Measurements of Two-Particle Correlations in pp Collisions with CMS at the LHC

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on behalf of the CMS collaboration

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Outline

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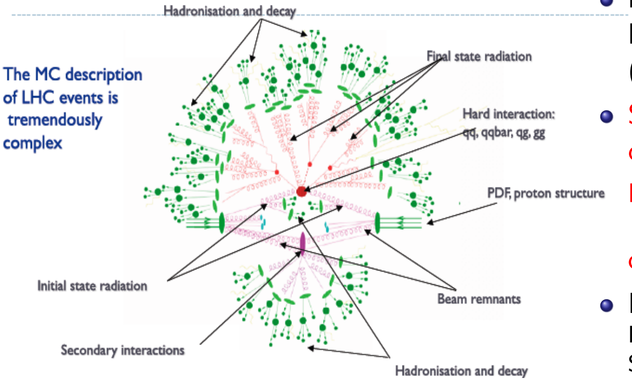
1. Two-Particle Angular Correlations
   - Analysis Technique
   - Independent Cluster Model
   - Results
2. Bose–Einstein Correlations
   - Measurement
   - Signal cross check with PID
   - Results
3. Conclusion

Motivation



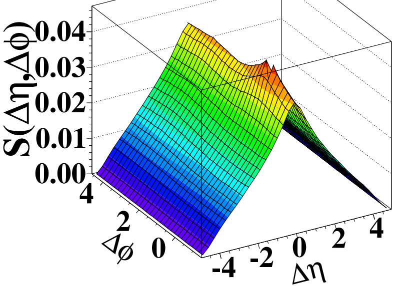
- in p-p, particles tend to be produced correlated (clusters)
- Study of angular correlations in soft particle production (left fig. outer "shell") give information on hadronization process;
- Extensive studies at
  ISR $25 \leq \sqrt{s} \leq 62$ GeV,
  SPS $\sqrt{s} = 200, 546, 900$ GeV
  RICH $\sqrt{s} = 200, 410$ GeV

Analysis Technique

Signal distribution

correlated and uncorrelated pairs

$$S_N(\Delta\eta,\Delta\phi) = \frac{1}{N(N-1)}\frac{d^2N^{\text{signal}}}{d\Delta\eta d\Delta\phi}$$



Two tracks from the same event

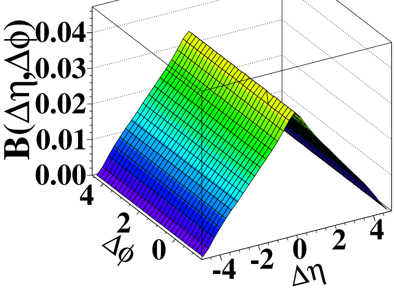
$\Delta\eta = \eta_1 - \eta_2$, $\Delta\phi = \phi_1 - \phi_2$,

for each total multiplicity (N) bin.

Background distribution

uncorrelated pairs

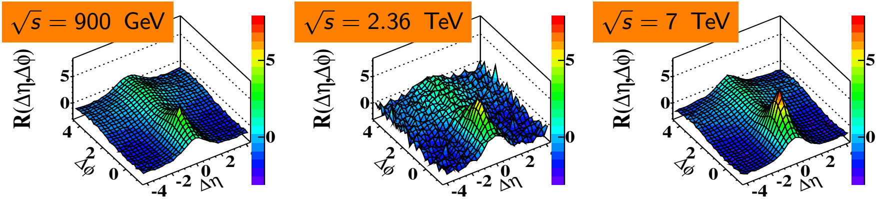
$$B_N(\Delta\eta,\Delta\phi) = \frac{1}{N^2}\frac{d^2N^{\text{mixed}}}{d\Delta\eta d\Delta\phi}$$



Two tracks from the different events with similar vertex z_{pos} and multiplicity

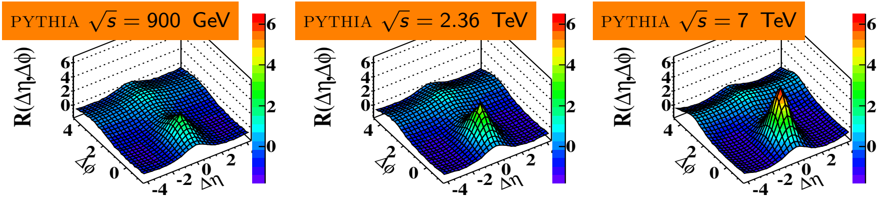
Two particle correlation: 2D

2D results: $R(\Delta\eta, \Delta\phi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\phi)}{B_N(\Delta\eta,\Delta\phi)} - 1\right)\right\rangle_N$



Gaussian like in $\Delta\eta$, broader at large $\Delta\phi$

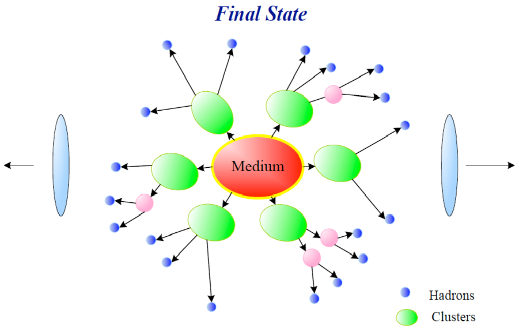
Small $\Delta\eta$ $\Delta\phi$ peak enhanced at high energy



MC (Pythia D6T) Simulation qualitatively similar to data.

Independent Cluster Model (ICM)

- Clusters are produced independently;
- Decay isotropically into hadrons in their *c.m.s.*;
- Just 2 parameters (cluster size and width) characterize short-range correlations.



- ICM provides a simple way to quantitatively parameterize two-particle correlations to compare with other experiment as well as various dynamical models such as PYTHIA.
- It is NOT a fundamental model to test against the data.

C.Quigg, Phys.Rev.D 9, 2016 (1974) - E.L.Berger, Nucl.Phys.B 85, 61 (1975).

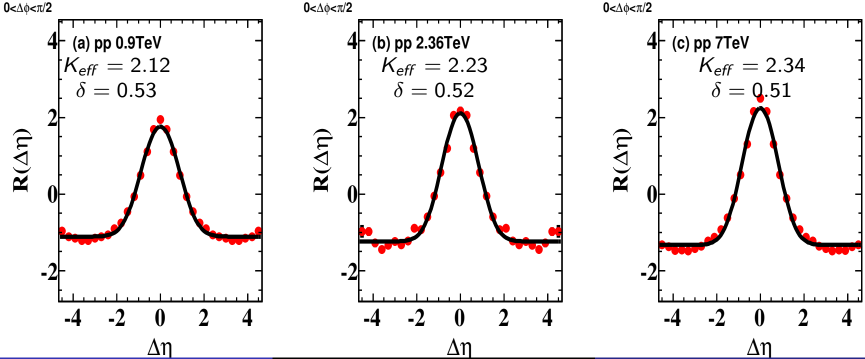
Quantitative analysis

Cluster parametrization vs $\Delta\eta$:

$$R(\Delta\eta) = (K_{eff} - 1)\left[\frac{\Gamma(\Delta\eta)}{B(\Delta\eta)} - 1\right],$$ K.Eggert *et al*, Nucl.Phys.B 86 (1975) 201

$\Gamma(\Delta\eta) \propto exp\left[-\frac{(\Delta\eta)^2}{(4\delta^2)}\right]$, $B(\Delta\eta)$ measured from mixed event background

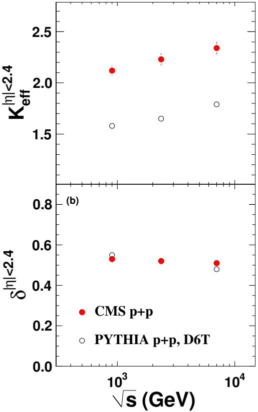
K_{eff}: effective cluster size. δ: cluster width



Energy dependence of cluster analysis

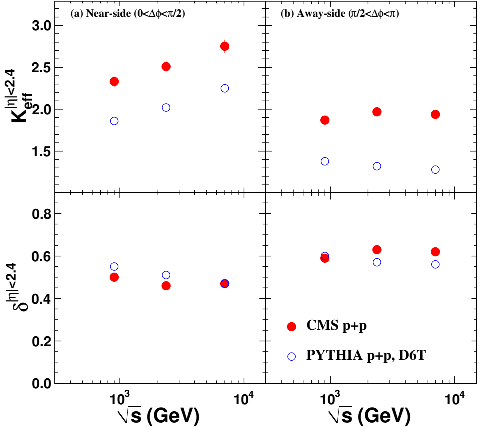
$|\eta| < 2.4$

$p_T > 0.1$ GeV



Near-side: $\Delta\Phi \in (0, \pi/2)$

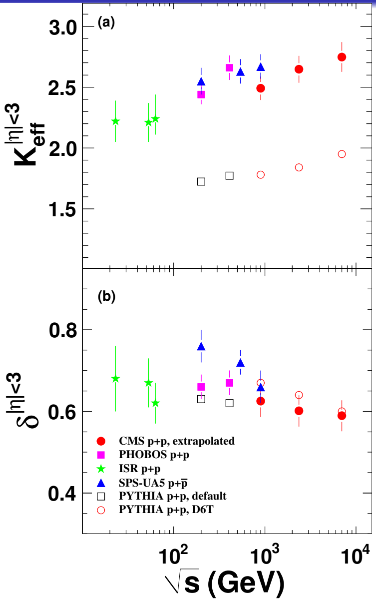
Away-side: $\Delta\Phi \in (\pi/2, \pi)$



Pythia: correct trend but smaller cluster size K_{eff}: width $\sim$ well reproduced.

Comparison with other experiments

- CMS uses $p_T > 0.1$ GeV and $|\eta| < 2.4$.
- To compare with other experiments, need to extrapolate results to $p_T = 0$ (Tsallis function) and $|\eta| < 3$.
- Systematics due to extrapolation $\sim 5\%$.



Outline

Bose–Einstein Correlation

- When wave-functions of identical bosons overlaps, Bose–Einstein statistics changes their dynamics;
- Seen as an enhancement probability for identical boson with small relative momenta.
- BEC measurements give informations about size, shape and space-time development of the emitting source

$R(Q) = \frac{dN/dQ}{dN/dQ_{ref}}$. $Q = \sqrt{-(p_1 - p_2)^2} = \sqrt{M_{inv}^2 - 4m_\pi^2}$

Q distribution of same-charged tracks (π) vs reference sample w/o BEC.

Parametrization

$$R(Q) = C\left[1 + \lambda\Omega(Qr)\right] \cdot (1 + \delta Q).$$

$\Omega(Qr)$: Fourier transform of the emission region (in static model), effective radius r, strength λ, δ long range correlation.

Using 7 Reference Samples:

Pairs from same event

1. Opposite charge ρ, η `resonances` ;
2. Opposite charge with one track $\vec{p}$ inverted;
3. Same charge with $\vec{p}$ inverted;
4. Same charge with $\vec{p}$ rotated in transverse plane;

Pairs from different events

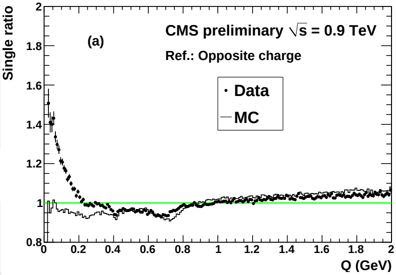
5. Chosen randomly;
6. Similar $dN_{tracks}/d\eta$;
7. Similar total invariant mass of charged tracks.

Use Double Ratio. (no BEC in MC)

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

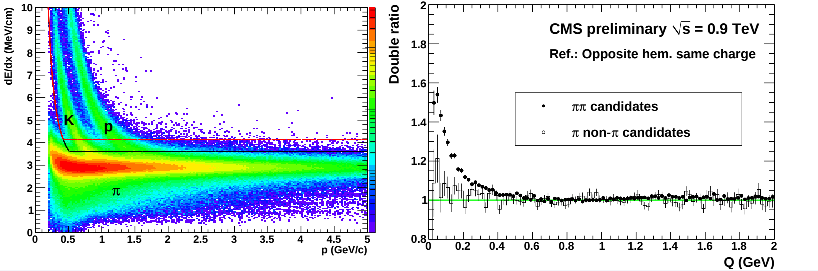
Build a combined reference sample

$$\mathcal{R}^{comb} = \frac{\mathrm{d}N/\mathrm{d}Q}{\mathrm{d}N/\mathrm{d}Q_{\mathrm{MC}}} \left(\frac{\sum_{i=1}^{7} \mathrm{d}N/\mathrm{d}Q^{i}_{\mathrm{MC}}}{\sum_{i=1}^{7} \mathrm{d}N/\mathrm{d}Q^{i}}\right).$$



BEC with identical/non identical particles

- using PID in CMS ($\frac{dE}{dx}$ measurement with CMS silicon tracker)
- Construct two samples: one with two identified π and one with π, not-π particles,
- Enhancement present only in $\pi\pi$ candidates, not in π–not-π



- Small π contamination in not-π
- PID works only at low p_{T}, not using π–not-π as ref. sample.

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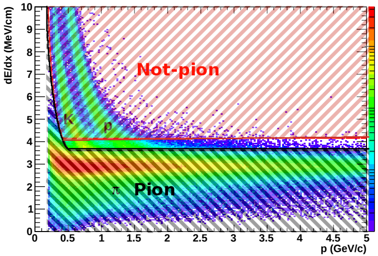

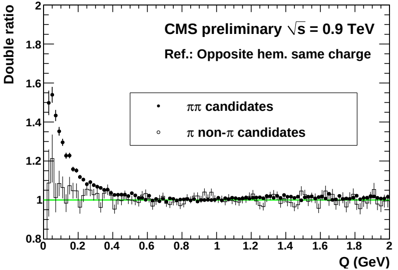

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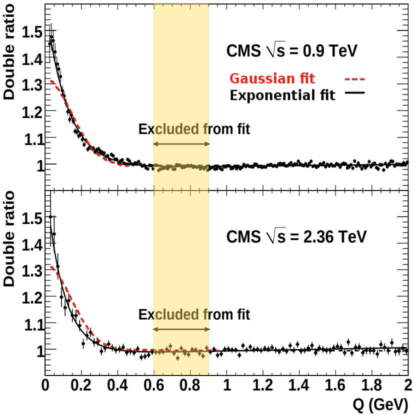
Results: combined ref. sample



Results at 900 GeV: exponential

$r = 1.59 \pm 0.05$ (stat.) ± 0.19 (syst.) *fm*
$\lambda = 0.625 \pm 0.021$ (stat.) ± 0.046 (syst.)

Results at 2.36 TeV: exponential

$r = 1.99 \pm 0.18$ (stat.) ± 0.24(syst.) fm
$\lambda = 0.663 \pm 0.073$ (stat.) ± 0.048 (syst.)

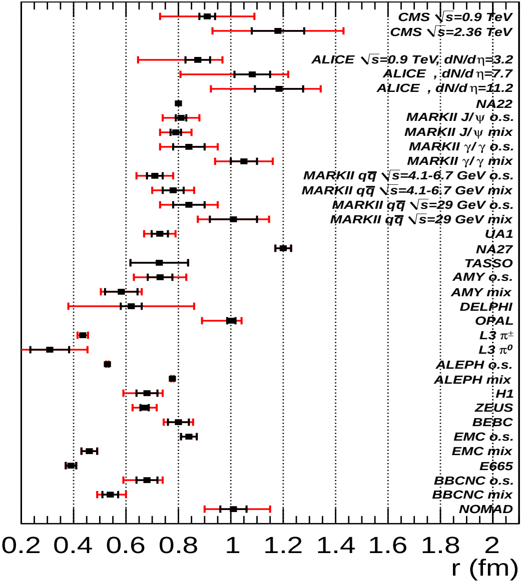
Systematics mostly from spread of 7 reference samples

ρ resonance region excluded from fit

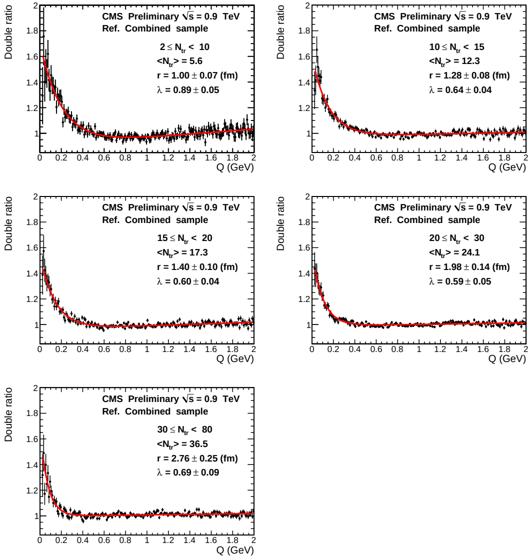
Exponential form for $\Omega(Qr) = e^{-Qr}$ fits data much better then the widely used Gaussian one $\Omega(Qr) = e^{-(Qr)^2}$.

Previous experiment results

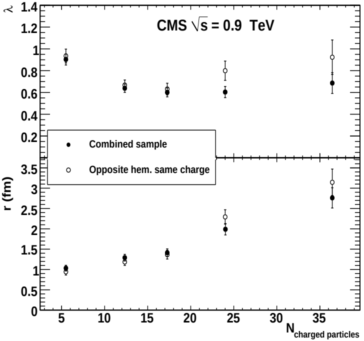
- Many different $\sqrt{s}$ and initial states: e^+e^- $\bar{p}p$, pp, πN, ep, and ν_μN
- Previous experiments used Gaussian parametrization.
- First moment of exponential: $1/r$, Gaussian $\frac{1}{r\sqrt{\pi}}$.
- CMS values with exponential fits scaled by $1/\sqrt{\pi}$
- Apologise for any missing past experiment!



Dependence on $N_{\text{charged tracks}}$



Clear dependence of effective radius with event charged track multiplicity



Outline

Conclusions

Two-particle angular correlations measured @ 900 GeV, 2.36 and 7 TeV

- Compared with simple cluster model;
- Cluster size and width compatible with previous experiments but not reproduced by Pythia;
- Will be good baseline to measure cluster properties with Heavy Ions at LHC.

Bose–Einstein Correlation measured @ 900 GeV and 2.36 TeV

- Used double ratio combining many reference samples;
- Exponential shape fits better than gaussian;
- Clear dependence from track multipicity;
- Measurement at 7 TeV is in progress

Backup

BACKUP

Two Particle Correlation

Two Particle Correlation

CMS inner tracker

Si Pixel surrounded by Si strips.
$|\eta| < 2.5$

Pixel

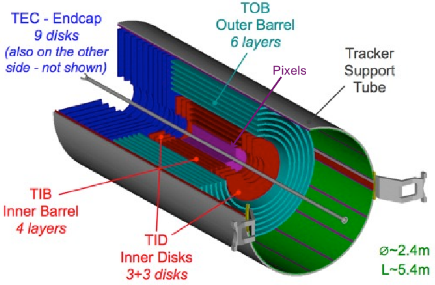
- 3 barrel layers ($r = 4, 7, 11$ *cm*)
- 2x2 endcap disks
- $\approx 1\ m^2$ of Si sensors
- $\approx 66M$ channels
- 1440 modules

Strips

- 10 barrel layers
- 9+3x2 endcap disks
- $\approx 200\ m^2$ of Si sensors
- $\approx 6.4M$ channels
- 15148 modules

Performances

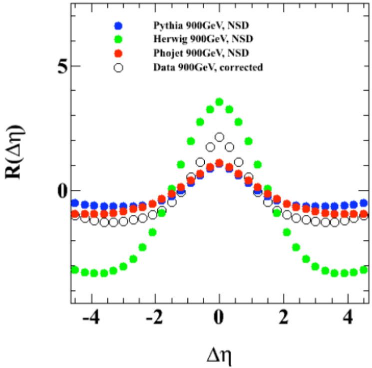
- 2-track separation: 1 *mrad*
- different hits on 3*rd* pixel layers $Q > 20$ MeV
- ≥ 3 hits for $p_{\mathrm{T}} > 100$ MeV
- $\Delta p_{\mathrm{T}}/p_{\mathrm{T}} \approx 1 - 2\%$ @ 1 GeV

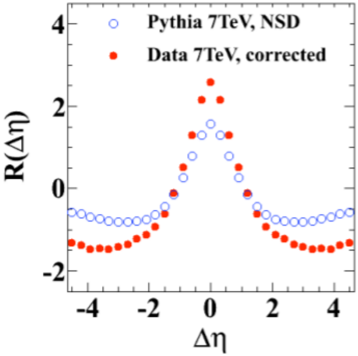


Events and track selections

- data collected in December 2009 $\sqrt{s} = 0.9$ and 2.36 TeV and March 2010 $\sqrt{s} = 7$ TeV.
- Trigger: MinimumBias. Activity in both Beam Scintillator Counters
- Coincidence with at least one HF tower with > 3 GeV (select Non-Single Diffractive events);
- Reject halo muons by time coincidence BSC;
- > 150 pixel clusters;
- One Primary Vertex $dz < 4.5$ cm, $\rho < 0.15$ cm.
- *High-Purity tracks*, $d_{xy}/\sigma_{xy} < 3$ $d_z/\sigma_z < 3$

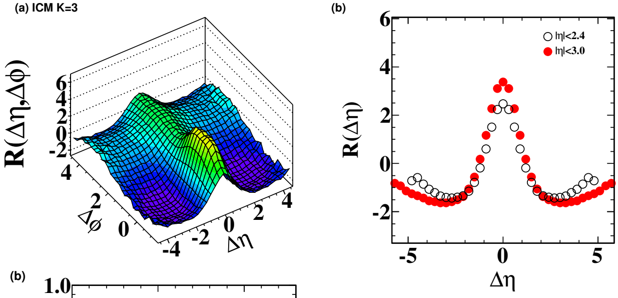
Comparison with other Model

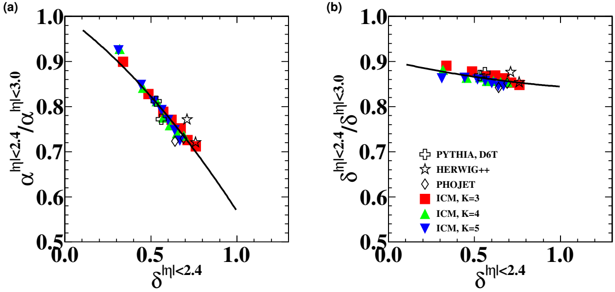




η Extrapolation

MC 2d Prediction shape distortion due to $|\eta|$ cut



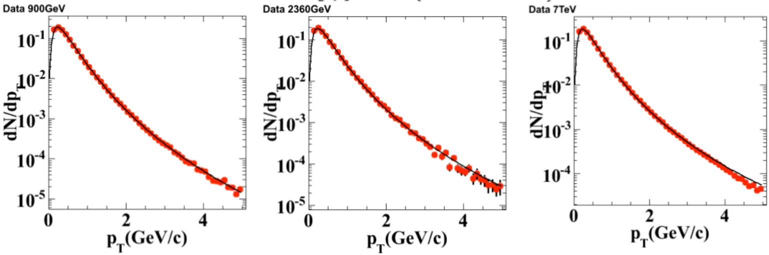


Relative variation of $\alpha = K_{eff} - 1$ and δ vs different $|\eta|$ cut for various MC model.

p_T Extrapolation

Use Tsallis fit to estimate fraction of lost tracks $p_T < 100$ MeV

$$dN/dp_T \sim p_T \frac{p_T}{\sqrt{p_T^2+m^2}} \left(1+\frac{\sqrt{p_T^2+m^2}}{nT}\right)^{-n}$$



n=8.2
T=0.139GeV

n=7.3
T=0.136GeV

n=6.5
T=0.132GeV

Reweight $100 < p_T < 200$ MeV distribution to compensate.

cluster size increases by $\sim 6-7\%$

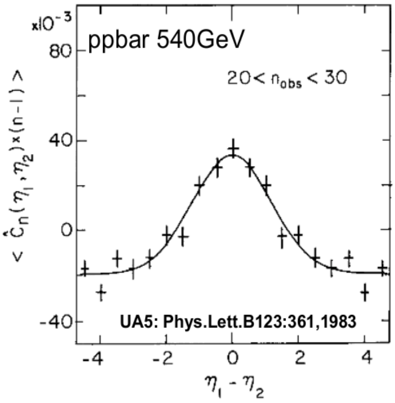
systematics and results

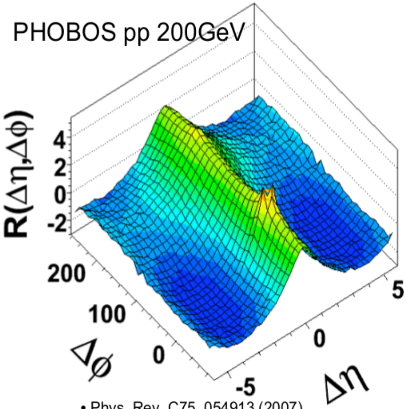
	Systematic uncertainties [%]	
Source	α	δ
Correction on event selection efficiency	2.6	2.8
Correction on tracking/acceptance efficiency and fake rate	1.3	1.4
Track quality cuts	1.2	1.0
Model dependence on the corrections	2.6	1.3
Total systematic uncertainties	4.1	3.5

Table: Final results on $K_{\rm eff}$ and δ with both systematic and statistical errors.

$\sqrt{s}$	$K_{\rm eff}$	δ
0.9 TeV	$2.12 \pm 0.00\,(\text{stat.}) \pm 0.05\,(\text{syst.})$	$0.53 \pm 0.01\,(\text{stat.}) \pm 0.02\,(\text{syst.})$
2.36 TeV	$2.23 \pm 0.02\,(\text{stat.}) \pm 0.05\,(\text{syst.})$	$0.52 \pm 0.01\,(\text{stat.}) \pm 0.02\,(\text{syst.})$
7 TeV	$2.34 \pm 0.00\,(\text{stat.}) \pm 0.06\,(\text{syst.})$	$0.51 \pm 0.01\,(\text{stat.}) \pm 0.02\,(\text{syst.})$

UA5 and Phobos results





- Phys. Rev. C75, 054913 (2007)
- Phys. Rev. C81, 024904 (2010) (heavy ion)

Bose–Einstein Correlation

Bose–Einstein Correlation

Events and track selections

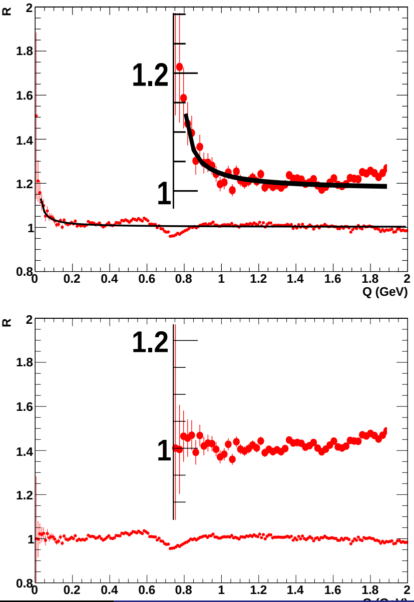
- data collected in December 2009 $\sqrt{s} = 0.9$ and 2.36 TeV.
- Trigger: MinimumBias. Activity in both Beam Scintillator Counters
- $NDoF > 5$;
- $\chi^2/NDoF < 5$;
- Trasverse impact parameter $d_{xy} < 1.5\ mm$;
- Innermost hit $R < 20\ cm$ impact point;
- $|\eta| < 2.4$;
- $p_{\mathrm{T}} > 200$ MeV;
- $2 \leq N_{trk} \leq 150$
- @ 900 GeV: 270 472 events and 2 903 754 track pairs;
- @ 2.36 TeV: 13 548 events and 188 140 track pairs.

Coulomb correction

- Coulomb repulsion between same charged particles depletes the Q distribution at low Q.
- Corrected with Gamow factor:

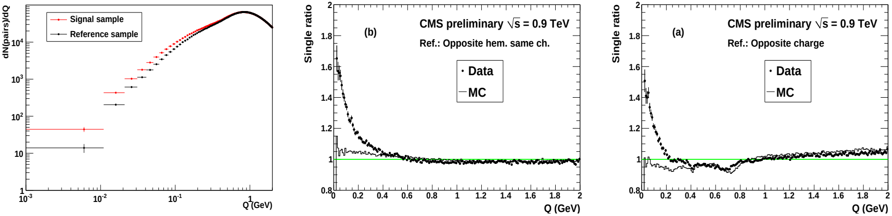
$$W_S(\eta) = \frac{e^{2\pi\eta}-1}{2\pi\eta}$$
$$W_D(\eta) = \frac{1-e^{-2\pi\eta}}{2\pi\eta}$$
$$\eta = \frac{\alpha_{em} m_\pi}{Q}$$

- Tested with opposite-charge Q-distribution normalized to MC (no coulomb effect simulated)
- Up: opposite charge Q distribution with Gamow factor superimposed (not fitted)
- Bottom: same after applying Coulomb correction



Single ratios and double ratios

- Q distribution for signal and one reference sample
- Enhancement at low-Q show the expected correlation
- MonteCarlo (w/o BEC simulation) is flat

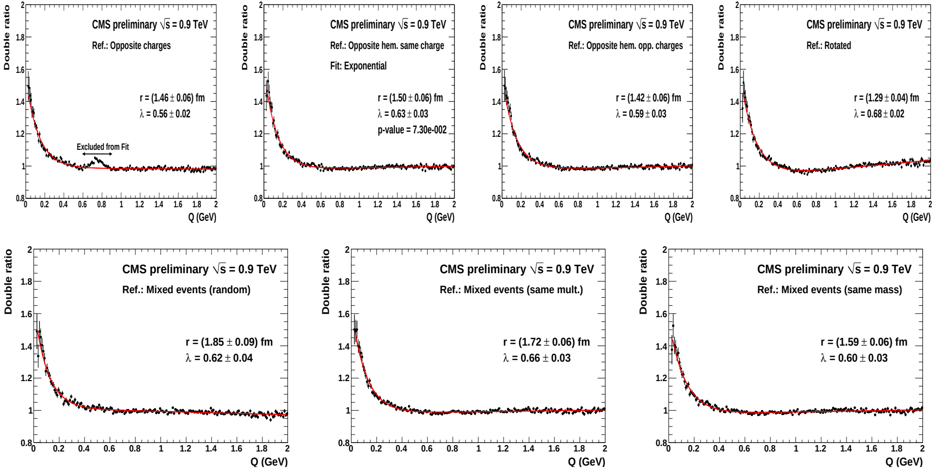


- Opposite charge distribution show structure due to resonances (ρ)
- Long range correlation well described by simulation

Use Double Ratio for measurement.

$$\mathcal{R} = R/R_{\mathrm{MC}} = \left(\frac{dN/dQ}{dN/dQ_{\mathrm{ref}}}\right) / \left(\frac{dN/dQ_{\mathrm{MC}}}{dN/dQ_{\mathrm{MC,ref}}}\right)$$

R(Q) for all reference sample @ 900 GeV



Fit with exponential form for Ω: $R(Q) = C\left[1 + \lambda e^{-(Qr)}\right] \cdot (1 + \delta Q)$.

Detailed results @ 900 GeV

Results of fits to 0.9 TeV data

Reference sample	P-value	C	λ	r (fm)	δ (GeV^{-1})
Opposite charges	2.19×10^{-1}	0.988 ± 0.003	0.557 ± 0.025	1.46 ± 0.06	$(-3.5 \pm 2.4) \times 10^{-3}$
Opposite hem. same ch.	7.30×10^{-2}	0.978 ± 0.003	0.633 ± 0.027	1.50 ± 0.06	$(1.1 \pm 0.2) \times 10^{-2}$
Opposite hem. opp. ch.	1.19×10^{-1}	0.975 ± 0.003	0.591 ± 0.025	1.42 ± 0.06	$(1.3 \pm 0.2) \times 10^{-2}$
Rotated	2.42×10^{-4}	0.929 ± 0.003	0.677 ± 0.022	1.29 ± 0.04	$(5.8 \pm 0.2) \times 10^{-2}$
Mixed evts. (random)	1.90×10^{-2}	1.014 ± 0.002	0.621 ± 0.038	1.85 ± 0.09	$(-2.0 \pm 0.2) \times 10^{-2}$
Mixed evts. (same mult.)	1.22×10^{-1}	0.981 ± 0.002	0.664 ± 0.030	1.72 ± 0.06	$(1.1 \pm 0.2) \times 10^{-2}$
Mixed evts. (same mass)	1.70×10^{-2}	0.976 ± 0.002	0.600 ± 0.030	1.59 ± 0.06	$(1.4 \pm 0.2) \times 10^{-2}$
Combined sample	2.92×10^{-2}	0.984 ± 0.002	0.625 ± 0.021	1.59 ± 0.05	$(8.2 \pm 0.2) \times 10^{-3}$

Results of fits to 0.9 TeV data

Multiplicity range	P-value	C	λ	r (fm)	δ (GeV^{-1})
2 - 9	9.7×10^{-1}	0.90 ± 0.01	0.89 ± 0.05	1.00 ± 0.07 (stat.)± 0.05 (syst.)	$(7.2 \pm 1.2) \times 10^{-2}$
10 - 14	3.8×10^{-1}	0.97 ± 0.01	0.64 ± 0.04	1.28 ± 0.08 (stat.)± 0.09 (syst.)	$(1.8 \pm 0.5) \times 10^{-2}$
15 - 19	2.7×10^{-1}	0.96 ± 0.01	0.60 ± 0.04	1.40 ± 0.10 (stat.)± 0.05 (syst.)	$(2.8 \pm 0.5) \times 10^{-2}$
20 - 29	2.4×10^{-1}	0.99 ± 0.01	0.59 ± 0.05	1.98 ± 0.14 (stat.)± 0.45 (syst.)	$(1.3 \pm 0.3) \times 10^{-2}$
30 - 79	2.8×10^{-1}	1.00 ± 0.01	0.69 ± 0.09	2.76 ± 0.25 (stat.)± 0.44 (syst.)	$(1.0 \pm 0.3) \times 10^{-2}$

Detailed results @ 2.36 TeV

Results of fits to 2.36 TeV data

Reference sample	P-value	C	λ	r (fm)	δ (GeV^{-1})
Opposite charges	5.71×10^{-1}	1.004 ± 0.008	0.529 ± 0.081	1.65 ± 0.23	$(-1.57 \pm 0.58) \times 10^{-2}$
Opposite hem. same ch.	4.19×10^{-1}	0.977 ± 0.006	0.678 ± 0.110	1.95 ± 0.24	$(1.49 \pm 0.48) \times 10^{-2}$
Opposite hem. opp. ch.	4.61×10^{-1}	0.969 ± 0.005	0.700 ± 0.107	2.02 ± 0.23	$(2.36 \pm 0.47) \times 10^{-2}$
Rotated	4.24×10^{-1}	0.933 ± 0.007	0.610 ± 0.070	1.49 ± 0.15	$(5.75 \pm 0.59) \times 10^{-2}$
Mixed evts. (random)	2.26×10^{-1}	1.041 ± 0.005	0.743 ± 0.154	2.78 ± 0.36	$(-4.02 \pm 0.41) \times 10^{-2}$
Mixed evts. (same mult.)	3.52×10^{-1}	0.974 ± 0.005	0.626 ± 0.096	2.01 ± 0.23	$(2.03 \pm 0.46) \times 10^{-2}$
Mixed evts. (same mass)	7.31×10^{-1}	0.964 ± 0.005	0.728 ± 0.107	2.18 ± 0.23	$(2.84 \pm 0.46) \times 10^{-2}$
Combined sample	8.90×10^{-1}	0.981 ± 0.005	0.663 ± 0.073	1.99 ± 0.18	$(1.31 \pm 0.41) \times 10^{-2}$

Results of fits to 2.36 TeV data		
2 - 19	0.65 ± 0.08	1.19 ± 0.17 (stat.)
20 - 60	0.85 ± 0.17	2.38 ± 0.38 (stat.)
Results of fits to 0.9 TeV data		
Multiplicity range	λ	r (fm)
2 - 19	0.65 ± 0.02	1.25 ± 0.05 (stat.)
20 - 60	0.63 ± 0.05	2.27 ± 0.12 (stat.)

Correlation coefficient of exponential fit

Table: Correlation coefficients for the fit parameters obtained with the combined reference samples. Left: coefficients from the fit to 0.9 TeV data; right: coefficients from the fit to 2.36 TeV data.

	0.9 TeV				2.36 TeV			
	C	λ	r	δ	C	λ	r	δ
C	1				1			
λ	0.33	1			0.27	1		
r	0.72	0.82	1		0.62	0.83	1	
δ	-0.97	-0.30	-0.67	1	-0.96	-0.24	-0.57	1

Results and systematics

- Use spread between reference samples ±7% for λ and ±12% for r
- Coulomb correction syst by propagating agreement margin of opposite charge fit ±2.8% for λ and ±0.8% for r
- Compared BEC parameter at generation and reconstruction level with dedicated simulation: no bias, agreement within statistical errors.

Results at 900 GeV

$r = 1.59 \pm 0.05\ (\text{stat.}) \pm 0.19\ (\text{syst.})$ fm

$\lambda = 0.625 \pm 0.021\ (\text{stat.}) \pm 0.046\ (\text{syst.})$

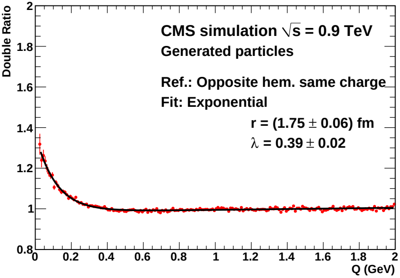
Results at 2.36 TeV

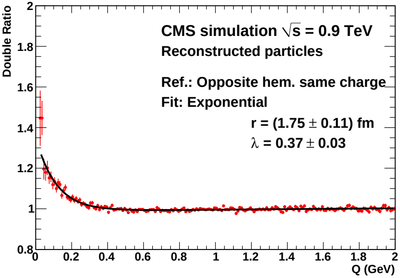
$r = 1.99 \pm 0.18\ (\text{stat.}) \pm 0.24\ (\text{syst.})$ fm

$\lambda = 0.663 \pm 0.073\ (\text{stat.}) \pm 0.048\ (\text{syst.})$

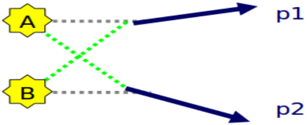
Test for reconstruction Bias

- Dedicated MonteCarlo simulation with BEC enabled
- Pythia, exponential shape
  `MSTJ(51)=1, PARJ(92)=0.9, PARJ(93)=0.125`
- Performed analysis at Generated (left) and Reconstruction (right) level
- found no bias within the statistical uncertainties





Physics of Bose–Einstein Correlation



Two particles

1. from source A, momentum p_1
2. from source B, momentum p_2

System wave-function

$\Psi_A(1) = f_A e^{-i\vec{p}_1\vec{x}_A}, \ldots$

Complete wave-funtion for Bosons is

$\Psi(1,2) = (\Psi_A(1)\Psi_B(2) + \Psi_B(1)\Psi_A(2))/\sqrt{2}$

Joint probability is just the product of P of single particles.

$< \Pi_{12} >= (f_A^2 + f_B^2 + [f_A^* f_B e^{i\vec{p_1}(\vec{x_A - x_B})} + c.c.])(\ldots e^{i\vec{p_2}(\vec{x_A - x_B})} \ldots)$

In a chaotic source $f_A^* f_B + c.c.$ fluctuate randomly and drop out of expectation value.

$R = \frac{<\Pi_{12}>}{<\Pi_1><\Pi_2>} = \frac{|\Psi(1,2)|^2}{|\Psi(1)|^2|\Psi(2)|^2} = 1 + 2\frac{2f_A^2 f_B^2}{(f_A^2+f_B^2)^2} \cos(\Delta x \Delta p)$

NA22 [?]	Kp, πp	250	0.800	uses q_t
MARK II [?]	J/ψ	3.1	$0.810 \pm 0.020 \pm 0.050$	opp. sign
	J/ψ	3.1	$0.790 \pm 0.020 \pm 0.040$	mix event
	$\gamma\gamma$	39	$0.840 \pm 0.060 \pm 0.050$	opp. sign
	$\gamma\gamma$	39	$1.050 \pm 0.050 \pm 0.060$	mix event
	$q\bar{q}$	$4.1 \div 6.7$	$0.710 \pm 0.030 \pm 0.040$	opp. sign
	$q\bar{q}$	$4.1 \div 6.7$	$0.780 \pm 0.040 \pm 0.040$	mix event
	$q\bar{q}$	29	$0.840 \pm 0.060 \pm 0.050$	opp. sign
	$q\bar{q}$	29	$1.010 \pm 0.090 \pm 0.046$	mix event
UA1 [?]	pp	$200 \div 900$	$0.729 \pm 0.031 \pm 0.029$	opp. sign
NA27 [?]	pp	400	1.200 ± 0.030	mix event
ALICE [?]	pp	900	$0.874 \pm 0.047^{+0.047}_{-0.181}$	mix event $dN/d\eta = 3.2$
	pp	900	$1.082 \pm 0.068^{+0.069}_{-0.206}$	mix event $dN/d\eta = 7.7$
	pp	900	$1.184 \pm 0.092^{+0.067}_{-0.168}$	mix event $dN/d\eta = 11.2$
TASSO [?]	e^+e^-	34	0.727 ± 0.110	
AMY [?]	e^+e^-	58	$0.730 \pm 0.047 \pm 0.053$	opp. sign
	e^+e^-	58	$0.582 \pm 0.062 \pm 0.016$	mix event
DELPHI [?]	e^+e^-	91	$0.620 \pm 0.04 \pm 0.20$	opp. sign + mix event
OPAL [?]	e^+e^-	91	$1.002 \pm 0.016^{+0.023}_{-0.096}$	opp. sign
L3 [?]	e^+e^-	91	$0.435 \pm 0.010 \pm 0.010$	$\pi^\pm$ MonteCarlo
	e^+e^-	91	$0.309 \pm 0.074 \pm 0.070$	π^0 MonteCarlo
ALEPH [?]	e^+e^-	91	0.529 ± 0.005	mix event
ALEPH [?]	e^+e^-	91	0.777 ± 0.005	opp. sign
H1 [?]	ep	230	$0.680 \pm 0.040^{+0.020}_{-0.050}$	
ZEUS [?]	ep	230	$0.671 \pm 0.016 \pm 0.030$	opp. sign
BEBC [?]	$\nu_\mu N$	10	$0.800 \pm 0.040 \pm 0.160$	
EMC [?]	μp	23	0.840 ± 0.030	opp. sign
	μp	23	0.460 ± 0.030	mix event
E665 [?]	μN	30	0.39 ± 0.02	mix event
BBCNC[?]	μN	> 10	$0.68 \pm 0.04^{+0.020}_{-0.050}$	opp. sign
	μN	> 10	$0.54 \pm 0.03^{+0.030}_{-0.020}$	mix event
NOMAD [?]	$\nu_\mu N$	8	$1.010 \pm 0.05^{+0.09}_{-0.06}$	opp. sign + mix event

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