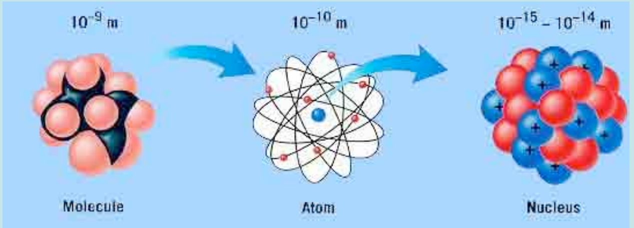
Dissertation Agnes Lundborg

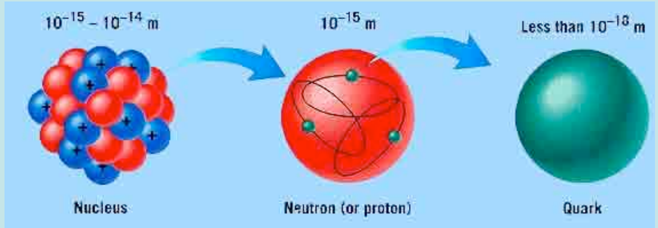
The Charm of Excited Glue

Uppsala, February 23, 2007

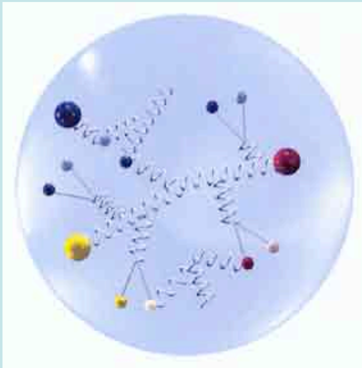
Exotic Particles in Meson Spectroscopy (1)

Constituents of matter





Constituents of a proton: Quarks and Gluons



Flavor (q)	Mass [MeV]	Q/e
u	5	+ 2/3
d	7	– 1/3
s	95	– 1/3
c	1250	+ 2/3
b	4200	– 1/3
t	174200	+ 2/3

Theory: Quantum Chromo Dynamics (QCD)

Naive Quark Model:

Baryons: qqq — Proton = uud — Antiproton = $\bar{u}\bar{u}\bar{d}$

Mesons : $q\bar{q}$ — $\pi^+ = u\bar{d}$ — $\pi^- = \bar{u}d$

Characterization: Mass (m), Decaytime (τ) or Width ($\Gamma = \hbar/\tau$), Decay modes, Quantum numbers (J^{PC})

Exotic Particles in Meson Spectroscopy (2)

Problems with the naive Quark Model

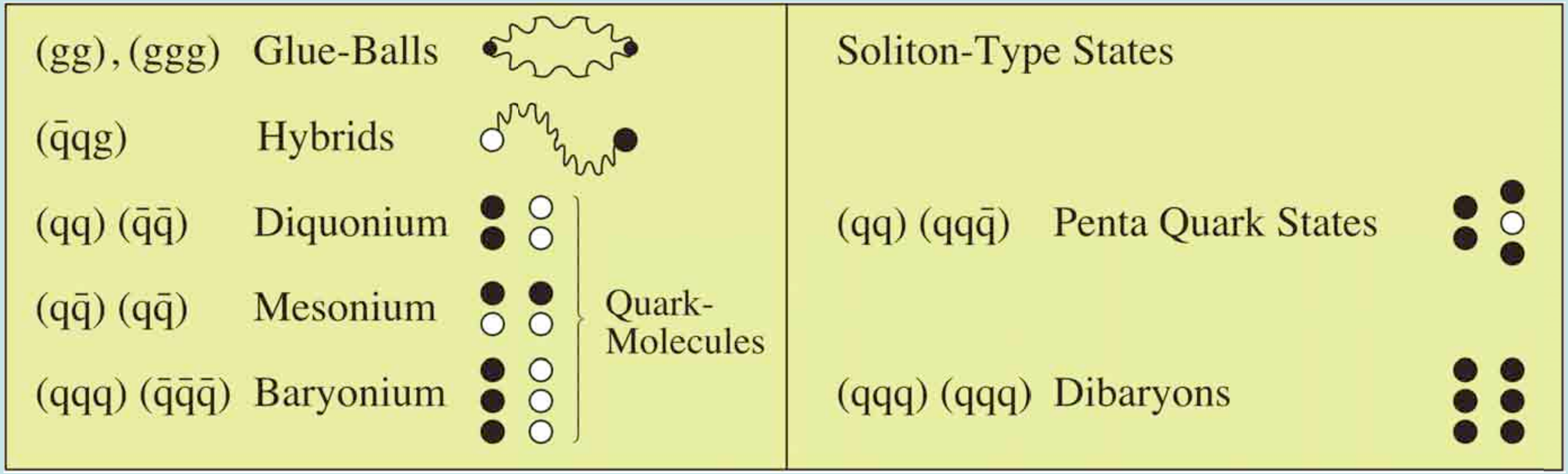
– DIS-Experiments

– Mass of the Hadrons much heavier than expected

Example (Proton): $M \approx 17$ MeV, $M_{exp.} = 938$MeV } Large dynamical mass generation process

– Many of the new discoveries don't fit into the picture (see later)

– QCD allows many more states than described by the naive model (Exotic Particles)



New feature: Spin-exotic quantum numbers possible, not allowed in $q\bar{q}$ ($J^{PC} = 0^{+-}$, 1^{-+}, ...)

Exotic Particles in Meson Spectroscopy (3)

Glueballs (gg)

Predictions:

Masses:

1.5-5.0 GeV/c^2 (Ground state found? ;

Candidates for further states?)

Quantum numbers:

Several spin exotics (oddballs), e.g.

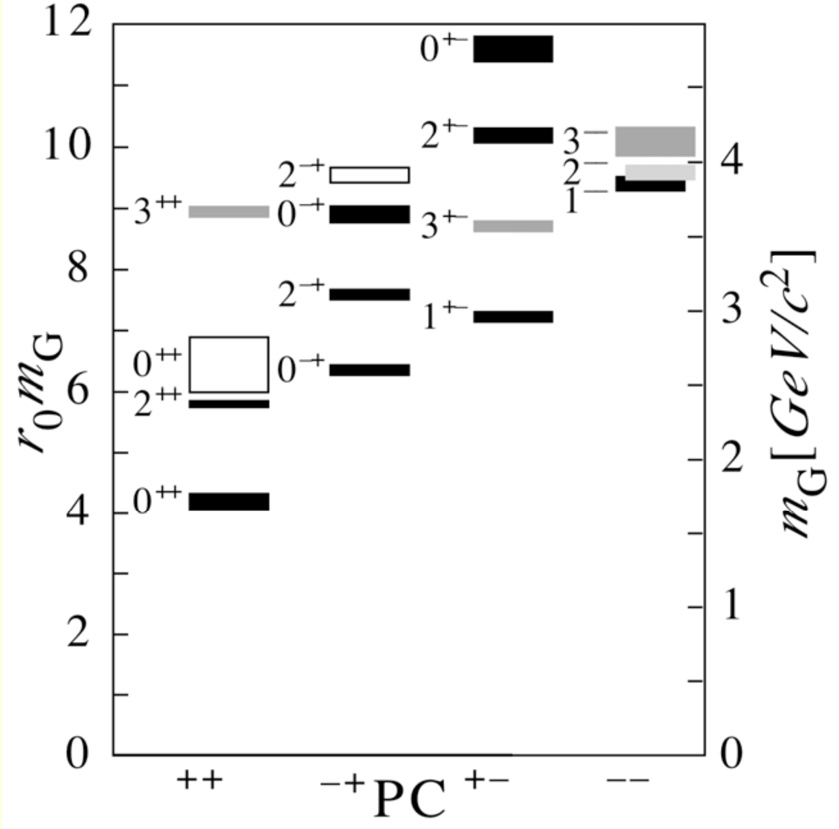
$J^{PC} = 2^{+-}$ (4.3 GeV/c^2)

Widths: ≥ 100 MeV/c^2

– Decay into two lighter glueballs often forbidden because of q.-n.

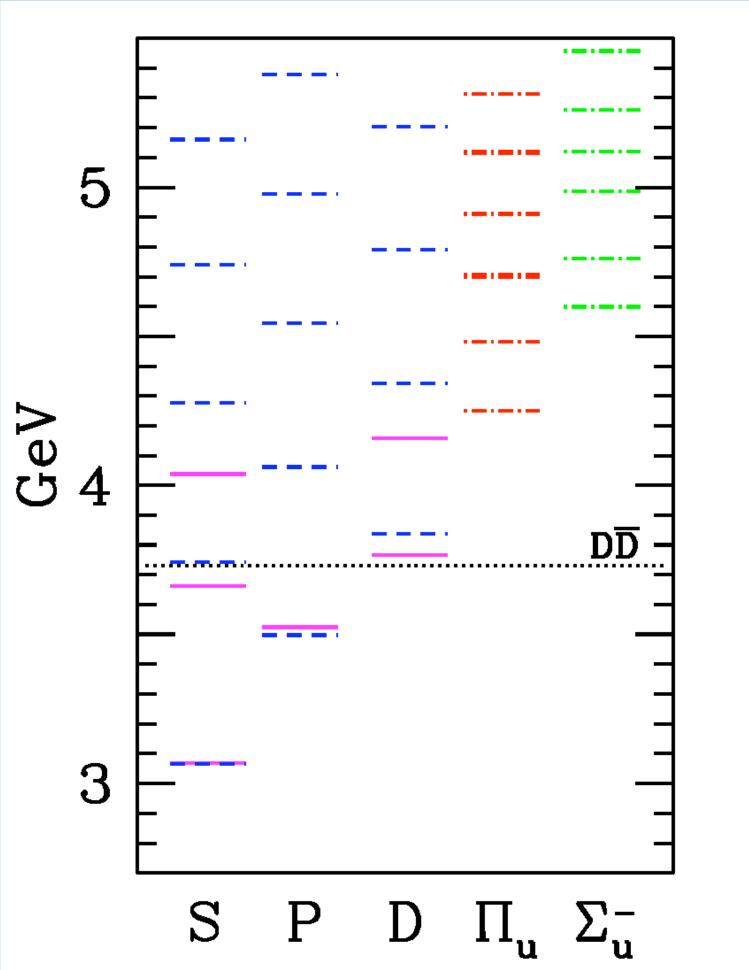
– No mixing effects for oddballs

Decays: ϕϕ, ϕη, ηπ



Exotic Particles in Meson Spectroscopy (4)

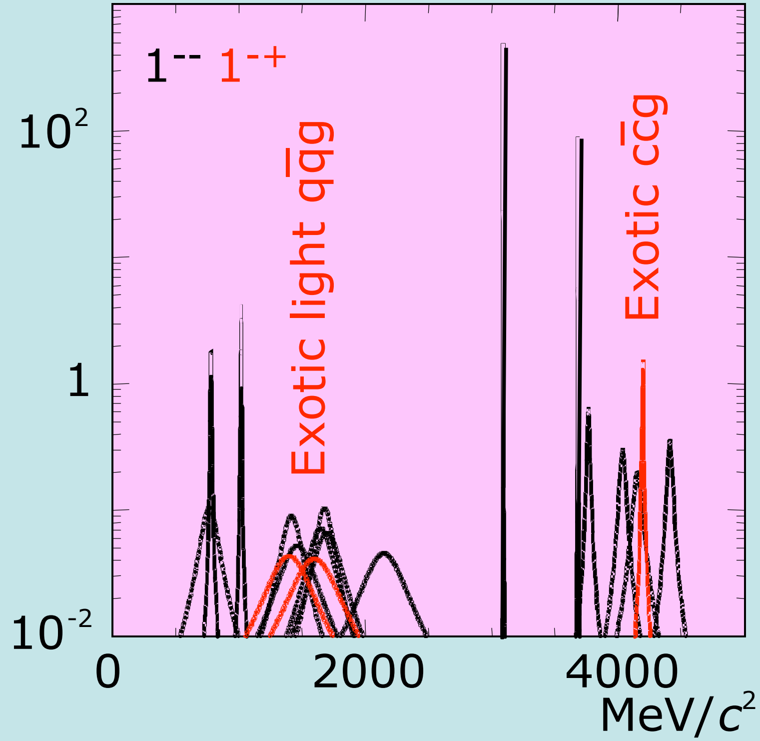
Charmonium Hybrids ($c\bar{c}g$, H_c)



[42] K. Juge, J. Kuti, and C. Morningstar, Phys. Rev. Lett. 90, 161601 (2003).

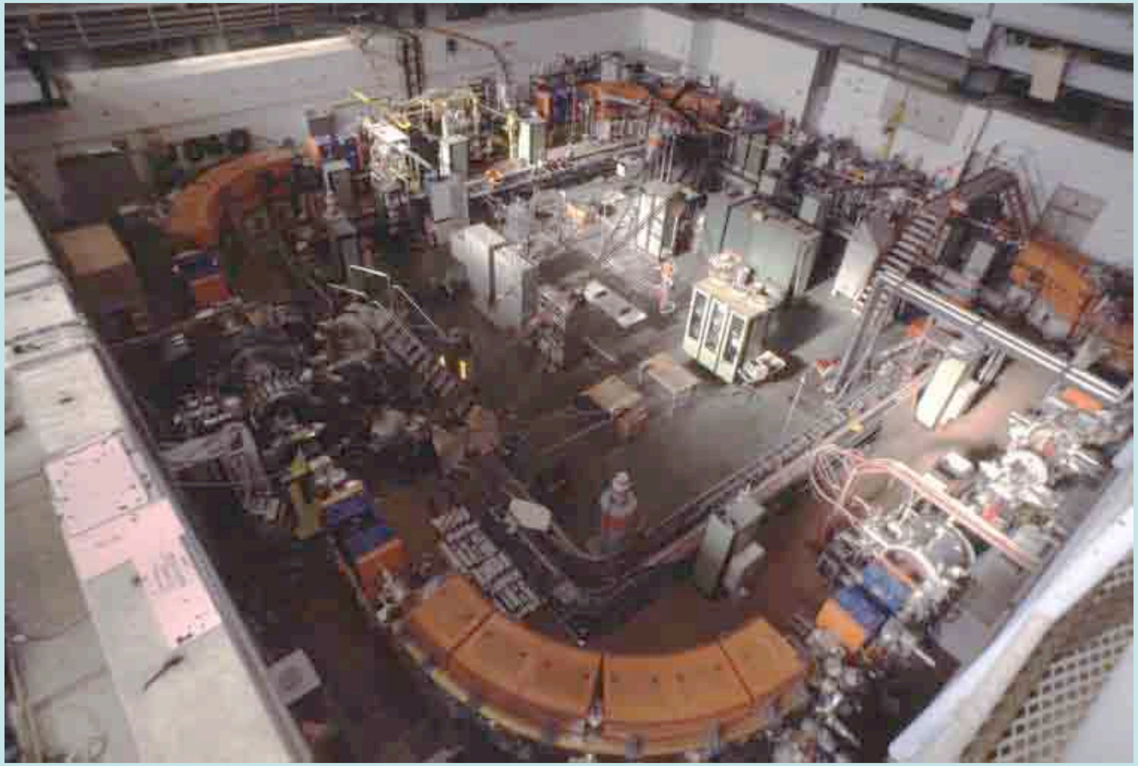
Decay modes:
$J/\psi\omega$; $D^*\bar{D}$

Small overlap with $c\bar{c}$-states

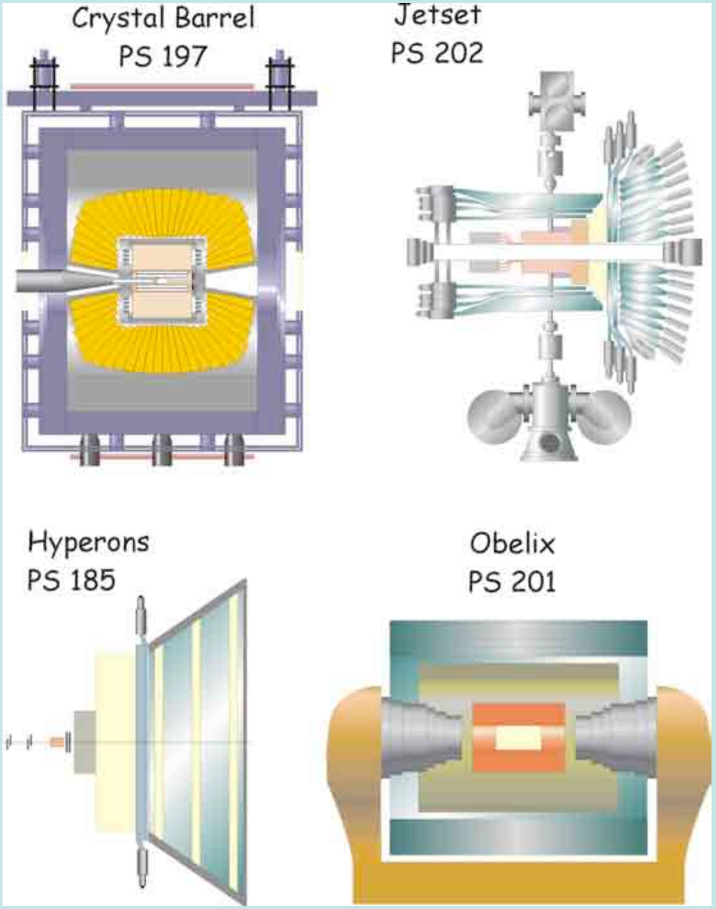


Exotic Particles in Meson Spectroscopy (5)

Candidates for Exotics in the low mass sector (mainly from LEAR/CERN)



LEAR-Ring



Exotic Particles in Meson Spectroscopy (6)

Glue-Ball Candidate

$f_0(1500)$ (Best candidat for the Glueball-ground state)

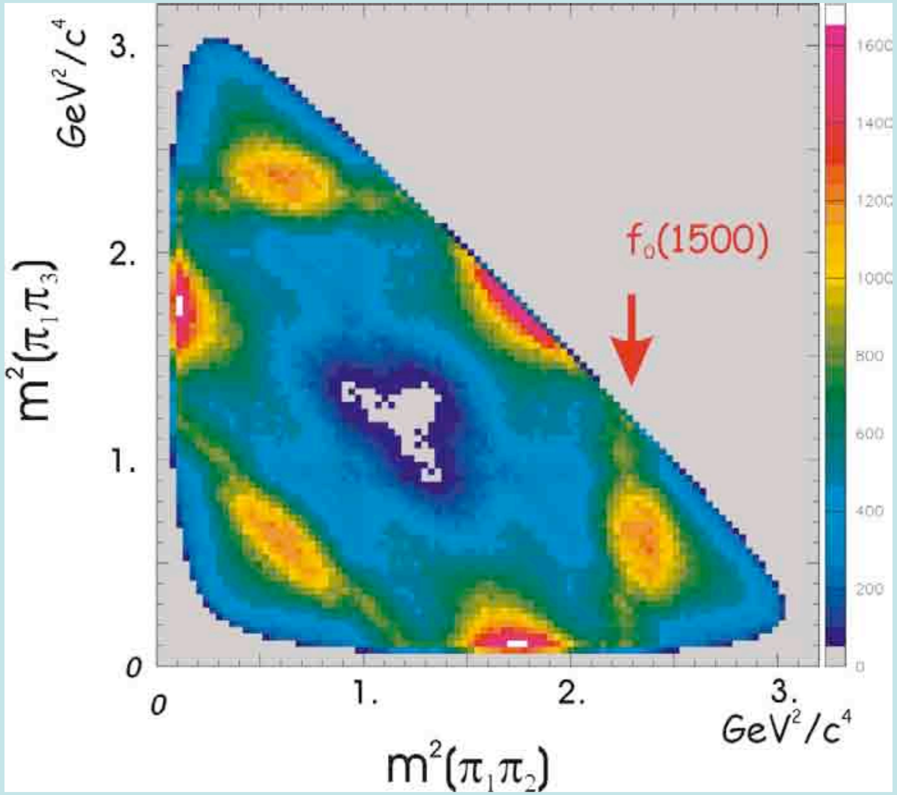
Production : $p\bar{p} \rightarrow f_0(1500)\pi^0$ (Crystal Barrel/LEAR)

Decays : $f_0(1500) \rightarrow 2\pi, 4\pi, \eta\eta, \eta\eta', K\bar{K}$

$M = (1505 \pm 9)$ MeV ; $\Gamma = (111 \pm 12)$ MeV ; $J^{PC} = 0^{++}$

Exotic?

- Surplus state in 0^{++}-Nonett
- Relatively narrow width
- Decays in particles, which contain u, d and s-Quarks
- Mass and Quantum numbers in good agreement with Lattice QCD-predictions for the Glueball-ground state



Exotic Particles in Meson Spectroscopy (7)

Hybrid Candidates with exotic quantum number combination

$\pi_1(1400)$ / $\pi_1(1600)$

Production/Decays :

$\pi^- p \rightarrow \pi_1(1400)p$ (E835/BNL) and $\bar{p}n \rightarrow \pi_1(1400)\pi^0$ (Crystal Barrel/LEAR)

$\quad\hookrightarrow \eta\pi^-$ $\quad\quad\hookrightarrow \eta\pi^-$

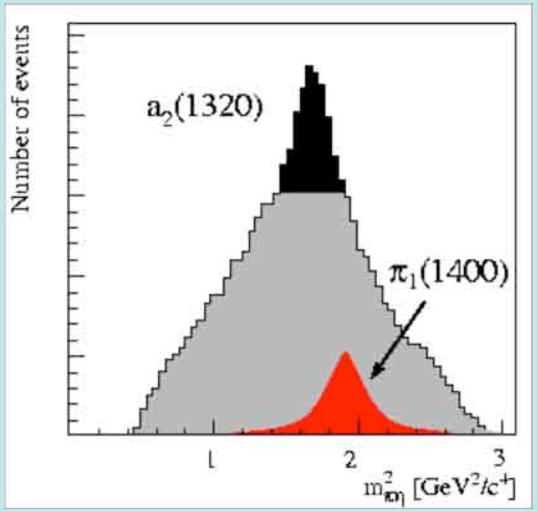
$\pi^- p \rightarrow \pi_1(1600)p$ (E835 BNL) and $\bar{p}p \rightarrow \pi_1(1600)\pi^+$ (Crystal Barrel/LEAR)

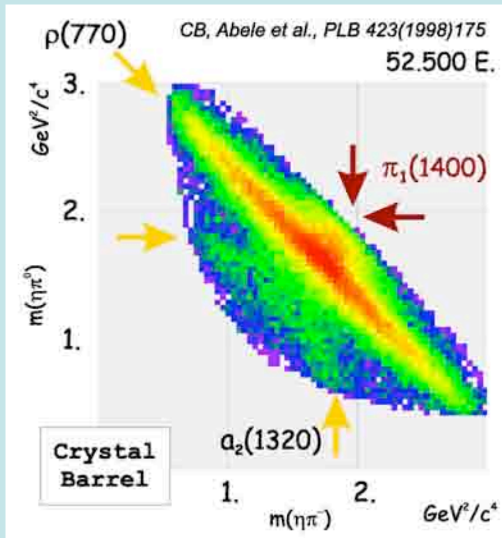
$\quad\hookrightarrow \pi^-\eta$ $\quad\quad\hookrightarrow \pi^-\eta$

$M \approx 1400, 1600$ MeV ; $\Gamma \approx 300$ MeV ; $J^{PC} = 1^{-+}$ (Exotic Q.-N., At variance with naive Quark-model)

Exotic?
Exotic J^{PC}-combination

Hybrids?
Multi-Quark-states?





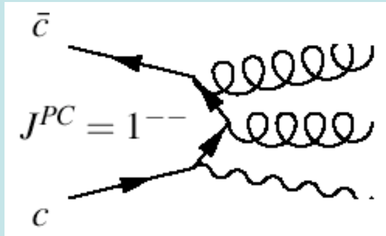
Exotic Particles in Meson Spectroscopy (8)

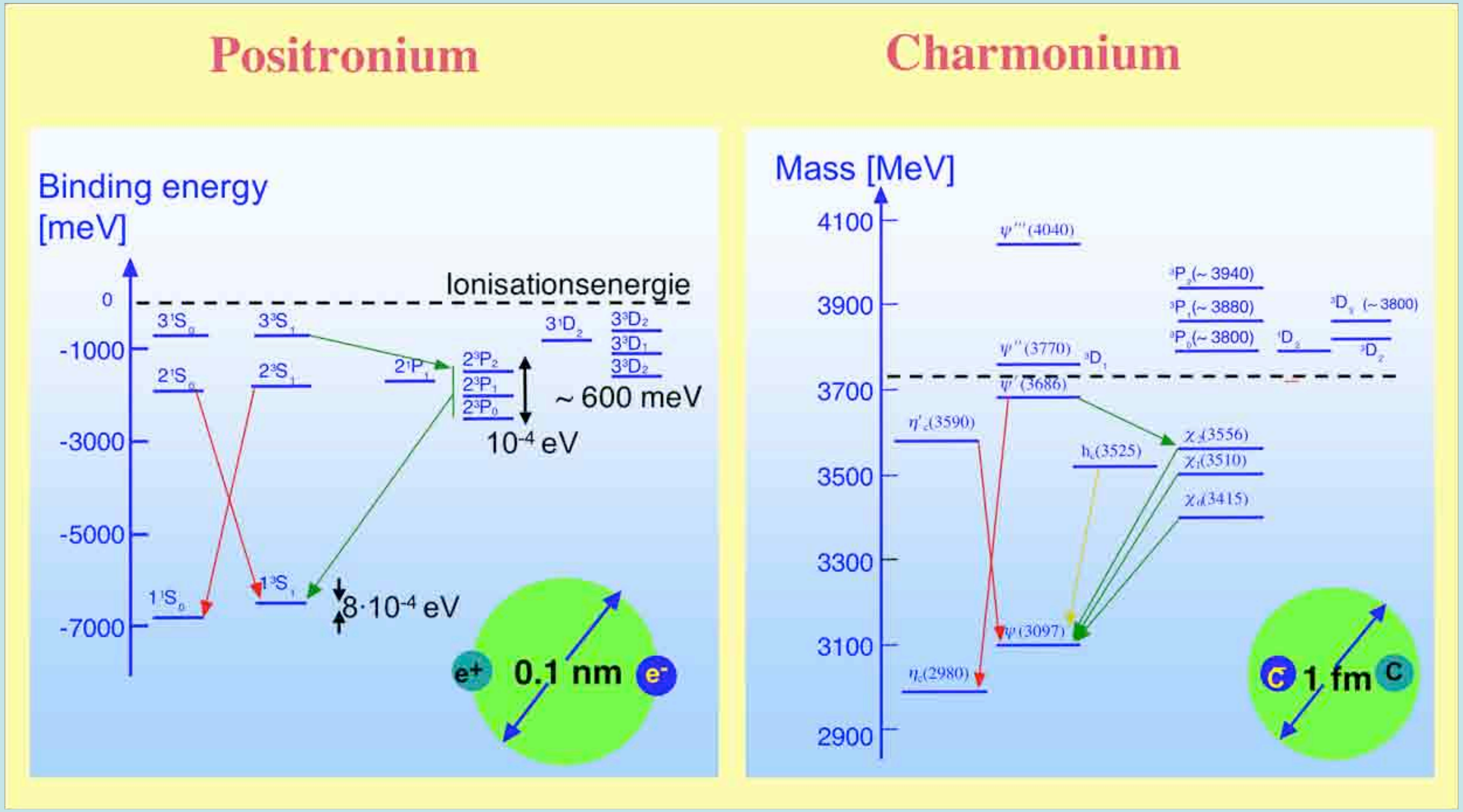
Contributions of A. Lundborg:

Look for Glueballs in radiative decays:

$(c\bar{c}) \rightarrow \gamma + f_0(1500), \ldots$

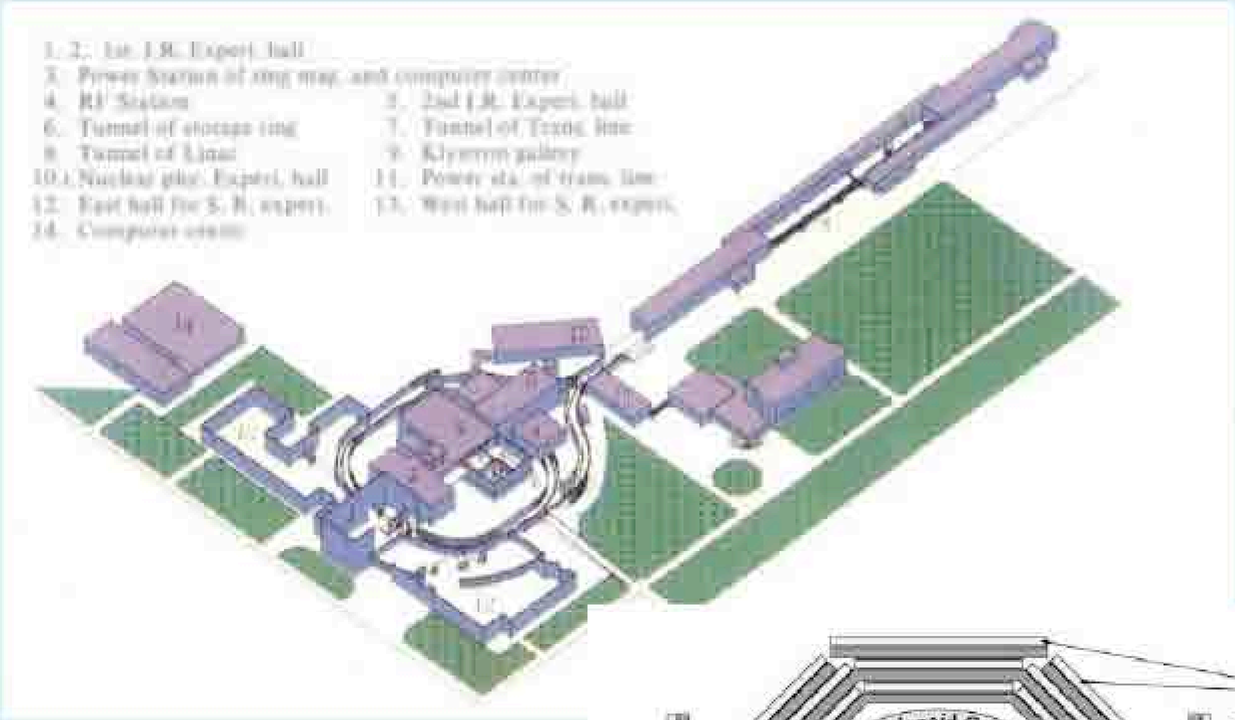
Production of $(c\bar{c})$: $e^+e^- \rightarrow (c\bar{c})$





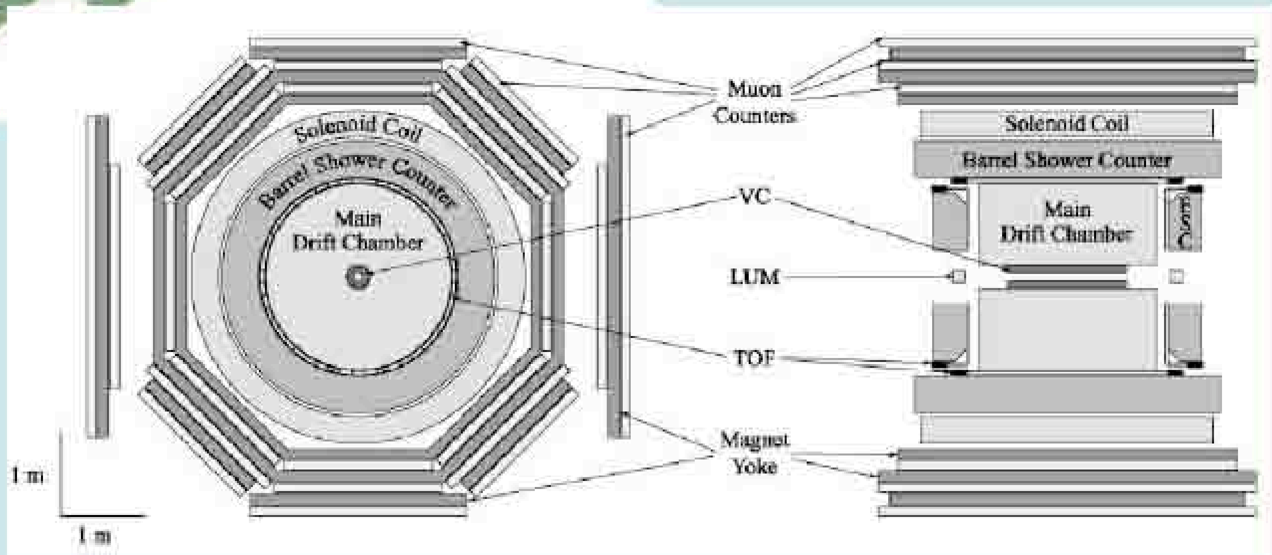
Exotic Particles in Meson Spectroscopy (9)

Beijing Electron Positron Collider (BEPC)



$$e^+e^- \rightarrow (c\bar{c})$$

BES II



Exotic Particles in Meson Spectroscopy (10)

Results: $\psi' \to \gamma + X$

$\hookrightarrow \pi^+\pi^-,\ K^+K^-$

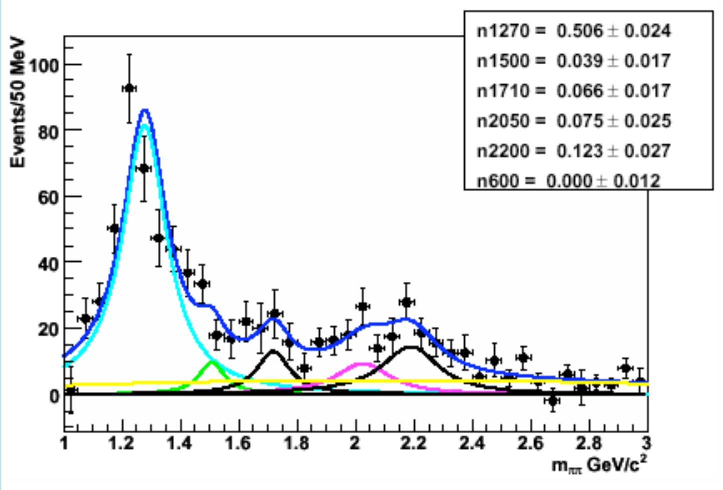
$$BR(\psi' \to \gamma f_2\,(1270) \to \gamma\pi^+\pi^-) = \left(2.2 \pm 0.1^{+0.2}_{-0.2}\right) x10^{-4}$$

$$BR(\psi' \to \gamma f_0\,(1500) \to \gamma\pi^+\pi^-) = \left(1.5 \pm 0.7^{+0.9}_{-0.4}\right) x10^{-5}$$

$$BR(\psi' \to \gamma f_0\,(1710) \to \gamma\pi^+\pi^-) = \left(2.4 \pm 0.6^{+0.7}_{-1.1}\right) x10^{-5}$$

$$BR(\psi' \to \gamma f_4\,(2050) \to \gamma\pi^+\pi^-) = \left(2.8 \pm 0.9^{+0.8}_{-0.6}\right) x10^{-5}$$

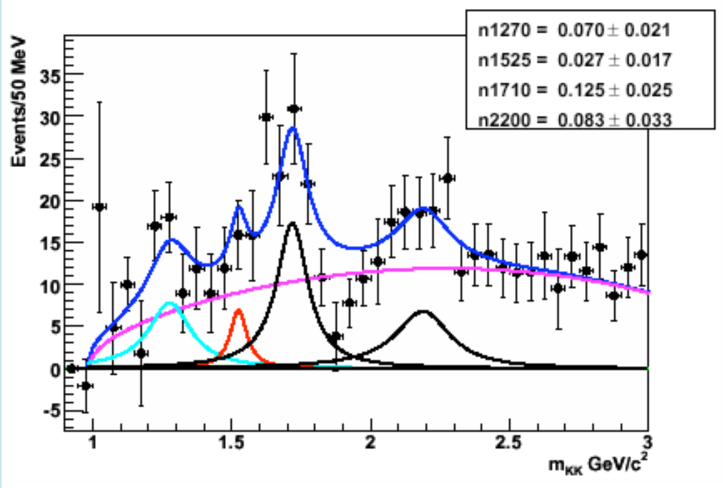
$$BR(\psi' \to \gamma f_0\,(2200) \to \gamma\pi^+\pi^-) = \left(4.6 \pm 1.0^{+4.5}_{-1.0}\right) x10^{-5}$$



$$BR(\psi' \to \gamma f_2\,(1270) \to \gamma K^+K^-) = \left(1.9 \pm 0.6^{+1.0}_{-0.6}\right) x10^{-5}$$

$$BR(\psi' \to \gamma f_2'(1525) \to \gamma K^+K^-) = \left(6.9 \pm 4.4^{+4.1}_{-2.1}\right) x10^{-6}$$

$$BR(\psi' \to \gamma f_0\,(1710) \to \gamma K^+K^-) = \left(3.1 \pm 0.6^{+1.1}_{-0.7}\right) x10^{-5}$$



Significance much higher than for BES I-data. Further improvements expected from BES III

For the first time BR was given for $\psi' \to \gamma f_0(1500)$

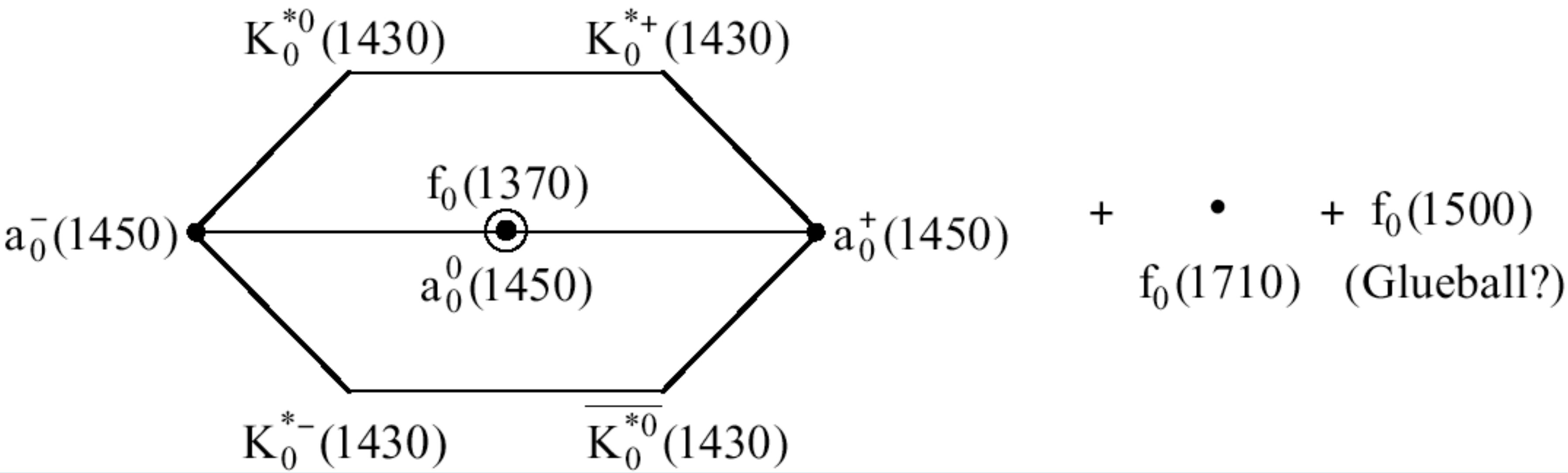
The appearances of $f_0(1500)$ and $f_0(1710)$ are consistent with the hypothesis, that $f_0(1500)$ is the ground state glue ball

Exotic Particles in Meson Spectroscopy (11)

Discussion of the $J^{PC} = 0^{++}$ nonet

Nine open slots, but twelve candidates

Possible scenario:

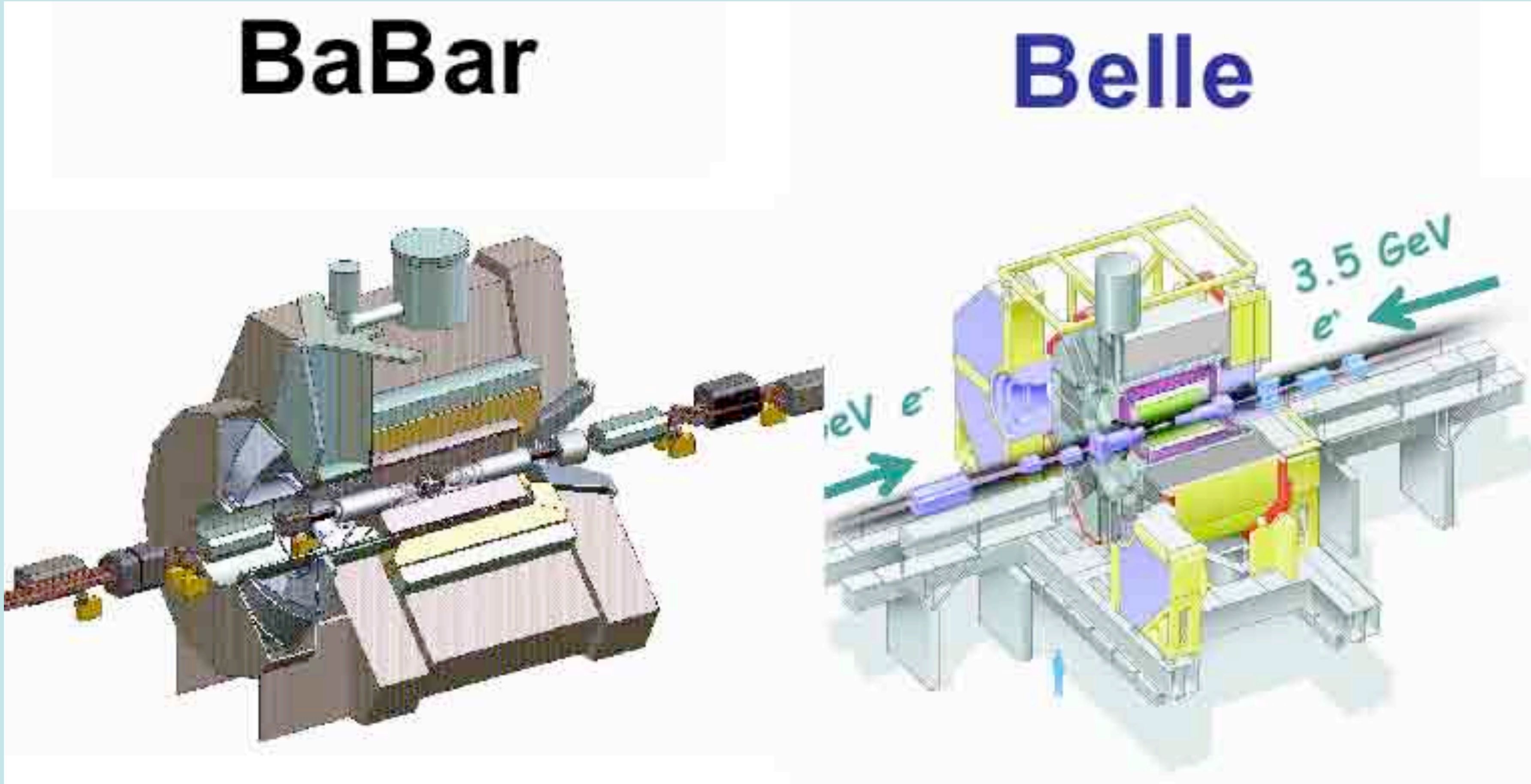


$a_0(980)$, $f_0(980)$: 4 quark states

Exotic Particles in Meson Spectroscopy (12)

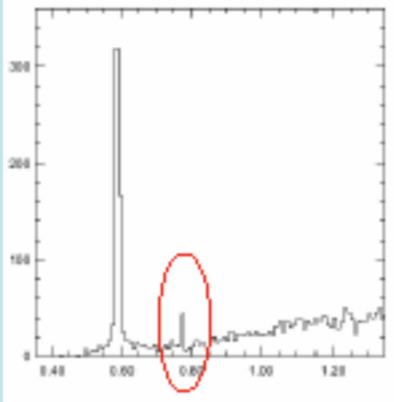
Candidates for Exotics in the high mass sector (BaBar/BELLE/CLEO-c/...)

$$e^+e^- \rightarrow Y(4s) \rightarrow B\overline{B}$$
$$\rightarrow (c\overline{c}) + (J/\psi) + X, \; ....$$

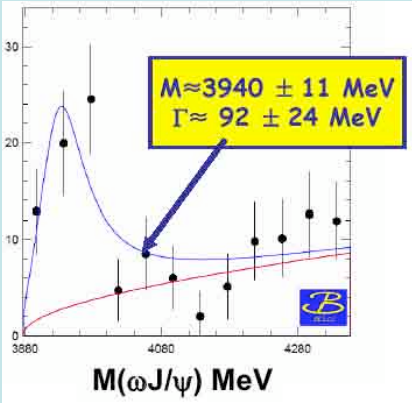


Exotic Particles in Meson Spectroscopy (13)

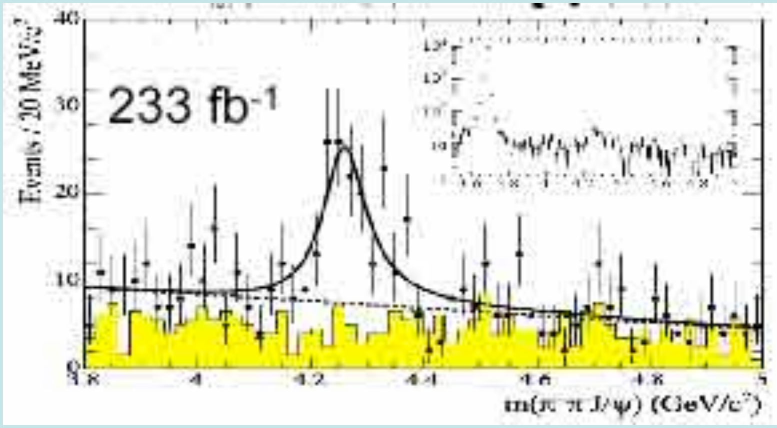
Candidates for exotics states



$X(3872),\ J^{PC}=1^{++}(?),\ \Gamma<2.3\ \text{MeV!!}$
$\hookrightarrow \pi^+\pi^- J/\psi$



$Y(3949),\ J^{PC}=?,\ \Gamma=(92\pm24)\ \text{MeV}$
$\hookrightarrow \omega J/\psi$

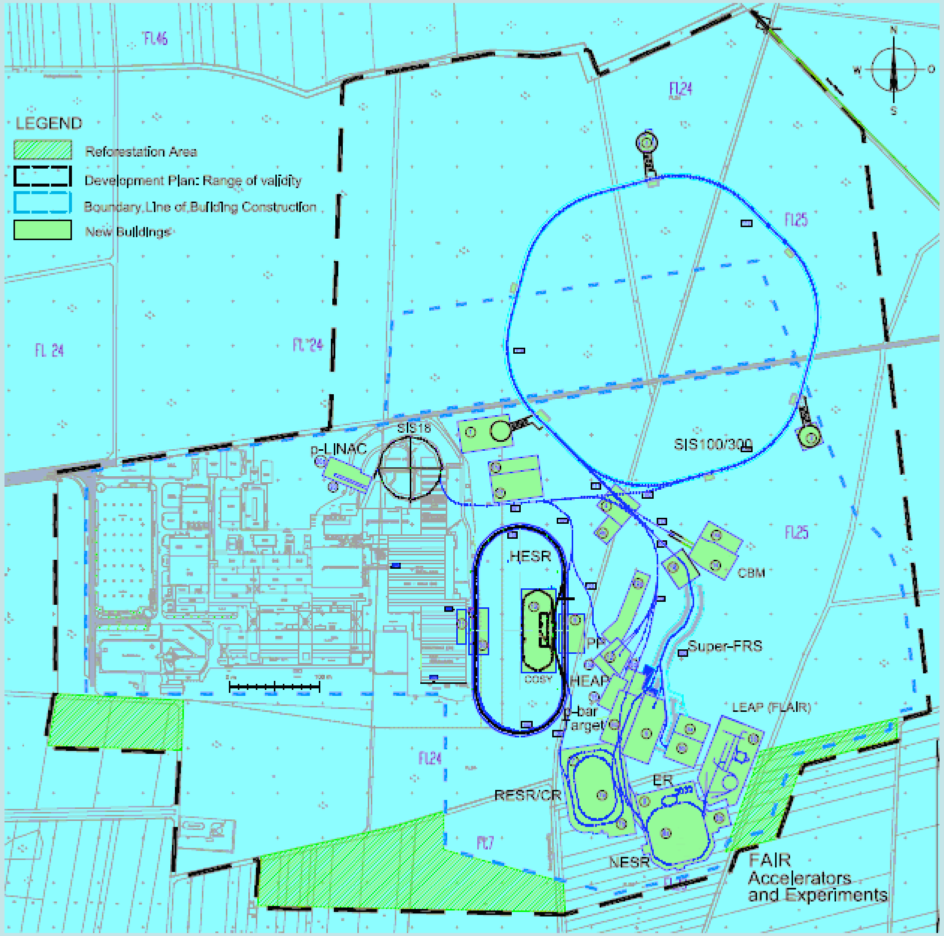


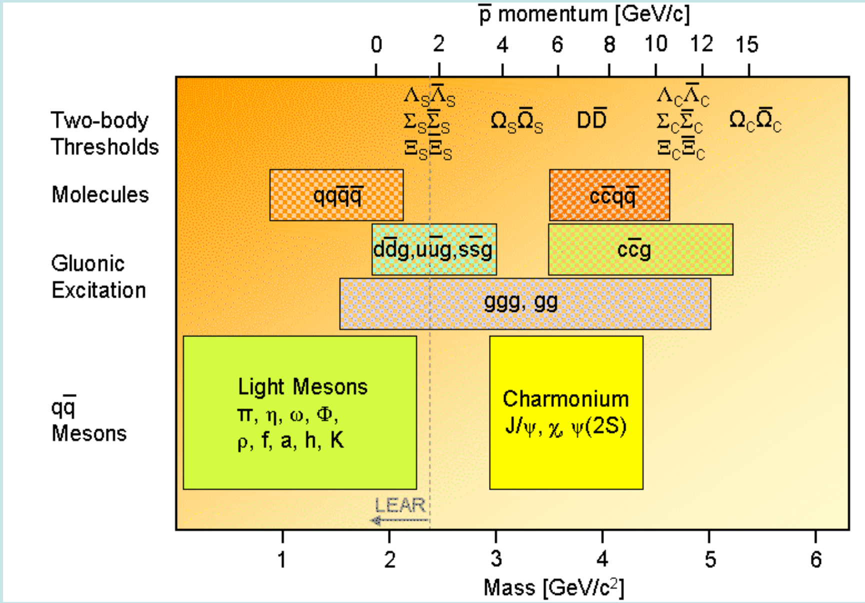
$Y(4260),\ J^{PC}=1^{--},\ \Gamma=(88\pm23)\ \text{MeV}$
$\hookrightarrow \pi^+\pi^- J/\psi$ H_c?

Exotic Particles in Meson Spectroscopy (14)

Contributions of A. Lundborg

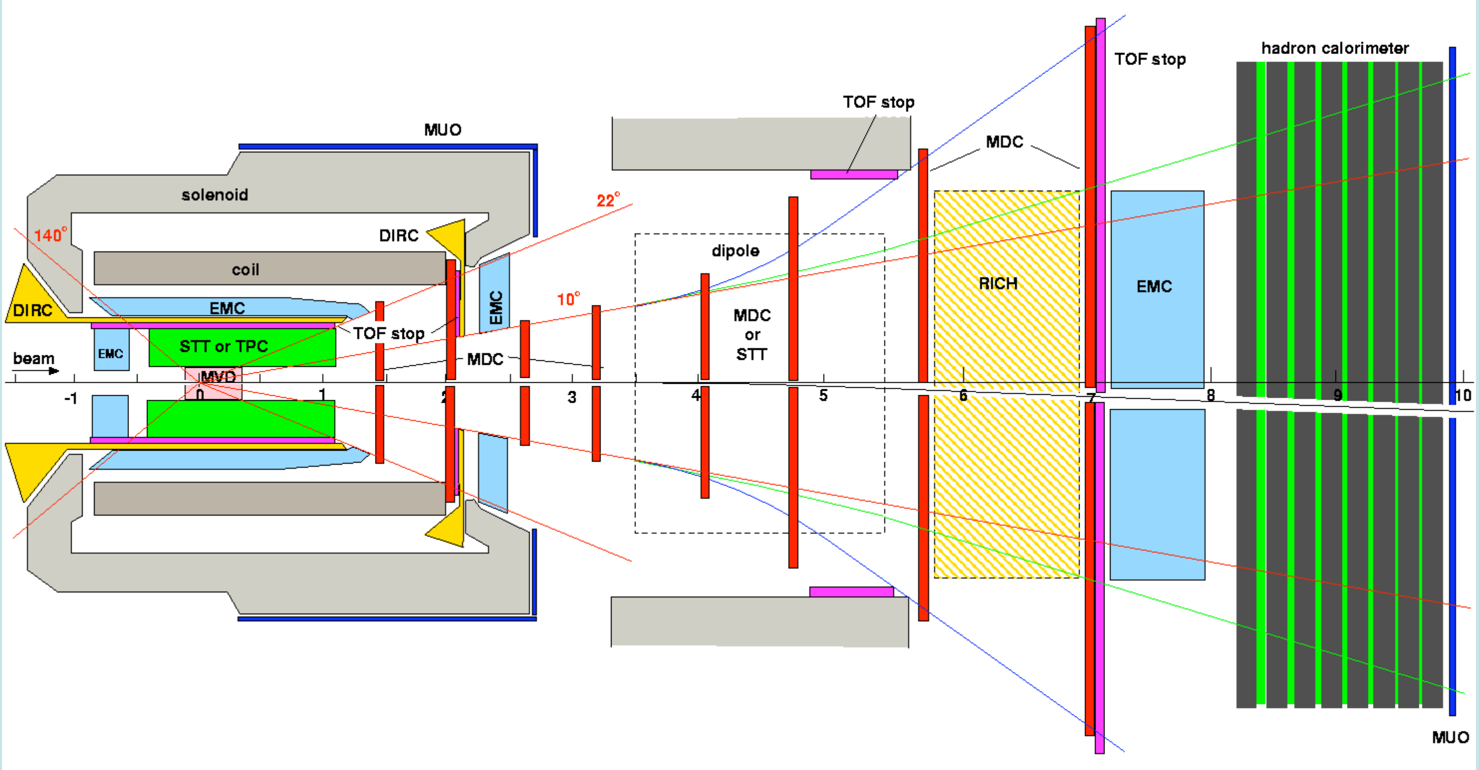
High energies antiprotons at GSI: FAIR-Project





Exotic Particles in Meson Spectroscopy (15)

The PANDA-Detector



Detector requirements

- full angular acceptance and angular resolution for charged particles and γ, π^0
- particle identification (π, K , e, μ) in the range up to ~ 8 GeV/c
- high momentum resolution in a wide energy range
- high rate capabilities, especially in interaction point region and forward detector : expected interaction rate ~ 10^7/s
- precise vertex reconstruction for fast decaying particles

Exotic Particles in Meson Spectroscopy (16)

Simulation of a Charmed Hybrid (H_c)

$\bar{p}p \rightarrow H_c\pi^0/\eta;\ H_c \rightarrow \chi_{c_1}(\pi^0\pi^0)_{S\text{-wave}};\ \chi_{c_1} \rightarrow \gamma J/\psi;\ J/\psi \rightarrow e^+e^-(\mu^+\mu^-) \quad \rightarrow \ell^+\ell^- + 7\gamma's$

Assumption: $M(H_c) = 4.28$ GeV $\quad \Gamma(H_c) = 20$ MeV $\quad \sigma(\bar{p}p \rightarrow H_c\pi^0) = 100$pb

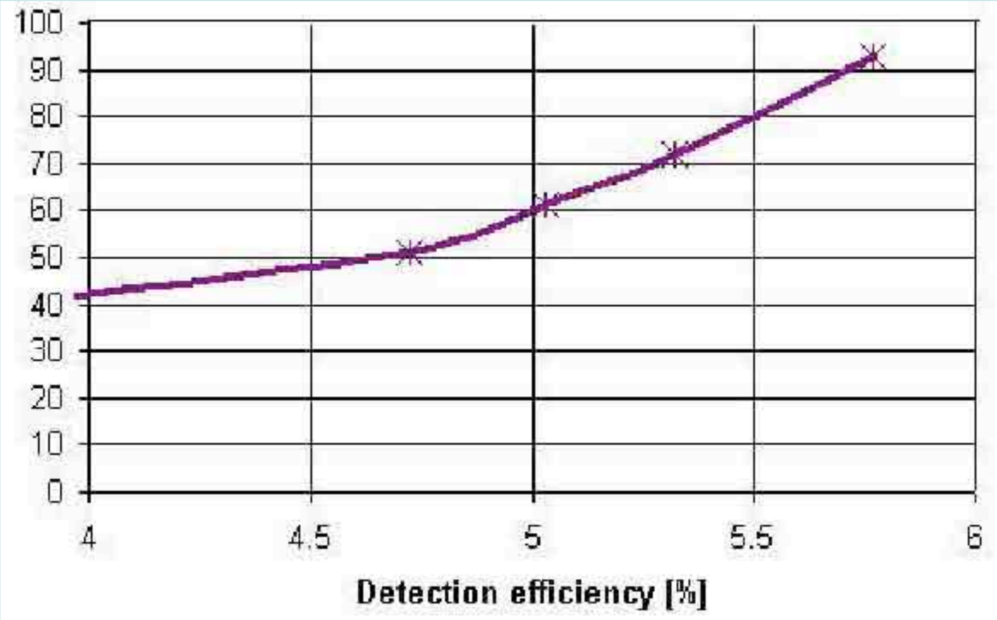
Problem: Signal/Hadronic background $\approx 10^{-9}$

Good test case for requests of EMC-properties: Energy resolution/Energy threshold/ solid angle coverage

Work not yet finished because of lacking description of components and kinematical fits

Preliminary, very encouraging results:

- Channel measurable in spite of a high hadronic background



- Many detailed results relevant for the final design of EMC

Exotic Particles in Meson Spectroscopy (17)

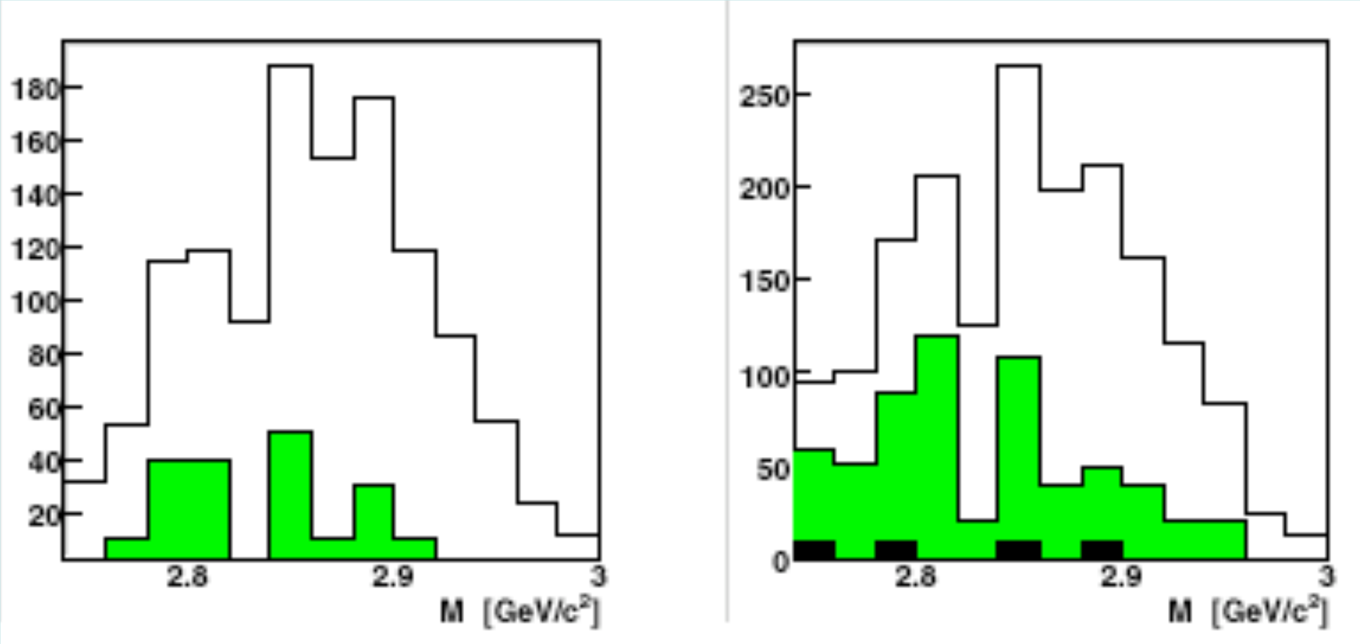
Simulation of $\gamma\gamma$-decay of the Charmonium ground state: $\eta_c \rightarrow \gamma\gamma$

Reasons for a refined measurement:

Precision determination of α_s(2.9 GeV)

Precision determination of total width

Result:



(a) (b)

Peak/Background: 5.4 ± 0.4 ± 1.1

(In spite of dominant background channels: $\bar{p}p \rightarrow \pi^0\pi^0, \pi^0\gamma$)

Exotic Particles in Meson Spectroscopy (18)

Production of $(c\bar{c})$-states in $p\bar{p}$-annihilations (Lundborg, Barnes, Wiedner)

Example: $p\bar{p} \rightarrow J/\psi + \pi^0(m)$

Knowledge of cross section very important for PANDA-research program

Until now: Only one measurement, only one calculation

New Method: Use $J/\psi \rightarrow m\bar{p}p$ branching ratio to determine the cross section

Good result for $J/\psi + \pi^0$, in reasonable agreement with data

Resumee

- The thesis of A. Lundborg deals with a very exciting part of modern Hadron Physics
- A. Lundborg has used high level and very sophisticated tools for her analysis
- The results contributed essentially to a further understanding of exotic hadronic states