New states, rare decays and branching ratios

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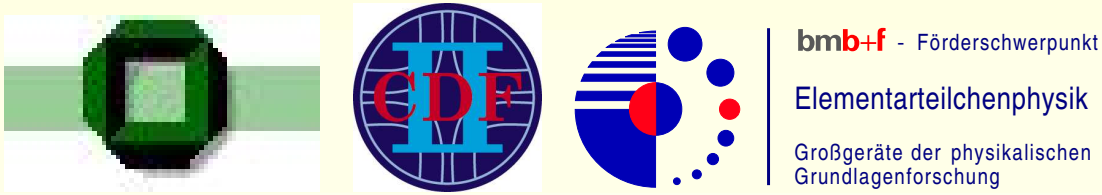

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16th June 2004

Overview

1. Detectors

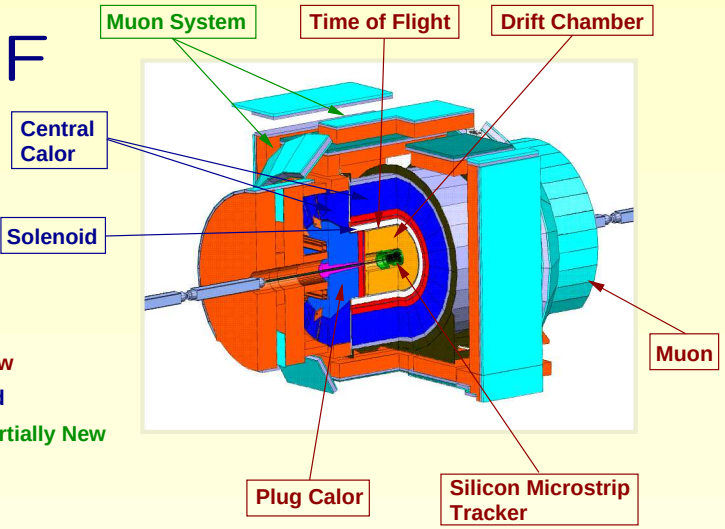
2. Rare decays and branching ratios

3. New states:
   - PentaQuarks
   - $X \to J/\Psi\pi^+\pi^-$

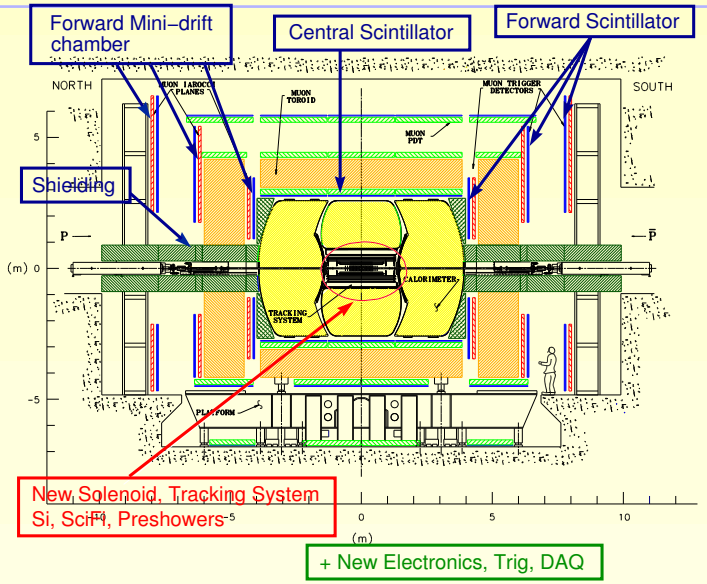
4. Conclusion

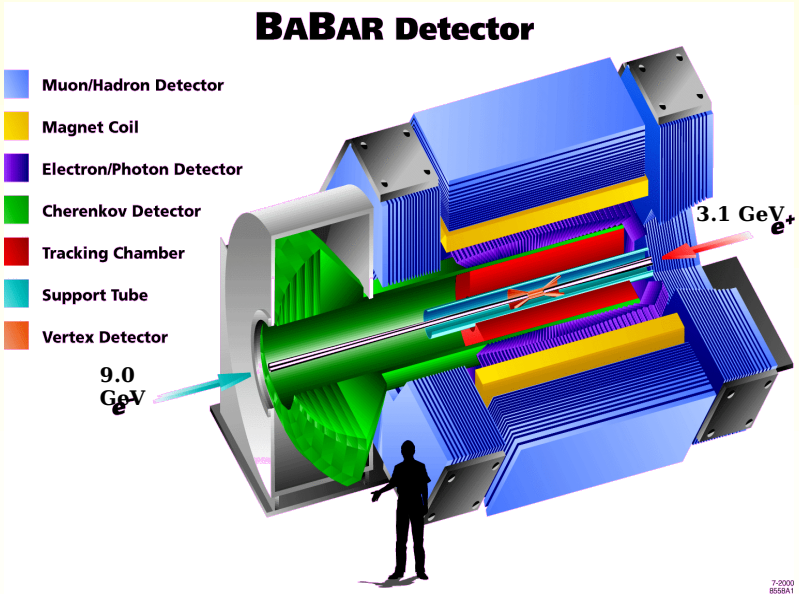
Detectors I

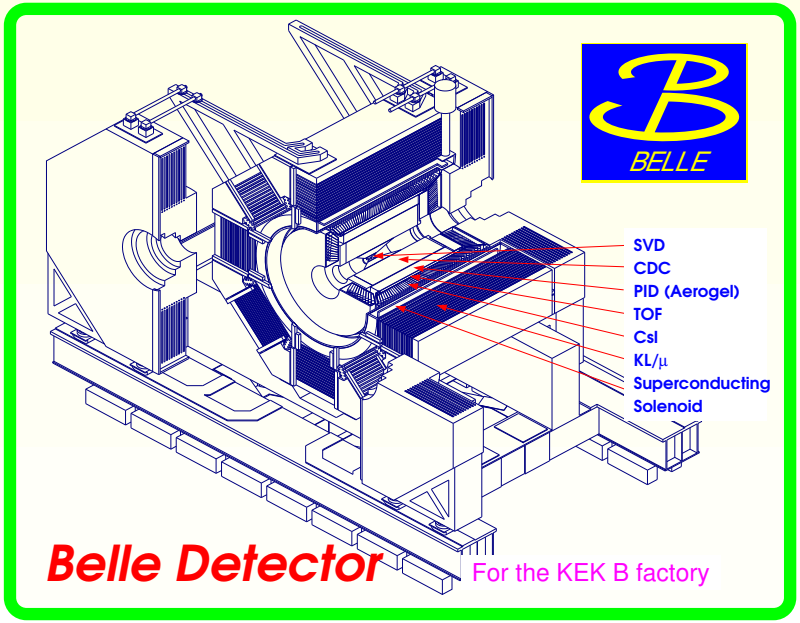
CDF



DØ

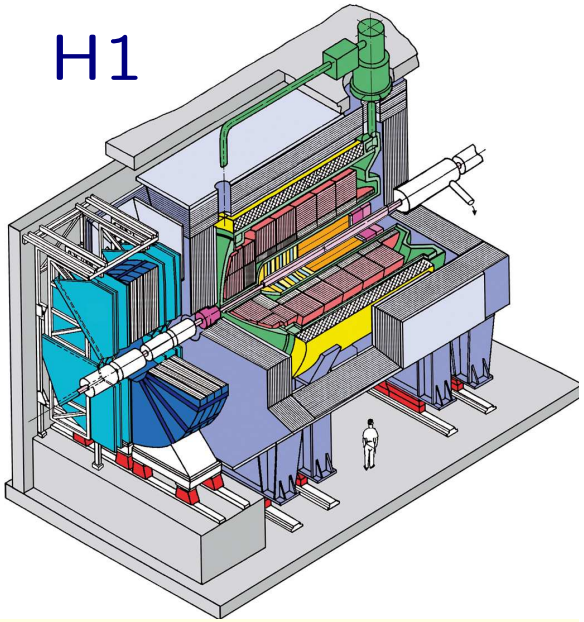




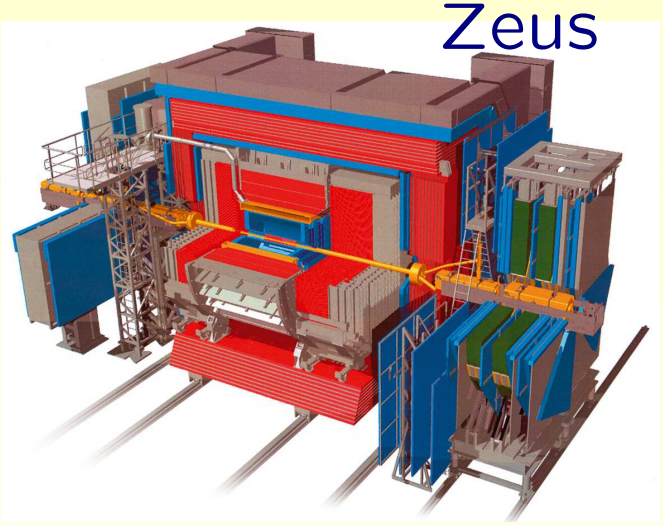


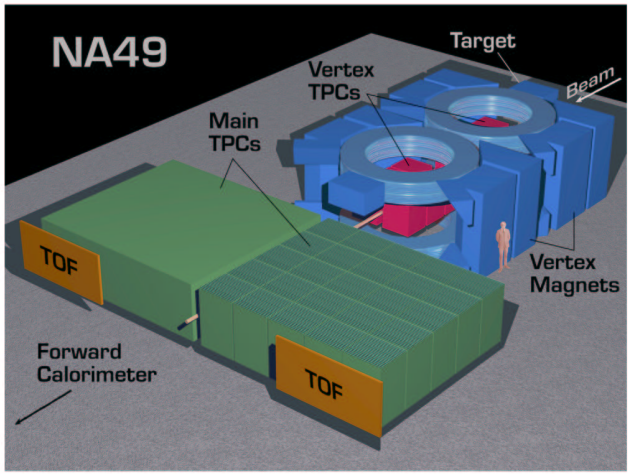
Detectors II

H1

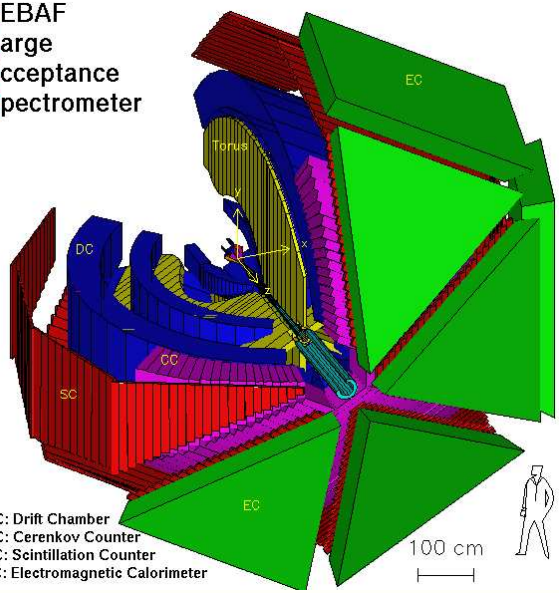


Zeus

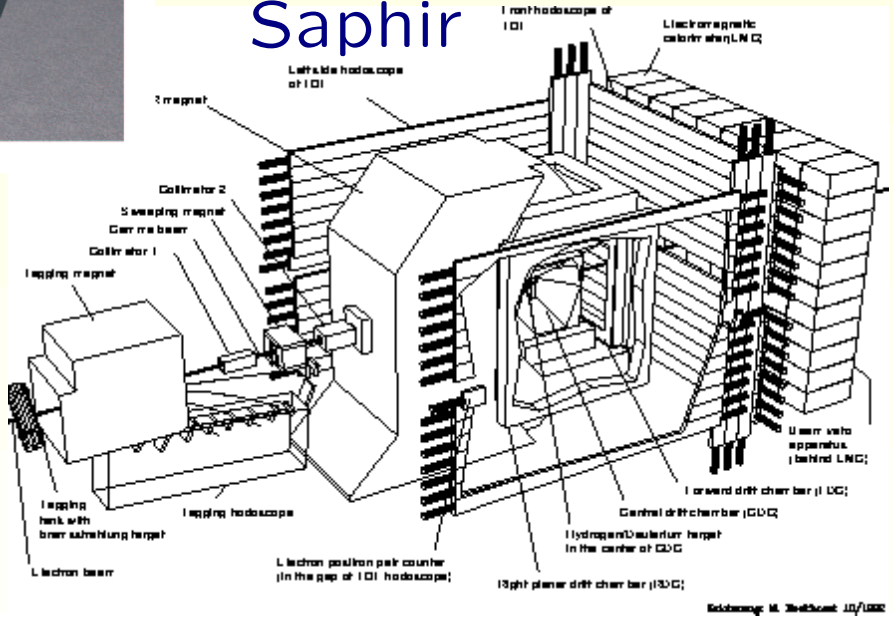




CEBAF
Large
Acceptance
Spectrometer



Saphir



Branching ratios and rare decays

selected results from 2004

Branching Ratios I

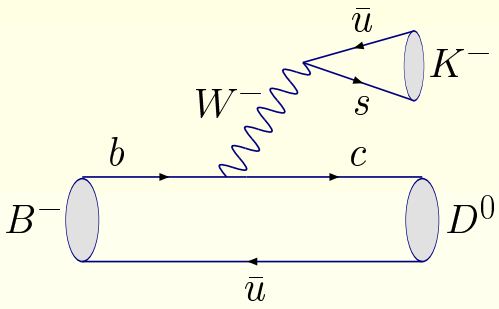
BaBar $B \to X_c l \nu$

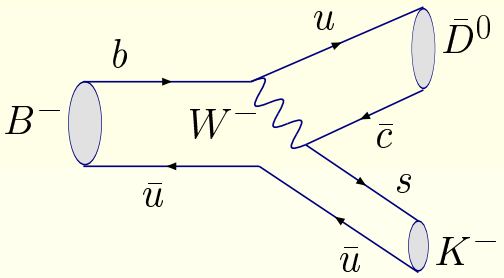
$$|V_{cb}| = (41.4 \pm 0.4_{exp} \pm 0.4_{HQE} \pm 0.6_{th}) \cdot 10^{-3}$$

$$\mathcal{BR}(b \to c l \nu) = (10.61 \pm 0.16_{exp} \pm 0.06_{HQE})\%$$

Results are in agreement with recent calculations

BaBar $B^{\pm} \to [K^{\mp}\pi^{\pm}]_D K^{\pm}$





no signal seen

$\to r_B = \left|\frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)}\right| < 0.22\ (90\% CL)$

$\to$ amplitude $b \to u$ small?

$\to \gamma = arg(-V_{ub}^* V_{ud} / V_{cb}^* V_{cd})$ difficult from this mode

Belle $B^0 \to p\bar{p}$

New $\mathcal{BR} < 2.7 \cdot 10^{-7}$ factor 10 lower

$\to$ constrain theory: rule out QCD sum-rule based prediction, consistent with pole model

Belle $B \to \omega K$; $B \to \omega\pi$

Originate from interference of $b \to s$ penguin loop and $b \to u$ spectator tree

$$\mathcal{BR}(B^+ \to \omega K^+) = (6.5^{+1.3}_{-1.2} \pm 0.6) \cdot 10^{-6}$$

$\to$ large $\mathcal{BR}$ problematic in factorisation approach

$$\mathcal{BR}(B^+ \to \omega\pi^+) = (5.7^{+1.4}_{-1.3} \pm 0.6) \cdot 10^{-6}$$

$$\mathcal{A}_{CP}(B^+ \to \omega K^+) = 0.06^{+0.21}_{-0.18} \pm 0.01$$

$$\mathcal{A}_{CP}(B^+ \to \omega\pi^+) = 0.50^{+0.23}_{-0.20} \pm 0.02$$

2.4σ sign.

Branching Ratios III

BaBar $B \to \eta^{(\prime)} K^*,\ \eta^{(\prime)}\rho,\ \eta^{(\prime)}\pi^0,\ \omega\pi^0,\ \phi\pi^0$

$\to$ interf. penguin tree, constrain CKM parameters

$$\mathcal{BR}(B^+ \to \eta K^{*+}) = (25.6 \pm 4.0 \pm 2.4) \cdot 10^{-6}$$

$$\mathcal{BR}(B^0 \to \eta K^{*0}) = (18.6 \pm 2.3 \pm 1.2) \cdot 10^{-6}$$

$$\mathcal{BR}(B^+ \to \eta \rho^{+}) = (9.2 \pm 3.4 \pm 1.02) \cdot 10^{-6}$$

$\to 3.5\sigma$ sig. for new mode $B^+ \to \eta\rho^+$

Belle $B \to K^*\gamma$

$\to$ Isospin, CP asymmetries

$$\mathcal{BR}(B^+ \to K^{*+}\gamma) = (4.01 \pm 0.21 \pm 0.15) \cdot 10^{-5}$$

$$\mathcal{BR}(B^0 \to K^{*0}\gamma) = (4.25 \pm 0.31 \pm 0.24) \cdot 10^{-5}$$

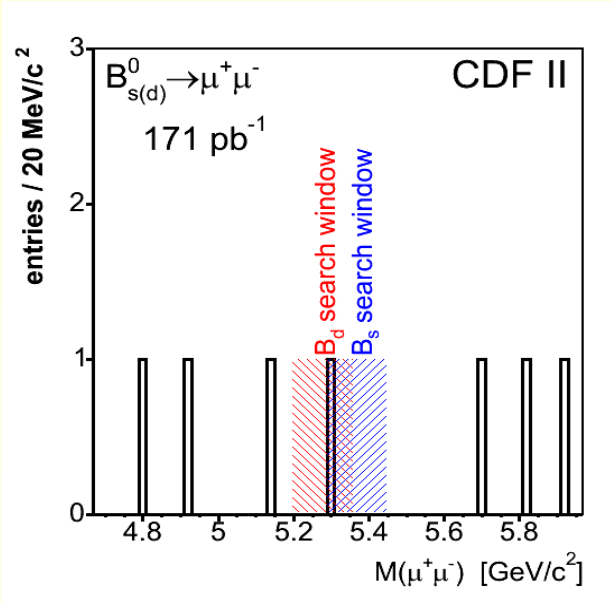
Isospin asymm.: $\Delta = 0.012 \pm 0.044 \pm 0.026$

CP asymm.: $A_{CP} = -0.015 \pm 0.044 \pm 0.012$

$B \to \mu^+\mu^-$

forbidden in SM at tree level (FCNC),
higher order process $\to \mathcal{BR} \approx 3 \cdot 10^{-9}$

$\to$new physics: enhancements in some SuSy, SO(10) models



CDF

$\mathcal{BR}(B_s \to \mu^+\mu^-) < 5.8 \cdot 10^{-7}$ @ $90\% CL$

$\mathcal{BR}(B_d \to \mu^+\mu^-) < 1.5 \cdot 10^{-7}$ @ $90\% CL$

Belle

$\mathcal{BR}(B_d \to \mu^+\mu^-) < 1.6 \cdot 10^{-7}$ @ $90\% CL$

D0

$< \mathcal{BR}(B_s \to \mu^+\mu^-) > \approx 1.01 \cdot 10^{-6}$ @ $95\% CL$

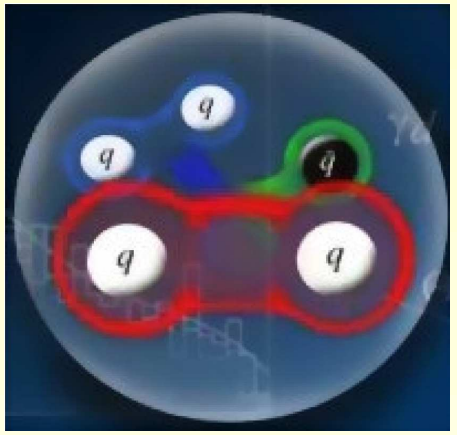
(expected value, not yet unblinded)

New states

- PentaQuarks
- X

PentaQuarks introduction

PentaQuarks:
bound 5 quark state ($qqqq\bar{q}$)
$\rightarrow$ "Baryon + Meson"



- not prohibited by QCD ...
- ... but not seen so far either
- Since summer 2003:
  much activity regarding 5-quark state
  also from smaller experiments

PentaQuarks - overview I

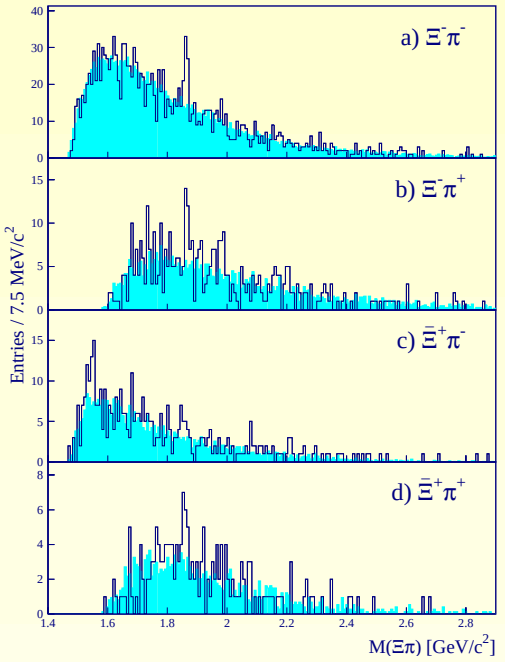
$\Xi : \Xi^{+}_{\frac{3}{2}}, \Xi^{0}_{\frac{3}{2}}, \Xi^{-}_{\frac{3}{2}}, \Xi^{--}_{\frac{3}{2}}$

NA49 (CERN): evidence (4.0σ sign.)

for narrow resonance in $\Xi^{-}\pi^{-}$ channel

$M = 1.862 \pm 0.002\ GeV/c^2$

not seen by CDF, DELPHI, Hera-B

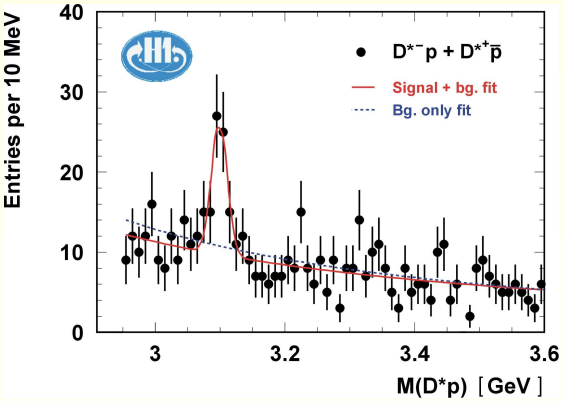


$\Theta_c \rightarrow D^{*}pX$

H1 (Desy): evidence in $M(D^{*+}p), M(D^{*-}\bar{p})$

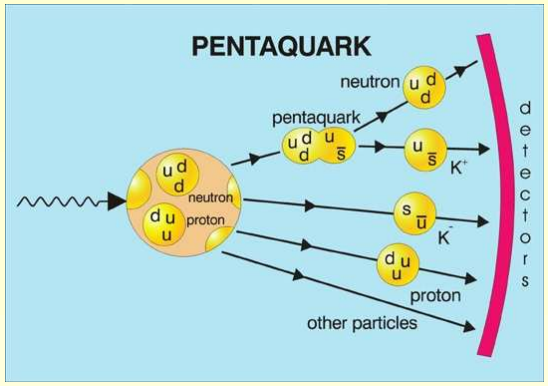
$M = 3099 \pm 3 \pm 5\ MeV/c^2$

not seen by Zeus, CDF



all widths reported compatible with resolution

PentaQuarks - overview II



Most evidence: Θ^+ $(uudd\bar{s})$

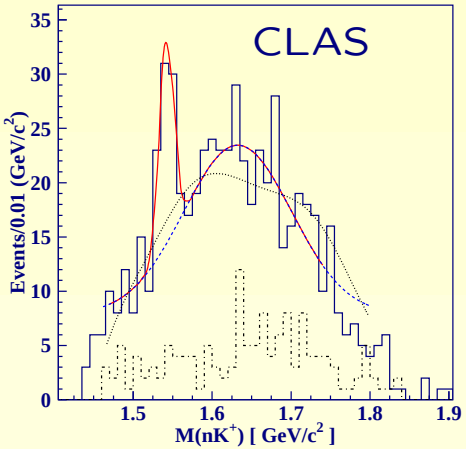
predicted 1997 by Diakonov, Petrov, Polyakov

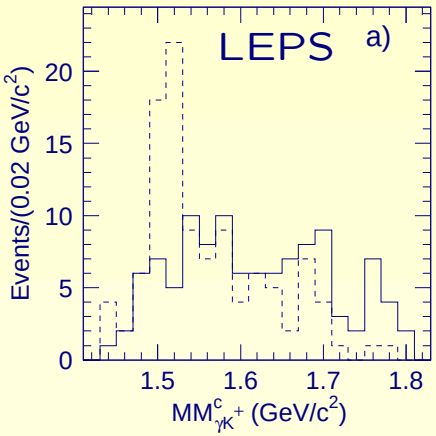
should decay equally to $K^+n, K^0_s p$

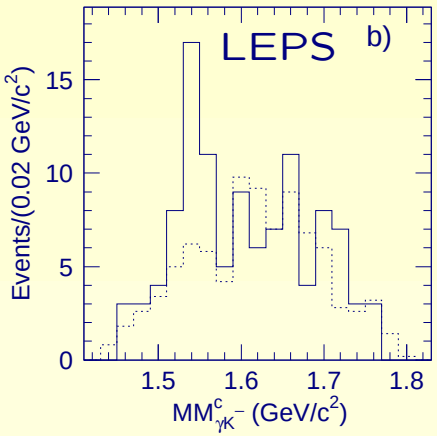
Experiment	$\Theta^+ \rightarrow$	Mass / GeV/c^2	stat. sign.
CLAS	K^+n	1.542 ± 0.005	5.2σ
LEPS	K^+n	1.54 ± 0.01	4.6σ
SAPHIR	K^+n	$1.540 \pm 0.004 \pm 0.002$	4.8σ
DIANA	K^0p	1.539 ± 0.002	4.4σ
HERMES	$K^0_s p$	$1.528 \pm 0.0026 \pm 0.0021$	$\approx 4\sigma$
Zeus	$K^0_s p$	$1.521 \pm 0.0015^{+0.0028}_{-0.0015}$,	$\approx 4\sigma$

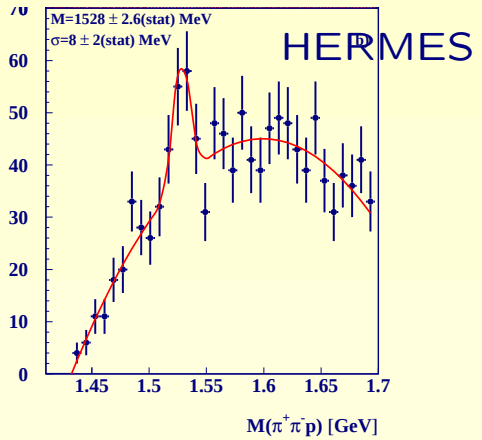
all widths reported around detector resolution.

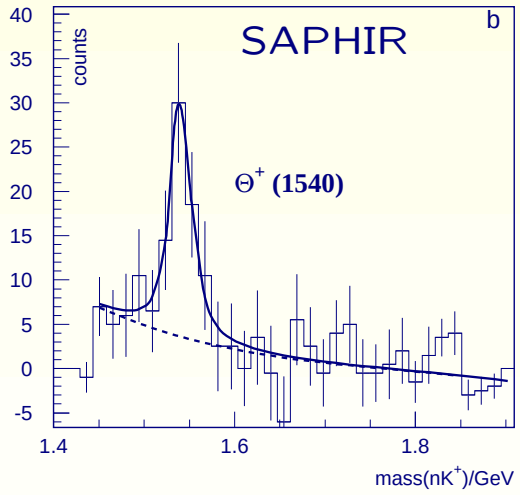
Reported Θ^+ signals

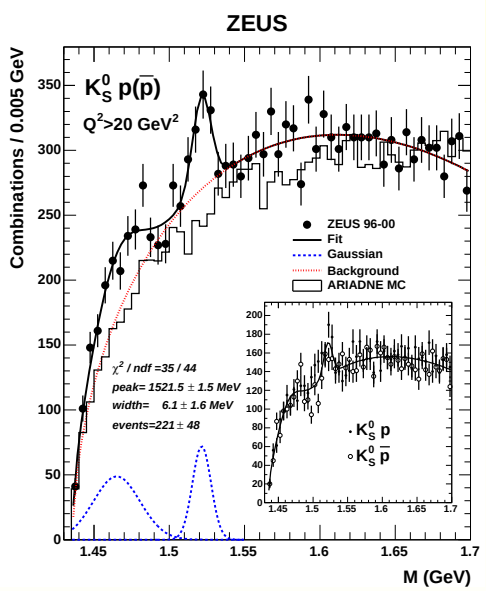


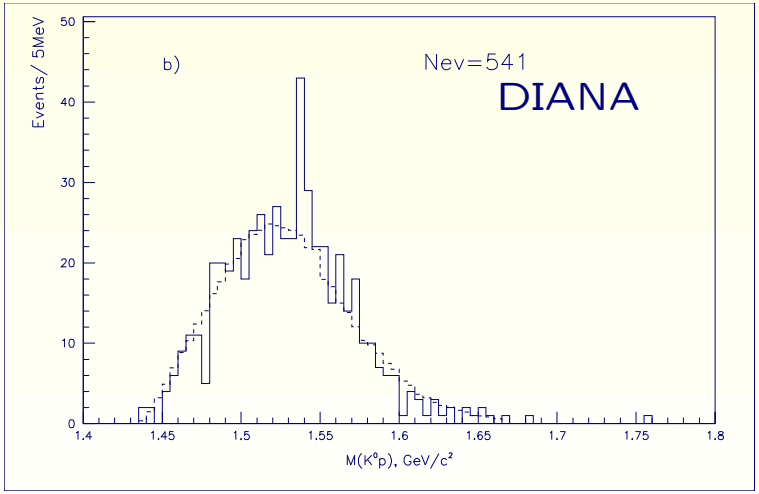












PentaQuark situation now

- Experimental situation rather unclear:
  - All results have low significance
  - Not seen by all experiments
  - $\Theta^+ \to K^+ n$ heavier than $\Theta^+ \to K^0_s p$?
  - No evidence at Tevatron so far
    $\to$ Physics? Prod. mechanism unclear
- Many different predictions/explanations from theory
- Systematic searches needed:
  - establish signal
  - rule out evidences
- Determine properties to constrain models

$X \to J/\Psi\pi^+\pi^-$ hint then

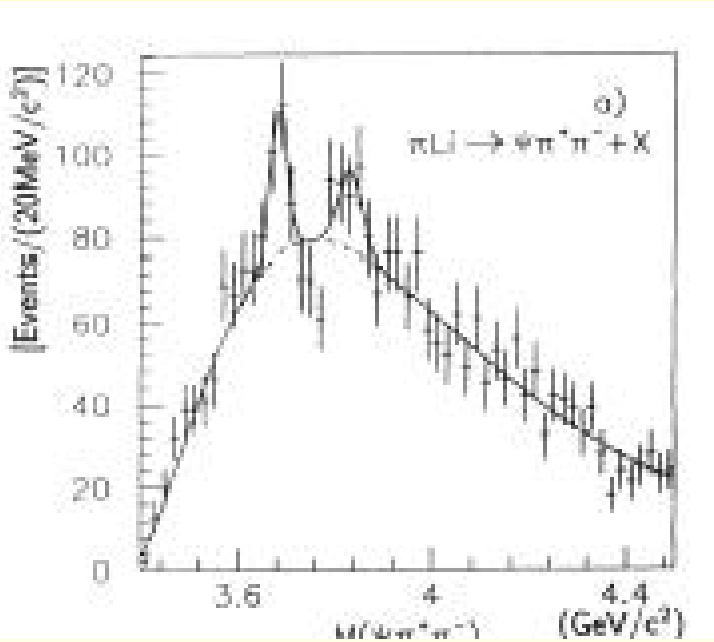
history:

1994: E705 (fixed-target at FNAL) :

in $\pi\ Li \to \Psi\pi^+\pi^- +$ anything

observed 58 ± 21 excess events

at $3.8638 \pm 0.013 GeV/c^2$



possible interpretations:

${}^1P_1(1^{+-})$, ${}^3D_2(2^{--})$, ${}^1F_3(3^{+-})$ $c\bar{c}$ or $c\bar{c}q\bar{q}$

However:

1998: BES (e^+e^- @ 4.03 GeV centre-of-mass energy):

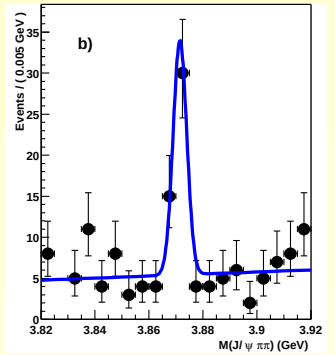
cannot confirm signal, no excess found

$X \to J/\Psi\pi^+\pi^-$ present situation

Belle (Observation): $B^\pm \to K^\pm J/\Psi\pi^+\pi^-$

35.7 ± 6.8 events $\to 10.3\sigma$ significance

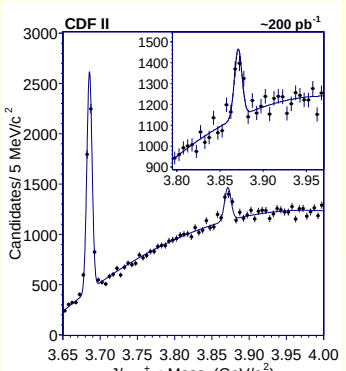
$M = 3872.0 \pm 0.6 \pm 0.5\ MeV/c^2$



CDF (confirm): $X \to J/\Psi\pi^+\pi^-$

779 ± 90 events $\to 10.9\sigma$ significance

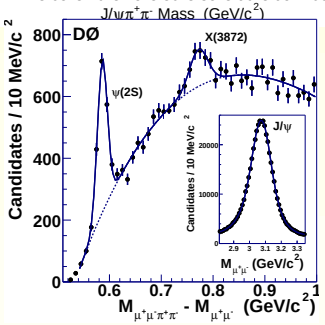
$M = 3871.4 \pm 0.7 \pm 0.4\ MeV/c^2$



DØ $X \to J/\Psi\pi^+\pi^-$ (prelim)

522 ± 100 events $\to 5.2\sigma$ significance

$\Delta M = 774.9 \pm 3.1 \pm 3.0\ MeV/c^2$



BaBar $B^\pm \to J/\Psi\pi^+\pi^- K^\pm$ (prelim)

$M = 3873.4 \pm 1.4\ MeV/c^2$

Signals $\Psi(2s)$ and X represented by single Gaussians

Belle

$\sigma = 2.5 \pm 0.5\ MeV/c^2$ (consistent with MC expectation)

$\Gamma = 1.4 \pm 0.7\ MeV/c^2$ (resolution-broaded Breit-Wigner)

$\to$ width compatible with zero

CDF

$\sigma = 5.44 \pm 0.722\ MeV/c^2$

$\to$ consistent with detector resolution

D0

$\sigma = 17 \pm 3\ MeV/c^2$

$\to$ consistent with detector resolution

$X \to J/\Psi\pi^+\pi^-$ reconstruction

similar approach by Belle, CDF, DØ:

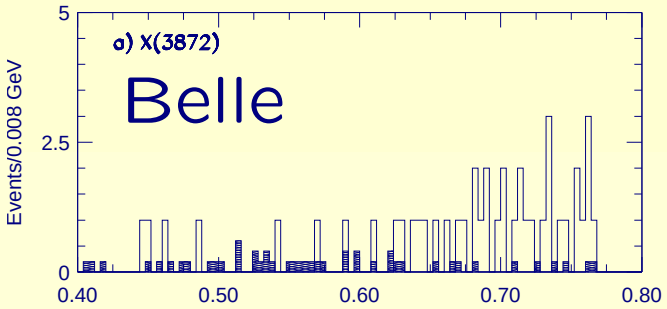
- $J/\Psi \to \mu^+\mu^-$ (add. $J/\Psi \to e^+e^-$ for Belle)
- add two oppositely charged tracks as Pion
  (+ loosely identified Kaon for Belle from B decay)
- cut on $M(\pi^+\pi^-) >$
  - $0.4\,GeV/c^2$ (Belle)
  - $0.5\,GeV/c^2$ (CDF)
  - $0.52\,GeV/c^2$ (D0)
- "BG-suppression":

  event-shape for Belle ($|\cos(\theta_B)|$, R_2)
  $p_\perp$, ΔR, fit χ^2, number cands/tracks for CDF/DØ

Further X properties

X seems to favour high $M(\pi^+\pi^-)$

- Belle events "cluster" at high end
- CDF sees signal enhancement if cutting on $M(\pi^+\pi^-)$



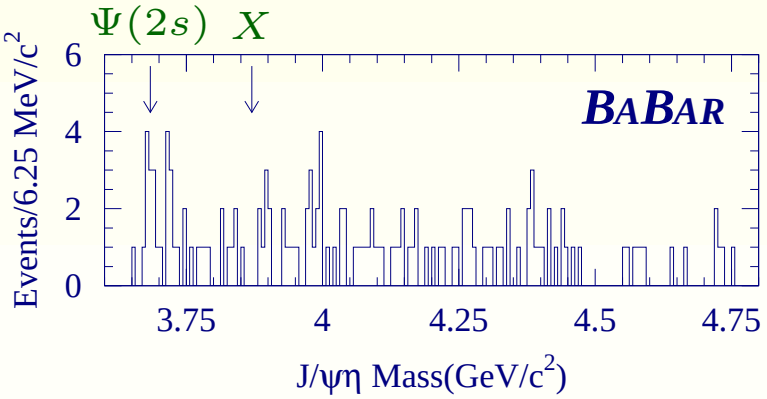
$\rightarrow$ intermediate ρ resonance ($X \rightarrow J/\Psi\rho$)?

BaBar looks for $X \rightarrow J/\Psi\eta$ in $B^\pm \rightarrow X K^\pm$

Motivation: if X $c\bar{c}$ state, decay may be similar to $\Psi(2s)$

expect: $\mathcal{BR} \approx 3 \cdot 10^{-6}$

Limit: $\mathcal{BR} < 7.7 \cdot 10^{-6}$ @ 90 CL



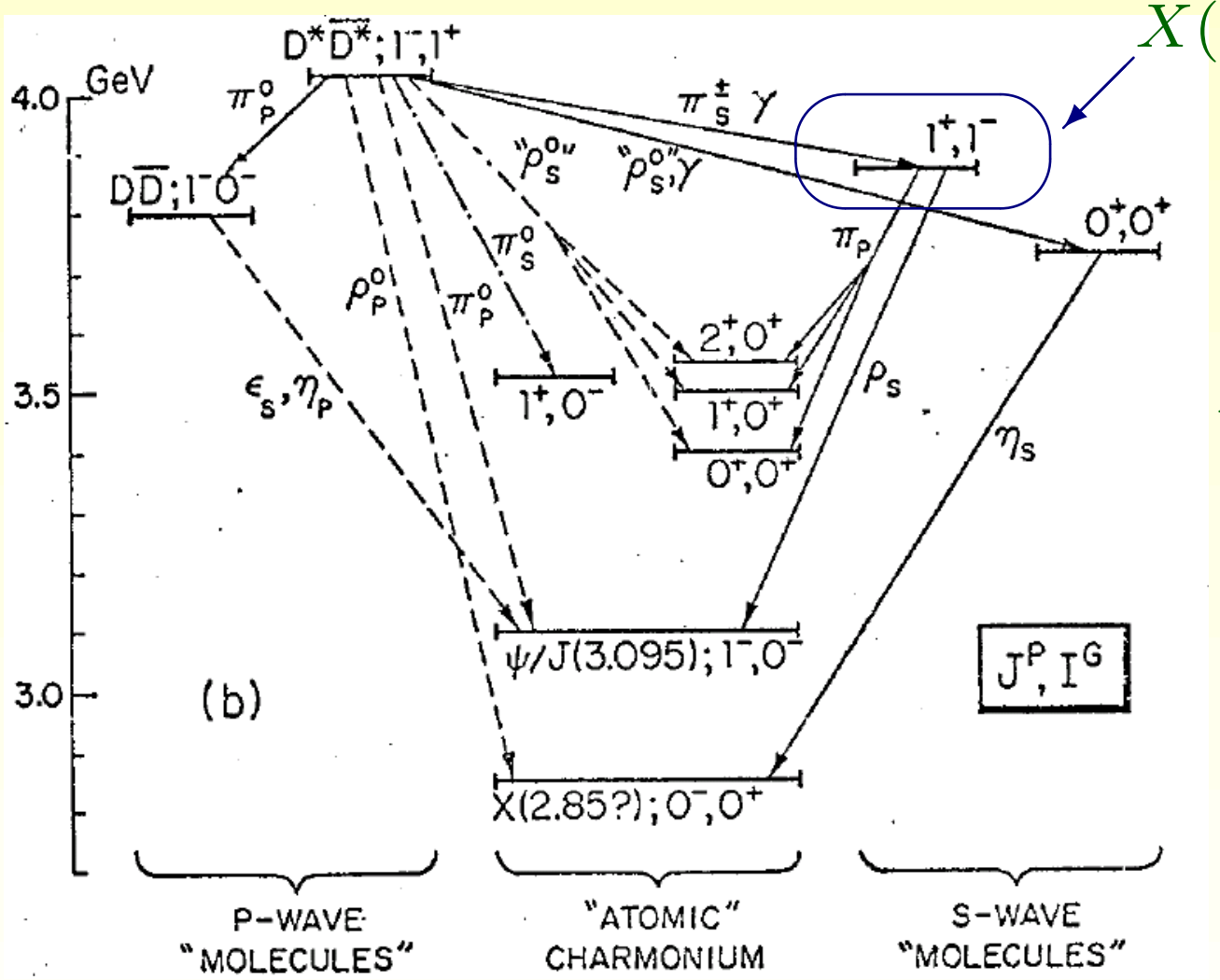
X a charmonium?

Various possible explanations on the market:

X as a charmonium ($c\bar{c}$) state?

- 2^1P_1, i.e. $h_c'(1^{+-})$?
  Belle claims disfavoured (looking at $|\cos\theta_{J/\Psi}|$)
- $1^3D_2(2^{--})$, $1^3D_3(3^{--})$?
  then also: $X \to \chi_{c1}\gamma(344)$, $X \to \chi_{c2}\gamma(303)$
  but: no signal by Belle in $\chi_{c1}\gamma$ mode seen
- BES estimates e^+e^- partial width
  using ISR data: disfavour vector state

DeRujula, Georgi, Glashow (1977): Molecular Chamonium



$X(3872)$?

$4q$ molecules poss.:
$D\bar{D}$, $D\bar{D}^*$, $D^*\bar{D}^*$
$D\bar{D}^{**}$, $D^*\bar{D}^{**}$

decay via
interm. states
$J/\Psi\eta$, $J/\Psi\rho$
(molec. trans.)

X a "Deuson"?

Törnquist (2004):

($D\bar{D}^*$ meson-meson state bound by π exchange
$\rightarrow$ "deuteron-like meson")

Expect:

- $J^{PC} = 1^{++}$, 0^{-+}
  (otherwise π exchange too weak/repulsive)
- very small binding energy:
  $\rightarrow$ large spatial size, very narrow width
- decay to $J/\Psi \rightarrow \rho$ allowed,
  $J/\Psi \rightarrow \sigma$; $J/\Psi \rightarrow \pi^0\pi^0$ forbidden (C-, spin parity)

X todo

So far, we know very litte about X

Need to determine its properties:

- Quantum numbers J^{PC}
  $\rightarrow$ angular distributions, helicity
- lifetime, fraction prompt/from B
- other decay modes?
- is the X a molecular state?
  if yes, do others exist?
  Where are the expected $c\bar{c}$ states?

Conclusion

- Branching ratios:
  - many new results
  - exp. sensitivity $\approx$ theory accuracy
    $\rightarrow$ constrain param., distinguish between models
- PentaQuarks:
  - many hints reported
  - stat. significance rather low
    $\rightarrow$ further studies needed to determine existence
- X:
  - obs. by Belle, conf. by CDF, seen by D0, BaBar
  - nature of X? $c\bar{c}$? molecule?

BACKUP

Experiments I

BaBar PEP-II (SLAC, USA)

$e^+(3.1GeV)\ e^-(9GeV)$ collider at $\Upsilon(4s)$ resonance

$(\sqrt{s} = 10.58GeV)$

Belle: KEKB (Japan)

$e^+(3.5GeV)\ e^-(8GeV)$ collider at $\Upsilon(4s)$ resonance

BES Beijing Electron Positron Collider

e^+e^- collider at $\sqrt{s} = 4.03GeV$

CDF, D0 FermiLab (USA)

$p\bar{p}$ collider at $\sqrt{s} = 1.96TeV$

Experiments II

CLAS Jefferson Lab, USA

$e^-(2.474, 3.115GeV)$ on Bremsstrahlung radiator,
resulting γ on $10cm$ liquid deuterium target

DIANA ITEP proton synchrotron (Moskow, Russia)

$850MeV$ K^+ beam on Xe bubble chamber

E705 FermiLab (USA)

$300GeV$ $\pi^{\pm}$, p, $\bar{p}$ on Li target

H1, Zeus DESY (Hamburg, Germany)

$e^-(27.6GeV)$ $p(820GeV, 920GeV)$ collider

Experiments III

Hermes DESY (Hamburg, Germany)
using $e^-(27.6GeV)$ beam on H, D, He_3 target

LEPS SPring-8 (Japan)
Use $351nm$ Ar laser on $8GeV$ electrons
Compton scattered γ on H, C plastic scintillator

NA49 SPS (CERN, Switzerland)
$158GeVp$ on liquid hydrogen target

Saphir ELSA (Bonn, Germany)
$e^-(2.8GeV)$ on copper foil, bremsstrahlung γ on liquid H

Motivation: weak decay rate $b \to c l \nu$ proprotional to $|V_{cb}|^2$
use OPE to relate to measurement of $\mathcal{BR}(B \to X_c l \nu)$
$\to$ input: $m_b(\mu), m_c(\mu)$, 4 non-pert param.

Use measured moments of hadronic mass distribution in semi-leponic B decays:

- detemine input parameters
- determine $\mathcal{BR}(B \to X_c l \nu)$, $|V_{cb}|$

in a simultanious χ^2 fit.

Results in agreement with recent they predictions

Motivation:

- measure $\mathcal{A}_{ch}$ for $B \to \eta K^{\star +}$, $B \to \eta K^{\star 0}$
- η/η' mixing might enhace $B \to \eta' K$, suppress $B \to \eta K$
- reversed for K^* modes due to opposite K^* parity
- decay with ρ^0, π^0 in final state from penguin/colour suppressed

  $\mathcal{BR}(B \to \eta' K)$ 10^{-6} rather large,
  $\mathcal{BR}(B \to \eta K^*)$ also rather large
  3.5σ hint for new mode $B^+ \to \eta \rho^+$
  charge asym. compatible with zero