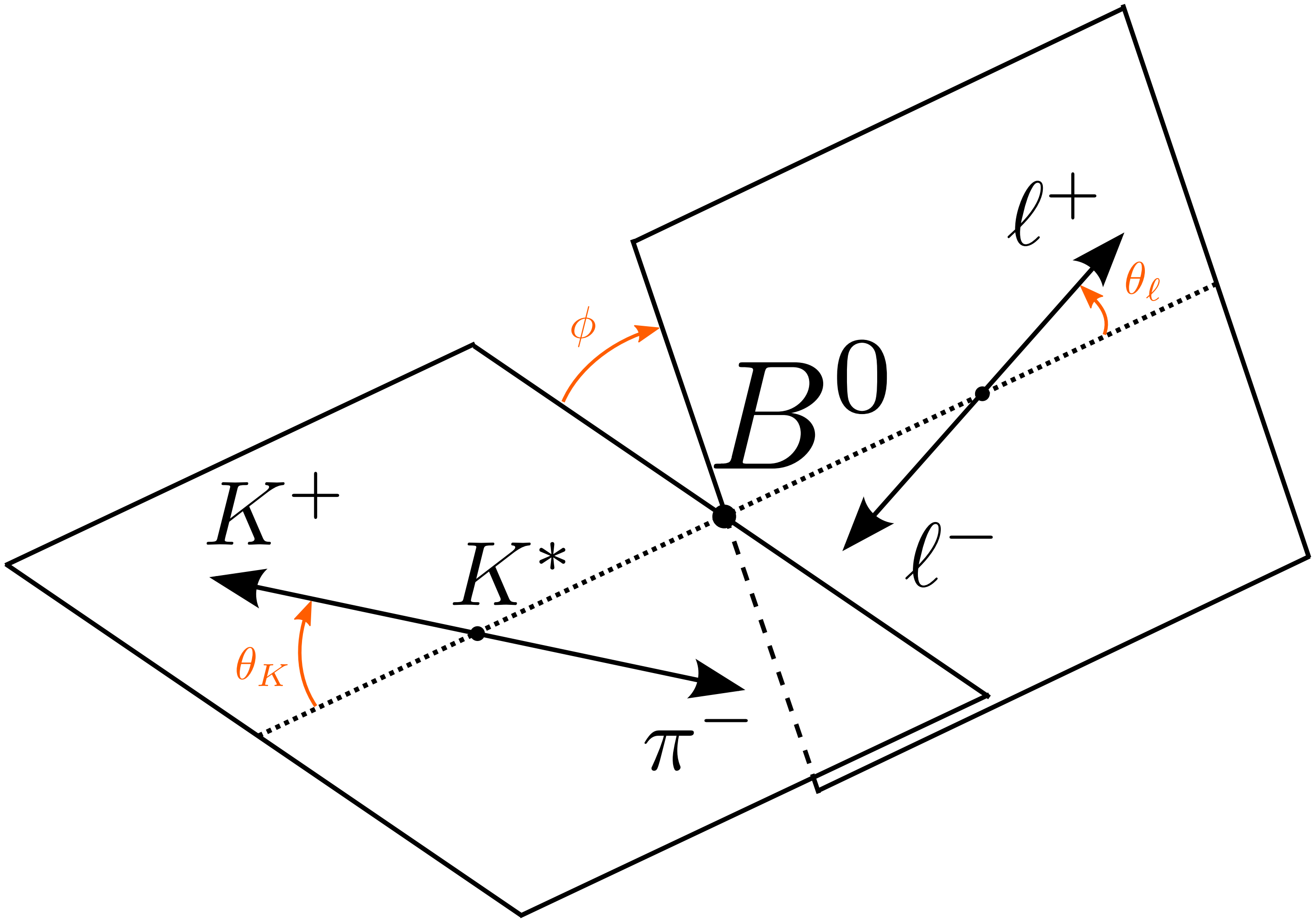




Angular Analysis of $B \to K^*ll$



Angular Analysis of $B \to K^*ll$



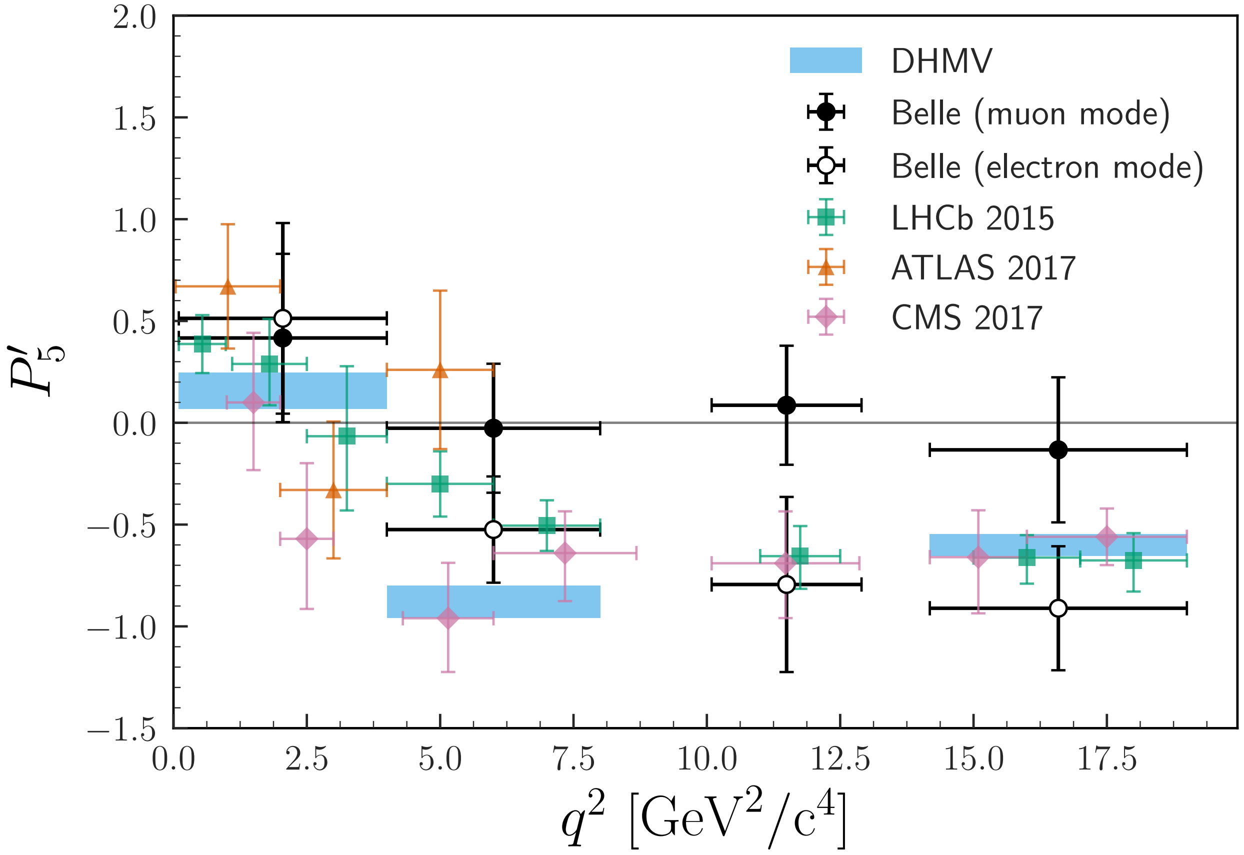
3 decay angles: ϕ, θ_l, θ_K

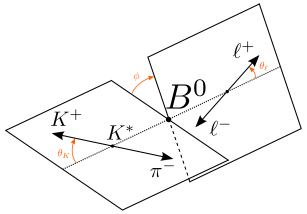
$q^2 = M_{ll}^2$

Belle 1 Angular Analysis

Results

- Many analyses have measured the angular distribution in B->K*ll
- LHCb sees the largest deviation in the low q² region
- Atlas and Belle can confirm the anomaly with less significance
- CMS is in good agreement with SM





Overview of the b->sll puzzle

Combining the results

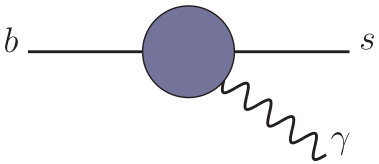
- Effective Hamiltonian approach

$$\mathcal{L}_{\text{eff}} = \sum_i C_i(\varrho)\mathcal{O}_i.$$

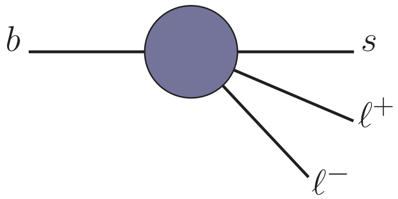
  - Effective Operators O_i
  - Effective Couplings C_i

- Combine measurements and fit for

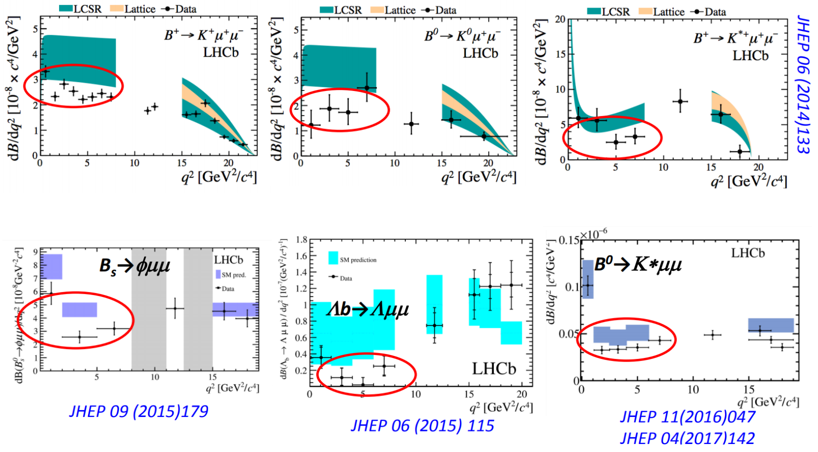
$$\mathcal{C}_9 = \mathcal{C}_9^{\mathsf{SM}} + \mathcal{C}_9^{NP}$$



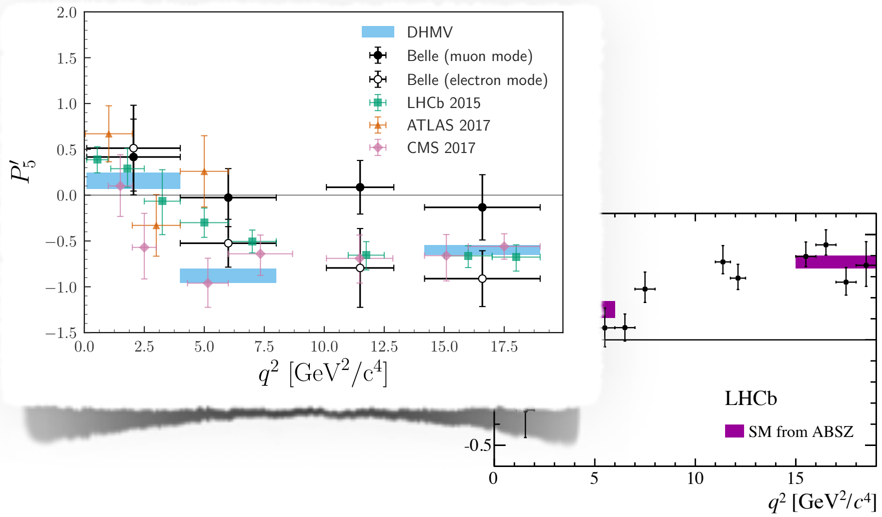
$\mathcal{O}_7$



$\mathcal{O}_{9,10}$

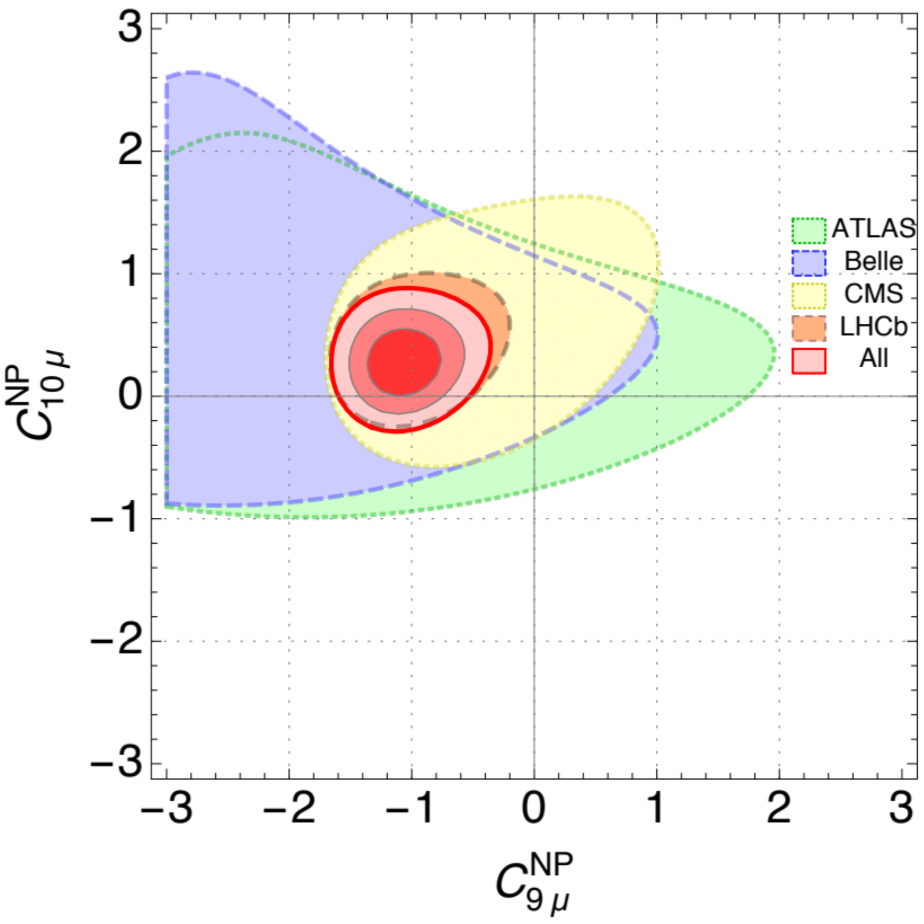


+

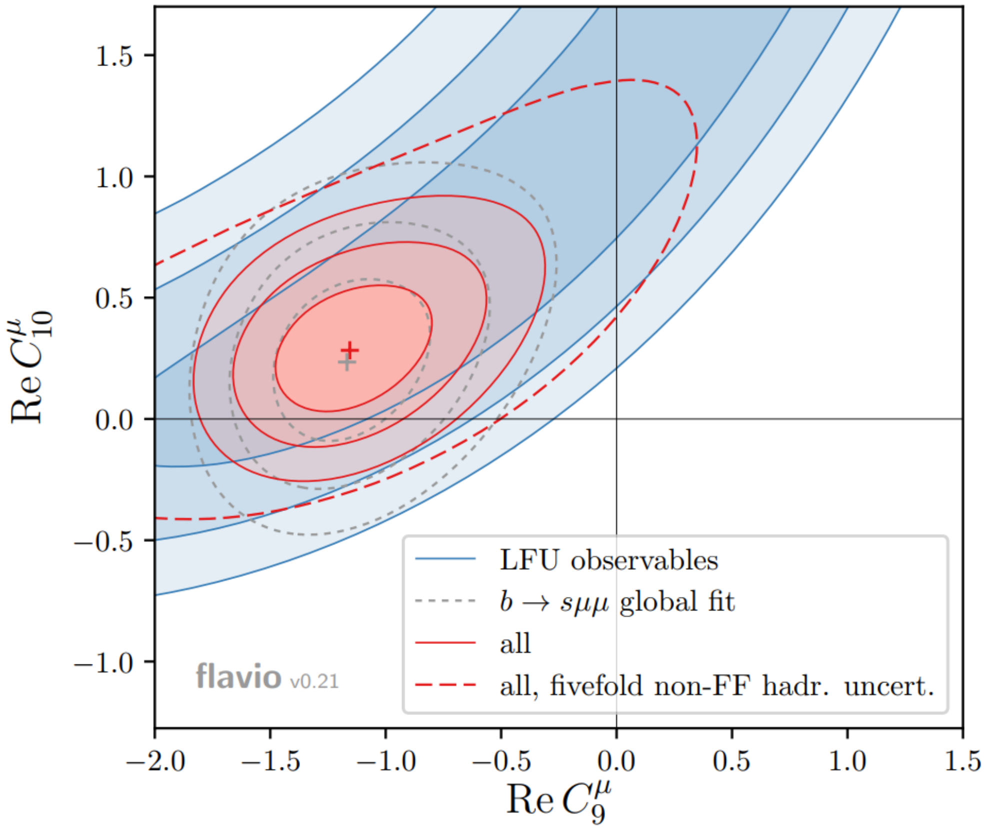


Combined Fit for New Physics

Fit for New Physics



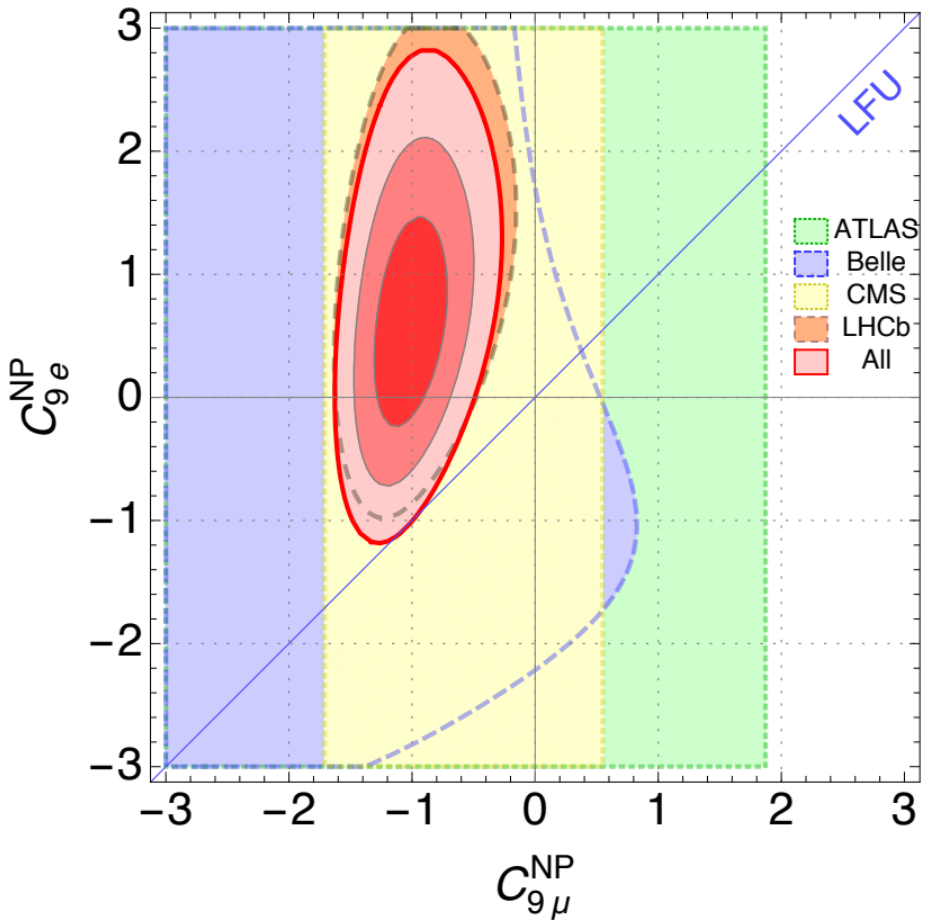
1704.05340



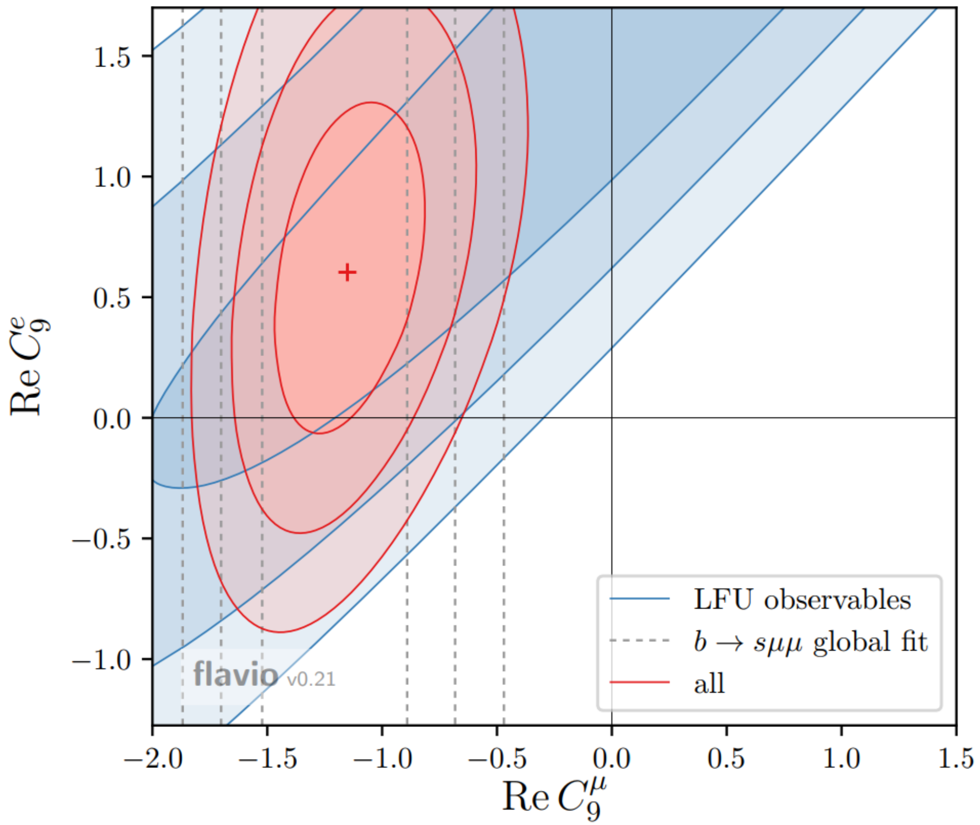
Phys. Rev. D 96, 055008 (2017)

Combined Fit for New Physics

Fit for Lepton Flavour Universality



1704.05340



Phys. Rev. D 96, 055008 (2017)

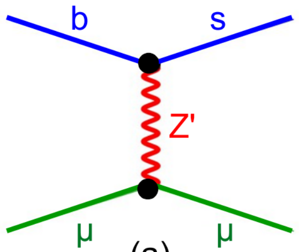
Where else to look?

The taus!

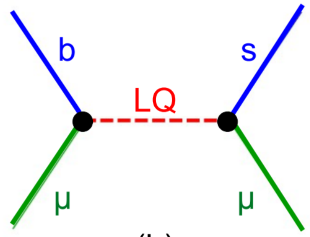
Discussion

- Many new physics models imply large contributions to b→s $\tau\tau$

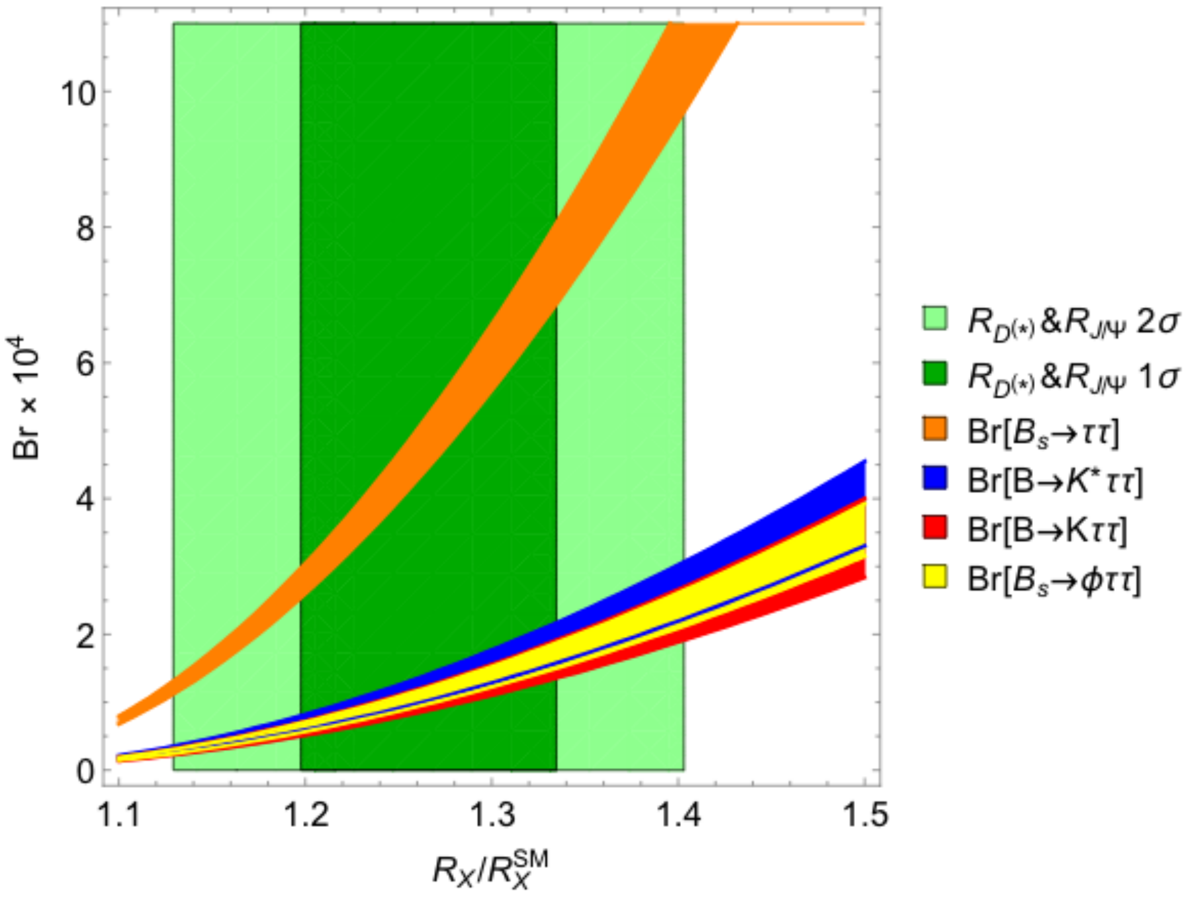
- CEPC will have the unique ability to study couplings to the third lepton family



(a)

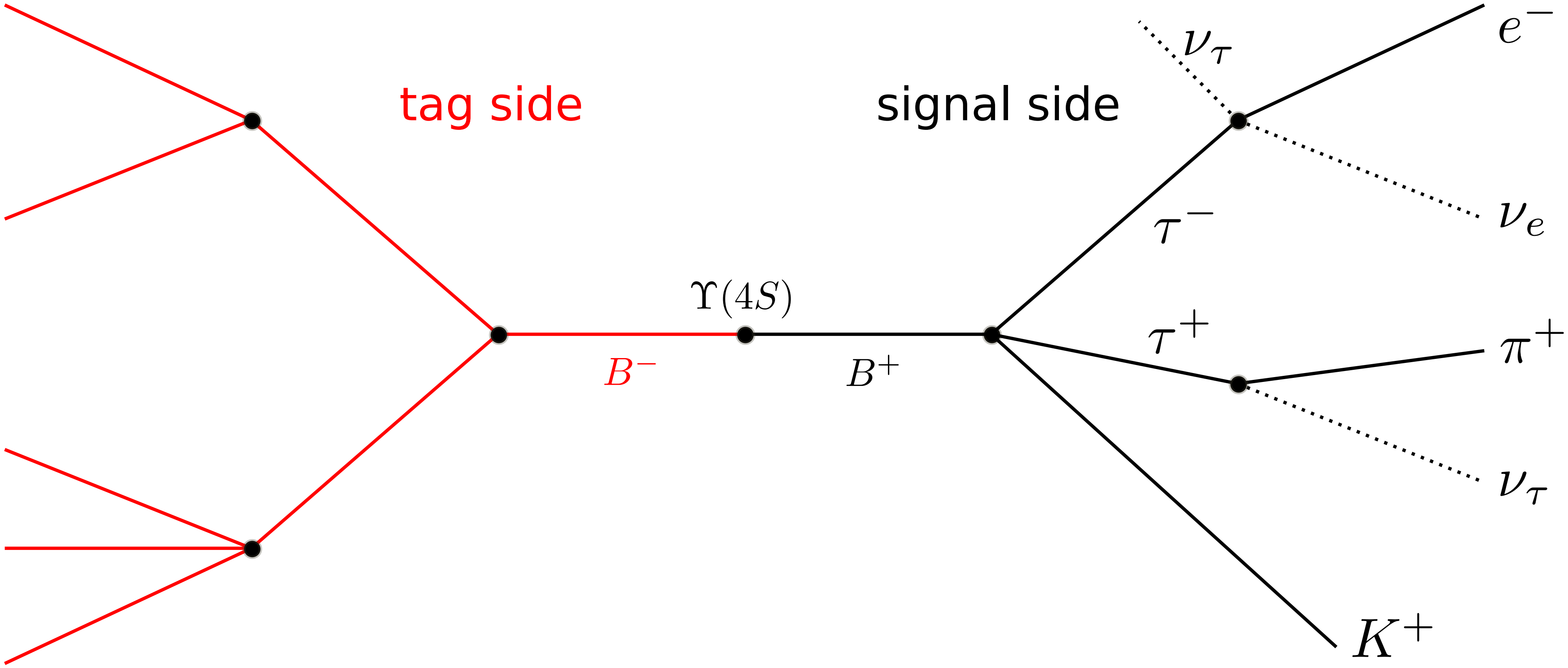


(b)



Capdevila *et al.* 1712.01919

B → K⁺$\tau^+\tau^-$ at Belle

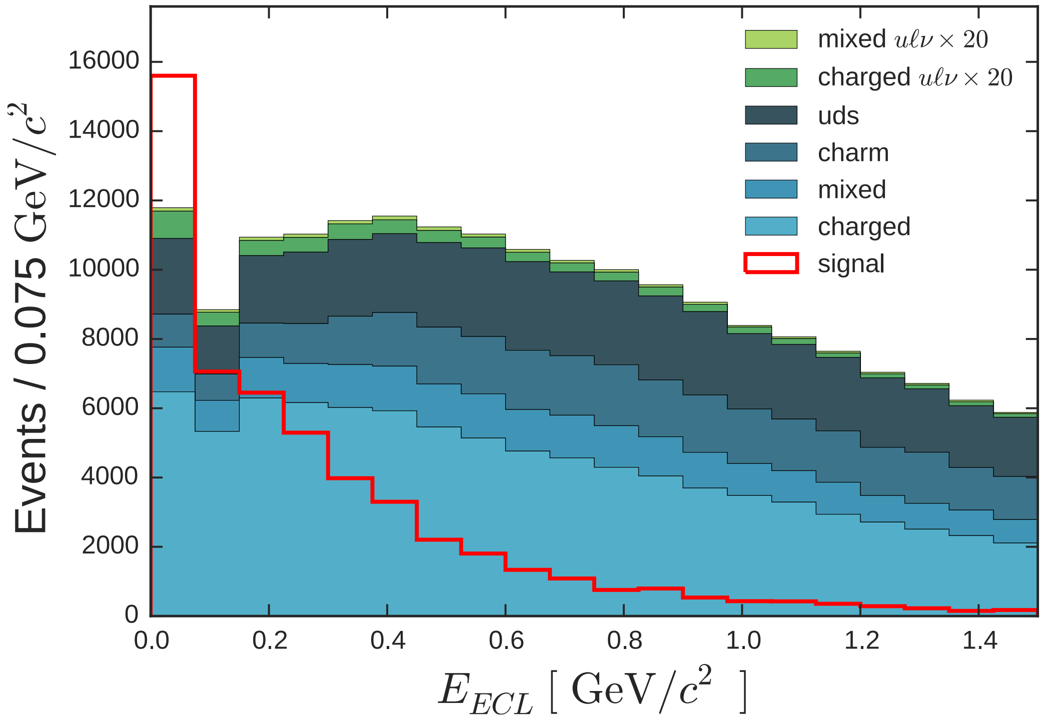


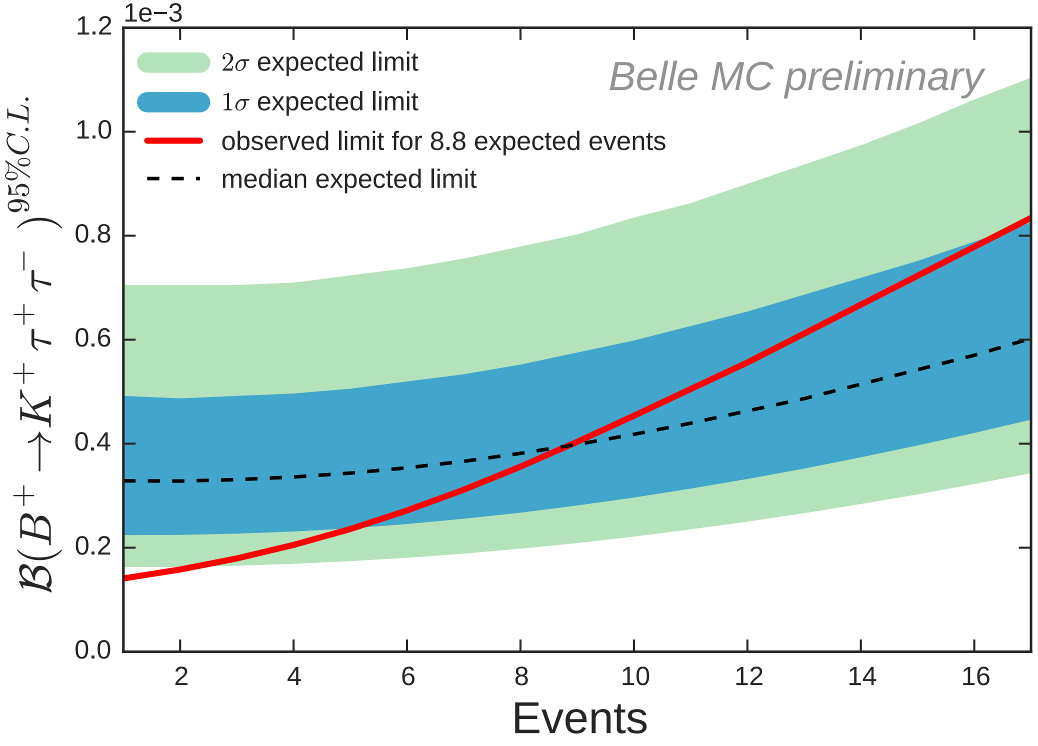
The tag side is reconstructed in more than 1000 exclusive hadronic decay channels using more than 70 neural networks

$$\mathcal{P}_{e^+} + \mathcal{P}_{e^-} = \mathcal{P}_{\text{tag-side}} + \mathcal{P}_{\text{signal-side}}.$$

B → K⁺$\tau^+\tau^-$ at Belle

Preliminary study on simulated events





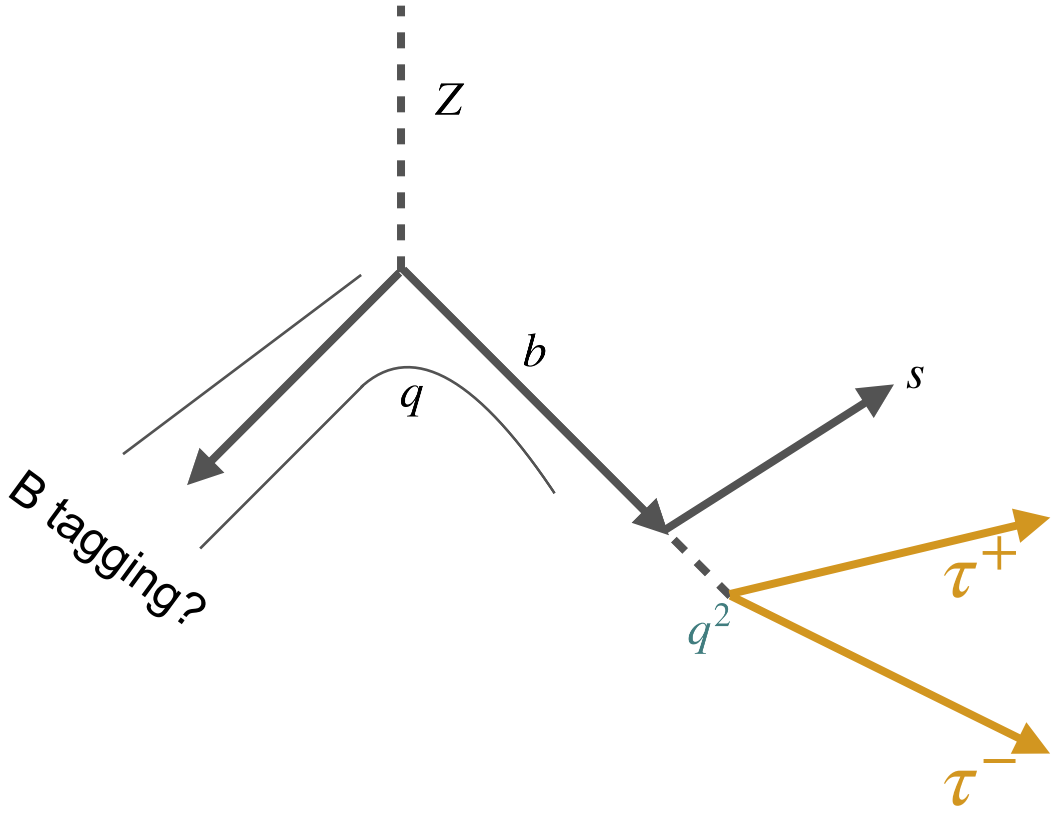
b$\longrightarrow$s $\tau\tau$ at CEPC

Reconstruction Methods

Untagged using three prong decays of the tau

$B \to K^+\tau\tau,\ B \to K^*\tau\tau,\ B \to \phi\tau\tau,\ B_s \to \tau\tau$

- Partial reconstruction could be sufficient
- Sensitive to
  - Polarisation
  - **Angular analysis!**
- Important benchmarks:
  - vertex and momentum resolution of the taus
  - vertex separation depending on q^2

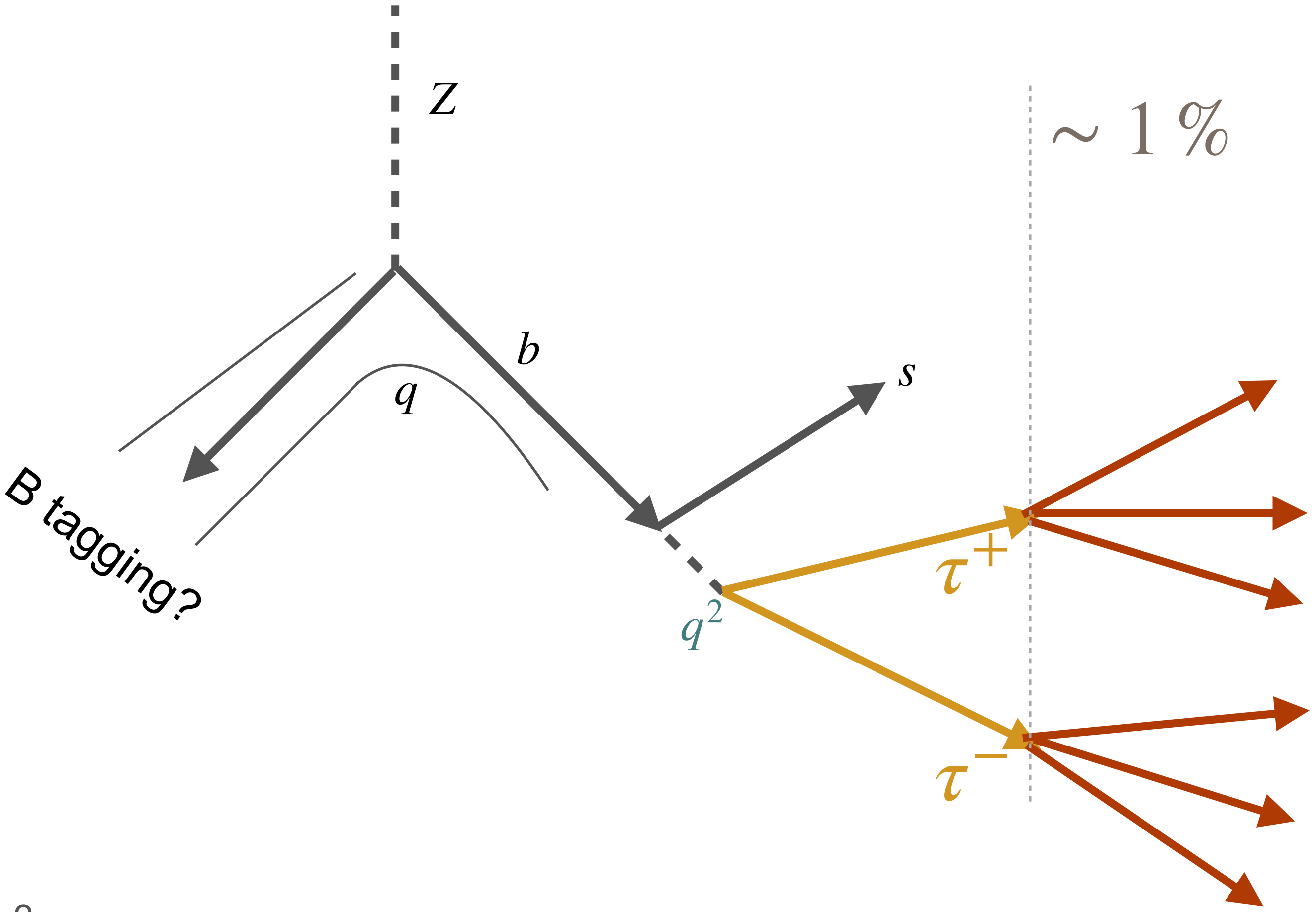


Reconstruction Methods

Untagged using three prong decays of the tau

$B \to K^+\tau\tau,\ B \to K^*\tau\tau,\ B \to \phi\tau\tau,\ B_s \to \tau\tau$

- Partial reconstruction could be sufficient
- Sensitive to
  - Polarisation
  - **Angular analysis!**
- Important benchmarks:
  - vertex and momentum resolution of the taus
  - vertex separation depending on q^2

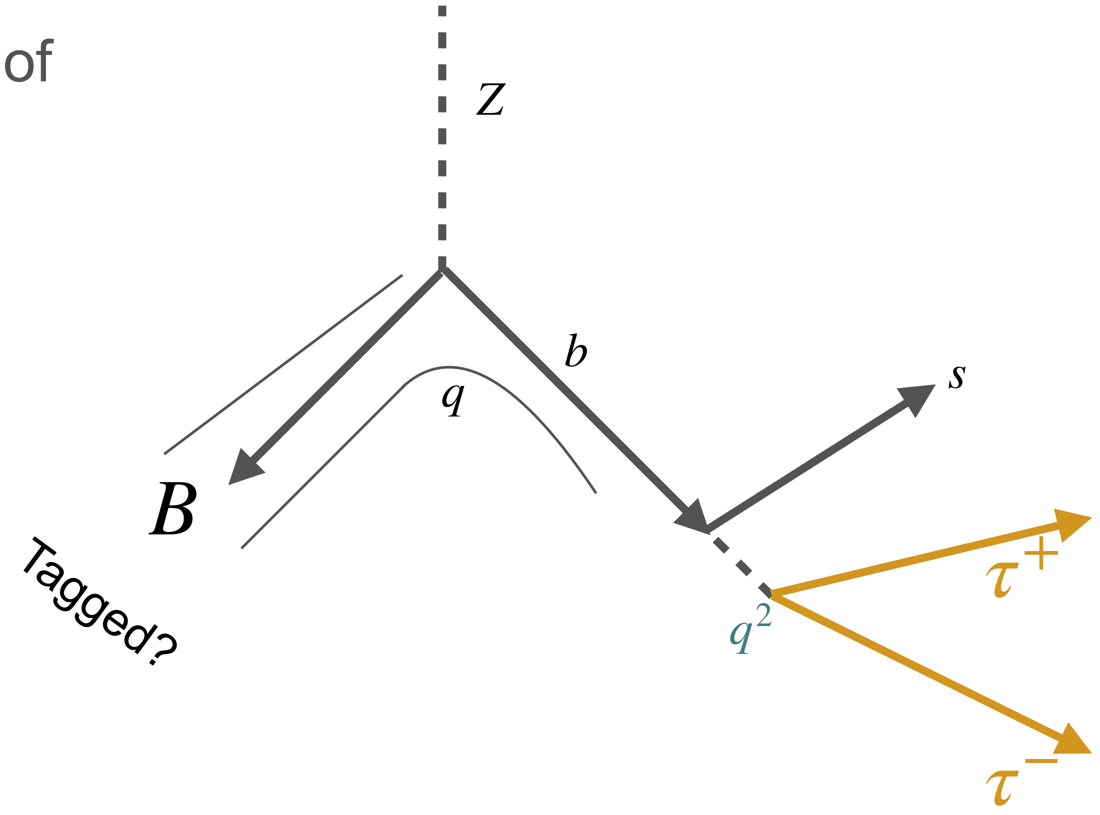


Reconstruction Methods

Tagged in single prong decays

$B \to K^+\tau\tau,\ B \to K^*\tau\tau,\ B \to \phi\tau\tau,\ B_s \to \tau\tau$

- Signal side efficiency an order of magnitude higher
- Dependent on the efficiency of the B-tagging algorithm this would be a viable option



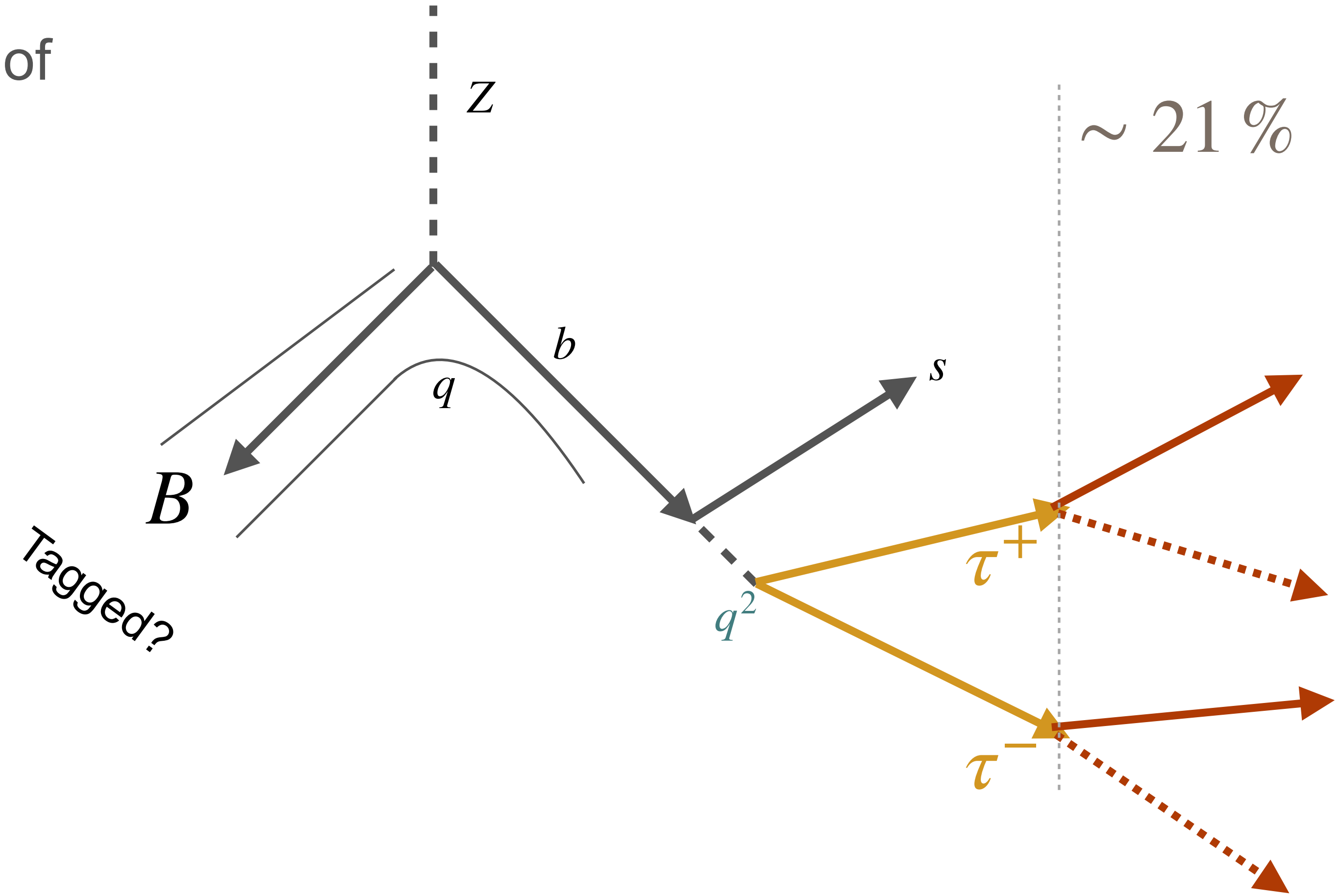
- Challenges
  - Spatial separation of B tracks
  - Backgrounds

Reconstruction Methods

Tagged in single prong decays

- Signal side efficiency an order of magnitude higher
- Dependent on the efficiency of the B-tagging algorithm this would be a viable option
- Challenges
  - Spatial separation of B tracks
  - Backgrounds

$B \to K^+\tau\tau,\ B \to K^*\tau\tau,\ B \to \phi\tau\tau,\ B_s \to \tau\tau$



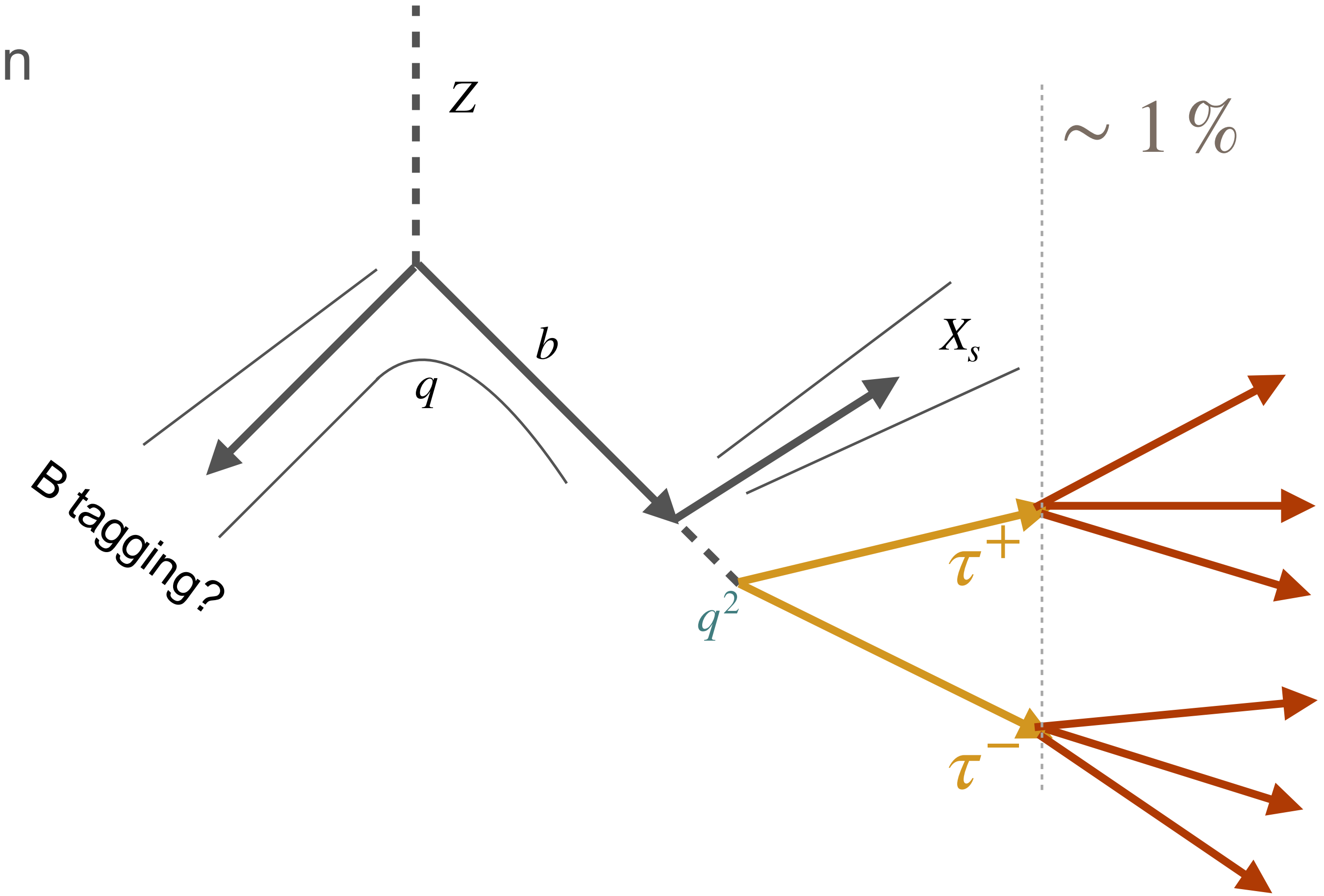
Reconstruction Methods

Inclusive

- Inclusive decays offer very clean theoretical observables

- Important benchmarks:
  - Kaon identification
  - K_S finding

- Possible problems
  - difficult to estimate spectator

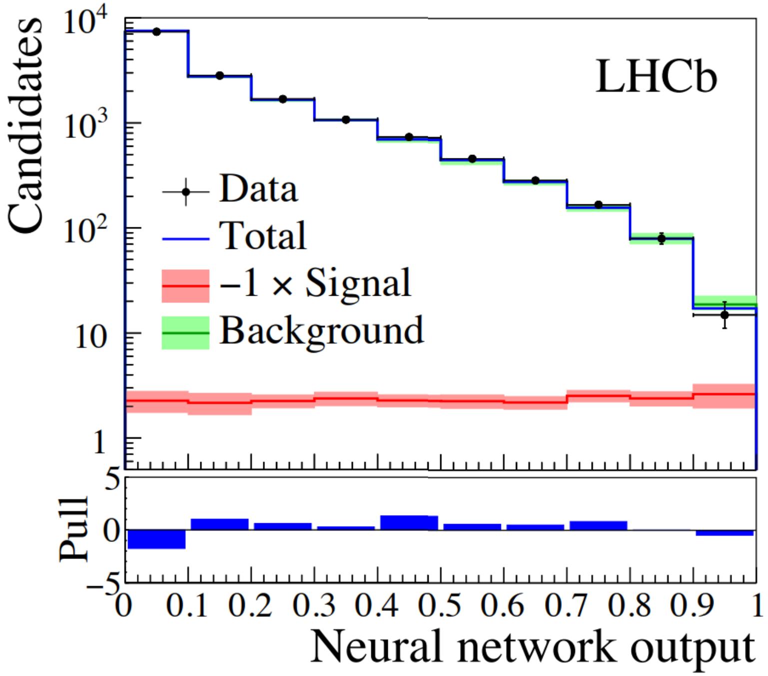


$B_s \rightarrow \tau\tau$

$B_{d,s} \rightarrow \tau\tau$

- LHCb measurement using $\tau \rightarrow \pi^-\pi^+\pi^-\nu_\tau$
- $\mathcal{B}(B_s^0 \rightarrow \tau^+\tau^-) < 6.8 \times 10^{-3}(95\%\mathrm{CL})$
- $\mathcal{B}(B_d^0 \rightarrow \tau^+\tau^-) < 2.1 \times 10^{-3}(95\%\mathrm{CL})$

$$\mathscr{B}_{SM}(B_s \rightarrow \tau\tau) = \sim 10^{-7}$$



[LHCb, PRL 118 (2017) 251802]

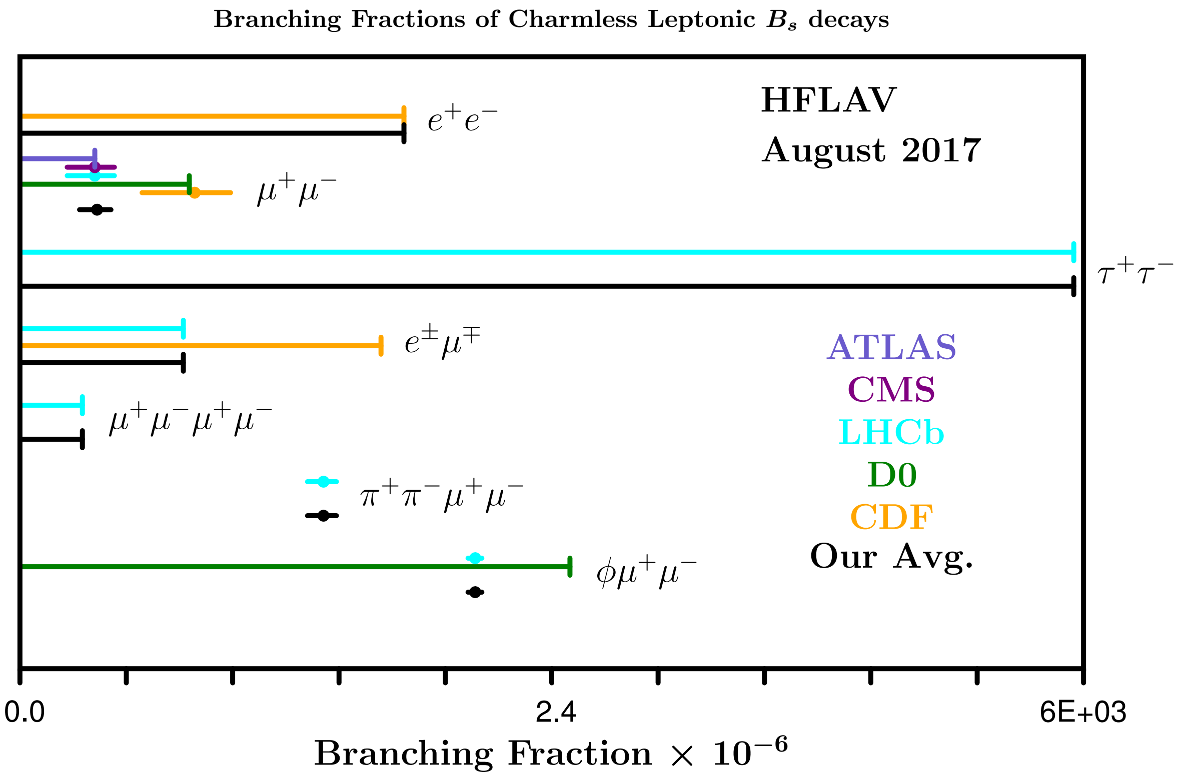
- LHCb currently sets the strongest limits on B→$\tau\tau$ but is missing the constraint from the other b
- CEPC can be leading this analysis

$\mathbf{B_s} \to \tau\tau$

$B_{d,s} \to \tau\tau$

- LHCb measurement using $\tau \to \pi^-\pi^+\pi^-\nu_\tau$
- $\mathcal{B}(B_s^0 \to \tau^+\tau^-) < 6.8 \times 10^{-3}(95\%\mathrm{CL})$
- $\mathcal{B}(B_d^0 \to \tau^+\tau^-) < 2.1 \times 10^{-3}(95\%\mathrm{CL})$

$$\mathscr{B}_{SM}(B_s \to \tau\tau) = \sim 10^{-7}$$

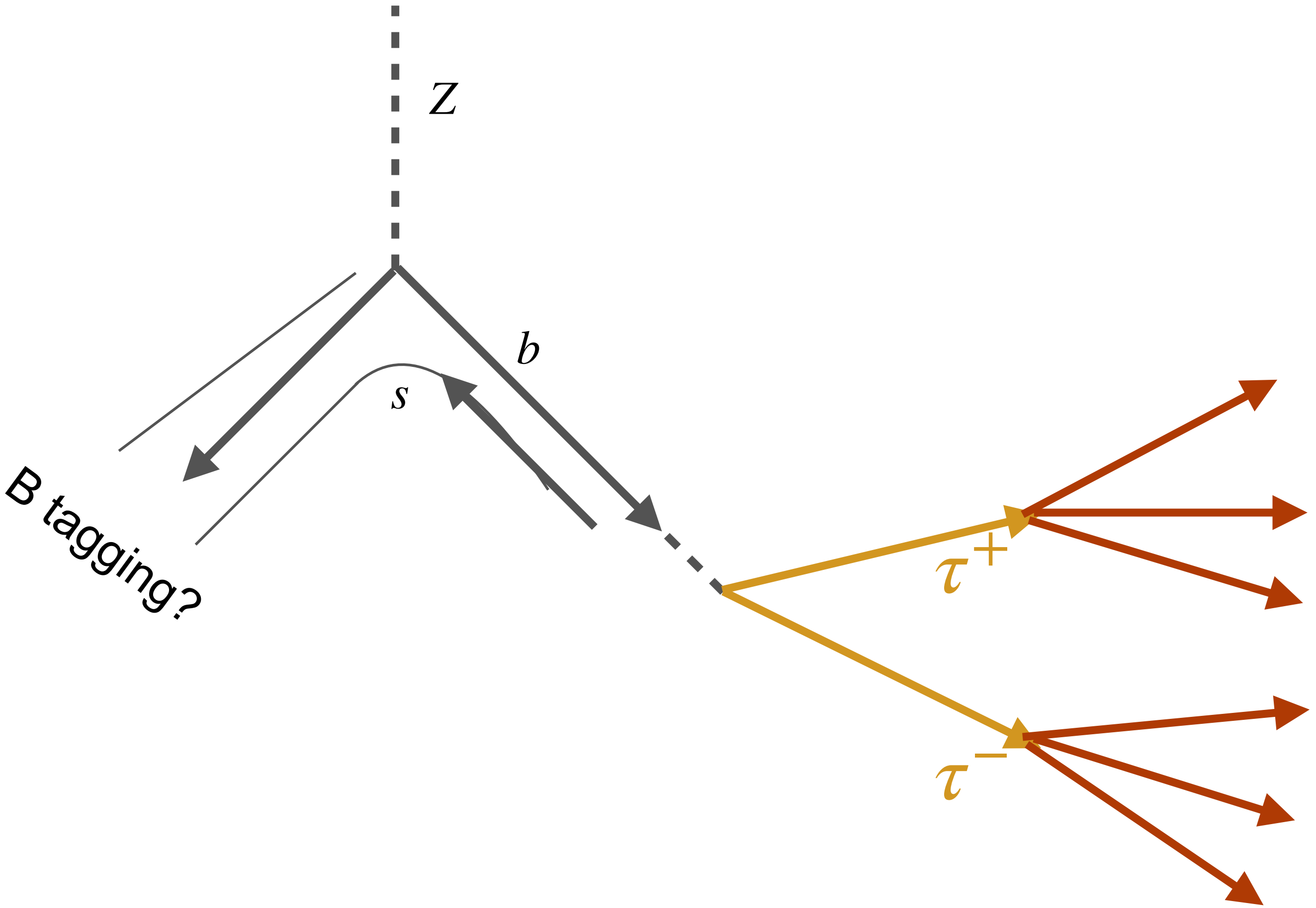


- LHCb currently sets the strongest limits on B→$\tau\tau$ but is missing the constraint from the other b
- CEPC can be leading this analysis

$B_s \rightarrow \tau\tau$

Untagged using three prong decays of the tau

- Partial reconstruction should be sufficient
- Full decay solvable at CEPC



- Important benchmarks:
  - vertex and momentum resolution of the taus
  - B mass resolution

Other Analyses

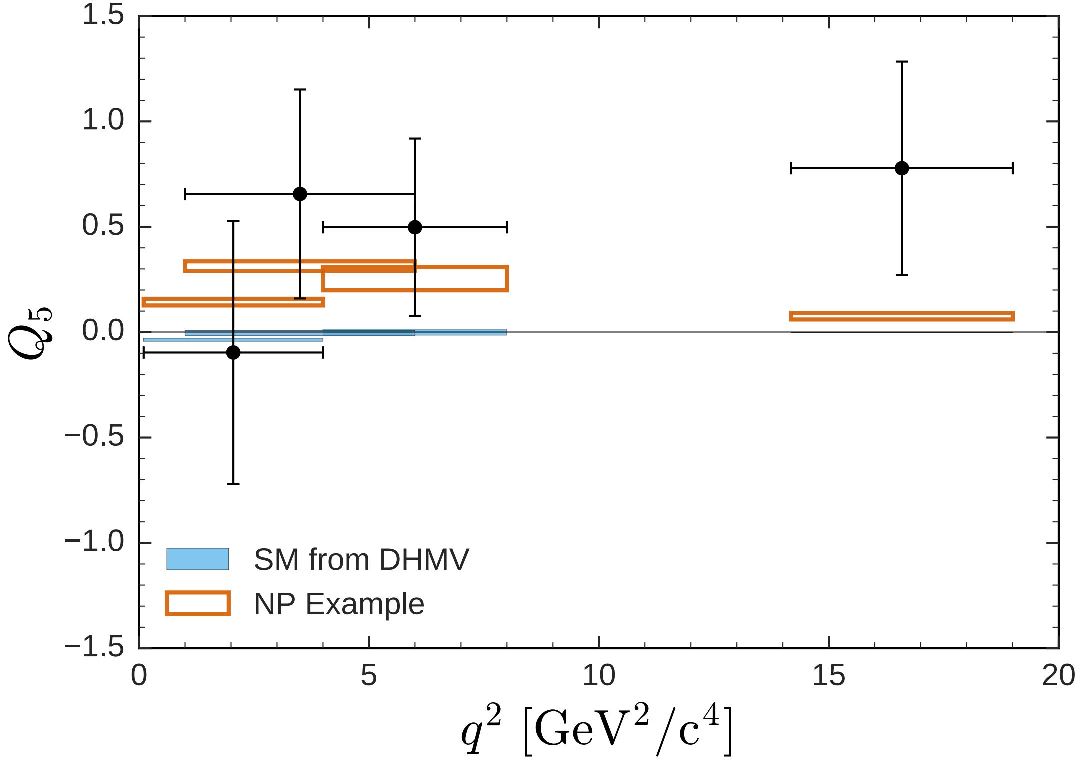
- LHCb has difficulties with mass resolution of decays with electrons in the final state
  - LFU tests in angular observables can be competitive with Belle II
    - Benchmark: q2 resolution and mass resolution for B → K* ll
- Probing Lepton Flavour Violating decays

$$B \to K^{(*)}\tau l$$

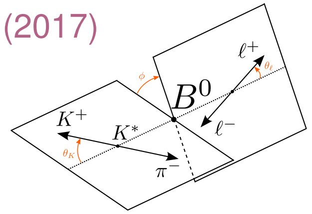
- CEPC might have the unique opportunity to measure

$$R^{\tau/e}_{K^{(*)}},\ R^{\tau/\mu}_{K^{(*)}}$$

$$Q_i = P_i'^{\mu} - P_i'^{e}$$



Phys. Rev. Lett. 118, 111801 (2017)



Conclusions

- $b \to s\tau\tau$ decays are a promising candidate to find physics beyond the SM
  - CEPC could play a dominant role to investigate these decays
  - If the anomalies persist, CEPC will have excellent prospects studying NP effects in couplings to the third generation of leptons
- Important features
  - good K/π separation
  - Bremsstrahlung recovery for electrons
  - vertex resolution for tau three prong decays
- Best experimental setup for $B_s \to \tau\tau$!

Thank you very much for your attention!

Contact

DESY. Deutsches
Elektronen-Synchrotron

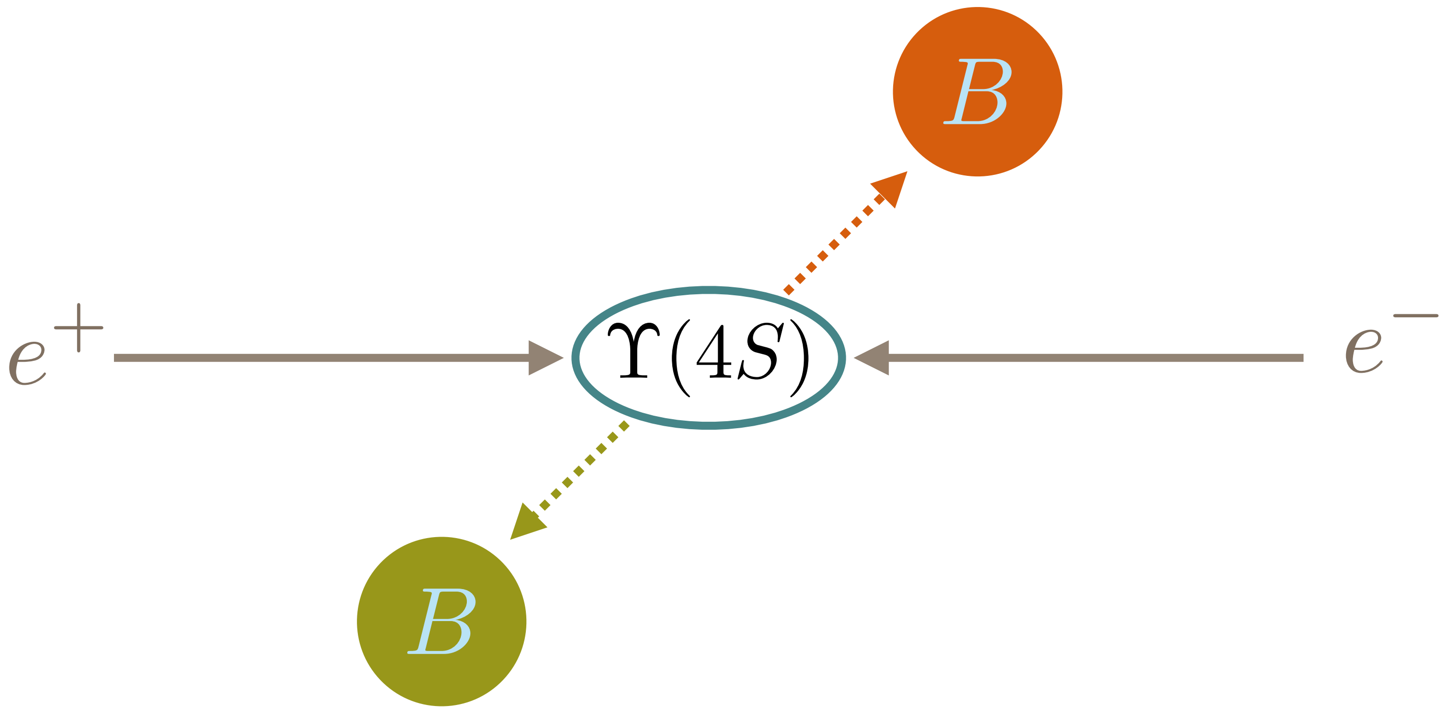
www.desy.de

Simon Wehle
Belle & Belle II
simon.wehle@desy.de
+49 40 4994 3789

Experimental setup for Belle (II)

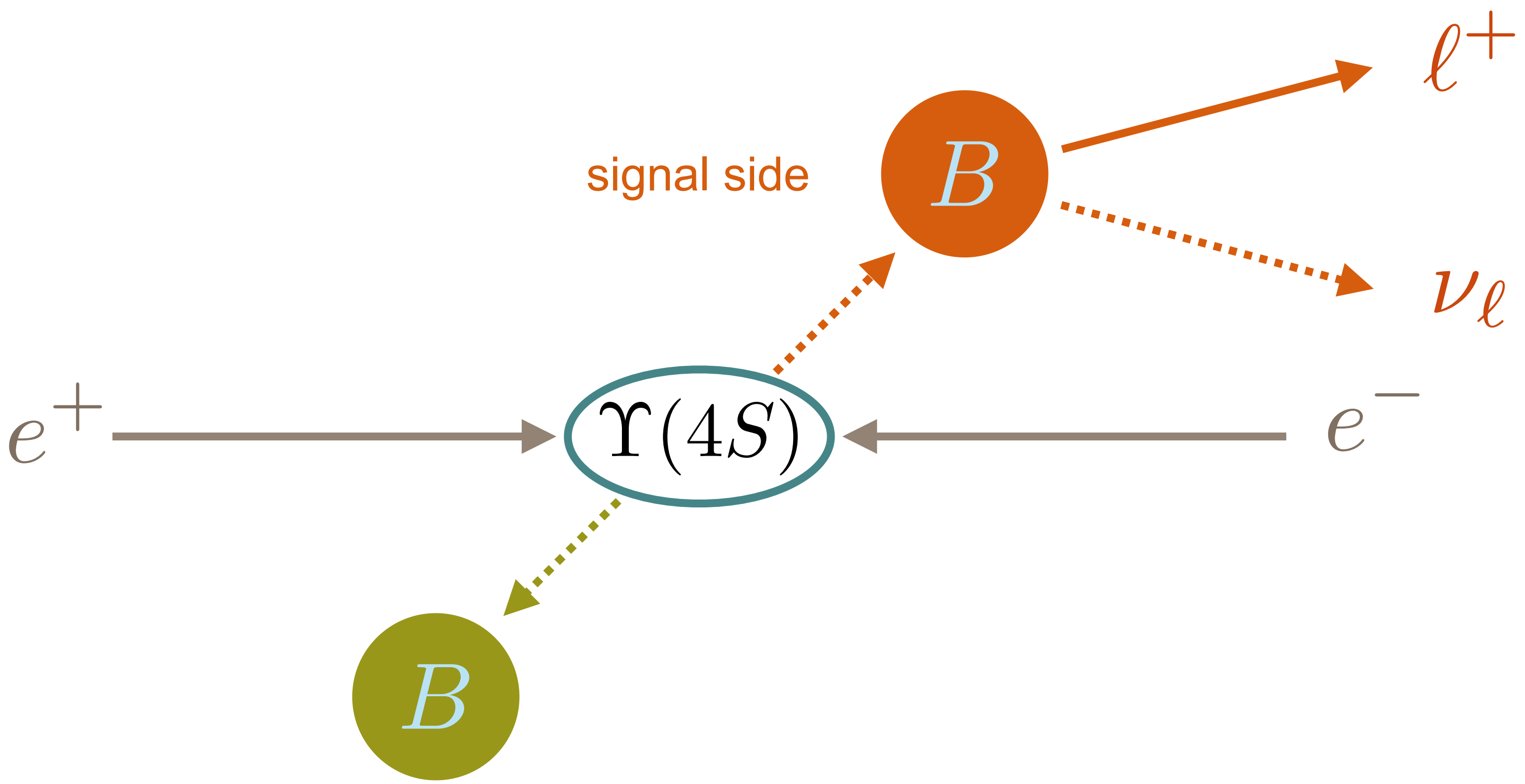
Experimental Setup for Belle II

Advantages at e^+e^- colliders



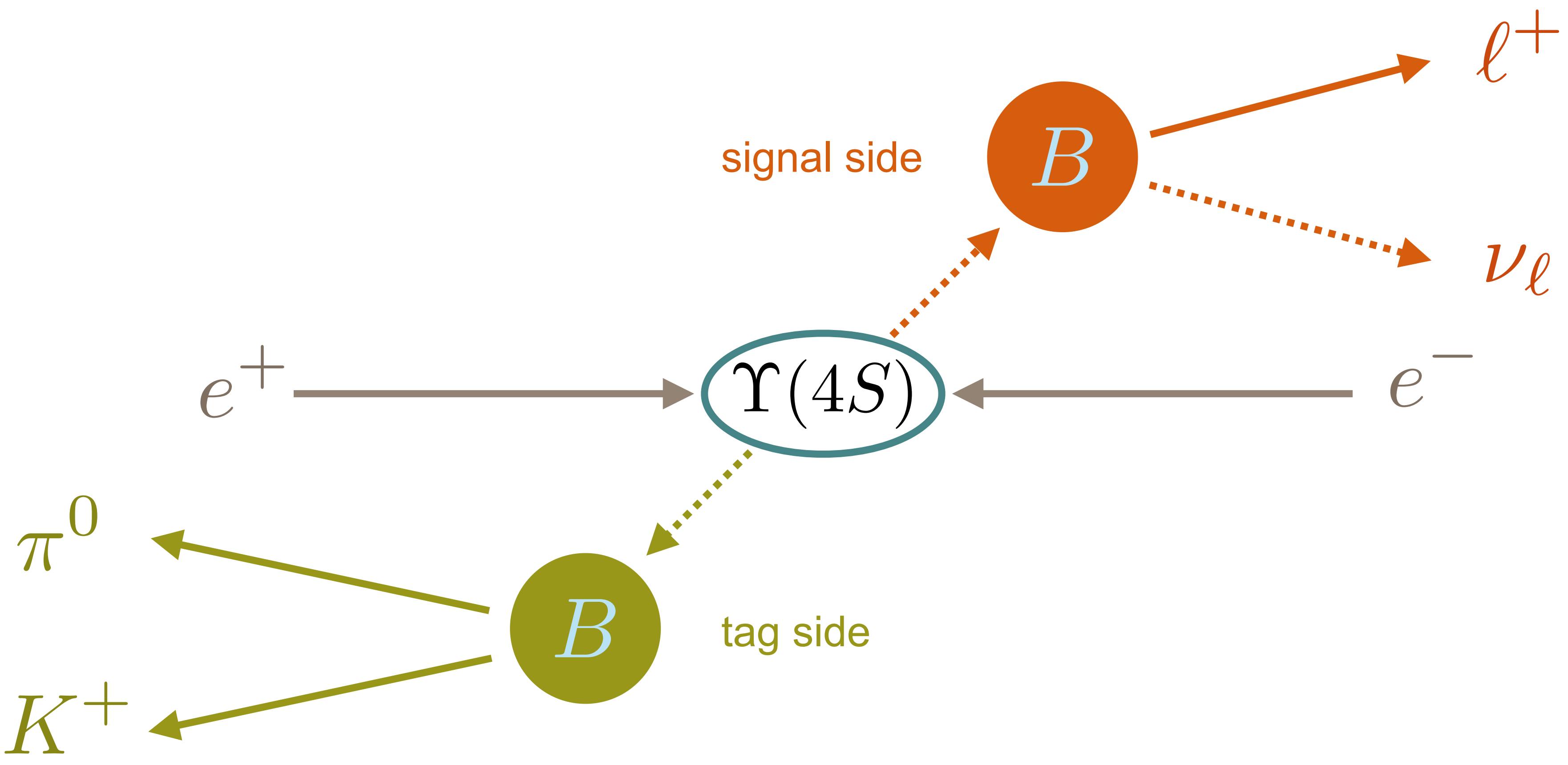
Experimental Setup for Belle II

Advantages at e+e- colliders



Experimental Setup for Belle II

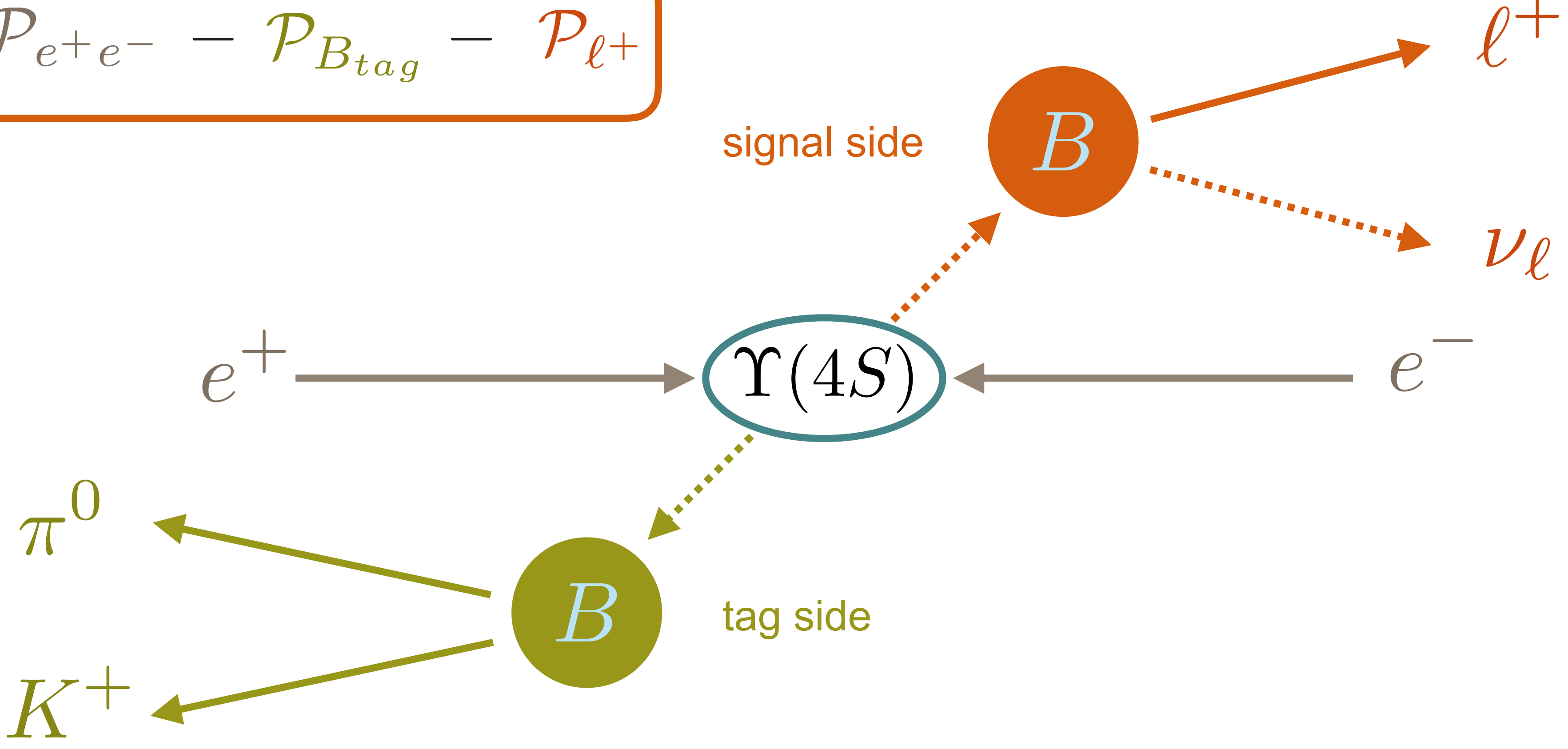
Advantages at e⁺e⁻ colliders



Experimental Setup for Belle II

Advantages at e^+e^- colliders

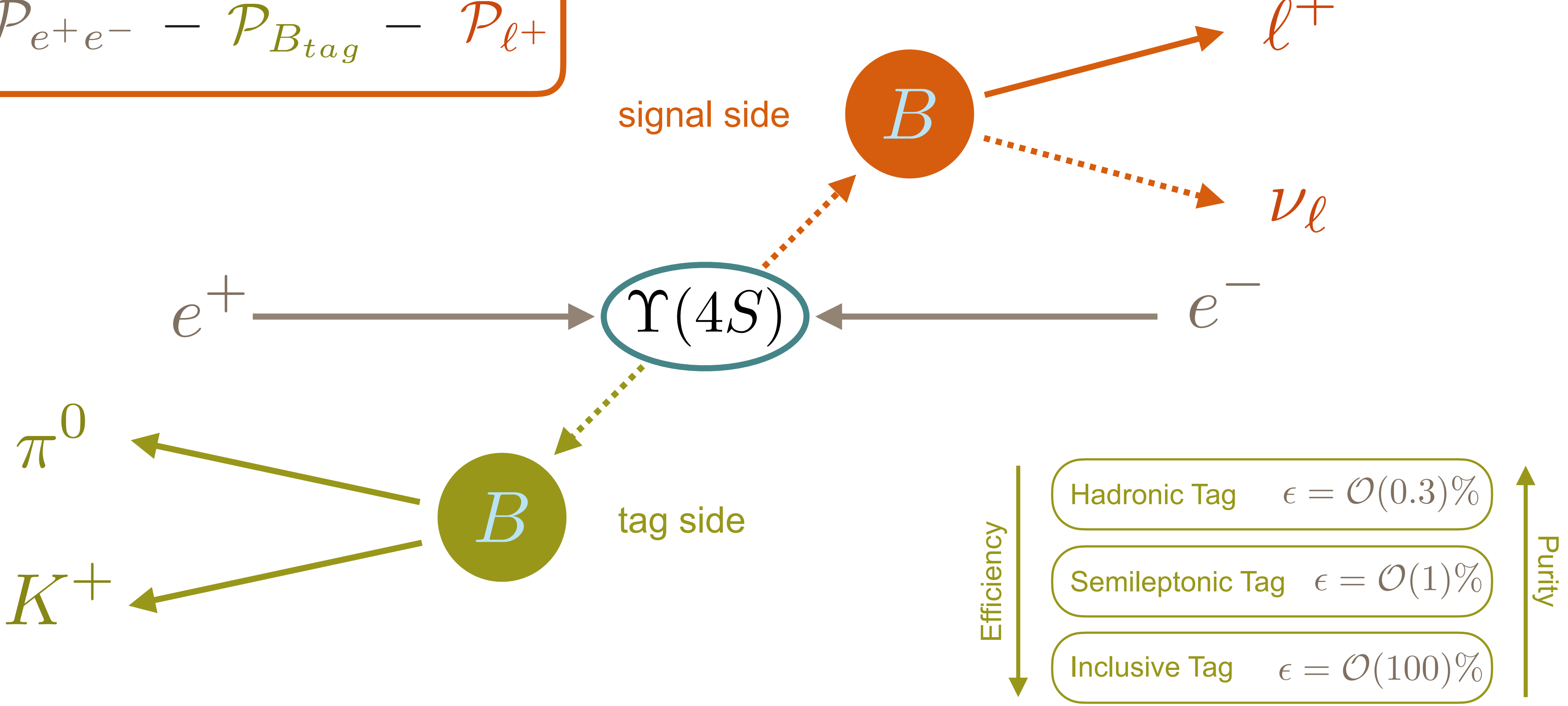
$$\boxed{\mathcal{P}_{\nu_\ell} = \mathcal{P}_{e^+e^-} - \mathcal{P}_{B_{tag}} - \mathcal{P}_{\ell^+}}$$



Experimental Setup for Belle II

Advantages at e^+e^- colliders

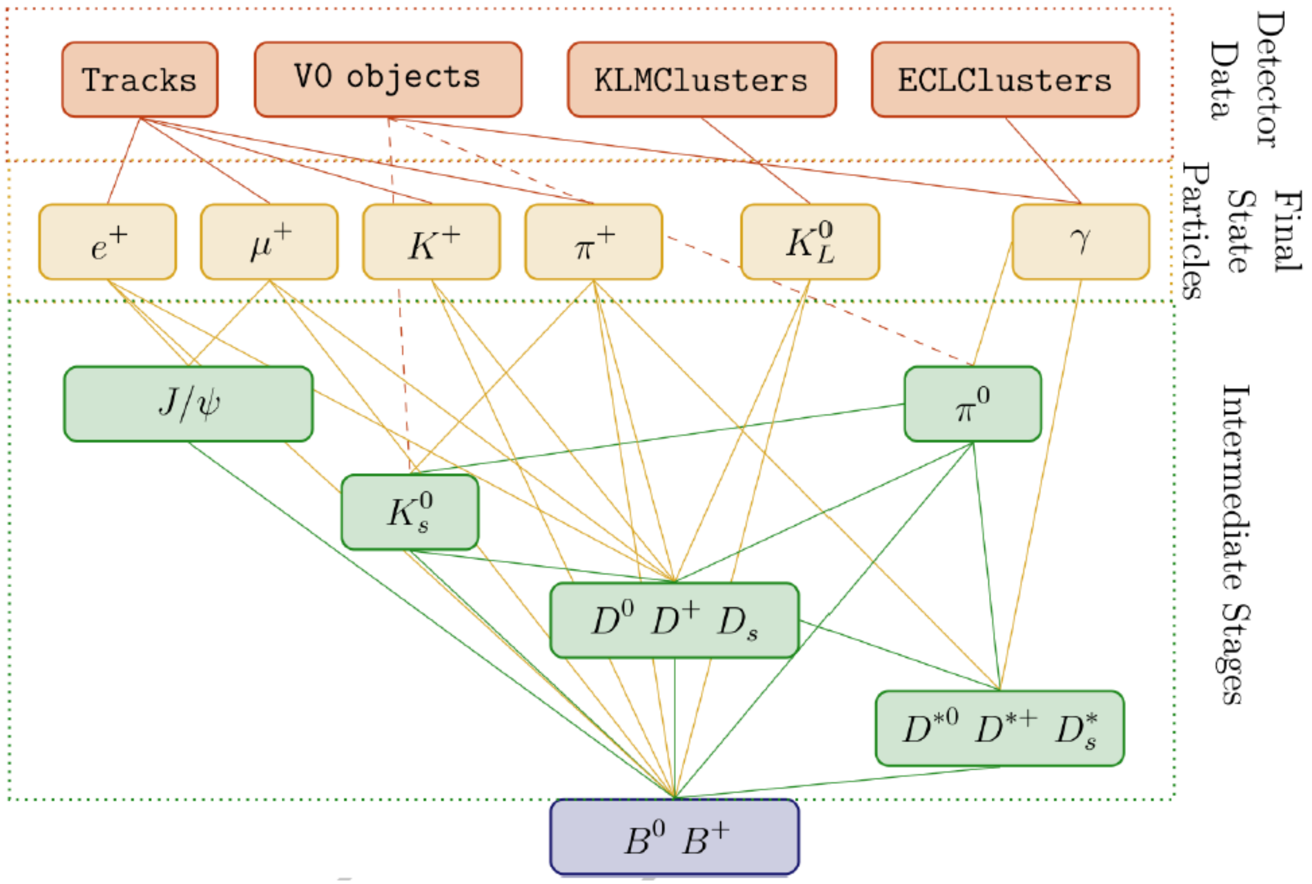
$$\boxed{\mathcal{P}_{\nu_\ell} = \mathcal{P}_{e^+e^-} - \mathcal{P}_{B_{tag}} - \mathcal{P}_{\ell^+}}$$



Missing Energy Channels

Full Event Interpretation (FEI)

- Hierarchical approach
  - Multivariate classifier for each state
  - Gather all information in the signal probability
- FEI can provide hadronic and semileptonic final states



Maximum reconstruction efficiency

Tag	FR @ Belle	FEI @ Belle	FEI @ Belle II
Hadronic B^+	0.28 %	0.49 %	0.61 %
Semileptonic B^+	0.67 %	1.42 %	1.45 %
Hadronic B^0	0.18 %	0.33%	0.34 %
Semileptonic B^0	0.63 %	1.33%	1.25 %

B → $K^+\tau^+\tau^-$ at Belle

- $\mathcal{B}(B^+ \to K^+\tau\tau)^{SM} < 1.44(15) \times 10^{-7}$
- Some models may lead to a strong enhancement
- $\mathcal{B}(B \to K\tau^-\tau^+)^{MLFV} < 2 \times 10^{-4}$

  Alonso, R., Grinstein, B. & Camalich, J.M. J. High Energ. Phys. (2015) 2015

- Only experimental constraints by BaBar with
  $\mathcal{B}(B^+ \to K^+\tau^+\tau^-) < 2.25 \times 10^{-3}$ at 90% C.L..

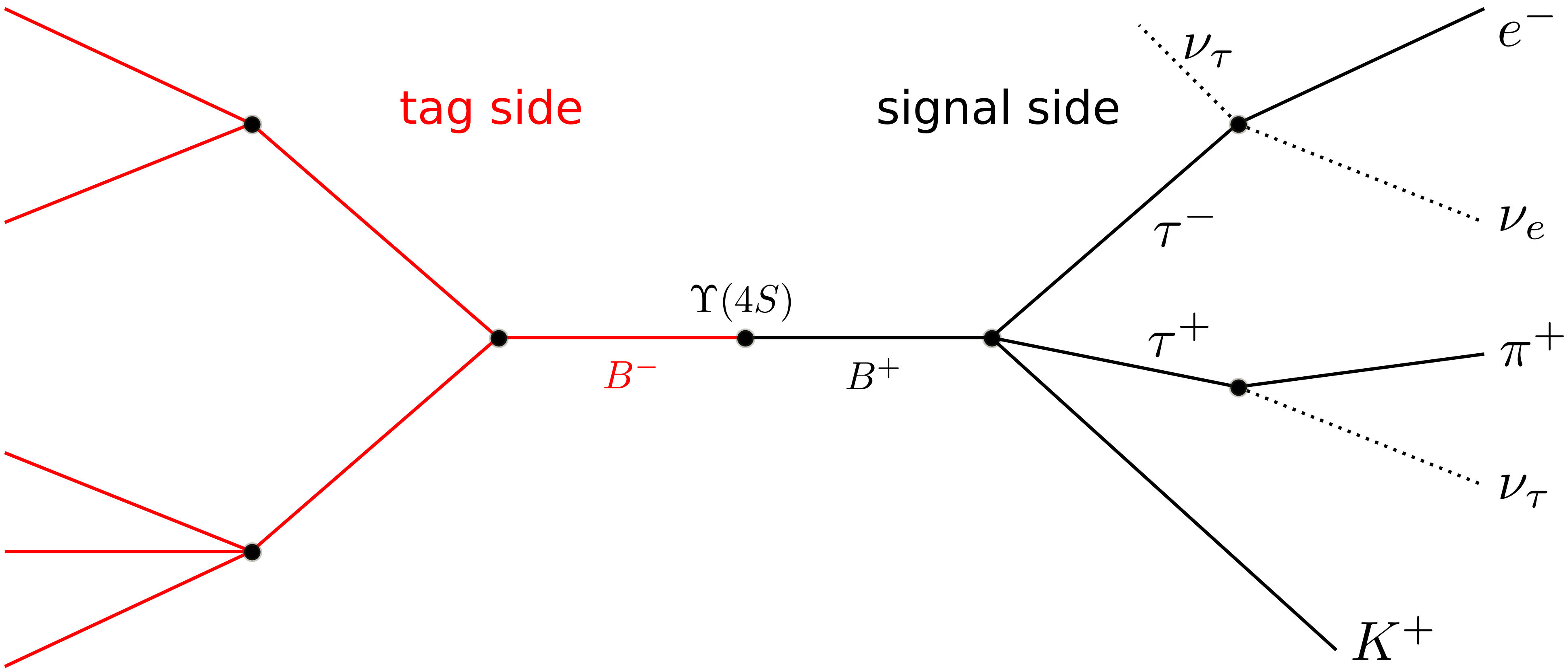
single prong decays

$$\tau \to e\nu\bar{\nu}$$

$$\tau \to \mu\nu\bar{\nu}$$

$$\tau \to \pi\nu\bar{\nu}$$

B → K$^+\tau^+\tau^-$ at Belle



The tag side is reconstructed in more than 1000 exclusive hadronic decay channels using more than 70 neural networks

$$\mathcal{P}_{e^+} + \mathcal{P}_{e^-} = \mathcal{P}_{\text{tag-side}} + \mathcal{P}_{\text{signal-side}}.$$

B → $K^+\tau^+\tau^-$ at Belle

Preliminary study on simulated events