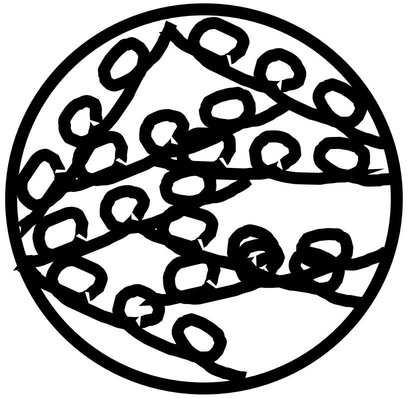
Search for glueballs



Peter Madigan

Outline

- Predictions from QCD
- Searching for the glueball (and why it’s hard)
- Potential candidates
- The future

EM vs. strong bound states

	EM	**Strong**
Charge	+/-	r, g, b
Charge neutral bound state	Atoms	Mesons, Baryons
Force carrier	Photons	Gluons
Mass	0	0
Spin	1	1
Charge	0	$\neq 0!$

A important difference! The force carrier couples to itself, so can you create a charge neutral bound state of only gluons?

Confinement and color singlets

Due to QCD confinement, only color singlet states can exist:

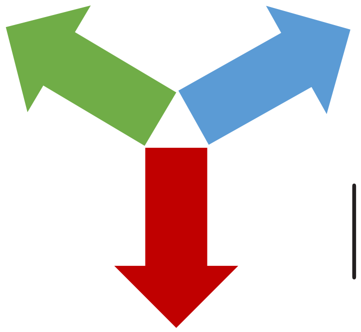
- Baryons
- Mesons

Exotic states could also exist:

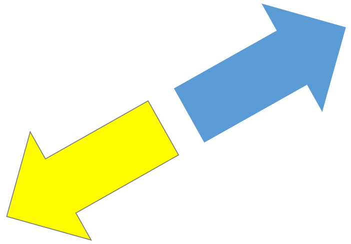
- Tetraquark states
- Glueballs

Eight gluon color combinations:

- 2+ gluons in a glueball



$$|rgb\rangle$$



$$|b\bar{b}\rangle$$

Symmetry predictions

Since gluons are spin 1 massless particles, so
Two polarizations

- J = 0,2 for 2 gluon,
- J = 1,3 for 3 gluon

C parity

- C = +1/-1 for either

P parity

- P = +1/-1 for either

Expect states:
2 gluons: $J^{PC} = 0^{++}, 0^{-+}, 2^{++}$
3 gluons: $1^{++}, 1^{+-}, 1^{--}, 3^{--}$

Lattice QCD predictions

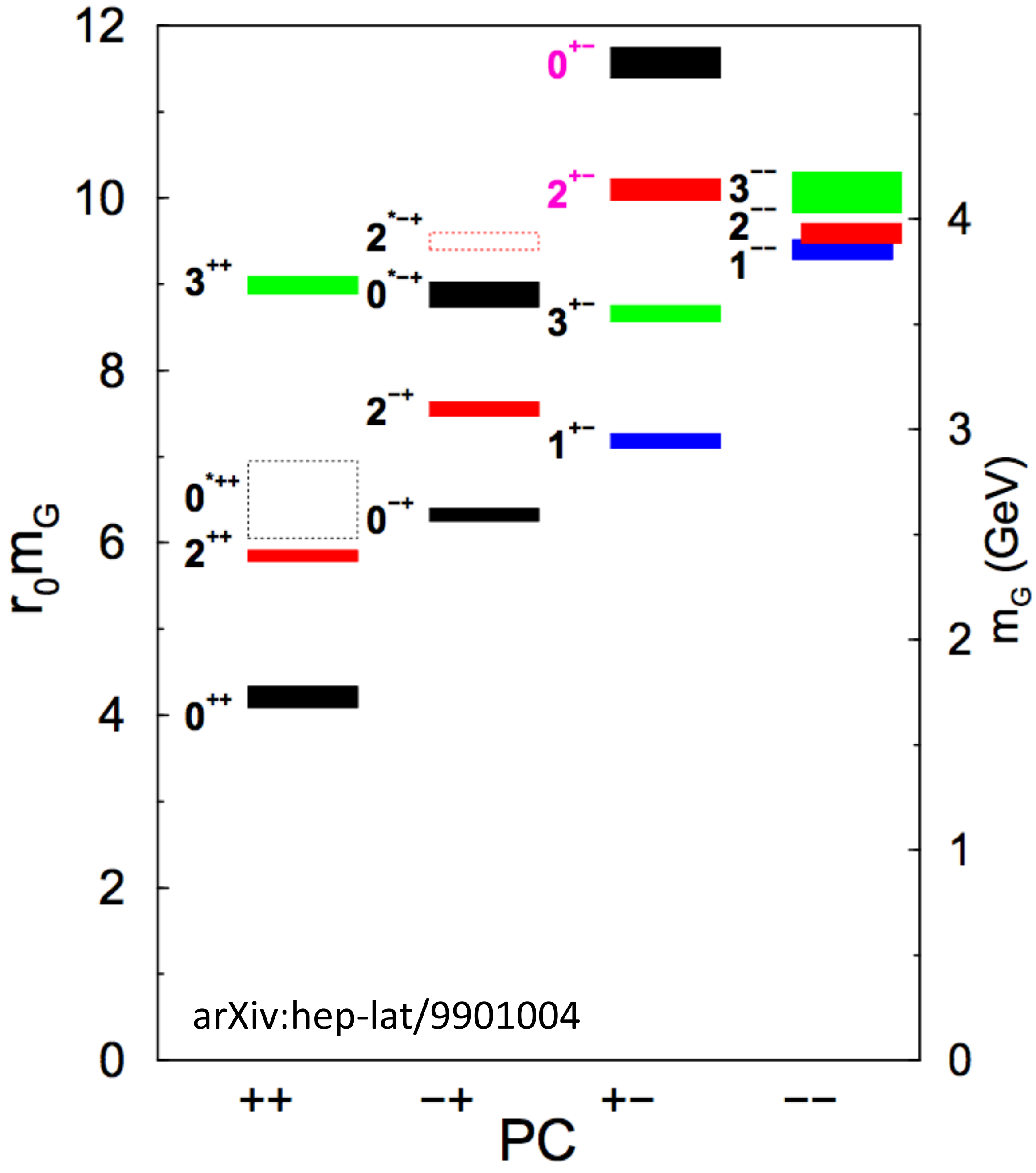
$$C_{ij}(t) = \frac{1}{Z} \int d\psi \int d\bar{\psi} \int dU e^{-S_F - S_G} \langle 0|O_i(t)^\dagger O_j(0)|0\rangle$$

Generally, lattice QCD mass predictions come from the evaluation of the 2 point correlation functions

Glueball mass predictions are difficult because

- Glueball masses are relatively large
- Mixing between gluon/fermion degrees of freedom

As a first approximation, ignore quark loop contributions, a.k.a. quenched lattice QCD .

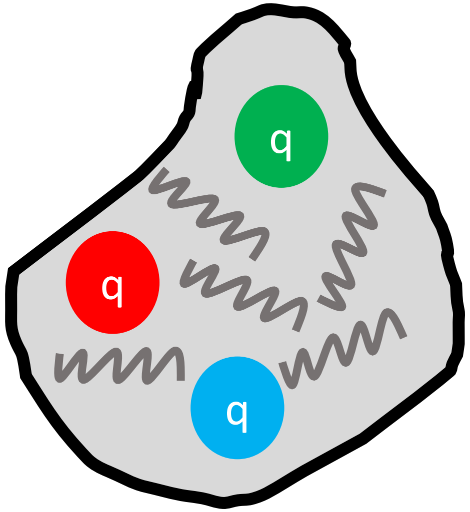


12
10
8
6
4
2
0
$r_0 m_G$
m_G (GeV)
4
3
2
1
0
0^{+-}
2^{+-}
3^{--}
2^{--}
1^{--}
2^{*-+}
3^{++}
0^{*-+}
3^{+-}
2^{-+}
1^{+-}
0^{*++}
0^{-+}
2^{++}
0^{++}
arXiv:hep-lat/9901004
++
−+
+−
−−
PC

Bag model for gluons

Create a Lagrangian in the following way:

1. Select a region of space (bag)
2. Allow quarks and gluons to live in this bag (asymptotic freedom)
3. Don't let your quarks and gluons out of the bag (confinement)
4. Add a "bag" term to the lagrangian to account for the energy associated with creating your bag
5. Solve?



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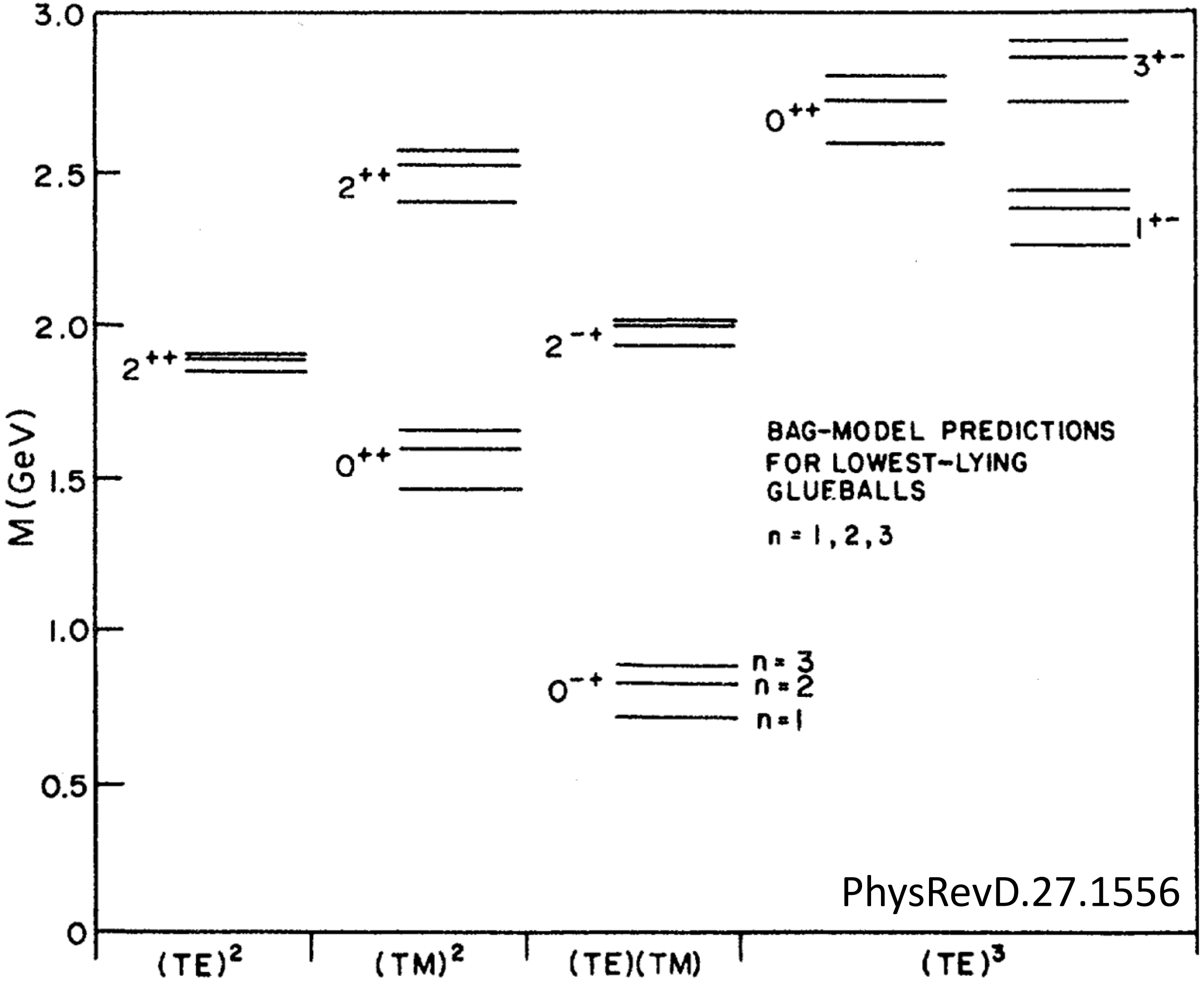

PhysRevD.27.1556

Combined expectations

1. Neutral particle
2. Lowest-lying glueball are likely scalar particles
3. Both lattice QCD and bag model predicts energy around 1.5GeV for 0^{++}
4. Suppression of radiative decay

Looking for a glueball

Where to search?

Gluon rich processes

- Radiative J/psi decay
- Central region collision
- Proton-antiproton annihilation

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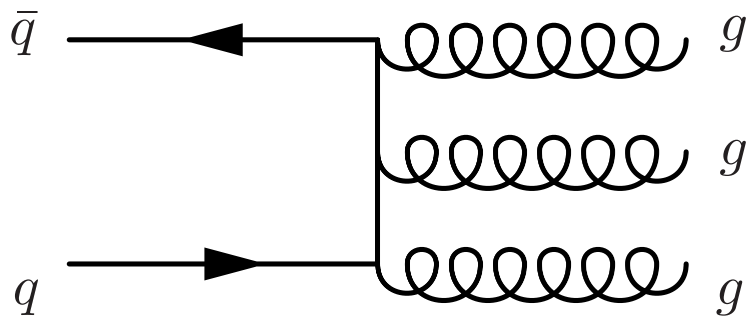
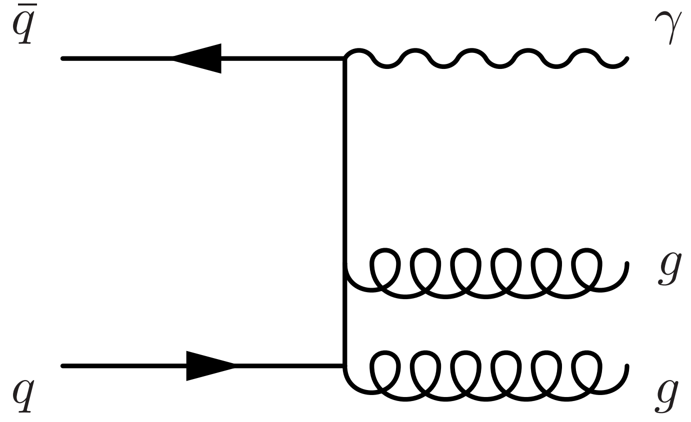
OZI suppressed:





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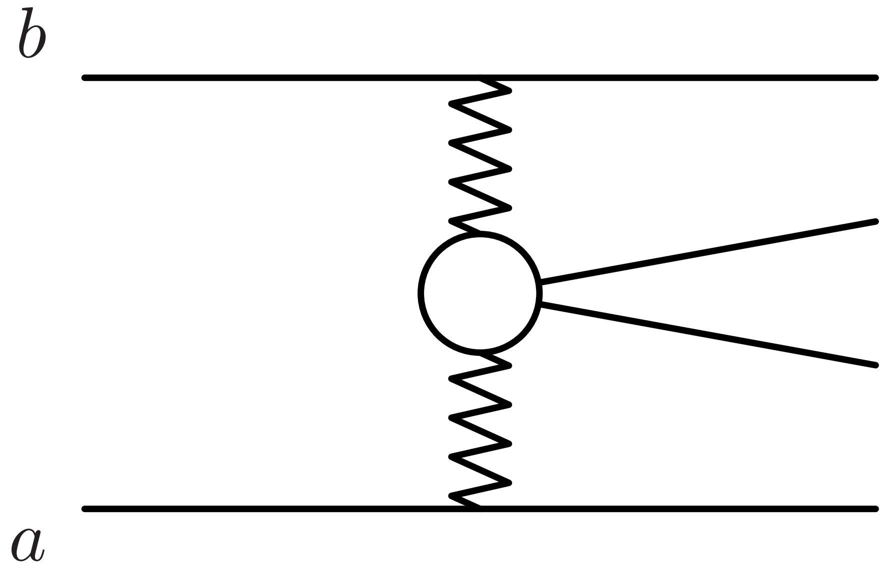

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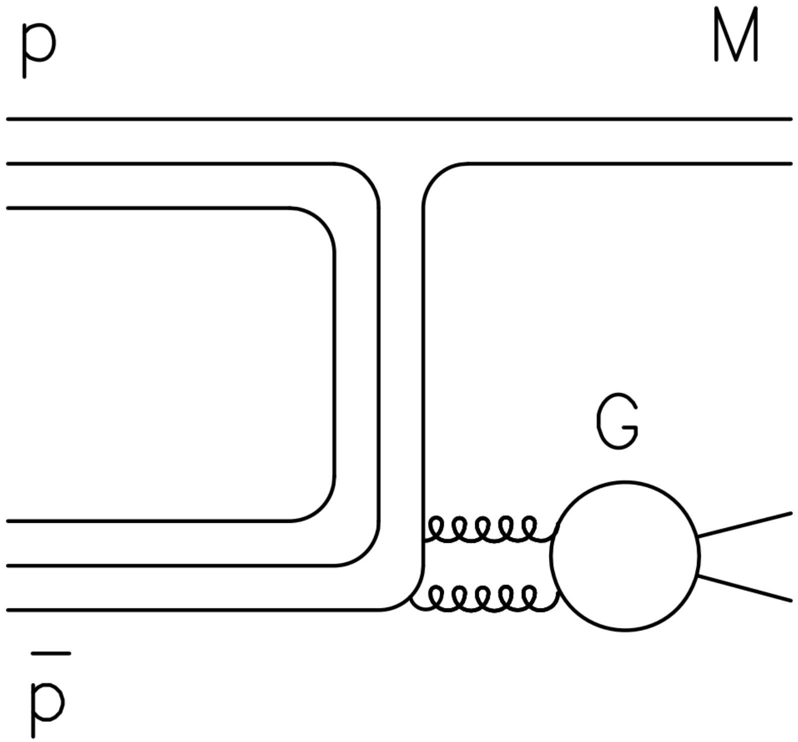

Candidates

- $f_0(500)$ $J^{PC}=0^{++}$
- $f_0(980)$ $J^{PC}=0^{++}$
- $f_0(1370)$, $f_0(1500)$, $f_0(1710)$ $J^{PC}=0^{++}$
- X(1835) $J^{PC}=0^{-+}$
- …

$f_0(500)$

Mass: 400-550MeV

Decay: 2 pions or 2 photons

2 photon decay width: 2keV

Expected gluonic photon width: ~0.2keV
(http://dro.dur.ac.uk/4243/1/4243.pdf)

Coupling to photons is greater than would be expected for a pure glueball

$f_0(980)$

Mass: 990MeV

Decay: 2 pions, 2 Kaons, 2 photons

g_K^2/g_{pi}^2 = 4.2, BES collab in J/psi decays

coupling to K suggests a significant s component (https://arxiv.org/pdf/1301.5183v3.pdf)

Large s component and models can account for resonance without large glueball mixing

$f_0(1370)$, $f_0(1500)$, $f_0(1710)$

$f_0(1370)$, $f_0(1500)$ discovered by Crystal Barrel collaboration

Fall into the region predicted by theory

Produced in gluon-rich processes

Small 2 photon widths

Quark model predicts 2 f_0 states near $f_0(1500)$, but there are 3!

Glueball discovery!

Table 13: Partial decay widths of the $f_0(1370)$ and $f_0(1500)$.

	$f_0(1370)$	$f_0(1500)$
Γ_{tot}	~ 350	~ 109
$\Gamma_{\pi\pi}$	~ 90	~ 32
$\Gamma_{\eta\eta}$	~ 1	~ 6
$\Gamma_{\eta\eta'}$		~ 3
$\Gamma_{\bar{K}K}$	~ 50	~ 6
$\Gamma_{4\pi}$	~ 210	~ 62
$\Gamma_{\sigma\sigma}$	~ 106	~ 20
$\Gamma_{\rho\rho}$	~ 55	~ 10
$\Gamma_{\pi^*\pi}$	~ 36	~ 25
$\Gamma_{a_1\pi}$	~ 13	~ 7

$f_0(1370)$, $f_0(1500)$, $f_0(1710)$

Decay channels:

- Expect pi:eta eta:eta eta':K = 3:1:0:4
- None can be a *pure* glueball

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Mixing between quark state and gluon state:

$$\cos\phi\,|q\bar{q}\rangle + \sin\phi\,|gg\rangle$$

In PhysRevD.92.094006,

$$\begin{pmatrix} |f_0(1370)\rangle \\ |f_0(1500)\rangle \\ |f_0(1710)\rangle \end{pmatrix} = \begin{pmatrix} 0.78 \pm 0.02 & 0.52 \pm 0.03 & -0.36 \pm 0.01 \\ -0.55 \pm 0.03 & 0.84 \pm 0.02 & 0.03 \pm 0.02 \\ 0.31 \pm 0.01 & 0.17 \pm 0.01 & 0.934 \pm 0.004 \end{pmatrix} \begin{pmatrix} |N\rangle \\ |S\rangle \\ |G\rangle \end{pmatrix}$$

$f_0(1370)$, $f_0(1500)$, $f_0(1710)$

Mixing between quark state and gluon state:

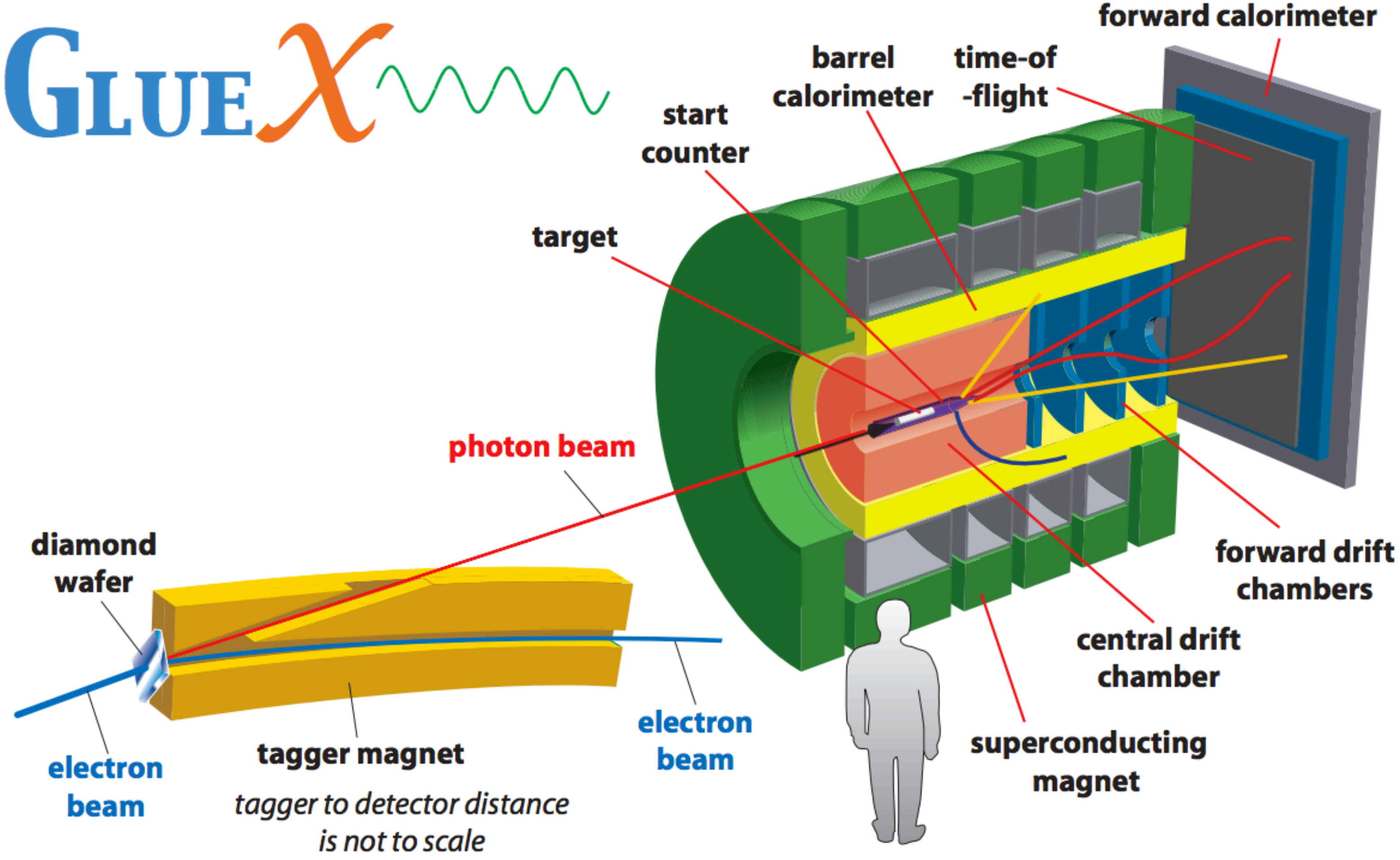
$$\cos\phi\,|q\bar{q}\rangle + \sin\phi\,|gg\rangle$$

In arXiv:hep-ph/0504033,

$$\begin{pmatrix} |f_1\rangle \equiv |f_0(1370)\rangle \\ |f_2\rangle \equiv |f_0(1500)\rangle \\ |f_3\rangle \equiv |f_0(1710)\rangle \end{pmatrix} = \begin{pmatrix} 0.86 & 0.45 & 0.24 \\ -0.45 & 0.89 & -0.06 \\ -0.24 & -0.06 & 0.97 \end{pmatrix} \begin{pmatrix} |N\rangle \equiv |\bar{n}n\rangle \\ |G\rangle \equiv |gg\rangle \\ |S\rangle \equiv |\bar{s}s\rangle \end{pmatrix}$$

swapped positions

GlueX



Experiment located at the JLab accelerator

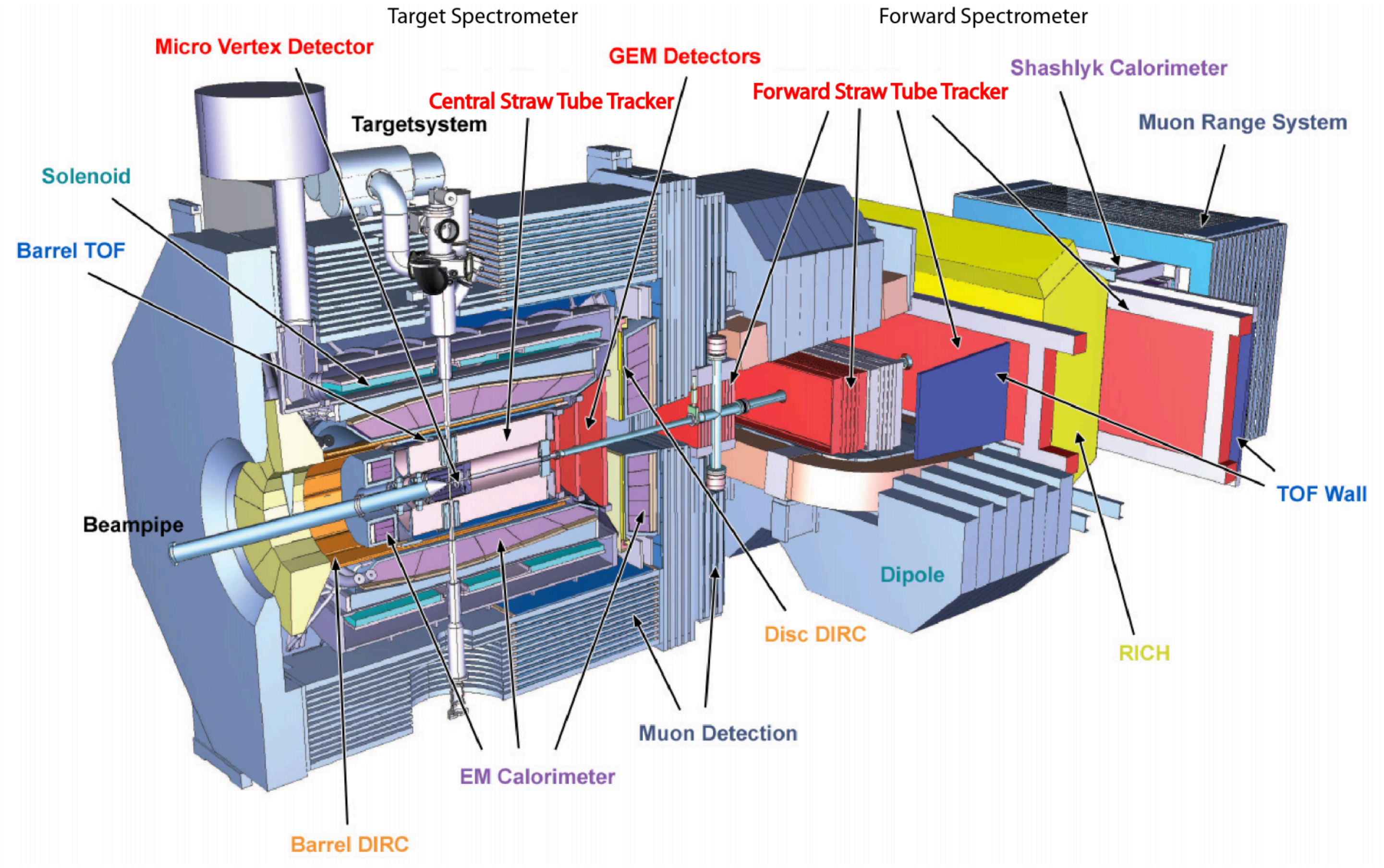
12GeV electron beam delivers 40% polarized 9GeV photons to liquid hydrogen target

Aim is to discover exotic meson states with $J^{PC} = 0^{+-}$, 1^{-+}, 2^{+-}

These exotic states could include glueballs

arXiv:1512.03699

PANDA



German experiment based at FAIR

Antiproton beam between 1.5GeV and 15GeV incident on target

Will search for glueballs through exotic J^{PC} states

Broad physics program from hypernuclei to nucleon structure

arXiv:1312.0953

Conclusion

- QCD says that glueballs *should* exist
- Glueballs are hard to find due to strong mixing with other quark states
- There are many observed particles that could be partially glueball states
- Looking for exotic quantum numbers could be where to find the “pure” glueball