New EPOS femto package

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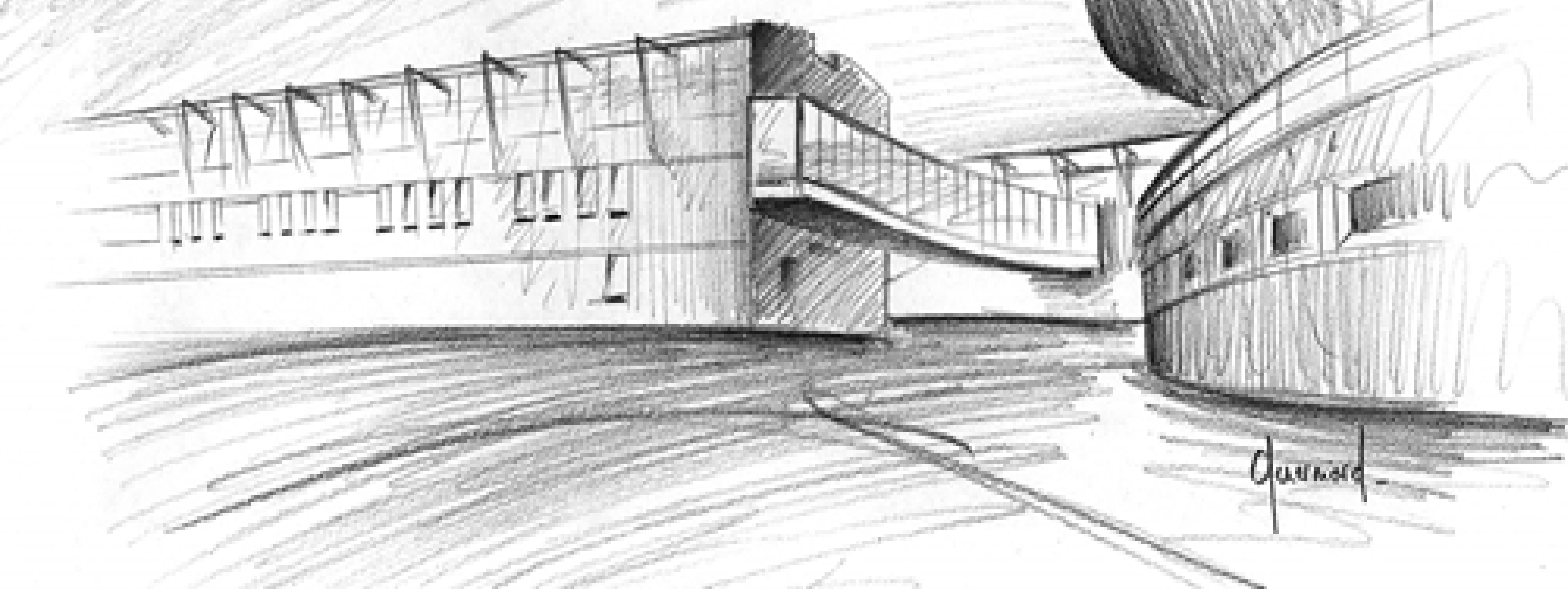


Outline

- Motivation of the femtoscopy study with the Epos model
- Technical details of the Epos Femto package
- First results from Epos Femto package and comparison with STAR data (AuAu at 200 GeV)
- Long range correlation
- Conclusions and next steps

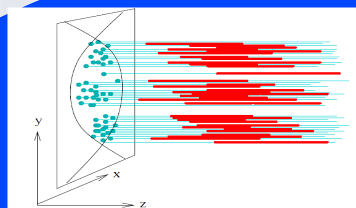
Motivation

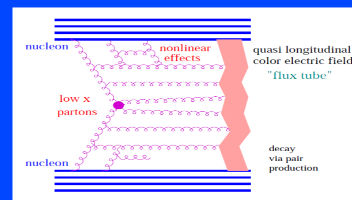
- EPOS is not a simple MC event generator, Epos is a physical event model which includes all stages of collision (init. conditions from flux tube, EbE procedure, 3+1 hydrodynamics, realistic EoS, complete resonance table, hardonic cascade)
- EPOS provides space-time coordinates of hadrons
- Possibility to study femtoscopy with EPOS
- EPOS pretends to be a model for energy scan

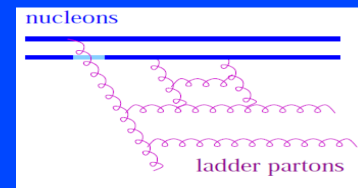
(applicability: pp, pA, AA a few GeV < $\sqrt{s}$ < a few TeV)

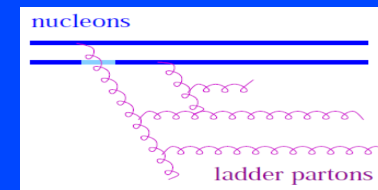
Epos and Femto

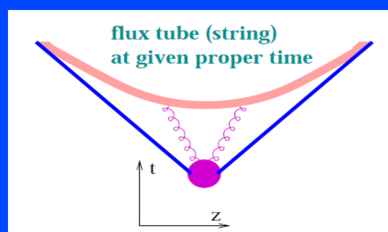
EPOS code v.2.0 [arxiv.org/abs/1004.0805]

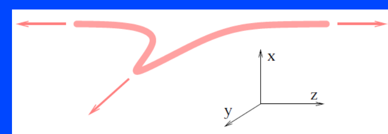


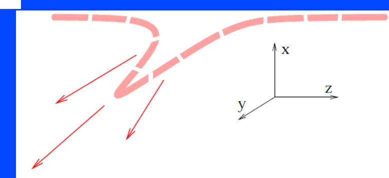


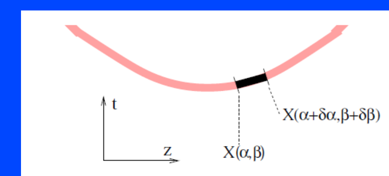




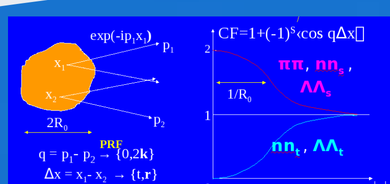




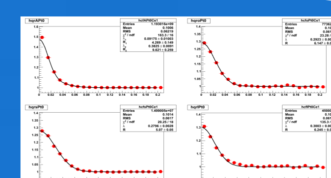




Connection via Epos Tree



Femtoscopy analysis
1d, 3d, ππ,KK,pp,
πp,pΛ,...



Radii, k_T (m_T) dependence, centrality dependence, etc

Epos Femto Package features

- Epos Femto package is a part of Epos2 code
- Femto could be used as a stand alone code (input Epos Root Tree events)
- Femto is a C++ code based on root framework
- The correlation function is calculated with event mixing technique: $C= (dN_{real}/dQ)/(dN_{mixed}/dQ)$
- The correlation weight provided by R.Lednicky code
- All pairs of particles which is in Lednicky's cod could be studied in Epos Femto package
- It is possible to smear the momentum of the particle according to the detector response

EPOS tree structure

```
//Head tree
fEposHeadTree=(TTree*)fTreeFile->Get("teposhead");
//Set head tree branches
fEposHeadTree->SetBranchAddress("iversn", &fiversn);   //version of epos code
fEposHeadTree->SetBranchAddress("laproj", &flaproj);    //projectile Z
fEposHeadTree->SetBranchAddress("maproj", &fmaproj); //projectile A
fEposHeadTree->SetBranchAddress("latarg", &flatarg);     //target Z
fEposHeadTree->SetBranchAddress("matarg", &fmatarg); //target A
fEposHeadTree->SetBranchAddress("engy",   &fengy  );    //energy per nucleon-nucleon in cms
fEposHeadTree->SetBranchAddress("nfreeze",&fnfreeze); //Blocksize for given init. conditions+hydro evolutions
fEposHeadTree->SetBranchAddress("nfull",  &fnfull );      //number of nfreeze blocks

    //Event tree
    fEposTree=(TTree*)fTreeFile->Get("teposevent");
    //Set tree branches
    fEposTree->SetBranchAddress("np",  &npostree_np); //number of particles in event
    fEposTree->SetBranchAddress("bim", &epostree_bim);//impact parameter (multiplicity in case of pp
    fEposTree->SetBranchAddress("px",  epostree_px); //momentum X
    fEposTree->SetBranchAddress("py",  epostree_py); //momentum Y
    fEposTree->SetBranchAddress("pz",  epostree_pz); //momentum Z
    fEposTree->SetBranchAddress("e",   epostree_e);   //energy
    fEposTree->SetBranchAddress("x",   epostree_x);  //coordinate X
    fEposTree->SetBranchAddress("y",   epostree_y);  //coordinate Y
    fEposTree->SetBranchAddress("z",   epostree_z);  //coordinate Z
    fEposTree->SetBranchAddress("t",   epostree_t);    //time
    fEposTree->SetBranchAddress("id",  epostree_id); //particle ID
    fEposTree->SetBranchAddress("mnu", epostree_mnu); //reference to the mother (=-1 if does not exist)
```

Run Femto Package

- Many Epos runs are processed in batch (or in grid) to gain statistics
- Each run has “nfull” events, each one containing “nfeeze” sub-events with the same initial conditions (for mixing technique)
- The Epos Tree writes for each run
- The set of correlation function histograms (real, mixed, 1d, 3d, etc) is created by Femto for each run
- The results of different run is collected and the fit procedure applies to whole statistics
- The fit parameters are printed out, plotted and written to file

Histograms

- Source function histograms:
  ΔR_{out}, ΔR_{side}, ΔR_{long} in LCMS

- 1D correlation function histograms:
  dN_{real}/dQ, projections: dN_{real}/dQ_{out}, dN_{real}/dQ_{side}, dN_{real}/dQ_{long}
  dN_{mix}/dQ, projections: dN_{mix}/dQ_{out}, dN_{mix}/dQ_{side}, dN_{mix}/dQ_{long}
  $CF(Q)$, projections: $CF(Q_{out})$, $CF(Q_{side})$, $CF(Q_{long})$

- 3D correlation function histograms:
  $d^3N_{real}/dQ_{out}dQ_{side}dQ_{long}$
  $d^3N_{mix}/dQ_{out}dQ_{side}dQ_{long}$
  $CF(Q_{out},Q_{side},Q_{long})$

- A few technical histograms in addition

Collect statistics

Example of script to run femto with a lot of tree files

emacs@localhost.localdomain <2>

File Edit Options Buffers Tools Insert Help

```bash
#!/bin/bash
# epos femto script for a lot of trees (.root) files from data_path
# to create one histogram (HistSumFile.fto) file for a given centrality

echo ========================================================
echo =============== Start script tree2fto =================
echo ========================================================

echo You type: $0 $1 $2
data_path=$1
if [ not $data_path ] ; then
    echo Please add path
    echo ./tree2fto.sh path_to_root_files_directory
    exit 1
fi
tmp_file1=outhist.fto
j=0
#stop=2 # if we need do a few files
stop=0
if [ $stop -eq 0 ] ; then
stop=ls $data_path/*.root |wc -w
fi
echo Number of files: $stop
for i in $( ls $data_path/*.root );
do
    j=`expr $j + 1`
    if [ $j -le $stop ] ; then
    echo -------- Run file: $i number $j of $stop ---------

    echo ln -sf $i batch.root
         ln -sf $i batch.root

    echo ./run
         ./run
```

--:-- **tree2fto.sh** Top L2 (Shell-script[bash])----Mon Jun 14 19:38 0.23------

```bash
    if [ $j -eq 0 ] ; then
        echo *** j=$j
        echo hadd -f res3.fto $tmp_file1
             hadd -f res3.fto $tmp_file1
        echo mv res3.fto tmpres.fto
             mv res3.fto tmpres.fto
    fi
    if [ $j -gt 0 ] ; then
        echo ++++ j=$j
        echo hadd -f res3.fto tmpres.fto $tmp_file1
             hadd -f res3.fto tmpres.fto $tmp_file1
        echo mv res3.fto tmpres.fto
             mv res3.fto tmpres.fto
    fi

    fi
done

echo -----------------------
echo --- remove tmp files ---
echo -----------------------
echo rm -f outhist.fto
echo mv tmpres.fto HistSumFile.fto
rm -f outhist.fto
mv tmpres.fto HistSumFile.fto
rm -f batch.root
echo
echo
echo '    Histograms are in file HistSumFile.fto'
echo
echo
echo ========================================================
echo ================ script tree2fto done =================
echo ========================================================
exit 2
```

--:-- **tree2fto.sh** Bot L64 (Shell-script[bash])----Mon Jun 14 19:38 0.23----

Wrote /home/kmikhail/Nant2010/fto_feb8.short/tree2fto.sh

Fit functions

- 1D fit function:

$1+\lambda \exp(-R_{inv}^2 Q_{inv}^2)$

$1+\lambda_1 \exp(-R_1^2 Q_{inv}^2)+\lambda_2 \exp(-R_2^2 Q_{inv}^2)$

$(1+\lambda \exp(-R_{inv}^2 Q_{inv}^2))*(1+\delta Q_{inv}^2)$

- 3D fit function:

$1+\lambda \exp(-R_{out}^2 Q_{out}^2 - R_{side}^2 Q_{side}^2 - R_{long}^2 Q_{long}^2)$

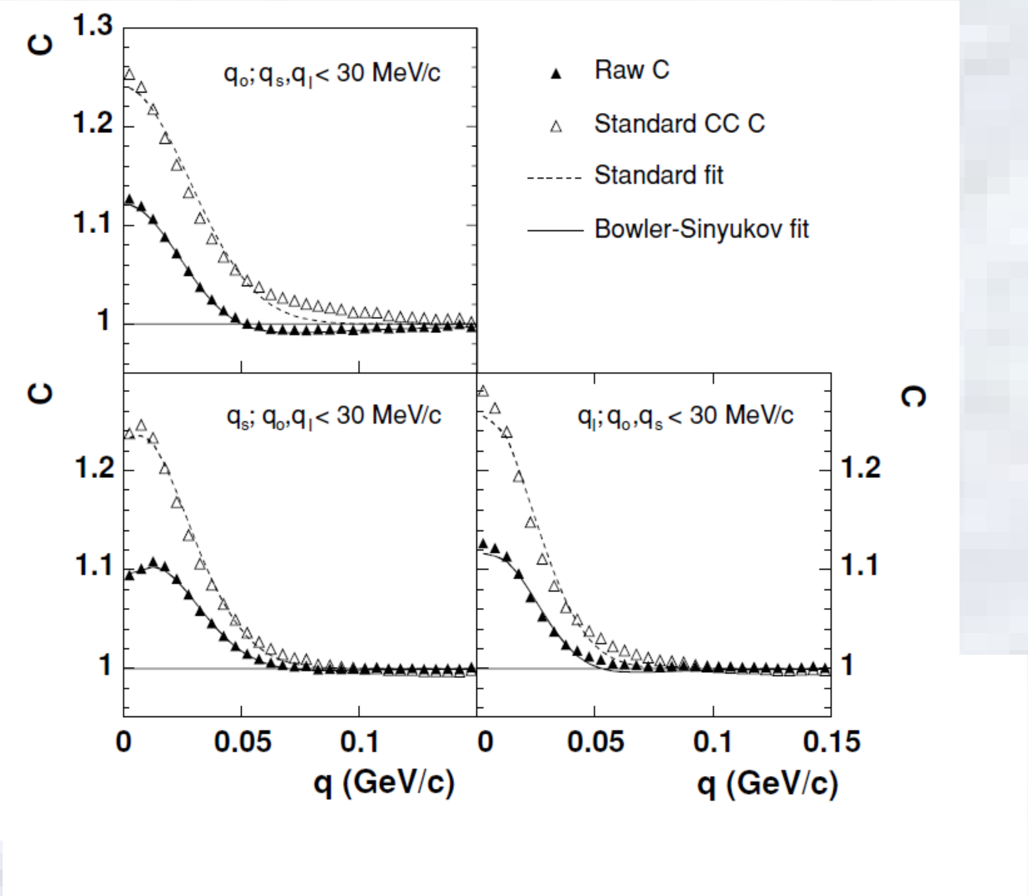
Go to the First results ...

STAR experimental results

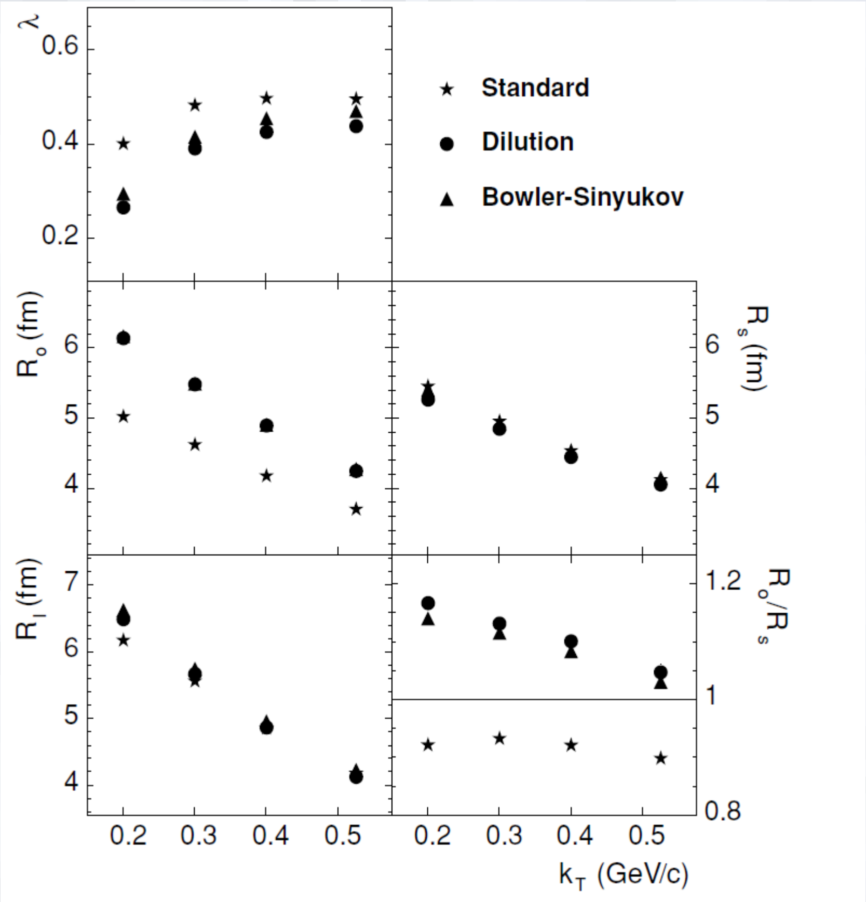
RHIC-STAR: ππ femtoscopy for Au+Au sqrt(S_{NN})=200GeV

[PHYSICAL REVIEW C 71, 044906 (2005)]

Projection of 3-d correlation function



3-d fit results (3 variants of Coulomb)



Simulation: software and input

- Compare with STAR HBT ππ in AuAu collisions at √s 200 GeV
- EPOS 2.0, model details in http://arxiv.org/abs/1004.0805
- Analysis of Epos events

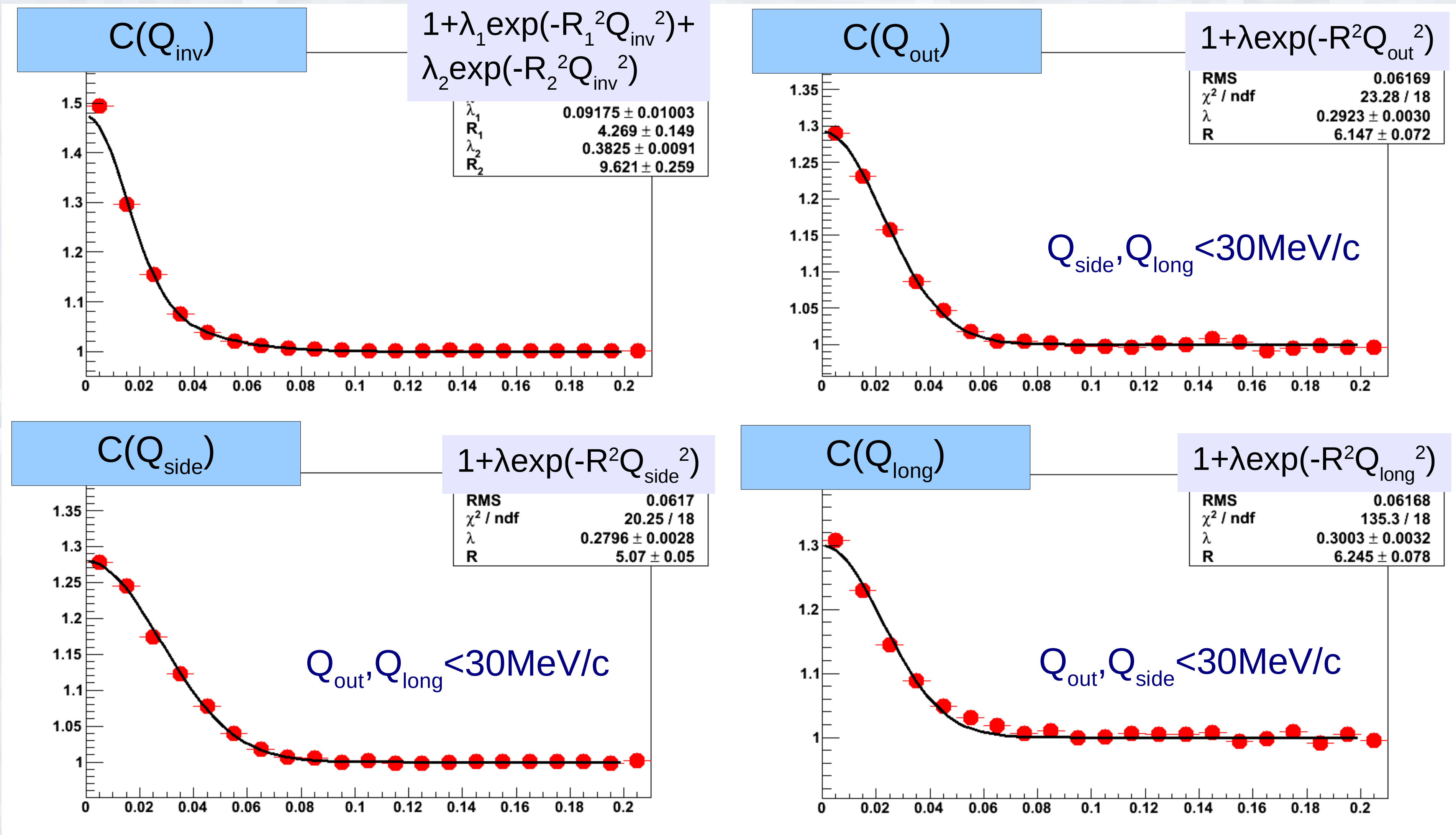
  ~0.5 M events of AuAu collisions at 200 GeV ,
  5 centrality regions: 0–5%,5–10%, 10–20%, 20–30%, 30–50%, and 50–80%

- k_T regions: 150-250,250-350,350-450,450-600 MeV/c
- STAR accepnace: $0.15<P_T<0.8$ GeV/c, $|\eta|<0.5$
- Only Q.S. weight for π+π+ pairs
- Fit function (3d):

$$1+\lambda \exp(-R_{out}^2 Q_{out}^2 - R_{side}^2 Q_{side}^2 - R_{long}^2 Q_{long}^2)$$

Femto package: 1d CF

Example of 1d pi+pi+ correlation function for central events



Different Epos model scenarios

We will compare three scenarios:

1.) The full calculation (hydro&cascade)

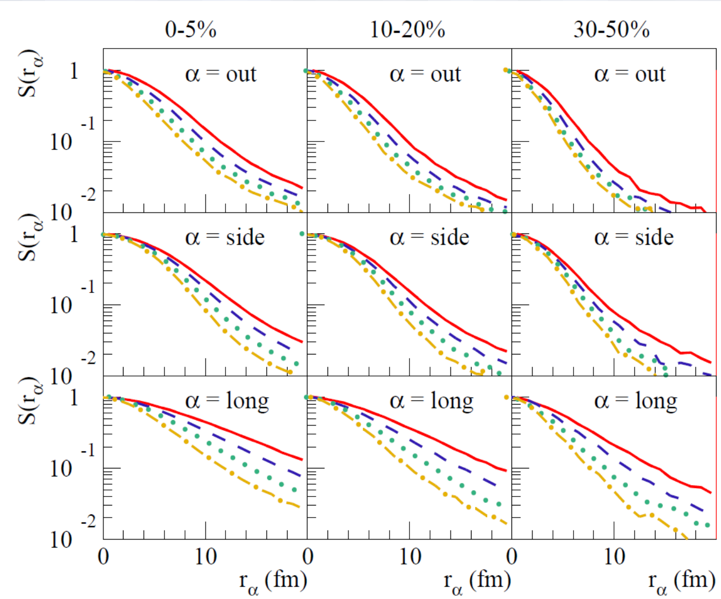
2.) The calculation without hadronic cascade
(final freeze out at 166 MeV)

3.) The fully thermal scenario, where we continue the
hydrodynamical evolution till a late freeze-out
at 130 MeV (and no cascade afterwards either)

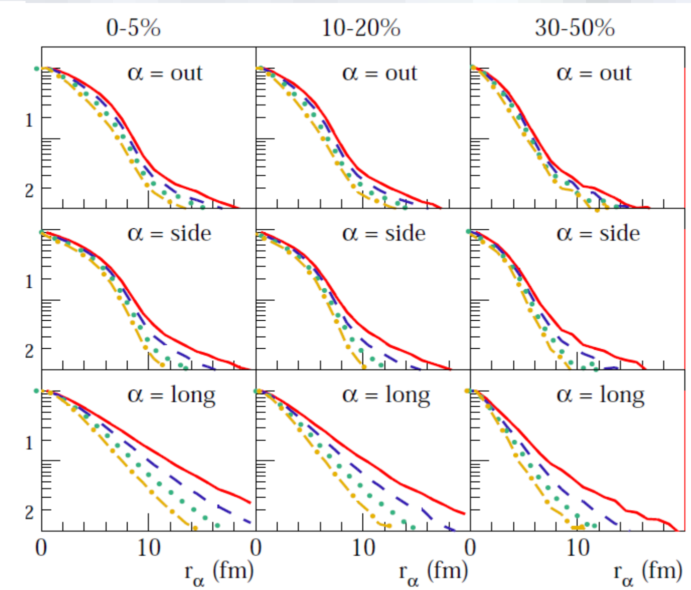
Source functions

The source functions as obtained from our simulations, for three different centralities (0-5%, 10-20%, and 30-50%), representing the distribution of the space separation of the emission points of the pairs, in LCMS. Full curves – first k_T bin, dashed – second k_T bin, and so on. The curves get narrower with increasing k_T (decreasing radii). The curves get narrower with decreasing centrality (decrease of radii with decreasing centrality).

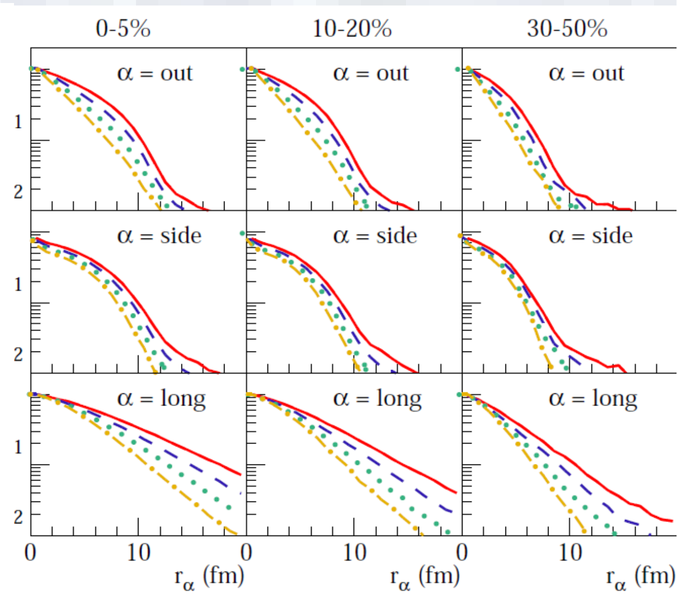
1.Full calculation



2.Without hadronic cascade



3.Hydro evolution is continued till freeze-out at 130 MeV

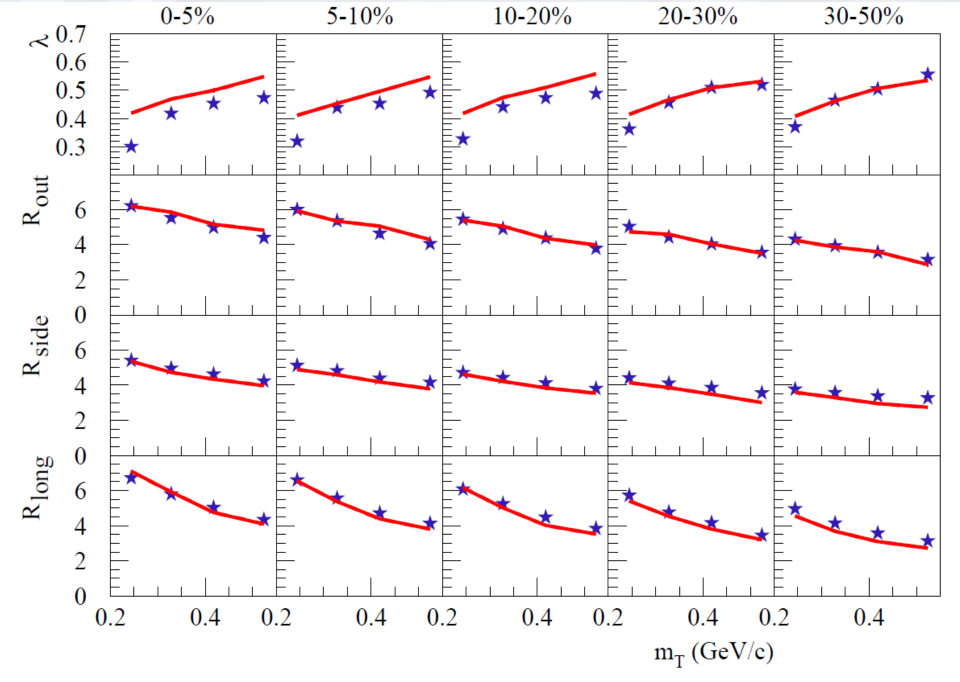


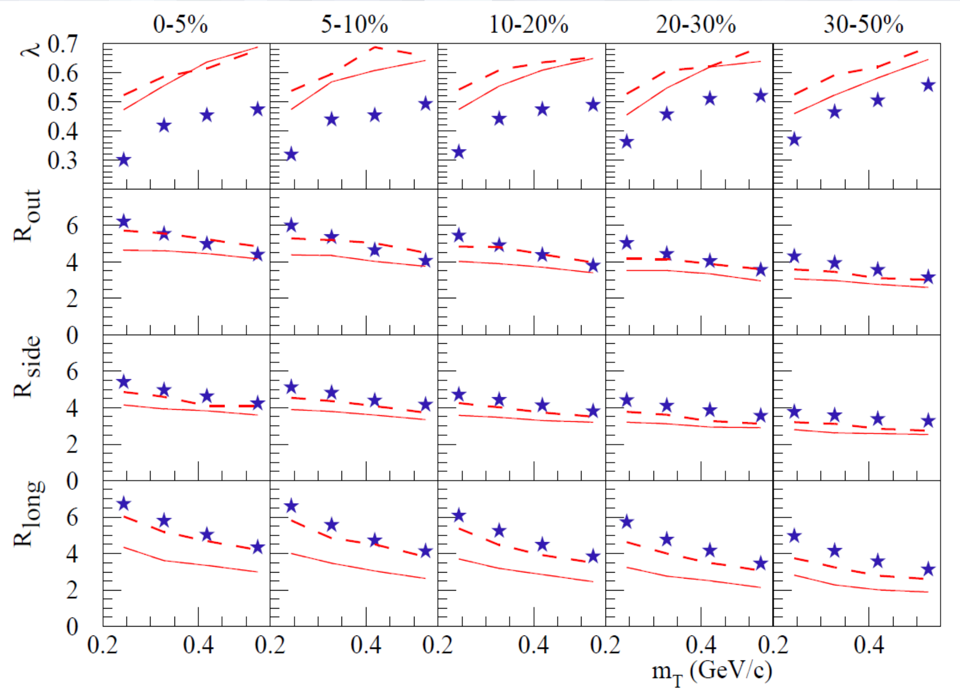
The fitting procedure based on the hypothesis that the source function Gaussians and it does not sensitive to the non-Gaussian tails.

One can expect similar results for scenario 1 and 3.

Femtoscopic radii (differnt scenarios)

R_{out}, R_{side}, and R_{long} as a function of m_T for different centralities (0-5% most central, 5-10% most central, and so on). The star sybols are the data of STAR.
Left: Thick full line - full calculation, hydro&cascade (scenario 1).
Right: Thin full line - the calculations are done without hadronic cascade (scenario 2).
Dashed lines - with a hydrodynamic evolution through the hadronic phase with freeze-out at 130 MeV (scenario 3).



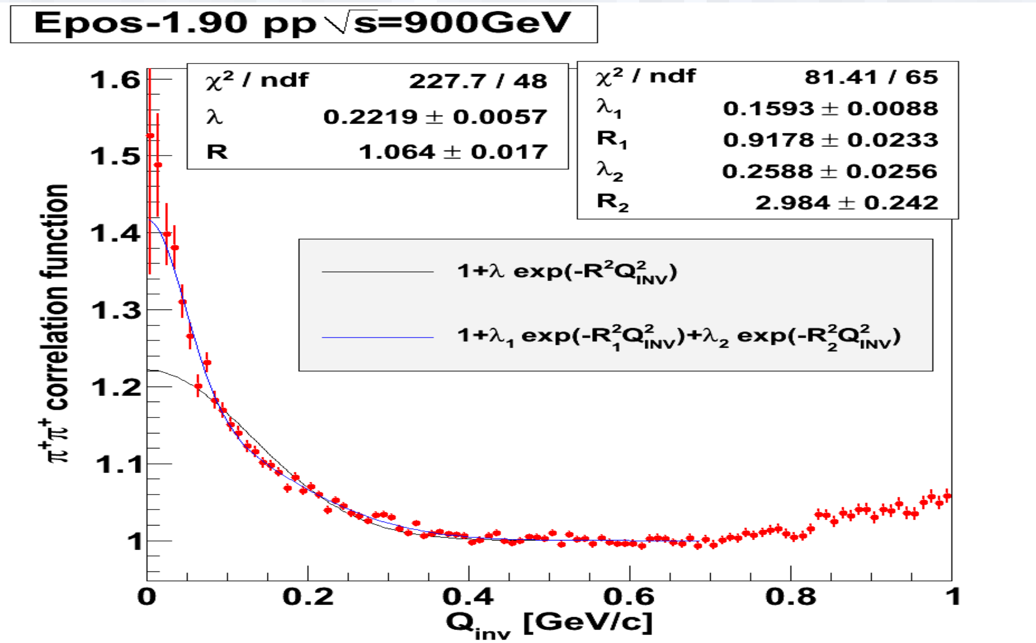


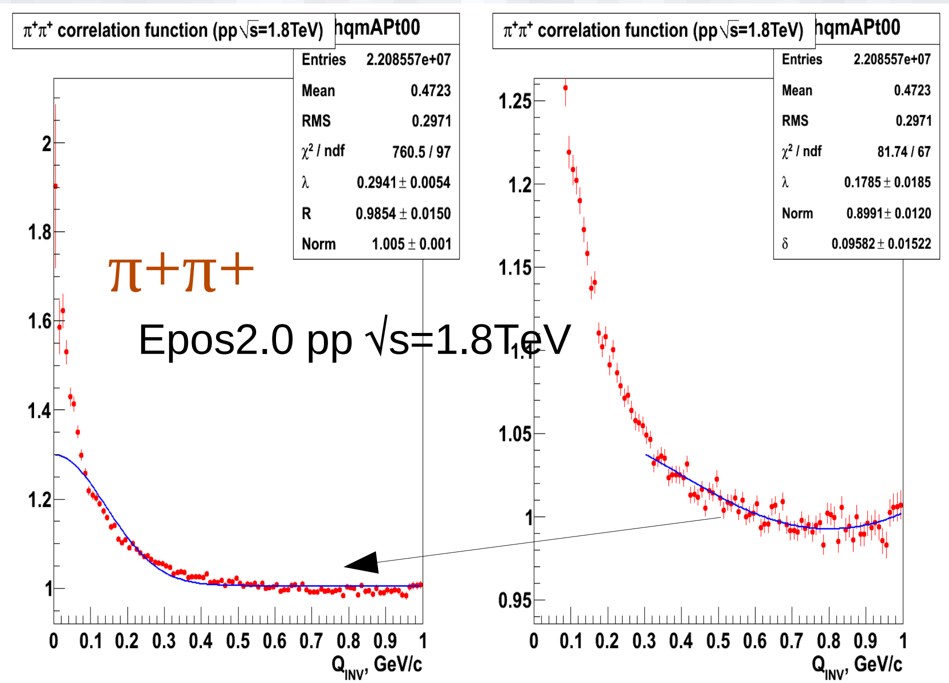
It could be better to compare the shape of CF, not only radii

Non-femtoscopic effects...

Long range correlation

These correlations (so-called “long-range correlations "— LRC) arise mainly from momentum conservation for real events, which is not a requirement for mixed pairs. LRC cause a smooth increase of CF with q, which reflects the fact that due to momentum conservation the probability of two particles emitted in the same direction is smaller than that of two particles emitted in opposite directions. Empirically, LRC can be parametrized as R ∝exp(b cos ψ), in which ψ is the angle between the two particles and b is a constant [A. V. Vlassov et al., Phys. At. Nucl. 58, 613 (1995)]. Practically, accounting for such a weak dependence of the correlation function on q is usually taken into account by introducing into data fit a factor $(1 + \text{const } Q^2)$





PYTHIA 7e5 pp events √s=14 TeV

$\pi^+\pi^+$ correlation function

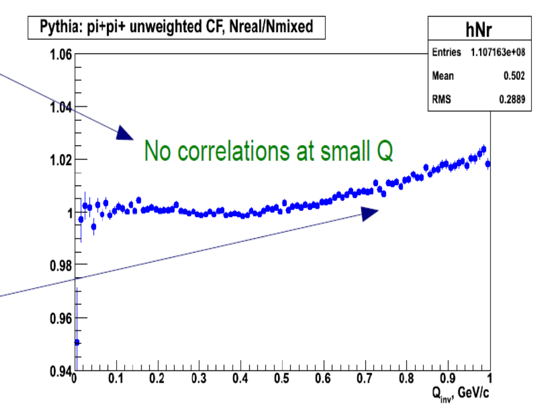
Cuts:

- $0.1 < P_T < 1.0$ GeV/c
- $-1. < \eta < +1.$

CF=Real/Mixed

Energy and Momentum Conservation-Induced Correlations:

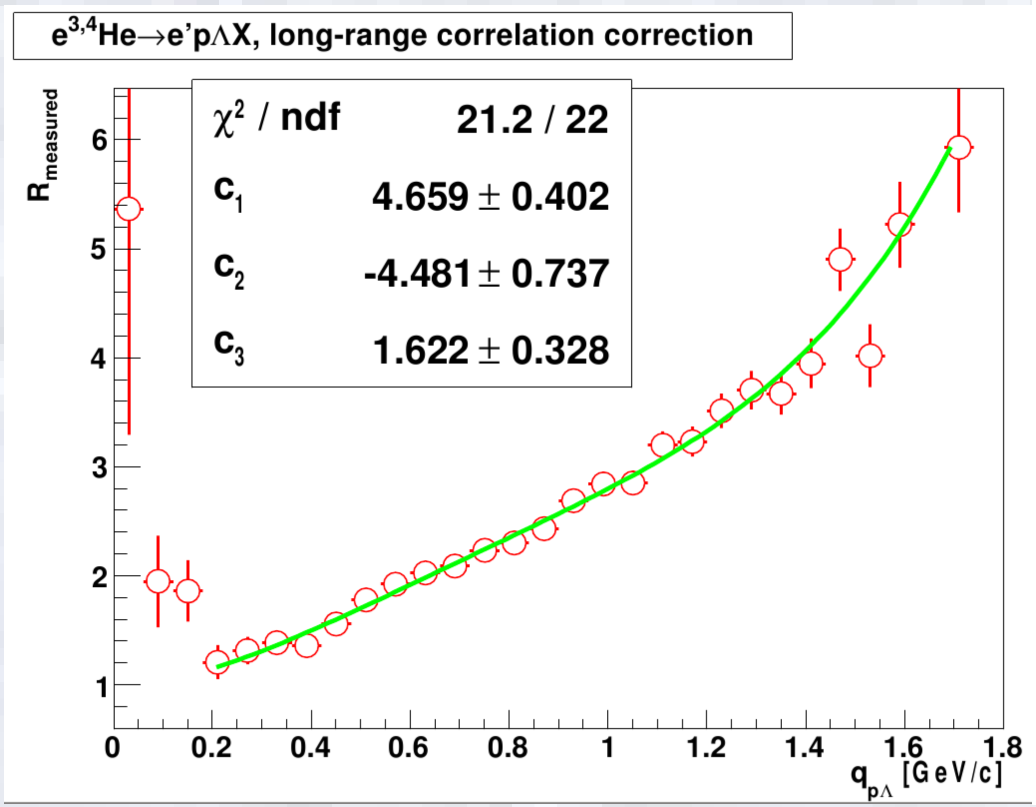
Due to energy-momentum conservation probability of two particle emitted at same direction is smaller than in opposite direction

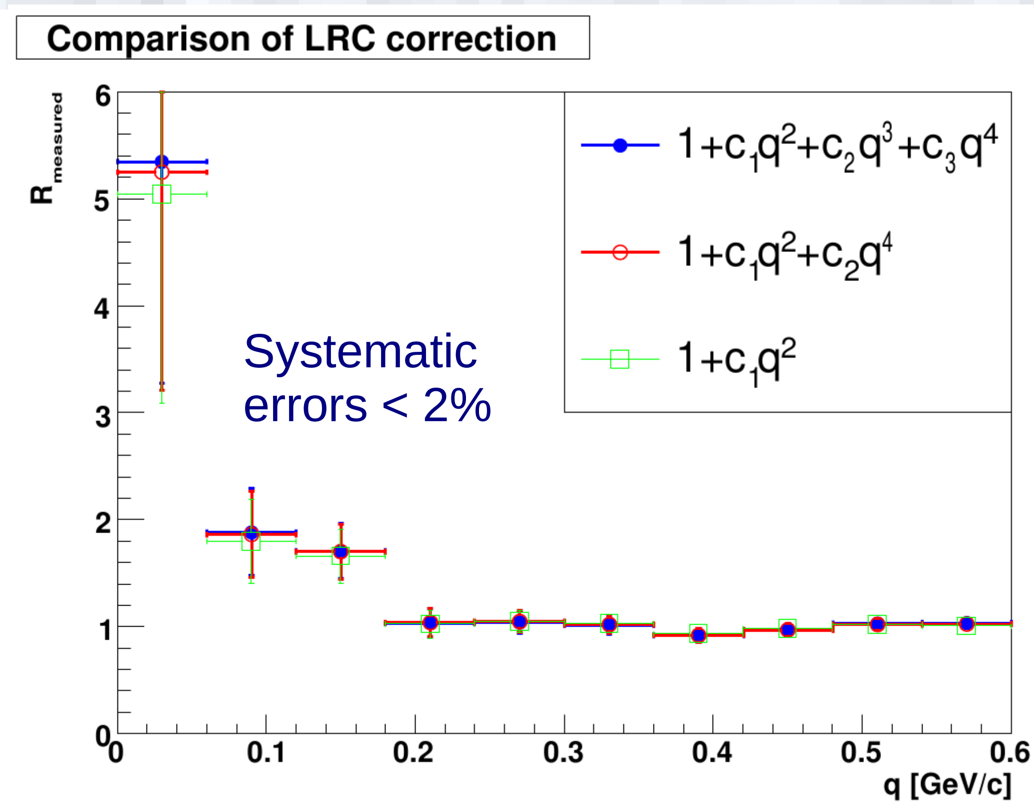


CEBAF data

Source-Size Measurements in the $e^3He(^4He) \rightarrow e'p\Lambda X$ Reaction

[Physics of Atomic Nuclei, 2009, Vol. 72, No. 4, pp. 668–674.]





Conclusion

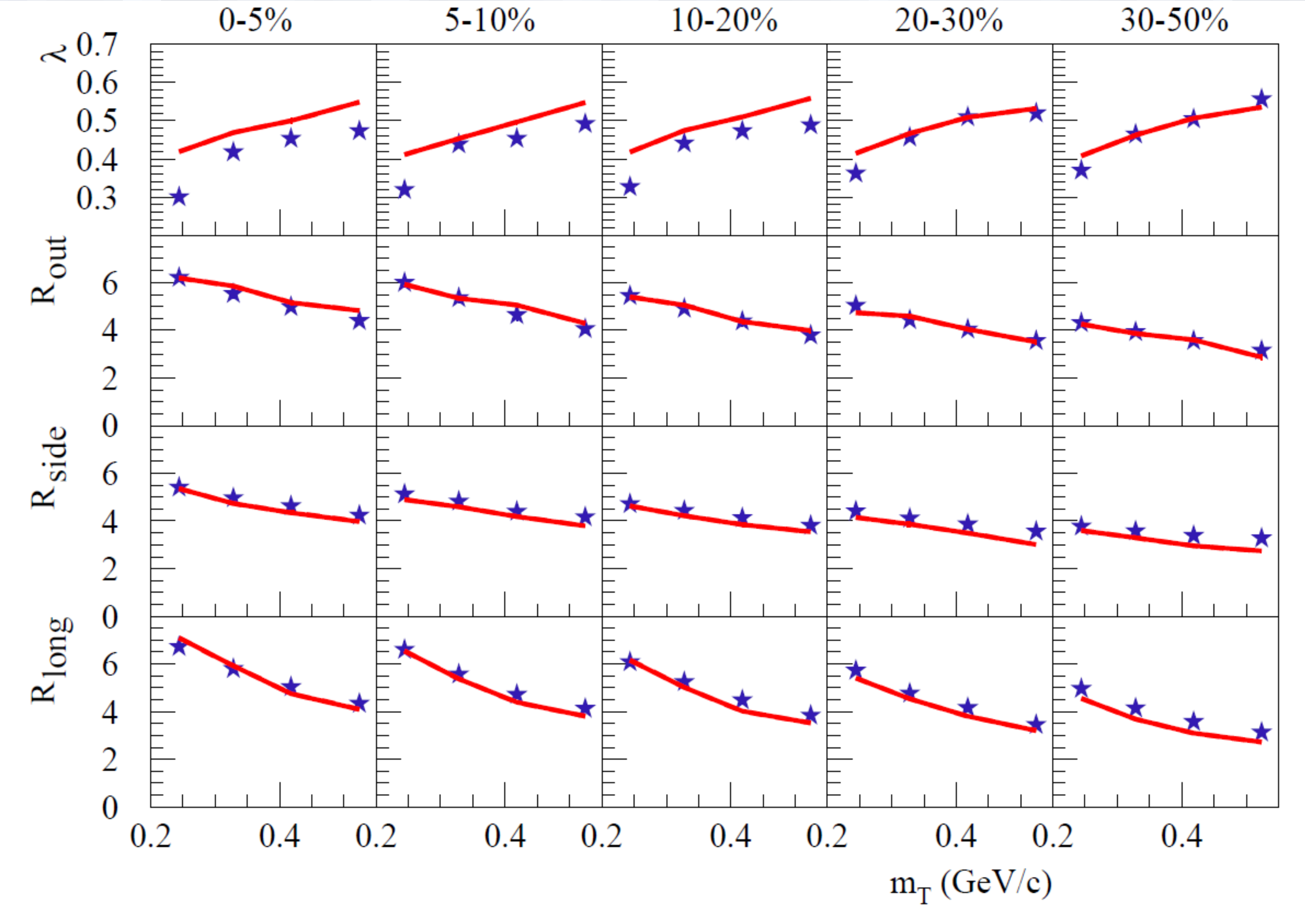
1. The Epos Femto package exists and works
2. STAR HBT pipi data was described with Epos2+Femto
3. New study (pp collisions at LHC energies) with Epos Femto are in progress
4. Long range correlation could be very important in case of low multiplicity, e.g. pp collisions

Thank you for your attention!

Extra Slides

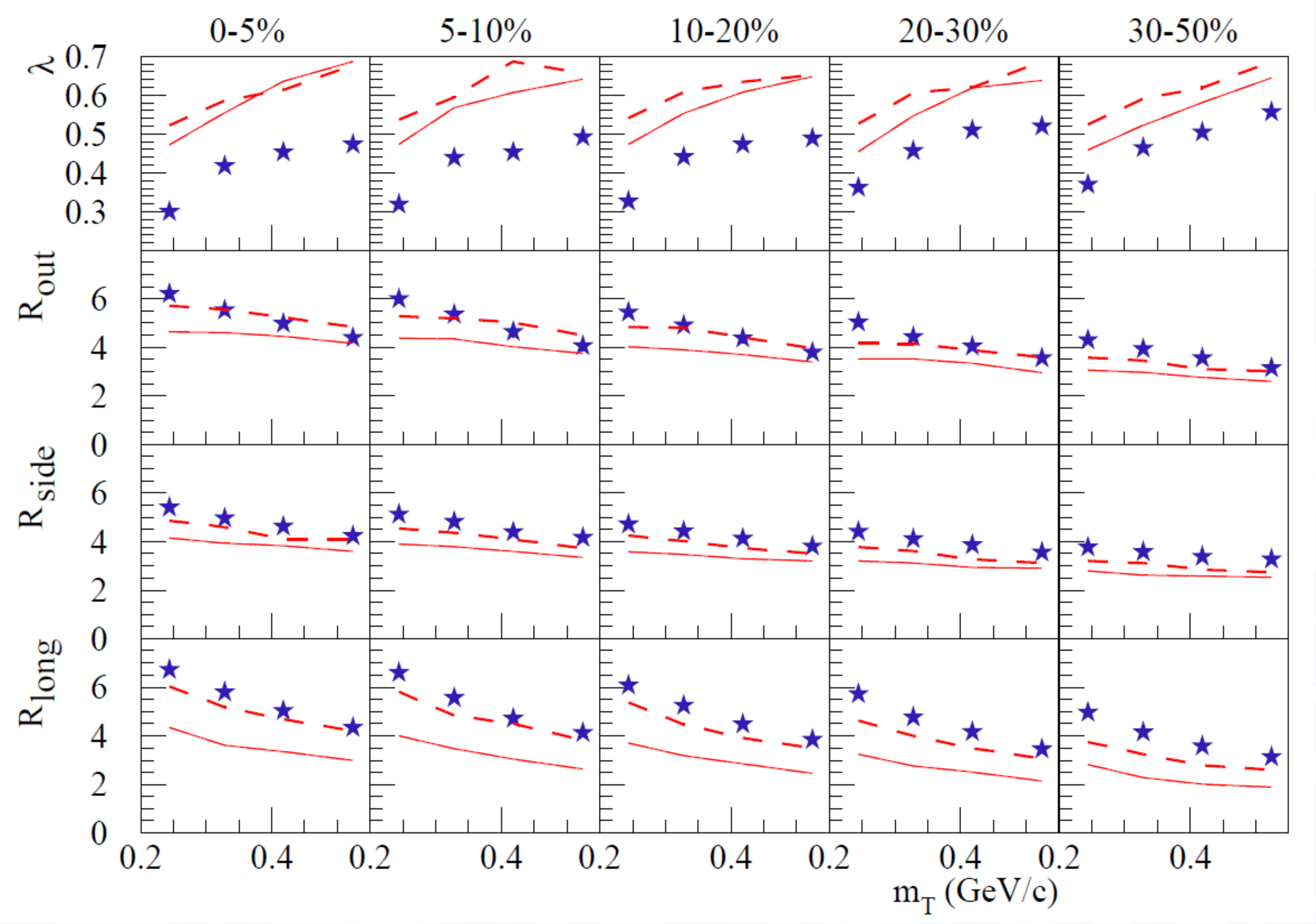
Femtoscopic radii (full calculation)

Rout, Rside, and Rlong as a function of m_T for different centralities (0-5% most central, 5-10% most central, and so on). The full lines are the full calculations (including hadronic cascade), the stars data of STAR

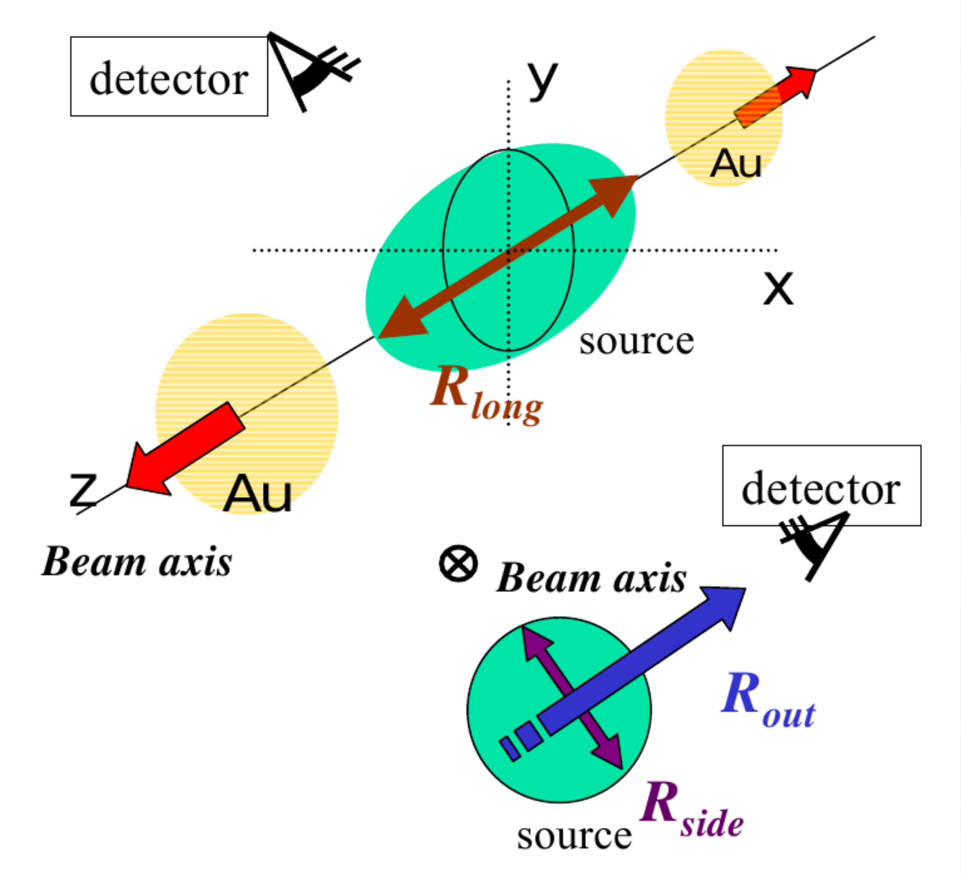


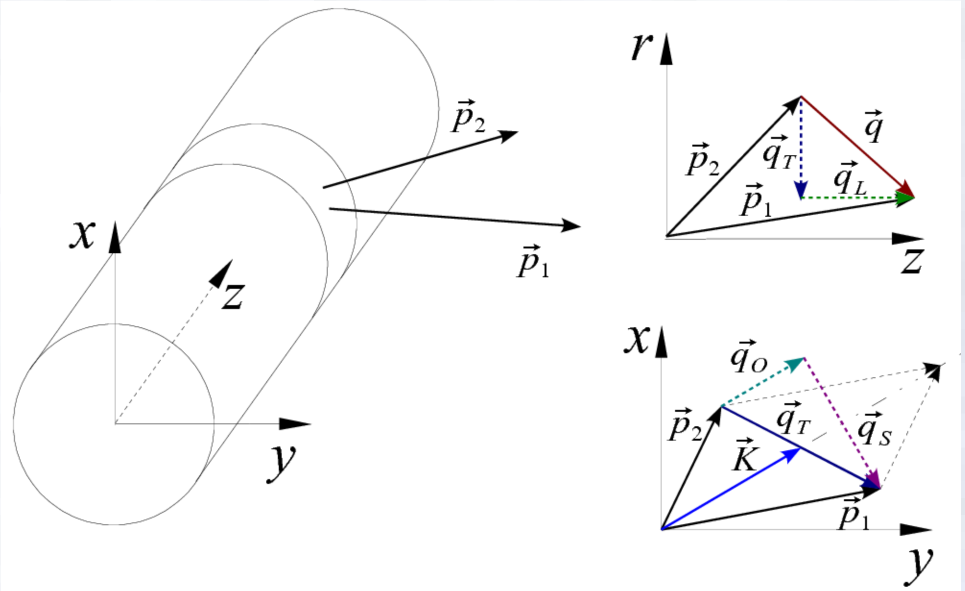
Femtoscopic radii (other scenarios)

Full line the calculations are done without hadronic cascade (scenario 2).
Dashed lines with a hydrodynamic evolution through the hadronic phase with freeze-out at 130 MeV (scenario 3).

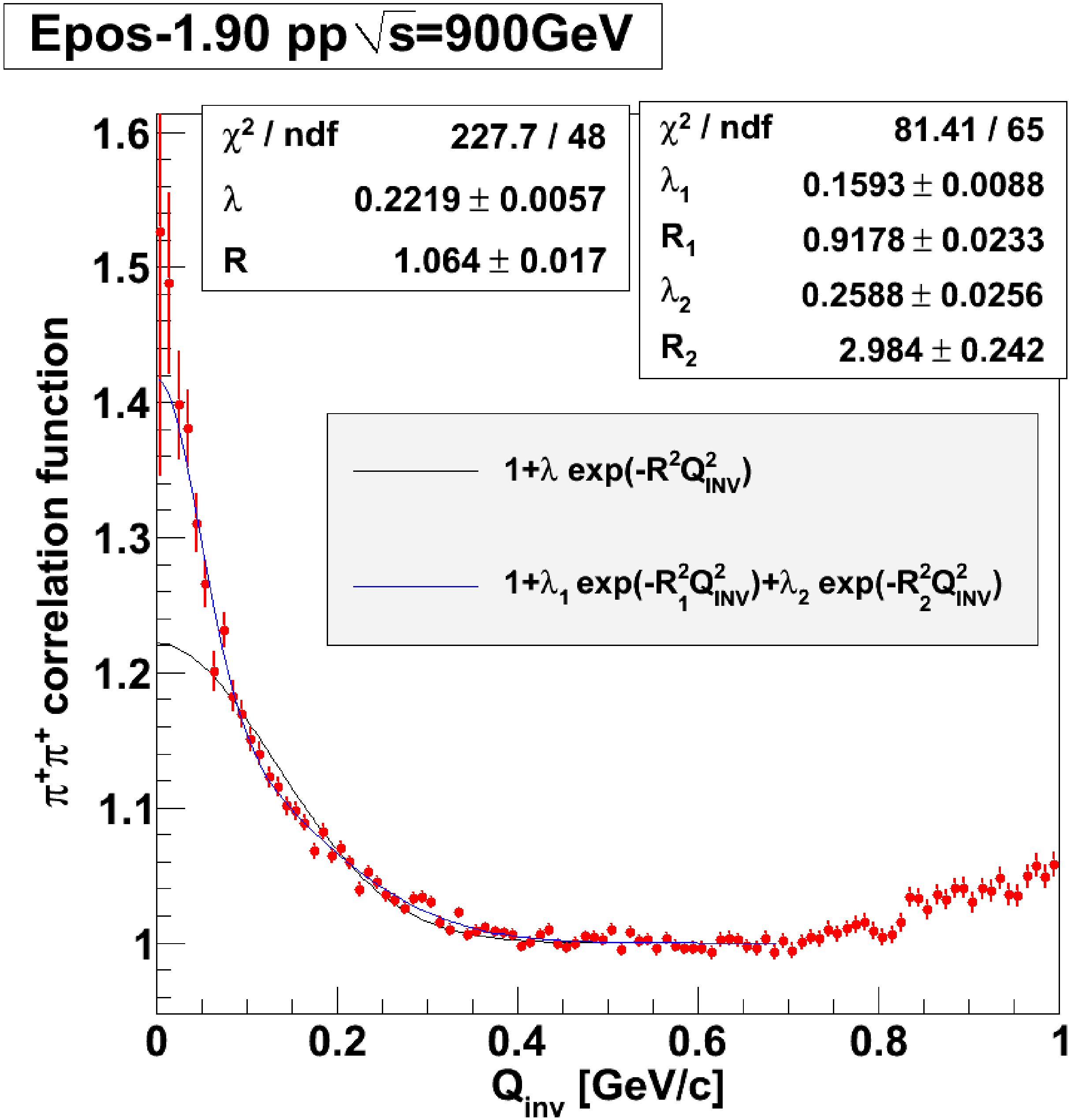


Longitudinally CoMoving Sysytem





CF $\pi^+\pi^+$ in pp@900GeV



$2*10^6$ events generated by EPOS 1.90

Cut on pions:

$0.05<p_T<2.0$GeV/c

$|y|<1$

$\pi^+\pi^+$ correlation function: QS weight (Coulomb switched off)

1D fit – superposition of two Gaussians:

$R=1+\lambda_1 exp(-R_1^2 Q_{inv}^2) + \lambda_2(-R_2^2 Q_{inv}^2)$

Source function, etc.

$$C(\mathbf{P},\mathbf{q}) = \int d^3r' \, S(\mathbf{P},\mathbf{r}') \, |\Psi(\mathbf{q}',\mathbf{r}')|^2$$

$$C(\mathbf{P},\mathbf{q}) = 1 + \lambda \exp\left(-R_{\mathrm{out}}^2 \, q_{\mathrm{out}}^2 - R_{\mathrm{side}}^2 \, q_{\mathrm{side}}^2 - R_{\mathrm{long}}^2 \, q_{\mathrm{long}}^2\right)$$

$$k_T = \frac{1}{2} \left(|\vec{p}_T(\mathrm{pion}\,1) + \vec{p}_T(\mathrm{pion}\,2)| \right)$$