Università degli Studi di Perugia, Dipartimento di Fisica e Geologia

PhD in Physics, XXXVI cycle

25 ottobre 2021

End of 1st year report

UNIVERSITÀ DEGLI STUDI
DI PERUGIA

student: **Stefano Moneta**

tutor: **Claudia Cecchi**

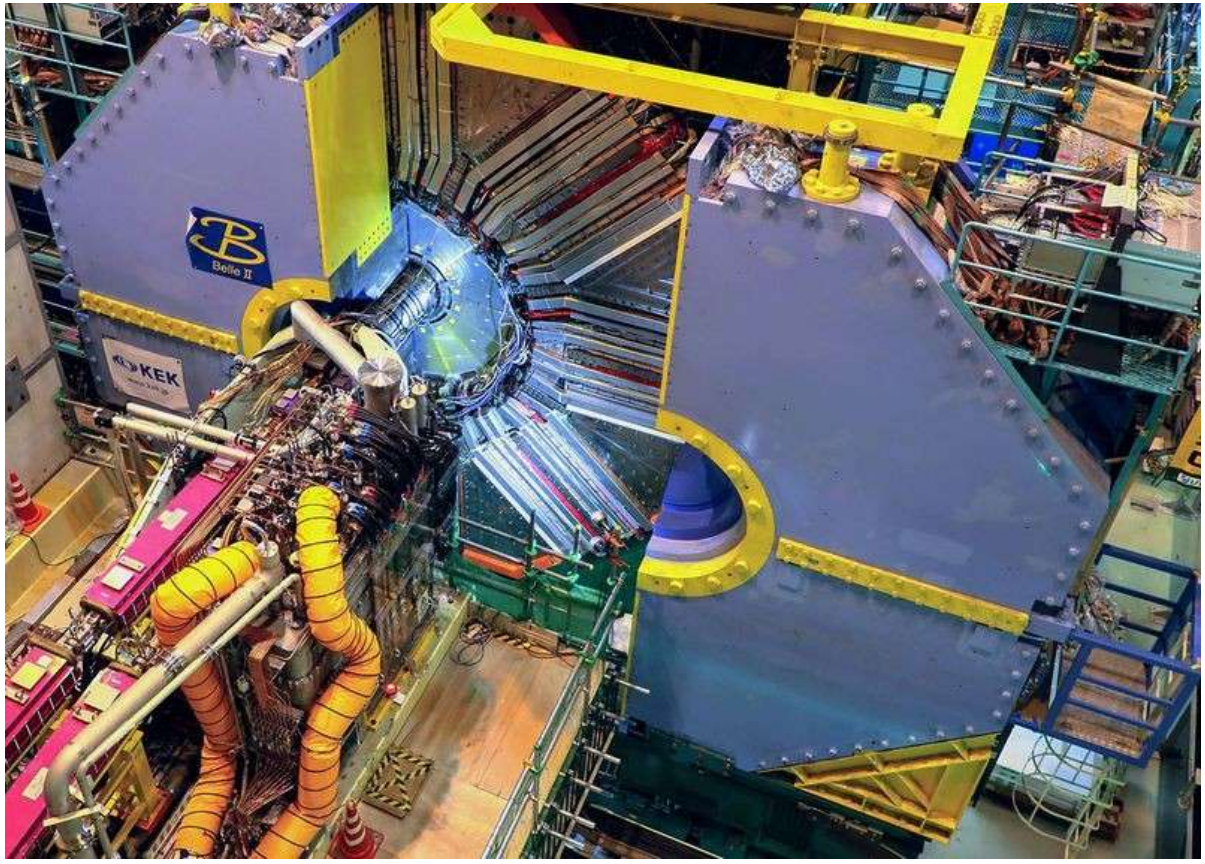
Outline

1) Research activity: **Belle II**

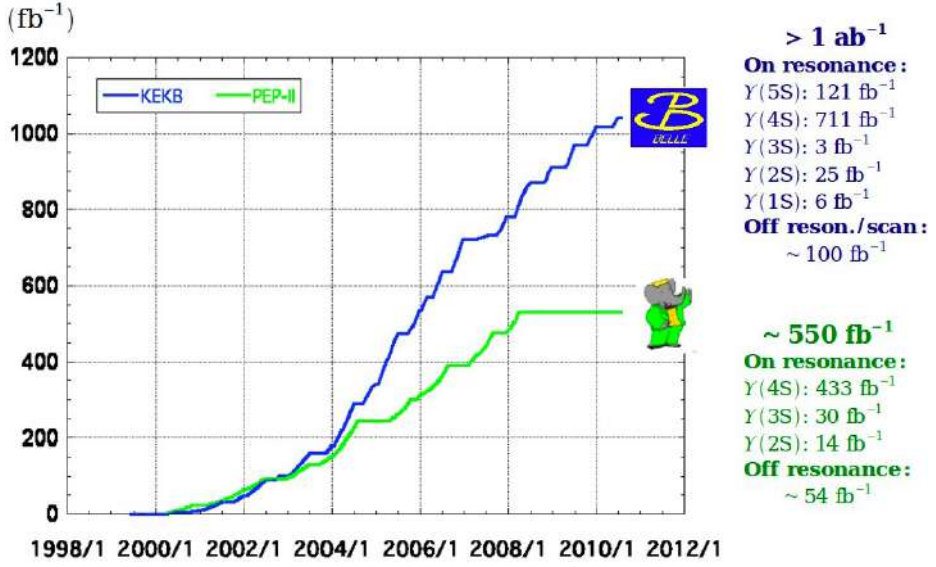
- τ-lepton lifetime
- Search for B$\rightarrow$ K*$\tau\tau$ decay
- Detector work

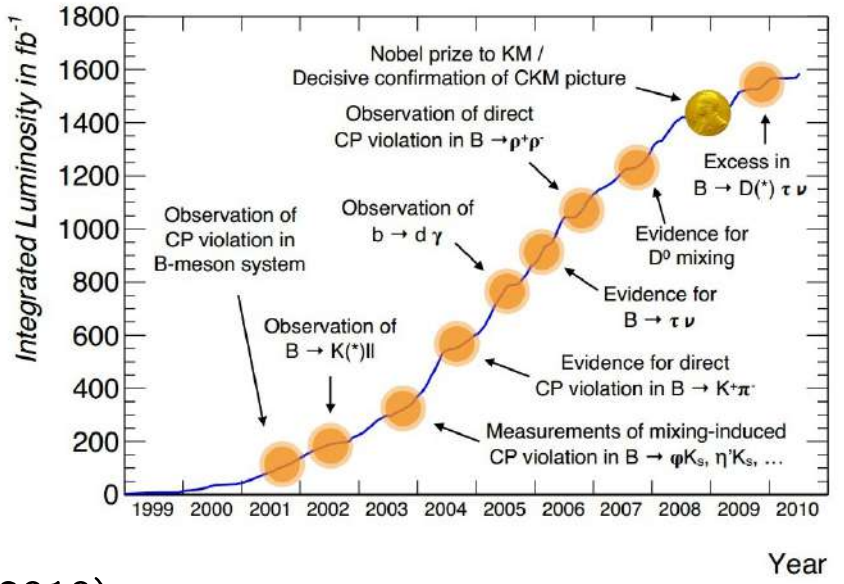
2) Other PhD activities at **Perugia**

1) Belle II



Physics at B-factories

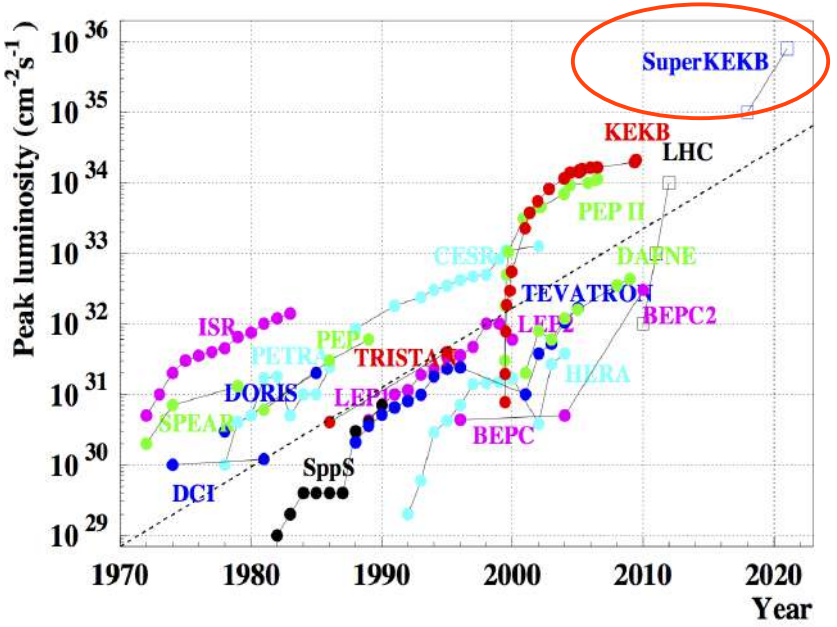




B-factory di 1ª generazione (2000-2010):

- Belle + BaBar → 1.5 ab^{-1}
- Confirmation of CKM mechanism
- Not yet evidence of physics beyond SM...

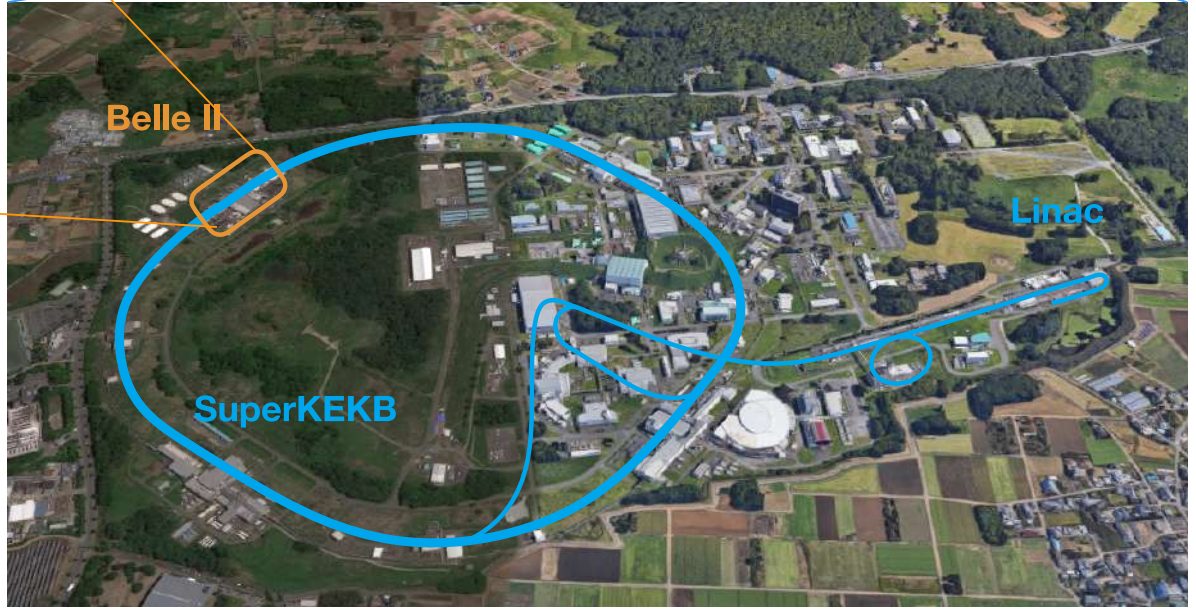
Extend the high intensity frontier



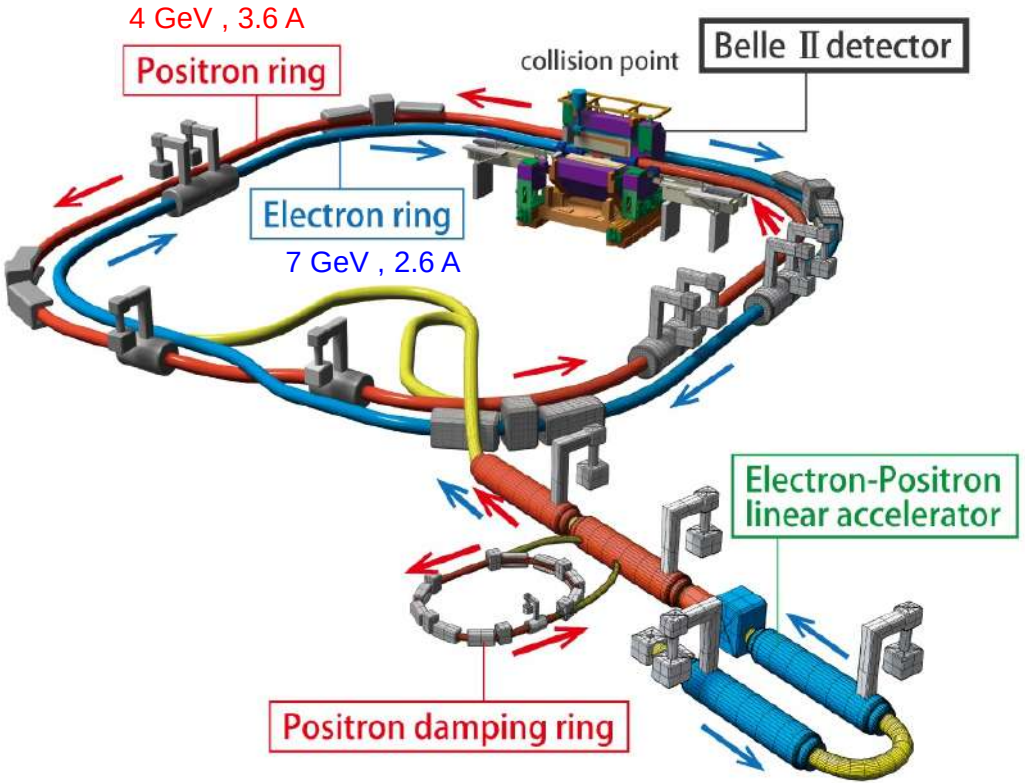
1st generation B-factories

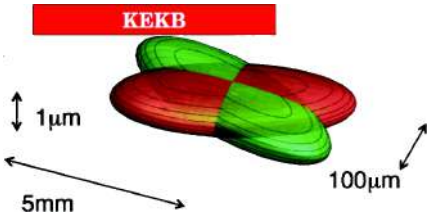
2nd generation B-factory

The Belle II experiment

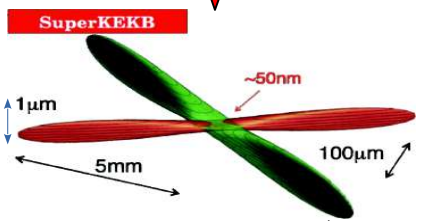


SuperKEKB





$\mathcal{L} \times 30$ $I \times 1.5$ $\beta_y^* \div 20$

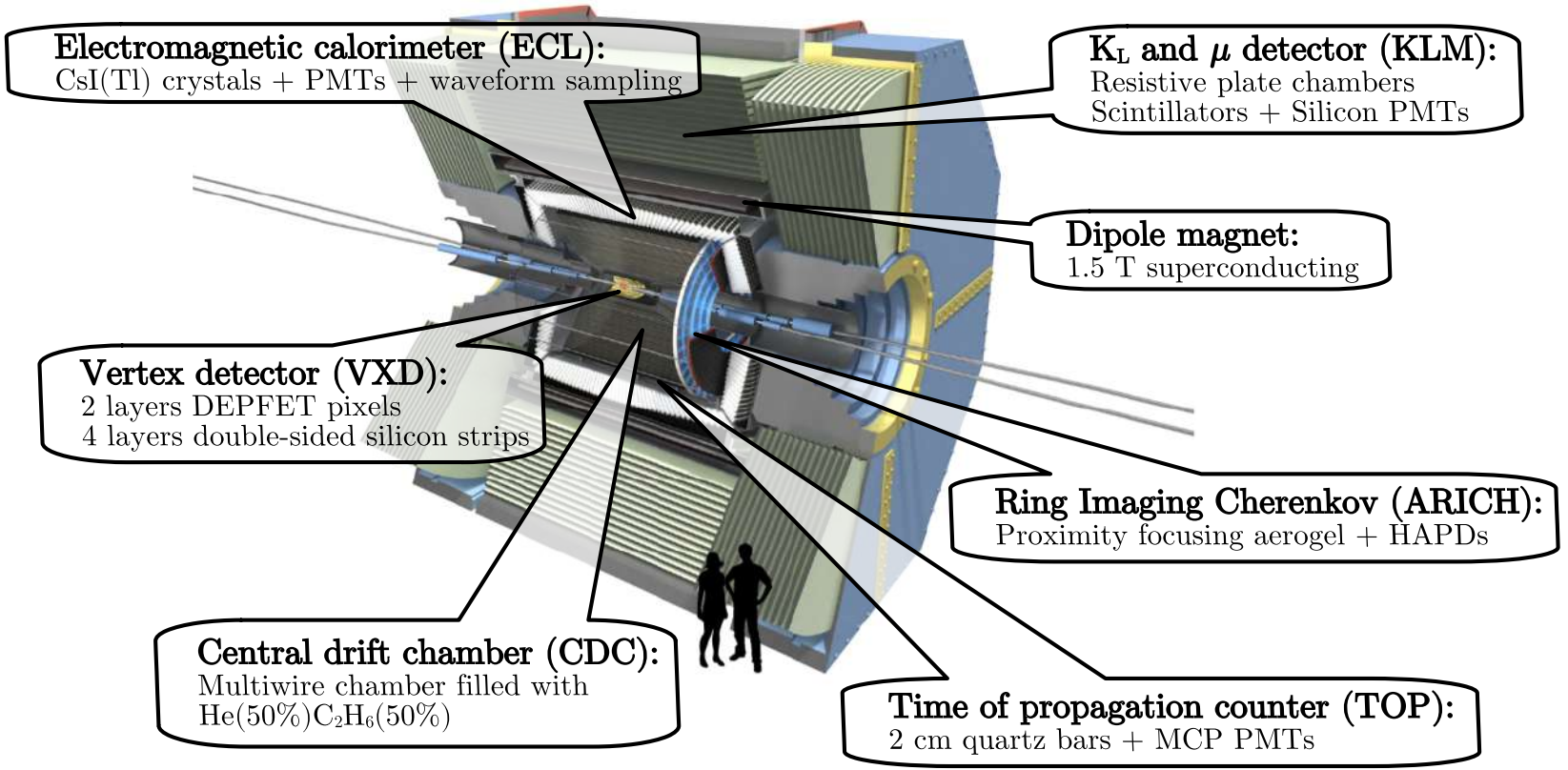


"nanobeam" scheme (P. Raimondi)

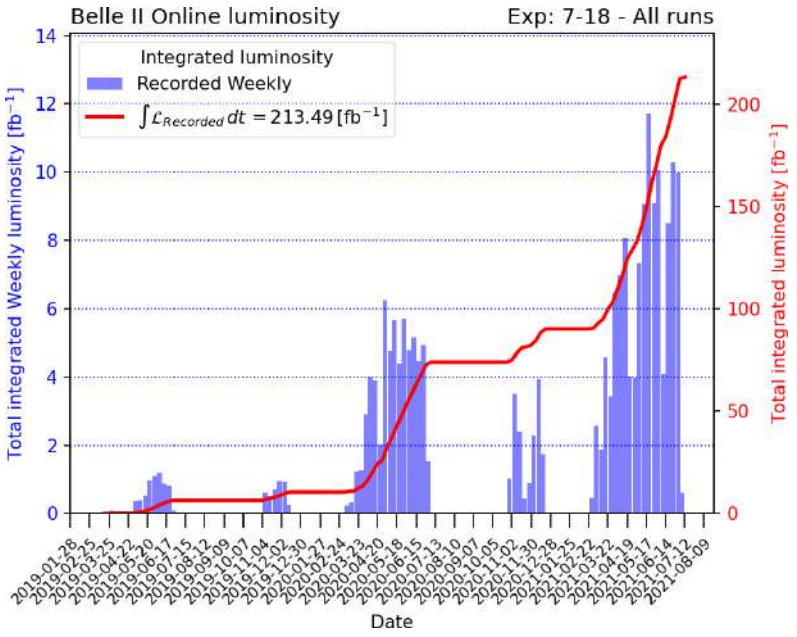
$\sqrt{s} = 10.58\,\text{GeV}$

$\beta\gamma = 0.28$ ($\rightarrow$ 0.5 @PEP2, 0.67 @KEKB)

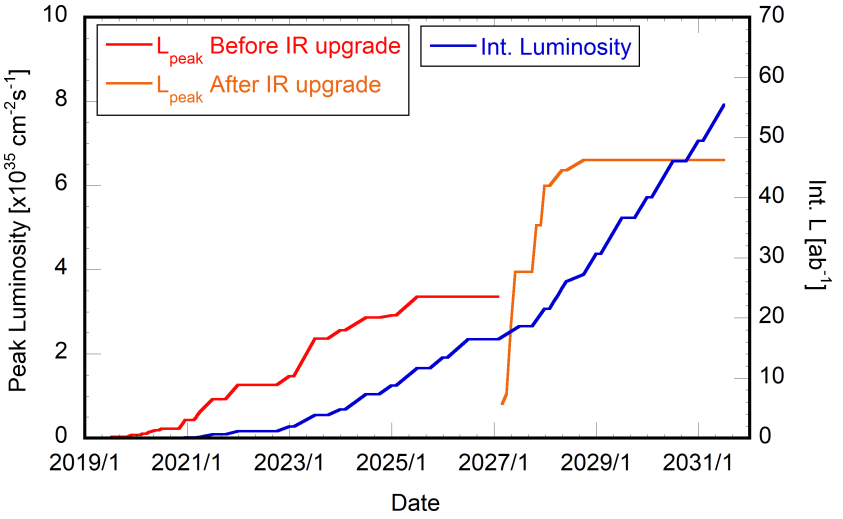
The Belle II detector



Belle II data-taking



- Instantaneous luminosity record 3.1×10^{34} cm^{-2} s^{-1} (on June 21, 2021)
- 213 fb^{-1} recorded $\rightarrow \simeq$ 800 fb^{-1} before the long-shutdown on 2023

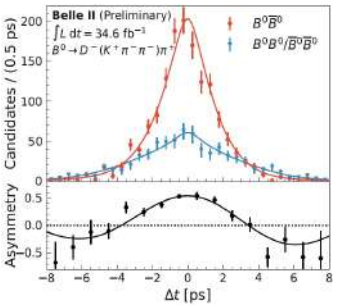


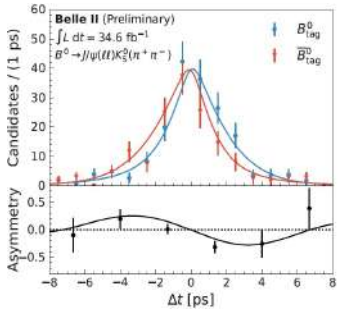
Goals:

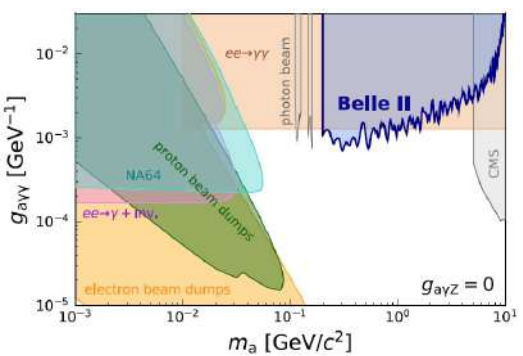
- Instantaneous luminosity 6×10^{35} cm^{-2} s^{-1}
- 50 ab^{-1} in the next decade ($\times$50 Belle + BaBar sample)

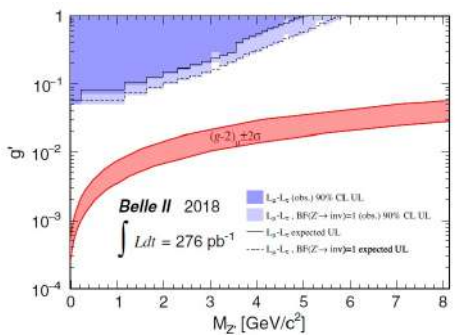
Physics at Belle II… not only B-factory!

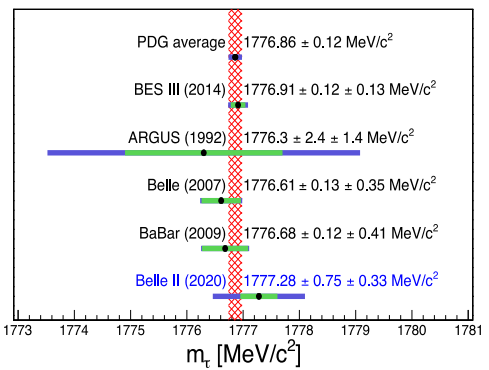
- $\sigma(e^+e^- \to \Upsilon(4S)) = 1.11\,\text{nb} \;\to$ **B-factory**
- $\sigma(e^+e^- \to c\bar{c}) = 1.3\,\text{nb} \;\to$ **charm-factory**
- $\sigma(e^+e^- \to \tau^+\tau^-) = 0.92\,\text{nb} \;\to$ **tau-factory**
- $\Upsilon(1S) \div \Upsilon(6S) \;\to$ **Quarkonium + exhotic resonances**
- **Dark sector**

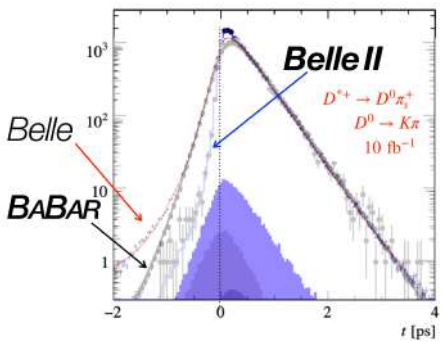






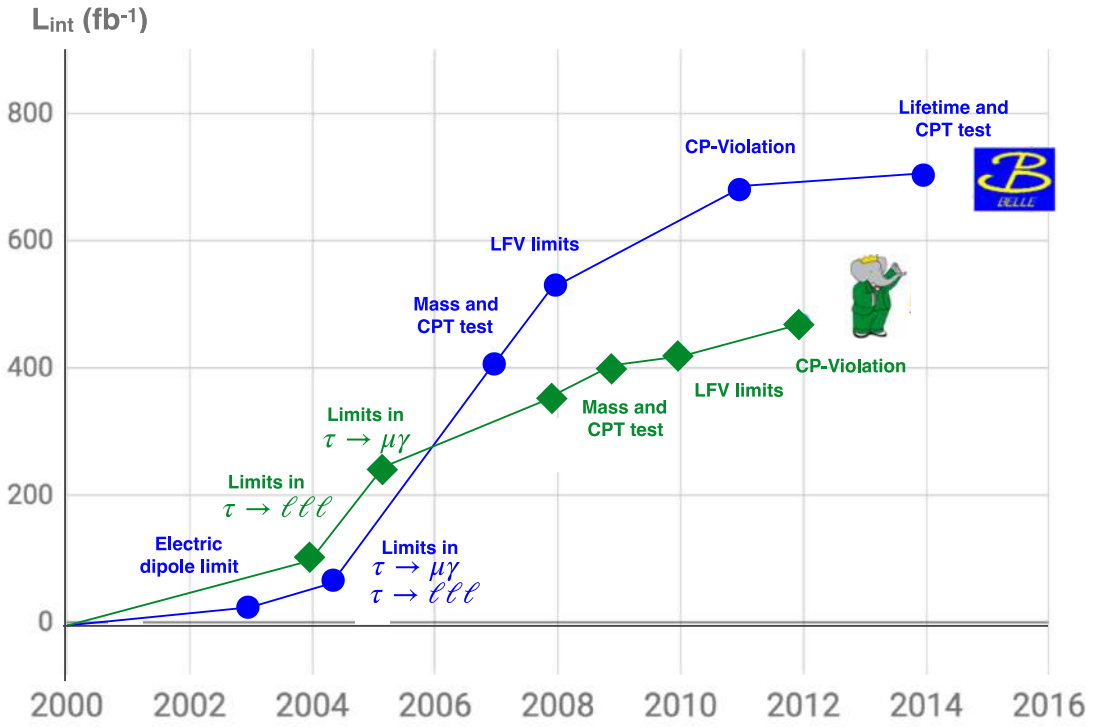






τ factories

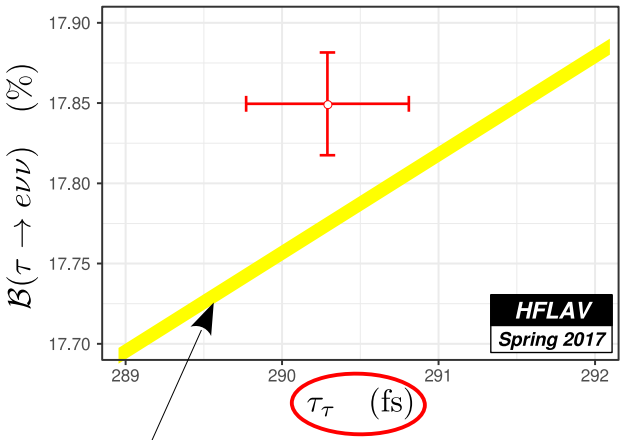
1st generation B-factories → unique results in τ-lepton sector



- "Clean" environment
  - Initial kinematics well-known $e^+e^- \to \tau^+\tau^-$
  - Can reconstruct missing energy and neutrinos
- Hermetic detector with:
  - High tracking efficiency
  - High vertex resolution
  - Good γ and π^0 reconstruction

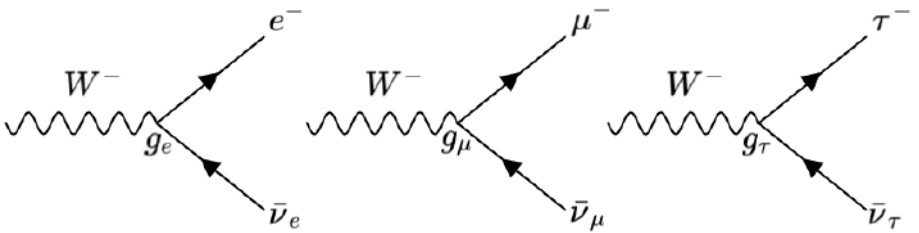
τ lifetime: physics motivation

- Important parameter in SM (e.g. measure α_S QCD at m_τ)
- Test **lepton flavor universality** (LFU)



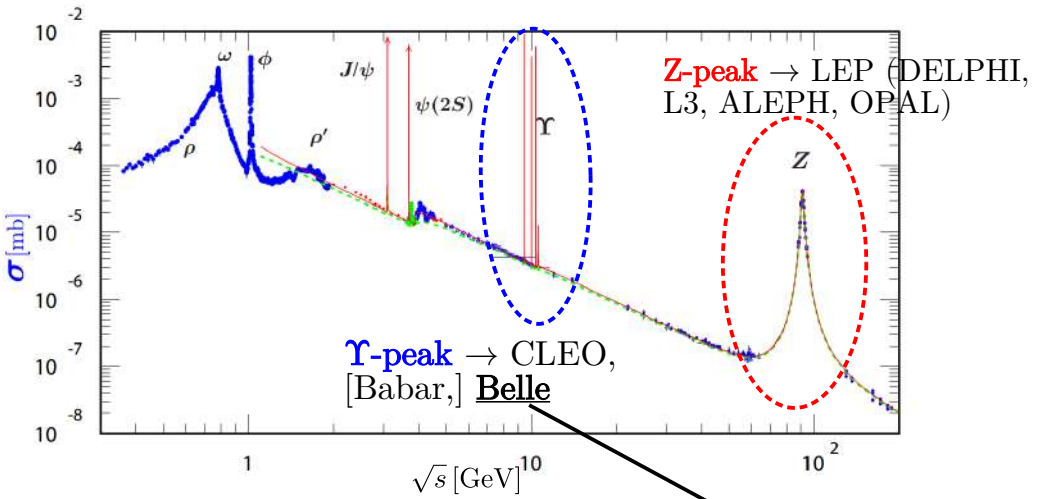
SM assuming LFU (g_τ/g_ℓ)=1
Uncertainty dominated by **τ mass**

Another **Belle II** measurement
arXiv:2008.04665



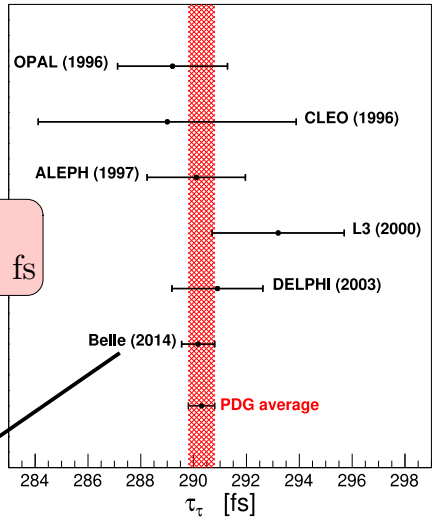
$$g_e \stackrel{?}{=} g_\mu \stackrel{?}{=} g_\tau$$

τ lifetime: previous measurements



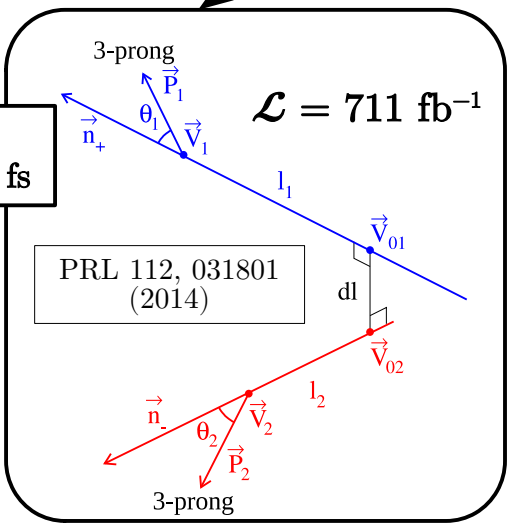
Z-peak → LEP (DELPHI, L3, ALEPH, OPAL)

Υ-peak → CLEO, [Babar,] Belle



PDG average:
$\tau_\tau = (290.3 \pm 0.5)$ fs

World-best measurement
$\tau_\tau = (290.17 \pm 0.53_{\text{stat}} \pm 0.33_{\text{syst}})$ fs



$\mathcal{L} = 711$ fb^{-1}

PRL 112, 031801 (2014)

τ-lifetime: measurement strategy

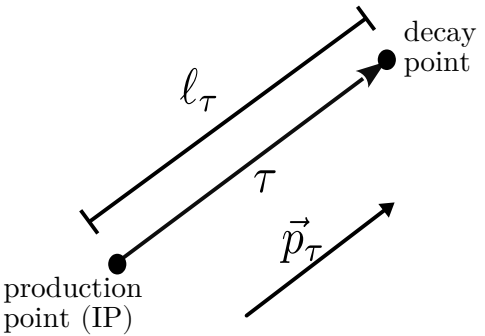
Proper decay time distribution: $p(t;\,\tau_\tau) = \frac{1}{\tau_\tau} e^{-\frac{t}{\tau_\tau}} * \mathcal{R}(t)$

Proper time resolution

$$t = \frac{\ell_\tau}{\beta\gamma c} = \ell_\tau \frac{m_\tau}{p_\tau c}$$

- **decay length** $\ell_\tau \rightarrow$ **production vertex + decay vertex**
- **momentum** $p_\tau \rightarrow$ neutrinos in final state

$\langle \ell_\tau \rangle \approx 250\,\mu\text{m}$

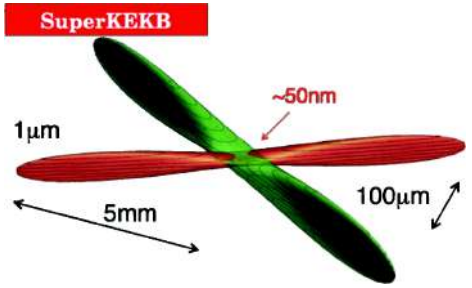


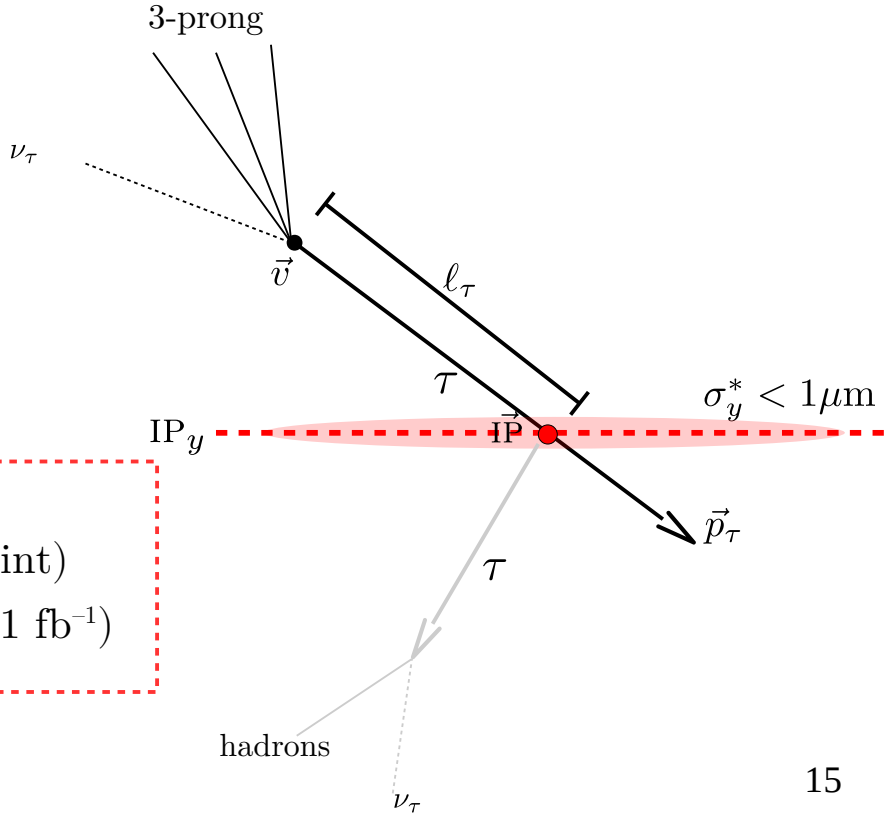
τ-lifetime: measurement strategy

(1) **decay vertex** $\rightarrow$ reconstruct vertex for 3-prong τ

(2) estimate **tau momentum** $\vec{p}_\tau \rightarrow$ use events where both τ decay to hadrons

(3) **production vertex** $\rightarrow$ intersection of $\vec{p}_\tau$ direction with plane $y = \mathrm{IP_y}$





With respect to Belle:

- exploit **nanobeam scheme** (use beam-spot constraint)
- need **just one 3-prong τ** $\rightarrow$ higher statistics ($<$711 fb^{-1})

τ-lifetime: signal topology

1-prong×3-prong inclusive topology:

$$e^+e^- \to \tau^+\tau^-$$

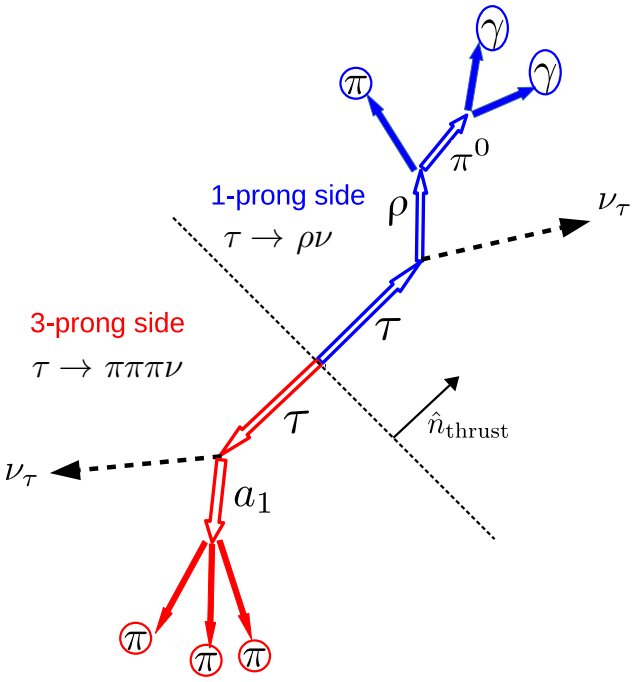
$$\tau \to \rho\nu \quad \times \quad \tau \to \pi\pi\pi\nu$$

- BR($\tau \to \rho\nu$)$\simeq$25%

$\rho \to \pi\pi^0$

- Good signature (ρ-peak)
- Need π^0 reconstruction

Roughly ×5 more events than in the Belle channel ($\tau \to \pi\pi\pi\nu \times \tau \to \pi\pi\pi\nu$)

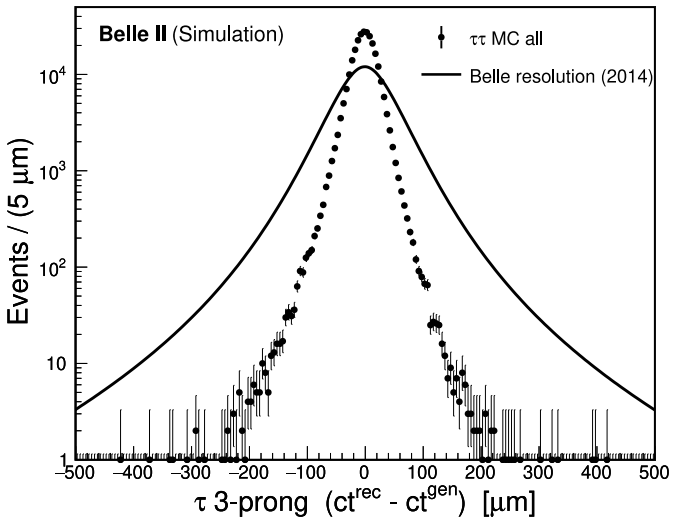


τ-lifetime: statistical uncertainty

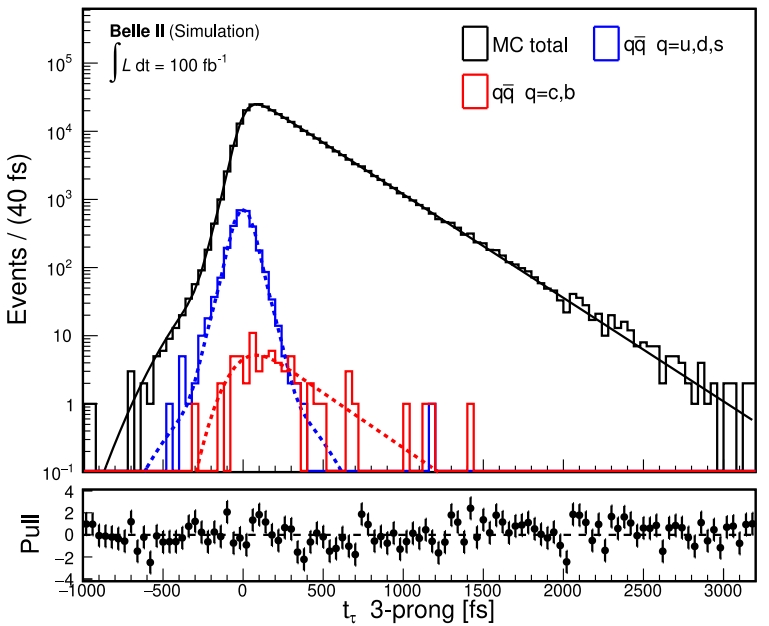
- Study on 200 fb^{-1} of Monte Carlo
- Fit proper time distribution with **convolution** of resolution function and exponential distribution:

$$p(t;\,\tau_\tau) = \frac{1}{\tau_\tau} e^{-\frac{t}{\tau_\tau}} * \mathcal{R}(t) \quad \Rightarrow \quad \tau_\tau = (285.85 \pm 0.64)\ \text{fs}$$

Compare to Belle resolution



Belle II $\rightarrow \simeq$2 narrower than Belle



τ-lifetime measurement: summary

1) **Statistical uncertainty** competitive with **Belle** (± 0.53 fs with 711 fb^{-1})

- Use different topology ($3\times3 \rightarrow 1\times3$)
  - more events available $\rightarrow$ less statistics needed (711 fb^{-1} at Belle)
- Use information on beam-spot region (**nanobeam scheme**) + improved **vertex detector**
  - **$\times2$** narrower proper time **resolution**

2) **Systematic** evaluation ongoing

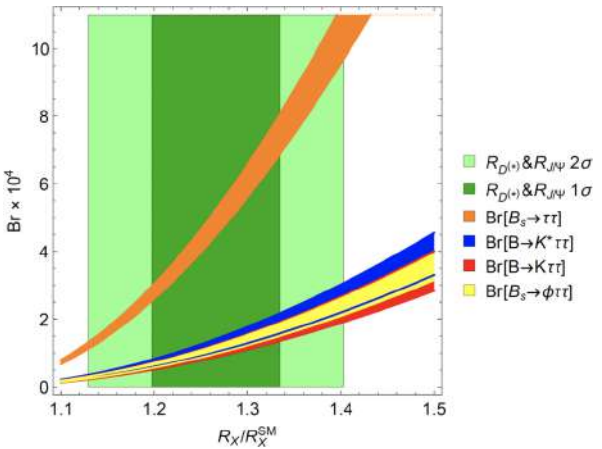
- Dominant source $\rightarrow$ vertex detector alignment (dominant also at Belle)

3) Plan to publication

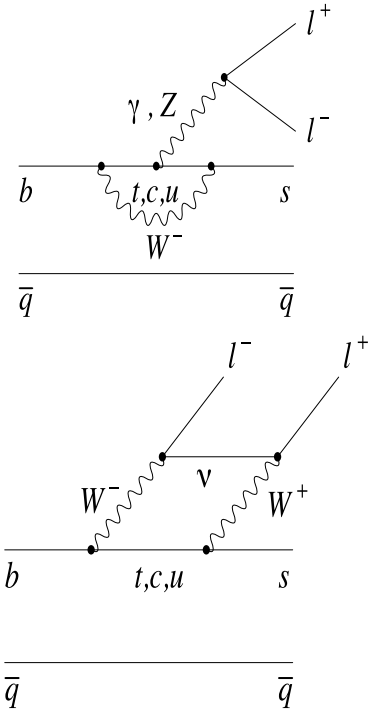
- Collected 213 fb^{-1} $\Longrightarrow$ statistical uncertainty already competitive with world average
- Show preliminary result (stat. + syst.) at winter conferences
- Publication with full 2021 dataset ($\simeq$ 500 fb^{-1})

Search for $B \to K^* \tau\tau$ decay

- Semileptonic FCNC B decay involving **3rd generation** leptons
  - In SM $\to \mathcal{B}(B \to K^* \tau\tau) \simeq 10^{-7}$
  - Enhanced by NP models coupling only to 3rd generation or with coupling proportional to particle mass



B. Capdevila, A. Crivellin, S. Descotes-Genon, L. Hofer, et J. Matias, *arXiv:1712.01919, PRL 120, 181802*



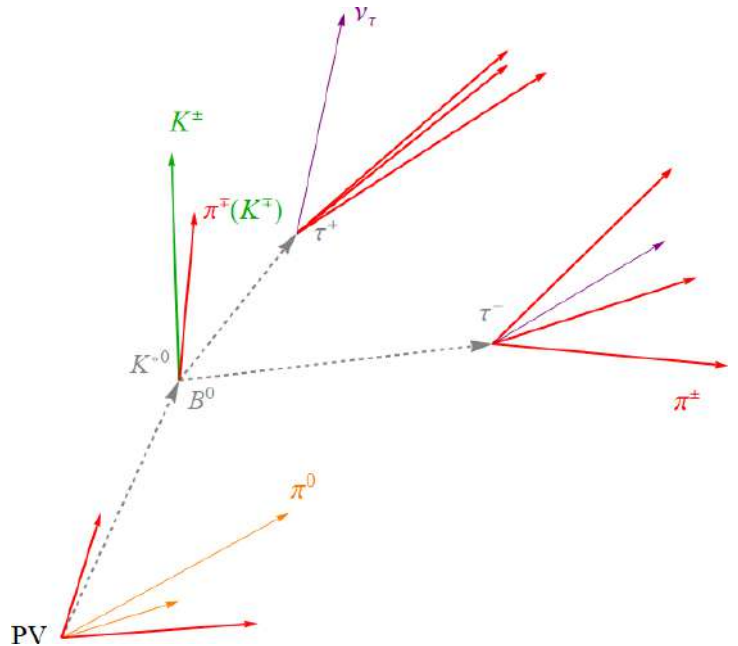
- First limit just set by **Belle** [arXiv:2110.03871]:

  $\mathcal{B}(B^0 \to K^{*0} \tau\tau) < 2.0 \times 10^{-3}$ @90% CL
  - 711 fb^{-1}
  - Hadronic tag reconstructed with **NeuroBayes** algorithm [j.nima.2011.06.008]
  - τ decay leptonically or $\tau \to \pi\nu$

Search for $B \to K^* \tau\tau$ decay

- Plan for **Belle II**:
  - Exploit "Full Event Reconstruction" algorithm → higher B_{tag} efficiency expected wrt Belle. Explore also semi-leptonic tag
  - Include more τ decay modes ($\tau \to \rho\nu$, $\tau \to 3\pi\nu$...)
  - Reconstruct kinematics and/or τ vertexes

- Analysis targeted by **LHCB** as well

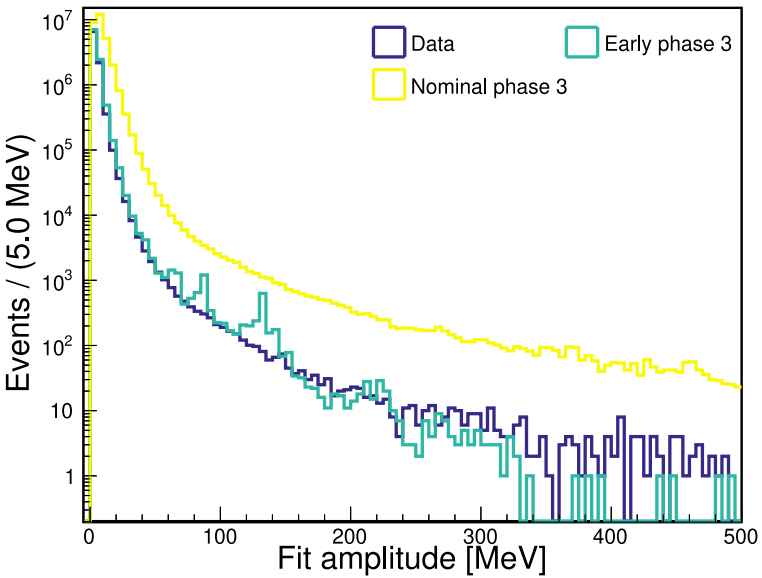


Detector activities

Beam background study:

Belle II will cope with an elevated beam-background level → performance of Electromagnetic Calorimeter (**ECL**) is critical

- Investigate the effect of beam-background on cluster reconstruction
- Compare the ECL response at different background levels
- Study possible ECL upgrade options for dealing with higher backgrounds



Laboratory measurements:

- Investigate different update options
- Started in Perugia comparison with CsI(Tl) and pure CsI crystals, with APD photosensors

Contributions to data-taking:

- Completed 72 hours of ECL remote shift
- Completed 16 hours of Control Room remote shift
- No local activity because of travel restrictions

2) PhD at Perugia

PhD courses in Perugia (1st semester)

- **Introduction to EFTs**
  - EFT in the framework of the Standard Model physics (Buttazzo – SNS)
  - Effective gauge theory in spintronics (Tatara – Riken)
  - Experimental searches EFT-based (Govoni – MIB) ✓
- **Measurements, uncertainties and probabilistic inference/forecasting**
  - (D'Agostini – Roma1) ✓
- **Nanosystems and advanced materials**
  - Raman spectroscopy on low dimensional materials (Postorino – Roma1) ✓
  - Spectroscopy characterization of nanostructured materials (Pedio – CNR)
  - Molecular nanomagnets and quantum computing (Garlatti, Chiesa – Unipr)

* ✓ = with final exam/seminar/laboratory

PhD courses in Perugia (2nd semester)

- **Introduction to Atmospheric Physics, Climate and CDS**
  - (Cerlini – Unipg) ✓
- **Multimessenger Astrophysics - from em multifrequency to gravitational waves**
  - Gamma-Ray Astrophysics (Tosti – Unipg)
  - Neutrino astrophysics (Germani - Unipg)
  - Introduction to gravitational waves (Punturo - INFN Pg)
  - Multimessenger laboratory (Greco – INFN) ✓
- **Teaching and Learning Physics at University**
  - (Organtini – Roma1) ✓
- **Physics at LHC**
  - (Gallinaro – Lisbona) ✓

* ✓ = with final exam/seminar/laboratory

Seminars

- Perugia Advanced Physics Seminars
- Physics Highlights Perugia 2021
- Other seminars
  - PHYSTAT seminars
  - B-physics anomalies
  - g–2 measurement
- Belle II physics week 2020
- Belle II accademy

Collaboration meetings

- Belle II general meetings
- Italian Belle II meetings

Conferences

- January 7 – 10, 2021: "XXVII Cracow **EPIPHANY** Conference on Future of particle physics"

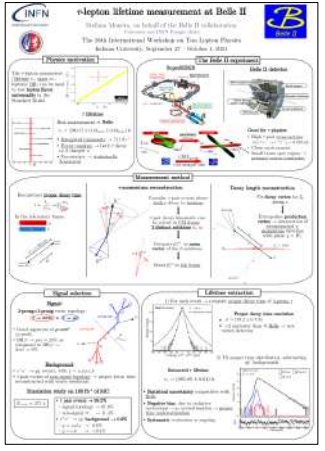
  → PhD student session: "Early τ-lifetime measurement with Belle II"

- September 13 – 17, 2021: "107^{O} Congresso Nazionale **SIF**"

  → Comunicazione: "τ-lepton lifetime measurement at Belle II"

- September 27 – October 1, 2021: "The 16th International Workshop on Tau Lepton Physics (**TAU2021**)"

  → Poster session: "Tau lifetime measurement at Belle II"



Miscellaneous

- **Held exercitations at Unipg courses:**
  - Fisica 1 $\rightarrow$ 1st year degree in Mathematics
  - Fisica 2 $\rightarrow$ 2nd year degree in Mathematics

- **Received prize in memory of Prof. Anna Maria Cartacci**
  - Seminar at Firenze physics department on September 30, 2021

PREMIO DI LAUREA "ANNA CARTACCI" 2021

PER I LAUREATI IN "FISICA SPERIMENTALE DELLE PARTICELLE ELEMENTARI" O IN "DIDATTICA DELLA FISICA"

CONSEGNA DEL PREMIO:

GIOVEDÌ 30 SETTEMBRE 2021

DIPARTIMENTO DI FISICA E ASTRONOMIA, AULA MAGNA
VIA G. SANSONE, 1 - SESTO FIORENTINO

ore 17:00
introduzione e saluti
prof. Duccio Fanelli - Direttore del Dipartimento di Fisica e Astronomia
prof. Cesar Adriani - Direttore della sezione di Firenze dell'Istituto Nazionale di Fisica Nucleare
prof.ssa Antonella Salvini - Presidente di OpenLab

ore 17:15
consegna del premio (1000 €) al dott. Stefano Moretti, laureato all'Università di Pisa.

ore 17:20
seminario del dott. Stefano Moretti: **A novel method for tau-lepton lifetime measurement with early Belle II data**

ore 17:50 - 18:10
ricordi della prof.ssa Annamaria Cartacci da parte di colleghi e familiari

Tracce su emulsione fotografica, al microscopio, del primo evento osservato di produzione associata di un mesone *charmato* e di un barione *charmato* (esperimento WA58, 1981). Anna Cartacci collaborò in maniera determinante a questa ricerca.

Per partecipare all'evento sarà necessario esibire la Certificazione Verde (*green pass*). Il numero di posti è limitato (39): chi desidera essere presente, deve inviare entro il 29 settembre 2021 una richiesta all'indirizzo e-mail: rosalba.filippini@unifi.it

Grazie per l'attenzione

INFN
Istituto Nazionale di Fisica Nucleare

Stefano Moneta

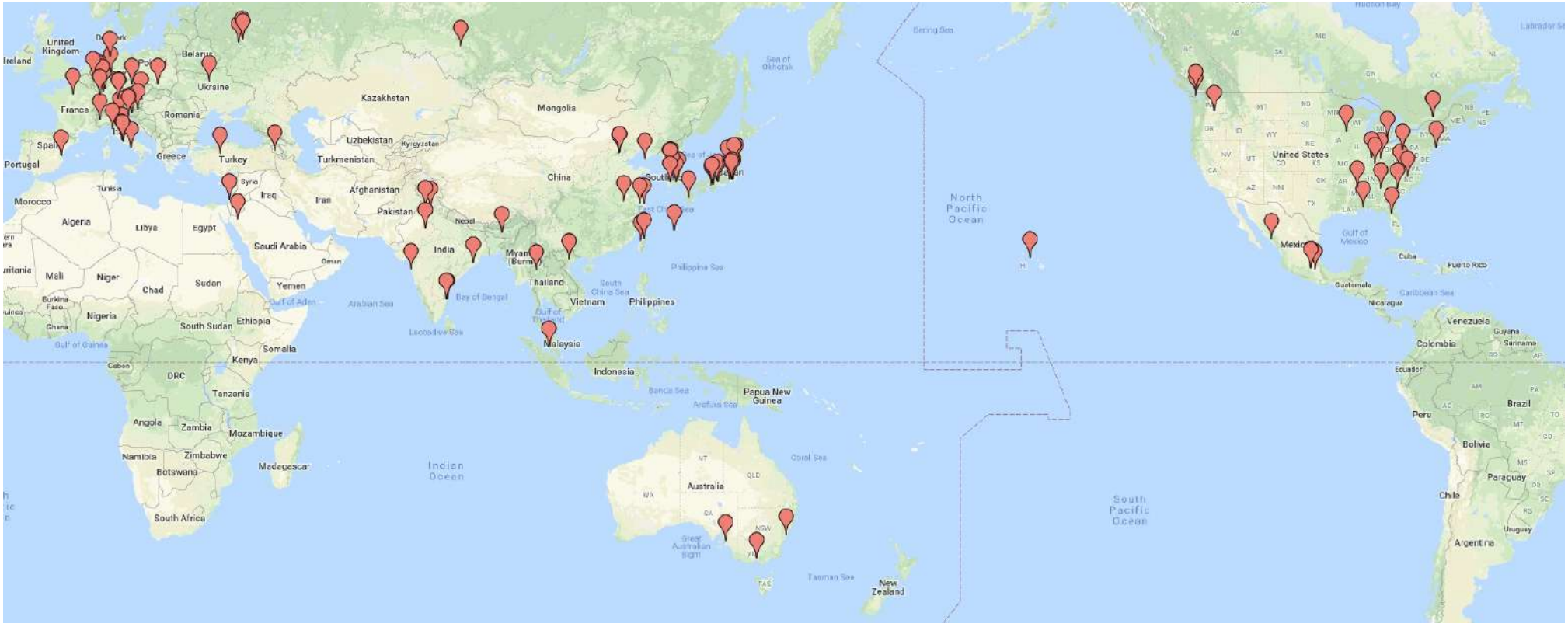
tutor → **Claudia Cecchi**

UNIVERSITÀ DEGLI STUDI
DI PERUGIA

Backup slides

The Belle II collaboration

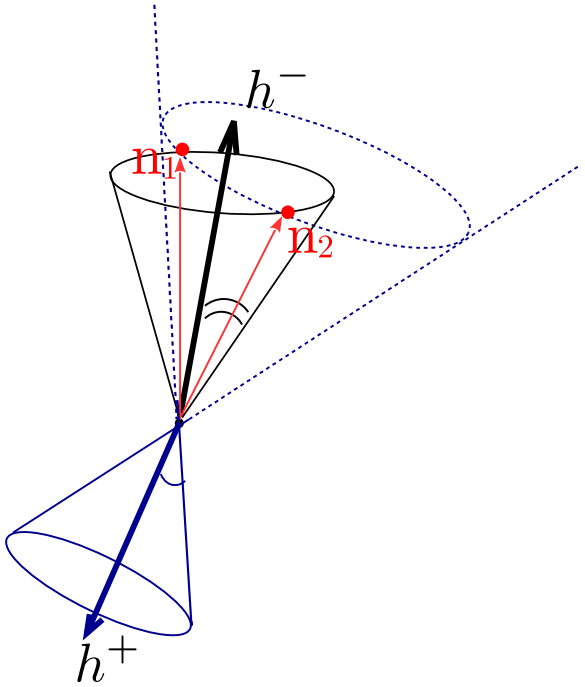
- ≃ 1100 active members
- ≃ 120 institutions, 3 continents
- ≃ 10% from INFN



τ-lifetime: p_τ reconstruction

When <u>both</u> τ decay <u>to hadrons</u> $h^\pm$ (i.e. only 1 neutrino)

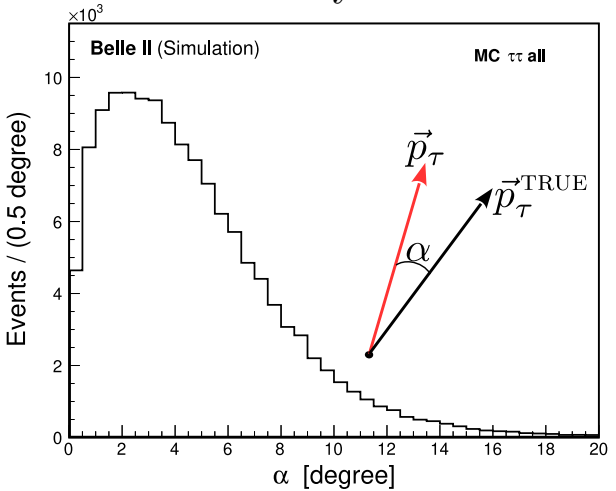
$\Longrightarrow$ tau momentum $\vec{p}_\tau^{\,\mathrm{CM}}$ can be found explicitly in **CM frame** (intersection of 2 cones).

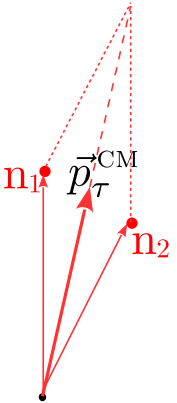


N.B.: in general there are **2 distinct solutions**: n_1, n_2

1) estimate $\vec{p}_\tau^{\,\mathrm{CM}}$ as **mean** vector of the 2 solutions

2) **boost** $\vec{p}_\tau^{\,\mathrm{CM}}$ to the laboratory frame

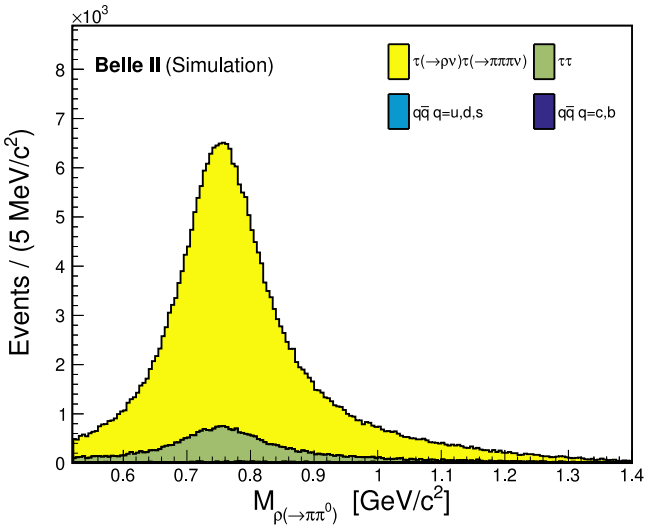




τ-lifetime: signal selection

Simulation study on 100 fb^{-1} of MC:

- Divide event into **two hemispheres**:
  - **3-prong side** $\rightarrow$ 3 charged π
  - **1-prong side** $\rightarrow$ 1 charged π + 1 π^0
- Total energy of additional photons: $\sum E_\gamma < 600$ MeV
- **ρ-peak**: 0.52 GeV $< M_\rho <$ 1.4 GeV
- Reject possible kaons
- At least 1 **hit** in **pixel detector** for each π on 3-prong side



$N_{\text{events}} \simeq 271$ k

- **τ pair events $\rightarrow$ 99.2%**
  - signal topology $\rightarrow$ 87.8%
  - Non-signal $\tau\tau$ $\rightarrow$ 11.4%
- **$e^+e^- \rightarrow q\bar{q}$ background $\rightarrow$ 0.8%**
  - $q = u,d,s$ $\rightarrow$ 0.8%
  - $q = c,b$ $\rightarrow$ <0.1%