Institut für Theoretische Physik Technische Universität Wien



# Glueballs and Vector Mesons at NICA

**Denis Parganlija**

**Based on**
**D. Parganlija, Eur. Phys. J. A 52, no. 8, 229 (2016)**
**[arXiv:1601.05328 [hep-ph]] – NICA White Paper**

Thanks to:
F. Brünner and A. Rebhan (Vienna);
F. Giacosa (Kielce);
D. Bugg (London)

# Glueballs

# Quantum Chromodynamics

- **QCD Lagrangian:**

$$\mathcal{L} = \bar{q}_f\left(i\gamma^\mu D_\mu - m_f\right)q_f - \frac{1}{4}G^a_{\mu\nu}G^{\mu\nu}_a$$

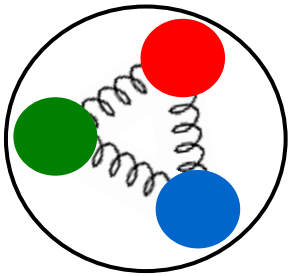
$$D_\mu = \partial_\mu - igA^a_\mu t^a$$

$$G^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g f^{abc} A^b_\mu A^c_\nu$$

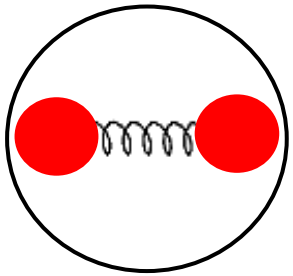
**Strong Coupling**
**Energy-Dependent**

↕

**Hadrons Emerge**
**at Small Energies**

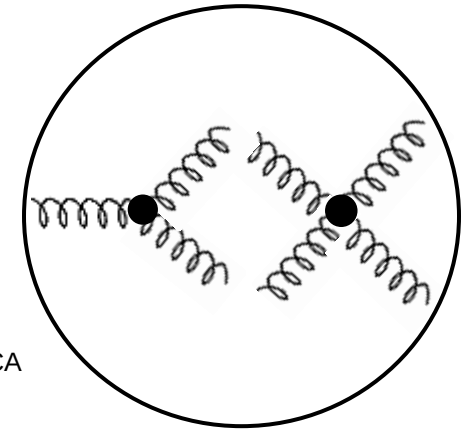


**Half-Integer Spin**
**Baryons**



**Integer Spin**
**Mesons**

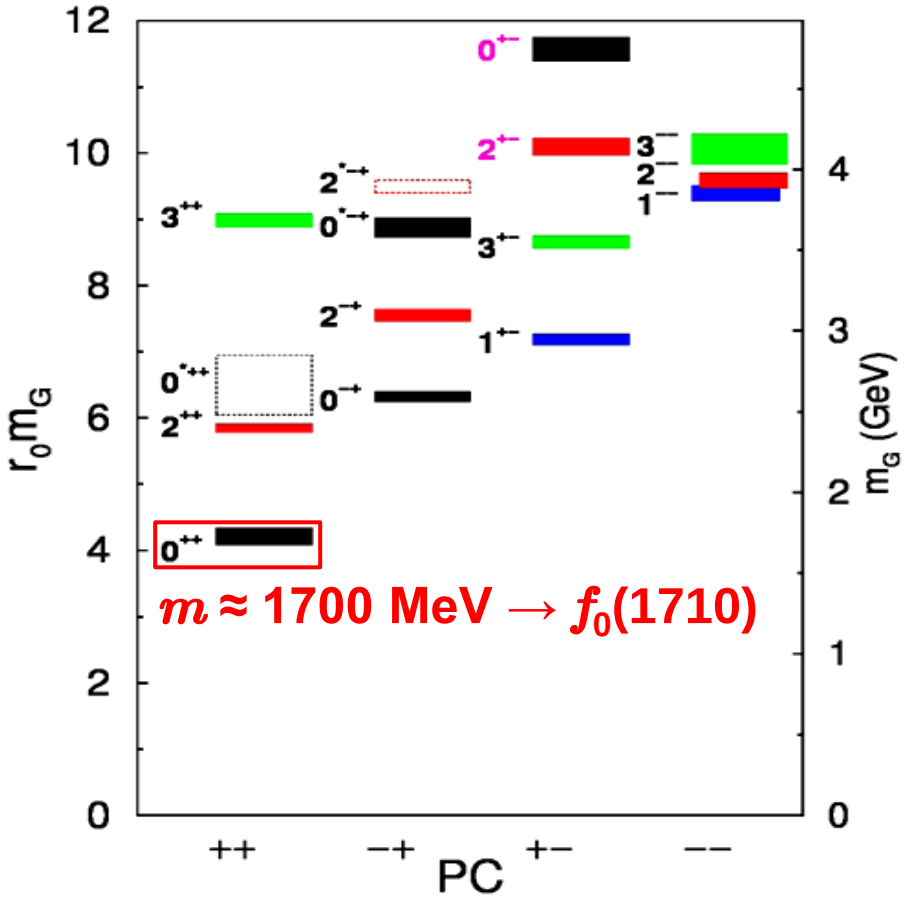
- **Gluons are self-interacting**
- **Gluon bound states: Glueballs!**



**Leading-order mass generated only by the strong interaction!**

# Glueballs on the Lattice

Morningstar & Peardon hep-lat/9901004:




**Pure gluodynamics**

**Glueball spectrum predicted**

Denis Parganlija, Glueballs and Vector Mesons at NICA -- EPJ A 52 (2016) no.8, 229 [1601.05328]

# Glueball Dynamics: an Example

- **AdS/CFT Correspondence**
  **→ Witten-Sakai-Sugimoto (WSS) Model**

| Decay | $M_{\text{exp.}}$ | $\Gamma/M$ (exp.) | $\Gamma/M$ (holography) |
|---|---|---|---|
| $f_0(1710)$ (total) | 1723 | $0.078(4)$ | $0.059 \ldots 0.076$ |
| $f_0(1710) \to 2K$ | 1723 | $0.047(17)^*$ | $0.012 \ldots 0.016$ |
| $f_0(1710) \to 2\eta$ | 1723 | $0.022(11)^*$ | $0.003 \ldots 0.004$ |
| $f_0(1710) \to 2\pi$ | 1723 | $0.009(2)^*$ | $0.009 \ldots 0.012$ |
| $f_0(1710) \to 4\pi$ | 1723 | ? | $0.024 \ldots 0.030$ |
| $f_0(1710) \to 2\omega \to 6\pi$ | 1723 | seen | $0.011 \ldots 0.014$ |

**[F. Brünner, D. Parganlija, A. Rebhan, Phys. Rev. D 91, 106002 (2015) 93, 109903(E) (2016) arXiv:1501.07906 [hep-ph]]**

**… but it is not the only candidate for the scalar glueball**

# Candidates for the Glueball Ground State

- States up to 1.8 GeV (PDG)

| State | Mass [MeV] | Width [MeV] |
|---|---|---|
| $f_0(500)$ [Particle Data Group (PDG)] | 400 - 550 | 400 - 700 |
| $f_0(980)$ [PDG] | 990 ± 20 | 40 - 100 |
| $f_0(1370)$ [PDG] | 1200 - 1500 | 200 - 500 |
| $f_0(1500)$ [PDG] | 1504 ± 6 | 109 ± 7 |
| $f_0(1710)$ [PDG] | $1723^{+6}_{-5}$ | 139 ± 8 |
| $f_0(1790)$ [BES II (2005); LHCb (2014)] | $1790^{+40}_{-30}$ | $270^{+60}_{-30}$ |

# Glueball Production

## Main production channels for low-energy mesons:

- $pp$ [Axial Field Spectrometer Collaboration; Ames-Bologna-CERN-Dortmund-Heidelberg-Warsaw Collaboration; GAMS; WA76; WA91; WA102; LHCb]
- $\bar{p}p$ [Crystal Barrel; OBELIX]
- $e^+e^- \to \varphi(1020)$ or $e^+e^- \to J/\psi$ [CMD-2; MARK-III; Crystal Ball; KLOE; BES; BES II; BES III; Belle; Belle-II]
- $\pi -$ nucleon [CERN-Cracow-Munich Collaboration; CERN-Munich Collaboration; E791; WA76; GAMS]

**Glueballs should be • produced in radiative decays**
**• absent from $\gamma\gamma$ collisions**

[U. Wiedner, Excited QCD Winter Workshop (Sarajevo, 2013)]

**The latest candidate for the scalar glueball comes from $J/\psi$ decays and proton-proton collisions**

# How can NICA help?

# Possible NICA Contribution to the Glueball Search

- **Spin Physics Detector (SPD)**

Eur. Phys. J. A (2016) **52**: 215
DOI 10.1140/epja/i2016-16215-x

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Experimental Physics

## Spin physics experiments at NICA-SPD with polarized proton and deuteron beams*

I. Savin, A. Efremov, D. Pshekhonov, A. Kovalenko, O. Teryaev[a], O. Shevchenko, A V. Kukhtin, and N. Toplilin

JINR, 141980 Dubna, Russia

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Published online: 12 August 2016 – © Società Italiana di Fisica / Springer-Verlag
Communicated by D. Blaschke

**Abstract.** This is a brief description of suggested measurements of asymmetries of tl production in collisions of non-polarized, longitudinally and transversally polarized which provide an access to all leading-twist collinear and TMD PDFs of quarks and a Other spin effects in hadronic and heavy-ion collisions may be also studied consti program at NICA.

| Experiment | NICA, SPD |
|---|---|
| *mode* | *collider* |
| *Beam/target* | *pp, pd,dd* |
| *Polarization:b/t* | *0.9* |
| *Luminosity* | $10^{32}$ |
| *√s , GeV* | *10-26* |

[NICA LoI-02.06.14]

14 September 2000

PHYSICS LETTERS B

Physics Letters B 489 (2000) 29–37

www.elsevier.nl/locate/npe

## Resonance production in central *pp* collisions at the CERN Omega Spectrometer

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Received 21 July 2000; accepted 7 August 2000
Editor: L. Montanet

**Abstract**

A study of resonance production in central *pp* collisions is presented as a function of several kinematical variables. In particular the difference in the transverse momentum ($dP_T$) of the exchanged particles shows that undisputed $q\bar{q}$ mesons are suppressed at small $dP_T$ whereas glueball candidates are enhanced and in addition, the azimuthal angle $\phi$ gives information on the nature of the Pomeron. 

The experiments have been performed at incident beam momenta of 85, 300 and 450 GeV/c, corresponding to centre-of-mass energies of $\sqrt{s} = 12.7$, 23.8 and 29 GeV.

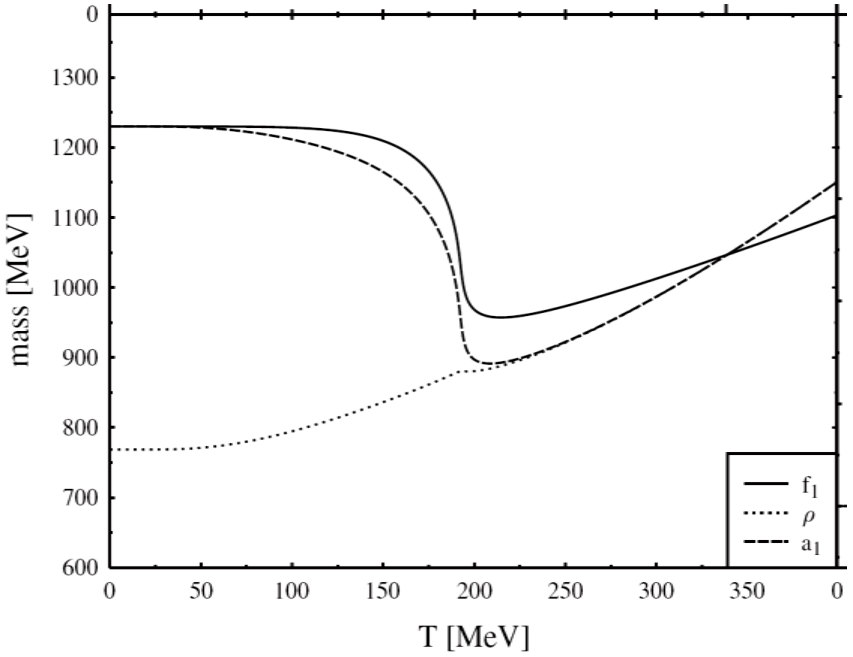
# What I Propose To Be Done:

- Look into $\pi\pi$ final states starting at ~ (1.5 – 2) GeV; can the glueball candidate $f_0(1790)$ be reconstructed?
- Look into $4\pi$ final states starting at ~ (1.5 – 2) GeV: glueball coupling may be strong
- Look into $KK$ final states starting at ~ (1.5 – 2) GeV: glueball should couple due to flavour symmetry

# But there is more

# Thermal Vector Mesons I

- **Glueballs couple to the vector and axial-vector mesons in vacuum, e.g. $\rho$ and $a_1$**
- **Mass degeneration of $\rho$ and $a_1$ at finite $T$ and $\mu$ is an order parameter for the chiral-symmetry restoration**




**[See the talk by Su Houng Lee at this Meeting]**

**[S. Struber and D. H. Rischke, Phys. Rev. D 77, 085004 (2008) arXiv:0708.2389 [hep-th]]**

# Thermal Vector Mesons II

- **Glueball coupling to the (axial-)vectors can persist at finite *T* and *μ* → glueball influence on the chiral-symmetry restoration**
- **Both $\langle \bar{q}q \rangle$ and $\langle G^{\mu\nu}G_{\mu\nu} \rangle$ contribute to the (axial-)vector masses**
- **How does $\langle G^{\mu\nu}G_{\mu\nu} \rangle$ change away from vacuum?**

# Thermal Vector Mesons III

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PHYSICS OF ELEMENTARY PARTICLES AND ATOMIC NUCLEI. THEORY

## Ultralight Glueballs in Quark-Gluon Plasma[1]

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*ved October 10, 2015*

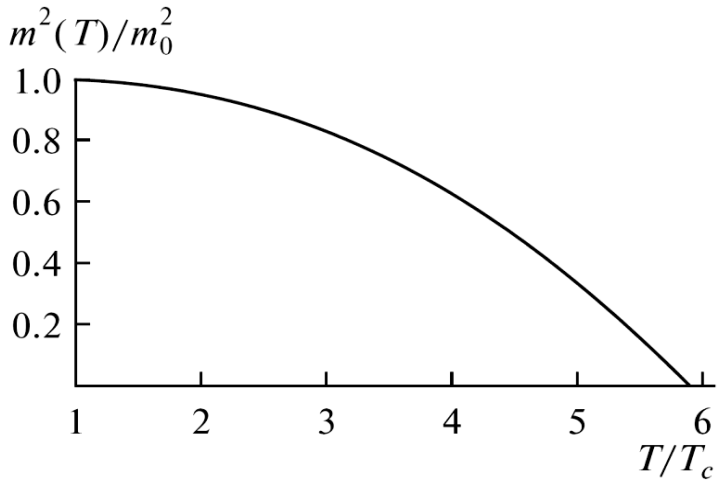


**Fig. 4.** The ratio of $m_\Phi^2(T))/m_0^2$ as a function of $T/T_c$

**Scalar glueball becomes massless at ~ 900 MeV**

Denis Parganlija, Glueballs and Vector Mesons at NICA -- EPJ A 52 (2016) no.8, 229 [1601.05328]

# How can NICA help?

# Thermal Vector Mesons IV

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DOI 10.1140/epja/i2016-16212-1

THE EUROPEAN PHYSICAL JOURNAL A

Review

## The Multi-Purpose Detector (MPD) of the collider experiment*

V. Golovatyuk[1], V. Kekelidze[1,a], V. Kolesnikov[1], O. Rogachevsky[1], and A. Sorin[1,2] on behalf of the MPD Collaboration

Eur. Phys. J. A (2016) **52**: 213
DOI 10.1140/epja/i2016-16213-0

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Experimental Physics

## The fixed target experiment for studies of baryonic matter at the Nuclotron (BM@N)*

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Received: 25 January 2016 / Revised: 28 March 2016
Published online: 9 August 2016 – © Società Italiana di Fisica / Springer-Verlag 2016
Communicated by D. Blaschke

**Abstract.** BM@N (Baryonic Matter at Nuclotron) is the first experiment to be realized at the accelerator complex of NICA-Nuclotron. The aim of the BM@N experiment is to study interactions of relativistic heavy-ion beams with fixed targets. The BM@N setup, results of Monte Carlo simulations and the BM@N experimental program are presented.

**My suggestion:**

**NICA can study spectral functions of (axial-)vectors away from vacuum**

↓

**Hints for the behaviour of the gluon condensate**

Denis Parganlija, Glueballs and Vector Mesons at NICA -- EPJ A 52 (2016) no.8, 229 [1601.05328]

# Summary

- **NICA can help us gain insight into QCD both in vacuum and away from vacuum**
- **Vacuum: new resonance/glueball discovery is possible**
- **Away from vacuum: (axial-)vector spectral functions as means to study the phase diagram, including glueball contribution**