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Physics prospects for first experiments at $\bar{\mathrm{P}}$ANDA

Outline

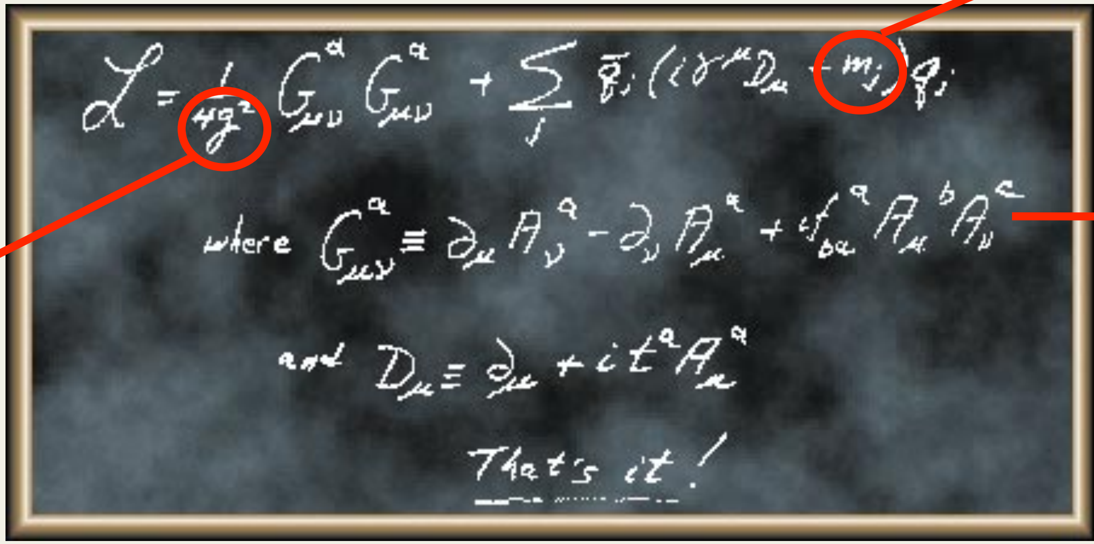
- Hadron spectroscopy with antiprotons;
- The FAIR accelerator complex;
- Low energy sector;
- Open-Charm and Charmonium spectroscopy;
- Exotic states;
- Baryonic states.

Quantum Chromodynamics

Quantum ChromoDynamics (QCD) is the theory of strong interactions that bind quarks and gluons together to form hadrons.

QCD is a nonlinear theory that is not analytically solvable

masses of the 6 quark flavours



gluon field

g
coupling constant

From F.A. Wilczek QCD Lecture

For the equivalent quantum field theory of weak force and electromagnetism, approximations using perturbation expansions in the interaction strength give very accurate results. However, since the QCD interaction is "so strong", perturbative approximations often fail.

Hadron structure

The quark flavors can be divided into two categories, depending on their masses: the light flavors *(u, d, s)*, and the heavy flavors *(c, b, t)*

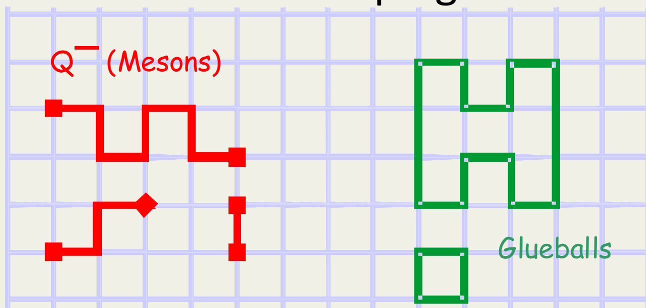
The study of the light hadron sector has led to the creation of the ***Chiral Symmetry Breaking*** picture in which the ground state mesons and baryons can be explained well with the constituent (valence) quarks and the sum of the quark masses roughly gives the hadron mass.

At very high energy, in the heavy quark sector asymptotic freedom allows accurate calculations at high energy with perturbation theory.

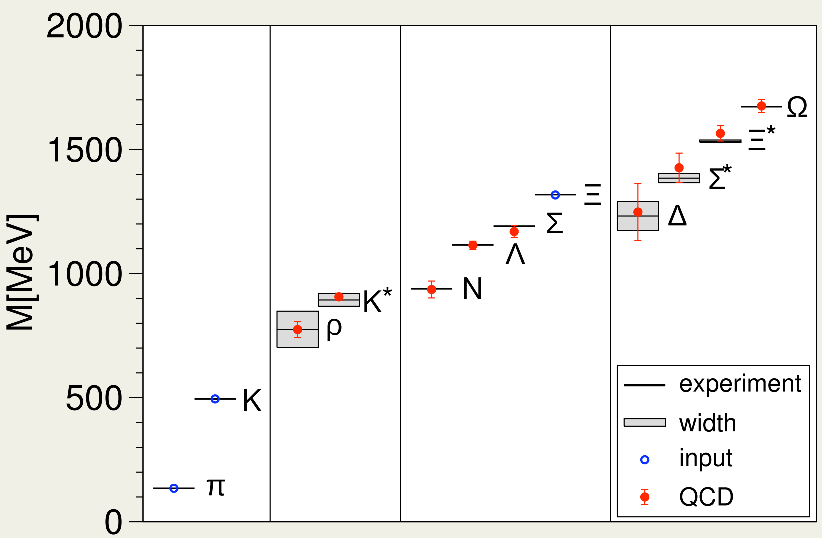
Charm sits between heavy and light quarks ➔ it allow a test of theory methods and physics phenomena it is then the best playground to understand QCD.

Lattice QCD

In order to solve QCD at long distances, Wilson [*PRD* 10:2445-2459, 1974] introduced lattice gauge theory, in which the space-time continuum is discretized on a lattice keeping the gauge symmetry intact.



This discretization allows a non-perturbative approximation to the theory that is successively improvable by increasing the lattice size and decreasing the lattice spacing.
It also makes the gauge theory amenable to numerical simulation by computer.



Science **322** (2008) 1224 [arXiv:0906.3599 [hep-lat]].

The simulation of the quark interactions requires the computation of a large, highly non-local matrix determinant, which is extremely time consuming. This determinant arises from the dynamics of the quarks. The simplest way to proceed is thus to ignore the quark dynamics and work in the so-called quenched approximation, with only gluonic degrees of freedom.

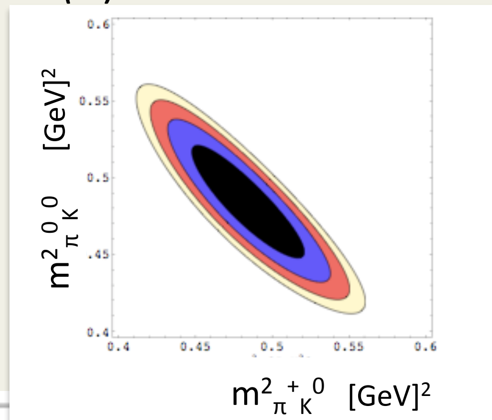
Nowadays the agreement with the measured masses is at the few % level.

Effective Field Theories

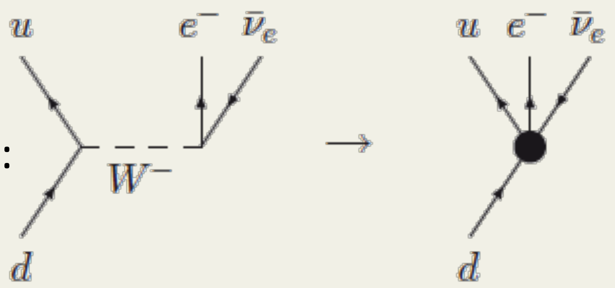
Effective Field Theories (EFT) are based on the assumption that scales much smaller/bigger than those under study shouldn't matter.

i.e. One can calculate the hydrogen atom spectrum very precisely without knowing top quark mass!

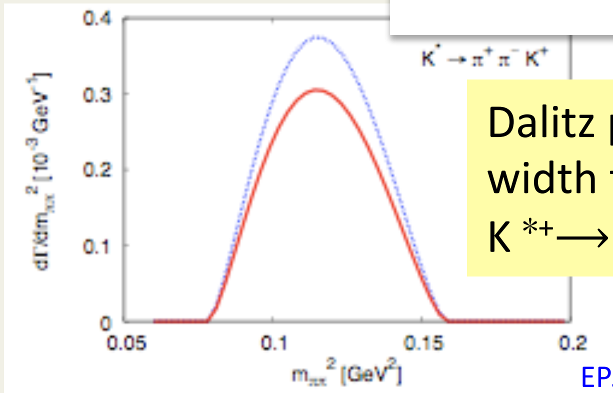
Classical dynamics(mechanics) $v << c(Ext>>\hbar)$ can be seen as an EFT because it does not consider the contribution of the terms that are related with $c(\hbar)$.



Weak interaction:



Within this framework ChPT is the EFT of QCD in the light quark sector and it has significantly contributed to our understanding of strong interaction at hadron scale.



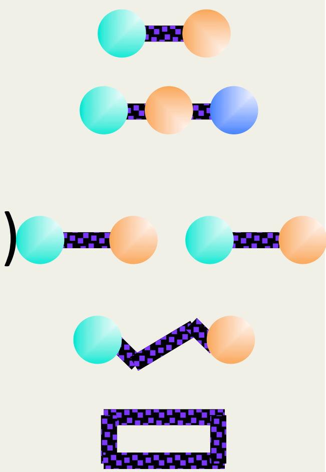
Dalitz plot and decay width for the channel $K^{*+} \longrightarrow \pi^+ K^0 \pi^0$

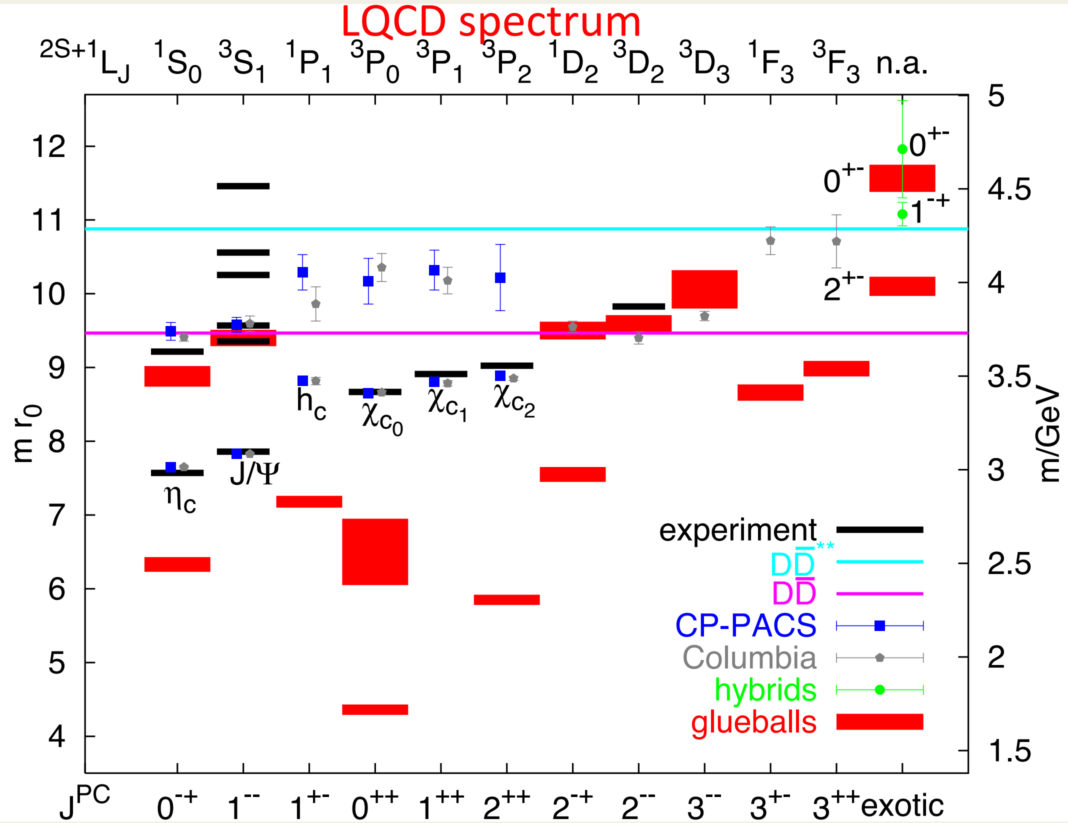
EPJA39:205,2009
arXiv:0807.4686 [hep-ph]

The hadron spectrum

The whole set of theoretical approaches rely on approximations and/or free parameters that must be constrained. Furthermore, They all predict states with explicit gluon content.

Mesons	$q\bar{q}$	
Baryons	qqq	
Multiquarks	$(q\bar{q})(q\bar{q})$	
Hybrids	$(q\bar{q})$ g	
Glueballs	gg	





G. S. Bali, Int.J.Mod.Phys. A21 (2006) 5610-5617

The experimental point of view

- Can we observe experimentally gluonic degrees of freedom?

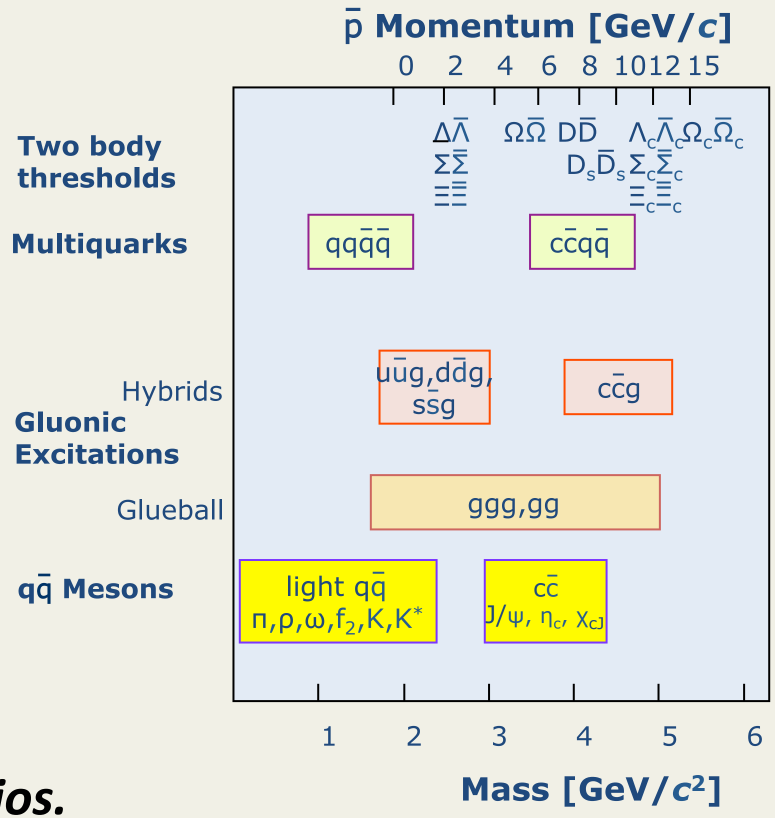
- How would these manifest themselves in terms of the excitation spectrum and also in the strong decays of hadrons?

Three are the main goals of hadron spectroscopy:

- *Identify the physical states and their quantum numbers, and measure their **masses and widths.***

- *Determine their **decay modes and branching ratios.***

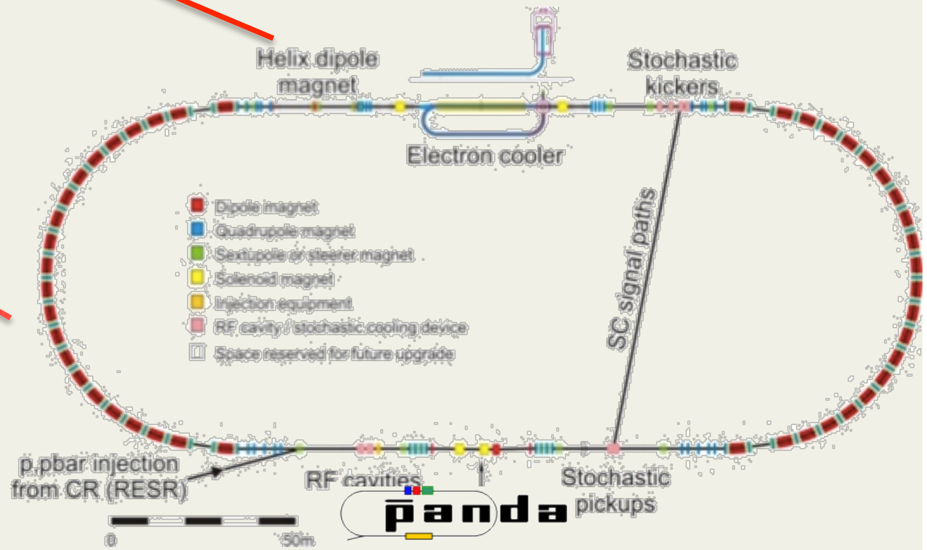
- *Study the underlying **dynamics of production and decay.***



Facility for Antiproton and Ion Research

Antiproton production

- Proton Linac 70 MeV
- Accelerate p in SIS18 / 100
- Produce $\bar{p}$ on Cu target
- Collection in CR, fast cooling
- Accumulation in RESR
- Storage and usage in HESR

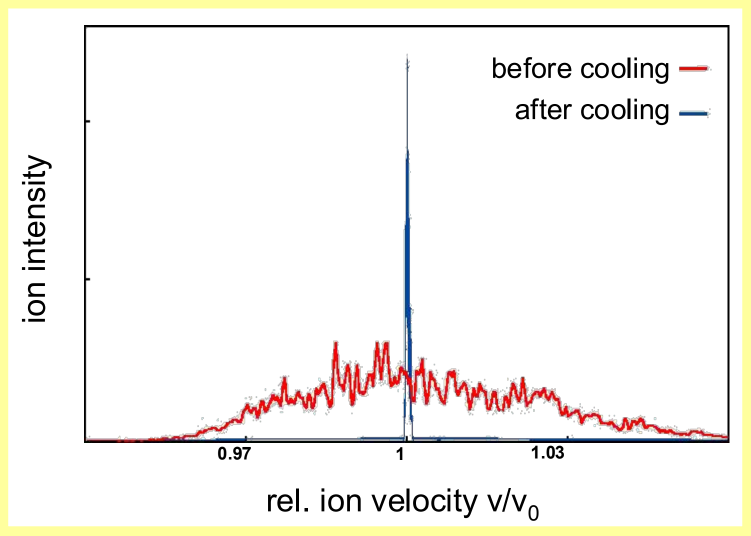


HESR: Storage ring for $\bar{p}$

- Injection of $\bar{p}$ at 3.7 GeV/*c*
- Slow synchrotron (1.5-15 GeV/*c*)
- Luminosity up to L~ 2×10^{32} $cm^{-2}s^{-1}$
- Beam cooling (stochastic & electron)

Antiproton power

$\bar{p}$-beams can be cooled → Excellent resonance resolution



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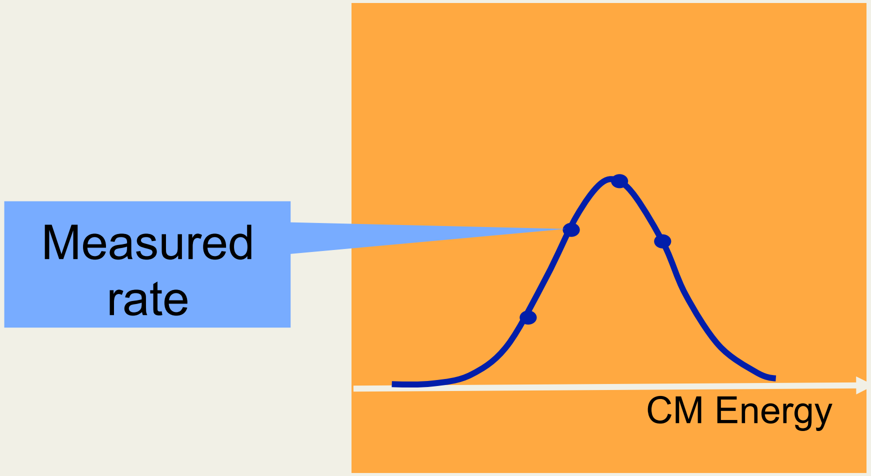

The production rate of a certain final state ν

Antiproton power

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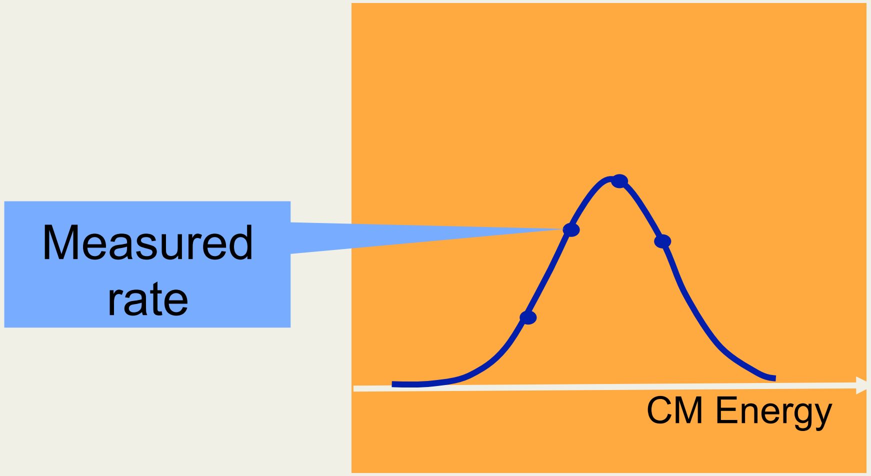

The production rate of a certain final state ν is a convolution of the

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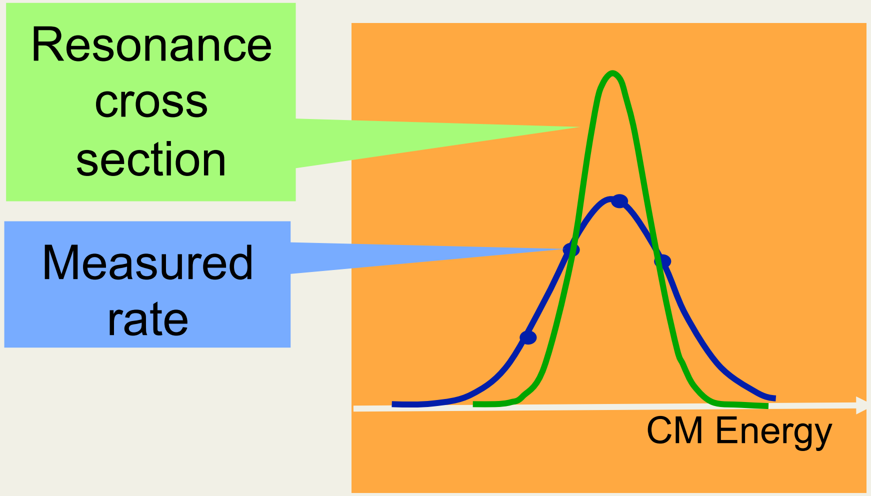

The production rate of a certain final state ν is a convolution of the BW cross section

Antiproton power

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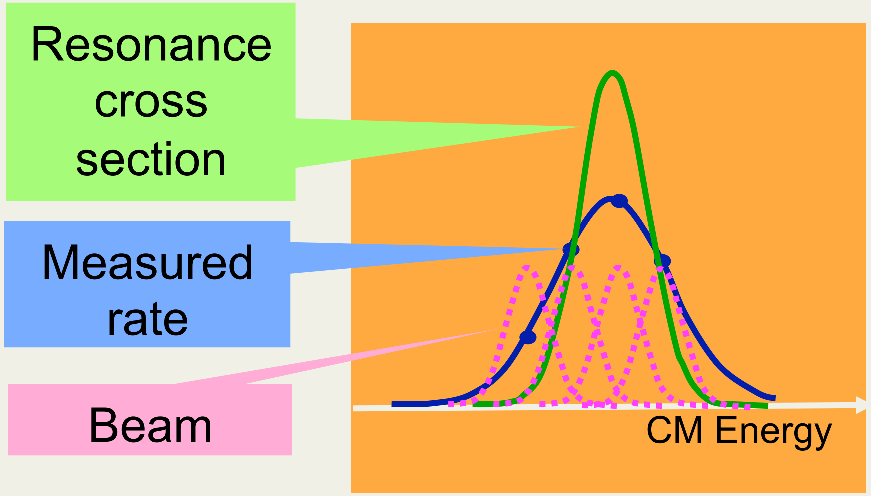

The production rate of a certain final state ν is a convolution of the BW cross section and the beam energy distribution function $f(E, \Delta E)$:

Antiproton power

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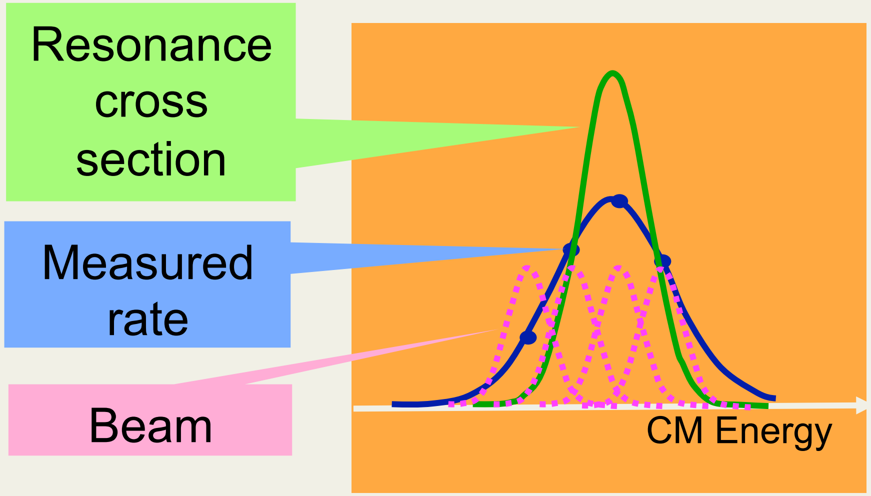
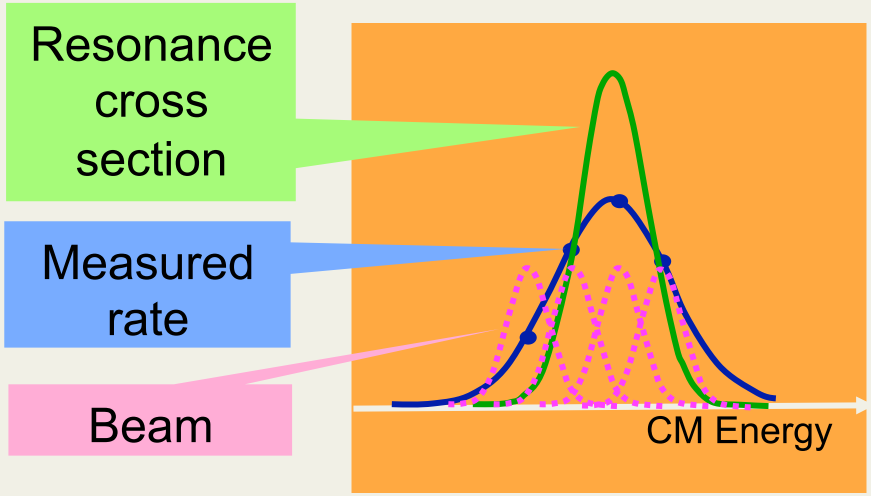


The production rate of a certain final state ν is a convolution of the BW cross section and the beam energy distribution function $f(E,\Delta E)$:

$$\nu = L_0 \left\{ \varepsilon \int dE f(E,\Delta E) \sigma_{BW}(E) + \sigma_b \right\}$$

Antiproton power



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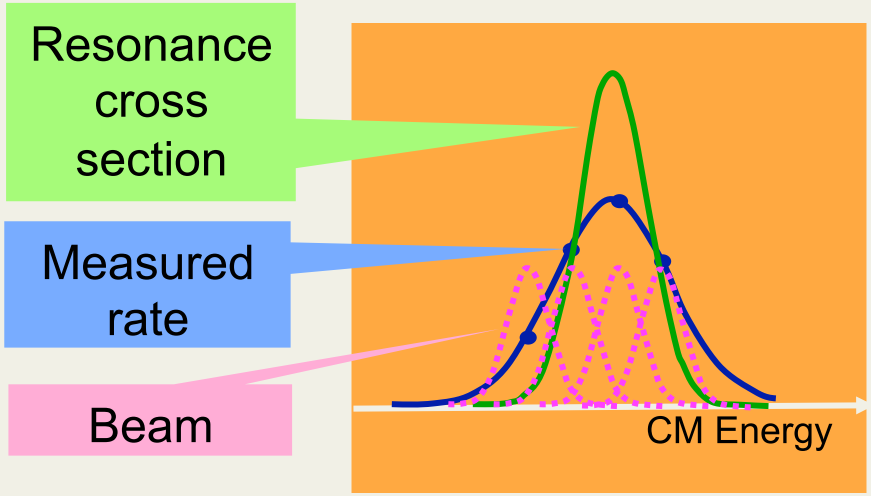
The resonance mass M_R, total width Γ_R and product of branching ratios into the initial and final state $B_{in}B_{out}$ can be extracted by measuring the formation rate for that resonance as a function of the cm energy E.

Antiproton power



- e^+e^-: typical mass res. ~ 10 MeV
- Fermilab: 240 keV
- HESR: ~50 keV

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- e^+e^- interactions:

- $p\bar{p}$ reactions:

Antiproton power

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  - Only 1^{--} states are formed
  - Other states only by secondary decays (moderate mass resolution related to the detector 5÷10 MeV)

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  - Most states directly formed (very good mass resolution; $\bar{p}$-beam can be efficiently cooled $\Delta p/p \sim 10^{-5}$)

Antiproton power

$e^+e^- \to \psi(2S)$
$\to \gamma\chi_{1,2}$
$\to \gamma\gamma J/\psi$
$\to \gamma\gamma e^+e^-$

$\bar{p}\,p \to \chi_{1,2}$
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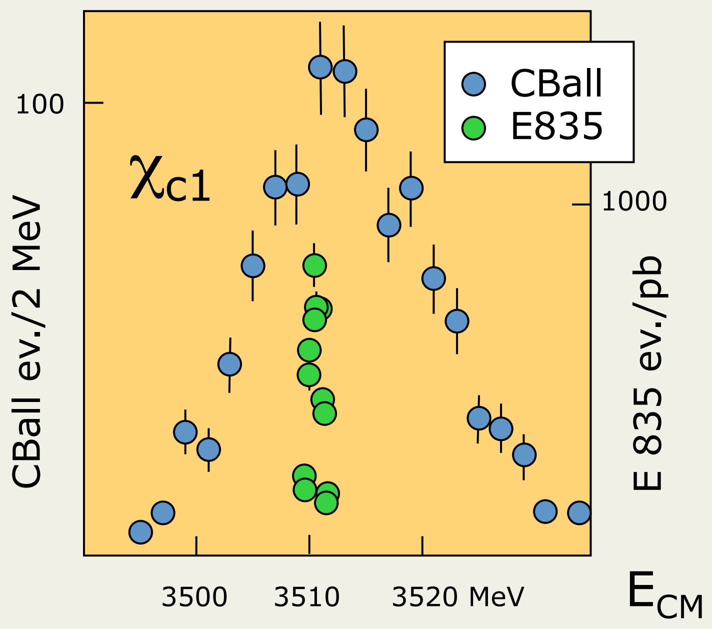

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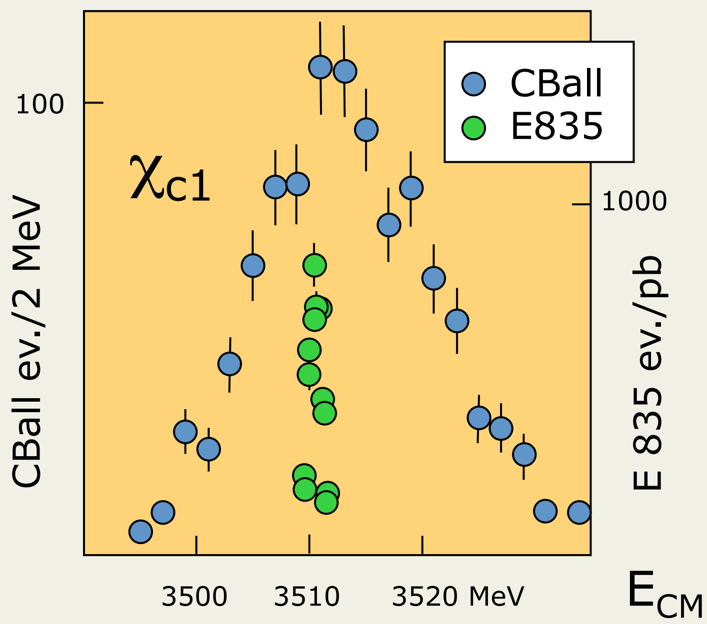
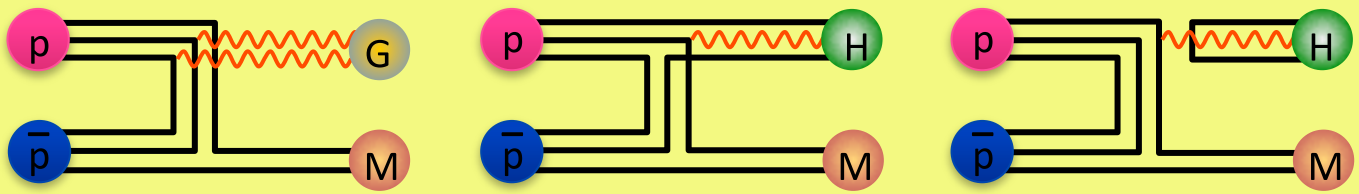


$Br(\bar{p}p \to \eta_c) = 1.2\ 10^{-3}$

$Br(e^+e^- \to \psi') \cdot Br(\psi' \to \gamma\eta_c) = 2.5\ 10^{-5}$

Spectroscopy with antiprotons

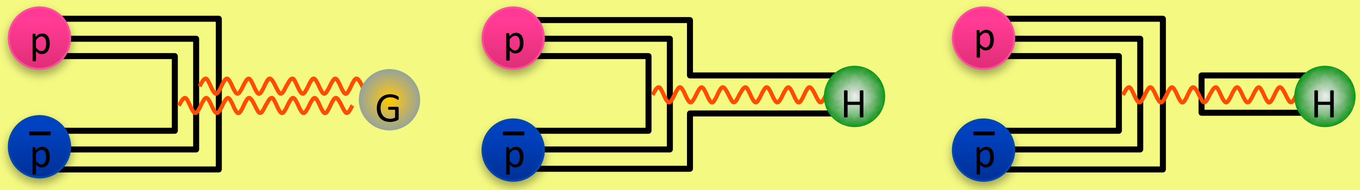
Two are the mechanisms to access particular final states:



Even exotic quantum numbers can be reached σ ~100 pb

We can play with the two different mechanisms to determine quantum numbers

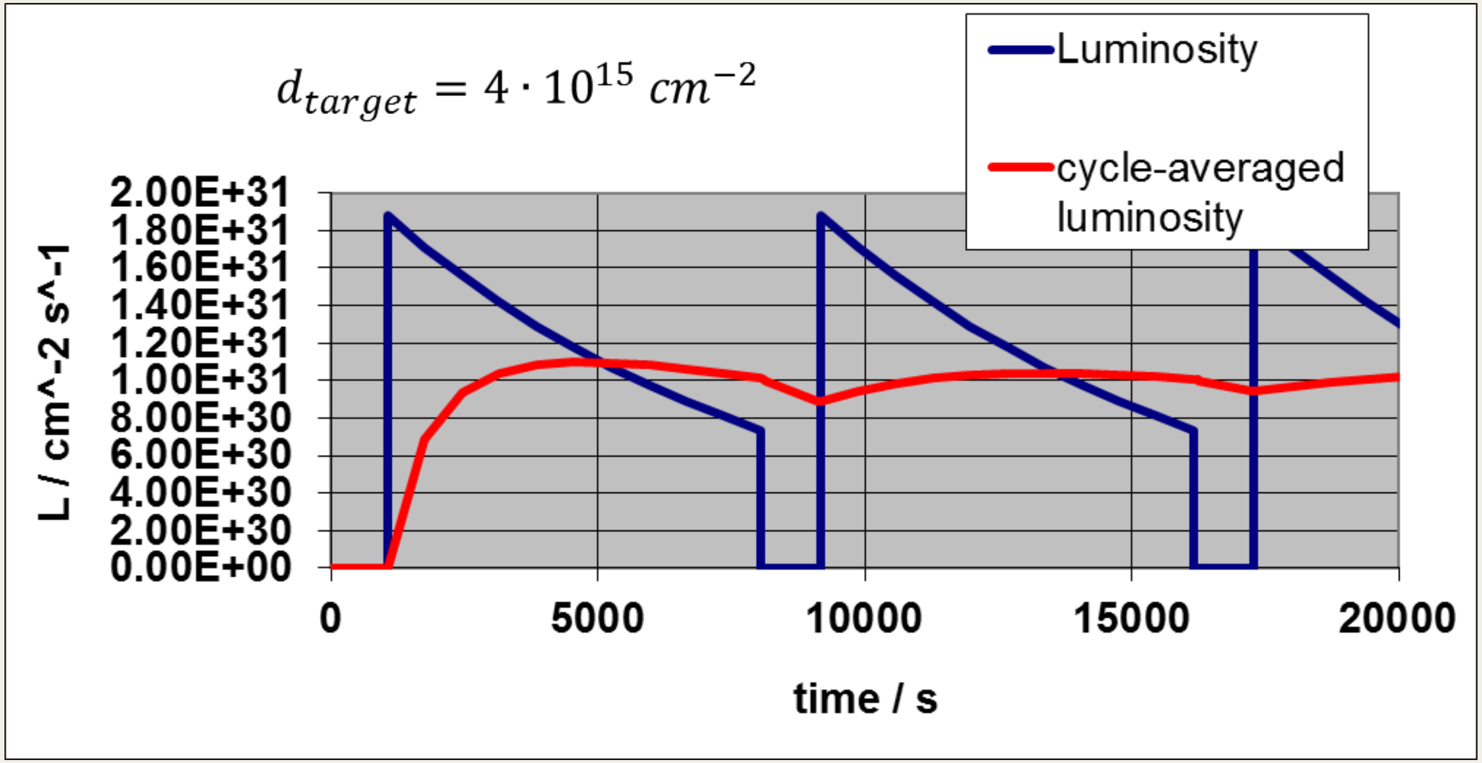
All ordinary quantum numbers can be reached σ ~1 μb



P

HESR in the MSV

- The intensity in the HESR in the MSV is limited to 10^{10} p-bars due to the cooling and injection efficiencies (RESR will not be present and is work will be done in the HESR).
- This means for PANDA:
  1. Less intensity (only high resolution mode)
  2. Worse duty cycle due to 20 minutes accumulation time



The low energy range

In the last 20 years many steps forward in the field were possible thanks to the variety of facilities available all over the world.

Main non-$q\bar{q}$ candidates	
$f_0(980)$	4q state - molecule
$f_0(1500)$	0^{++} glueball candidate
$f_0(1370)$	0^{++} glueball candidate
$f_0(1710)$	0^{++} glueball candidate
$\eta(1410)$; $\eta(1460)$	0^{-+} glueball candidate
$f_1(1420)$	hybrid, 4q state
$\pi_1(1400)$	hybrid candidate 1^{-+}
$\pi_1(1600)$	hybrid candidate 1^{-+}
π (1800)	hybrid candidate 0^{-+}
$\pi_2(1900)$	hybrid candidate 2^{-+}
$\pi_1(2000)$	hybrid candidate 1^{-+}
$a_2'(2100)$	hybrid candidate 1^{++}
$\phi(2170)$	hybrid/tetraquark candidate 1^{--}

Nowadays confirmation of predictions, together with unexpected results, are still coming out mainly from $e^+ e^-$ collider.

$Y_S(2175)$

The Y_S [X](2175) [or ϕ(2170) on PDG] was first observed by BABAR in the process $e^+e^- \to \phi(1020) f_0(980)$ and identified as a 1^{--} state, M = (2.175±0.010±0.015) GeV, Γ = (58±16±20) MeV. Then was confirmed by BES in the decay $J/\Psi \to \eta\phi f_0(980)$ with M = (2.186±0.010±0.006) GeV and Γ = (65±25±17) MeV.

We performed a preliminary study for this channel looking to the following reaction: $\bar{p}p \to Y_S(2175) + X$ with X being a π^0 or $\pi^+\pi^-$

$$Y_S(2175) \to \phi\pi^+\pi^-, \phi\pi^0\pi^0$$

assuming different hypotheses for the signal cross-section and the decay B.R.

This is an example of "meson production" where for which we can investigate different decay channels.

Light meson spectroscopy

Assuming cross sections of about 10 nb for glueball/hybrid candidates important topics of the PANDA light hadron spectroscopy program can be addressed:

- with an integrated luminosity of about 2 pb^{-1} /channel;
- for new resonances, which do not require a Partial Wave Analysis, results can be obtained with data samples of 0.1 pb^{-1}.

Two data samples of 2 pb^{-1} recorded in the low and high energy region, will allow to start first spin-parity analyses for spectroscopy.
These corresponds to 5 days with a Luminosity of 10^{31} cm^{-2} s^{-1} that is foreseen for the PANDA Day-1.

Exotic hadrons

The identification of exotic states is an important key to understand hadron spectrum and the process of mass generation.

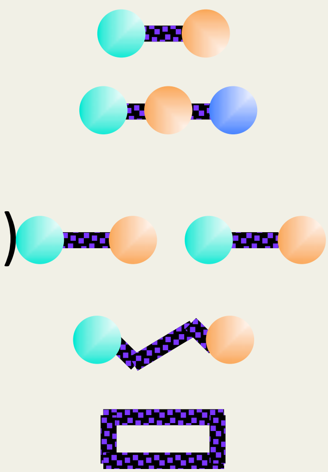
Mesons $q\bar{q}$

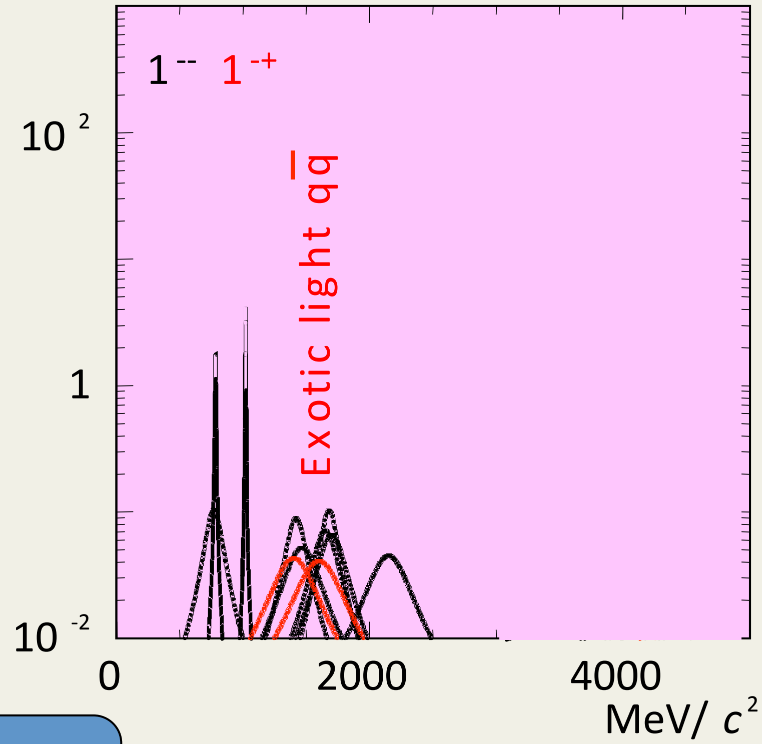
Baryons qqq

Multiquarks $(q\bar{q})(q\bar{q})$

Hybrids $(q\bar{q})\ g$

Glueballs gg





In the light meson energy range exotic states overlap with conventional states

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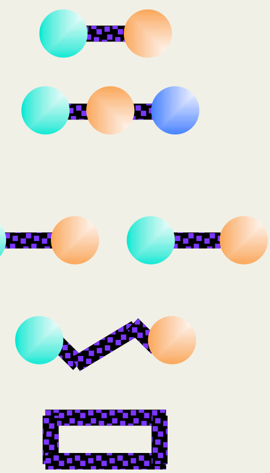
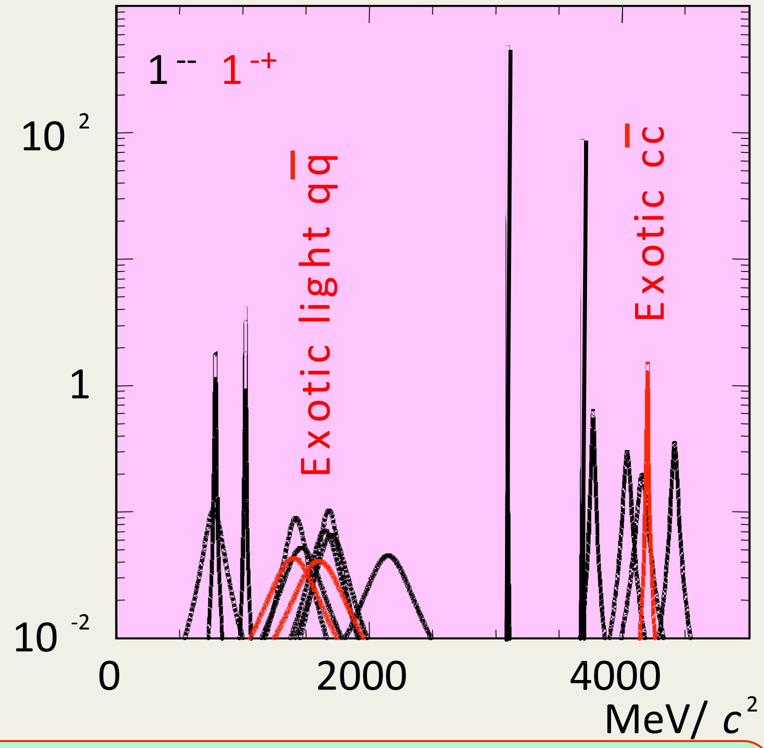
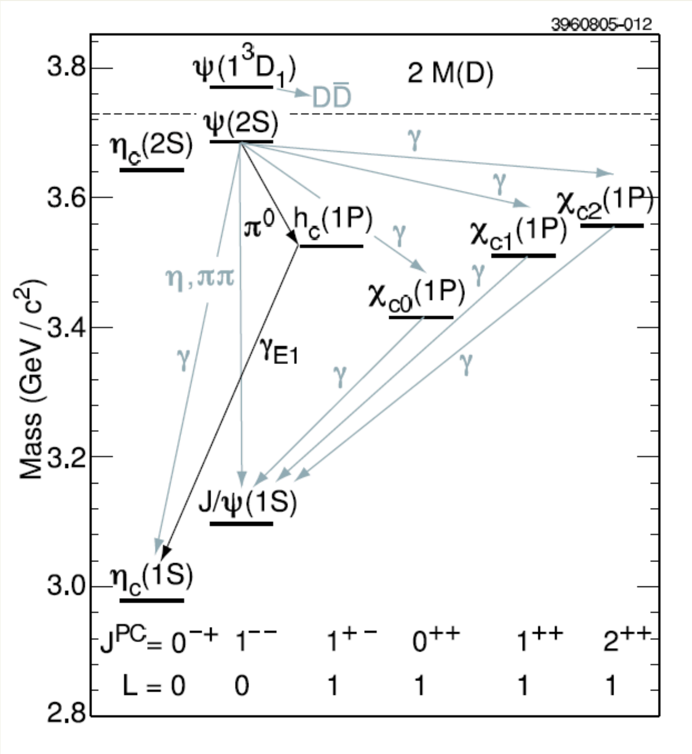




In the charmonium energy region the density of states is lower and also the overlap

Charmonium states

Charmonium states are under study since many years since this is the energy range where potential models are tuned.



Hyperfine splitting of charmonium states give access to V_{SS} component of quark potential model

The only measured hyperfine splitting was

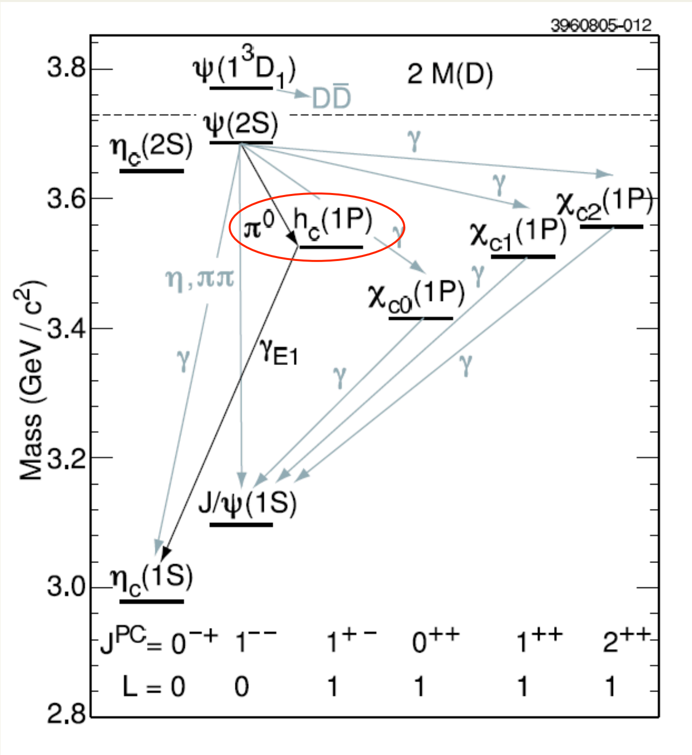
$$\Delta M_{hf}(1S)_{c\bar{c}} \equiv M(J/\psi) - M(\eta_c) = 116.6 \pm 1.0 \text{ MeV}$$

Recently $\eta'_C(2^1S_0)$ has been identified by Belle [PRL89(2002)102001] and the mass measured also by CLEO and BaBar in two photon fusion.

$$\Delta M_{hf}(2S)_{c\bar{c}} \equiv M(\psi'(2^3S_1)) - M(\eta'_c(2^1S_0)) = 49 \pm 4 \text{ MeV}$$

$h_C(^1P_1)$ charmonium state

The process $\psi' \rightarrow \pi^0 h_c$ is the only way to produce h_c from ψ' decay ➔ Limited phase space



From the assumption of a small V_{SS} interaction it was expected

$$\Delta M_{hf}(1P) \equiv M(^3P) - M(^1P) = 0$$

Theoretical predictions of branching ratios:

$B(\psi(2S) \rightarrow \pi^0 h_c) = (0.4\text{-}1.3) \times 10^{-3}$

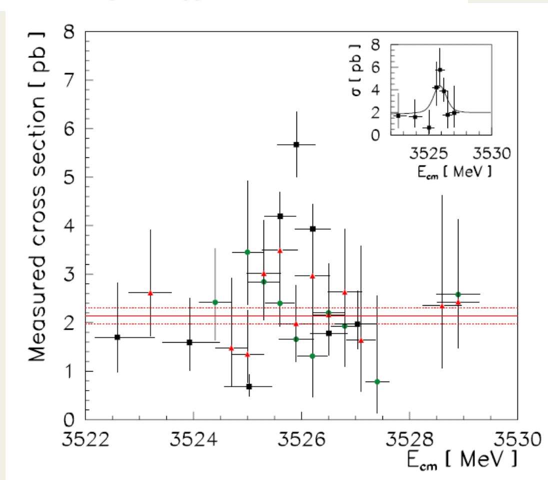
$B(h_c \rightarrow \gamma\eta_c) = 41\%$ (NRQCD)

$B(h_c \rightarrow \gamma\eta_c) = 88\%$ (PQCD)

(Y.P.Kuang, PRD65,094024 (2002))

$B(h_c \rightarrow \gamma\eta_c) = 38\%$

(S. Godfrey and J.Rosner,PRD66,014012(2002))



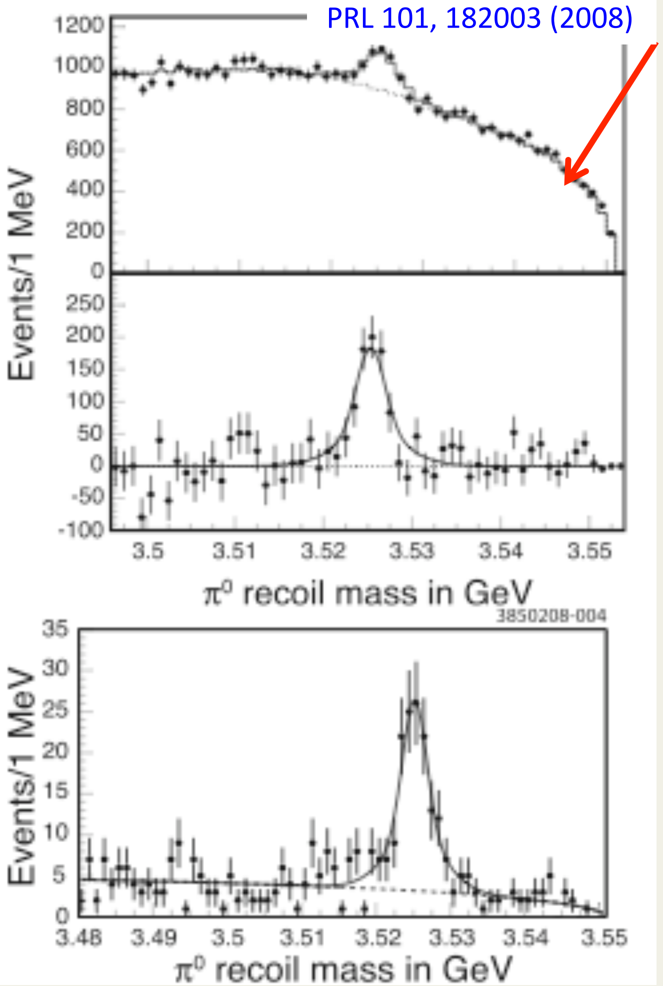
There were attempt to produce h_c in $p\bar{p}$ annhilitation at Fermilab (E760,E835) but the statistic was very poor.

$h_C(^1P_1)$ charmonium state

$$e^+e^- \to \psi' \to \pi^0 h_c \to (\gamma\gamma)(\gamma\eta_c)$$

The ψ' decay mode is isospin violating

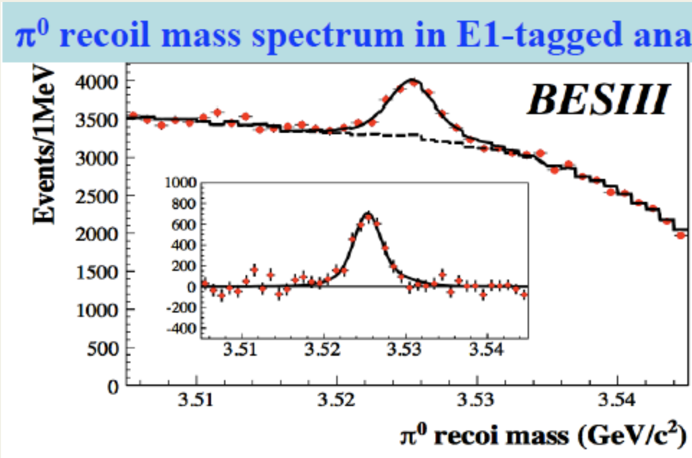
PRL 101, 182003 (2008)



The CLEO experiment was able to find it with a significance of 13 σ in ψ' decay by means of an exclusive analysis.

The width and the BF $\psi' \to \pi^0 h_c$ were not measured.

A similar analysis, with higher statistic, was also done by BES



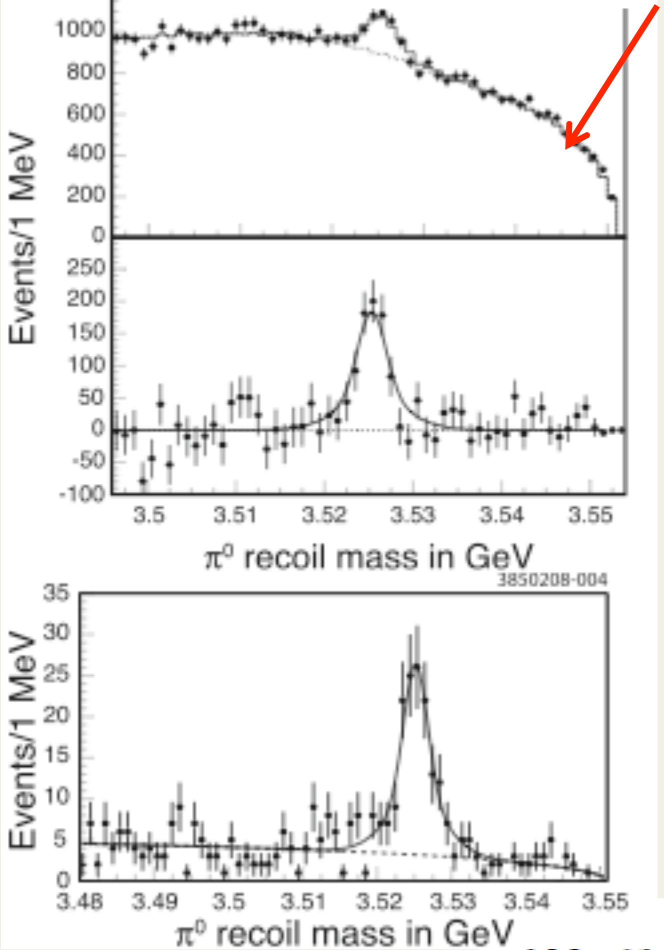
$M(h_C) = 3525.40 \pm 0.13$ MeV/c^2
$\Gamma(h_C) = 0.73 \pm 0.45$ MeV/c^2

$Br(\psi' \to \pi^0 h_c)$	$(8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$
$Br(h_c \to \gamma\eta_c)$	$(54.3 \pm 6.7 \pm 5.2)\%$

$h_C(^1P_1)$ charmonium state

$e^+e^- \rightarrow \psi' \rightarrow \pi^0 h_c \rightarrow (\gamma\gamma)(\gamma\eta_c)$ The ψ' decay mode is isospin violating

PRL 101, 182003 (208)



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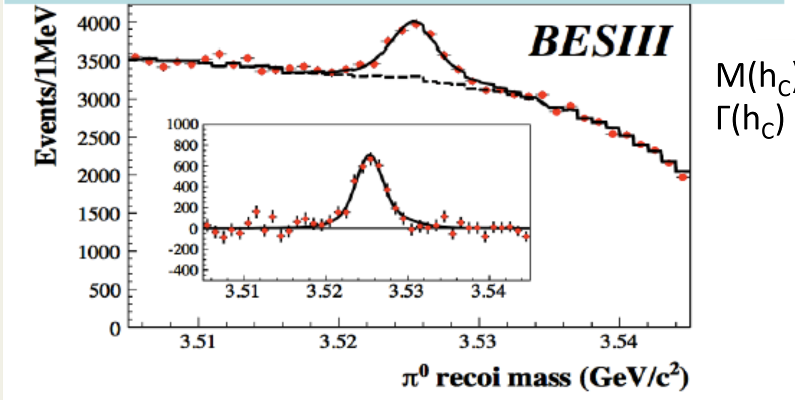
π^0 recoil mass spectrum in E1-tagged analysis



$M(h_C) = 3525.40 \pm 0.13$ MeV/c^2
$\Gamma(h_C) = 0.73 \pm 0.45$ MeV/c^2

$Br(\psi' \rightarrow \pi^0 h_c)$	$(8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$
$Br(h_c \rightarrow \gamma\eta_c)$	$(54.3 \pm 6.7 \pm 5.2)\%$

$$\Delta M_{hf}(1P) \equiv M(^3P) - M(^1P) = -0.10 \pm 0.13 \pm 0.18\,\mathrm{MeV}/c^2$$

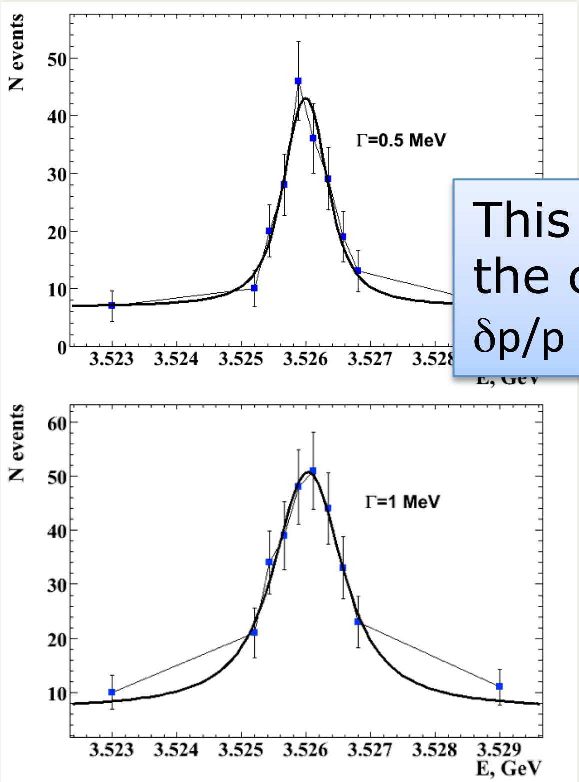
Center of gravity of P-states

Charmonium states width

Thanks to the precise HESR momentum definition, widths of known states can be precisely measured with an energy scan.

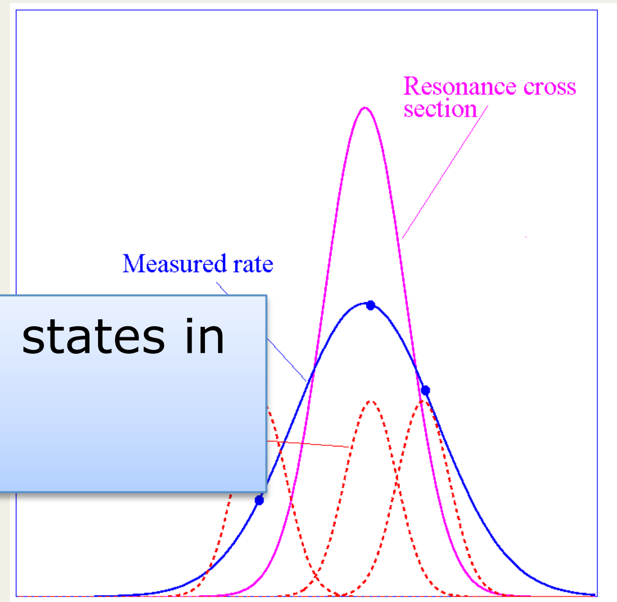
Energy scan of 10 values around the h_c mass; each point represents a 5 day data taking in high luminosity mode, for the channel: $h_c \longrightarrow \eta_c\gamma \longrightarrow \phi\phi\gamma \longrightarrow 4K\gamma$ with a S/B 8:1.

Cross section $\sigma_{\bar{p}p \to h_c \to \eta_c + \gamma} = 40nb$



This holds for all known states in the charmonium region

$\delta p/p \; 2\times10^{-5} \longrightarrow \Gamma$ 50 KeV



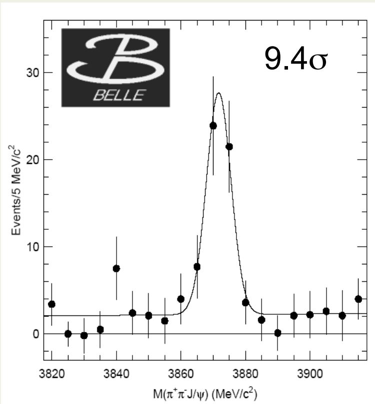
Sensitivity

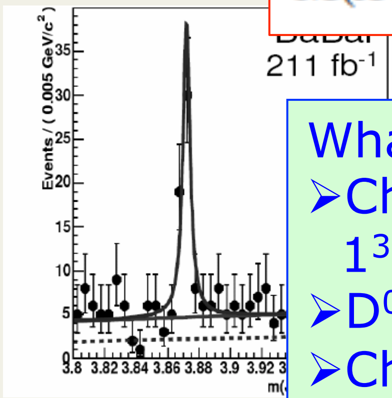
$\Gamma_{R,MC}$[MeV]	$\Gamma_{R,reco}$[MeV]	$\Delta\Gamma_R$[MeV]
1	0.92	0.24
0.75	0.72	0.18
0.5	0.52	0.14

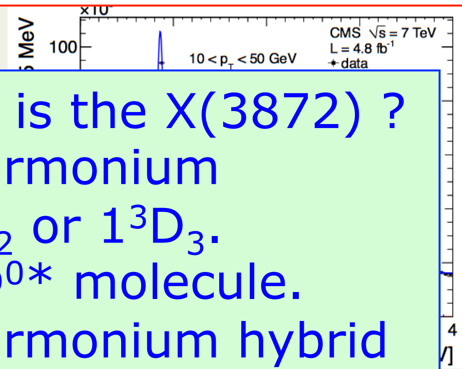
X(3872)

Discovered in 2003 by Belle (+ CDF, D0, BaBar, LHC …) in $B^+ \to X K^+$ $X \to J/\psi\pi^+\pi^-$ is the big brother of the new "charmonium like" states. The mass is currently known with < 1.0 MeV/c^2 precision. For the width we have only an upper limit.

$$M(X(3872)) = 3871.95 \pm 0.48(\text{stat}) \pm 0.12(\text{syst})\ \text{MeV}/c^2$$







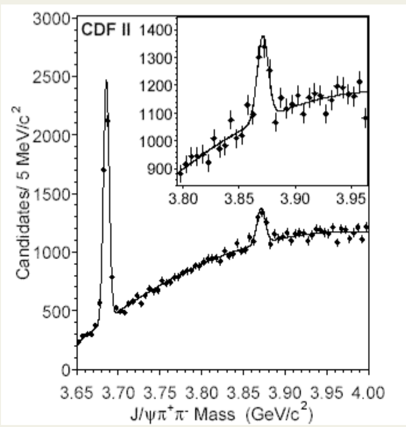
What is the X(3872) ?

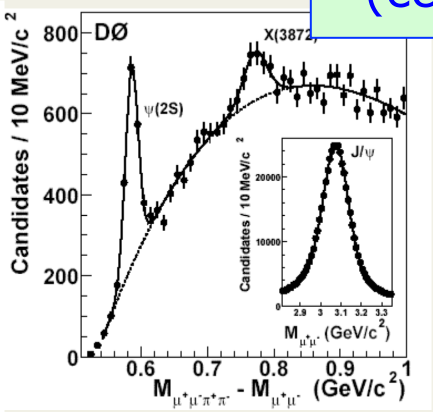
- Charmonium 1^3D_2 or 1^3D_3.
- D^0D^{0*} molecule.
- Charmonium hybrid ($c\bar{c}g$).

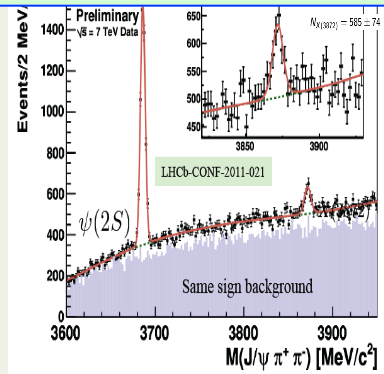
X(3872) has been observed in several decay channels $J/\psi\pi^+\pi^-$, D^*D^0, $\gamma J/\psi$, $\omega J/\psi$

Interpretations oscillate:

- charmonium state;
- D^*D^0 molecule;
- tetra-quark state.

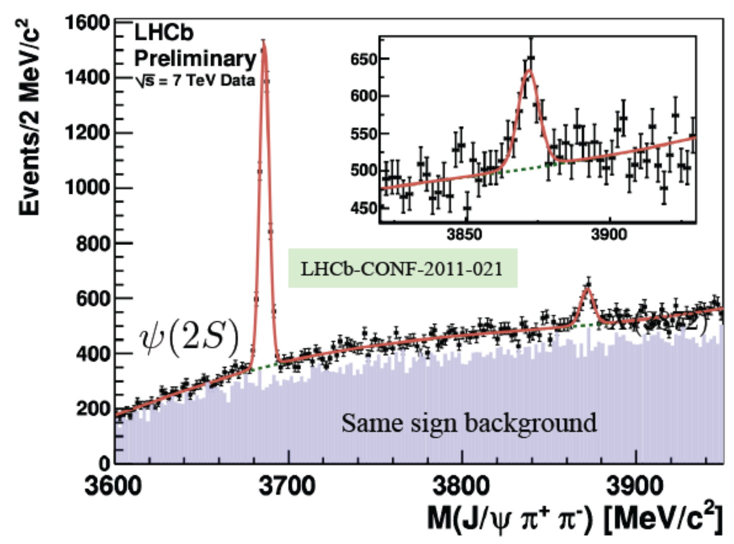






X(3872) lays 0.42 MeV below $D^{*0}\bar{D}^0$. Width is narrow < 1.2 MeV/c^2 @ 90% C.L.

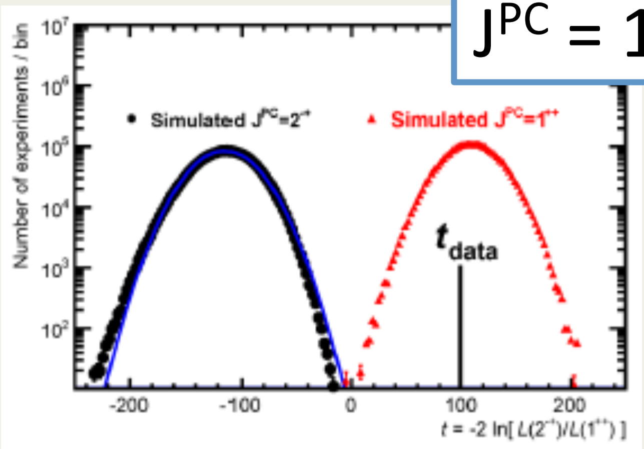
The X(3872) at LHCb



Recently LHCb using a sample of 313 ± 26 candidates performed a full five-dimensional amplitude analysis of the angular correlations between the decay products: $B^+ \to K^+X(3872)$; $X(3872) \to J/\Psi\, \pi^+\pi^-$, $J/\Psi \to \mu^+\mu^-$.

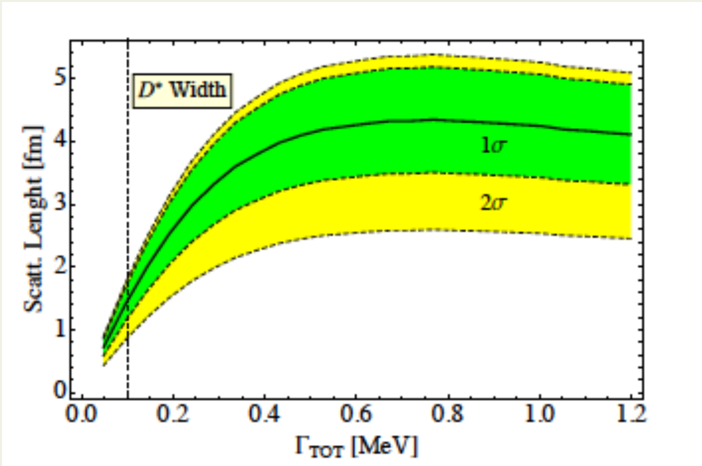
The result of the multidimensional likelihood-ratio test favors $J^{PC} = 1^{++}$ with more than 8σ significance.

$J^{PC} = 1^{++}$



This ruled out some interpretations. Nowadays, the most accredited ascriptions are a four-quark state ($c\bar{c}q\bar{q}$) or a $D^0\bar{D}^{0*}$ molecule.

Scattering length for the $D^0\bar{D}^{0*} \to X \to D^0\bar{D}^{0*}$ process as a function of the X total width.
[J.M.P. 4 (2013) 1569]



A precise knowledge of the state width will help in constraining these hypotheses.

X(3872) @ PANDA

Thanks to the precise HESR momentum definition, widths of known states can be precisely measured with an energy scan.

Martin Galuska
(Giessen)

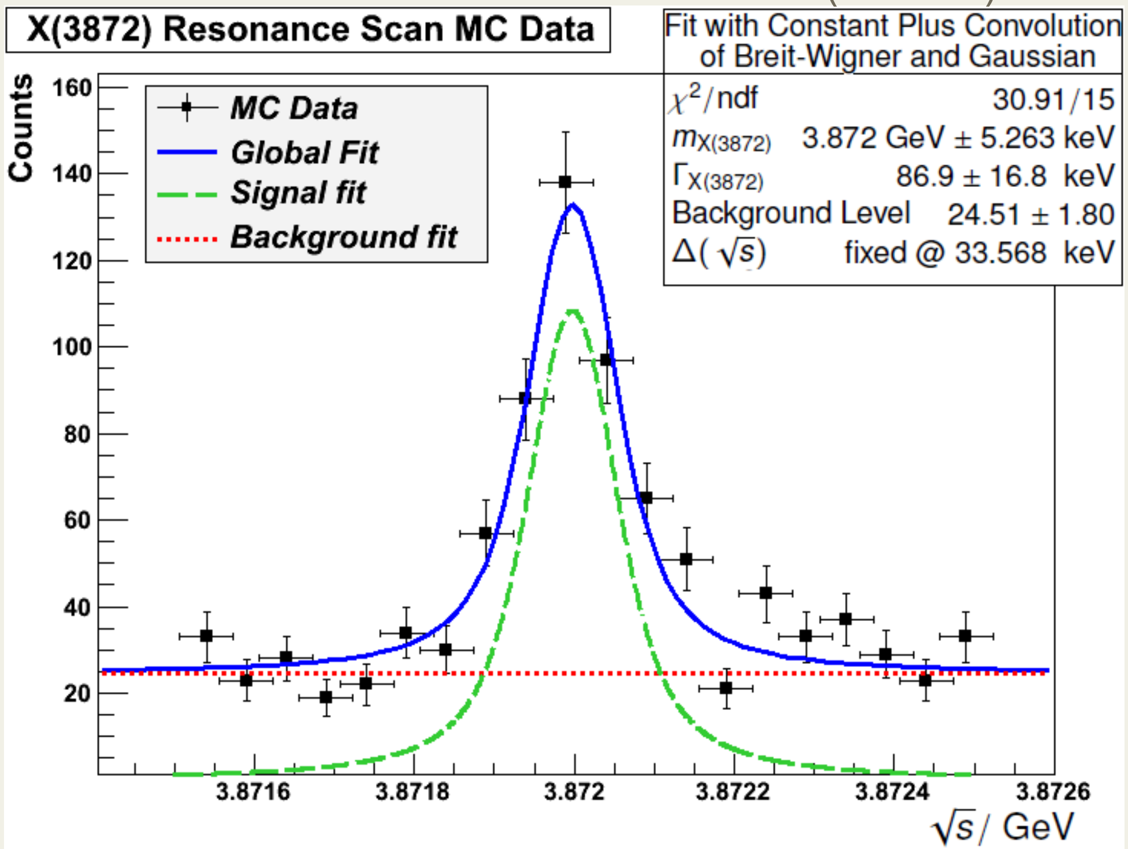
Input parameters:

m = 3.872 GeV/c^2

Γ = 1 MeV/c^2

$\bar{p}p \rightarrow X(3872)$ (σ_{BW}= 50 nb)

$\bar{p}p \rightarrow J/\psi\ \pi^+\pi^-$ (σ= 1.2 nb)



Mass resolution~ 5 keV/c^2

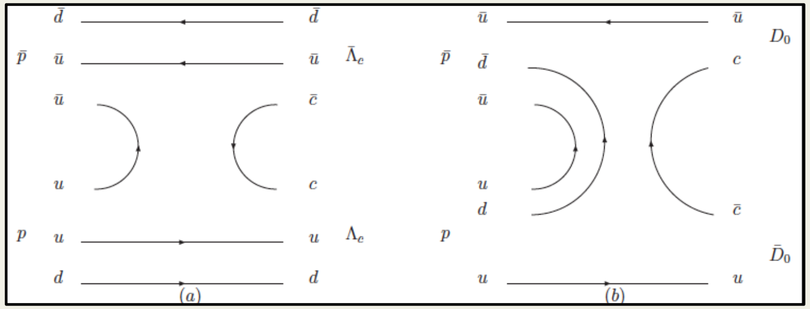
Width precision~ 10-20%

All narrow widths of the states in the charmonium energy range will be precisely determined.

OpenCharm states

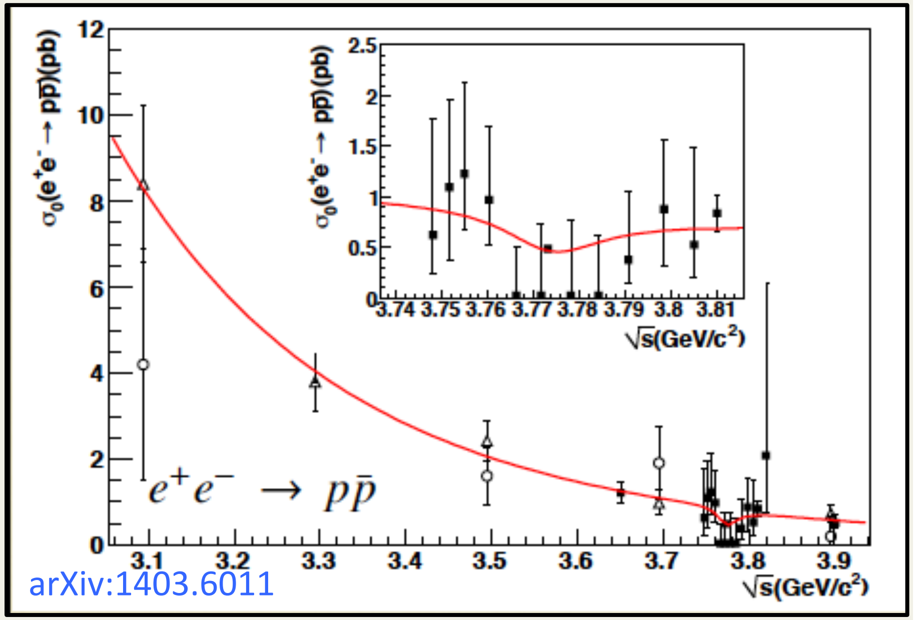
The study of charmed hadrons give access to interesting aspects of strong and weak interactions. Predicted cross sections vary from nano to micro barns

Interesting physics in production mechanisms.

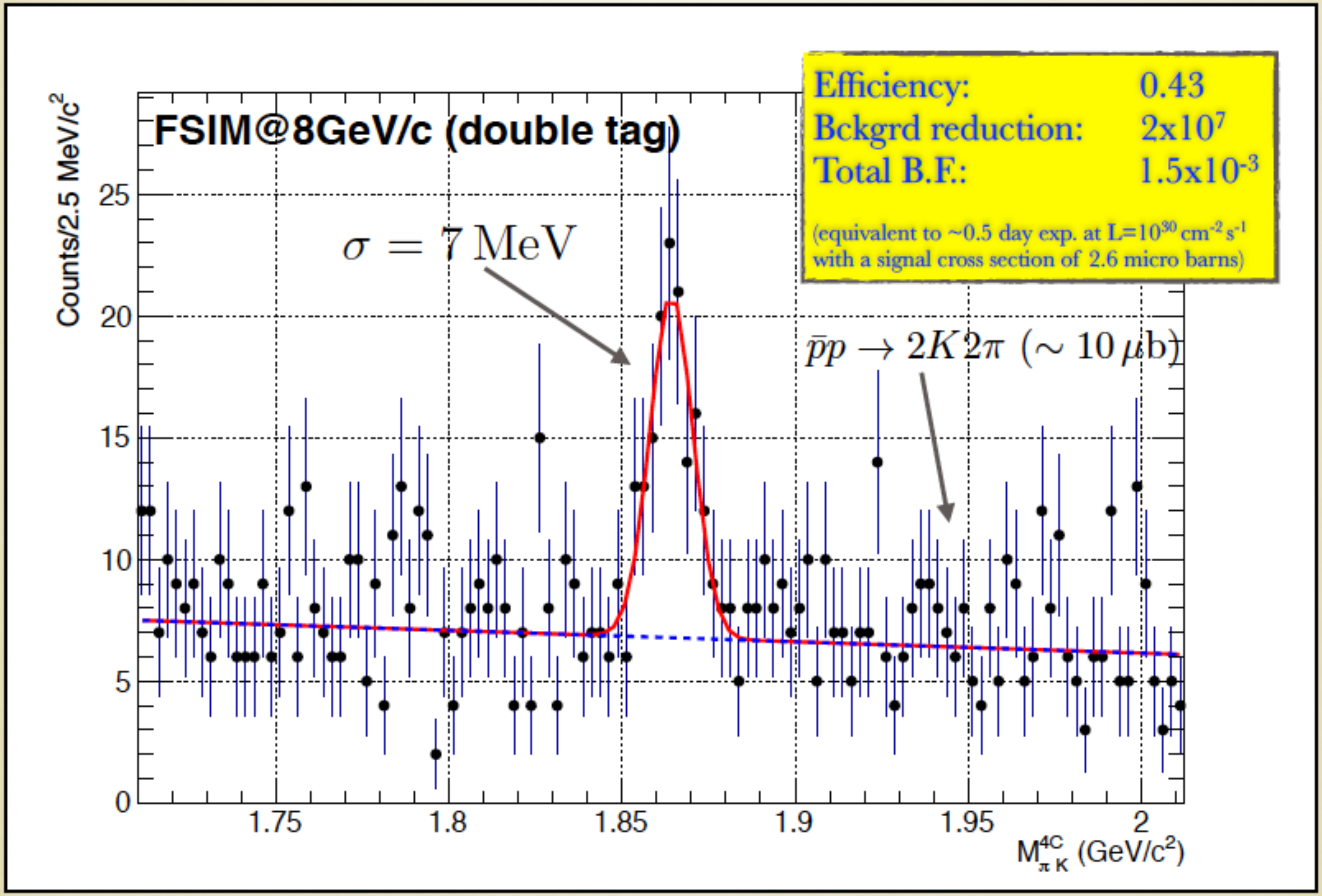


Two solutions for the cross section $\sigma(p\bar{p}) \rightarrow \psi(3770)$ are obtained:

- (9.8+11.8−3.9) nb, is compatible with a simple scaling from J/ψ
- (425.6+42.9−43.7) nb, is two order of magnitudes larger.

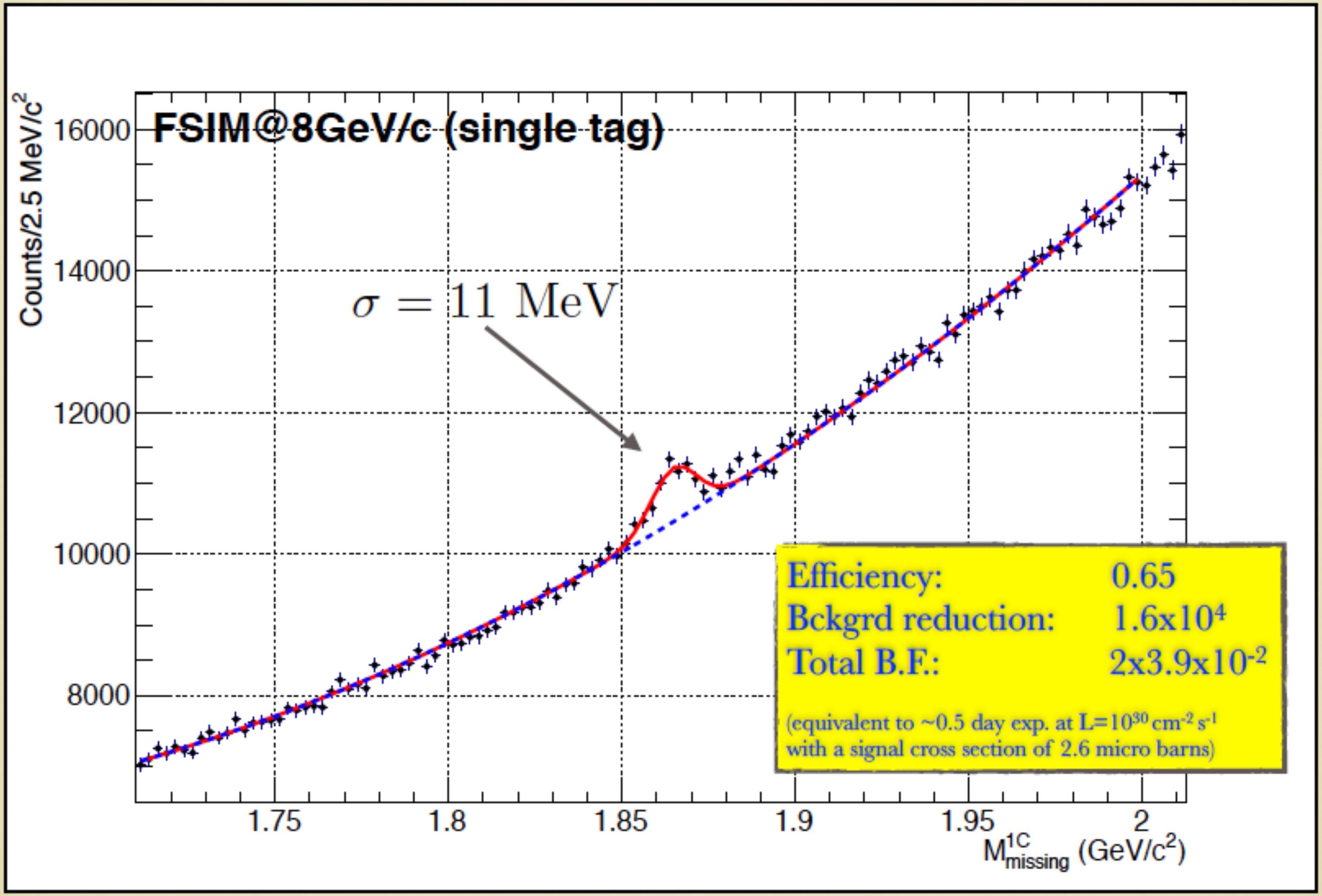


Exclusive: $p\bar{p} \to D^0\bar{D}^0 \to (K^-\pi^+)(K^+\pi^-)$ *Alexandros Apostolou, J.M. (KVI-CART)*



Only cuts on kinematics: 4C kin.fit, mass window on opposite Kpi pair

Inclusive: $p\bar{p} \to D^0 \bar{D}^0 \to (K\pi) + X$ *Alexandros Apostolou, J.M. (KVI-CART)*

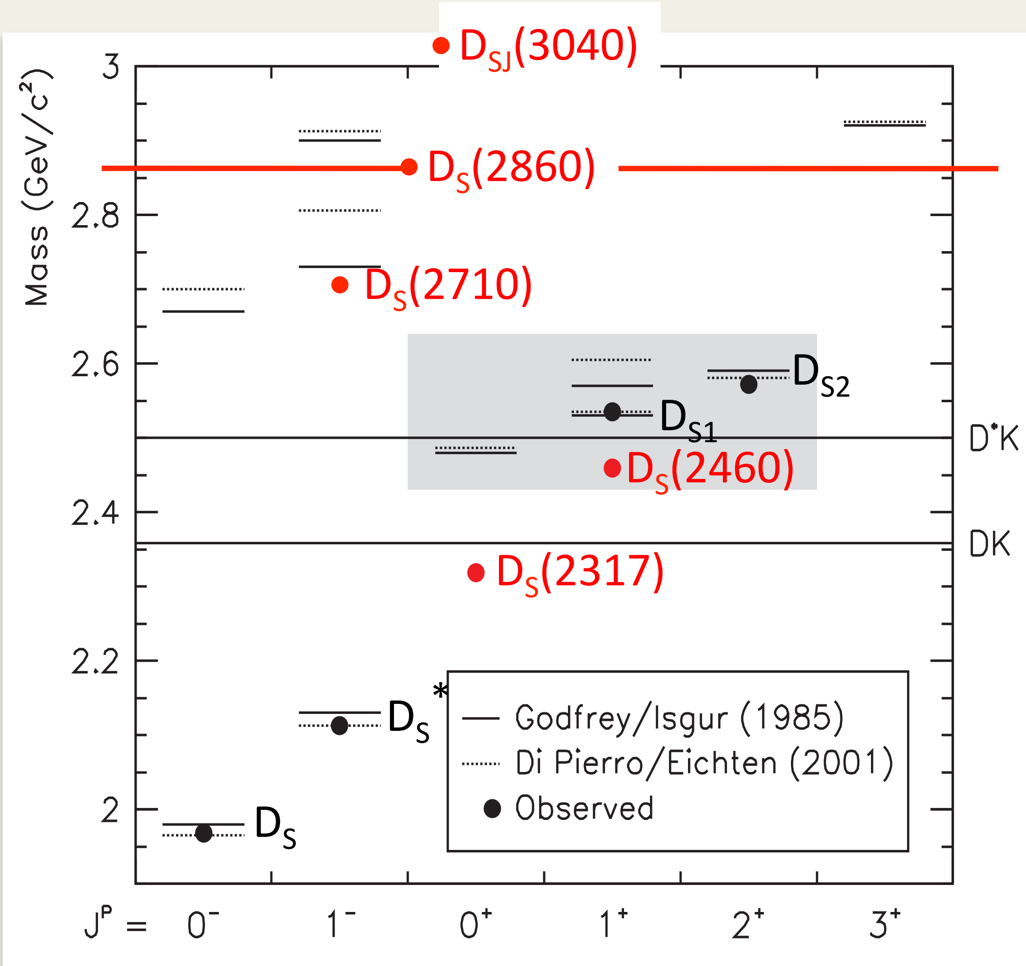


Only cuts on kinematics: 1C kin.fit, mass window on tagged Kpi pair

D_S states

For the states $c(\bar{u}/\bar{d})$ theory and experiment were in agreement, but the discovery of new D_{SJ} states has brought into question theoretical models.

The quantum numbers of $D_{s0}(2317)$ and $D_{s1}(2460)$ are not yet really established, and in order to answer important questions related to their interpretation, we need to measure their widths.



B. Aubert et al., PRD74, 032007 (2006).

PANDA opportunity D_s meson spectroscopy

D_{s0}*(2317) world average (PDG)
- *Mass: 2317.8 ± 0.6 MeV/c²*
- *Width: < 3.8 MeV/c²*

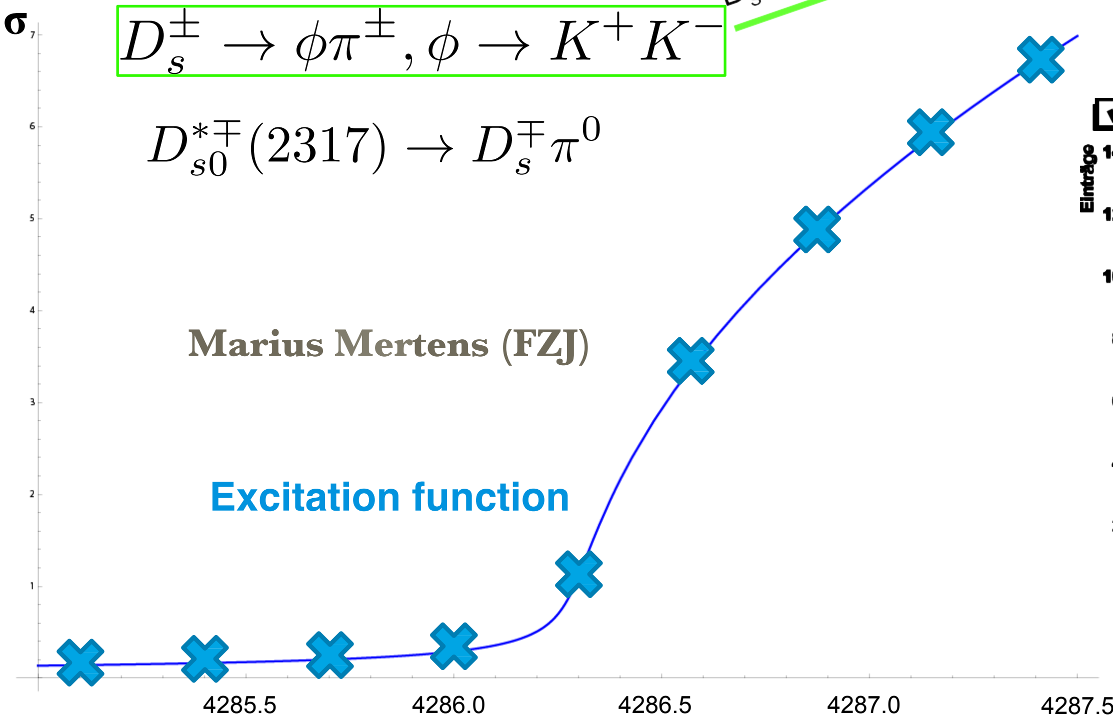
D_{s0}*(2317) Energy Scan

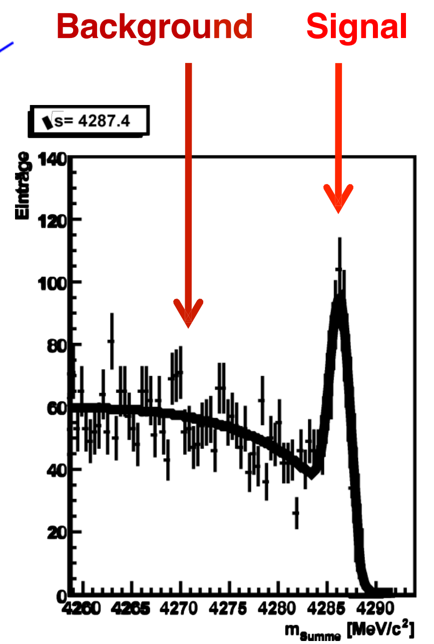
$$\bar{p}p \rightarrow D_s^{\pm} D_{s0}^{*\mp}(2317)$$

$$D_s^{\pm} \rightarrow \phi\pi^{\pm}, \phi \rightarrow K^+K^-$$

$$D_{s0}^{*\mp}(2317) \rightarrow D_s^{\mp}\pi^0$$

Inclusive reconstruction
D_s + missing mass

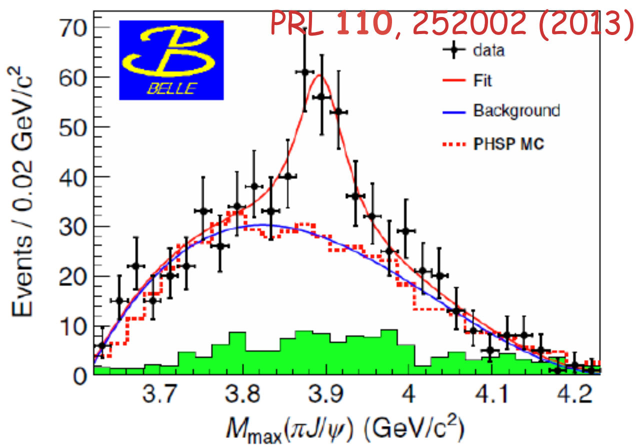


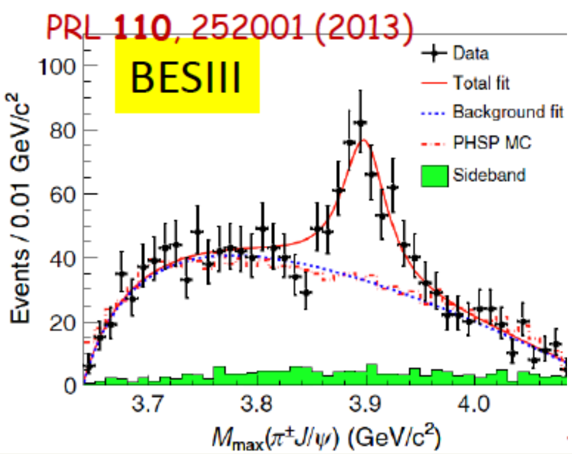


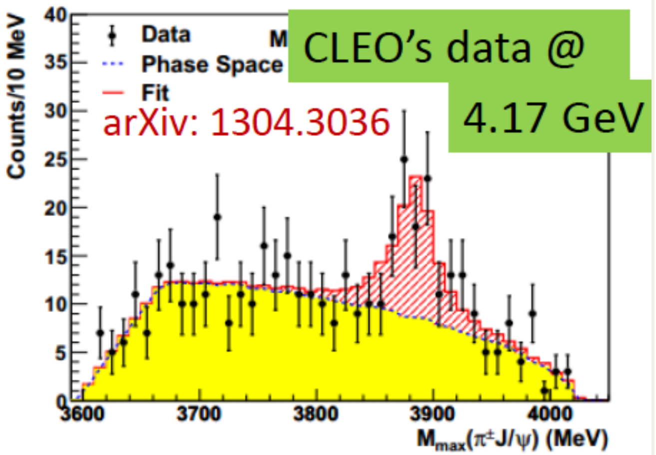
Charged multi-quark states

The first has been the Z(4430) observed in the invariant mass $\Psi'\pi^{\pm}$ by Belle, followed by other states in the bottomomium energy range. Recently, BESIII collaboration discovered an other charged charmonium-like axial meson $Z^{+}_{c} \rightarrow J/\Psi\pi^{\pm}$ (M= 3899±6 MeV, Γ = 46±22 MeV), confirmed by Belle and CLEO. The simplest quantum numbers assignment is $J^{PG} = 1^{++}$, G being the G-parity.

particle	decay	collaboration
$Z^{+}(4430)$	$\psi(2S)\ \pi^{+}$	Belle
$Z^{+}(4050)$ $Z^{+}(4250)$	$\chi_{c1}\ \ \pi^{+}$	Belle, unconfirmed
$Z_{c}^{+}(3900)$	$J/\psi\ \ \pi^{+}$	BESIII, Belle, CLEOc
$Z_{c}^{+}(4020)$	$h_{c}(1P)\ \pi^{+}$	BESIII preliminary
$Z_{c}^{+}(4025)$	$(\ D^{*}\ D^{*})^{+}$	BES III preliminary







Z± states @ P̄ANDA

P̄ANDA can study the Z± states in both production and formation experiments.

In the production experiment, the Z± would be produced, e.g., in the reaction

$$\bar{p}p \rightarrow Z^{\pm}\pi^{\mp}$$

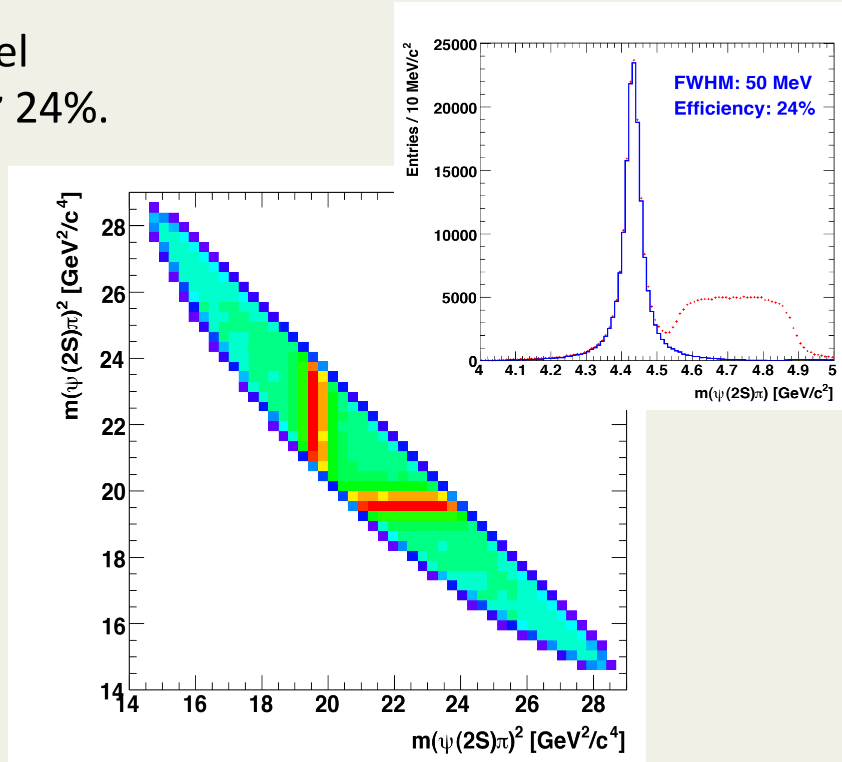
The subsequent decay chain could then be: $Z^{+}(4430) \rightarrow \psi(2S)\pi^{+} \rightarrow J/\psi\pi^{+}\pi^{-}\pi^{+} \rightarrow e^{+}e^{-}\pi^{+}\pi^{-}\pi^{+}$

The reconstruction efficiency for the $Z^{+}(4430)$ channel has been studied in Monte Carlo calculations and is ~ 24%.

In formation mode Z± states can be produced by using a deuterium target:

$$\bar{p}d \rightarrow Z^{-}p_{spectator}$$

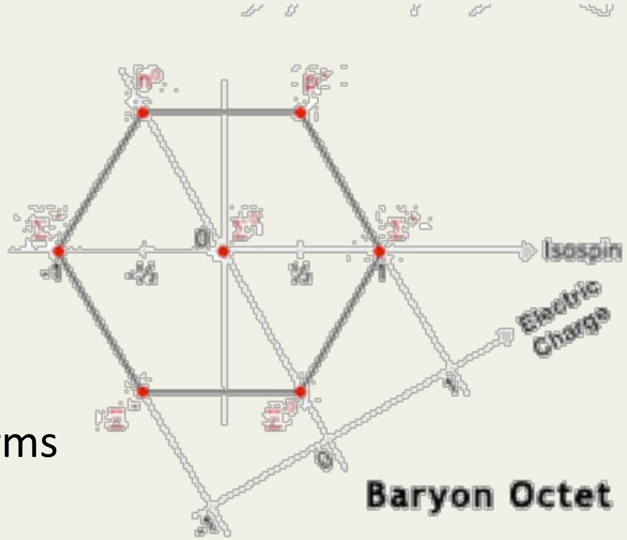
The reconstruction efficiency for this channel studied in Monte Carlo reactions is ~ 35%.

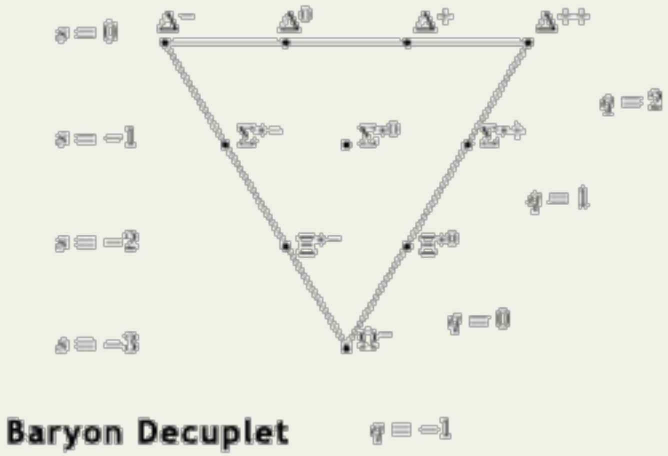


Baryon sector

The investigation of the baryon-baryon interactions is crucial for a deeper understanding of nuclei, structure of neutron matter and astrophysics aspects, etc...

Chiral effective field theories have tried since long time to describe baryon-baryon interaction and recently also lattice QCD calculations allowed to approach nuclear physics in terms of fundamental theory of the strong interaction.





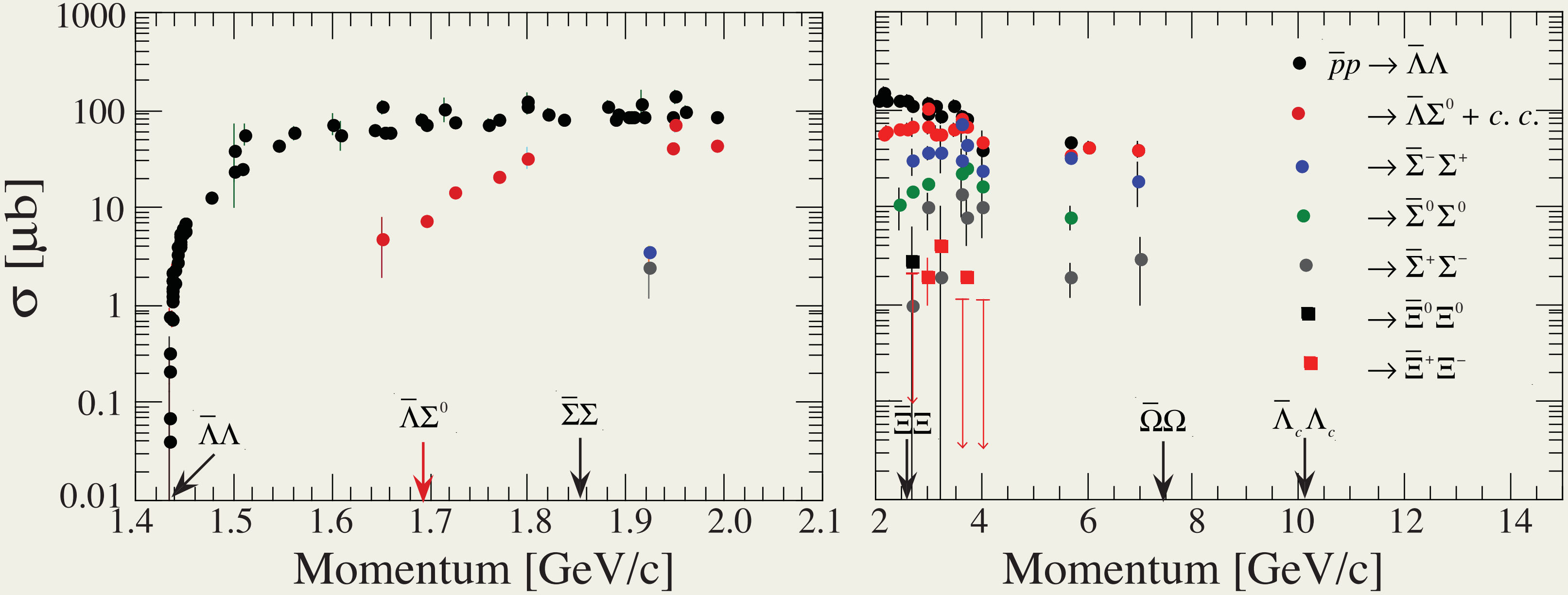
The experimental investigation of the nature of baryon bound states has gone in parallel with meson spectroscopy, nevertheless there are still many open problems and there is lack of high quality data.

Baryon Spectroscopy

In the quark picture hyperon pair production either involves the creation of a quark-antiquark pair or the knock out of such pairs out of the nucleon sea.

Hence, the importance of quark degrees of freedom with respect to the hadronic ones can be studied by measuring the reactions of the type

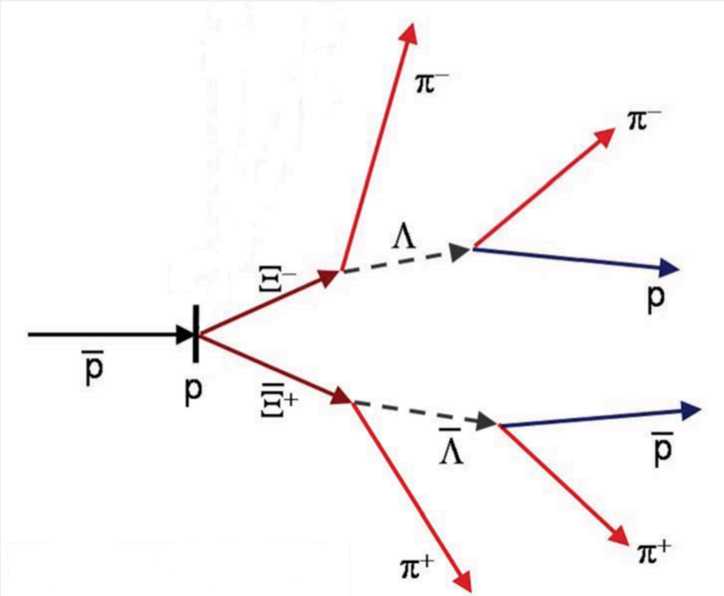
$$\bar{p}p \rightarrow \bar{Y}Y$$



QCD Dynamics

The experimental data set available is far from being complete. All strange hyperons and single charmed hyperons are energetically accessible in $\bar{p}p$ collisions at $\bar{P}$ANDA.

In $\bar{P}$ANDA $\bar{p}p \rightarrow \Lambda\bar{\Lambda}$, $\bar{\Lambda}\Xi$, $\Lambda\bar{\Xi}$, $\Xi\bar{\Xi}$, $\Sigma\bar{\Sigma}$, $\Omega\bar{\Omega}$, $\Lambda_c\bar{\Lambda}_c$, $\Sigma_c\bar{\Sigma}_c$, $\Omega_c\bar{\Omega}_c$
can be produced allowing the study of the dependences on spin observables.



Channel 1.64 GeV/c	Rec. eff.	σ [μb]	Signal
$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	0.11	64	1
$\bar{p}p \rightarrow \bar{p}p\pi^+\pi^-$	$1.2 \cdot 10^{-5}$	~ 10	$4.2 \cdot 10^{-5}$
Channel 4 GeV/c			
$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	0.23	~ 50	1
$\bar{p}p \rightarrow \bar{p}p\pi^+\pi^-$	$< 3 \cdot 10^{-6}$	$3.5 \cdot 10^3$	$< 2.2 \cdot 10^{-3}$
$\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$	$5.1 \cdot 10^{-4}$	~ 50	$2.2 \cdot 10^{-3}$
$\bar{p}p \rightarrow \bar{\Lambda}\Sigma(1385)$	$< 3 \cdot 10^{-6}$	~ 50	$< 1.3 \cdot 10^{-5}$
$\bar{p}p \rightarrow \bar{\Sigma}^0\Sigma^0$	$< 3 \cdot 10^{-6}$	~ 50	$< 1.3 \cdot 10^{-5}$
Channel 15 GeV/c			
$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	0.14	~ 10	1
$\bar{p}p \rightarrow \bar{p}p\pi^+\pi^-$	$< 1 \cdot 10^{-6}$	$1 \cdot 10^3$	$< 2 \cdot 10^{-3}$
$\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$	$2.3 \cdot 10^{-3}$	~ 10	$1.6 \cdot 10^{-2}$
$\bar{p}p \rightarrow \bar{\Lambda}\Sigma(1385)$	$3.3 \cdot 10^{-5}$	60	$1.4 \cdot 10^{-3}$
$\bar{p}p \rightarrow \bar{\Sigma}^0\Sigma^0$	$3.0 \cdot 10^{-4}$	~ 10	$2.1 \cdot 10^{-3}$
DPM	$< 1 \cdot 10^{-6}$	$5 \cdot 10^4$	$< .09$
Channel 4 GeV/c	Rec. eff.	σ (μb)	Signal
$\bar{p}p \rightarrow \bar{\Xi}^+\Xi^-$	0.19	~ 2	1
$\bar{p}p \rightarrow \bar{\Sigma}^+(1385)\Sigma^-(1385)$	$< 1 \cdot 10^{-6}$	~ 60	$< 2 \cdot 10^{-4}$

By comparing several reactions involving different quark flavors the OZI rule and its possible violation, can be tested.

UPPSALA UNIVERSITET

Baryon spectroscopy @ PANDA startup version

Assumptions: 10x lower luminosity
PANDARoot with idealised tracking

	$\bar{\Lambda}\Lambda$			$\bar{\Lambda}_c^+\Lambda_c^-$
1.64 GeV/c	$2\text{x}10^5$ h^{-1}			
4 GeV/c	$4\text{x}10^4$ h^{-1}	2500 h^{-1}		
15 GeV/c	$2\text{x}10^4$ h^{-1}	(≈ 1000 h^{-1})	(30 h^{-1})	((5 day^{-1}))

1. Single strangeness production: $\bar{p}p \to \bar{\Lambda}\Lambda$ **OK**
2. Double strangeness production: $\bar{p}p \to \bar{\Xi}\Xi$ **OK**
3. Triple charm production: $\bar{p}p \to \Omega^+\Omega^-$ **Probably OK**
4. Charm production $\bar{p}p \to \bar{\Lambda}_c^+\Lambda_c^-$ **Questionable**

$\bar{p}p \to \Lambda_c \bar{\Lambda}_c$ @ PANDA

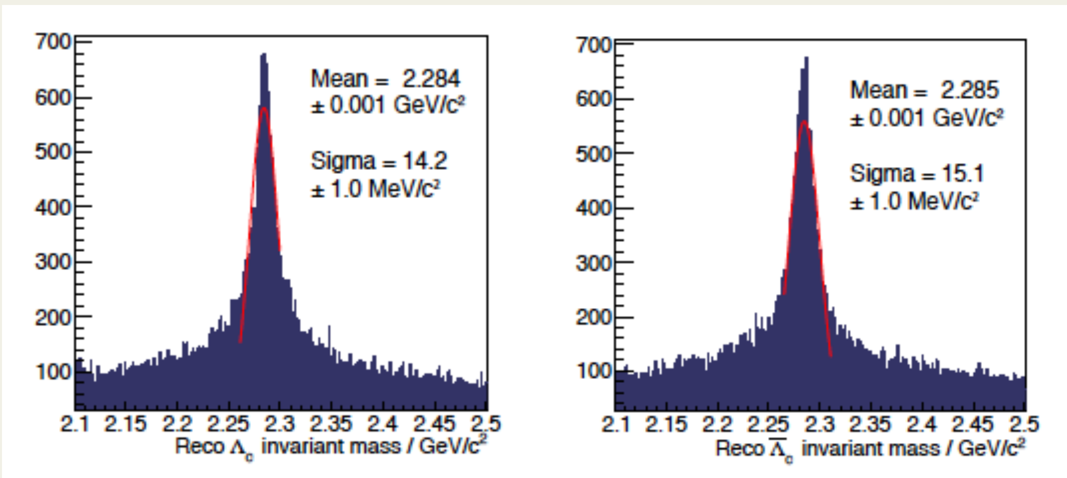
Different theoretical predictions estimated the $p\bar{p} \to \Lambda_c + \bar{\Lambda}_c$ cross section at the $\bar{\text{P}}$ANDA energies: the value ranges between some tens of nb to 200 nb.

We considered the following decay chain: $\bar{p}p \to \Lambda_c^+(2286)\bar{\Lambda}_c^-(2286)$

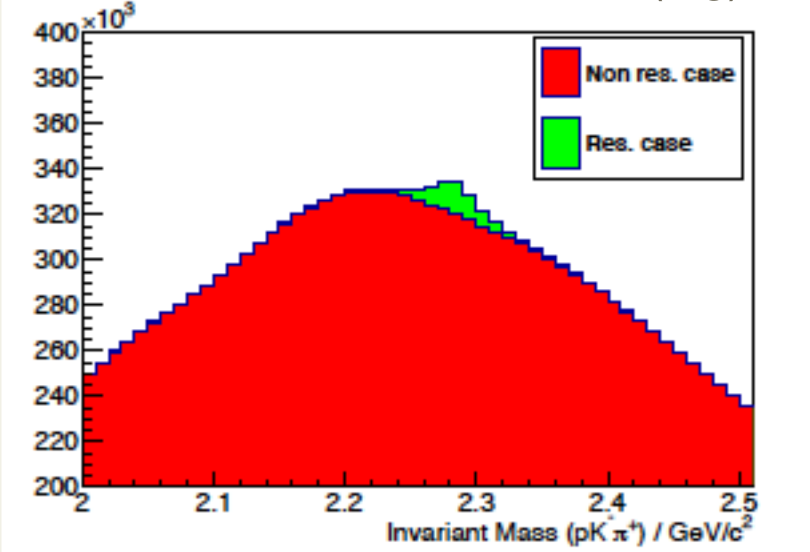
$$\hookrightarrow pK^-\pi^+ \hookrightarrow \bar{p}K^+\pi^-$$

at the maximum beam momentum (15 GeV/c; $\sqrt{s}$ = 5.474 GeV)

For the background we assumed $\sigma(\sqrt{s} = 5.474\ \text{GeV})_{\bar{p}p \to pK^-\pi^+\bar{p}K^+\pi^-} = 0.020\ \text{mb}$ extrapolating from measurements at $\sqrt{s}$ = 7.862 GeV



Simone Bianco (FZJ)



Conclusions

- Hadron spectroscopy is experiencing a new renascence;
- New high quality measurements are coming form e^+-e^- colliders and LHC experiments reveling unexpected properties of hadrons;
- All over the world there is lack of antiproton beams that in the past were showing great capabilities in the field;
- It is urgent to have an high-quality antiproton beam to contribute to the field;
- The $\bar{\text{P}}$ANDA detector coped to the HESR will be the perfect combination of tools to make a break-through!