Tau physics at Belle II

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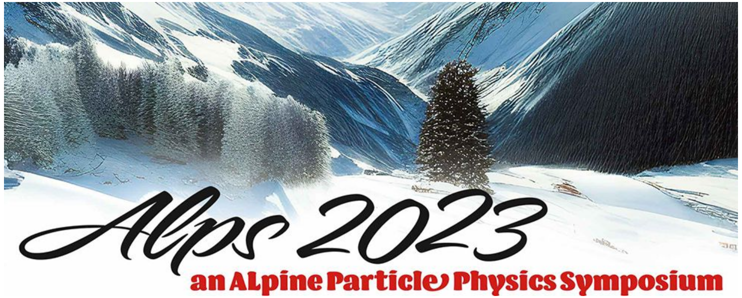
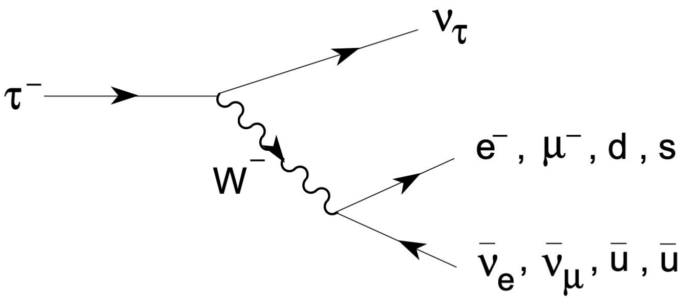
on behalf of the Belle II collaboration

ALPS 2023 Conference
28.03.2023



Why Taus?

- The odd one in the charged lepton family!
  - heaviest of the charged leptons
    - 3500 times more massive than electron
  - shortest lifetime
    - 10^{-7} times smaller lifetime than muon
  - only lepton that decays into hadrons
    - ~ 250 decay modes!



- The big question:
  - does new physics preferentially couple to the 3rd generation!
- How can we answer this?
  - **precision measurements** of the tau properties
    - **tau lepton mass**, lifetime, branching ratios
    - deviations from SM: indirect signs of NP
  - searches for **forbidden decays** of tau
    - observation would be direct sign of NP
    - lepton flavor violating (LFV) decays:
      - $\tau \to \ell V^0$, $\tau \to \ell\ell\ell$, $\tau \to \ell\gamma$, …
      - $\tau \to \ell \alpha$

Tau leptons at B factories

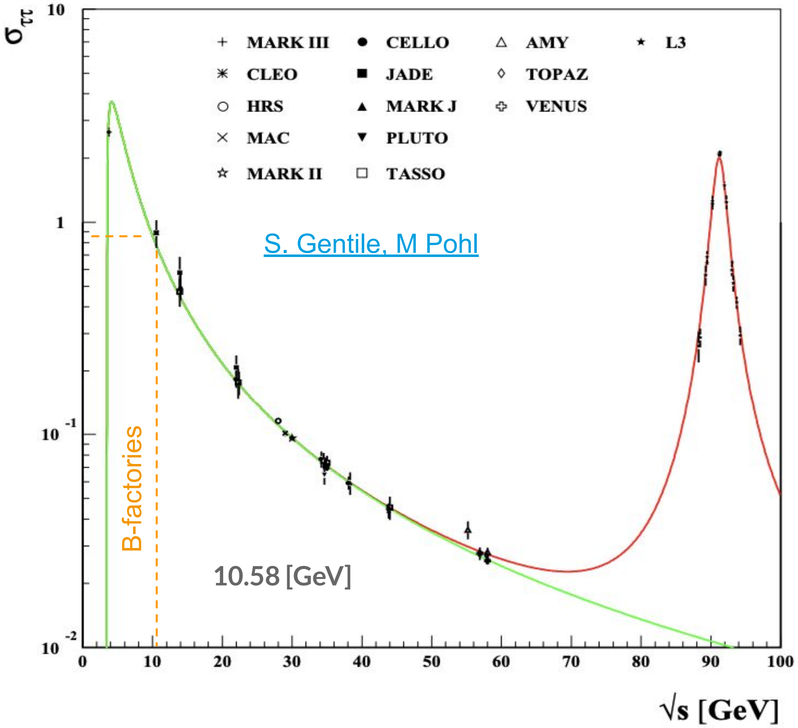
- Experimental requirements:
  - good missing energy reconstruction
    - clean and well understood initial state
    - hermetic detector
  - excellent vertexing and tracking capabilities
  - ability to trigger low-multiplicity event
- These are all met at B factories!
  - tau pair production cross section comparable to that of B pairs

$\sigma(e^+e^- \rightarrow \Upsilon(4S)) = 1.11$ nb

$\boldsymbol{\sigma(e^+e^- \rightarrow \tau^+\tau^-) = 0.92}$ **nb**

⇒ **B Factories are also tau factories!**

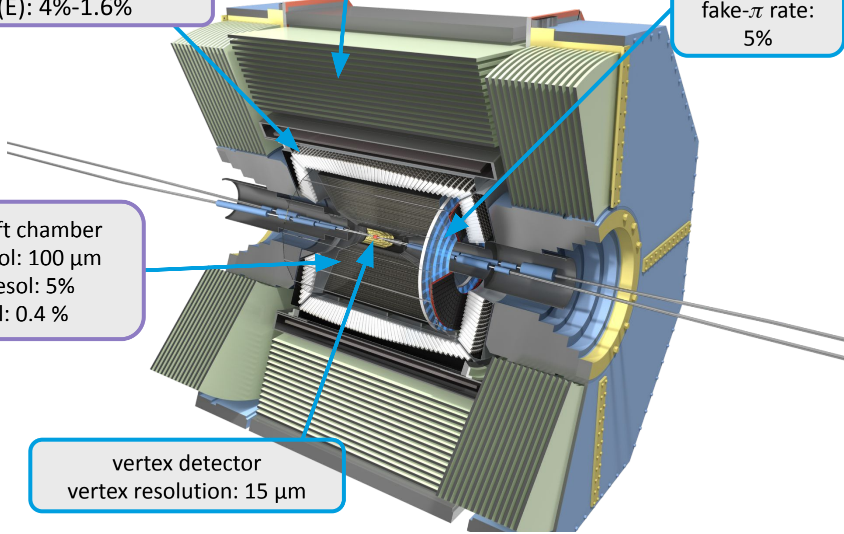
$\sigma(e^+e^- \rightarrow \tau^+\tau^-)$



S. Gentile, M Pohl

SuperKEKB and Belle II

- SuperKEKB accelerator
  - energy-asymmetric e^+e^- collider located in Tsukuba, Japan
  - running at (and near) $m(\Upsilon(4S))=10.58$ GeV
  - world record inst. lumi of $4.7x10^{34}$ $cm^{-2}s^{-1}$
- Belle II detector
  - data collected since 2019: 428 fb^{-1}
  - currently in long shutdown
  - expected to restart by the end 2023



K_L and muon detector
μ ID-eff: ~90%

EM Calorimeter
σ(E): 4%-1.6%

particle ID
fake-π rate:
5%

central drift chamber
spacial resol: 100 μm
dE/dx resol: 5%
p_T resol: 0.4 %

vertex detector
vertex resolution: 15 μm

trigger:
hardware rate (L1) < 30 kHZ
software rate (HLT) < 10 kHZ

Today:

- Direct searches:
  - search for an invisible BSM boson (α) : $\tau \to \ell\alpha$
  - LFV violating decay of tau: $\tau \to \ell\varphi$
- Precision measurement:
  - tau lepton mass

Accepted by PRL:
arXiv:2212.03634

- **Direct searches:**
  - **search for an invisible BSM boson (α) : $\tau \rightarrow \ell\alpha$**
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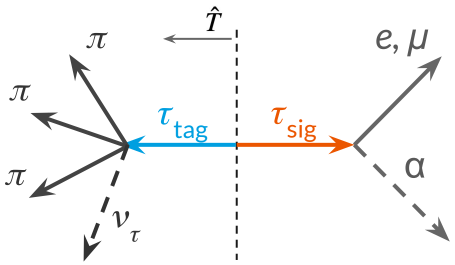
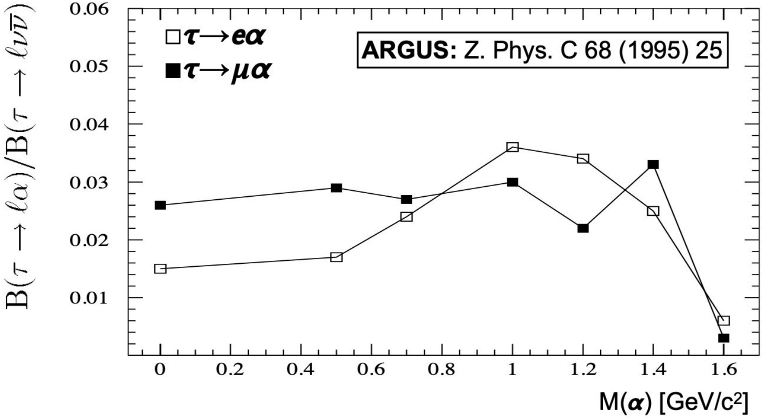
search for BSM boson: $\tau \longrightarrow \ell\alpha$



- Motivation:
  - α could be any invisible spin-0 boson, light ALP, etc..
  - current best limits set by ARGUS (476 pb^{-1})
- Common strategy:
  - split event in two hemispheres based on the thrust axis
  - use 3x1-prong decays (3 track on one side, 1 track on the other)
- **tag side**: $\boldsymbol{\tau \rightarrow \pi\pi\pi\ \nu}$**:**
- **signal side**: $\boldsymbol{\tau \rightarrow \ell\alpha}$**,** $\boldsymbol{\ell = e, \mu}$
- Challenge:
  - **irreducible background:** $\boldsymbol{\tau \rightarrow \ell\nu\nu}$
  - but we can exploit the <u>shape differences</u>: 3-body decay vs. 2-body decay of signal

$$\vec{T} = max\left(\sum_i \frac{\vec{p_i} \cdot \hat{T}}{|p_i|}\right)$$

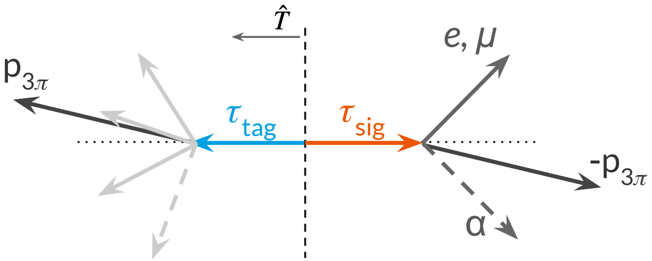


$\tau \rightarrow \ell\alpha$: the "pseudo-rest-frame"

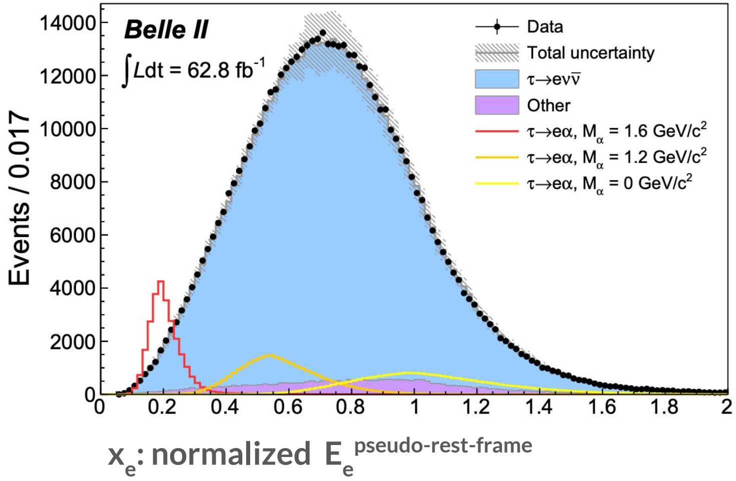
- shape differences are most prominent in the τ rest frame:
  - true rest frame is not accessible due to ν's (or α)
  - use the tag-side:
    - **tau momentum:** use $p_{3\pi}$ as an approximation
    - **tau energy:** √s/2 (true up to ISR/FSR)
  - we now can boost to the approximate rest frame **"pseudo-rest-frame"**
- Bump search in x_ℓ (normalized $E_\ell^{\text{pseudo-frame}}$ spectrum)

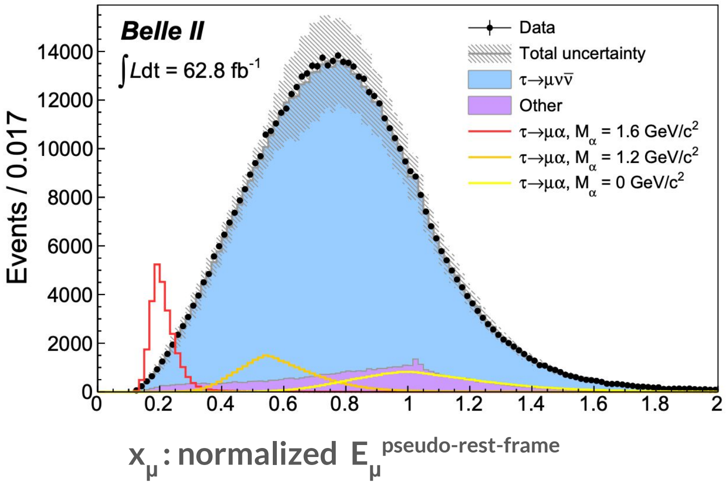
$$\hat{p}_\tau \approx -\frac{\vec{p}_{tag}}{|\vec{p}_{tag}|}$$

$$E_\tau \approx \sqrt{s}/2$$



$$x_\ell \equiv \frac{E_\ell^{pseudo\text{-}rest\text{-}frame}}{m_\tau c^2/2}$$



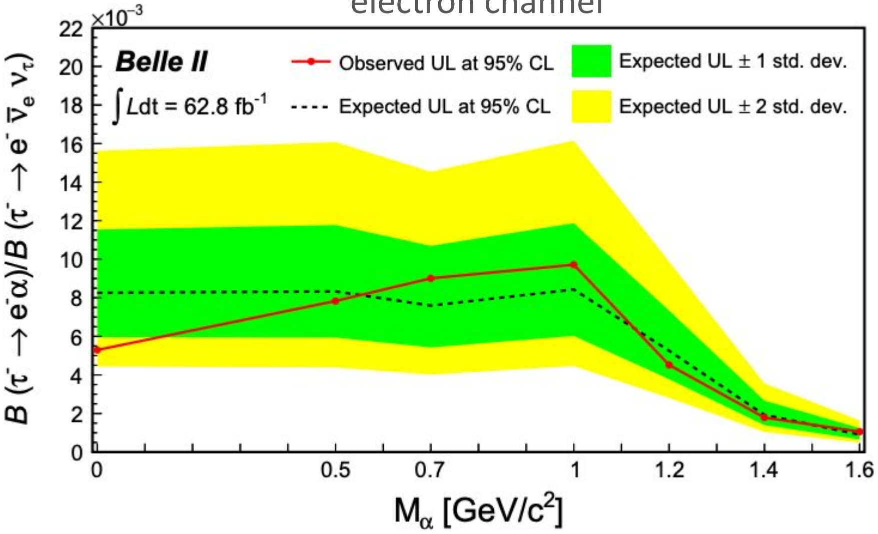


$\tau \to \ell\alpha$: results

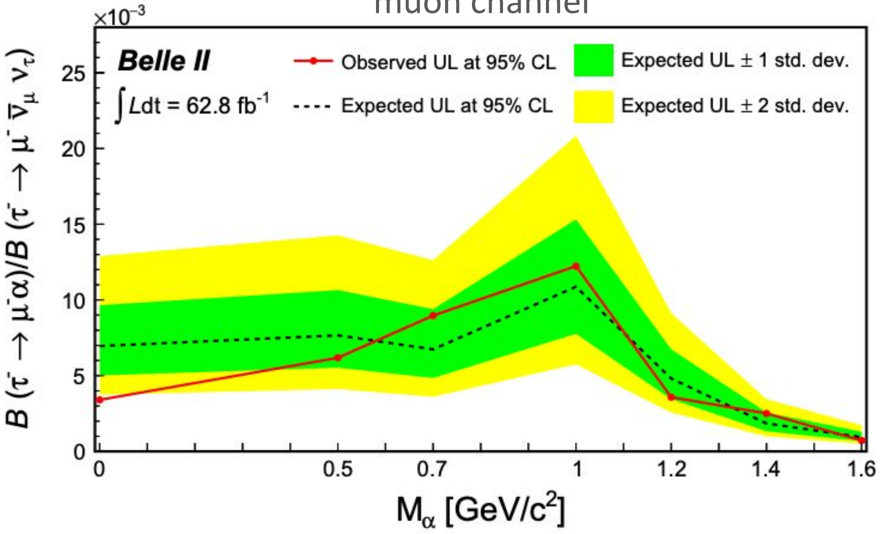
Accepted by PRL:
arXiv:2212.03634

- Using 62.8 fb^{-1} no signal is observed…
  - 95% CL upper limits are set on $B(\tau \to \ell\alpha)/B(\tau \to \ell\nu\nu)$ using asymptotic CLs method.

electron channel



muon channel



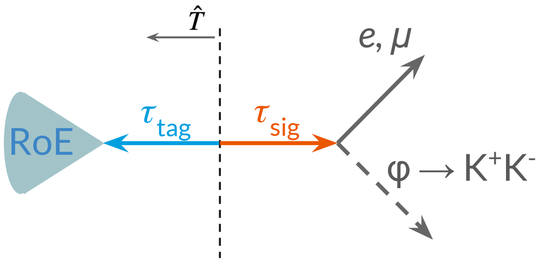
⇒ Most stringent limits in these channels to date!
(2-14 times more constraining than Argus)

preliminary for winter conferences

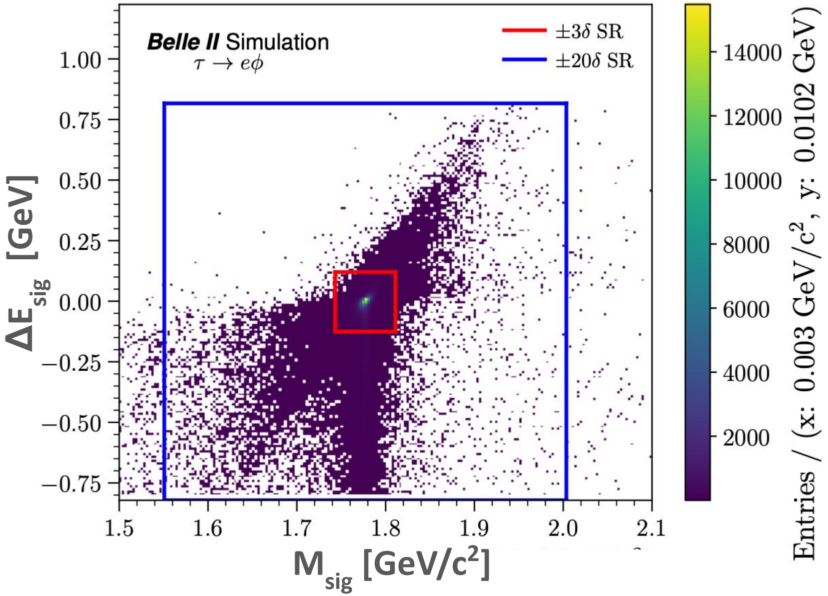
- **Direct searches:**
  - search for a invisible BSM boson (α) : $\tau\longrightarrow\ell\alpha$
  - **LFV violating decay of tau: $\tau\longrightarrow\ell\varphi$**
- Precision measurement:
  - tau lepton mass

search for LFV decay: $\tau \to \ell\varphi$

- Motivation:
  - highly suppressed in SM (~10^{-50})
  - leptoquark models predict BF of up to 10^{-8}-10^{-10}
- Challenge:
  - keep signal efficiency high while suppressing the bkg
- **Signal side**: **$\tau \to \ell\varphi$**
  - **ℓ=e, μ and $\varphi \to K^+K^-$ (~50% BF of φ)**
- **Tag side: inclusive (novel approach)**
  - everything except for signal: “Rest of Event” (RoE)
  - RoE and signal kinematics in BDT classifier to suppress the continuum backgrounds
- signal efficiency of 6.1% (6.5%) for *e* (*μ*) channel
- The trick: no neutrino in the signal tau decay
  - Inv. mass on the signal side (M_{sig}) is expected to peak at actual tau mass!
  - $\Delta E_{sig} = E^*_{sig} - \sqrt{s}/2$ expected to peak at zero for signal



electron channel

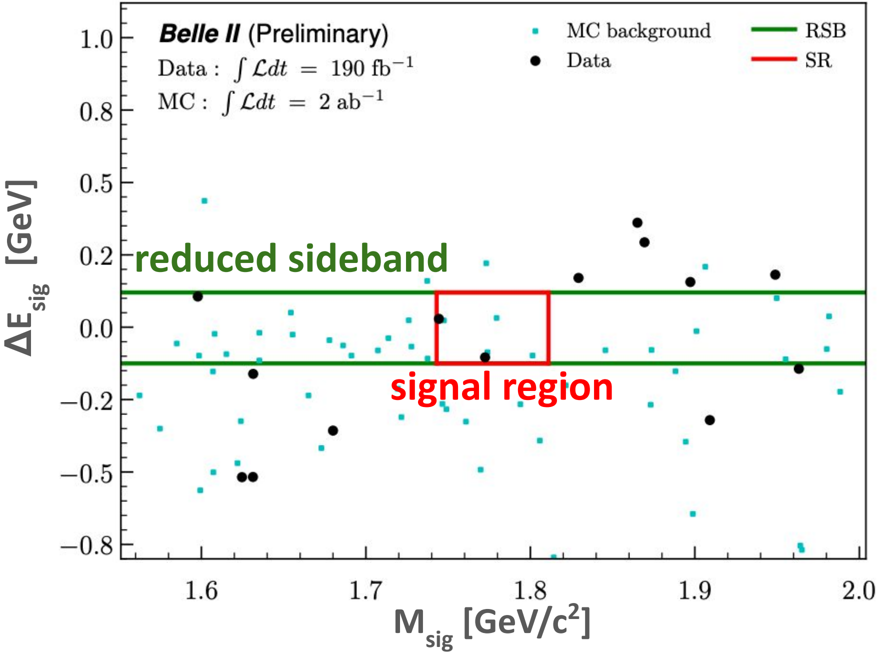


search for LFV decay: $\tau \to \ell \varphi$

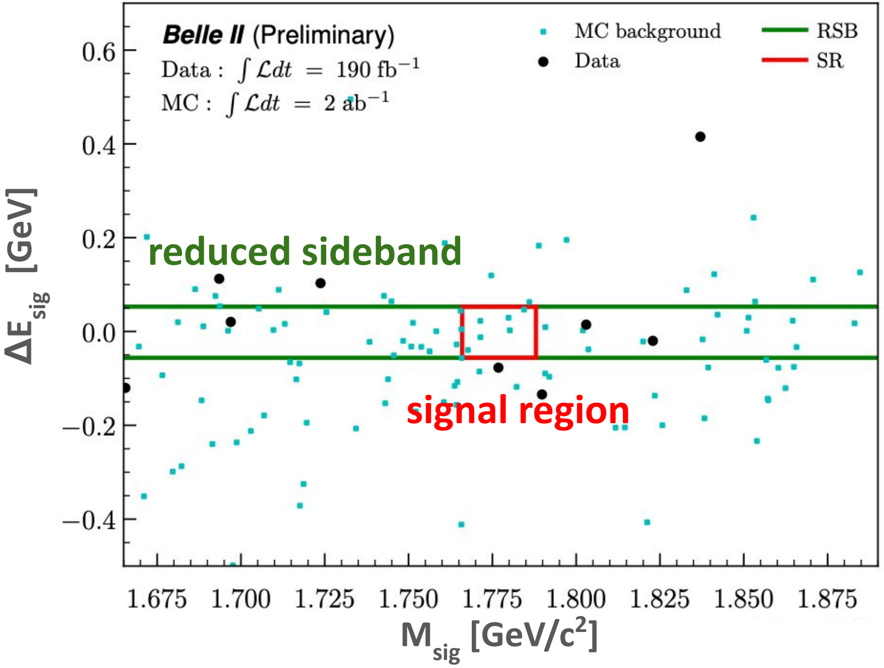
- Background estimation
    - using data in the reduced sidebands
    - obtain transfer factor from simulation

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

electron channel



muon channel

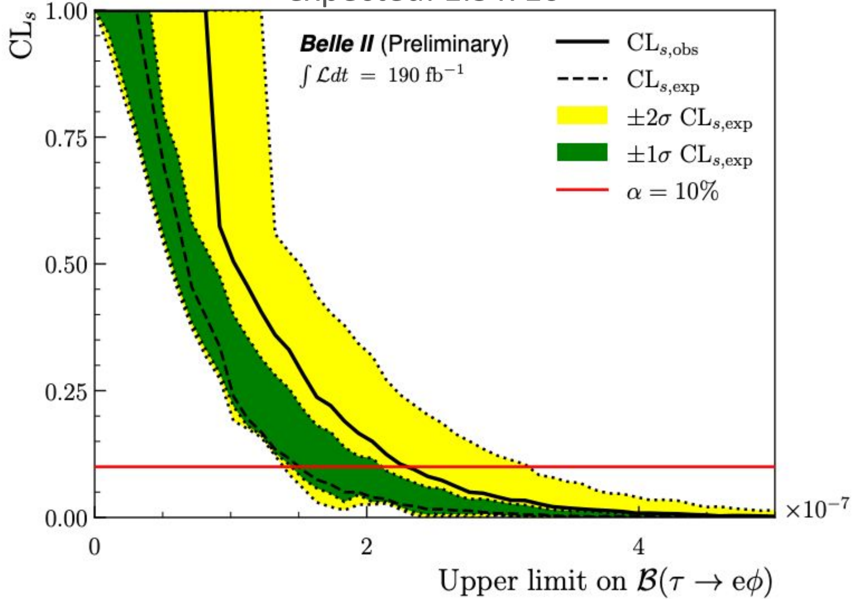


$\tau \rightarrow \ell\varphi$: the results

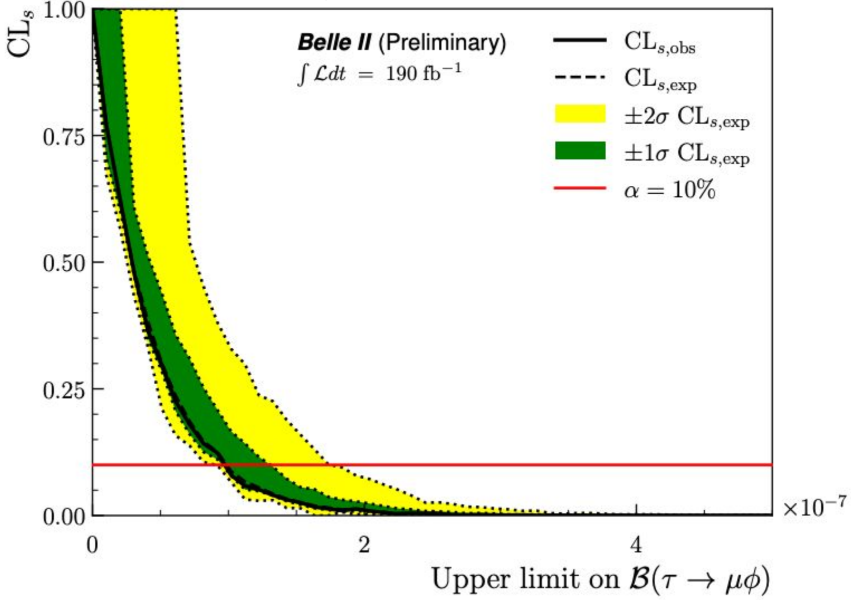
preliminary for winter conferences

- No significant excess is observed.
    - we set 90% CL upper limits on BF($\tau \rightarrow \ell\varphi$)

electron channel: $\tau \rightarrow e\varphi$
observed: 2.3×10^{-7}
expected: 1.5×10^{-7}



muon channel: $\tau \rightarrow \mu\varphi$
observed: 9.7×10^{-8}
expected: 9.9×10^{-8}



⇒ not yet competitive with Belle/BaBar…
but a successful first application of inclusive tagging at Belle II

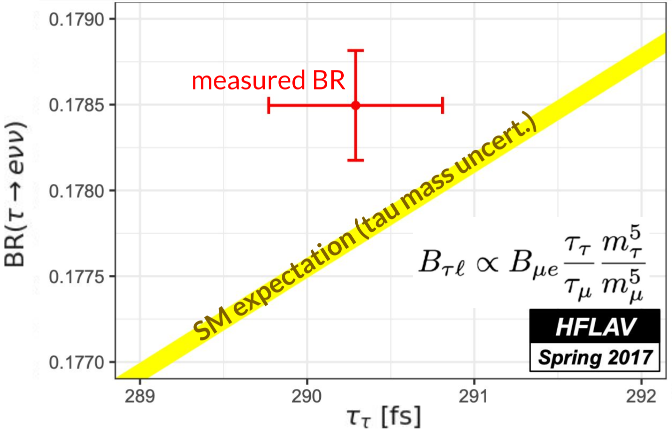
new for winter conferences

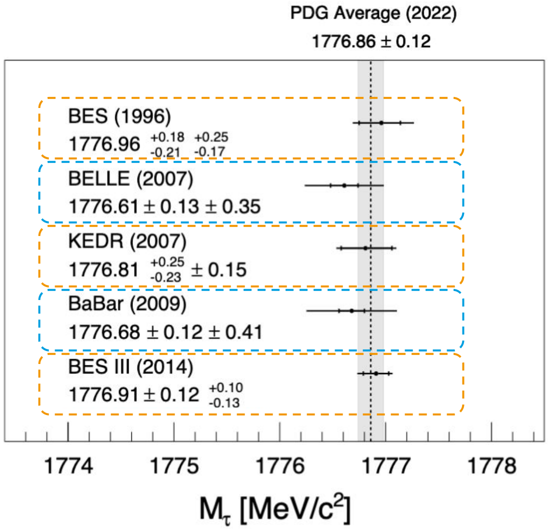
- Direct searches:
  - search for a invisible BSM boson (α) : $\tau \longrightarrow \ell \alpha$
  - LFV violating decay of tau: $\tau \longrightarrow \ell \varphi$
- **Precision measurement:**
  - **tau lepton mass**

tau lepton mass measurement

- The why:
  - lepton masses are fundamental parameters of SM
    - tau mass uncertainty is ~10^3 worse than m(μ)
  - tau mass (and lifetime) uncertainties are important for lepton flavor universality (LFU) tests of SM
- Two main methods for measuring the mass:
  - pair production cross section:
    - energy scan around the tau pair production threshold
    - extract the mass from the dependence of cross section on collision energy
    - used by BESIII (most precise in the PDG)
  - **Pseudomass method (used here)**
    - developed by ARGUS, and used at BaBar, Belle and Belle II
    - exploit the kinematics of the 3π system in the $\tau\rightarrow\pi\pi\pi\nu$

arXiv:1804.08436



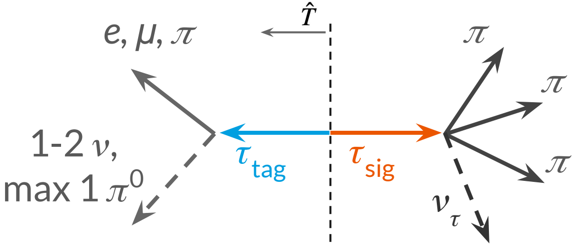


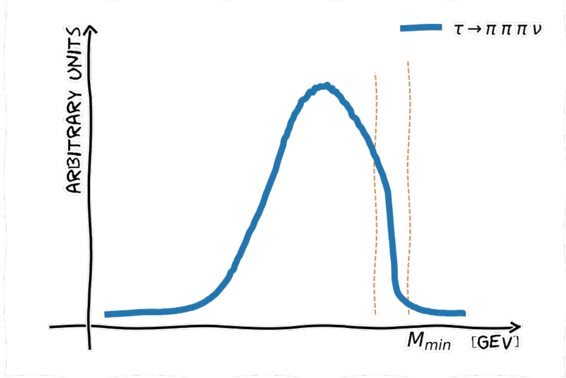
Pseudomass (M_{min}) method

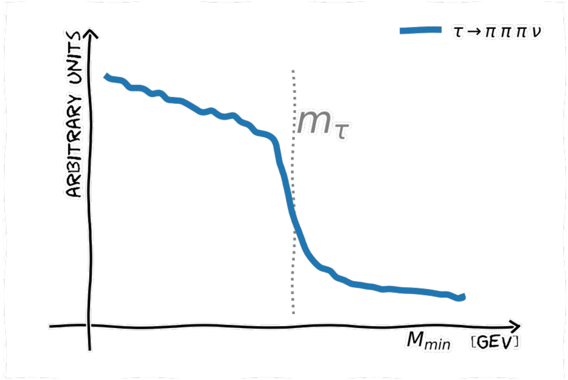
- The challenge:
  - the tau mass cannot be accessed directly due to the presence of the neutrinos…
- The trick:
  - use 3-prong decays of tau: $\boldsymbol{\tau \rightarrow \pi\pi\pi\nu}$
  - make some simple assumptions:
    - $E_\tau \approx \sqrt{s}/2$ (true up to ISR/FSR)
    - neutrinos: massless and
    - collinear with the 3π system (this minimizes the tau inv. mass)

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

- The nice part:
  - This variable has a kinematic edge at the tau mass!
- not so nice:
  - there is a large tail from ISR/FSR and detector resolution
  - we need to extract the mass from the threshold position



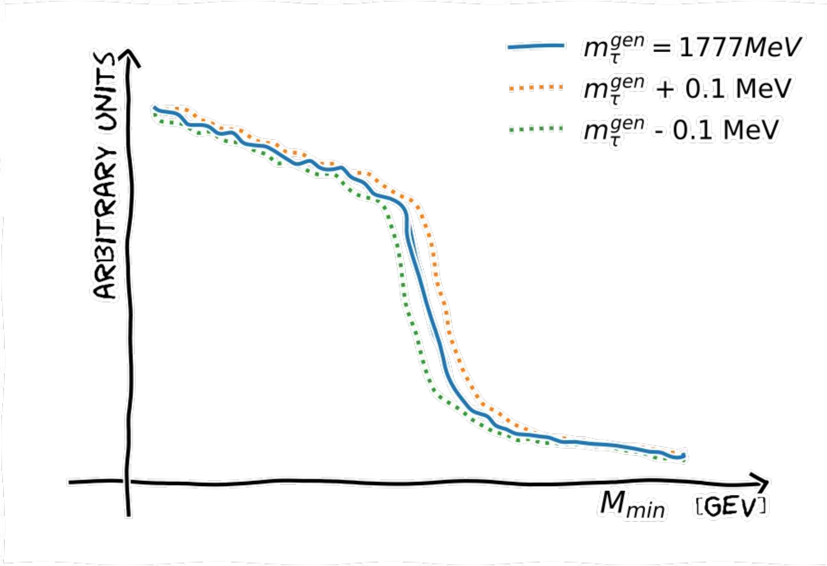




extracting the mass

- The method:
  - Use an empirical fit function to extract the mass:

$$F(M_{\rm min}) = 1 - P_3 \cdot \arctan\left(\frac{M_{\rm min} - P_1}{P_2}\right) + P_4(M_{\rm min} - P_1) + P_5(M_{\rm min} - P_1)^2$$



  - P_1: depends on the position of threshold
  - P_2: the slope of the threshold
  - P_3-P_5: the shape away the threshold
- P_1 is an estimator of tau mass!
  - This is a biased estimator of 0.40 MeV, determined from simulation samples, with various generated tau masses
  - **~3x smaller bias** compare to Belle and BaBar (they had slightly different parameterizations)
  - The bias can also depend on the overall shape of the distribution as well

A bit of history:

- Historically, the systematics have been dominated by:
  - momentum scale of the tracks
  - beam energy scale

$$M_{\text{min}} = \sqrt{M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - P_{3\pi}^*)}$$

Belle (414 fb^{-1}) arXiv:hep-ex/0608046

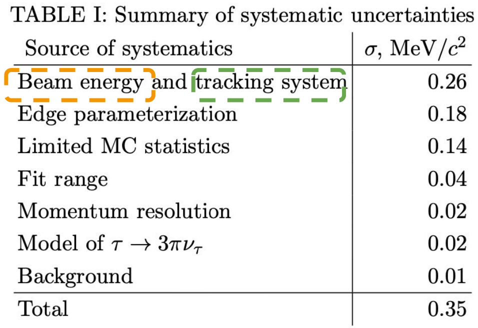


TABLE I: Summary of systematic uncertainties

Source of systematics	σ, MeV/c^2
Beam energy and tracking system	0.26
Edge parameterization	0.18
Limited MC statistics	0.14
Fit range	0.04
Momentum resolution	0.02
Model of $\tau \to 3\pi\nu_\tau$	0.02
Background	0.01
Total	0.35

stat: 0.13 MeV

BaBar (423 fb^{-1}) arXiv:0909.3562

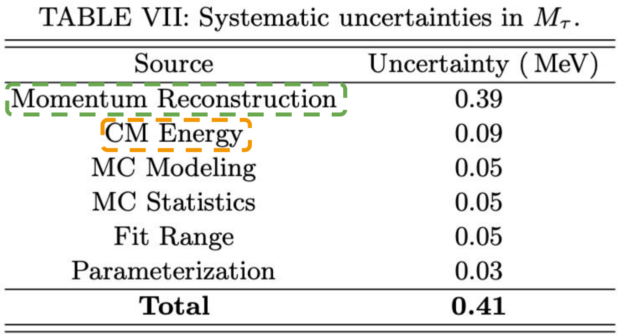


TABLE VII: Systematic uncertainties in M_τ.

Source	Uncertainty (MeV)
Momentum Reconstruction	0.39
CM Energy	0.09
MC Modeling	0.05
MC Statistics	0.05
Fit Range	0.05
Parameterization	0.03
Total	**0.41**

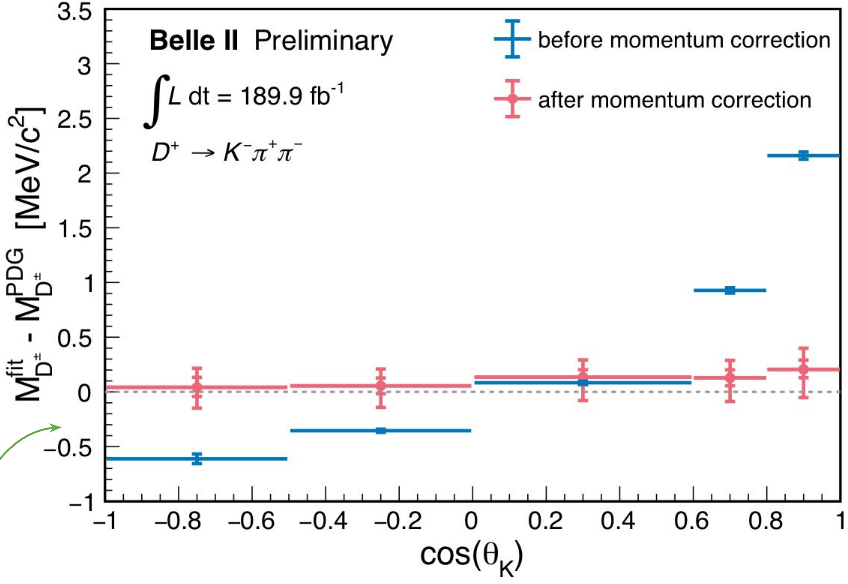
stat: 0.12 MeV

⇒ **Challenge for Belle II:** improve the understanding of these effects and squeeze the systematics! (also… only 190/fb used here!)

Tau mass systematics: momentum scale

$$M_{\min} = \sqrt{\boxed{M_{3\pi}^2} + 2(\sqrt{s}/2 - E_{3\pi}^*)(\boxed{E_{3\pi}^* - P_{3\pi}^*})}$$

- Momentum of the 3π's is an important ingredient in the $M_{\min}$!
- We use $D^0 \to K\pi$ as a standard candle!
  - get scale factors (SF) for K and π based on difference in peak position and PDG value of D^0
    - phase-space dependent SFs: as a function of charge and cos(θ) of the tracks
  - various systematic effects included for the SF's:
    - m(D^0) PDG uncertainty
    - peak position modelling
    - additional kinematical dependence
    - detector misalignment
- Use other mass peaks as cross check: $D^0 \to K\pi\pi\pi$, $J/\psi \to \mu\mu$, $K_S^0 \to \pi\pi$, $\boxed{D^\pm \to K\pi\pi}$

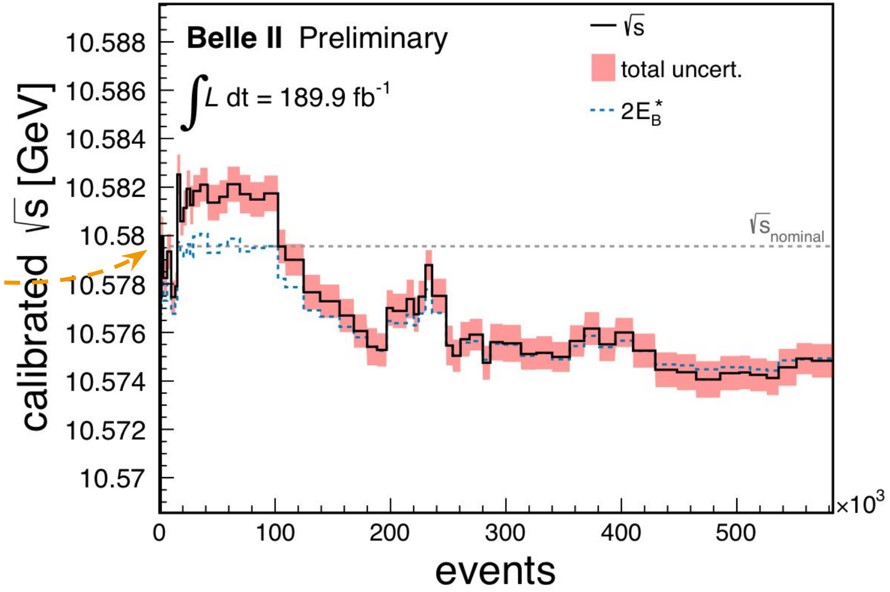


⇒ impact on tau mass: **0.06 MeV**

Tau mass systematics: energy scale

$$M_{\min} = \sqrt{M_{3\pi}^2 + 2(\boxed{\sqrt{s}/2} - E_{3\pi}^*)(E_{3\pi}^* - P_{3\pi}^*)}$$

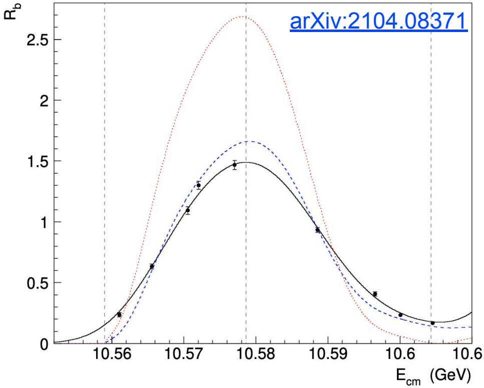
- Center-of-mass collision energy (√s):
    - used to approximate the energy of the tau
- Use energy of fully reconstructed B mesons (E^*_B) to calibrate √s
    - E^*_B <u>only approximately equals</u> √s, need extra corrections due to subtle effects from:
    - ISR photons
    - spread of the beam energy
    - dependence of ϒ(4S) cross section on the beam energy:



e.g when √s is below the ϒ(4S) peak, due to the beam-energy spread, we produce:

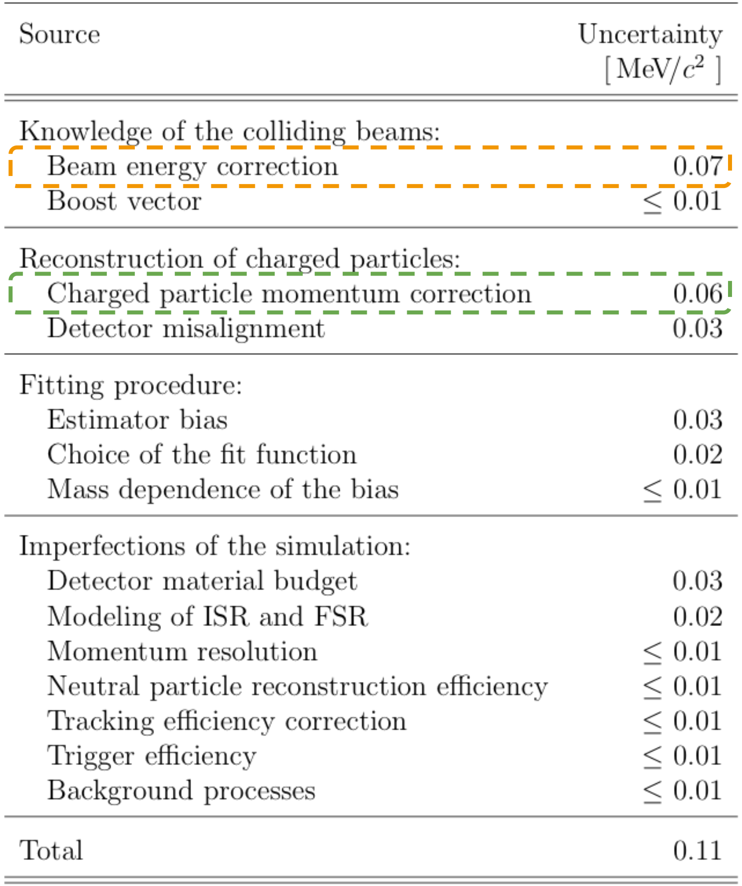
- less low energy B mesons
- more high energy B's

⇒ resulting in a bias in E^*_B values towards the ϒ(4S) peak



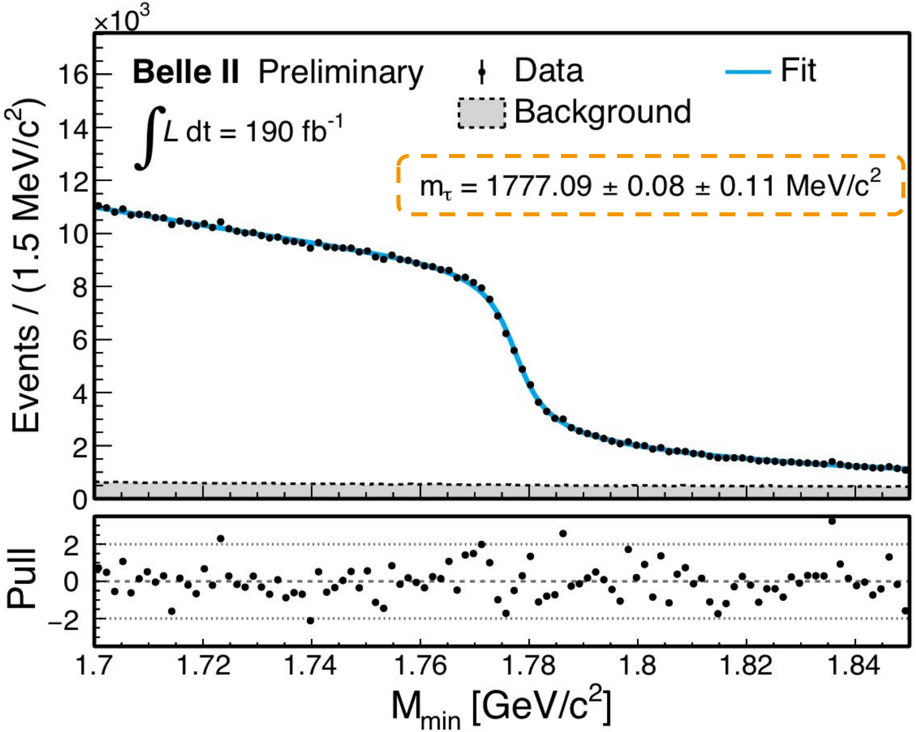
⇒ impact on tau mass: **0.07 MeV**

Tau mass measurement: results

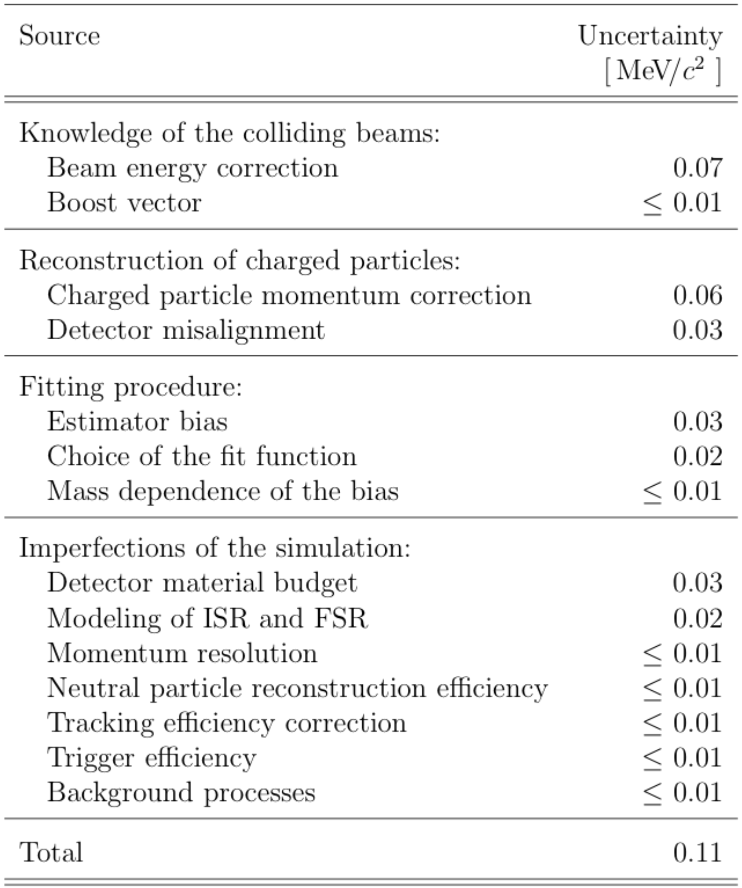


Source	Uncertainty [MeV/c^2]
Knowledge of the colliding beams:	
Beam energy correction	0.07
Boost vector	$\leq$ 0.01
Reconstruction of charged particles:	
Charged particle momentum correction	0.06
Detector misalignment	0.03
Fitting procedure:	
Estimator bias	0.03
Choice of the fit function	0.02
Mass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

Tau mass measurement: results

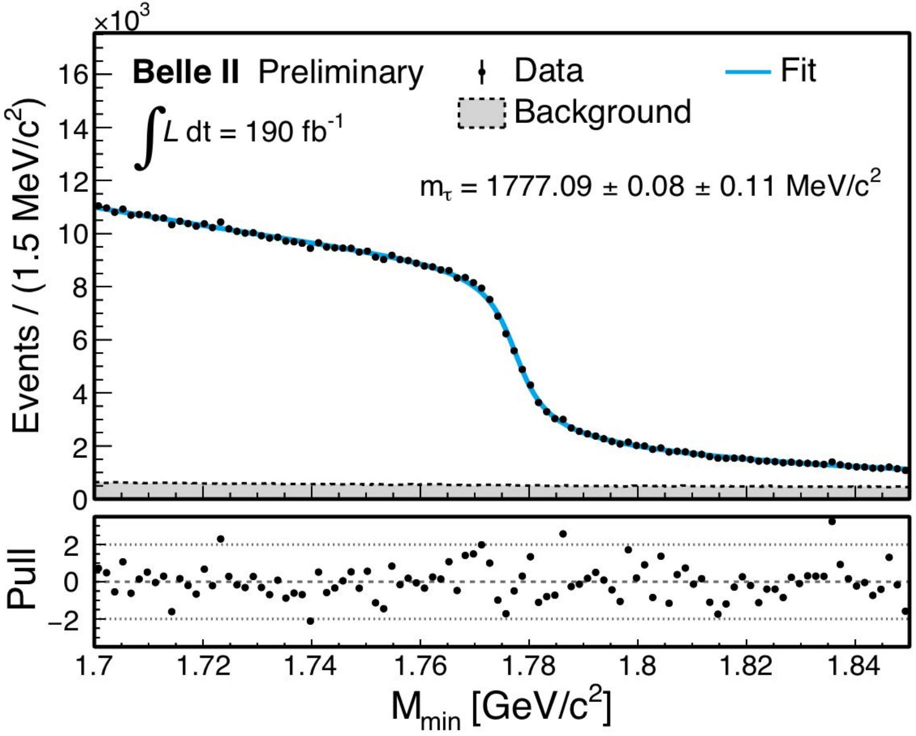


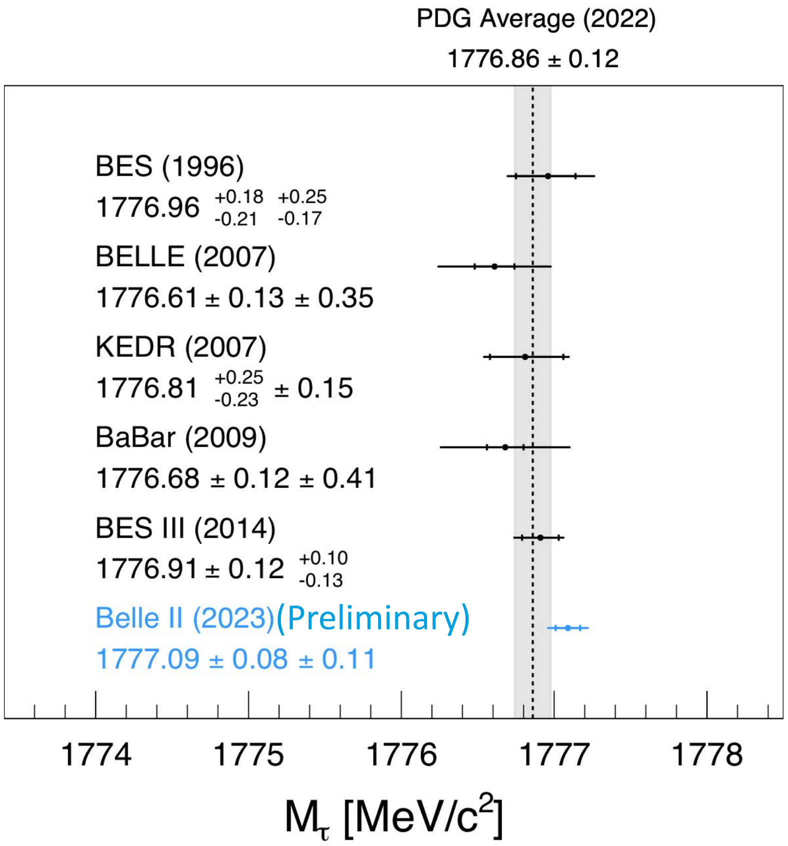
⇒ **With less than half data size as Belle and BaBar we have better statistical precision!**



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

Tau mass measurement: results





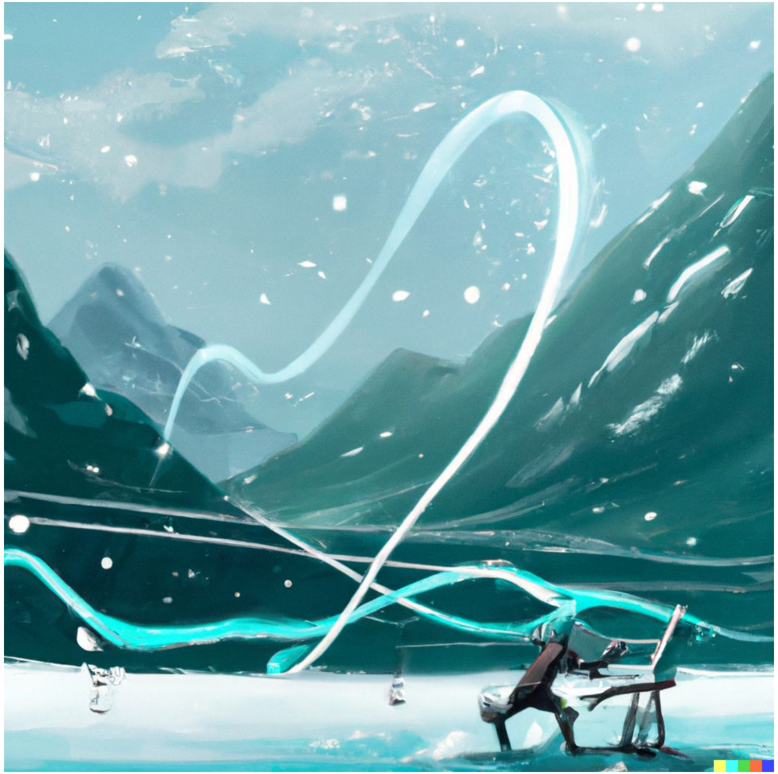
⇒ **With less than half data size as Belle and BaBar we have better statistical precision!**

⇒ **World's best measurement of the tau lepton mass!**

Summary

- Tau physics can provide a window into new physics
  - directly via searches for forbidden/highly suppressed decay modes
  - indirectly via precision measurements of tau properties
  - Belle II and superKEKB provide a near-ideal environment for studying the tau leptons!
- Direct searches for new physics signature already getting competitive or better than previous results!
  - search for a new scalar: $\tau \rightarrow \ell \alpha$
    - **world's most stringents limit**
  - search for LFV decay: $\tau \rightarrow \ell \varphi$
    - successful application of inclusive tagging, with only half of the on-tape data
- World's most precise measurement for the tau lepton mass!
  - Precision measurement capabilities are proven!

Thank You!

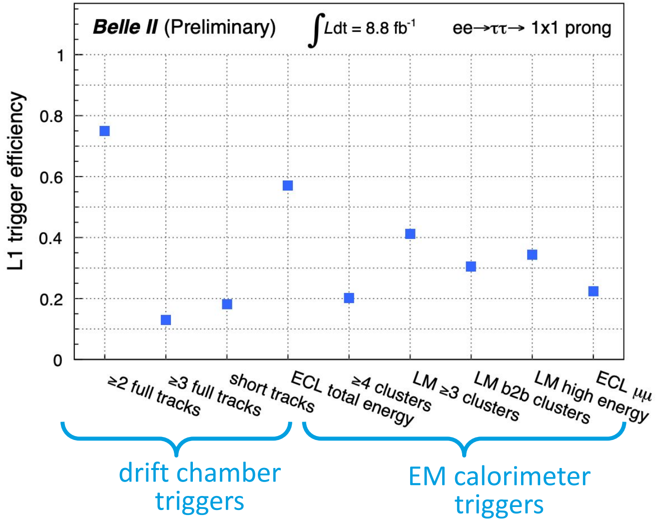


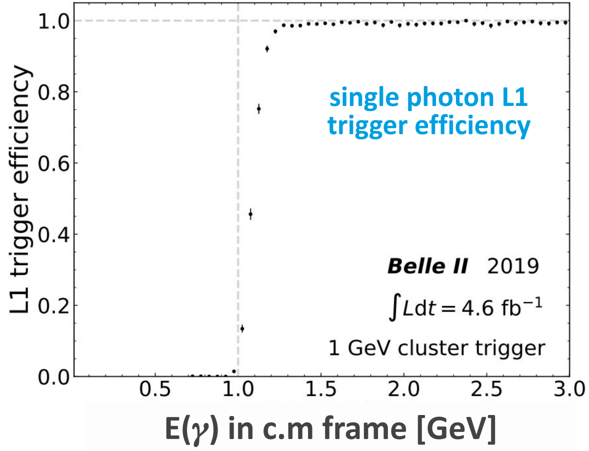
AI's (DALL-E's) interpretation of "doing physics in the ALPS"

BACKUP

Trigger performance

- essential for dark-sector and tau physics
    - typical signatures include low-multiplicity of tracks, and energy deposits in EM calorimeter
    - large background from radiative Bhabha and two-photon processes
- some of the dedicated low-multiplicity triggers:
    - single muon
        - combine drift chamber and muon detector information
    - single track:
        - neural-net based hardware trigger
    - single photon:
        - high efficiency for $E(\gamma) > 1$ GeV

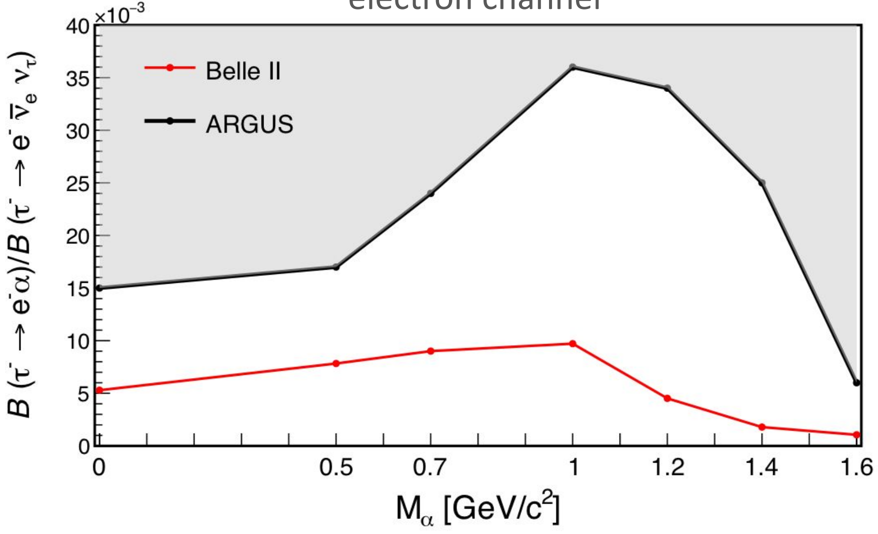




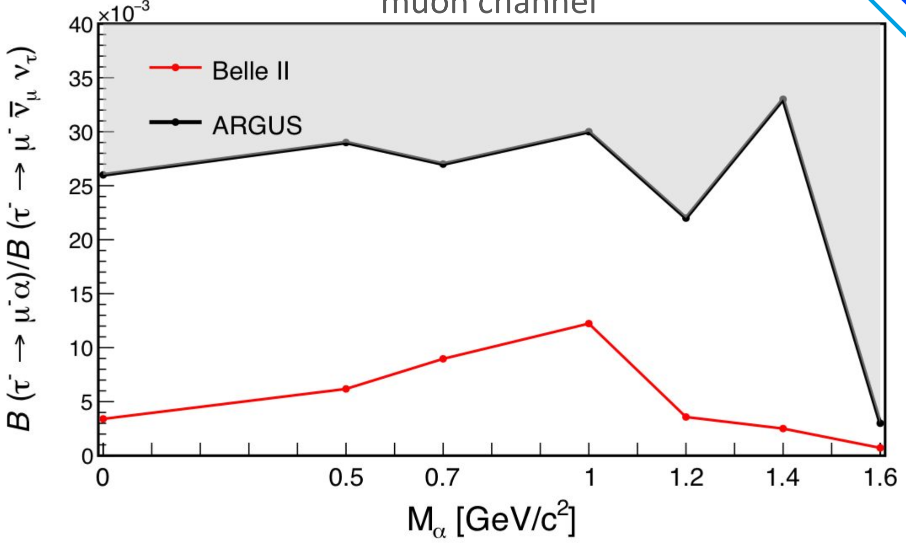
$\tau \rightarrow \ell\alpha$: comparison with ARGUS

Accepted by PRL:
arXiv:2212.03634

electron channel



muon channel



⇒ **Most stringent limits in these channels to date!**

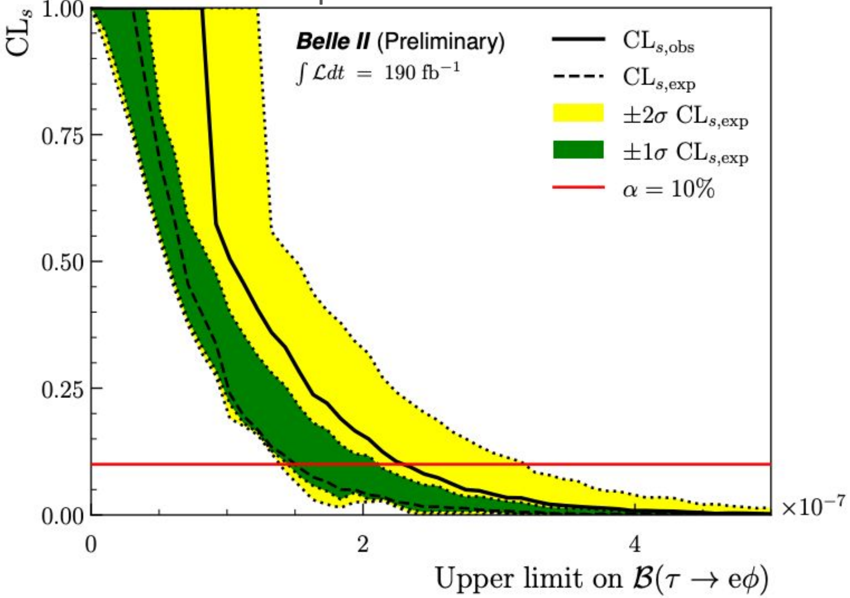
$\tau \rightarrow \ell\varphi$: the results

preliminary for winter conferences

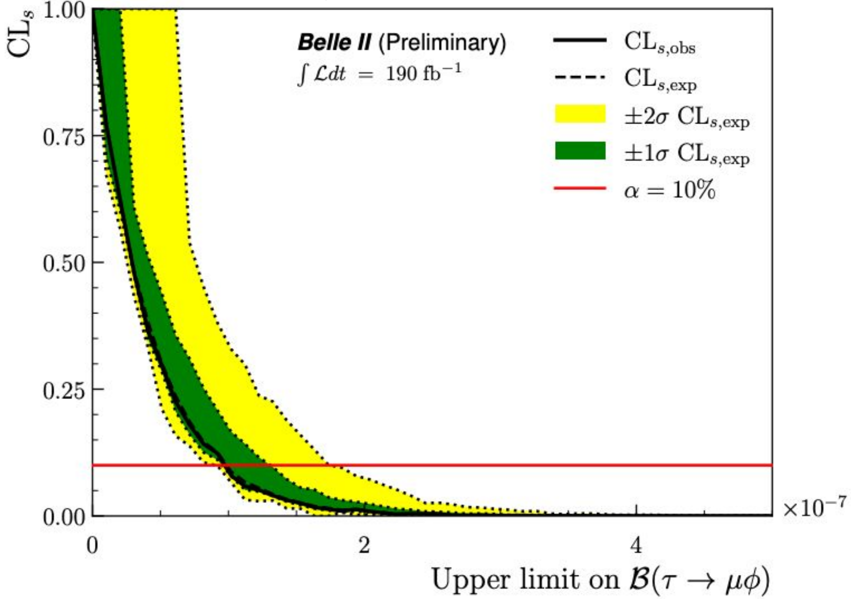
TABLE I: 90% confidence level upper limits on $\tau \to \ell\phi$ branching fractions obtained by BaBar (451 fb^{-1}) and Belle (854 fb^{-1}) [4, 5].

Experiment	$\mathcal{B}^{90}_{\mathrm{UL}}(e\phi)$ $(\times 10^{-8})$ exp. / obs.	$\mathcal{B}^{90}_{\mathrm{UL}}(\mu\phi)$ $(\times 10^{-8})$ exp / obs.
BaBar	5.0 / 3.1	8.2 / 19
Belle	4.3 / 3.1	4.9 / 8.4

electron channel: $\tau \rightarrow e\varphi$
observed: 2.3 x 10^{-7}
expected: 1.5 x 10^{-7}



muon channel: $\tau \rightarrow \mu\varphi$
observed: 9.7 x 10^{-8}
expected: 9.9 x 10^{-8}

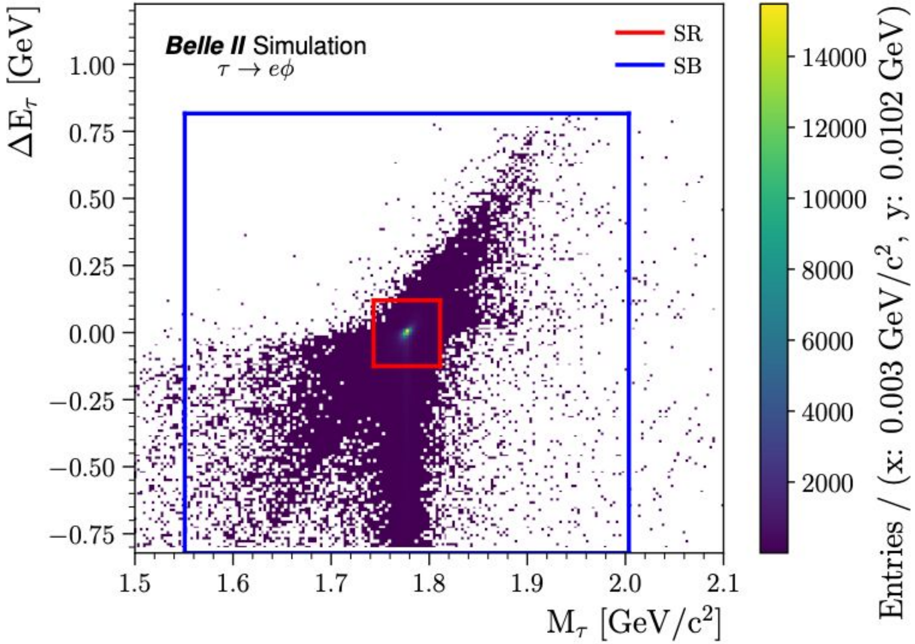


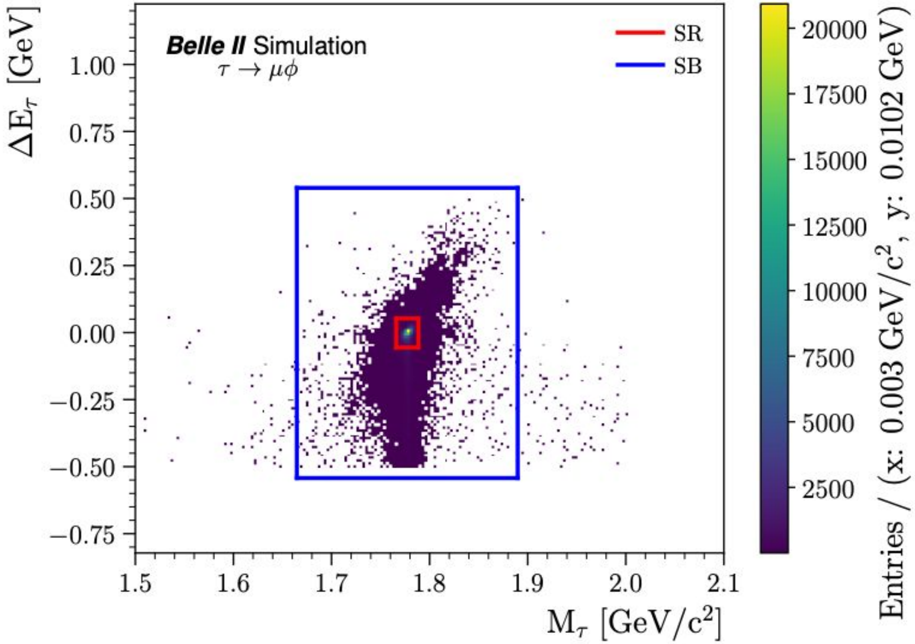
⇒ not yet competitive with Belle/BaBar, but a successful first application of inclusive tagging at Belle II

$\tau \to \ell\varphi$: signal region and side bands

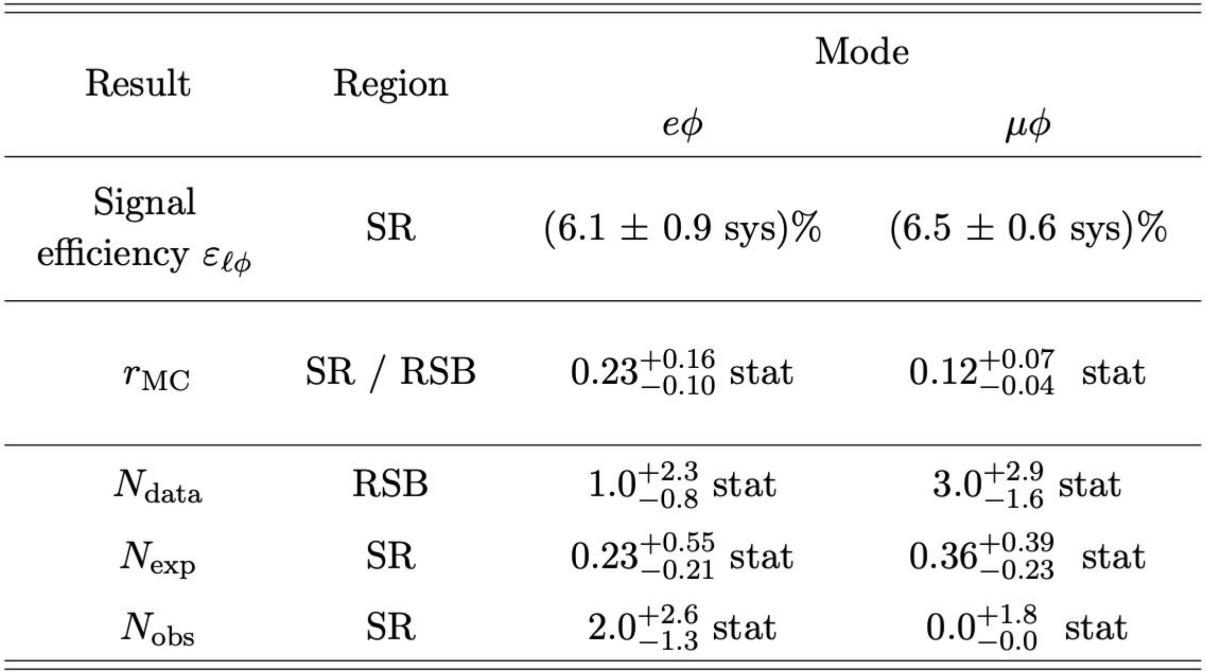
electron channel: $\tau \to e\varphi$

muon channel: $\tau \to \mu\varphi$





$\tau \rightarrow \ell\varphi$: yields

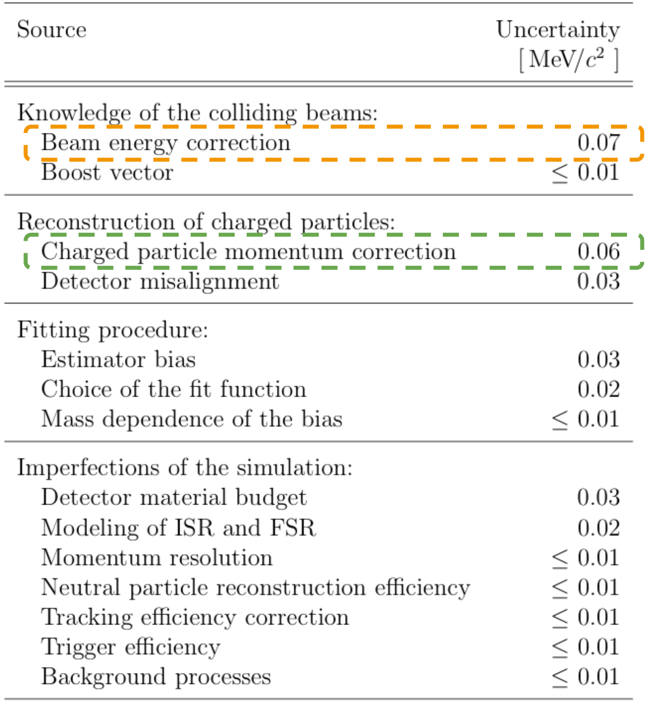


Result	Region	Mode	
		$e\phi$	$\mu\phi$
Signal efficiency $\varepsilon_{\ell\phi}$	SR	$(6.1 \pm 0.9$ sys$)\%$	$(6.5 \pm 0.6$ sys$)\%$
r_{MC}	SR / RSB	$0.23^{+0.16}_{-0.10}$ stat	$0.12^{+0.07}_{-0.04}$ stat
N_{data}	RSB	$1.0^{+2.3}_{-0.8}$ stat	$3.0^{+2.9}_{-1.6}$ stat
N_{exp}	SR	$0.23^{+0.55}_{-0.21}$ stat	$0.36^{+0.39}_{-0.23}$ stat
N_{obs}	SR	$2.0^{+2.6}_{-1.3}$ stat	$0.0^{+1.8}_{-0.0}$ stat

tau mass uncertainties at Belle II

- Statistical precision with 190fb^{-1}: 0.08 MeV
  - even with roughly half the data as Belle and BaBar (0.13 MeV), we have better precision!
    - inclusive tagging (Belle and BaBar use the leptonic tag only)
  - Improved tracking resolution also helps!
    - better resolution => steeper threshold => more precise determination of mass

- the dominant systematics: **momentum and energy scales**!
  - Various other effects are also considered:
    - detector misalignments
    - uncertainty in the bias, fit function, fit window
    - mismodeling of material budget
    - generator mismodellings

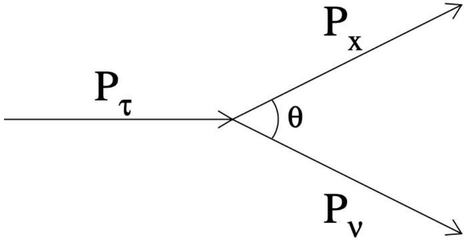


Source	Uncertainty [MeV/c^2]
Knowledge of the colliding beams:	
Beam energy correction	0.07
Boost vector	≤ 0.01
Reconstruction of charged particles:	
Charged particle momentum correction	0.06
Detector misalignment	0.03
Fitting procedure:	
Estimator bias	0.03
Choice of the fit function	0.02
Mass dependence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

Let’s get the mass….

- Use conservation of momentum and energy in the τ $\longrightarrow \nu\, 3\pi$ decay and solve for m_τ:

$$\begin{aligned}
&\mathcal{P}_\tau^2 = (\mathcal{P}_\nu + \mathcal{P}_{3\pi})^2 \\
\Rightarrow\ & m_\tau^2 = m_\nu^2 + m_{3\pi}^2 + 2(E_\nu\ E_{3\pi} - \vec{p_\nu} \cdot \vec{p_{3\pi}}) \\
& = m_\nu^2 + m_{3\pi}^2 + 2(E_\nu\ E_{3\pi} - p_\nu p_{3\pi} \cos\theta)
\end{aligned} \qquad (1)$$



Use:

$$\begin{aligned}
&E_\nu = E_\tau - E_{3\pi}, \mathit{and} \\
&p_\nu = \sqrt{E_\nu^2 - m_\nu^2} = E_\nu = E_\tau - E_{3\pi}
\end{aligned} \qquad (2)$$

To get:

$$\begin{aligned}
m_\tau^2 &= m_{3\pi}^2 + 2\Big((E_\tau - E_{3\pi})\ E_{3\pi} - (E_\tau - E_{3\pi}) p_{3\pi} \cos\theta_{\nu,3\pi}\Big) \\
&= m_{3\pi}^2 + 2(E_\tau - E_{3\pi})(E_{3\pi} - p_{3\pi} \cos\theta_{\nu,3\pi})
\end{aligned} \qquad (3)$$

- What are the knowns?
- What are the unknowns?
- Which unknowns can we maybe “sweep under the rug”?

...the pseudomass….

$$M_\tau^2 = M_{3\pi}^2 + 2(E_\tau - E_{3\pi})(E_{3\pi} - P_{3\pi}\cos\theta_{\nu,3\pi}) \tag{4}$$

In the center of mass frame:

$$E_\tau = E_{beam} = \sqrt{s}/2 \tag{5}$$

Also the equation will have a minimum when $\cos\theta_{\nu,3\pi} = 1$.

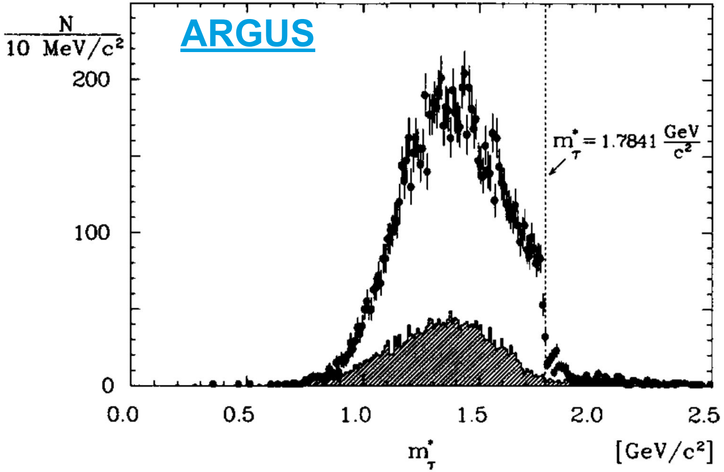
if we set $\cos\theta_{\nu,3\pi} = 1$, then we can write:

$$M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi}) \leq M_\tau^2 \tag{6}$$

So then we can define a new variable:

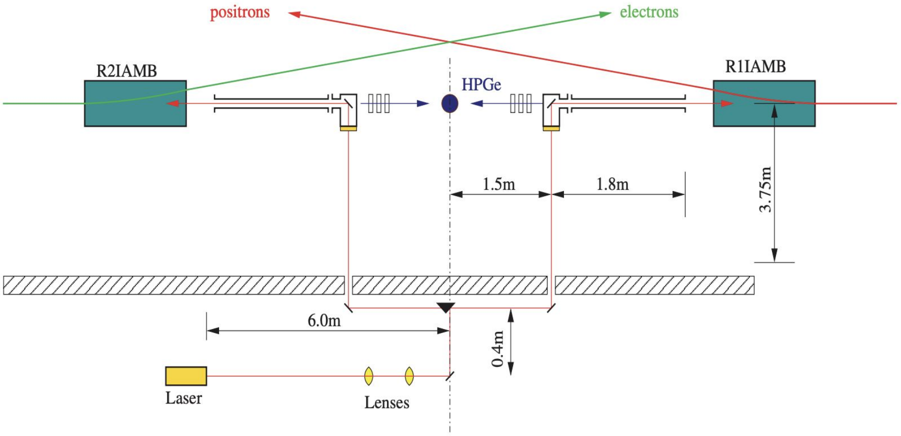
$$M_{min} = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})} \leq M_\tau \tag{7}$$

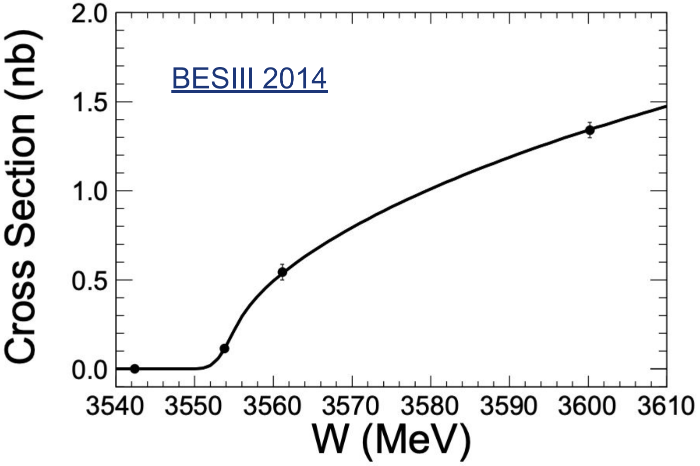
- This is called the pseudomass
  - defined in this way, the distribution has a kinematic edge around the tau mass
  - the edge can be exploited to extract the mass
  - first used by ARGUS in 1992, later by Opal, Belle and now by BelleII

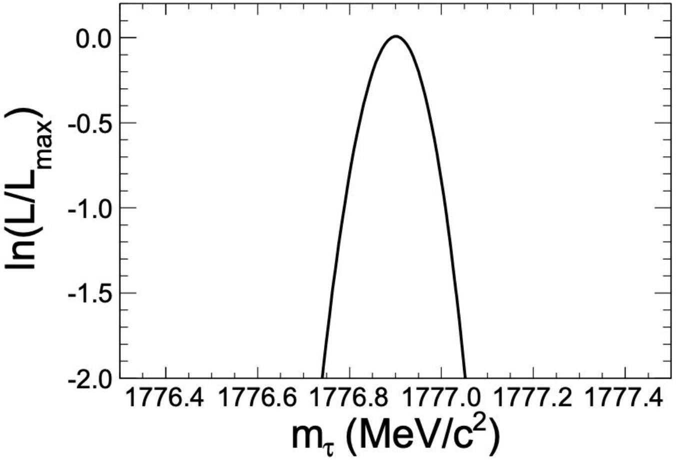


Tau mass measurement: threshold production

- exploit dependance of xsec on CM energy (near the tau pair production threshold)
- use a likelihood fit to extract the mass
- laser + optical system to accurately measure the beam energy



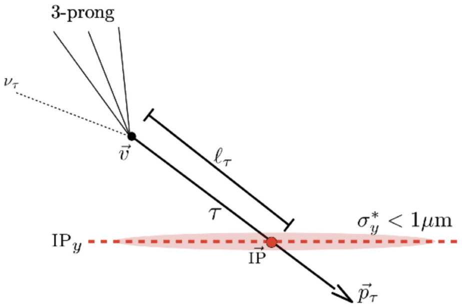




but this wouldn't work in BelleII ...

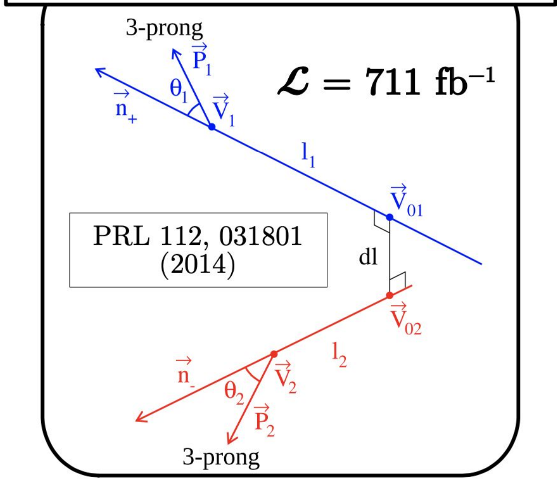
Tau lifetime, teaser

- at Belle:
  - the 3x3 tau decays
  - 700/fb
- at BelleII:
  - Factor 5 gain in stat. by using 3x1 instead of 3x3
  - With 200/fb already statistically compatible with Belle results
  - Systematics still to be studied… but, proper time resolution already 2x better than Belle!

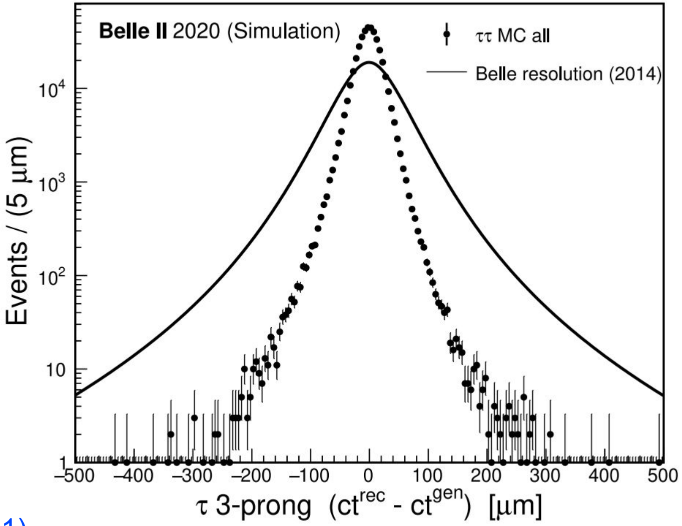


World-best measurement

$\tau_\tau = (290.17 \pm 0.53_{stat} \pm 0.33_{syst})$ fs



PRL 112, 031801 (2014)



Stefano Moneta (EPIPHANY 2021)

Belle II → Factor ≃2 narrower

Physics at Belle II

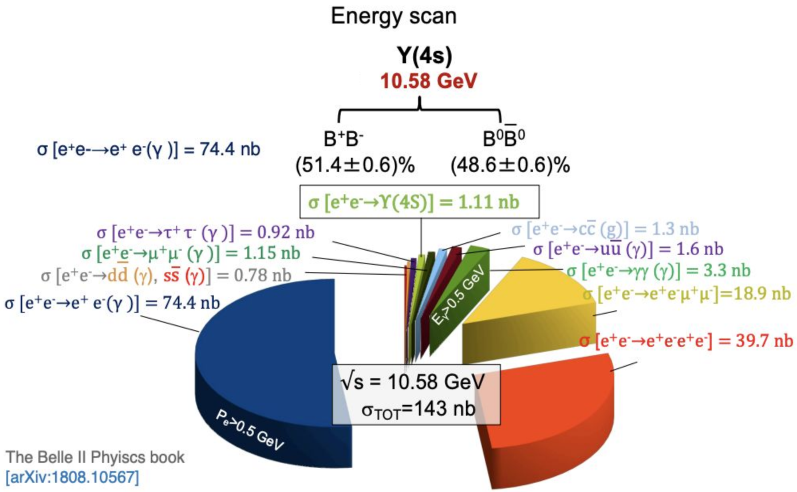
- Not *just* a B-factory!
  - τ, c, and b pairs have similar cross sections at √s = 10.58 GeV

$\sigma(e^+e^- \rightarrow \Upsilon(4S)) = 1.11$ nb

$\sigma(e^+e^- \rightarrow c\bar{c}) = 1.3$ nb

$\sigma(e^+e^- \rightarrow \tau^+\tau^-) = 0.92$ nb

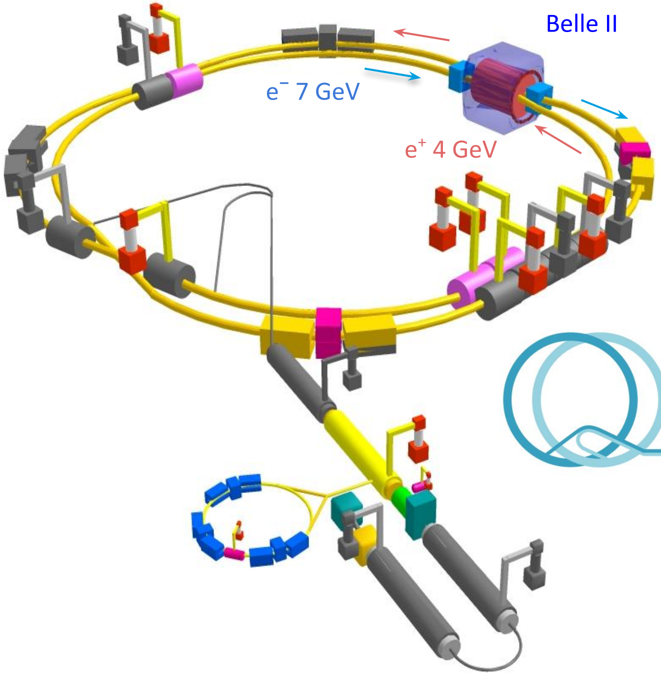
- Wide physics program
  - precision measurements of time-dependent CPV and CKM parameters
  - searches for lepton flavor/universality/number violations
  - dark-sector searches
  - and many more

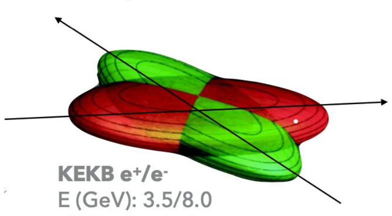


The Belle II Phyiscs book
[arXiv:1808.10567]

SuperKEKB

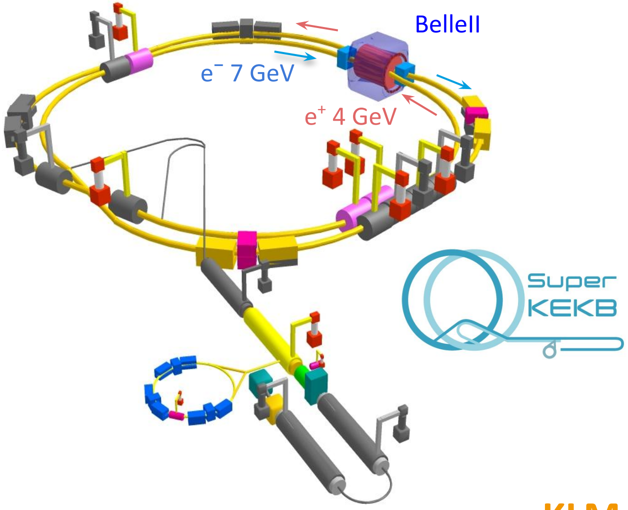
- energy-asymmetric e^+e^- collider in Tsukuba, Japan
- collision energy (mostly) at $\Upsilon(4S)$ $\sqrt{s} = 10.58$ GeV
- target:
  - instantaneous lumi: $6\text{x}10^{35}\text{cm}^{-2}\text{s}^{-1}$
    30 larger than KEKB
- improvement achieved via the nanobeam scheme (20x smaller beam spot) and higher beam current



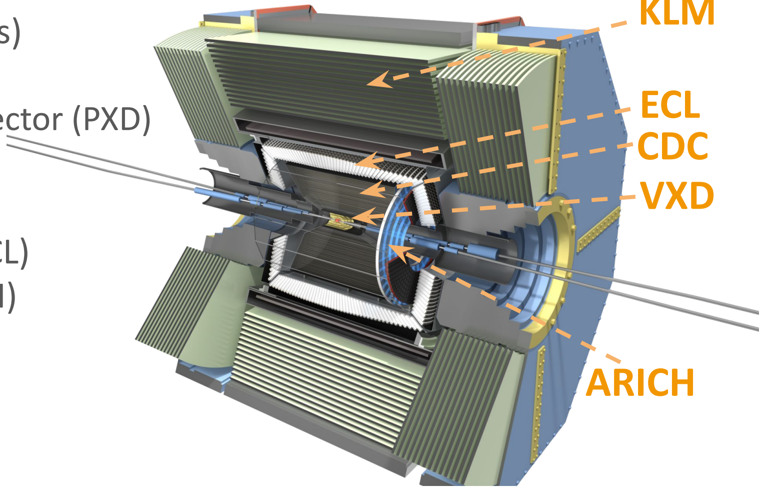

KEKB e^+/e^-
E (GeV): 3.5/8.0


SuperKEKB e^+/e^-
E (GeV): 4.0/7.0

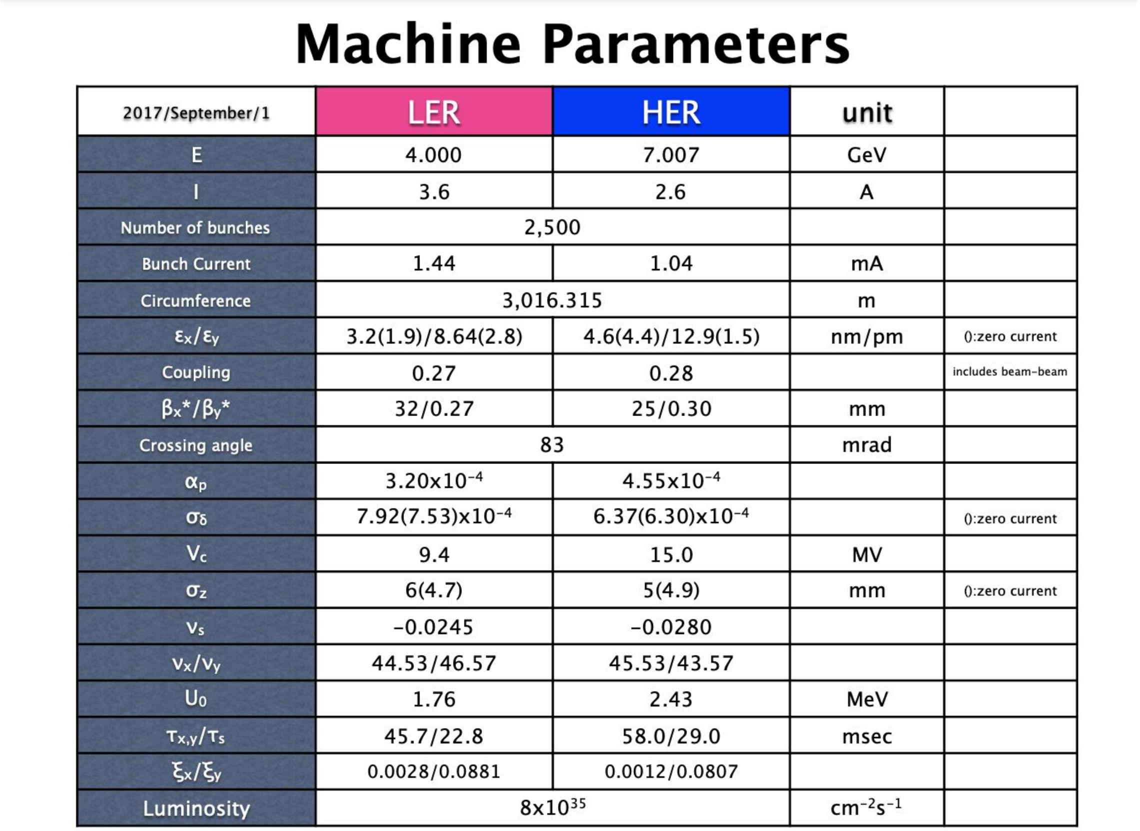
SuperKEKB and the BelleII detector



- SuperKEKB
  - energy-asymmetric e^+e^- collider in Tsukuba, Japan
  - center-of-mass energy at (and near) $m(\Upsilon(4S))=10.58$ GeV
  - Target:
    - instantaneous lumi of $6\text{x}10^{35}\text{cm}^{-2}\text{s}^{-1}$ (30 larger than KEKB)
    - integrated lumi: 50 ab^{-1} (50 times larger than KEKB)
  - improvement achieved via the nanobeam scheme
- BelleII detector
  - upgraded Belle for higher luminosities (and its challenges)
  - inner track detectors system (VXD) fully replaced
    - 2 (currently 1+2/12) new layers of DEPFET pixel detector (PXD)
    - 4 layers of double-sided silicon strip detector
  - new drift chamber (CDC) within the 1.5 T magnet
  - upgraded electronic readouts for the EM calorimeter (ECL)
  - Cherenkov detectors for particle ID (PID) (TOP and ARICH)
  - K_L and muon detector (KLM)



SuperKEKB designed machine parameters



Machine Parameters

2017/September/1	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28		includes beam-beam
β_x^*/β_y^*	32/0.27	25/0.30	mm	
Crossing angle	83		mrad	
α_p	$3.20\text{x}10^{-4}$	$4.55\text{x}10^{-4}$		
σ_δ	$7.92(7.53)\text{x}10^{-4}$	$6.37(6.30)\text{x}10^{-4}$		():zero current
V_c	9.4	15.0	MV	
σ_z	6(4.7)	5(4.9)	mm	():zero current
ν_s	-0.0245	-0.0280		
ν_x/ν_y	44.53/46.57	45.53/43.57		
U_0	1.76	2.43	MeV	
$\tau_{x,y}/\tau_s$	45.7/22.8	58.0/29.0	msec	
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity	$8\text{x}10^{35}$		$\text{cm}^{-2}\text{s}^{-1}$	