LFU Tests in Tau Decays at Belle II

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on behalf of the Belle II Collaboration

Anomalies and Precision in the Belle II Era - Workshop

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HEPHY INSTITUTE OF HIGH ENERGY PHYSICS

EUROPEAN COMMISSION

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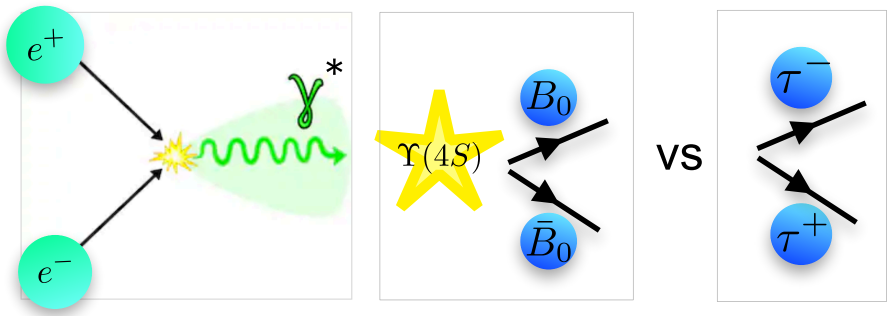
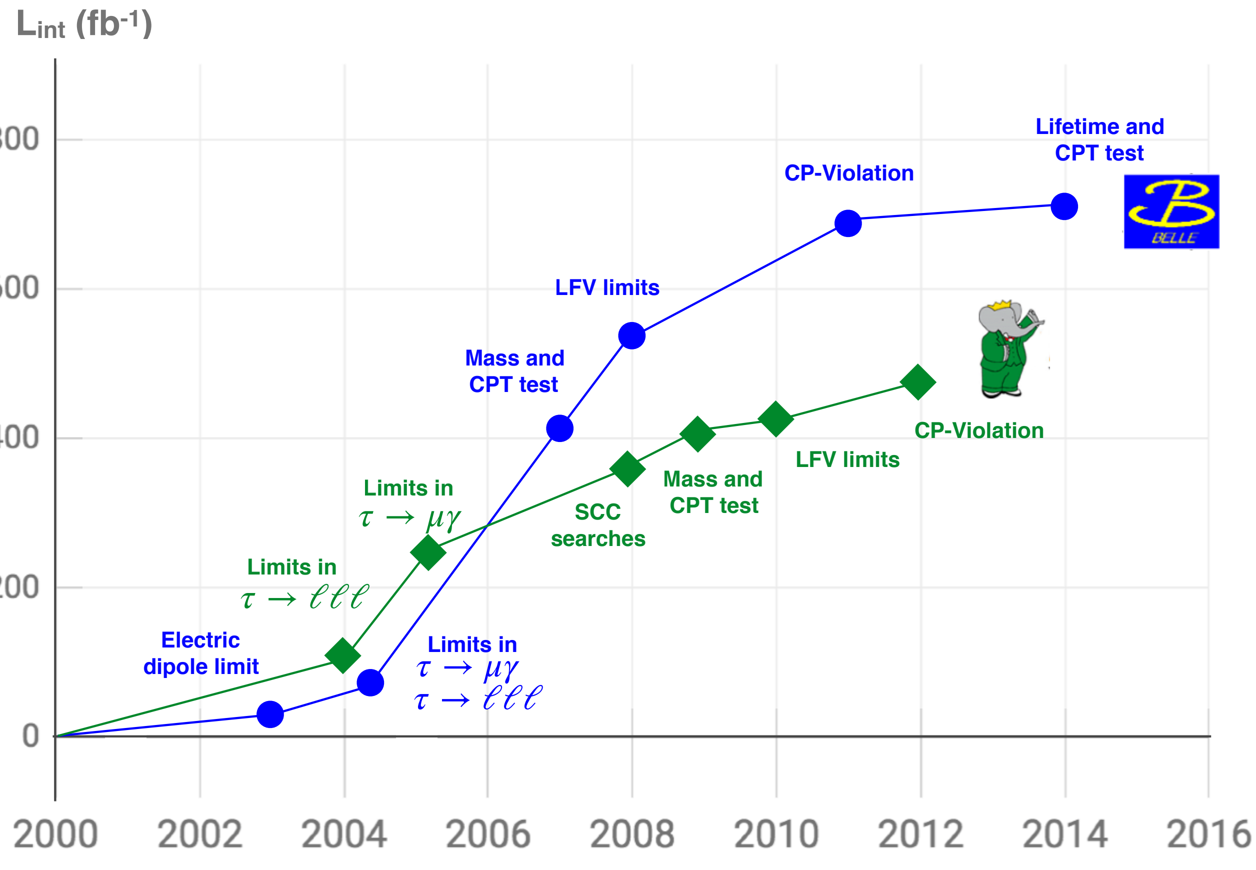
Belle II

Belle II as a τ-factory

- **B-factories are also τ-factories!**
  - $\sigma(e^+e^- \to \Upsilon(4s)) = 1.05$ nb
  - $\sigma(e^+e^- \to \tau^+\tau^-) = 0.92$ nb





- Last generation B-factories provided a variety of very interesting τ physics results in the last two decades

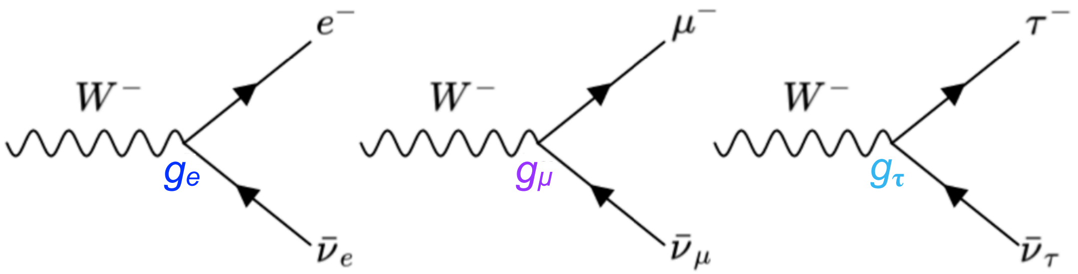
- Over its lifetime Belle II will deliver an enormous sample of ~4.6×10^{10} τ-pair events

⇒ a unique environment to study τ physics with high precision!

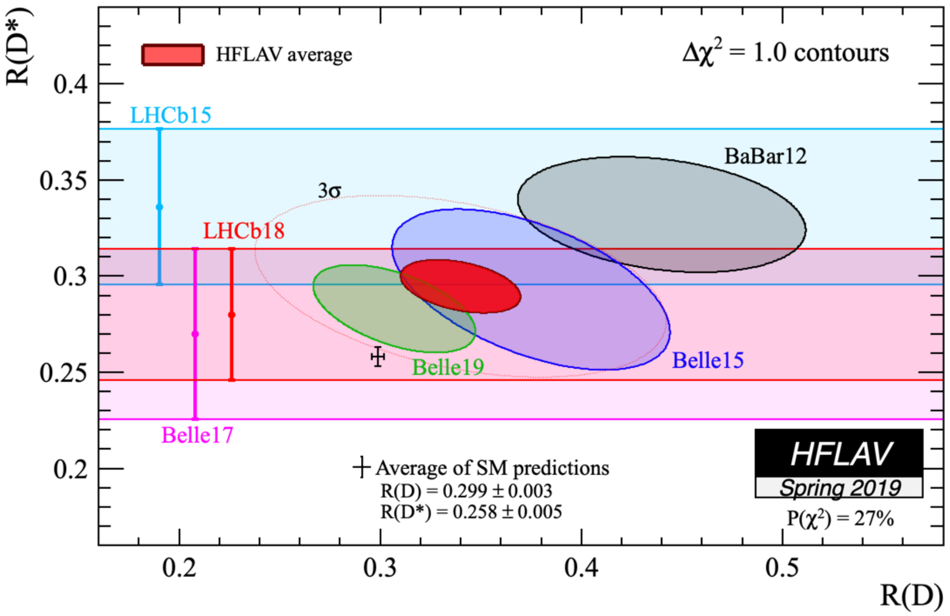
Lepton Flavour Universality

- LFU ⇒ couplings of leptons to W bosons is flavour independent

$$g_e = g_\mu = g_\tau$$



- Anomalies in **quark sector**
  - R(D)-R(D*) (3.1σ)
  - R(K) (3.1σ)
  - P_5' in $B \to K^* \mu\mu$ (3.4σ)
  - $B_s \to \varphi ll$ (3.6σ)
  - and more…
- also **lepton sector**
  - $(g-2)_\mu$ (4.2σ) and also for e (2.5σ)



- **Hints of a new fundamental interaction that violates LFU?**
- If so, then we could see evidence also in the **tau sector**

⇒ test of e-μ universality $$\left(\frac{g_\mu}{g_e}\right)^2_\tau \propto \frac{B(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{B(\tau^- \to e^- \bar{\nu}_e \nu_\tau)}$$

⇒ test of τ-μ universality $$\left(\frac{g_\tau}{g_\mu}\right)^2_h \propto \frac{B(\tau \to h \nu_\tau)}{B(h \to \mu \nu_\mu)}$$

Test of e-μ universality

- The most stringent test of μ-e universality in the tau sector comes from measurement of the ratio R_μ :

$$R_\mu = \frac{\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau)} \quad \Rightarrow \quad \left(\frac{g_\mu}{g_e}\right)^2_\tau = R_\mu \cdot \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}$$

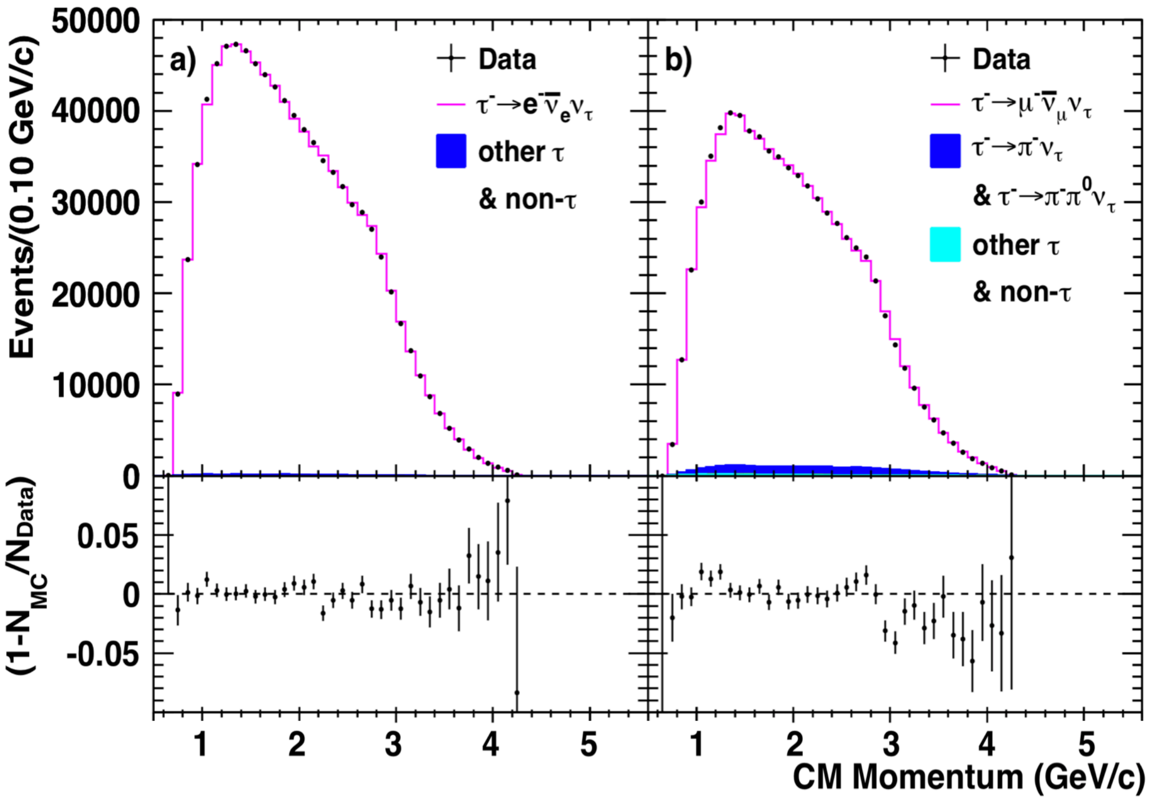
, where: $f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \log x$

- World-leading measurement from *BABAR* (467 fb^{-1}) with $e^+e^- \to \tau^\pm(\to \ell^\pm \nu\bar{\nu})\ \tau^\mp(\to 3h^\mp(n\pi^0)\nu)$

PRL 105:051602 (2010)

R_μ = 0.9796 ± 0.0016 (stat) ± 0.0036 (sys)

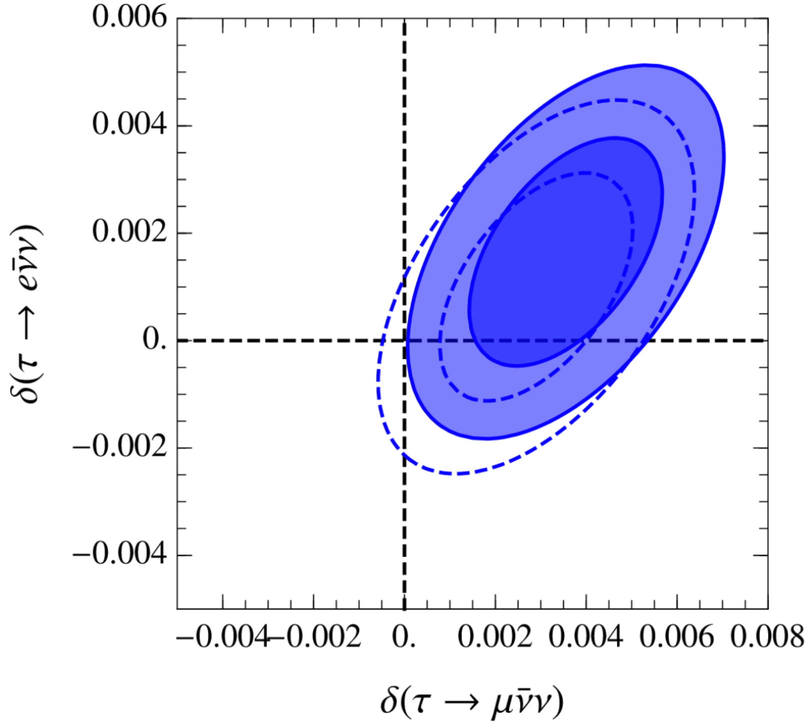
$$\left(\frac{g_\mu}{g_e}\right)_\tau = 1.0036 \pm 0.0020$$



- High purity samples were achieved:
  - 99.7% in the $\tau \to e\bar{\nu}\nu$ channel
  - 97.3% in the $\tau \to \mu\bar{\nu}\nu$ channel

Search for LFUV in $\tau \to \ell\bar{\nu}\nu$

arXiv:2105.06734



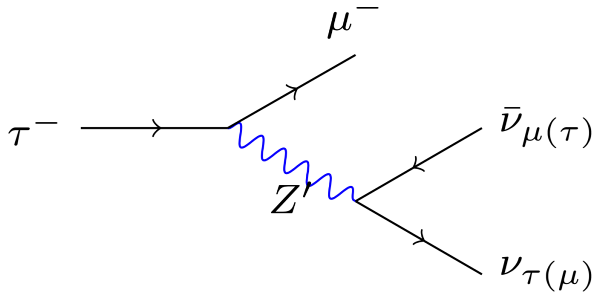
$$\frac{A_{EXP}(\tau \to \mu\nu\bar{\nu})}{A_{SM}(\mu \to e\nu\bar{\nu})} = 1.0029 \pm 0.0014$$

$$\frac{A_{EXP}(\tau \to \mu\nu\bar{\nu})}{A_{SM}(\tau \to e\nu\bar{\nu})} = 1.0018 \pm 0.0014$$

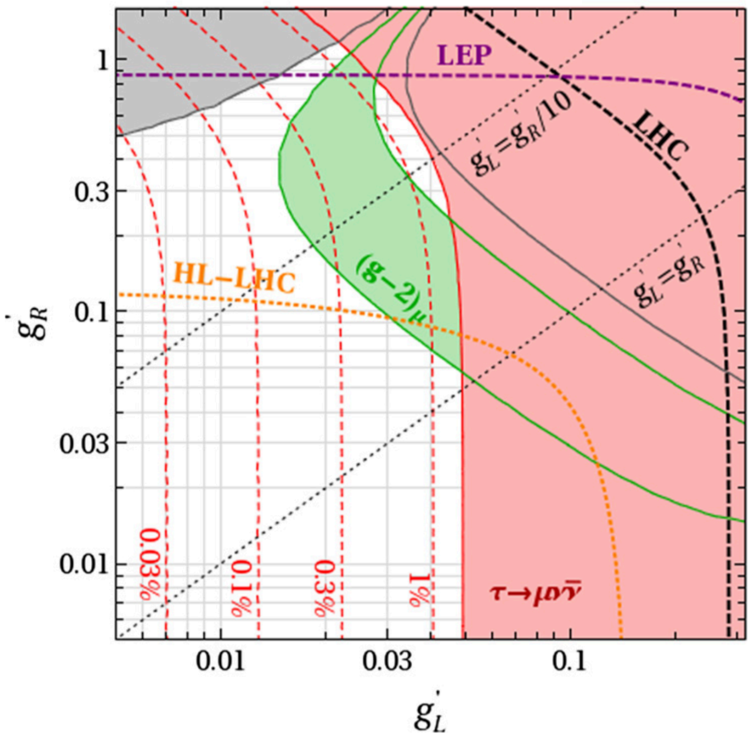
$$\frac{A_{EXP}(\tau \to e\nu\bar{\nu})}{A_{SM}(\mu \to e\nu\bar{\nu})} = 1.0010 \pm 0.0014$$

- Global fit to $\tau \to \ell\bar{\nu}\nu$ and $\mu \to e\bar{\nu}\nu$ ratios (latter well constrained by EW data)
  $\Rightarrow$ **2σ** tension with SM

- NP could enter in a variety of ways
  - LFV violating *Z'*
  - Singly charged scalar
  - *W'*
  - L_μ-L_τ Z' (box diagrams)
  - Modified *Wlv* couplings, and more…



$m_{Z'}$ = 100 GeV arXiv:1607.06832v1

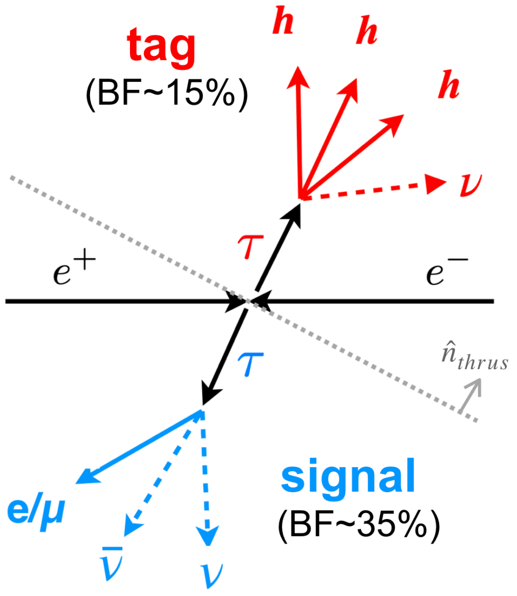


- Will this tension become more significant with better precision on R_μ?
  Belle II can provide answers!

Belle II analysis

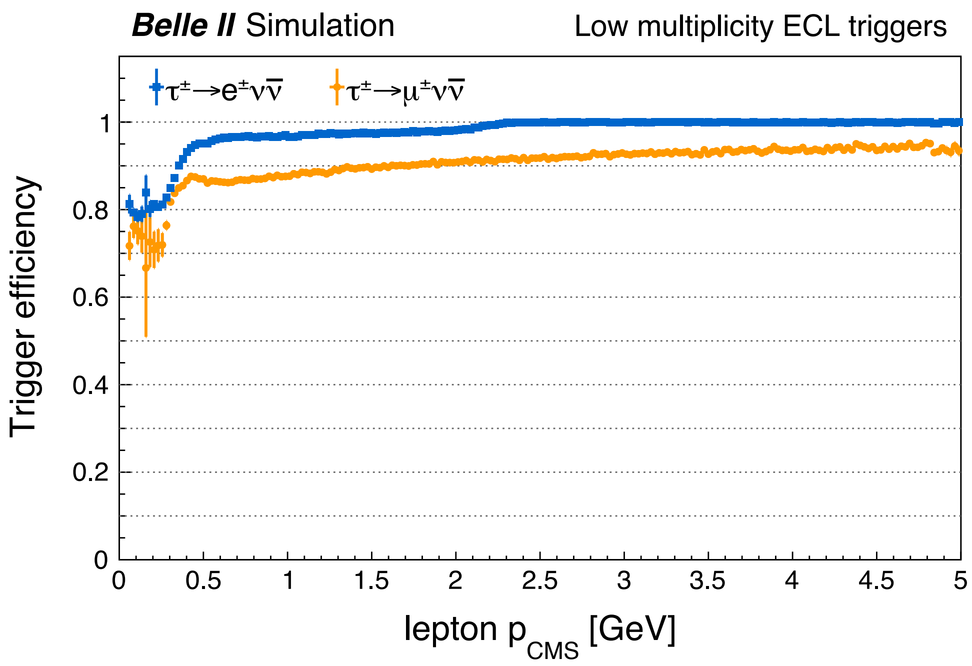
- MC sensitivity study for the test of **e-μ universality** using $e^+e^- \rightarrow \tau^-(\rightarrow l^-\bar{\nu}\nu)\ \tau^+(\rightarrow 3h^+(n\pi^0)\nu)$ events @ Belle II

BELLE2-NOTE-PL-2021-009



- Use thrust vector to separate events into **signal** (1-prong) and **tag** (3-prong) hemispheres

$$V_{thrust} = \sum \frac{|\vec{p}_i^{\,CMS} \cdot \hat{n}_{trust}|}{\sum \vec{p}_i^{\,CMS}} \qquad |\vec{p}_{signal}^{\,CMS} \cdot \hat{n}_{thrust}| \cdot |\vec{p}_{tag,i}^{\,CMS} \cdot \hat{n}_{trust}| < 0\ , \forall\ i \in \text{tag}$$



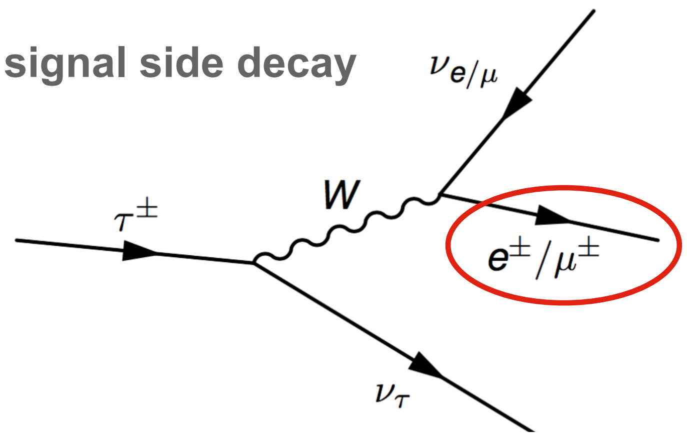
- New @ Belle II:
  dedicated ECL triggers for low multiplicity signatures (**lml**)

- Efficiency for 3x1 topology driven by **lml0**:
  - ≥3 ECL clusters, one with E > 300 MeV and not an ECL Bhabha

- Further boost efficiency by taking logical OR with **9 other lml triggers**

- For p > 1 GeV: **> 95% efficiency in τ→eν̄ν channel**
  > 90% efficiency in the τ→μν̄ν channel

Lepton identification



- @ Belle II we have available two kinds of **lepton identification (ID)**
  - **Likelihood**-based:

$$\frac{\mathcal{L}_\ell}{\mathcal{L}_e + \mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K + \mathcal{L}_p}, \quad \mathcal{L}_i = \prod_d^{d\in D} \mathcal{L}_i^d \quad \Rightarrow \quad \text{leptonID} > 0.9$$

  - **Boosted Decision Tree (BDT)** -based $\Rightarrow$ leptonID > 0.9 (0.99) for $\tau\to\mu(e)\nu\bar{\nu}$

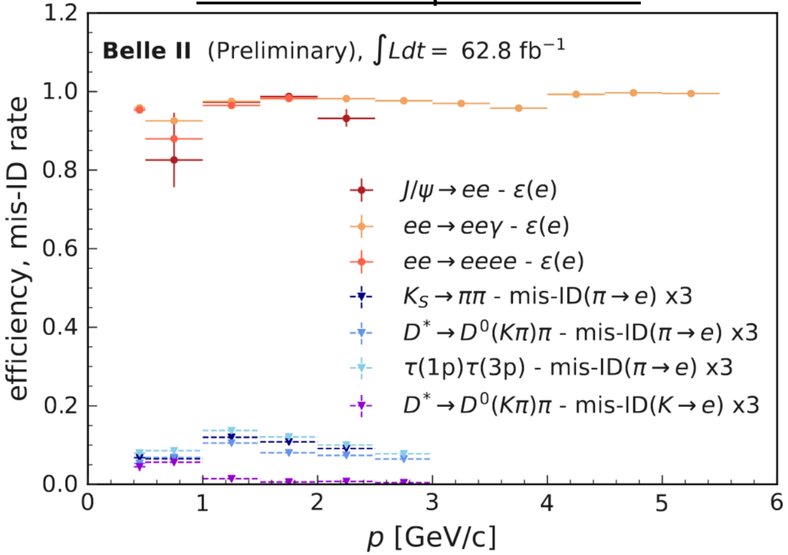
    factor ~10 (~2) $\pi\to e$ (μ) fake reduction at p < 1 GeV for same efficiency

- Data/MC correction factors and systematic uncertainties have been measured from several tag-and-probe studies

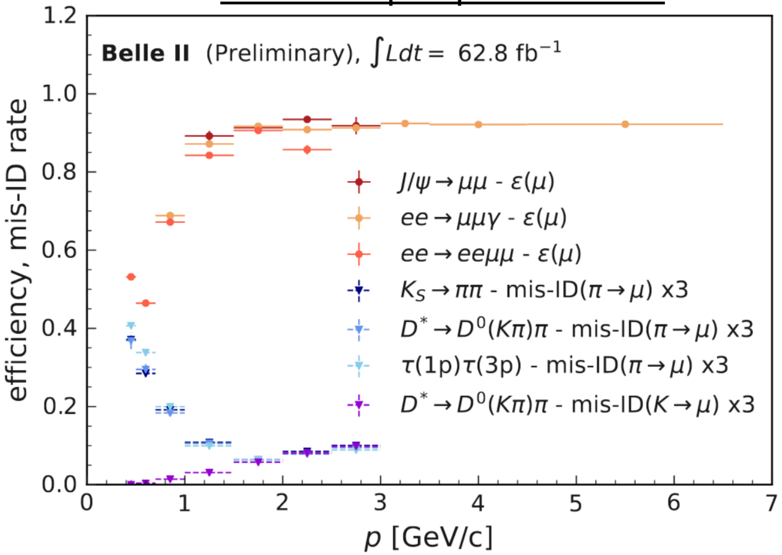
  BELLE2-CONF-PH-2021-002

  - Efficiency studies: $\ell\ell(\gamma)$, $ee\ell\ell$ & $J/\psi \to \ell\ell$
  - Fake rate studies: $K_S^0 \to \pi\pi$, $\tau\tau$ & $D^* \to D^0(\to K\pi)\pi$

likelihood eID performance



likelihood μID performance

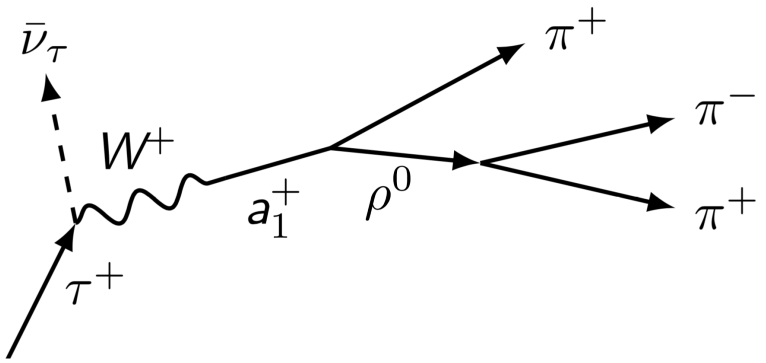


- Optimisation of cut-based analysis. Factor 100 penalty to background in FOM, favouring purity over efficiency.

$$FOM = \frac{N_{sig}}{\sqrt{N_{sig} + 100 \cdot N_{bkg}}}.$$

		$\tau \to e\bar{\nu}\nu$ channel	$\tau \to \mu\bar{\nu}\nu$ channel
tag side	track p_T [GeV]	*lead*: (0.75, 4.39) *sub*: (0.45, 2.43) *third*: (0.12, 1.76)	(0.68, 3.59) (0.17, 2.45) (0.04, 1.68)
	track E/p	< 0.8	< 0.8
	vertex prob(χ^2)	[0, 0.99)	≥ 0
	neutrals	$\# \pi^0 \leq 1$ $\# \gamma \leq 1$	≤ 1 ≤ 1
	mass [GeV]	(0.5, 1.5)	(0.55, 1.4)
signal side	track cluster energy [GeV]	(0.4, 5.6)	(0.17, 0.3)
	track E/p	(0.95, 1.04)	(0.06, 0.2)
	track p (CMS) [GeV]	(0.6, 4.8)	(0.6, 3.6)
	neutrals	π^0 veto γ veto	veto veto

tag side decay



- **Tag strategy at Belle II**:
  - E/p < 0.8 (or undefined)
  - asymmetric thresholds on lead, sublead and third $\pi^\pm$ p_T

- ***BABAR* style**:
  - rely instead on tighter pion ID requirements to reach required level of purity

Background suppression

- Optimisation of cut-based analysis. Factor 100 penalty to background in FOM, favouring purity over efficiency.

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	track E/p	< 0.8	< 0.8
	vertex prob(χ^2)	[0, 0.99)	≥ 0
	neutrals	# π^0 ≤ 1 # γ ≤ 1	≤ 1 ≤ 1
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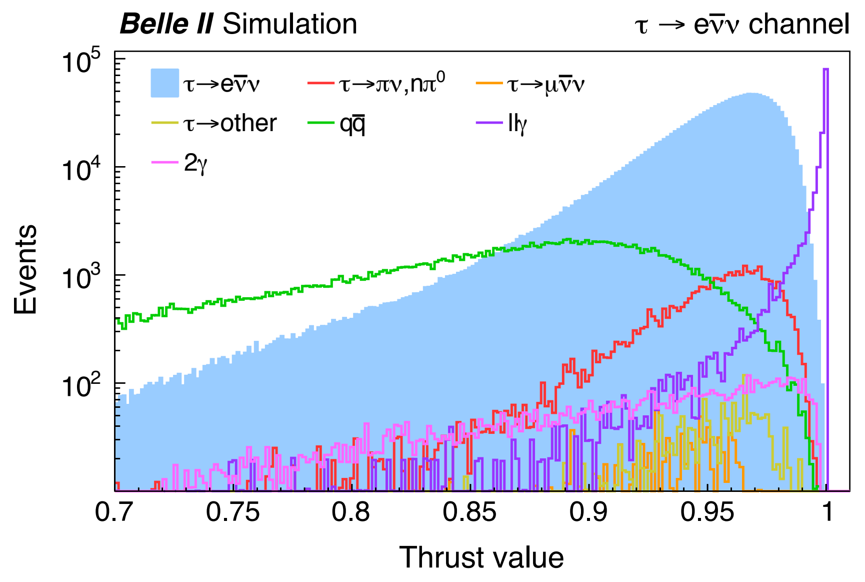
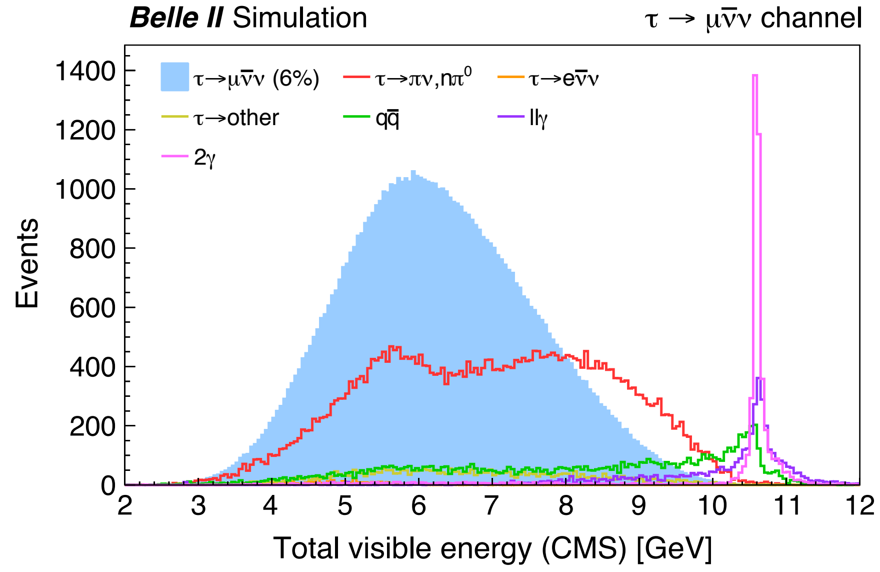
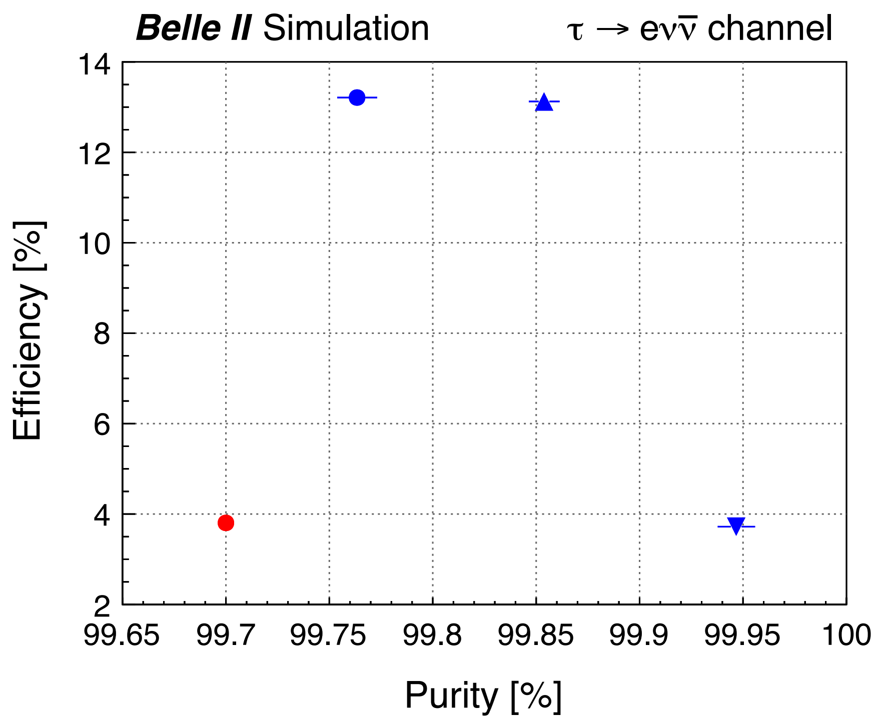
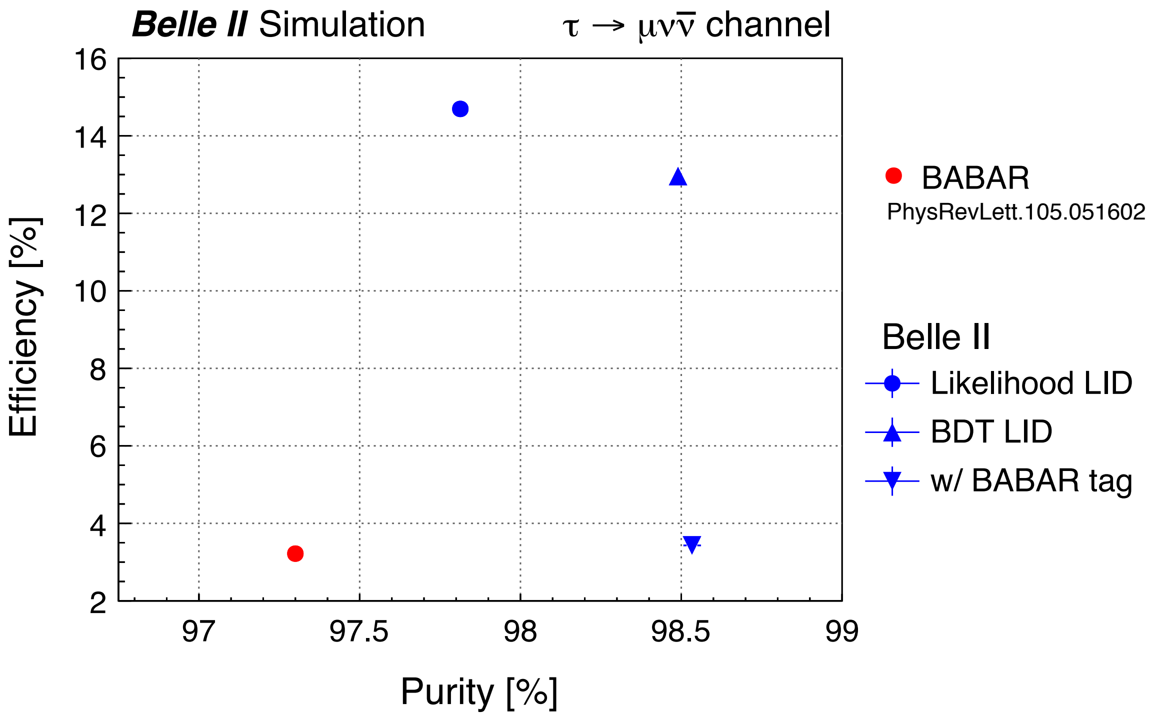
	track p (CMS) [GeV]	(0.6, 4.8)	(0.6, 3.6)
	neutrals	π^0 veto γ veto	veto veto
event shape & kinematics	Missing momentum θ [deg]	(13, 172)	(5, 170)
	Thrust value	(0.9, 0.98)	(0.92, 0.99)
	Total visible E (CMS) [GeV]	(2.5, 8)	(3, 8)





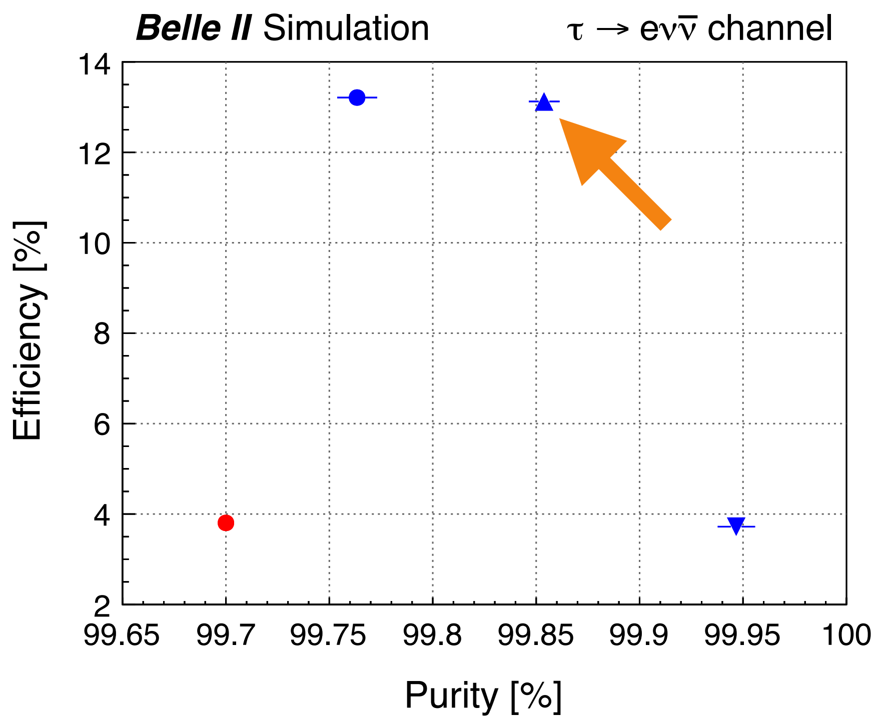


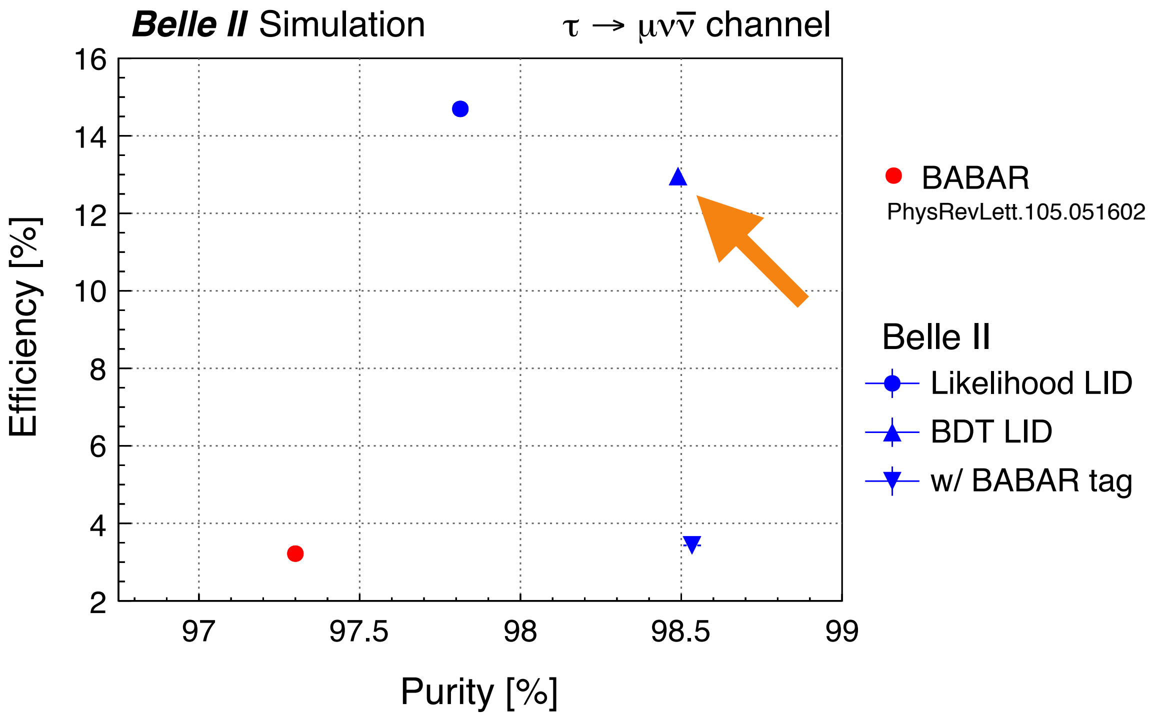


$$\varepsilon = \frac{N^{signal}_{selected}}{N^{signal}_{generated}} \qquad P = \frac{N^{signal}_{selected}}{N^{total}_{selected}}$$

$$N^{signal}_{generated} = 2 \cdot \sigma_{\tau\tau} \cdot \mathcal{L} \cdot \mathcal{B}_{\tau\to\ell\bar{\nu}\nu} \cdot \mathcal{B}_{tag}$$

- Comparing three Belle II working points:
  - Belle II tag selection, and either **likelihood** or **BDT-based lepton ID**
  - **BABAR-style tag** (pion ID > 0.5 for the 3-prong tracks)





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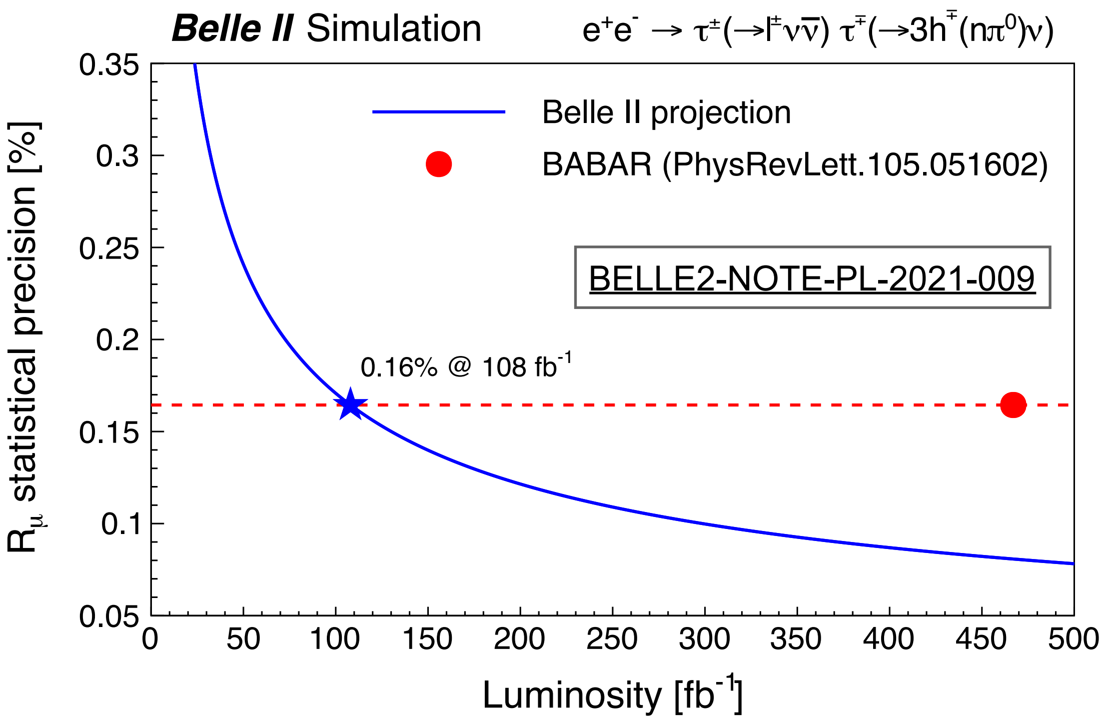
Compared to BABAR, Belle II has **~4x higher efficiency with better purity**

Belle II sensitivity

- Projection of statistical precision on R_μ as function of luminosity

$$R_\mu = \frac{\mathcal{B}[\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau]}{\mathcal{B}[\tau^- \to e^- \bar{\nu}_e \nu_\tau]}$$

Belle II can match BABAR stat. precision with ~100 fb^{-1} of data.
Expect to reach <0.1% precision on Summer 2022 dataset.



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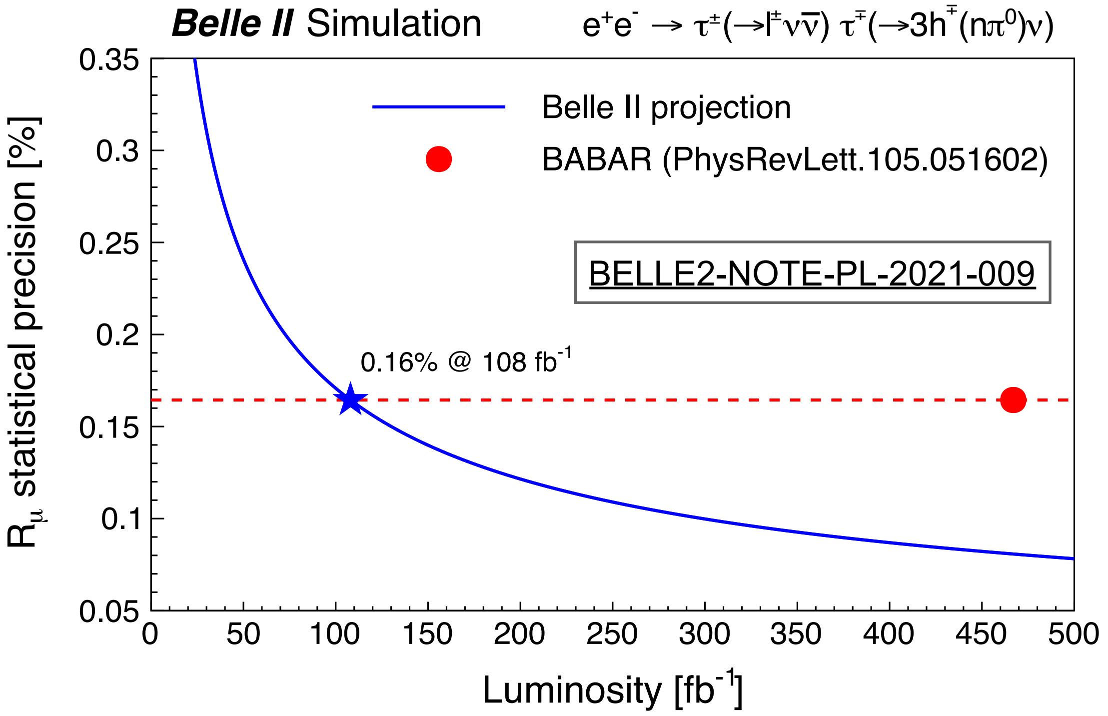
- However, like at BABAR, the measurement in the end will be systematics limited!

systematics @BABAR

Systematic uncertainties:	
Particle ID	0.32
Detector response	0.08
Backgrounds	0.08
Trigger	0.10
$\pi^-\pi^-\pi^+$ modelling	0.01
Radiation	0.04
$\mathcal{B}(\tau^- \to \pi^-\pi^-\pi^+\nu_\tau)$	0.05
$\mathcal{L}\sigma_{e^+e^- \to \tau^+\tau^-}$	0.02
Total [%]	0.36



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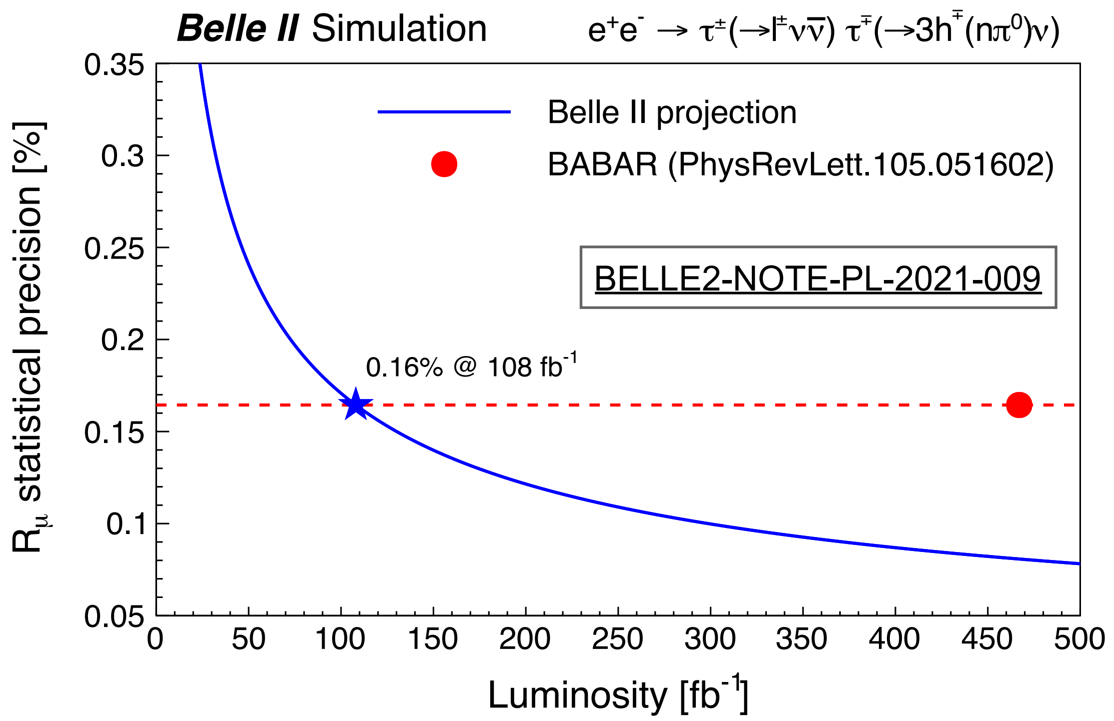

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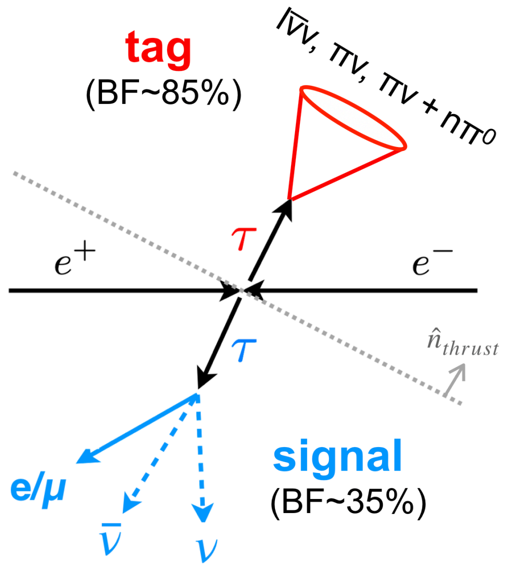
⇒ **Can we do better at Belle II?**

- LID uncertainties for isolated leptons should scale well with luminosity + higher stat MC. Important to understand differences b/w T&P studies (J/Ψ→ll, ee→llγ and 2γ).
- Trigger uncertainty will depend on stable L1 operation and reliable simulation. At Belle II we are already at the ~1% level (vs 10% at BABAR).
- A lot of work ahead and already underway…

Search for LFUV with 1x1 topology

- Belle II also plans to test **e-μ universality** using the **1x1 topology**.
- Never studied by Belle/BABAR. Most recent result from CLEO (3.56 fb^{-1}). SLAC-PUB-9839
- 1x1 benefits from larger signal sample: **inclusive 1-prong tag** (BR~85%). However, both the backgrounds and trigger more challenging.



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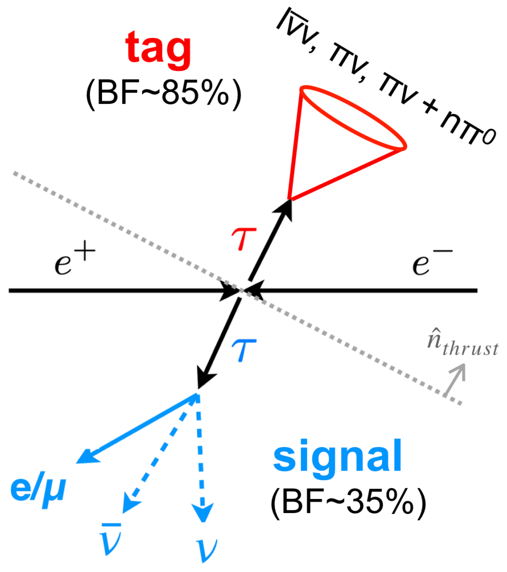
- @ Belle II we are starting with the clean **muon tag** ($\tau \to \mu \bar{\nu} \nu$) BELLE2-NOTE-PL-2021-009



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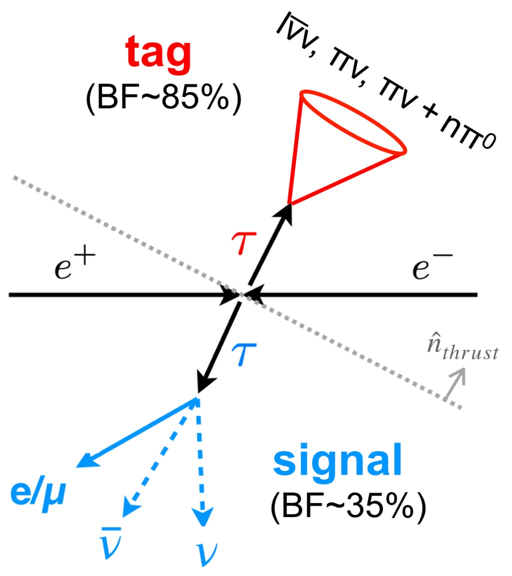
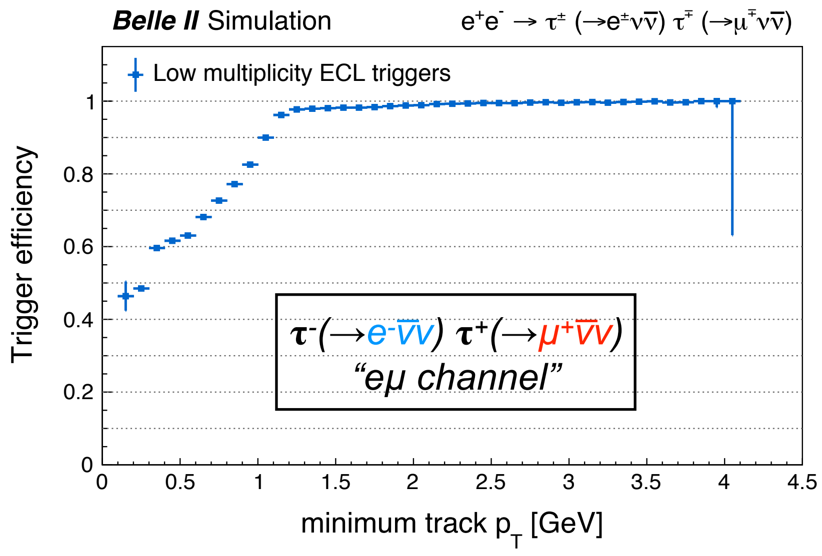
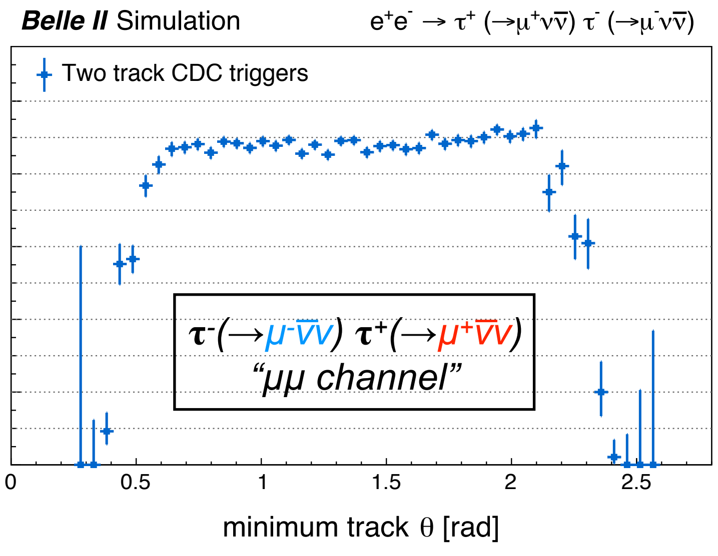


- Lepton ID for **tag** and **signal** side:
  - again, considering both likelihood and BDT-based LID
- Trigger:
  - **eμ channel**: logical OR of ECL lml triggers
  - **μμ channel**: CDC track triggers (long & short)





1x1 analysis: background suppression

- In order to suppress the significantly larger backgrounds in the 1x1 topology, we have developed two MVA techniques:

(1) Two-step Boosted Decision Tree (**BDT**)

(2) Neural Network (**NN**)

Baseline

- 1x1 topology wrt thrust
- lepton ID
- trigger

BDT pre-selection

	eμ	**μμ**
signal p [GeV]	> 0.2	> 0.2
signal clusterE [GeV]	> 0.4	> 0.4
visible E (CMS) [GeV]	[2,7.6)	[1.5, 7.6)

- 2D selection on M_{miss}^2 vs θ of p_{miss}

NN pre-selection

	eμ	**μμ**
p_T^{max} (CMS) [GeV]	[0.62, 5.08)	[1.64, 5.0)
M_{miss}^2 [GeV^2]	[1.23, 99.23)	[2.85, 91)
p_{miss} (CMS) [GeV]	[0.03, 4.2)	[0.46, 4.47)
θ of p_{miss} (CMS) [rad]	[0.18, 2.96)	[0.53, 2.65)
visible E (CMS) [GeV]	[1.1, 10.76)	[1.12, 8.54)
total ECL E [GeV]	[0, 4.32)	[0, 1.18)
#γ	[0, 4)	[0, 4)

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BDT step 1

- Training **generic** τ-pair vs everything else
- FastBDT
- Parameters:
  - nTrees = 500
  - shrinkage = 0.2
  - nLevels = 2
- Training variables:
  - tracks p_T, p, θ, ϕ, E/p, clusterE
  - tracks cos(θ) to thrust, mass
  - visible E (CMS), thrust
  - M_{miss}^2, θ of p_{miss} (CMS), p_{miss}
  - $\#\pi^0$, #γ, total γ energy

NN pre-selection

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M_{miss}^2 [GeV^2]	[1.23, 99.23)	[2.85, 91)
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θ of p_{miss} (CMS) [rad]	[0.18, 2.96)	[0.53, 2.65)
visible E (CMS) [GeV]	[1.1, 10.76)	[1.12, 8.54)
total ECL E [GeV]	[0, 4.32)	[0, 1.18)
#γ	[0, 4)	[0, 4)

1x1 analysis: background suppression

- In order to suppress the significantly larger backgrounds in the 1x1 topology, we have developed two MVA techniques:

(1) Two-step Boosted Decision Tree (**BDT**)
(2) Neural Network (**NN**)

Baseline

- 1x1 topology wrt thrust
- lepton ID
- trigger

BDT pre-selection

	eμ	μμ
signal p [GeV]	> 0.2	> 0.2
signal clusterE [GeV]	> 0.4	> 0.4
visible E (CMS) [GeV]	[2,7.6)	[1.5, 7.6)

- 2D selection on M_{miss}^2 vs θ of p_{miss}

BDT step 1

- Training **generic** τ-pair vs everything else
- FastBDT
- Parameters:
  - nTrees = 500
  - shrinkage = 0.2
  - nLevels = 2
- Training variables:
  - tracks p_T, p, θ, ϕ, E/p, clusterE
  - tracks cos(θ) to thrust, mass
  - visible E (CMS), thrust
  - M_{miss}^2, θ of p_{miss} (CMS), p_{miss}
  - #π^0, #γ, total γ energy

BDT step 2

- Training **signal** τ-pair vs all remaining bkgs.
- Same parameters & training variables.

NN pre-selection

	eμ	μμ
p_T^{max} (CMS) [GeV]	[0.62, 5.08)	[1.64, 5.0)
M_{miss}^2 [GeV^2]	[1.23, 99.23)	[2.85, 91)
p_{miss} (CMS) [GeV]	[0.03, 4.2)	[0.46, 4.47)
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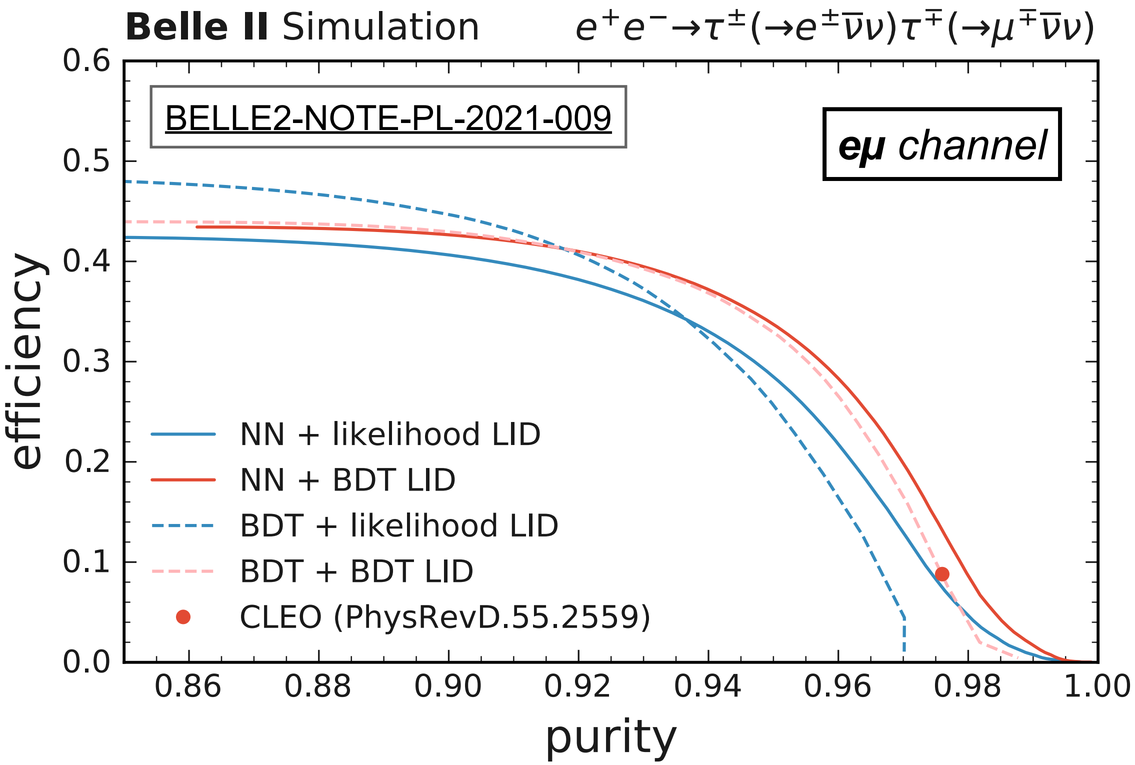
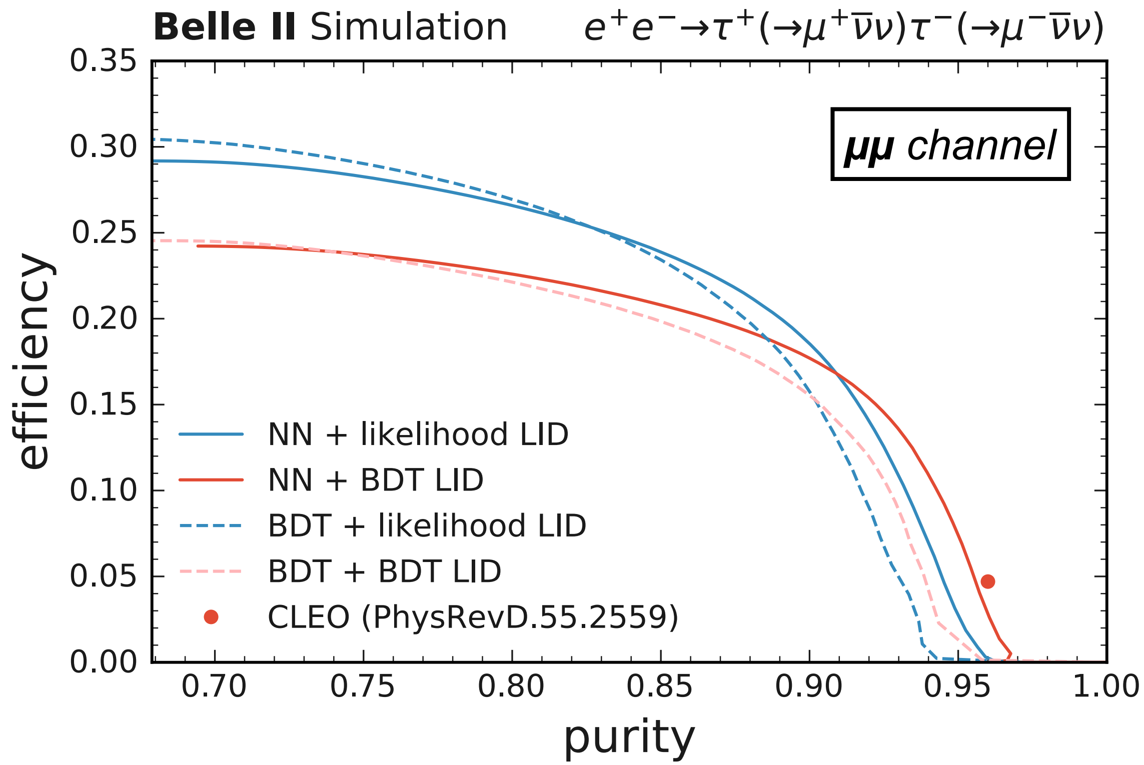
#γ	[0, 4)	[0, 4)

NN
- Training **signal** τ-pair vs everything else
- 3 fully connected layers (20 neurons each)
- loss = weighted cross entropy
- optimiser = stochastic gradient descent
- Parameters:
  - batch size = 2048, epochs = 200
  - LR = 0.1, test size = 40%, momentum = 0.15
- Features:
  - visible E (CMS), M_{miss}^2
  - p_{miss} (CMS), θ of p_{miss}
  - thrust, #γ, total γ energy
  - tracks Δϕ, cos(θ) to thrust
  - thrust frame p_T & p_l
  - tracks p_T, p, E/p

- Using MVA we can go beyond CLEO performance for **eμ** events, and get very close for **μμ** events



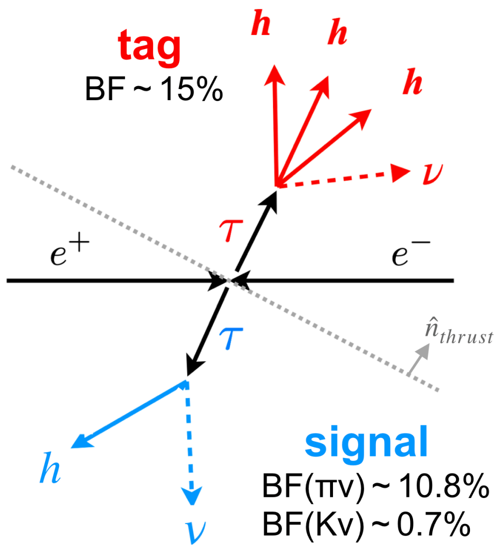


- Belle II can already exceed CLEO on statistical precision for R_μ.
- There is a lot of work ahead to get systematic uncertainties at or below CLEO-level (especially lepton ID).

LFU in τ→hν and V_{us}

- We can also test **τ-μ universality** using **τ→hν** (h = π,K) decays

$$\left(\frac{g_\tau}{g_\mu}\right)_h^2 = \frac{\mathcal{B}(\tau \to h\nu_\tau)}{\mathcal{B}(h \to \mu\nu_\mu)} \frac{2m_h m_\mu^2 \tau_h}{(1+\delta_h)m_\tau^3 \tau_\tau} \left(\frac{1-m_\mu^2/m_h^2}{1-m_h^2/m_\tau^2}\right)^2$$



- World-leading measurement from BABAR: Phys.Rev.Lett.105:051602 (2010)

$$\left(\frac{g_\tau}{g_\mu}\right)_h = 0.9850 \pm 0.0054$$ ⇒ **2.8σ** below the SM expectation

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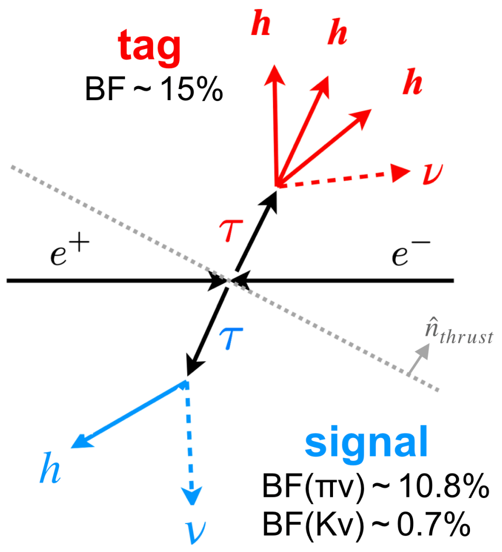

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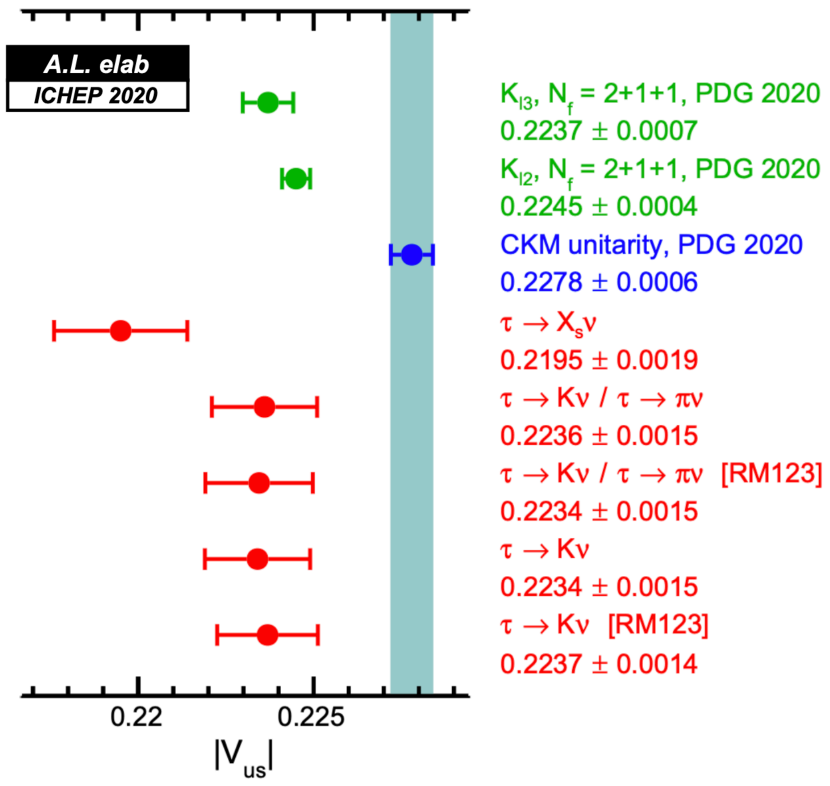


- From this analysis one can also extract the CKM element **$|V_{us}|$**:

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

- Several methods for measuring $|V_{us}|$ ⇒ **Hot topic!**
  - Neutral kaon decays, like $K_L^0 \to \pi^- e^+ \nu$
  - CKM unitarity
  - Tau decays

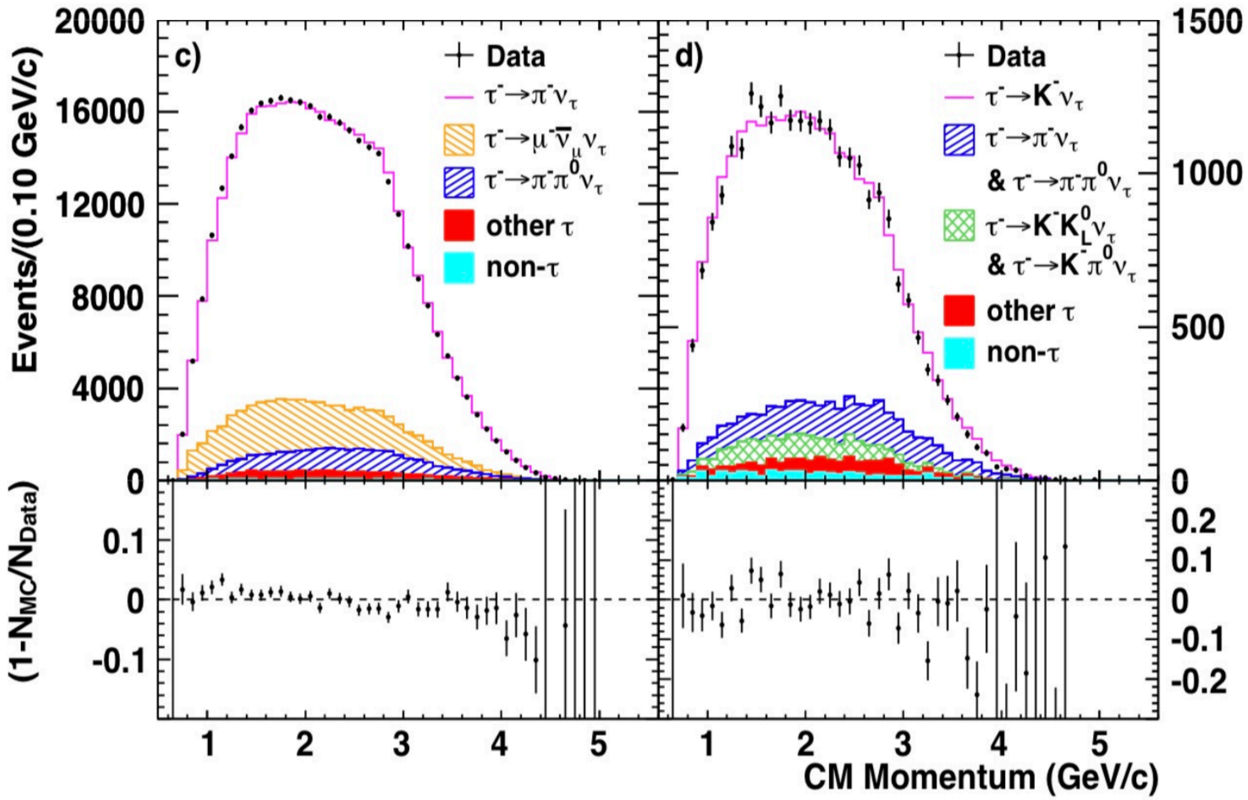
there is a tension b/w the unitarity and other two approaches…

New Physics? PRL 127.071801 PRL 125.111801

- BABAR achieved a purity of **78.7%** (**76.6%**) in the π (K) channel

⇒ excellent hadron ID (π vs K) performance will be critical to achieving this level of purity at Belle II

π-channel K-channel



Systematics @BABAR

	π	K
Particle ID	0.51	0.94
Detector response	0.64	0.54
Backgrounds	0.44	0.85
Trigger	0.10	0.10
$\pi^-\pi^-\pi^+$ modelling	0.07	0.27
Radiation	0.10	0.04
$\mathcal{B}(\tau^- \rightarrow \pi^-\pi^-\pi^+\nu_\tau)$	0.15	0.40
$\mathcal{L}\sigma_{e^+e^-\rightarrow\tau^+\tau^-}$	0.39	0.20
Total [%]	1.0	1.5

- Measurement systematics dominated, led by: **hadron ID**, **detector response** and the **background modelling**.

- **The corresponding analysis at Belle II is now in full swing!**

Summary

- Belle II prospects for testing of **e–μ universality** in **$\tau \to l\bar{\nu}\nu$ (l = e,μ)**: BELLE2-NOTE-PL-2021-009
  - **3x1 topology**:
    - match statistical precision of BABAR with ~100 fb^{-1} of data (we currently have 213 fb^{-1})
    - working hard to get LID systematics to a level that is competitive with BABAR
  - **1x1 topology**:
    - starting with clean muon tag (plan to eventually include other 1-prong decays)
    - MVA techniques allow us to exceed (eμ) or closely approach (μμ) CLEO performance
    - again, we are working hard to get LID systematics to a competitive level

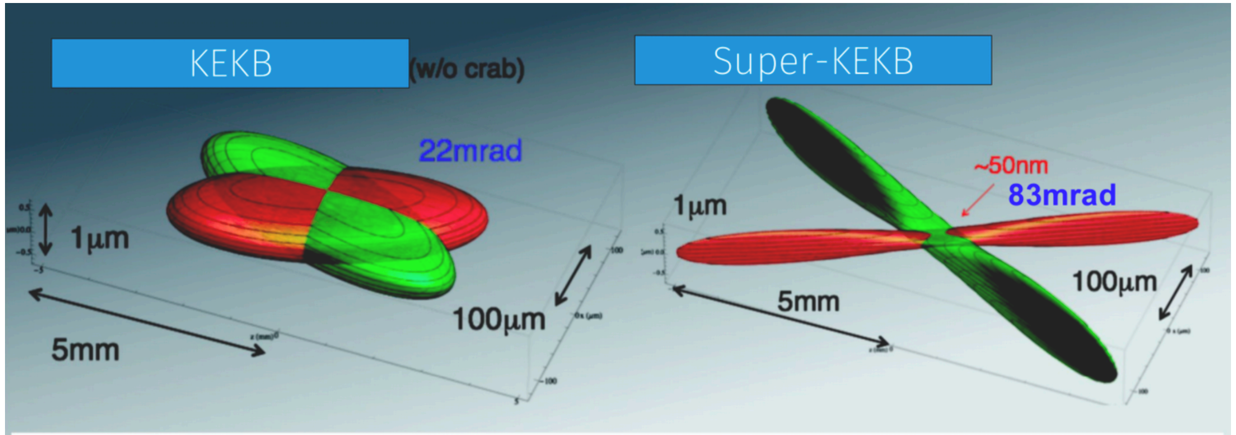
- **τ–μ universality** (and **$|V_{us}|$**) analysis in **$\tau \to h\nu$ (h = π,K)** is now also in full swing.

- Belle II will soon become a major player in the search for LFUV in tau decays. **Exciting times ahead!**

BACKUP

SuperKEKB Accelerator

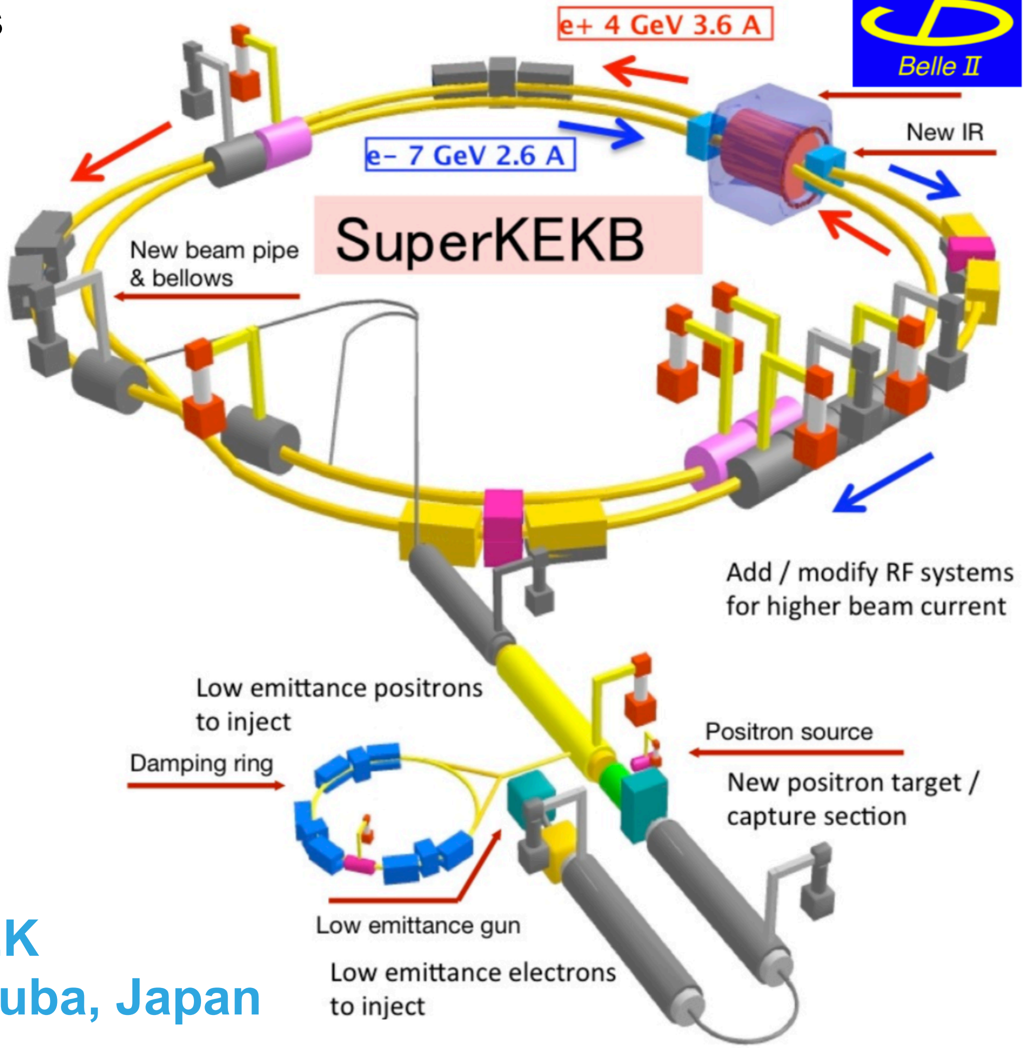
- Next generation B-factory: $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$, $\sqrt{s} \approx 10.58$ GeV
  + rich program of tau, dark sector and other low-multiplicity physics



	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	60 x 10^{34}

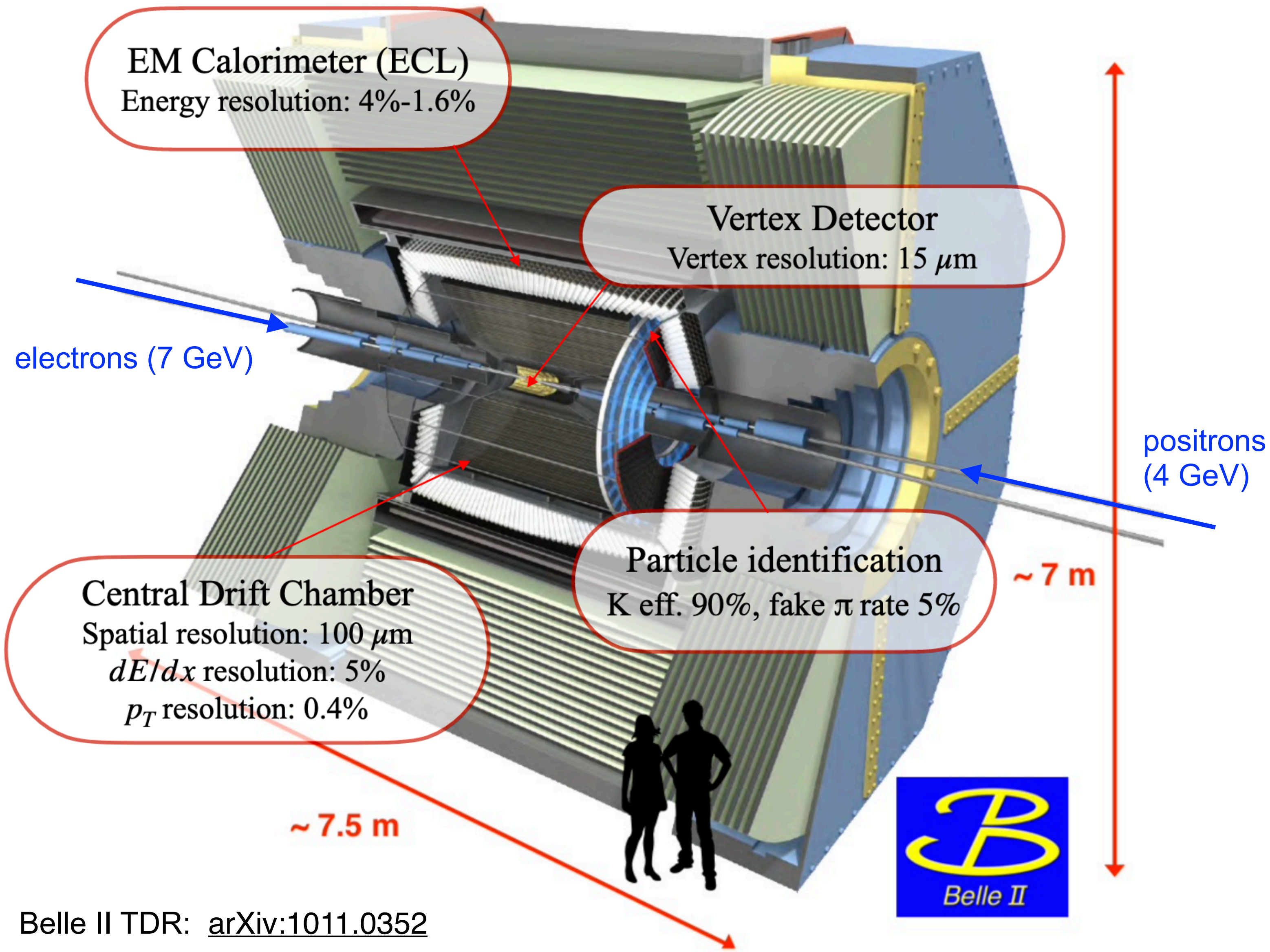
factor 20 factor 2-3

- Unprecedented design luminosity of ~6×10^{35} $cm^{-2}s^{-1}$
- First e^+e^- collisions in April 2018. Current holder of the luminosity world record (2.9×10^{34} $cm^{-2}s^{-1}$).



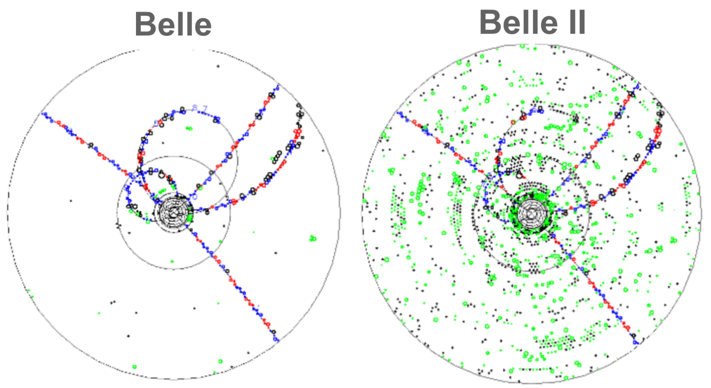
**@KEK
Tsukuba, Japan**

Belle II Detector



Belle II TDR: arXiv:1011.0352

- Increased beam backgrounds



⇒ upgraded trigger system and sub-detectors

- $\beta\gamma$ = 0.28 (vs 0.42 @ Belle)

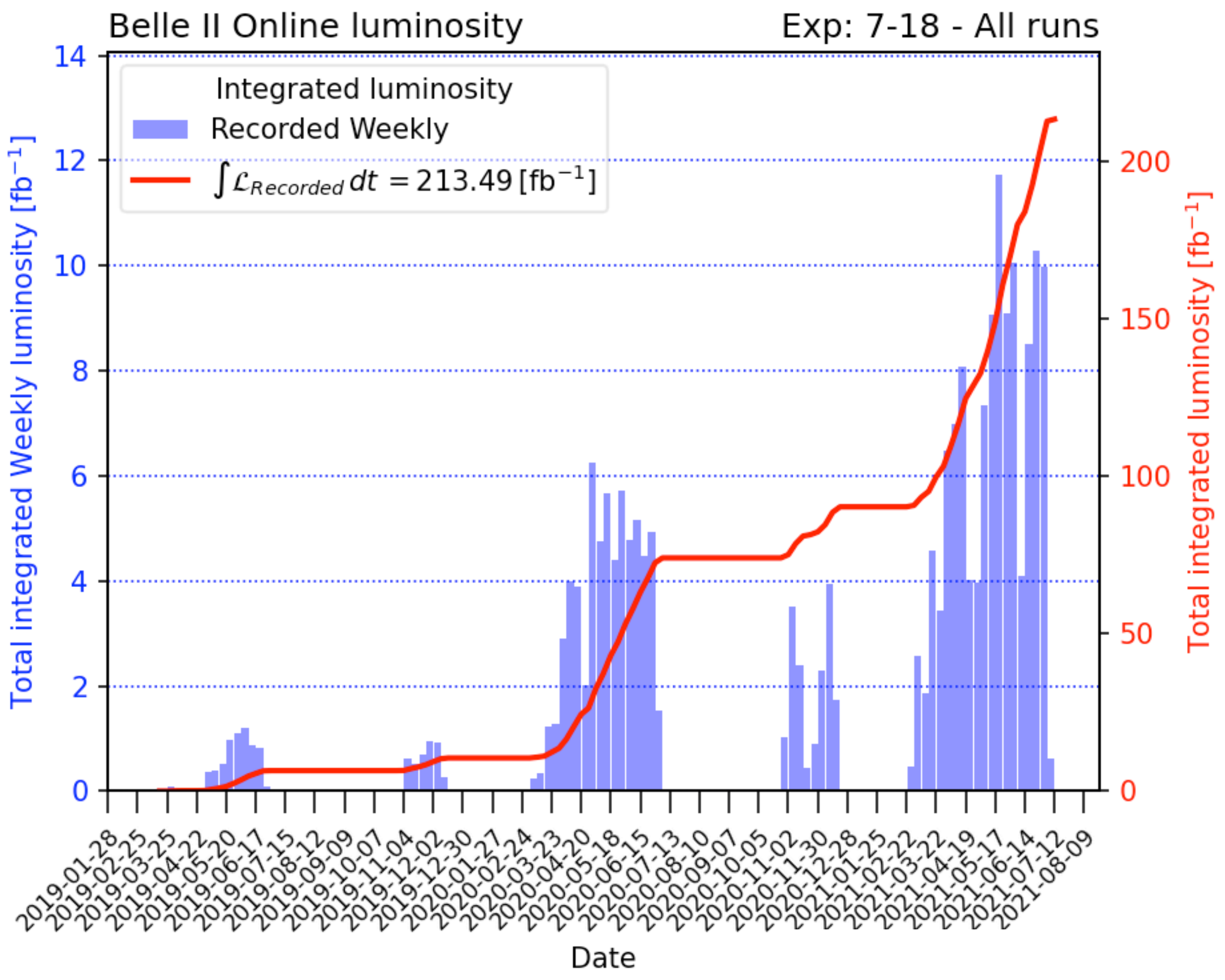
  ⇒ reduced boost requiring improved vertex reconstruction

- Solid angle coverage > 90%

  ⇒ high hermeticity for E_{miss} measurements

Luminosity status and goals

- Since 2019 Belle II has recorded ~**213 fb^{-1}** of data.
- Aiming for a similar data sample size as BABAR by summer 2022.
- Over the next ~10 years our goal is to accumulate **50 ab^{-1}** (50 x Belle dataset).



MC samples

- MC14 run-independent (MC14ri_a), release-05-02-00
- Nominal beam bkg conditions (BGx1), early Phase 3 geometry
- Considering the generic and low-multiplicity samples shown on right
- Unskimmed mDSTs
- basf2 light-2106-rhea for steering file

Process	cross section [nb]	MC luminosity [fb^{-1}]
$ee \to \tau\tau$	0.919	100
$ee \to u\bar{u}$	1.605	100
$ee \to d\bar{d}$	0.401	100
$ee \to s\bar{s}$	0.383	100
$ee \to c\bar{c}$	1.329	100
$ee \to B^+B^-$	0.54	100
$ee \to B^0\overline{B}^0$	0.51	100
$ee \to ee(\gamma)$	295.8	10
$ee \to \mu\mu(\gamma)$	1.148	100
$ee \to eeee$	39.55	100
$ee \to ee\mu\mu$	18.83	100
$ee \to ee\pi\pi$	1.895	100
$ee \to eeKK$	0.0798	1000
$ee \to eepp$	0.0117	1000
$ee \to \mu\mu\mu\mu$	0.3512×10^{-3}	1000

Pre-selections

- Events required to contain exactly 4 good quality tracks (from interaction region)

Good tracks
- −3.0 < dz < 3.0 cm
- dr < 1.0 cm

- Thrust computed from good tracks, π^0s and additional photons (E > 200 MeV)

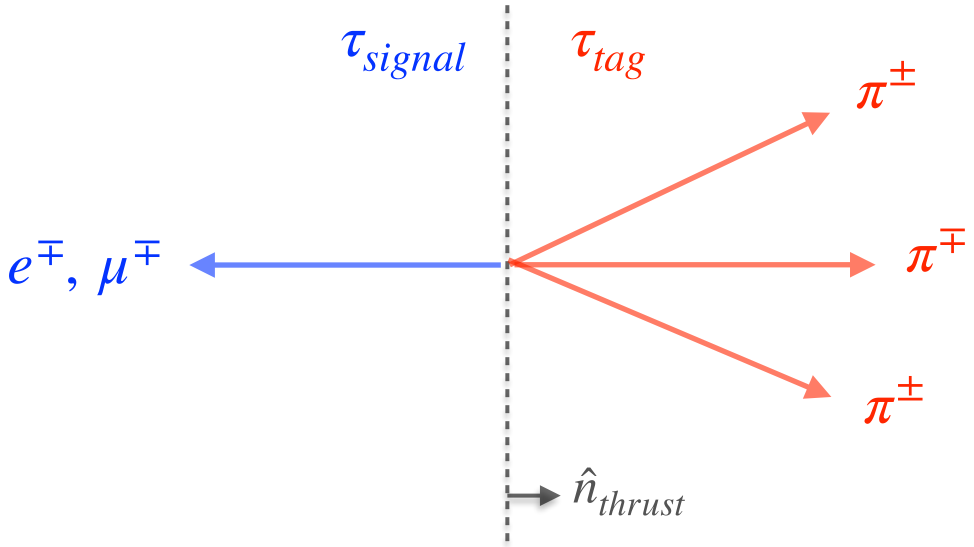
$$V_{thrust} = \sum \frac{|\, \vec{p}_i^{\,CMS} \cdot \hat{n}_{trust} \,|}{\sum \vec{p}_i^{\,CMS}}$$

π^0
- E_γ > 100 MeV
- -0.8660 < cosθ < 0.9563
- clusterNHits > 1.5
- 115 < $M_{\gamma\gamma}$ < 152 MeV

additional γ
- E_γ > 200 MeV
- -0.8660 < cosθ < 0.9563
- clusterNHits > 1.5
- not π^0 photon

- Use thrust vector to separate events into **signal** (1-prong) and **tag** (3-prong) hemispheres

$$|\, \vec{p}_{signal}^{\,CMS} \cdot \hat{n}_{trust} \,| \cdot |\, \vec{p}_{tag,i}^{\,CMS} \cdot \hat{n}_{trust} \,| < 0 \,, \forall\, i \in \text{tag}.$$



- Loose PID requirements:
  - tag tracks: E/p < 0.8
  - signal track: electronID (noTOP) > 0.5 or muonID > 0.5

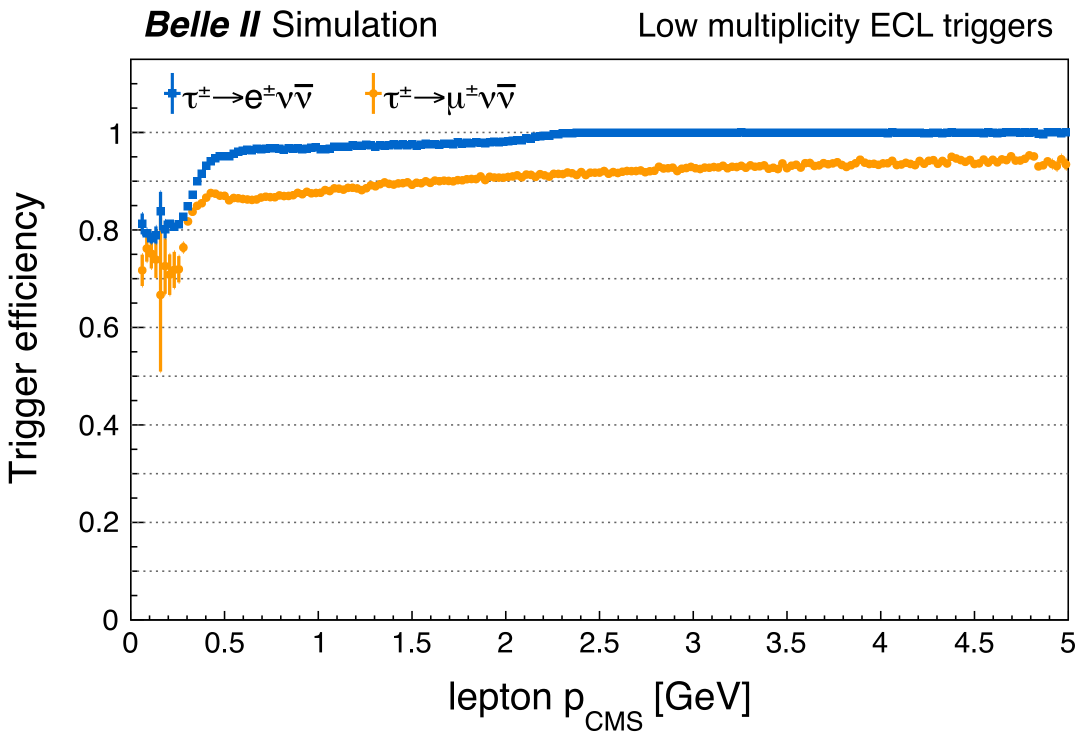
Trigger

- Events are required to fire the logical OR of several unprescaled low-multiplicity (**lml**) ECL triggers

- **lml0** : $\geq$ 3 clusters with at least one having $E^* > 300$ MeV, $1 < \theta_{ID} < 17$ (corresponding to $12.4° < \theta < 154.7°$, full ECL) and not an ECL Bhabha.
- **lml1** : exactly 1 cluster with $E^* > 2$ GeV and $4 < \theta_{ID} < 14$ ($32.2° < \theta < 124.6°$)
- **lml2** : $\geq$ 1 cluster with $E^* > 2$ GeV, $\theta_{ID} = 2, 3, 15$, or 16 ($18.5° < \theta < 32.2°$ or $124.6° < \theta < 139.3°$) and not an ECL Bhabha.
- **lml4** : $\geq$ 1 cluster with $E^* > 2$ GeV, $\theta_{ID} = 1$ or 17 ($12.4° < \theta < 154.7°$) and not an ECL Bhabha.
- **lml6** : exactly 1 cluster with $E^* > 1$ GeV, $4 < \theta_{ID} < 15$ ($32.2° < \theta < 128.7°$, full ECL barrel) and no other cluster with $E >$ 300 MeV anywhere.
- **lml7** : exactly 1 cluster with $E^* > 1$ GeV, $\theta_{ID} = 2, 3$ or 16 ($18.5° < \theta < 31.9°$ or $128.7° < \theta > 139.3°$) and no other cluster with $E >$ 300 MeV anywhere.
- **lml8** : cluster pair with $170° < \Delta\phi < 190°$, both clusters with $E^* > 250$ MeV and no 2 GeV cluster in the event.
- **lml9** : cluster pair with $170° < \Delta\phi < 190°$, one cluster with $E^* < 250$ MeV with the other having $E^* > 250$ MeV, and no 2 GeV cluster in the event.
- **lml10** : cluster pair with $160° < \Delta\phi < 200°$, $160° < \sum\theta < 200°$ and no 2 GeV cluster in the event.
- **lml12** : $\geq$ 3 clusters with at least one having $E^* > 500$ MeV, $2 < \theta_{ID} < 16$ (corresponding to $18.5° < \theta < 139.3°$, full ECL) and not an ECL Bhabha. (θ_{ID} values have to be double checked).

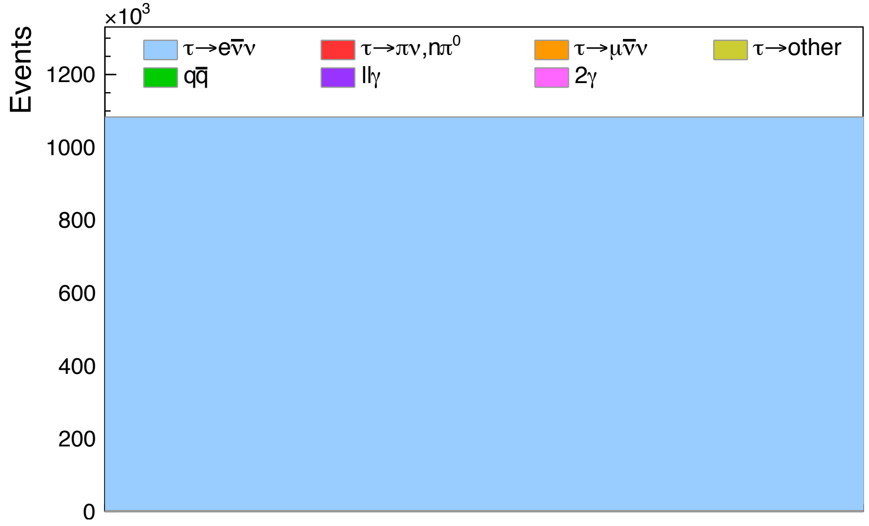
- Absolute trigger efficiency in MC (TSIM, release-05-02-00):

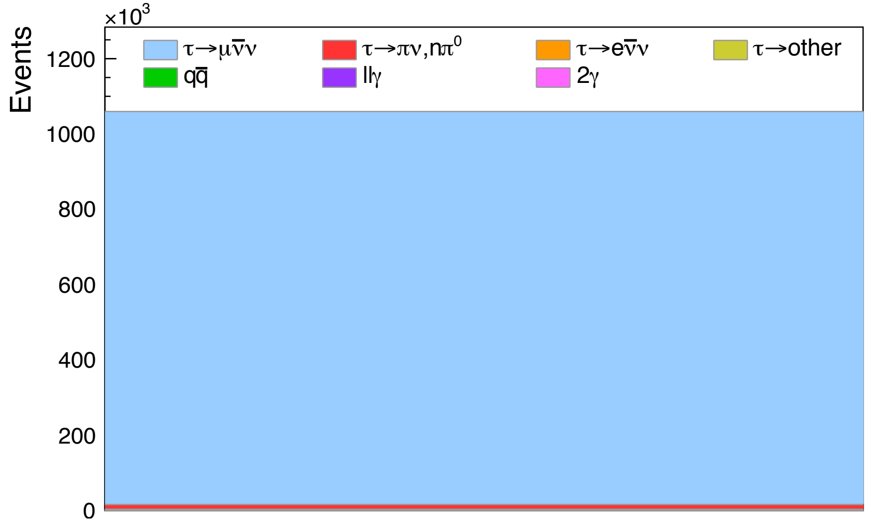
$$\epsilon_{L1} = \frac{\textbf{lml0}\ or\ \textbf{lml1}\ or\ \textbf{lml2}\ or\ \textbf{lml4}\ or\ \textbf{lml6}\ or\ \textbf{lml7}\ or\ \textbf{lml8}\ or\ \textbf{lml9}\ or\ \textbf{lml10}\ or\ \textbf{lml12}}{\text{all events}}$$



- For this trigger configuration, TSIM has been shown to reproduce data efficiency within ~1%.

Pseudodata measurement





- Pseudodata = int(total MC yield), with √N uncertainty
- In each channel compute:

$$N_i^{sig} = \epsilon^{-1}(N_i^{pseudodata} - N_i^{bkg}) \qquad \text{where: } \epsilon = \frac{N^{selected}}{N^{generated}}$$

$$\mathcal{B}_i = \frac{\mathbf{N}_i^{Sig}}{2\mathcal{L}\sigma_{e^+e^-\to\tau^+\tau^-}}$$

- Then taking ratio: $R_\mu = \frac{\mathcal{B}(\tau^-\to\mu^-\nu_\tau\bar{\nu}_\mu)}{\mathcal{B}(\tau^-\to e^-\nu_\tau\bar{\nu}_e)}$

- Belle II (108 fb^{-1}): $\delta R_\mu / R_\mu^{pseudodata} = 0.16\,\%\ (stat)$
- BABAR (467 fb^{-1}): $\delta R_\mu / R_\mu^{data} = 0.16\,\%\ (stat) \pm\ 0.37\,\%\ (sys)$

With only ~100 fb^{-1} we can reach the statistical precision of BABAR on R_μ

Alberto Lusiani, ICHEP 2020:

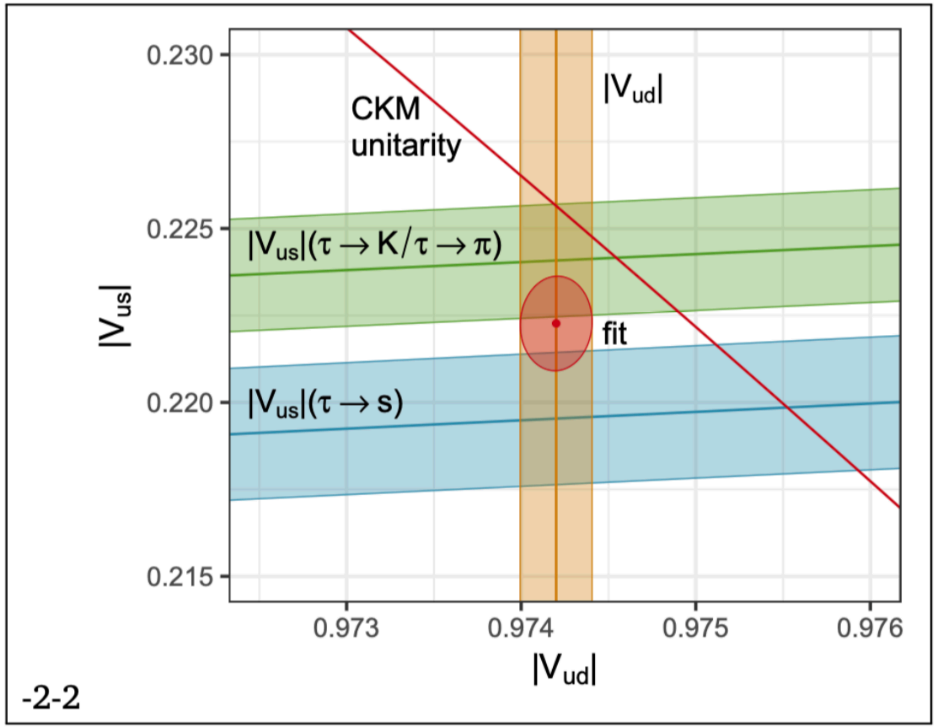
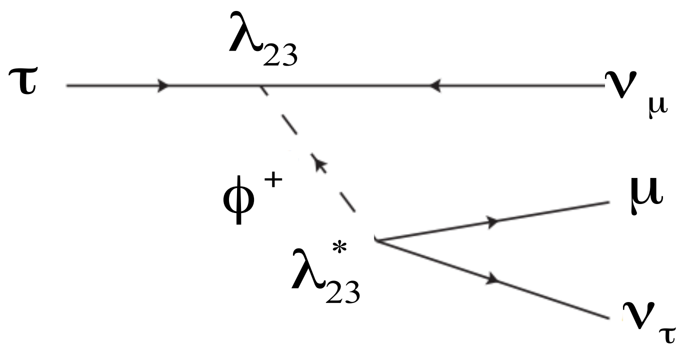
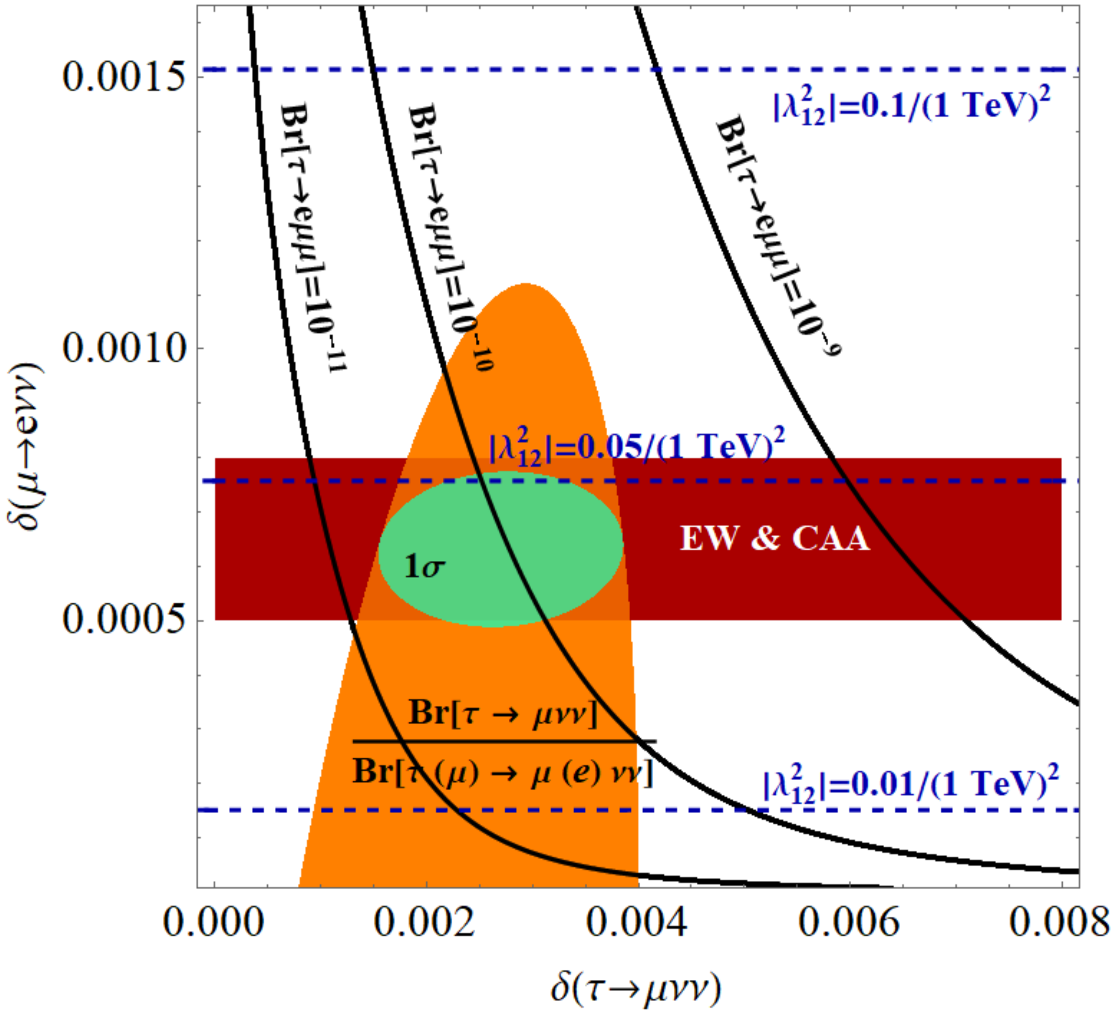


Figure 2: Results of a $|V_{ud}|$-$|V_{us}|$ simultaneous fit. The bands describe the constraints corresponding to the $|V_{ud}|$ measurement, the $|V_{us}|_{\tau s}$ and the $|V_{us}|_{\tau K/\pi}$ determinations that use the τ measurements. The oblique line corresponds to the CKM matrix unitarity constraint. The ellipse corresponds to 1σ uncertainty on the $|V_{ud}|$ and $|V_{us}|$ fit results.

- Singly charged scalar





A.C., F. Kirk, C. Manzari, L. Panizzi, arXiv:2012.09845