A method to identify dynamicaly generated states

and its application to $X(3872)$ *and* $X(3875)$

Christoph Hanhart

Forschungszentrum Jülich

In collaboration with

Yu. Kalashnikova, A. Kudryavtsev, A. Nefediev

Key references:

S. Weinberg, Phys. Rev. **130**, 776 (1963); **131**, 440 (1963); **137** B672 (1965).

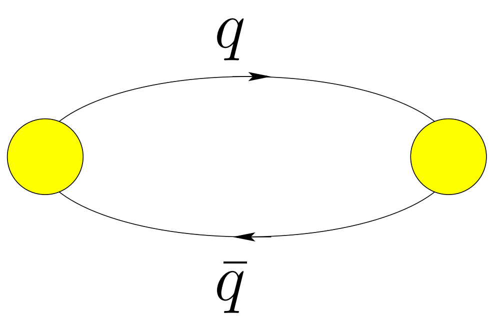
V. Baru et al., Phys. Lett. B **586** (2004) 53; C.H. et al., Phys. Rev. **D 76** (2007) 034007

The Idea

Difference between bound states of quarks or hadrons?

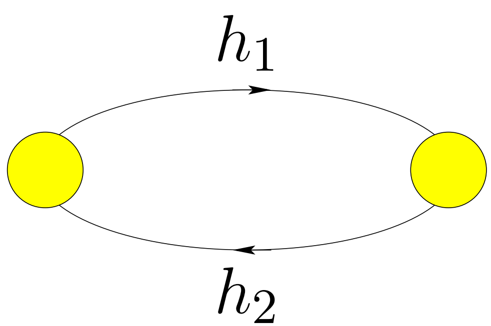
Hadrons can go on–shell $\longrightarrow$ non–analyticities

Quark–loop:



$= ($Polynomial in $E)$

Hadron–loop:



$$= \begin{cases} i\mu\sqrt{E\mu} + (\text{Pol. in } E); & E > 0 \\ -\mu\sqrt{-E\mu} + (\text{Pol. in } E); & E < 0 \end{cases}$$

Focus on resonances very near thresholds

non–rel. QM

Weinberg (1963)

Expand in terms of non–interacting quark and meson states

$$|\Psi\rangle = \begin{pmatrix} \cos(\theta)|\psi_0\rangle \\ \sin(\theta)\chi(\mathbf{p})|h_1h_2\rangle \end{pmatrix},$$

here $|\psi_0\rangle$ = quark state and $|h_1h_2\rangle$ = two–hadron continuum
with $\langle\Psi|\Psi\rangle = 1$ and $\int d^3p\chi^2 = 1$. Let

$$\mathcal{Z} = |\langle\Psi|\psi_0\rangle|^2 = \cos(\theta)^2$$

Equals probability to find the bare state in the physical state

$\rightarrow$ the quantity of interest!

Use Schrödinger equation to fix $\mathcal{Z}$.
When can we make model–independent statements?

Coupled channels II

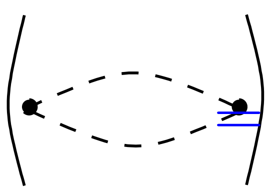
The Schrödinger equation reads

$$\hat{\mathcal{H}}|\Psi\rangle = E|\Psi\rangle, \;\; \hat{\mathcal{H}} = \begin{pmatrix} \hat{H}_c & \hat{V} \\ \hat{V} & \hat{H}^0_{hh} \end{pmatrix},$$

Note: $\hat{H}^0_{hh}$ contains only meson kinetic terms!

Introducing the transition form factor $\langle\psi_0|\hat{V}|hh\rangle = f(p^2)$,

$$\frac{\partial}{\partial E}$$



$$= \frac{1}{Z} - 1 = \tan^2\theta = \int \frac{f^2(p^2)d^3p}{(p^2/(2\mu)+\epsilon)^2} = \frac{4\pi^2\mu^2 f(0)^2}{\sqrt{2\mu\epsilon}}$$

for s–waves and ϵ smaller than any scale of problem; then it depends only on $f(0)$=effective coupling and binding energy ϵ

$\rightarrow$ model–independent!

Discussion

We can now define effective coupling; from scattering amplitude we get, using $8\pi^2\mu f^2 = g = 2\sqrt{2\epsilon/\mu}(1/\mathcal{Z} - 1)$

$$F_{MM} = -\frac{g/2}{E + \epsilon + (g/2)\left(\sqrt{2\mu\epsilon} + i\sqrt{2\mu E}\right)} + \ldots$$

$$= -\left(\frac{1}{64\pi m_1 m_2}\right)\frac{g_{\rm eff}^2}{E+\epsilon} + \ldots \qquad \text{(rel.-norm.)}$$

$$\rightarrow \frac{g_{\rm eff}^2}{4\pi} = \mathcal{Z} 8 m_1 m_2 g$$

$$= 16(m_1 + m_2)(1-\mathcal{Z})\sqrt{2\mu\epsilon} \leq 16(m_1+m_2)\sqrt{2\epsilon\mu}$$

For bound state low E amplitude fixed in hh channel!

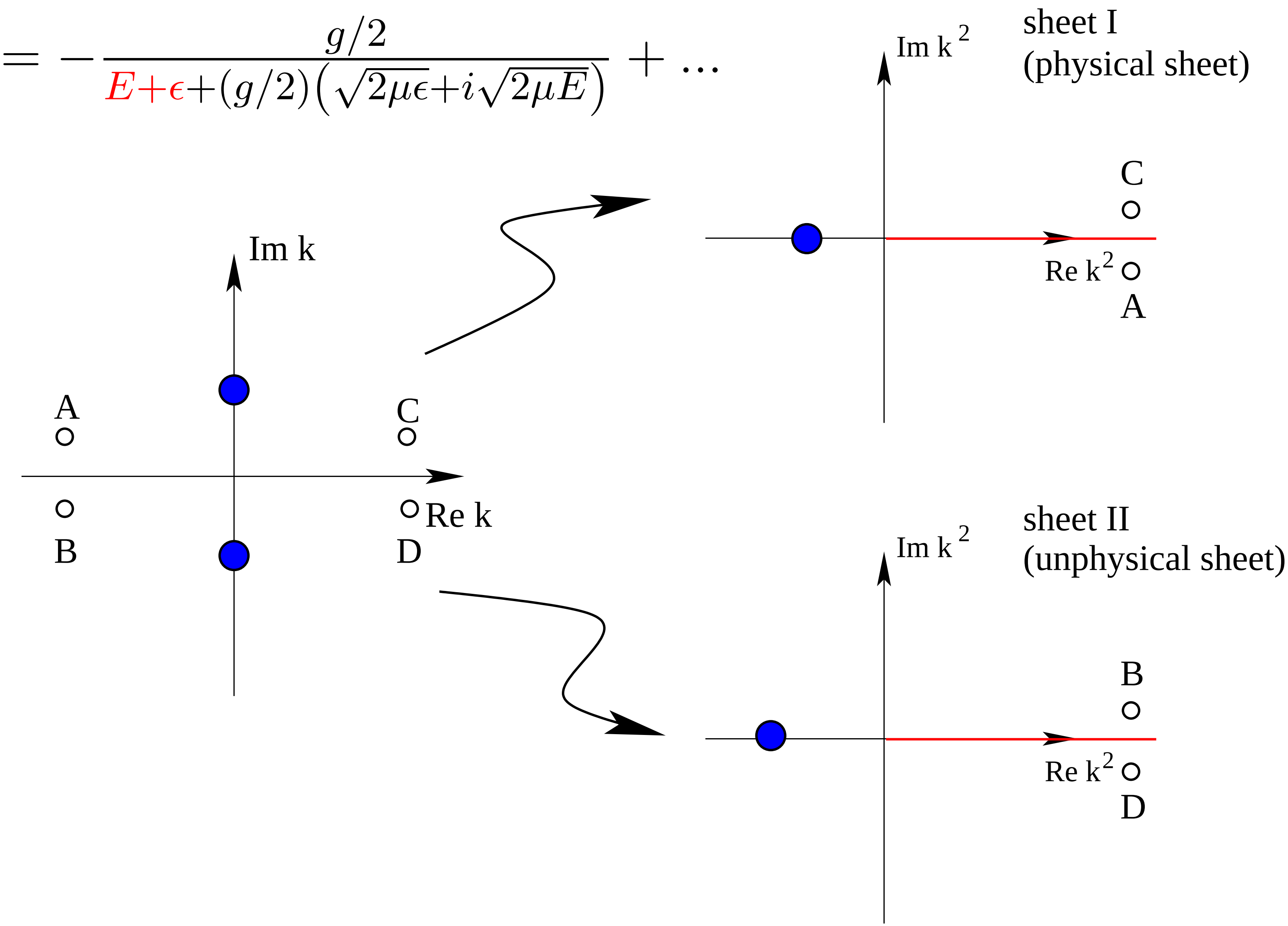
Picture not changed by far away threshold — Baru et al. (2004)

Equivalent to, e.g., — Morgan and Pennington (1991), Törnqvist (1995)

Pole counting I

g small $\longrightarrow$ elementary state; with $k = \sqrt{2\mu E}$

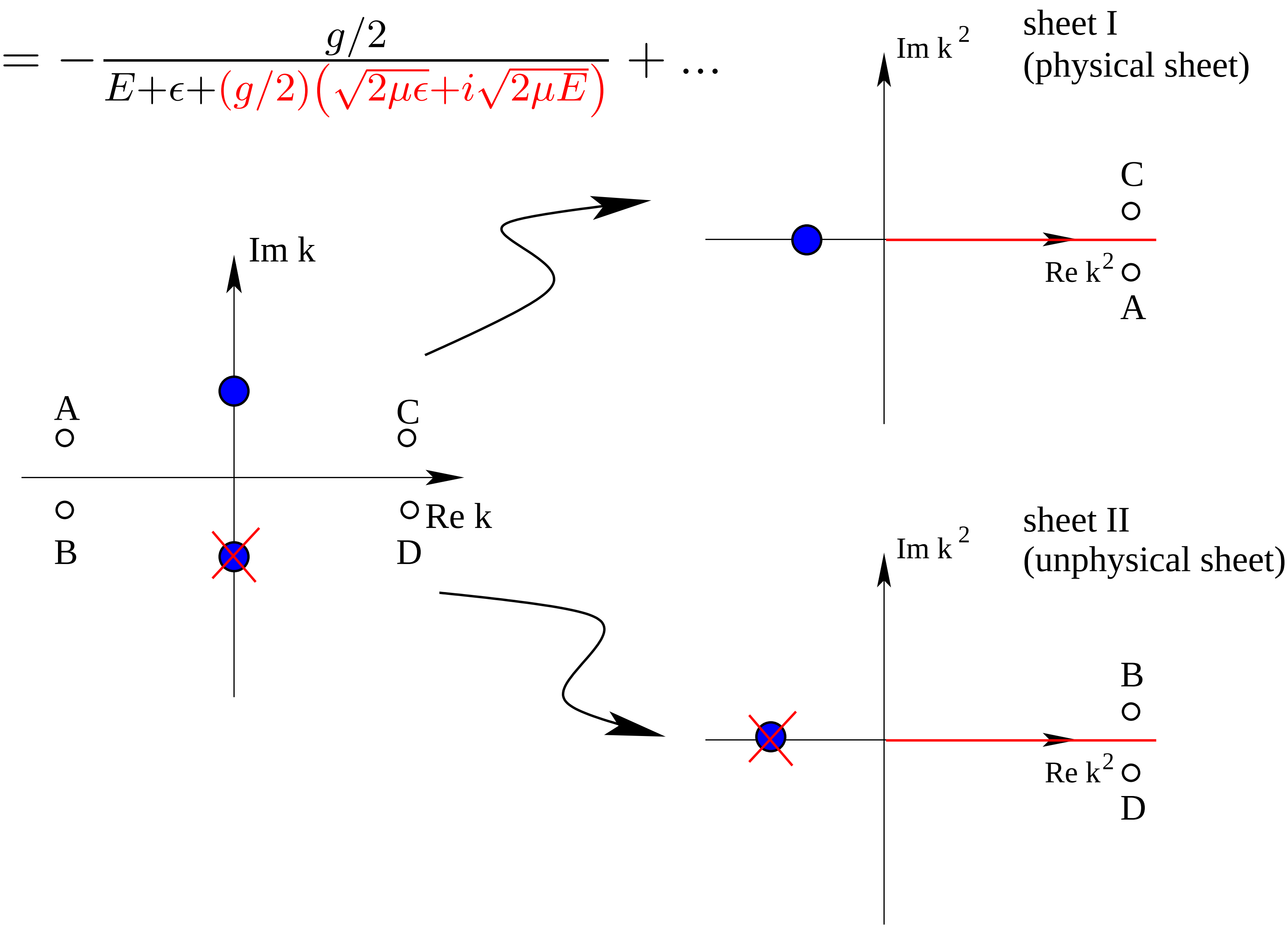
$$F_{MM} = -\frac{g/2}{E+\epsilon+(g/2)\left(\sqrt{2\mu\epsilon}+i\sqrt{2\mu E}\right)} + \ldots$$



Pole counting II

g large $\longrightarrow$ molecule; with $k=\sqrt{2\mu E}$

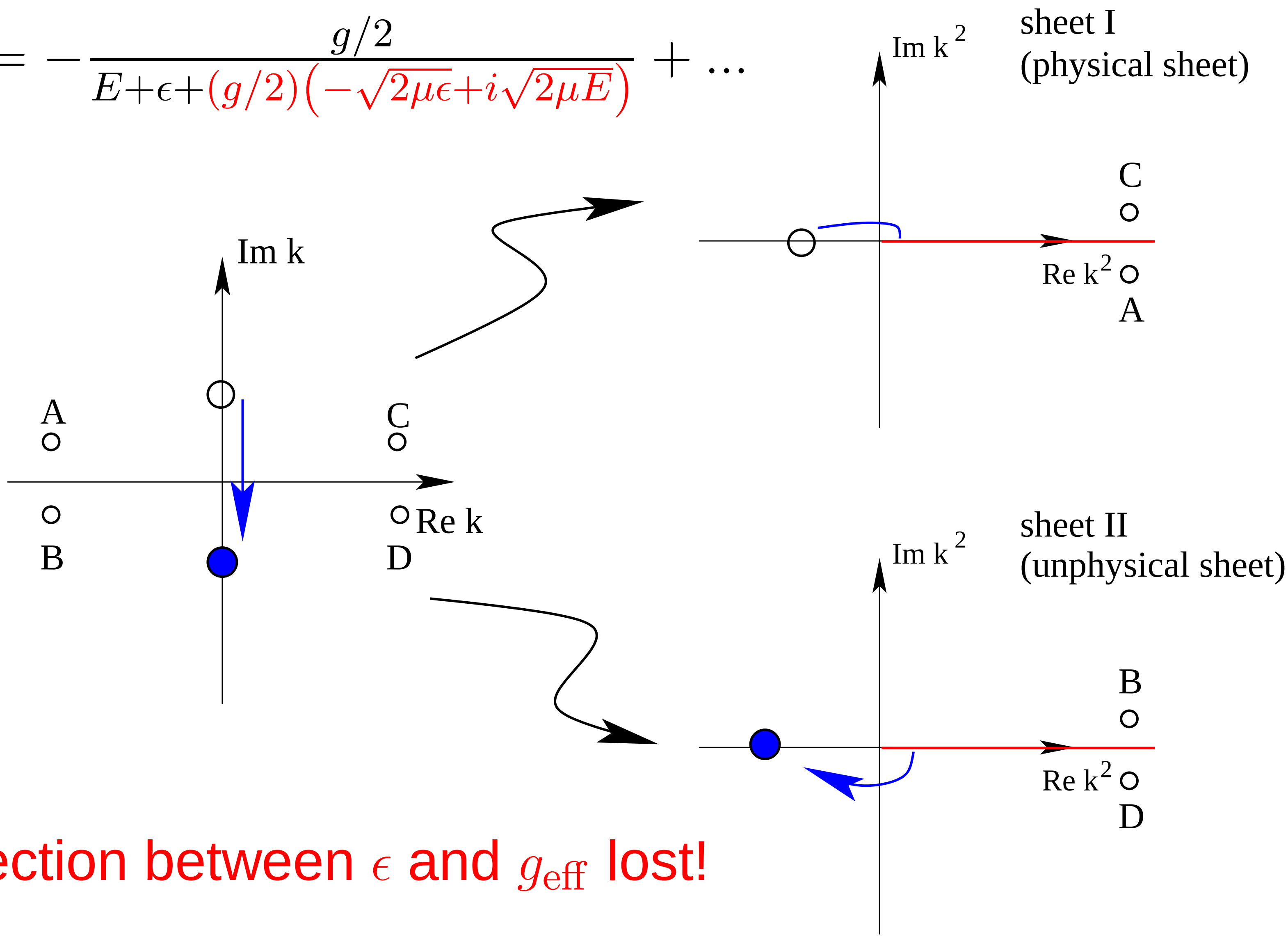
$$F_{MM} = -\frac{g/2}{E+\epsilon+(g/2)\left(\sqrt{2\mu\epsilon}+i\sqrt{2\mu E}\right)} + \ldots$$



Pole counting III

For weaker binding potentials: virtual state

$$F_{MM} = -\frac{g/2}{E+\epsilon+(g/2)\left(-\sqrt{2\mu\epsilon}+i\sqrt{2\mu E}\right)} + \ldots$$



Connection between ϵ and g_{eff} lost!

Thus ...

Summary: the structure information is hidden in the effective coupling, adjusted to experiment, independent of the phenomenology used to introduce the pole(s)

Focus on light scalar mesons $f_0(980)$ and $a_0(980)$

poles located very close to the $\bar{K}K$ threshold ($2m_K = 992$ MeV)

$\longrightarrow$ Binding energy $\epsilon \simeq 10$ MeV <u>IDEAL</u>

Our analyses for radiative decays $\phi \to \gamma s$, $s \to \gamma\gamma$ are

$\rightarrow$ consistent with molecular interpretation for f_0;

$\rightarrow$ less clear for a_0;

it either has non–molecular component, or is a virtual state

The $X(3872)$ vs. $X(3875)$

Can signal in $D^0\bar{D}^0\pi$ (at 3875 MeV) and in $J/\Psi\pi\pi$ (at 3872 MeV) come from the same state?

We have

$$M_{X(3872)} - M_{D^0} - M_{D^{*0}} = -0.4 \pm 0.6 \text{ MeV}$$
$$M_{X(3875)} - M_{D^0} - M_{D^{*0}} = +4.0 \pm 0.7 \text{ MeV}$$

Analysis tool:

Flatte analysis: $F_{ij} \propto \left(E - E_f - i/2\,(g(k_1 + k_2) + \Gamma)\right)^{-1}$

where

$k_1 = \sqrt{2\mu_1 E}$ (for $X \to D^0\bar{D}^{0\,*}$),

$k_2 = \sqrt{2\mu_2(E-\delta)}$ (for $X \to D^+\bar{D}^{-\,*} + h.c.$),

Γ for remaining inelastic channels ($J/\Psi\pi\pi$ and $J/\Psi\pi\pi\pi$)

C.H., Y. Kalashnikova, A. Kudryavtsev, and A. Nefediev (2007)

Results

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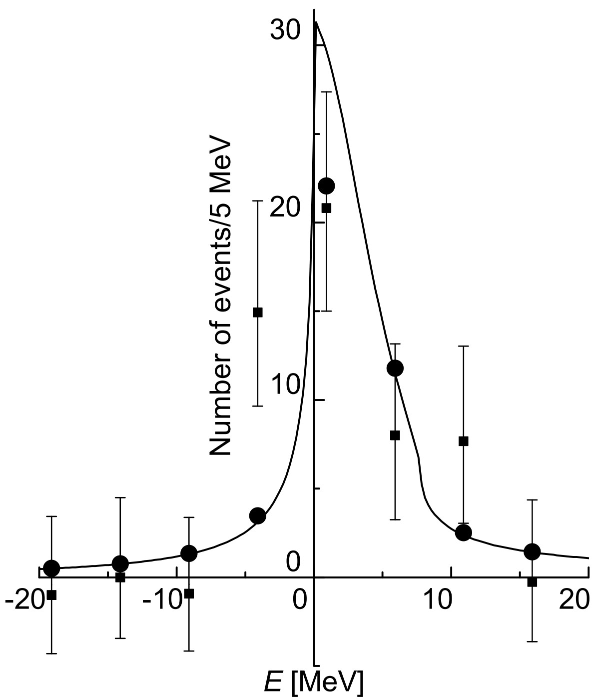
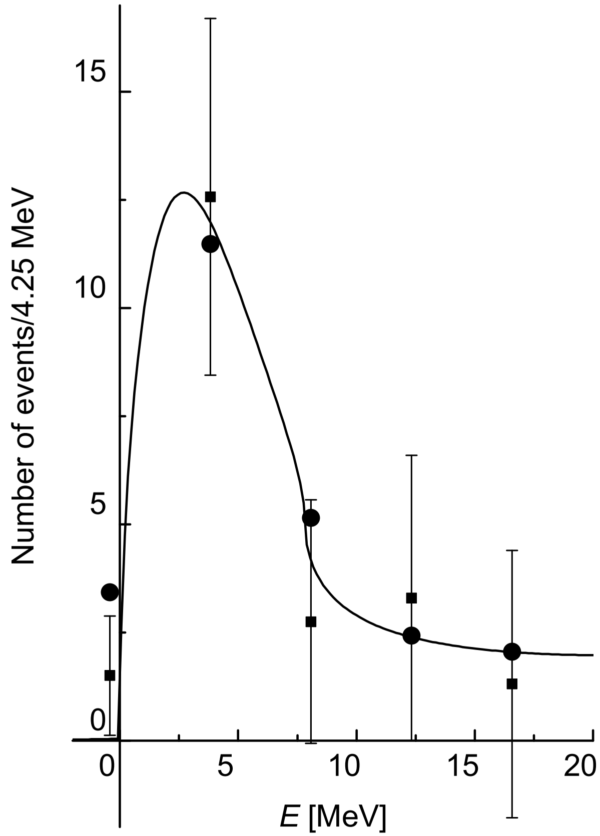
in der Helmholtz-Gemeinschaft

Fits individually to Belle and Babar with different assumptions
Here: Fit to Babar assuming non–interfering background





Features:

g large
$\longrightarrow$ dynamical state

cusp in $J/\Psi\pi\pi$
$\longrightarrow$ virtual state

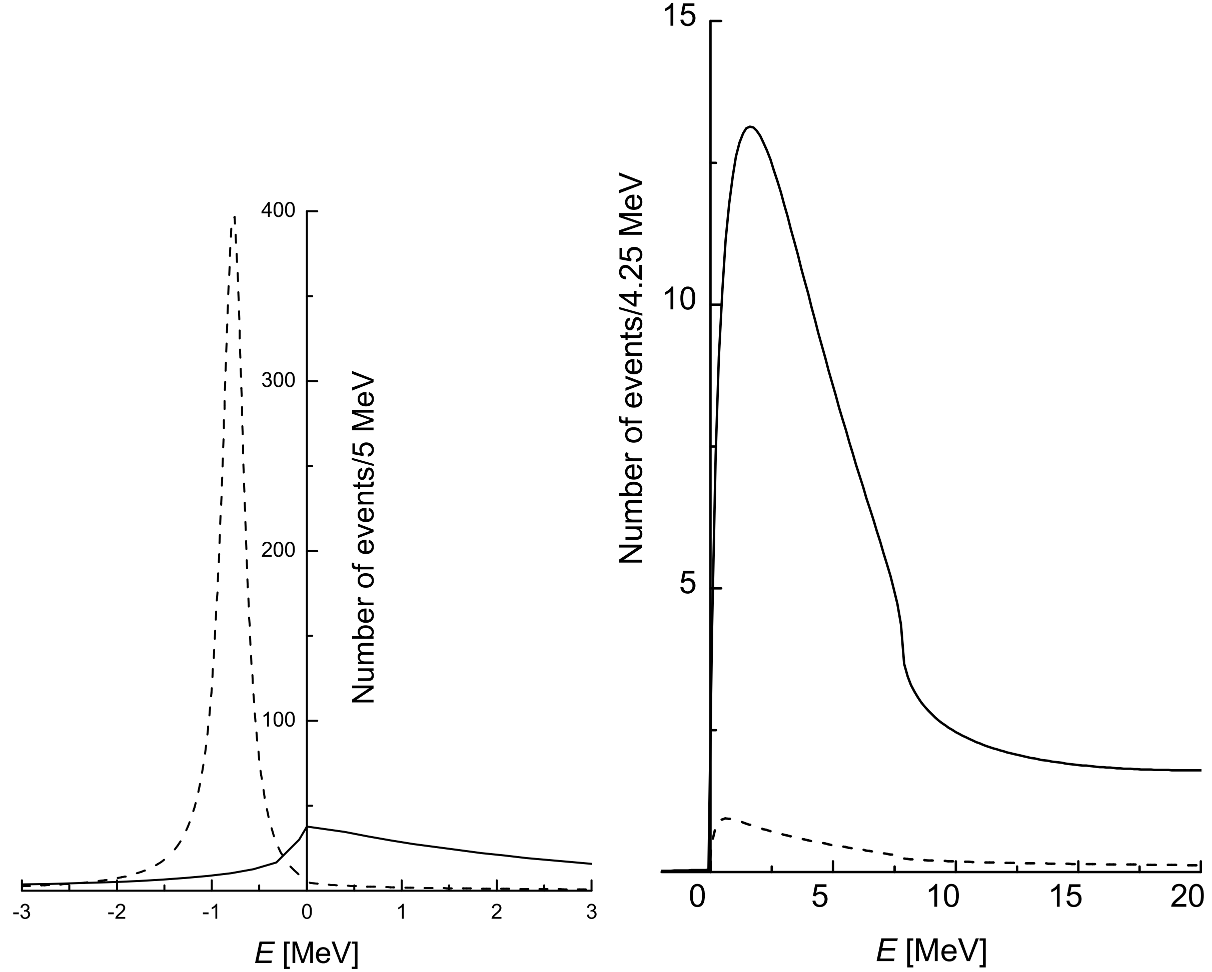
$$\frac{\text{Br}(X\to D^*D)}{\text{Br}(X\to J/\Psi\pi\pi)} \sim 10$$
$\longrightarrow$ virtual state

Note:
result in scaling regime:
$g \to \lambda g;\ \Gamma \to \lambda\Gamma;\ E_f \to \lambda E_f$ does not change shapes

Baru et al. (2005)

bound vs. virtual state

Change pole position from virtual to bound state:



in general $\left(\frac{\text{Br}(X\to D^*D)}{\text{Br}(X\to J/\Psi\pi\pi)}\right)_{\text{virtual } X} \gg \left(\frac{\text{Br}(X\to D^*D)}{\text{Br}(X\to J/\Psi\pi\pi)}\right)_{\text{bound } X}$

Braaten and Kusunoki (2005), C.H. et al. (2007)

Summary/Outlook

$\rightarrow$ Experiment can not distinguish bound and elementary state

For both (almost) no signal in $D\bar{D}\pi$

$\rightarrow$ If $X(3872)$ is molecule or elementary state ($\bar{q}q$, tetraquark ...) , $X(3875)$ must be additional state

see talk by E. Oset and Gamermann and Oset (2007)

$\rightarrow$ Signal in $D\bar{D}\pi$ related to $X(3872)$ only

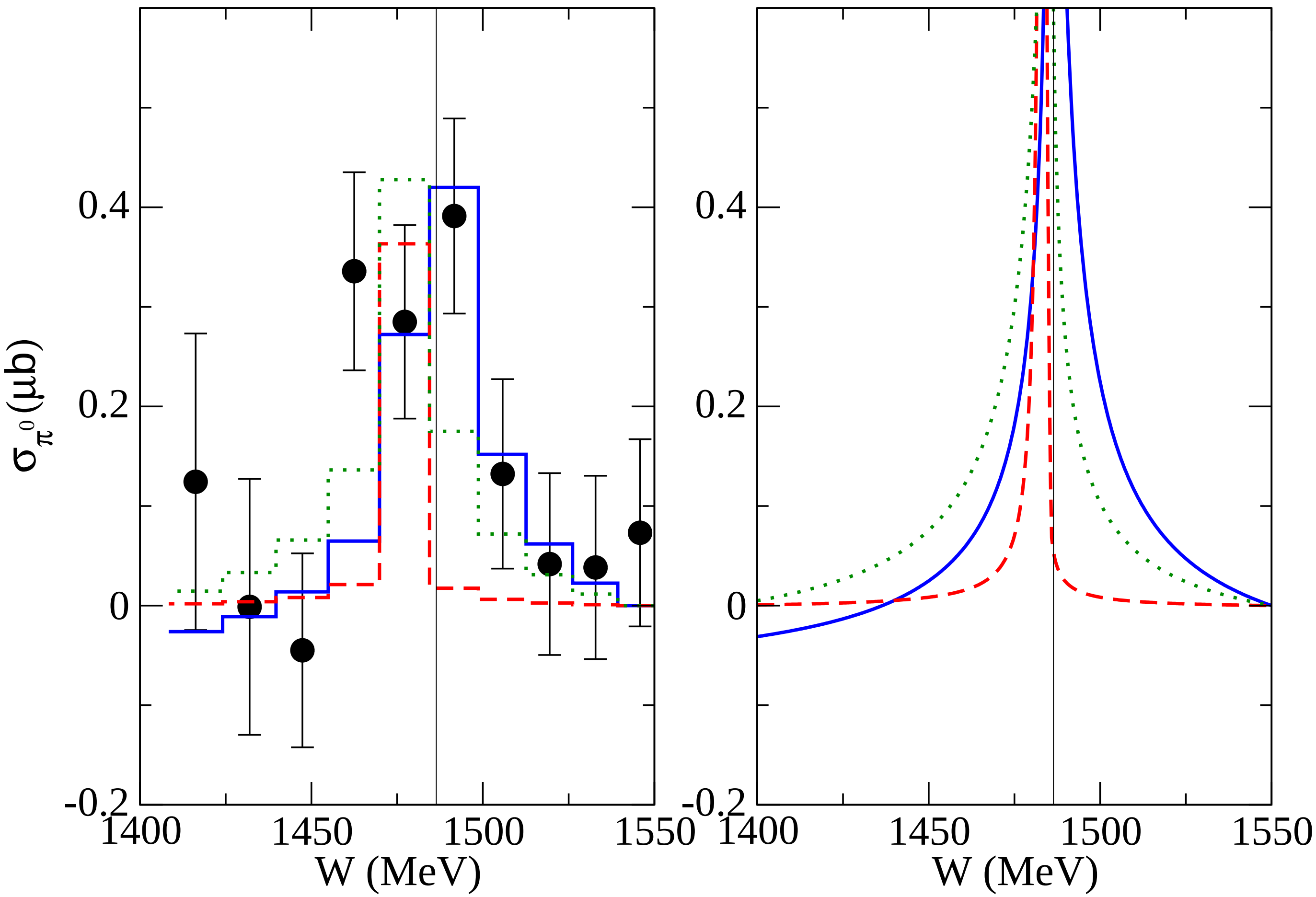
if $X(3872)$ virtual state

note:

then there must be same signal in $D\bar{D}\gamma$ with strength down by 38/62 (possibly different background?)

Side remark

virtual vs. bound state for η^3He system:



Pole fixed from $pd \to \eta^3$He;

red: virtual state; blue: virtual state; green: Im a > Re a

Data: γ^3He $\to [\eta^3$He$] \to \pi p$... Pfeiffer et al. (2004), Calc.: C.H. (2004)