

Detector requirements from Tau Physics

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2023**

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Introduction

- ▶ estimate detector features required to fully exploit the FCC-ee statistics for Tau Physics measurements
- ▶ some representative measurements are considered
 - ▶ tau lifetime, tau mass, tau leptonic branching fractions
 - ▶ search for lepton-flavour-violating tau decays to $\mu\gamma$, $\mu\mu\mu$
 - ▶ Physics motivation considerations omitted today to stay in the time
- ▶ caveat: mostly on-paper estimations, with limited past studies on fast-simulated data

using new baseline FCC-ee performance

- ▶ new figures, communicated in Physics Performance meeting of May 22, 2023
- ▶ FCC-ee with 4 IP, integrated luminosity $4 \times 60 = 240 \text{ ab}^{-1}$ corresponding to $8 \cdot 10^{12} Z$ bosons
- ▶ $2.7 \cdot 10^{11}$ tau pairs, $5.9 \times \text{BelleII}$ (50 ab^{-1}), $200 \times B$ -factories, $0.44 \cdot 10^6 \times \text{LEP}$

Detector requirements

assumed baseline FCC-ee detector performance

track momentum $\frac{\sigma_p}{p} = 0.02 \cdot 10^{-3} \cdot p_T(\text{GeV}) \oplus 1 \cdot 10^{-3}$

track impact parameter $\sigma_{d_0} = \frac{15 \mu\text{m}}{\sin^{3/2} \theta} \oplus 5 \mu\text{m}$

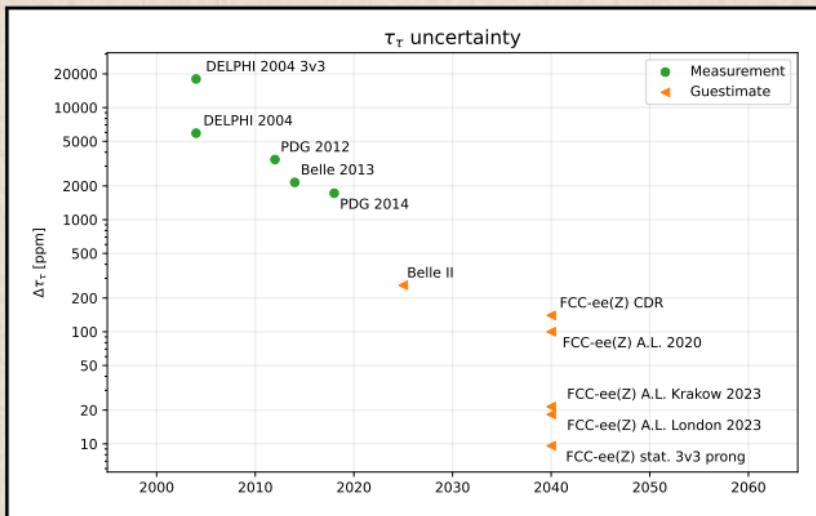
electromagnetic energy $\frac{\sigma_{E_\gamma}}{E_\gamma} = \frac{15\%}{E_\gamma} \oplus 1\%$

electromagnetic energy xy position $\sigma_{\gamma,xy} = \frac{6 \text{ mm}}{E(\text{GeV})} \oplus 2 \text{ mm}$

reported detector requirements

- ▶ when possible, specify detector requirements corresponding to adding 1/2 statistical precision
- ▶ otherwise, highlight when physics reach is significantly dependent on specific detector features
- ▶ in some cases, baseline performance just adequate, no expected gain from improvements

Tau Lifetime uncertainty



FCC total uncertainty estimates

- ▶ M. Dam, 1999, FCC CDR
- ▶ A.L. FCC Krakow Jan 2023
- ▶ A.L. FCC London Jun 2023

Other estimates

- ▶ Belle II Physics Book

τ_τ statistical precision [ppm]

4800	DELPHI 2004, 144 pb^{-1}
18000	DELPHI 2004, 3-prong vs. 3-prong (3v3), 144 pb^{-1}
12	FCC-ee(Z) $5 \cdot 10^{12} \text{ Z}$, 150 ab^{-1} , from DELPHI 2004 3v3 (*)
9.6	FCC-ee(Z) $8 \cdot 10^{12} \text{ Z}$, 240 ab^{-1} , from DELPHI 2004 3v3 (*)

(*) accounting for much smaller beam spot and quite better impact parameter resolution at FCC-ee w.r.t. LEP

Tau Lifetime uncertainty notes

- ▶ consider just tau pairs in 3-prong vs. 3-prong topology (3v3)
 - ▶ Belle 2013 best measurement uses these events
 - ▶ τ direction reconstruction using vertices reduces importance of simulation
- ▶ extrapolate FCC-ee statistical precision starting from [Delphi 2004](#) 3v3 events statistical precision
 - ▶ expect no significant differences on selection efficiency
 - ▶ Delphi 2004 3v3 precision by rescaling 3v1+3v3 measurement to number of 3v3 candidates
 - ▶ τ_τ measurement is a measurement of transverse i.p. $\langle d_0 \sin \theta \rangle \approx 70 \mu\text{m}$
 - ▶ Delphi 2004 3v3 precision consistent with a d_0 resolution $\approx 70 \mu\text{m}$ (tracking, beam spot)
 - ▶ assume FCC-ee has both transverse beam spot and can have d_0 resolution $\ll 70 \mu\text{m}$
⇒ precision improvement factor $\sim (70 \mu\text{m} \oplus 70 \mu\text{m}) / 70 \mu\text{m} \simeq 1.41$
- ▶ assume DELPHI systematics for background, reconstruction bias and alignment (total 1.3 fs) scale with luminosity to 3.5 ppm at FCC-ee
 - ▶ very optimistic, and revised w.r.t. estimate in Krakow 2023, which was 12 ppm
- ▶ assume 30× better KKMC simulation can reduce uncertainty on ISR+FSR energy loss in tau pair production to reduce the associated systematic contribution from 350 ppm to 12 ppm
- ▶ assume 9 ppm tau mass measurement at SCT/STCF or at FCC-ee
- ▶ assume 2 ppm vertex detector length scale (possible with optical methods)
- ▶ see Krakow Jan 2023 presentation for more details

Tau Lifetime at FCC-ee(Z) uncertainty budget

τ_τ precision [ppm]

9.6	statistical
2.0	length scale of vertex detector
9.0	$\sigma(m_\tau)$
12.0	average tau pair production radiative energy loss
3.5	systematics optimistically expected to scale with statistics - detector alignment - background - fit model
18.3	total

detector requirements to limit effects below 1/2 of statistical uncertainty

- ▶ impact parameter resolution for tau decay tracks $\leq 70/2 \cdot \sqrt{3} = 61 \mu\text{m}$
 - ▶ taking into account that each single event measurement uses three tracks
- ▶ uncertainty on average length scale of vertex detector elements $\leq 9.6/2 = 4.8 \text{ ppm}$

other detector requirements

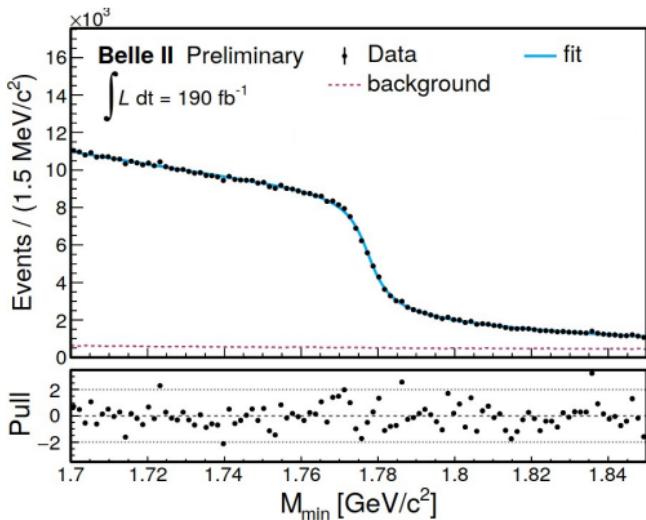
- ▶ $75\times$ precision improvement for simulation of radiation in tau pair production
 - ▶ not detector but worth noting
 - ▶ $30\times$ assumed to be more realistic in the uncertainty budget

Tau mass Belle II preliminary measurement [Moriond 2023]

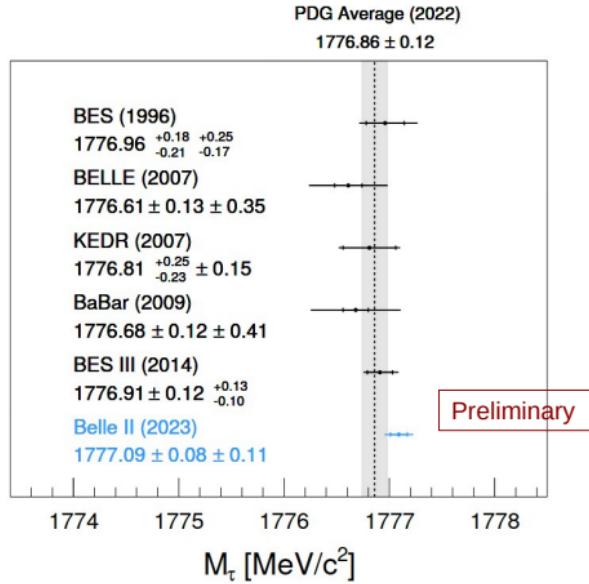
**NEW
for Moriond!**

World's most precise measurement

- World's most precise measurement of $m_\tau = 1777.09 \pm 0.08_{\text{stat}} \pm 0.11_{\text{sys}} \text{ MeV}/c^2$



Proof of high precision capability of Belle II!



Tau mass Belle II preliminary measurement [Moriond 2023], systematics

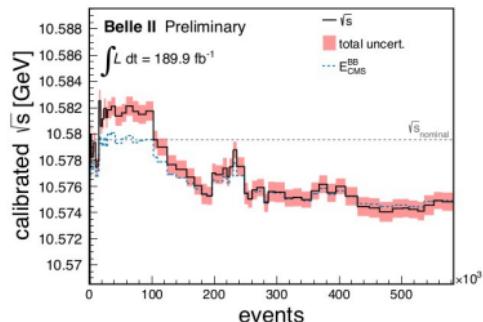
NEW
for Moriond!

τ mass: precision challenge

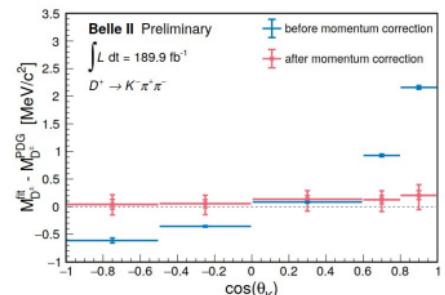
- Excellent control of systematic uncertainties thanks to precise understanding of beam energies and tracking: $M_{\min} = \sqrt{M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - P_{3\pi}^*)} \leq M_\tau$

Source	Uncertainty [MeV/c ²]
Knowledge of the colliding beams:	
Beam energy correction	0.07
Boost vector	≤ 0.01
Reconstruction of charged particles:	
Charged particle momentum correction	0.06
Detector misalignment	0.03
Fitting procedure:	
Estimator bias	0.03
Choice of the fit function	0.02
Mass dependence of the bias	≤ 0.01
Imperfections of the simulation:	
Detector material budget	0.03
Modeling of ISR and FSR	0.02
Momentum resolution	≤ 0.01
Neutral particle reconstruction efficiency	≤ 0.01
Tracking efficiency correction	≤ 0.01
Trigger efficiency	≤ 0.01
Background processes	≤ 0.01
Total	
Total	0.11

Beam energy calibration
with B-meson hadronic decays
method and Y(4S) lineshape
measurement to get \sqrt{s}



Momentum scale factor
cures the bias due to imperfect B-field:
extract corrections dependent
on $\cos\theta_{\text{track}}$ by comparing $D^0 \rightarrow K^- \pi^+$
mass peak w.r.t PDG mass.



arXiv:2305.19116 [hep-ex], May 30, 2023

L.Zani - Dark sectors and tau physics at Belle II - Moriond 2023

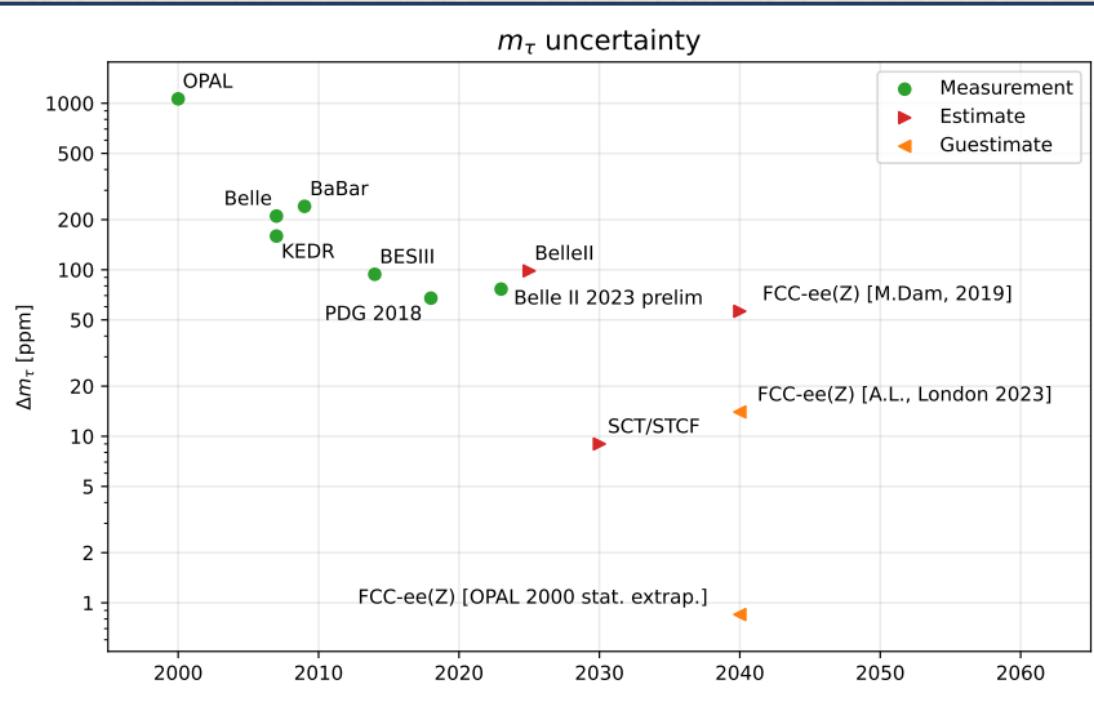
Tau mass prospects at FCC-ee

- ▶ Belle II statistical uncertainty is 45 ppm with 190 fb^{-1} , 175 M tau pairs
- ▶ FCC-ee statistical uncertainty with $8 \cdot 10^{12} Z$, $2.7 \cdot 10^{11}$ tau pairs would be 1.1 ppm
 - ▶ neglecting surely better FCC-ee efficiency
- ▶ Belle II dominant systematics expected very reduced at FCC-ee
 - ▶ beam energy (1 ppm at FCC-ee)
 - ▶ track momentum scale (2 ppm calibration maybe possible at FCC-ee with $m_{J/\psi}$)
- ▶ alignment systematics can be expected to scale with statistics
- ▶ limiting systematics from empirical fit function, 0.05 MeV or 28 ppm
- ▶ may expect to reduce this limiting systematic uncertainty to 1/2 of 14 ppm at FCC-ee
- ▶ guestimate FCC-ee tau mass precision at 14 ppm

detector requirements

- ▶ baseline performance is adequate, no gain expected from improvements

Tau mass prospects at FCC-ee and other facilities



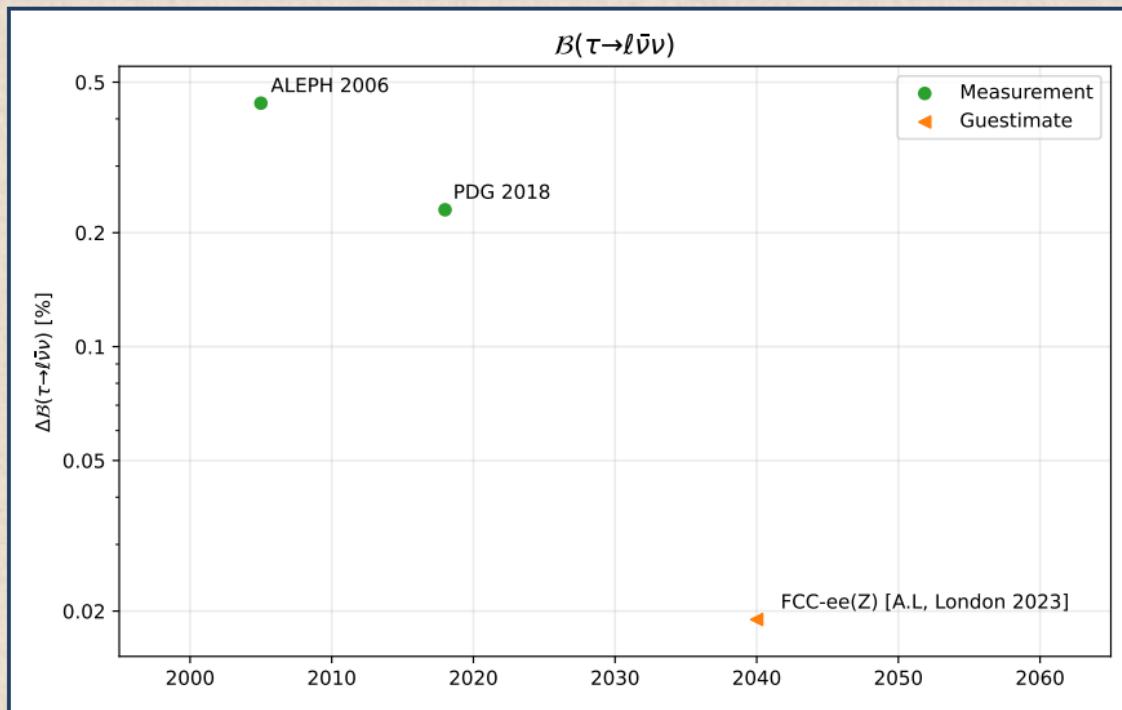
Tau leptonic branching fractions prospects at FCC-ee

- ▶ ALEPH 2006 measurement precision: $4400 \text{ ppm} = [4000(\text{stat.}) \oplus 1900(\text{syst.})] \text{ ppm}$
(average of the two similar electron and muon decays branching fractions)
 - ▶ complex simultaneous measurement of 12 tau branching fractions
 - ▶ many systematic uncertainties, no reliable extrapolations to FCC-ee statistics
 - ▶ several systematics related to photon and $\pi^0 \rightarrow \gamma\gamma$ reconstruction
 - ▶ more details in presentation at FCC Liverpool Feb 2022
- ▶ FCC-ee extrapolated statistical precision: $4000 \text{ ppm} \cdot \sqrt{6.2 \cdot 10^6 (\text{ALEPH Z bosons}) / 8 \cdot 10^{12}} = 4.5 \text{ ppm}$
- ▶ today guestimate: FCC-ee precision may be limited to about 1/10 of ALEPH systematics, 190 ppm

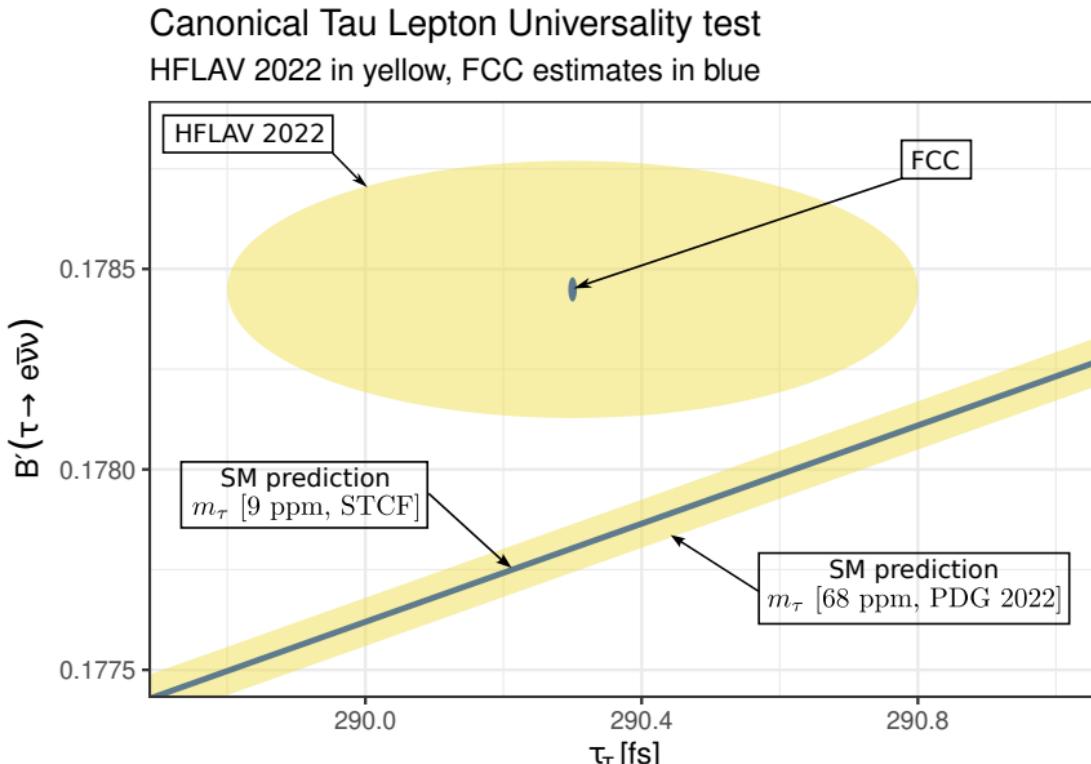
detector requirements

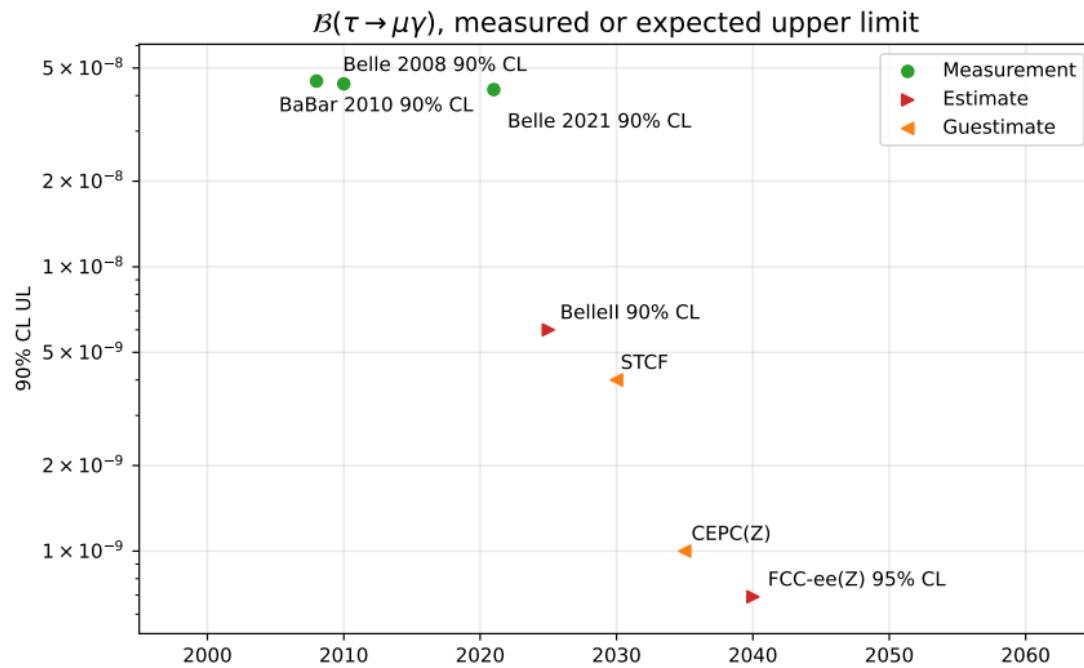
- ▶ unable to reliably estimate detector requirements corresponding to 1/2 of 190 ppm precision
- ▶ generic requirements (probably better ascertained on some other simpler Flavour measurement)
 - ▶ good electromagnetic energy resolution, at least better than LEP $20\%/\sqrt{E(\text{GeV})}$
 - ▶ granular electromagnetic calorimeter, at least better than LEP $15 \times 15 \text{ mrad}^2$

Tau leptonic Branching fractions prospects at FCC-ee and other facilities



Canonical tau lepton universality plot extrapolation to FCC-ee



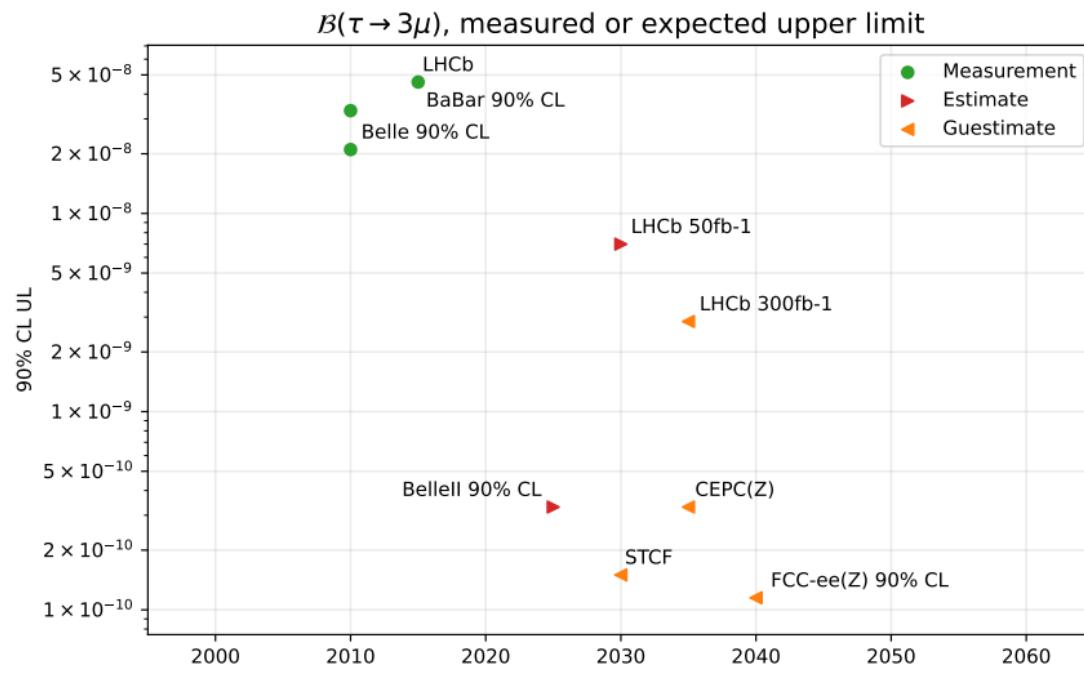
LFV $\tau \rightarrow \mu\gamma$ measured / expected upper limits

- M.Dam simulation with 2% of FCC statistics, updated to $8 \cdot 10^{12}$ Z bosons

LFV $\tau \rightarrow \mu\gamma$ detector requirements

- ▶ detector resolutions better or equal to parameters in M.Dam simulation
- ▶ photon energy resolution $\frac{\sigma_{E_\gamma}}{E_\gamma} \leq \left(\frac{15\%}{E_\gamma} \oplus 1\% \right)$
- ▶ photon xy position resolution $\sigma_{\gamma,xy} \leq \left(\frac{6}{E(\text{GeV})} \oplus 2 \right) \text{ mm}$
- ▶ improvements of above performances will reduce background and increase Physics reach of the search

LFV $\tau \rightarrow 3\mu$ measured / expected upper limits



► guestimate updated to $8 \cdot 10^{12}$ Z bosons

Notes on guesstimate of FCC expected 90% upper limit on $\tau \rightarrow 3\mu$

- ▶ $2.1 \cdot 10^{-8}$ published Belle limit at 0.782 ab^{-1}
- ▶ $\dots / (50 \text{ ab}^{-1} / 0.782 \text{ ab}^{-1}) = 3.3 \cdot 10^{-10}$, Bellell expected upper limit assuming background-free search
- ▶ FCC: $8 \cdot 10^{12} Z^0$, $2.7 \cdot 10^{11}$ tau pairs, $\sim 5.9 \times 46 \cdot 10^9$ Bellell tau pairs
- ▶ estimate $4 \times$ better efficiency at FCC vs. Bellell
 - ▶ from [DELPHI Phys.Lett. B359 \(1995\) 411-421](#) vs. [BABAR Phys.Rev.Lett. 104 \(2010\) 021802](#)
- ▶ muon PID efficiency and purity expected to be better for FCC
- ▶ in the improbable assumption that search remains background free
 - ▶ $3.3 \cdot 10^{-10} / 3.6 / 4.0 = 0.23 \cdot 10^{-10}$ estimated FCC 90% upper limit
- ▶ estimate / assume that
 - ▶ m_τ resolution comparable with B -factories
 - ▶ E resolution worse (850 MeV in M. Dam $\tau \rightarrow \mu\gamma$ study vs. 50-100 MeV \approx 75 MeV in *BABAR*)
 - ▶ therefore search remains background free until $N_{\tau^+\tau^-}^{\text{Bellell}} / (850 \text{ MeV} / 75 \text{ MeV})$
 - ▶ additional tau pairs improve upper limit proportionally to the square root (estimated bkg uncertainty)
- ▶ $3.3 \cdot 10^{-10} \cdot (850 \text{ MeV} / 75 \text{ MeV}) / \sqrt{[5.9 \cdot (850 \text{ MeV} / 75 \text{ MeV})]} / 4.0 \simeq 1.15 \cdot 10^{-10}$ FCC 90% CL UL

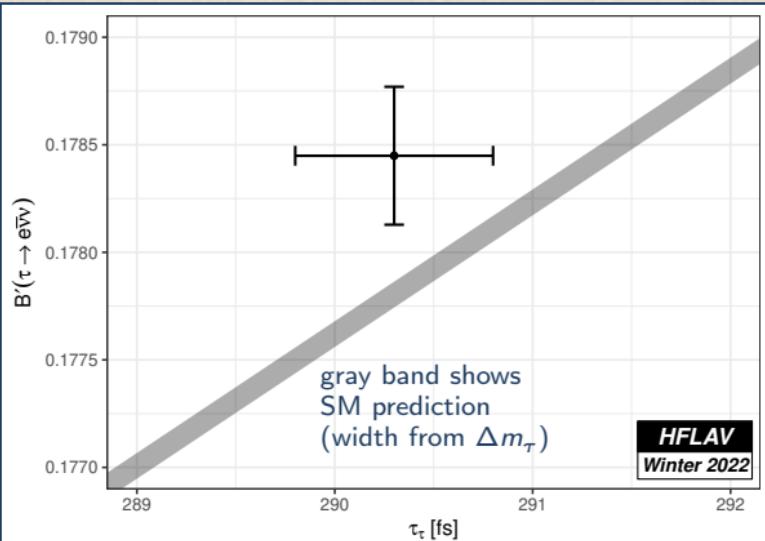
LFV $\tau \rightarrow 3\mu$ detector requirements

- ▶ reconstructed candidate tau mass precision $\sigma[m_\tau(3\mu)] \leq 25 \text{ MeV}$
⇒ momentum resolution $\frac{\sigma_p}{p} \leq \left(0.02 \cdot 10^{-3} \cdot p_T(\text{GeV}) \oplus 1 \cdot 10^{-3} \right)$
- ▶ pion misidentification to muon $\leq 2\%$ with efficiency $\geq 80\%$ [guesstimate, more studies needed]
- ▶ any improvement on the above will increase the physics reach

Thanks for your attention!

Backup Slides

Canonical tau lepton universality test plot



$$(g_\tau/g_{e\mu}) = 1.0018 \pm 0.0013$$

$[g_{e\mu} = g_e = g_\mu \text{ assuming } g_e = g_\mu]$

$\Delta(g_\tau/g_{e\mu})$ contributions before 2023

input	Δ input	$\Delta(g_\tau/g_{e\mu})$
$\mathcal{B}'_{\tau \rightarrow e}$	0.180%	0.090%
τ_τ	0.172%	0.086%
m_τ	0.007%	0.017%
total		0.126%

best measurements before 2023

$\mathcal{B}'_{\tau \rightarrow e}$	ALEPH
τ_τ	Belle
m_τ	BES III

Belle II 2023 prelim. m_τ best single meas.

m_τ Belle II, prelim, [0.008%]

- $\mathcal{B}'(\tau \rightarrow e\bar{\nu}\nu) = \text{average of } \begin{cases} \mathcal{B}(\tau \rightarrow e\bar{\nu}\nu) \\ \mathcal{B}(\tau \rightarrow \mu\bar{\nu}\nu) \cdot \frac{f_{\tau e} R_W^{\tau e}}{f_{\tau \mu} R_W^{\tau \mu}} \end{cases}$
- $\frac{\mathcal{B}'(\tau \rightarrow e\bar{\nu}\nu) \tau_\mu}{\mathcal{B}(\mu \rightarrow e\bar{\nu}\nu) \tau_\tau} = \frac{g_\tau^2}{g_{e\mu}^2} \frac{m_\tau^5 f_{\tau e} R_\gamma^\tau R_W^{\tau e}}{m_\mu^5 f_{\mu e} R_\gamma^\mu R_W^{\mu e}}$
- $\left(\frac{g_\tau}{g_{e\mu}} \right)^2 = \frac{\mathcal{B}'(\tau \rightarrow e\bar{\nu}\nu)}{\mathcal{B}(\mu \rightarrow e\bar{\nu}\nu)} \frac{\tau_\mu}{\tau_\tau} \frac{m_\mu^5}{m_\tau^5} \frac{f_{\mu e} R_\gamma^\mu R_W^{\mu e}}{f_{\tau e} R_\gamma^\tau R_W^{\tau e}}$

Vertex detector absolute length scale systematic

- ▶ vertex detector misalignment can have large effect but can be suppressed and calibrated
- ▶ average radius of the vertex detector can be constrained with data using overlapping wafer modules: radius will be known with the same relative precision of the knowledge of the size of the silicon modules, or equivalently the average strip pitch
- ▶ LEP, B -factories, absolute length scale knowledge of silicon vertex detector believed to be 100 ppm
- ▶ A.L. Jan 2020 guestimate for FCC tau lifetime uncertainty limited to 100 ppm by this limitation

MUonE interferometric monitoring of detector to $1\text{ }\mu\text{m}/50\text{ cm}$, 2 ppm

- ▶ A. Arena, G. Cantatore, M. Karuza, Digital holographic interferometry for particle detector diagnostic, Proceedings of the International Convention MIPRO, May 2022, [doi:10.23919/MIPRO55190.2022.9803636](https://doi.org/10.23919/MIPRO55190.2022.9803636)
- ▶ During preliminary tests, we have obtained reconstructed holographic images with interference fringes showing a displacement of the monitored object, over time, of the order of $\sim 1\text{ }\mu\text{m}$. This experimentally demonstrated resolution is already sufficient to satisfy the $10\text{ }\mu\text{m}$ resolution mandated by MUonE. [MUonE silicon modules are 50 cm apart]
- ▶ also absolute calibration required in addition to monitoring, appears feasible with optical techniques
- ▶ 2 ppm tau lifetime systematics from vertex detector length scale appears attainable

Tau pairs at past, present and future e^+e^- colliders

	CLEO, CLEOIII	LEP 100	Belle, <i>BABAR</i>	BelleII	SCT	STCF	CEPC(Z)	FCC-ee(Z)
E_{CM} [GeV]	~10.6	92	~10.6	~10.6	2 – 6	2 – 7		92
$\int \mathcal{L} dt$ [ab^{-1}]	0.01		1.5	50		10		240
tau pairs	$1 \cdot 10^7$	$0.8 \cdot 10^6$	$1.4 \cdot 10^9$	$46 \cdot 10^9$		$30 \cdot 10^9$	$30 \cdot 10^9$	$270 \cdot 10^9$

note: SCT & SCFT tau pairs estimate assuming 10 years of tau-pairs-optimized CM energies running

Conditions for tau physics measurements

- ▶ Z peak collisions best for most measurements
 - ▶ pure and efficient tau pair selection selecting on just one of the two taus
 - ▶ track multiplicity separates very well $\tau^+\tau^-$ from $q\bar{q}$
 - ▶ high momenta reduce multiple scattering uncertainty in impact parameter measurements
- ▶ threshold measurements at $E = 2m_\tau \sim 3.5$ GeV best for tau mass
 - ▶ threshold measurements help some LFV searches and tau BRs (super charm-tau factories)
- ▶ B -factories bested LEP with statistics on e.g. small branching fractionss, LFV searches, tau lifetime

FCC tau physics references (non exhaustive)

- ▶ FCC CDR, EPJC 79 (2019) 474
- ▶ Mogens Dam
 - ▶ Tau2021
 - ▶ M. Dam, EPJ+ 136 (2021) 963, [doi:10.1140/epjp/s13360-021-01894-y](https://doi.org/10.1140/epjp/s13360-021-01894-y), [arXiv:2107.12832 \[hep-ex\]](https://arxiv.org/abs/2107.12832)
 - ▶ M. Dam, SciPost Phys.Proc. 1 (2019) 041
- ▶ A.L.
 - ▶ FCC meetings Jan 2020, Dec 2021, Feb 2022, Sep 2022
 - ▶ Charm 2021, Tau 2021
 - ▶ European Strategy Update 2019, [arXiv:1910.11775 \[hep-ex\]](https://arxiv.org/abs/1910.11775).

Tau branching fractions notes

- ▶ world averages of large BRs still dominated by LEP
 - ▶ background separation from dileptons and hadrons much better
 - ▶ higher selection purity and efficiency
 - ▶ possible to tag single tau with good efficiency and purity and observe the other one
⇒ wonderful base for reducing systematics using data, exploited in particular by ALEPH
- ▶ B -factories improved on small branching fractions using statistics
⇒ FCC statistics $1300^2 \times$ ALEPH, $175 \times$ Belle, $3.5 \times$ BelleII (& better efficiency w.r.t. B -factories)

Important ingredients for precise BR measurements

- ▶ PID efficiency, purity, **accurate PID modeling with control samples**
- ▶ efficiency, purity of π^0 reconstruction, **accurate modeling with control samples**
- ▶ improve current poor simulation of high multiplicity invariant mass distributions
- ▶ **improvements on tau pairs Monte Carlo simulations highly desirable**
- ▶ high statistics samples will help very much on first 3 points, but analyses will be very complex
- ▶ FCC is best imaginable context for tau BR measurements

Systematics of main ALEPH tau BR paper, Phys. Rept. 421 (2005) 191

systematics

Total systematic errors for branching ratios measured from the 1994–1995 data sample

Topology	π^0	sel	bkg	pid	int	trk	dyn	mcs	Total
e	0.011	0.021	0.029	0.019	0.009	0.000	0.000	0.015	0.045
μ	0.004	0.020	0.020	0.021	0.008	0.000	0.000	0.015	0.039
h	0.071	0.016	0.010	0.022	0.022	0.014	0.000	0.019	0.083
$h\pi^0$	0.063	0.027	0.019	0.011	0.045	0.009	0.000	0.027	0.090
$h2\pi^0$	0.089	0.021	0.014	0.004	0.007	0.003	0.040	0.028	0.105
$h3\pi^0$	0.056	0.012	0.015	0.000	0.008	0.001	0.008	0.030	0.068
$h4\pi^0$	0.029	0.005	0.011	0.000	0.015	0.000	0.000	0.019	0.040
$3h$	0.047	0.021	0.018	0.004	0.012	0.014	0.006	0.015	0.059
$3h\pi^0$	0.033	0.017	0.029	0.002	0.041	0.009	0.007	0.018	0.066
$3h2\pi^0$	0.027	0.008	0.015	0.000	0.009	0.003	0.012	0.014	0.038
$3h3\pi^0$	0.010	0.012	0.002	0.000	0.002	0.001	0.010	0.006	0.019
$5h$	0.002	0.000	0.002	0.000	0.000	0.001	0.000	0.003	0.004
$5h\pi^0$	0.002	0.000	0.006	0.000	0.000	0.000	0.000	0.002	0.007
Class 14	0.013	0.003	0.022	0.002	0.024	0.000	0.000	0.011	0.037

All numbers are absolute in per cent. The labels are defined as follows: photon and π^0 reconstruction (π^0), event selection efficiency (sel), non-t background (bkg), charged particle identification (pid), secondary interactions (int), tracking (trk), Monte Carlo dynamics (dyn), Monte Carlo statistics (mcs), total systematic uncertainty (total).

π^0 systematics

Total systematic errors for branching ratios measured from the 1994–1995 data sample

Topology	π^0	sel	bkg	pid	int	trk	dyn	mcs	Total
e	0.011	0.021	0.029	0.019	0.009	0.000	0.000	0.015	0.045
μ	0.004	0.020	0.020	0.021	0.008	0.000	0.000	0.015	0.039
h	0.071	0.016	0.010	0.022	0.022	0.014	0.000	0.019	0.083
$h\pi^0$	0.063	0.027	0.019	0.011	0.045	0.009	0.000	0.027	0.090
$h2\pi^0$	0.089	0.021	0.014	0.004	0.007	0.003	0.040	0.028	0.105
$h3\pi^0$	0.056	0.012	0.015	0.000	0.008	0.001	0.008	0.030	0.068
$h4\pi^0$	0.029	0.005	0.011	0.000	0.015	0.000	0.000	0.019	0.040
$3h$	0.047	0.021	0.018	0.004	0.012	0.014	0.006	0.015	0.059
$3h\pi^0$	0.033	0.017	0.029	0.002	0.041	0.009	0.007	0.018	0.066
$3h2\pi^0$	0.027	0.008	0.015	0.000	0.009	0.003	0.012	0.014	0.038
$3h3\pi^0$	0.010	0.012	0.002	0.000	0.002	0.001	0.010	0.006	0.019
$5h$	0.002	0.000	0.002	0.000	0.000	0.001	0.000	0.003	0.004
$5h\pi^0$	0.002	0.000	0.006	0.000	0.000	0.000	0.000	0.002	0.007
Class 14	0.013	0.003	0.022	0.002	0.024	0.000	0.000	0.011	0.037

All numbers are absolute in per cent. The labels are defined as follows: photon and π^0 reconstruction (π^0), event selection efficiency (sel), non-t background (bkg), charged particle identification (pid), secondary interactions (int), tracking (trk), Monte Carlo dynamics (dyn), Monte Carlo statistics (mcs), total systematic uncertainty (total).

- ▶ many systematics but in general all limited only by data vs. MC comparisons
- ▶ non-trivial to extrapolate to 1300^2 more data

Main systematics of ALEPH tau BR paper, Phys. Rept. 421 (2005) 191

- ▶ non-tau backgrounds
 - ▶ estimated by varying MC estimate by 30%
 - ▶ **does not trivially scale with luminosity**, but can be improved
- ▶ tau pair selection
 - ▶ use break-mix method on data and MC, 0.1-0.2% uncertainties
dominant systematics from data statistics of tau vs. hadron cut separation
 - ▶ scales with luminosity, **but correlations between hemispheres limit how much**
- ▶ PID
 - ▶ uncertainties from control samples studies
 - ▶ partially scales with luminosity, but **limited by achievable purity of control samples**
- ▶ photon efficiency
 - ▶ uncertainties from control samples studies data-MC comparisons
 - ▶ fit data using predicted MC fake and genuine photon distributions and compare number of genuine photons
 - ▶ compare photons $> 3 \text{ GeV}$ as function of separation from tracks
 - ▶ compare converted photons
 - ▶ compare hadron to electron misidentification
 - ▶ compare photon identification efficiency
 - ▶ photon energy scale calibrated with momentum measurement on high-energy e from tau decay
 - ▶ compare fake photons

Main systematics of ALEPH tau BR paper, Phys. Rept. 421 (2005) 191

- ▶ π^0 efficiency
 - ▶ compare data and MC D_{ij} distributions (probability γ_i, γ_j) of π^0 mass fit
- ▶ efficiency for π^0 with unresolved photons
 - ▶ compare data and MC 2nd moment of transverse energy in calorimeter cells
- ▶ radiative and bremsstrahlung photons
 - ▶ compare data and MC distributions
 - ▶ compare PHOTOS vs. exact calculation for $\tau \rightarrow \pi\pi^0\nu$ with radiative $E_\gamma > 12$ MeV
- ▶ tracking
 - ▶ compare data and MC on same sign events events (two tracks missing in one hemisphere)
- ▶ tau decay dynamic
 - ▶ reduced because acceptances are large and flat
 - ▶ will become important with higher statistics
 - ▶ can be partially addressed with iterative concurrent measurements where also invariant mass distributions are fitted on data (complicate)