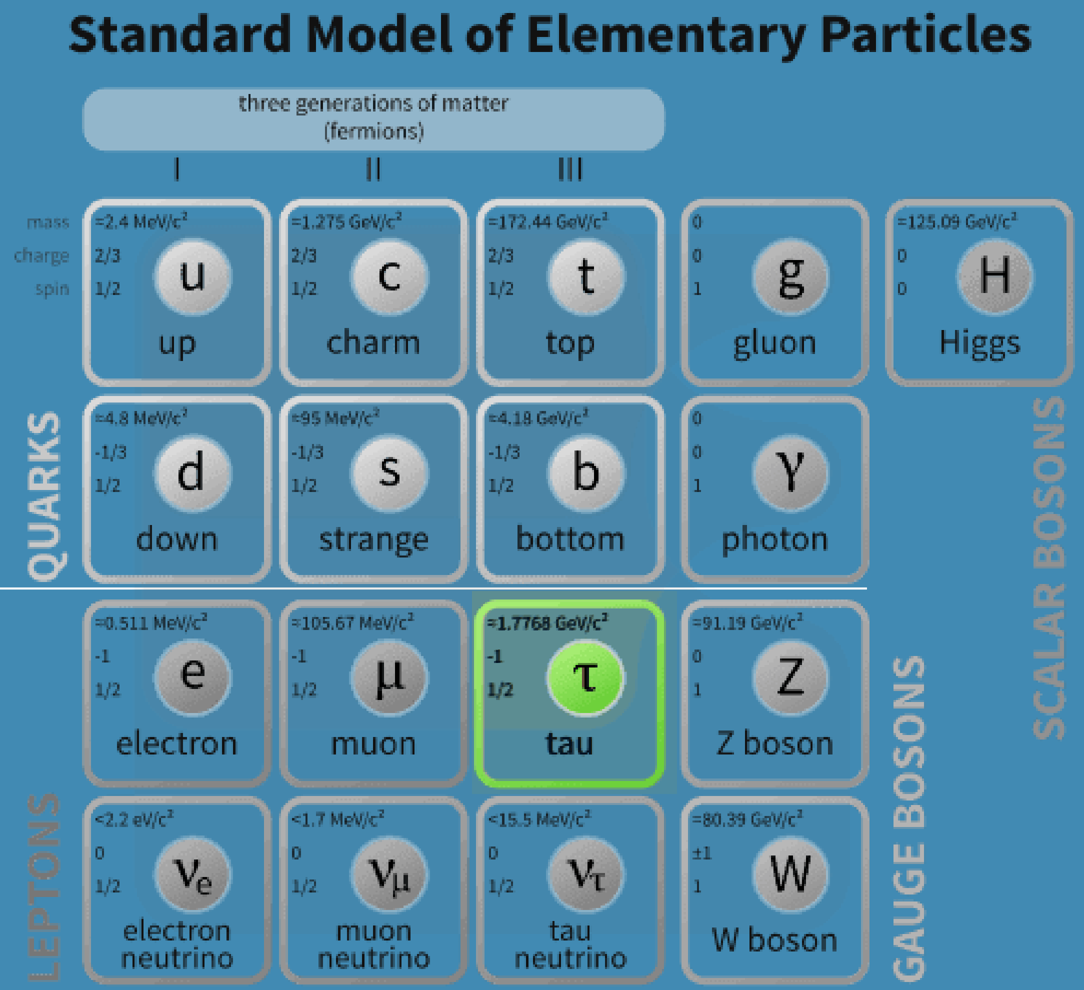
TAU PHYSICS AT BELLE II



Eduard De La Cruz Burelo

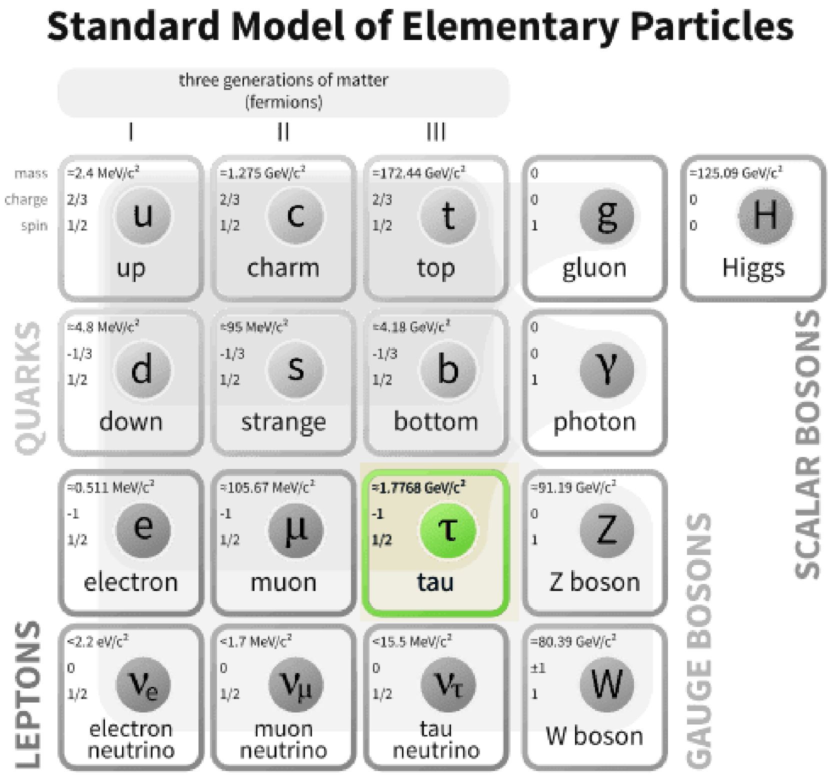
Department of Physics

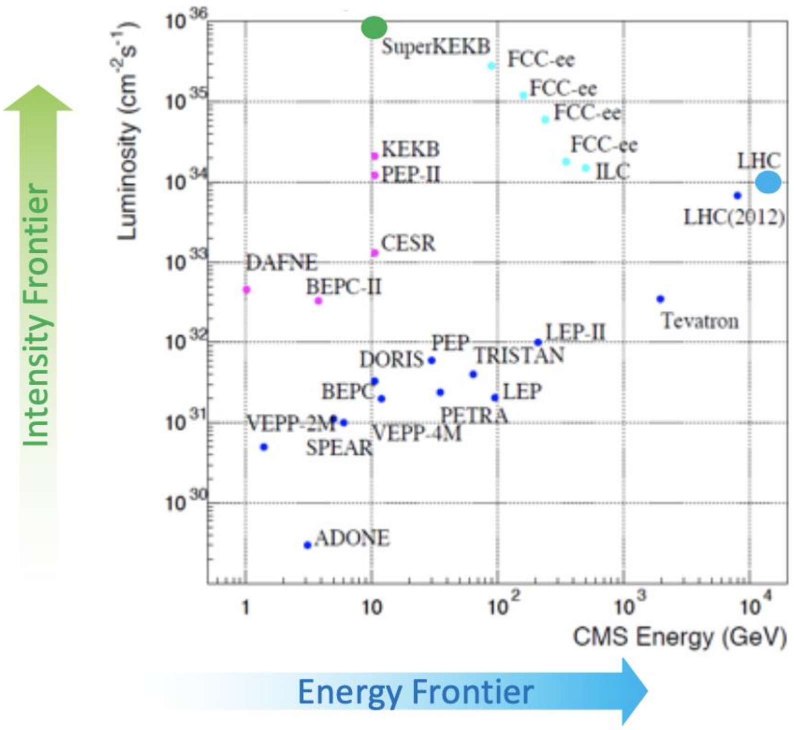
Cinvestav

Tau lepton

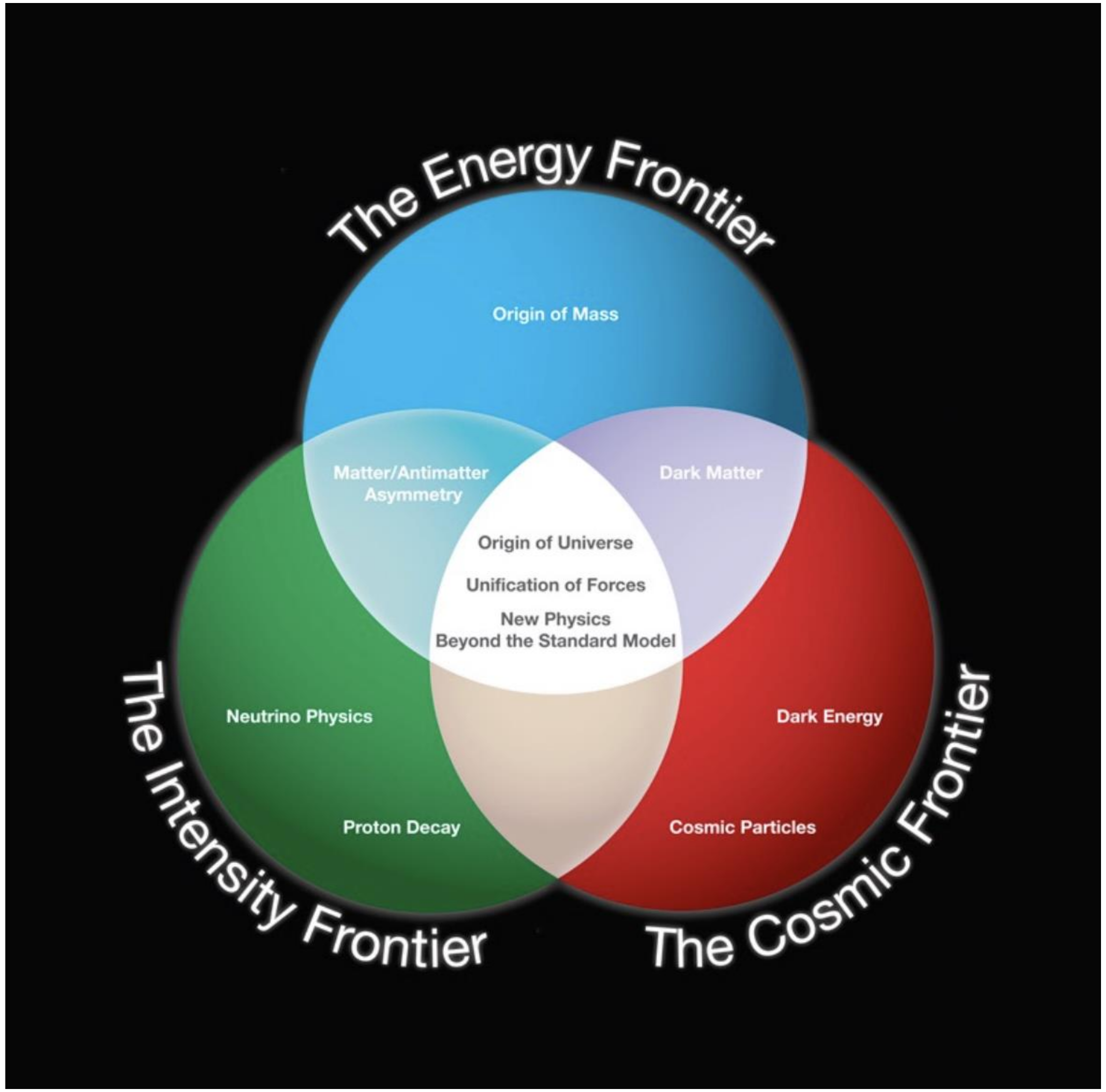
Lepton	Mass	Relative standard uncertainty
Electron	$0.510\,998\,950\,69(16)\ MeV$	$3.1\ \times\ 10^{-10}$
Muon	$105.658\,3755(23)\ MeV$	$2.2\ \times\ 10^{-8}$
Tau	$1776.86\ (12)\ MeV$	$6.8\ \times\ 10^{-5}$

[Source: 2022 CODATA recommended values]

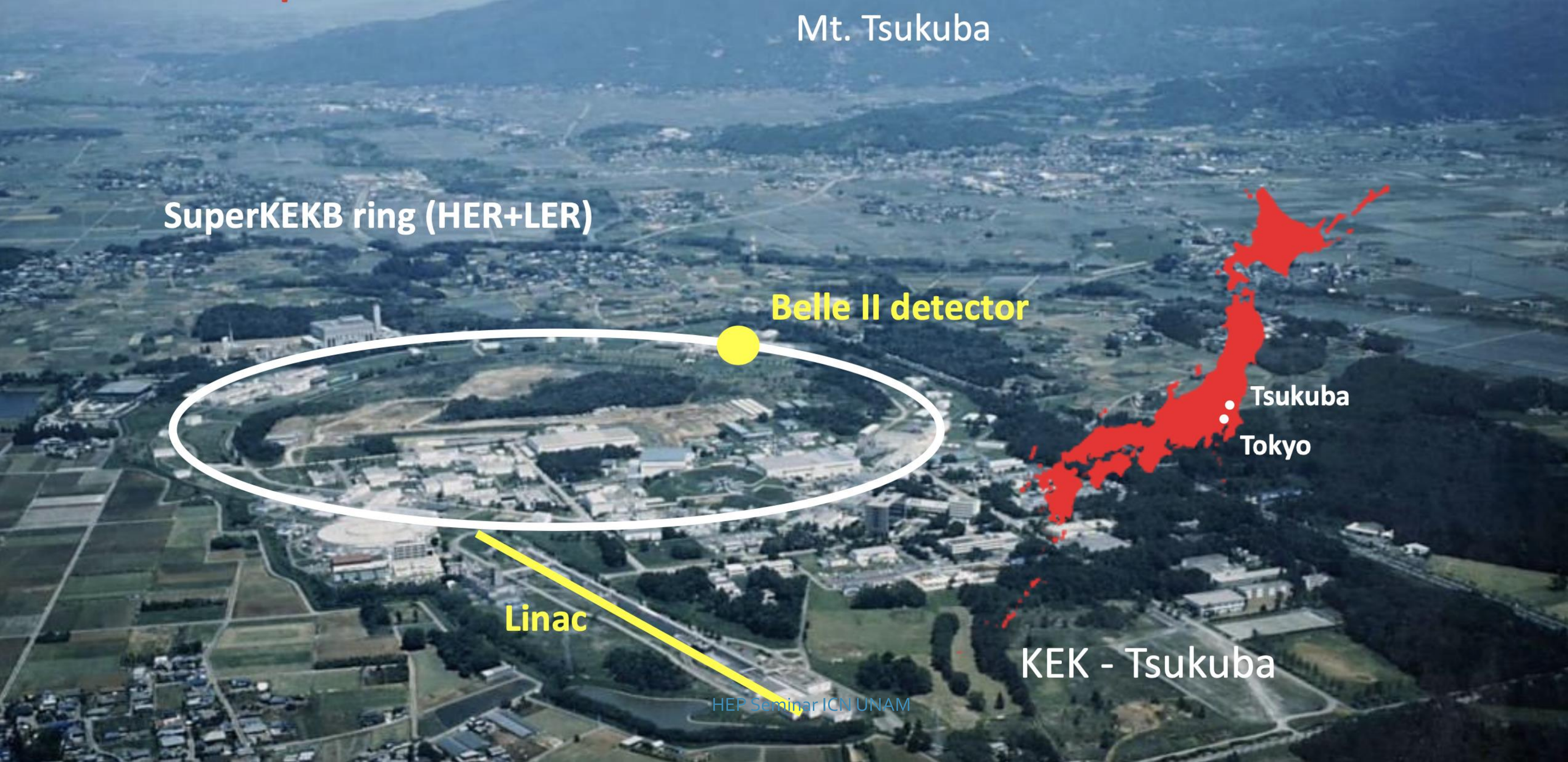




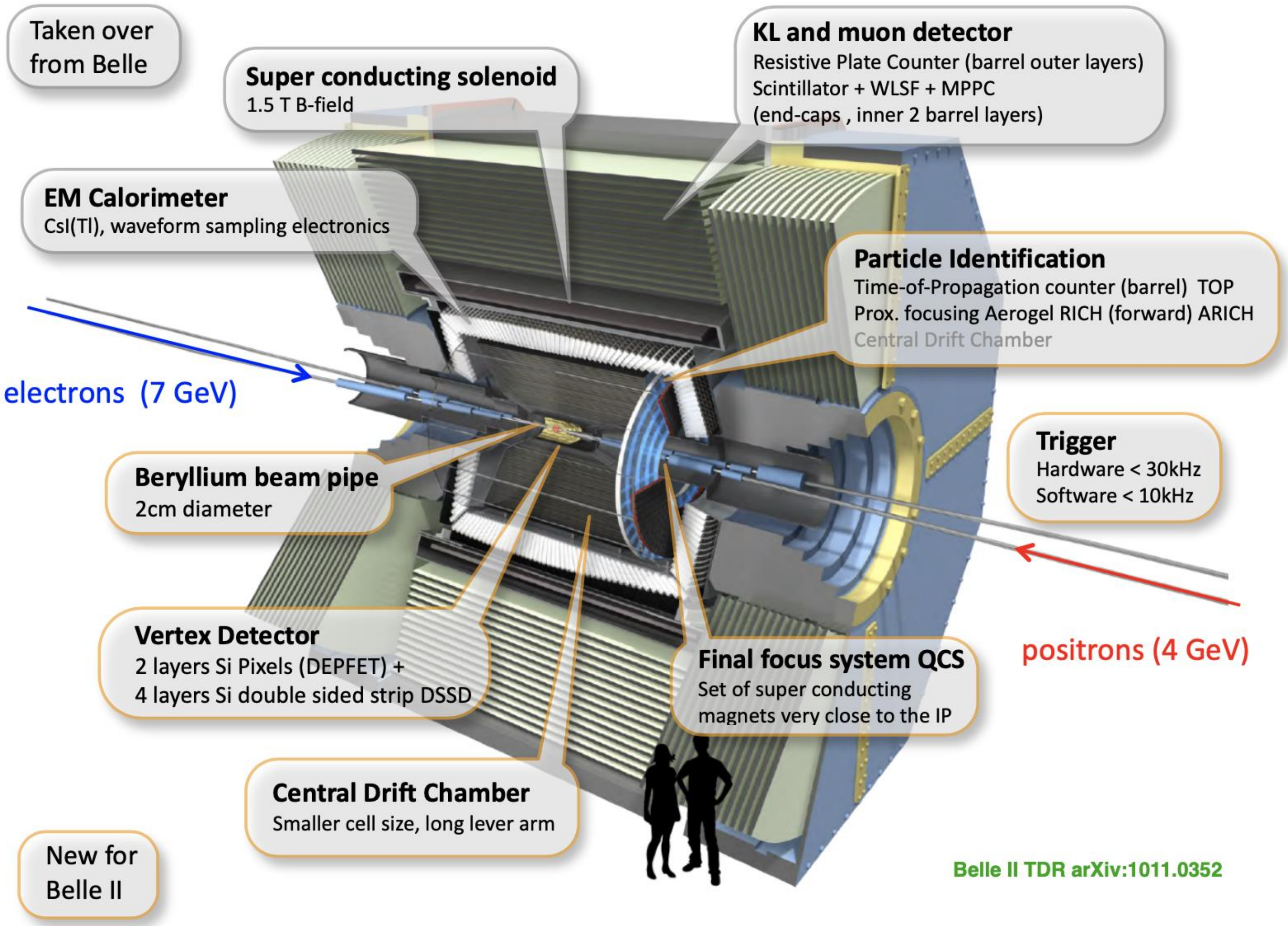
- The **Intensity Frontier**: Search for rare new phenomena using *medium-energy high-luminosity* machines



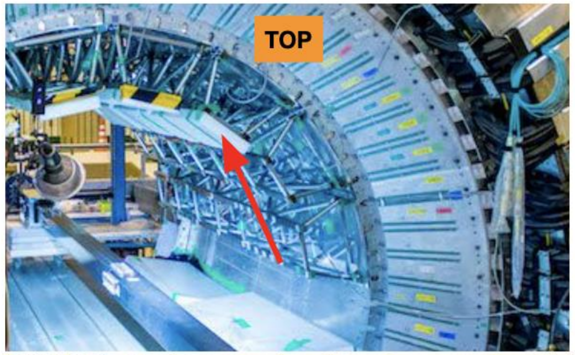
The SuperKEKB Accelerator

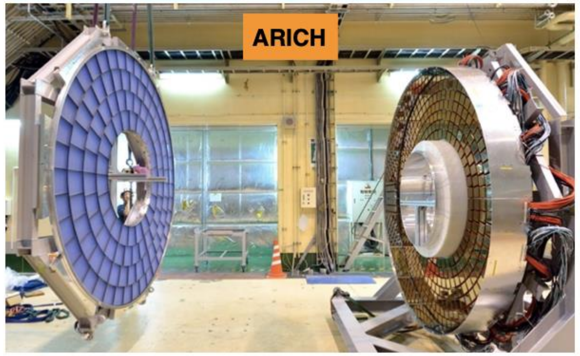


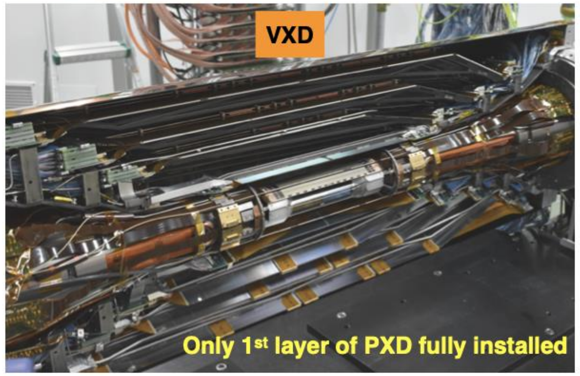
Belle II Detector



Belle II TDR arXiv:1011.0352





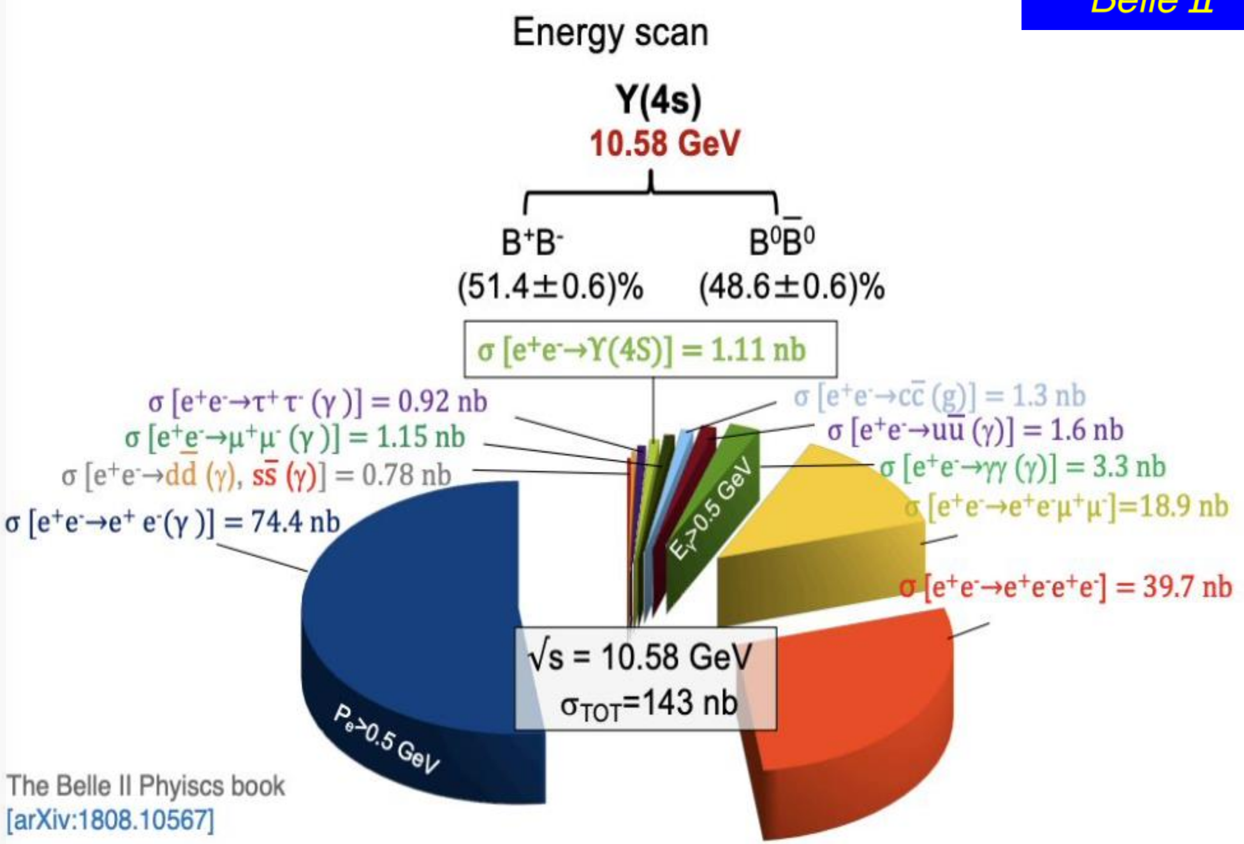


Physics at Belle II

- Not *just* a B-factory!
  - τ, c, and b pairs have similar cross sections at $\sqrt{s}$ = 10.58 GeV

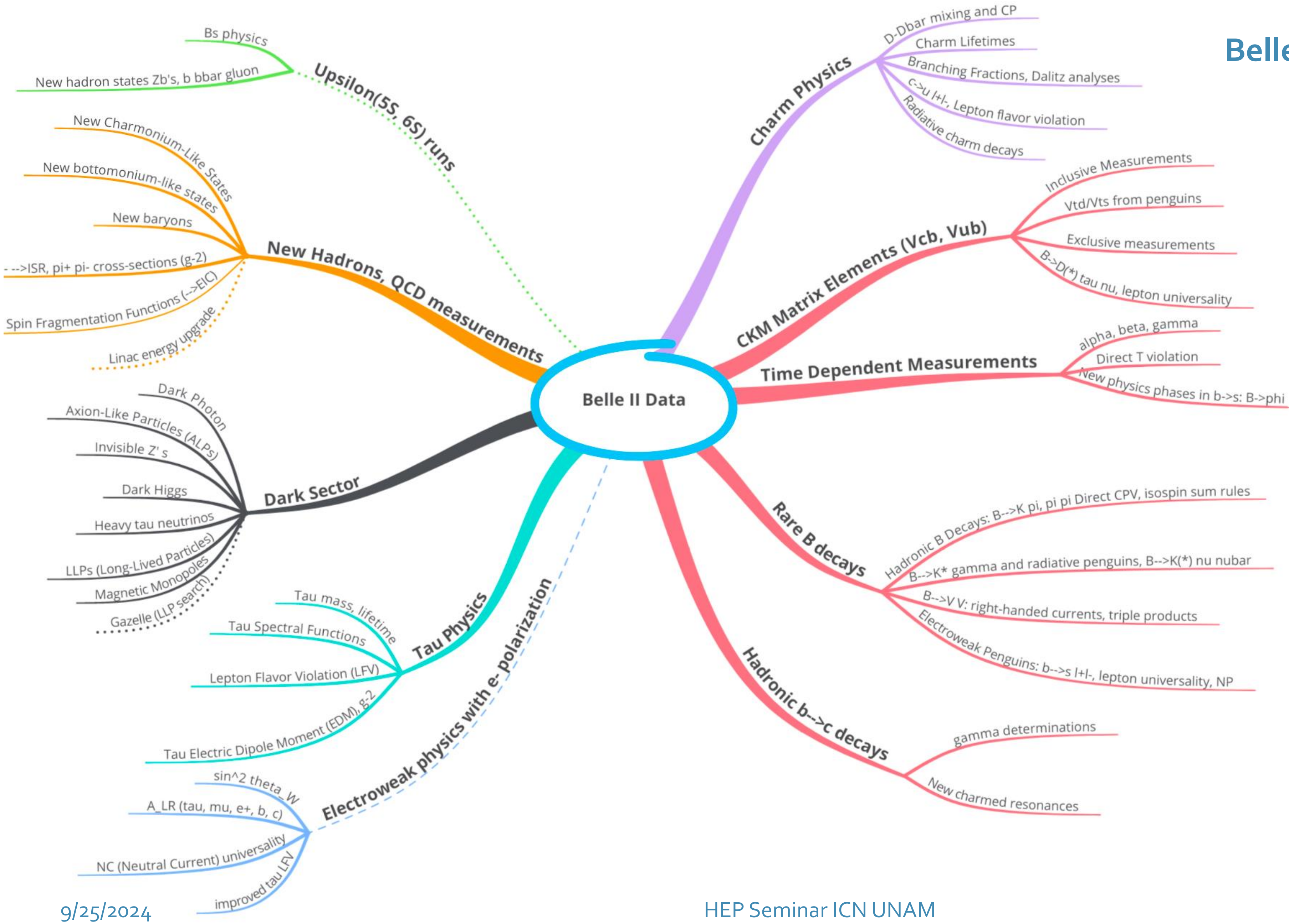
$$\sigma(e^+e^- \to \Upsilon(4S)) = 1.11\ \text{nb}$$
$$\sigma(e^+e^- \to c\bar{c}) = 1.3\ \text{nb}$$
$$\sigma(e^+e^- \to \tau^+\tau^-) = 0.92\ \text{nb}$$

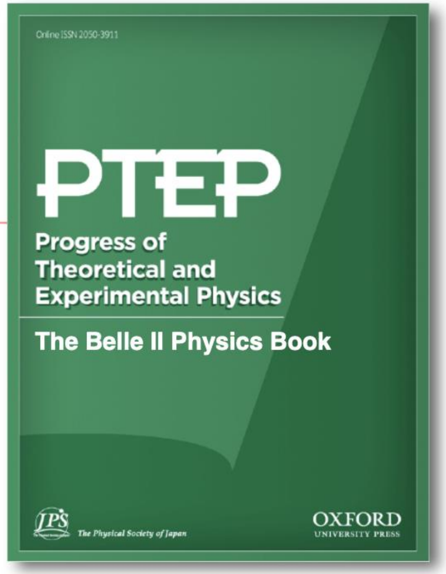
- Wide physics program
  - precision measurements of time-dependent CPV and CKM parameters
  - searches for lepton flavor universality/number violations
  - dark-sector searches
  - and many more



The Belle II Phyiscs book
[arXiv:1808.10567]

Belle II Physics mind map

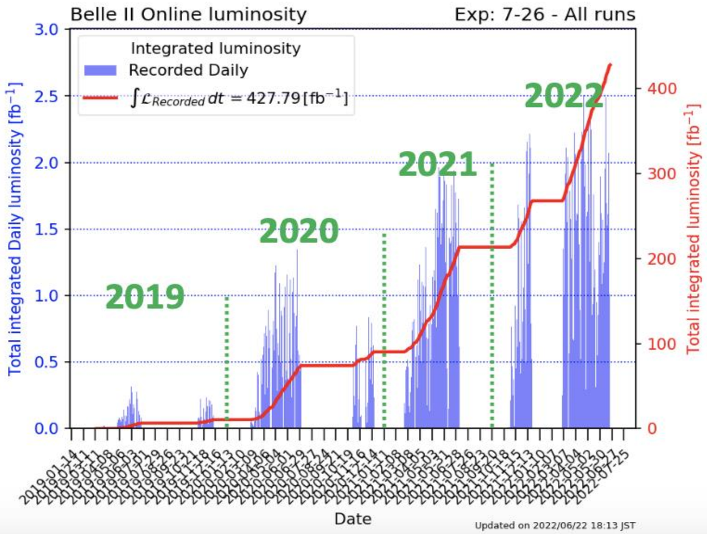




Prog. Theor. Exp. Phys. 2019, 123C01
arXiv:1808.10567

The SuperKEKB – Belle II Roadmap

- Phase 1 (2016): No detector, no collision. Machine startup and baking
- Phase 2 (2018): Pilot run. First collisions with complete accelerator
  Only partial vertex detector and background monitors (BEAST)
- Phase 3 (2019): Physics runs with complete detector
  Run 1 (2019 - 2022): Only partial PXD → 1st Physics paper in 2020
  Run 2 (2024 -): Full detector

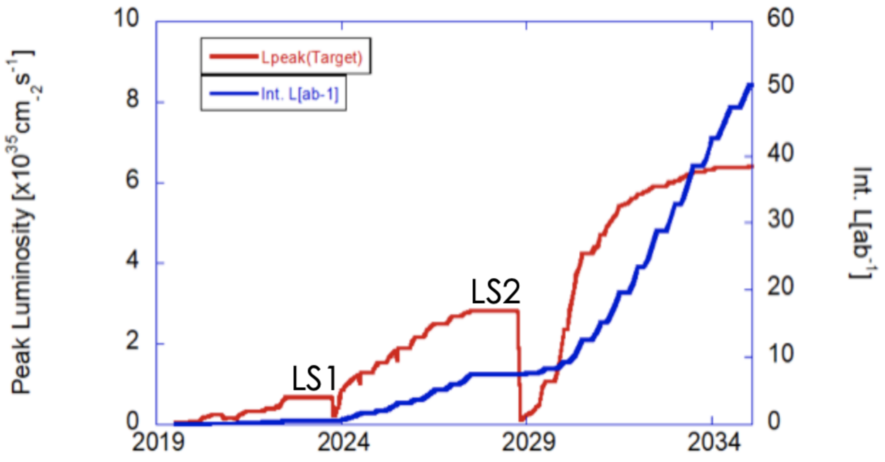


Achievements:

- L_{peak} = 4.7x10^{34} cm^{-2}s^{-1} (x2 KEKB)
- $L_{integrated}$ = 430 fb^{-1} (~BaBar)
- Data taking efficiency >90%
- Path identified to reach 2x10^{35} cm^{-2}s^{-1}
- Ultimate goal: 50 ab^{-1} by operating at 6x10^{35} cm^{-2}s^{-1}

Belle II Upgrade Program

SuperKEKB **peak** & **integrated** luminosity vs time



LS1 (2022): Actual detector consolidation
LS2 (2027): IR and detector upgrades

→ Currently: CDR preparation

Path to the future:

1) Improve machine performance and stability
Beam blowup, lifetime, injection power, beam losses

2) Reduce detector backgrounds
Single beam, injection and luminosity backgrounds

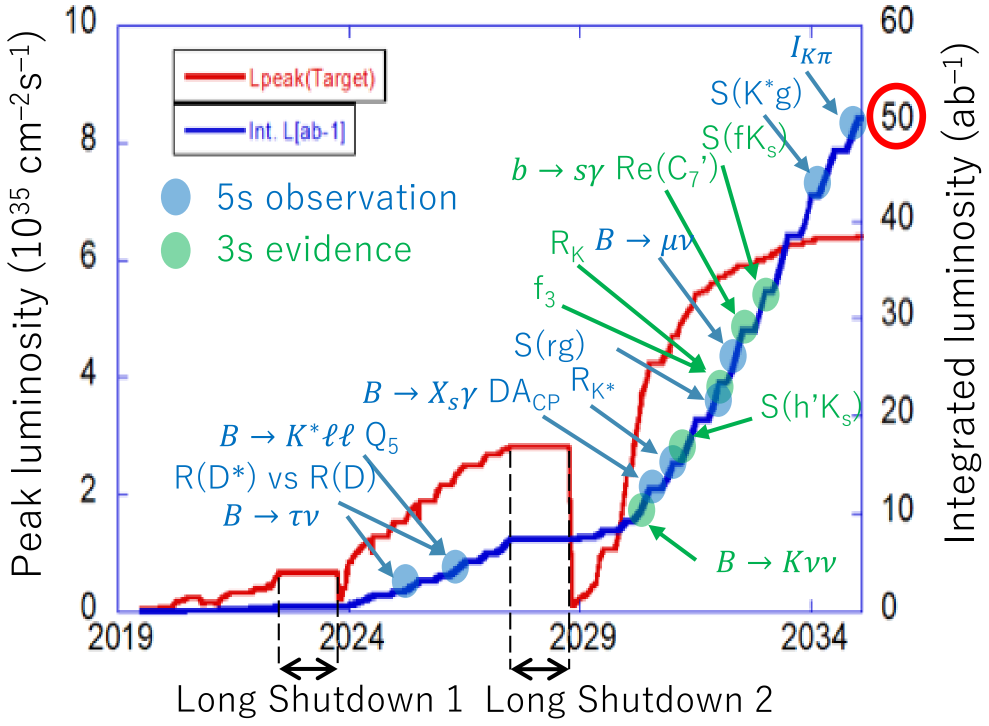
3) LS1 Detector consolidation toward $2x10^{35}$ $cm^{-2}s^{-1}$
Installation of more robust components

4) LS2 Detector upgrade toward $6x10^{35}$ $cm^{-2}s^{-1}$
Including a redesign of the interaction region

→ More performant detector and robust against machine-induced backgrounds

Prospects toward 50 ab^{-1}

Squeeze $\sigma_y^* \approx$ 200 nm → 50 nm,
and increase $I \approx$ 1 A → 3 A



Boost up the peak luminosity

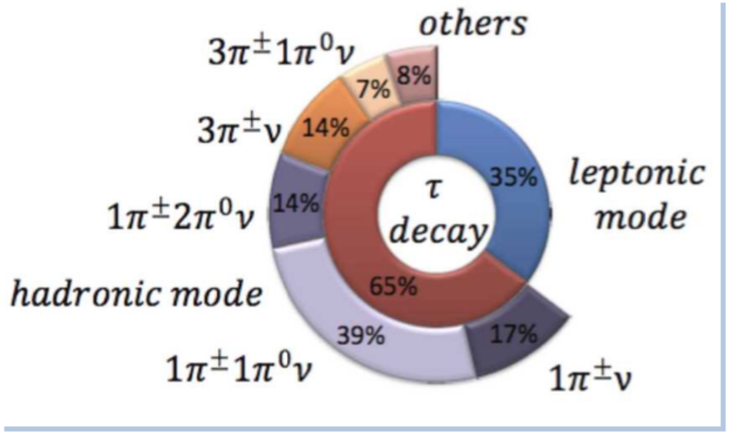
1. Long shutdown 1 (Jul 2022 – Dec 2023)
   - Detector upgrade
   - Beam background mitigation
   - Improvement of beam injection
2. Run 2 (Dec 2023 –)
   - Extensive machine tuning and studies toward $\mathcal{L} = 2.4 \times 10^{35}$ cm^{-2}s^{-1} (≈ KEKB x 10)
3. Long Shutdown 2 (To be confirmed)
   - Need new ideas and technology for upgrade of SuperKEKB interaction region to enable $\mathcal{L} = 6 \times 10^{35}$ cm^{-2}s^{-1} e.g. QCS (final focusing system) upgrade with Nb_3Sn

➢ Many challenges and R&D items ahead of us
→ Need more collaborative work in the framework of
- SuperKEKB International Task Force
- Etc.

Many physics discoveries are expected along the luminosity improvement.

Tau physics @ Belle II

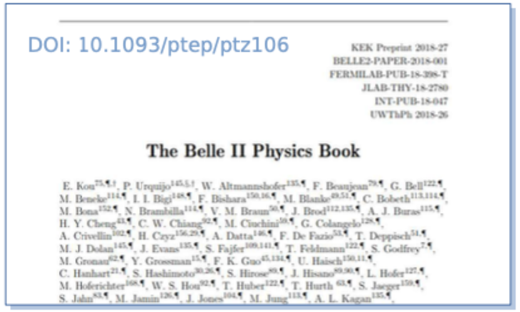
- Why τ ***physics***?
  - Large production cs:
    $\sigma(e^+e^- \rightarrow \tau^+\tau^-)$ = 0.9 nb (τ –factory)
  - The τ is the only lepton massive enough to decay into hadrons:
    - Leptonic decays: BR ~ 35%
    - Hadronic decays: BR ~ 65%



- τ **physics** program
  Rich program of precision SM measurements and new physics searches @ Belle II

Some physics analysis @ Belle II:

- Precision SM measurements / Indirect NP searches (deviations from the SM)
  - Mass
  - Lifetime
  - Lepton universality in $\tau \rightarrow l\nu\nu$ decays
  - τ EDM and MDM
  - $\tau \rightarrow ee e\nu\nu$
  - CP violation $\tau \rightarrow K_S\pi\nu$
- Direct NP searches (forbidden / strongly suppressed decays)
  - $\tau \rightarrow l\,\alpha$
  - $\tau \rightarrow l\,\phi$
  - $\tau \rightarrow l\,\gamma$
  - $\tau \rightarrow \mu\mu\mu$
  - $\tau \rightarrow l\pi^0$
  - $\tau \rightarrow lhh$


DOI: 10.1093/ptep/ptz106

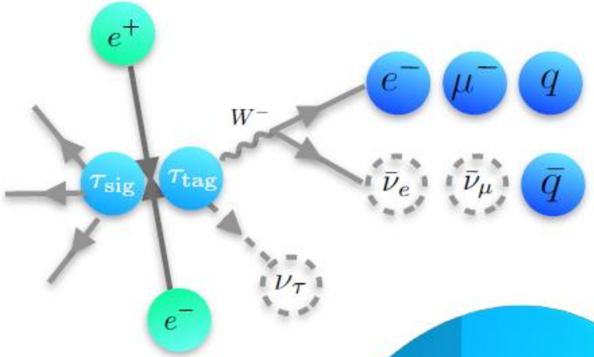
KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047
UWThPh 2018-26

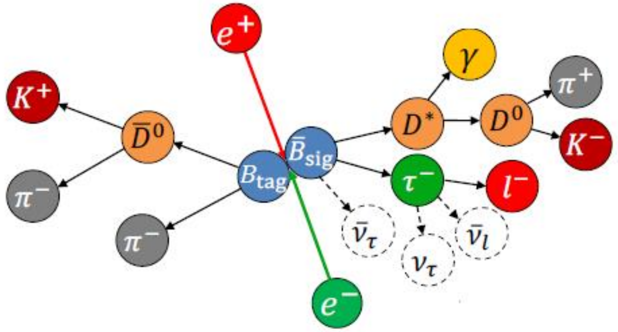
The Belle II Physics Book

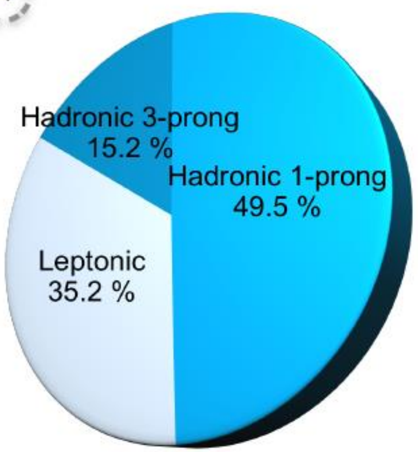
E. Kou, P. Urquijo, W. Altmannshofer, F. Beaujean, G. Bell, M. Beneke, I. I. Bigi, F. Bishara, M. Blanke, C. Bobeth, M. Bona, N. Brambilla, V. M. Braun, J. Brod, A. J. Buras, H. Y. Cheng, C. W. Chiang, M. Ciuchini, G. Colangelo, A. Crivellin, H. Czyz, A. Datta, F. De Fazio, T. Deppisch, M. J. Dolan, J. Evans, S. Fajfer, T. Feldmann, S. Godfrey, M. Gronau, Y. Grossman, F. K. Guo, U. Haisch, C. Hanhart, S. Hashimoto, S. Hirose, J. Hisano, L. Hofer, M. Hoferichter, W. S. Hou, T. Huber, T. Hurth, S. Jaeger, S. Jahn, M. Jamin, J. Jones, M. Jung, A. L. Kagan,

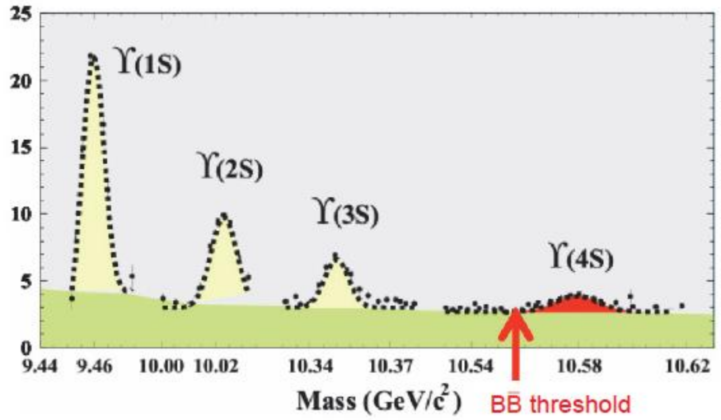
Tau lepton physics in Belle II

Not possible to fully reconstruct the full event









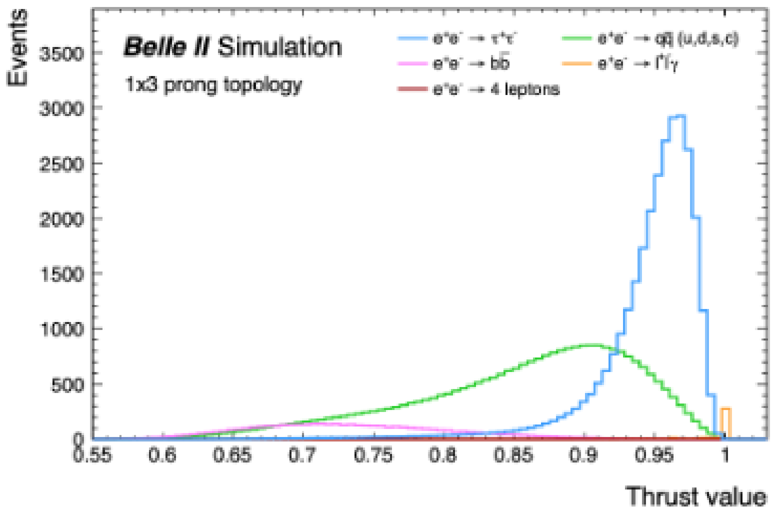
e^+e^- annihilation data is ideal for missing energy channels

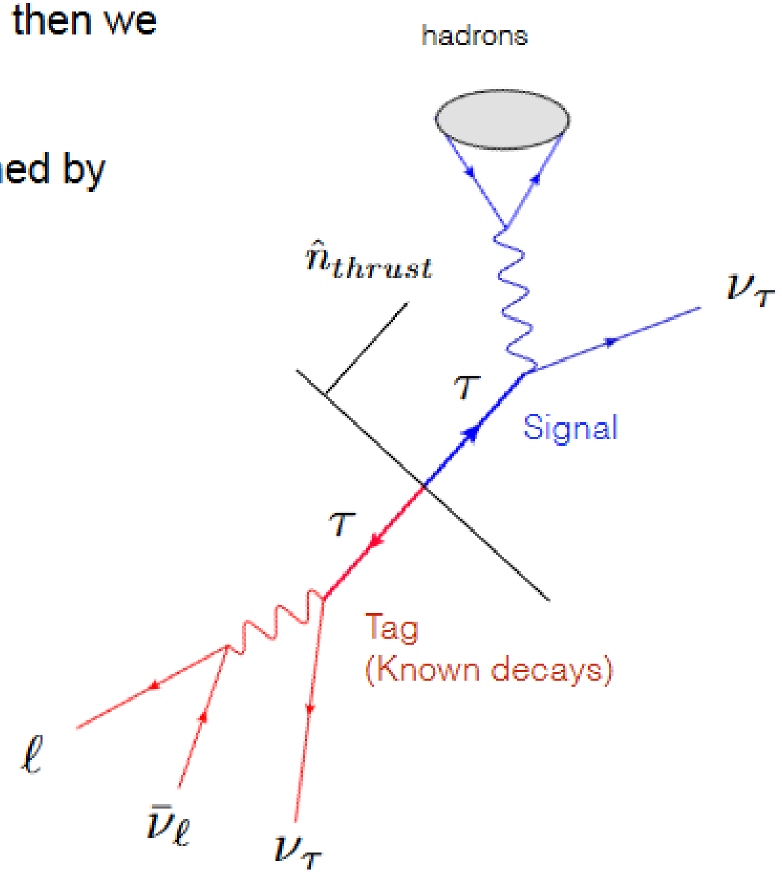
- the kinematics of the initial state is precisely known
- the neutrino energy can be determined precisely

How do we reconstruct τ's at Belle II

Tag and signal

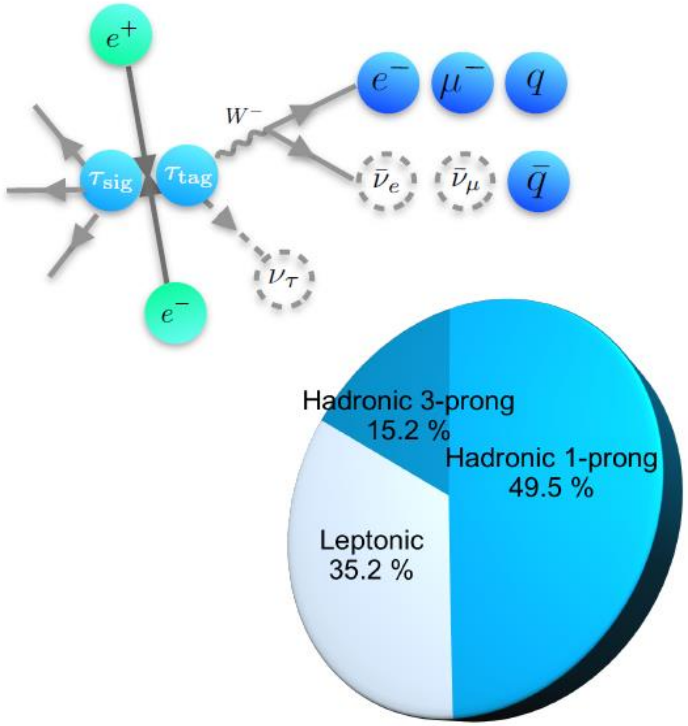
- A τ event is never reconstructed completely (we lose neutrinos), then we use features of the event to identify τ-pair candidates.
- Event is divided in two sides (signal and tag) using a plane defined by a **thrust axis**, built with all the final state particles:
- $$V_{thrust} = \frac{\sum_i |\vec{p}_i^{\,cm} \cdot \hat{n}_{thrust}|}{\sum_i |\vec{p}_i^{\,cm}|}$$
- Thrust axis: $\hat{n}_{thrust}$ such that V_{thrust} is maximum.



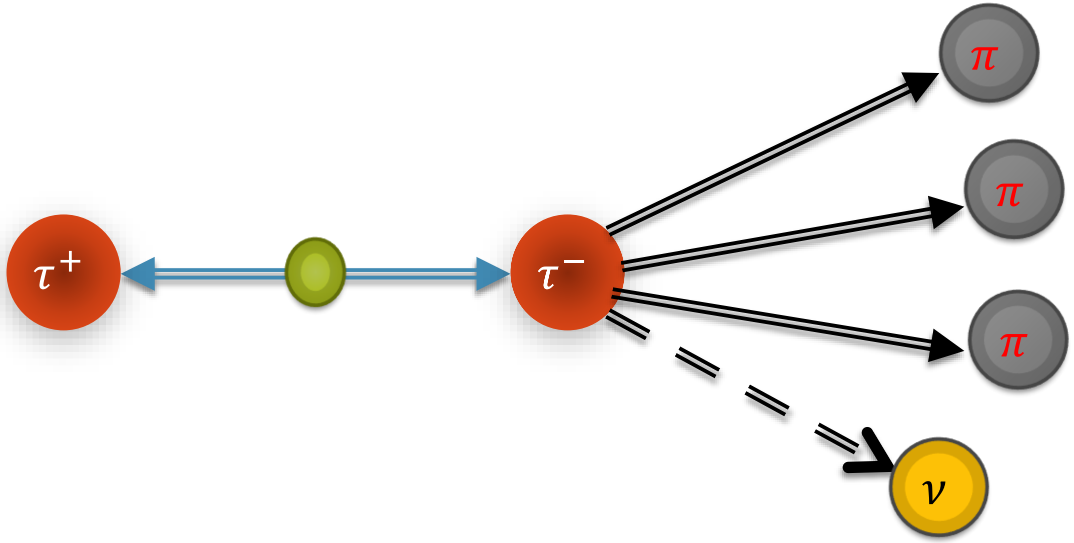


TAU MASS

$\tau \to 3\pi$

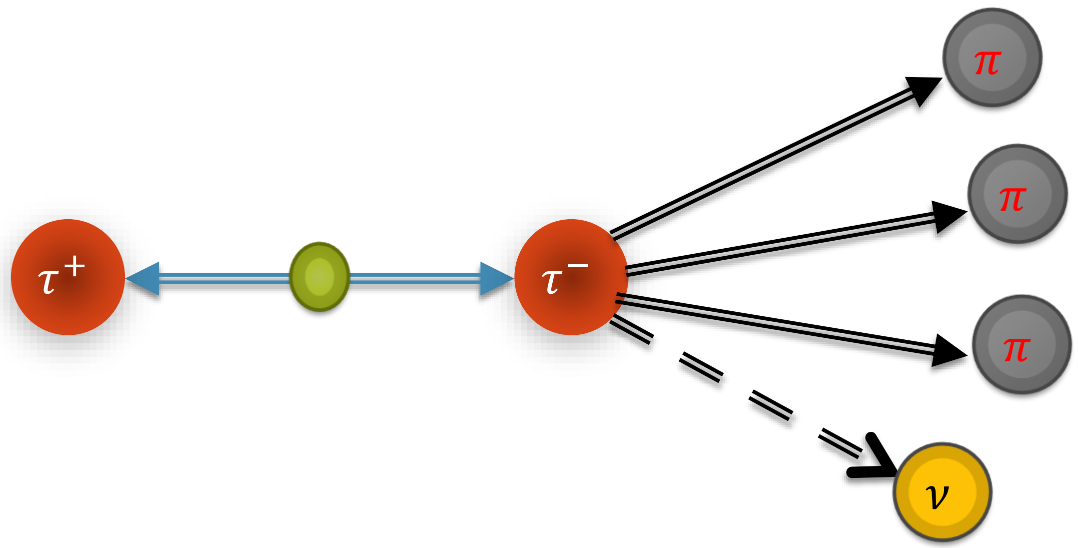


e^+
W^-
e^- μ^- q
τ_{sig} τ_{tag}
$\bar{\nu}_e$ $\bar{\nu}_\mu$ $\bar{q}$
ν_τ
e^-
Hadronic 3-prong 15.2 %
Hadronic 1-prong 49.5 %
Leptonic 35.2 %



τ^+
τ^-
π
π
π
ν

The ARGUS method



$$m_\tau^2 = (p_{3\pi} + p_\nu)^\mu (p_{3\pi} + p_\nu)_\mu$$

$$m_\tau^2 = p_{3\pi}^2 + p_\nu^2 + 2E_{3\pi}E_\nu - 2P_{3\pi}P_\nu \cos\theta$$

$\cos\theta \approx 1$

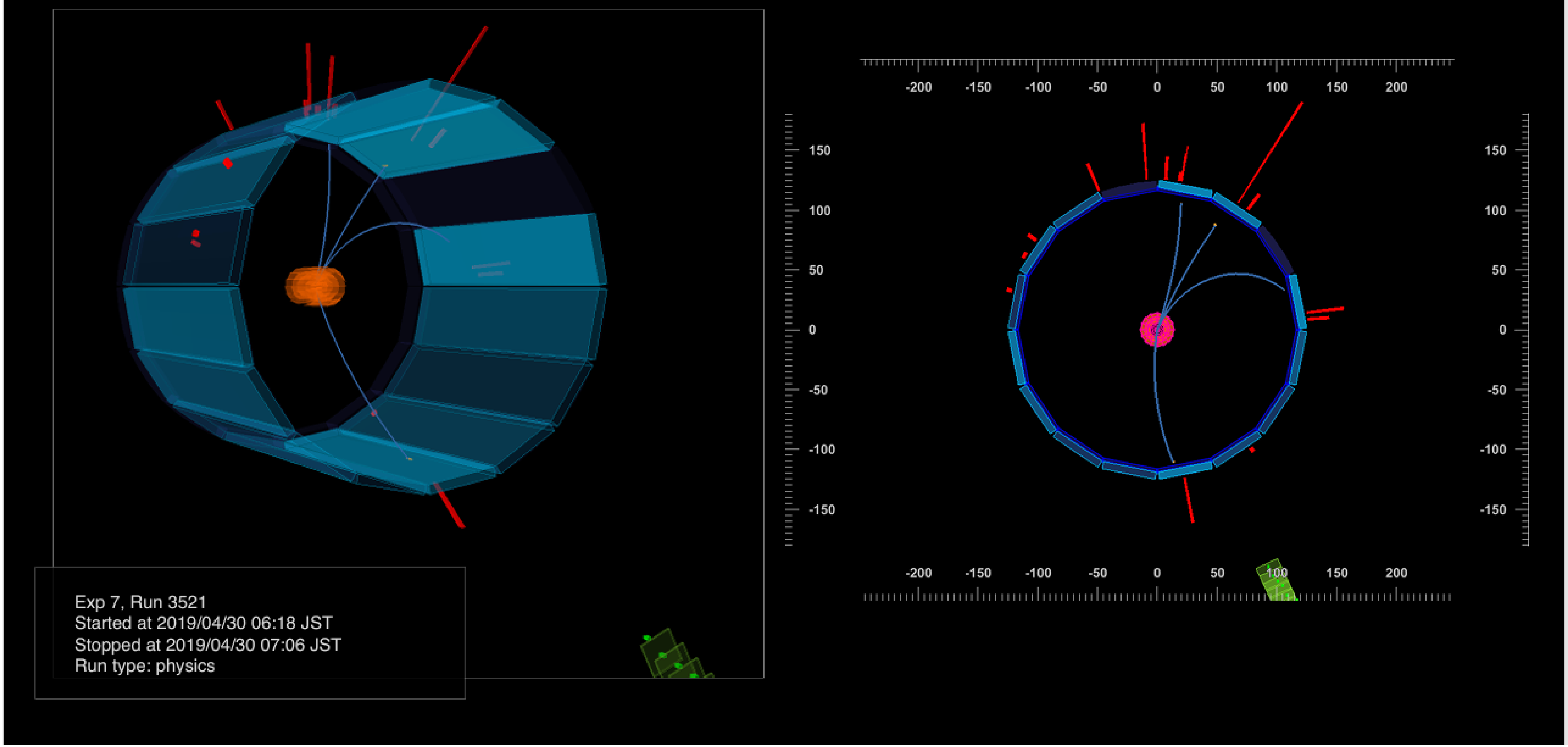
$$E_\nu = E_\tau - E_{3\pi}$$

$$P_\nu = \sqrt{E_\nu^2 - m_\nu^2} \approx E_\nu$$

$$m_\tau^2 \approx m_{3\pi}^2 + m_\nu^2 + 2E_{3\pi}(E_\tau - E_{3\pi}) - 2P_{3\pi}(E_\tau - E_{3\pi})$$

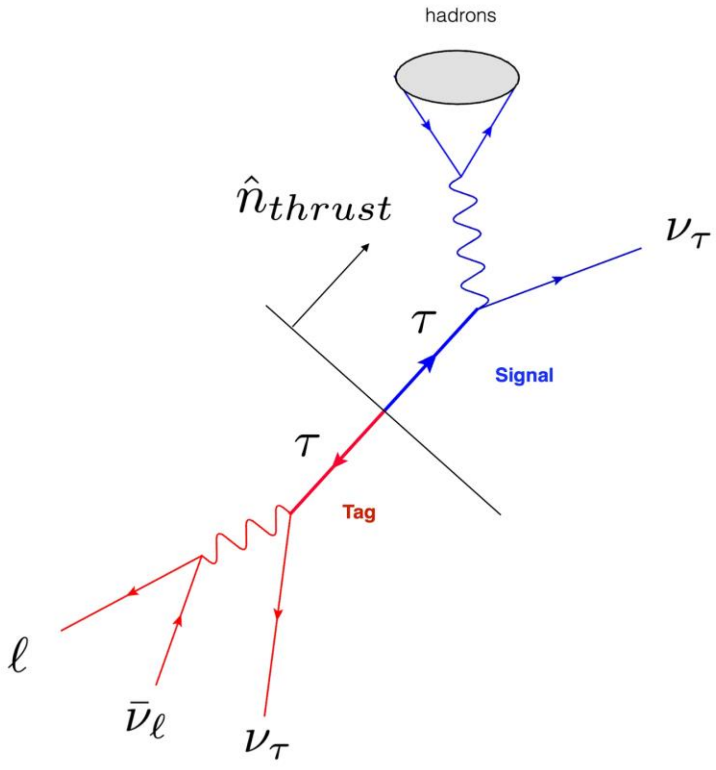
$$\boxed{m_\tau^2 \approx m_{3\pi}^2 + 2(E_\tau - E_{3\pi})(E_{3\pi} - P_{3\pi})}$$

$\tau \to 3\pi$


Exp 7, Run 3521
Started at 2019/04/30 06:18 JST
Stopped at 2019/04/30 07:06 JST
Run type: physics
-200
-150
-100
-50
0
50
100
150
200
150
100
50
0
-50
-100
-150

Data selection

- <u>3x1 prong decays of tau:</u>
  Signal: 3π
  Tag: $e, \pi, \mu, \pi\pi^0$



- <u>Tracks:</u>
  |dr| < 1 cm
  -3 < dz < 3 cm

- <u>γ selection for **π**^{0} reconstruction:</u>
  0.115 < M < 0.152
  -0.8660 < cos(θ) < 0.9563
  clusterNHits > 1.5
  region dependent Eγ (see backup)
  |clusterTiming| < 200
  (minC2TDist > 40cm or E > 400 MeV)

- <u>γ selection for the rest of photons:</u>
  Eγ > 200 MeV
  -0.8660 < cos(θ) < 0.9563
  clusterNHits > 1.5
  |clusterTiming| < 200
  (minC2TDist > 40cm or E > 400 MeV)

Event shape variables	
M_{min} [GeV]	[1.7, 1.85]
thrust	[0.87, 0.97]
E^{CMS}_{vis} [GeV]	[2.5, 9]
θ^{CMS}_{miss}	[0.5, 2.7]
p^{CMS}_{miss} [GeV]	[0.05, 3.5]
M^2_{miss} [GeV^2]	[0, 0.54]
neutrals	
N(3-prong π^0)	0
N(1-prong π^0)	≤ 1
N(extra γ)	0
3-prong tracks	
lead, sub, trail pt [GeV]	≥ 0.6, ≥ 0.2, ≥ 0.1
min($M_{ij}^{e\text{-hypo}}$) [GeV]	[0.7, 1.5]
max($M_{ij}^{e\text{-hypo}}$) [GeV]	[0.8, 1.5]

ARGUS Method: Pseudomass (M_{min})

Kinematic edge M_{min} variable defined as:

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

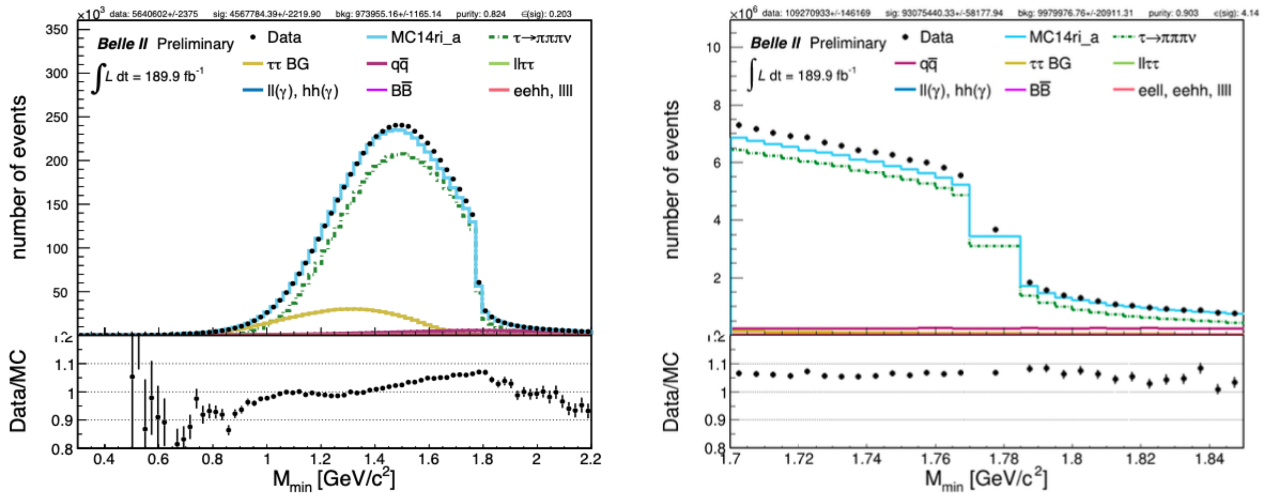
- **Assumptions:**
  - m_ν=0
  - ν collinear with 3π's

In window of 1.7 < M_{min} <1.85, fit the distribution with an edge function. we use:

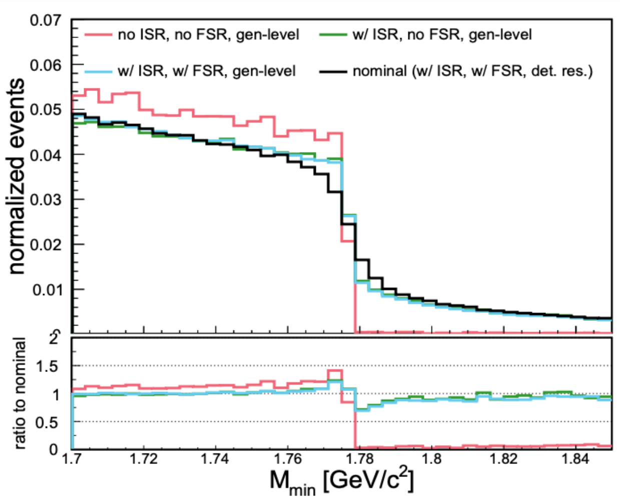
$$F(x) = -P_3 tan^{-1}\left(\frac{x - P_1}{P_2}\right) + P_7(x - P_1)^2 + P_5(x - P_1) + 1.$$

where P_1 is a biassed estimator of the mass

Data vs MC



MC



tail due to:

- mostly ISR
- Imperfect detector resolution

Relating P1 (m_τ^{fit}) and true m_τ

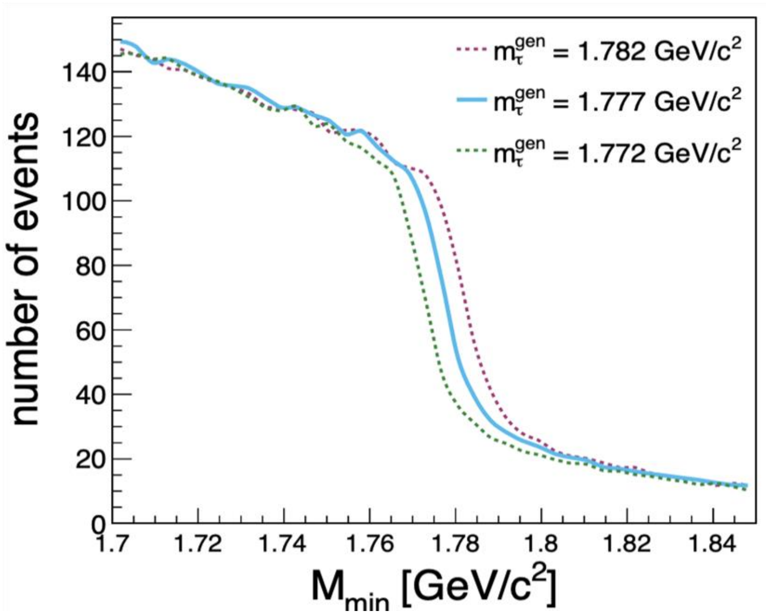
- To estimate the fit bias and possible dependance on m(τ):
  - 200/fb of generic taupair MC,
  - +10 signal samples, 100 fb^{-1} each, with shifted $m_{gen}(\tau)$

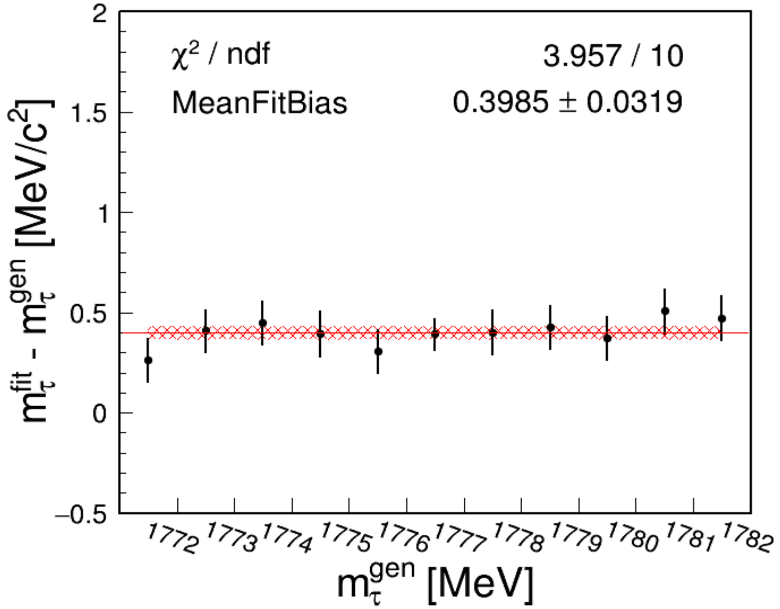
- Fit performed on each sample:
  - Fit bias correction: $\Delta m = m^{fit}_\tau - m^{gen}_\tau$

    Δm = 0.40 ± 0.03 MeV

  - for Belle and BaBar the fit bias was more than 1MeV!

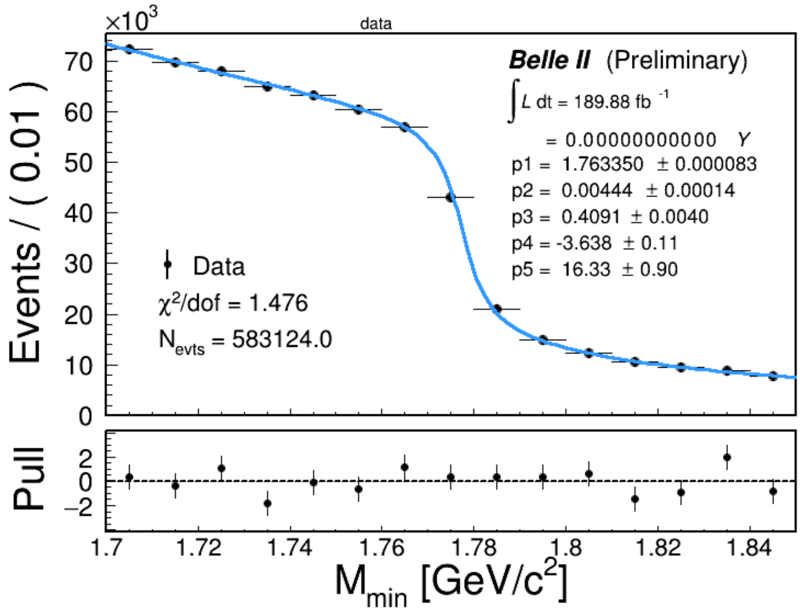
- this is used to correct for the fit bias when performing the fit on data

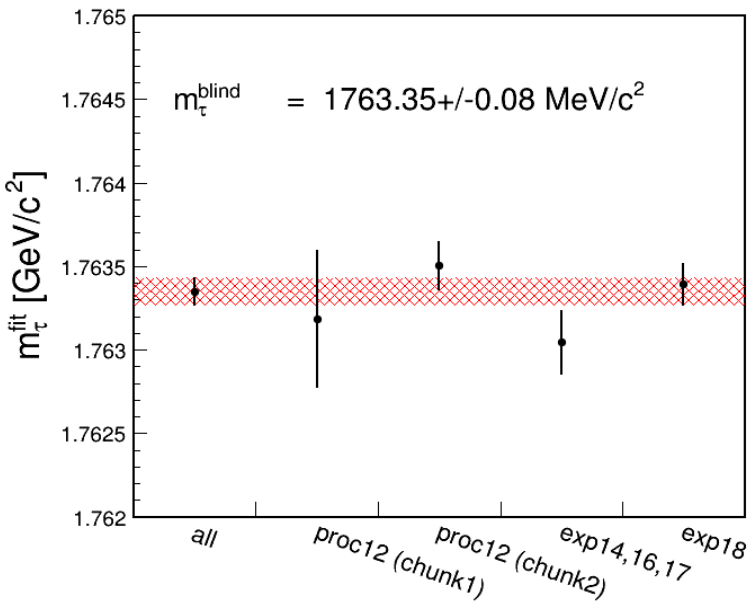




Blind fit to data

- Fit results are stable across the experiments!
- statistical uncertainty: 0.08 MeV





Belle and Babar stat unc: ~0.12 MeV w/ ~400/fb

⇒ with less than half the data we have ~30% better precision!

TABLE II. Summary of systematic uncertainties in the τ-mass measurement.

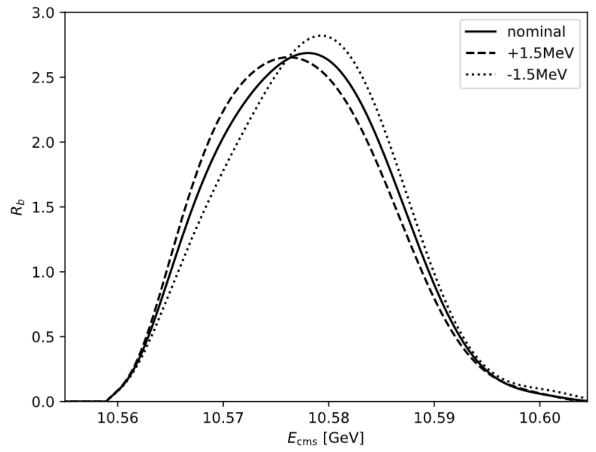
Source	Uncertainty (MeV/c^2)
Knowledge of the colliding beams:	
Beam-energy correction	0.07
Boost vector	< 0.01
Reconstruction of charged particles:	
Charged-particle momentum correction	0.06
Detector misalignment	0.03
Fit model:	
Estimator bias	0.03
Choice of the fit function	0.02
Mass dependence of the bias	< 0.01
Imperfections of the simulation:	
Detector material density	0.03
Modeling of ISR, FSR and τ decay	0.02
Neutral particle reconstruction efficiency	≤ 0.01
Momentum resolution	< 0.01
Tracking efficiency correction	< 0.01
Trigger efficiency	< 0.01
Background processes	< 0.01
Total	0.11

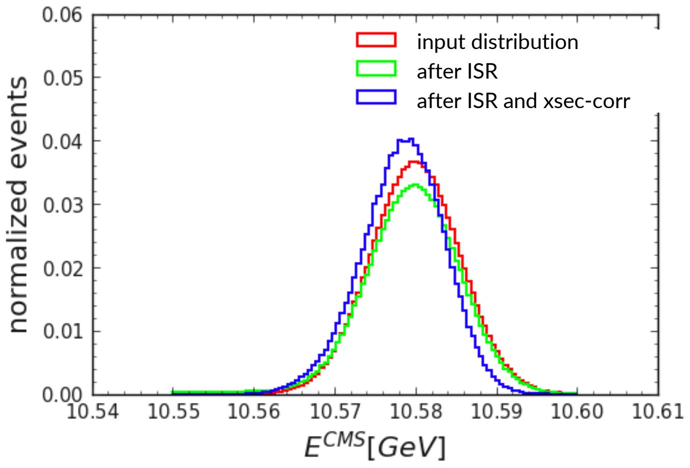
SYSTEMATIC UNCERTAINTIES

beam energy

- In the beam energy calibration we measure the energy of B-mesons, not the colliding e^+e^-:
  - ISR take away energy from the colliding e^+e^-
  - Y(4S) xsec-dependence on the beam energy:
    - when we run lower/higher than the Y(4S) peak, we get B-meson energies are biased toward Y(4S) mass
- To correct for these, we generate toy MC events:
  - start with different input B energy and energy spread
  - use Kuraev-Fadin ISR Kernel @NLO [hep-ph/9910523]
  - Use Y(4S) lineshapes measured by Belle/BaBar [hep-ex:2104.08371]
  - get the “measured” B energy and energy spread.
- This now allows us to “unfold” the actual E_B^* in data to the true E_{CMS} of the e^+e^-

Y(4S) x-sec shape:





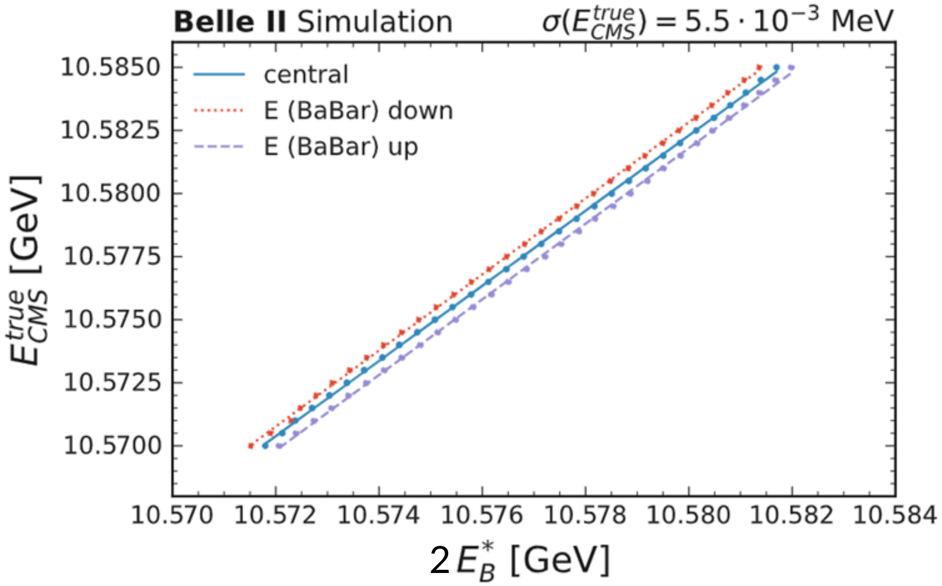
*for visualization only: in the actual method and ARGUS BKG component is also included.

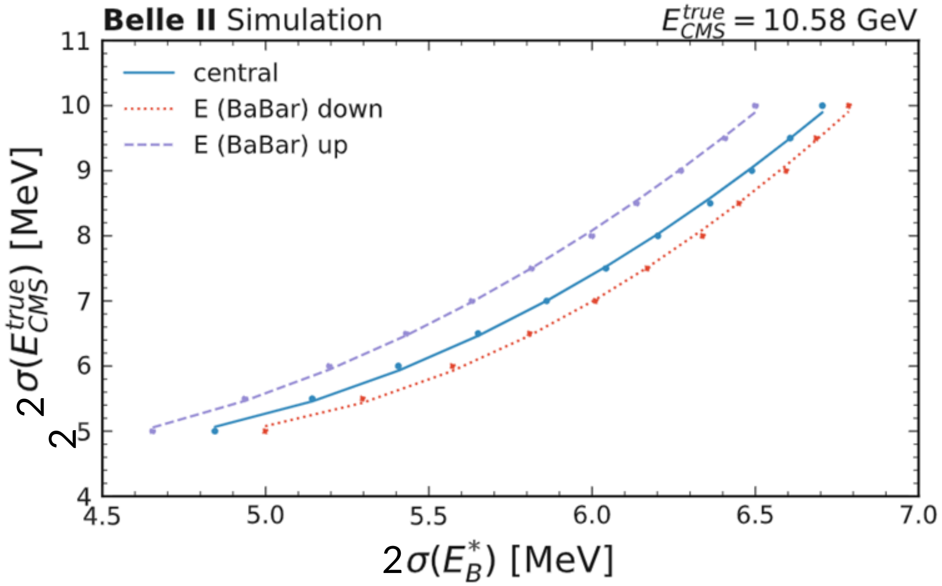
9

9

beam energy corrections:

- This now allows us to “unfold” the actual E_B^* in data to the true E_{CMS} of the e^+e^-

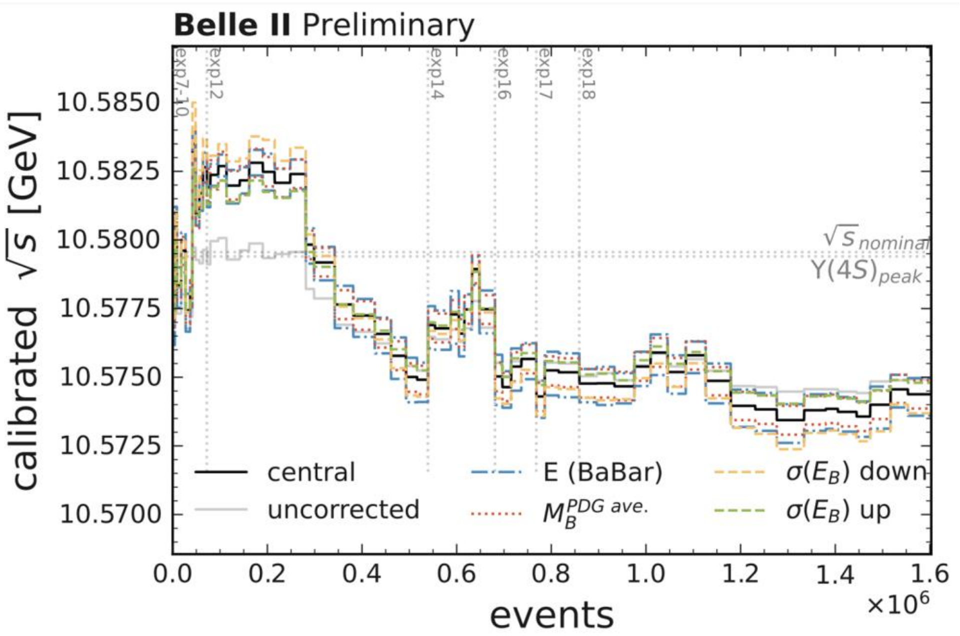




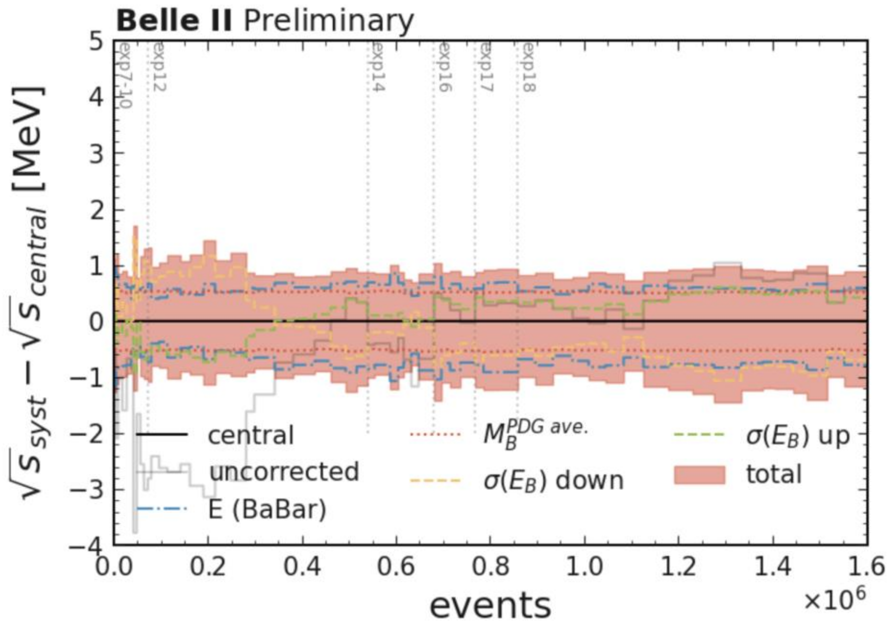
⇒ in the end of the day we have a 2D table which for each measured E_B^* and $\sigma(E_B^*)$ give us the true values

beam energies for tau mass

The evolution of the measured sqrt(s) values for the events used in the tau mass measurement:



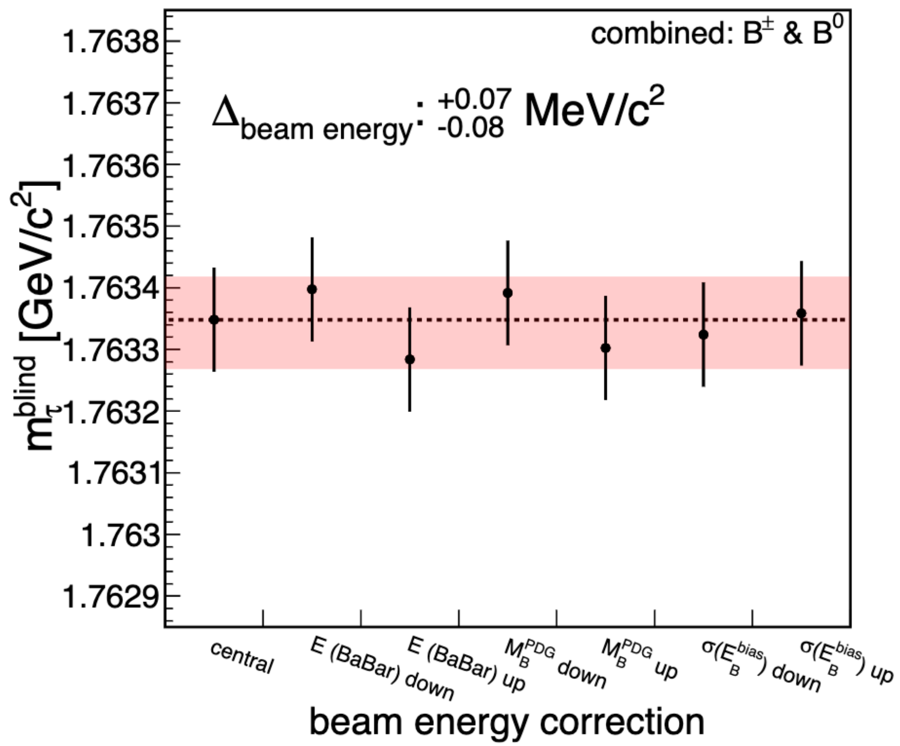
the uncertainties impacting the sqrt(s) measurements:



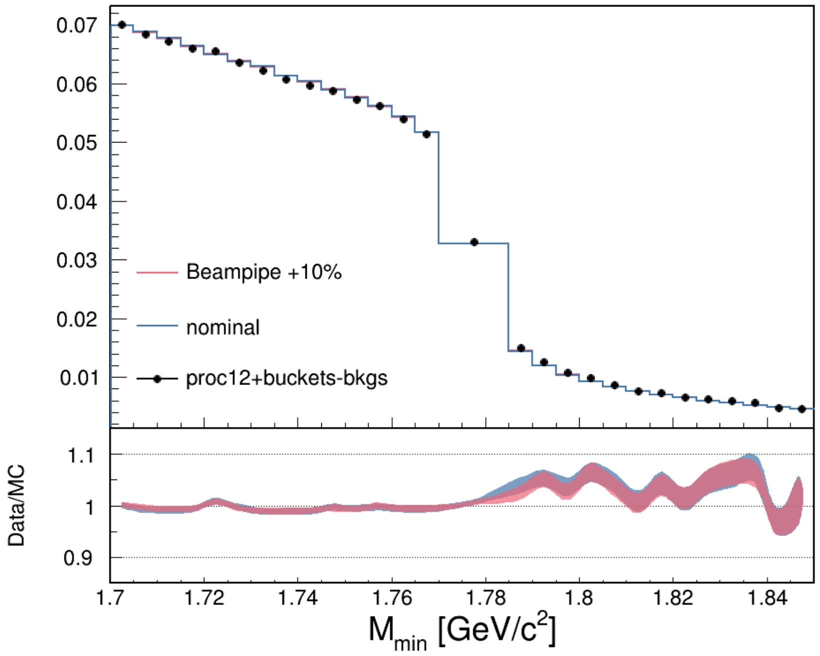
⇒ the x-sec correction is in general small (compared to it's uncertainties) except for the first half of exp12 data taking

beam energy impact on the tau mass:

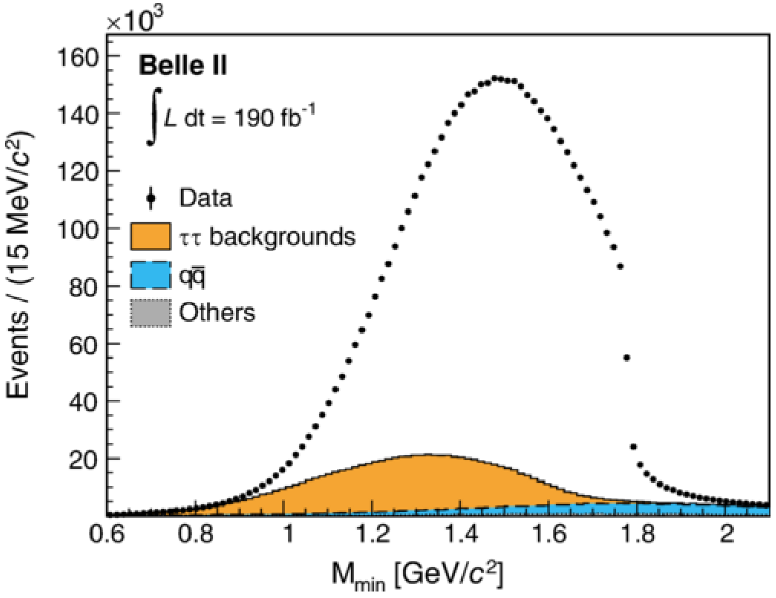
- The overall impact of the x-sec correction on the tau mass is 0.035 MeV
- Systematics:
  - The leading systematic of the beam energy is the energy scale of BaBar (1.5 MeV)
  - followed by the B-meson PDG mass:
    - here we use the AVERAGE PDG not the FIT PDG (FIT uncertainties are believed to be underestimated)
  - Bias $\sigma(E_B)$ when tested on MC
- The quadrature sum of different variations gives a systematic uncert of **+0.07-0.08 MeV** for the tau mass

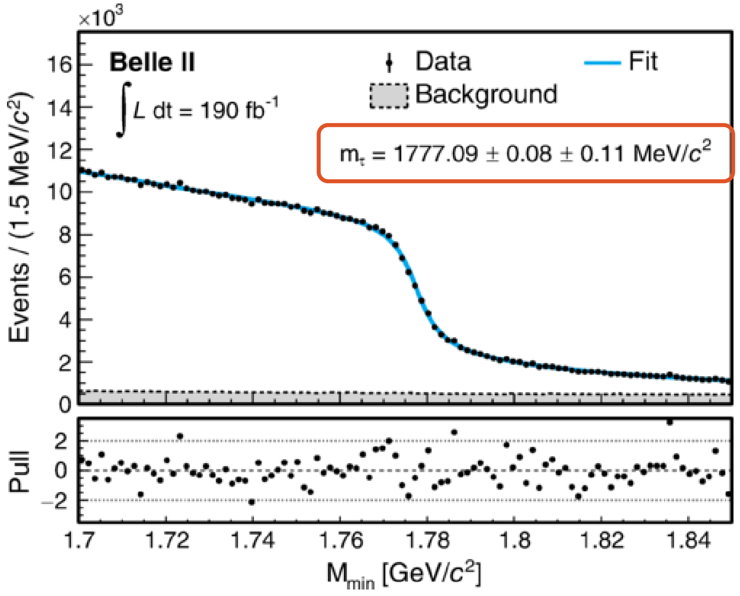


Detector material budget in simulations

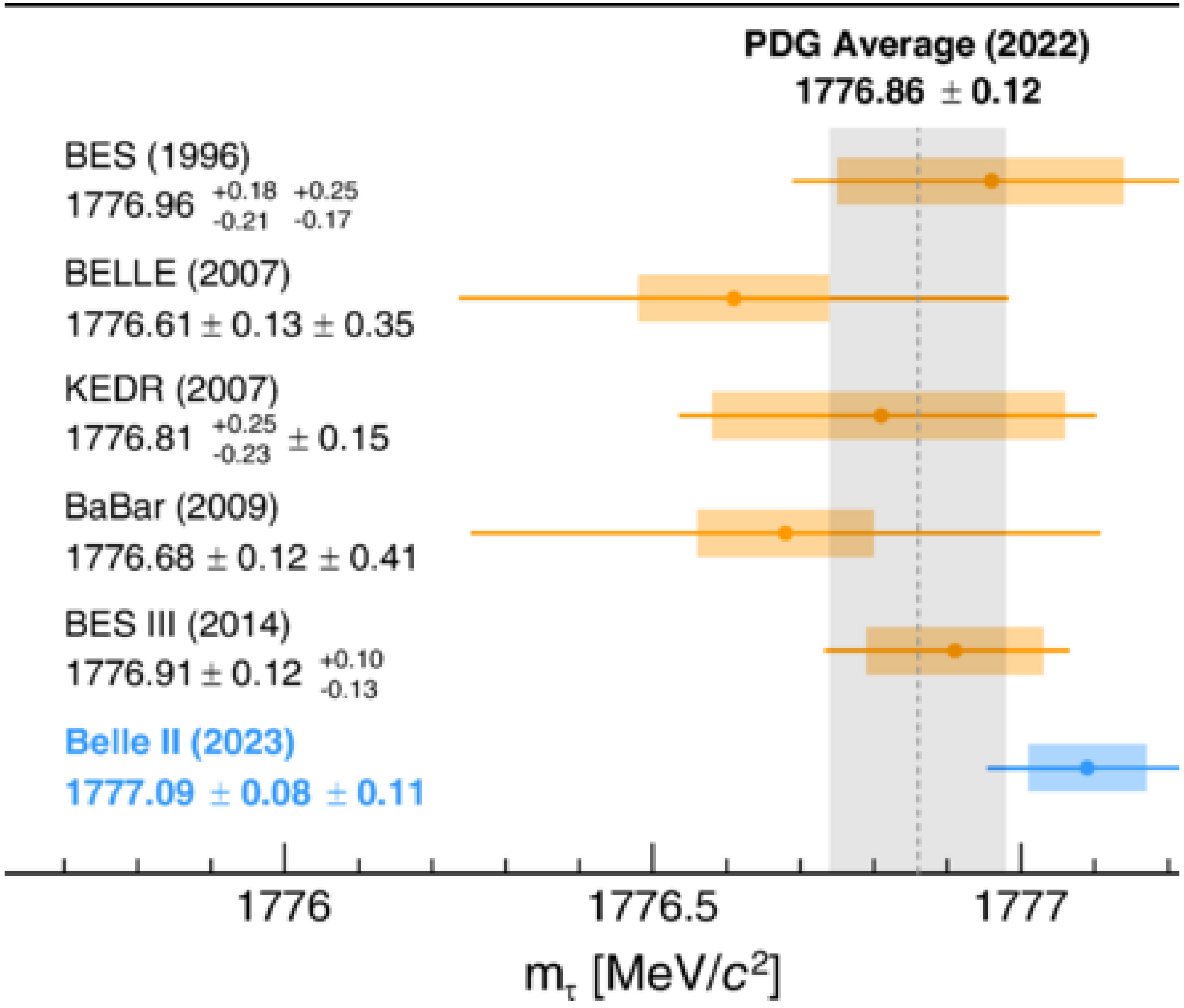


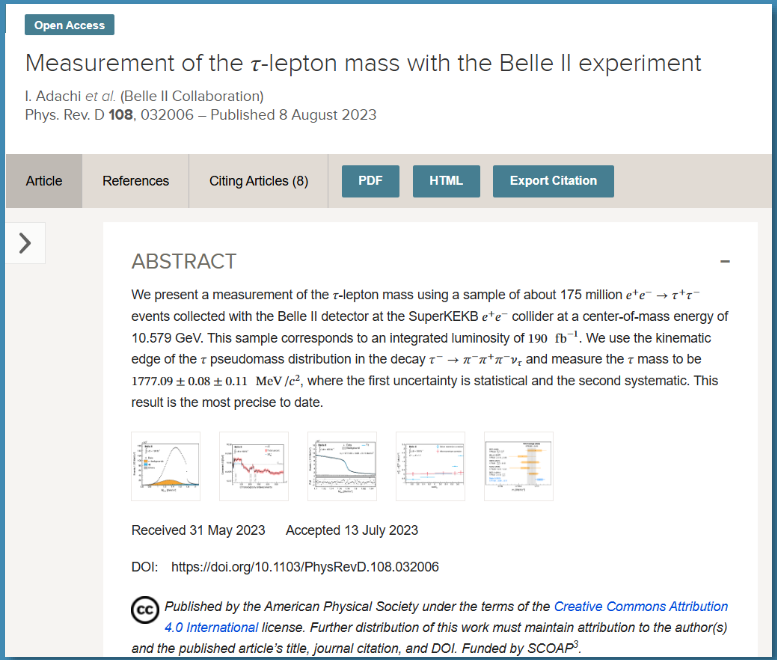
- increasing the material budget of the beampipe by 10% during simulation (nominal MB for reconstruction)
  - no real data/MC improvement in any of the main distribution
  - difference w.r.t nominal smaller than stat. error
  - we assign the statistical uncertainty as the systematic (0.03 MeV)





TAU LEPTON MASS @ BELLE II





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Measurement of the τ-lepton mass with the Belle II experiment

I. Adachi *et al.* (Belle II Collaboration)

Phys. Rev. D **108**, 032006 – Published 8 August 2023

Article | References | Citing Articles (8) | PDF | HTML | Export Citation

ABSTRACT

We present a measurement of the τ-lepton mass using a sample of about 175 million $e^+e^- \to \tau^+\tau^-$ events collected with the Belle II detector at the SuperKEKB e^+e^- collider at a center-of-mass energy of 10.579 GeV. This sample corresponds to an integrated luminosity of $190\ \mathrm{fb}^{-1}$. We use the kinematic edge of the τ pseudomass distribution in the decay $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ and measure the τ mass to be $1777.09 \pm 0.08 \pm 0.11\ \mathrm{MeV}/c^2$, where the first uncertainty is statistical and the second systematic. This result is the most precise to date.

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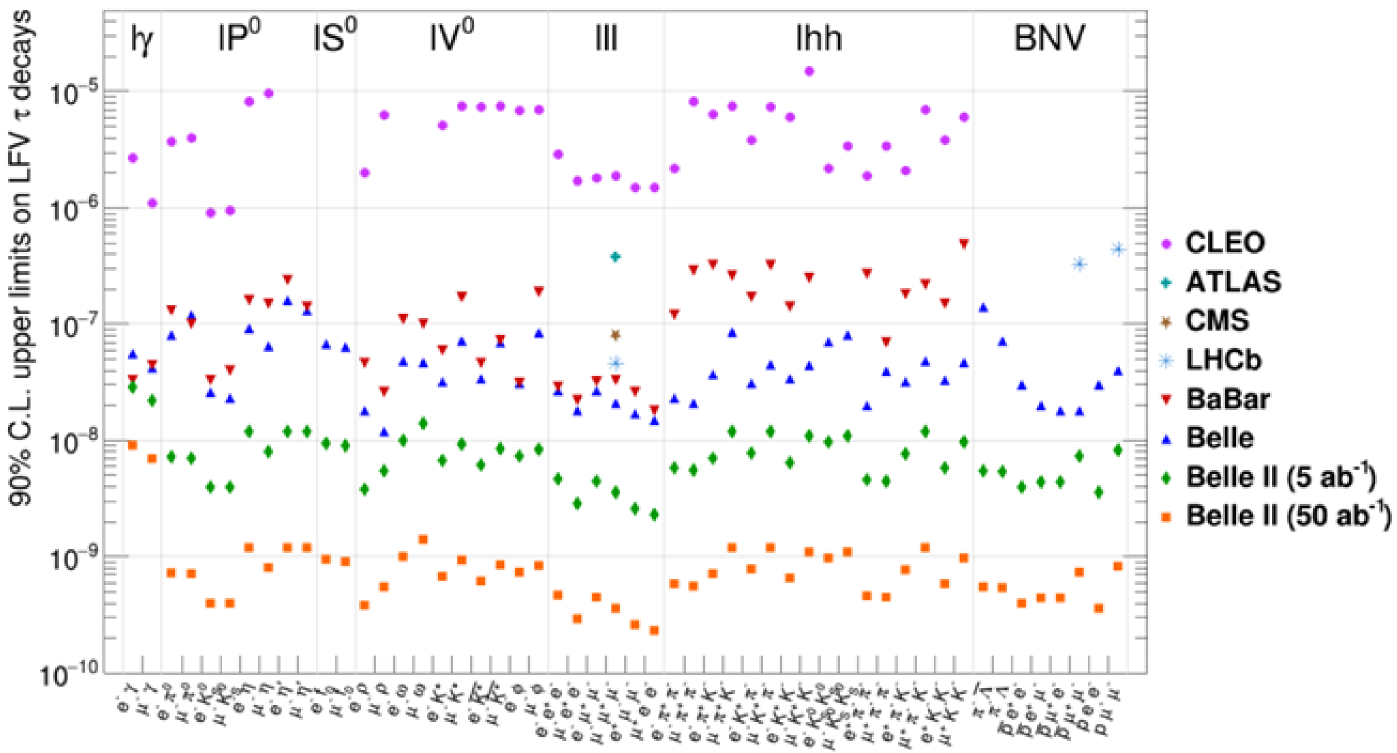
TAU LEPTON MASS MEASUREMENTS

$$\tau \to l(e, \mu) + \alpha$$

Lepton number violation

Lepton Flavor Violation (LFV) is allowed in various extensions of the Standard Model, but it has never been observed



Projection of expected upper limits at the Belle II experiment and cur rent status of observed upper limits at CLEO, BaBar, Belle, ATLAS, CMS and LHCb experiments on LFV, LNV and BNV processes in decays.

Tau LFV channels

Search various decay modes:

- ★ – $\tau \to \ell\ell\ell$
- – $\tau \to \ell K_S, \Lambda h$
- ★ – $\tau \to \ell V^0(\to hh')$
- – $\tau \to \ell P^0\ (\to \gamma\gamma)$
- – $\tau \to \ell hh'$
- – $\tau \to \ell\gamma$
- ★ – $\tau \to l\ \alpha$

Simple

Hard

Difficulty of background reduction

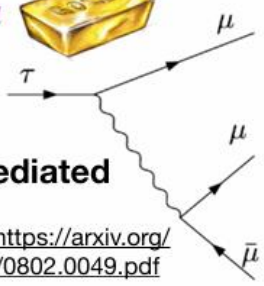
Simple → Good determination of τ mass and energy + few SM background sources

Hard → Tough determination of τ mass and energy + irreducible SM backgrounds

Golden channel: $\tau \to \mu\mu\mu$
experimentally the most accessible

ref: https://arxiv.org/pdf/1808.10567.pdf

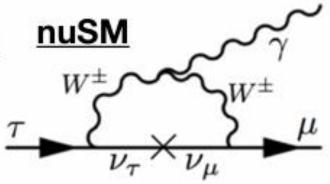
Z' mediated



ref: https://arxiv.org/pdf/0802.0049.pdf

Golden channel: $\tau \to \mu\gamma$
Largest BF in models where a one-loop diagram is involved

nuSM



Ref: https://arxiv.org/pdf/1301.4652.pdf

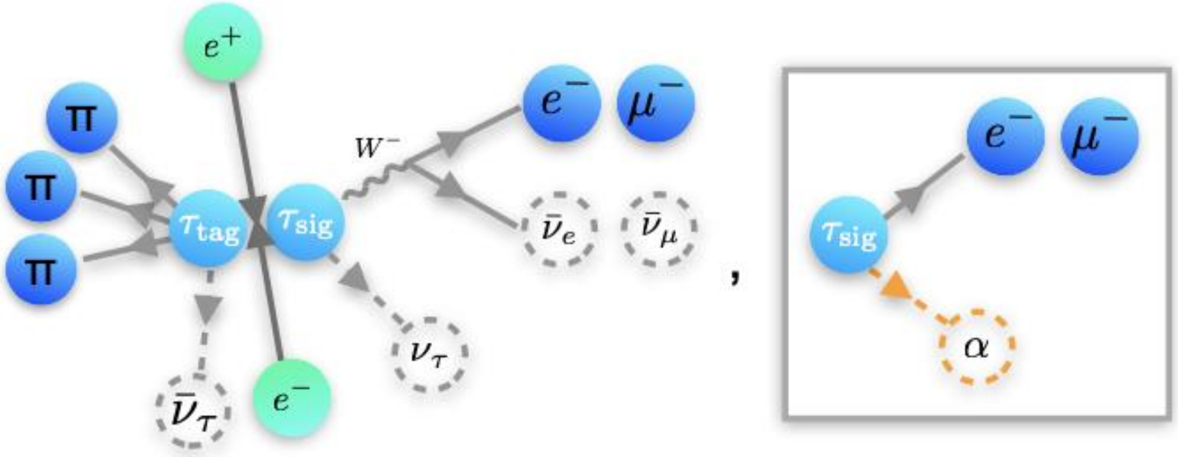
Physics models	$B(\tau \to \mu\gamma)$	$B(\tau \to \mu\mu\mu)$
SM + ν mixing	$10^{-49} \sim 10^{-52}$	$10^{-53} \sim 10^{-56}$
SM+heavy Majorana ν_R	10^{-9}	10^{-10}
Non-universal Z'	10^{-9}	10^{-8}
SUSY SO(10)	10^{-8}	10^{-10}
mSUGRA + seesaw	10^{-7}	10^{-9}
SUSY Higgs	10^{-10}	10^{-7}

Ref: https://arxiv.org/abs/hep-ph/0702136

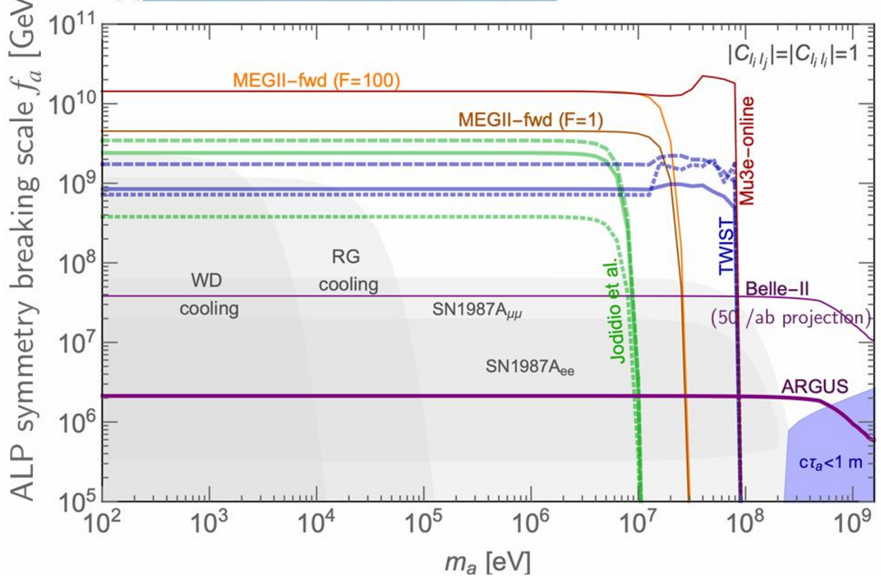
An observation would be a clear signature of NP!

$\tau \to l(e,\mu) + invisible$

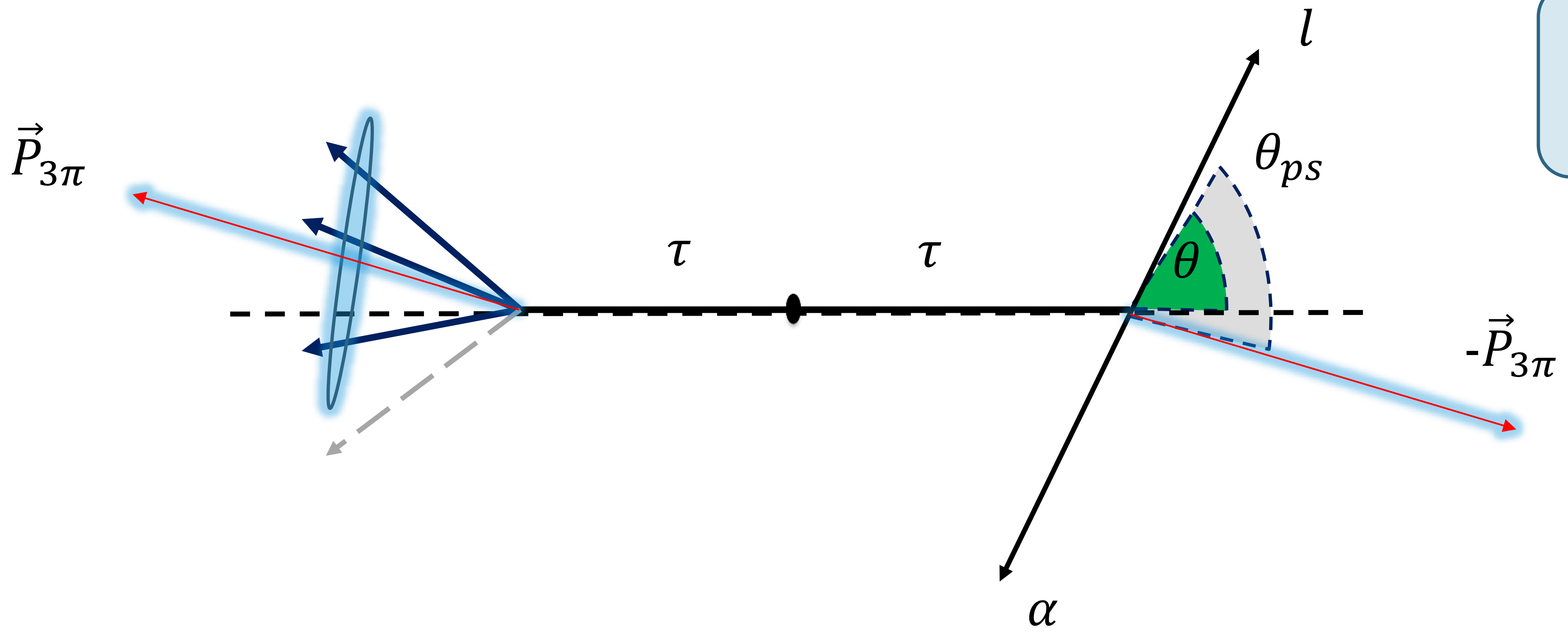
- Search for the two-body decay $\boldsymbol{\tau} \to \boldsymbol{l}(\boldsymbol{e},\boldsymbol{\mu}) + \boldsymbol{\alpha}$ where α is an unobserved particle (missing energy).
- Lepton Flavor Violating process not present in the SM but appears in several NP models, e.g., LFV Z′, light ALP candidate, more ..
- Model independent search – minimal assumptions are made on the nature of α.



[*] L. Calibbi et al., JHEP09 (2021) 173



$\tau \rightarrow l + invisible$



$\tau \rightarrow l\bar{\nu}_l\nu_\tau$

$\tau \rightarrow l\alpha$

Two-body decay $\tau \to e + \alpha$

3 *48. Kinematics*

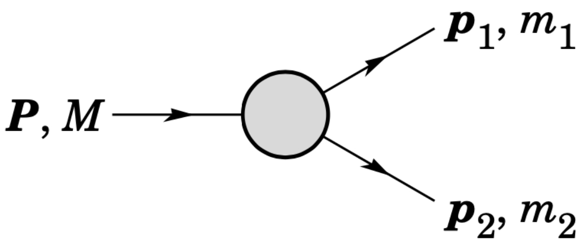


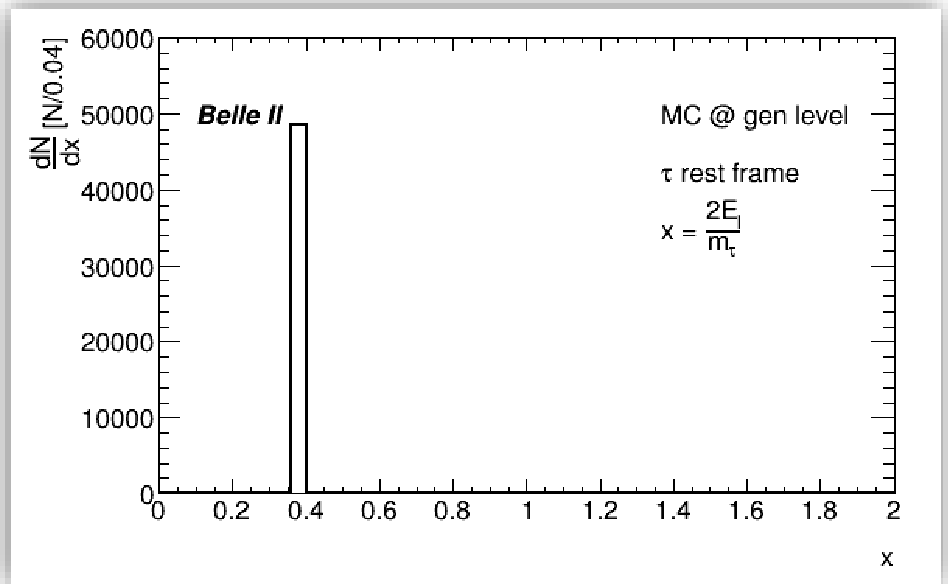
Figure 48.1: Definitions of variables for two-body decays.

48.4.2 *Two-body decays*

In the rest frame of a particle of mass M, decaying into 2 particles labeled 1 and 2,

$$E_1 = \frac{M^2 - m_2^2 + m_1^2}{2M} , \tag{48.16}$$

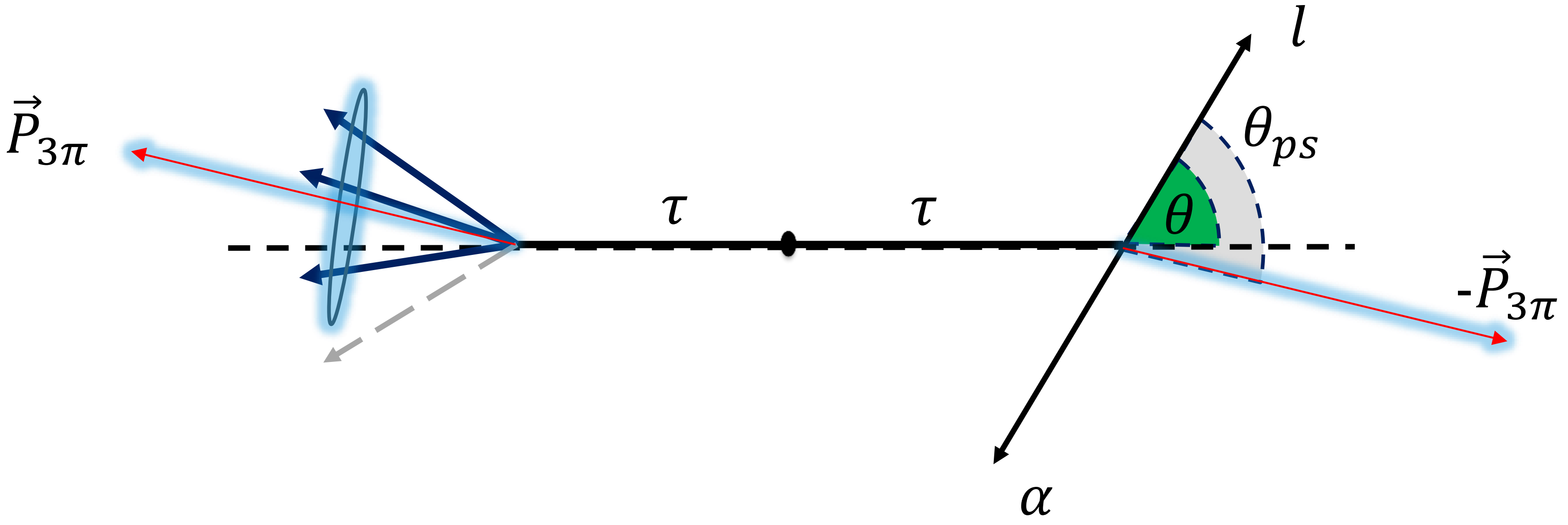
$$|\boldsymbol{p}_1| = |\boldsymbol{p}_2|$$
$$= \frac{\left[(M^2 - (m_1 + m_2)^2)\,(M^2 - (m_1 - m_2)^2) \right]^{1/2}}{2M} , \tag{48.17}$$



Here $x = \dfrac{2E_l}{m_\tau}$

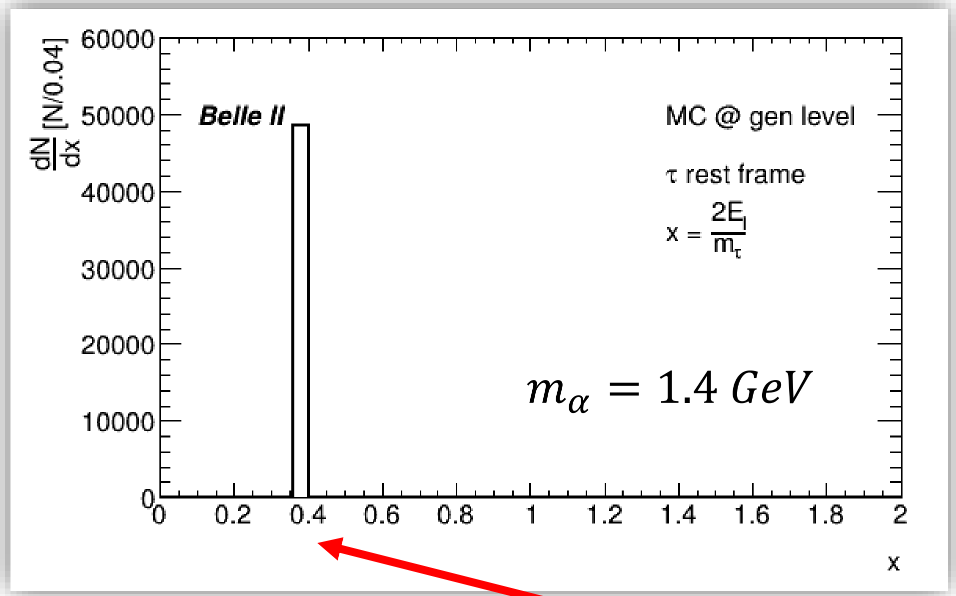
The pseudo rest frame (ps)

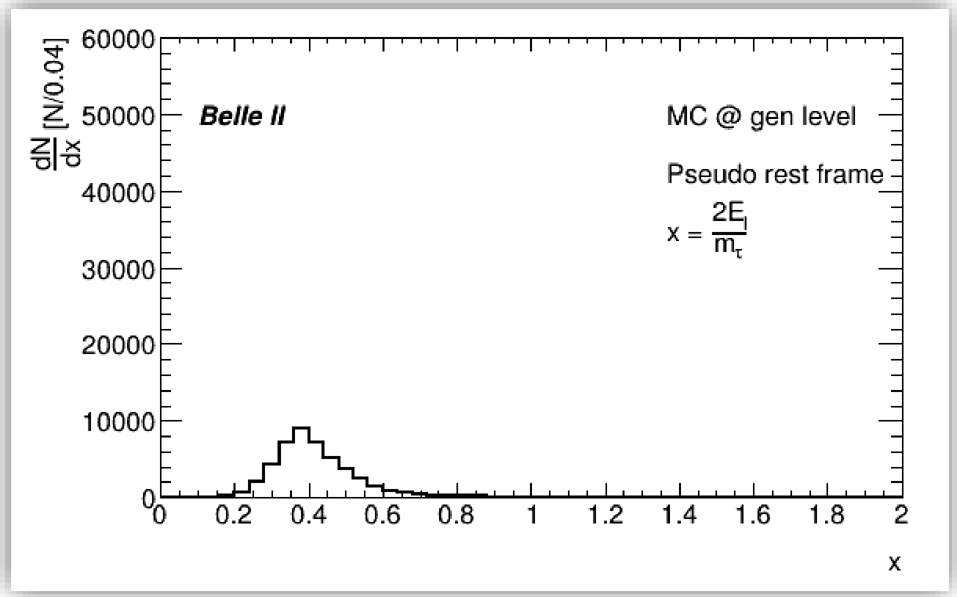
- $E_\tau \approx \frac{E_{cm}}{2}$
- Direction of the τ given by the opposite to the 3π direction



What is the effect of using ps?

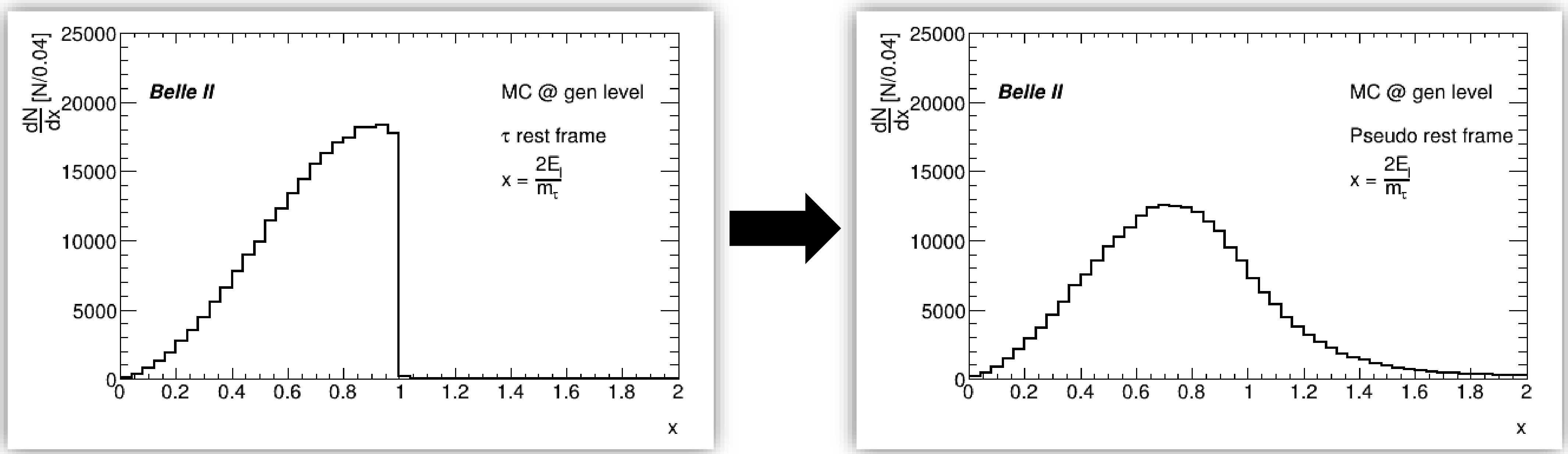
2-body decay case





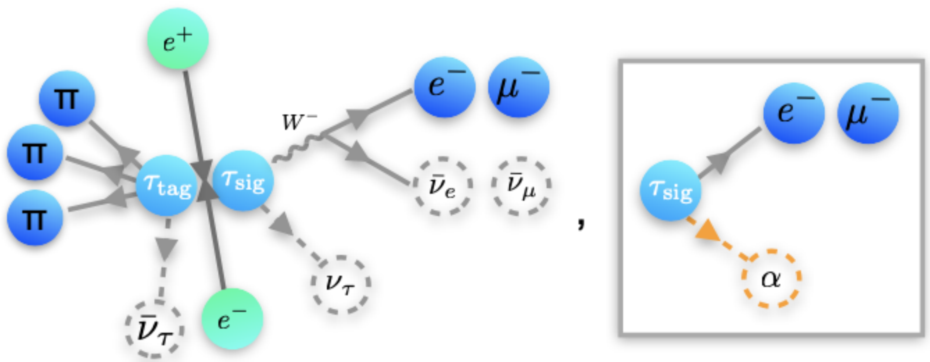
$$x_m = 1 + \frac{m_l^2}{m_\tau^2} - \frac{m_\alpha^2}{m_\tau^2}$$

In the 3-body decay case ($\tau \to l\bar{\nu}_l\nu_\tau$)

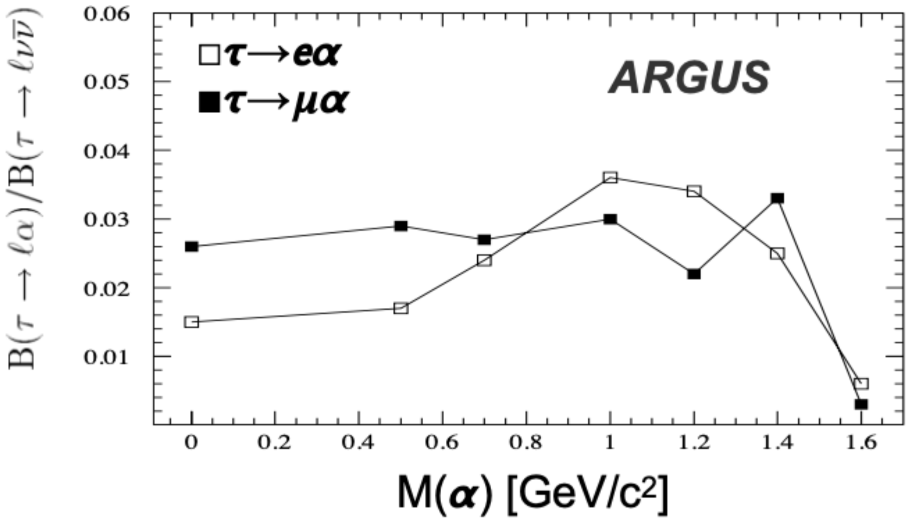


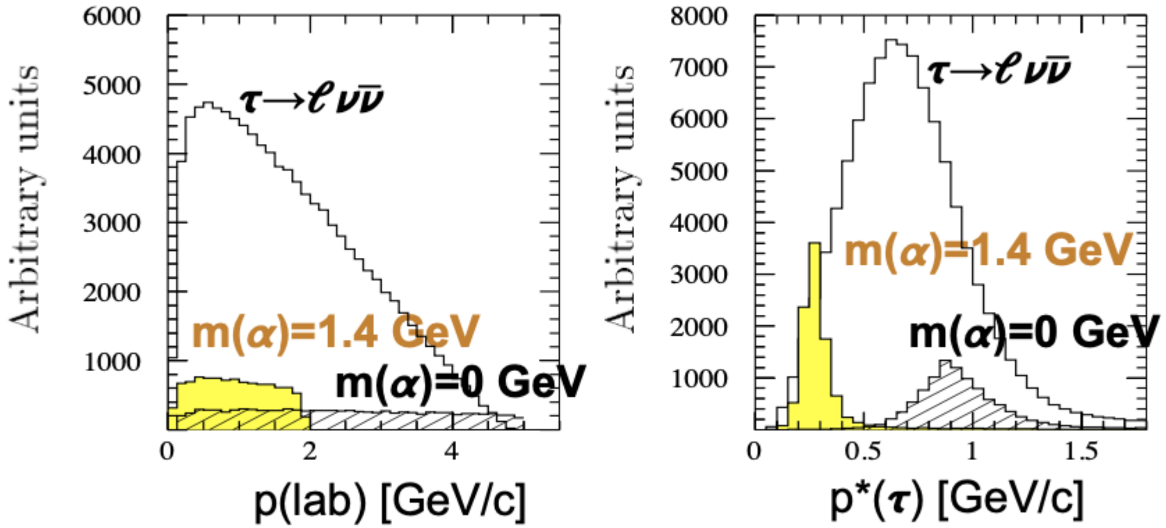
Previous Searches

- **Mark III (1985, 9.4 pb^{-1})**
- **ARGUS (1995, 476 pb^{-1})**



- Here the lepton momentum is studied in the $\boldsymbol{\tau}$ rest frame, where it manifests as a peak against the SM $\boldsymbol{\tau \to \ell \nu \nu}$ background.

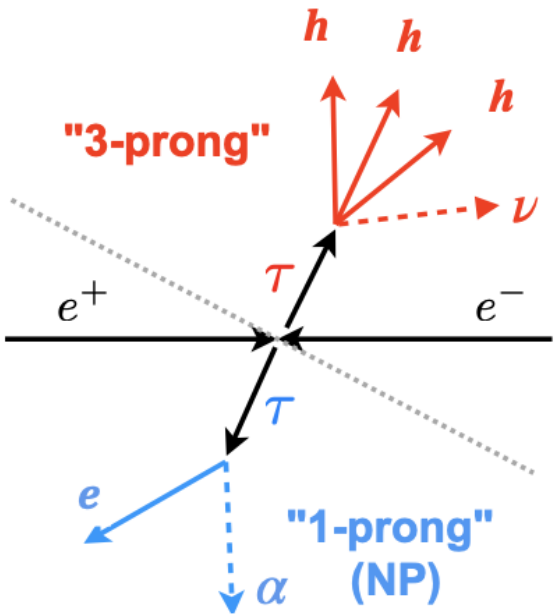


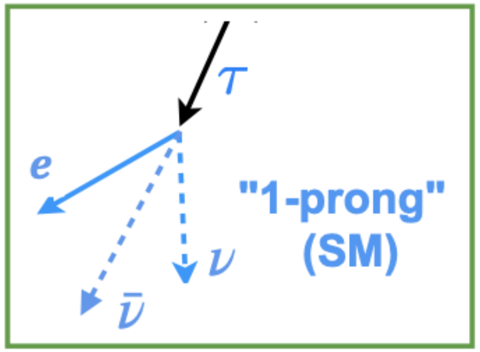


Z.Phys. C68 (1995) 25-28

Event Reconstruction

- 3x1-prong decay: $\boldsymbol{\tau \rightarrow e\alpha}$ **(signal)** , $\boldsymbol{\tau \rightarrow 3\pi\nu}$ **(tag)**
  - Exactly 4 good tracks required.
  - Hemisphere separation using thrust vector $\vec{T} = max\left(\sum_i \frac{\vec{p}_i \cdot \hat{T}}{|p_i|}\right)$
- Dominant background: SM $\boldsymbol{\tau \rightarrow e\nu\nu}$ **(irreducible)**
  - Since we don't know **M(**$\boldsymbol{\alpha}$**)** we optimise for the SM.
- Other BG: $\boldsymbol{\tau\tau}$ (non-3x1), BBbar, qqbar, ee(γ), μμ(γ), ee$\ell\ell$, beam
- Initially rejected by:
  - **Vertex fit** of the 3-prong tag (reject displaced vertices).
  - **Veto** neutral pions and gamma (qqbar, beam bg).



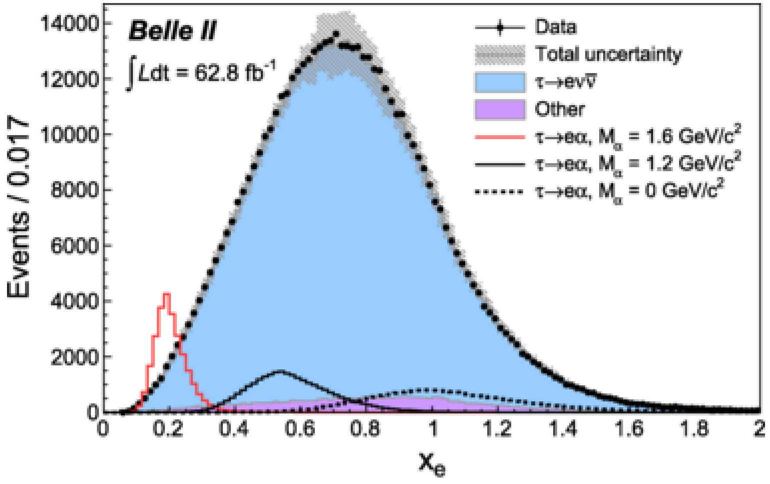


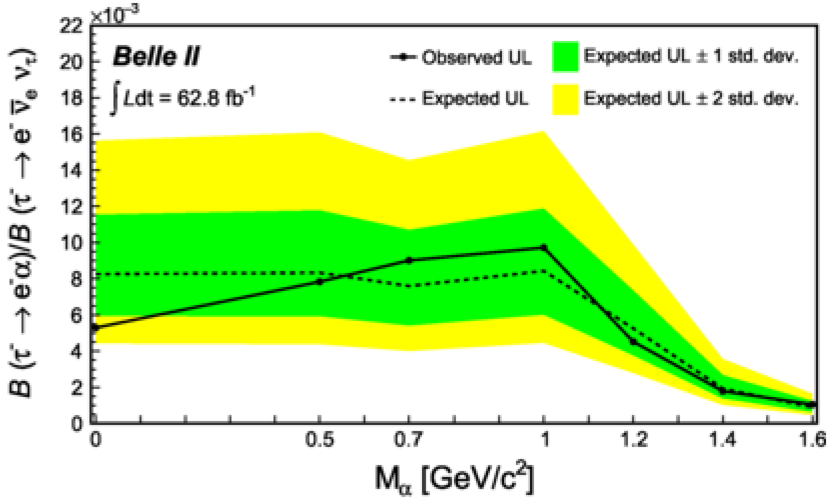
Tracks
-3< dz<3 cm
dr < 1 cm

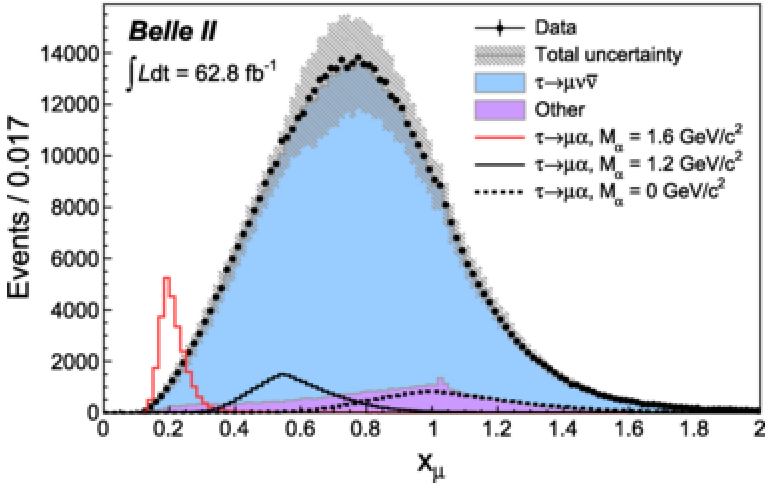
PID
e: E/p > 0.8
π: E/p < 0.8

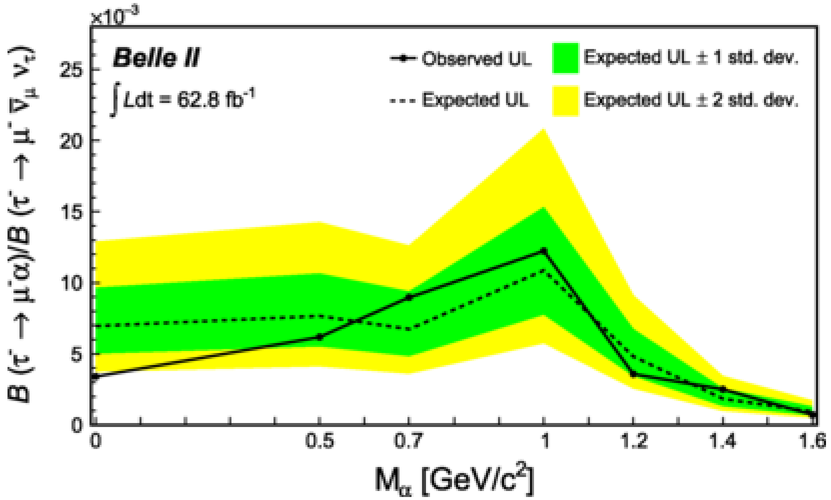
Photons
Within tracking acceptance and
E(γ) > 100 MeV
115<M(γγ)<152 MeV
or
E(γ)>200 MeV

$\tau \to l(e,\mu) + \alpha$ @ Belle II









$\tau \rightarrow l(e,\mu) + \alpha$ @ Belle II

TABLE III. Central values with their uncertainties, 95% C.L., and 90% C.L. upper limits (UL) for the branching-fraction ratios $\mathcal{B}_{e\alpha}/\mathcal{B}_{e\bar{\nu}\nu}$ (top) and $\mathcal{B}_{\mu\alpha}/\mathcal{B}_{\mu\bar{\nu}\nu}$ (bottom) for various masses of the α boson. Corresponding absolute upper limits for $\mathcal{B}(\tau^- \to \ell^-\alpha)$, computed using standard-model branching fractions from Ref. [35], are provided in parentheses for convenience.

M_α [GeV/c^2]	$\mathcal{B}_{e\alpha}/\mathcal{B}_{e\bar{\nu}\nu}$ ($\times 10^{-3}$)	UL at 95% C.L. ($\times 10^{-3}$)	UL at 90% C.L. ($\times 10^{-3}$)
0.0	-8.1 ± 3.9	5.3(0.94)	4.3(0.76)
0.5	-0.9 ± 4.3	7.8(1.40)	6.5(1.15)
0.7	1.7 ± 4.0	9.0(1.61)	7.6(1.36)
1.0	1.7 ± 4.2	9.7(1.73)	8.2(1.47)
1.2	-1.1 ± 2.6	4.5(0.80)	3.7(0.66)
1.4	-0.3 ± 1.0	1.8(0.32)	1.5(0.26)
1.6	0.2 ± 0.5	1.1(0.19)	0.9(0.16)

M_α [GeV/c^2]	$\mathcal{B}_{\mu\alpha}/\mathcal{B}_{\mu\bar{\nu}\nu}$ ($\times 10^{-3}$)	UL at 95% C.L. ($\times 10^{-3}$)	UL at 90% C.L. ($\times 10^{-3}$)
0.0	-9.4 ± 3.7	3.4(0.59)	2.7(0.47)
0.5	-3.2 ± 3.9	6.2(1.07)	5.1(0.88)
0.7	2.7 ± 3.4	9.0(1.56)	7.8(1.35)
1.0	1.7 ± 5.4	12.2(2.13)	10.3(1.80)
1.2	-0.2 ± 2.4	3.6(0.62)	2.9(0.51)
1.4	0.9 ± 0.9	2.5(0.44)	2.2(0.38)
1.6	-0.3 ± 0.5	0.7(0.13)	0.6(0.10)

Search for Lepton-Flavor-Violating τ Decays to a Lepton and an Invisible Boson at Belle II

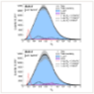
I. Adachi *et al.* (Belle II Collaboration)

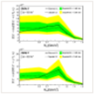
Phys. Rev. Lett. **130**, 181803 – Published 2 May 2023

Article | References | Citing Articles (7) | PDF | HTML | Export Citation

ABSTRACT

We search for lepton-flavor-violating $\tau^- \to e^-\alpha$ and $\tau^- \to \mu^-\alpha$ decays, where α is an invisible spin-0 boson. The search uses electron-positron collisions at 10.58 GeV center-of-mass energy with an integrated luminosity of $62.8\ \mathrm{fb}^{-1}$, produced by the SuperKEKB collider and collected with the Belle II detector. We search for an excess in the lepton-energy spectrum of the known $\tau^- \to e^-\bar{\nu}_e\nu_\tau$ and $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$ decays. We report 95% confidence-level upper limits on the branching-fraction ratio $\mathcal{B}(\tau^- \to e^-\alpha)/\mathcal{B}(\tau^- \to e^-\bar{\nu}_e\nu_\tau)$ in the range $(1.1\text{–}9.7)\times 10^{-3}$ and on $\mathcal{B}(\tau^- \to \mu^-\alpha)/\mathcal{B}(\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau)$ in the range $(0.7\text{–}12.2)\times 10^{-3}$ for α masses between 0 and 1.6 GeV/c^2. These results provide the most stringent bounds on invisible boson production from τ decays.

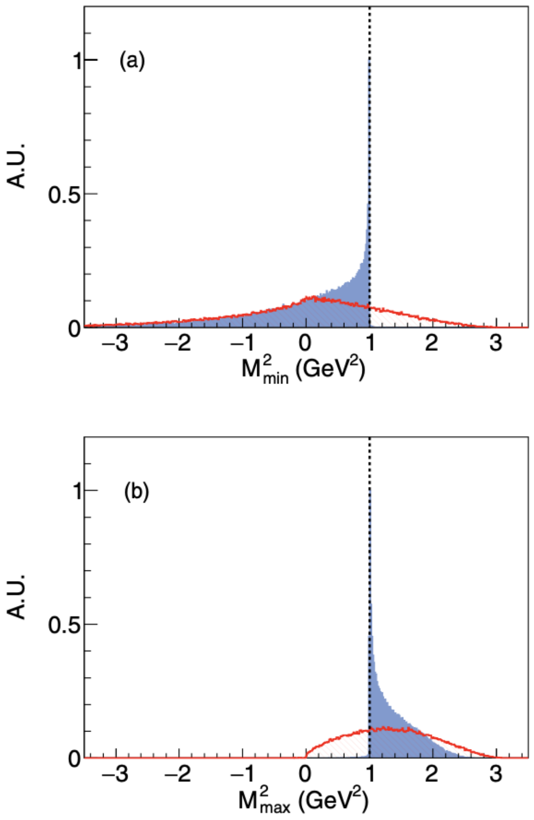




Received 7 December 2022 Accepted 23 February 2023

DOI: https://doi.org/10.1103/PhysRevLett.130.181803

What's next …



$$M^2_{\min} \le m^2_\alpha \le M^2_{\max},$$

where

$$M^2_{\min} = (\sqrt{s})^2\left(\frac{-B_0 - \sqrt{B_0^2 - 4A_0C_0}}{2A_0}\right),$$

$$M^2_{\max} = (\sqrt{s})^2\left(\frac{-B_0 + \sqrt{B_0^2 - 4A_0C_0}}{2A_0}\right).$$

PHYSICAL REVIEW D **102,** 115001 (2020)

New method for beyond the Standard Model invisible particle searches in tau lepton decays

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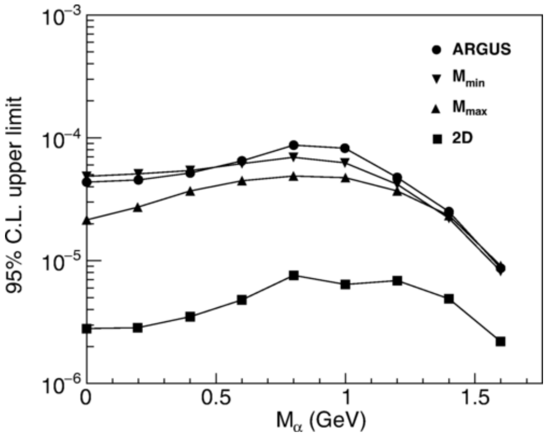
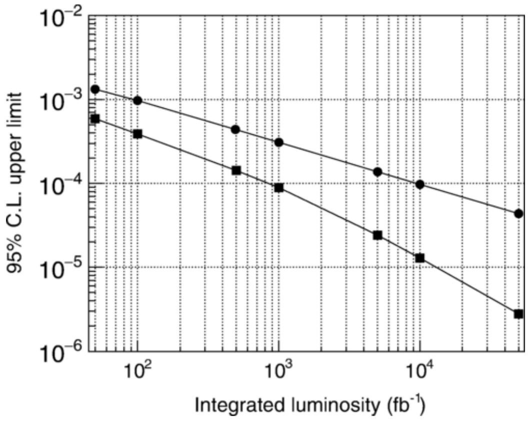
(Received 25 July 2020; accepted 15 November 2020; published 1 December 2020)

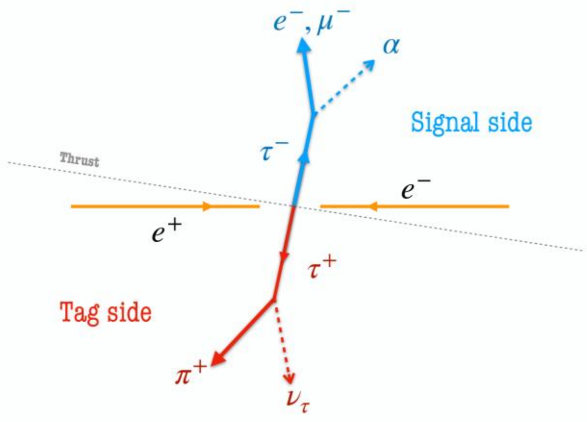
Motivated by models proposed to explain Standard Model anomalies, and the unprecedented $\tau^+\tau^-$ data to be collected by the Belle II experiment during the next years, we study the kinematics of tau pair decays and propose a new method to search for lepton flavor violating processes in tau lepton decays to invisible beyond Standard Model particles, such as $\tau \to \ell\alpha$, where ℓ is either an electron or a muon, and α is a massive particle that escapes undetected. The new method improves by one order of magnitude the expected upper limit on the $\tau \to \ell\alpha$ production in 3×1 prong tau decays and establishes the possibility of performing this search in 1×1 prong tau decays which has not been previously considered.

DOI: 10.1103/PhysRevD.102.115001





What´s next…



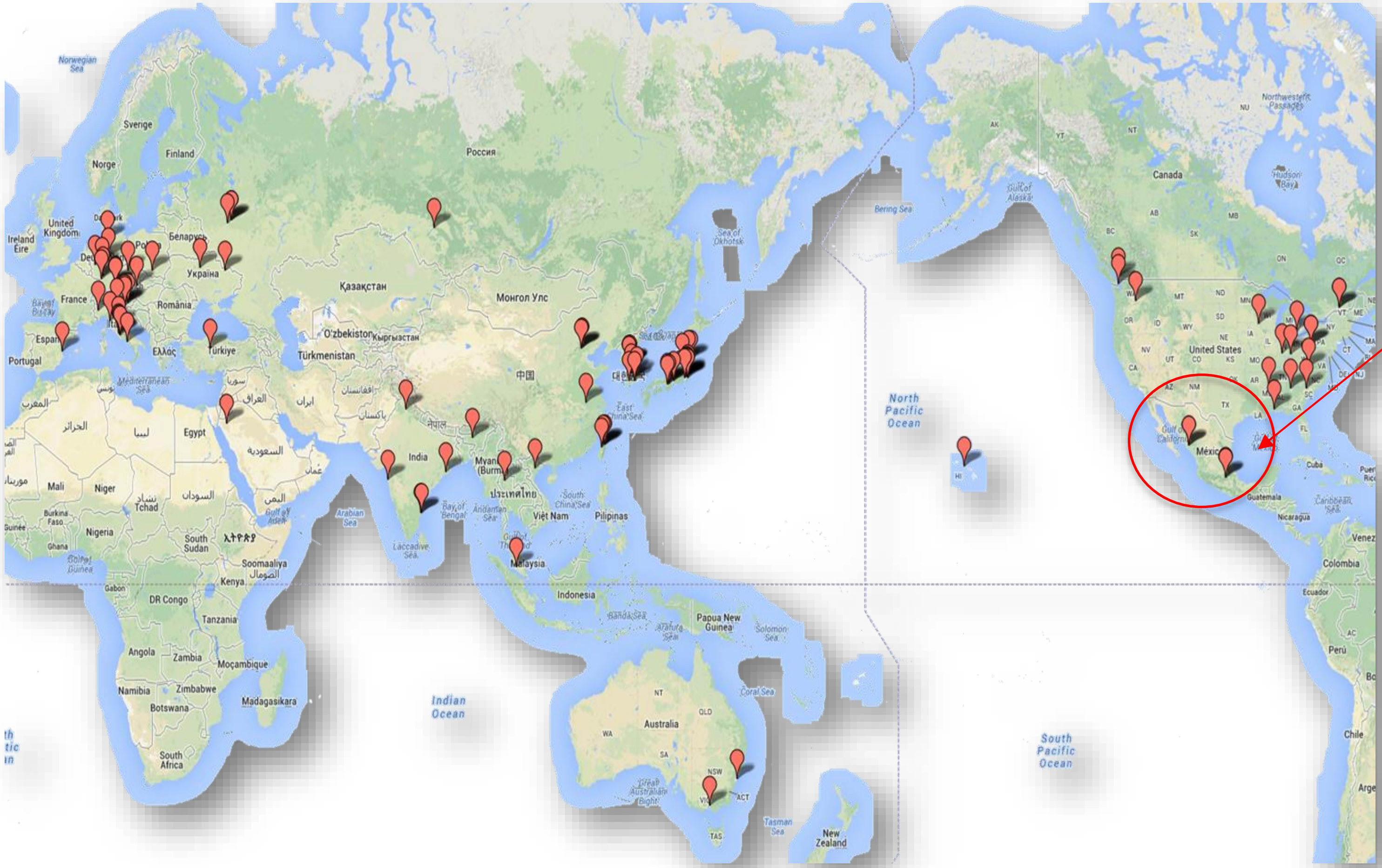
Work in progress …

Perspective …

- Belle II started operation in 2019, and the luminosity has achieved $0.5 \times 10^{35} cm^{-2} s^{-1}$.
- Belle II is getting more and more productive in publication, based on the excellent performance of the Belle II detector. So far with first data we have 52 publications: https://www.belle2.org/research/physics/publications
- Tau physics have produced 6 of Belle II publications: mass, LFV(3), light-lepton universality, and more.
- We plan to operate Belle II to around 2035 to reach the 50 ab^{-1} of data.

BACKUP

México in Belle II



Cinvestav

- Mexico requested to join Belle II in 2013
- Currently four institutions: CINVESTAV IPN, UAS and UNAM (IF).
- Eight faculty researchers (6 exp. & 2 theo.)