The Berkeley School – May/19-27/2005

Two-Particle Correlations: *open issues*

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From recent achievements & challenges...

- Impressive amount of good quality HBT data and analysis (M. Lisa's talk)
- Finally (after suggestion in 1987!) →directional HBT experiment
- Reconstruction of emission geometry through variances!
- Step forward: beyond Gaussian variances → checking validity of approximations & subsequent conclusions
- Remember, the start of the whole story:

$$C(q,K) \approx 1 + \left| \frac{\int d^4x\, e^{iq^\mu x_\mu} S(x,K)}{\int d^4x\, S(x,K)} \right|^2$$

⇨ Smoothness + on mass-shell approx. + on-shell constraint:

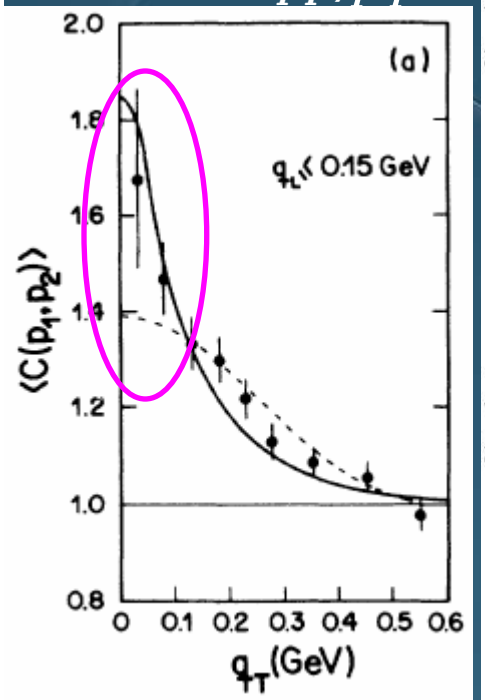
$$S(x_i,k_i) \equiv S(x_i, K \pm q/2) \approx S(x_i,K)$$

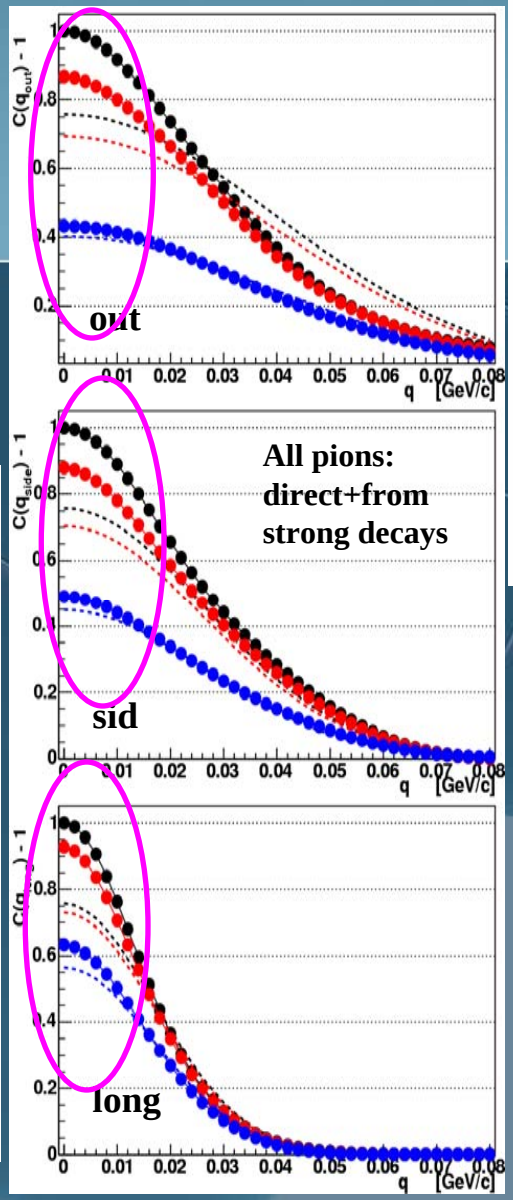
$$K^0 \approx \sqrt{K^2 + m^2} = E_k$$

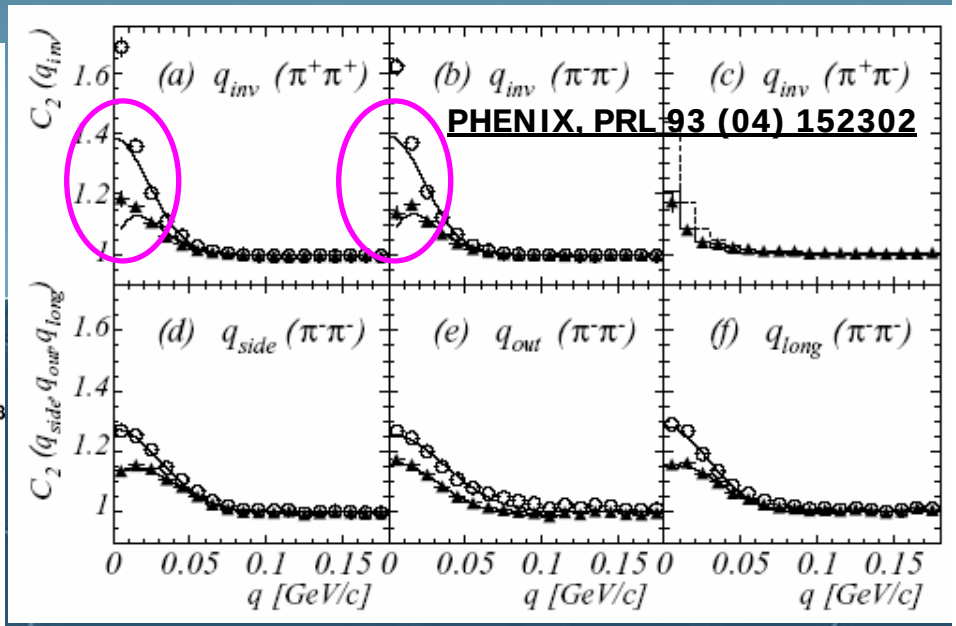
$$q^0 = \frac{\vec{q}.\vec{K}}{K^0} \approx \frac{\vec{q}.\vec{K}}{E_K}$$

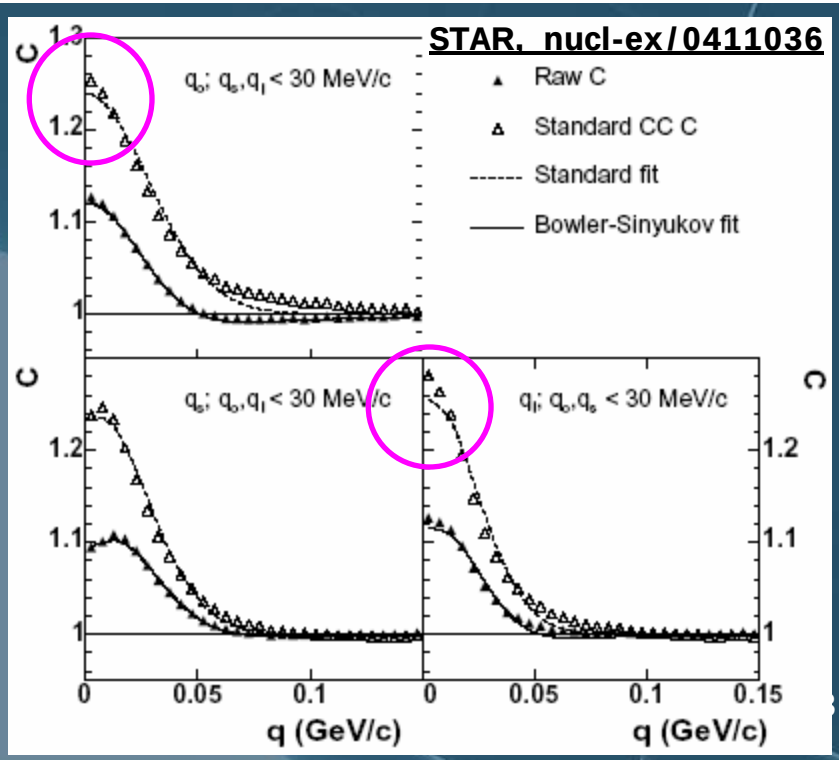
- The Gaussian variances came from that expression
- However, many experimental results shown to be non-Gaussian

PRD 37 ('88) 3237
Data: ISR $pp, \bar{p}p$









Results from
Adam Kisiel's talk
on Therminator

Step forward: beyond Gaussian variances in HBT

- **Suggested procedure in the future: (qualitative)**
  - **Calculate Gaussian variances → shown to be useful for studying dependence on K_T, $\sqrt{s}$, selected directions, etc.**
  - **Construct 3(n)-D Gaussian correlation function with the variances**
  - **Calculate *real* 3(n)-D correlation functions with dynamical models or model-inspired parameterizations**
    - **i) within smoothness approx.**
    - **ii) without assuming smoothness**
  - **Compare 3(n)-D CF generated in each case with data and SHOW them**
  - **Project the CF in q -components for each case and compare w/ data**
  - **How far or how close are the variances from CF data and models ?? (quantitative procedure)**
  - **Perform χ^2 analysis for choosing dynamical models that best describe data; may need to look into $|\langle\chi^2\rangle/\mathrm{dof} - 1|$ in (q_i, q_j, ...) plane**

Back-to-back correlations

for completeness and challenge...

Asakawa, Csörgö & Gyulassy [P.R.L. 83 (1999) 4013] → showed that BBC correlations existed among particle-antiparticle pairs, if the mass of the particles is modified in a hot and dense medium (→ signal)

→ precursors: Weiner et al. , Sinyukov (although they did not had it all right)

$$N_1(\vec{k}_1) = \omega_{k_1} \frac{d^3N}{d^3k} = \omega_{k_1} \left\langle a^\dagger_{k_1} a_{k_1} \right\rangle \quad ; \quad N_2(\vec{k}_1, \vec{k}_2) = \omega_{k_1}\omega_{k_2} \left\langle a^\dagger_{k_1} a^\dagger_{k_2} a_{k_1} a_{k_2} \right\rangle$$

$$\left\langle a^\dagger_{k_1} a^\dagger_{k_2} a_{k_1} a_{k_2} \right\rangle = \underbrace{\left\langle a^\dagger_{k_1} a_{k_1} \right\rangle \left\langle a^\dagger_{k_2} a_{k_2} \right\rangle} + \underbrace{\left\langle a^\dagger_{k_1} a_{k_2} \right\rangle \left\langle a^\dagger_{k_2} a_{k_1} \right\rangle} + \underbrace{\left\langle a^\dagger_{k_1} a^\dagger_{k_2} \right\rangle \left\langle a_{k_1} a_{k_2} \right\rangle}$$

(chaotic) (squeezed)

$$C_2(\vec{k}_1, \vec{k}_2) = 1 + \underbrace{\frac{|G_c(1,2)|^2}{G_c(1,1)G_c(2,2)}}_{\text{HBT}} + \frac{|G_s(1,2)|^2}{G_c(1,1)G_c(2,2)}$$

→ $\pi^0\pi^0$

BBC

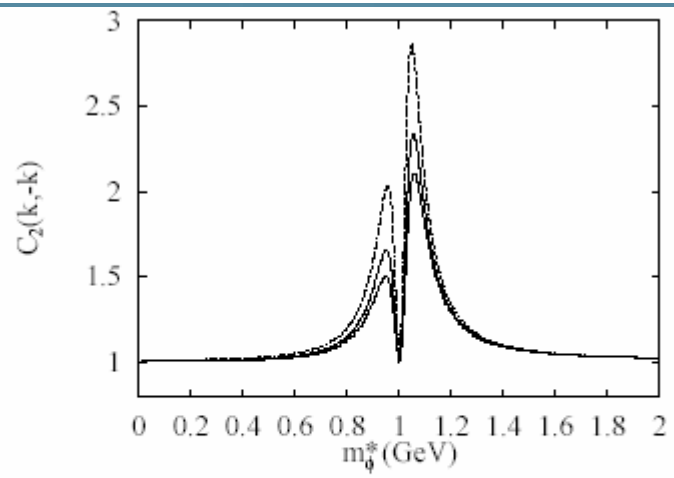


FIG. 1. Dependence of the back-to-back correlations (BBC) on the medium modified ϕ meson mass, m_ϕ^*, for $T = 140$ MeV and $\mu = 0$, where solid, dashed, and dotted lines stand for $|\mathbf{k}| = 0$, 300, and 500 MeV, respectively. The magnitude of the BBC is large in spite of the finite time suppression factor $1/[1 + (2\delta t\,\omega_{\mathbf{k}})^2] \sim 0.001$, for $\delta t = 2$ fm/c.

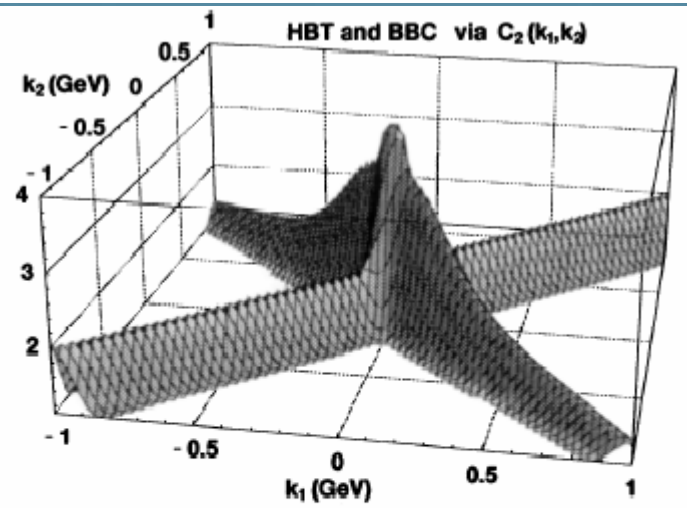


FIG. 2. Schematic illustration of the new kind of correlations for mass-shifted π^0 pairs, assuming $T = 140$ MeV, $G_c \sim \exp[-q_{12}^2 R_G^2/2]$, $G_s \sim \exp[-2K_{12}^2 R_G^2]$, with $R_G = 2$ fm. The fall of the BBC for increasing values of $|\mathbf{k}|$ is controlled here by a momentum-dependent effective mass, $m_\pi^* = m_\pi[1 + \exp(-\mathbf{k}^2/\Lambda_s^2)]$, with $\Lambda_s = 325$ MeV in the sudden approximation. Without the Λ_s cutoff, the BBC would increase indefinitely as $|\mathbf{k}| \to \infty$.

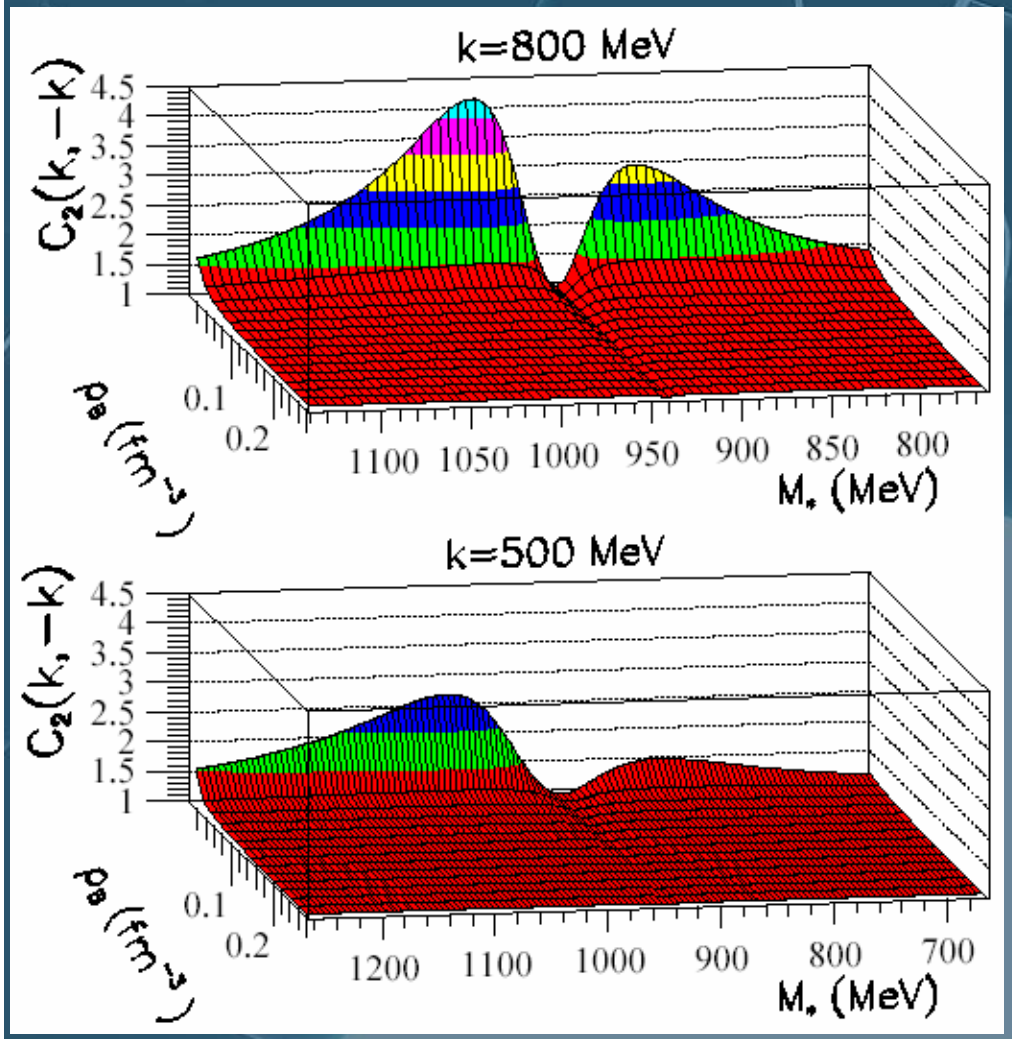
Asakawa, Csörgö & Gyulassy [PRL 83 (1999) 4013]

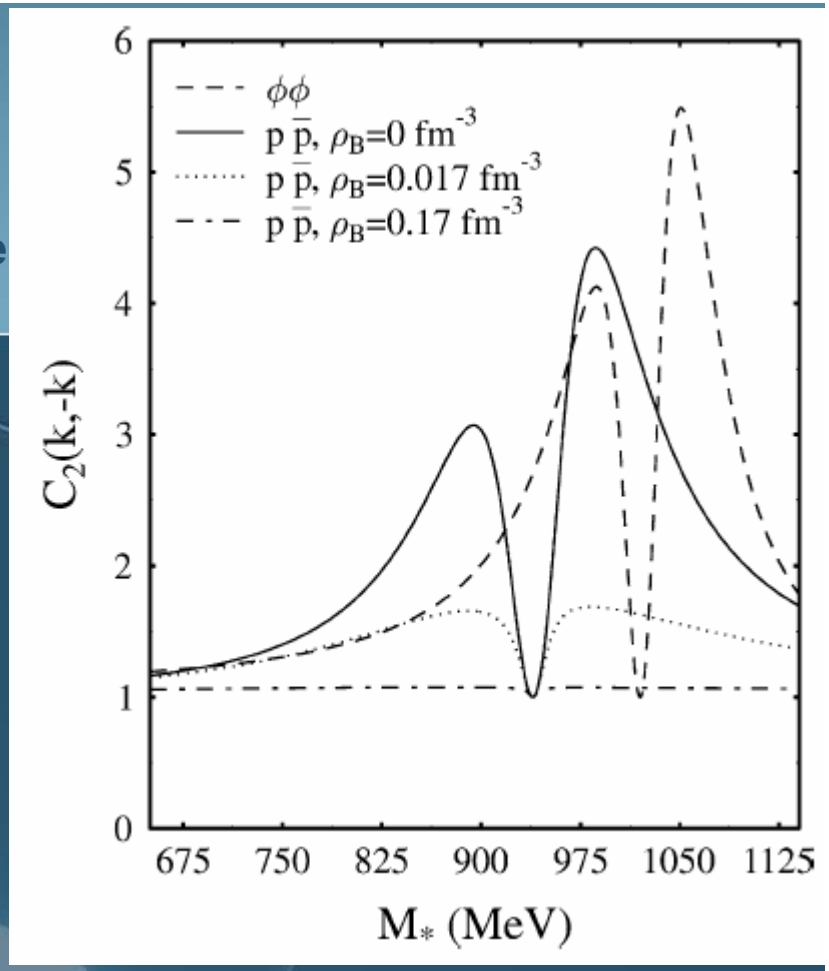
Mass-shifts resulting in different dispersion relation: $\Omega_k^2 = \omega_k^2 - \delta M^2$

Panda, Csörgö, Hama, Krein & SSP, P. L. B512 (2001) 49:

- **Similar formalism for both bosonic (bBBC) and fermionic (fBBC) cases**
- **Similar (and unlimited) intensity for BBC in both fermionic and bosonic cases**

Results for proton-antiproton pairs compared to ϕ-pairs (T=140 MeV; $\Delta t = 2fm/c$ and $|k|$=800 MeV/c) (increases approaching baryon-free region)





- Unlimited BBC: but effect is smaller for finite emission interval
- Effect increases for
  - * increasing k
  - * ≈ baryon-free region

BBC signal found to survive:

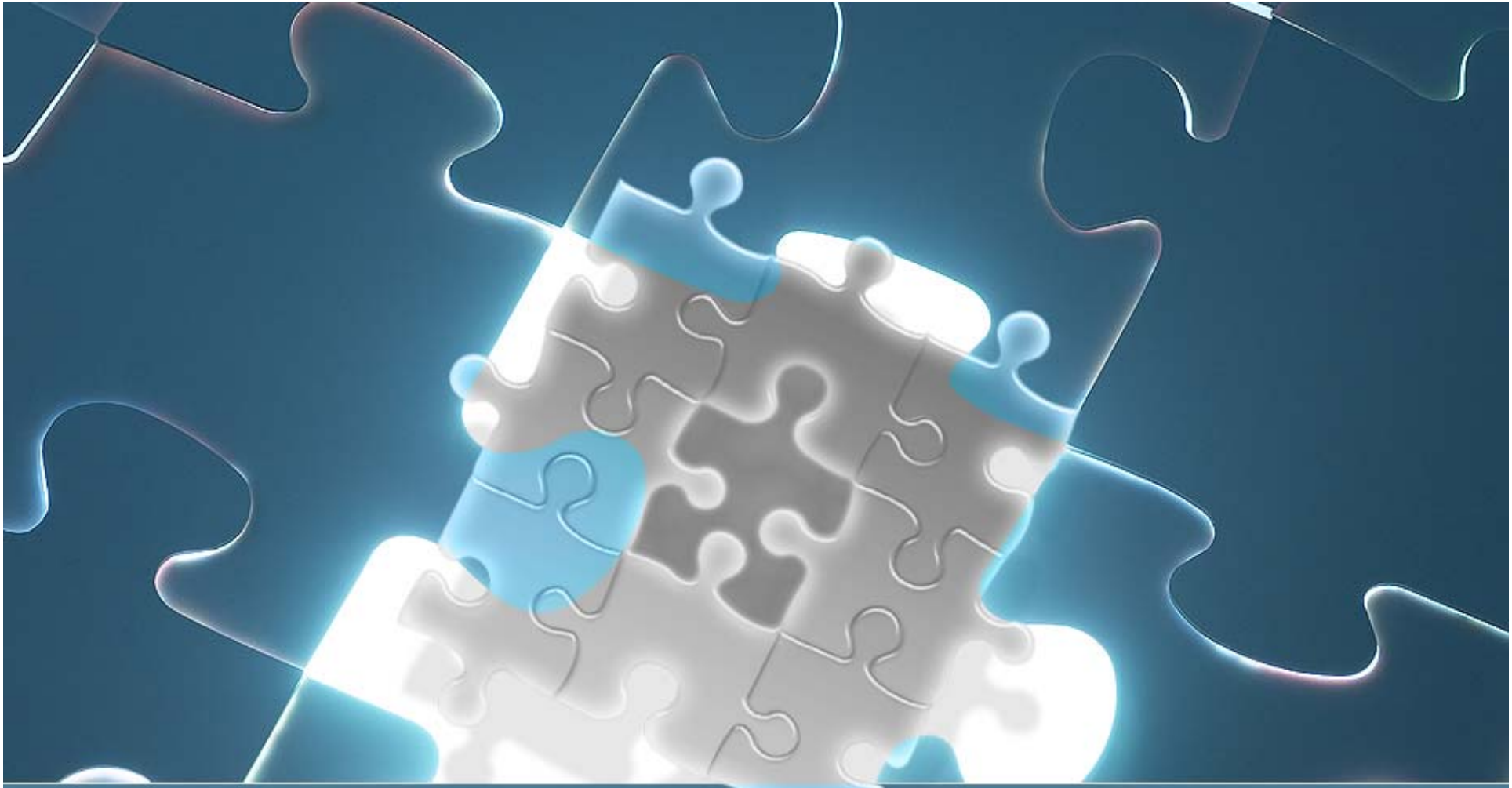
- finite emission times
- finite system sizes and finite squeezing volumes
- even if you have flow (radially expanding system)

So, that poses

NEW CHALLENGE TO EXPERIMENTALISTS:

LOOK FOR BBC in back-to-back

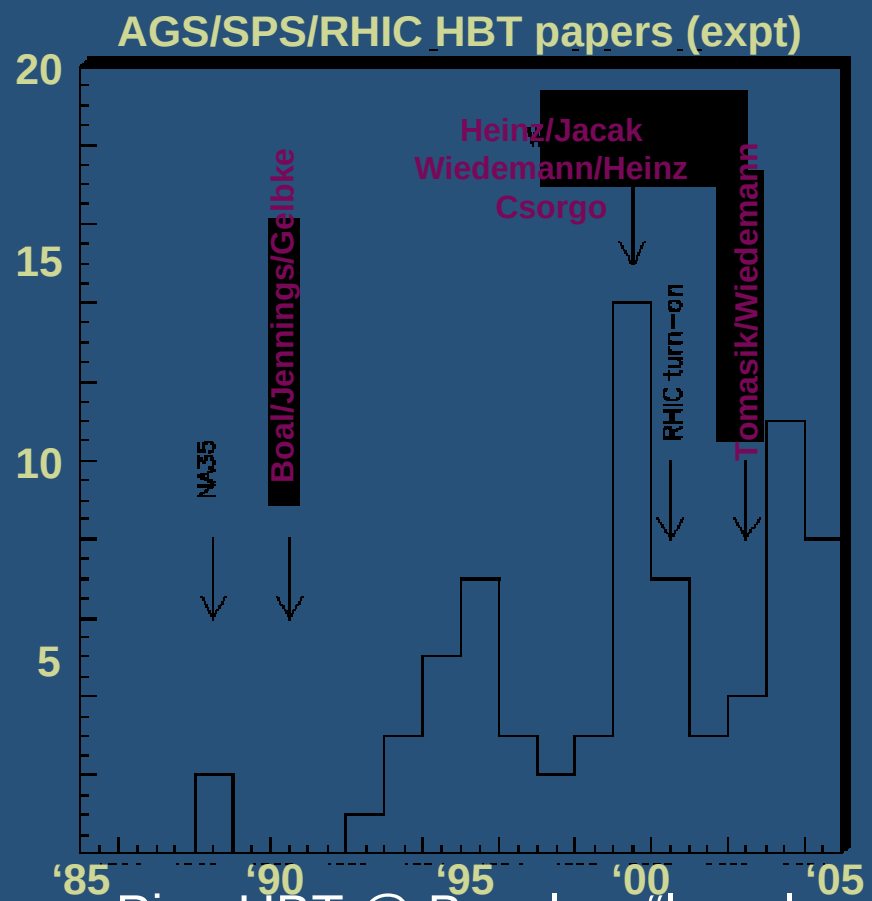
- $\phi\phi$ **correlations**
- $\bar{p}p$ **correlations**
- $\pi^+\pi^-$, $\pi^0\pi^0$ **correlations (?)**



Open Issues

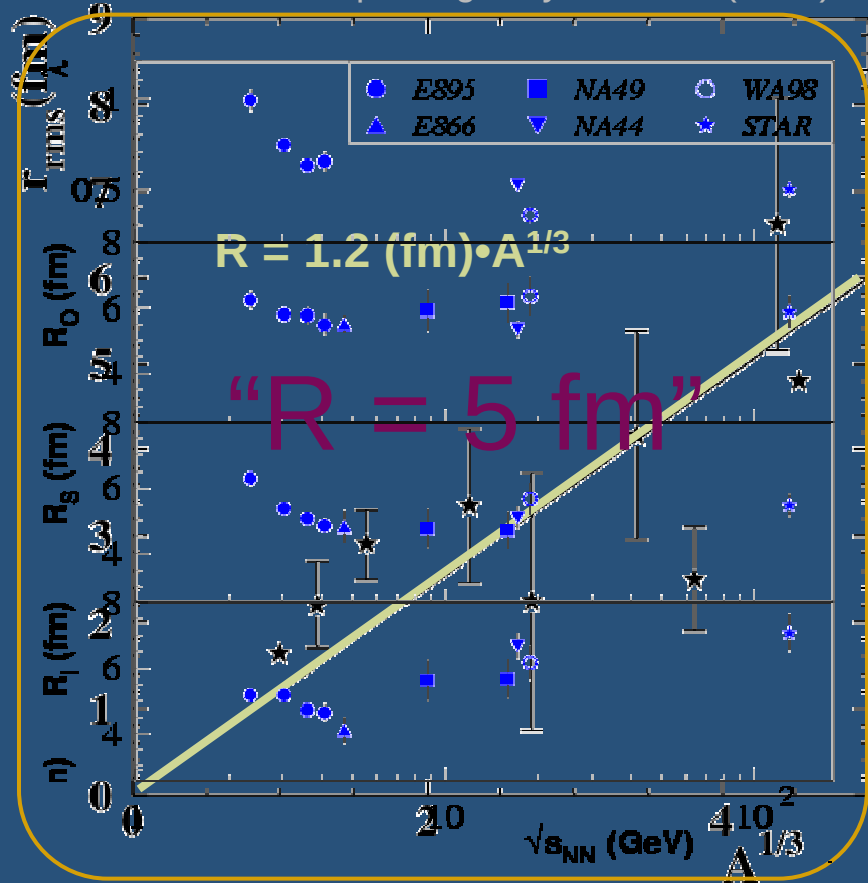
Mike's few slides

Systematic decadence



HBT($\sqrt{s}$)

A.D. Chacon et al, Phys. Rev. **C43** 2670 (1991)
G. Alexander, Rep. Prog. Phys. **66** 481 (2003)



- Pion HBT @ Bevalac: "largely confirming nuclear dimensions"
- Since 90's: increasingly detailed understanding and study w/ high stats

Non-gaussianness

- CF is NEVER Gaussian
- sometimes confusion: nobody expects Gaussian CF. It is Gaussian S(Dx,p) which is assumed.
  - source characterized by 2 params (in each direction): average and variance
  - true also for non-id CF results thus far
- Practical issue: each modern paper contains typically 100's of CFs, each with ~60K bins in q.
  - to observe source systematics, obviously need to reduce the information.
    - Information is always lost in such a procedure.
    - is it *crucial* information? Not clear (for large systems)
  - comparing full 3D CFs with models: not practical-- insight unlikely to be gained.
  - similar for imaging

Questions for Miller / Cramer

- obvious to expect agreement/consistency between “all” particle types?
- what’s about zero-th HBT puzzle?
- expect “trivial” centrality dependence? (Geometry and potential change in “lock-step”?)
- what’s about similar (but just scaled) behaviour of pp, dA collisions?
- piplus-piminus - any “predictions”?

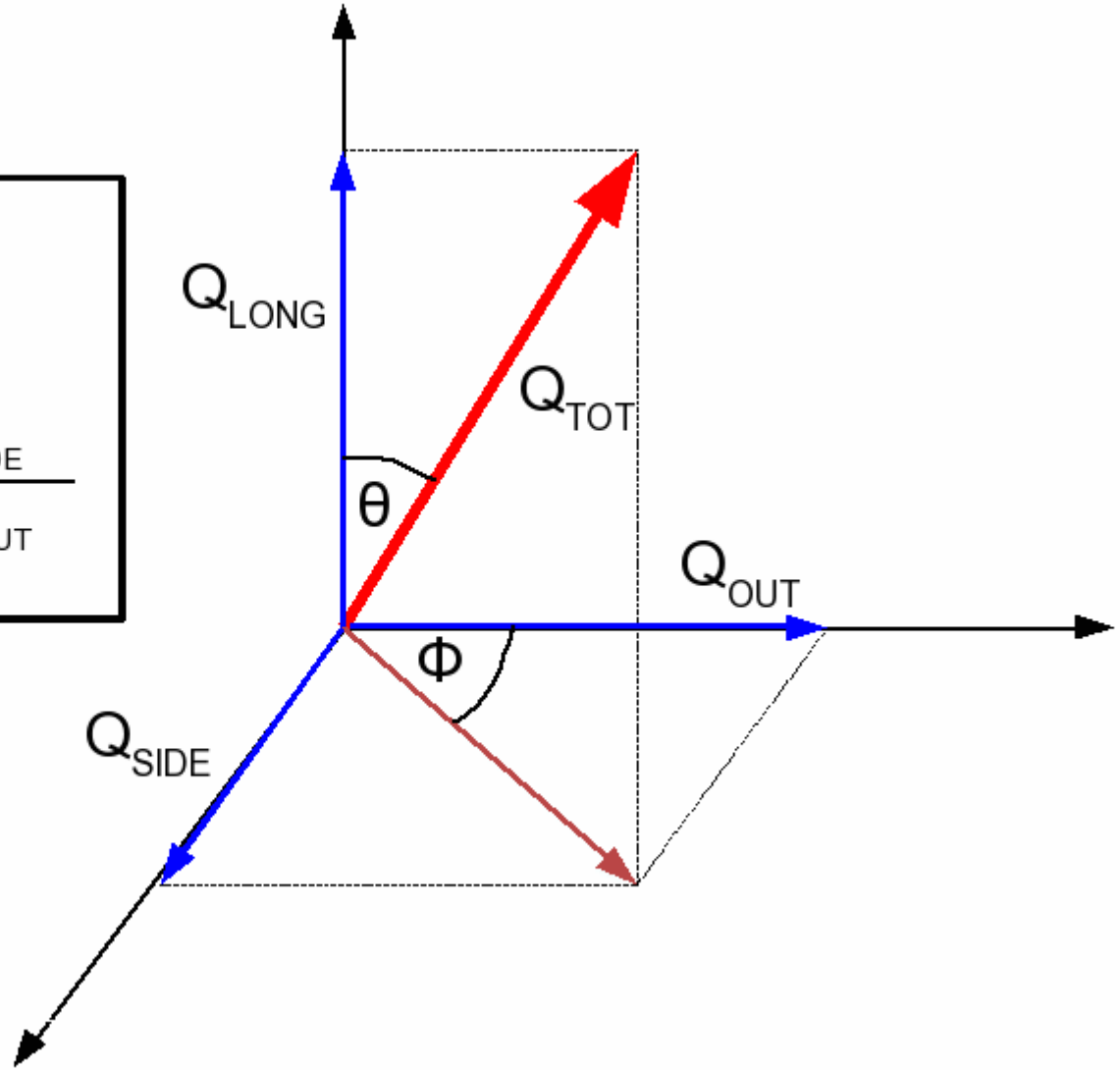
An alternate universe…

- v2 as expected; HBT ~ 40 %
  - → Announcement of success !
- HBT as expected (hoped); v2 ~ 40 %
  - → Announcement of success ?
  - my guess: yes.
- What about *neither* HBT *nor* v2?
  - would that be a “discovery” ??

Whole CF at a glance

$$\cos(\theta) = \frac{Q_{LONG}}{Q_{TOT}}$$

$$\Phi = \operatorname{atan}\frac{Q_{SIDE}}{Q_{OUT}}$$



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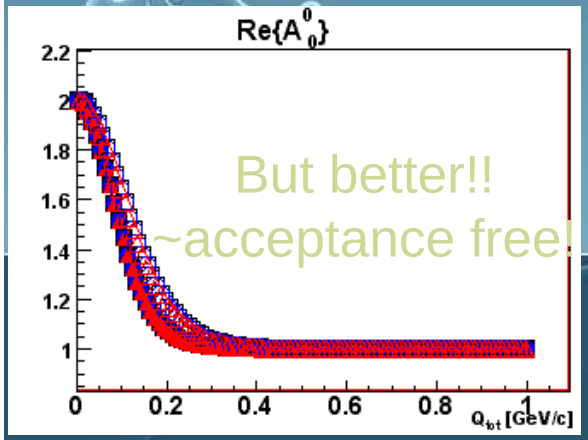
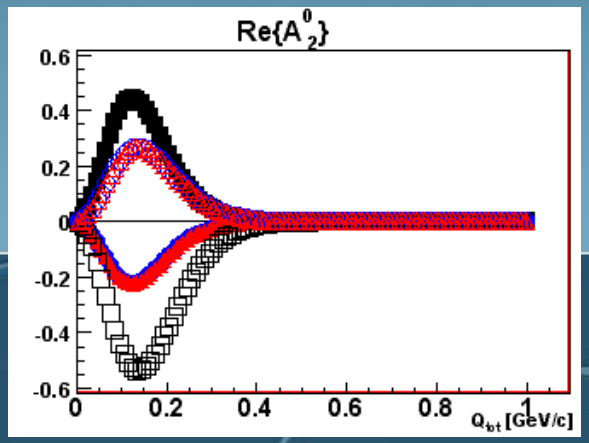
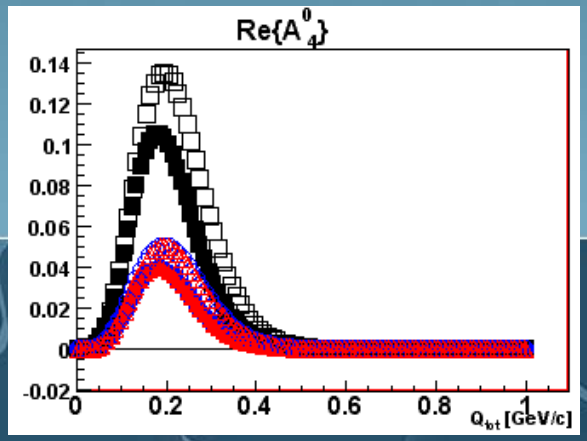
L=0 L=2 L=4

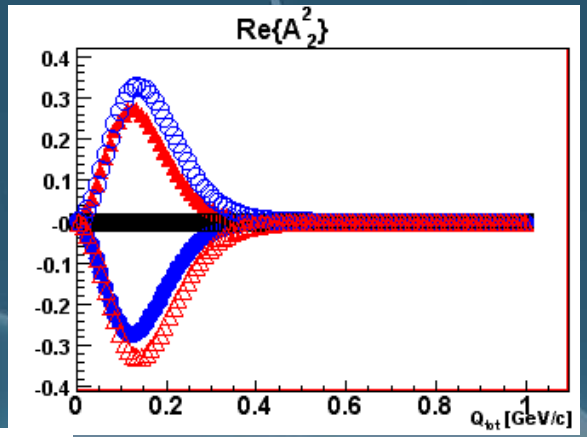


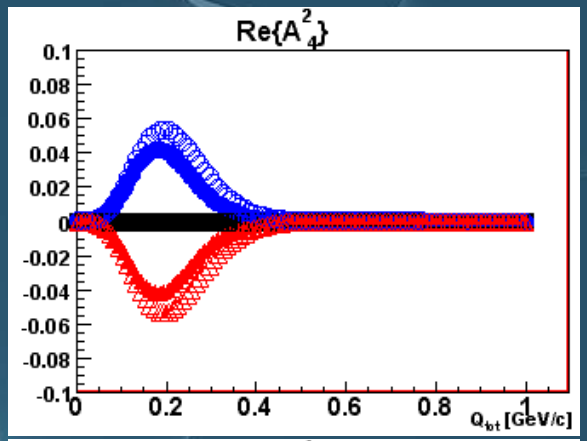
But better!!
~acceptance free!





M=0

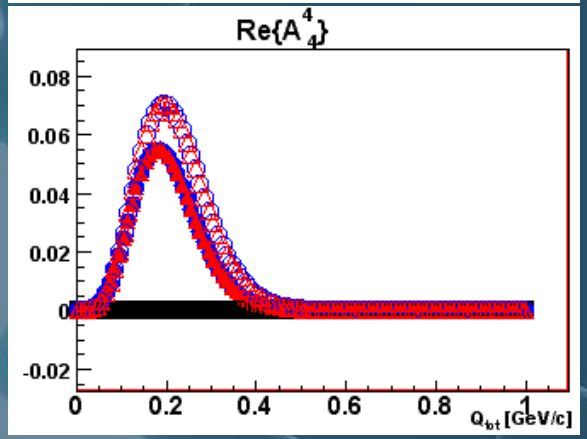




M=2

Simple, Gaussian source calculations

- ▲ R_{out}=1fm , R_{side}=2fm , R_{long}=2fm
- ● R_{out}=2fm , R_{side}=1fm , R_{long}=2fm
- ■ R_{out}=2fm , R_{side}=2fm , R_{long}=1fm
- △ R_{out}=2fm , R_{side}=1fm , R_{long}=1fm
- ○ R_{out}=1fm , R_{side}=2fm , R_{long}=1fm
- □ R_{out}=1fm , R_{side}=1fm , R_{long}=2fm



M=4