Observation of a New Particle at BABAR

QuarkNet - 5/18/2003

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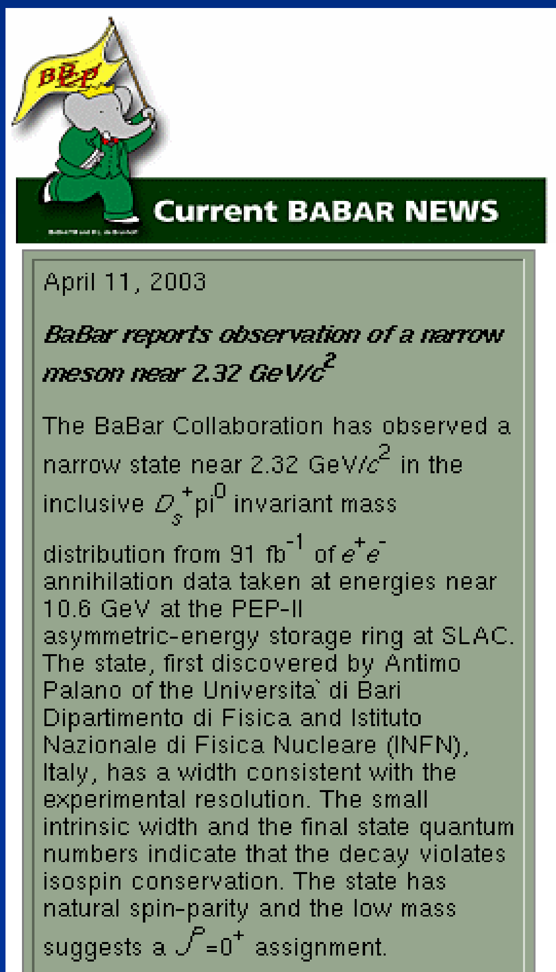
So what's this all about….



Current BABAR NEWS

April 11, 2003

BaBar reports observation of a narrow meson near 2.32 GeV/c^2

The BaBar Collaboration has observed a narrow state near 2.32 GeV/c^2 in the inclusive D_s^+pi^0 invariant mass distribution from 91 fb^{-1} of e^+e^- annihilation data taken at energies near 10.6 GeV at the PEP-II asymmetric-energy storage ring at SLAC. The state, first discovered by Antimo Palano of the Universita` di Bari Dipartimento di Fisica and Istituto Nazionale di Fisica Nucleare (INFN), Italy, has a width consistent with the experimental resolution. The small intrinsic width and the final state quantum numbers indicate that the decay violates isospin conservation. The state has natural spin-parity and the low mass suggests a $J^P=0^+$ assignment.

Current BABAR web page

What makes this interesting?

Why do we care?

A Short Summary of the Quark Model

Quarks

Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	175	2/3
b bottom	4.3	−1/3

Mesons:

- (Quasi-) bound states of Quark and Antiquark (quark-antiquark "atoms")

Mesons $q\bar{q}$ Mesons are bosonic hadrons. There are about 140 types of mesons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

Mesons – as known …

LIGHT UNFLAVORED ($S = C = B = 0$)

	$I^G(J^{PC})$
• $\pi^\pm$	$1^-(0^-)$
• π^0	$1^-(0^{-+})$
• η	$0^+(0^{-+})$
• $f_0(600)$	$0^+(0^{++})$
• $\rho(770)$	$1^+(1^{--})$
• $\omega(782)$	$0^-(1^{--})$
• $\eta'(958)$	$0^+(0^{-+})$
• $f_0(980)$	$0^+(0^{++})$
• $a_0(980)$	$1^-(0^{++})$
• $\phi(1020)$	$0^-(1^{--})$
• $h_1(1170)$	$0^-(1^{+-})$
• $b_1(1235)$	$1^+(1^{+-})$
• $a_1(1260)$	$1^-(1^{++})$
• $f_2(1270)$	$0^+(2^{++})$
• $f_1(1285)$	$0^+(1^{++})$
• $\eta(1295)$	$0^+(0^{-+})$
• $\pi(1300)$	$1^-(0^{-+})$
• $a_2(1320)$	$1^-(2^{++})$
• $f_0(1370)$	$0^+(0^{++})$
$h_1(1380)$	$?^-(1^{+-})$
$\pi_1(1400)$	$1^-(1^{-+})$
• $f_1(1420)$	$0^+(1^{++})$
• $\omega(1420)$	$0^-(1^{--})$
$f_2(1430)$	$0^+(2^{++})$
• $\eta(1440)$	$0^+(0^{-+})$
• $a_0(1450)$	$1^-(0^{++})$
• $\rho(1450)$	$1^+(1^{--})$
• $f_0(1500)$	$0^+(0^{++})$
$f_1(1510)$	$0^+(1^{++})$
• $f_2'(1525)$	$0^+(2^{++})$
$f_2(1565)$	$0^+(2^{++})$
$h_1(1595)$	$0^-(1^{+-})$
$\pi_1(1600)$	$1^-(1^{-+})$
$X(1600)$	$2^+(2^{++})$
$a_1(1640)$	$1^+(1^{++})$
$f_2(1640)$	$0^+(2^{++})$
$\eta_2(1645)$	$0^+(2^{-+})$
• $\omega(1650)$	$0^-(1^{--})$
• $\omega_3(1670)$	$0^-(3^{--})$
• $\pi_2(1670)$	$1^-(2^{-+})$

	$I^G(J^{PC})$
• $\phi(1680)$	$0^-(1^{--})$
• $\rho_3(1690)$	$1^+(3^{--})$
• $\rho(1700)$	$1^+(1^{--})$
$a_2(1700)$	$1^-(2^{++})$
• $f_0(1710)$	$0^+(0^{++})$
$\eta(1760)$	$0^+(0^{-+})$
• $\pi(1800)$	$1^-(0^{-+})$
$f_2(1810)$	$0^+(2^{++})$
• $\phi_3(1850)$	$0^-(3^{--})$
$\eta_2(1870)$	$0^+(2^{-+})$
$\rho(1900)$	$1^+(1^{--})$
$f_2(1910)$	$0^+(2^{++})$
$f_2(1950)$	$0^+(2^{++})$
$\rho_3(1990)$	$1^+(3^{--})$
$X(2000)$	$1^-(?^{?+})$
• $f_2(2010)$	$0^+(2^{++})$
$f_0(2020)$	$0^+(0^{++})$
• $a_4(2040)$	$1^-(4^{++})$
• $f_4(2050)$	$0^+(4^{++})$
$\pi_2(2100)$	$1^-(2^{-+})$
$f_0(2100)$	$0^+(0^{++})$
$f_2(2150)$	$0^+(2^{++})$
$\rho(2150)$	$1^+(1^{--})$
$f_0(2200)$	$0^+(0^{++})$
$f_J(2220)$	$0^+(2^{++}$ or $4^{++})$
$\eta(2225)$	$0^+(0^{-+})$
$\rho_3(2250)$	$1^+(3^{--})$
• $f_2(2300)$	$0^+(2^{++})$
$f_4(2300)$	$0^+(4^{++})$
$f_0(2330)$	$0^+(0^{++})$
• $f_2(2340)$	$0^+(2^{++})$
$\rho_5(2350)$	$1^+(5^{--})$
$a_6(2450)$	$1^-(6^{++})$
$f_6(2510)$	$0^+(6^{++})$

OTHER LIGHT UNFLAVORED ($S = C = B = 0$)

Further States

STRANGE ($S = \pm 1$, $C = B = 0$)

	$I(J^P)$
• $K^\pm$	$1/2(0^-)$
• K^0	$1/2(0^-)$
• K^0_S	$1/2(0^-)$
• K^0_L	$1/2(0^-)$
• $K^*(892)$	$1/2(1^-)$
• $K_1(1270)$	$1/2(1^+)$
• $K_1(1400)$	$1/2(1^+)$
• $K^*(1410)$	$1/2(1^-)$
• $K^*_0(1430)$	$1/2(0^+)$
• $K^*_2(1430)$	$1/2(2^+)$
$K(1460)$	$1/2(0^-)$
$K_2(1580)$	$1/2(2^-)$
$K(1630)$	$1/2(?^?)$
$K_1(1650)$	$1/2(1^+)$
• $K^*(1680)$	$1/2(1^-)$
• $K_2(1770)$	$1/2(2^-)$
• $K^*_3(1780)$	$1/2(3^-)$
• $K_2(1820)$	$1/2(2^-)$
$K(1830)$	$1/2(0^-)$
$K^*_0(1950)$	$1/2(0^+)$
$K^*_2(1980)$	$1/2(2^+)$
• $K^*_4(2045)$	$1/2(4^+)$
$K_2(2250)$	$1/2(2^-)$
$K_3(2320)$	$1/2(3^+)$
$K^*_5(2380)$	$1/2(5^-)$
$K_4(2500)$	$1/2(4^-)$
$K(3100)$	$?^?(?^{??})$

CHARMED ($C = \pm 1$)

• $D^\pm$	$1/2(0^-)$
• D^0	$1/2(0^-)$
• $D^*(2007)^0$	$1/2(1^-)$
• $D^*(2010)^\pm$	$1/2(1^-)$
• $D_1(2420)^0$	$1/2(1^+)$
$D_1(2420)^\pm$	$1/2(?^?)$
• $D^*_2(2460)^0$	$1/2(2^+)$
• $D^*_2(2460)^+$	$1/2(2^+)$
$D^*(2640)^\pm$	$1/2(?^?)$

CHARMED, STRANGE ($C = S = \pm 1$)

• $D^\pm_s$	$0(0^-)$
• $D^{*\pm}_s$	$0(?^?)$
• $D_{s1}(2536)^\pm$	$0(1^+)$
• $D_{sJ}(2573)^\pm$	$0(?^?)$

BOTTOM ($B = \pm 1$)

	$I^G(J^{PC})$
• $B^\pm$	$1/2(0^-)$
• B^0	$1/2(0^-)$
• $B^\pm/B^0$ ADMIXTURE	
• $B^\pm/B^0/B^0_s/b$-baryon ADMIXTURE	
V_{cb} and V_{ub} CKM Matrix Elements	
• B^*	$1/2(1^-)$
$B^*_J(5732)$	$?(?^?)$

BOTTOM, STRANGE ($B = \pm 1$, $S = \mp 1$)

• B^0_s	$0(0^-)$
B^*_s	$0(1^-)$
$B^*_{sJ}(5850)$	$?(?^?)$

BOTTOM, CHARMED ($B = C = \pm 1$)

• $B^\pm_c$	$0(0^-)$

$c\bar{c}$

• $\eta_c(1S)$	$0^+(0^{-+})$
• $J/\psi(1S)$	$0^-(1^{--})$
• $\chi_{c0}(1P)$	$0^+(0^{++})$
• $\chi_{c1}(1P)$	$0^+(1^{++})$
$h_c(1P)$	$?^?(?^{??})$
• $\chi_{c2}(1P)$	$0^+(2^{++})$
$\eta_c(2S)$	$0^+(0^{-+})$
• $\psi(2S)$	$0^-(1^{--})$
• $\psi(3770)$	$0^-(1^{--})$
$\psi(3836)$	$0^-(2^{--})$
• $\psi(4040)$	$0^-(1^{--})$
• $\psi(4160)$	$0^-(1^{--})$
• $\psi(4415)$	$0^-(1^{--})$

$b\bar{b}$

$\eta_b(1S)$	$0^+(0^{-+})$
• $\Upsilon(1S)$	$0^-(1^{--})$
• $\chi_{b0}(1P)$	$0^+(0^{++})$
• $\chi_{b1}(1P)$	$0^+(1^{++})$
• $\chi_{b2}(1P)$	$0^+(2^{++})$
• $\Upsilon(2S)$	$0^-(1^{--})$
• $\chi_{b0}(2P)$	$0^+(0^{++})$
• $\chi_{b1}(2P)$	$0^+(1^{++})$
• $\chi_{b2}(2P)$	$0^+(2^{++})$
• $\Upsilon(3S)$	$0^-(1^{--})$
• $\Upsilon(4S)$	$0^-(1^{--})$
• $\Upsilon(10860)$	$0^-(1^{--})$
• $\Upsilon(11020)$	$0^-(1^{--})$

In the following we will need:

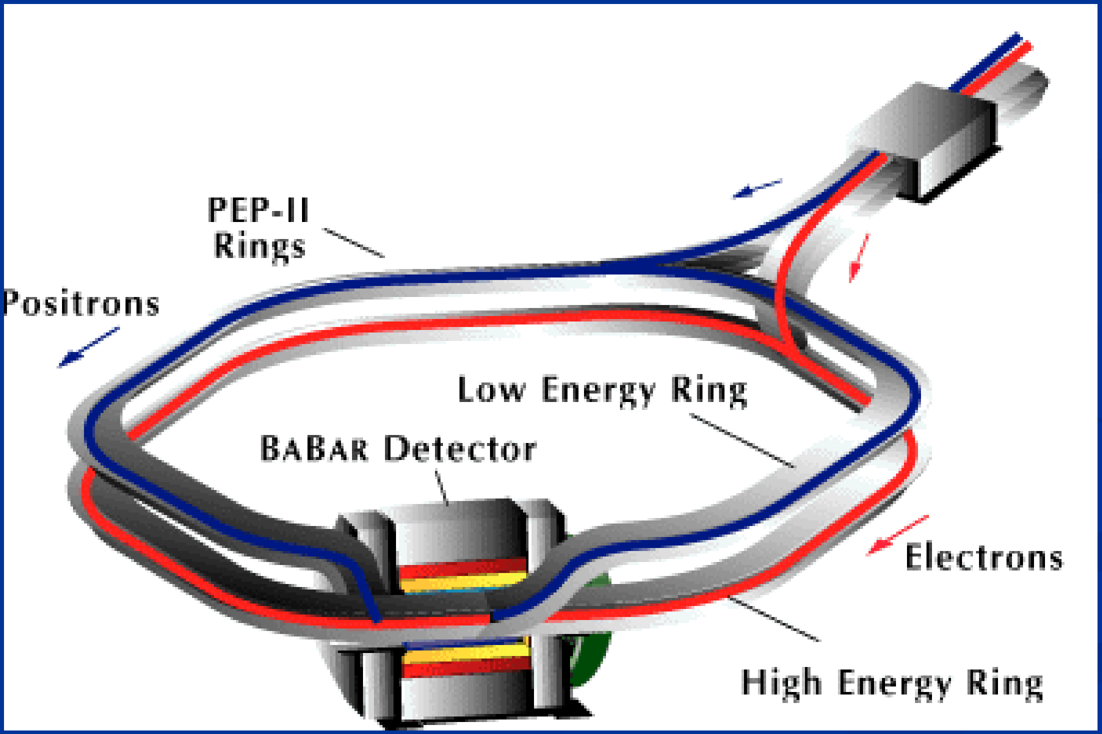
- $\pi^0\ (u\bar{u}, d\bar{d})$
- $\pi^\pm\ (u\bar{d})$
- $K^\pm\ (u\bar{s})$
- $K^*\ (d\bar{s})$
- $\phi\ (s\bar{s})$
- $D^\pm_S\ (c\bar{s})$

Note: every meson (almost) has it's own unique mass…

The BABAR Experiment

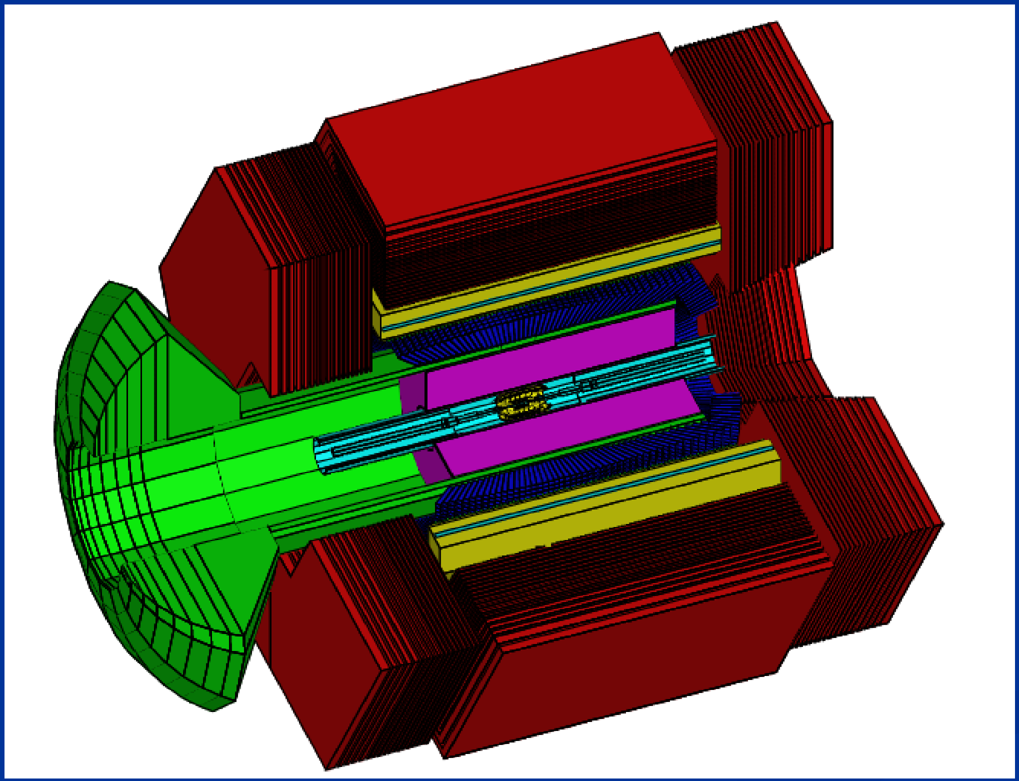
- Uses the PEPII ring at SLAC:

  → e^+e^- Reaction



The BABAR Experiment

- The BABAR Detector



Measures:

- energy and momentum of photons
- momentum of charged particles ($\pi^{\pm}$, $K^{\pm}$, $\mu^{\pm}$, $e^{\pm}$)
- identification of particle types ($\pi^{\pm}$, $K^{\pm}$, $\mu^{\pm}$, $e^{\pm}$)

Reaction

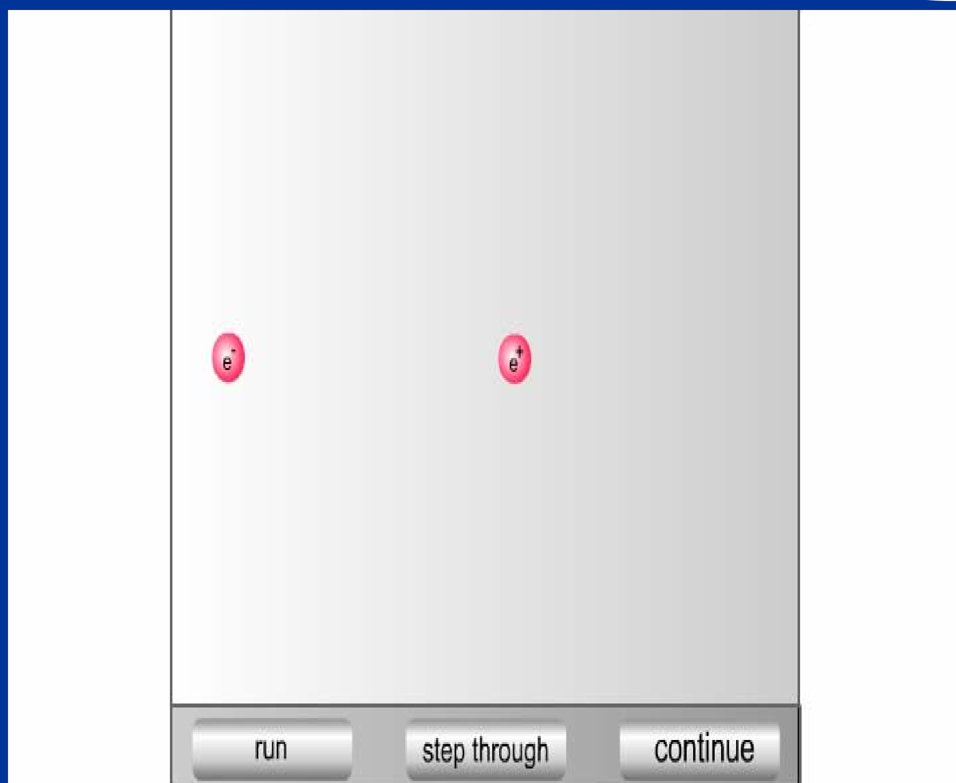
$e^+e^- \to (Y)\ X$

$\hookrightarrow D_S^\pm\ \pi^0 \longrightarrow \gamma\gamma$

$\hookrightarrow K^* K^\pm \rightarrow K^+\ K^-\ \pi^\pm$

$\hookrightarrow \phi\ \pi^\pm \rightarrow K^+\ K^-\ \pi^\pm$

measured particles



Reconstruction of intermediate states

- Energy and momentum of intermediate states:

Energy and momentum conservation

→ Energy and momentum of the intermediate state is the sum of it's daughter particles

- How do we identify an intermediate state:

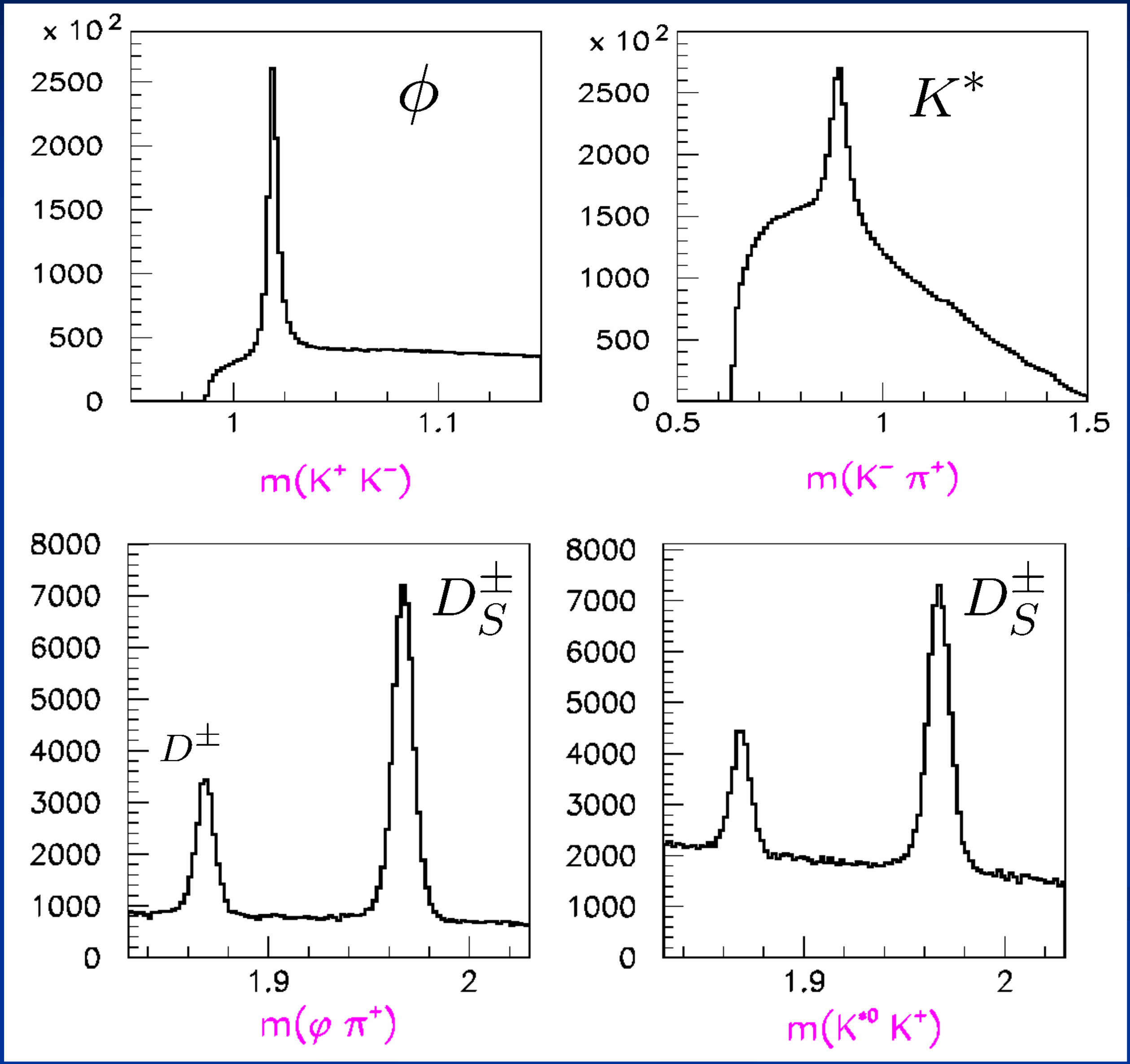
Invariant mass: energy of a particle in it's own rest-frame

Can easily be calculated in any reference frame:

$$\boxed{m_{12} = \sqrt{(E_1 + E_2)^2 - (p_{x1} + p_{x2})^2 - (p_{y1} + p_{y2})^2 - (p_{z1} + p_{z2})^2}}$$

with $E_{1,2}$, $p_{1,2}$ energy, momentum of daughters

Example inv. mass spectra



Data Selection

Data sample: 91 fb^{-1} ~ 500 mill. interaction (events)

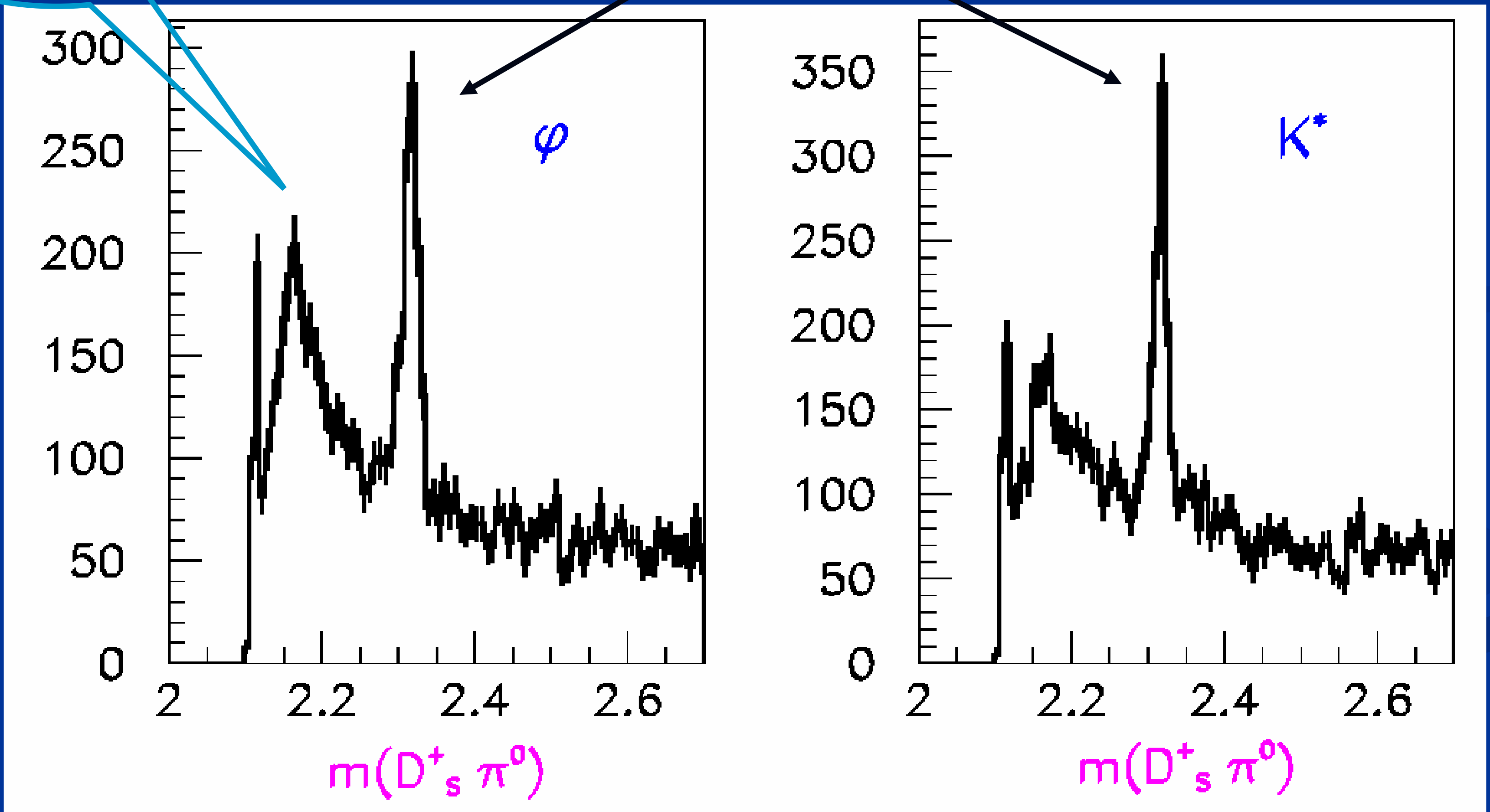
- select events with $K^+, \ K^-, \ \pi^\pm, \ \gamma, \ \gamma \ + \ldots.$
- $K^+K^-\pi^\pm$ should all come from the same point
- $\gamma\gamma \to \pi^0$
- $K^\mp\pi^\pm \to K^*$ or $K^+K^- \to \phi$
- $K^*K^\pm$ or $\phi\pi^\pm \to D_S^\pm$

→ Then look at the inv. mass spectrum of the $D_S^\pm\pi^0$

Ok…. here we go:

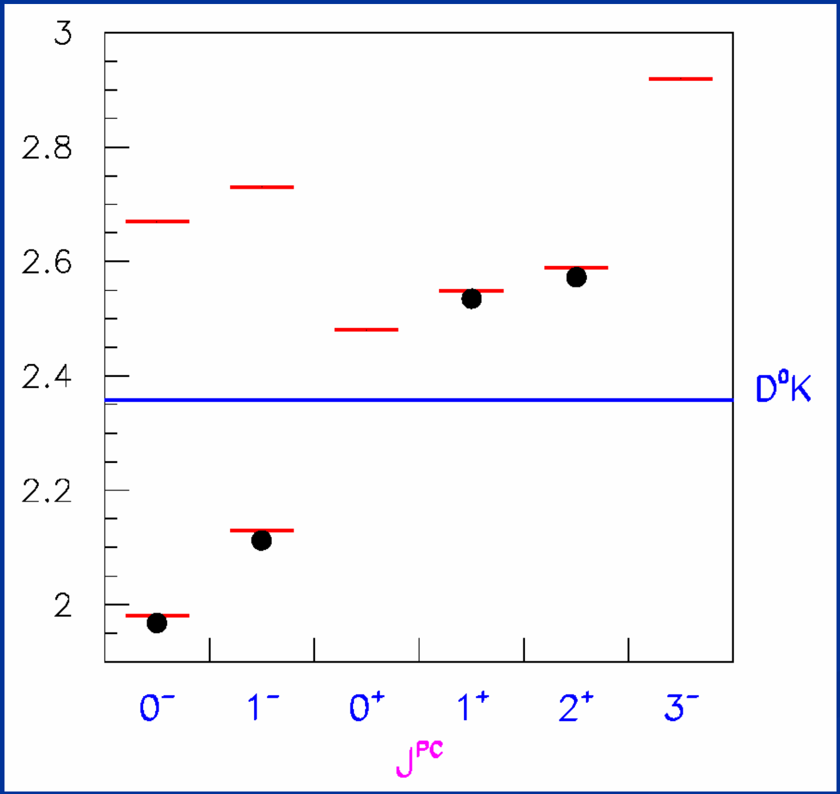
background
$D_S^*(2112) \to D_S^{\pm}\gamma$

inv. mass: $m_{inv} = 2316 MeV/c^2; \Gamma \approx$ exp. resolution



Interpretation

- $(c\bar{s})$ state
- predicted spectrum



- low inv. mass $\longrightarrow 0^+$

- But:

  What's with the difference from predictions?

So, now again - why do we care?

- meson are really simple objects
  - 2 quarks (quark – antiquark)
  - (quasi-) bound states

So why do we have such problems predicting:

- masses of mesons,
- decays of mesons,
- how mesons (hadrons) are ‘created’

→ we need better understanding of mechanisms in QCD → need more information!