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DETERMINATION OF *Z*-BOZON SOURCE RADIUS PRODUCTION BY IDENTICAL PARTICLES INTERFEROMETRY

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1-1. Both particles come from the two sources

Bose-Einstein correlations arise from the interference of identical bosons emitted from different points of external sources [1-5].

When the sources are "close", we are unable to distinguish, which particle comes from which source.

The probability of the emission of two identical spinless bosons with 4-momenta p_1 and p_2 from two sources with the average 4-coordinates x_1 and x_2 has the form:

$$W(p_1,p_2)= 2|U(p_1)|^2 \, |U(p_2)|^2\{1.+\cos[(p_1-p_2)(x_1-x_2)]\},$$

where $x_1=(t_1, r_1)$, $x_2=(t_2, r_2)$,

$|U(p)|$ is the one-particle momentum spectrum. We obtain, averaging over the distribution of points x_1 and x_2 :

$$W(p_1,p_2) = 2W_0 \, (1. + <\cos qx>),$$

where $W_0 =|U(p)|^2$, $q= p_1- p_2$, $x= x_1-x_2.$

In case of independent one-particle sources with the same distribution we can pass directly to the space-time parameter distribution instead of difference one. Then the correlation function looks like:

$$W(p_1, p_2) = W(p_1,p_2)/(2W_0) = 1.+ |F(q)|^2 \;,$$

where $F(q) = \int f(z)(\exp(-iqz)d^4z$ is a Fourier transformation (a form factor) of the function $f(x)$, that describes the space-time distribution of sources.

Experimentally the correlation effect is determined by the expression:

$$S(q_i) = W(p_1, p_2)/W_{bg}(p_1, p_2) = 1. + \lambda\, H(q_i)$$

where W_{bg} is a background of two-particle spectrum, λ is an additional parameter. In a case of full interference $H(q_i)$ has a value 1 at p_1-p_2 ($H(0)=1$) and tends to 0 as p_1-p_2 increases. $MAX(S(q_i)) = 2$.

Within the framework of the simple model of a radiating spherical surface of radius R with incoherent point-like oscillators of lifetime T, Kopylov and Podgoretsky [2,5] suggest the following parameterization:

$$S(q_t,q_o)=\gamma\{(1.+\delta\, q_t)(1.+4\lambda J^2_1(\beta q_t)/(\beta\, q_t)^2\}(1+(T\, q_0)^2) \qquad (1)$$

where J_1 is the first-order Bessel function, $q_0 = E_i - E_j$,

q_t is the projection square of the vector $q = (p_1 - p_2)$ onto the plane perpendicular to the total momentum of the particles pair and represents the transverse momentum difference of the two particles relatively to the direction $(p_1+ p_2)/Mod(p_1+ p_2)$, γ is a normalization factor, δ allows small variations of R at large $q_{h,t}$.

The transverse size of the source is related to β by $R_t=hc/\beta$ where T is the time of emission. It can be mentioned that any contamination of non-identity particles in the analyzed sample reduces the value of λ.

Goldhaber's et. al[1] parameterization suggests the gaussian shape of the source spatial distribution. This is a relativistic invariant form:

$$S(q_h)=\gamma(1.+\delta q_h)(1.+\lambda\Phi). \qquad (2)$$

Here

$$\Phi \sim \exp(-\alpha q_h), \qquad (3)$$

where $q_h = M_{ii}^2 - 4m_i^2$, M_{ii} is an effective mass of two particles, α is connected with effective dimension of the source as $R=hc/\sqrt{\alpha}$.

In the framework of independent one-particle sources model the correlation function S(q) for identical particles with spin 1/2 without polarization will be equal to [8] :

$$S(q) = 1.- 1/2\, |F(q)|^2. \qquad (4)$$

As follows, the correlation function S(q) of two identical fermions will approach to ½ , when $q \rightarrow 0$ (instead to 2 for identical spinless bosons). Then it should be noted , if two particles with spin ½, are polarized totally in the same direction, the correlation function, as well as the cross-section of their generation, tends to zero.

Usually the next kind of correlation function is taken:

$$S(dp)=(N/N_b)dN(dp)/dN_b(dp) \qquad (5)$$

where dp=abs(p_1- p_2), p_1 and p_2 are particles momenta, dN(dp) is the number particles pairs, $dN_b(dp)$ is the number of background pair.

Here we note , that when $p_1= p_2$, then $dp^2 = q_t^2$.

1-2. One particle from the pair comes from the intervening particle (or resonance)

Let us see now the case with two identical particles, one of them coming directly from the origin source and the other one - a decay's product of the intervening particle (or resonance) (see Fig. 1). The correlation between such particles is determined by the intervening particle decay range L as well as by the dimension R of the producing region [11] .

```
A|      B||          A|       B||
 |       |\           |        |\\
μ|      μ |          μ |       μ |
p2      p1           p1       p2
```

Fig 1.

The correlation function S(q) here is parameterized as follows:

$$S(q_t)=\gamma(1+\delta q_t)(1-(\lambda \exp(-q_t^2R_t^2- q_0^{\,2}(T^2+R_{||}/v_p^{\,2})/(1+y^{\,2}))), \qquad (6)$$

where $y=q_0\,\tau+ q\,L$,

τ , L are the intervening particle decay time and the range, T is the emitting source, v_p is the resonance velocity.

Following[14] , we shall write:

$$S(q_h)=\gamma(1.+\delta q_h)(1.-\lambda\ \Phi_{Res}\ ). \qquad (7)$$

Here

$$\Phi_{Res} =C\exp(-\alpha q_h)(1./\xi)\arctan\xi \qquad (8)$$

and $\xi = (2p_{c.m.}/\Gamma)SQRT(q_h/(4\mu^2 +q_h))$.

2-1. The proposed experiment

We propose to measure the q_h and q_t spectra of muon pairs within a range $0 \div 0.4\ (GeV/c)^2$ for the following QCD processes:

$$q_iq_j \rightarrow q_iq_j, \quad q_i\,(\text{anti}\ q_i)\rightarrow q_k\,(\text{anti}q_k)\,,$$
$$q_i\,(\text{anti}\ q_I) \rightarrow g\,g\,, \quad q_i\,g \rightarrow q_i\,g, \qquad \{A\}$$
$$g\,g\rightarrow q_k\,(\text{anti}q_k)\,, \quad g\,g\rightarrow g\,g\ .$$

Nor higher-order processes are explicitly included, nor any higher-order loop corrections to the $2\Rightarrow 2$ processes.

In addition to above QCD-JETs, the samples of the Z-bosons generations and decays:

$$f+f \rightarrow g+\gamma/Z, \qquad f+f \rightarrow Z^0+Z^0,\ f+f \rightarrow Z^0+W$$

were simulated.

Effective mass spectra for Z-bozons are shown in fig. 2.

The samples of muon pairs for 10 JETS energy and 5 samples of Z-decays to $\mu+$, μ^--mesons were generated with PYTHIA 5-7.

The next selection cuts were used:

1. P_t of muons: [5 ÷ 20] GeV/c;
2. $\Delta q_h < 0.4$ GeV/c. Δq_h – distribution is shown in Fig. 3.
3. Muons production radius precision must be not more than 10 %.

The q_h and q_t errors are nearly the same as ones for p_t . We note here, that the CMS –detector (matching with a central tracker) will have the following expecting p_t - resolution [10] :

for $0< |\eta|<2.4$ relative errors $\Delta p_t/p_t$ are estimated as [0.5÷1.]% for p_t <10GeV/c , as [1.5÷5.] % for p_t <100GeV/c and as [5. ÷20.] % for $p_t \sim 1$ TeV/c.

So, the necessary resolution may be reached only after matching with central tracker for the muons with p_t <20 GeV/c.

2.2 Results

2.2.1. Errors

From the point of view of the Q_h -errors for muon pairs from E_{JET} =2000 GeV nearly 1/3 of all events have the suitable errors. Therefore the factor that will reduce the statistics will be 0.31 for all events from [0. ÷0.4] $(GeV/c)^2$ interval. Now we get the estimation for the statistics required for radius measuring with resolution not exceeding 10%, if we take in account the next demands:

$s=n_{eff}/N_{pair} = 10^{-2}$, the upper limit of the interference effect;

k=3 is the number of standard deviations of the effect above the background;

$\delta_q = 0.01(Gev/c)^2$ is the disposition of maximum;

$q_s = 0.04\ (GeV/c)^2$ is a studying interval of q.

Thus: $N_{tot} = 3k^2\, \delta_q / (q_s\, s^2) = 10^5$ muon pairs, or 10^5 Z-decays.

2.2.2. Background problem

In quantitative studies on the interference signal, the question of what is to be taken as a background is of importance. In most publications I_{BGD} is created from the pairs of unlike charged particles. This background is obviously not free from dynamic correlation. To avoid this, we take advantage of a generated background. 10 000 muon pairs for 10 JETS energy were generated with PYTHIA 5.7 and later used for background investigations.

In the tables 1÷3 are represented the numbers of tried events at E_{jet}=50, 500, 2000 GeV and the numbers of events, received at the end for each of the simulated processes.

Table 1. E_{jet}= 50 GeV

Processes	Cross section (mb)	Generated	Good events
q_iq_j →--- q_iq_j	9.278E-04	24649	
q_i (anti q_i-)→q_k(antiq_k)	1.256E-05	322	
q_i (anti q_I) →---g g	1.257E-05	341	
q_i g -→--- q_i g	8.057E-04	211160	
g g-→--- q_k (antiq_k)	6.287E-04	16549	
g g-→---- g g	1.722E-02	454301	
All incl. subprocesses	2.686E-02	707322	384

Table 2 E_{jet}= 500 GeV

Processes	Cross section (mb)	Generated	Good
q_iq_j →--- q_i q_j	1.437E-07	55207	
q_i (anti q_i-)→q_k(antiq_k)	3.634E-09	1448	
q_i (anti q_I) →---g g	2.447E-09	952	
q_i g -→--- q_i g	4.720E-07	181135	
g g-→--- q_k (antiq_k)q_i	1.929E-08	7365	
g g----- g g	3.390E-07	129637	
All incl. subprocesses	9.801E-07	375744	209

Table 3. E_{jet}= 2000 GeV

Processes	Cross section (mb)	Generated	Good events
$q_i q_j \rightarrow$--- $q_i\, q_j$	4.168E-11	236989	
q_i (anti q_i-)$\rightarrow q_k$(antiq_k)	4.471E-13	2546	
q_i (anti q_I) $\rightarrow$---g g	2.458E-13	1403	
q_i g --$\rightarrow$--- q_i g	3.055E-11	173798	
g g-$\rightarrow$--- q_k (antiq_k)q_I	2.808E-13	1598	
g g-$\rightarrow$---- g g	4.354E-12	24519	
All incl. subprocesses	7.756E-11	440853	169

2.2.3 Counting rates for CMS

The collecting rates of the subprocesses {A} with the minimum bias trigger for certain JET's energy are shown in Tabl.4.

Table 4.

E_{-jet} (GeV)	Number of events per one Sec
50	10^2
200	$4x10^{-2}$
500	$3x10^{-3}$
1000	$5x10^{-5}$
2000	$1x10^{-7}$

Analysing the proposed Tables, we can see that 1000 Sec are necessary to obtain, for example, 10^5 events and ≈ 100 Z-decays !

2. Source radius for Z – bosons

To reach the producing space dimension of Z-bozons, we simulated at 1 Gev a sample of events , containing Z-bosons, which further suffer a decay into muons or into muons and other particles. The pairs of muons were constituted by combination from from Z-sample and from the simulated QCD-JET . Simulated q_h - spectra from the 1 TeV jets for different values of muons pairs are presented in the Fig. 4.

Interference effects ,corresponding to different values of source radius, carried in q_h-spectra by (5) . As we see from Fig. 5, for small values of producing radius {0.25, 0.5, or 1.} fm, an essential difference between two corresponding q_h-distributions can be observed. This result allows us to determine the producing region of Z-bosons until 1fm.

CONCLUSION

It is shown, that interference effect, coming from Z-bosons, can be scrupulous studied, when Z-bosons are produced within small space regions. The space radius of Z-bozons production may be determined as satisfactory, if Z-bosons are born in the region of ~ 1fm.

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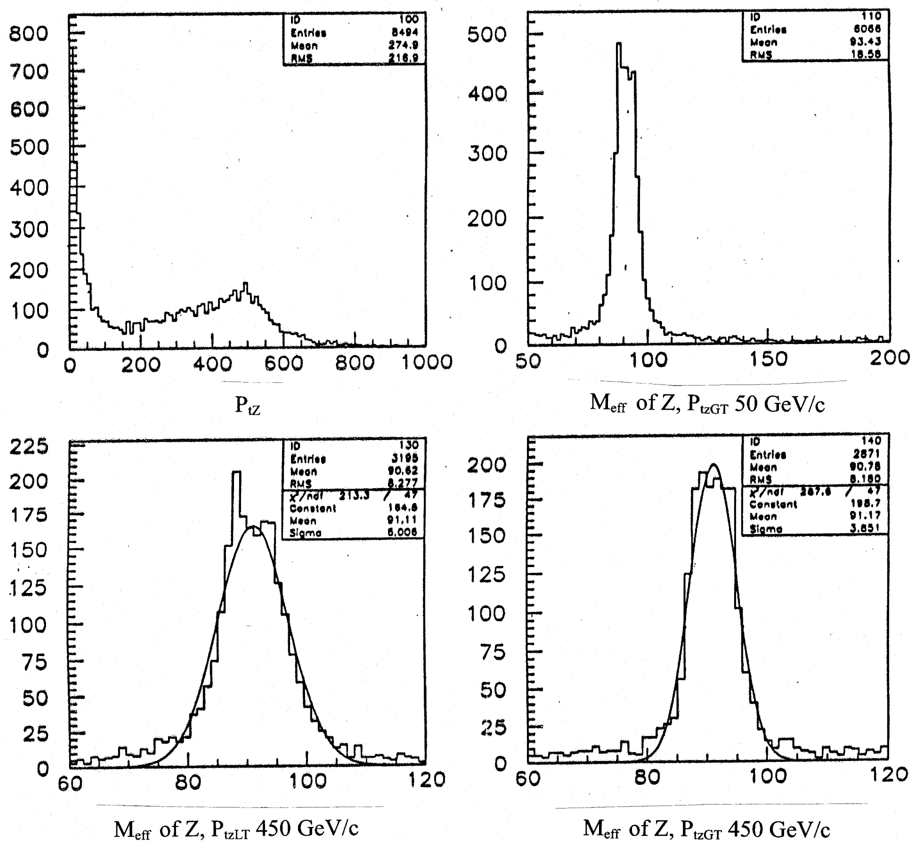

Fig. 2. Effective mass spectrum of simulated Z-bozons.

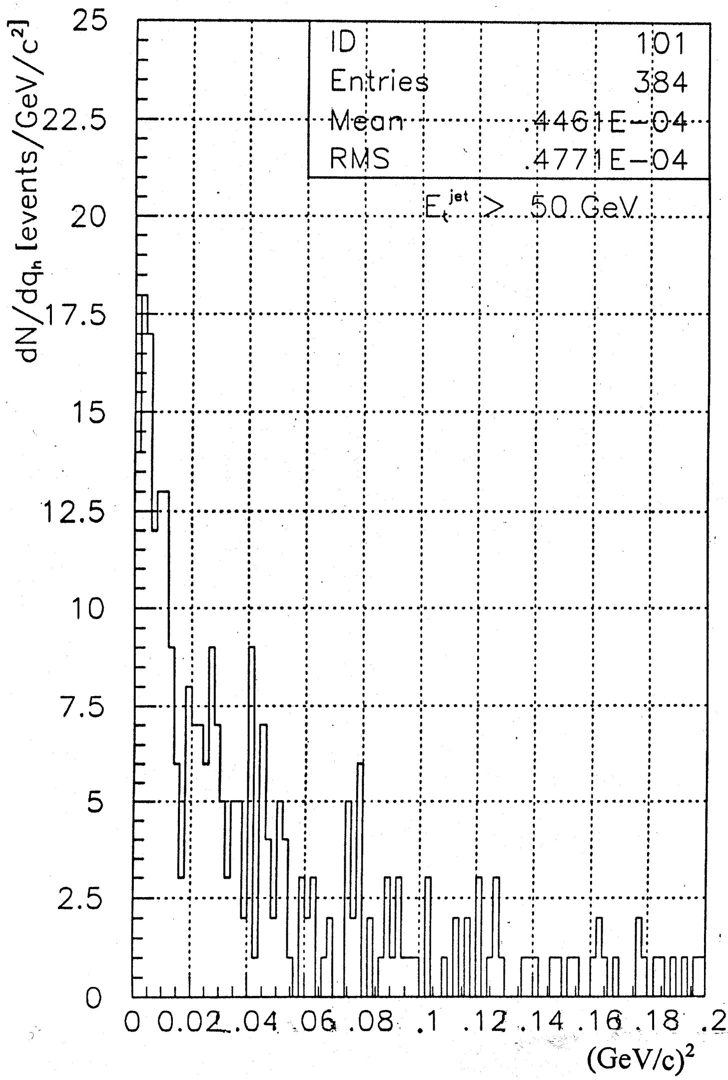

Fig. 3. Δq_h – distribution

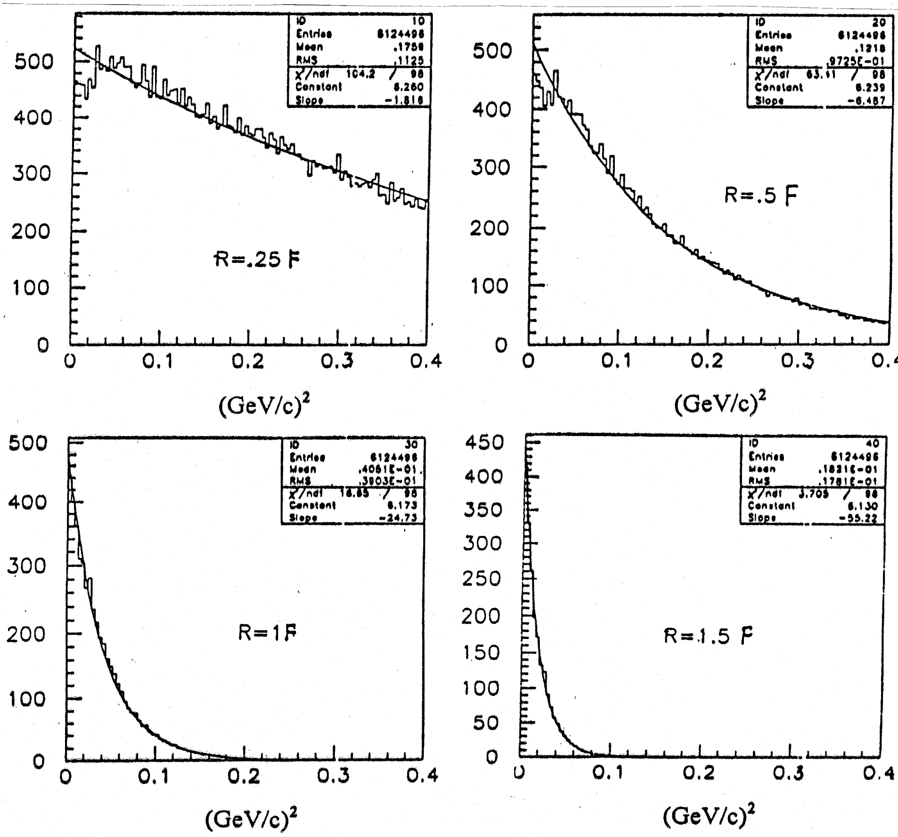

Fig. 4. q_h –distributions of Φ - functions for different values of source dimension R.

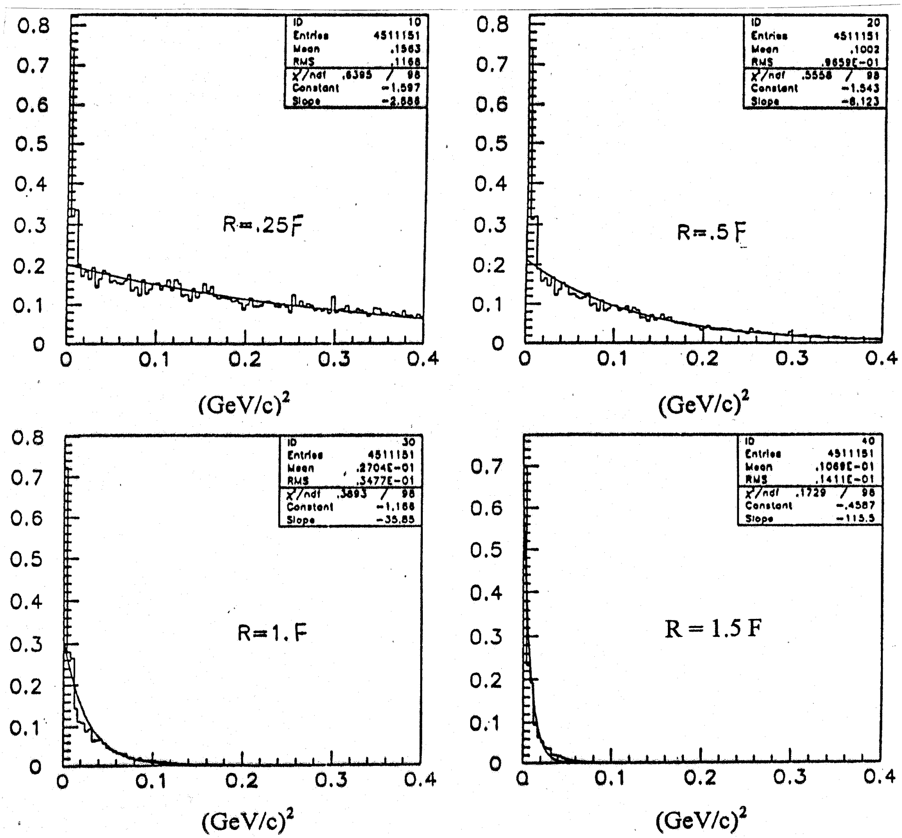

Fig. 5. q_h –distributions of Φ_{Res} - functions for different values of source dimension R.

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Определение радиуса области рождения Z-бозонов
методом интерференции тождественных частиц

Метод определения радиуса области рождения Z-бозонов основан на интерференционном эффекте двух идентичных мюонов, один из которых происходит от Z-бозона, а другой — взят из фона. Разница в четырехмерных импульсах двух партнеров пары стремится к нулю. На основе большого числа моделированных пар, проходящих через CMS-детектор, показано, что радиус области рождения Z-бозонов в пределах 1 фм может быть определен с удовлетворительной точностью.

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Determination of Z-Bozon Source Radius Production
by Identical Particles Interferometry

The method of determination of Z-bozon source radius production is based on interference effect between two identical muons, one of which comes from Z-bozon, and the other is taken from the background. The difference between the four-momenta of these two partners of the pair tends to zero. It is shown on the basis of simulated samples of muon pairs passing through the CMS-detectors, that the Z-bozon sources radius of ~ 1 fm can be clearly determined.

The investigation has been performed at the Laboratory of High Energies, JINR.

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