Generation and analysis of events for pPb collisions using the MC generator – Therminator 2

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Outline

- Structure of the simulation software
- What does it offer
- The physics behind it
- Simulating and interpreting results
- Comparison of obtained results to experiment
- Conclusions

What is THERMINATOR 2?

- THERMINATOR = THERMal heavy IoN generATOR
- Monte Carlo generator written in C++
- It can perform the statistical hadronization in relativistic heavy ion collisions
- It uses the standard ROOT environment

THERMINATOR 2 - modules

- ParticleDB.cxx ← Parcer.cxx

- EventGenerator.cxx :

  → Integrator.cxx

  → Event.cxx

  → ParticleDecayer.cxx

- Writing to the output file, containing the ROOT histograms and also text files

What's special about THERMINATOR 2?

- It's a very flexible tool
- Different theoretical frameworks can be implemented with only slight modifications to the code
- Therminator considers the events from the moment of statistical hadronization (freeze-out)
- Freeze-out happens on a hypersurface
- Other simulation packages in the field:
  UrQMD , PYTHIA

Heavy-Ion collisions

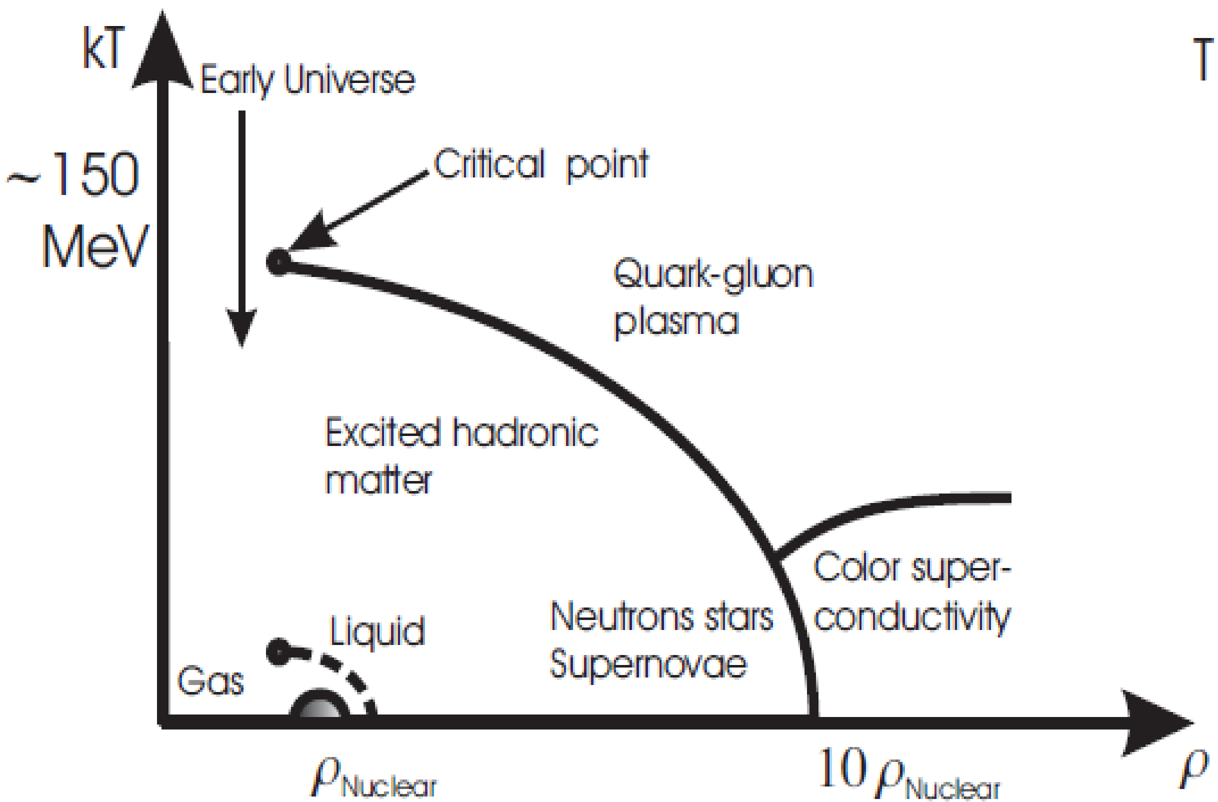
Strong interactions exhibit asymptotic freedom

$$\mathcal{M}(q) = 4\pi \int_0^\infty V(r)\left[\frac{\sin(qr)}{qr}\right] r^2 \mathrm{d}r$$

The coupling constant decreases with increased momentum transfer

$$\alpha_s(\mu) = \alpha_s(\mu_0)\left[1 + \frac{(33 - 2N_f)}{6\pi}\alpha_s(\mu_0)\ln(\mu/\mu_0)\right]^{-1}$$

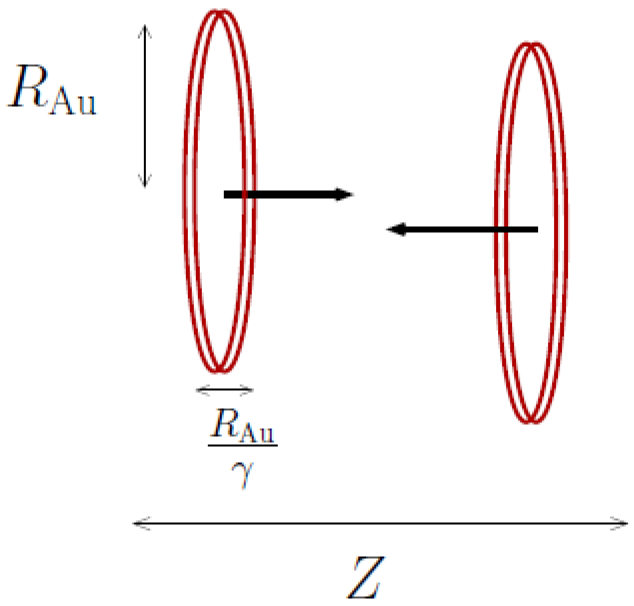
This should be observed in heavy-ion collisions

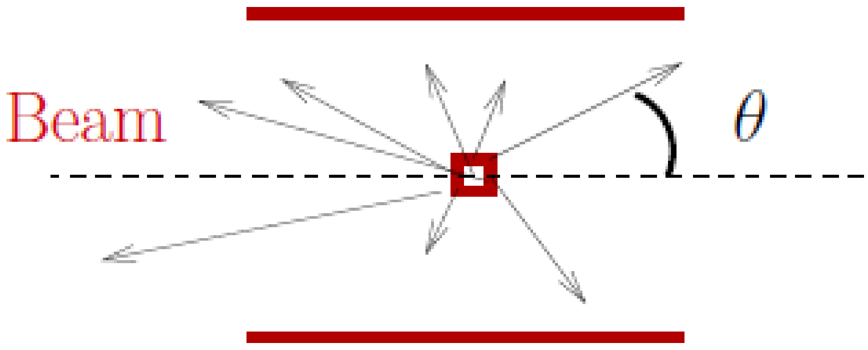


$T_c = 170$ MeV
$\sim 2 \times 10^{12}$ °K

Experiments at RHIC

- Au-Au collisions





Elliptic flow, a measure of anisotropy →

$$v_2 \equiv \left\langle \frac{p_X^2 - p_Y^2}{p_X^2 + p_Y^2} \right\rangle$$

With the increase in transverse momentum the elliptic flow increases

How to reproduce this flow theoretically?

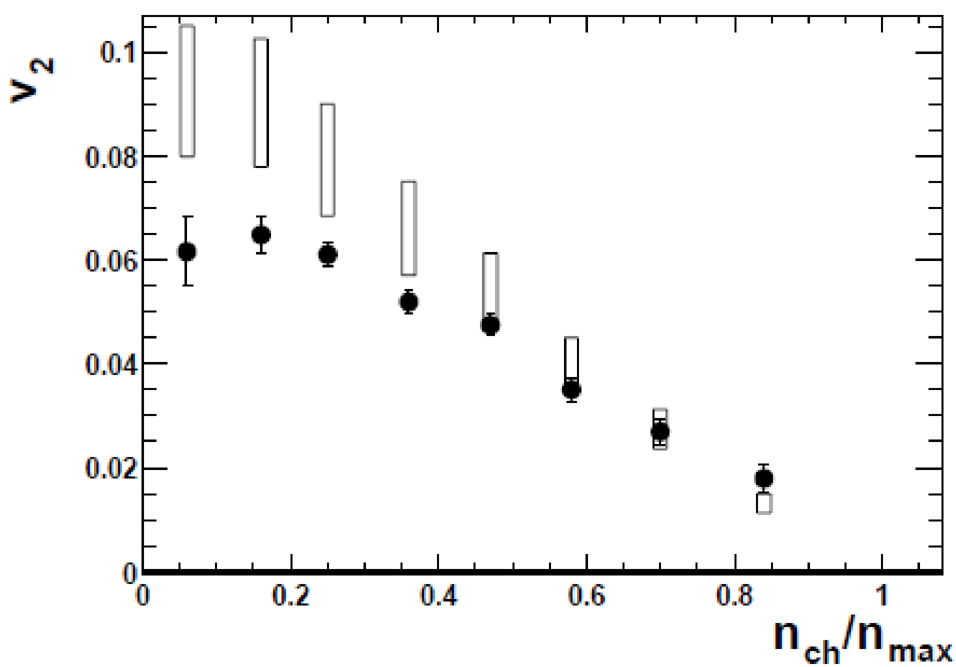
→ Turns out that this state of matter (QGP) exhibits collective behavior!

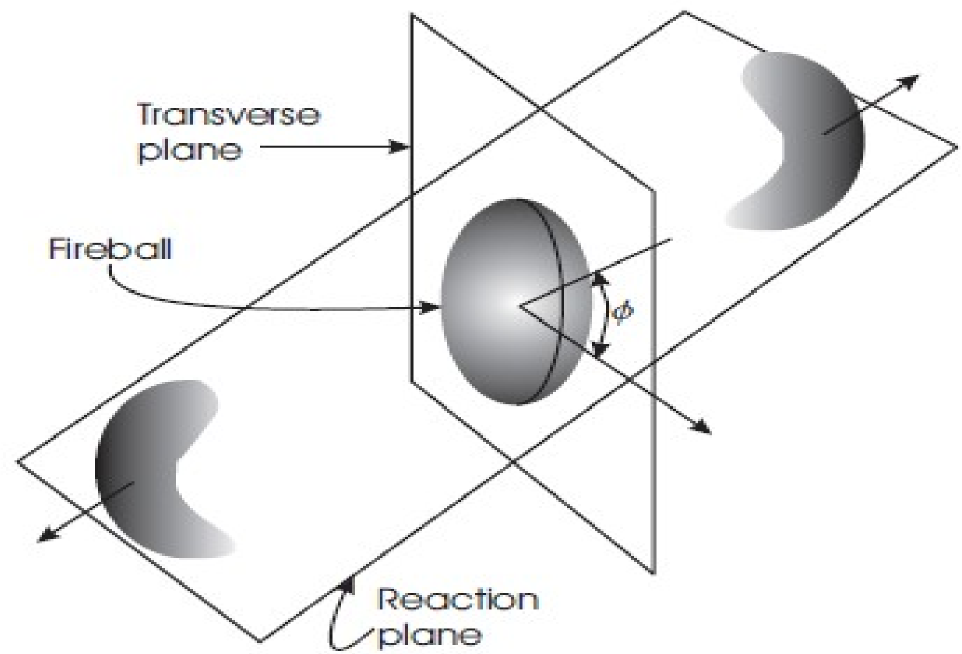
Hydrodynamical description

- The collective fluid-like behavior of the QGP created in heavy ion collisions can be described by hydrodynamical models

$$\frac{dN}{d\phi} = A(1 + 2v_1 \cos\phi + 2v_2 \cos 2\phi + ..)$$

The second term, the elliptical anisotropy can be interpreted as the viscosity in the hydro-models





Femtoscopy

- Femtoscopy is a technique that allows us to extract information about collective behaviour
- For the same purpose the correlation functions for non-identical particle pairs are extracted

$$C(\boldsymbol{p}_a, \boldsymbol{p}_b) = \frac{P_2(\boldsymbol{p}_a, \boldsymbol{p}_b)}{P_1(\boldsymbol{p}_a) P_1(\boldsymbol{p}_b)}$$

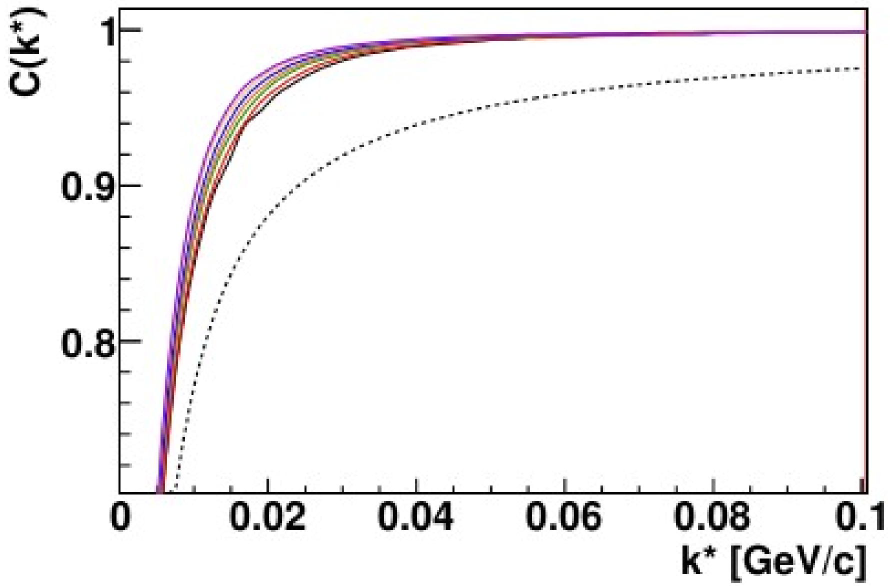
$$C(\boldsymbol{k}^*) = \frac{\int A(\boldsymbol{p}_a, \boldsymbol{p}_b)\delta(\boldsymbol{k}^* - \frac{1}{2}(\boldsymbol{p}_a^* - \boldsymbol{p}_b^*))d^3p_a d^3p_b}{\int B(\boldsymbol{p}_a, \boldsymbol{p}_b)\delta(\boldsymbol{k}^* - \frac{1}{2}(\boldsymbol{p}_a^* - \boldsymbol{p}_b^*))d^3p_a d^3p_b} \equiv \frac{A(\boldsymbol{k}^*)}{B(\boldsymbol{k}^*)}$$

- Here A and B are the distribution functions for particles from the same event and different events, respectively

In theoretical models:

$$S_A(\boldsymbol{x}_1, \boldsymbol{p}_1) = \int S(x_1, p_1, x_2, p_2, ..., x_N, p_N) dx_2 dp_2 ... dx_N dp_N$$

$$S_{AB}(\boldsymbol{x}_1, \boldsymbol{p}_1, \boldsymbol{x}_2, \boldsymbol{p}_2) = \int S(x_1, p_1, x_2, p_2, ..., x_N, p_N) dx_3 dp_3 ... dx_N dp_N$$



Pion-Kaon pair CF

$$K^* = \frac{|p_a - p_b|}{2}$$

This shows that the correlation function is sensitive to the size of the emitting system

Analysing procedure

- 5347 events generated using THERMINATOR 2
- 1 event = 1 collision
- proton – Pb central collisions at $\sqrt{s_{NN}} = 5.02\,TeV$
- Data processing done in ROOT 6.19

Analysing procedure

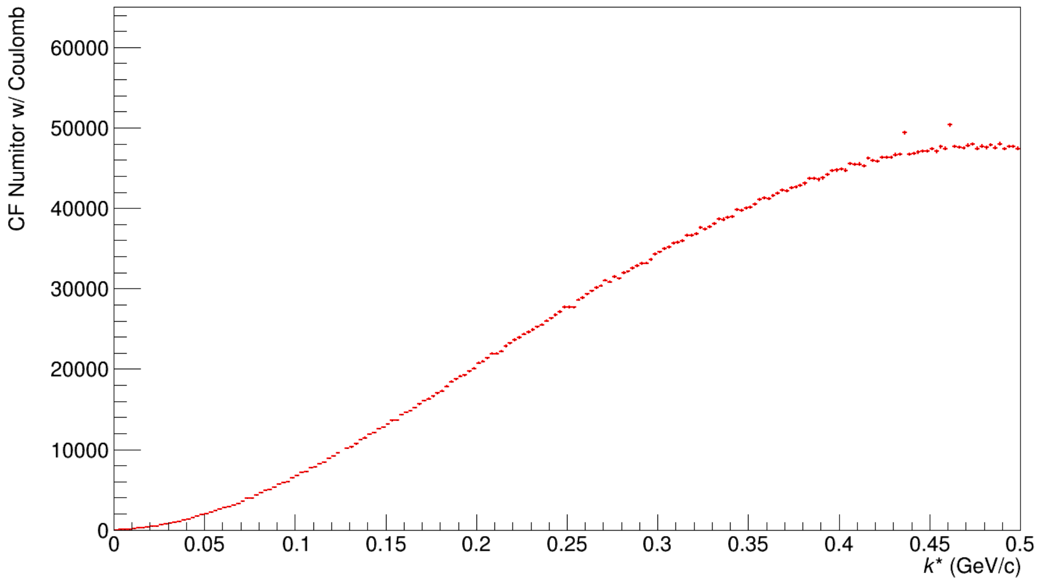
- The events are processed using a macro which computes the numerator and denominator of the correlation function between positive and negative kaons.
- It takes into account only the Coulomb interaction.
- To get the full picture, we need to take into account the strong interaction and the phi meson decay

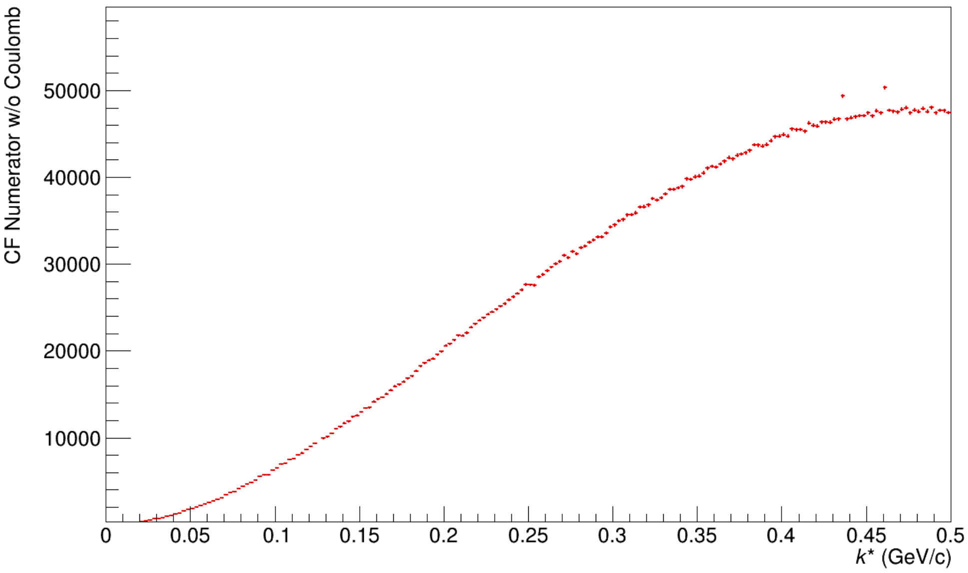
The output of the macro

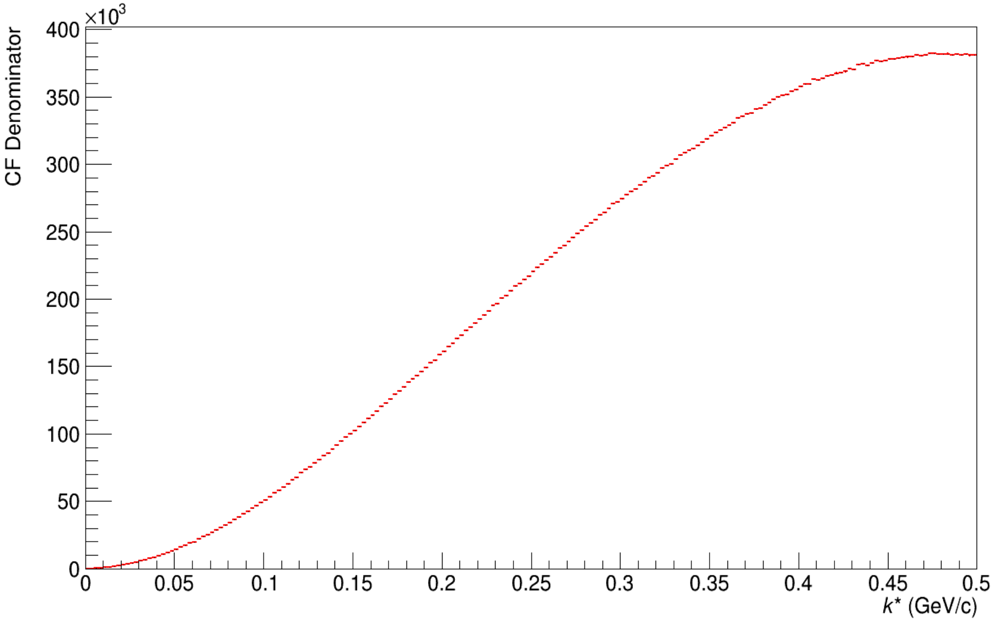
- 3 Histograms:
  - Numerator with Coulomb interaction (NC)
  - Numerator without Coulomb interaction (NP)
  - Denominator (D)

- We can make 3 correlation functions
  - NC/D → Correlation function with Coulomb
  - NP/D → CF without Coulomb
  - NC/NP → Pure Coulomb

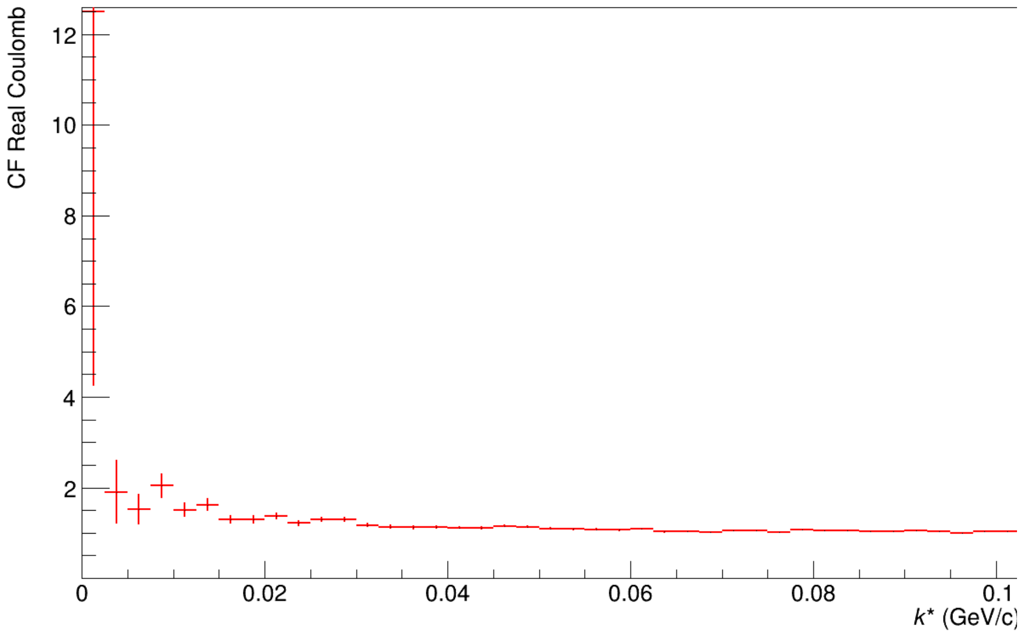
The output of the macro

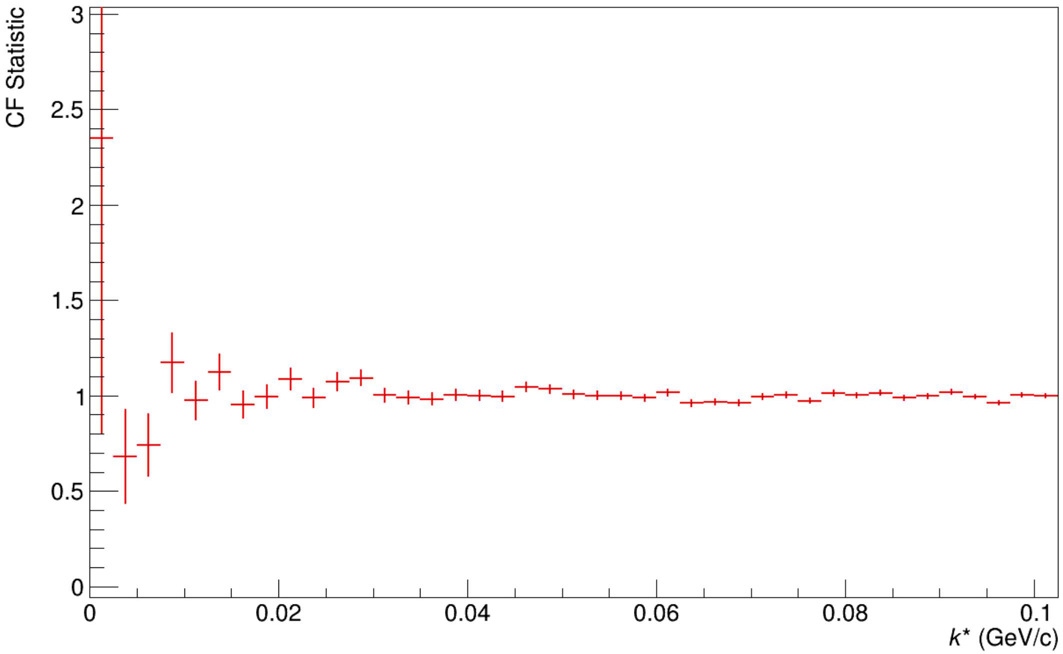






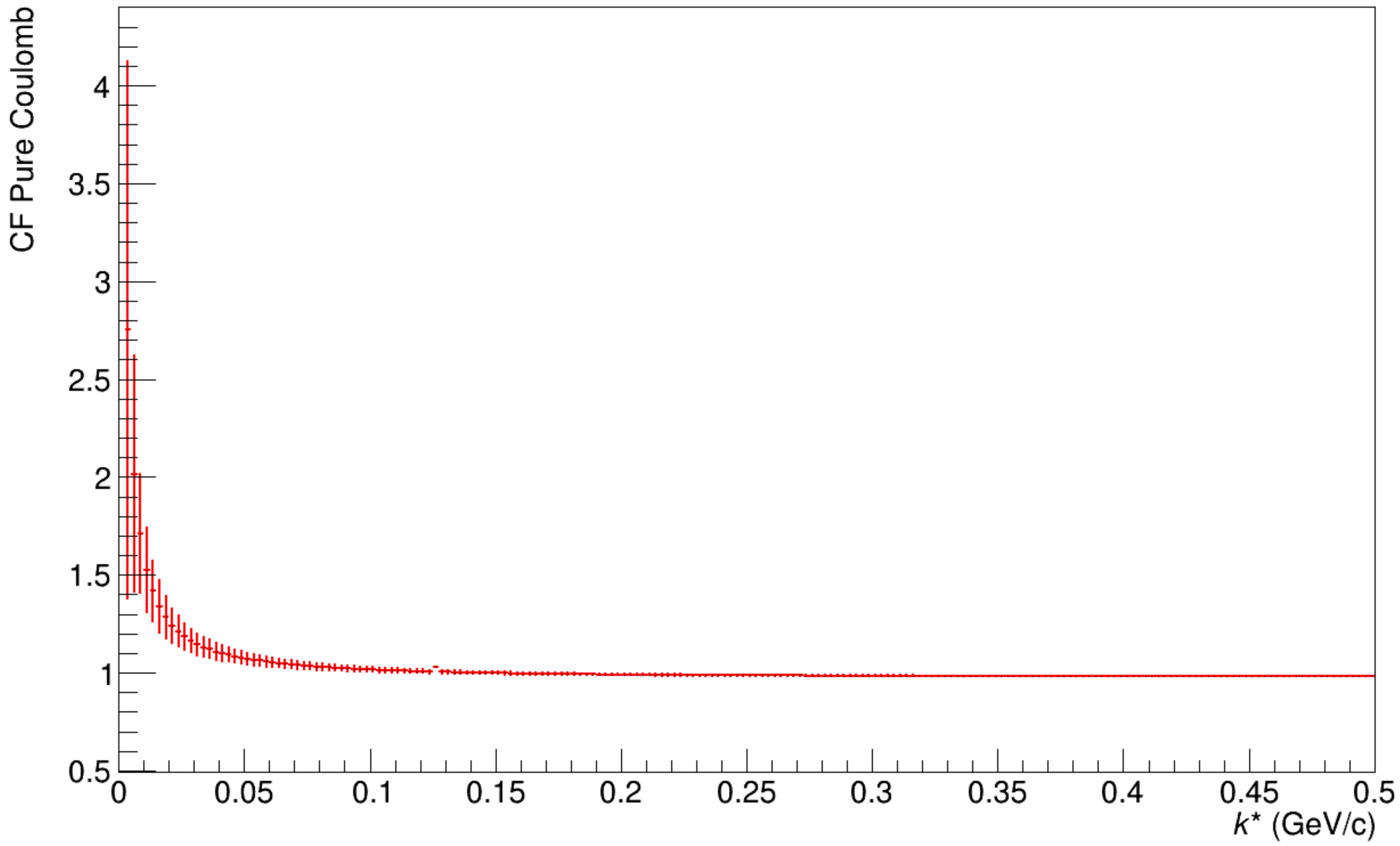
Correlation function w/ and w/o Coulomb





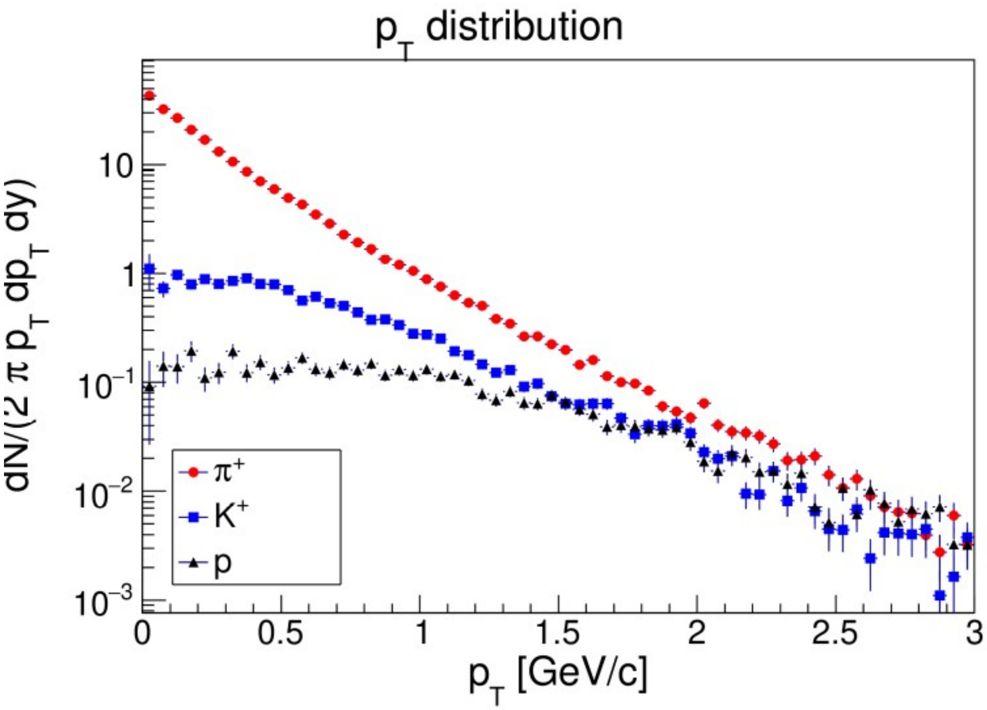
- Left → with Coulomb interaction (stronger correlation)
- Right → without Coulomb interaction

The pure Coulomb correlation function

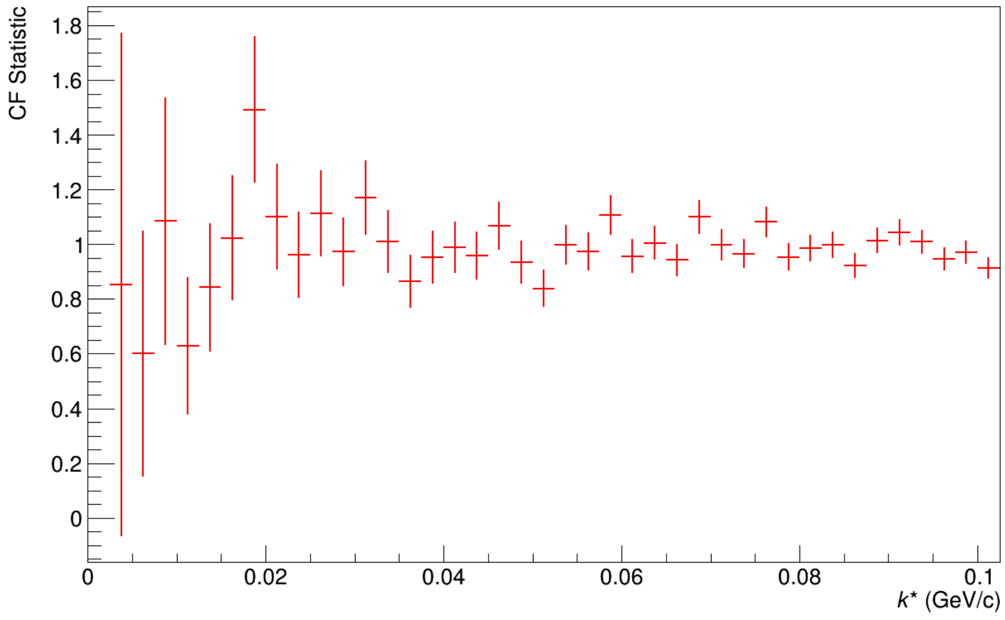


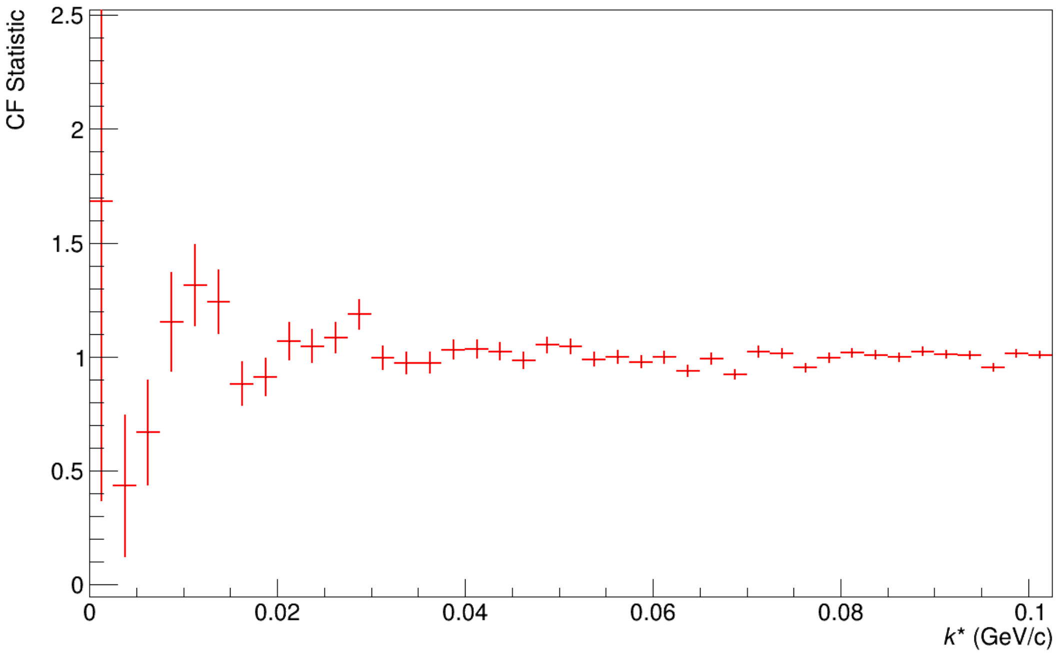
p_t Distribution

- This distribution is used for dividing the kaons into two regimes: small and large p_t.
- The division is done such as the number of kaons with small p_t is the same as the number of kaons with large p_t
- The value of p_t which satisfies this condition is p_t = 0.45 GeV/c



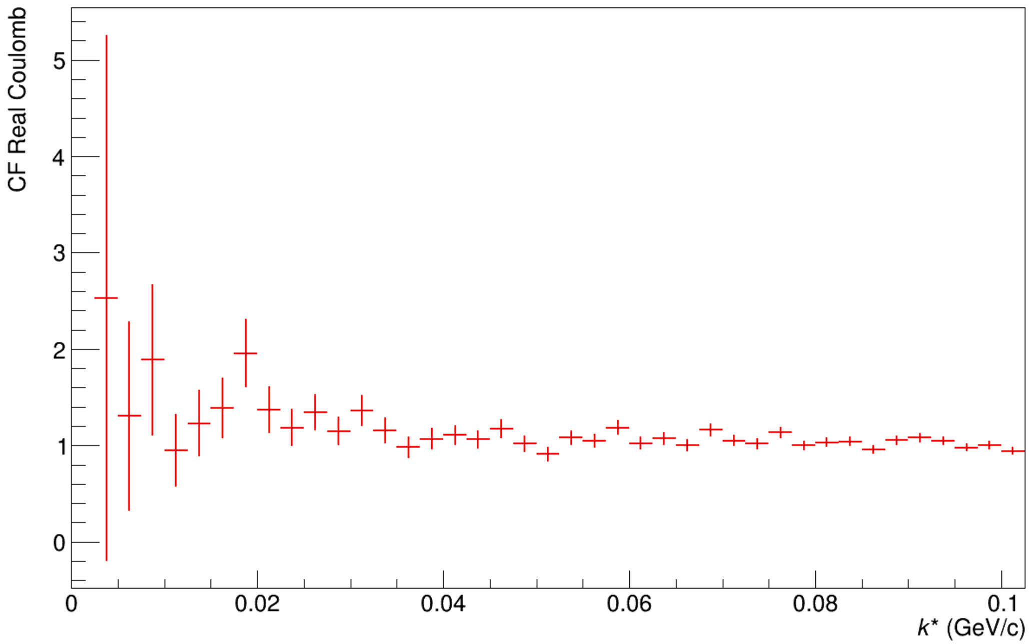
Correlation function without Coulomb interaction for the two regimes

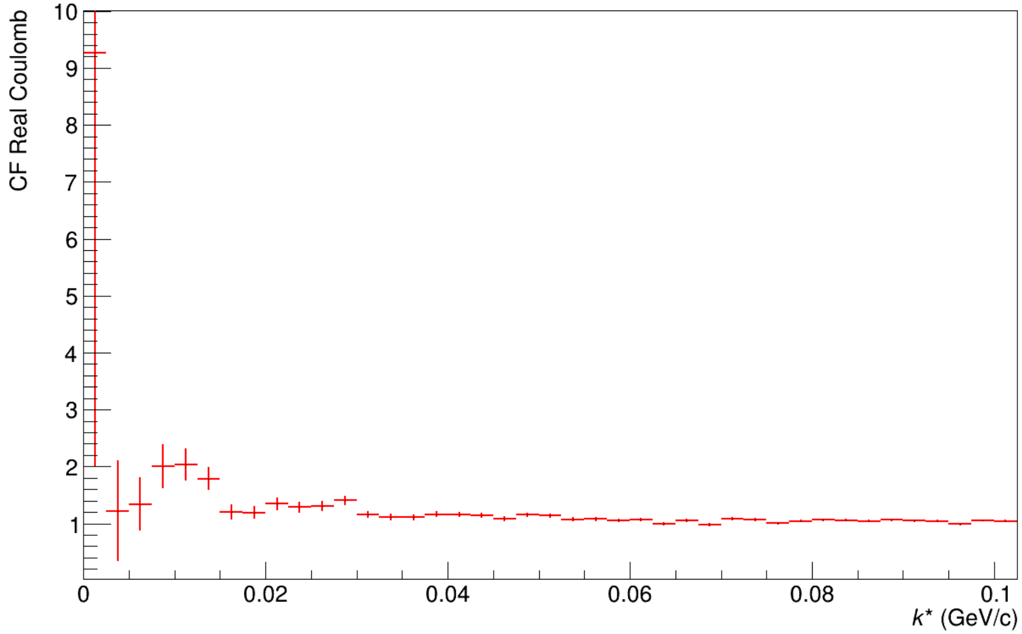




- Left → p_t <0.45 GeV/c
- Right → p_t >= 0.45 GeV/c

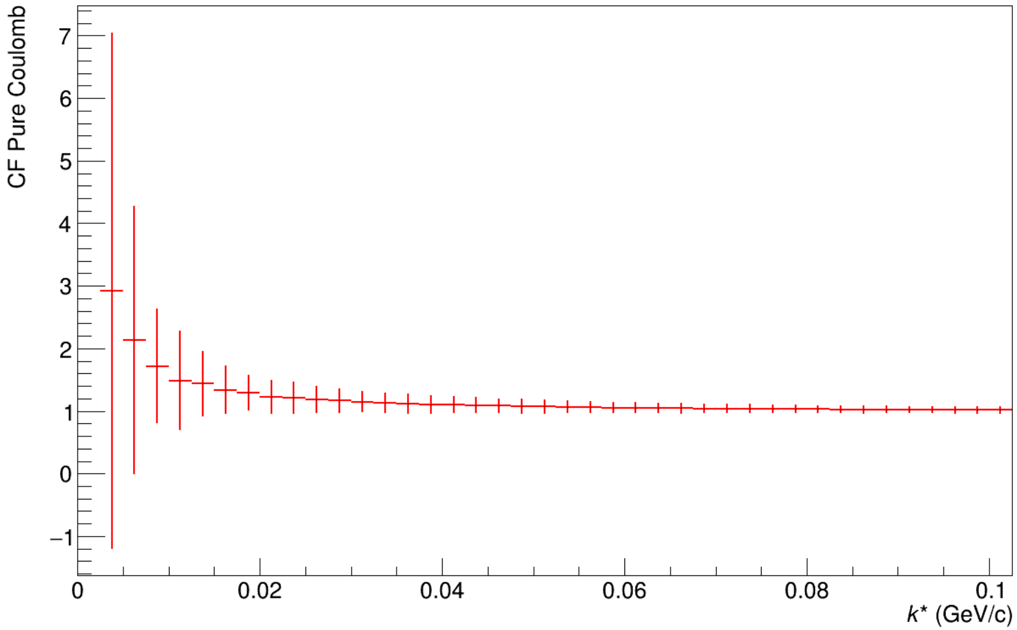
Correlation function with Coulomb interaction for the two regimes

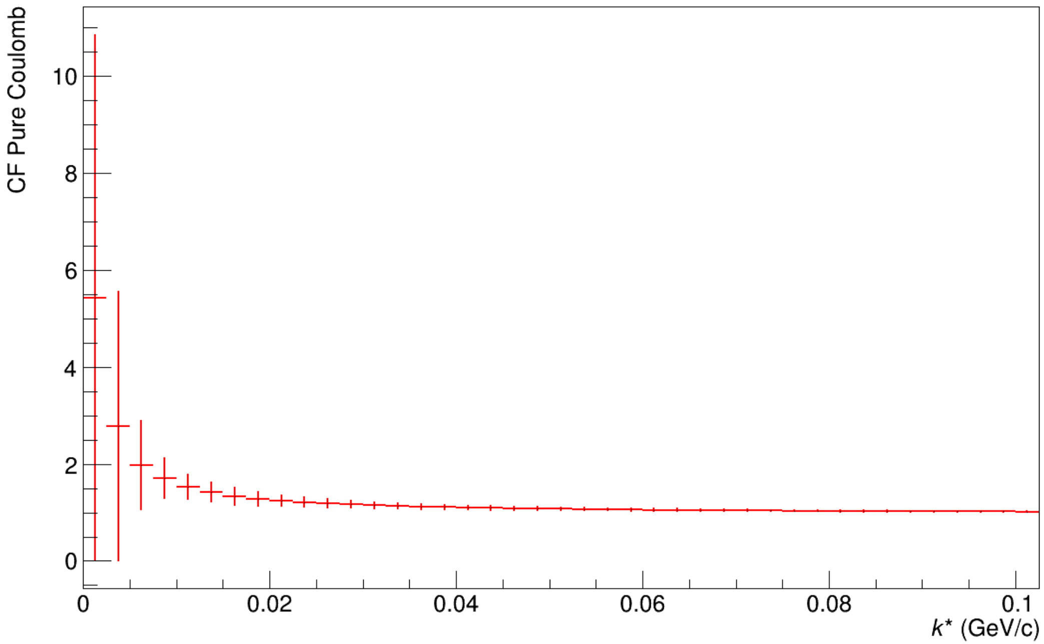




- Left → p_t <0.45 GeV/c
- Right → p_t >= 0.45 GeV/c

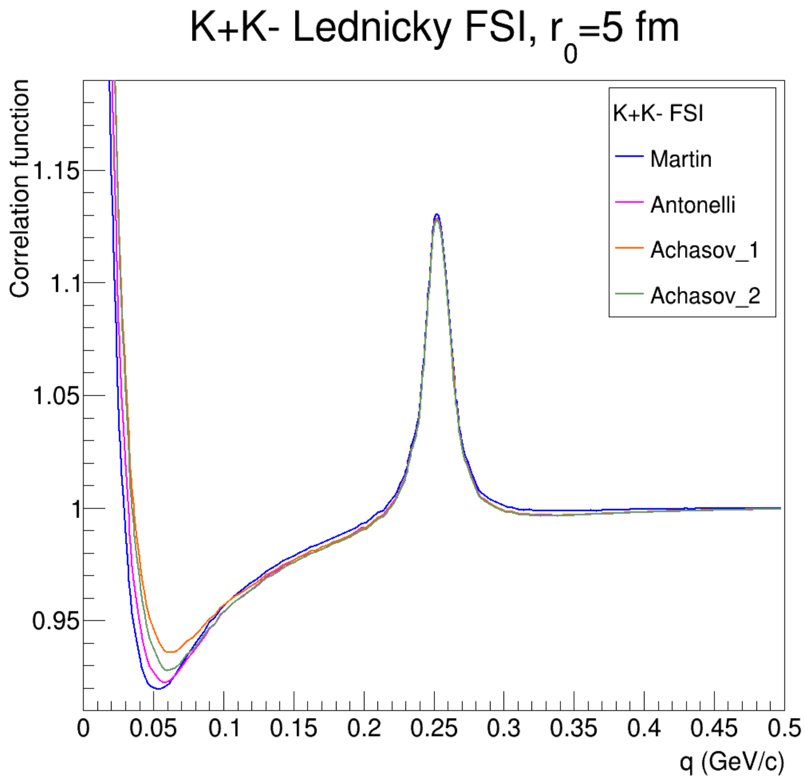
Pure Coulomb correlation function

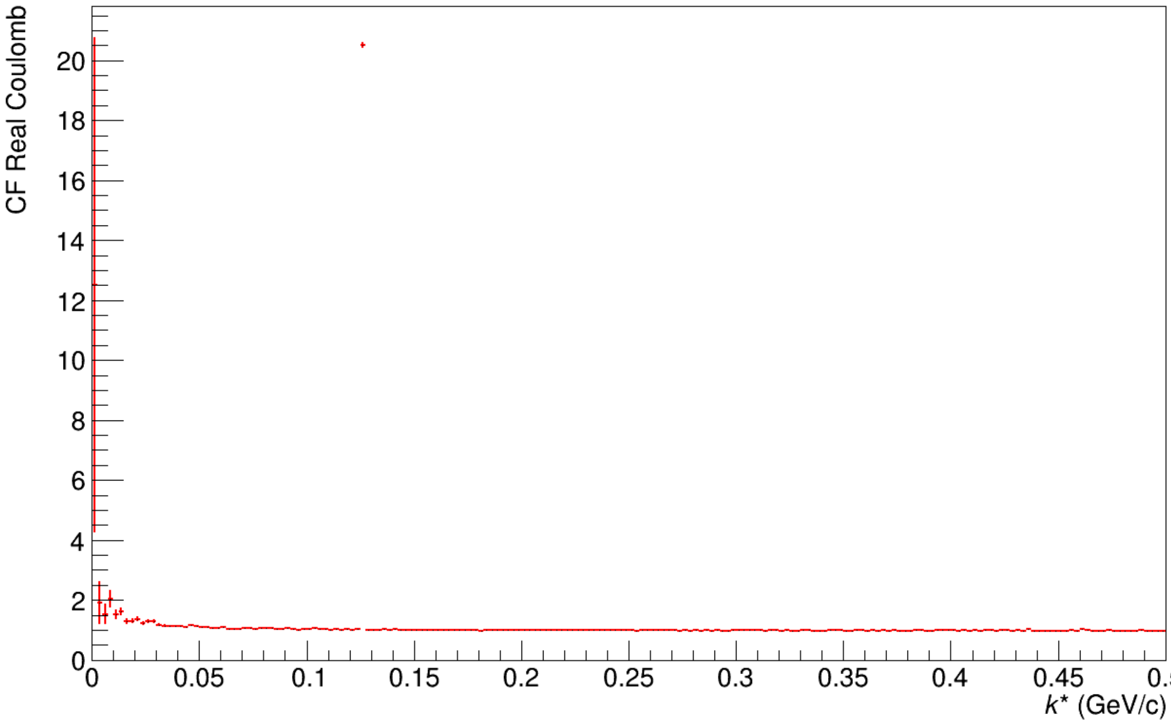




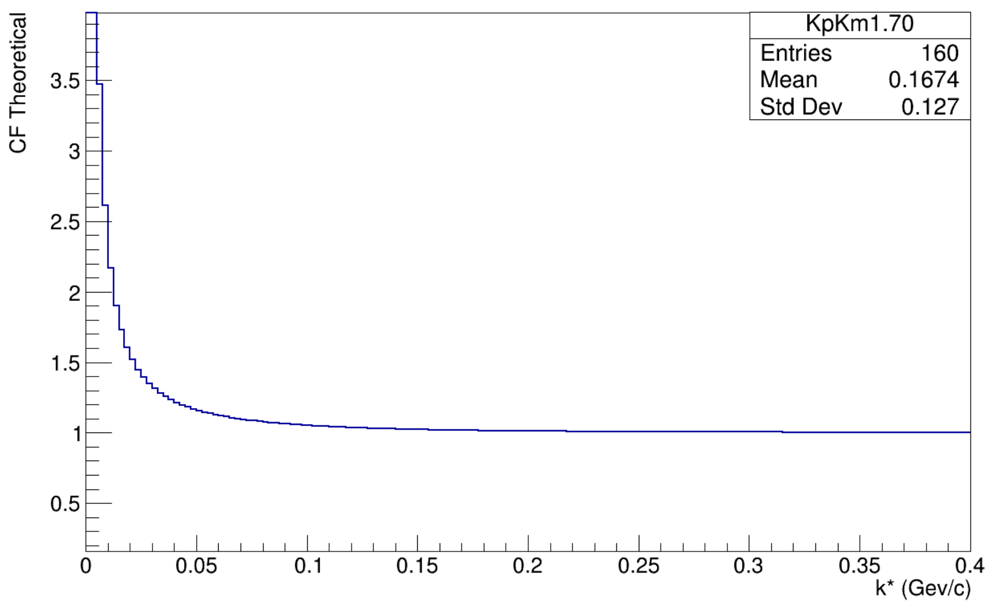
- Left → p_t <0.45 GeV/c
- Right → p_t >= 0.45 GeV/c

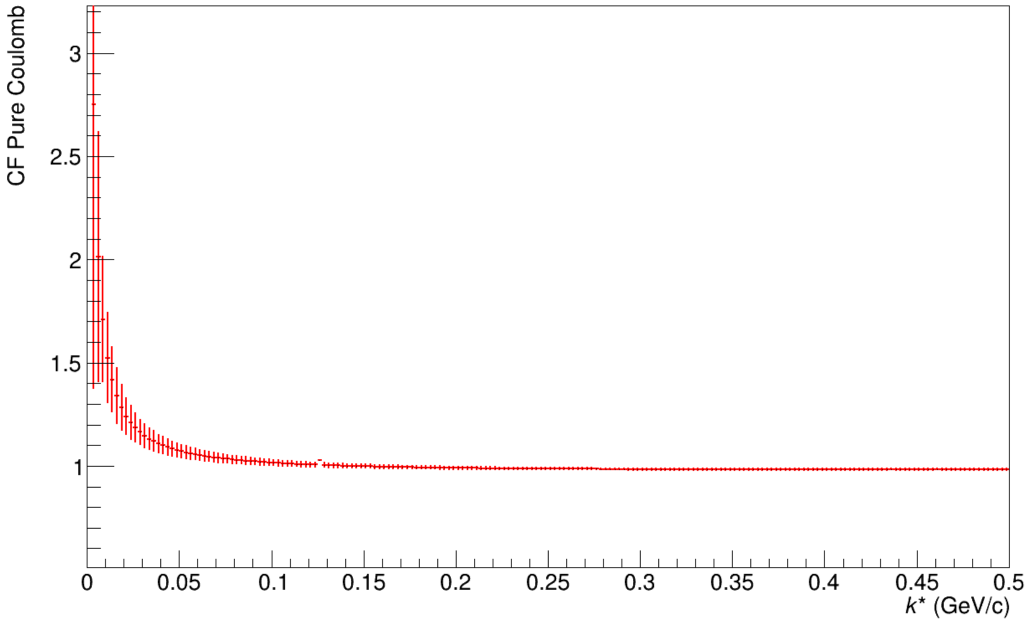
Comparison with theory (correlation function)





Comparison with theory (pure Coulomb)





Conclusions

- THERMINATOR 2 is a flexible tool allowing the exploration of different theoretical frameworks
- It is able to reproduce experimental data using the hydrodynamical framework, that is, assuming collective behavior
- It is therefore a tool to choose the most appropriate parameters for the theoretical model
- The data showed the effect of the Coulomb interaction on the CF
- THERMINATOR 2 can be further developed by including the strong interaction and other effects

References

- Mikolaj Chojnacki, Adam Kisiel, Wojciech Florkowski, Wojciech Broniowski THERMINATOR 2: THERMal heavy IoN generATOR 2
- Adam Kisiel Non-identical particle femtoscopy at√sNN= 200GeV in hydrodynamics withstatistical hadronization
- Adam Kisiel, Wojciech Florkowski, Wojciech Broniowski, Jan Pluta Femtoscopy in hydro-inspired models with resonances

THANK YOU FOR YOUR ATTENTION!

WE OUT!