Tau Polarimetry Update

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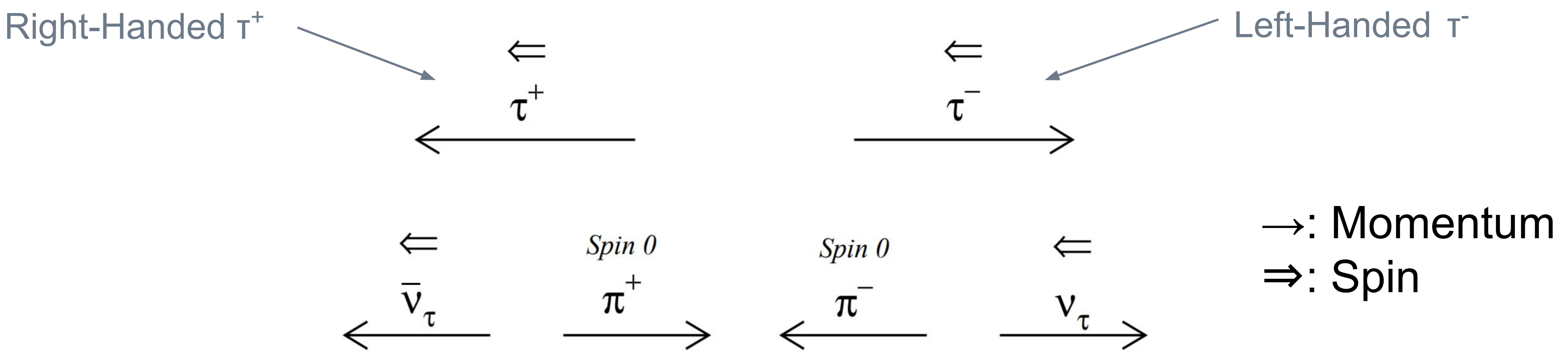
Tau Polarimetry

- 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:

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

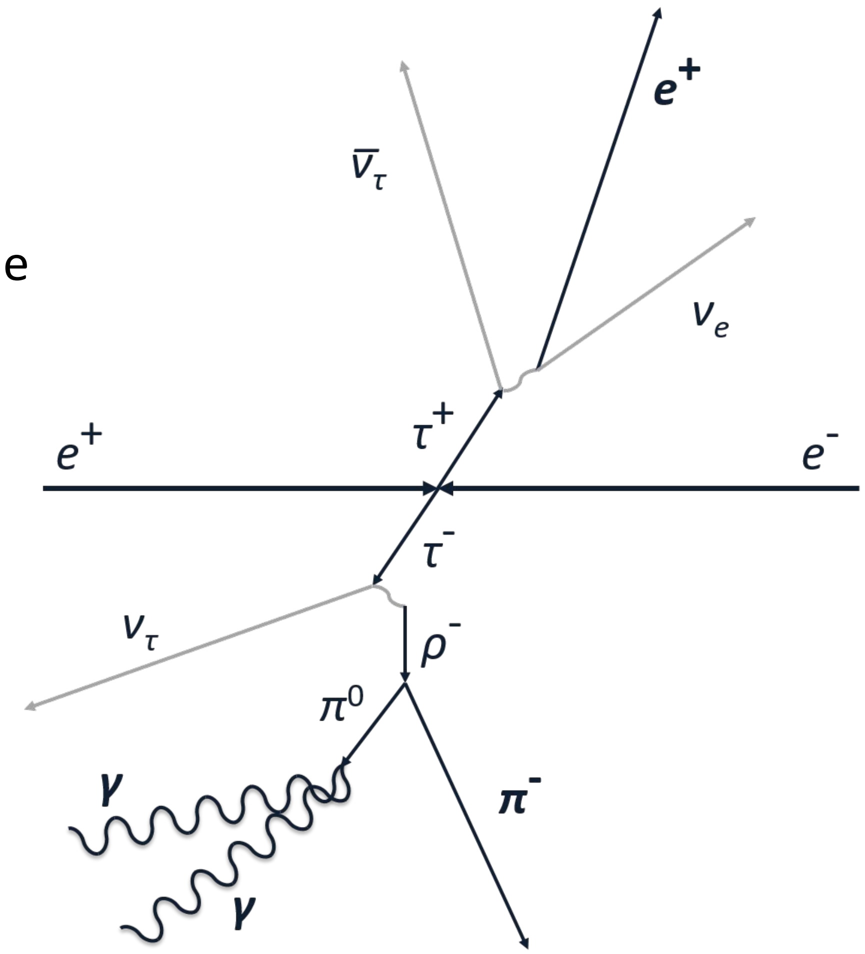
Note: cosθ defined as the polar angle of the τ^- with respect to the electron beam

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



Tau 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

Status from June CM

- Preliminary measurement shown at a number of conferences

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

- Plan to extend analysis in two ways
  - Include low p_T events, increases efficiency by 71%
  - Add muon tag to double statistics
- Preliminary tests of run 3 showed improvement in systematic uncertainties

e-mu Tagged Measurement

- Completed full polarization measurement with both lepton tags

$$\langle P \rangle = -0.0002 \pm 0.0025_{stat} \pm 0.0023_{sys} \pm 0.xxxx_{sys}$$

- Significant improvement in statistical and systematic uncertainties
- Analysis is now an unblinded analysis
  - Goal is on providing best tool for Chiral Belle, rather than a physics measurement at BaBar
- Working on refining a few new variables which will slightly increase the final systematic uncertainty
- Expectation is that total uncertainty will remain under 0.0050 (0.5%)

Post Unblinding

- Due to the tensions with the measurement a number of investigations were made
- Quality Improvements
  - ⇒ Minimum Track p_T
  - ⇒ Minimum Track EMC Deposit
  - ⇒ Event p_T > 0.25 MeV -> 0.35 MeV
  - ⇒ Rho decay product angular separation
- Other Improvements/Investigations
  - ⇒ cosθ definition
  - ⇒ charge asymmetry in fits
  - ⇒ cancellation of systematic effects in charge asymmetry
  - ⇒ polarization dependence on Event p_T

Charge Asymmetry in Fit

- Fit results show tension between fit results for positive and negative charge

Sample	Positive	Negative	Tension
Run 1	-0.0324±0.0124	-0.0073±0.0126	-1.42
Run 2	-0.0051±0.0075	-0.0175±0.0079	1.14
Run 3	0.0145±0.0100	-0.0071±0.0105	1.49
Run 4	-0.0103±0.0057	-0.0213±0.0061	1.12
Run 5	-0.0038±0.0050	-0.0160±0.0053	1.67
Run 6	0.0066±0.0068	-0.0105±0.0066	1.80
Total	**-0.0038±0.0028**	**-0.0152±0.0029**	**2.80**

- Tension could indicate unaccounted for bias

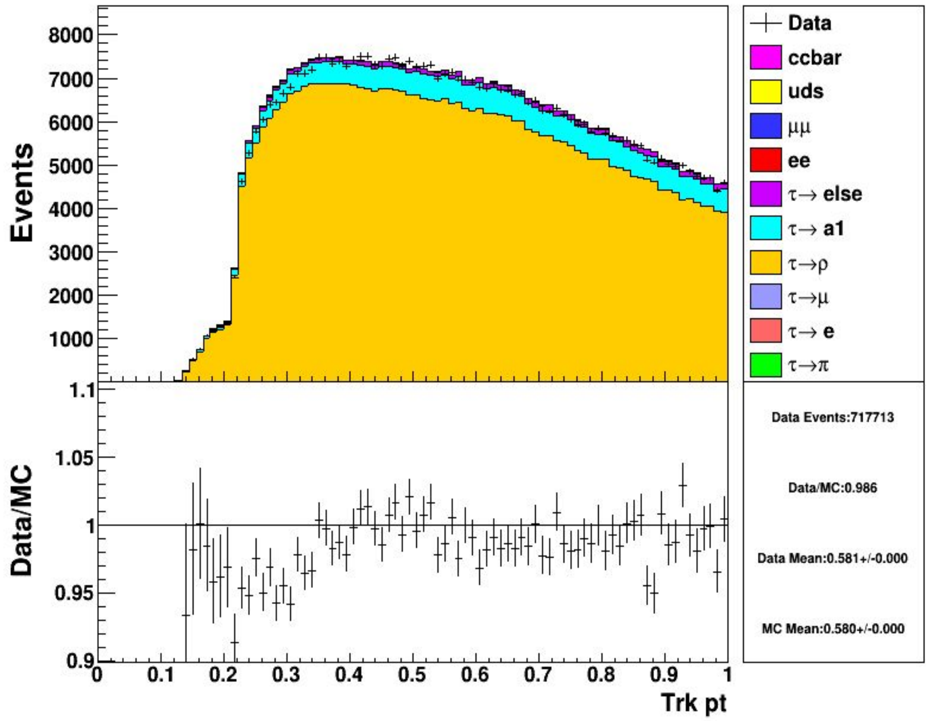
Charge Asymmetry Systematic Cancellation

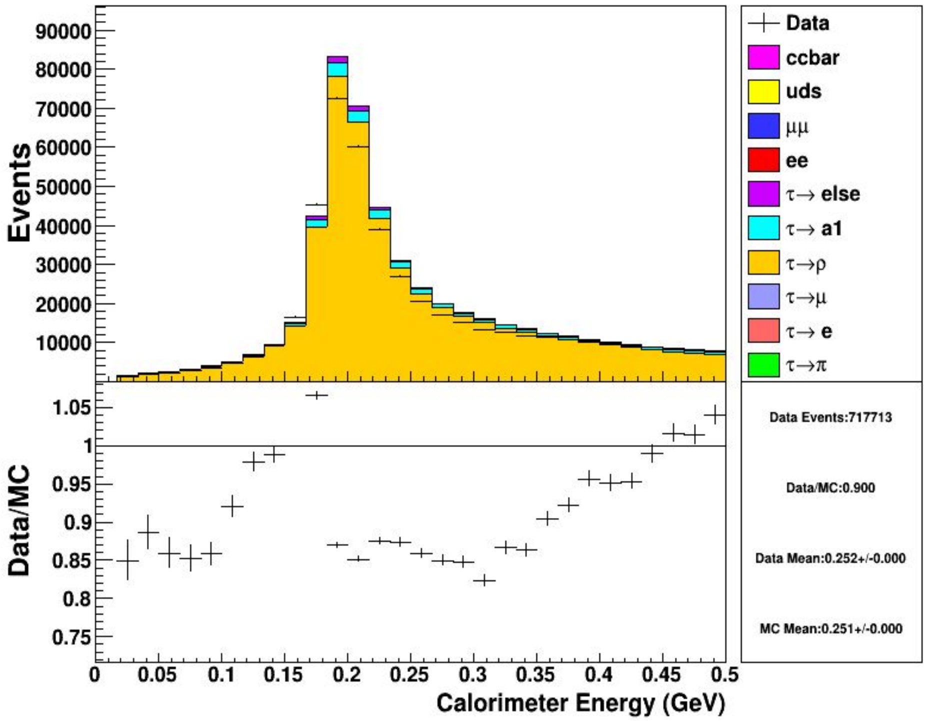
- Sign of polarization sensitivity flips with charge
- As such non-polarization sensitive biases largely cancel in the combined average
- In order to demonstrate this a 1% slope bias was added to cosθ
- Shifts in fit from no bias added:

-1% slope	Pos	Neg	Ave
MC 1	0.0004	-0.0005	0.0000
MC 2	0.0007	-0.0013	-0.0002
MC 3	0.0013	0.0008	0.0014
Data	-0.0001	-0.0005	-0.0001
+1% slope	**Pos**	**Neg**	**Ave**
MC 1	-0.0004	0.0004	0.0000
MC 2	0.0011	-0.0005	0.0003
MC 3	0.0008	0.0011	0.0009
Data	-0.0020	0.0006	-0.0012

Minimum Track p_T and Energy Deposition

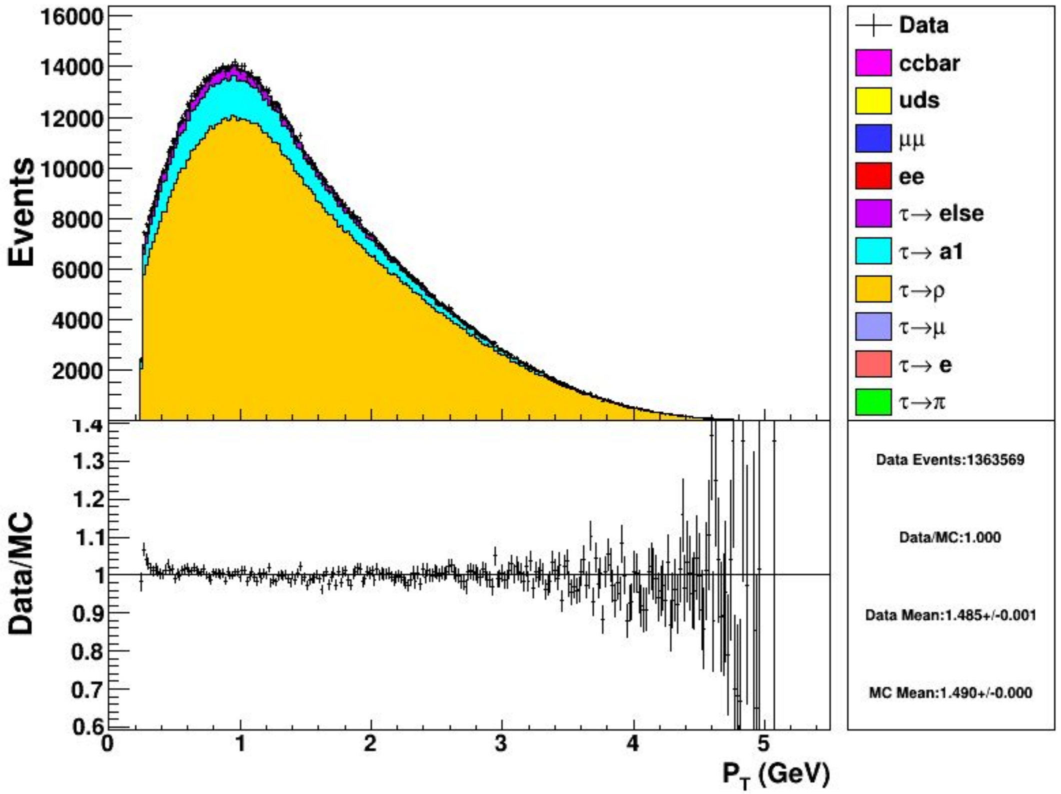
- In order to improve the quality of particles selected and their MC modelling two requirements were investigated
  - ➢ For each track: p_T>350 MeV and EMC>50 MeV
  - ➢ p_T was implemented, while the EMC cut was found to be unnecessary





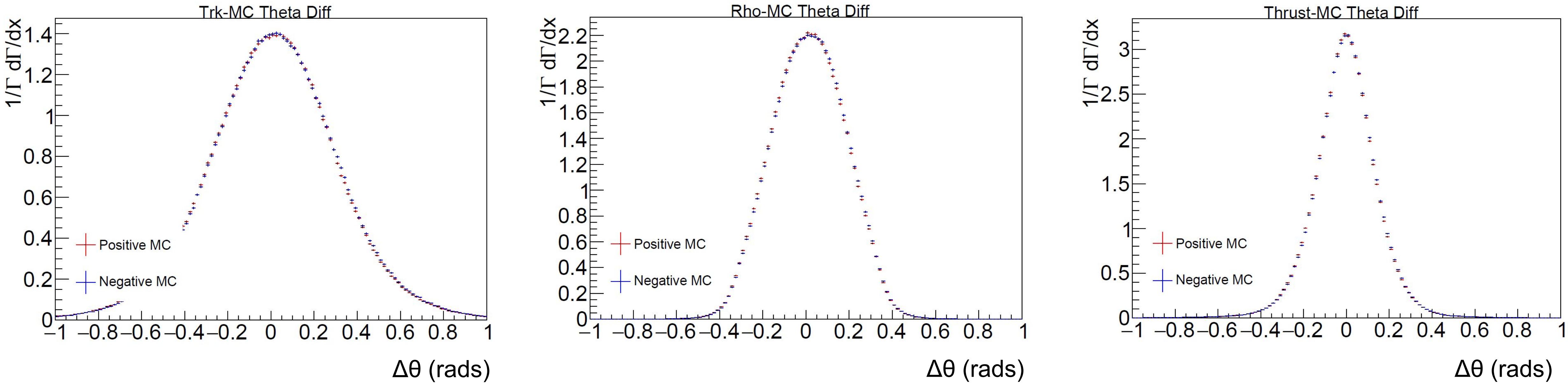
Event pT change

- After unblinding some two-photon backgrounds were observed in the Event p_T distributions in Run 5 which were not observed in Run 3
- Increasing the cut to 350 MeV from 250 MeV removes the two-photon events



cosθ Definition

- The polarization theory on slide 2 defines cosθ as the direction of the negative τ
- The polarization fit has used the direction of the final state pion as a proxy for this variable
- Using rho or thrust direction could provide better sensitivity
- Differences between track, rho, thrust direction and MC Truth:



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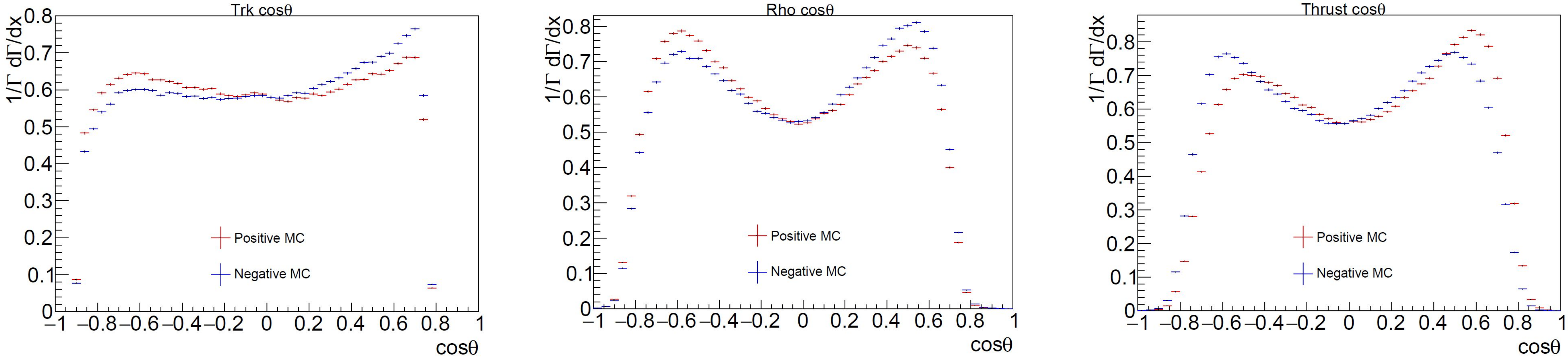
- Using rho or thrust direction could provide better sensitivity
- cosθ distributions for track, rho, thrust direction:



cosθ Definition

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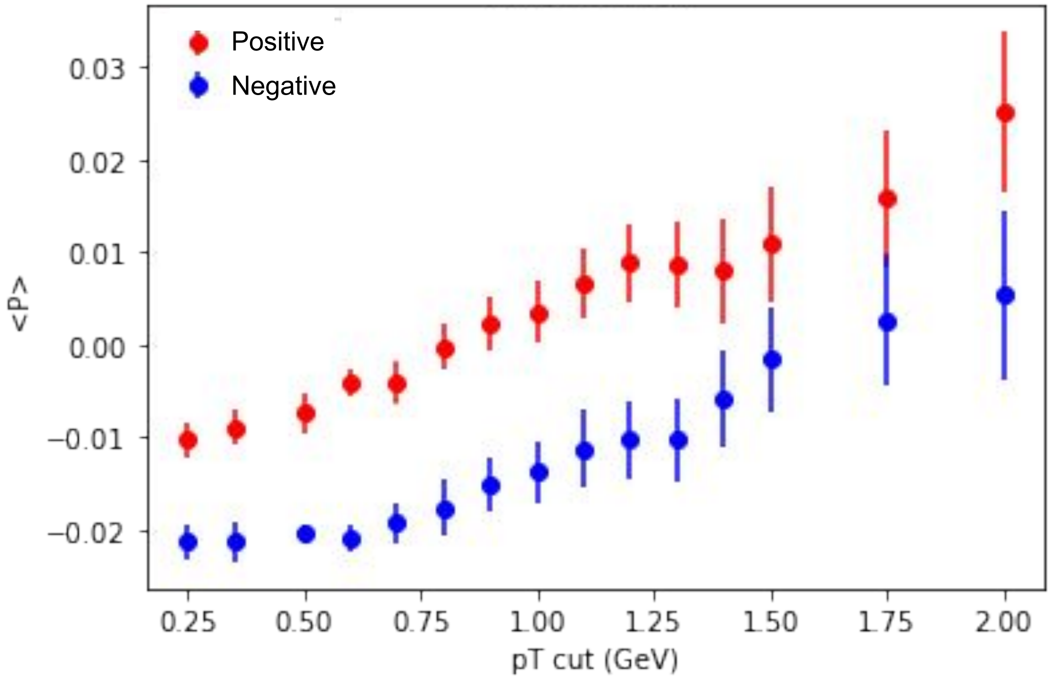
- The polarization fit has used the direction of the final state pion as a proxy for this variable
- Using rho or thrust direction could provide better sensitivity
  - Improves sensitivity 0.0073 -> 0.0062
  - Shifts fit ~1.5% towards positive
  - Run 2 test suggests systematic uncertainty O(0.0004)

p_T Dependence

- Polarization fits are showing a linear dependence on the p_T cut
- Unclear what the origin of the dependence is

Polarization fits as function of p_T cut

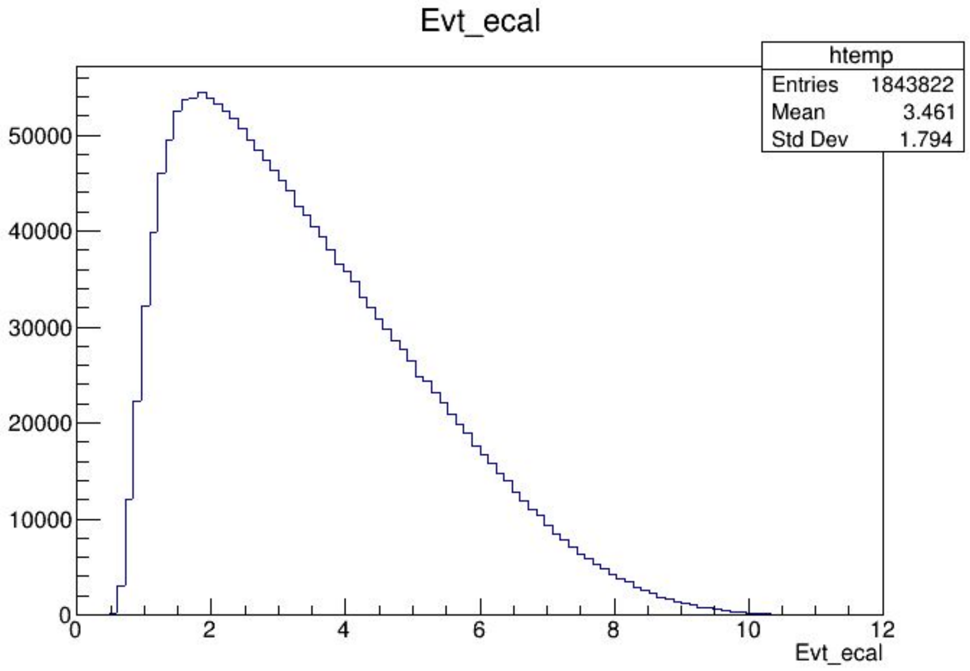


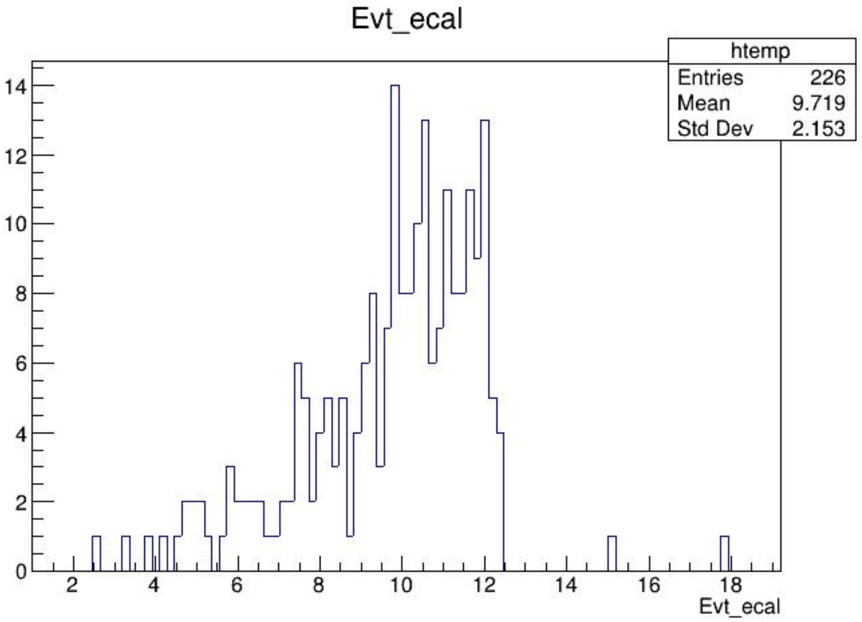
Central values of polarization fits as function of p_T cut, plot shows uncorrelated errors only

- p_T dependence seems flat at low values of the cut

Maximum EMC Energy

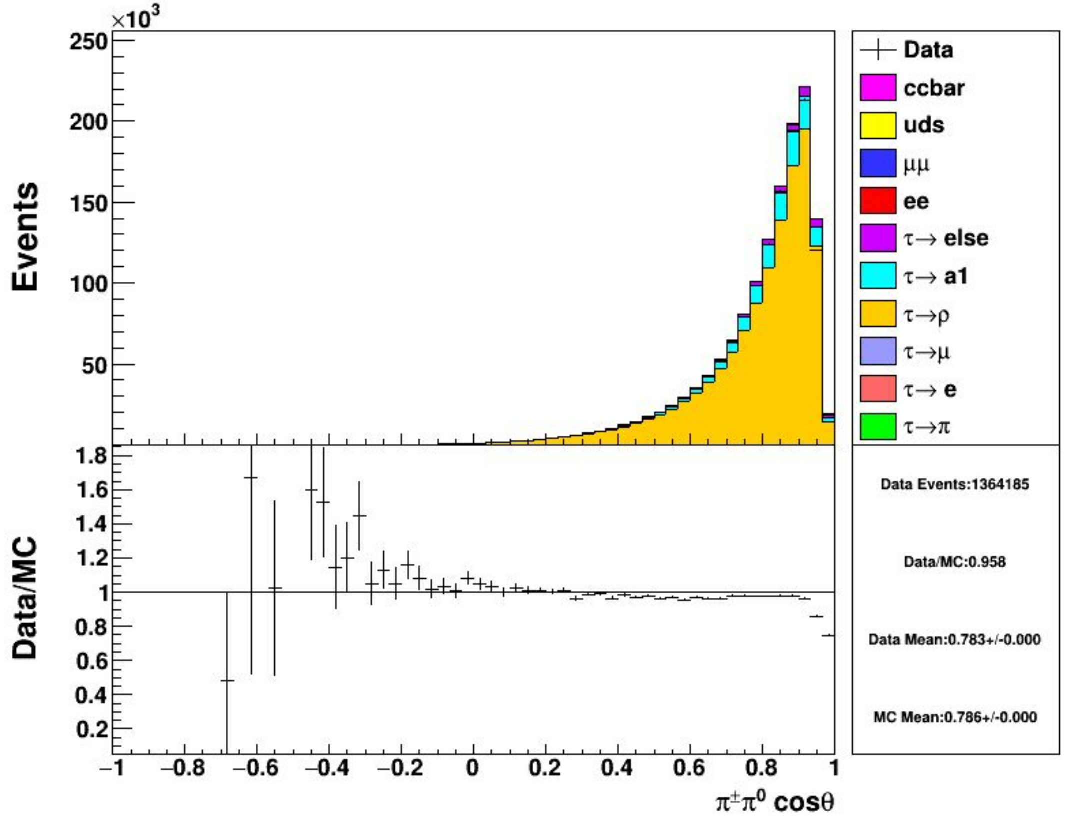
- A cut on the maximum calorimeter energy can eliminate 50% Bhabhas at minimal loss of signal
- At 10 GeV cut 521/1843822 signal events are cut, and 119/226 Bhabhas are cut
- Results in no significant changes to fits





pi-pi0 angular separation

- The angular separation between the pions from the rho was investigated in the past as a source of data/mc discrepancy and was found to improve the agreement slightly, but have minimal effect of the average beam polarization
- The effects of a cut on charge asymmetry had not been studied
- By placing a cut at 0.9 can improve data/mc as well as improve charged fit agreement



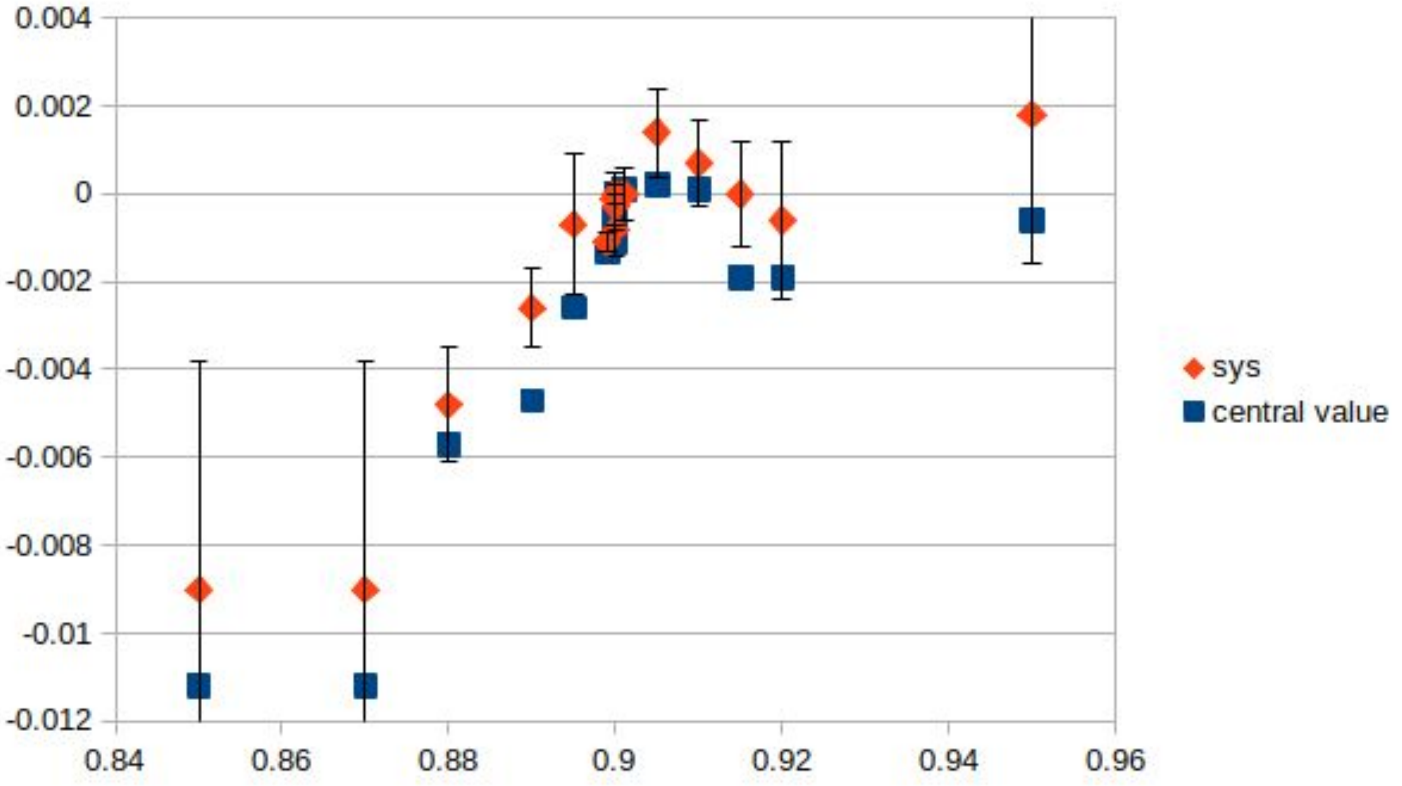
pi-pi0 angular separation

- Tension between charged data fits in each run:

Data	No angular cut	cut at <0.9
Run 1	-1.12σ	-0.60σ
Run 2	2.18σ	1.43σ
Run 3	3.17σ	1.79σ
Run 4	2.62σ	-0.28σ
Run 5	4.42σ	0.02σ
Run 6	3.27σ	0.60σ

pi-pi0 angular separation

- MC/Data agreement in rho mass suggests agreement on the order of 2 MeV
- Corresponds to an angular separation of $\Delta\cos\theta \approx (m_\rho * \Delta m_\rho)/(E_\pi E_{\pi 0}) \approx 0.0005\text{-}0.004$
  - Run 3 test suggests systematic uncertainty O(0.0005)
- Study of cut shows some stability above 0.9



blue squares show the data polarization fit as a function of angular cut. Stat uncertainty of ~0.01 not shown.

red triangles show data-MC polarization, error bars represent MC fluctuations

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Conclusions

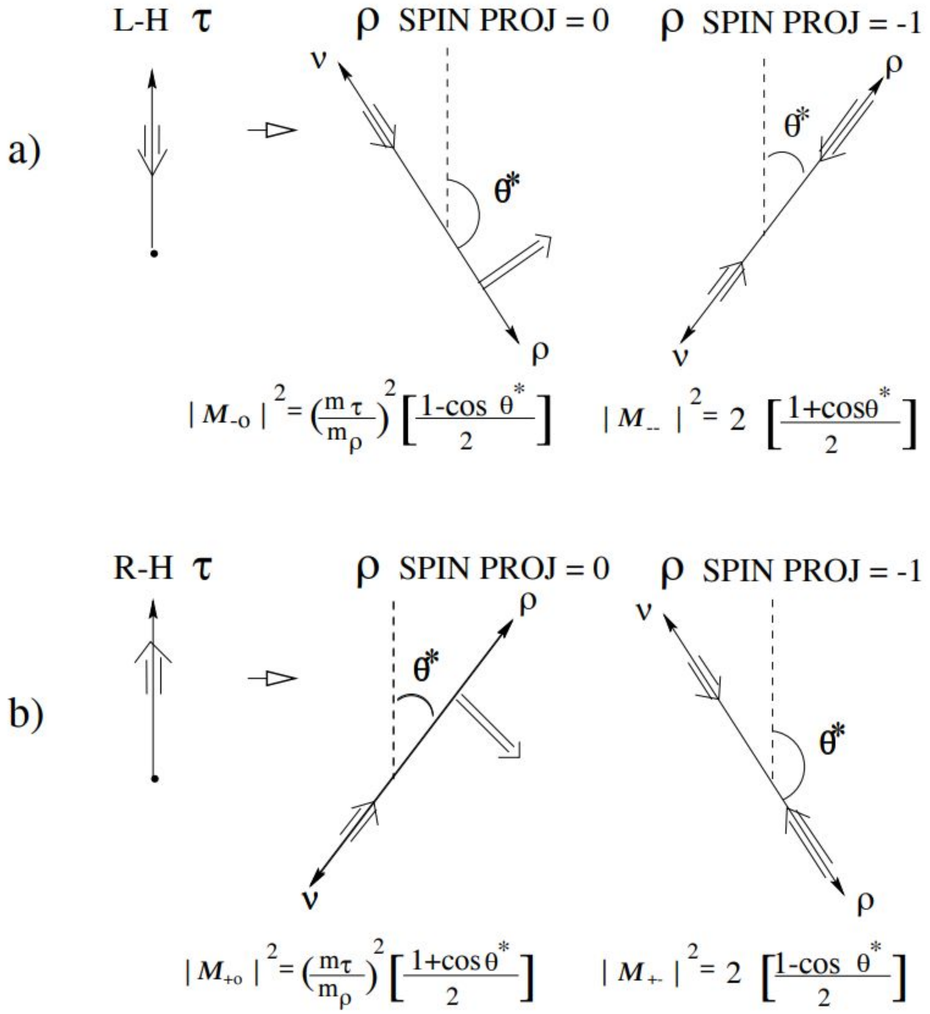
- Processing systematic uncertainties for new selection
  - ⇒ should have final result by the end of the month
- All previously established systematic uncertainties seem to remain at a similar level to prior studies
- Expecting to arrive at a final systematic uncertainty of <0.0030
  - ⇒ Corresponds to a total uncertainty of <0.0040 for the BaBar data

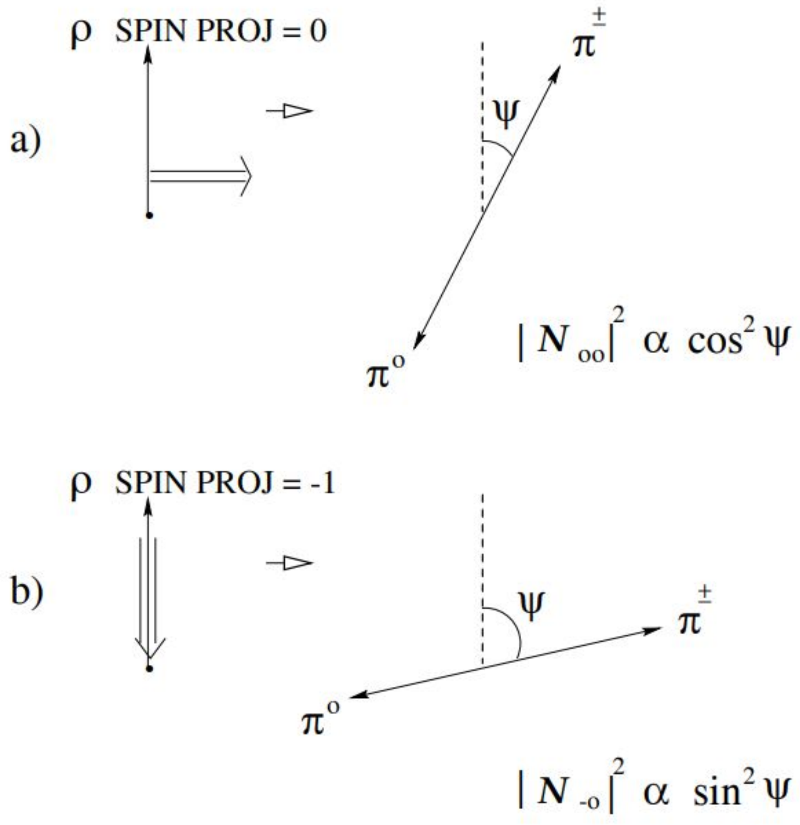
Thank You!

Backup Slides

Rho Spin Analysis

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

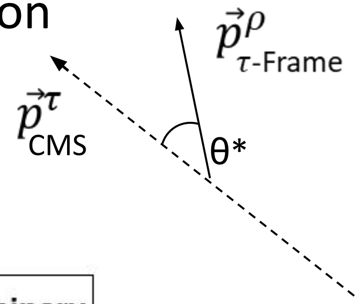




From Dr. Manuella Vincter, PhD thesis, UVIC, 1996

Polarization Observables

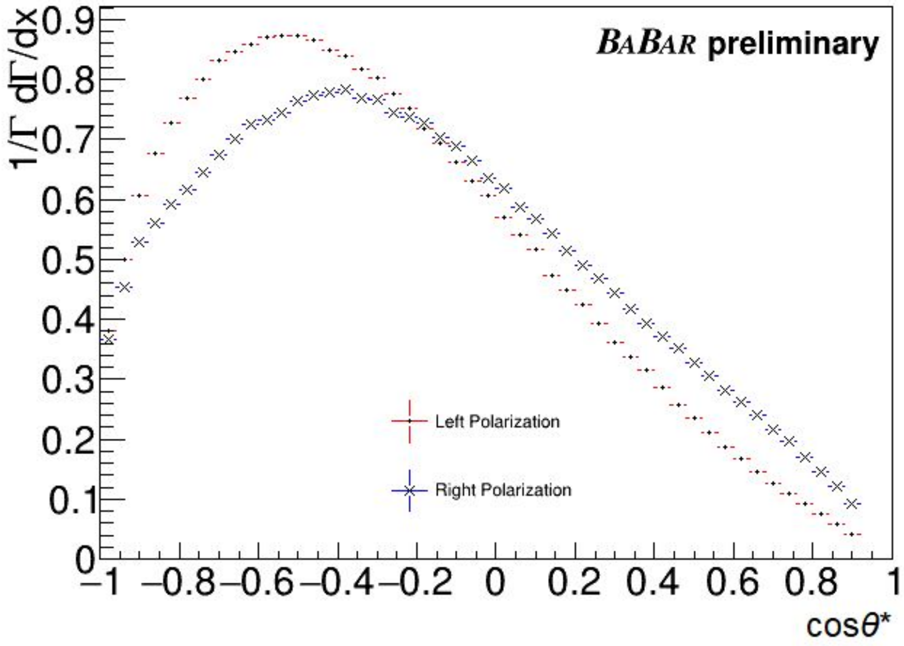
- Polarization sensitivity in a rho decay is maximized by analyzing two angular variables[2] in addition to cosθ. 2 variables required due to rho being spin-1, while only one needed for pion



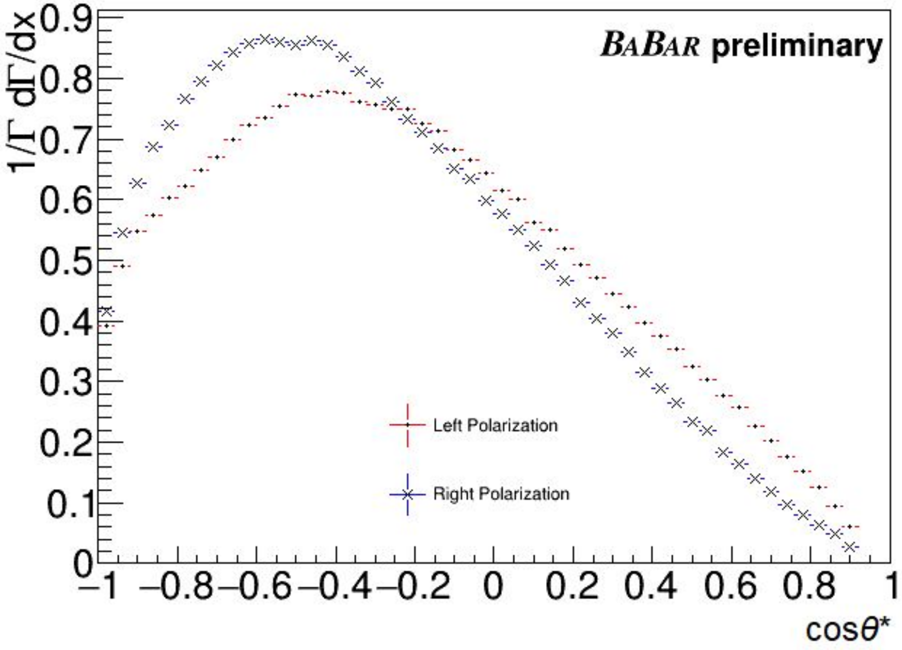
$$\cos\theta^* = \frac{2z - 1 - m_\rho^2/m_\tau^2}{1 - m_\rho^2/m_\tau^2}$$

$$z \equiv E_\rho / E_{\text{beam}}$$

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

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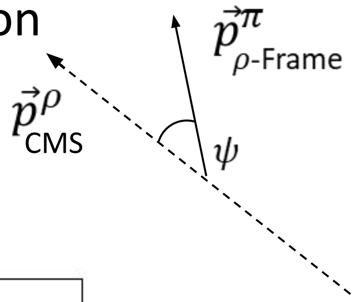
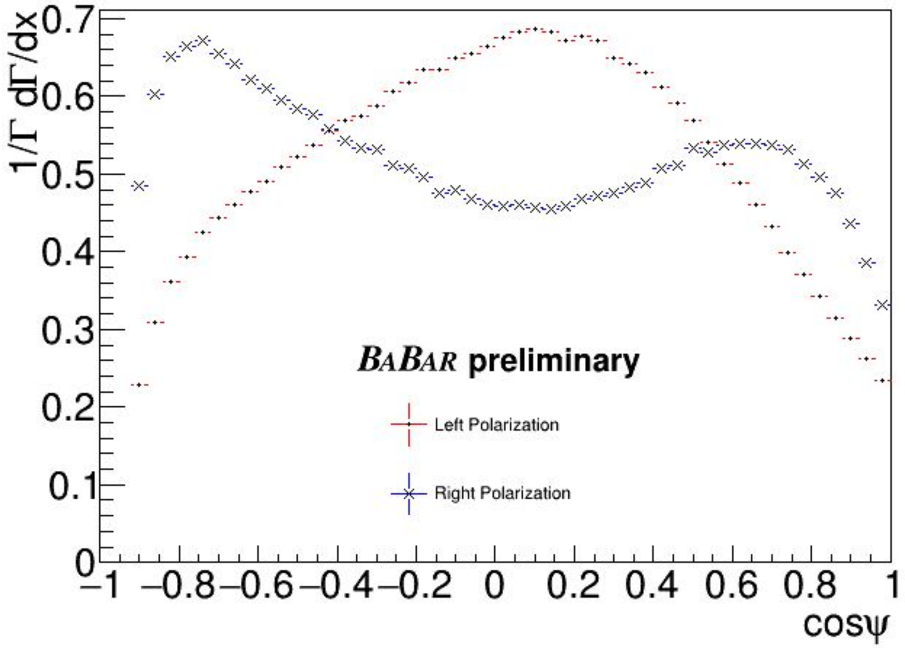


$$\cos\psi = \frac{2x-1}{\sqrt{1-4m_\pi^2/m_\rho^2}}$$

$$x \equiv E_\pi / E_\rho$$

cosθ<0



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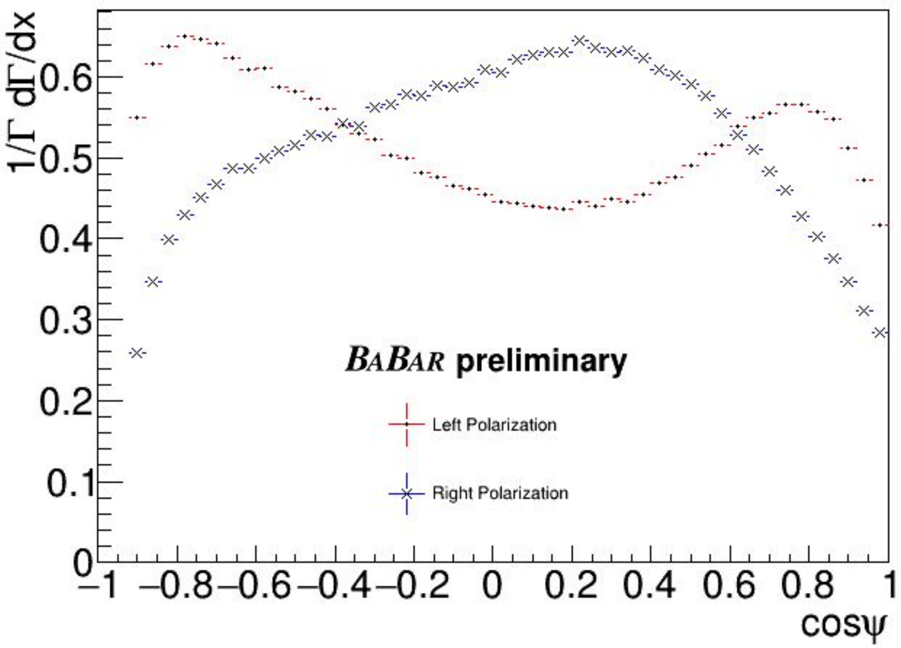

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