Measurements of $|V_{us}|$ at Belle II

Workshop on Tau Physics at Belle II and STCF

31st August, Jilin University, Changchun, China

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HELMHOLTZ

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The $|V_{us}|$ element of the CKM matrix

SM parameters:

- 3 gauge couplings
- 2 Higgs parameters
- 3 charged lepton masses
- 6 quark masses
- **3 mixing angles + 1 phase**

Quark flavor

$$\text{CKM}= \begin{array}{c c} & \begin{array}{ccc} d & s & b \end{array} \\ \begin{array}{c} u \\ c \\ t \end{array} & \begin{pmatrix} 1 & \lambda & A\lambda^3\rho e^{i\phi} \\ -\lambda & 1 & A\lambda^2 \\ -A\lambda^3\rho e^{i\phi} & -A\lambda^2 & 1 \end{pmatrix} \end{array}$$

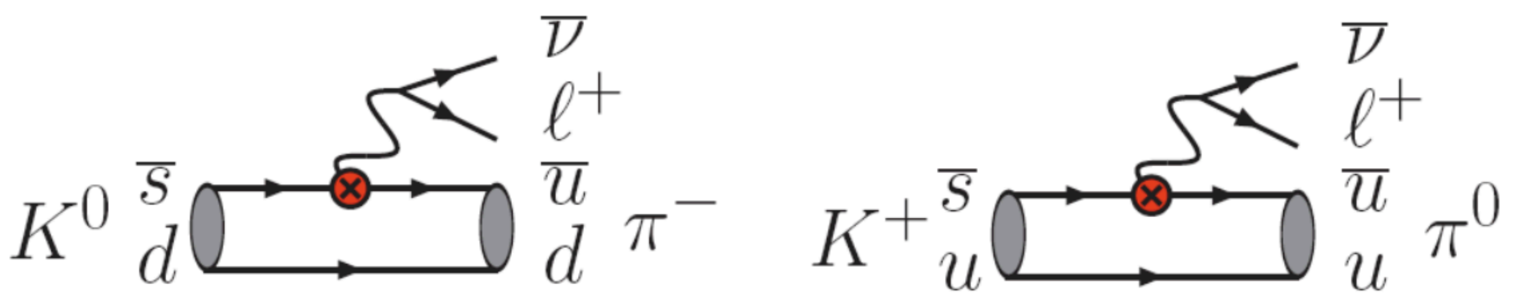
$$\boxed{|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1}$$

- $|V_{ud}| = 0.97384 \pm 0.00021$ (from nuclear β & neutron decays)
- $|V_{ub}| = (3.82 \pm 0.20) \times 10^{-3}$ (from $B \to X_u \ell \nu$ decays)
- $|V_{us}| = 0.2272 \pm 0.0011$ [see next slides]

Precision measurement of $|V_{us}|$ is a stringent test of CKM unitarity

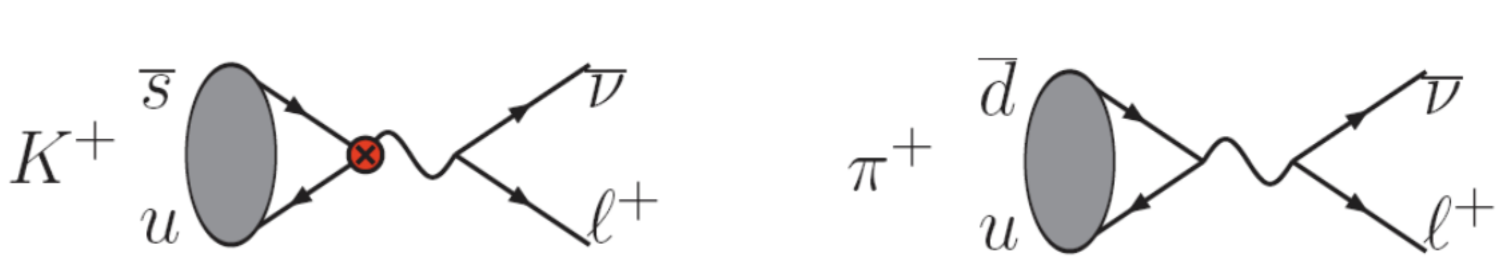
$|V_{us}|$ determination

Kl3 decays:



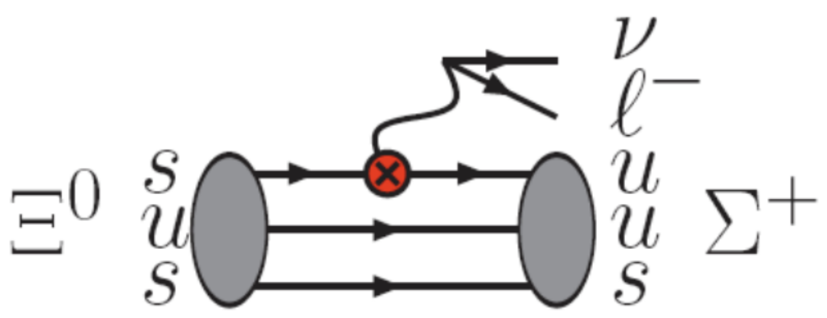
$\longrightarrow |V_{us}| f_+(0)$

Kl2 decays:



$$\longrightarrow \frac{|V_{us}|}{|V_{ud}|} \frac{F_K}{F_\pi}$$

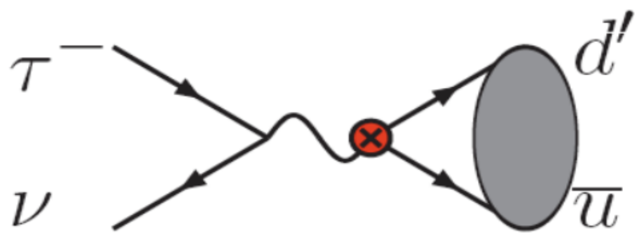
Hyperon decays:



$\longrightarrow |V_{us}| f_1(0)$

τ decays:

Focus of this talk



$d' = V_{ud} d + V_{us} s$

$\longrightarrow \alpha_s, m_s, |V_{us}|$

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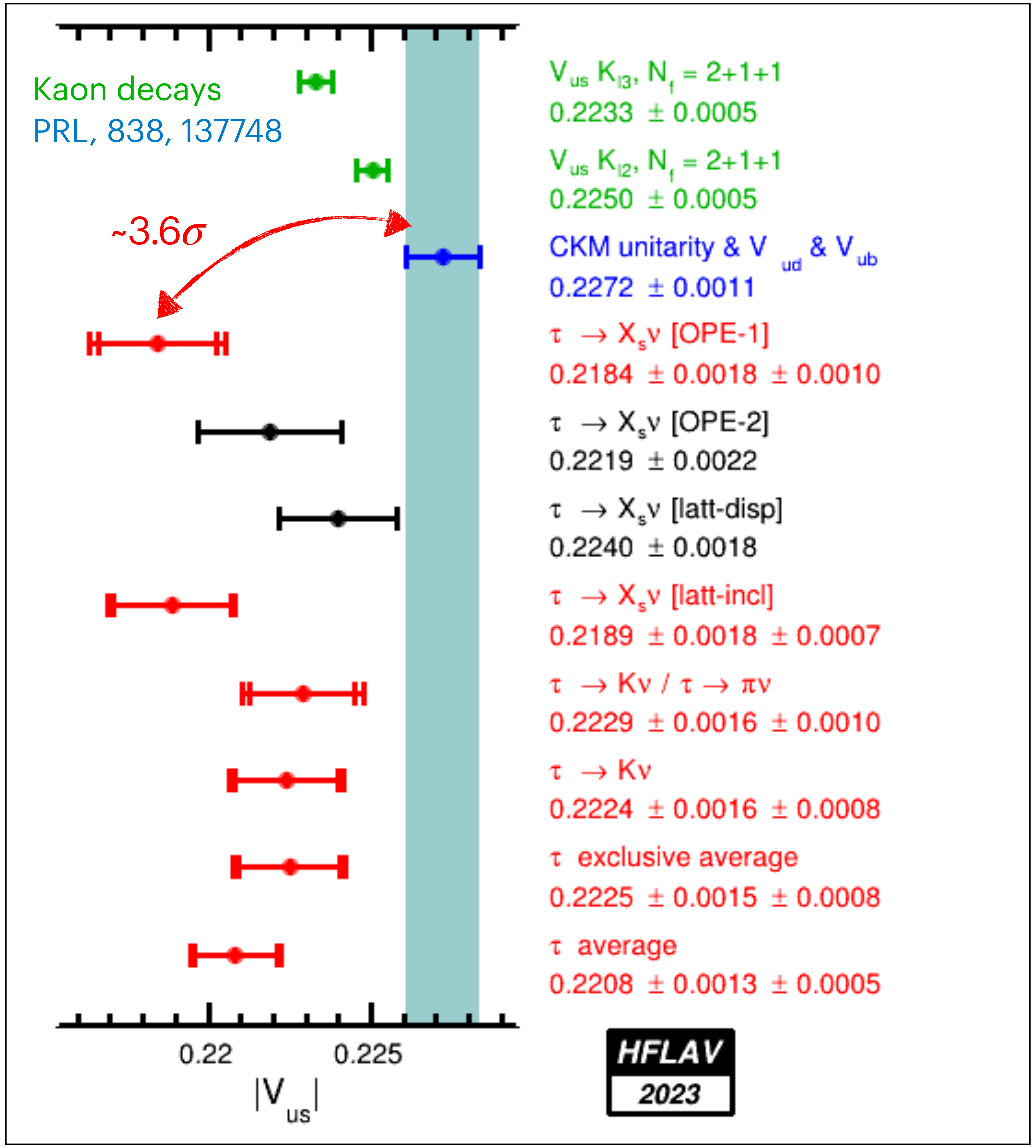
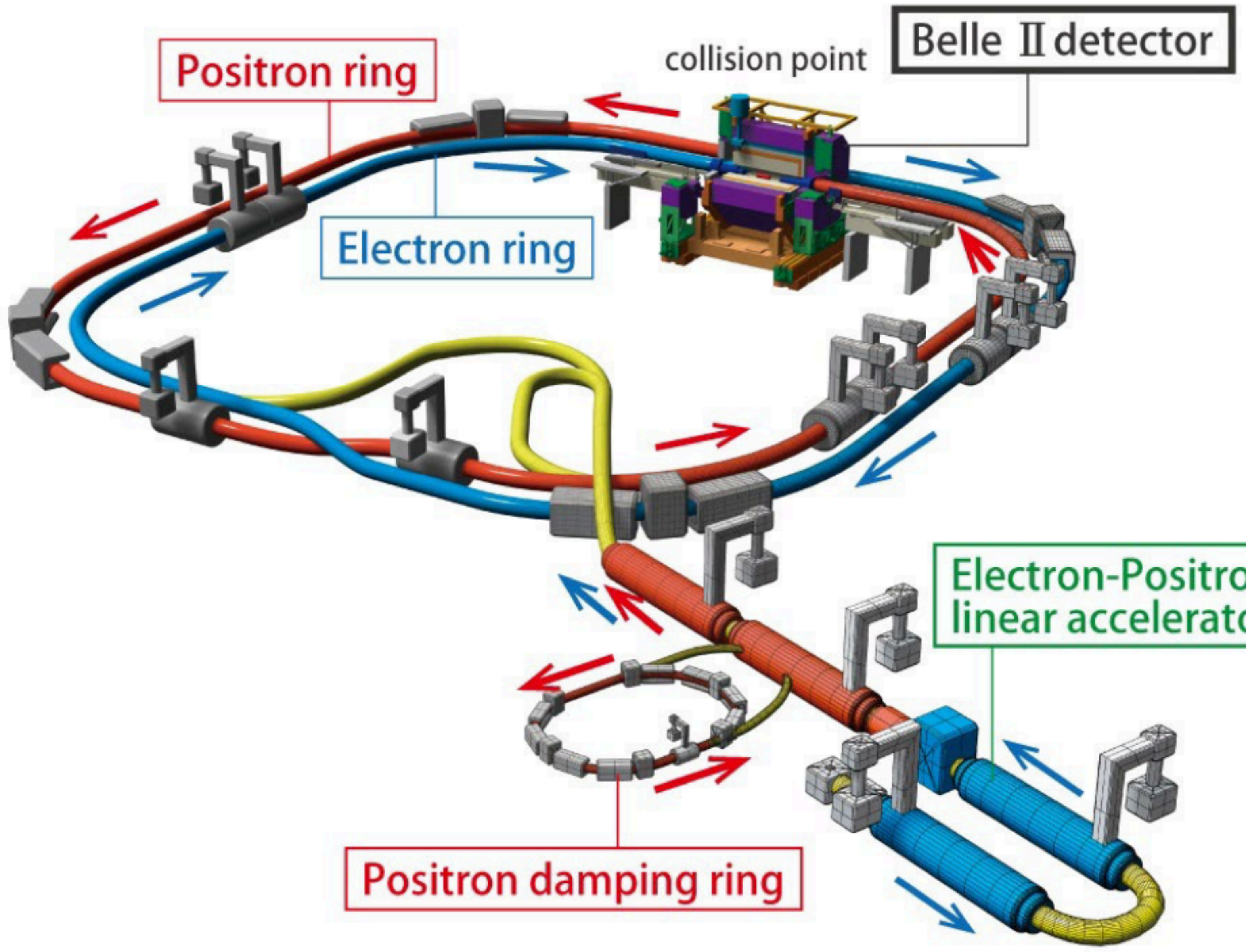


See also Petar's and Denis's talks

SuperKEKB and Belle II experiment

More than just B-factories

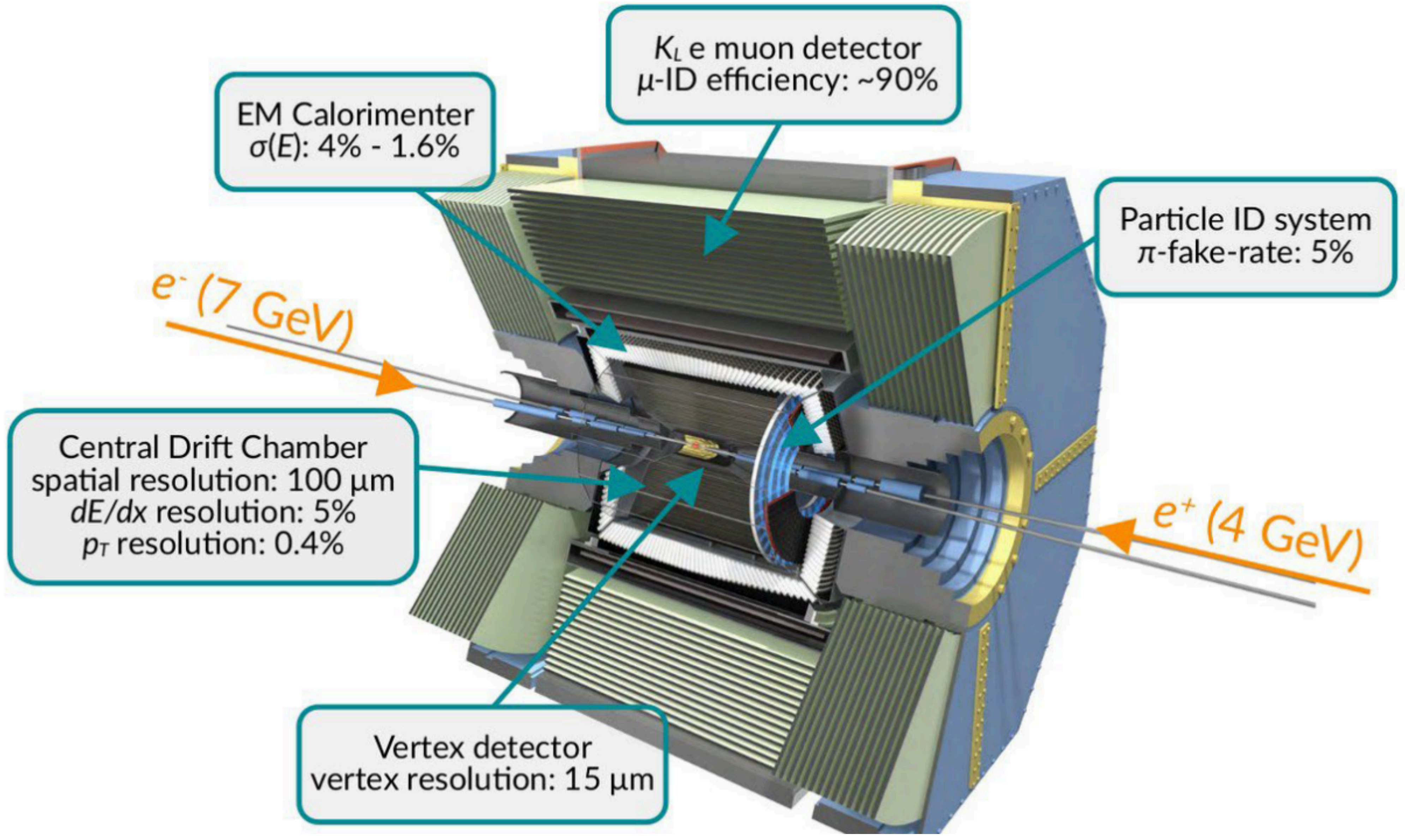
- Mostly operating at the $\Upsilon(4S)$ resonance ($\sqrt{s} = 10.58\,\mathrm{GeV}$)
- **World record instantaneous luminosity of** $5.32 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Belle II explores the intensity frontier at SuperKEKB:
  - Accumulated world's largest $\Upsilon(4S)$ dataset, surpassing Belle:
    - $808\,\mathrm{fb}^{-1}$ at $\Upsilon(4S)$ and $914\,\mathrm{fb}^{-1}$ overall



Ideal for τ physics

- Clean experimental environment with high trigger efficiency
- Hermetic detector with well-known initial state → **strong in searches with missing energy**
- Efficient reconstruction of neutrals (γ, π^0, η) & excellent charged PID capabilities (e, μ, π, K)
- Excellent track momentum & vertex resolution (e.g. τ lifetime)

See Fabian's talk

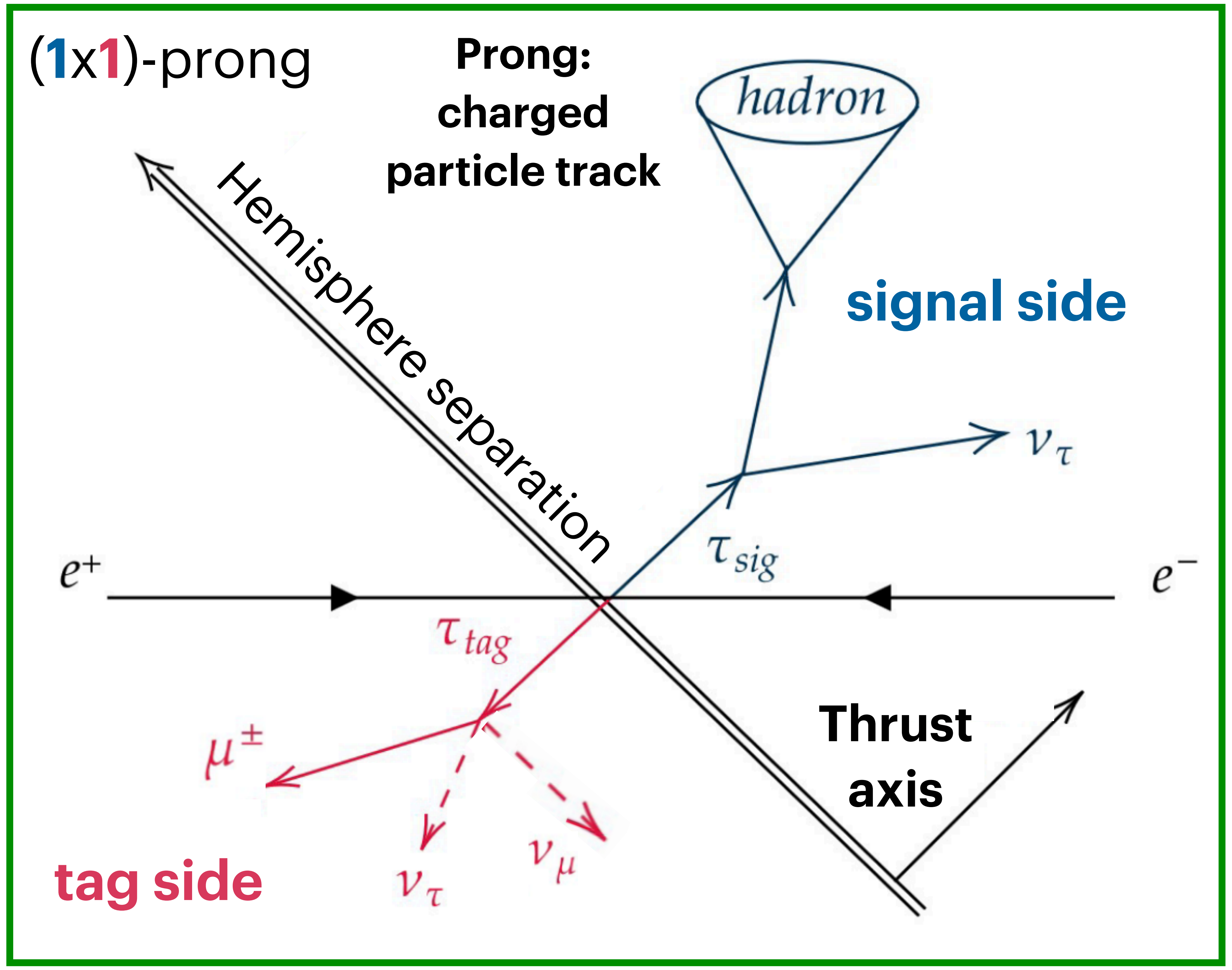


τ topologies and signatures @ Belle II

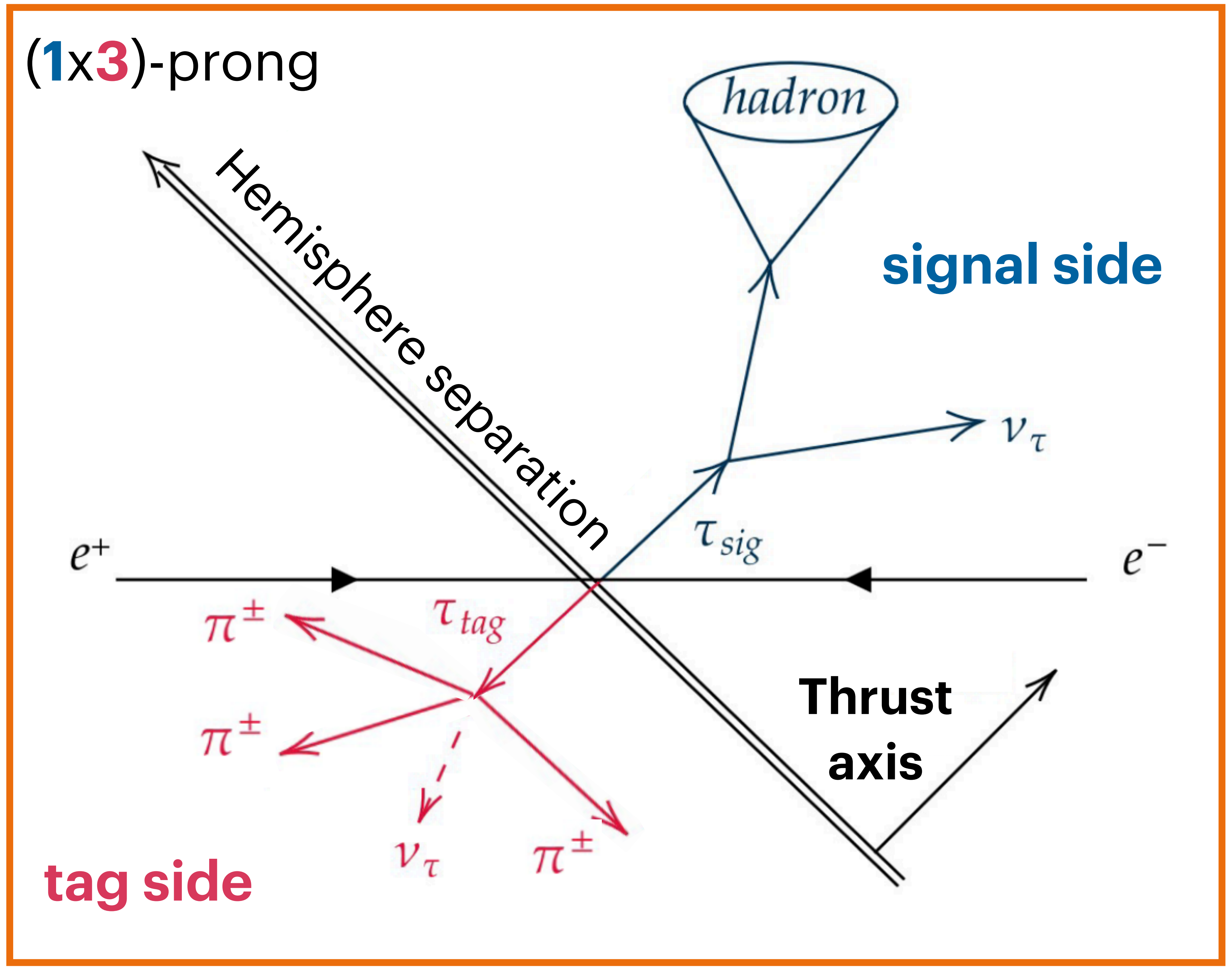
- Large cross section for $e^+e^- \to \tau^+\tau^-$. SM τ cannot be fully reconstructed due to the missing neutrino(s)
- Identify $e^+e^- \to \tau^+\tau^-$ events using the thrust direction of the event (**thrust axis**)

$$\sigma(e^+e^- \to b\bar{b}) = 1.05\,nb$$
$$\sigma(e^+e^- \to \tau^+\tau^-) = 0.92\,nb$$

- Two hemispheres defined in the centre-of mass system by a plane perpendicular to the thrust axis



Large QED background
Small continuum background



Small QED background
Large continuum background

Overview

Multiple ongoing analyses to measure both exclusive and inclusive $|V_{us}|$ at Belle II

Exclusive determination

Exclusive $|V_{us}|$ measurement using 1x1 topology

Exclusive $|V_{us}|$ measurement using 1x3 topology

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Main topic of this talk

Inclusive determination

First inclusive $|V_{us}|$ measurement using a 1-prong tag and all possible signal-side topologies

Overview

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Inclusive determination

First inclusive $|V_{us}|$ measurement using a 1-prong tag and all possible signal-side topologies

+ additional ongoing studies providing useful inputs to $|V_{us}|$: e.g. BR and spectral functions of the decay channels with open strangeness $\tau \to KX\nu$ [see backup and Petar's and Alexander's talks]

Exclusive $|V_{us}|$ determination

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Compare the $\mathscr{B}(\tau \to \pi\nu)$ **and** $\mathscr{B}(\tau \to K\nu)$ [best measurement from BaBar **PRL 105,051602**]

Exclusive $|V_{us}|$ determination

Compare the $\mathscr{B}(\tau \to \pi\nu)$ **and** $\mathscr{B}(\tau \to K\nu)$ [best measurement from BaBar **PRL 105,051602**]

- Ratio method

$$\frac{\mathscr{B}(\tau^- \to K^-\nu_\tau)}{\mathscr{B}(\tau^- \to \pi^-\nu_\tau)} = \frac{f_K^2 |V_{us}|^2}{f_\pi^2 |V_{ud}|^2} \frac{\left(m_\tau^2 - m_K^2\right)^2}{\left(m_\tau^2 - m_\pi^2\right)^2}(1 + \delta_{LD})$$

decay constant

electroweak corrections

$$|V_{us}| = 0.2255 \pm 0.0024$$

consistent with CKM unitarity

Exclusive $|V_{us}|$ determination

Compare the $\mathscr{B}(\tau \to \pi\nu)$ **and** $\mathscr{B}(\tau \to K\nu)$ [best measurement from BaBar **PRL 105,051602**]

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$$\frac{\mathscr{B}(\tau^- \to K^-\nu_\tau)}{\mathscr{B}(\tau^- \to \pi^-\nu_\tau)} = \frac{f_K^2 |V_{us}|^2}{f_\pi^2 |V_{ud}|^2} \frac{(m_\tau^2 - m_K^2)^2}{(m_\tau^2 - m_\pi^2)^2}(1 + \delta_{LD})$$

decay constant

electroweak corrections

$$|V_{us}| = 0.2255 \pm 0.0024$$

consistent with CKM unitarity

- Absolute decay

Fermi constant

electroweak corrections

$$\mathscr{B}(\tau^- \to K^-\nu_\tau) = \frac{G_F^2 f_K^2 |V_{us}|^2 m_\tau^3 \tau_\tau}{16\pi}\left(1 - \frac{m_K^2}{m_\tau^2}\right)^2 S_{\mathrm{EW}}$$

$$|V_{us}| = 0.2193 \pm 0.0032$$

within 2σ of the value predicted by the CKM unitarity

Exclusive $|V_{us}|$ determination @ Belle II

Aim precision:

Measure of $R_{K/\pi} = \frac{\mathcal{B}(\tau \to K\nu)}{\mathcal{B}(\tau \to \pi\nu)} \propto \frac{|V_{us}|^2}{|V_{ud}|^2}$ with a total systematic uncertainty < 1%

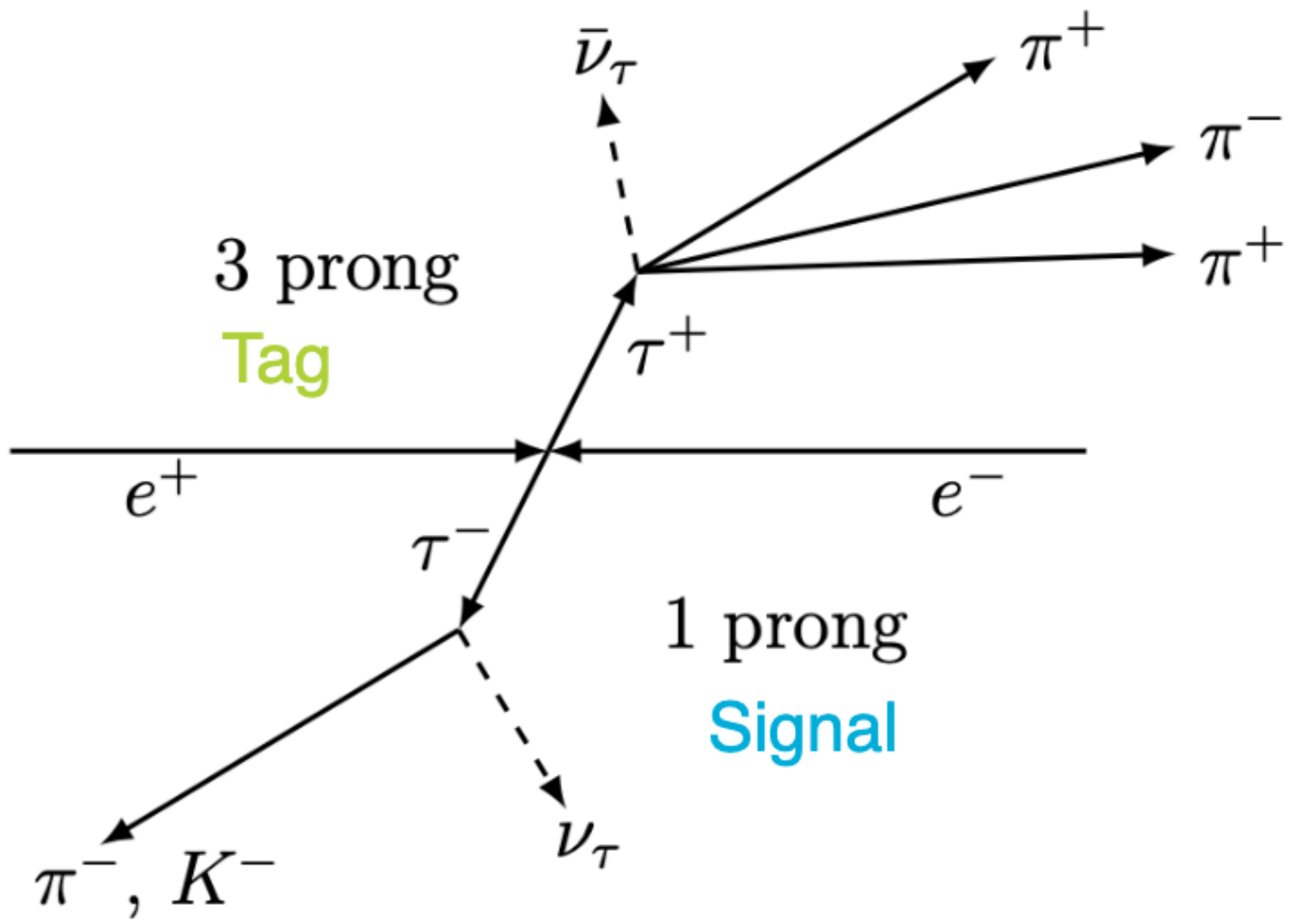
Strategy:

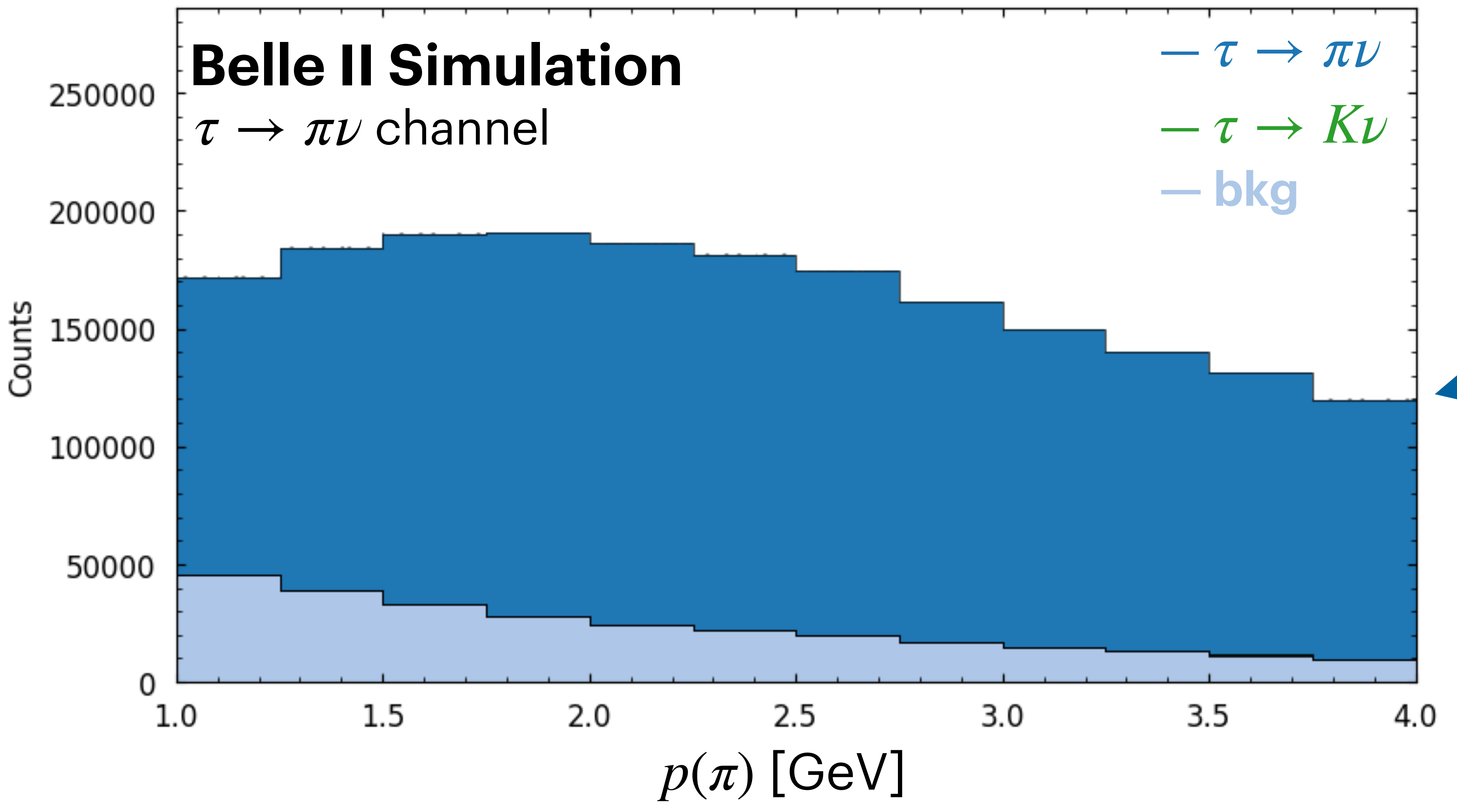
Signal side: $\tau \to h\nu$, tag side: $\tau \to \ell\nu\nu, \tau \to n(h)\nu$ where $h = \pi, K$

Simultaneous template fit to both the pion and kaon channels

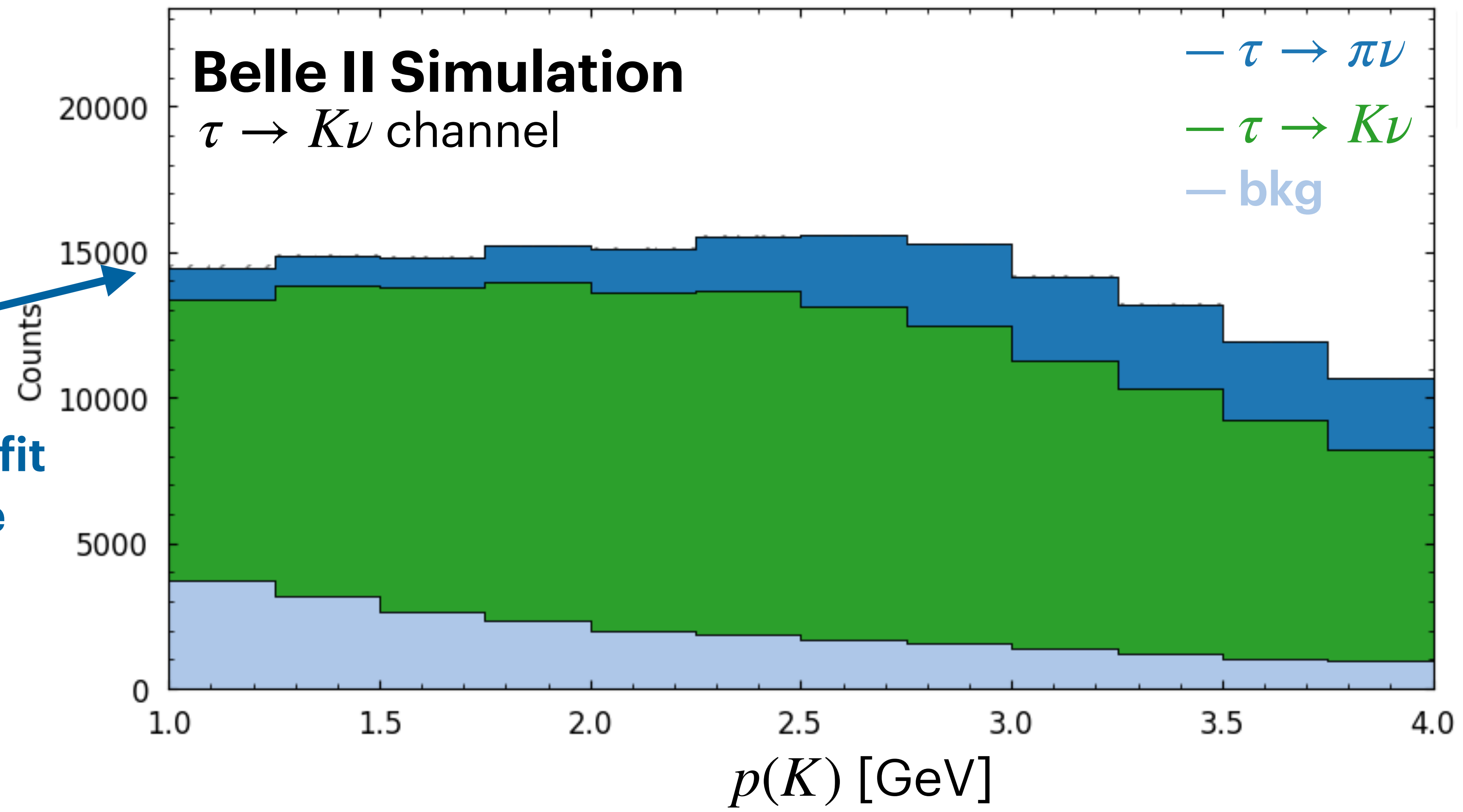
Main backgrounds:

- Pion channel: 60% from $\tau \to \pi\pi^0\nu$, 20% from $\tau \to \mu\nu\nu$
- Kaon channel: 28% from $\tau \to \mu\nu\nu$, 22% from $\tau \to KK_L\nu$, 14% from $\tau \to K\pi^0\nu$, 9% from $\tau \to \pi\pi^0\nu$





simultaneous fit between the channels



Inclusive $|V_{us}|$ determination

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Compare the $\mathscr{B}(\tau \to (\bar{u}d)\,\nu)$ **and** $\mathscr{B}(\tau \to (\bar{u}s)\,\nu)$ $\longrightarrow$ $\boxed{\textbf{fundamental parameters of SM} \quad (\alpha_s\,,\, m_s\,,\, |V_{us}|)}$

Inclusive $|V_{us}|$ determination

Compare the $\mathscr{B}(\tau \to (\bar{u}d)\,\nu)$ and $\mathscr{B}(\tau \to (\bar{u}s)\,\nu)$

fundamental parameters of SM

$(\alpha_s\,, m_s\,, |V_{us}|)$

Theory:

- OPE-1: uses perturbative QCD and experimental low energy scattering measurements

hadrons with S=1

BR w.r.t. $\mathscr{B}(\tau \to e\nu\nu)$

hadrons with S=0

$$|V_{us}|_{\tau\text{-OPE-1}} = \sqrt{R_{us} / \left[\frac{R_{ud}}{|V_{ud}|^2} - \delta R_{\tau\text{-}SU(3)\text{-break}}\right]} = 0.2184 \pm 0.0021$$

SU(3)-breaking effects

- OPE-2 and latt-disp: alternative procedures using τ spectral functions and lattice QCD methods
- Latt-incl: $|V_{us}|_{\tau-\text{latt-incl}} = \sqrt{\left(\frac{|V_{us}|^2}{R_{us}}\right)_{\text{latt-incl}} \cdot R_{us}}$

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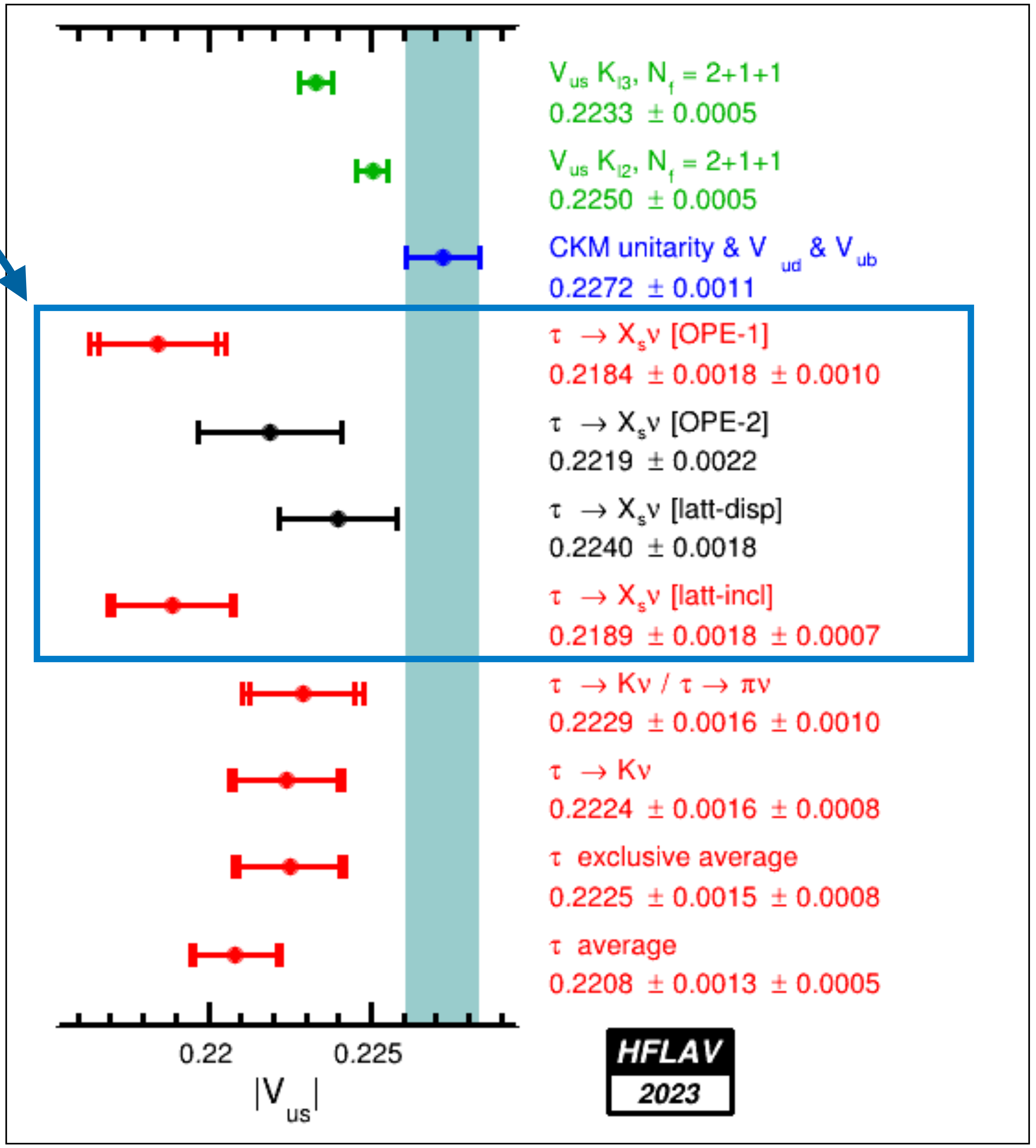

Inclusive $|V_{us}|$ determination

Compare the $\mathscr{B}(\tau \to (\bar{u}d)\,\nu)$ and $\mathscr{B}(\tau \to (\bar{u}s)\,\nu)$ → **fundamental parameters of SM** $(\alpha_s, m_s, |V_{us}|)$

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SU(3)-breaking effects

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Experiment:

- No $\mathscr{B}(\tau \to X_s \nu_\tau)$
- Sum of exclusive modes

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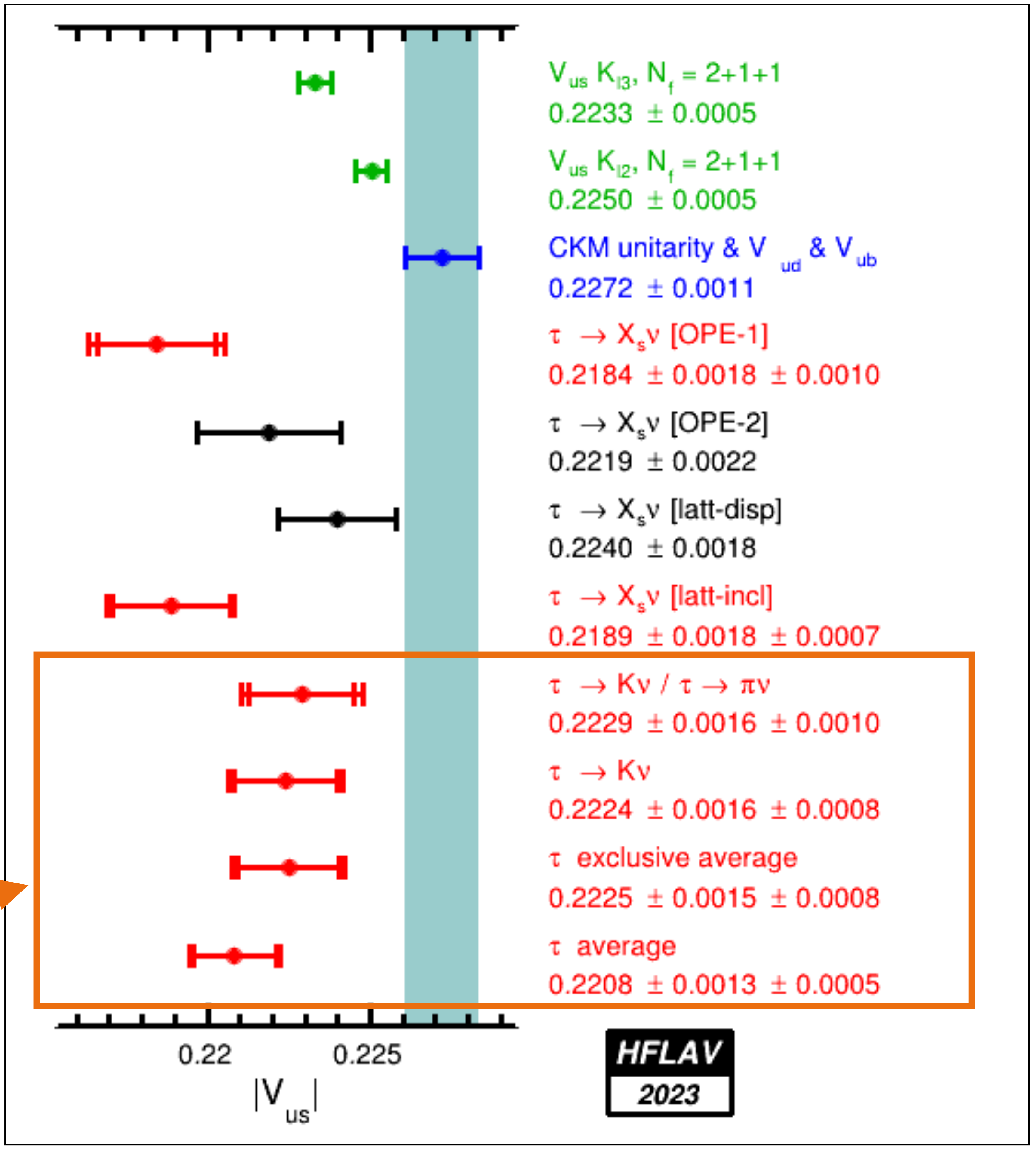
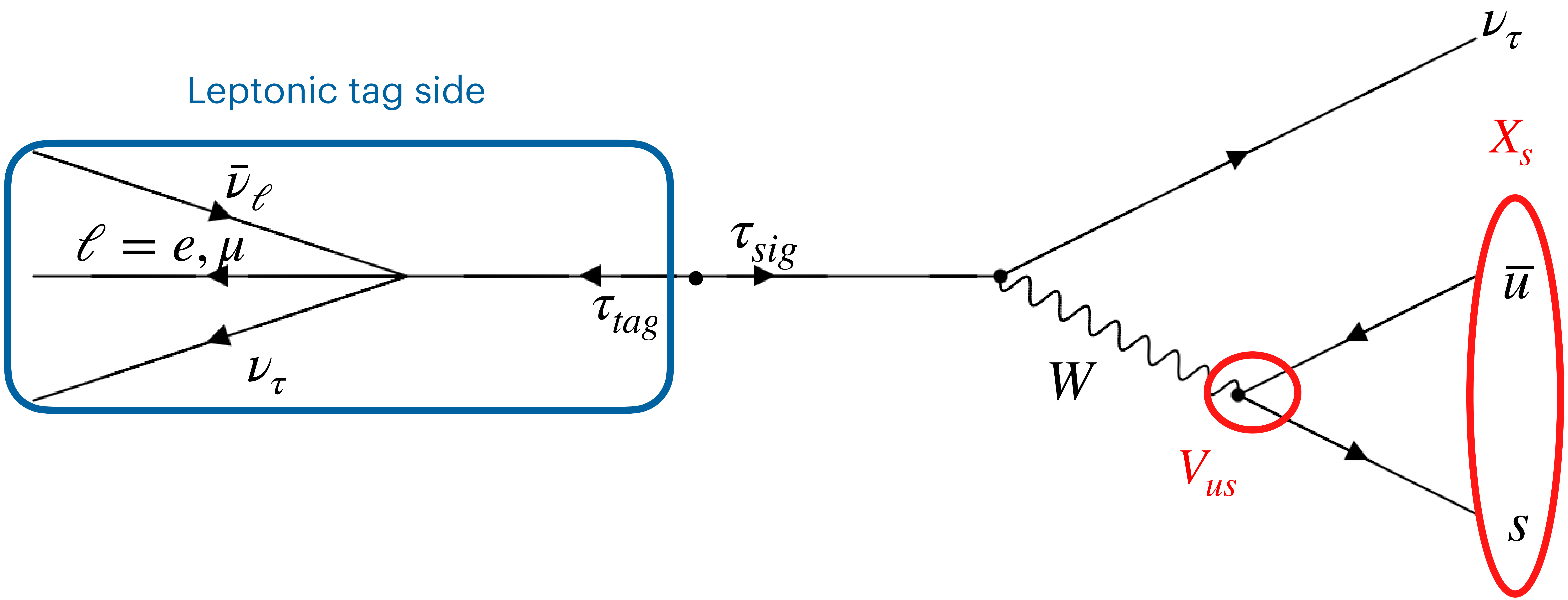


$X = n(\pi^0), \pi^+\pi^-, K^0, \bar{K}^0, K^+\pi^-$

Inclusive $|V_{us}|$ determination @ Belle II

Goal: first inclusive $|V_{us}|$ measurement by measuring the inclusive $\mathscr{B}(\tau \to X_s \nu_\tau)$



$$V_{us}^{incl.} \propto \mathscr{B}(\tau \to X_s \nu_\tau) \to \mathscr{B}(\tau \to K^+ X \nu_\tau) + \mathscr{B}(\tau \to \pi K^0 X \nu_\tau)$$

Challenges vs advantages

Main focus of today

Challenge 1: access $\tau^+ \to K^+ X \nu$ and $\tau^+ \to \pi^+ K^0 X \nu$ from unfolded yields

- Decide how many modes to subtract, how many to unfold

Challenge 2: be maximally model independent

- Unfolding need MC for efficiencies
- Independent of modelling: perform the measurement relying only on phase-space MC

Challenge 3: need to measure $\mathscr{B}(\tau^+ \to \pi^+ K_L^0 K_S^0 n(\pi^0)\nu)$

- No isospin relations or assumptions
- Challenging K_L^0 detection at Belle II

Challenge 4: measure $|V_{us}|$ with a target precision of ~1% (systematics limited)

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Advantage 1: independent of the sum of exclusive modes from different experiments

Advantage 2: insight into the historical shift of $\mathscr{B}(\tau \to X_s \nu_\tau)$ towards lower values

.....

Challenge 1

Access $\tau^+ \to K^+ X \nu$ and $\tau^+ \to \pi^+ K^0 X \nu$: strategy

$$V_{us}^{incl.} \propto \mathscr{B}(\tau \to K^+ X \nu_\tau) + \mathscr{B}(\tau \to \pi K_S^0 X \nu_\tau) + \mathscr{B}(\tau \to \pi K_L^0 X \nu_\tau)$$

Decay mode		Contribution
1	$\tau^+ \to K^+ X \nu$	$V_{us} + V_{ud}(K)$
1.1	$\tau^+ \to K^+ n(\pi^0)\nu$	V_{us}
1.2	$\tau^+ \to K^+ K_S n(\pi^0)\nu$	$V_{ud}(K)$
1.3	$\tau^+ \to K^+ K^- \pi^+ n(\pi^0)\nu$	$V_{ud}(K)$

Decay mode		Contribution
2	$\tau^+ \to \pi^+ K_S X \nu$	$V_{us} + V_{ud}(K)$
2.1	$\tau^+ \to \pi^+ K_S n(\pi^0)\nu$	V_{us}
2.2	$\tau^+ \to \pi^+ K_S K_S n(\pi^0)\nu$	$V_{ud}(K)$
2.3	$\tau^+ \to \pi^+ K_L K_S n(\pi^0)\nu$	$V_{ud}(K)$

Even more challenging

- Alternative: $\mathscr{B}(\tau \to \pi K_L n(\pi^0)\nu_\tau) = \mathscr{B}(\tau \to \pi K_S n(\pi^0)\nu_\tau)$
- Add systematic uncertainty

NB: assume a negligible impact from the modes with 3K ($\mathscr{B}(3K) < 10^{-7}$)

X-talk between the channels due to $\pi \leftrightarrow K$ misID

$$N_1 + 2N_2 = \underbrace{N_{V_{us},1.1} + 2N_{V_{us},2.1}}_{V_{us}} + \underbrace{2N_{1.2} + N_{1.3} + 2N_{2.2} + N_{2.3}}_{V_{ud}}$$

Extract the inclusive $|V_{us}|$ and the $|V_{ud}|$ contributions using the **unfolding procedure**

Challenge 1

Access $\tau^+ \to K^+ X\nu$ and $\tau^+ \to \pi^+ K^0 X\nu$: sample composition

Reconstruct the $\tau \to \pi K_S n(\pi^0)\nu$, $\tau \to \pi K_S K_S n(\pi^0)\nu$ and $\tau \to \pi K_S K_L n(\pi^0)\nu$ channels, with a leptonic tag side.

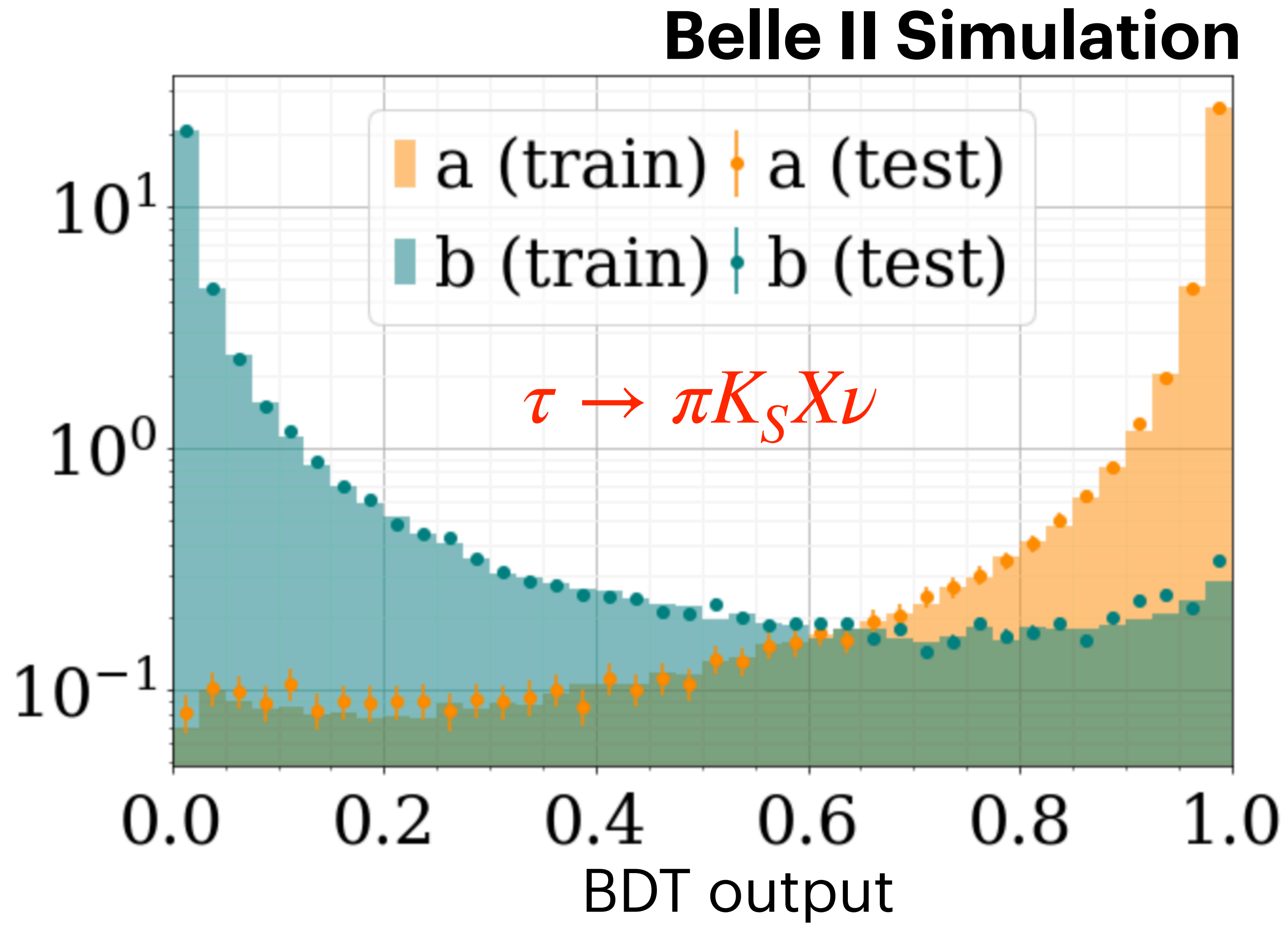
1. Suppress continuum and low-multiplicity events using a BDT

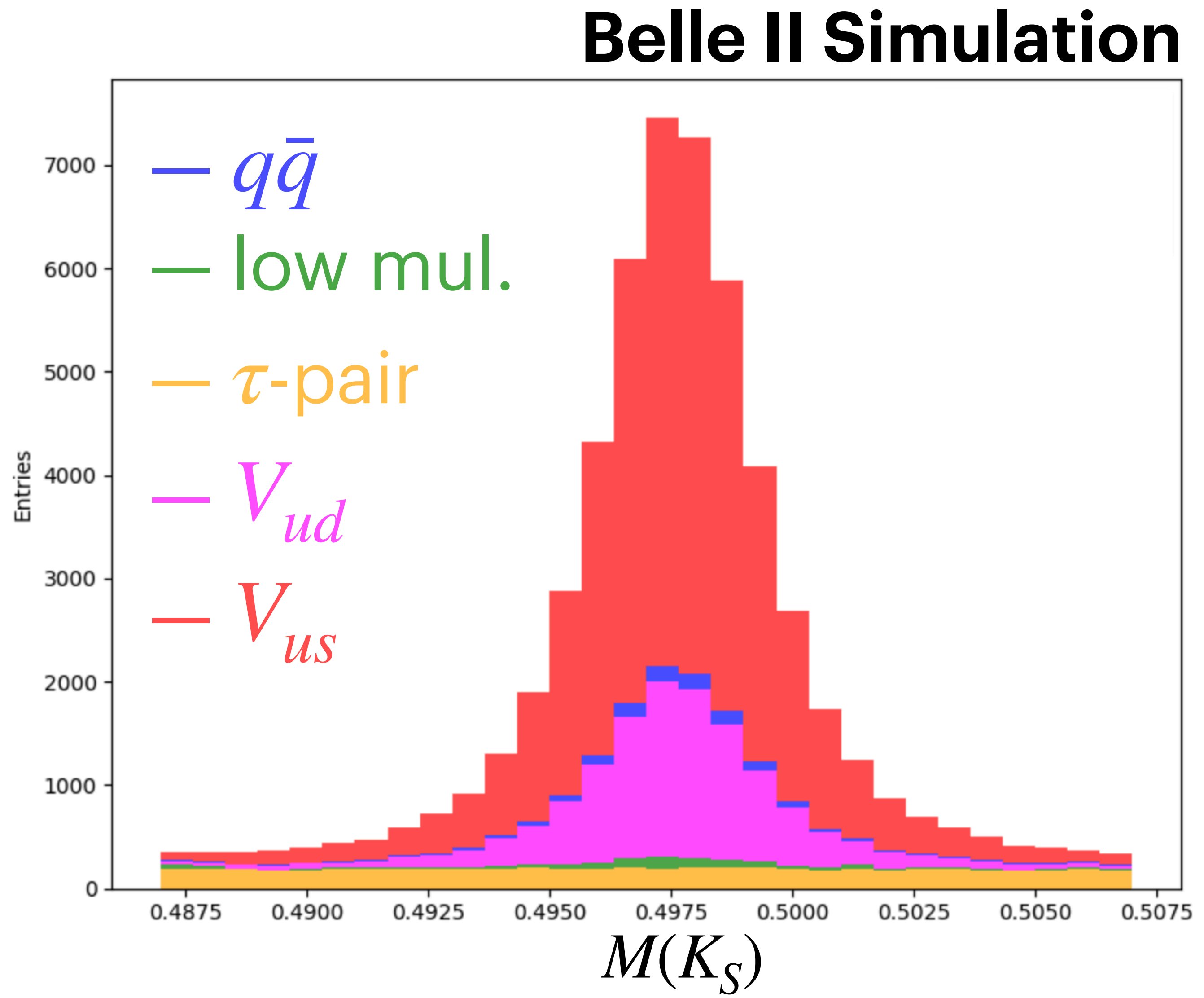
2. After the BDT, the samples are dominated by $|V_{us}|$, $|V_{ud}|$ and remaining τ-pair events

3. Suppress the remaining τ-pair events using a fit to $M(K_S)$

4. After 2. and 3., the sample are dominated by only $|V_{us}|$, $|V_{ud}|$
   $\to$ ready for the unfolding

Exploring different strategies to suppress background for the $\tau^+ \to K^+ n(\pi^0)\nu$ channel. For the $\tau \to K K_S n(\pi^0)\nu$, we can apply the same methodology described above.





Challenge 1

Access $\tau^+ \to K^+ X \nu$ and $\tau^+ \to \pi^+ K^0 X \nu$: unfolding

To extract the inclusive $|V_{us}|$ and separate the $|V_{ud}|$ contributions, we aim to apply the unfolding procedure to account for the migration between channels due to misidentification.

Define the migration matrix $S(i, j)$ as:

$$S_{(i,j)} = \frac{n^{reco}_{(i,j)}}{n^{gen}_{j}}$$

where:

$n^{reco}_{(i,j)}$ = number of events generated in the channel j and reconstructed in the channel i.

n^{gen}_{j} = number of events generated in the channel j.

Reco \ Gen	$\tau^+ \to \pi^+ K_S n(\pi^0)\nu$	$\tau^+ \to \pi^+ K_S K_S n(\pi^0)\nu$	$\tau^+ \to \pi^+ K_S K_L n(\pi^0)\nu$	…
$\tau^+ \to \pi^+ K_S n(\pi^0)\nu$	ϵ_1	$S(1,2)$	$S(1,3)$	… $S(1,j)$
$\tau^+ \to \pi^+ K_S K_S n(\pi^0)\nu$	$S(2,1)$	ϵ_2	$S(2,3)$	
$\tau^+ \to \pi^+ K_L K_L n(\pi^0)\nu$	$S(3,1)$	$S(3,2)$	ϵ_3	
	⋮ $S(i,1)$			⋱ ϵ_i

By using the inverted $S(i, j)$ matrix, we can extract the true number of events for each channel from the reconstructed ones

Challenge 2

Model independence: strategy

Rely on MC only for the efficiencies and remain as model-independent as possible

Idea: perform the measurement using only phase-space MC and test whether other generation models can be reproduced by reweighting the main kinematic variables

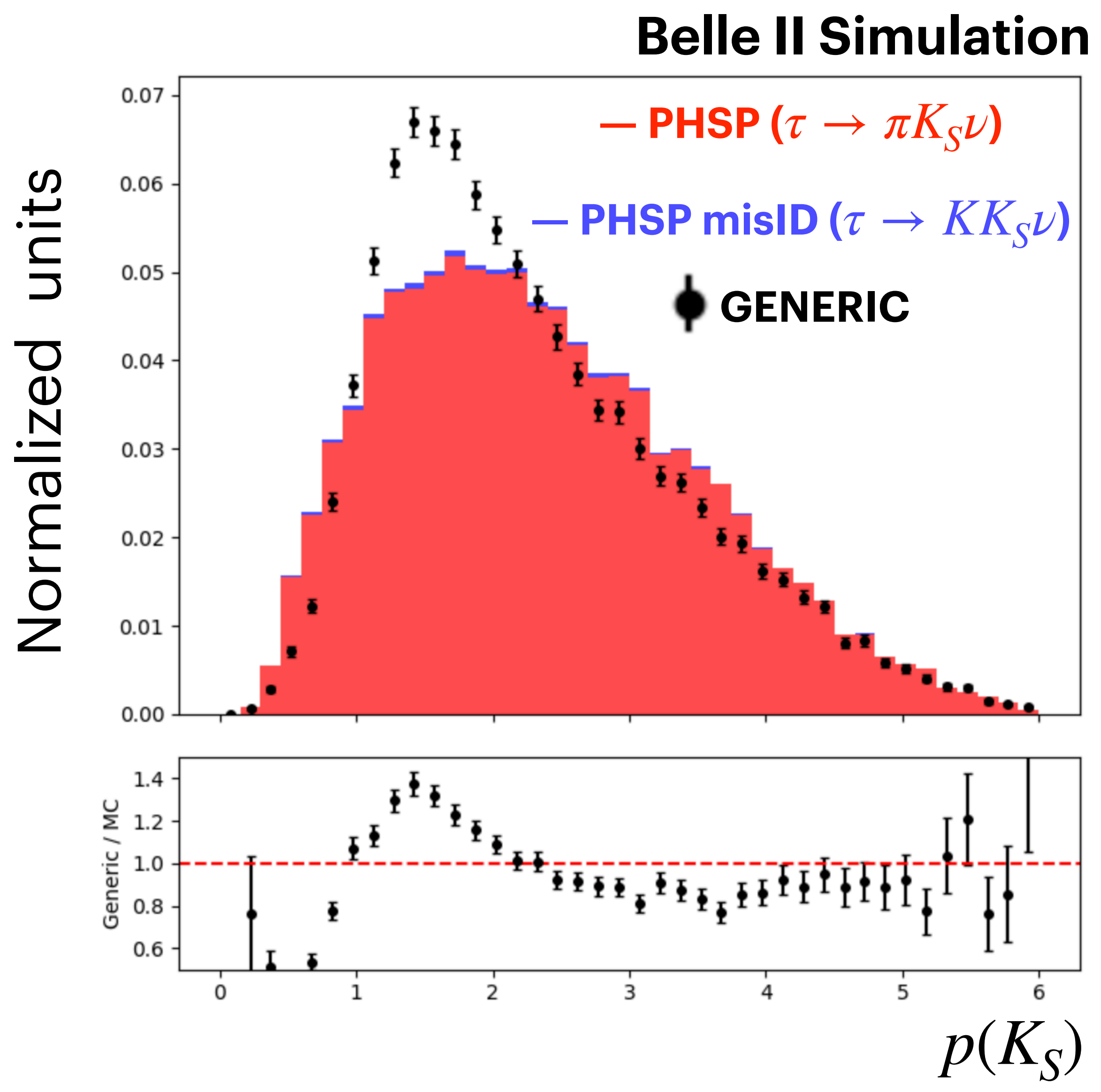
Methodology

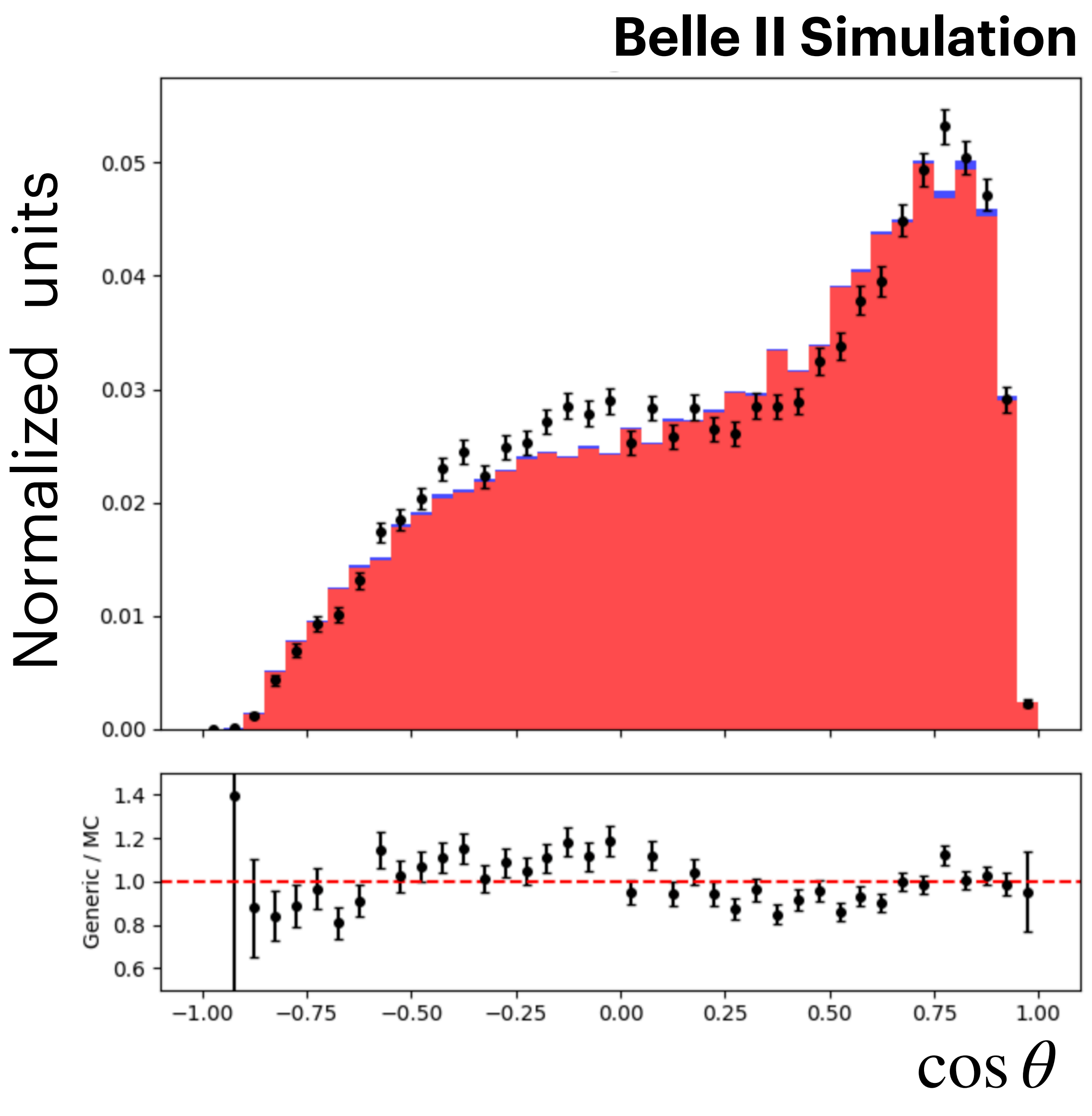
- Let's consider two decay channels $\tau \to \pi K_S \nu$ and $\tau \to K K_S \nu$ (without additional π^0s)
- Generate both channels using two different MC configurations: PHSP and GENERIC
- Compare the main kinematic variables (momentum, polar and azimuthal angles, ...) and identify those showing the largest discrepancies
- Reweight the discrepant kinematic distributions and check whether the reweighted PHSP distributions reproduce the GENERIC ones
- Evaluate the impact on the unfolding using the reweighed samples

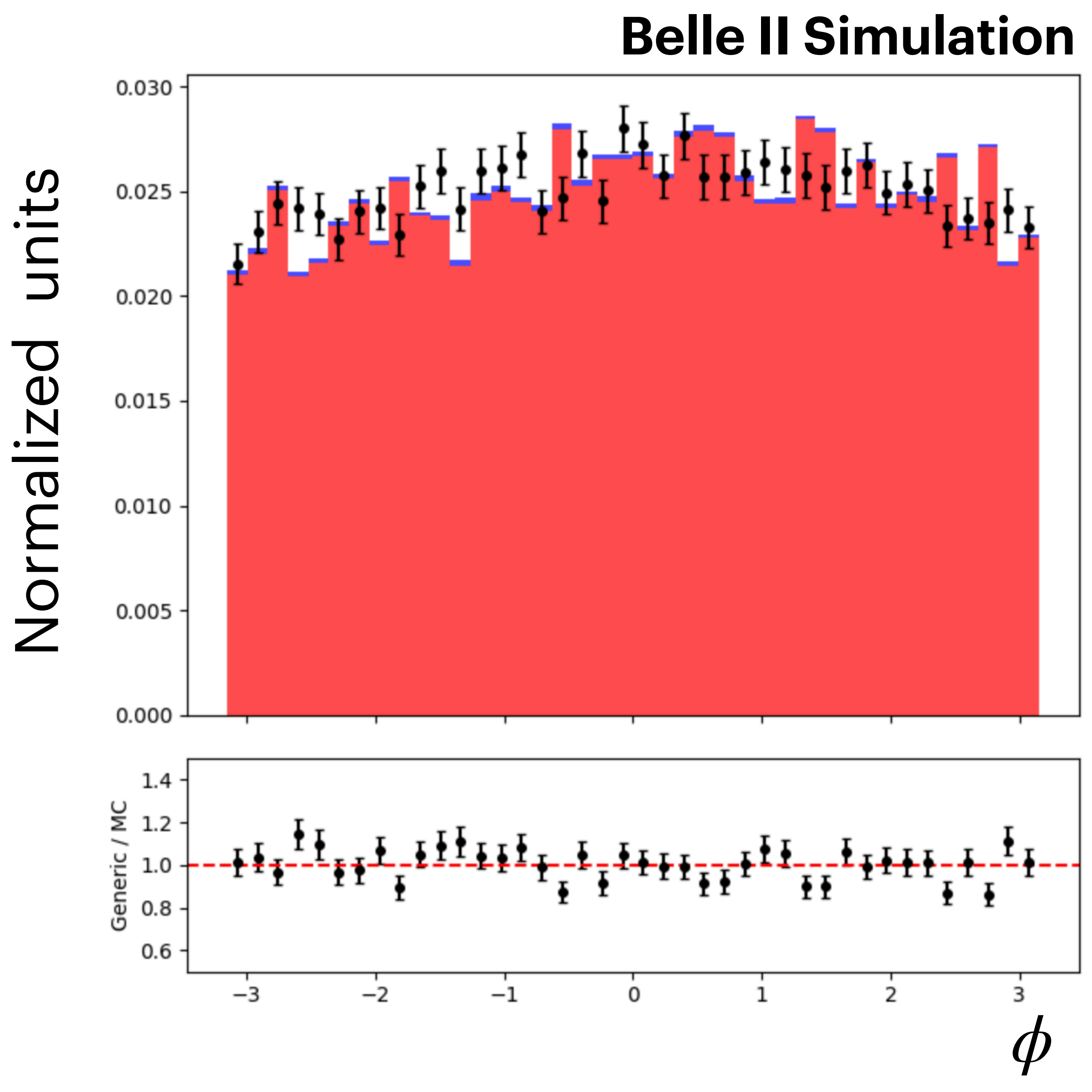
Challenge 2

Model independence: kinematic distributions

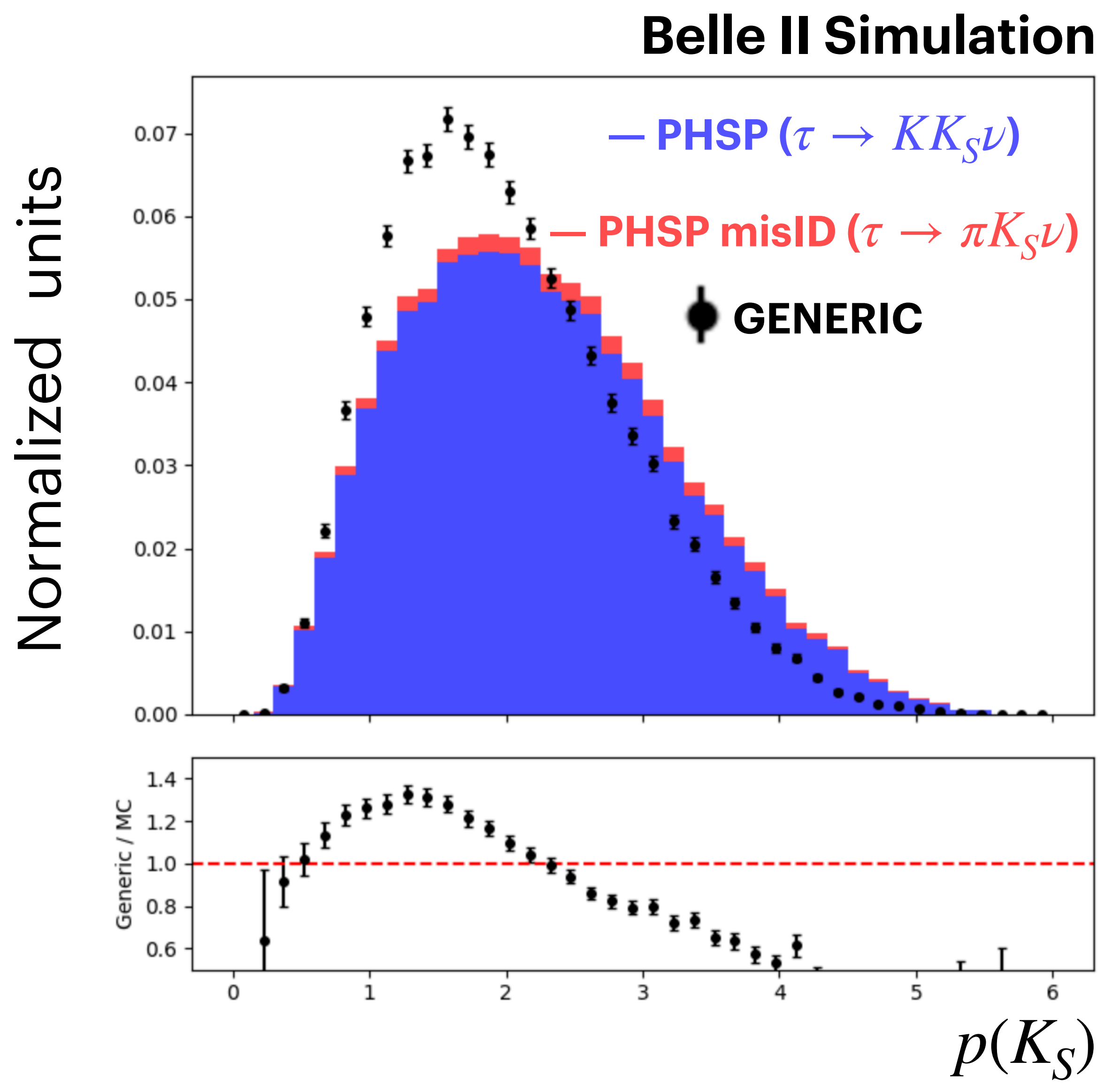
$\tau \to \pi K_S \nu$ channel

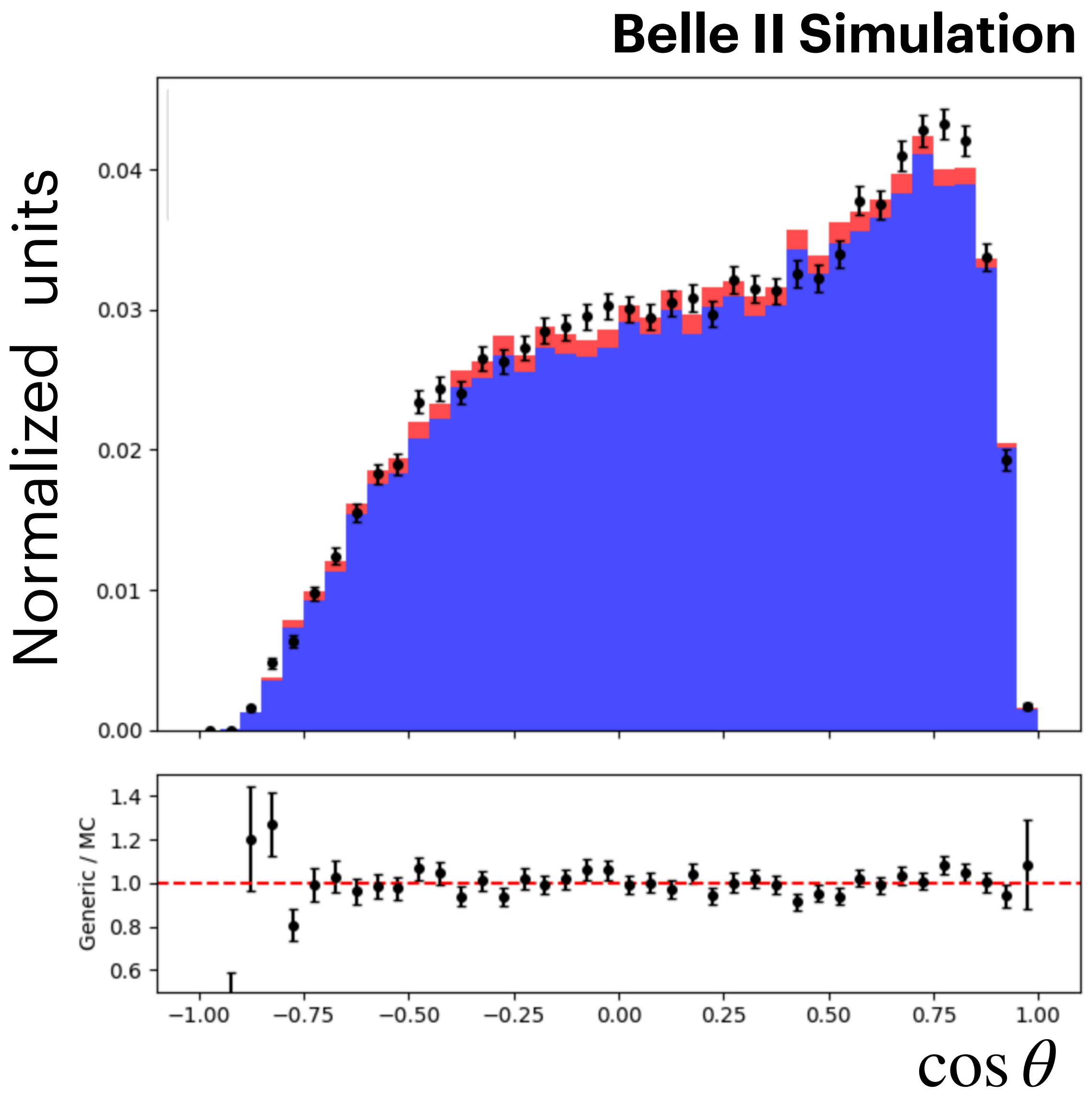


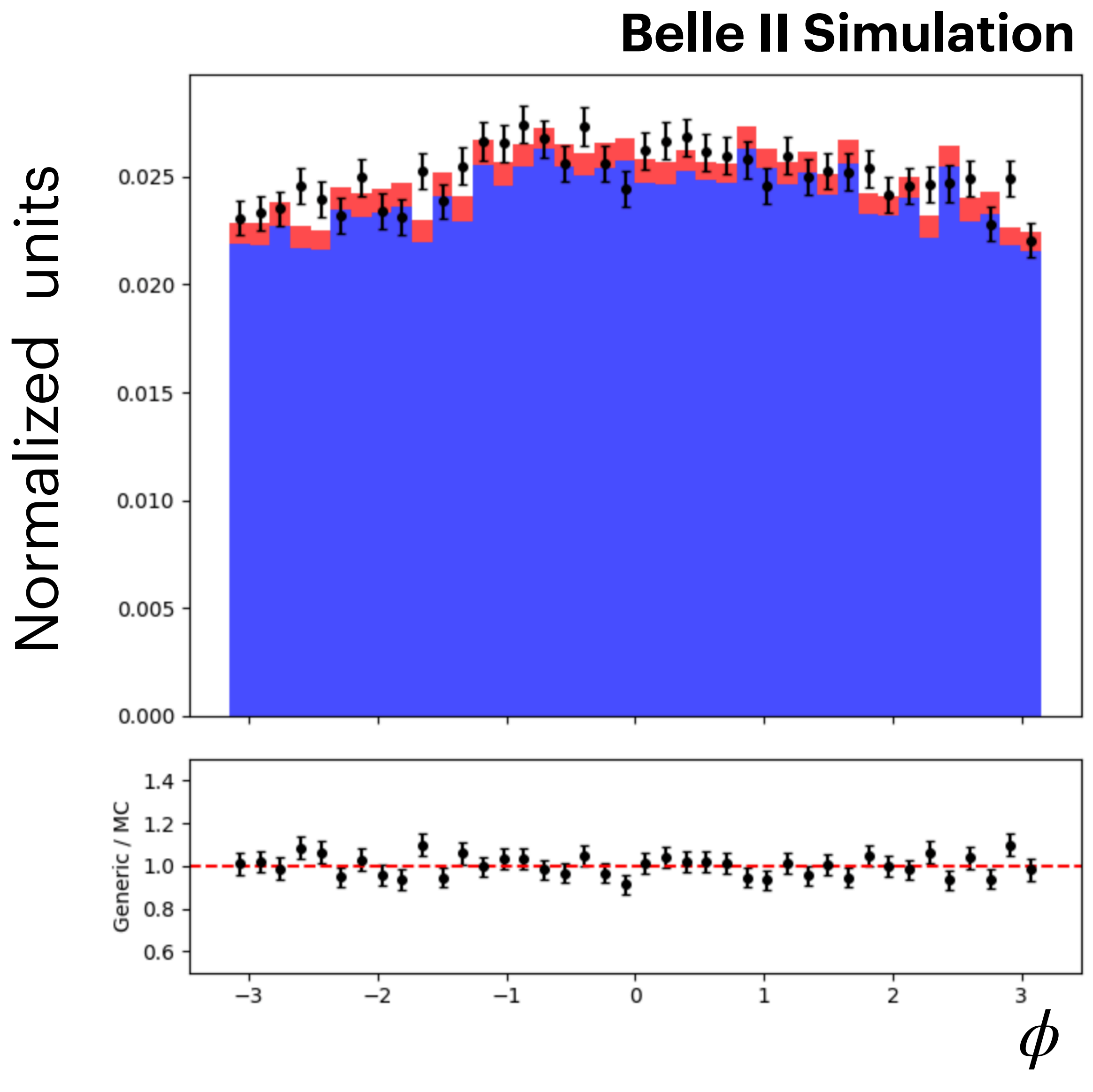




$\tau \to K K_S \nu$ channel







Challenge 2

Model independence: reweighting

1. Correct the $\tau \to \pi K_S \nu$ component using weights derived from the ratio of the PHSP and GENERIC distributions (e.g. p_{K_S}) in the $\tau \to \pi K_S \nu$ channel, assuming that the disagreement is mostly due to $\tau \to \pi K_S \nu$

2. Apply the weights evaluated in 1. to the misID component $\tau \to \pi K_S \nu$ in the $\tau \to K K_S \nu$ channel

3. Calculate additional weights to account for the remaining disagreement between PHSP and GENERIC in the $\tau \to K K_S \nu$ channel

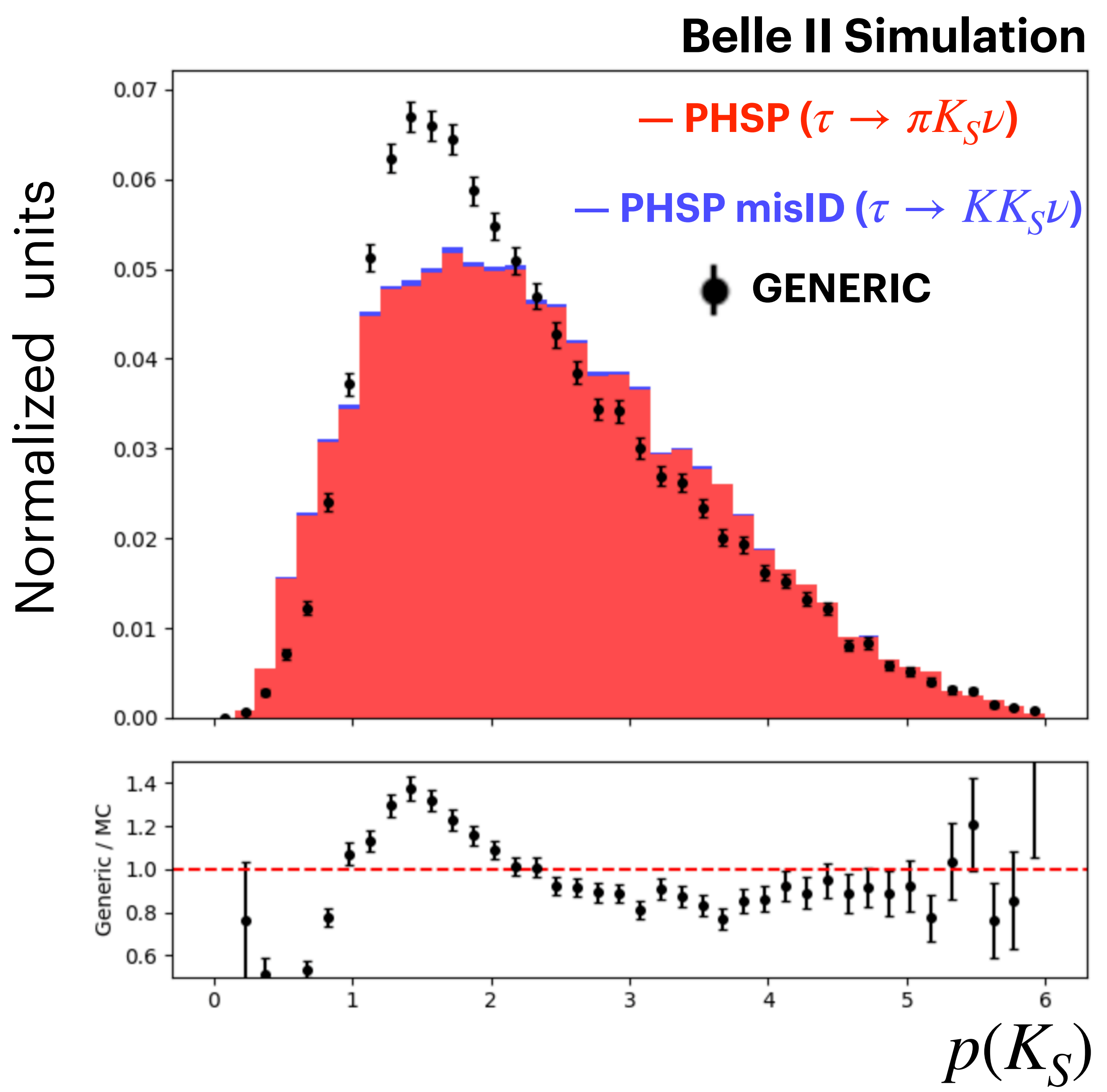
4. Apply the new weights only to the $\tau \to K K_S \nu$ component in the $\tau \to K K_S \nu$ channel

Iterate the procedure until good agreement is achieved

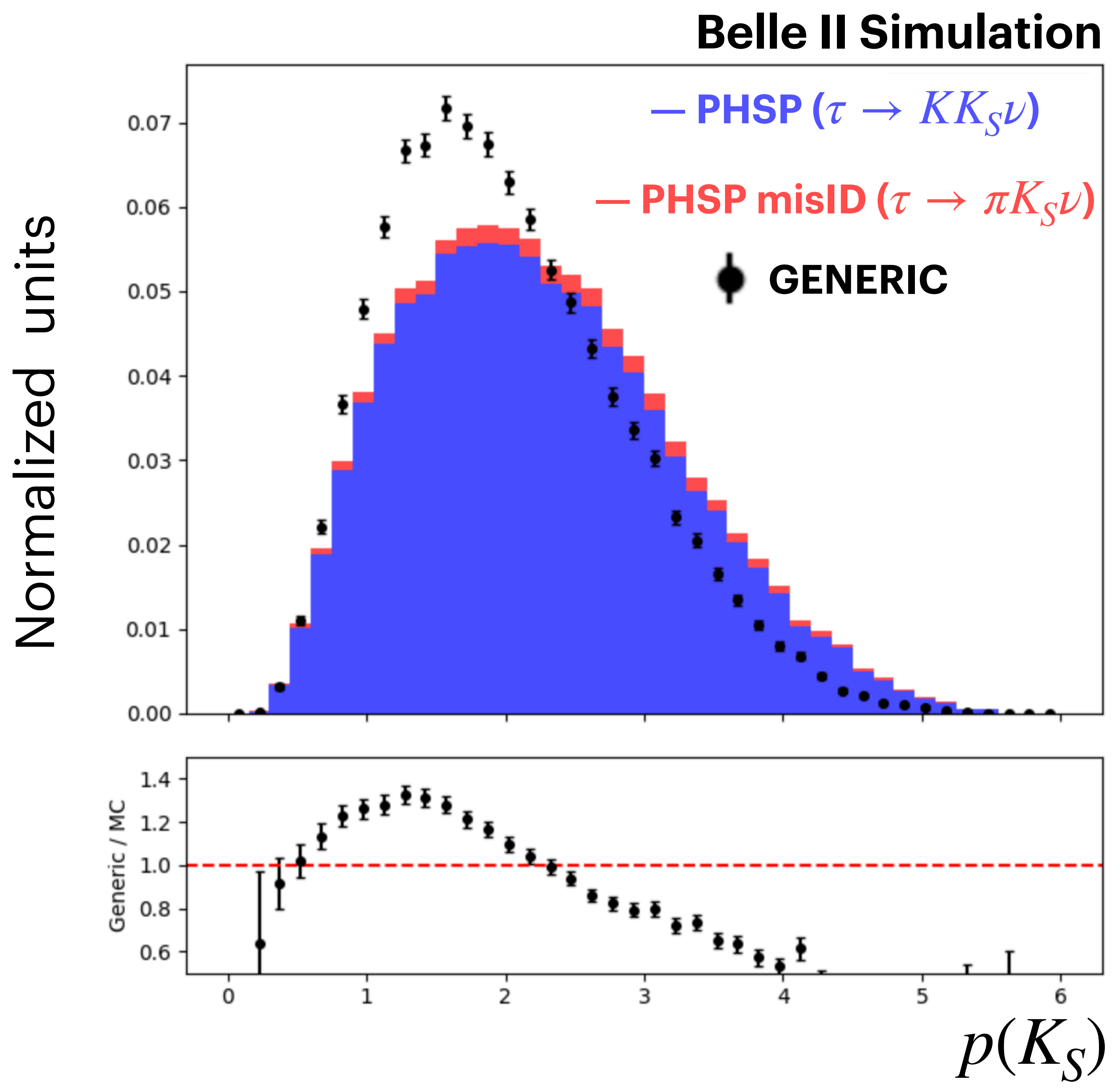
Ongoing work to extend the procedure to more complex cases

(e.g. multiple channels and/or multiple variables to reweigh)

$\tau \to \pi K_S \nu$ channel



$\tau \to K K_S \nu$ channel



Challenge 2

Model independence: impact on the unfolding

Use unfolding procedure to obtain the true number of events needed to measure $|V_{us}|$

$$\begin{pmatrix} N_{true}(\tau \to \pi K_S \nu) \\ N_{true}(\tau \to K K_S \nu) \end{pmatrix} = \left(\begin{array}{c|cc} \text{Reconstructed} \backslash \text{Generated} & \color{red}{\tau^+ \to \pi^+ K_S \nu} & \color{blue}{\tau^+ \to K^+ K_S \nu} \\ \hline \color{red}{\tau^+ \to \pi^+ K_S \nu} & \epsilon_{\tau \to \pi K_s \nu} & \mathrm{misID}_{\pi \to \mathrm{K}} \\ \color{blue}{\tau^+ \to K^+ K_S \nu} & \mathrm{misID}_{\mathrm{K} \to \pi} & \epsilon_{\tau \to K K_s \nu} \end{array} \right)^{-1} \cdot \begin{pmatrix} N_{reco}(\tau \to \pi K_S \nu) \\ N_{reco}(\tau \to K K_S \nu) \end{pmatrix}$$

Check the reweighted PHSP against the GENERIC unfolding matrix (and reconstructed events)

PHSP

$\epsilon_{\tau \to \pi K_s \nu}$	$\mathrm{misID}_{\pi \to \mathrm{K}}$
$\mathrm{misID}_{\mathrm{K} \to \pi}$	$\epsilon_{\tau \to K K_s \nu}$

Reweigthting $\longrightarrow$

PHSP reweighted

$\epsilon_{\tau \to \pi K_s \nu}$	$\mathrm{misID}_{\pi \to \mathrm{K}}$
$\mathrm{misID}_{\mathrm{K} \to \pi}$	$\epsilon_{\tau \to K K_s \nu}$

$\sim$

GENERIC

$\epsilon_{\tau \to \pi K_s \nu}$	$\mathrm{misID}_{\pi \to \mathrm{K}}$
$\mathrm{misID}_{\mathrm{K} \to \pi}$	$\epsilon_{\tau \to K K_s \nu}$

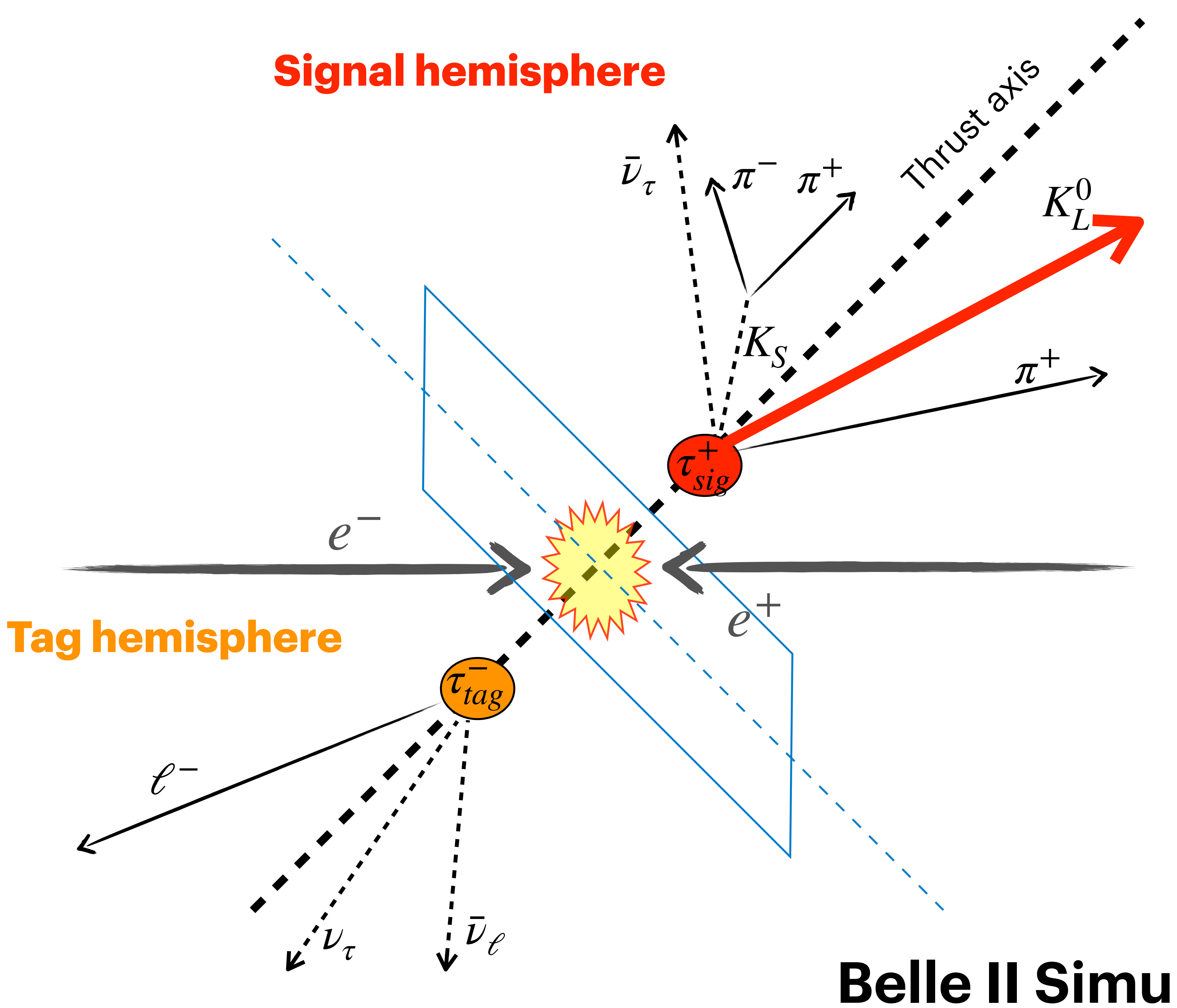
Preliminary studies show that the method works well

Challenge 3

Strategy on $\tau^+ \to \pi^+ K_S K_L n(\pi^0)\nu$: strategy

$$\mathscr{B}(\tau^+ \to \pi^+ K_L K_S \nu) = (1.08 \pm 0.24) \times 10^{-3}$$
$$\mathscr{B}(\tau^+ \to \pi^+ K_L K_S \pi^0 \nu) = (0.32 \pm 0.12) \times 10^{-3}$$

LEP measurements

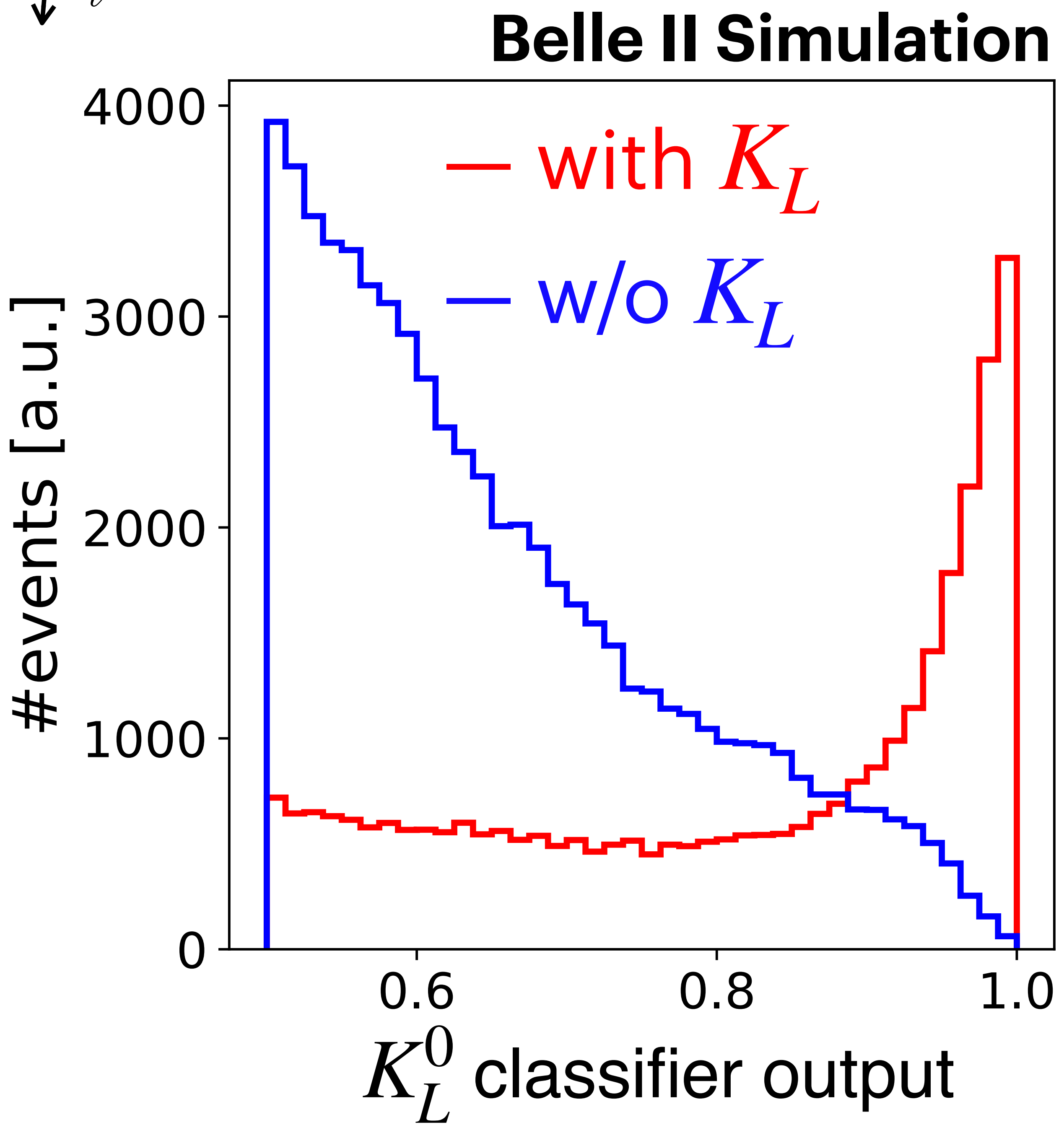


Belle II cannot measure K_L energy:

- EM calorimeter has $< 1\,\lambda_{\text{had. int.}}$
- KLM system is more of a muon system rather than HCAL

How we can select a true K_L?

- Apply same selection of $\tau^+ \to \pi^+ K_S n(\pi^0)\nu$
- Specific K_L selection exploiting the ECL + KLM clusters information
- Dedicated BDT to identify ECL + KLM clusters compatible with a true K_L
- Visible peak of the true K_L in the BDT output.



Final step: fit BDT output to count the number of events with a true K_L in the $\tau^+ \to \pi^+ K_S K_L n(\pi^0)\nu$ channel.

Challenge 3

Strategy on $\tau^+ \to \pi^+ K_S K_L n(\pi^0)\nu$: control channels

Use two independent control channels to validate the K_L BDT:

- $D^{+*} \to \pi^+ D^0(\to \pi^- \pi^+ K_L)$ [p_{K_L}<1.5 GeV]
- $e^+e^- \to \gamma\Phi(\to K_L K_S)$ [p_{K_L}>1.5 GeV]

Can control:

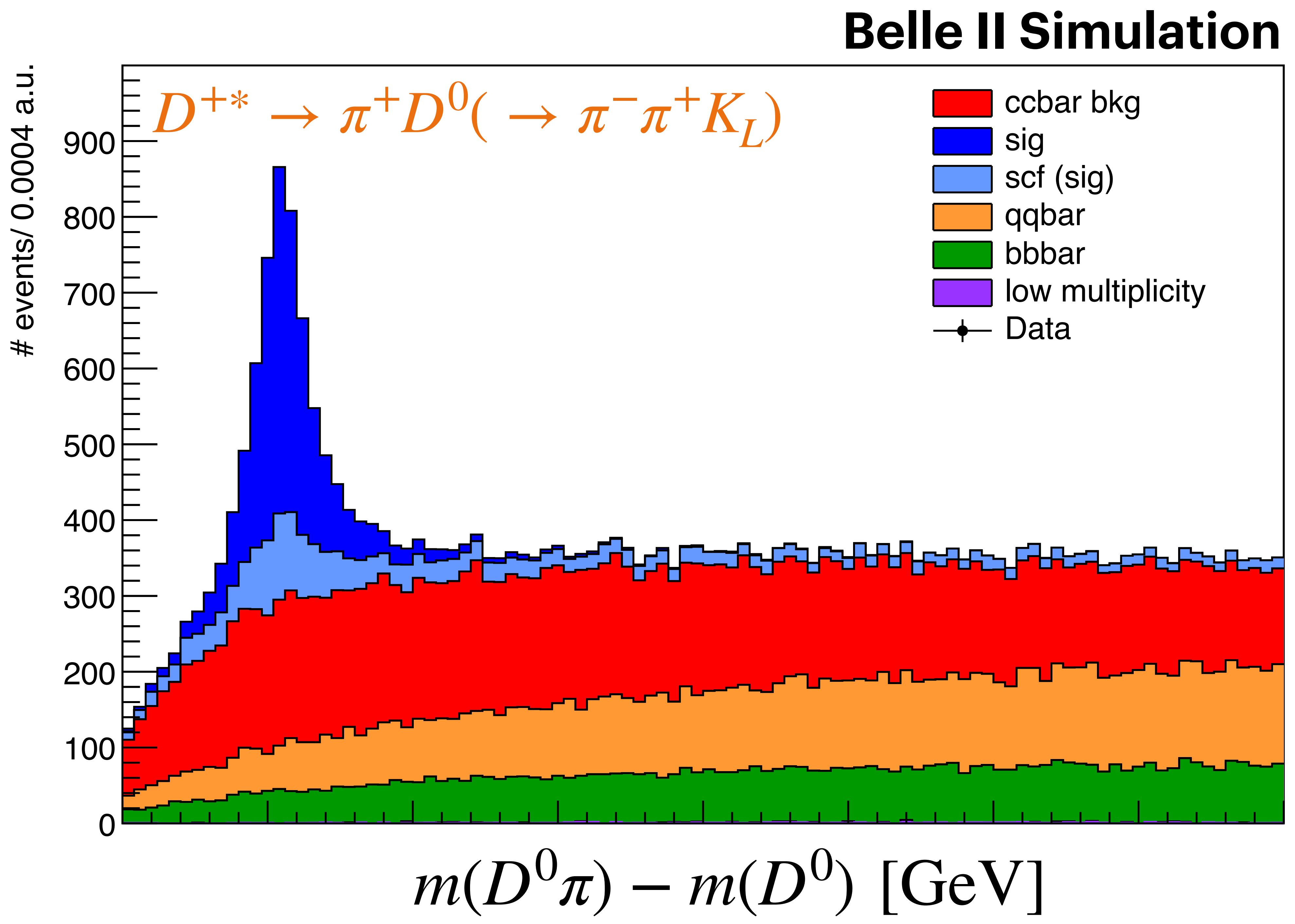
- Shape of the multivariate output for signal after reweighting the K_L variables to match those in the control channel
- K_L reco efficiency, e.g.:

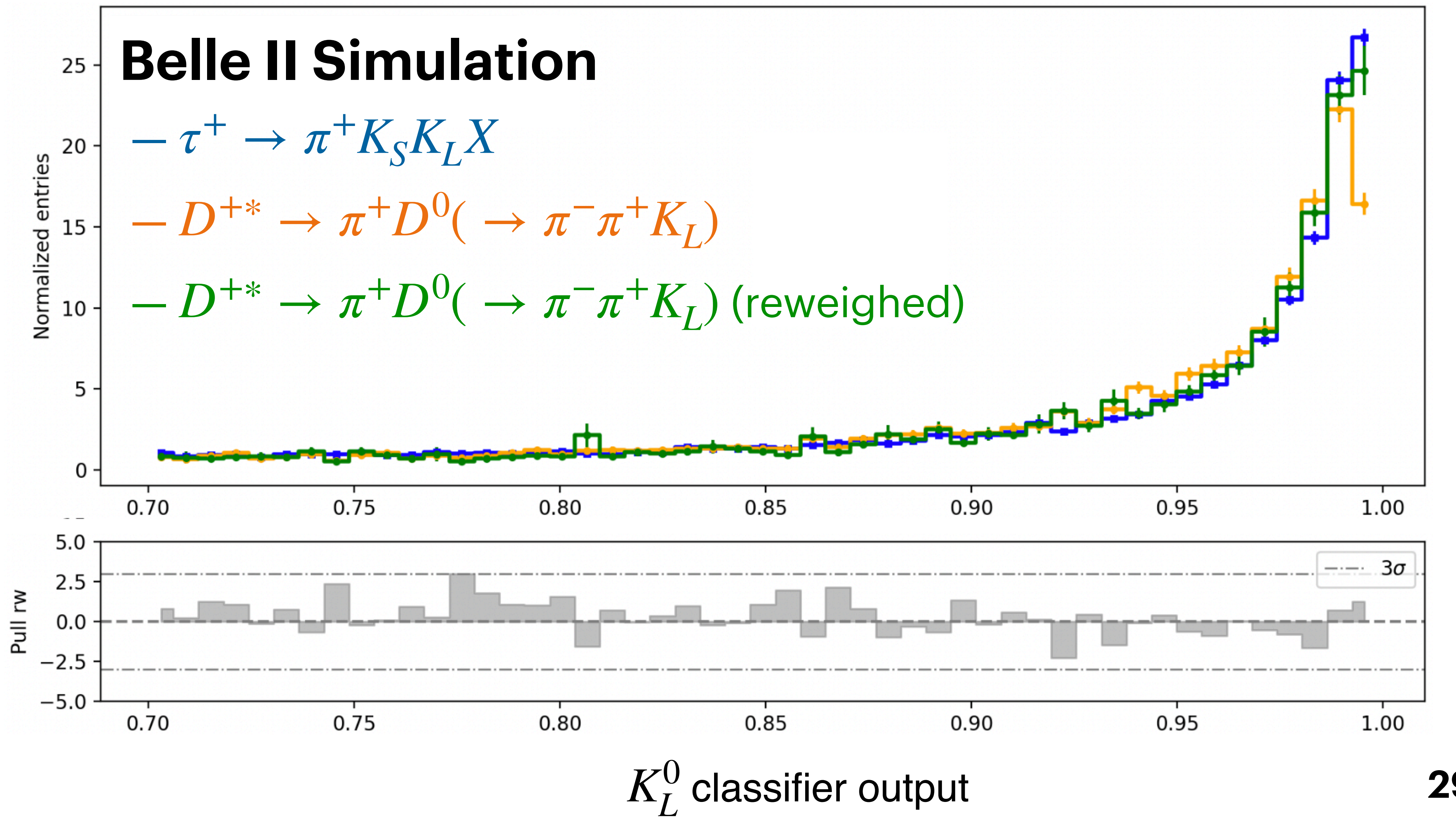
$$\frac{N(D^0 \to K_S^0 \pi^+ \pi^-)}{\varepsilon(D^0 \to K_S^0 \pi^+ \pi^-)} = \frac{N(D^0 \to K_L^0 \pi^+ \pi^-)}{\varepsilon(D^0 \to K_L^0 \pi^+ \pi^-)}$$

Work in progress, but ~10% of precision on the BR seems feasible

→ plan to validate by checking

$$\mathscr{B}(\tau \to K_S^0 \pi^+ n(\pi^0)\nu) = \mathscr{B}(\tau \to K_L^0 \pi^+ n(\pi^0)\nu)$$





Challenge 4

Expected systematic uncertainty on $|V_{us}|$

Ongoing work to evaluate the total systematic uncertainty on $|V_{us}|$

Systematic uncertainties evaluated so far:

- Luminosity and cross section → possibility to get rid of using a normalization channel
- Particle ID efficiencies and misID
- CP-violation effects for the assumption $\mathscr{B}(\tau \to \pi K_L n(\pi^0)\nu) = \mathscr{B}(\tau \to \pi K_S n(\pi^0)\nu)$

→ all found to be well below 1%

Remaining systematic uncertainties:

- Model dependence of the unfolding
- Kinematic dependence of the efficiencies

……

Conclusion

Multiple ongoing analyses to measure both exclusive and inclusive $|V_{us}|$ at Belle II

Competitive results expected from exclusive $|V_{us}|$ measurements using both 1x1 and 1x3 topologies

First-ever inclusive $|V_{us}|$ measurement expected to be highly competitive and provide interesting insight into the tension with the CKM unitary

Backup

Inclusive $|V_{us}|$ determination @ Belle II

BR and $|V_{us}|$ extraction

Extract the true number of events (N_{sig}^{true}) for the $\tau \rightarrow X_s \nu$ decay from the unfolding procedure

$BR(\tau \rightarrow X_s)$ can be measured by using

$$BR(\tau \rightarrow X_s) = \frac{N_{sig}^{true}}{2 \cdot \epsilon \cdot \mathscr{L} \cdot \sigma_{\tau\tau} \cdot BR(X_s) \cdot BR(\tau \rightarrow \ell\nu\nu)}$$

$BR(\tau \rightarrow \ell\nu\nu) = (0.3521 \pm 0.04)\,\%$

$BR(X_s)$ = depends on the specific channel

$\mathscr{L} \cdot \sigma_{\tau\tau} = N_{\tau\tau} \sim 4.59 \cdot 10^8$ in $500\,fb^{-1}$

ϵ = reconstruction efficiency

$|V_{us}|$ can be extracted from the measurement of $BR(\tau \rightarrow X_s)$

$$|V_{us}| = \sqrt{\frac{R_{\tau,s}}{\frac{R_{\tau,no\,s}}{|V_{ud}|^2} - \delta R_{QCD}}}$$

$R_{\tau,s} = BR(\tau \rightarrow X_s)/BR(\tau \rightarrow e\nu\nu)$

$\delta R_{QCD} \sim (0.240 \pm 0.032)$

$R_{\tau,no\,s} = \sum_i BR_i(X_{no\,s})$

$|V_{ud}| \sim 0.974$

Inclusive $|V_{us}|$ determination @ Belle II

Current systematic uncertainties on BR and $|V_{us}|$

Different sources of systematic uncertainties for BR and $|V_{us}|$:

1. **PID:** efficiency and fake-rate correction for hadrons and leptons. Systematic uncertainties come from Data/MC corrections derived from different control channels.

2. **Luminosity and cross section:** the relative uncertainty on $\mathscr{L} = (498.41 \pm 2.5)\mathrm{fb}^{-1}$ [0.5%] and $\sigma_{tt} = (919 \pm 3)\mathrm{pb}$ [0.33%] contribute equally to the uncertainties on BR and $|V_{us}|$.

   Possibility to get rid of using a normalization channel.

3. **CP breaking effect:** to take into account the small difference in CP violation between K_s and K_L when assuming $BR(K_s) = BR(K_L)$. Conservative uncertainty of 0.3% is assigned, of the same order as ϵ_K.

Other possible systematic uncertainties are currently being evaluated

Precise measurement of τ hadronic decays @ Belle II

BR and spectral functions (SF) of τ hadronic decays provide important input for $|V_{us}|$ and a_μ^{had}:

- Persistent >3σ discrepancy exists in $|V_{us}|$ between τ measurements and unitary expectation
- Persistent discrepancy exists between $a_\mu^{e^+e^-}$ and a_μ^{exp}, and $\tau \to n(\pi)\nu$ can contribute

Precise results on BR from LEP (ALEPH mainly)
→ Belle II can perform an independent measurement!

Precise results on SF from BaBar and Belle
→ Belle II can provide much larger statistics!

Ongoing studies at Belle II to measure:

- BR of τ hadronic decays normalised to $\tau \to \ell\nu\nu$ decays
- SF measurement via unfolding