Beam Polarimetry with Taus for an Upgraded SuperKEKB

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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

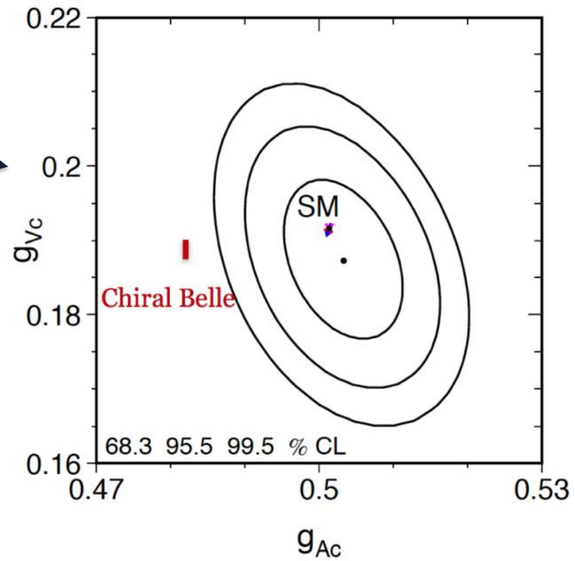
$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}}\left(\frac{G_f s}{4\pi\alpha Q_f}\right) g_A^e g_V^f \langle P \rangle \propto T_3^f - 2Q_f \sin^2\theta_W$$

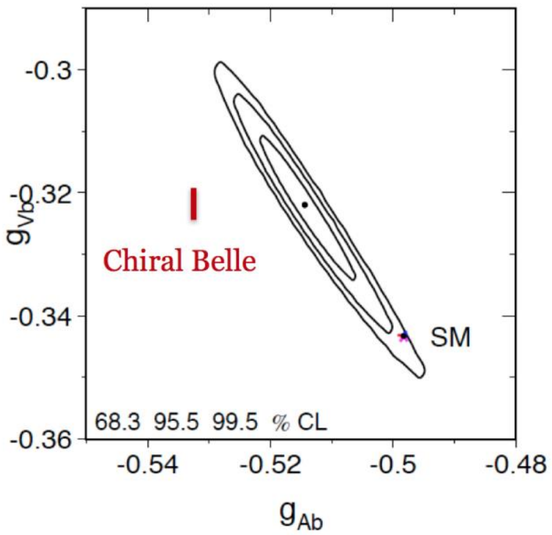
c-quark: **with 20 ab^{-1}** **b-quark:**

Chiral Belle ~7 times more precise

Chiral Belle ~4 times more precise

Red bars show expected +/- 1 sigma uncertainty





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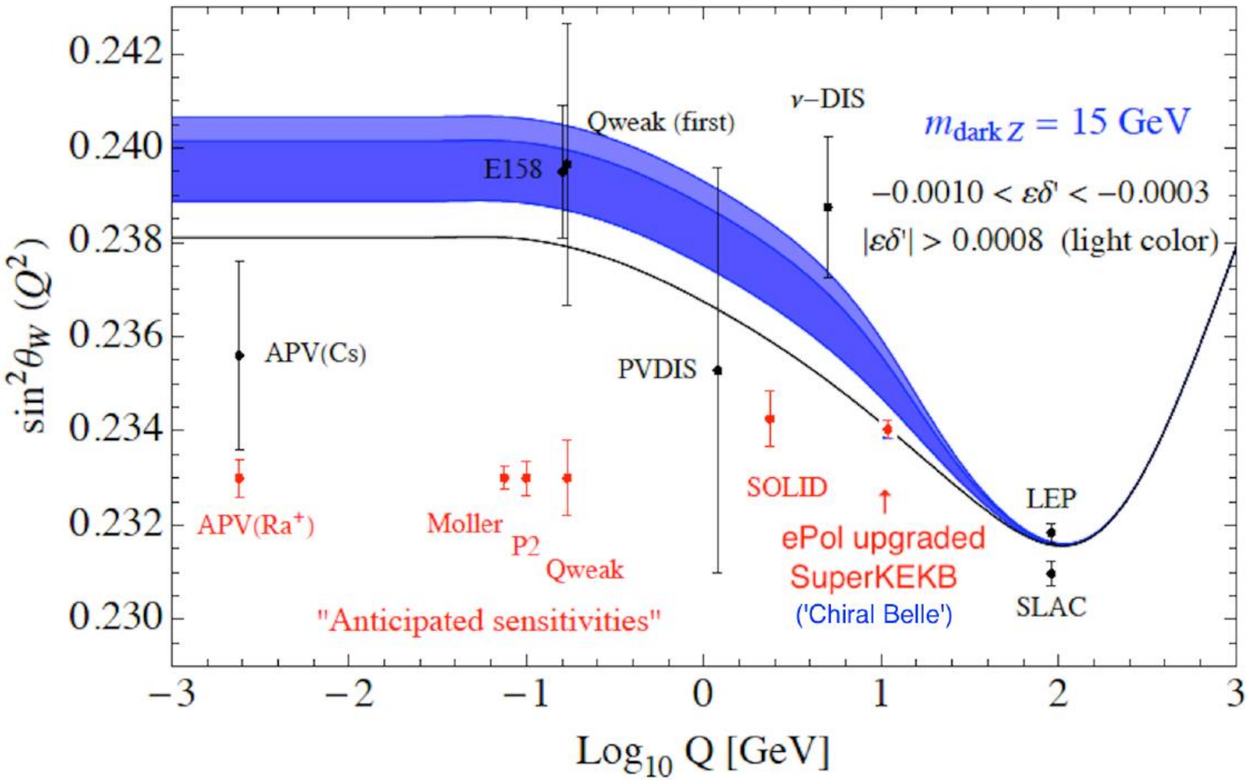

Red bars show expected sensitivity of future experiments

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

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Beam Polarization Motivation, Tau anomalous magnetic moment

- Beam polarization is being considered as a future upgrade to SuperKEKB
- Measurement of tau magnetic moment could be sensitive to new physics
- From Martin Hoferichter's presentation:

$$a_\mu^{\text{exp}} = 116{,}592{,}061(41) \times 10^{-11} \quad \textit{vs.} \quad a_\mu^{\text{SM}} = 116{,}591{,}810(43) \times 10^{-11}$$

Significant deviation in Muon g-2:

$$a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = 251(59) \times 10^{-11} [4.2\sigma]$$

Tau g-2 could scale with mass:

$$a_\tau^{\text{BSM}} \simeq a_\mu^{\text{BSM}} \left(\frac{m_\tau}{m_\mu} \right)^2 \simeq 0.7 \times 10^{-6}$$

- Polarized beams would give Belle II sensitivity to probe the tau magnetic moment at a level of sensitivity equivalent to the muon g-2 discrepancy in Minimal Flavour Violation scenarios

- Theory will need to be full NNLO for comparisons

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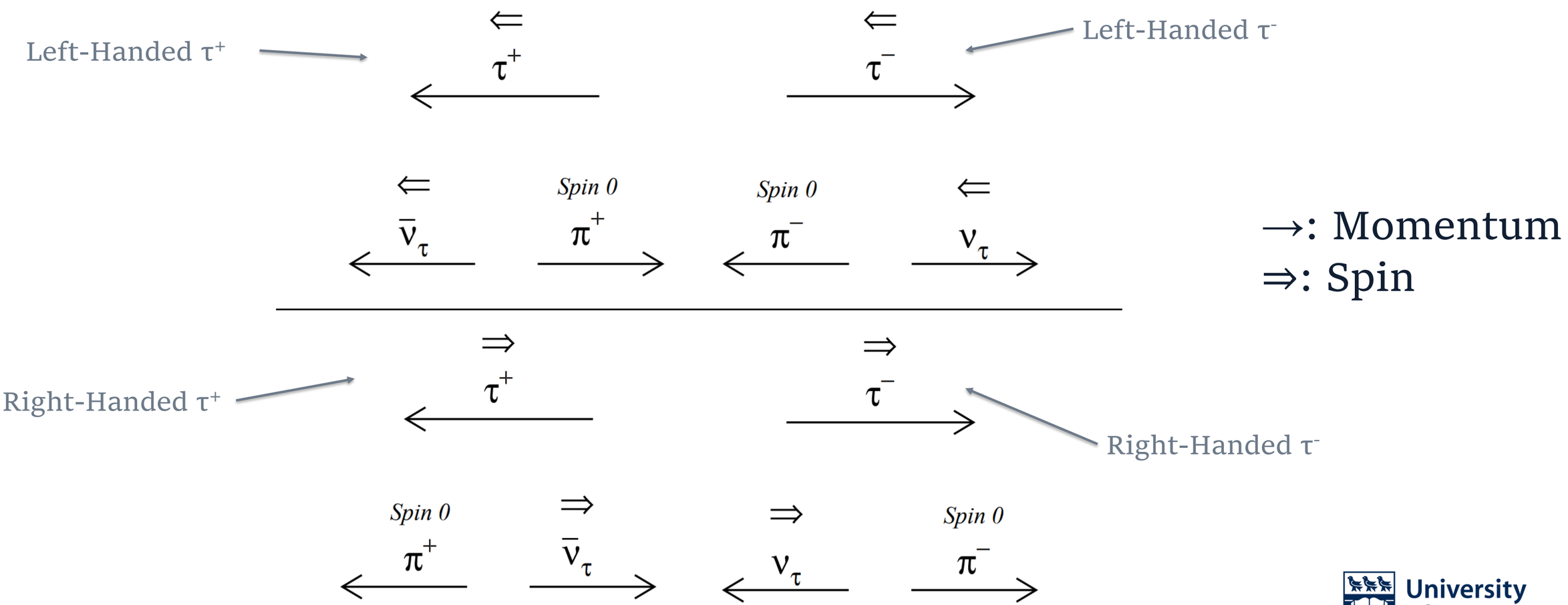
Polarization Sensitivity in Tau Decays

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



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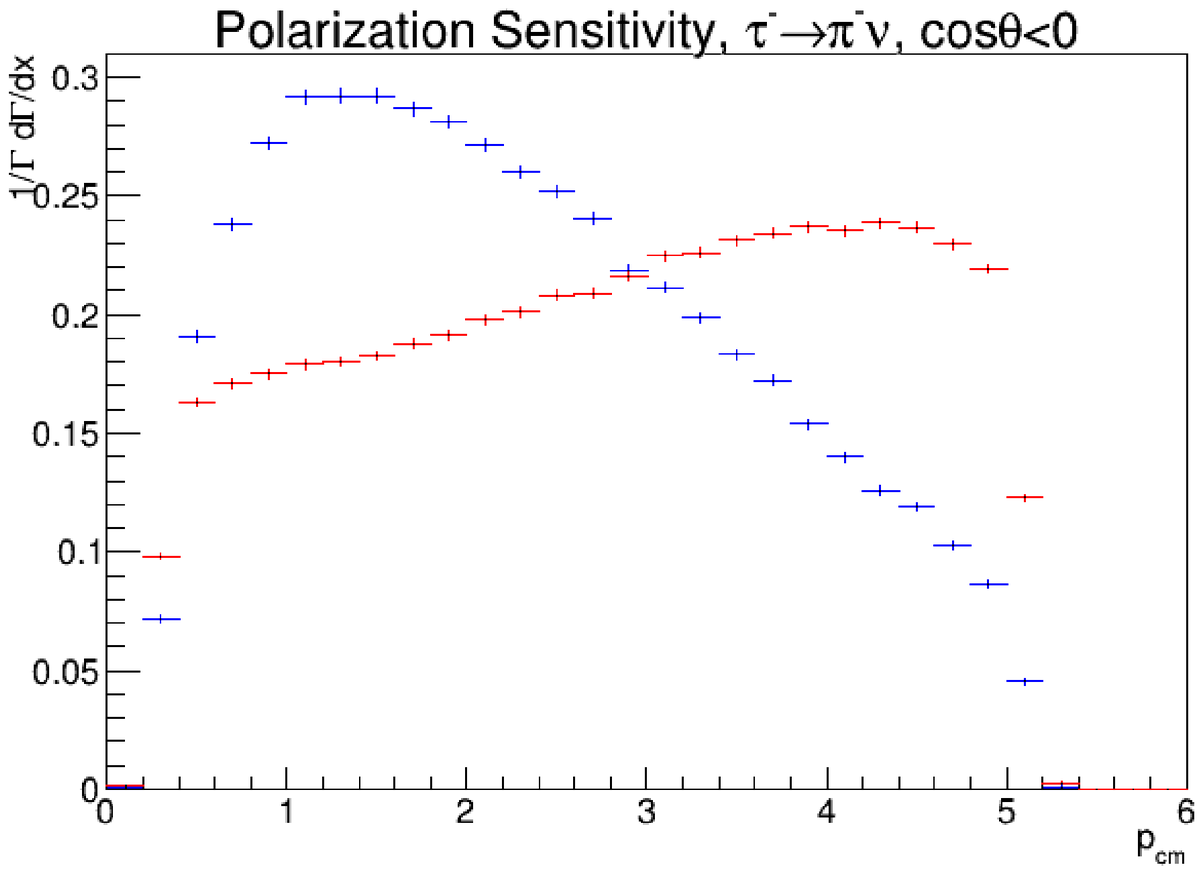
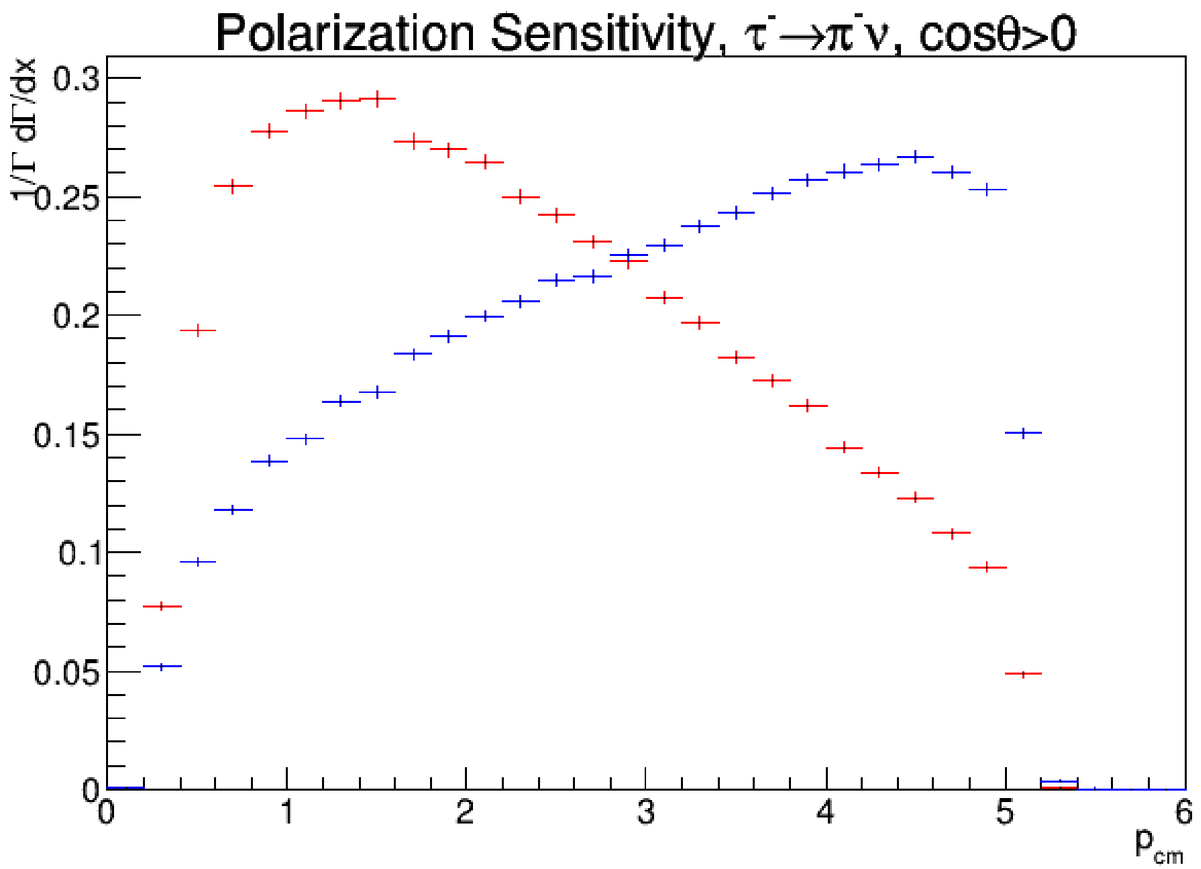
Pion Momentum, Polarization Sensitivity

- Polarization sensitivity is mirrored between the forward and backward region of the detector
- Theta is defined as the angle between the pion and the electron beam direction





Red: Left-Handed e^- beam, Blue: Right-Handed e^- beam

Rho, Polarization Sensitivity

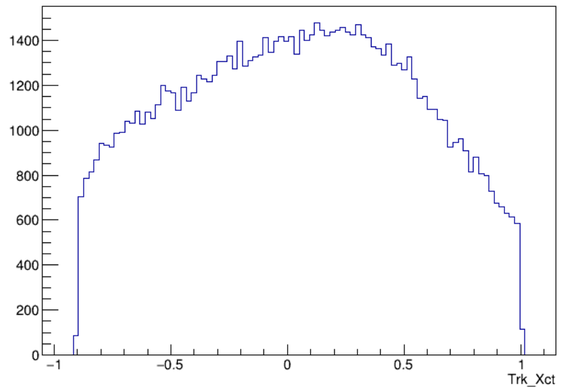
- Rho polarization sensitivity appears in two variables[1]

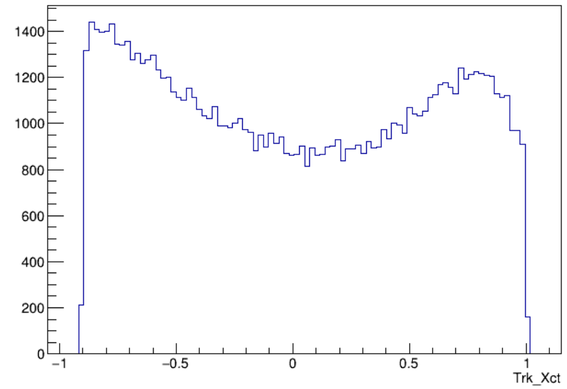
$$\cos\varphi = \frac{2x-1}{\sqrt{1-4m_\pi^2/m_\rho^2}} \qquad x = {E_\pi}/{E_\rho}$$

cosθ<0

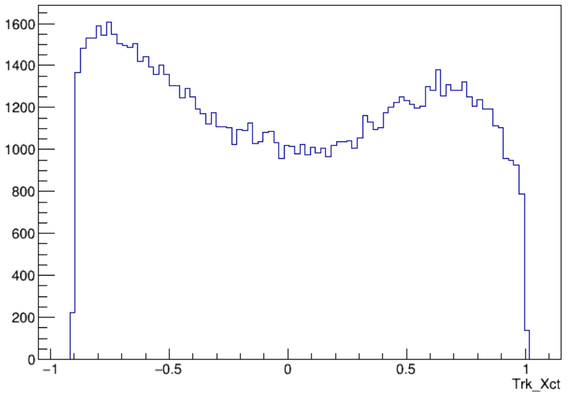
cosθ>0

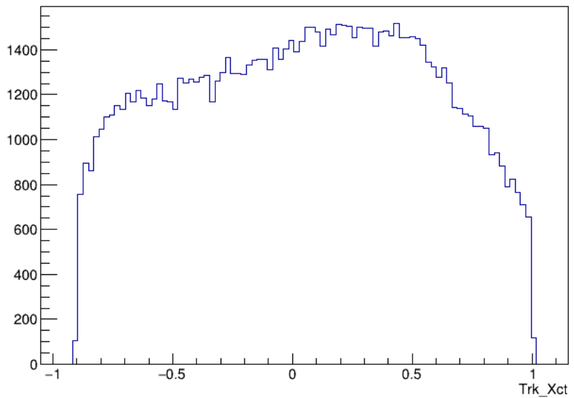
Left Polarized





Right Polarized





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[1] K. Hagiwara, A. Martin, D. Zeppenfeld, Tau Polarization Measurements at LEP and SLC, Phys. Lett. B. 235, 1998, DOI: 10.1016/0370-2693(90)90120-U

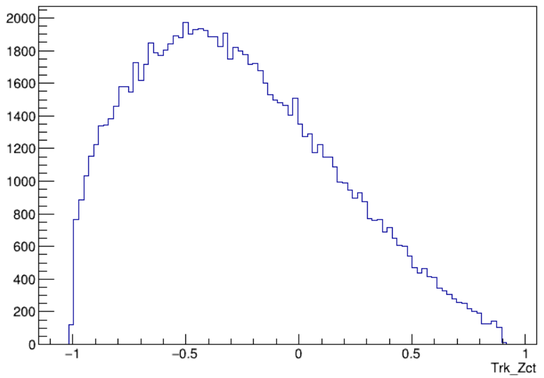
Rho, Polarization Sensitivity

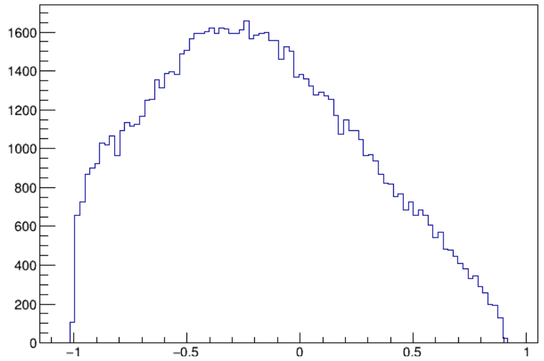
- Rho polarization sensitivity appears in two variables[1]

$$\cos\omega = \frac{2z - 1 - m_\rho^2/m_\tau^2}{1 - m_\rho^2/m_\tau^2} \qquad z = {E_\rho}\Big/{E_{\text{beam}}}$$

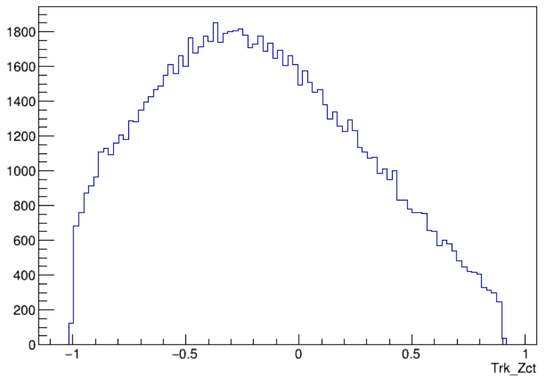
cosθ<0 cosθ>0

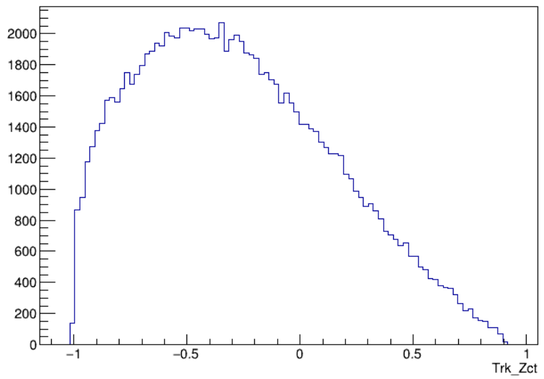
Left Polarized





Right Polarized





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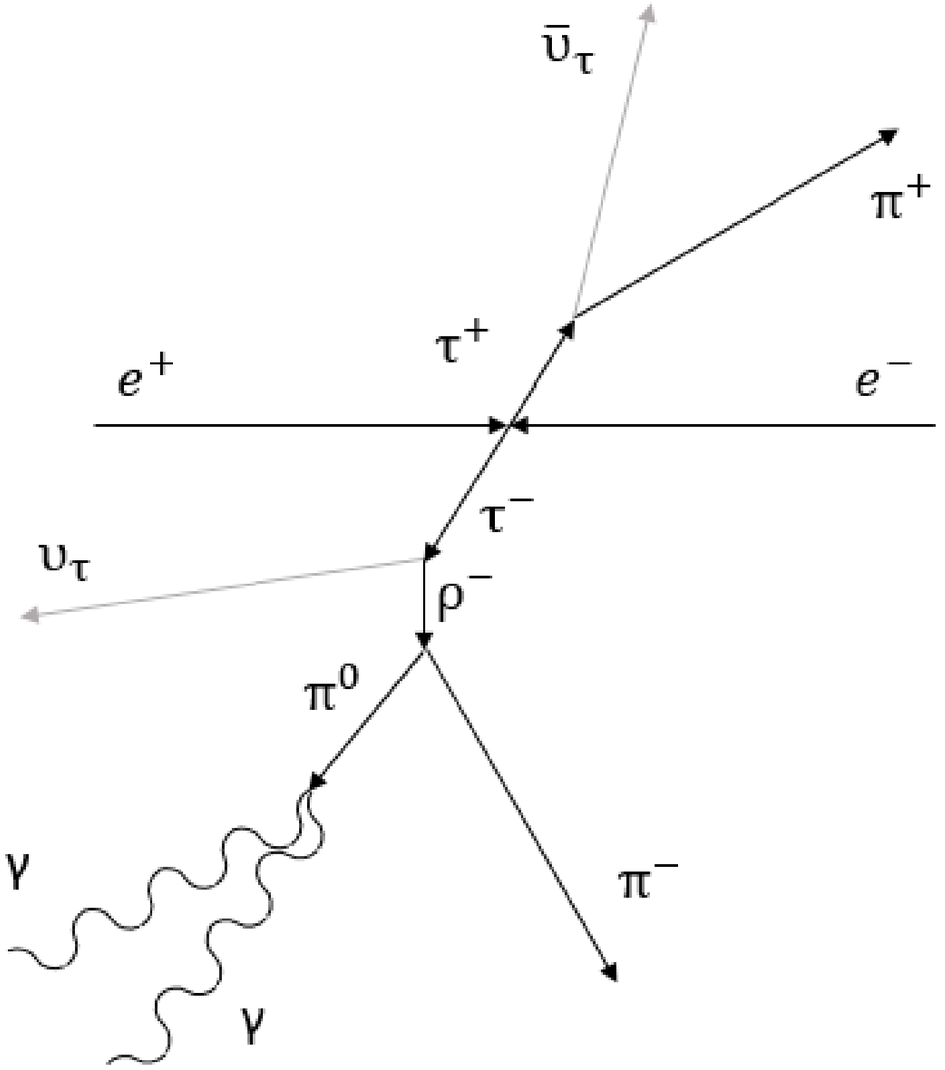
[1] K. Hagiwara, A. Martin, D. Zeppenfeld, Tau Polarization Measurements at LEP and SLC, Phys. Lett. B. 235, 1998, DOI: 10.1016/0370-2693(90)90120-U

Pion Analysis Status

- We developed the technique on BaBar
  - Using 32.28 fb^{-1} as a blind sample (424.18 fb^{-1} On-peak data available)
- We tag tau events by $\tau^{\pm} \rightarrow \pi^{\pm} n\pi^{0}\nu$
  - One charged track, n π^0s in $115\ \text{MeV} < M_{\pi^0} < 155\ \text{MeV}$
- Signal is $\tau^{\pm} \rightarrow \pi^{\pm}\nu$
  - Require no neutrals in signal hemisphere
  - Fail muon and electron PID
- P_T>1.2 GeV to remove 2 photon backgrounds
- Gives 98% pure tau sample
- 60% $\tau^{\pm} \rightarrow \pi^{\pm}\nu$ decays



- Pion analysis paused while we resolve an unidentified issue
- Developing Rho analysis in the mean time for conference results
- No PID on signal removes dominant systematic

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Polarization Modes

Tau Signal	Tau Tag	Status
$\tau \rightarrow \pi\nu$	$\tau \rightarrow \pi\nu$	Large Muon Backgrounds
$\tau \rightarrow \pi\nu$	$\tau \rightarrow e\nu\nu$	Large Bhabha Background
$\tau \rightarrow \pi\nu$	$\tau \rightarrow \pi\pi\pi\nu$	Low Statistics
$\tau \rightarrow \pi\nu$	$\tau \rightarrow \pi\pi^0\nu$	Unresolved Issue
$\tau \rightarrow \pi\pi^0\nu$	$\tau \rightarrow e\nu\nu$	In Progress
$\tau \rightarrow \pi\pi^0\nu$	$\tau \rightarrow \mu\nu\nu$	Future Possibility
$\tau \rightarrow \pi\pi^0\nu$	$\tau \rightarrow \pi\nu$	Future Possibility

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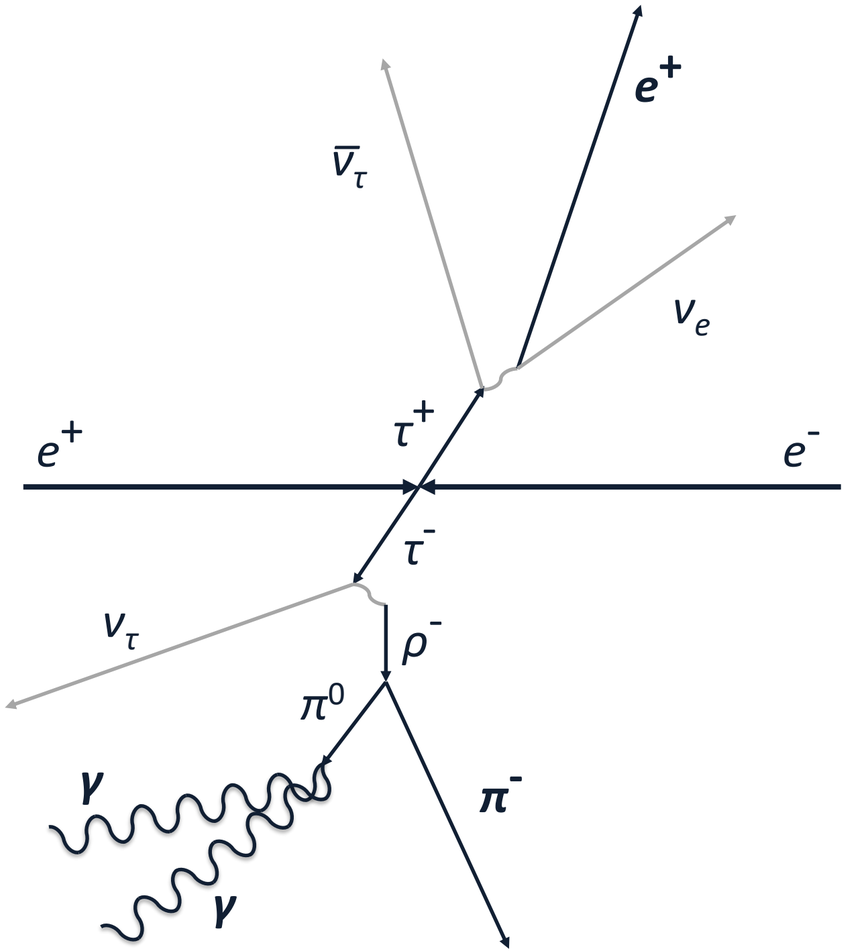
Rho Event Selection

- We developed the technique on BaBar
  - Using 32.28 fb^{-1} as a blind sample (424.18 fb^{-1} On-peak data available)
- Signal events are $\tau^{\pm} \rightarrow \pi^{\pm}\pi^{o}\nu_{\tau}$
  - One charged track, a π^{o} in $115\ \mathrm{MeV} < m_{\pi^0} < 155\ \mathrm{MeV}$
- Tag event with $\tau^{\pm} \rightarrow e^{\pm}\nu_{e}\nu_{\tau}$
  - Require no neutrals in signal hemisphere
  - Accepted by electron PID
- P_T>1.2 GeV to remove 2 photon backgrounds
- Gives 99.7% pure tau sample
- 90% $\tau^{\pm} \rightarrow \pi^{\pm}\pi^{o}\nu_{\tau}$ decays



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Event Selection

- Largest background source is bhabhas
- MC predicted number of events in the selected data sample

MC Type	Luminosity Weighted	Ratio
Bhabha	598	0.003
μμ	0	0.000
uds	10	0.000
cc̄	4	0.000
ττ	206089	0.997

Tau Decay	Ratio
$\tau \to e\nu$	0.000
$\tau \to \mu\nu$	0.000
$\tau \to \pi\nu$	0.000
$\tau \to \pi\pi^0\nu$	0.900
$\tau \to \pi\pi^0\pi^0\nu$	0.080
$\tau \to$ else	0.019

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Polarization Fit

- We employ the Barlow&Beeston[2] template fit methodology
- MC and data is binned in 3D histograms of cosω vs cosϕ 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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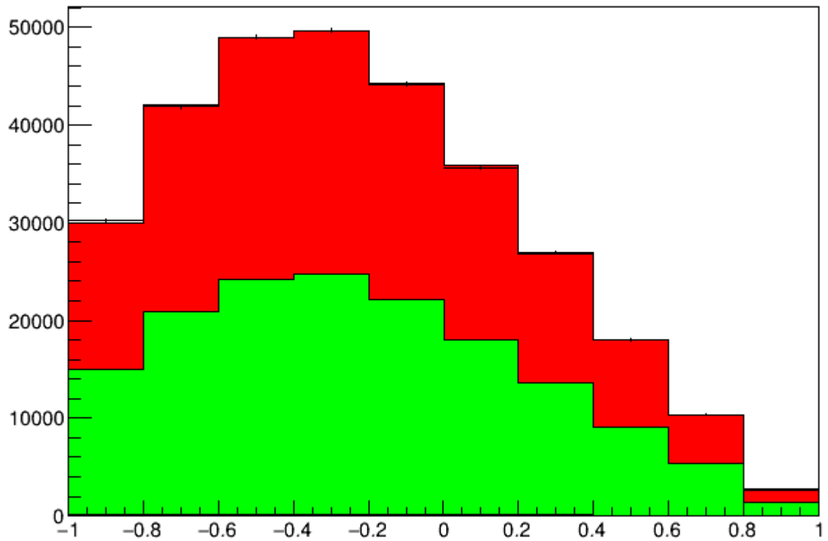
[2] R. Barlow, C. Beeston; Computer Physics Communications, Volume 77, Issue 2, 1993, Pages 219-228, https://doi.org/10.1016/0010-4655(93)90005-W

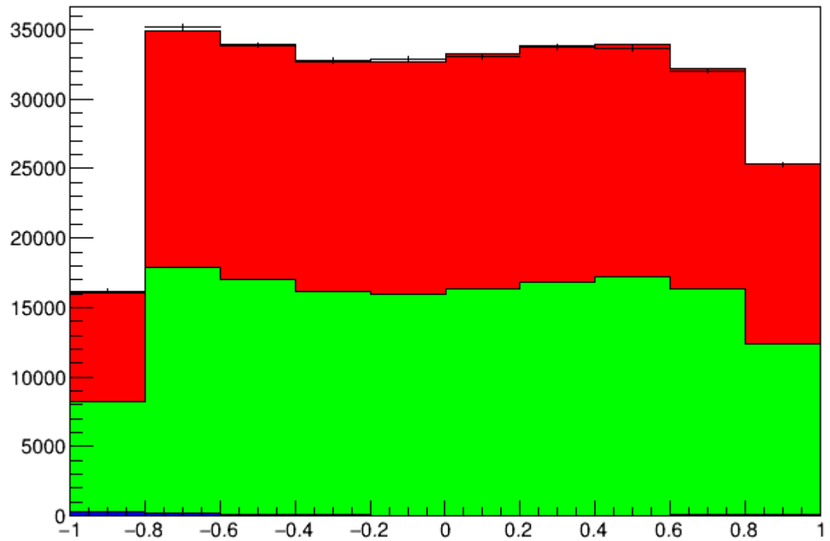
Template Example

- Fit Projections
- Data as points
- Left Polarized Contribution is red, Right Polarized in green
- Bhabha background is dark blue

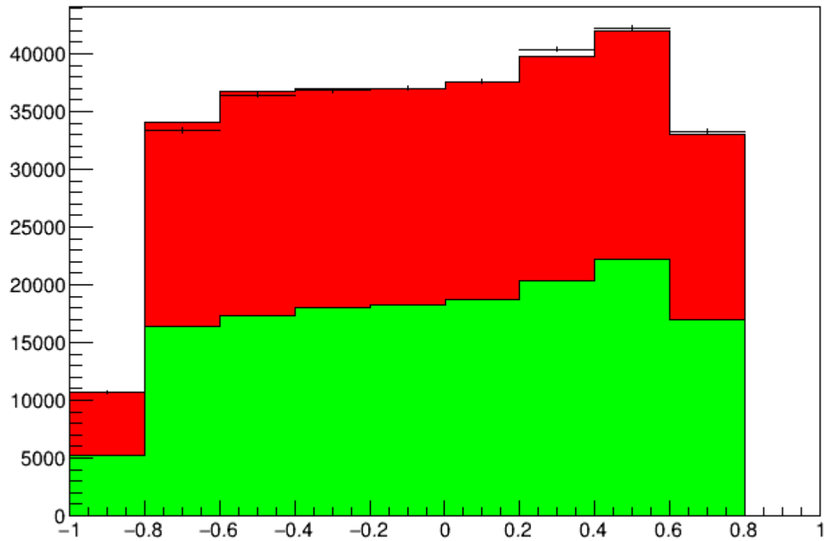
cosω



cosϕ



cosθ



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Fit Results and Systematic Uncertainties

Source	Value
Track-Neutral Association	0.0027
Pi0 Likelihood	0.0013
Neutrals, 50 MeV Cut	0.0013
$\cos\varphi$	0.0013
Neutrals, 100 MeV Cut	0.0011
Pi0 Upper Mass Cut	0.0011
Angular Resolution	0.0010
Pi0 Lower Mass Cut	0.0009
Electron PID	0.0006
Backgrounds	0.0006
Event p_T	0.0006
$\cos\omega$	0.0002
Boost	0.0002
Momentum Resolution	0.0002
Rho Mass	0.0002
Branching Fraction	0.0001
Sum	0.0042

BaBar systematics, 32.28 fb^{-1} study sample

Dataset, Rho Analysis	Statistical Uncertainty
Run 3 (32.28 fb^{-1})	0.0125
Run 2 (68.19 fb^{-1})	0.0090
Projected 424.18 fb^{-1}	0.0035

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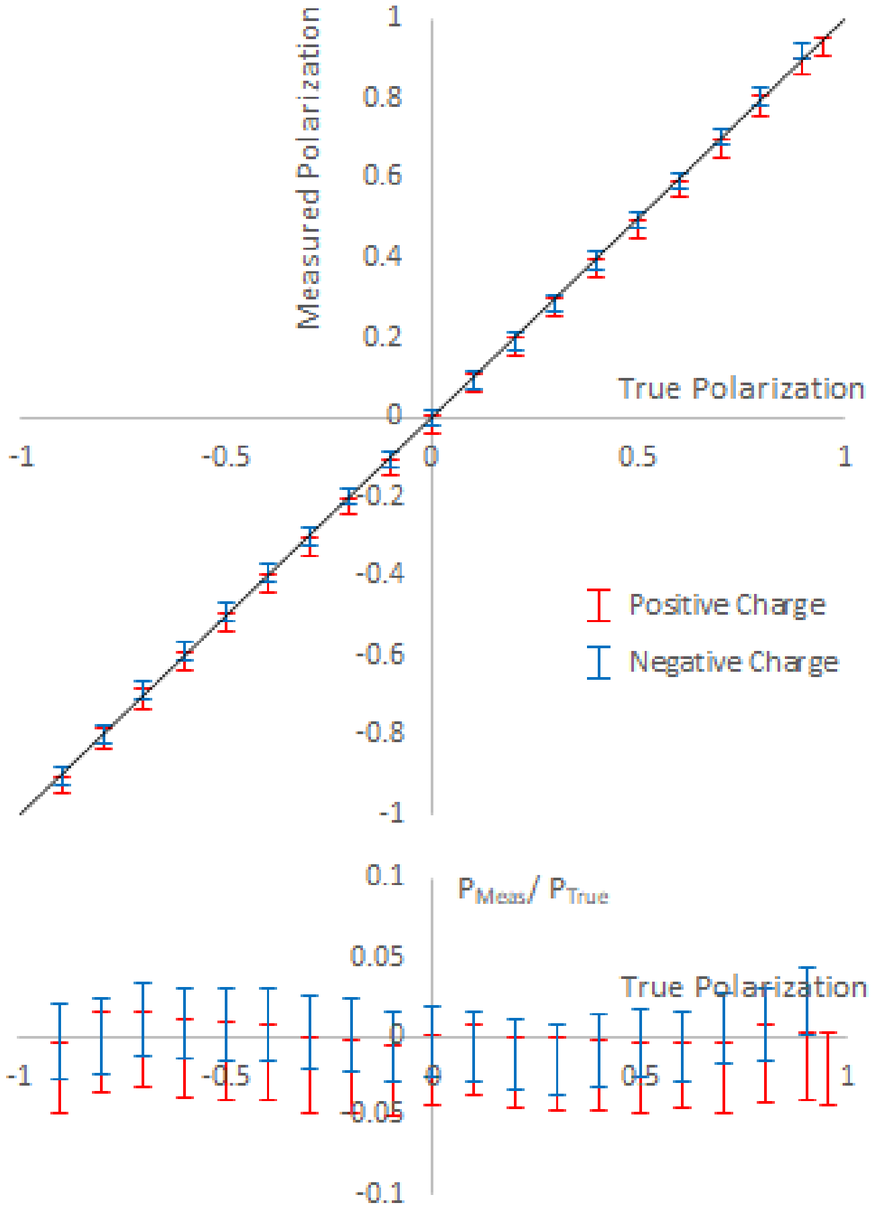
Absolute Polarization Sensitivity

- By mixing the polarized tau MC together, data-like samples with any beam polarization can be created and measured



Conclusions

- Pion Analysis identified muon PID as dominant systematic effect
  - Currently working to resolve an unidentified issue before proceeding
  - Will finish analysis in the future
- Rho Analysis is showing a similar level of sensitivity to polarization
  - Fit reported statistical uncertainty with the rho mode in 32 fb^{-1} data of 0.0125, compared to uncertainty of 0.0112 from the pion mode
  - Approved to unblind and analyze full data set
  - Currently finished Run 2 and Run 3
  - Run 2 has ~60fb^{-1} of data and the systematic uncertainties drop to 0.0034
    - Don’t expect any further reductions with more statistics
- Pending BaBar approval will show results of Rho analysis at Lake Louise

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