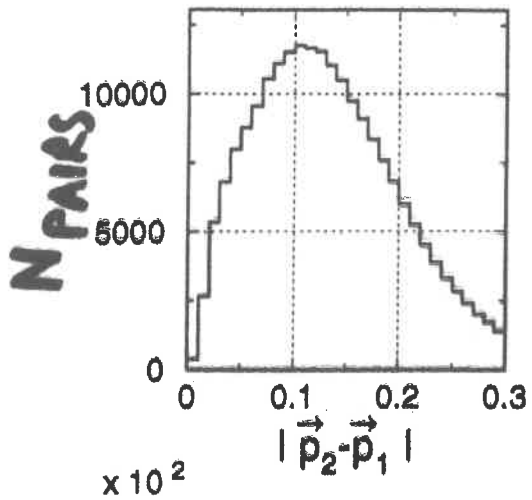
HIRSCHEGG, JANUARY 1997

TWO-PARTICLE CORRELATIONS IN AU+AU COLLISIONS AT AGS

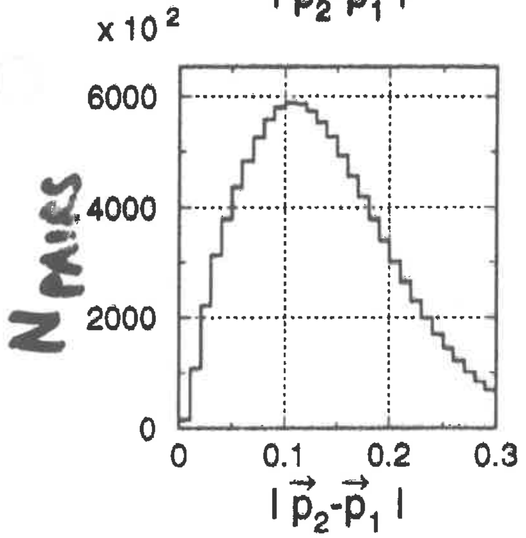
DARIUSZ MIŚKOWIEC
(E877 COLLABORATION)

1. PION-PROTON PUZZLE
2. PION HALO
3. PION PHASE-SPACE DENSITY

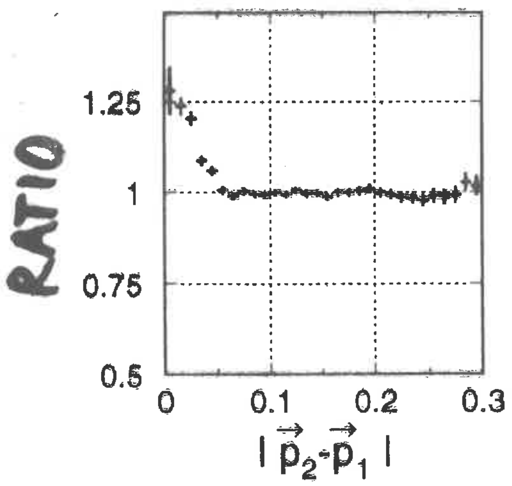
TWO-BOSON INTERFEROMETRY



"TRUE" PAIRS (SIGNAL)

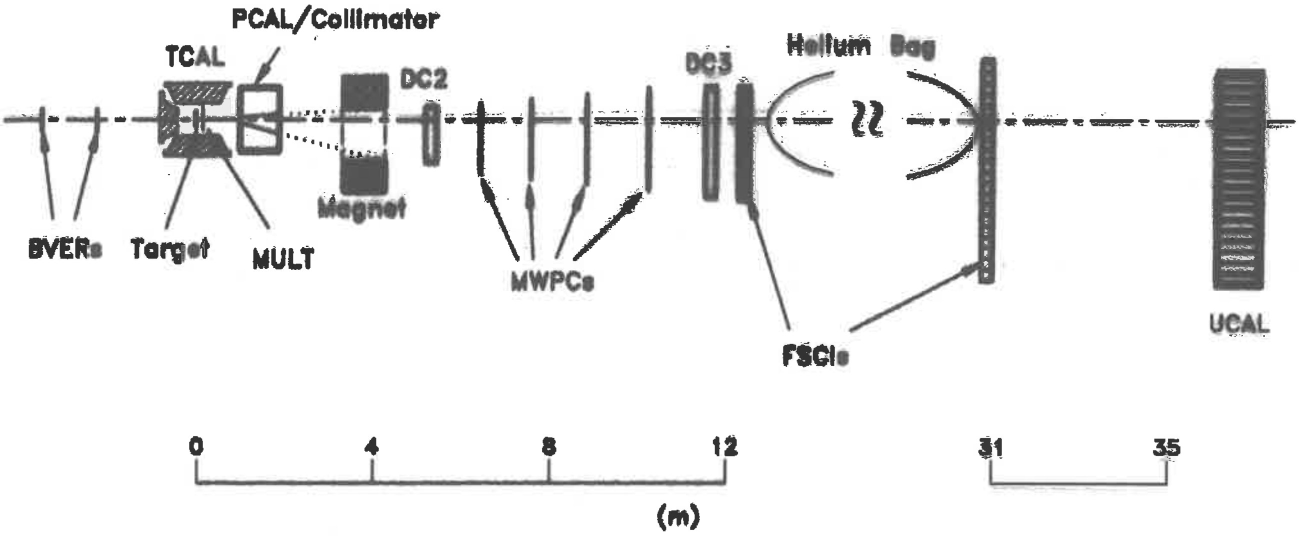


PAIRS FROM EVENT MIXING (BACKGROUND)



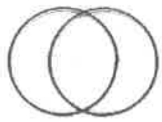
CORRELATION FUNCTION (C OR C_2)

E877 setup at the AGS



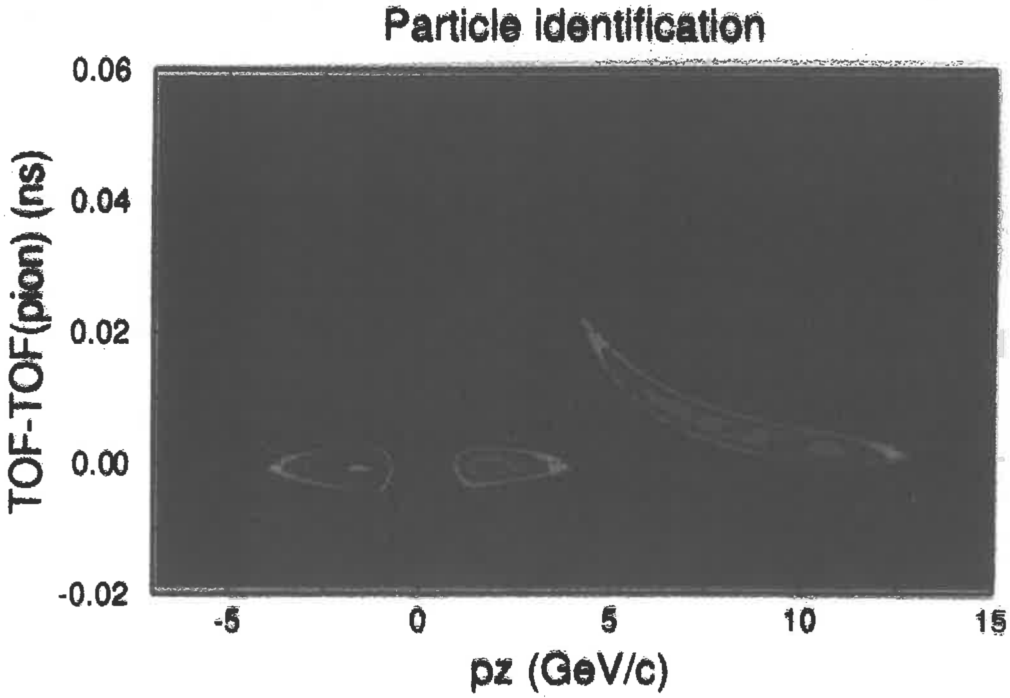
- **Beam detectors** – event selection, TOF start
- **Calorimeters** – centrality, reaction plane
- **Forward spectrometer** – pions, kaons, protons, deutrons identified, $\Delta p/p \approx 4\%$, $\Delta Q_{inv} \approx 7$ MeV/c

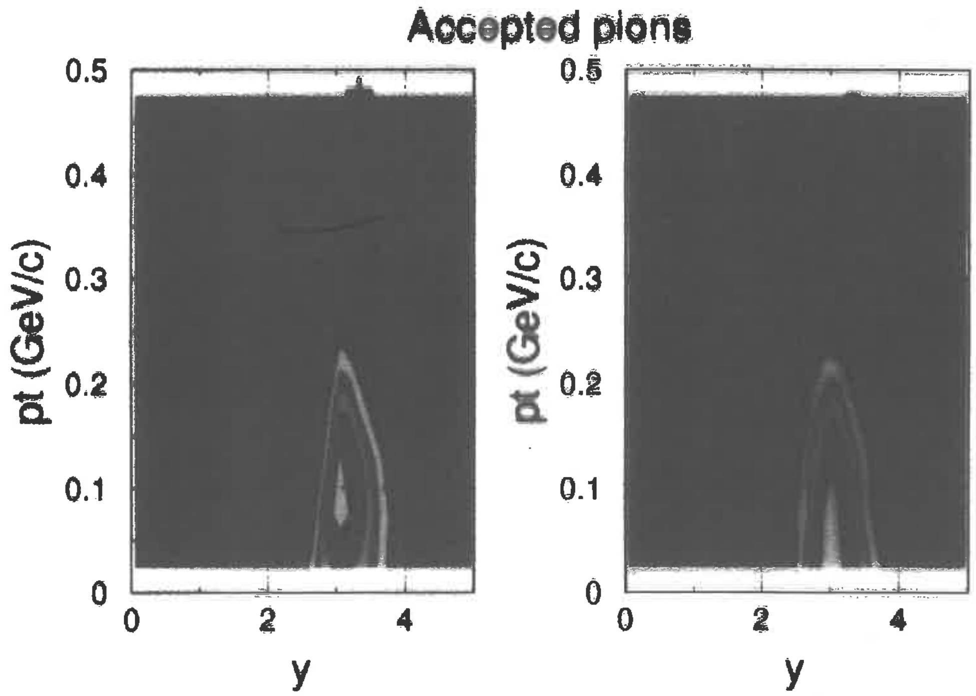
Experiment

- **^{197}Au + ^{197}Au at 10.8 GeV/c per nucleon**
- **Central trigger (14% σ_g)** 
- **Beam intensity 10^5 per spill**

- Fall 1993 – 1 M central events (100 k-200 k identical pion pairs)
- Fall 1994 – 5 times more
- Fall 1995 – 5 times more

Pions from E877





▷ *System: Au+Au* ▷ *Beam energy: 10.8 GeV/c per nucleon* ▷ *Acceptance: around beam rapidity, pt <0.7 GeV/c* ▷ *Trigger: central 10%* ▷ *Corrected for: nothing* ▷ *Kinematic cuts: none* ▷ *Reference frame: LAB*

Data analysis

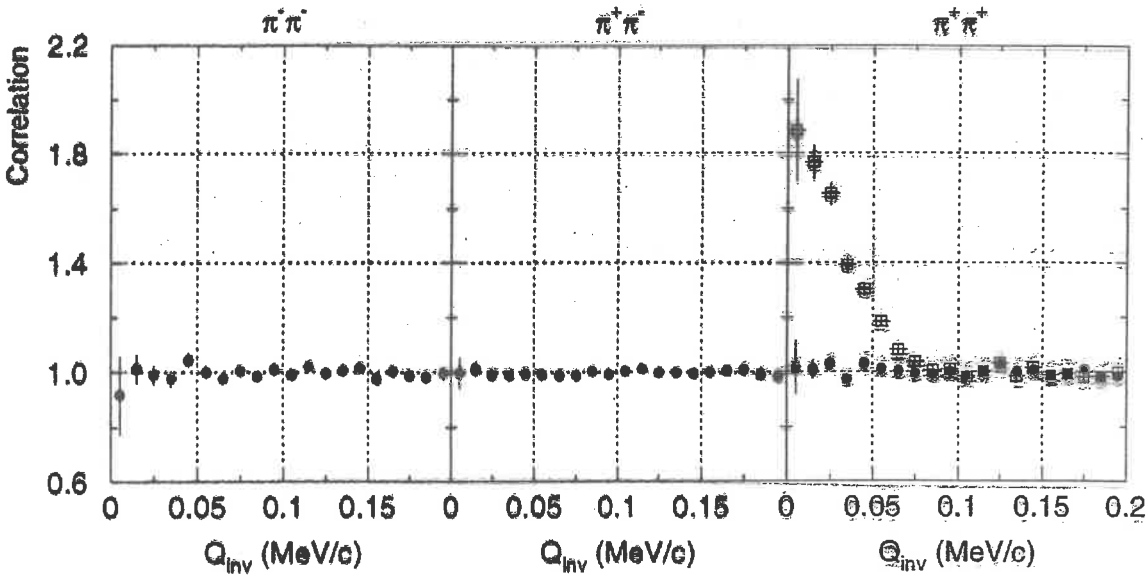
1. Select good central events
2. Select good pion tracks
3. Combine pions into pairs → signal
4. Use event mixing → background
5. Correlation = signal : background
6. Fit correlation

Special attention required:

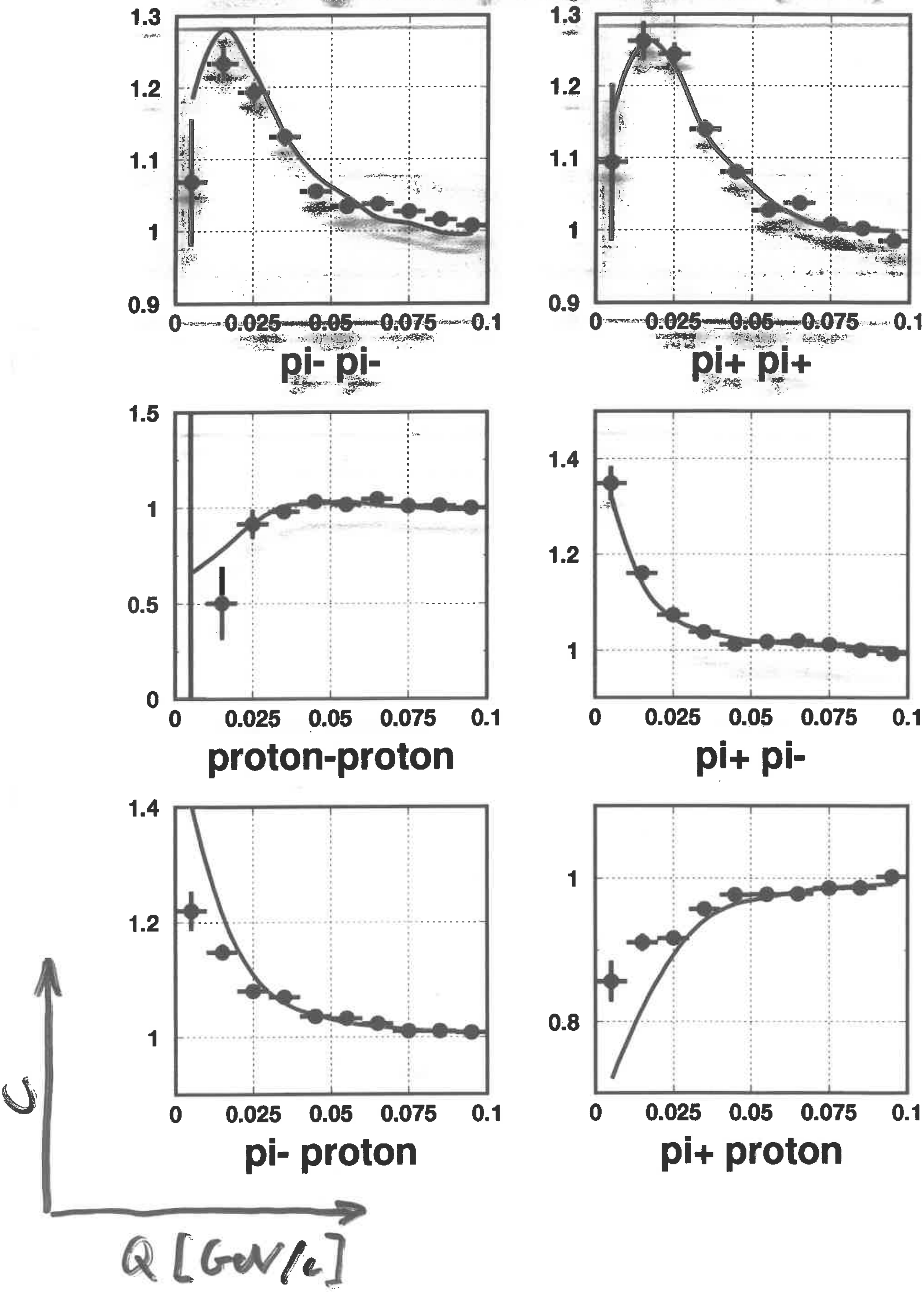
1. Two track efficiency
2. Track order in event
3. Background fluctuations
4. Normalization
5. Singles distortion
   - -enhancement of pion multiplicity by BE
   - -distortion of the single particle acceptance by the two-particle trigger
6. Combination of different measurements
7. Fitting: Maximum Likelihood and not Least Squares
8. Coulomb "correction"
9. Momentum resolution

MONTE CARLO

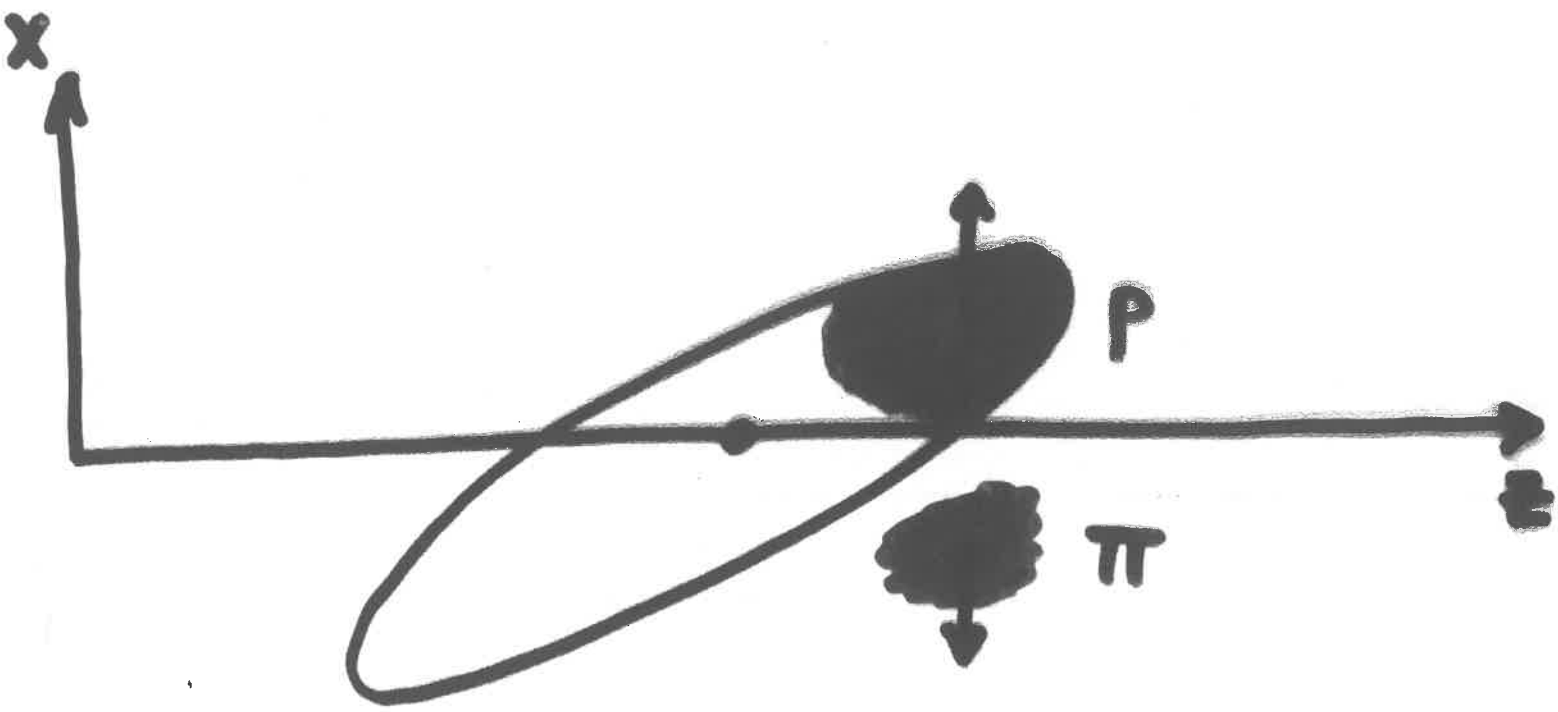
Figure 4

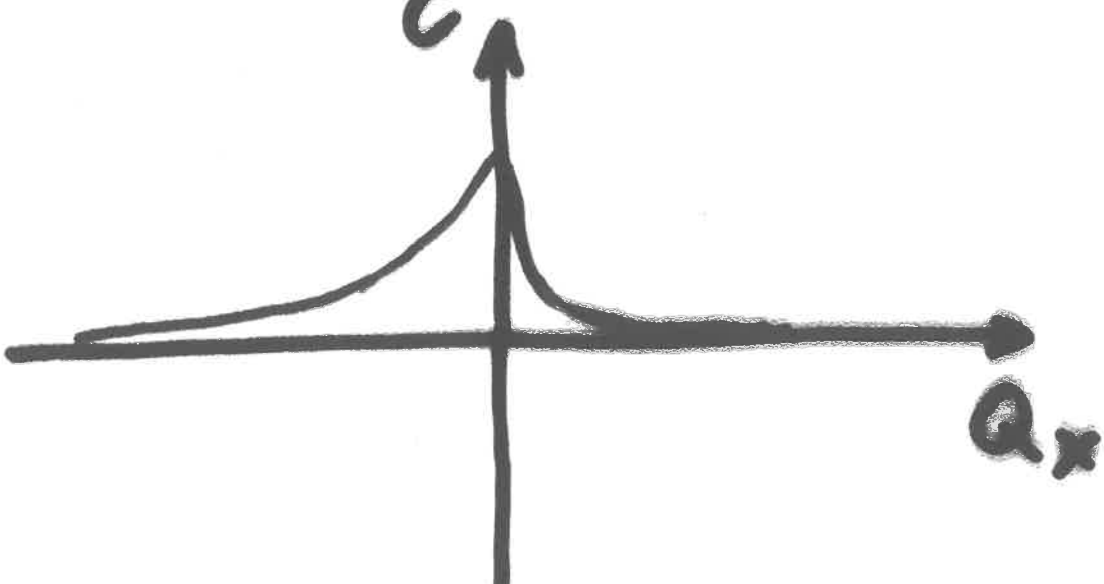


Data (points) and RQMD (line)



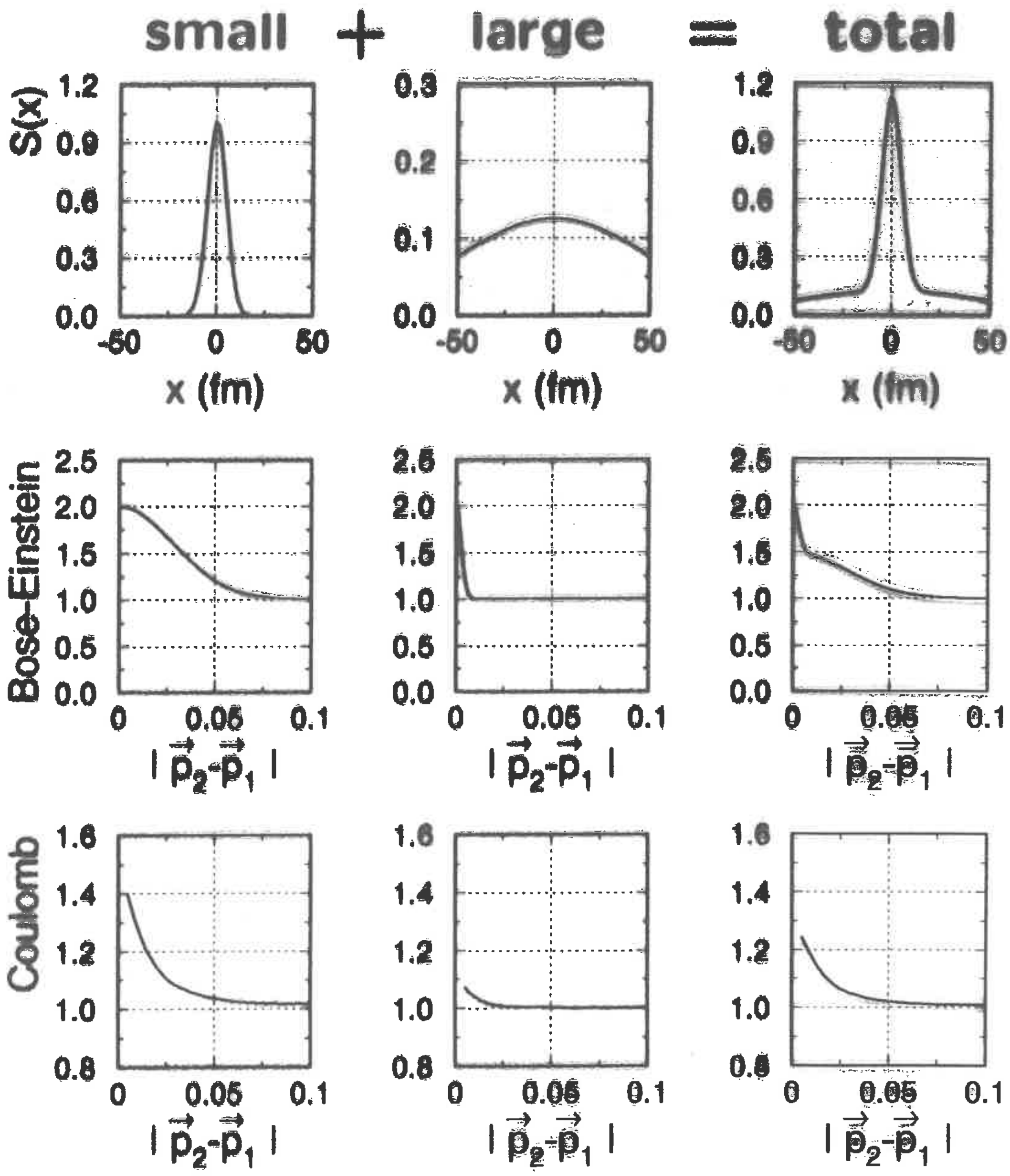
(S. VOLOSHIN)





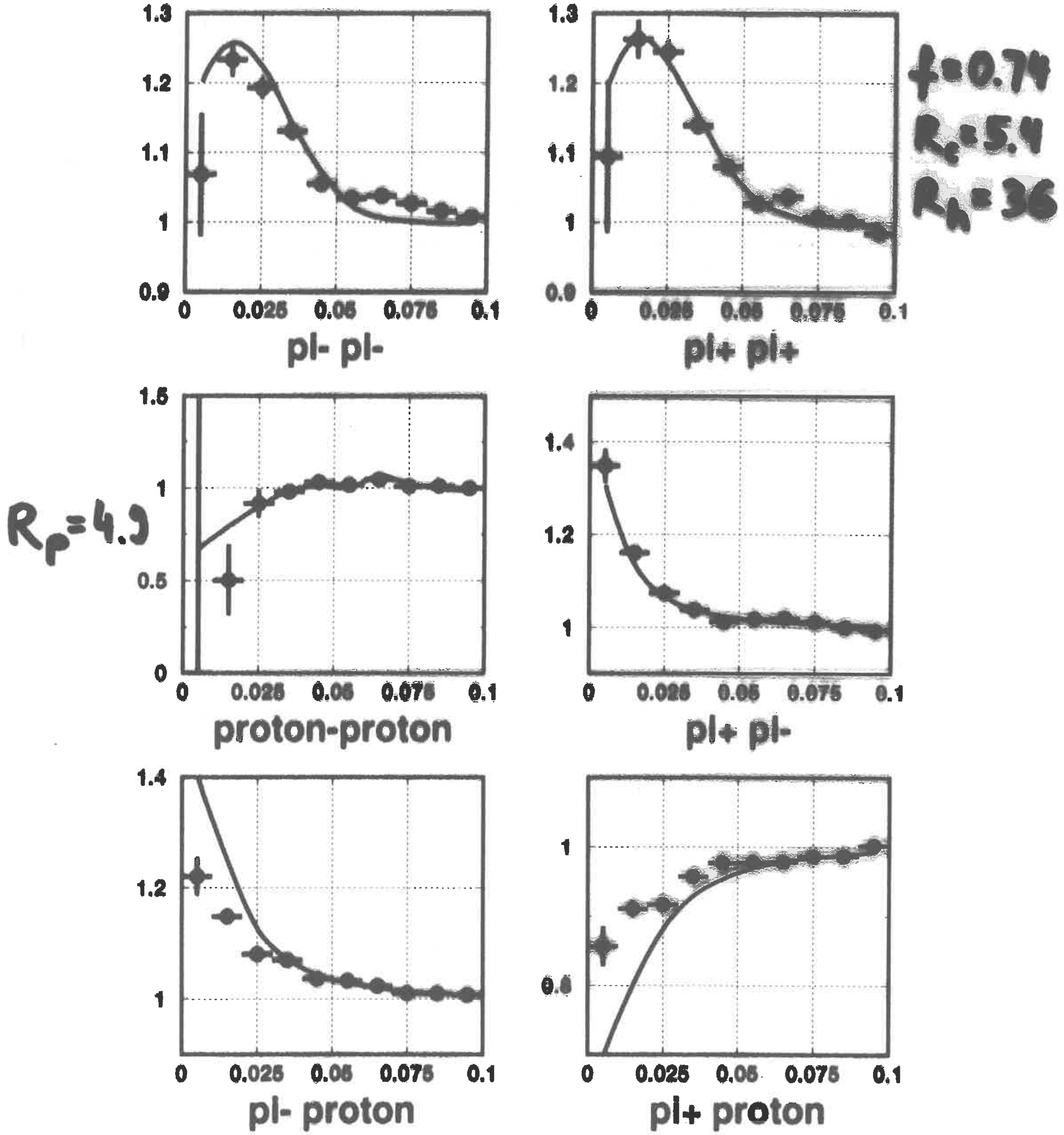
$Q_x = p_x^{prot} - p_x^{pion}$

Core–halo model



- Rescattering, resonances → halo
- Halo → lower intercept in BE correl.
- Halo → different shape in Coulomb cor.

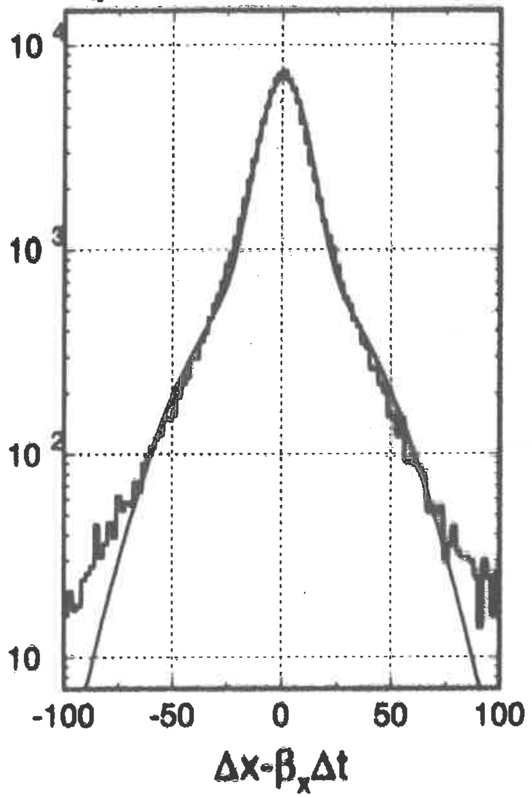
Data (points) and 2-Gauss fit (line)



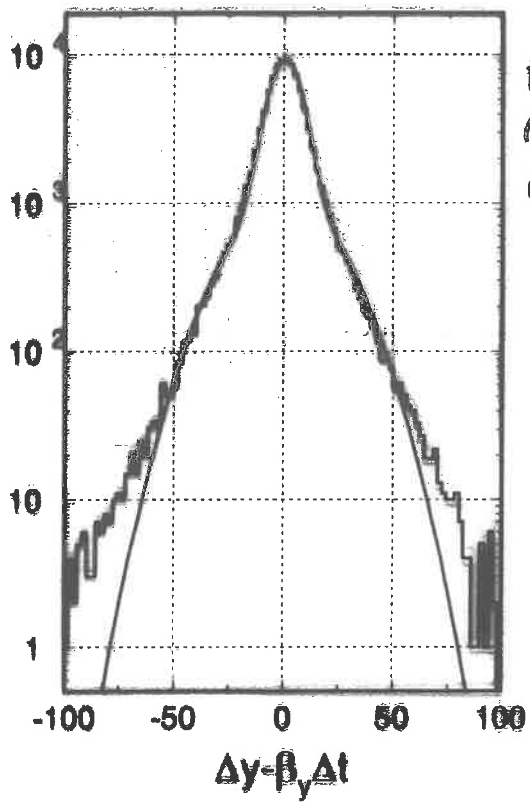
96/12/16 11.50

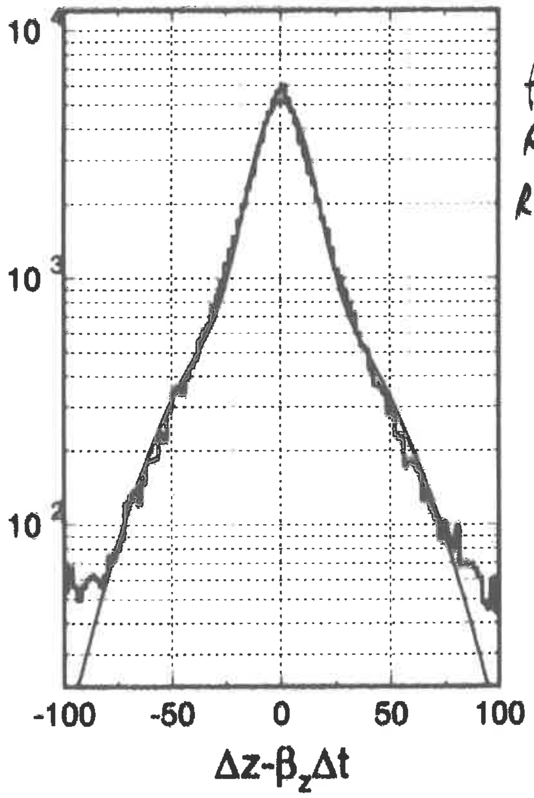
pi- from RQMD 2.2

$f = 0.82$
$R_c = 6.3$
$R_h = 21$



$f = 0.85$
$R_c = 4.9$
$R_h = 15$

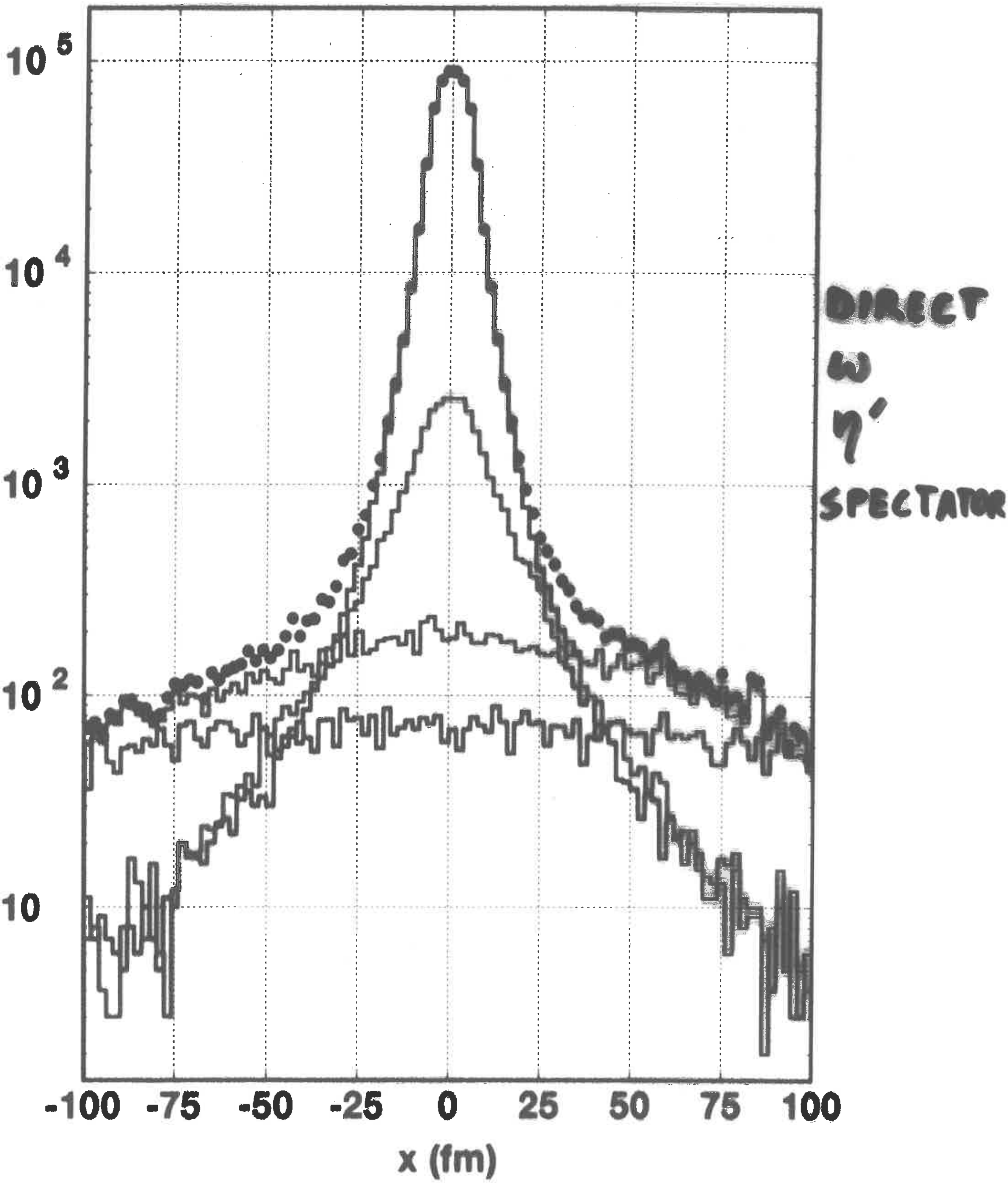




$f = 0.77$
$R_c = 7.6$
$R_h = 24$

$\langle f \rangle = 0.81$
$\langle R_c \rangle = 6.3$
$\langle R_h \rangle = 20$

HALO IN RQMD



10^5
10^4
10^3
10^2
10
-100
-75
-50
-25
0
25
50
75
100
x (fm)
DIRECT
ω
η'
SPECTATOR

Coulomb correction (nonrel. QM)

$$H(\vec{k},\vec{r}) = |\Psi_{\vec{k}}(\vec{r})|^2$$

$$H(\vec{k},\vec{r}) = \frac{2\pi\eta}{e^{2\pi\eta}-1} \; |F(-i\eta;1;ik(r-\frac{\vec{r}\vec{k}}{k}))|^2$$

F - confluent hypergeometric function
$k = Q_{inv}/2$
$\vec{r}$ - distance between the two pions
$\eta = Z_1 Z_2 m_\pi \alpha / Q_{inv}$

Point-source: Gamov

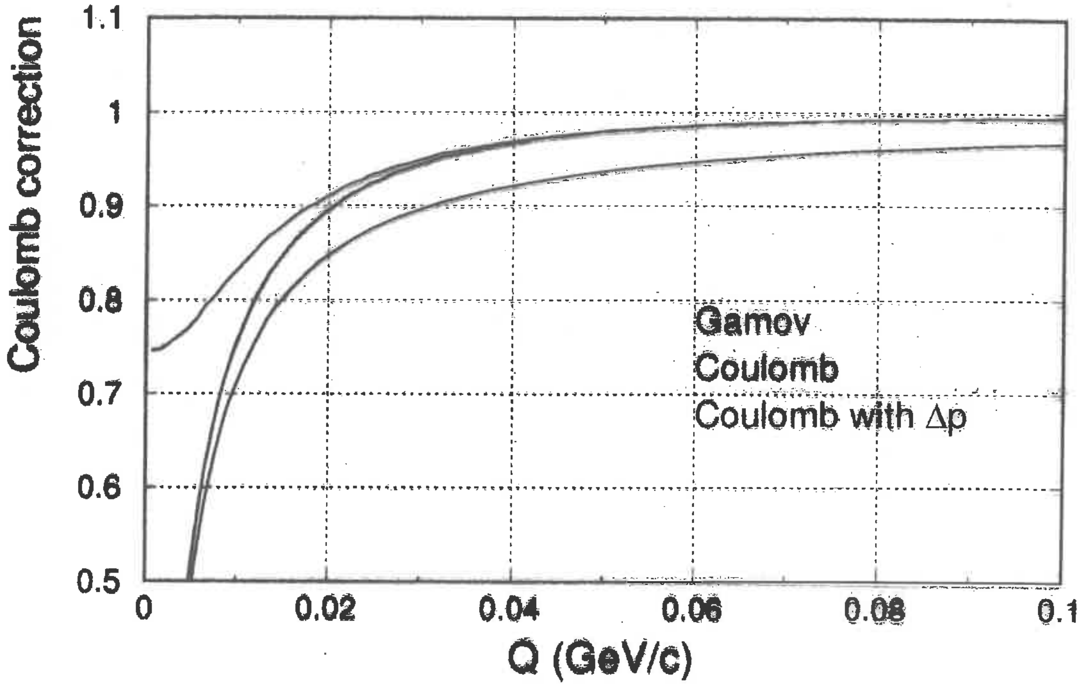
$$H(\vec{k},0) = G(Q_{inv}) = \frac{2\pi\eta}{e^{2\pi\eta}-1}$$

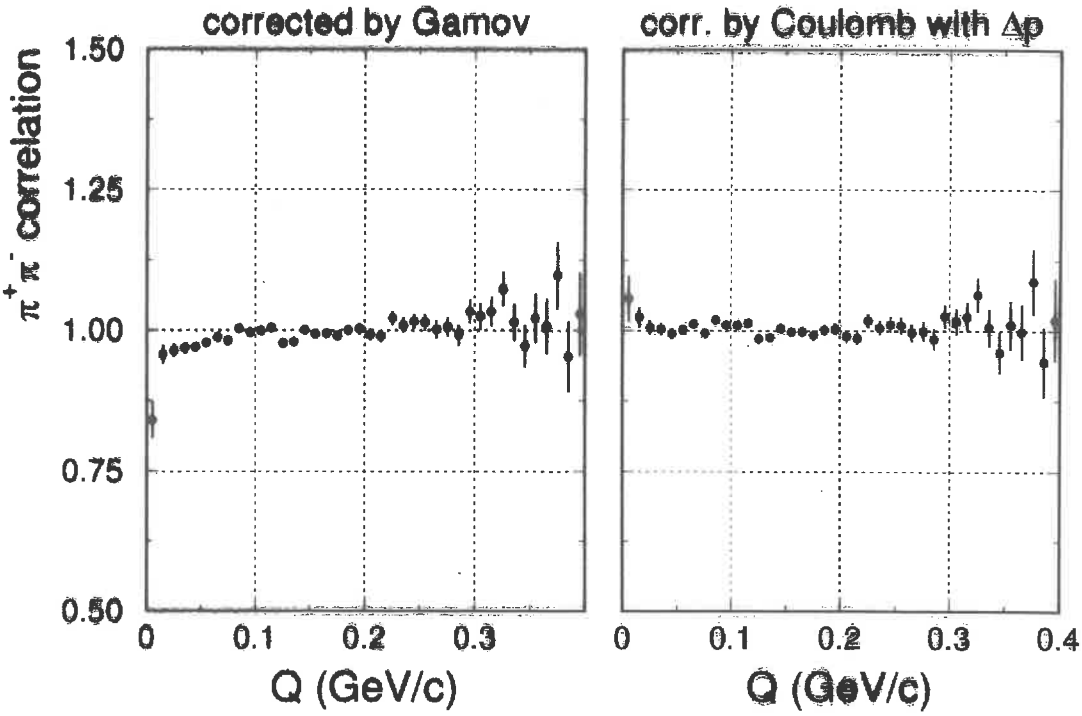
Finite-size source:

$$H(k) = < H(\vec{k},\vec{r}) >$$

average over Gaussian distribution of $\vec{r}$,
with $R_{rel} = \sqrt{2} \cdot 5$ fm=7.1 fm

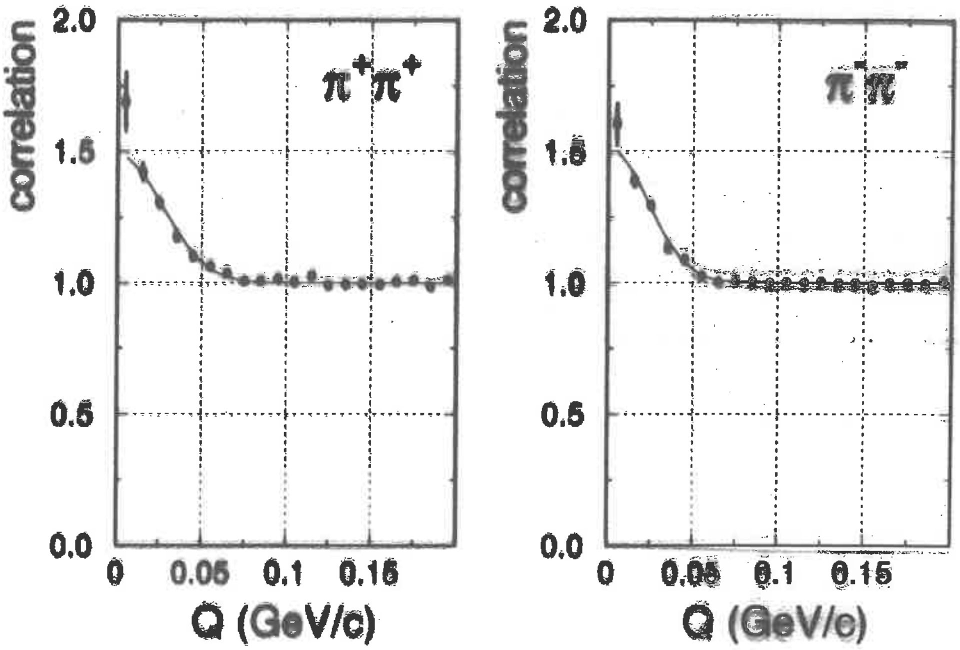
Coulomb correction





▷ *System: Au+Au* ▷ *Beam energy: 10.8 GeV/c per nucleon* ▷ *Acceptance: around beam rapidity,* $p_t < 0.7$ *GeV/c* ▷ *Trigger: central 10%* ▷ *Corrected for: two track resolution, Coulomb* ▷ *Not corrected for: momentum resolution* ▷ *Kinematic cuts: 0.5 GeV/c<* p_{LAB} *<5 GeV/c* ▷ *Reference frame: irrelevant*

Gaussian fit to 1-dim correlations



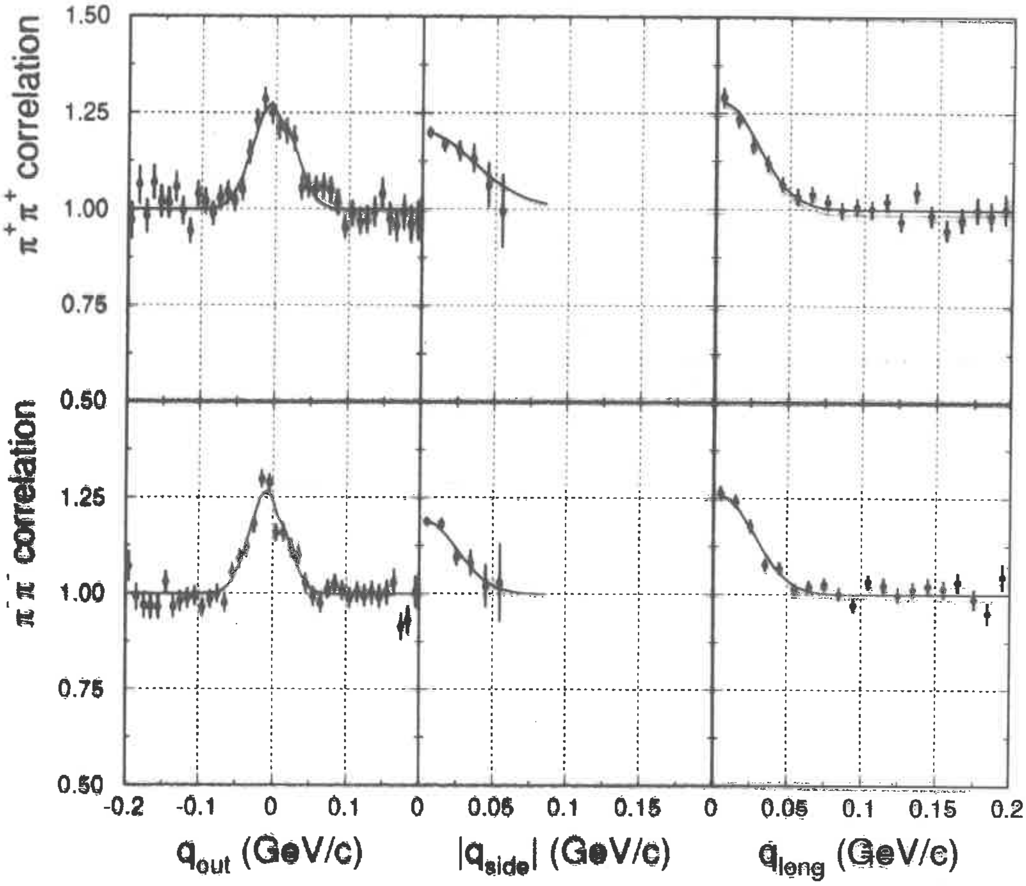
Fit function: $1 + \lambda \exp(-Q^2 R^2)$

Coulomb	λ	R (fm)
$\pi^+\pi^+$	0.48±0.04	5.4±0.3
$\pi^-\pi^-$	0.51±0.03	6.2±0.2

Gamow	λ	R (fm)
$\pi^+\pi^+$	0.56±0.04	5.1±0.2
$\pi^-\pi^-$	0.62±0.03	5.9±0.2

▷ *System: Au+Au* ▷ *Beam energy: 10.8 GeV/c per nucleon* ▷ *Acceptance: around beam rapidity, pt <0.7 GeV/c* ▷ *Trigger: central 10%* ▷ *Corrected for: two track resolution, Coulomb* ▷ *Not corrected for: momentum resolution* ▷ *Kinematic cuts: 0.5 GeV/c< p_{LAB} <5 GeV/c* ▷ *Reference frame: irrelevant*

Out-side-long fit



Fit function:

$$C(q_o, q_s, q_l) = 1 + \lambda \exp(-R_o{}^2 q_o{}^2 - R_s{}^2 q_s{}^2 - R_l{}^2 q_l{}^2 - 2|R_{ol}| R_{ol} q_o q_l)$$

Fit results:

	λ	R_o(fm)	R_s(fm)	R_l(fm)	R_{ol}(fm)
$\pi^+\pi^+$	0.50±0.04	5.1±0.4	3.8±0.7	5.5±0.4	2.3±0.6
$\pi^-\pi^-$	0.53±0.03	5.9±0.3	5.8±0.6	6.0±0.3	3.7±0.4

▷ *System:* *Au+Au* ▷ ***Beam energy:*** *10.8 GeV/c per nucleon* ▷ ***Acceptance:*** *around beam rapidity, p_t <0.7 GeV/c* ▷ ***Trigger:*** *central 10%* ▷ ***Corrected for:*** *two track resolution, Coulomb* ▷ ***Not corrected for:*** *momentum resolution* ▷ ***Kinematic cuts:*** *0.5 GeV/c< p_{LAB} <5 GeV/c* ▷ ***Reference frame:*** *3.14*

Phase space density from BE correlations

G. Bertsch, Phys.Rev.Lett. 72(1994)2349

Phase space density $f(\vec{r}, \vec{p})$ – number of pions per h^3 volume in 6-dim phase space

Source function $g(\vec{r}, t, \vec{p})$ – number of pions which have their last interaction in a h^3 volume in 6-dim phase space per unit time

Relation between f and g:

$$g(\vec{r}, t, \vec{p}) = \delta(t - t_0) f(\vec{r}, \vec{p})/(2\pi)^3$$

Mean phase space density:

$$< f >_{\vec{p}} := \frac{\int d^3r\ [f(\vec{r}, \vec{p})]^2}{\int d^3r\ f(\vec{r}, \vec{p})}$$

Denominator:

$$\int d^3r \; f(\vec{r},\vec{p}) = (2\pi)^3 \; \frac{d^3n}{d^3p}$$

Numerator:

$$(2\pi)^3 \int d^3q \int d^4r_1 \int d^4r_2 \; g_1 \; g_2 \; \cos(q\Delta r)$$
$$= (2\pi)^{-3} \int d^3r_1 \int d^3r_2 \; f_1 \; f_2 \int d^3q \cos(q\Delta r)$$
$$= \int d^3r \, f^2$$

Mean phase space density:

$$< f >_{\vec{p}} = \left(\frac{d^3n}{d^3p}\right)^{-1} \int d^3q \int d^4r_1 \int d^4r_2 \; g_1 \; g_2 \cos(q\Delta$$

But from Pratt's Formula

$$\int d^4r_1 d^4r_2\, g_1 g_2 \cos(q\Delta r) = \frac{d^6n}{d^3p_1 d^3p_2} - \frac{d^3n}{d^3p_1}\frac{d^3n}{d^3p_2}$$

and thus

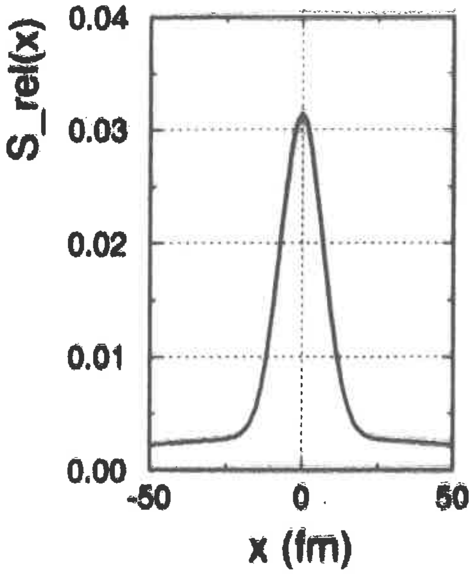
$$< f >_{\vec{p}} = \left(\frac{d^3n}{d^3p}\right)^{-1} \int d^3q \left[\frac{d^6n}{d^3p_1 d^3p_2} - \frac{d^3n}{d^3p_1}\frac{d^3n}{d^3p_2}\right]$$

or, even better,

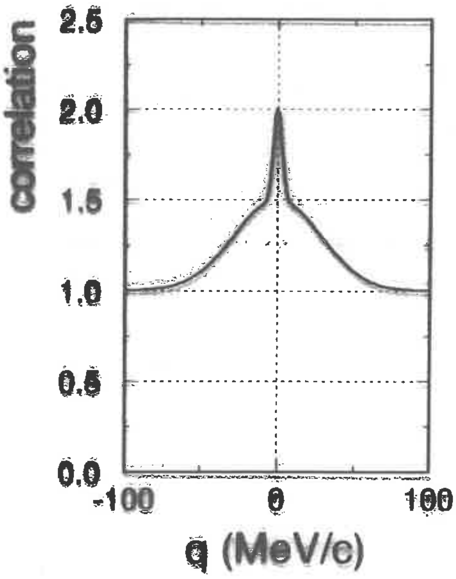
$$< f >_{\vec{p}} = \frac{d^3n}{d^3p} \int d^3q\, [C(\vec{q}) - 1]$$

What is this all about?

Relative source distribution $S(x)$



Correlation $1+\tilde{S}(q)$



$\tilde{S}$ is a Fourier transform of S

$$\Downarrow$$

$$\int S\,dx = \tilde{S}(0) = 1$$

$$\int x\,S\,dx = \tilde{S}'(0) = 0$$

$$\int x^2\,S\,dx = \tilde{S}''(0) =$$ Relative source siz *including tails*

$(2\pi)^3 S$ is a Fourier transform of $\tilde{S}$

$$\Downarrow$$

$$\int \tilde{S}\,dq = (2\pi)^3 S(0) =$$ HERE!

$$\int q\,\tilde{S}\,dq = (2\pi)^3 S'(0) = 0$$

$$\int q^2\,\tilde{S}\,dq = (2\pi)^3 S''(0) = (\text{Rel. s. size})^{-1}$$ *only core*

Let's parametrize the correlation function.

$$C(\vec{q}) = 1 + \lambda \exp(-{R_o}^2 {q_o}^2 - {R_s}^2 {q_s}^2 ...)$$

Then

$$< f >_{\vec{p}} = \frac{d^3 n}{d^3 p} \, \frac{\sqrt{\pi^3}\lambda}{R_s \sqrt{R_o^2 R_l^2 - R_{ol}^4}}$$

or, to make it look simpler,

$$< f >_{\vec{p}} = \frac{d^3 n}{d^3 p} \, \frac{\sqrt{\pi^3}\lambda}{R^3}$$

How to get rid of pions from halo

Suppose there is no halo. Then

$$< f >_{\vec{p}} = \frac{d^3n}{d^3p} \frac{\sqrt{\pi}^3}{R^3}$$

Thus

$$< f >_{\vec{p}}^{core} = \left(\frac{d^3n}{d^3p}\right)^{core} \left(\frac{\sqrt{\pi}^3}{R^3}\right)^{core}$$

But

$$\left(\frac{d^3n}{d^3p}\right)^{core} = \sqrt{\lambda} \left(\frac{d^3n}{d^3p}\right)^{total}$$

Thus

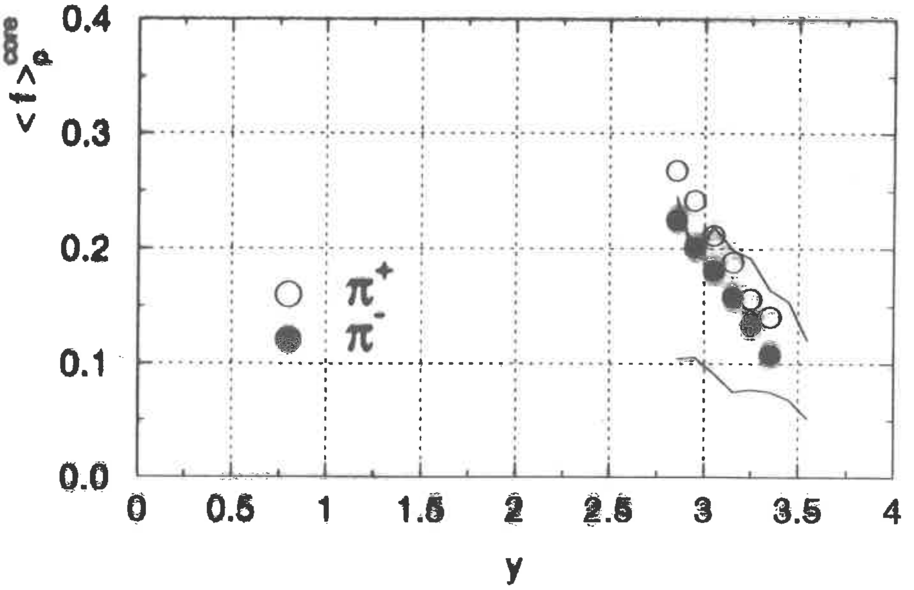
$$< f >_{\vec{p}}^{core} = \frac{d^3n}{d^3p} \frac{\sqrt{\pi}^3 \sqrt{\lambda}}{R^3}$$

By the way, the circle closes:

$$< f >_{\vec{p}}^{total} = \sqrt{\lambda} < f >_{\vec{p}}^{core} + (1 - \sqrt{\lambda}) \underbrace{< f >_{\vec{p}}^{halo}}_{0}$$

Phase space density at pt=0 from out-side-long

$$< f >_{\vec{p}}^{core} = \frac{d^3n}{d^3p} \; \frac{\sqrt{\pi}^3 \sqrt{\lambda}}{R_O R_s R_l}$$



▷ *System: Au+Au* ▷ *Beam energy: 10.8 GeV/c per nucleon* ▷ *Acceptance: around beam rapidity, pt <0.7 GeV/c* ▷ *Trigger: central 10%* ▷ *Corrected for: two track resolution, Coulomb* ▷ *Not corrected for: momentum resolution* ▷ *Kinematic cuts: 0.5 GeV/c< p_{LAB} <5 GeV/c* ▷ *Reference frame: 3.14, should not matter*

Let's parametrize spectra

$$\frac{d^3n}{d^3p} = \frac{A}{\exp(m_t/T_{eff}) - 1}$$

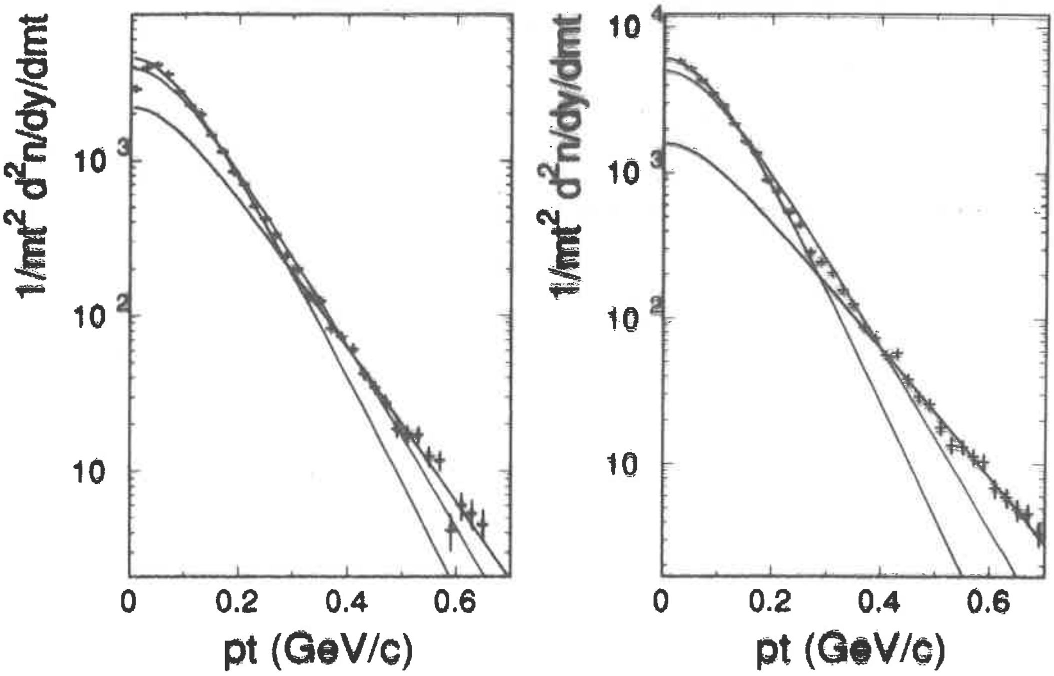
Comparison between experimental and thermal phase space density

$$\frac{< f >_{\vec{p}}^{core}}{f^{BE}(\vec{p})} = A \cdot \frac{\sqrt{\pi}^3 \sqrt{\lambda}}{R^3}$$

This ratio is 0.94±0.21 for π^+ and 0.91±0.15 for π^- in the rapidity range 3.0-3.3.

BE fit to pion mt-spectra y=3.1-3.2

π^+ π^-



	π^+		π^-	
Fit range	A	T (MeV)	A	T (MeV/c)
low pt	40225	61	80847	53
high pt	9334	84	5420	95
all pt	23711	71	35614	67

▷ *System: Au+Au* ▷ *Beam energy: 10.8 GeV/c per nucleon* ▷ *Acceptance: around beam rapidity,* pt *<0.7 GeV/c* ▷ *Trigger: central 10%* ▷ *Corrected for: two track resolution, Coulomb* ▷ *Not corrected for: momentum resolution* ▷ *Kinematic cuts: 0.5 GeV/c<* p_{LAB} *<5 GeV/c* ▷ *Reference frame: irrelevant*

CONCLUSION

- HALO SIZE IS MEASURABLE
- PION AND PROTON SOURCES ARE POSSIBLY DETACHED

- PION PHASE SPACE DENSITY AT FREEZE-OUT IS CONSISTENT WITH LOCAL EQUILIBRIUM

WHY 1-DIMENSIONAL ANALYSIS IS BAD ?

NOT SO

1. PAIR C.M. SYSTEM ...

   ... BUT YKP → $Y_{SOURCE} \approx Y_{PIONS}$

2. R CONTAINS R_x, R_y, R_z ...

   ... BUT YKP → $R_x \approx R_y \approx R_z$

3. R CONTAINS $\Delta\tau$ ...

   ... BUT $\Delta\tau \approx 0$