WPCF, Kroměříž, August 2005

Non-Gaussian Effects in Identical Pion Correlation Function at STAR

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Outline

- Motivation
- STAR data
- Event and Track selection
- Identical π-π correlation function
- Bowler-Sinyukov fit to data
- Levy source distribution fit
- Edgeworth expansion
- Summary

Motivation

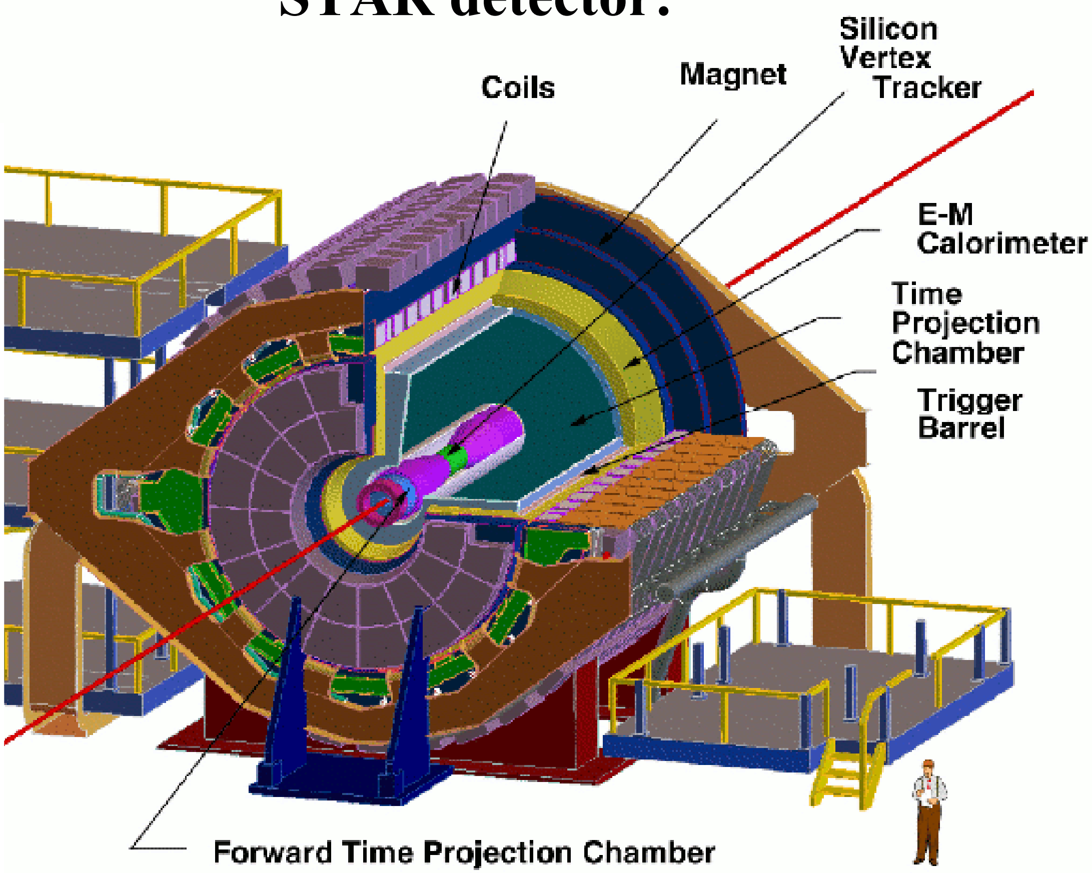
- Why do we care about non-Gaussian issue?
  - Source distribution function is in most models non-Gaussian and standard methods of fitting experimental CF assume Gaussian source.
  - Need to parametrize source properly in order to minimize systematic errors.

- Possible methods of studying the non-Gaussian effects of CF include:
  - Source imaging, see talk by P.Danielewicz, P.Chung, D.Brown
    - Spherical harmonics, see talk by Z.Chajęcki
  - Levy stable source distribution, see talk by T.Csörgő
  - Edgeworth expansion

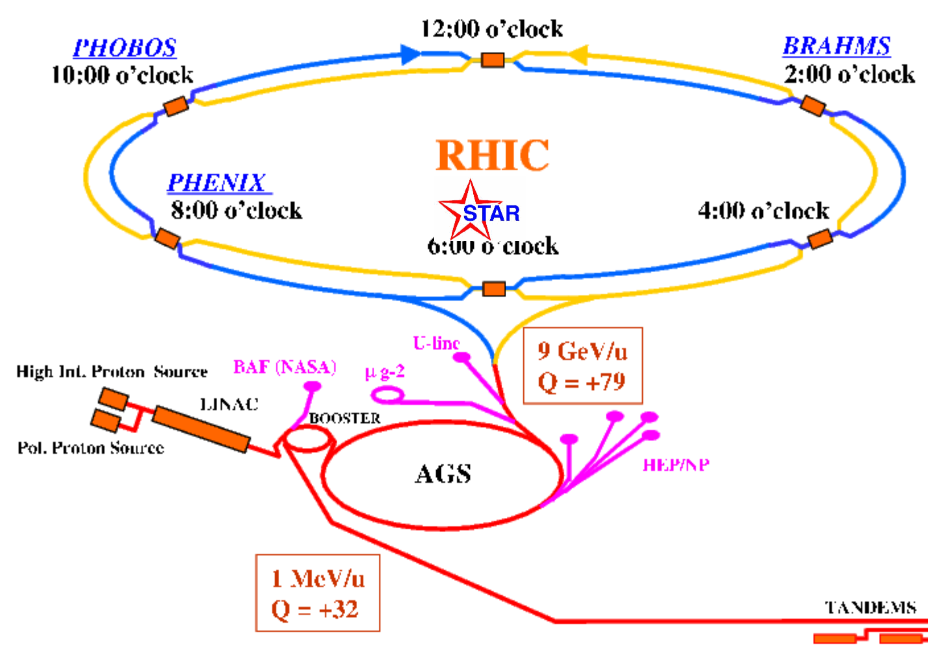
STAR data

- Au+Au collisions at energy $\sqrt{s_{NN}} = 200$ GeV
- Year 2004 data, Full Field (0.5 T)
- ~11 M MinBias events

STAR detector:

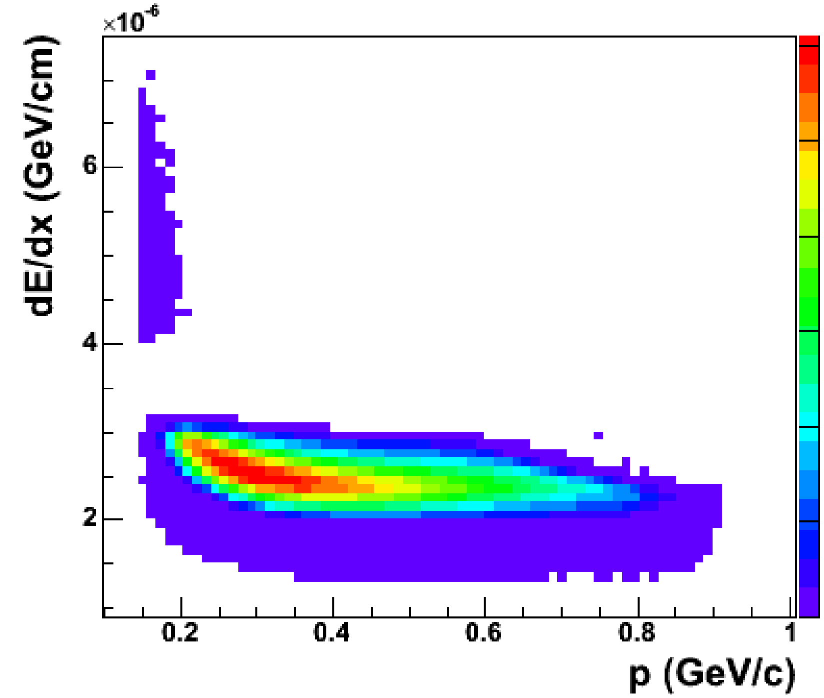


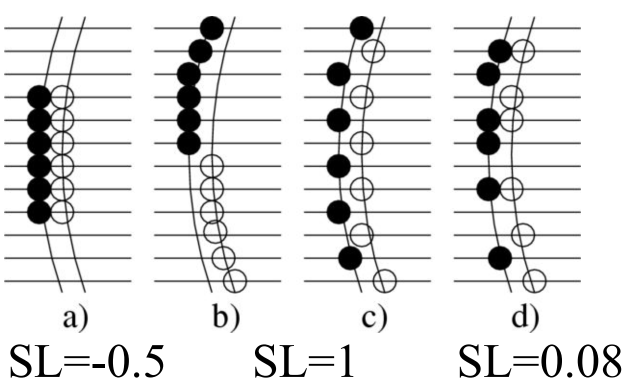
RHIC complex at BNL:



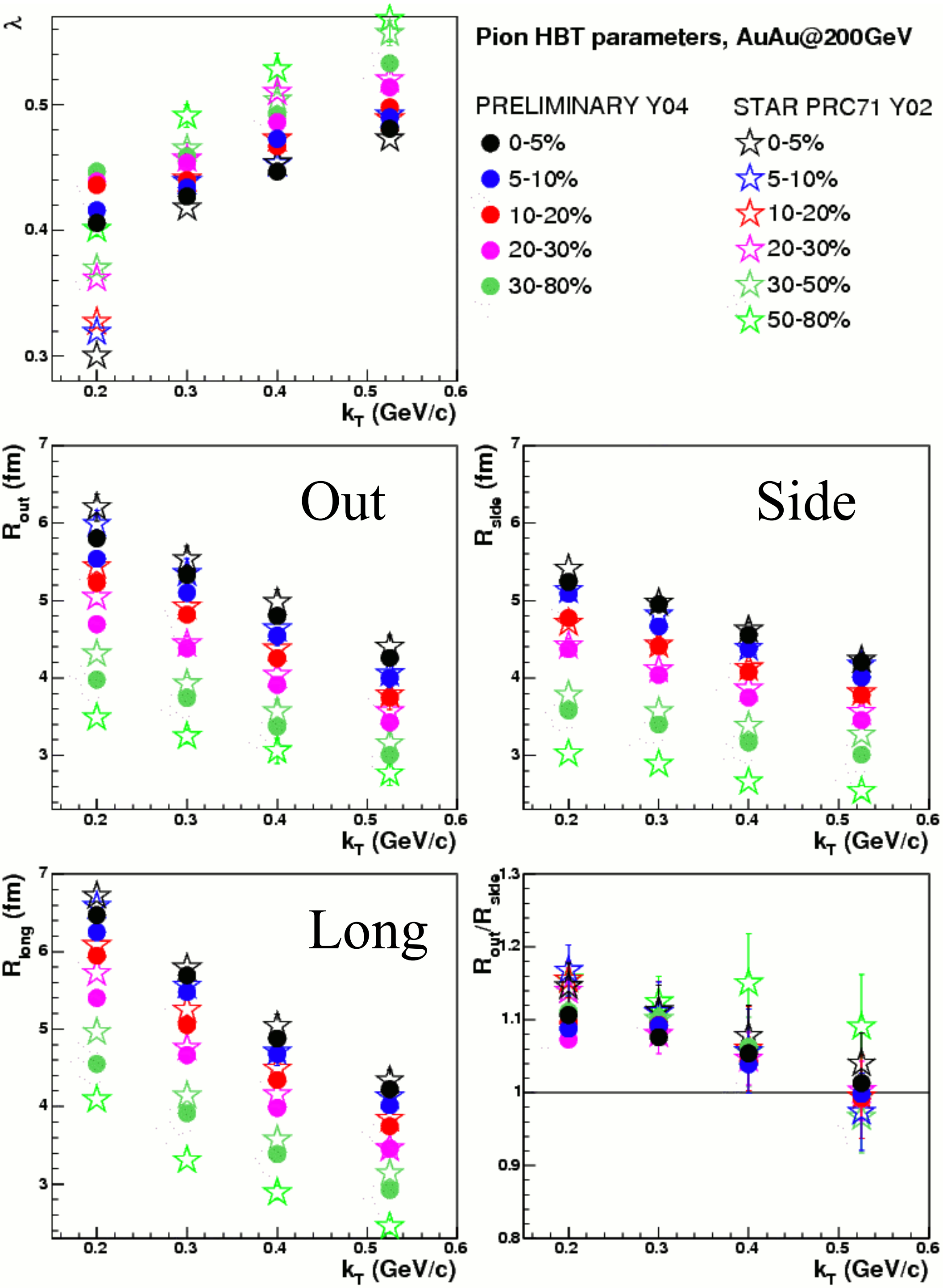
Event and Track selection

- Same cuts as in STAR, Phys. Rev. C 71 (2005) 044906
- Event cuts:
  - Centrality binning {0-5, 5-10, 10-20, 20-30, 30-80} %
  - zVertex ± 25 cm
- Track cuts:
  - pion dE/dx band ± 2 s
  - remove dE/dx electron band
  - p_T = {0.15,0.80} GeV/c
  - y = {-0.5,0.5}
- Pair cuts:
  - Id: π^+-π^+, π^--π^-
  - anti-splitting (-0.5 < SL < 0.6)
  - anti-merging (max. 5 % merged)
  - k_T = {0.15-0.25, 0.25-0.35, 0.35-0.45, 0.45-0.60} GeV/c





Comparison to published STAR data

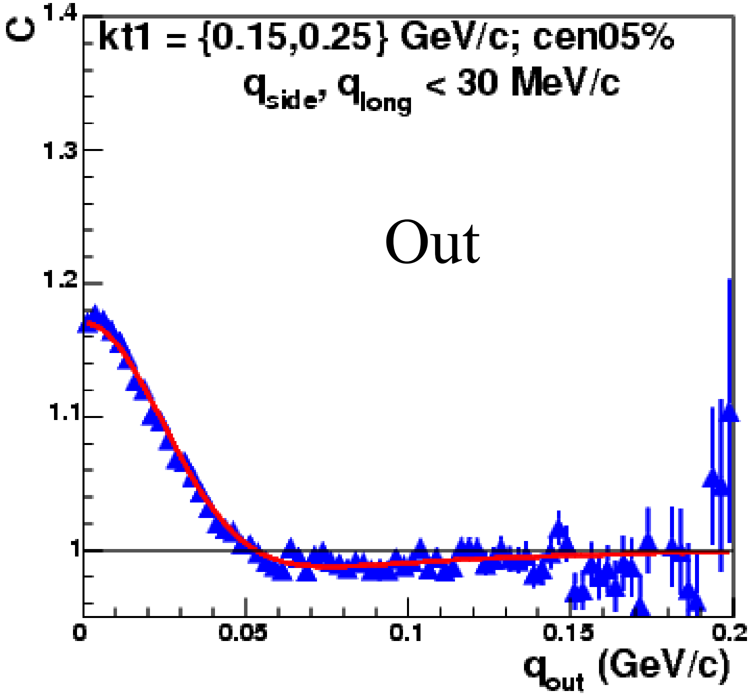


- Bowler-Sinyukov fit to data

$$C(q)=(1-\lambda)+\lambda\, K_c(1+\exp(-\sum R_{ij}^2 q_i q_j))$$

- 3D identical pion CF is fit using the Bertsch-Pratt parametrization in LCMS frame without crossterms in asimuthally integrated analyses
- No momentum resolution correction yet
- Radii are consistent within errors with published STAR PRC71 data
- Difference in lambda in the lowest kT bin explained by improved purity of pion sample

Identical π–π correlation function



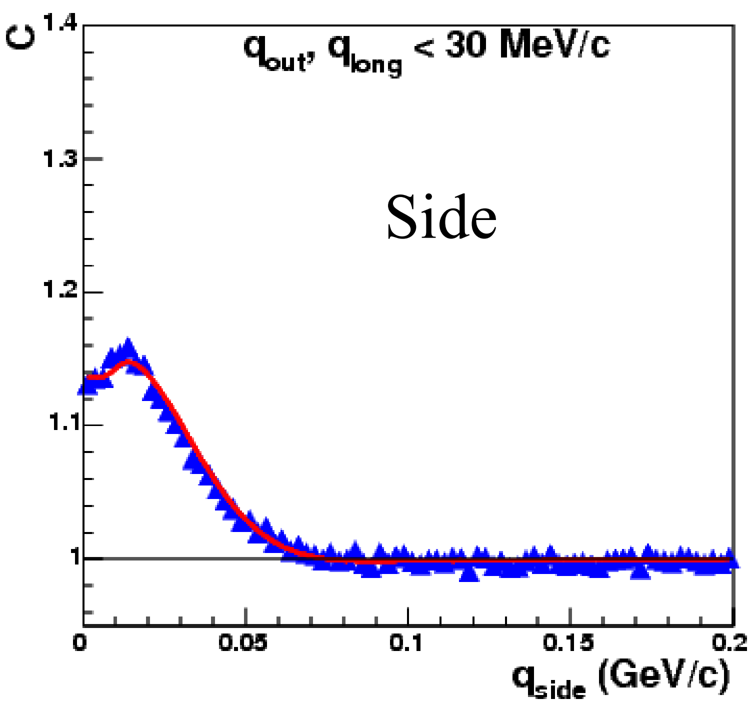
Identical ππ CF

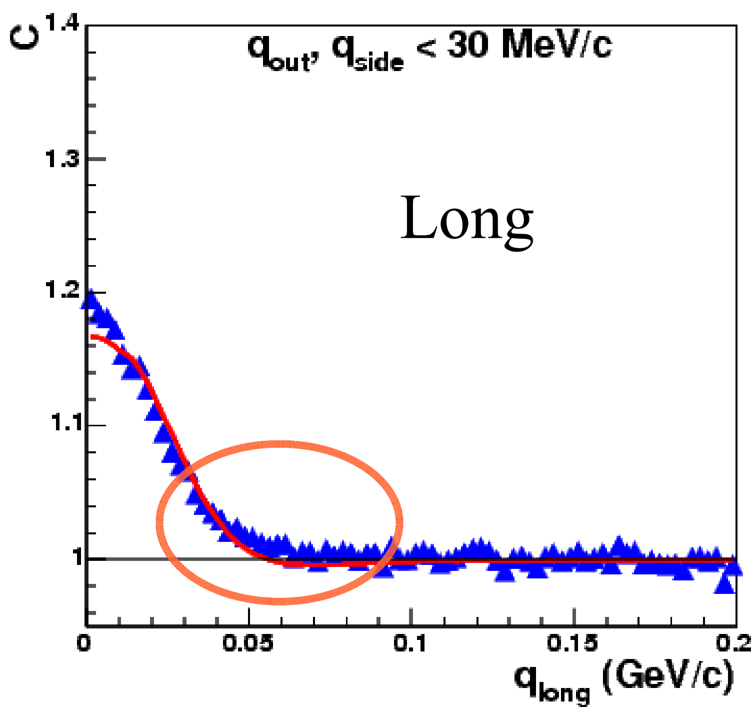
▲ Data - PRELIMINARY

— Bowler-Sinyukov fit

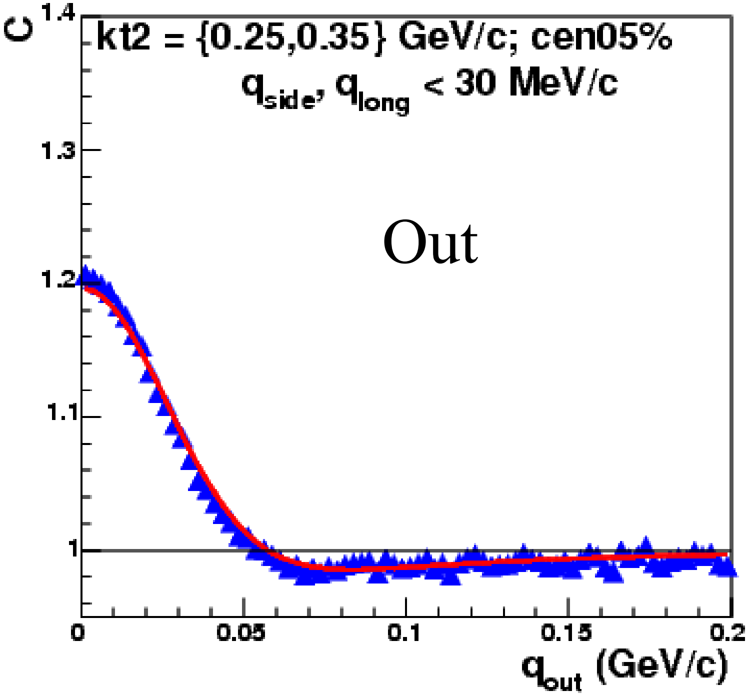
$\lambda = 0.406 \pm 0.002$
$R_{out} = 5.80 \pm 0.04$ fm
$R_{side} = 5.24 \pm 0.03$ fm
$R_{long} = 6.47 \pm 0.03$ fm
$\chi^2/NDF = 1.11750$

- λ increases with k_T
- All three radii $R_{o,s,l}$ decrease with k_T
- Non-Gaussian shape mostly visible in long direction





Identical π–π correlation function



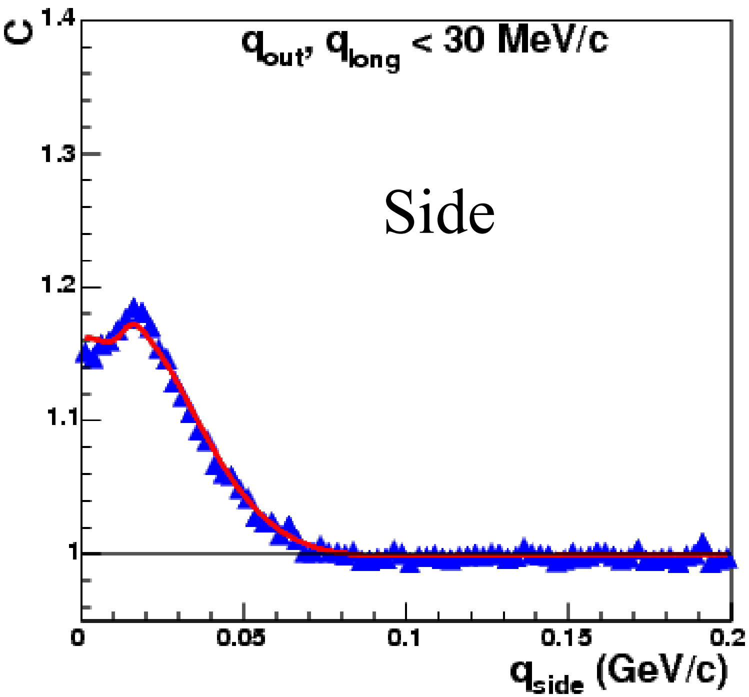
Identical ππ CF

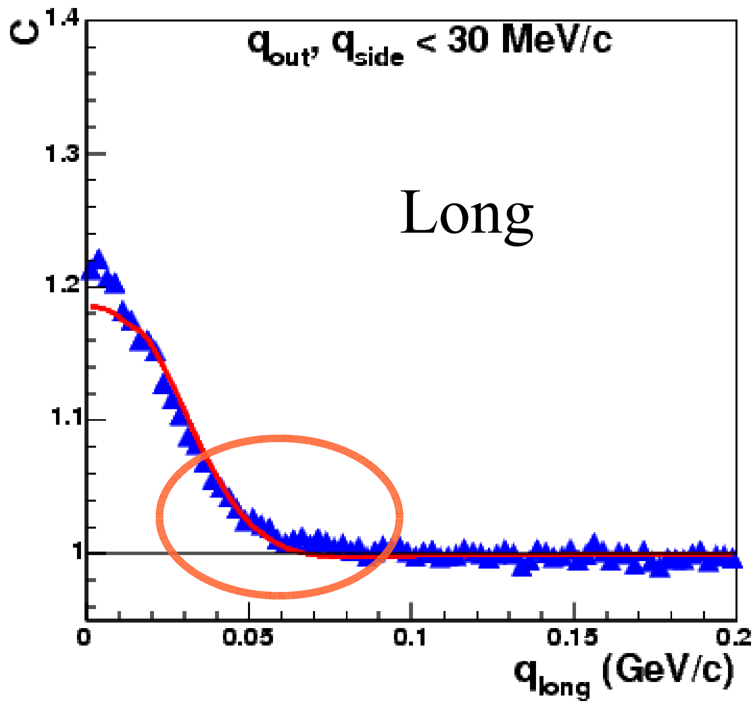
▲ Data - PRELIMINARY

Bowler-Sinyukov fit

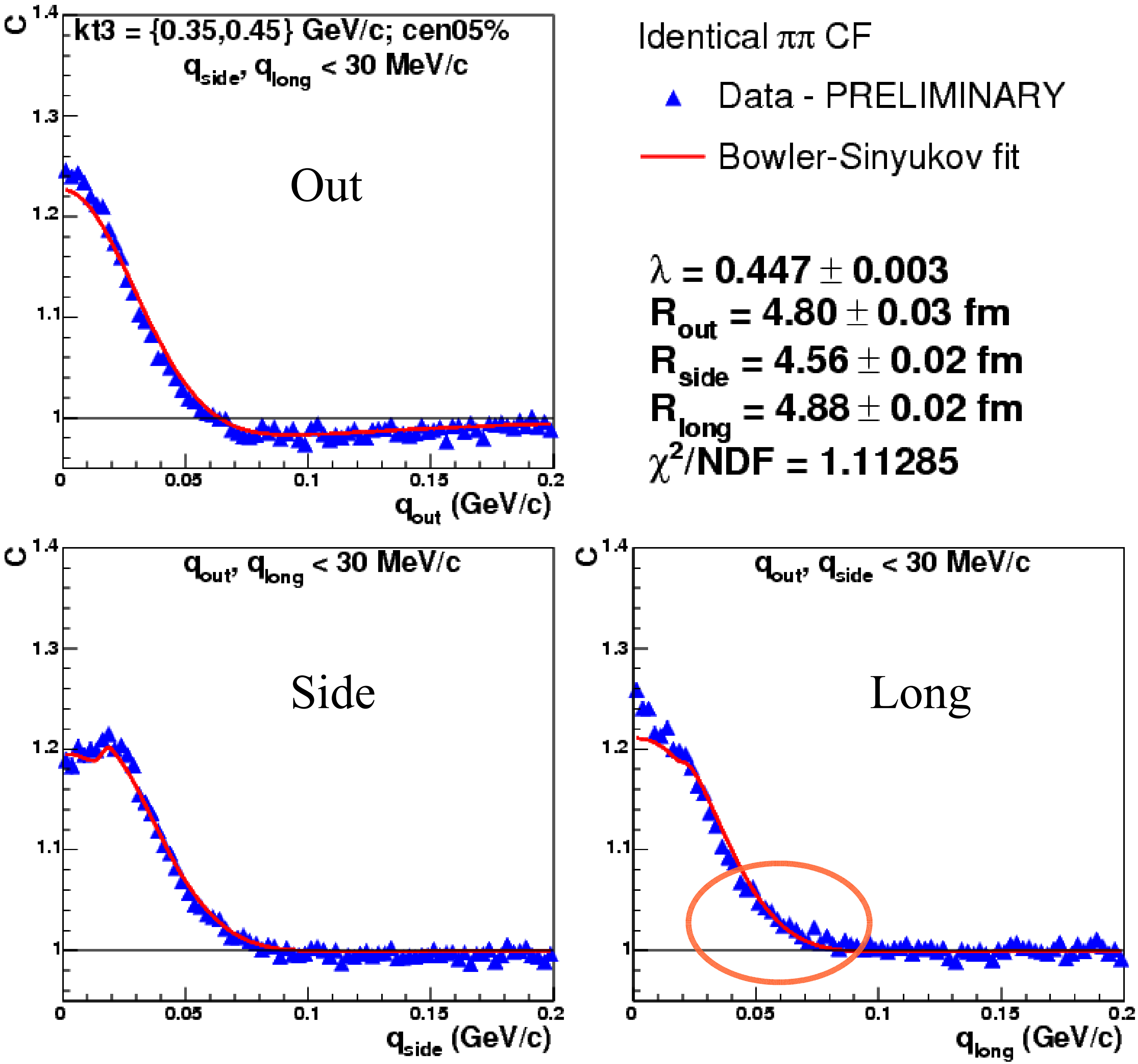
λ = 0.427 ± 0.002
R_{out} = 5.33 ± 0.02 fm
R_{side} = 4.95 ± 0.02 fm
R_{long} = 5.69 ± 0.03 fm
χ^2/NDF = 1.11024

- λ increases with k_T
- All three radii $R_{o,s,l}$ decrease with k_T
- Non-Gaussian shape mostly visible in long direction





Identical π–π correlation function



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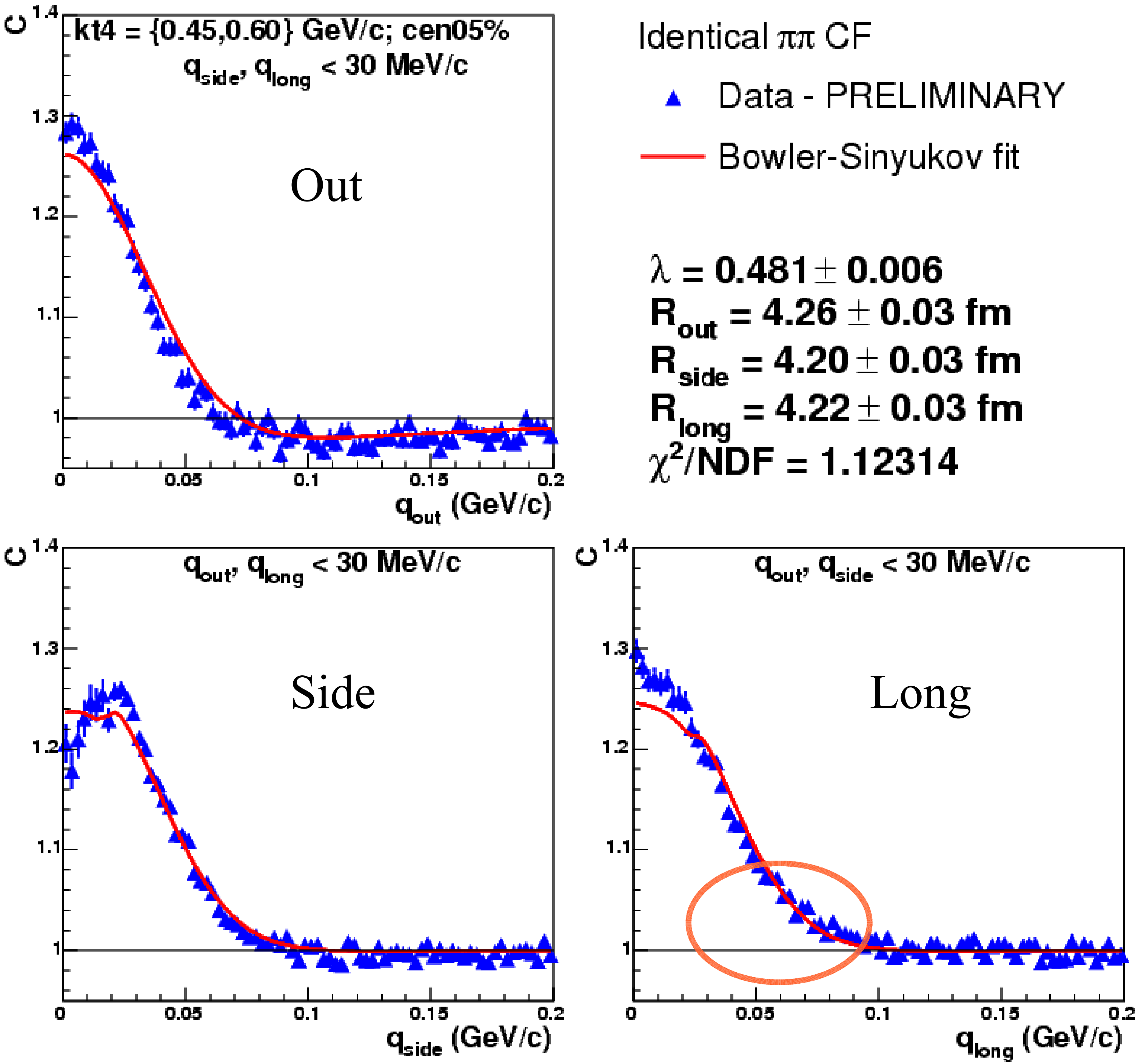

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Levy source distribution fit

- T.Csörgő, *et al.*: Bose-Einstein correlations for Levy stable source distributions, Eur.Phys.J. C36(2004)67
- The general form of two-particle BECF

$$C(q)=1+\lambda \exp(-(\sum R_{ij}^2 q_i q_j)^{\alpha/2})$$

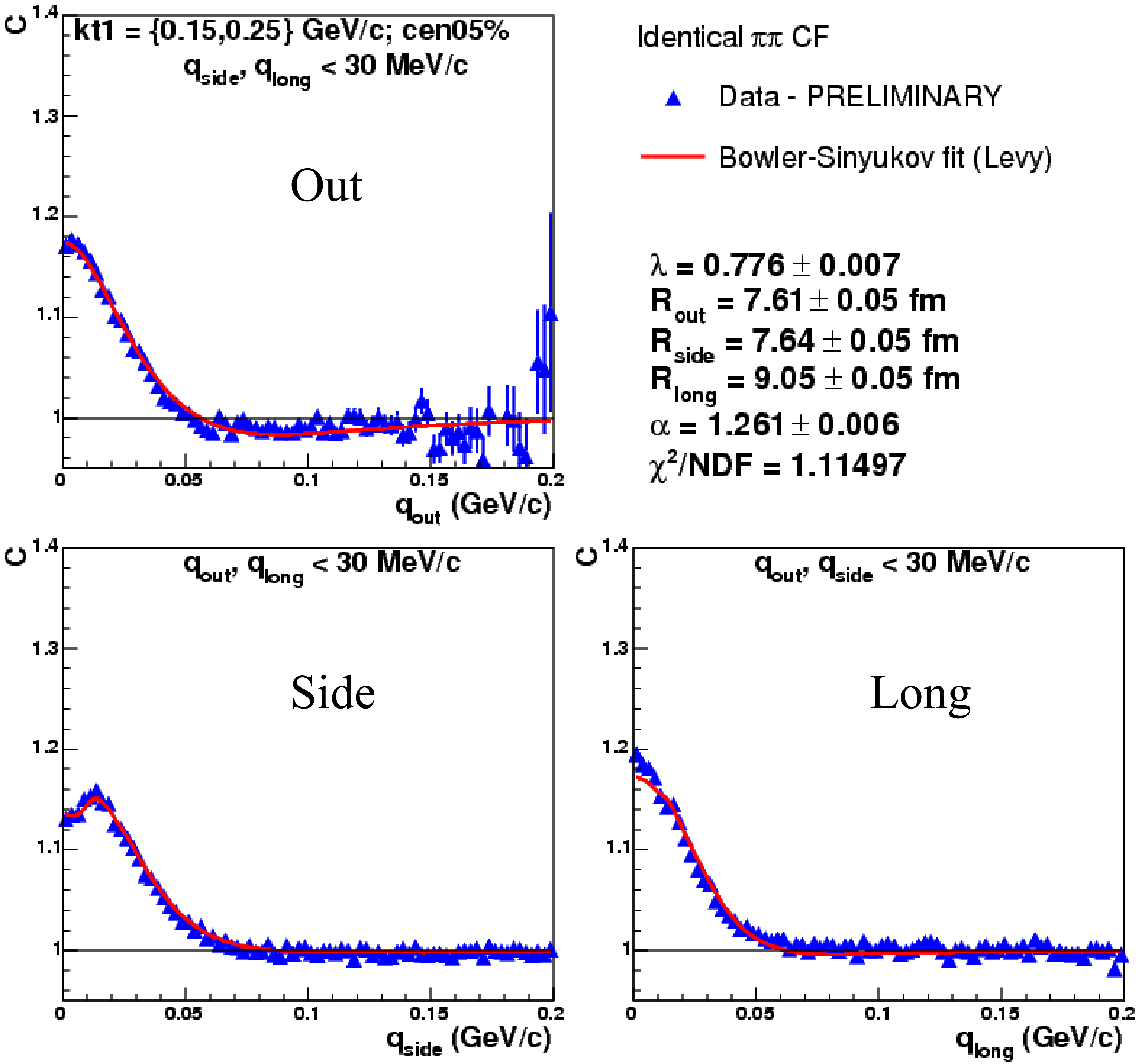
- $0 < \alpha \leq 2$ ...Levy index of stability
- $\alpha < 2$ ...CF becomes more peaked than a Gaussian and it develops longer tails

- Taking into account the Coulomb effect, Levy source distribution fit to data

$$C(q)=(1-\lambda)+\lambda K_c(1+\exp(-(\sum R_{ij}^2 q_i q_j)^{\alpha/2}))$$

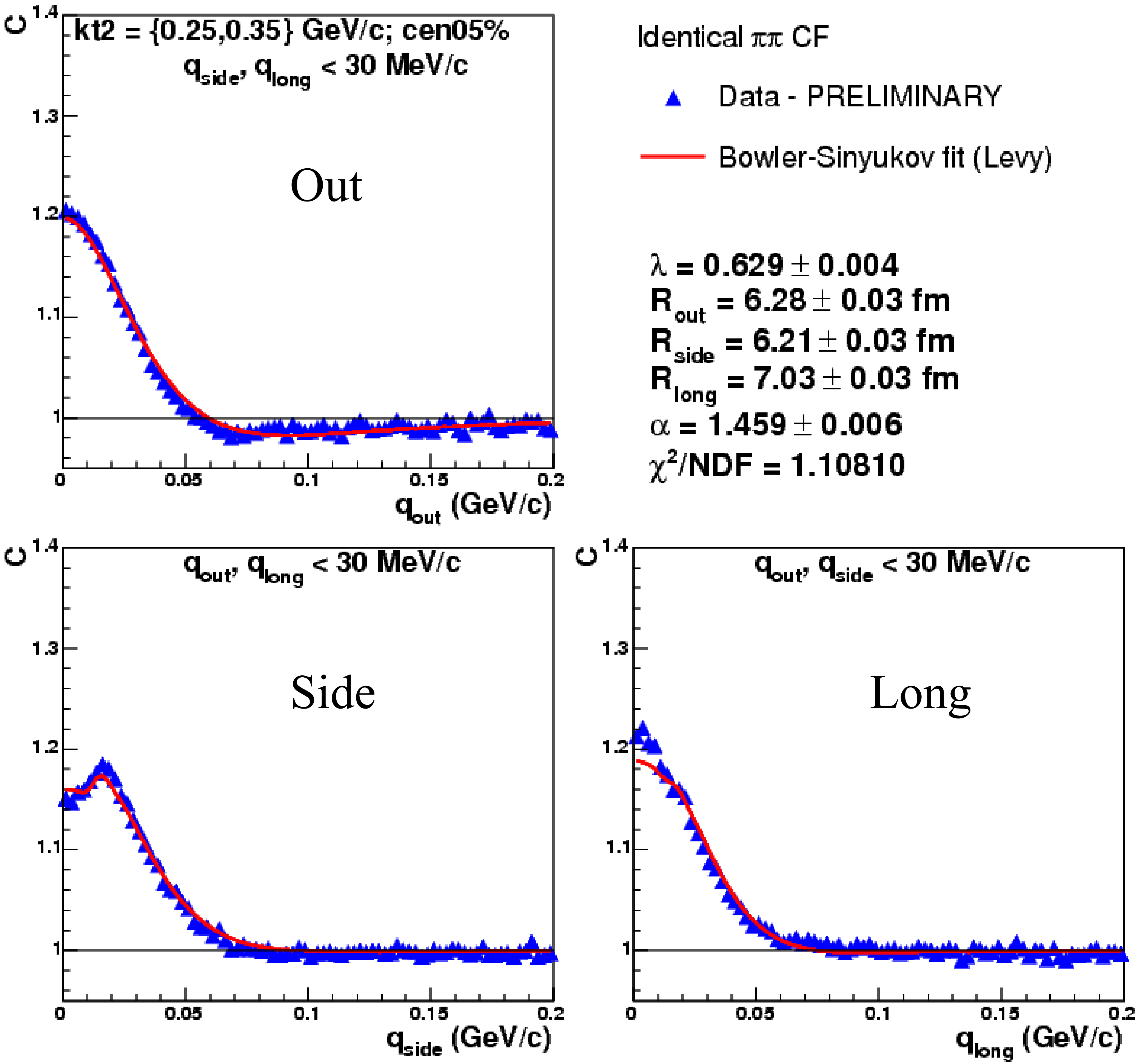
- Using Bertsch-Pratt parametrization in LCMS frame, asimuthally integrated analyses, $R_{ij}=0$ $i \neq j$

Levy fit to identical π–π correlation function



- λ increases with k_T
- All three radii $R_{o,s,l}$ decrease with k_T
- α parameter increases with k_T
- $\alpha < 2$

Levy fit to identical π–π correlation function



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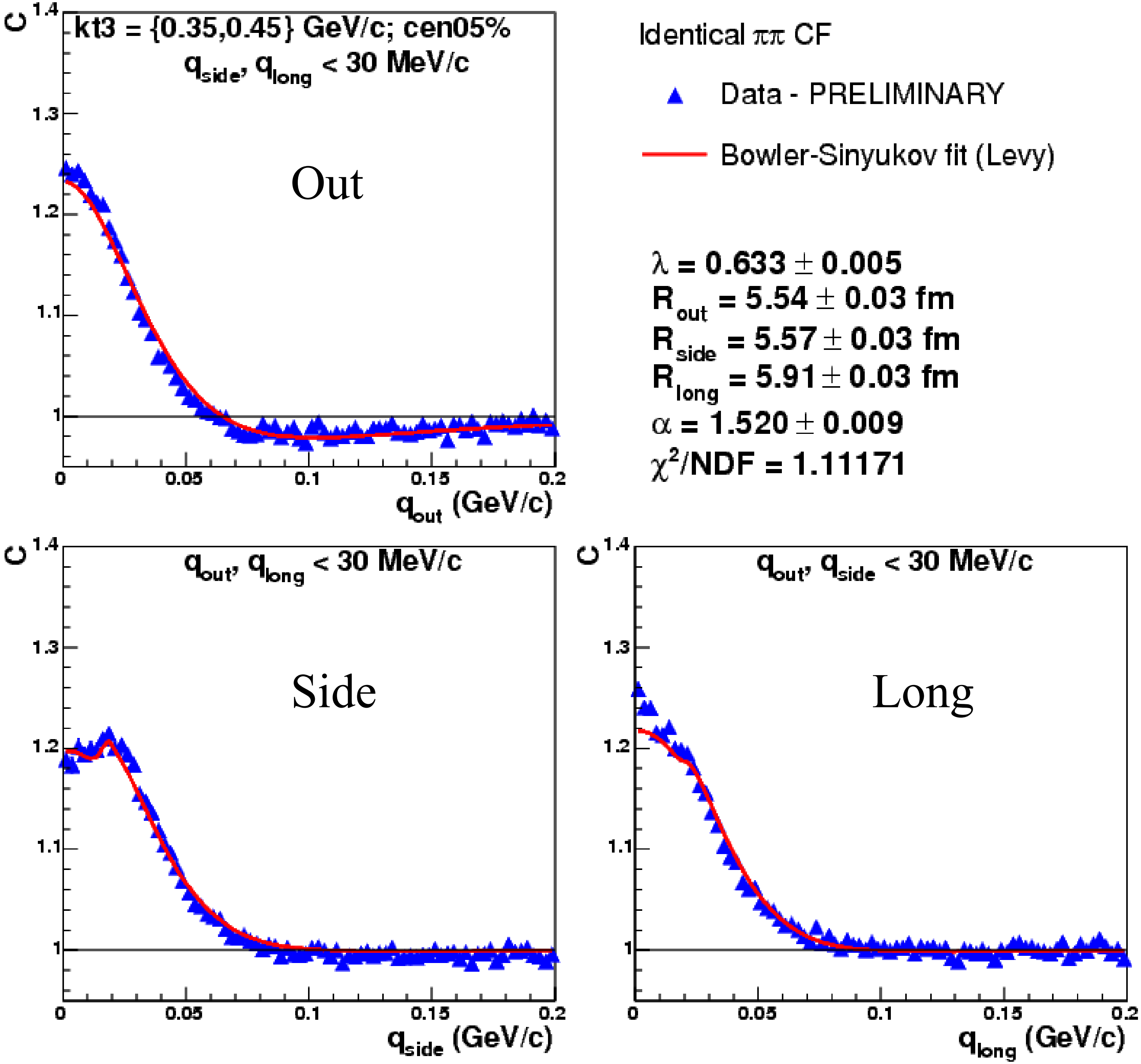

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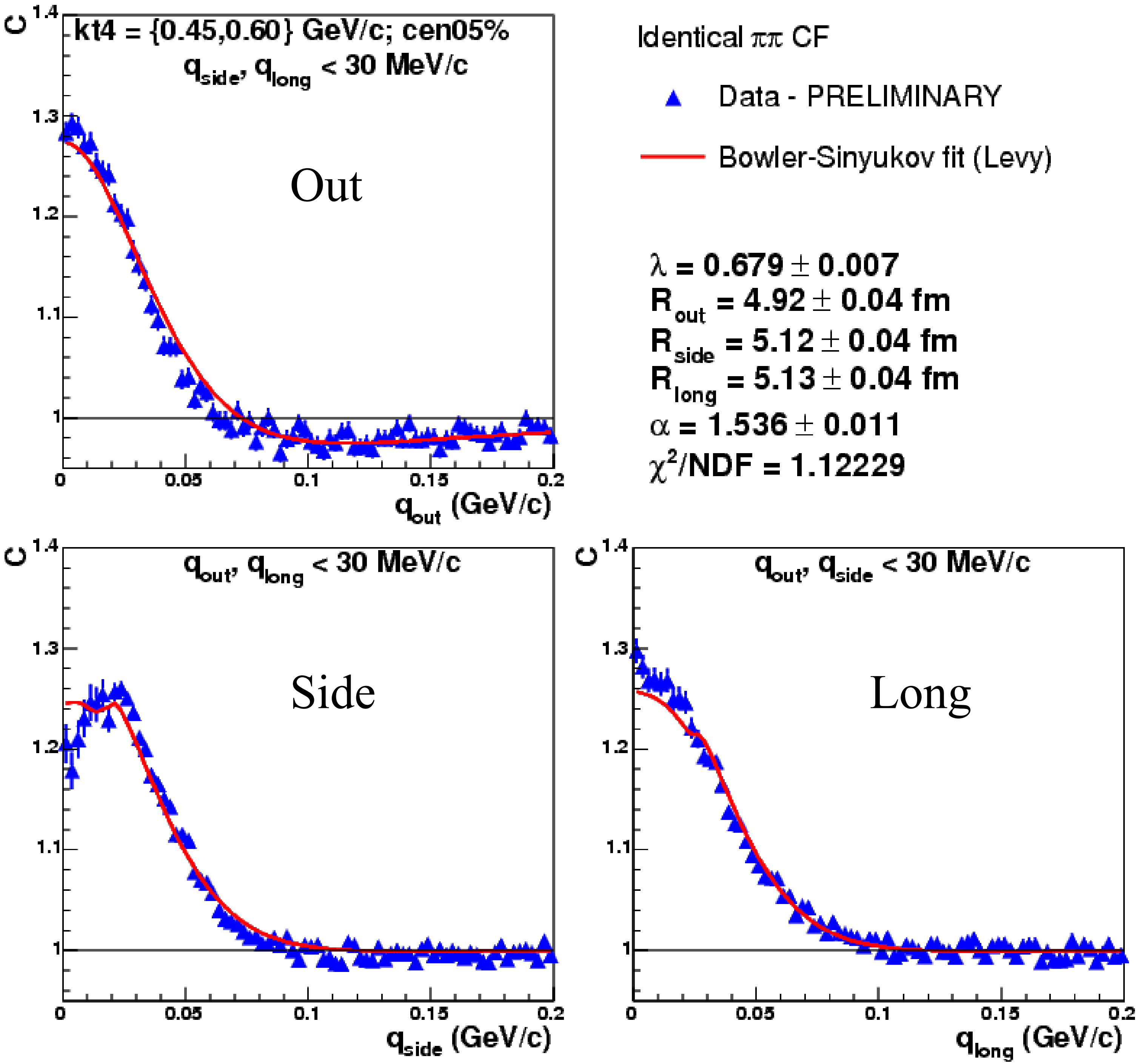

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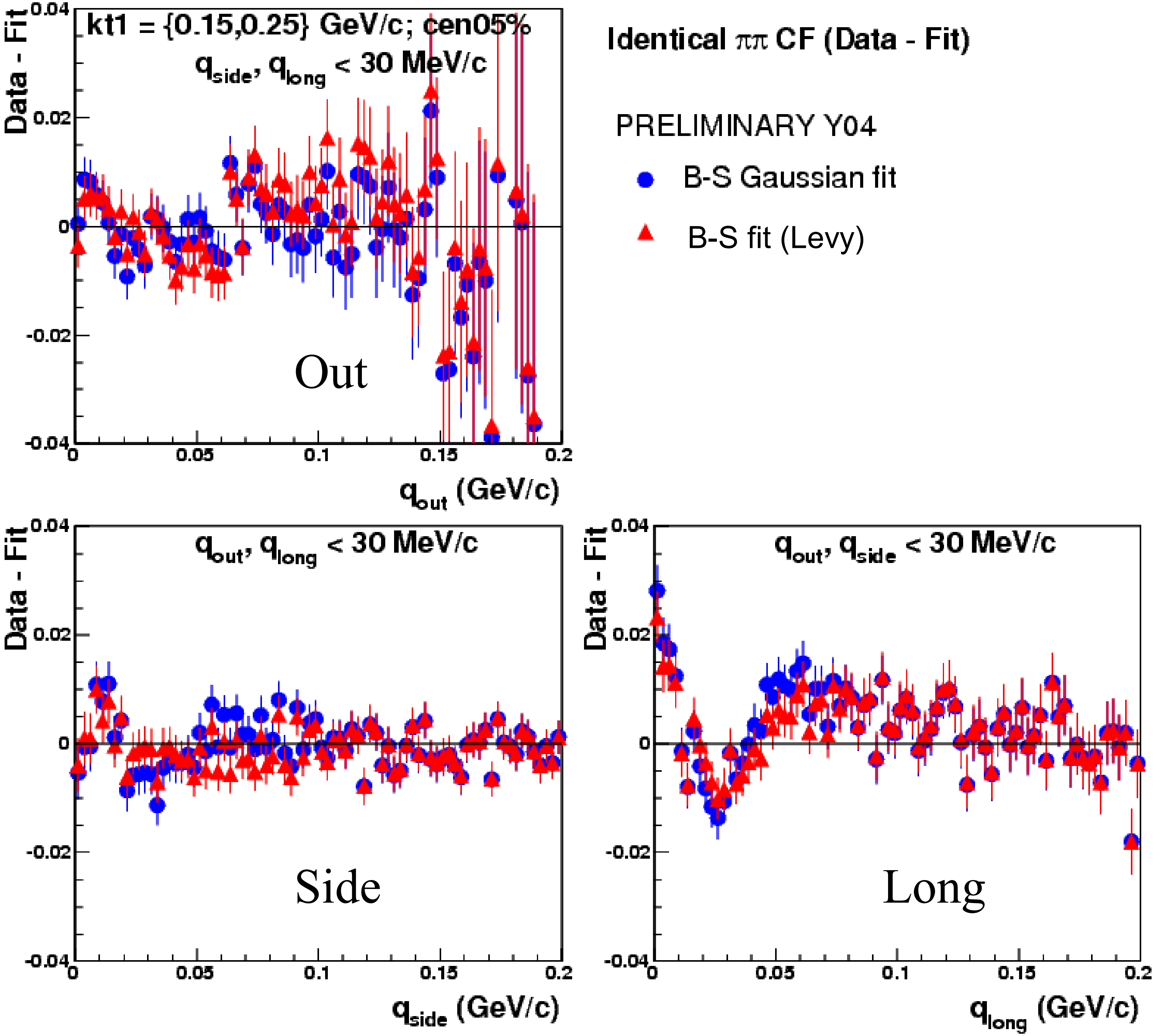
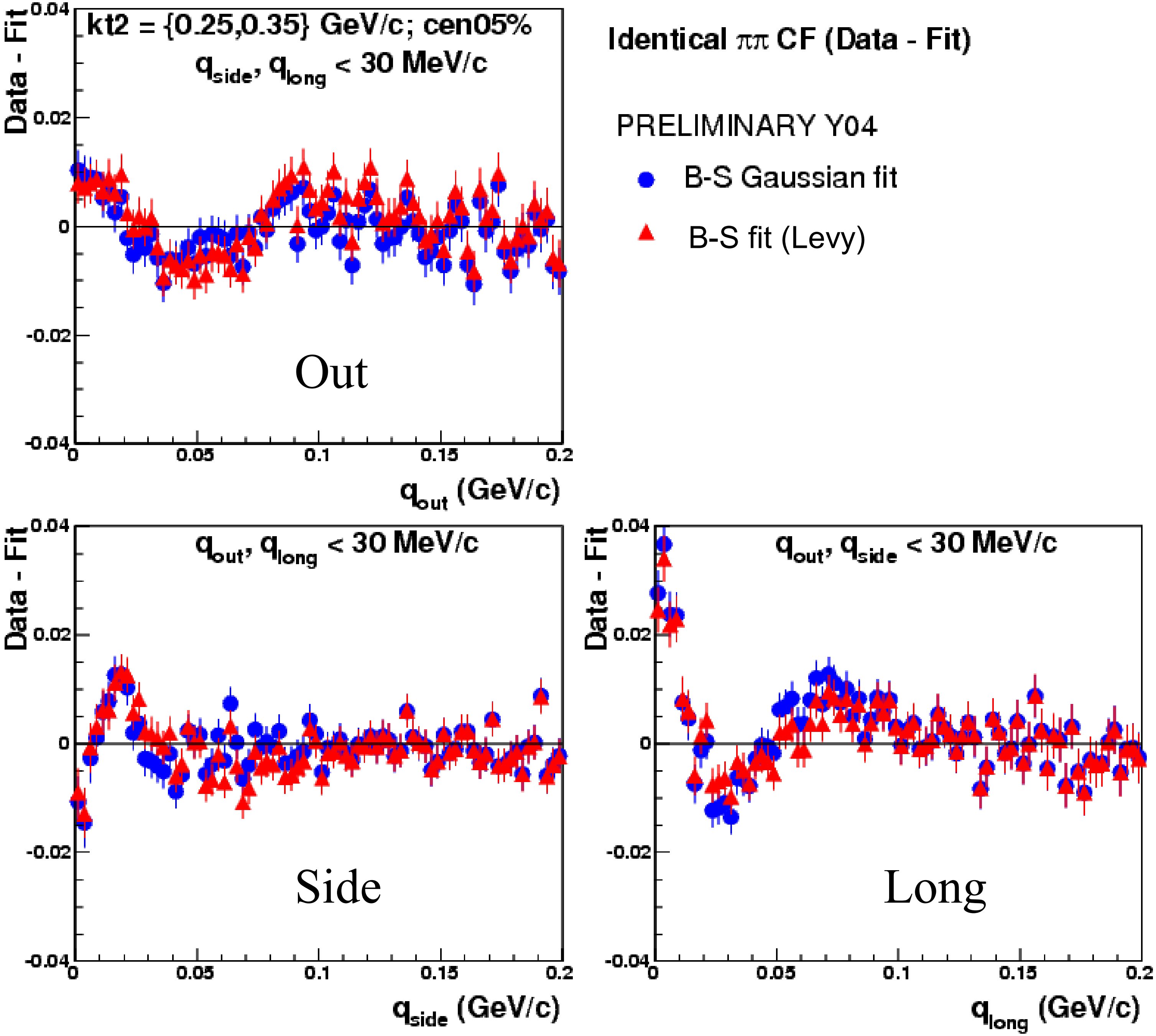
- α < 2

Levy source fit vs. Bowler-Sinyukov fit



- Both methods follow the same trend
- Niether is significantly better in fitting 3D experimental CF

Levy source fit vs. Bowler-Sinyukov fit



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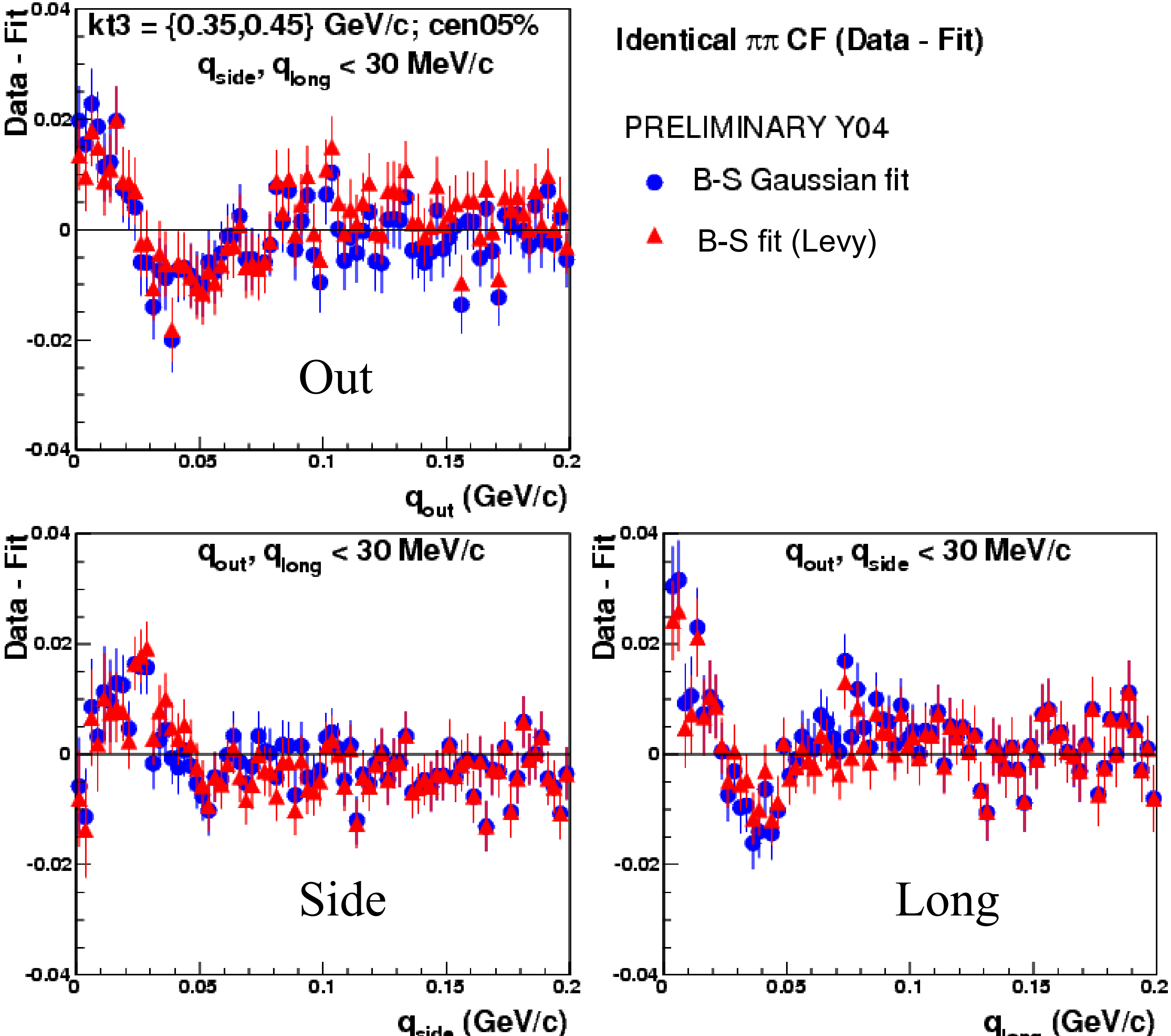
Levy source fit vs. Bowler-Sinyukov fit



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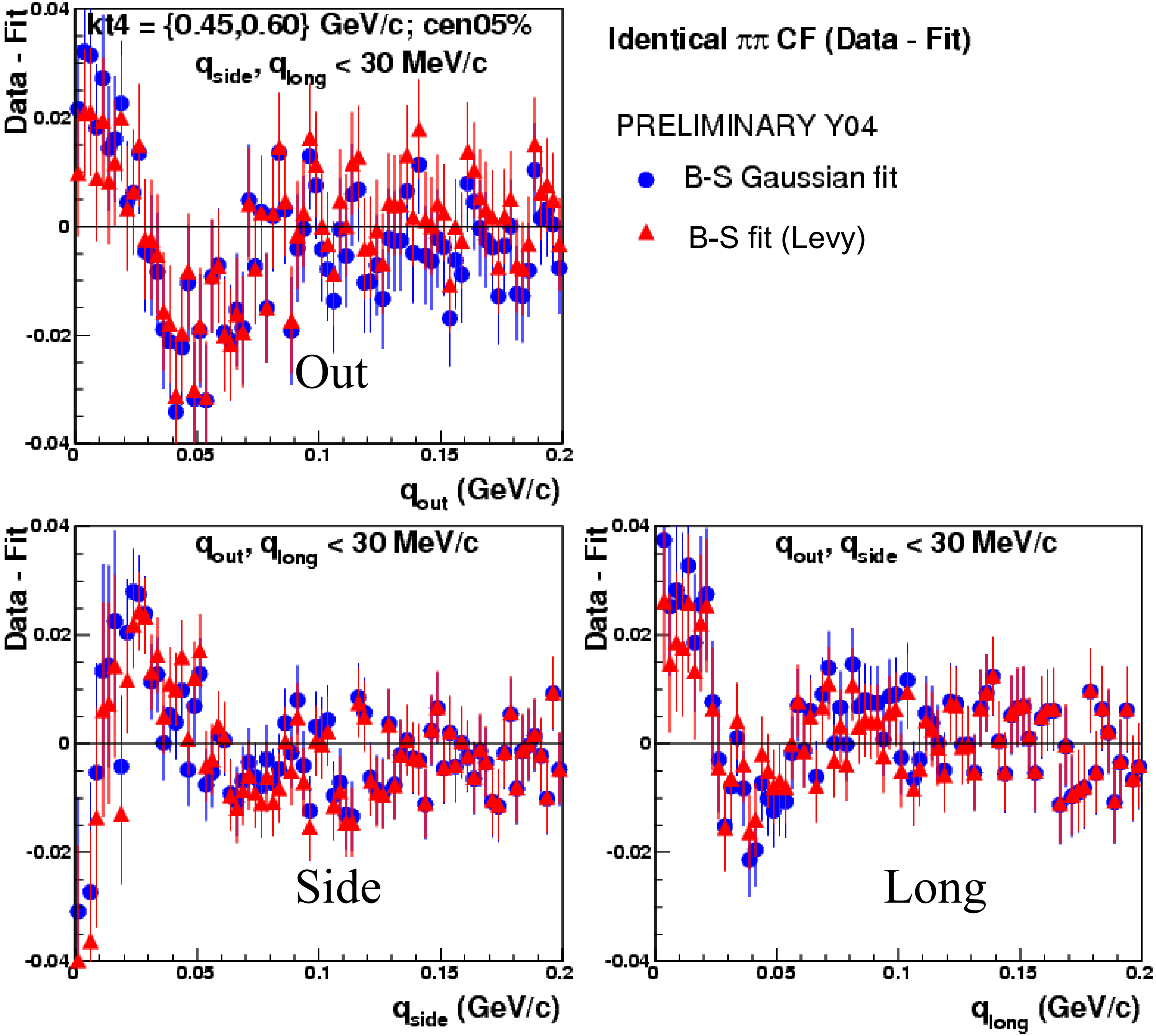
Levy source fit vs. Bowler-Sinyukov fit



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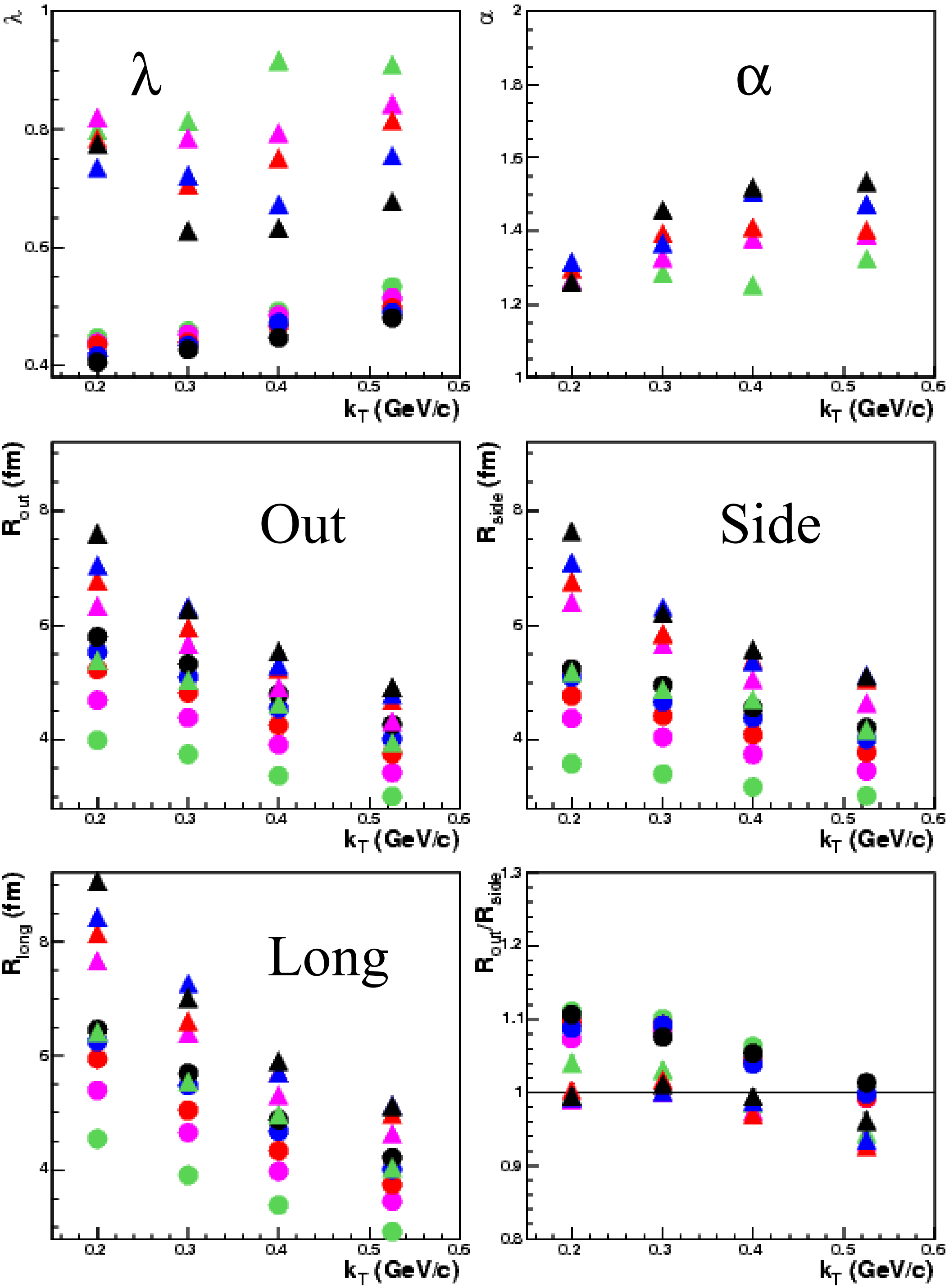
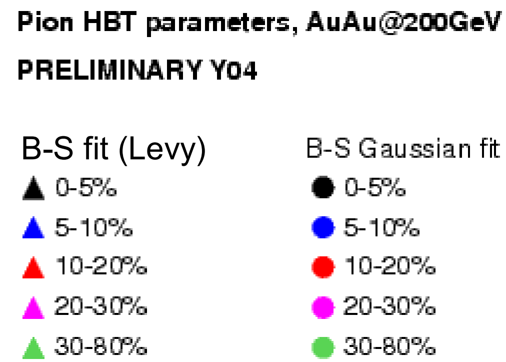
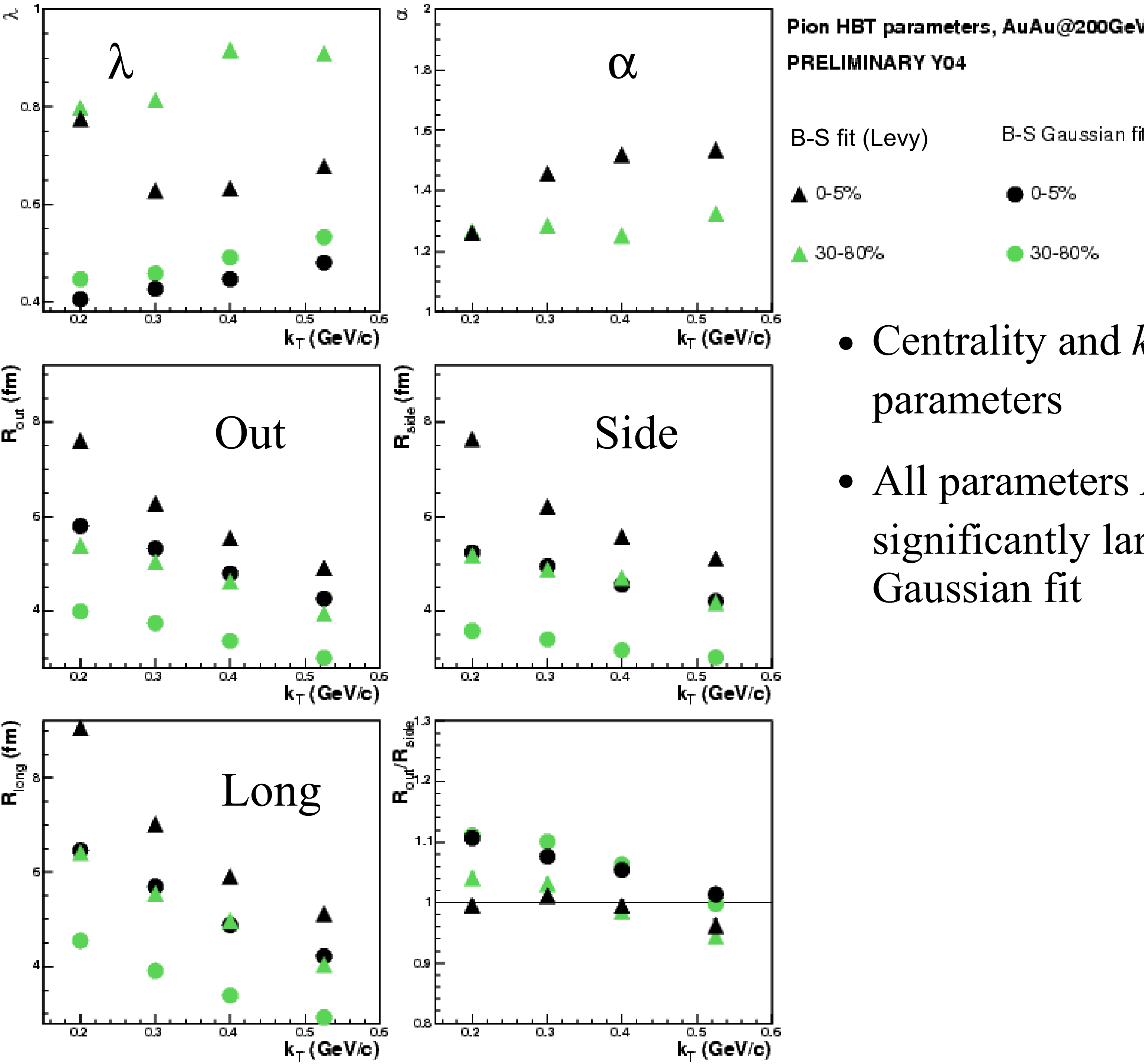
Levy source fit vs. Bowler-Sinyukov fit





- Centrality and k_T dependence of fit parameters
- All parameters $R_{o,s,l}$ and λ are significantly larger when compared to Gaussian fit

Levy source fit vs. Bowler-Sinyukov fit



- Centrality and k_T dependence of fit parameters
- All parameters $R_{o,s,l}$ and λ are significantly larger when compared to Gaussian fit

Edgeworth expansion

- Method suggested by T.Csörgő, *et al.*, Phys.Lett. B489(2000)15, to study deviations from Gaussian CF
- Edgeworth expansion arround 3D Gaussian in B-S procedure

$$
\begin{aligned}
C(q_o, q_s, q_l) = (1-\lambda) + \lambda K_{\mathrm{coul}}(q_{\mathrm{inv}}) \\
+\lambda K_{\mathrm{coul}}(q_{\mathrm{inv}}) \cdot e^{-q_o^2 R_o^2 - q_s^2 R_s^2 - q_l^2 R_l^2} \times \\
\left[1 + \sum_{n=4,\mathrm{n\ even}}^{\infty} \frac{\kappa_{o,n}}{n!(\sqrt{2})^n} H_n(q_o R_o)\right] \times \\
\left[1 + \sum_{n=4,\mathrm{n\ even}}^{\infty} \frac{\kappa_{s,n}}{n!(\sqrt{2})^n} H_n(q_s R_s)\right] \times \\
\left[1 + \sum_{n=4,\mathrm{n\ even}}^{\infty} \frac{\kappa_{l,n}}{n!(\sqrt{2})^n} H_n(q_l R_l)\right],
\end{aligned}
$$

- Unable to find the physical interpretation of the fit parameters, it is not clear how to compare extracted parameters to models that assume Gaussian CF

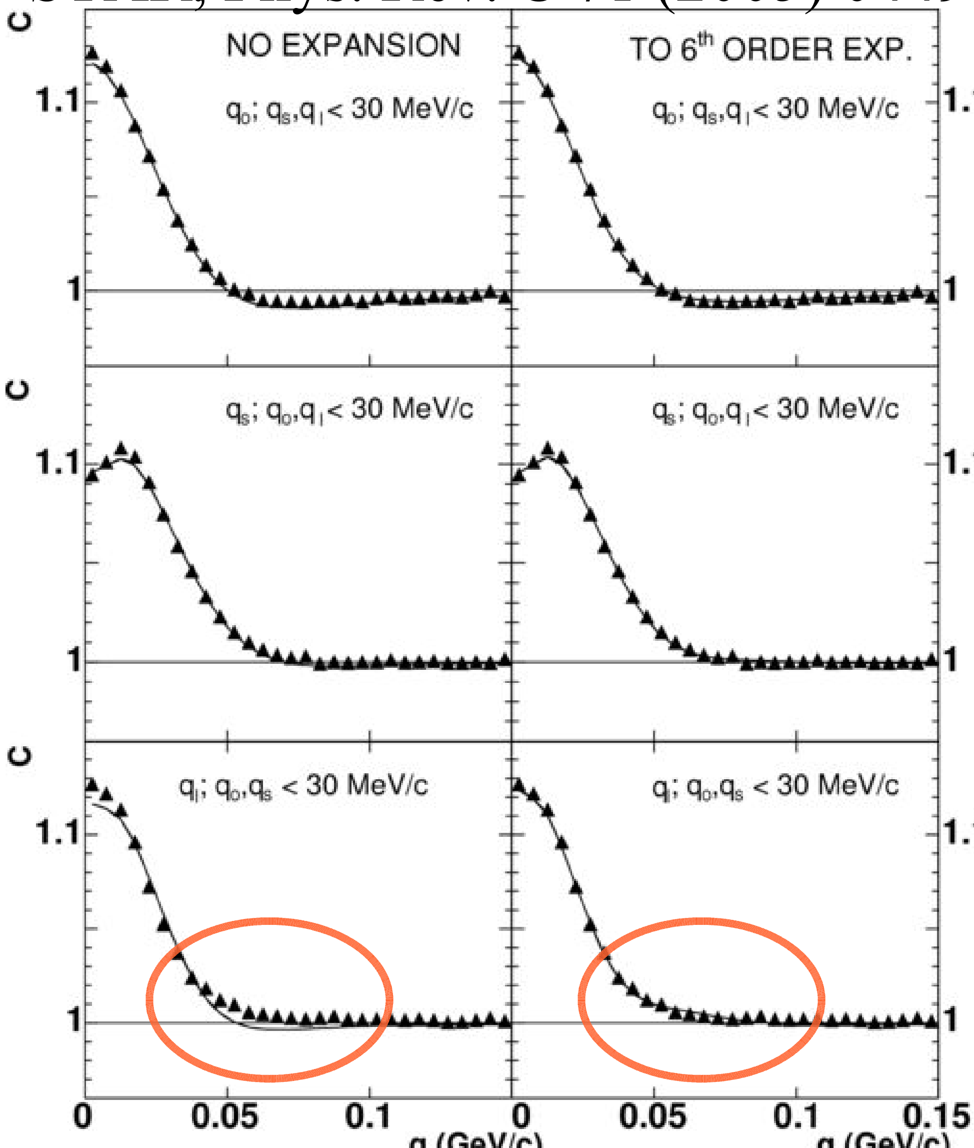
Numbr of parameters

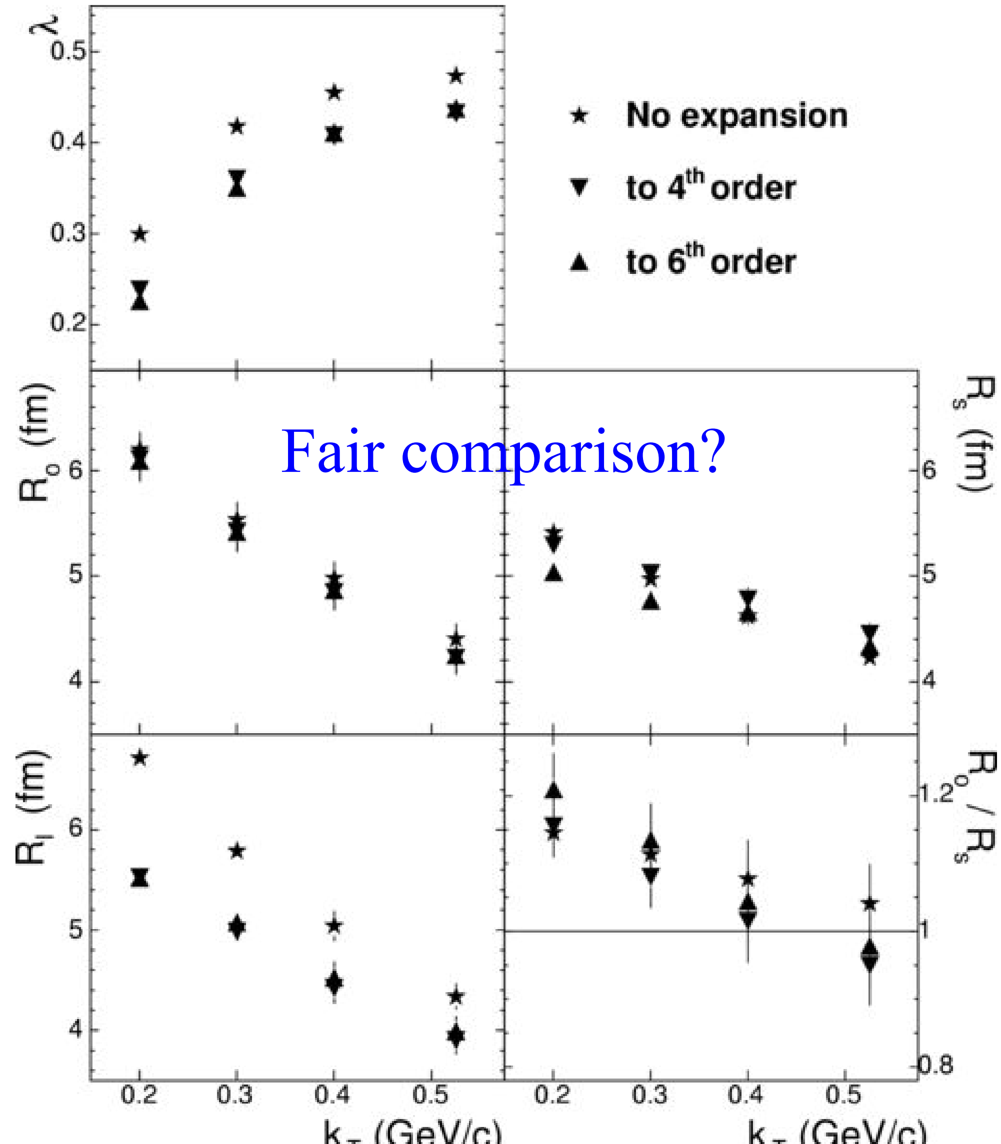
Gaussian	4
4th order	7
6th order	10

Edgeworth expansion fit to identical π–π CF

- Expansion up to 6th order is sufficient.

STAR, Phys. Rev. C 71 (2005) 044906





Summary

- Large statistics of year 2004 data ~11 M MinBias Au+Au events at $\sqrt{s_{NN}}$ = 200 GeV, is being processed with the extraction of the k_T dependence of interferometry parameters for 5 centrality bins.
- Gaussian fit to experimental CF is consistent within errors with STAR published data.
- Levy source distribution does not fit the experimental CF significantly better when compared to standard Gaussian fit.
- Edgeworth expansion is an improvement but there is no clear interpretation of higher order fit parameters yet.
- It seems that at RHIC Au+Au collisions Gaussian parameterization is suffient to represent experimental CF.

Thank you

Extra slides

Edgeworth expansion

- Method suggested by T.Csörgő, *et al.*, Phys.Lett. B489(2000)15, to study deviations from Gaussian CF
- Edgeworth expansion arround 3D Gaussian in B-S procedure

$$C(q_o,q_s,q_l) = (1-\lambda) + \lambda K_{\rm coul}(q_{\rm inv}) + \lambda K_{\rm coul}(q_{\rm inv}) \cdot e^{-q_o^2R_o^2 - q_s^2R_s^2 - q_l^2R_l^2} \times \left[1 + \sum_{n=4,\text{n even}}^{\infty} \frac{\kappa_{o,n}}{n!(\sqrt{2})^n} H_n(q_oR_o)\right] \times \left[1 + \sum_{n=4,\text{n even}}^{\infty} \frac{\kappa_{s,n}}{n!(\sqrt{2})^n} H_n(q_sR_s)\right] \times \left[1 + \sum_{n=4,\text{n even}}^{\infty} \frac{\kappa_{l,n}}{n!(\sqrt{2})^n} H_n(q_lR_l)\right],$$

- Unable to find the physical interpretation of the fit parameters, it is not clear how to compare extracted parameters to models that assume Gaussian CF

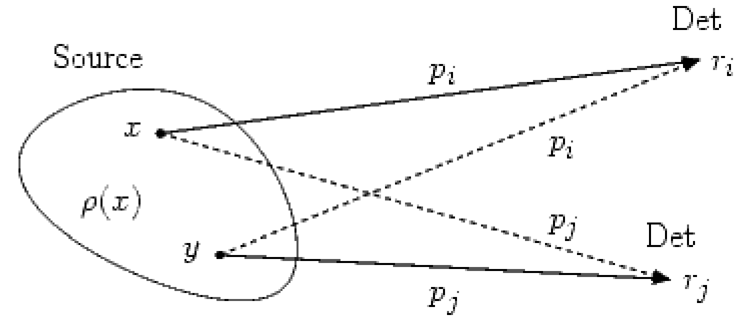
STAR, Phys. Rev. C 71 (2005) 044906

k_T (MeV/c)	150–250	250–350	350–450	450–600
λ	0.30 ± 0.01	0.42 ± 0.01	0.45 ± 0.01	0.47 ± 0.01
λ (4$^{\rm th}$ ord.)	0.24 ± 0.01	0.36 ± 0.01	0.41 ± 0.01	0.43 ± 0.01
λ (6$^{\rm th}$ ord.)	0.23 ± 0.01	0.35 ± 0.01	0.41 ± 0.01	0.44 ± 0.01
R_o	6.16 ± 0.01	5.51 ± 0.01	4.88 ± 0.02	4.32 ± 0.02
R_o (4$^{\rm th}$ ord.)	6.07 ± 0.04	5.40 ± 0.03	4.75 ± 0.03	4.14 ± 0.04
$\kappa_{o,4}$	0.37 ± 0.05	0.36 ± 0.04	0.33 ± 0.05	0.40 ± 0.06
R_o (6$^{\rm th}$ ord.)	6.05 ± 0.05	5.40 ± 0.04	4.78 ± 0.04	4.17 ± 0.04
$\kappa_{o,4}$	0.53 ± 0.11	0.45 ± 0.10	0.20 ± 0.11	0.22 ± 0.13
$\kappa_{o,6}$	0.83 ± 0.39	0.53 ± 0.38	0.63 ± 0.44	–0.84 ± 0.53
R_s	5.39 ± 0.01	4.93 ± 0.01	4.53 ± 0.01	4.14 ± 0.02
R_s (4$^{\rm th}$ ord.)	5.27 ± 0.03	4.98 ± 0.03	4.68 ± 0.03	4.36 ± 0.03
$\kappa_{s,4}$	0.22 ± 0.04	–0.03 ± 0.04	–0.27 ± 0.04	–0.50 ± 0.05
R_s (6$^{\rm th}$ ord.)	5.01 ± 0.05	4.74 ± 0.04	4.57 ± 0.04	4.26 ± 0.04
$\kappa_{s,4}$	0.99 ± 0.10	0.79 ± 0.10	0.16 ± 0.11	–0.07 ± 0.13
$\kappa_{s,6}$	3.07 ± 0.35	3.21 ± 0.37	1.71 ± 0.44	1.80 ± 0.51
R_l	6.64 ± 0.02	5.72 ± 0.02	4.94 ± 0.02	4.25 ± 0.02
R_l (4$^{\rm th}$ ord.)	5.47 ± 0.04	4.92 ± 0.03	4.33 ± 0.04	3.82 ± 0.04
$\kappa_{l,4}$	1.60 ± 0.06	1.25 ± 0.05	1.04 ± 0.06	0.78 ± 0.06
R_l (6$^{\rm th}$ ord.)	5.01 ± 0.05	5.01 ± 0.04	4.43 ± 0.04	3.91 ± 0.04
$\kappa_{l,4}$	1.32 ± 0.07	0.70 ± 0.07	0.54 ± 0.09	0.32 ± 0.11
$\kappa_{l,6}$	–1.76 ± 0.29	–2.82 ± 0.29	–2.41 ± 0.35	–2.12 ± 0.43

Correlation function for two identical bosons

- CF:

$$C_2(p_i, p_j) = \frac{P_2(p_i, p_j)}{P_1(p_i)P_1(p_j)} = 1 + \langle \cos(q \cdot r) \rangle$$



$$q = p_i - p_j$$
$$r = x - y$$
$$k = ½ (p_i + p_j)$$

- Bowler-Sinyukov fit in 3D Bertsch-Pratt parametrization:

$$C_2(\vec{q}, \vec{k}) = \left(1 - \lambda(\vec{k})\right) + \lambda(\vec{k}) K_{\mathrm{coul}}(q_{\mathrm{inv}}) \left(1 + \exp\left(-R^2_{\mathrm{out}}(\vec{k}) q^2_{\mathrm{out}} - R^2_{\mathrm{side}}(\vec{k}) q^2_{\mathrm{side}} - R^2_{\mathrm{long}}(\vec{k}) q^2_{\mathrm{long}} - 2R^2_{\mathrm{outlong}}(\vec{k}) q_{\mathrm{out}} q_{\mathrm{long}}\right)\right)$$

$K_{\mathrm{coul}}(q_{\mathrm{inv}}) =$ squared Coulomb wavefunction integrated over source R = 5 fm

$\lambda(\vec{k}) =$ correlation strength, chaoticity

$$q_{\mathrm{out}} = \frac{|\vec{q}_\top \cdot \vec{k}_\top|}{|\vec{k}_\top|}$$

$$q_{\mathrm{side}} = \frac{|\vec{q}_\top \times \vec{k}_\top|}{|\vec{k}_\top|}$$

$$q_{\mathrm{long}} = p_{z,i} - p_{z,j}$$