# *Search for the lepton flavour violating* $\tau \to l\phi$ *decay at Belle II*

Léonard Polat
Supervisor: Justine Serrano
Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France

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# The tau lepton as part of the Standard Model

**The Standard Model (SM) of particle physics**:

- To this day, best description of interactions between particles.
- Still doesn't explain some phenomena (baryon asymmetry, dark matter/energy, neutrino oscillations...).

  → *search for **new physics** (NP).*

**The tau lepton**:

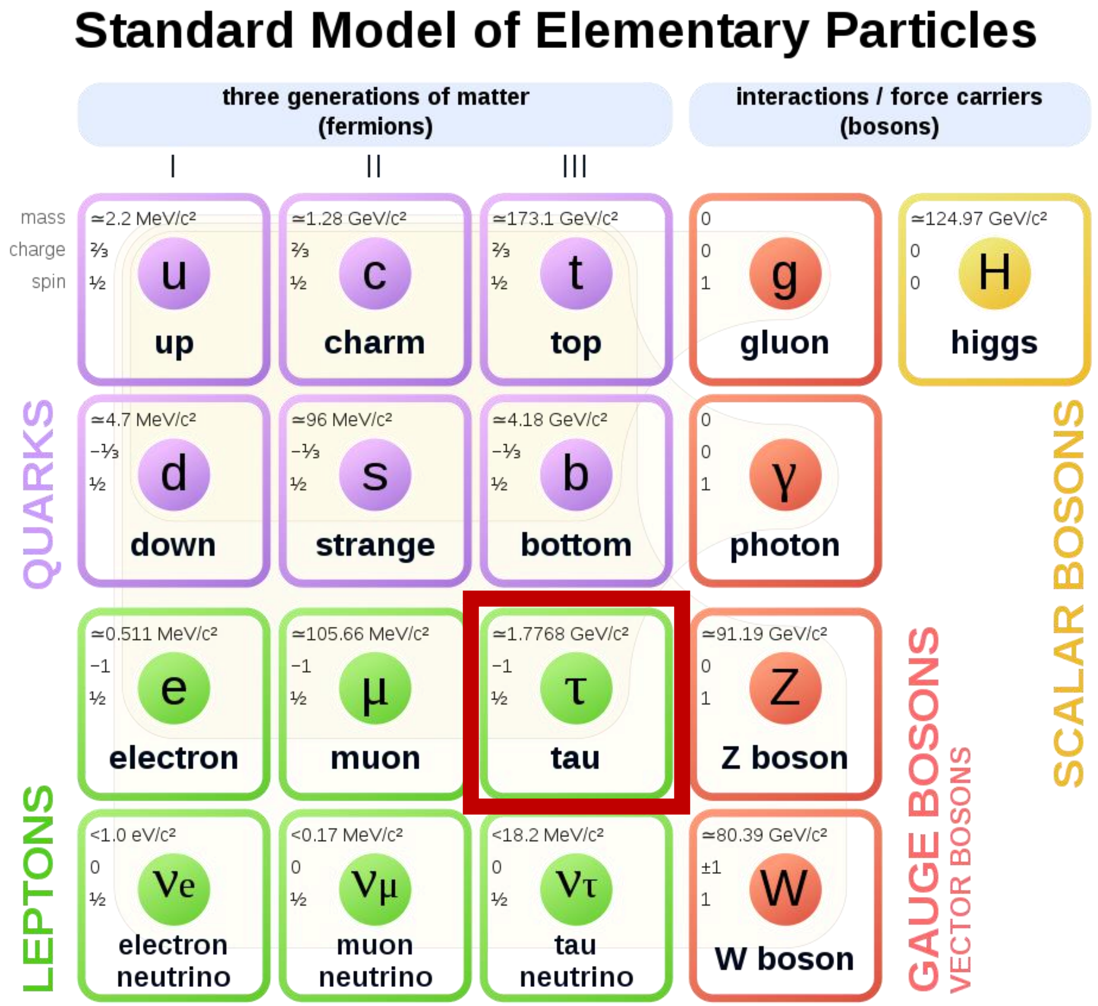
- Discovered in 1974-1977 at SLAC-LBL, California.
- Heaviest lepton: $M_\tau = 1.777\ \mathrm{GeV}/c^2$.
- Lifetime: $\sim 3 \times 10^{-13}$ s (shorter than muon lifetime by 7 orders of magnitude!).
- Preferred decay channels (95% of decays):

$$\tau^- \to e^-\bar{\nu}_e\nu_\tau \,/\, \mu^-\bar{\nu}_\mu\nu_\tau$$

$$\to \pi^-\nu_\tau$$

$$\to \pi^-\pi^0(\pi^0)\nu_\tau$$

$$\to \pi^-\pi^+\pi^-(\pi^0)\nu_\tau$$



# Tau lepton flavour violation with $\tau \to l\phi$

- **Lepton Flavour Violation (LFV)**:

  *when flavours of leptons (neutrinos included) are not conserved from initial to final state of the decay.*

**e.g.**:

$\mu^- \to e^- \bar{\nu}_e \nu_\mu$ no LFV

$\mu^- \to e^- \gamma$ LFV

- **Neutral LFV** was forbidden in the SM... until the discovery of neutrino oscillation!

  *Neutrinos have small masses → change of flavour following PMNS matrix.*

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

*Pontecorvo-Maki-Nakagawa-Sakata matrix*

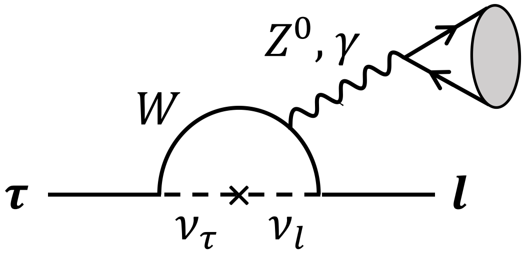
- **Charged LFV** is a consequence of neutrino oscillation.

  *Occurs via weak interaction, but highly suppressed!*

  *Any discovery would be an indication of NP.*

**Our study's decay channel is: τ→lϕ** (l = e,μ).

$\phi = s\bar{s}$ meson, mass = 1020 MeV/c²



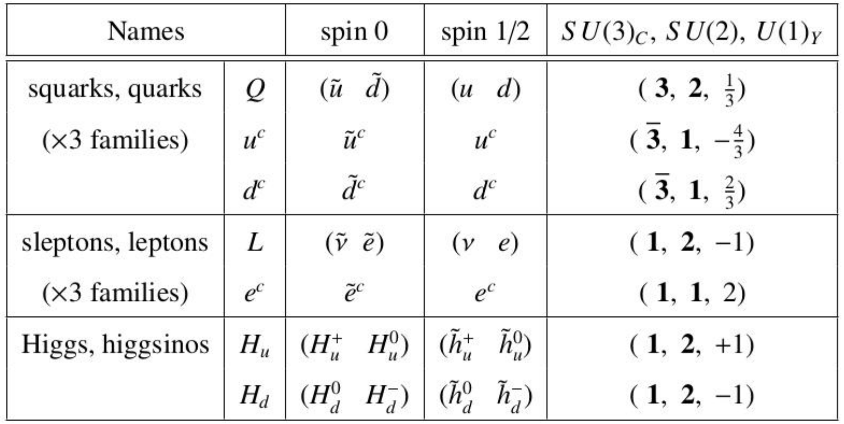
$\boldsymbol{\phi} \to K^+K^-$

$\mathbf{Br} \sim \mathcal{O}(\mathbf{10^{-54}})$ in SM*

* J. I. Illana et al., arXiv:hep-ph/0001273 (2000)

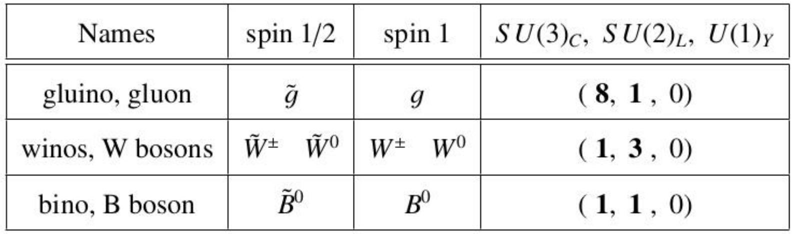
# LFV in New Physics: Supersymmetry

Table 1.1: **Chiral supermultiplets** in the Minimal Supersymmetric Standard Model. Spin-0 fields are complex scalars, and spin-$\frac{1}{2}$ fields are left-handed two-component Weyl fermions.



| Names | | spin 0 | spin 1/2 | $SU(3)_C,\ SU(2),\ U(1)_Y$ |
|---|---|---|---|---|
| squarks, quarks | $Q$ | $(\tilde{u}\ \ \tilde{d})$ | $(u\ \ d)$ | $(\ \mathbf{3},\ \mathbf{2},\ \frac{1}{3})$ |
| (×3 families) | $u^c$ | $\tilde{u}^c$ | $u^c$ | $(\ \overline{\mathbf{3}},\ \mathbf{1},\ -\frac{4}{3})$ |
| | $d^c$ | $\tilde{d}^c$ | $d^c$ | $(\ \overline{\mathbf{3}},\ \mathbf{1},\ \frac{2}{3})$ |
| sleptons, leptons | $L$ | $(\tilde{\nu}\ \ \tilde{e})$ | $(\nu\ \ e)$ | $(\ \mathbf{1},\ \mathbf{2},\ -1)$ |
| (×3 families) | $e^c$ | $\tilde{e}^c$ | $e^c$ | $(\ \mathbf{1},\ \mathbf{1},\ 2)$ |
| Higgs, higgsinos | $H_u$ | $(H_u^+\ \ H_u^0)$ | $(\tilde{h}_u^+\ \ \tilde{h}_u^0)$ | $(\ \mathbf{1},\ \mathbf{2},\ +1)$ |
| | $H_d$ | $(H_d^0\ \ H_d^-)$ | $(\tilde{h}_d^0\ \ \tilde{h}_d^-)$ | $(\ \mathbf{1},\ \mathbf{2},\ -1)$ |

Table 1.2: **Gauge supermultiplets** in the Minimal Supersymmetric Standard Model.



| Names | spin 1/2 | spin 1 | $SU(3)_C,\ SU(2)_L,\ U(1)_Y$ |
|---|---|---|---|
| gluino, gluon | $\tilde{g}$ | $g$ | $(\ \mathbf{8},\ \mathbf{1}\ ,\ 0)$ |
| winos, W bosons | $\tilde{W}^\pm\ \ \tilde{W}^0$ | $W^\pm\ \ W^0$ | $(\ \mathbf{1},\ \mathbf{3}\ ,\ 0)$ |
| bino, B boson | $\tilde{B}^0$ | $B^0$ | $(\ \mathbf{1},\ \mathbf{1}\ ,\ 0)$ |

Figure 2.1: Chargino diagrams contributing to $l_j \rightarrow 3l_i$

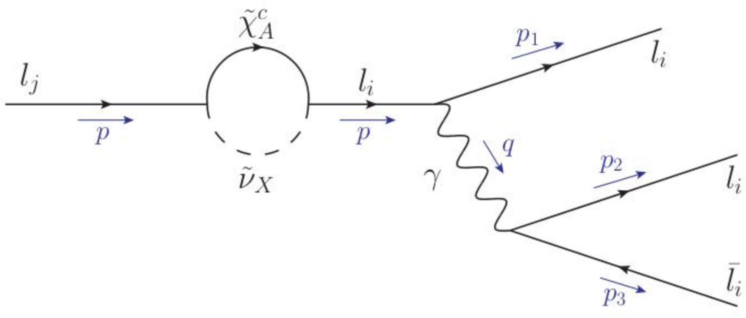
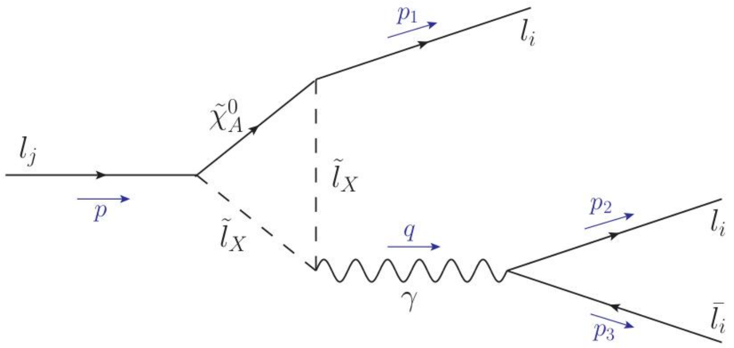


Figure 2.2: Neutralino diagrams contributing to $l_j \rightarrow 3l_i$



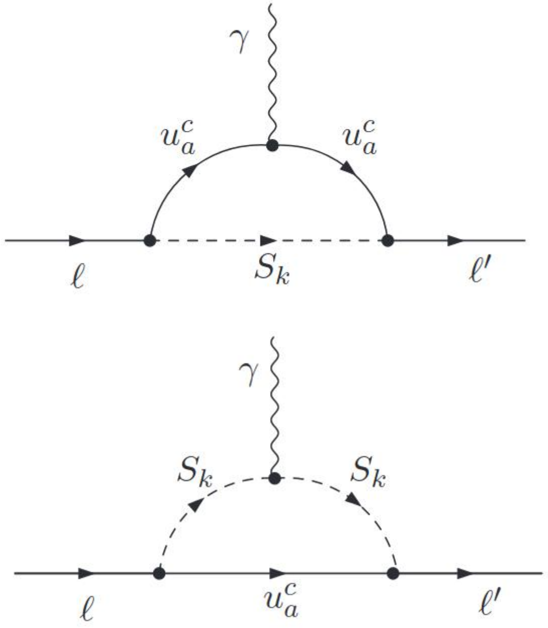
**Supersymmetry (SUSY)**: *symmetry relating bosons and fermions, where each boson (fermion) has a fermionic (bosonic) superpartner.*

- Could explain some shortcomings of the SM (hierarchy problem of Higgs boson, dark matter...).
- Introduces LFV from *chargino-sneutrino-lepton* and *neutralino-slepton-lepton* interactions.

M. Kovaľ, LFV τ and μ Decays in SUSY Theories (2012)

# LFV in New Physics: Leptoquarks

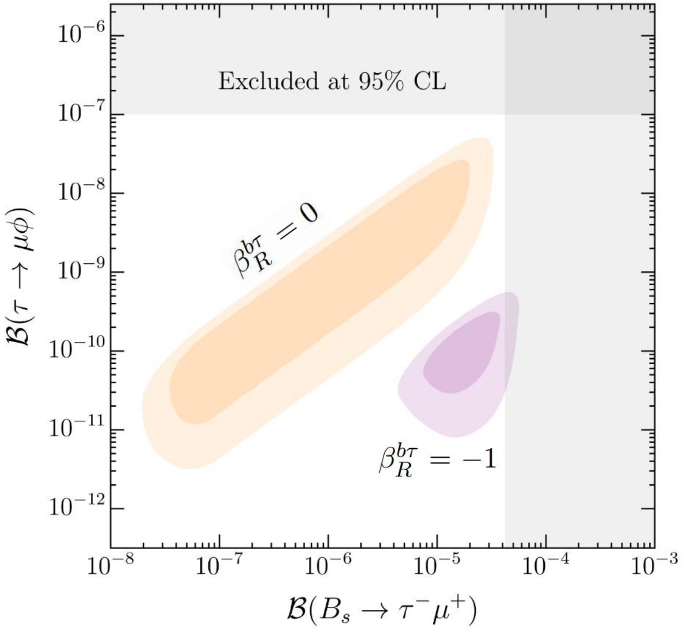
**τ→μϕ** decay channel is particularly interesting with regard to NP models involving **leptoquarks**, here the $U_1$ particle. Leptoquarks are expected in grand unification theories (GUT) and some technicolor models. They could be linked to lepton flavour universality violation as might suggest the anomalies seen in $b\to s\ell\ell$ and $b\to c\ell\nu$ transitions.



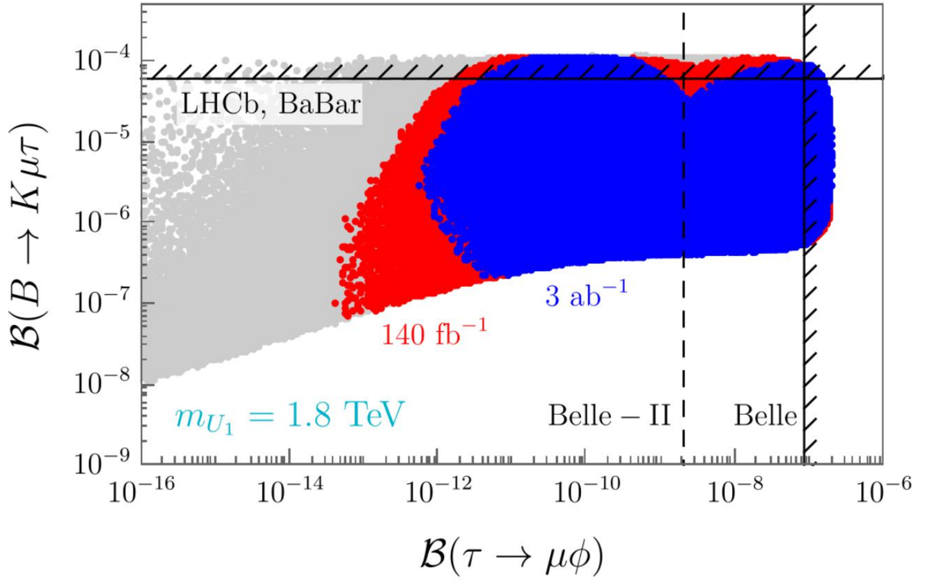
R. Benbrik et al., arXiv:1009.3886v1 (2010)

*Interaction current of $U_1$ with SM fermions:*

$$J_\mu^U = \beta_L^{i\alpha}\,(\bar{q}_L^i\gamma_\mu\ell_L^\alpha) + \beta_R^{i\alpha}\,(\bar{d}_R^i\gamma_\mu e_R^\alpha)$$

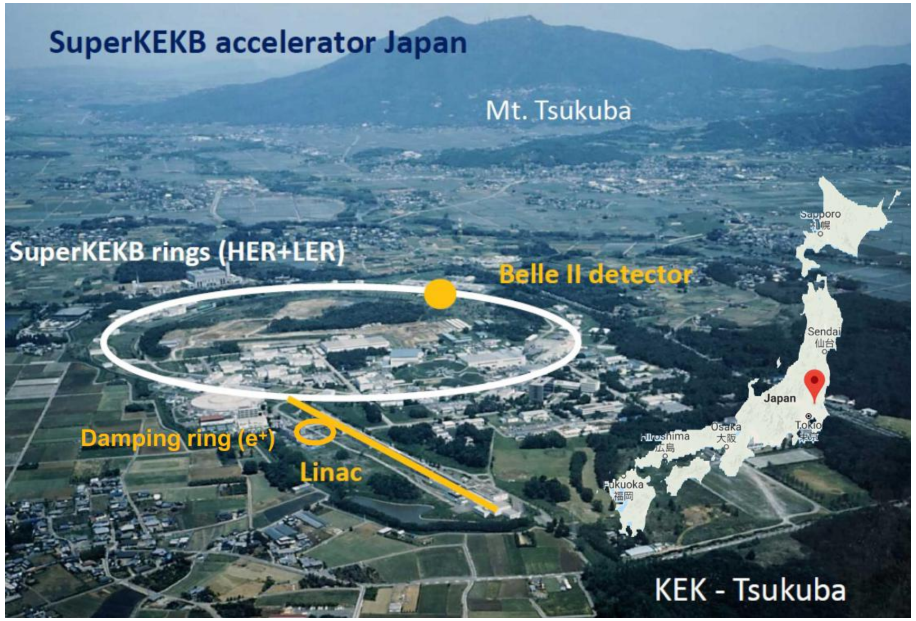


C. Cornella et al., arXiv:2103.16558v1 (30 Mar 2021)



A. Angelescu et al., arXiv:2103.12504v2 (21 Apr 2021)

# The Belle II experiment

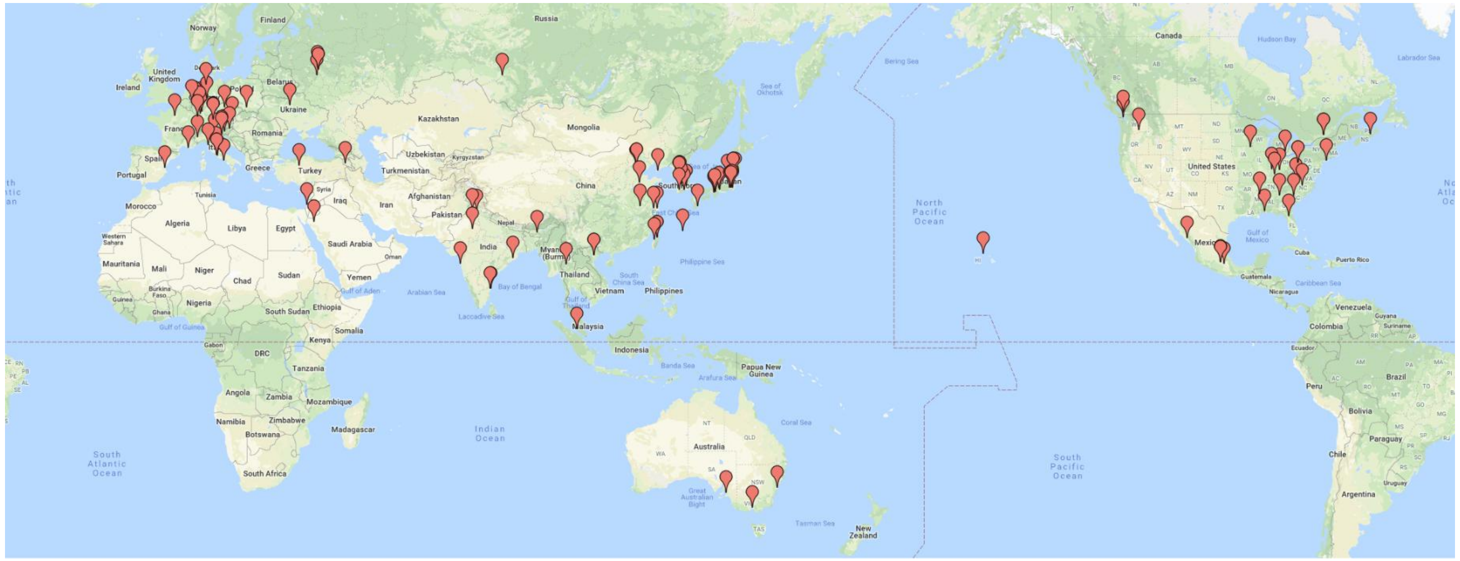


- KEK laboratory (Tsukuba, Japan), ~ 60 km from Tokyo.
- Successor to Belle, upgrade of KEKB collider.
- SuperKEKB: $e^+e^-$ collider, 3 km in circumference.
- Data taking with (almost) complete detector started in 2019.

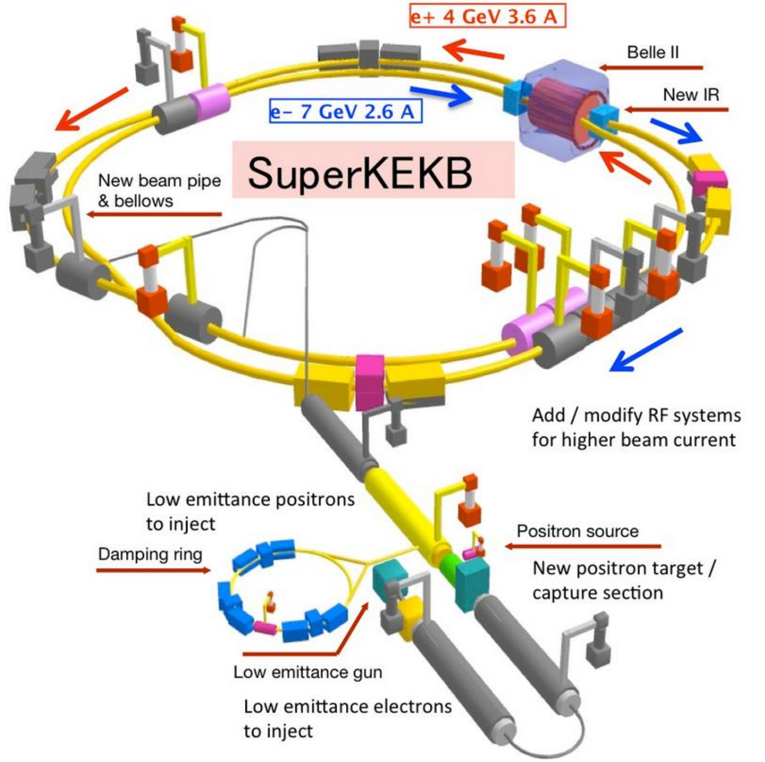
~ 26 countries

A thousand of members

300 students



# SuperKEKB and status of Belle II

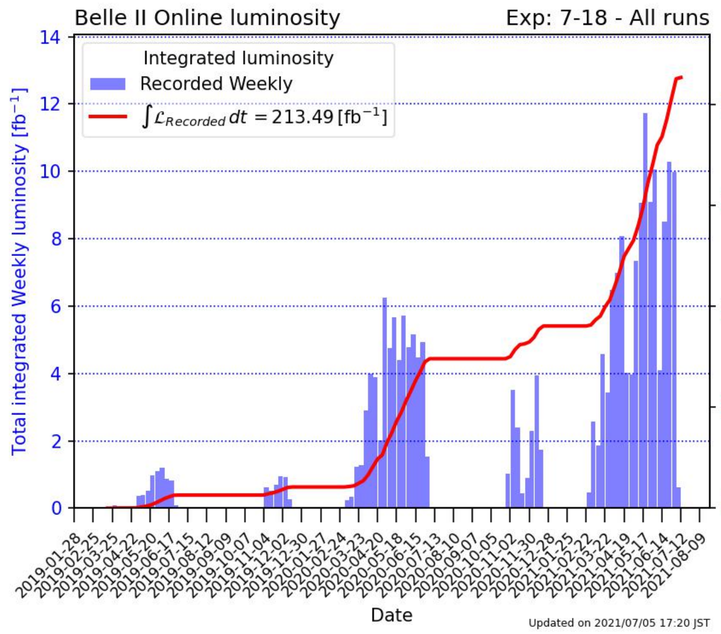


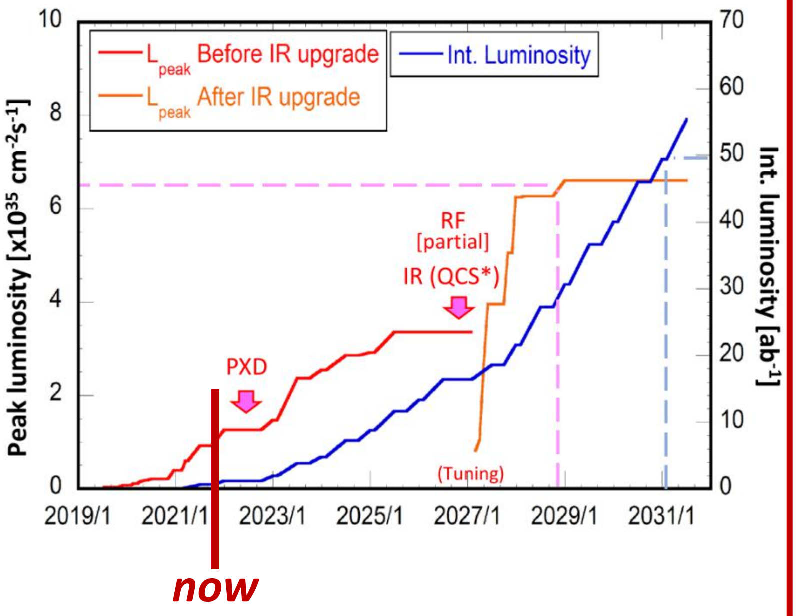
**Electron** (7 GeV) - **Positron** (4 GeV) collider.

$$e^+e^- \rightarrow \Upsilon(4S)[10.58\ \mathrm{GeV}] \rightarrow \boldsymbol{B\bar{B}}\ (\boldsymbol{\sigma = 1.1\ \mathrm{nb}})$$

$$e^+e^- \rightarrow \boldsymbol{\tau^+\tau^-}\ (\boldsymbol{\sigma = 0.9\ \mathrm{nb}})$$

but also $u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}, e^+e^-, \mu^+\mu^- \ldots$



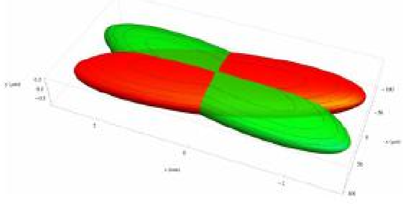


Targeted peak luminosity: **6×10$^{35}$ cm$^{-2}$ s$^{-1}$**

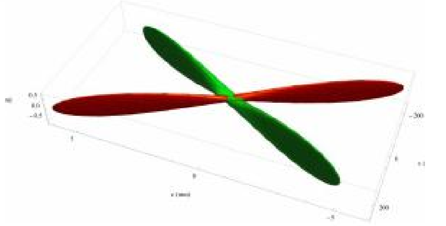
Today: ~ 213 fb$^{-1}$ of data collected | Goal: **50 ab$^{-1}$**

$$\underbrace{\text{Higher beam currents} \\ \text{Lower beam size}}$$

**30x** KEKB peak luminosity

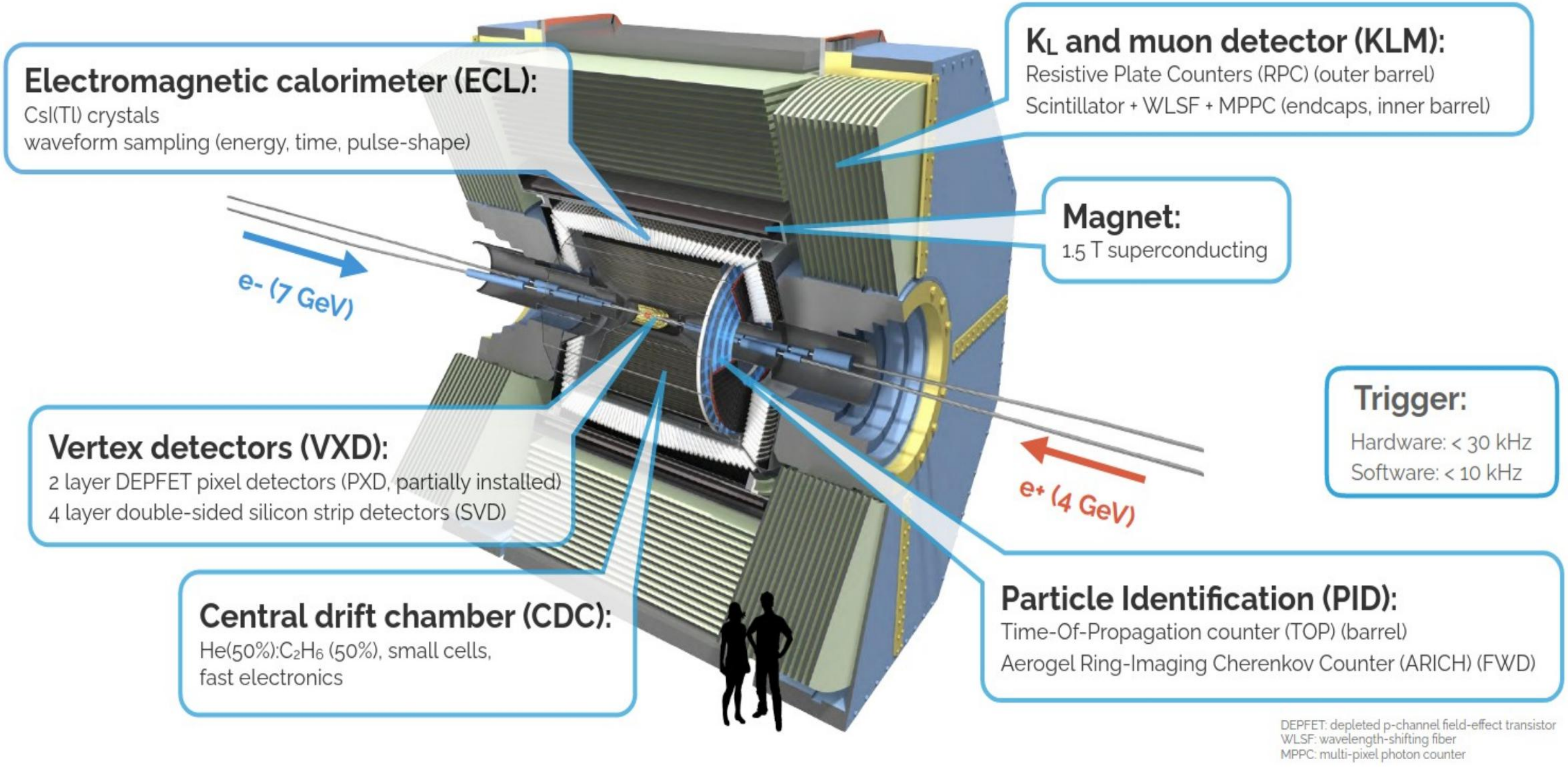


KEKB Interaction region beam overlap



SuperKEKB Interaction region beam overlap

# Belle II detector



**Electromagnetic calorimeter (ECL):**
CsI(Tl) crystals
waveform sampling (energy, time, pulse-shape)

**$K_L$ and muon detector (KLM):**
Resistive Plate Counters (RPC) (outer barrel)
Scintillator + WLSF + MPPC (endcaps, inner barrel)

**Magnet:**
1.5 T superconducting

**Vertex detectors (VXD):**
2 layer DEPFET pixel detectors (PXD, partially installed)
4 layer double-sided silicon strip detectors (SVD)

**Trigger:**
Hardware: < 30 kHz
Software: < 10 kHz

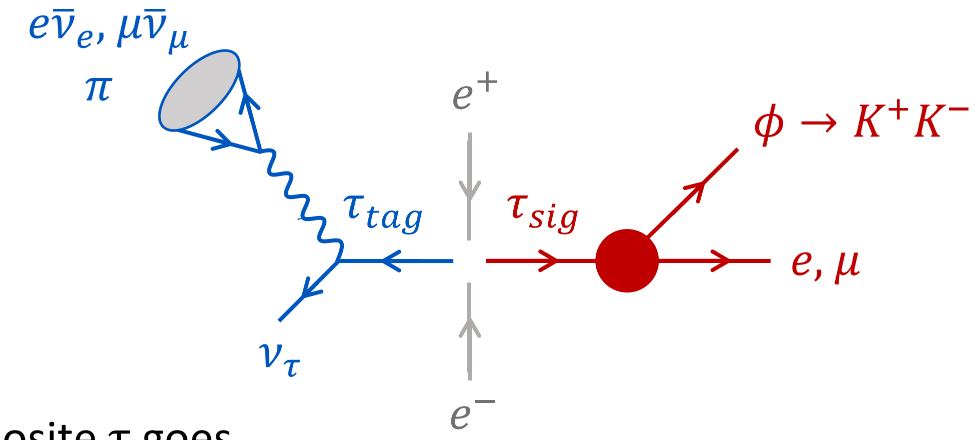
**Central drift chamber (CDC):**
He(50%):$C_2H_6$ (50%), small cells,
fast electronics

**Particle Identification (PID):**
Time-Of-Propagation counter (TOP) (barrel)
Aerogel Ring-Imaging Cherenkov Counter (ARICH) (FWD)

DEPFET: depleted p-channel field-effect transistor
WLSF: wavelength-shifting fiber
MPPC: multi-pixel photon counter

# Strategy of the analysis

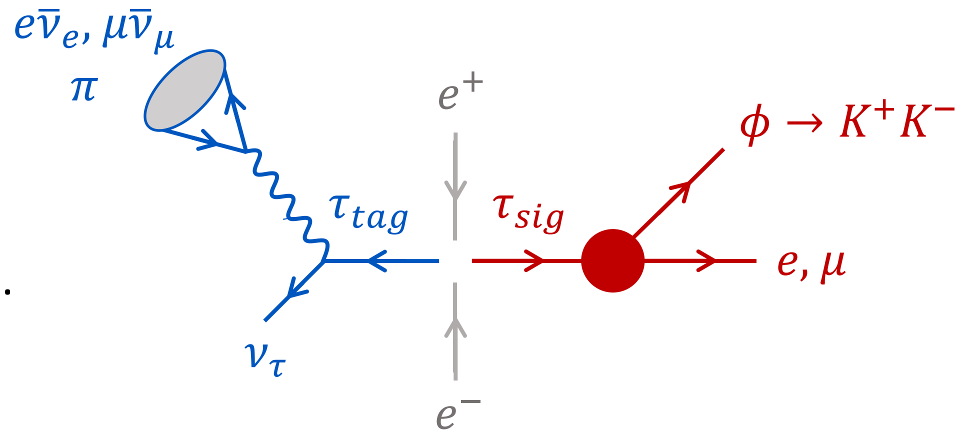
The analysis consists in reconstructing the **$\tau \to l\phi$** channel on data while applying a background suppression selection defined from Monte-Carlo (MC) simulation studies to seek signal events.



**Steps of the study on simulation**:

- Reconstruct the signal channel (**signal side, 3-prong**) for one $\tau$ while opposite $\tau$ goes into $e$, $\mu$ or $\pi$ (**tag side, 1-prong**),
- Define a **signal region** using the variables $\mathbf{M_{l\phi}}$ and $\mathbf{\Delta E_{l\phi}}$ $(= E_{l\phi} - E_{beam})$,
- Elaborate a strategy of **signal selection/background suppression** with some variables (kinematics, event based, etc.),
- Optimise the cuts on those variables with respect to a figure of merit (**Punzi**) to increase the sensitivity to signal events,
- Compare the sensitivities to the ones from the **Belle study** (https://arxiv.org/pdf/1101.0755v5.pdf),
- Perform **data-MC comparison** with control channels **$\tau \to 3\pi\nu$** and **$\tau \to \pi KK\nu$**.

# Reconstruction of the event



**MC samples**:

- **Signal**: $\tau^\pm \rightarrow e^\pm\phi / \tau^\pm \rightarrow \mu^\pm\phi$
- **Backgrounds**: $\tau^+\tau^-$ & quark-antiquark (*qqbar*)
  & ee, μμ, eeee, eeμμ, eepp, eeππ, eeKK (*low multiplicity*).

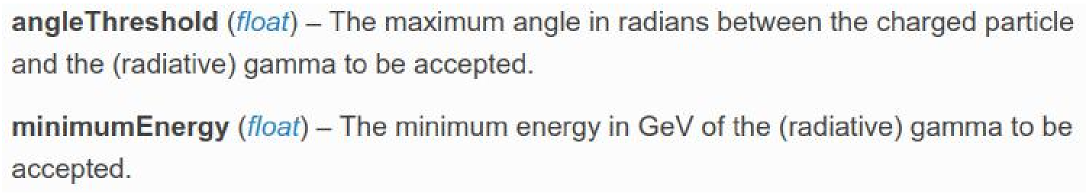
**Reconstruction**:

- **Selection of tracks with certain requirements**: production around interaction point & particle identification (PID) or equivalent requirements → for electrons, muons, kaons, pions and photons.
- Only **4 tracks** in the event, with lepton/ϕ and 1-prong in **opposite hemispheres** w.r.t. thrust axis.
- Loose **cut** around the **ϕ meson's mass** at reconstruction level, then much tighter cut optimised against background.
- **Bremsstrahlung** corrections for electrons.
- Taking into account the **lepton ID data-simulation corrections** (available only for muons) applied to MC.

# Bremsstrahlung corrections

Events are subject to **initial/final state radiations** (ISR/FSR) from **bremsstrahlung** by electrons. Corrections are needed to get as many signal events as possible around the peaking region in the $M_{l\phi}$-$\Delta E_{l\phi}$ plane.

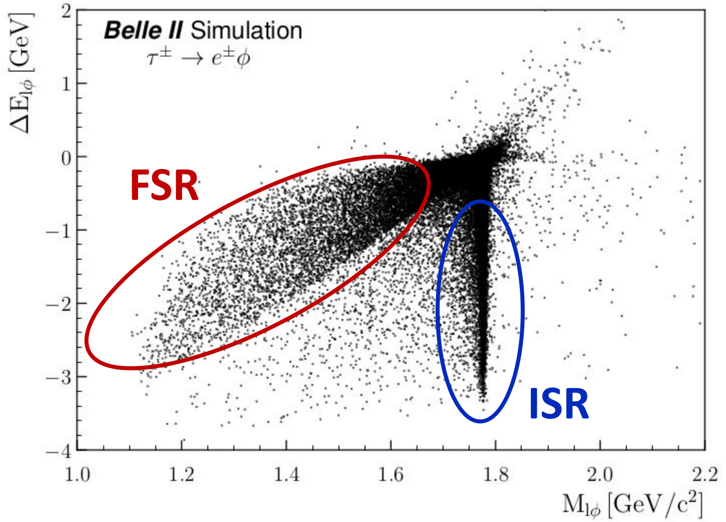
Bremsstrahlung correction for FSR needs two main parameters:



**angleThreshold** (*float*) – The maximum angle in radians between the charged particle and the (radiative) gamma to be accepted.

**minimumEnergy** (*float*) – The minimum energy in GeV of the (radiative) gamma to be accepted.

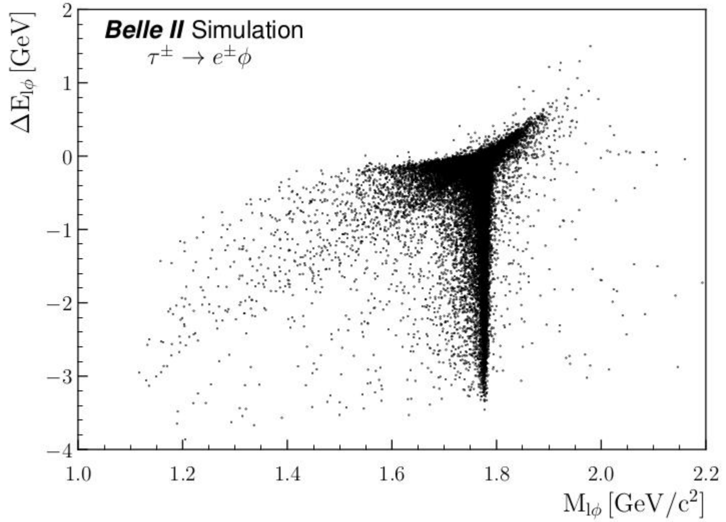
*Before bremsstrahlung correction*



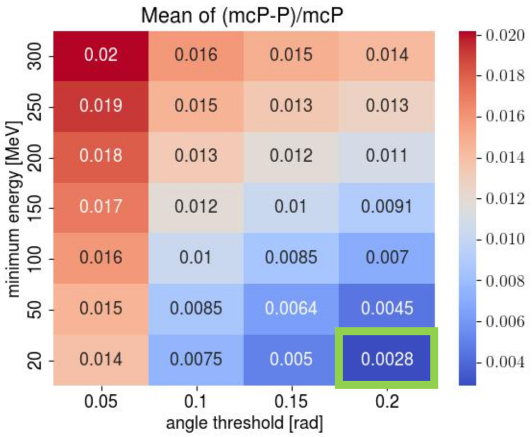
Parameters were optimised by minimising the mean and standard deviation of (p = momentum):

$$\frac{p_{electron}^{generated} - p_{electron}^{reconstructed}}{p_{electron}^{generated}}$$

*After bremsstrahlung correction*

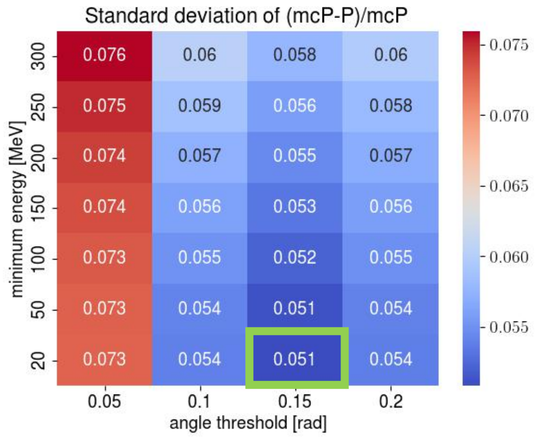


Mean of (mcP-P)/mcP



| minimum energy [MeV] \ angle threshold [rad] | 0.05 | 0.1 | 0.15 | 0.2 |
|---|---|---|---|---|
| 300 | 0.02 | 0.016 | 0.015 | 0.014 |
| 250 | 0.019 | 0.015 | 0.013 | 0.013 |
| 200 | 0.018 | 0.013 | 0.012 | 0.011 |
| 150 | 0.017 | 0.012 | 0.01 | 0.0091 |
| 100 | 0.016 | 0.01 | 0.0085 | 0.007 |
| 50 | 0.015 | 0.0085 | 0.0064 | 0.0045 |
| 20 | 0.014 | 0.0075 | 0.005 | 0.0028 |

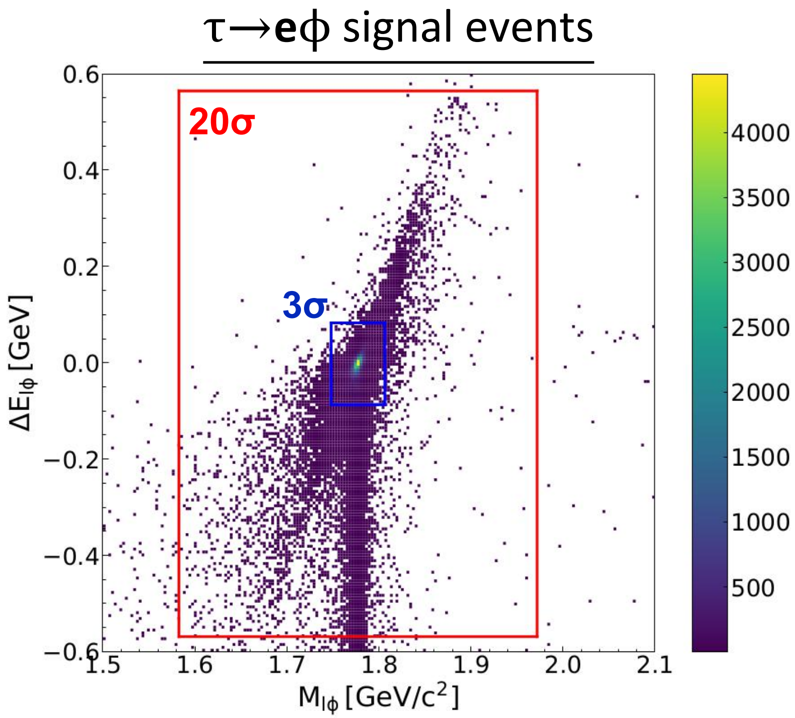
Standard deviation of (mcP-P)/mcP

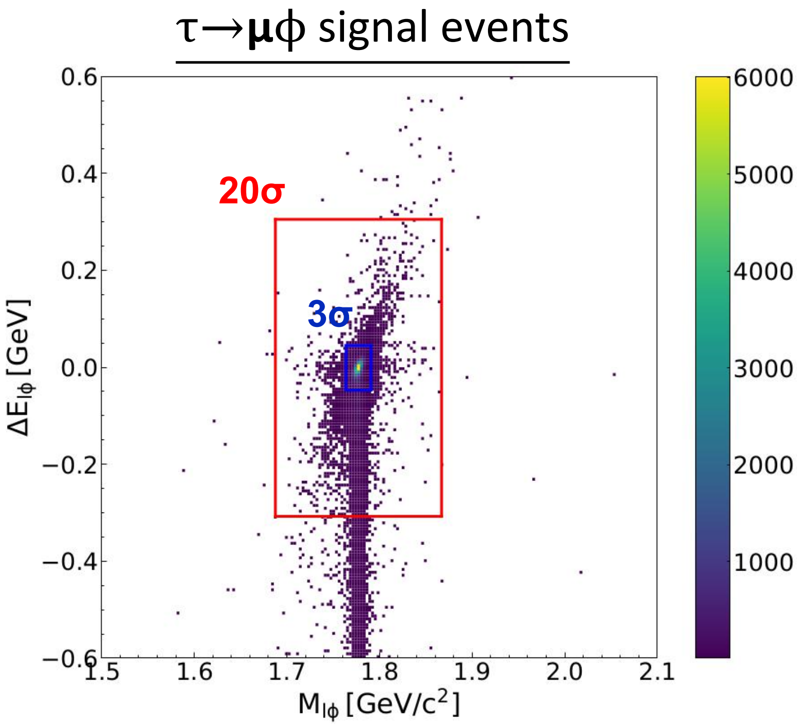


| minimum energy [MeV] \ angle threshold [rad] | 0.05 | 0.1 | 0.15 | 0.2 |
|---|---|---|---|---|
| 300 | 0.076 | 0.06 | 0.058 | 0.06 |
| 250 | 0.075 | 0.059 | 0.056 | 0.058 |
| 200 | 0.074 | 0.057 | 0.055 | 0.057 |
| 150 | 0.074 | 0.056 | 0.053 | 0.056 |
| 100 | 0.073 | 0.055 | 0.052 | 0.055 |
| 50 | 0.073 | 0.054 | 0.051 | 0.054 |
| 20 | 0.073 | 0.054 | 0.051 | 0.054 |

→ *minimumEnergy* = **0.02 GeV**, *angleThreshold* = **0.15 rad**

# Signal regions and resolutions


$\tau \rightarrow e\phi$ signal events


$\tau \rightarrow \mu\phi$ signal events

**20σ signal region:**
→ optimisation of the selection.

**5σ signal region:**
→ fit of background distribution.

**3σ signal region:**
→ region to be blinded, final results.

- Fit both variables with
  (*a*, *b*: weights, parameters of the fit):
  *a**Crystal Ball + *b**Core Gaussian
  + *(1-a-b)**Broad Gaussian

- Total sigma is the weighted sum of the three components' sigmas.

| Belle's resolutions: | Our resolutions: |
|---|---|
| $\sigma(M_{e\phi}) = \mathbf{4.1 - 4.5}\ \mathrm{MeV}/c^2$ | $\sigma(M_{e\phi}) = \mathbf{9.7}\ \mathrm{MeV}/c^2$ |
| $\sigma(\Delta E_{e\phi}) = \mathbf{14.0 - 22.0}\ \mathrm{MeV}$ | $\sigma(\Delta E_{e\phi}) = \mathbf{28.3}\ \mathrm{MeV}$ |
| $\sigma(M_{\mu\phi}) = \mathbf{3.7 - 3.8}\ \mathrm{MeV}/c^2$ | $\sigma(M_{\mu\phi}) = \mathbf{4.5}\ \mathrm{MeV}/c^2$ |
| $\sigma(\Delta E_{\mu\phi}) = \mathbf{14.2 - 19.9}\ \mathrm{MeV}$ | $\sigma(\Delta E_{\mu\phi}) = \mathbf{15.3}\ \mathrm{MeV}$ |

Belle's resolutions computed from asymmetric Gaussian fits thus not really comparable to ours.

# Strategy of the signal selection optimisation

Figure of merit: $\mathrm{FOM}_{\mathrm{Punzi}} = \frac{\epsilon_{sig}}{\frac{a}{2} + \sqrt{B}}, \; a = 3$

**Two MC samples**: one for **training** *(4 ab$^{-1}$, 20σ signal region)* and one for **testing** *(1 ab$^{-1}$, 3σ signal region)*.

I. **Scan+BDT**: cut-based selection (low multiplicity) + BDT (qqbar) + cut-based selection ($\tau^+\tau^-$).

II. **Cut-based** (full scan): single cut-based selection, w/o separating the backgrounds.

*Selection optimised separately for the different final states (leptonic/hadronic tag-sides) when enough statistics.*

Variables of interest:

Kaons:
- $\theta_{K1\text{-}K2}$

Lepton:
- $p^T_{lep}$
- $\theta^{CM}_{lep}$

1-prong:
- $p^{CM}_{1\text{-prong}}$
- $p^T_{1\text{-prong}}$
- $\theta^{CM}_{1\text{-prong}}$

ϕ meson:
- $E_\phi$
- $p^T_\phi$
- $M_\phi$

Neutrals:
- signal γ multiplicity
- tag γ multiplicity
- signal $\pi^0$ multiplicity
- tag $\pi^0$ multiplicity

Vertexing:
- ϕ vertex $\chi^2$
- τ vertex $\chi^2$

Event based:
- $E^{CM}_{vis}$
- thrust
- 1st/2nd/3rd $p^{T,CM}_{3\text{-prong}}$

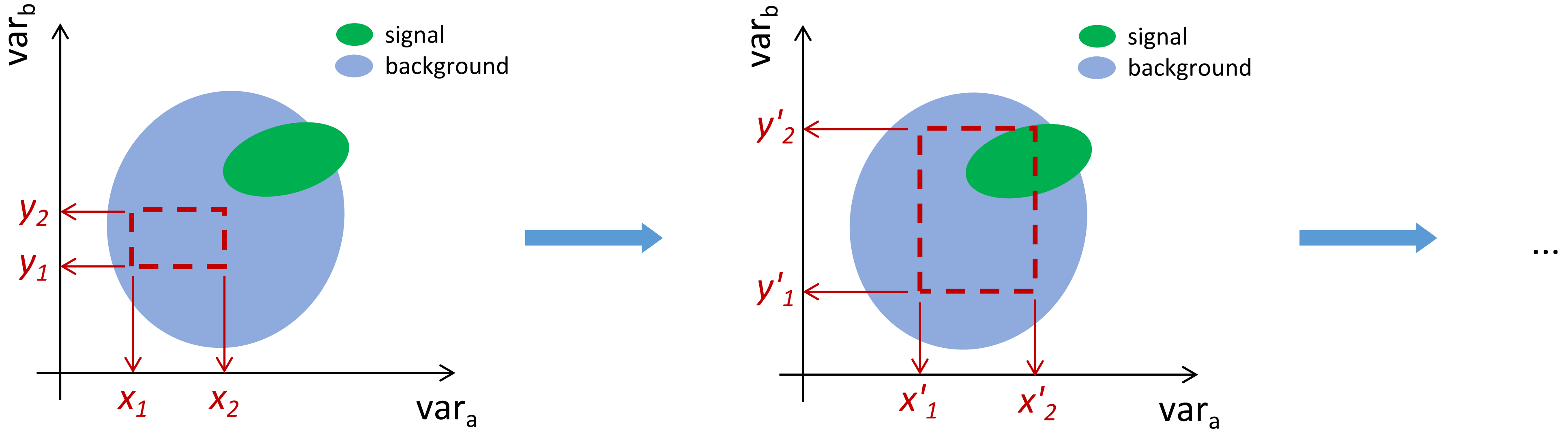
Missing:
- $p^T_{miss}$
- $\theta_{miss}$
- $M^2_{miss}$
- $\cos\theta^{CM}_{tag\text{-}miss}$
- $\cos\theta_{lep\text{-}miss}$

**green: variables used in the scan algorithm.*

**black+green: variables used in the BDT.*

# Cut-based (scan) algorithm

Using only **4 pairs** of variables (to reduce computation time).
For each pair of variables $var_a - var_b$, 2D window cuts (red dashed rectangles) of all possible sizes and positions are tested.



The signal and background yields of each window cut are collected to compute the corresponding Punzi F.O.M.s.

The process is repeated consecutively for each pair of variables (after applying best previous cuts),
and for each permutation of the pairs' order.

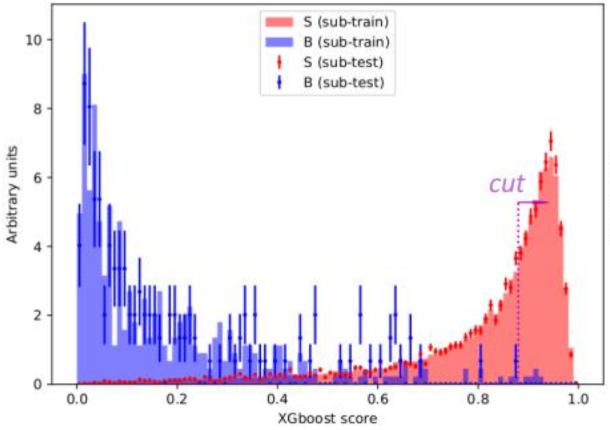
# BDT algorithm

- Using the **XGBoost** library in Python.

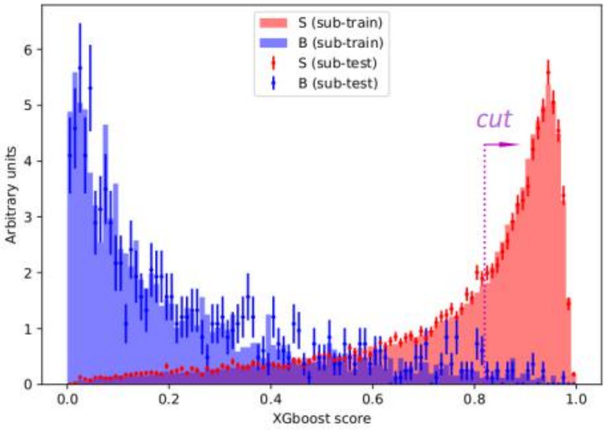
- The BDT uses the train sample, which is divided into sub-train and sub-test samples equivalent to 3 and 1 ab$^{-1}$, respectively. The evaluation metric for the classification is the logarithmic loss function.

- 4 parameters that are intended to help against overfitting are optimised in order to give the **lowest background efficiency** in the sub-test sample:
  a) '***n_estimators***': Number of boosting rounds.
  b) '***max_depth***': Maximum tree depth for base learners.
  c) '***min_child_weight***': Minimum sum of instance weight needed in a child.
  d) '***gamma***': Minimum loss reduction required to make a further partition on a leaf node of the tree.

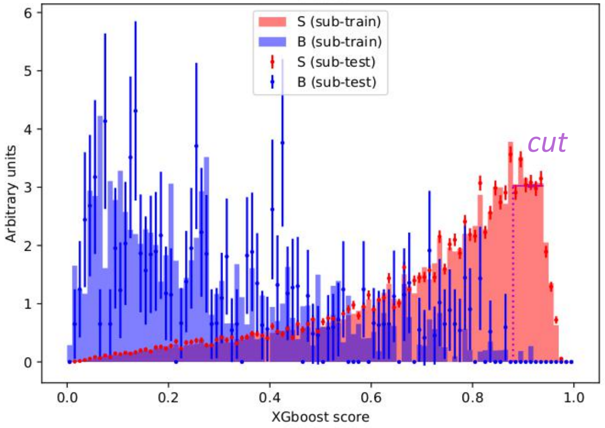
Electron mode - leptonic tag



Electron mode - hadronic tag



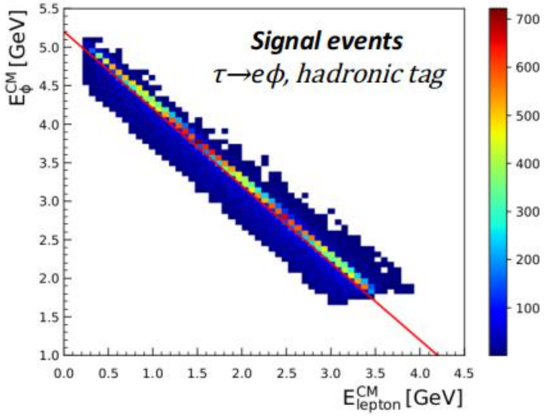
Muon mode

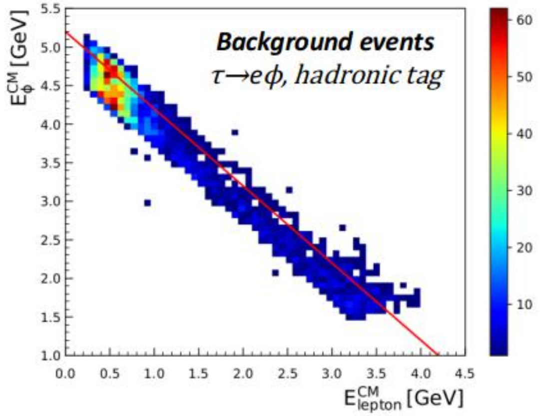


# Further reduction of remaining backgrounds

A lot of remaining background events after selection originate from misidentification of tracks (mainly πππ or KKK) or combinatorics (eKK/μKK events but not true signal events).

→ **2D cut on $E^{CM}_{\Phi}$ vs $E^{CM}_{lep}$**: '$E^{CM}_{\Phi} > -1*E^{CM}_{lep} + 5.2$', reduces background by a factor of ~ 2.





## τ→eϕ: remaining background

| taupair | Number of events (over 14) |
|---|---|
| πππ | 10 |
| Kππ | 1 |
| KKπ | 3 |
| eeπ | 0 |
| Other | 0 |

| qqbar | Number of events (over 57) |
|---|---|
| Kππ | 1 |
| KKπ | 4 |
| KKK | 34 |
| eKK | 10 |
| Other | 8 |

***before $E^{CM}_{\Phi}$-$E^{CM}_{lep}$ cut***

| taupair | Number of events (over 3) |
|---|---|
| πππ | 2 |
| Kππ | 0 |
| KKπ | 1 |
| eeπ | 0 |
| Other | 0 |

| qqbar | Number of events (over 23) |
|---|---|
| Kππ | 0 |
| KKπ | 0 |
| KKK | 22 |
| eKK | 0 |
| Other | 1 |

***after $E^{CM}_{\Phi}$-$E^{CM}_{lep}$ cut***

## τ→μϕ: remaining background

| taupair | Number of events (over 2) |
|---|---|
| πππ | 2 |
| KKπ | 0 |
| Other | 0 |

| qqbar | Number of events (over 22) |
|---|---|
| KKπ | 1 |
| KKK | 17 |
| μKK | 2 |
| Other | 2 |

***before $E^{CM}_{\Phi}$-$E^{CM}_{lep}$ cut***

| taupair | Number of events (over 2) |
|---|---|
| πππ | 2 |
| KKπ | 0 |
| Other | 0 |

| qqbar | Number of events (over 15) |
|---|---|
| KKπ | 0 |
| KKK | 12 |
| μKK | 2 |
| Other | 1 |

***after $E^{CM}_{\Phi}$-$E^{CM}_{lep}$ cut***

# Summary of the selection's results

In the **test** sample, comparing efficiencies, remaining background yields and sensitivities at **1 ab$^{-1}$** for both selections (20 and 3σ signal regions) and Belle's results (3σ SR only, 854 fb$^{-1}$, *https://arxiv.org/abs/1101.0755v5*).

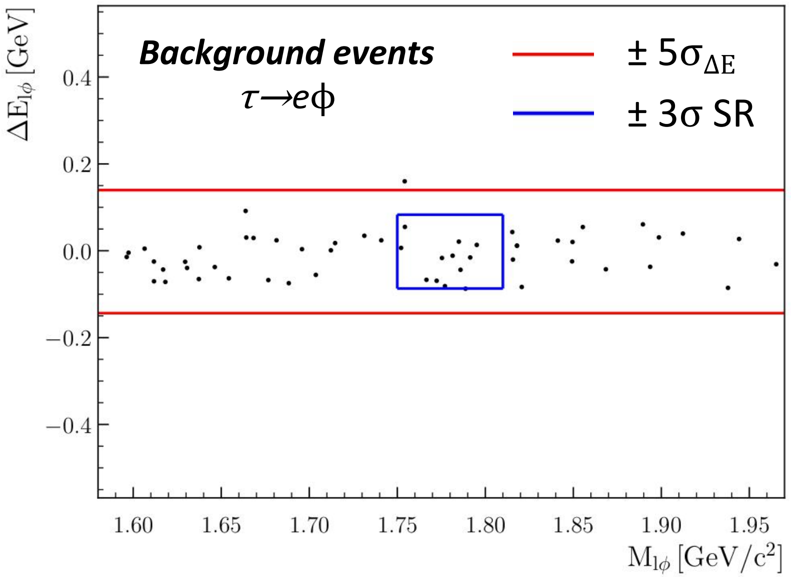
| **20σ SR** | | $\tau\to e\phi$ | | | $\tau\to\mu\phi$ | | |
|---|---|---|---|---|---|---|---|
| | | $\varepsilon_{sig}$ (%) | $N_{BG}$ (@ 1 ab$^{-1}$) | F.O.M. | $\varepsilon_{sig}$ (%) | $N_{BG}$ (@ 1 ab$^{-1}$) | F.O.M. |
| ***Belle II*** (MC) | Scan + BDT | 3.01 | 1 | 0.0120 | 1.05 | 0 | 0.0070 |
| | Cut-based | 3.62 | 11 | 0.0075 | 5.77 | 25 | 0.0089 |

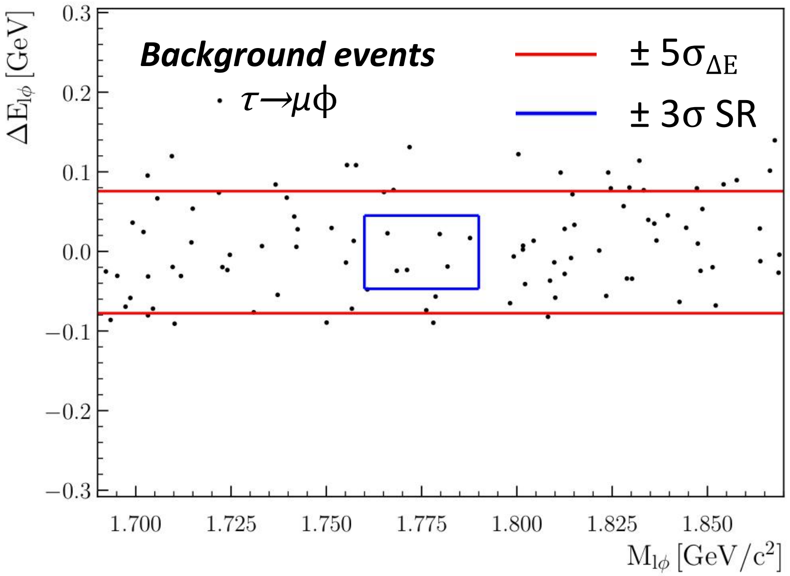
| **3σ SR** | | $\tau\to e\phi$ | | | $\tau\to\mu\phi$ | | |
|---|---|---|---|---|---|---|---|
| | | $\varepsilon_{sig}$ (%) | $N_{BG}$ (@ 1 ab$^{-1}$) | F.O.M. | $\varepsilon_{sig}$ (%) | $N_{BG}$ (@ 1 ab$^{-1}$) | F.O.M. |
| ***Belle*** (data) | | 4.18 | 0.55 | 0.0186 | 3.21 | 0.07 | 0.0182 |
| ***Belle II*** (MC) | Scan + BDT | 2.91 | 0 | 0.0194 | 0.98 | 0 | 0.0065 |
| | Cut-based | 3.49 | 1 | 0.0139 | 5.28 | 2 | 0.0181 |

- 20σ SR: Scan+BDT more beneficial than cut-based in electronic mode, while the opposite in muonic mode.
- 3σ SR: Results sensitive to fluctuations, background yields not yet comparable between Belle (fit) and Belle II.

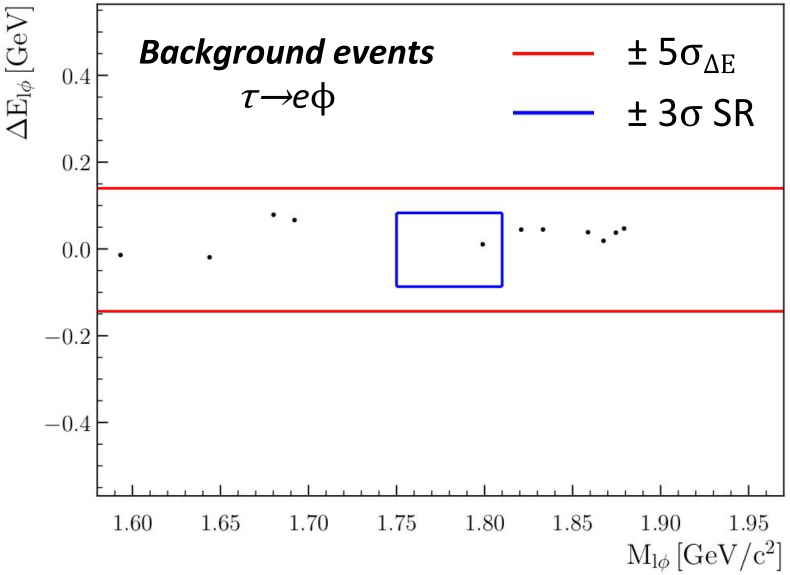
# Background estimation strategy after selection

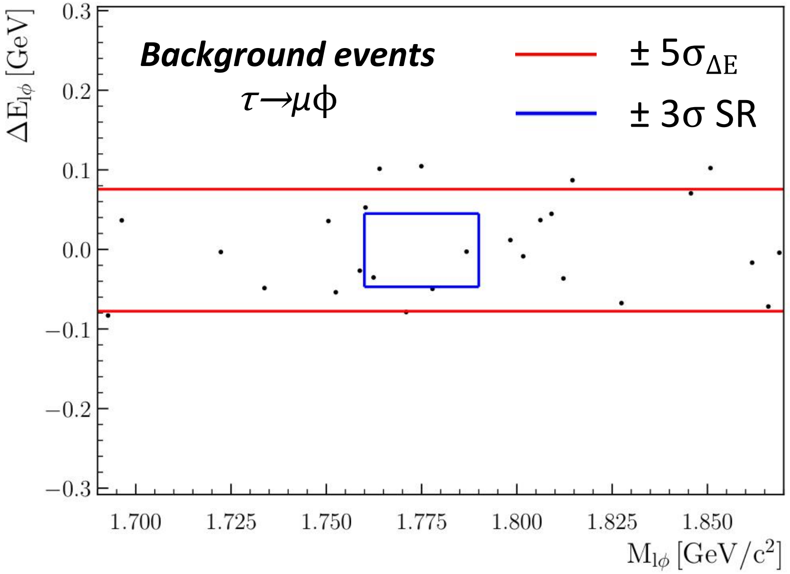
Train sample, 20σ SR





Test sample, 20σ SR





Selection applied here: cut-based

Following Belle's study:

- Blinding the signal region (3σ), here in blue.
- Constraining the $\Delta E_{l\Phi}$ range to ±5$\sigma_{\Delta E}$ (red).
- Fitting the $M_{l\Phi}$ background distribution and interpolating to the signal region.

Remaining background seems to be homogeneously distributed in the ±5$\sigma_{\Delta E}$ range according to the train sample.

# Data-MC comparison: τ→3πν control channel

**Controlling data and MC agreement**

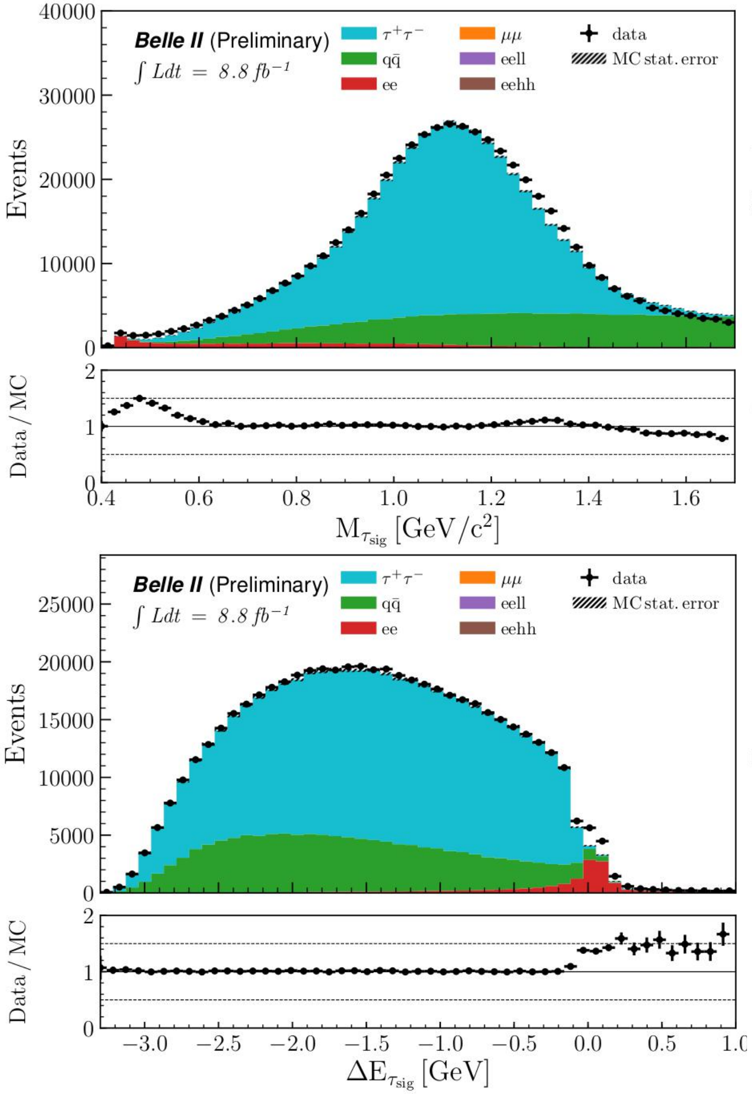
*Reconstructing:*

**τ→3πν**

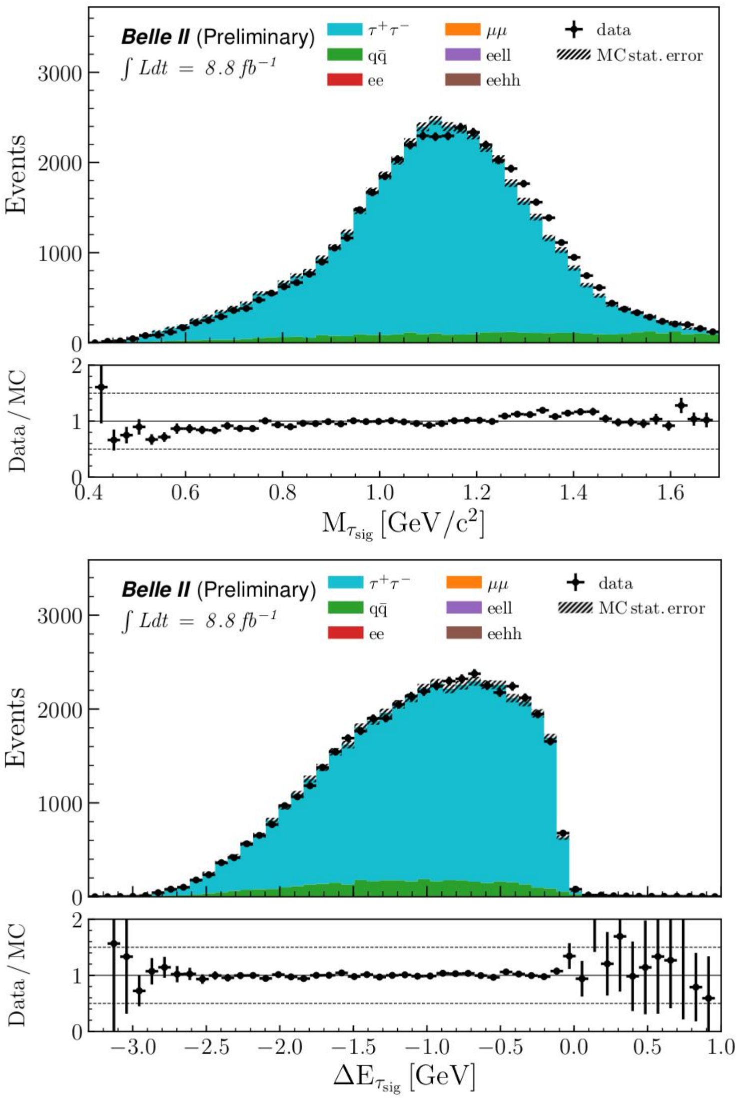
*on data (**8.8 fb$^{-1}$**, 2019)*

*and simulation ($\tau^+\tau^-$ + qqbar + low multiplicity)*

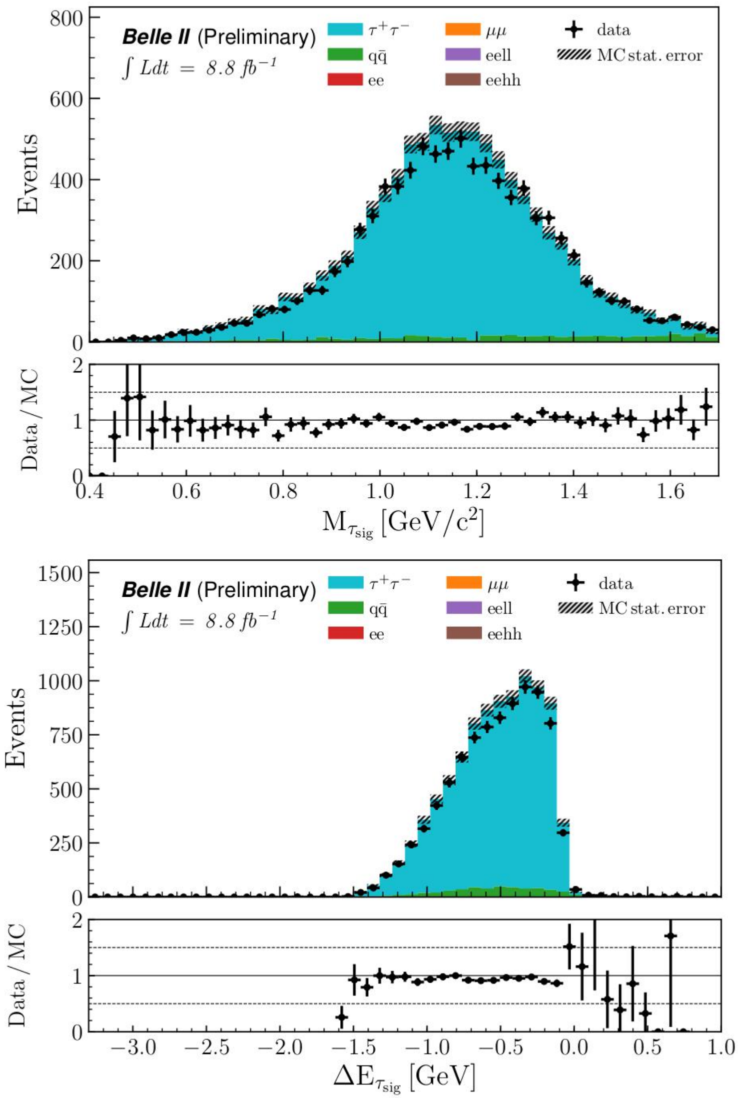
***Before any selection***



***After part of e-mode selection***



***After part of μ-mode selection***



# Data-MC comparison: $\tau \to \pi K K \nu$ control channel

**Controlling data and MC agreement**

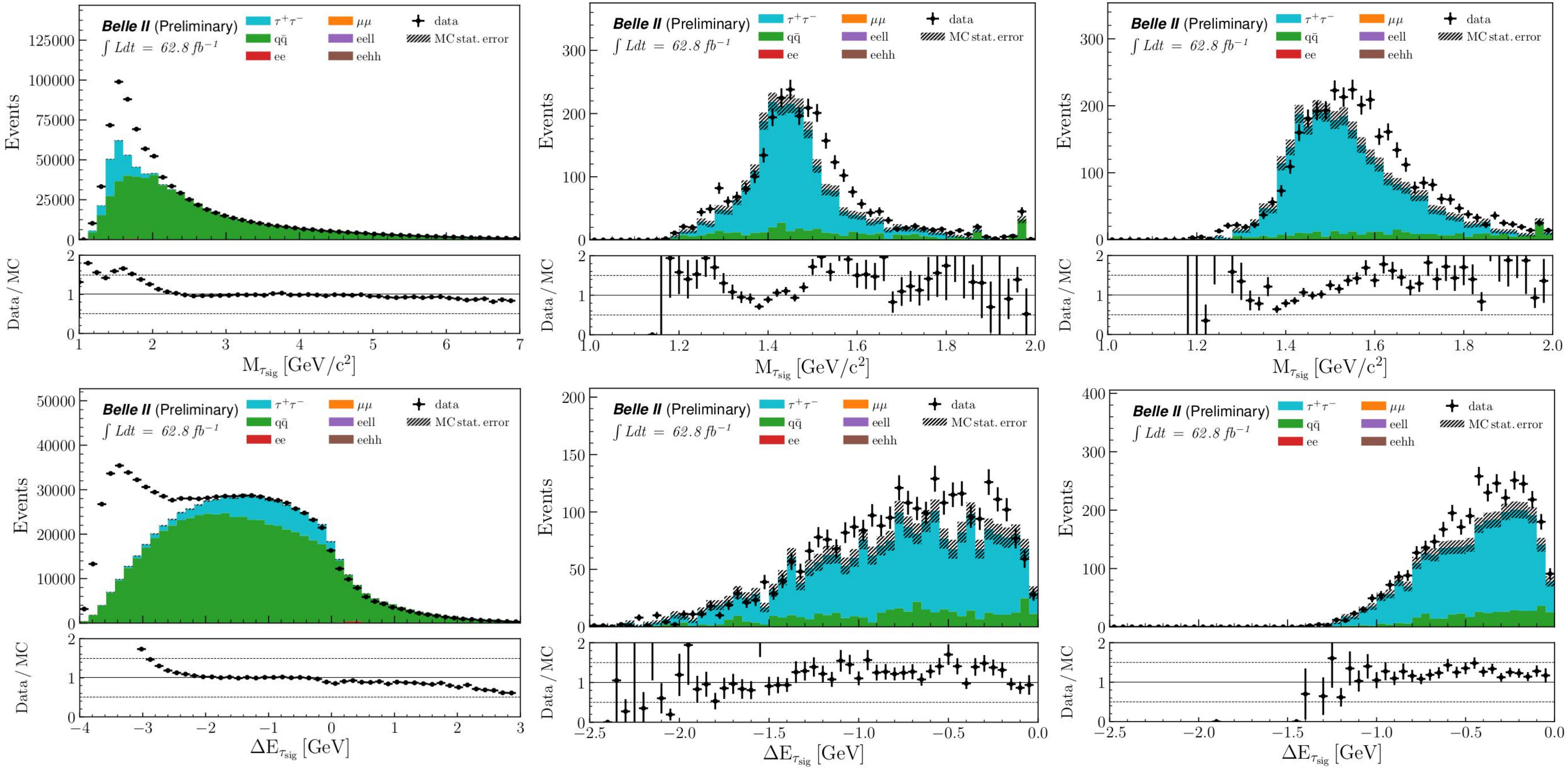
*Reconstructing:*

**$\tau \to \pi K K \nu$ ($\pi \phi \nu$)**

*on data (**62.8 fb$^{-1}$**, 2019 + 1st semester 2020)*

*and simulation ($\tau^+\tau^-$ + qqbar + low multiplicity)*

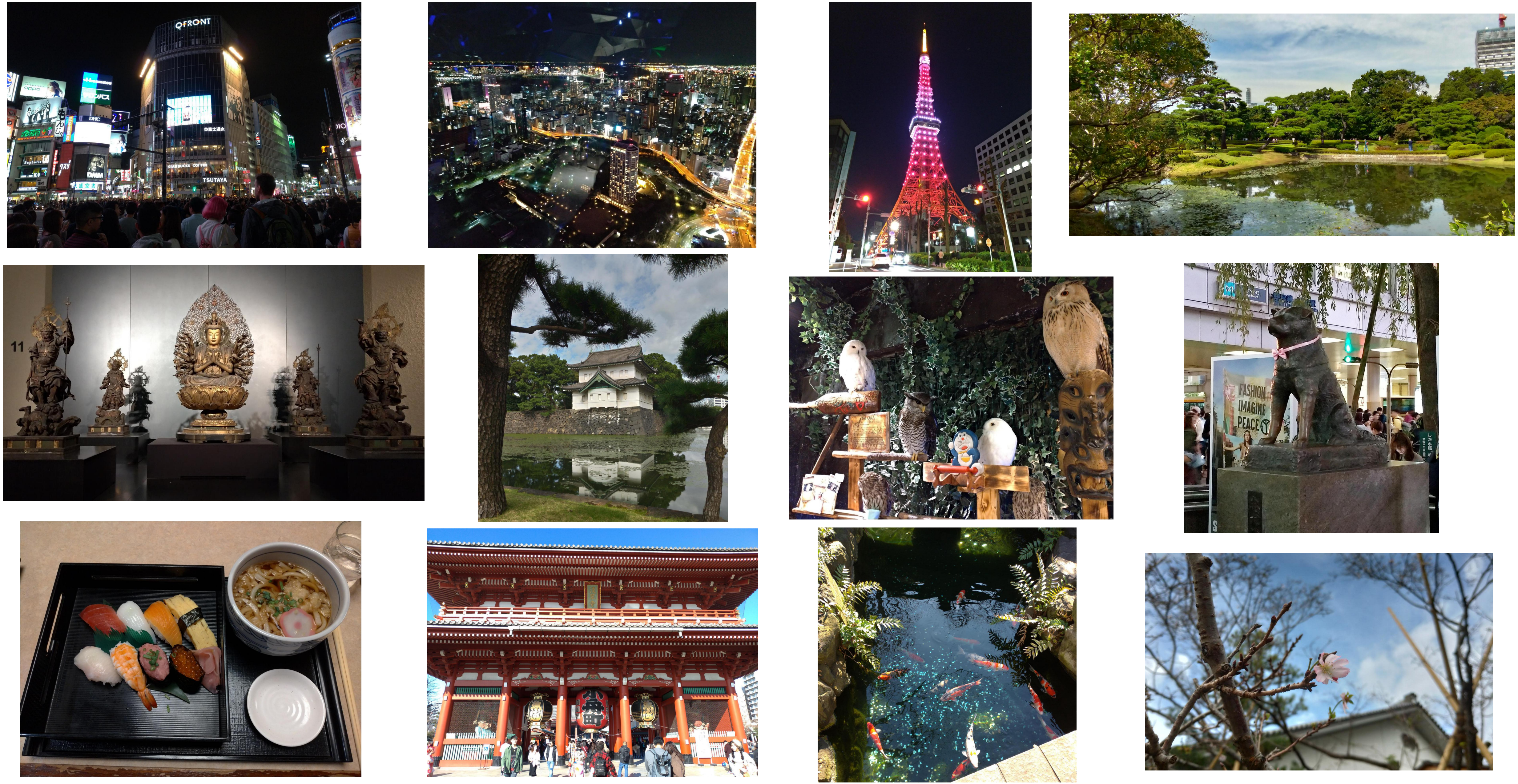
***Before any selection*** ***After part of e-mode selection*** ***After part of μ-mode selection***



# Summary and prospects

- The standard model, although quite effective for describing interactions between particles, doesn't explain all the physical phenomena we observe, hence the need for new physics models.
- Some of those models imply lepton flavour violation in tau or muon decays, for example **$\tau \to l\phi$**. We study this channel at the Belle II experiment, among others.
- After devising a background suppression strategy that involves cut-based selections and BDTs, we measure signal sensitivities on simulation that are close to the ones in data from the previous Belle experiment.
- Data-MC comparison using the $\tau \to 3\pi\nu$ control channel shows a good agreement, while we observe from the $\tau \to \pi K K \nu$ control channel that the simulation is lacking, with probably some corrections that also need to be applied.
- The study will be redone with an updated version of the simulation.
- Soon, we intend to proceed with the estimation of the expected limits on the branching fractions.

# Thank you for your attention!



# *Backup*

# Samples and reconstruction

## Samples

$\tau \to l\phi$ samples: MC13a BGx1 (500K events each)

- $\tau^- \to e^- \phi$, event type: 3420930002
- $\tau^+ \to e^+ \phi$, event type: 3420930003
- $\tau^- \to \mu^- \phi$, event type: 3420930008
- $\tau^+ \to \mu^+ \phi$, event type: 3420930009

Other samples: MC13a BGx1

- $\tau$-pair, qqbar: 5 $ab^{-1}$
- mumu, eeee, eemumu, eepp, eepipi, eeKK: 1 $ab^{-1}$
- ee: 100 $fb^{-1}$

## Track selections

Electron:

- $-3 < dz < 3$ cm
- $dr < 1$ cm
- $0.8 < E/p < 1.2$

Muon:

- $-3 < dz < 3$ cm
- $dr < 1$ cm
- $E/p < 0.6$
- muonID > 0.9

Pion:

- $-3 < dz < 3$ cm
- $dr < 1$ cm
- $E/p < 0.6$
- muonID ≤ 0.9

Kaon:

- $-3 < dz < 3$ cm
- $dr < 1$ cm
- thetaInCDCAcceptance
- nCDCHits > 20
- kaonID > 0.5

Photon:

- E > 0.02 GeV
- $-0.8660 < \cos\Theta < 0.9563$
- clusterNHits > 1.5
- not from $\pi^0$

## Event requirements

- Number of tracks in event = **4**.
- $\phi \to K^+K^-$ with $\mathbf{0.95 < M_\phi < 1.30}$ GeV.
- lepton/$\phi$ and 1-prong in **opposite hemispheres** w.r.t. thrust axis.
- correctBremsBelle: multiplePhotons=**True**, minEnergy=**0.02 GeV**, angleThreshold=**0.15 rad**

## Release

release-05-02-00

# Sensitivities (Scan+BDT)

## Electron mode

**Train** sample (4 ab$^{-1}$, **20σ** region):

- Signal efficiency:
  2.98 % ⟶ 23838 / ($10^6$*4/5)
- Remaining background:
  2 (τ-pair) + 23 (qqbar)
- F.O.M. (at 1 ab$^{-1}$): **0.0074 ± 0.0009**

**Test** sample (1 ab$^{-1}$, **20σ** region):

- Signal efficiency:
  3.01 % ⟶ 6021 / ($10^6$/5)
- Remaining background:
  1 (qqbar)
- F.O.M.: **0.00120 ± 0.0024**

**Test** sample (1 ab$^{-1}$, **3σ** region):

- Signal efficiency:
  2.91 % ⟶ 5818 / ($10^6$/5)
- Remaining background: 0
- F.O.M.: **0.0194 ± 0.0065**

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## Muon mode

**Train** sample (4 ab$^{-1}$, **20σ** region):

- Signal efficiency:
  1.07 % ⟶ 8552 / ($10^6$*4/5)
- Remaining background:
  1 (τ-pair) + 2 (qqbar)
- F.O.M. (at 1 ab$^{-1}$): **0.0045 ± 0.0010**

**Test** sample (1 ab$^{-1}$, **20σ** region):

- Signal efficiency:
  1.05 % ⟶ 2106 / ($10^6$/5)
- Remaining background: 0
- F.O.M.: **0.0070 ± 0.0023**

**Test** sample (1 ab$^{-1}$, **3σ** region):

- Signal efficiency:
  0.98 % ⟶ 1956 / ($10^6$/5)
- Remaining background: 0
- F.O.M.: **0.0065 ± 0.0022**

# Sensitivities (Cut-based)

**Electron mode**

**Train** sample (4 ab$^{-1}$, **20σ** region):
- Signal efficiency:
  3.63 % → 29054 / ($10^6$*4/5)
- Remaining background:
  5 (τ-pair) + 50 (qqbar)
- F.O.M. (at 1 ab$^{-1}$): **0.0070 ± 0.007**

**Test** sample (1 ab$^{-1}$, **20σ** region):
- Signal efficiency:
  3.62 % → 7230 / ($10^6$/5)
- Remaining background:
  3 (τ-pair) + 8 (qqbar)
- F.O.M.: **0.0075 ± 0.0008**

**Test** sample (1 ab$^{-1}$, **3σ** region):
- Signal efficiency:
  3.49 % → 6973 / ($10^6$/5)
- Remaining background:
  1 (qqbar)
- F.O.M.: **0.0139 ± 0.0028**

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**Muon mode**

**Train** sample (4 ab$^{-1}$, **20σ** region):
- Signal efficiency:
  5.72 % → 45782 / ($10^6$*4/5)
- Remaining background:
  13 (τ-pair) + 77 (qqbar)
- F.O.M. (at 1 ab$^{-1}$): **0.0092 ± 0.0007**

**Test** sample (1 ab$^{-1}$, **20σ** region):
- Signal efficiency:
  5.77 % → 11539 / ($10^6$/5)
- Remaining background:
  6 (τ-pair) + 19 (qqbar)
- F.O.M.: **0.0089 ± 0.0007**

**Test** sample (1 ab$^{-1}$, **3σ** region):
- Signal efficiency:
  5.28 % → 10558 / ($10^6$/5)
- Remaining background:
  1 (τ-pair) + 1 (qqbar)
- F.O.M.: **0.0181 ± 0.0031**