Measurement of Beam Polarization at an e^+e^- B-Factory with New Tau Polarimetry Technique

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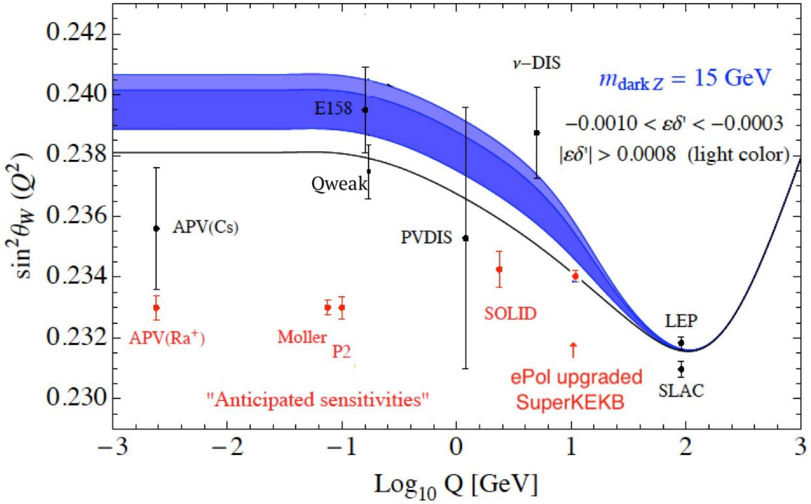
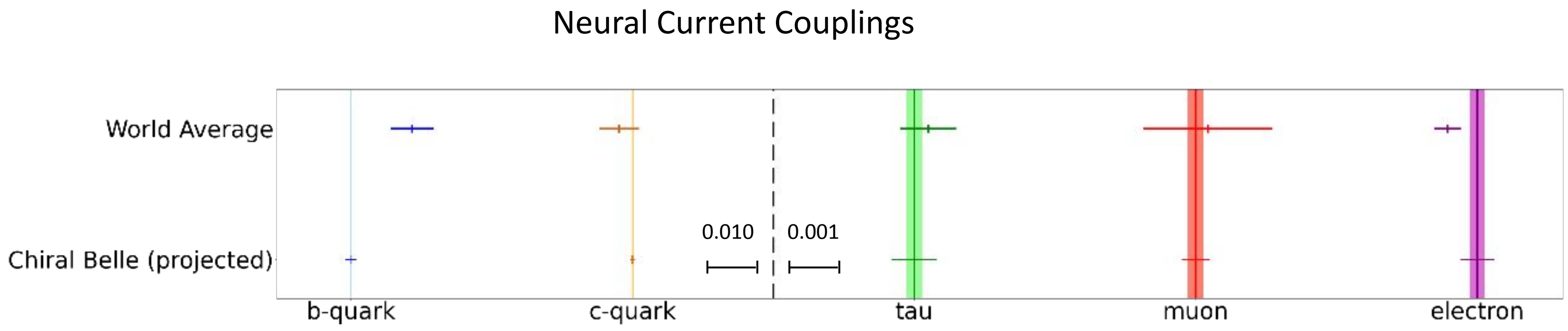
Beam Polarization Motivation

From Michael Roney's talk before the break we saw the motivations behind Chiral Belle and beam polarization





For these future measurements we expect the dominant systematic uncertainty to be the precision with which the average beam polarization, <P>, is known

Compton polarimeters, have an uncertainty associated with modelling the spin transport from the polarimeter to the interaction point (IP)

By using Tau Polarimetry we can extract the average beam polarization directly from the data at the IP

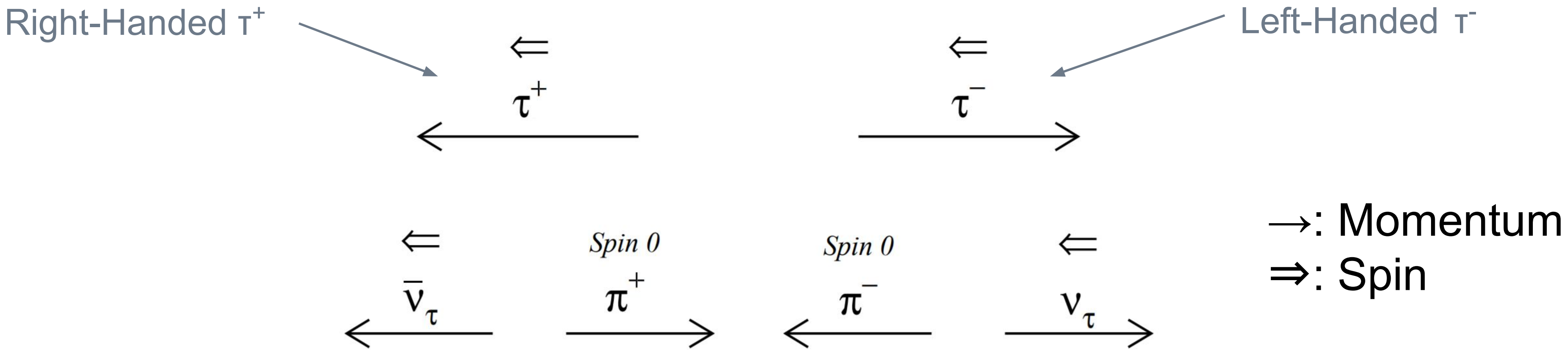
Tau Polarimetry

- The polarization of tau's (P_τ) produced in e^+e^- collisions at 10.58 GeV is related to the electron beam polarization (P_e) through:

$$P_{\tau^-} = P_e \frac{\cos\theta}{1+\cos^2\theta} - \frac{8G_F s g_V^\tau}{4\sqrt{2}\pi\alpha}\left(g_A^\tau \frac{|\vec{p}|}{p^0} + 2g_A^e \frac{\cos\theta}{1+\cos^2\theta}\right)$$

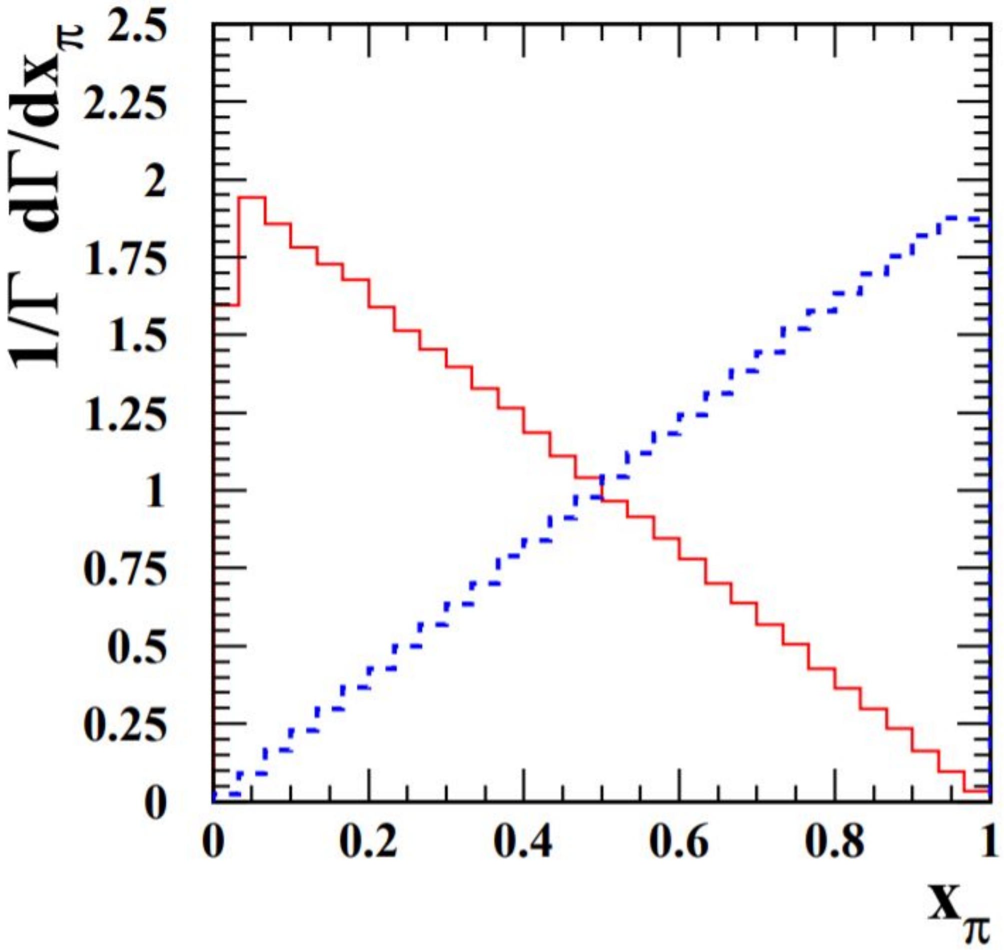
Note: cosθ defined as the polar angle of the τ^- with respect to the electron beam

- Tau polarization information can be extracted from the kinematics of the tau decay



Tau Polarimetry

- With a large statistical sample, the kinematic biases due to τ polarization are quite distinguishable

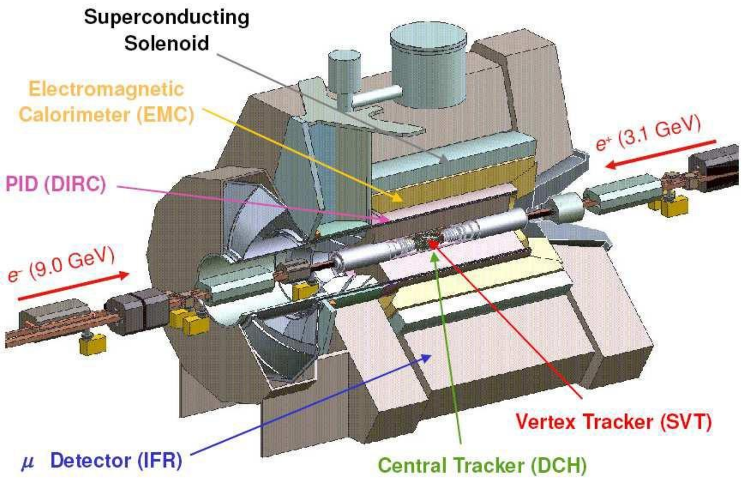


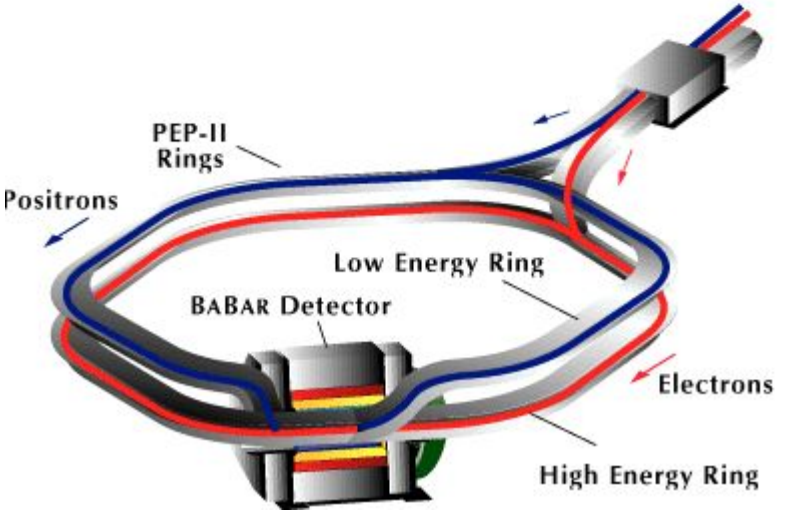
Red: Left-handed τ^- / Right-handed τ^+
Blue: Right-handed τ^- / Left-handed τ^+

momentum/Energy

*B*A*B*AR and PEP-II

*B*A*B*AR and PEP-II operated at SLAC from 1999-2008

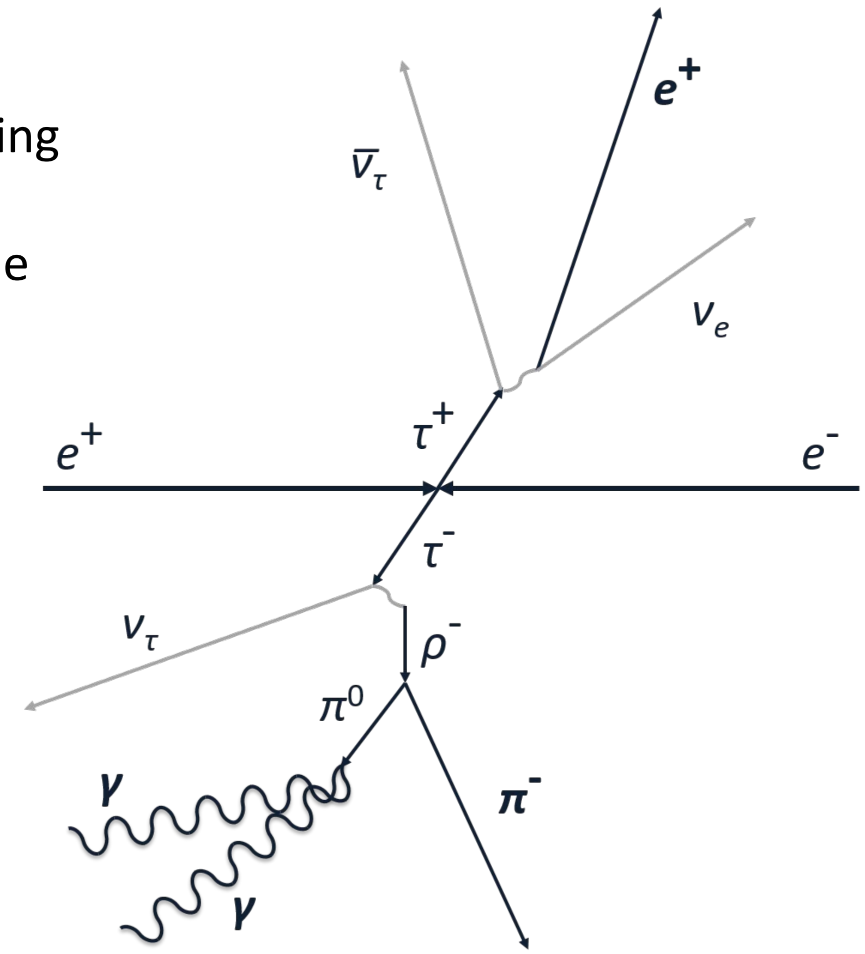




- Over 6 run periods *B*A*B*AR collected 432 fb^{-1} of data on the ϒ(4S) resonance (10.58 GeV)
- PEP-II collided electrons and positrons together at 9.0 and 3.1 GeV
- No beam polarization is expected at PEP-II
- Similarities between *B*A*B*AR and Belle II detectors means results should be comparable

Tau Event Selection

- As a proof of concept we have developed Tau Polarimetry at *BABAR* using $\tau^{\pm} \rightarrow \rho^{\pm}\nu_{\tau} \rightarrow \pi^{\pm}\pi^{0}\nu_{\tau}$ decays
- We expect uncertainties to be highly correlated between detectors due to similar designs
- Developed the technique on 32.28 fb^{-1} of data
  - Final measurement performed on remaining 391.90 fb^{-1}
- Selected tau events in a 1v1 topology, (ρ vs. e)
  - ρ has large branching fraction, e for clean tag
- Signal candidates are defined as a charged particle with a π^{0}
- $q\bar{q}$ events are eliminated with the electron requirement
- Angular cuts and a minimum p_T of 1.2 GeV reduce two photon and Bhabha contamination

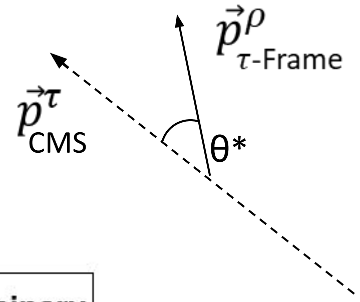


- Achieve a 99.7% pure tau-pair sample (0.3% Bhabha)
- 90% of selected events contain a $\tau^{\pm} \rightarrow \pi^{\pm}\pi^{0}\nu_{\tau}$ decay
  - 8% a1 decays, 2% other hadronic

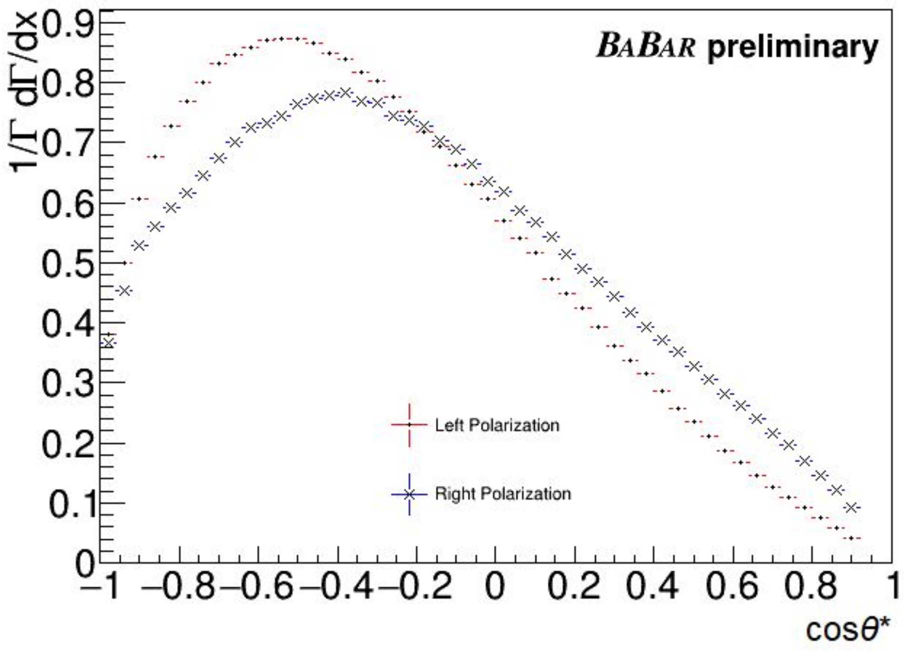
Polarization Observables

- Polarization sensitivity in a rho decay is maximized by analyzing two angular variables[2] in addition to cosθ

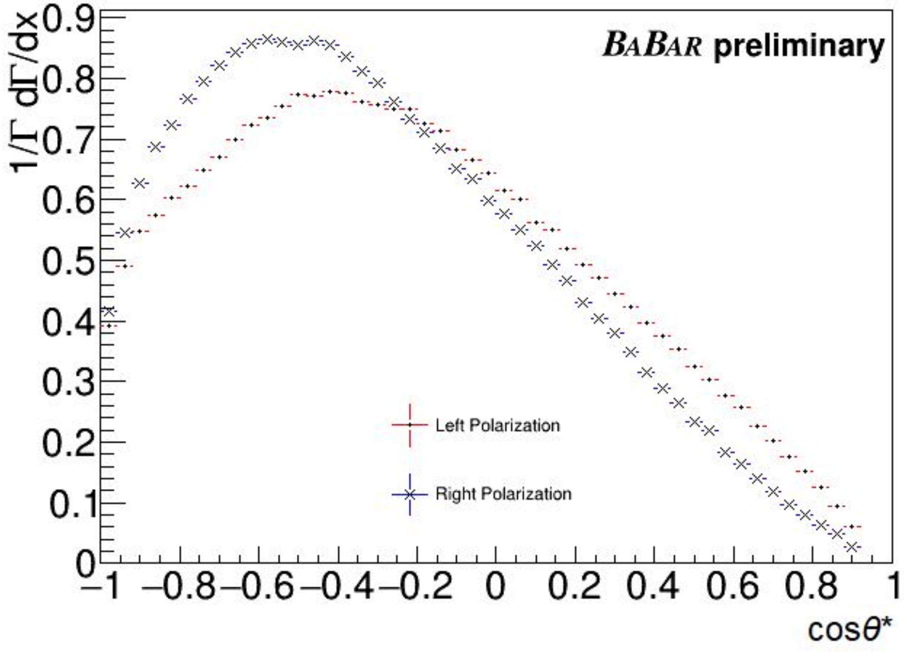
$$\cos\theta^* = \frac{2z - 1 - m_\rho^2/m_\tau^2}{1 - m_\rho^2/m_\tau^2} \qquad z \equiv {E_\rho}/{E_{\text{beam}}}$$



cosθ<0



cosθ>0

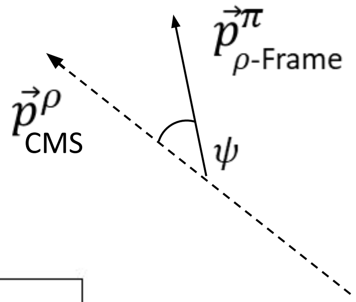


[2] K. Hagiwara, A. Martin, D. Zeppenfeld, Tau Polarization Measurements at LEP and SLC, Phys. Lett. B. 235, 1998, DOI: 10.1016/0370-2693(90)90120-U

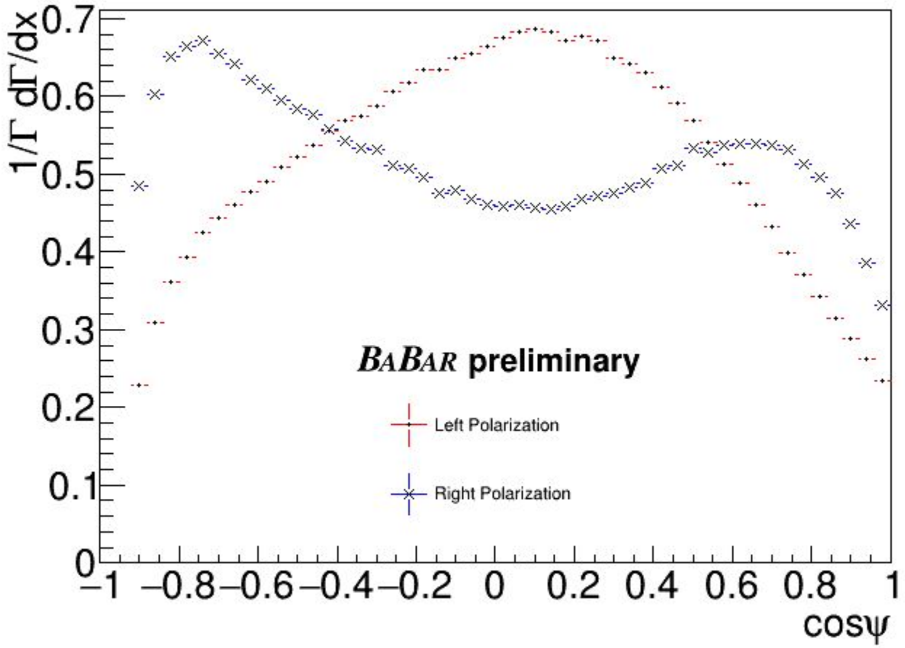
Polarization Observables

- Polarization sensitivity in a rho decay is maximized by analyzing two angular variables[2] in addition to cosθ

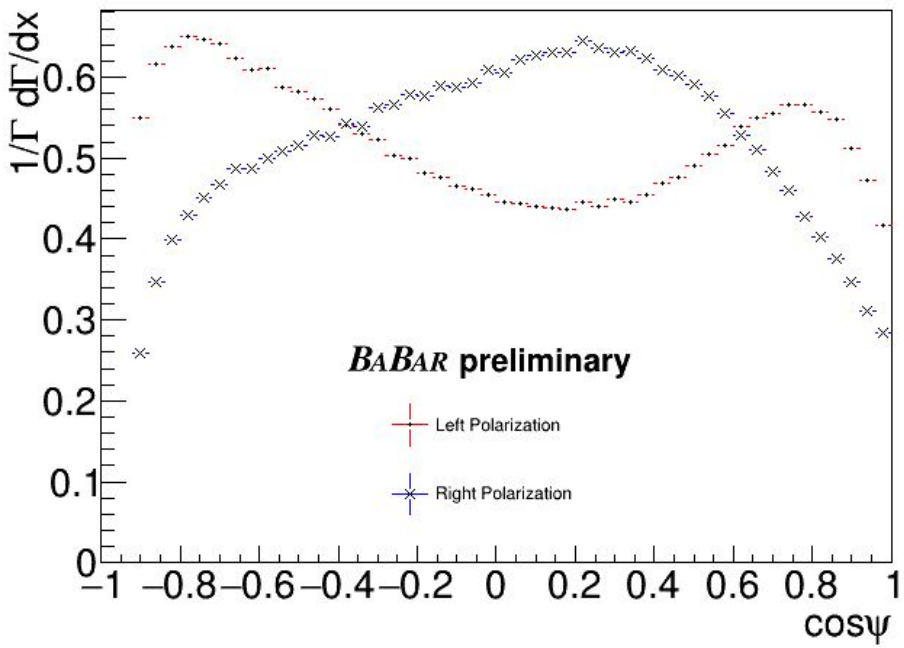
$$\cos\psi = \frac{2x-1}{\sqrt{1-4m_\pi^2/m_\rho^2}} \qquad x \equiv E_\pi / E_\rho$$



cosθ<0



cosθ>0



[2] 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

Polarization Fit

- To extract the average beam polarization from a data set we employ a binned maximum likelihood fit using Barlow and Beeston[3] template fit methodology
- Data and MC is binned in 3D histograms of cosθ*, cosψ, and cosθ
- Tau MC was produced for a left and right polarized electron beam
- The data is fit as a linear combination of the histograms

a_l	0.499
a_r	0.499
a_b	$3.8\text{x}10^{-5}$
a_m	$1.4\text{x}10^{-3}$
a_u	$3.8\text{x}10^{-4}$
a_c	$4.8\text{x}10^{-5}$

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

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

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

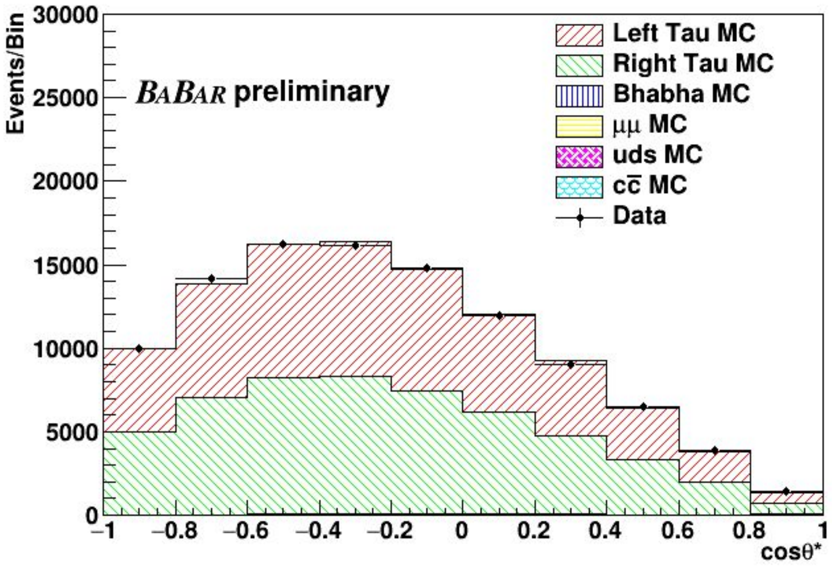
a_i = fit contribution

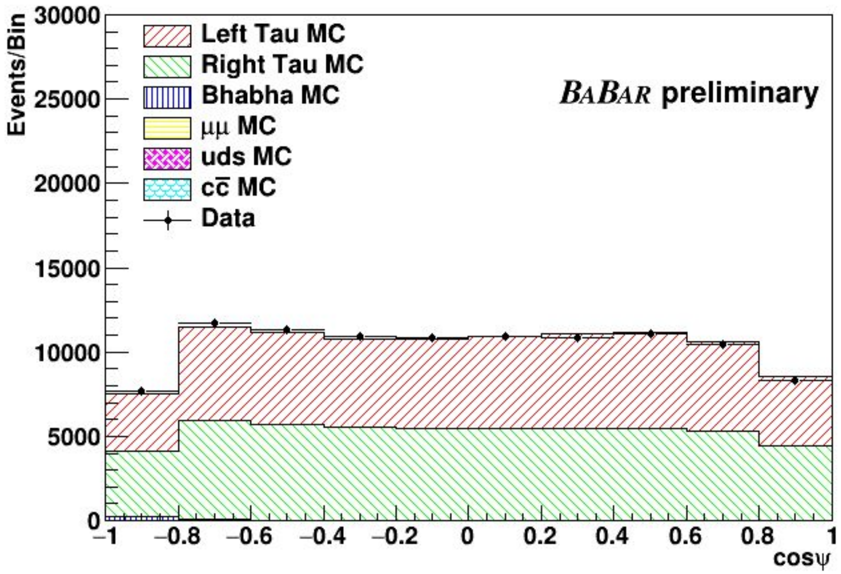
[3] R. Barlow, C. Beeston; Computer Physics Communications, Volume 77, Issue 2, 1993, Pages 219-228, https://doi.org/10.1016/0010-4655(93)90005-W

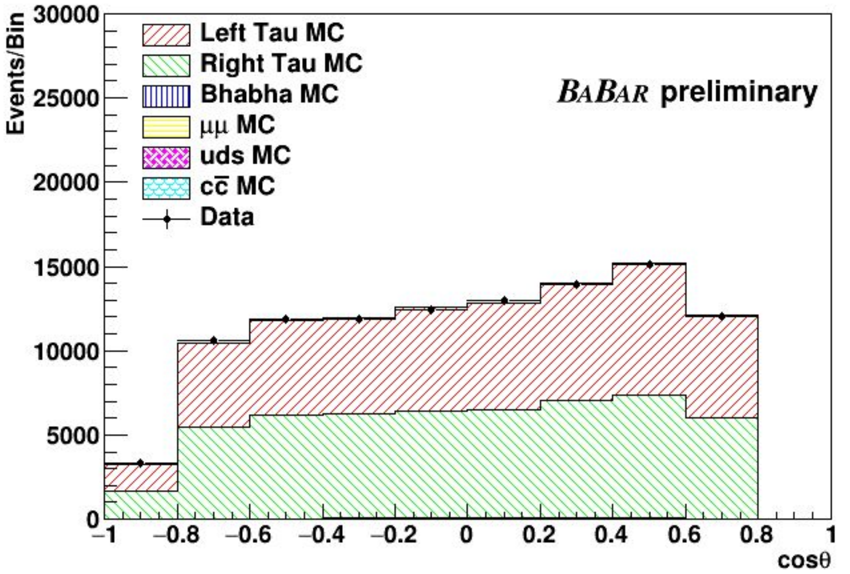
Fit Result

Sample	Positive	Negative	Total
Run 3 (32.28 fb^{-1})	0.0277±0.0177	-0.0031±0.0177	0.0123±0.0125

- Fit result projected to each of the fit variables
- Result from preliminary Run 3 fit, Negative charges
- $\langle P \rangle = -0.0031$, $\chi^2/NDF = 770/872$

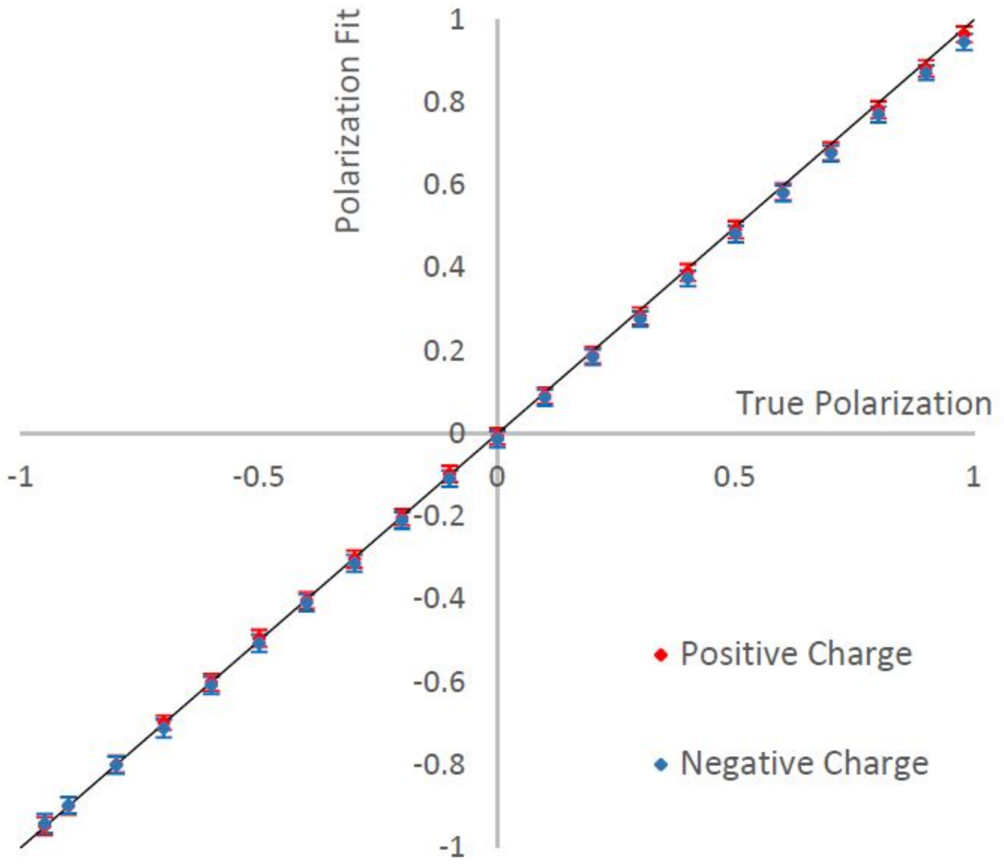






Beam Polarization MC “Measurement”

- As PEP-II had no beam polarization we performed MC studies of the polarimetry technique for arbitrary beam polarization states for validation of the method
- This is done by splitting each of the polarized tau MC samples in half
- One half of each is used to perform the polarization fit
- The other half is used to mix specific beam polarization states
  - e.g. 70% polarized = 85% left +15% right
- Simulated beam polarization states are produced in steps of 10% beam polarization
- We found the fit responded well and was able to correctly measure any designed beam state



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Full Measurement

- Performing the measurement on the remaining data, 391.9 fb^{-1}

Sample	Luminosity (fb^{-1})	Average Polarization
Run 1	20.37	0.0062±0.0157
Run 2	61.32	-0.0004±0.0090
Run 4	99.58	-0.0114±0.0071
Run 5	132.33	-0.0040±0.0063
Run 6	78.31	0.0157±0.0082
Total	**391.9**	**-0.0010±0.0036**

- Preliminary measurement:

$$\langle P \rangle = -0.0010 \pm 0.0036_{\text{stat}} \pm 0.0030_{\text{sys}}$$

Preliminary

Study	Run 1	Run 2	Run 4	Run 5	Run 6	Final
π^0 Likelihood	0.0032	0.0012	0.0009	0.0010	0.0020	**0.0015**
Hadronic Split-off Modelling	0.0035	0.0012	0.0015	0.0011	0.0005	**0.0011**
$\cos\psi$	0.0022	0.0012	0.0006	0.0008	0.0010	**0.0010**
Angular Resolution	0.0010	0.0015	0.0012	0.0002	0.0007	**0.0009**
Minimum Neutral Energy	0.0006	0.0009	0.0005	0.0006	0.0016	**0.0009**
π^0 Mass	0.0018	0.0005	0.0009	0.0006	0.0014	**0.0009**
$\cos\theta^\star$	0.0012	0.0007	0.0012	0.0009	0.0007	**0.0008**
Electron PID	0.0022	0.0008	0.0007	0.0014	0.0010	**0.0007**
Tau Branching Fraction	0.0007	0.0006	0.0010	0.0006	0.0005	**0.0006**
Event Transverse Momentum	0.0013	0.0006	0.0006	0.0002	0.0005	**0.0005**
Momentum Resolution	0.0005	0.0008	0.0004	0.0003	0.0006	**0.0005**
π^0 Minimum Photon Energy	0.0008	0.0008	0.0009	0.0003	0.0010	**0.0004**
Rho Mass	0.0007	0.0002	0.0002	0.0004	0.0005	**0.0003**
Background Modelling	0.0027	0.0002	0.0002	0.0007	0.0009	**0.0003**
Boost	0.0000	0.0002	0.0001	0.0005	0.0004	**0.0002**
Total	0.0070	0.0033	0.0032	0.0027	0.0038	**0.0030**

Conclusions

- *BaBar* has implemented the first application of the new Tau Polarimetery technique to preliminarily measure the PEP-II average beam polarization

$$\langle P \rangle = -0.0010 \pm 0.0036_{\mathrm{stat}} \pm 0.0030_{\mathrm{sys}}$$

Preliminary

- Strongly motivates adding a polarized electron beam to SuperKEKB
- Currently processing rho vs muon selection for additional statistics
- Parallel development on extracting the beam polarization from tau to pion decays ongoing
- Tau Polarimetry could be applied at other e^+e^- colliders
- Look forward to a publication this summer

Thank You!

Backup Slides

Positron Polarization

- In this implementation of tau polarimetry it is assumed only the electron beam is polarized
- Tau polarimetry works for any beam polarizations in both beams

$e^+ \backslash e^-$	L^-	R^-
L^+	L^+L^-	L^+R^-
R^+	R^+L^-	R^+R^-

- Interaction matrix, only the LL and RR boxes result in a e^+e^- interaction
- The LR and RL fraction continue down the beam pipe
- For unpolarized beams L=R=0.5
- Average beam polarization can be expressed as $\frac{LL-RR}{LL+RR}$

$e^+ \backslash e^-$	L^-	R^-
L^+	0.425	0.075
R^+	0.425	0.075

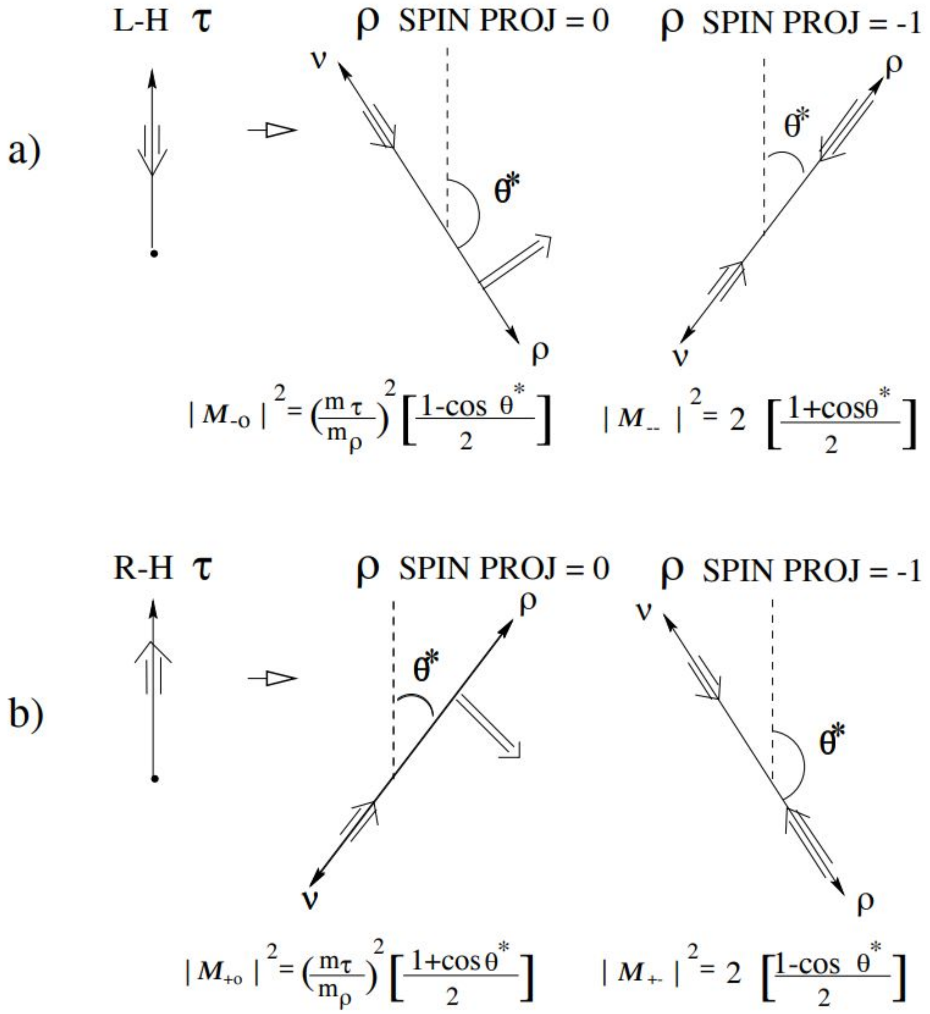
- For 70% polarized electron beam, L^-=0.85 R^-=0.15
- Average beam polarization is $\frac{0.425-0.075}{0.425+0.075}$=0.7

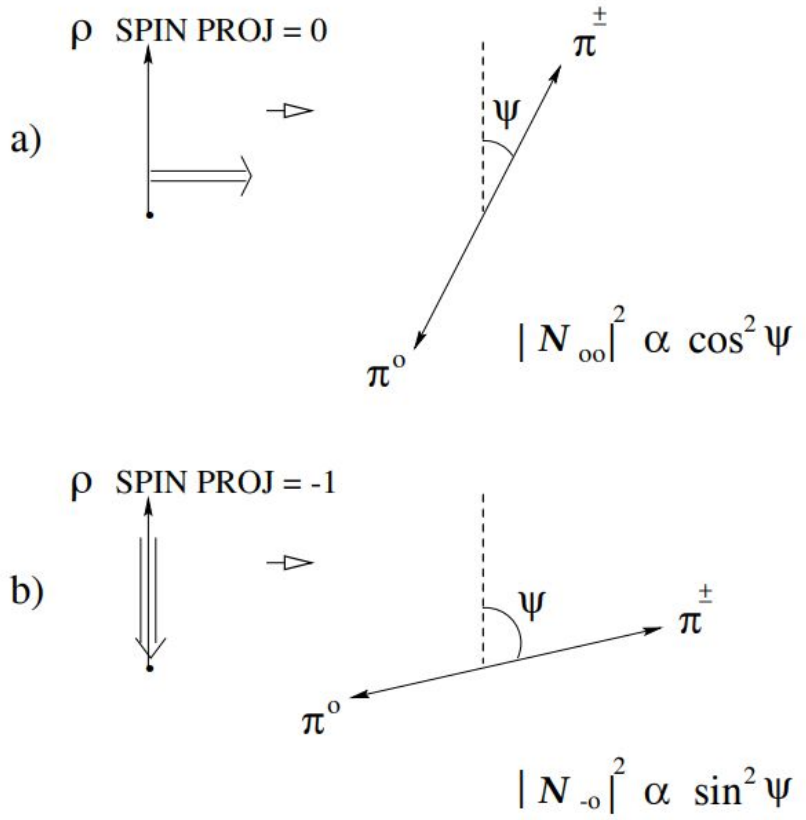
$e^+ \backslash e^-$	L^-	R^-
L^+	0.49	0.21
R^+	0.21	0.09

- For both beams being 40% polarized, L=0.7, R=0.3
- Average beam polarization is $\frac{0.49-0.09}{0.49+0.09}$=0.69
- Also note 58% of encounters result in a collision, extra data for same luminosity

Rho Spin Analysis

- The rho complicates the spin projections, which necessitates two variables to extract the polarization





From Dr. Manuella Vincter, PhD thesis, UVIC, 1996

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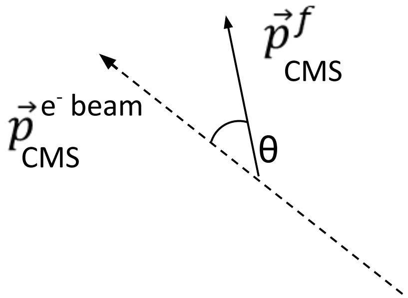
$\vec{p}^{\,f}_{CMS}$
$\vec{p}^{\,e^- \text{beam}}_{CMS}$
θ

Systematic Uncertainties

- Systematic uncertainties were evaluated by studying the relative shift in agreement between the MC and data polarization fits
- The 3 independent MC measurements from also give us a way to approximate the statistical uncertainty of each systematic uncertainty
- Our study of the Run 3 sample found the MC modelling of the hadronic split-offs to be the largest uncertainty
- Uncertainties associated with π^0's also contribute significantly to the final uncertainty
- Study sample (Run 3) measurement:

$$\langle P \rangle = 0.0123 \pm 0.0125_{\text{stat}} \pm 0.0041_{\text{sys}}$$

PRELIMINARY

Study	Run 3
π^0 Likelihood	0.0013
Hadronic Split-off Modelling	0.0027
Minimum Neutral Energy	0.0013
π^0 Mass	0.0011
$\cos\psi$	0.0013
Angular Resolution	0.0010
Electron PID	0.0006
$\cos\theta^\star$	0.0002
Event Transverse Momentum	0.0006
Momentum Resolution	0.0002
π^0 Minimum Photon Energy	0.0011
Tau Branching Fraction	0.0001
Rho Mass	0.0002
Boost	0.0002
Background Modelling	0.0006
Total	0.0041