# Femtoscopy: the way back in the energy scale from ALICE to NICA - part II

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NICA DAYS / XI WORKSHOP ON PARTICLE CORRELATIONS AND FEMTOSCOPY

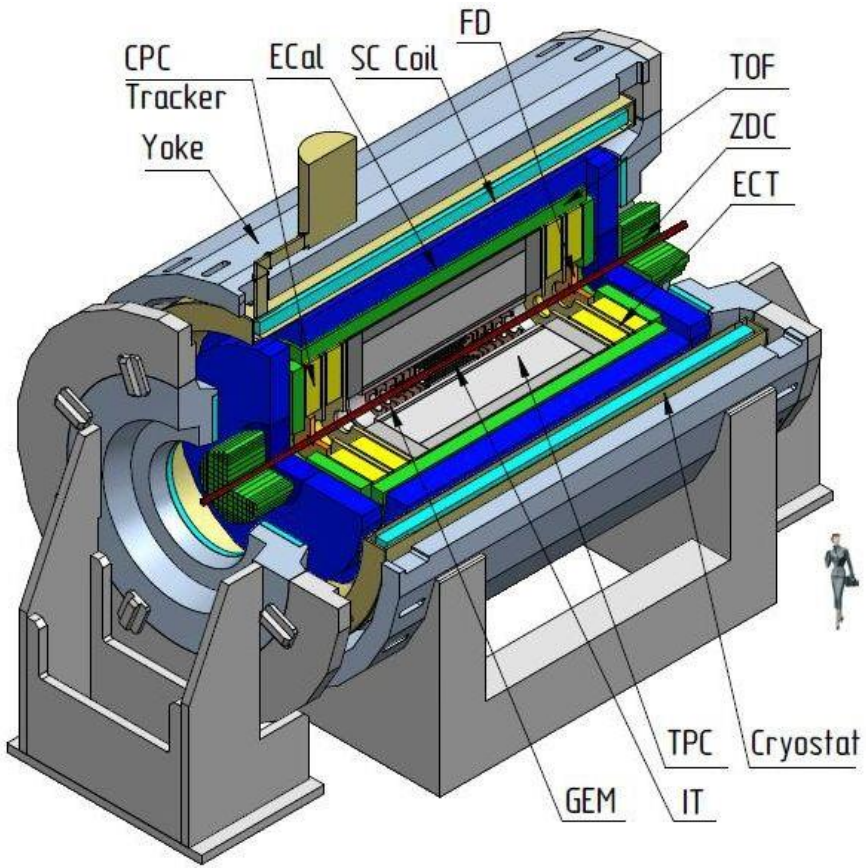
# Outline

- Short description of MPD experiment
- MC generators for MPD energies
- Plans for future

# MPD

- Multi Purpose Detector
- Collider experiment
- At NICA facility
- Energy 4-11 GeV per nucleon for AuAu

Femtoscopic measurement –
one of most important.



# MC models

- Before experiment starts
  - Statistic prediction
  - Information about needed resolution -> detector optimization
  - Testing software for tracking and analysis
  - Testing/developing new methods of analysis that will be used
- When experiment starts
  - Explanation of observables measured by experiment

# MC model requirement

Model used in MPD experiment must fulfill following criteria:

- Taking into account CP/phase transition physics
- Use full 3+1D hydrodynamics
- Reasonable simulation time
- Good description of data available today

# NicaFemto package

NicaFemto was used for analysis:

- tool for femtoscopic analysis
- allow to make other analysis – simplified flow analysis and spectra
- based on FairROOT, created for MPD – can be transferred between different experiments like MPD, BM@N, CBM (future software for femtoscopic analysis in those experiments)

# Comparison of models

Two models were tested :

- UrQMD 3.4 with ideal hydro mode enabled and chiral equation of state (crossover)
- vHLLE+UrQMD model (Iu. Karpenko) – crossover (chiral) or 1st order transition (Bag Model), with or without viscosity

And compared with data from:

- STAR (10.1103/PhysRevC.92.014904 same sign pion analysis)
- Na-49 (10.1103/PhysRevC.77.064908 $\pi^-\pi^-$ analysis)

Convention in this talk:  all energies written in this presentation are sqrt(sNN) energies!

# Comparison of models – Na49 sample

Fitted pairs of negatively charged pions where fitted by :

$$C(q) = 1 + \lambda e^{-q_{out}^2 R_{out}^2 - q_{side}^2 R_{side}^2 - q_{long}^2 R_{long}^2 - 2q_{out-long}^2 R_{out-long}^2}$$

Pairs where grouped in rapidity bins, where rapidity was defined for each pair as:

$$Y_{pair} = \frac{1}{2} ln \left( \frac{(E_1 + E_2) + (p_{z1} + p_{z2})}{(E_1 + E_2) - (p_{z1} + p_{z2})} \right)$$

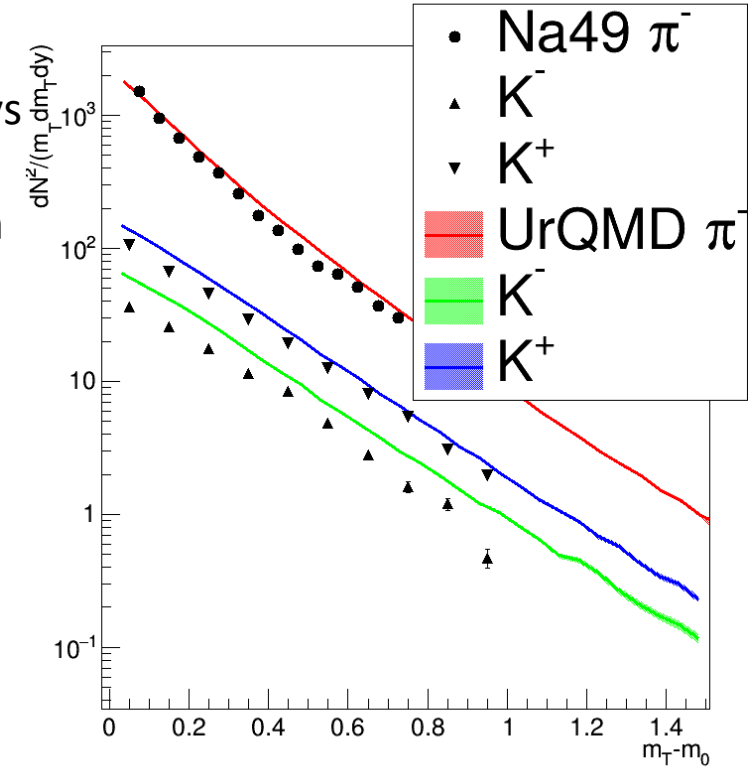
## Compared data

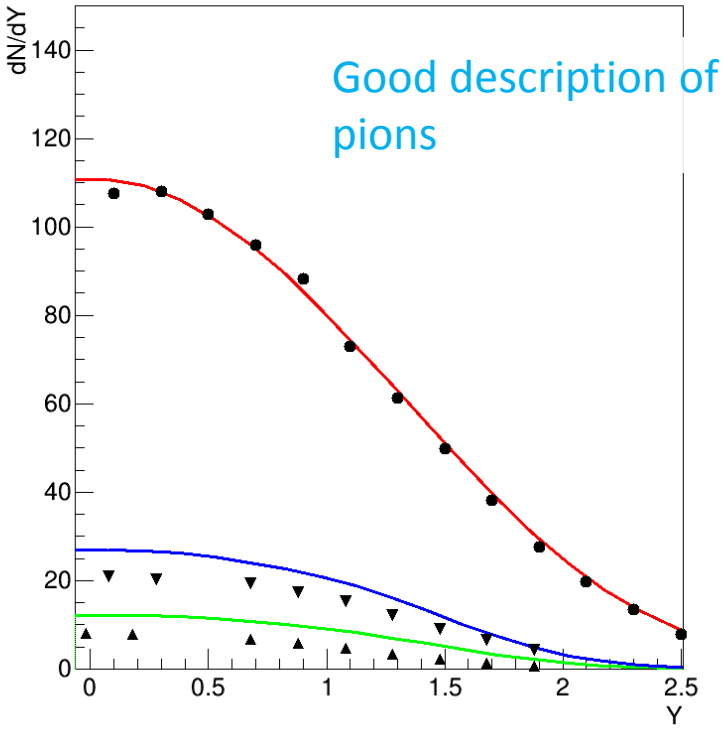
STAR data were with Gaussian fit

$$C(q) = 1 + \lambda e^{-q_{out}^2 R_{out}^2 - q_{side}^2 R_{side}^2 - q_{long}^2 R_{long}^2}$$

# Spectra from UrQMD

Note:
Similar Energy (Na49 8.7 vs 9 GeV for UrQMD)
Similar system (PbPb from Na49 vs AuAu in UrQMD)

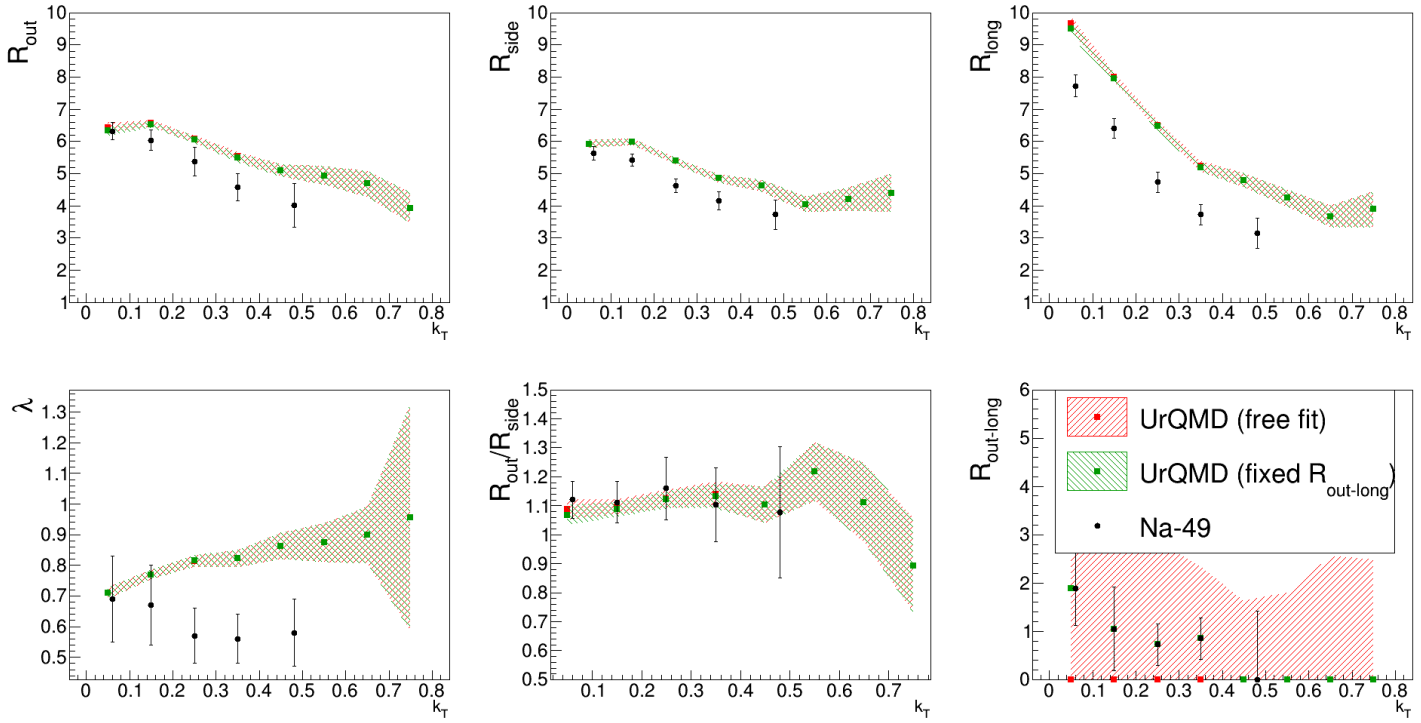


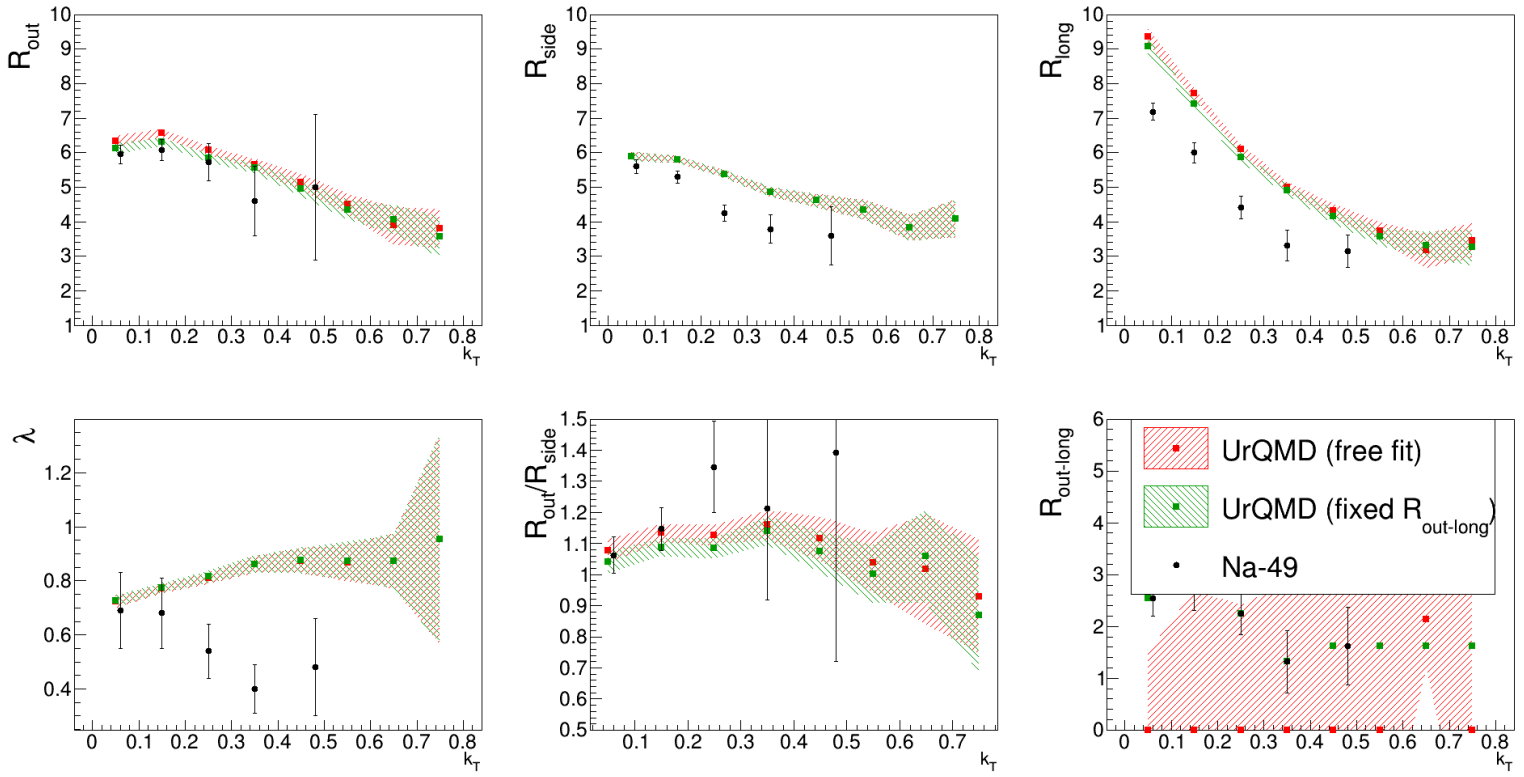
# UrQMD $0<Y_{pair}<0.5$

Note:
Similar Energy (Na49 8.7 vs 9 GeV for UrQMD)
Similar system (PbPb from Na49 vs AuAu in UrQMD)
Applied cuts: as acceptance

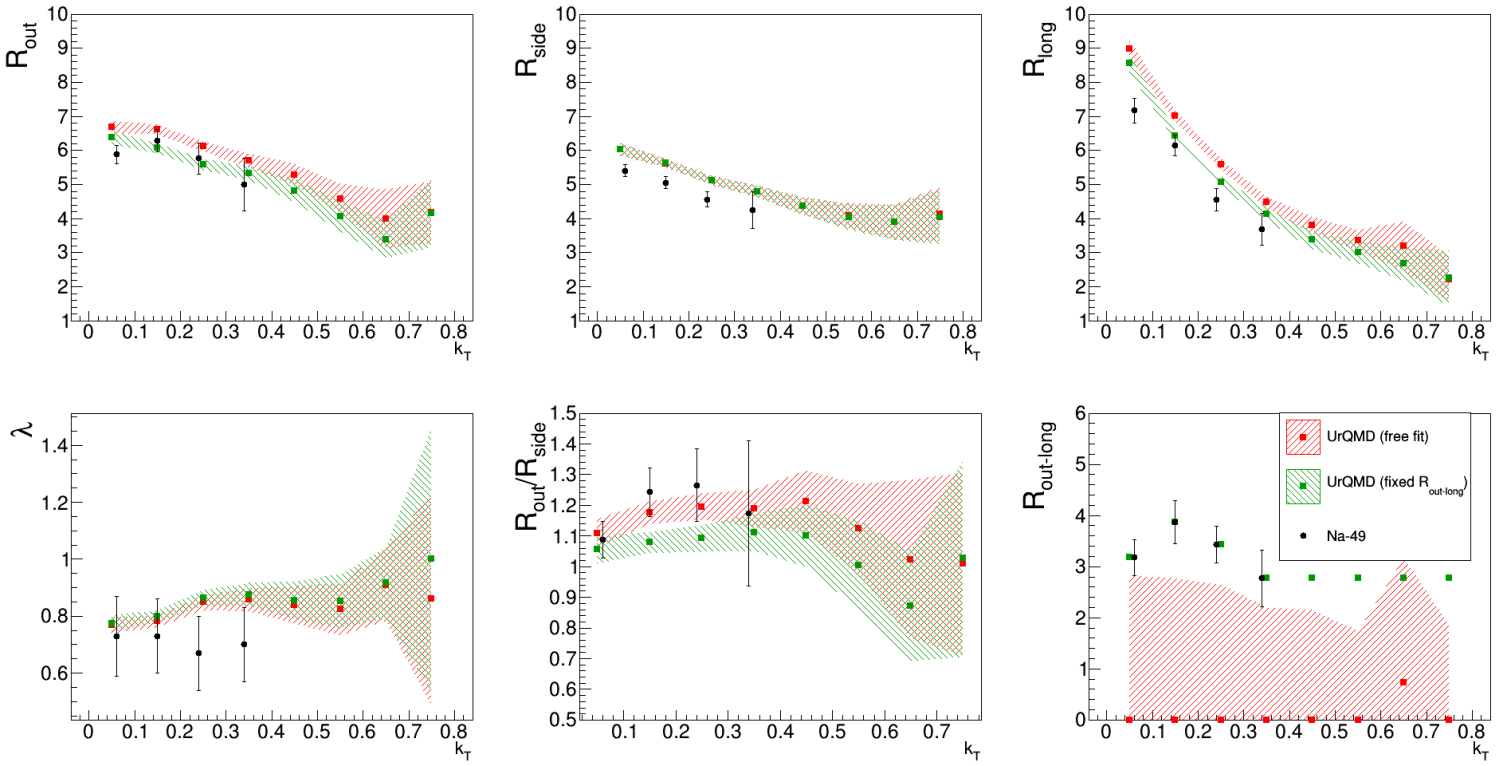
Radii overestimated
Not enough statistic to fit $R_{out\text{-}long}$ properly



# UrQMD 0.5<$Y_{pair}$<1.0

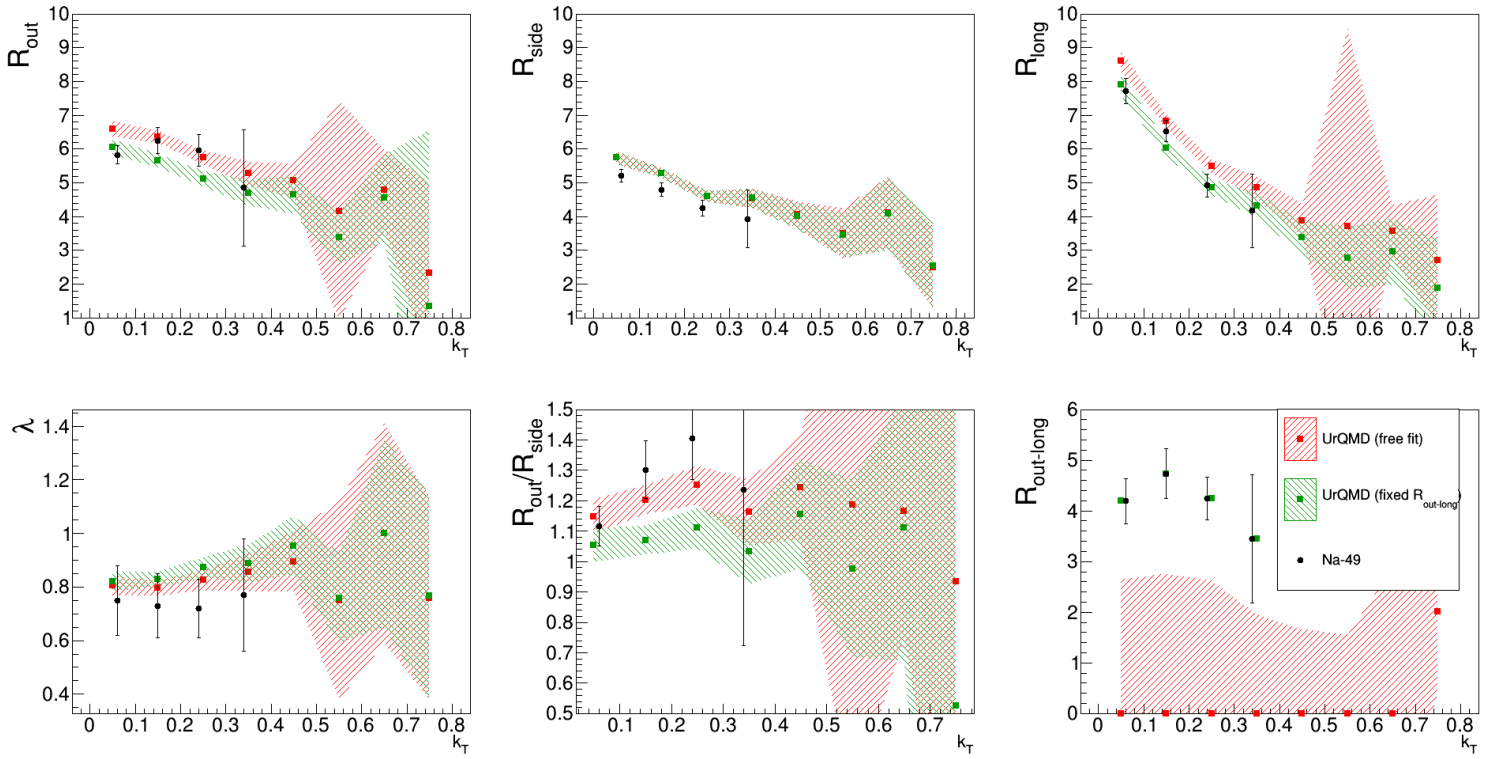


# UrQMD 1.0<$Y_{pair}$<1.5

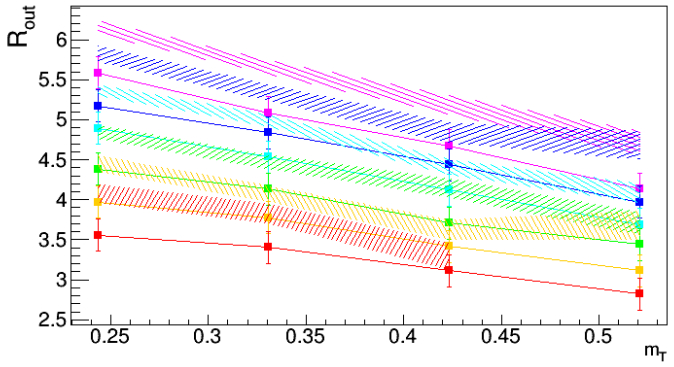


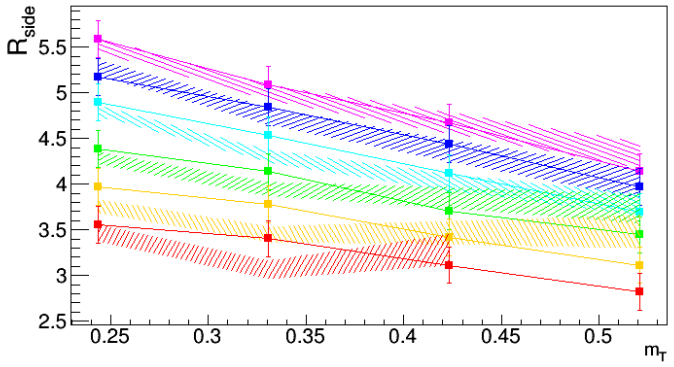
# UrQMD 1.5<$Y_{pair}$<2.0

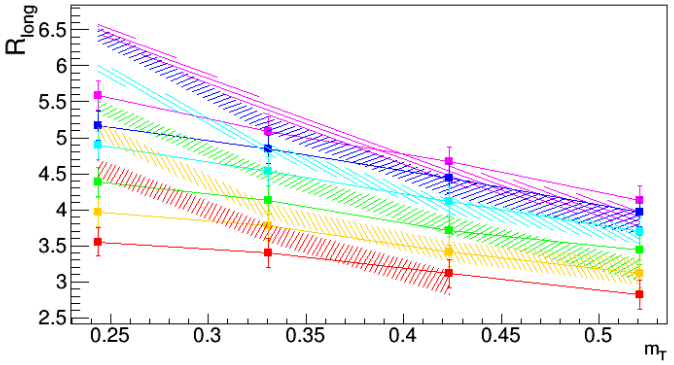
Quite good description of radii for „forward” rapidity pairs

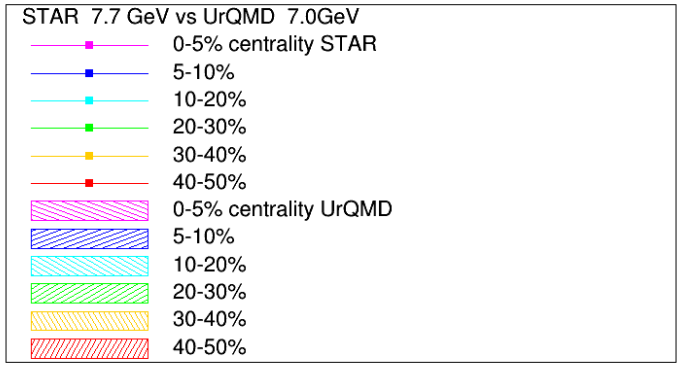


# UrQMD and STAR data



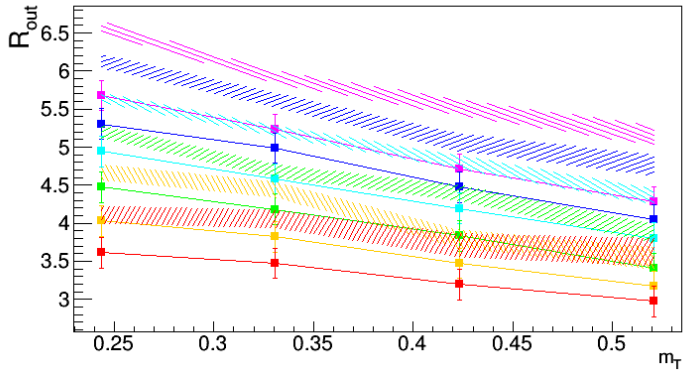



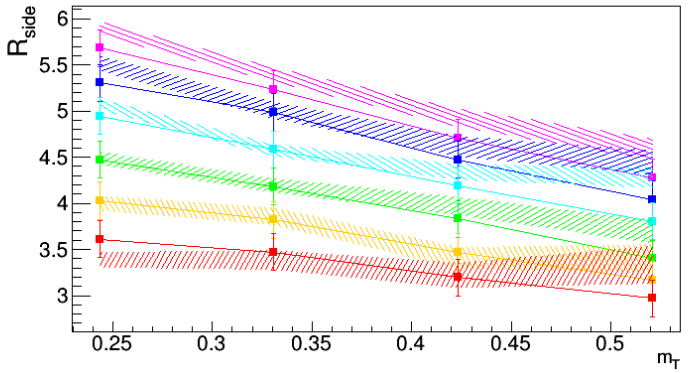



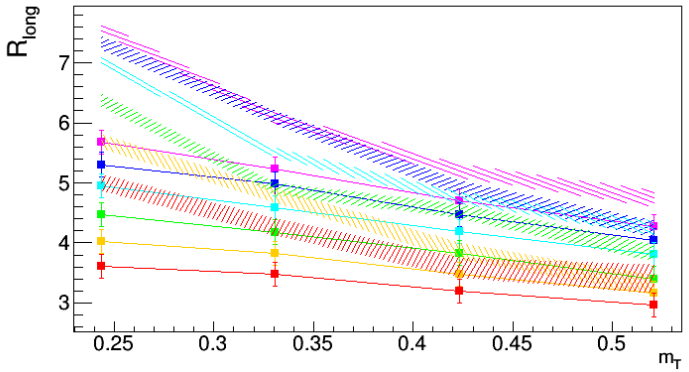



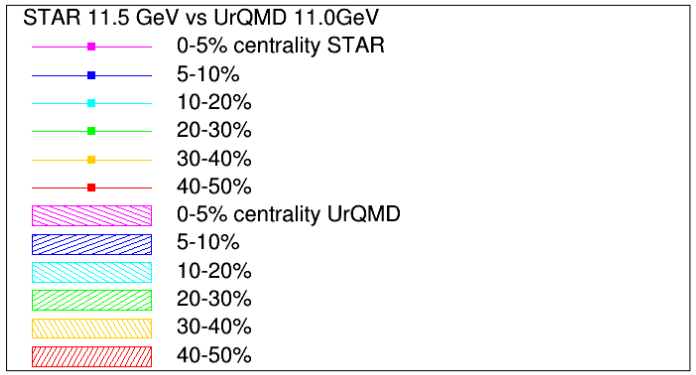

$R_{side}$ – good
$R_{out}$ – overestimated
$R_{long}$ – strongly overestimated, different slope

# UrQMD and STAR data




Effects of overestimation it's bigger!

# UrQMD model

- Not well reproduction of femtoscopic observables, radii are usualy overestimated
- Huge computer resources required – about 1h per single event (with hydrodynamics enabled)
- Probably can be tuned by manipulating parameters – but this require too much time

# vHLLE+UrQMD model

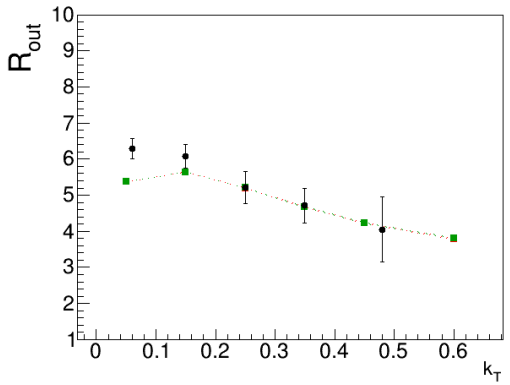
- Simulation steps:
  - Initial conditions – taken from UrQMD
  - From fixed $\tau$ till fixed value of $\varepsilon$ – 3+1D hydro code is used
  - Particlization, switching to UrQMD code for cascades

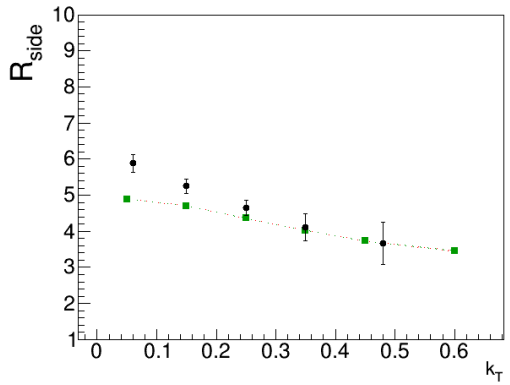
Parameters are tuned for transverse momentum, rapidity distributions and elliptic flow. Many cascade simulations for one hydro simulation can be done (oversampling).

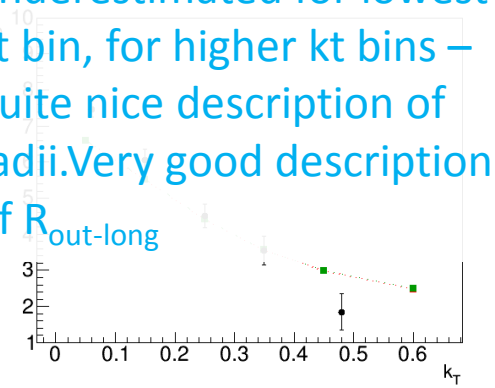
In Na49 like analysis - crossover with perfect hydro was used.

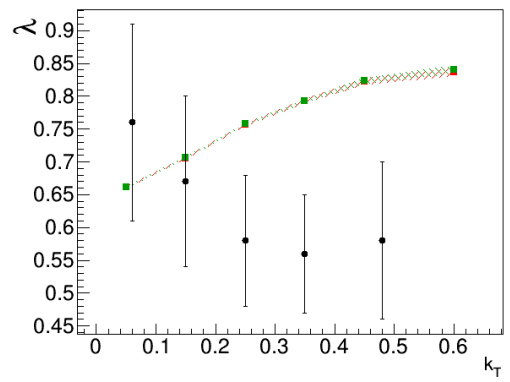
# vHLLE + UrQMD $0<Y_{pair}<0.5$

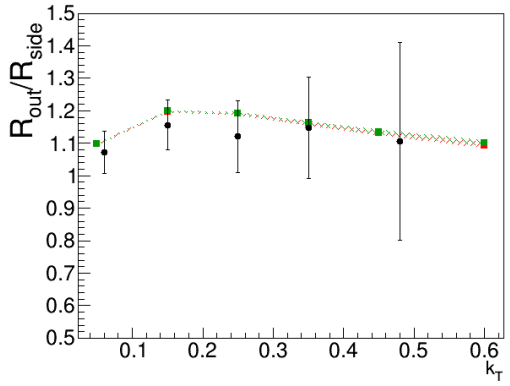
Note:
Similar events :Na49 PbPb vs model AuAu
Similar centrality:
0-7.2% for Na49 data and 0-5% for model
Similar Energy – 7.6 for Na49 data and 7.7 for model
Cuts applied – like Na49 acceptance

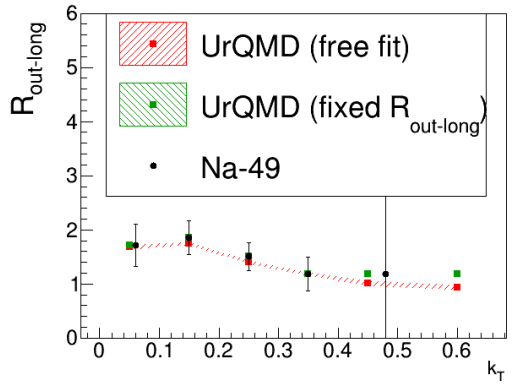


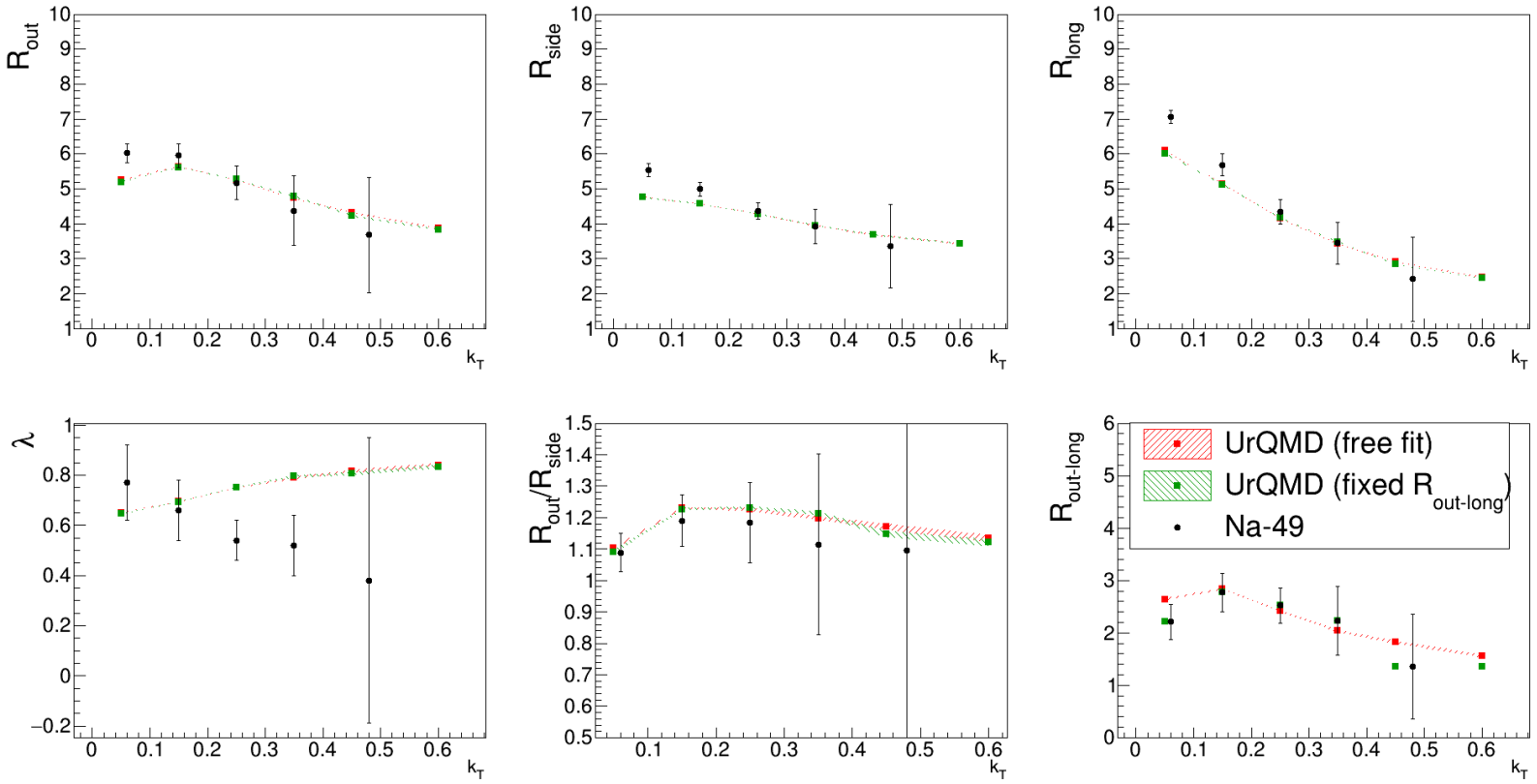



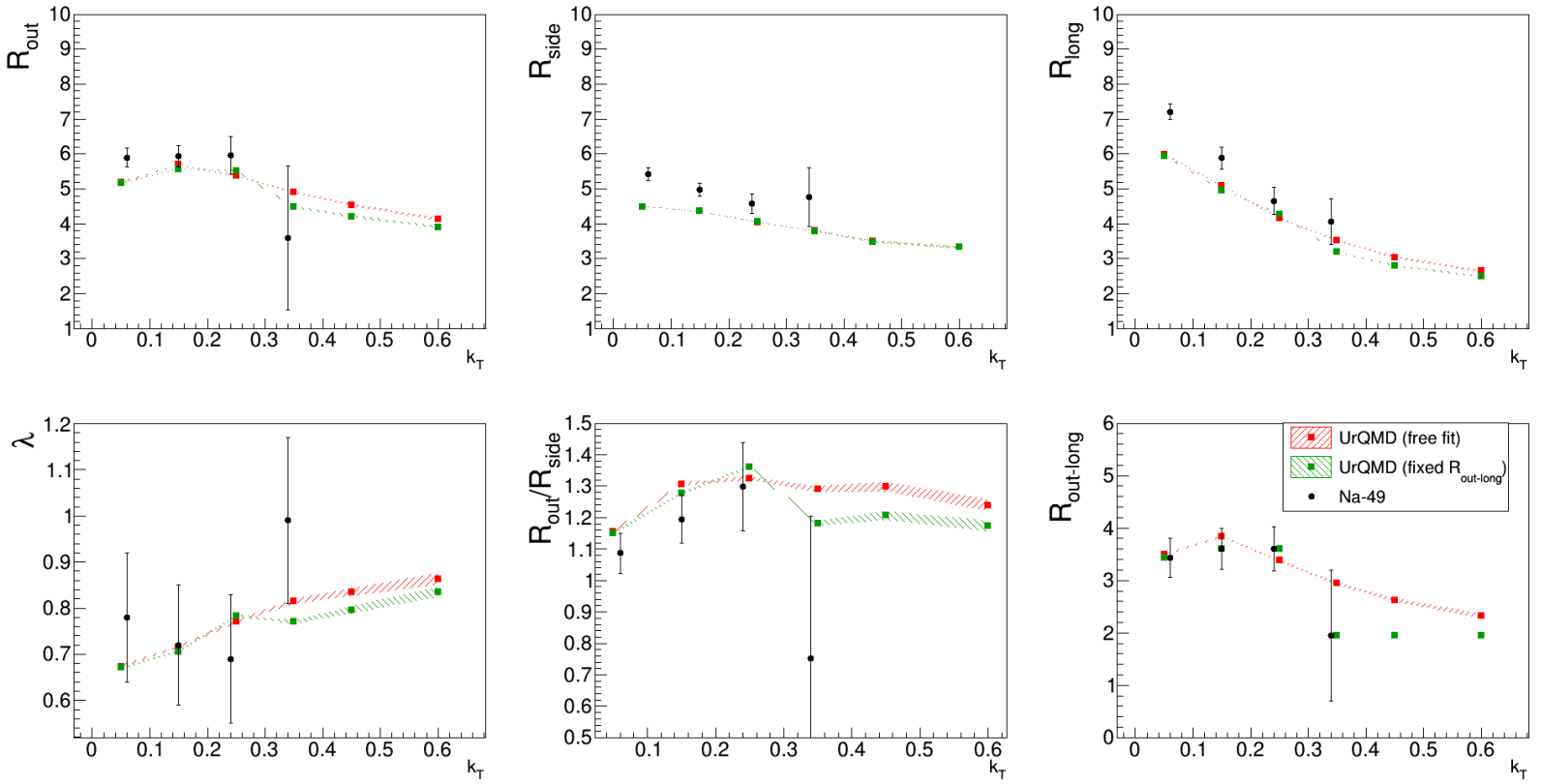




Much better statistic- better fits, smaller uncertainties, radii seems to be rather underestimated for lowest kt bin, for higher kt bins – quite nice description of radii.Very good description of $R_{out-long}$

# vHLLE + UrQMD 0.5<$Y_{pair}$<1.0

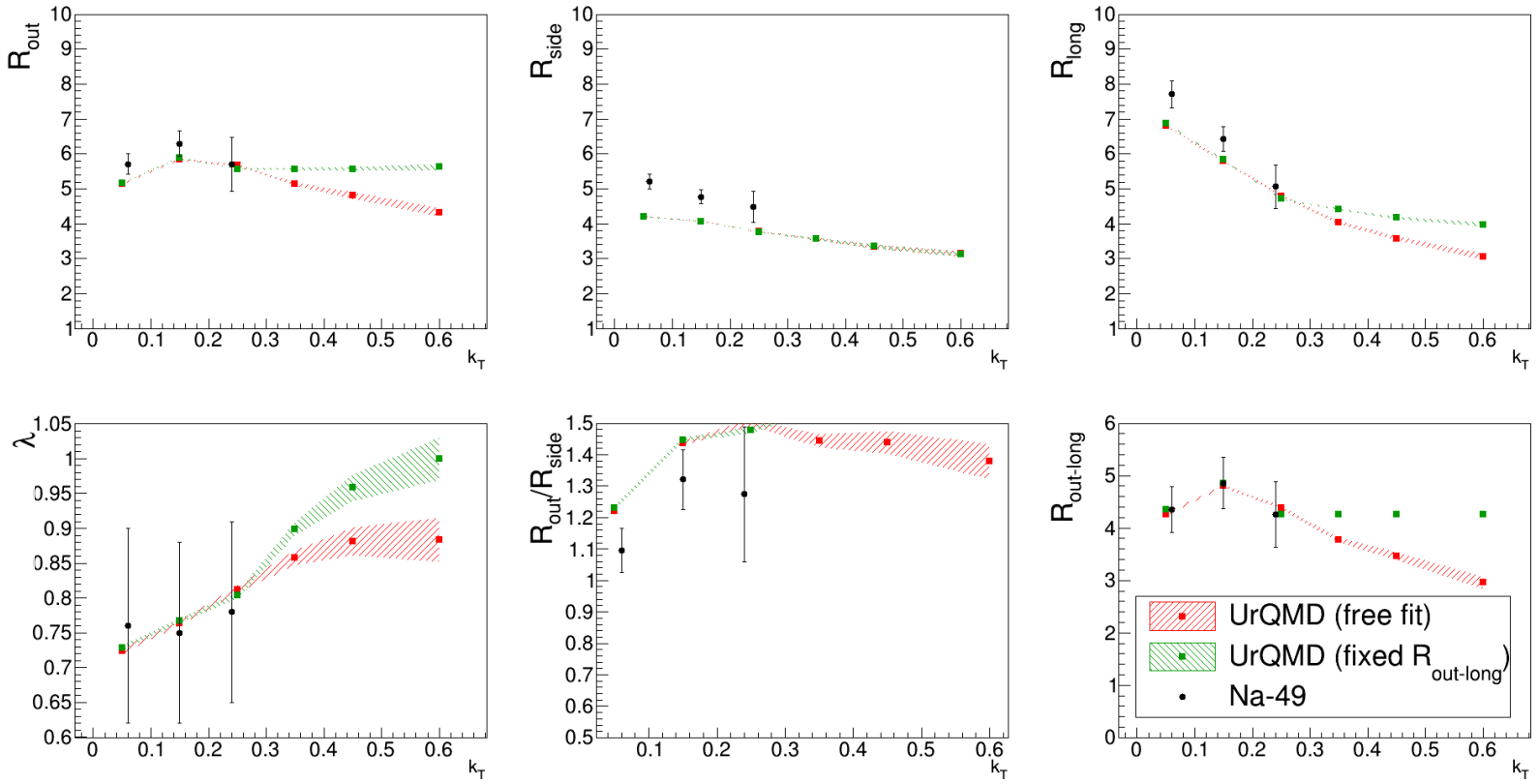


# vHLLE + UrQMD 1.0<$Y_{pair}$<1.5



# vHLLE + UrQMD 1.5<$Y_{pair}$<2.0

Problem with description of $R_{side}$



# vHLLE+UrQMD vs STAR data

Following convention is used

Blue line – perfect hydro + crossover phase transition

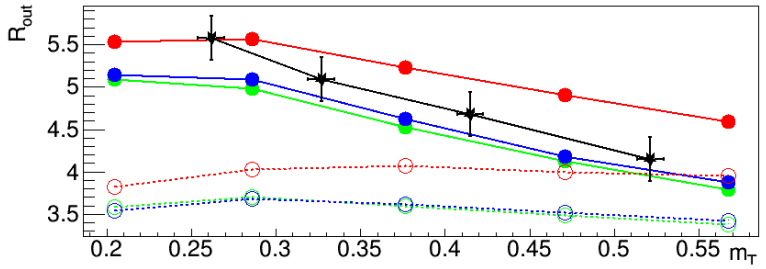
Red line – perfect hydro + 1st order phase transition

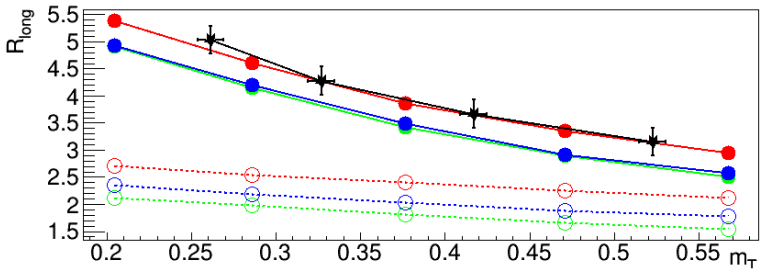
Green line – viscous hydro + crossover phase transition

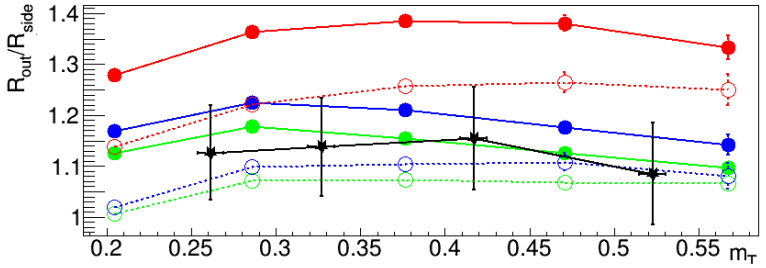
**Full line – full simulation**

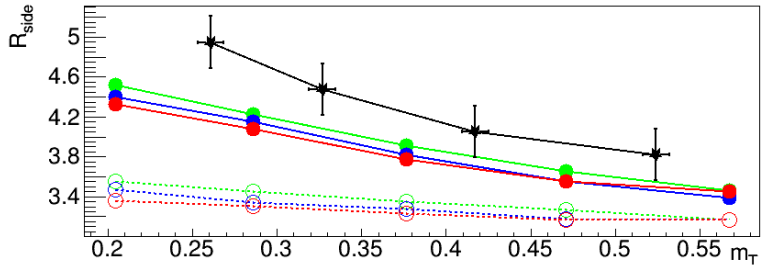
*Dotted line – no cascade processes*

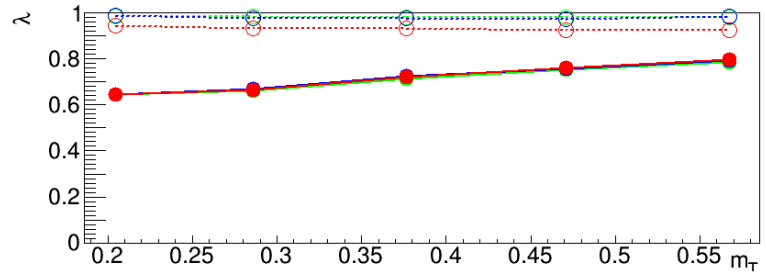
# vHLLE + UrQMD and STAR data



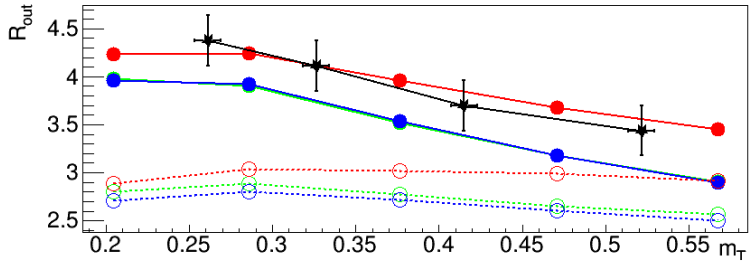



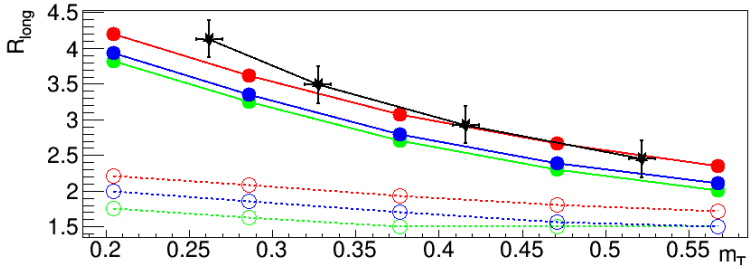



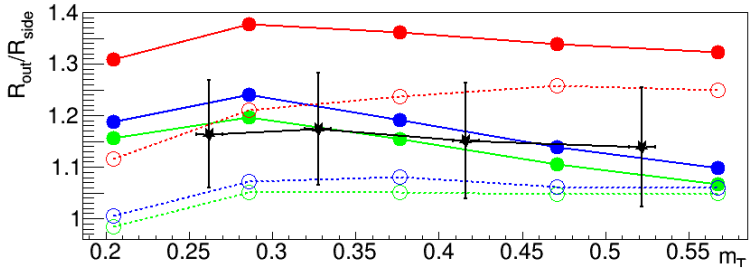



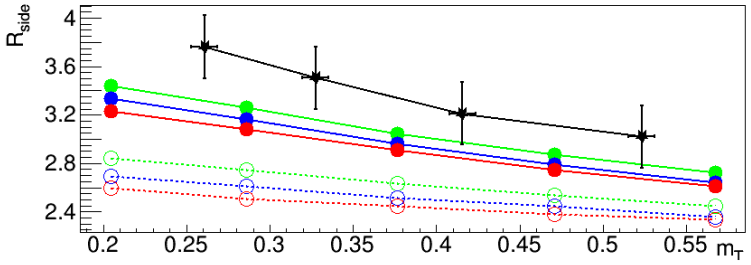

7.7 GeV centrality: 0-5%

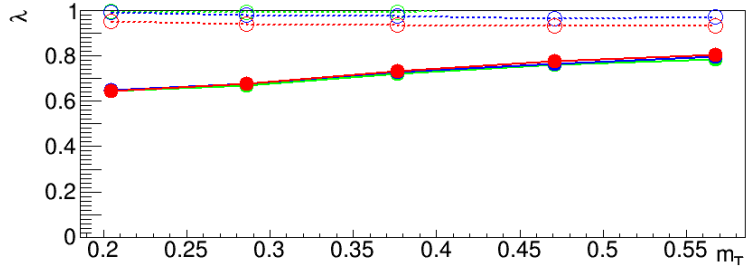
# vHLLE + UrQMD and STAR data



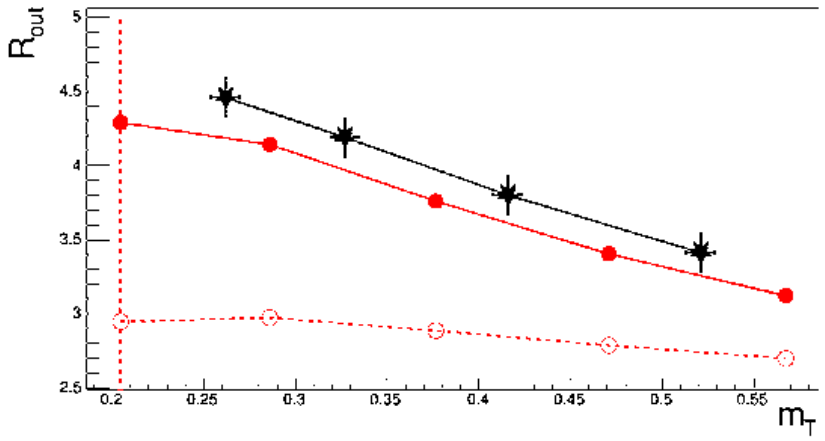



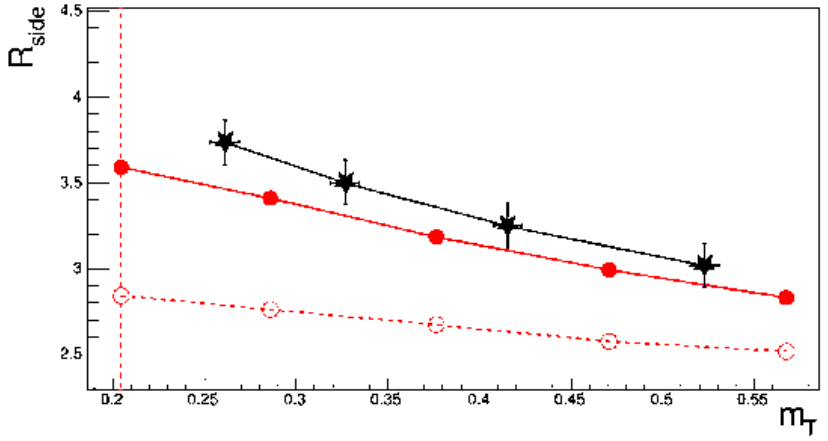



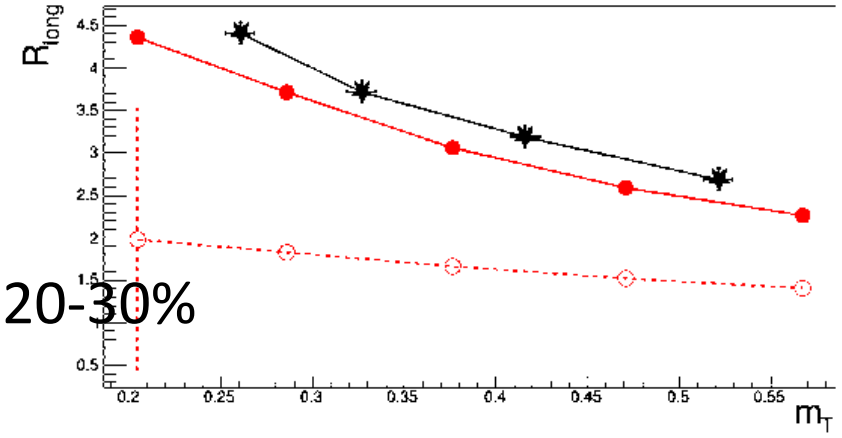



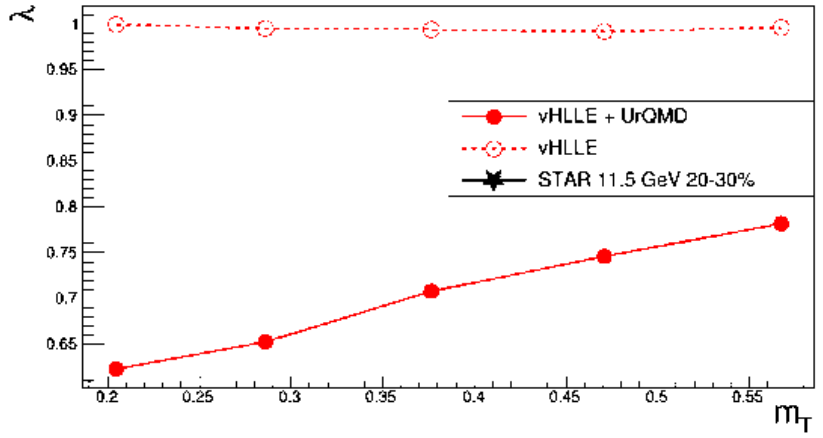

7.7 GeV
centrality: 20-30%

# vHLLE + UrQMD and STAR data



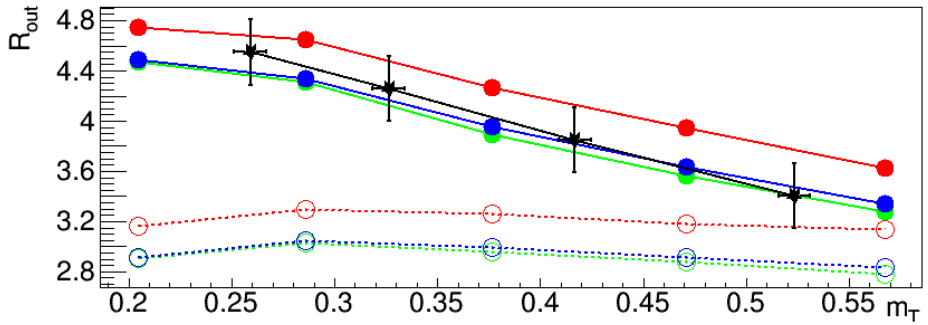



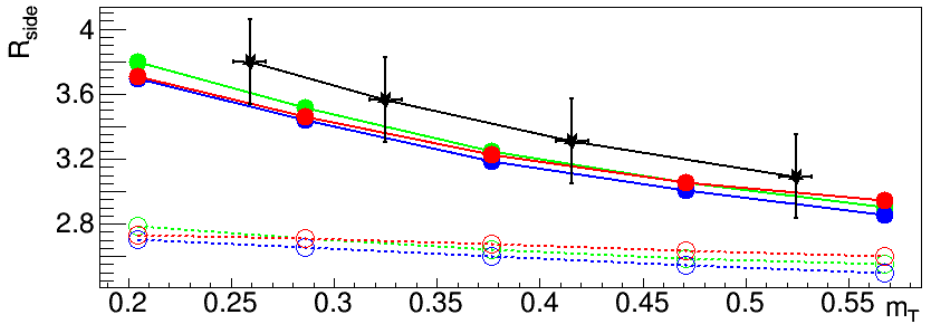



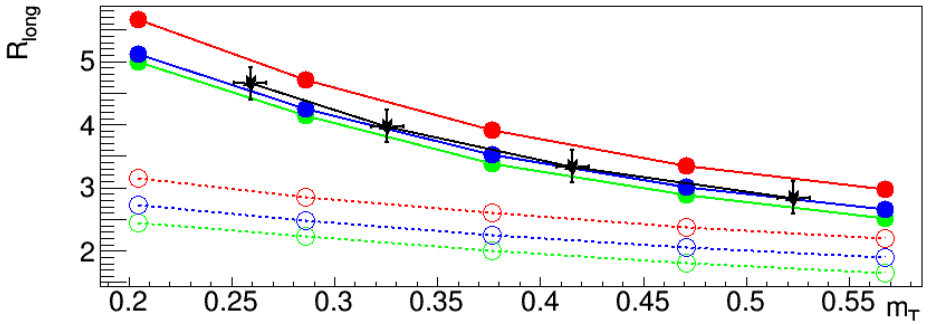



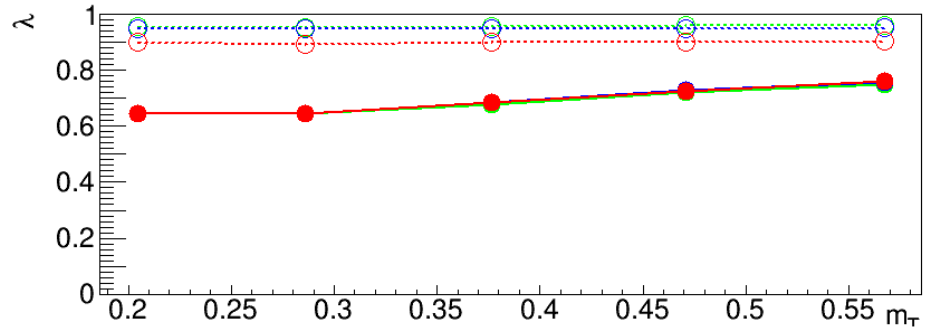

11 GeV
centrality 20-30%

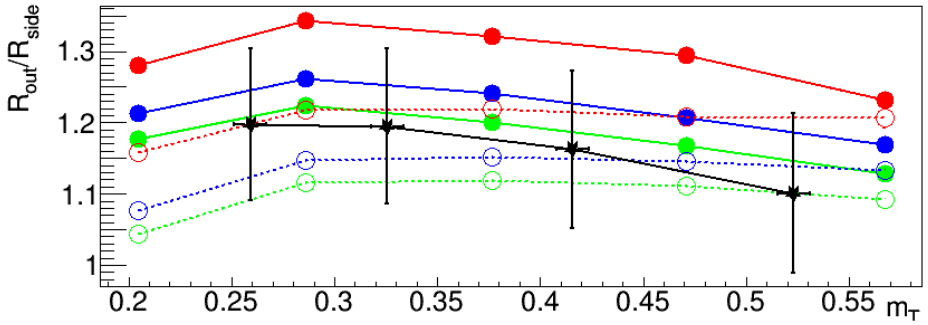
# vHLLE+UrQMD and femtoscopic radii




Difference in Rout/Rside observed.
Is it useful?

# vHLLE+UrQMD model

- Better description of femtoscopic radii (except $R_{side}$)
- Femtoscopic observables are reproduced „out of box” (model wasn’t tuned for femtoscopy)
- Much faster – oversampling (many cascade simulations for one single hydro simulation)
  - For example 2h of computing gives:
  - ~2 full hydro events in UrQMD
  - ~1 full hydro event in vHLLE + ~60 „posthydro” events - >60 „effective” events (or one „superevent”)

Statistic for track based observables multiplied by factor of 30
Statistic for two-track observables multiplied by factor of 1800!
(but there are some „hooks”)

# What we have learned from UrQMD and vHLLE+UrQMD?

- Standard $R_{out}/R_{side}$ ratio measurements might be not enough to distinguish between different phase transition types – imaging method might be very promising
- Rescaterring, resonance decays strongly affect femtoscopic measurements, however final radii still depend on phase transition
- $R_{long}$ observable seems to be more promising than simple looking on $R_{out}/R_{side}$ measurements
- Femtoscopic radii changes dynamically with different rapidity bin – data from „standard” measurements are not enough for tuning MC models

# First result of reconstruction

Two track reconstruction is crucial for femtoscopic analysis. Due to limited resolution of detector following cases can occur:

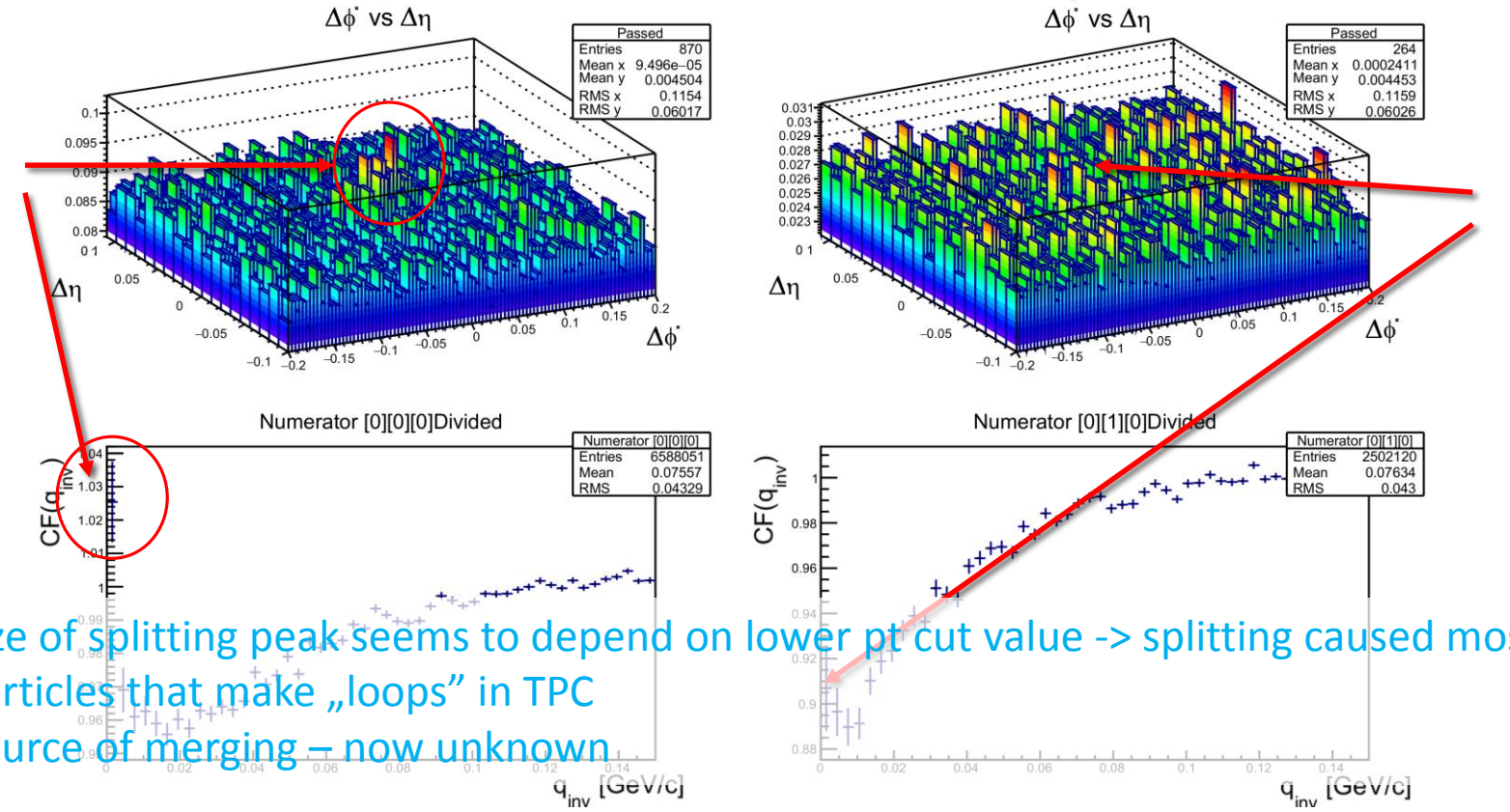
- Merging - real pair of tracks is reconstructed as single track –pair is missing -> value of CF is artificially reduced
- Splitting – real track is reconstructed as two tracks – artificial pair is added -> increase value of CF

First analysis was made with:

- Kalman tracks obtained from MC hits in TPC
- „Anti double-track” cut – pair of Kalman tracks is removed if both have the same parent MC
- Cut monitor for $\Delta\phi^*\Delta\eta$ ($\Delta\phi^*$ - is kind of analogy for $\Delta\phi$ but take into account influence of magnetic field inside detector)

# First result of using MPD reconstruction chain

No" anti double-tracks cut", splitting is visible




With anti double-tracks cut, splitting has been removed/reduced

Size of splitting peak seems to depend on lower pt cut value -> splitting caused mostly by particles that make „loops" in TPC

Source of merging – now unknown

# Summary

We tested two models with hydro, vHLLE + UrQMD seems to be promising model that fulfil all conditions necessary for our needs.

We tested software for femtoscopic analysis (NicaFemto) with both kind of data – from generator and after reconstruction.

# Plans for future

- Expanding comparison by using more MC event generators like PHSD
- Testing new methods of analysis like differential femtoscopy
- Making analysis with MPD reconstruction algorithms

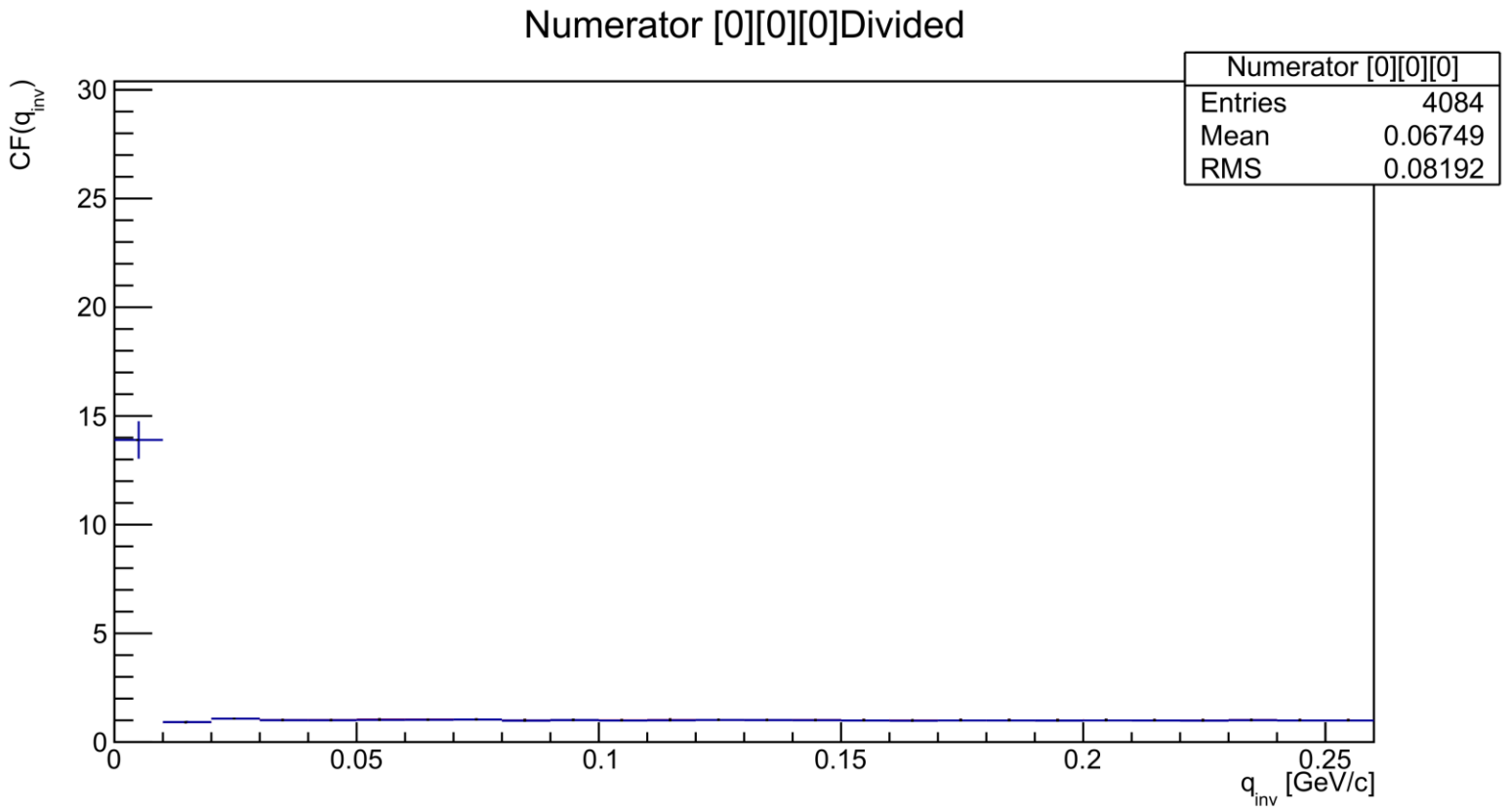
# Thank you for your attention

# References

Presentation about hybrid model

Beam Energy Scan using a viscous hydro + cascade model

# Backup slides




CF for Kalman tracks with 0.15<pT<1.0