A simple model for $\pi^{ch}\pi^{ch}$, K^0K^0, and $K^{ch}K^{ch}$ femtoscopy in 7 TeV p-p collisions

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Introduction

* The LHC ALICE collaboration has published three 7 TeV pp collision femtoscopy papers:

$K^{ch}K^{ch}$ -- Phys. Rev. D 87, 052016 (2013) (1d analysis)
$K^0_sK^0_s$ -- Physics Letters B 717, 151 (2012) (1d analysis)
$\pi^{ch}\pi^{ch}$ -- Phys. Rev. D 84, 112004 (2011) (1d and 3d analyses)

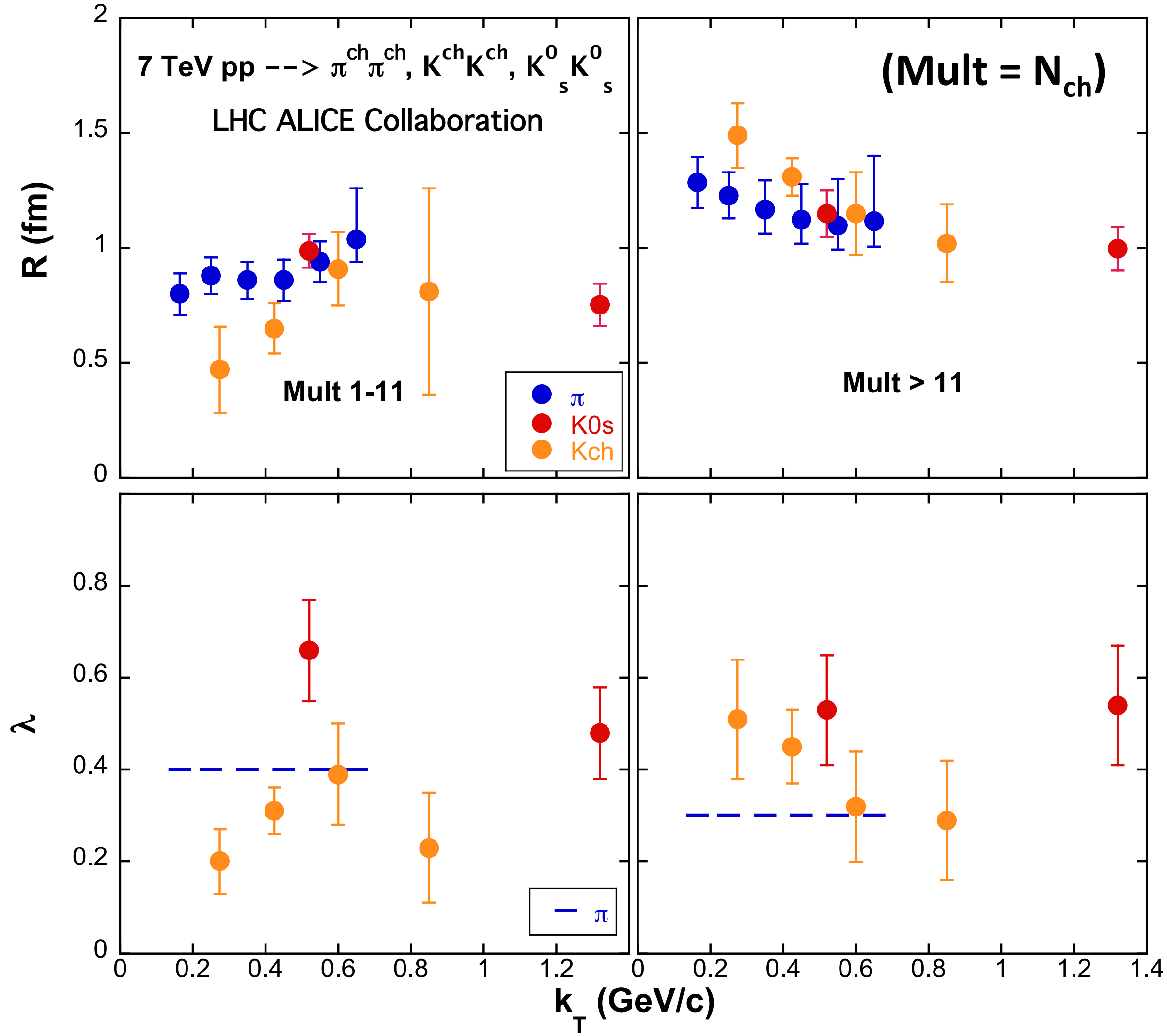
* Y. Sinyukov et al. and K. Werner et al. have used hydro to describe the multiplicity and k_T dependence of the 3d *R* parameters for $\pi^{ch}\pi^{ch}$

➔ **Consider extracted 1d Gaussian radius parameters, *R* and λ, in two charged multiplicity bins which overlap in all three sets of measurements:**

$$C_{QS}(q_{inv}) = 1 + \lambda \exp(-q_{inv}^2 R^2)$$

ALICE R and λ parameters vs. k_T bin for two charged multiplicity ranges: N_{ch} 1 - 11 and N_{ch} > 11

(Error bars statistical + systematic)



Qualitative features of these measurements:

* $R_{Kch} \sim R_{K0s} \sim R_{\pi} \sim 0.5 - 1.5$ fm
* $\lambda \sim 0.2 - 0.6$
* $R_{Mult > 11} > R_{Mult\ 1\text{-}11}$
* R has a weak k_T dependence

What physics can we learn from this?

First impressions of the ALICE 1d femto results

* $R_{Kch} \sim R_{K0s} \sim R_{\pi} \sim 0.5 - 1.5$ fm

➔ since pp collisions, expect size and time scales to be ~ 1 fm and ~ 1 fm/c ?

* $\lambda \sim 0.2 - 0.6$

➔ $\lambda < 1$ due to long-lived resonances, non-Gaussian shapes …. ?

* $R_{Mult > 11} > R_{Mult\ 1\text{-}11}$
* R has a weak k_T dependence

➔ flow and/or resonance effects?

➔ Compare R and λ extracted from a simple model to the ALICE measurements

particles + initial geometry + rescattering + QS + fit Gaussian ➔ *R, λ*

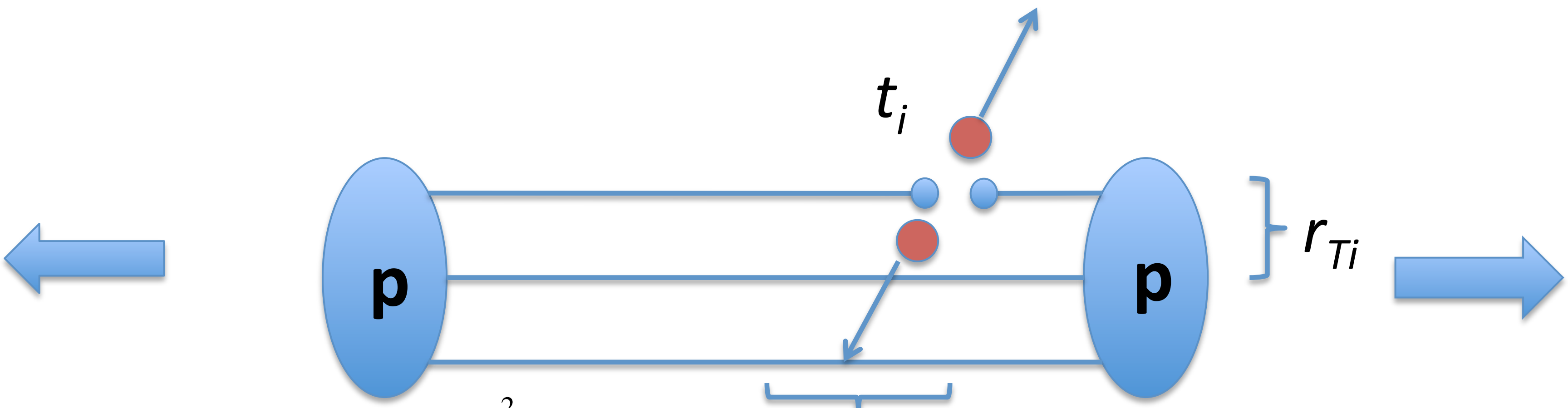
Description of the model

*** Start with 7 TeV pp PYTHIA 6.4 events to generate initial particles and momenta**
(ALICE used PYTHIA to model the CF background for π^{ch}, K^{ch}, K^0_s in 7 TeV pp)

-- Include in the model all charge states and anti-particles of:

π, p, n, K, K*, ρ, ω, η, η', Δ, Λ, ϕ

*** Generate initial space-time geometry of particles in the spirit of the Lund Model:**



$$P(r_{Ti}) \propto \exp(-\frac{r_{Ti}^2}{2\sigma_r^2}), \quad x_i = r_{Ti}\cos\phi_i, \quad y_i = r_{Ti}\sin\phi_i, \quad \sigma_r = 1\ fm$$ ← **fixed**

$$P(\tau) \propto \exp(-\frac{\tau^2}{2\tau_{had}^2}), \quad z_i = \tau\frac{p_{zi}}{m_{0i}}, \quad t_i = \tau\frac{E_i}{m_{0i}}, \quad \tau_{had} = 0.4\ fm/c$$ ← **adjust τ_{had} to fit data**

Description of the model -- continued

* Follow the time evolution of the particles and allow them to rescatter and decay according to their scattering cross sections and decay times.

Allowed processes (obey conservation of energy, momentum, charge, baryon #, strangeness):

$$elastic: (all\ \ particles)$$

$$XY \rightarrow XY$$

$$inelastic\ and\ decays:$$

$$\pi N \leftrightarrow \Delta, \pi\Delta, K\Lambda \quad NN \leftrightarrow N\Delta \quad KN \leftrightarrow \pi\Lambda$$

$$\pi K \leftrightarrow K^{*} \quad \pi\pi \leftrightarrow \rho, \eta \quad \pi\pi \rightarrow \phi \leftrightarrow KK$$

$$\pi\pi \rightarrow \omega, \eta' \rightarrow \pi\pi\pi \quad \Lambda \rightarrow \pi N$$

* The "freeze out" space-time of a particle occurs at the last scattering or decay.

Description of the model -- continued

*** Quantum statistics are imposed pair-wise on boson pairs by weighting them at their freeze out space-times with:**

$$W_{12} = 1 + \cos(\Delta\vec{r} \bullet \Delta\vec{p} - \Delta t \Delta E)$$

$$where,$$

$$\Delta\vec{r} = \vec{r}_1 - \vec{r}_2 \quad \Delta\vec{p} = \vec{p}_1 - \vec{p}_2 \quad \Delta t = t_1 - t_2 \quad \Delta E = E_1 - E_2$$

*** The correlation function, $C(q_{inv})$, is formed in terms of the invariant momentum difference as the ratio of weighted pairs, $N(q_{inv})$, to unweighted pairs, $D(q_{inv})$,**

$$C(q_{inv}) = \frac{N(q_{inv})}{D(q_{inv})}$$

Description of the model -- continued

* Since there are no final-state interactions in the model (Coulomb, strong….), R and λ parameters are extracted from the model by fitting $C_{QS}(q_{inv})$ to $C(q_{inv})$, where,

$$C_{QS}(q_{inv}) = 1 + \lambda \exp(-q_{inv}^2 R^2)$$

* Multiplicity, p_T, η, k_T and q_{inv} ranges are applied to the model particles to duplicate those made by ALICE to the data.

* Also, as done in ALICE

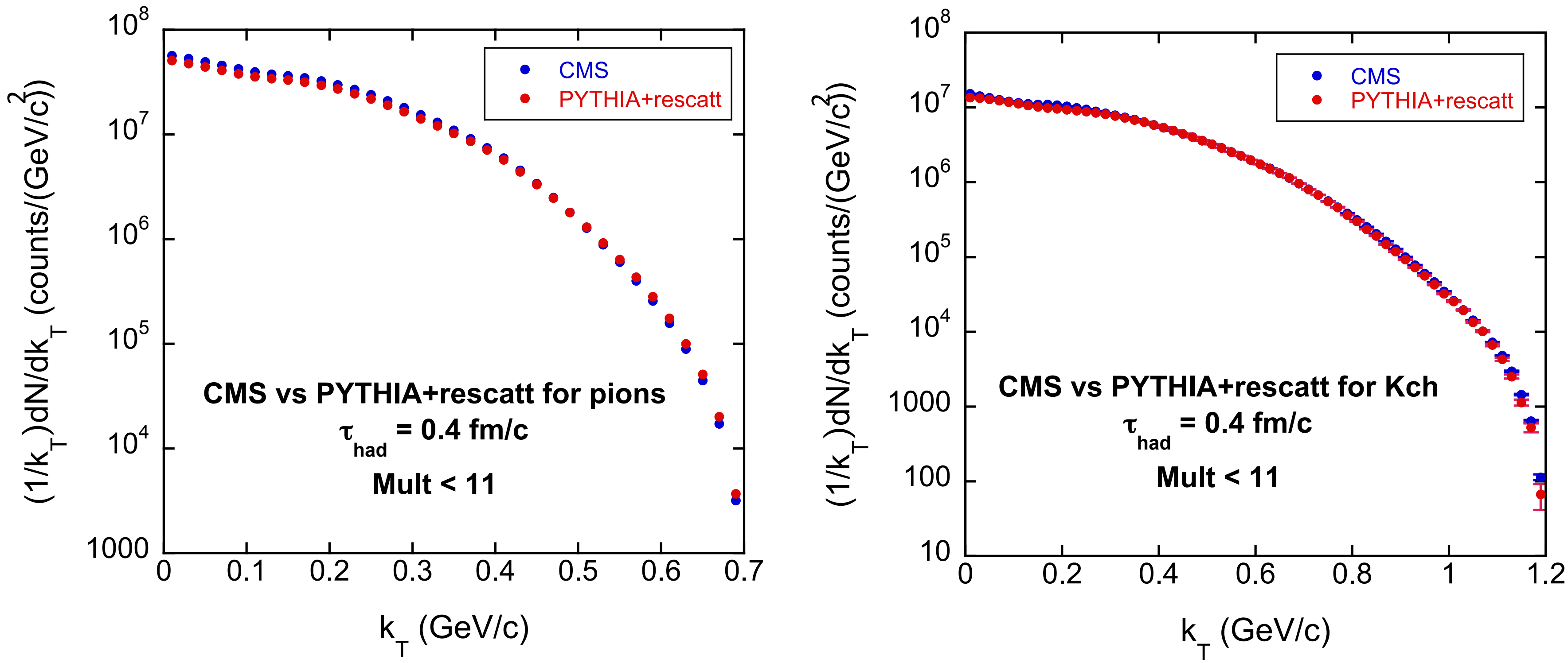
-- like-charge pairs of particles are added for pions and Kch,

i.e. $\pi^+\pi^+ + \pi^-\pi^-$, $K^+K^+ + K^-K^-$

-- for neutral kaons, all combinations are added, i.e. $K^0K^0 + \bar{K}^0K^0 + \bar{K}^0\bar{K}^0$

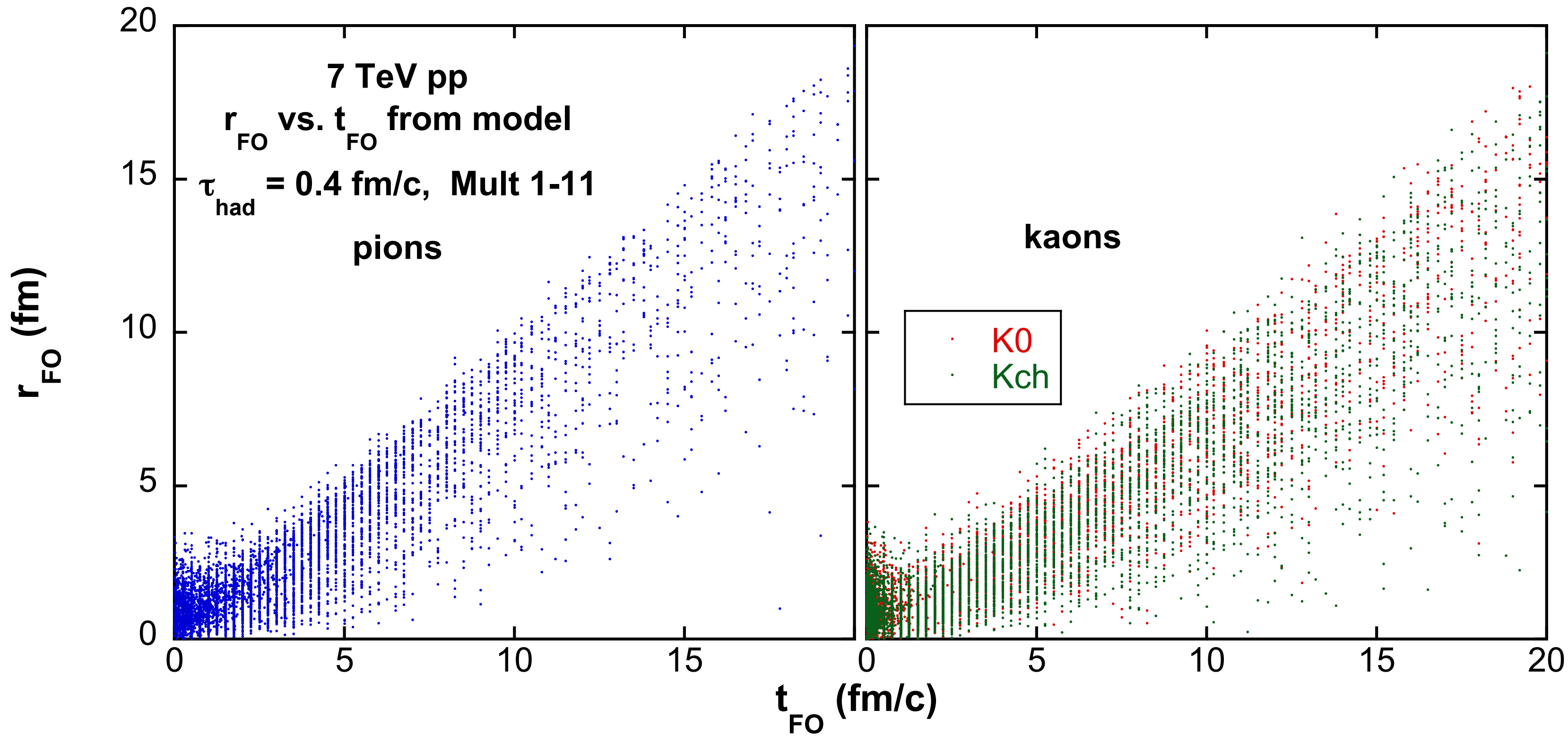
Comparison of k_T distributions calculated from the LHC CMS experiment with model distributions for charged pions and kaons

7 TeV pp collisions CMS: Eur.Phys.J.,C72(2012)



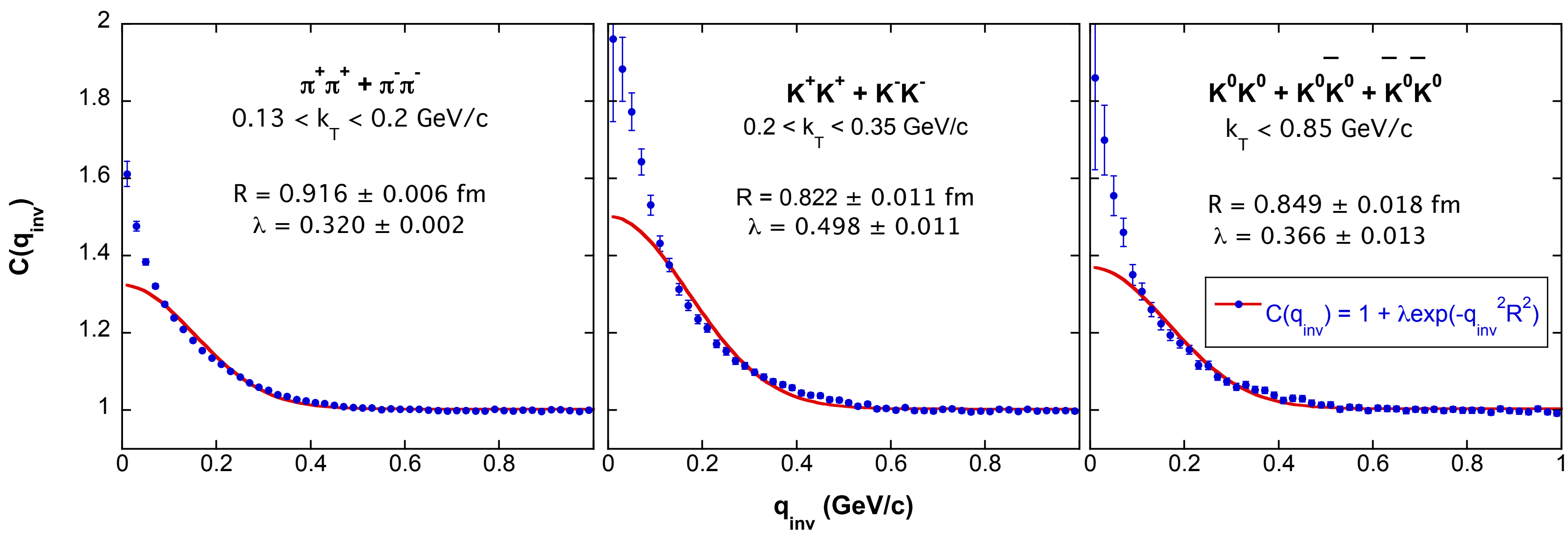
(CMS min bias p_T distributions for K^{ch} and K^0_s have essentially the same shape – also true in PYTHIA)

freezeout radius vs. freezeout time for charged pions, kaons and neutral kaons from the model (all k_T)



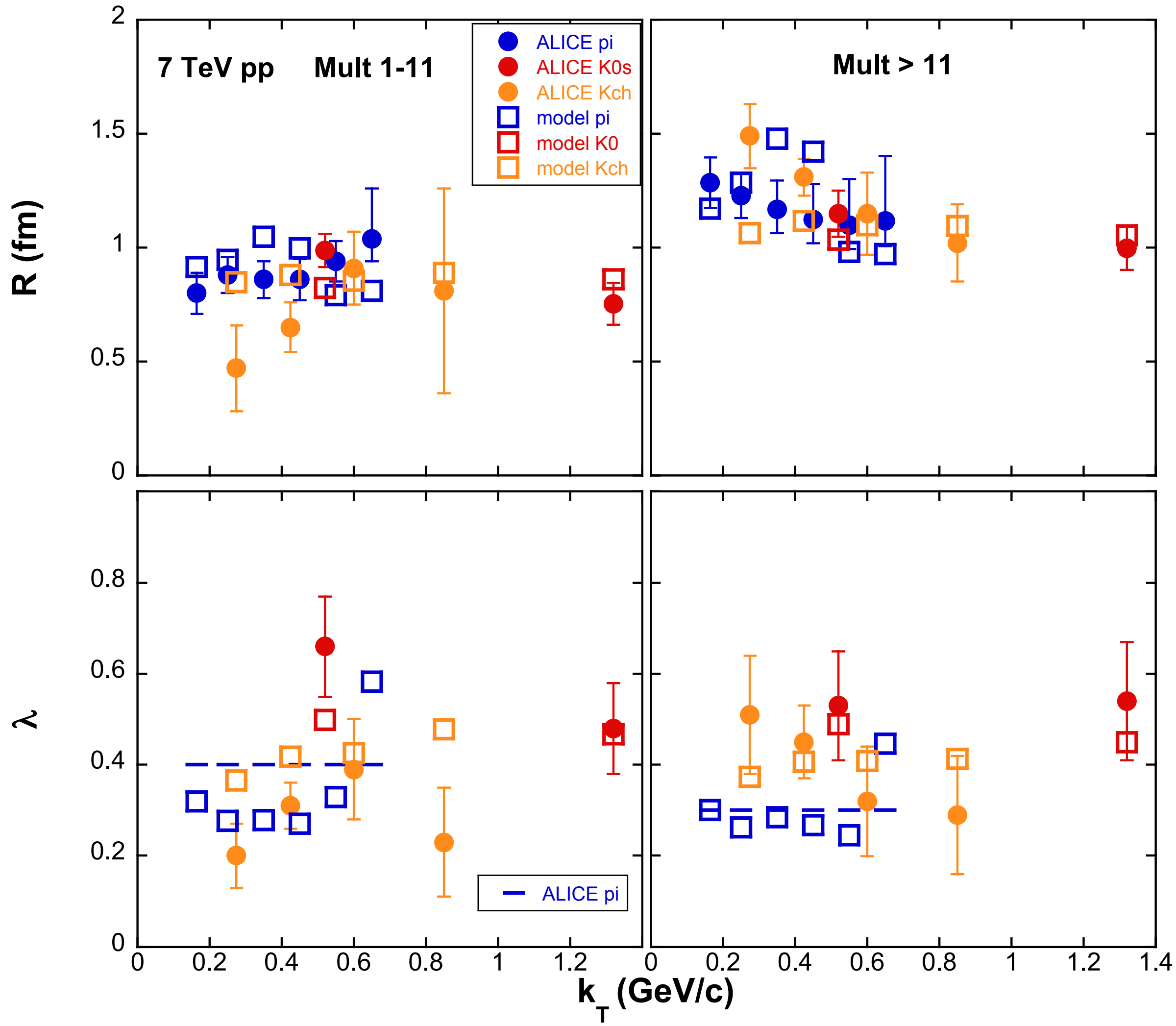
Sample correlation functions from the model with Gaussian fits and fit parameters

7 TeV pp collisions, τ_{had} =0.4 fm/c, Mult 1-11



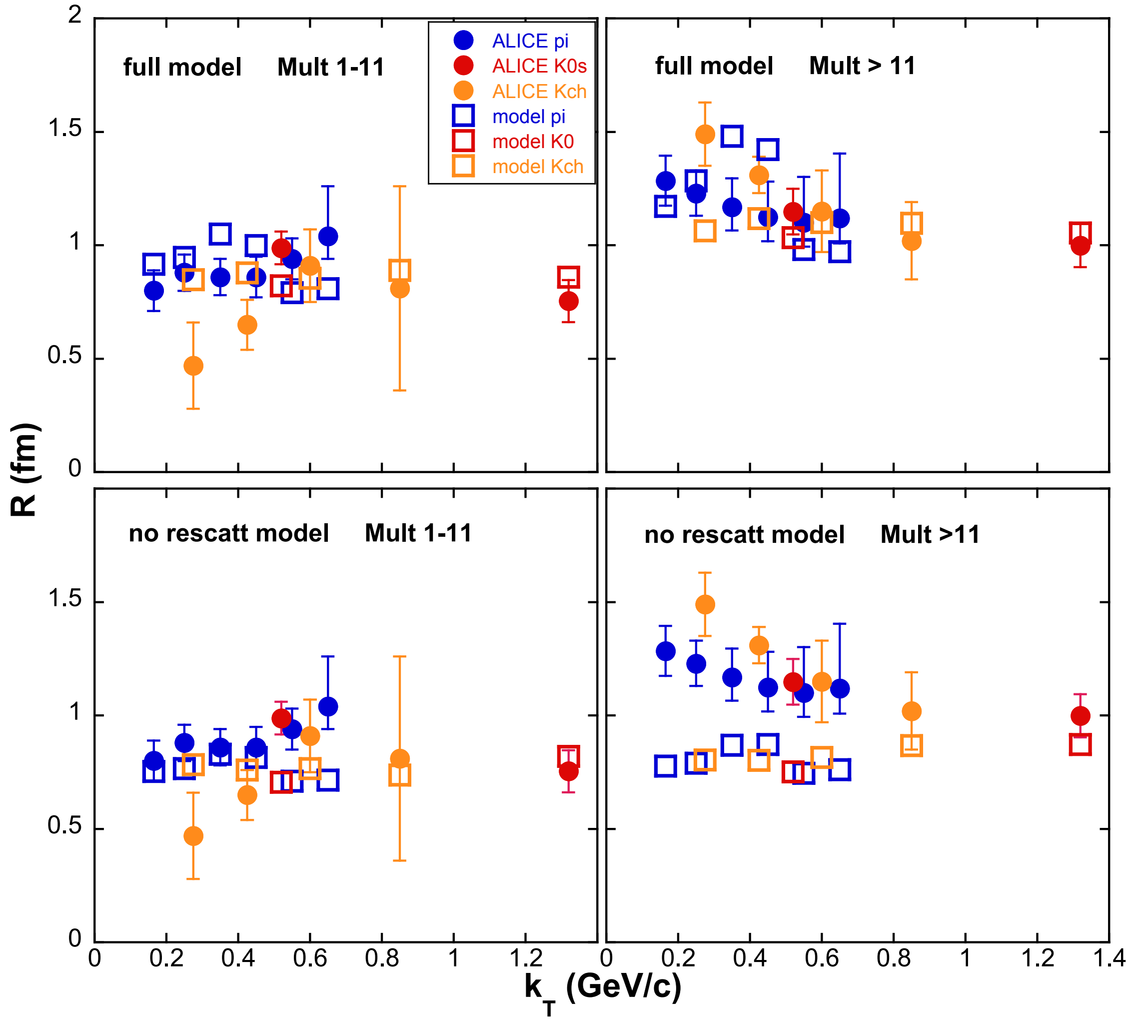
$C(q_{inv})$ looks more exponential than Gaussian…….

Results:
Model R and λ (τ_{had} = 0.4 fm/c) vs. ALICE



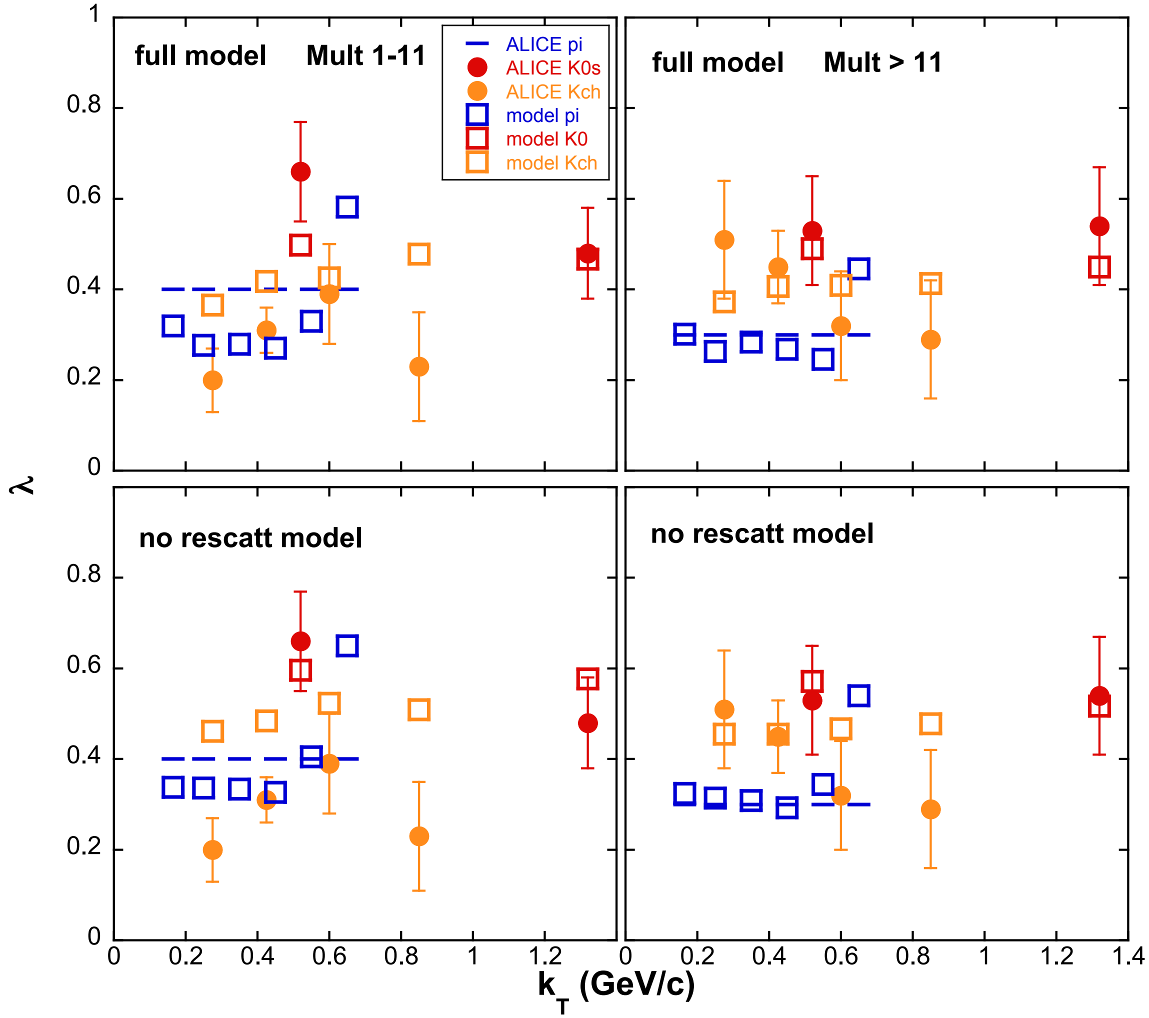
The simple model qualitatively describes the gross features the ALICE experimental R and λ parameters.

Full model vs. no rescattering model (τ_{had} = 0.4 fm/c): R



For R, rescattering is needed in the model to get agreement with ALICE for both multiplicity ranges simultaneously ➔ resonances alone are not enough!

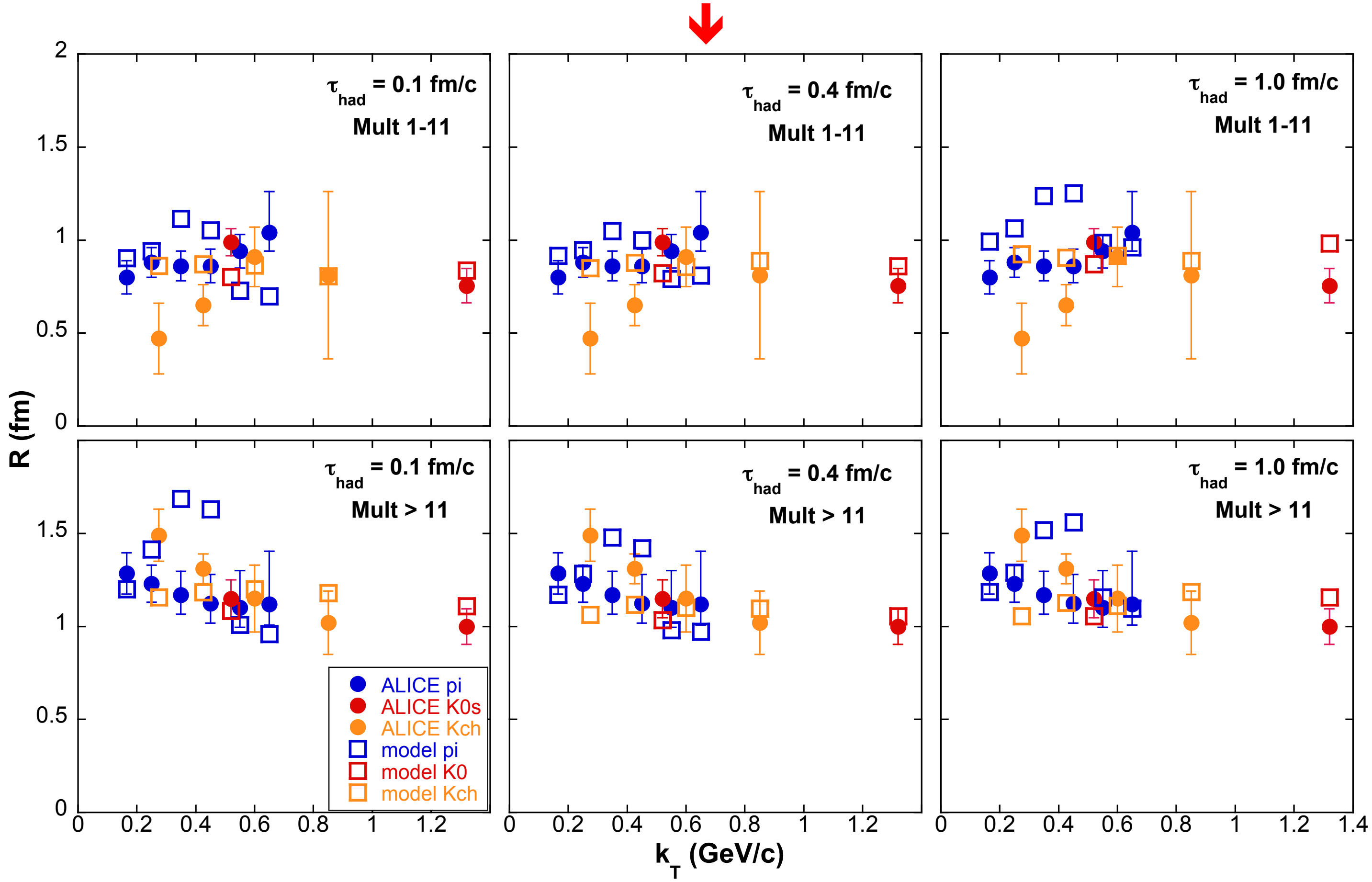
Full model vs. no-rescattering model (τ_{had} = 0.4 fm/c): λ



For λ, agreement with ALICE is insensitive to whether rescattering is turned on or not ➔ λ is mostly determined by non-Gaussian $C(q_{inv})$ and L-L resonance decay.

Sensitivity of model agreement with ALICE on τ_{had}

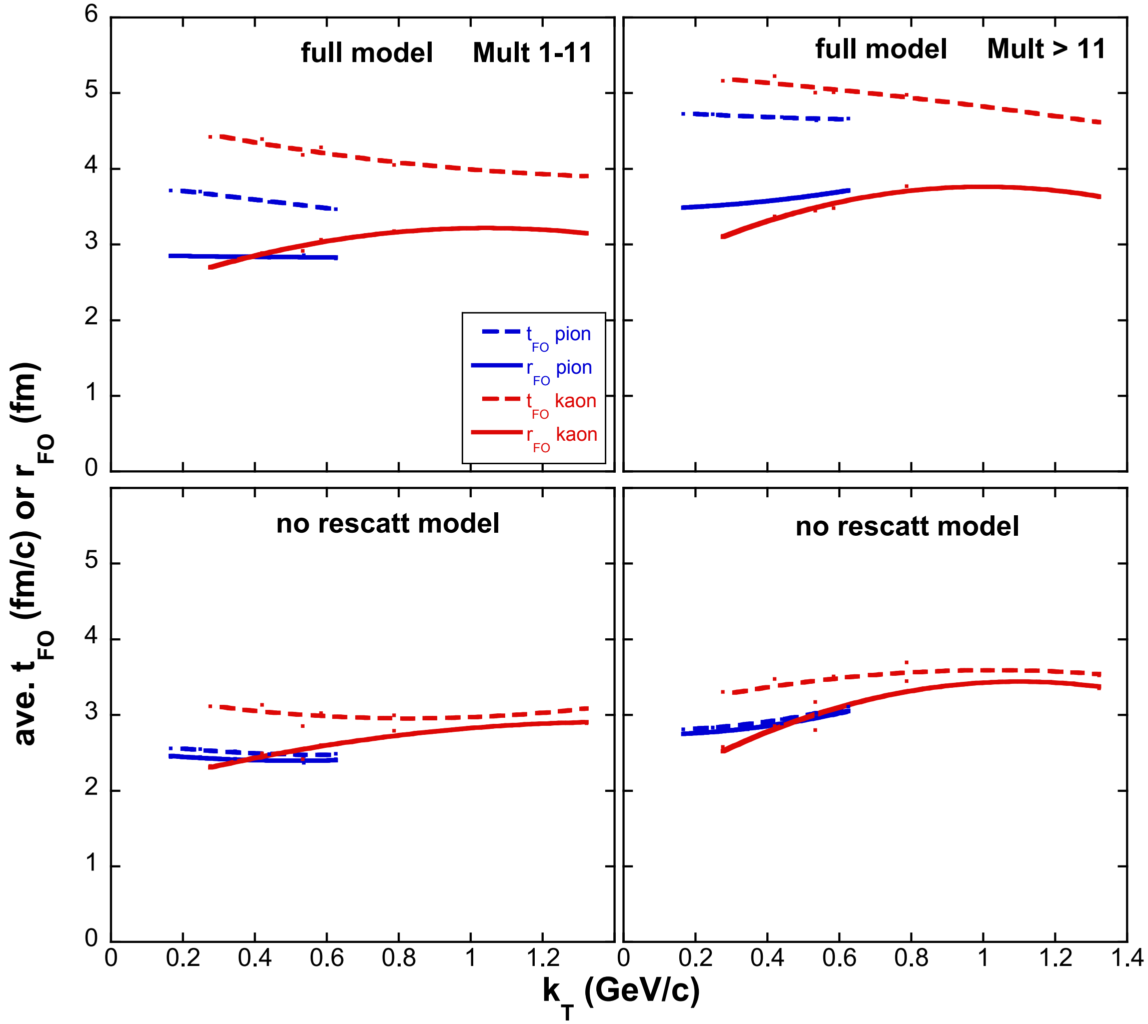
“Best agreement”



Extracted particle hadronization proper time width (errors approximate range of sensitivity)

τ_{had} = 0.4 ± 0.1 fm/c

Underlying geometry of the collision from the model: Average t_{FO} and average r_{FO} vs. k_T for pions and kaons



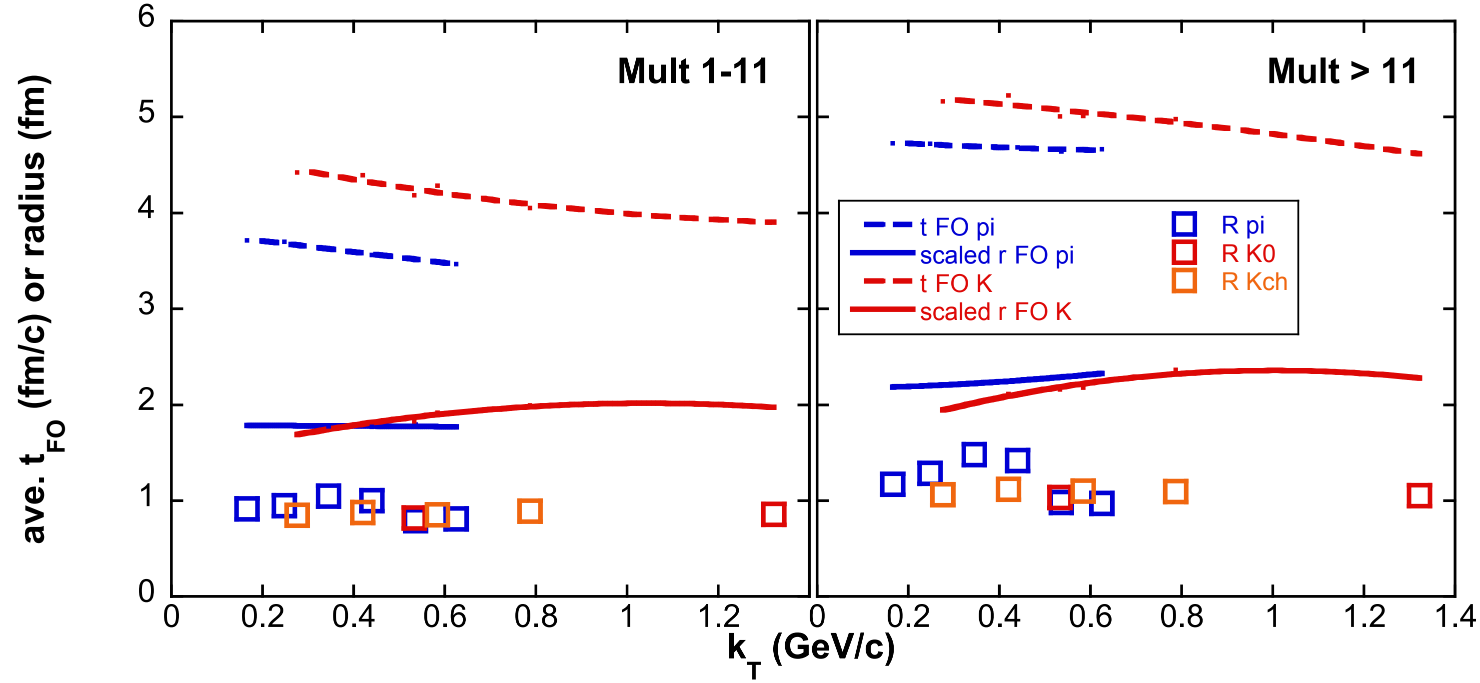
(τ_{had} = 0.4 fm/c)

Underlying space-time scale > 1 fm and > 1 fm/c

Comparison of the underlying space-time geometric scales of the collision with the extracted R parameters from the model

$$scaled\ r_{FO} = \sqrt{\frac{\pi}{8}}\langle r_{FO}\rangle \rightarrow Gaussian\ equivalent$$

(τ_{had} = 0.4 fm/c)



R ≈ ½ of the average physical radius of the source

Summary of observations from the model for 7 TeV pp

* The simple model describes the gross features of the ALICE experimental 1d R and λ parameters for charged pions and charged and neutral kaons in the k_T and multiplicity ranges considered.

* Rescattering ("flow") is required to obtain reasonable agreement of the model with ALICE for R for both multiplicity ranges simultaneously.

* λ is relatively insensitive to rescattering in the model – mostly determined by the non-Gaussian $C(q_{inv})$ and resonance decay.

* In order for the model source parameters to obtain reasonable agreement with ALICE, a value of the proper hadronization time width of $\tau_{had} = 0.4 \pm 0.1$ fm/c must be used.

* The underlying average physical radius in this collision system is about a factor of 2 larger than R extracted from femtoscopy; also average $t_{FO} \sim 4\text{-}5$ fm/c