PERSPECTIVE STUDIES OF CHARMONIUM AND EXOTICS ABOVE $D\bar{D}$ THRESHOLD IN ANTIPROTON-PROTON ANNIHILATION

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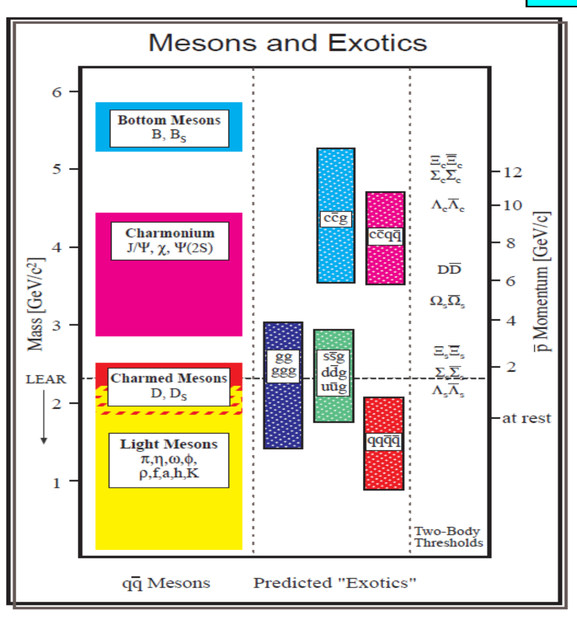
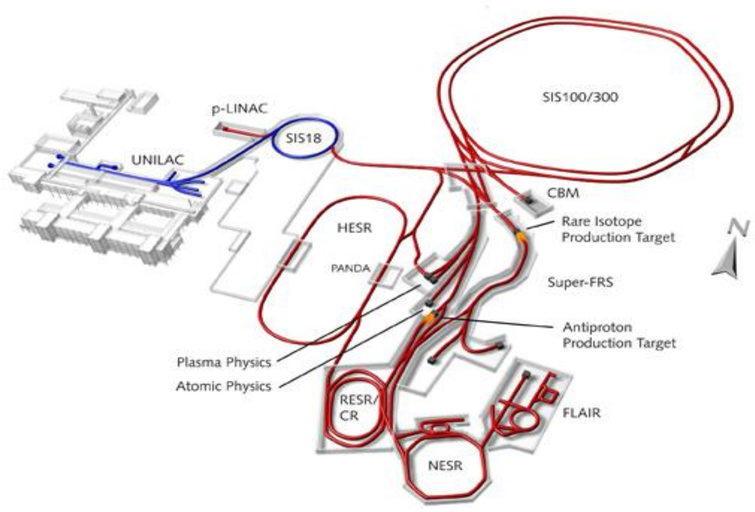
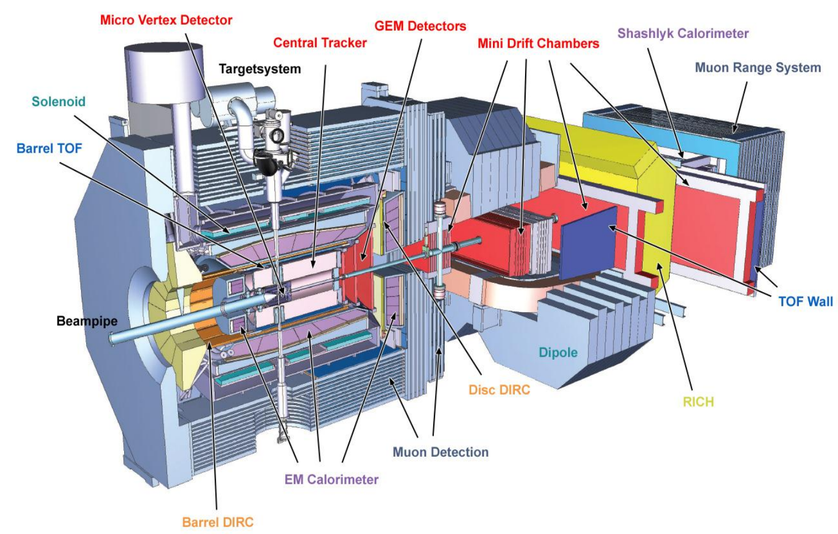
WHY WE CONCENTRATE ON PHYSICS WITH ANTIPROTONS:



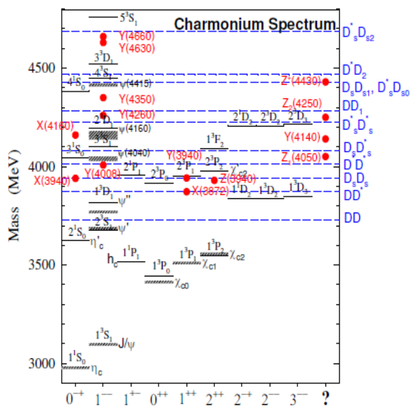


The FAIR complex.



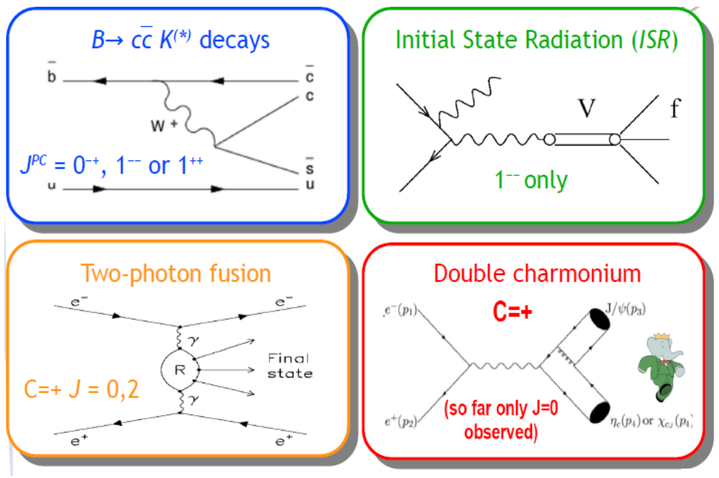
Modular universal detector for HESR.

charmonium spectrum



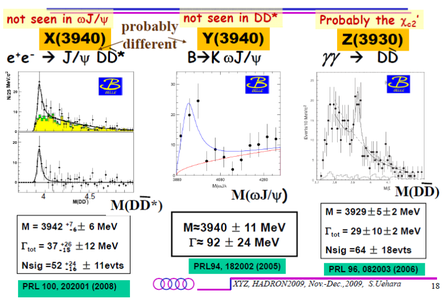
- all $c\bar{c}$ states below open charm threshold have been identified
- good agreement between data and theory
- something new above open charm threshold
- the theoretical picture for exotic states is far from being clear at present

S. Godfrey, arXiv:0910.3409[hep-ph]

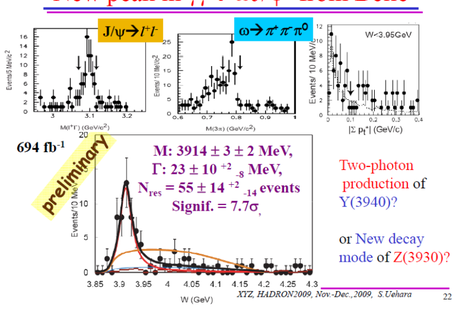


CHARMONIUM PRODUCTION MECHANISMS

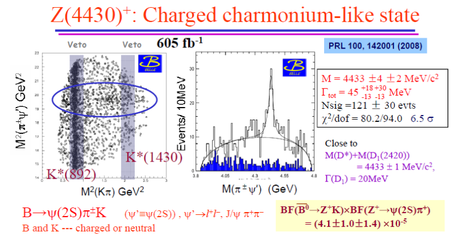
The X,Y,Z near 3940 MeV



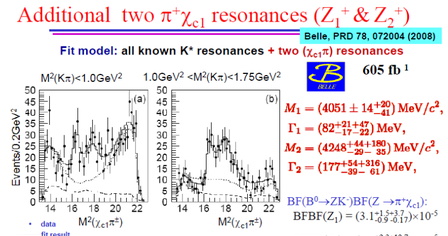
New peak in γγ→ωJ/ψ from Belle



Z(4430)⁺: Charged charmonium-like state

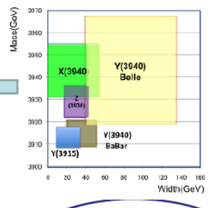


Additional two $\pi^+\chi_{c1}$ resonances (Z_1^+ & Z_2^+)



very schematically, clusters of new states

- $X(3872)$, the first surprise
- the 3940 family
- the Y family (1^{--} states):
  - $Y(4260) \to J/\psi\pi\pi$, K^+K^-
  - $Y(4350) \to \psi(2S)\pi^+\pi^-$
  - $Y(4630) \to \Lambda_c\Lambda_c$
  - $Y(4660) \to \psi(2S)\pi^+\pi^-$
- charged states
  - $Z(4430) \to \psi(2S)\pi^\pm$
  - $Z_1(4050)$, $Z_2(4250)$ $\to \chi_{c1}(2S)\pi^\pm$
- $C = +$ states
- $X(4160) \to D^*\bar{D}^*$
- $Y(4140) \to J/\psi\phi$
- $X(4350)$



$Z_c(3900)^\pm \to J/\Psi\pi^\pm$
$Z_c(4025)^\pm \to D\bar{D}^*$
$Z_c(4020)^\pm \to h_c\,\pi^\pm$
new charged states!
BES III

WHAT ARE THESE STATES?
CHARMONIUM OR EXOTICS?

QCD and exotic hadrons

Besides mesons and baryons, other "exotic" combinations of quarks and gluons could exist (i.e. are not forbidden by QCD). This include for example

Hybrid
State with excited gluonic degree of freedom
Lattice predictions for lowest mass $c\bar{c}g$ ~ 4.2 GeV

Glueball
Bound state of gluons

Tetraquark
Four-quark bound states
Large number of states expected

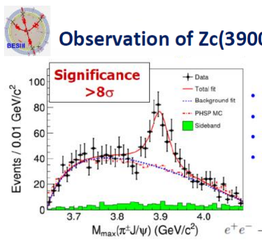
Pentaquark
Five-quark bound states

$DD^{(*)}$ molecule
Loosely bound state of pair of mesons
Small number of states

Hadrocharmonium
Charmonium state embedded in a 'shell' of light quark

And many more...

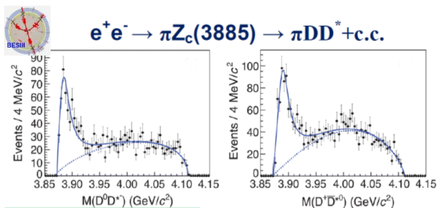
Observation of Zc(3900) in $e^+e^- \to \pi^+\pi^- J/\psi$



- Couples to cc
- Has electric charge
- At least 4-quarks
- What is its nature?

- S-wave Breit-Wigner with efficiency correction
- Mass = (3899.0±3.6±4.9) MeV
- Width = (46±10±20) MeV
- Fraction = (21.5±3.3±7.5)%

$e^+e^- \to \pi Z_c(3885) \to \pi DD^*$+c.c.



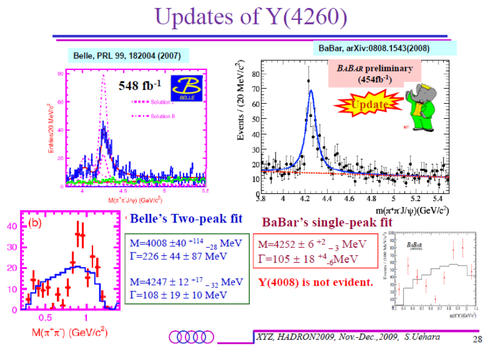
M = (3883.9±1.5±4.2) MeV/c²
Γ = (24.8±3.3±11.0) MeV/c²
>18σ

πZc(3885) ang. dist. favours $J^P = 1^+$ disfavours 1^- e 0^-

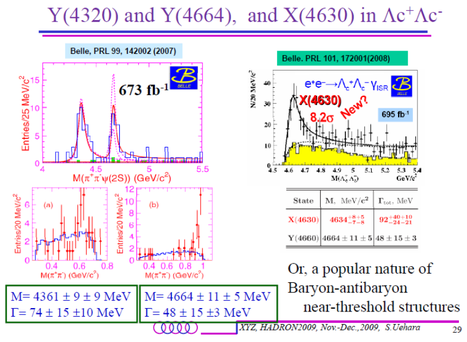
σ(e⁺e⁻→ π⁻ Zc(3885)⁺ × Zc(3885)⁺ → (DD̄*)⁺ +c.c.) = (83.5±6.6±22.0) pb

$R = \frac{\Gamma(Z_c(3885) \to D^*\bar{D}^*)}{\Gamma(Z_c(3900) \to \pi J/\psi)} = (6.2 \pm 1.1 \pm 2.7)$

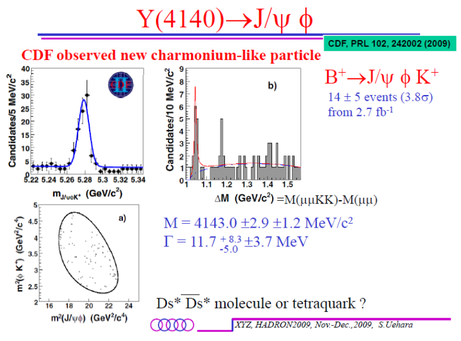
Updates of Y(4260)



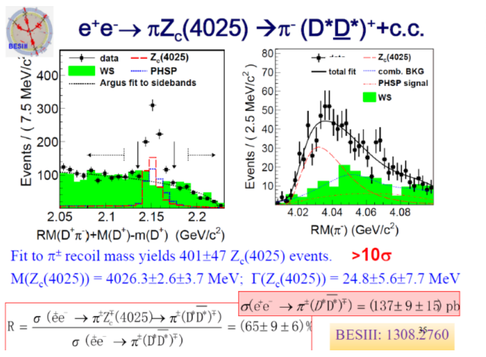
Y(4320) and Y(4664), and X(4630) in $\Lambda c^+\Lambda c^-$



Y(4140)→J/ψ φ



$e^+e^- \to \pi Z_c(4025) \to \pi^-(D^*\bar{D}^*)^+$+c.c.



Fit to π± recoil mass yields 401±47 $Z_c(4025)$ events. >10σ

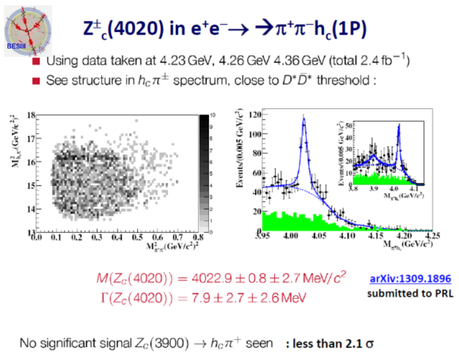
M(Zc(4025)) = 4026.3±2.6±3.7 MeV; Γ(Zc(4025)) = 24.8±5.6±7.7 MeV

$R = \frac{\sigma(e^+e^- \to \pi^\pm Z_c^\mp(4025) \to \pi^\pm(D^*\bar{D}^*)^\mp)}{\sigma(e^+e^- \to \pi^+(D^*\bar{D}^*)^-)} = (65 \pm 9 \pm 6)\%$

$\sigma(e^+e^- \to \pi^+(D^*\bar{D}^*)^-) = (137 \pm 9 \pm 15)$ pb

BESIII: 1308.2760

$Z_c^\pm(4020)$ in $e^+e^- \to \pi^+\pi^- h_c(1P)$

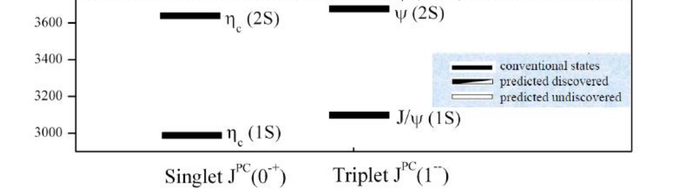


$M(Z_c(4020)) = 4022.9 \pm 0.8 \pm 2.7$ MeV/c^2
$\Gamma(Z_c(4020)) = 7.9 \pm 2.7 \pm 2.6$ MeV

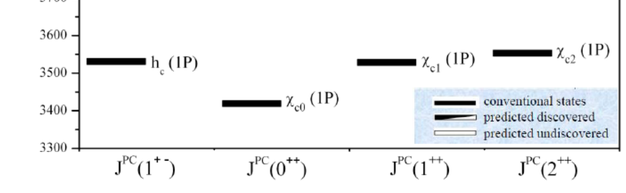
arXiv:1309.1896 submitted to PRL

No significant signal $Z_c(3900) \to h_c\pi^+$ seen : less than 2.1 σ

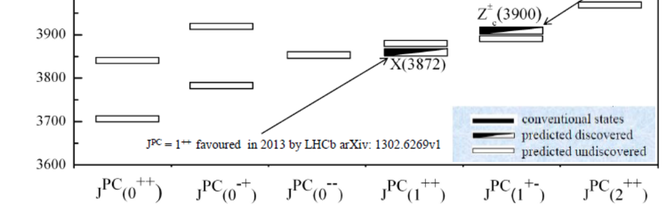
THE SPECTRUM OF SINGLET ($^1S_0$) AND TRIPLET ($^3S_1$) STATES OF CHARMONIUM



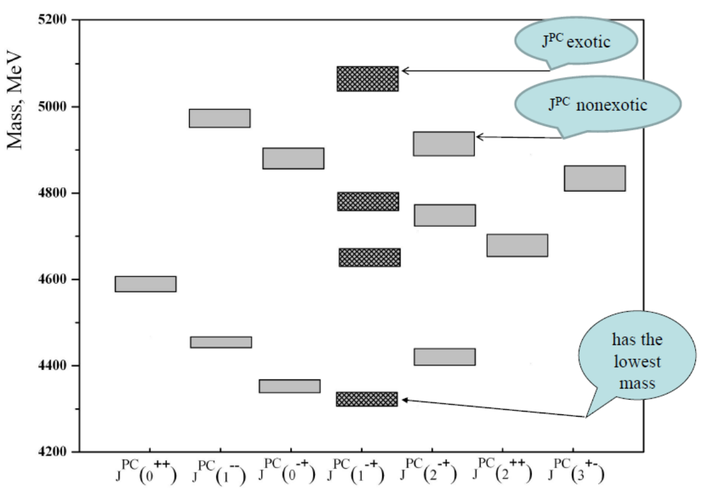
THE SPECTRUM OF SINGLET ($^1P_1$) AND TRIPLET (^3P_J) STATES OF CHARMONIUM



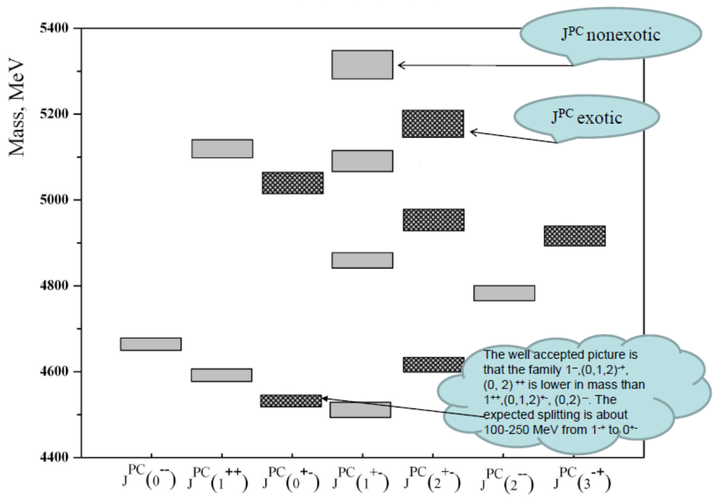
THE SPECTRUM OF TETRAQUARKS WITH THE HIDDEN CHARM



SPECTRUM OF CHARMED HYBRIDS WITH QUANTUM NUMBERS $J^{PC} = 3^{+-}, 2^{++}, 2^{-+}, 1^{-+}, 1^{--}, 0^{-+}, 0^{++}$.

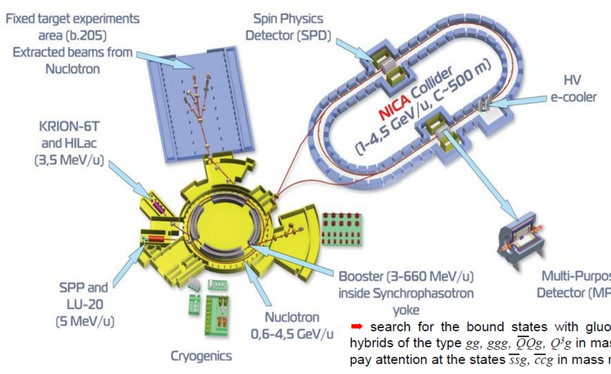


SPECTRUM OF CHARMED HYBRIDS WITH QUANTUM NUMBERS $J^{PC} = 3^{-+}, 2^{--}, 2^{+-}, 1^{+-}, 1^{++}, 0^{+-}, 0^{--}$.



Superconducting accelerator complex NICA

(Nuclotron based Ion Collider fAcility)



New physics researches at NICA in pp-collisions

$\sqrt{s_{pp}} = 20$ GeV

- search for the bound states with gluonic degrees of freedom: glueballs and hybrids of the type gg, ggg, $\bar{Q}Qg$, Q^2g in mass range from 1.3 to 5.0 GeV. Especially pay attention at the states $\bar{s}sg$, $\bar{c}cg$ in mass range from 1.8 – 5.0 GeV.
- charmonium spectroscopy $c\bar{c}$ in mass range up to 5.2 GeV: $pA \to \bar{p}pA$.
- spectroscopy of baryons with strangeness and charm Ω^0_c, Ξ_c, Ξ'_c, Ξ^+_{cc}, Ω^+_{cc}, Σ^*_b, Ω_b, Ξ^0_b, Ξ^-_b.
- charmed and bottom physics: $pp \to \Lambda_c X$; $pp \to \Lambda_c pX$; $pp \to \Lambda_c pD$; $pp \to \Lambda_b pB$.