Results and discussion of Bose-Einstein correlations in pPb from LHCb

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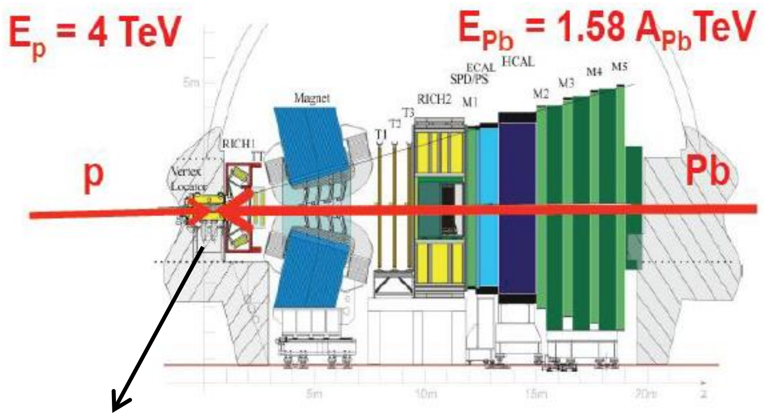
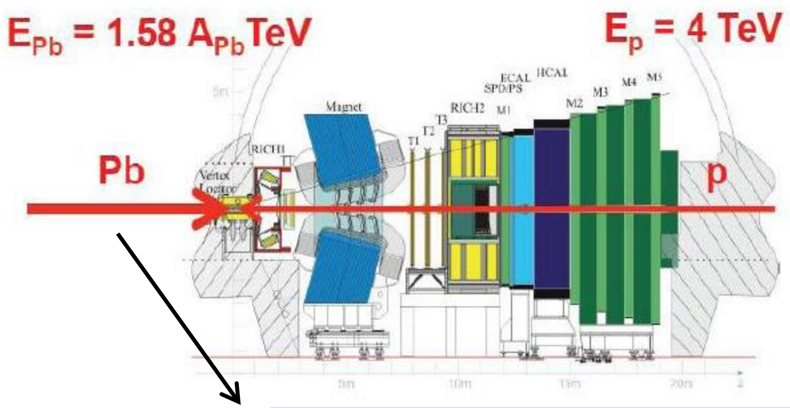
Outline

- LHCb experiment
- analysis method
- results from pp collisions
- summary

LHCb and BEC analyses

- LHCb detector: **JINST 3 (2008) S08005, IJMPA 30 (2015) 1530022**
  - single-arm spectrometer designed mainly to study CP violation in B physics
  - fully instrumented in $2 < \eta < 5$ -> can serve as a **general purpose detector**
- BEC analyses at LHCb:
  - in proton-proton collisions @ 7 TeV (published: **JHEP 12 (2017) 025**)
  - in proton-lead collisions @ 5 TeV (ongoing)
- p-Pb data taking:
  - two beam modes (pPb/Pbp) with **asymmetric beams**





VELO detector used in definition of **event activity**

higher activity expected when Pb goes `towards` the detector

Event multiplicity bins

- BEC parameters depend on total multiplicity of an event
- **VELO track multiplicity (*N_{ch}*)** is a good probe of that quantity
- PVs are split into multiplicity bins based on N_{ch} distribution (optimized to ensure similar statistics in each bin)
- **unfolding of *N_{ch}*** allows for comparison between experiments after taking into account different η acceptances (model-dependent)
  - done for pp using PYTHIA 8 in $2 < \eta < 5$
  - planned also for pPb

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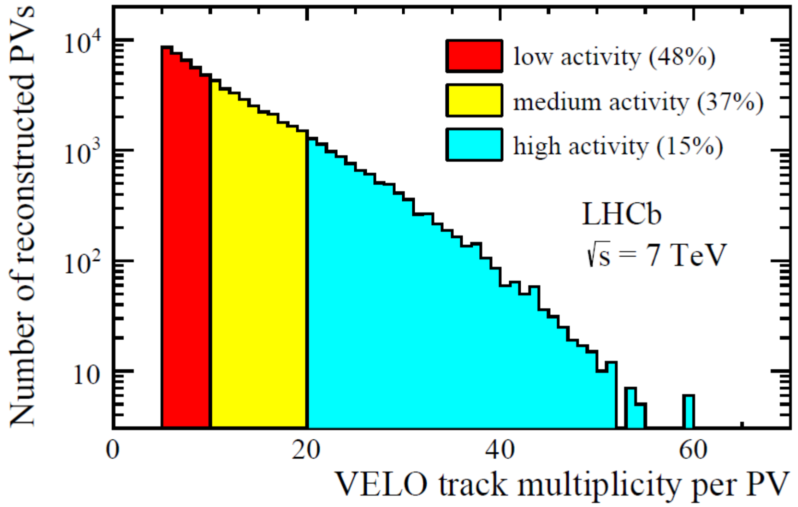
- in pp: corresponding **activity classes** defined as fractions of N_{ch} distribution (independent of specific experiment features, e.g. efficiency, acceptance)



Datasets

pp

- pp data 2011@7 TeV
  (40M minimum bias events)
- MC – PYTHIA 8
  (20M minimum bias events)
- 3 bins in N_{ch}

bin #	VELO N_{ch}	activity class	unfolded N_{ch}
1	5-10	low	8-18
2	11-20	medium	19-35
3	21-60	high	36-96

pPb

- pPb/Pbp data 2013@ 5 TeV
  (70M minimum bias events for each beam configuration)
- MC – EPOS
  (12M for each beam configuration)
- 6 bins in N_{ch}
- 3 bins in N_{ch} + 3 bins in k_T (preliminary)

bin #	VELO N_{ch}	
	p-Pb	Pb-p
1	5 - 25	5 - 30
2	26 - 33	31 - 45
3	34 – 40	46 – 55
4	41 – 47	56 – 65
5	48 – 54	66 – 80
6	55 – 80	81 - 140

Correlation function

- **correlation function** (experimentally):

$$C_2(Q) = \frac{N(Q)^{SAME}}{N(Q)^{REF}}$$

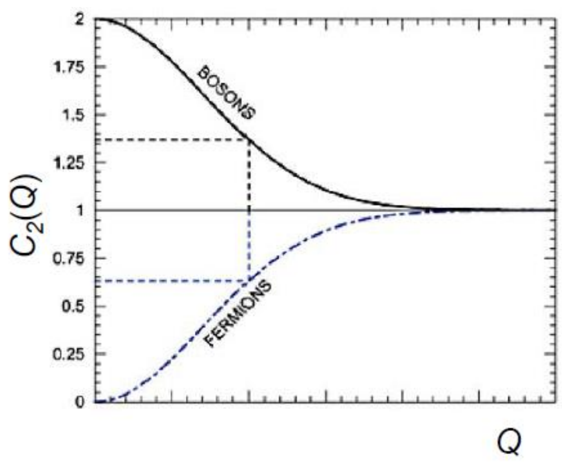
distribution for pairs of same-sign pions from same PV **[BEC effect present]**

distribution for reference sample **[no BEC effect]**

- **event-mixed reference sample** is used:
  - pairs of pions from different events from PVs with same VELO N_{ch}
  - other correlations also removed -> construct **double ratio** (next slide)
- in this analysis - **Levy parametrization** (with **α=1**) + long-range correlations:

$$C_2(Q) = N\left(1 \pm \lambda e^{-|RQ|^{\alpha}}\right) * (1 + \delta Q)$$

R – radius of a spherical static source
λ – chaoticity parameter
(0 – coherent source, 1 – chaotic emission)
N – normalization factor
δ – long-range correlations
α – index of stability



Double ratio

- **double ratio** $r_d(Q)$ – an improved correlation function:

$$r_d(Q) = \frac{C_2(Q)^{DATA}}{C_2(Q)^{MC}}$$

BEC effect **not simulated** in MC

- MC correlation function contains **similar pattern of distortions** as correlation function for data, therefore constructing double ratio:
  - reduces possible imperfections of the reference sample
  - eliminates second order effects to large extent
  - corrects for long-range correlations (if properly simulated)

Coulomb correction

- **Coulomb effect** is not simulated in MC
- in pp analysis: corrected by applying **Gamov penetration factor** $G_2(Q)$ to the Q distribution for signal pairs in data:

$$G_2(Q) = \frac{2\pi\zeta}{e^{2\pi\zeta-1}}, \text{ where } \zeta = \pm\frac{\alpha m}{Q}$$

- in pPb analysis: **Bowler-Sinyukov formalism** planned to be used to account for the Coulomb effect

BEC in pp collisions

[JHEP 12 (2017) 025]

Results – BEC pp (I)

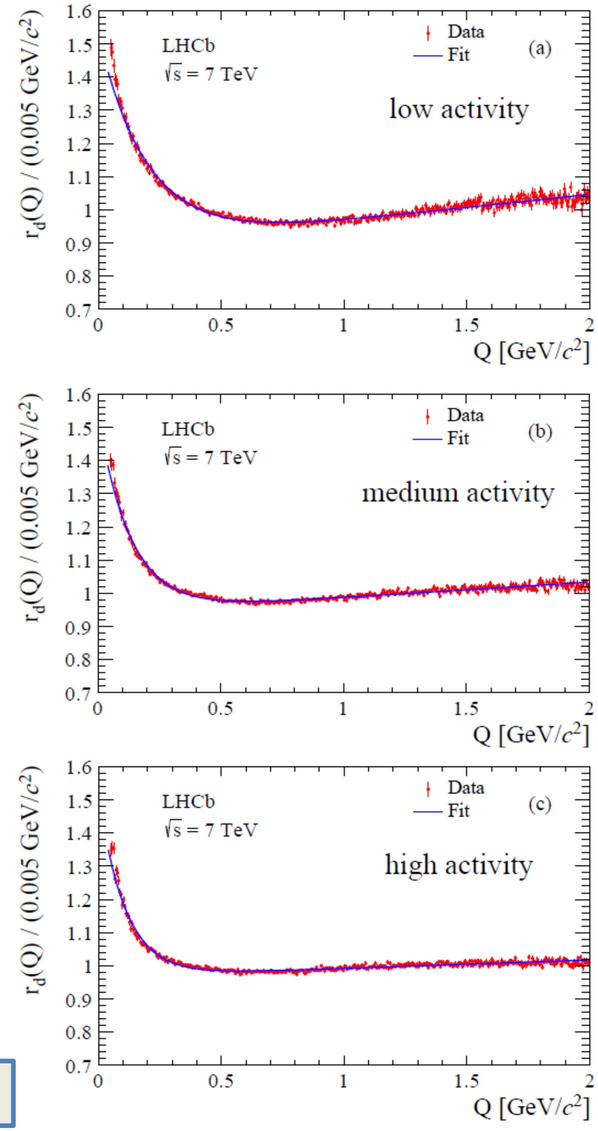
- fits to double ratio with Levy parametrization with α=1:

$$C_2(Q) = N(1 \pm \lambda e^{-RQ}) * (1 + \delta Q)$$

- clear **enhancement due to BEC** effect observed in Q->0

Activity class	R [fm]	λ
low	1.01 ± 0.01 ± 0.10	0.72 ± 0.01 ± 05
medium	1.48 ± 0.02 ± 0.17	0.63 ± 0.01 ± 0.05
high	1.80 ± 0.03 ± 0.16	0.57 ± 0.01 ± 0.03

Systematic uncertainty (~10%) dominated by generator tunings and pile-up effects.



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Results – BEC pp (II)

Results show a trend compatible with previous observations at LEP and other LHC experiments:

- **source size increases with activity**
- ***λ* decreases with growing activity**

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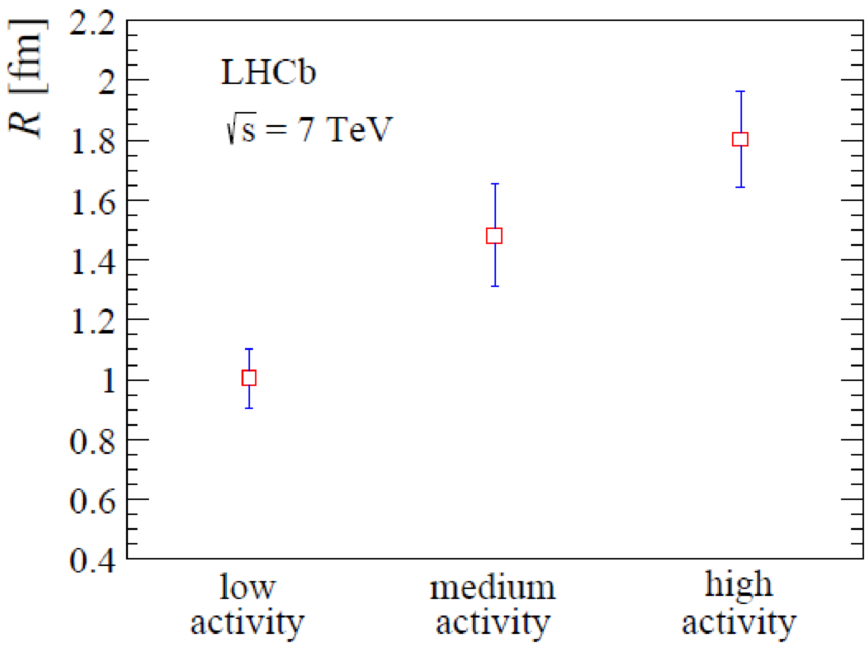

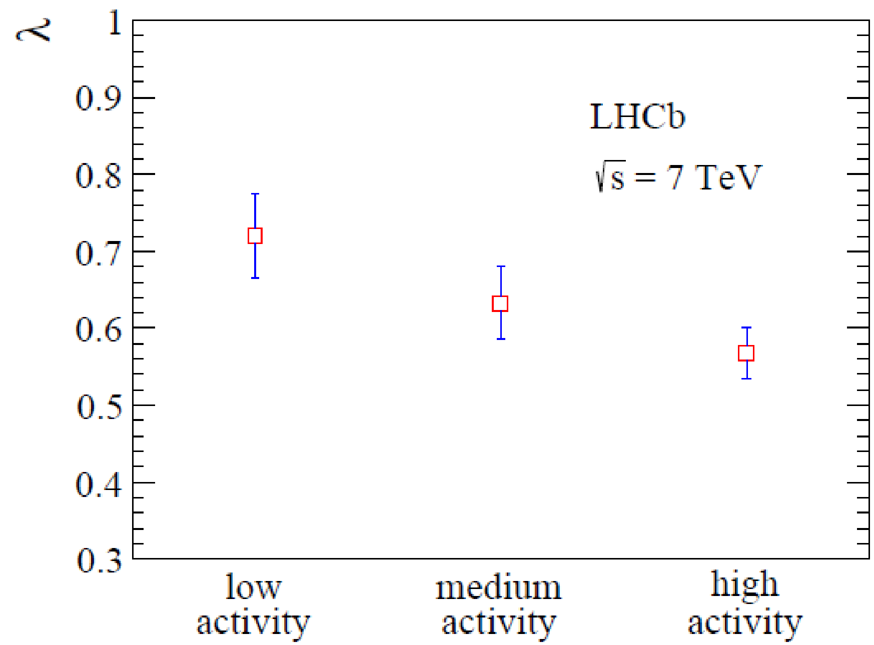

***R* and *λ* parameters** measured **in the forward region are slightly lower** than results for central rapidity obtained by ATLAS

Summary

Bose-Einstein correlations studied for same-sign pions at 7 TeV

- first measurement in the forward region $2 < \eta < 5$
- observed trends compatible with previous results and predictions
- BEC parameters in the forward region slightly lower wrt central rapidities

BEC analysis for 5 TeV p-Pb collisions ongoing

- analysis planned in 6 N_{ch} and 3 N_{ch} + 3 k_T bins (statistics sufficient)
- the τ-model will be used for fits, to study possible oscillations

Thank you for your attention

BACKUP SLIDES

Motivation

HBT interferometry in particle physics

- correlations in four-momenta (q_1, q_2) of indistinguishable particles emitted from the same source:

$$Q = \sqrt{-(q_1 - q_2)^2}$$

- due to symmetrization (Bose-Einstein correlations – BEC) or antisymmetrization (Fermi-Dirac correlations – FDC) of the total wave function
- useful **tool to probe** the spatial and temporal **structure of the hadron emission volume**
- many results on BEC from SPS, LEP, RHIC, LHC (ALICE, ATLAS, CMS)
- LHCb measurement in a unique acceptance region

Offline selection

Single track:

- false isMuon flag
- if tracks share all VELO hits -> keep one with best χ^2
- $2 < \eta < 5$
- track $\chi^2 < 2.0$
- probNN(ghost) < 0.25
- probNN(kaon,proton) < 0.5
- probNN(pion) > 0.65

Pairs with Q<0.05 GeV are rejected (clones and ghosts removal).

BEC pp- systematics

Source	Low activity		Medium activity		High activity	
	ΔR [%]	$\Delta\lambda$ [%]	ΔR [%]	$\Delta\lambda$ [%]	ΔR [%]	$\Delta\lambda$ [%]
Generator tunings	6.6	4.3	8.9	3.5	6.5	1.5
PV multiplicity	5.9	5.8	6.1	4.5	3.9	4.3
PV reconstruction	1.8	0.1	1.4	1.2	0.1	<0.1
Fake tracks	0.4	1.1	1.7	3.9	1.1	0.8
PID calibration	1.3	0.3	0.8	0.6	2.7	0.9
Requirement on pion PID	2.9	1.8	1.6	0.1	1.3	0.1
Fit range at low-Q	1.2	1.0	1.2	1.5	1.8	2.7
Fit range at high-Q	1.8	0.1	2.1	0.8	2.4	1.4
Total	9.8	7.6	11.4	7.3	8.8	5.6