Корреляции Бозе-Эйнштейна Вчера,сегодня и завтра

Щегельский В.А.

ОФВЭ-ОТФ Семинар

ПИЯФ, 4 июня 2015г

Краткая история

- **Что это такое? Немного формул.**
- **Наше первое наблюдение. Повезло?**
- **Связь с динамикой столкновений частиц при высоких энергий, Померон? Мультипериферическая модель.**
- **Изучение методов выделения сигнала.**
- **Наконец-то, публикация коллаборацией АТЛАС с объявлением наблюдения нового явления.**
- **БАК-2 набирает обороты**…..

Тождественность частиц и интерференция

3. Identical particles correlation

Another way to study the space-time picture of hadronic interaction is to measure the correlations between two identical particles which momenta are close to each other[1]. Such tool was proposed by G.Goldhaber, W.B.Fowler and S.Goldhaber[7] and for the high energy hadron-hadron interactions by G.I.Kopylov and M.I.Podgotetskii [8]. Now it is also known as Bose-Einstein correlation(BEC)[9]. The correlations of identical particles are used to study the size of the domain, from which the scondaries were emitted.

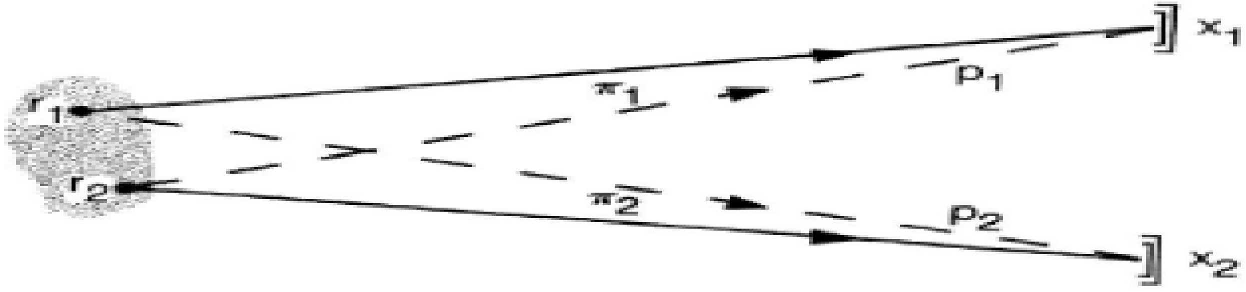


Figure 3: Illustration of two pion correlation experiment

$$M_a(p_1,p_2) = \int \frac{d^4r_1}{(2\pi)^4} e^{ip_1r_1} \frac{d^4r_1}{(2\pi)^4} e^{ip_2r_2} M(r_1,r_2).$$

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 $Q = p_2 - p_1$.

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 brackets indicates the averaging over the (r_1,r_2) space distribution. Assuming, for simplicity, the Gaussian form we get $< e^{irQ} >= e^{-<r^2>Q^2}$.

Correlations will be seen in the region of Q-value smaller than 300 MeV. To extract the effect one can compare measured Q-spectra with similar one but without BEC, so called reference spectra . Then the ratio

$$R(Q) = \frac{\frac{dN}{dQ}}{\frac{dN_{ref}}{dQ}}$$

can be fitted with an appropriate formulae

$$R(Q) = F(rQ) + a + bQ$$

Как все просто! Никакой динамики (ни электро-.., ни хромо-…). Из распределения массового спектра двух бозонов легко измерить размеры излучающего объекта.

ОДНАКО

Чтобы выделить эффект, надо измеренный спектр “сравнить” с подобным, но БЕЗ БЭК ,т.н. рефференсным спектром

Сделать руками из того, что есть в наличии

Using 7 reference samples, widely used in literature, for measurements and systematic uncertainties estimation.
1 Opposite charge pairs;
2 Opposite charge pairs with one track ~p inverted;
3 Same charge pairs with ~p inverted;
4 Same charge pairs with ~p rotated in transverse plane;
5 Pairs of tracks from dierent events, chosen randomly;
6 Pairs of tracks from dierent events with similar dNtracks=d ;
7 Pairs of tracks from dierent event with similar total invariant mass of charged tracks.

CMS впервые на LHC исследовал БЭК

As an example, the ratios $R(Q)$ obtained with the opposite-hemisphere, same-charge reference samples are shown in Fig. 1 both for data and simulation without BEC. A significant excess at small values of Q is observed in the data. Additional details are given in [10].

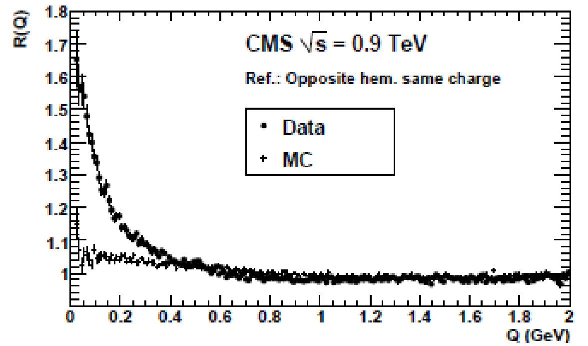


Figure 1: Ratios $R(Q)$ obtained with the opposite-hemisphere, same-charge reference samples for data (dots) and MC with no BEC effect (crosses).

In order to reduce the bias due to the construction of the reference samples, a double ratio $\mathcal{R}$ is defined:

$$\mathcal{R}(Q) = \frac{R}{R_{\mathrm{MC}}} = \left(\frac{\mathrm{d}N/\mathrm{d}Q}{\mathrm{d}N_{\mathrm{ref}}/\mathrm{d}Q}\right) \Big/ \left(\frac{\mathrm{d}N_{\mathrm{MC}}/\mathrm{d}Q}{\mathrm{d}N_{\mathrm{MC,ref}}/\mathrm{d}Q}\right), \tag{3}$$

Bose-Einstein Correlations in multi-particle final state in proton-proton collisions at beam energy 900 GeV and 7 TeV at LHC with ATLAS

V.A.Schegelsky

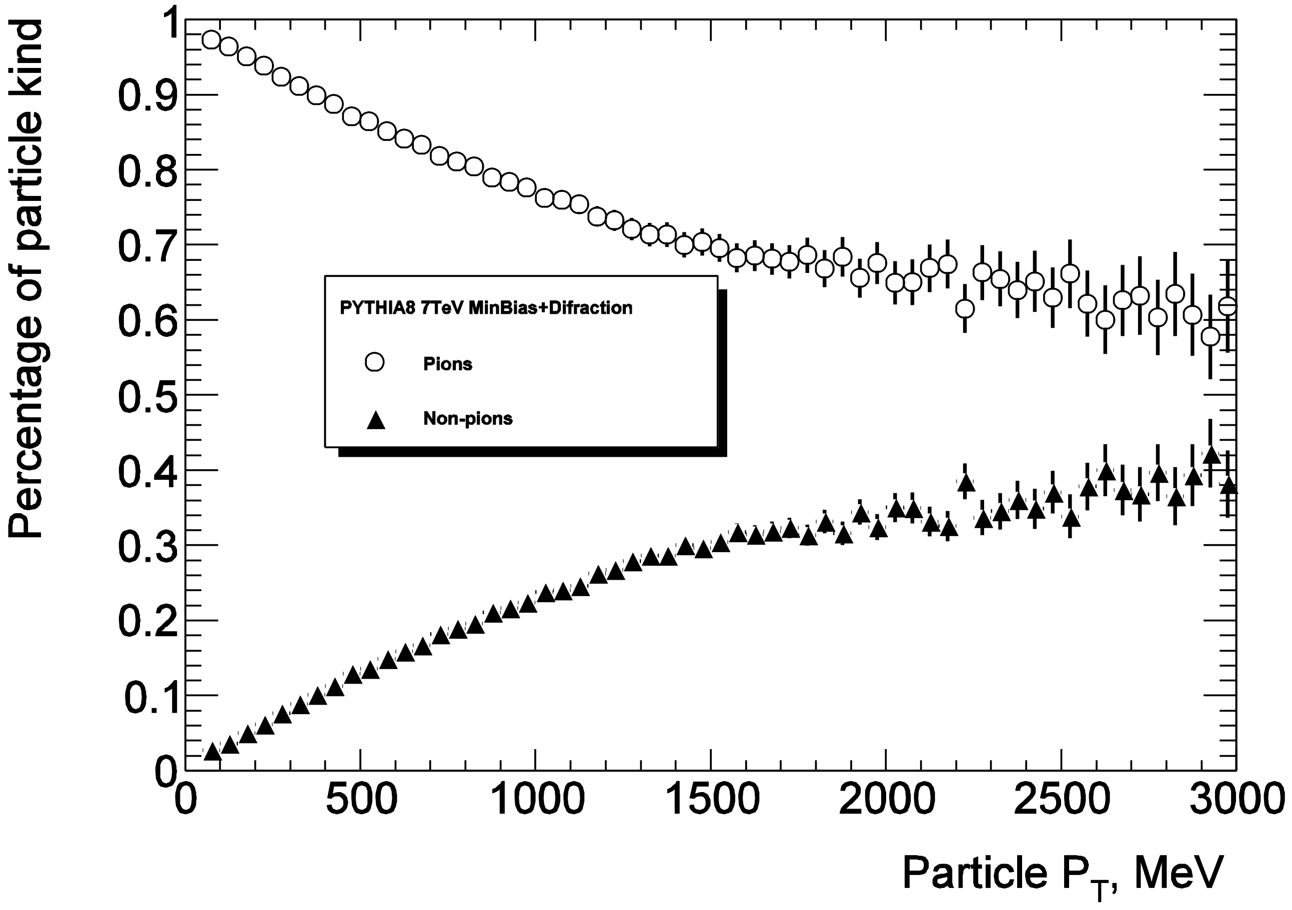
December 2010

The proximity in phase space between final state particles with 4-momenta p1 and p2 can be quantified by

$$Q = \sqrt{-(p_1 - p_2)^2}$$

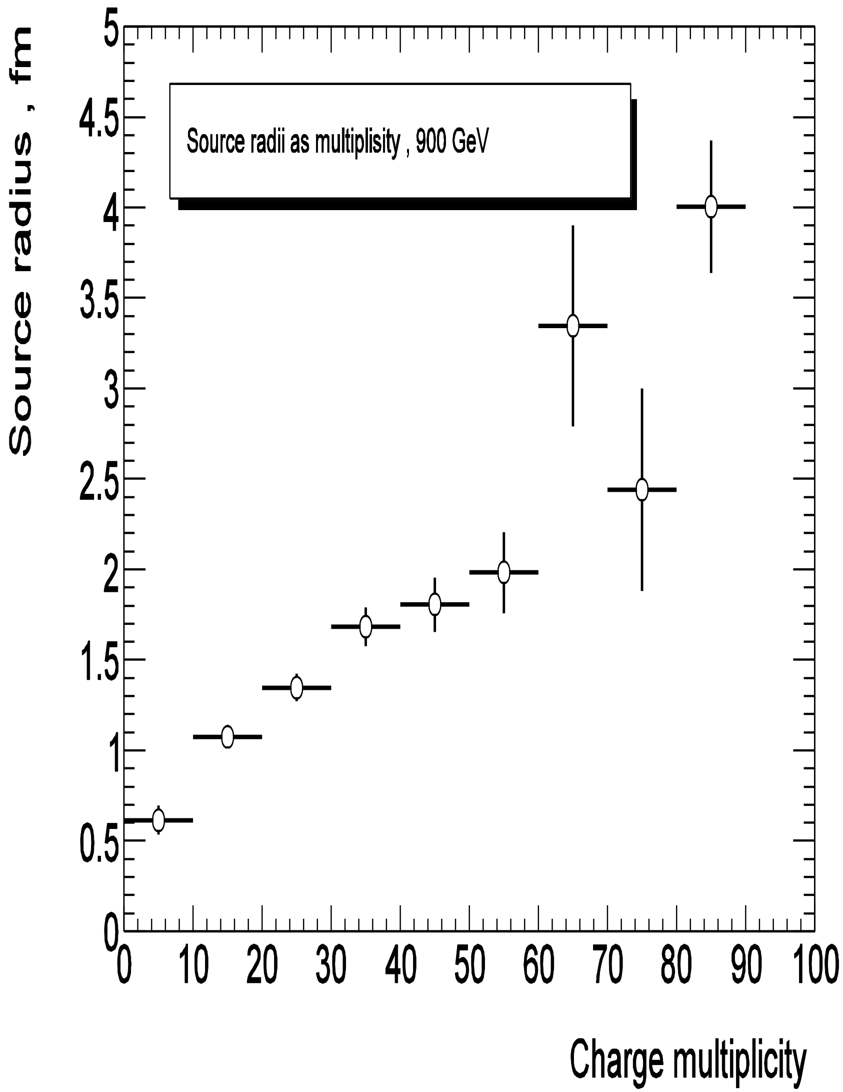
All pairs of the same-charge particles with Pt in the range of (100-500) MeV are used. As a reference Opposite-hemisphere pairs (E,p)->(E,-p) is used

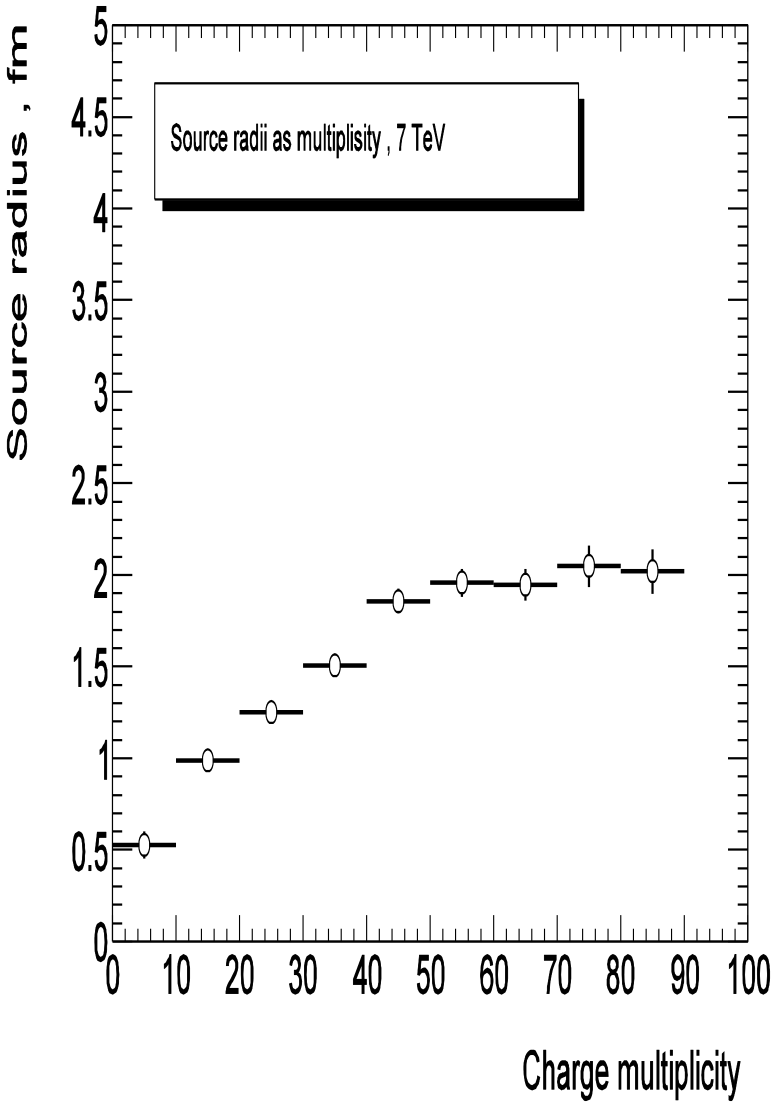
All pairs of the same-charge particles with Pt in the range of (100-500) MeV are used. The reason for the Pt limitation is dictated by small contribution of non-pion particles, as one look from PYTHIA8 model.



In the very first publication on BEC interferometry with LHC (CMS, 900 GeV, arXiv:1005.3294v1, May 18, 2010) it was shown that measured source radius depends on particle multiplicity. Unfortunately, statistics for 900 GeV run is quite limited. In ATLAS we have “only” ~400K events, twice more then CMS. For 7 TeV run we have unlimited statistics. Results presented based on 400K events for 7 TeV as for 900 GeV (what I have in my laptop).

Only tracks with Pt smaller 500 MeV are selected. One can see rather impressive plateau. Moreover source radius is NOT dependent on beam energy BUT multiplicity!





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ATLAS Note

December 29, 2010

Multi-particle Radiation Source Size Determination via the identical pion correlations with ATLAS experiment at the LHC

M.G.Ryskin, V.A.Schegelsky

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Abstract

ATLAS Minimum Bias Event Collections from the LHC proton-proton collision at center-of-mass beam energies $\sqrt{S}$ = 900 GeV and 7 TeV are used to determine the particle emission source size. It occurs that this parameter depends essentially on charged particle multiplicity but not on the beam energy.

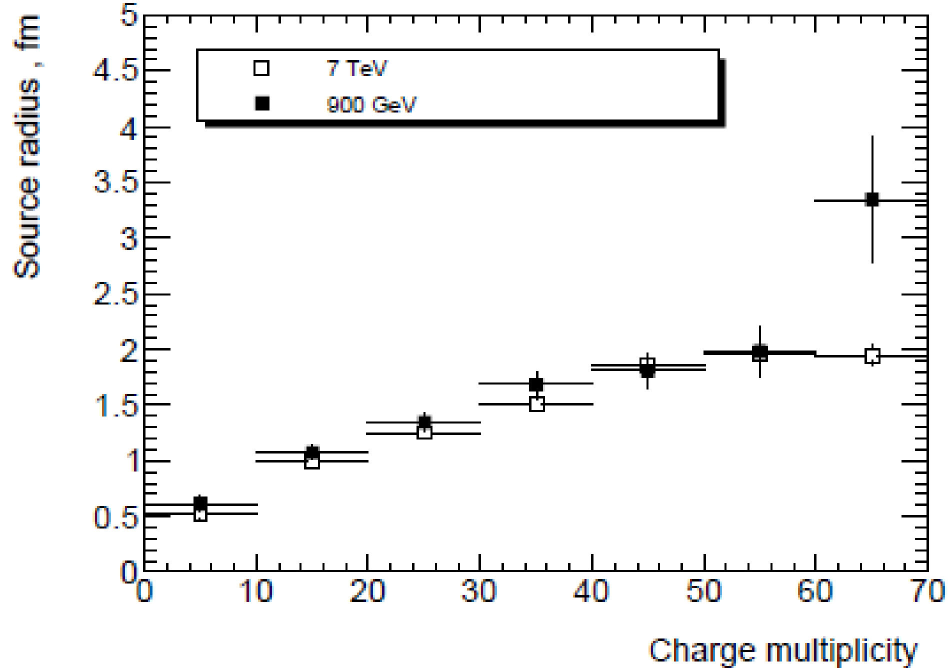

Figure 8: Source size as a function of particle multiplicity at $\sqrt{s}$ = 900 GeV and $\sqrt{s}$ = 7TeV

4 Conclusion

The multiplicity dependence of the radiation source size shown in In Fig. 5 can be explained if particles are emitted from one or few small size sources while the size of each individual source practically does not depend on energy (at least in the interval from 0.9 to 7 TeV considered here). Then the low multiplicities correspond to the events where only one small size source was originally produced and the radius $r = 0.5$ fm reflects the size of this source. A higher multiplicities are caused by the events with few sources and now the value of r is driven by the mean distance between two sources.

In terms of the Regge-Pomeron theory this can be described as follows:

To satisfy the s-channel unitarity we have to consider not only one-Pomeron but the multi-Pomeron exchange contributions as well. At high energies the multiparticle production is described by the emission from one or few cut Pomerons. Each cut Pomeron plays the role of the relatively small size source mentioned above. The low multiplicity corresponds to the case of only one cut Pomeron. Thus the smallest radius ~ 0.5 fm should be considered as the radius of one individual Pomeron (to be more precise – as the size of the source formed by a single Pomeron). At a higher multiplicities we deal with the events with a larger number of cut Pomerons and now via the identical particle correlation we measure the mean separation between the Pomerons.

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Pomeron universality from identical pion correlations at the LHC

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ABSTRACT

Bose–Einstein correlations of identical pions produced in high-energy *pp* collisions at the LHC allow a probe of the Pomeron exchange mechanism. The size of the domain which emits the pions depends on the multiplicity of events, but not on the collider energy. This confirms the universal structure of Pomeron exchange. The data at relatively low multiplicities indicate that the size of the source created by one-Pomeron exchange is much less than the size of the proton.

In the Regge approach each soft Pomeron can be regarded as a multiperipheral ladder, see Fig. 1. The ladder shown in (a) corresponds to the elastic *pp* scattering amplitude, while on cutting the Pomeron, as in (b), we obtain the cross section for multiparticle production. Cutting *n* Pomerons in a multi-Pomeron exchange diagram, (c), gives a final density of secondaries in the central region that is *n* times larger than that for one-Pomeron exchange, see, for example, [15] for more details.

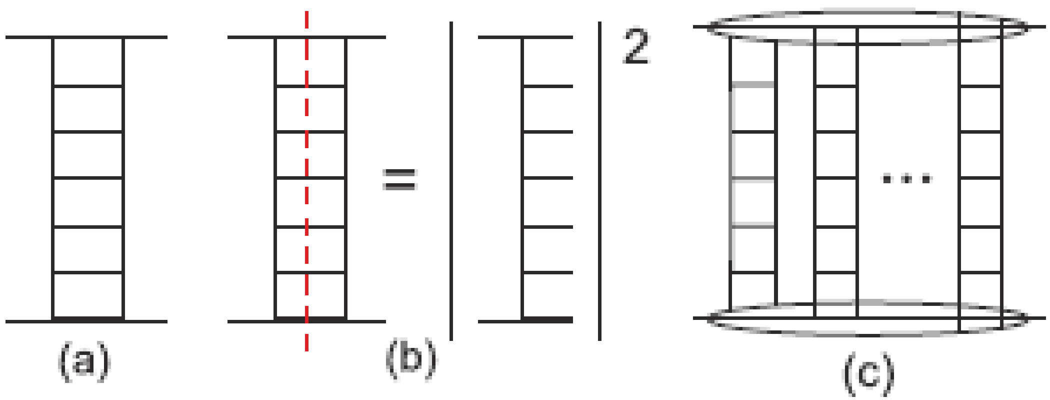

Fig. 1. (a) The ladder diagram for one-Pomeron exchange; (b) cutting one-Pomeron exchange leads to the multiperipheral chain of final state particles; (c) a multi-Pomeron exchange diagram.

4. Saturation of source radius at large N_{ch}

Let us return to pp collisions, and recall the partonic structure of the proton. In a pp collision the parton–parton interaction is analogous to a NN collision in heavy-ion collisions. Thus we expect $\langle r \rangle$ to saturate at the value of N_{ch} when the partonic discs of the colliding protons overlap, that is at a value of $\langle r \rangle$ characteristic of the pp interaction. Let us compare the value of $\langle r \rangle \sim 2$ fm observed for large N_{ch} with that obtained from the t-slope of the elastic pp cross section. The slope expected at 7 TeV is about $B_{el} \sim 20\ \text{GeV}^{-2}$; see, for example, [16]. Now the relation between the slope and the radius is[2]

$$B_{el}/2 = \langle r^2 \rangle / 4 \quad \text{gives} \quad \langle r^2 \rangle \sim 1.55\ \text{fm}^2. \tag{3}$$

However, the above relation is obtained with a Gaussian form $e^{-Q^2 r^2}$, while the correlation is observed [8] to be better described by the exponential form e^{-Qr}. The relation between $\langle r \rangle$ for the two forms is

$$\langle r \rangle_{\exp} = \sqrt{\pi} \langle r \rangle_{\text{Gaussian}}. \tag{4}$$

Thus we obtain $\langle r \rangle_{\exp} = 2.2$ fm close to the value found in the BEC data [9,12]. That is, we have correspondence between the value of $\langle r \rangle$ at large N_{ch} and the interaction radius determined via the elastic slope B_{el}. Since B_{el} increases with energy, we therefore expect that the 'saturated' BEC value of $\langle r \rangle$ will also increase a little.

To conclude our discussion so far, we see that the BEC effects at the LHC offer the opportunity to confirm the universal small-size structure expected for the Pomeron[3] and to measure both the size of individual Pomeron (at comparatively small N_{ch}) and the radius of the proton–proton interaction (at large N_{ch}). We sketch the expected behaviour of the average radius of the identical particle emission region, $\langle r \rangle$ with N_{ch} in Fig. 2. At low N_{ch} we measure the size of the pion source created by one Pomeron, while at larger N_{ch} the result is mainly driven by the spatial separation between two-Pomeron exchanges. An important result of the observation of BEC is that at low N_{ch} the size of the source does not depend on energy, within the experimental accuracy. This confirms the universal structure of the Pomeron pole. At large N_{ch} we expect saturation of $\langle r \rangle$ at a value corresponding to the radius, R_{pp}, of the pp interaction. The corresponding plateau in the N_{ch}-plot should therefore increase slowly with energy, as $\langle r \rangle \propto \sqrt{B_{el}(s)}$.

Предсказание-ожидание картины при «асимтотических» энергиях(2011г)

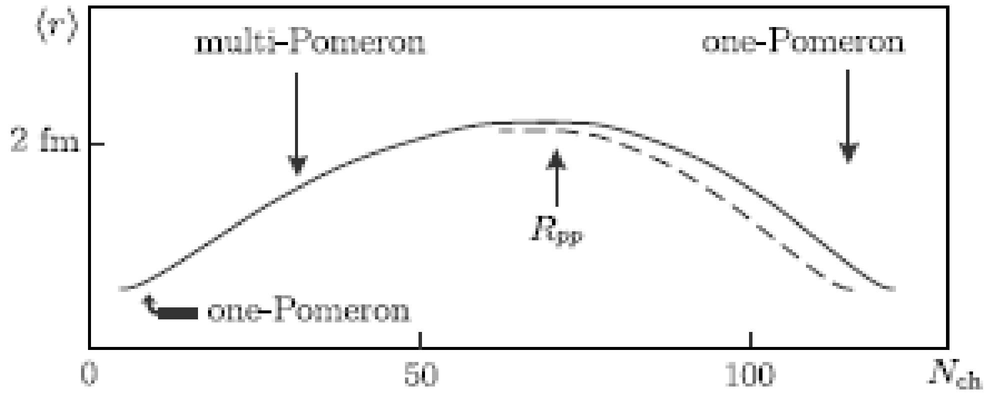

Fig. 2. A sketch of the expected values of $\langle r \rangle$ as a function of the multiplicity of charged particles, N_{ch}. The size $\langle r \rangle$ of the source of identical pions originating from different mechanisms is indicated. The continuous and dashed curves correspond to, say, $\sqrt{s} = 7$ and 0.9 TeV respectively. At low N_{ch} we expect $\langle r \rangle$ to be independent of the collider energy $\sqrt{s}$, while for the plateau we expect $\langle r \rangle \sim R_{pp} \propto \sqrt{B_{el}(s)}$ to increase very slowly with energy. Very large multiplicities are expected to arise from high-E_T events originating from a single ladder. The scale for the N_{ch} axis depends on the experimental acceptance domain. Here, we indicate an approximate typical scale for N_{ch} corresponding to a relevant experimental η interval, $|\eta| < 2.5$, and p_t cut.

До сих пор непонятно- почему CMS не показал результаты при больших множественностях, но «обнаружил явление» антикорреляции

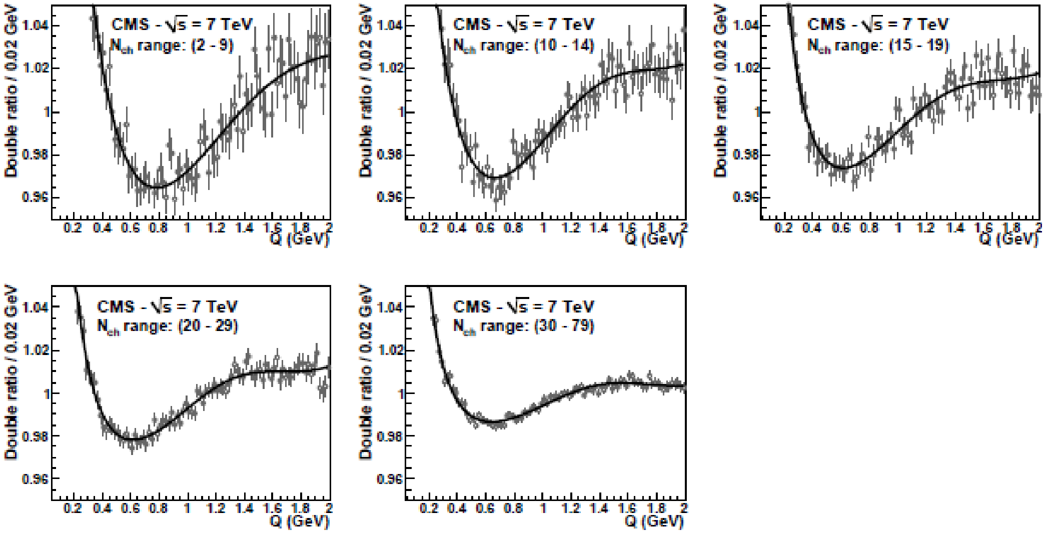

Figure 6: Detail of the distribution of the double ratio $\mathcal{R}$ for $\sqrt{s} = 7$ TeV using different intervals of charged-particle multiplicity in the event (N_{ch}). The lines are fits to the data with Eq. (4). The error bars are statistical only.

Наш семинар 16.09.2012

Bose-Einsten and other two particle correlations - MC study

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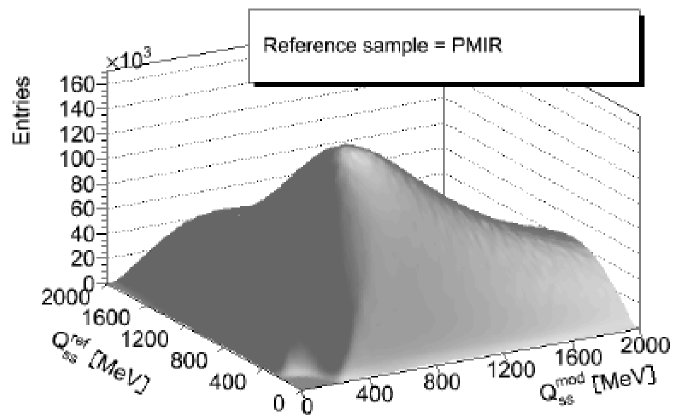
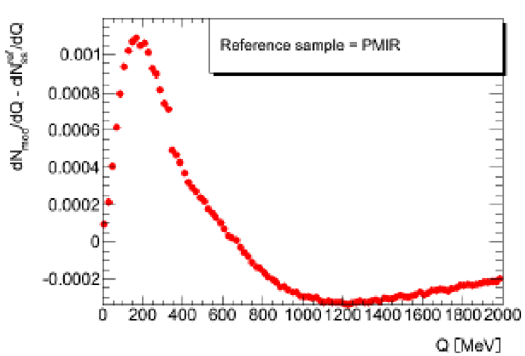
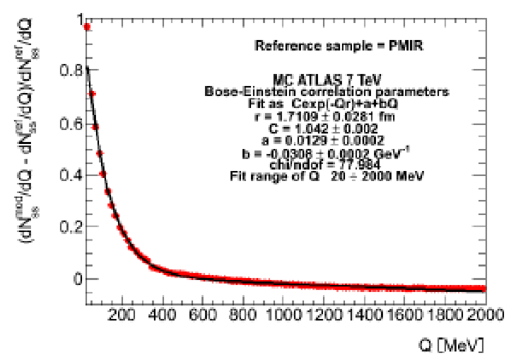
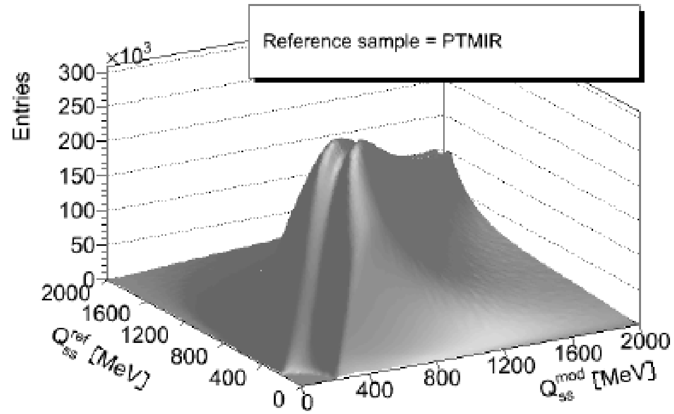
The simplest way is to prepare mirror sample from the original one,i.e. to change in the event all momenta 3-vectors as $\vec{p} \to -\vec{p}$ (PMIR case).

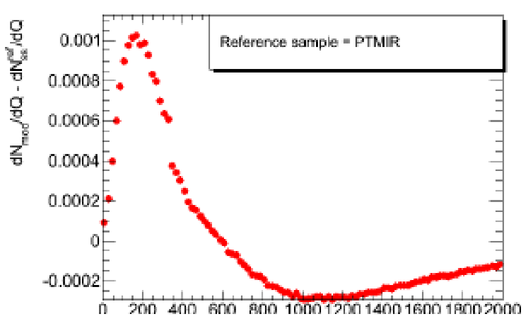


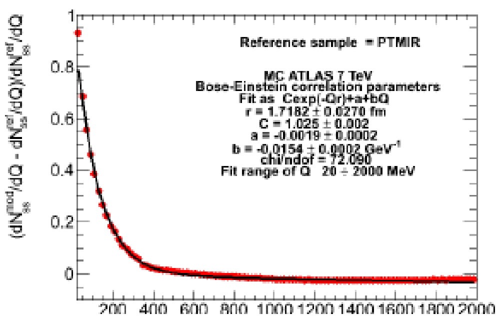




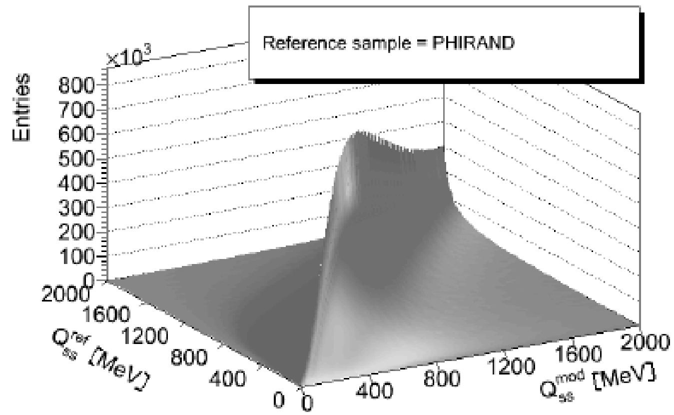
The better way should be if the reflection is made in the transverse plane $\vec{p}_t \to -\vec{p}_t$ (PTMIR case). The results are a bit closer to the model values but still there is no small Q events in the reference distribution if the model Q-values is smaller than $\sim 300 MeV$.

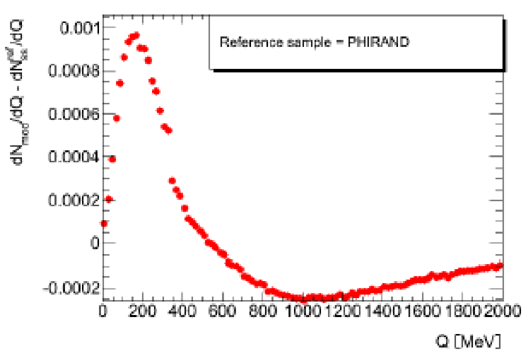


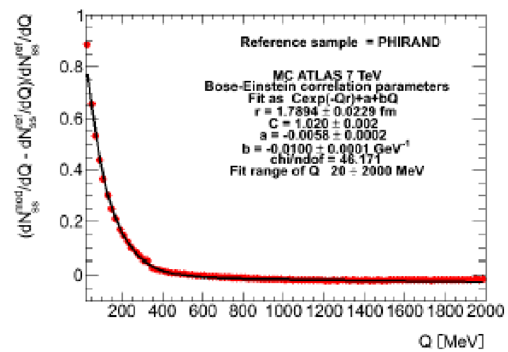




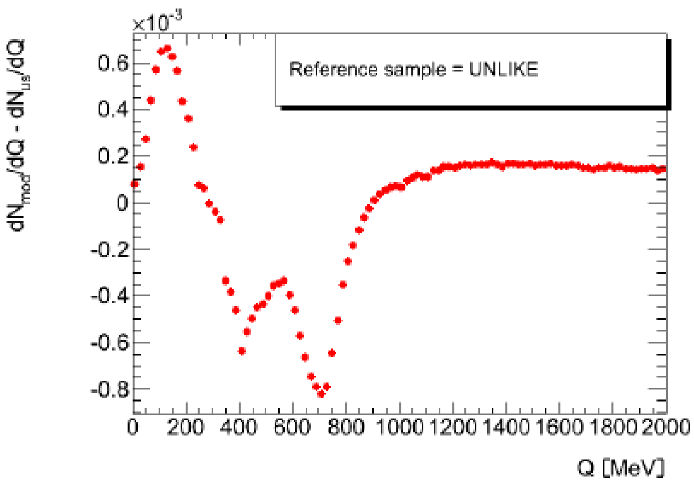
One gets a bit better reference distribution if vectors $\vec{p}_t$ in an observed event will be turned by a random value of $\delta\phi$, the same turn for all tracks - PHIRAND case.

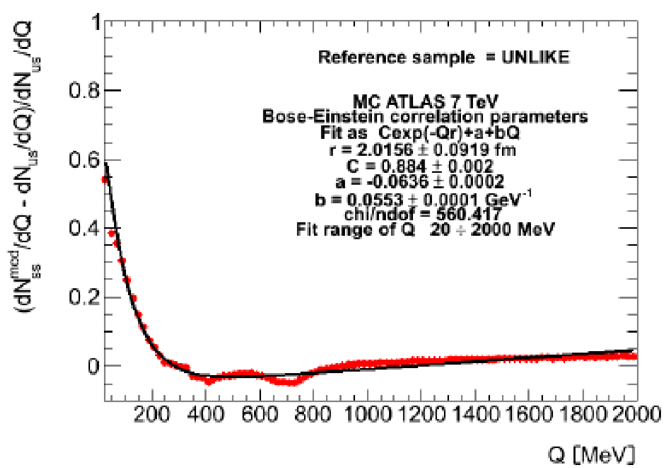






The unlike Q-distribution looks as a natural choice because there should be no BEC for the unlike sign pairs. The source radius from the fit is close to the model value , however the resonances contribution makes fit quality bad. The contributions of the ρ^0 and the remnants of η mesons are clearly seen. To make fit better, one has to exclude quite large region in Q : 200-1000 MeV. In the data analysis the situation will be even worse because the MC models does not describe the contribution of (multi-particle) resonances in this Q-region.





EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2014-264

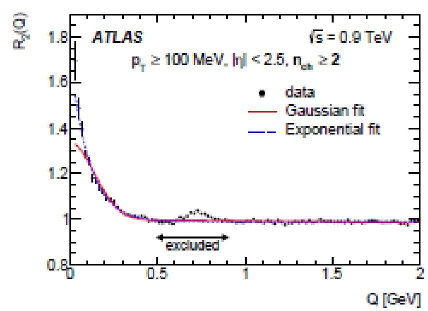
Submitted to: Eur. Phys. J. C

Two-particle Bose–Einstein correlations in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV measured with the ATLAS detector

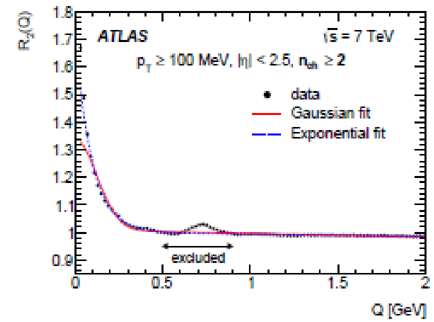
The ATLAS Collaboration

Abstract

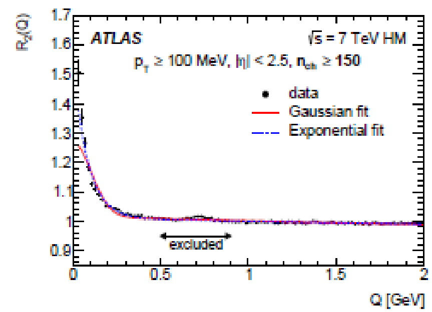
The paper presents studies of Bose–Einstein Correlations (BEC) for pairs of like-sign charged particles measured in the kinematic range $p_T > 100$ MeV and $|\eta| < 2.5$ in proton–proton collisions at centre-of-mass energies of 0.9 and 7 TeV with the ATLAS detector at the CERN Large Hadron Collider. The integrated luminosities are approximately 7 μb^{-1}, 190 μb^{-1} and 12.4 nb^{-1} for 0.9 TeV, 7 TeV minimum-bias and 7 TeV high-multiplicity data samples, respectively. The multiplicity dependence of the BEC parameters characterizing the correlation strength and the correlation source size are investigated for charged-particle multiplicities of up to 240. A saturation effect in the multiplicity dependence of the correlation source size is observed using the high-multiplicity 7 TeV data sample. The dependence of the BEC parameters on the average transverse momentum of the particle pair is also investigated.



(a)

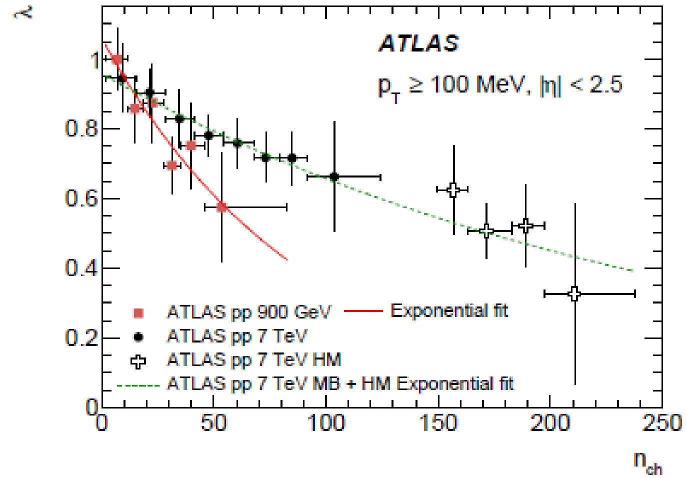


(b)

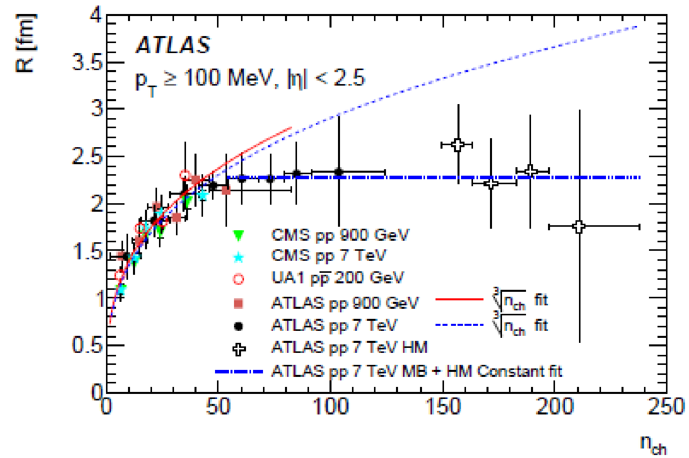


(c)

Fig. 1. The two-particle double-ratio correlation function $R_2(Q)$ for charged particles in pp collisions at (a) $\sqrt{s}$ =0.9 TeV, (b) 7 TeV and (c) 7 TeV high-multiplicity events. The lines show the Gaussian and exponential fits as described in the legend. The region excluded from the fits is indicated. The error bars represent the statistical uncertainties.

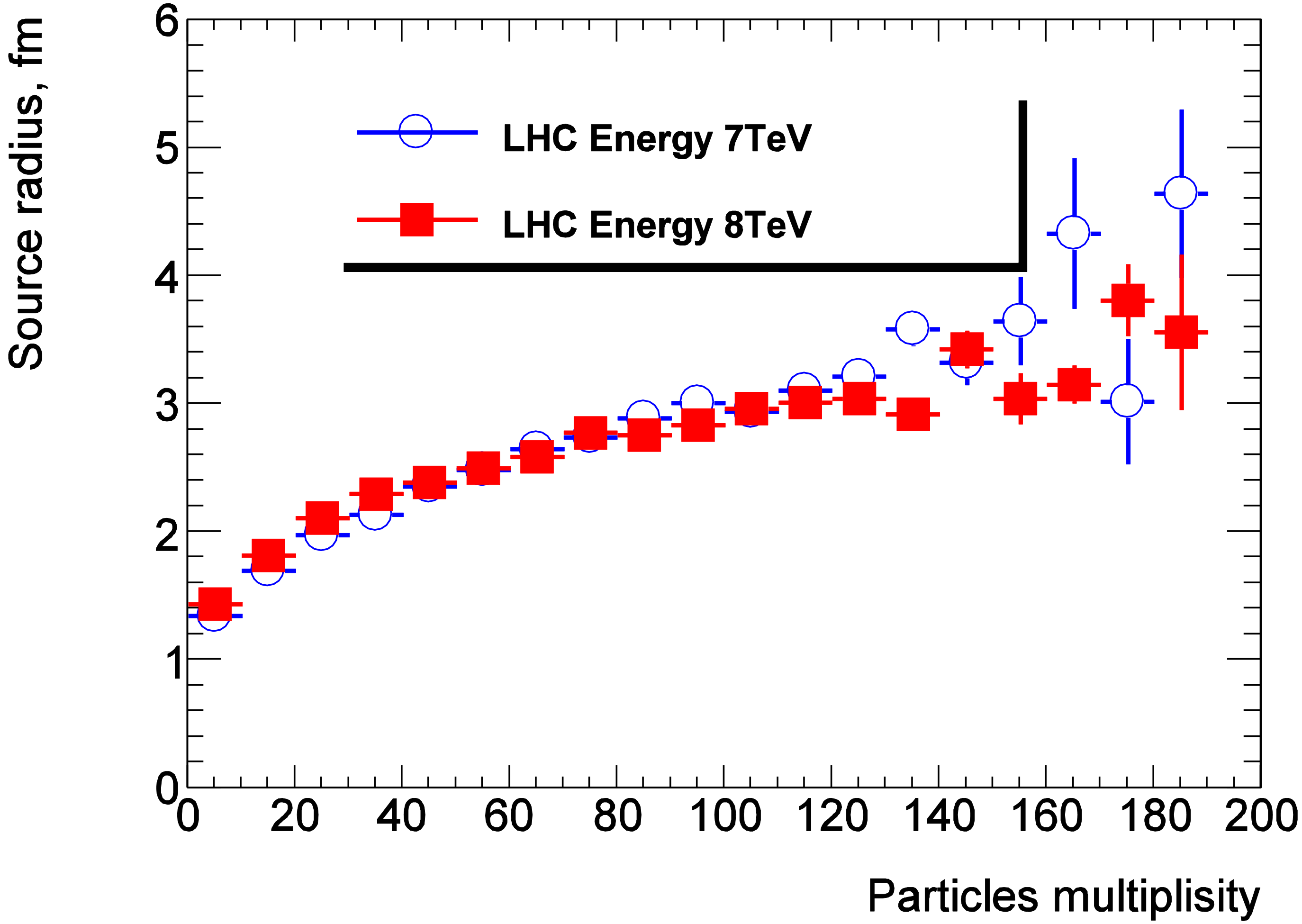


(a)



(b)

Fig. 3. Multiplicity, n_{ch}, dependence of the parameters (a) λ and (b) R obtained from the exponential fit to the two-particle double-ratio correlation functions $R_2(Q)$ at $\sqrt{s}$ =0.9 and 7 TeV, compared to the equivalent measurements of the CMS [38, 39] and UA1 [67] experiments. The solid and dashed curves are the results of (a) the exponential and (b) $\sqrt[3]{n_{ch}}$ for $n_{ch} < 55$ fits. The dotted line in (b) is a result of a constant fit to minimum-bias and high-multiplicity events data at 7 TeVfor $n_{ch} \geq 55$. The error bars represent the quadratic sum of the statistical and systematic uncertainties.



Source radius, fm
LHC Energy 7TeV
LHC Energy 8TeV
Particles multiplisity
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140
160
180
200

“Еще не вечер, возможны варианты….”(см картины 22)

**Последние новости:
БАК эксперименты(ATLAS,CMS..) работают в полном объеме(все суб-детекторы) при сцм энергии 13 ТэВ. Пучок стабильный.**