Hadron Spectroscopy at $\bar{P}$ANDA

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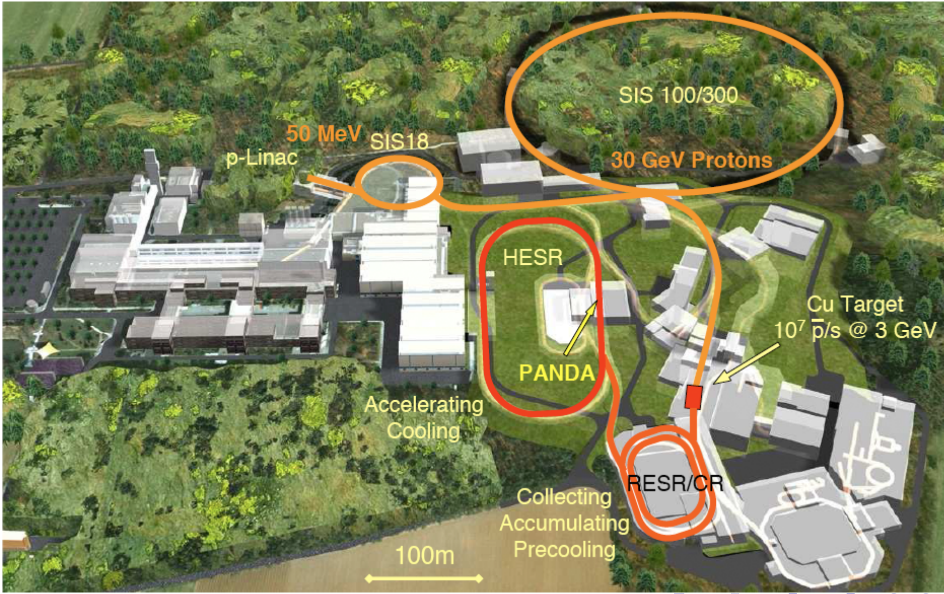
On behalf of $\bar{P}$ANDA collaboration

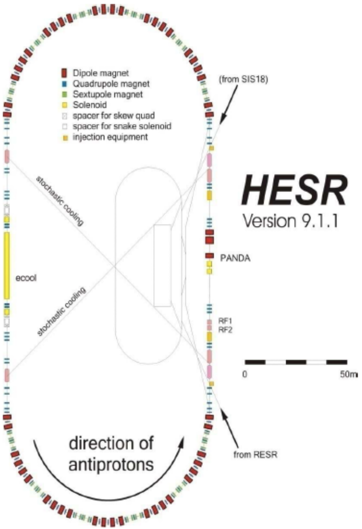
The 8th International Workshop on the Physics of Excited Nucleons
May 16th - 20th, 2011

Outline

Facility for Antiproton and Ion Research



High Energy Storage Ring (HESR)



- Internal target
- Antiproton production rate: $2 \cdot 10^7/sec$
- $\bar{P}$ beam momentum: 1.5 - 15 GeV/c
- N_{stored} = up to $1 \cdot 10^{11}\bar{p}$

High resolution mode

- Electron cooling
- $\delta p/p \sim 10^{-5}$
- $L = 10^{31} cm^{-2} s^{-1}$

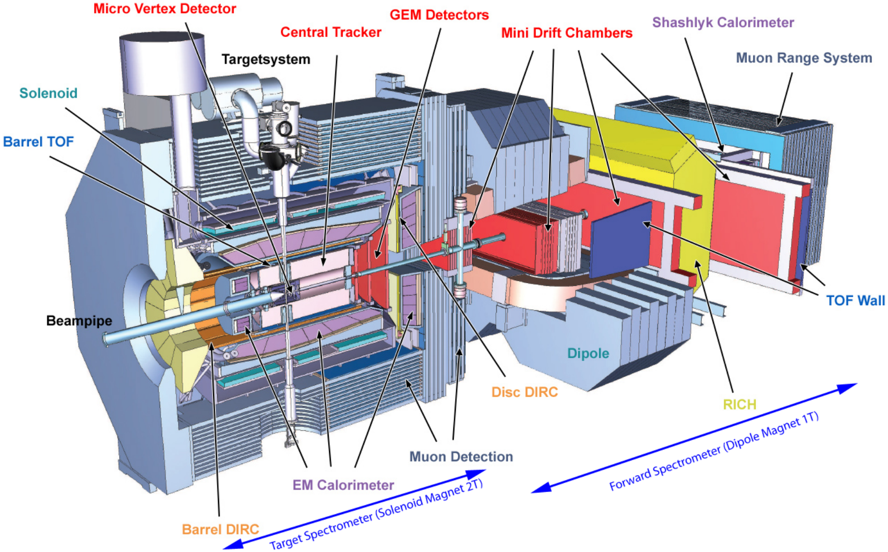
High luminosity mode

- Stochastic cooling
- $\delta p/p \sim 10^{-4}$
- $L = 2 \cdot 10^{32} cm^{-2} s^{-1}$

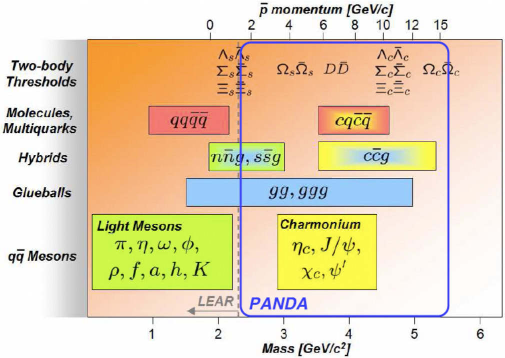
Detector Requirements

- 4π acceptance
- High rate capability: $2{\cdot}10^7 s^{-1}$ interactions
- Efficient event selection: continuous acquisition
- Momentum resolution $\sim 1\%$
- Vertex info for D, K_S^0
- Good tracking
- Good PID $(\gamma, e, \mu, \pi, K, p)$: Cherenkov detector, Time of Flight detector
- γ detection from 1 MeV to 10 GeV: Crystal Calorimeter

Anti-Proton ANnihilation at DArmstadt - $\bar{P}$ANDA Detector

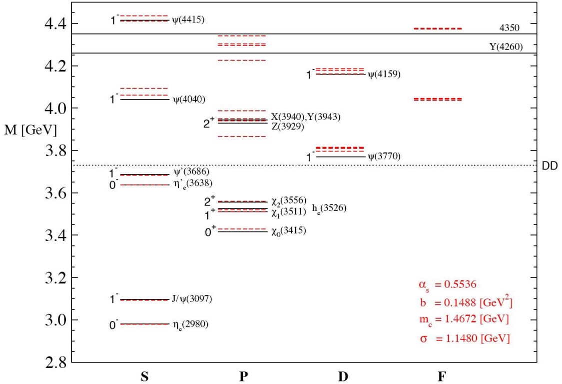


$\bar{P}$ANDA Physics Program



- Charmonium Spectroscopy: precision spectroscopy, study of confinement potential, access to all these puzzling X,Y and Z
- Search for exotics excitation: look for glueballs and hybrids
- Hadrons in the nuclear medium: study in-medium modification of hadrons
- Hypernuclear Physics
- Nucleon structure: generalized parton distribution, timelike form factor of the proton, Drell-Yan process

Charmonium Spectroscopy



- Charmonium is a powerful tool for the understanding of the strong interaction.
- The charmonium spectrum consists of eight narrow states below the threshold for open charm ($m_{D\bar{D}}$=3.73 GeV/c^2) and several tens of states above this threshold.
- States below the $D\bar{D}$ threshold are well established but for some it is necessary to improve the width and the mass measurements.
- The region above $D\bar{D}$ threshold is rich of interesting physics but, on the other hand, very little is known about it.

Experimental Study of Charmonium

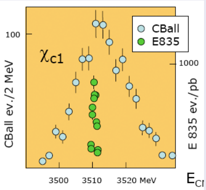
e^+e^- Annihilation

- Direct formation only possible for $J^{PC} = 1^{--}$ states.
- All the other sates must be produced via radiative decays of the vector states, or via two-photon processes, ISR, B-decay, double charmonium

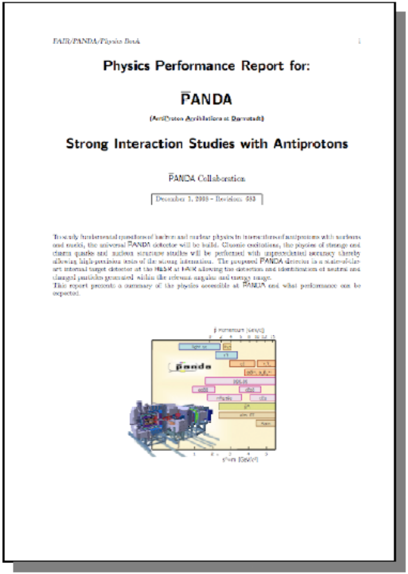
Good mass and width resolution for the vector states. For the other state modest resolutions (detector-limited).
In general, the measurement of sub-MeV widths is not possible in e^+e^- annihilation.

$p\bar{p}$ Annihilation

- Direct formation possible for all non-exotic quantum numbers.
- Excellent measurement of masses and widths for all states, given by beam energy resolution and not detector-limited.



Physics Performance Report for PANDA


FAIR/PANDA/Physics Book

Physics Performance Report for:

$\bar{\mathrm{P}}$ANDA

(AntiProton Annihilations at Darmstadt)

Strong Interaction Studies with Antiprotons

$\bar{\mathrm{P}}$ANDA Collaboration

December 1, 2008 – Revision: [illegible]

To study fundamental questions of hadron and nuclear physics in interactions of antiprotons with nucleons and nuclei, the universal $\bar{\mathrm{P}}$ANDA detector will be build. Gluonic excitations, the physics of strange and charm quarks and nucleon structure studies will be performed with unprecedented accuracy thereby allowing high-precision tests of the strong interaction. The proposed $\bar{\mathrm{P}}$ANDA detector is a state-of-the-art internal target detector at the HESR at FAIR allowing the detection and identification of neutral and charged particles generated within the relevant angular and energy range.
This report presents a summary of the physics accessible at $\bar{\mathrm{P}}$ANDA and what performance can be expected.

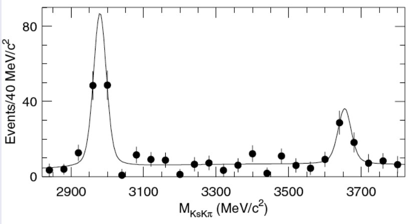
- A big effort has been made to create the PHYSICS PERFORMANCE REPORT FOR PANDA
- Detailed description of the intended scientific program
- More than 20 channels have been studied in detail to determine the experimental sensitivity
- If interested take a look under: http://arxiv.org/abs/0903.3905v1

Hot Topics in Charmonium Spectroscopy - 1

$\eta_c' - 2^1S_0$

Discovery of the η_c' by Belle and then confirmed by *BABAR* and CLEO.

	$\eta_c'(0^{-+})$
Mass	(3637 ± 4) MeV/c^2
Width	(14 ± 7) KeV



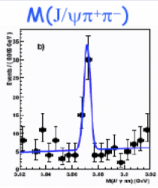
S.C.Choi et al., [Belle Collaboration], Phys. Rev. Lett. 89, 102201 (2002)

X(3872)

Discovery of a new narrow state above $D\bar{D}$ threshold X(3872) at Belle and then confirmed by CDF, D0, *BABAR* .

S.C.Choi et al., [Belle Collaboration], Phys. Rev. Lett. 91, 262001 (2003)

	X(3872)
Mass	(3871.56 ± 0.22) MeV/c^2
Width	< 2.3 MeV (90% C.L.)



What is the X(3872)?

- Charmonium: 1^3D_2 or 1^3D_3
- D^0D^{0*} molecule
- Charmonium hybrid $(c\bar{c}g)$.

X(3872)

- In 2003, Belle discovered a new signal in $B^+ \to XK^+$ where $X \to J/\psi\pi^+\pi^-$.
  S.C.Choi et al., [Belle Collaboration], Phys. Rev. Lett. 91, 262001 (2003)
- Narrow ($\Gamma < 2.3$ MeV) particle with mass $m_x(3872) = (3871.56 \pm 0.22)\mathrm{MeV/c^2}$.

X(3872) highlights

- $X(3872) \to J/\psi\gamma$ radiative decay confirmed by *BABAR* determines C=+1
- Belle/CDF dipion angular analysis in $X \to J/\psi\pi^+\pi^-$ favours $J^{PC} = 1^{++}$
- No charged partners found, doesn't decay to $\chi_{c1}\gamma$ or $J/\psi\eta_c$

X(3872) interpretation

- X(3872) is puzzling
  - Similar to charmonium, ie: narrow state decaying to $J/\psi\pi^+\pi^-$
  - However, above DD threshold expect to be wide and $X \to DD$ dominant
  - It does not fit into the charmonium model
- Leading contender is that this could be a bound state of two D mesons:
  - i.e. a DD^{*0} molecule
  - supported by predictions of mass, decay modes, J^{PC}, branching fractions
- Other exotic predictions:
  - tetraquark 4-quark bound state
  - Glueball gluon bound state or charmonium-gluon hybrid

Hot Topics in Charmonium Spectroscopy - 2

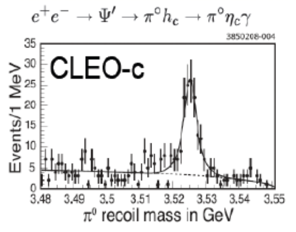
$h_c(1^1P_1)$

Reconstructed at CLEO-c and E835

$m_{CLEO-c} = 3525.8 \pm 0.28$ GeV/c^2

$m_{E835} = 3525.28 \pm 0.22$ GeV/c^2

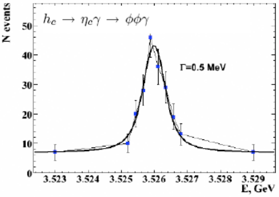
Width→ From PDG: < 1 MeV



J.L.Rosner et al., [CLEO Collaboration], Phys. Rev. Lett. 95, 102003 (2005)

PANDA (5 day scan)

10 different energies around the h_c mass

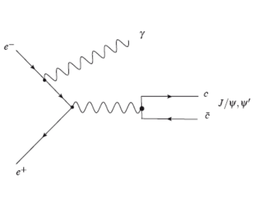


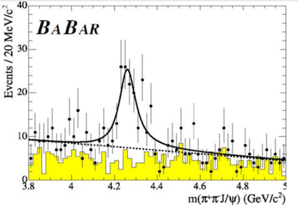
$\Gamma_{R,MC}$ [MeV]	$\Gamma_{R,reco}$ [MeV]	$\Delta\Gamma_R$ [MeV]
1	0.92	0.24
0.75	0.72	0.18
0.5	0.52	0.14

Hot Topics in Charmonium Spectroscopy - 3

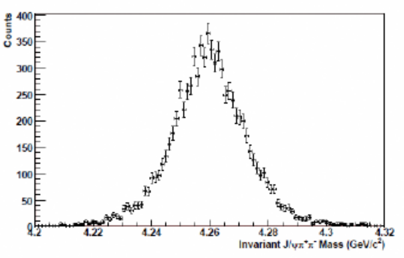
Y(4260) - Discovered by *BABAR* in Initial State Radiation

B. Aubert et al., [*BABAR* Collaboration], Phys. Rev. Lett. 95, 142001 (2005)





PANDA - $p\bar{p} \rightarrow Y(4260) \rightarrow J/\psi\pi^+\pi^-$



σ =13.4 MeV (Detector resolution)
Efficiency=33%

Charmonium at PANDA

- At $2 \cdot 10^{32} cm^{-2} s^{-1}$ accumulate 8 pb^{-1}/day (assuming 50% overall efficiency). It means $10^4 - 10^7$ $(c\bar{c})$ states/day.
- Total integrated luminosity 1.5 fb^{-1}/year (at $2 \cdot 10^{32} cm^{-2} s^{-1}$, assuming 6 months/year data taking).
- Improvements with respect to Fermilab E760/E835:
  - Up to ten times higher instantaneous luminosity.
  - Better beam momentum resolution $\Delta p/p$=10^{-5} (GSI) vs $2 \cdot 10^{-4}$ (FNAL)
  - Better detector (higher angular coverage, magnetic field, ability to detect hadronic decay modes.

Charmonium below and above the $\bar{D}D$ threshold

- Thanks to high beam momentum resolution and high luminosity we can make accurate measurement of all the eight states below the $\bar{D}D$ threshold

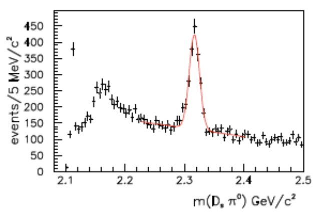
- Thanks to high-statistic and small-step scans of the entire energy region accessible at GSI we can identify all missing states above the open charm threshold and confirm the ones for which we only have a weak evidence.

$D_{s0}^*(2317)$

Discovered by *BABAR*

$m_{PDG} = 2316.8 \pm 0.4$ MeV/c^2

Width→ From PDG: < 3.8 MeV



Aubert et al., [*BABAR* Collaboration], Phys. Rev. Lett. 90, 242001 (2003)

PANDA

$\bar{p}p \rightarrow D_s^{\mp} D_{s0}^*(2317)^{\pm}$

14 Days scan close threshold

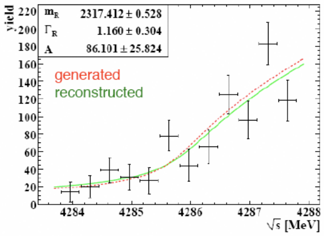
The selected parameters are:

- $m = 2317.30$ MeV/c^2; Γ=1 MeV/c^2

For this parameters set the fit yelds:

$$m = 2317.41 \pm 0.53 \text{ MeV/c}^2$$

$$\Gamma = 1.16 \pm 0.30 \text{ MeV/c}^2$$

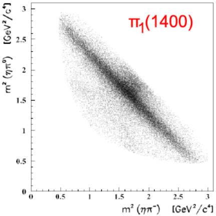


Exotic hadrons

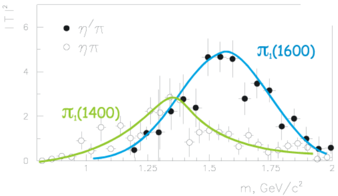
- The QCD spectrum is much richer than that of the naive quark model as the gluons can act as hadron components.
- The exotic hadrons fall in 3 general categories:
  - Multiquarks $(q\bar{q})(q\bar{q})$
  - Hybrids $(q\bar{q})$g
  - Glueballs gg
- Spin-exotic quantum numbers J^{PC} are powerful signature of gluonic hadrons.
- Hybrids candidates: $\pi_1(1400)$ and $\pi_1(1600)$ with $J^{PC} = 1^{-+}$

  S.U.Chung [E852 Collaboration], Phys Lett D 65, 072001 (2002)
- Narrow state at 1500 MeV/c^2 seen by Crystal Barrel best candidate for glueball ground state ($J^{PC} = 0^{++}$)

  C.Amsler et al., [Crystal Barrel], Phys Lett B 342, 433 (1995)



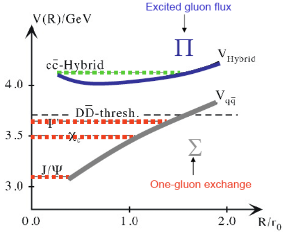
Crystal Barrel Collaboration - A.Abele
Phys Lett B423, 175 (1998)

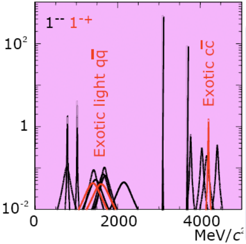


VES Collaboration - G.M.Beladidze,
Phys Lett B 313, 276 (1993)

Charmonium Hybrids

- The charmonium hybrids predictions come from different theoretical models: bag model, flux tube model, constituent gluon model and LQCD.
- Three of the lowest charmonium hybrids have exotic J^{PC}: 0^{+-}, 1^{-+}, 2^{+-}. The mixing with nearby $c\bar{c}$ states is excluded.
- The charmonium hybrids are predicted in the range mass: 4.2 - 4.5 GeV/c^2.
- Charmonium hybrids expected to be much narrower than light hybrids (open charm decays is forbidden or suppressed below DD^{**} threshold).
- Cross sections for formation and production of charmonium hybrids are similar to normal $c\bar{c}$ states ($\sim$ 100-150 pb).

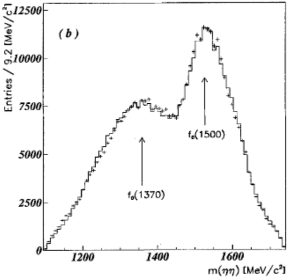




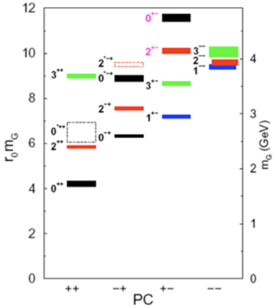
- In the light meson spectrum exotic states overlap with conventional states.
- In the $c\bar{c}$ meson spectrum the density of states is lower and the exotics can be resolved unambiguously.

Glueballs

- Light gg/ggg-system are complicated to be identified.
- Detailed predictions of mass spectrum from LQCD.
- Exotic heavy glueballs:
  - $m(0^{+-})=4140(50)(200)$ MeV
  - $m(2^{+-})=4340(70)(230)$ MeV
- Width unknown but there is a good probability to see glueballs in charm channels



Crystal Barell Collaboration
C. Amsler, Phys Lett B 355 (1995)



PANDA Collaboration

About 420 physicists from 53 institutions in 16 countries

U Basel
IHEP Beijing
U Bochum
IIT Bombay
U Bonn
IFIN-HH Bucharest
U & INFN Brescia
U & INFN Catania
JU Cracow
TU Cracow
IFJ PAN Cracow
GSI Darmstadt
TU Dresden
JINR Dubna
(LIT,LPP,VBLHE)
U Edinburgh
U Erlangen
NWU Evanston

U & INFN Ferrara
U Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Glasgow
U Gießen
KVI Groningen
IKP Jülich I + II
U Katowice
IMP Lanzhou
U Lund
U Mainz
U Minsk
ITEP Moscow
MPEI Moscow
TU München
U Münster
BINP Novosibirsk

IPN Orsay
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PNPI Gatchina
U of Silesia
U Stockholm
KTH Stockholm
U & INFN Torino
Politechnico di Torino
U Piemonte Orientale, Torino
U & INFN Trieste
U Tübingen
TSL Uppsala
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw

Conclusions

The HESR at the GSI FAIR facility will deliver high-quality antiproton beams with momenta up to 15 GeV/c ($\sqrt{s}$ ~5.5 GeV).

This will allow PANDA to carry out the following measurements:

- High resolution charmonium spectroscopy in formation experiments
- Study of exotic hadrons (multiquarks, glueballs, hybrids)
- Study of hadrons in nuclear matter
- Hypernuclear physics
- Nucleon structure studies

THANKS FOR YOUR ATTENTION

BACKUP SLIDES

BACKUP SLIDES

$\bar{p}p \to Y(4260) \to J/\psi\pi^+\pi^-$: PANDA results

Event Selection:

- select a well reconstructed J/ψ in the event;
- select two pion candidates from charged tracks with VeryLoose PID criteria;
- kinematical fit of the $J/\psi\pi^+\pi^-$ candidates with vertex constraint;
- probability of $J/\psi\pi^+\pi^-$ vertex fit: $P_{J/\psi\pi^+\pi^-} >$0.001.

The reconstruction efficiencies is about 33% and the RMS is about 13 MeV.

The main background for this channel comes from $\bar{p}p \to \pi^+\pi^-\pi^+\pi^-$ where two pions may be misidentified as electrons and contaminate the signal.
The cross section at $\sqrt{s} = 4.260$ is approximately equal to 0.046 mb (V. Flaminio et al., CERN-HERA 70-03 (1970)), while the cross section of $\bar{p}p \to Y(4260) \to J/\psi\pi^+\pi^-$ is about 60 pb (M. Negrini, Measurement of the branching ratios $\psi(2S) \to J/\psi X$ in the experiment E835 at FNAL, PhD thesis, University of Ferrara, 2003).

We obtain a signal/noise ratio of about 2.

$\bar{p}p \rightarrow h_c \rightarrow \eta_c\gamma$: PANDA results

The energy of the photon is E_γ=503 MeV. The η_c can be detected through many exclusive decay modes, neutral ($\eta_c \rightarrow \gamma\gamma$) or hadronic.
Using the value measured by E825 we have σ=33 nb.

Event Selection:

- An η_c candidate is formed by pairing γ's with an invariant mass in the window [2.6;3.2] GeV. The third γ is added to this pair to form the h_c candidate.
- A 4C-fit to beam energy-momentum is applied to the h_c candidate.
- Events with 3 γ's were selected.
- Cut on the confidence level of the 4C-fit: $CL > 10^{-4}$.
- Cut on the CM energy of the γ from the $h_c \rightarrow \eta_c\gamma$: 0.4 GeV$< E_\gamma <$ 0.6 GeV.
- - Angular cut —cosθ_{CM}— to reject the background which is strongly peaked in the forward and backward directions.
- The cut for invariant mass of combination $M(\gamma_1, \gamma_3) > 1.0 GeV$ and $M(\gamma_2, \gamma_3) > 1.0 GeV$.

The expected event rate for the luminosity in high luminosity mode is 20 events/day and for high resolution mode is 2.0 events/day.

h_c width measurement: ($h_c \rightarrow \eta_c\gamma \rightarrow \phi\phi\gamma$) Events were generated at 10 different energies around the h_c mass, each point corresponding to 5 days of running the experiment in high resolution mode. We assumed a S/B∼8 and the background was assumed to be energy indip.

$\bar{p}p \to h_c \to \eta_c \gamma$: PANDA results

Cut	h_c	$\pi^0\gamma$	$\pi^0\pi^0$	$\pi^0\eta$	$\eta\eta$	$\pi^0\eta'$
preselection	0.70	0.43	0.14	$8.2 \cdot 10^{-2}$	$4.0 \cdot 10^{-2}$	$8.5 \cdot 10^{-2}$
$3\ \gamma$	0.47	0.31	$1.3 \cdot 10^{-2}$	$7.5 \cdot 10^{-3}$	$2.7 \cdot 10^{-3}$	$8.7 \cdot 10^{-3}$
$CL > 10^{-4}$	0.44	0.30	$9.9 \cdot 10^{-3}$	$4.9 \cdot 10^{-3}$	$7.2 \cdot 10^{-4}$	$5.7 \cdot 10^{-3}$
E_γ [0.4;0.6] GeV	0.43	0.12	$3.9 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$	$2.8 \cdot 10^{-4}$	$2.3 \cdot 10^{-3}$
$\|\cos(\theta)\| < 0.6$	0.22	$9.2 \cdot 10^{-2}$	$2.7 \cdot 10^{-3}$	$1.1 \cdot 10^{-3}$	$7.0 \cdot 10^{-5}$	$7.5 \cdot 10^{-4}$
$m^2_{12}, m^2_{23} > 1.0$ GeV	$8.1 \cdot 10^{-2}$	0	0	0	0	0

Table 4.11: Selection efficiencies for $h_c \to 3\gamma$ and its background channels.

Channel	σ (nb)	number of events
$\overline{p}p \to h_c \to 3\gamma$		20 k
$\overline{p}p \to \pi^0\pi^0$	31.4	1.3 M
$\overline{p}p \to \pi^0\gamma$	1.4	100 k
$\overline{p}p \to \pi^0\eta$	33.6	1.3 M
$\overline{p}p \to \eta\eta$	34.0	1.3 M
$\overline{p}p \to \pi^0\eta'$	50.0	100 k

Table 4.10: The main background contributors to $h_c \to 3\gamma$ with corresponding cross-section integrated over $|\cos(\theta_{CM})| < 0.6$.

Channel	S/B ratio
$\overline{p}p \to \pi^0\pi^0$	> 94
$\overline{p}p \to \pi^0\gamma$	> 164
$\overline{p}p \to \pi^0\eta$	> 88
$\overline{p}p \to \eta\eta$	> 87
$\overline{p}p \to \pi^0\eta'$	> 250

Table 4.12: Signal to background ratio for $h_c \to 3\gamma$ and different background channels.

$\bar{p}p \to h_c \to \phi\phi\gamma$: PANDA results

Selection criteria	signal	$4K\pi^0$	$\phi K^+K^-\pi^0$	$\phi\phi\pi^0$	$K^+K^-\pi^+\pi^-\pi^0$
pre-selection	0.51	$9.8 \cdot 10^{-3}$	$1.3 \cdot 10^{-2}$	$4.9 \cdot 10^{-2}$	$9.0 \cdot 10^{-6}$
$CL > 0.05$	0.36	$1.5 \cdot 10^{-3}$	$2.0 \cdot 10^{-3}$	$7.0 \cdot 10^{-3}$	$4.0 \cdot 10^{-8}$
$m(\eta_c), E_\gamma$	0.34	$4.1 \cdot 10^{-4}$	$5.2 \cdot 10^{-4}$	$1.8 \cdot 10^{-3}$	0
$m(\phi)$	0.31	$4.5 \cdot 10^{-6}$	$1.2 \cdot 10^{-4}$	$1.7 \cdot 10^{-3}$	0
$no\ \pi^0(30\,MeV)$	0.26	$2.7 \cdot 10^{-6}$	$4.5 \cdot 10^{-5}$	$9.2 \cdot 10^{-4}$	0
$no\ \pi^0(10\,MeV)$	0.24	$1.8 \cdot 10^{-6}$	$3.0 \cdot 10^{-5}$	$7.1 \cdot 10^{-4}$	0

Table 4.14: Efficiency of different event selection criteria.

Channel	N of events
$\overline{p}p \to h_c \to \phi\phi\gamma$	20 k
$\overline{p}p \to K^+K^-K^+K^-\pi^0$	6.2 M
$\overline{p}p \to \phi K^+K^-\pi^0$	200 k
$\overline{p}p \to \phi\phi\pi^0$	4.2 M
$\overline{p}p \to K^+K^-\pi^+\pi^-\pi^0$	5 M + 15 M
	100 k

Table 4.13: The numbers of analysed events for h_c decay

channel	Signal/Background
$\overline{p}p \to K^+K^-K^+K^-\pi^0$	8
$\overline{p}p \to \phi K^+K^-\pi^0$	8
$\overline{p}p \to \phi\phi\pi^0$	> 10
$\overline{p}p \to K^+K^-\pi^+\pi^-\pi^0$	> 12

Table 4.15: Signal to background ratio for different h_c background channels

$D_{s0}^*(2317)$: PANDA results

The signal events are $\bar{p}p \rightarrow D_s^{\pm} D_{s0}^*(2317)^{\mp}$ where $D^{\pm} \rightarrow \phi\pi^{\pm}$ (or anything) and $\phi \rightarrow K^+K^-$; $D_{s0}^*(2317)^{\mp} \rightarrow$ anything.

Event selection:
- Select kaon candidates from charged tracks with VeryLoose PID criteria.
- Create a list of ϕ candidates by forming all combinations of a negative with a positive charged kaon candidate.
- Kinematic fit of the single ϕ candidates with vertex constraint.
- Select pion canddates from charged tracks with VeryLoose PID criteria.
- Combine ϕ candidates with pion candidates to form $D_s^{\pm}$ candidates.
- Kinematic fit of the $D_s^{\pm}$ candidates with vertex constraint.
- Probability of ϕ vertex fit: $P_{\phi} > 0.001$.
- Probability of $D_s^{\pm}$ vertex fit: $P_{D_S} > 0.001$.
- ϕ mass window: $|m(K^+K^-) - m_{PDG}(\phi)| < 10 MeV/c^2$.
- ϕ decay angle: $|cos\theta_{dec} > 0.5$.
- $D_s^{\pm}$ mass window: $|m(\phi\pi^{\pm}) - m_{PDG}(D_s^{\pm})| < 30 MeV/c^2$.

Scan procedure: The background level is assumed to be energy independent and also the signal reconstruction efficiency is assumed to be constant for all energy steps. (T=14 days, S/B=0.3, $\Delta_{E_{MAX}}$=2 MeV, n=12.)

$D_{s0}^{*}(2317)$: PANDA results

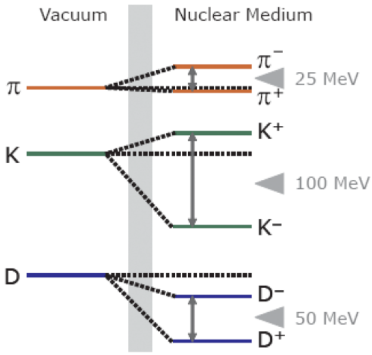
Channel	rel. X-sec	ϵ(VL)[%]	ϵ(L)[%]	ϵ(T)[%]	ϵ(VT)[%]
Signal	1	36.2	28.1	21.0	19.0
$\overline{p}p \to D_s^{\pm} D_s^{\mp} \pi^0$	1	0.8	0.6	0.5	0.4
$\overline{p}p \to D_s^{\pm} D_s^{\mp} 2\pi^0$	1	6.9	5.2	4.0	3.6
$\overline{p}p \to D_s^{\pm} D_s^{\mp} \pi^+ \pi^-$	1	8.1	6.1	4.6	4.2
$\overline{p}p \to D_s^{\pm} D_s^{*\mp}$	1	0.0	0.0	0.0	0.0
$\overline{p}p \to D_s^{\pm} D_s^{*\mp} \pi^0$	1	3.7	2.8	2.1	1.9
$\overline{p}p \to D_s^{\pm} D_s^{\mp} \gamma$	0.1	0.6	0.4	0.3	0.3
$\overline{p}p \to D_s^{\pm} D_s^{*\mp} \gamma$	0.1	1.1	0.9	0.6	0.6
DPM generic	10^6	$2.5 \cdot 10^{-4}$	$4.5 \cdot 10^{-5}$	$1.9 \cdot 10^{-5}$	$1.9 \cdot 10^{-5}$
r_{SB} (w/ DPM)	–	1 : 318	1 : 74	1 : 43	1 : 47
r_{SB} (w/o DPM)	–	1.86	1.90	1.89	1.88

Table 4.39: Results of the simulation studies of signal reconstruction and background suppression. Only relative cross sections are given. ϵ denotes the signal reconstruction efficiency for the signal channel and the fake signal finding probability for the studied background channels, respectively. The resulting values for the signal-to-noise ratio r_{SB} including or excluding the generic DPM background are also given (see text).

Hadrons in Nuclear Matter

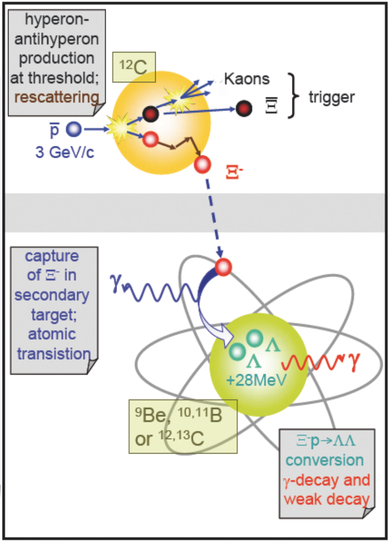
One of the fundamental questions of QCD is the generation of MASS.
The light hadron masses are large than the sum of the constituent quark masses.
Spontaneous chiral symmetry breaking seems to play a decisive role in the mass generation of light hadrons. How can we check this?

- Since density increase in nuclear matter is possible a partial restoration of chiral symmetry.
- Evidence for mass changes of pions and kaons has been observed.
- $c\bar{c}$ states are sensitive to gluon condensate:
  - Small (5-10 MeV/c^2 in medium modifications for low-lying $c\bar{c}$ (J/ψ and η_c)
  - Significant mass shifts for excited states: 40, 100, 140 MeV/c^2 for χ_{cJ}, ψ' and $\psi(3770)$ respectively (S.Lee, Phys. Rev. C67, 038202 (2003)).
- D mesons are the QCD analog of the H-atom.
  - chiral symmetry to be studied on a single light quark
  - theoretical calculations disagree in size and sign of mass shift (50 MeV/c^2 attractive - 160 MeV/c^2 repulsive) (Phys. Rev. B487, 96 (2000) - Eur. Phys. J A7, 279 (2000)).



Hypernuclear Physics

- Hypernuclei come from the substitution of a *u* or *d* quark with a *s* quark into a nucleous. So the strangeness open a 3rd dimension in the nuclear chart.
- Double-hypernuclei: very little data
- Hyperon is not limited by the Pauli principle
- Baryon-baryon interactions:
  - $\Lambda - N$ only short ranged
  - $\Lambda - \Lambda$ impossible in scattering reactions.



Electromagnetic form factors of the proton in the timelike region

The electromagnetic form factors of the proton in the time-like region can be extracted from the cross section for the process $\bar{p}p \rightarrow e^+e^-$. First order QED predicts:

$$\frac{d\sigma}{dcos\theta^*} = \frac{\pi\alpha^2\hbar^2c^2}{2xs}\left[|G_M^2(1+cos^2\theta^*)+\frac{4m_p^2}{s}|G_E|^2(1-cos^2\theta^*)\right]$$

where G_E and G_M are the electric and magnetic form factos respectively.
The proton time-like form factors have been measured by several experiments in the low Q^2 region, but at high Q^2 the only measurements have been achived by E760 and E835 at Fermilab up to $Q^2 \sim (15\ \mathrm{GeV/c})^2$. M. Ambrogiani [E835 Collaboration], Phys. Rev. D60, 032002 (1999) .
However, due to limited statistics $|G_M|$ and $|G_E|$ have not been measured separately and could only be extracte using the assumption $|G_M| = |G_E|$.
Recently new measurements of $|G_M|$ have been obtained by the *BABAR* collaboration using Initial State Radiation. B. Aubert [*BABAR* Collaboration], Phys. Rev. D73, 051105 (2000) .

In PANDA it will be possible to determine the form factos over the widest Q^2 range ever covered by a single experiment, from threshold to 20 $(\mathrm{GeV/c})^2$ or above. Due to much higher statistics it will be possible to measure $|G_M|$ and $|G_E|$ separately.