クォークと超弦理論

橋本幸士

橋本数理物理学研究室

2014.12.26 仁科センター コロキウム

クォークと異次元

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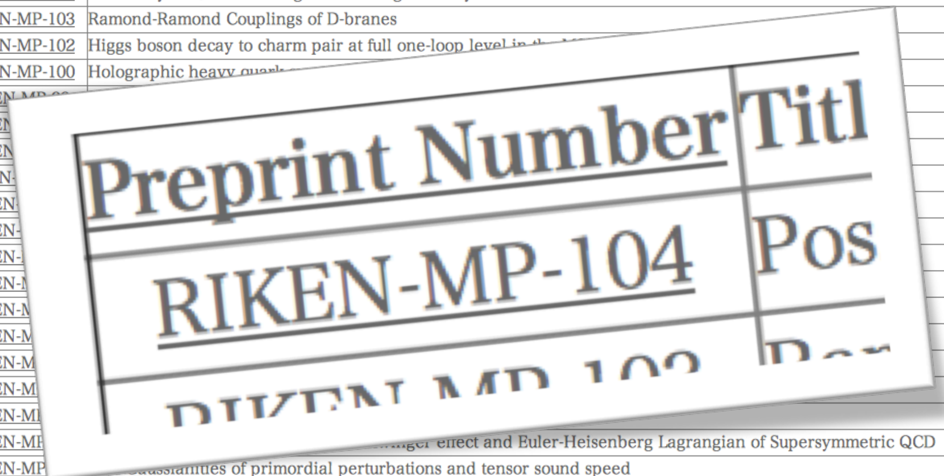
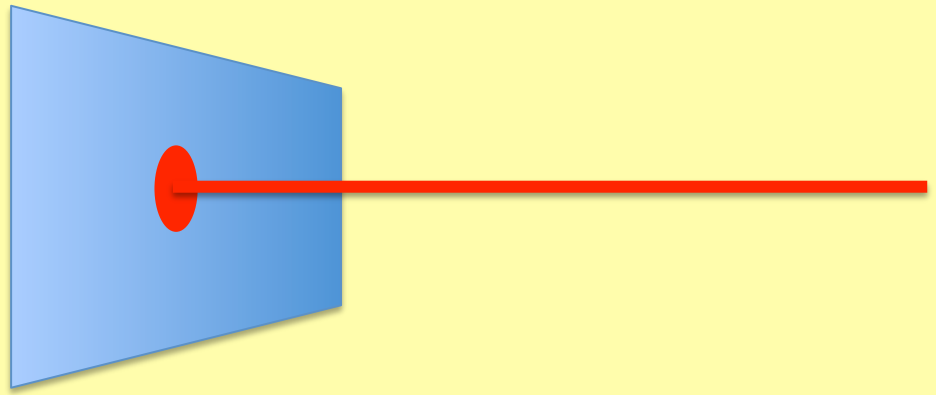


0 クォーク ＝ 異次元方向に伸びた弦



1 チャーモニウム と ブラックホール

2 重イオン衝突 と「とがった」異次元

3 原子核 と 隠れた対称性

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1. **The Large N limit of superconformal field theories and supergravity**
(10389) Juan Martin Maldacena (Harvard U.). Nov 1997. 19 pp.
Published in **Int.J.Theor.Phys. 38 (1999) 1113-1133, Adv.Theor.Math.Phys. 2 (1998) 231-252**
HUTP-97-A097, HUTP-98-A097
DOI: 10.1023/A:1026654312961
e-Print: **hep-th/9711200** | **PDF**
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AdS/CFT対応

2. **A Model of Leptons**
(9196) Steven Weinberg (MIT, LNS). Nov 1967. 3 pp.
Published in **Phys.Rev.Lett. 19 (1967) 1264-1266**
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3. **Measurements of Omega and Lambda from 42 high redshift supernovae**
(8187) Supernova Cosmology Project Collaboration (S. Perlmutter (UC, Berkeley, CfPA) *et al.*). Dec 1998. 33 pp.
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LBNL-41801, LBL-41801
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e-Print: **astro-ph/9812133** | **PDF**
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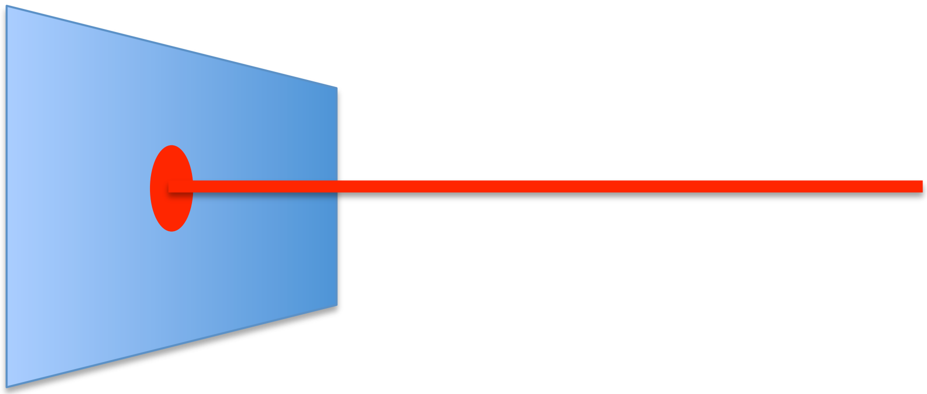
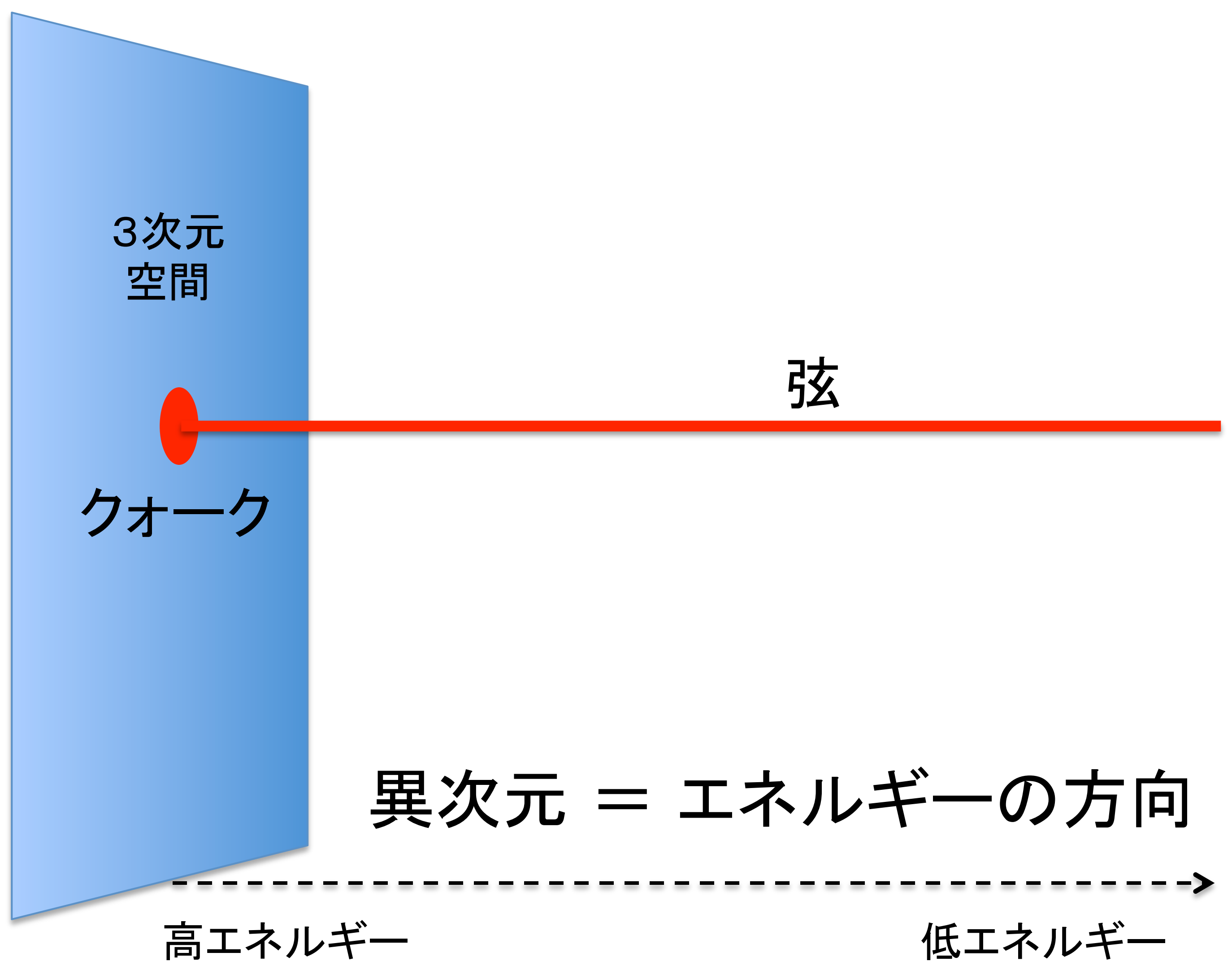


0-1 クォーク間ポテンシャル ＝ 弦の影

0-2 QCDスケール ＝ 異次元の終わり

0-3 閉じ込め力 ＝ 終わりを這う弦

0-0 クォーク ＝ 異次元方向に伸びた弦



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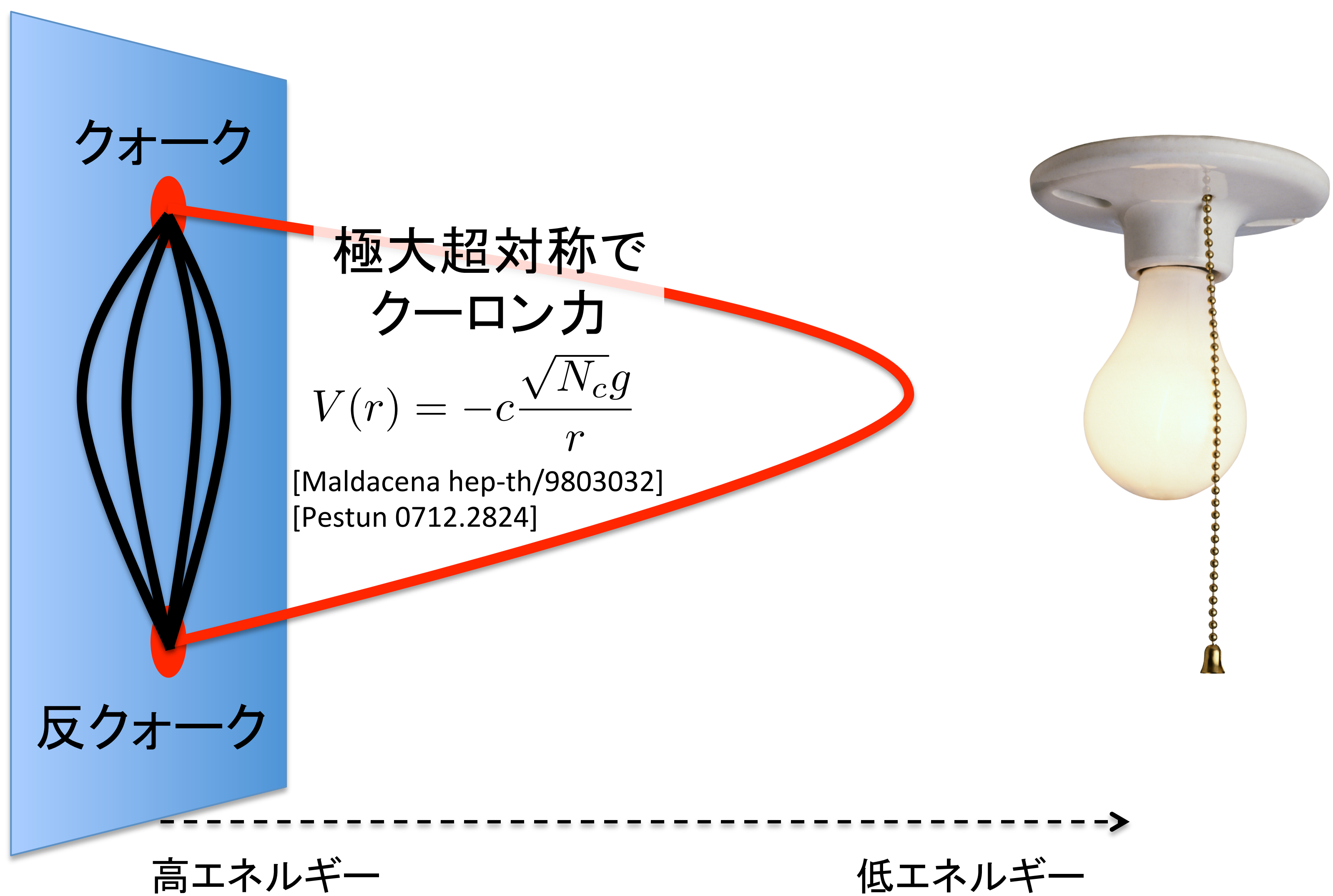

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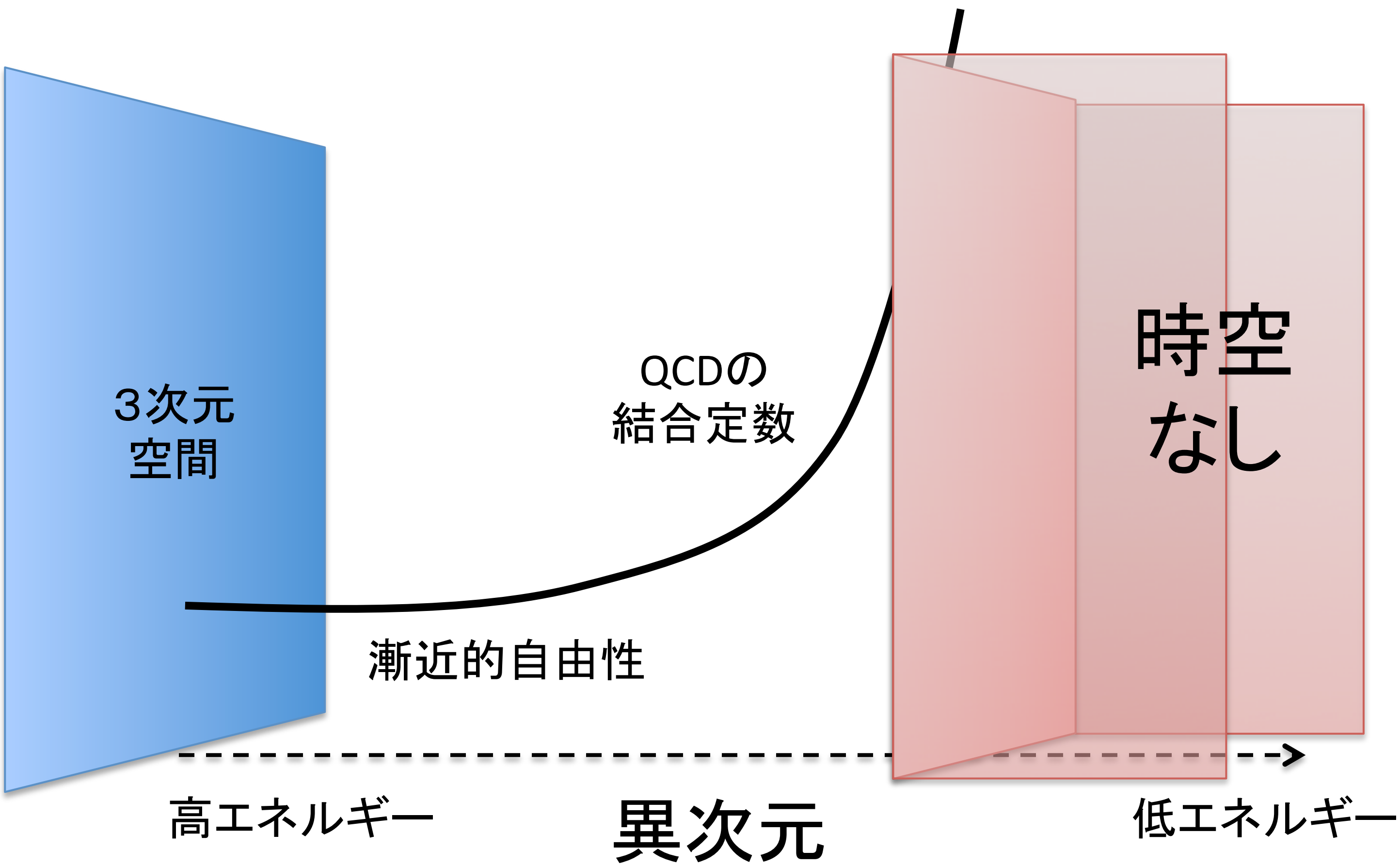

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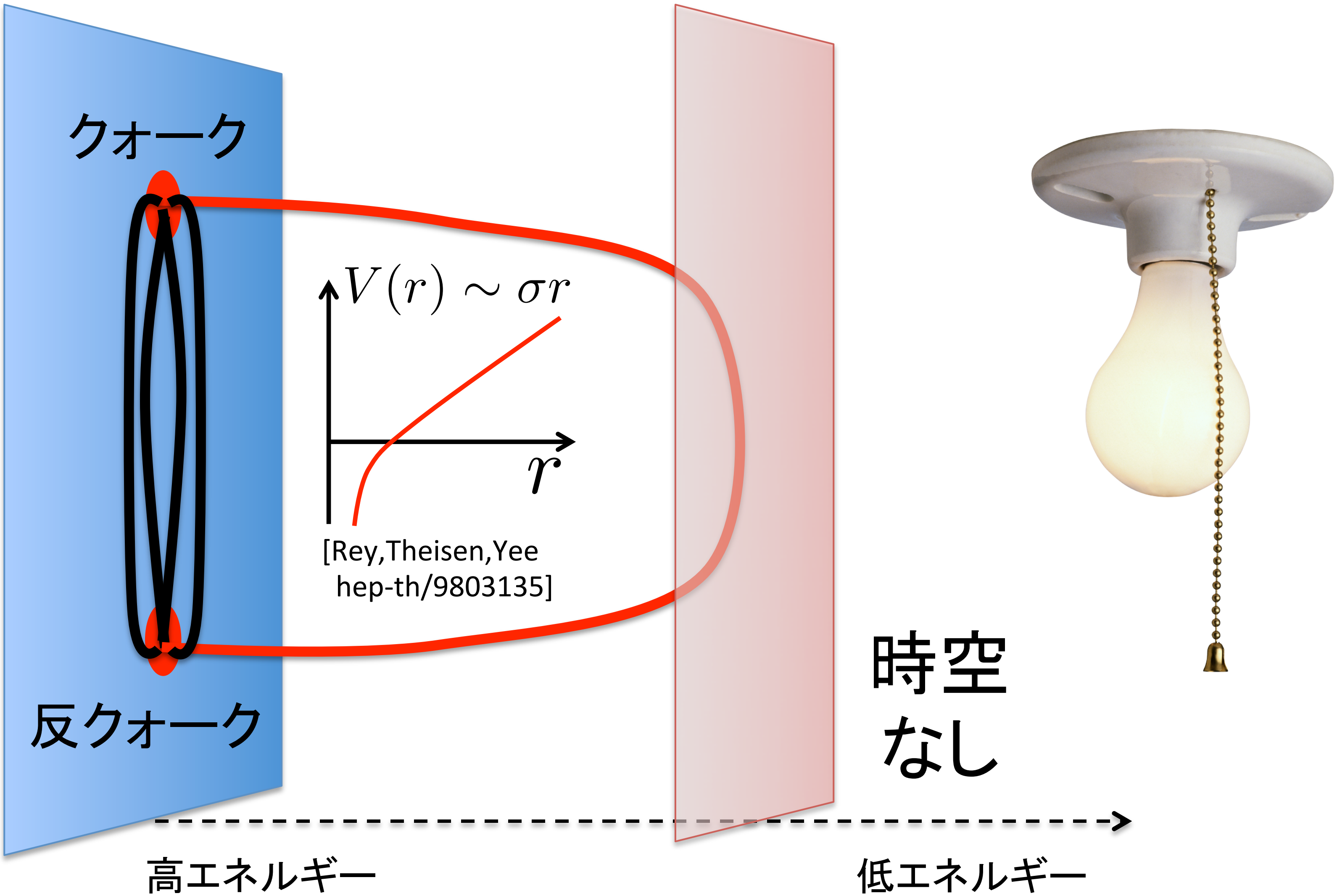

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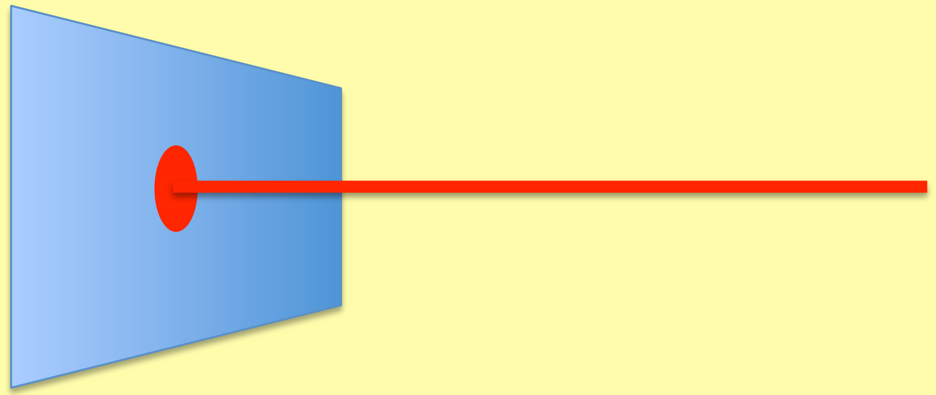


1 チャーモニウム と ブラックホール

2 重イオン衝突 と「とがった」異次元

3 原子核 と 隠れた対称性

1 チャーモニウム と ブラックホール

ArXiv:1411.0618 OU-HET-837, RIKEN-MP-95

Entropic destruction of heavy quarkonium in non-Abelian plasma from holography

Koji Hashimoto[1,2] and Dmitri E. Kharzeev[3,4]

[1] *Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*
[2] *Mathematical Physics Lab., RIKEN Nishina Center, Saitama 351-0198, Japan*

1-1 チャーモニウムの謎

Lattice QCD indicates a large amount of entropy associated with the heavy quark-antiquark pair immersed in the quark-gluon plasma. This entropy grows as a function of the inter-quark distance giving rise to an entropic force that can be very effective in dissociating the bound quarkonium

1-2 クォーク対のエントロピー：格子VS超弦

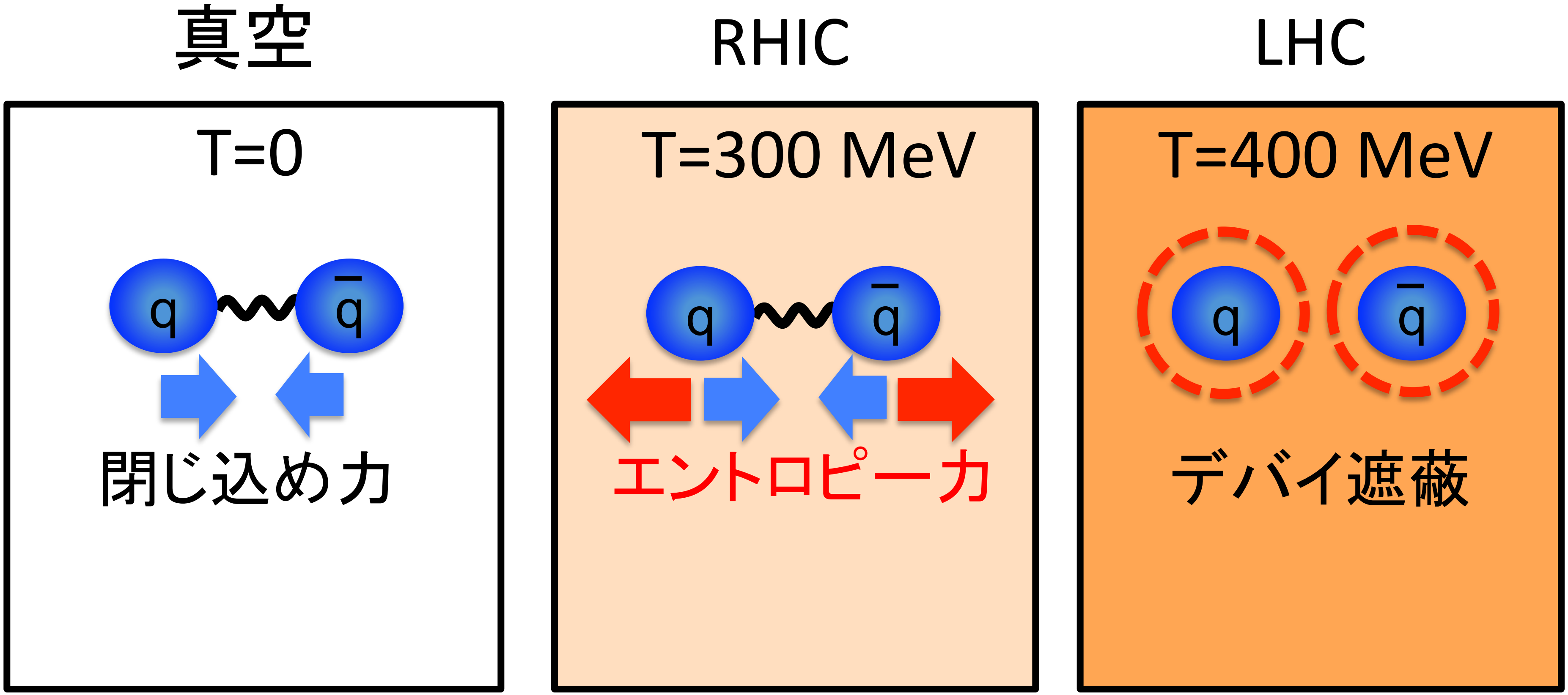
with the heavy quark-antiquark pair in two theories: i) $\mathcal{N} = 4$ supersymmetric Yang-Mills and ii) a confining Yang-Mills theory obtained by compactification on a Kaluza-Klein circle. In both cases we find the entropy growing with the inter-quark distance and evaluate the effect of the corresponding

1-3 ブラックホールを見ている

that describes the deconfinement transition. In terms of the boundary theory, this entropy likely emerges from the entanglement of a "long string" connecting the quark and antiquark with the rest of the system.

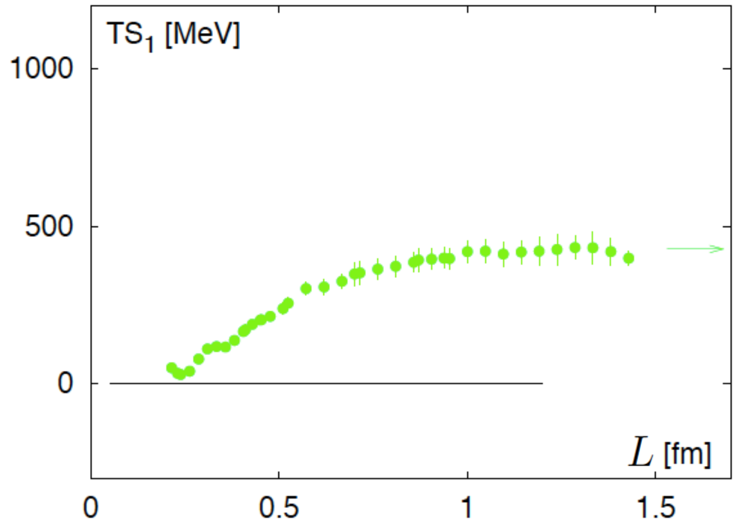
1-1 チャーモニウムの謎

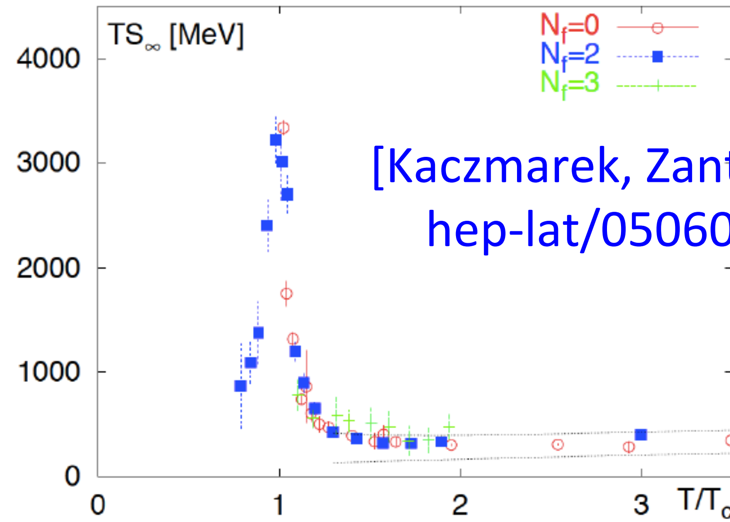
[Kharzeev, 1409.2496]



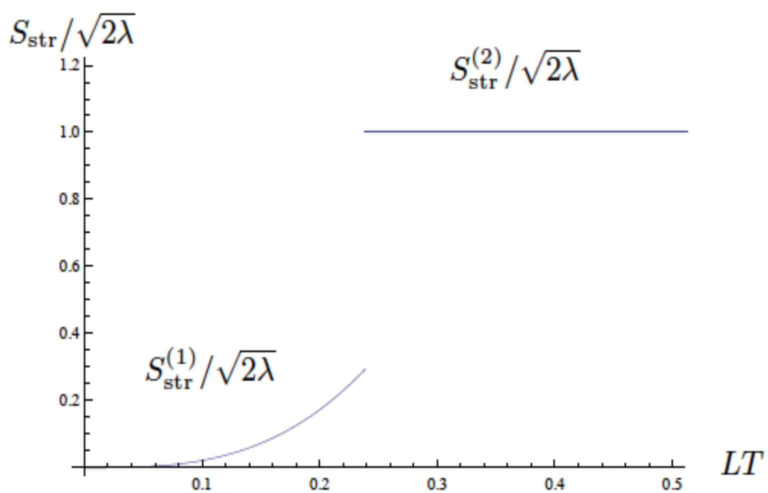
$$F = T\,\frac{\partial S}{\partial L}$$

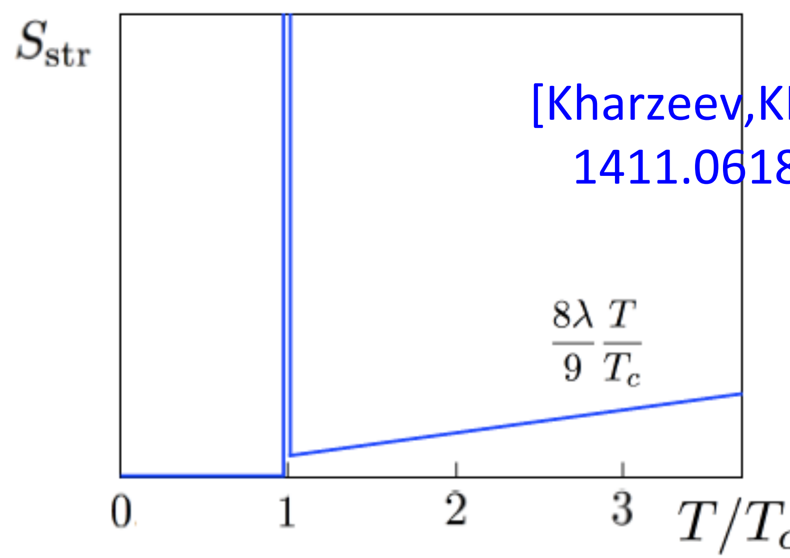
1-2 クォーク対のエントロピー：格子 VS 超弦





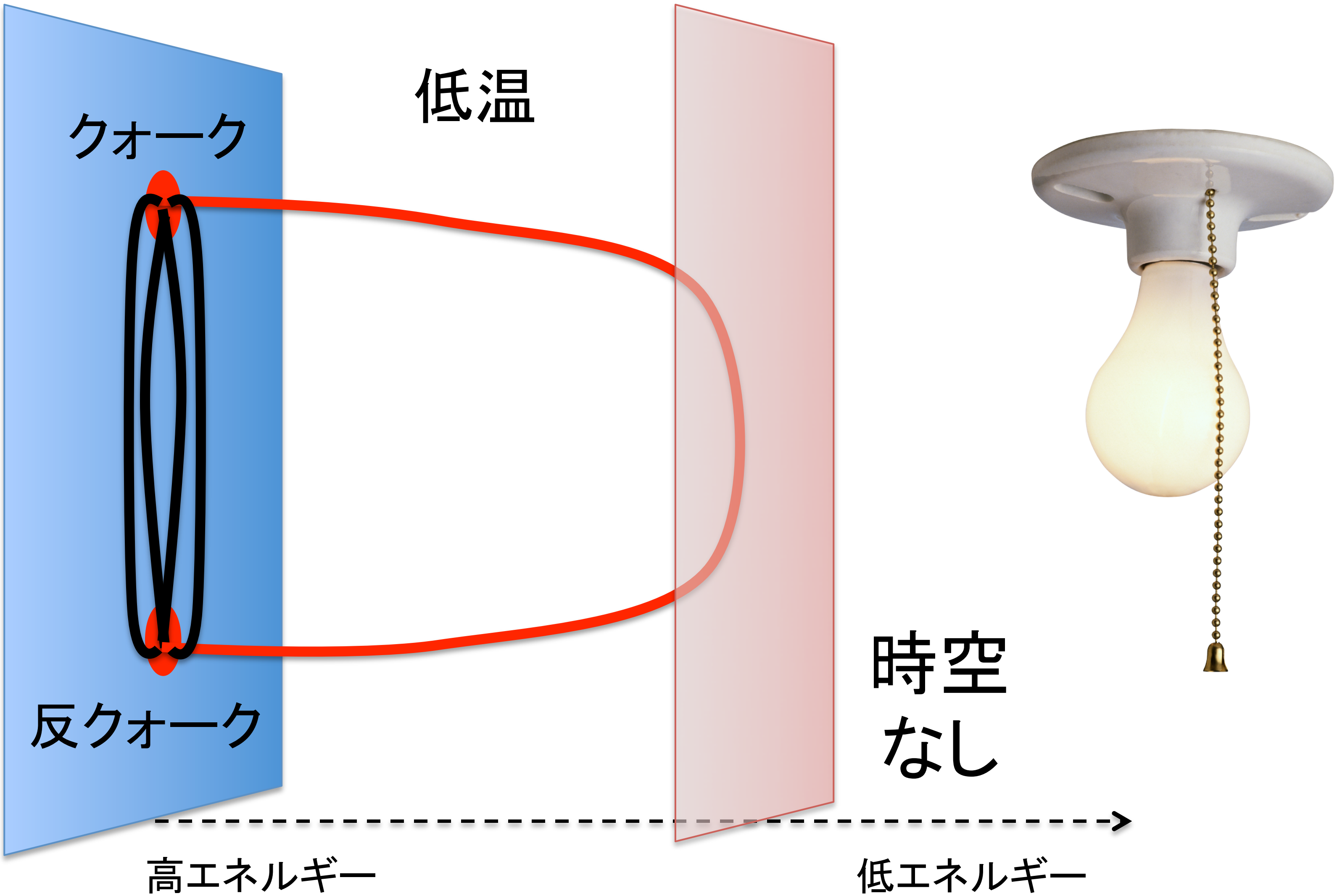
[Kaczmarek, Zantow
hep-lat/0506019]



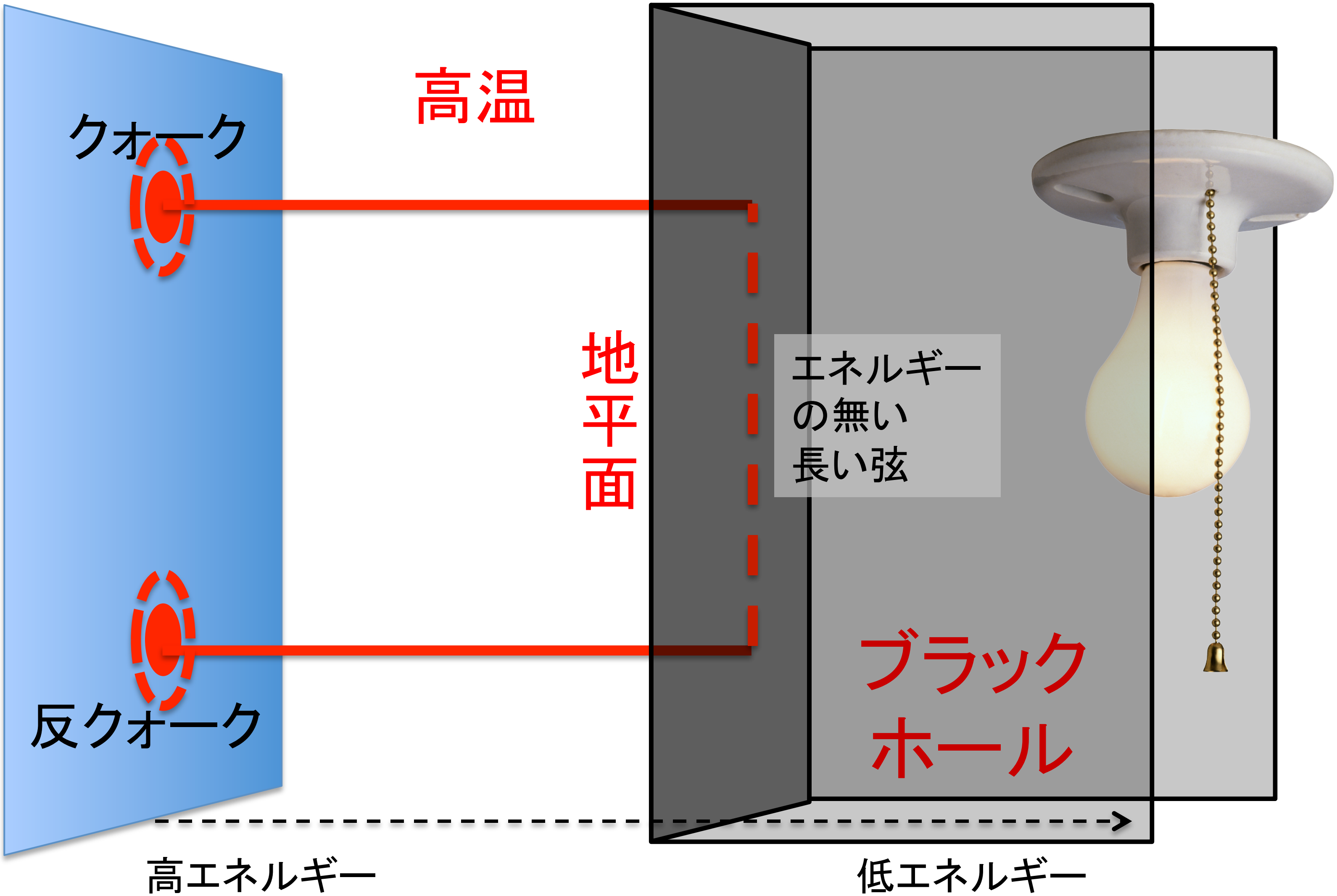


[Kharzeev,KH
1411.0618]

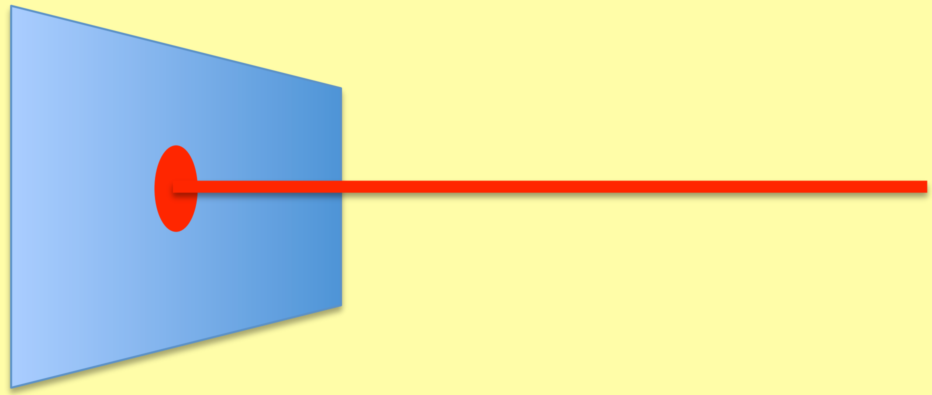
1-3 ブラックホールを見ている



1-3 ブラックホールを見ている



0 クォーク ＝ 異次元方向に伸びた弦



1 チャーモニウム と ブラックホール

2 重イオン衝突 と「とがった」異次元

3 原子核 と 隠れた対称性

2 重イオン衝突と「とがった」異次元

ArXiv:1412.4964
1412.4254
1408.6293
1407.0798
1403.6336
1307.7423

Meson turbulence at quark deconfinement from AdS/CFT

Koji Hashimoto[1,2], Shunichiro Kinoshita[3], Keiju Murata[4], and Takashi Oka[5]
[1] *Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*
[2] *Mathematical Physics Lab., RIKEN Nishina Center, Saitama 351-0198, Japan*
[3] *Osaka City University Advanced Mathematical Institute, Osaka 558-8585, Japan*
[4] *Keio University, 4-1-1 Hiyoshi, Yokohama 223-8521, Japan and*
[5] *Department of Applied Physics, University of Tokyo, Tokyo 113-8656, Japan*

Based on the QCD string picture at confining phase, we conjecture that the deconfinement tran-

distribution to each meson level n scales as n^α with the universal scaling $\alpha = -5$. The universality is checked for various ways to attain the quark deconfinement: a static electric field below/around the critical value, a time-dependent electric field quench, and a time-dependent quark mass quench, all result in the turbulent meson condensation with the universal power $\alpha = -5$ around the decon-

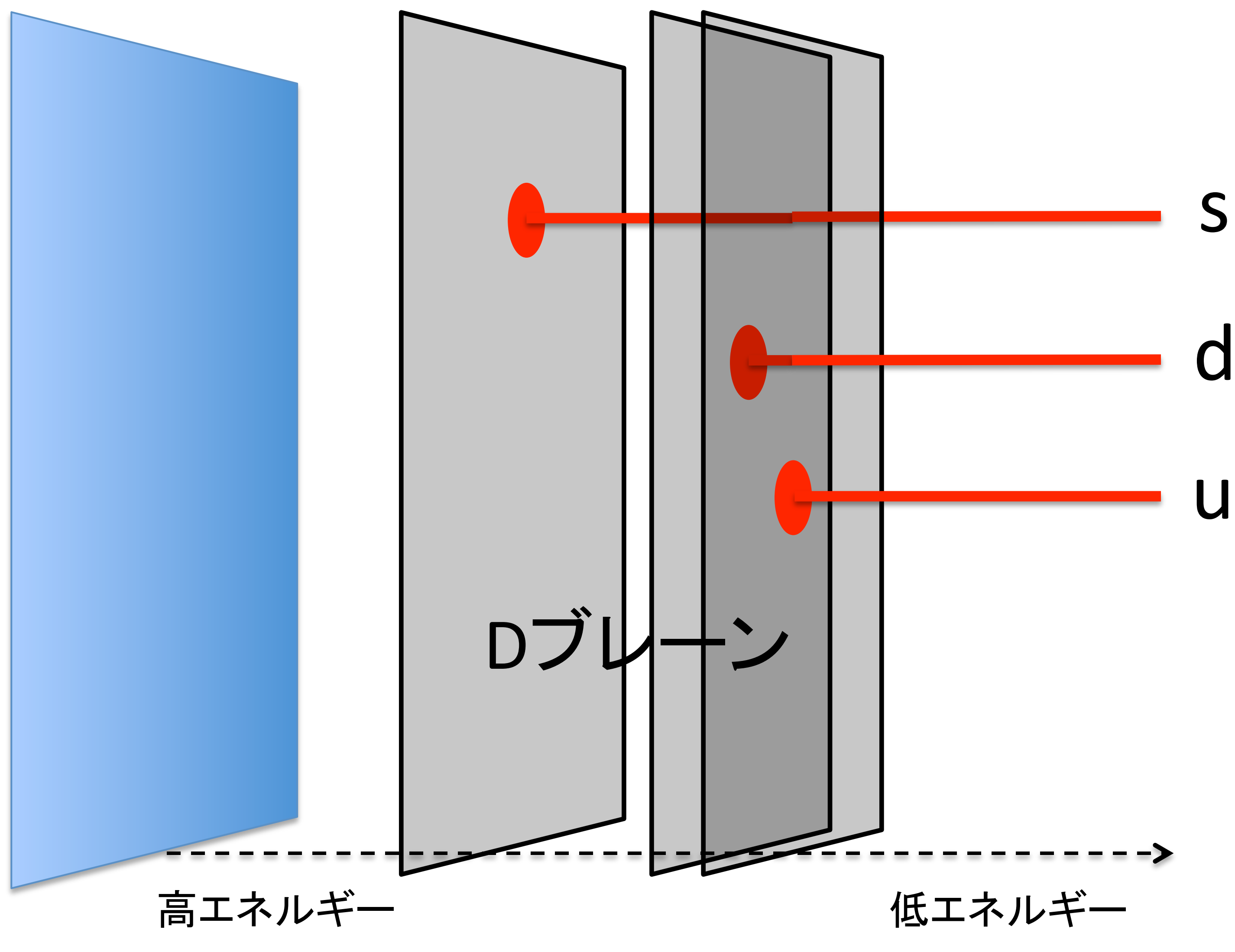
I. TURBULENCE AND QUARK DECONFINEMENT

How the quarks are confined at the vacuum of quantum chromodynamics (QCD) is one of the most fundamental

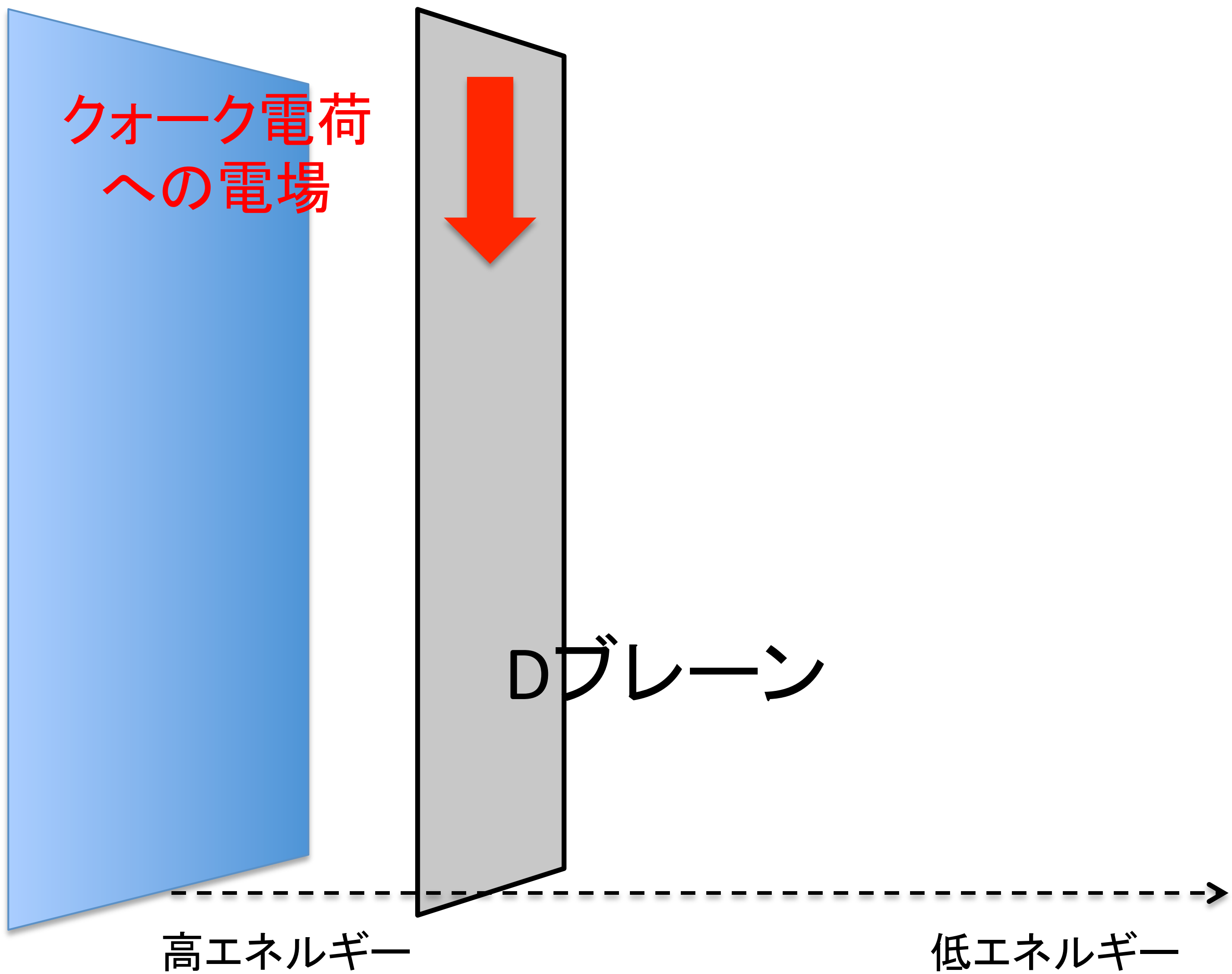
in various manner as one departs from the vacuum with the help of some external forces. The forces include for example a finite temperature, a finite quark density and electric fields. Depending on how you break the vacuum confinement, the resultant deconfined phases show various aspects with various global symmetries. This variety makes

- **2-1** クォーク質量はDブレーンで
- **2-2** 電場でとがるDブレーン
- **2-3** 重イオン衝突：変化する弱電場で非閉じ込め

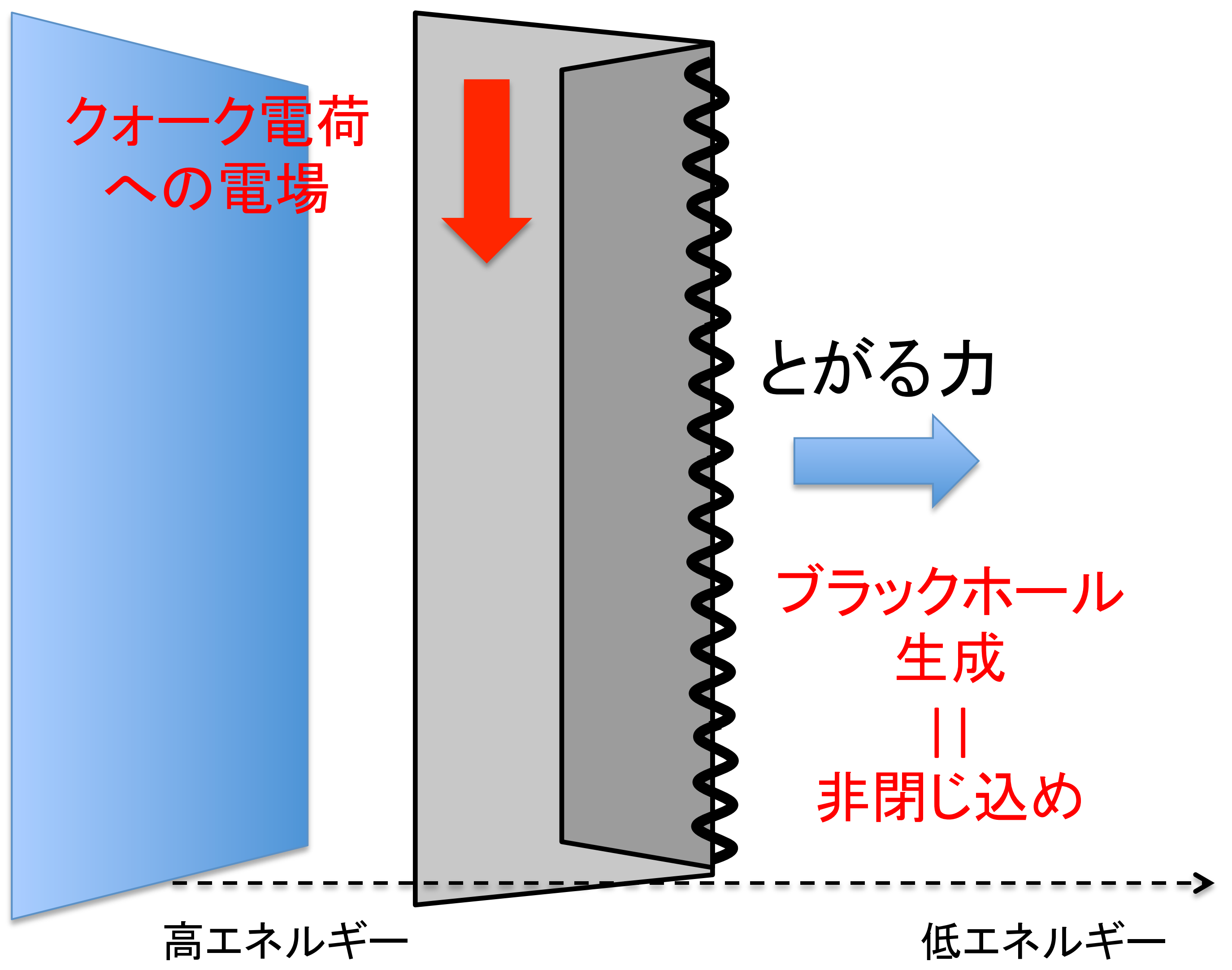
2-1 クォーク質量はDブレーンで



2-2 電場でとがるDブレーン



2-2 電場でとがるDブレーン



2-3 重イオン衝突:変化する弱電場で非閉じ込め

衝突では時間変化する弱い電場が存在

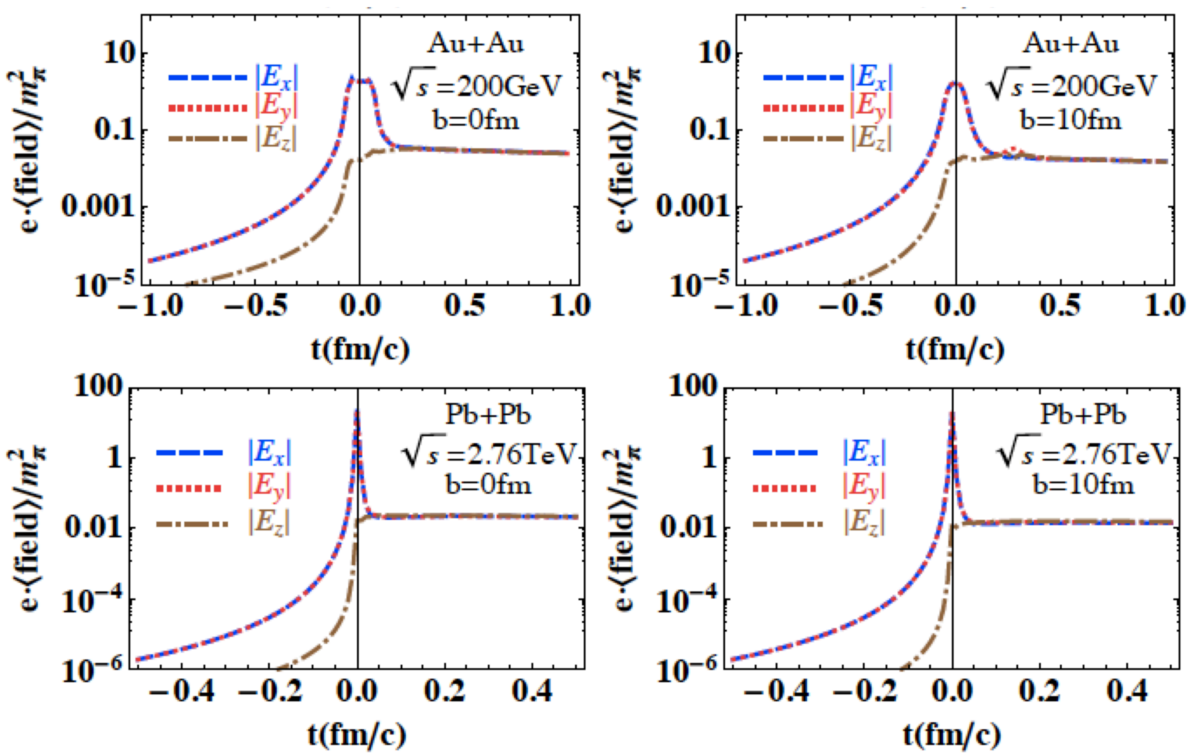
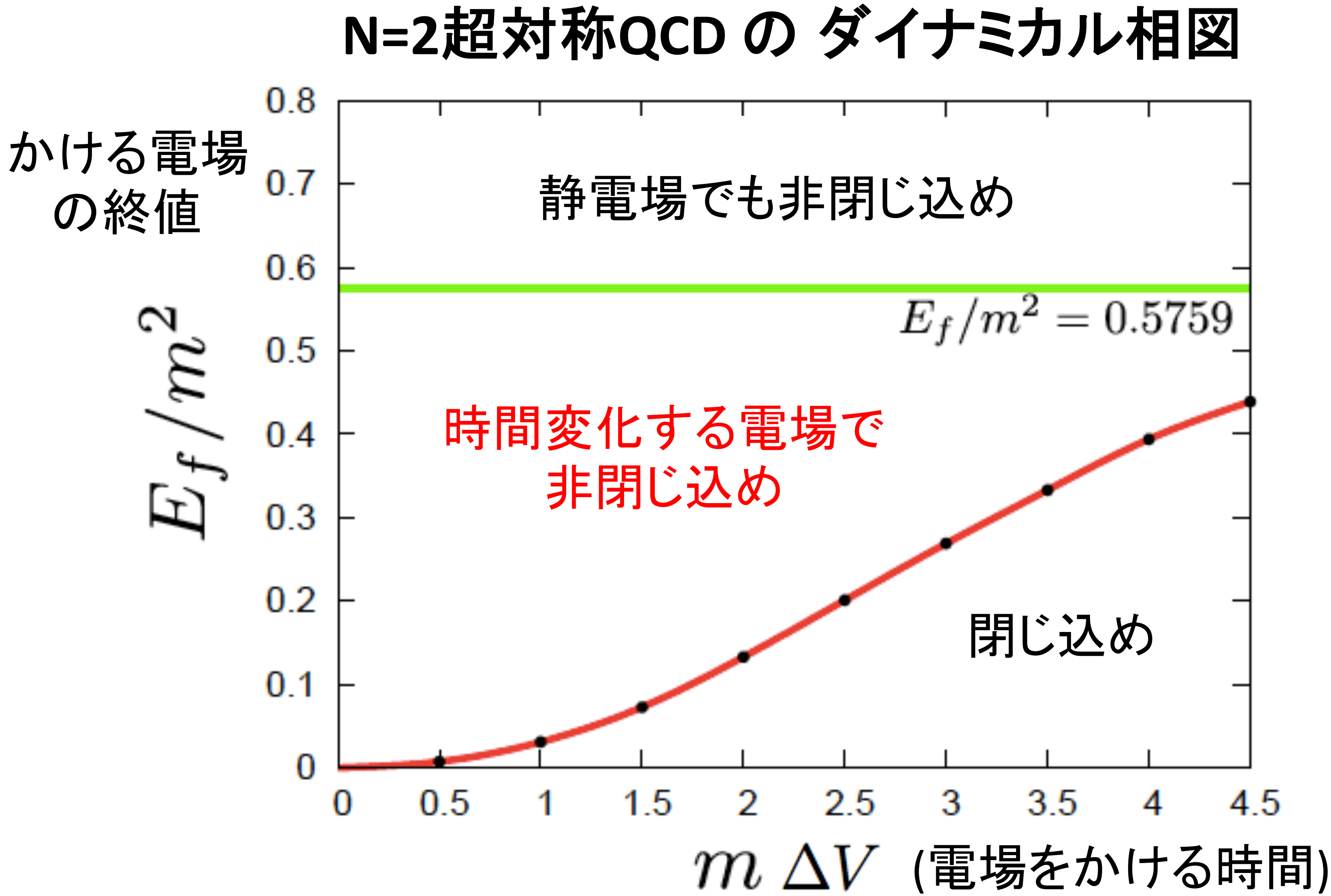


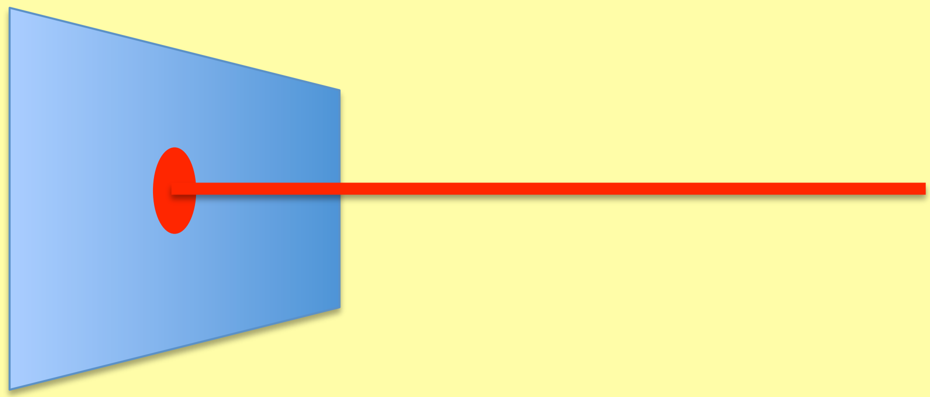
FIG. 7: (Color online) The time evolution of electromagnetic fields at $\mathbf{r} = 0$ with impact parameter $b = 0$, and $b = 10$ for Au + Au collisions at $\sqrt{s} = 200$ GeV and Pb + Pb collisions at $\sqrt{s} = 2.76$ TeV. After collision, the remnants can essentially slow down the decay of the transverse fields, and enhance the longitudinal fields.

[Deng, Huang, 1201.5108]

2-3 重イオン衝突:変化する弱電場で非閉じ込め



0 クォーク ＝ 異次元方向に伸びた弦



1 チャーモニウム と ブラックホール

2 重イオン衝突 と「とがった」異次元

3 原子核 と 隠れたゲージ対称性

3 原子核 と 隠れた対称性

ArXiv:1003.4988
0809.3141
0910.2303
0911.1035
1005.4412
1006.3612
1103.5688
1203.5386

A Matrix Model for Baryons and Nuclear Forces

3-1 核子は小さなDブレーン

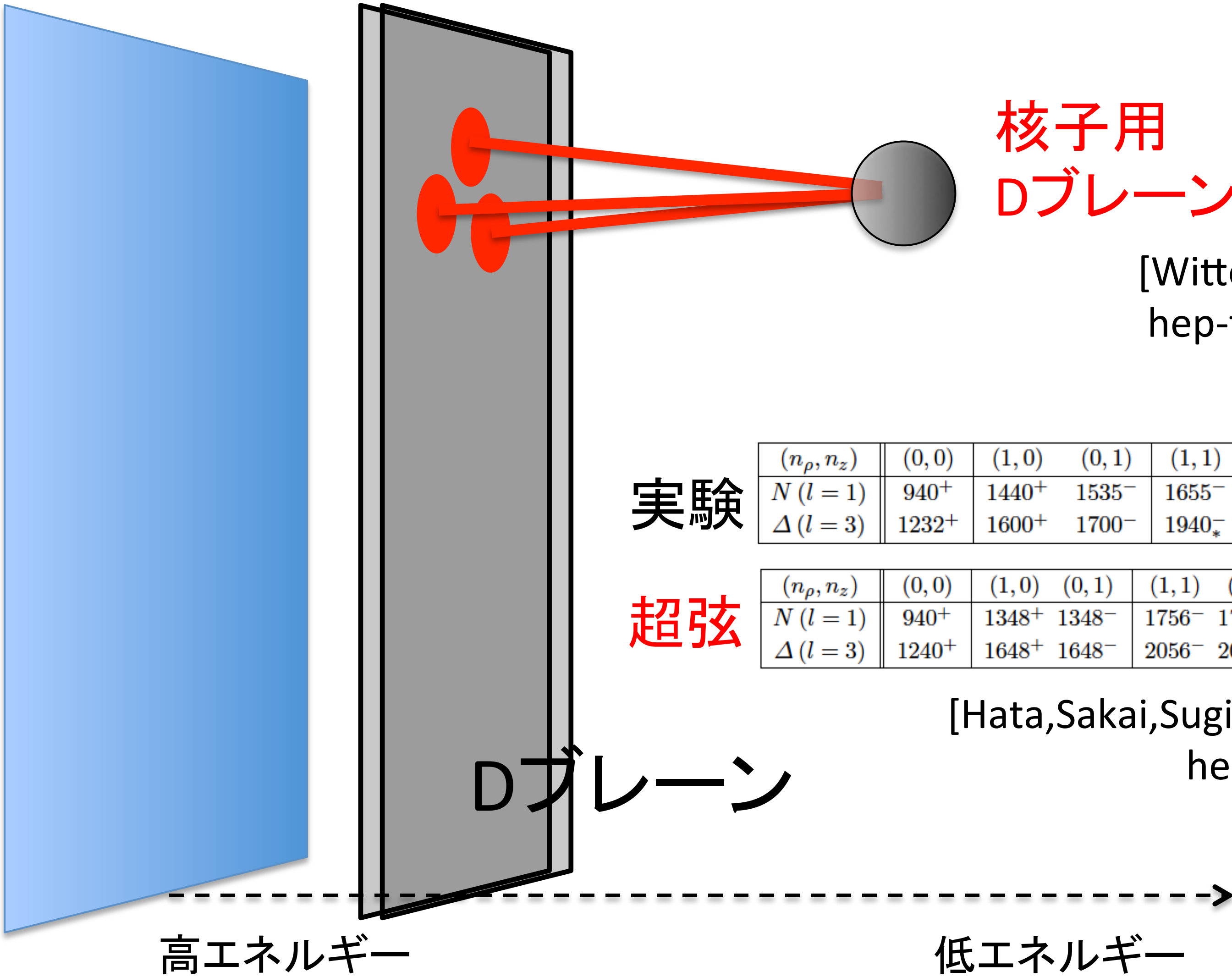
† *Theory Division, CERN, CH-1211 Geneva 23, Switzerland*
‡ *School of Physics, Korea Institute for Advanced Study, Seoul 130-722, Korea*

3-2 核力は弦の励起

3-3 原子核は行列

embedded in the D4-D8 model of large N_c holographic QCD. The positions of k baryons are unified into $k \times k$ matrices, with spin/isospin of the baryons encoded in

3-1 核子は小さなDブレーン



[Witten
hep-th/9805112]

実験

(n_ρ, n_z)	$(0,0)$	$(1,0)$	$(0,1)$	$(1,1)$	$(2,0)/(0,2)$	$(2,1)/(0,3)$
$N\,(l=1)$	940^+	1440^+	1535^-	1655^-	1710^+, ?	2090^-_*, ?
$\Delta\,(l=3)$	1232^+	1600^+	1700^-	1940^-_*	1920^+, ?	?, ?

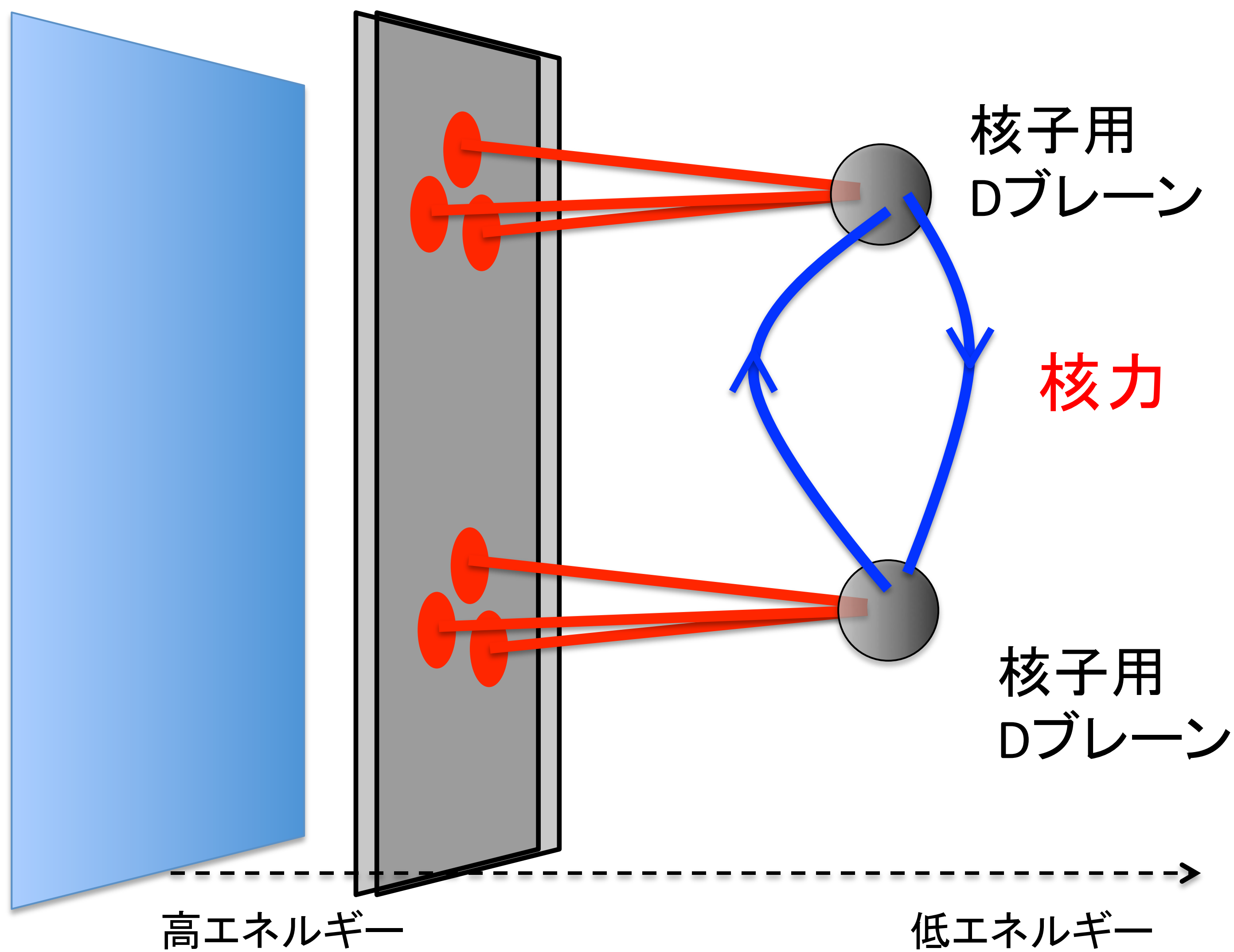
超弦

(n_ρ, n_z)	$(0,0)$	$(1,0)$	$(0,1)$	$(1,1)$	$(2,0)/(0,2)$	$(2,1)/(0,3)$
$N\,(l=1)$	940^+	1348^+	1348^-	1756^-	$1756^+, 1756^+$	$2164^-, 2164^-$
$\Delta\,(l=3)$	1240^+	1648^+	1648^-	2056^-	$2056^+, 2056^+$	$2464^-, 2464^-$

[Hata,Sakai,Sugimoto,Yamato
hep-th/0701280]

3-2

核力 は 弦の励起

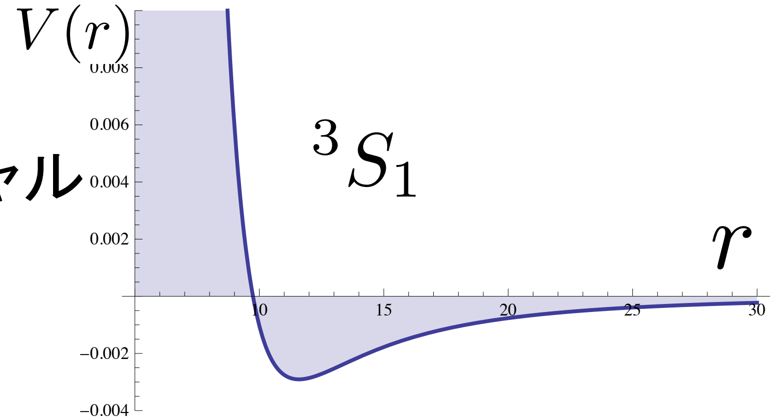


3-2 核力 は 弦の励起

[Sakai,Sugimoto,KH (0901.4449)]

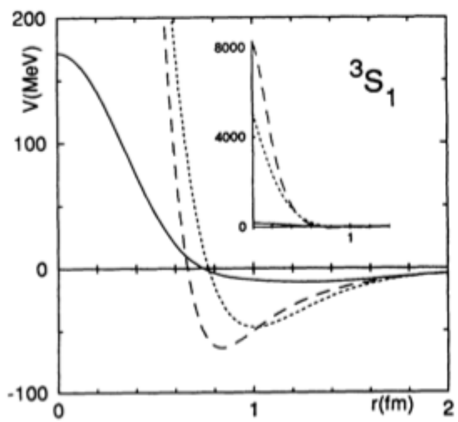
超弦理論 :

核子間
ポテンシャル



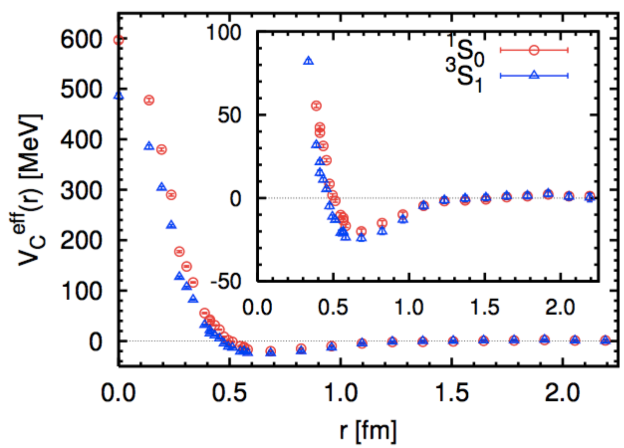
r (核子間距離)

実験



[Stoks,Klomp,Terheggen,deSwart ('94)]

格子QCD
数値計算

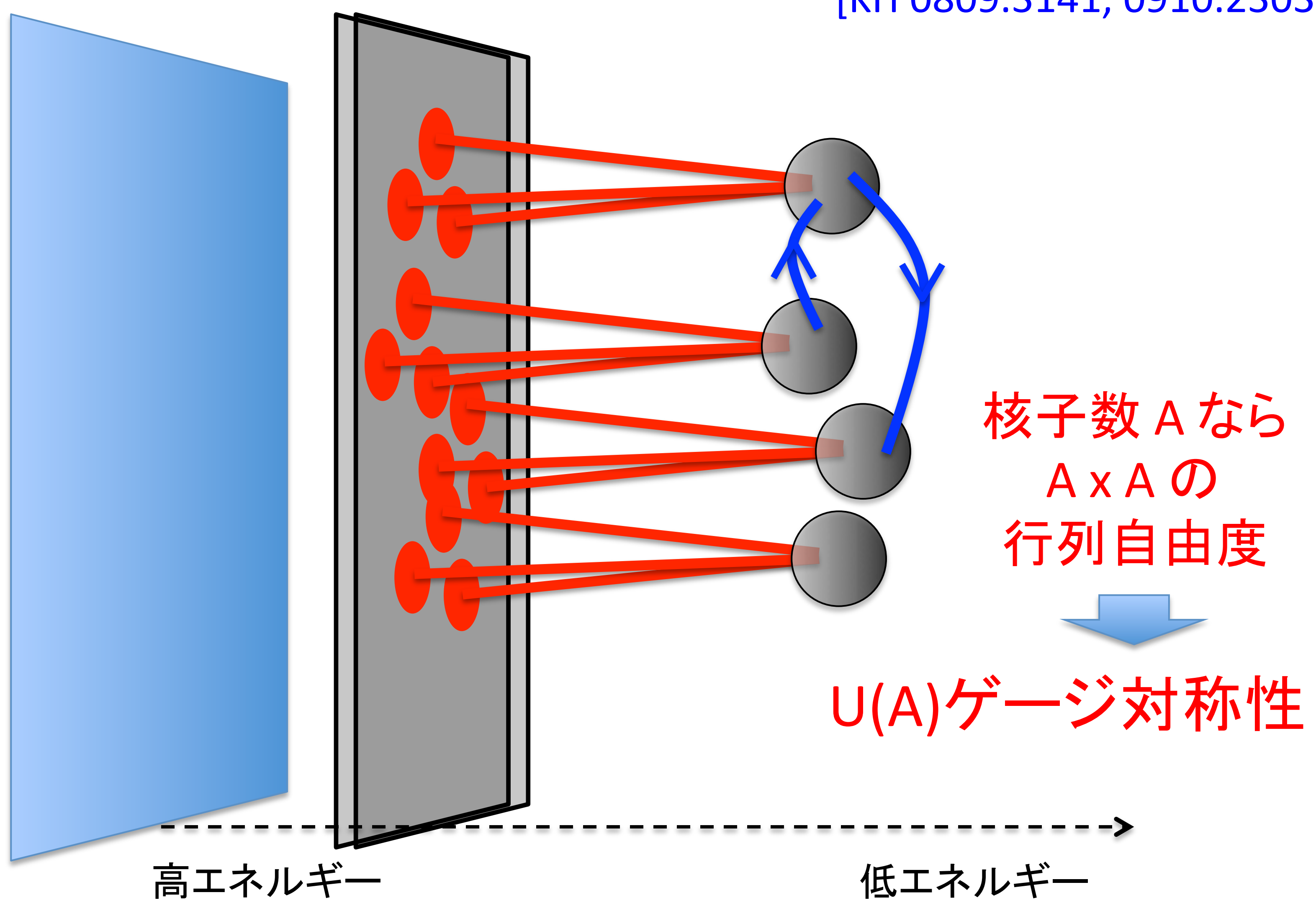


[Aoki,Ishii,Hatsuda ('07)]

3-3

原子核 は 行列

[KH 0809.3141, 0910.2303]



3-3 原子核 は 行列

[Iizuka,Yi, KH 1003.4988]

$$S = c\int dt\ \mathrm{tr}\left[\frac{1}{2}(D_t X^I)^2 - \frac{g^2}{4}[X^I, X^J]^2\right] + \cdots$$

$X^M\ (M = 1,2,3,4)$: A x A エルミート行列

$X^{M=1,2,3}$ の固有値 ＝ A個の核子の位置

パラメータは二つだけ: $c, g \ \leftrightarrow\ \lambda, M_{\mathrm{KK}} \ \leftrightarrow\ m_\rho, f_\pi$

原子核は
量子力学

$$S \sim \int dt \left[\sum_{i=1}^{A} \frac{1}{2} m_N |\partial_t \vec{x}^{(i)}|^2 + \sum_{i\neq j} V(x^{(i)} - x^{(j)}, \cdots) + \cdots\right]$$

A=1 : 励起スペクトル

バリオンはフェルミオンで、スペクトルは :

[Iizuka,Yi, KH 1003.4988]
[Iizuka, KH 1006.3612]

$$M = M_0 + \frac{1}{\sqrt{6}}\left[\sqrt{(I/2+1)^2 + N_c^2} + 2n_\rho + 2n_{X^4} + 2\right]$$

$I = J = 1/2$　　940⁺,1359⁺,1359⁻,1778⁺,1778⁻,...

$M_N, M_\triangle$　　実験：940⁺,1440⁺,1535⁻,1710⁺,1655⁻,...

A=2 : 斥力芯

[Iizuka,Yi, KH 1003.4988]
[Iizuka, S.Aoki, KH, 1203.5386]

$$V_{\mathrm{T}}(\vec{r}) = 2\pi I_1^i I_2^i \frac{N_c}{\lambda M_{\mathrm{KK}}} \frac{1}{r^2}$$

$$V_{\mathrm{C}}(\vec{r}) = \pi \left(\frac{3^3}{2} - 8 I_1^i I_2^i J_1^j J_2^j \right) \frac{N_c}{\lambda M_{\mathrm{KK}}} \frac{1}{r^2}$$

斥力芯を再現、1/r²の依存性、3フレーバーでユニバーサル

A=3 : 三体力

[Iizuka, KH,1005.4412]

問題1： 原子核の形成

[T.Morita, KH 1103.5688]

問題： 次の量子力学を A が大きい時に解きなさい.

$$S = c\int dt\, \mathrm{tr}\left[\frac{1}{2}(D_t X^I)^2 - \frac{g^2}{4}[X^I, X^J]^2\right]$$

答： 量子力学の真空：固有値が中心に集まる [Luscher, 1983]

→ **必然的に原子核が形成する**

問題2： 原子核半径 $\propto \mathbf{A}^{1/3}$

[T.Morita, KH 1103.5688]

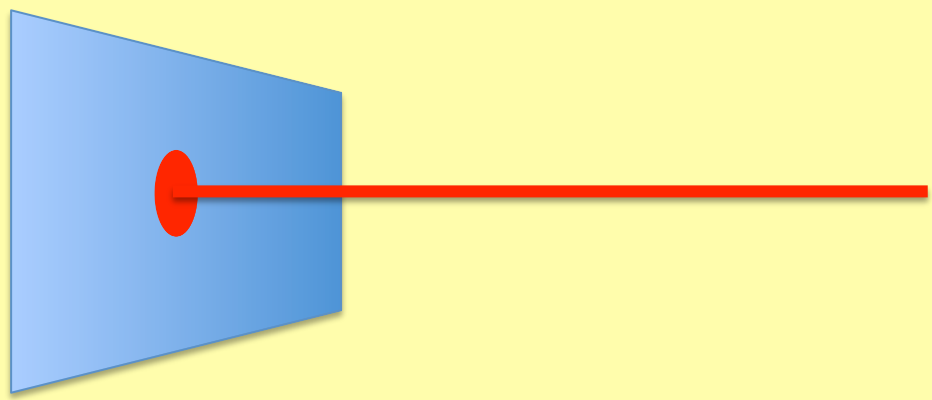
$$\sqrt{r^2_{\mathrm{mean}}} \equiv \sqrt{\frac{1}{A}\mathrm{tr}\langle X^I X^I\rangle}$$

$$= \frac{3^{5/2}\pi^{2/3}}{2^{5/6}5^{1/6}} \frac{A^{1/3}}{M_{\mathrm{KK}}(N_c\lambda^2)^{1/3}}$$

⇨ $\sqrt{r^2_{\mathrm{mean}}} \sim 0.7 A^{1/3}\ [\mathrm{fm}]$

現実的な原子核半径の解析的導出

0 クォーク ＝ 異次元方向に伸びた弦



1 チャーモニウム と ブラックホール

2 重イオン衝突 と 「とがった」異次元

3 原子核 と 隠れた対称性

異次元