Beam Polarimetry with Taus for an Upgraded SuperKEKB

Caleb Miller

Oct 18, 2021

University of Victoria

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

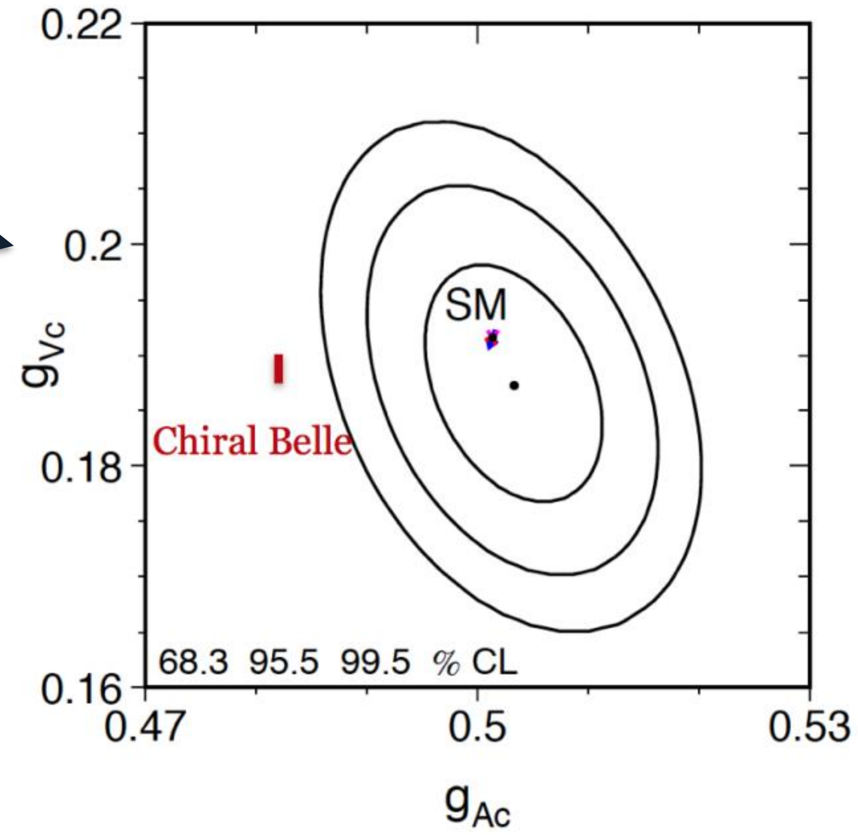
$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}}\left(\frac{G_f s}{4\pi\alpha Q_f}\right) g_A^e g_V^f \langle P \rangle \propto T_3^f - 2Q_f \sin^2\theta_W$$

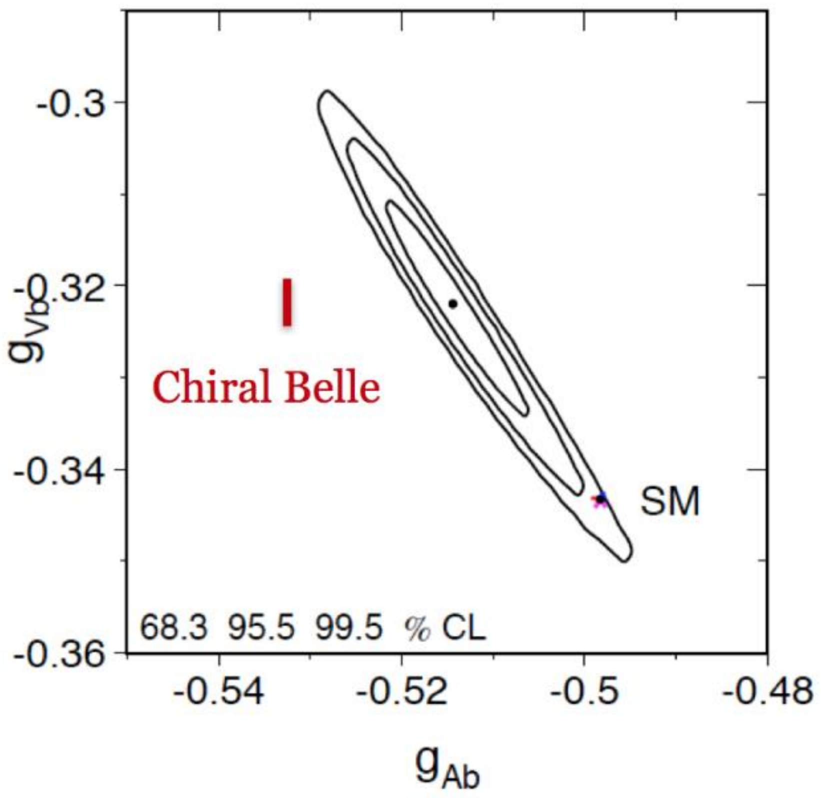
c-quark: Chiral Belle ~7 times more precise

with 20 ab^-1

b-quark: Chiral Belle ~4 times more precise

Red bars show expected +/- 1 sigma uncertainty



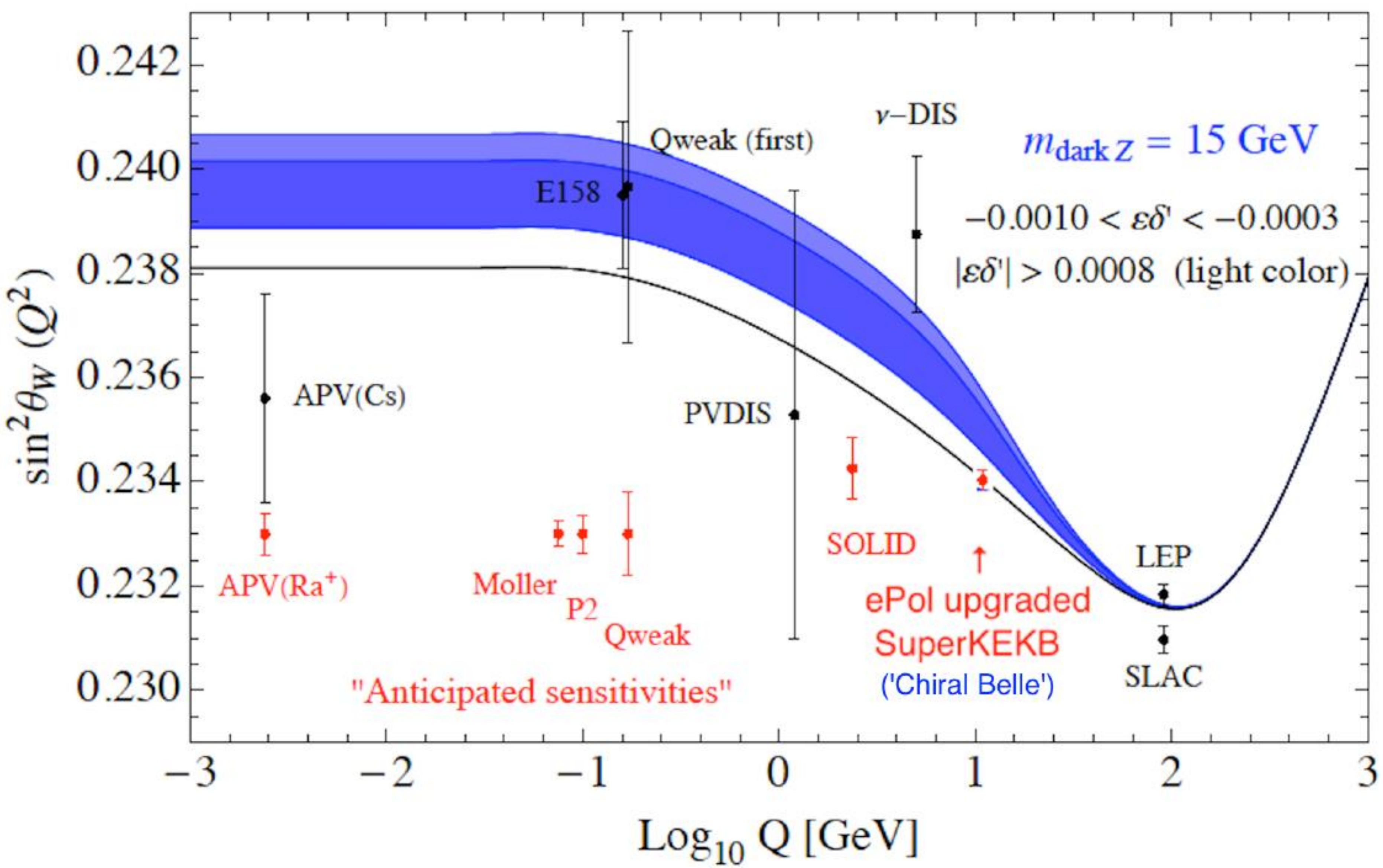


University of Victoria

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

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



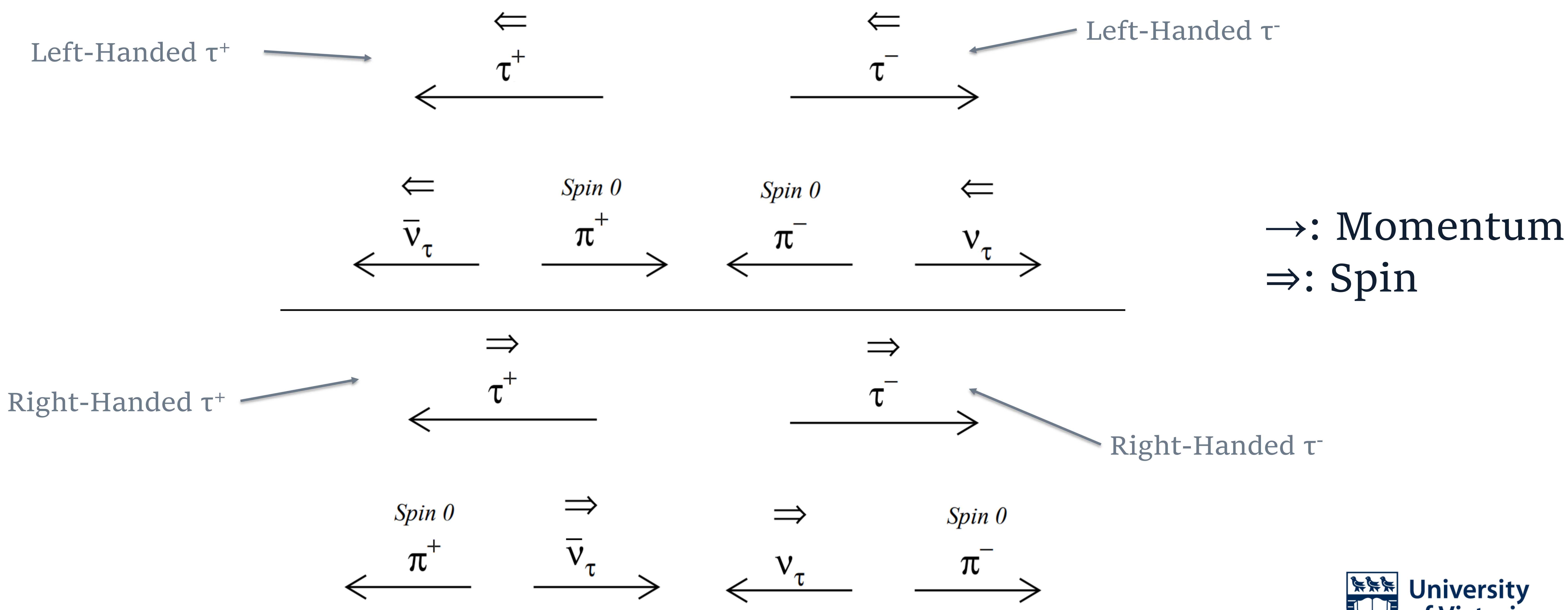
Red bars show expected sensitivity of future experiments

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

University of Victoria

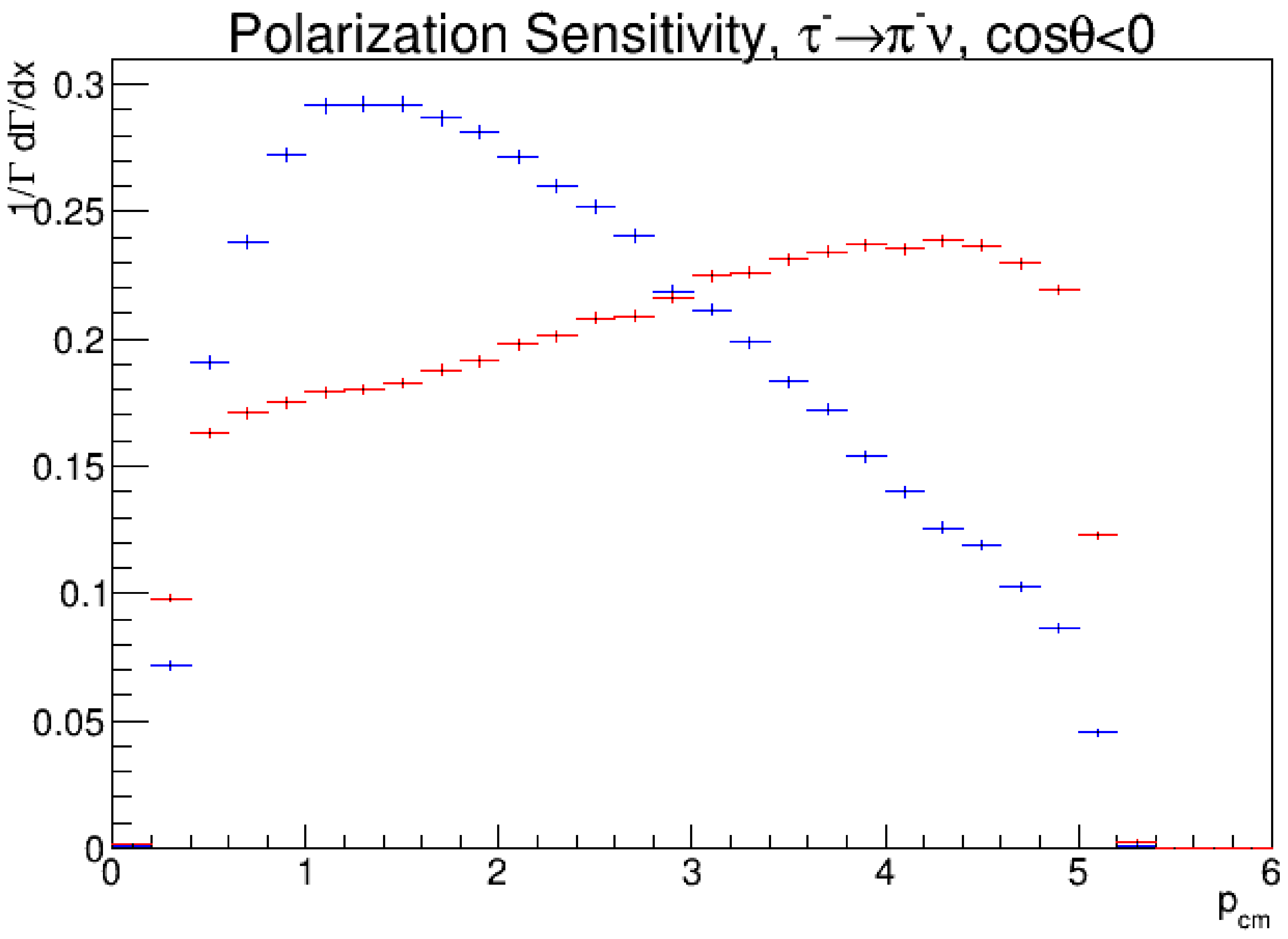
Polarization Sensitivity in Tau Decays

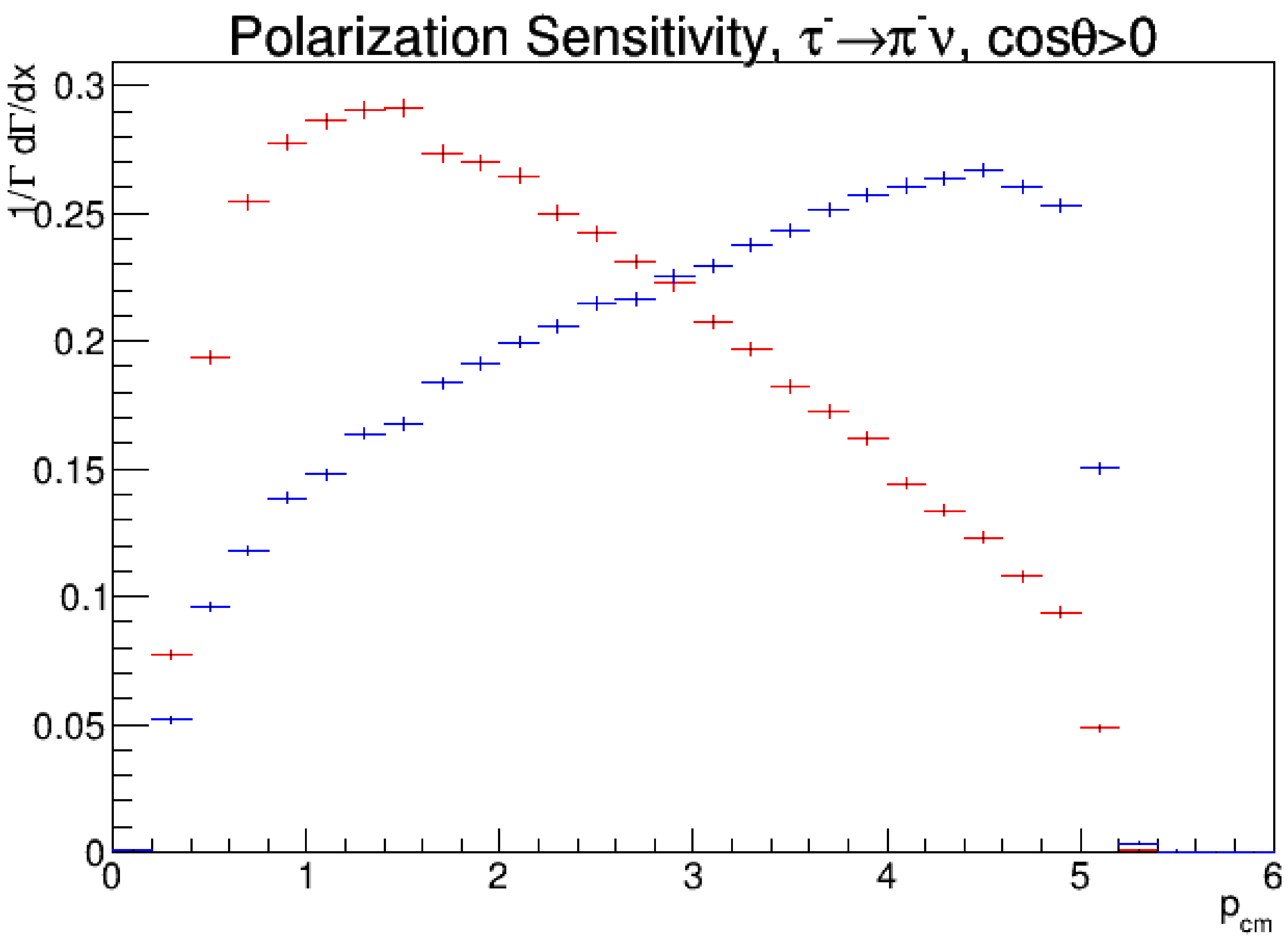
- The kinematics of the $\tau \rightarrow \pi \nu$ provide a powerful insight into the polarization



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



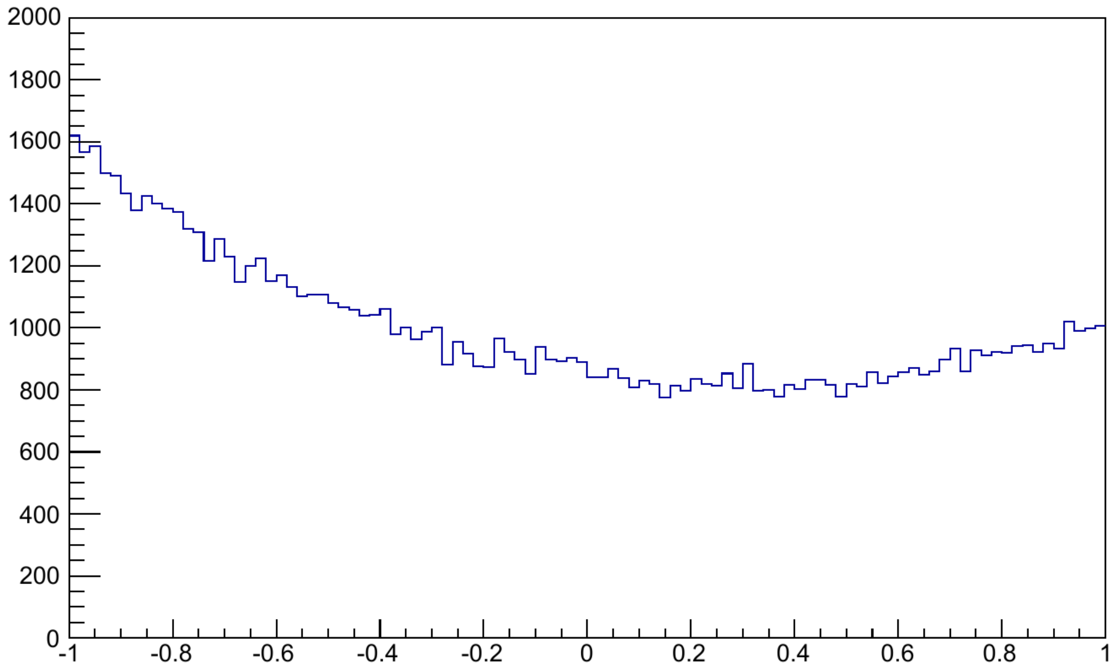


Red: Left-Handed e^- beam, Blue: Right-Handed e^- beam

Pion Angular Distribution, Polarization Sensitivity

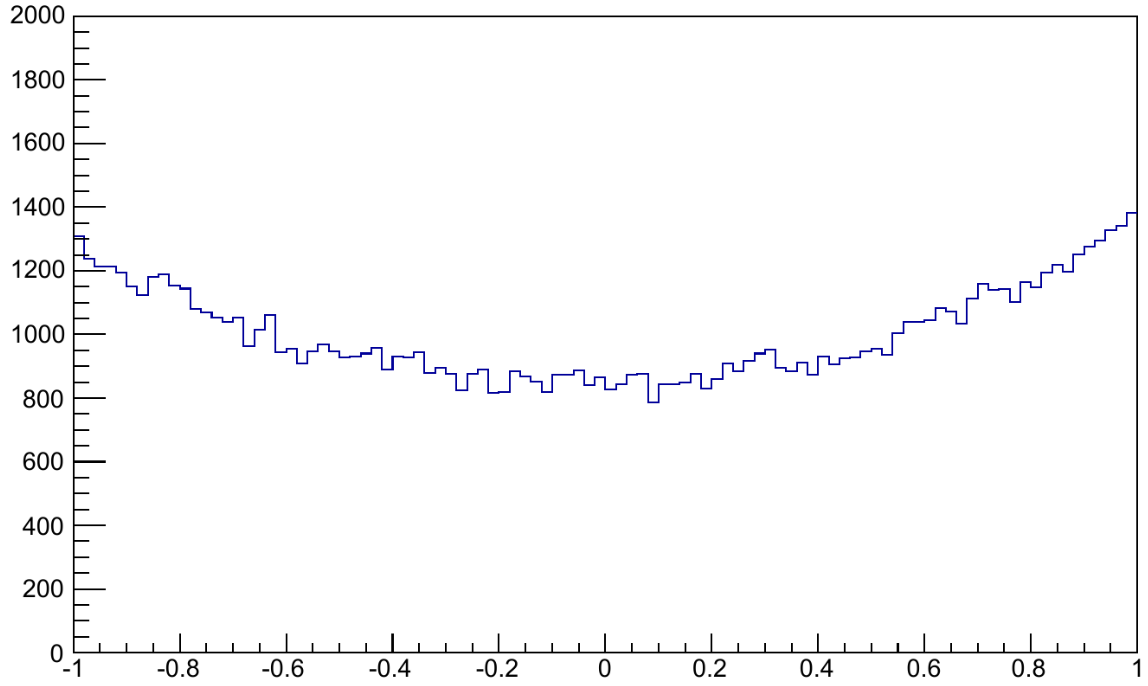
- Using momentum and cosθ gives together improves sensitivity

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



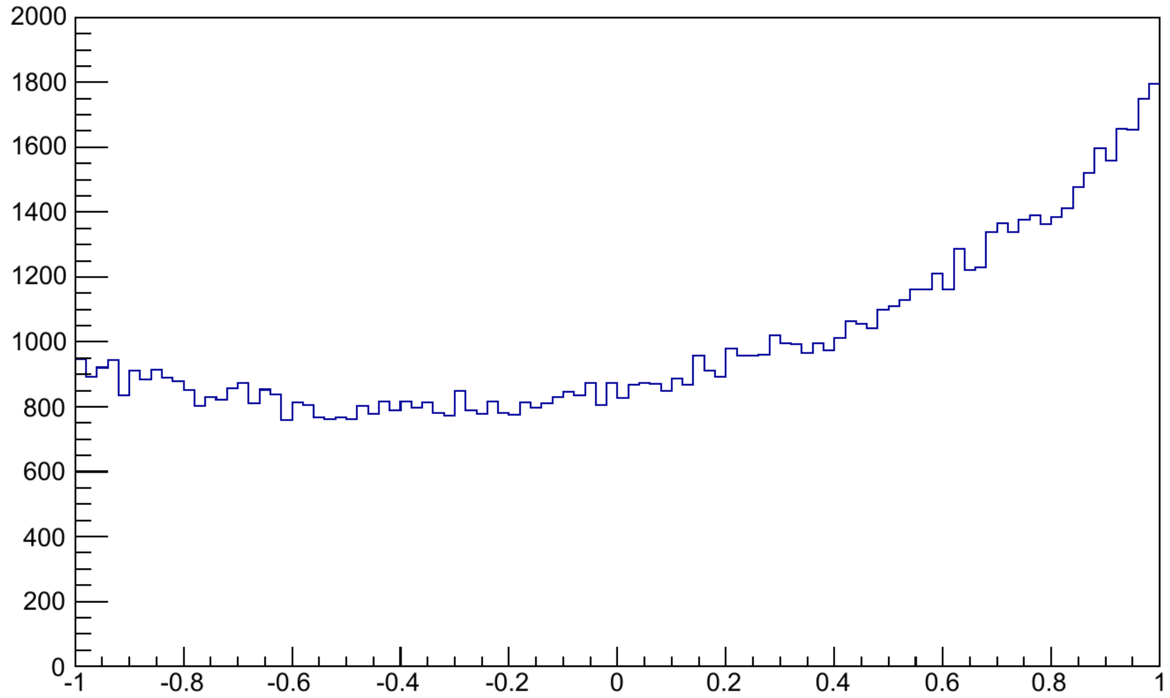
cosθ

Unpolarized e^- beam, π^- cosθ distribution



cosθ

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

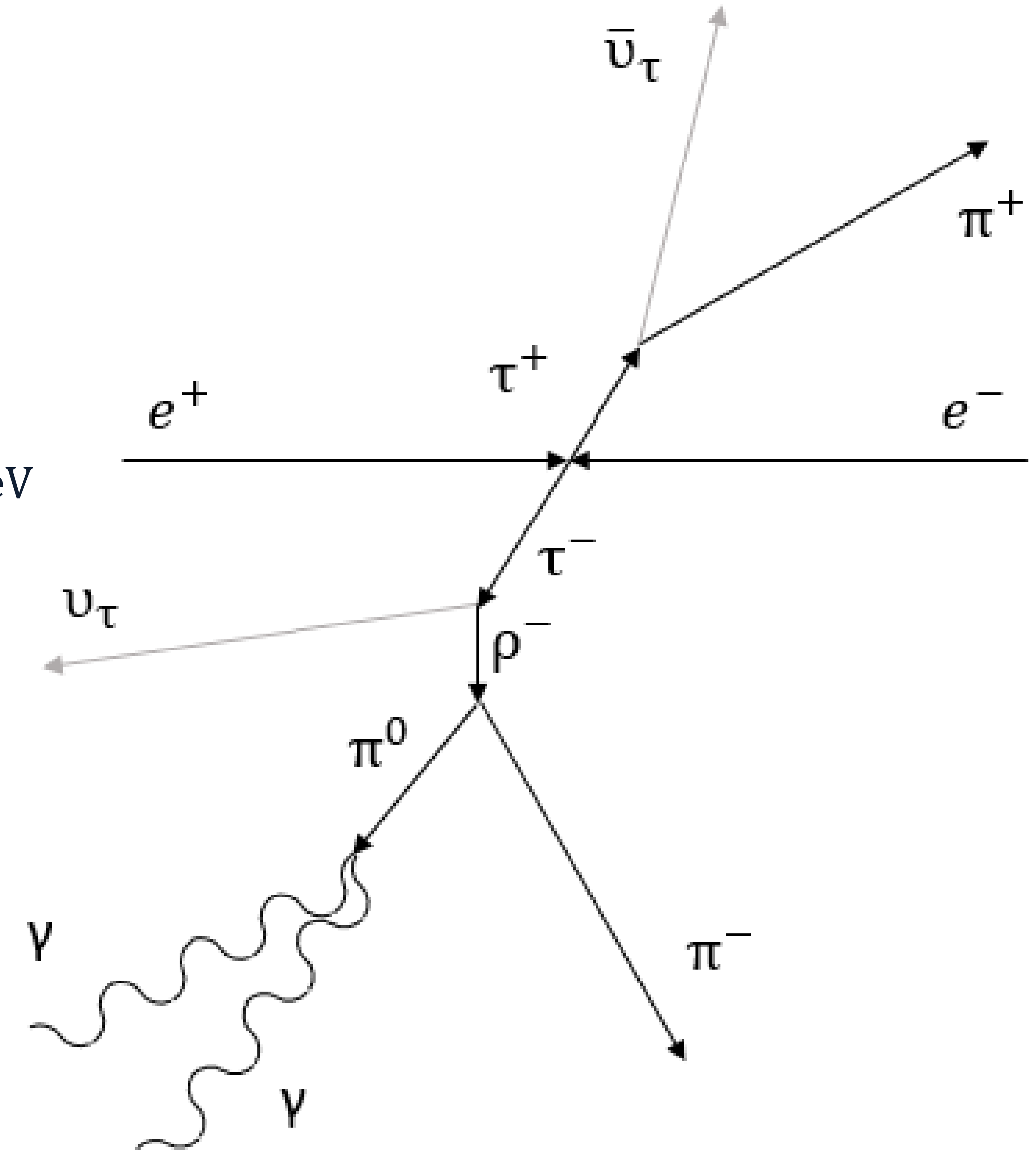


cosθ

University of Victoria

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)
- 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



Event Selection

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

	Luminosity Scaled Events	Ratio
uds	4469	0.0167
$c\bar{c}$	113	0.0004
bhabhas	1051	0.0039
$\mu\mu$	27	0.0001
$\tau\tau$	262329	0.9789
$\tau \to e\nu\nu$	5366	0.0200
$\tau \to \mu\nu\nu$	45018	0.1680
$\tau \to \pi\nu$	163213	0.6090
$\tau \to$ else	48732	0.1818

University of Victoria

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=$c\bar{c}$

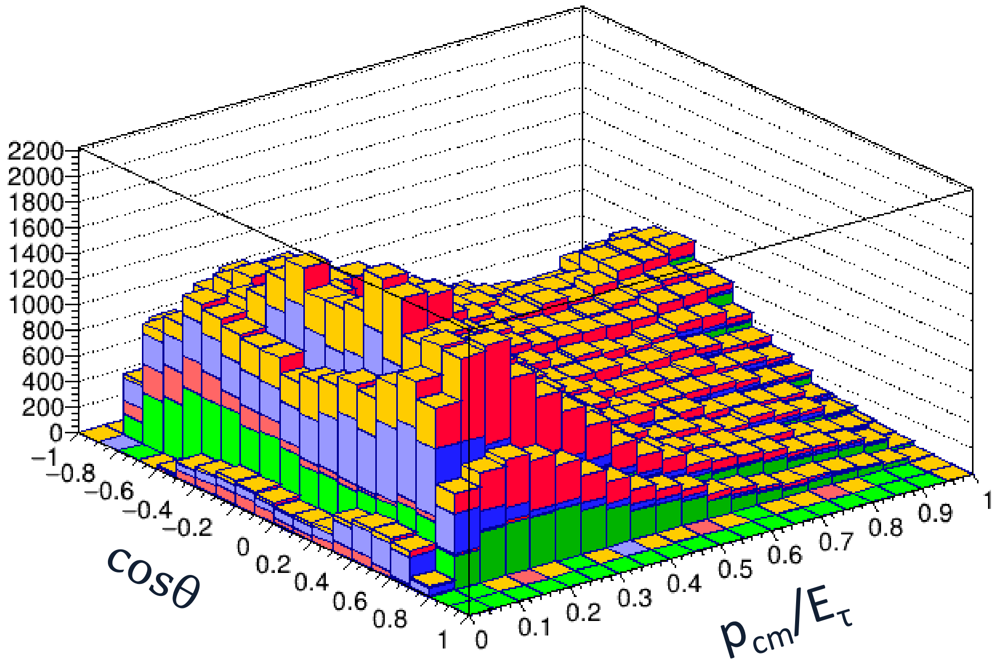
University of Victoria

[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

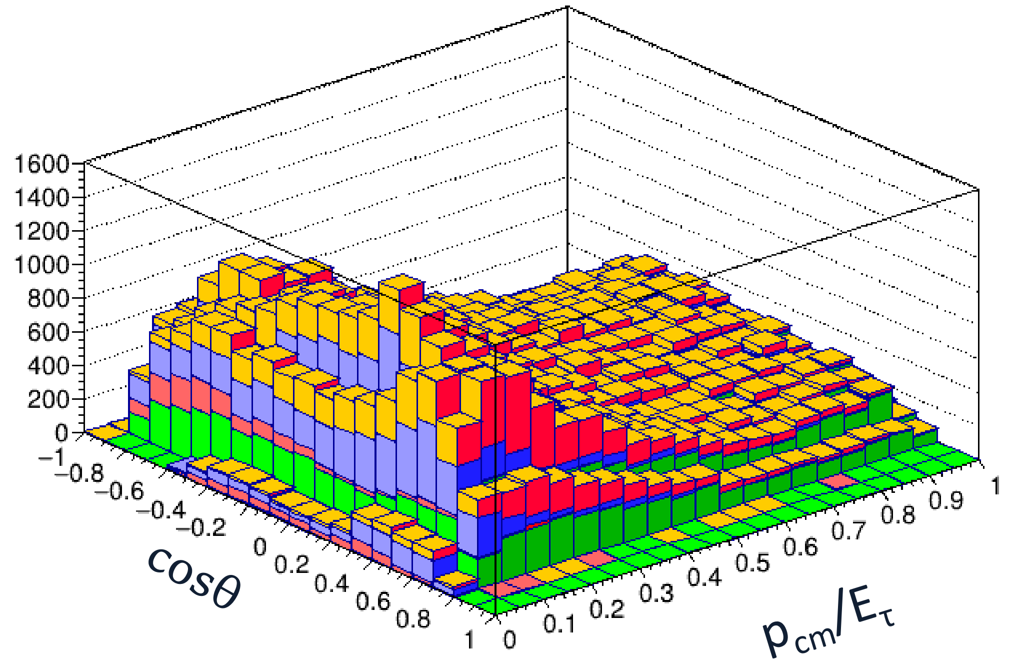
Template Example

- Templates for the tau MC

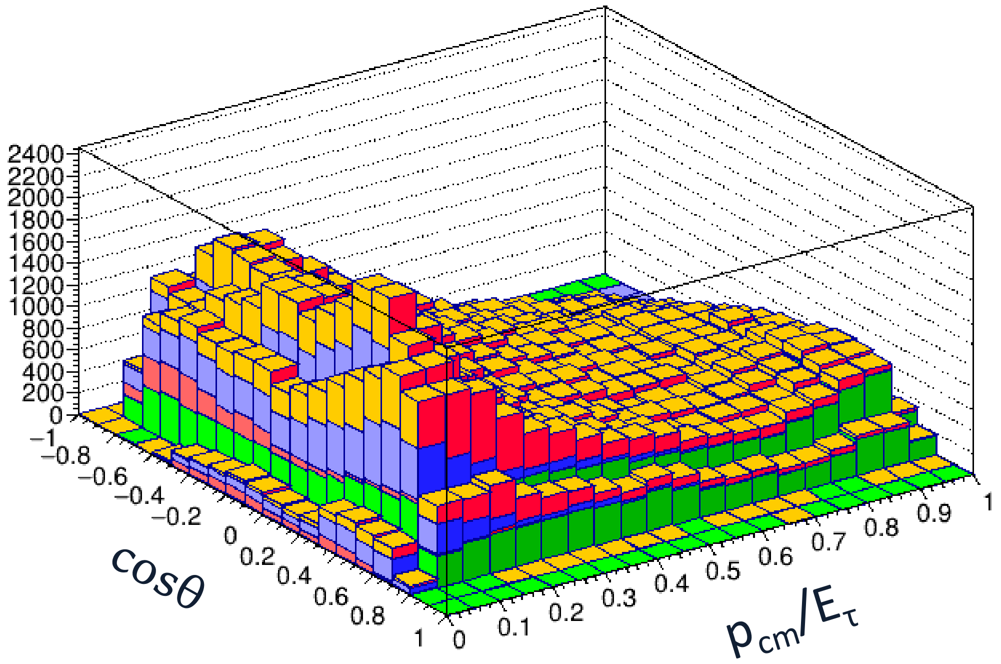
Left-handed e⁻ beam, π⁻ distribution



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

University of Victoria

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

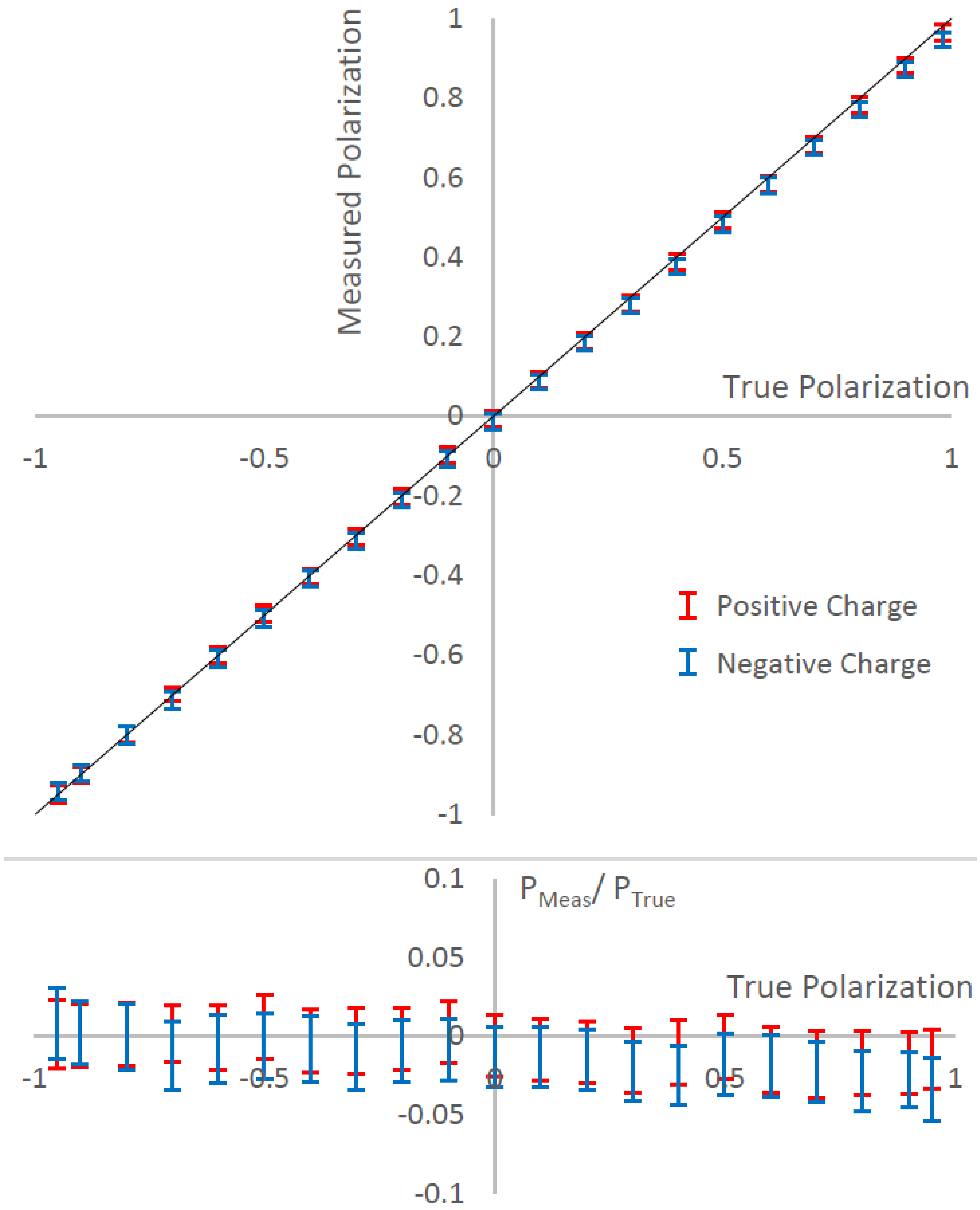
BaBar beam polarization fit, 32.28 fb^{-1} study sample

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

Absolute Polarization Sensitivity

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



Babar Summary

- Currently muon PID systematic is the most significant however there are large MC statistical uncertainties associated with it
  - Muon PID σ_{sys}=0.3%±0.2%
- Run 5 studies(~30% of data) show the MC there has a much smaller uncertainity
  - Muon PID Run 5 σ_{sys}=x.x%±0.05%
- We have approval to unblind and are in the process of doing so
- Run 5 is expected to give strong evidence for the "true" systematic uncertainties
- Run 3 polarization measurement:

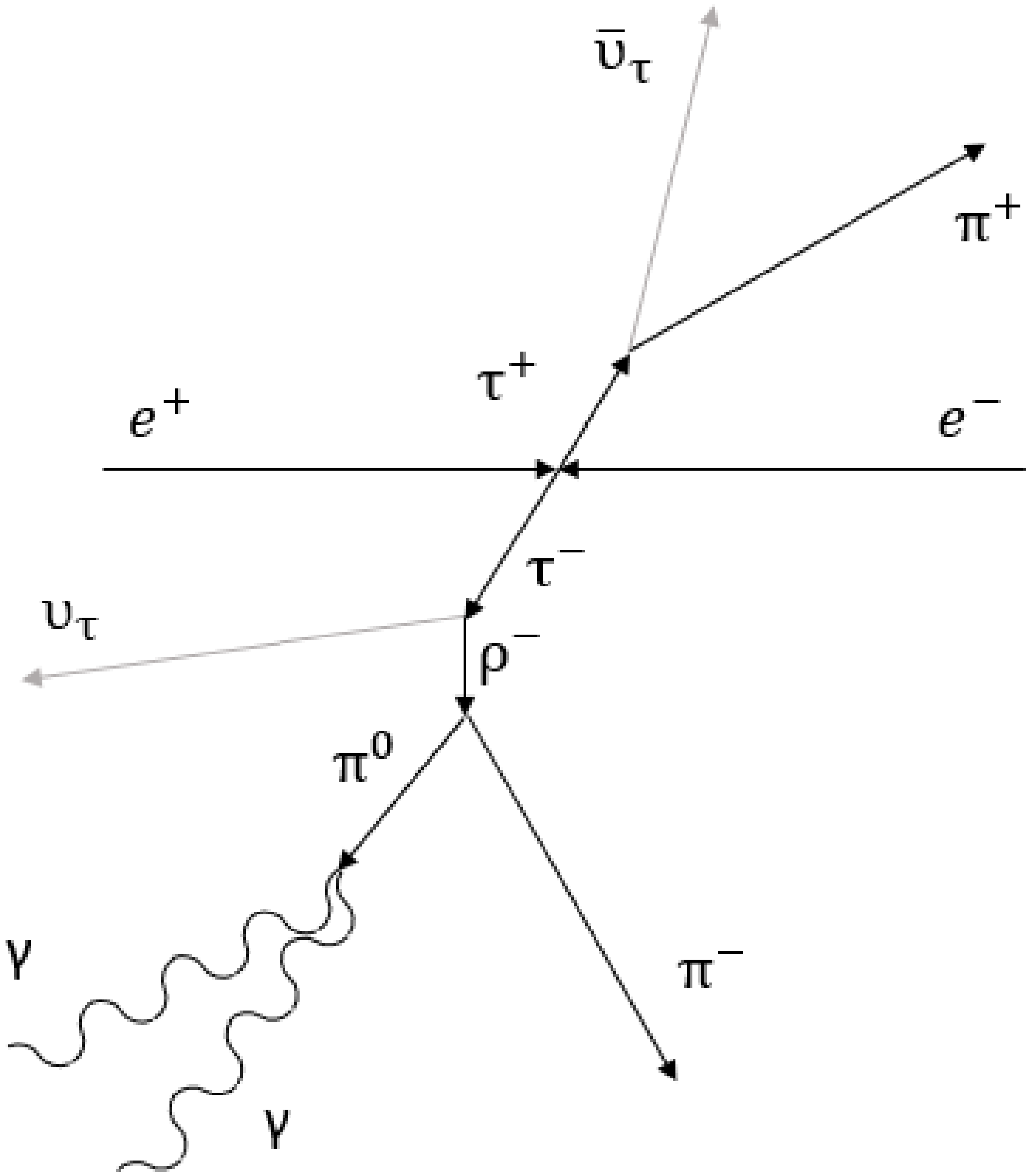
$$\langle P \rangle = 0.012 \pm 0.012_{stat} \pm 0.0045_{sys}$$

PRELIMINARY

University of Victoria

Initial Belle II Event Selection

- Initial Belle II studies carried out by Dhwani Sutariya
- Found an initial selection with high purity
- Muon PID cuts seem to introduce bias
- Selection:
    - 2 charged tracks
    - 2 photons /neutral clusters
    - π^0 within $80\ \text{MeV} < M_{\pi^0} < 200\ \text{MeV}$
    - Tag particles and signal track on opposite sides of thrust plane
    - TauGeneric skim
    - $-0.7 < \cos\theta < 0.7$
    - $E/p < 0.8$
    - Visible Energy of Event > 2.5 GeV
    - Transverse Momentum > 1 GeV
    - Muon PID



University of Victoria

CMS Momentum without Muon PID

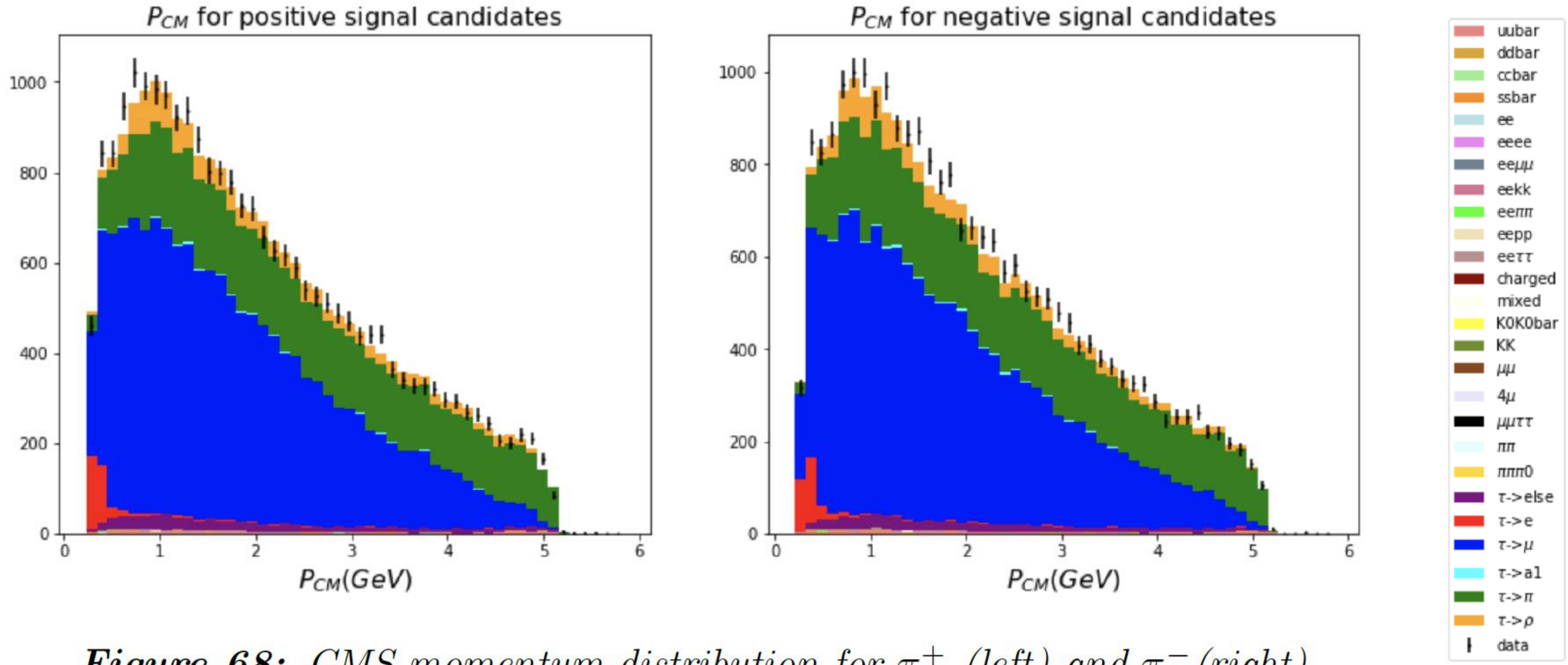


Figure 68: *CMS momentum distribution for* π^+ *(left) and* π^- *(right)*

University of Victoria

CMS cosθ without Muon PID

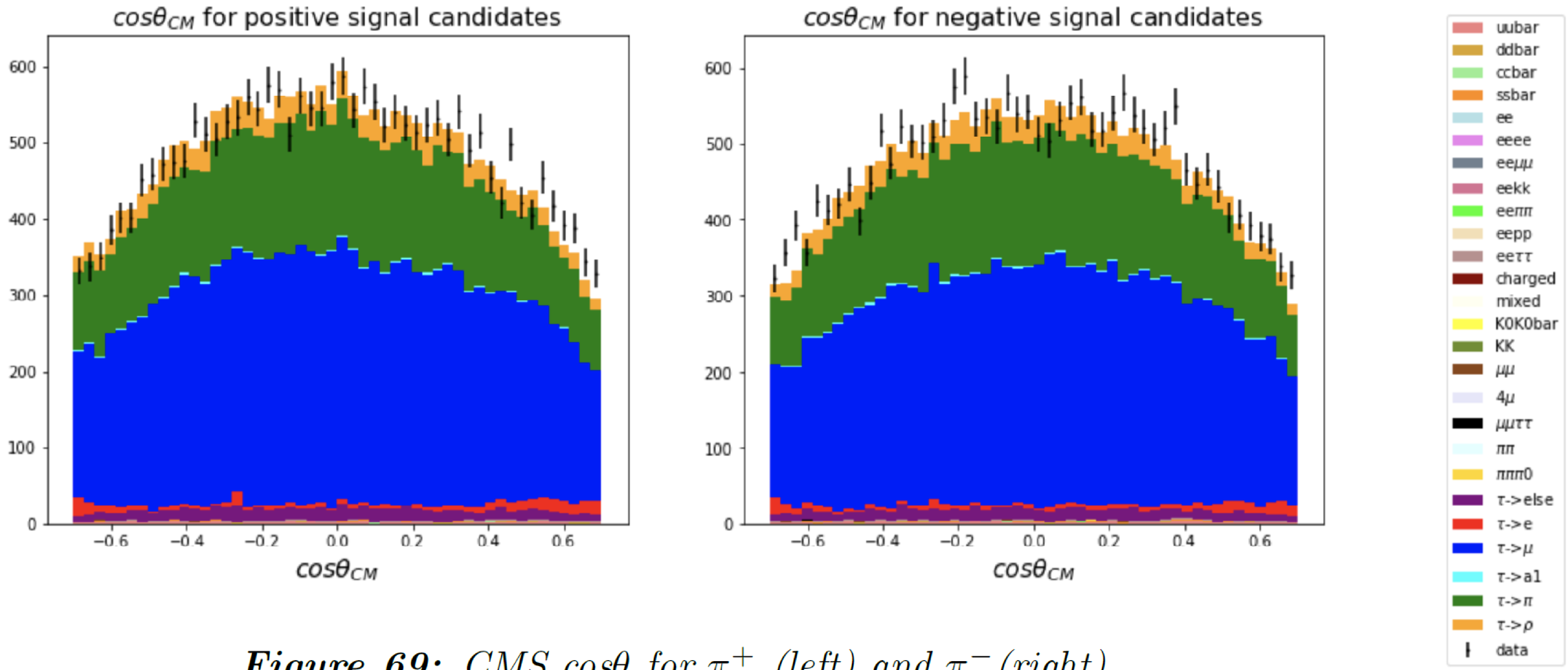


Figure 69: *CMS cosθ for π^+ (left) and π^-(right)*

CMS Momentum with muon PID veto

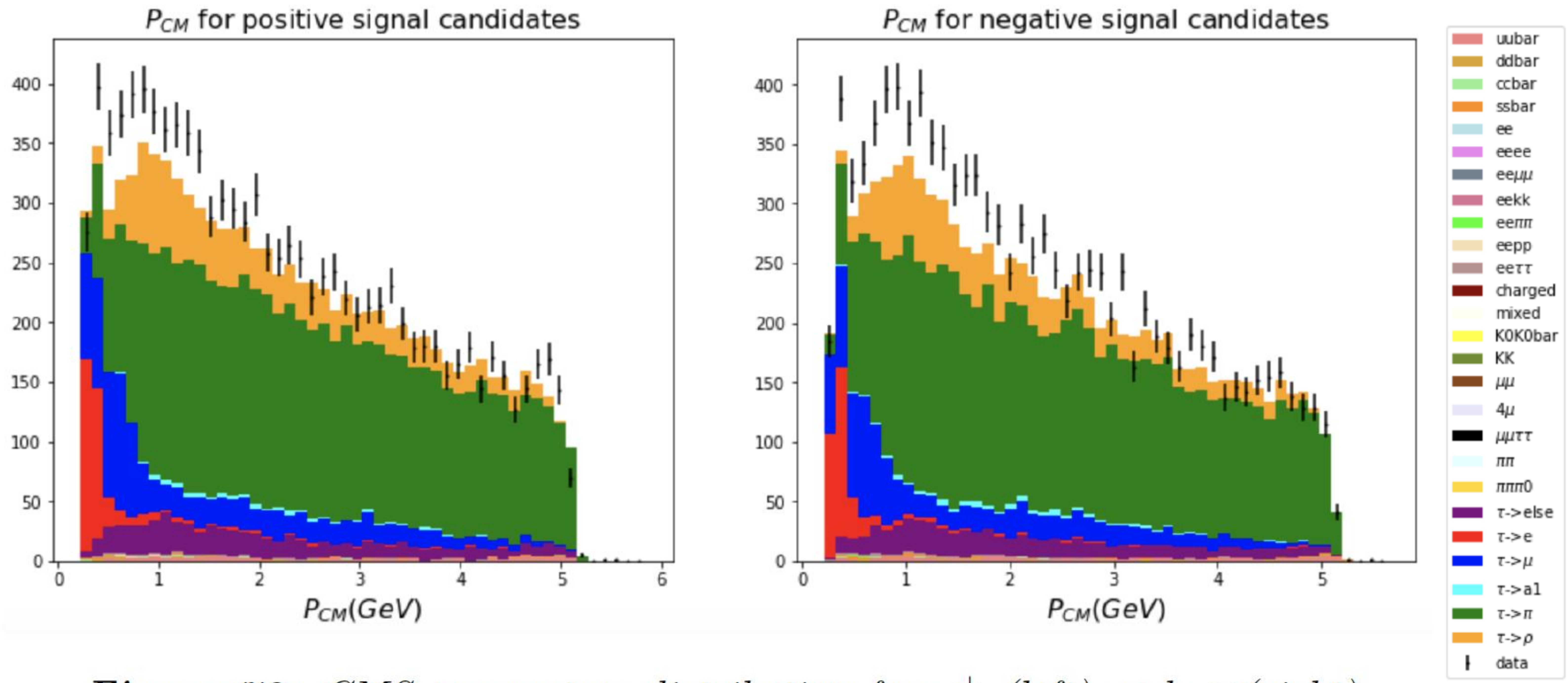


Figure 72: CMS momentum distribution for π^+ (left) and π^- (right)

University of Victoria

CMS cosθ with muon PID veto

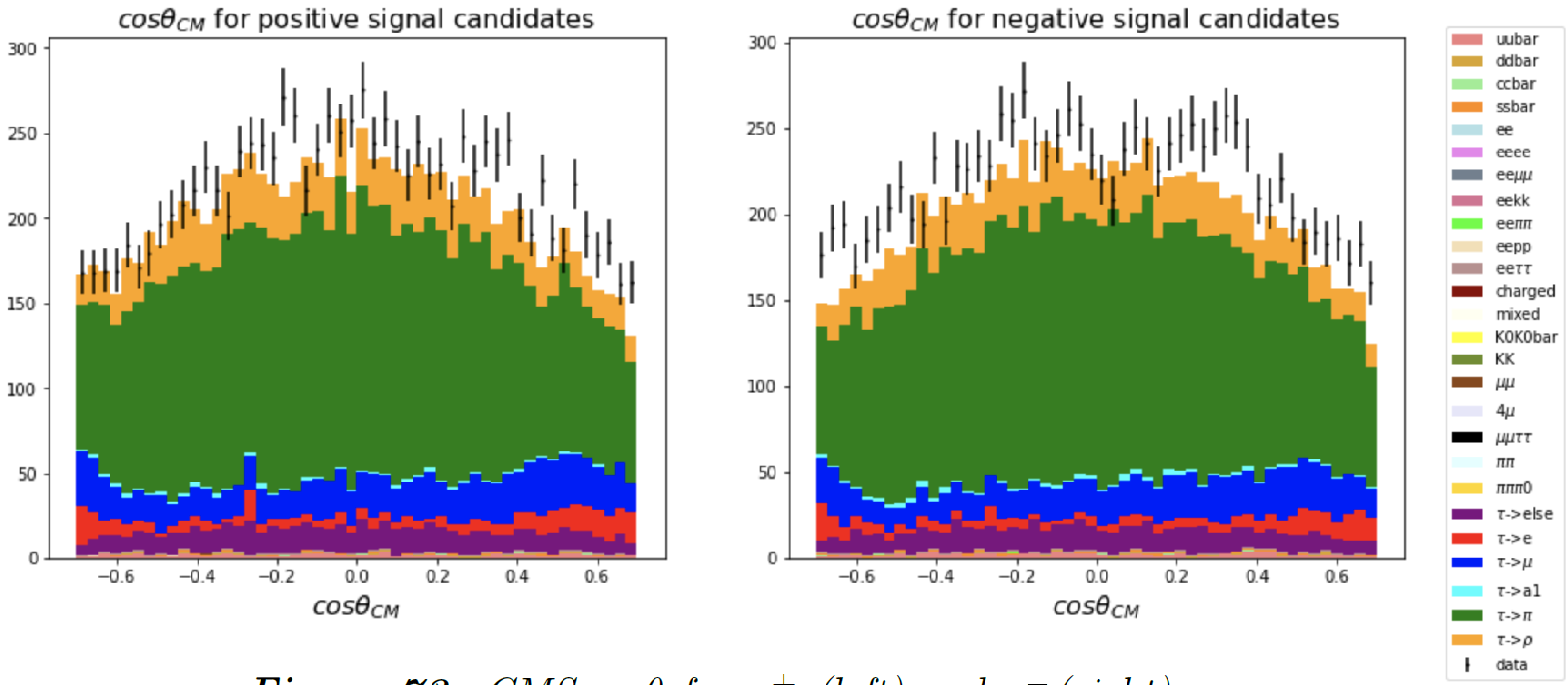


Figure 73: *CMS cosθ for π^+ (left) and π^- (right)*

University of Victoria

Conclusions

- BaBar research is progressing, will have unblinded results soon
- Paper on BaBar results expected by the end of the year
- Belle II studies show strong evidence for similar performance
- Muon PID studies were done without PID corrections
    - Corrections are available but not able to be implemented this summer

University of Victoria