$\tau \to \ell$+hadrons decays at Belle II

Laura Zani*

On behalf of the Belle II collaboration

Topical workshop on LFV decays of the τ

Orsay, 2024.04.12

Istituto Nazionale di Fisica Nucleare
SEZIONE DI ROMA TRE

*laura.zani@roma3.infn.it

Outline

- Motivation, experimental challenges
  - Search for $\tau \to \ell V^0$ at Belle
  - Search for $\tau \to \ell \varphi$ at Belle II
  - Search for $\tau \to \ell K^0_S$ at Belle + Belle II and baryon and lepton number violation in $\tau \to \Lambda(\bar{\Lambda})\pi$ at Belle II
- Conclusion

Why τ decays?

τ pairs produced in the e^+e^- collisions are a unique laboratory to **test the standard model (SM)** through **precision** measurements and **search** for **non-SM physics**!

- $M_\tau = 1777.09$ MeV/c^2
  - → heavy enough to decay into final states with hadrons
  - → **search for non-SM physics**, possible enhancement due to mass-dependent couplings
- Lifetime: 290.17 fs
  - → not a long-lived particle
  - → **missing energy** due to neutrinos

The challenges

High precision measurements of the SM properties

- ***Control of systematic sources*** → excellent understanding of the experiment performance and background description necessary to improve results **mainly systematically limited**

↓

e.g. tau mass, lifetime, branching fractions measurement

< fractions of per mill level

World's **leading sensitivities** for direct searches

- ***Largest data sets*** → attain highest luminosity, collect (unique) data set suitable to study rare processes + new techniques to **increase** the signal **efficiency** while keeping background under control

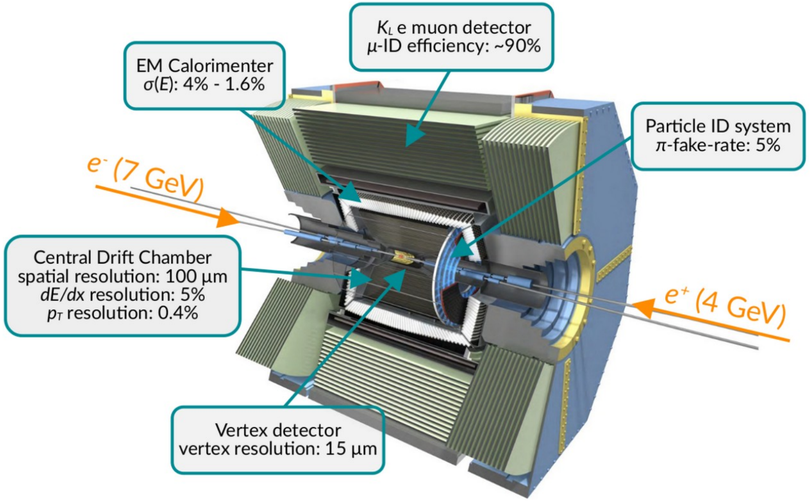
↓

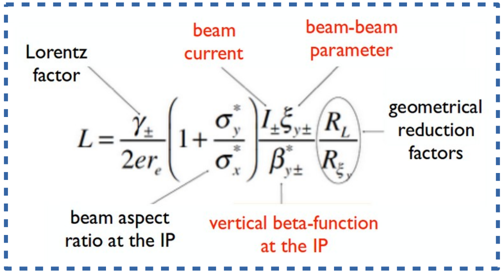
e.g. LFV decays, $\tau \to \ell\Phi$, $\tau \to \mu\mu\mu$, ...

< 10^{-8} level

Working at ~~B~~ tau factories

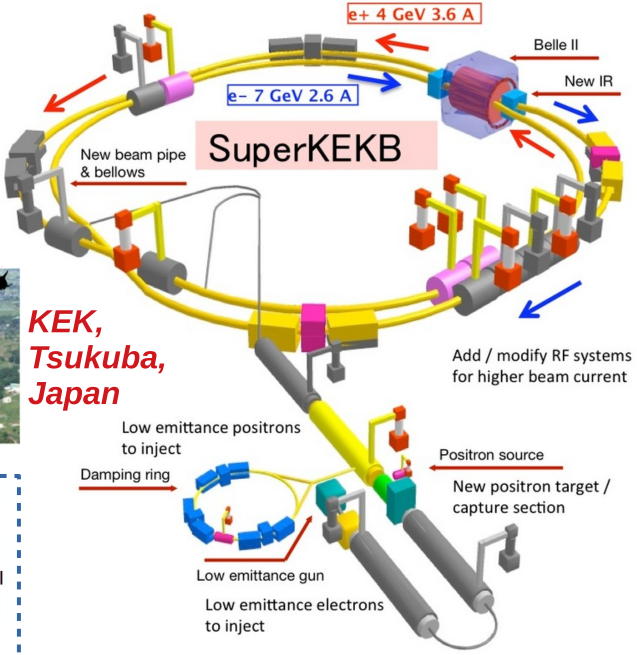
- **Clean environment** at asymmetric energy e^+e^- collider + ~ **hermetic detector:**
  - → at $\sqrt{s}$ = 10.58 GeV: $\sigma_{bb} \sim \sigma_{\tau\tau} \sim 1$ nb, B & **τ factory**
  - → known initial state + efficient reconstruction of **neutrals** (π^0, η), **recoiling system** and **missing energy**
  - → specific **low-multiplicity triggers** (previously not available at Belle)





$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}\left(\frac{R_L}{R_{\xi_y}}\right)$$

KEK, Tsukuba, Japan



- **GOAL:** 30 x KEKB peak luminosity, **L= 6 · 10^{35} $cm^{-2}s^{-1}$** *(nano-beam scheme technique*)*
- Collect 50 x Belle → 50 ab^{-1}

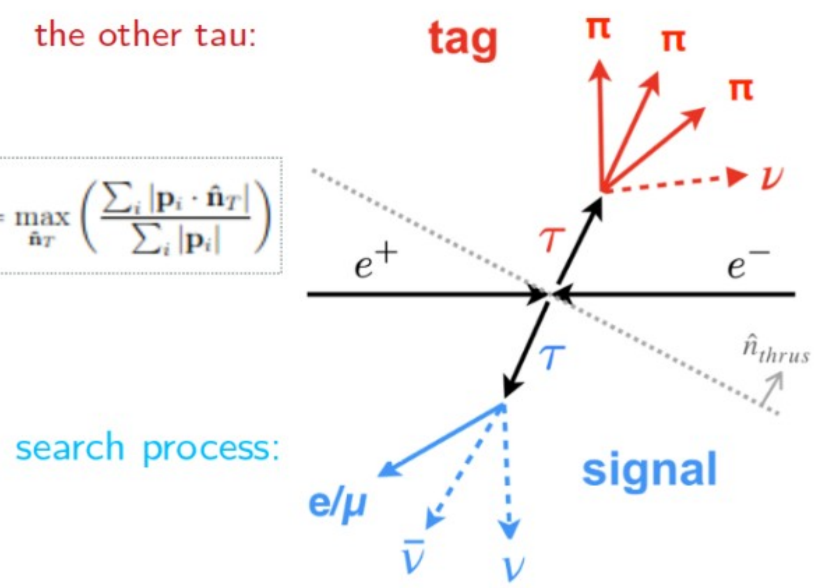
- **Accumulated 424 fb^{-1}** (~ Babar, ~ half of Belle) and unique energy scan samples during run 1
- Resumed data taking in February 2024: **run 2 started**!

*https://arxiv.org/abs/0709.0451

Tau topologies and signatures

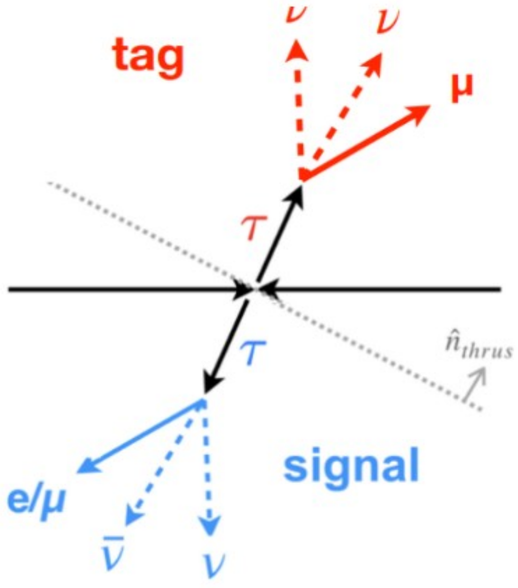
- Tau pairs in $\mathbf{e^+e^- \rightarrow \tau^+\tau^-}$ events produced back-to-back in CM system
- Possible to separate them in **two opposite hemispheres** defined by the plane perpendicular to the **thrust axis** $\tilde{\mathbf{n}}_\mathbf{T}$

$$T = \max_{\hat{\mathbf{n}}_T} \left(\frac{\sum_i |\mathbf{p}_i \cdot \hat{\mathbf{n}}_T|}{\sum_i |\mathbf{p}_i|} \right)$$



(1x3)-prong Vs
(1x1)-prong

Reconstruct a **specific topology** to suppress background, mainly from $\mathrm{e^+e^-} \rightarrow \mathbf{q\bar{q}}$



Beyond SM searches

Lepton flavor violation

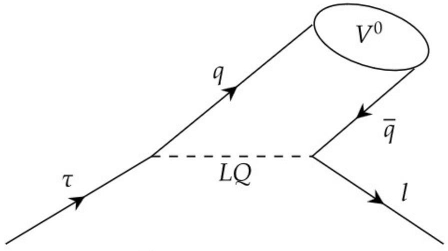
- ***Charged Lepton Flavor Violation (LFV)*** via SM weak interaction charged currents and neutrino mixing $< O(10^{-50}) \rightarrow$ below any experiment sensitivity

  $\rightarrow$ **observation of LFV decays is *per se* a proof of non-SM physics!**

- Hints of Lepton Flavor Universality (LFU) violation and deviation from SM predictions in rare B decays (***flavor anomalies***):
  - $b \rightarrow c l \nu$ (τ Vs light leptons), $b \rightarrow sll$

New interaction that violates flavor (Z' boson, leptoquark)

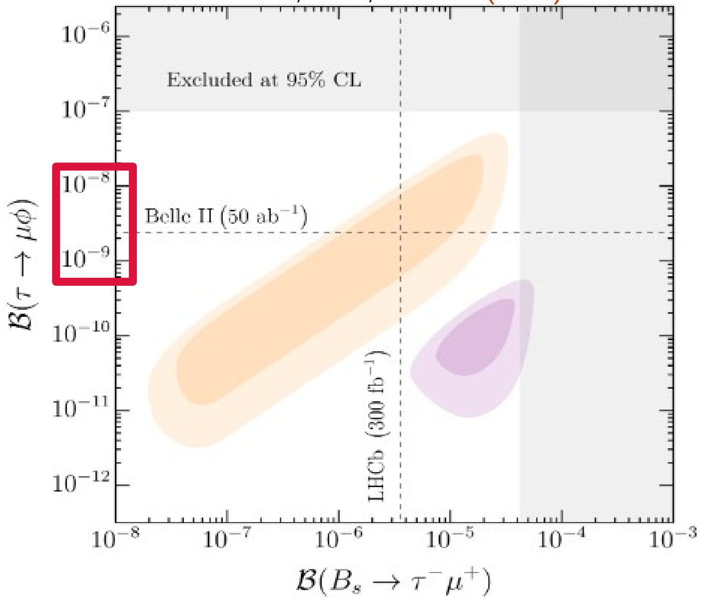
$\rightarrow$ ***Special role of the third family***



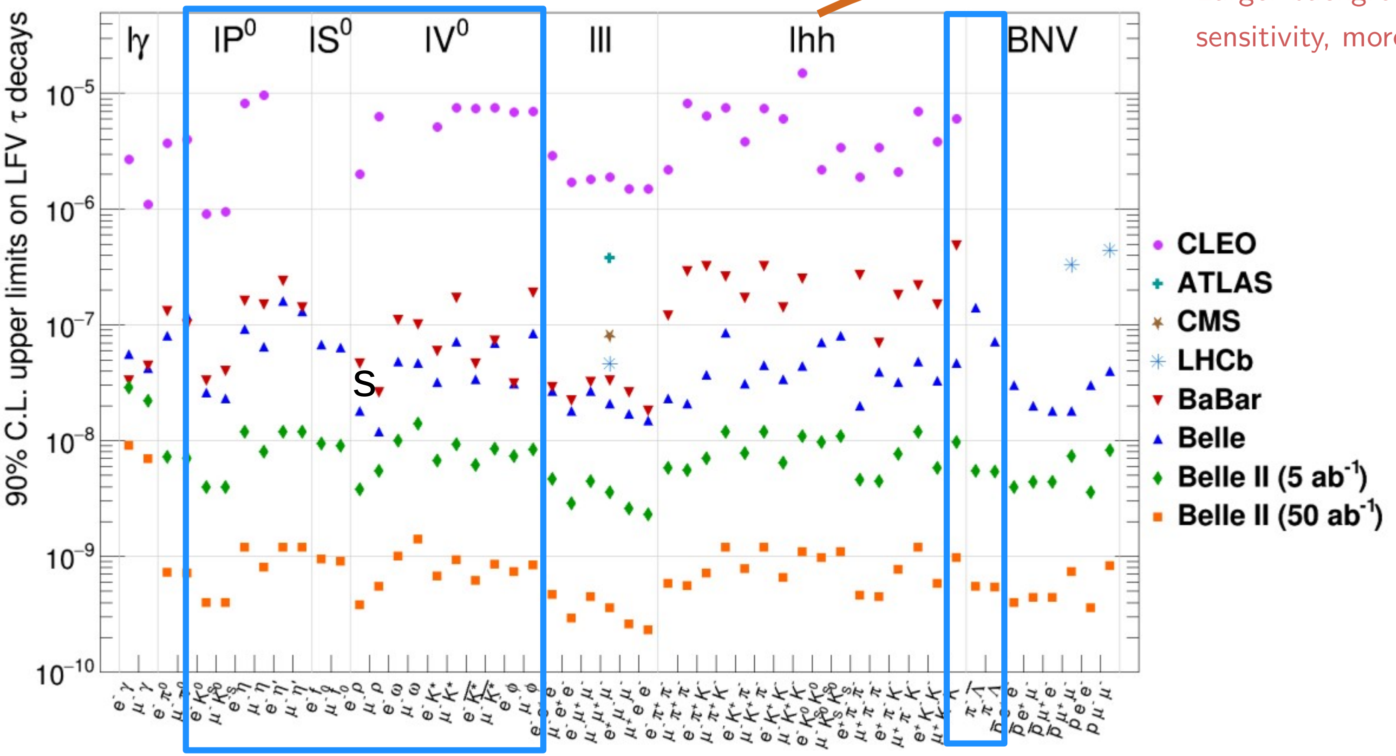
$\tau \rightarrow l\, V^0$ *via leptoquark interaction*

Simplified U_1 model (with $\beta^{b\tau}_R = 0$)

C. Cornella, et al., JHEP08 (2021) 050



LFV sensitivities



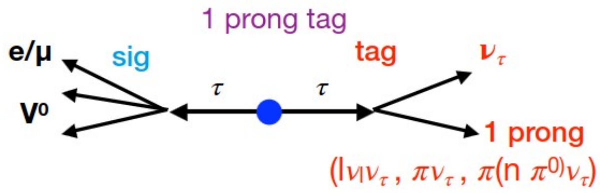
Larger background degrades sensitivity, more challenging

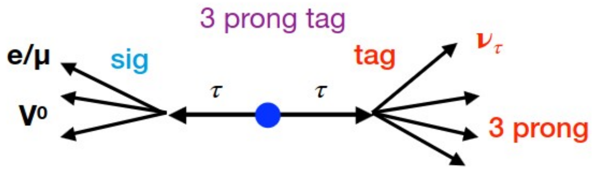
- Belle II expected to provide world's leading limits on many channels

JHEP06(2023)118

Search for $\tau \rightarrow \ell V^0$ at Belle:

strategy

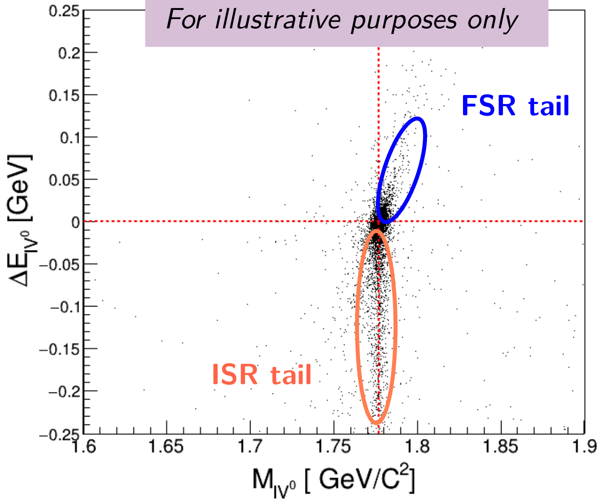




Full Belle data set of 980 $fb^{-1} \rightarrow$ 905M tau pairs

- **Signal side**: reconstruct lepton and $V^0 \in [\rho, \phi, \omega, K^*]$ from invariant mass windows around M_{V0}
  - Use particle identification (PID) variables, likelihood ratios to identify(veto) leptons and hadrons
- **Tag side**: reconstruct 1 or 3-prong decays
- Exploit kinematics of the signal as *neutrinoless* decays
  - M_{lV0} expected to peak at known tau mass
  - $\Delta E_{lV0} = E^*_{sig} - \sqrt{s}/2$ peaks at 0 $\rightarrow$ up to initial/final state radiation (ISR, FSR) effects
- Count in elliptical signal region (SR) in ΔE_{lV0} and M_{lV0} plane

For illustrative purposes only

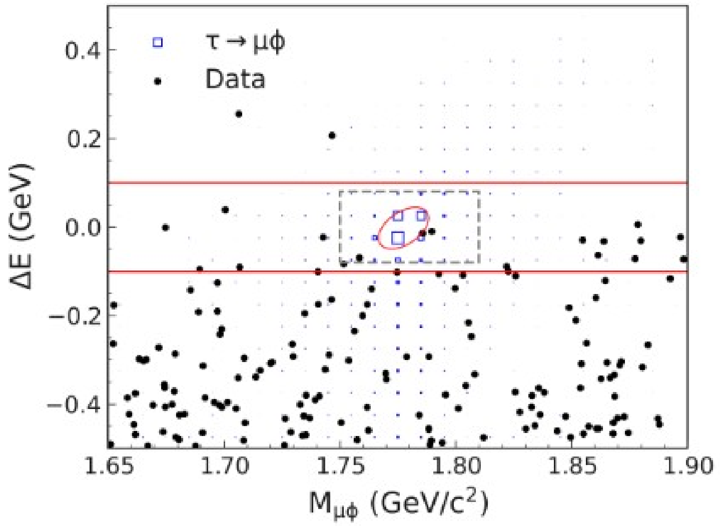


JHEP06(2023)118

Search for $\tau \to \ell V^0$ at Belle:

background suppression and yields extraction

- Backgrounds mimic the presence of neutrinos in the tag side (detector inefficiencies), wrong PID in the signal side $\to$ exploit topology and tag kinematics to reject low-multiplicity: $e^+e^- \to e^+e^-(\gamma)$, $e^+e^- \to \mu\mu(\gamma)$, $e^+e^- \to e^+e^- ll$
- Further suppress $\tau \to 3\pi\nu$ and $ee \to q\bar{q}$ with BDT
  - use **missing momentum** and **V⁰** properties, and **event tag** categorical variables
- Estimate expected background in SR from **sideband interpolation**
  - Model the shape from hadron enhanced data samples scaled to sideband
  - Integrate over the elliptical SR area



(b) $\tau \to \mu\phi$

$\to$ **Count number of observed events in data inside SR**

- Dominant systematic uncertainties from tracking and PID (negligible impact compared to the **statistical** one)

Search for $\tau \to \ell V^0$ at Belle:

results

- No significant excess observed → set ULs at 90% CL

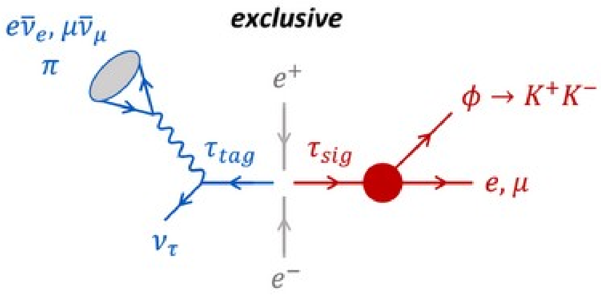
Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	$\mathcal{B}_{obs}$ ($\times 10^{-8}$)
$\tau^\pm \to \mu^\pm \rho^0$	7.78	0.95±0.20(stat.) ±0.15(syst.)	4.6	0	< 1.7
$\tau^\pm \to e^\pm \rho^0$	8.49	0.80±0.27(stat.) ±0.04(syst.)	4.4	1	< 2.2
$\tau^\pm \to \mu^\pm \phi$	5.59	0.47±0.15(stat.) ±0.05(syst.)	4.8	0	< 2.3
$\tau^\pm \to e^\pm \phi$	6.45	0.38±0.21(stat.) ±0.00(syst.)	4.5	0	< 2.0
$\tau^\pm \to \mu^\pm \omega$	3.27	0.32±0.23(stat.) ±0.19(syst.)	4.8	0	< 3.9
$\tau^\pm \to e^\pm \omega$	5.41	0.74±0.43(stat.) ±0.06(syst.)	4.5	0	< 2.4
$\tau^\pm \to \mu^\pm K^{*0}$	4.52	0.84±0.25(stat.) ±0.31(syst.)	4.3	0	< 2.9
$\tau^\pm \to e^\pm K^{*0}$	6.94	0.54±0.21(stat.) ±0.16(syst.)	4.1	0	< 1.9
$\tau^\pm \to \mu^\pm \overline{K}^{*0}$	4.58	0.58±0.17(stat.) ±0.12(syst.)	4.3	1	< 4.3
$\tau^\pm \to e^\pm \overline{K}^{*0}$	7.45	0.25±0.11(stat.) ±0.02(syst.)	4.1	0	< 1.7

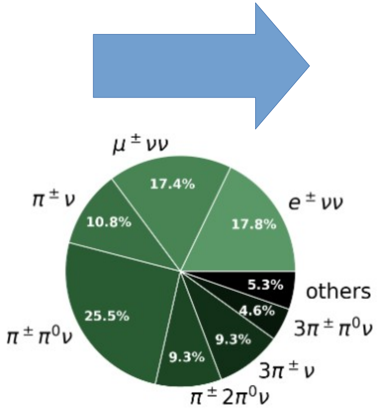
Average 30% improvement from both increased statistics (+ 124 fb^{-1}) and improved analysis (+ 9% efficiency)

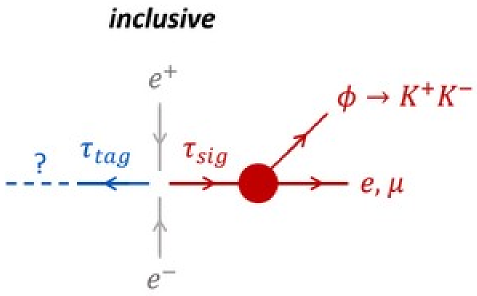
PubConf arXiv:2305.04759

$\tau \to \ell\Phi$ at Belle II

untagged approach







→ **Increase signal efficiency:** reconstruct explicitly only **signal side**, no requirement on the **tag side** (**untagged inclusive reconstruction**)

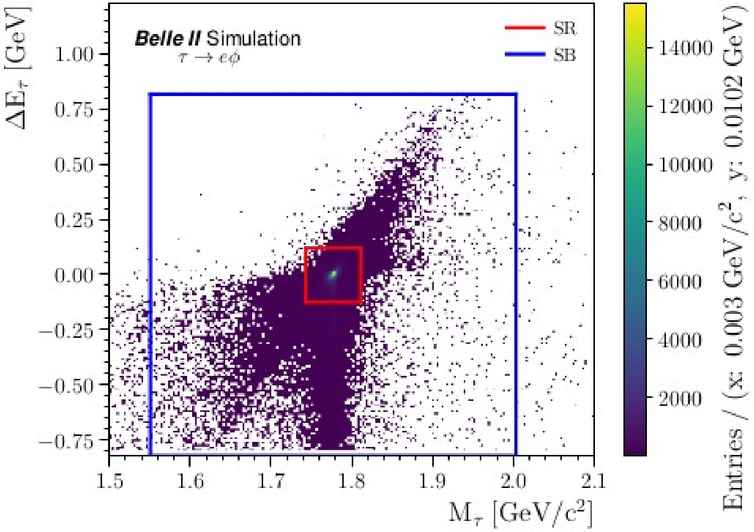
- Exploit signal and event features in **BDT classifiers** to suppress background

- First application for $\tau \to l\Phi$ search on 190 fb^{-1}

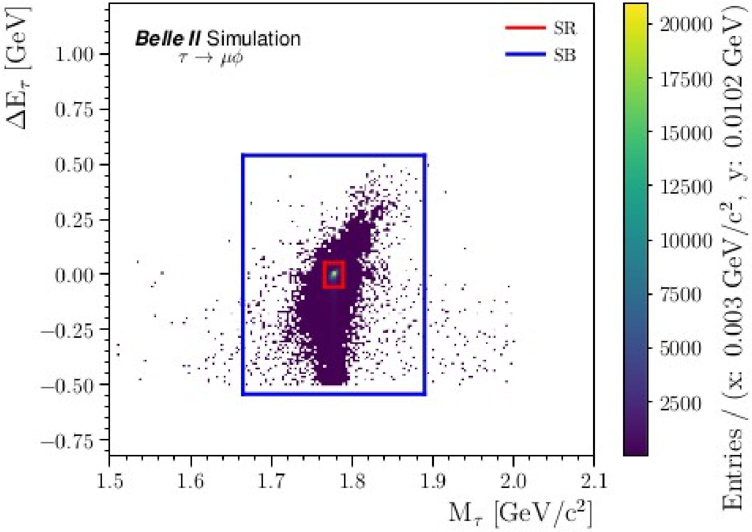
$\tau \to \ell\Phi$: strategy

- Signal candidate: two oppositely charged **kaon** candidates with invariant mass at M_Φ and a **lepton** (electron or muon)
  - use of kaonID and muonID as likelihood ratios of different particle hypothesis; BDT-based electronID (uses ECL and CDC information)
- Define **analysis** and **signal** box regions in the the (M_τ , ΔE_τ) plane, in units of fitted signal resolutions modeled on signal simulations.

Electron mode: $\tau \to e\Phi$



Muon mode: $\tau \to \mu\Phi$



$\tau \to \ell\Phi$: background suppression

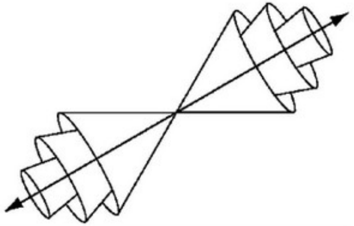
- Reject radiative dilepton (Bhabha) with **pre-selections based on event geometry**
- Exploit rest of event (ROE), missing momentum and event shape, signal side kinematics in a **BDT classfier** (XGBoost, overtraining checked with log loss function)

$$R_2 = H_2/H_0,\ H_l = \sum_{i,j} \frac{|p_i| \times |p_j|}{s} P_l(\cos\phi_{ij})$$

i,j: final state particles.
ϕ_{ij}: angle between them.
P_l: Legendre polynomial of degree l.

- Most discriminating variables related to:
  - **Rest Of Event (ROE)** → combines all non-signal tracks and remaining ECL clusters
  - **Missing momentum** → good accuracy from Belle II hermetic detector's configuration
  - **Topology** → thrust, reduced Fox-Wolfram moment R2 and CLEO cones (w.r.t. thrust or beam axis)
  - **Ranked transverse momenta** of signal side tracks
  - **Charged and neutral** particles multiplicities.

CLEO cones

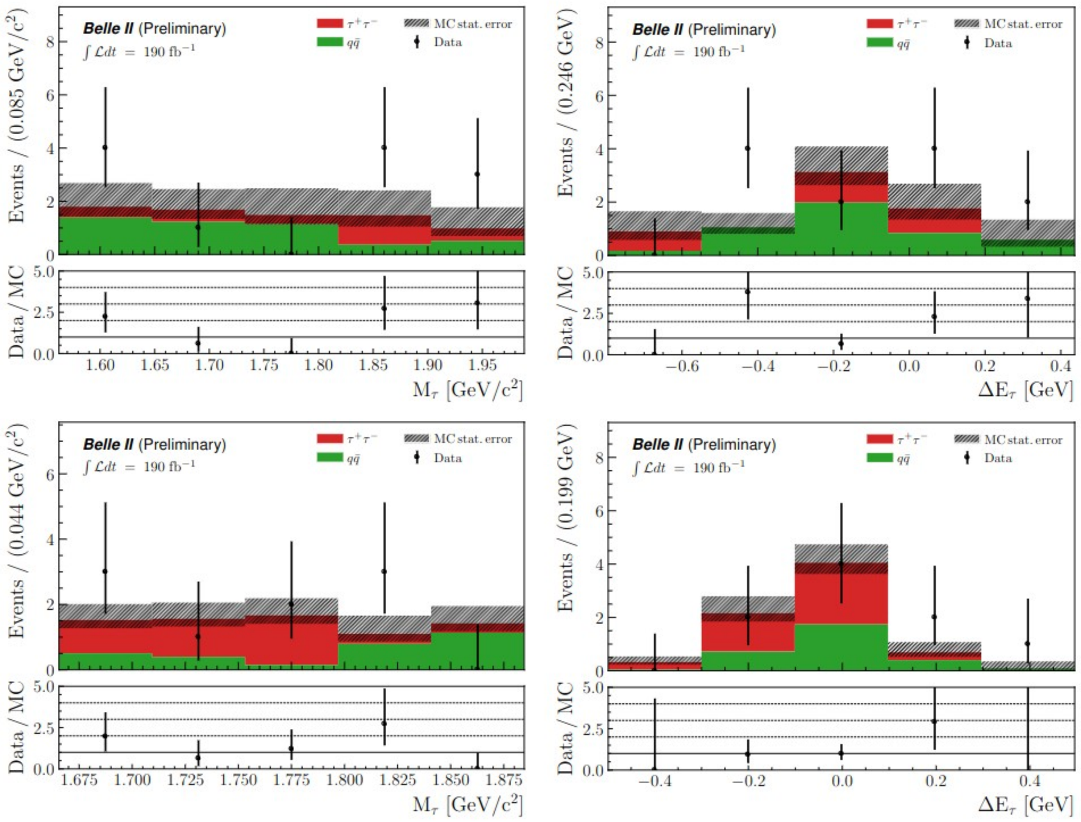


D. M. Asner et al., *Search for Exclusive Charmless Hadronic B Decays*, Phys. Rev. D 53 1039, https://arxiv.org/abs/hep-ex/9508004v1

- **Final signal efficiencies: $\varepsilon_{e\Phi}$ = 6.1 %, $\varepsilon_{\mu\Phi}$ =6.5% → 16% improvement wrt tagged approach**

$\tau \to \ell\Phi$: data validation

- Remaining backgrounds due to **misidentification of hadrons**
  - Electron channel: KKK, Kππ, eππ, eeπ
  - Muon channel: KKK, KKπ, Kππ, πππ, μππ
- Assess systematic uncertainties from data-MC agreement in control samples
  - Largest contribution due to simulation mis-modeling of some selection variables, but negligible compare to **statistical** uncertainty

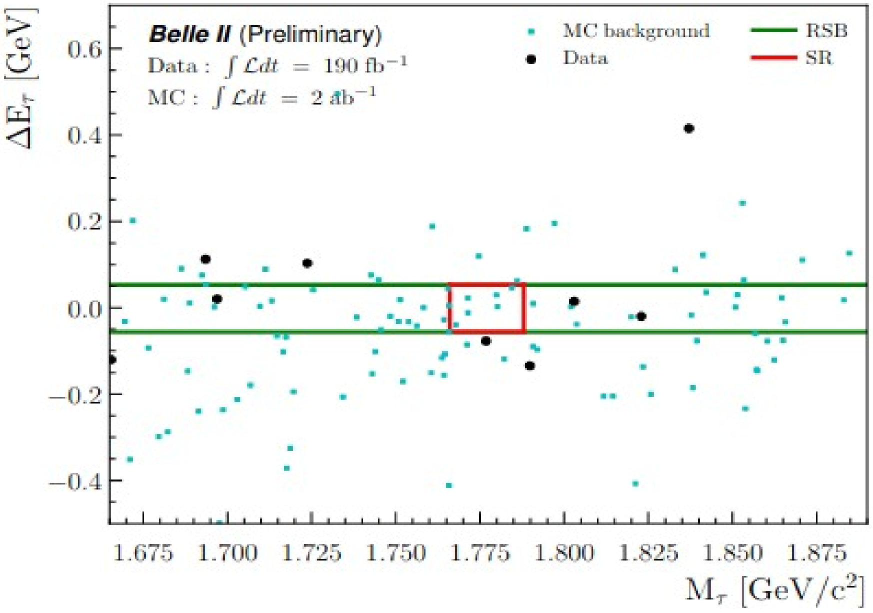


$\tau \to \ell\Phi$: yields extraction

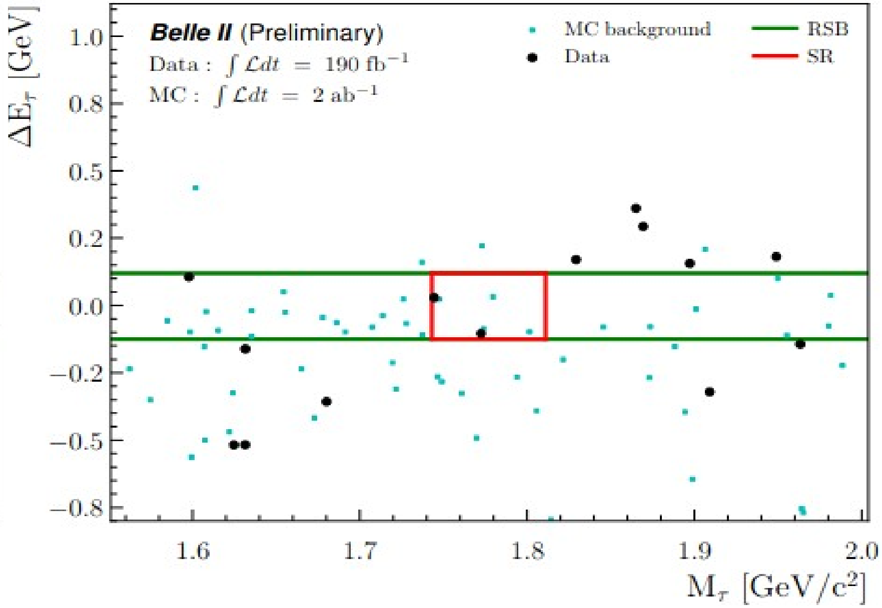
- Poisson counting experiment approach in **signal regions** in M_τ and $\Delta E_\tau = E^*_{sig} - \sqrt{s}/2$ plane
  - $\to$ expected background N_{exp} evaluated from data **reduced sidebands** with scaling from simulation

Result	Region	Mode	
		$e\phi$	$\mu\phi$
N_{exp}	SR	$0.23^{+0.55}_{-0.21}$ stat	$0.36^{+0.39}_{-0.23}$ stat
N_{obs}	SR	$2.0^{+2.6}_{-1.3}$ stat	$0.0^{+1.8}_{-0.0}$ stat

Muon mode: $\tau \to \mu\Phi$



Electron mode: $\tau \to e\Phi$



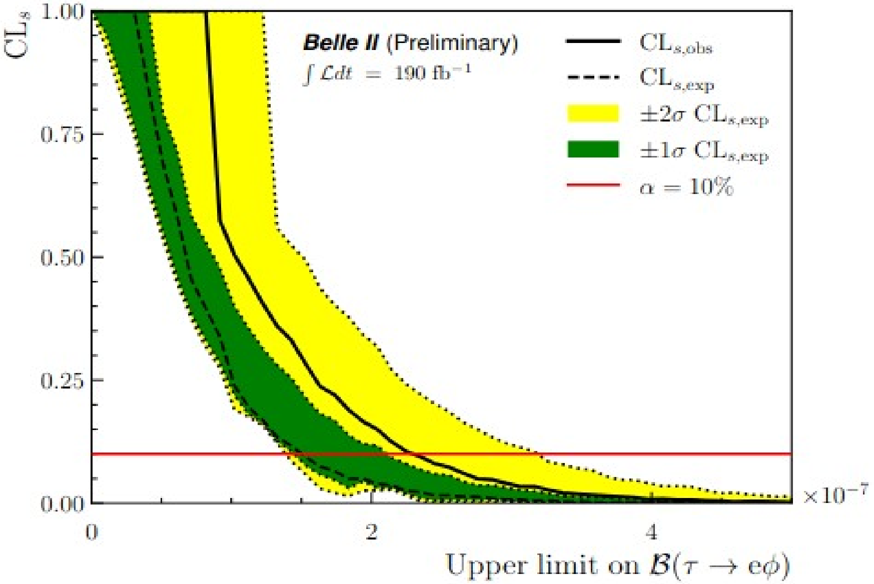
$\tau \to \ell\Phi$: results

- No significant excess in **190 fb^{-1}**
- Set 90% CL upper limits on the BF with CL_s method: $\mathcal{B}_{\rm UL}(\tau \to \ell\phi) = \dfrac{N_{\rm obs} - N_{\rm exp}}{L \times 2\sigma_{\tau\tau} \times \varepsilon_{\ell\phi}}$,

Electron mode: $\tau \to e\Phi$

Observed: BF_{UL} ($\tau \to e\Phi$) = 23 x 10^{-8}

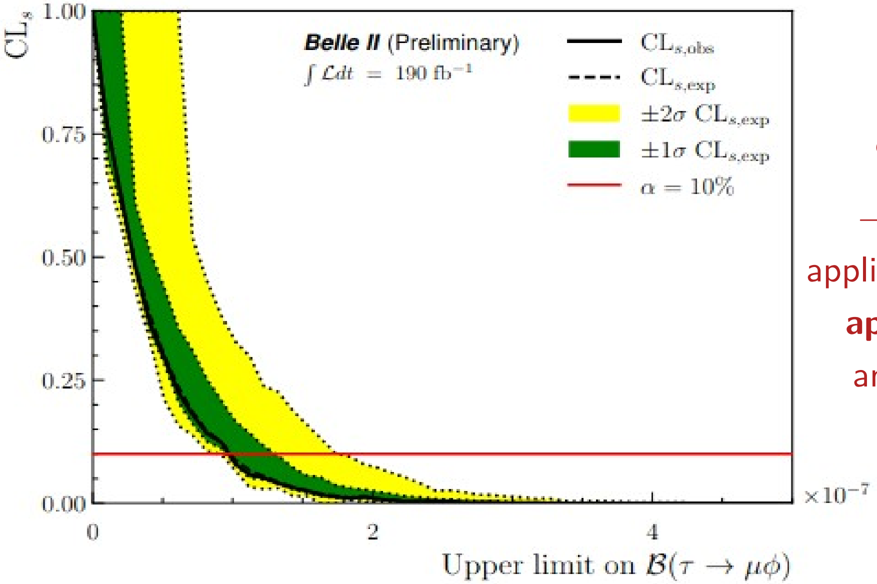
Expected: BF_{UL} ($\tau \to e\Phi$) = 15 x 10^{-8}



Muon mode: $\tau \to \mu\Phi$

Observed: BF_{UL} ($\tau \to \mu\Phi$) = 9.7 x 10^{-8}

Expected: BF_{UL} ($\tau \to \mu\Phi$) = 9.9 x 10^{-8}



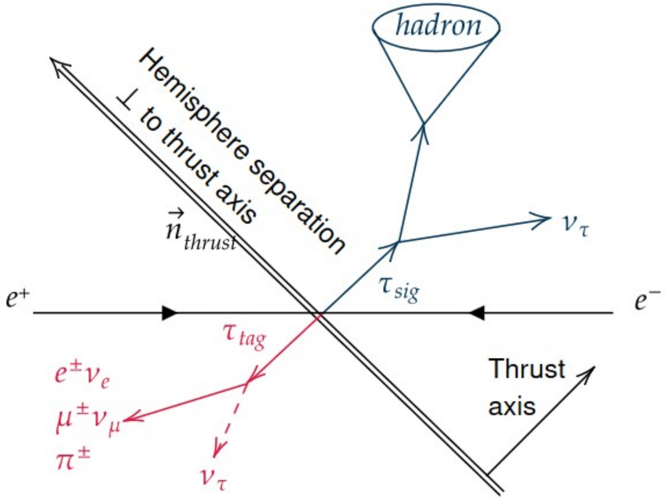
Results not competitive yet

→ successful first application of **untagged approach** in τ-pair analysis at Belle II

Search for $\tau \to \ell K_S^0$ at Belle and Belle II

- First analysis for LFV search on the combined data set **Belle (980 fb^{-1}) + Belle II, run 1 (424 fb^{-1})**

Experiment	Luminosity [fb $^{-1}$]	UL at 90% CL [x10^{-8}] (expected) eK_S^0	μK_S^0	Ref.
BaBar	469	3.3	4.0	Phys. Rev. D, 79 (2009)
Belle	671	2.6	2.3	Physics Letters B, Vol. 692, 1, (2010)
Belle + Belle II	**1404**	**< 2**	**< 2**	**This analysis! NOT UNBOXED YET**



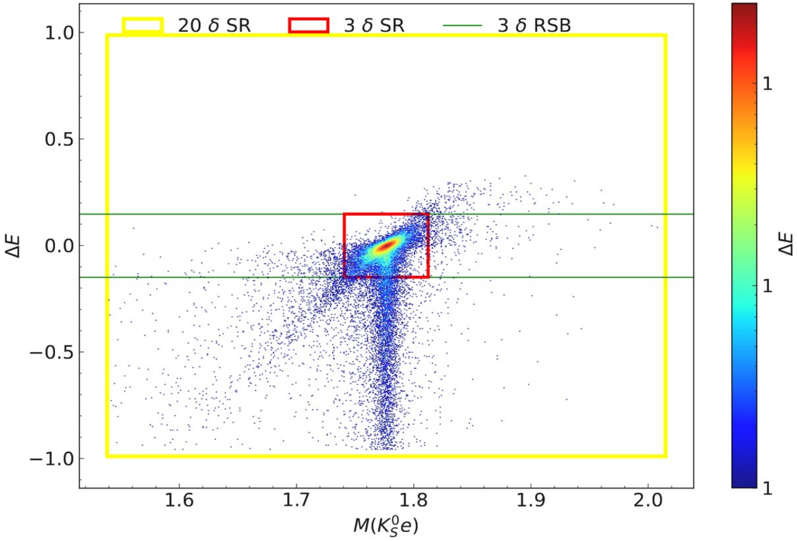
- Reconstruct signal in one-pong tag approach
- Use lepton ID to distinguish two channels and tag sides
- BDT-based selection to reject main background from $e^+e^- \to q\bar{q}$

$\tau \rightarrow \ell K_S^0$: signal region

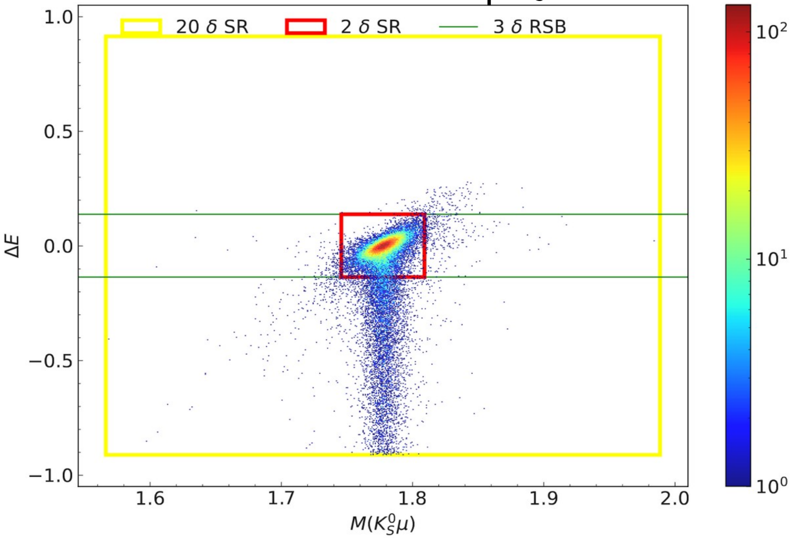
- Define region for analysis optimization in M_{lK_S} vs $\Delta E = E^*_{sig} - \sqrt{s}/2$ plane, blind signal region (SR) and use sidebands (RSB) for data validation
- Tag-type dependent pre-selections against radiative dilepton and four-lepton final states
- Exploit tag side, missing momentum and event shape properties + K_S^0 properties from signal side to train a **BDT** against $ee \rightarrow q\bar{q}$
  - Find optimal hyper-parameters by maximizing **$FOM_{Punzi} = \varepsilon_{sig} / (a/2 + \sqrt{B})$**, a= 3, optimized in elliptical signal region for yield extraction
  - Final **efficiencies** > **10%** for both channels

Belle II Simulation

Electron mode: $\tau \rightarrow eK_S^0$



Muon mode: $\tau \rightarrow \mu K_S^0$

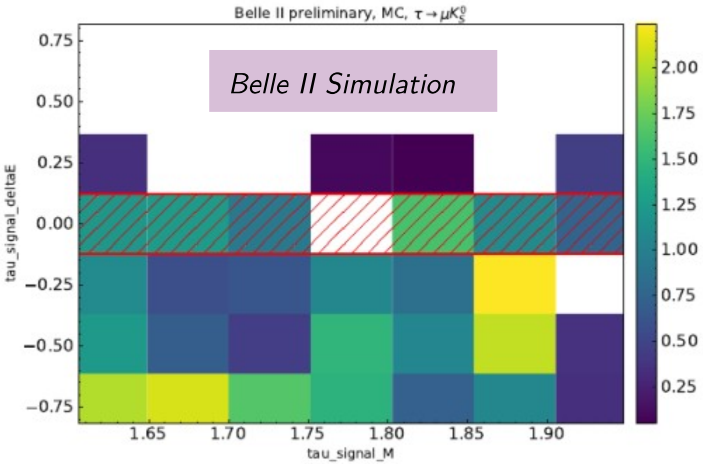


$\tau \to \ell K_S^0$: expected events and yield extraction

- Number of expected events N_{exp} after final selections extracted by a linear fit to 6 bins of M_{lKS} in the data reduced sideband (RSB)
  - Take central value of the SR fitted bin and scale by the ratio of $A^{SR}_{ellipse}/A^{SR}_{rectangular}$
  - Use 68% CL of the fit to assess uncertainty on N_{exp}
  - Use simulation to validate fit results, found unbiased

$$\mathcal{B}(\tau^\pm \to l^\pm K_S^0) = \frac{N_{obs} - N_{exp}}{L \times 2\sigma_{\tau\tau} \times \varepsilon_{\ell K_S^0}}$$

?



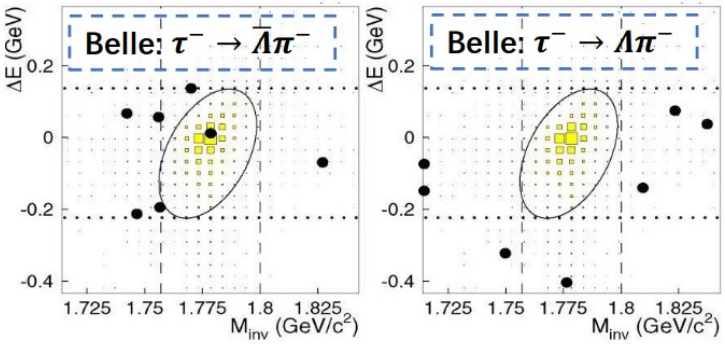
- **Still blinded analysis!**
  - **Count the number of event in SR ellipse after unboxing, N_{obs}**
- Statistically limited; systematics uncertainties evaluated from data-MC agreement in sidebands and dedicated calibration samples
- Estimate expected upper limit at 90% CL including **systematics** uncertainties exploiting **CLs method** in a Poisson counting experiment model

	eK_S^0		μK_S^0	
	Belle	Belle II	Belle	Belle II
Lepton identification [%]	2.3	0.7	2.4	1.3
Tracking efficiency [%]	1.05	0.96	1.05	0.96
Trigger efficiency [%]	0.9	0.68	0.9	0.68
K_S^0 efficiency [%]	4.5	5.9	4.5	6.0
BDT efficiency [%]	0.3	1.6	3.7	8.1
Momentum scale [%]	-	0.3	-	0.2
Luminosity [%]	1.4	0.6	1.4	0.6
Tau-pair cross-section [%]	0.3	0.3	0.3	0.3

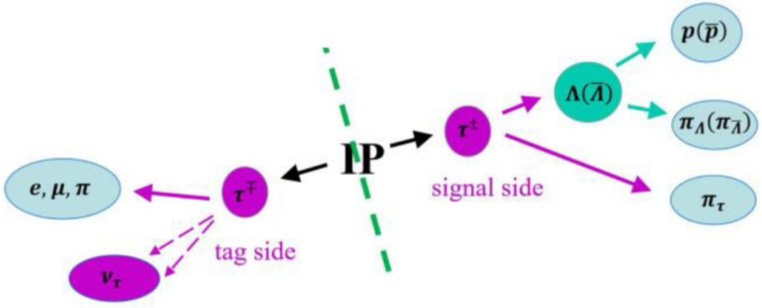
Search for $\tau^- \to \Lambda(\bar{\Lambda})\pi^-$

- Baryon number violation (BNV) required for explaining matter antimatter asymmetry
- Baryon and lepton numbers conserved in the SM, might be violated in beyond SM scenarios
- Previous search on 154 fb^{-1} at Belle [1] set limits at 90% CL of 0.72 (1.4) x 10^{-7} for BR($\tau^- \to \Lambda(\bar{\Lambda})\pi^-$)

	$\tau^- \to \Lambda\pi^-$		$\tau^- \to \bar{\Lambda}\pi^-$	
	initial state	final state	initial state	final state
B	0	1	0	-1
L	1	0	1	0
$B-L$	-1	1	-1	-1
$\lvert\Delta(B-L)\rvert$	2		0	



- Reconstruct exactly 4 charged tracks (total null charge) in one-prong tag approach
- Apply loose pre-selections and MVA classifier to isolate signal
- Poisson counting experiment technique in elliptical signal regions SR in M_τ and $\Delta E_\tau = E^*_{sig} - \sqrt{s}/2$ plane

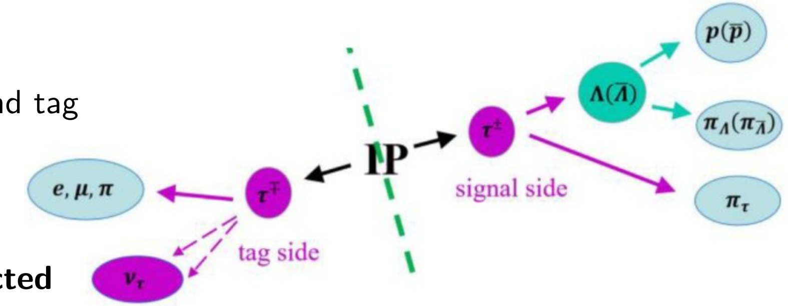


[1] Physics Letters B,Volume 632, 1 (2006)

$\tau^- \to \Lambda(\bar{\Lambda})\pi^-$

background suppression and expected sensitivity

- Particle hypothesis likelihood ratio (proton Vs pion, pion Vs kaon) for signal identification: confined around $M_{\Lambda,}$ with flight distance at least twice its uncertainty
  - Lepton identification to distinguish tag side on
- Reject $e^+e^- \to e^+e^-$, $e^+e^- \to \mu\mu$- , $e^+e^- \to e^+e^-$ hh requiring missing momentum and tag side track separation, thrust >0.9 and limit photon multiplicities
- Use MVA with to reject $e^+e^- \to qq$ and $e^+e^- \to \tau^+\tau^-$
- Final signal efficiencies of **9.52 (9.90) %** for $\tau^- \to \Lambda(\bar{\Lambda})\pi^-$ with **1 (0.5) expected events** in SR, evaluated from sidebands and rescaled according to simulation



$$\mathcal{B}(\tau^- \to \Lambda\pi^-) = \frac{N_{obs} - N_{exp}}{2\epsilon_{sig}\mathcal{L}\sigma_{\tau\bar{\tau}}\mathcal{B}(\Lambda \to p\pi)}$$

- **Still blinded analysis!**
  - **Count the number of event in SR ellipse after unboxing, N_{obs}**
- Compute upper limit in a Bayesian approach including **systematic uncertainties:** PID dominant contribution, negligible compared to statistical → Expect world's leading limits < $5\text{x}10^{-8}$

Summary and outlook

- Study of LFV decays of tau with hadrons in final states is ongoing at Belle II
- Devised new strategies to boost signal efficiency keeping the background under control
  - First proof of concept in $\tau \to \ell\Phi$, Pub.Conf. arxiv:2305.04759
  - Improving hadron ID performance, exploit MVA methods
- Increasing the available statistics by combining with Belle data set, first combined analysis for $\tau \to \ell K_S^0$
- Expect world's best limit on BNV and LNV decays $\tau \to \Lambda(\bar{\Lambda})\pi$

$\to$ Run 2 started, with more data possible to improve LFV channels

Thanks for your attention!

backup

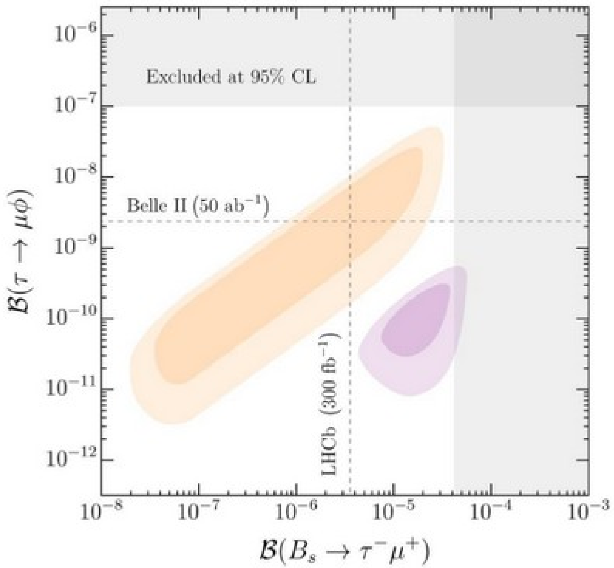
New physics in neutrinoless tau decays

$\tau \to \ell V^0$ (ℓ = e, μ; V^0: neutral vector meson) LFV decays can be enhanced in many new physics (**NP**) models: MSSM, Type-III Seesaw, $SO(10)$ GUT, SM + Heavy Dirac Neutrinos, Littlest Higgs Model with T-parity, Unparticles…

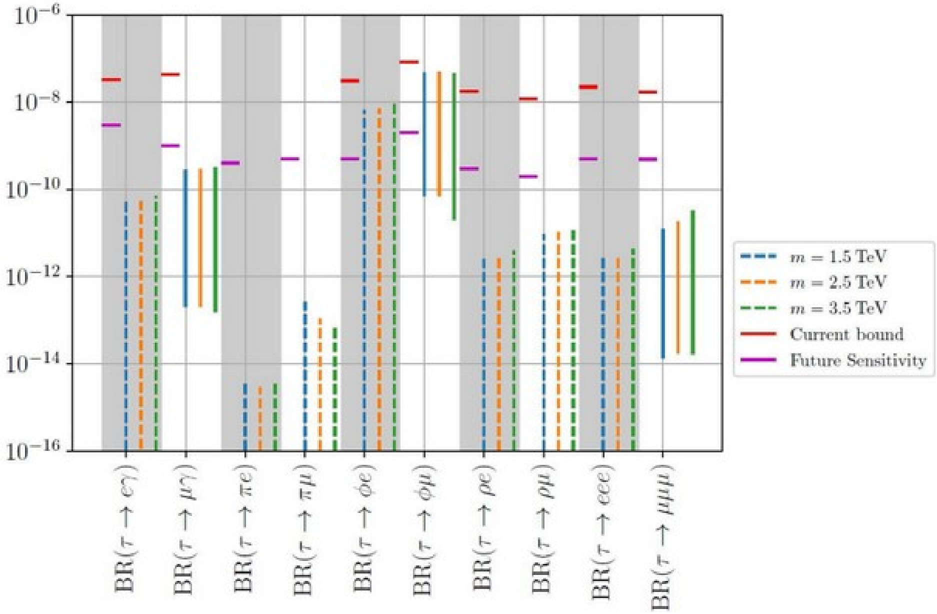
$\tau \to \ell\phi$ (ϕ = ssbar meson of mass ~1020 MeV/c^2) in particular is related to the U_1 vector leptoquark hypothesis.
→ **could explain both $R_{D(*)}$ and $R_{K(*)}$ anomalies.**

Model	$\mathcal{B}(\tau \to e\phi)$	$\mathcal{B}(\tau \to \mu\phi)$
U_1 leptoquark	< 10^{-8}	10^{-10} – 5×10^{-8}
$SO(10)$ GUT	(1 – 5)×10^{-9}	4×10^{-9} – 2×10^{-8}
Littlest Higgs	(1 – 2)×10^{-8}	
Unparticles	6×10^{-11} – 10^{-9}	6×10^{-9} – 10^{-7}

C. Cornella et al.,
Reading the footprints of the B-meson flavor anomalies,
JHEP 08 (2021) 050

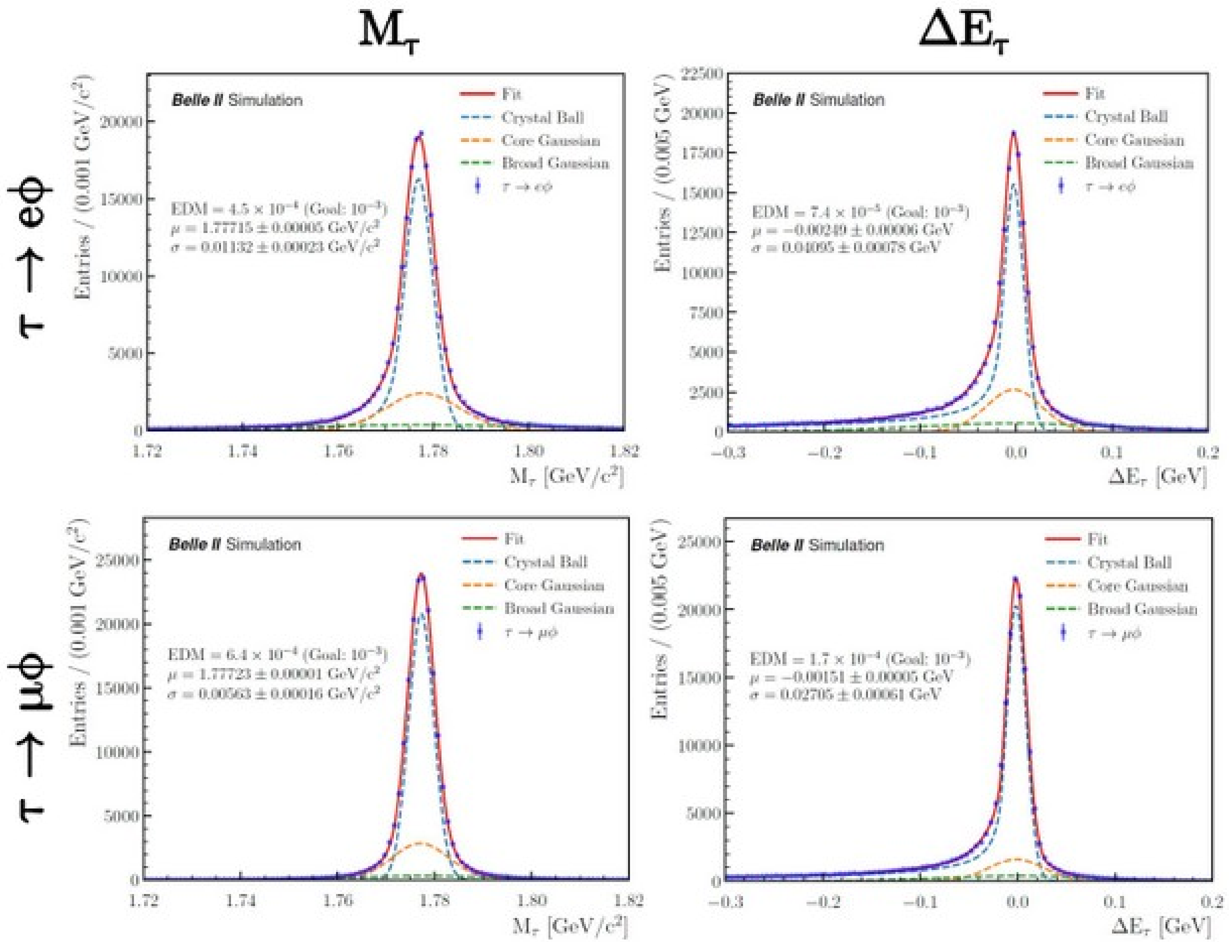


C. Hati et al.,
The fate of V_1 vector leptoquarks: the impact of future flavour data,
Eur.Phys.J.C 81 (2021) 12, 1066



$\tau \to \ell\Phi$: fitted signal resolutions

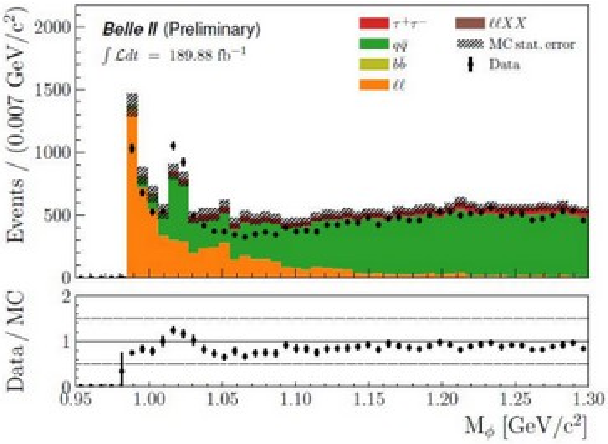
- Fit both variables with (a, b: parameters of the fit):
  - a*Crystal Ball + b*Core Gaussian + (1-a-b)*Broad Gaussian
- Total sigma: weighted sum of the three components' sigmas.

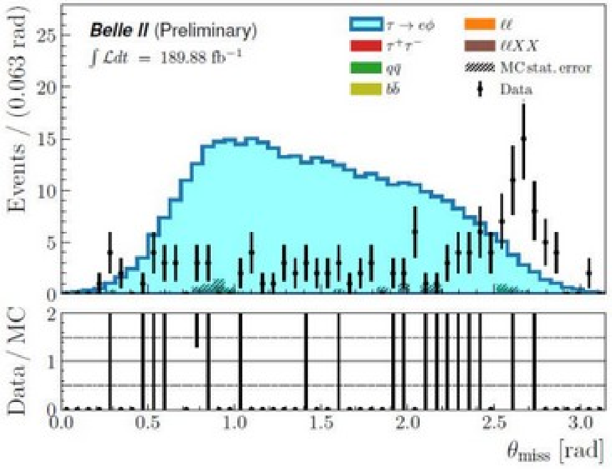


$\tau \to \ell\Phi$: data driven suppression

- Remaining contamination observed in data control regions for the electron mode
  - V^0-photoproduction process $e^+e^- \to e^+e^-\varphi \to$ **not simulated**
  - data driven veto applied to the electron channel requiring a single electron candidate in the event and constraining the event topology (2nd moment CLEO cone, angle between tau flight direction and reconstructed momentum)
- Final signal efficiencies: Electron = 6.1 %, Muon = 6.5%
- Dominant systematics due to simulation mismodeling, negligible compared to statistical uncertainty

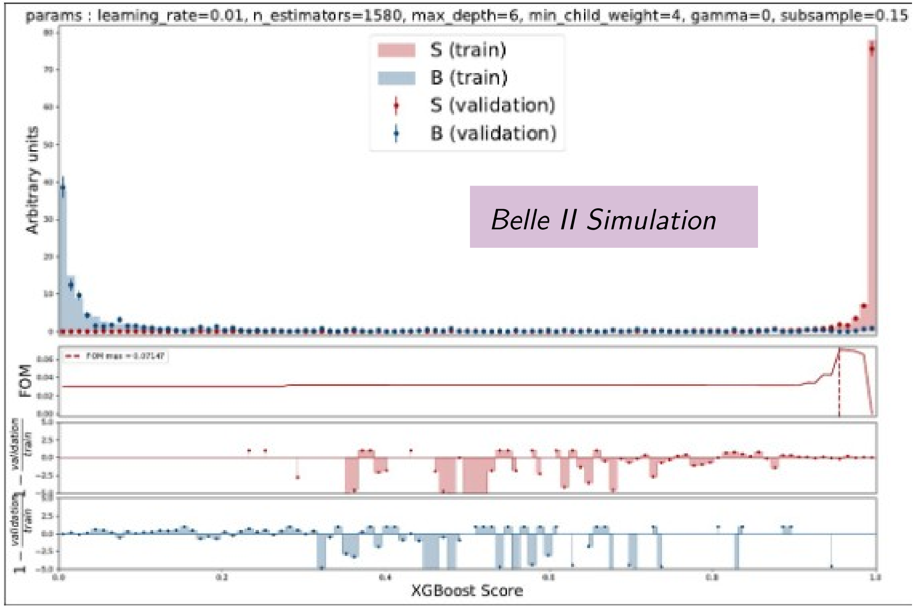
Affected quantity	Source	Mode $e\phi$	Mode $\mu\phi$
$\varepsilon_{\ell\phi}$	Particle identification	0.8%	0.3%
	Tracking efficiency	0.9%	
	Trigger efficiency	0.4%	0.9%
	Signal variable mismodeling	15.2%	8.5%
N_{exp}	Momentum scale	0.6%	0.4%
L	Luminosity	0.6%	
$\sigma_{\tau\tau}$	Tau-pair cross section	0.3%	





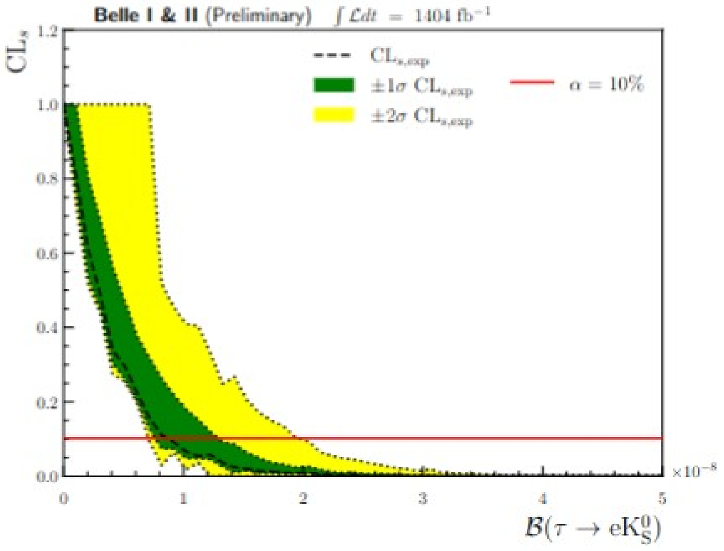
$\tau \to \ell K_S^0$: background suppression

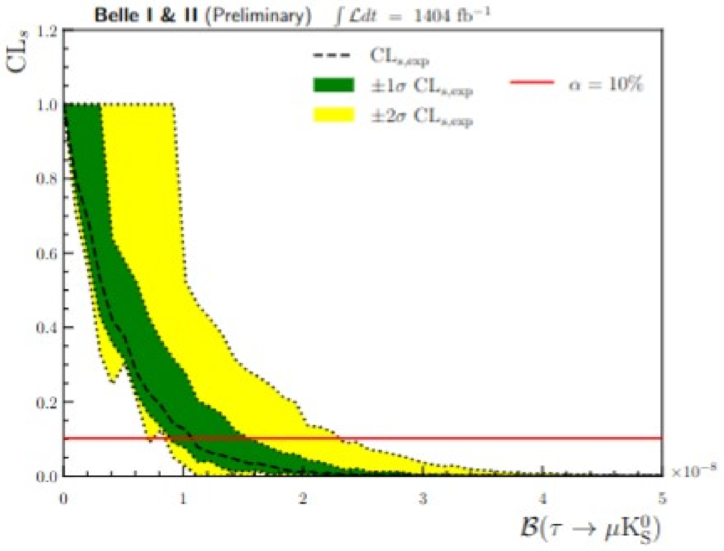
- Main background from $e^+e^- \to q\bar{q}$
  - Overall normalization for muon tag derived from $D \to K_S^0\pi$ control sample
- Exploit tag kinematics, missing momentum and event shape properties + K_S^0 properties from signal side to train a BDT (XGBoost library)
- Find optimal parameters tuning by maximizing $\mathbf{FOM_{Punzi} = \varepsilon_{sig} / (a/2 + \sqrt{B})}$, a= 3
  - Good separation achieved
- Optimize elliptical signal region for yield extraction
- Final **efficiencies** > **10%** for both channels



$\tau \to \ell K_S^0$: sensitivity

- Estimate expected upper limit at 90% CL including **systematics** uncertainties exploiting **CLs method** in a Poisson counting experiment model
  - Generate 5000 toys for 50 uniformly distributed points of BR in the range $(0 - 5) \times 10^{-8}$ for each data set (Belle and Belle II)

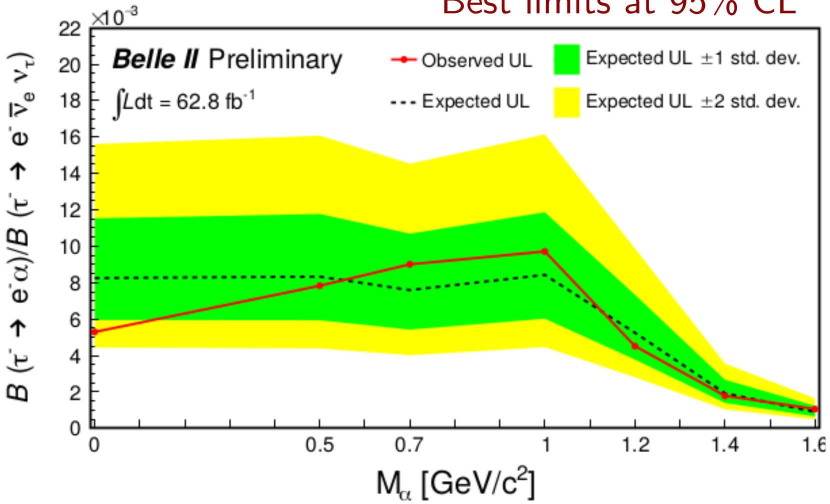




Also dark searches, chiral Belle…and other tests

- τ decays to **new LFV bosons**, possible ALP candidates [1]
- Search for **τ→ *l*α** decays with l=e or μ looking for bumps in normalized lepton energy spectrum over irreducible background from **τ_{SM}→ lνν**

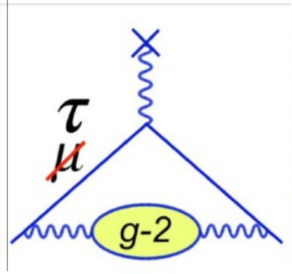
Best limits at 95% CL



- Possbile SuperKEKB upgrade with **polarized electron beam** [2] → precision electroweak physics and non-SM searches!
  - Use tau polarimetry for 0.5% precision (BaBar method [3])

$$P_\tau = P\frac{\cos\theta}{1+\cos^2\theta} - \frac{8G_F s}{4\sqrt{2}\pi\alpha} g_V^\tau \left(g_A^\tau \frac{|\vec{p}|}{p^0} + 2g_A^e \frac{\cos\theta}{1+\cos^2\theta} \right).$$

  - Unprecedented precision on *edm* and MDM of the τ



$$a_\tau^{BSM} \sim a_\mu^{BSM} \left(\frac{m_\tau}{m_\mu}\right)^2 \sim 10^{-6}$$

Current bound in tau ~ $\mathcal{O}(10^{-2})$
Chiral Belle reach ~ $\mathcal{O}(10^{-5})$ with 50ab^{-1}

- Test Bell Inequality violation (non-locality of quantum mechanics) with e^+e^-→ **ττ**?

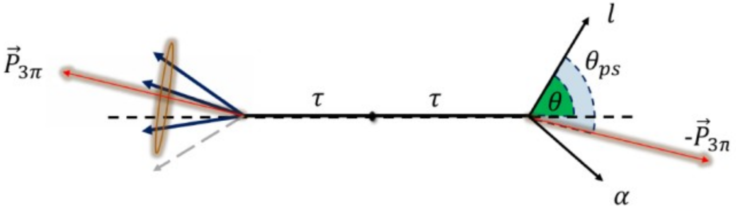
  → Measure **τ** spin orientation with polarimeter-vector method, **arXiv:2311.17555 M. Fabbrichesi et al.**

[1] M. Bauer, et al. Phys. Rev. Lett. 124, 211803 (2020)
[2] arXiv: 2205.12847 , [3] PRD 108 (2023) 092001

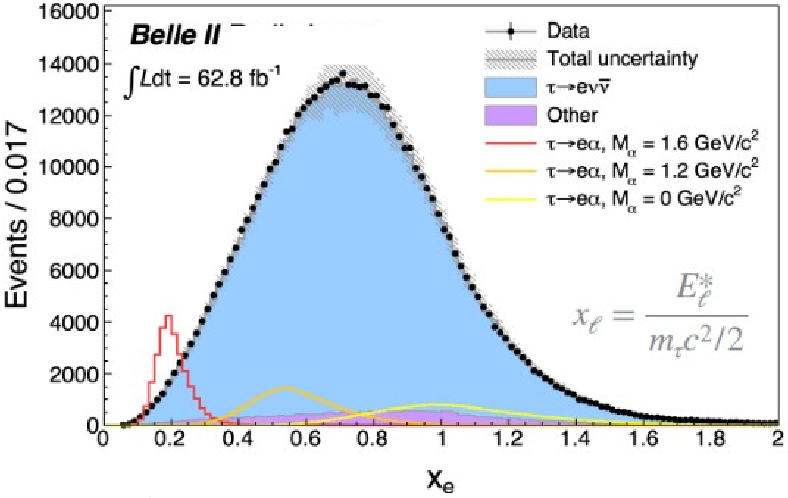
Invisible boson in LFV τ decays

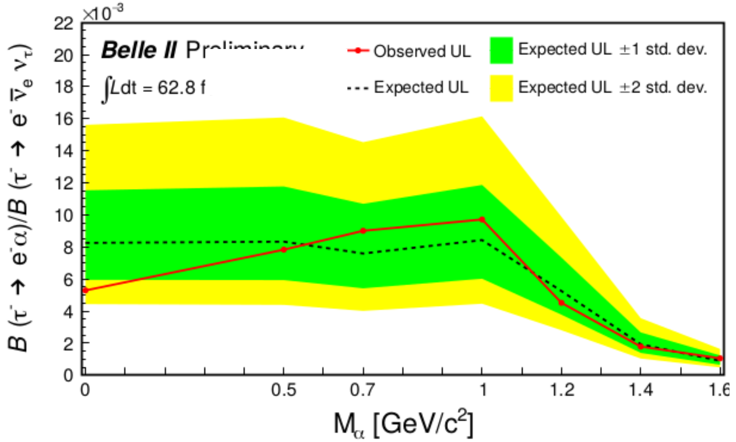
PRL 130 (2023) 181803

- τ decays to **new LFV bosons** (ALPs) predicted in many models [1]
- Search for the process $\mathbf{e^+e^- \to \tau_{sig} (\to \ell\alpha)\, \tau_{tag}(\to 3\pi\nu)}$, with l=e or l=μ



- Approximate $\boldsymbol{\tau_{sig}}$ pseudo-rest frame as $E_{sig} \sim \sqrt{s}/2$ and $\hat{p}_{sig} \approx -\vec{p}_{\tau_{tag}}/|\vec{p}_{\tau_{tag}}|$
- Two-body decay: search a bump in normalized lepton energy x_l spectrum over irreducible background from $\boldsymbol{\tau_{SM} \to l\nu\nu}$
- No signal found in ***62.8 fb⁻¹*** $\to$ set 95% CL upper limits on BF ratios of ***BF***$\boldsymbol{(\tau_{sig} \to l\alpha)}$ normalized to $BF(\tau_{SM} \to l\nu\nu)$





Between 2-14 times more stringent than previous limits (ARGUS, 1995 [2])

[1] M. Bauer, et al. Phys. Rev. Lett. 124, 211803 (2020)
[2] ARGUS Collaboration, Z. Phys. C 68, 25 (1995)