Investigation of Dimuon Combinatorial Background at FAIR SIS100

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Contents

Motivation and Physics of Di-Muon Studies

- **Dimuons** are penetrating probes of the strongly interacting matter formed in heavy-ion collisions.
- Since they do not undergo strong final-state interactions, they preserve information from all stages of the collision.
- Their invariant mass spectrum reflects contributions from:
  - Vector meson decays (ρ, ω, ϕ)
  - Drell–Yan and open charm processes(very small in sis100 A-A collision)
  - Thermal radiation from the QGP and hadronic medium
- These studies reveal:
  - In-medium modification of vector mesons
  - Restoration of chiral symmetry and deconfinement
  - Space–time evolution of the fireball
- To isolate these physics signals from the raw di-muon spectra, an accurate estimation and subtraction of the **combinatorial background** .

$\rightarrow$ *A realistics and precise modeling of combinatorial background is therefore a crucial step.*

Origin of Combinatorial Background

- The **combinatorial background** originates from the **random pairing** of two uncorrelated muon candidates (μ^+ and μ^-) produced in high-energy collision events.
- These random combinations form a **non-physical, continuous background** in the invariant mass spectrum, often obscuring the true resonance peaks.
- **Primary sources of uncorrelated muons:**
  - **Decays of Light Hadrons:** Muons from the abundant decays of charged pions ($\pi^\pm$) and kaons ($K^\pm$); this is typically the dominant source.
  - **Heavy-Flavor Decays:** Muons originating from unrelated semi-leptonic decays of charm (c) and bottom (b) hadrons.(Not present at FAIR energy)
  - **Misidentified Hadrons:** Non-muon tracks (e.g., pions) mistakenly identified as muons.
- The invariant mass distribution of the raw di-muons show a **broad, smooth continuum** beneath the true signal, which must be carefully modeled and subtracted to obtain the genuine resonance yield.

Techniques for Combinatorial Background Estimation

Available techniques for combinatorial background estimations are,

- Super Event (SE) Technique
- Like-Sign (LS) Technique
- Mixed Event (ME) Technique
- Event-by-Event (EbE) Technique

Super-Event Technique

Physics Principle:

- Each muon candidate is combined with all oppositely charged muon candidates from all other events in a given sample to construct an uncorrelated invariant mass distribution.

Pros:

- Provides large statistics for smooth background spectra.
- Statistical uncertainties in large mass bins are significantly reduced.

Cons:

- Applicable only within the same centrality class.
- All merged events must have similar track multiplicities.

Like-Sign Technique

Physics Principle:

- The combinatorial background is estimated using like-sign (LS) pairs within the same event.
- The unlike-sign (OS) combinatorial background is then calculated using:

$$N_{\mathrm{BG}}^{OS} = 2\sqrt{N^{\mu^{+}\mu^{+}} \cdot N^{\mu^{-}\mu^{-}}}$$

Pros:

- Uses same-event information .
- Simple and computationally fast.

Cons:

- Low statistics for LS pairs.
- Sensitive to charge asymmetries or reconstruction biases.
- Possible residual correlations in high-multiplicity events.

Mixed-Event Technique

Physics Principle:

- Oppositely charged muon candidates from different events are randomly combined, provided the events have similar global properties (e.g., multiplicity or impact parameter).
- This breaks all real correlations and provides a purely combinatorial background.

Pros:

- Provides high statistics.
- By design, generates a purely uncorrelated background.
- Naturally handles charge symmetry.

Cons:

- Computationally intensive.
- Requires careful event matching (impact parameter, multiplicity, vertex position, etc.).

Event-by-Event Technique

Physics Principle:

- Oppositely charged muon candidates are combined within the same event to form the invariant mass spectrum.
- This represents the most direct and realistic method to calculate the combinatorial background in raw data.

Pros:

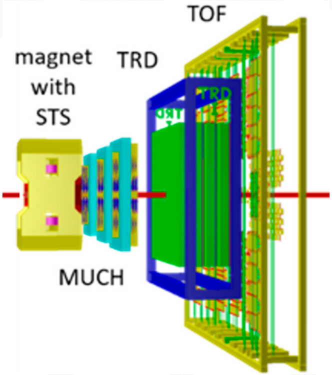
- Uses same-event information .
- Simple and computationally fast.

Cons:

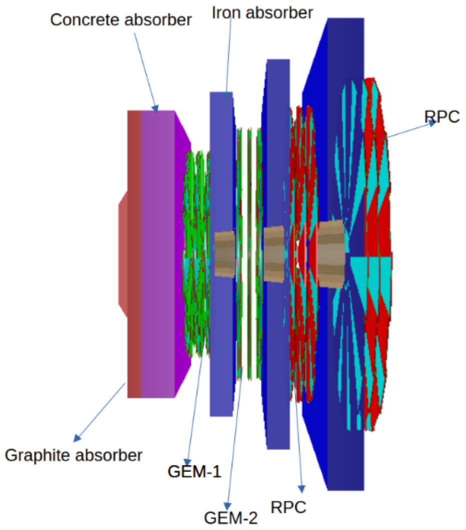
- Poor statistics per event lead to noisy spectra.
- Not suitable for precise background subtraction without large statistics.
- Requires significantly higher statistics to achieve comparable uncertainties in mass bins.

Simulation Setup

- **Event generator:UrQmd**
- **Input File:** /lustre/cbm/prod/gen/urqmd/auau/10gev/centr
- **System:** Au + Au collisions
- **Centrality:** 0-10%
- **Energy:** 10 AGeV
- **Transport Engine:** Geant3
- **CBMROOT Version:** July 25
- **Setup:** `sis100_muon_lmvm`
- **No of events:** 1 million



Muon Chamber (MUCH) for LMVM setup



- **Purpose:** Identification and tracking of muons produced in heavy-ion collisions.
- **Structure:**
  - Each station has 3 layers.
  - GEM detectors in first two stations.
  - RPC detectors in last two stations.
  - Segmented absorber design.
  - First absorber is made of 28 cm graphite + 30 cm concrete.
  - Remaining absorber are made of iron (20 cm + 20 cm + 30 cm).
- **Key Feature:** High-rate capability and excellent spatial resolution.

Selection of Muon Candidate

Apply the following cuts to the reconstructed global tracks to select muon candidates:

- **STShits:** ≥ 7
- **MUCHhits:** ≥ 11
- **TRDhits:** ≥ 1
- **TOFhits:** ≥ 1
- **MUCHchi2:** ≤ 3.0
- **STSchi2:** ≤ 3.0
- **Vchi2:** ≤ 3.0

Kinematics of reconstructed global tarcks

Momentum distribution of muon candidate from global track.

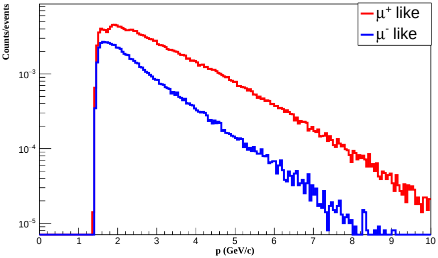


Fig: Momentum distribution from global track.

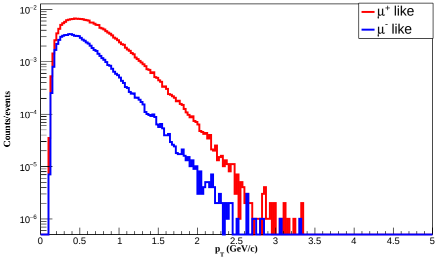


Fig:Transverse momentum distribution from global track .

Invariant Mass Distributions: SE and ME Methods

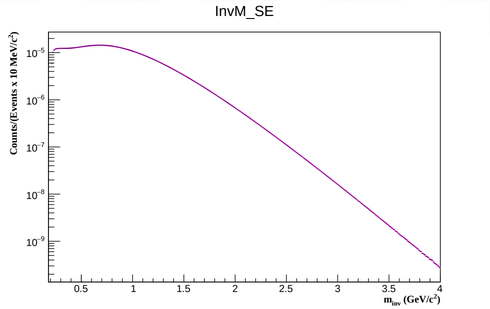


Fig: invariant mass distribution using Super Event(SE) method.

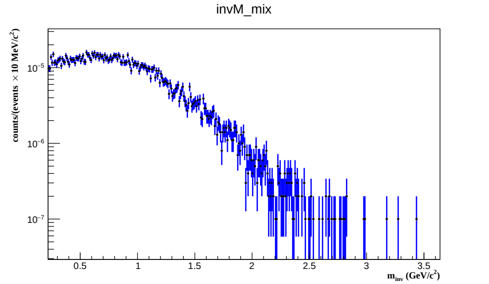


Fig: invariant mass distribution using mix event(ME) method .

Invariant Mass Distributions: LS and EbE Methods

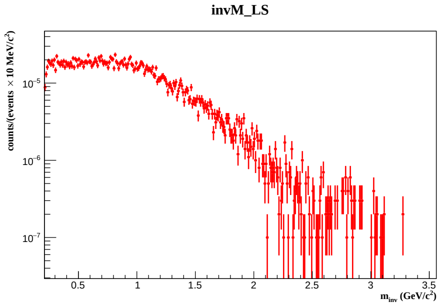


Fig: invariant mass distribution using LS method event by event.

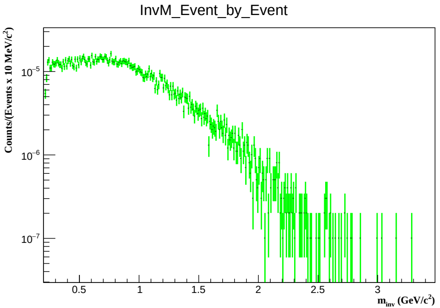


Fig: invariant mass distribution in Event by Event method .

- Charge asymmetry at the single track reconstruction level ($\mu^+ > \mu^-$) reflected in the pair mass distribution.
- More LS pairs than ULS pairs in event by event analysis.

Comparison of All Methods

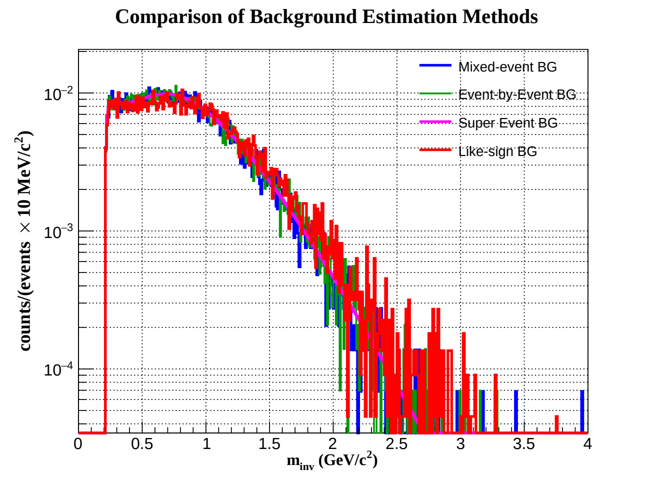


Fig: Comparison of all four methods for background estimation.

Background estimation of Different Techniques

Central Au-Au collision

Mass Window (GeV/c^2)	Mixed Event	Event-by-Event	Super Event	Like-Sign
ρ(770) (0.730–0.830)	1.49×10^{-4}	1.47×10^{-4}	1.53×10^{-4}	2.09×10^{-4}
ω(782) (0.770–0.790)	4.05×10^{-5}	3.93×10^{-5}	4.18×10^{-5}	6.27×10^{-5}
ϕ(1020) (0.990–1.050)	7.27×10^{-5}	6.71×10^{-5}	7.26×10^{-5}	1.19×10^{-4}
High Mass (1.200–1.300)	6.79×10^{-5}	6.94×10^{-5}	7.06×10^{-5}	1.12×10^{-4}

Comparison of the central values (counts per (event $\times$ 10 MeV/c^2)) for different invariant mass windows using various techniques.

Summary

- **Combinatorial background** arises from **random, uncorrelated muon pairs** in high-energy collisions.
- Systematic evaluation of different techniques of bkg estimation using muon setup at top SIS100 energy and GEANT3 transport engine.
- **Key findings from simulations:**

  Super Event methods provide smooth background templates.
  Mix Event method is more realistic one because it breaks all correlation .
  Like Sign method is simple but can suffer from low statistics and charge asymmetry.
  Event by Event method needs more statistics.

Future plan

- Utilize full available stats(5 million events)
- Repeat the simulations with currently foreseen realistic MuCH setup: MuCH+MUST (2 GEM +2 Straw Tube tracker)
- Examine the S/B for different di-muon signals

Thank You!

Back Up

Kinematics of the Accepted MC tracks

Accepted tracks:

- **STSpoints:** ≥ 7
- **MuCHpoints:** ≥ 11
- **TRDpoints:** ≥ 1
- **TOFpoints:** ≥ 1

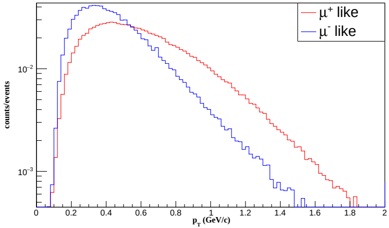


Fig: Momentum distribution at MC level.

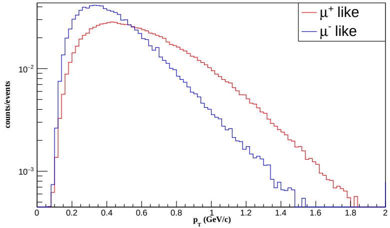


Fig:Transverse momentum distribution at MC level .

MC and Reconstructed level Rapidity comparison

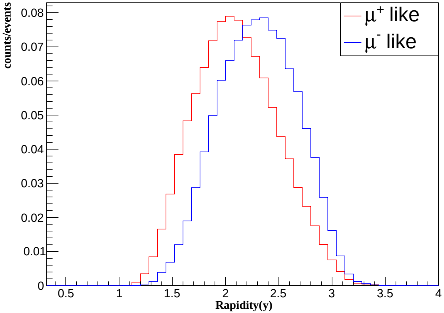


Fig: Rapidity distribution at MC level.

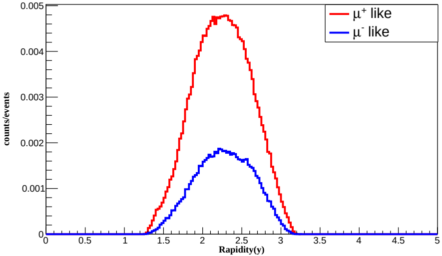


Fig:Rapidity distribution at reconstruction level .