# Inter-W BEC
# (or lack thereof)

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# Inter-W BEC

Method to study inter-W BEC:

Chekanov, De Wolf, Kittel; Eur. Phys. J. C6, 403 (1999)

Uses two-particle density in 4-momenta $p_1$, $p_2$

$$\rho(p_1, p_2) = \frac{1}{N_{\mathrm{ev}}} \frac{\mathrm{d}n_{\mathrm{pairs}}(p_1, p_2)}{\mathrm{d}p_1\, \mathrm{d}p_2}$$

If independent decay, $\mathrm{W}^+\mathrm{W}^- \to \mathrm{q\bar{q}q\bar{q}}$ has

$$\begin{aligned} \rho_{\mathrm{4q}}(p_1, p_2) = & \quad \rho^+(p_1, p_2) && 1,2 \text{ from } \mathrm{W}^+ \\ + & \quad \rho^-(p_1, p_2) && 1,2 \text{ from } \mathrm{W}^- \\ + & \quad \rho^+(p_1)\rho^-(p_2) && 1 \text{ from } \mathrm{W}^+,\ 2 \text{ from } \mathrm{W}^- \\ + & \quad \rho^+(p_2)\rho^-(p_1) && 1 \text{ from } \mathrm{W}^-,\ 2 \text{ from } \mathrm{W}^+ \end{aligned}$$

Or, since $\rho^+ = \rho^- = \rho_{\mathrm{2q}}$,

$$\rho_{\mathrm{4q}}(p_1, p_2) = 2\rho_{\mathrm{2q}}(p_1, p_2) + 2\rho_{\mathrm{2q}}(p_1)\rho_{\mathrm{2q}}(p_2)$$

If inter-W BEC exist, W decays are *not* independent

$\Longrightarrow$ this relation does *not* hold.

Experimentally measure

- $\rho_{\mathrm{4q}}(p_1, p_2)$ from $\mathrm{e^+e^-} \to \mathrm{W^+W^-} \to \mathrm{q\bar{q}q\bar{q}}$
- $\rho_{\mathrm{2q}}(p_1, p_2)$ from $\mathrm{e^+e^-} \to \mathrm{W^+W^-} \to \mathrm{q\bar{q}}\ell\nu$
- $\rho_{\mathrm{2q}}(p_1)\rho_{\mathrm{2q}}(p_2)$ from $\rho_{\mathrm{mix}}(p_1, p_2)$ obtained by mixing $\mathrm{e^+e^-} \to \mathrm{W^+W^-} \to \ell^+\nu\mathrm{q\bar{q}}$ and $\mathrm{q\bar{q}}\ell^-\nu$ events

# Inter-W BEC – $\Delta\rho$

So, if W decays are independent,

$$\rho_{4q}(p_1, p_2) = 2\rho_{2q}(p_1, p_2) + 2\rho_{mix}(p_1, p_2)$$

Hence, test independence by subtracting r.h.s. from l.h.s.

$$\Delta\rho(p_1, p_2) = \rho_{4q}(p_1, p_2) - [2\rho_{2q}(p_1, p_2) + 2\rho_{mix}(p_1, p_2)]$$

Other inter-W correlations are possible,
*e.g.*, color reconnection
However, they affect all pairs of particles
and BE affects only identical bosons
And BE effects are mostly at small $Q^2 = -(p_1 - p_2)^2$
Therefore, compare

| | | |
|---|---|---|
| | $\Delta\rho_{\pm\pm}(Q)$ | same sign |
| to | $\Delta\rho_{+-}(Q)$ | opposite sign |

$$\delta\rho(Q) = \Delta\rho_{\pm\pm}(Q) - \Delta\rho_{+-}(Q)$$

Assuming contributions to $\Delta\rho$ are additive
and charge-independent,
$\delta\rho$ is just the contribution of inter-W BE to $\rho_{4q}$:

$$\delta\rho(Q) = \Delta\rho^{BE}(Q)$$

# Inter-W BEC – $D$ and $D'$

Recall, if independent W decay,

$$\rho_{\mathrm{4q}}(p_1, p_2) = 2\rho_{\mathrm{2q}}(p_1, p_2) + 2\rho_{\mathrm{mix}}(p_1, p_2)$$

Instead of subtracting r.h.s. from l.h.s. to get $\Delta\rho$, divide:

$$\begin{aligned} D(Q) &= \frac{\rho_{\mathrm{4q}}(Q)}{2\rho_{\mathrm{2q}}(Q) + 2\rho_{\mathrm{mix}}(Q)} \\ &= \frac{\Delta\rho(Q)}{2\rho_{\mathrm{2q}}(Q) + 2\rho_{\mathrm{mix}}(Q)} + 1 \end{aligned}$$

and compare $D_{\pm\pm}$ to $D_{+-}$

To minimize effects of non-BE correlations,
detector systematics, *etc.*.,
use double ratio:

$$D'(Q) = \frac{D(Q)}{D_{\mathrm{MC,no\,BE}}(Q)}$$

and compare $D'_{\pm\pm}$ to $D'_{+-}$

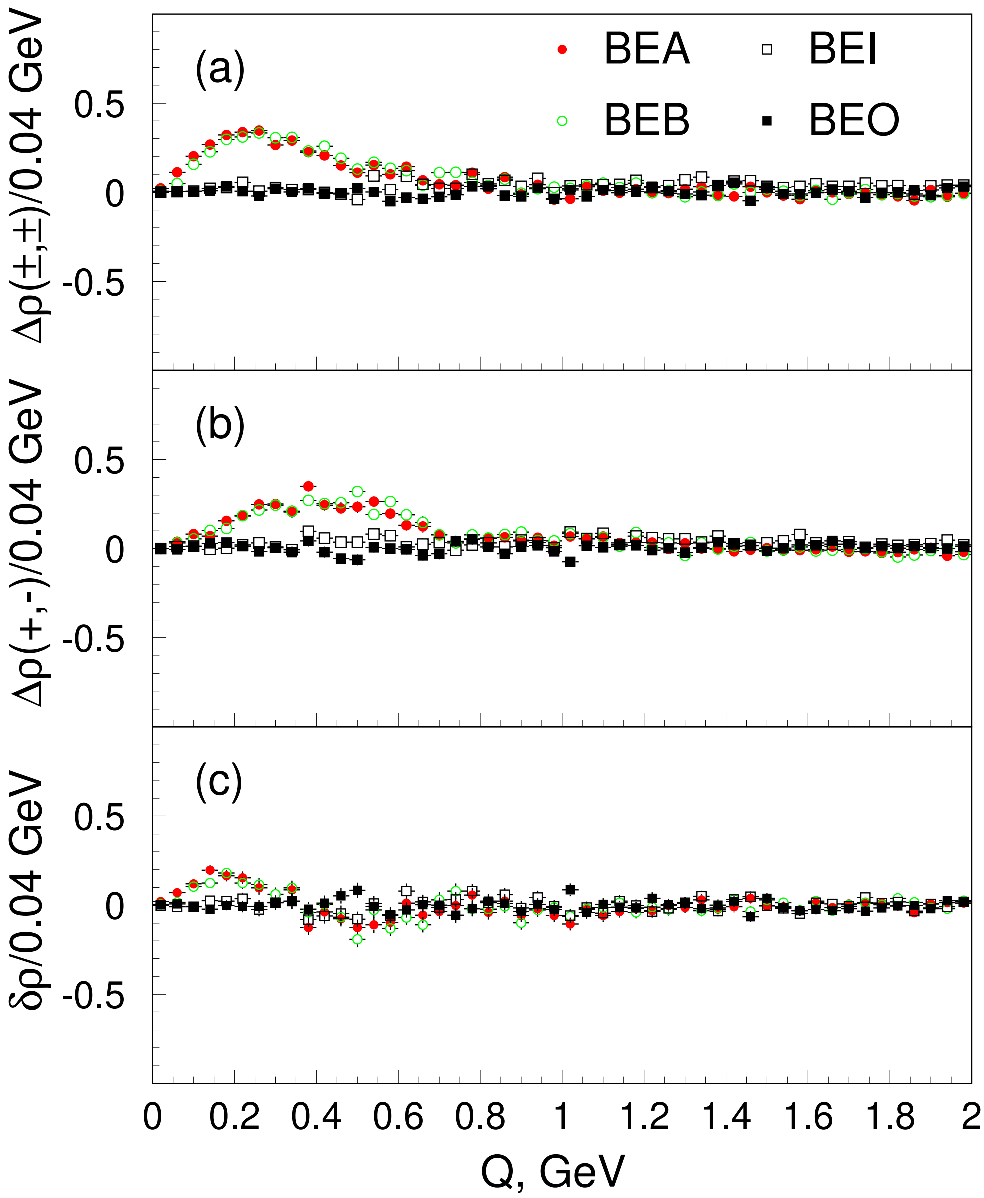
If W decays are independent,

$$\Delta\rho = 0 \qquad\qquad D = D' = 1$$

# Monte Carlo test

First test on generator-level PYTHIA (LUBOEI)

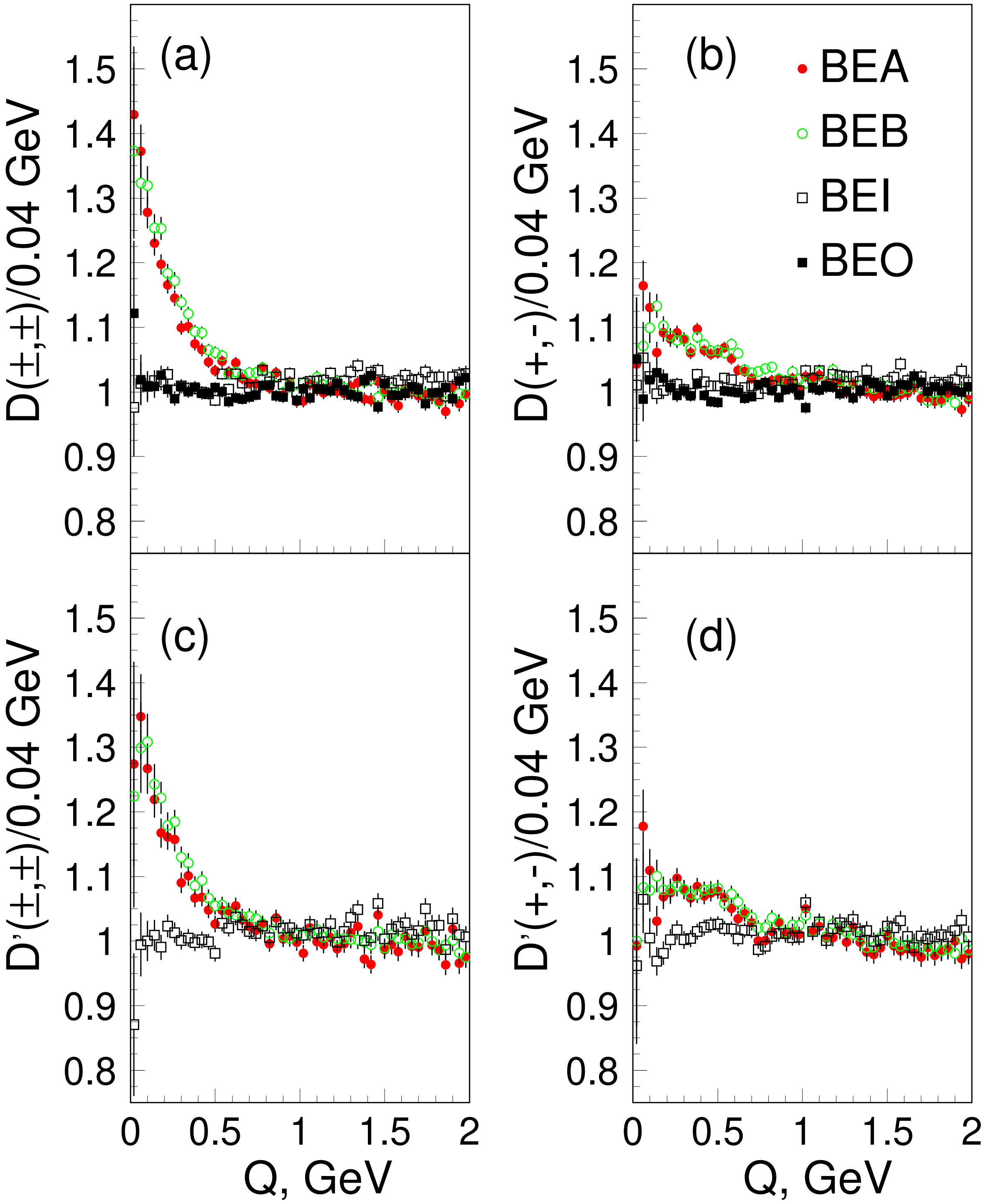
BEA – BEC between all particles
BEB – BEC only for particles from different W's
BEI – BEC only for particles from same W
BEO – no BEC




enhancement at small $Q$ only if BE from different W's as expected

enhancement at larger $Q$ if BE from different W's (LUBOEI!)

# Monte Carlo test




If inter-W BEC,

- Large enhancement at small $Q$ for both $D$,$D'_{\pm\pm}$
- Smaller enhancement extending to larger $Q$ for $D$,$D'(+-)$

# Data

1998 189 GeV $\mathcal{L}$=176.4 pb$^{-1}$

After selection,

1026 semi-hadronic events ($q\bar{q}\ell\nu$)

1514 fully hadronic events ($q\bar{q}q\bar{q}$)

| | efficiency (%) | background (%) ($q\bar{q}$,ZZ,Z$e^+e^-$) |
|---|---|---|
| $q\bar{q}e\nu$ | 75.3 | 6.0 |
| $q\bar{q}\mu\nu$ | 78.5 | 4.1 |
| $q\bar{q}\tau\nu$ | 49.4 | 12.2 |
| $q\bar{q}q\bar{q}$ | 88.9 | 19.9 |

After selecting well-measured tracks,

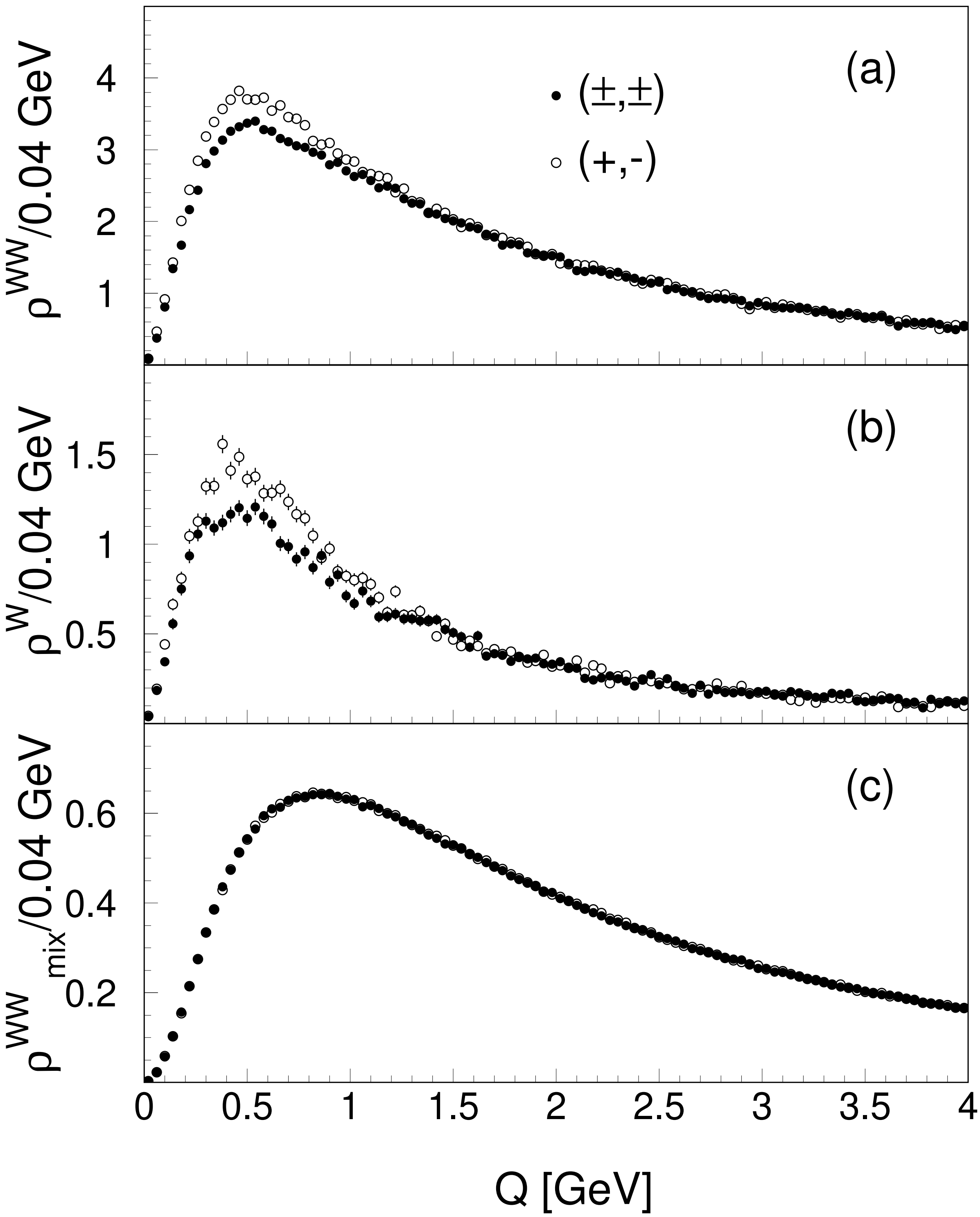
52k like-sign pairs in semi-hadronic events

302k like-sign pairs in fully hadronic events

# Data

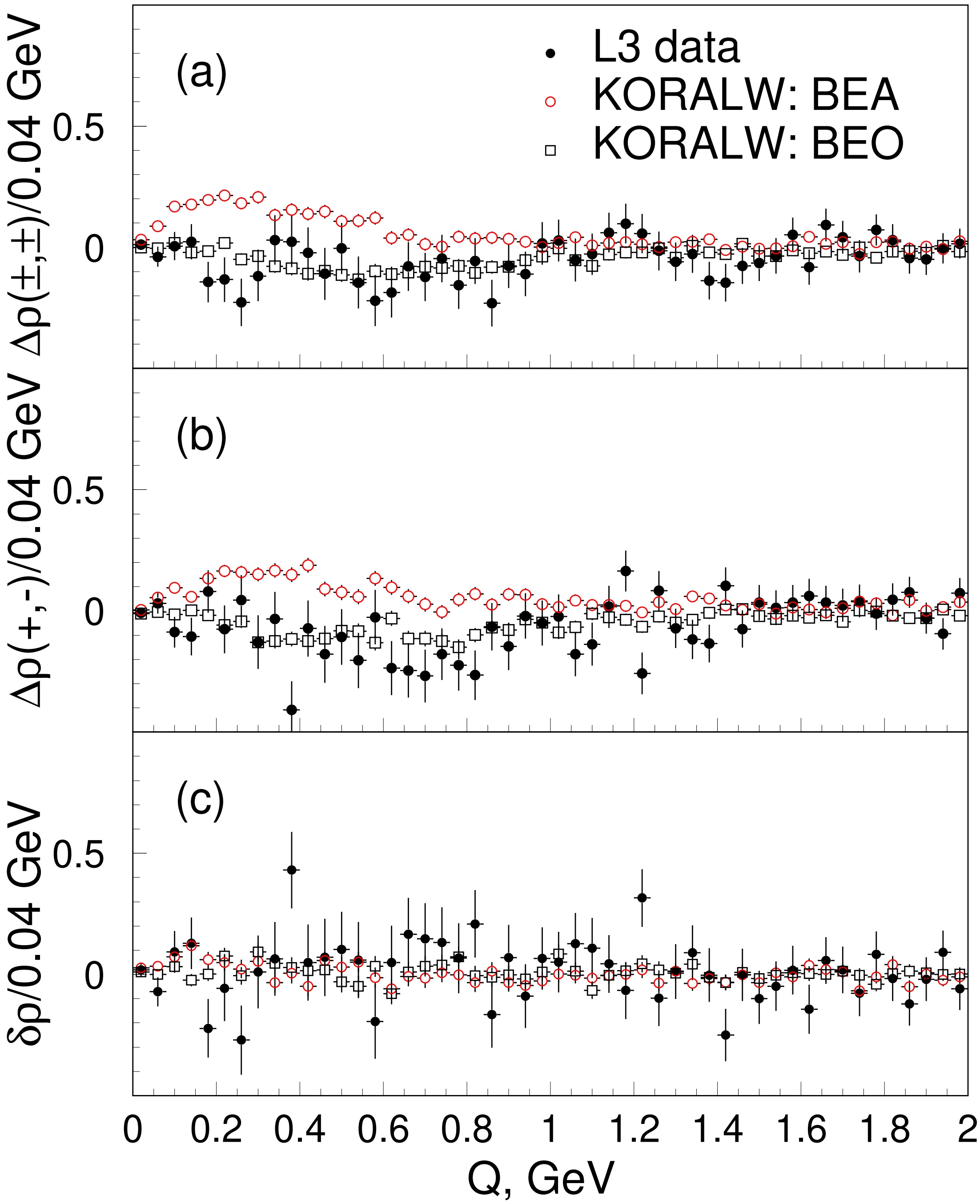
Raw data after background subtraction:

$$\Delta\rho(p_1,p_2) = \rho_{4q}(p_1,p_2) - [2\rho_{2q}(p_1,p_2) + 2\rho_{mix}(p_1,p_2)]$$



# Data

Raw data after background subtraction:
KORALW MC at detector level
- with BE (LUBOEI) for all particles (BEA)
- no BE (BEO)




Data consistent with no BE MC and with $\Delta\rho = 0$
MC with BE has $\Delta\rho \neq 0$ at small $Q$

# Data

Raw data after background subtraction:
KORALW MC at detector level

- with BE (LUBOEI) for all particles (BEA)
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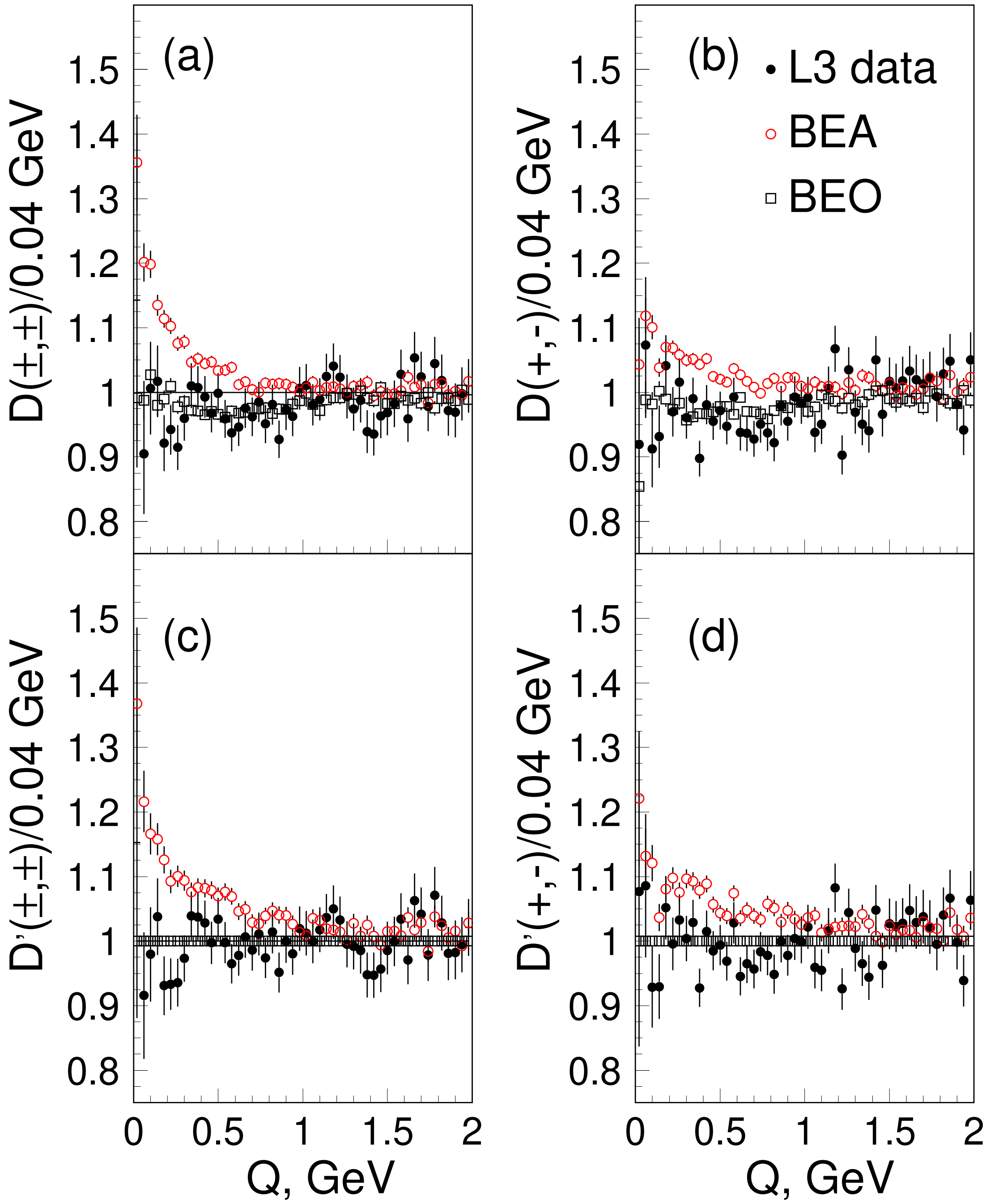


Data consistent with no BE MC and with $D = D' = 1$
MC with BE has $D \neq 1$ at small $Q$

# Data – KORALW comparison

KORALW
- with BE (LUBOEI) for all particles (BEA)
- no BE (BEO)

| | $0 < Q < 2$ GeV | | $0 < Q < 0.6$ GeV | |
|---|---|---|---|---|
| | $\chi^2$/NDF | C.L. (%) | $\chi^2$/NDF | C.L. (%) |
| $\Delta\rho_{\pm\pm}$, BEA | 144/49 | $3 \cdot 10^{-9}$ | 102/14 | $2 \cdot 10^{-13}$ |
| $\Delta\rho_{\pm\pm}$, BEO | 39/49 | 85 | 15/14 | 39 |
| $\Delta\rho_{+-}$, BEA | 154/49 | $9 \cdot 10^{-11}$ | 68/14 | $3 \cdot 10^{-6}$ |
| $\Delta\rho_{+-}$, BEO | 58/49 | 19 | 14/14 | 43 |
| $\delta\rho$, BEA | 52/49 | 36 | 22/14 | 8 |
| $\delta\rho$, BEO | 49/49 | 47 | 21/14 | 10 |
| $D_{\pm\pm}$, BEA | 160/49 | $1 \cdot 10^{-11}$ | 115/14 | $8 \cdot 10^{-16}$ |
| $D_{\pm\pm}$, BEO | 39/49 | 85 | 15/14 | 37 |
| $D'_{\pm\pm}$, BEA | 136/49 | $5 \cdot 10^{-8}$ | 97/14 | $2 \cdot 10^{-12}$ |
| $D'_{\pm\pm}$, BEO | 40/49 | 84 | 15/14 | 36 |

stat. errors only

KORALW with LUBOEI excluded

# Summary

- At small $Q$ data and MC without BE have

$$\begin{aligned} \Delta\rho_{\pm\pm}(Q) &= 0 \\ D_{\pm\pm}(Q) &= 1 \\ D'_{\pm\pm}(Q) &= 1 \end{aligned}$$

- Hence, no evidence for inter-W BEC

- KORALW with LUBOEI excluded

$D'_{\pm\pm}(Q)$ distribution is similar to what DELPHI has studied (Moriond)

Fit $$D'_{\pm\pm}(Q) \propto 1 + \Delta e^{-k^2 Q^2}$$

L3 : $\Delta = -0.063 \pm 0.039$ (stat. only)
DELPHI : $\Delta = \ 0.073 \pm 0.025 \pm 0.018$

Both are preliminary results
L3 has only statistical errors
But assuming L3 systematics $\approx$ DELPHI, $\sim 3\sigma$ difference

Ref.: L3 Note 2405
http://l3www.cern.ch/conferences/EPS99/papers/note_2405.ps