CP Violation in the $\tau^- \to \pi^- \pi^+ \pi^- (\geq 0\pi^0)\, \nu_\tau$ decay with Belle II detector

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Introduction:

For tau decays in the Standard Model (SM) there is no CP Violation. Therefore, CPV in tau decays is a clean signature for New Physics. It requires very large tau samples to be studied.

CP asymmetry in $\tau^- \to K_S^0 \pi^- \nu_\tau$ decays [1,2,3,4]

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

SM prediction

$A_{CP} = (0.36 \pm 0.01)\%$ due to the (neutral) kaon mixing

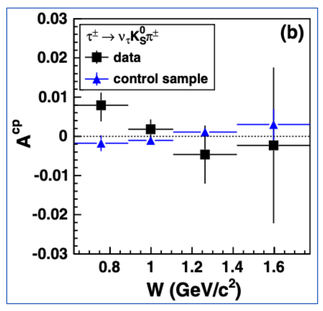
BABAR measurement

A_{CP} = (−0.36 ± 0.23 ± 0.11)% with 476 fb^{-1} of integrated luminosity

2.8 σ deviation from the SM expectation

compatible results

Belle measurement

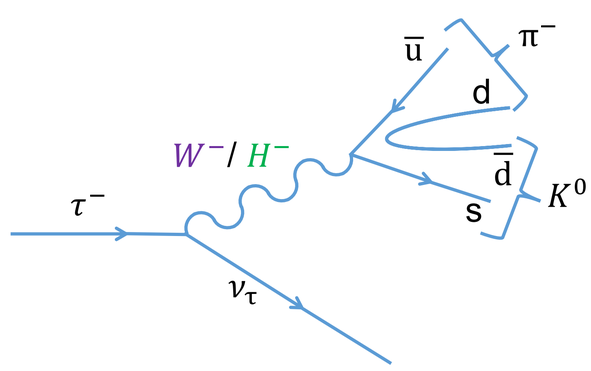


No asymmetry seen at the 10^{-2} level

Interpretation of CPV in tau decays [5]

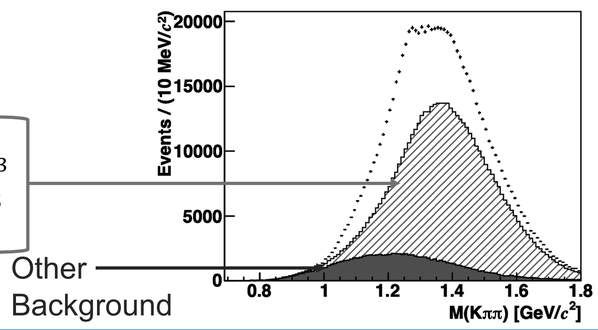
CPV could be due to an interference of 2 diagrams, SM and NP

Feynmann diagram



A particularly interesting case: $\tau^- \to K^- \pi^- \pi^+ \nu_\tau$ [6]

- BR($\tau^- \to K^- \pi^- \pi^+ \nu_\tau$) = $(3.30 \pm 0.01) \times 10^{-3}$ → possibly large A_{CP}
- But large background :
  - $\tau \to \pi\pi\pi\nu_\tau$: $(8.4 \pm 0.3)\%$
  - $\tau \to K\pi\pi\nu_\tau$: $(1.5 \pm 0.1) \times 10^{-3}$
  - $\tau \to KK\pi\nu_\tau$: $(3.3 \pm 0.3) \times 10^{-5}$

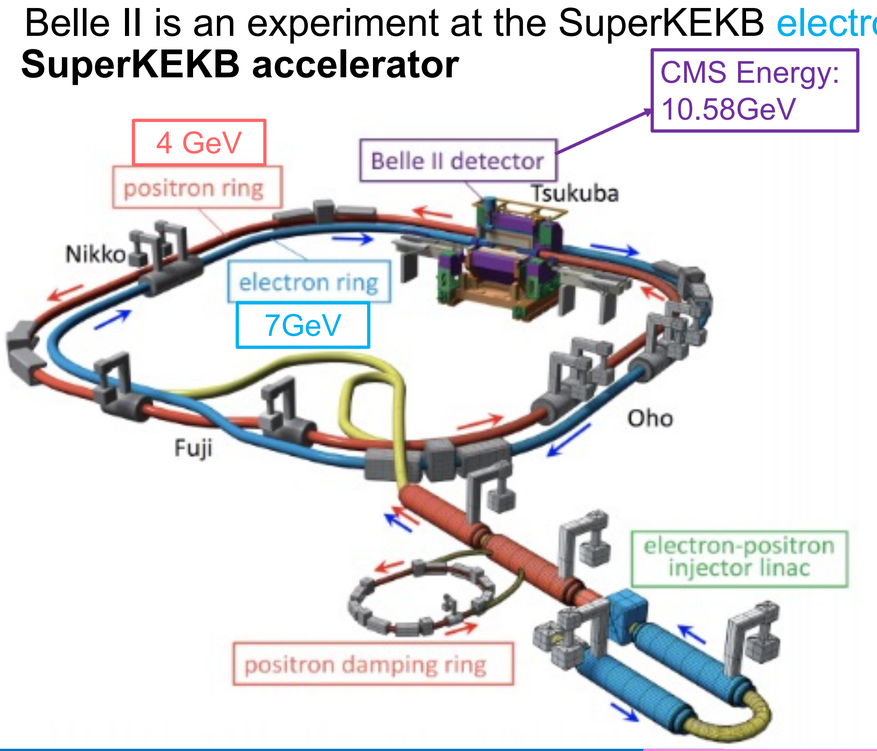


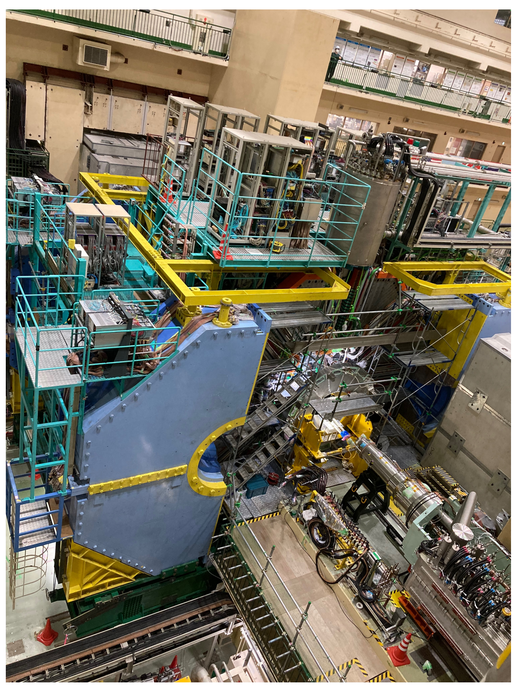
Problem:

- Measuring CPV in $K\pi\pi$ requires to have control on CPV in backgrounds.
- Background dominated by pionic decays of tau.
- π^0's are more difficult to reconstruct.
- No measurement yet of CPV in $\pi^- \pi^+ \pi^- (\geq 0\pi^0)\, \nu_\tau$ decays.
- Expect CPV in $\pi^- \pi^+ \pi^- \pi^0\, \nu_\tau$ [8] → measure it.

Belle II is an experiment at the SuperKEKB electron-positron collider (Tsukuba, Japan)

SuperKEKB accelerator





Belle II detector

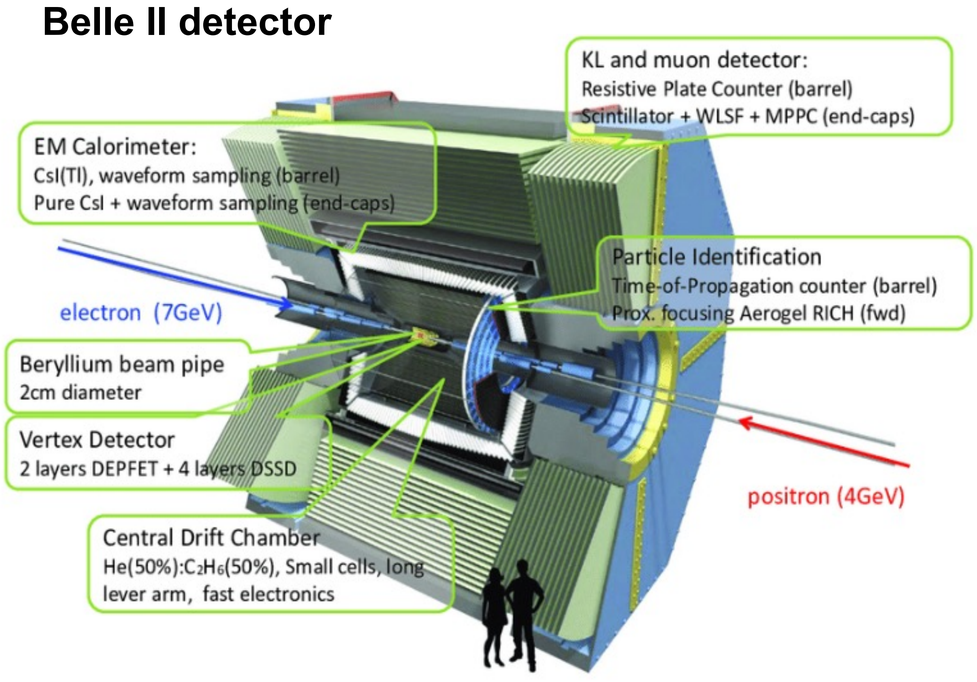
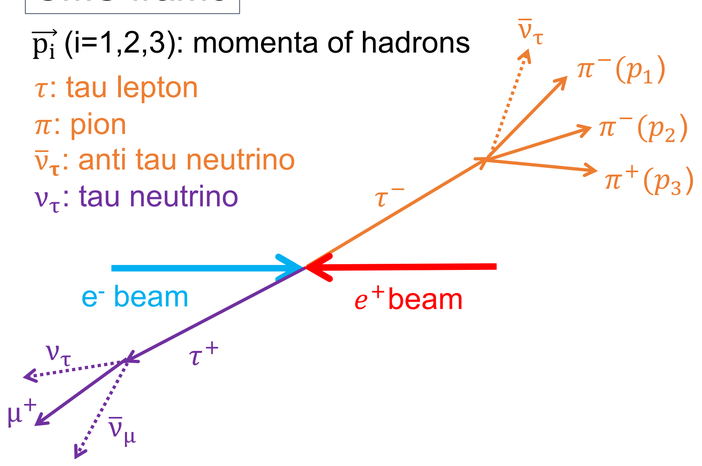


Diagram of the event studied

CMS frame

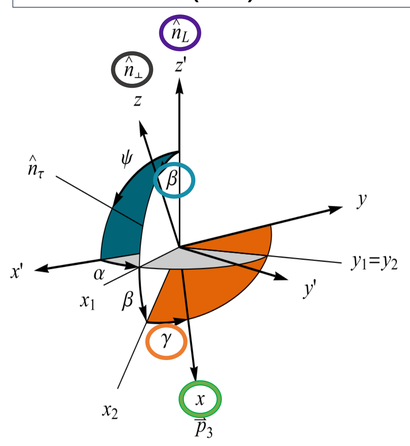
$\overrightarrow{p_i}$ (i=1,2,3): momenta of hadrons

τ: tau lepton
π: pion
$\bar{\nu}_\tau$: anti tau neutrino
ν_τ: tau neutrino



$\tau \to \pi\pi\pi(n\pi^0)\nu_\tau$ study formalism

Hadronic (3π) rest frame



Angular observables [7]

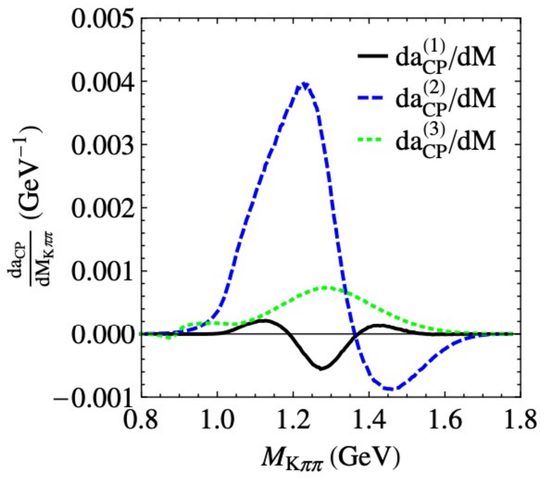
$\hat{n}_L$: lab direction

$$\hat{n}_\perp = \frac{\overrightarrow{p_1} \times \overrightarrow{p_2}}{|\overrightarrow{p_1} \times \overrightarrow{p_2}|}$$

$$\hat{x} = \frac{\overrightarrow{p_3}}{|\overrightarrow{p_3}|}$$

$$\beta = \arccos(\hat{n}_L, \hat{n}_\perp)$$
$$\gamma = \arccos\big((\hat{n}_L, \hat{n}_\perp)\text{plane}, (\hat{n}_\perp, \hat{x})\text{plane}\big)$$

Example of $K\pi\pi\ \nu_\tau$ decays [7]



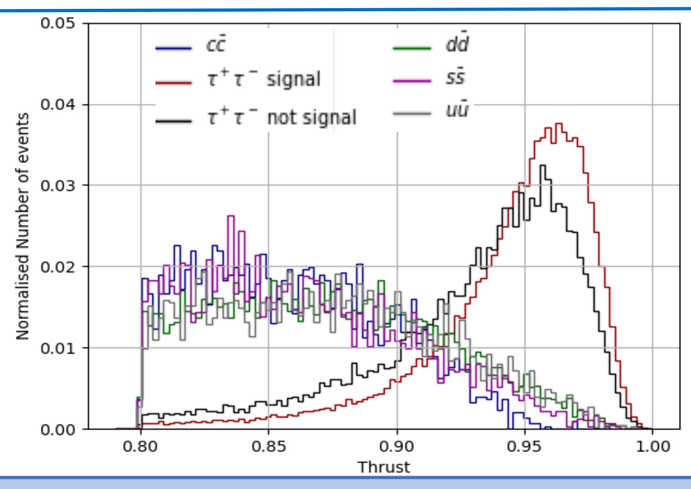
Preselections (ongoing work)

Thrust is defined in the center of mass frame as [10] :

$d = \frac{max_{\hat{r}} d(\hat{r})}{\sum_a |\vec{p}_a|}$ 0<d<1,

$d(\hat{r}) = \sum_a \vec{p}_a \,.\hat{r}\theta(\vec{p}_a.\hat{r})$,

$\hat{r}$: an arbitrary unit vector,
θ: a unit step function.



$$\frac{d\Gamma_\pm}{dQ^2} = \int \frac{d\Gamma(\tau^\pm \to \pi^\pm \pi^+ \pi^- n\pi^0 \nu_\tau) w_i(\gamma,\beta)}{dQ^2 ds_1 ds_2 d\gamma d\cos\beta d\cos\theta} ds_1 ds_2 d\gamma d\cos\beta d\cos\theta$$

$$\frac{dA_{CP}^i}{dQ^2} = \frac{\frac{d\Gamma_+}{dQ^2} - \frac{d\Gamma_-}{dQ^2}}{\frac{d\Gamma_+}{dQ^2} + \frac{d\Gamma_-}{dQ^2}}$$ [9] ; $w_i(\gamma,\beta)$ a weight function.

- Get the angular distributions.
- Correct for instrumental asymmetries.
- Measure local CP asymmetries.

Conclusion:

- Some intriguing results in $\tau \to K_S^0 \pi$, call for more measurements ideally in kaonic tau decays.
- Purely pionic tau decays are huge background in kaonic tau decays and may also have CPV contributions.
- We propose to measure CPV in 3 charged (+neutrals) pion decays of tau in an 'inclusive' manner.

References:
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