# Machine Learning Techniques for ${\cal B}^0 \to {\cal K}^* \; \mu^+ \; \mu^-$

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# Overview

#### Task:

- Compare ML methods for fitting  $\delta C_9$
- $\blacktriangleright$  C<sub>9</sub> is Wilson Coefficient 9
- $\blacktriangleright \ \delta C_9 = C_9^{BSM} C_9^{SM}$

#### Dataset:

- $\blacktriangleright \ B^0 \to K^* \ \mu^+ \ \mu^- \ (\mathsf{MC})$
- Background (MC)
- Models:



Event



Ken Wilson Image: philosophyofscienceportal.blogspot.com









# Dataset - Overview

#### Signal

- $\blacktriangleright \quad \begin{array}{l} B^0 \rightarrow K^* \ \mu^+ \ \mu^- \ \text{and} \\ \bar{B^0} \rightarrow \bar{K^*} \ \mu^- \ \mu^+ \end{array}$
- A. Sibidanov MC generator
- 44 values of  $\delta C_9$
- ▶ w/ and w/o Geant4

#### Background

*M*<sub>bc</sub> sideband (Generic MC)

#### Variables

•  $q^2$ ,  $\cos \theta_{\mu}$ ,  $\cos \theta_K$ ,  $\chi$ 



Figure: Sibidanov et al. arXiv:2203.06827 [hep-ph]

## Dataset - Variables and Comparison



- Distributions given  $\delta C_9$
- Inputs to model
- Model learns distribution to δC<sub>9</sub> mapping

# Dataset - Asymmetries and Comparison











# Models - Overview

- Two approaches
  - Set
  - Event

#### Set

- Input: set of events
- Output:  $\delta C_9$
- e.g. CNN, Deep Sets

#### Event

- Input: individual event
- Output:  $p(\delta C_9)$
- e.g. Event-by-event



# $\mathsf{Models} - \mathsf{CNN}$

- Set Model: Conv. Neural Net.
- Dataset to 'image'
  - Pixel are bins
  - Bins contain avg. q<sup>2</sup>
- Easy to add background image
- Original work by Shawn Dubey
  - arXiv:2311.13060 [hep-ex]



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## Models - Deep Sets



- Set Model: Deep Sets
- Unbinned (unlike CNN)
- $\triangleright \hat{y} = f(\sum_i g(x_i))$ 
  - Permutation invariant
- Easy to add backgrounds to set
- arXiv:1703.06114 [cs.LG]

# Models - Event-by-event

Event Model: Event-by-event

$$p(\delta C_9 \mid x_1, ..., x_N) = \frac{\prod_{i=1}^N p(\delta C_9 \mid x_i)}{\sum_{\delta C'_9} \prod_{i=1}^N p(\delta C'_9 \mid x_i)}$$

- Approximate:  $p(\delta C_9 | x_i)$ , Obtain:  $p(\delta C_9 | x_1, ..., x_N)$
- Binned and no backgrounds
- Suggested by Peter Sadowski

Level: gen Events per Set: 70000











# Results - Mean Squared Error



Num boots./label: 50

# Results - Sensitivity





## Results - Bias



**Task:** Compare ML methods for fitting  $\delta C_9$ 

• Dataset: 
$$B^0 \rightarrow K^* \mu^+ \mu^-$$
 (MC)

Performance metrics: Error, sensitivity, and bias

# Details

Thank you for listening!

- Email: elee20@hawaii.edu
- Github: https://github.com/ethanlee20/btokstll

#### Computing resources:

- NVIDIA RTX 4090 laptop GPU (16 GB VRAM)
- Intel i9 processor
- 32 GB RAM