Correlation functions for resonance states: the case of p $f_1(1285)$

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General considerations on three body systems

The Fixed Center Approximation for an external particle and a molecular state

Elastic unitarity in the FCA

Bound state of p $f_1(1285)$

Correlation function for p f_1 interaction

Open issues

Correlation functions are catching up: in pp , p A, AA high energy collisions

C(p) = P (a,b) (a,b produced in the same event) / P(a,b) (from independent events, mixed event)

Allows to study the interaction of any pair, a,b, in principle, at low relative energies

ALICE coll. , Acharya et al…..STAR, L. Adamczyk et al. ….

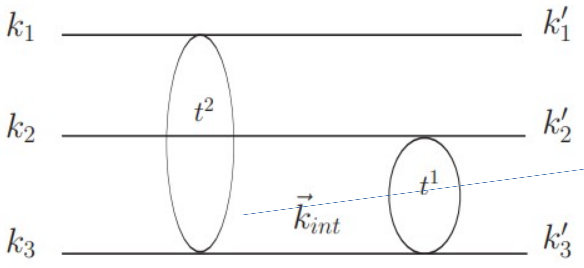
After the successful work with a,b stable particles, CF for three body are emerging

One particular case is the interaction of a stable particle with a bound state of two, or with a resonance in general.

WARNING ABOUT THREE BODY:

The aim in many cases is to find out the three body forces. But

THE THREE BODY FORCE IS NOT AN OBSERVABLE !!!

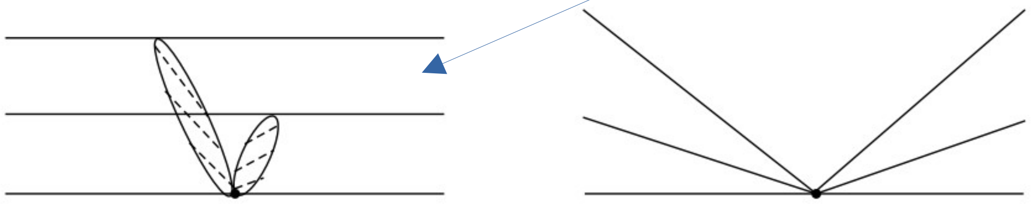


Not observable

$T^2 = t_{on} + a\,(k_{int}^2 - m^2)$

Propagator= $1/\,(k_{int}^2 - m^2)$

Off shell part x propagator → contact term= three body force



(a) (b)

Three body contact term in Chiral Lagrangians.

THEY CANCEL EXACTLY

Khemchandani .., Eur.Phys. J. A 37, 233 (2008). Martinez.., Phys. Rev. D 78, 074031 (2008).

When using chiral Lagrangians you can :

a) use the full two body amplitudes and add the chiral three body force
b) put only the two body on shell amplitudes and ignore the three body force.

The second option can be taken if one uses other methods that give the same two body amplitudes.

This puts extra value in methods like the Fixed Center Approximation, which relies upon on shell two body amplitudes.

Scattering of a particle A against a molecular state of two particles

We use the FCA where the molecule is the cluster and the particle A the external particle

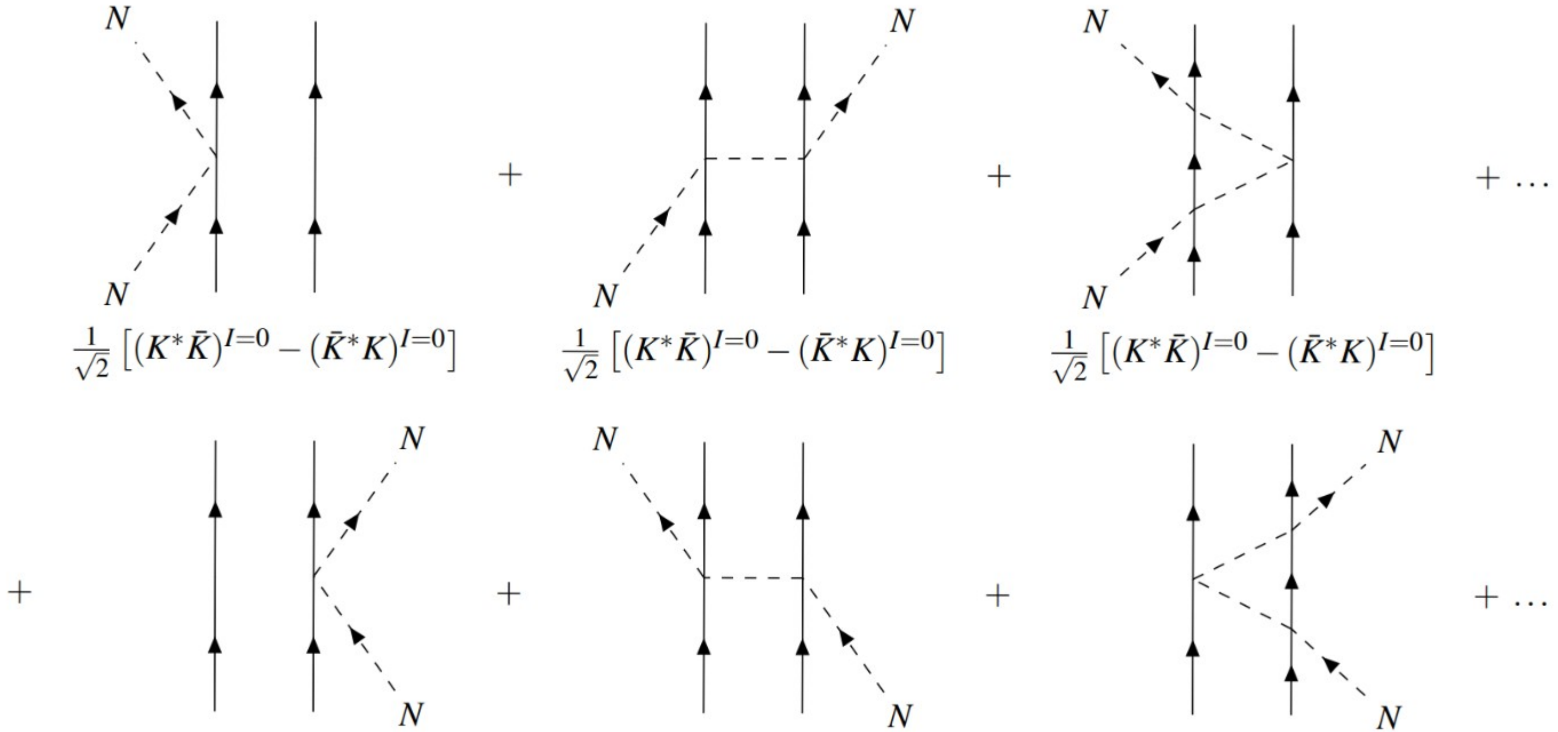
Example with p $f_1(1285)$, under study in ALICE (Korwieser et al.)

The $f_1(1285)$ is an axial vector state $I^G(J^{PC}) = 0^+(1^{++})$

In the chiral unitary approach it comes from the interaction of K K*bar -cc

Lutz and Kolomeitsev, NPA 730, 392 (2004), Roca, Oset, Singh, PRD 72, 014002 (2005)

$$
\begin{aligned}
f_1(1285) &= \frac{1}{\sqrt{2}}\left[(K^*\bar{K})^{I=0} - (\bar{K}^*K)^{I=0}\right] \\
&= \frac{1}{2}(K^{*+}K^- + K^{*0}\bar{K}^0 - K^{*-}K^+ - \bar{K}^{*0}K^0)
\end{aligned}
$$



$\frac{1}{\sqrt{2}}\left[(K^*\bar{K})^{I=0} - (\bar{K}^*K)^{I=0}\right]$ $\frac{1}{\sqrt{2}}\left[(K^*\bar{K})^{I=0} - (\bar{K}^*K)^{I=0}\right]$ $\frac{1}{\sqrt{2}}\left[(K^*\bar{K})^{I=0} - (\bar{K}^*K)^{I=0}\right]$

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Since the pK^* does not mix with $p\bar{K}^*$

$$
\begin{aligned}
T &= T_1 + T_2 \\
T_1 &= t_1 + t_1 \bar{G} T_2 \\
T_2 &= t_2 + t_2 \bar{G} T_1
\end{aligned}
$$

$$
\begin{aligned}
t_1 &= \frac{3}{4} t^{(1)}_{pK^*} + \frac{1}{4} t^{(0)}_{pK^*} & t_2 &= \frac{3}{4} t^{(1)}_{p\bar{K}} + \frac{1}{4} t^{(0)}_{p\bar{K}} \\
t_1' &= \frac{3}{4} t^{(1)}_{p\bar{K}^*} + \frac{1}{4} t^{(0)}_{p\bar{K}^*} & t_2' &= \frac{3}{4} t^{(1)}_{pK} + \frac{1}{4} t^{(0)}_{pK}
\end{aligned}
$$

$$
t_{1,av} = \frac{1}{2}(t_1 + t_1')
$$

$$
t_{2,av} = \frac{1}{2}(t_2 + t_2')
$$

Different field normalization for p K , p K* and p f1 reverts into

$$t_1 \to \tilde{t}_1 = \frac{M_c}{M_{K^*}} t_1 \;\; ; \;\; t_2 \to \tilde{t}_2 = \frac{M_c}{M_K} t_2$$

$$\tilde{G} = \frac{1}{2M_c} \int \frac{d^3q}{(2\pi)^3} F_c(q) \frac{M_N}{E_N(q)} \frac{1}{q^0 - E_N(q) + i\varepsilon}$$

$$\tilde{F}_c(q) = \int \frac{d^3p}{(2\pi)^3} \frac{1}{M_c - \omega_{K^*}(p) - \omega_{\bar{K}}(p)} \times \frac{1}{M_c - \omega_{K^*}(\vec{p}-\vec{q}) - \omega_{\bar{K}}(\vec{p}-\vec{q})}$$

$$|\vec{p}| < q_{max}$$

$$|\vec{p}-\vec{q}| < q_{max}$$

$$F_c(q) = \tilde{F}_c(q)/\tilde{F}_c(q=0)$$

$$q^0 = \frac{s - m_p^2 - M_c^2}{2M_c}$$

$$\tilde{T} = \frac{\tilde{t}_{1,av} + \tilde{t}_{2,av} + 2\tilde{t}_{1,av}\tilde{t}_{2,av}\tilde{G}}{1 - \tilde{t}_{1,av}\tilde{t}_{2,av}\tilde{G}^2}$$

$$s_1(NK^*) = m_N^2 + (\xi m_{K^*})^2 + 2\xi m_{K^*} q^0$$

$$s_2(N\bar{K}) = m_N^2 + (\xi m_{\bar{K}})^2 + 2\xi m_{\bar{K}} q^0$$

$$\xi = M_c/(m_{K^*} + m_{\bar{K}})$$

Elastic unitarity of the $\tilde{T}$ matrix

$$\tilde{T} = -\frac{8\pi\sqrt{s}}{2M_N} f^{QM} \quad ;$$

$$-\frac{8\pi\sqrt{s}}{2M_N}\tilde{T}^{-1} = (f^{QM})^{-1} \simeq -\frac{1}{a_0} + \frac{1}{2} r_0 q_{cm}^2 - i q_{cm}$$

The term $-iq_{cm}$ comes from Im $\tilde{G}$

$$\mathrm{Im}\tilde{G} = -\frac{1}{2M_c}\frac{1}{2\pi} q F_c(q) M_N$$

Equating terms linear in q_{cm}

$$-\frac{8\pi\sqrt{s}}{2M_N}(-A)(-\frac{1}{2M_c}\frac{1}{2\pi} q F_c(0) M_N) \equiv -q_{cm}$$

$$A = \left(\frac{1}{2} - \frac{1}{2}\frac{(\tilde{t}_1 - \tilde{t}_2)^2}{(\tilde{t}_1 + \tilde{t}_2 + 2\tilde{t}_1\tilde{t}_2 \mathrm{Re}\tilde{G})^2}\right)$$

$$\frac{q}{q_{cm}} = \frac{\sqrt{s}}{M_c}$$

$$\frac{s}{M_c^2} A\Big|_{th} q_{cm} \equiv q_{cm}$$

Through different approximations elastic unitarity is not exactly fulfilled, but approximately.

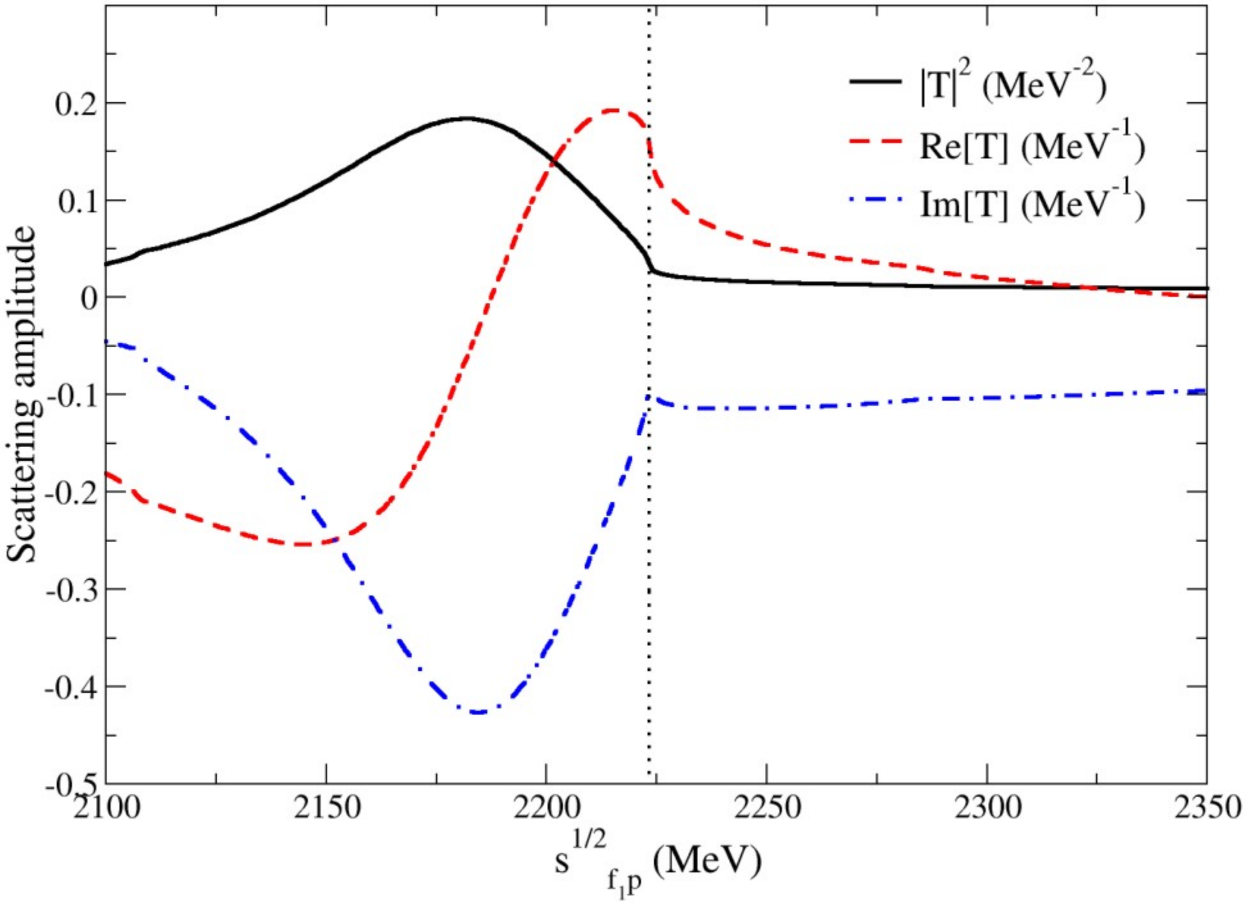
Exact elastic unitarity is restored through

$$\tilde{T} \to \tilde{T}_{uni} = \frac{s}{M_c} A \Big|_{th} \tilde{T}$$

We find the correction factor of the order of 1.5

$$\frac{1}{a_0} = \frac{8\pi\sqrt{s}}{2M_N} (\tilde{T}_{uni}^{-1}) \Big|_{th}$$

$$r_0 = \frac{1}{\mu} \left[\frac{\partial}{\partial\sqrt{s}} \left(-\frac{8\pi\sqrt{s}}{2M_N} (\tilde{T}_{uni}^{-1}) + i q_{cm} \right) \right]_{th}$$



We find a resonance structure
For the f_1 p amplitude

Resonant state bound by about 40 Mev and a width around 50 MeV

$$a_0 = 1.04 - i0.57 \text{ fm}$$
$$r_0 = 1.17 + i1.16 \text{ fm}$$

Correlation function

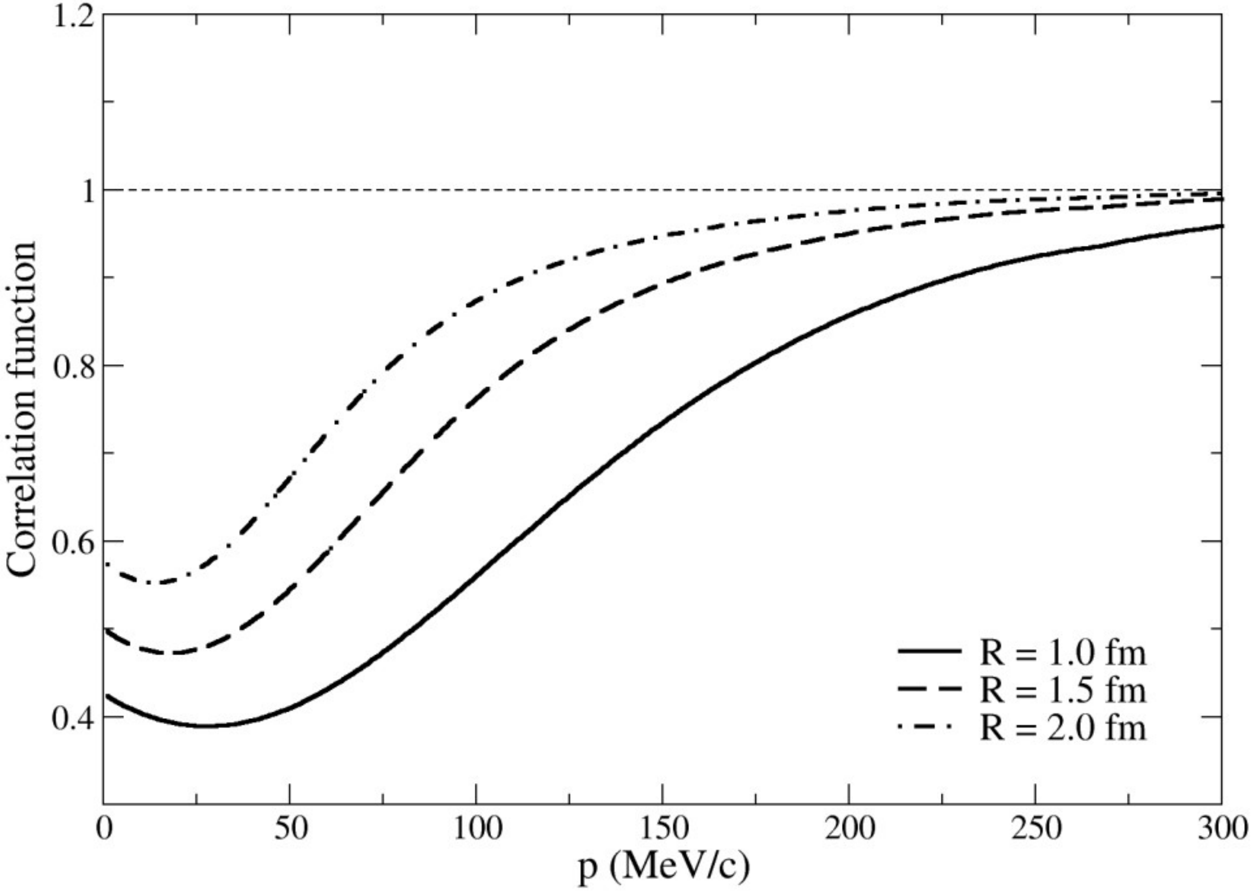
$$C_{p\ f_1}(p) = 1 \ + \ 4\pi \int_0^\infty drr^2 S_{12}(r)\theta(q'_{max} - |\vec{p}|)$$
$$\{|j_0(pr) + \tilde{T}(\sqrt{s})\tilde{G}(s,r)|^2 - j_0^2(pr)\}$$

$$S_{12}(r) = \frac{1}{(4\pi R^2)^{3/2}} \exp(-r^2/4R^2)$$

$$\tilde{G}(s,r) = \int \frac{d^3q}{(2\pi)^3} \frac{1}{2\omega_{f_1}(q)} \frac{M_N}{E_N(q)} \frac{j_0(qr)}{\sqrt{s} - \omega_{f1}(q) - E_N(q) + i\varepsilon}$$
$$|\vec{q}| < q'_{max} \tag{24}$$

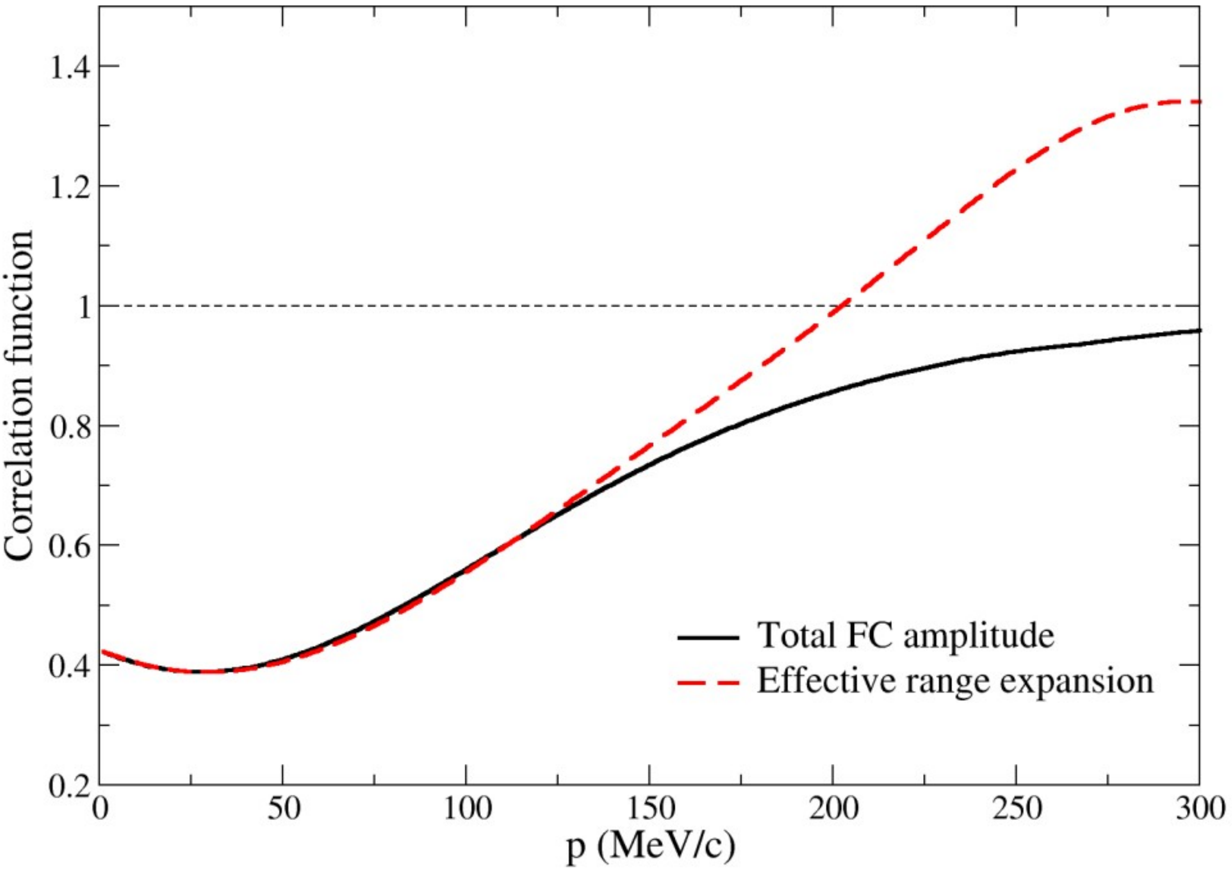
Slight modification of Koonin Pratt from I. Vidana, A. Feijoo, M. Albaladejo, J. Nieves and E. Oset,

PLB 70, 43, 1977 PLB 846, 138201, 2023

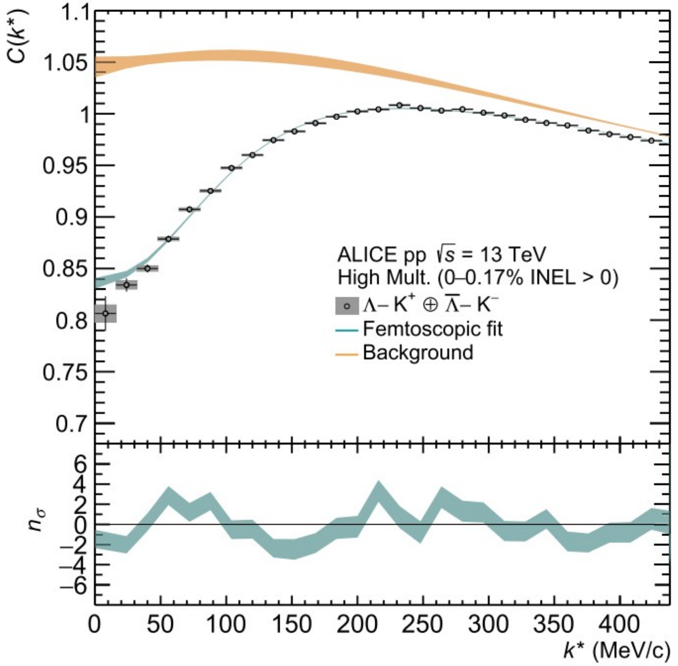


1.2
1
0.8
0.6
0.4
Correlation function
0
50
100
150
200
250
300
p (MeV/c)
R = 1.0 fm
R = 1.5 fm
R = 2.0 fm

Comparison with effective range Approximation, R=1fm



Qualitatively similar to K Λ



This is related to the existence of the N*(1535)

Conclusions:

We present a general framework to evaluate correlation functions for the interaction of a stable particle with a two body molecular state

We evaluate the scattering amplitude of a proton with the f_1(1285) resonance
And find a bound state of this system, equivalent to a bound state of p K K*bar,
Bound by about 40 MeV and with a width of about 50 MeV

We also determine a and r_0 for the p f_1 system

Then determine the correlation function . Similar to experimental K Λ (related to the existence of the N*(1535)).

Open questions: when the correlation function experiment is done

Can one determine a, r_0 , R simultaneously?

Can one induce the existence of the predicted bound three body bound state?

Can one say something about the nature of the f_1(1285)?