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

With preliminary results from BaBar

Caleb Miller

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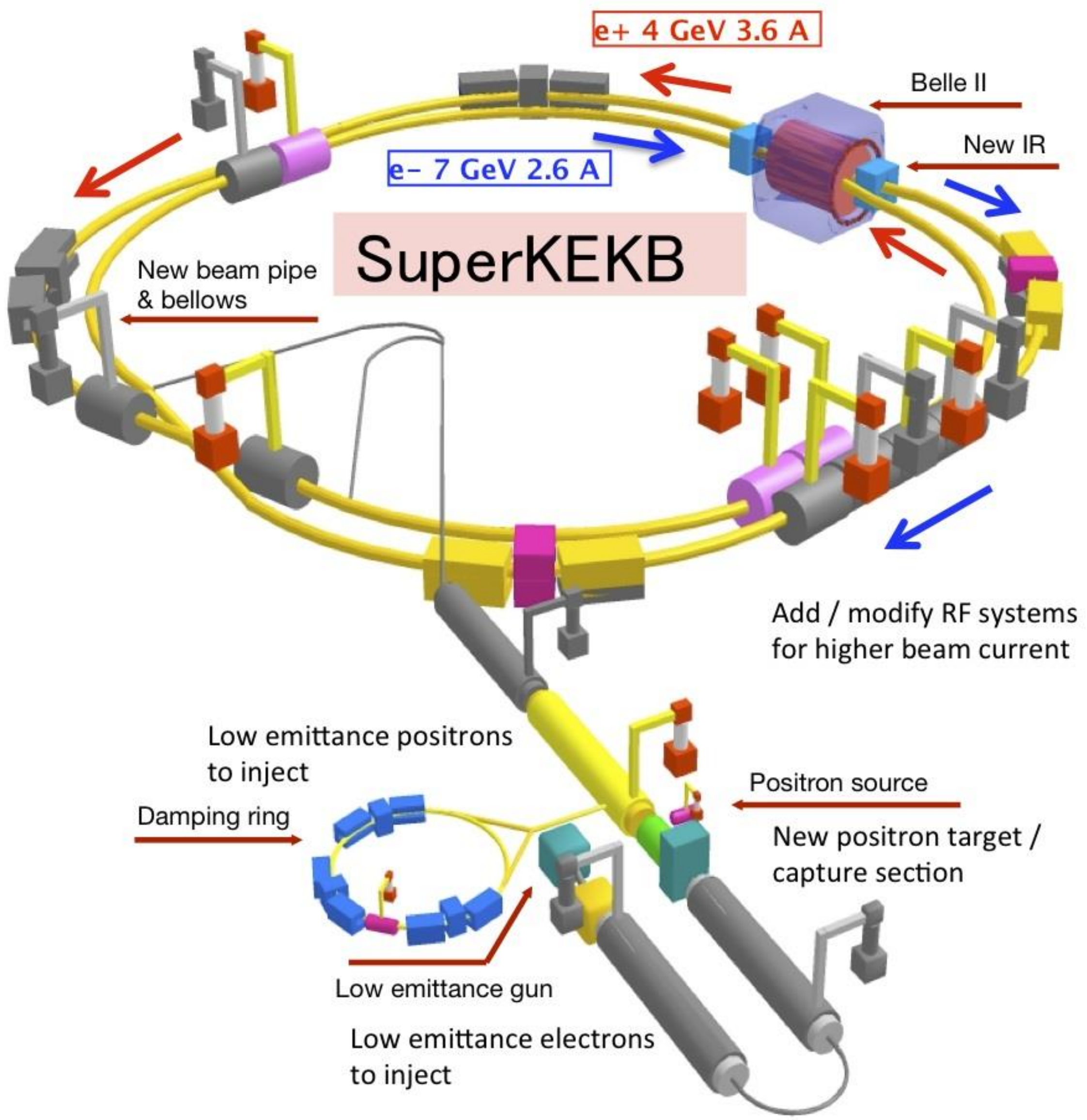
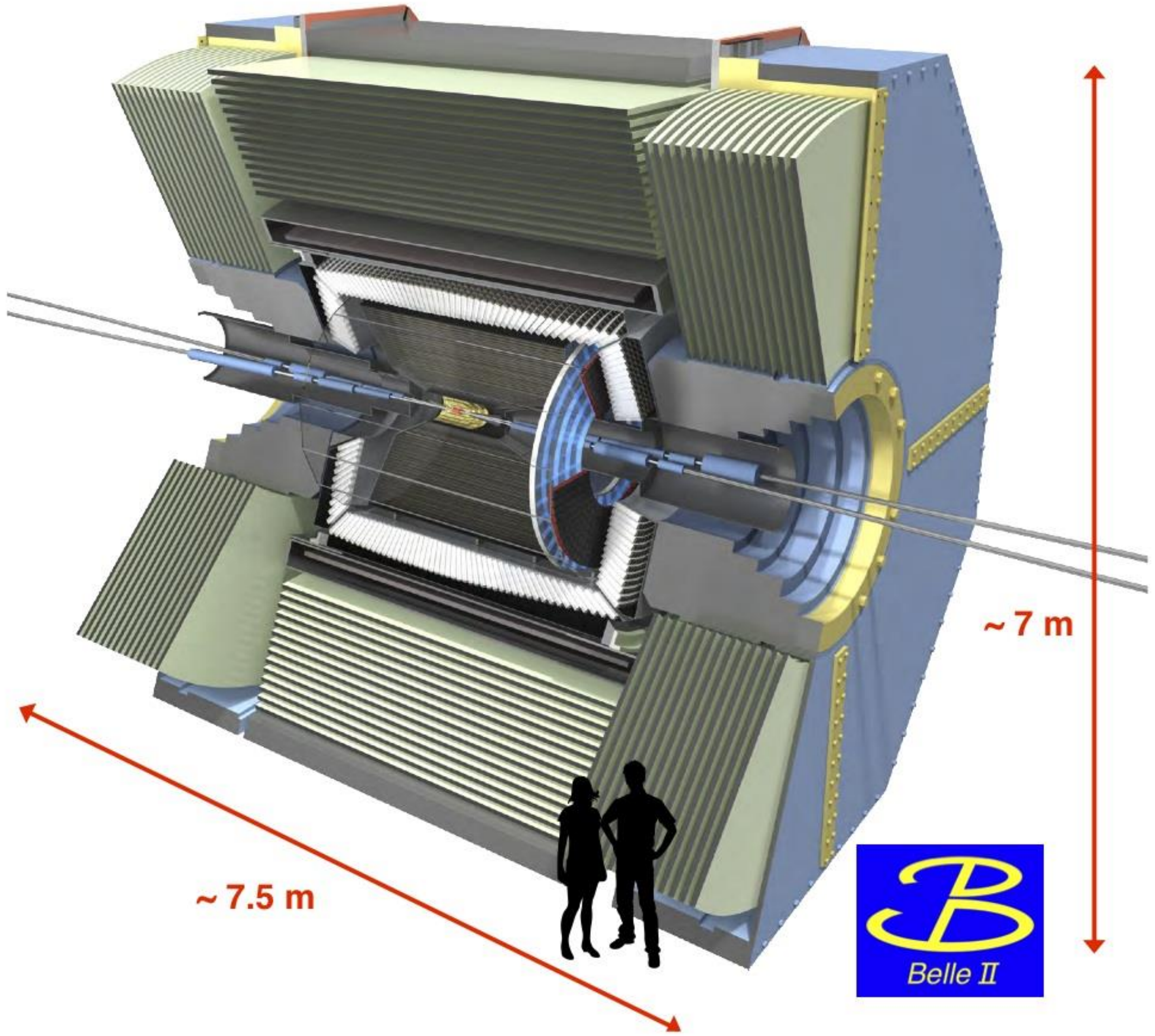
SuperKEKB and Belle II

- 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 physics results will be presented on Wednesday(W1-10) by Dr. Ewan Hill





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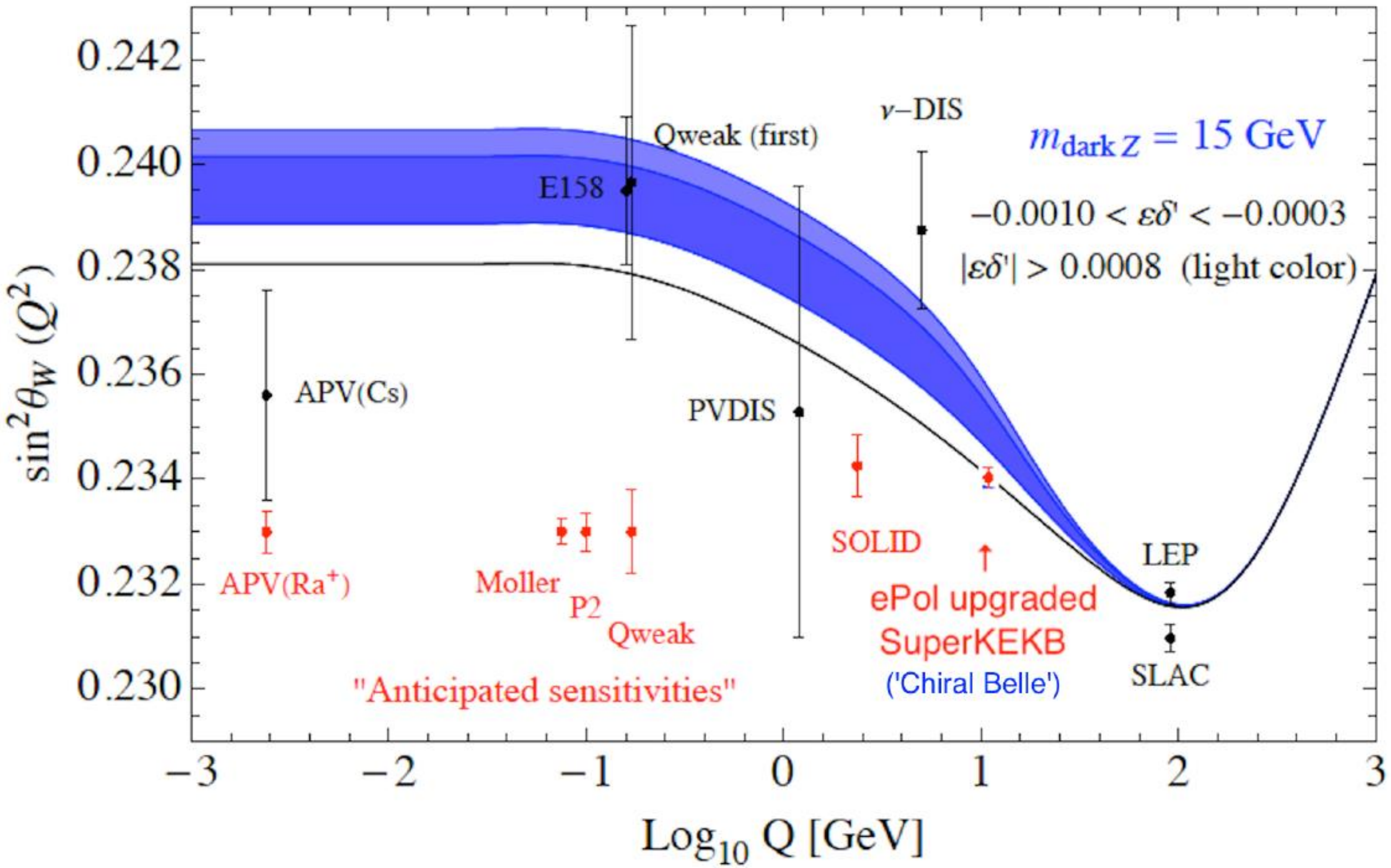
Beam Polarization Motivation

- 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

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



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 during transport
    - Collaborators in Novosibirsk, USA, UVic, TRIUMF
    - See Yuhao Peng's talk in 20 min

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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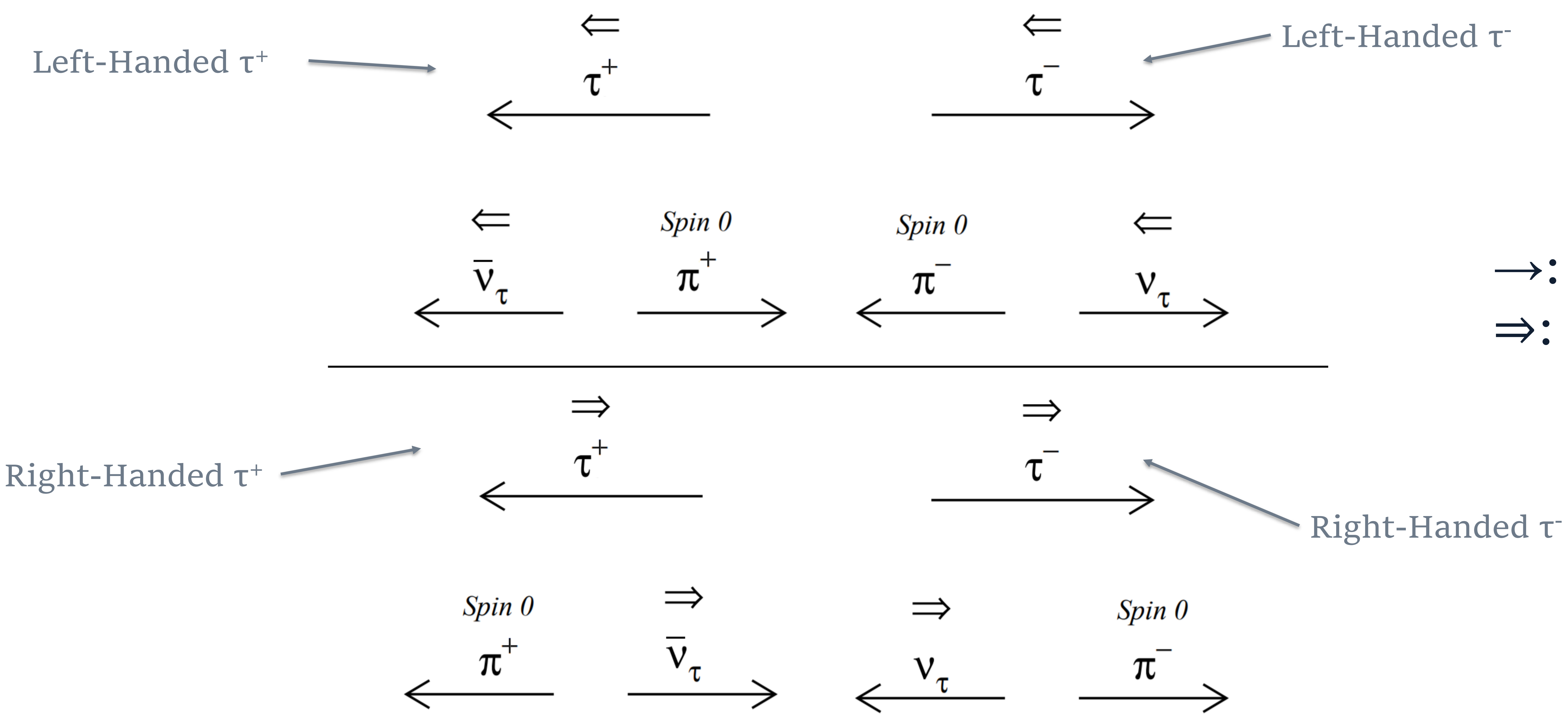
Polarization Sensitivity in Tau Decays

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



→: Momentum

⇒: Spin

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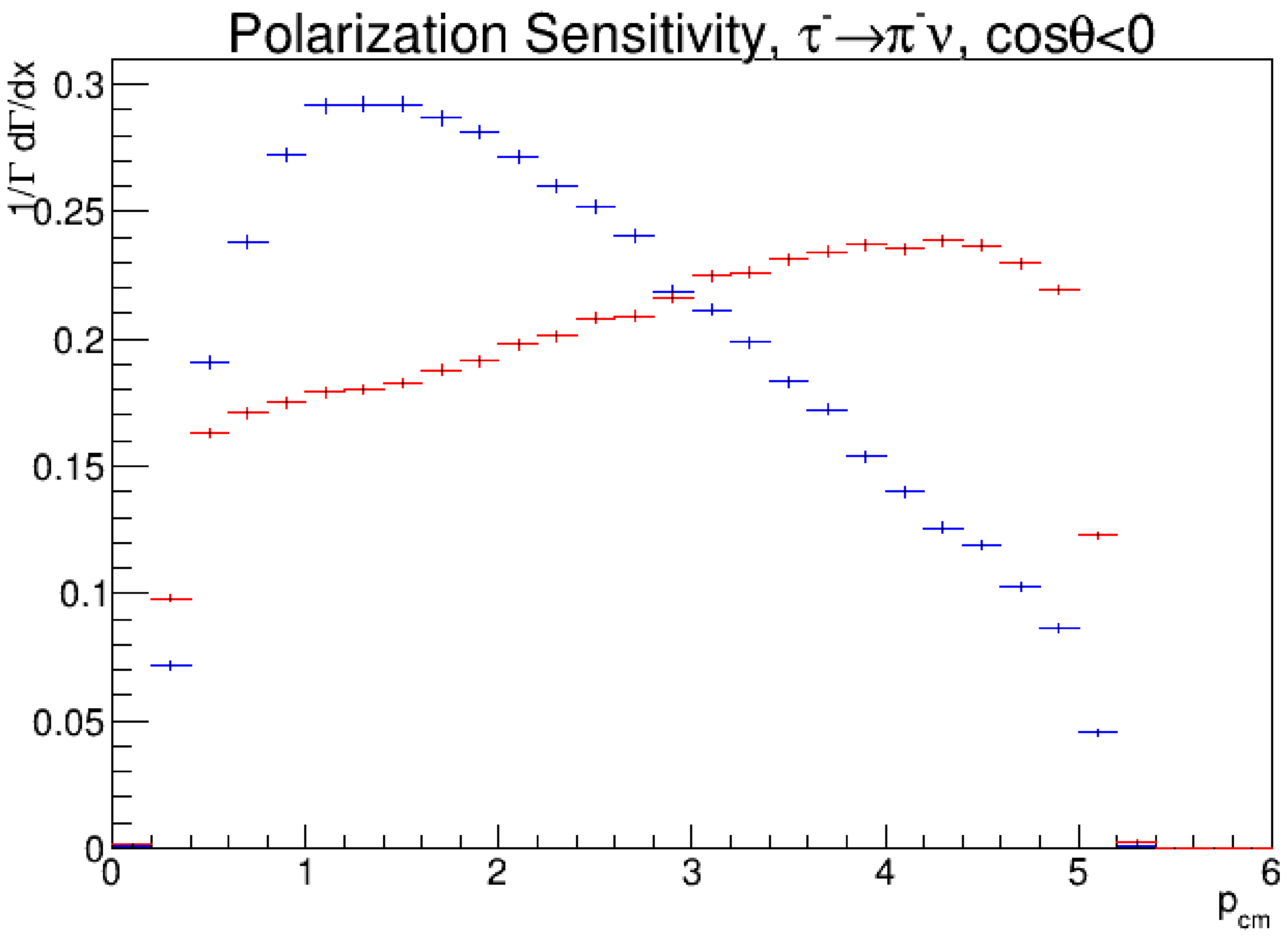
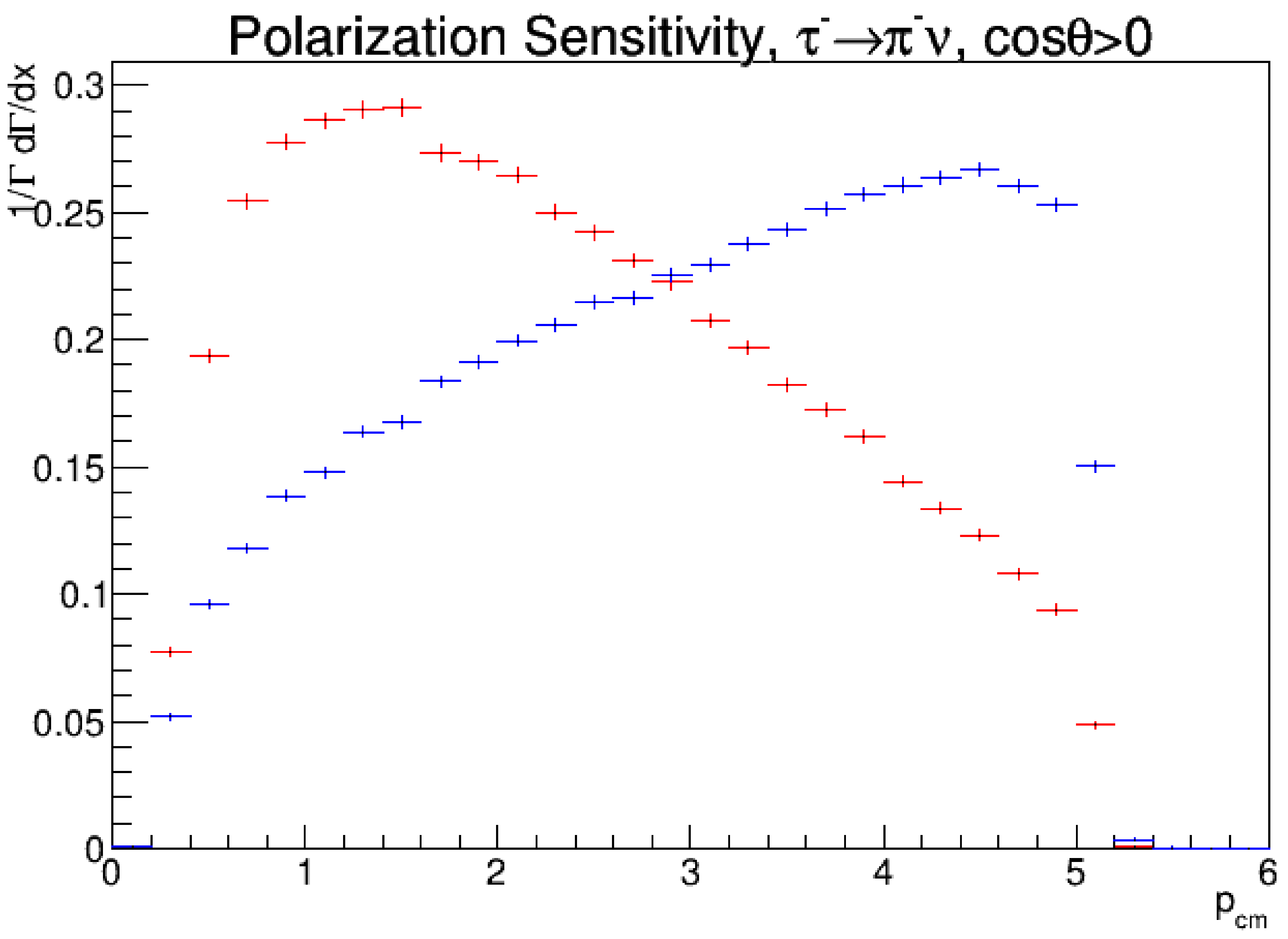
Pion Momentum, Polarization Sensitivity

- 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



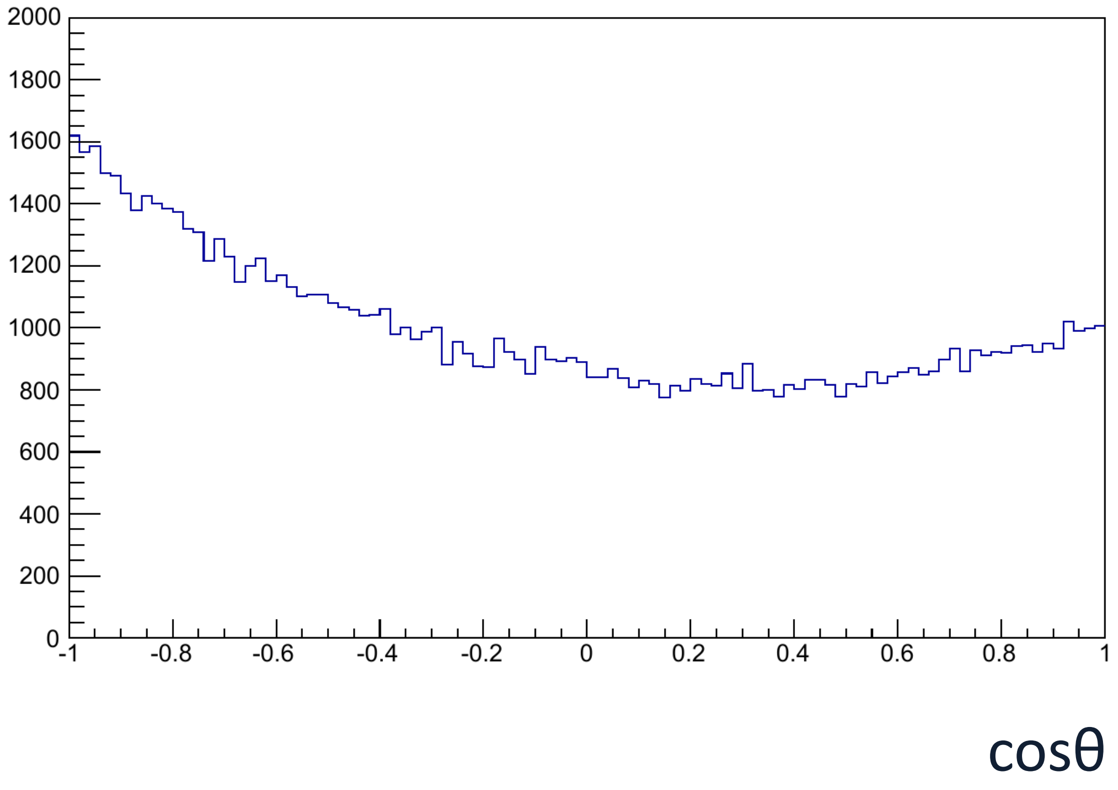


Red: Left-Handed e^- beam, Blue: Right-Handed e^- beam

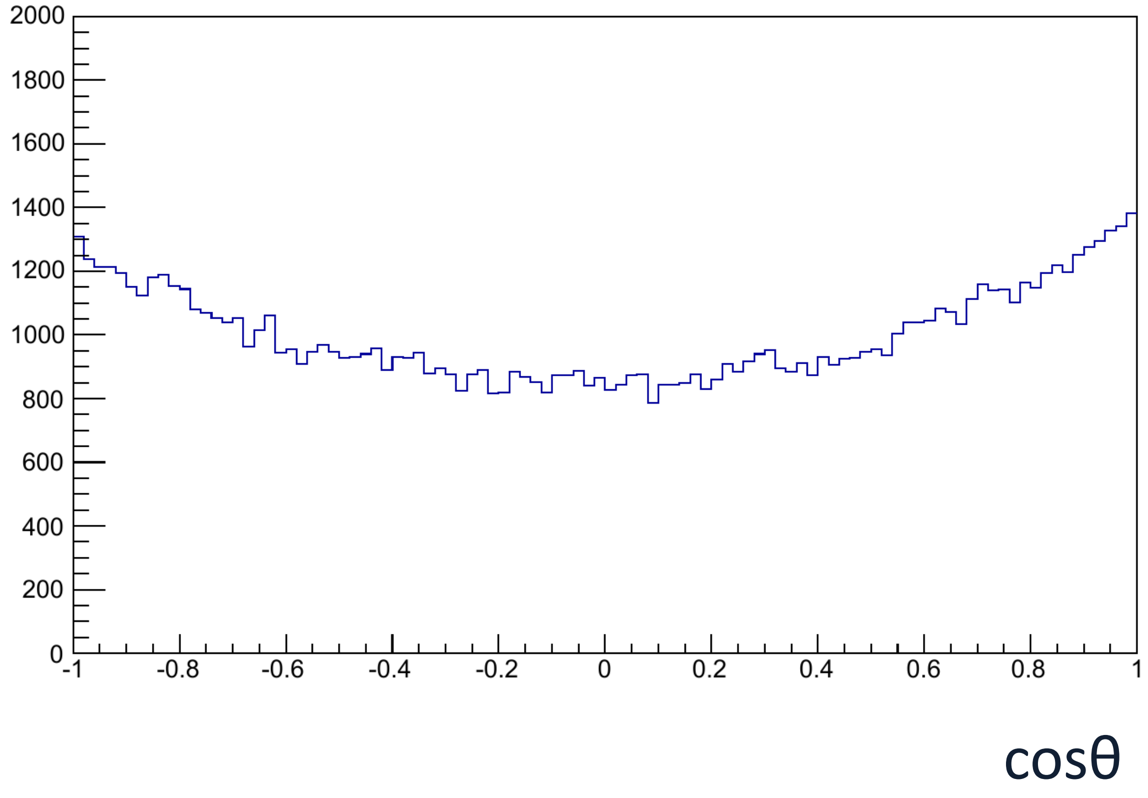
Pion Angular Distribution, Polarization Sensitivity

- Using momentum and cosθ gives together improves sensitivity

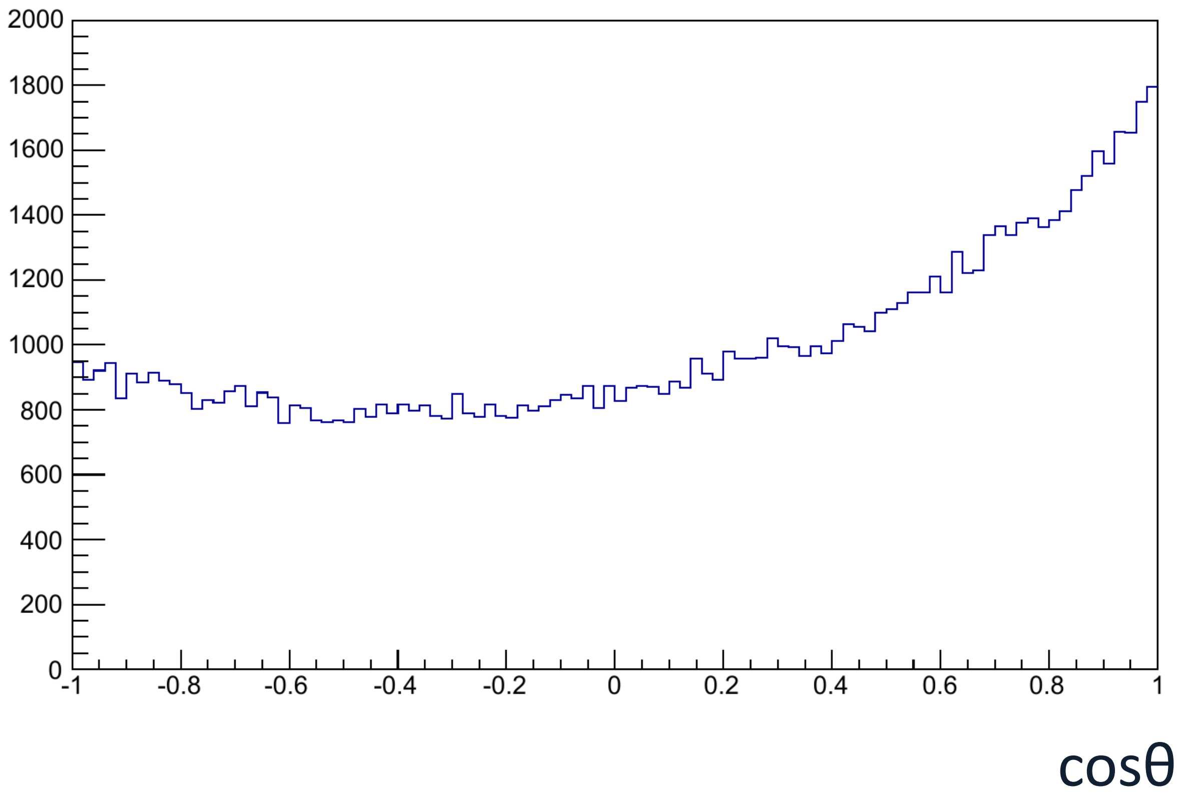
Left-handed e^- beam, π^- cosθ distribution



Unpolarized e^- beam, π^- cosθ distribution



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



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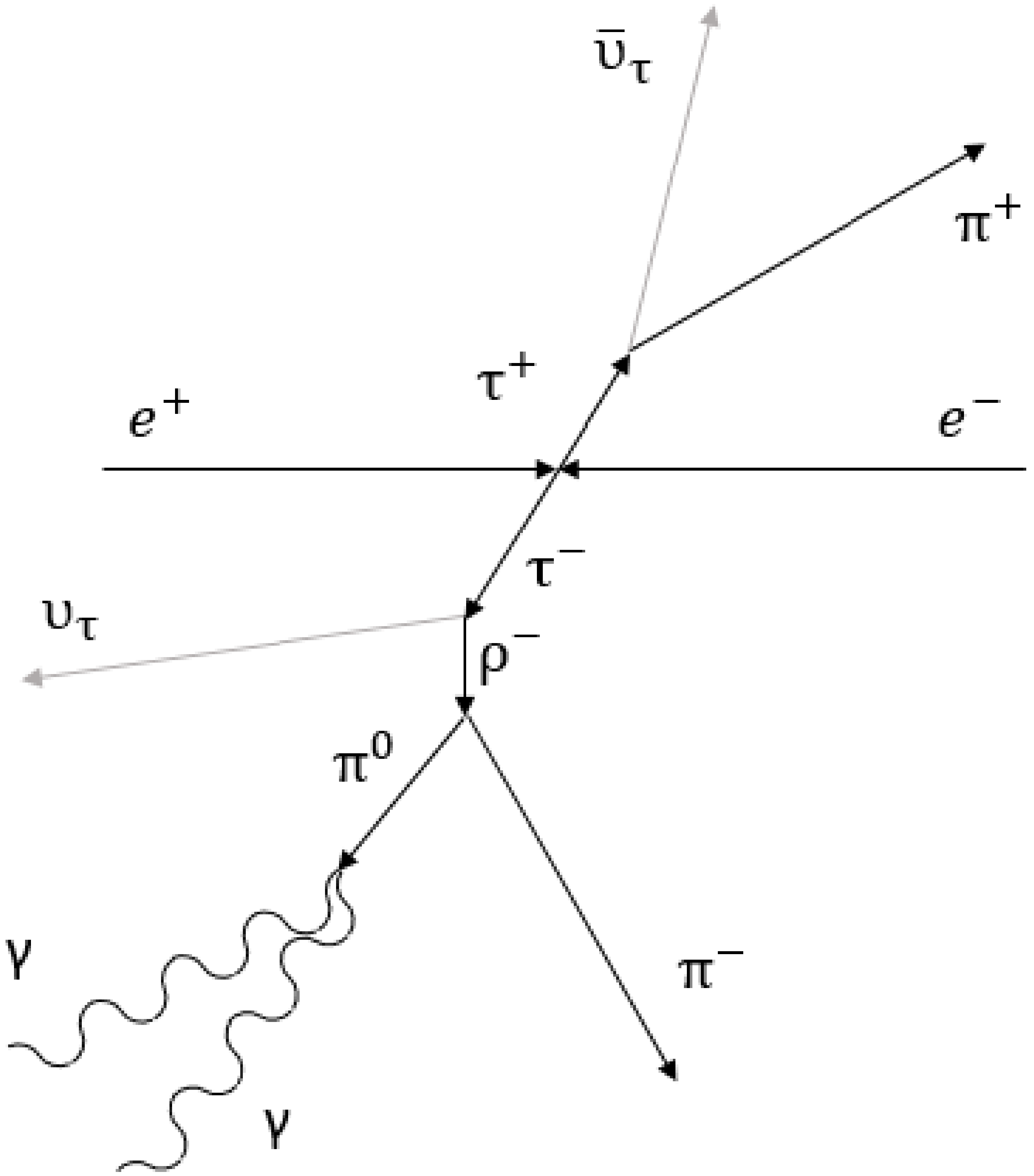
Event Selection

- As Belle II is just now collecting significant data, We used the well understood BaBar data to develop this technique
  - BaBar is a predecessor to Belle II
    - Similar detector design
    - Full BaBar dataset is 513.7 fb^{-1}
  - Using a 32.28 fb^{-1} subset as a study sample
- 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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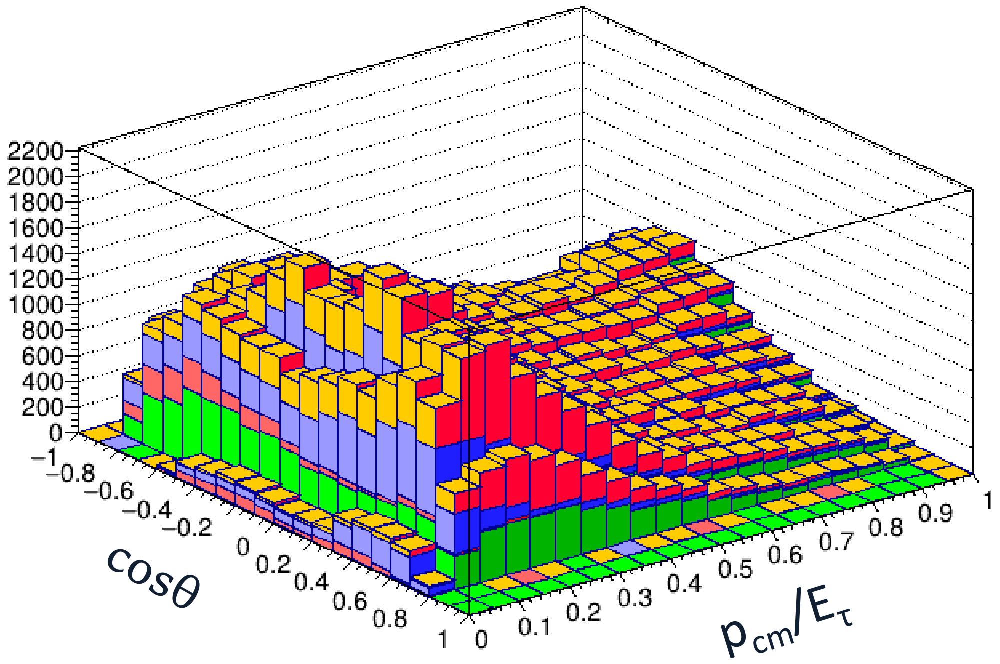
[1] R. Barlow, C. Beeston; Computer Physics Communications, Volume 77, Issue 2, 1993, Pages 219-228, https://doi.org/10.1016/0010-4655(93)90005-W

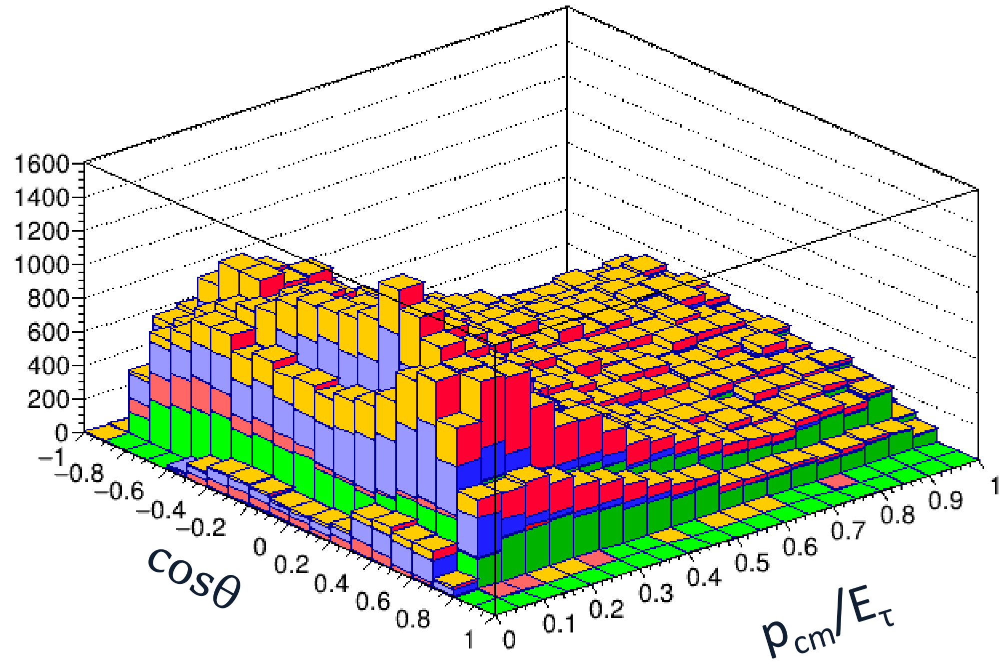
Template Example

- Templates for the tau MC

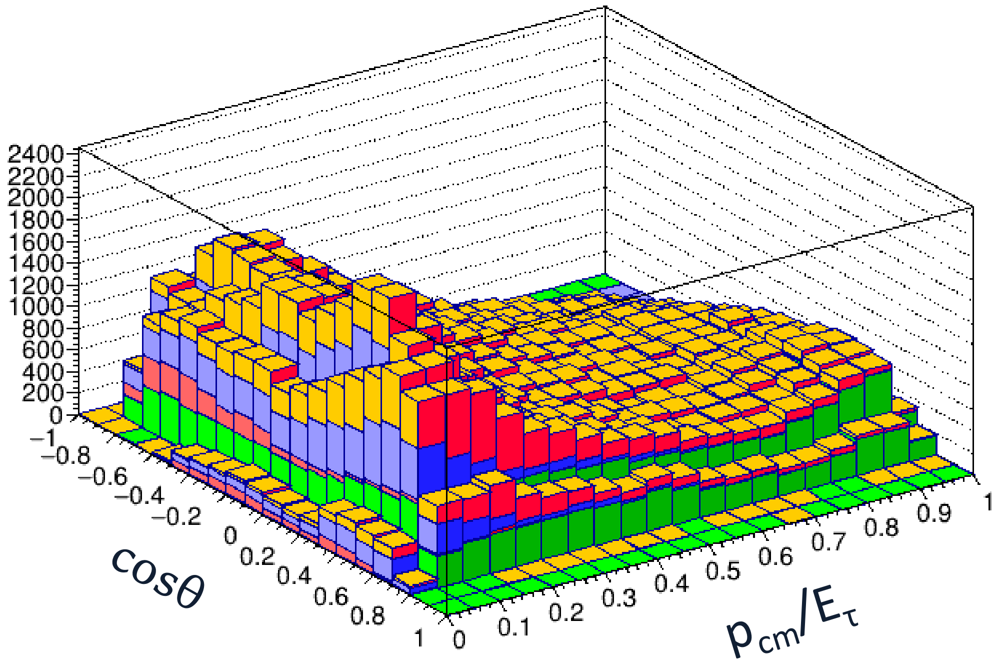
Left-handed e⁻ beam, π⁻ distribution



Unpolarized e⁻ beam, π⁻ distribution



Right-handed e⁻ beam, π⁻ distribution



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

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Fit Results and Systematic Uncertainties

	Positive Charge	Negative Charge	Combined Average
MC 1	-0.0064±0.0156	0.0093±0.0158	0.0013±0.0111
MC 2	-0.0018±0.0156	-0.0369±0.0158	-0.0191±0.0111
MC 3	-0.0038±0.0155	0.0036±0.0157	-0.0002±0.0110
Data	0.0258±0.0164	-0.0027±0.0167	0.0118±0.0117

BaBar beam polarization fit, 32.28 fb^{-1} study sample

Study	Systematic
Muon PID	0.0030
Neutral Clusters	0.0024
Momentum Resolution	0.0015
Electron PID	0.0012
BGFTau	0.0009
Other	0.0007
Total	0.0045

Summary of dominant systematic uncertainties

Conclusions

- Identified dominant systematic uncertainties for this measurement technique
- Measured the beam polarization in the BaBar study data to be:

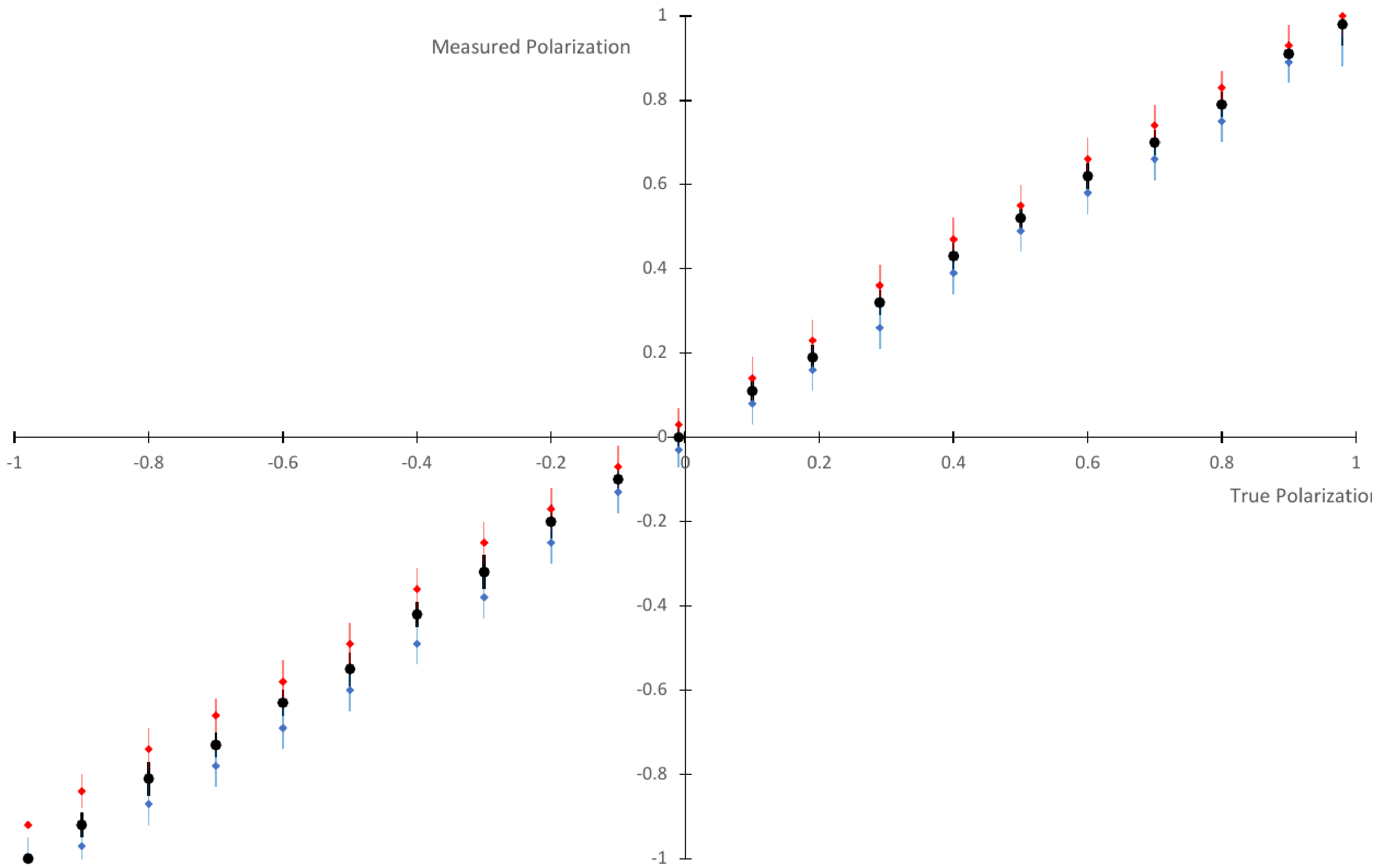
$$\langle P \rangle = 0.012 \pm 0.012_{\text{stat}} \pm 0.0045_{\text{sys}}$$

- With full BaBar dataset we expect the statistical uncertainty to drop to 0.0029
- Currently working through the BaBar approval process to analyze the full dataset
- We have begun implementing this measurement technique at Belle II
- Carrying out feasibility studies for Tau Polarimetry at the ILC

Backup Slides

Absolute Polarization Sensitivity

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



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