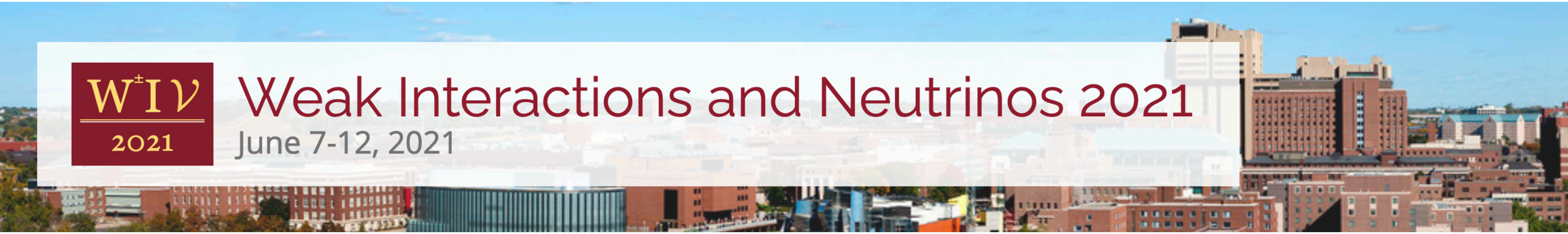
Tau Measurements & Prospects

Petar Rados (DESY)

on behalf of the Belle II Collaboration

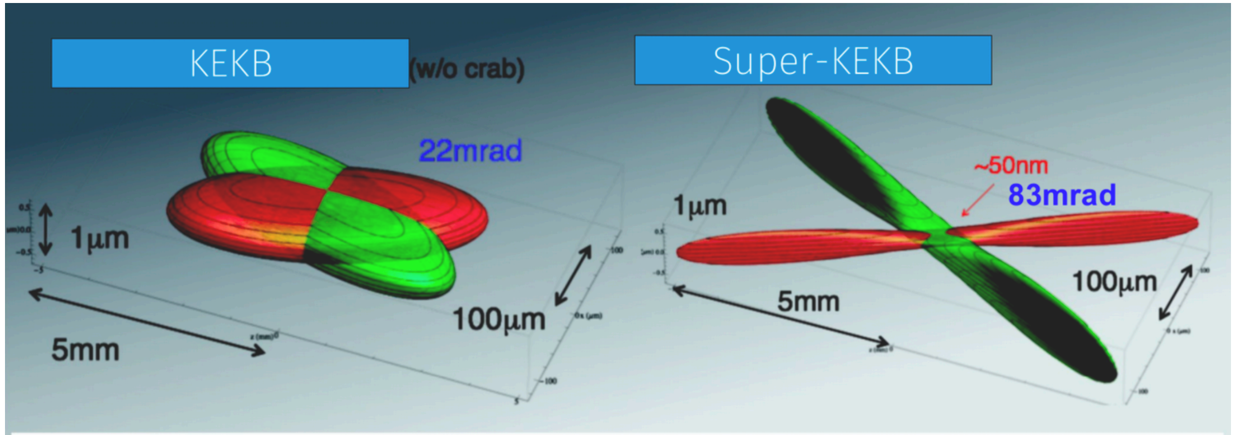
WIN 2021

University of Minnesota (virtual), 7-12 June 2021

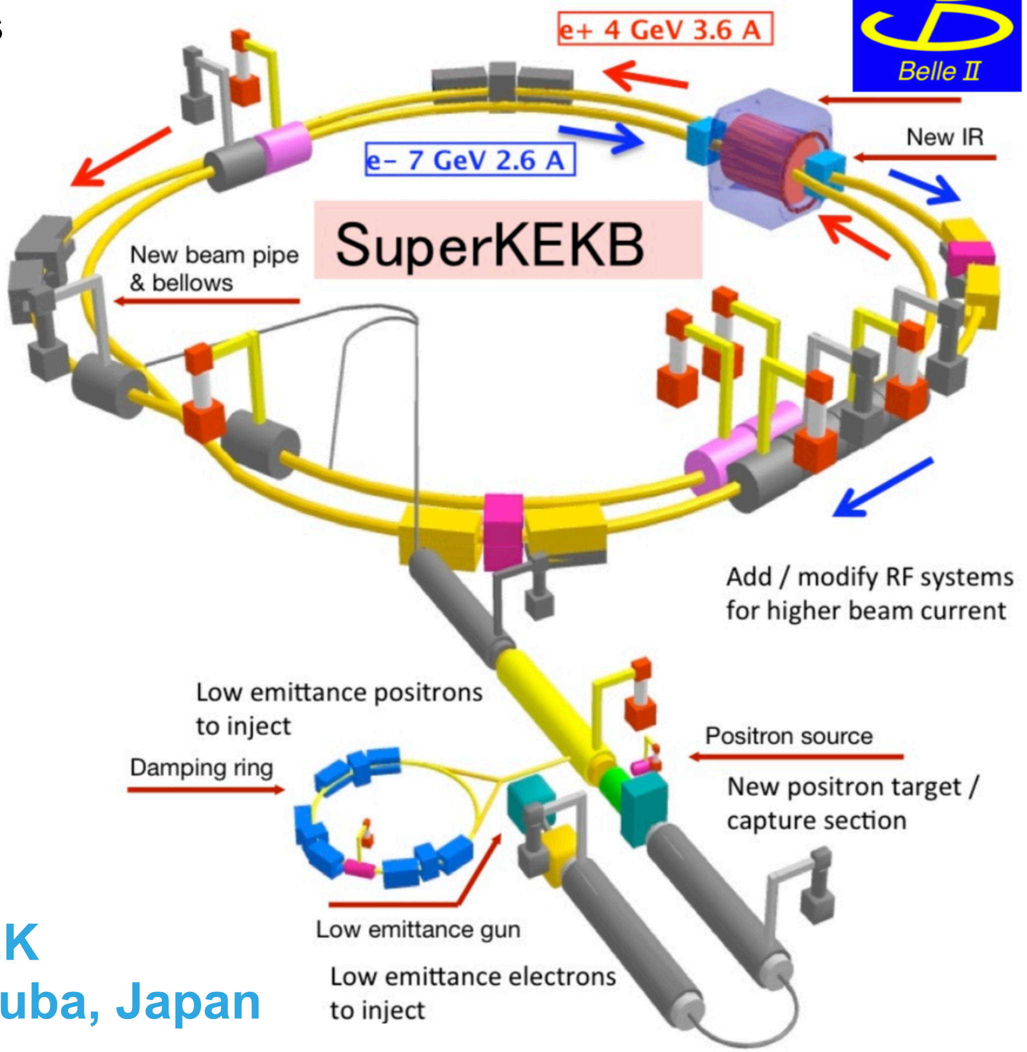


SuperKEKB Accelerator

- 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



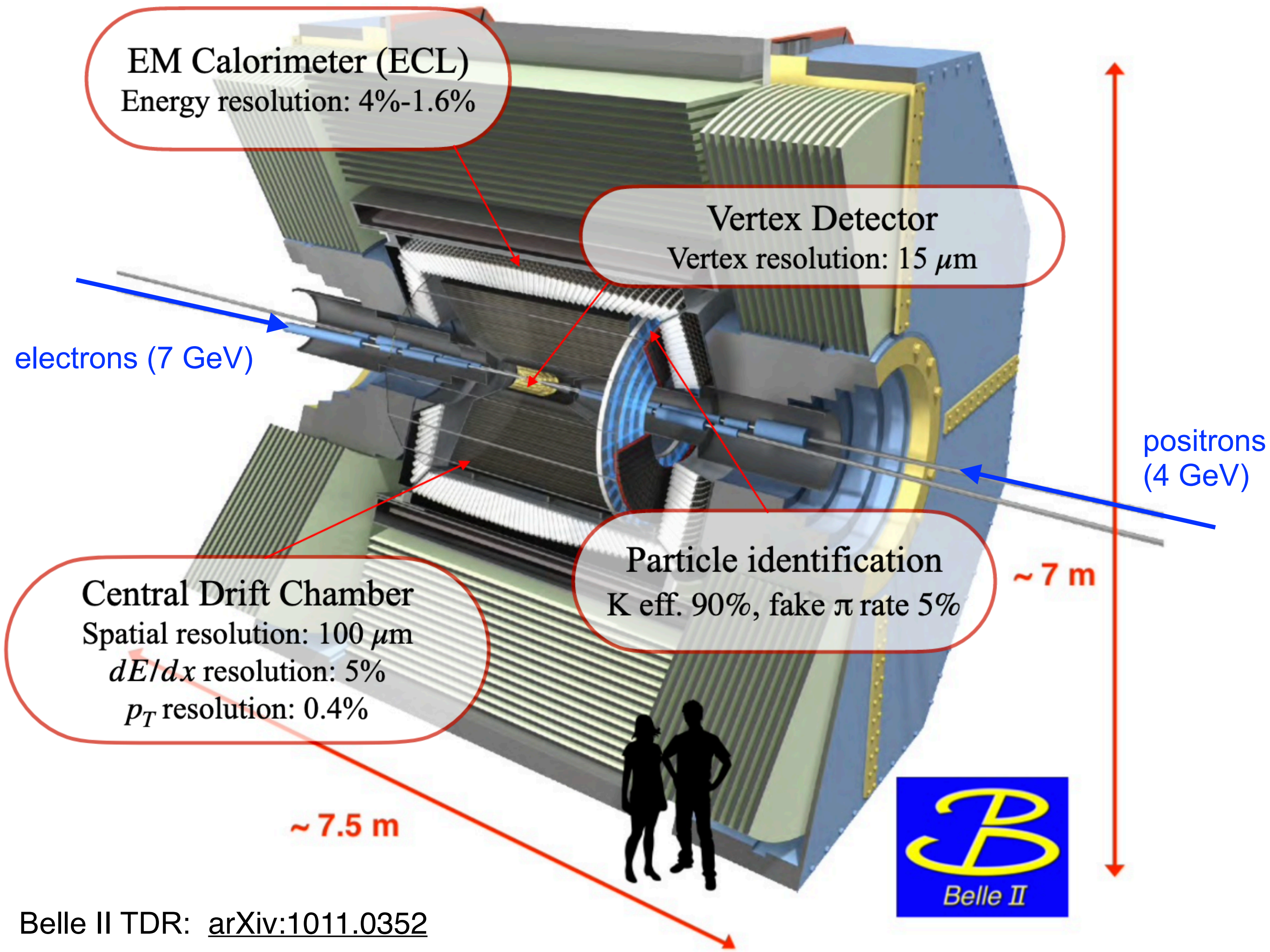
	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	60 x 10^{34}
		factor 20			factor 2-3	



- 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} $cm^{-2}s^{-1}$).

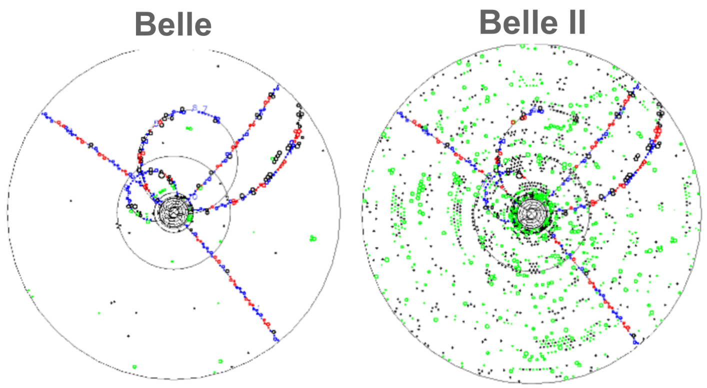
@KEK
Tsukuba, Japan

Belle II Detector



Belle II TDR: arXiv:1011.0352

- Increased beam backgrounds



⇒ upgraded trigger system and sub-detectors

- β_y = 0.28 (vs 0.42 @ Belle)

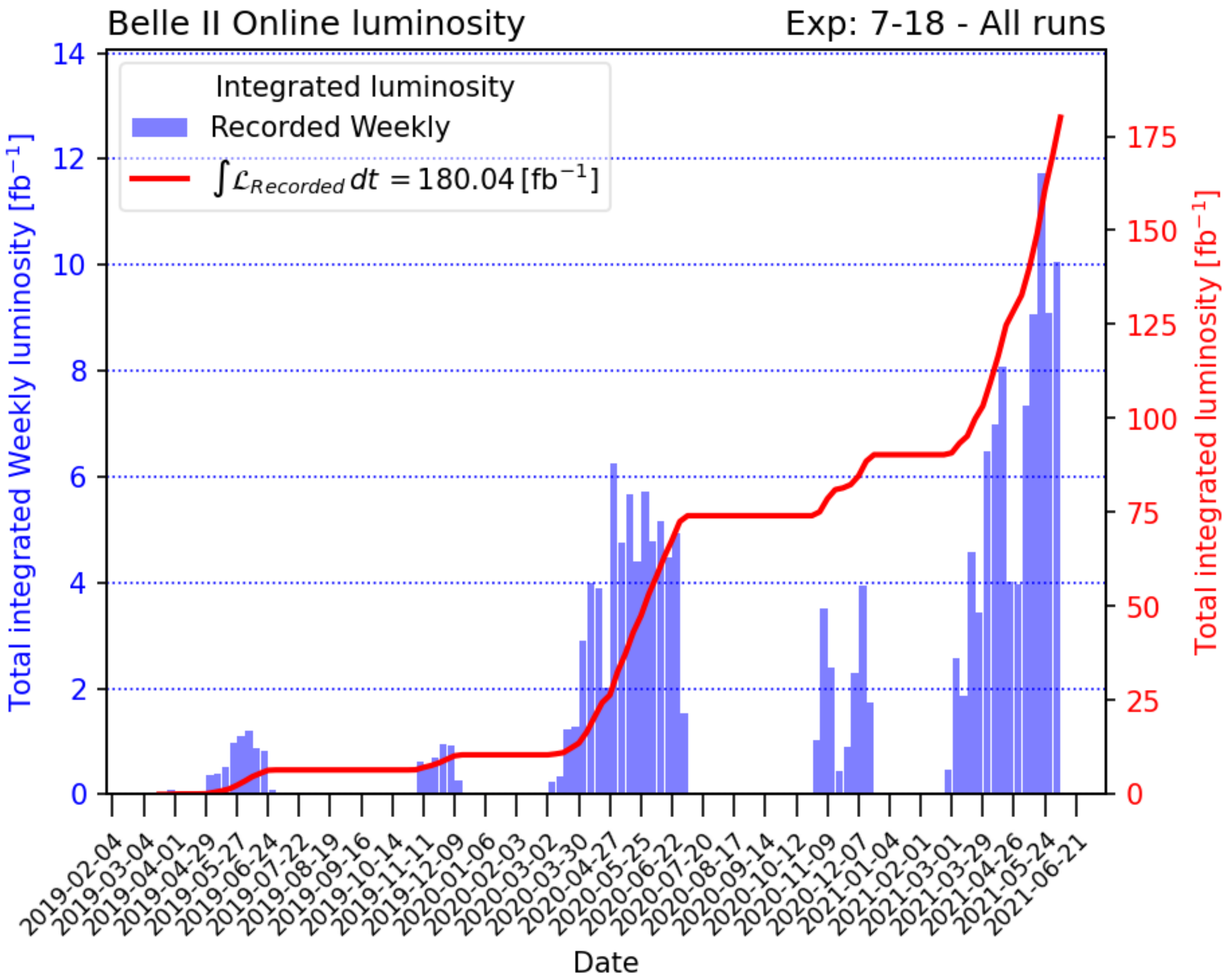
⇒ reduced boost requiring improved vertex reconstruction

- Solid angle coverage > 90%

⇒ high hermeticity for E_{miss} measurements

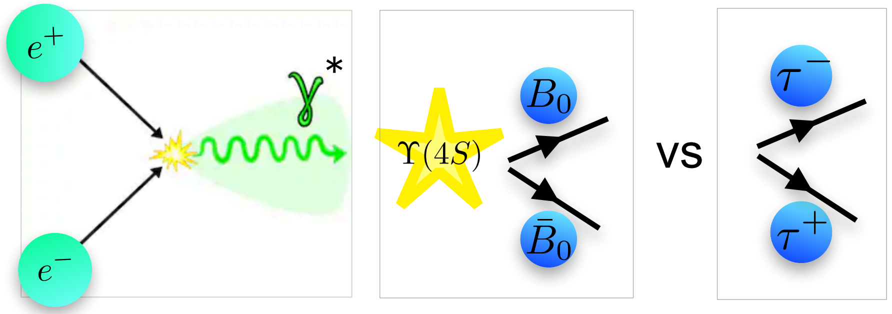
Luminosity status and goals

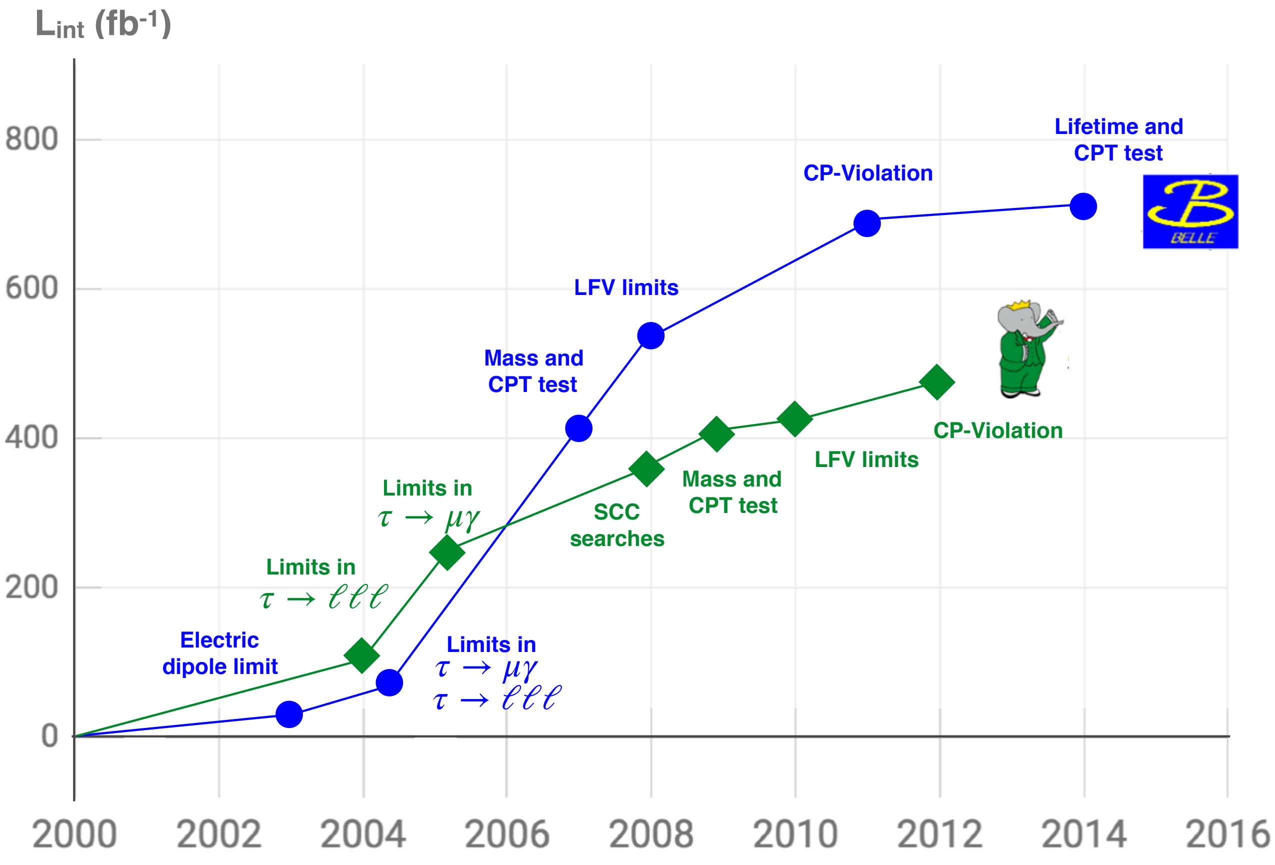
- Since 2019 Belle II has recorded **~180 fb^{-1}** of data.
- Aiming for a similar data sample size as BABAR by summer 2022.
- Over the next ~10 years our goal is to accumulate **50 ab^{-1}** (50 x Belle dataset).



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





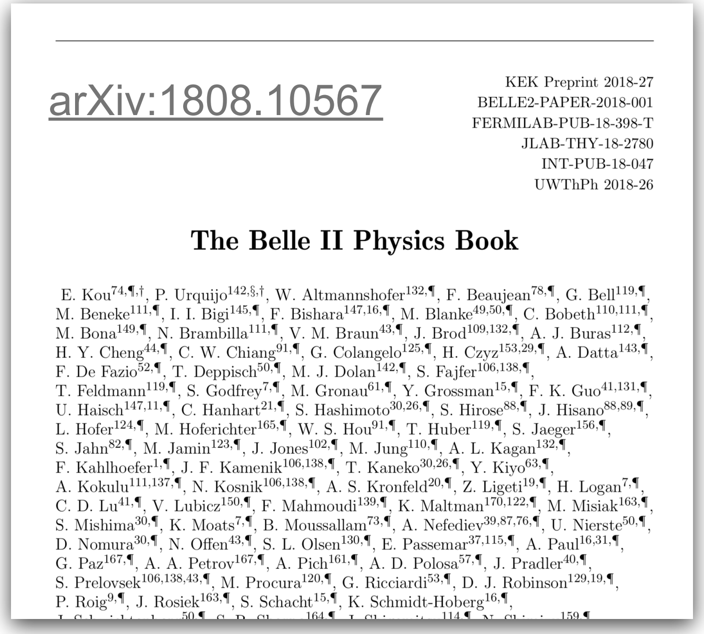
- Last generation B-factories provided a variety of very interesting τ physics results in the last two decades

- 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!

- Belle II has a rich program of precision SM measurements and new physics searches with taus

  - **tau mass measurement**
  - **tau lifetime measurement**
  - **tests of lepton flavour universality**
  - **searches for lepton flavour/number violating decays: $\tau \to l\gamma,\ lll,\ lh(h),\ l\alpha,\ \ldots$**



arXiv:1808.10567

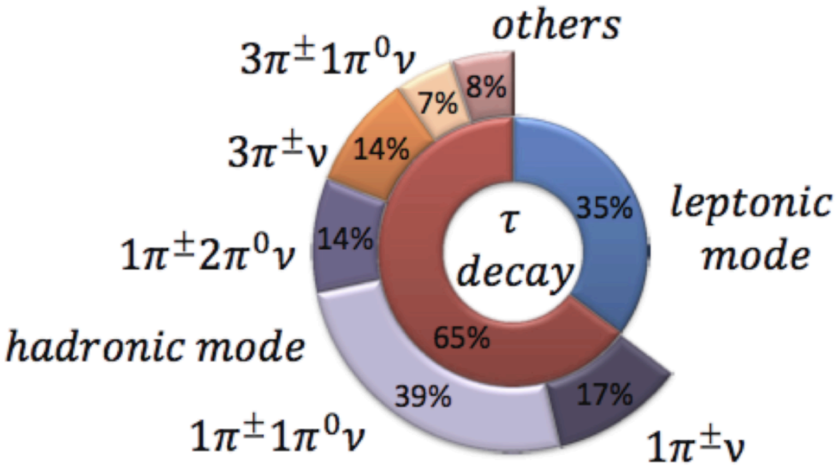
KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047
UWThPh 2018-26

The Belle II Physics Book

E. Kou[74,¶,†], P. Urquijo[142,§,†], W. Altmannshofer[132,¶], F. Beaujean[78,¶], G. Bell[119,¶], M. Beneke[111,¶], I. I. Bigi[145,¶], F. Bishara[147,16,¶], M. Blanke[49,50,¶], C. Bobeth[110,111,¶], M. Bona[149,¶], N. Brambilla[111,¶], V. M. Braun[43,¶], J. Brod[109,132,¶], A. J. Buras[112,¶], H. Y. Cheng[44,¶], C. W. Chiang[91,¶], G. Colangelo[125,¶], H. Czyz[153,29,¶], A. Datta[143,¶], F. De Fazio[52,¶], T. Deppisch[50,¶], M. J. Dolan[142,¶], S. Fajfer[106,138,¶], T. Feldmann[119,¶], S. Godfrey[7,¶], M. Gronau[61,¶], Y. Grossman[15,¶], F. K. Guo[41,131,¶], U. Haisch[147,11,¶], C. Hanhart[21,¶], S. Hashimoto[30,26,¶], S. Hirose[88,¶], J. Hisano[88,89,¶], L. Hofer[124,¶], M. Hoferichter[165,¶], W. S. Hou[91,¶], T. Huber[119,¶], S. Jaeger[156,¶], S. Jahn[82,¶], M. Jamin[123,¶], J. Jones[102,¶], M. Jung[110,¶], A. L. Kagan[132,¶], F. Kahlhoefer[1,¶], J. F. Kamenik[106,138,¶], T. Kaneko[30,26,¶], Y. Kiyo[63,¶], A. Kokulu[111,137,¶], N. Kosnik[106,138,¶], A. S. Kronfeld[20,¶], Z. Ligeti[19,¶], H. Logan[7,¶], C. D. Lu[41,¶], V. Lubicz[150,¶], F. Mahmoudi[139,¶], K. Maltman[170,122,¶], M. Misiak[163,¶], S. Mishima[30,¶], K. Moats[7,¶], B. Moussallam[73,¶], A. Nefediev[39,87,76,¶], U. Nierste[50,¶], D. Nomura[30,¶], N. Offen[43,¶], S. L. Olsen[130,¶], E. Passemar[37,115,¶], A. Paul[16,31,¶], G. Paz[167,¶], A. A. Petrov[167,¶], A. Pich[161,¶], A. D. Polosa[57,¶], J. Pradler[40,¶], S. Prelovsek[106,138,43,¶], M. Procura[120,¶], G. Ricciardi[53,¶], D. J. Robinson[129,19,¶], P. Roig[9,¶], J. Rosiek[163,¶], S. Schacht[15,¶], K. Schmidt-Hoberg[16,¶],

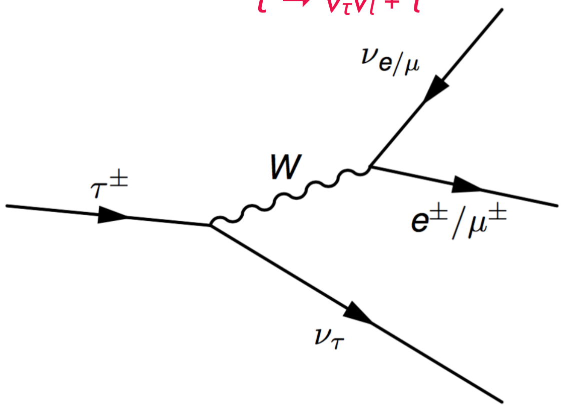
  - and much more!
    - electric dipole moment (CP/T violation)
    - $|V_{us}|$ and g_τ/g_l from ratio of $\tau\to K\nu$ & $\pi\nu$
    - search for heavy neutral leptons
    - …
    - $\Upsilon(nS)\to\tau\mu$ decays
    - second class currents in $\tau\to\pi\eta^{(*)}\nu$
    - CP violation in $\tau\to K_S\pi\nu$

- Tau leptons will decay before reaching the active regions of the Belle II detector
- Identified via decay products:
  - 1-prong: 35.2% leptonic, 49.5% hadronic
  - 3-prong: 15.2% hadronic
- Wide variety of low multiplicity signatures involving $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, π^{0} and neutrinos (missing energy)



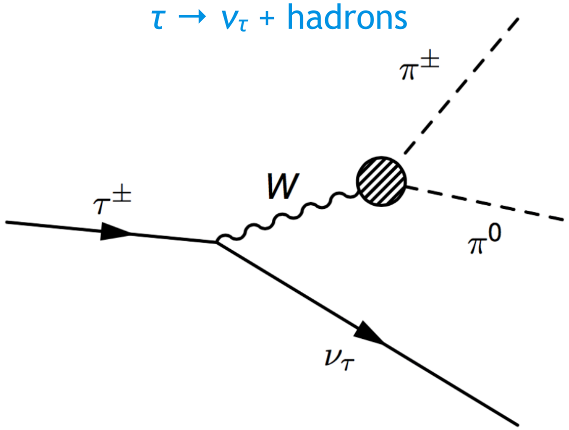
leptonic decay

$\tau \rightarrow \nu_\tau \nu_l + l$

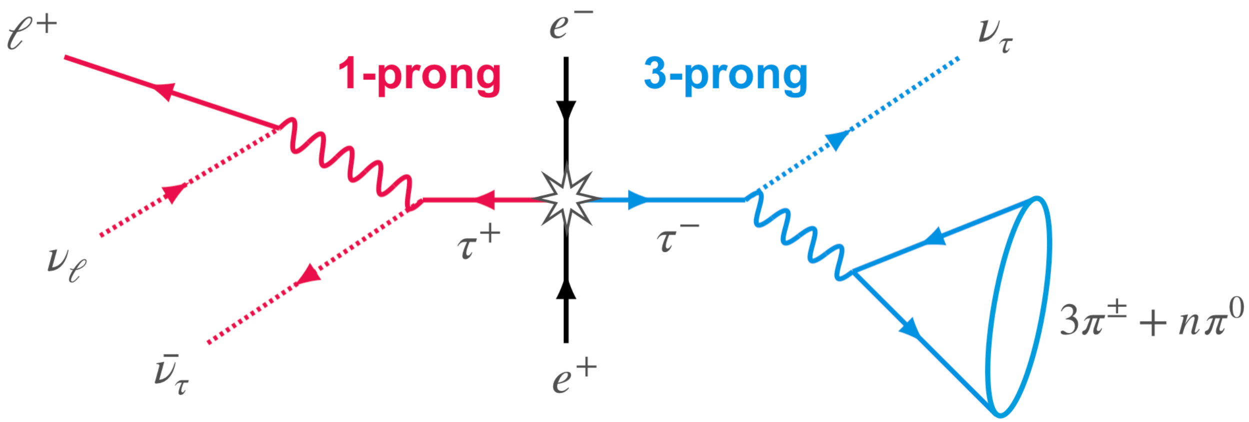


hadronic decay

$\tau \rightarrow \nu_\tau$ + hadrons

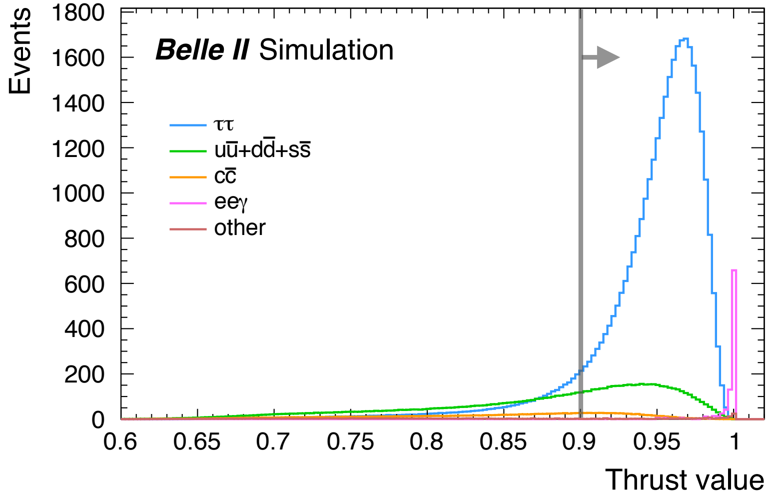


- τ-pairs reconstructed as 1x3 (4 track) or 1x1 (2 track) events



τ-pair reconstruction

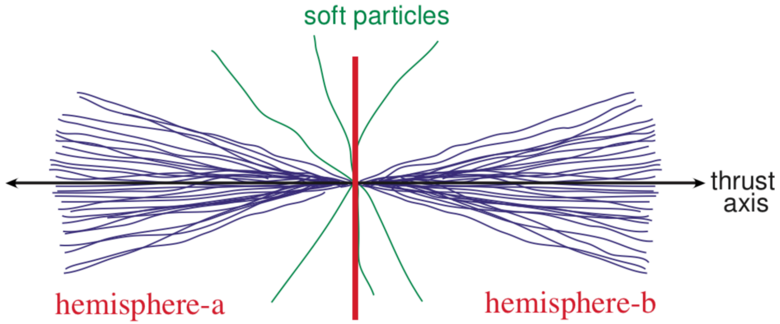
- We exploit the unique topology and kinematic of τ-pair events to suppress the main $q\bar{q}$ and eeɣ backgrounds

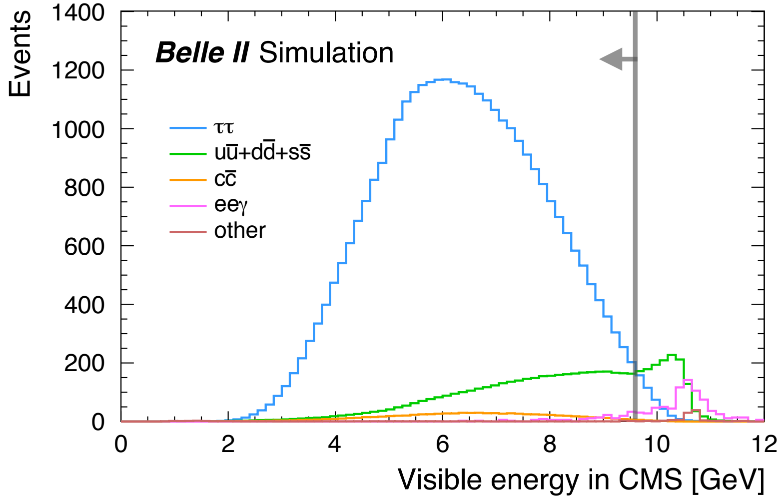


⇒ **Relatively mild deviation of τ decay particles from the primary trajectory**

$$\text{thrust value} = \sum_h \frac{\vec{p}_h \cdot \hat{T}}{|p_h|}$$

thrust axis ($\check{T}$) is maximising the event shape variable

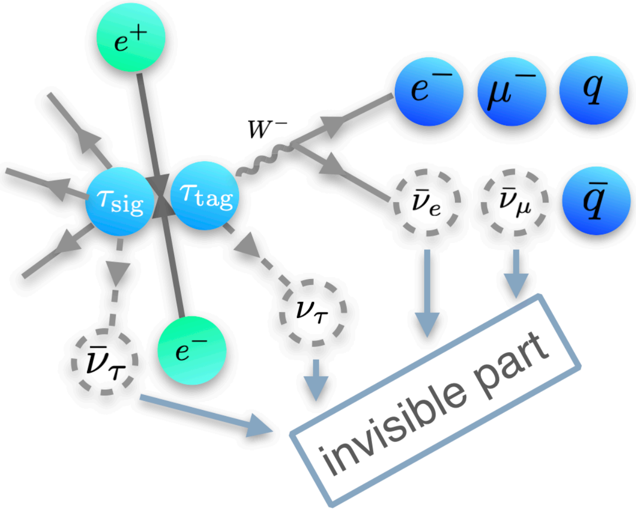




⇒ **Undetected neutrinos in τ events**

$$\text{visible energy} = \sum_h E_h$$

e^+e^- data allows for precise determination of the missing energy

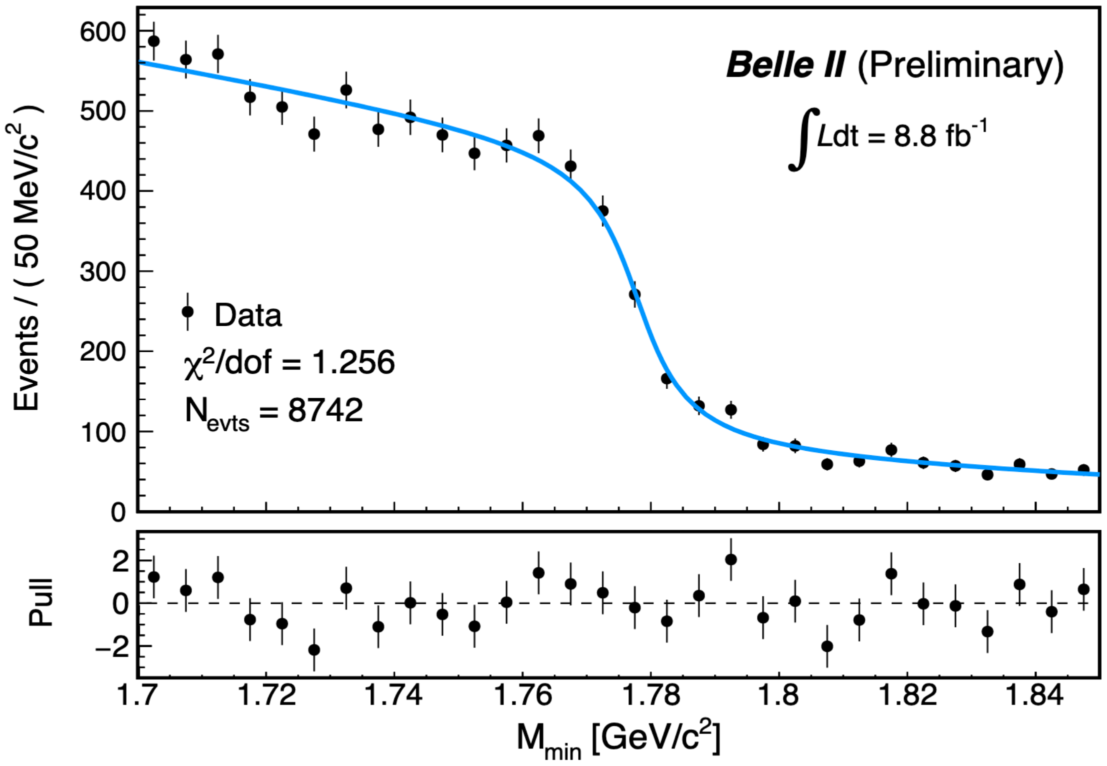


Tau Mass

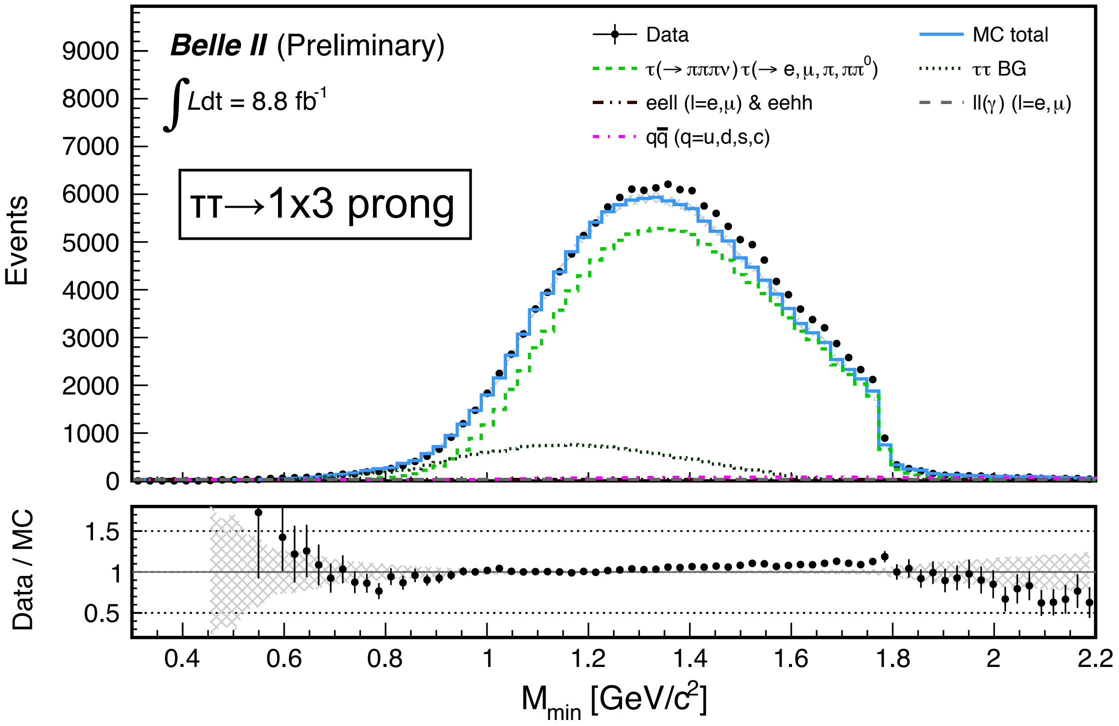
- Tau mass measurement in early Belle II data (8.8 fb^{-1})
- Using a pseudomass technique on τ→3πν decays

$$M_{min} = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})} \leq m_\tau$$

- sharp threshold behaviour in region close to m_τ



arXiv:2008.04665



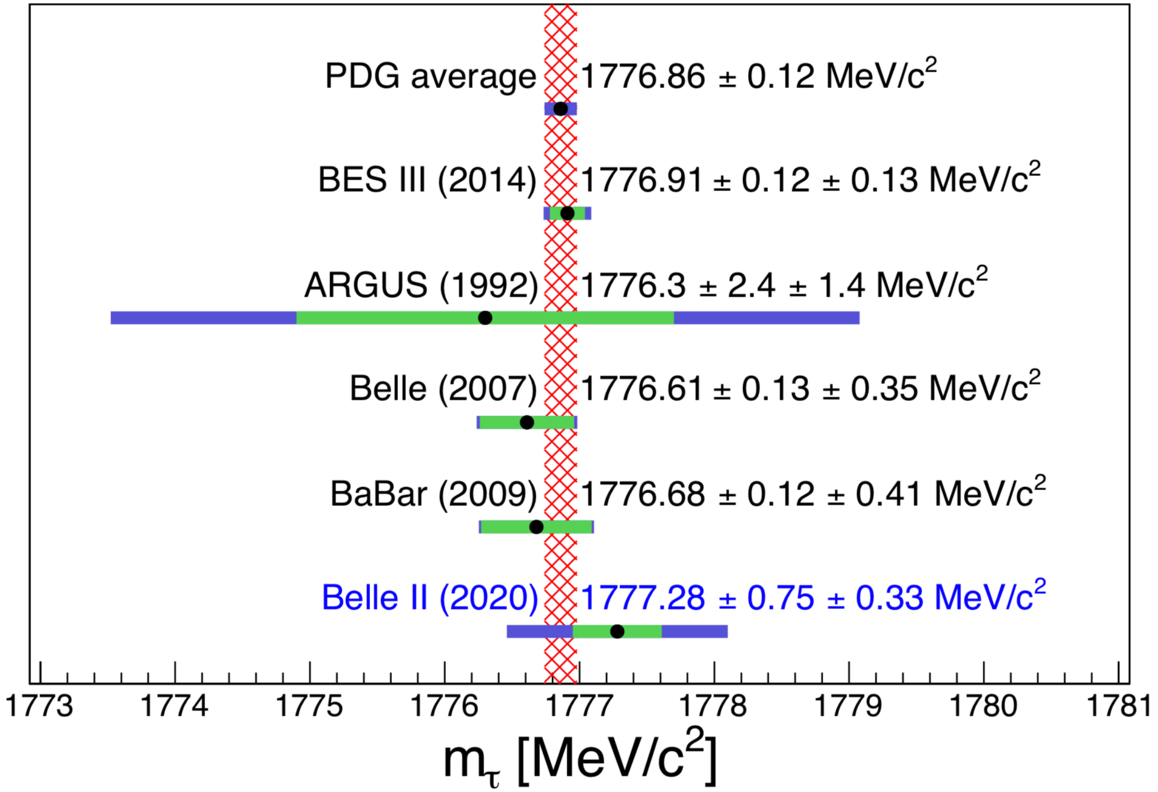
- M_{min} is fitted to an empirical mass function ($P_1 \Rightarrow m_\tau$) within a 1.7-1.85 GeV window:

$$F(M, \vec{P}) = (P_3 + P_4 M) \cdot \tan^{-1}[(M - P_1/P_2)] + P_5 M + 1$$

$$m_\tau = 1777.28 \pm 0.75 \text{ (stat)} \pm 0.33 \text{ (sys) MeV/c}^2$$

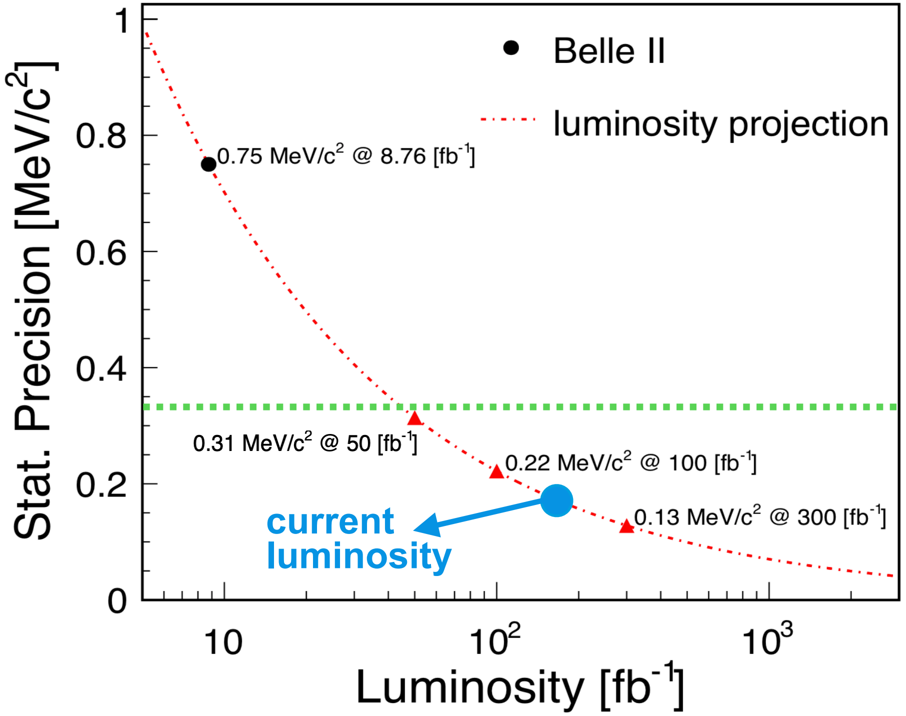
Tau Mass

arXiv:2008.04665



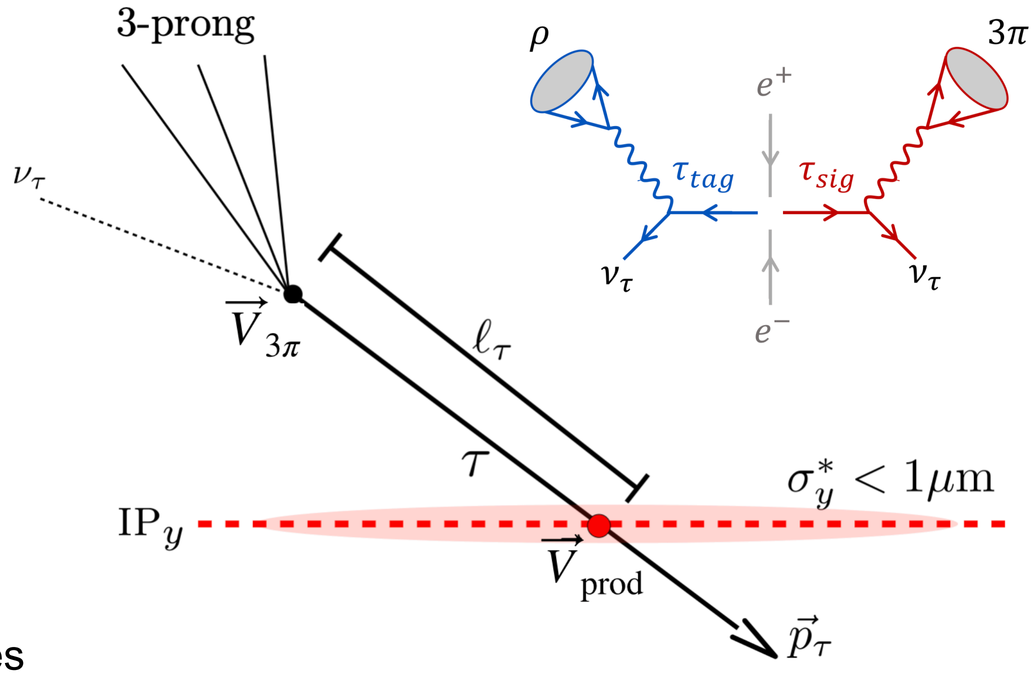
- Belle II has comparable **systematic error** to Belle/BABAR
- Dominant systematic uncertainty associated to the track momentum scale (±0.29 MeV)

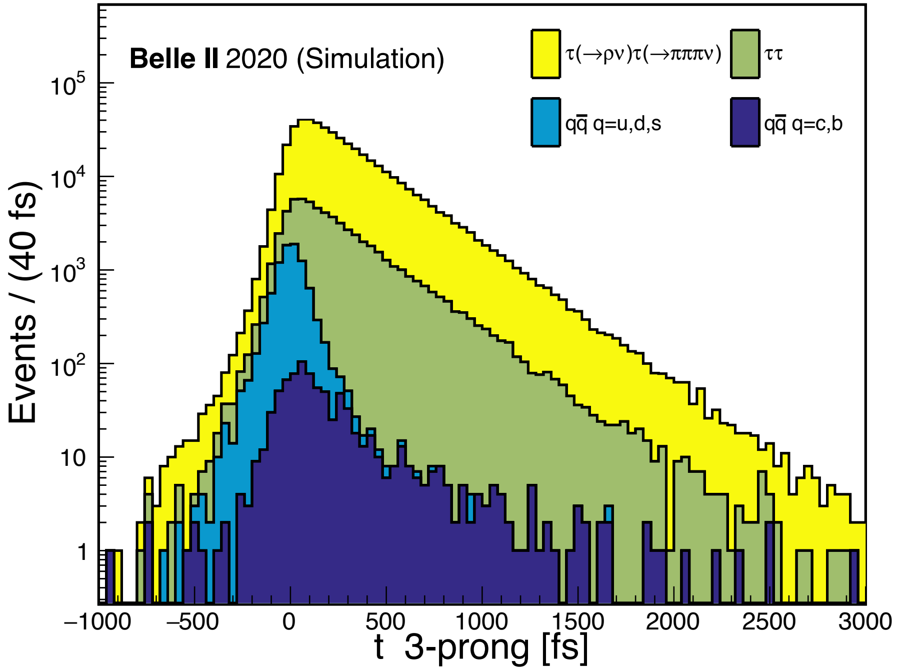
- **Goal**: achieve the best tau mass precision amongst the pseudomass techniques
- New data reprocessing with improved B-field map
  ⇒ reduced p-scale uncertainty
- Expect to match statistical precision of Belle/BABAR with **~300 fb^{-1}**



Tau Lifetime

- Can relate proper time to flight distance and momentum in lab frame: $t = \frac{l_\tau}{\beta\gamma c} = m\frac{l_\tau}{p_\tau}$ → measure these!
- Reconstruct 3-prong vertex and estimate p_τ using decay products
- Exploit the tiny beam spot size near IP ⇒ estimate production vertex as the intersection of p-direction with plane = IP_y





- World-best measurement comes from Belle (711 fb^{-1}):

τ_τ = 290.1 ± 0.53 (stat) ± 0.33 (sys) fs   Phys. Rev. Lett. 112, 031801

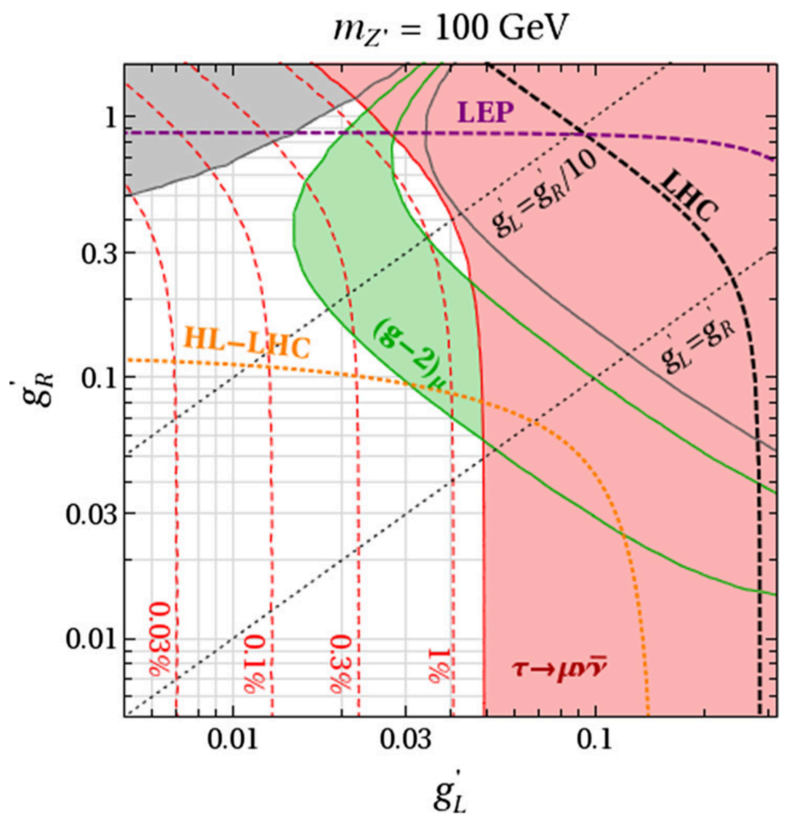
- Belle II has **5x higher efficiency** (1x3 vs 3x3 prong @ Belle), and **2x better proper decay time resolution**

⇒ **expect competitive results with only ~150 fb^{-1}**

Test of Lepton Flavour Universality

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

Are these hints of a new fundamental interaction that violates LFU?



- If so, then we could also see hints in the **tau sector**, where most stringent test of μ-e universality comes from the ratio:

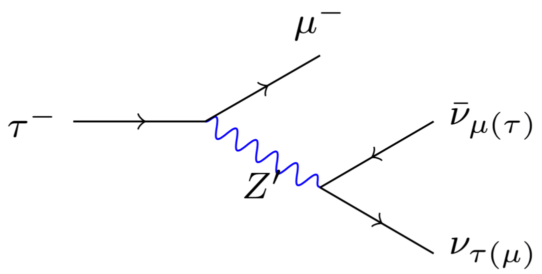
$$\frac{\mathcal{B}(\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \overline{\nu}_e \nu_\tau)}$$

$$\left(\frac{g_\mu}{g_e}\right)^2_\tau = \frac{\mathcal{B}(\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \overline{\nu}_e \nu_\tau)} \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}, \qquad \text{where } f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \log x$$

- World-best measurement comes from BABAR (467 fb^{-1}):

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

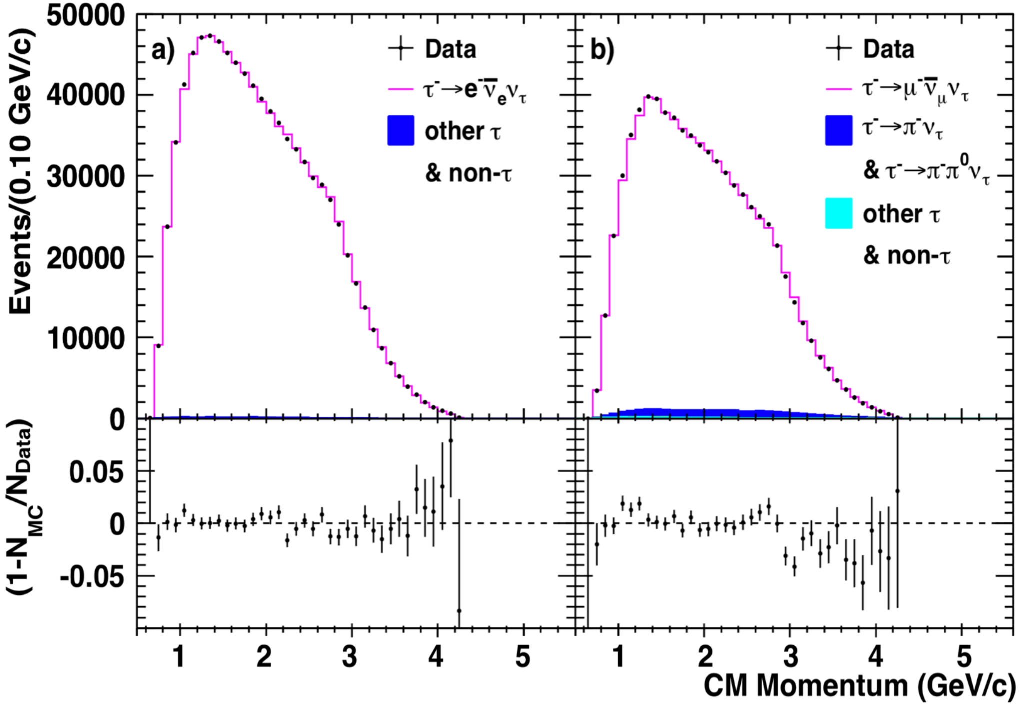
Phys.Rev.Lett.105:051602 (2010)



- Can put strong constraints on lepton flavour violating Z' models (arXiv:1607.06832v1)

Test of Lepton Flavour Universality

Phys.Rev.Lett.105:051602 (2010)

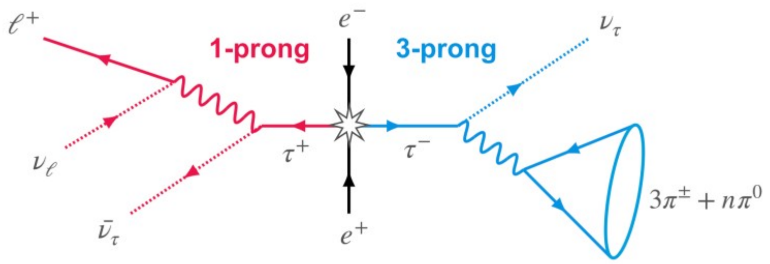


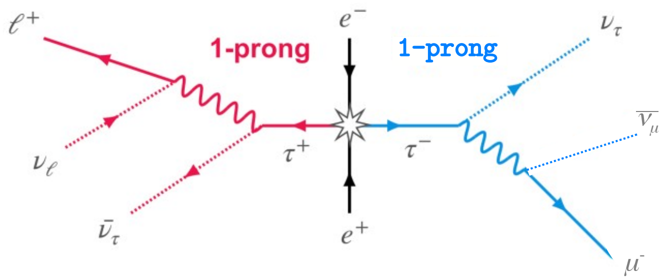
	μ
N^D	731102
Purity	97.3%
Total Efficiency	0.485%
Particle ID Efficiency	74.5%
Systematic uncertainties:	
Particle ID	0.32
Detector response	0.08
Backgrounds	0.08
Trigger	0.10
$\pi^-\pi^-\pi^+$ modelling	0.01
Radiation	0.04
$\mathcal{B}(\tau^- \to \pi^-\pi^-\pi^+\nu_\tau)$	0.05
$\mathcal{L}\sigma_{e^+e^-\to\tau^+\tau^-}$	0.02
Total [%]	0.36

Can we do better at Belle II?

Yes!

- Higher signal reconstruction efficiency and (eventually) more data
- PID uncertainties should scale well with luminosity and higher stat MC samples





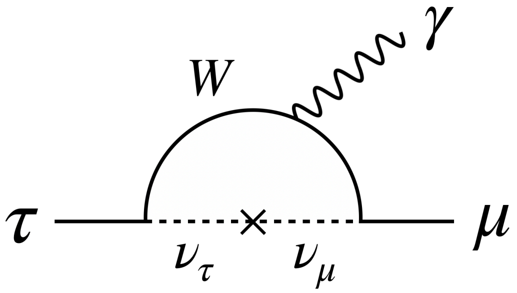
- Sensitivity studies indicate we can match stat precision of BABAR with **~100 fb^{-1}**, but must work hard to improve systematics
- Plan to include also 1x1 prong topology (not attempted @BABAR)

Searches for charged LFV

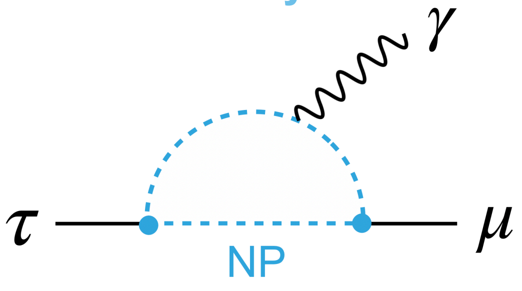
- LFV has been established for the neutrinos, but what about their charged partners (e, μ and τ)?
- In the SM, charged LFV decays via neutrino oscillation are highly suppressed and immeasurably small:

$$Br(\ell_1 \to \ell_2\gamma)_{SM} \propto \left(\frac{\delta m_\nu^2}{m_W^2}\right)^2 \sim 10^{-54}\text{-}10^{-49}$$

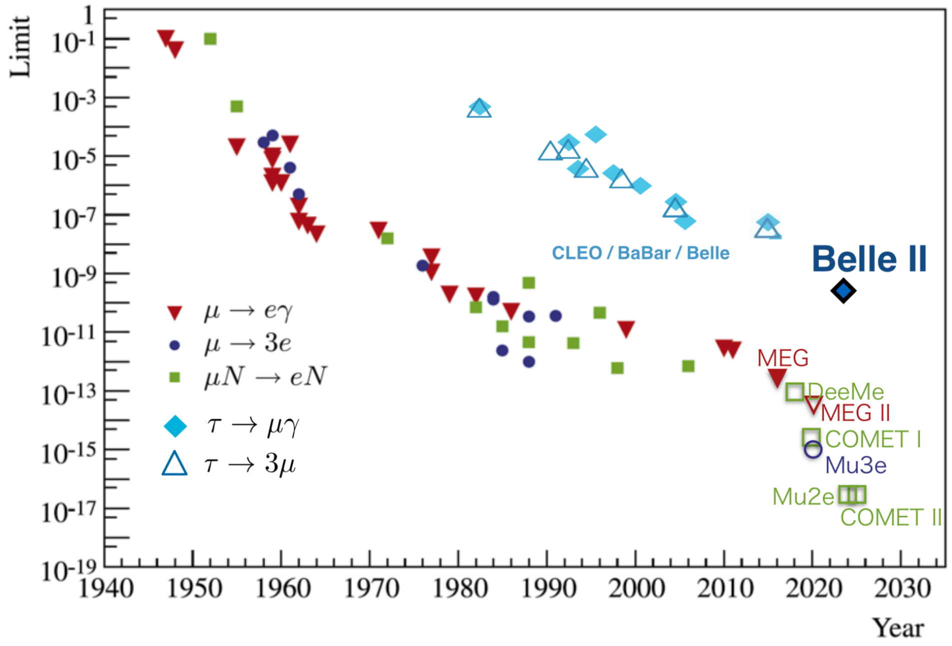
Standard Model



New Physics



- **Observation of charged LFV would be a clear signature for New Physics!**
  - *Br* enhanced in many NP models (10^{-10}-10^{-7})
  - SUSY, extended Higgs sector, seesaw, leptoquarks, non-universal Z', and many more
  - **μ→e**: stringent bounds exist from MEG
  - **τ→μ/e**: weaker bounds (Belle, BaBar and CLEO)



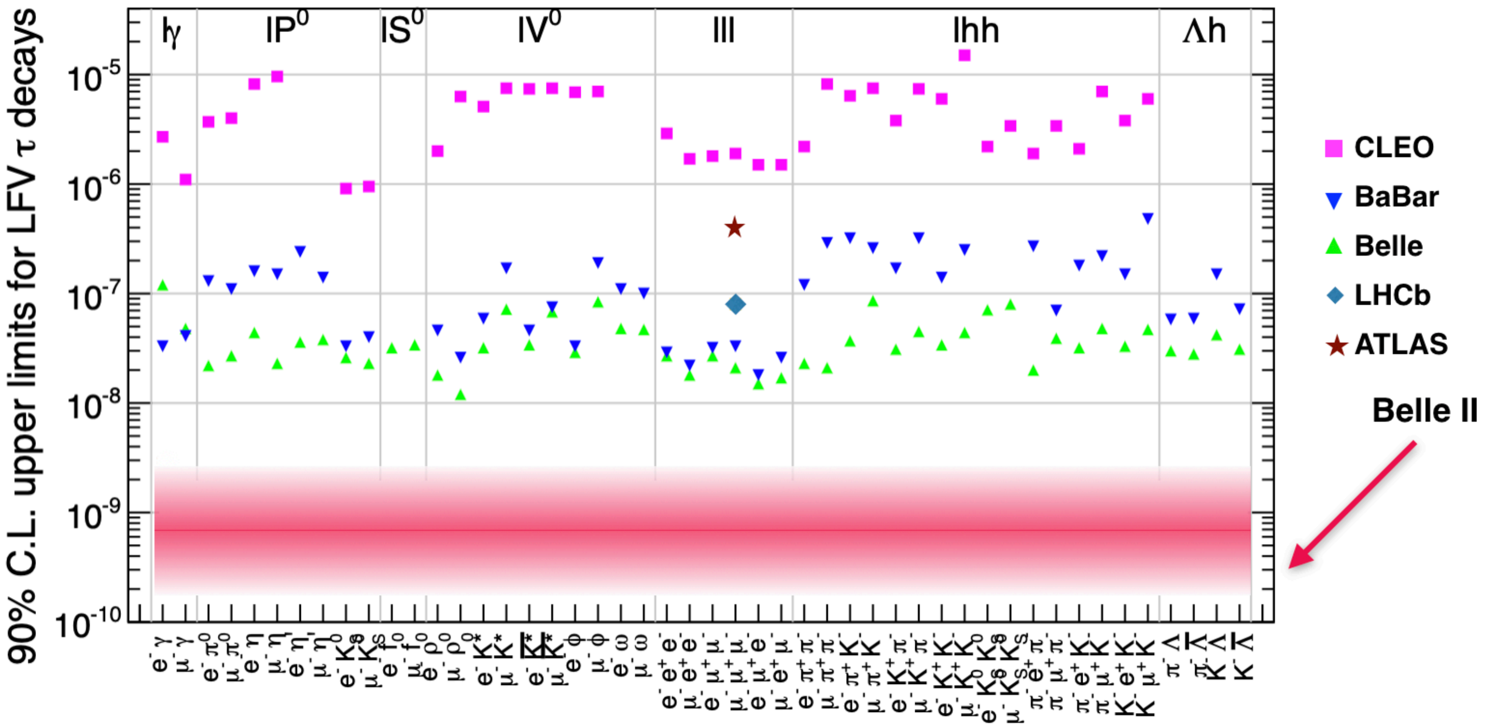
- As heaviest lepton, NP can have preferential τ LFV couplings

Prospects for τ LFV

- Due to their large mass, τ leptons provide a wide variety of LFV (and LNV) decay modes to study:
  - radiative: $\tau \to \ell\gamma$
  - leptonic: $\tau \to \ell\ell\ell$
  - semileptonic: $\tau \to \ell h(h)$

  - "golden channels" for discovery: τ→μμμ, τ→μγ
  - complementary: semileptonic modes allow us to test LFV couplings b/w quarks and leptons, and better discriminate b/w NP models

arXiv:1808.10567



Extrapolating from Belle results (50 ab^{-1}):

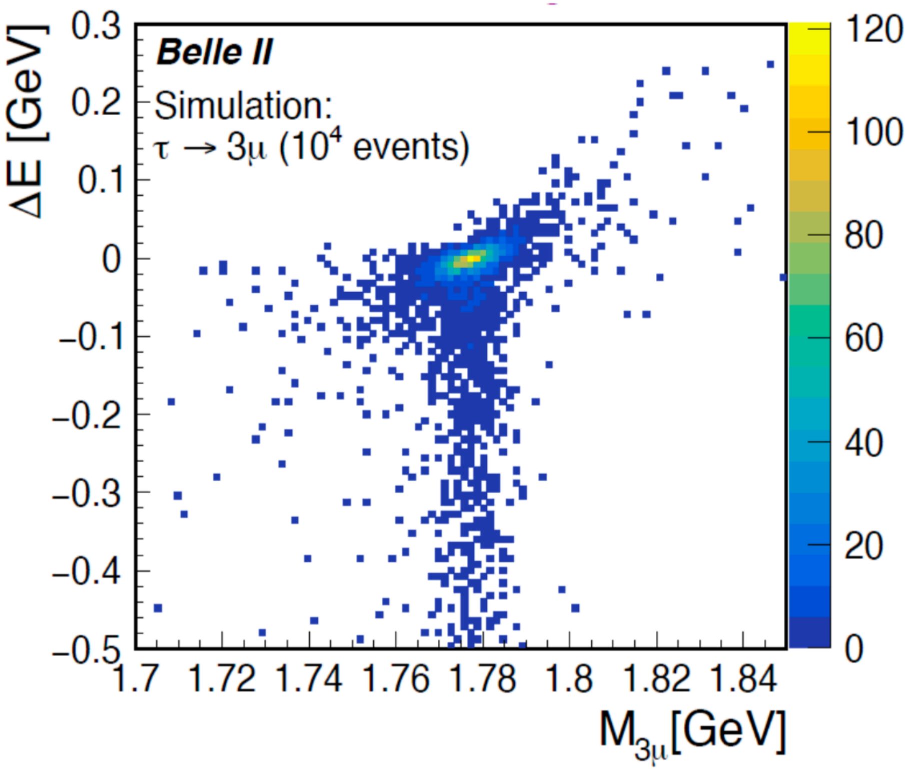
Belle II will push the current bounds forward by at least one order of magnitude!

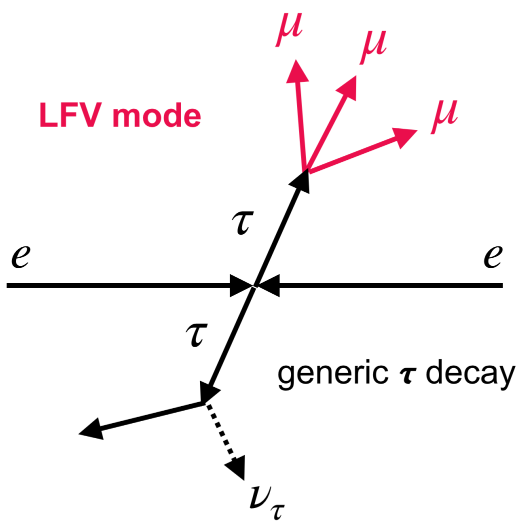
- This only accounts for ↑ luminosity
- Equally important will be improvements in signal detection efficiency

  better trigger, tracking, vertexing, PID, π^0 reconstruction, more refined analysis techniques, …

Search for LFV $\tau \to \mu\mu\mu$

- Consider two independent variables: $M_\tau = \sqrt{E^2_{\mu\mu\mu} - P^2_{\mu\mu\mu}}$ $\Delta E = E^{CMS}_{\mu\mu\mu} - E^{CMS}_{\text{beam}}$
- Signal extraction in $M_{3\mu}$-ΔE plane (or rotated plane to reduce correlation)
- Side-bands to study / evaluate background contributions
- Excellent muon ID is critical to achieving necessary level of background suppression



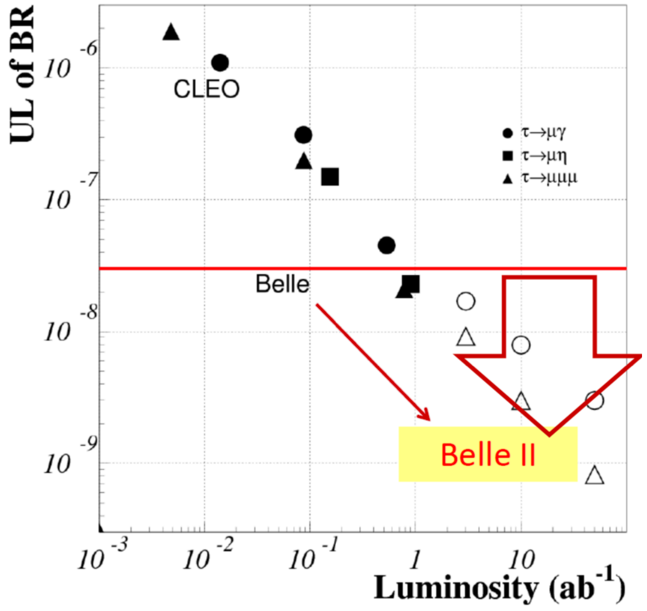


- p-dependent muon ID selection:
  - $p_\mu < 0.7$ GeV ⇒ not reaching KLM
  - $0.7 < p_\mu < 1$ GeV ⇒ reaches KLM, not crossing many layers
  - $p_\mu > 1$ GeV ⇒ reaches KLM with many layers

- Avoids tag μ-veto and $p_\mu > 0.6$ GeV requirements used @Belle.

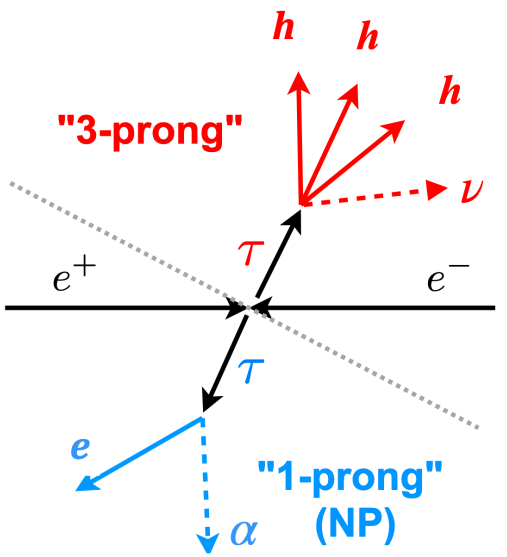
  Belle II has new 3-cluster ECL triggers (>95% efficiency for ΔE~0).

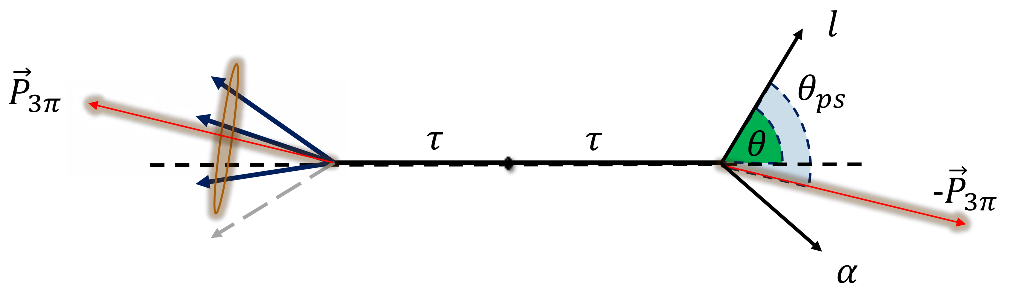
  ⇒ higher efficiency wrt Belle!



Search for LFV τ→lα

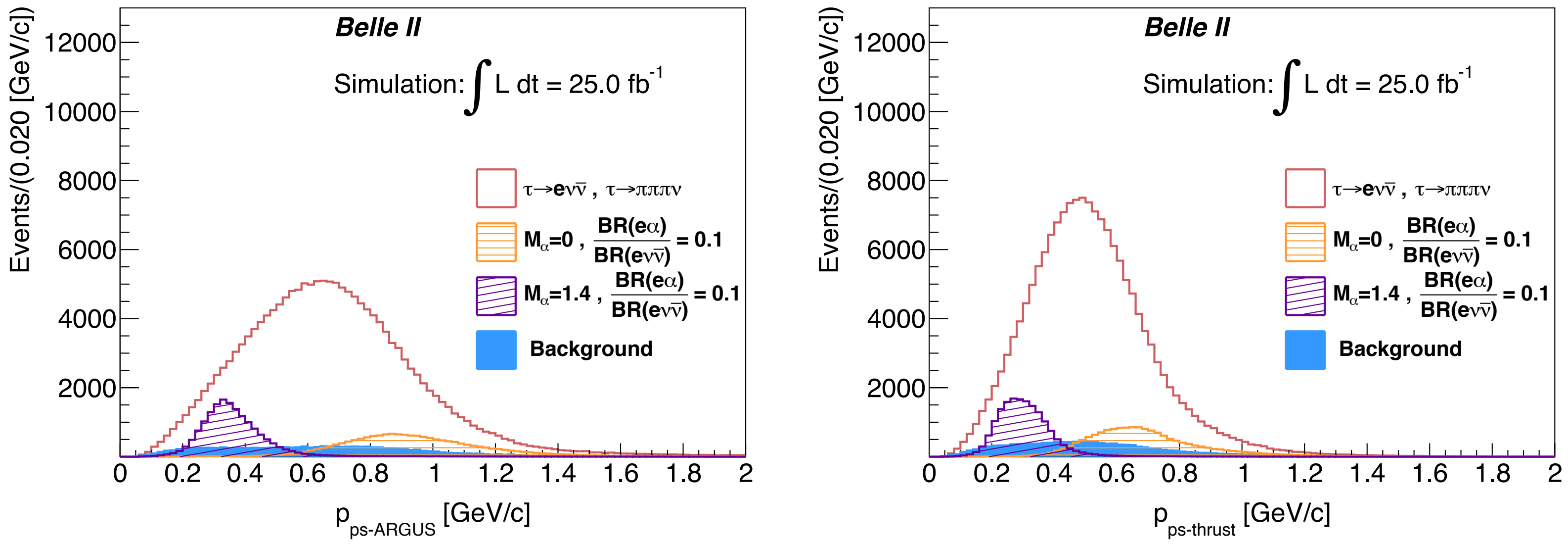
- Search for two body decay **τ→ e/μ + α**, where α escapes detector (missing energy)
- LFV process that appears in several NP models (α = Goldstone boson, LFV Z', light ALP, …)
- Previously studied at MARK III (9.5 pb^{-1}) and ARGUS (476 pb^{-1})





- Signal will manifest as a peak in the τ rest frame, against the SM τ→lνν background

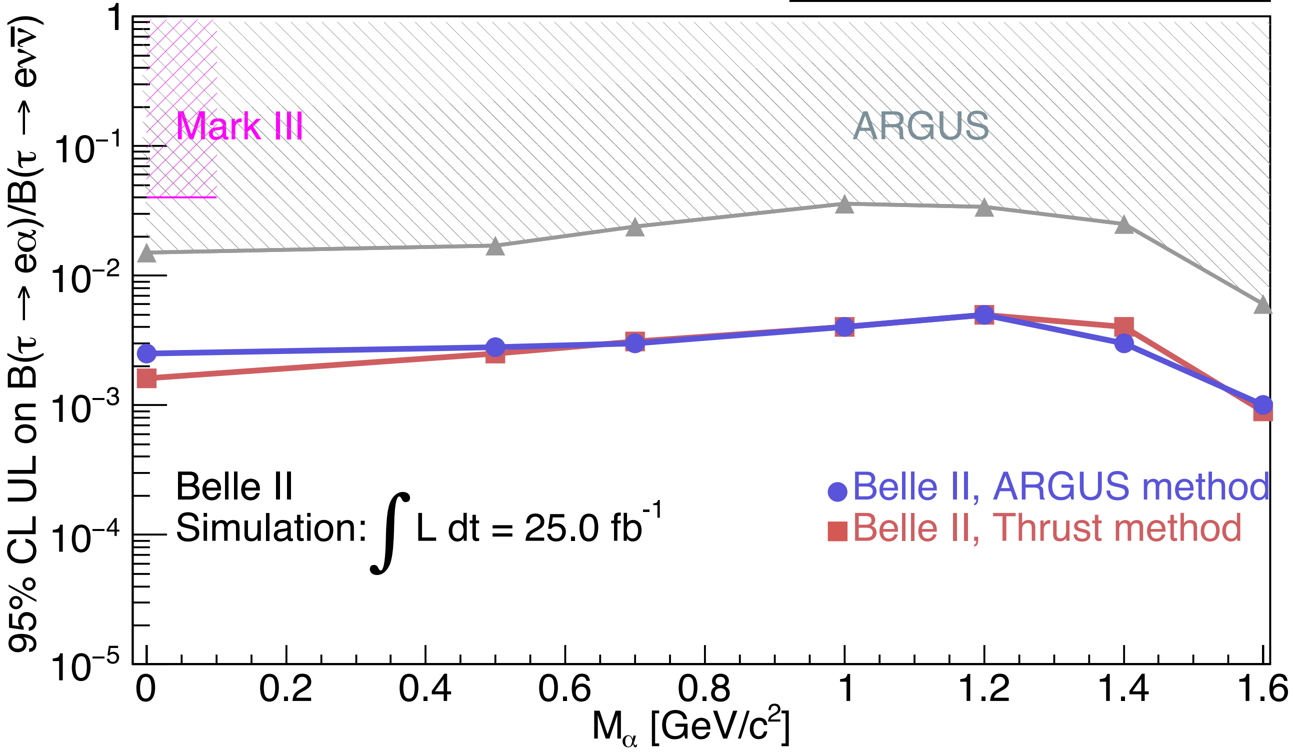
BELLE2-NOTE-PL-2020-018



- cannot access τ rest frame directly due to neutrino
- approximate with the following assumptions:
  - $E_\tau = \sqrt{s}/2$
  - ARGUS method: $\overrightarrow{p_\tau} \approx -\overrightarrow{p_{3\pi}}$
  - Thrust method: $\overrightarrow{p_\tau} \approx \overrightarrow{T}$

- UL estimation for the ratio **Br(τ→eα) / Br(τ→eνν)** @ Belle II

BELLE2-NOTE-PL-2020-018

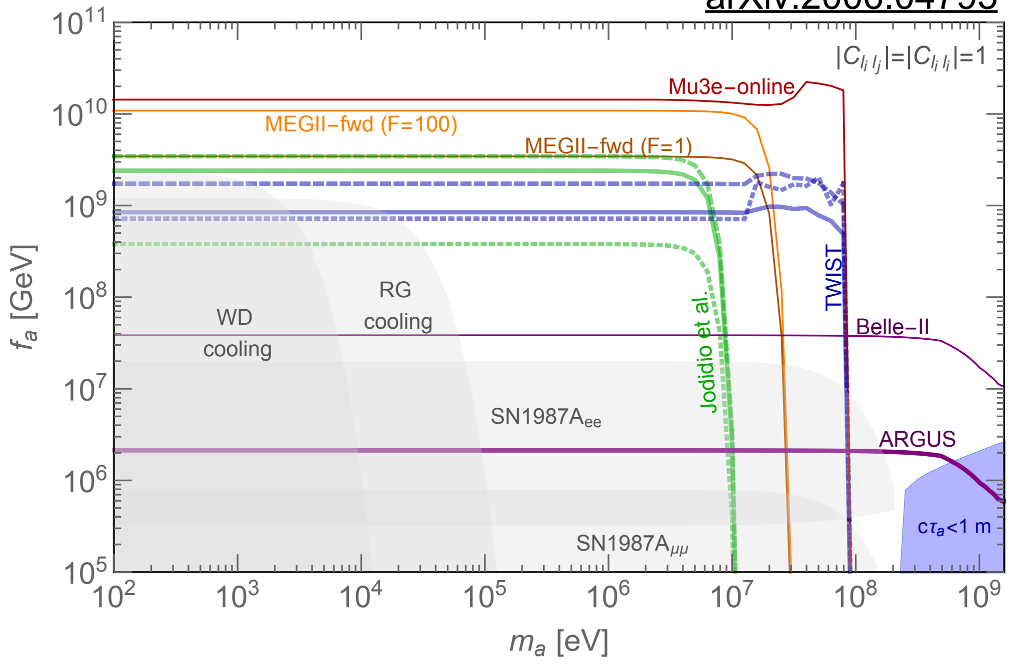


⇒ **With only 25 fb^{-1} of data, Belle II can push forward current bounds by an order of magnitude!**

Can set strong constraints on NP models, e.g:

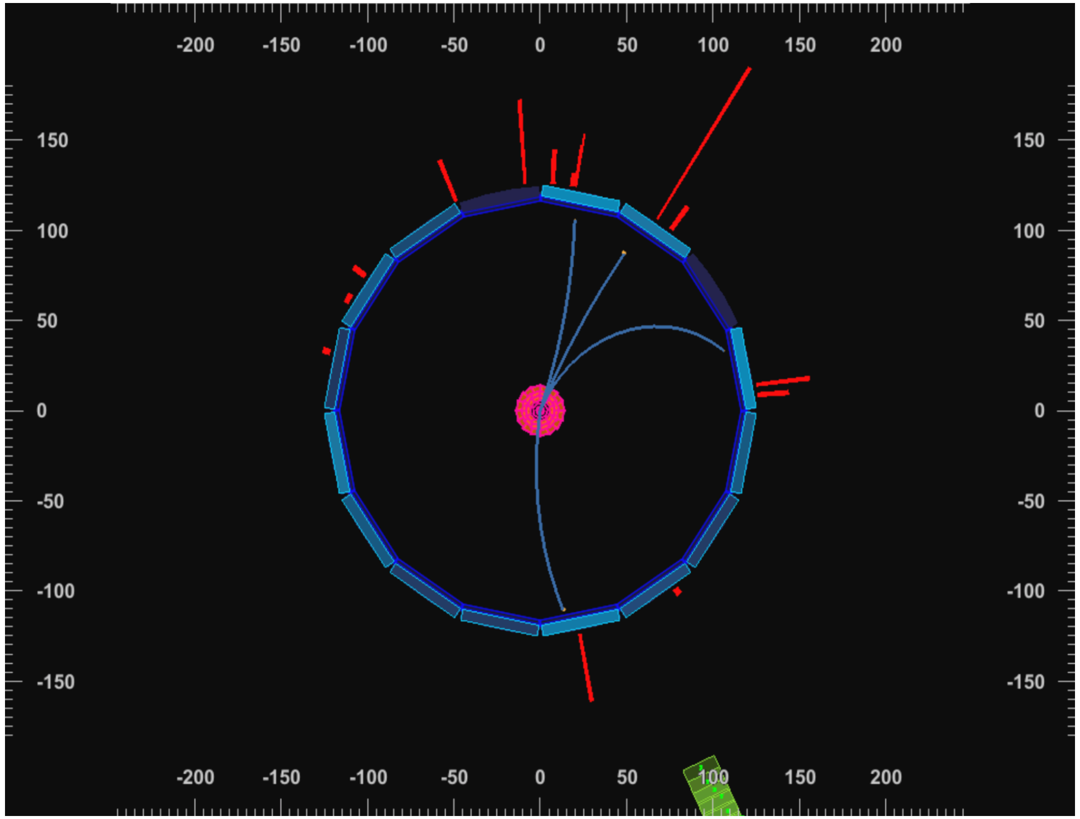
- LFV Z' ⇒ extend the strong bound already set by ARGUS for $m_{Z'} \lesssim m_\tau - m_\mu$
- light ALP ⇒ exploring regions of parameter space not reachable by other experiments

arXiv:2006.04795



Summary and Outlook

- Belle II has recorded ~180 fb^{-1} of data so far. On target to deliver a dataset similar to BABAR by summer 2022.
- Over the coming years Belle II has planned a rich program of precision SM measurements and new physics searches with taus.



- Prospects on 2019-2022 data:
  - Most precise τ mass measurement amongst the pseudomass techniques.
  - World-best measurement of τ lifetime.
  - Pushing the limits of LFU with world leading measurement of R_μ.
  - Searches for LFV τ decays, with first LFV paper on τ→lα coming soon.
  - and <u>much</u> more!

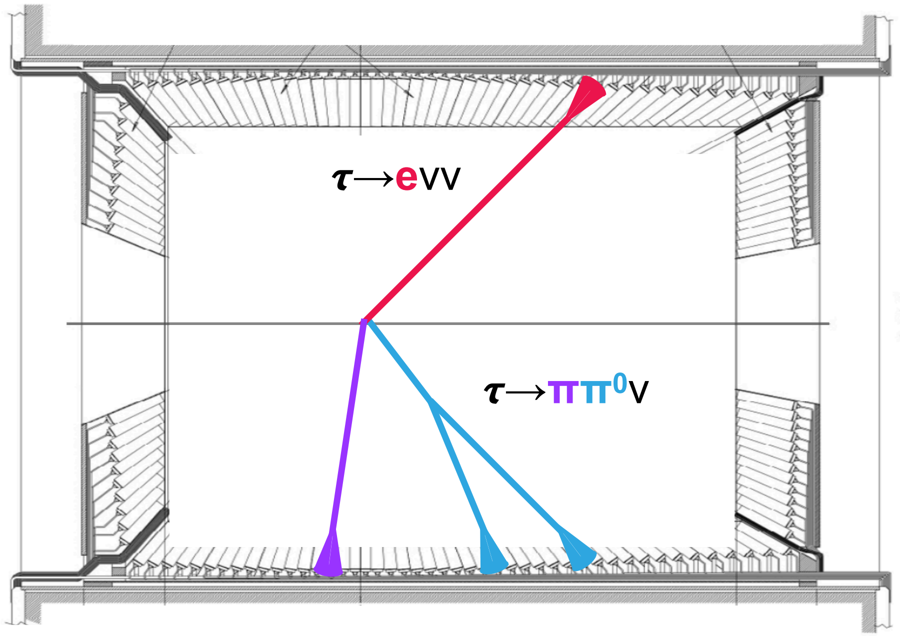
⇒ **Exciting times ahead!**

BACKUP

ECL Triggers

- Unprescaled total energy trigger has a 1 GeV threshold. Sum over L1 Cells. ⇒ 4x4 tower of CsI(Tl) crystals.

- Performs well for ee→ττ events that have high EM energy deposition (e.g. τ → eνν, 3ππ^{0}ν, ππ^{0}ν)



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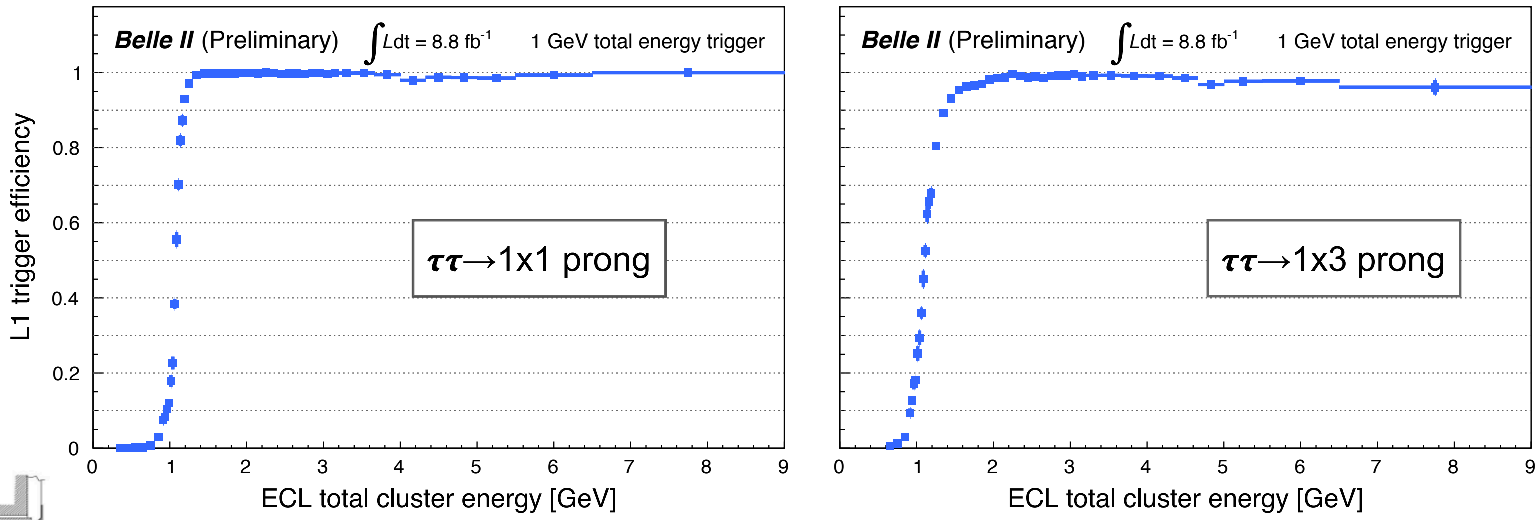
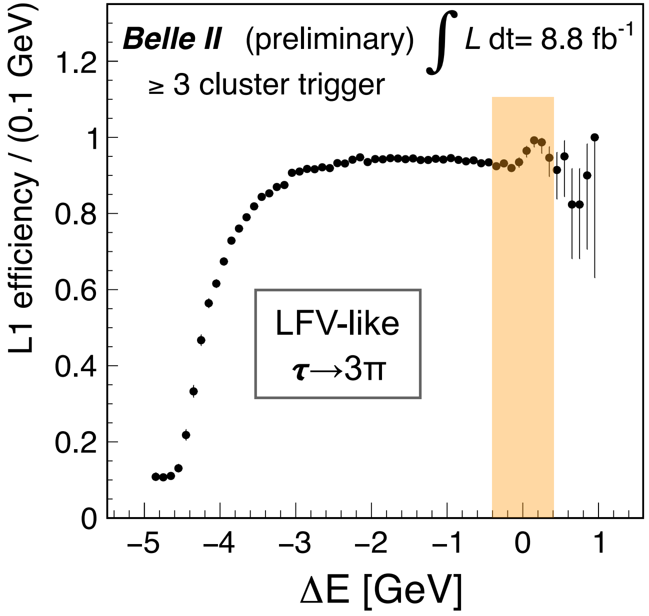


- τ→3μ is one of the most difficult LFV signatures to trigger on @ L1.

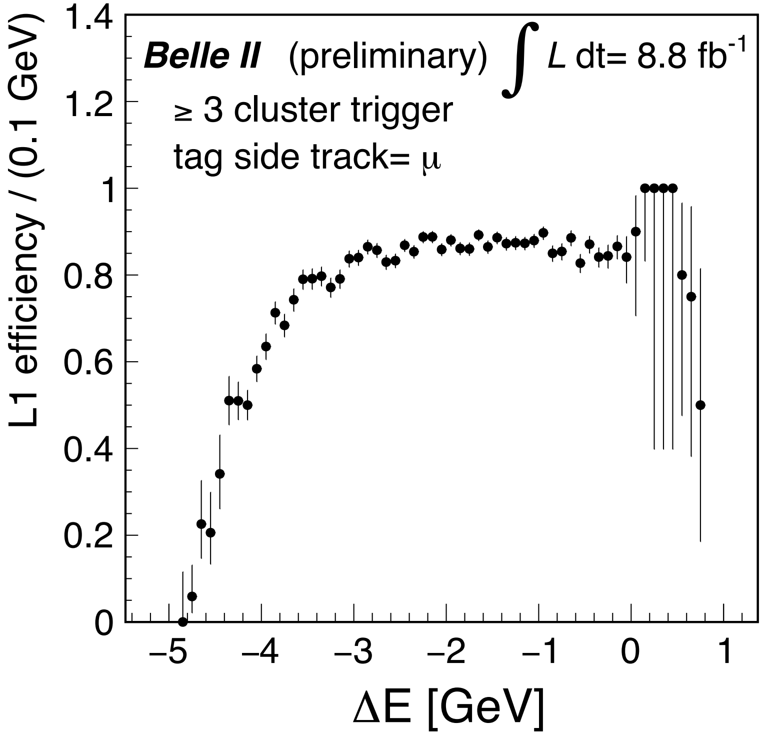
- ECL low multiplicity triggers are new at Belle II.

  Most performant for LFV-like events is the ≥3 ECL isolated cluster trigger

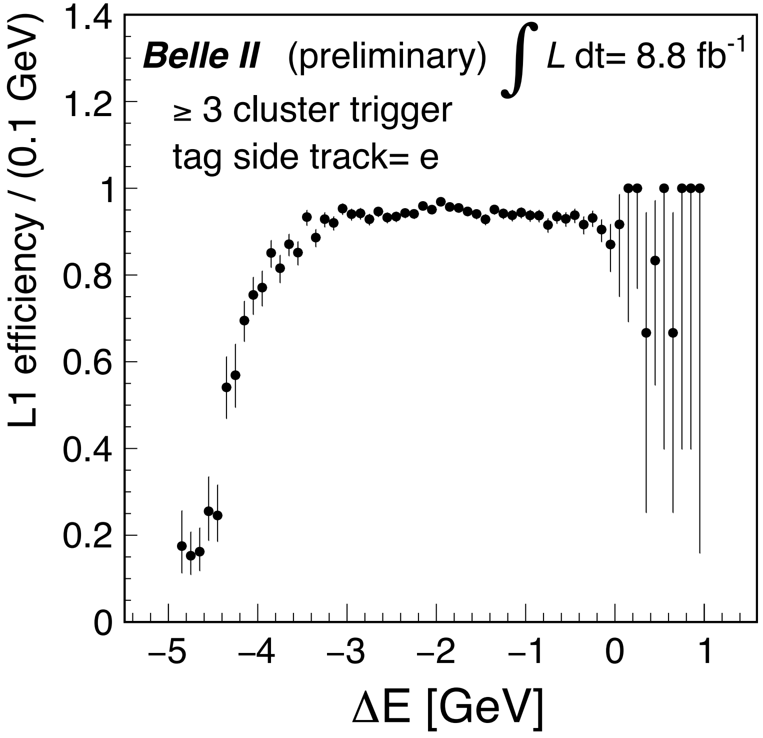


Trigger efficiency for τ LFV

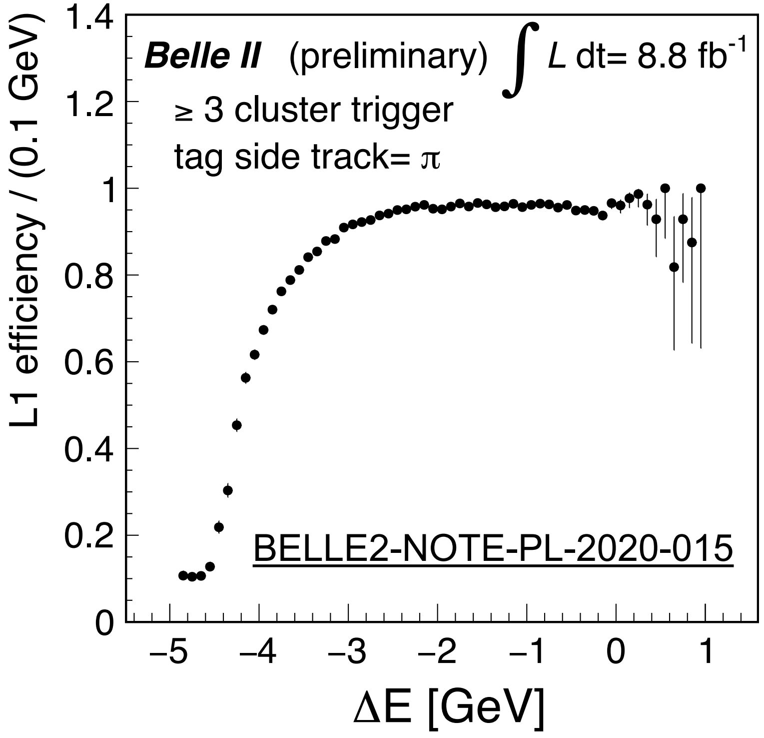
μ-3π, LFV-like event



e-3π, LFV-like event

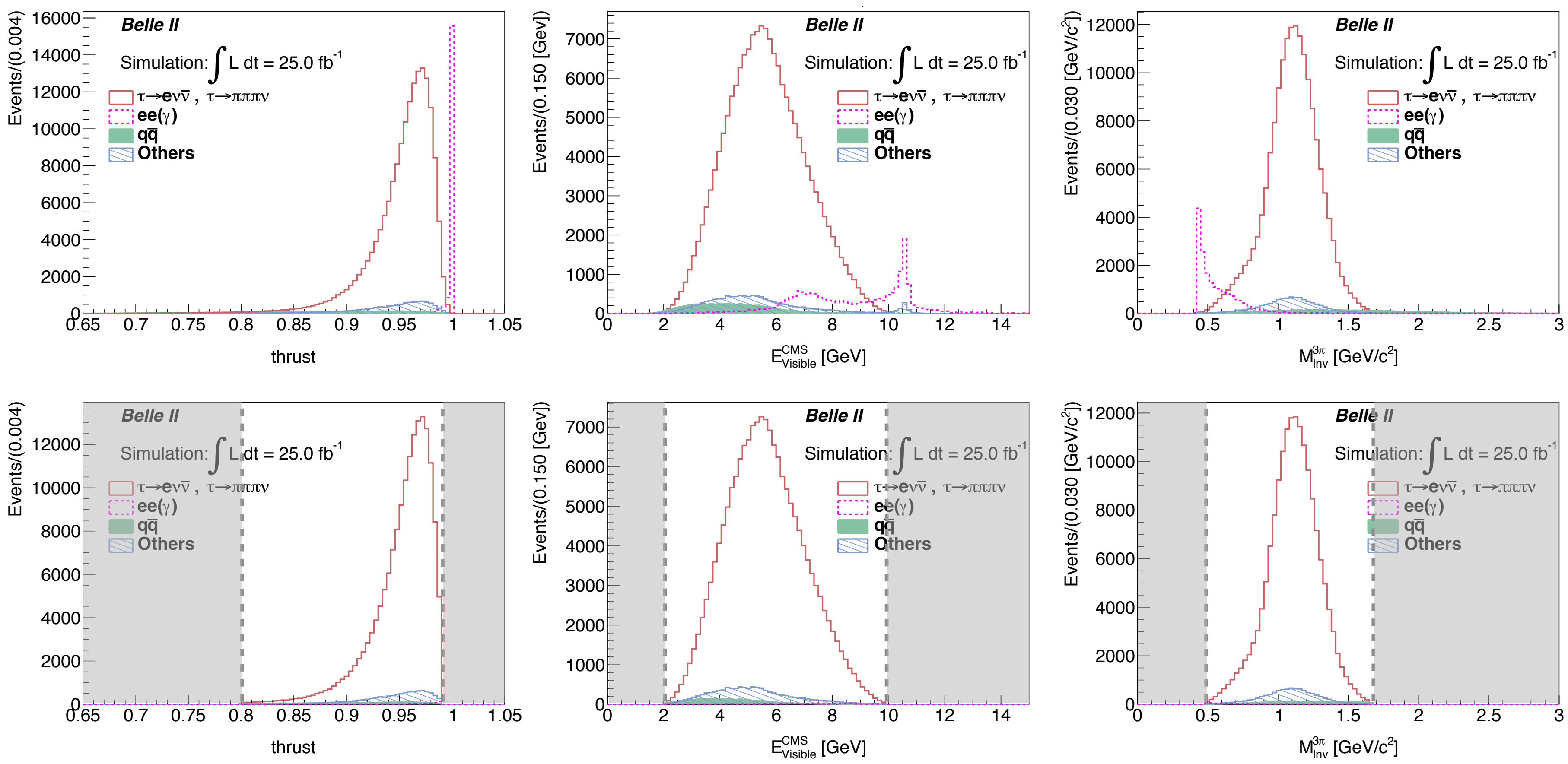


π-3π, LFV-like event



Search for τ→lα

- Follows τ-pair 1x3 prong reconstruction criteria described earlier (4 good tracks, thrust-based hemisphere separation)
- Dominant background is **SM τ→lνν (irreducible)**. Since we don't know M_α, we optimise for the SM.



- Cut-based selection

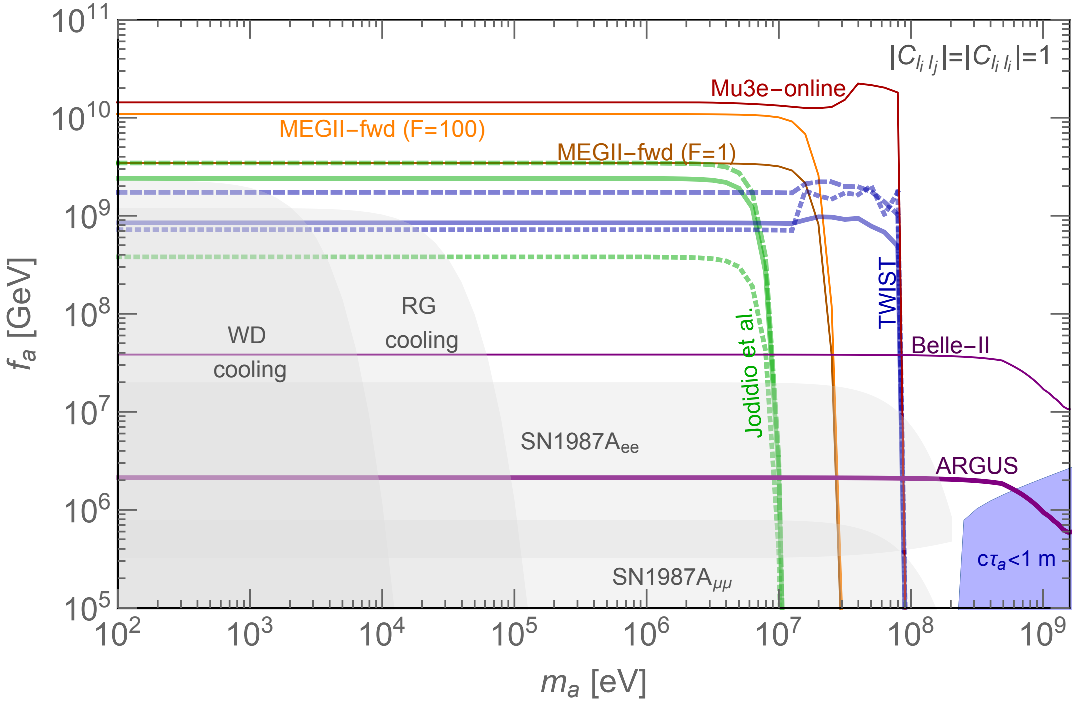
$$\text{FOM} = \frac{S_{SM}}{\sqrt{S_{SM} + B}}$$

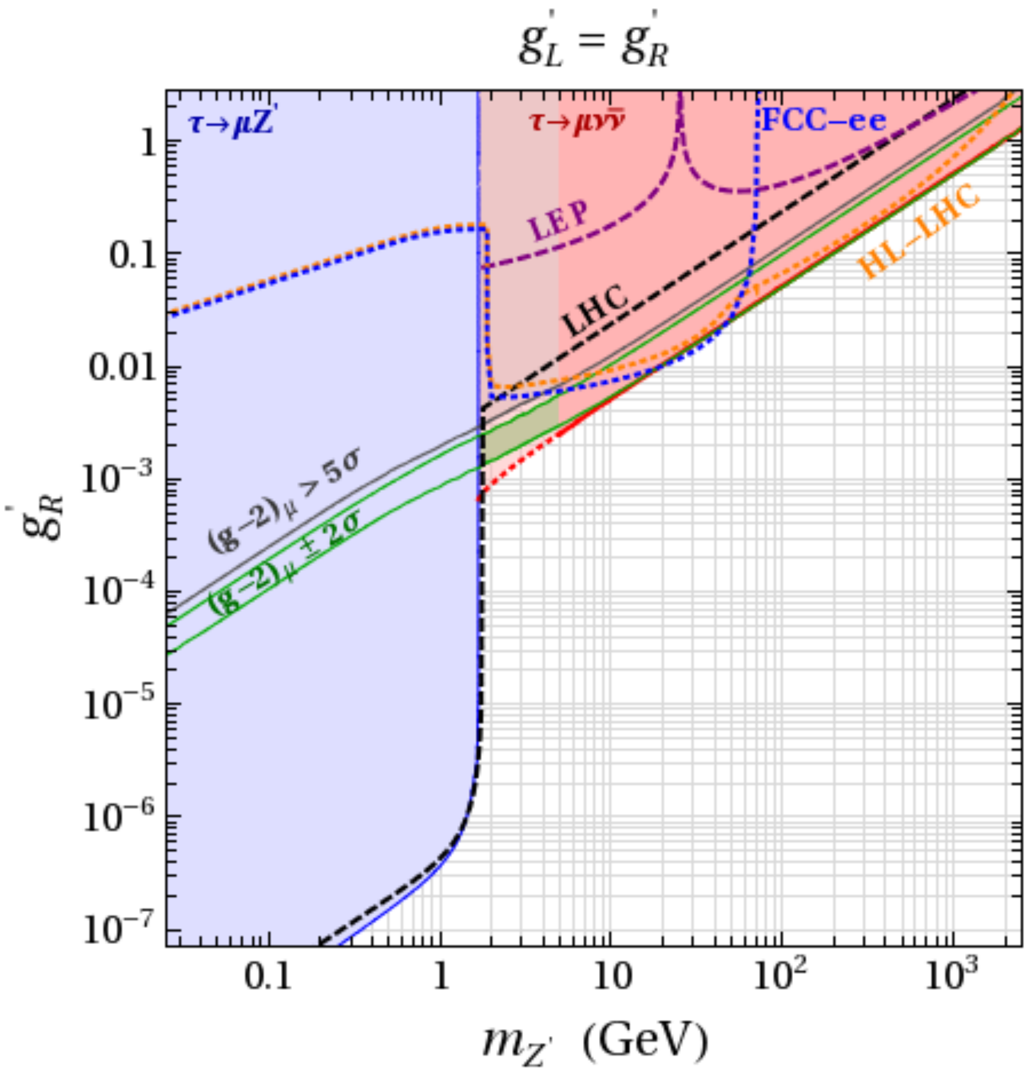
- $0.8 < \text{thrust} < 0.99$
- $2.0 < E_{vis}^{CMS} < 9.9$ GeV
- $0.48 < M_{3\pi} < 1.66$ GeV

Search for τ→lα

Can set strong constraints on NP models, e.g:

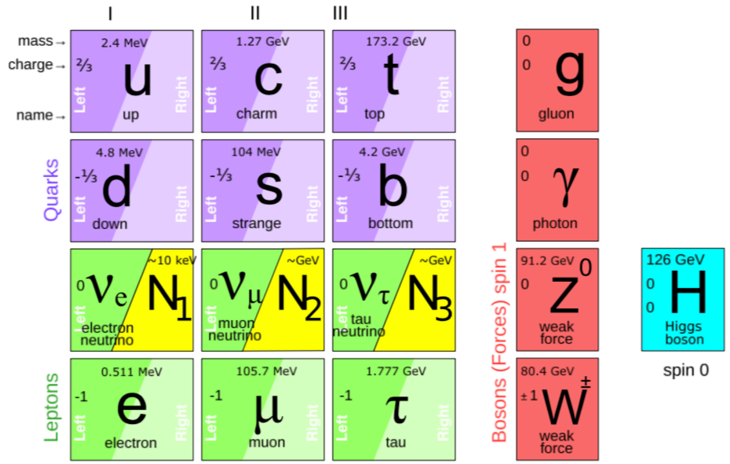
- LFV Z' ⇒ strong bound already set from ARGUS for $m_{Z'} \lesssim m_\tau - m_\mu$
- light ALP ⇒ exploring regions of parameter space not reachable by other experiments





Search for Heavy Neutral Leptons

- Neutrino masses can be incorporated into the SM by introducing sterile RH (Majorana) neutrino(s)



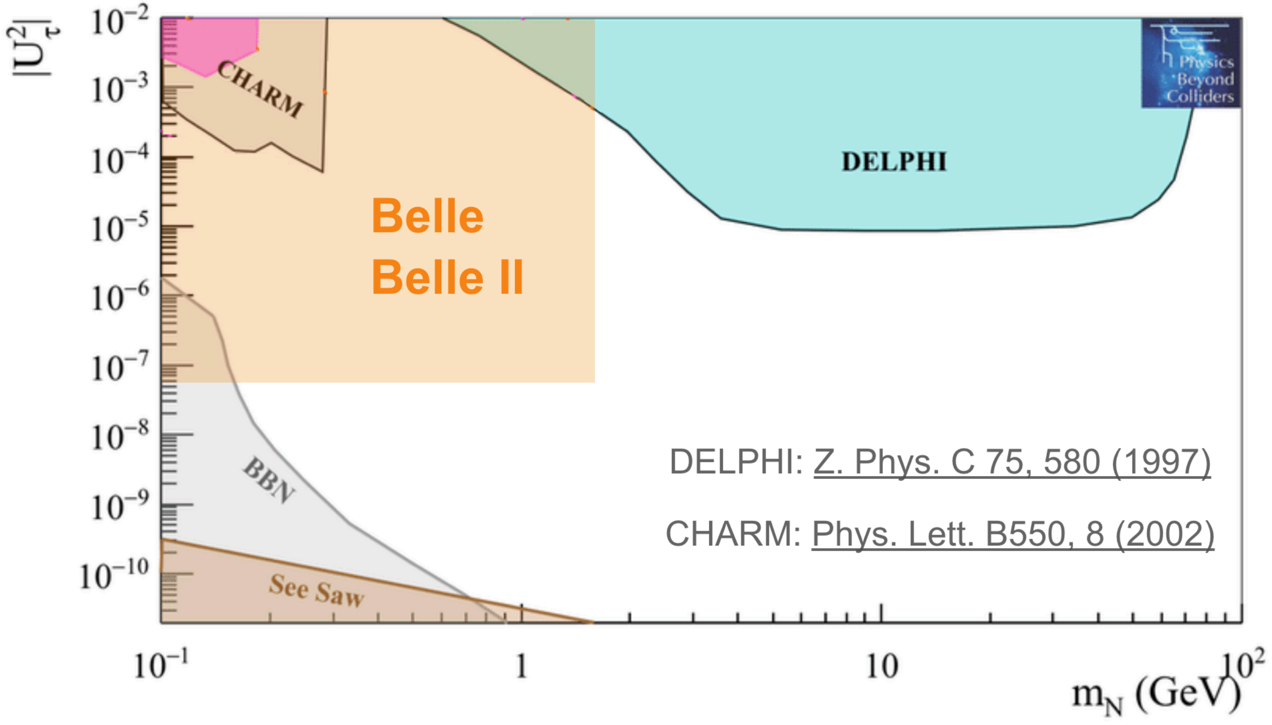
- For example, the ***ν*MSM** model introduces three RH singlet HNLs. Can solve:
  - origin and smallness of ν_{SM} mass (with GeV scale $N_{1,2}$ and see-saw mechanism)
  - dark matter (N_1 with mass ~keV)
  - BAU: leptogenesis due to Majorana mass term

- HNL interacts with ν_{SM} via $N \leftrightarrow \nu_{SM}$ mixing.
  Long lifetime due to small M_N and small mixing.

- Tight limits already exist on HNL mixing with ν_e and ν_μ.
  Weaker limits on $|U_{\tau N}|^2$, motivating $\mathbf{|U_{\tau N}|^2 \gg |U_{eN}|^2, |U_{\mu N}|^2}$

- By studying τ decays at **Belle II**, we can significantly improve existing limits for **$M_N < M_\tau$**

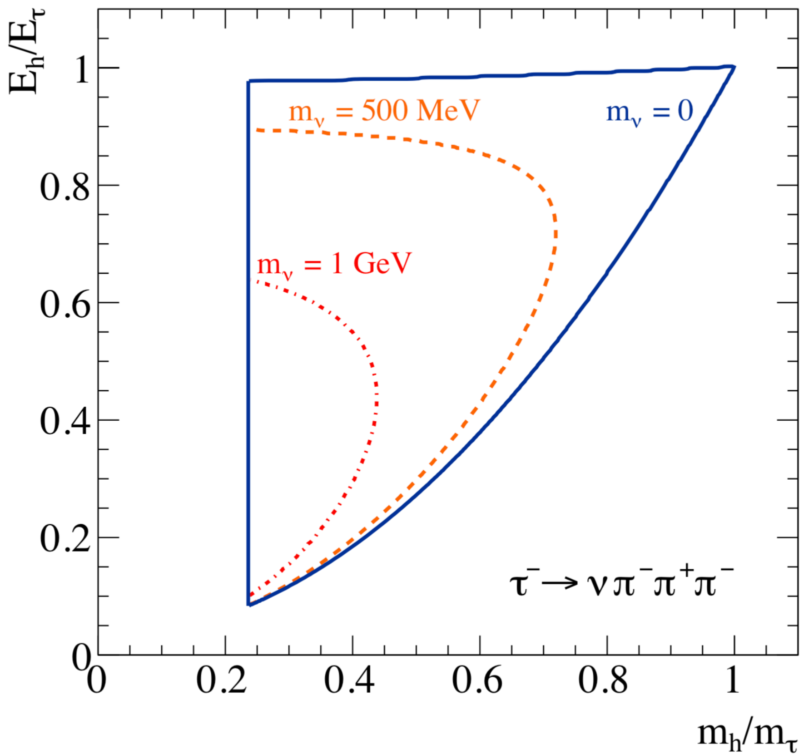
⇒ **No measurement was done at Belle/BaBar!**



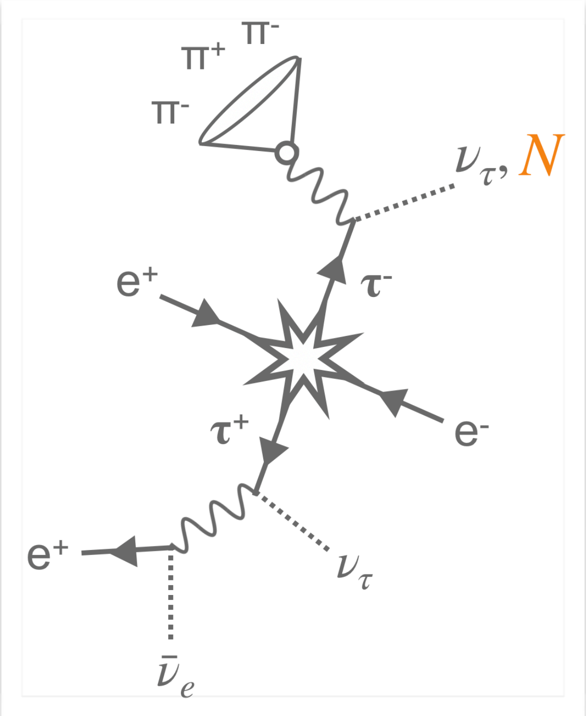
HNL in τ decay kinematics

- Proposed search for HNL in $\tau \to 3\pi\nu$ decays   arXiv:1412.4785v2
- Phase space of 3π-system could be superposition of massless neutrinos and HNL

$$\frac{d\Gamma_{\rm tot}(\tau^- \to \nu h^-)}{dm_h dE_h} = (1 - |U_{\tau 4}|^2)\, \frac{d\Gamma(\tau^- \to \nu h^-)}{dm_h dE_h}\bigg|_{m_\nu = 0} + |U_{\tau 4}|^2 \frac{d\Gamma(\tau^- \to \nu h^-)}{dm_h dE_h}\bigg|_{m_\nu = m_4}$$



- Kinematics of τ decay will contain info on whether 3π recoiled against HNL
- **General idea**:
  Measure a crescent-shaped endpoint in the $E_{3\pi}$-$M_{3\pi}$ plane

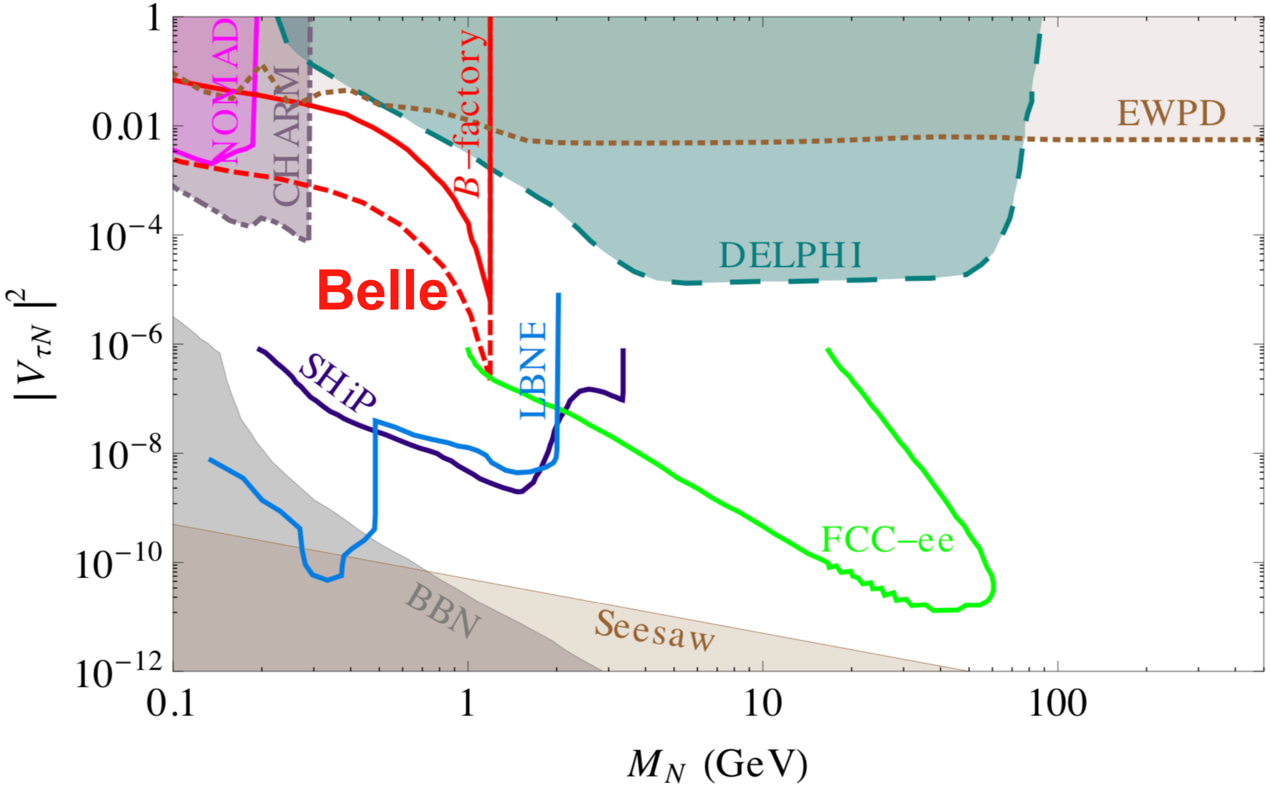


- Method is insensitive to details of HNL decay, lifetime or whether it is Majorana/Dirac
- Would require large data statistics and excellent E/M resolution

  ⇒ **Possible at Belle and definitely at Belle II!**

HNL in τ decay kinematics

aXiv:1502.06541v3



- Sensitivity estimate based on pseudo-data study
- MC sample of ee→ττ with τ→3πν decay(s)
  - assuming Belle lumi
  - smearing to mimic typical Belle resolution
  - both optimistic and conservative scenarios wrt systematics
- **Belle** may be able to place stringent limits on $|U_{\tau N}|^2$ as low as $\mathcal{O}(10^{-7} - 10^{-3})$ for **100 MeV ≲ M_N ≲ 1.2 GeV**

⇒ In the coming years **Belle II** will be able to push these limits even further!

Other players in the game will be **SHiP**, **LBNE** and **FCC-ee**

CP violation in $\tau \to K_S \pi^\pm \nu_\tau + n\pi^0$

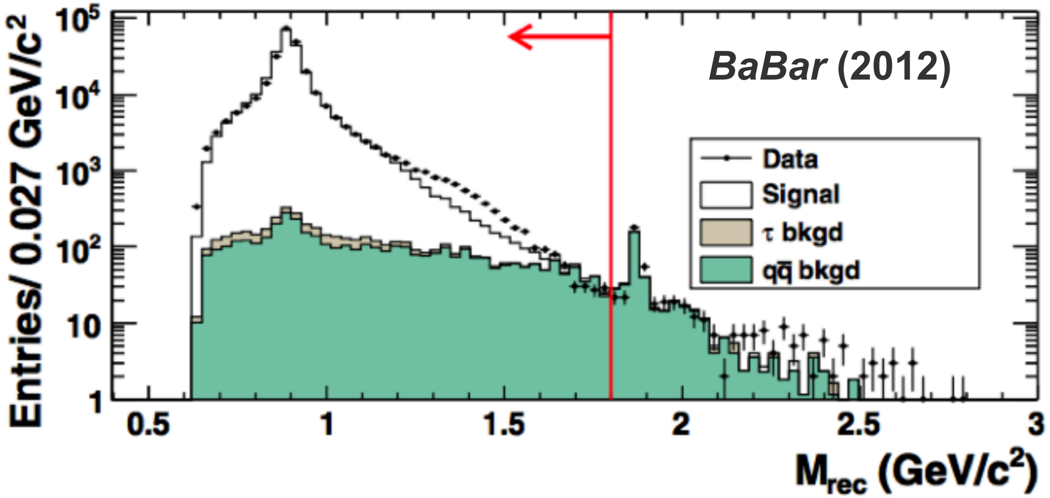
- Due to CP violation in the kaon sector, $\tau \to K_S \pi^\pm \nu_\tau$ decays in the SM have a nonzero decay-rate asymmetry:

$$A_\tau = \frac{\Gamma(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)}$$

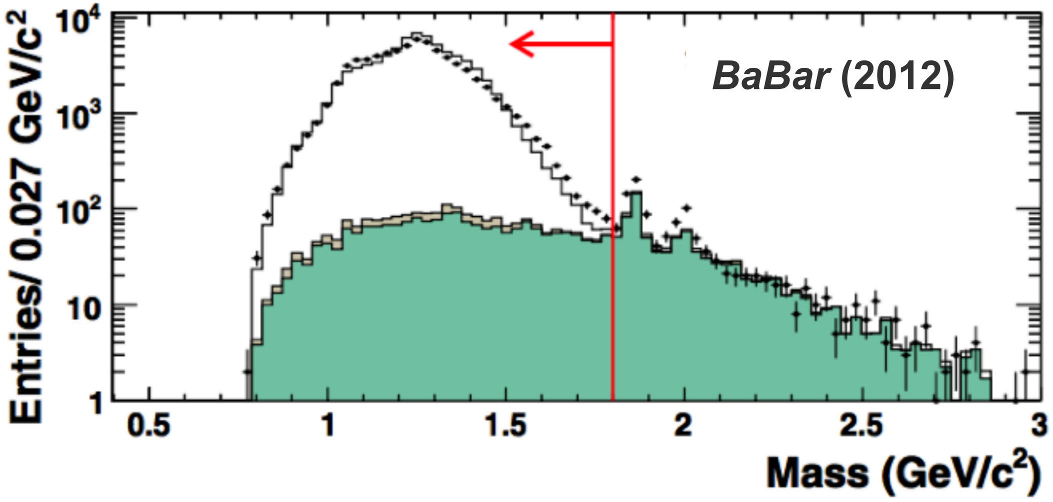
  - SM prediction: $(3.6 \pm 0.1) \times 10^{-3}$
  - BaBar measurement: $(-3.6 \pm 2.3 \pm 1.1) \times 10^{-3}$ **(2.8σ)**

- **An improved A_τ measurement is a priority at Belle II**

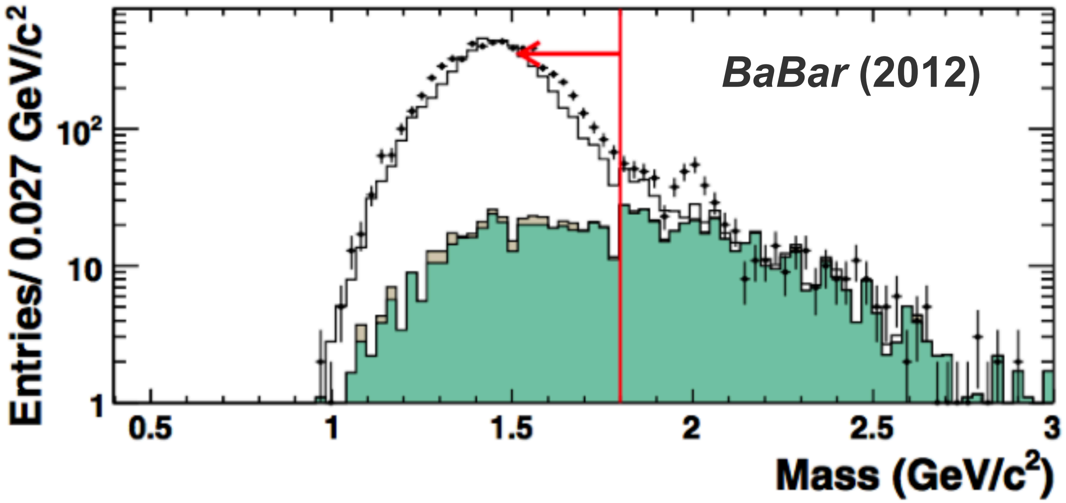
$\tau \to K_S \pi^\pm \nu_\tau$ Phys.Rev D85 (2012) 031102



$\tau \to K_S \pi^\pm \nu_\tau + \pi^0$



$\tau \to K_S \pi^\pm \nu_\tau + 2\pi^0$

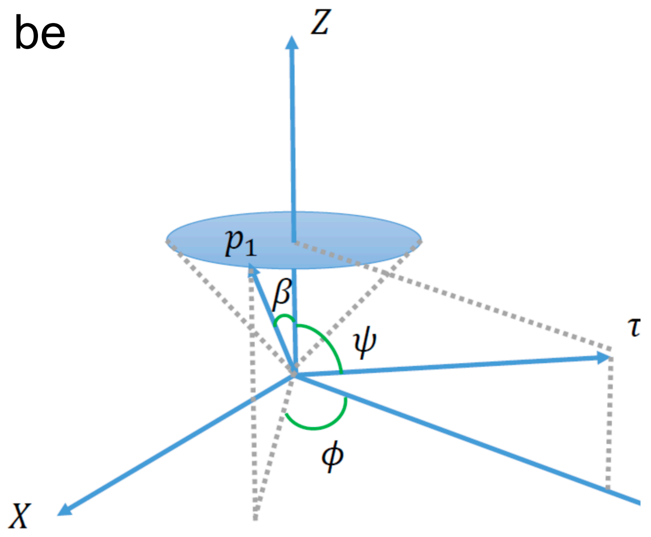


CP violation in $\tau \to K_S \pi^\pm \nu_\tau$

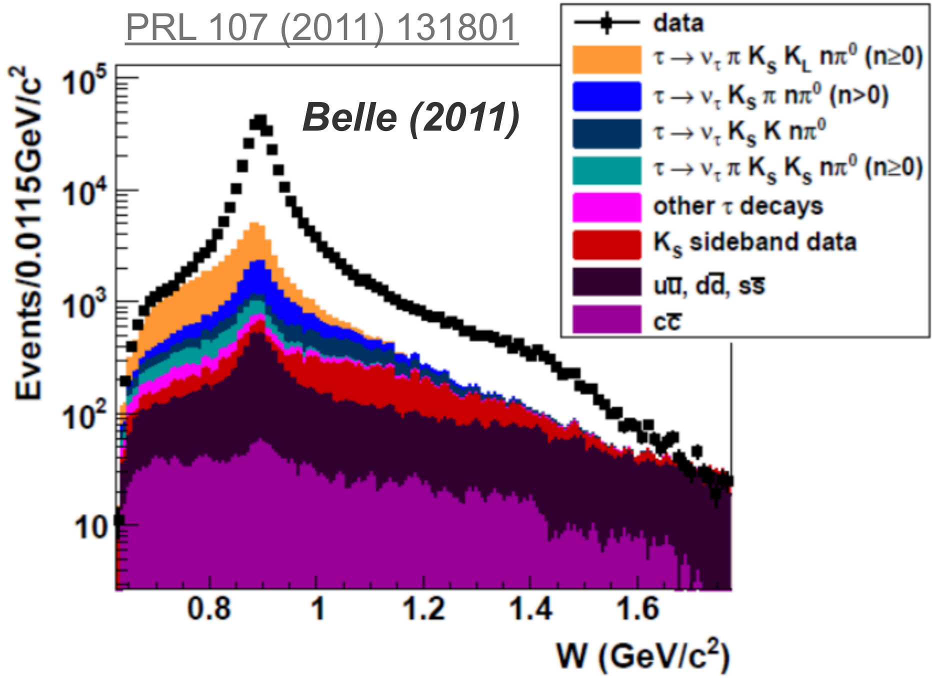
- CP violation could also arise from a charged scalar boson exchange. It would be detected as a difference in the decay angular distributions:

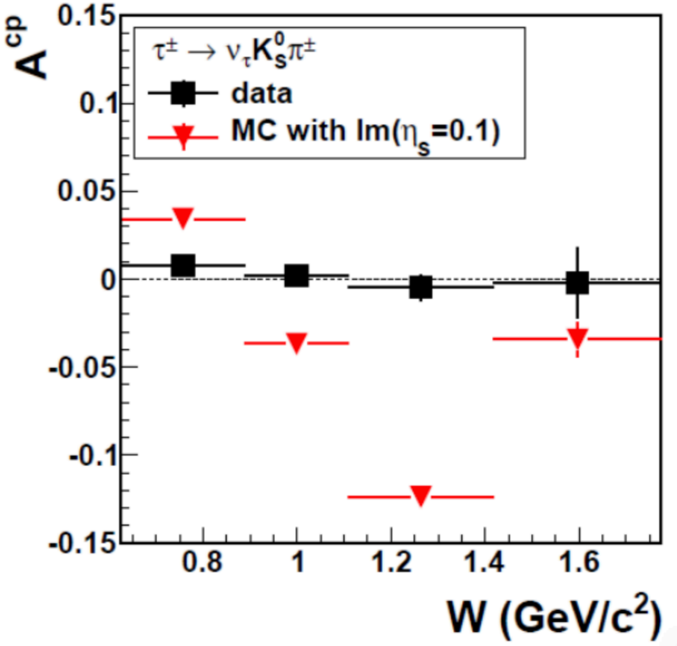
$$A_i^{CP} = \frac{\iint_{Q_{1,i}^2}^{Q_{2,i}^2} \cos\beta \cos\psi \left(\frac{d\Gamma_{\tau^-}}{d\omega} - \frac{d\Gamma_{\tau^+}}{d\omega}\right) d\omega}{\frac{1}{2}\iint_{Q_{1,i}^2}^{Q_{2,i}^2} \left(\frac{d\Gamma_{\tau^-}}{d\omega} + \frac{d\Gamma_{\tau^+}}{d\omega}\right) d\omega} \simeq \langle \cos\beta \cos\psi \rangle_{\tau^-}^i - \langle \cos\beta \cos\psi \rangle_{\tau^+}^i,$$

$$d\omega = dQ^2 d\cos\theta d\cos\beta$$



PRL 107 (2011) 131801





- With 50 ab^{-1} of data, Belle II is expected to provide a x70 more precise measurement:

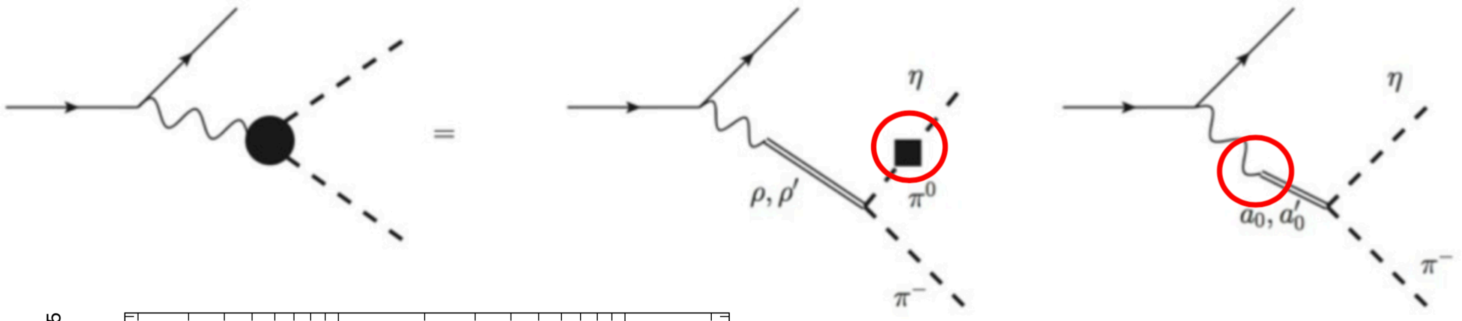
$|A_{CP}| < (0.5\text{-}3.8) \times 10^{-4}$

(assuming central value $A^{CP} = 0$)

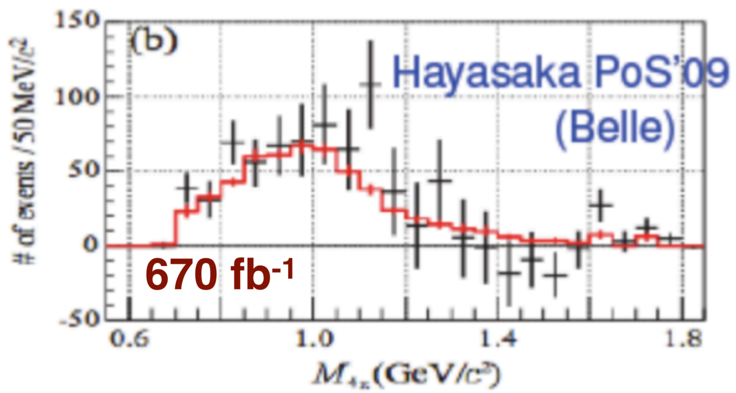
Second class currents in $\tau \to \eta\pi\nu$

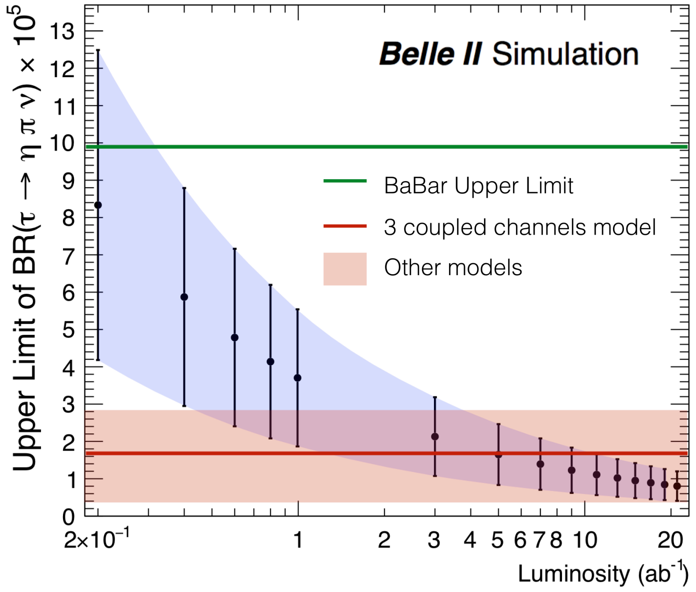
- Hadronic currents classified as first or second class according to their spin, parity and G-parity quantum numbers
  - Second Class Current (SCC): J^{PG} = 0^{+-} (a_0), 0^{-+} (η), 1^{++} (b_1), 1^{--} (ω) ⇒ **yet to be observed!**

- In the SM, **$\tau \to \eta\pi\nu$** decays proceed via SCCs (isospin-violating) with tiny BRs $\lesssim \mathcal{O}(10^{-5})$



- Searched for at last-gen *B* factories:
  - Belle: ***Br*** **< 7.3 x 10^{-5}**
  - BaBar: ***Br*** **< 9.9 x 10^{-5}**





- The observation of SCC via $\tau \to \eta\pi\nu$ decay is a priority at Belle II

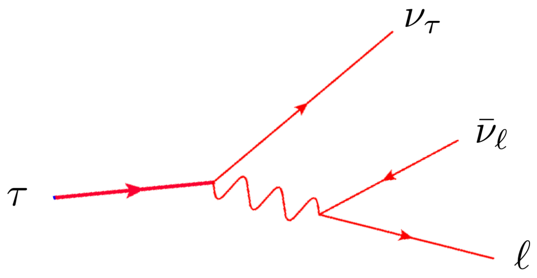
- SM predictions can be tested for the first time with the first years data taking (1 ab^{-1})

- **Clear signal could suggest New Physics!**

Michel Parameters

- In SM, τ lepton decay is due to the interaction with a charged weak current

- Leptonic decays are of particular interest since absence of strong interaction allows precise study of EW Lorentz structure



- When spin of τ lepton is not determined, only four bilinear combinations of the coupling constants are experimentally accessible:
  - ρ, η, ξ and δ
  - in SM: 3/4, 0, 1 and 3/4

- With full dataset (50 ab^{-1}), the stat uncertainty is expected to be ~10^{-4}

- Systematic uncertainties will be challenging at Belle II (~10^{-3})