Neutral- and charged-kaon Bose-Einstein correlations in DIS

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on behalf of the

ZEUS

Collaboration

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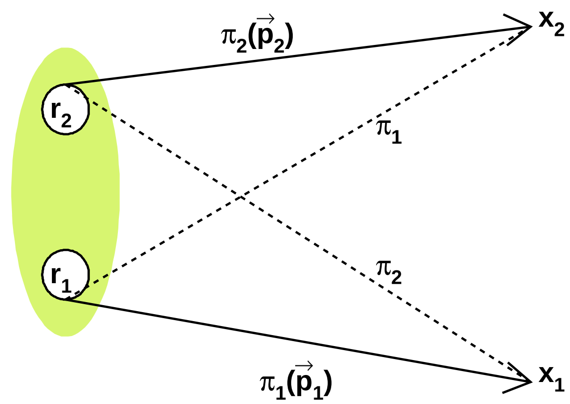
Bose-Einstein effect

Consider two bosons with momenta $\vec{p_1}, \vec{p_2}$ produced at points r_1 and r_2:

From the symmetrization of wave function of identical bosons QM probability of finding a pair of bosons is given:

$$|A|^2 = 1 + cos((\vec{p_1} - \vec{p_2}) \cdot (\vec{r_1} - \vec{r_2}))$$

Related to the particle interferometry



π_1, π_2 - bosons

- reflected in the two particle densities of identical boson as an enhacement in the production of identical bosons with similar momenta
- related to the space-time characteristic of the particle emission source

Why do we study BEC?

- New information about non-perturbative QCD and hadronization processes.
  - emission volume in different reactions: ee, ep, hh, AA.
  - radius dependence on the produced hadron mass $r(m)$.

What was done?

- LEP results indicate a hierarchy in emission-source radius:

$$r(m_\pi) > r(m_K) > r(m_\Lambda)$$

Bose-Einstein effect in experiment

Experimentally the correlation function can be measured from two-particle distribution $\boxed{R(Q_{12}) = \frac{P(Q_{12})}{P_{ref}(Q_{12})}}$ as a function of the four-momenta difference of the two particles:

$$Q_{12} = \sqrt{-(p_1 - p_2)^2} = \sqrt{M^2 - 4m_{boson}^2}$$

where:

- $P(Q_{12})$ - normalized density distribution of the number of identical boson-pairs
- $P_{ref}(Q_{12})$ - the number of boson-pairs in reference sample (no BEC)

Method of measurement

Reference sample to extract the Bose-Einstein effect:

- main experimental problem
- should be identical to the data sample and not contain BE effect

Solution:

- reference sample $\Rightarrow$ Monte Carlo without BEC - sensitive to the differences between DATA and MC

$$R(Q_{12}) = \frac{P(Q_{12})_{data}}{P(Q_{12})_{MCnoBEC}}$$

- reference sample $\Rightarrow$ two bosons are taken from different events all correlations are removed

$$R'_{mix}(Q_{12}) = \frac{P(Q_{12})_{data}}{P_{mix}(Q_{12})_{data}}$$

- double ratio method $\Rightarrow$ mixed

$$R_{mix}(Q_{12}) = \frac{P(Q_{12})_{data}}{P_{mix}(Q_{12})_{data}} \Big/ \frac{P(Q_{12})_{MCnoBEC}}{P_{mix}(Q_{12})_{MCnoBEC}}$$

$\Leftarrow$correction coeficient

Goldhaber parametrisation

Standard parametrisation of $R(Q_{12})$ is Goldhaber parametrisation:

$$\boxed{R(Q_{12}) = \alpha(1 + \lambda e^{-Q_{12}^2 \mathbf{r}^2})(1 + \delta Q_{12})}$$

where:

- λ - coherence strength factor (meaning $\lambda = 0$ for fully coherent and $\lambda = 1$ for fully incoherent source)
- r - is a geometrical radius of the presumably spherical boson emitting source
- α - the normalization factor
- $(1 + \delta Q_{12})$ - background

This parametrisation is expected for a spherical boson emitting source (r).

Event & particle selection

DIS event sample

$2 < Q^2 < 15000\ GeV^2$

Data sample (ZEUS)

$96/00\ e^{\pm}p \Rightarrow \mathcal{L} = 121 pb^{-1}$

Track selection requirements:

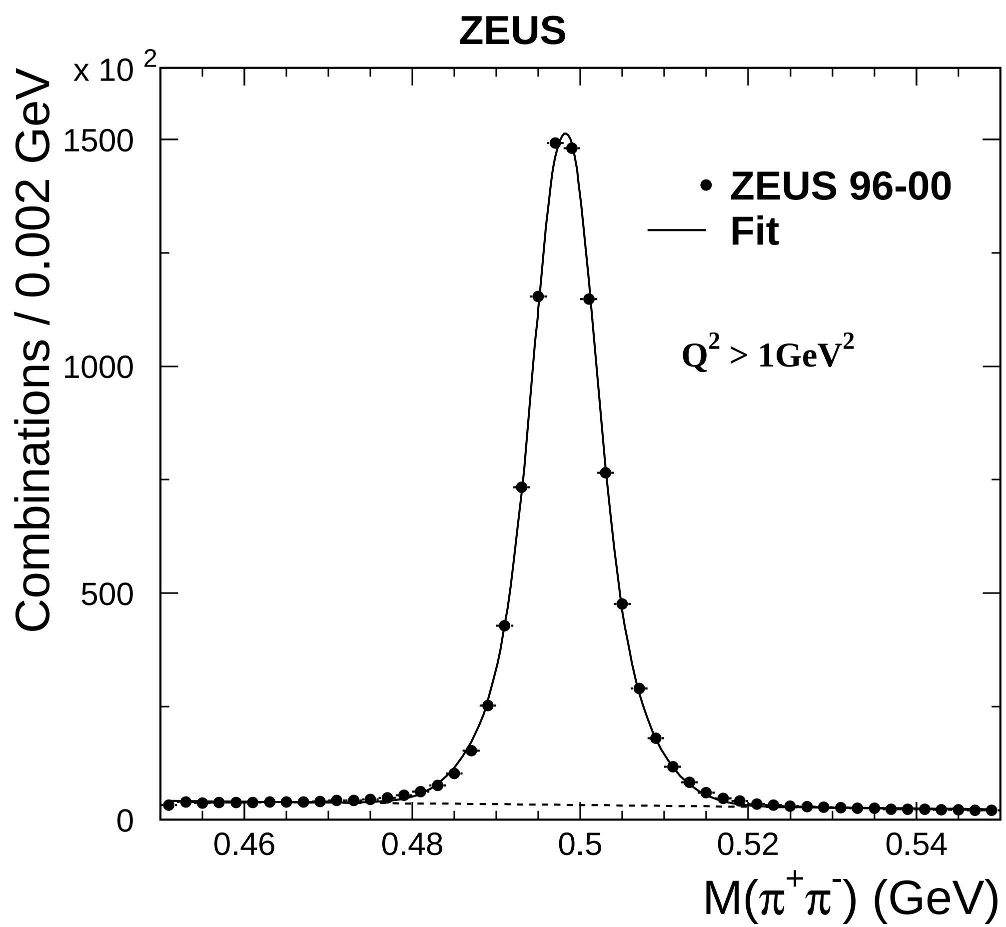
- $p_T > 0.15\ GeV$
- $|\eta| < 1.75$

Charged kaons selection:

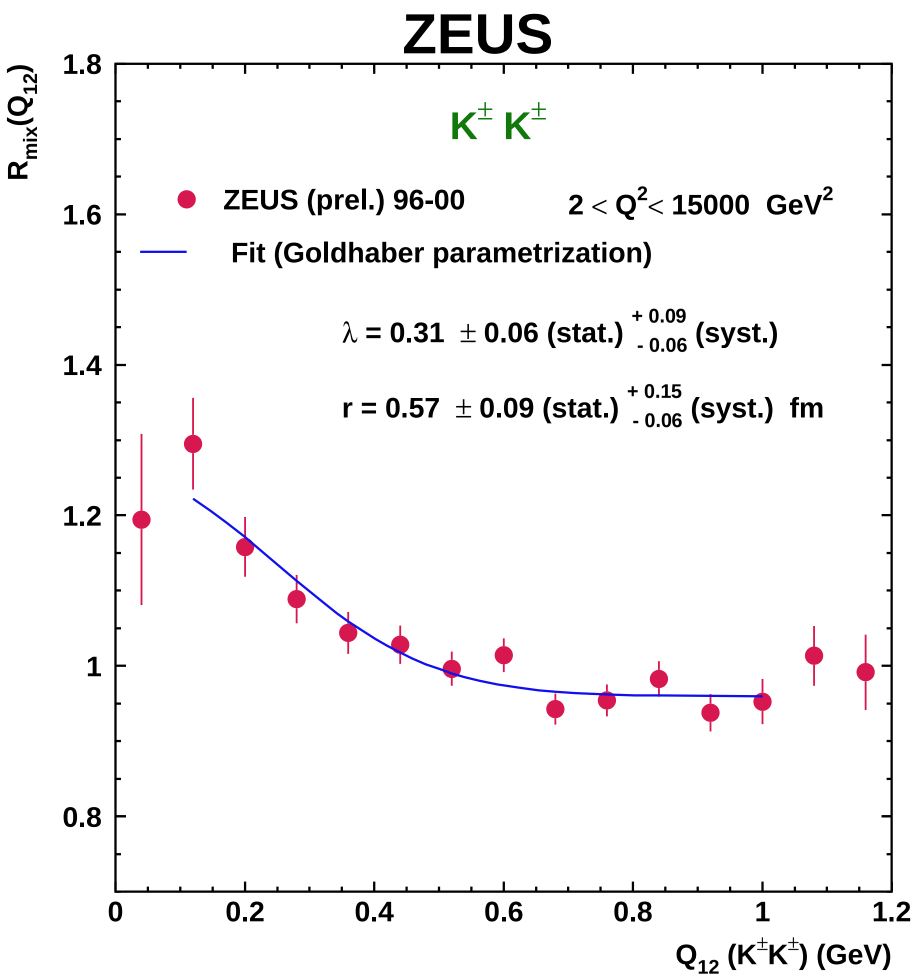
- cuts on the ionization $(\frac{dE}{dx})$ and
- total track momentum $p < 0.9\ GeV$

Neutral kaons selection reconstructed from V^0:

- cuts on the $M_{p\pi} > 1.12\ GeV$ and
- $|M_{\pi\pi} - M(K_s^0)| < 20\ MeV$



Results for $K^\pm K^\pm$

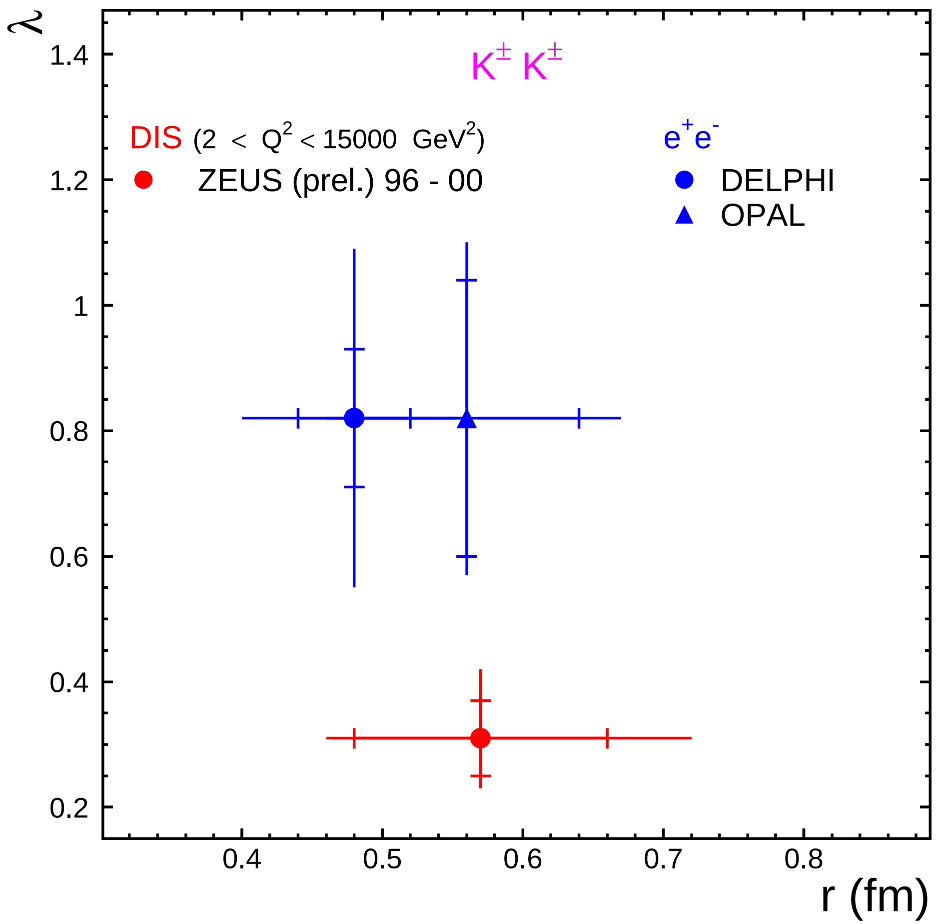


- BE effect cleary visible
- double ratio method
- 3 - parameter fit ($\delta = 0$)
- r value for $K^\pm$ similar to π (ZEUS)

  charged pions (ZEUS)

  $r = 0.666 \pm 0.009(stat)^{+0.022}_{-0.036}(sys)fm$
- somewhat smaller λ value than for pions

Comparison with LEP for $K^{\pm}K^{\pm}$



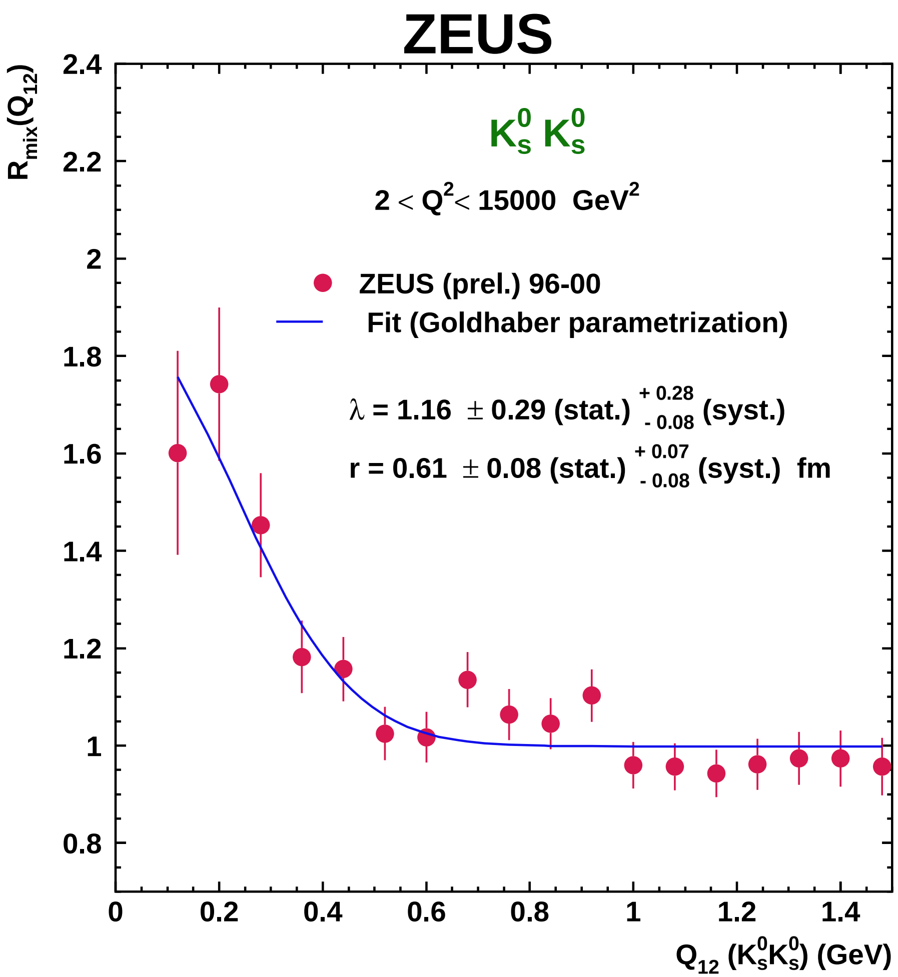
- Good agreement with LEP for radius
- Smaller λ value

Possible explanation

- High probability that at least one kaon in the kaon-pair is produced in $\phi_0(1020)$ decay (strong signal in data).
- DATA populate mostly proton fragmentation region - different than in e^+e^-.

$\Rightarrow$ Proton influence is expected.

Results for $K_s^0 K_s^0$



- BE effect cleary visible
- double ratio method
- 3 - parameter fit ($\delta = 0$)
- r value for K_s^0 is in good agreement with $K^\pm$

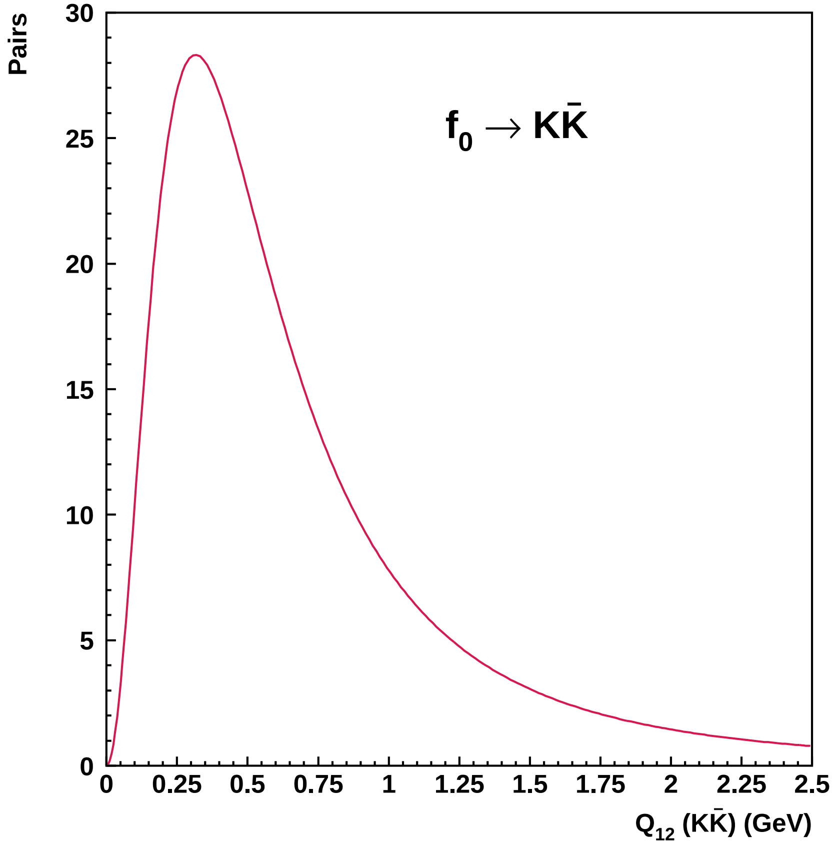
  charged kaons (ZEUS)

  $r = 0.57 \pm 0.09(stat)^{+0.15}_{-0.06}(sys) fm$
- r value for K_s^0 is similar to π (ZEUS)

  charged pions (ZEUS)

  $r = 0.666 \pm 0.009(stat)^{+0.022}_{-0.036}(sys) fm$
- rather large λ value

Why is our λ so high?



derived from:

Breit-Wigner distribution proposed by Flatte[a]:

$$\frac{d\sigma}{dm_{KK}} = \frac{N_F \cdot m_0^2 \cdot \Gamma_{KK}}{(m_0^2 - m_{KK}^2)^2 + (m_0 \cdot (\Gamma_{\pi\pi} + \Gamma_{KK}))^2}$$

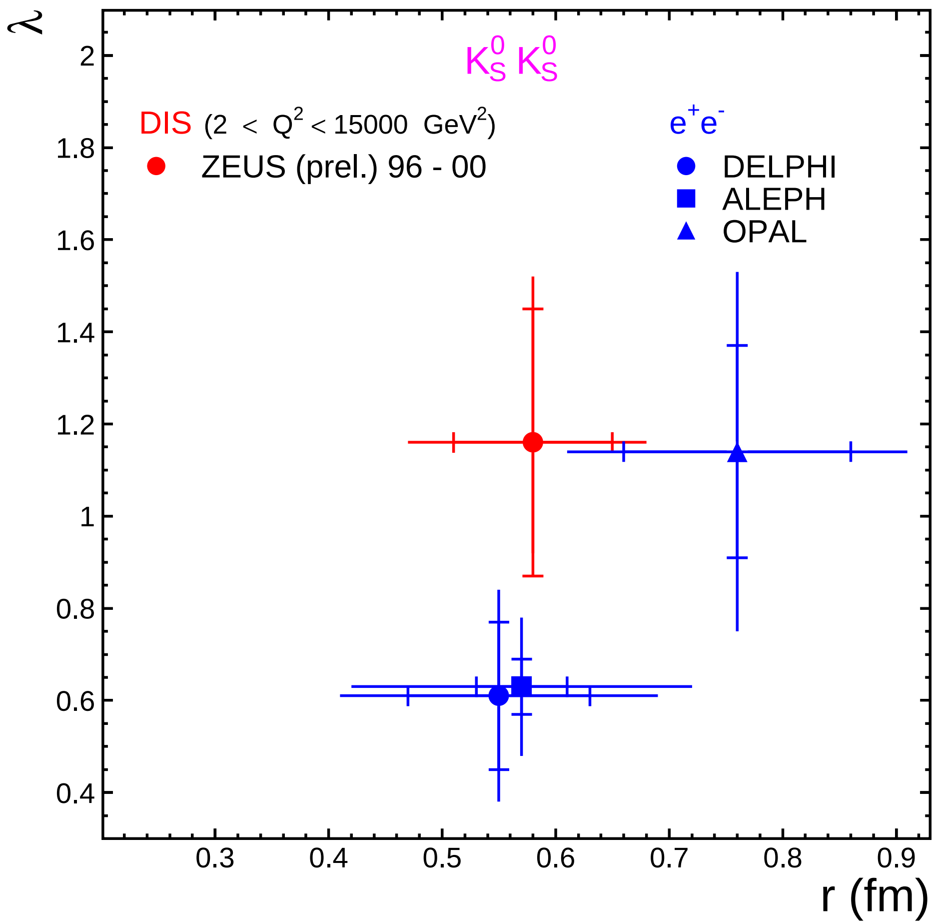
[a] Phys. Lett. B63 (1976) 224

- Low Q_{12} region is affected by the $f_0(980)$ resonance (not well described by the simulation).
- Using Breit-Wigner curve we subtracted 5% f_0 contribution from data sample.

Conclusion

- Small contribution of such resonance can significantly decrease λ value.

Comparison with LEP for $K_s^0 K_s^0$

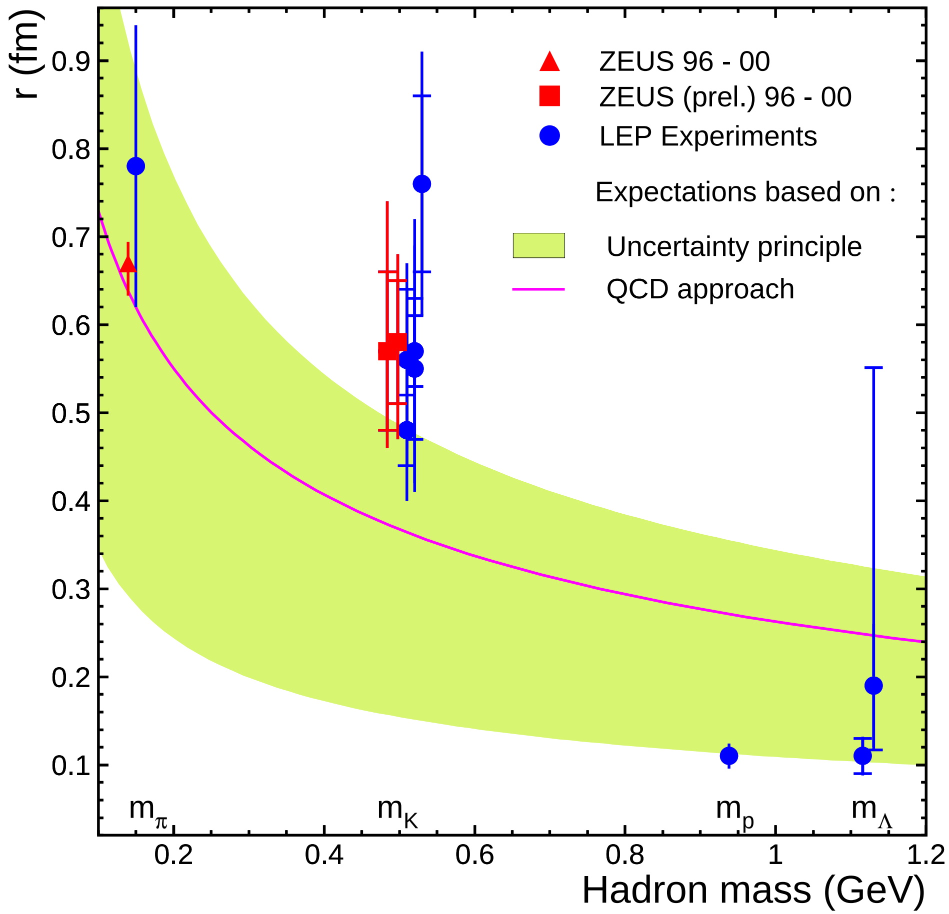


- Agreement with LEP for radius within systematic errors
- Higher λ value (ALEPH, DELPHI)

  Possible explanation

  - Low Q_{12} region is affected by the $f_0(980)$ resonance
  - We do not know the percentage contribution of this resonance in our data sample
  - Some LEP's experiments removed an influence of $f_0(980)$ (ALEPH, DELPHI).

The dependence of r on the mass



- Experiment
  - Results seem to show the r dependence on the hadron mass:

    $r(m_\pi) > r(m_K) > r(m_\Lambda)$
- Theory[bcd]
  - The string LUND model predicts the rather inverse dependence $r(m)$.
  - Heisenberg uncertainty relations and
  - QCD via virial theorem describe the tendency in the data.

Conclusions

- Still not clear situation.
- We need more precise r measurements for the source size to better explore $r(m)$ behavior.
- We need more mesurements for heavier particles (proton, $\Lambda \Rightarrow$ DIS - ZEUS).

[b] G.Alexander, I.Cohen, E.Levin Phys. Lett. B452 (1999) 159
[c] G.Alexander Rep. Prog. Phys. 66 (2003) 481-522
[d] B.Andersson, 1983 Phys. Rep. 97 31

Conclusions

- Radius for kaons is consistent with pions.
- Results for radius are compatible with LEP.
- The λ strength factor is different for neutral and charged kaons.
- The influence of $f_0(980)$ resonance in the correlation function for neutral kaons may change the λ value.

Next step

- More studies on the influence of resonances are needed.
- Radius for protons from Fermi-Dirac correlations.

Thank you for your attention!