Measurement of Bose-Einstein correlations in pp collisions at LHC with CMS

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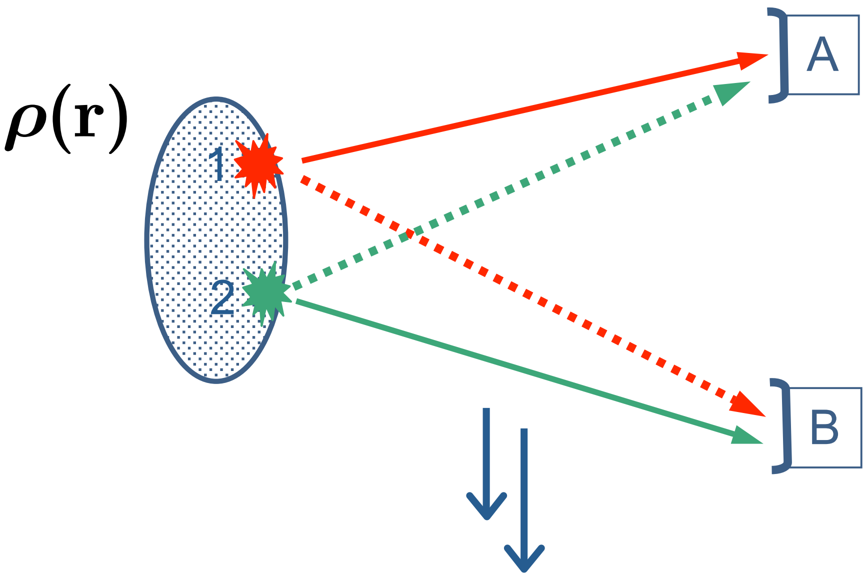
for the CMS Collaboration

HBT - BEC basics

- Detecting two identical bosons emitted from sources 1 & 2 at A & B



- Two-boson correlation function ⟶ reflects source dimensions

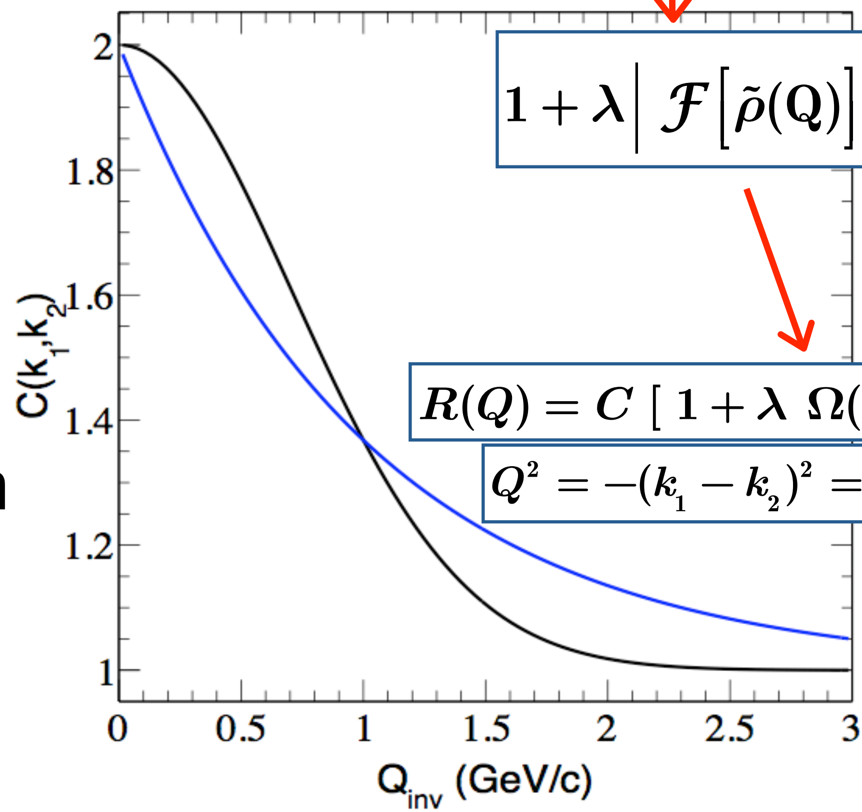
– Correlation Function:

$$R\left(Q = k_1 - k_2\right) = \frac{P_2(k_1,k_2)}{P_1(k_1)P_1(k_2)}$$

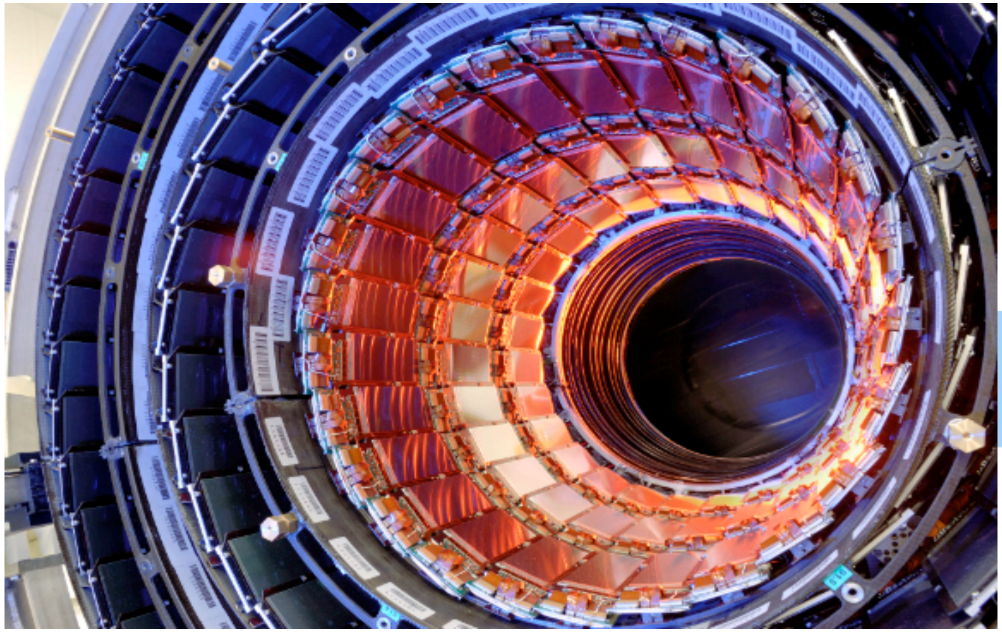
$$1 + \lambda \left| \mathcal{F}\left[\tilde{\rho}(\mathbf{Q})\right] \right|^2$$ (ideal)

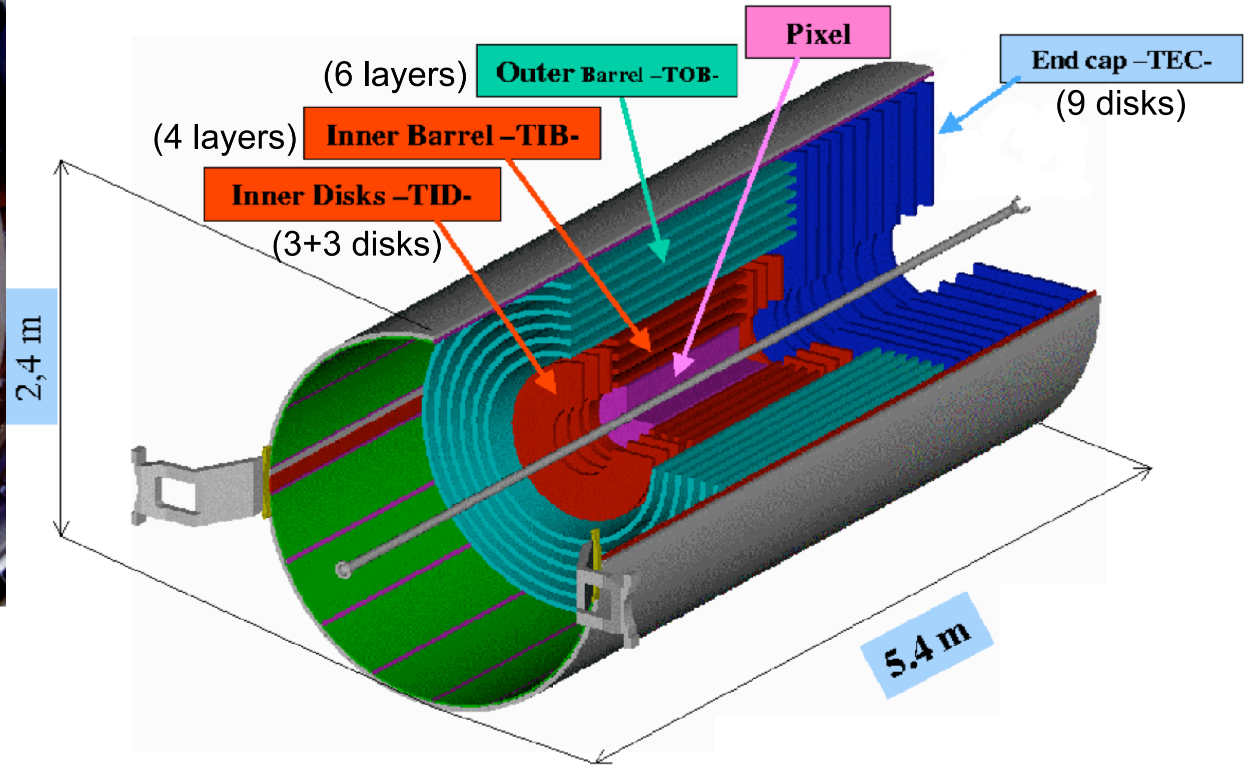
$$R(Q) = C\ [\ 1 + \lambda\ \Omega(Qr)\ ]\ (1 + \delta Q)$$

$$Q^2 = -(k_1 - k_2)^2 = M^2_{inv} - 4m^2_\pi$$



The CMS detector - tracker system





– Pixels
  » 3 barrel layers (r = 4, 7, 11 cm)
  » 2 × 2 endcap disks
  » ~ 1 m^2 Si sensor

– Strips
  » 10 barrel layers
  » 9 + 3 × 2 endcap disks
  » 200 m^2 Si sensor

BEC - pp @ 0.9 & 2.36 TeV - 2009 data

- Experimentally

$$R^{\exp}\left(Q = k_1 - k_2\right) = \frac{S(k_1, k_2)}{\mathcal{B}(k_1, k_2)}$$

Same event pairs (with BEC)

Different backgrounds (no BEC)

  – Background pair selection
    - » Same event, ≠ charges (resonances)
    - » Rotation of 1 track of the pair
    - » Mixed events ( )

Coulomb FSI
Gamow factor applied to data

$$\Upsilon_{ss}(\eta) = \frac{\eta / Q}{e^{\eta/Q} - 1}$$

$$\eta = 2\pi\alpha_{em} m_{\pi}$$

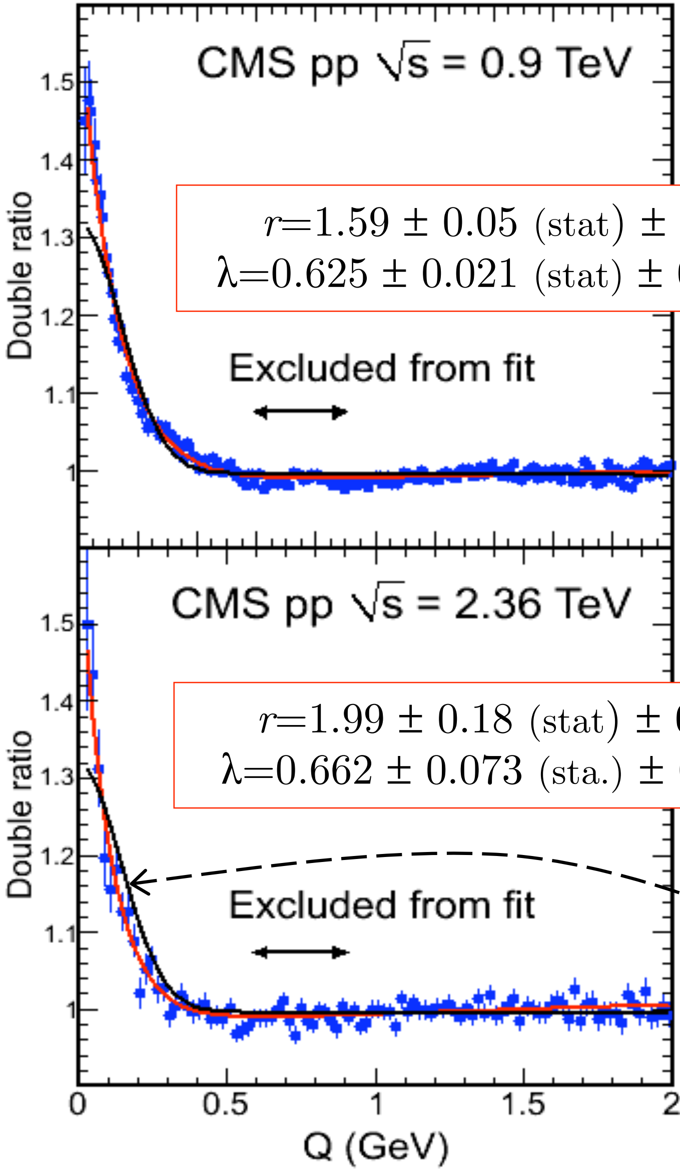
  – Double ratios ⟶ reduce bias:

$$\mathcal{R}(Q) = \frac{R(Q)}{R_{MC}(Q)} = \frac{\left(\dfrac{dN_{signal} / dQ}{dN_{ref} / dQ}\right)}{\left(\dfrac{dN_{MC,\, like} / dQ}{dN_{MC,\, ref} / dQ}\right)}$$

⟶ (No BEC in MC)

Summary of results - pp 0.9 TeV

[PRL 105, 32001 (2010)]



– Leading syst. uncertainties: choice of ref. sample → r.m.s. spread between results (λ: 7% ; r : 12%)

$$\mathcal{R}^{COMB} = \left(\frac{dN/dQ}{dN_{MC}/dQ}\right)\left(\frac{\sum_{i=1}^{7} dN/dQ^{i}_{MC}}{\sum_{i=1}^{7} dN/dQ^{i}}\right)$$

↓ Fit

$$\mathcal{R}(Q) = C\,[\,1+\lambda\;\Omega(Qr)\,]\,(1+\delta Q)$$

$$\Omega(Qr) = \exp(-Qr)$$

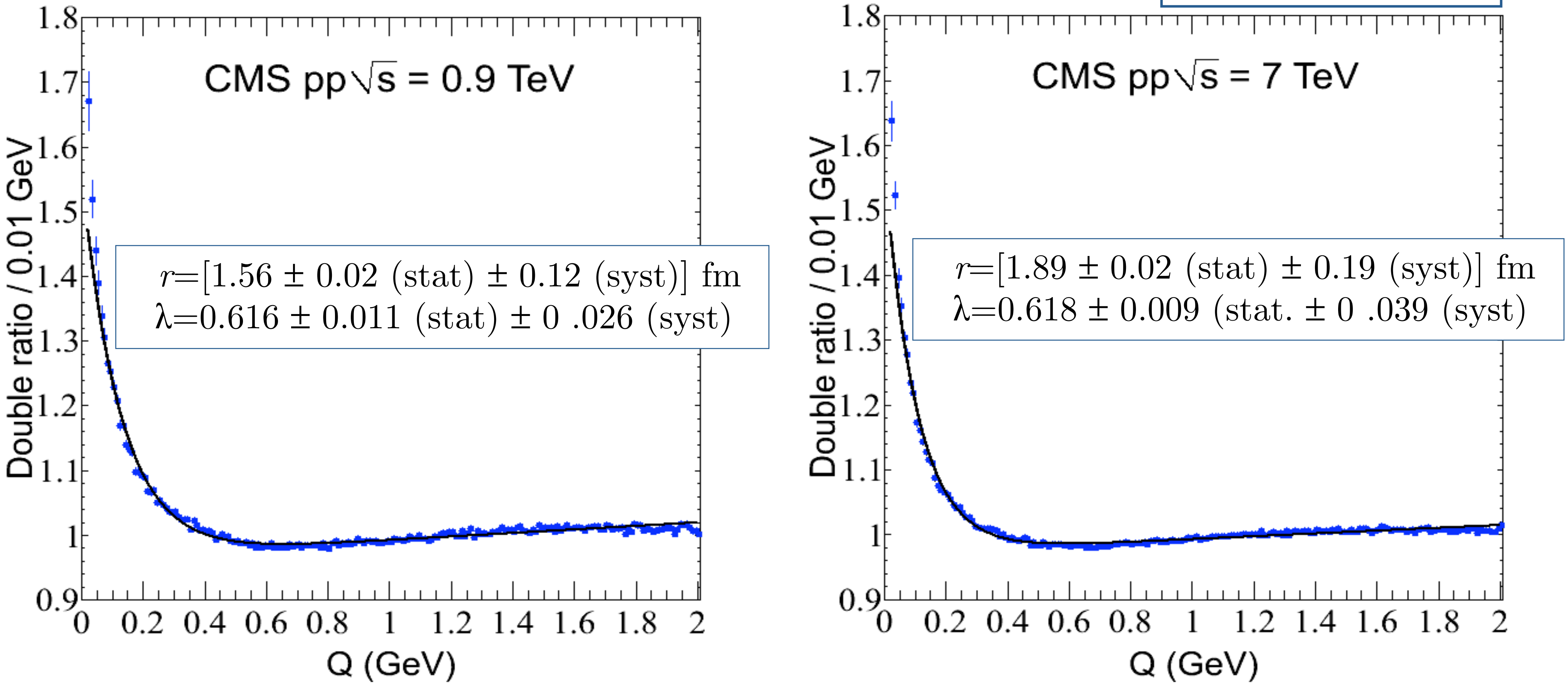
$$\Omega(Qr) \propto \exp\left[-(Qr)^2\right] \rightarrow \chi^2/N_{dof} > 9$$

$\sqrt{s}$	Min bias 2009	Min bias 2010
0.9 TeV	~ 280 k	~ 4.8 M
2.36 TeV	~ 14 k	
7 TeV		~ 2.7 M

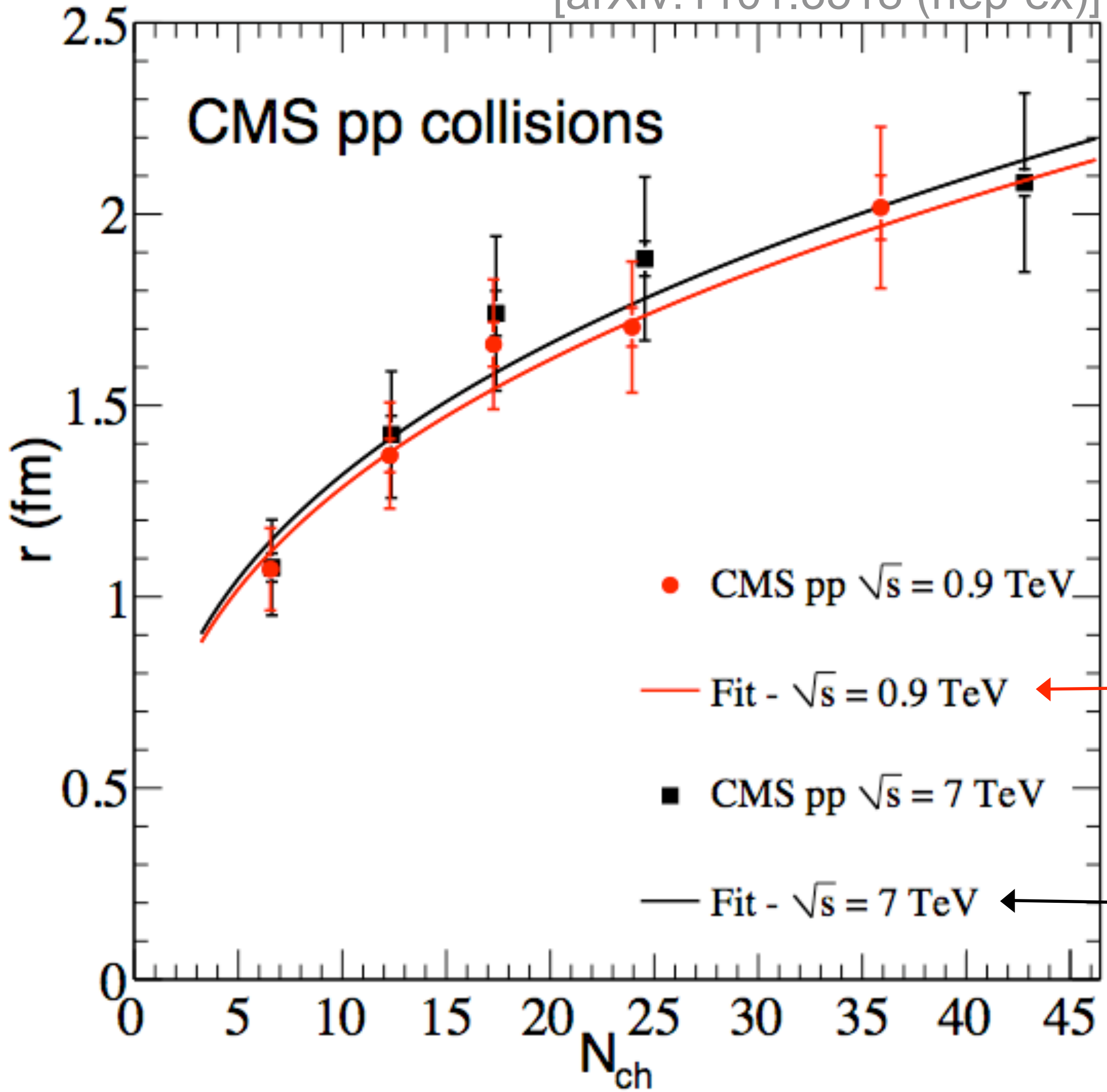
2010 results - pp collisions 0.9 & 7 TeV

- Reference sample: same sign tracks, mixed events, ~ multiplicity
- MC simulation: Pythia 6 - Tune Z2

$$\Omega(Qr) = e^{-Qr}$$



[arXiv:1101.3518 (hep-ex); to be published in JHEP] [arXiv:1101.3518 (hep-ex)]



– Fit to data

$$r\,(N_{ch}) = a \cdot N_{ch}^{1/3}$$

M. Lisa, AIP Conf. Proc. V. 828, 226 (2006)

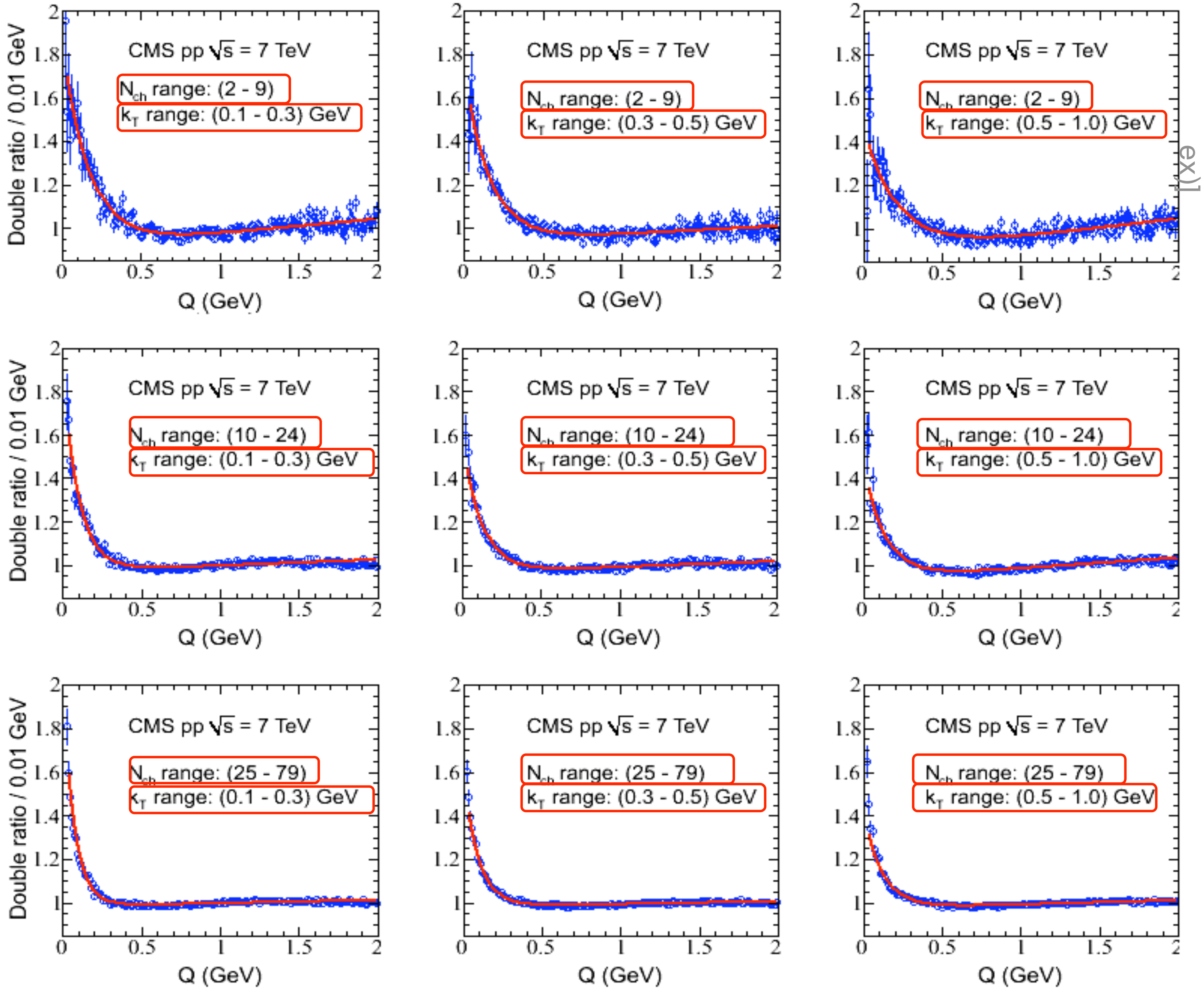
$a = [0.597 \pm 0.009(\text{stat}) \pm 0.057(\text{syst})]$ (fm)

$\langle N_{ch} \rangle \sim 12.1$

$a = [0.612 \pm 0.007(\text{stat}) \pm 0.068(\text{syst})]$ (fm)

$\langle N_{ch} \rangle \sim 19.2$

Dependence on k_T and N_{ch}



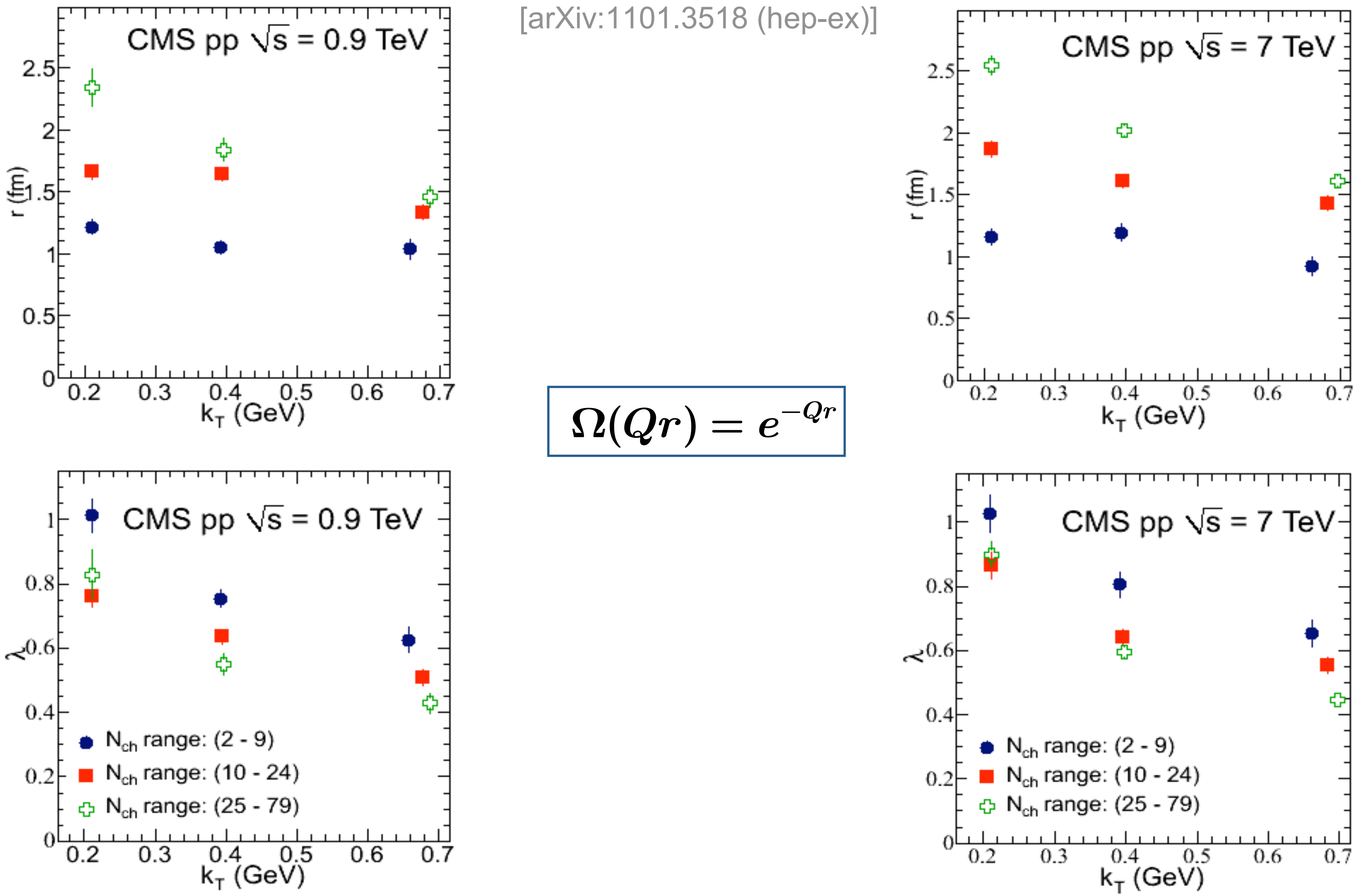
[arXiv:1101.3518 ([hep-ex)]

N_{ch}

$$\left|\vec{k}_T\right| = \frac{1}{2}\left|\vec{k}_{1_T} + \vec{k}_{2_T}\right|$$

Fit parameters vs. k_T and N_{ch}

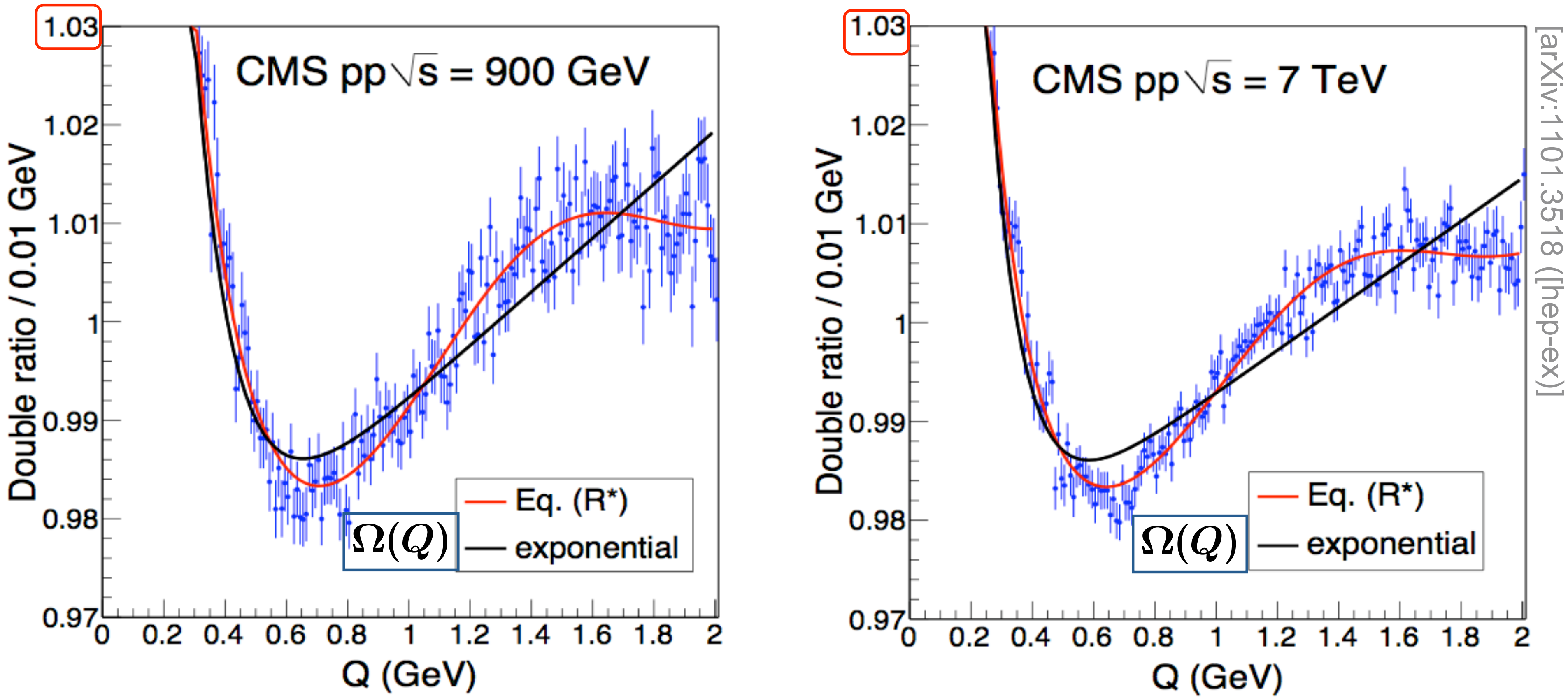
[arXiv:1101.3518 (hep-ex)]



$$\Omega(Qr) = e^{-Qr}$$

The dip structure - 1

- For $\Omega = e^{-(Qr)}$: χ^2 / N_{dof}=485/194 (0.9 TeV) & 739/194 (7 TeV)
  - Reason: anticorrelation for same sign pairs (zoomed axis)

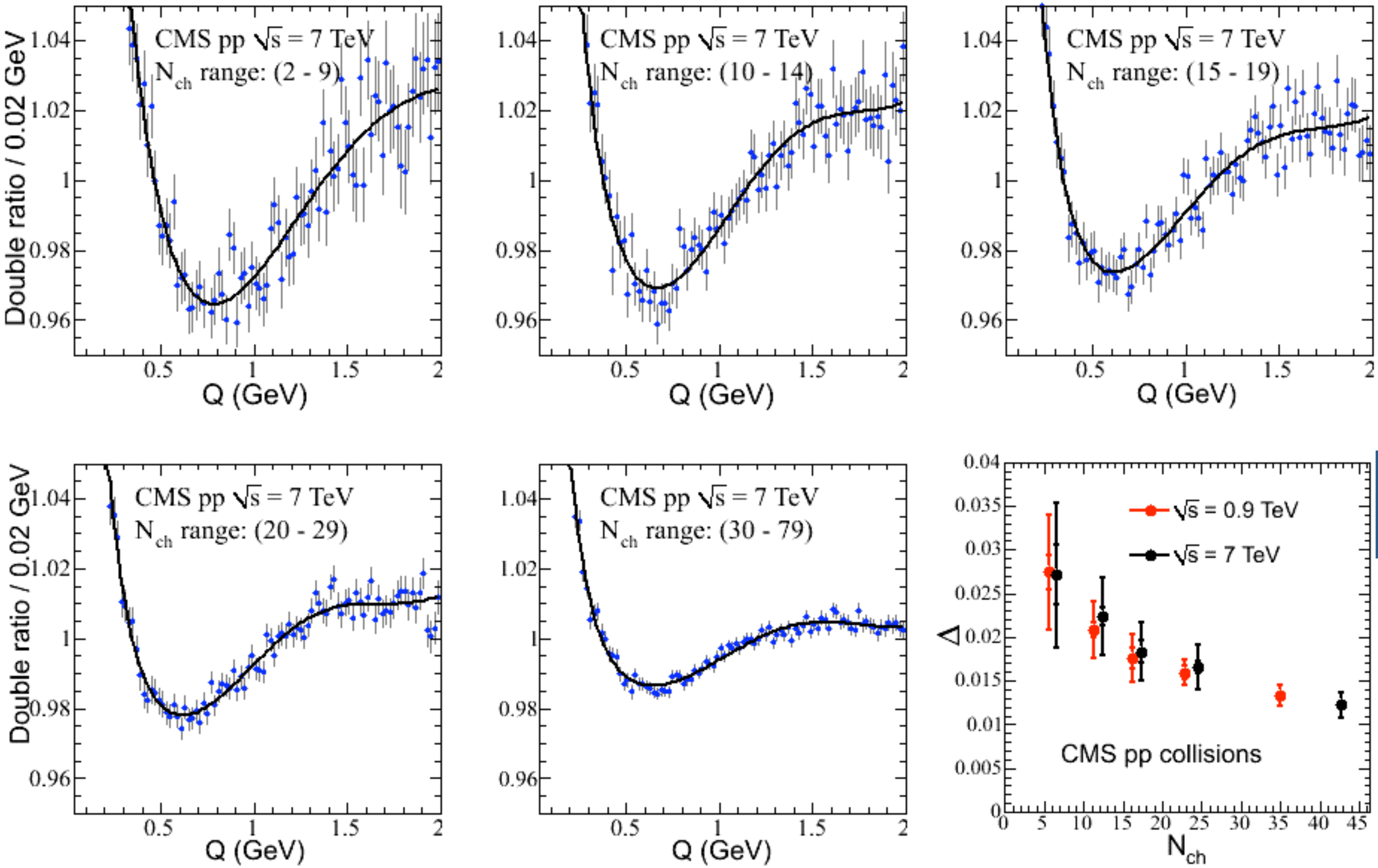


$$R^*(Q) = C\left[1 + \lambda\left(\cos\left[(r_0 Q)^2 + \tan(\alpha\pi / 4)(Qr_\alpha)^\alpha\right] e^{-(Qr_\alpha)^\alpha}\right)\right] \cdot (1 + \delta Q)$$

[τ-model → Csörgő & Zimányi, N.P. A 517, 588 (1990); Metzger et al., P. L. B663, 114 (2008)]

The dip structure - 2

- Observed in e^+e^- experiments at LEP [arXiv:1002.1303(2010)]
- This is the first observation of this anticorrelation in pp interactions!
- Using Eq. (R*) to fit data: χ^2/N_{dof}=213/192 (0.9 TeV) and χ^2/N_{dof}= 215/192 (7 TeV)



[arXiv:1101.3518 (hep-ex)]

$\Delta = C\,(1+\delta Q) - (R^*)$
(at the minimum)

Summary & conclusions

- Bose-Einstein Correlations $\longrightarrow$ measured at CMS detector in 0.9 TeV, 2.36 TeV and 7 TeV pp collisions
- Shown: BEC data & parameter fits $\longrightarrow$ $\boldsymbol{\Omega = e^{-(Qr)}}$
  - trends seen in parameters do not depend on fit function (checked with r first moments)
- Inclusive radius parameter : $\boldsymbol{r_{7\ TeV} > r_{0.9\ TeV}}$
  - reflects increase in N_{ch} with $\sqrt{s}$
- Correlations as Double Ratios binned in N_{ch} & k_T
  - r decreases with k_T for high multiplicity events N_{ch}
    - » similar behavior with k_T is seen in AA collisions $\longleftrightarrow$ collective behavior
    - » in pp collisions also seen by E735 (Tevatron), STAR, PHENIX and ALICE
- Anticorrelation of like-sign pairs $\longrightarrow$ 1st observation in pp collisions
  - better χ^2/N_{dof} $\longrightarrow$ param. describing time evolution of the source (assumes broad distr. in τ and strong $x-p$ corr.)
  - decreases with increasing N_{ch}

Acknowledgments

THANK YOU !!

I thank CAPES for the support to attend this conference.

EXTRAS

Fit functions - pp √s=0.9 & 7 TeV

– Double ratios

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

- Gaussian fit $\Omega(qr) \sim \exp[-(Qr)^2]$ bad (reduced $\chi^2 > 9$)

- Exponential fit $\Omega(qr) \sim \exp(-Qr)$

$\sqrt{s}$	$\chi^2/N_{\rm dof}$	C	λ	r (fm)	δ (10^{-2} GeV^{-1})
0.9 TeV	485/194	0.965 ± 0.001	0.616 ± 0.011	1.56 ± 0.02	2.8 ± 0.1
7 TeV	739/194	0.971 ± 0.001	0.618 ± 0.009	1.89 ± 0.02	2.2 ± 0.1

- Levy fit

$$\Omega(qr) \sim \exp[-(Qr)^\alpha]$$

$\sqrt{s}$	$\chi^2/N_{\rm dof}$	λ	r (fm)	α
0.9 TeV	453/193	0.847 ± 0.057	2.20 ± 0.17	0.806 ± 0.033
7 TeV	676/193	0.896 ± 0.051	2.83 ± 018	$0.792 \pm 0.0.024$

Dependence on k_T and N_{ch} – tables

- Double ratios (2010 pp data) - exponential fits

$$\Omega(Qr) = e^{-Qr}$$

k_T (GeV)	N_{ch} ($< N_{ch} >$)	χ^2/N_{dof}	C	λ	r (fm)	δ (10^{-2} GeV^{-1})
$\sqrt{s} = 0.9$ TeV						
0.10 - 0.30	2 - 9 (6.6)	220/194	0.925 ± 0.006	1.011 ± 0.051	1.211 ± 0.057	6.1 ± 0.6
0.10 - 0.30	10 - 24 (15.5)	285/194	0.969 ± 0.002	0.761 ± 0.034	1.652 ± 0.057	2.9 ± 0.2
0.10 - 0.30	25 - 79 (31.2)	216/194	0.984 ± 0.002	0.828 ± 0.077	2.331 ± 0.153	1.6 ± 0.2
0.30 - 0.50	2 - 9 (6.6)	213/194	0.912 ± 0.007	0.754 ± 0.027	1.046 ± 0.049	6.0 ± 0.6
0.30 - 0.50	10 - 24 (15.5)	247/194	0.970 ± 0.002	0.636 ± 0.023	1.643 ± 0.051	2.3 ± 0.2
0.30 - 0.50	25 - 79 (31.2)	223/194	0.984 ± 0.002	0.549 ± 0.033	1.839 ± 0.089	1.2 ± 0.2
0.50 - 1.00	2 - 9 (6.6)	228/194	0.911 ± 0.009	0.626 ± 0.039	1.034 ± 0.079	6.6 ± 0.8
0.50 - 1.00	10 - 24 (15.5)	218/194	0.957 ± 0.003	0.508 ± 0.024	1.331 ± 0.059	3.4 ± 0.2
0.50 - 1.00	25 - 79 (31.2)	211/194	0.979 ± 0.003	0.428 ± 0.029	1.456 ± 0.086	1.5 ± 0.2
$\sqrt{s} = 7$ TeV						
0.10 - 0.30	2 - 9 (6.6)	216/194	0.910 ± 0.008	1.025 ± 0.057	1.144 ± 0.062	7.3 ± 0.7
0.10 - 0.30	10 - 24 (16.4)	287/194	0.970 ± 0.002	0.865 ± 0.041	1.856 ± 0.065	2.8 ± 0.2
0.10 - 0.30	25 - 79 (38.5)	295/194	0.984 ± 0.001	0.899 ± 0.039	2.544 ± 0.076	1.5 ± 0.1
0.30 - 0.50	2 - 9 (6.6)	202/194	0.935 ± 0.008	0.807 ± 0.039	1.187 ± 0.066	4.1 ± 0.7
0.30 - 0.50	10 - 24 (16.4)	288/194	0.964 ± 0.002	0.639 ± 0.023	1.606 ± 0.050	2.8 ± 0.2
0.30 - 0.50	25 - 79 (38.5)	328/194	0.982 ± 0.001	0.592 ± 0.018	2.015 ± 0.048	1.3 ± 0.1
0.50 - 1.00	2 - 9 (6.6)	181/194	0.883 ± 0.013	0.655 ± 0.042	0.919 ± 0.078	9.4 ± 1.1
0.50 - 1.00	10 - 24 (16.4)	263/194	0.936 ± 0.003	0.554 ± 0.026	1.430 ± 0.057	5.2 ± 0.2
0.50 - 1.00	25 - 79 (38.5)	341/194	0.973 ± 0.001	0.446 ± 0.016	1.611 ± 0.048	2.0 ± 0.1

Double ratios

– Construction of reference sample ↔ to reduce bias:

$$\mathcal{R}(Q) = \frac{R(Q)}{R_{MC}(Q)} = \frac{\left(\dfrac{dN_{signal}/dQ}{dN_{ref}/dQ}\right)}{\left(\dfrac{dN_{MC,\,like}/dQ}{dN_{MC,\,ref}/dQ}\right)}$$

$$\mathcal{R}(Q) = C\,[\,1 + \lambda\,\Omega(Qr)\,]\,(1 + \delta Q)$$

$$\Omega(Qr) = \exp(-Qr)$$

– Calculated for all 7 reference samples [PRL 105, 32001 (2010)]

Results of fits to 0.9data

Reference sample	p value (%)	C	λ	r (fm)	δ (10^{-3})
Opposite charge	21.9	0.988 ± 0.003	0.56 ± 0.03	1.46 ± 0.06	-4 ± 2
Opposite hem. same ch.	7.3	0.978 ± 0.003	0.63 ± 0.03	1.50 ± 0.06	11 ± 2
Opposite hem. opp. ch.	11.9	0.975 ± 0.003	0.59 ± 0.03	1.42 ± 0.06	13 ± 2
Rotated	0.02	0.929 ± 0.003	0.68 ± 0.02	1.29 ± 0.04	58 ± 3
Mixed evts. (random)	1.9	1.014 ± 0.002	0.62 ± 0.04	1.85 ± 0.09	-20 ± 2
Mixed evts. (same mult.)	12.2	0.981 ± 0.002	0.66 ± 0.03	1.72 ± 0.06	11 ± 2
Mixed evts. (same mass)	1.7	0.976 ± 0.002	0.60 ± 0.03	1.59 ± 0.06	14 ± 2
Combined	2.9	0.984 ± 0.002	0.63 ± 0.02	1.59 ± 0.05	8 ± 2

Systematic Uncertainties- 2010 pp run

- Choice of reference sample $\rightarrow$ main uncertainty in r
  - Estimate with r.m.s. spread with ≠ ref. samples
  - Additional $\rightarrow$ choice of MC sample (r.m.s. spread with ≠ samples)
  - 7 TeV data more affected by MC choice

$\sqrt{s}$	0.9 TeV		7 TeV	
	λ	r (fm)	λ	r (fm)
Choice of the reference sample	0.017	0.11	0.015	0.10
Choice of MC dataset	0.009	0.05	0.032	0.16
Effect of Coulomb corrections	0.017	0.01	0.017	0.02
Fit range	0.014	0.08	0.016	0.08
Total	0.029	0.15	0.042	0.21

Coulomb FSI - Gamow factor

- Charged pairs: Coulomb interaction ⟶ affect the low-Q region
- Can be parametrized by Gamow factors:

$$\Upsilon_{SS}(\eta) = \frac{\eta / Q}{e^{2\pi\eta/Q} - 1} \; ; \; \Upsilon_{OS}(\eta) = \frac{\eta / Q}{1 - e^{-2\pi\eta/Q}} \quad (\eta = \alpha_{em} m_{\pi})$$

- Testing compatibility: $[dN_{OS}/dQ(data)]/[dN/dQ(MC)]$ vs $\Upsilon_{OS}(\eta)$