What is a real resonance we are searching for?

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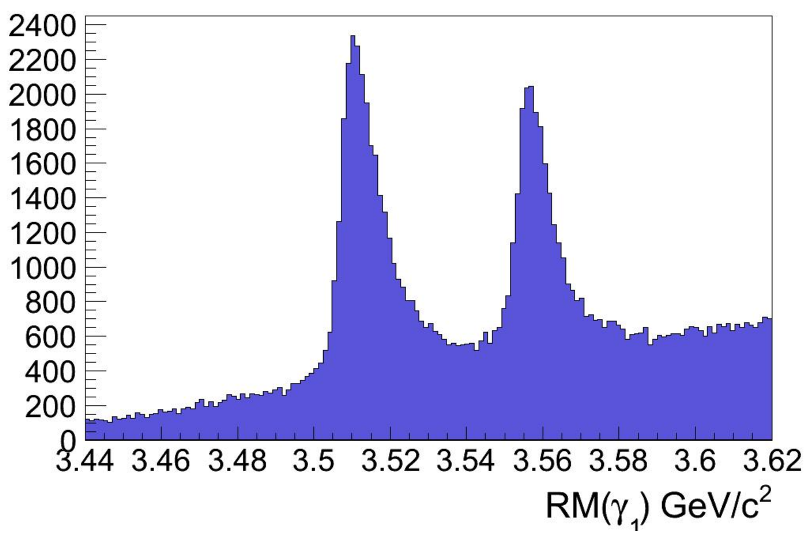
special topic of Journal Club

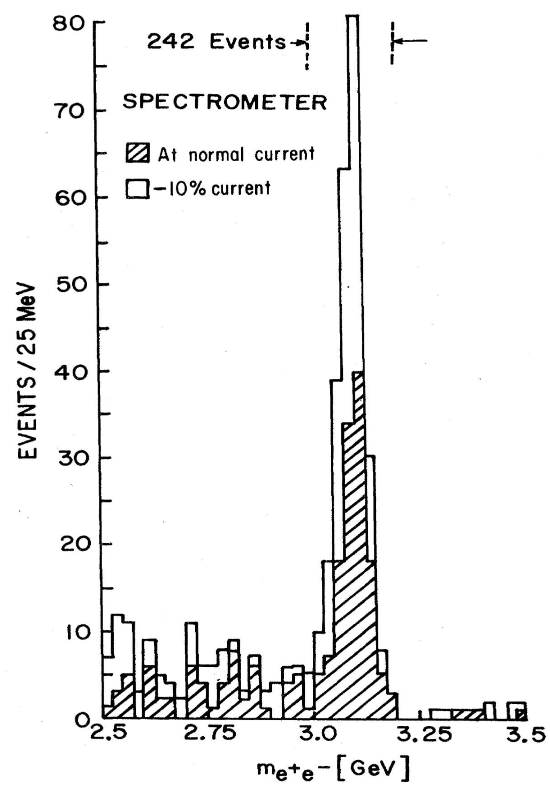
Outline

- **Resonance NOT only show up as a peak**
  - Resonance show up as a peak
  - could also be a pure dip, nothingness
- **A peak may be NOT a real resonance**

Resonance show up as a peak

- Normally, we claim that a new state is observed/discovered by **reporting the existance of a peak in real data sample**



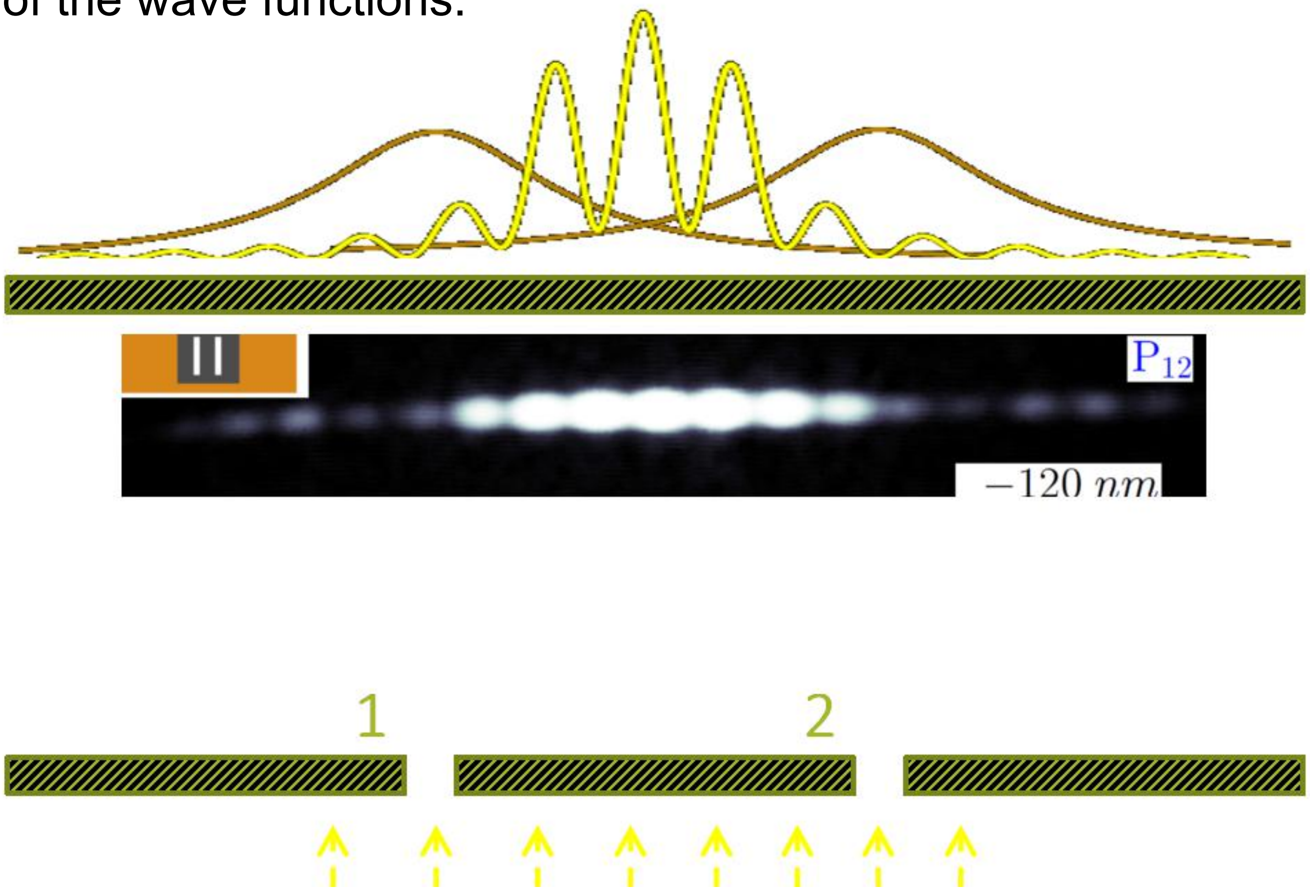


Could be a dip, nothingness, or a mixing

- Resonances do not always appear as peaks.
- Due to the presence of coupled channels and/or the interference effect with the background contributions, a resonance could also show up as a dip.
- Classical examples could be easilly found in some textbooks about scattering physics

Interference in Quantum mechanics

- One of the most important thing is quantum mechanics is the interference effect of the wave functions.



Example in high energy physics

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Dip or nothingness of a Higgs resonance from the interference with a complex phase

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We show that new resonance shapes—a pure dip, nothingness, and an enhanced pure peak—can be produced from the interference between the resonance and continuum with a relative phase. Production conditions of those new shapes are derived based on a general parametrization of the interference. The narrow width approximation is modified to work with the nonzero imaginary part of interference, and the correction factor can characterize the resonance shape. We demonstrate that the new resonance shapes of heavy Higgs bosons, H^0 and A^0 in the type-II aligned two Higgs doublet model, generally show up in $gg \to H^0/A^0 \to t\bar{t}$ as well as $b\bar{b}$ and $\gamma\gamma$ channels. The pure A^0 resonance dip in the $t\bar{t}$ channel is a particularly interesting signal as it can be probed by the current search techniques that do not even take into account interferences; the high-luminosity LHC 14 TeV can perhaps probe a large part of its parameter space.

Example in high energy physics

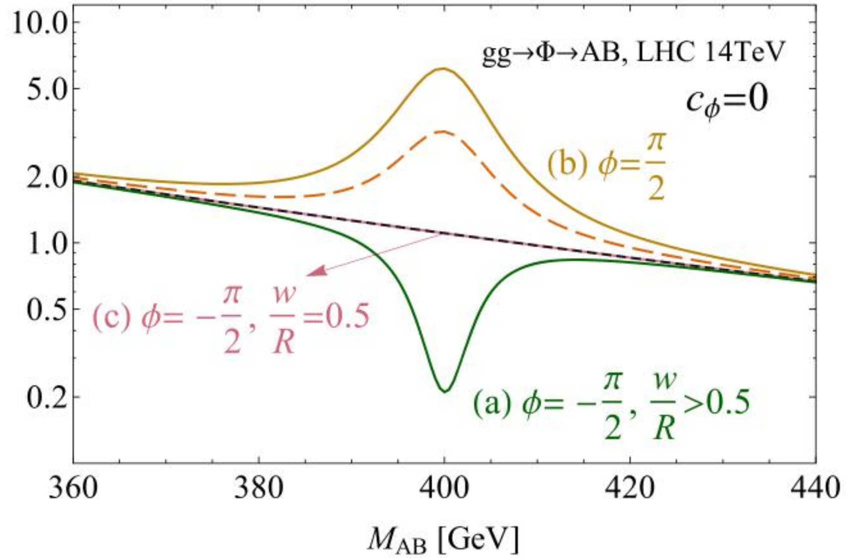


FIG. 1 (color online). Resonance shapes from the imaginary-part interferences ($c_\phi = 0$) for $M = 400$ GeV, $\Gamma = 10$ GeV, and $R = 0.035$ [$R = 0.05$ for the case (c)]. The vertical axis uses an arbitrary unit. Solid lines are the results for (a) a pure dip in Eq. (7), (b) a pure enhanced peak ($\phi = \pi/2$), and (c) nothingness ($\phi = -\pi/2, w/R = 0.5$). For comparison, we also show a resonance without any interference (orange-dashed line) and the continuum alone (black-dotted line).

A peak may be not a real resonance

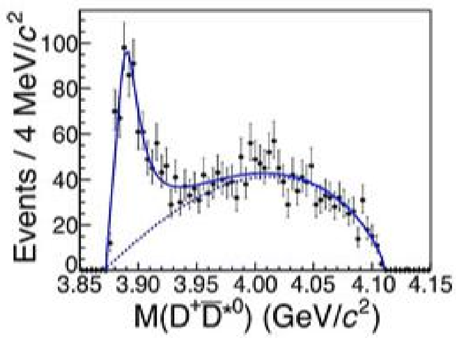
- Not all peaks are due to resonances.
- Normally when we talk about a resonance, we refer to poles of the S-matrix:
- which is of **dynamical** origion in the sense that a resonance is generated as pole in the scattering amplitudes by the interactions among quarks and gluons.

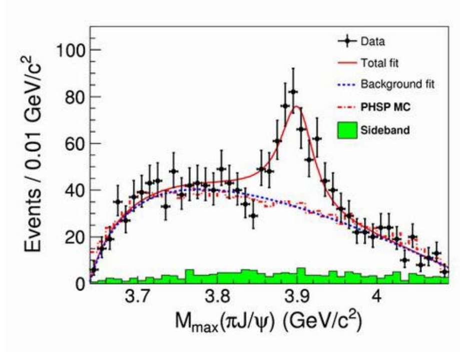
Some basic theoretical concepts

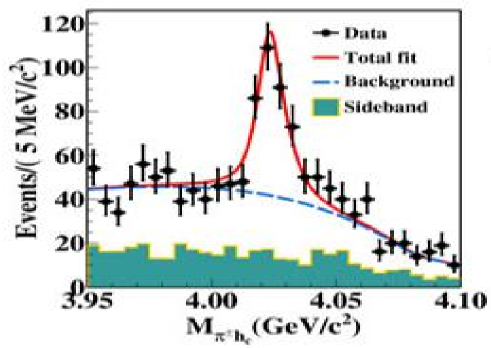
- In the amplitude for producing a pair of final states
- kinematic effect may cause a cusp at an S-wave threshold
- this is very important when we claim that the existance of a newly observed resonance is widely accepted.

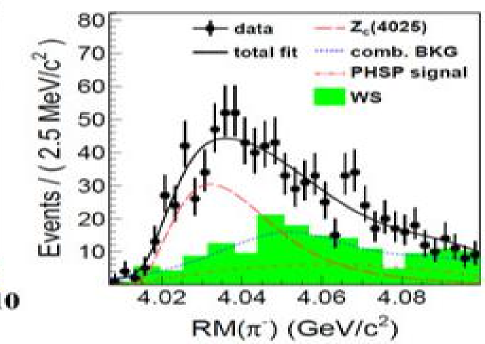
example in XYZ sector

- Zc(3900) is very close to the DD* threshold, Zc(4020) is close to D*D* threshold
- The quantum numbers of them are the same as the corresponding S-wave meson pairs.
- Similiar things happen in the Zb states.
- Some models has been published by speculating these states are threshod cusps.









How to understand the underlying structures of $X(4140)$, $X(4274)$, $X(4500)$ and $X(4700)$

CrossMark

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ABSTRACT

We investigate the possible rescattering effects which may contribute to the process $B^+ \to J/\psi\phi K^+$. It is shown that the $\psi'\phi$ rescattering via the $\psi' K_1$ loop can simulate the structure of $X(4700)$. The cusp effect due to the $D_s^{*+} D_s^-$ rescattering may possibly simulate the $X(4140)$ structure, but it depends on the cusp model parameters. If the quantum numbers of $X(4274)$ ($X(4500)$) are 1^{++} (0^{++}), it is hard to ascribe the observation of $X(4274)$ and $X(4500)$ to the P-wave threshold rescattering effects, which implies that $X(4274)$ and $X(4500)$ could be genuine resonances. We also suggest that $X(4274)$ may be the conventional orbitally excited state $\chi_{c1}(3P)$.

An explanation of Belle states $Z_b(10610)$ and $Z_b(10650)$

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Abstract

Belle report data on $\Upsilon(5S) \to \Upsilon(1S,2S,3S)\pi^+\pi^-$ and $\chi_b(1P,2P)\pi^+\pi^-$; they observe peaks in $\Upsilon\pi^\pm$ and $\chi_b\pi^\pm$ consistent with $J^P = 1^+$. They interpret the peaks as molecular states $Z_b(10608)$ and $Z_b(10653)$. Their masses are just above $\bar{B}B^*$ and $\bar{B}^*B^*$ thresholds at 10604.6 and 10650.2 MeV. An explanation in terms of cusps at these thresholds is presented here. The product of the rising phase space for $\bar{B}B^*$ and $\bar{B}^*B^*$ with the cusps creates peaks a few MeV higher in $\bar{B}B^*$ and $\bar{B}^*B^*$, and these peaks can de-excite to $\pi^+\pi^-\Upsilon(1S,2S,3S)$ and $\pi^+\pi^-\chi_b(1P,2P)$.

A candidate of fake resonance

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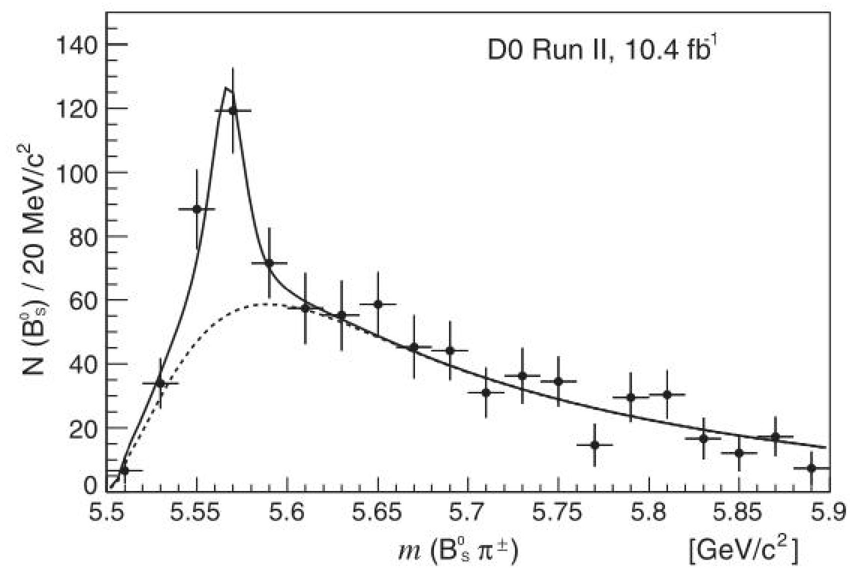
Evidence for a $B_s^0\pi^\pm$ State

- This peak is observed by D0 Collaboration
- the existance of it not supported theoretically
- lattice QCD calculation has no signal of it
- not confirmed in other experiments
- may be it is a peak from kinematic effect



Summary

- Resonances not always show up as peaks
- Could also be a pure dip, nothingness..
- When you observed a peak in real data, it may not be a real resonance, perhaps it is just a structure from kinematic effect.

THANKS