Measurement of Beam Polarization with Tau Polarimetry for a Potential SuperKEKB e^- Beam Polarization Upgrade

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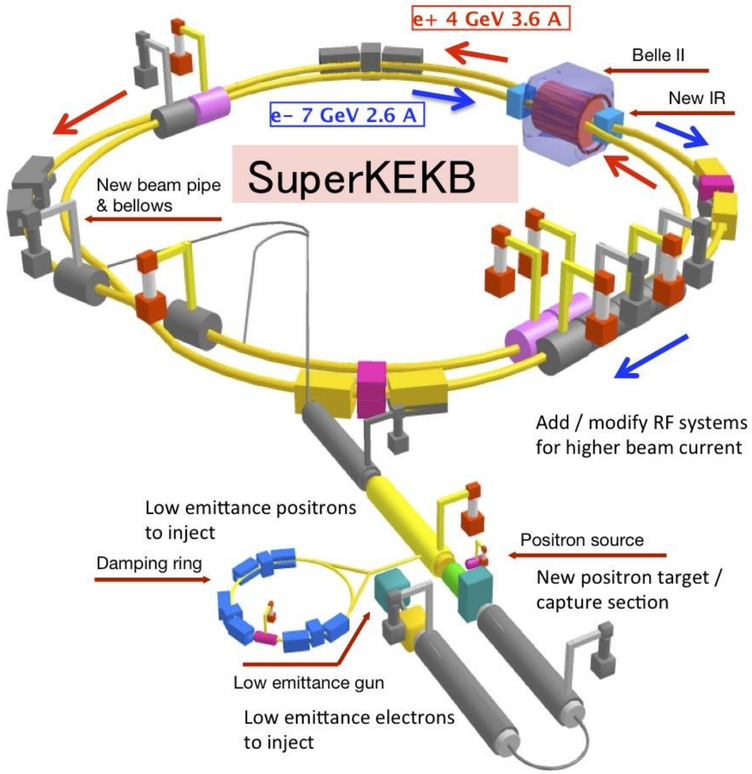
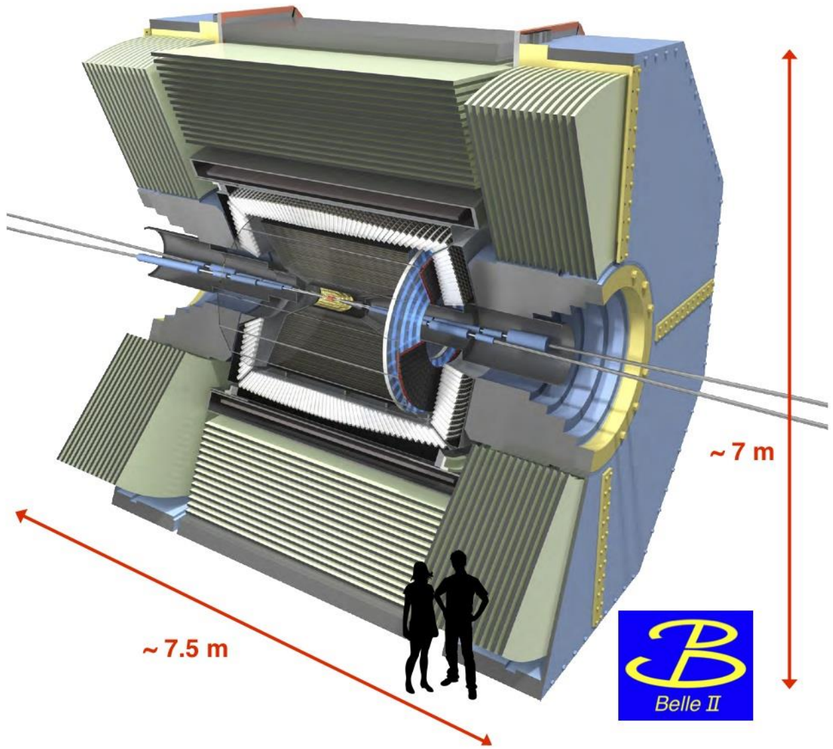
SuperKEKB and Belle II

- SuperKEKB and Belle II operate as a B-Factory, e^+e^- collisions at 10.577 GeV
- SuperKEKB is designed to deliver a record luminosity of $8x10^{35}$ $cm^{-2}s^{-1}$
- Belle II intends to integrate 50 ab^{-1} of data by early 2030's
- Potential upgrade being planned to polarize the electron beam
- Full polarized physics program presented by M. Roney in future facilities yesterday





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Beam Polarization Motivation

- Beam polarization is being considered as a future upgrade to SuperKEKB
- A polarized electron beam would allow Belle II to make many precise measurements of electro-weak parameters. Including A_{LR} for e,μ,τ,c,b

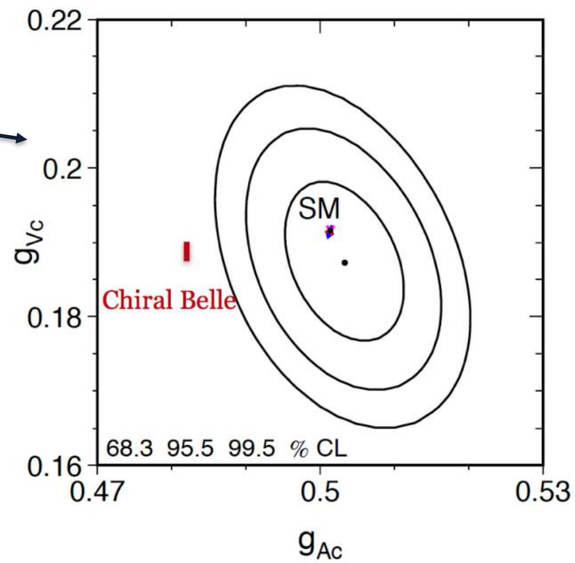
$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}}\left(\frac{G_f s}{4\pi\alpha Q_f}\right) g_A^e g_V^f \langle P \rangle \propto T_3^f - 2Q_f \sin^2\theta_W$$

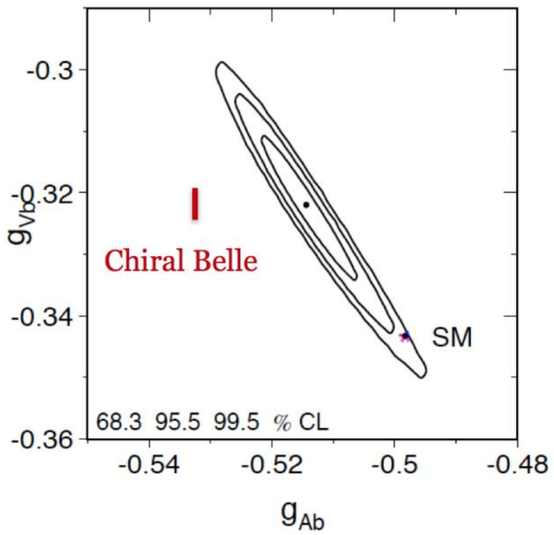
c-quark: **with 20 ab^{-1}** **b-quark:**

Chiral Belle ~7 times more precise

Chiral Belle ~4 times more precise

Red bars show expected +/- 1 sigma uncertainty





Recent theory work on A_{LR} in muons:

A. Aleksejevs, S. Barkanova, C. Miller, J. M. Roney, V. Zykunov; DOI: 10.1103/PhysRevD.101.053003

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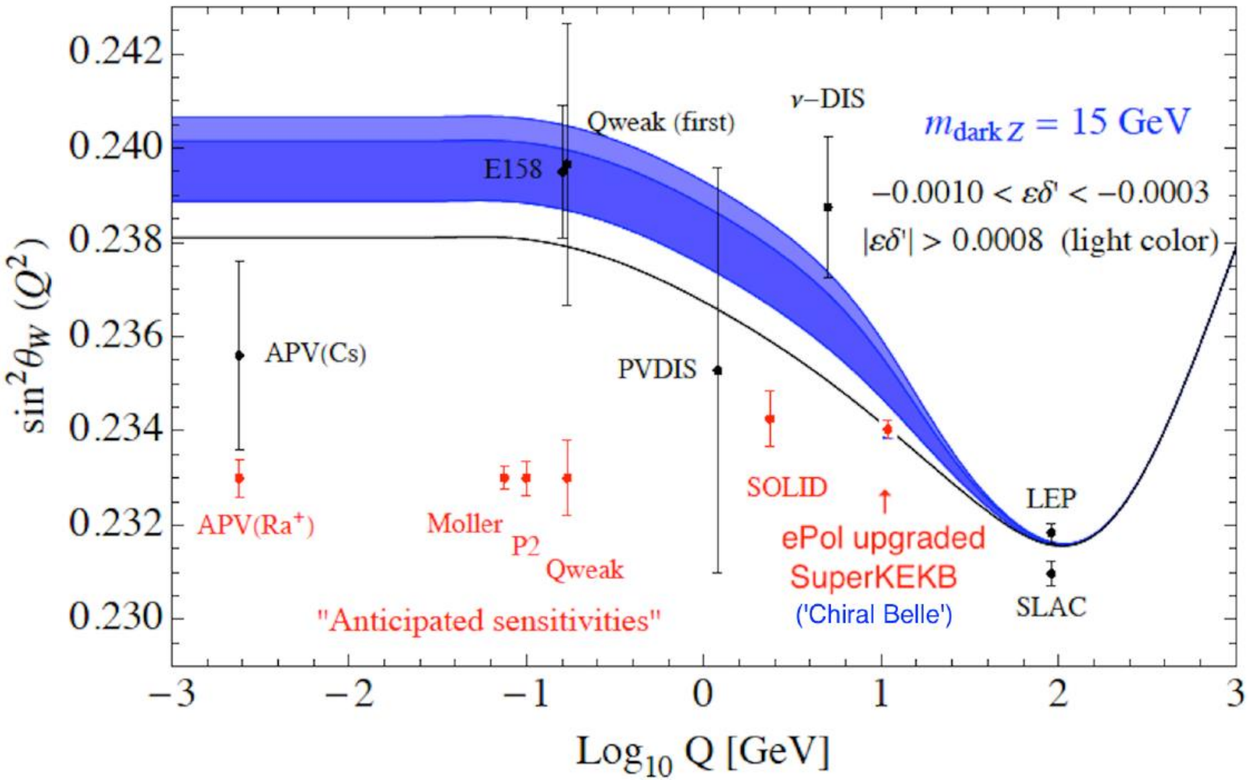

Red bars show expected sensitivity of future experiments

Chiral Belle expects: $\sigma(\sin_2\theta_W) \approx 0.0002$ (40 ab^{-1})

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Beam Polarization Requirements

- Multiple hardware projects underway in preparation for polarization
- Circularly polarized laser source for produce polarized electrons
  - Being worked on by our Japanese collaborators
- A Compton polarimeter for instantaneous beam polarization measurements
  - Collaborators in Manitoba and France
  - Complimentary to this measurement technique
- Beam rotators to preserve the beam polarization during transport
  - Collaborators in Novosibirsk, USA, UVic, TRIUMF

In order to make the precision physics measurements the average polarization in the data must be known

We use Tau Polarimetry to measure the polarization from the data

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Tau Polarization as Beam Polarimeter

$$P_{Z'}^{(\tau^-)}(\theta, P_e) = -\frac{8G_F s}{4\sqrt{2}\pi\alpha}\,\mathrm{Re}\left\{\frac{g_v^l - Q_b g_v^b Y_{1S,2S,3S}(s)}{1 + Q_b^2 Y_{1S,2S,3S}(s)}\right\}\left(g_A^\tau \frac{|\vec{p}|}{p^0} + 2g_A^e \frac{\cos\theta}{1+\cos^2\theta}\right)$$

$$+P_e \frac{\cos\theta}{1+\cos^2\theta}$$

- Strong coupling between beam polarization (P_e) and tau polarization
- Beam polarization contribution switches sign for cosθ<o and cosθ>o

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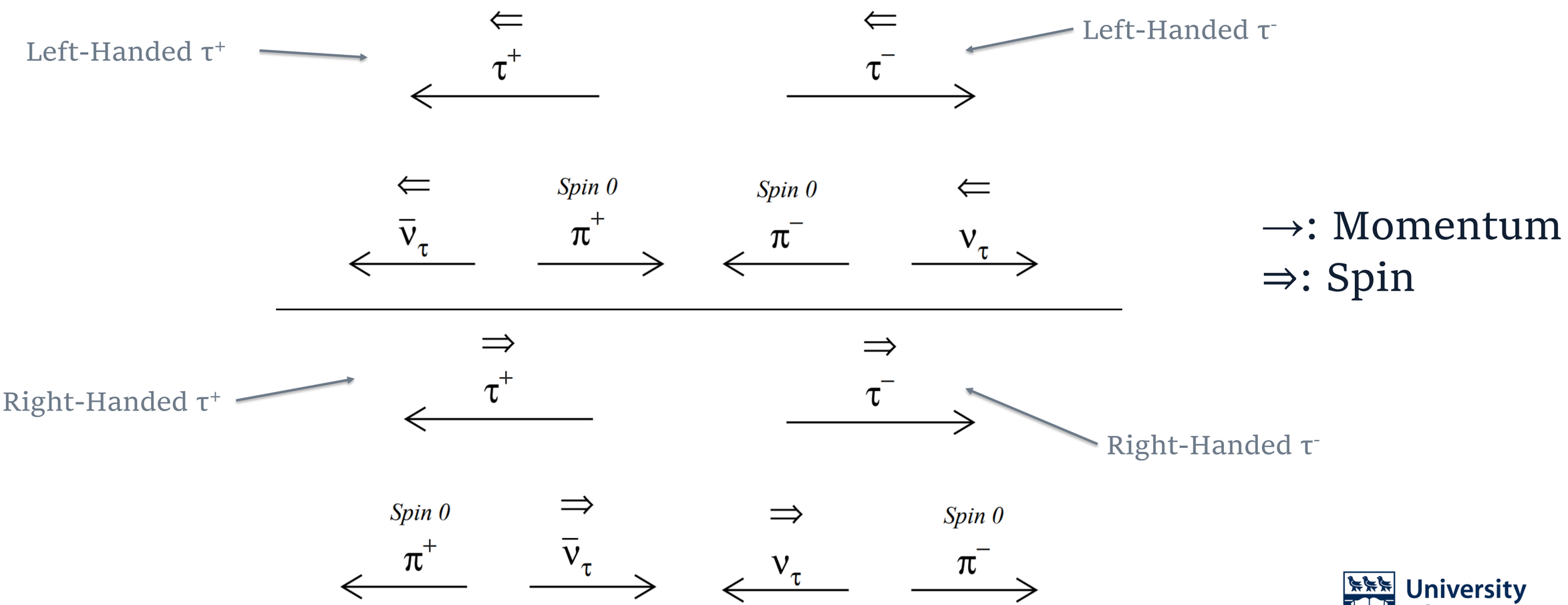
Polarization Sensitivity in Tau Decays

- The kinematics of the $\tau \to \pi\nu$ provide a powerful insight into the polarization



Assumes tau neutrinos are 100% left handed

KKMC Generator

- In order to study the effects of beam polarization we use the KKMC generator
  - S. Jadach, B.F.L. Ward, Z. Wąs; Computer Physics Communications, Volume 130, Issue 3, 2000, Pages 260-325, https://doi.org/10.1016/S0010-4655(00)00048-5.
- In KKMC we can set the polarization of the electron beam
- Produced ~1 ab^{-1} equivalent of tau events for a left and right handed e^- beam

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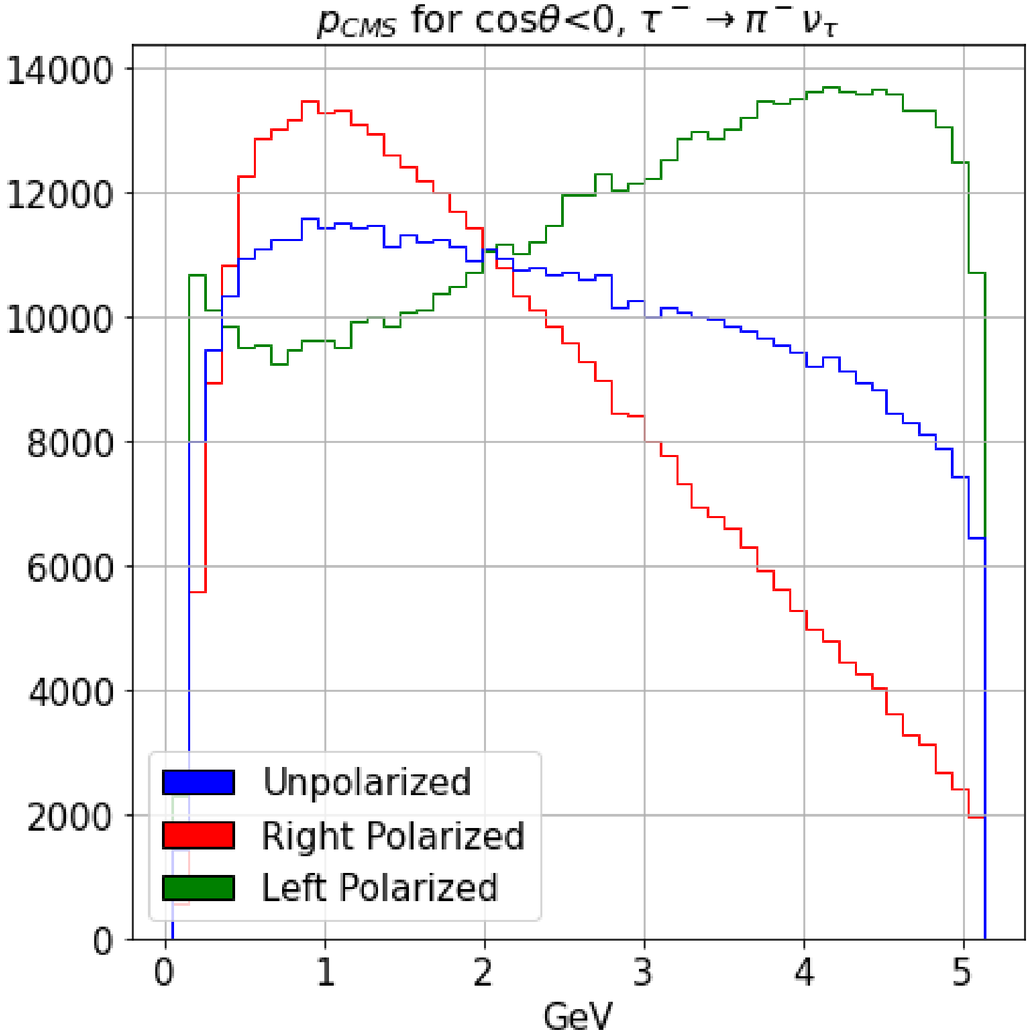
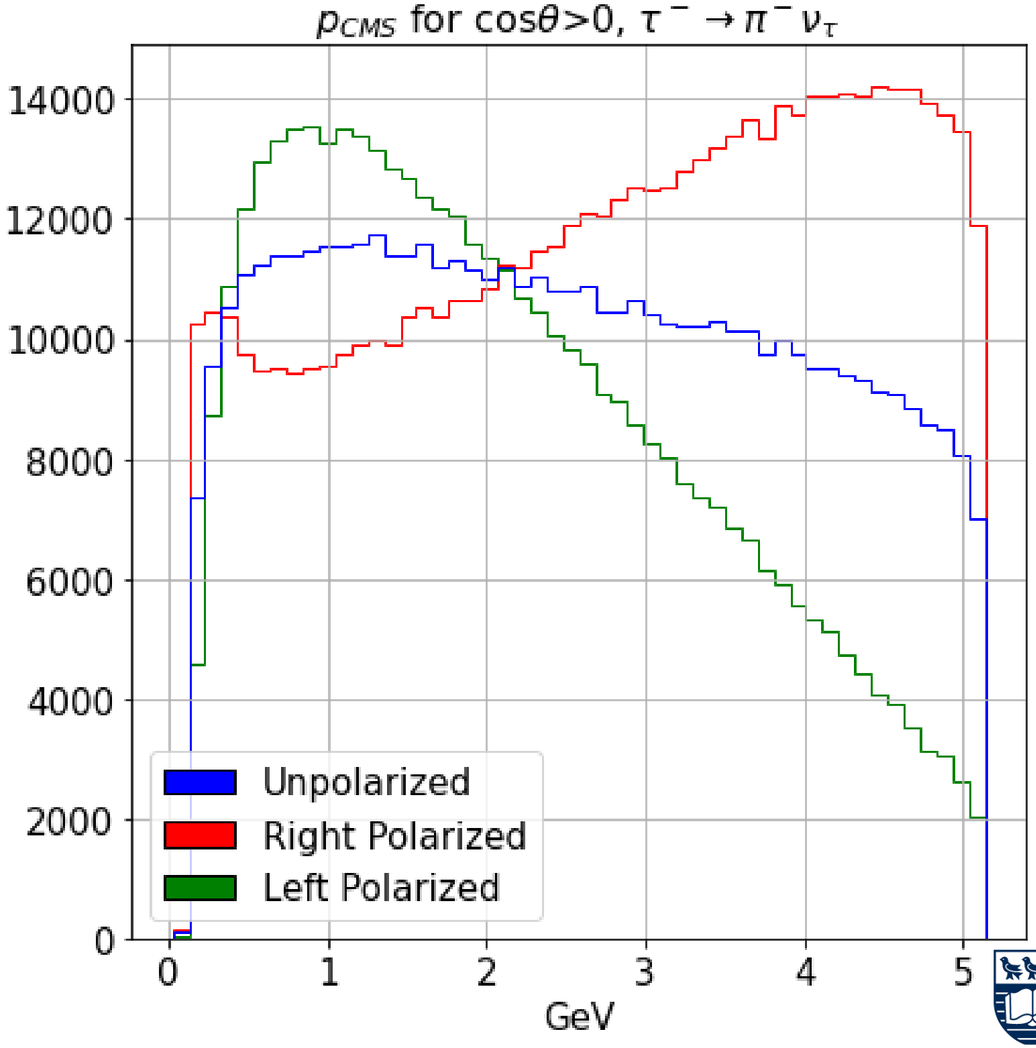
Polarization Sensitivity at 10.58 GeV

- Momentum distributions for final state pion in Tau decay





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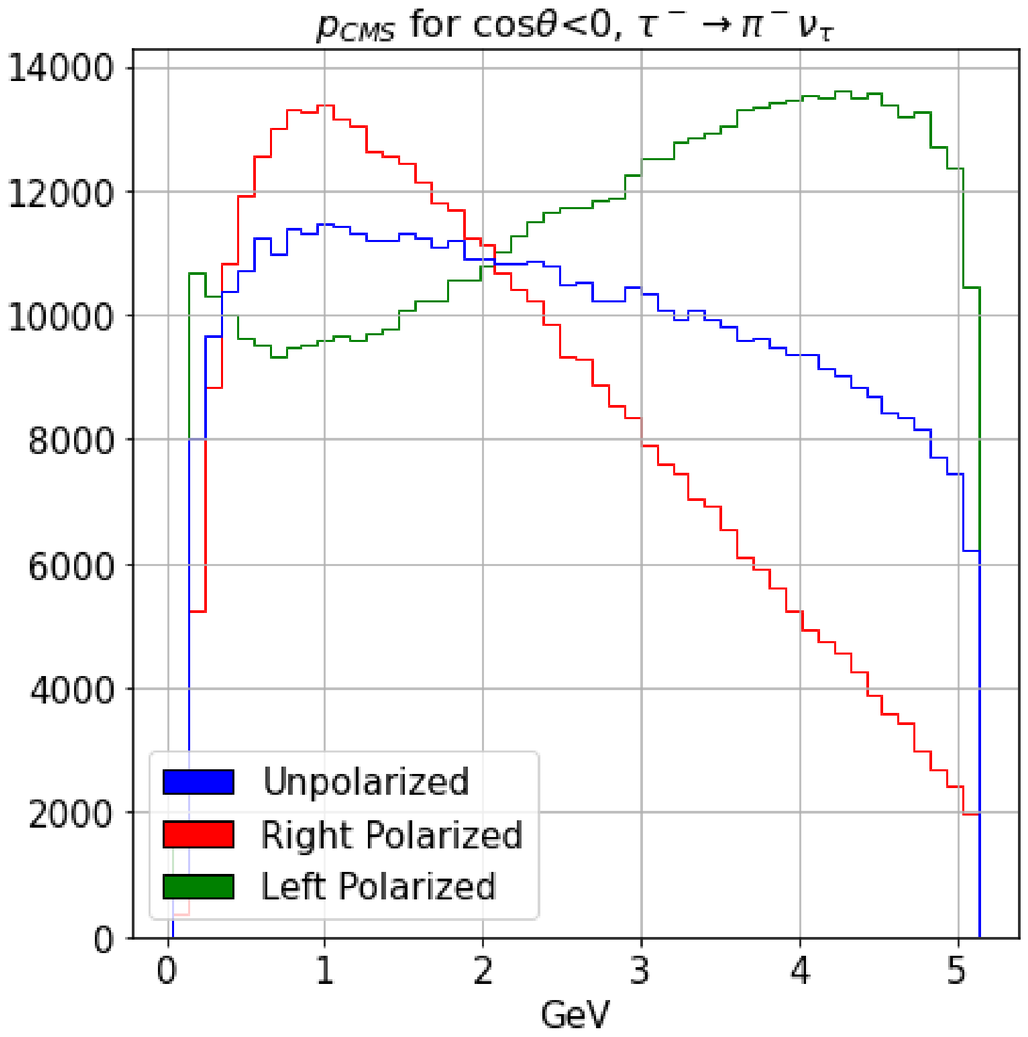
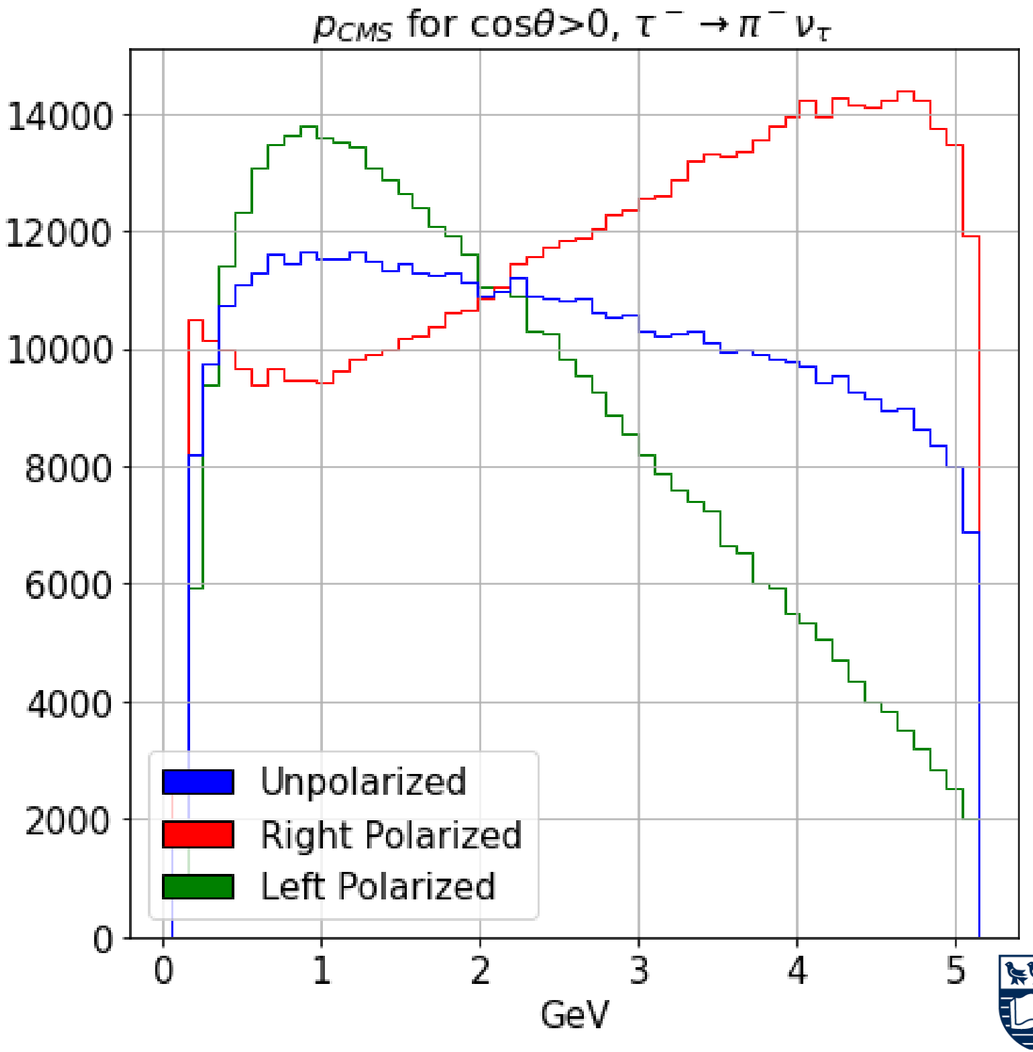
Polarization Sensitivity at 10.58 GeV

- Turning off weak contribution in the mediator (QED only)





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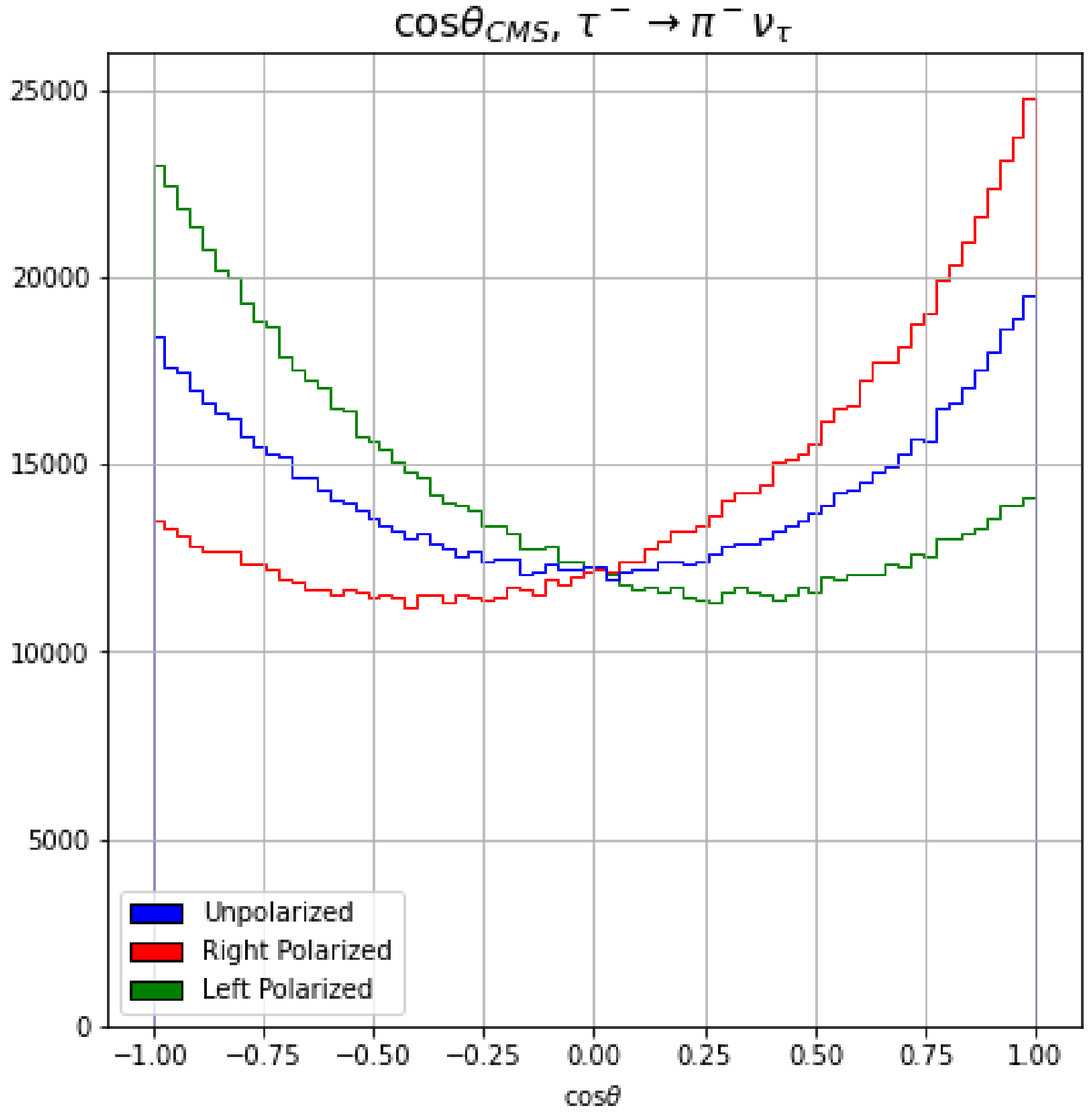
Polarization Sensitivity at 10.58 GeV

- Angular distributions for final state pion in Tau decay



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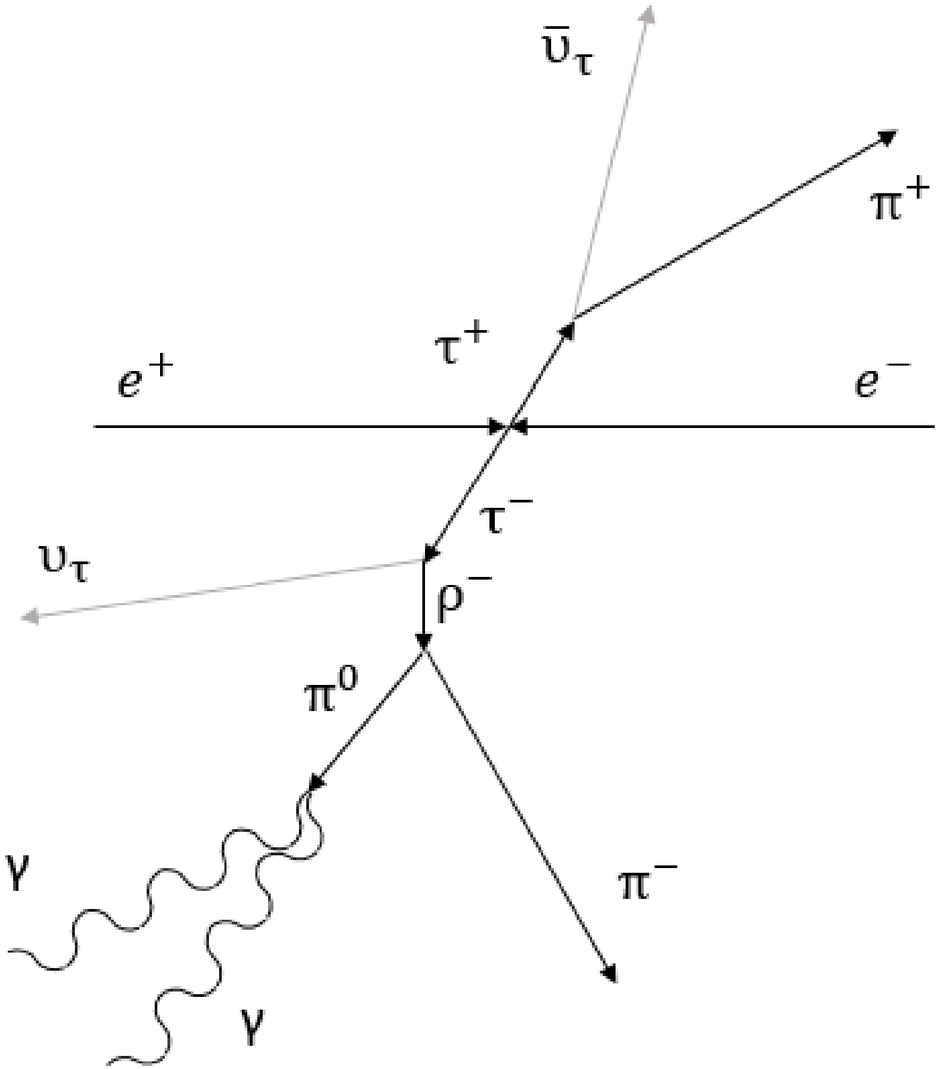
Event Selection

- As Belle II is just now collecting significant data, We are using the well understood BaBar data to develop this technique
  - BaBar is a predecessor to Belle II
    - Similar detector design
    - On-Peak BaBar dataset is 424.2 fb^{-1}
  - Only showing MC studies in this presentation
- We tag tau events by $\tau^{\pm} \rightarrow \pi^{\pm}\pi^{0}\nu$
- Our signal is $\tau^{\pm} \rightarrow \pi^{\pm}\nu$ events
- We are able to achieve a 98% pure tau sample
- 60% are the desired $\tau^{\pm} \rightarrow \pi^{\pm}\nu$ decays
- All tau decays have some polarization sensitivity
- We fit all tau modes in our selection simultaneously



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Polarization Fit

- We employ the Barlow&Beeston[1] template fit methodology
- MC and data is binned in 2D histograms of momentum vs cosθ
- Polarized tau MC was generated to be able to measure the polarization
- The unpolarized MC is split into 3 statistically independent sets to make 3 data-like samples
- The data (or data-like MC) is fit as a linear combination of the templates

$$D = a_l L + a_r R + a_b B + a_m M + a_u U + a_c C$$

$$\sum a_i \equiv 1$$

$$\langle P \rangle \equiv a_l - a_r$$

L=Left Polarized Tau MC, R=Right Polarized Tau MC, B=Bhabha(e^+e^-),M=μμ, U=uds, C=$c\bar{c}$

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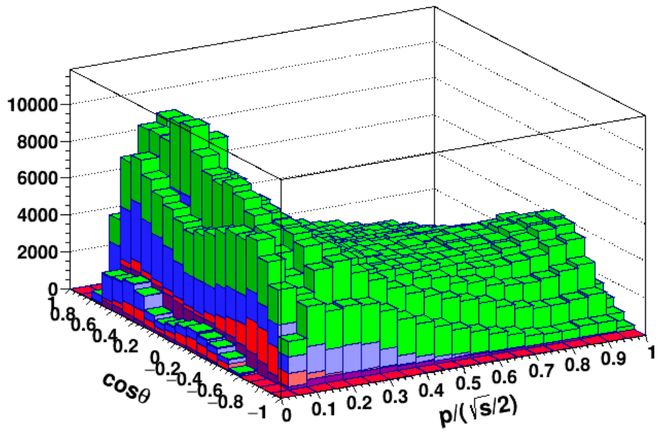
[1] R. Barlow, C. Beeston; Computer Physics Communications, Volume 77, Issue 2, 1993, Pages 219-228, https://doi.org/10.1016/0010-4655(93)90005-W

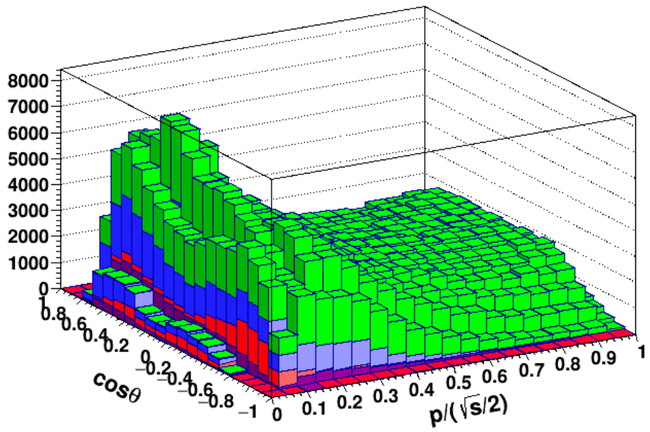
Template Example

- Templates for the Tau MC from KKMC

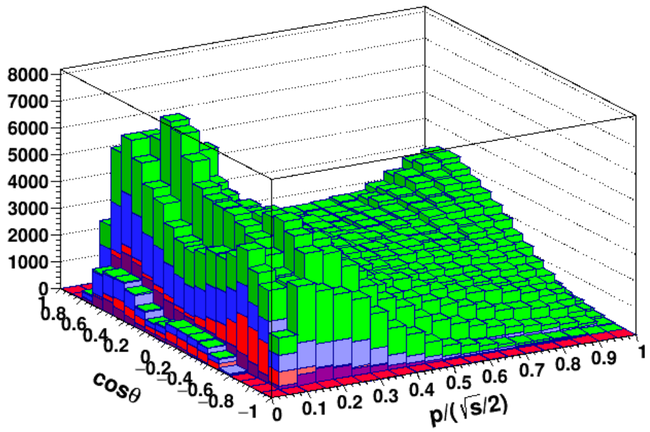
Left-handed e^- beam, π^- distribution



Unpolarized e^- beam, π^- distribution



Right-handed e^- beam, π^- distribution



$\tau \rightarrow \pi\nu$ $\tau \rightarrow \mu\nu\nu$ $\tau \rightarrow e\nu\nu$ $\tau \rightarrow$ else

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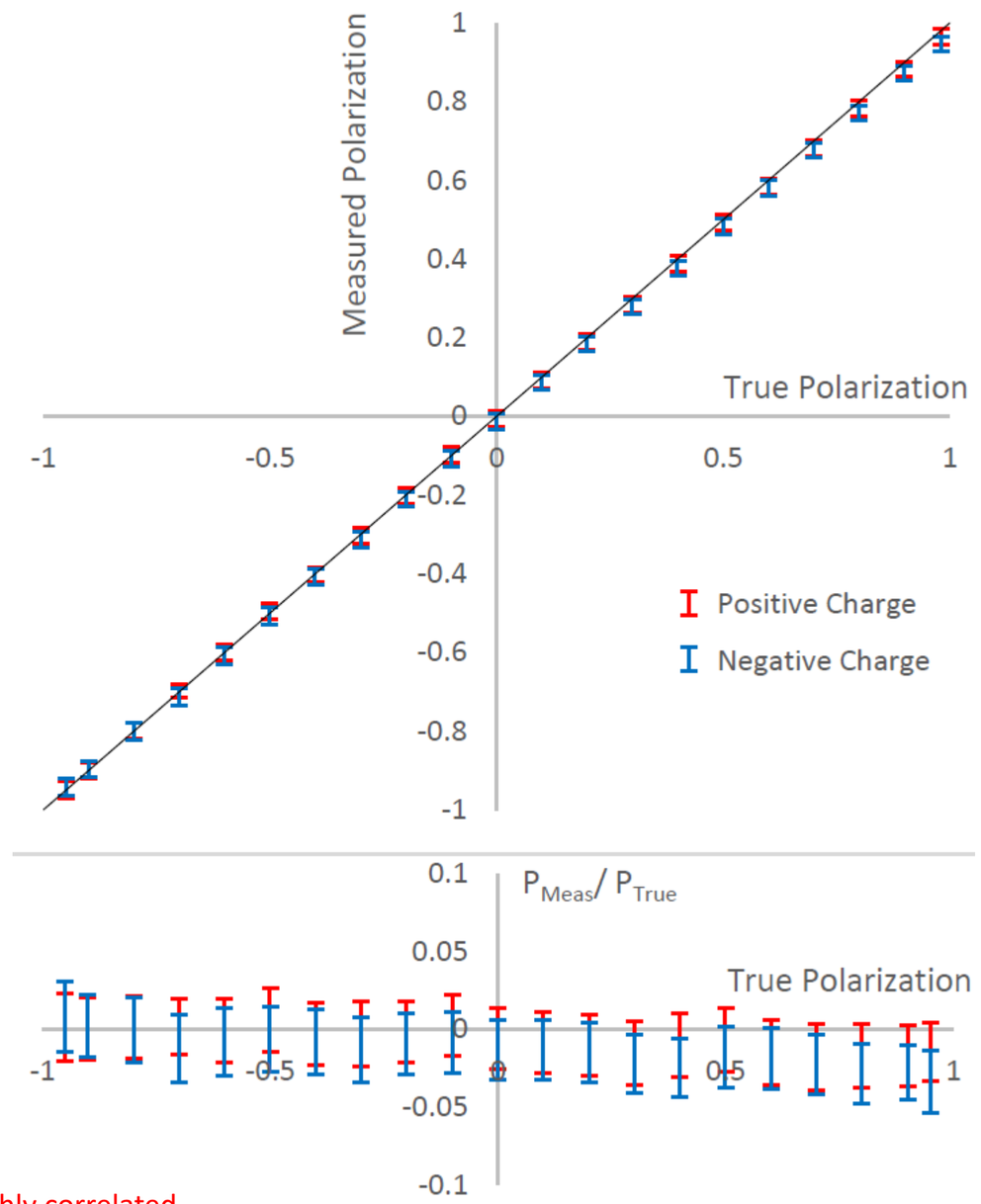
Absolute Polarization Sensitivity

- We have tested the technique at various beam polarization states
- The generated polarized Tau MC is split in half
  - One half is reserved for performing the polarization measurement
  - The other half is mixed in specific ratios to produce desired beam polarization states



Statistical error only
Note: adjacent points are highly correlated

Fit Results and Systematic Uncertainties

- BaBar full dataset projects to a statistical uncertainty of 0.003 on the beam polarization
  - Corresponds to a relative uncertainty of 0.4% for a 70% polarized beam
- Systematic uncertainty studies have identified the dominant parameters
  1. Muon Particle Identification
  2. Neutral Particle Modelling
  3. Momentum Resolution
  4. Angular Resolution
  5. Electron Particle Identification
- Initial studies suggest a systematic uncertainty of around a half percent is achievable

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Tau Polarimetry at the ILC

- As the ILC is intended to have polarized beams we investigated polarization sensitivity at 500 GeV
- Work was carried out by University of Victoria student Dhwani Sutariya
- Study was carried out with the KKMC generator
- Generated momentum distributions for $\tau^{\pm} \rightarrow \pi^{\pm} \nu_{\tau}$ final state
- Compared the increased role of the Z-boson as a mediator compared to 10.58 GeV

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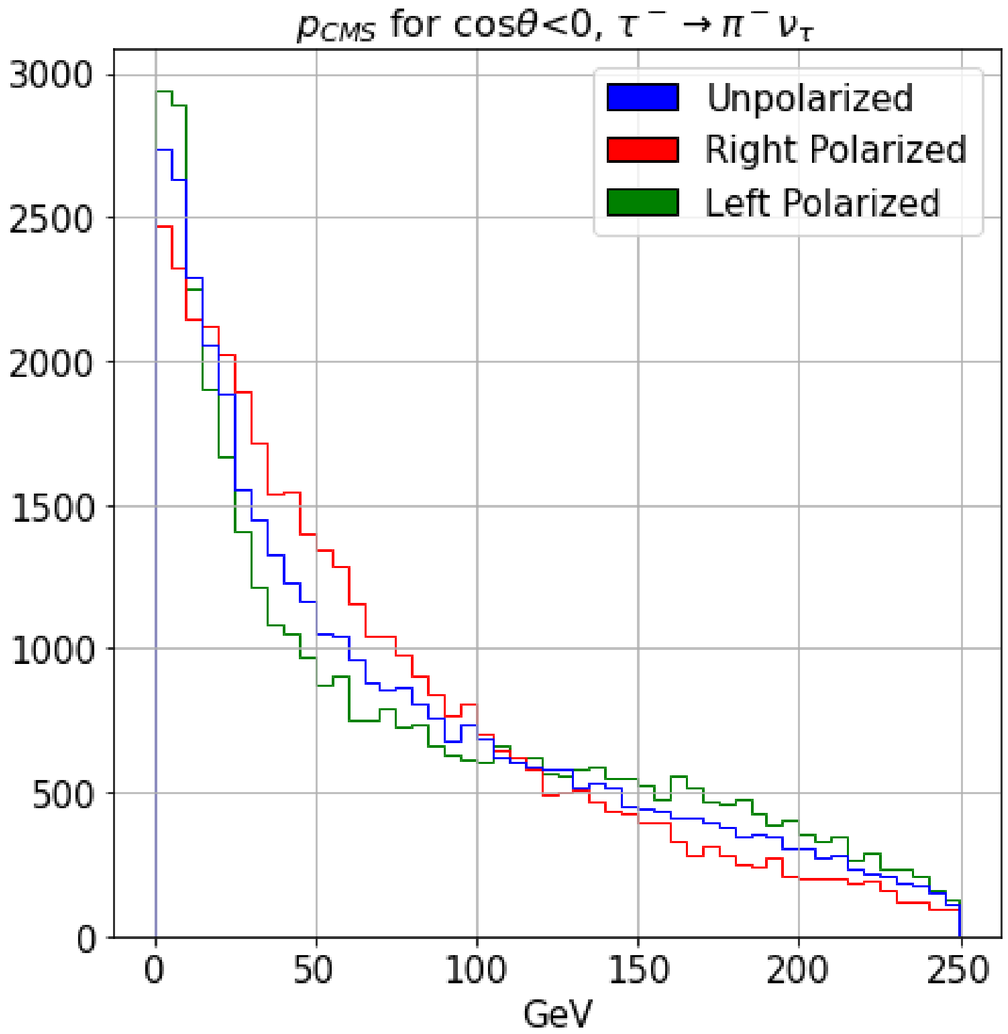
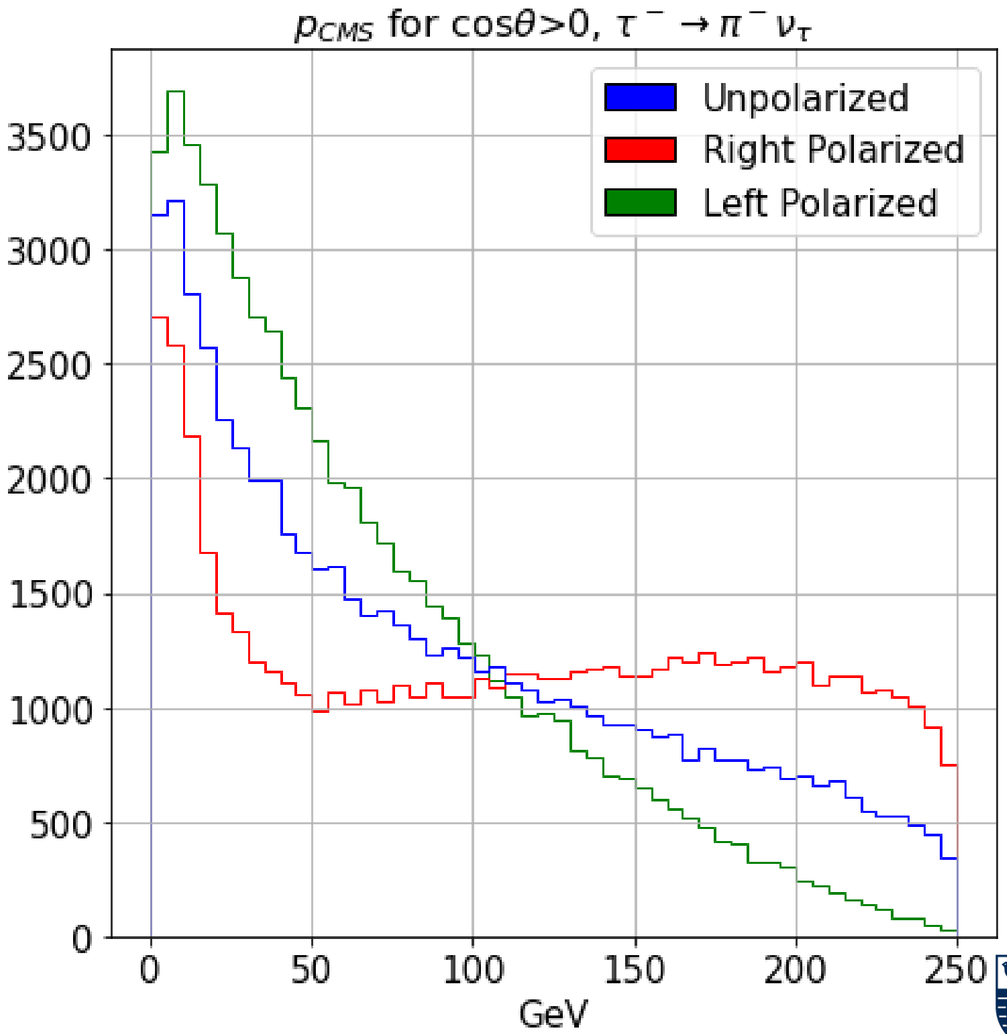
Polarization Sensitivity at 500 GeV

- Momentum distributions for final state pion in Tau decay





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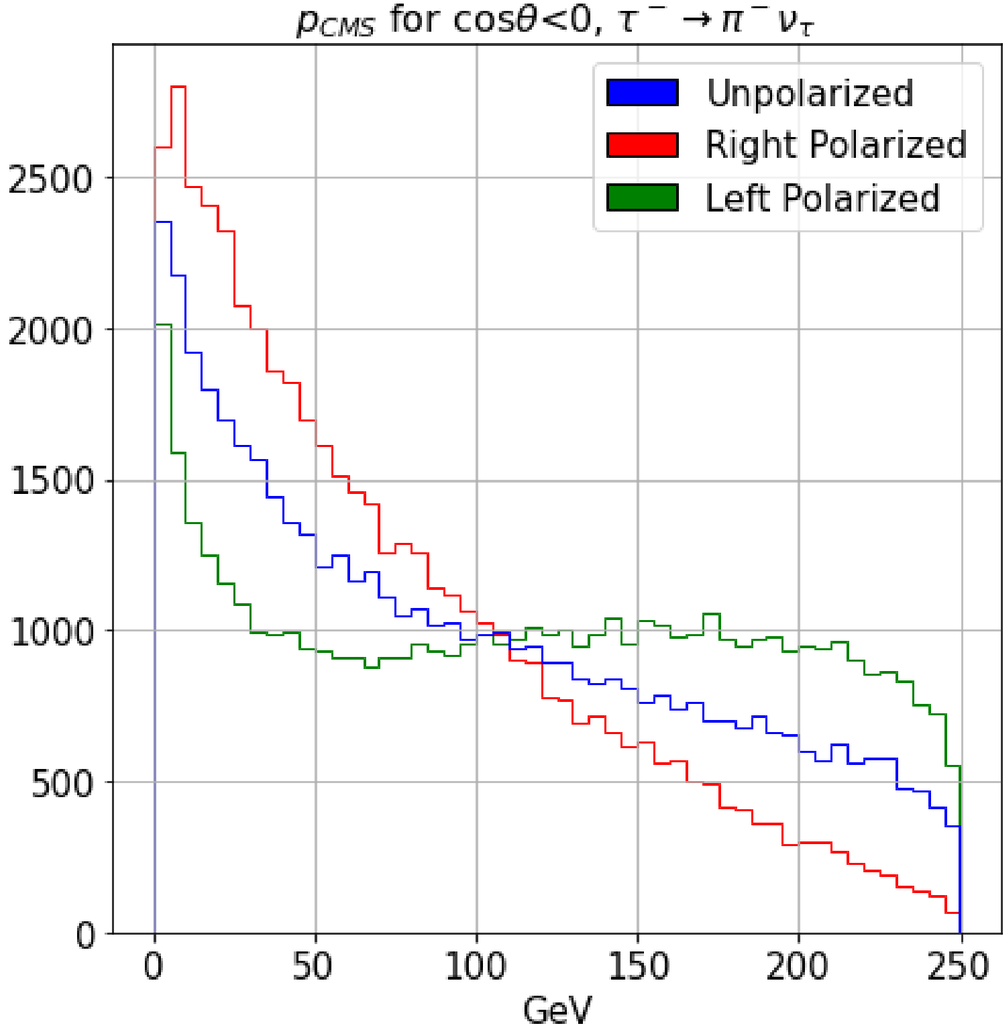
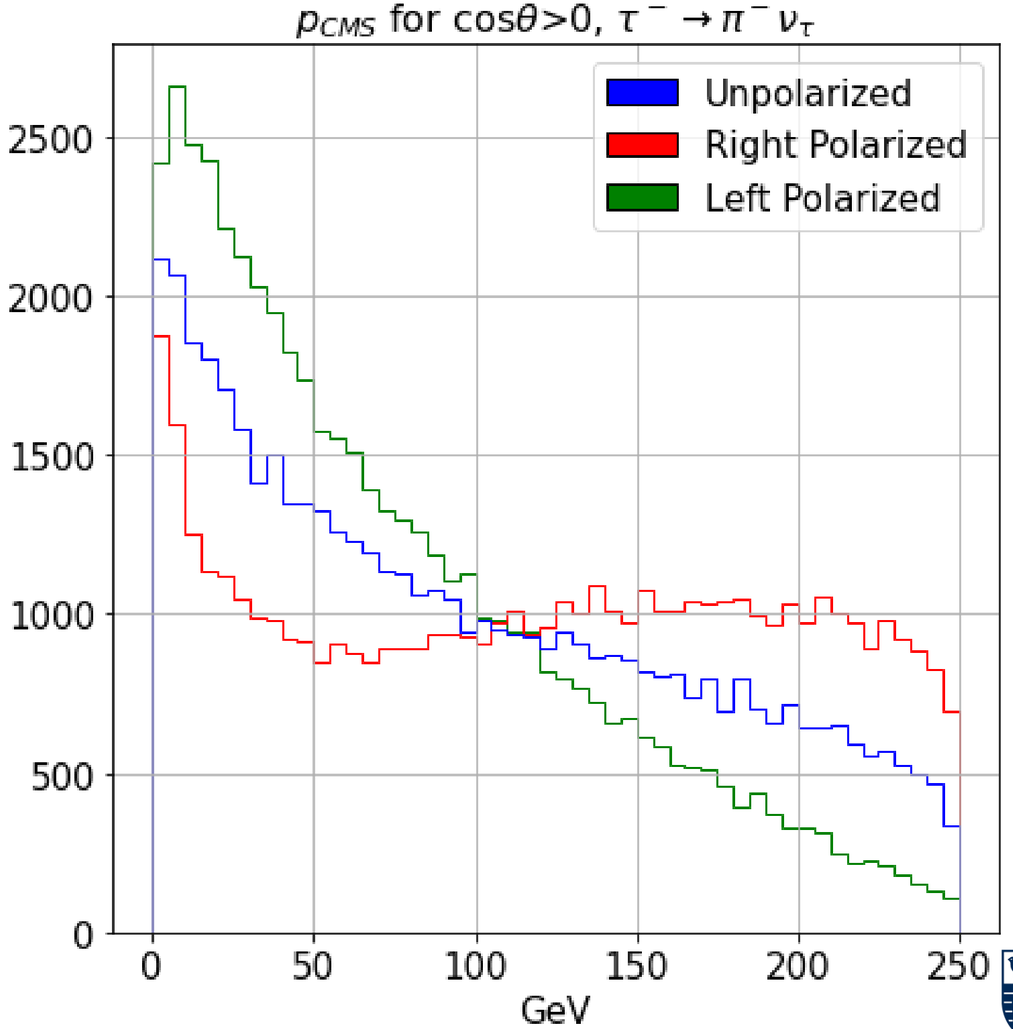
- Turning off weak contribution in the mediator (QED only)





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Conclusions

- Tau Polarimetry provides a tool for precision measurements of beam polarization at 10.58 GeV as could be applied to an upgraded SuperKEKB
- At ILC energies the increased role of the Z-boson as a mediator impacts the way the technique might be exploited for polarimetery compared to 10.58 GeV
- Exploiting existing 10.58 GeV data to assess systematic uncertainty limitations – stay tuned

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Backup Slides

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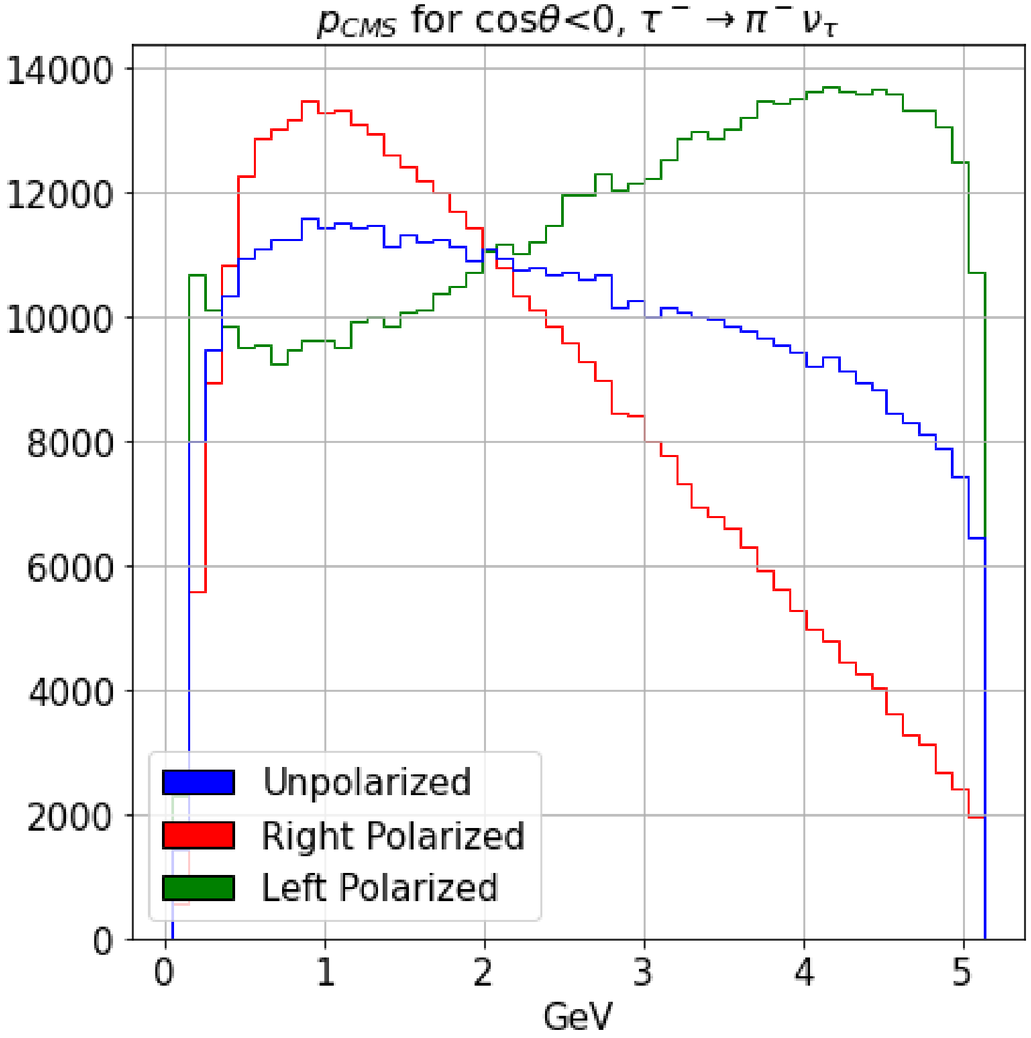
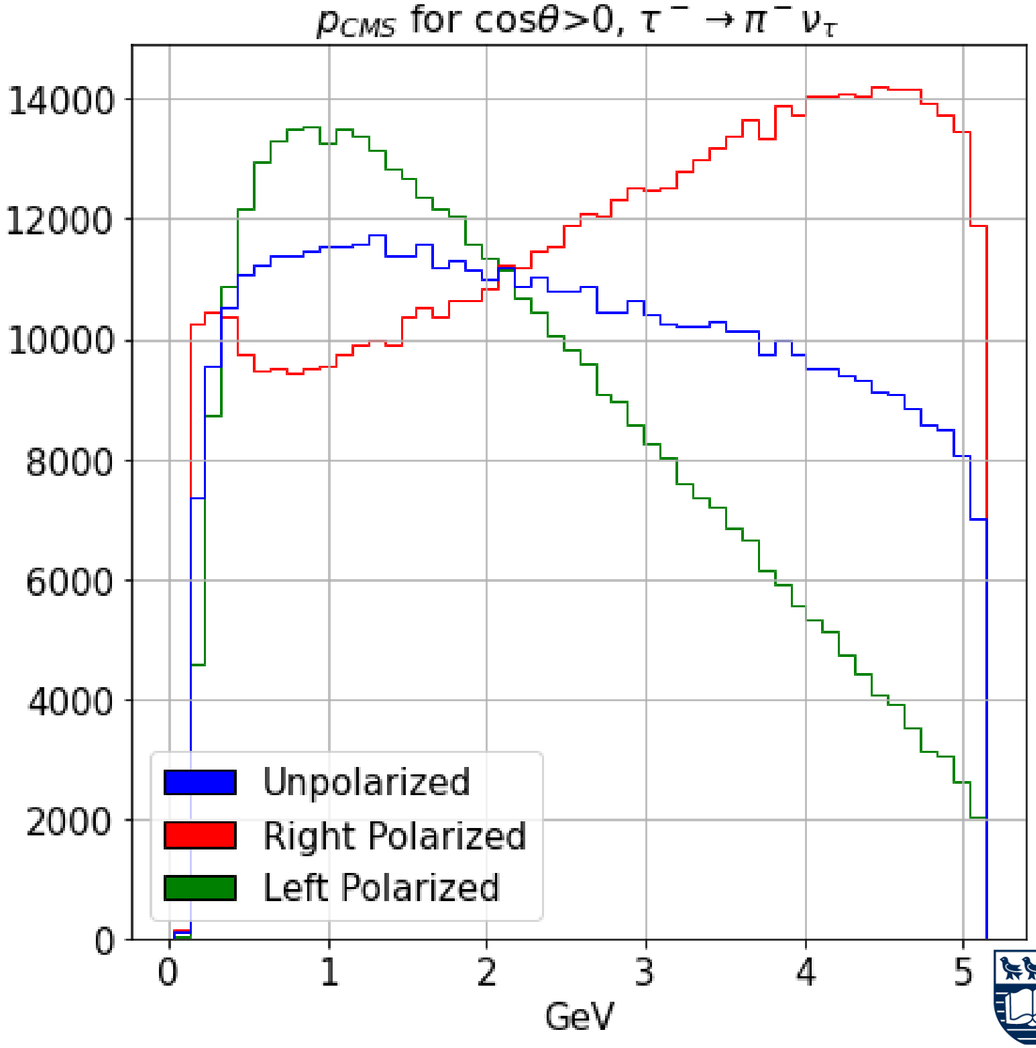
Polarization Sensitivity at 10.58 GeV, charge comparison

- Momentum distributions for final state pion in Tau decay





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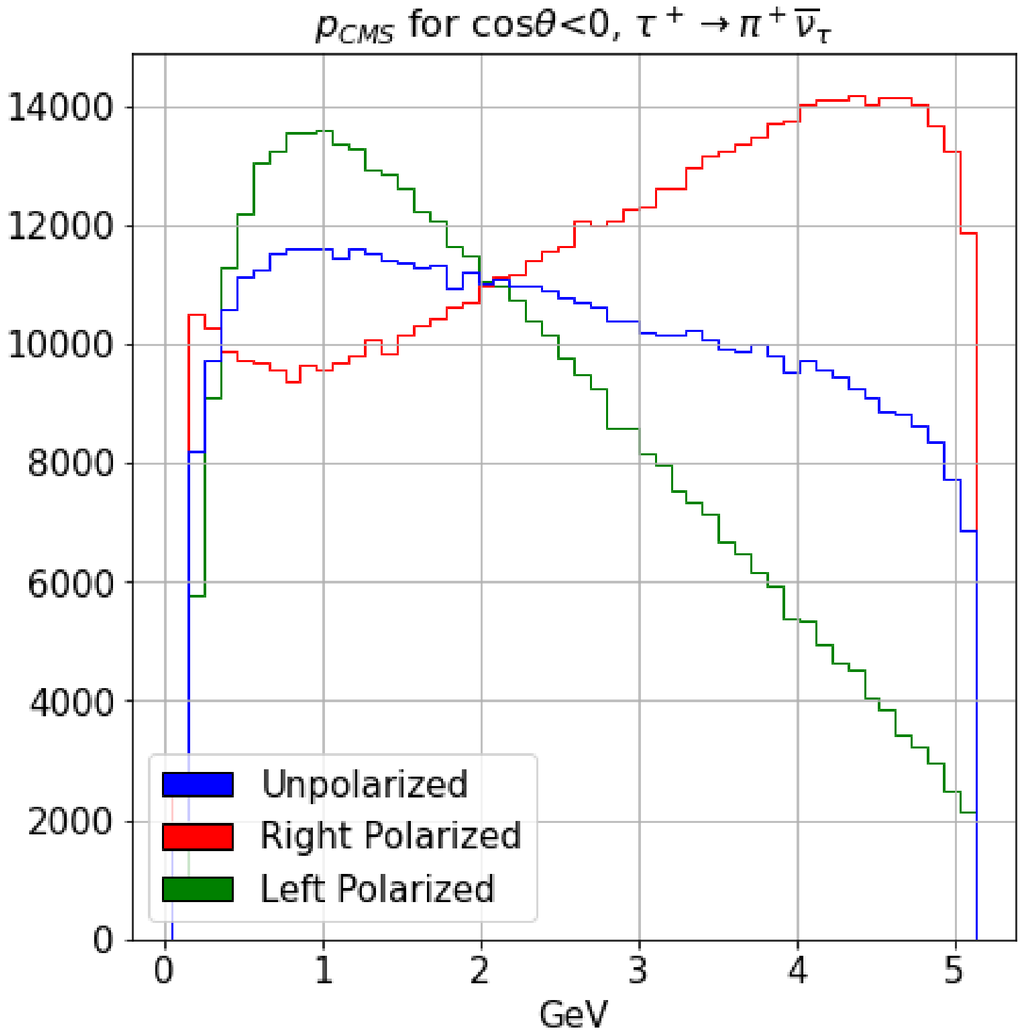

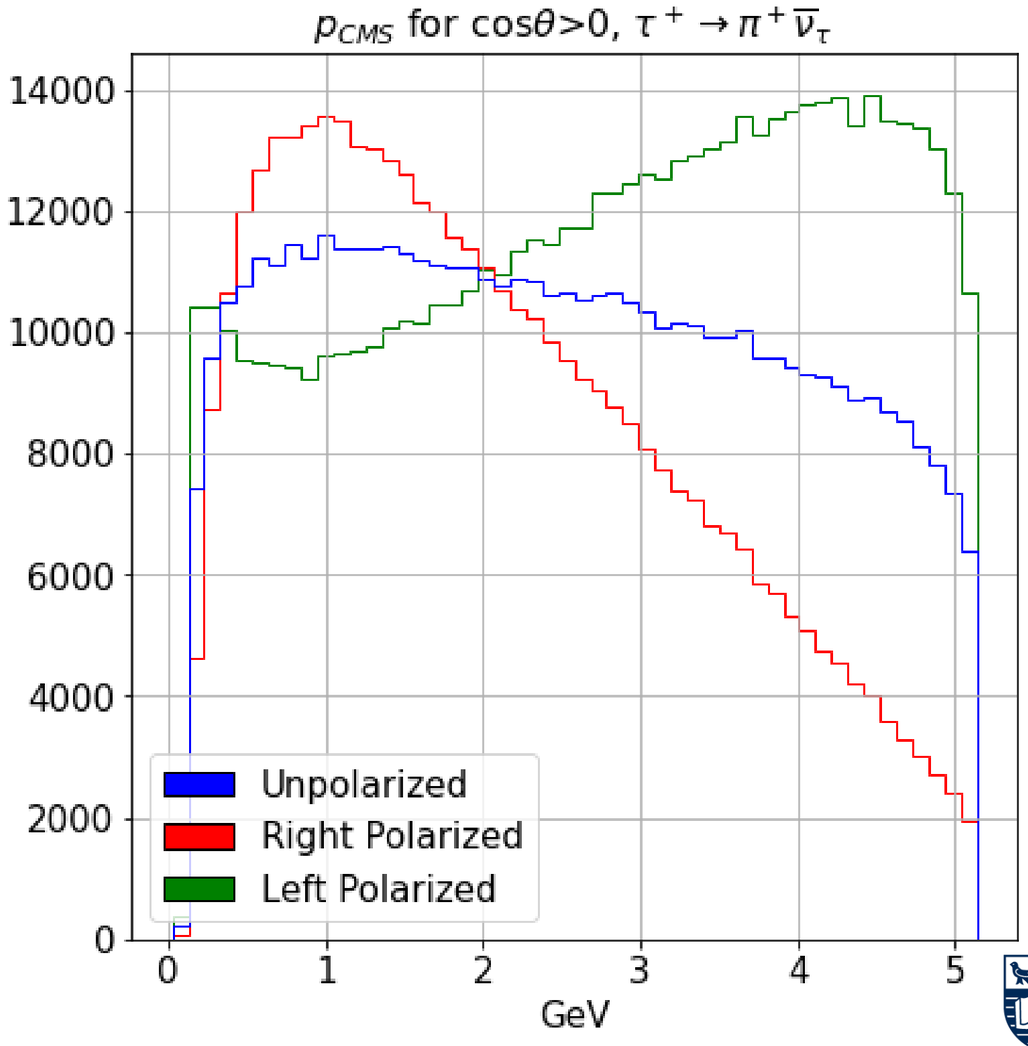

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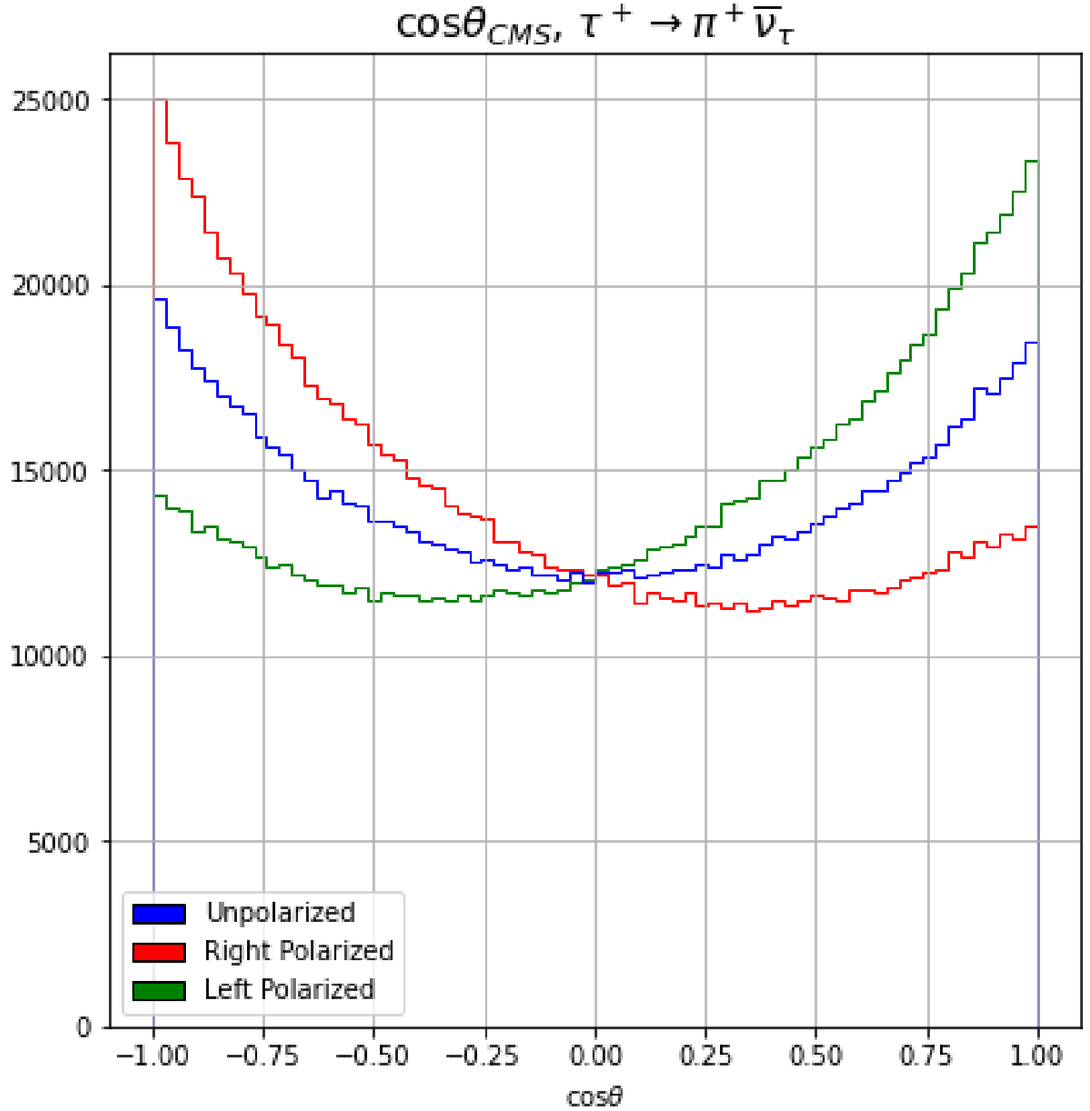

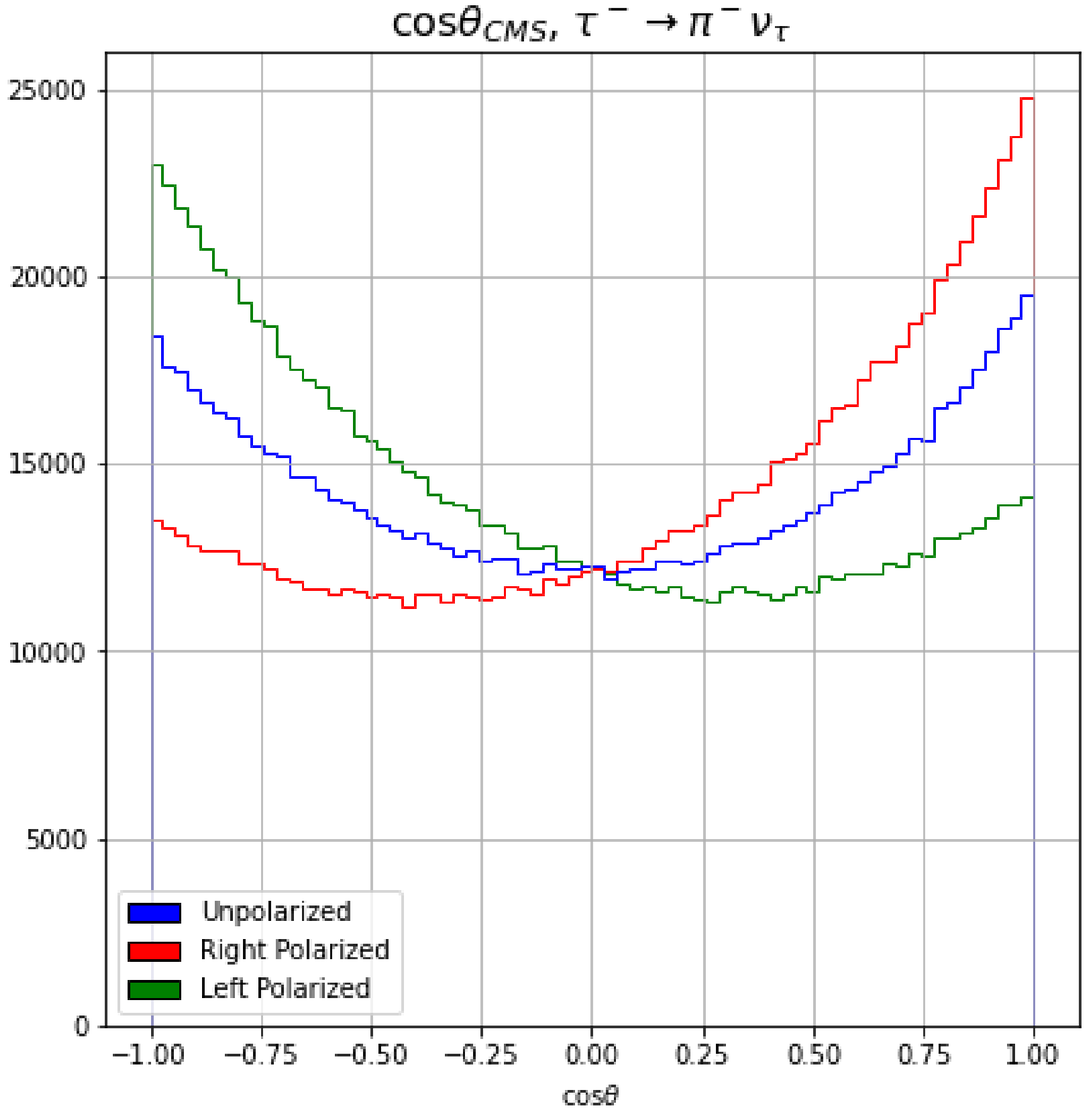

Polarization Sensitivity at 500 GeV, charge comparison

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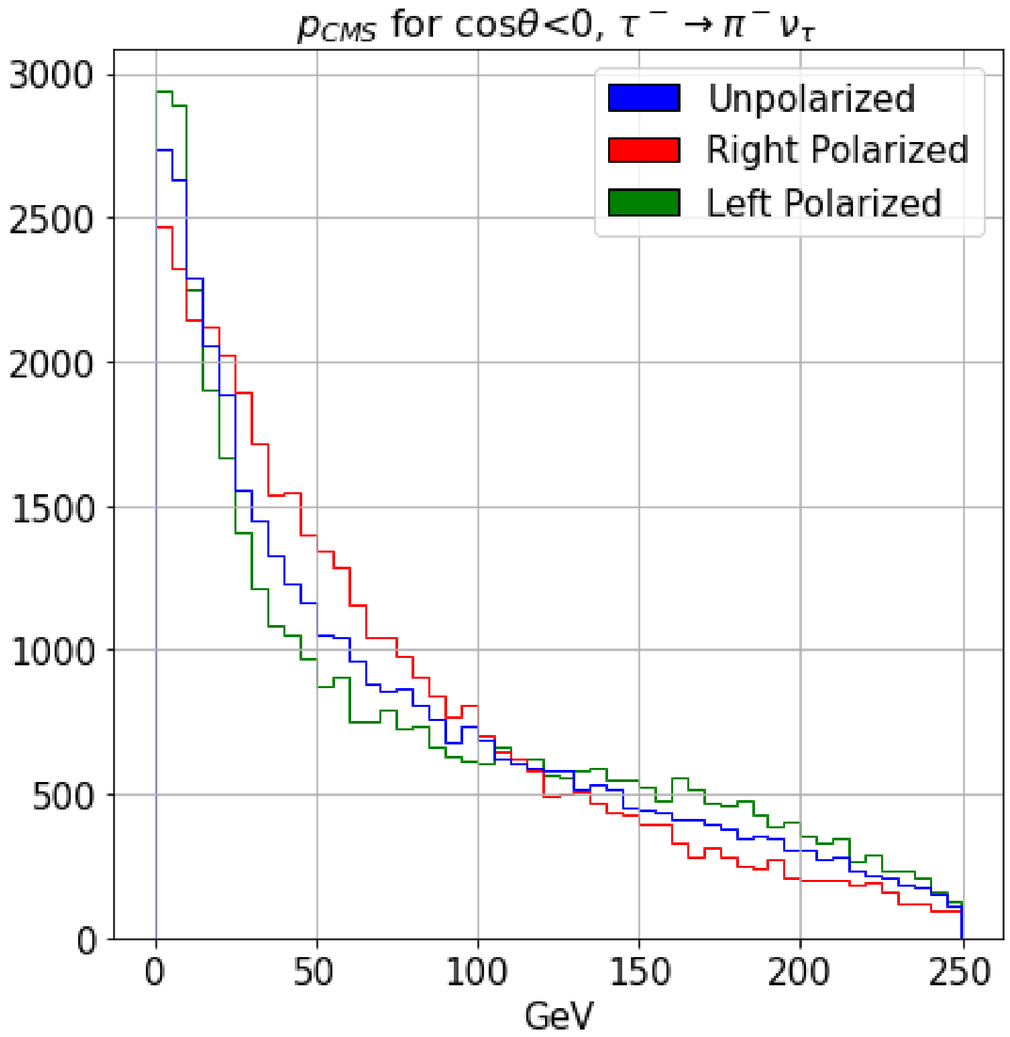

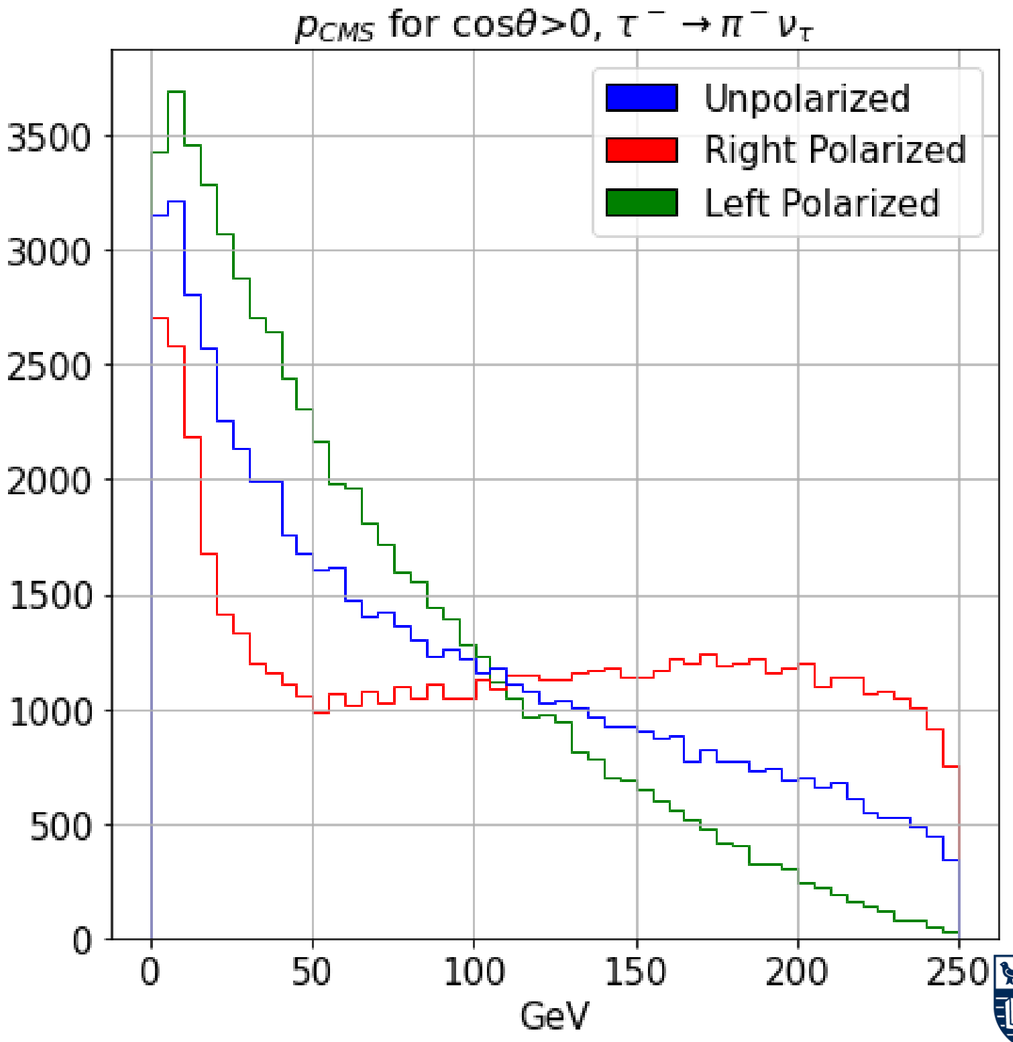

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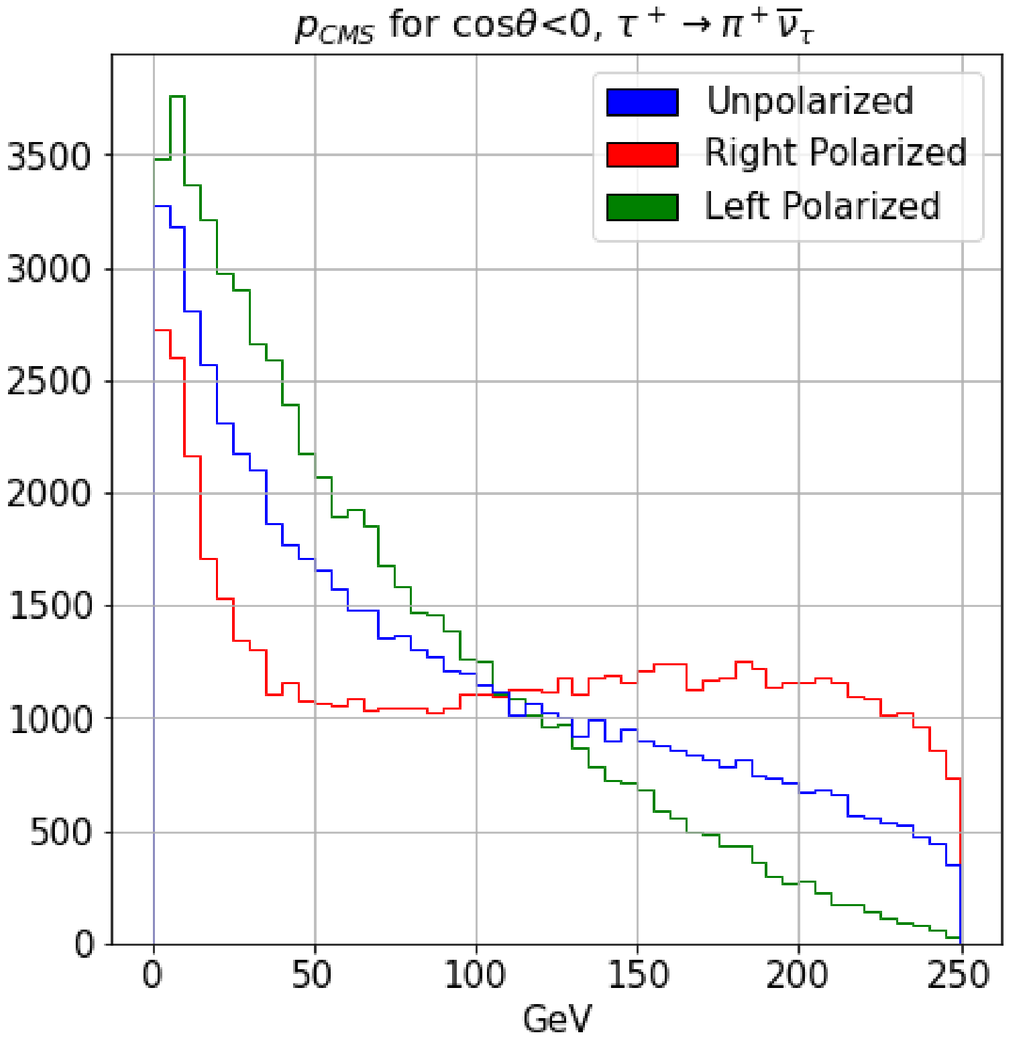

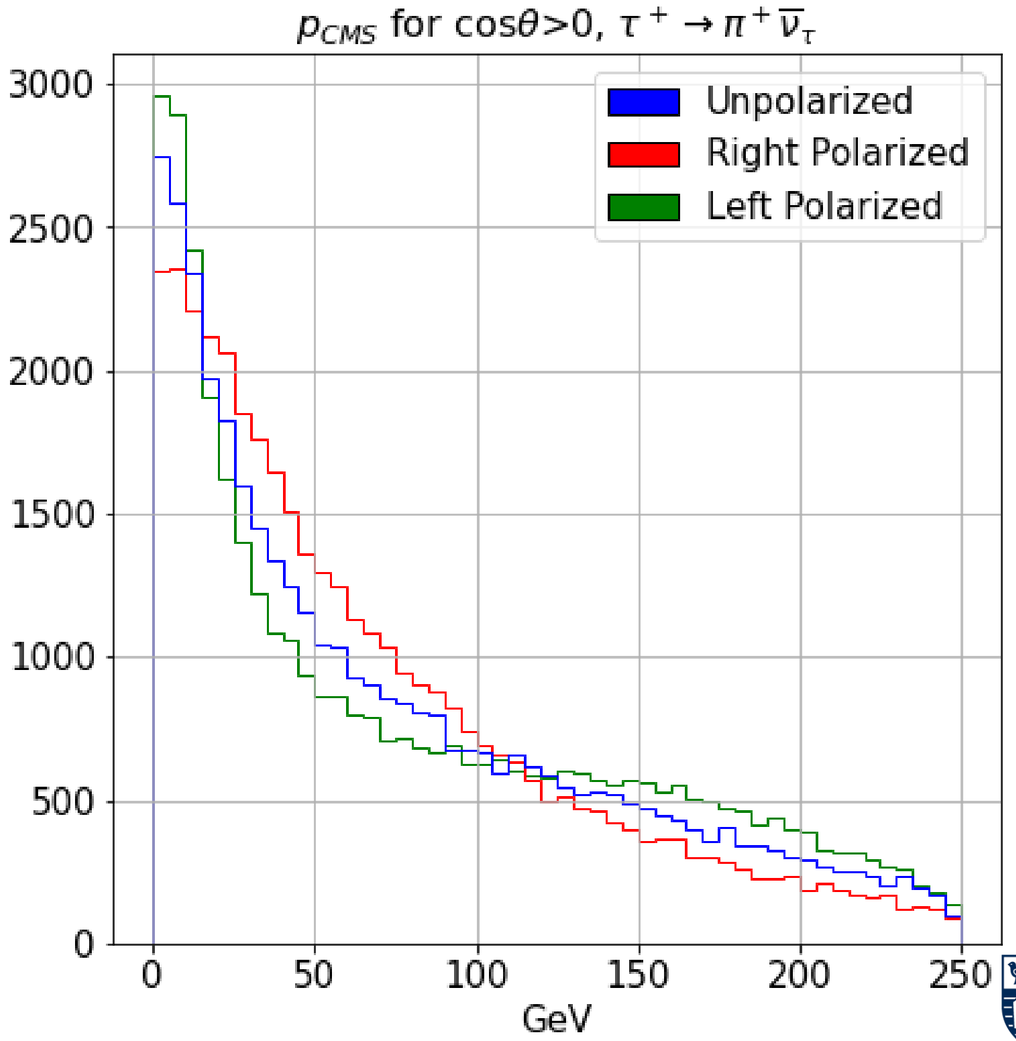

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