STUDY OF CHARMONIUM-LIKE MESONS IN *pp* & *pA* COLLISIONS AT NICA

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Outline

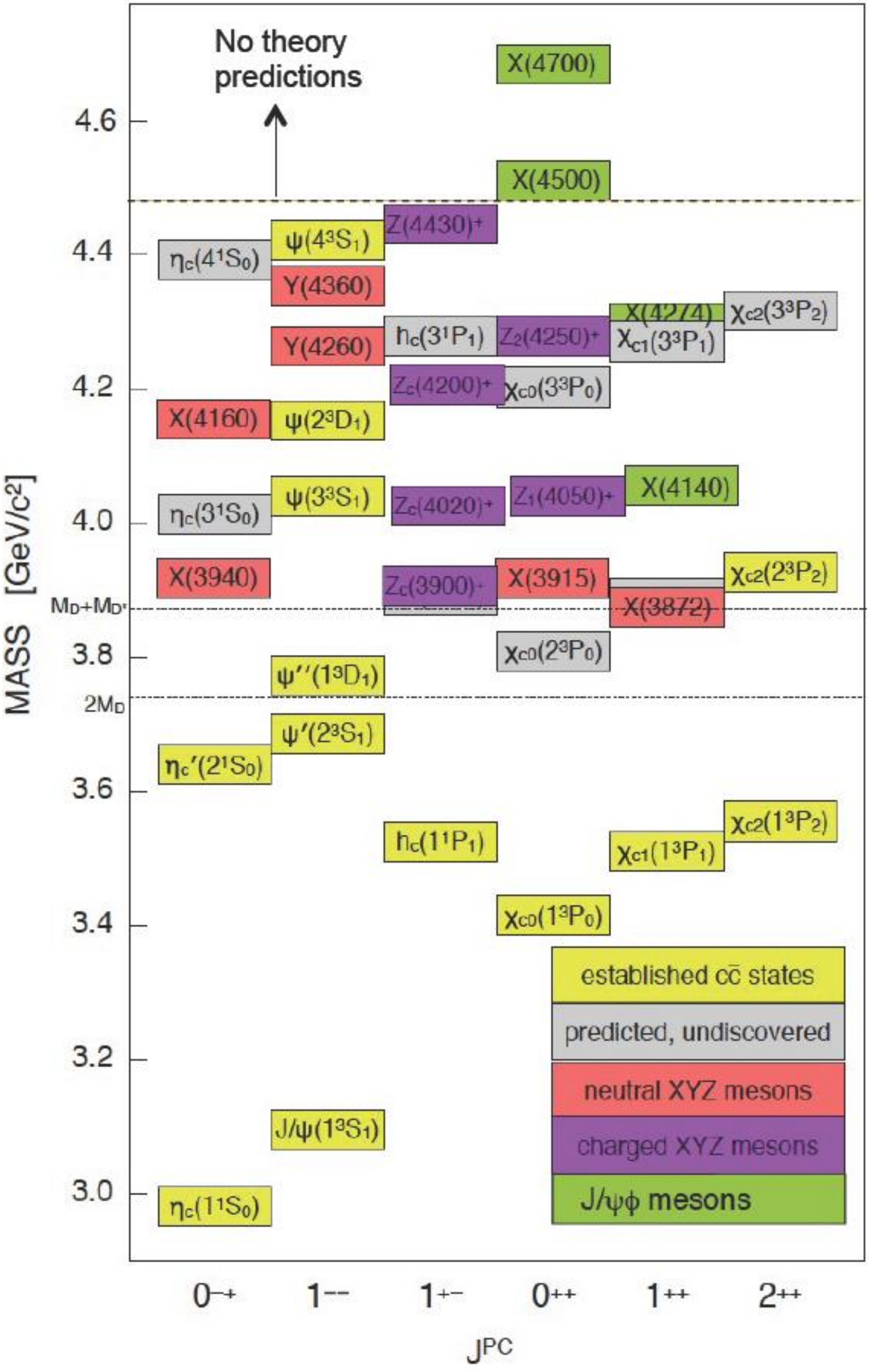
- Physics case & motivation
- Conventional & exotic hadrons
- Recent experimental review
- Physics analysis & results

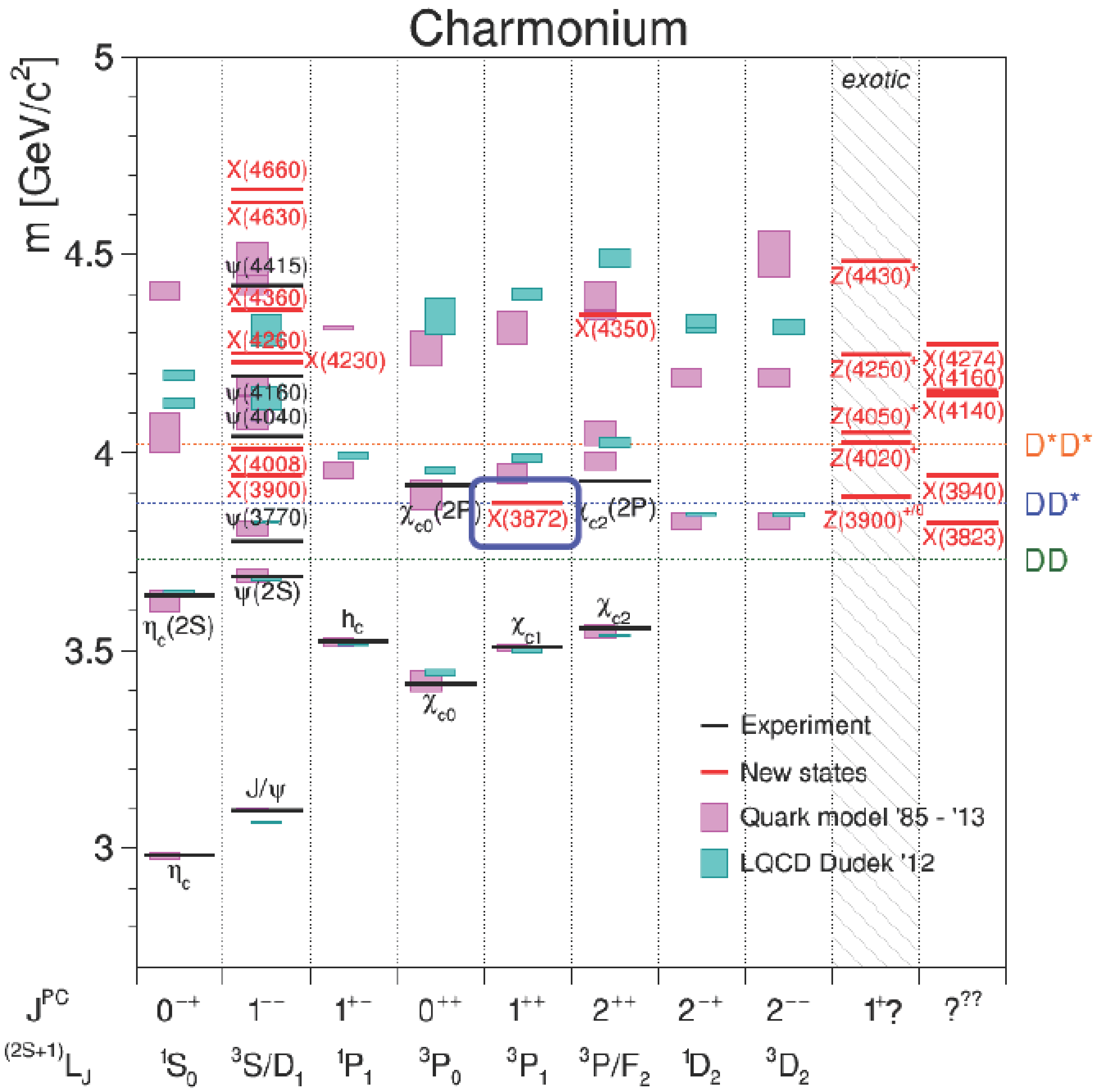
MOTIVATION

To look for charmonium-like states above DD\bar threshold (conventional and exotic) in *pp* and *pA* collisions to obtain complementary results to the ones from *e*+*e*- interactions, *B*-meson decays and *pp\bar* interactions

Motivation

- Predicted neutral charmonium states compared with found $c\bar{c}$ states, & both neutral & charged exotic candidates
- Based on Olsen [arXiv:1511.01589]
- Added 4 new J/ψϕ states




Charmonium
m [GeV/c²]
5
4.5
4
3.5
3
exotic
X(4660)
X(4630)
ψ(4415)
X(4360)
X(4260)
X(4230)
ψ(4160)
ψ(4040)
X(4008)
X(3900)
ψ(3770)
ψ(2S)
J/ψ
η_c(2S)
η_c
h_c
χ_c0
χ_c0(2P)
X(3872)
χ_c2(2P)
χ_c1
χ_c2
X(4350)
Z(4430)⁺
Z(4250)⁺
Z(4050)⁺
Z(4020)⁺
Z(3900)⁺/⁰
X(4274)
X(4160)
X(4140)
X(3940)
X(3823)
D*D*
DD*
DD
Experiment
New states
Quark model '85 - '13
LQCD Dudek '12
J^PC
0⁻⁺
1⁻⁻
1⁺⁻
0⁺⁺
1⁺⁺
2⁺⁺
2⁻⁺
2⁻⁻
1⁺?
?^??
^(2S+1)L_J
¹S₀
³S/D₁
¹P₁
³P₀
³P₁
³P/F₂
¹D₂
³D₂

Charmonium-like states possess some well favored characteristics:

- is the simplest two-particle system consisting of quark & antiquark;
- is a compact bound system with small widths varying from several tens of keV to several tens of MeV compared to the light unflavored mesons and baryons
- charm quark *c* has a large mass (1.27 ± 0.07 GeV) compared to the masses of *u, d* & *s* (~ 0.1 GeV) quarks, that makes it plausible to attempt a description of the dynamical properties of charmonium-like system in terms of non-relativistic potential models and phenomenological models;
- quark motion velocities in charmonium-like systems are non-relativistic (the coupling constant, $\alpha_s \approx 0.3$ is not too large, and relativistic effects are manageable ($v^2/c^2 \approx 0.2$));
- the size of charmonium-like systems is of the order of less than 1 Fm $(R_{c\bar{c}} \sim \alpha_s \cdot m_q)$ so that one of the main doctrines of QCD – asymptotic freedom is emerging;

<u>Therefore</u>:

♦ charmonium-like studies are promising for understanding the dynamics of quark interaction at small distances;

♦ charmonium-like spectroscopy represents itself a good testing ground for the theories of strong interactions:

    - QCD in both perturbative and nonperturbative regimes
    - QCD inspired potential models and phenomenological models

The $\overline{c}c$ system has been investigated in great detail first in e^+e^--reactions, and afterwards on a restricted scale ($E_{\bar{p}} \leq 9$ GeV), but with high precision in $\bar{p}p$-annihilation (the experiments R704 at CERN and E760/E835 at Fermilab).

The number of unsolved questions related to charmonium has remained:

- **singlet $^1D_2$ and triplet ^3D_J charmonium states are almost not determined yet;**
- **little is known about partial width of $^1D_2$ and ^3D_J charmonium states**.
- **higher laying singlet $^1S_0$, $^1P_1$ and triplet $^3S_1$, ^3P_J – charmonium states are poorly investigated;**
- **only few partial widths of ^3P_J-states are known** (some of the measured decay widths don't fit theoretical schemes and additional experimental check or reconsideration of the corresponding theoretical models is needed, more data on different decay modes are desirable to clarify the situation)**;**

AS RESULT :

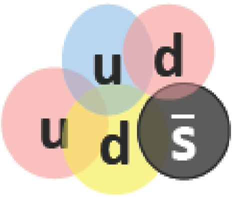
- **little is known on charmonium states above the the $D\overline{D}$ – threshold ($S, P, D, \ldots$);**
- **many recently discovered states above $D\overline{D}$ - threshold (*XYZ*-states) expect their verification and explanation (their interpretation now is far from being obvious).**

IN GENERAL ONE CAN IDENTIFY FOUR MAIN CLASSES OF CHARMONIUM DECAYS:

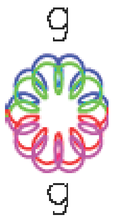
- decays into particle-antiparticle or $D\overline{D}$-pair: $\overline{c}c \to (\Psi, \eta_c, \chi_{cJ}, ..) \to \Sigma^0\overline{\Sigma}^0$, $\Lambda\overline{\Lambda}$, $\Sigma^0\overline{\Sigma}^0\pi$, $\Lambda\overline{\Lambda}\pi$;
- decays into light hadrons: $\overline{c}c \to (\Psi, \eta_c, ..) \to \rho\pi$; $\overline{c}c \to \Psi \to \pi^+\pi^-$, $\overline{c}c \to \Psi \to \omega\pi^0, \eta\pi^0, \ldots$;
- radiative decays: $\overline{c}c \to \gamma\,\eta_c$, $\gamma\,\chi_{cJ}$, $\gamma\,J/\Psi$, $\gamma\,\Psi'$, ...;
- decays with J/Ψ, Ψ' and h_c in the final state: $\overline{c}c \to J/\Psi + X \Rightarrow \overline{c}c \to J/\Psi\,\pi^+\pi^-$, $\overline{c}c \to J/\Psi\,\pi^0\pi^0$;
$\overline{c}c \to \Psi' + X \Rightarrow \overline{c}c \to \Psi'\,\pi^+\pi^-$, $\overline{c}c \to \Psi'\,\pi^0\pi^0$; $\overline{c}c \to h_c + X \Rightarrow \overline{c}c \to h_c\,\pi^+\pi^-$, $\overline{c}c \to h_c\,\pi^0\pi^0$.

non-standard hadrons

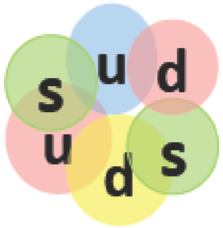
non-$q\bar{q}$ & non-qqq color-singlet combinations



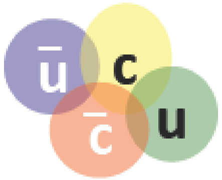
pentaquarks



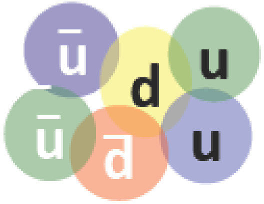
glueballs



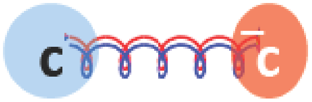
H-dibaryon



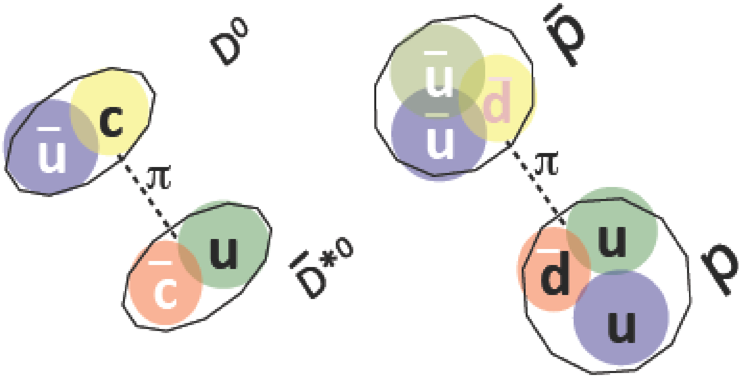
diquark-diantiquarks



heptaquarks



hybrids



deusons

protonium

molecules

Multiquark states have been discussed since the 1st page of the quark model

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A SCHEMATIC MODEL OF BARYONS AND MESONS *

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Where are they??

If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" 1-3), we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dynamical "bootstrap" model for all the strongly interacting particles within which one may try to derive isotopic spin and strangeness conservation and broken eightfold symmetry from self-consistency alone 4). Of course, with only strong interactions, the orientation of the asymmetry in the unitary space cannot be specified; one hopes that in some way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hypercharge directions.

Even if we consider the scattering amplitudes of strongly interacting particles on the mass shell only and treat the matrix elements of the weak, electromagnetic, and gravitational interactions by means

ber $n_t - n_{\bar{t}}$ would be zero for all known baryons and mesons. The most interesting example of such a model is one in which the triplet has spin $\frac{1}{2}$ and $z = -1$, so that the four particles d^-, s^-, u^0 and b^0 exhibit a parallel with the leptons.

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" 6) q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations (qqq), $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. It is assuming that the lowest baryon configuration (qqq) gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q\bar{q})$ similarly gives just **1** and **8**.

Two different kinds of experiments to study exotics:

- production experiment – $\overline{c}cg \rightarrow X + M$, where $M = \pi, \eta, \omega, \ldots$ (conventional states plus states with exotic quantum numbers)
- formation experiment (annihilation process) – $\overline{c}cg \rightarrow X \rightarrow M_1M_2$ (conventional states plus states with non-exotic quantum numbers)

The low laying charmonium hybrid states:

	Gluon	
$(q\overline{q})_8$	1^- (TM)	1^+ (TE)
$^1S_0$, 0^{-+}	1^{++}	1^{--}
$^3S_1$, 1^{--}	0^{+-} ← exotic	0^{-+}
	1^{+-}	1^{-+} ← exotic
	2^{+-} ← exotic	2^{-+}

Charmonium-like exotics (hybrids, tetraquarks) predominantly decay via electromagnetic and hadronic transitions and into the open charm final states:

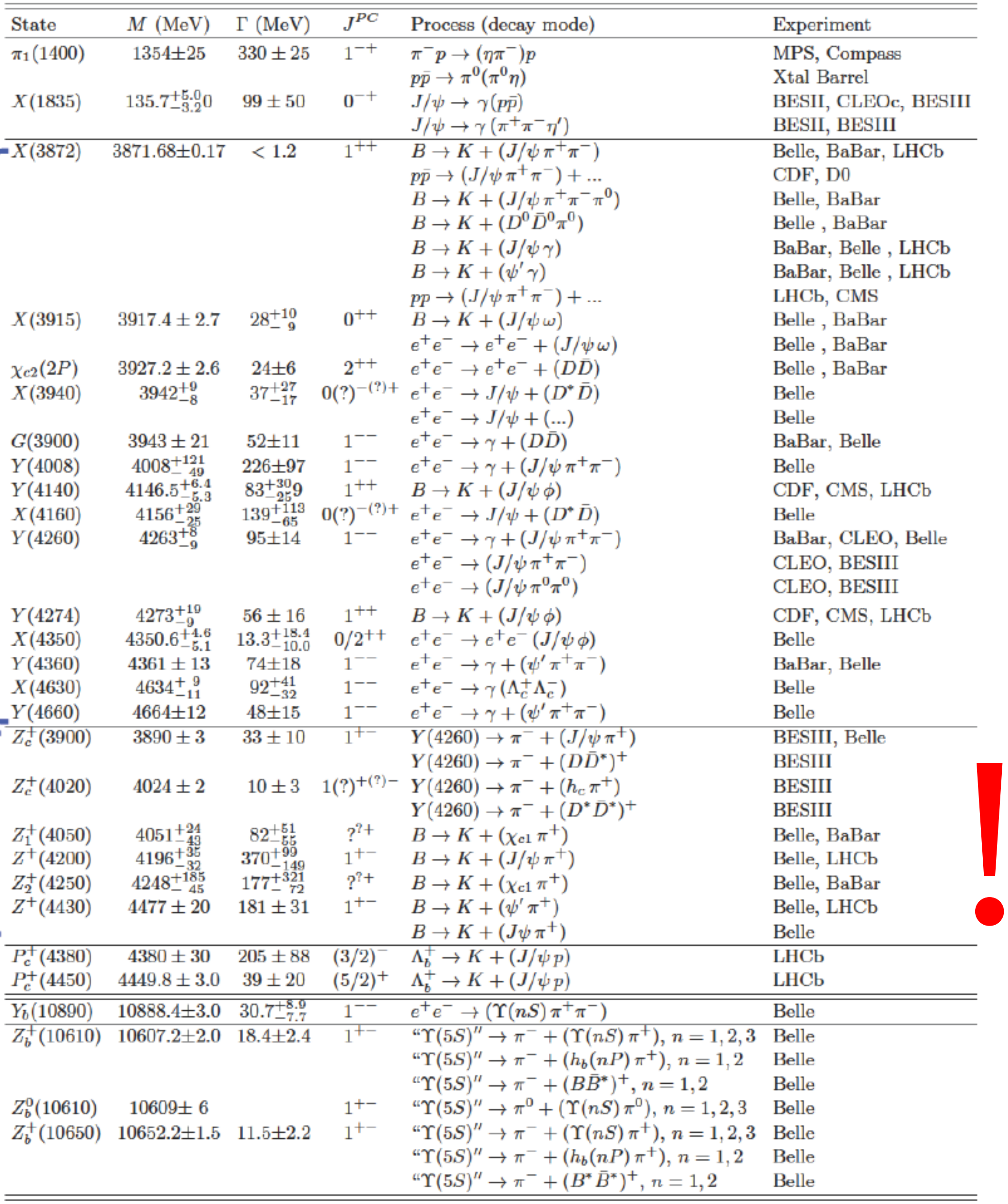
- $\overline{c}cg \rightarrow (\Psi, \chi_{cJ})$ + light mesons (η, η', ω, φ) and $(\Psi, \chi_{cJ}) + \gamma$ - these modes supply small widths and significant branch fractions;
- $\overline{c}cg \rightarrow DD_J^*$. In this case *S-wave (L = 0) + P-wave (L = 1)* final states should dominate over decays to $D\overline{D}$ (are forbidden → *CP* violation) and partial width to should be very small.

The most interesting and promising decay channels of charmed hybrids have been, in particular, analyzed:

- $\overline{c}c \rightarrow \tilde{\eta}_{c0,1,2}\ (0^{-+}, 1^{-+}, 2^{-+})\ \eta \rightarrow \chi_{c0,1,2}\ (\eta, \pi\pi, \gamma; \ldots)$;
- $\overline{c}c \rightarrow \tilde{h}_{c0,1,2}(0^{+-}, 1^{+-}, 2^{+-})\ \eta \rightarrow \chi_{c0,1,2}\ (\eta, \pi\pi, \gamma; \ldots)$;
- $\overline{c}c \rightarrow \tilde{\Psi}\ (0^{--}, 1^{--}, 2^{--}) \rightarrow J/\Psi\ (\eta, \omega, \pi\pi, \gamma \ldots)$;
- $\overline{c}c \rightarrow \tilde{\eta}_{c0,1,2}, \tilde{h}_{c0,1,2}, \tilde{\chi}_{c1}\ (0^{-+}, 1^{-+}, 2^{-+}, 0^{+-}, 1^{+-}, 2^{+-}, 1^{++})\ \eta \rightarrow D\overline{D}_J^*\ (\eta, \gamma)$.

$J^{PC} = 0^{--}$ → exotic!

Candidate exotic hadrons

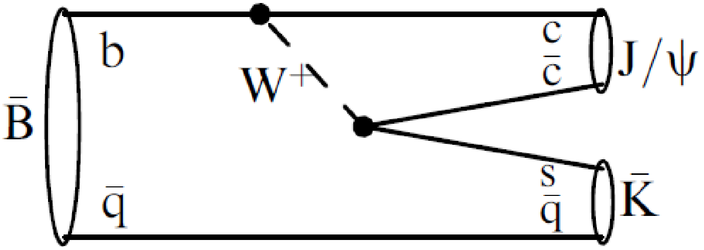


	State	M (MeV)	Γ (MeV)	J^{PC}	Process (decay mode)	Experiment
Light quark sector	$\pi_1(1400)$	1354 ± 25	330 ± 25	1^{-+}	$\pi^- p \to (\eta\pi^-)p$	MPS, Compass
					$p\bar{p} \to \pi^0(\pi^0\eta)$	Xtal Barrel
	$X(1835)$	$135.7^{+5.0}_{-3.2}0$	99 ± 50	0^{-+}	$J/\psi \to \gamma(p\bar{p})$	BESII, CLEOc, BESIII
					$J/\psi \to \gamma\,(\pi^+\pi^-\eta')$	BESII, BESIII
Charmonium-like	$X(3872)$	3871.68 ± 0.17	<1.2	1^{++}	$B \to K + (J/\psi\,\pi^+\pi^-)$	Belle, BaBar, LHCb
					$p\bar{p} \to (J/\psi\,\pi^+\pi^-) + ...$	CDF, D0
					$B \to K + (J/\psi\,\pi^+\pi^-\pi^0)$	Belle, BaBar
					$B \to K + (D^0\bar{D}^0\pi^0)$	Belle , BaBar
					$B \to K + (J/\psi\,\gamma)$	BaBar, Belle , LHCb
					$B \to K + (\psi'\,\gamma)$	BaBar, Belle , LHCb
					$pp \to (J/\psi\,\pi^+\pi^-) + ...$	LHCb, CMS
	$X(3915)$	3917.4 ± 2.7	$28^{+10}_{-\ 9}$	0^{++}	$B \to K + (J/\psi\,\omega)$	Belle , BaBar
					$e^+e^- \to e^+e^- + (J/\psi\,\omega)$	Belle , BaBar
	$\chi_{c2}(2P)$	3927.2 ± 2.6	24 ± 6	2^{++}	$e^+e^- \to e^+e^- + (D\bar{D})$	Belle , BaBar
	$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$0(?)^{-(?)+}$	$e^+e^- \to J/\psi + (D^*\bar{D})$	Belle
					$e^+e^- \to J/\psi + (...)$	Belle
	$G(3900)$	3943 ± 21	52 ± 11	1^{--}	$e^+e^- \to \gamma + (D\bar{D})$	BaBar, Belle
	$Y(4008)$	$4008^{+121}_{-\ 49}$	226 ± 97	1^{--}	$e^+e^- \to \gamma + (J/\psi\,\pi^+\pi^-)$	Belle
	$Y(4140)$	$4146.5^{+6.4}_{-5.3}$	$83^{+30}_{-25}9$	1^{++}	$B \to K + (J/\psi\,\phi)$	CDF, CMS, LHCb
	$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$0(?)^{-(?)+}$	$e^+e^- \to J/\psi + (D^*\bar{D})$	Belle
	$Y(4260)$	4263^{+8}_{-9}	95 ± 14	1^{--}	$e^+e^- \to \gamma + (J/\psi\,\pi^+\pi^-)$	BaBar, CLEO, Belle
					$e^+e^- \to (J/\psi\,\pi^+\pi^-)$	CLEO, BESIII
					$e^+e^- \to (J/\psi\,\pi^0\pi^0)$	CLEO, BESIII
	$Y(4274)$	4273^{+19}_{-9}	56 ± 16	1^{++}	$B \to K + (J/\psi\,\phi)$	CDF, CMS, LHCb
	$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0/2^{++}$	$e^+e^- \to e^+e^-\,(J/\psi\,\phi)$	Belle
	$Y(4360)$	4361 ± 13	74 ± 18	1^{--}	$e^+e^- \to \gamma + (\psi'\,\pi^+\pi^-)$	BaBar, Belle
	$X(4630)$	$4634^{+\ 9}_{-11}$	92^{+41}_{-32}	1^{--}	$e^+e^- \to \gamma\,(\Lambda_c^+\Lambda_c^-)$	Belle
	$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$e^+e^- \to \gamma + (\psi'\,\pi^+\pi^-)$	Belle
Charged charmonium-like	$Z_c^+(3900)$	3890 ± 3	33 ± 10	1^{+-}	$Y(4260) \to \pi^- + (J/\psi\,\pi^+)$	BESIII, Belle
					$Y(4260) \to \pi^- + (D\bar{D}^*)^+$	BESIII
	$Z_c^+(4020)$	4024 ± 2	10 ± 3	$1(?)^{+(?)-}$	$Y(4260) \to \pi^- + (h_c\,\pi^+)$	BESIII
					$Y(4260) \to \pi^- + (D^*\bar{D}^*)^+$	BESIII
	$Z_1^+(4050)$	4051^{+24}_{-43}	82^{+51}_{-55}	$?^{?+}$	$B \to K + (\chi_{c1}\,\pi^+)$	Belle, BaBar
	$Z^+(4200)$	4196^{+35}_{-32}	370^{+99}_{-149}	1^{+-}	$B \to K + (J/\psi\,\pi^+)$	Belle, LHCb
	$Z_2^+(4250)$	$4248^{+185}_{-\ 45}$	$177^{+321}_{-\ 72}$	$?^{?+}$	$B \to K + (\chi_{c1}\,\pi^+)$	Belle, BaBar
	$Z^+(4430)$	4477 ± 20	181 ± 31	1^{+-}	$B \to K + (\psi'\,\pi^+)$	Belle, LHCb
					$B \to K + (J\psi\,\pi^+)$	Belle
Hidden charmed pentaquarks	$P_c^+(4380)$	4380 ± 30	205 ± 88	$(3/2)^-$	$\Lambda_b^+ \to K + (J/\psi\,p)$	LHCb
	$P_c^+(4450)$	4449.8 ± 3.0	39 ± 20	$(5/2)^+$	$\Lambda_b^+ \to K + (J/\psi\,p)$	LHCb
b-quark sector	$Y_b(10890)$	10888.4 ± 3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^- \to (\Upsilon(nS)\,\pi^+\pi^-)$	Belle
	$Z_b^+(10610)$	10607.2 ± 2.0	18.4 ± 2.4	1^{+-}	"$\Upsilon(5S)$" $\to \pi^- + (\Upsilon(nS)\,\pi^+)$, $n=1,2,3$	Belle
					"$\Upsilon(5S)$" $\to \pi^- + (h_b(nP)\,\pi^+)$, $n=1,2$	Belle
					"$\Upsilon(5S)$" $\to \pi^- + (B\bar{B}^*)^+$, $n=1,2$	Belle
	$Z_b^0(10610)$	10609 ± 6		1^{+-}	"$\Upsilon(5S)$" $\to \pi^0 + (\Upsilon(nS)\,\pi^0)$, $n=1,2,3$	Belle
	$Z_b^+(10650)$	10652.2 ± 1.5	11.5 ± 2.2	1^{+-}	"$\Upsilon(5S)$" $\to \pi^- + (\Upsilon(nS)\,\pi^+)$, $n=1,2,3$	Belle
					"$\Upsilon(5S)$" $\to \pi^- + (h_b(nP)\,\pi^+)$, $n=1,2$	Belle
					"$\Upsilon(5S)$" $\to \pi^- + (B^*\bar{B}^*)^+$, $n=1,2$	Belle

!

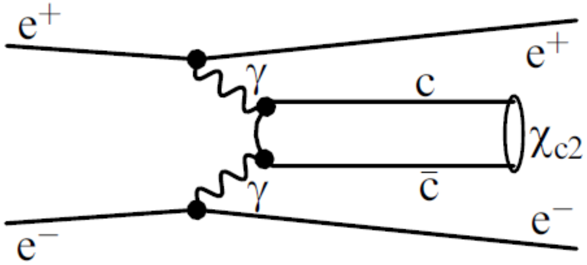
CHARMONIUM – LIKE PRODUCTION MECHANISMS RELEVANT TO THE *XYZ* – STATES

B-decays



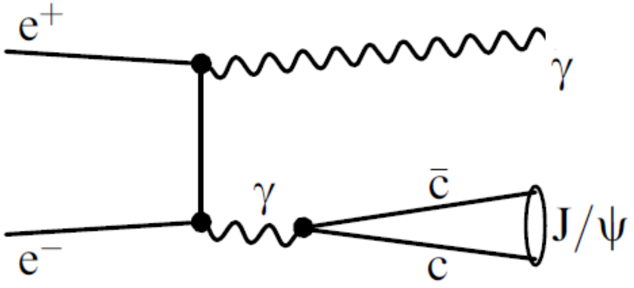
Any quantum numbers are possible

γγ fusion



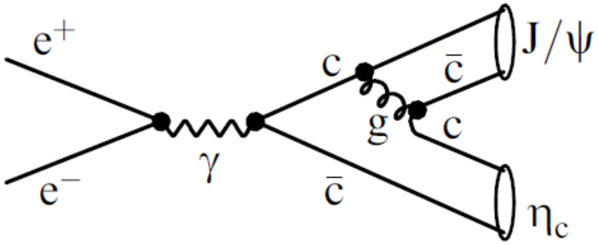
$J^{PC}=0^{-+}, 0^{++}, 2^{-+}, 2^{++}$

annihilation with initial state radiation



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

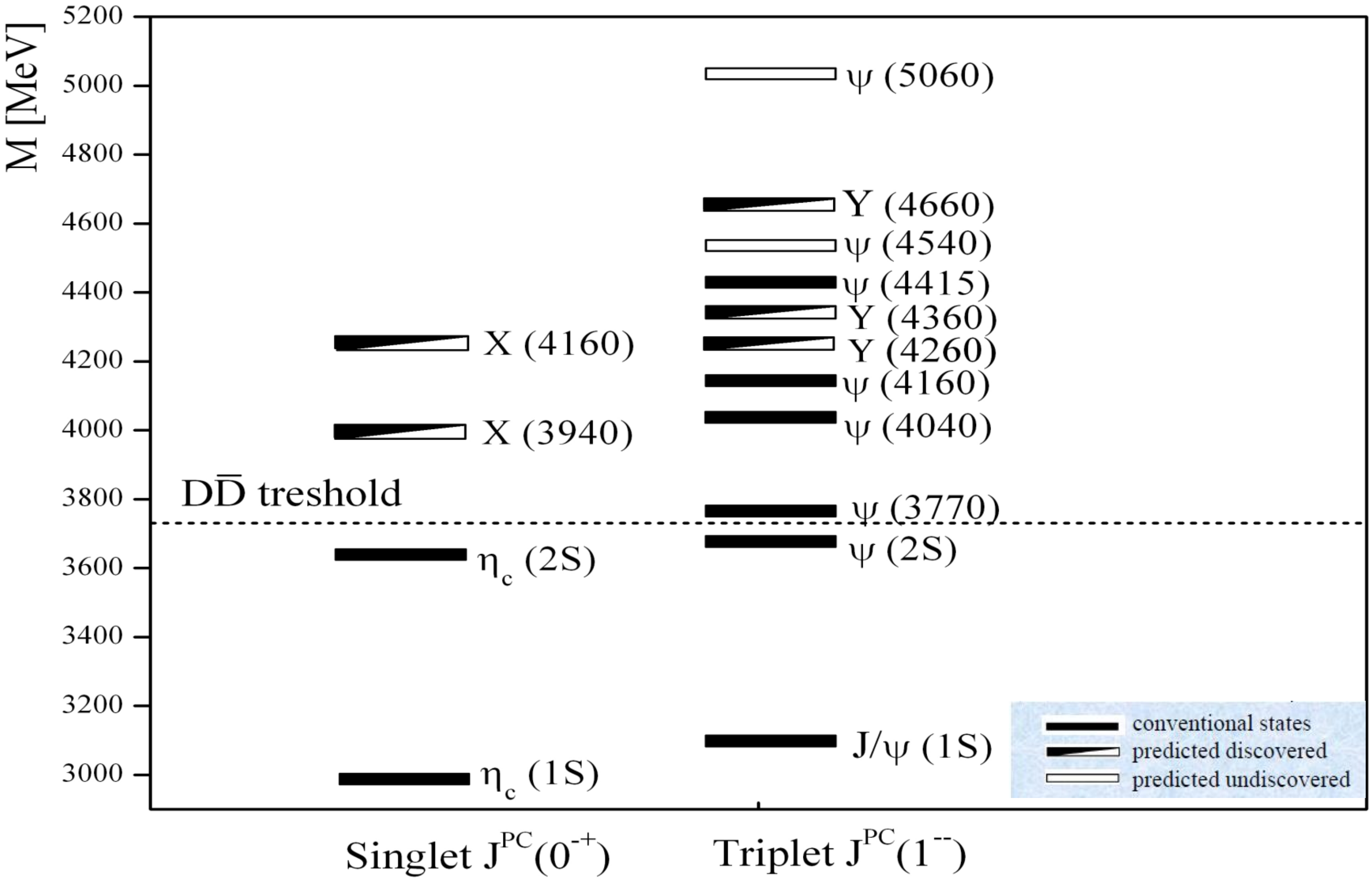
double charmonium production



in association with J/ψ only $J^{PC} = 0^{-+}, 0^{++}$ seen

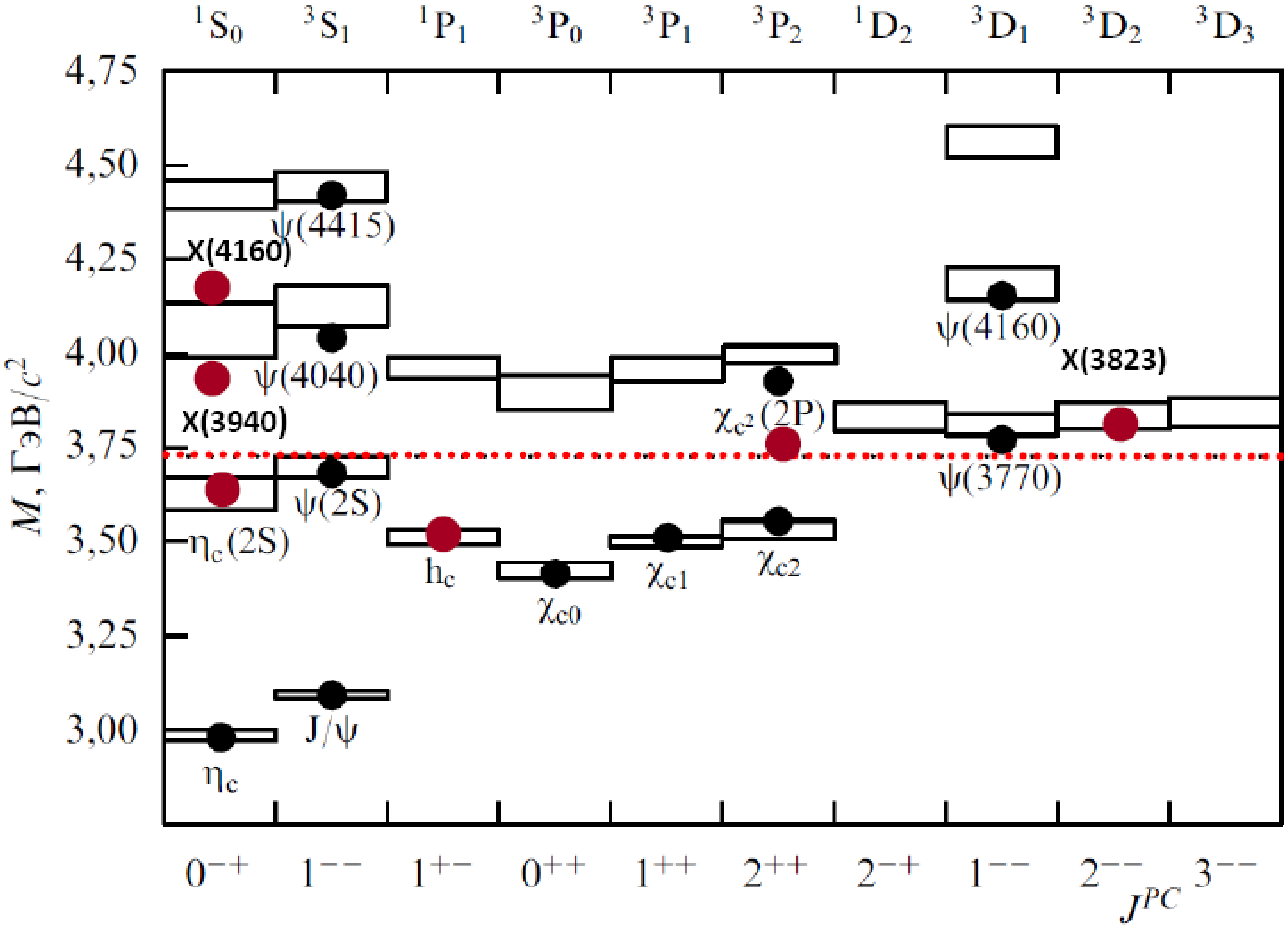
Motivation

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



M.Yu. Barabanov, A.S. Vodopyanov, S.L. Olsen, Yadernaya Fizica, V.77, N.1, pp. 1 - 5 (2014) / Phys. At. Nucl., V.77, N.1, pp. 126 -130 (2014)

6 observed states can fit* into charmonium table

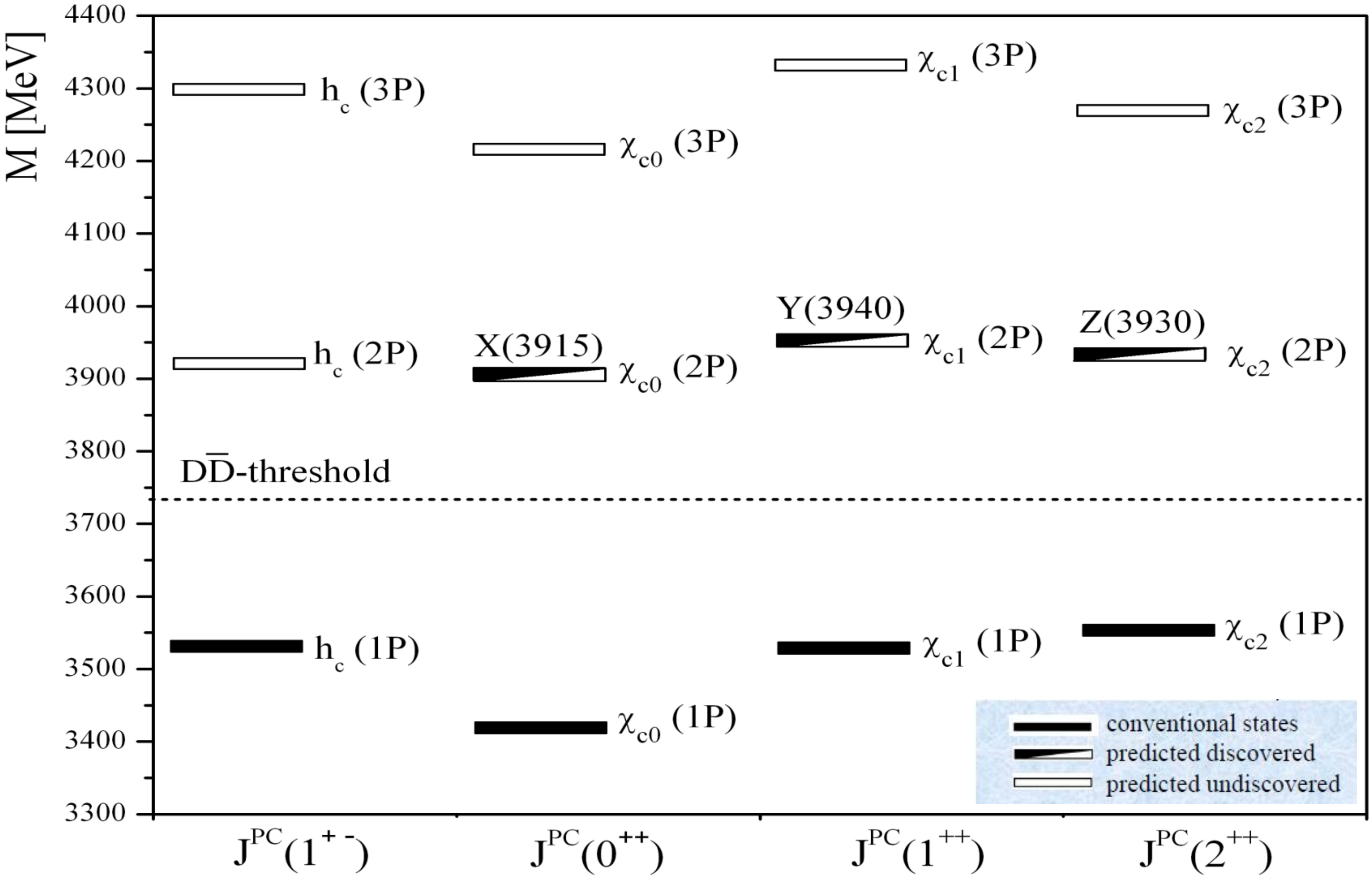


* However, not easily: potential models need to be elaborated to describe new masses

What about others?

Motivation

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



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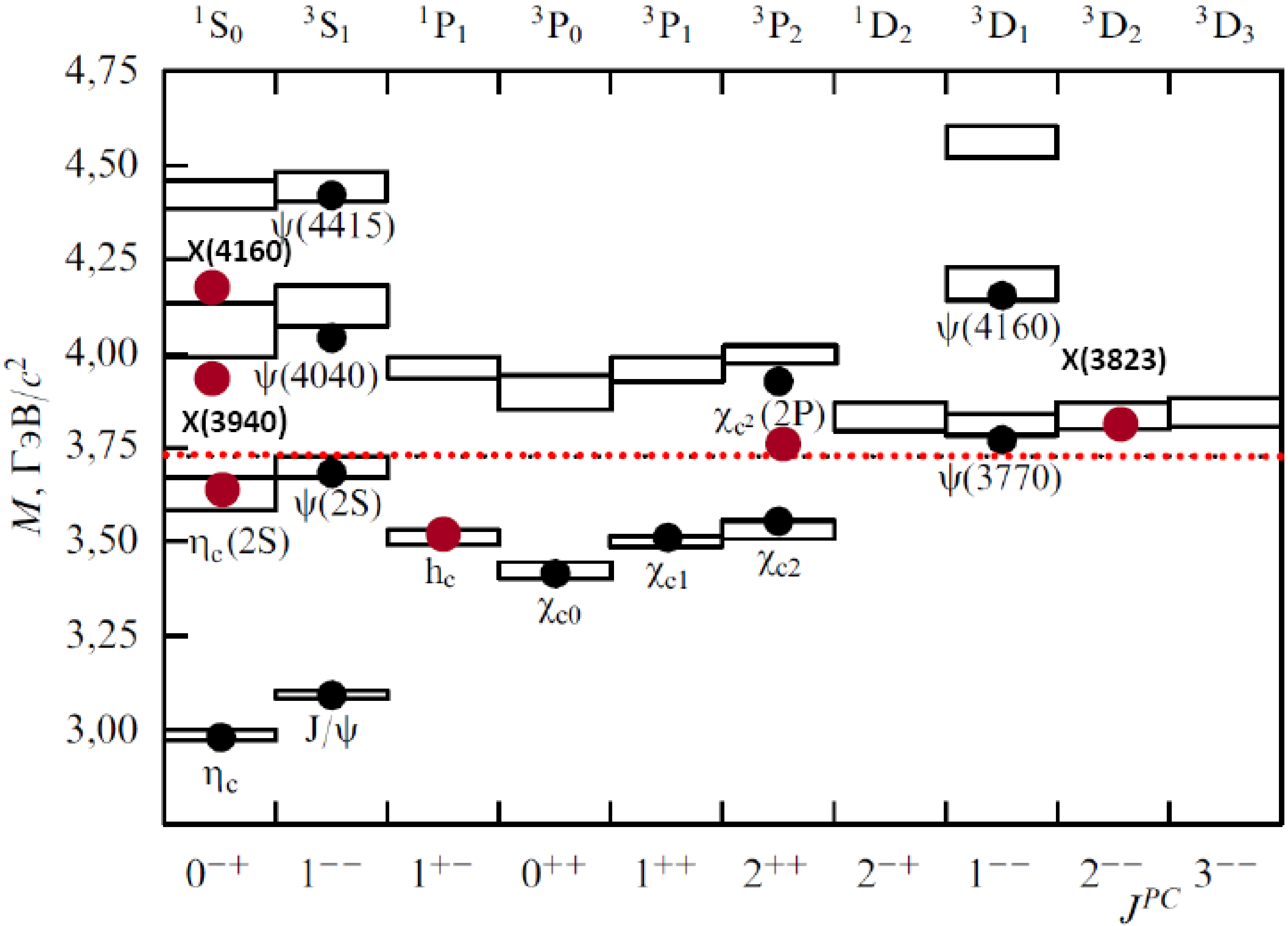
6 observed states can fit* into charmonium table

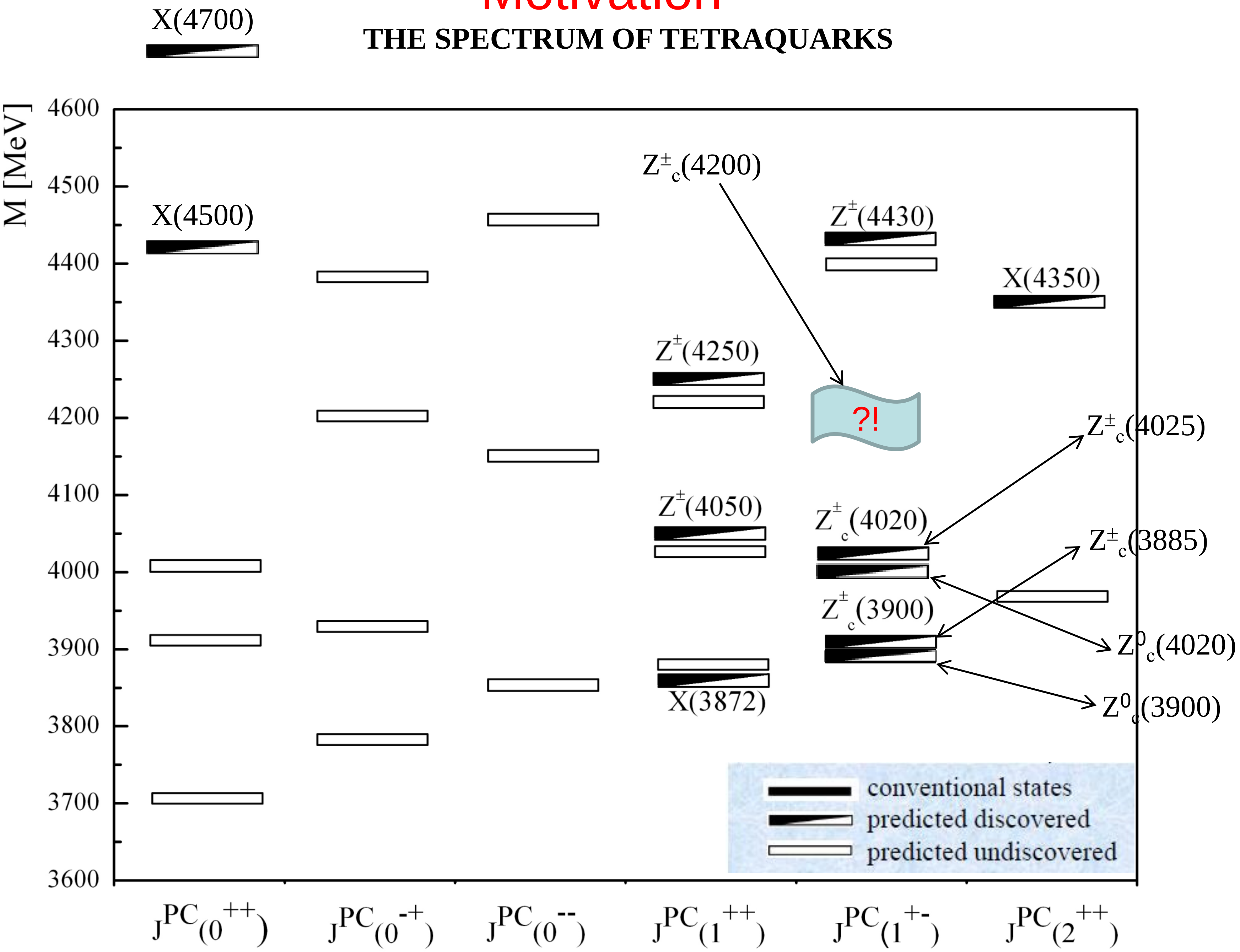


* However, not easily: potential models need to be elaborated to describe new masses

What about others?

Motivation

THE SPECTRUM OF TETRAQUARKS



M.Yu. Barabanov, A.S. Vodopyanov, S.L. Olsen, A.I. Zinchenko, Yad. Fiz., V.79, N.1, pp. 1 - 4 (2016) / Phys. At. Nucl., V.79, N.1, pp. 126 - 129 (2016)
M.Yu. Barabanov, A.S. Vodopyanov, A.I. Zinchenko, Nuovo Cimento C, 2018, in print

What to look for

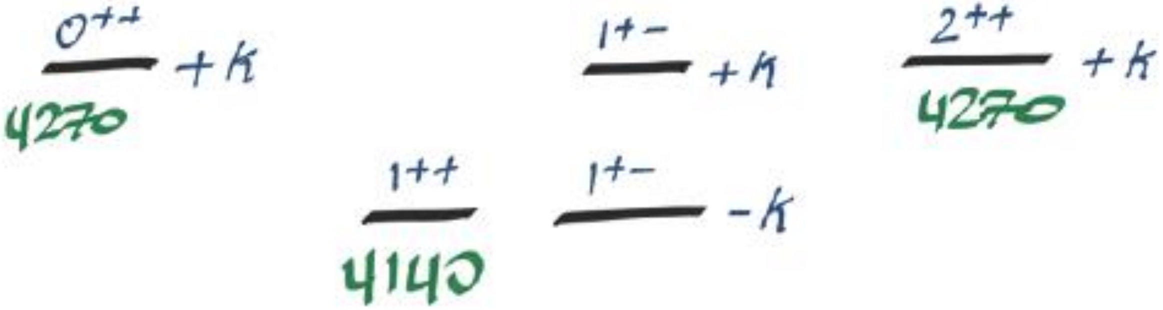
- Does the Z(4433) exist??
- Better to find charged X !
- Neutral partners of Z(4433)~$X(1^{+-},2S)$ should be close by few MeV and decaying to $\psi(2S)\ \pi/\eta$ or $\eta_c(2S)\ \rho/\omega$
- What about $X(1^{+-},1S)$? Look for any charged state at ≈ 3880 MeV (decaying to $\psi\pi$ or $\eta_c\rho$)
- Similarly one expects $X(1^{++},2S)$ states. Look at M~4200-4300: $X(1^{++},2S)\text{->}D^{(*)}D^{(*)}$
- Baryon-anti-baryon thresholds at hand (4572 MeV for $2M_{\Lambda c}$ and 4379 MeV for $M_{\Lambda c}+M_{\Sigma c}$). $X(2^{++},2S)$ might be over bb-threshold.

(L.Maiani, A.D.Polosa, V.Riquer, 0708.3997

TETRAQUARK STATES

There are indications of structures in $J/\psi\,\phi$ of the kind $[cs]_0[\bar{c}\bar{s}]_1 + [cs]_1[\bar{c}\bar{s}]_0$ — FROM LHCb.

SPECTRUM



and 4500 0^{++}
4700 0^{++}
(RADIAL EXCITATIONS
LIKE Z(4430)?)

PROBLEM: 4270 seems at the moment a 1^{++}!!

A.D. Polosa, “Bound states in QCD and beyond II”, Germany, 20th - 23rd Feb, 2017

Software

1. *MpdRoot as a framework*
2. *Pythia8, UrQMD3.3 generators*
3. *MpdRoot Geant3 transport*
4. *MpdRoot TPC Kalman filter – based track and vertex reconstruction*

Running conditions

1. $p+p$ at $\sqrt{s} = 25$ GeV

2. Luminosity $L = 10^{29}\ cm^{-2}c^{-1}$ - $10^{31}\ cm^{-2}c^{-1}$

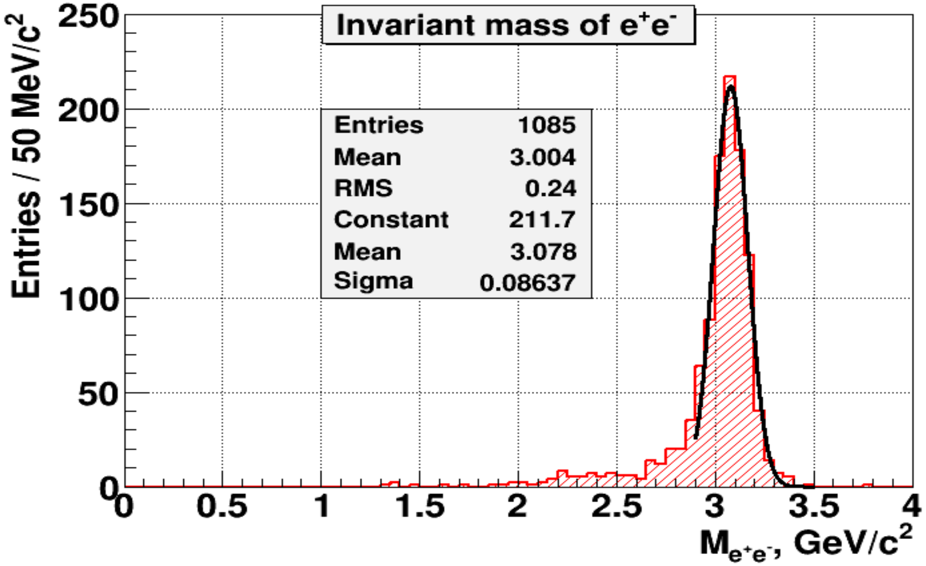
3. Running time 10 weeks:
integrated luminosity $L_{int} = 604.8\ nb^{-1}$ - $60.48\ pb^{-1}$

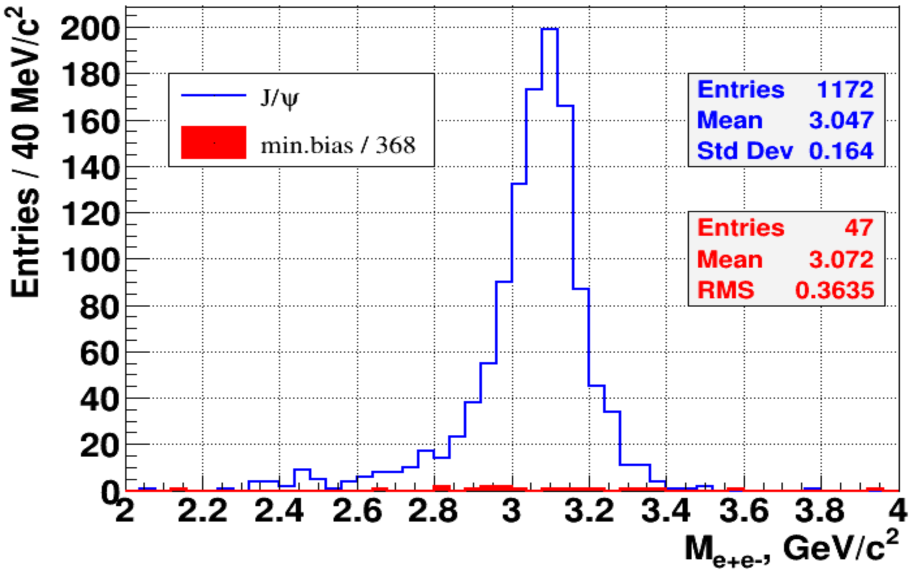
Expectations for J/ψ

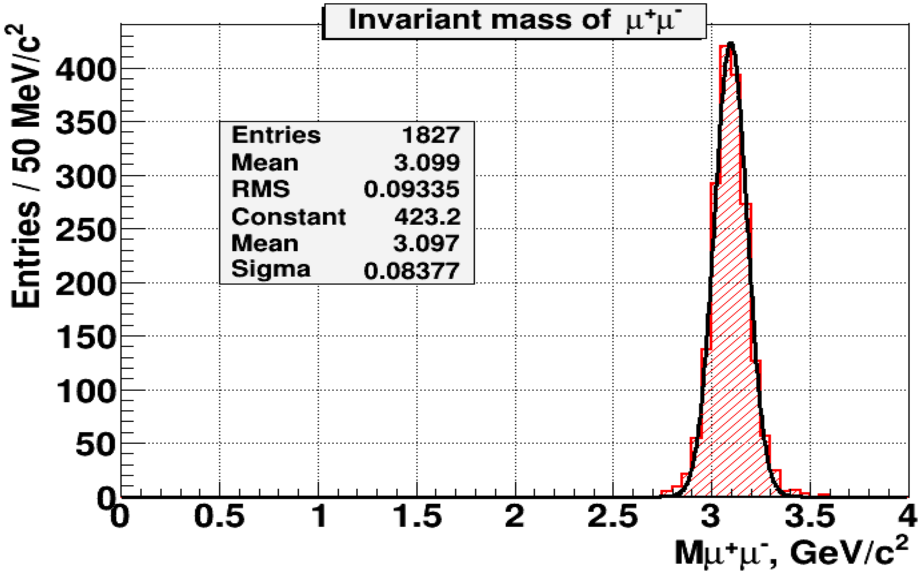
1. X-section $\sigma_{J/\psi}$ from Pythia8 108.7 nb

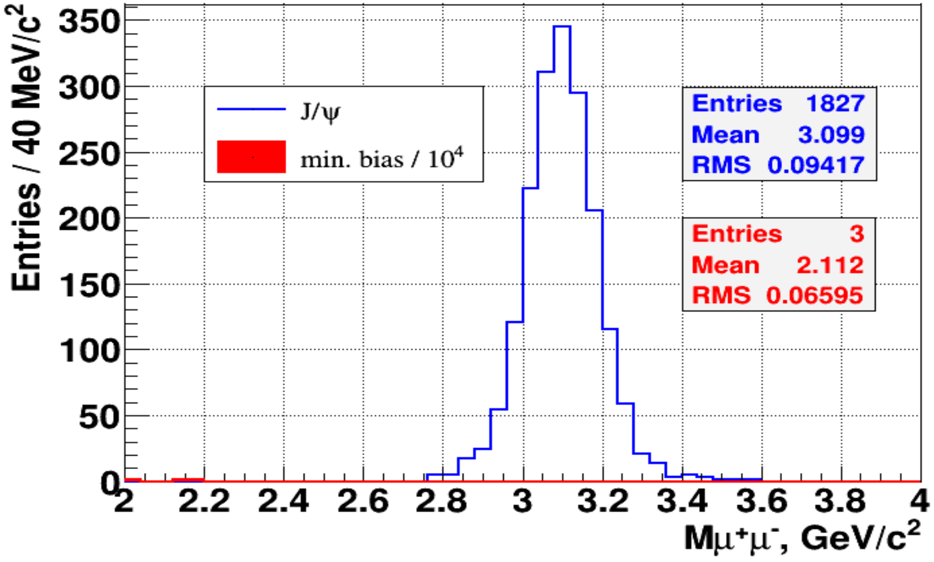
2. Statistics: $N_{J/\psi} = L_{int} \cdot \sigma_{J/\psi} \cdot Br_{J/\psi \rightarrow e+e-} \cdot Eff._{\Delta\eta=\pm 1.5} =$
$604.8 \cdot 108.7 \cdot 0.06 \cdot 0.8 = 3156$

Invariant mass: $e^- + e^+$ or $\mu^- + \mu^+$









Reconstructed invariant mass $J/\psi\pi^+\pi^-$ (from CDF)

VOLUME 93, NUMBER 7 PHYSICAL REVIEW LETTERS week ending 13 AUGUST 2004

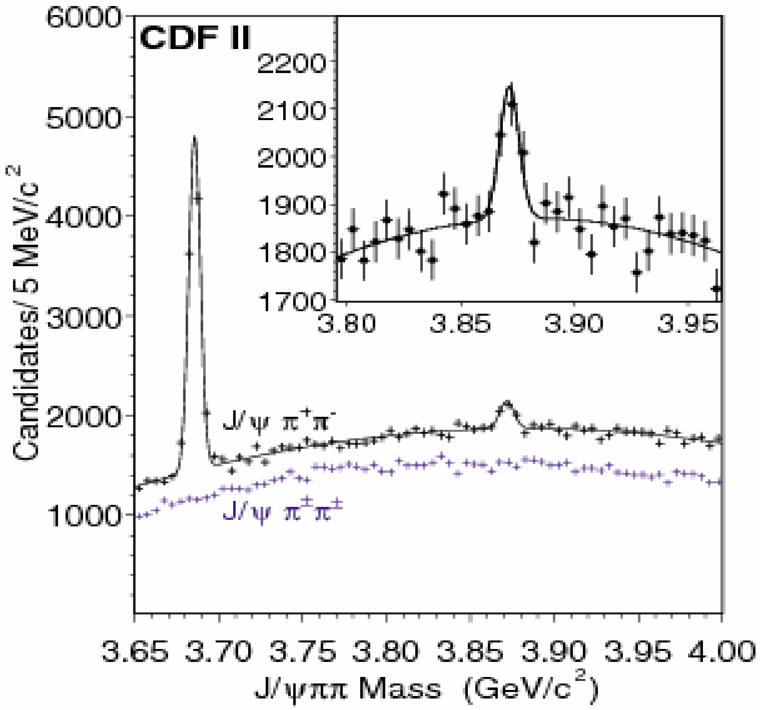


FIG. 1 (color online). The mass distributions of $J/\psi\pi^+\pi^-$ and $J/\psi\pi^\pm\pi^\pm$ candidates passing the selection described in the text. A large peak for the $\psi(2S)$ is seen in the $J/\psi\pi^+\pi^-$ distribution as well as a small signal near a mass of 3872 MeV/c^2. The curve is a fit using two Gaussians and a quadratic background to describe the data. The inset shows an enlargement of the $J/\psi\pi^+\pi^-$ data and fit around 3872 MeV/c^2.

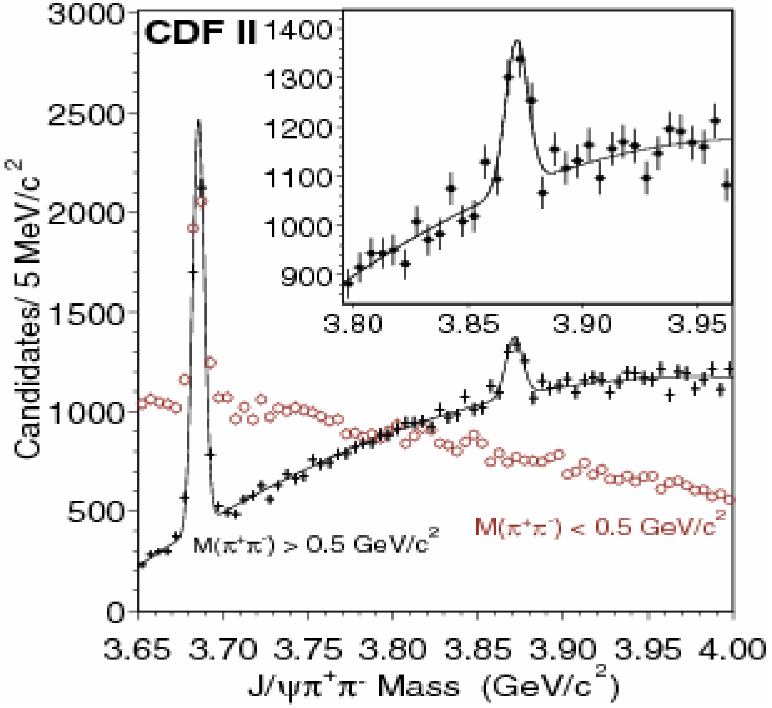


FIG. 2 (color online). The mass distributions of $J/\psi\pi^+\pi^-$ candidates with $m(\pi^+\pi^-) > 0.5$ GeV/c^2 (points) and $m(\pi^+\pi^-) < 0.5$ GeV/c^2 (open circles). The curve is a fit with two Gaussians and a quadratic background. The inset shows an enlargement of the high dipion-mass data and fit.

Requiring $M(\pi^+\pi^-) > 0.5$ MeV/c^2 reduces the back-

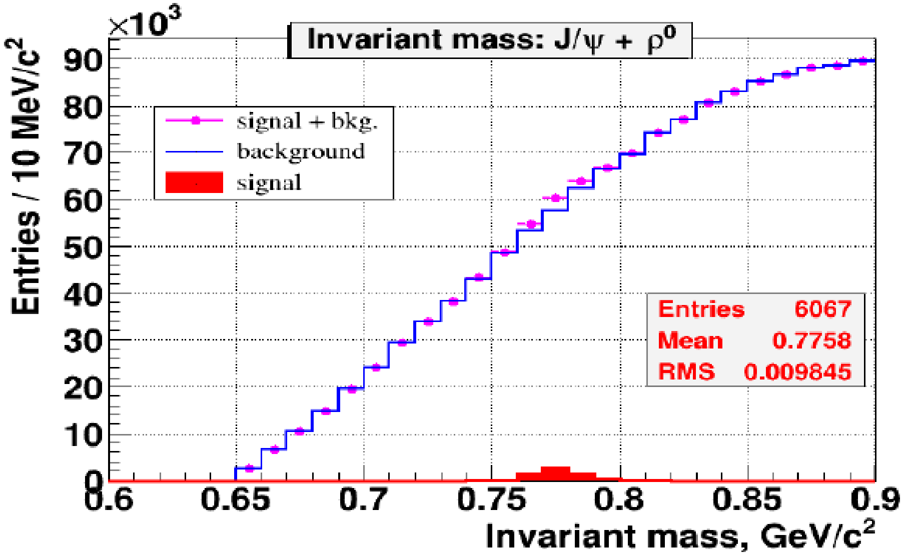
X(3872) state

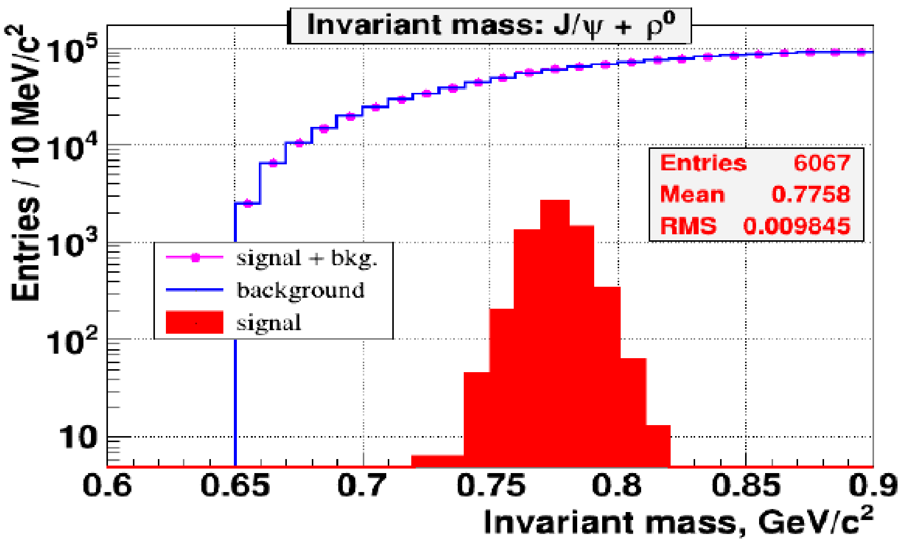
1. X-section in Pythia8 for X(3872) is 4 nb (X(3872) $\equiv \psi(3770)$ with mass 3.872 GeV)

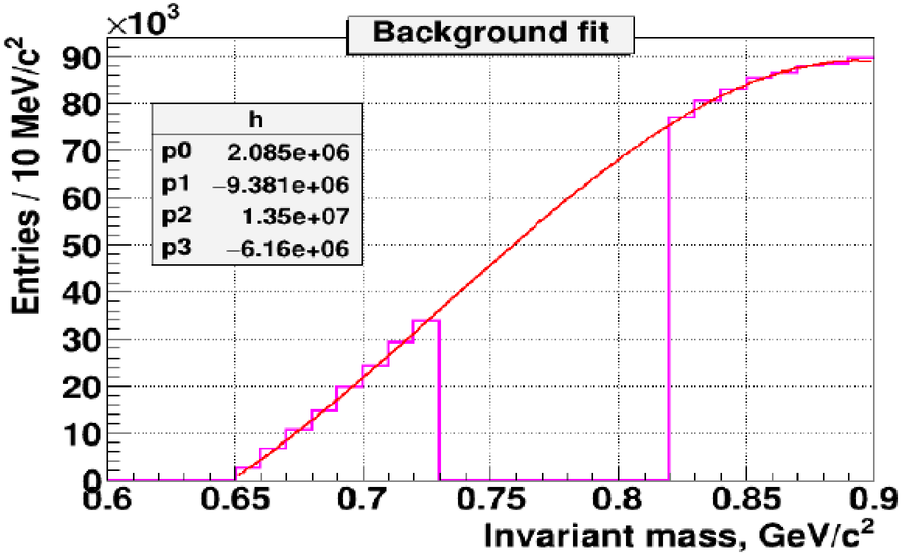
2. Br (X3872$\rightarrow J/\psi\ \rho^0$) = 5.0%
   Br (X3872$\rightarrow e^+e^-\ \pi^+\pi^-$) = 0.3% → X-section = 12.2 pb
   1000 events at L = 10^{31} cm^{-2}s^{-1} : 95 days
   10^{32} cm^{-2}s^{-1} and 10 months: 31600 events

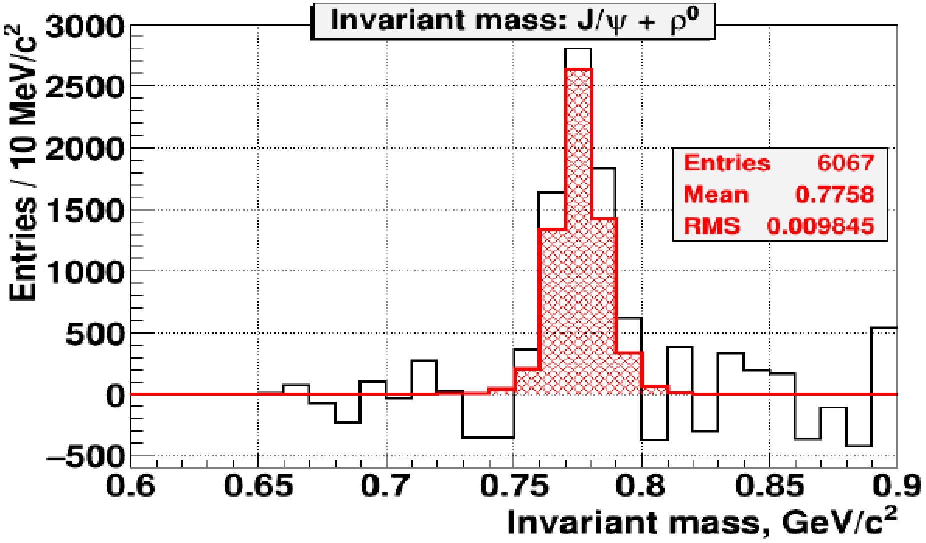
$X(3872) \rightarrow J/\psi + \rho^0$

Using mass combination: $M_{e+e-\pi+\pi-} - M_{e+e-}$









Probing the X(3872) meson structure with near-threshold pp and pA collisions at NICA

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Pythia8 predictions for X(3872)

1. *X-section of $\psi(3770)$ with m = 3.872 GeV at pp 12.5+6.5 GeV: 1.3 nb*

2. *X-section at pCu: 1.3 * A (=63) = 81.9 nb*

3. *Br (X(3872)$\rightarrow J/\psi\ \pi+\pi-$) = 5.00%*
   Br (X(3872)$\rightarrow D^+D^-$) = 40.45%
   Br (X(3872)$\rightarrow D^0D^{*0}$bar) = 54.55% ⇒ D^0D^0barπ^0 = 35.29%

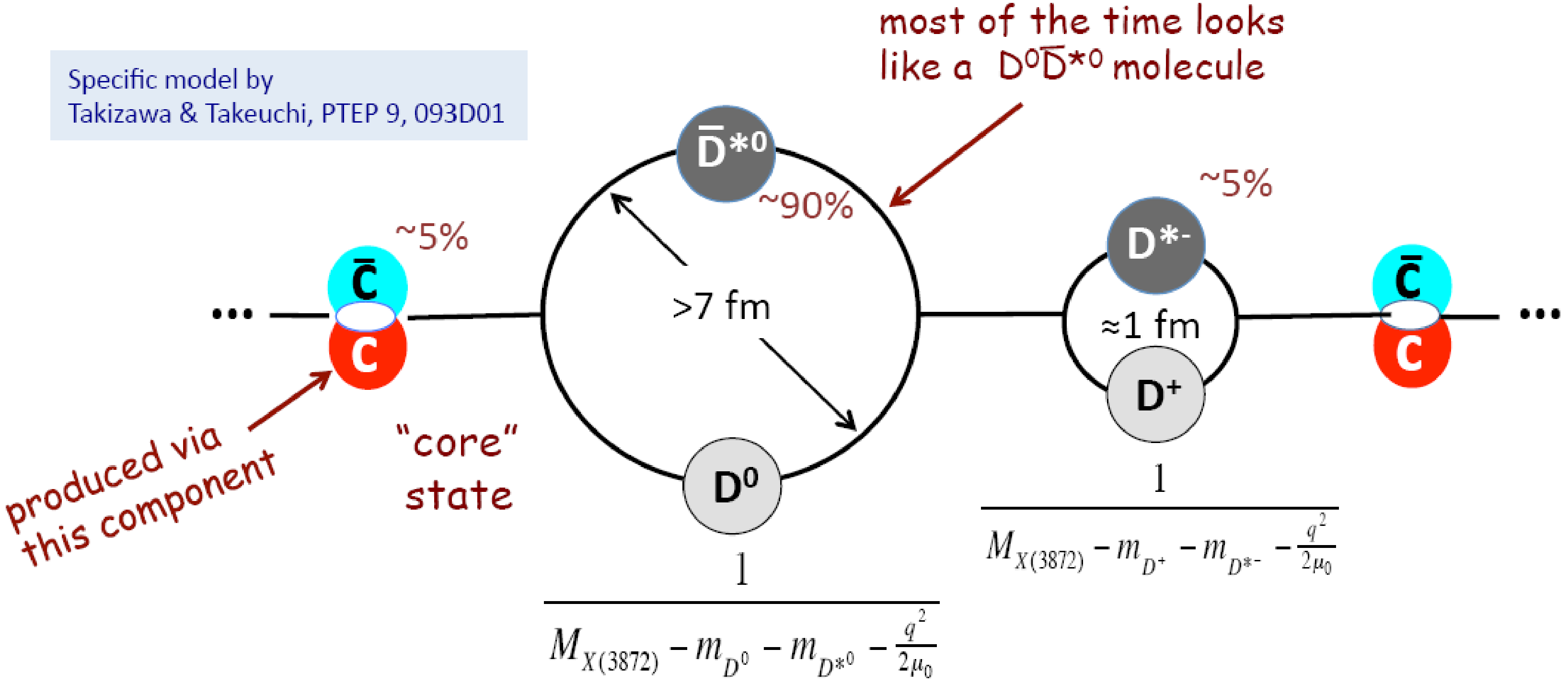
4. *Br (D+->K-π+π+) = 9.2%, Br (D0->K-π+) = 3.8%*

5. *σ(pCu) * Br(J/ψ $\pi+\pi-$) * Br(e+e-) = 81.9 * 0.05 * 0.06 = 0.246 nb*
   *σ(pCu) * Br(D+D-) * Br(K$\pi\pi$)^2 = 81.9 * 0.4045 * 0.092 * 0.092 = 0.280 nb*
   *σ(pCu) * Br(D^0D^0barπ^0) * Br(Kπ)^2 = 81.9 * 0.3529 * 0.039 * 0.039 = 0.044 nb*

0.280 nb => L = 5.9 x 10^{29} (1000 events / 10 weeks)

Probably a mixture of $D\bar{D}^*$ & a $c\bar{c}$ “core”

Specific model by
Takizawa & Takeuchi, PTEP 9, 093D01



most of the time looks like a $D^0\bar{D}^{*0}$ molecule

produced via this component

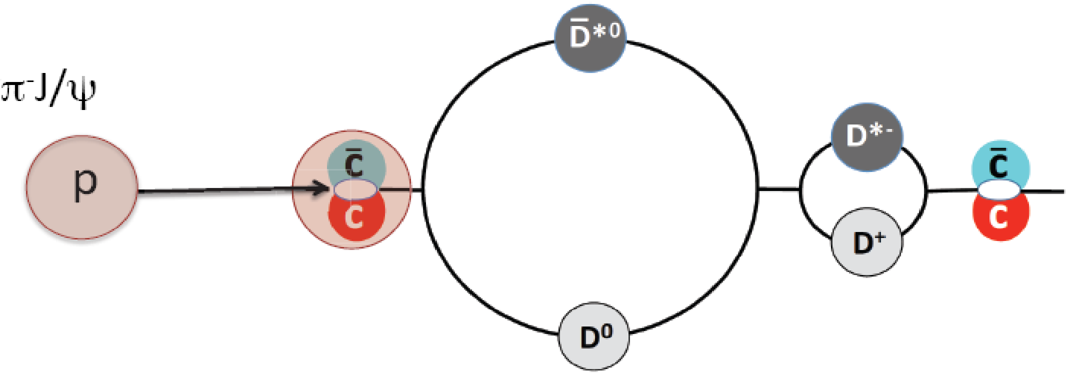
“core” state

$$\frac{1}{M_{X(3872)} - m_{D^0} - m_{D^{*0}} - \frac{q^2}{2\mu_0}}$$

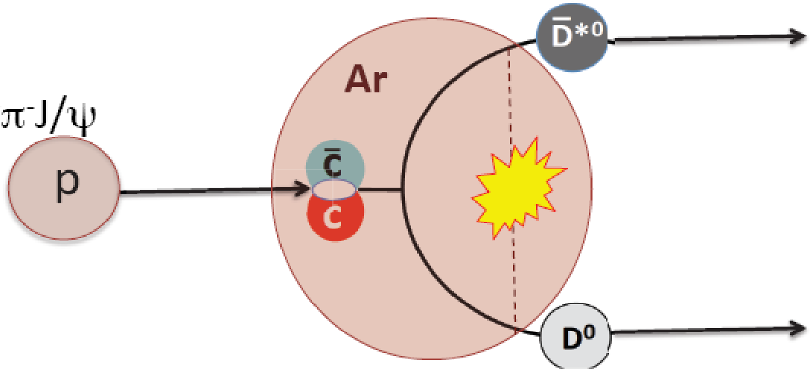
$$\frac{1}{M_{X(3872)} - m_{D^+} - m_{D^{*-}} - \frac{q^2}{2\mu_0}}$$

Near-threshold prod. via pp & pA

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



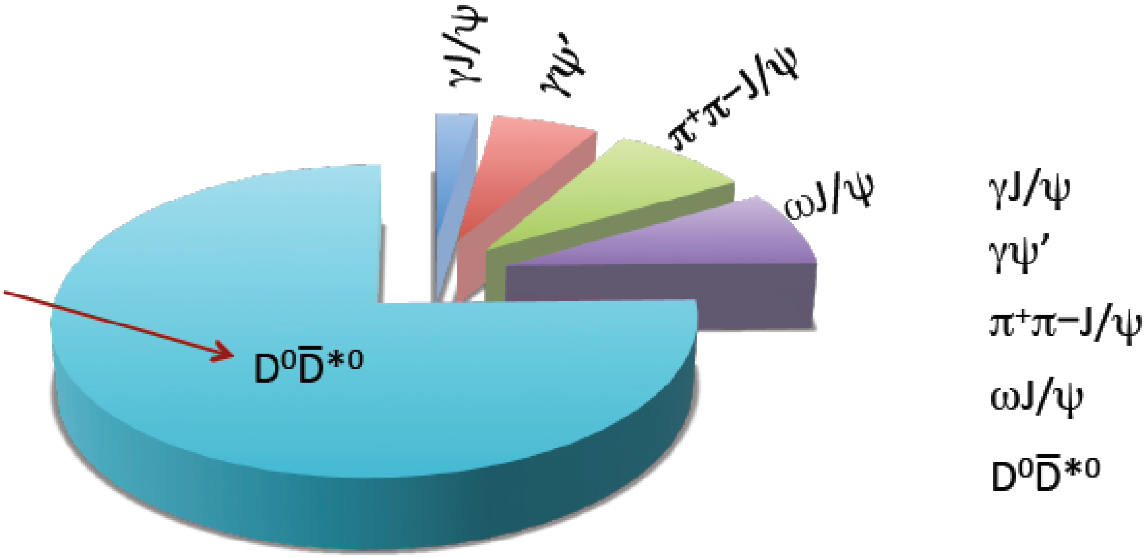
$pAr \rightarrow X(3872) \rightarrow \pi^+\pi^- J/\psi$



Strong quenching for A~40 nuclei??

$$\sqrt{s_{pN}} \simeq 8\ \mathrm{GeV}$$

X(3872) decay channels



strong $D\bar{D}^*$ coupling

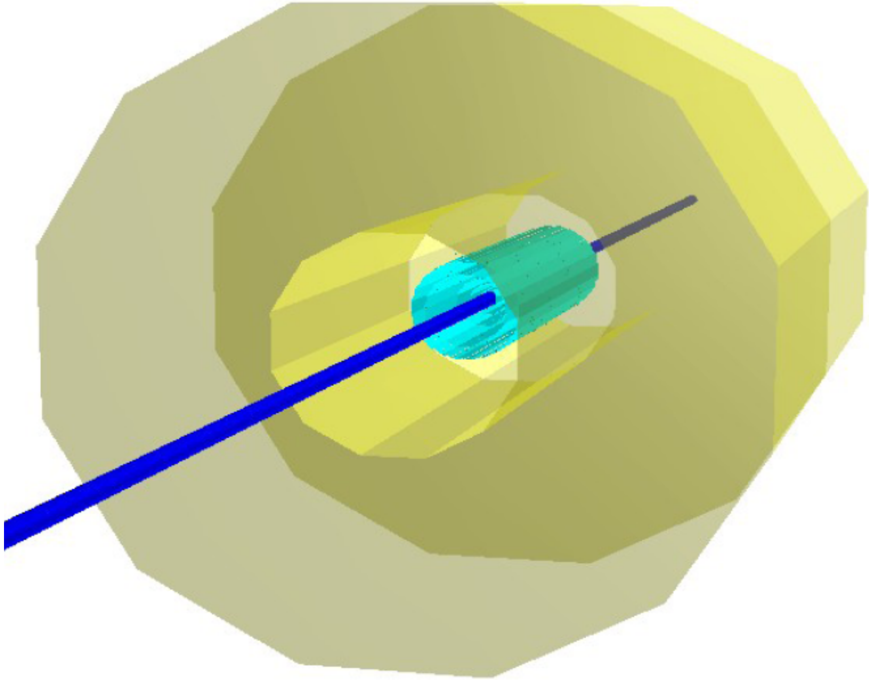
$$\Gamma_{\text{“tot”}} \approx 15\,\Gamma(X(3872)\rightarrow\pi^+\pi^- J/\psi)$$

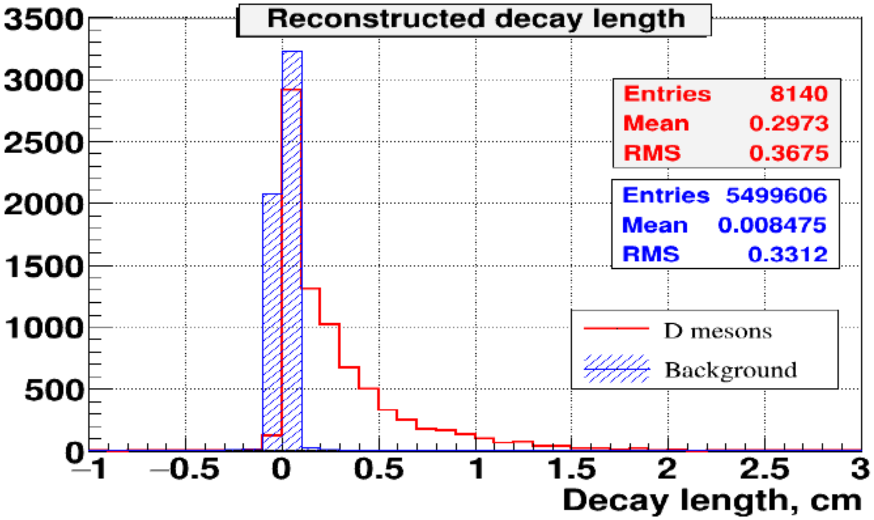
$$\Gamma(X(3872)\rightarrow\pi^+\pi^- J/\psi) < 80\ \text{keV}$$

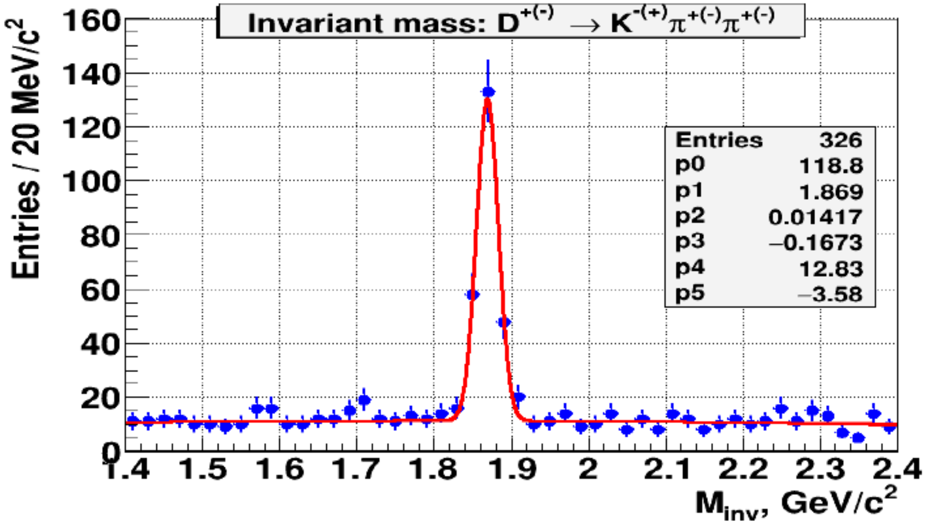
$$\Gamma(X(3872) \rightarrow p\bar{p}) < 0.002\Gamma(\pi^+\pi^- J/\psi) < 160eV$$

MPD Inner Tracking System (ITS)

MAPS (Monolithic Active Pixel Sensors)







Summary / Conclusions

♦ Many observed states remain puzzling and can not be explained for many years. This stimulates and motivates for new searches and ideas to obtain the nature of multiquark states.

♦ Physics analysis for the *pp* & *pA* collisions is in progress nowadays. Preliminary results have been obtained.

♦ The experiments with *pp* & *pA* collisions can obtain some valuable information on the charm production.

♦ Measurements of charmonium-like states can be considered as one of the “pillars” of *pp* & *pA* program.

♦ For hadronic decays the silicon ITS should greatly enhance the research potential (reconstruction and selection).

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Acknolegement

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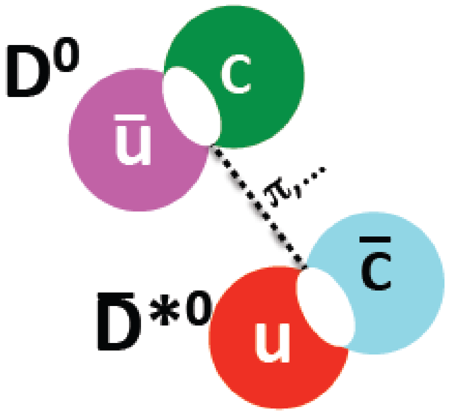
R. Tsenov

Models for the Y(3872)

D^0-$\bar{D}^{*0}$ molecule?

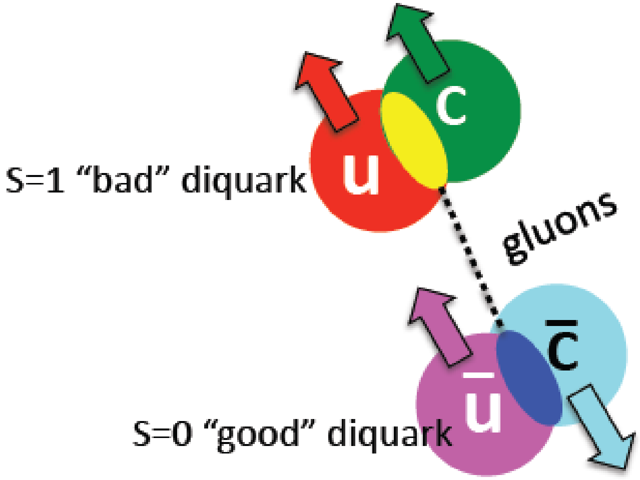
Lots of literature about this



Impossible to produce such an fragile extended object in prompt high energy hadron colliders at the rates reported by CDF & CMS

QCD diquark-diantiquark?

Maiani et al. PRD 71, 014028 (2005)



Predicts partner states (e.g., a nearby state with u→d) that have yet be seen.