Femtoscopic correlations of identical charged particles in pp collisions at LHC energies with event-shape selection.

(for the ICPPA-2020)

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for the ALICE Collaboration

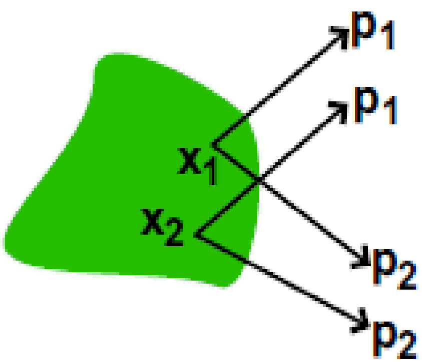
Overview

- Introduction
- Motivation
- ALICE at LHC
- Analysis details
- Results

  - $\pi^{\pm}\pi^{\pm}$
  - $K^{\pm}K^{\pm}$
- Summary

Introduction: What is Femtoscopy ?

Correlation femtoscopy : measurement of space-time characteristics R, cτ ~fm of particle production. Which uses particle correlations due to the effects of quantum statistics (QS) and final state interactions (FSI)



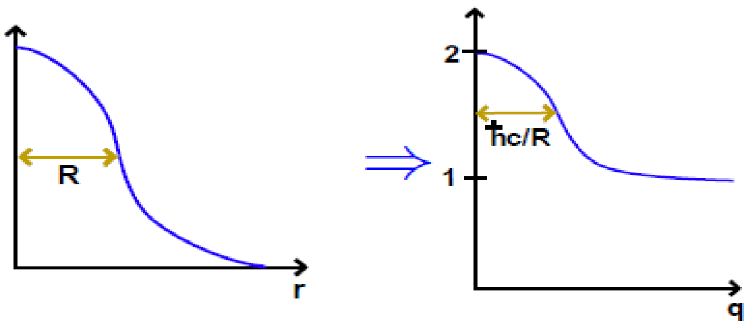
- Two particle Correlation Function (CF):

Theory: $$C(q)=\frac{N_2(p_1,p_2)}{N_1(p_1)\cdot N_2(p_1)}, C(\infty)=1$$

Experiment: $$C(q)=\frac{S(q)}{B(q)}, q=p_1-p_2$$

$S(q)$ – pairs from same event

$B(q)$ – pairs from different event



- Parametrization:

1D: $C(q_{inv})=1+\lambda\exp(-R^2 q_{inv}^2)$

R Gaussian radius in Pair Rest Frame (**PRF**),

λ correlation strength parameter

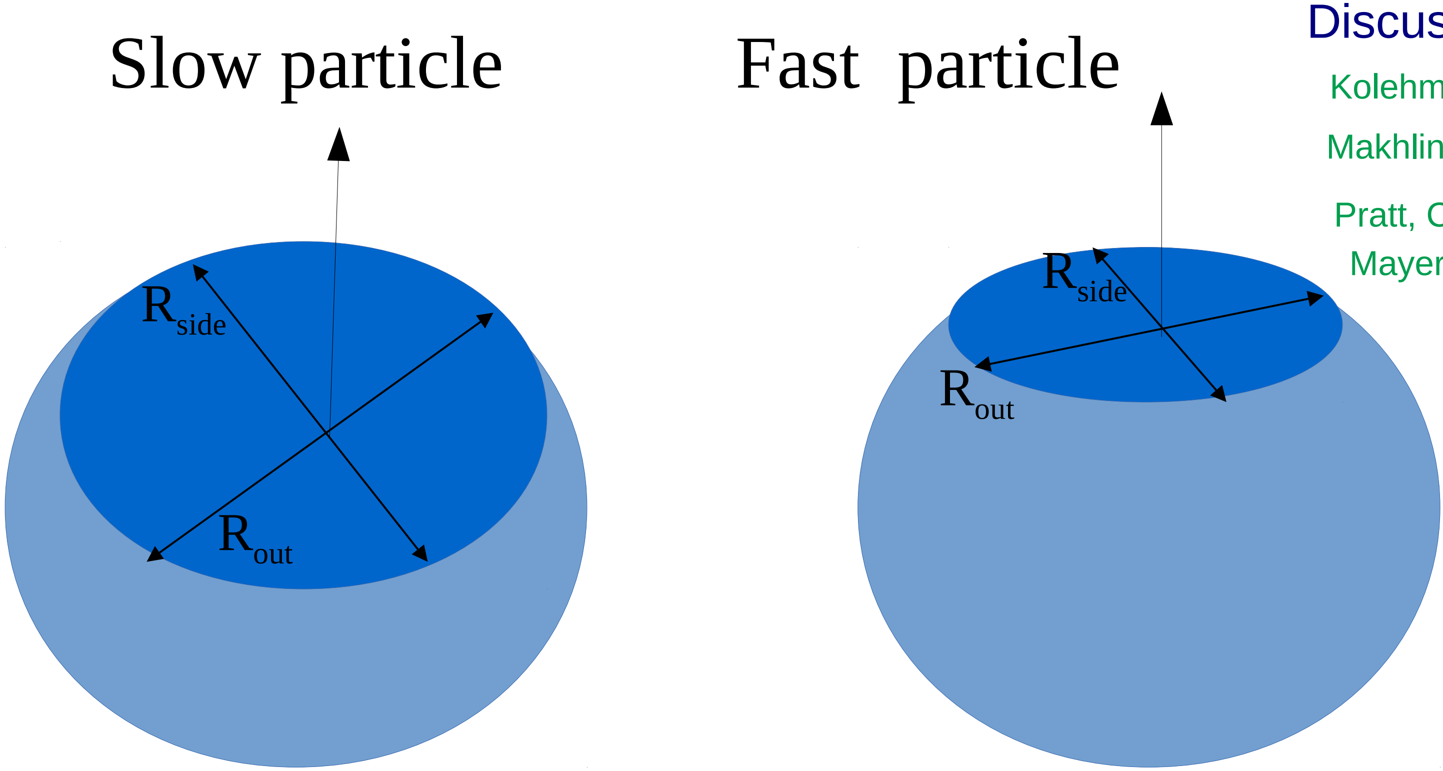
3D: $$C(q_{out}, q_{side}, q_{long})=1+\lambda\exp(-R_{out}^2 q_{out}^2-R_{side}^2 q_{side}^2-R_{long}^2 q_{long}^2)$$

where both ***R*** and ***q*** are in Longitudinally Co-Moving Frame (**LCMS**)

long || beam; out || transverse pair velocity $\boldsymbol{v}_T$; side normal to out,long

Femtoscopy: expanding source in HI collisions

- **x-p** correlations -> interference dominated by particles from nearby emitters.
- interference probes only parts of the source at close momenta – **homogeneity regions.**
- longitudinal and transverse expansion of the source -> significant reduction of the radii with increasing pair velocity, consequently with k_T (or $m_T=(m^2+k_T^2)^{1/2}$)



Discussed in e.g.:

Kolehmainen, Gyulassy'86

Makhlin-Sinyukov'87

Pratt, Csörgö, Zimanyi'90

Mayer, Schnedermann,Heinz'92

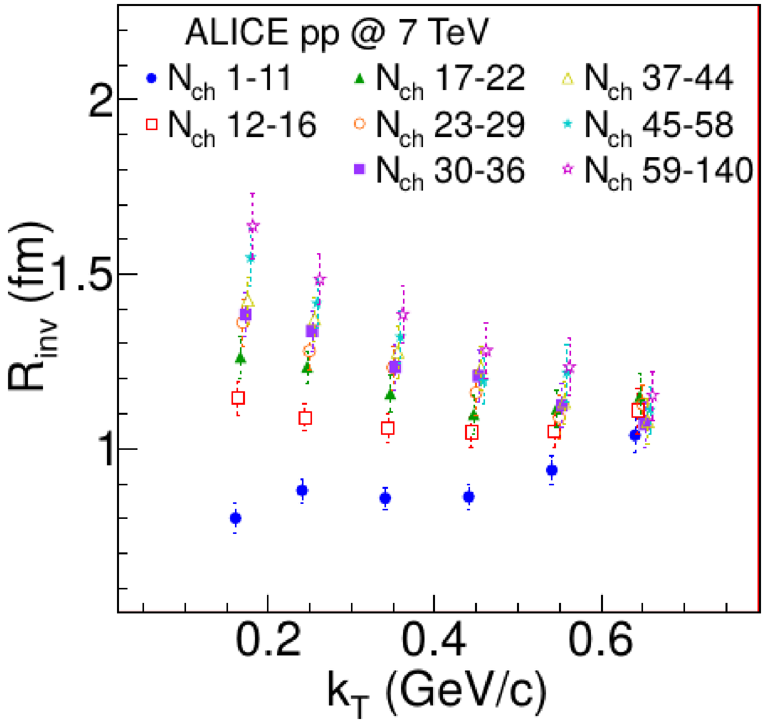
$R_{side} \sim R/(1+m_T\beta_T^2/T)^{1/2}$ β_T collective transverse flow

$R_{long} = \tau\ (T/m_T)^{1/2}$, assuming a longitudinal boost invariant expansion

Motivation of Femtoscopy study in pp collisions

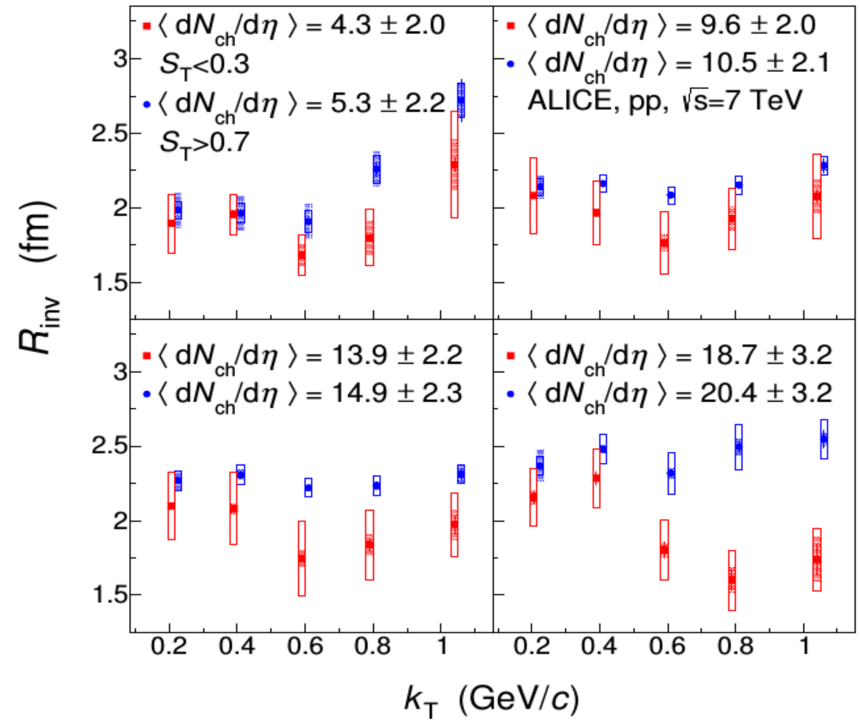
ALICE Collaboration,PRD84 (2011)

1D Gaussian MB Pion radii for 7 TeV



ALICE Collaboration,JHEP1909 (2019)

1D Exponential Pion radii for 7 TeV, Sphericity selection



- **Try to use global characteristics of events (*Sphericity*) to separate "soft" and "hard" processes**
  (ALICE Collaboration., JHEP 1909 (2019), arXiv:1901.05518 [nucl-ex].)

- **Study of m_T , k_T and multiplicity dependencies of pion & kaon femtoscopic radii separately for "jet-like" events and "spherical events".** (ALICE Collaboration, Phys. Rev. D84 (2011) 112004, ALICE Collaboration, Phys. Rev. D87 no. 5, (2013) 052016; CMS Collaboration); ATLAS Collaboration, Eur. Phys. J. C 75 (2015) 466.)

Motivation of Femtoscopy study in pp collisions

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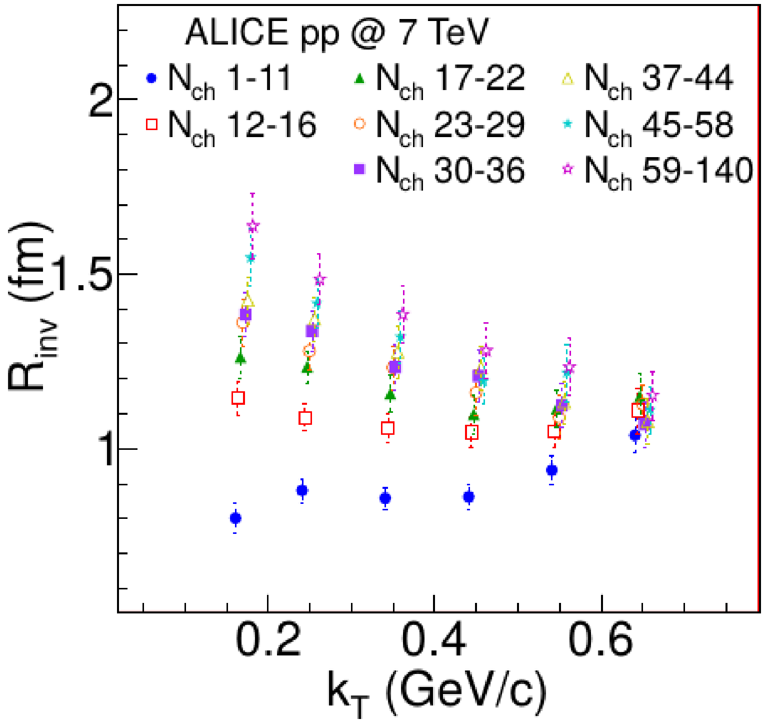
1D Gaussian MB Pion radii for 7 TeV



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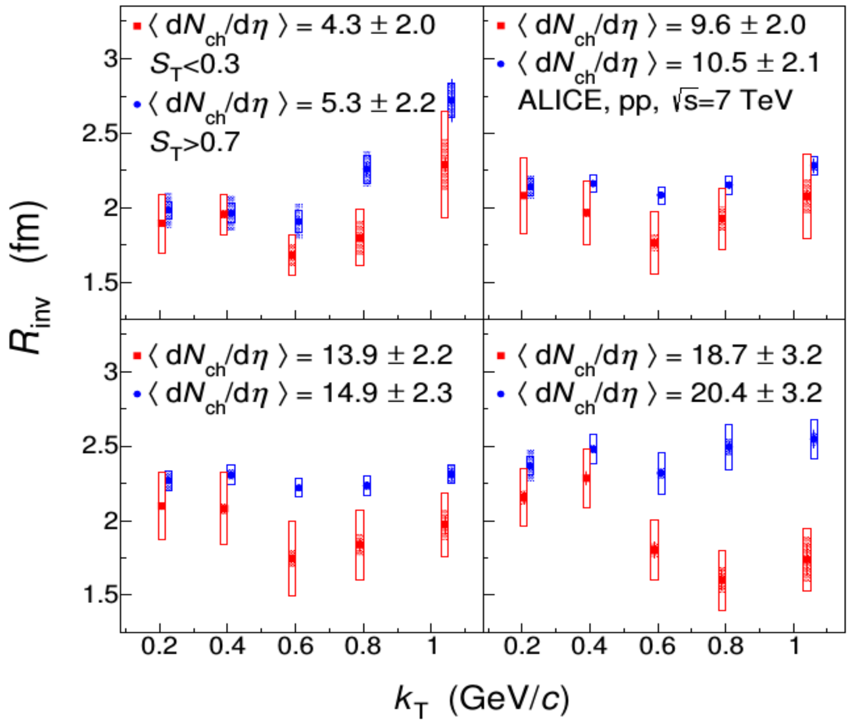
1D Exponential Pion radii for 7 TeV, Sphericity selection



- Is it due to momentum-coordinate correlations similar to Pb-Pb (radial flow) ? Contribution of particles from resonance decays ? mini-jets influence ?

Transverse Sphericity

- Transverse Sphericity:

$$S_{XY} = \frac{1}{\sum_i p_T^i} \sum_i \frac{1}{p_T^i} \begin{pmatrix} (p_x^i)^2 & p_x^i \cdot p_y^i \\ p_x^i \cdot p_y^i & (p_y^i)^2 \end{pmatrix},$$

$$S_T = \frac{2 \cdot \min(\lambda_1, \lambda_2)}{\lambda_1 + \lambda_2}.$$

eigenvalues λ1 and λ2.

Good resolution on the transverse sphericity: only events with **more than two primary tracks** in **|η| < 0.8 & p_T > 0.5 GeV/c** were selected.

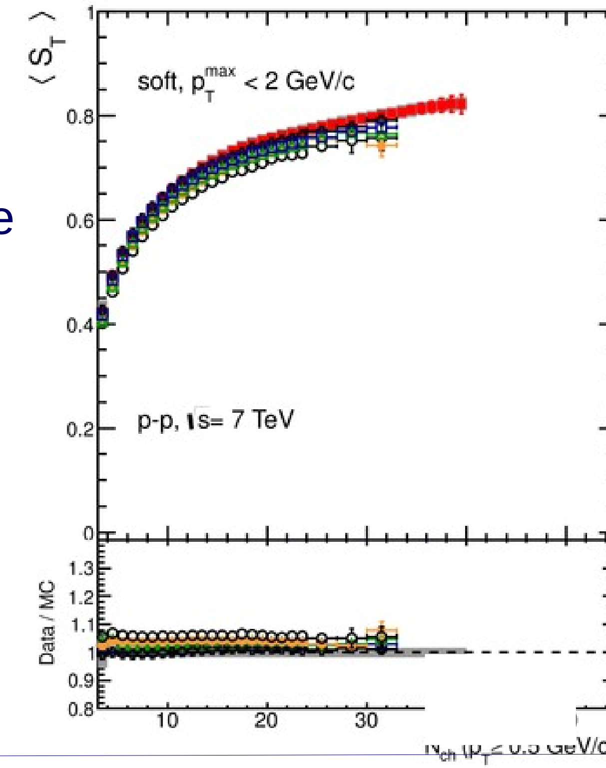
ALICE Collaboration., Eur.Phys.J. C72 (2012) 2124;
ALICE Collaboration, JHEP 1909 (2019), arXiv:1901.05518 [nucl-ex].

Experimental sphericity distributions

ALICE Collaboration., Eur.Phys.J. C72 (2012) 2124;

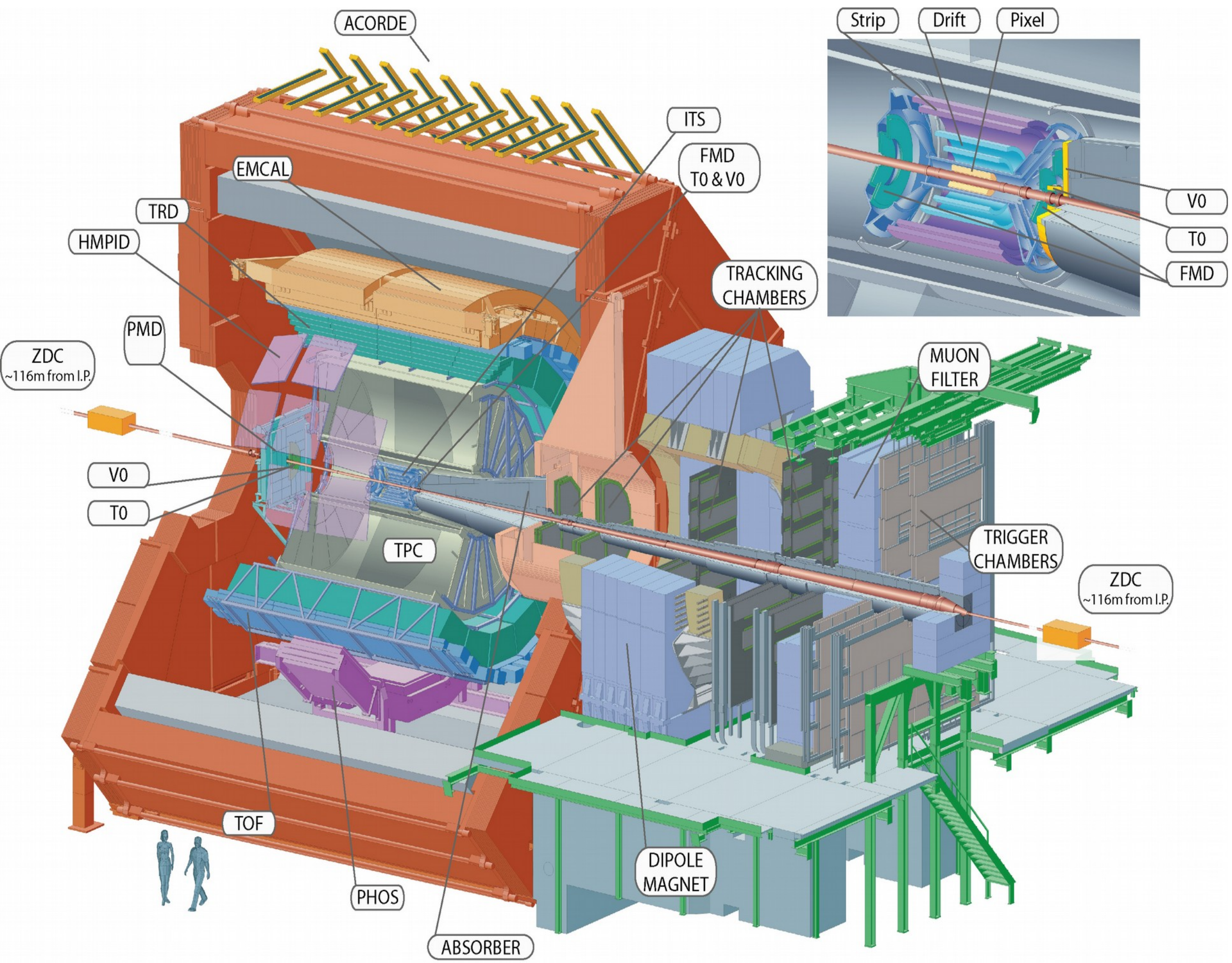
- Sphericity → 1 " isotropic limit "
spherical events, there are no jet structure, thermal production dominates.
In this analysis: S_T > 0.7

- Large Sphericity values are preferable for large multiplicity events.



- Sphericity → 0 "pencil-like limit"
Jet-like events : jets, mini-jets.
In this analysis : S_T < 0.3

ALICE detector



- Main tracking detector:
  Time Projection Chamber (TPC)
- Vertexing and tracking:
  Inner Tracking System (ITS)
- Centrality determination:
  V0
- Particle identification (PID):
  TPC (energy loss)
  Time-of-Flight (TOF)

Details of Analysis ππ & $K^{\pm}K^{\pm}$

- **Data :** $2 \cdot 10^7$ MB events; **Monte Carlo:** PYTHIA 8 (Monash 2013) ~ $1 \cdot 10^7$ MB events

- **Event selection**
  - Triggers: Minimum Bias trigger
  - Reconstructed vertex |Vz|<10 cm
  - At least one particle must be reconstructed as a pion (kaon)

- **Single track cuts**
  - $|\eta| < 0.8$ and $0.15 < p_T < 1.5$ GeV/c (kaons), $0.15 < p_T < 4.0$ GeV/c (pions)
  - Global tracks TPC+ITS, DCA XY < 0.3 cm; DCA Z < 0.3 cm

- **Double track cuts:**
  - Pairs which share more than 5% of clusters in the TPC were removed
  - Cut on the average separation of tracks in the TPC: $\langle \Delta r \rangle < 12$ cm

- **Fitting procedure:** Bowler-Sinyukov formula for pions and for kaons:

  $C(q_{inv}) = [\,1 - \lambda + \lambda\, K(q_{inv})(1 + \exp(-R^n q_{inv}^{\ n}))\,]\, D(q_{inv})$, $n=1$ for pions, $n=2$ for kaons

  $K(q) = C(q)(QS+Coulomb)/C(q)$,

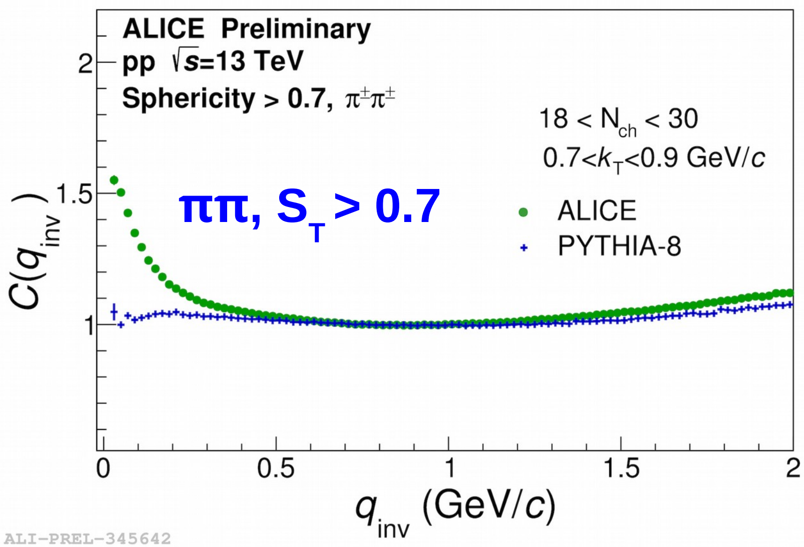
  $D(q_{inv}) = N(1+bq_{inv})$

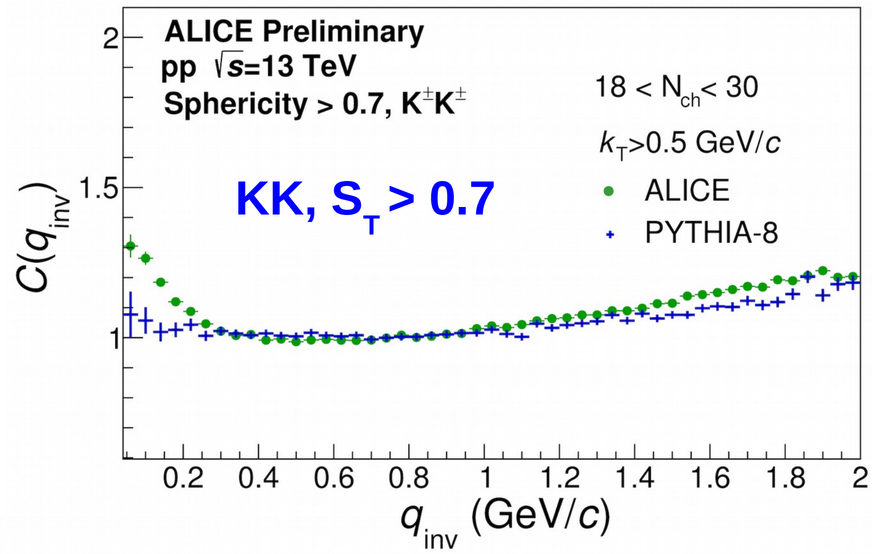
  and Double Gaussian for pions:

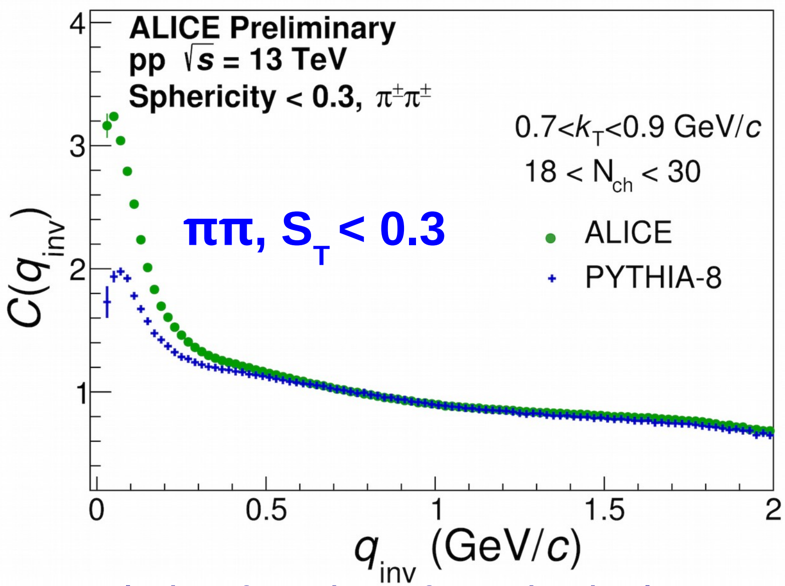
  $C(q_{inv}) = [\,1 - \lambda + \lambda\, K(q_{inv}) C_{2G}(q_{inv})\,]\, D(q_{inv})$,

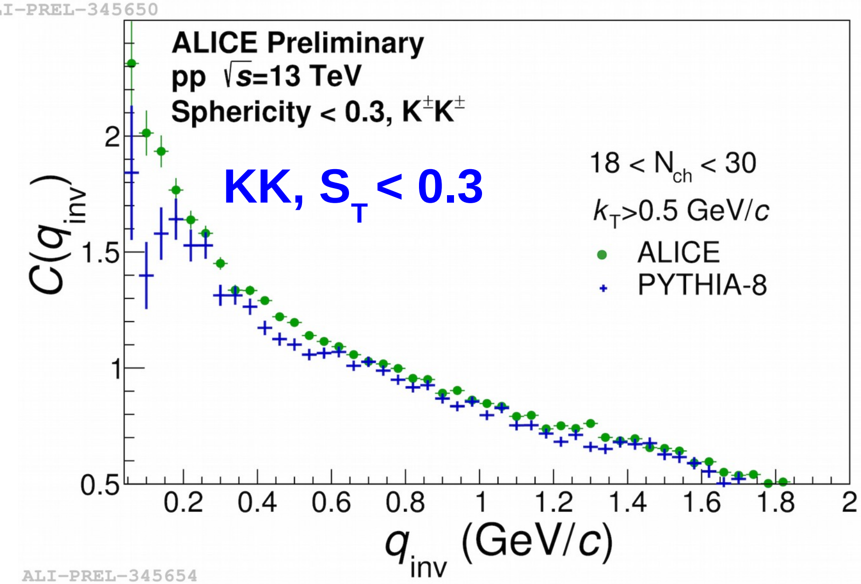
  $C_{2G} = (1 + (1-f)\exp(-R_1^{\,2} q_{inv}^{\ 2}) + f \exp(-R_2^{\,2} q_{inv}^{\ 2}))$

Correlation Functions with Sphericity selection



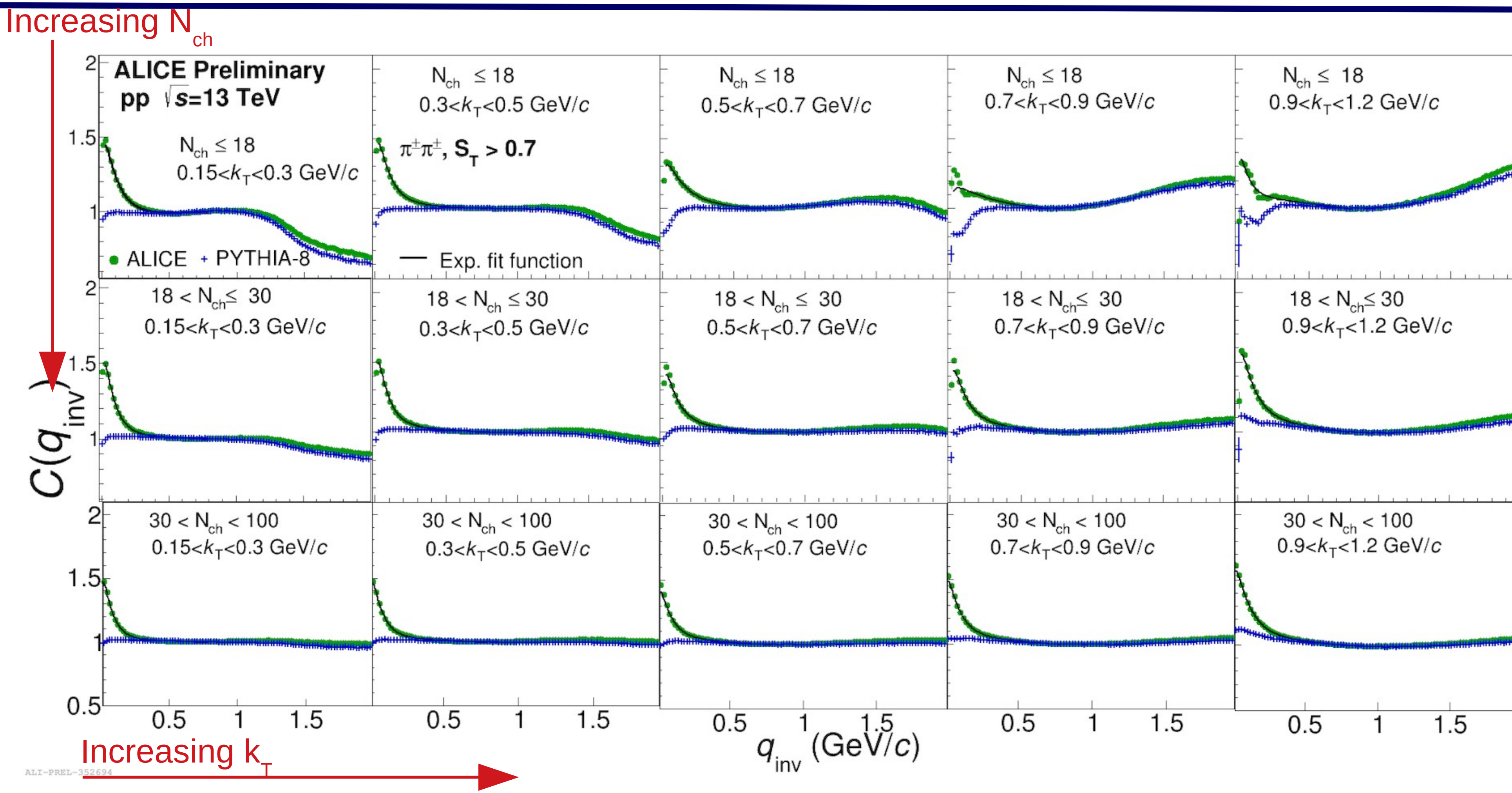






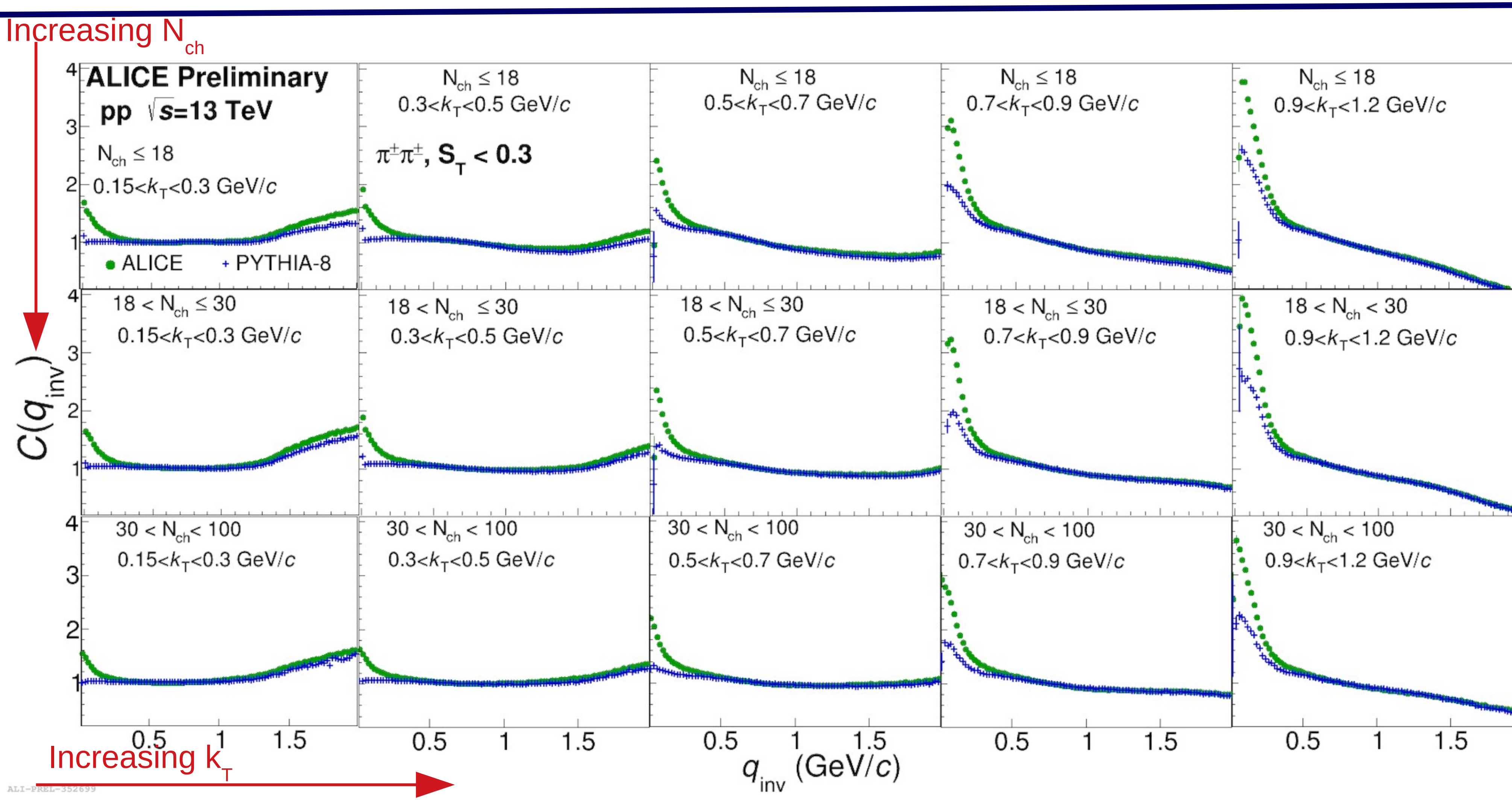
- Correlation functions for spherical events demonstrate a strong suppression of mini-jet contributions in contrast to jet-like events.
- PYTHIA 8 describes well the shape of pion and kaon CF.

ππ CF : Sphericity > 0.7



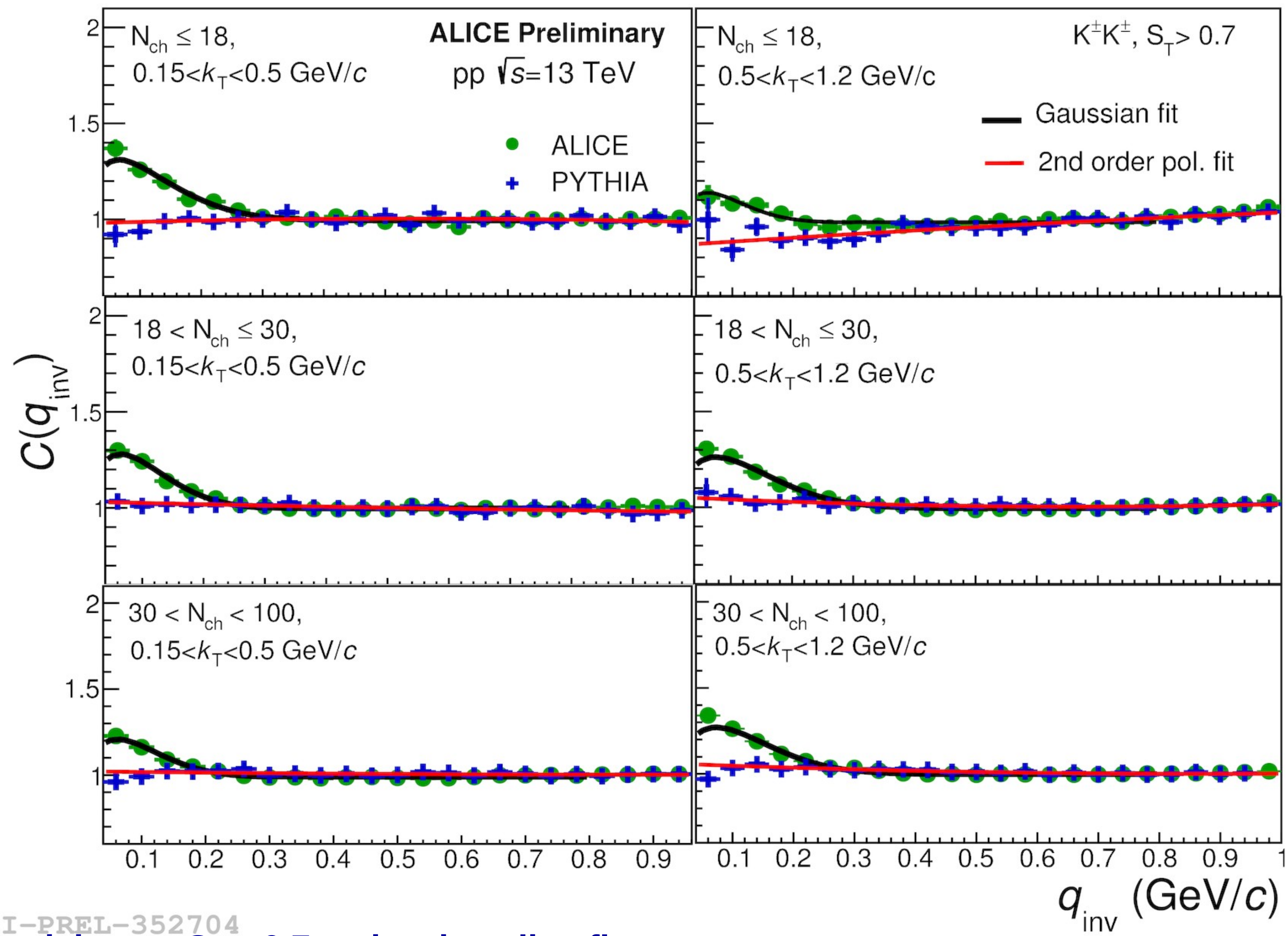
- **Sphericity cut S_T > 0.7 makes baseline flatter**
- PYTHIA 8 with sphericity cut S_T > 0.7 describes baseline well
- Wide minimum appears at q_{inv}->0 in small multiplicity bins (N_{ch}< 18) at k_T > 0.5 GeV/*c* due to lack of tracks with $q_{inv} \to 0$.

ππ CF : Sphericity < 0.3



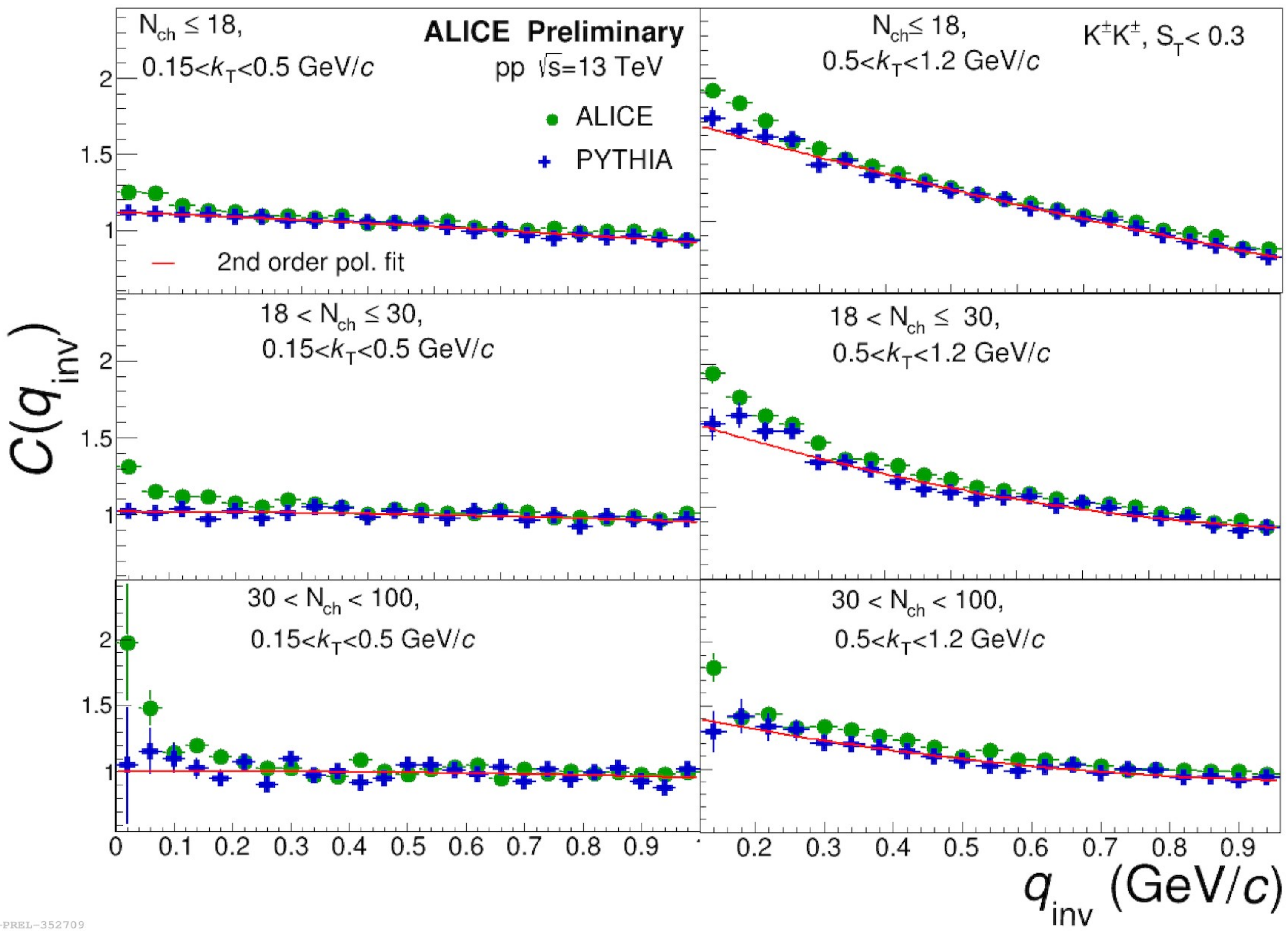
- **Sphericity cut S_T < 0.3 increases the relative contribution of mini-jets in CF**
- Contribution of mini-jets increasing with k_T
- PYTHIA 8 with sphericity cut S_T < 0.3 describes baseline well

KK CF : Sphericity > 0.7



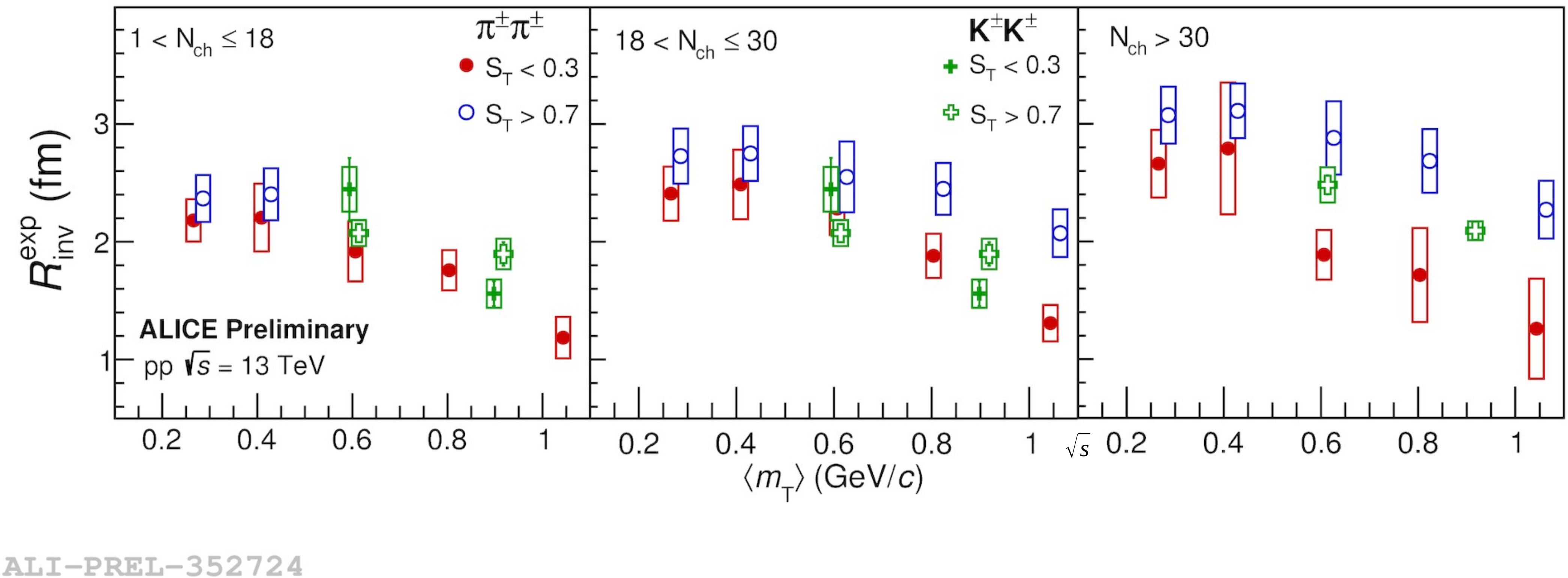
- **Sphericity cut S_T > 0.7 makes baseline flatter**
- PYTHIA-8 with sphericity cut S_T > 0.7 describes baseline well

KK CF : Sphericity < 0.3



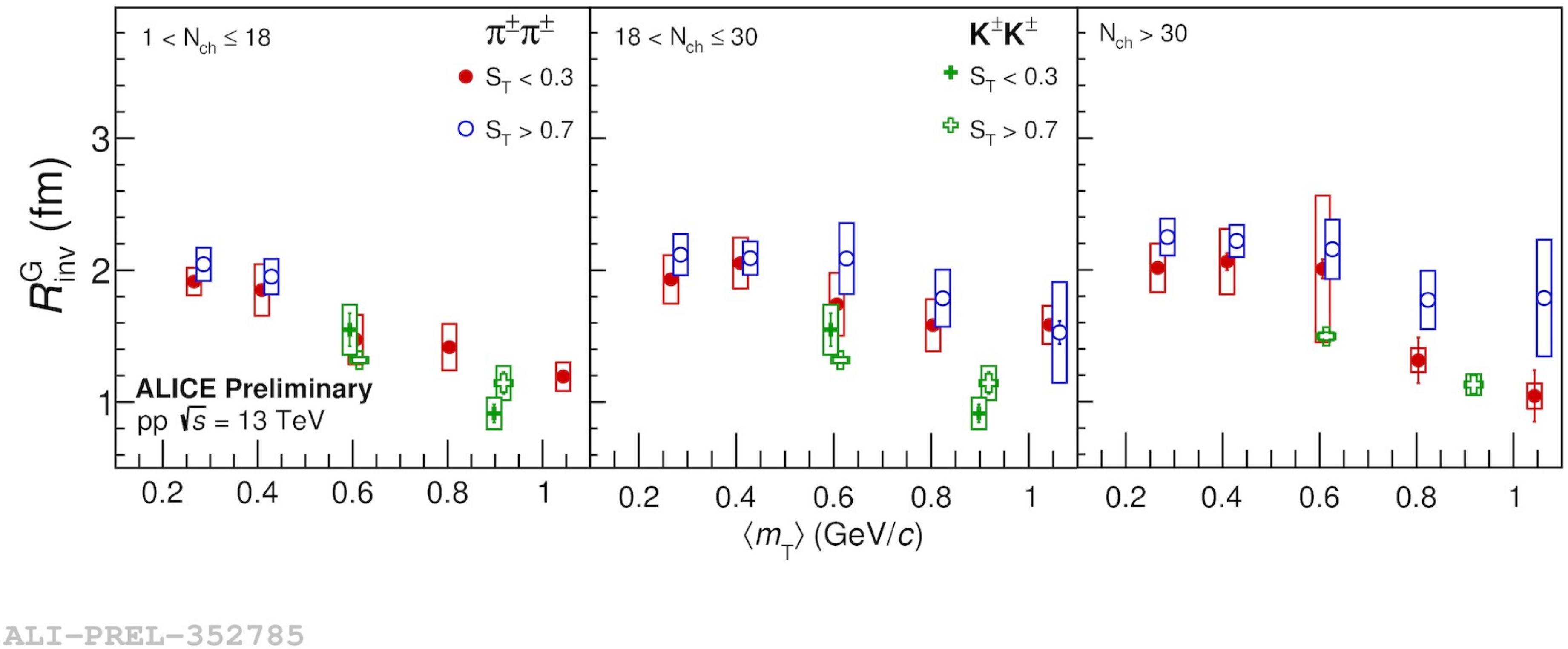
- **At k_T> 0.5 GeV/c strong mini-jet contribution appears and increases with k_T**
- PYTHIA-8 with sphericity cut S_T < 0.3 describes baseline well

Exponential pion and kaon radii: m_T dependence



- Gaussian kaon radii were converted to Exponential ones by multiplying by sqrt(π)
- Spherical pion and kaon radii demonstrate flatter behavior compared with jet-like ones; more “pronounced” slope appears for N_{ch} > 30
- Spherical kaon radii are smaller than the corresponding spherical pion radii, the difference increases with increasing multiplicity
- Jet-like pion radii are smaller than spherical ones and the difference increases with multiplicity.

Gaussian pion and kaon radii: m_T dependence



- Pion double Gaussian radii were averaged over the large (resonances) and the small (direct) scales and compared with kaon Gaussian radii
- Gaussian radii behave very similarly to Exponential ones
- Not even approximate mass scaling is observed. Kaon radii are always smaller than pion ones.

Conclusions

- Correlations of two charged identical pions ($\pi^{\pm}\pi^{\pm}$) and kaons ($K^{\pm} K^{\pm}$) were measured in pp collisions at $\sqrt{s}$ = 13 TeV by the ALICE collaboration at the LHC using the global event shape variable transverse sphericity.
- It is seen from MC simulations with PYTHIA that correlation functions for spherical events demonstrate a strong suppression of mini-jet contributions in contrast to jet-like events.
- It was shown that the PYTHIA model reasonably describes both spherical and jet-like pion and kaon correlation functions outside the femtoscopic region effect, therefore it was used to exclude the non-femtoscopic correlations.
- In general, the pion femtoscopic parameters extracted for spherical events are larger than those for jet-like events.
- Spherical pion and kaon radii demonstrate flatter behavior with respect to k_T compared with jet-like ones; more ``pronounced'' slope appears for N_{ch} > 30.
- Not even approximate mass scaling is observed. Kaon radii are always smaller than pion ones.

Additional slides

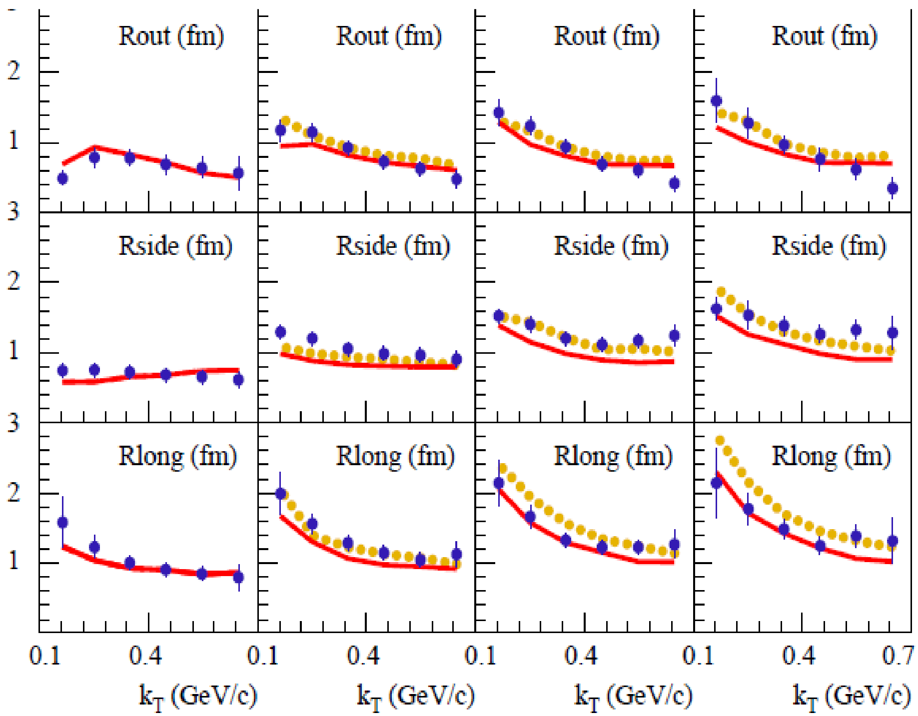
Interpretations of pion femtoscopy results for pp collisions at 7 TeV

ALICE data from: Aamodt, et al., Phys. Rev. D 84 (2011) 112004.

K. Werner, K. Mikhailov, Yu. Karpenko, T. Pierog arXiv:1104.2405

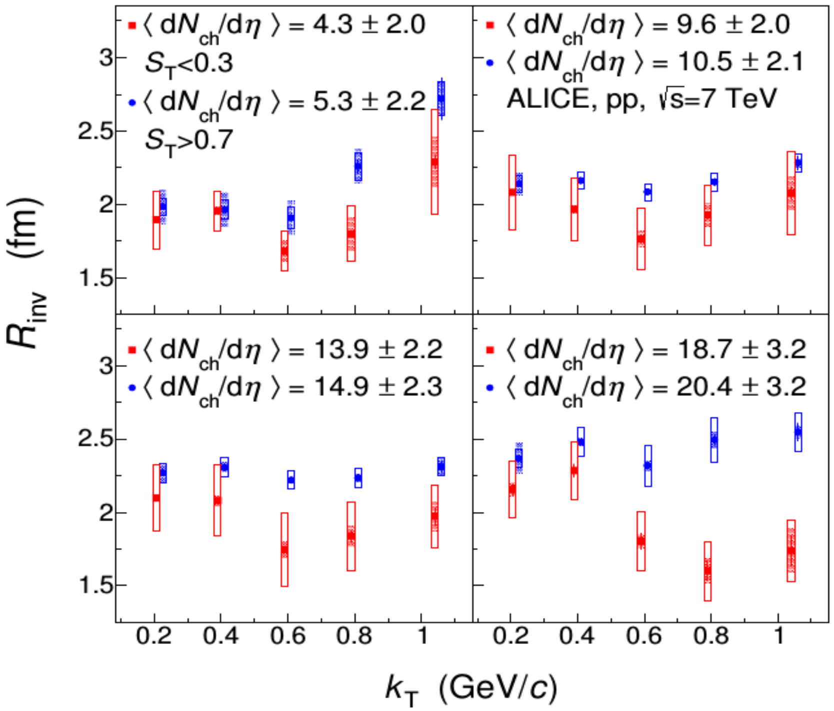
EPOS model combining string dynamic, hydrodynamics and hadron cascade

$dN_{ch}/d\eta$	3.2	13.6	24.3	31.1
	Mult 1-11	23-29	45-57	58-149



In large multiplicity bins the strings will constitute multiple flux tubes matter **used as initial conditions for hydrodynamical evolution**

ALICE Collaboration JHEP 1909 (2019), arXiv:1901.05518 [nucl-ex].)

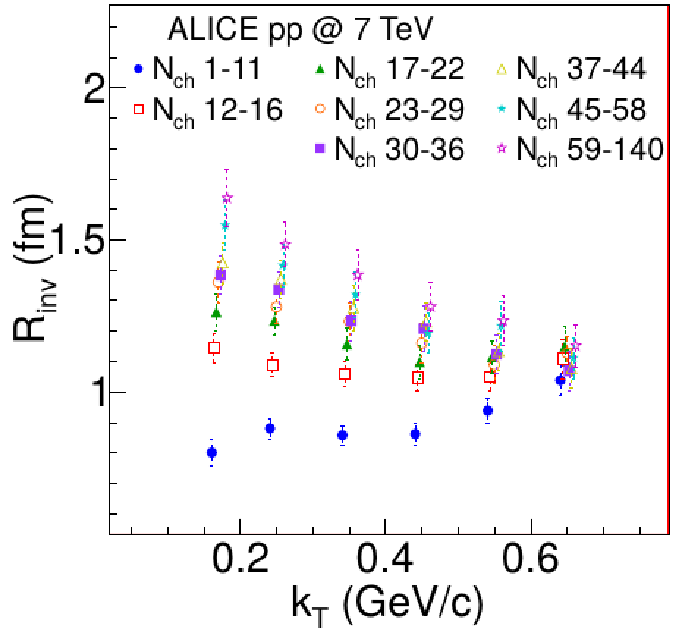


"Spherical" radii demonstrate a flat trend with increasing k_T, which differs from the k_T dependence previously observed. The authors suggest that the observed slope in MB events could appear from the lower part of the transverse sphericity spectrum in pp collisions.

Pion and kaon radii results w/o sphericity selection for pp collisions at 7 TeV

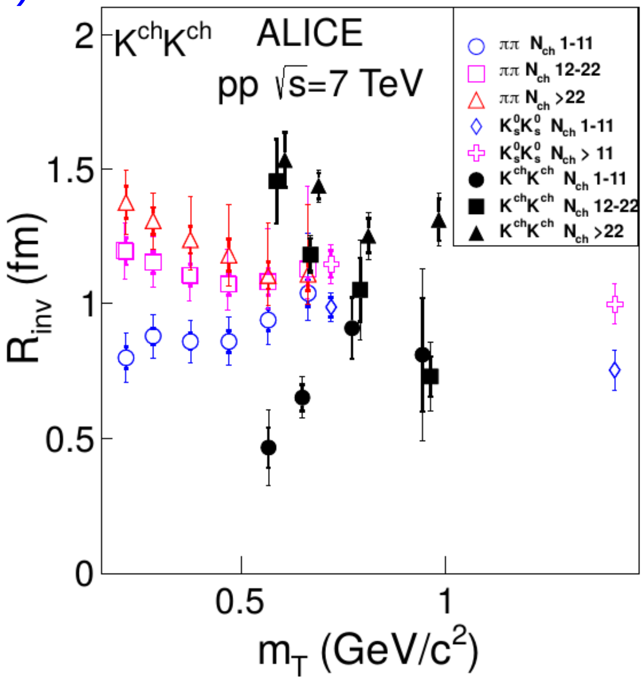
ALICE Collaboration,PRD84 (2011)

1D Gaussian MB Pion radii at sqrt(s)=7TeV



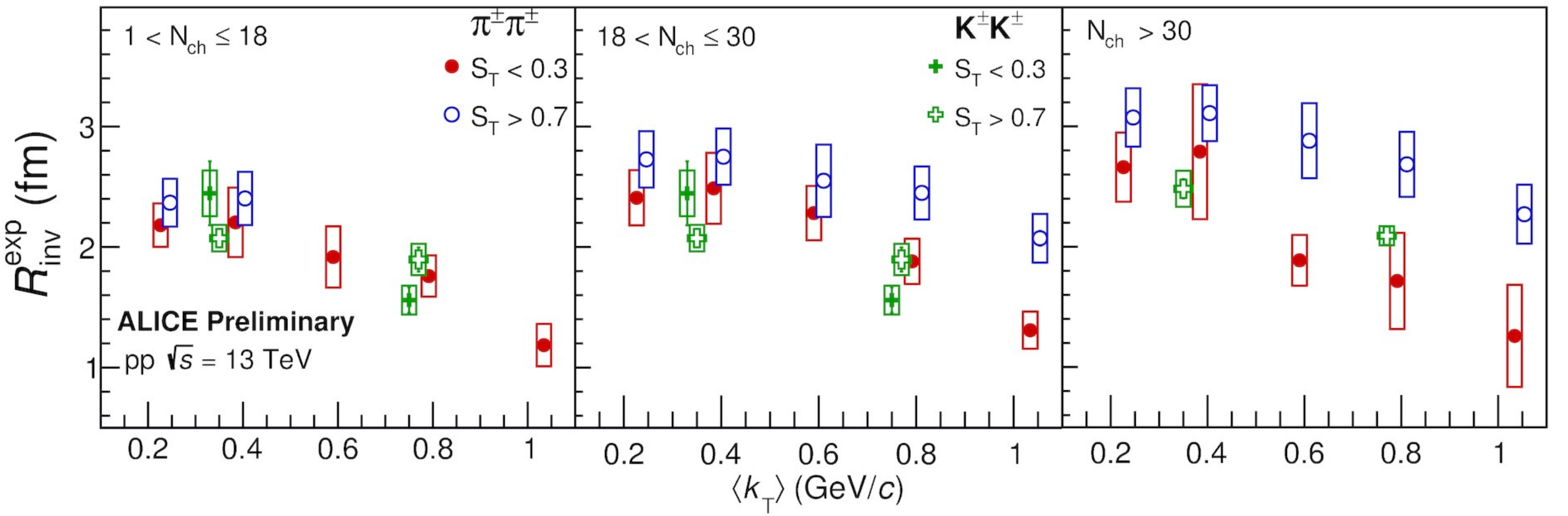
ALICE Collaboration,PRD87 (2013), 5 052016

1D Gaussian MB Pion and kaon radii at sqrt(s)=7TeV



- For single Gaussian 1D pion and kaon radii at sqrt(s) = 7 TeV no mT scaling observed;
- Kaon radii are larger than pion ones.

Exponential pion and kaon radii: k_T dependence



ALI−PREL−352734

- Gaussian kaon radii were recalculated in Exponential ones by multiplying by sqrt(π)
- Spherical kaon radii are smaller than the corresponding spherical pion radii, the difference increases with increasing multiplicity
- Jet-like pion radii are smaller than spherical ones and the difference increases with multiplicity.