Estimation of Combinatoric Background in SeaQuest using an Event-Mixing Method

Abinash Pun

(For SeaQuest Collaboration)

SeaQuest E906

New Perspectives 2023, Fermilab

June 26-27

FERMILAB-SLIDES-23-130-PPD

Fermilab

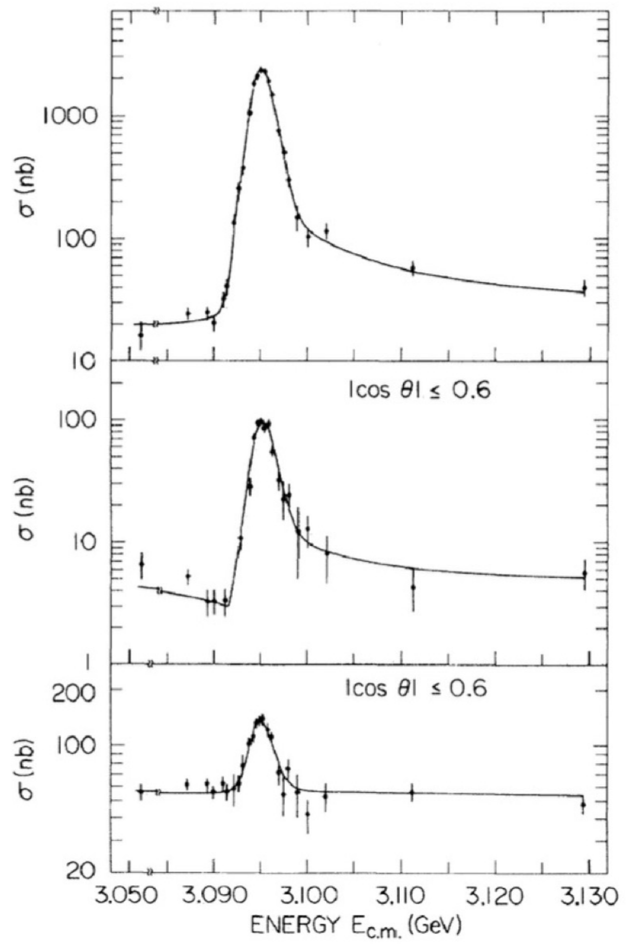
NM STATE UNIVERSITY

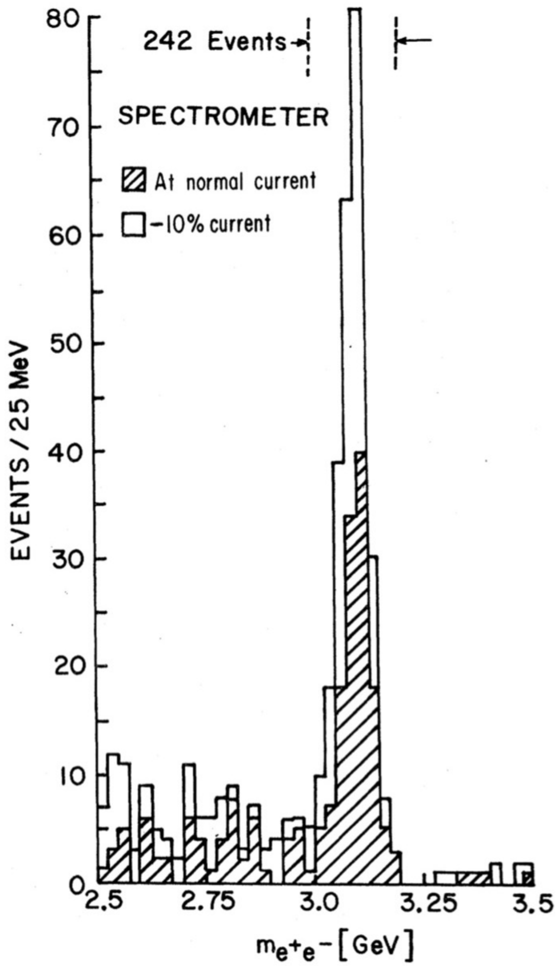
U.S. DEPARTMENT OF ENERGY | Office of Science

J/ψ: History

- Bound state of $c\bar{c}$ pair, discovered in 1974 A.D
- Richter et al. at SLAC (SPEAR) Ting et al. at BNL (AGS)
- Vector meson with spin 1 and invariant mass = 3.0969 GeV/c^2
- Decays into $\mu^+\mu^-$ or e^+e^- with a large branching ratio ($\approx$ 6% each)
- The discovery got Nobel prize in 1976

Phys. Rev. Lett., 33:1404-1406 Phys. Rev. Lett., 33:1406-1408





Pair particles production from e^+e^- collisions at SPEAR [left] and Electron-positron invariant mass distribution from 20 GeV/c protons on fixed target at AGS[Right].

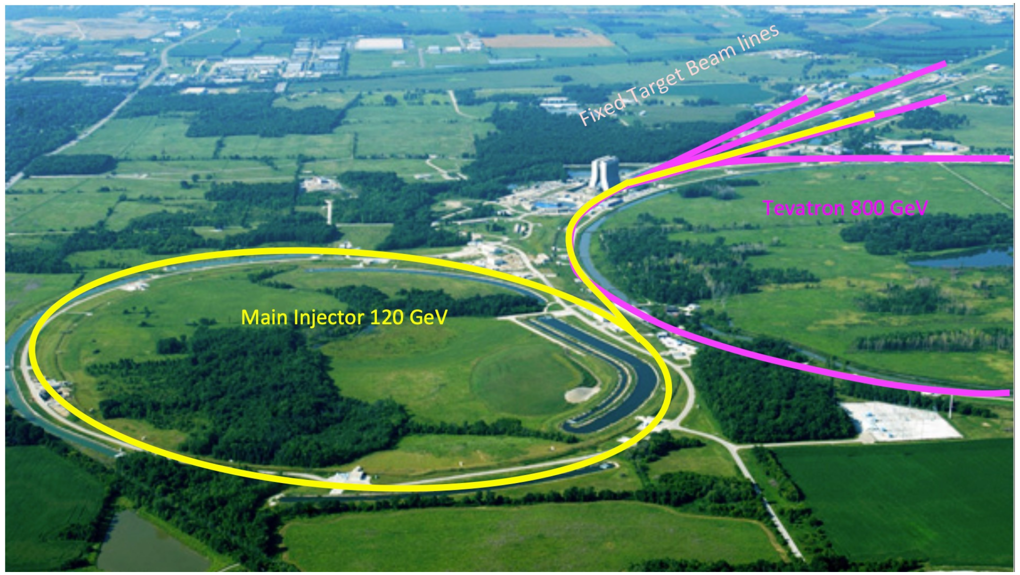
Motivation

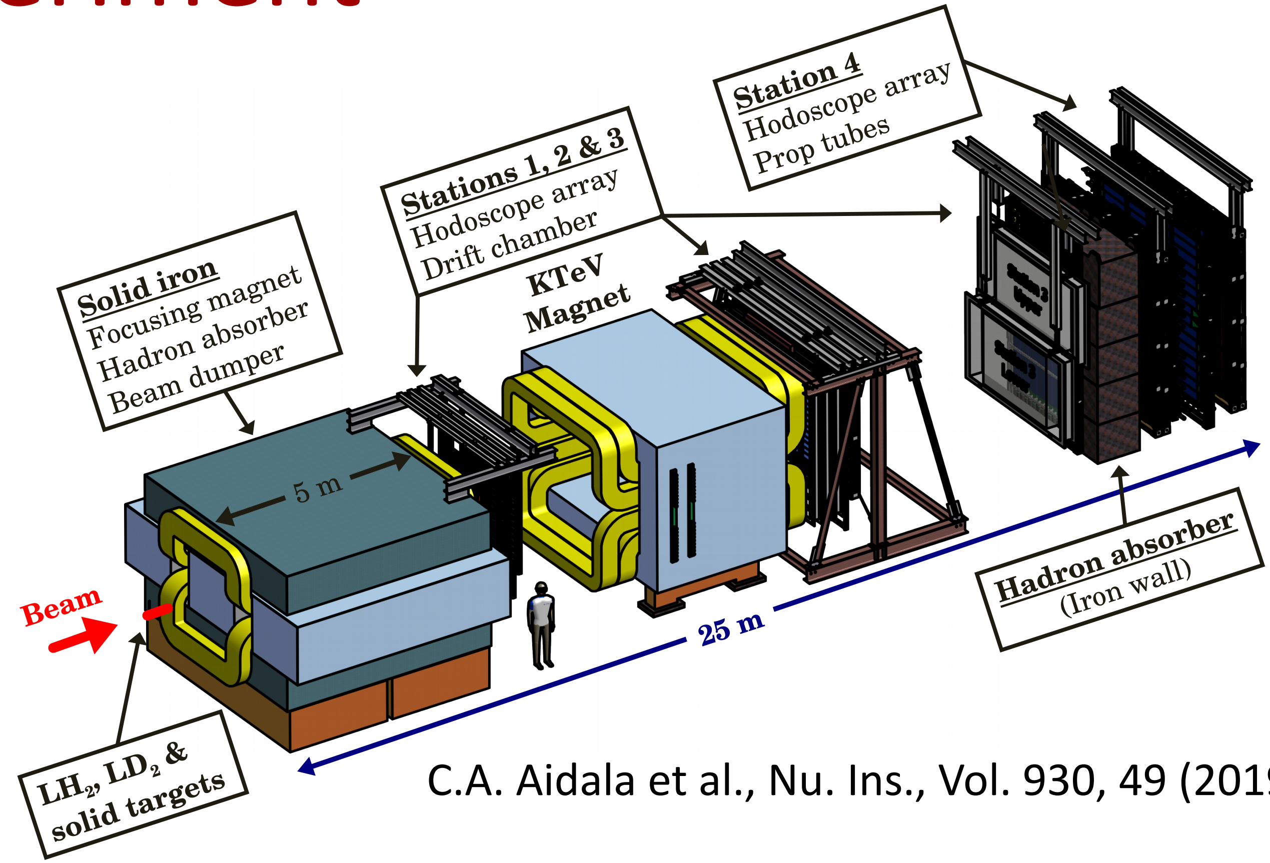
- **J/ψ Spin Alignment**
  - The distribution of decay particles ($\mu^+\mu^-$) influenced by J/ψ spin alignment =>insight into different production mechanisms

$$\frac{dN}{dcos\theta d\phi} \propto 1 + \lambda\cos^2\theta + \mu sin2\theta cos\phi + \frac{\nu}{2}\sin^2\theta cos2\phi$$

- **Issue:** In addition to desired dimuon signal the recorded data also contains random combinations of single muons from uncorrelated processes.
- **Mixing method**: Estimate the combinatorial background with proper normalization

SeaQuest(E906) Experiment



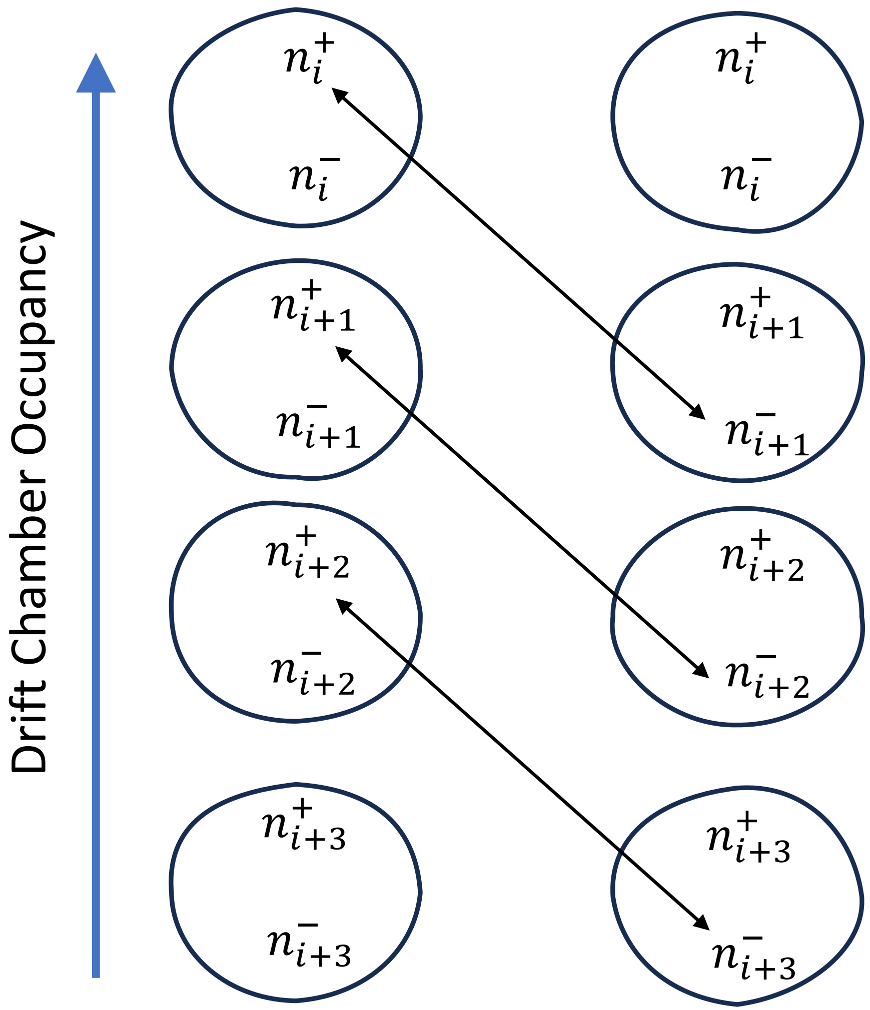


C.A. Aidala et al., Nu. Ins., Vol. 930, 49 (2019)

- 120 GeV proton Beam
- Spectrometer
  - Four tracking stations (Drift chambers, proportional tubes)
  - Trigger hodoscopes
  - Focusing (beam dump) and Analyzing Magnets

Mixing Method

- Positive tracks from one event is combined with negative tracks from another event
- Requirements:
  - The tacks must be mixed from events that are “similar” (track multiplicity) to each other
  - Signal-rate in even stream should be small
- For E906-Data
  - The events are **sorted** by drift chamber occupancy before mixing
- N.B.: All cuts and conditions should be identical for the mixing events and real events



Mixing Method: Mathematical Argument

- N_E = No. of events events in a run.
- Each event i has zero or more reconstructed tracks, which are broken up into four groups.
    1. s_i^+ = no. of +ve tracks from a signal (J/ψ or DY) = 0 or 1
    2. s_i^- = no. of –ve tracks from a signal (J/ψ or DY) = 0 or 1
    3. b_i^+ = no. of +ve tracks from backgrounds = 0, 1, 2, …
    4. b_i^- = no. of –ve tracks from backgrounds = 0, 1, 2, …
- The signal tracks (positive and negative) come from a correlated source; these only appear in pairs in the same event.
- The background tracks come from uncorrelated sources.
- N.B. If only one of a pair of tracks from a signal is reconstructed, then it falls into the background category.

Mixing Method: Mathematical Argument

- Total number of unlike-sign track pairs within an event

$$N_S = \sum_{i=1}^{N_E} s_i^+ s_i^-$$

$$N_P = \sum_{i=1}^{N_E} (s_i^+ s_i^- + s_i^+ b_i^- + b_i^+ s_i^- + b_i^+ b_i^-)$$

- Combining Tracks from adjacent events

$$N_P' = \sum_{i=1}^{N_E} (s_i^+ s_{i+1}^- + s_i^+ b_{i+1}^- + b_i^+ s_{i+1}^- + b_i^+ b_{i+1}^-)$$

Mixing Method: Mathematical Argument

- Total number of unlike-sign track pairs within an event

$$N_S = \sum_{i=1}^{N_E} s_i^+ s_i^-$$

$$N_P = \sum_{i=1}^{N_E} (s_i^+ s_i^- + s_i^+ b_i^- + b_i^+ s_i^- + b_i^+ b_i^-)$$

- Combining Tracks from adjacent events

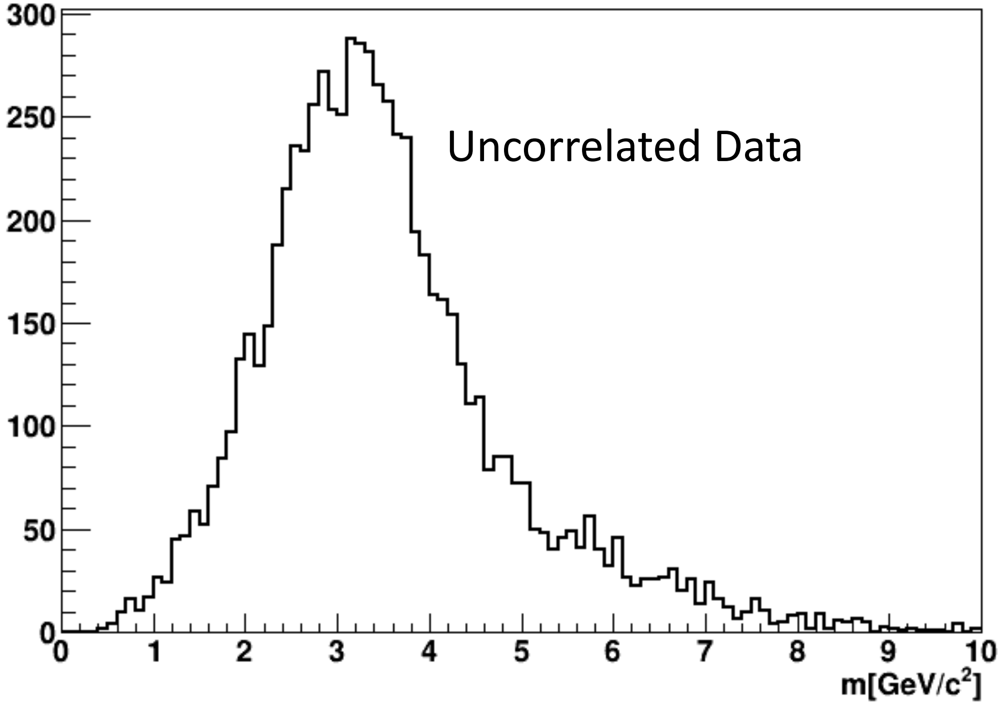
equal within uncertainties

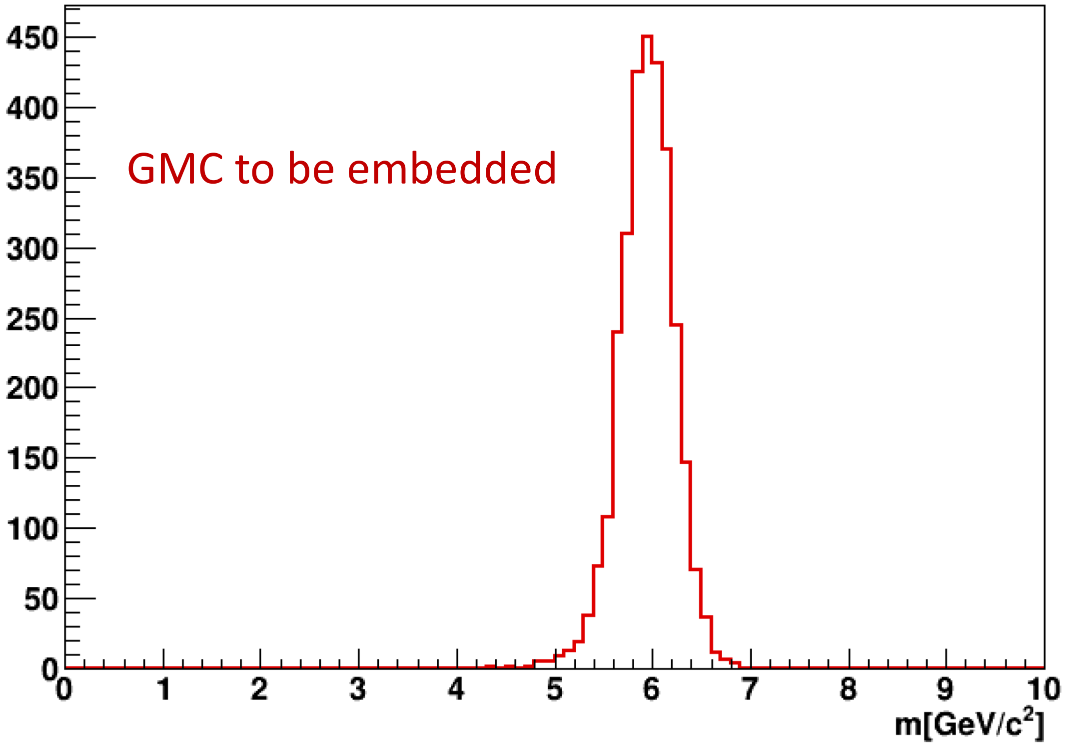
$$N_P' = \sum_{i=1}^{N_E} (s_i^+ s_{i+1}^- + s_i^+ b_{i+1}^- + b_i^+ s_{i+1}^- + b_i^+ b_{i+1}^-)$$

- Negligible if the signal rate is small enough. Can be estimated from MonteCarlo embedding method.

$$N_p - N_p' \approx N_s$$

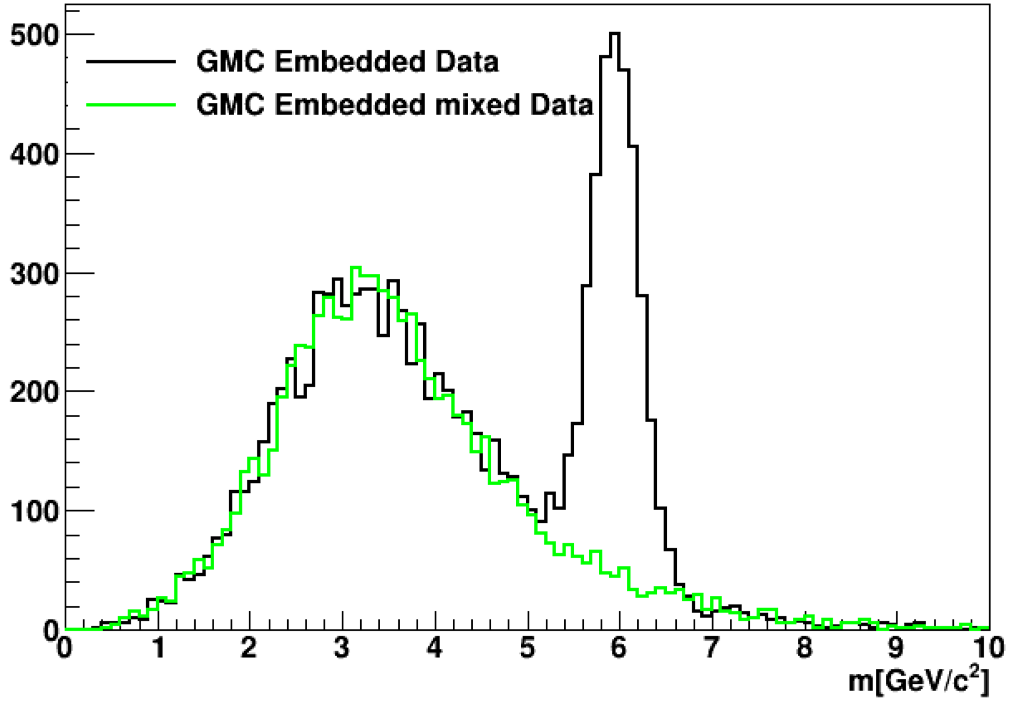
Mixing Method: GMC Embedding Check





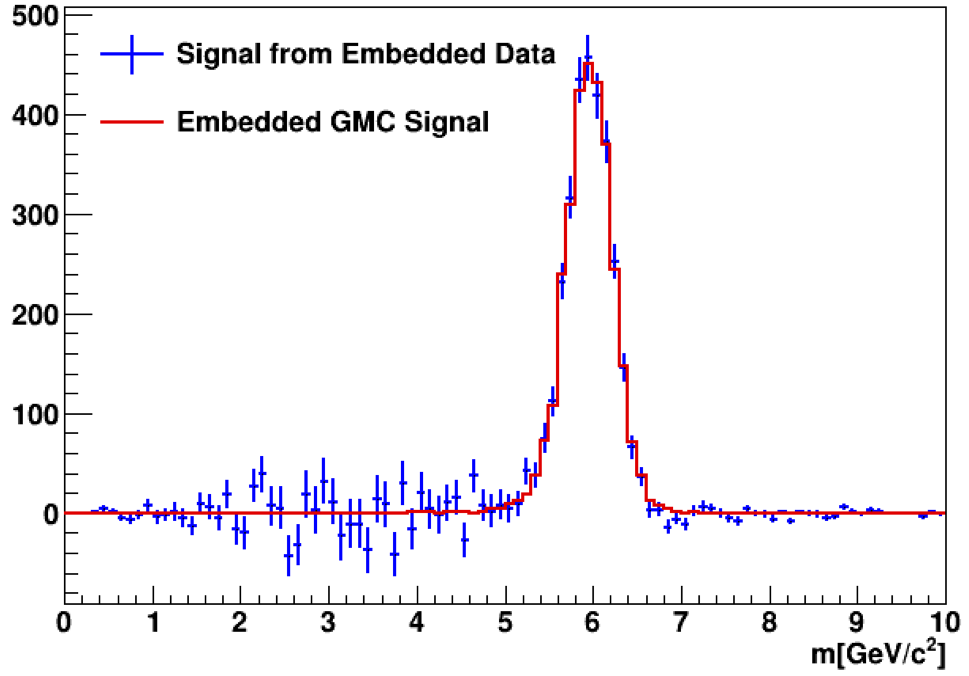
- Started with uncorrelated Data (already mixed) in the left
- The 6 GeV Dimuons are embedded randomly in the event stream at the rate of 2 %

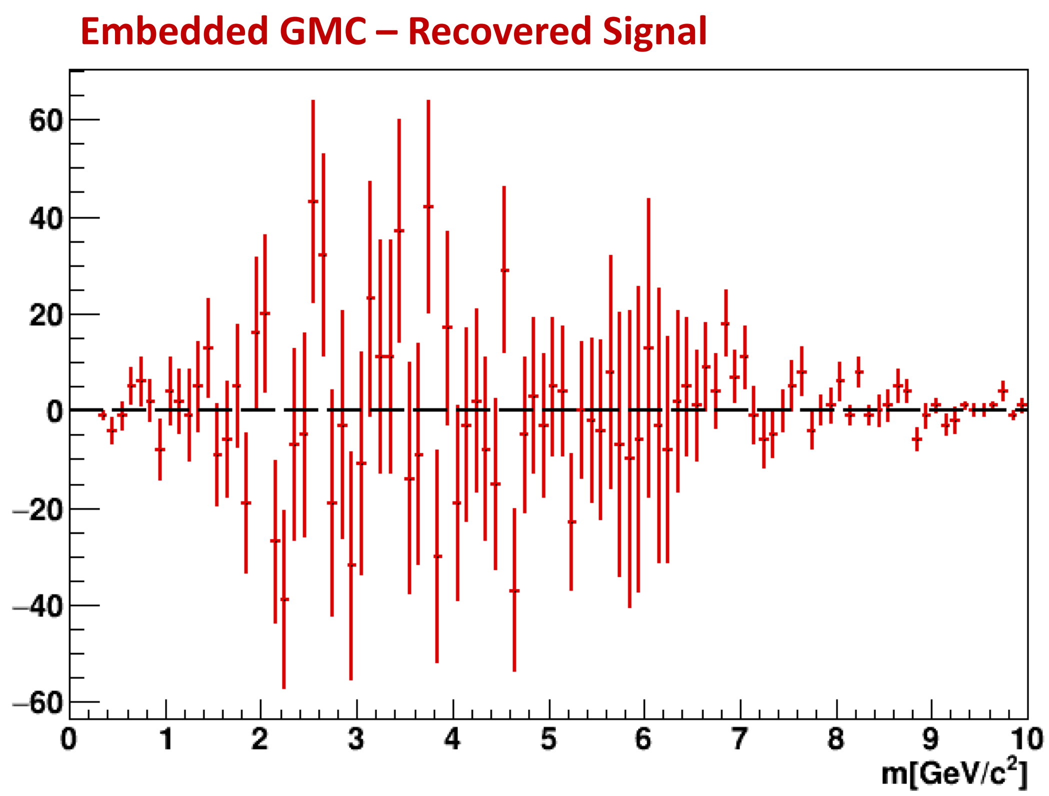
Mixing Method: GMC Embedding Check



- The dimuon distribution after embedding GMC is shown in black histogram
- The green histogram shows the dimuon spectrum after the mixing method applied to the GMC embedded data
- GMC embedded data, GMC embedded mixed data went through identical procedure and cut

Mixing Method: GMC Embedding Check





- The signal recovered from mixing method is almost same as signal embedded
- Embedded GMC signal – Recovered Signal = $\mathbf{32.00 \pm 149.45}$

Summary

- An event mixing method is developed to estimate the combinatorial background with correct normalization
- The method was tested with embedding 6 GeV GMC signal into the uncorrelated data.
  - The embedded signal was recovered successfully
- Paper related to the study has been submitted to JINST; https://arxiv.org/abs/2302.04152
- Acknowledgement
  - This work is funded by DOE Office of Science, Medium-Energy Nuclear Physics Program

The Combinatoric Background Sum – Normal Run

$$N_C = \sum_{i=1}^{N_E} (s_i^+ b_i^- + b_i^+ s_i^- + b_i^+ b_i^-)$$

Let's sort the events in order of occupancy, ω, from low to high. Then the sum can be broken into sub-sums where all events have the same occupancy. The number of events at a given occupancy is N_ω.

$$N_C = \sum_{\omega=0}^{\omega_{max}} \sum_{i=1}^{N_\omega} (s_i^+ b_i^- + b_i^+ s_i^- + b_i^+ b_i^-)$$

The numbers s_i^+, etc., are all small integers (see DocDB 10059) drawn from a distribution. But N_ω will tend to be large, certainly a few hundred within a run. The sum over events with the same occupancy will sample all possible values of $s_i^+ b_i^-$ (e.q.) at that occupancy several times. <u>We can replace the sum with averages</u>.

The Combinatoric Background Sum – Normal Run

$$N_C = \sum_{\omega=0}^{\omega_{max}} \sum_{i=1}^{N_\omega} (s_i^+ b_i^- + b_i^+ s_i^- + b_i^+ b_i^-)$$

$$= \sum_{\omega=0}^{\omega_{max}} N_\omega [\langle s^+ b^- \rangle_\omega + \langle b^+ s^- \rangle_\omega + \langle b^+ b^- \rangle_\omega]$$

where $\langle s^+ b^- \rangle_\omega$ is the average value of the product $s_i^+ b_i^-$ at the given occupancy ω, etc.

Then the total number of pairs is $N_P = N_S + N_C$.

The Combinatoric Background Sum – Mixed Run

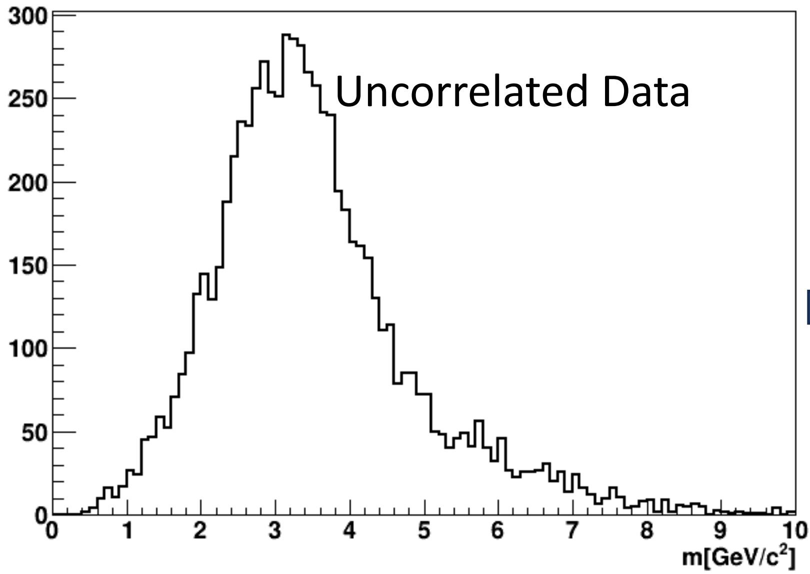
The remaining three terms can be treated the same way as in the normal run.

$$N_C' = \sum_{\omega=0}^{\omega_{max}} \sum_{i=1}^{N_\omega} (s_i^+ b_{i+1}^- + b_i^+ s_{i+1}^- + b_i^+ b_{i+1}^-)$$

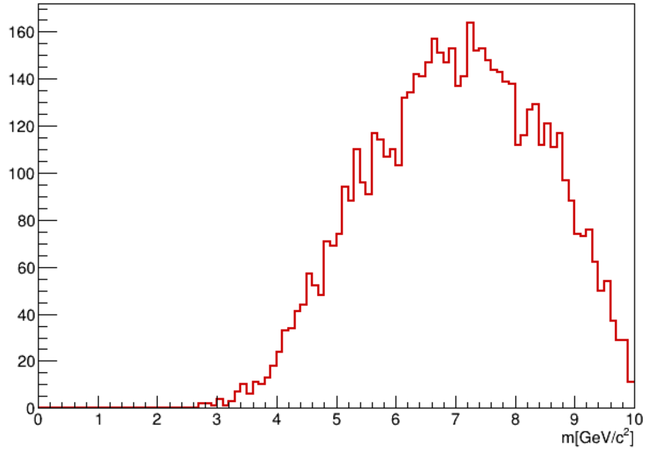
$$= \sum_{\omega=0}^{\omega_{max}} N_\omega [\langle s^+ b^- \rangle_\omega + \langle b^+ s^- \rangle_\omega + \langle b^+ b^- \rangle_\omega]$$

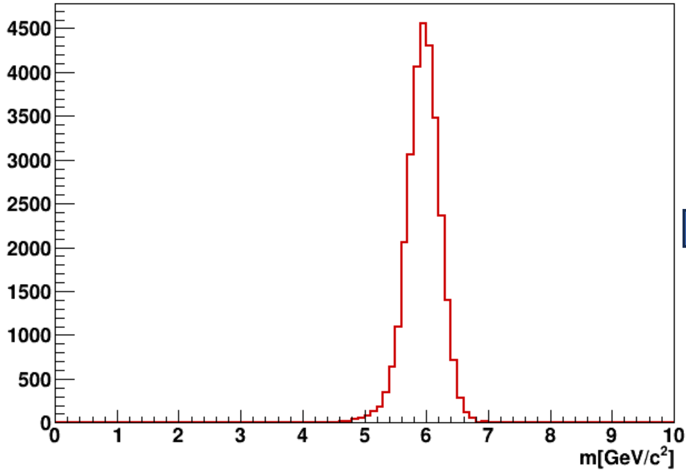
The sums N_C (from the normal run) and N_C' (from the mixed run) are only equal in the limit of very large statistics. <u>With limited statistics, they will be equal within uncertainties.</u>

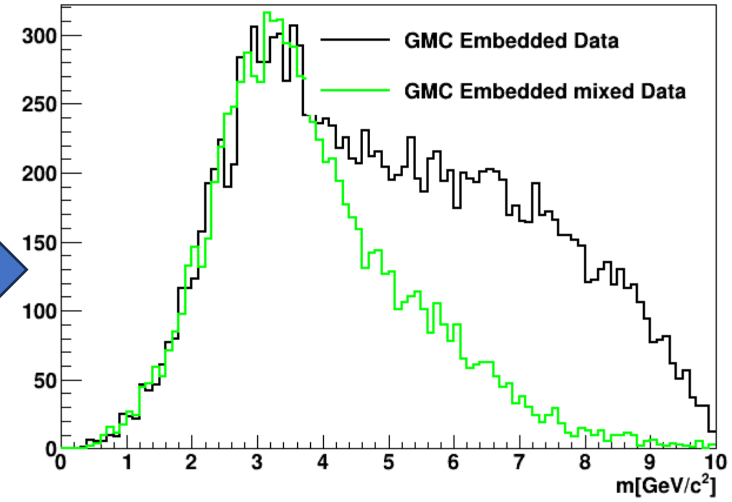
Mixing Method: GMC Embedding Check

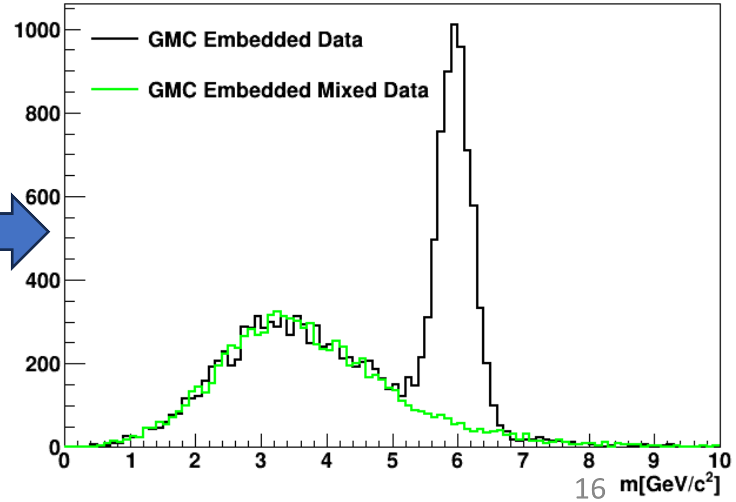


GMC to be embedded

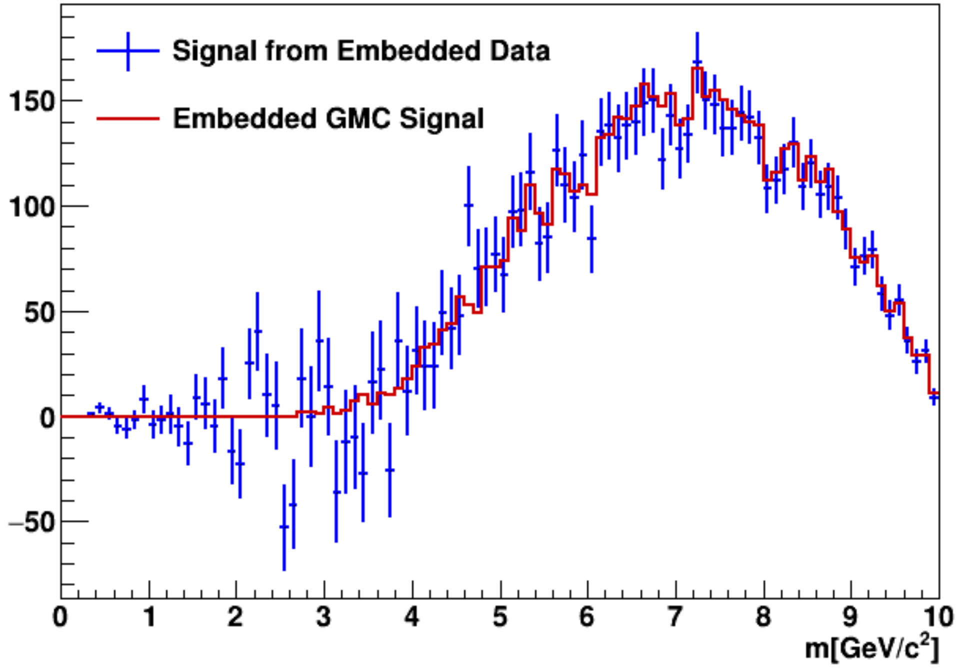


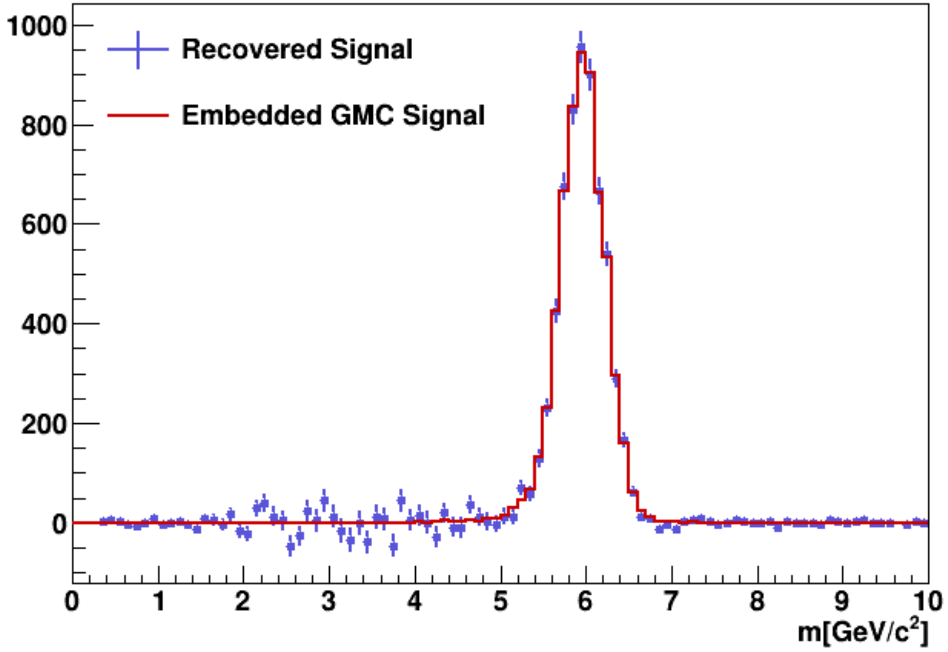






Mixing Method: GMC Embedding Check





J/ψ Spin Alignment

- J/ψ is a vector meson with non-zero mass, there are three possible values of J_z;
  - ± 1: "*Transverse*" and 0: "*Longitudinal*"
- Study of the angular asymmetries of the decay products can give information on the alignment of mother particle

$$\frac{dN}{dcos\theta d\phi} \propto 1 + \lambda cos^2\theta + \mu sin2\theta cos\phi + \nu sin^2\theta cos2\phi$$

  - $\lambda = -1$; Longitudinal and $\lambda = 1$; Transverse
- Analysis Goal: Measure the angular decay coefficients of $J/\psi(\rightarrow \mu^+\mu^-)$ from 120 GeV p - Fe interaction at SeaQuest.
  - First measurement of μ and ν for proton induced fixed target experiment (already measured in pion induced fixed target experiment and collision experiments)