Time evolution of particle production in e+e- annihilation from Bose-Einstein Correlations

Tamás Novák

Károly Róbert College

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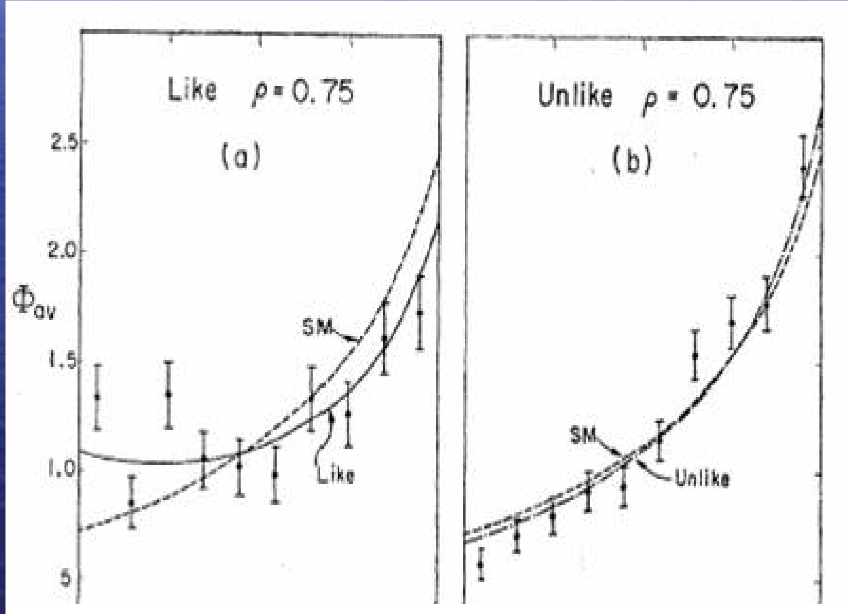
Questions and answers

What is the aim of this work?	To reconstract the pion emission function.
What is the emission function?	It says where and when and how many pions are produced. (See later)
How to reach it?	Using the Bose-Einstein Correlations. (See now)

Bose-Einstein Correlations

- This topic is almost 50 years old in high energy physics (Intensity Interferometry)
- In multiple particle production BECs were discovered accidentally as a byproduct of an unsuccessfull attempt to find the ρ meson.
- GGLP effect



G. Goldhaber et al., *Phys. Rev. Lett.* **3**(1959)181.

Bose-Einstein Correlation

- Analogous effect had been discovered earlier

(HBT effect)

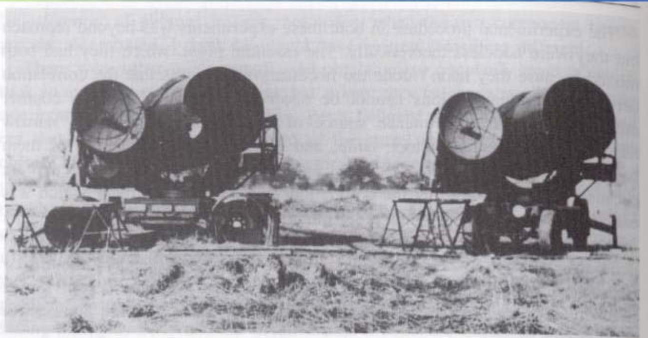


Figure 10.1 The first stellar intensity interferometer; the pilot model of the stellar intensity interferometer at Jodrell Bank in 1955. Two Army searchlights were used to make the first measurement of the angular diameter of a main sequence star (Sirius).

Figure 11.1 Narrabri Observatory in 1963, showing the circular railway track (618 foot diameter), the two optical reflectors (22 foot diameter), the central mast and control room, and the very large garage for the reflectors.

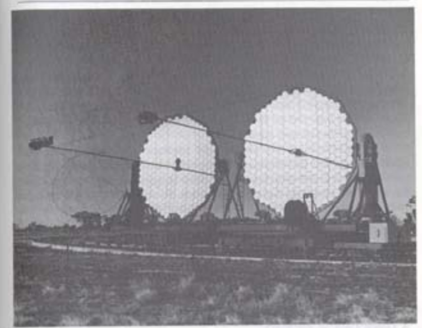
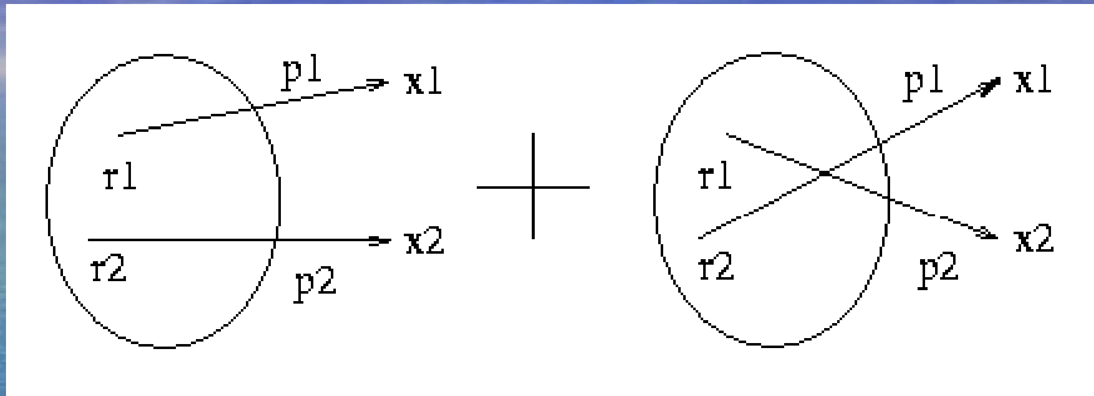


Figure 11.2 The two giant reflectors at Narrabri Observatory; the two optical reflectors of the Stellar Intensity Interferometer. Their reflecting surface was parabolic (diameter 22 feet and focal length 36 feet) and composed of 252 glass hexagonal mirrors front-aluminised and coated with silicon. Each mirror was heated electrically to prevent dew forming.

Determination of the angular radii of stars ~ Determination of the size of the source

Bose-Einstein Correlation



In theory:

$$C_2(p_1,p_2)=\frac{\frac{d^6n}{d^3p_1d^3p_2}}{\frac{d^3n}{d^3p_1}\frac{d^3n}{d^3p_2}}=\frac{\int d^4x_1d^4x_2f(x_1)f(x_2)|\Psi(1,2)|^2}{\int d^4x_1|\Psi(1)|^2\int d^4x_2|\Psi(2)|^2}=1+|\tilde{f}(\Delta p)|^2$$

Examples

The correlation function will be investigated as a function of Q, the invariant four-momentum difference. (See later)

Source function	Correlation function
Gaussian	$R_2(Q) = 1 + \lambda \exp\left(-(RQ)^2\right)$
Edgeworth expansion	$R_2(Q) = 1 + \lambda \exp\left[-(RQ)^2\right]\left[1 + \frac{\kappa}{3!}H_3(RQ)\right]$
Symmetric Lévy stable	$R_2(Q) = 1 + \lambda \exp\left(-\lvert RQ\rvert^{\alpha}\right)$

Coherence parameter

Bose-Einstein Correlation

In experience: $$R_2(p_1, p_2) = \frac{\rho_2(p_1, p_2)}{\rho_0(p_1, p_2)}$$

Two particle number density (Data)

Two particle density without BEC (Reference sample)

Puzzles in the late 80's

First, the measured correlation functions are consistent with the invariant Q dependence.

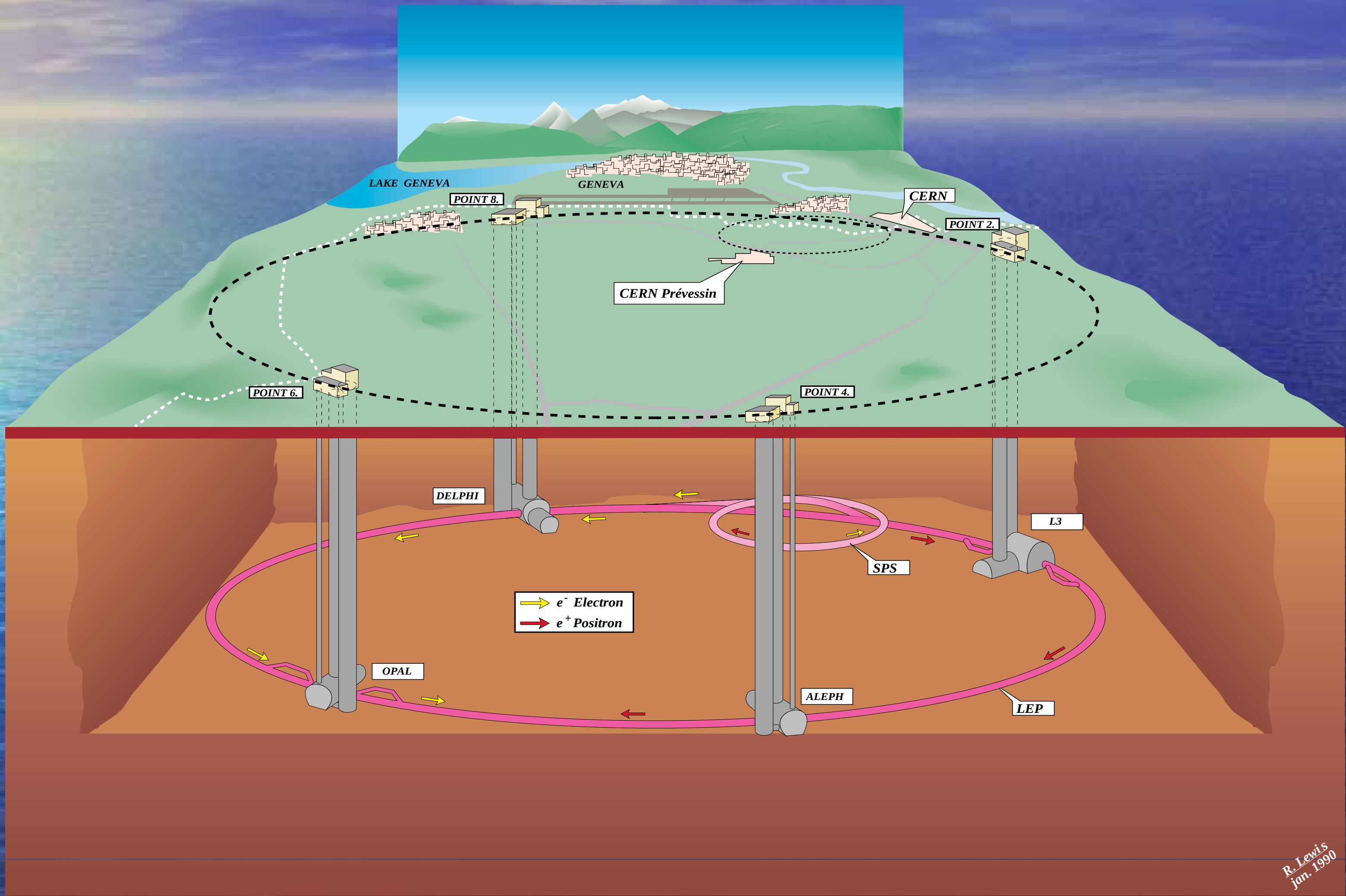
TASSO Collab., Althoff, M, Z. Phys. C30 (1986) 355–369.

(the statistics were not large enough)

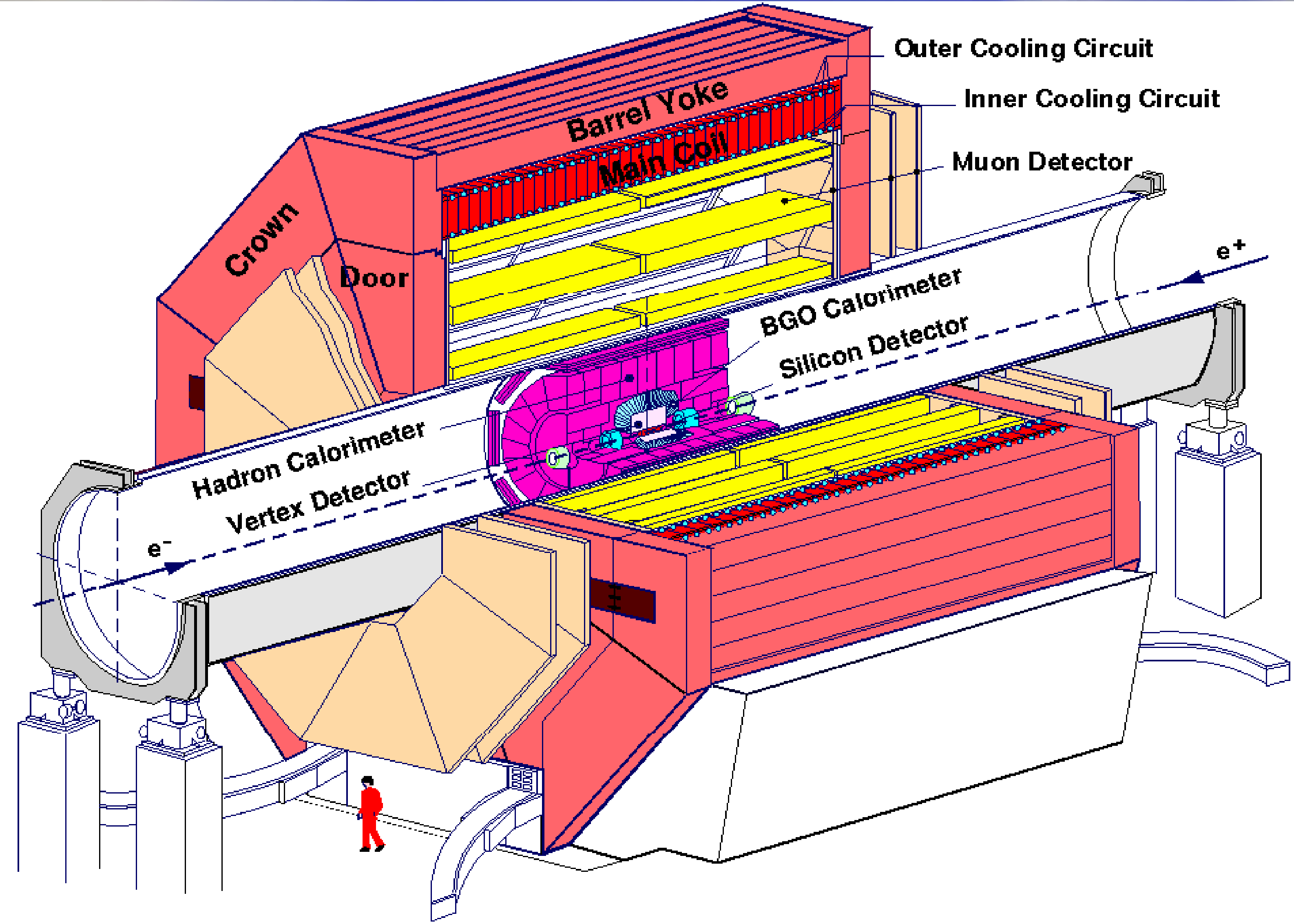
Second, the correlation function is more peaked than a Gaussian.

There was no theoretical model which predicted a mere Q dependence.

Large Electron Positron (LEP) collider



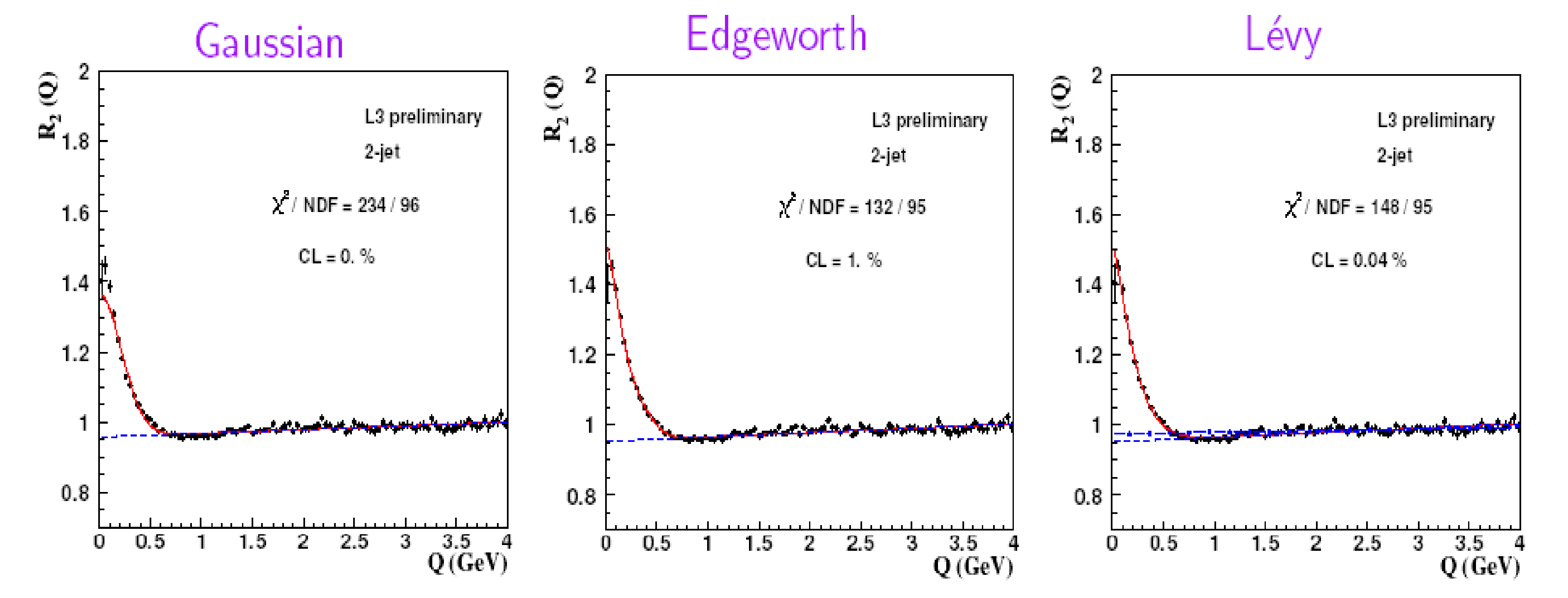
The L3 detector



Data Sample

- Hadronic Z decays using L3 detector
- 'Standard' event and track selection ≈ *1 million events*
- Concentrate on 2-jet events using *Durham* algorithm ≈ *0,5 million events*
- Correct distribution *bin-by-bin* by MC

Beyond the Gaussian



Far from Gaussian κ =0,71 ± 0,06 α=1,34 ± 0,04

Poor CLs. Edgeworth and Lévy better than Gaussian.

Problem is the dip in the region $0{,}6 < Q < 1{,}5$ GeV.

The τ-model

It is assumed that the average production point of particles and the four momentum are strongly correlated.

This correlation is much narrower than the proper-time distribution.

In the plane-wave approxiamtion, using the Yano-Koonin formula, one gets for two-jet events:

$$R_2(p_1, p_2) = 1 + \lambda \mathrm{Re} \widetilde{H}^2 \left(\frac{Q^2}{2\overline{m}_t} \right)$$

T. Csörgő and J. Zimányi, Nucl. Phys. **A517** (1990) 588.

Further assumptions

Assume a Lévy distribution for $H(\tau)$.

Since no particle production before the interaction, $H(\tau)$ is one-sided.

Then

$$R_2(Q,\overline{m}_t) = \gamma\left[1+\lambda\cos\left(\frac{\tau_0 Q^2}{\overline{m}_t}+\tan\left(\frac{\alpha\pi}{2}\right)\left(\frac{\Delta\tau Q^2}{2\overline{m}_t}\right)^{\alpha}\right)\exp\left(-\left(\frac{\Delta\tau Q^2}{2\overline{m}_t}\right)^{\alpha}\right)\right](1+\delta Q)$$

where
- α is the index of stability
- τ_0 is the proper time of the onset of particle production
- $\Delta\tau$ is a measure of the width of the dist.

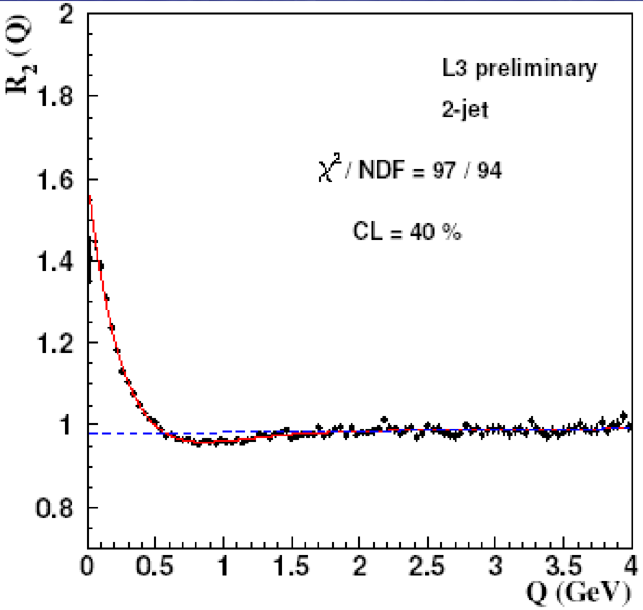
$$R_2(Q,\overline{m}_t) = \gamma\left[1+\lambda\cos\left(\frac{\tau_0 Q^2}{\overline{m}_t} + \tan\left(\frac{\alpha\pi}{2}\right)\left(\frac{\Delta\tau Q^2}{2\overline{m}_t}\right)^{\alpha}\right)\exp\left(-\left(\frac{\Delta\tau Q^2}{2\overline{m}_t}\right)^{\alpha}\right)\right](1+\delta Q)$$

Before fitting in two dimensions $(Q,\overline{m}_t)$, assume an 'average' $\overline{m}_t$ dependence by introducing effective radius $R=\sqrt{\Delta\tau/(2\overline{m}_t)}$

Also assumed $\tau_0 = 0$. Then

$$R_2(Q) = \gamma\left[1+\lambda\cos\left[(R_a Q)^{2\alpha}\right]\exp\left(-(RQ)^{2\alpha}\right)\right](1+\delta Q) \qquad R_a^{2\alpha} = \tan\left(\frac{\alpha\pi}{2}\right)R^{2\alpha}$$

parameter	R_a free	$R_a^{2\alpha} = \tan\left(\frac{\alpha\pi}{2}\right)R^{2\alpha}$
α	0.42 ± 0.02	0.42 ± 0.01
λ	0.67 ± 0.03	0.67 ± 0.03
R (fm)	0.79 ± 0.04	0.79 ± 0.03
R_a (fm)	0.59 ± 0.03	—
δ	0.003 ± 0.002	0.003 ± 0.001
γ	0.979 ± 0.005	0.979 ± 0.005
χ^2/DoF	97/94	97/95
CL	40%	42%



R_a free or not gives same results. – Good CL

$$R_2(Q,\overline{m}_t) = \gamma\left[1+\lambda\cos\left(\frac{\tau_0 Q^2}{\overline{m}_t} + \tan\left(\frac{\alpha\pi}{2}\right)\left(\frac{\Delta\tau Q^2}{2\overline{m}_t}\right)^{\alpha}\right)\exp\left(-\left(\frac{\Delta\tau Q^2}{2\overline{m}_t}\right)^{\alpha}\right)\right](1+\delta Q)$$

Before fitting in two dimensions $(Q,\overline{m}_t)$, assume an 'average' $\overline{m}_t$ dependence by introducing effective radius $R=\sqrt{\Delta\tau/(2\overline{m}_t)}$

Also assumed $\tau_0 = 0$. Then

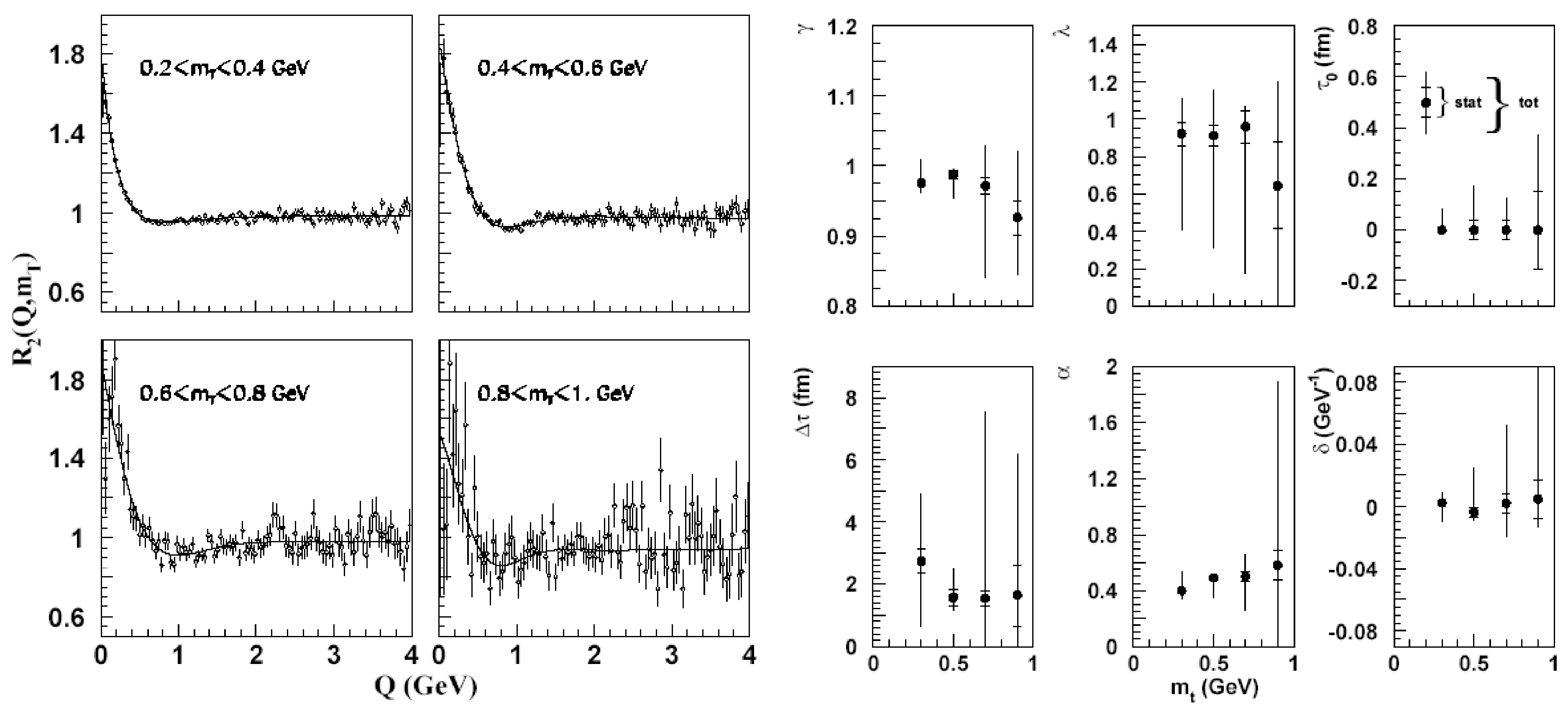
$$R_2(Q) = \gamma\left[1+\lambda\cos\left[(R_a Q)^{2\alpha}\right]\exp\left(-(RQ)^{2\alpha}\right)\right](1+\delta Q)$$

$$R_a^{2\alpha} = \tan\left(\frac{\alpha\pi}{2}\right) R^{2\alpha}$$

parameter	R_a free	$R_a^{2\alpha} = \tan\left(\frac{\alpha\pi}{2}\right) R^{2\alpha}$
α	0.35 ± 0.01	0.44 ± 0.01
λ	0.84 ± 0.04	0.77 ± 0.04
R (fm)	0.89 ± 0.03	0.84 ± 0.04
R_a (fm)	0.88 ± 0.04	—
δ	-0.003 ± 0.002	0.010 ± 0.001
γ	1.001 ± 0.005	0.972 ± 0.001
χ^2/DoF	102/94	174/95
CL	27%	10^{-6}

For three-jet event

Results



CLs are good. Parameters are approx. independent of m_T.

τ_0=0,0 ± 0,01 fm α=0,43 ± 0,01 Δτ=1,8 ± 0,4 fm

Emission function of 2-jet events

In the τ-model, the emission function is:

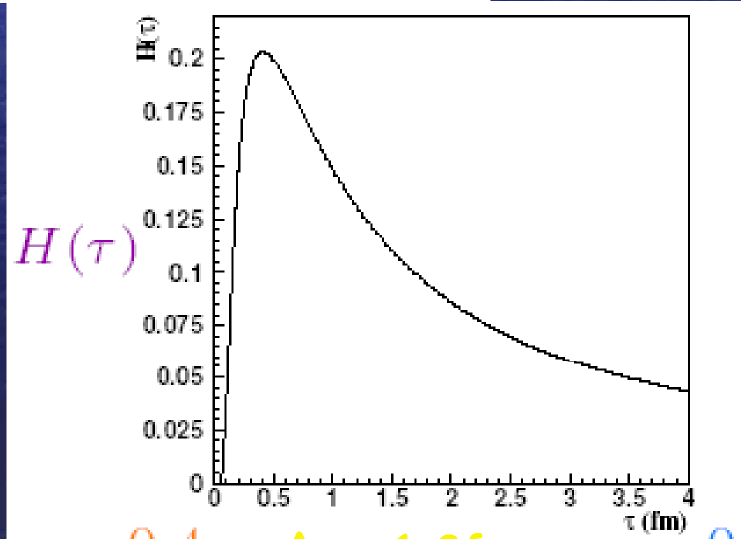
$$S(x) = \frac{d^4 n}{d\tau d^3 r} = \left(\frac{m_t}{\tau}\right)^3 H(\tau) \rho_1 \left(k = \frac{r m_t}{\tau}\right)$$

For simplicity, assume $S(r,z,t) = G(\eta) I(r) H(\tau)$

where

$G(\eta) = N_y(\eta) \qquad I(r) = \left(\frac{m_t}{\tau}\right)^3 N_{p_t}(r m_t/\tau)$

(N_y, N_{p_t} are inclusive single-particle distributions)

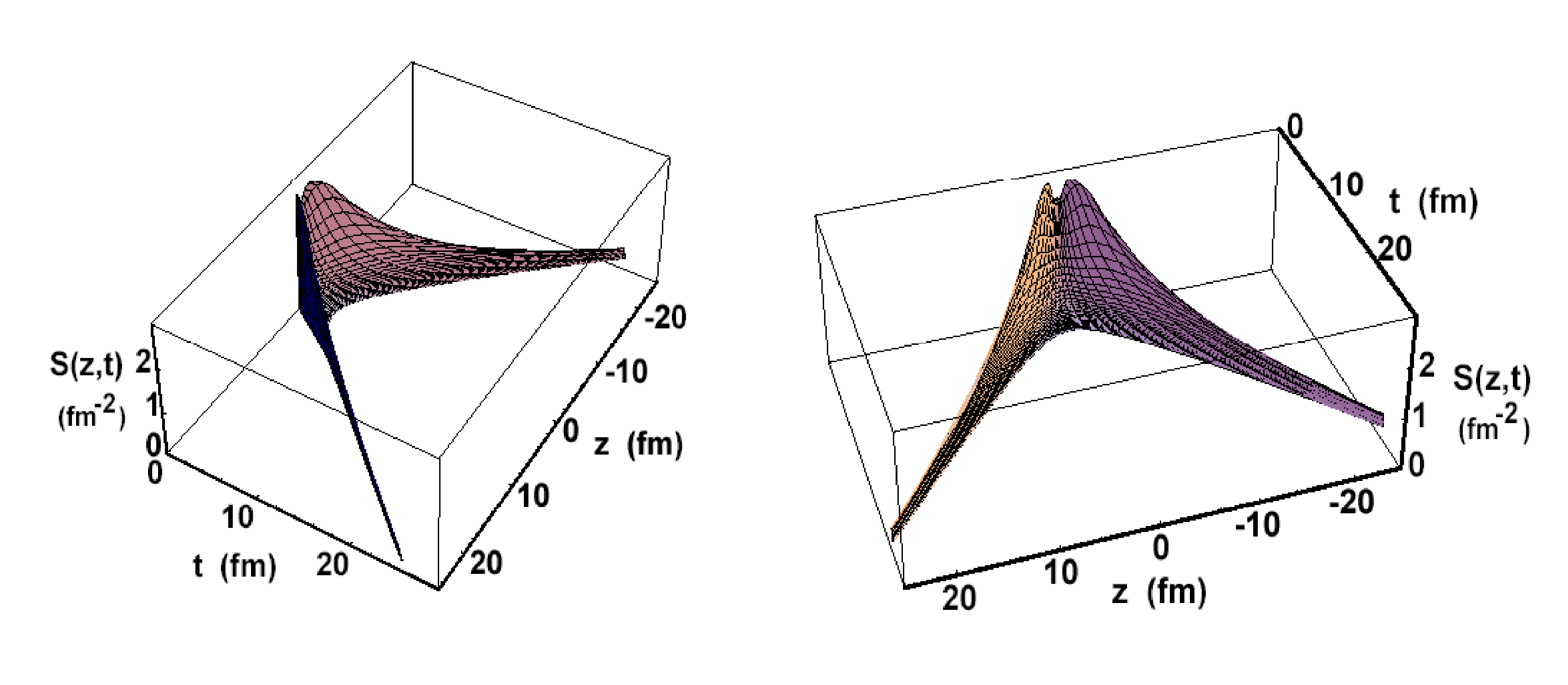


$\alpha = 0.4$ $\Delta\tau \approx 1,8$fm $\tau_0 = 0$

So using experimental distributions and , H(τ) from BEC, we can reconstruct the emission function.

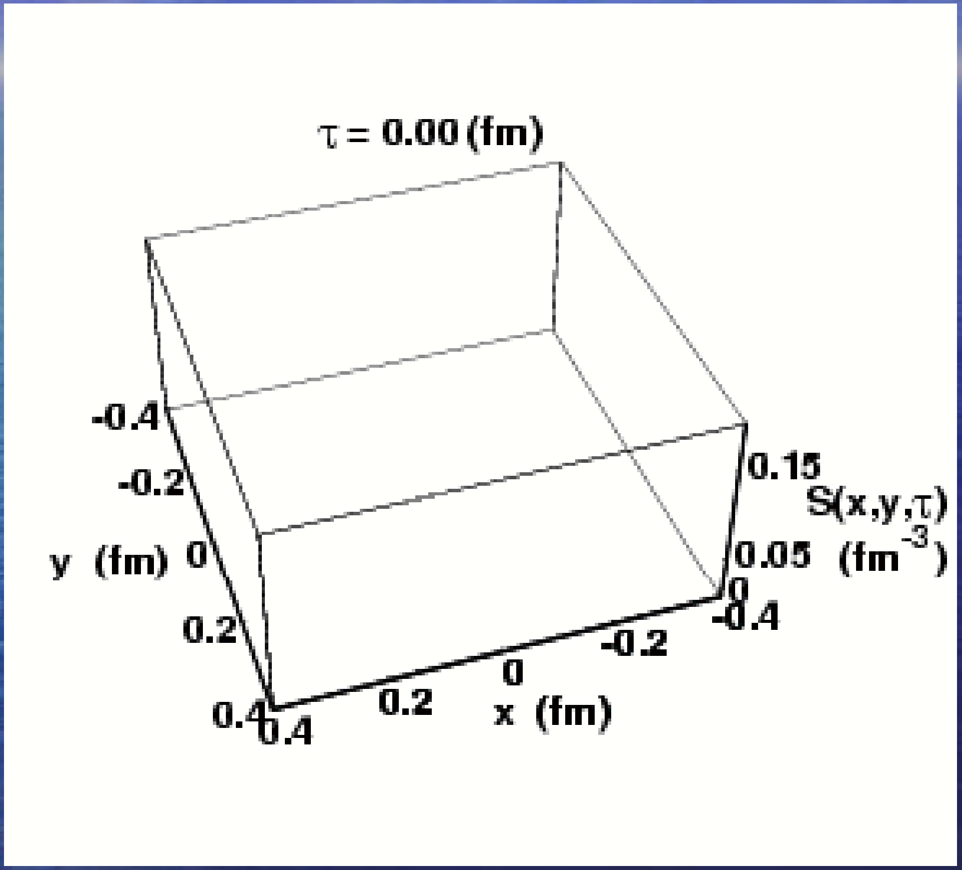
The emission function

Integrating over *r*



'Boomerang shape'; Particle production close to the light cone

The shortest movie of nature



Summary

- Parametrizing R_2 as a function of Q only is a reasonably good approximation

- Symmetric Gaussian, Edgeworth, Lévy parametrizations of R_2 do not fit well

- The τ-model with a one-sided Lévy proper-time distribution leads to $R_2(Q, m_\mathrm{t})$, which successfully fits R_2 for 2-jet events

- Emission function shaped like a boomerang in z-t and an expanding ring in x-y
  Particle production is close to the light-cone

Thank you for your attention!