Probing violation of CP & T invariance of the τ lepton

Ikaros Bigi, Notre Dame du Lac

09/30/2021

This book (published July 2021) is dedicated to Lev Okun, who was my `coach'. You can see a picture of him. He had more courage than me in different `directions'.

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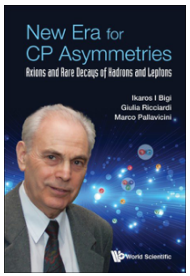

New Era for CP Asymmetries

Axions and Rare Decays of Hadrons and Leptons

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https://doi.org/10.1142/10791 |
July 2021
Pages: 356

By (author): Ikaros I Bigi (*University of Notre Dame, USA*), Giulia Ricciardi (*Università di Napoli Federico II, Italy*) and Marco Pallavicini (*University of Genova, Italy*)

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Description Chapters Authors Supplementary

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The book has two objectives. First is to showcase Okun's impact for decades since 1963, when he published his remarkable book *Weak Interaction of Elementary Particles*. Second is to present the current progress of our scientific community in the studies of our Universe. New directions and possible future developments are discussed, often using the past as a guide. The authors mostly focus on CP asymmetries in the transitions of hadrons and leptons, but they also discuss their rare decays, and talk about axions and supersymmetry,

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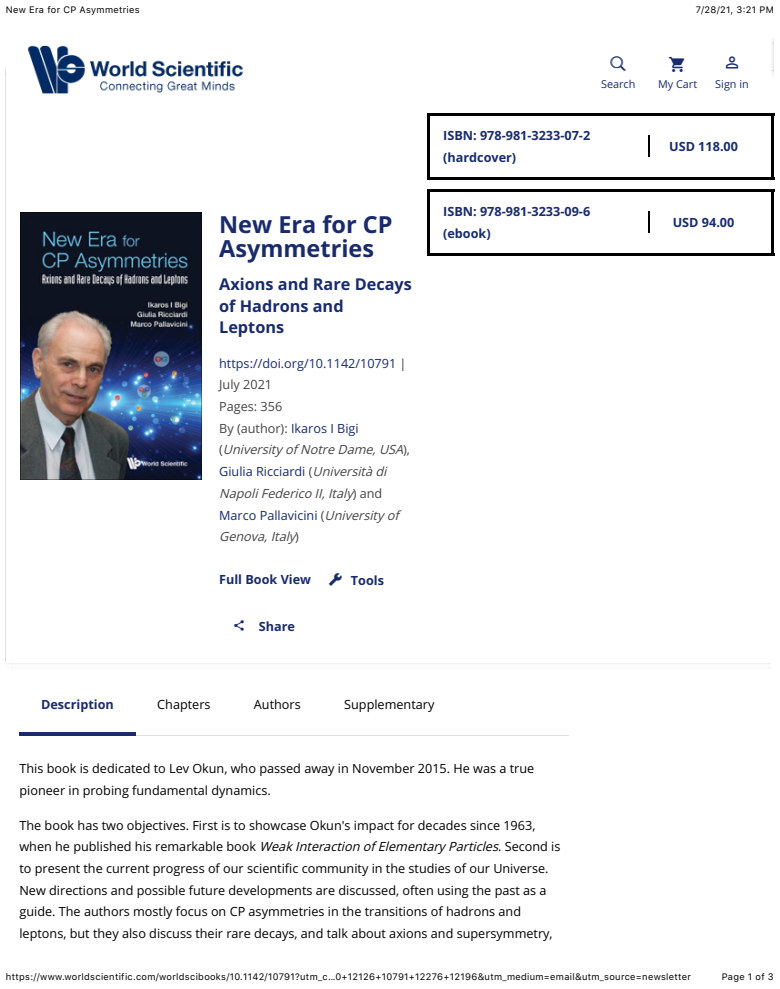
This WS is dedicated to the early passing away of Simon Eidelman. I have learnt from discussions from him in person (& by internet) & enjoyed them.



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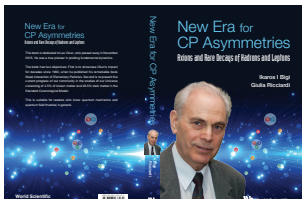
(I) My Summary

Convince both experimenters to work on & theorists to think about them.



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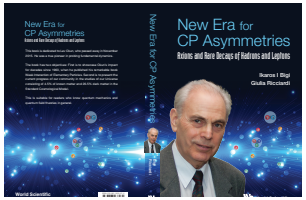
$A_{CP}(\tau^- \to \nu K^0_S \pi^-)|_{BaBar2012}$ = + (0.36 +/- 0.25) %

My goals are here to find impact of ND

[ND: New Dynamics / Notre Dame].



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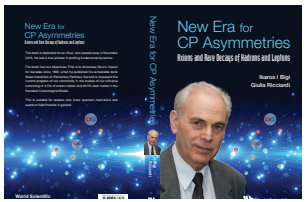

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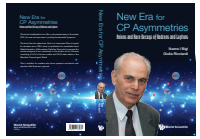
-- I think that τ decays might give bronze medals for CPV & TV in $\tau^- \to \nu K$ [$\pi/\pi\pi/\eta$]. Their hadronic final states are enough `complex'.

-- Remember: Leptoquarks have non-zero color!

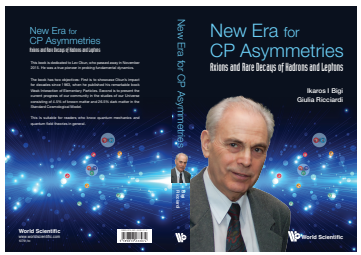


(II) My First Point

-- I am fan of "leptogenesis driving baryogenesis". However, CPV in the decays of the τ leptons can hardly `dream' about "leptogenesis" about $M \gg \overline{M}$.

-- On the other hand (in the worlds of theorists) it is a wonderful hunting for ND on CPV & TV.

Not surprising what most experimenters (except Roney, Kowalewski ···) tell me: `Good point, however, I am busy with other things.'



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-- Yet τ decays provide a better stage for CPV because its large mass & large numbers of possible FS; they could enhance CPV/TV since CPT symmetry is less restrictive; more types of T odd correlations; a better chance for ND like multi-Higgs or leptoquarks models to create an observable impact.

-- In the worlds of theorists: the SM can*not* produce `backgrounds' for CPV, where the situations are very different for charm hadrons & much more for beauty ones; examples: $D^0 \to h^+h^-$, $B^+ \to K^+\pi^+\pi^-$/ $K^+K^+K^-$!

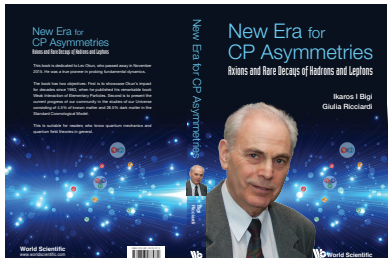
Establish non-zero CPV in *one* transition of

$$\tau^- \to \nu K\,[\pi/\pi\pi/\eta]$$

[or $A_{CP}(\tau^- \to \nu K^0_S\,\pi^-) \neq -(0.36 \pm 0.01)\,\%$]

→ New Dynamics !

Most of my two points were covered by the TAU2012 Summary you can guess with



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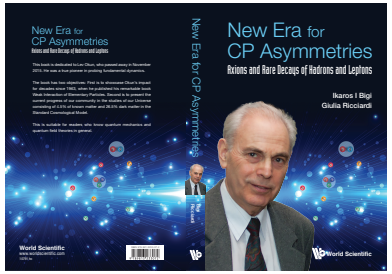
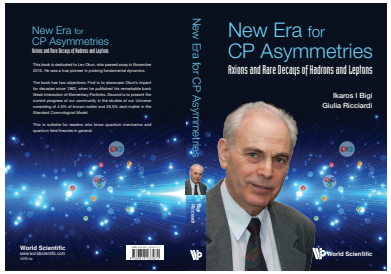


New idea or project as before with a
team of Bernabeau, see Nucl.Phys. B763 (2007) 283.

-- Having polarized τ leptons as powerful handle on CPV & control over systematics, in particular with a polarized electron beam of the region of $\Upsilon(4S)$.



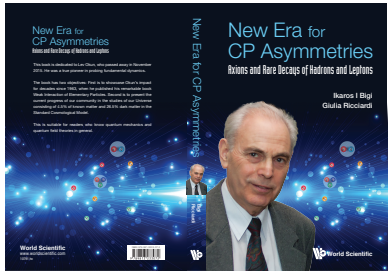
(III) My Second Point

Now about my second point, namely impact of theories & how to apply tools. Go back to slide 8:

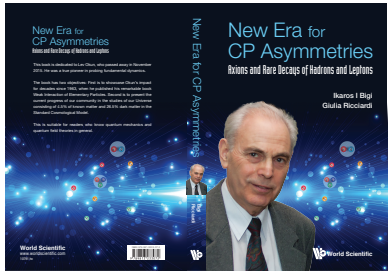
-- τ decays provide a better stage for CPV because its large mass & large numbers of possible FS;

-- they could enhance CPV/TV since CPT symmetry is less restrictive;

-- more types of T odd correlations; a better chance for ND like multi-Higgs or leptoquarks models to create an observable impact; see TAU2012 Summary of (bearded) Antonio Pich again.



-- Having polarized τ provides a powerful handle on CPV with control over systematics; it allows to construct new types of CP & T odd correlations. Using e-e+ -> τ- τ+ collections -> in the region of $\Upsilon(4S)$ with longitudinally polarized electrons



We should give credit to our colleague Takuya Morozumi with his co-authors Kimura, Lee & Nakagawa. I had many discussions with Takuya, in particular in Japan.

Here I list very good articles about CPV in τ decays from arXiv [hep-ph]:

1201.1794; $\tau^- \to \nu K [\pi/\eta]$ 25 citations

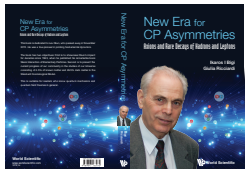
1012.5369 $\tau^- \to \nu K\text{-}\pi^0$ (TAU2010) 1 citation

0905.1802; $\tau^- \to \nu K_S\pi^-, \nu K^- [\pi^0 \eta /\eta]$ 6 citations

0808.0674. $\tau \to \nu K [\pi/\eta/\eta']$ 12 citations

These are not an idea – they show the analyses that are needed based on chiral symmetry & duality ⋯ (at least in the world of theorists)!

None of these are participant.



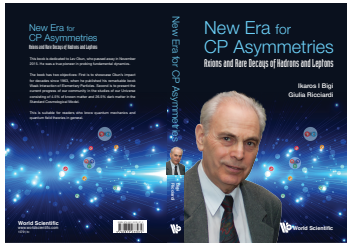
My traveling of the `road' is different for

$\tau \to \nu K [\pi/\eta/\eta'/\pi\pi]$ with Belle II

First goal to establish CPV in one of these (non-polarized) τ decays.

The second goal is to *predict* CPV in another FS and *find* it.

Thus we would have gotten novel information about ND both weak & strong dynamics.



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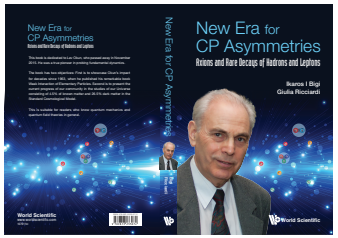

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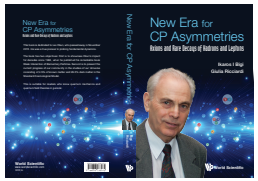

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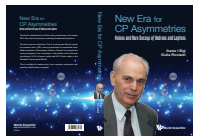
I have learnt from the first day of this WS that Belle II is planned to probe CPV for the future – excellent!



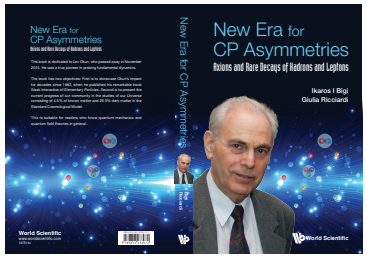
We have different `cultures':

HEP and MEP/Hadrodynamics

Needed Collaboration of

HEP and MEP/Hadrodynamics

to make progress about Tau dynamics, as you can see at the Tau2021, namely chiral & isospin symmetries and their limits, dispersion relations ···



Despite my names I am a Bavarian born in Munich; therefore often I follow the Bavarian tradition, namely the `brag'; in this case about my (last) book "New Era for CP Asymmetries, Axions and Rare Decay of Hadrons and Leptions"

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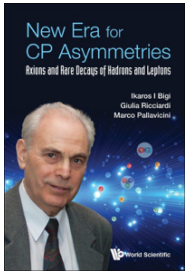

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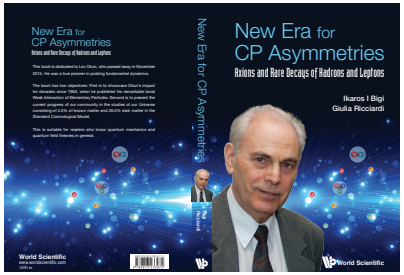
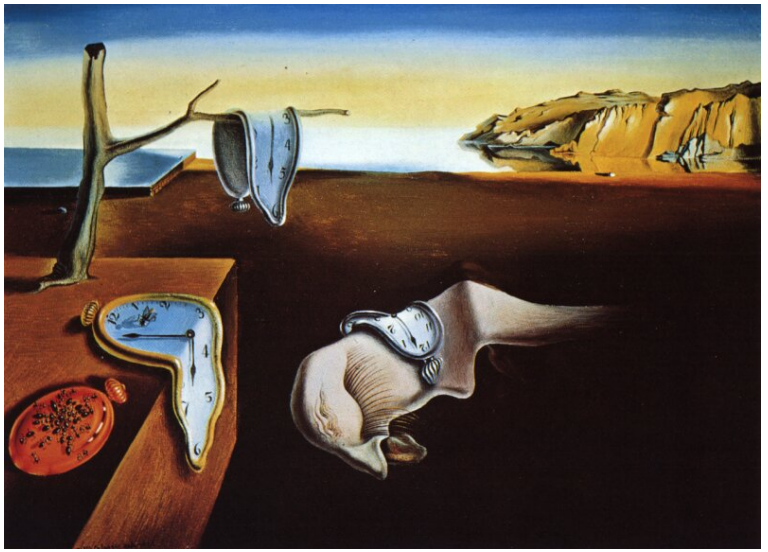
It is not cheap, but deep. Can you order your libraries to order a copy of this book?

`dreaming in more dimensions'

Mont Saint-Michel island (picture taken by IIB)





Time & Change