Combinatorial background of muon pairs

Internship Final Presentation

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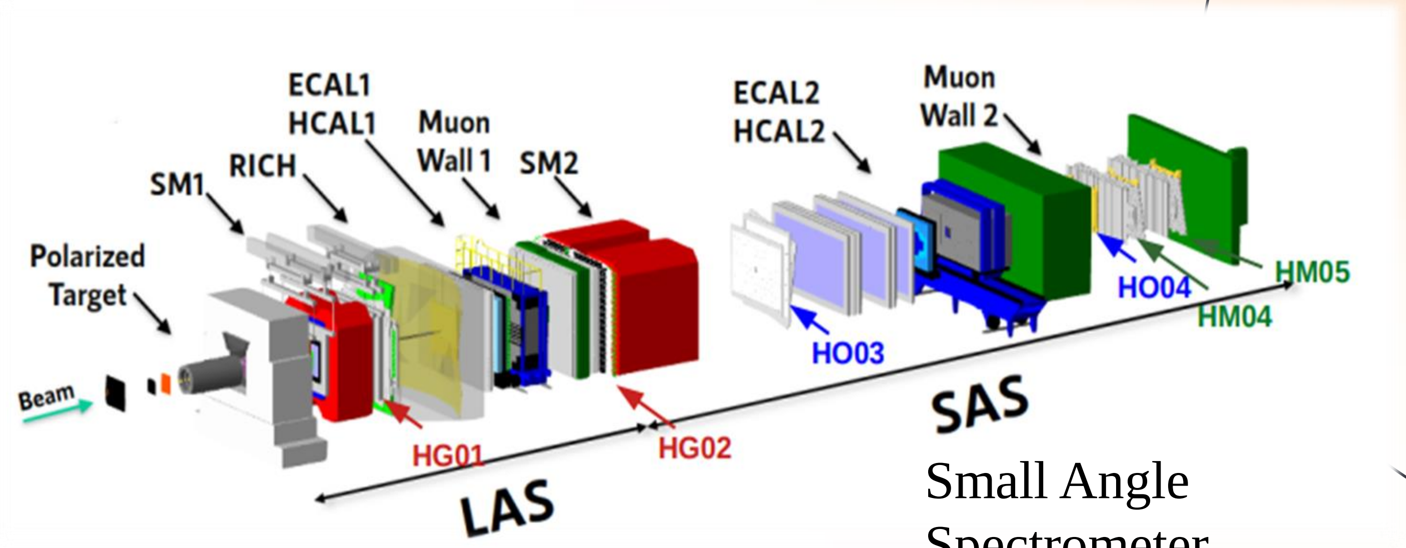
COMPASS Experiment

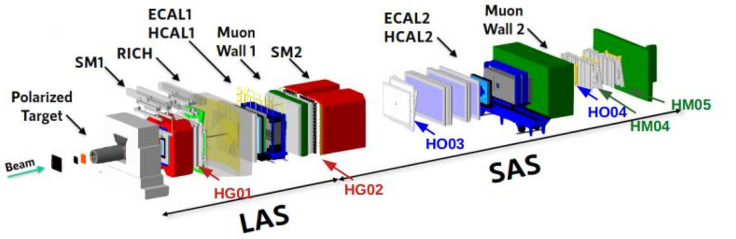
01



Small Angle Spectrometer

Large Angle Spectrometer

COMPASS Experiment



High-energy Experiment

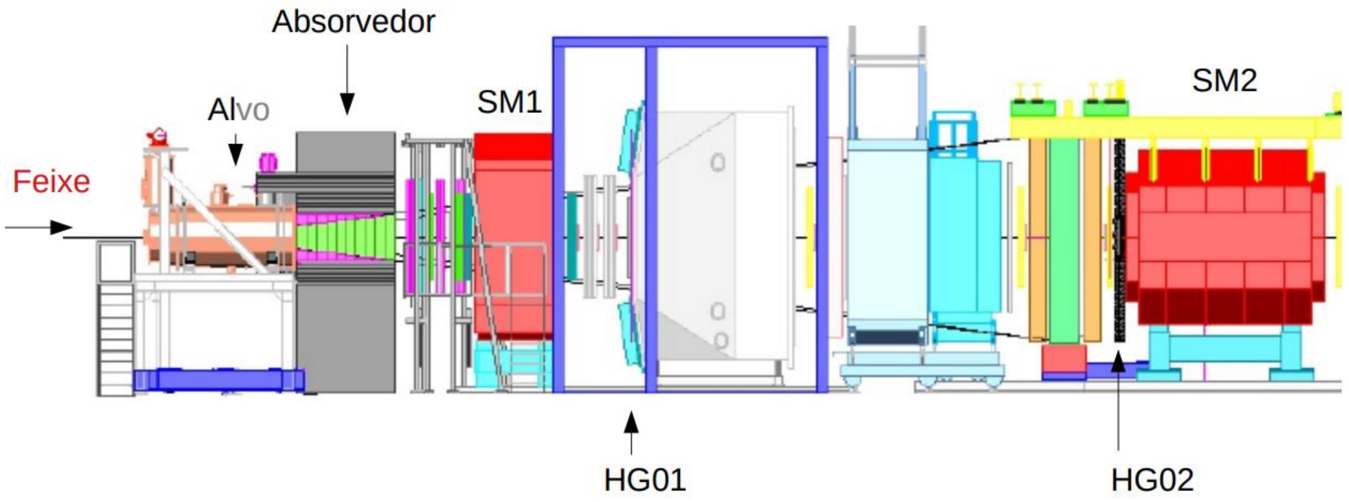
Consisting in
beam-fixed target colisions

Beam:

- Negative Pion

Fixed targets:

- 2 Polarized NH_3 Cells
- 1 Al Cell
- 1 W Cell



LAS setup side-view

LAS Angles between 50 and 200 mrad

SAS Angles between 20 and 70 mrad

Trigger for 2 muons

Drell-Yan (DY) vs. Combinatorial Background (CB)

02

Drell-Yan (DY)

vs.

Combinatorial Background (CB)

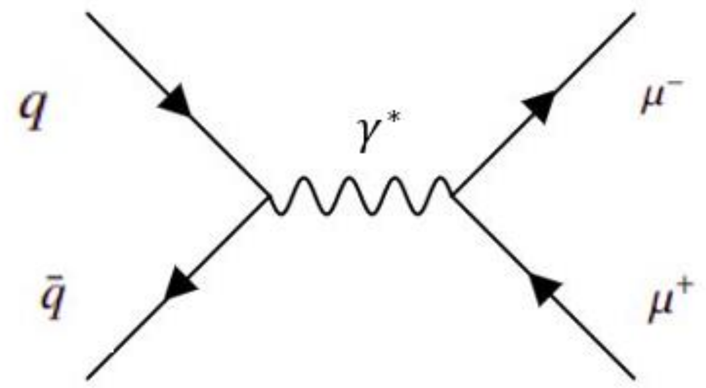
It´s a physics process between quarks

In the high energy collision of 2 hadrons, the quark-antiquark annihilation produces a virtual photon that converts into a pair of lepton-antilepton in the final state.

Muons that are close enough in time and space that will be seen as coming out of the same vertex

Statistically can be determined through like sign pairs of muons with the expression:

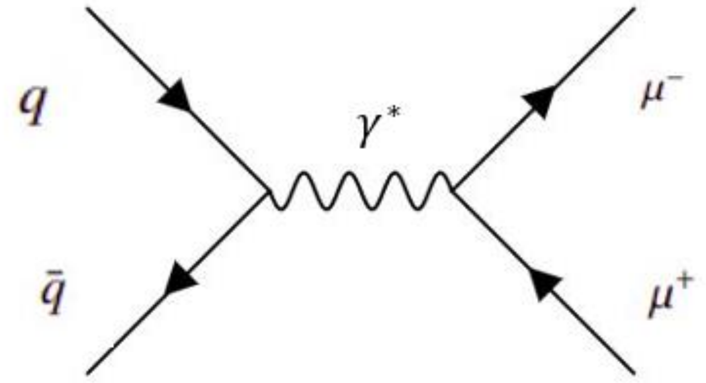
$$(+\,-) = 2\sqrt{(+\,+)\cdot(-\,-)}$$



Drell-Yan (DY)

It´s a physics process between quarks

In the high energy collision of 2 hadrons, the quark-antiquark annihilation produces a virtual photon that converts into a pair of lepton-antilepton in the final state.



vs.

Combinatorial Background (CB)

Muons that are close enough in time and space that will be seen as coming out of the same vertex

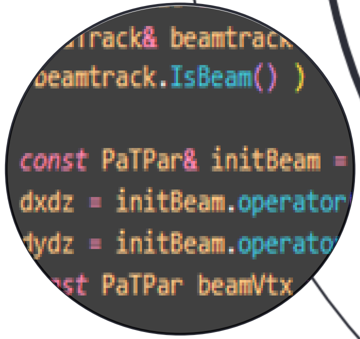
Statistically can be determined through like sign pairs of muons with the expression:

$$(+\,-) = 2\sqrt{(+\,+)\cdot(-\,-)}$$

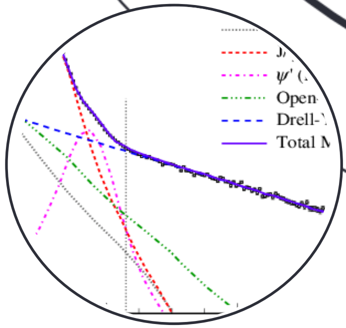
Important:

- **The spectrometer must have the same acceptance for both charges for this to apply**

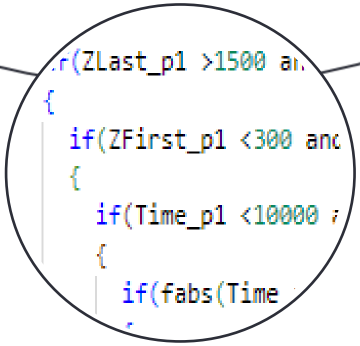
Objectives



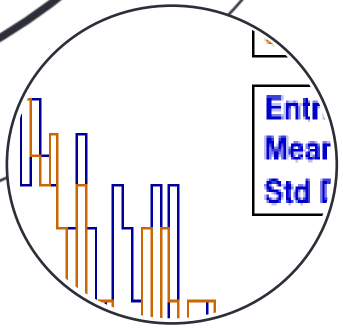
Build a code for event selection



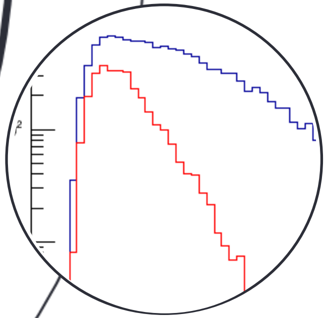
Calculate Kinematic Variables



Apply Quality Cuts



Build dimuon and like-sign pair´s histograms



Estimate the Combinatorial Background

Kinematic Variables and Cuts

04

Most used variables – Single Muons

Theta Angle

- Aperture angle with the respect to the Z-axis in the laboratory frame

Most used variables – Single Muons

Theta Angle

Total Momentum

- Aperture angle with the respect to the Z-axis in the laboratory frame

Most used variables – Single Muons

Theta Angle

- Aperture angle with the respect to the Z-axis in the laboratory frame

Total Momentum

ZFirst and ZLast

- First and last measured points along z of the muon´s track

Most used variables – Single Muons

Theta Angle	• Aperture angle with the respect to the Z-axis in the laboratory frame
Total Momentum	
ZFirst and ZLast	• First and last measured points along z of the muon´s track
Time of Detection	• Mean time of the particle´s track with respect to the trigger

Most used variables – Single Muons

Theta Angle	• Aperture angle with the respect to the Z-axis in the laboratory frame
Total Momentum	
ZFirst and ZLast	• First and last measured points along z of the muon´s track
Time of Detection	• Mean time of the particle´s track with respect to the trigger
Vertex Coordinates	• X, Y and Z positions of the vertex from where the particles came out

Most used variables – Single Muons

Theta Angle	• Aperture angle with the respect to the Z-axis in the laboratory frame
Total Momentum	
ZFirst and ZLast	• First and last measured points along z of the muon´s track
Time of Detection	• Mean time of the particle´s track with respect to the trigger
Vertex Coordinates	• X, Y and Z positions of the vertex from where the particles came out
Track Chi Squared	• Chi distribution squared, that will be divided by the number of degrees of freedom

Most used variables - Pairs

Invariant Mass

- Mass before particle´s decay, calculated from the energies and momenta of the decay products.

Most used variables - Pairs

Invariant Mass

Total Momentum

- Mass before particle´s decay, calculated from the energies and momenta of the decay products.

Most used variables - Pairs

Invariant Mass	Mass before particle´s decay, calculated from the energies and momenta of the decay products.
Total Momentum	
Transverse Momentum	$\sqrt{P_x^2 + P_y^2}$

Most used variables - Pairs

Invariant Mass	● Mass before particle´s decay, calculated from the energies and momenta of the decay products.
Total Momentum	
Transverse Momentum	$\sqrt{P_x^2 + P_y^2}$
Feynman X - x_F	$\frac{P_l}{\sqrt{s}/2}$

Cuts applied

- ZLast > 1500 cm
- Zfirst < 300 cm
- Trigger: 2 muons on LAS
- Time of detection defined
- Time difference between 2 muons < 3 ns
- $\chi^2/ndf \; < \; 8$
- $\sqrt{X_{vertex}^2 + Y_{vertex}^2} \; < \; 2$ cm
- Invariant Mass > 1,5 GeV/c^2
- -1 < x_F <1

- Separation by target:

NH3 Cell 1	$-300 \; < Z_{vertex}(cm) < -240$
NH3 Cell 2	$-220 \; < Z_{vertex}(cm) < -164$
Al Cell	$-80 \; < Z_{vertex}(cm) < -60$
W Cell	$-40 \; < Z_{vertex}(cm) < -10$

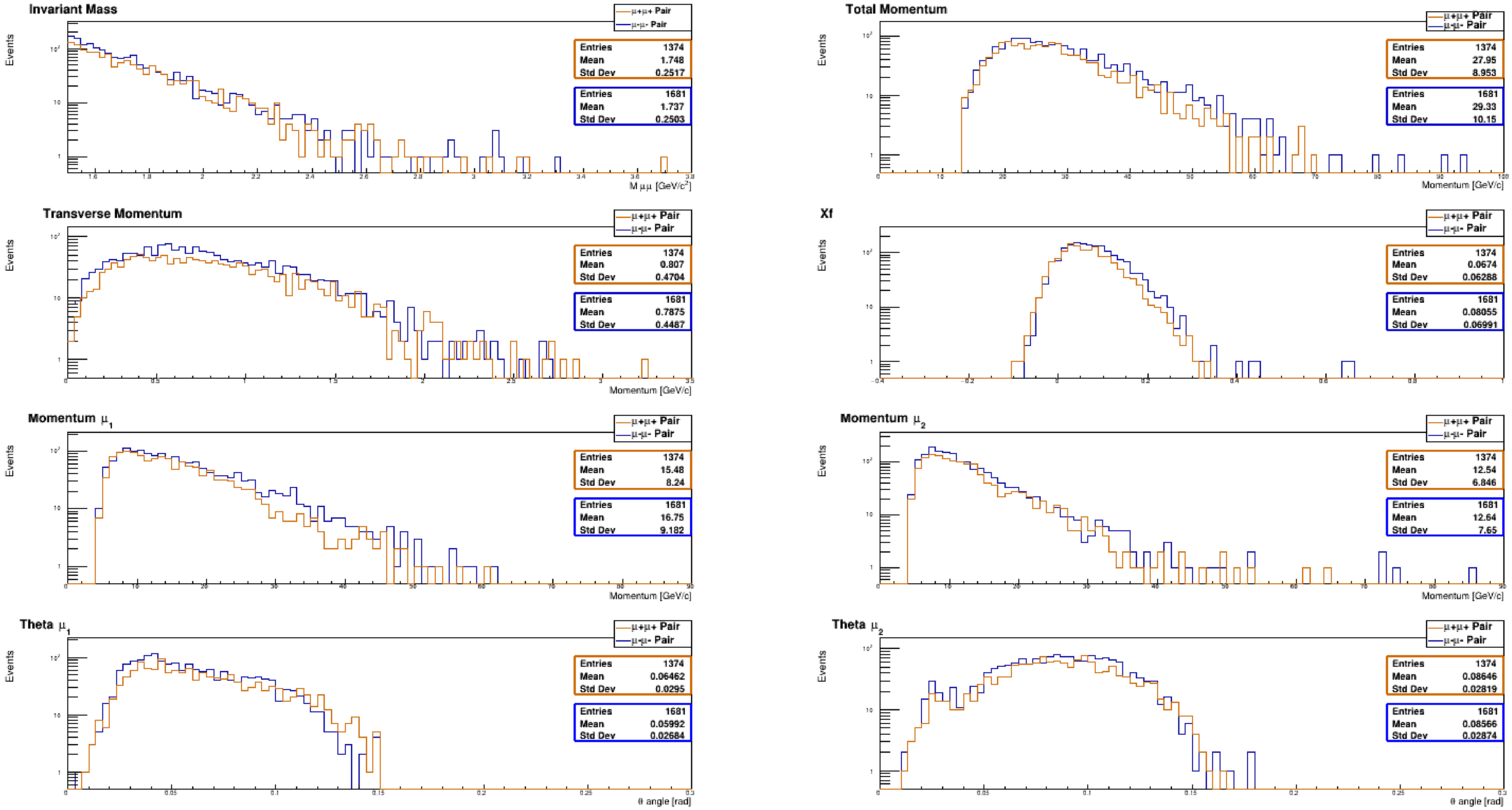
Results and Data Analysis

05

Super-Imposing Like-Signs histograms

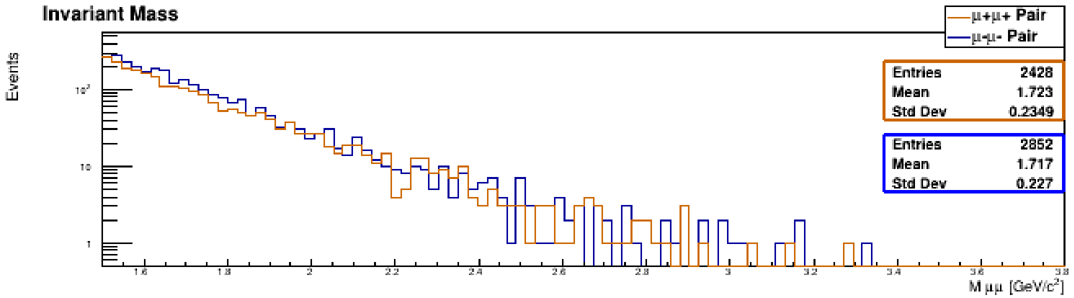
Verifying if two charges from like-sign look identical (assumption of similar acceptance from slide 8)

NH3 Cell 1

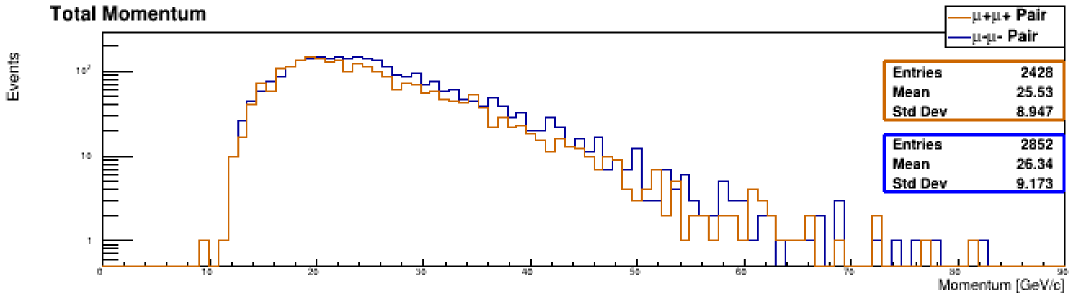


Invariant Mass
μ+μ+ Pair
μ-μ- Pair
Entries 1374
Mean 1.748
Std Dev 0.2517
Entries 1681
Mean 1.737
Std Dev 0.2503
Events
M μμ [GeV/c²]
Total Momentum
μ+μ+ Pair
μ-μ- Pair
Entries 1374
Mean 27.95
Std Dev 8.953
Entries 1681
Mean 29.33
Std Dev 10.15
Events
Momentum [GeV/c]
Transverse Momentum
μ+μ+ Pair
μ-μ- Pair
Entries 1374
Mean 0.807
Std Dev 0.4704
Entries 1681
Mean 0.7875
Std Dev 0.4487
Events
Momentum [GeV/c]
Xf
μ+μ+ Pair
μ-μ- Pair
Entries 1374
Mean 0.0674
Std Dev 0.06288
Entries 1681
Mean 0.08055
Std Dev 0.06991
Events
Momentum μ1
μ+μ+ Pair
μ-μ- Pair
Entries 1374
Mean 15.48
Std Dev 8.24
Entries 1681
Mean 16.75
Std Dev 9.182
Events
Momentum [GeV/c]
Momentum μ2
μ+μ+ Pair
μ-μ- Pair
Entries 1374
Mean 12.54
Std Dev 6.846
Entries 1681
Mean 12.64
Std Dev 7.65
Events
Momentum [GeV/c]
Theta μ1
μ+μ+ Pair
μ-μ- Pair
Entries 1374
Mean 0.06462
Std Dev 0.0295
Entries 1681
Mean 0.05992
Std Dev 0.02684
Events
θ angle [rad]
Theta μ2
μ+μ+ Pair
μ-μ- Pair
Entries 1374
Mean 0.08646
Std Dev 0.02819
Entries 1681
Mean 0.08566
Std Dev 0.02874
Events
θ angle [rad]

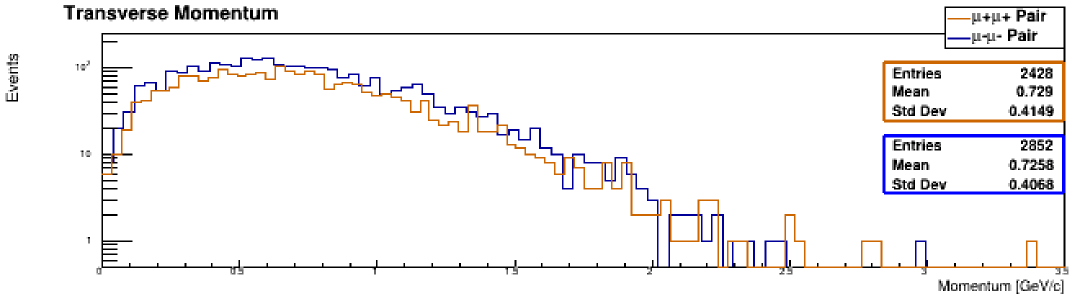
NH_3 Cell 2



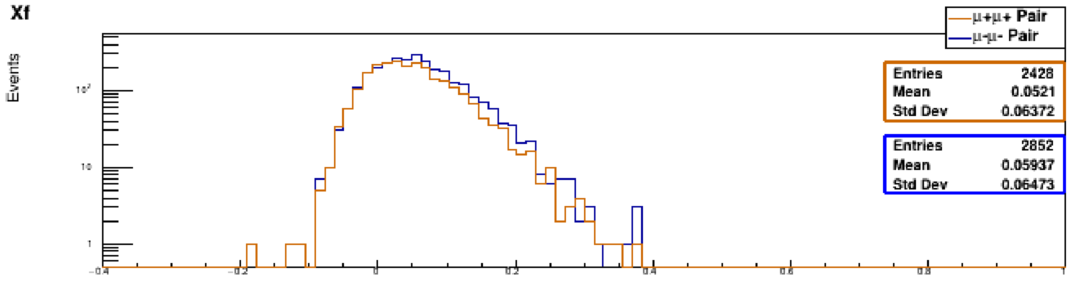
Invariant Mass
μ+μ+ Pair
μ-μ- Pair
Entries 2428
Mean 1.723
Std Dev 0.2349
Entries 2852
Mean 1.717
Std Dev 0.227
Events
M μμ [GeV/c²]



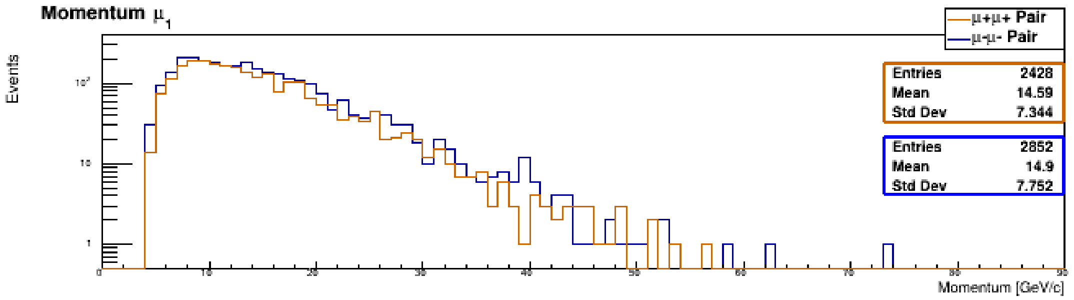
Total Momentum
μ+μ+ Pair
μ-μ- Pair
Entries 2428
Mean 25.53
Std Dev 8.947
Entries 2852
Mean 26.34
Std Dev 9.173
Events
Momentum [GeV/c]



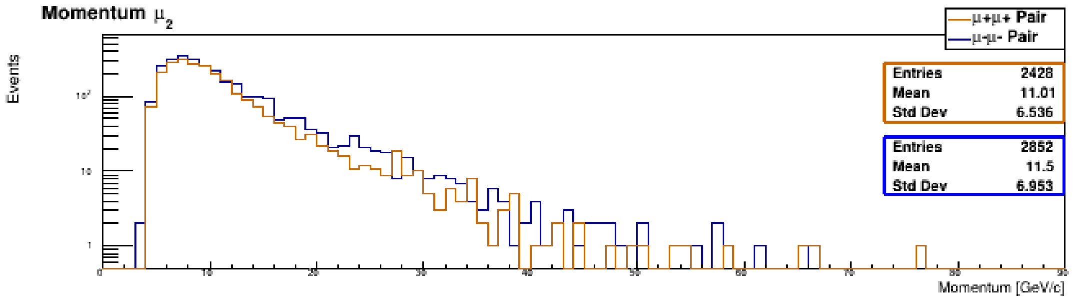
Transverse Momentum
μ+μ+ Pair
μ-μ- Pair
Entries 2428
Mean 0.729
Std Dev 0.4149
Entries 2852
Mean 0.7258
Std Dev 0.4068
Events
Momentum [GeV/c]



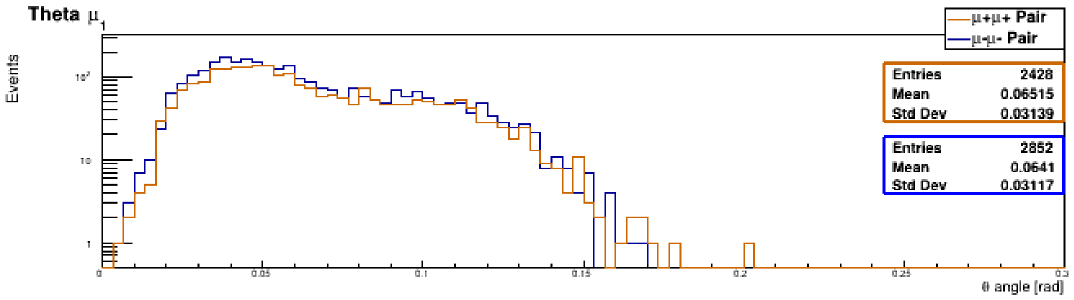
Xf
μ+μ+ Pair
μ-μ- Pair
Entries 2428
Mean 0.0521
Std Dev 0.06372
Entries 2852
Mean 0.05937
Std Dev 0.06473
Events



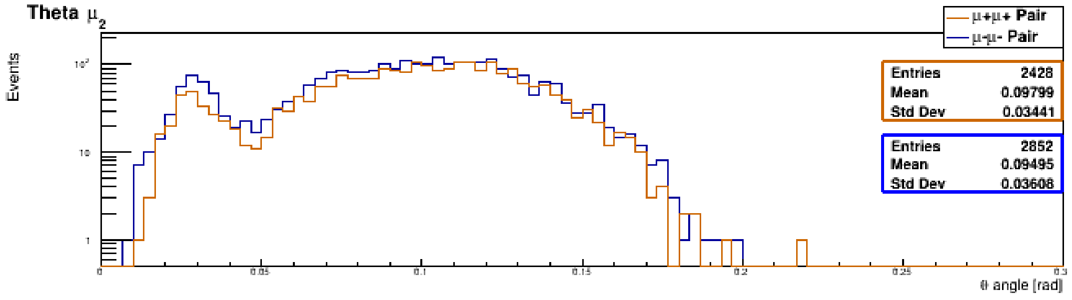
Momentum μ1
μ+μ+ Pair
μ-μ- Pair
Entries 2428
Mean 14.59
Std Dev 7.344
Entries 2852
Mean 14.9
Std Dev 7.752
Events
Momentum [GeV/c]



Momentum μ2
μ+μ+ Pair
μ-μ- Pair
Entries 2428
Mean 11.01
Std Dev 6.536
Entries 2852
Mean 11.5
Std Dev 6.953
Events
Momentum [GeV/c]

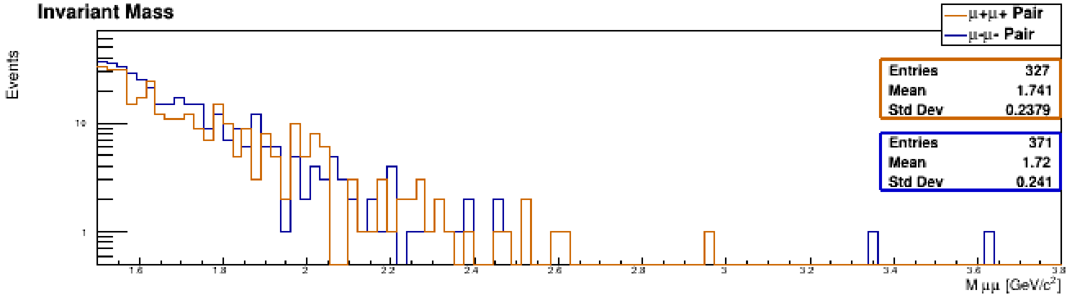


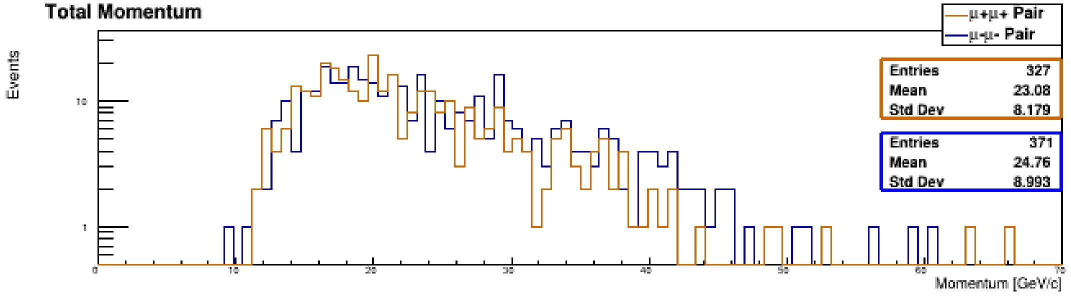
Theta μ1
μ+μ+ Pair
μ-μ- Pair
Entries 2428
Mean 0.06515
Std Dev 0.03139
Entries 2852
Mean 0.0641
Std Dev 0.03117
Events
θ angle [rad]

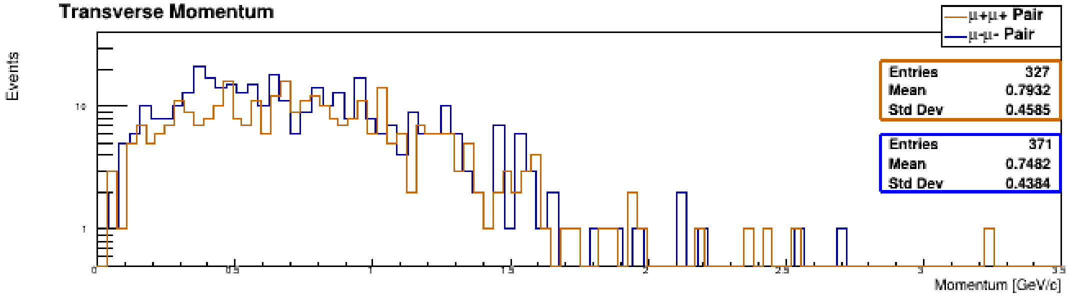


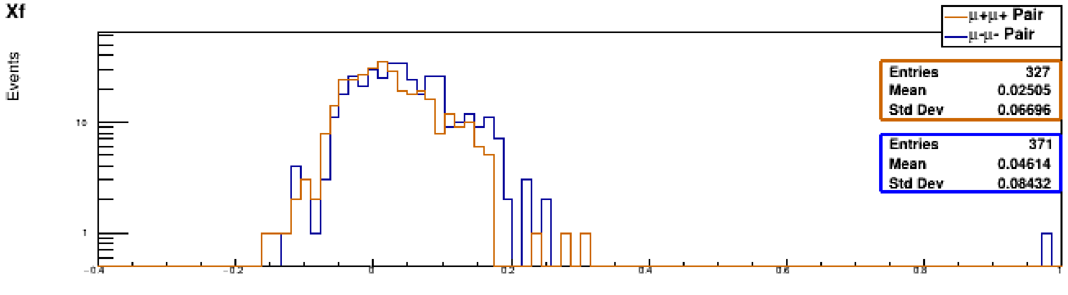
Theta μ2
μ+μ+ Pair
μ-μ- Pair
Entries 2428
Mean 0.09799
Std Dev 0.03441
Entries 2852
Mean 0.09495
Std Dev 0.03608
Events
θ angle [rad]

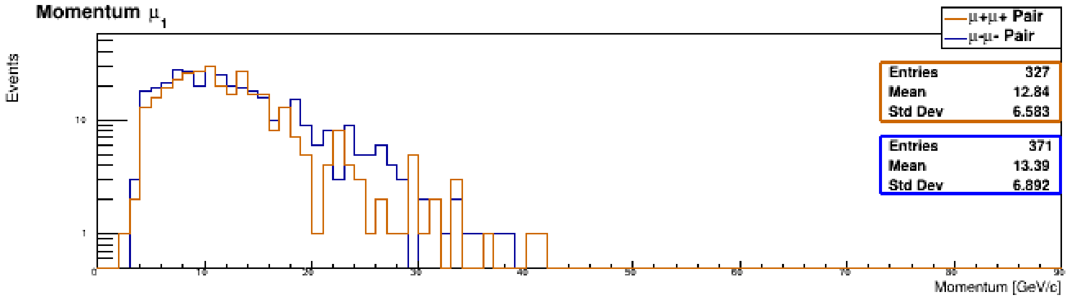
Al Cell

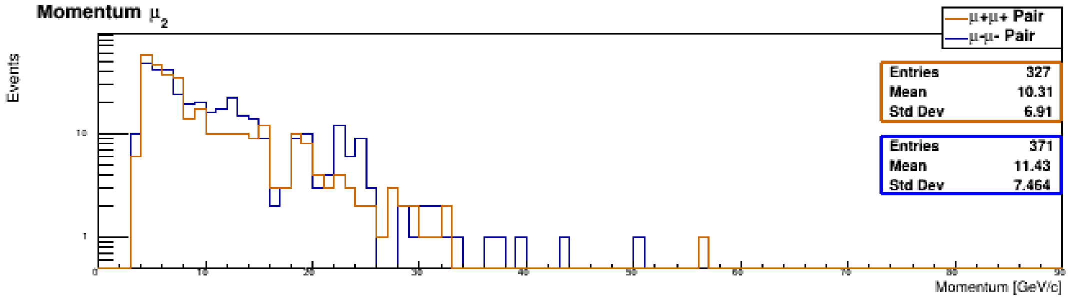

Invariant Mass
μ+μ+ Pair
μ-μ- Pair
Entries 327
Mean 1.741
Std Dev 0.2379
Entries 371
Mean 1.72
Std Dev 0.241
Events
M μμ [GeV/c²]

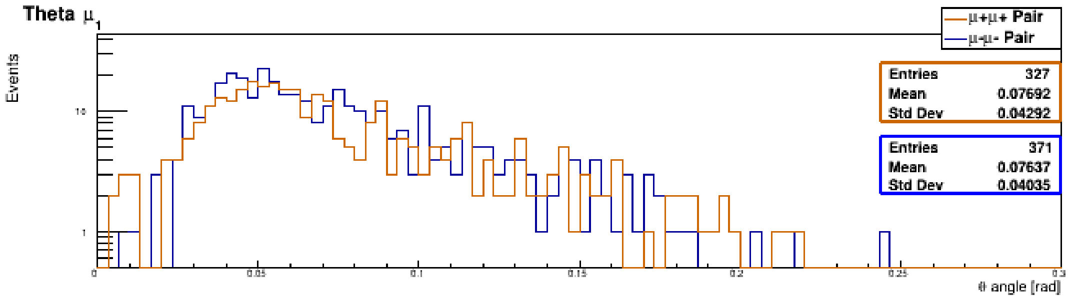

Total Momentum
μ+μ+ Pair
μ-μ- Pair
Entries 327
Mean 23.08
Std Dev 8.179
Entries 371
Mean 24.76
Std Dev 8.993
Events
Momentum [GeV/c]

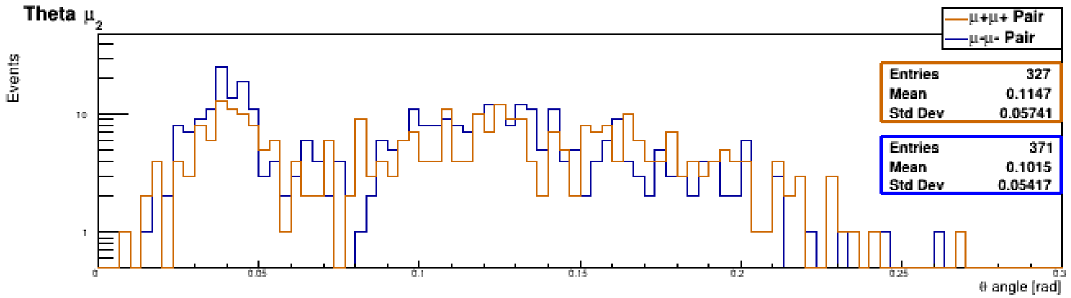

Transverse Momentum
μ+μ+ Pair
μ-μ- Pair
Entries 327
Mean 0.7932
Std Dev 0.4585
Entries 371
Mean 0.7482
Std Dev 0.4384
Events
Momentum [GeV/c]


Xf
μ+μ+ Pair
μ-μ- Pair
Entries 327
Mean 0.02505
Std Dev 0.06696
Entries 371
Mean 0.04614
Std Dev 0.08432
Events

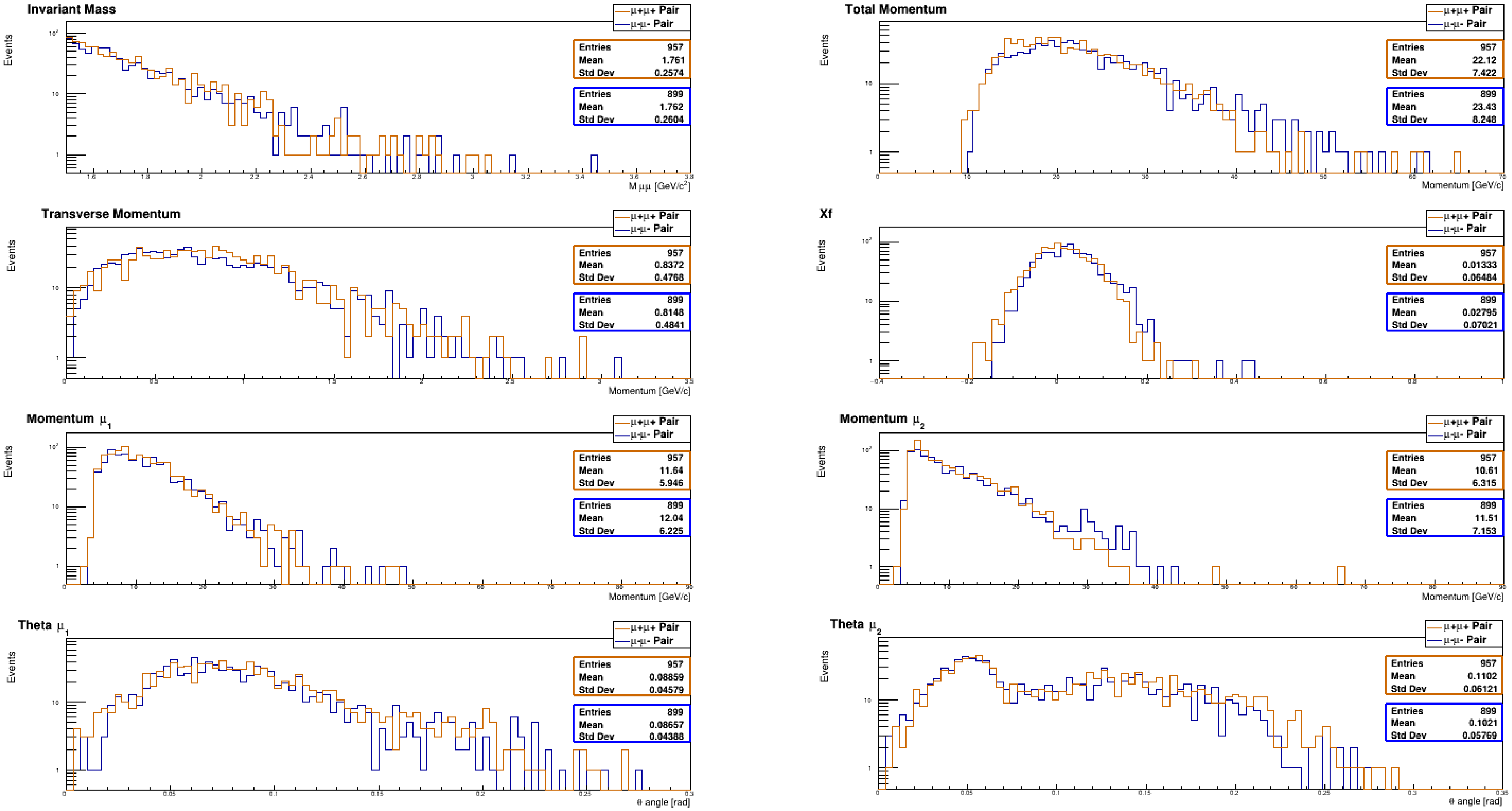

Momentum μ1
μ+μ+ Pair
μ-μ- Pair
Entries 327
Mean 12.84
Std Dev 6.583
Entries 371
Mean 13.39
Std Dev 6.892
Events
Momentum [GeV/c]


Momentum μ2
μ+μ+ Pair
μ-μ- Pair
Entries 327
Mean 10.31
Std Dev 6.91
Entries 371
Mean 11.43
Std Dev 7.464
Events
Momentum [GeV/c]


Theta μ1
μ+μ+ Pair
μ-μ- Pair
Entries 327
Mean 0.07692
Std Dev 0.04292
Entries 371
Mean 0.07637
Std Dev 0.04035
Events
θ angle [rad]


Theta μ2
μ+μ+ Pair
μ-μ- Pair
Entries 327
Mean 0.1147
Std Dev 0.05741
Entries 371
Mean 0.1015
Std Dev 0.05417
Events
θ angle [rad]

W Cell



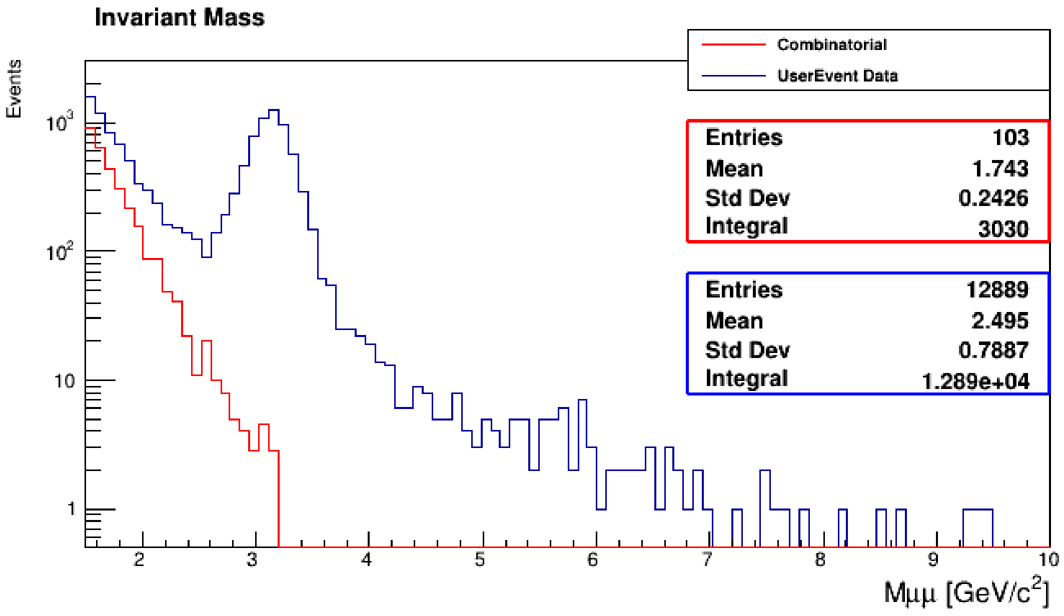
Invariant Mass
μ+μ+ Pair
μ-μ- Pair
Entries 957
Mean 1.761
Std Dev 0.2574
Entries 899
Mean 1.762
Std Dev 0.2604
Events
M μμ [GeV/c²]
Total Momentum
μ+μ+ Pair
μ-μ- Pair
Entries 957
Mean 22.12
Std Dev 7.422
Entries 899
Mean 23.43
Std Dev 8.248
Events
Momentum [GeV/c]
Transverse Momentum
μ+μ+ Pair
μ-μ- Pair
Entries 957
Mean 0.8372
Std Dev 0.4768
Entries 899
Mean 0.8148
Std Dev 0.4841
Events
Momentum [GeV/c]
Xf
μ+μ+ Pair
μ-μ- Pair
Entries 957
Mean 0.01333
Std Dev 0.06484
Entries 899
Mean 0.02795
Std Dev 0.07021
Events
Momentum μ1
μ+μ+ Pair
μ-μ- Pair
Entries 957
Mean 11.64
Std Dev 5.946
Entries 899
Mean 12.04
Std Dev 6.225
Events
Momentum [GeV/c]
Momentum μ2
μ+μ+ Pair
μ-μ- Pair
Entries 957
Mean 10.61
Std Dev 6.315
Entries 899
Mean 11.51
Std Dev 7.153
Events
Momentum [GeV/c]
Theta μ1
μ+μ+ Pair
μ-μ- Pair
Entries 957
Mean 0.08859
Std Dev 0.04579
Entries 899
Mean 0.08657
Std Dev 0.04388
Events
θ angle [rad]
Theta μ2
μ+μ+ Pair
μ-μ- Pair
Entries 957
Mean 0.1102
Std Dev 0.06121
Entries 899
Mean 0.1021
Std Dev 0.05769
Events
θ angle [rad]

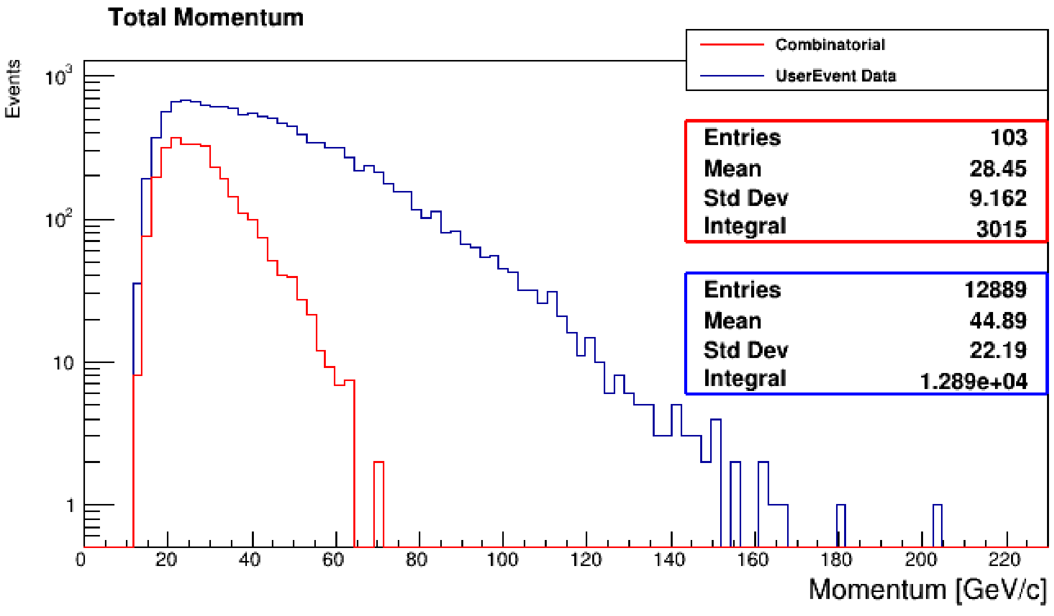
Super-Imposing Combinatorial background and Dimuon Data

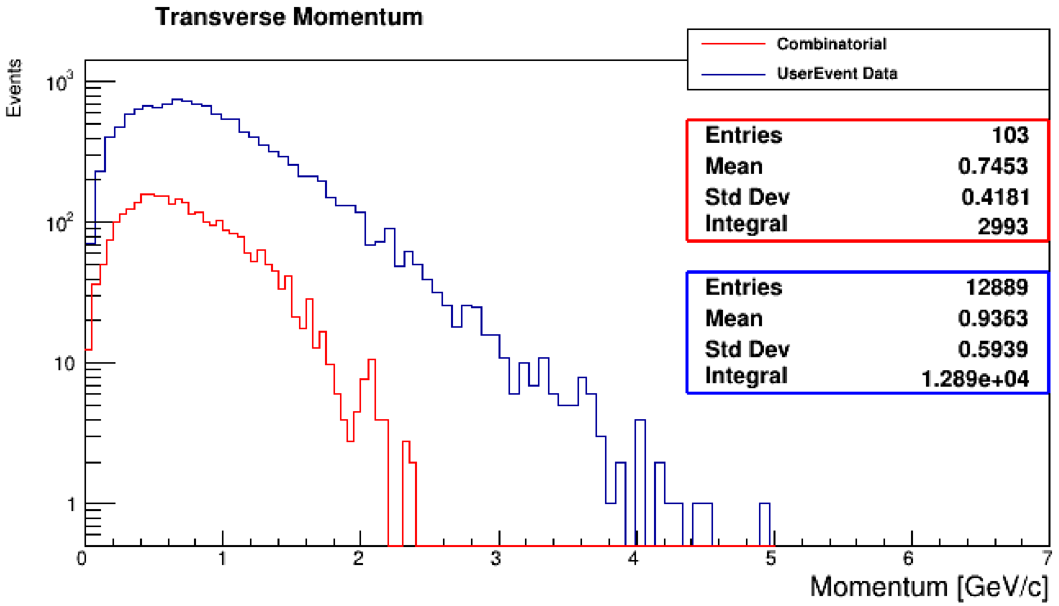
Bin by bin we are using the number of entries of each value in the previous expression (revisiting slide 8 expression):

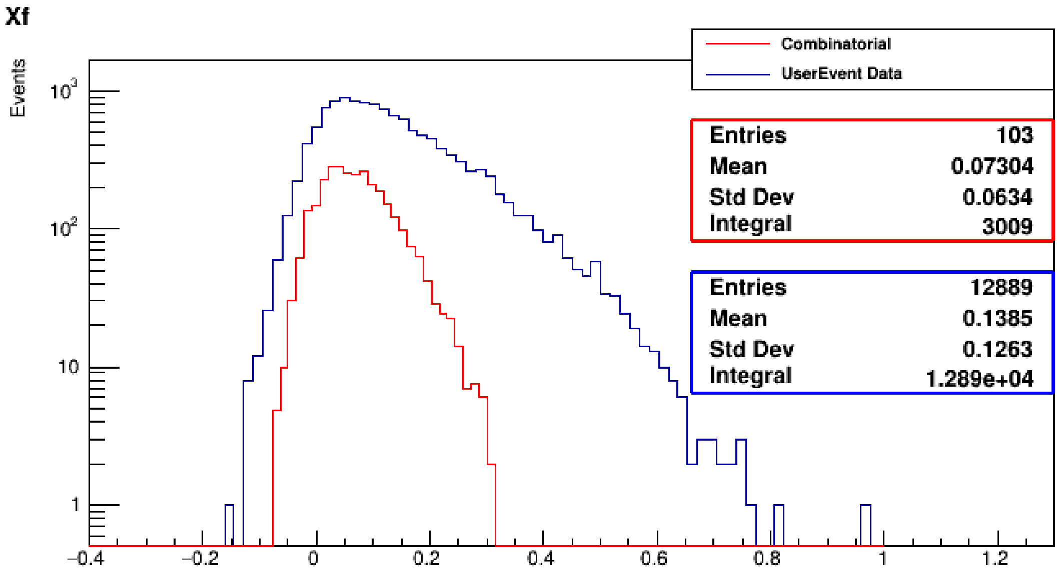
$$(+\,-) \;=\; 2\sqrt{(+\,+)\cdot(-\,-)}$$

NH3 Cell 1

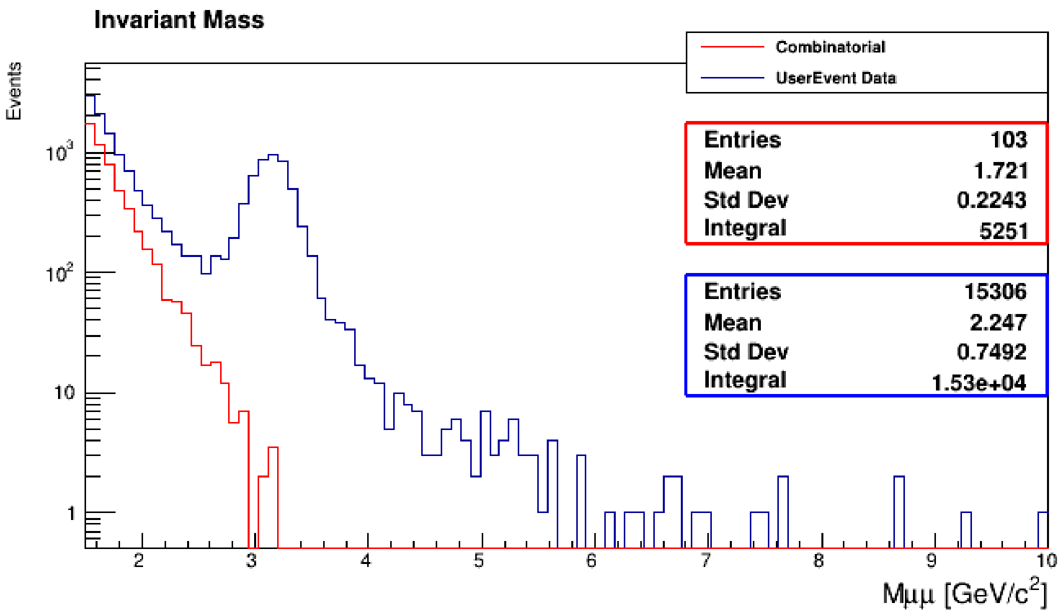

Invariant Mass
Combinatorial
UserEvent Data
Entries 103
Mean 1.743
Std Dev 0.2426
Integral 3030
Entries 12889
Mean 2.495
Std Dev 0.7887
Integral 1.289e+04
Events
Mμμ [GeV/c²]

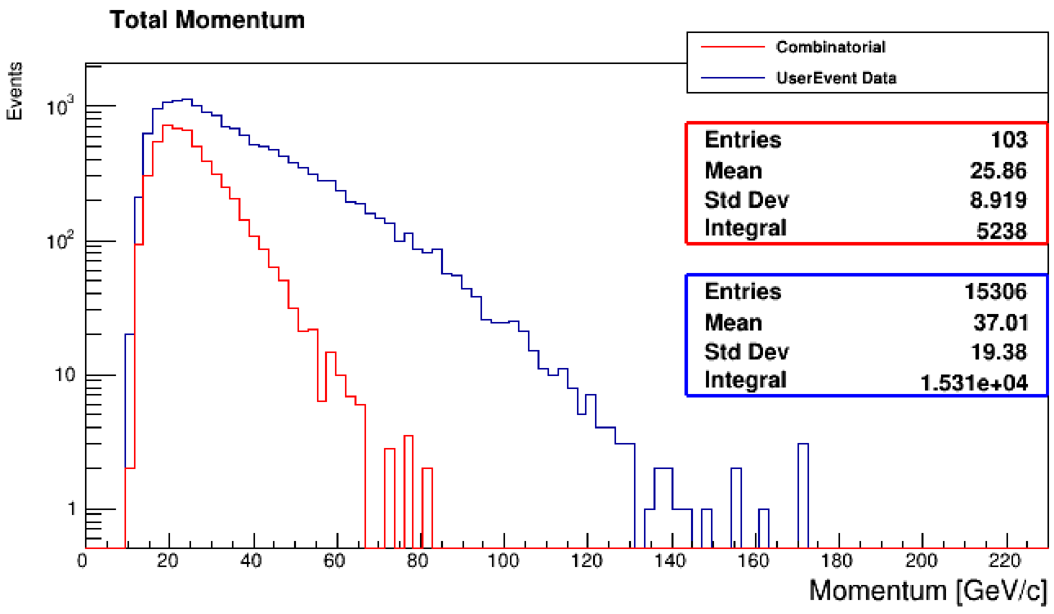

Total Momentum
Combinatorial
UserEvent Data
Entries 103
Mean 28.45
Std Dev 9.162
Integral 3015
Entries 12889
Mean 44.89
Std Dev 22.19
Integral 1.289e+04
Events
Momentum [GeV/c]

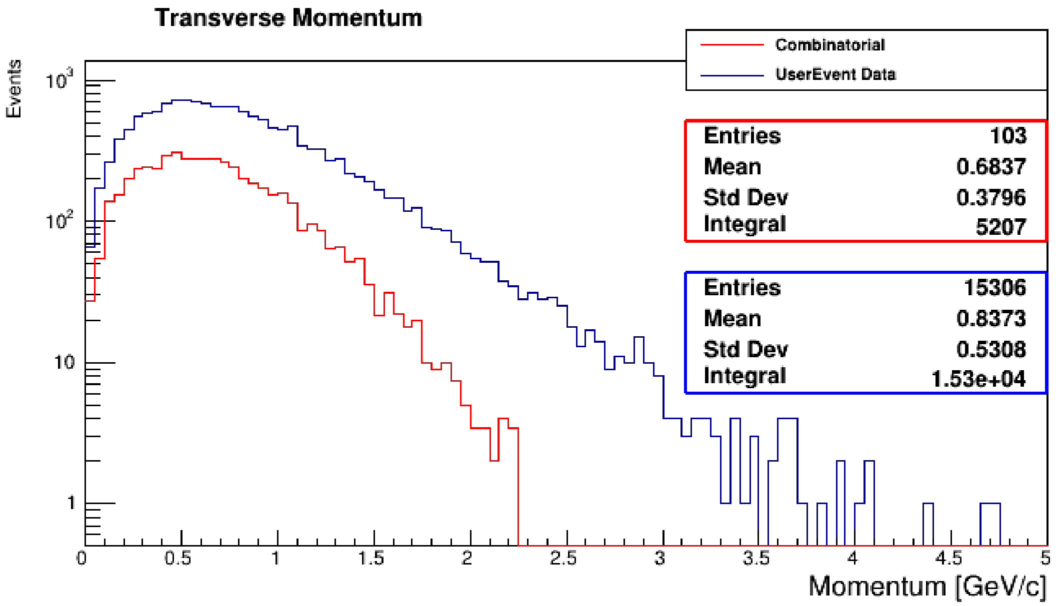

Transverse Momentum
Combinatorial
UserEvent Data
Entries 103
Mean 0.7453
Std Dev 0.4181
Integral 2993
Entries 12889
Mean 0.9363
Std Dev 0.5939
Integral 1.289e+04
Events
Momentum [GeV/c]

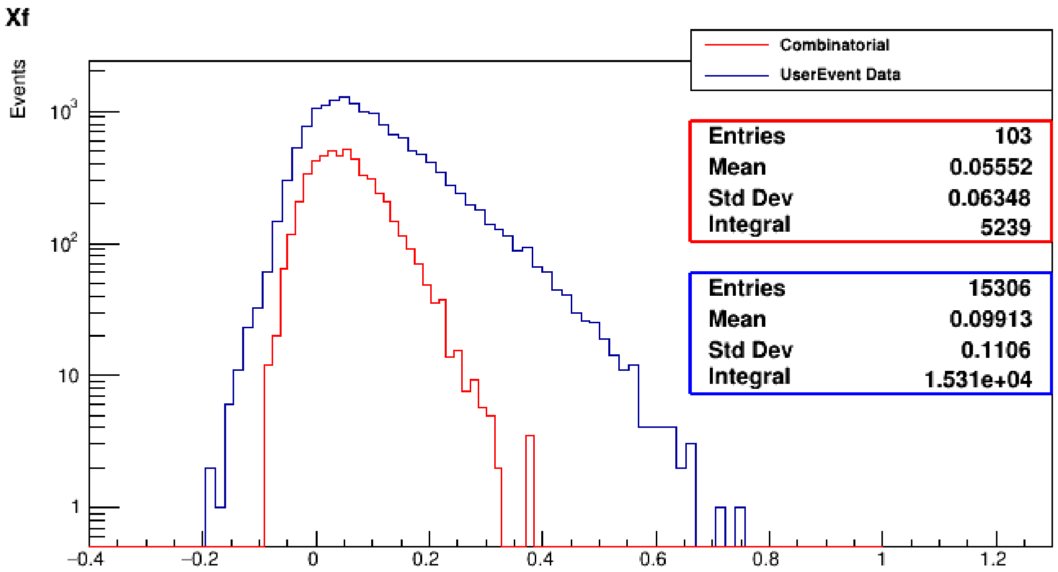

Xf
Combinatorial
UserEvent Data
Entries 103
Mean 0.07304
Std Dev 0.0634
Integral 3009
Entries 12889
Mean 0.1385
Std Dev 0.1263
Integral 1.289e+04
Events

NH3 Cell 2

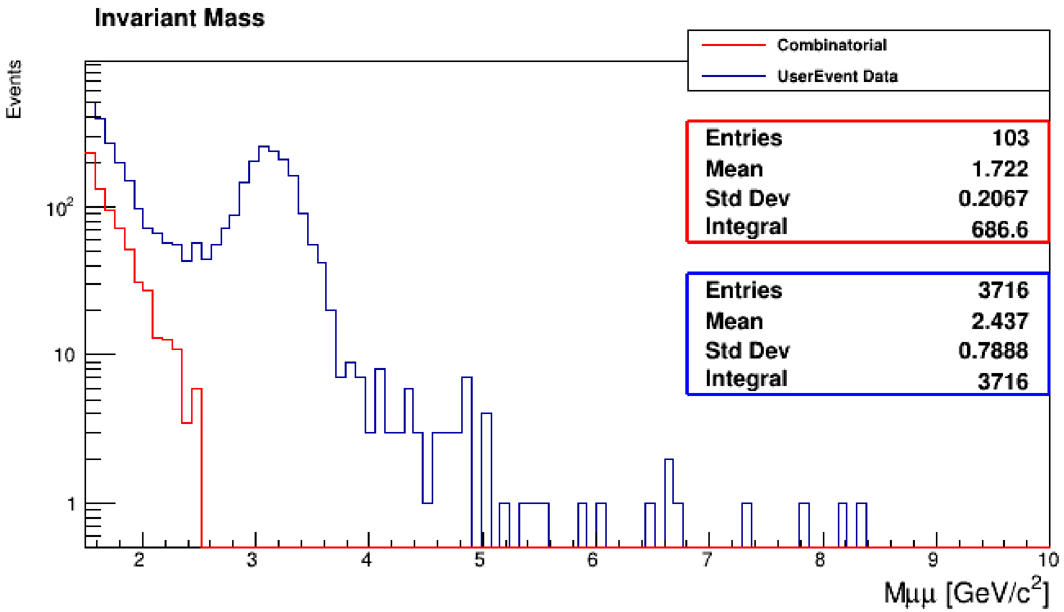

Invariant Mass
Combinatorial
UserEvent Data
Entries 103
Mean 1.721
Std Dev 0.2243
Integral 5251
Entries 15306
Mean 2.247
Std Dev 0.7492
Integral 1.53e+04
Events
Mμμ [GeV/c^2]


Total Momentum
Combinatorial
UserEvent Data
Entries 103
Mean 25.86
Std Dev 8.919
Integral 5238
Entries 15306
Mean 37.01
Std Dev 19.38
Integral 1.531e+04
Events
Momentum [GeV/c]

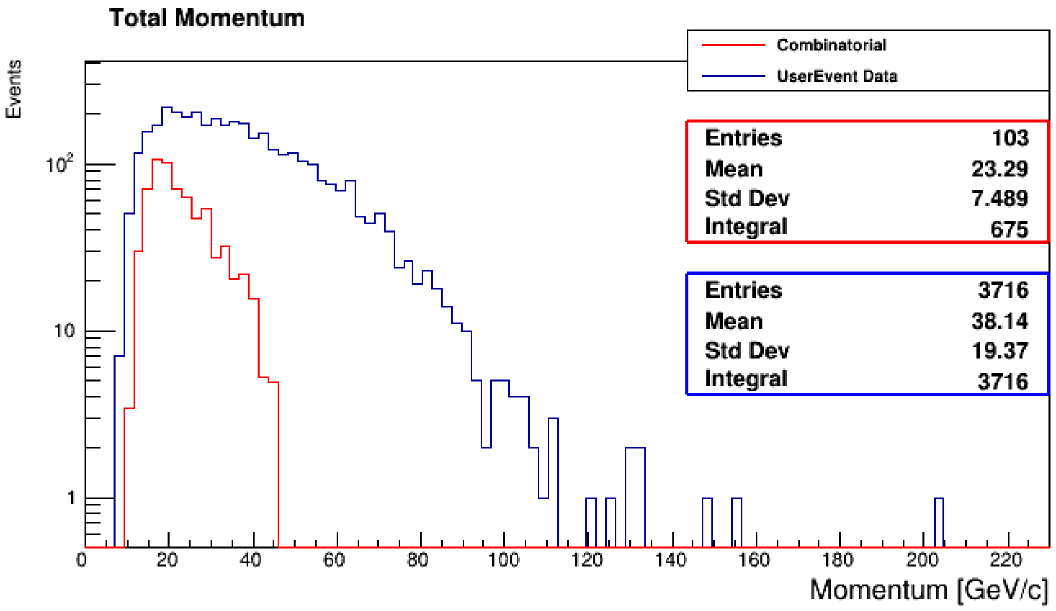

Transverse Momentum
Combinatorial
UserEvent Data
Entries 103
Mean 0.6837
Std Dev 0.3796
Integral 5207
Entries 15306
Mean 0.8373
Std Dev 0.5308
Integral 1.53e+04
Events
Momentum [GeV/c]


Xf
Combinatorial
UserEvent Data
Entries 103
Mean 0.05552
Std Dev 0.06348
Integral 5239
Entries 15306
Mean 0.09913
Std Dev 0.1106
Integral 1.531e+04
Events

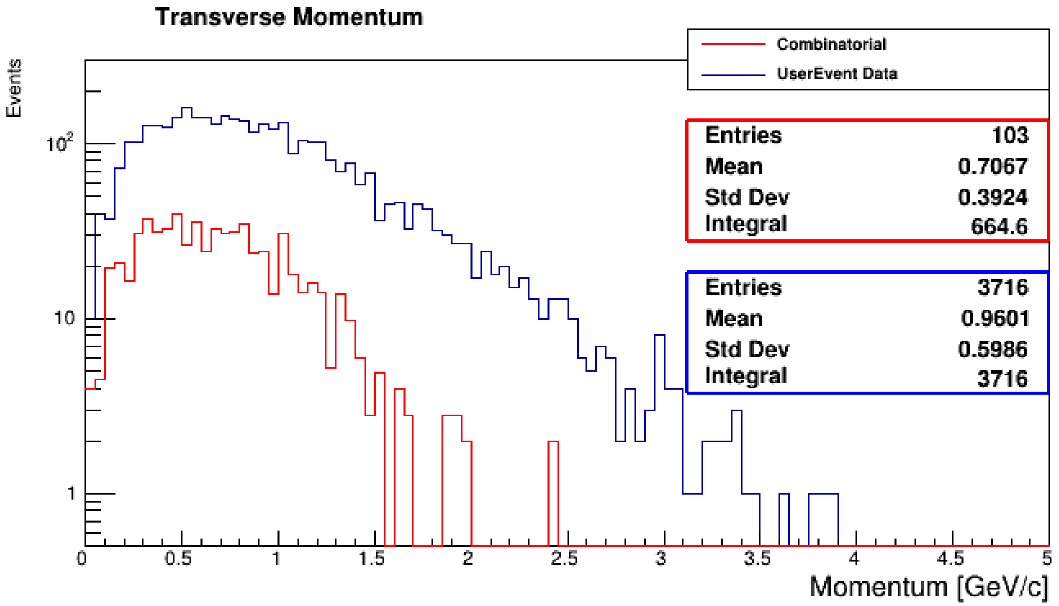
Al Cell



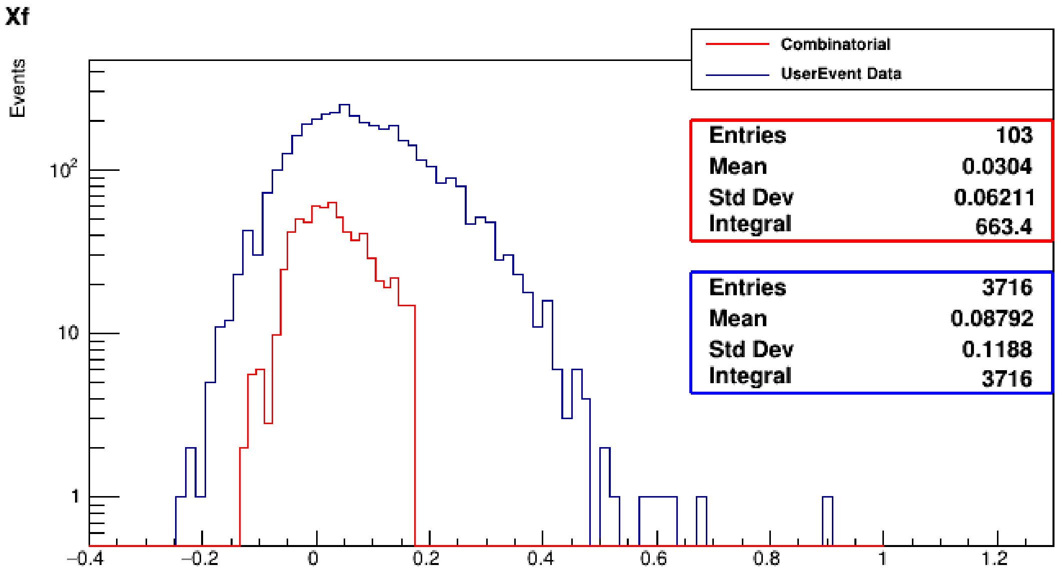
Invariant Mass
Combinatorial
UserEvent Data
Entries 103
Mean 1.722
Std Dev 0.2067
Integral 686.6
Entries 3716
Mean 2.437
Std Dev 0.7888
Integral 3716
Events
Mμμ [GeV/c^2]



Total Momentum
Combinatorial
UserEvent Data
Entries 103
Mean 23.29
Std Dev 7.489
Integral 675
Entries 3716
Mean 38.14
Std Dev 19.37
Integral 3716
Events
Momentum [GeV/c]

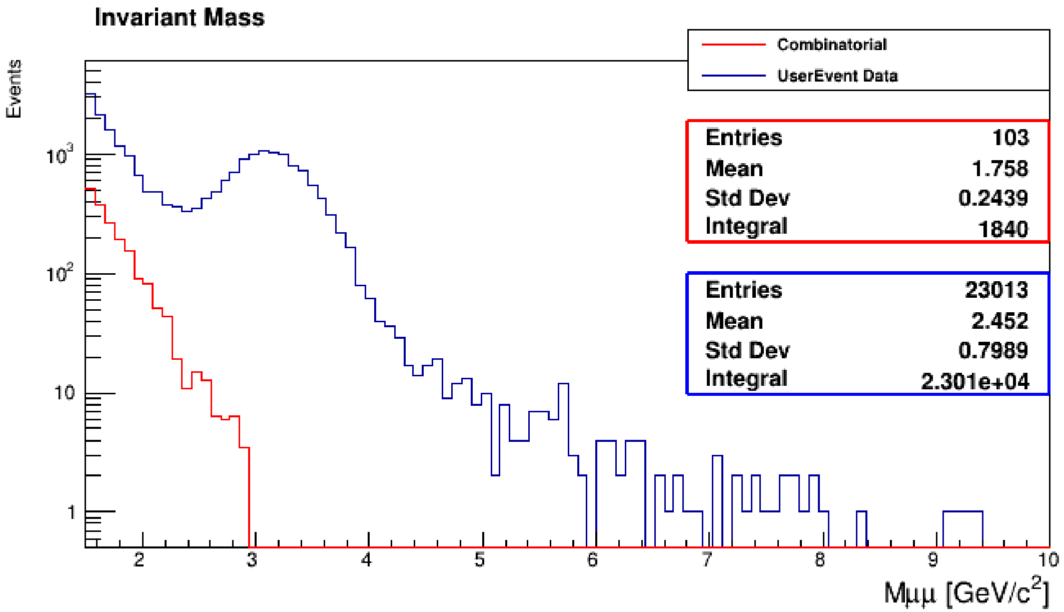


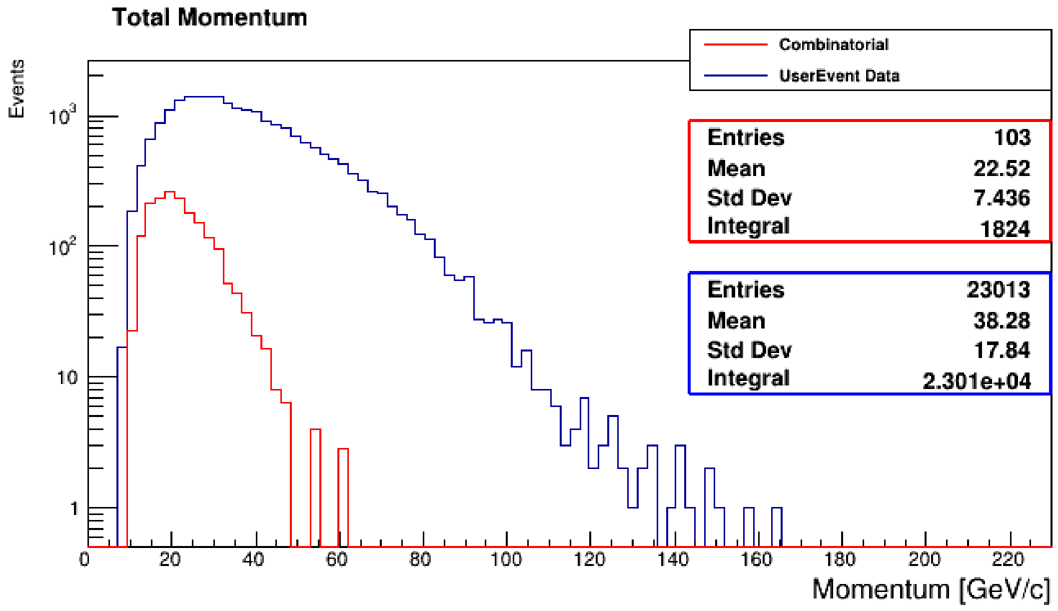
Transverse Momentum
Combinatorial
UserEvent Data
Entries 103
Mean 0.7067
Std Dev 0.3924
Integral 664.6
Entries 3716
Mean 0.9601
Std Dev 0.5986
Integral 3716
Events
Momentum [GeV/c]

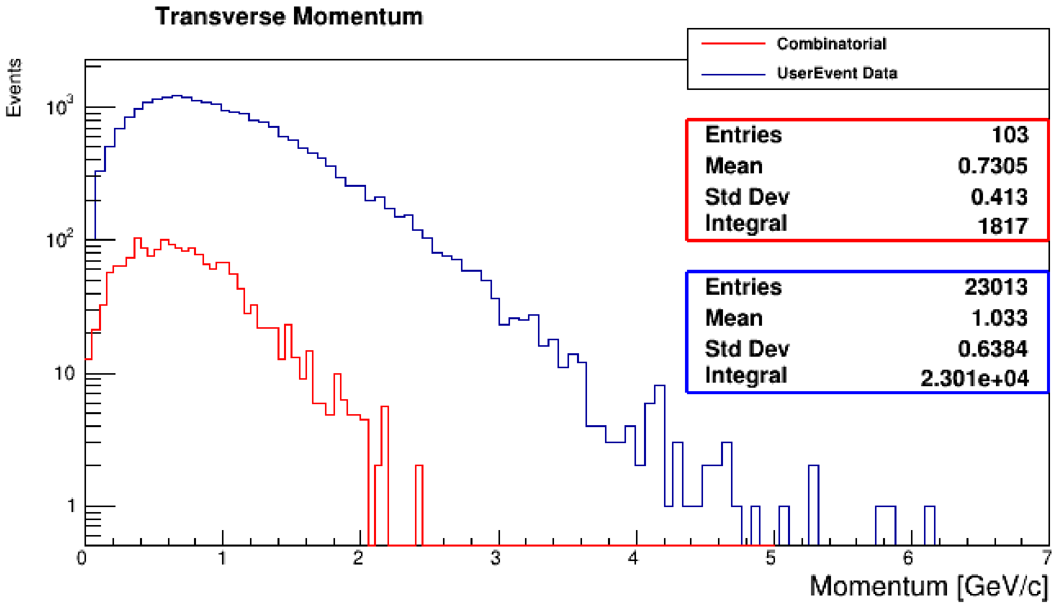


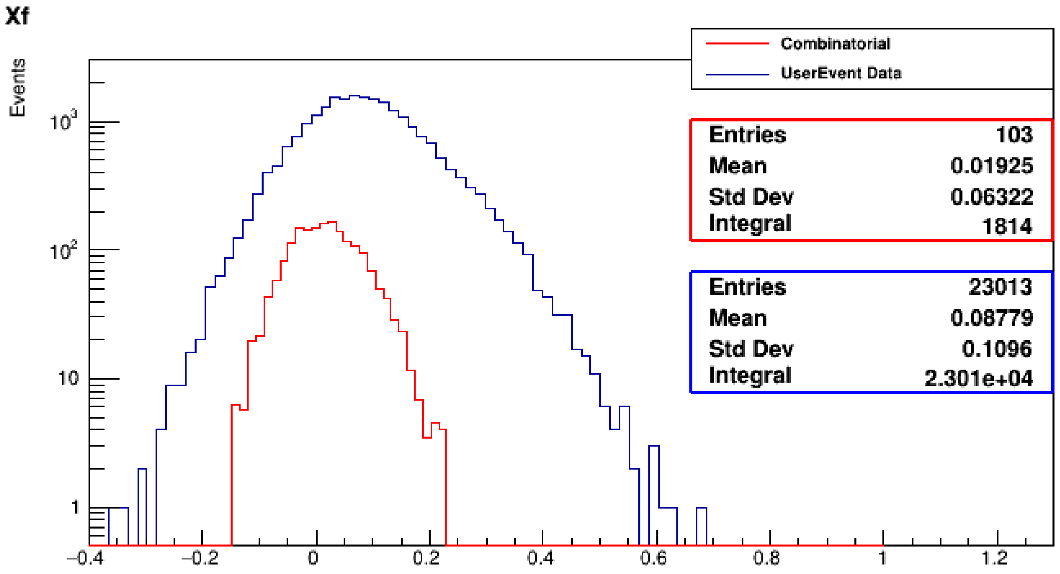
Xf
Combinatorial
UserEvent Data
Entries 103
Mean 0.0304
Std Dev 0.06211
Integral 663.4
Entries 3716
Mean 0.08792
Std Dev 0.1188
Integral 3716
Events

W Cell


Invariant Mass
Combinatorial
UserEvent Data
Entries 103
Mean 1.758
Std Dev 0.2439
Integral 1840
Entries 23013
Mean 2.452
Std Dev 0.7989
Integral 2.301e+04
Events
Mμμ [GeV/c²]


Total Momentum
Combinatorial
UserEvent Data
Entries 103
Mean 22.52
Std Dev 7.436
Integral 1824
Entries 23013
Mean 38.28
Std Dev 17.84
Integral 2.301e+04
Events
Momentum [GeV/c]


Transverse Momentum
Combinatorial
UserEvent Data
Entries 103
Mean 0.7305
Std Dev 0.413
Integral 1817
Entries 23013
Mean 1.033
Std Dev 0.6384
Integral 2.301e+04
Events
Momentum [GeV/c]


Xf
Combinatorial
UserEvent Data
Entries 103
Mean 0.01925
Std Dev 0.06322
Integral 1814
Entries 23013
Mean 0.08779
Std Dev 0.1096
Integral 2.301e+04
Events

Conclusion

06

Conclusion

- Combinatorial background cannot be avoided, but can be estimated statistically from like-sign pairs;
- We can see that there is some other physics processes happening at low masses other than this background;
- To better understand the entire mass spectrum, we need to consider all contributions: Drell-Yan, open-charm, J/ψ, ψ' but also combinatorial background;
- This method always suffers from low statistics, which implies large uncertainties. $\Longrightarrow$ An alternative method was studied by another student.