Two scales in Bose-Einstein correlations

V.A. Schegelsky and M.G. Ryskin

BEC is the way to probe the size/structure of the domain which radiates secondaries.

Huge ATLAS statistics
($\sim 10^7$ events corresponding to $\sim 10^9$ same sign pairs)
allows the *detailed* study of the space-time structure of multiparticle production.

Consider the amplitude $M(r_1, r_2)$ in coordinate representation in which two identical pions, π_1 and π_2, are emitted at the points r_1 and r_2 correspondingly. The coordinates r_1, r_2 can not be measured. 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

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

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

$$\frac{E_1 E_2 d^2\sigma}{d^3 p_1 d^3 p_2} = \frac{1}{2!} |M_a|^2 < 2 + 2e^{irQ} >= |M_a|^2 (1+ < e^{irQ} >).$$

Inclusive cross section for the two identical particles takes the form

$$\frac{E_1 E_2 d^2\sigma}{d^3p_1 d^3p_2} = \frac{1}{2!}|M|^2\langle 2 + 2e^{irQ}\rangle = |M|^2 \langle 1 + e^{irQ}\rangle,$$

where M is the production amplitude, and $Q = p_2 - p_1$ and $r = r_1 - r_2$.

The proximity in phase space between final state particles with 4-momenta p_1 and p_2 can be quantified by

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

The BEC effect is observed as an enhancement at low $Q \sim 300 MeV$. To extract the effect one can compare measured Q-spectra with similar one but without BEC, with reference spectra. Then the ratio

$$R(Q) = \frac{\frac{dN}{dQ} - \frac{dN_{ref}}{dQ}}{\frac{dN_{ref}}{dQ}} \tag{1}$$

can be fitted with an appropriate formulae

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

F(rQ) is the Fourier transformation of the spatial distribution of the emission region with an effective size $\langle r \rangle$. The function simplest parametrization can be a linear exponent

$$SF1 = \lambda e^{-r1Q} + a + bQ$$

Parameter λ can be called as a strength of BEC, and a and b describe a simplest background to BEC.

Do we expect the homogeneous distribution? – NO

we expect few/many small size sources of secondaries distributed over a larger area.

$B_{el} = B_0 + 2\alpha' \ln(s/s_0)$

$B_0 \sim 10 GeV^{-2}, \quad 2\alpha' \sim 0.5 GeV^{-2}$

Two different scales!

α' ==> transverse size of the Pomeron

. (BFKL/multiperipheral ladder)

B_0 ==> size of beam/target hadrons.

Multipomeron exchange

(Multiple Interaction option in Monte Carlo)

is caused by the unitarity $2ImA(b) = |A(b)|^2 + G_{in}(b))$

The solution is

$A(b) = i(1 - \exp(2i\delta_l) = i(1 - \exp(-\Omega(b)/2)$

. $(l = b\sqrt{s}/2)$

mean number of Pomerons, $N_P = \Omega(b)$; $\Omega_{LHC}(b = 0) = 9$

N_P depends on b

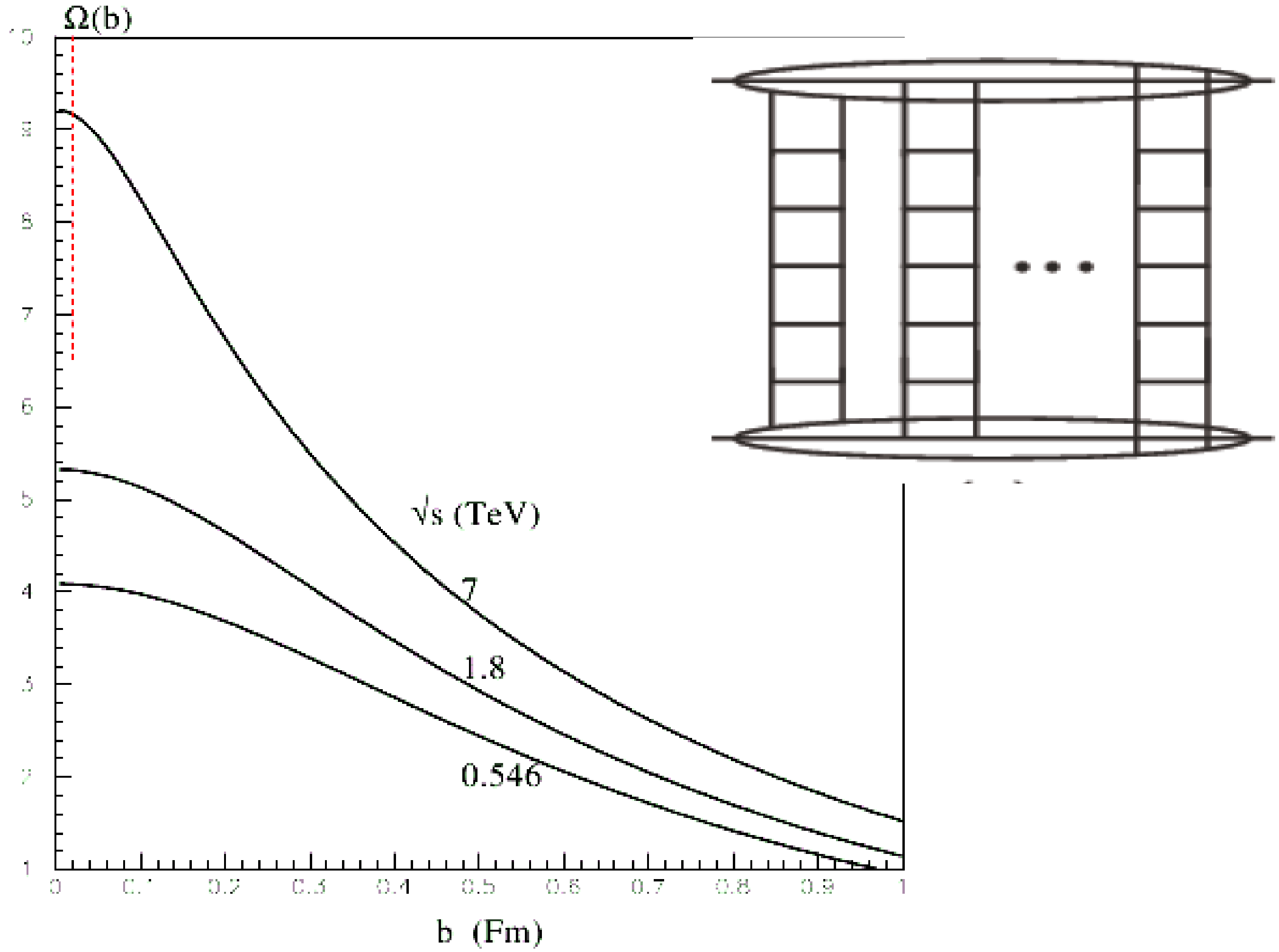


Figure 1: The proton opacity $\Omega(b)$ determined directly from the pp $d\sigma_{\rm el}/dt$ data at 546 GeV [6], 1.8 TeV [7] and 7 TeV [2] data. The uncertainty on the LHC value at $b = 0$ is indicated by a dashed line.

Expect few small size sources distributed over a much larger area (overlap of beam and target hadrons)

*** Try to fit BEC with two radii ***

$$R(Q) \; = \; \lambda \; e^{-r_1 Q} + (1-\lambda) \; e^{-r_2 Q}$$

Expectations: $r_1 \sim 2-3$ fm (correspons to the whole B_{el})

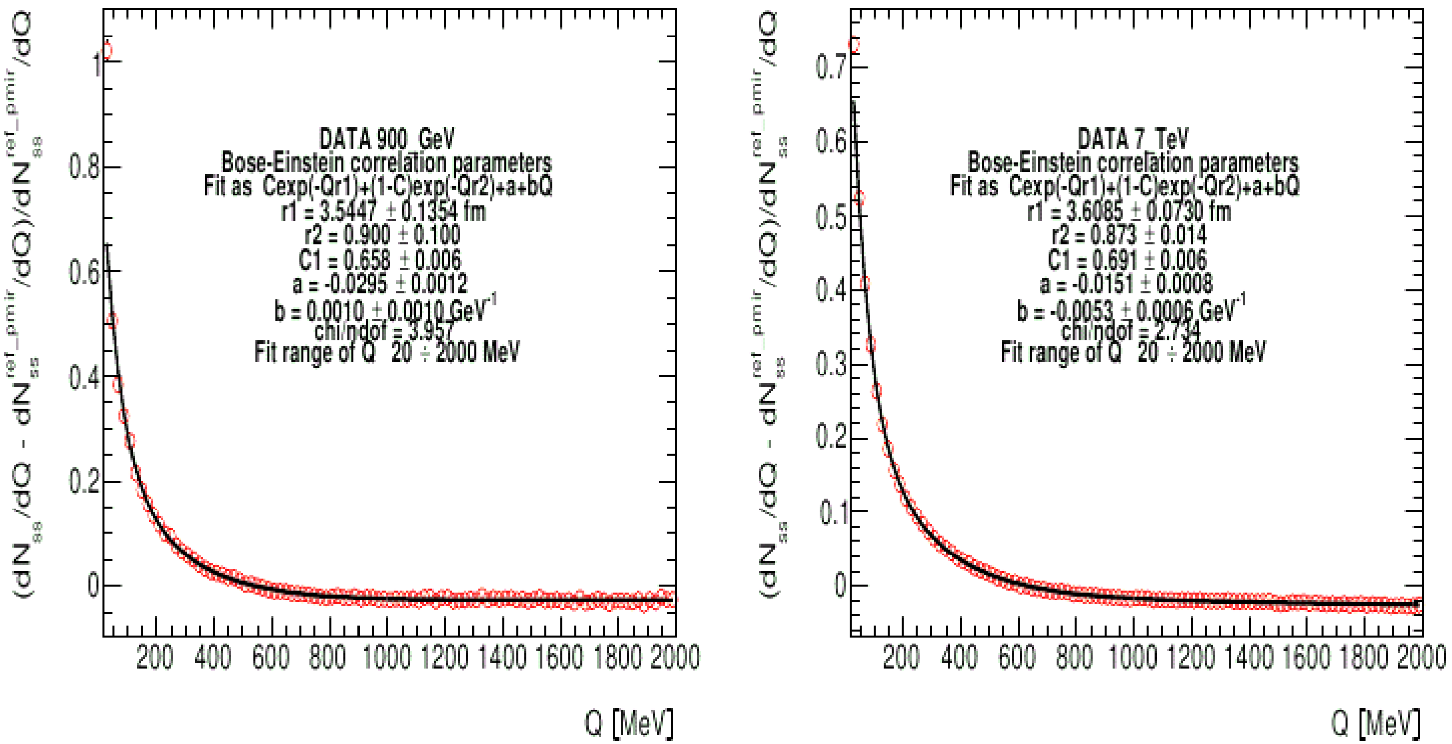
. $r_2 \sim 0.5-1$ fm (size of the Pomeron/pion)

r_1 and λ_1 increase with N_{ch}

$r_2 \sim const(N_{ch})$; do not depend on incoming particle

λ_2 close to 1 at low N_{ch} (one Pomeron); decreases with N_{ch}

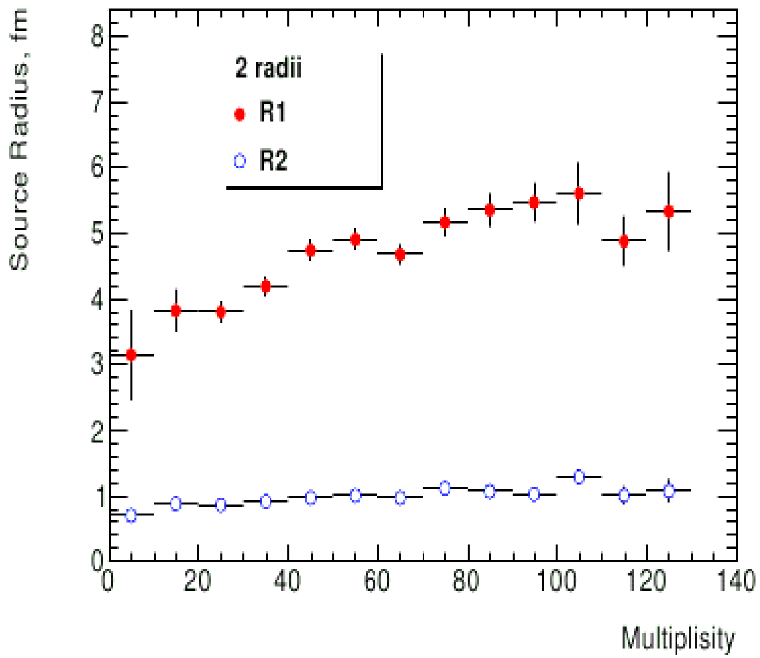
Fit with two radii. An acceptable quality of a statistical description indicates that radii of a radiation zone is a weak (if any) function of hidden parameters.



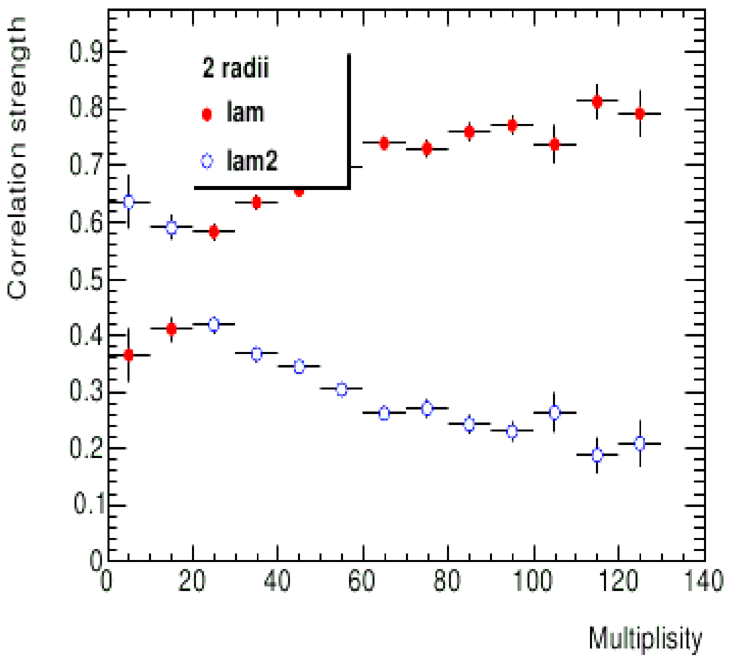
(a) 900 GeV data Q-distribution with two radii structure functions

(b) 7TeV data Q-distribution with two radii structure function

In the following, only 7TeV pictures will be shown. 900 GeV statistics is too low. One can see that r1 dependence on the multiplicity is rather smooth. Value r2 is independent on the multiplicity. Correlation strength spectacular dependence on multiplicity "regulates" error bars in radii estimations.

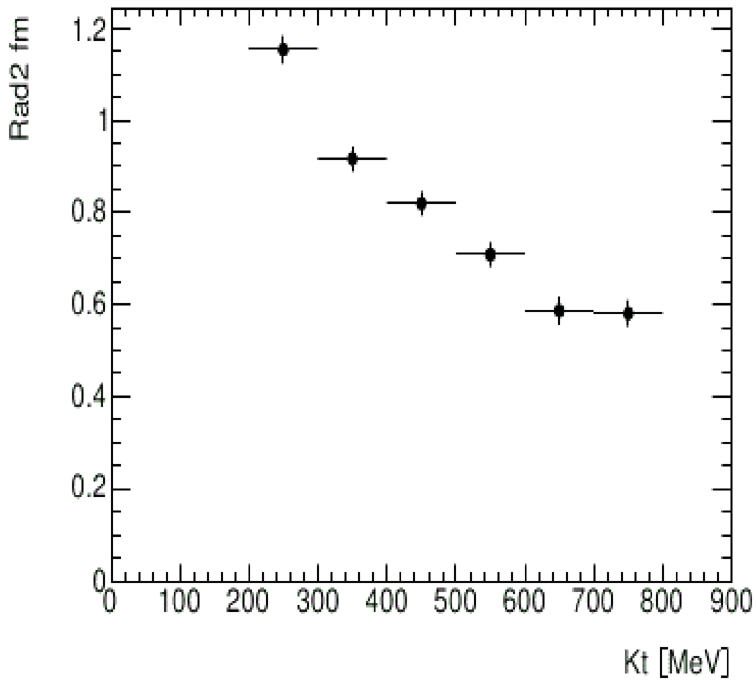


(a) Radiation source size as multiplicity

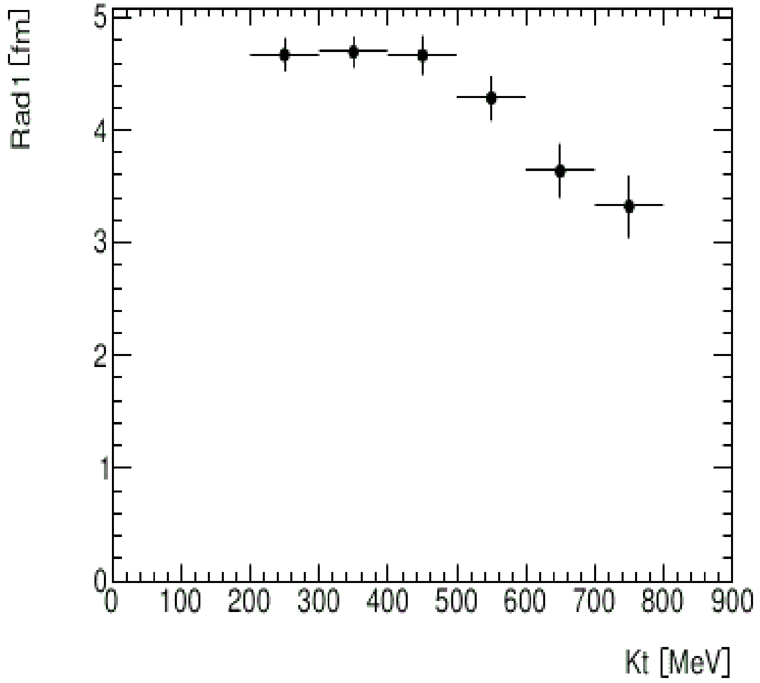


(b) Correlation strength

One may have a look radii dependencies on Kt - half of BEC pair transverse momentum - under suggestion that radii are independent of multiplicity



(a) r2 Kt dependence



(b) r1 Kt dependence

Conclusion:

It is First time observed that the secondaries are produced by a number of SMALL size sources (hot spots)
($r_2 \sim R_\pi$, $r_1 \sim (1-2)R_N$ is the distance between 'hot spots')

For a low particle density $dN_{ch}/d\eta < 10$ the radiation area is less than the proton size - (one hot spot)

At high $dN_{ch}/d\eta$ the size of radiation zone may be larger than that given by B_{el} due to the final state rescattering.

Radiative parton/Pomeron size decreases with $k_T = (p_{1T} + p_{2T})/2$ (Femptoscope resolution) approaching to the pion radius ~ 0.6 fm

Due to small size (r_2) of radiative sources the probability of this "hot spots" to overlap is rather small even in nuclear-nuclear collisions while the energy density inside each "hot spot" is large.

Outlook

It would be interesting:

to have particle identification

Are BEC between kaons and/or protons the same as that in pion case ?

to study BEC in events with Large Rapidity Gap

to study BEC in events with high E_T jet and/or W/Z bosons

Backup

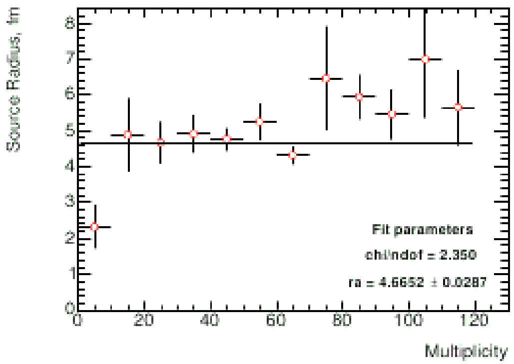
high $k_T = (p_{1T} + p_{2T})/2 ===>$ both pions from one minijet

. r_2 component dominates

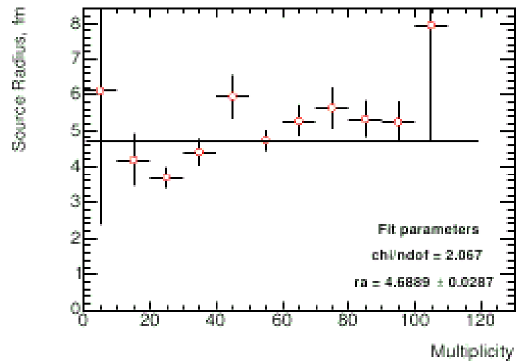
The structure may be changed by the final state interactions

IF so – r_2=size of bubbles in QGLuquid

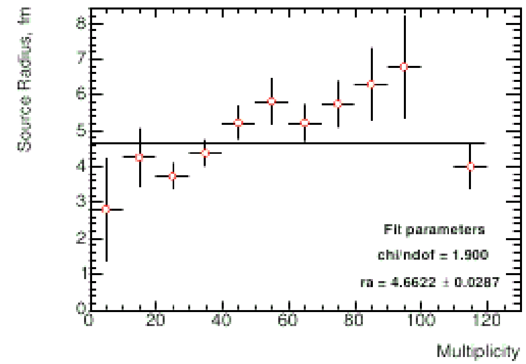
$r_1 \propto N_{ch}^{1/3}$



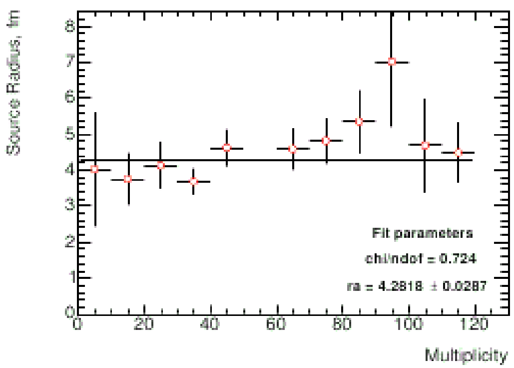
(a) r1 as multiplicity with Kt in the interval (200,300) MeV



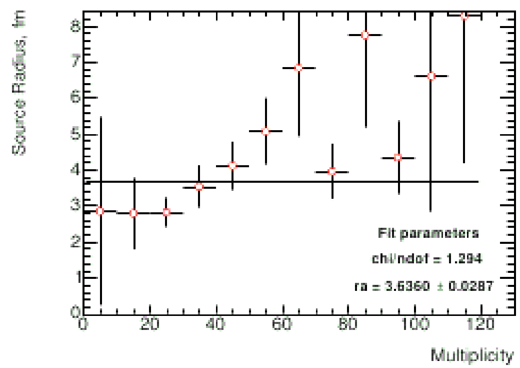
(b) r1 as multiplicity with Kt in the interval (300,400) MeV



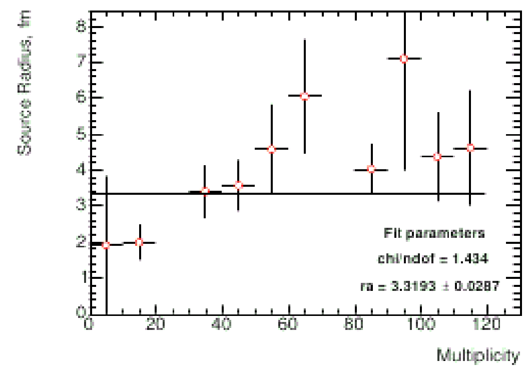
(c) r1 as multiplicity with Kt in the interval (400,500) MeV



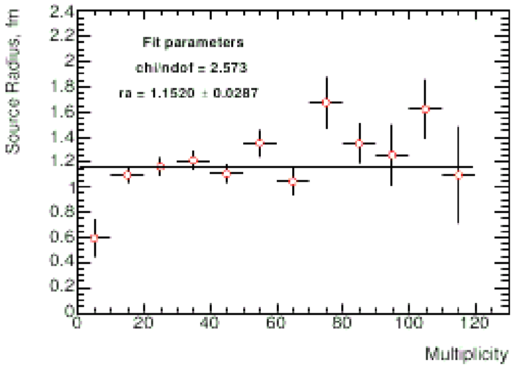
(d) r1 as multiplicity with Kt in the interval (500,600) MeV



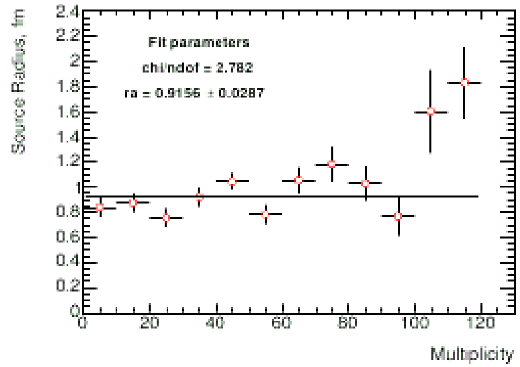
(e) r1 as multiplicity with Kt in the interval (600,700) MeV



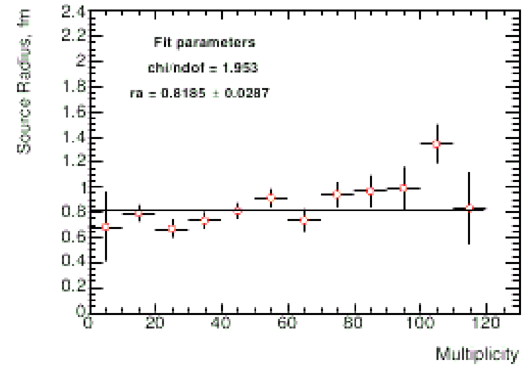
(f) r1 as multiplicity with Kt in the interval (700,800) MeV



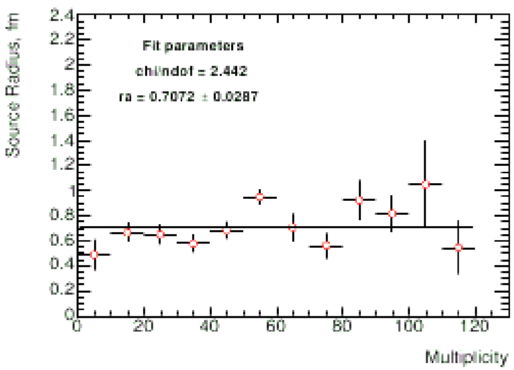
(a) r2 as multiplicity with Kt in the interval (200,300) MeV



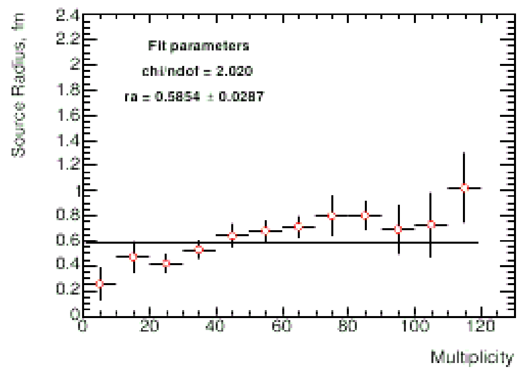
(b) r2 as multiplicity with Kt in the interval (300,400) MeV



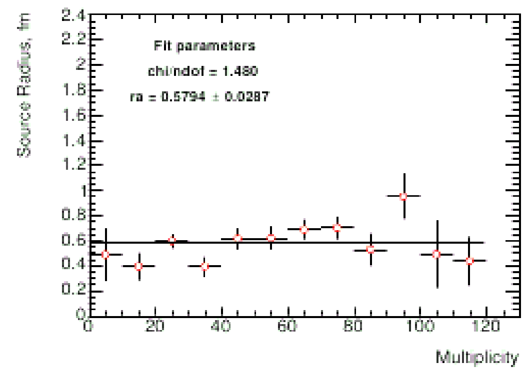
(c) r2 as multiplicity with Kt in the interval (400,500) MeV



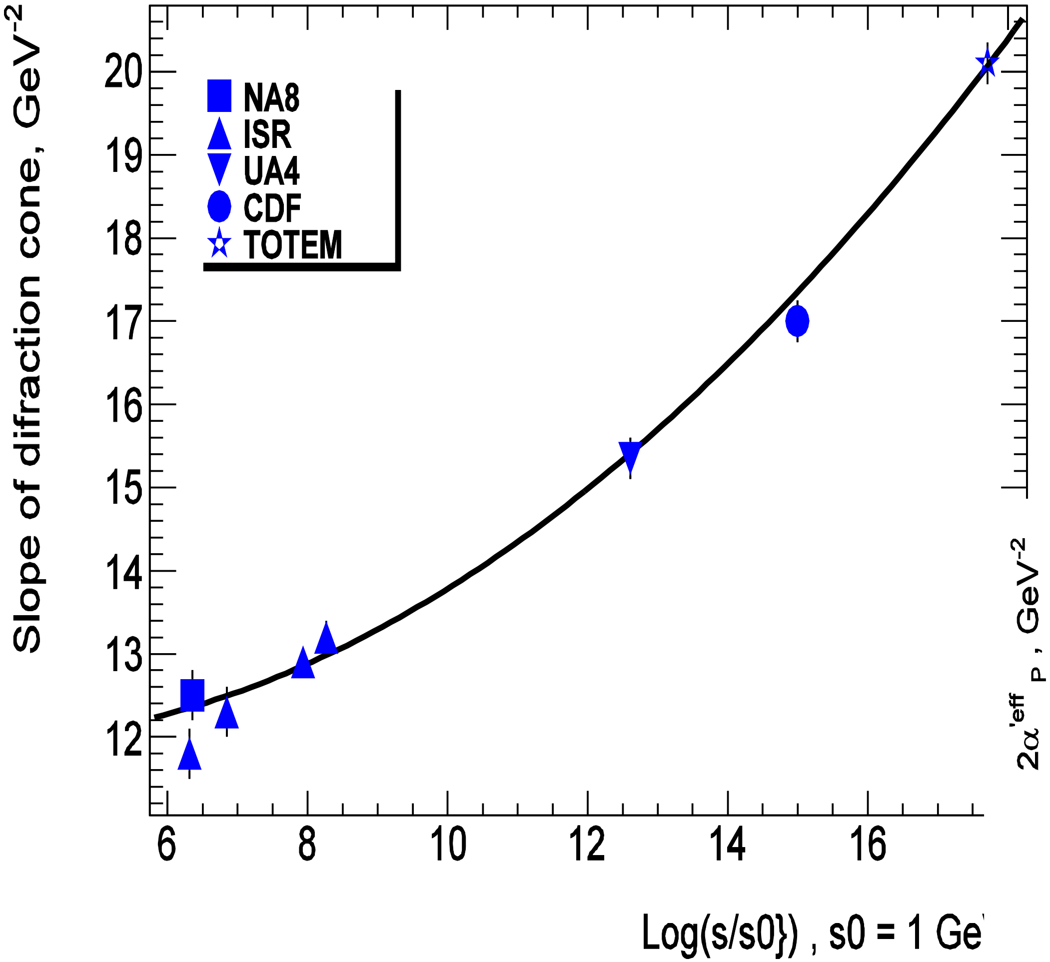
(d) r2 as multiplicity with Kt in the interval (500,600) MeV

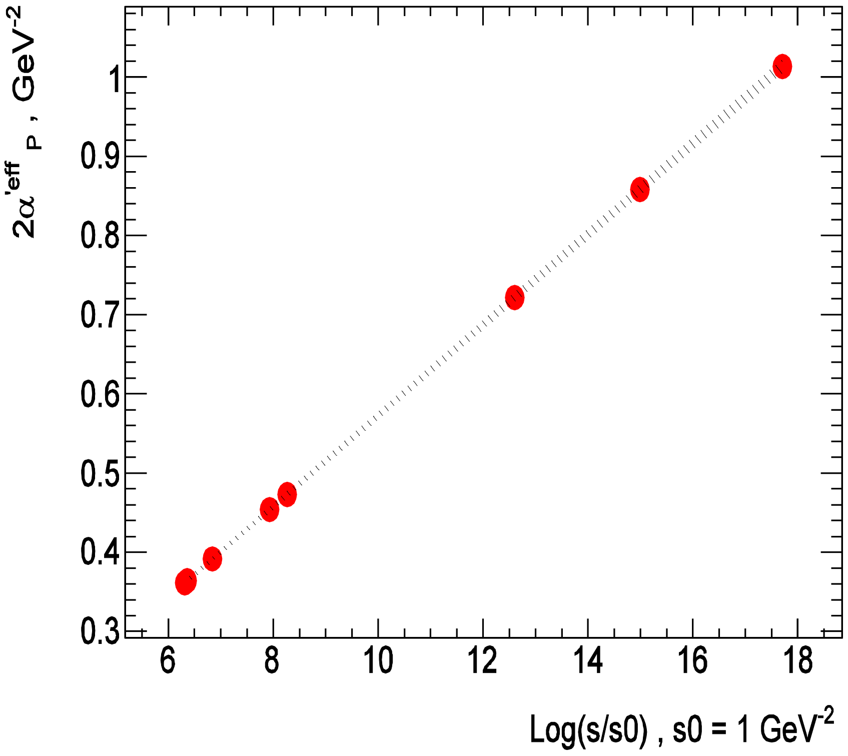


(e) r2 as multiplicity with Kt in the interval (600,700) MeV



(f) r2 as multiplicity with Kt in the interval (700,800) MeV


NA8
ISR
UA4
CDF
TOTEM
Slope of difraction cone, GeV-2
Log(s/s0}) , s0 = 1 Ge


2α'eff P , GeV-2
Log(s/s0) , s0 = 1 GeV-2