Spectroscopy in the Charm Domain

– Introduction
– Merits of Experiments with Antiprotons
– Charmonium Spectroscopy
– Charmed Hybrids
– Heavier Glueballs
– Open Charm States
– Further Options
– PANDA-Detector
– Conclusions

Introduction

Open problems in non-perturbative QCD

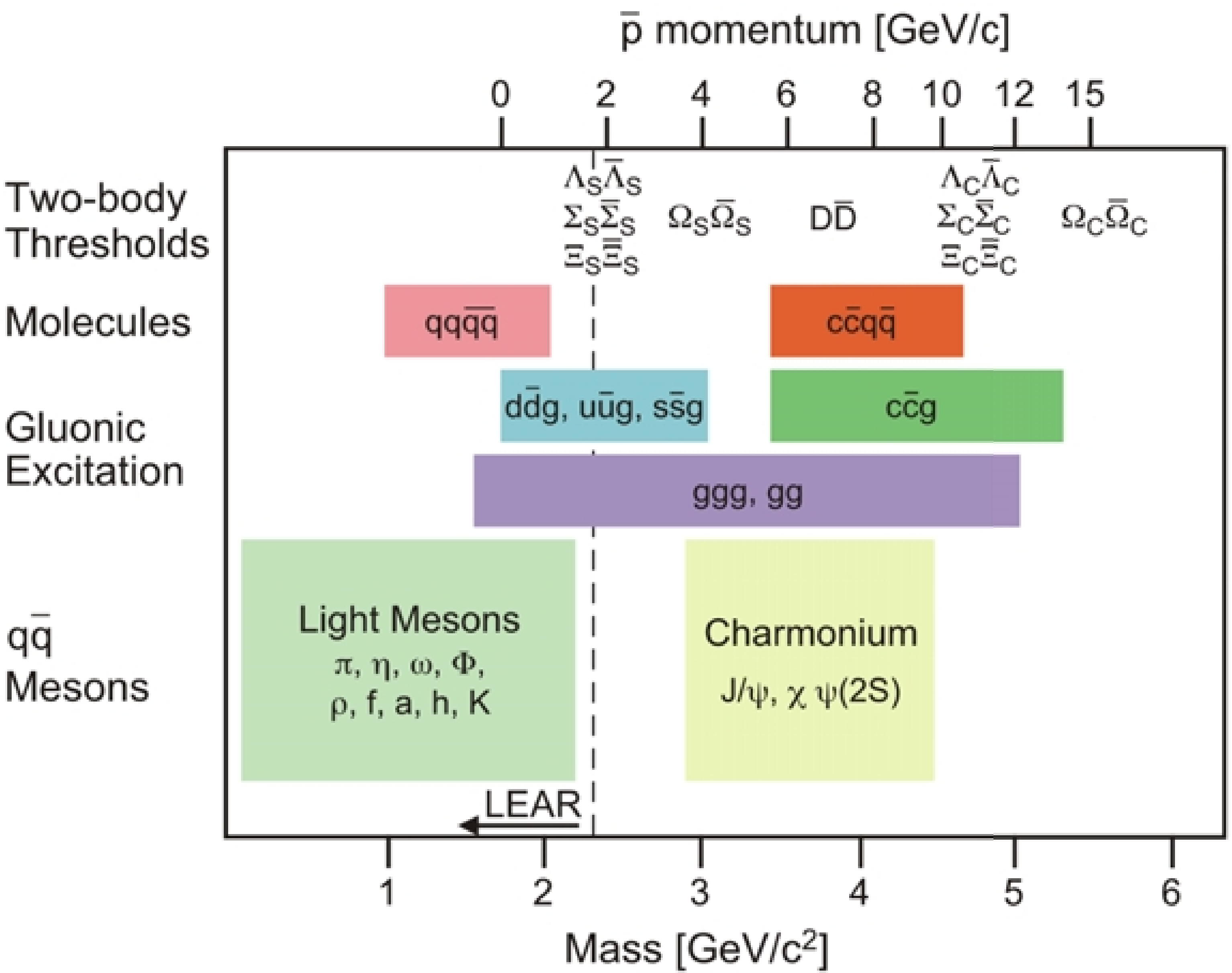
Confinement

Violation of chiral symmetry

Masses of Hadrons

Important : Gluonic degrees of freedom

QCD systems to be studied at HESR



HESR / PANDA

Production Rates (1-2 $(fb)^{-1}/y$)

Final State	cross section	# reconstr. events/y
Meson resonance + anything	100μb	10^{10}
$\Lambda\bar{\Lambda}$	50μb	10^{10}
$\Xi\bar{\Xi}$ $(\rightarrow_{\Lambda\Lambda} A)$	2μb	10^{8} (10^{5})
$D\bar{D}$	250nb	10^{7}
$J/\psi\,(\rightarrow e^{+}e^{-}, \mu^{+}\mu^{-})$	630nb	10^{9}
$\chi_2\,(\rightarrow J/\psi + \gamma)$	3.7nb	10^{7}
$\Lambda_c\bar{\Lambda}_c$	20nb	10^{7}
$\Omega_c\bar{\Omega}_c$	0.1nb	10^{5}

Common Feature : Low multiplicity events
Moderate particle energies

For Pairs : Charge symmetric conditions
Trigger on one, investigate the other

Merits of experiments with Antiprotons

– High cross sections

↳Facilitates search for rare particles (Glueball Groundstate)

– Most particles can be directly created in formation processes regardless of their J^{PC} quantum numbers ($\bar{c}c$-spectroscopy)

– Exotic states are produced with rates similar to $\bar{q}q$, qqq-systems (Glueball-, Hybrid candidates)

– (Cooled) beams have small $\Delta p/p$ and small emittances

↳Clean experimental conditions

– $\bar{p}$-induced reactions ($\leq$ 15 GeV) have low particle multiplities

↳Reconstruction of full events, Reliable PWA

Merits of experiments with Antiprotons

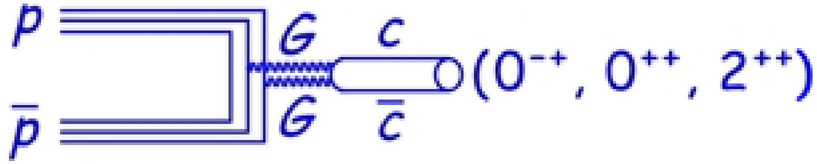
Charmonium - States

e^+e^-- collisions:

Only 1^{--} -states are directly formed
(Well measured, $e^- e^+$ energy scans)
The other states only visible through
secondary reactions,
e.g.: $e^+e^- \rightarrow \psi' \rightarrow \chi + \gamma$ (moderate mass resolution)

$p\bar{p}$ - collisions:

All states can be directly formed (Very good mass resolution, scans with $\bar{p}$)



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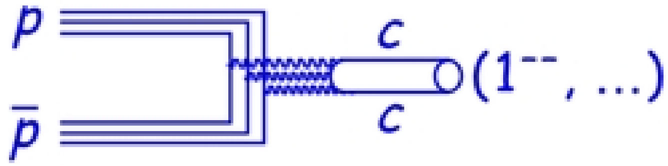
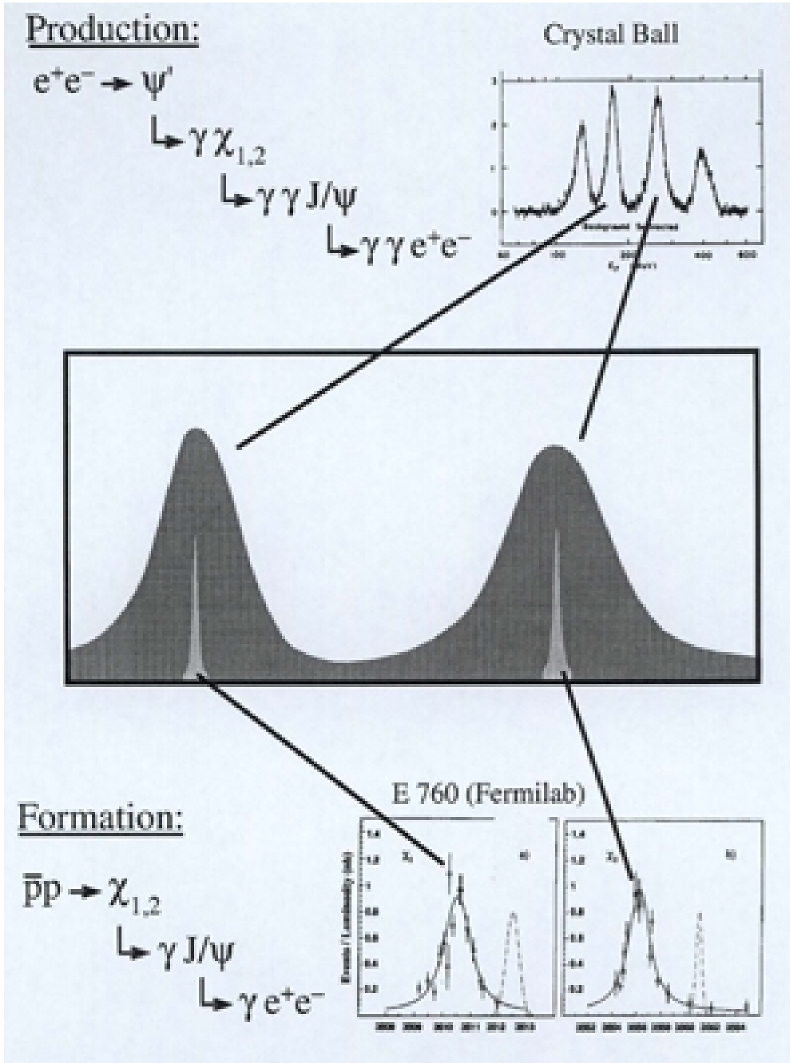
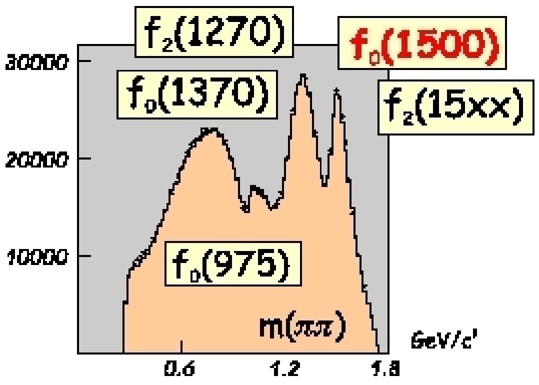


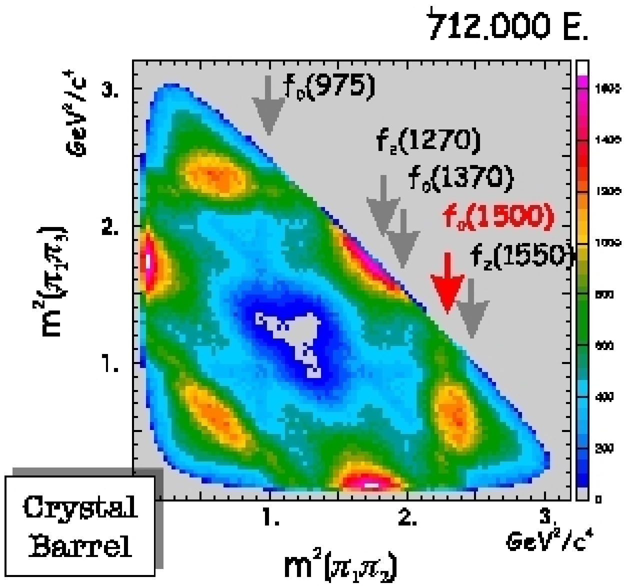


Physics with Antiprotons

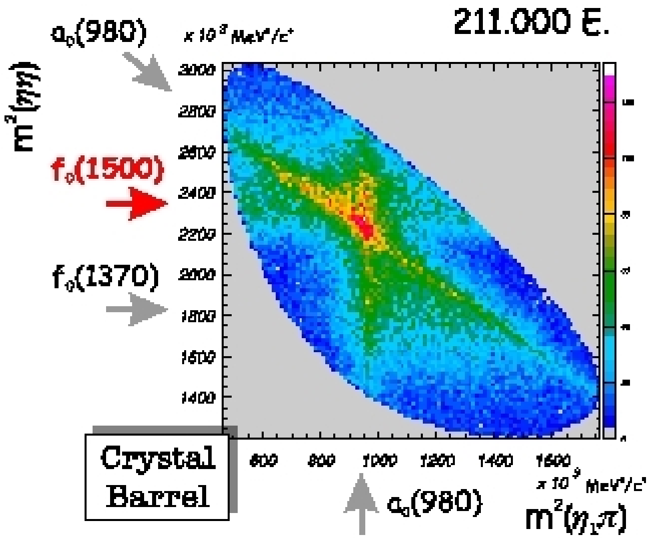
LEAR: Candidate for Glueball Groundstate

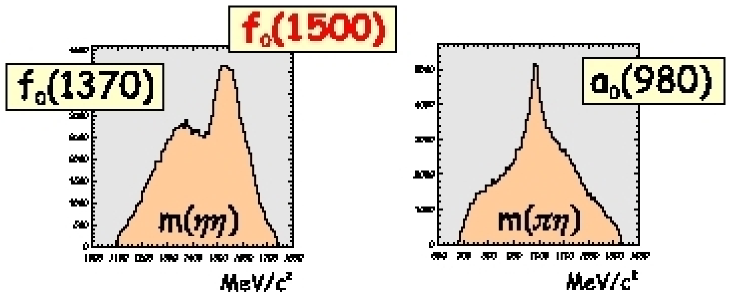
$p\bar{p} \rightarrow 3\pi^0$ at Rest





$p\bar{p} \rightarrow 2\eta\pi^0$ at Rest





Merits of experiments with Antiprotons

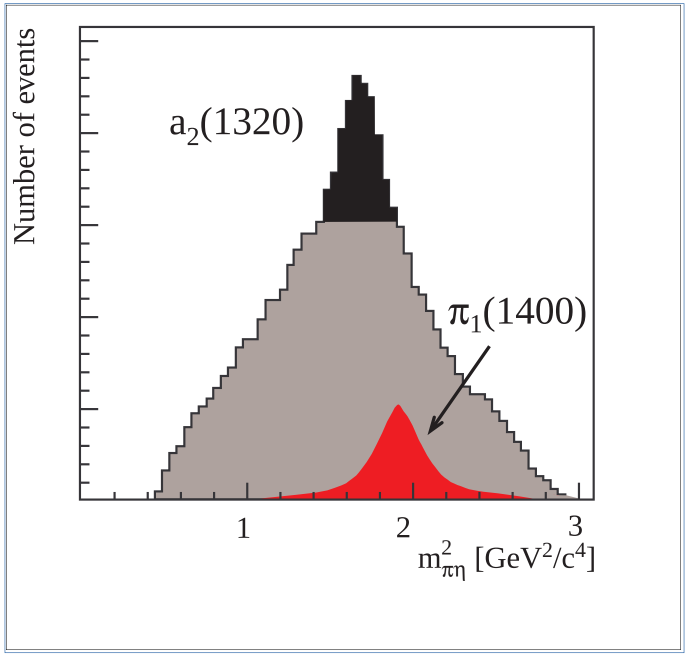
LEAR : Spin Exotics

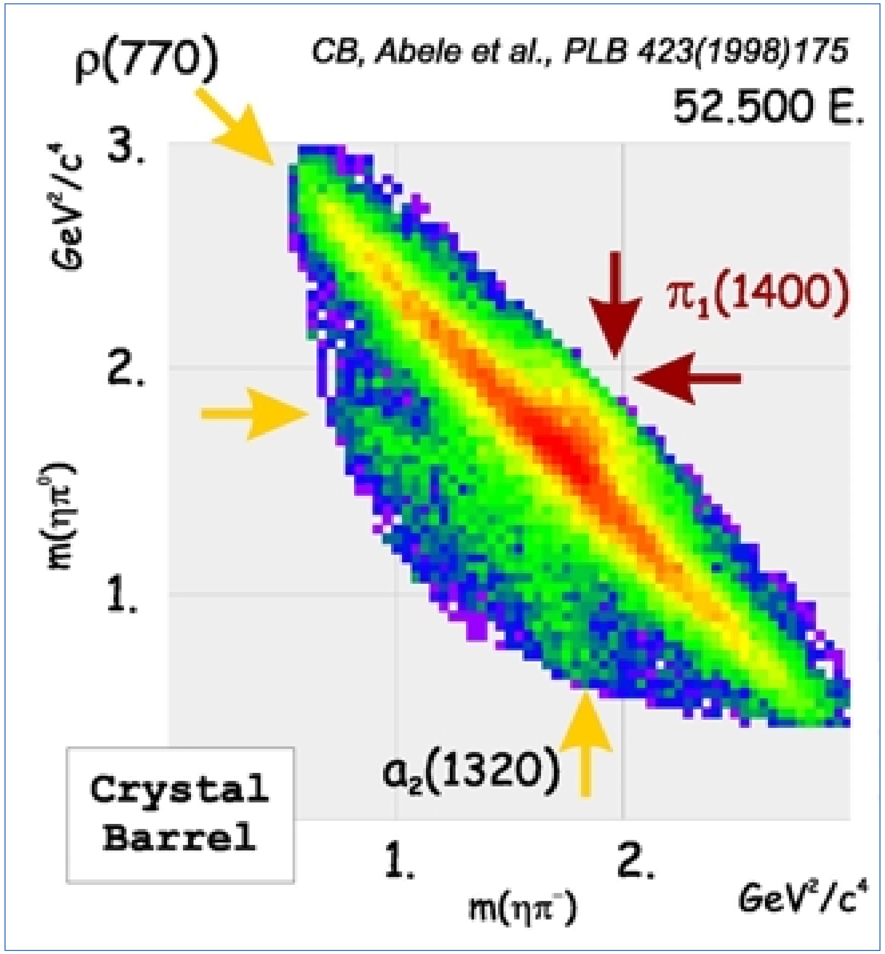
$\bar{p}_{Stop}\, d \rightarrow X(1^{-+}) + \pi + p,\ X(1400) \rightarrow \eta\pi^0, \eta\pi^-;\ X(1600) \rightarrow \pi\eta'$ (Established by BNL; First hints: VES, GAMS)

General observations

– High Statistics data needed

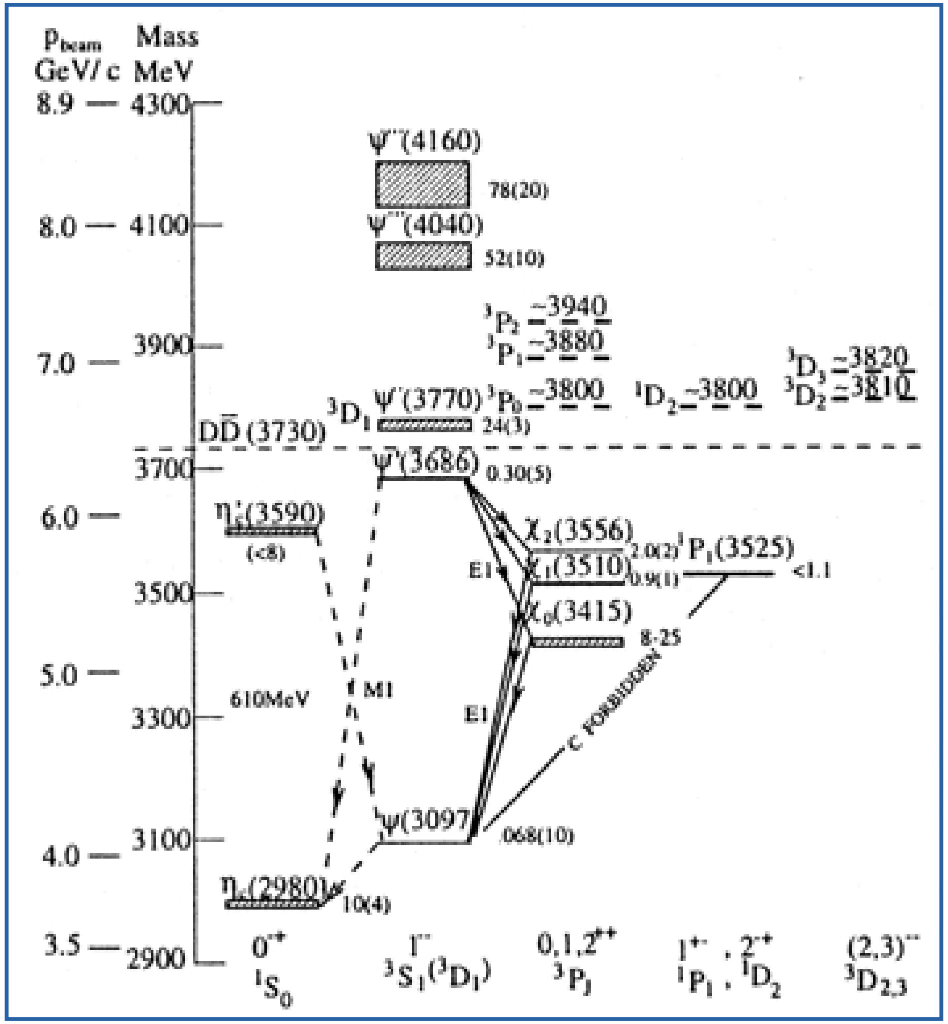
– Exotics couple to $\bar{p}p$ with a strength similar to $q\bar{q}$-states





Physics Program / Charmonium Spectroscopy

$c\bar{c}$ - system (QCD) ≙ e^+e^--system (QED)



Energies/Energy splittings/Widths of states

↳ Details of $Q\bar{Q}$-interactions

Confinement Potential

Exclusive Decays

↳ Mixing of perturbative/non-pert. effects

Physics Program / Charmonium Spectroscopy

Experimental situation

R704 (CERN/ISR) / E760/835 (Fermilab)

↳ Very precise values for masses and withs of χ_c, η_c-states
Measurement of previously unknown branching ratios
Determination of α_s (m_c)

But : Severe limitations (Non magnetic detector, beamtime, beam momentum reproducibility, ...)

Many questions left open:

– $^1P_1$ (E760) unconfirmed
– D-wave states (some of them very narrow) and radially P-states not fully understood (Structure of states)
– Angular distributions of radiative decays not understood (Mixing of pert./non-pert. Effects)

e.g. $J/\psi \rightarrow \rho\pi^0; \eta_c, \chi_{co} \rightarrow B\overline{B}$ (Hadron helicity non conserving process)
$J/\psi \rightarrow \pi^+\pi^-, \omega\pi^0, \rho\eta$ (G–parity violating decays)
$\psi' \rightarrow \gamma + \pi, \eta \ldots$ (Radiative ψ'–decays)
$\chi_{cJ} \rightarrow \rho\rho, \phi\phi, \rho\eta, \rho\eta', \eta'\eta'$ (Higher Fock state contributions)

Physics Program / Charmed Hybrids

Charmed Hybrids : ($c\bar{c}g$)

Predictions: (LQCD, Bag-Model, Flux-Tube-Model,…)

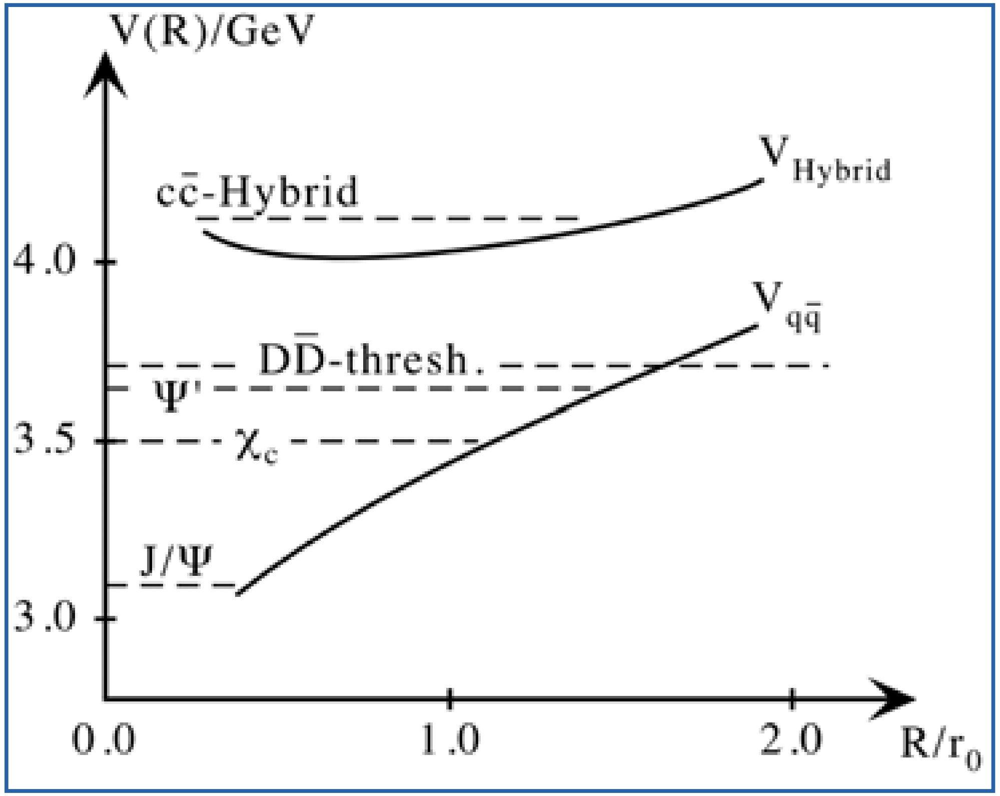
Masses

Lowest energy states: 3.9-4.5 GeV/c^2

Ground state: $J^{PC} = 1^{-+}$ (spin-exotic)

Widths

Could be narrow in some cases (≈MeV)



Physics Program / Heavier Glueballs

Glueballs (gg)

Predictions:

Masses:

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

Candidates for further states?)

Quantum numbers:

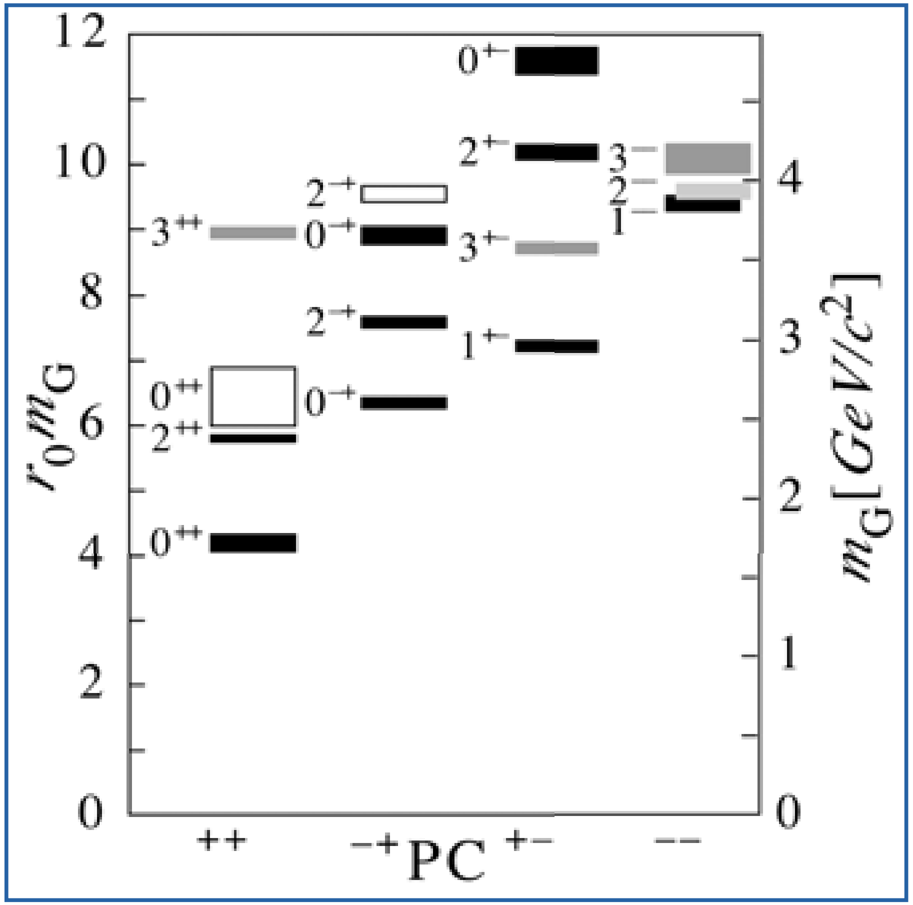
Several spin exotics (oddballs), e.g.

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

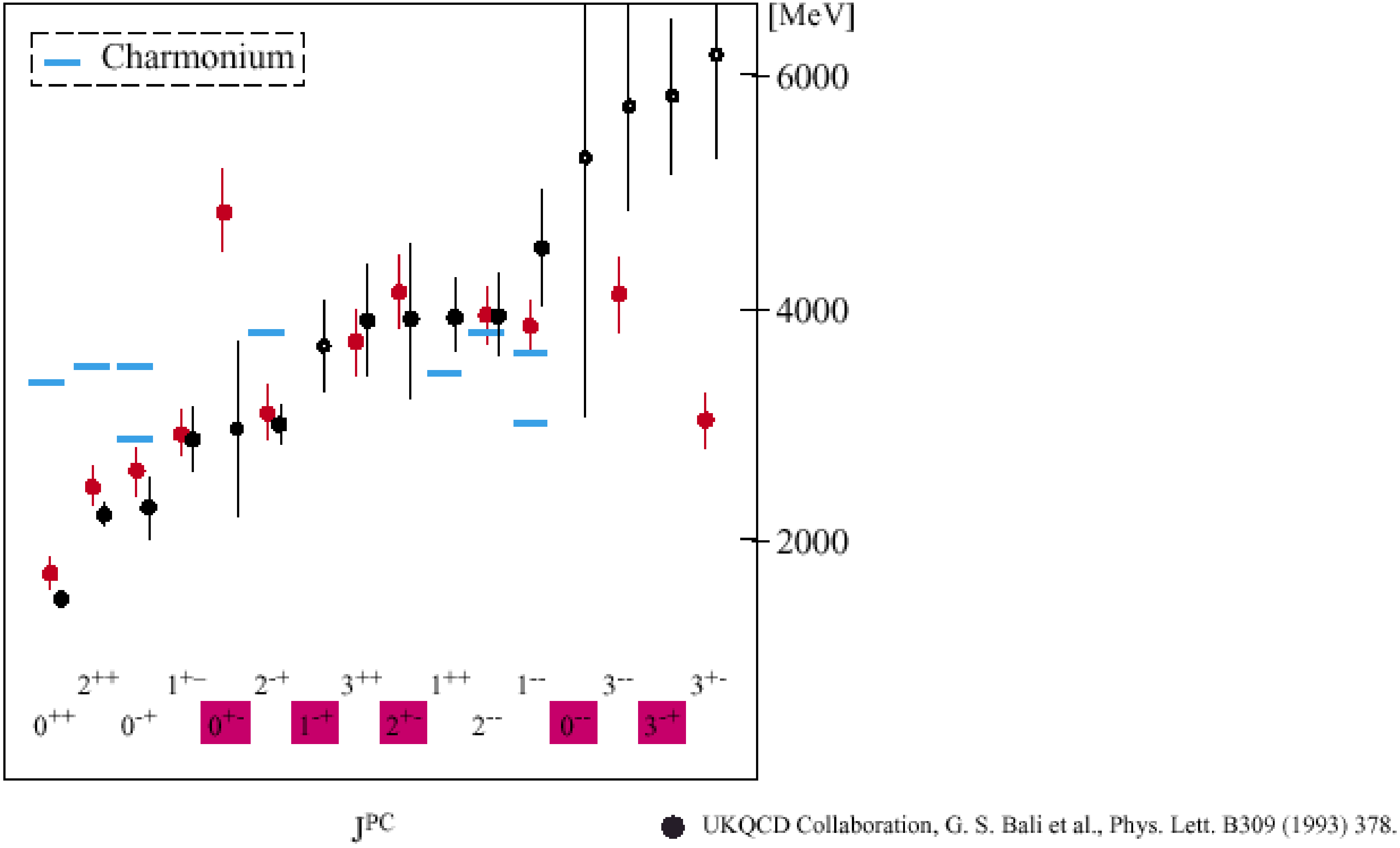
Widths: ≥ 100 MeV/c^2

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

– No mixing effects for oddballs



Charmonium States and Predicted Glueballs

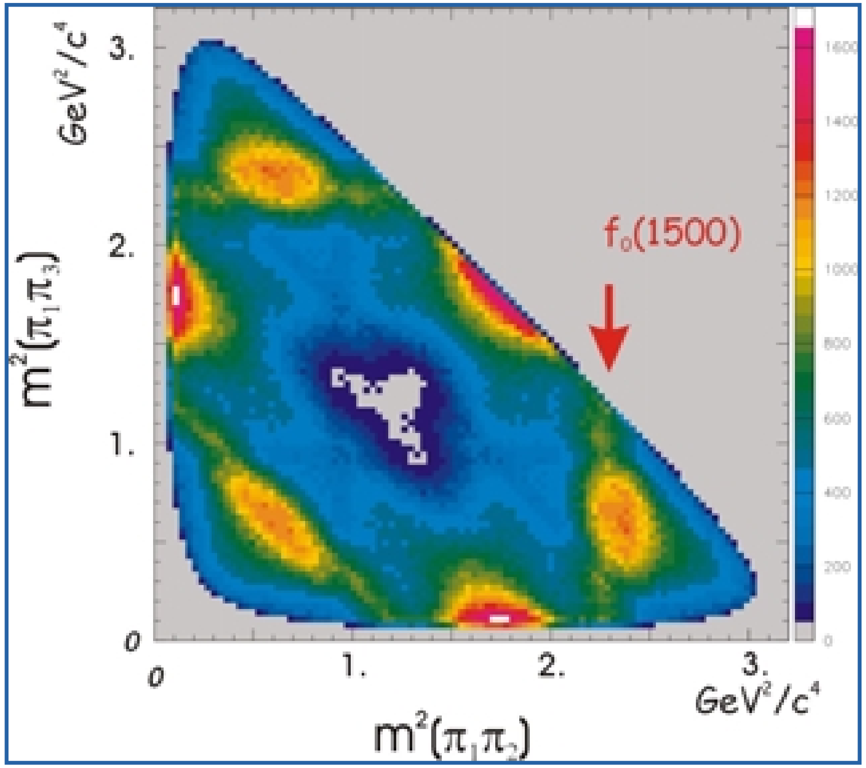


Physics Program / Heavier Glueballs

Production cross section:

Maybe high in $\bar{p}p$-annihilation (see $f_0(1500)$)

Comparable to $q\bar{q}$-systems (! μb)



Experimental program at HESR

$\bar{p}$-scan for non-exotics: $\bar{p}p \rightarrow (gg) \rightarrow \phi\phi, \phi\eta$

(Most reasonable channels, easily distinguishable, low l - waves (simple PWA))

Production exp. for exotics: $\bar{p}p \rightarrow (gg) + \pi$

Reasonable measuring times

Physics Program / Measurements in the Charm Region

Spin non-exotic states $X : \bar{p}p \rightarrow X \, (\bar{p}-\text{scan})$

X : Heavier $q\bar{q}$-mesons $\rightarrow n\pi + mK,...$

Heavier Glueballs $\rightarrow \phi\phi, \phi\eta,...$

Charmed Hybrids $\rightarrow J/\psi\eta,...$

Spin-exotic states $(\# q\bar{q}) Y : \bar{p}p \rightarrow Y + \pi, \eta,...$ (Production mode)

Y : Oddballs $\rightarrow \eta\pi, \phi\phi,...$

Charmed Hybrids $\rightarrow \chi(\pi\pi)_S,...$ (e.g. groundstate)

Physics with Open Charm

Many open questions yet

e.g. $BR(D^+ \to \mu^+\gamma) \to |\psi_D(0)|^2$, Sensitive Test of LQCD

Decay Branching Ratios of D's: Mixture of perturbative/non perturbative effects

⋮

Very recent development (BaBar, Belle, Cleo)

One extremely narrow state found: $D^*_{sj}(2317)$, Γ compatible with exper. resolution

↳ $D_s\pi^0$

Explanations:

Excited $c\bar{s}$-state improbable. Mass from quark-model does not fit (Chiral extension)

DK-molecular state (see $f_0(980)$, $a_0(980)$-Problem)?

Baryonium-state?

⋮

Latest news: Further state found: $D^*_{sj}(2460)$

Rich physics program in reach

Physics Program / Further Options

– Baryon Spectroscopy

New states, Quantum numbers and decay rates

– Direct CP-Violation in Λ, $\bar{\Lambda}$-decays

Compare angular decay asymmetries $(\alpha, \bar{\alpha})$ for $\Lambda \to p\pi^- / \bar{\Lambda} \to \bar{p}\pi^+$

$$A \approx \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}}$$

Prediction (SM) $\approx 2\text{x}10^{-5}$ HESR: 1 year of beamtime

Physics Program / Further Options

CP-Violation in charmed region

$D^0/\overline{D}^0 -$ Mixing $(r) < 10^{-8} (SM)$ HESR : $\Delta r/r \sim 10^{-4}$

Direct CP-Violation (SCS)

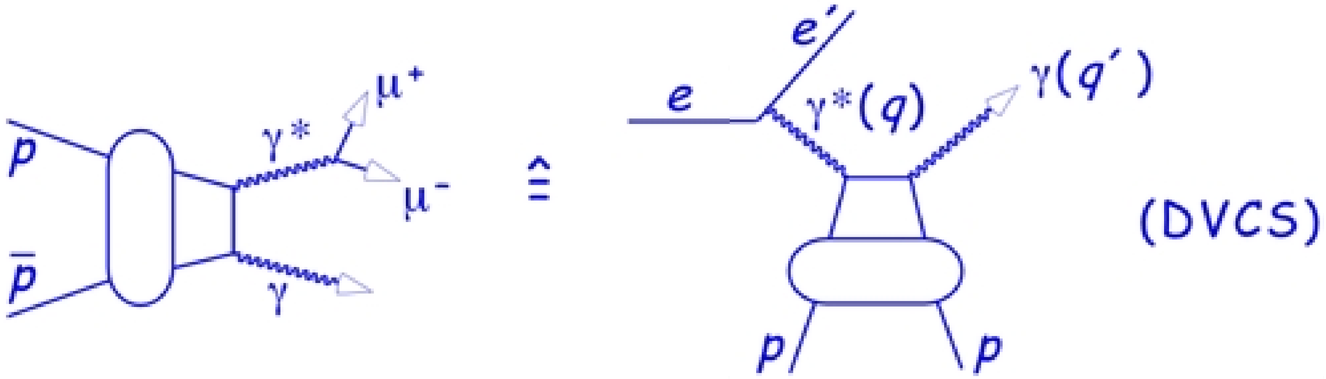
Compare $D^+ \rightarrow K^+ \overline{K}^{0*} / D^- \rightarrow K^- K^{0*}$ Asymmetries $A\ (SM) < 10^{-3}$

HESR $= \Delta A / A \approx 10^{-4} - 10^{-3}$

Physics Program / Further Options

Study of reversed Deeply Virtual Compton Scattering (DVCS)

$\bar{p} + p \rightarrow \gamma^* + \gamma \rightarrow l^+ l^- + \gamma \rightarrow$ Nucleon structure functions



Low energy p̄-physics

– p̄p-annihilation process
– Antiprotonic atoms
– Antihydrogen

PANDA – Detector

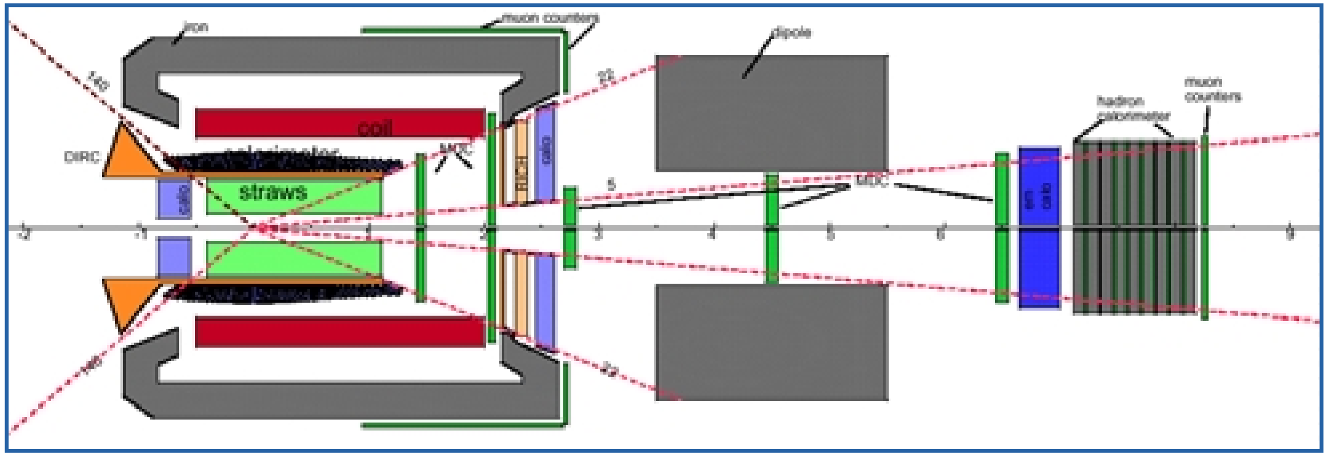
Detector requests

– Nearly full solid angle for charged particles and Gammas

– High rate capability

– Good particle identification (e, μ, π, K, p)

– Efficient trigger on e, μ, K, D



General purpose detector

– Target: Jet/Pellet/Wire

– Tracking: Pixels (MVD) / Straws / Mini-Drift-Chambers (MDC)

– E.M. Calorimeter: $PbWO_4$, APD-Readout

– Muons: Plastic Scint. Strips

– PID: Aerogel Cerenkov (ACC) / DIRC

– Trigger: High $p_\perp$ electrons/muons / Multiplicity jump (K^0_S, Λ, …)

Secondary vertex (D's,…) / Invariant masses / Global kinematical conditions

Conclusion

– HESR will deliver cooled high quality antiproton beams with energies up to 15 GeV

– Antiproton induced reactions exhibit unique features

  – High statistics data
  – Low multiplicity events
  – Symmetric production of particles and antiparticles
  – High production rates for gluonic hadrons
  – Many states can be directly formed

– Rich and unique Physics Program with emphasis on charmed particles

  – Precision charmonium spectroscopy
  – Search for charmed hybrids and heavier Glueballs
  – Investigation of Open Charm Systems (Molecules)
  – CP-violation in the charm sector
  – Low energy $\bar{p}$ - physics, including Antihydrogen experiments