Bose-Einsten and other two particle correlations - MC study

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1 Conclusions

Rather simple MC model for Bose-Einstein Correlations is used to judge the quality of different ways to extract the BEC from observable distribution. Several generated reference samples have been considered. The reference sample with random turn of observed transverse momentum vector $\vec{p}_t$ (ϕ randomization) provides the fit results closest to the model values.

Such approach is implemented for the analysis of $C_2(\Delta\phi, \Delta\eta)$ correlation. In the traditional definition of $\Delta\phi$, to extract correlations the subtraction of a reference distribution is the must. New definition $\Delta\phi$ as the angle between $\vec{p}_{t1}$ and $\vec{p}_{t2}$ makes $\Delta\phi$ distribution uniform (as ϕ) with small contribution from correlations. Then the $C_1(\Delta\phi)$ can be studied without any reference. It is shown that at small Q-value there are two kind of $C_1(\Delta\phi)$ correlation - kinematical and dynamical. At large Q there is $C_1(\Delta\phi)$ *anticorrelation*. Then

so called short-range correlation ($\Delta\phi \sim 0$) can be suppressed by an appropriate cut in the Q- value.

First, to investigate $C_2(\Delta\phi, \Delta\eta)$, for reference sample generation only ϕ randomization is used. At very soft Q-cut (120 MeV) the ”Long-Range, Near-Side Correlations” (ridge) starts to be seen. However, if the reference sample with ϕ AND η randomization is used, the ridge does not appear. Unfortunately, such approach destroys correlation $C_2(Q, Q_{ref})$ completely, and Q-value can not be used as a meaningful cut variable.

Details may not persist in the case of the experimental data analysis because of many reasons, in particular if additional sources of correlations exists. However the procedure of the reference sample generation can still be an appropriate.

Ridge effect is not found in the data.

Bose-Einsten Correlations - to-day looks simple and natural. The general definition of a correlation function of 2 variables - p_1 and p_2 can be written as

$$C_2(p_1, p_2) = \frac{P(p_1, p_2)}{P_{ref}(p_1, p_2)}.$$

The value $P_{ref}(p_1, p_2)$ is called a reference function, artificial function with switched off the correlation under search .

The coordinates r_1, r_2 can not be measured, and instead one does estimate pions momenta quantities p_1 and p_2 . So we have to take the Fourier transform

$$M_a(p_1, p_2) = \int \frac{d^4 r_1}{(2\pi)^4} e^{ip_1 r_1} \frac{d^4 r_1}{(2\pi)^4} e^{ip_2 r_2} M(r_1, r_2).$$

Besides this we have to consider the permutation of two identical pions. That

is we have to add to M_a the amplitude

$$M_b(p_1,p_2) = \int \frac{d^4r_1}{(2\pi)^4} e^{ip_2r_1} \frac{d^4r_1}{(2\pi)^4} e^{ip_1r_2} M(r_1,r_2),$$

where the pion with momentum p_2 was emitted from the point r_1 and wise versa. This can be written as

$$M(p_1,p_2) = M_a + M_b = M_a \cdot (1 + e^{irQ}),$$

where the 4-vectors $r = r_1 - r_2$ and $Q = p_2 - p_1$ [a] .

Finally the cross section takes the form

$$\frac{E_1E_2d^2\sigma}{d^3p_1d^3p_2} = \frac{1}{2!}|M_a|^2 < 2 + 2e^{irQ} >= |M_a|^2(1+ < e^{irQ} >).$$

Here the factor $1/2!$ reflects the identity of two pions and the angular

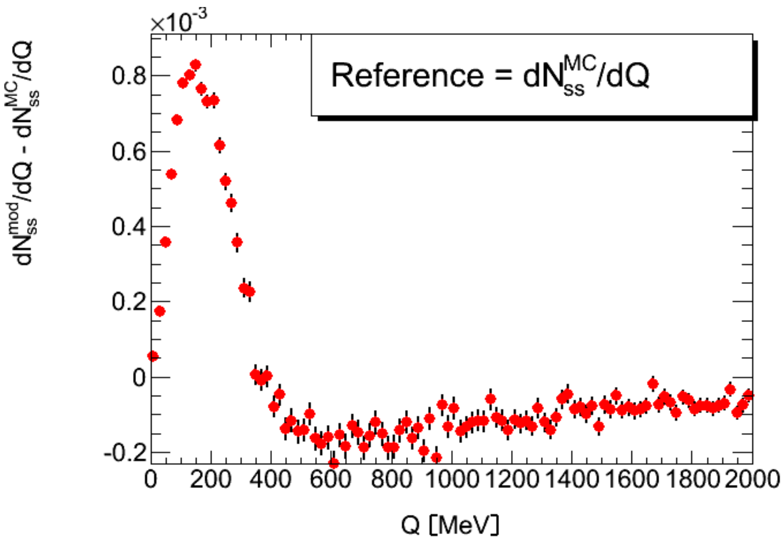
[a] Everywhere we suppose that particles are pions

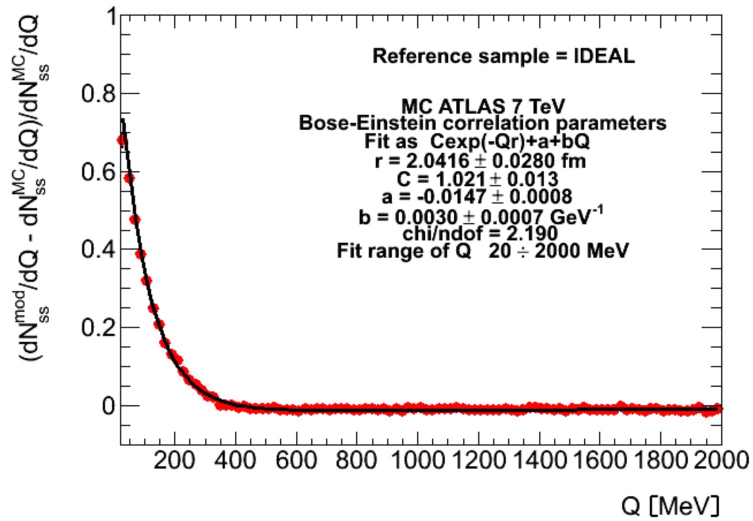
brackets indicates the averaging over the (r_1, r_2) space distribution.

Assuming, for simplicity, the Gaussian form we get $< e^{irQ} >= e^{-<r^2>Q^2}$.

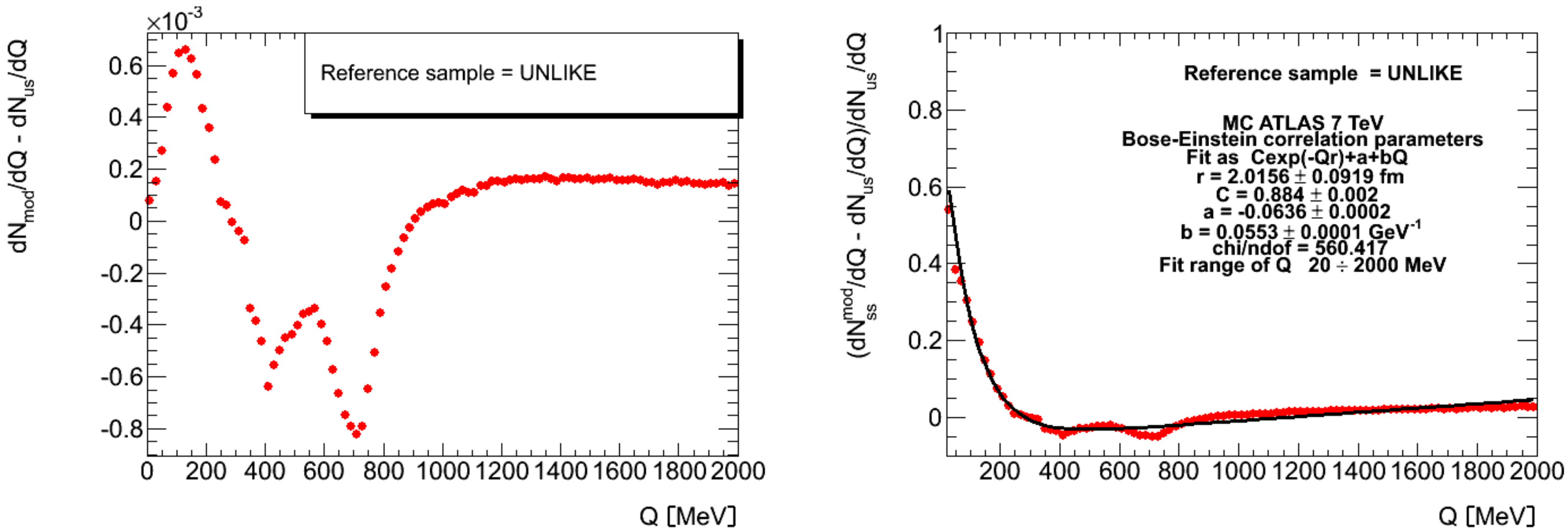
Thus the width of a peak at small momenta difference $Q \to 0$ characterizes the size $< r >$ of the domain from which the pions were emitted.

First consider the ideal case when MC $\frac{dN_{ss}}{dQ}$ will be used as the reference function $\frac{dN^{ref}_{ss}}{dQ}$. The result is somewhat trivial and can be considered as a ”goodness” of the MC generator. The procedure used might be looked as switching ON the BEC correlation, to add such correlation to MC procedure.





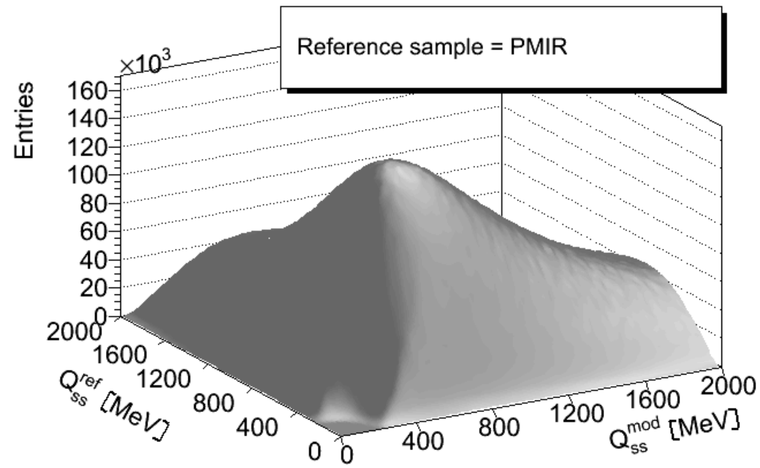
The unlike Q-distribution looks as a natural choice because there should be no BEC for the unlike sign pairs. The source radius from the fit is close to the model value , however the resonances contribution makes fit quality bad. The contributions of the ρ^0 and the remnants of η mesons are clearly seen.

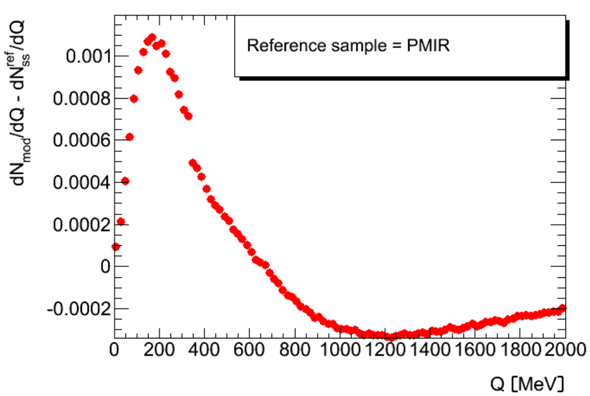


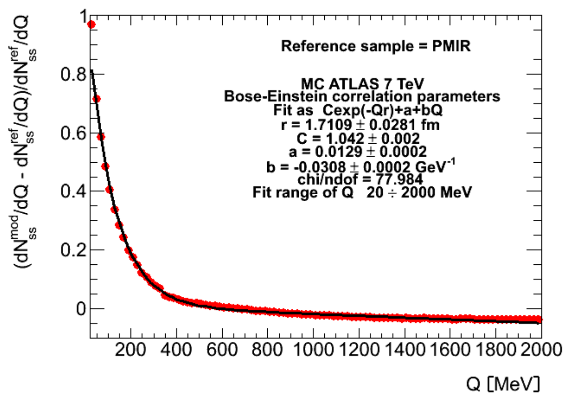
One has to find a way to switch OFF BEC from the ”observed” $\frac{dN_{mod}}{dQ}$ distributions. It looks as an easiest way to construct the $\frac{dN_{ss}{}^{ref}}{dQ}$ from two independently detected events: one momentum vector is taken from event under analysis, and the second - from a preceding events. The result is strongly dependent on requirements of such event selection.

Another approach is to generate independent event sample with the use of the event under consideration. The ”referenced” event will have at least the same particle multiplicity,the same numbers of positive and negative charged particles and the same values of particles momenta. Evidently, such procedure will work as a blind correlation terminator because there is no any BEC ”marker” on a particular entry. The hope can be that pairs with small Q-values will be replaced by pairs which had higher Q-value before the transformation. The reference distribution $\frac{dN_{ss}{}^{ref}}{dQ}$ will contain one vector from the real event and another from the reference one.

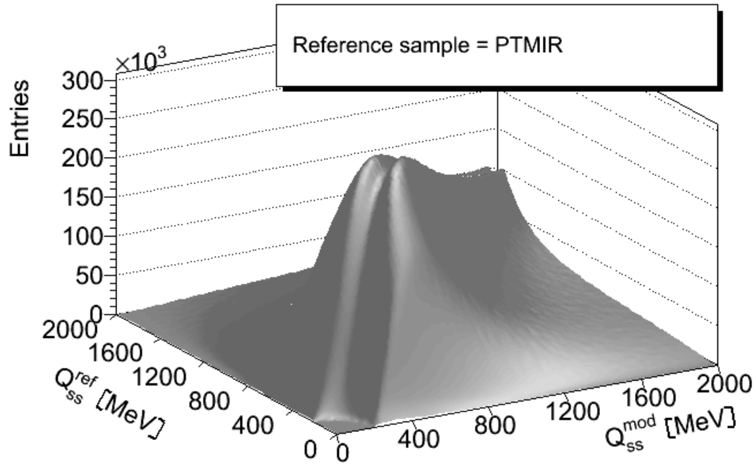
The simplest way is to prepare mirror sample from the original one,i.e. to change in the event all momenta 3-vectors as $\vec{p} \rightarrow -\vec{p}$ (PMIR case).

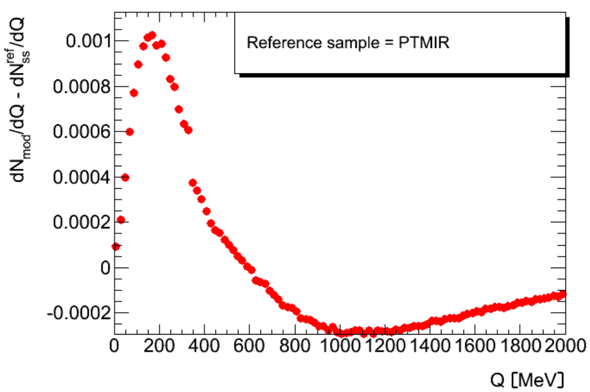


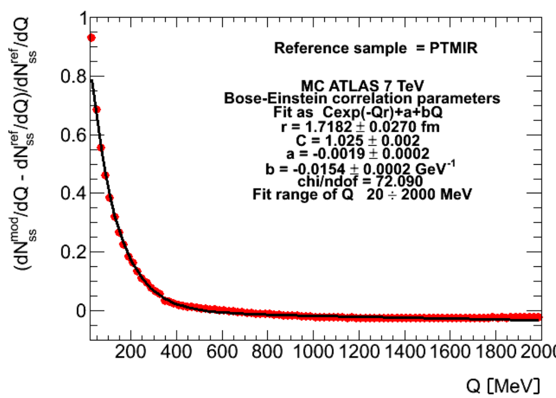




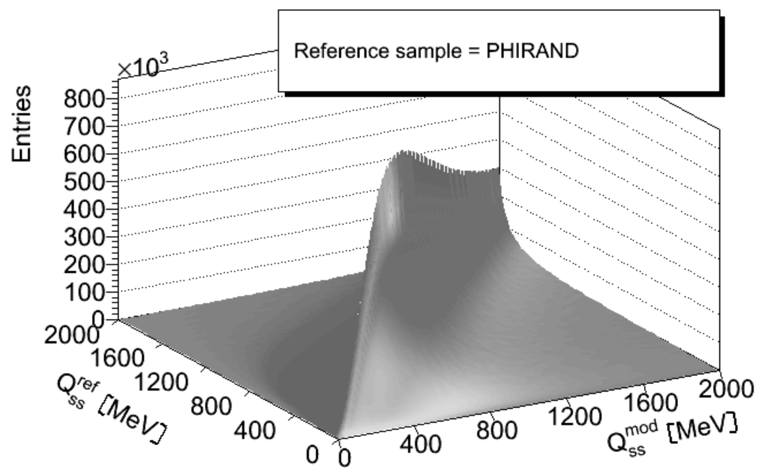
The better way should be if the reflection is made in the transverse plane $\vec{p}_t \rightarrow -\vec{p}_t$ (PTMIR case). The results are a bit closer to the model values but still there is no small Q events in the reference distribution if the model Q-values is smaller than $\sim 300MeV$.

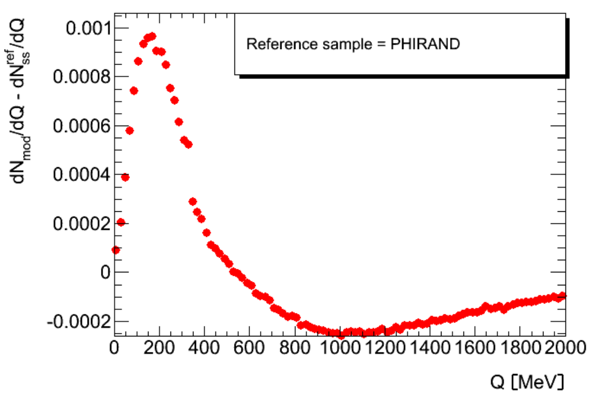


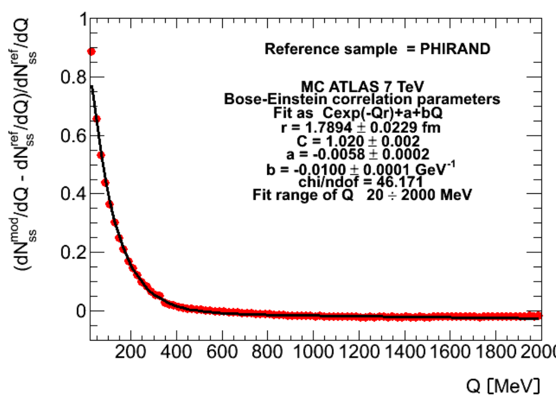




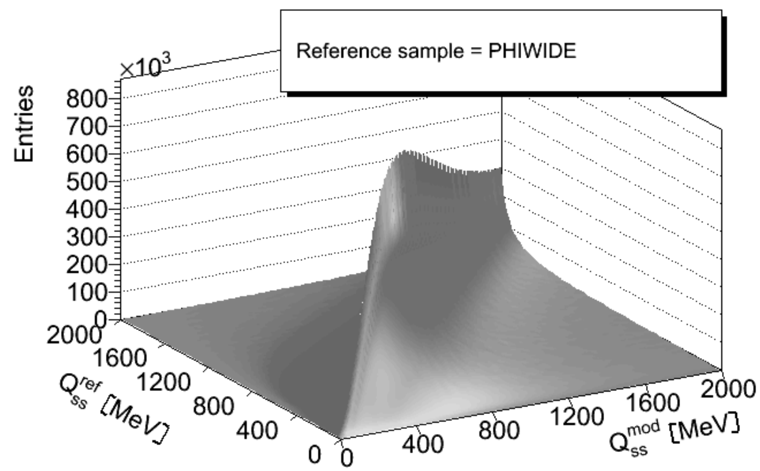
One gets a bit better reference distribution if vectors $\vec{p}_t$ in an observed event will be turned by a random value of $\delta\phi$, the same turn for all tracks - PHIRAND case.

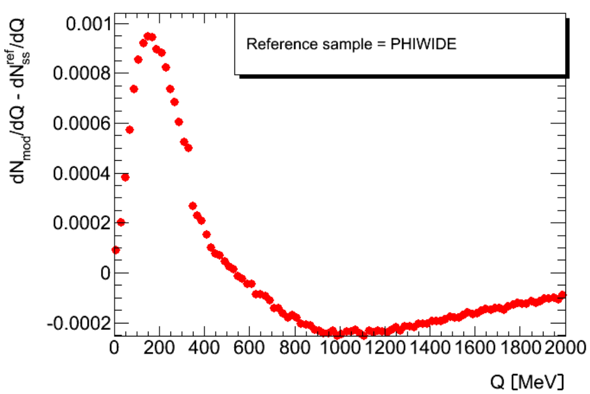


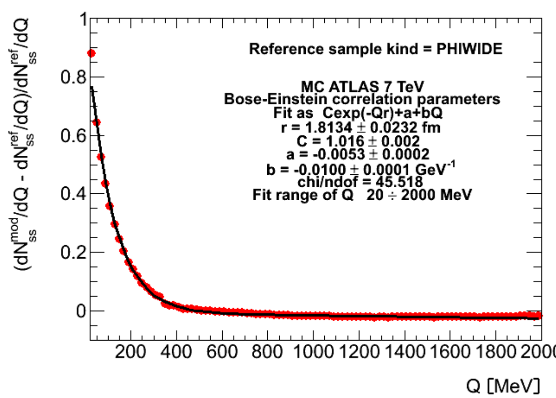




One gets good reference distribution if vectors $\vec{p}_t$ in an observed event will be turned by a random value of $\delta\phi$ for each track -PHIWIDE case.

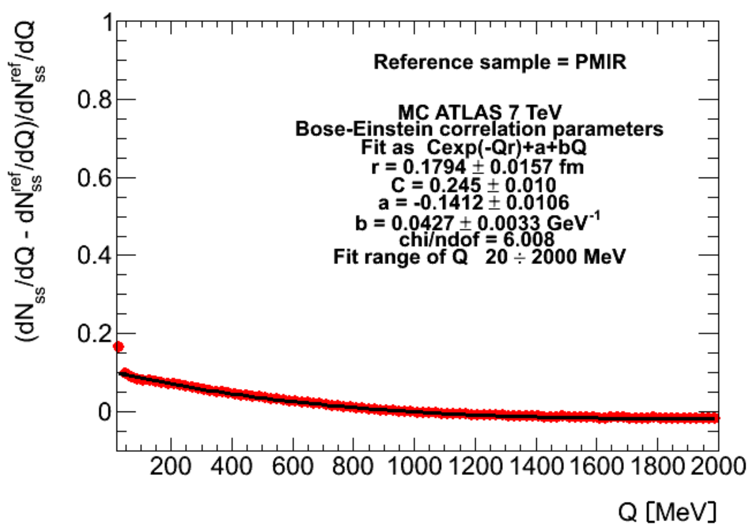


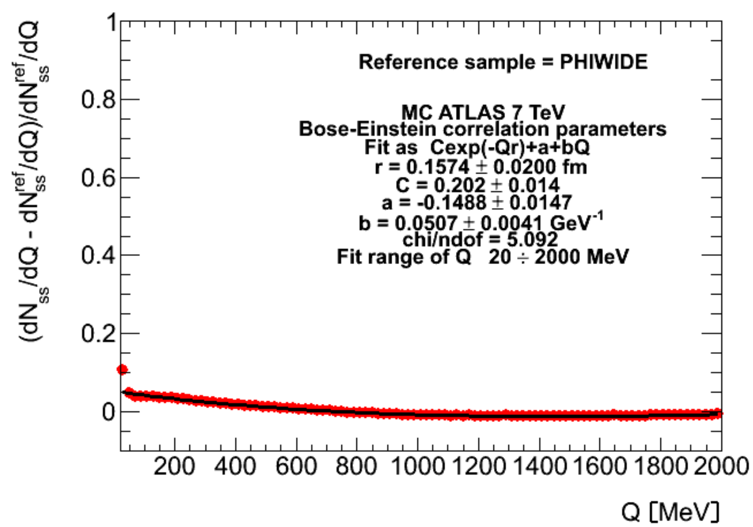




The model we consider has a constant value of radiation zone radius. However one might suspect that ”imperfection” of reference samples is larger at small particles multiplicity. This is the case indeed . The samples with the reflection algorithms produce quite detectable multiplicity dependence. The approach with the random $\vec{p}_t$ turn provides the best result.

Another important feature is the value of a systematic uncertainty. One can produce the reference sample of MC events without BEC and estimate a value of the source radius with different reference samples. It occurs that the value is quite small $\sim .15$ fm and might be consider as a contribution of non-BE correlation or as a systematic uncertainty. In the following, we will see that non-BE correlation at small Q exists.





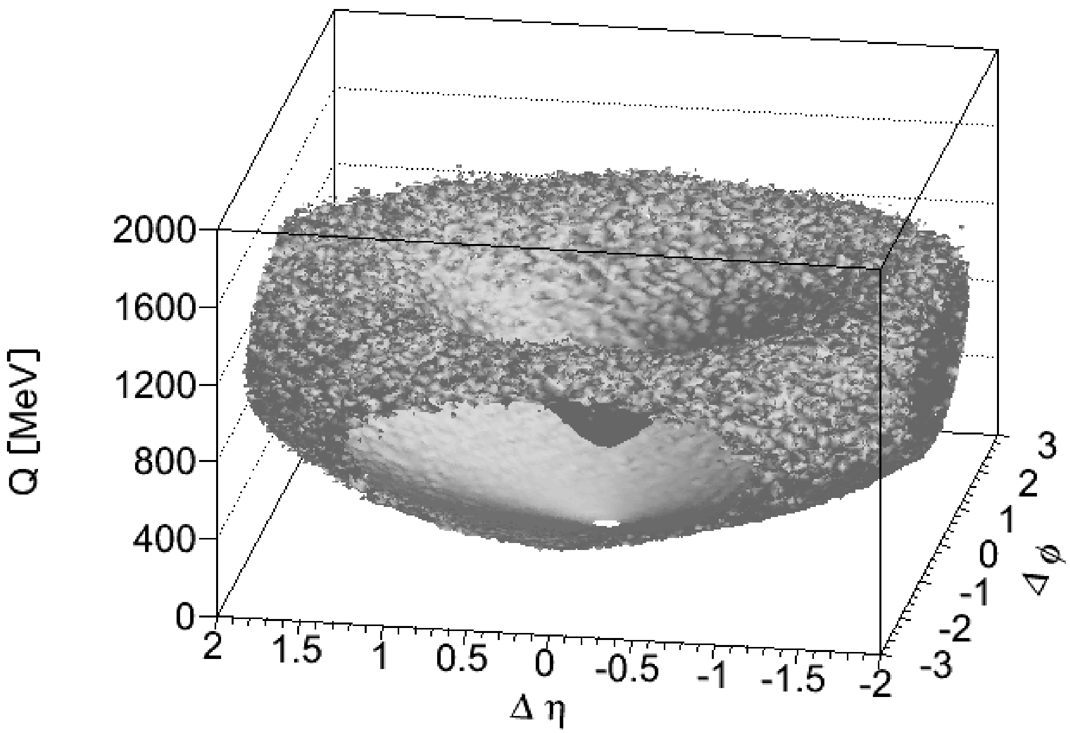
2 2- and 3-dimensional correlations

Until now, we have used 1-dimensional distribution - number of events as a function of Lorentz invariant value Q. This is a natural approach for a simple fit to *measure* phenomenon parameters . Another way have to be considered in the case of a *search* of deviations from a phase space prediction with a smooth reaction amplitude. Usually 2-dimensional correlations is being used. Let us consider the traditional correlation plot for like sign pairs where differences

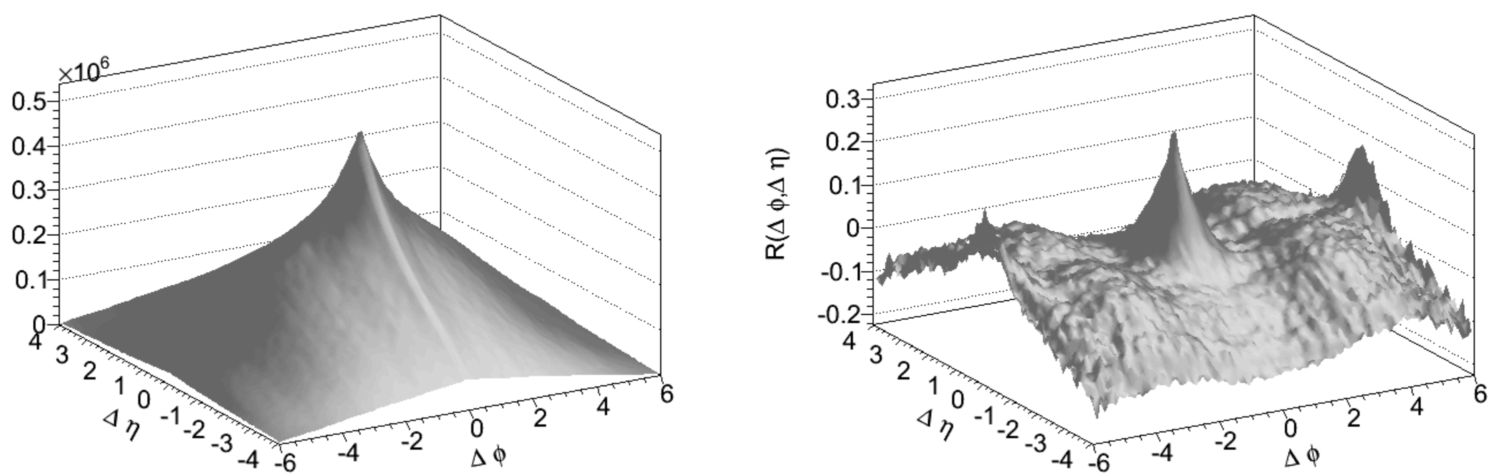
$$\Delta\phi_{2\pi} = \phi_2 - \phi_1,$$
$$\Delta\eta = \eta_2 - \eta_1$$

will be taken as arguments - $C_2(\Delta\phi_{2\pi}, \Delta\eta)$. Q-value and N_{ch} (number of charged particles in the event) can be used as additional arguments to form 3-dimensional correlations $C_3(\Delta\phi_{2\pi}, \Delta\eta, Q)$ and $C_3(\Delta\phi_{2\pi}, \Delta\eta, N_{ch})$. Following figures display some correlation plots from the ATLAC MC 7 TeV sample.

The central part of 3-dimensional plot $C_3(\Delta\phi_{2\pi}, \Delta\eta, Q)$ exhibits very strong ($\Delta\phi_{2\pi}, \Delta\eta$) correlation at small Q which is decreasing fast with Q increase. It resembles a funnel.



If particles would have the uniform distribution for $\eta(-2.5, 2.5)$ and for $\phi(-\pi, \pi)$, then the values $C_1(\Delta\eta)$ and $C_1(\Delta\phi_{2\pi})$ will have triangle distribution in the range $\eta(-5., 5.)$ and $\phi(-2\pi, 2\pi)$. For these reasons $C_2(\Delta\phi_{2\pi}, \Delta\eta)$ looks as a pyramid. Except rather strong correlation at $\Delta\phi_{2\pi} \approx \Delta\eta \approx 0$ nothing significant can be seen . One have to subtract a reference distribution (one of the p_t vector of the pair is turned by a random $\delta\phi$) to see some additional structure. Unfortunately small nonuniformity might appear artificially because of imperfections of the reference sample.Some features are connected with definition of $\Delta\phi_{2\pi}$: evidently,$\Delta\phi_{2\pi} = \pm 2\pi$ is the same as $\Delta\phi_{2\pi} = 0$.

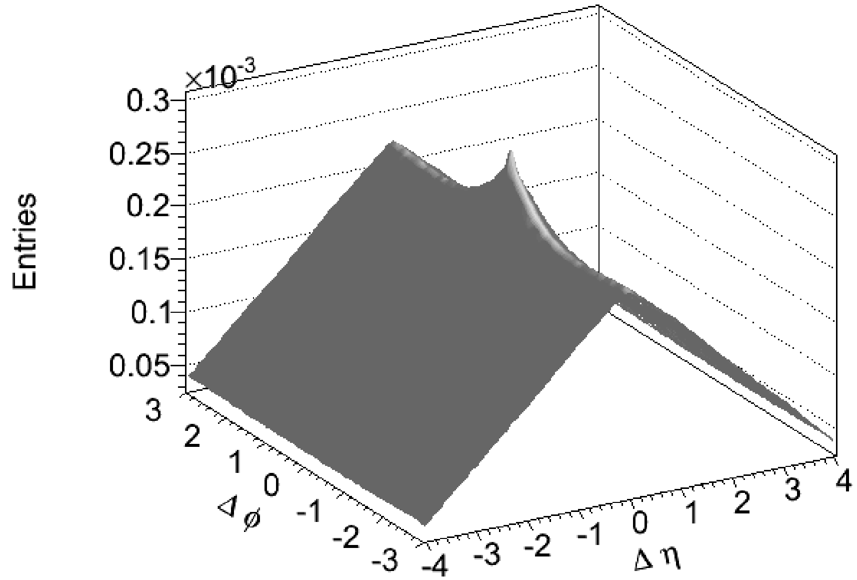


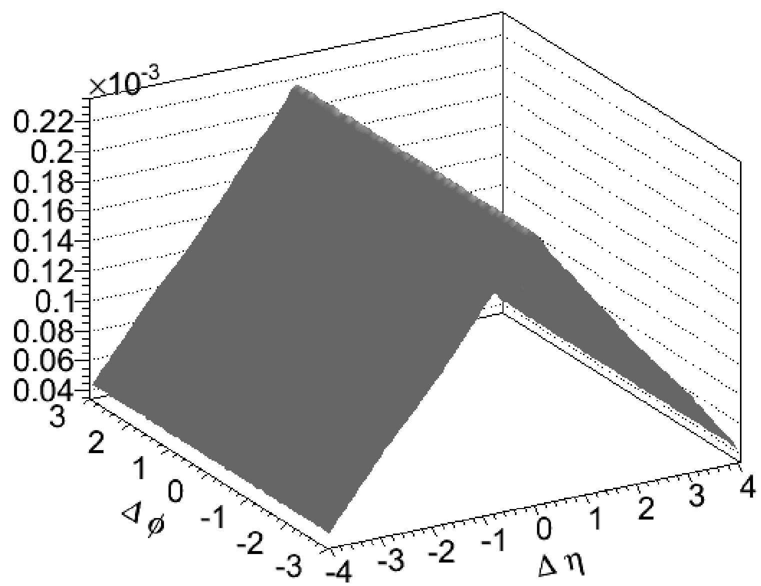
It is better to change the definition $\Delta\phi$:

$$\Delta\phi_\pi = \phi_2 - \phi_1, |\phi_2 - \phi_1| < \pi$$

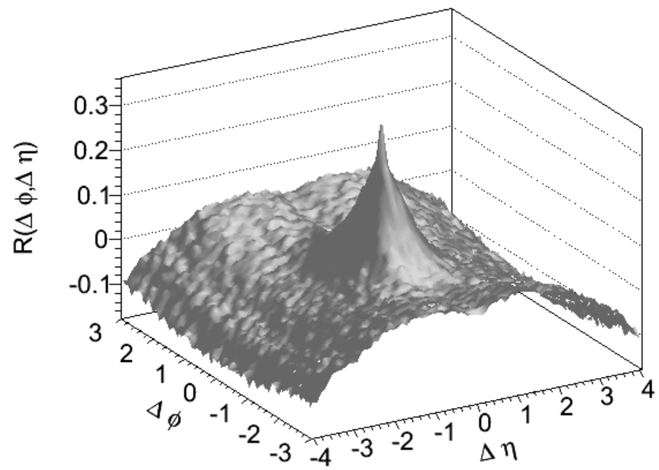
$$\Delta\phi_\pi = \phi_1 - \phi_2, |\phi_2 - \phi_1| > \pi$$

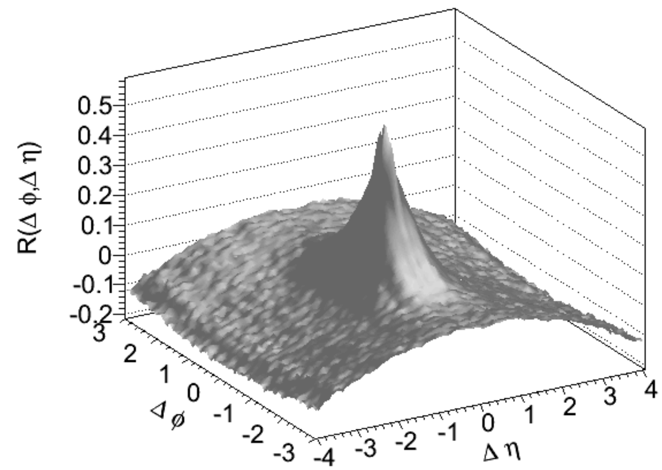
$\Delta\phi_\pi$ will have uniform distribution (with small ”resonance” on the top) in the range $(-\pi, \pi)$ and to study the correlations of this value one need not any reference to subtract. The reference distribution does not contain any nonuniformity by intention.


Entries
×10^-3
0.3
0.25
0.2
0.15
0.1
0.05
3
2
1
0
-1
-2
-3
Δφ
-4
-3
-2
-1
0
1
2
3
4
Δη

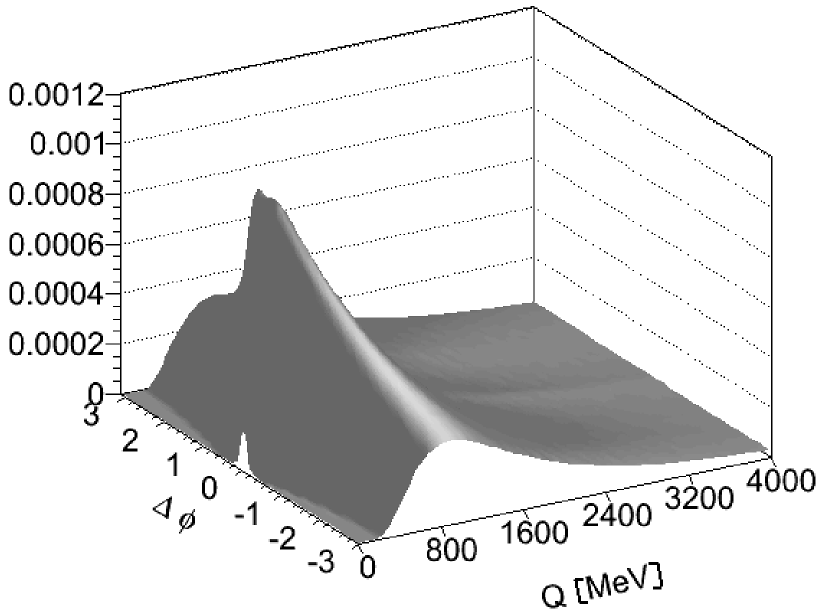

×10^-3
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
3
2
1
0
-1
-2
-3
Δφ
-4
-3
-2
-1
0
1
2
3
4
Δη

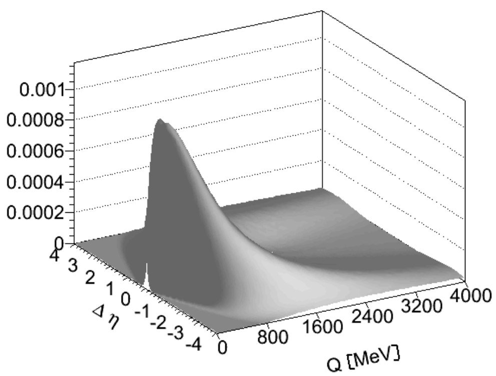
Following plots show $R_2(\Delta\phi, \Delta\eta)$ after reference subtraction for like sign and for unlike sign pairs. SURPRISE?? There is a $(\Delta\phi, \Delta\eta)$ correlation MC (no BEC)!? Yes, we already have measured the size of this radiation source - $\sim .15 fm$. This is so called "short range correlations".

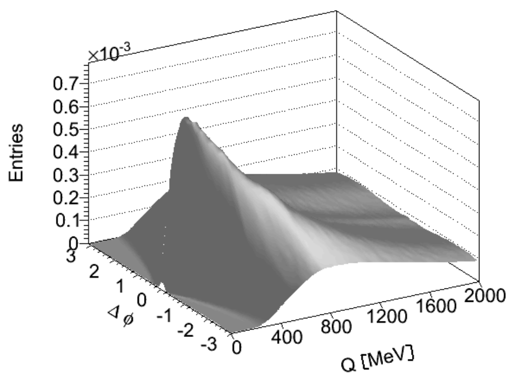




Let us look $R_2(Q, \Delta\phi)$ $R_2(Q, \Delta\eta)$ for like sign pairs and $R_2(Q, \Delta\phi)$ for unlike sign.







The enhancement with small $(\Delta\phi$ or/and $\Delta\eta)$ strongly depends on Q.

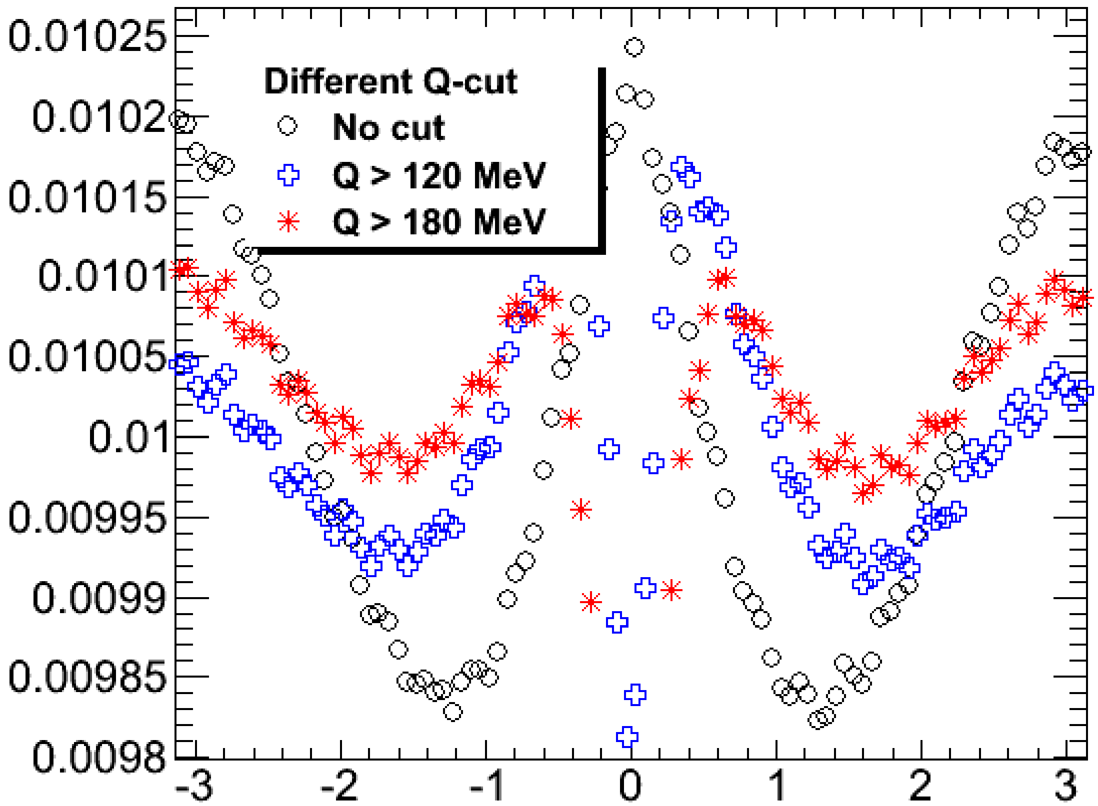
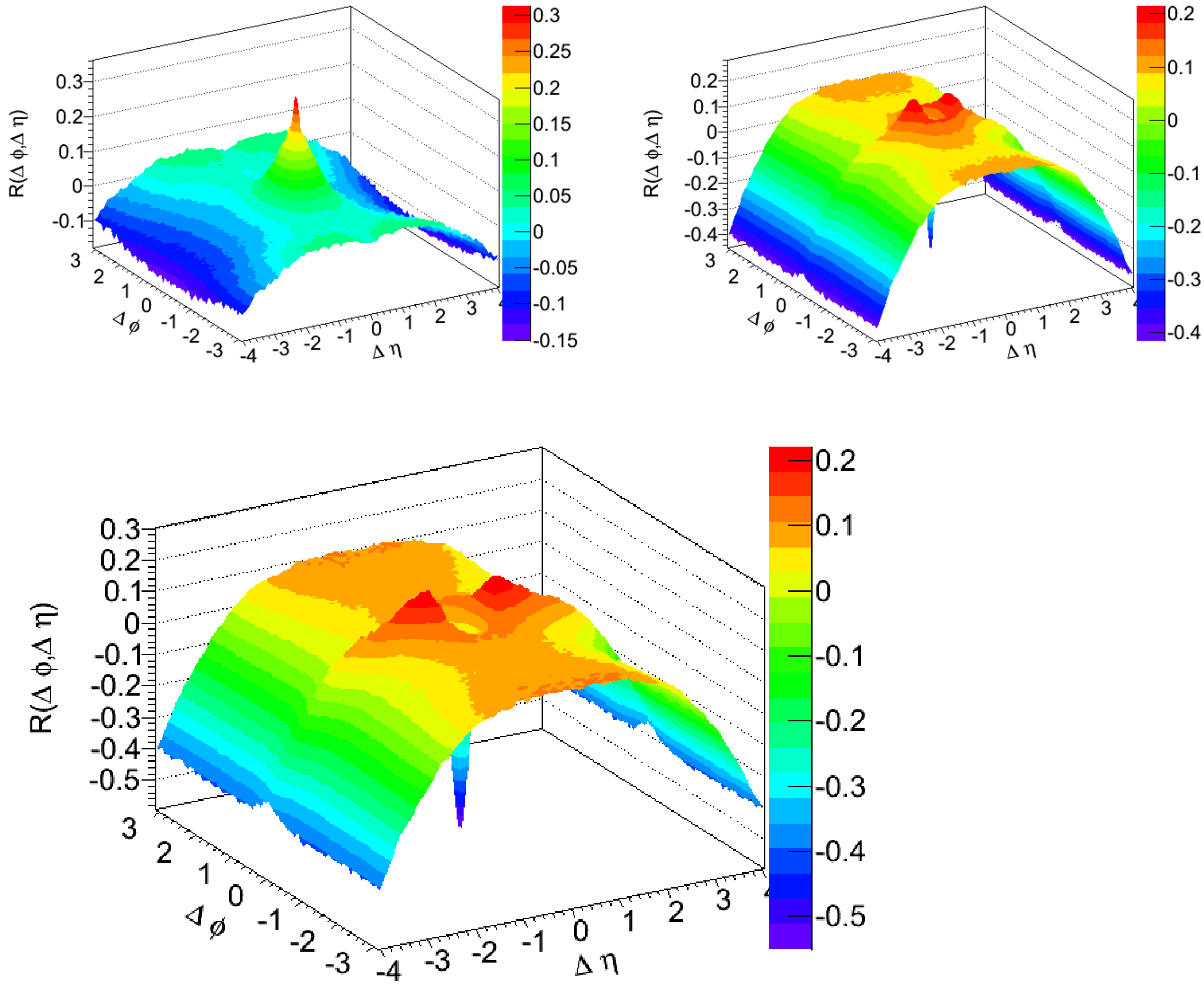
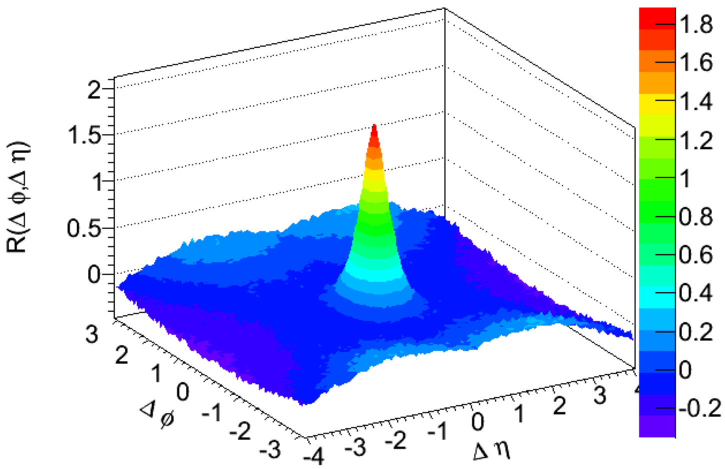


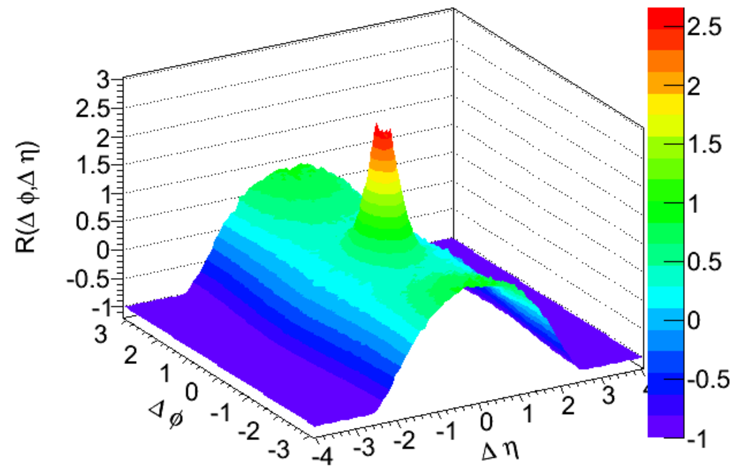
Figure 1: MC $C_1(\Delta\phi)$ distribution with different cuts in Q value

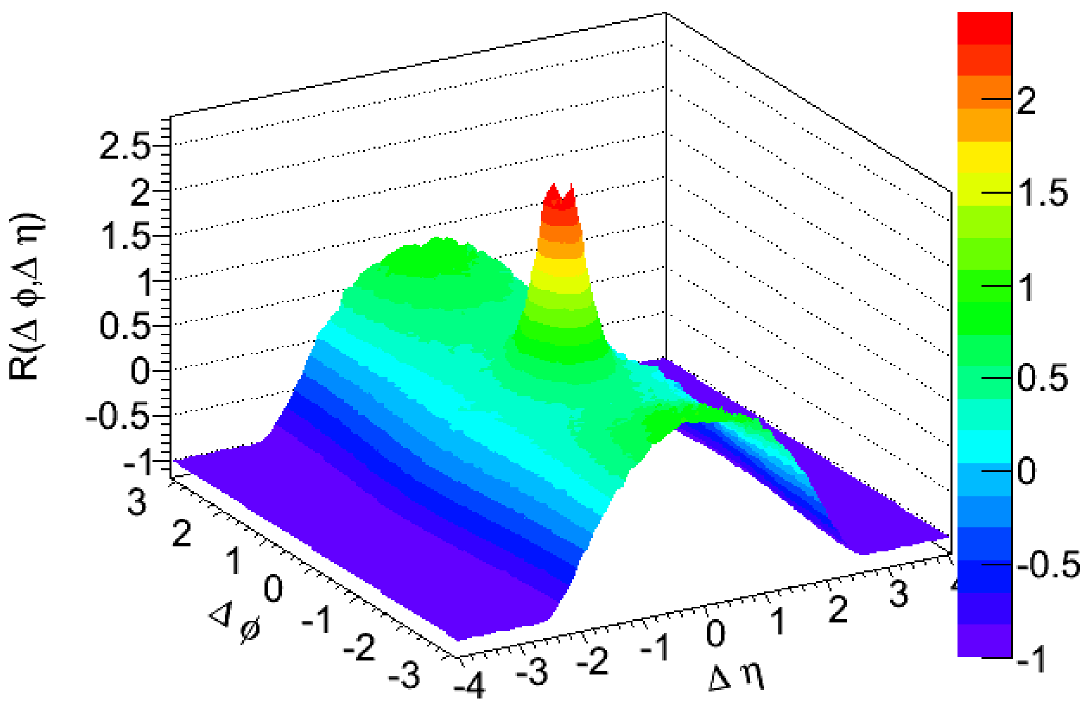
It is interesting to see $R_2(Q, \Delta\phi)$ $R_2(Q, \Delta\eta)$ correlation after cuts in Q-value. Ridge appears!


R(Δ ϕ,Δ η)
Δ φ
Δ η
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5

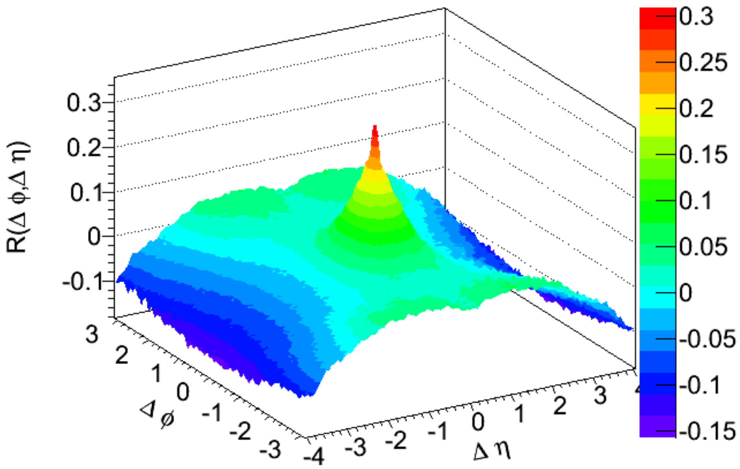
In the traditional study of $R_2(\Delta\phi, \Delta\eta)$ ridge effect becomes more important if particles P_t is large. This is not the case for MC.

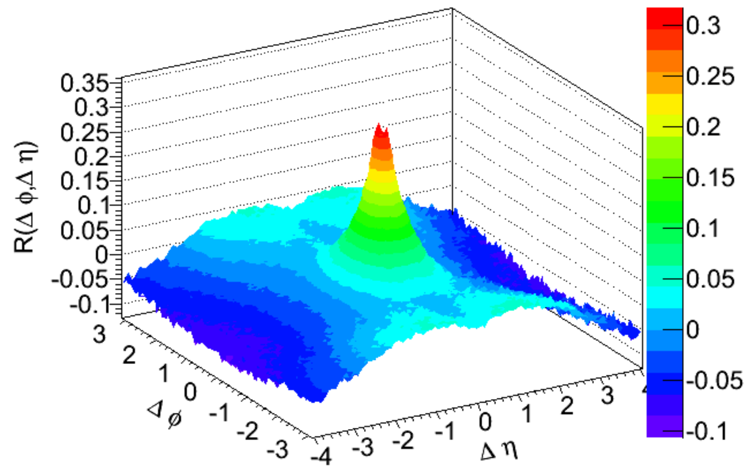

R(Δ φ,Δ η)
Δ φ
Δ η


R(Δ φ,Δ η)
Δ φ
Δ η


R(Δ φ,Δ η)
Δ φ
Δ η

If reference sample produced in a traditional way - with random $\Delta\phi$ AND $\Delta\eta$ - ridge is also does not appear.





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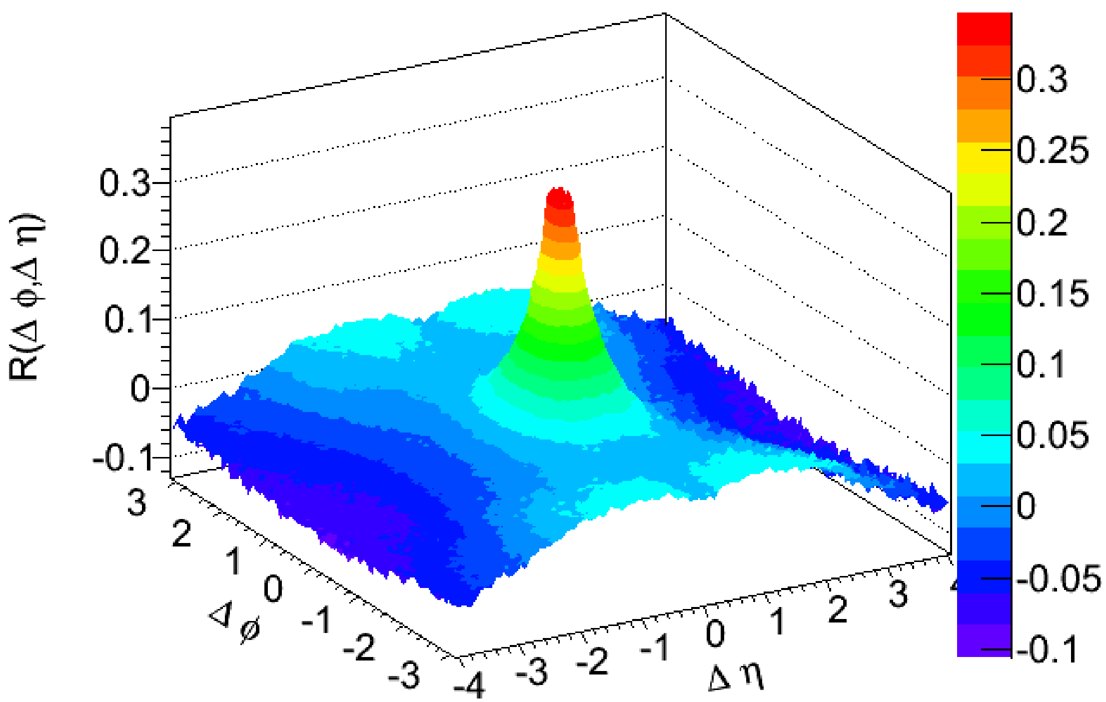
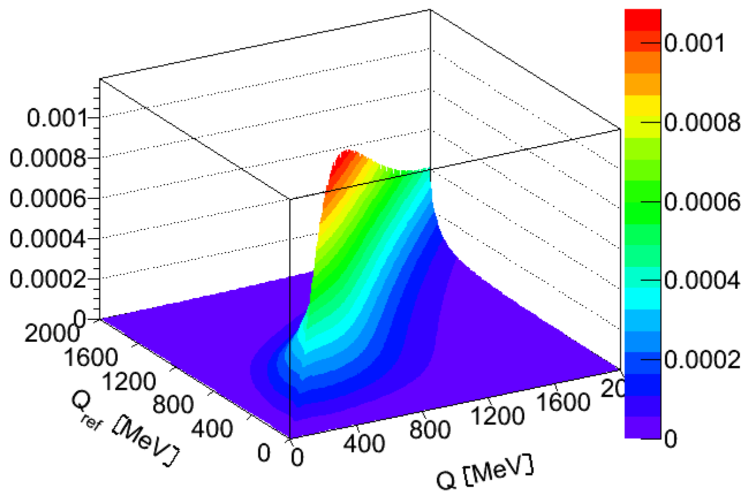
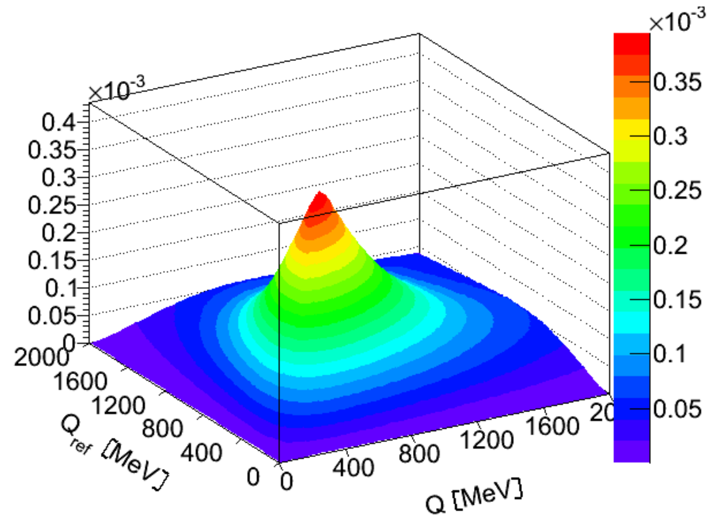


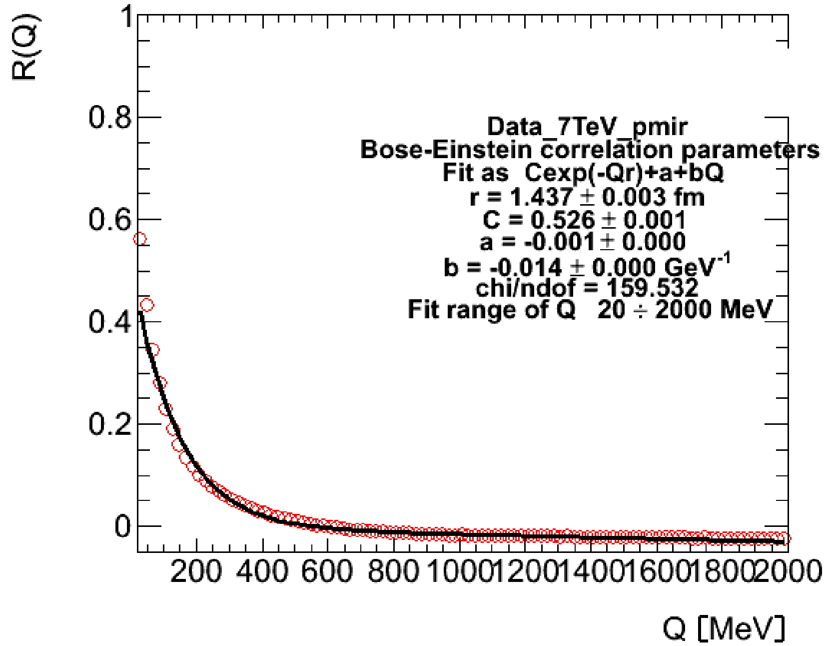
The reason: cut in Q is not applicable : correlation $C_2(Q, Q_{ref})$ is completely destroyed.

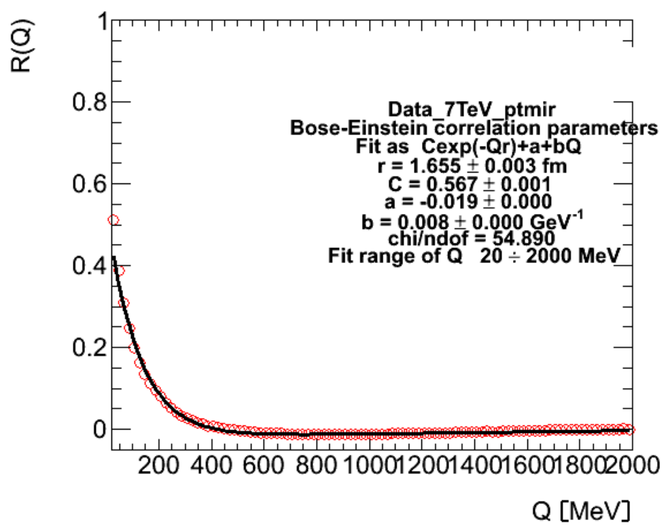


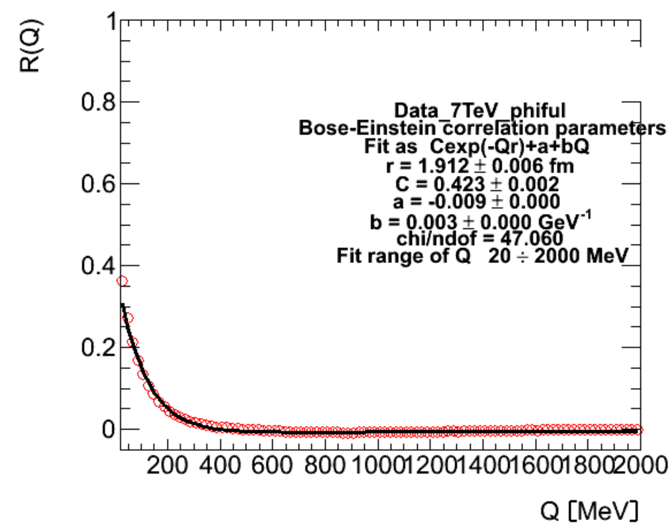


3 DATA ANALYSIS 7 TeV and 2.76 TeV - PRELIMINARY

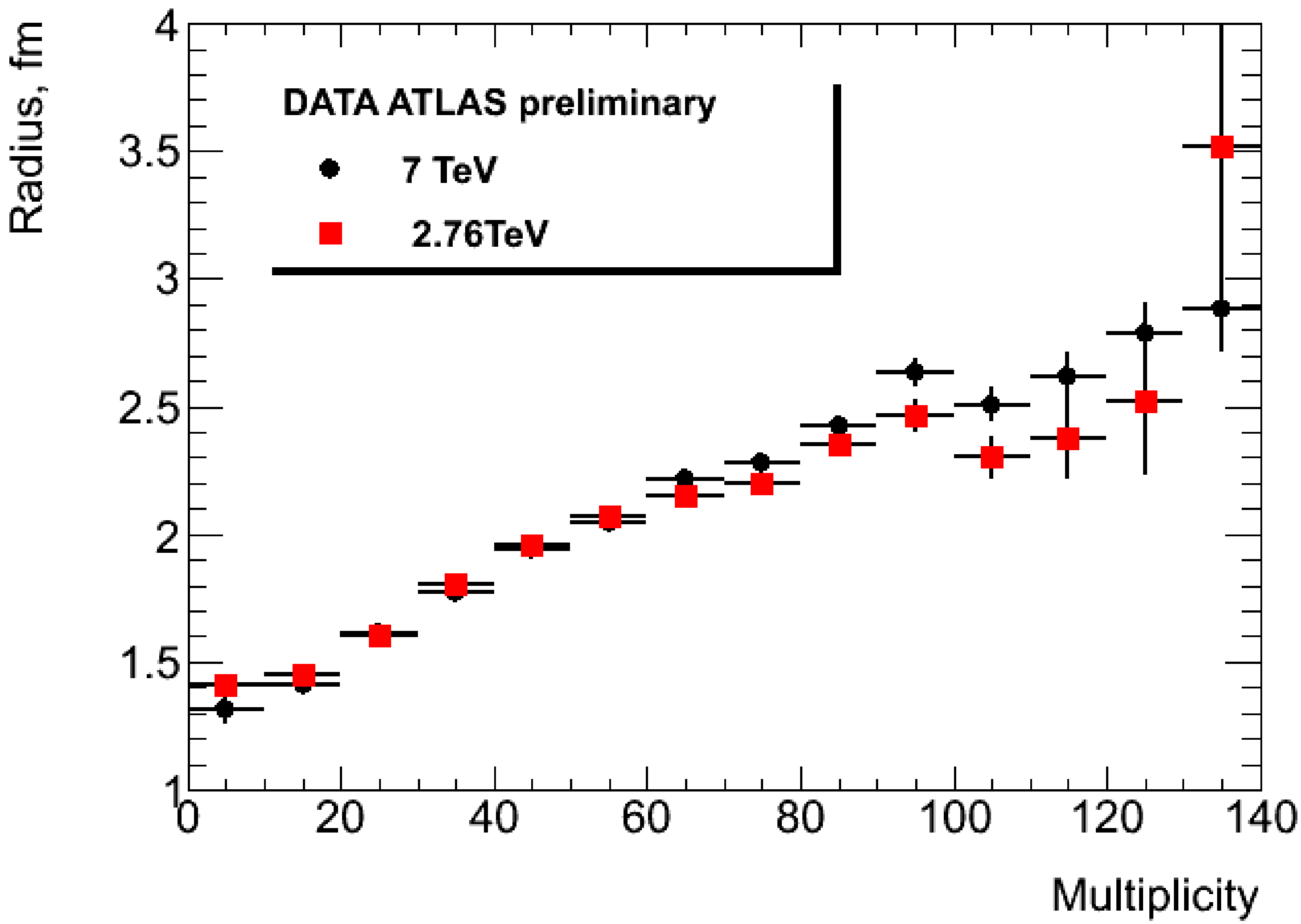
The data analysis has been done also with different reference samples.


R(Q)
Q [MeV]
Data_7TeV_pmir
Bose-Einstein correlation parameters
Fit as Cexp(-Qr)+a+bQ
r = 1.437 ± 0.003 fm
C = 0.526 ± 0.001
a = -0.001 ± 0.000
b = -0.014 ± 0.000 GeV-1
chi/ndof = 159.532
Fit range of Q 20 ÷ 2000 MeV

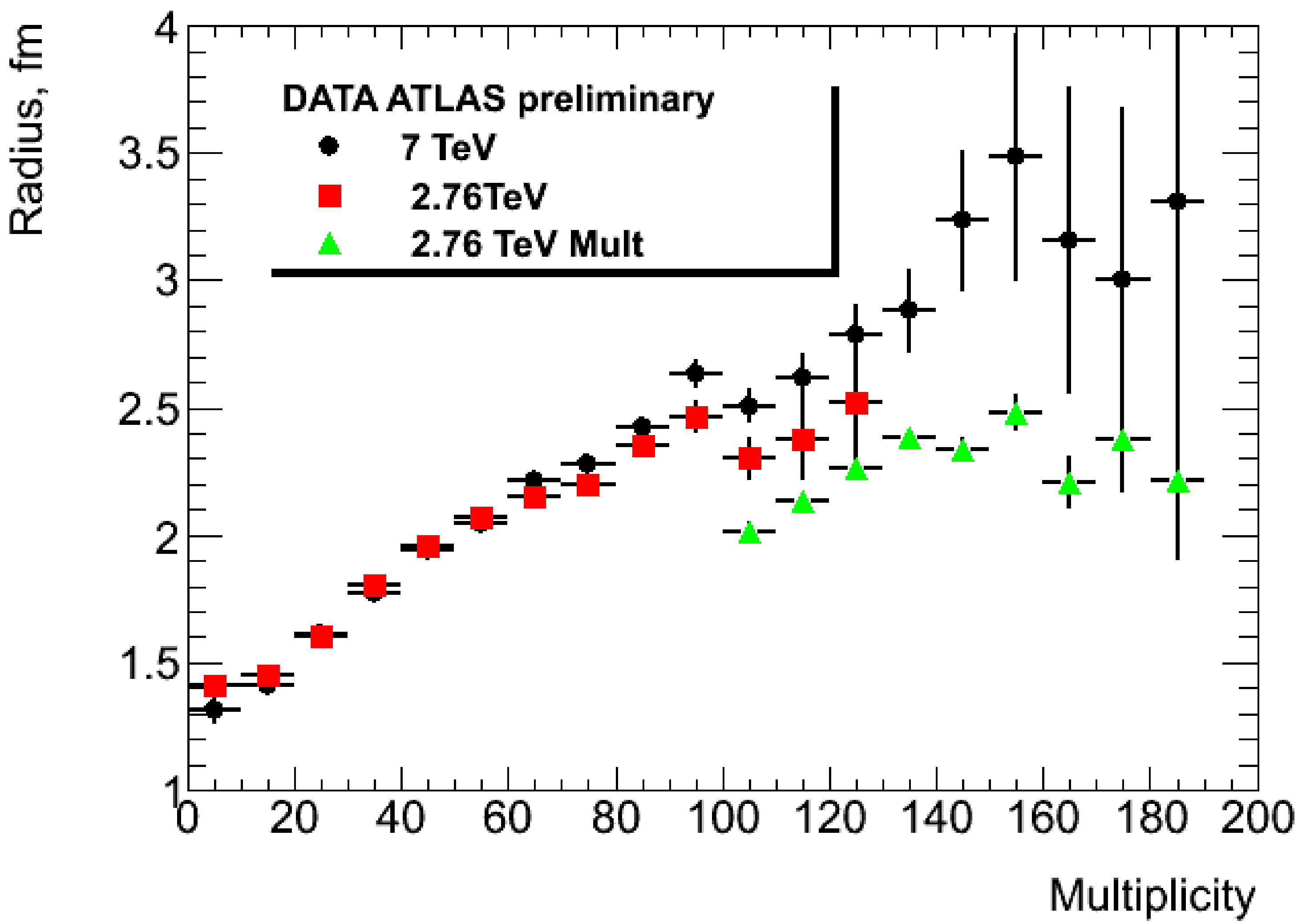

R(Q)
Q [MeV]
Data_7TeV_ptmir
Bose-Einstein correlation parameters
Fit as Cexp(-Qr)+a+bQ
r = 1.655 ± 0.003 fm
C = 0.567 ± 0.001
a = -0.019 ± 0.000
b = 0.008 ± 0.000 GeV-1
chi/ndof = 54.890
Fit range of Q 20 ÷ 2000 MeV


R(Q)
Q [MeV]
Data_7TeV_phiful
Bose-Einstein correlation parameters
Fit as Cexp(-Qr)+a+bQ
r = 1.912 ± 0.006 fm
C = 0.423 ± 0.002
a = -0.009 ± 0.000
b = 0.003 ± 0.000 GeV-1
chi/ndof = 47.060
Fit range of Q 20 ÷ 2000 MeV

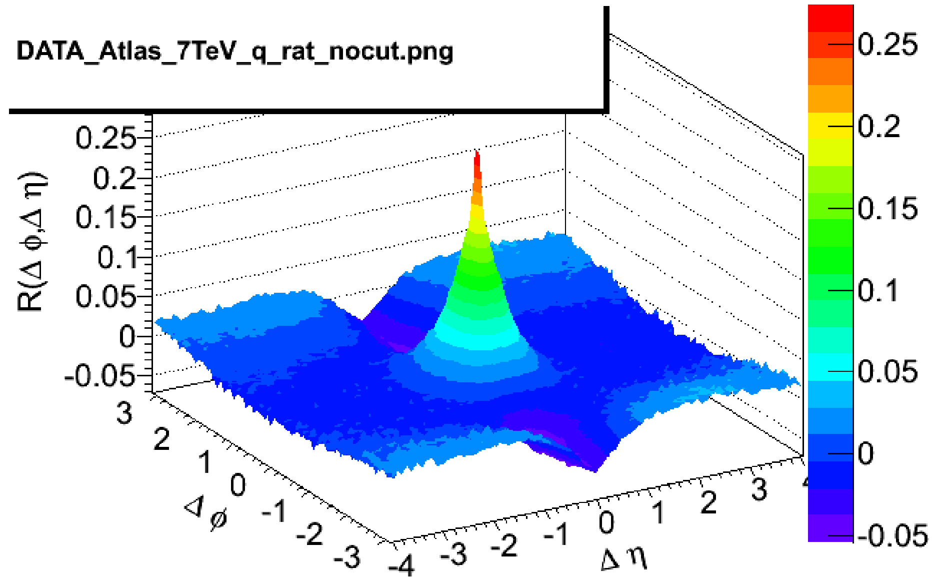
For the first time multiplicity dependence of BEC radius is measured at 2.76 TeV.



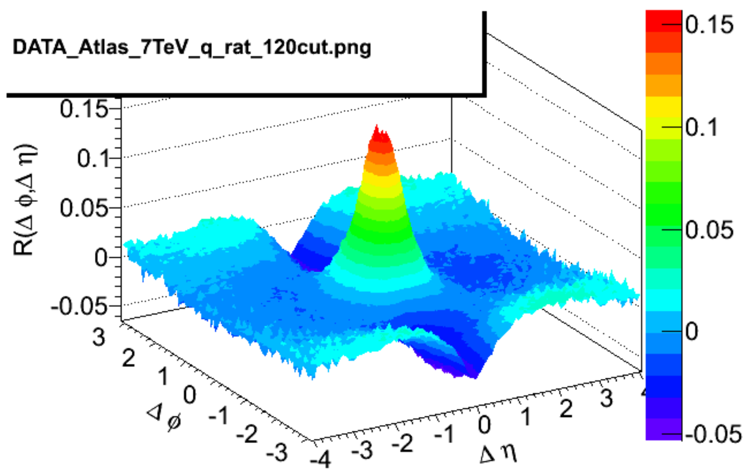
At beam energy 2.76 TeV special multiplicity trigger was implemented. Unfortunately, write up is not available. Possible trigger bias has to be discussed with experts.



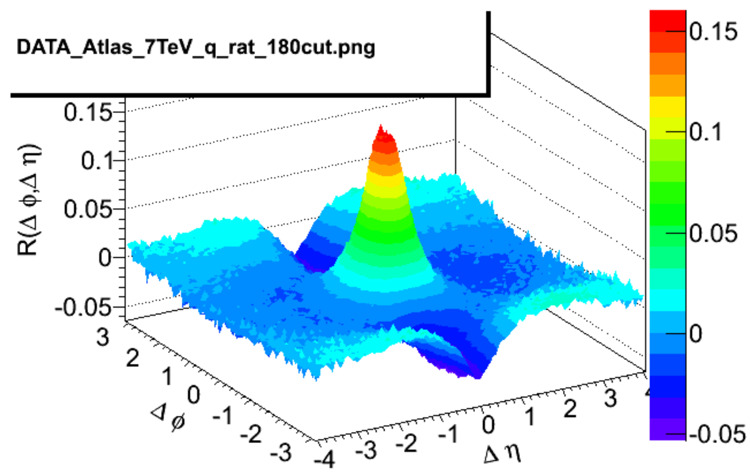
The search for the ridge is done. First, 7 TeV normal trigger, different Q-cuts as in MC study. No ridge.



DATA_Atlas_7TeV_q_rat_nocut.png
R(Δ ϕ,Δ η)
Δ φ
Δ η

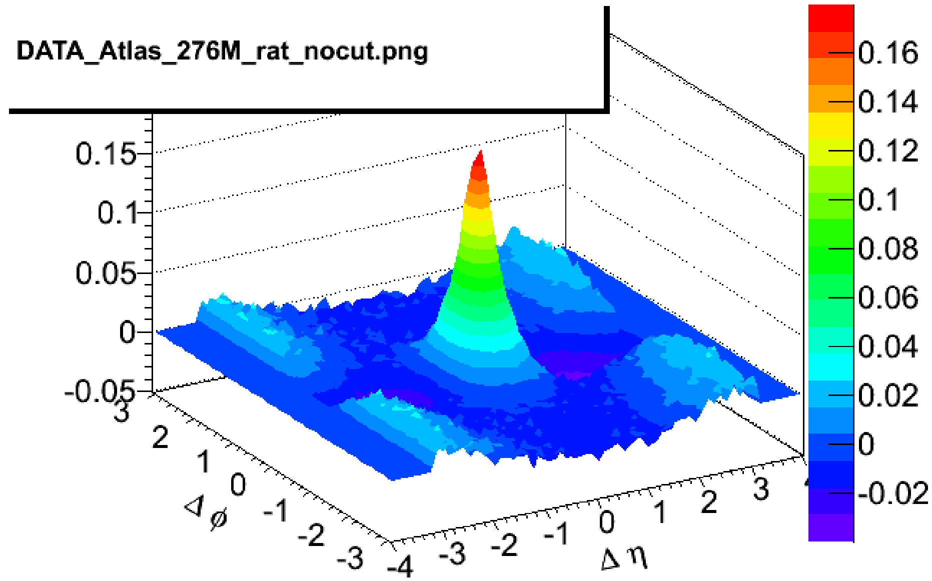


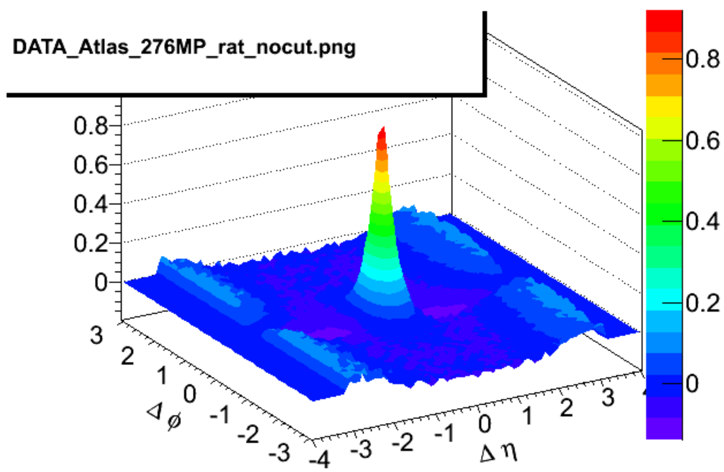
DATA_Atlas_7TeV_q_rat_120cut.png
R(Δ ϕ,Δ η)
Δ φ
Δ η

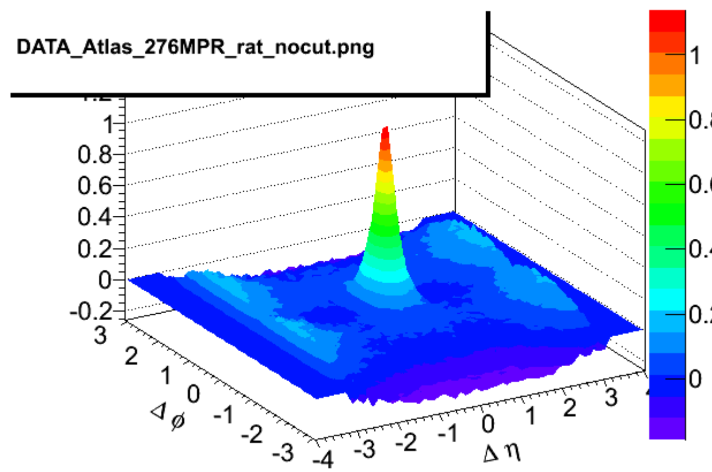


DATA_Atlas_7TeV_q_rat_180cut.png
R(Δ ϕ,Δ η)
Δ φ
Δ η

For the energy 2.76 TeV , selection has been done as in CMS Exp, with different Q-cuts as in MC study. No ridge again.


DATA_Atlas_276M_rat_nocut.png
Δ φ
Δ η


DATA_Atlas_276MP_rat_nocut.png
Δ φ
Δ η


DATA_Atlas_276MPR_rat_nocut.png
Δ φ
Δ η