Updates to
Tau Polarimetry Technique

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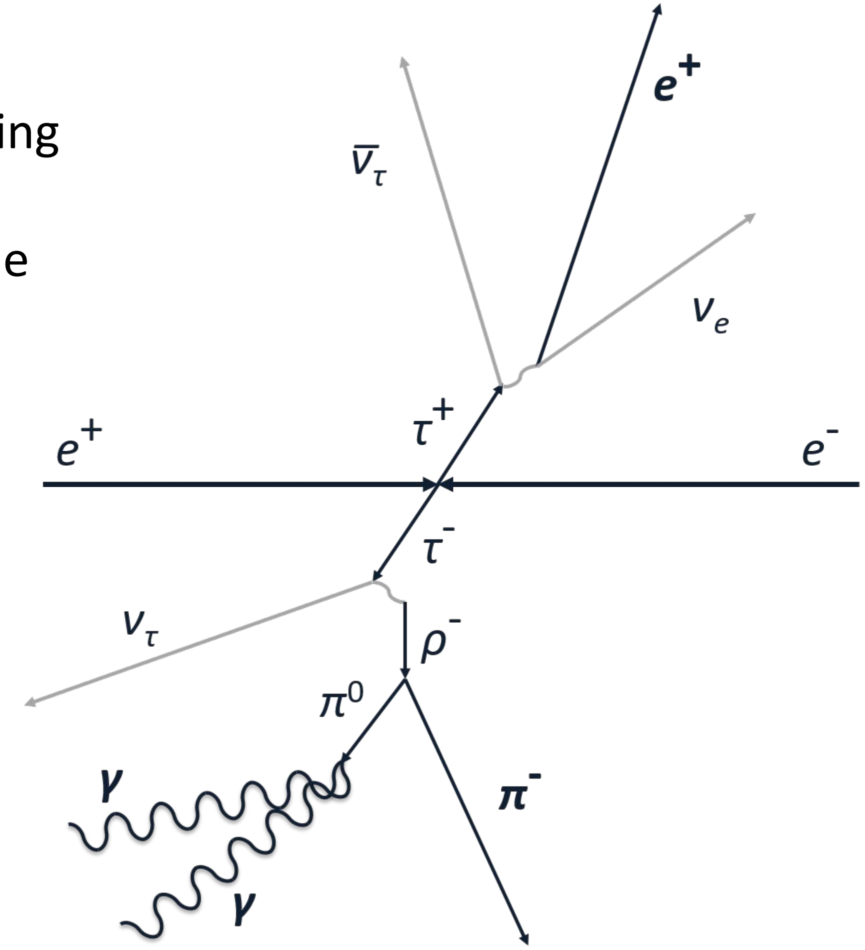
Last Meeting

- Last time I presented (Jan 2022) to the group the status was:
  - Polarization from pion mode put on hold
  - Polarization from rho mode approved to unblind
  - Planning to present rho results at Lake Louise
- Since then
  - pion mode debugging efforts unable to identify issue
    - approval to look at more data to help investigation
  - rho analysis “finished” and presented at Lake Louise, FPCP, and CAP
    - Working to extend analysis with better cuts and muon tag

Tau Event Selection

- As a proof of concept we have developed Tau Polarimetry at *BABAR* using $\tau^{\pm} \to \rho^{\pm}\nu_{\tau} \to \pi^{\pm}\pi^{0}\nu_{\tau}$ 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 $\tau^{\pm} \to \pi^{\pm}\pi^{0}\nu_{\tau}$ decay
  - 8% a1 decays, 2% other hadronic

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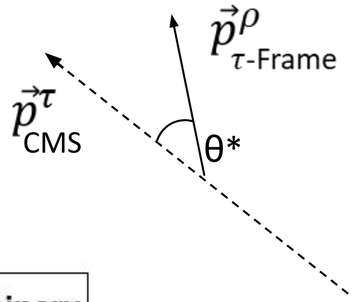
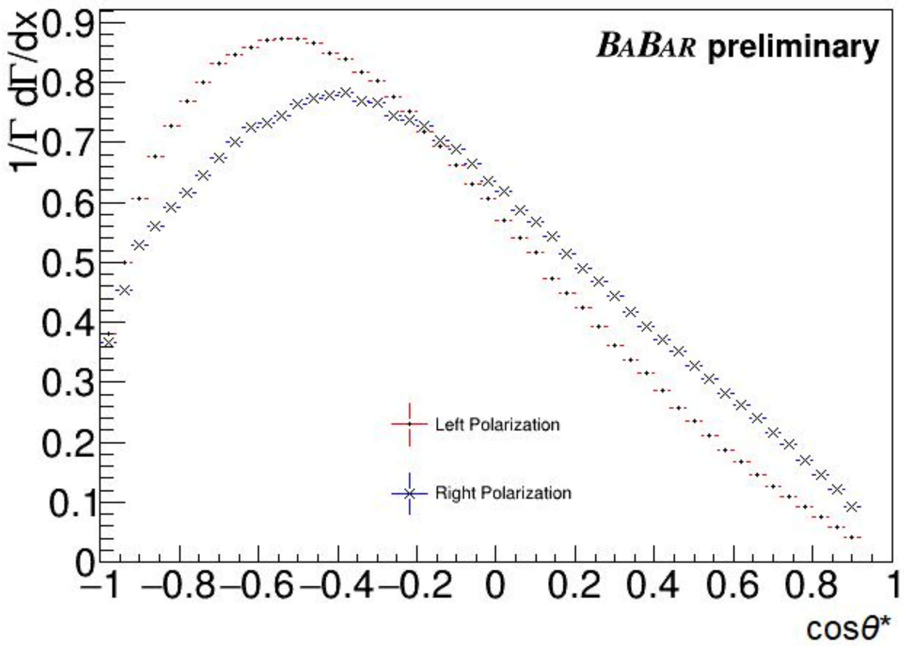
Polarization Observables

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

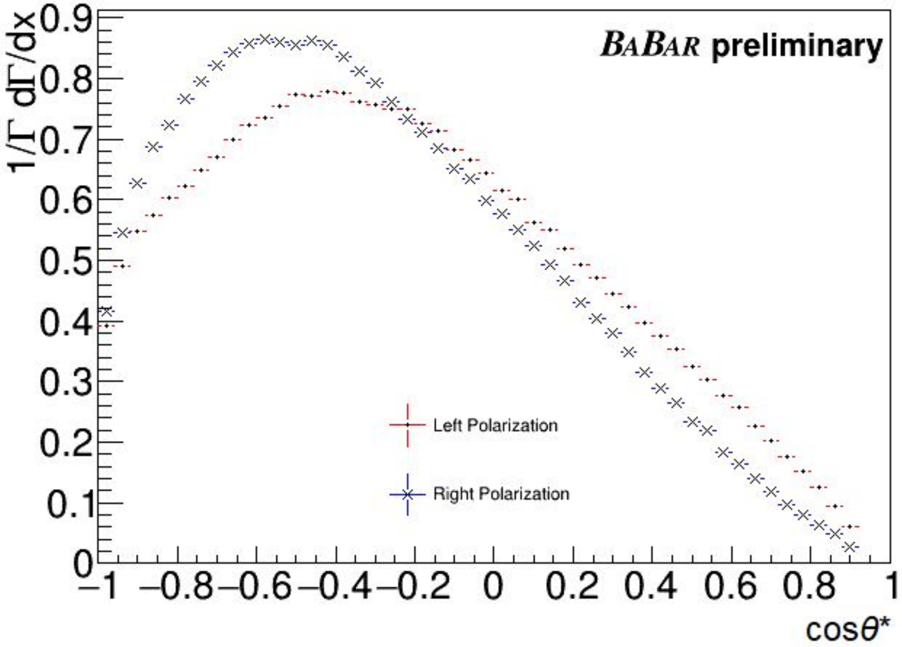
$$\cos\theta^* = \frac{2z - 1 - m_\rho^2/m_\tau^2}{1 - m_\rho^2/m_\tau^2} \qquad z \equiv {E_\rho}/{E_{\text{beam}}}$$



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

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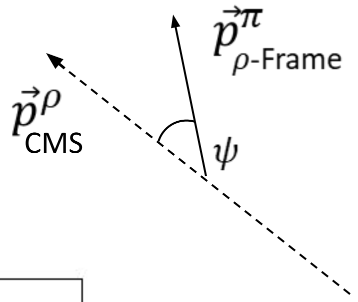
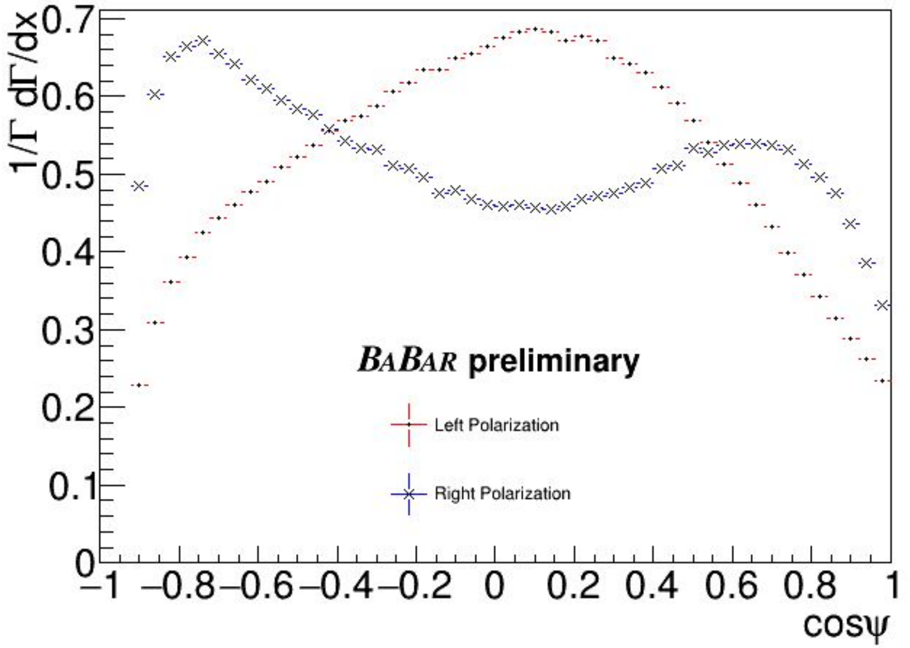
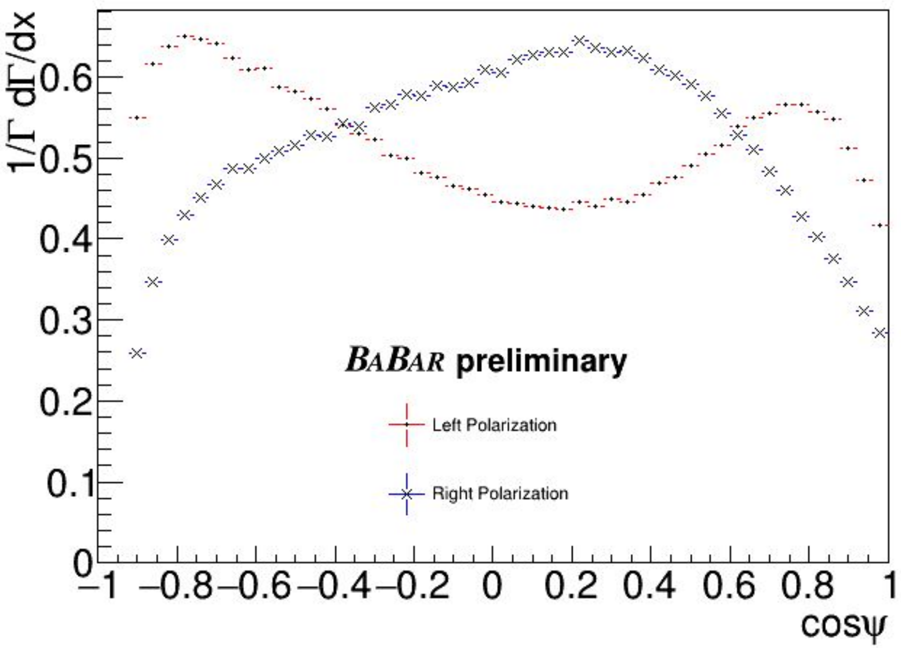
$$\cos\psi = \frac{2x-1}{\sqrt{1-4m_\pi^2/m_\rho^2}} \qquad x \equiv {E_\pi}/{E_\rho}$$



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	3.8×10^{-5}
a_m	1.4×10^{-3}
a_u	3.8×10^{-4}
a_c	4.8×10^{-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=$c\bar{c}$

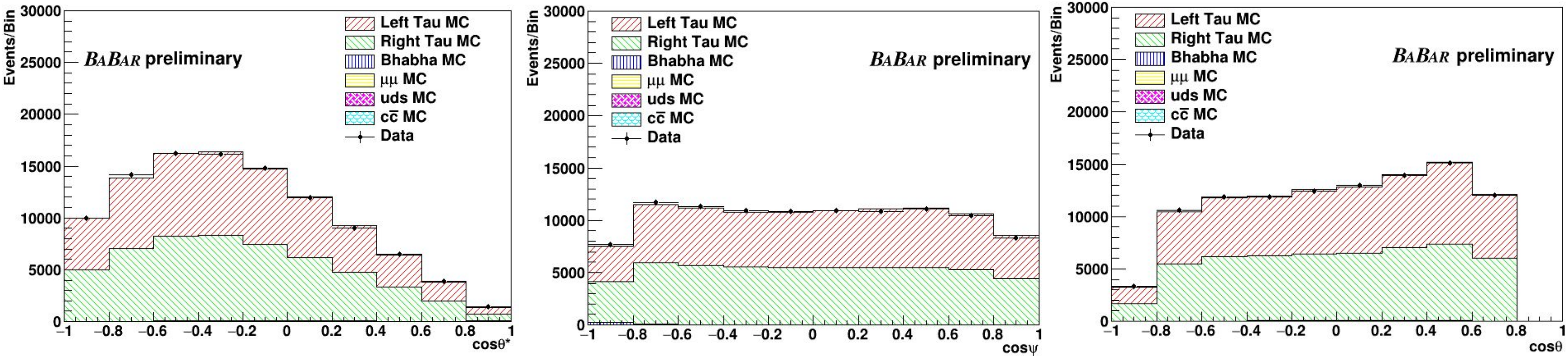
a_i = fit contribution

[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

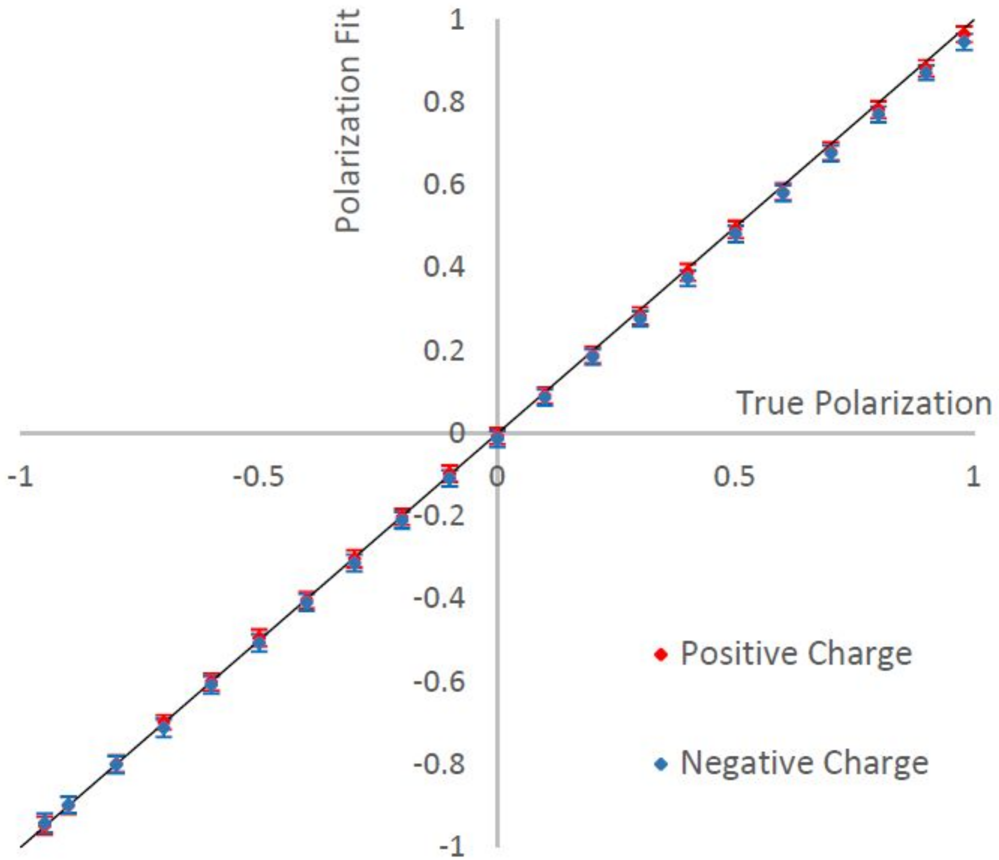
Sample	Positive	Negative	Total
Run 3 (32.28 fb^{-1})	0.0277±0.0177	-0.0031±0.0177	0.0123±0.0125

- 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**

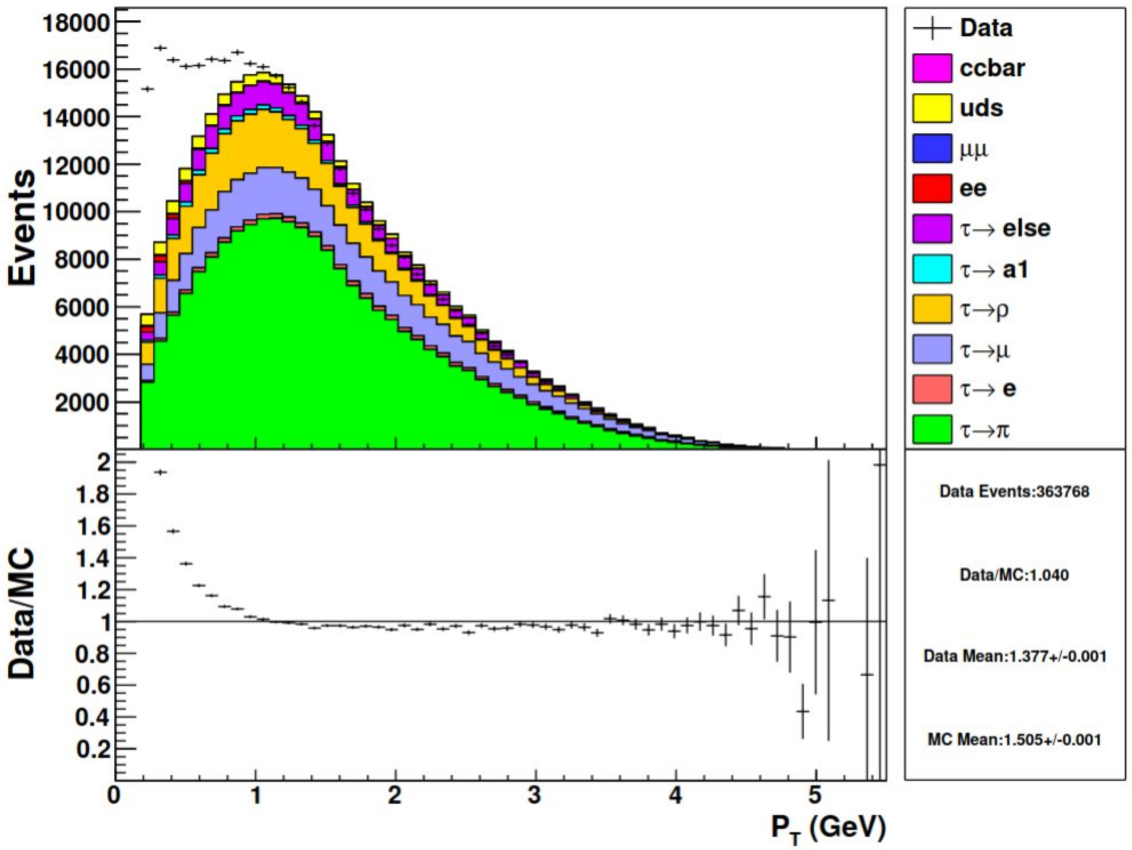
- Preliminary measurement:

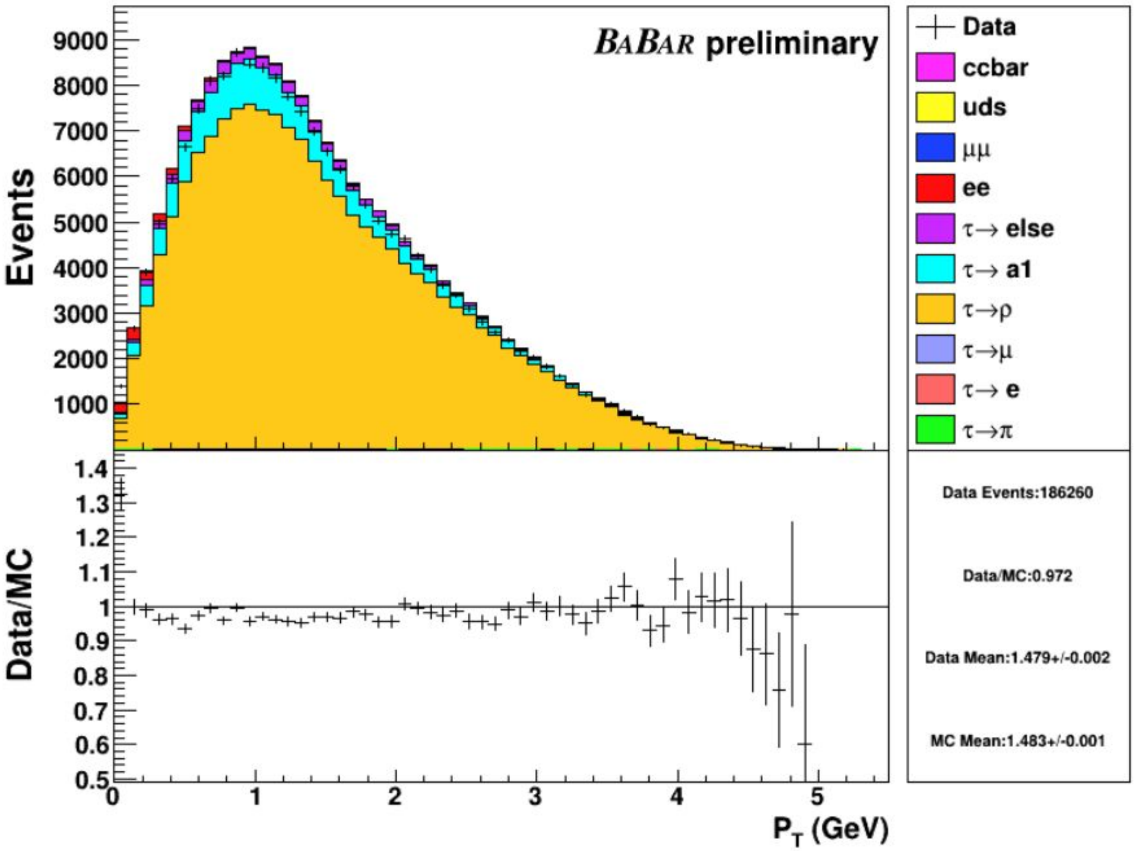
$$\langle P \rangle = -0.0010 \pm 0.0036_{stat} \pm 0.0030_{sys}$$

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**

Muon Tagging

- At request of BaBar extending analysis with muon tag
- Expect minimal gains in systematic uncertainty due to muon PID, but important to verify
- Simultaneously redoing electron analysis but higher efficiency, P_T cut not needed in Rho analysis





e/mu Tagging

- Initial tests done on Run 3
- Measurements performed independently and combined
- Results consistent with earlier e -tag only analysis
- Combined analysis performs better, accounts for correlations automatically

Source	Combined	e-Tag only	mu-Tag only
muon PID	0.0020	0.0000	0.0045
Pi0 Mass	0.0017	0.0010	0.0011
Hadronic Split-off	0.0013	0.0033	0.0023
Momentum	0.0011	0.0015	0.0014
P_T	0.0011	0.0004	0.0004
e PID	0.0009	0.0009	0.0000
50 MeV Neutrals	0.0009	0.0011	0.0017
Pi0 Likelihood	0.0008	0.0015	0.0011
100 MeV Neutrals	0.0008	0.0011	0.0008
cos psi	0.0008	0.0008	0.0022
Angular Resolution	0.0008	0.0007	0.0015
Backgrounds	0.0008	0.0014	0.0012
Tau BF	0.0007	0.0005	0.0007
boost	0.0004	0.0016	0.0009
Rho Mass	0.0004	0.0006	0.0010
cos theta*	0.0002	0.0009	0.0003
Sum	**0.0041**	**0.0052**	**0.0067**

Conclusions

- *BaBar* has initial measurement of beam polarization with e-tag only:

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

- Existing precision meets design goals for Chiral Belle projections
- Currently processing rho vs e/mu selection for additional statistics and potentially better systematics
- New electron selection which improves efficiency by ~40% being investigated
- Permission to fully unblind obtained
- Parallel development on tau to pion decays still ongoing
  - plan to analyze Run 6 data soon
- Lots of progress expected in the next few weeks

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

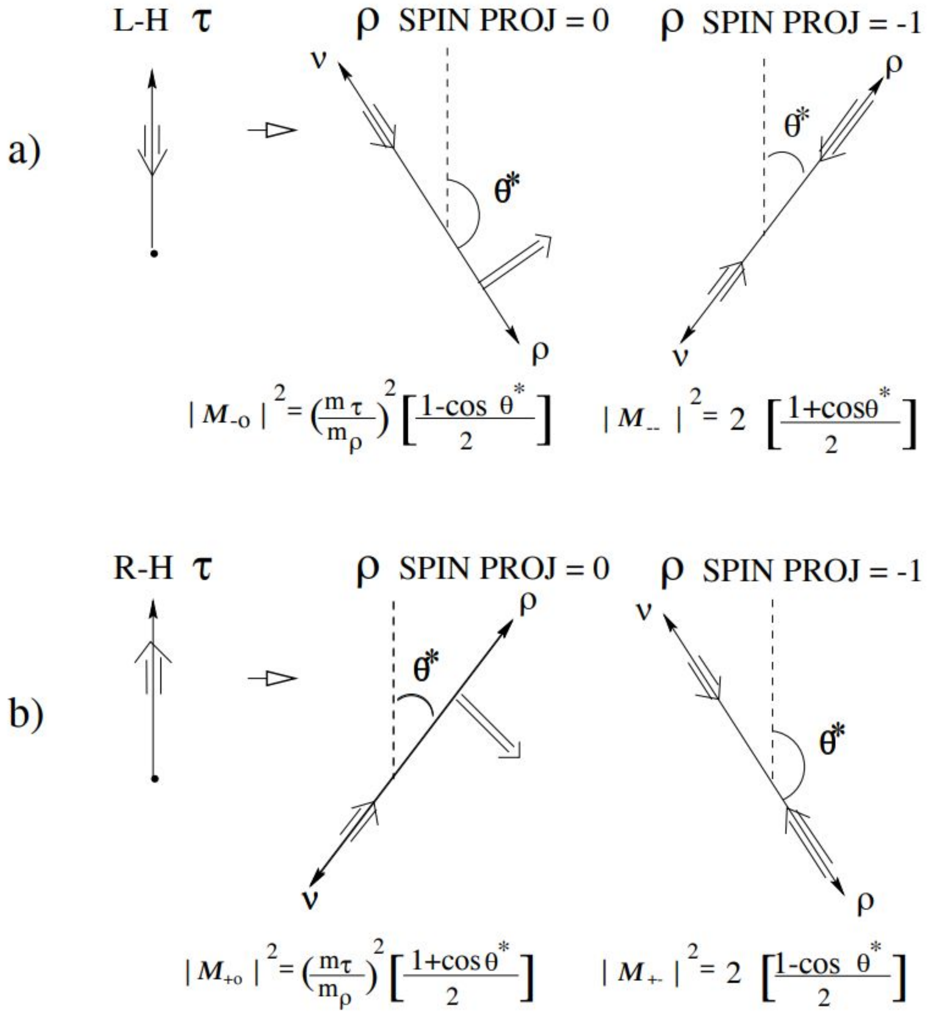
- For 70% polarized electron beam, L^-=0.85 R^-=0.15
- Average beam polarization is $\frac{0.425-0.075}{0.425+0.075}$=0.7

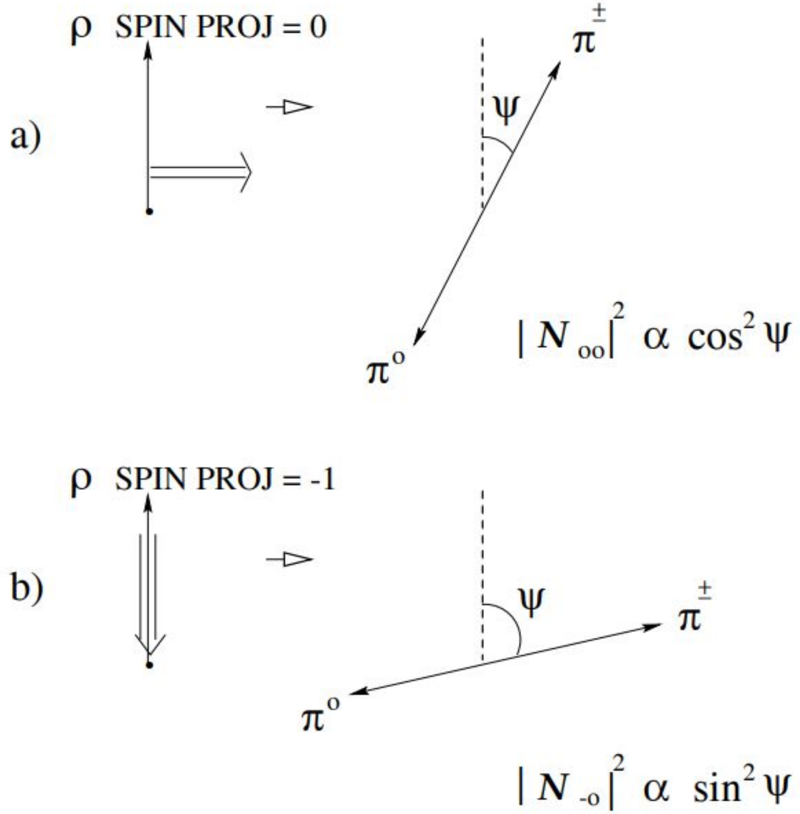
$e^+ \backslash e^-$	L^-	R^-
L^+	0.49	0.21
R^+	0.21	0.09

- 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

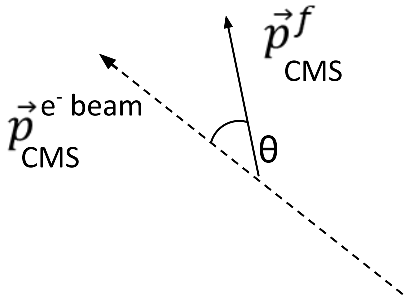
Rho Spin Analysis

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





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



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