SEARCH FOR FOUR- AND SIX- QUARK EXOTIC STATES WITH *CS* QUARK CONTENT

Program: MATTER AND THE UNIVERSE
Topic: Cosmic Matter in the Laboratory
Research Unit: **IKP-1**

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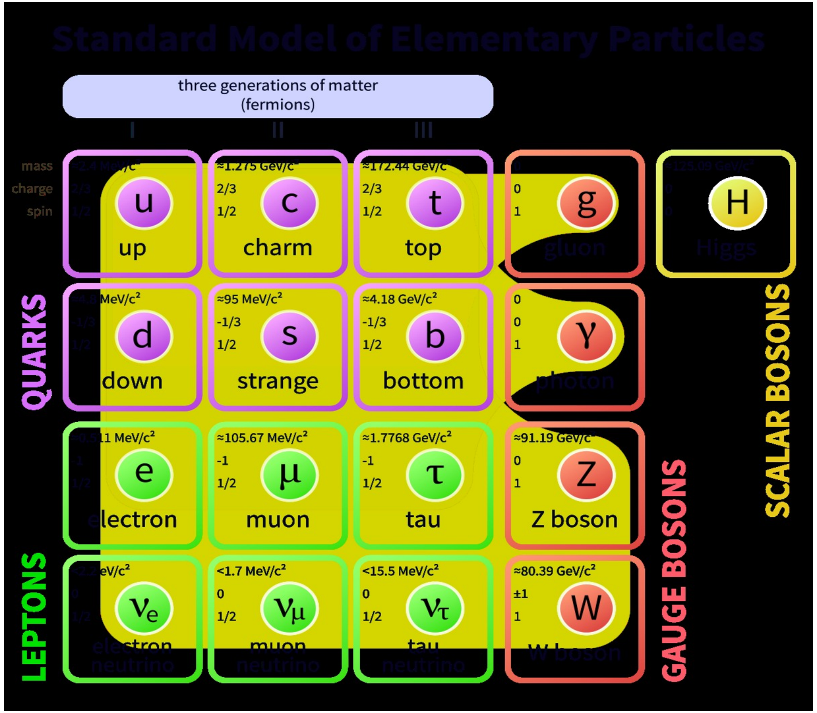
HIRSCHEGG 2018 – Multiple resonances in hadrons, nuclei and ultra-cold gases

OUTLINE

- Introduction
- Main achievements in *cs*-spectroscopy at e^+e^- colliders
- Resonances with hidden strange quark content
- Open questions and possible interpretation
- Looking forward to new experiments
- Summary

INTRODUCTION

- Standard model of particles physics:
  - Elementary particles
    - Mesons ($\bar{q}q$)
    - Baryons (qqq)
- Other possibilities considered, nowadays. Why?
- Since 2003 several observations not fitting the potential models
- New possibilities:
  - tetraquarks
  - hybrids
  - molecular states
  - hadrocharmonium
  - pentaquarks
  - hexaquarks.....



WHY CHARM- / CHARMONIUM?

- Gell-Mann Zweig idea: Constituent Quark Model (CQM). Still valid since half century
  →it classifies all known hadrons
- QCD describes the force binding quarks into hadrons
- Perturbation theory: limited applicability at scale corresponding to the separation between quarks inside hadrons
- Many models available to describe spectra and properties of hadrons: those incorporating features of the QCD are the most useful
- QCD-motivated models predict the existence of hadrons with more complex structures than simple *qq* or *qqq*.
- **Lot of experimental effort to prove it**!
- No unambiguous evidence for hadrons with non-CQM like structure has been found, but indeed....
- The study of Charm-*onium*(-like) spectrum (e.g., $c(\bar{c})$ + xx) have uncovered a number of candidates that not seem to conform CQM expectations
- *Exotic states* are predicted to exist in the light meson spectrum
  →difficult to disentangle from the dense background of conventional states
- Charmonium spectrum provide a cleaner environment: $\bar{c}c$ + xx exotics easier to identify

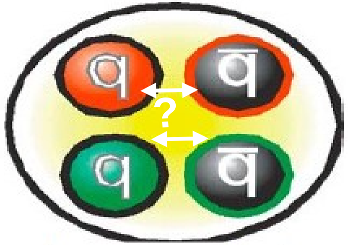
QUARK BOUND STATES

Lifetime:
< 10^{-8} s

Meson

Lifetime:
> 10^{30} (proton)
~ 10 min (neutron)
< 10^{-10} s (others)

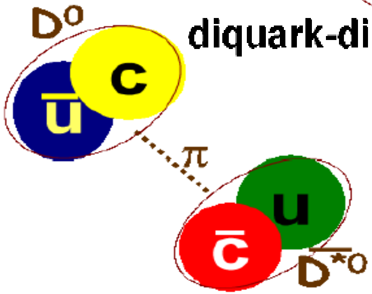
Baryon



Lifetime:
< 10^{-23} s

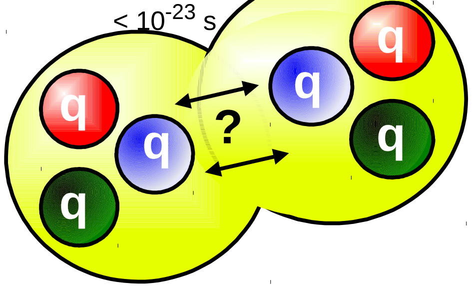
Tetraquark

diquark-diantiquark



$D^0 - \overline{D}^{*0}$ “molecule”

Lifetime:
< 10^{-23} s



Di-baryon

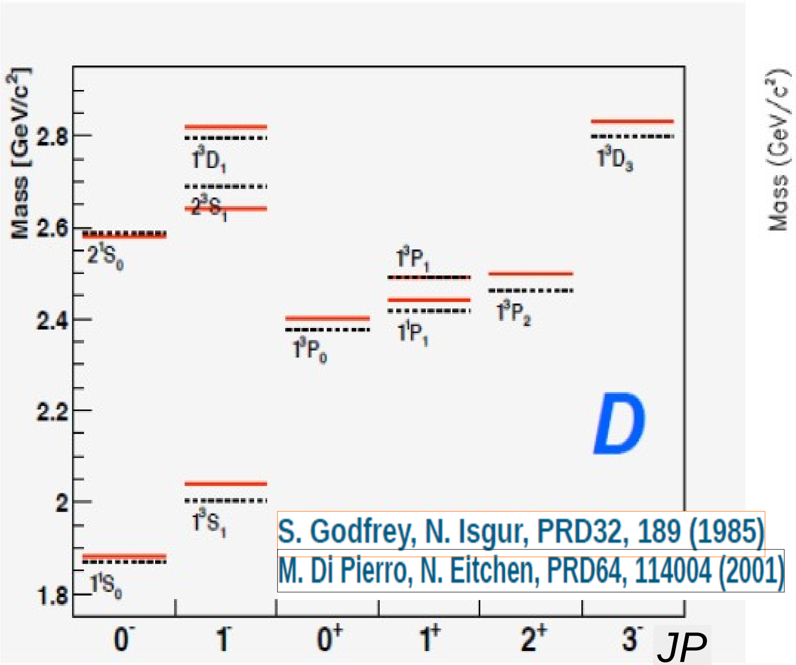
Lifetime:
< 10^{-20} s

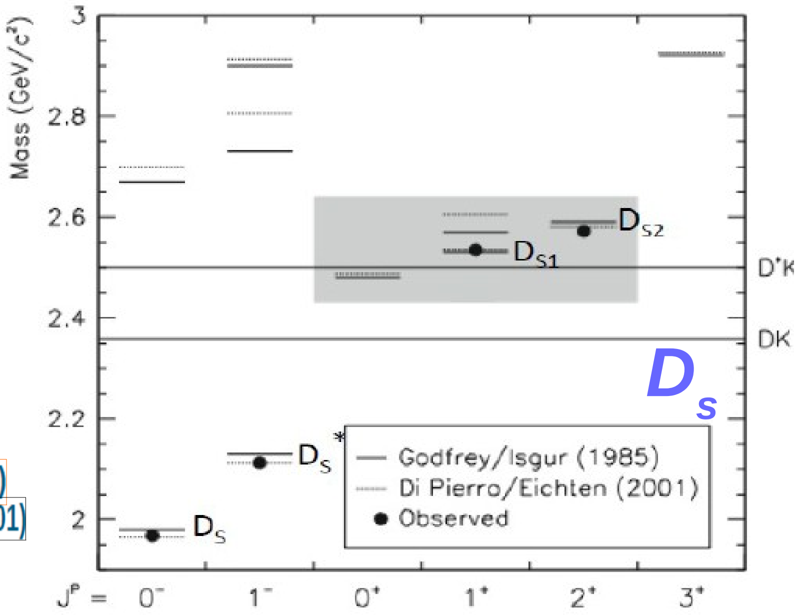
Pentaquark

Hybrid meson

Glueball

CHARM- AND CHARM-STRANGE SPECTRUM





$|c\bar{u}\rangle$ $|c\bar{d}\rangle$

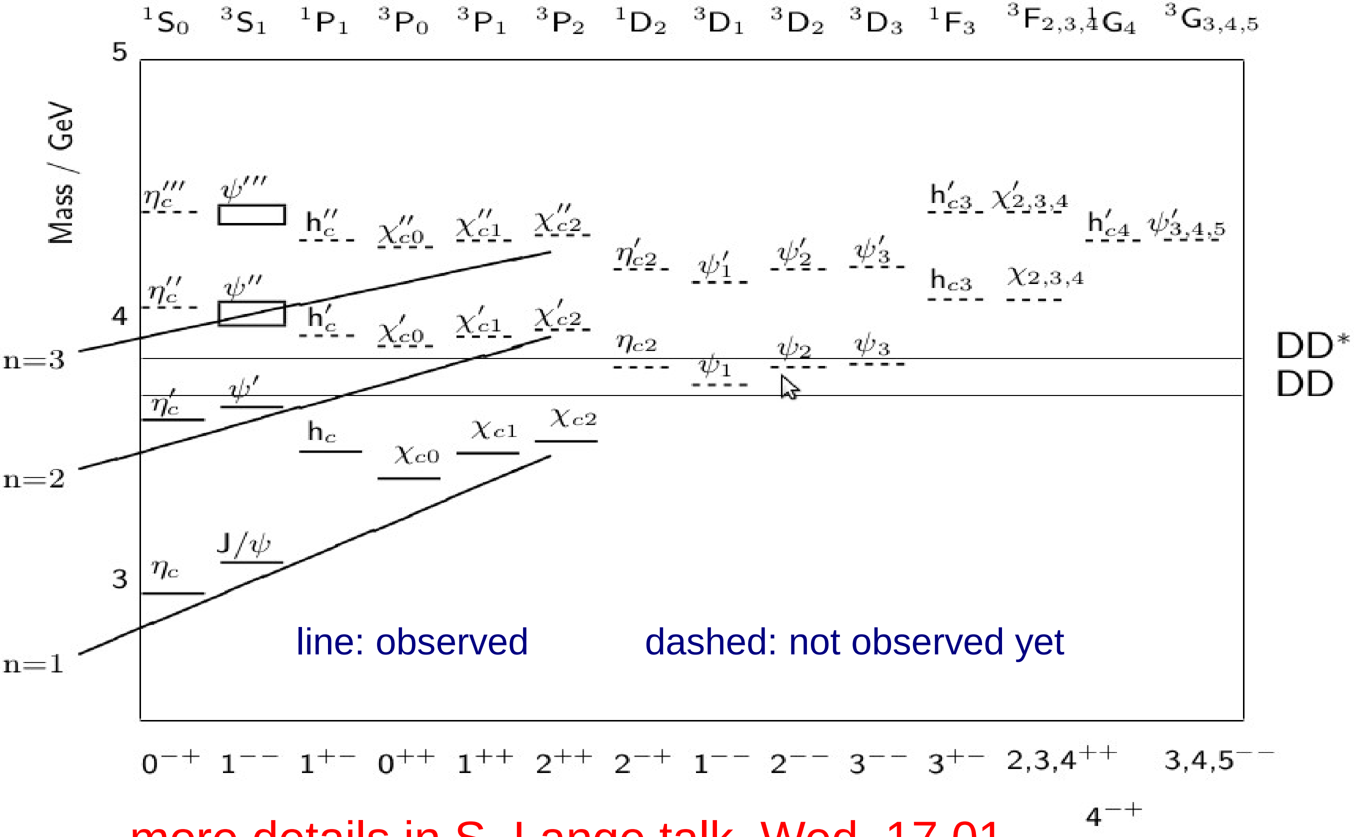
$|c\bar{s}\rangle$

$\overline{M}_D = (1864.91 \pm 0.17)\ \mathrm{MeV/c^2}$

$M_\pm - M_0 = (4.74 \pm 0.28)\ \mathrm{MeV/c^2}$

Theoretical prediction have been in qualitative agreement with experimental results...until 2003!

CHARMONIUM SPECTRUM



more details in S. Lange talk, Wed. 17.01

For >30 years theory and experiments agreed.
Then something happened.

How has the story begun?

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Phys. Rev. Lett. 90 (2003) 242001 BaBar, accepted 17 June 2003

Observation of a Narrow Meson State Decaying to $D^{+}_{s}\pi^{0}$ at a Mass of 2.32 GeV/c^2

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How has the story begun?

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Phys. Rev. Lett. 91 (2003) 262001 Belle, accepted 23 December 2003

Observation of a Narrow Charmoniumlike State in Exclusive $B^\pm \to K^\pm\pi^+\pi^- J/\psi$ Decays

HIGHLIGHT PAPER IN BABAR: $D_{s0}^*(2317)^+$

- BaBar experiment optimized for CP violation study, measurement of angles and sides of the CKM matrix. For comparison:

"Observation of CP violation in the B^0 meson system"

846 citations

Phys.Rev.Lett. 87 (2001) 091801
e-Print: hep-ex/0107013
Experiment: SLAC-PEP2-BABAR

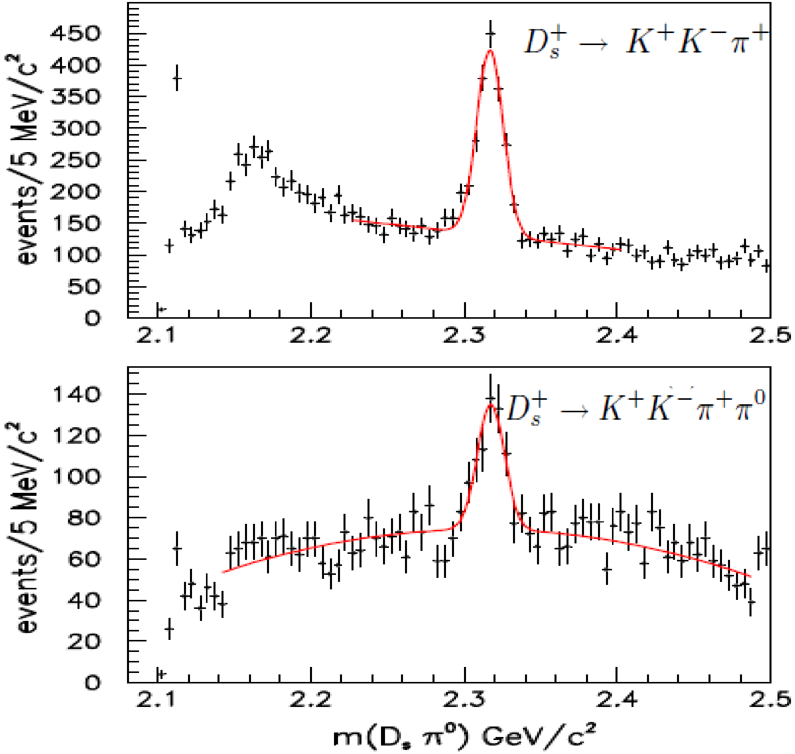
"Observation of a narrow meson decaying to $D^+_s\pi^0$ at a mass of 2.32-GeV/c^2 "

Phys.Rev.Lett. 90 (2003) 242001
e-Print: hep-ex/0304021
Experiment: SLAC-PEP2-BABAR

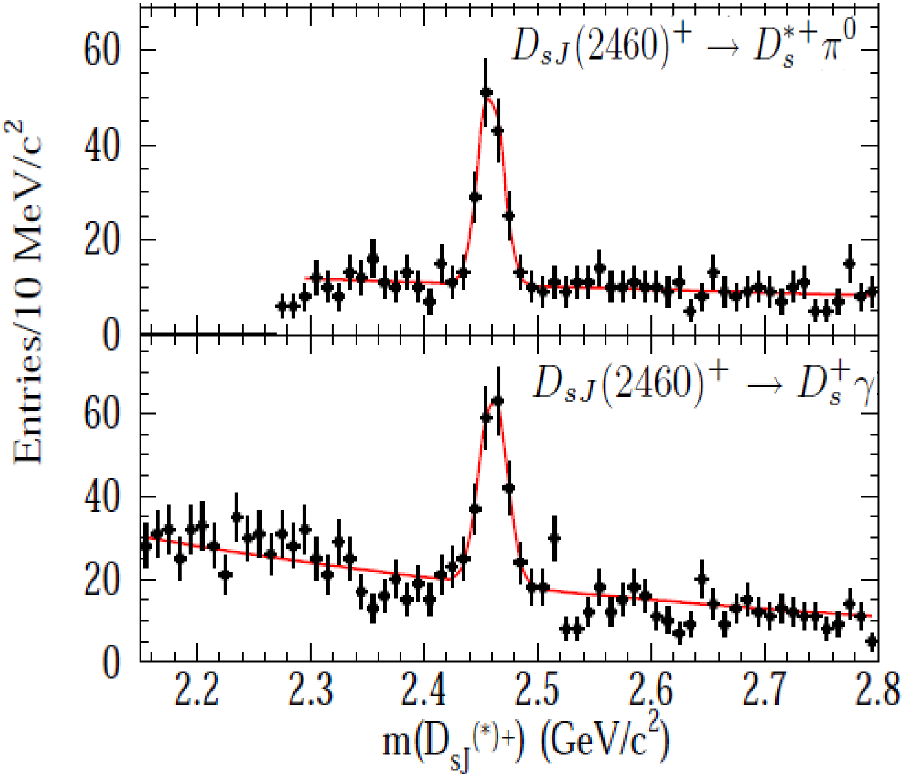
805 citations

THE PUZZLING CASE OF $D_{s0}^*(2317)^+$ AND $D_{s1}(2460)^+$

BABAR, PRL 90 (2003) 242001



BABAR, PRL 93 (2004) 181801



THE PUZZLING CASE OF $D_{s0}^*(2317)^+$ AND $D_{s1}(2460)^+$

Decay Channel	$D_{sJ}^*(2317)^+$	$D_{sJ}(2460)^+$
$D_s^+\pi^0$	Seen	Forbidden
$D_s^+\gamma$	Forbidden	Seen
$D_s^+\pi^0\gamma$ (a)	Allowed	Allowed
$D_s^*(2112)^+\pi^0$	Forbidden	Seen
$D_{sJ}^*(2317)^+\gamma$	—	Seen
$D_s^+\pi^0\pi^0$	Forbidden	Allowed
$D_s^+\gamma\gamma$ (a)	Allowed	Allowed
$D_s^*(2112)^+\gamma$	Allowed	Allowed
$D_s^+\pi^+\pi^-$	Forbidden	Seen

(a) Non-resonant only

- $D_{s0}^*(2317)^+$ is found below the DK threshold:
- $D_{s0}^*(2317)^+$ can in principle decay
  - electromagnetically (no exp. evidence); or
  - through isospin-violation $D_s^+\pi^0$ strong decay

Is D_{s0}^* the missing 0^+ state of the *cs-spectrum*?

- Most of theoretical works treat *cs-systems* as the hydrogen atom (potential models, *c* = heavy quark):
- $D_{s0}^*(2317)^+$ and $D_{s1}(2460)^+$ are predicted, found with good accuracy <u>but</u>:
- $m(D_{s0}^*(2317)^+)$ found 160 MeV/c^2 lower
- $m(D_{s1}(2460)^+)$ found 120 MeV/c^2 lower than predicted by potential models
- $D_{s1}(2460)^+$ is found in the inv. mass $D_s^+\gamma$
- Spin <u>at least</u> 1
- We can exclude the hypothesis 0^+, because $D_{s1}(2460)^+ \rightarrow D_s^+\gamma$

Is D_{s1} the missing 1^+ of the *cs-spectrum*?

THE PUZZLING CASE OF $D_{s0}^{*}(2317)^{+}$ AND $D_{s1}(2460)^{+}$

Decay Channel	$D_{sJ}^{*}(2317)^{+}$	$D_{sJ}(2460)^{+}$
$D_s^+\pi^0$	Seen	Forbidden
$D_s^+\gamma$	Forbidden	Seen
$D_s^+\pi^0\gamma$ (a)	Allowed	Allo[illegible]
$D_s^*(2112)^+\pi^0$	Forbidden	[illegible]
$D_{sJ}^*(2317)^+\gamma$	—	[illegible]
$D_s^+\pi^0\pi^0$	Forbidd[illegible]	[illegible]
$D_s^+\gamma\gamma$ (a)	All[illegible]	[illegible]
$D_s^*(2112)^+\gamma$	[illegible]	[illegible]
$D_s^+\pi^+\pi^-$	[illegible]	[illegible]

(a) Non-resonant only

Too narrow:
need to measure its width
to disclose its nature:
$UL(\Gamma)<3.8$ MeV@90% CL

- $D_{s0}^{*}(2317)^{+}$ is found be[illegible] threshold:
- $D_{s0}^{*}(2317)^{+}$ can in princip[illegible] decay
  - electromagnetically (no exp. evidence); or
  - through isospin-violation $D_s^+\pi^0$ strong decay

Is D_{s0}^{*} the missing 0^+ state of the *cs-spectrum*?

- Most of theoretical works treat *cs-systems* as the hydrogen atom (potential models, *c* = heavy quark):
- $D_{s0}^{*}(2317)^{+}$ and $D_{s1}(2460)^{+}$ are predicted, found with good accuracy

but:

$m(D_{s0}^{*}(2317)^{+})$ found 160 MeV/c^2 lower

$m(D_{s1}(2460)^{+})$ found 120 MeV/c^2 lower

than predicted by potential models

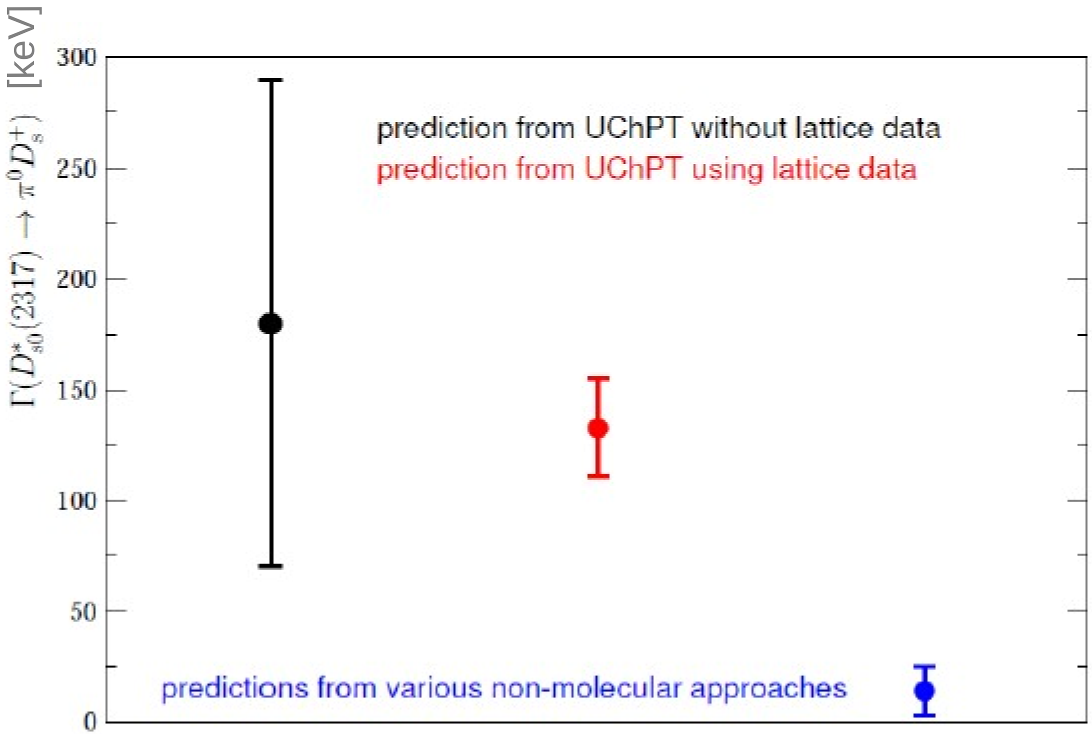
- $D_{s1}(2460)^{+}$ is found in the inv. mass $D_s^+\gamma$
- Spin at least 1
- We can exclude the hypothesis 0^+, because $D_{s1}(2460)^+ \rightarrow D_s^+\gamma$

Is D_{s1} the missing 1^+ of the *cs-spectrum*?

Different theoretical approaches, different interpretations	$\Gamma(D_{s0}^*(2317)^+ \rightarrow D_s \pi^0)$ (keV)
M. Nielsen, Phys. Lett. B 634, 35 (2006)	6 ± 2
P. Colangelo and F. De Fazio, Phys. Lett. B 570, 180 (2003)	7 ± 1
S. Godfrey, Phys. Lett. B 568, 254 (2003)	10 Pure $\bar{c}s$ state
Fayyazuddin and Riazuddin, Phys. Rev. D 69, 114008 (2004)	16
W. A. Bardeen, E. J. Eichten and C. T. Hill, Phys. Rev. D 68, 054024 (2003)	21.5
J. Lu, X. L. Chen, W. Z. Deng and S. L. Zhu, Phys. Rev. D 73, 054012 (2006)	32
W. Wei, P. Z. Huang and S. L. Zhu, Phys. Rev. D 73, 034004 (2006)	39 ± 5
S. Ishida, M. Ishida, T. Komada, T. Maeda, M. Oda, K. Yamada and I. Yamauchi, AIP Conf. Proc. 717, 716 (2004)	15 - 70
H. Y. Cheng and W. S. Hou, Phys. Lett. B 566, 193 (2003)	10 - 100 Tetraquark state
A. Faessler, T. Gutsche, V.E. Lyubovitskij, Y.L. Ma, Phys. Rev. D 76 (2007) 133	79.3 ± 32.6 DK had. molecule
M.F.M. Lutz, M. Soyeaur, Nucl. Phys. A 813, 14 (2008)	140 Dynamically gen. resonance
L. Liu, K. Orginos, F. K. Guo, C. Hanhart, Ulf-G. Meißner Phys. Rev. D 87, 014508 (2013)	133 ± 22 DK had. molecule
M. Cleven, H. W. Giesshammer, F. K. Guo, C. Hanhart, Ulf-G. Meißner Eur. Phys. J A (2014) 50 -149	Strong and radiative decays of $D_{s0}^*(2317)$ and $D_{s1}(2460)$

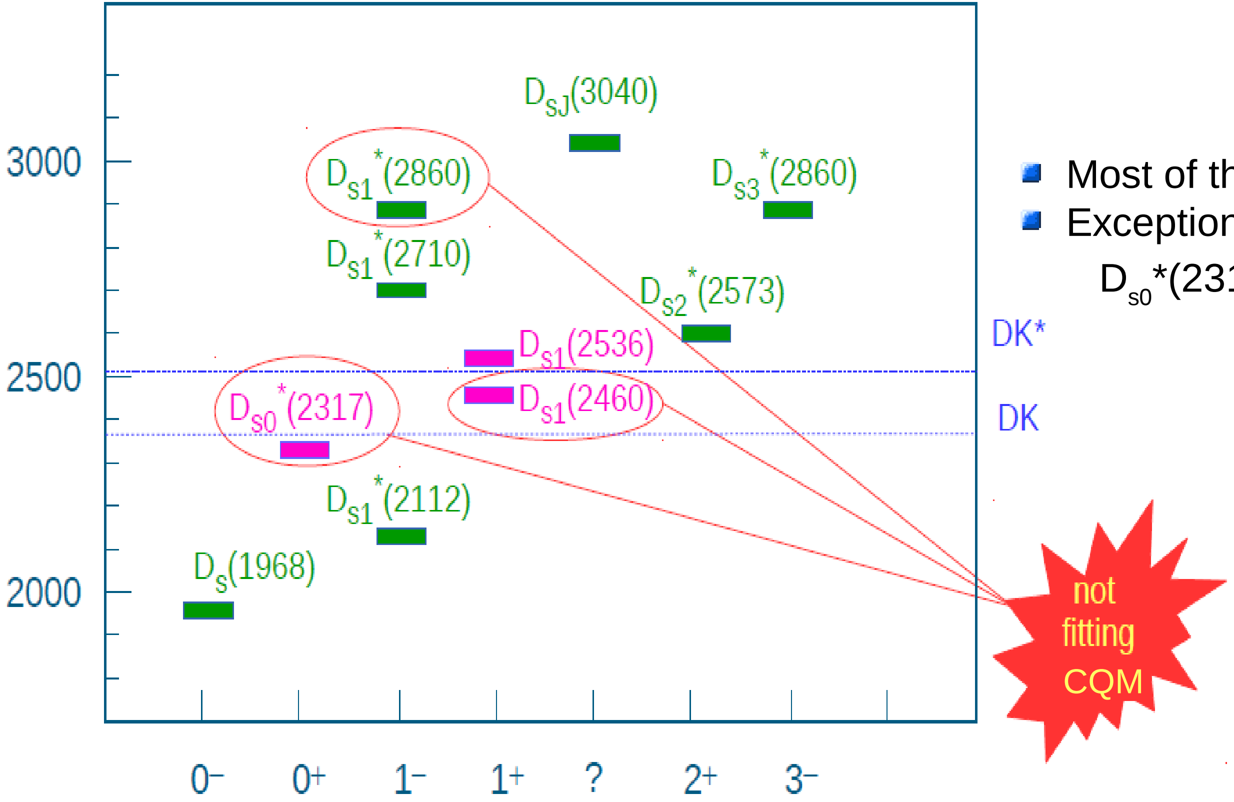
- The measurement of the **narrow width** plays a leading role in the interpretation of $D_{s0}^*(2317)^+$

PREDICTIONS FOR THE $D_{s0}^*(2317)^+$ WIDTH



How does the spectrum look like, nowadays?

CHARM-STRANGE SPECTRUM, TODAY



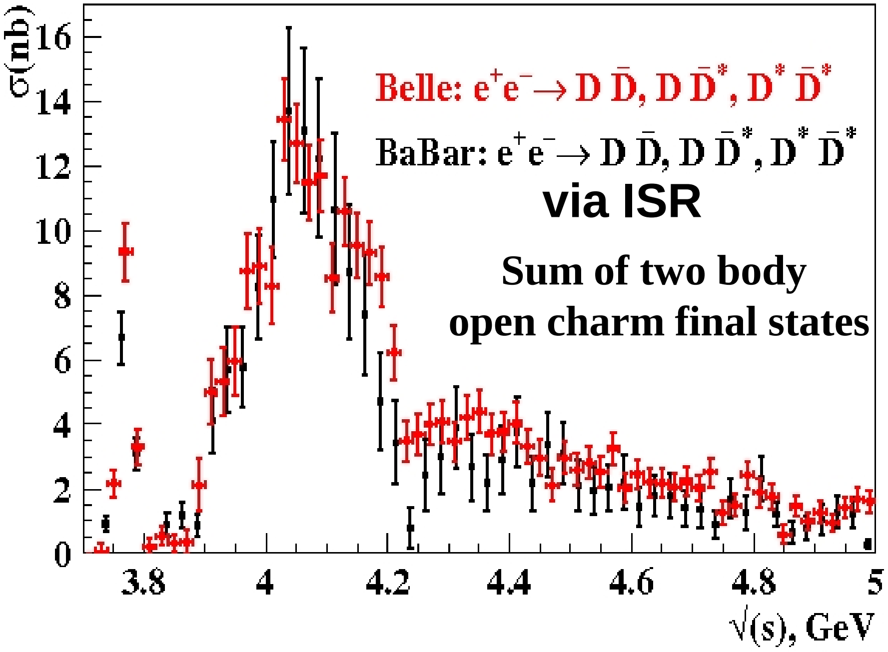
- Most of the states fit the potential models
- Exceptions:

  $D_{s0}*(2317)^+$, $D_{s1}(2460)^+$ and $D_{s1\text{-}3}'(2860)^+$

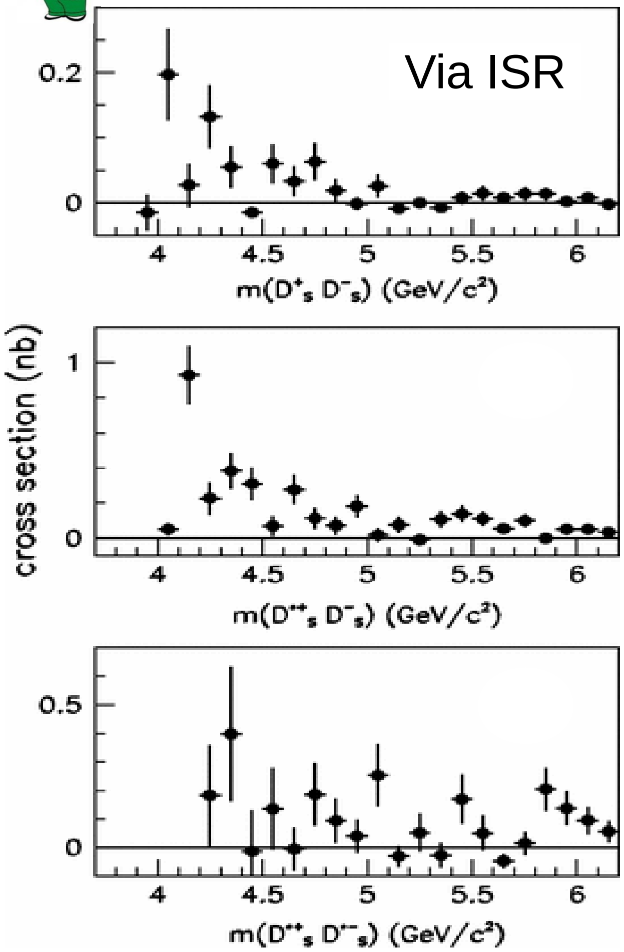
e^+e^- CHARM(-STRANGE) CROSS SECTION

Phys. Rev. Lett. 98 (2007) 092001

Phys. Rev. D79 (2009) 092001



Phys. Rev. D 82 (2010) 052004



LOOKING FOR EXOTIC STRUCTURES WITH DOUBLE *CS* QUARK CONTENT

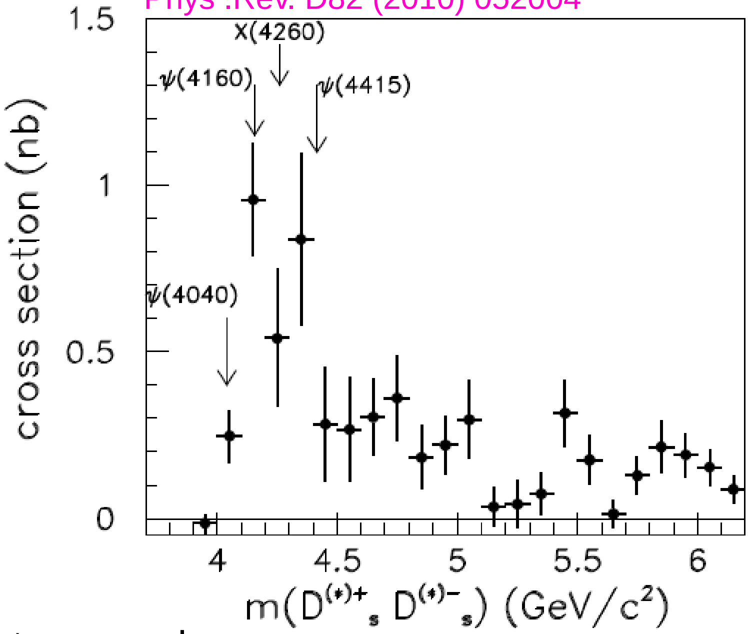
- Analyzing $e^+e^- \to D_s^+ D_s^-$, $e^+e^- \to D_s^{*+} D_s^-$, $e^+e^- \to D_s^{*+} D_s^{*-}$ via ISR, BaBar looked for the X(4260)

$$\frac{\mathcal{B}(X(4260) \to D_s^+ D_s^-)}{\mathcal{B}(X(4260) \to J/\psi \pi^+ \pi^-)} < 0.7,$$

$$\frac{\mathcal{B}(X(4260) \to D_s^{*+} D_s^-)}{\mathcal{B}(X(4260) \to J/\psi \pi^+ \pi^-)} < 44,$$

$$\frac{\mathcal{B}(X(4260) \to D_s^{*+} D_s^{*-})}{\mathcal{B}(X(4260) \to J/\psi \pi^+ \pi^-)} < 30$$

Phys .Rev. D82 (2010) 052004

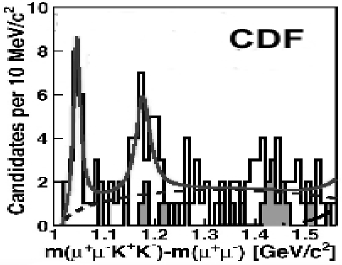


- If X(4260) is 1^{--} **charmonium state**, it should decay mostly to open charm
- If X(4260) is a **tetraquark**, it should decay to $D_s^- D_s^+$

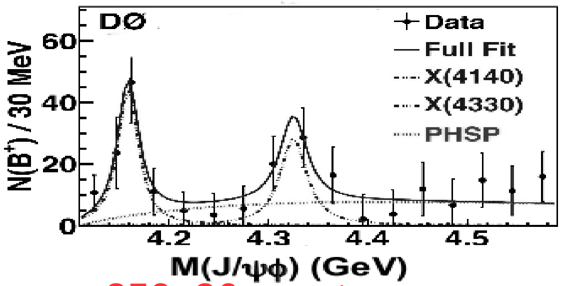
it does not happen @95%c.l. with 525 fb^{-1} (BaBar data set)!

THE X(4140)

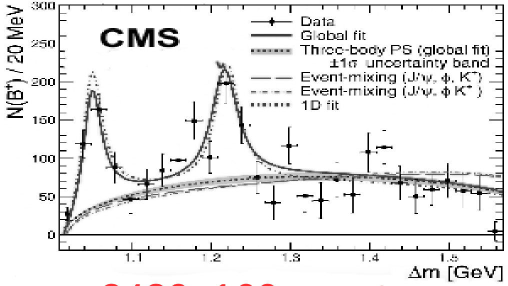
- The X(4140) was observed in the invariant mass system of J/ψKK ($\phi \to K^+K^-$) [$c\bar{c}s\bar{s}$]
- The X(4140) can be considered the *strange* counterpart of the X(3872)
- Is the X(4140) a real particle?



75±10 events

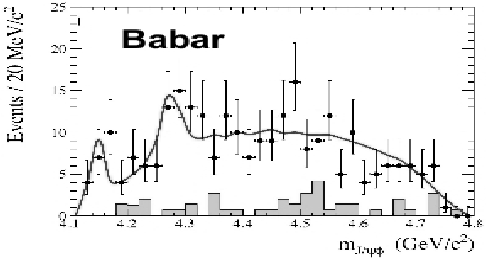


250±36 events

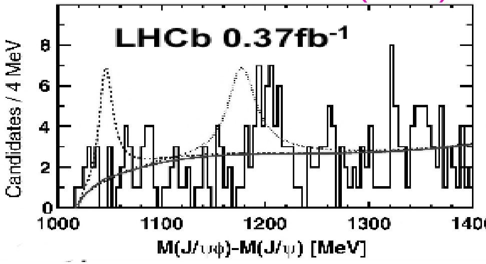


2480±160 events

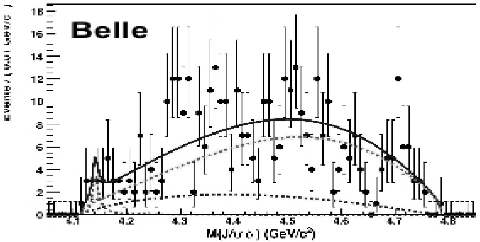
(2010)



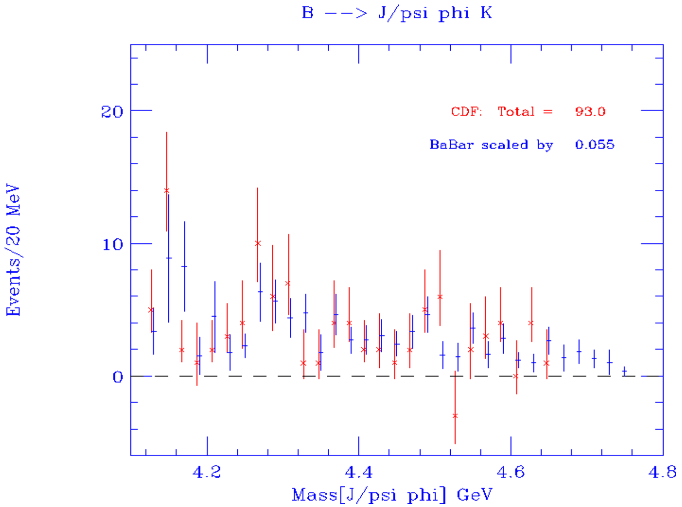
189±14 events

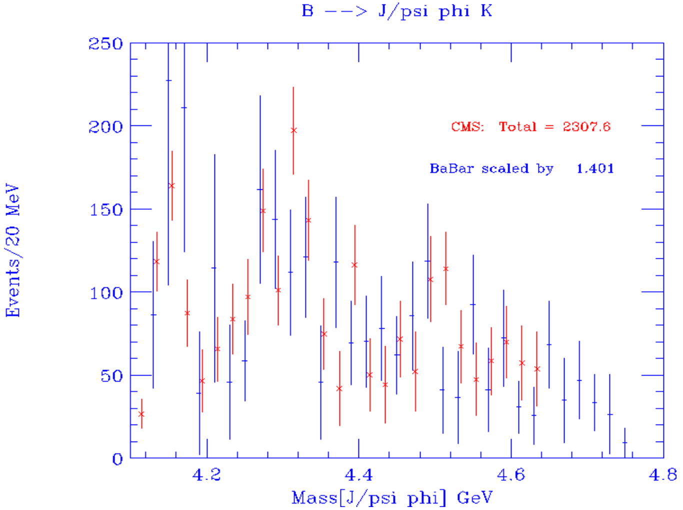


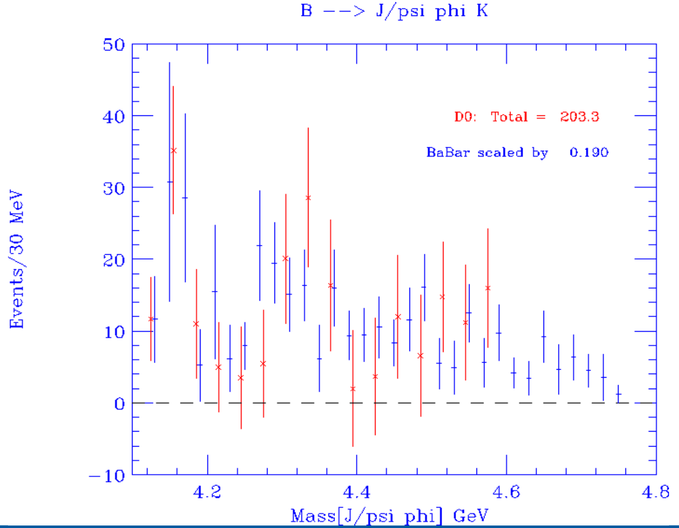
346±20 events

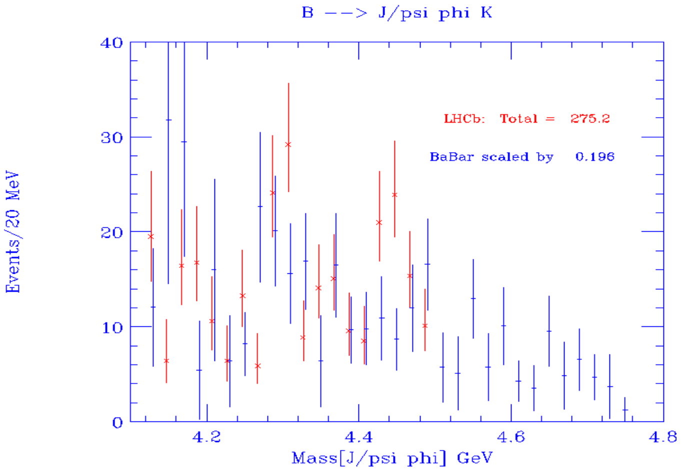


325±21 events







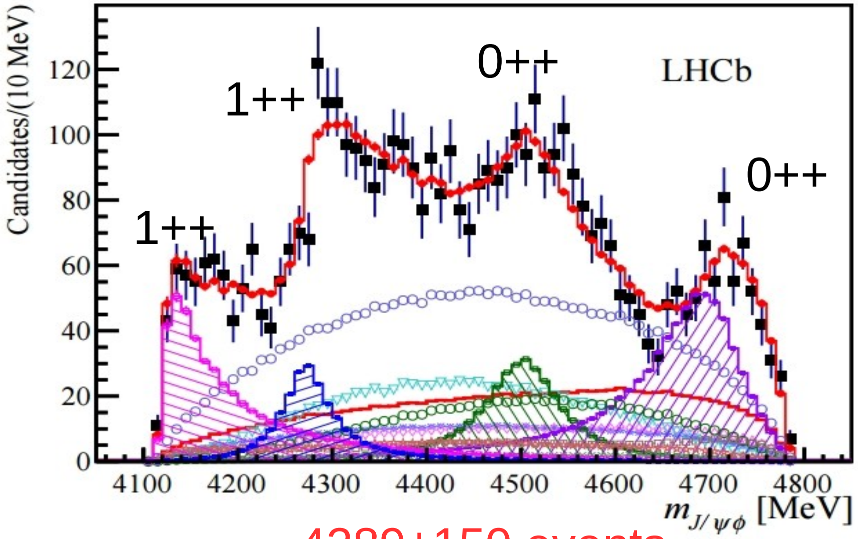


- Exercise: data comparison (2015) does not show big disagreement!

E.P, EPJ Web Conf 95 (2015) 05012

X(4140): INTERPRETATION

Phys. Rev. Lett. 118 (2016) 022003



4289±150 events

- In 2016 a new publication from LHCb (x10 data compared to 2010)
- 1^{++} doublet → problem for diquark anti-diquark tetraquarks
- Solution: interpret X(4140) as threshold effect
- $J/\psi\phi$ hadro–charmonium: doublet o.k., but:
  - sequence should be 0^{++}, 1^{++}, 0^{++}, 1^{++}
  - $m(J/\psi)+m(\phi)$= 4116 MeV
  - → <u>positive</u> „binding energy“ (~20 MeV)
  - molecules ? → no isospin! → *η* exchange

Karliner, Rosner, Nucl. Phys. A 954 (2016) 365

$\bar{c}c\bar{s}s$ bound states: it wold be interesting to look for those in $D_s^{(*)}D_s^{(*)}$ systems: C=1^- not seen here!

Remember: J/ψ is a “*nice*” object to reconstruct; D_s^* can be “*nasty*”: too many low momentum photons

LOW MOMENTUM PHOTONS: COMPARISON

$$R_\varepsilon = \frac{\varepsilon(B^+ \to J/\psi K^+)}{\varepsilon(B^+ \to J/\psi K^{*+})}$$

	LHCb (2012)	Belle (2003)
	CERN-LHCb-PROC-2015-009	PLB538 (2002) 11 PRD67 (2003) 032003
R_ε	13.57±0.12	4.68±0.49

- Belle can reconstruct photons at least 3 times better than LHCb:
  - LHCb: p_γ>500 keV/c
  - BaBar, Belle: p_γ>100 keV/c

ε = reco. efficiency

CUSP EFFECTS

- Cusp = kink in the amplitude of an observable
- There is always a cusp at the opening of S-wave threshold
- To produce peaks as pronounced and narrow, non-perturbative interactions among heavy mesons are needed → there should be a near-by pole
- How to distinguish S-matrix poles from cusps?
  - kinematic threshold cusps cannot produce narrow peaks in invariant mass distributions in elastic scattering processes [Guo et al, PRD91 (2015) 051504]
- Cusps are seen mostly in low-mass meson spectrum

CUSP EFFECTS

Exotic state X decaying to:	Sum of masses of the X daughters from PDG [GeV/c^2]	J^{PC} combination	Possible interpretation of X as a cusp
$X \to D_s D_s^*$	4080	$0^- \otimes 1^-$	X(4140) could be a cusp
$X \to D_s D^*_{s0}(2317)$	4285	$0^- \otimes 0^+$	X(4274) not OK for a cusp in S-wave, but still possible (unusual) in P-wave
$X \to D_s D_{s1}(2460)$	4428	$0^- \otimes 1^+$	mass not compatible with X found
$X \to D_s D_{s1}(2536)$	4504	$0^- \otimes 1^+$	compatible with $X(4500)$, but not a cusp
$X \to D_s D_{s2}(2573)$	4541	$0^- \otimes 2^+$	compatible with $X(4500)$, but not a cusp
$X \to D_s D_{s2}(2710)$	4678	$0^- \otimes 2^-$	it could be the $X(4700)$
$X \to D_s D_{s1\text{-}3}(2860)$	4828	$0^- \otimes 1^-, 0^- \otimes 3^-$	mass not compatible with X found

- Is the X(4140) a cusp? A signal in $D_s^{(*)} D_s^{(*)}$ would exclude its cusp hypothesis

WHERE ELSE TO LOOK FOR $c\bar{c}s\bar{s}$ POSSIBLE RESONACES?

EXAMPLE

Invariant Mass System	Decay from:	Range [GeV/c^2]
$D_s^- D_s^+$	B_s^0	[3.936 – 5.298]
$D_s^- D_s^+ \pi^0$	B_s^0	[4.071 – 5.433]
$D_s^- D_s^{*+}$	B_s^0	[4.080 - 5.433]
$D_s^- D^*_{s0}(2317)^+$	B_s^0	[4.285 – 5.433]
$J/\psi\phi$	B^0	[4.117 – 4.783]
$J/\psi\phi$	$B^\pm$	[4.117 – 4.787]
$J/\psi\phi$	continuum	all range
$D_s^- D^*_{s0}(2317)^+$, $D_s^- D_s^+ \pi^0$, $D_s^- D_s^{*+}$	continuum	all range

$B^0_s \to D_s^{(*)+} D_s^{(*)-} \pi^0$ ☑

$B^{0,\pm} \to J/\psi\phi K^{0,\pm}$ ☑

$e^+e^- \to J/\psi\phi$ + anything ☑

$e^+e^- \to D_s^{(*)+} D_s^{(*)-}$ + anything ☑

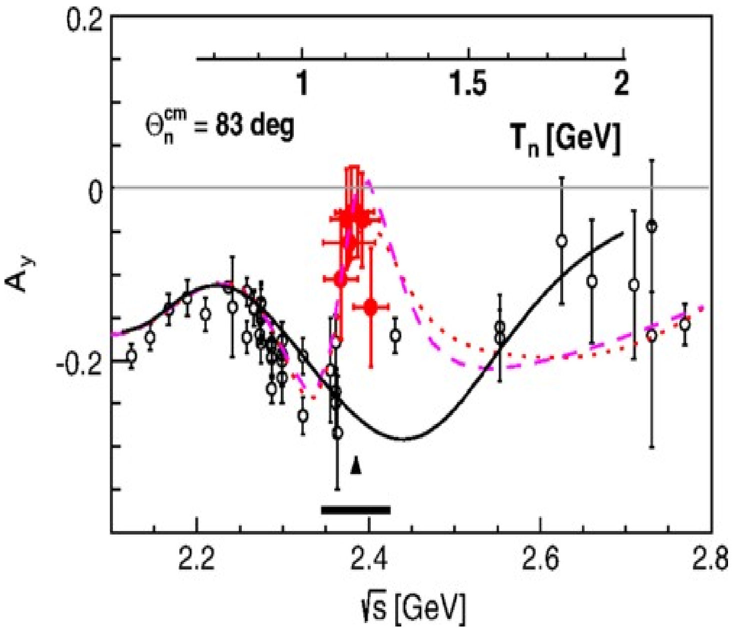
HEXAQUARK SEARCH

DIBARYONS

- Di-baryon search

  - R.L. Jaffe (1977) predictions (udsuds)
  - d*(2380) observed at WASA-at-COSY (2014) in *np* scattering fits the theoretical prediction.

  Phys. Rev. Lett 112 (2014) 202301



- Theoretically these particles could form in the interior of a neutron star.
- Accordingly, the study of neutron stars could fix constraints on di-baryon properties

  ⇨ quark-gluon plasma, new state of matter,...

HEXAQUARK SEARCH

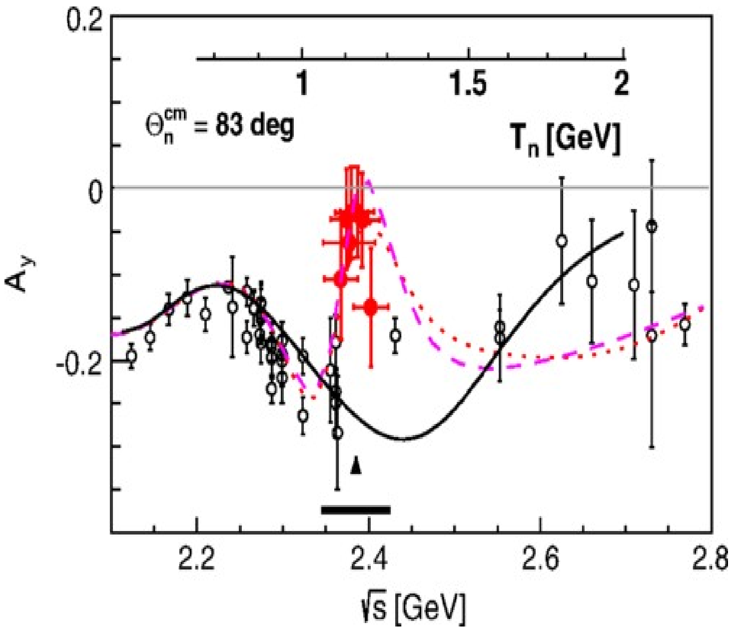
DIBARYONS & MORE...

- Di-baryon search

  - R.L. Jaffe (1977) predictions (udsuds)
  - d*(2380) observed at WASA-at-COSY (2014) in *np* scattering fits the theoretical prediction.

  Phys. Rev. Lett 112 (2014) 202301

- Other possibilities?



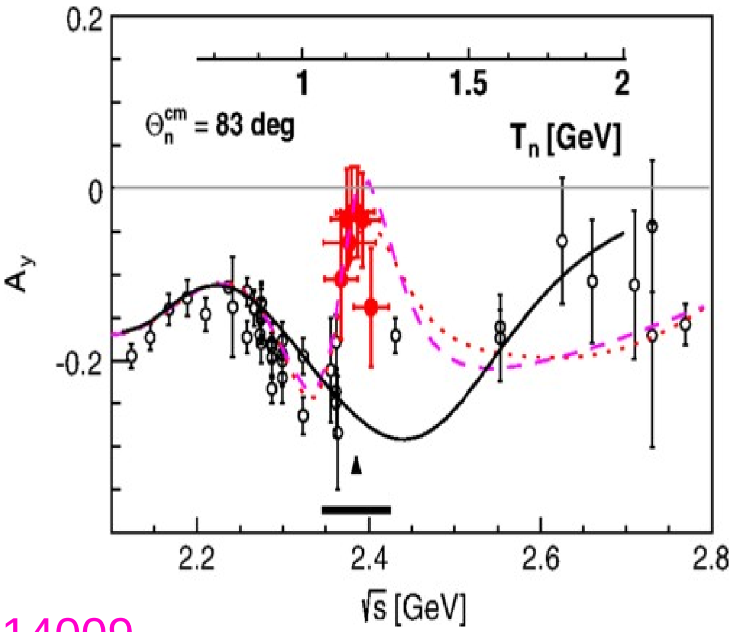
HEXAQUARK SEARCH

DIBARYONS & MORE...

- Di-baryon search

  - R.L. Jaffe (1977) predictions (udsuds)
  - d*(2380) observed at WASA-at-COSY (2014) in *np* scattering fits the theoretical prediction.

  Phys. Rev. Lett 112 (2014) 202301



- Other possibilities?

  3 $D^{(*)}$ meson bound states (non-strange dibaryon predicted by Goldman in 1989)

  Canham, Hammer, Springer, PRD 80 (2009) 014009

$D\bar{D}^{*}D^{(*)}$ ← X(3872)

- 3 c-quarks
- S-wave X(3872)-D scattering cross section can be evaluated

HEXAQUARK SEARCH

WITH CS QUARK CONTENT

- From X(3872)$D^{(*)}$ to X(4140) $D^{(*)}$

Hyp: X(4140) $\rightarrow D_s^{(*)} D_s^{(*)}$

BaBar+Belle suitable for this search (1.5 ab^{-1})

Belle II: x50 Belle luminosity(~2025)

Calculation non trivial with s-quark

Expected reconstruction efficiency $\leqslant$1%

Analysis in continuum

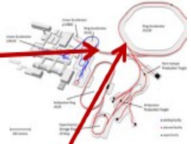
Future perspectives

Courtesy of S. Lange

JÜLICH
FORSCHUNGSZENTRUM

panda

GSI, Darmstadt (DE)



- $\bar{p}p$ interaction, antiproton beam up to 15.0 GeV/c
- Direct access to all quantum number
- High precision: will measure width $\geqslant$50 keV

CHARM-STRANGE SPECTROSCOPY AT PANDA

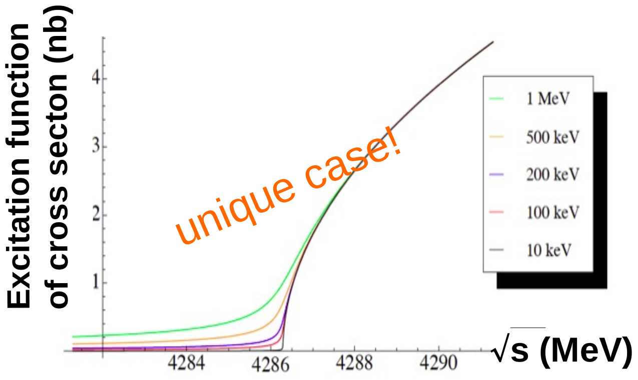
WIDTH OF THE $D_{s0}^*(2317)^+$

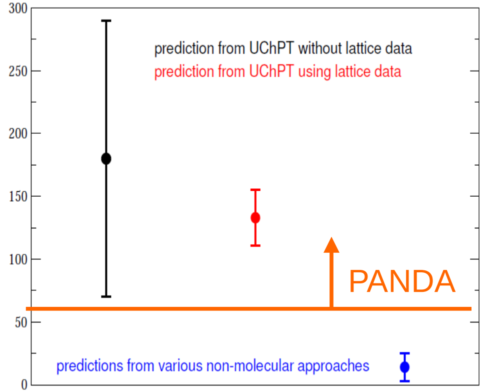
ICHEP2014, HADRON2017

- $\bar{p}p$ cross sections in the open-charm sector not measured yet (assumption: 1-100 nb)
- Threshold scan to measure $\Gamma(D_{s0}^*(2317)^+)$

  $\bar{p}p \rightarrow D_{s0}^*(2317)^+ D_s^-$, $D_{s0}^*(2317)^+ \rightarrow D_s^+ \pi^0$

  - Important role of HESR: $\Delta p/p < 10^{-4}$
  - Search for new decay modes of $D_s^{(*)}$
  - Chiral symmetry breaking studies





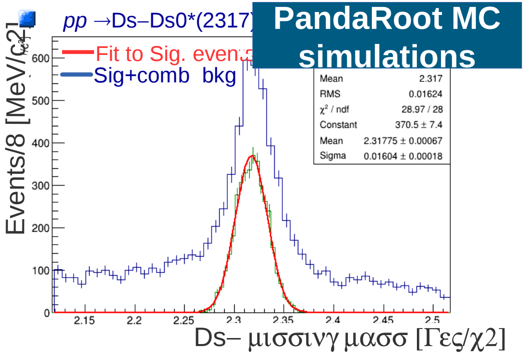
LHCb: $p_\gamma > 500$–600 MeV/c
BaBar, Belle(II): $p_\gamma > 100$, $p_{\pi 0} > 150$ MeV/c
PANDA: $p_\gamma > 30$ MeV/c

UL(Γ), LHCb ~1 MeV
UL(Γ), Belle ~500 keV
UL(Γ), PANDA > 56 keV

CHARM-STRANGE SPECTROSCOPY AT PANDA

ICHEP2014, HADRON2017

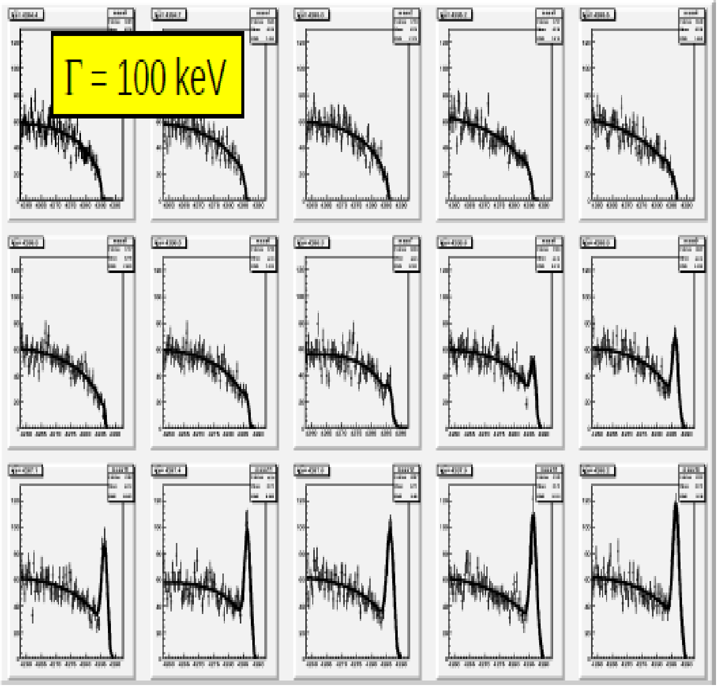
- Ongoing PandaRoot simulations

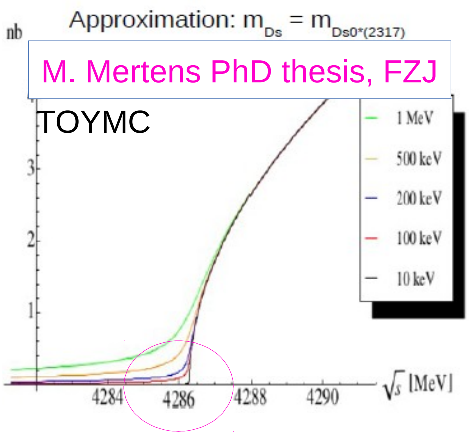


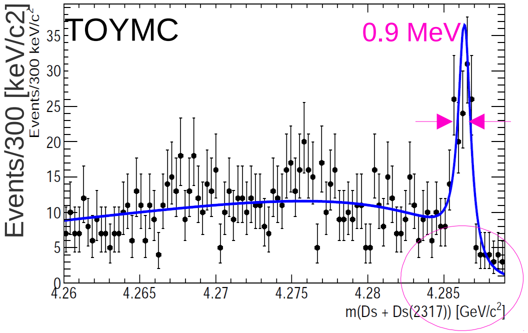
Expected 870 Ds/day ($\sigma = 1$nb) $\cong \mathscr{L}_{\text{initial}}$

$D_s D_s$(2317) system: expected $\varepsilon = 1–2\%$

TOYMC







EXTRAPOLATIONS

HADRON2017

Input σ (nb)	Produced events per day (Start up) $\bar{L} = 10^{31}\ cm^{-2}\ s^{-1}$	Produced events per day (Full lumi) $\bar{L} = 10^{32}\ cm^{-2}\ s^{-1}$
20	17280	172800
10	8640	86400
5	4320	43200
2	1728	17280
1	864	8640

PANDA

$\bar{p}p \to D_s^- D_s^*(2317)^+$

- Conservative range: σ [1 – 100] nb
- With **L = 10^{31} cm^{-2} s^{-1}** (average), **864** produced events/day (hyp: **σ = 1nb**)
- BR($D_s \to K^+K^-\pi^-$) = 5.34%
- $D_{s0}^*(2317)^+$ reconstructed on the D_s recoil
  efficiency = order of a few points per cent

PRL 92, 012002 (2004)
PRL 91, 262002 (2003)

- Comparison with B factories
  - S/B ~ 5/1, ε = 8.2% in e+e- $D_s D_{s0}^*(2317)$
  - S/B ~ 2/1, ε∈[0.42-2.75]10^{-4} through B decays

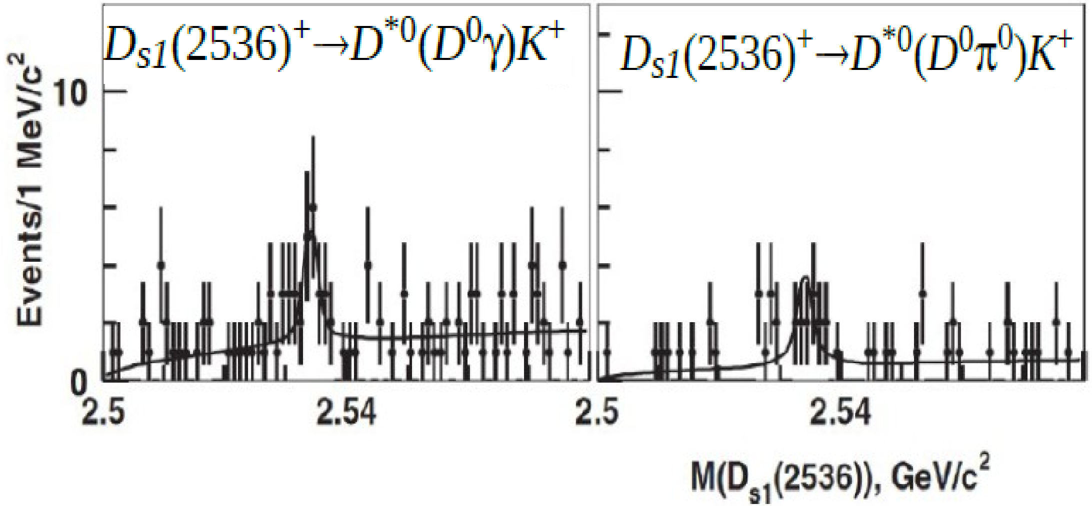
Belle II will collect ~ 44000 **Ds0*(2317)** in 10 years of data taking ($\mathcal{L}$ = 50 ab^{-1})

$D_{s0}^{*}(2317)^{+}$ REMARKS

- Two scenarios:

- the $D_{s0}^{*}(2317)^{+}$ is a meson: if a signal is found in $D_s^{-}D_{s0}^{*}(2317)^{+}$ this can be a 4-quark state
- the $D_{s0}^{*}(2317)^{+}$ is a tetraquark: if a signal is found in $D_s^{-}D_{s0}^{*}(2317)^{+}$ this can be hexaquark

- Known limit of Belle in width measurement:



(0.75±23) MeV

657 $\overline{B}$B million pairs

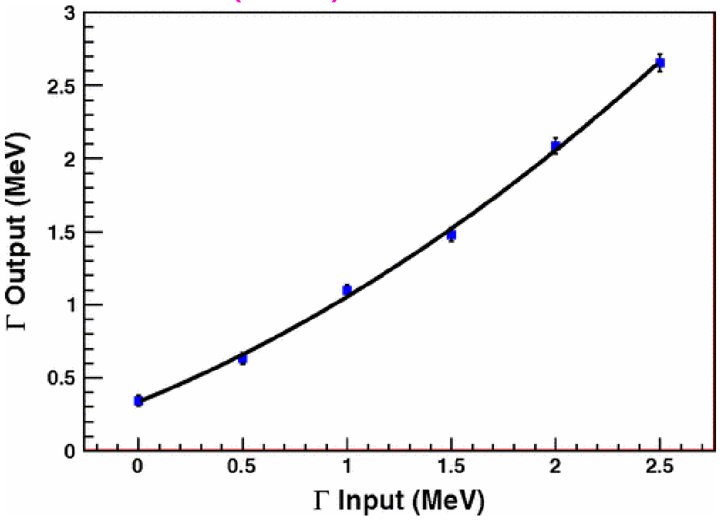
PRL 84 (2000) 2593

MEASUREMENT OF NARROW WIDTH AT BELLE

$X(3872) \to J/\psi \pi^+ \pi^-$

$\Gamma < 1.2$ MeV $\cong 90\%$ c.l.

PRD 84 (2011) 052004



- Control sample used for this analysis: B → ψ(2s)π+π–

$\Gamma_{\psi'} = (0.52 \pm 0.11)$ MeV

- A bias of (0.13±0.11) MeV has to be subtracted

Sensitivity to sub-MeV regime!

SUMMARY

JÜLICH FORSCHUNGSZENTRUM

- Exploring hadrons with *cs* quark content is important
- Charm-strange spectrum still under study from experimental point of view
- Search for four- and six quark states at the beginning
- e^+e^- machines: limitation in measuring the narrow width, but
  Belle demonstrated sensitivity up to 300 keV (Γ)
- Belle+BaBar combined analysis expected to contribute:
  high profile analysis!

DFG approved project @ Juelich:

"Search for four- and six quark states with cs quark content"

First combined BaBar+Belle analysis in spectroscopy

- Future $\bar{p}p$ machines suitable for this search
- Difficult theoretical predictions in evaluating $\bar{p}p \rightarrow$ open charm cross section: data are needed!

Thank you for your kind attention!

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"The greatest danger for most of us lies not in setting our aim too high and falling short; but in setting our aim too low, and achieve our mark." (Michelangelo, 1475 - 1564)