Update on measurement of Bose-Einstein Correlations

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Two particle Correlations

- Let $W(p_1, p_2, x_1, x_2)$ be a Wigner function.
- For identical particles observed distributions of momentum takes the form:

$$\Omega(p_1,p_2) = \int dx_1 dx_2 (W(p_1,p_2,x_1,x_2) + e^{(x_1-x_2)(p_1-p_2)} W(P_{12},P_{12},x_1,x_2)) \equiv \Omega_0(p_1,p_2)[1 + C(p_1,p_2)] \quad (1)$$

- Space distribution $x_1 - x_2$ can be access via $C(p_1, p_2)$.

Two particle Correlations

- Assuming no correlation in space Wiger function can be factorised:

$$W(p_1, p_2, x_1, x_2) = \Omega_0(p_1, p_2) w(p_1, x_1) w(p_2, x_2) \quad (2)$$

- This simplifies eq.(1): $\Omega(p_1, p_2) = \Omega_0(p_1, p_2)[1 + \int dx W(P_1 2, x) e^{ix(p1-p2)}]$
- The 2 body correlation can be written as:

$$C_2(p_1, p_2) = |\int dx W(P_{12}, x) e^{ix(p1-p2)}|^2 \quad (3)$$

- All LEP experiments measured BEC.

Goldhaber parametrisation

Following Goldhaber[1] we can parametrize the correlation function:

$$C_2(q_1, q_2) = N(1 \pm \lambda e^{-Q^2 R^2}) \tag{4}$$

,where $Q = q_1 - q_2$, R radius of the source, λ chaotic parameter, N normalization. Second order correlation function is defined:

$$C_2(q_1, q_2) = \frac{\mathcal{P}(q_1, q_2)}{\mathcal{P}(q_1)\mathcal{P}(q_2)} \equiv \frac{\mathcal{P}(q_1, q_2)}{\mathcal{P}(q_1, q_2)^{ref}} \tag{5}$$

[1] Goldhaber et. al. Phys. Rev. Lett 3 (1959)

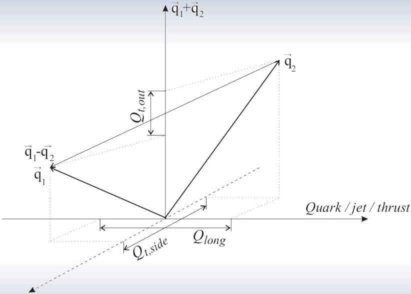
Reference samples

$\mathcal{P}(q_1, q_2)^{ref}$ can be estimated from reference samples:

1. MC without BEC.
   - Absence of Coulomb effects in generator.
   - Data-MC agreement.
2. Unlike-sign charge particles
   - Resonances contribution
   - Derived from data
3. Event-mixing
   - Mixing event by events.
   - PV mixing.

LCMS

- Longitudinal Centre-of-Mass System(LCMS) is defined as a system where sum of 3-momenta $\overrightarrow{q_1} + \overrightarrow{q_2}$ is perpendicular to a reference axis(jet, thrust, z).
- Q^2 can be written:
  $Q^2 = 1 + \lambda e^{-Q^2_{t,out} R^2_{t,out} - Q^2_{t,side} R^2_{t,side} - Q^2_{t,long} R^2_{t,long}} = 1 + \lambda e^{-Q^2_{t,\perp} R^2_{t,bot} - Q^2_{t,\parallel} R^2_{t,\parallel}}$
- One can perform 1,2 or 3 dim analysis.



LEP and CMS results

LEP *(pions)*: *1-dimensional analyses*

Hadron-hadron	Reference sample				Experiment
	Unlike		MC or event-mixed		
	R [fm]	λ	R [fm]	λ	
$\pi^\pm\pi^\pm$ (BEC)	0.82 ± 0.04	0.48 ± 0.03	0.52 ± 0.02	0.30 ± 0.01	ALEPH
	0.83 ± 0.03	0.31 ± 0.02	0.47 ± 0.03	0.24 ± 0.02	DELPHI
	–	–	0.46 ± 0.02	0.29 ± 0.03	L3
	0.96 ± 0.02	0.67 ± 0.03	0.79 ± 0.02	0.58 ± 0.01	OPAL
$\pi^0\pi^0$ (BEC)	–	–	0.31 ± 0.10	0.16 ± 0.09	L3
	–	–	0.59 ± 0.11	0.55 ± 0.15	OPAL

LEP *(pions)*: *2- and 3- dimensional analyses*

$R_{t,out}$ [fm]	$R_{t,side}$ [fm]	$R_\perp$ [fm]	$R_\parallel$ [fm]	Experiment
–	–	0.47 ± 0.01	0.77 ± 0.01	ALEPH
–	–	0.79 ± 0.01	0.87 ± 0.02	ALEPH
–	–	$0.53 \pm 0.02 \pm 0.07$	$0.85 \pm 0.02 \pm 0.07$	DELPHI
$0.53 \pm 0.02^{+0.05}_{-0.06}$	$0.59 \pm 0.01^{+0.03}_{-0.13}$	–	$0.74 \pm 0.02^{+0.04}_{-0.03}$	L3
$0.65 \pm 0.01^{+0.02}_{-0.12}$	$0.81 \pm 0.01^{+0.02}_{-0.03}$	–	$0.99 \pm 0.01^{+0.03}_{-0.02}$	OPAL

LEP and CMS results

LEP: *1-dimensional analyses*

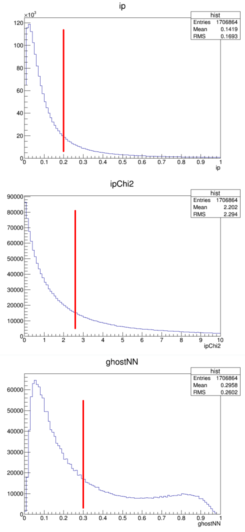
Hadron-hadron	R [fm]	λ	Experiment
$K^{\pm}K^{\pm}$ (BEC)	$0.48 \pm 0.04 \pm 0.07$	$0.82 \pm 0.11 \pm 0.25$	DELPHI [47]
	$0.56 \pm 0.08\ ^{+0.07}_{-0.06}$	$0.82 \pm 0.22\ ^{+0.17}_{-0.12}$	OPAL [48]
$K^0_S K^0_S$ (BEC)	$0.65 \pm 0.07 \pm 0.15$	$0.96 \pm 0.21 \pm 0.40$	ALEPH (MC ref.) [49]
	$0.57 \pm 0.04 \pm 0.14$	$0.63 \pm 0.06 \pm 0.14$	ALEPH (mix ref.) [50]
	$0.55 \pm 0.08 \pm 0.12$	$0.61 \pm 0.16 \pm 0.16$	DELPHI [47]
	$0.76 \pm 0.10 \pm 0.11$	$1.14 \pm 0.23 \pm 0.32$	OPAL [51]
$\bar{p}\bar{p}$ (FDC)	$0.11 \pm 0.01 \pm 0.01$	$0.49 \pm 0.04 \pm 0.08$	ALEPH [50]
	$0.142 \pm 0.035 \pm 0.047$	$0.76 \pm 0.16 \pm 0.29$	OPAL [52]
$\Lambda\Lambda$ (FDC)	$0.11 \pm 0.02 \pm 0.01$	–	ALEPH [53]
$\Lambda\Lambda$ (FDC)	$0.17 \pm 0.13 \pm 0.04$	–	ALEPH [53]
(spin analyses)	$0.11\ ^{+0.05}_{-0.03} \pm 0.01$	–	DELPHI [54]
	$0.19\ ^{+0.37}_{-0.07} \pm 0.02$	–	OPAL [55]

CMS (2010): *1-dimensional analysis, all charged particles, BEC*

Mult. range	p val. (%)	C	λ	r (fm)	δ (10^{-3} GeV^{-1})
2–9	97	0.90±0.01	0.89±0.05±0.20	1.00±0.07±0.05	72±12
10–14	38	0.97±0.01	0.64±0.04±0.09	1.28±0.08±0.09	18± 5
15–19	27	0.96±0.01	0.60±0.04±0.10	1.40±0.10±0.05	28± 5
20–29	24	0.99±0.01	0.59±0.05±0.17	1.98±0.14±0.45	13± 3
30–79	28	1.00±0.01	0.69±0.09±0.17	2.76±0.25±0.44	10± 3

Preselection

1. MiniBias Stripping lines.
2. 2011 data.
3. Select all particles that come from PV with cuts:
   - $TRKChi2 < 2.6$
   - $IP < 0.2mm$
   - $IPCHI2 < 2.6$
   - $PIDNN(\pi, K) > 0.25$
   - $ghostNN < 0.3$
   - $P > 0.2GeV$
   - $Pt > 0.1GeV$



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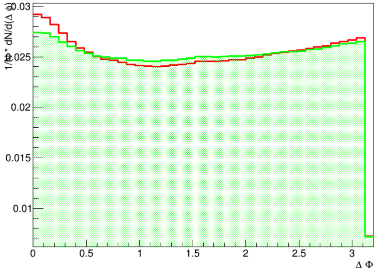
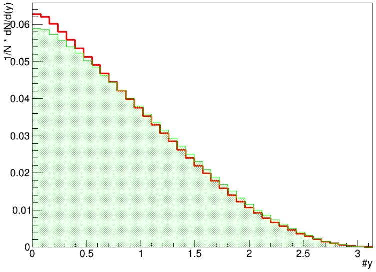
Results in 2011 data

We can rewrite Q in form:

$$Q = \sqrt{-2q_{\perp 1}q_{\perp 2}[cosh(y_1 - y_2) - cos(\phi_1 - \phi_2)]} \qquad (6)$$

,where y_i are the pseudo-rapidity, ϕ_i are azimuthal angles. We see BEC





Generalization of two body correlations

Assuming no correlations in space the Wigner function can be expressed)analogy to eg.(2):

$$W(p_1, p_2, p_3, x_1, x_2, x_3) = \Omega_0(p_1, p_2, p_3) w(p_1, x_1) w(p_2, x_2) w(p_3, x_3) \quad (7)$$

This leads to correlation function:

$$C_3(p1, p2, p3) = |\widehat{w}(P_{12}, \Delta_{12})|^2 + |\widehat{w}(P_{23}, \Delta_{23})|^2 + |\widehat{w}(P_{31}, \Delta_{31})|^2 + 2\mathcal{R}[\widehat{w}(P_{12}, \Delta_{12})\widehat{w}(P_{23}, \Delta_{23})\widehat{w}(P_{31}, \Delta_{31})] \quad (8)$$

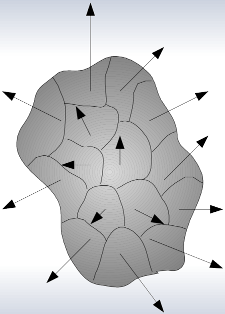
,where $\Delta_{ij} = p_i - p_j$, and $\widehat{w}(P_{ij}, \Delta_{ij}) = \int dx_i dx_j W(P_{ij}, x) e^{ix\Delta_{ij}}$

Probing Cluster Model

Let us consider simple ansatz:

$$W(p_1, p_2, x_1, x_2) = \Omega_0(p_1, p_2)[V(x_1)V(x_2) + \alpha V_2(x_1, x_2)] \quad (9)$$

,where $V(x) = \int \phi(x - X)V_c(X)dX$,
$V_2 = \int V_c(X)\phi(x_1 - X)\phi(x_2 - X)dX$



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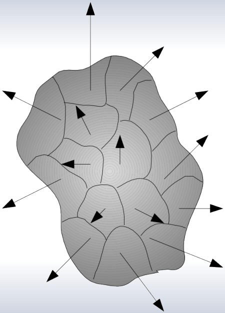


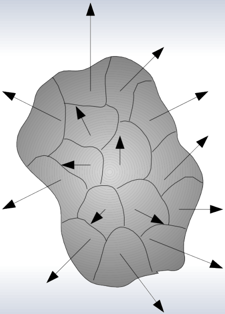
,where $V(x) = \int \phi(x - X)V_c(X)dX$,
$V_2 = \int V_c(X)\phi(x_1 - X)\phi(x_2 - X)dX$
$V_c(X)$ is the distribution of clusters in space.
$\phi(x - X)$ is the shape of the cluster.
$V(x_1)V(x_2)$ emission from two clusters.
$V_2(x_1, x_2)$ emission from single cluster.

Probing Cluster Model

The correlation function for this ansatz takes form:

$$C(p_1, p_2) = |\widehat{V_c}(\Delta_{12})\widehat{\phi}(\Delta_{12})|^2 + \alpha|\widehat{\phi}(\Delta_{12})|^2 \quad (10)$$

where $\widehat{\phi}(\Delta_{12}) = \int dx \phi(x) e^{ix\Delta_{1}2}$



Conclusions

- BEC clearly visible in data.
- Analysis systematically dominated.
- Enought events to perform first measurement of 3 body correlations.