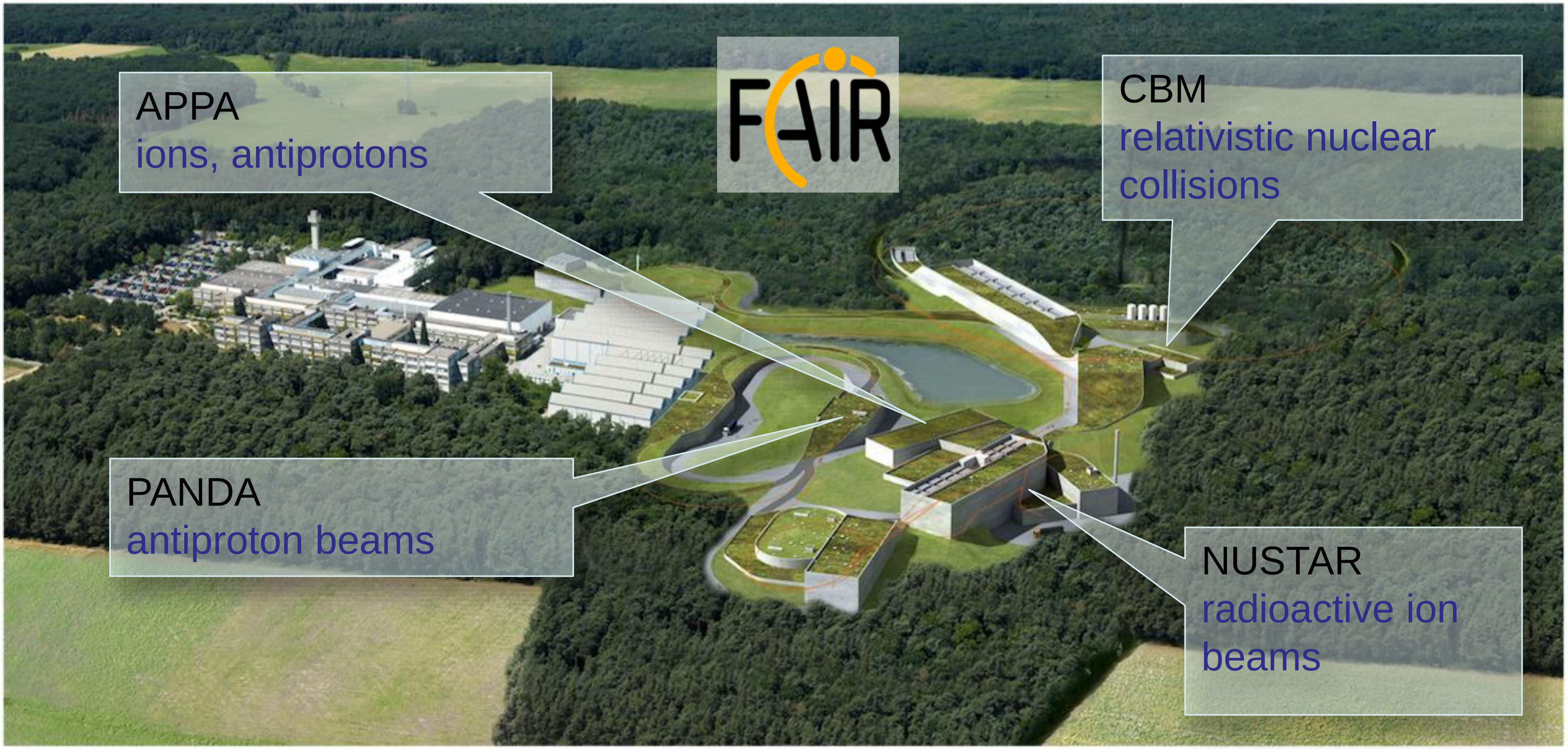
PERSPECTIVE STUDIES OF FLAVOR AND EXOTIC HADRONS WITH HEAVY ION COLLISIONS AT NICA

Mikhail Barabanov

for the MPD Collaboration

20th International Conference on Hadron Spectroscopy and Structure (HADRON 2023)
Genova, Italy, June 5th to 9th 2023

FAIR COMPLEX



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~ $2x10^{32}$ $cm^{-2}s^{-1}$
- Beam cooling (stochastic & electron)

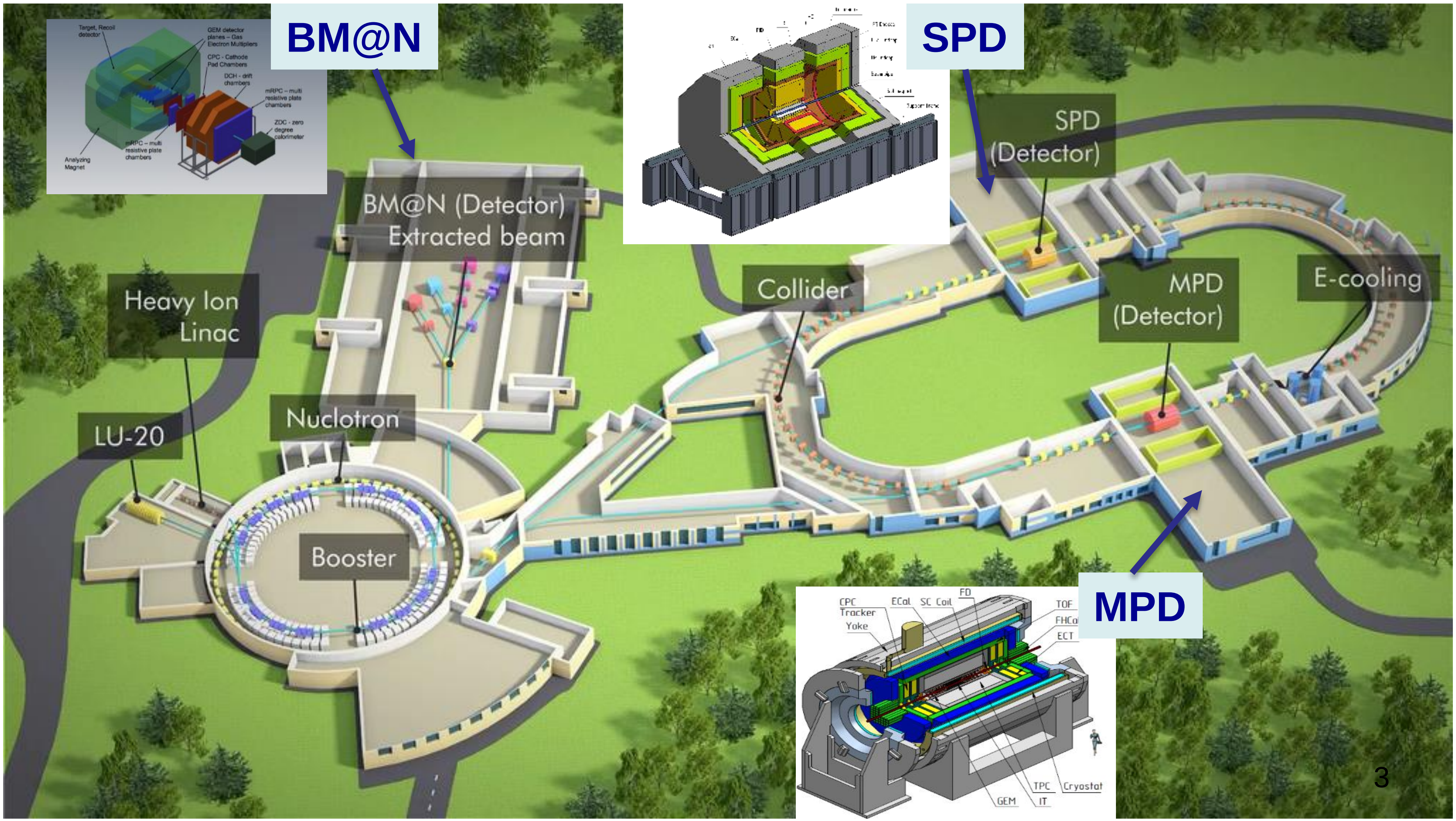
$\sqrt{s} \approx 5.5$ GeV

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

NICA COMPLEX

Collider basic requirements: beams from *p* to *Au*

L ~ 10^{27} $cm^{-2}c^{-1}$(*Au*) $\sqrt{S_{NN}}$= 4-11 GeV; L ~ 10^{32} $cm^{-2}c^{-1}$(*p*) $\sqrt{S_{pp}}$=12-27 GeV



PROGRESS OF CIVIL CONSTRUCTION

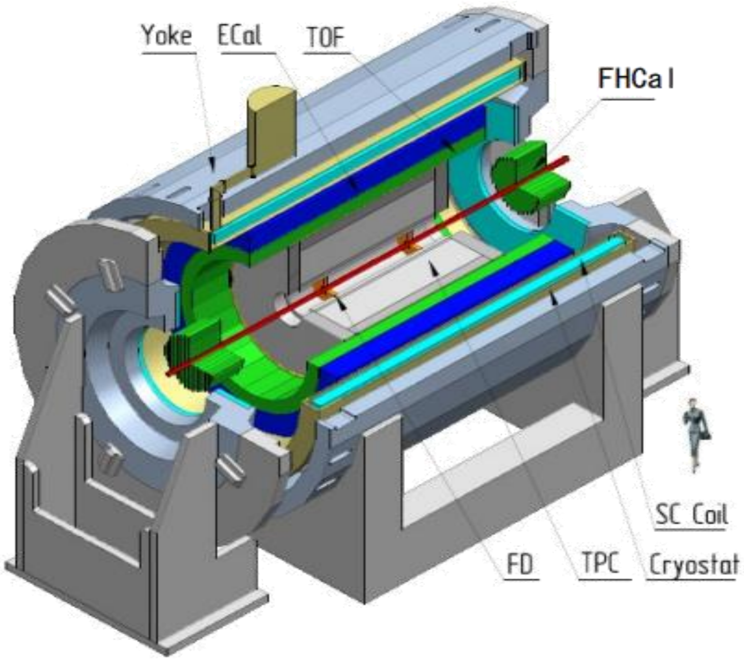
Multi-**P**urpose **D**etector (MPD) Collaboration

MPD *International Collaboration was established in* ***2018***
to construct, commission and operate the detector and develop its physics program

11 *Countries,* ***>500*** *participants,* ***35*** *Institutes and* ***JINR***

Organization

Acting Spokesperson:	***Victor Riabov***
Deputy Spokespersons:	***Zebo Tang, Arkadiy Taranenko***
Institutional Board Chair:	***Alejandro Ayala***
Project Manager:	***Slava Golovatyuk***



Joint Institute for Nuclear Research*;*
A.Alikhanyan National Lab of Armenia, Yerevan, ***Armenia;***
University of Plovdiv, ***Bulgaria;***
Tsinghua University, Beijing, ***China****;*
University of Science and Technology of China, Hefei, ***China****;*
Huzhou University, Huizhou, ***China****;*
Institute of Nuclear and Applied Physics, CAS, Shanghai, ***China****;*
Central China Normal University, ***China****;*
Shandong University, Shandong, ***China****;*
University of Chinese Academy of Sciences, Beijing, ***China****;*
University of South China, ***China****;*
Three Gorges University, ***China****;*
Institute of Modern Physics of CAS, Lanzhou, ***China****;*
Tbilisi State University, Tbilisi, ***Georgia****;*
Institute of Physics and Technology, Almaty, ***Kazakhstan****;*
Benemérita Universidad Autónoma de Puebla, ***Mexico****;*
Centro de Investigación y de Estudios Avanzados, ***Mexico****;*
Instituto de Ciencias Nucleares, UNAM, ***Mexico****;*
Universidad Autónoma de Sinaloa, ***Mexico****;*
Universidad de Colima, ***Mexico****;*
Universidad de Sonora, ***Mexico****;*
Institute of Applied Physics, Chisinev, ***Moldova****;*
Institute of Physics and Technology, ***Mongolia****;*

Belgorod National Research University, ***Russia****;*
Institute for Nuclear Research of the RAS, Moscow, ***Russia****;*
National Research Nuclear University MEPhI , Moscow, ***Russia****;*
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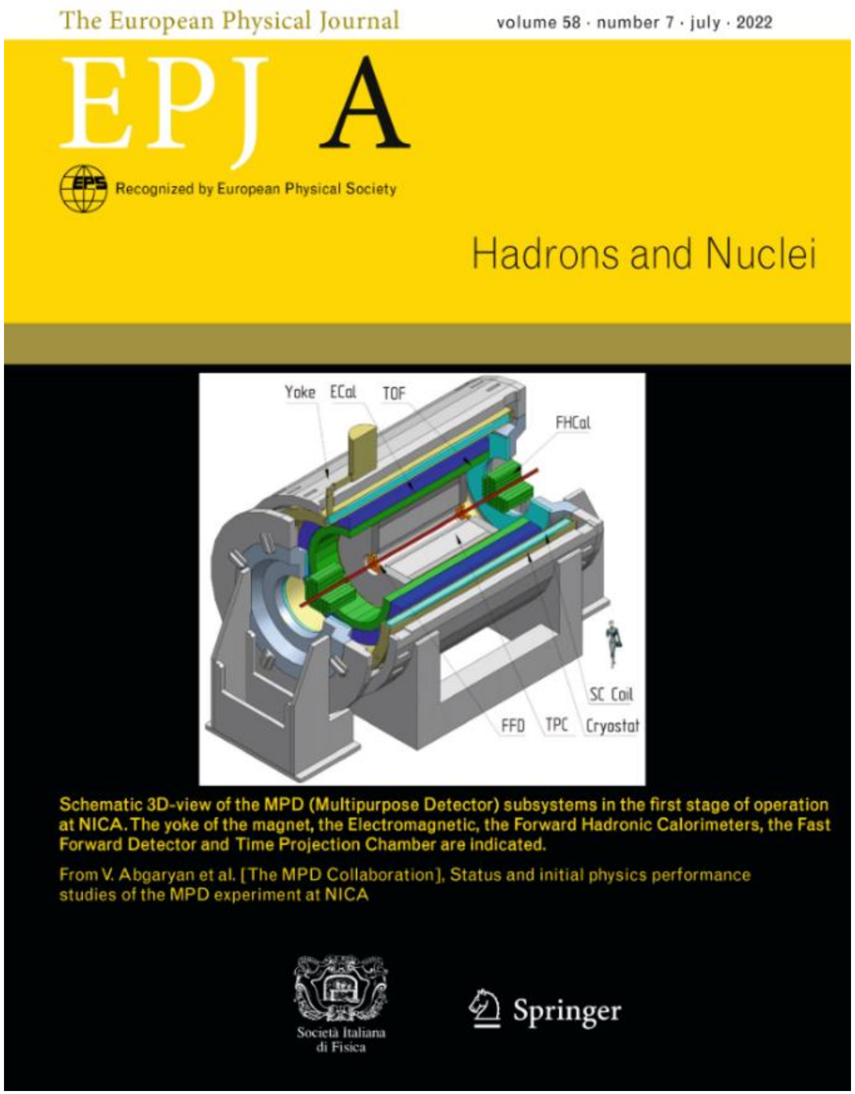
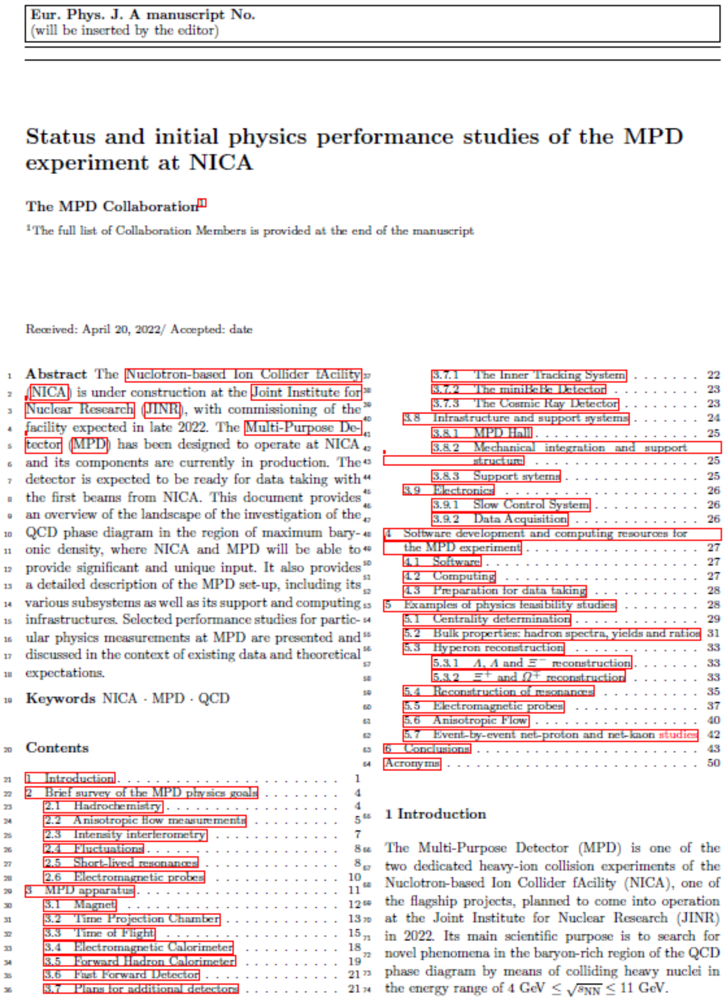
*Petersburg Nuclear Physics Institute, Gatchina****, Russia****;*
*Vinča Institute of Nuclear Sciences****, Serbia****;*
Pavol Jozef Šafárik University, Košice, ***Slovakia***

1ST COLLABORATION PAPER

Status and initial physics performance studies of the MPD experiment at NICA

First collaboration paper recently published EPJA (~ 50 pages): Eur.Phys.J.A 58 (2022) 7, 140





Eur. Phys. J. A manuscript No.
(will be inserted by the editor)

Status and initial physics performance studies of the MPD experiment at NICA

The MPD Collaboration[1]

[1]The full list of Collaboration Members is provided at the end of the manuscript

Received: April 20, 2022/ Accepted: date

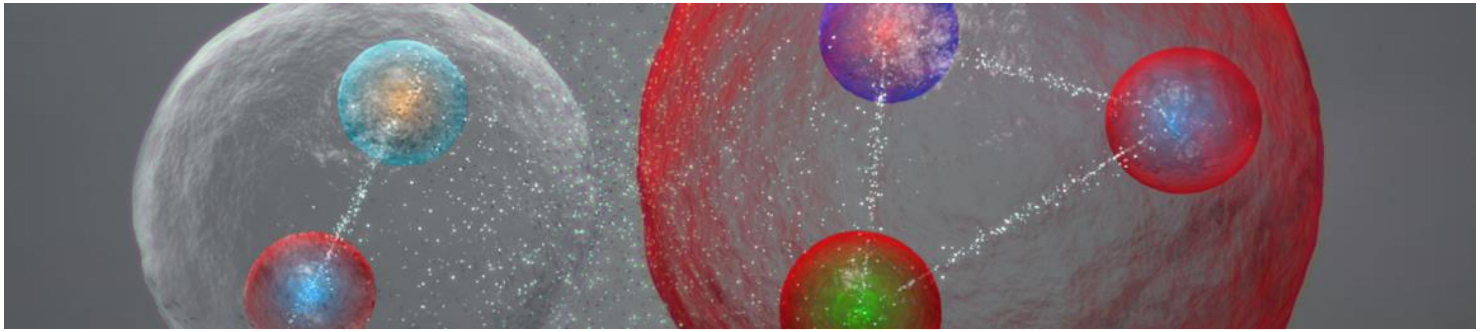
Abstract The Nuclotron-based Ion Collider fAcility (NICA) is under construction at the Joint Institute for Nuclear Research (JINR), with commissioning of the facility expected in late 2022. The Multi-Purpose Detector (MPD) has been designed to operate at NICA and its components are currently in production. The detector is expected to be ready for data taking with the first beams from NICA. This document provides an overview of the landscape of the investigation of the QCD phase diagram in the region of maximum baryonic density, where NICA and MPD will be able to provide significant and unique input. It also provides a detailed description of the MPD set-up, including its various subsystems as well as its support and computing infrastructures. Selected performance studies for particular physics measurements at MPD are presented and discussed in the context of existing data and theoretical expectations.

Keywords NICA · MPD · QCD

Contents

1 Introduction

The Multi-Purpose Detector (MPD) is one of the two dedicated heavy-ion collision experiments of the Nuclotron-based Ion Collider fAcility (NICA), one of the flagship projects, planned to come into operation at the Joint Institute for Nuclear Research (JINR) in 2022. Its main scientific purpose is to search for novel phenomena in the baryon-rich region of the QCD phase diagram by means of colliding heavy nuclei in the energy range of 4 GeV $\leq \sqrt{s_{NN}} \leq$ 11 GeV.



THE PRESENT AND FUTURE OF HEAVY FLAVOUR AND EXOTIC HADRON SPECTROSCOPY

Munich, Germany, 8 May - 2 June 2023

https://munich-iapbp.de/heavyflavour

ORGANIZERS:

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CONTRIBUTION

Status of the MPD detector at NICA and perspectives for heavy-flavor & exotics studies
Alejandro Ayala (Instituto de Ciencias Nucleares, UNAM)

MPD PHYSICS PROGRAM

G. Feofilov, A. Aparin

Global observables

- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Event plane measurement at all rapidities
- Spectator measurement

V. Kolesnikov, Xianglei Zhu

Spectra of light flavor and hypernuclei

- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase Diag.

K. Mikhailov, A. Taranenko

Correlations and Fluctuations

- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

D. Peresunko, Chi Yang

Electromagnetic probes

- Electromagnetic calorimeter meas.
- Photons in ECAL and central barrel
- Low mass dilepton spectra in-medium modification of resonances and intermediate mass region

Wangmei Zha, A. Zinchenko

Heavy flavor

- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

MOTIVATION

To look for different flavor hadrons together with charmonium-like states (conventional and exotic) in *pA* and *AA* collisions to obtain complementary results to the ones from *e+e-* interactions, *B*-meson decays and pp\bar interactions (on a restricted scale of energy)

HADRONIC PHYSICS BEFORE AND AFTER 2003

Consensus before 2003:

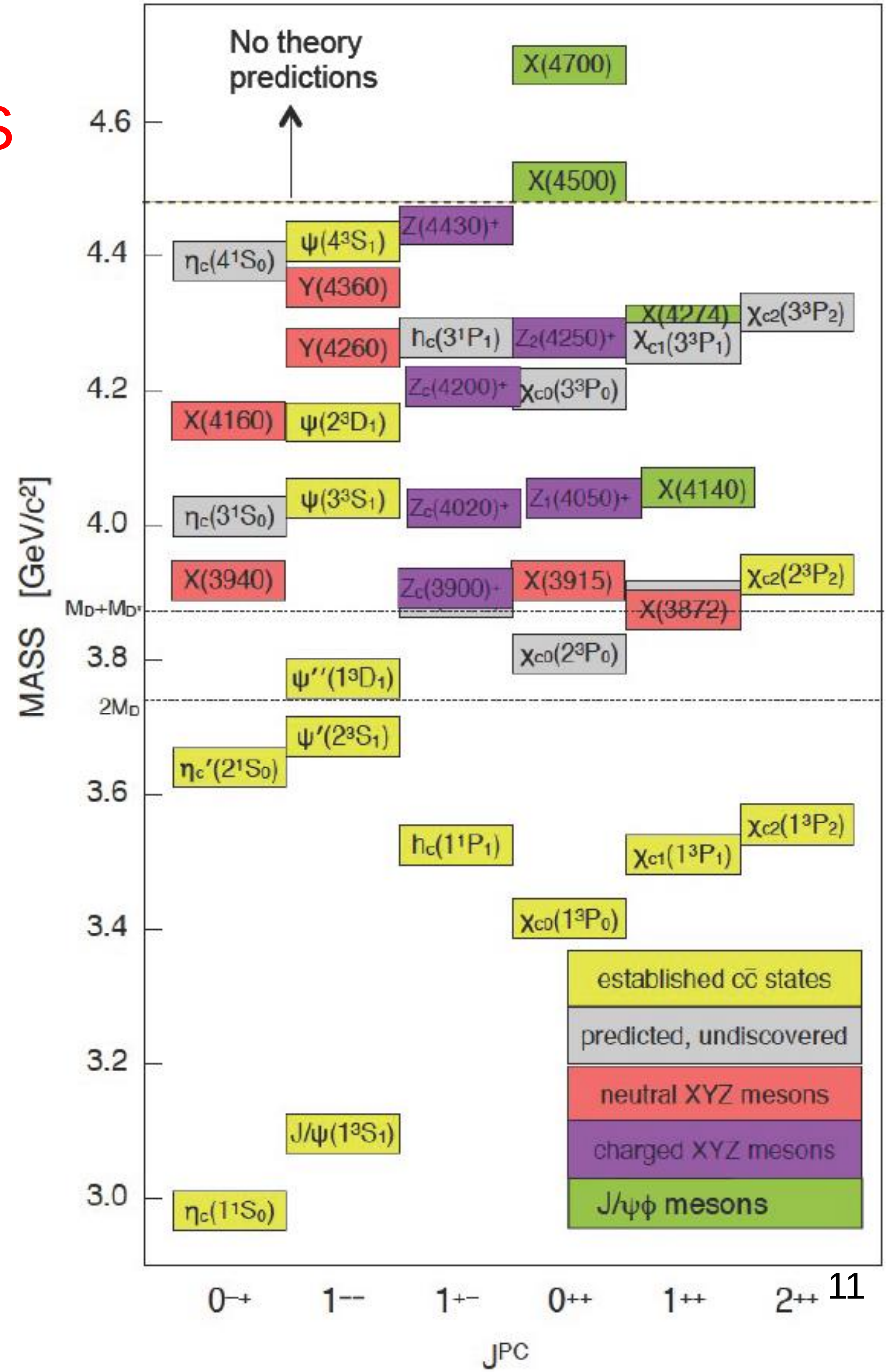
- Quark model provides a decent description of low-lying hadrons
- Quark model works surprisingly well even for light flavours
- Heavy flavours (c and b) comply with nonrelativistic theory
- Relatisitc corrections improve the description
- Experiment gradually fills "missing states"
- Lattice provides additional/alternative source of information

Situation after 2003:

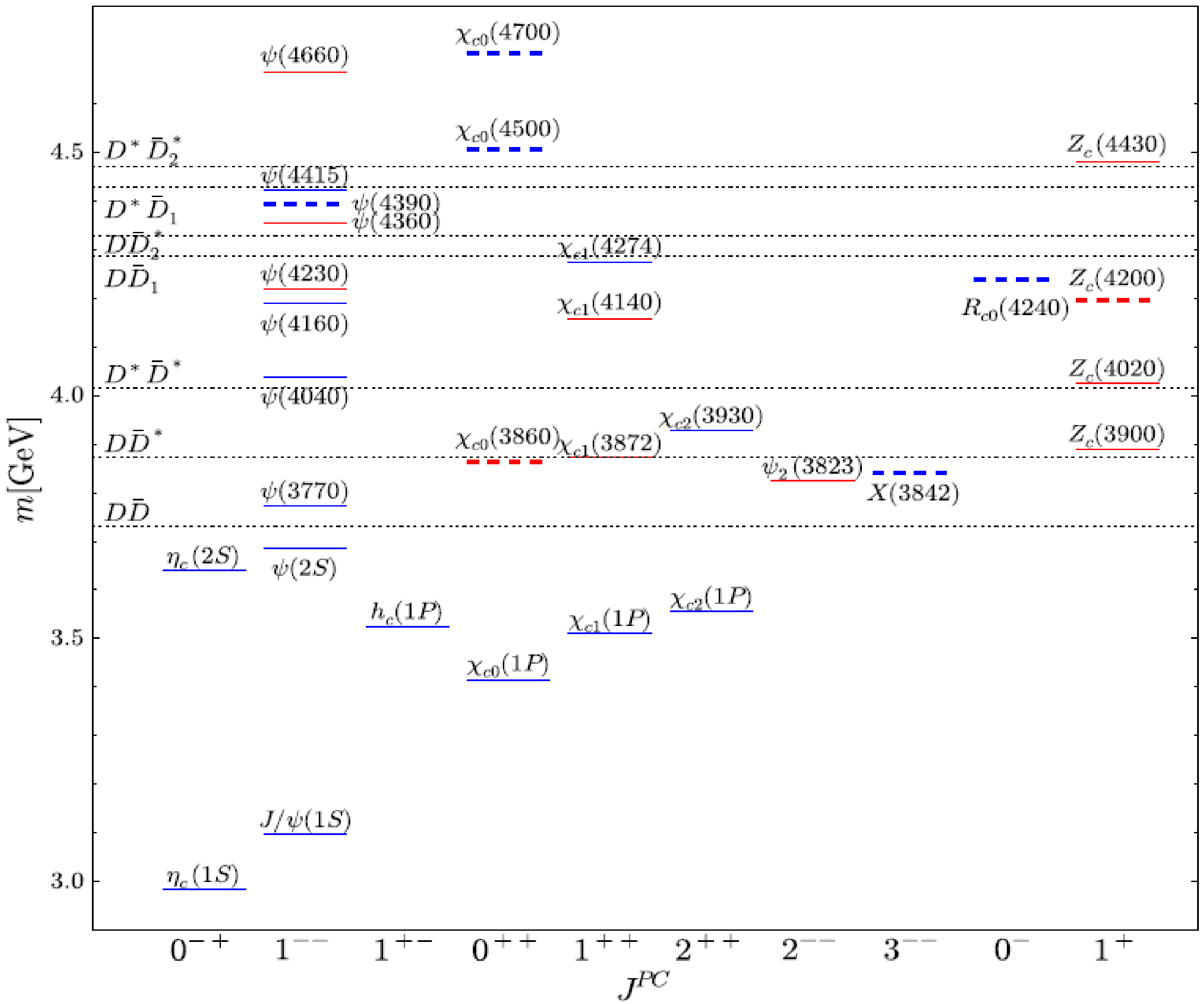
- $X(3872)$ observed by Belle with properties at odds with quark model
- Number of such unconventional hadrons with heavy quarks grows fast
- New branch of hadrons spectroscopy — exotic XYZ states

QUARKONIUM-LIKE STATES

- 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 $J/\psi\phi$ states

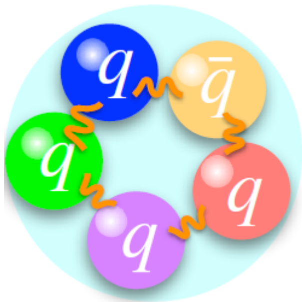


QUARKONIUM-LIKE STATES

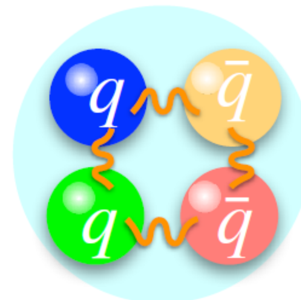


NON-STANDARD EXOTIC HADRONS

Evidence for QCD exotic states is a missing piece
of knowledge about the nature of strong QCD

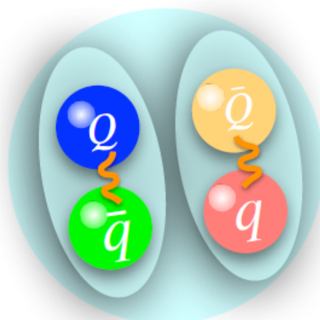


Pentaquarks
4 quarks and 1 antiquark

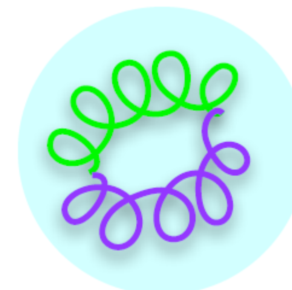


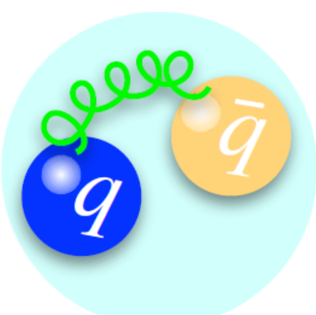
Tetraquarks
2 quarks and 2 antiquarks

Hadronic molecule
2 loosely bound heavy mesons

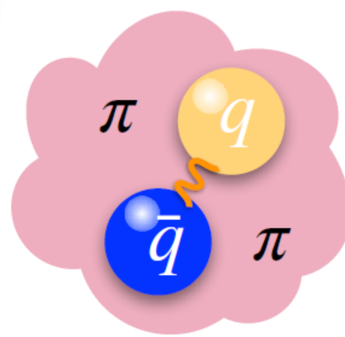


Glueball
only gluons, no quarks





Hybrid
states with excited gluonic
degrees of freedom



Hadroquarkonium
specific quarkonium core “coated” by
excited light-hadron matter

threshold effects should also be taken into account

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

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

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.

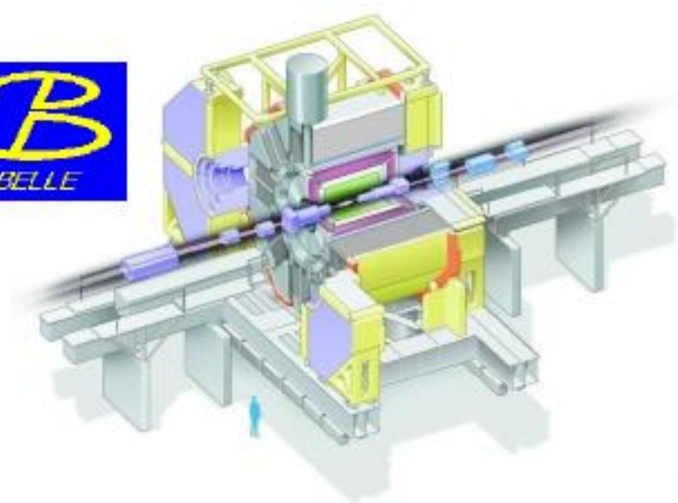
Even if we consider the scattering amplitudes of strongly interacting particles on the mass shell only and treat the matrix elements of the weak, electromagnetic, and gravitational interactions by means

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.

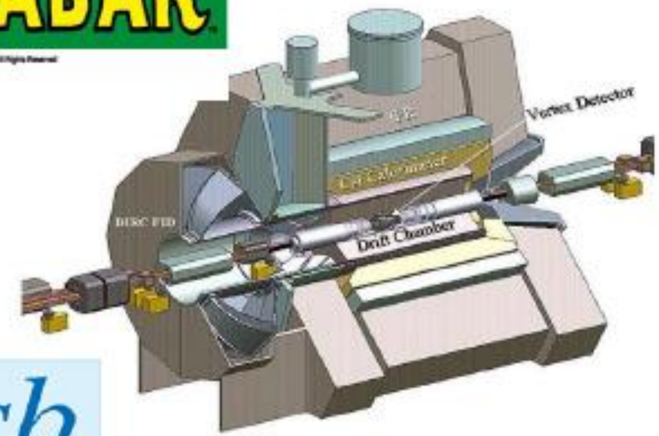
A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the 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**.

RESULTS WERE OBTAINED FROM THESE EXPERIMENTS

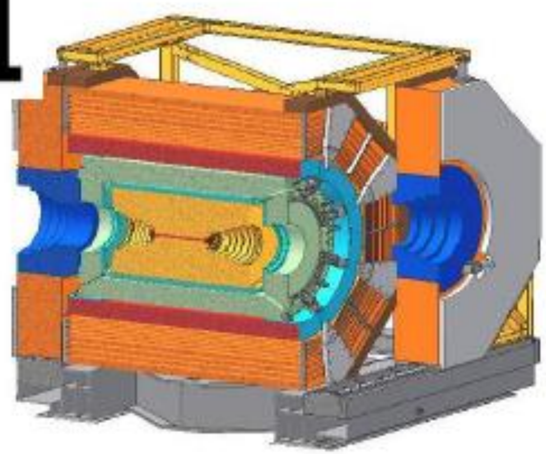
BELLE



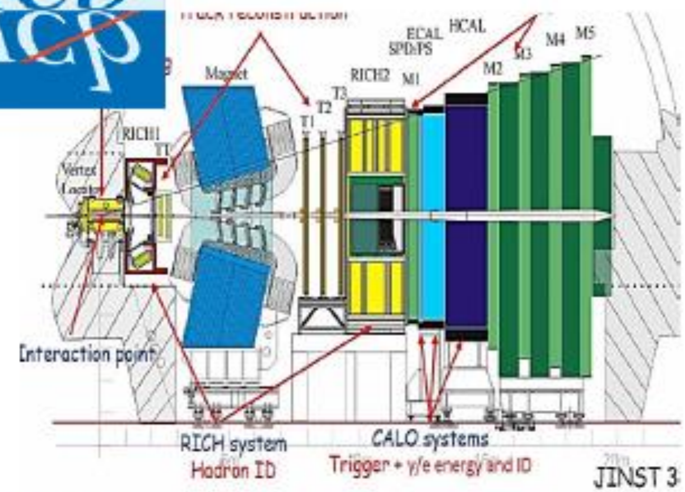
BABAR



BESIII

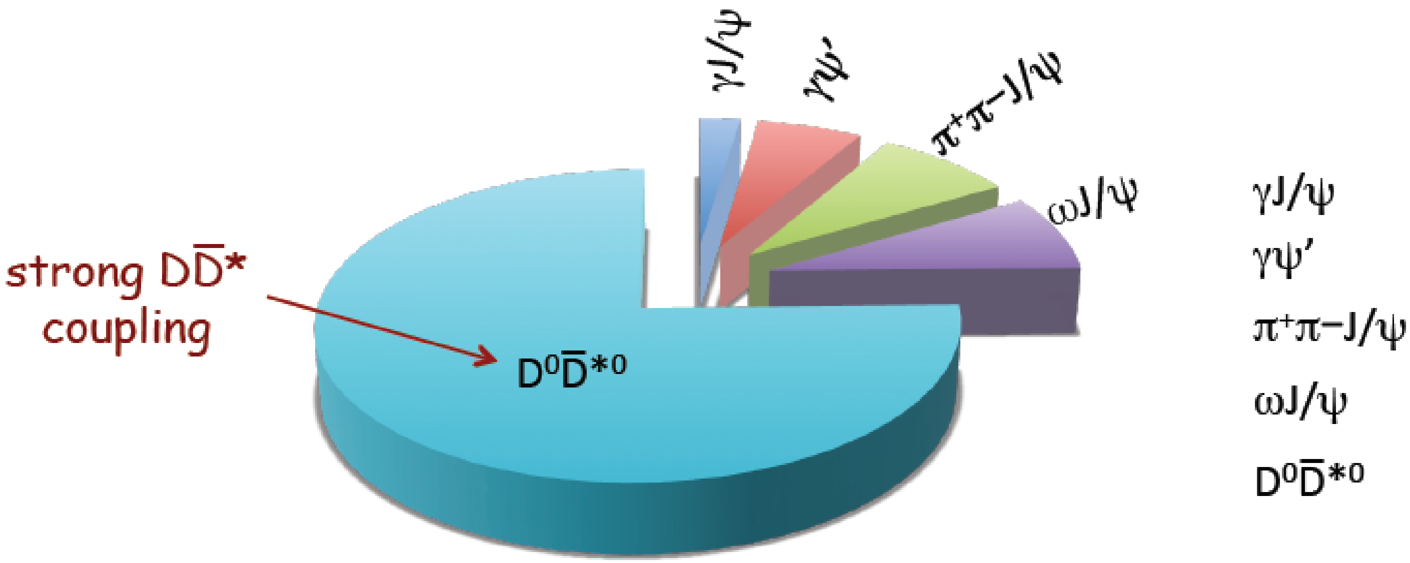


LHCb



+ CLEOc, CDF, CMS/ATLAS …

X(3872) decay channels



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

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

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

$\chi_{c1}(3872)$

$I^G(J^{PC}) = 0^+(1^{++})$

also known as $X(3872)$

This state shows properties different from a conventional $q\overline{q}$ state. A candidate for an exotic structure. See the review on non-$q\overline{q}$ states.

First observed by CHOI 03 in $B \to K\pi^+\pi^- J/\psi(1S)$ decays as a narrow peak in the invariant mass distribution of the $\pi^+\pi^- J/\psi(1S)$ final state. Isovector hypothesis excluded by AUBERT 05B and CHOI 11.

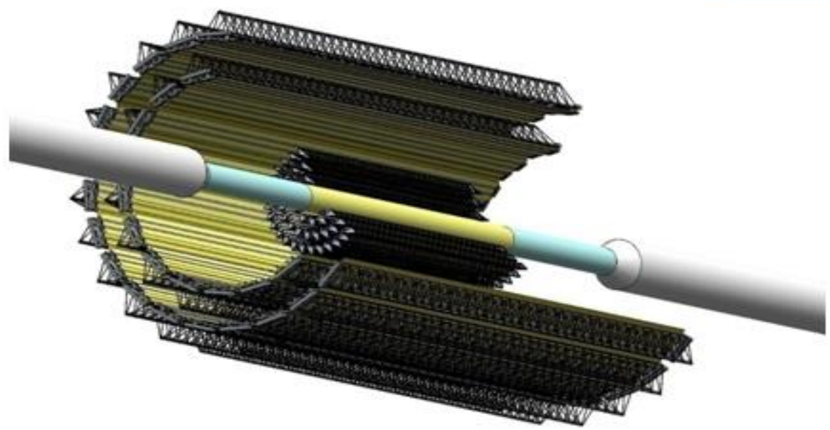
AAIJ 13Q perform a full five-dimensional amplitude analysis of the angular correlations between the decay products in $B^+ \to \chi_{c1}(3872)K^+$ decays, where $\chi_{c1}(3872) \to J/\psi\pi^+\pi^-$ and $J/\psi \to \mu^+\mu^-$, which unambiguously gives the $J^{PC} = 1^{++}$ assignment under the assumption that the $\pi^+\pi^-$ and J/ψ are in an S-wave. AAIJ 15AO extend this analysis with more data to limit D-wave contributions to $< 4\%$ at 95% CL.

$\chi_{c1}(3872)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	e^+e^-	$< 2.8 \times 10^{-6}$	90%
Γ_2	$\pi^+\pi^- J/\psi(1S)$	(3.8 ± 1.2) %	
Γ_3	$\pi^+\pi^-\pi^0 J/\psi(1S)$	not seen	
Γ_4	$\omega\eta_c(1S)$	< 33 %	90%
Γ_5	$\omega J/\psi(1S)$	(4.3 ± 2.1) %	
Γ_6	$\phi\phi$	not seen	
Γ_7	$D^0\overline{D}^0\pi^0$	$(49 {}^{+18}_{-20})$ %	
Γ_8	$\overline{D}^{*0}D^0$	(37 ± 9) %	
Γ_9	$\gamma\gamma$	< 11 %	90%
Γ_{10}	$D^0\overline{D}^0$	< 29 %	90%
Γ_{11}	D^+D^-	< 19 %	90%
Γ_{12}	$\pi^0\chi_{c2}$	< 4 %	90%
Γ_{13}	$\pi^0\chi_{c1}$	(3.4 ± 1.6) %	
Γ_{14}	$\pi^0\chi_{c0}$	< 70 %	90%
Γ_{15}	$\pi^+\pi^-\eta_c(1S)$	< 14 %	90%
Γ_{16}	$\pi^+\pi^-\chi_{c1}$	$< 7 \times 10^{-3}$	90%
Γ_{17}	$p\overline{p}$	$< 2.4 \times 10^{-5}$	95%

MPD INNER TRACKING SYSTEM BASED ON MAPS

Reconstruction of charmed particles in Au+Au central collisions with MPD ITS3+TPC tracking system



Open charm studies: exclusive decays ⟶ Inner tracking System (ITS). Dedicated track reconstruction methods ("Vector Finder").

mpd.jinr.ru/doc/mpd-tdr

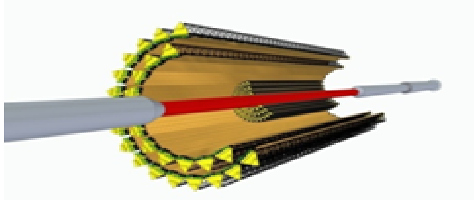
MPD INNER TRACKING SYSTEM BASED ON MAPS

MPD ITS geometric models

Two ITS geometric models were used for simulation:

1) project model (ITS-5-40) with 5 layers consisting of ladders with standard MAPS

Sensitive area: 15×30 mm^2
Thickness: 50 µm
Number of pixels: 512×1024
Pixel size: 28×28 µm^2.



2) ITS3-like model (ITS-5-35) with OB consisting of 2 layers of standard MAPS and IB consisting of 3 layers of bended staves of MAPS (15 um pitch) with large area and thickness of 30 µm

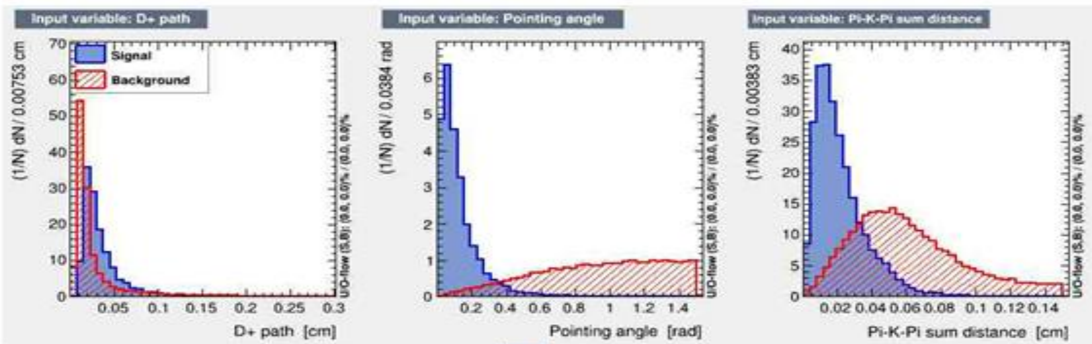
Size of bended MAPS:

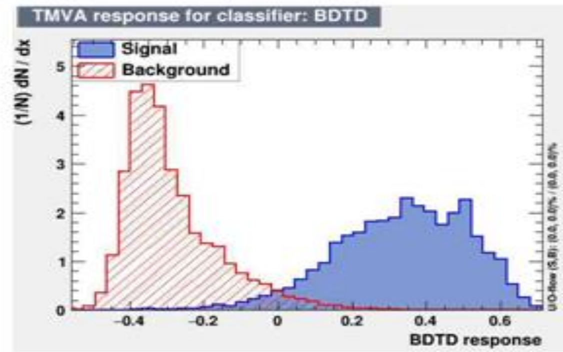
1 layer - 280*56.5 mm^2
2 layer - 280*75.5 mm^2
3 layer - 280*94.0 mm^2

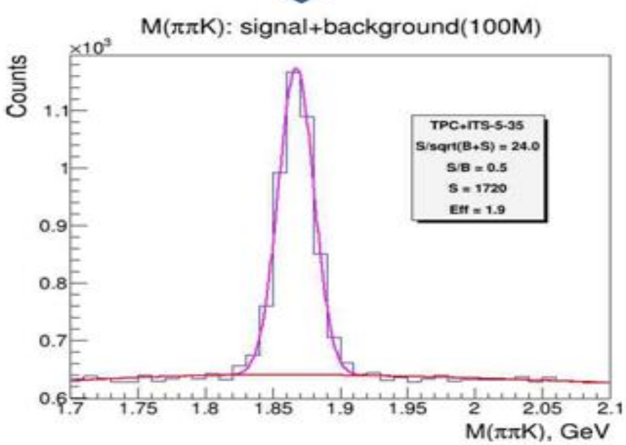
D$^+$ RECONSTRUCTION

D$^+$ reconstruction in ITS-5-35 + TPC using VF + TMVA

dca(π), dca(K), dist(πK), λ(D$^+$), θ(D$^+$) cuts → **BDT cut**





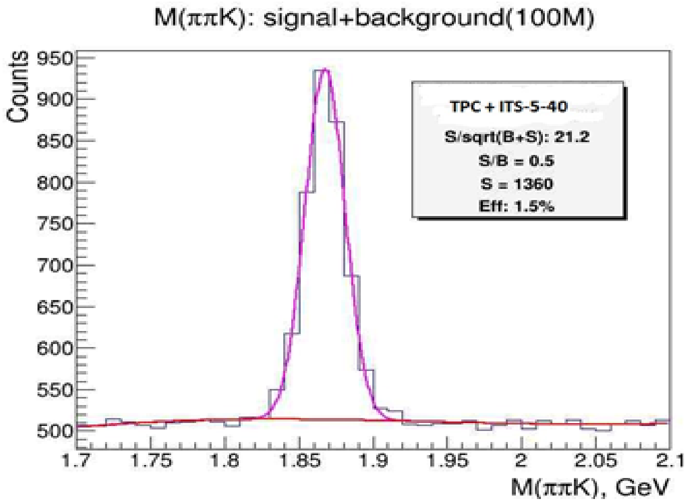


D$^+$ reconstruction efficiency obtained: **ε=1.9%**

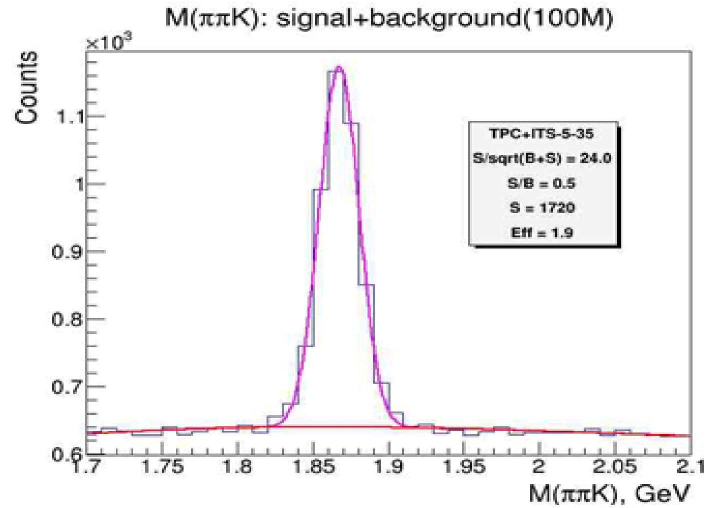
D+ RECONSTRUCTION

D+ reconstruction efficiency with two ITS models

Project model



ITS3-like model



ITS	S	S/B	$S/\sqrt{S+B}$	ε, %
ITS-5-40	1360	0.50	21.2	1.5
ITS-5-35	1720	0.50	24.0	1.9

The reconstruction efficiency increases by 25% when using ITS with an Internal Barrel built on the base of a new type of sensors (bended MAPS with large area)

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

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(2) *Department of Physics, Gyeongsang National University, Jinju 660-701, Korea*
(3) *Center for Underground Physics, Institute for Basic Science, Daejeon 34074, Korea*
† *E-mail: solsensnu@gmail.com*

The spectroscopy of charmonium-like mesons with masses above the $2m_D$ open charmed threshold has been full of surprises and remains poorly understood [1]. The currently most compelling theoretical descriptions of the mysterious XYZ mesons attributes them to hybrid stucture with a tightly bound $c\bar{c}$ diquark [2] or a $c\bar{c}q\bar{q}'$ tetraquark [3] core that strongly couples to S-wave $D^{(*)}\bar{D}^{(*)}$ molecule-like structures. In this picture, the production of an XYZ particle in high energy hadron collisions and its decays to light hadron + charmonium final states proceed via the core component of the meson, while decays to pairs of open-charmed mesons proceed via the $D^{(*)}\bar{D}^{(*)}$ component.

These ideas have been applied with some success to the $X(3872)$ [2], where a detailed calculation finds a $c\bar{c}$ core component that is only about 5 percent of the time, with the $D\bar{D}^*$ component (mostly $D^0\bar{D}^{*0}$) accounting for the rest. In this picture, illustrated in cartoon form in Fig. 1, the $X(3872)$ is composed of three rather disparate components: a small charmonium-like $c\bar{c}$ core with $r_{\rm rms} < 1$ fm, a larger D^+D^{*-} component with $r_{\rm rms} = \hbar/\sqrt{2\mu_+ B_+} \simeq 1.5$ fm and a dominant $D^0\bar{D}^{*0}$ component with a huge, $r_{\rm rms} = \hbar/\sqrt{2\mu_0 B_0} > 9$ fm spatial extent. Here μ_+ (μ_0) and B_+ (B_0) denote the reduced mass for the D^+D^{*-} ($D^0\bar{D}^{*0}$) system and the relevant *binding energy*: $|(m_D + m_{D^*}) - M_{X(3872)}|$ ($B_+ = 8.2$ MeV and $B_0 < 0.3$ MeV). The different amplitudes and spatial distributions of the D^+D^{*-} and $D^0\bar{D}^{*0}$ components ensure that the $X(3872)$ is not an isospin eigenstate; instead it is mostly $I = 0$, but has a significant (~ 25 percent) $I = 1$ component.

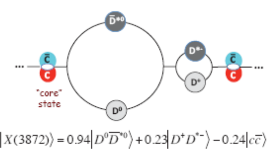


Figure 1: The $X(3872)$ in a hybrid picture. The numerical values come from ref. [2].

In the hybrid scheme, an $X(3872)$ is produced in high-energy pN collisions via its compact ($r_{\rm rms} < 1$ fm) charmonium-like structure and this rapidly mixes (in a time $t \sim \hbar/\delta M$) into huge and fragile, mostly $D^0\bar{D}^{*0}$, molecule-like structure; δM is the difference between the $X(3872)$ mass and that of the nearest $c\bar{c}$ mass pole core state, which we take to be that of the the $\chi_{c1}(2P)$ pure charmonium state that is expected to lie about $20 \sim 30$ MeV above $M_{X(3872)}$ [4]. In this case, the mixing time, $c\tau_{\rm mix} = 5 \sim 10$ fm, is much shorter than the the lifetime of the $X(3872)$, which is $c\tau_{X(3872)} > 150$ fm [5].

The NICA superconducting collider is uniquely well suited to test this picture for the $X(3872)$ (and, possibly, other XYZ mesons). In near-threshold production experiments in the $\sqrt{s_{pN}} \simeq 8$ GeV energy range, $X(3872)$ mesons can be produced with typical c.m.s. kinetic energies of a few hundred MeV (*i.e.*, with $\gamma\beta \simeq 0.3$). In the case of the $X(3872)$, its decay length will be greater than 50 fm while the distance scale for the $c\bar{c} \to D^0\bar{D}^{*0}$ transition would be $2 \sim 3$ fm. Since the survival probability of an $r_{\rm rms} \sim 9$ fm "molecule" inside nuclear matter should be very small, $X(3872)$ meson production on a nuclear target with $r_{\rm rms} \sim 5$ fm or more ($A \sim 60$ or larger) should be strongly quenched (see Fig. 2). Thus, if this hybrid picture is correct, the atomic number dependence of $X(3872)$ production at fixed $\sqrt{s_{pN}}$ should have a dramatically different behaviour than that of the ψ', which is a long-lived compact charmonium state.

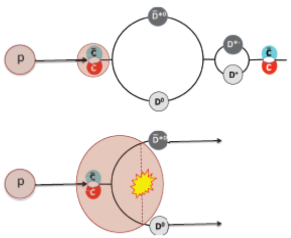


Figure 2: **(Top)** $X(3872)$ production on a proton target ($r_{\rm rms} \simeq 1$ fm). Here the $X(3872)$ escapes the target region before it establishes a significant $D\bar{D}^*$ component. **(Bottom)** $X(3872)$ production on a nuclear target. Here the presence nuclear material disrupts the (< 200 keV) coherence between the well separated D^0 and D^{*0} (represented by the dashed line).

In this talk I will summarize the current experimental status of the XYZ mesons and hidden-charm pentaquark candidates and present simulations of what we might expect from an A-dependence of $X(3872)$ mesons at NICA.

References

[1] See, for example, S.L. Olsen, Front. Phys. **10**, 101401 (2015).

[2] S. Takeuchi, K. Shimizu and M. Takizawa, Prog. Theor. Exp. Phys. **2015**, 079203 (2015).

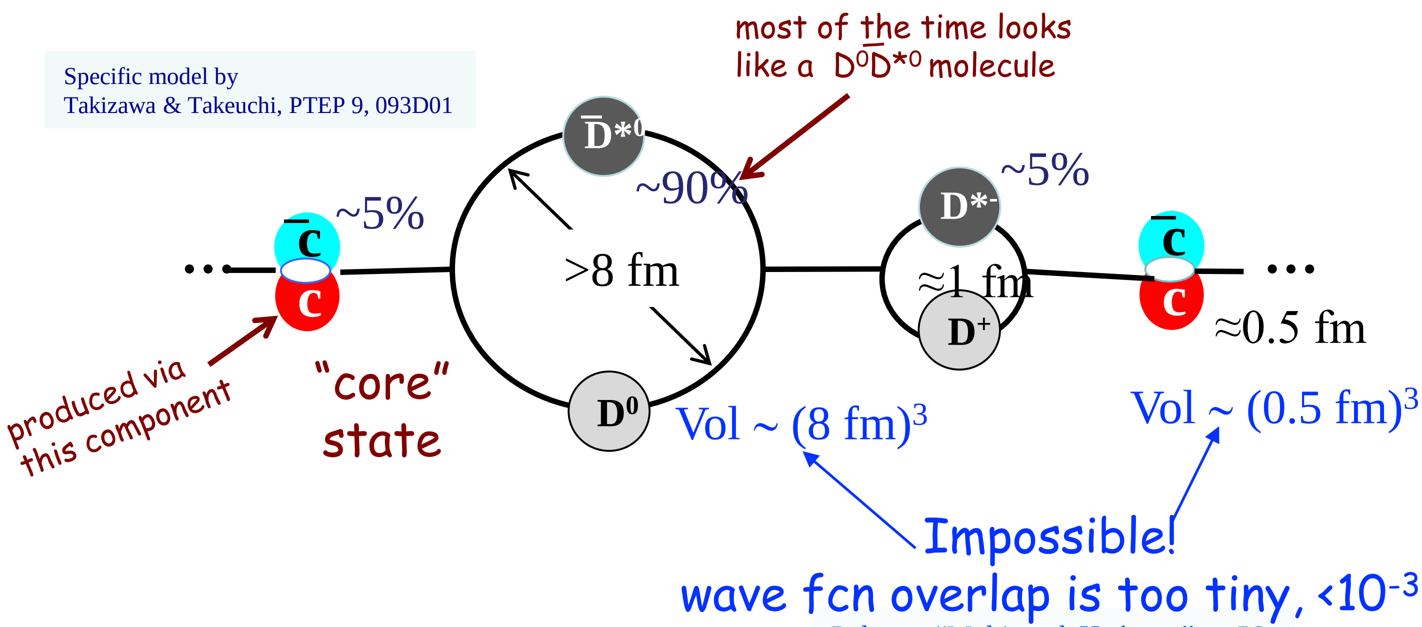
[3] A. Esposito, A. Pilloni and A.D. Polosa, arXiv:1603.07667 [hep-ph].

[4] Here we use $\chi_{c2}(2P)$-$\chi_{c1}(2P)$ mass splitting from S. Godfrey and N. Isgur, Phys. Rev. D **32**, 189 (1985) and scale the $\chi_{c1}(2P)$ mass from the measured $\chi_{c2}(2P)$ mass reported in K.A. Olive *et al.* (PDG), Chin. Phys. C **38**, 090001 (2014).

[5] The width of the $X(3872)$ is experimentally constrained to be $\Gamma_{X(3872} < 1.2$ (90% CL) in S.-K. Choi *et al.* (Belle Collaboration), Phys. Rev. D **84**, 052004 (2011).

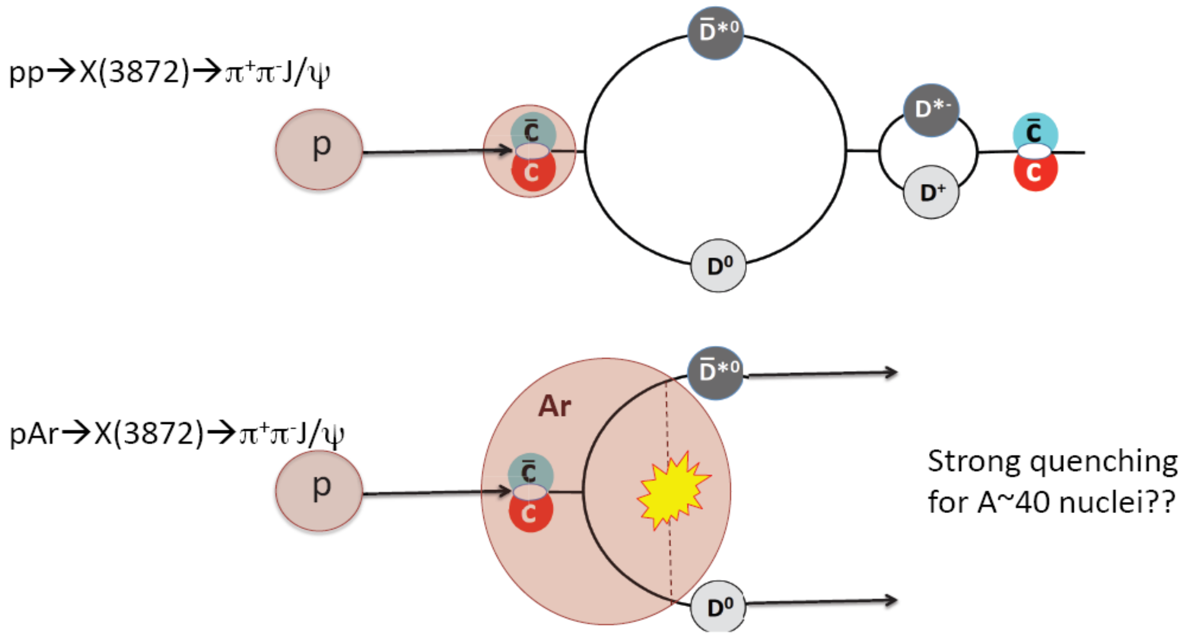
X(3872) as a $D\bar{D}^*$ molecule + a $c\bar{c}$-“core” mixture?

-- “consensus” opinion (?) --



Polosa: “Multiquark Hadrons,” pg 56
Achasov: MPLA 30, 1550181 (2015)

Near-threshold prod. via pp & pA



Use NICA, a new pp/pA/AA collider at JINR (Dubna)?

The production experiments with proton-proton and proton-nuclei collisions with $\sqrt{S_{pN}} \geq 8$ GeV may be well suited to test the structure of *X(3872)* and, possibly, other exotic mesons.

In near threshold production experiments with the $\sqrt{S_{pN}} \approx 8$ GeV energy range, *XYZ* mesons can be produced with typical low kinetic energies of a few hundred MeV.

Since the survival probability of such "molecular" inside nuclear matter should be very small, *XYZ* meson production on a nuclear target with A ~ 40 or larger should be strongly quenched.

Thus, if this hybrid picture is correct, the atomic number dependence of X(3872) production at fixed $\sqrt{S_{pN}}$ for A ~ 40 or larger should have a dramatically different behavior than that of the *Ψ'*, which is a long-lived compact charmonium state.

SUMMARY

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

♦ Modern facilities with hadron and heavy ion collisions should provide good opportunities for identification of charged and neutral particles and shed light on the nature of exotics.

♦ The experiments with *AA* and *pA* collisions at MPD can obtain some valuable information on the charm production. For hadronic decays the ITS should greatly enhance the research potential (reconstruction and selection).

♦ Measurements of charmonium-like states may be considered as one of the “pillars” of the *AA* and *pA* program at NICA.

♦ Physics program for the first years of MPD data taking is formulated and the first physics paper was published.

THANK YOU!

and

WELCOME FOR COLLABORATION…

Toolkit for MultiVariate Analysis

TMVA is a ROOT package for training, testing and performances evaluation of multivariate classification techniques.

Analysis is generally organized in 2 steps :

- **Training phase**

  At this stage the variables from the signal and background samples are trained according the classifier chosen by the user. The results of the classification is written into weight files, traducing the initial **N** input variables **V** to one dimensional variable **R** (response) :

$$V^N \rightarrow R$$

- **Application phase**

  At this stage the data classification, reading from the weight files, is applied to the data to be analyzed.

The classifier BDT (Boosted Decision Trees) has been chosen for the analysis phase when reconstructing D mesons

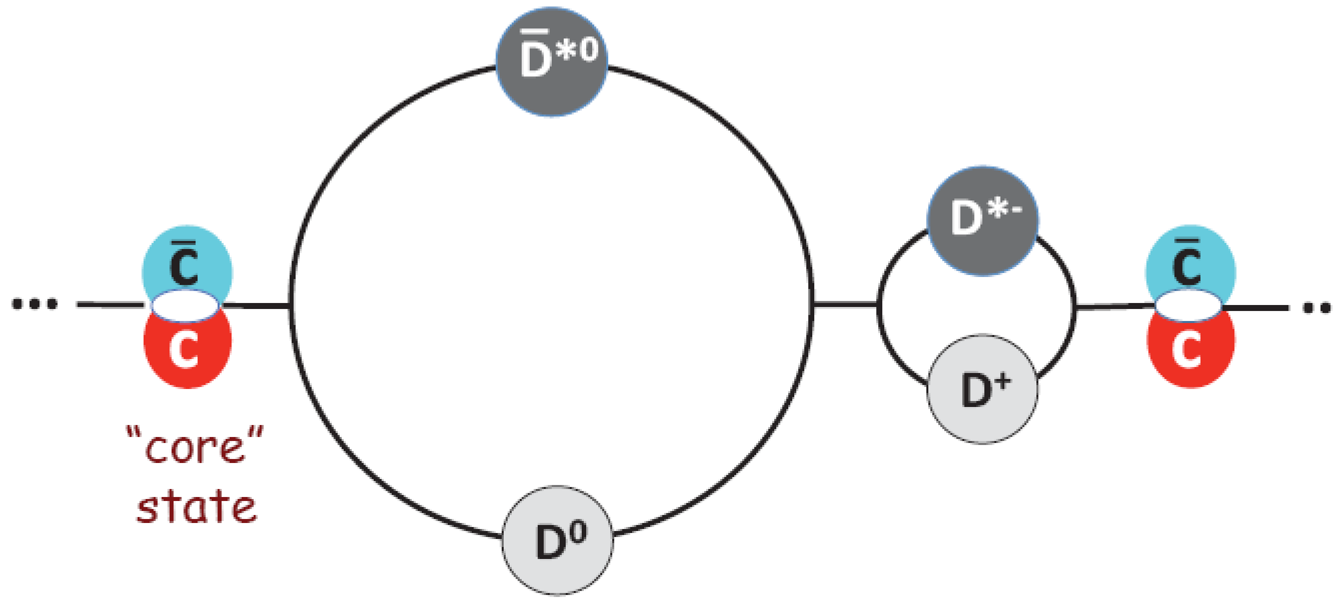
Charm in AA

1. J/ψ polarization studies

2. Open charm selection via hadronic decays

Can the X(3872) structure be probed?

Takizawa & Takeuchi, PTEP 9, 093D01



$$|X(3872)\rangle = 0.94|D^0\bar{D}^{*0}\rangle + 0.23|D^+D^{*-}\rangle - 0.24|c\bar{c}\rangle$$