Measurement of Bose-Einstein correlations in ATLAS

Rafał Staszewski

on behalf of the ATLAS Collaboration

Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences
(IFJ PAN Cracow)

Low-x Meeting 2015

1 – 5 September, Sandomierz, Poland

Supported in part by NCN grant DEC-2013/08/M/ST2/00320

Introduction – Bose-Einstein Correlations

- Correlations between identical bosons
- Due to Bose-Einstein statistics
- Enhancement of production close in phase space
- Probe of the space-time geometry of the hadronization region
- Determination of the size and the shape of the source of particle emission
- First ATLAS BEC results: arXiv:1502.07947

Contents

The idea

- Production of identical particles

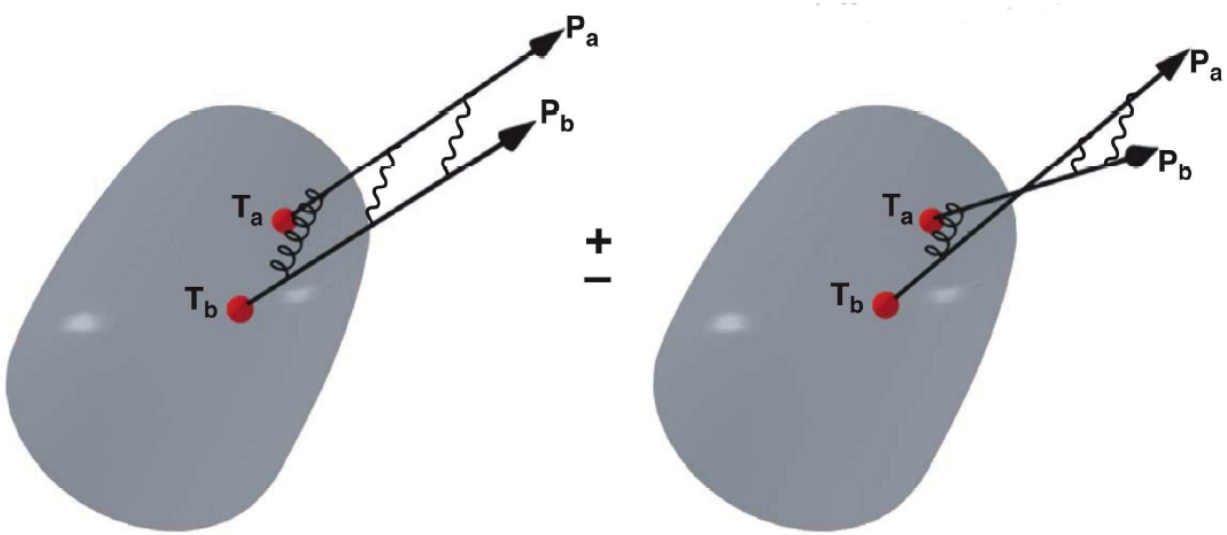


Figure from M. Lisa *at al.* Ann.Rev.Nucl.Part.Sci. 55 (2005) 357-402

- Bosons – positive interference
- Enhanced production of particles in the same state
- HEP experiments observe momenta $\rightarrow$ enhancement for small momentum difference between the two particles
- Observed enhancement depends on the size of the source

Two-particle correlation function

- Definition

$$C_2(p_1, p_2) = \frac{\rho(p_1, p_2)}{\rho(p_1)\rho(p_2)}$$

- For spherically symmetric Gaussian distribution of the emitting centres:

$$C_2(p_1, p_2) = 1 + e^{-r_0^2(p_1 - p_2)^2}$$

- Typically using C_2 averaged over momentum of the pair:

$$C_2(Q) = \frac{\rho(Q)}{\rho_0(Q)}$$

where

$$Q^2 = -(p_1 - p_2)^2$$

Parameterisation forms

$$C_2(Q) = C_0 \left[1 + \Omega(\lambda, QR)\right] (1 + \epsilon Q)$$

- C_0 – normalisation
- λ – strength (coherence) parameter:
  $\lambda = 0$ – fully coherent emission, $\lambda = 1$ – fully chaotic
- R – effective radius
- $\Omega(\lambda, QR)$ possibilities:
  - Gaussian parametrisation
    $$\Omega = \lambda \exp\left(-R^2 Q^2\right)$$
  - exponential parametrisation
    $$\Omega = \lambda \exp\left(-RQ\right)$$
- ϵ – takes into account long-distance correlations (energy-momentum conservation, *etc.*)

Contents

Reference sample

- $\rho(Q)$ – obtained from $\pi^+\pi^+$ and $\pi^-\pi^-$ pairs
- Problem: find $\rho_0(Q)$ that follows properties of $\rho(Q)$ except BEC
- Several possible methods
  - pairs taken from different events
  - pairs taken from opposite hemispheres
  - rotate p_T of one of the particles
- Drawback: violation of energy-momentum conservation
- ATLAS measurement: $\pi^+\pi^-$ pairs from the same event
- Contaminated by decay of resonances $\rightarrow$ correction from MC

$$R_2(Q) = C_2(Q)/C_2^{\mathrm{MC}}(Q) = \frac{\rho(++,--)}{\rho(+-)} \Big/ \frac{\rho^{\mathrm{MC}}(++,--)}{\rho^{\mathrm{MC}}(+-)}$$

- $\rho \rightarrow \pi^+\pi^-$ overestimated in MC $\rightarrow$ in addition, resonance region excluded from the fit

Coulomb correction

- Coulomb force $\rightarrow$ momentum shift for charged particles
- Opposite effect for like-sign and unlike-sign pairs
- Gamow penetration factor:

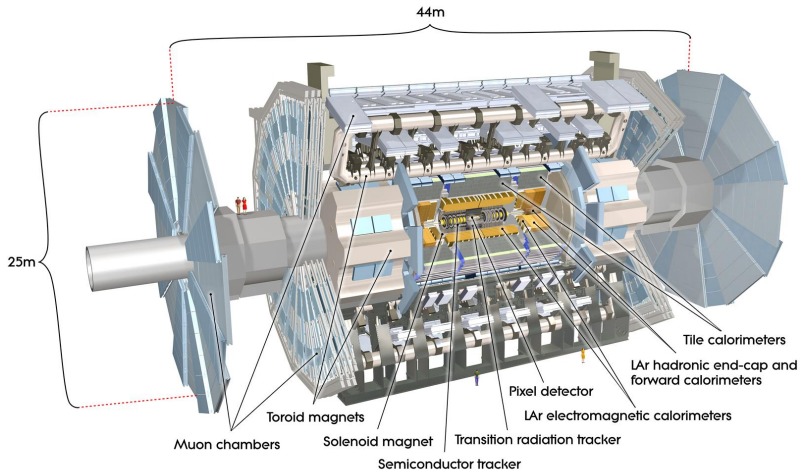
$$G(Q) = \frac{2\pi\zeta}{e^{2\pi\zeta} - 1}, \quad \zeta = \pm\frac{\alpha m_\pi}{Q}$$

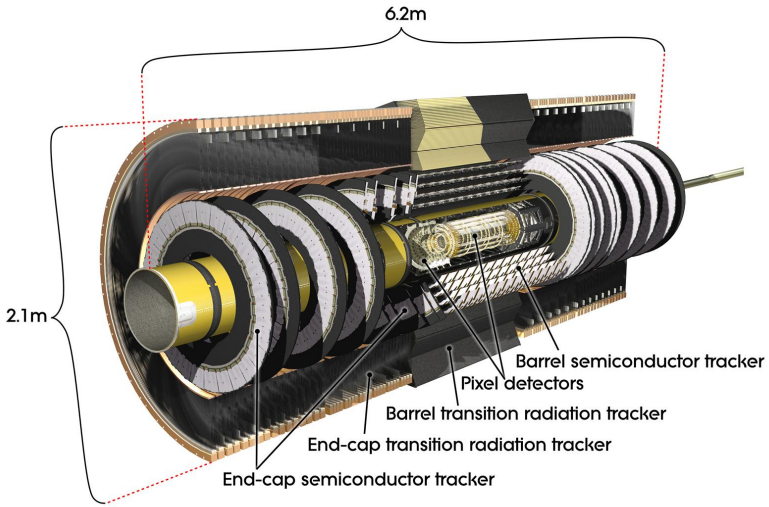
  like-sign: $+$, unlike-sign: $-$
- Corrected density:

$$\rho_{\mathrm{corr}}(Q) = \frac{\rho(Q)}{G(Q)}$$

- Correction up to 20 %
- Effect not present in MC $\rightarrow$ correction not needed there

ATLAS Detector and data selection





Track selection

- pt $>$ 100 MeV
- $|\eta| < 2.5$

Event selection

- reconstructed primary vertex
- at least two associated tracks

– No identification – assuming all tracks are charged pions

– Q resolution better than 5 MeV $\rightarrow$ 20 MeV Q-threshold

Data samples and MC

Data samples

$\sqrt{s} = 0.9$ **TeV**

- Luminosity: 7 μb^{-1}
- Minimum bias triggers
- 360K events, 4.5M tracks

$\sqrt{s} = 7$ **TeV**

- Luminosity: 190 μb^{-1}
- Minimum bias triggers
- 10M events, 210M tracks

$\sqrt{s} = 7$ **TeV HMT**

- Luminosity: 190 μb^{-1}
- High multiplicity triggers
- 18K events, 2.7M tracks

MC samples

- **PYTHIA 6.421 ATLAS MC09 tune**
- PHOJET 1.12.1.35
- PYTHIA 6 Perugia0 tune
- EPOS 1.99_v2965

The above MC models do not contain BEC effects.

Data corrections

Event-level weight

- Trigger efficiency
  - minimum bias trigger – inefficiency for $n < 5$
  - high multiplicity trigger – inefficiency for $n < 150$
- Vertex reconstruction efficiency
- Multiplicity distributions corrected using iterative method

Track-level weight

- Track reconstruction efficiency
- Secondary particles
- Selected tracks for which the primary particles are outside the kinematic range
- Fake tracks

Systematic uncertainties

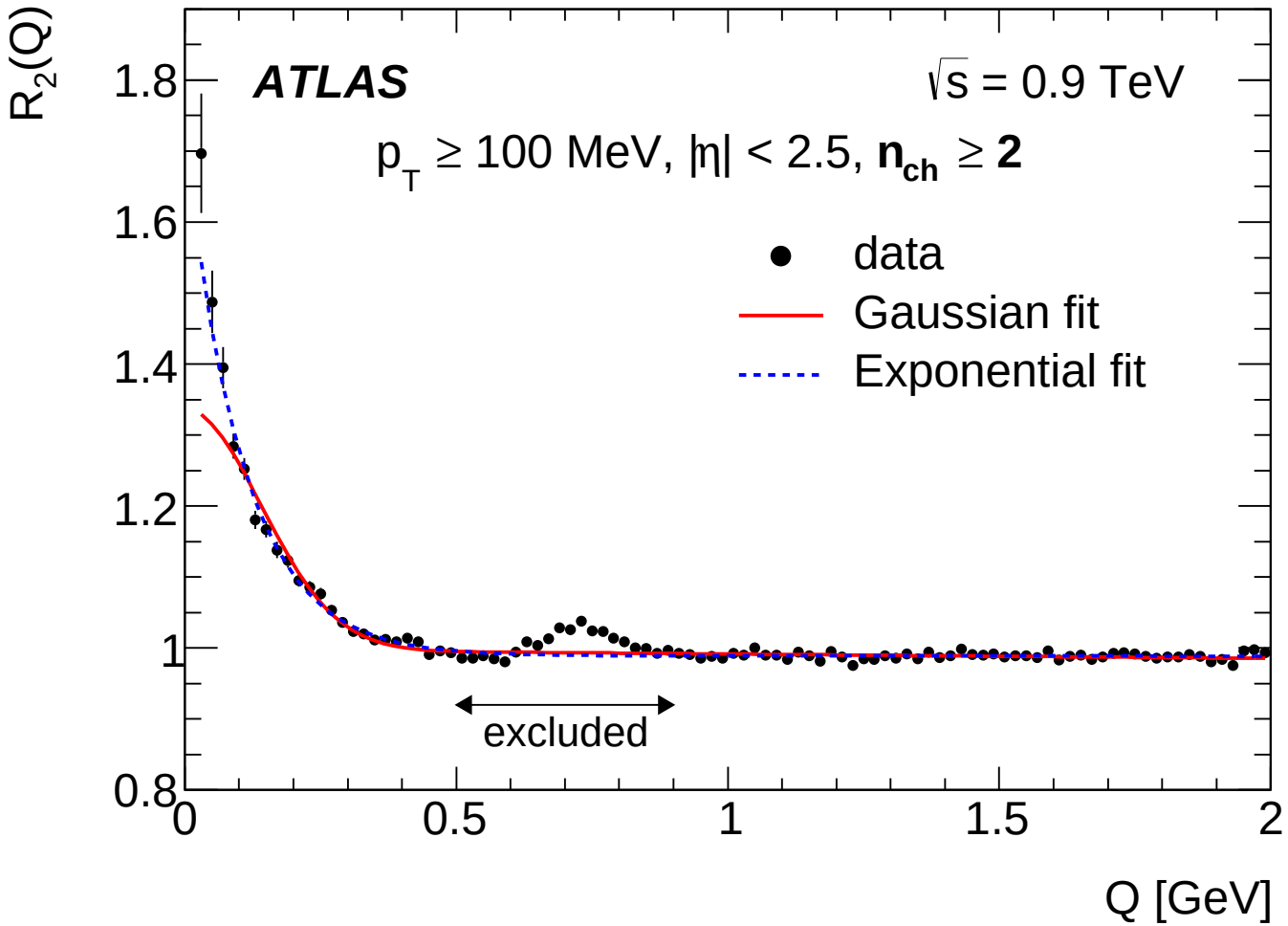
	0.9 TeV		7 TeV		7 TeV (HM)	
Source	λ	R	λ	R	λ	R
Track reconstruction efficiency	0.6%	0.7%	0.3%	0.2%	1.3%	0.3%
Track splitting and merging	negligible		negligible		negligible	
Monte Carlo samples	14.5%	12.9%	7.6%	10.4%	5.1%	8.4%
Coulomb correction	2.6%	0.1%	5.5%	0.1%	3.7%	0.5%
Fitted range of Q	1.0%	1.6%	1.6%	2.2%	5.5%	6.0%
Starting value of Q	0.4%	0.3%	0.9%	0.6%	0.5%	0.3%
Bin size	0.2%	0.2%	0.9%	0.5%	4.1%	3.4%
Exclusion interval	0.2%	0.2%	1%	0.6%	0.7%	1.1%
Total	14.8%	13.0%	9.6%	10.7%	9.4%	10.9%

- Main source – uncertainty of correction for resonances

$$R_2(Q) = C_2(Q)/C_2^{\mathrm{MC}}(Q) = \frac{\rho(++,--)}{\rho(+-)} \Bigg/ \frac{\rho^{\mathrm{MC}}(++,--)}{\rho^{\mathrm{MC}}(+-)}$$

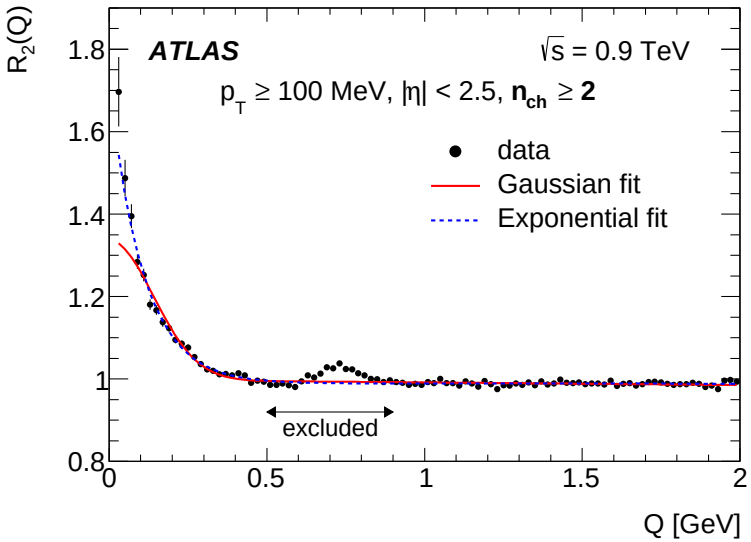
Contents

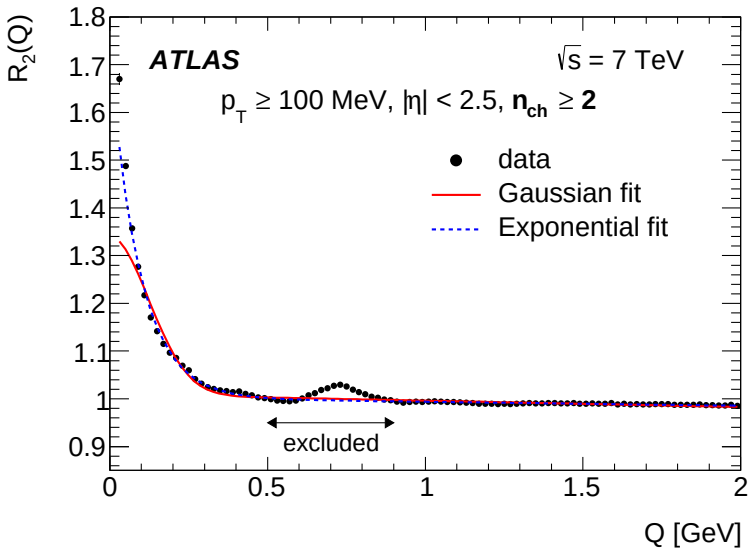
Correlation functions – shape

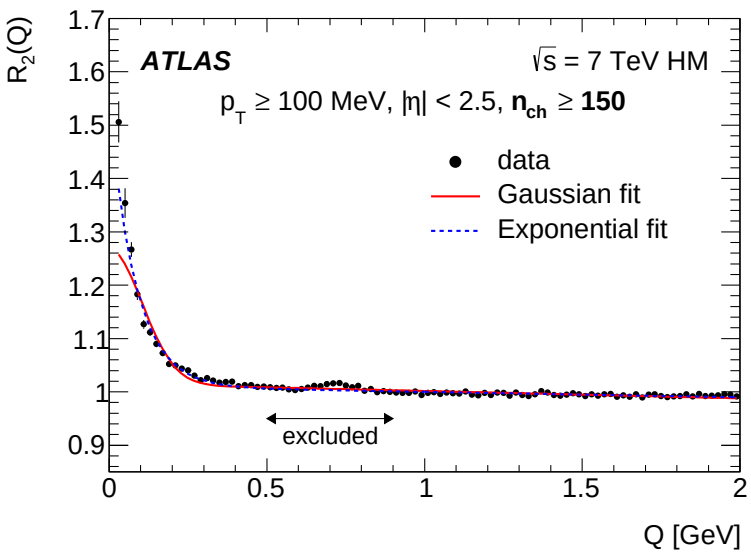


Excluded region of $\rho \to \pi^+\pi^-$ (overestimated in the MC)

Results for different samples



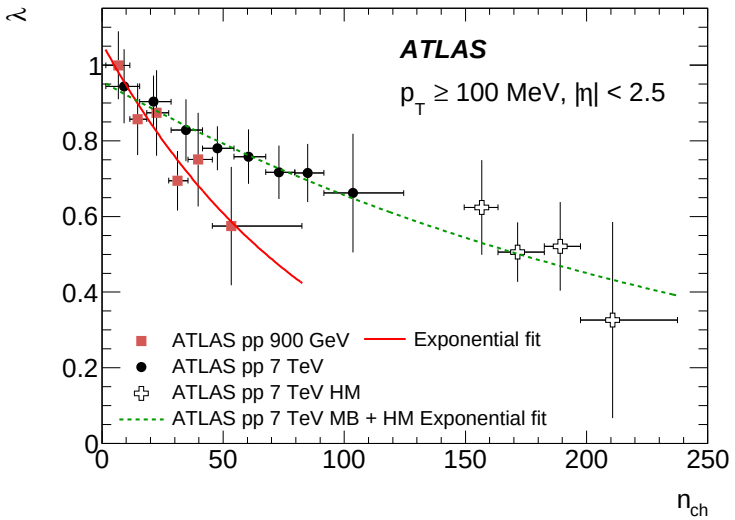




- $\sqrt{s} = 0.9$ TeV, $n_{\mathrm{ch}} \geq 2$:
  $\lambda = 0.74 \pm 0.11$
  $R = 1.83 \pm 0.25$ fm
- $\sqrt{s} = 7$ TeV, $n_{\mathrm{ch}} \geq 2$:
  $\lambda = 0.71 \pm 0.07$
  $R = 2.06 \pm 0.22$ fm
- $\sqrt{s} = 7$ TeV, $n_{\mathrm{ch}} \geq 150$:
  $\lambda = 0.52 \pm 0.06$
  $R = 2.36 \pm 0.30$ fm

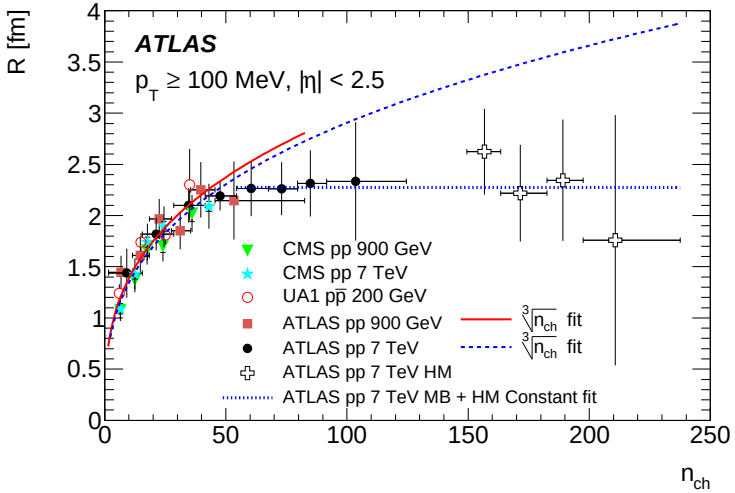
Multiplicity dependence

Parameter λ



- Exponential decrease with n_{ch}
- Decrease slower for higher $\sqrt{s}$

Parameter $\mathbf{R}$

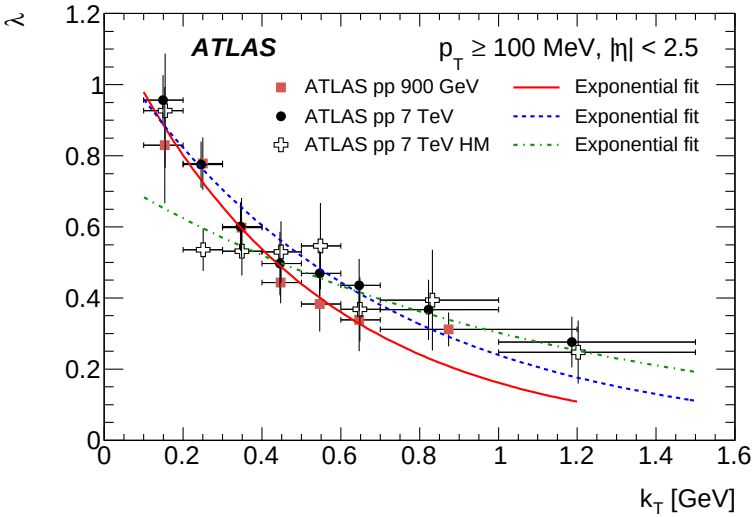


- Increase up to $n_{\mathrm{ch}} = 55$
- No clear $\sqrt{s}$ dependence
- Saturation for $n_{\mathrm{ch}} > 55$ (observed for the first time)
- Saturation R value: 2.28 ± 0.32 fm

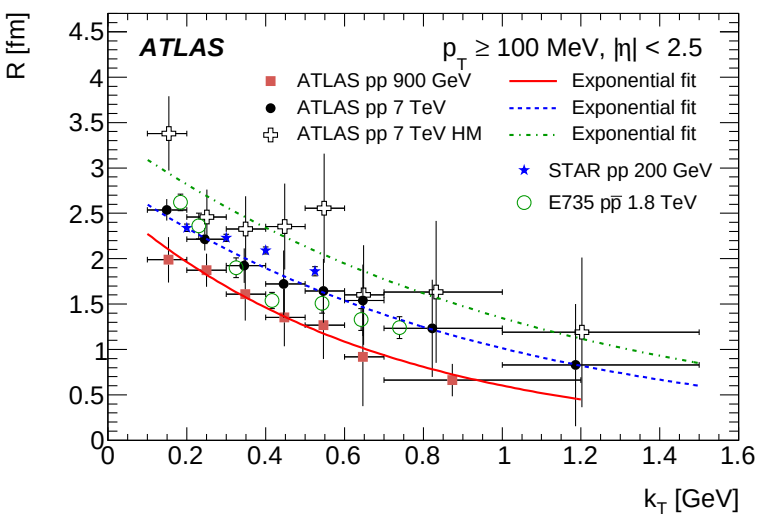
Transverse momentum dependence

- Average momentum of the pair: $k_T = |p_{T,1} + p_{T,2}|/2$

Parameter λ



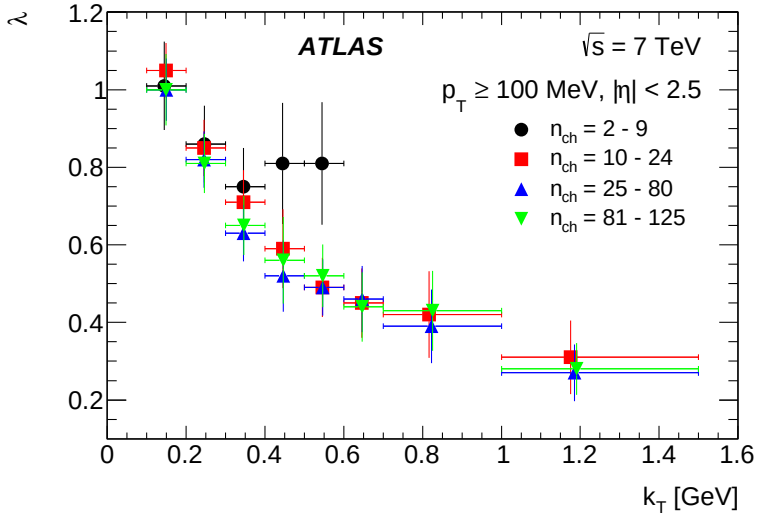
Parameter R



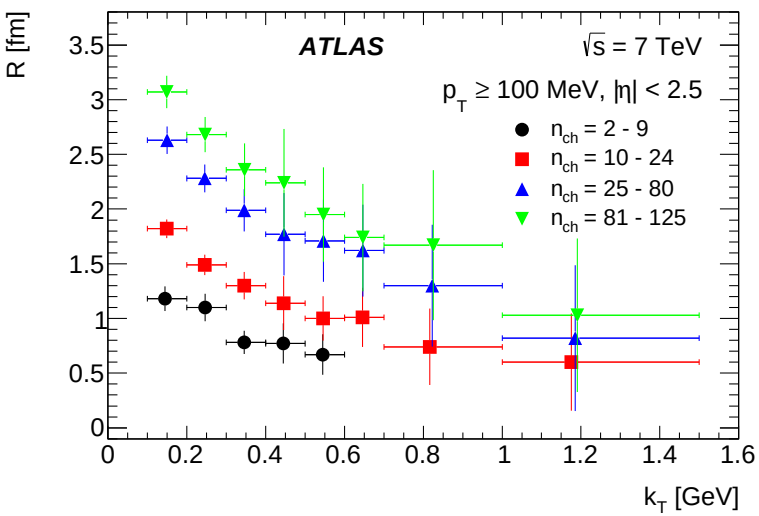
- Exponential decrease of λ and R with k_T
- No clear $\sqrt{s}$ dependence of the slopes

k_T and n_{ch} dependence

Parameter λ



Parameter R



- No n_{ch} dependence of λ
- R increases with multiplicity
- No clear change of $R(k_T)$ slope with n_{ch}

Summary

- ATLAS measured Bose-Einstein correlations in pp collisions for $\sqrt{s}$ of 0.9 and 7 TeV
- Reference from unlike-sign pairs corrected for resonances
- Clear BEC enhancement at small Q values
- Better description using exponential than Gaussian fit
- Measured BEC dependence on n_{ch} and k_T
- Events with multiplicity up to 250 studied
- Saturation observed in multiplicity dependence of R for $n_{\text{ch}} > 55$