Quantum Decoherence

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2024 US Belle II Summer Workshop
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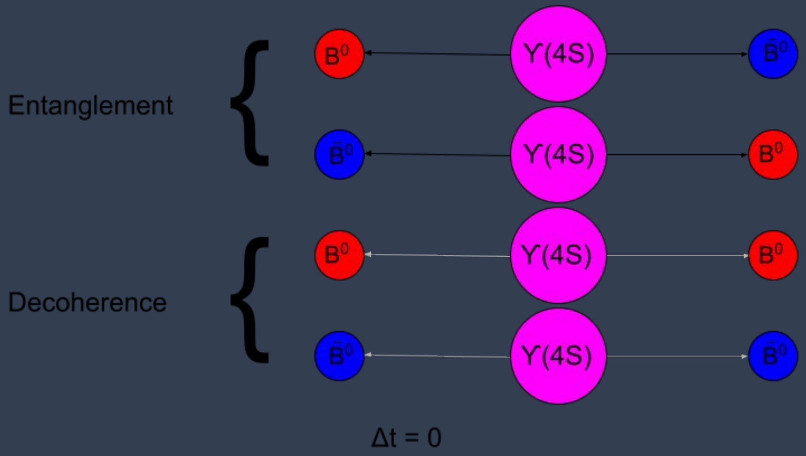
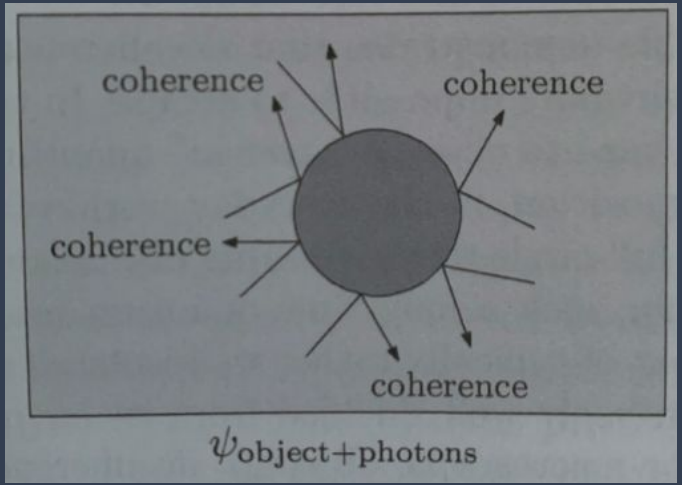
Hershel Weiner, U. Hawaii

Quantum Decoherence

- A loss of coherence, or entanglement in a state
- Two types:
    - Spontaneous
        - At entangled pair production
    - Environmental
        - Environmental interactions “carry off” coherence from the system
        - Time dependent

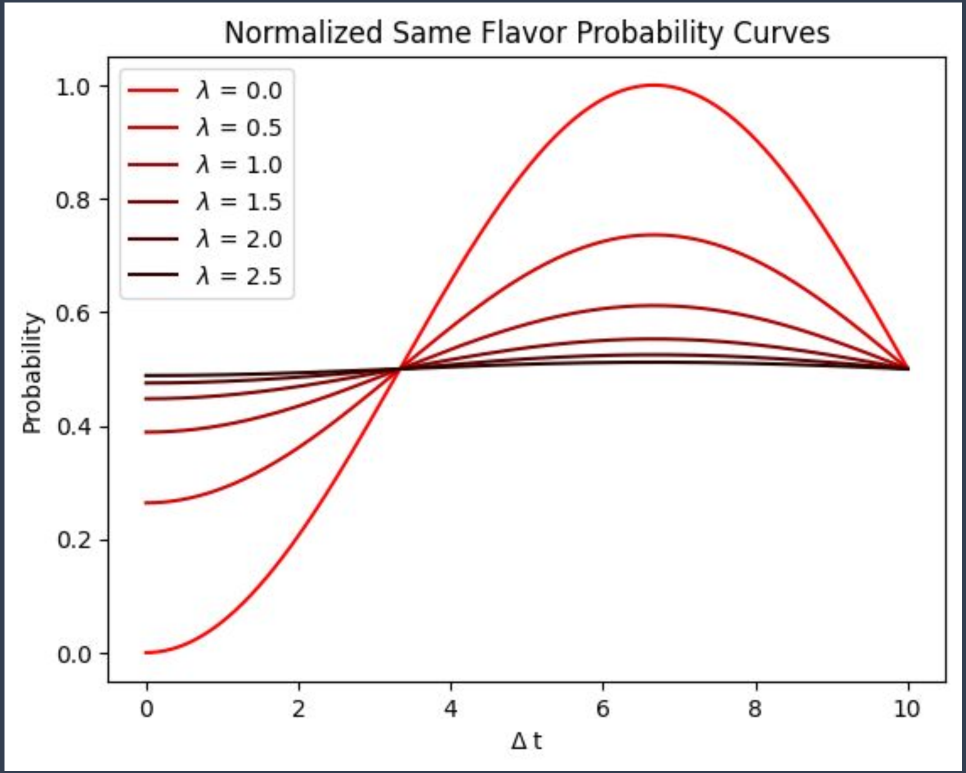




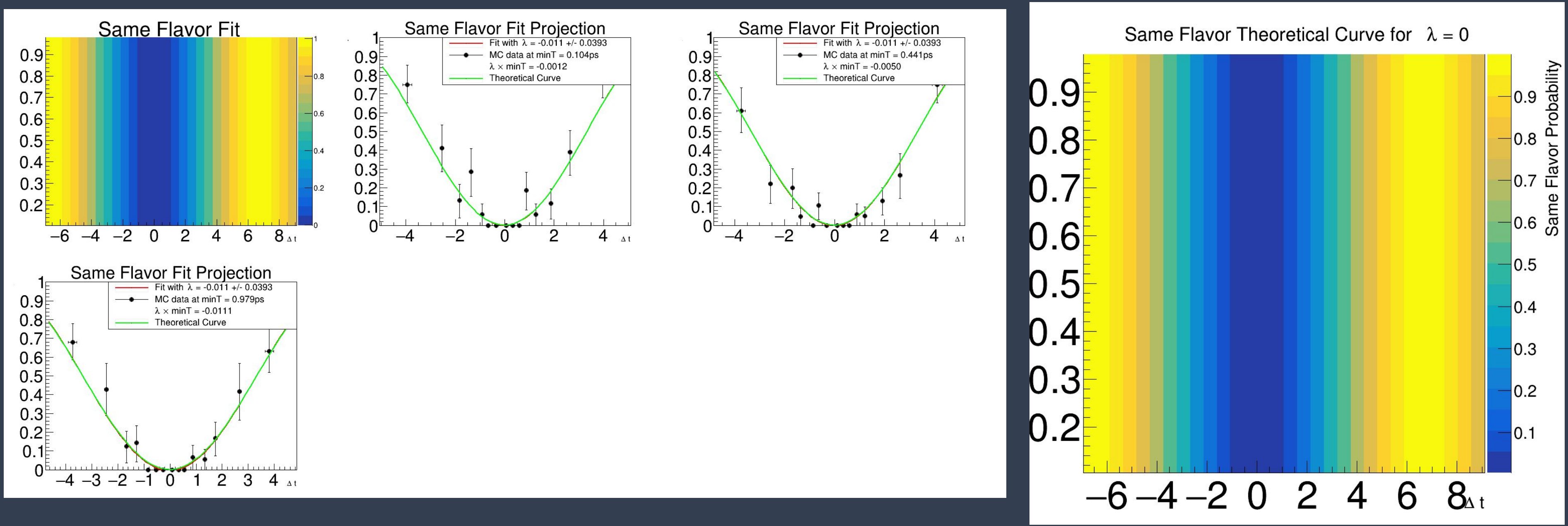
Environmental Decoherence (Lindblad Type)

- Probability of detecting same flavor B Mesons as a function of t_{min} and Δt
- Lambda characterizes the level of decoherence in the system
- Acts only during the lifetime of the entangled pair and ends after first meson decay t_{min}

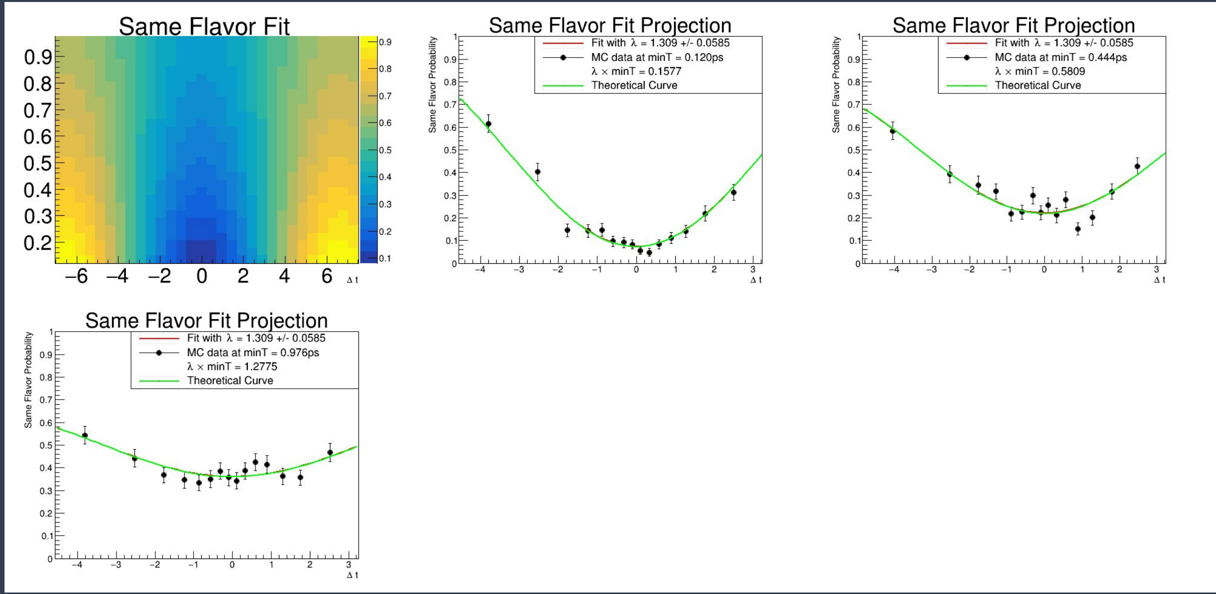
$$P = \frac{\cosh(\frac{\Delta\Gamma\Delta t}{2}) - \mu e^{-\lambda t_{min}} \cos(\Delta m \Delta t)}{2\cosh(\frac{\Delta\Gamma\Delta t}{2})}$$

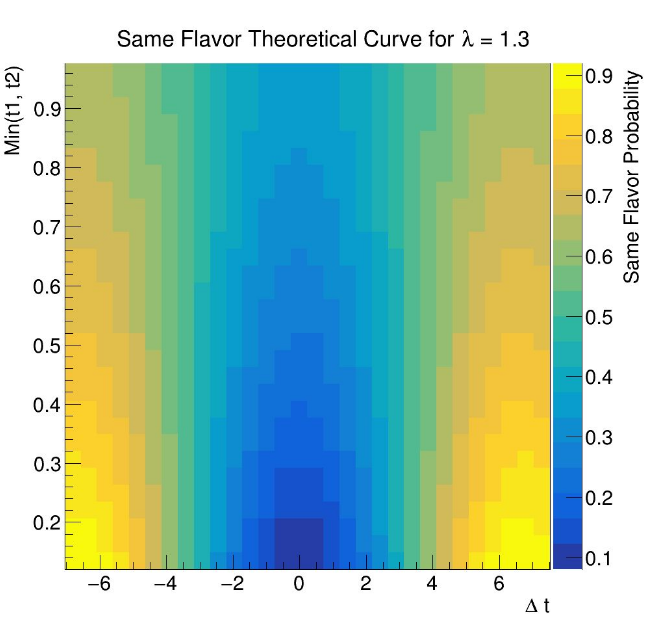


Fitting Data with λ=0



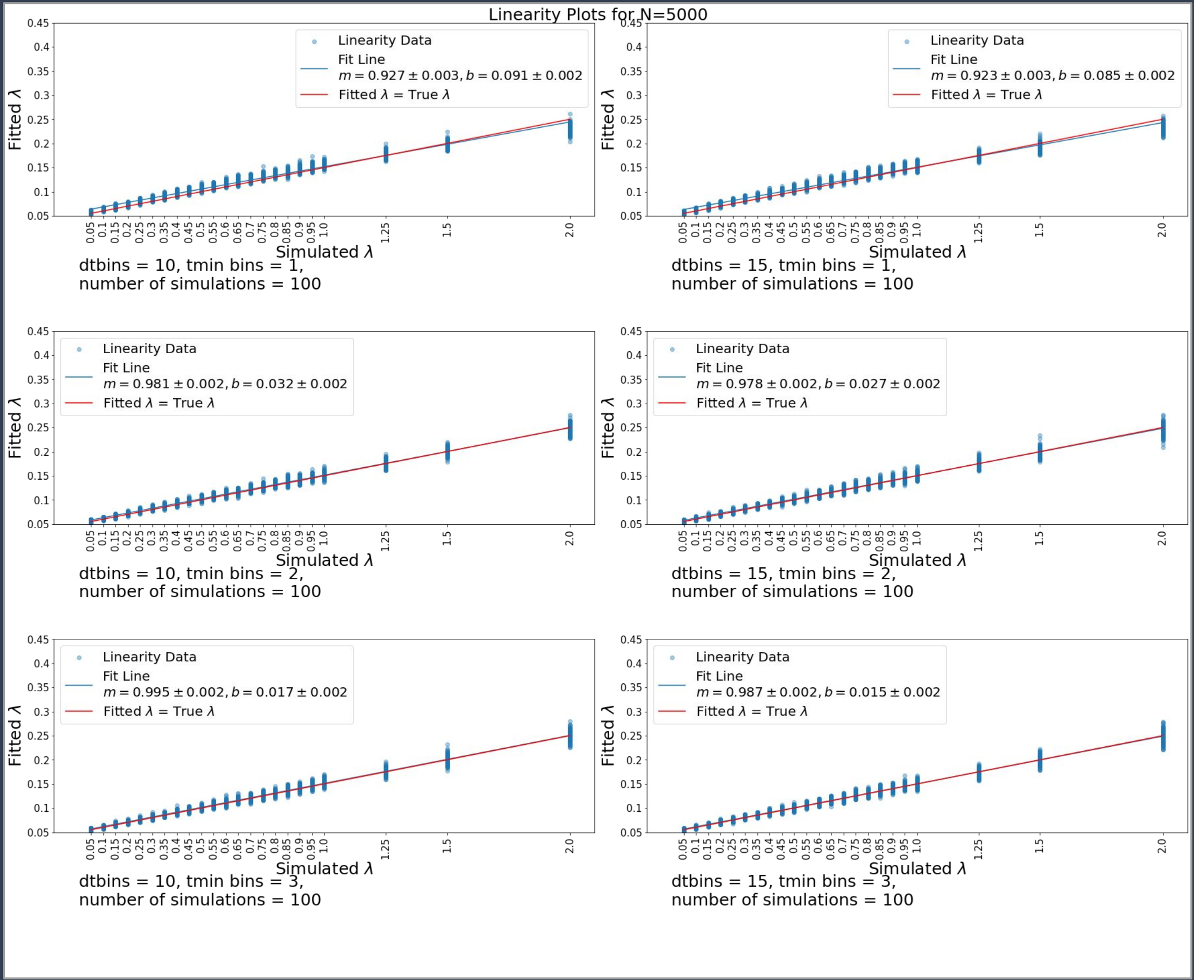
Fitting Data with λ = 1.3





Analysis

- Plot fitted lambda against simulated lambda and fit a line to test for fitting bias
    - Vary the number of bins in each axis to identify the optimal binning strategy
- See a slight increase in performance with more t_{min} bins

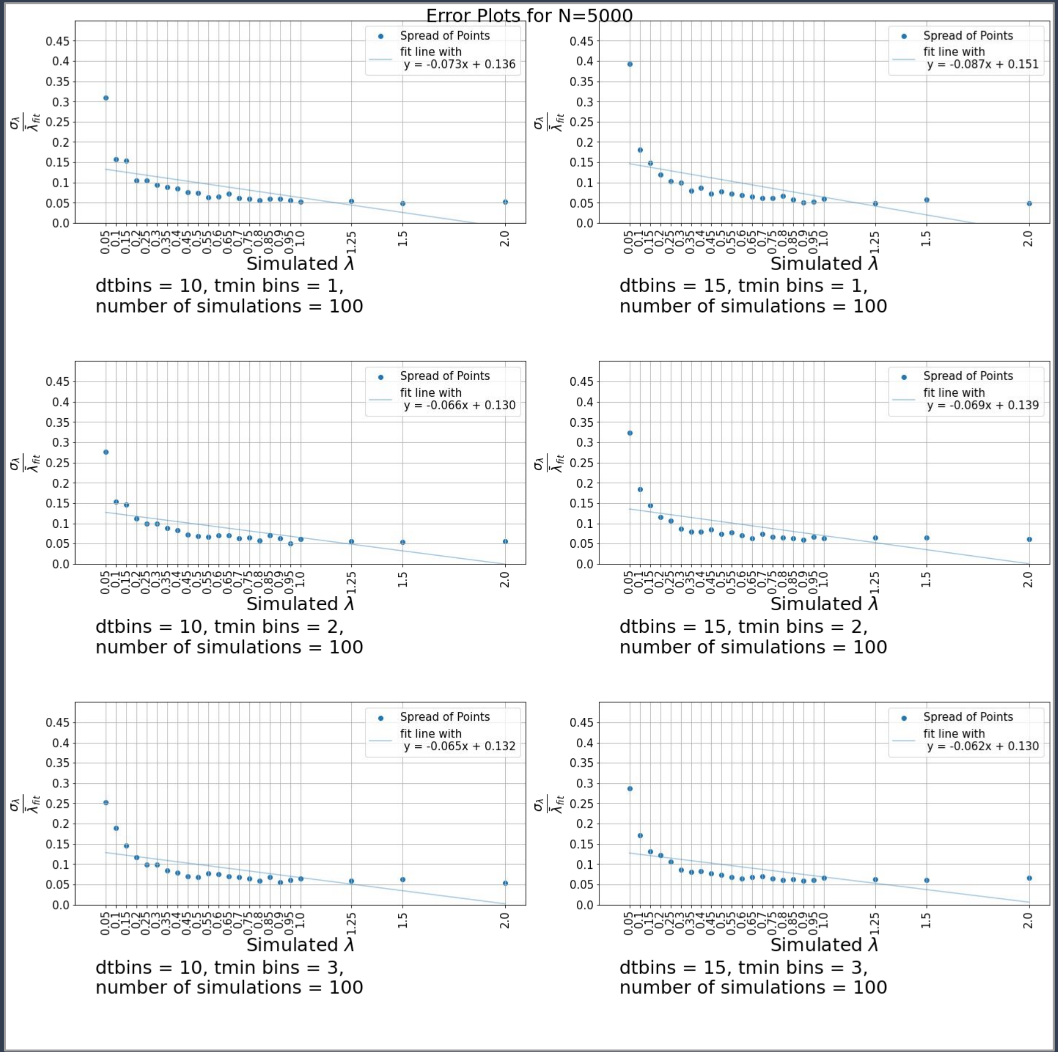


Analysis Cont.

- Gauge the sensitivity of the fitter by plotting

$$\frac{\sigma_\lambda}{\bar{\lambda}}$$

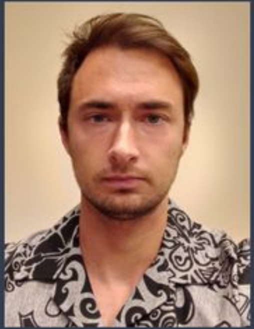
- See a <1 fractional error for small lambda
  - This is good!
- Expect ~80k hadronic events in our data sample



Thank you!

Sven Vahsen (group leader)

Alexei Sibidanov (postdoc)



Timothy Mahood (grad student)

Lucas Stötzer (grad student)

Aleczander Paul (undergrad)

Hershel Weiner (undergrad)

Lucas and Tim will give a more in depth talk on our group’s work on Thursday

Backup Slides

Quantum Decoherence

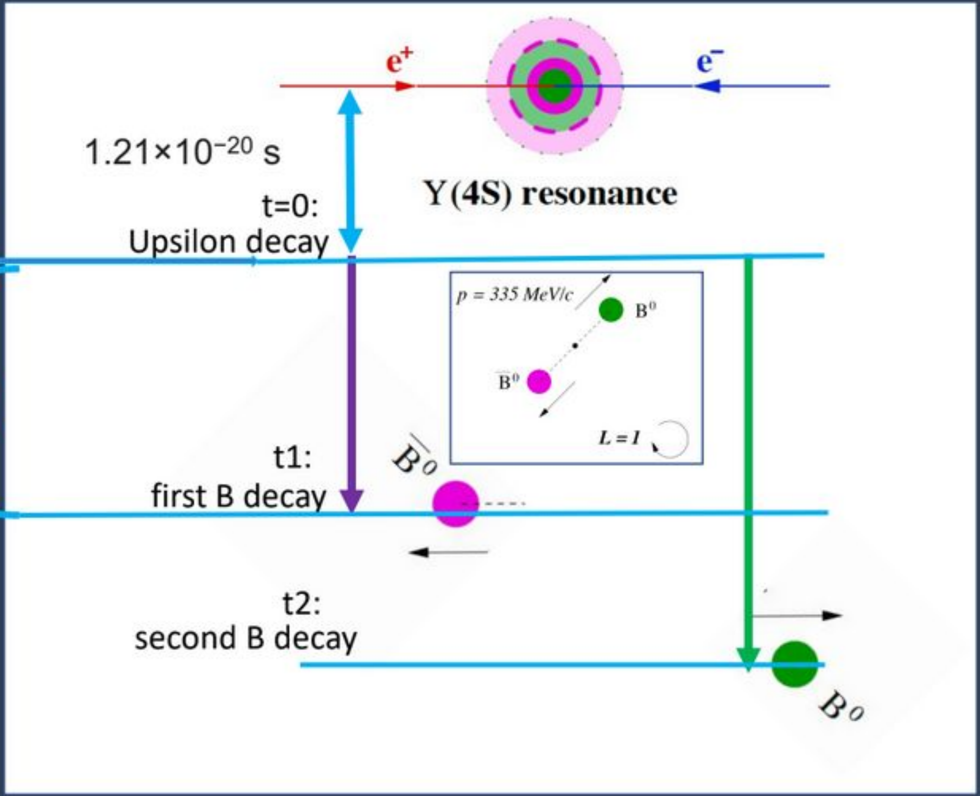
Measurement of Einstein-Podolsky-Rosen-Type Flavor Entanglement in $\Upsilon(4S) \to BB$ Decays
A. Go *et al.* (Belle Collaboration), PRL **99** (2007)

Spontaneous disentanglement or non-coherent production

Lindblad type decoherence

Model for decoherence of entangled beauty
R. A. Bertlmann and W. Grimus, PRD **64** (2001)

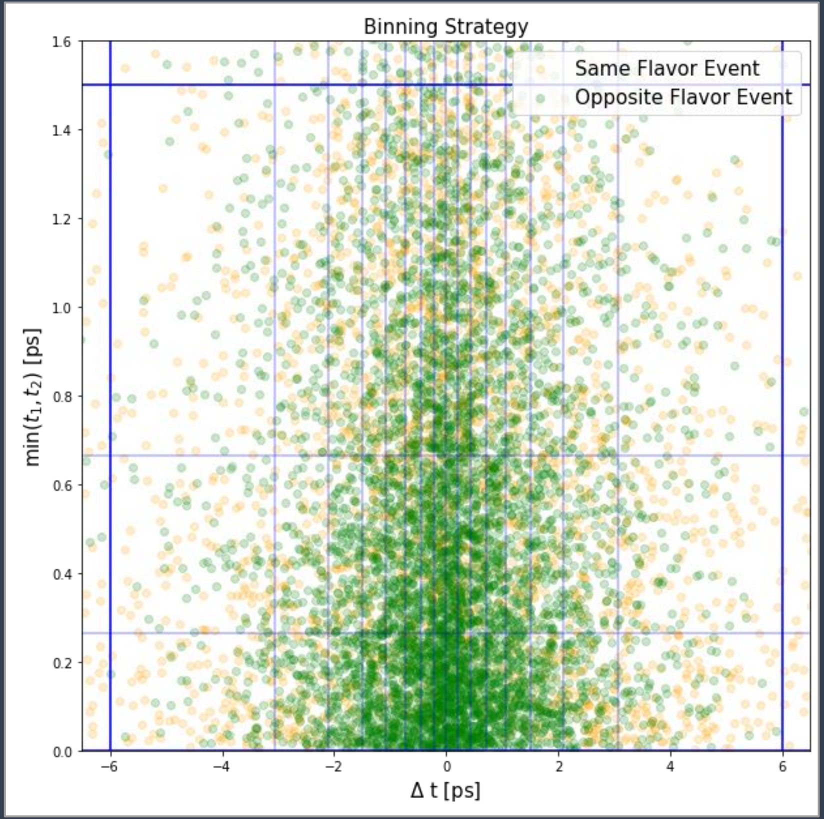
Measurement not attempted to date!



time

Binning the Data

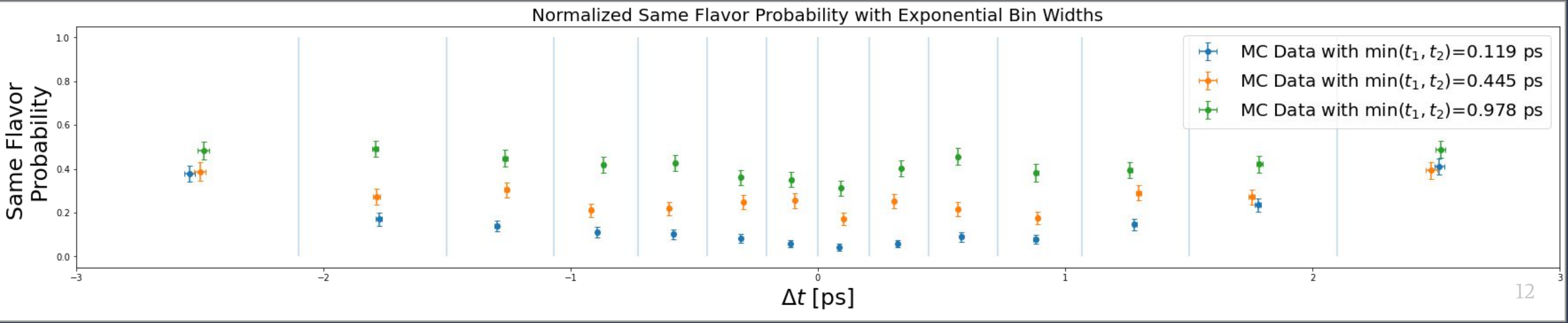
- Bin MC data by t_min and delta_t axis with equal number of events in each bin
    - 10,000 events, 16 delta_t bins, 3 t_min bins
- Take fractional count of same flavor events in each bin to derive probability



Deriving the Probability Curve More In-Depth

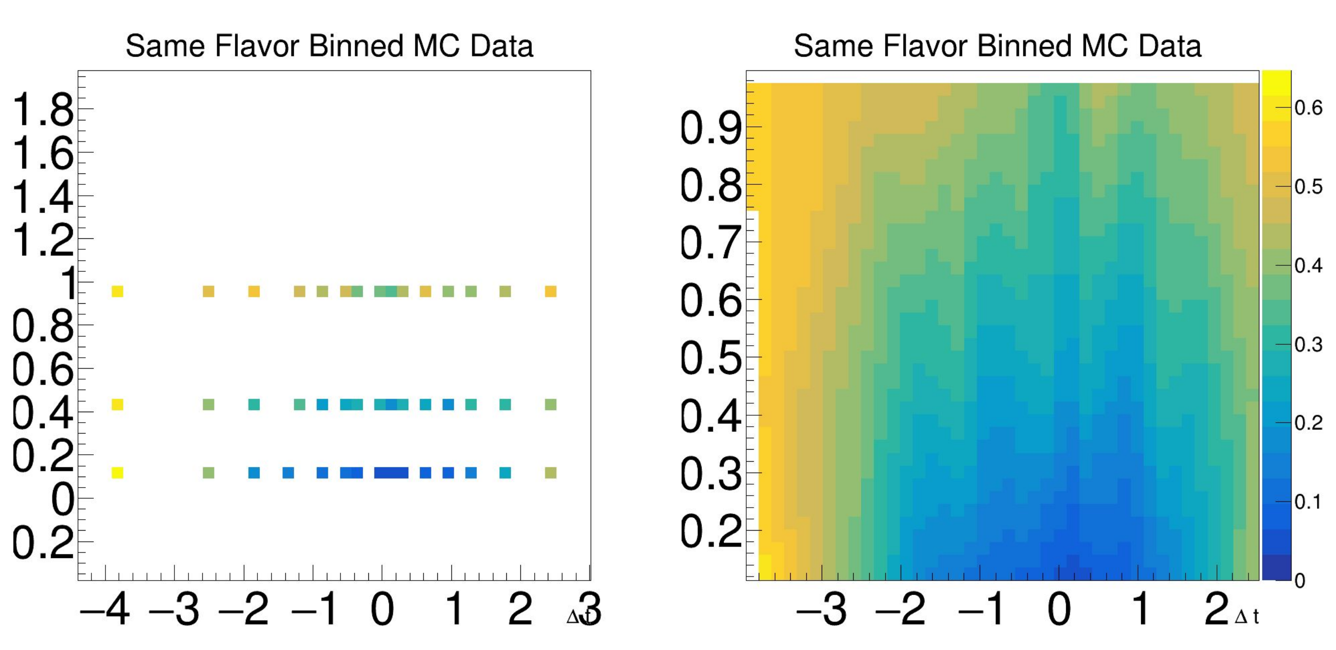
- Bin the data in each axis according to an exponential scale e^(-t / τ)
    - t_min axis τ = 0.8 ps, delta_t τ = 1.6
- Probability is the fractional count of same flavor events in each bin
- Bin centers are the median of t_min and delta_t in each bin

$$\frac{N_{BB}}{N_{BB} + N_{B\bar{B}}}$$



2D MC Data

- y-axes: t_min
- x-axes: delta_t
- Color axes: probability



t_min Fit Projections