KARL-FRANZENS-UNIVERSITÄT GRAZ
UNIVERSITY OF GRAZ

Der Wissenschaftsfonds.

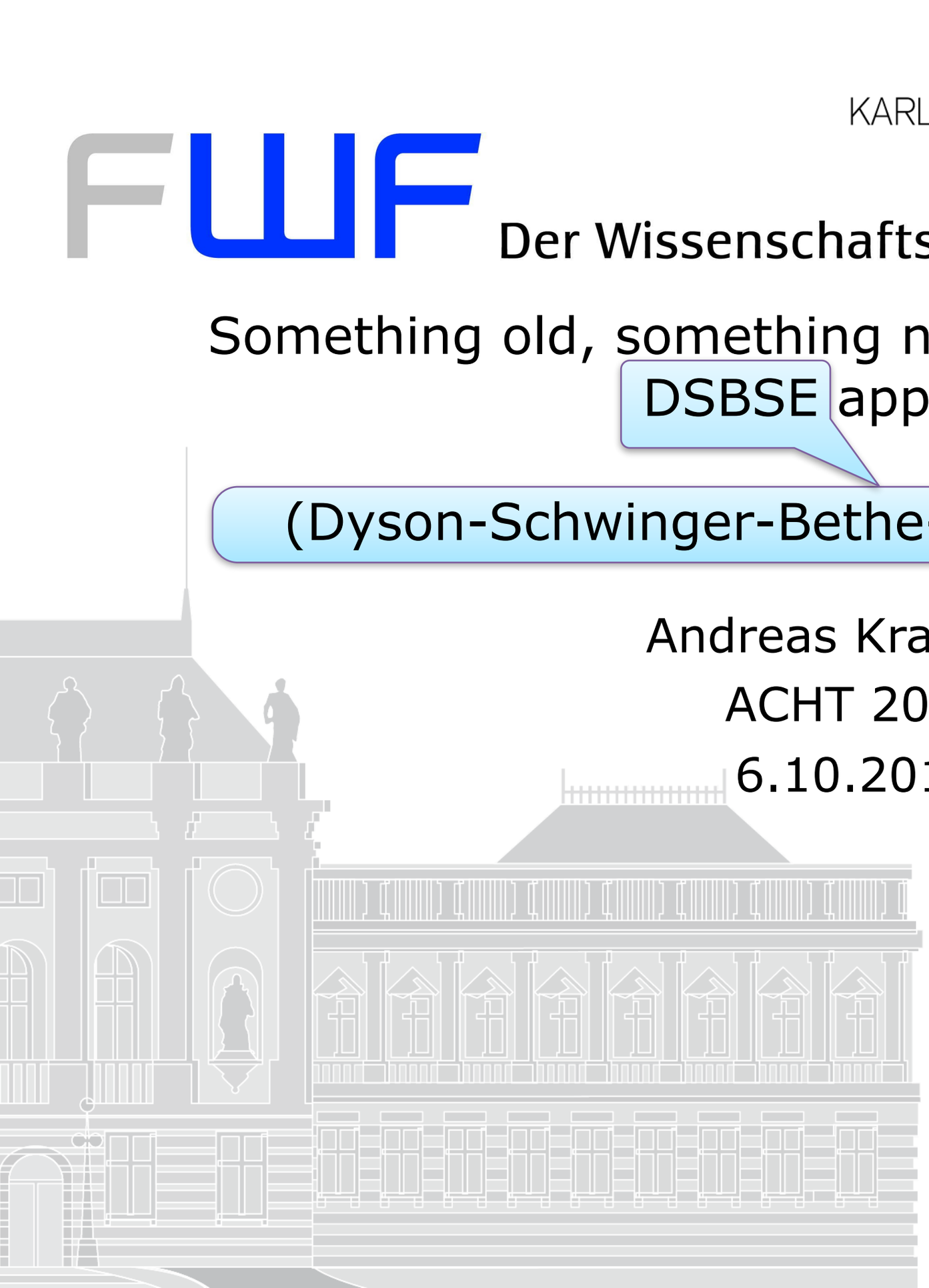
Something old, something new, and more from the DSBSE approach

(Dyson-Schwinger-Bethe-Salpeter-Equation)

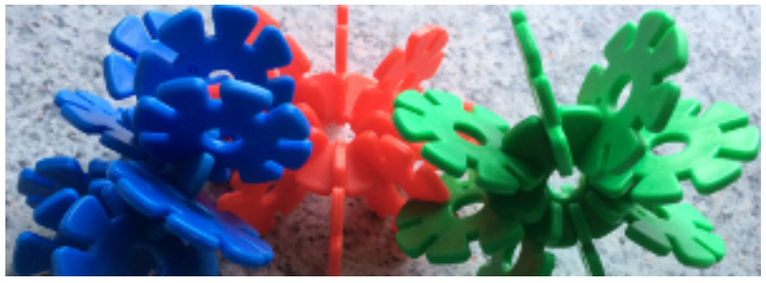
Andreas Krassnigg

ACHT 2016

6.10.2016



@akrassnigg



Metadata

Work done at:

University of Graz, Inst. f. Physik, NAWI Graz

Research group “Covariant Models of Hadrons”

http://Covariant.ModelsofHadrons.com

Collaborators:

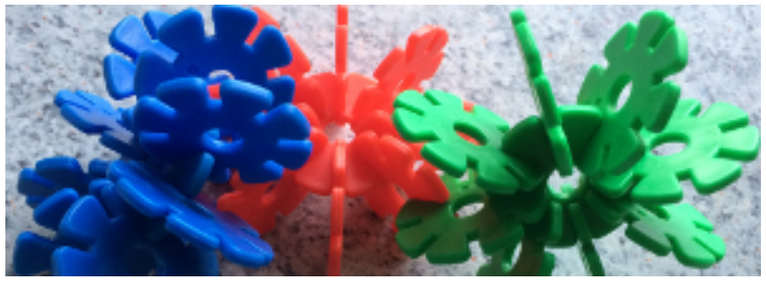
M. Blank, M. Gomez-Rocha, T. Hilger, C. Popovici,

G. Eichmann, V. Mader

Supported by the FWF (Austrian Science Fund):

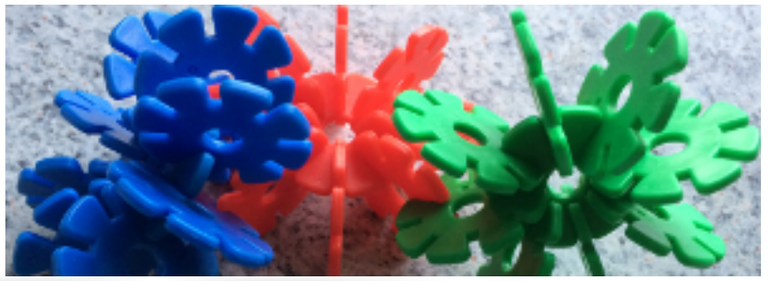
Project P25121-N27

Outline



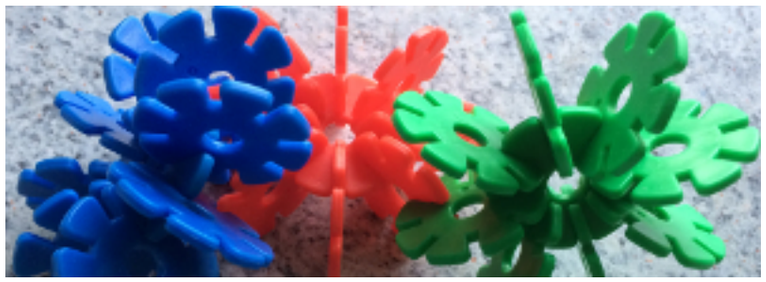
- Hadron Theory
- The Tool: DSBSE Formalism
- Spectroscopy
- Leptonic Decays
- Quasi-Exotic Open-Flavor States
- Orbital Angular Momentum
- Outlook

Hadron Theory



- Study hadrons as composites of quarks and gluons…
- … including:
  - Chiral symmetry and $D\chi SB$
  - correct perturbative limit (via $\alpha_{\rm p}(Q^2)$)
    - quark and gluon confinement
    - Poincare covariance
- Calculate Observables
- Provide comprehensive results for phenomenology

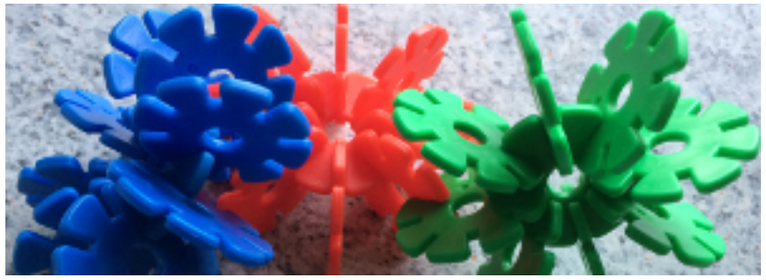
http://www.particlezoo.net/



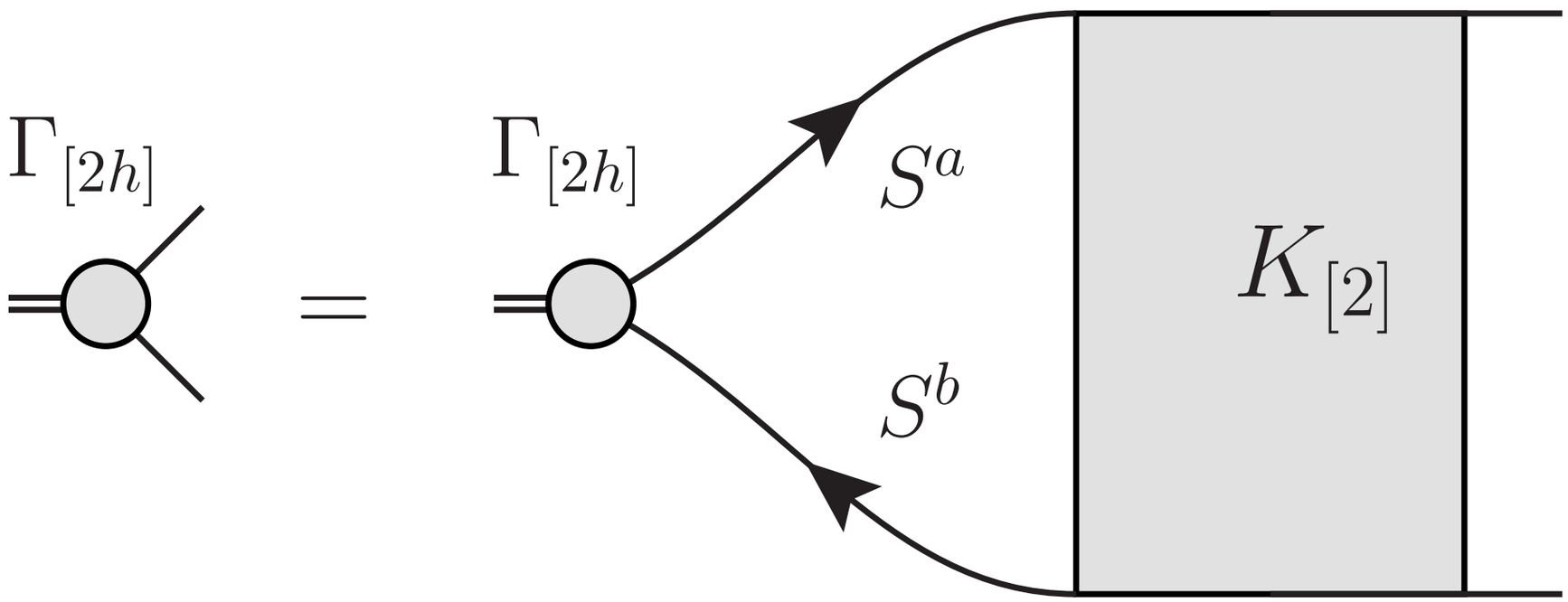
The Tool: DSBSE Formalism

- Dyson-Schwinger equations can be used to solve QCD
- Bethe-Salpeter and Faddeev-type equations allow covariant and symmetry-preserving study of bound-state problems
- Infinite set of coupled (and nonlinear) integral equations
- Numerical studies: Truncation $\leftrightarrow$ numerical effort
- Make the truncation respect symmetries
- Construct sophisticated models
- Perform reliable calculations of hadron properties
- Reviews:
  - C.D. Roberts and S.M. Schmidt, Prog. Part. Nucl. Phys. 45 (2000) S1
  - R. Alkofer and L. von Smekal, Phys. Rept. 353 (2001) 281
  - C. S. Fischer, J. Phys. G 32 (2006) R253
  - C.D. Roberts, M. S. Bhagwat, A. Holl, S. V. Wright, Eur. Phys. J. Special Topics 140 (2007) 53

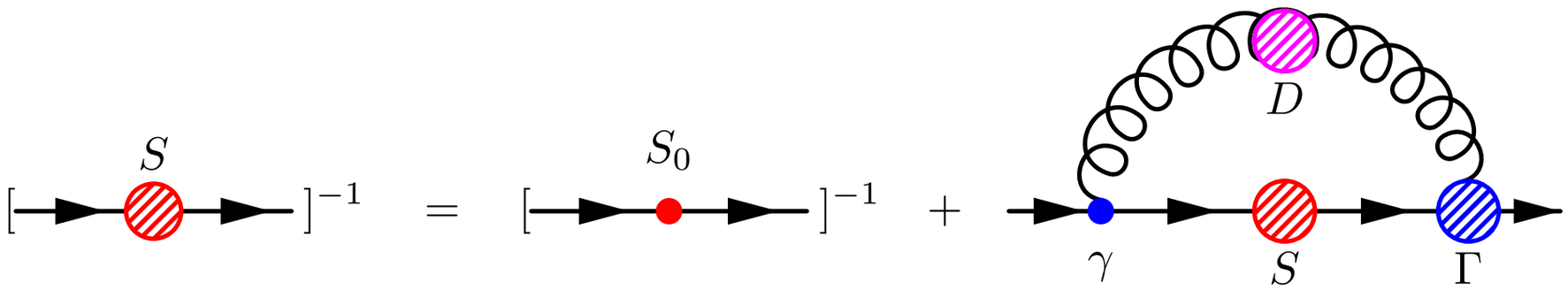
The DSBSE system



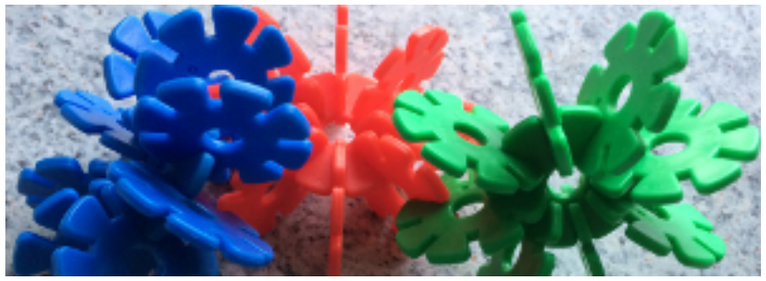
meson BSE

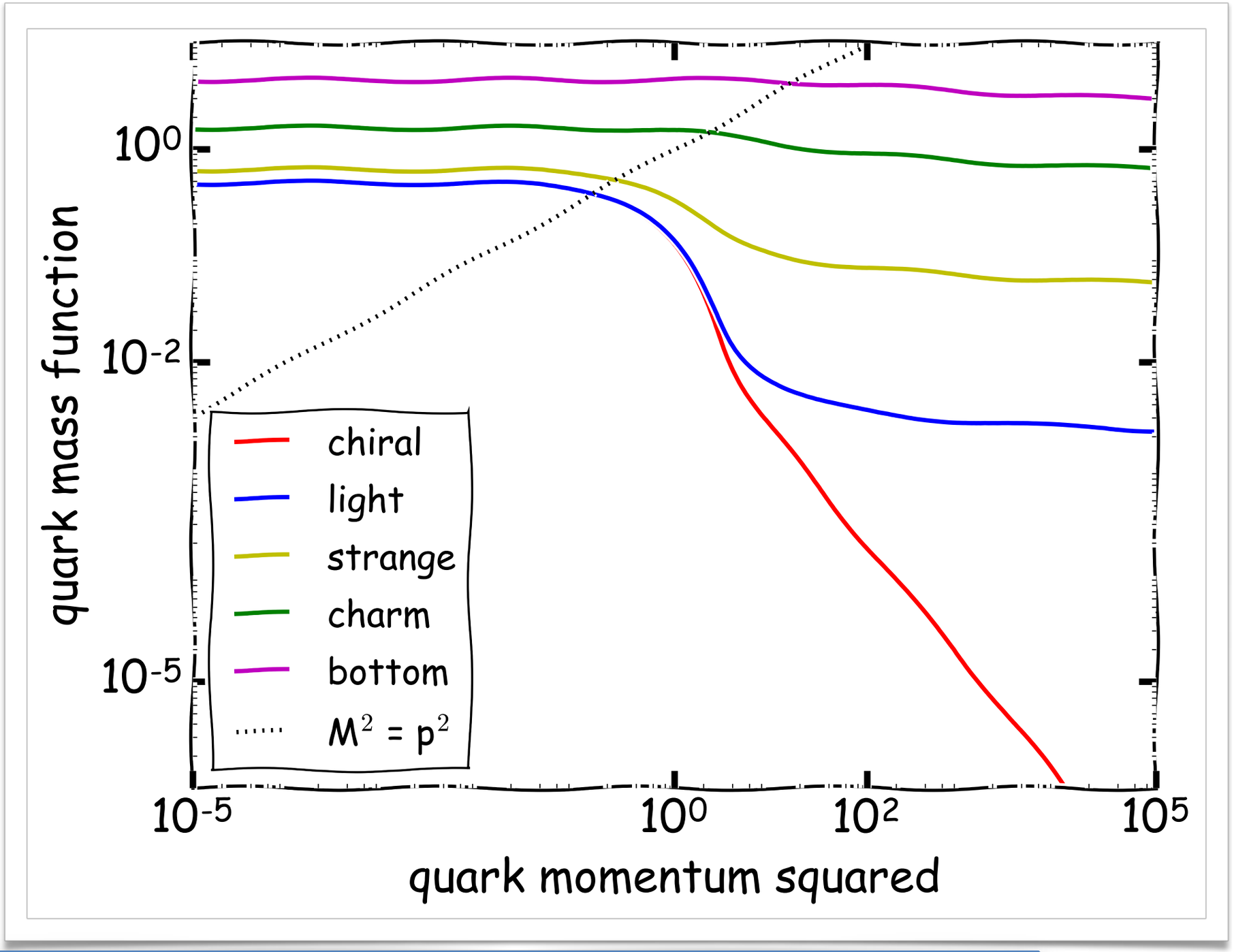


quark DSE



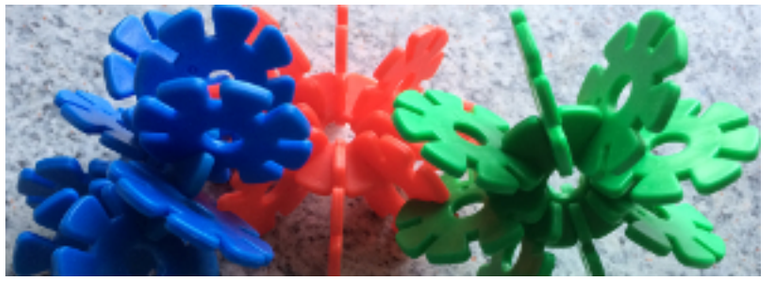
Solutions to the quark DSE



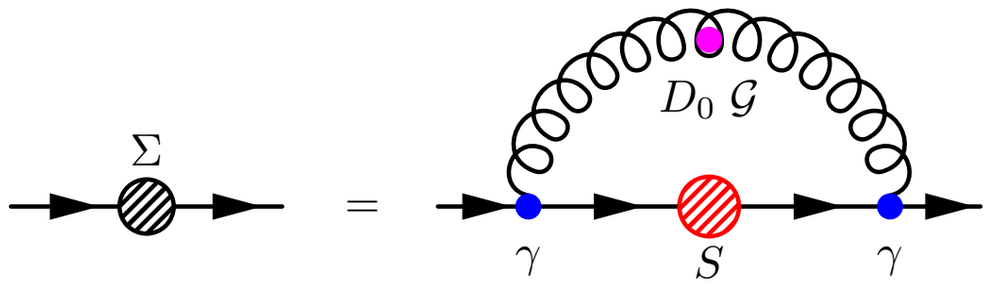


e.g.: A.K., M. Gomez-Rocha, T. Hilger, arXiv:1603.07232

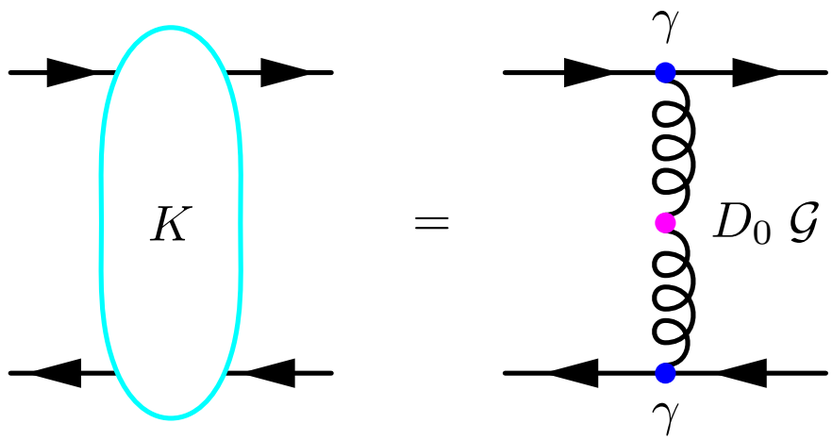
Rainbow-Ladder Truncation



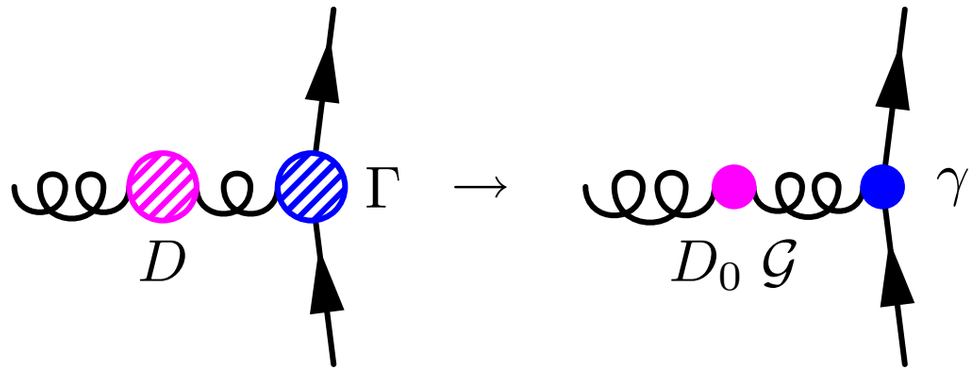
Gap equation / quark self-energy:



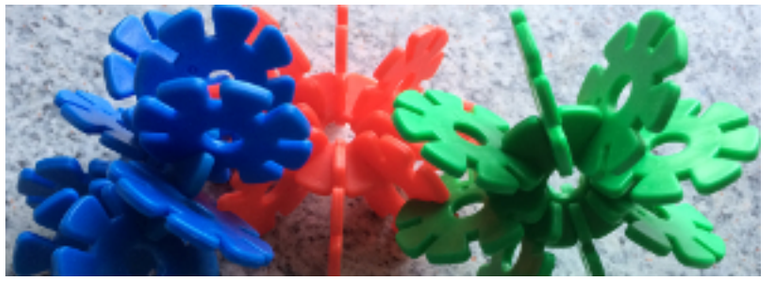
BSE:



Interaction:



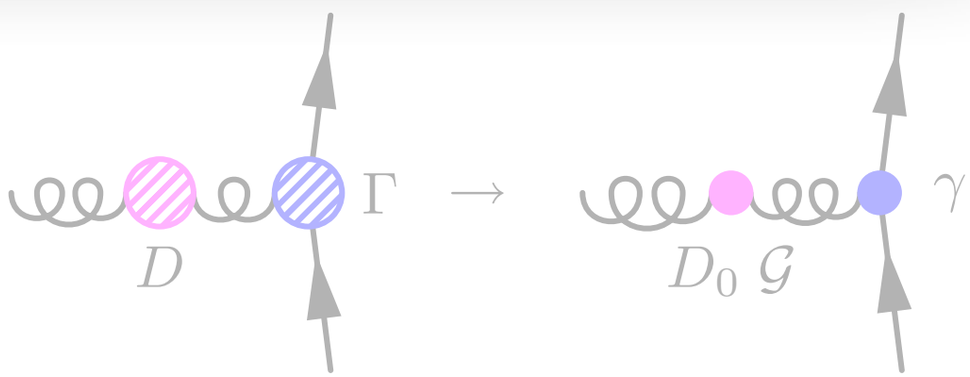
Rainbow-Ladder Truncation



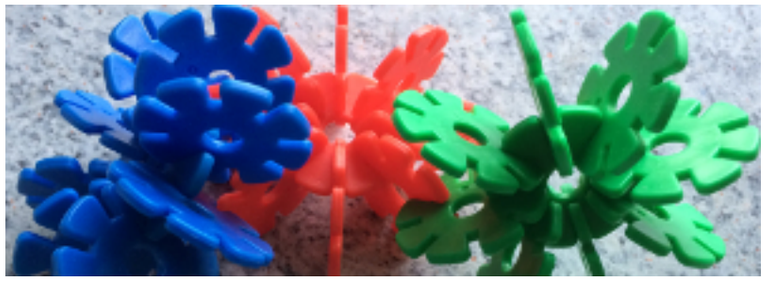
Gap equation / quark self-ener

BSE:

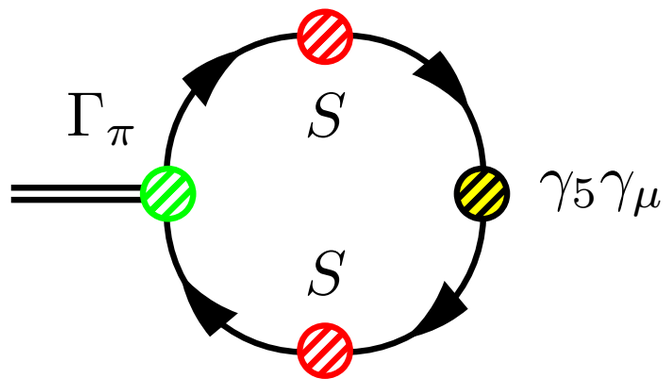
Interaction:



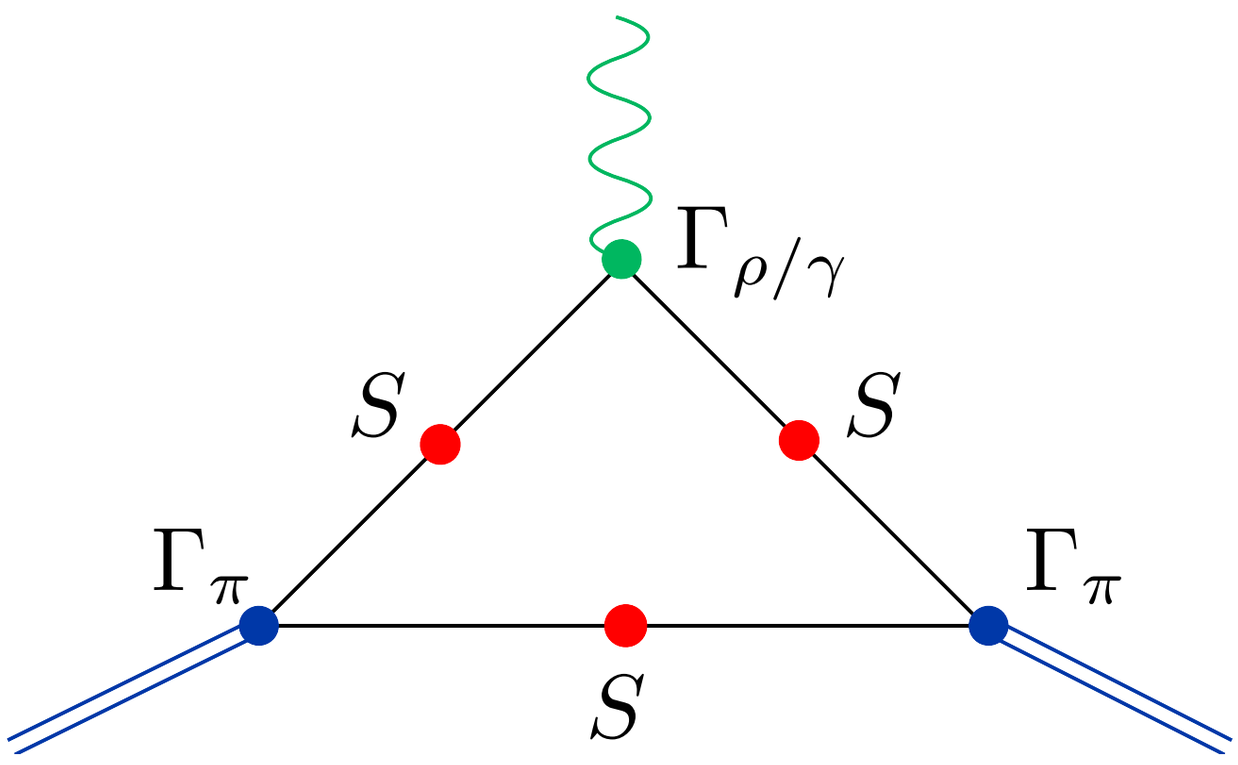
Beyond Spectroscopy



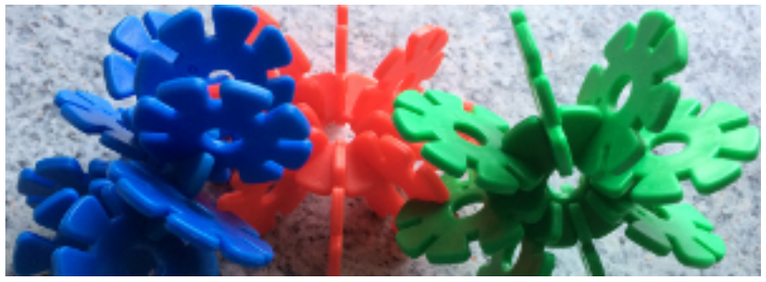
Leptonic decay:



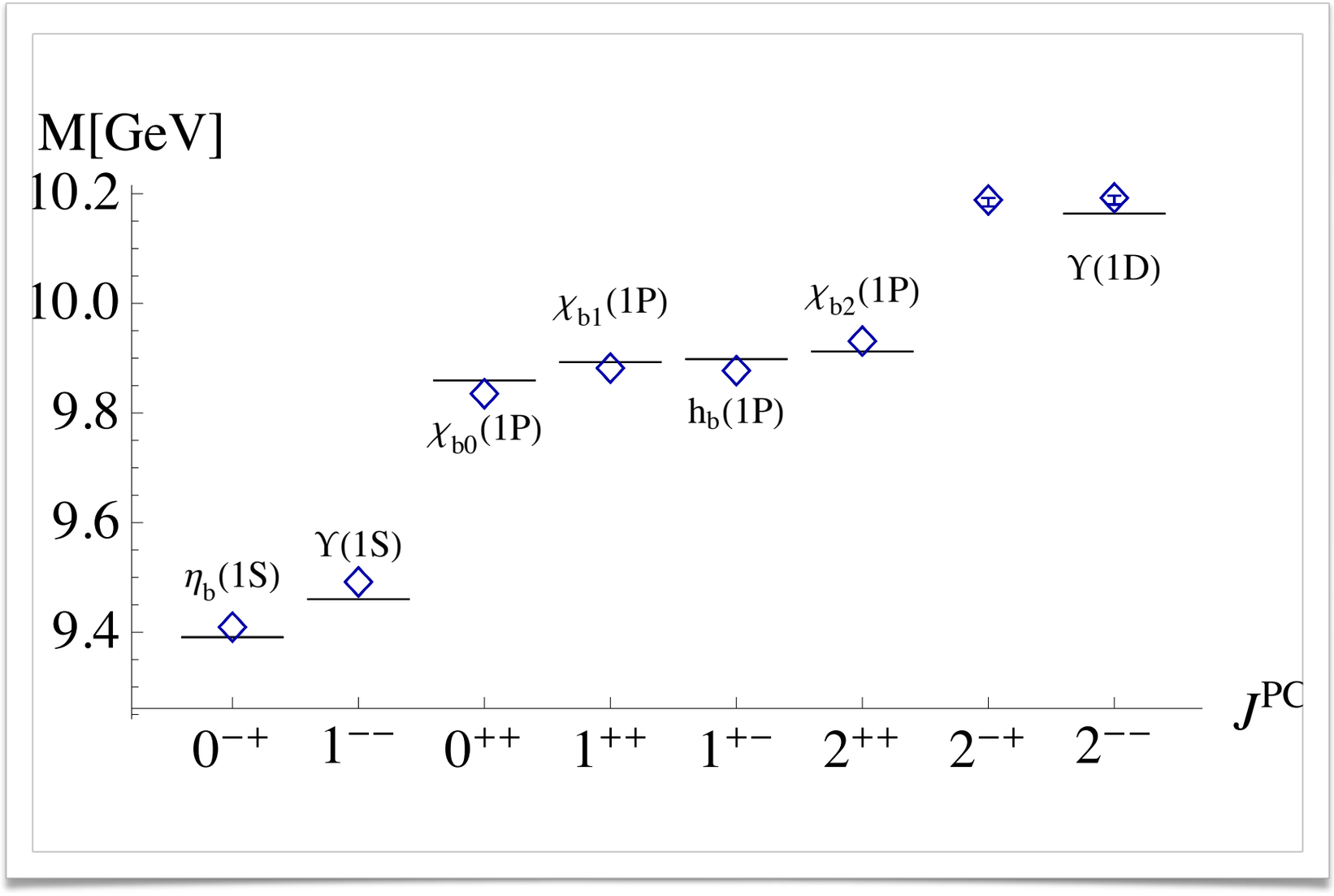
Hadronic decay
& Form factor:



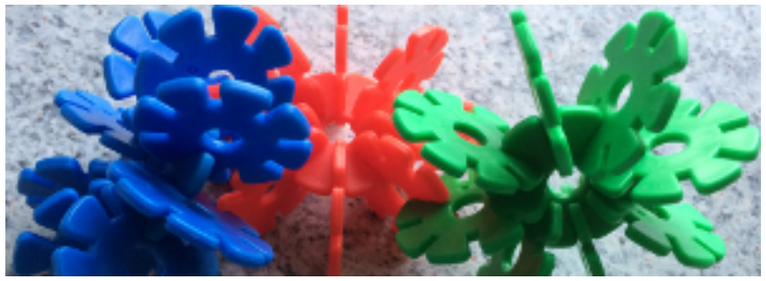
Spectroscopy



- Use RL truncation for simplicity on comprehensive scale
- apply it to systems where corrections beyond RL are expected least important
- First attempt: Bottomonium ground states:

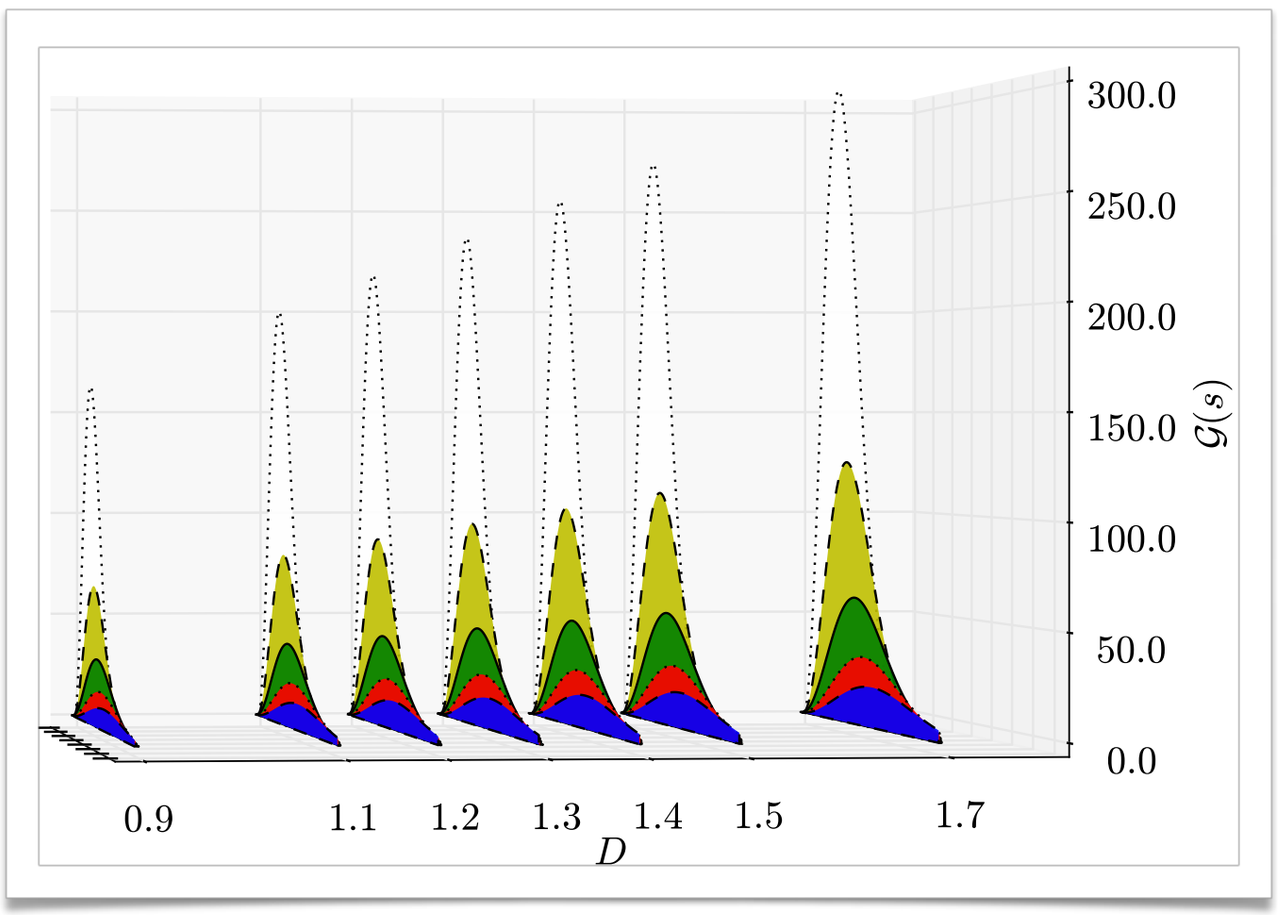


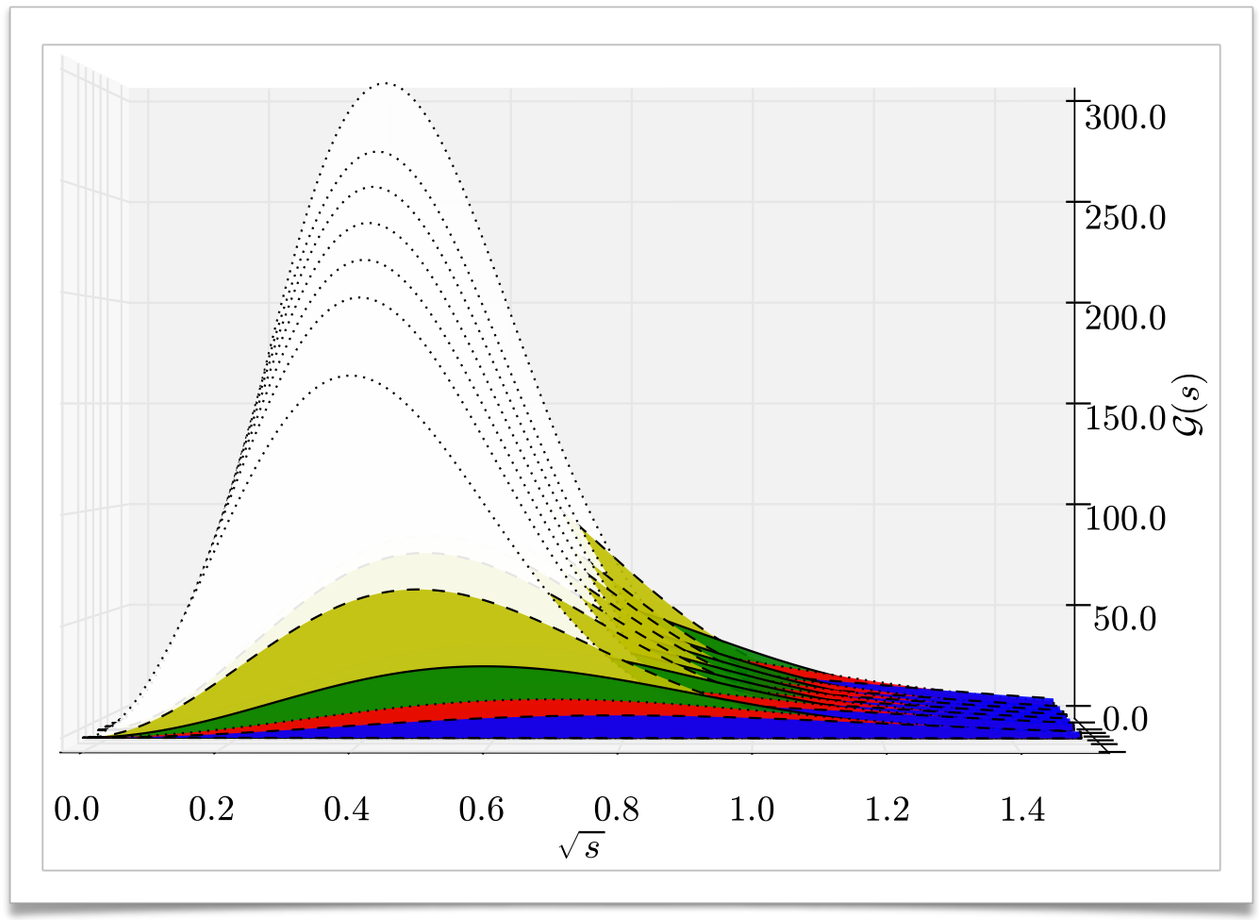
M. Blank, A.K., PRD 84 (2011) 096014



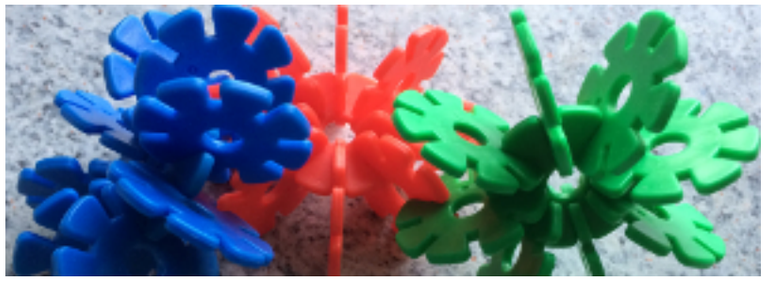
Parameters

- Next step: more freedom in effective interaction:
  Unchain MT: P. Maris, P.C. Tandy, PRC 60 (1999) 055214



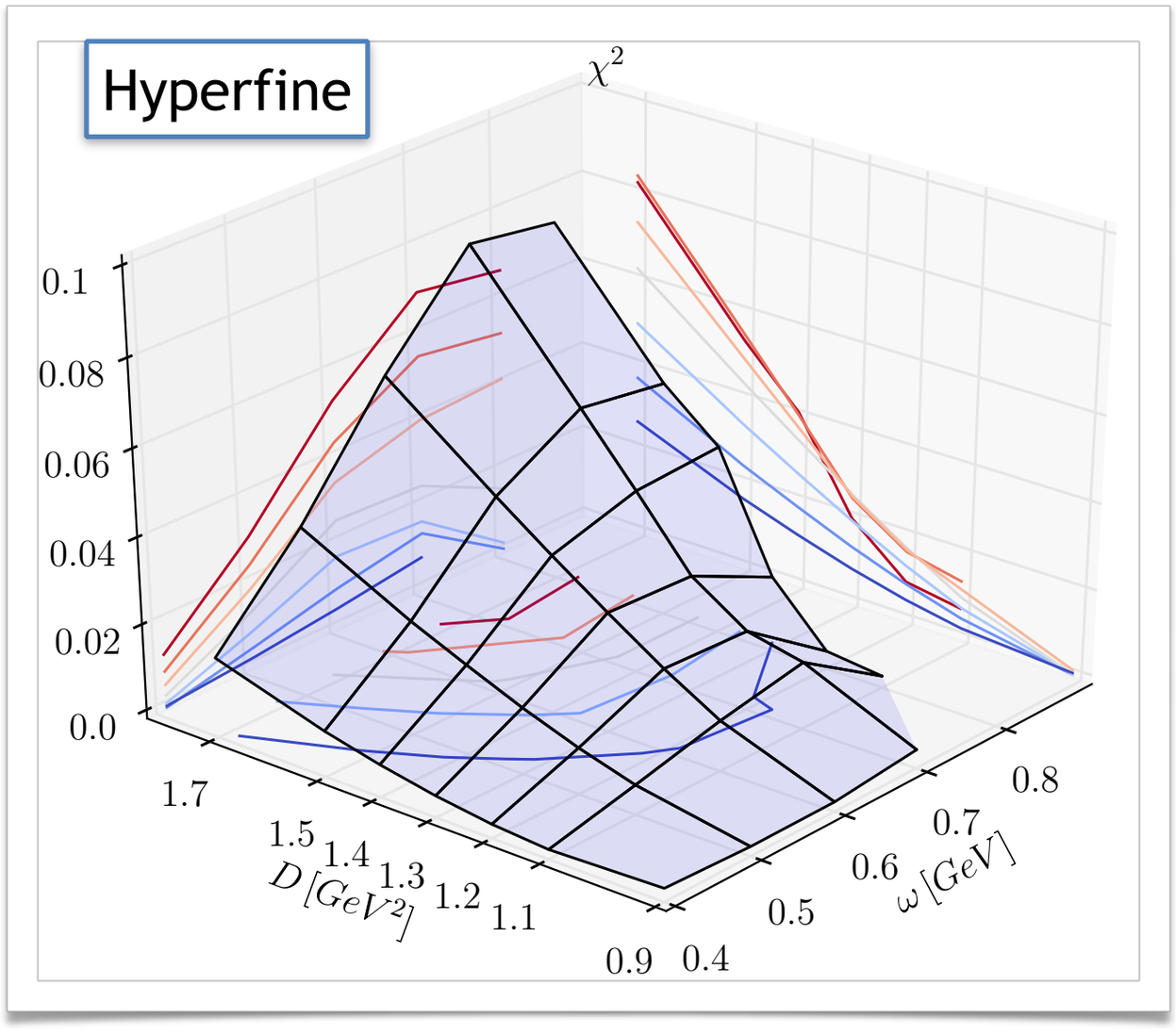


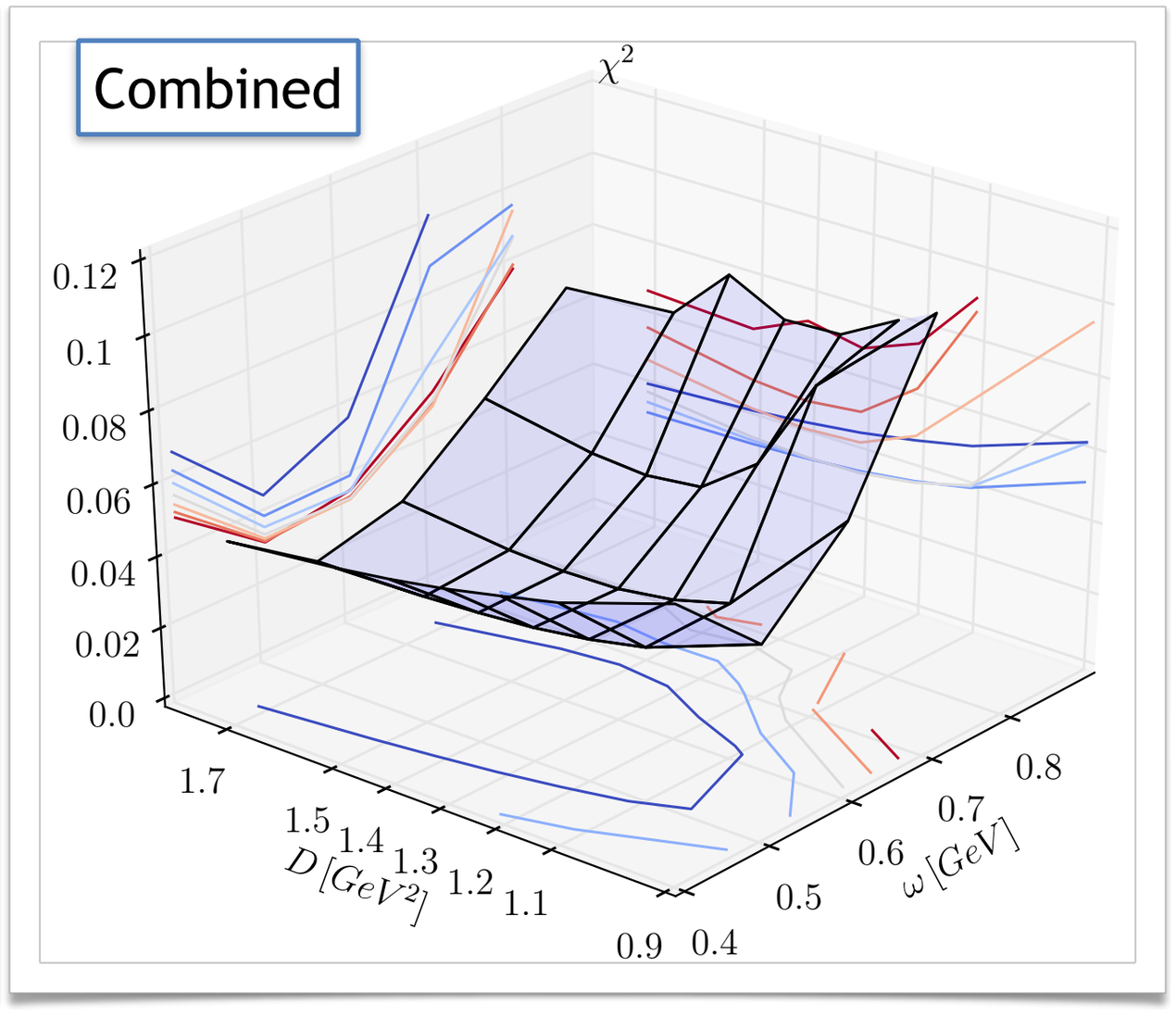
T. Hilger, M. Gomez-Rocha, A.K., arXiv:1508.07183



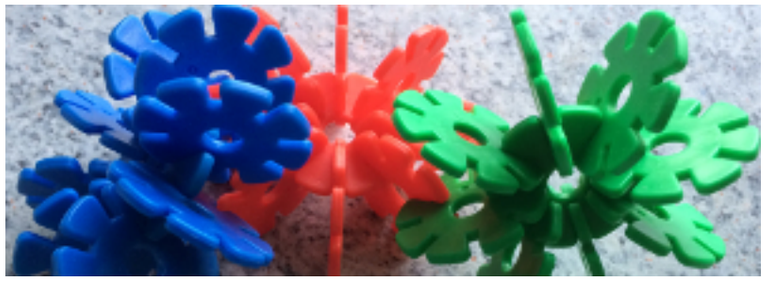
Fitting

- Next step: more freedom in effective interaction:
  Unchain overall strength D and inverse effective range ω



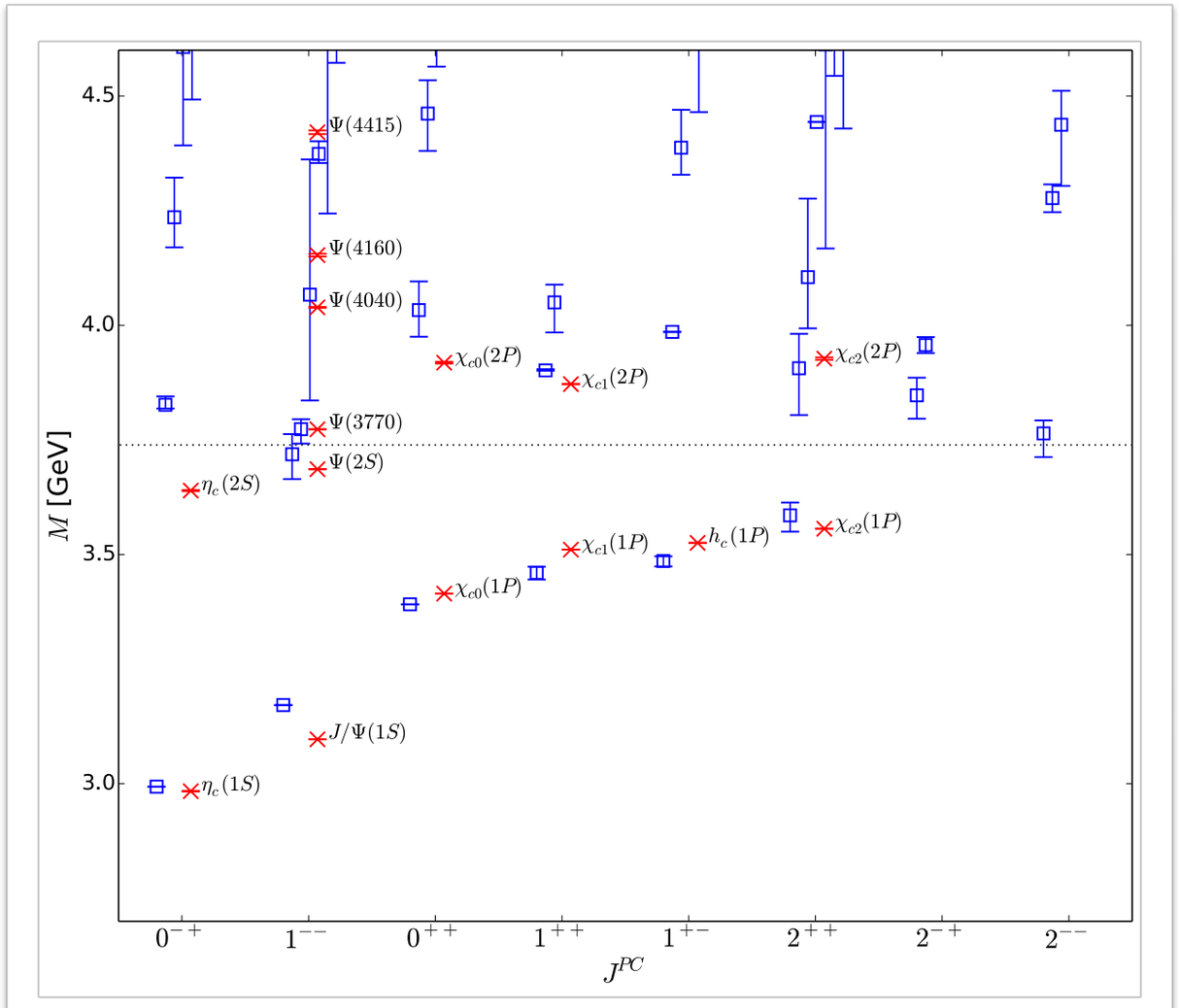


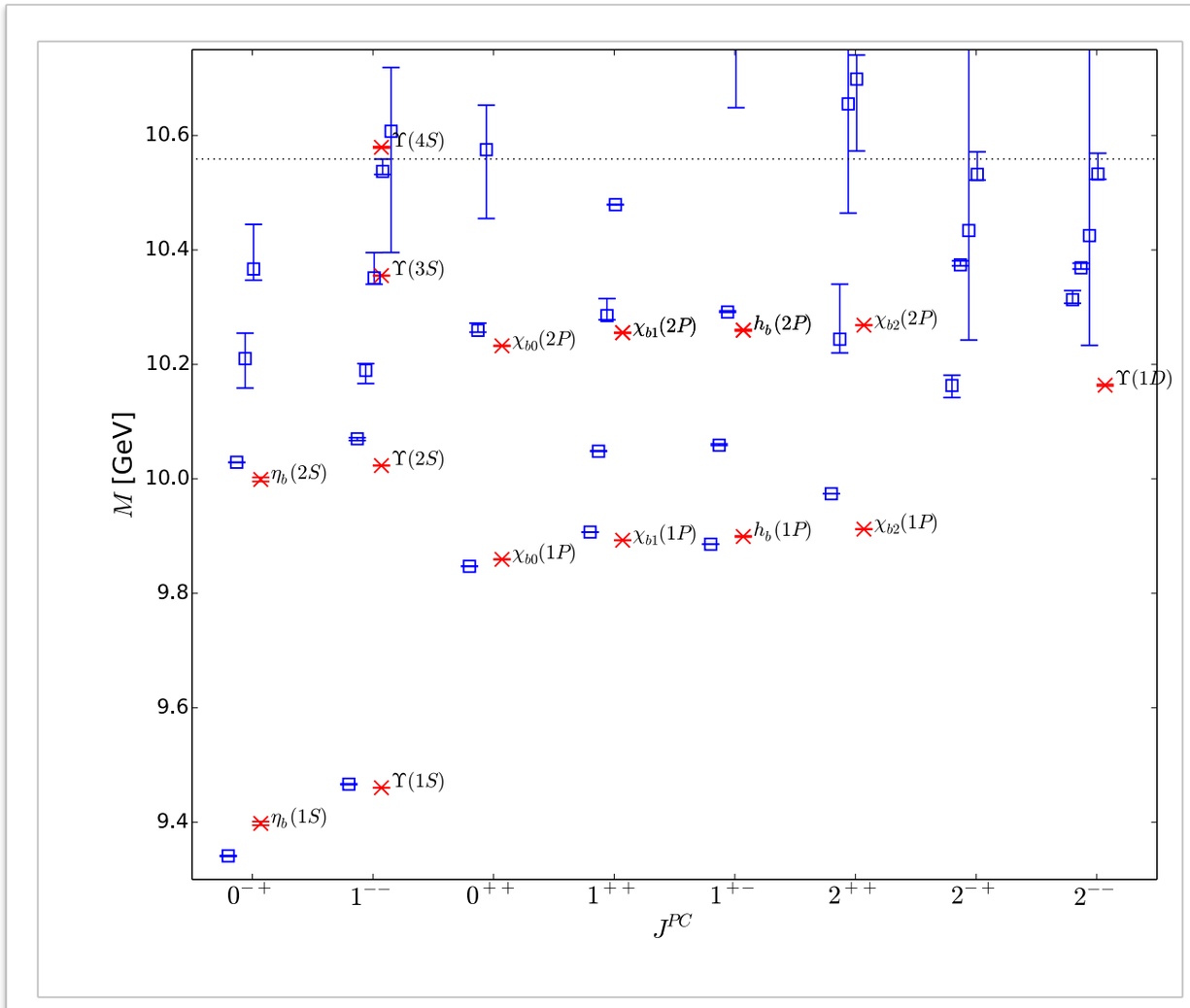
T. Hilger, M. Gomez-Rocha, A.K., arXiv:1508.07183



Spectroscopy

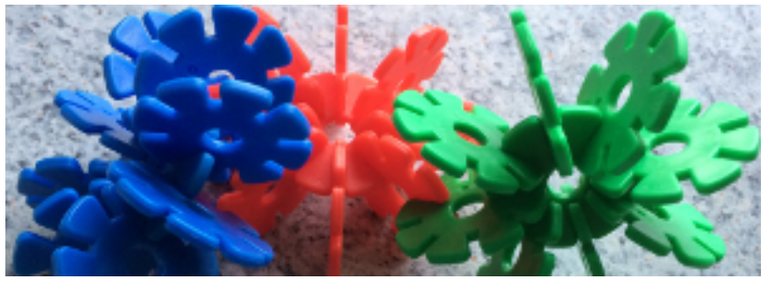
- Next step: more freedom in effective interaction: $b\bar{b}$ and $c\bar{c}$

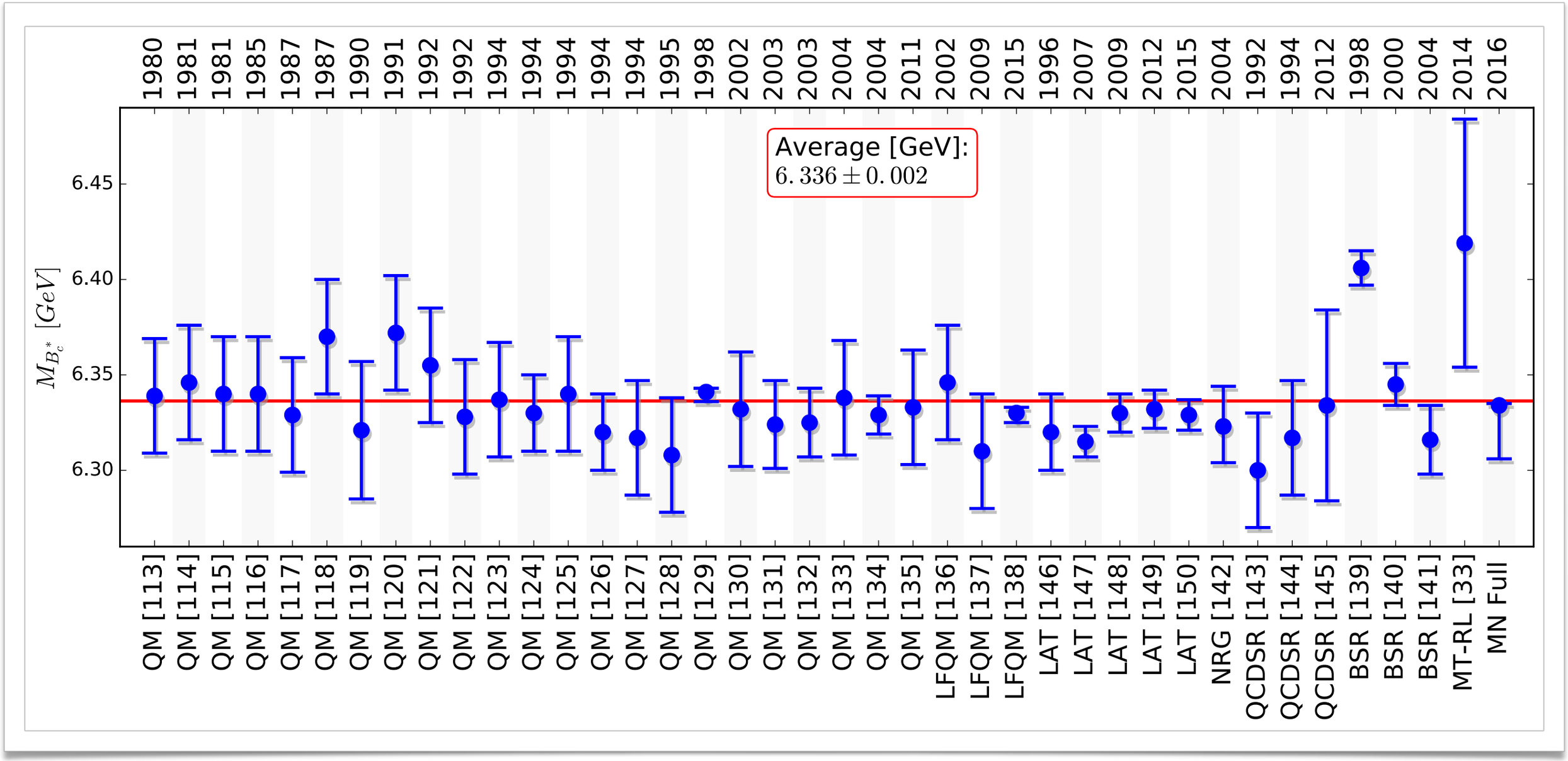




T. Hilger, C. Popovici, M. Gomez-Rocha, A.K., PRD 91 (2015) 034013

The mass of the B_c^*



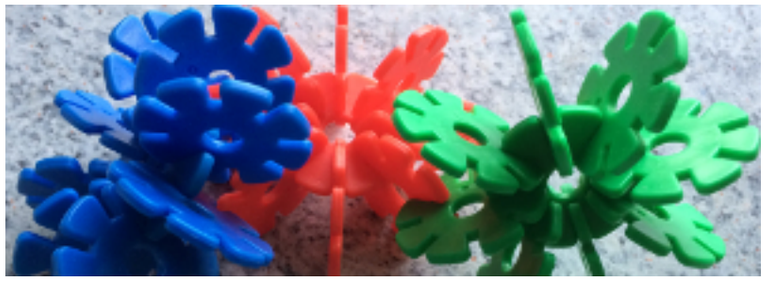


FWF Der Wissenschaf

M. Gomez-Rocha, T. Hilger, A.K., PRD 93 (2016) 074010

SITY OF GRAZ

Leptonic Decay Constants



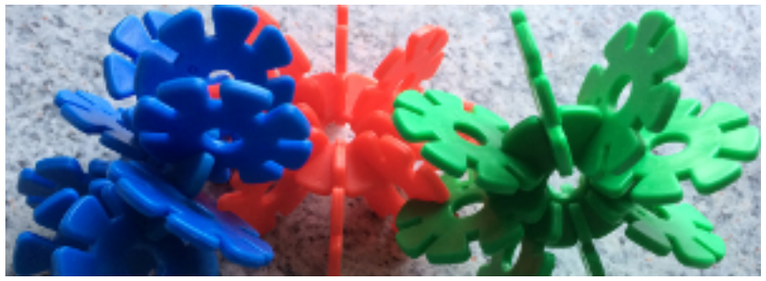
- f[MeV] for heavy quarkonia: S vs. D wave in $1^-\bar{c}$channel; missing states?

State	J^{PC}	Calc. I	II	Exp.
Pseudoscalar				
η_c	0^{-+}	401	378	339(14)
$\eta_c(2S)$	0^{-+}	244(12)	82	189(50)
$\eta_c(3S)$	0^{-+}	145(145)	206	–
$\eta_c(4S)$	0^{-+}	–	87	–
Vector				
J/Ψ	1^{--}	450	411	416(5)
$\Psi(2S)$	1^{--}	30(3)	155	294(4)
$\Psi(3770)$	1^{--}	118(91)	45	99(3)
$\Psi(4040)$	1^{--}	–	188	187(8)
$\Psi(4160)$	1^{--}	–	1	142(34)
$\Psi(4415)$	1^{--}	–	262	161(10)

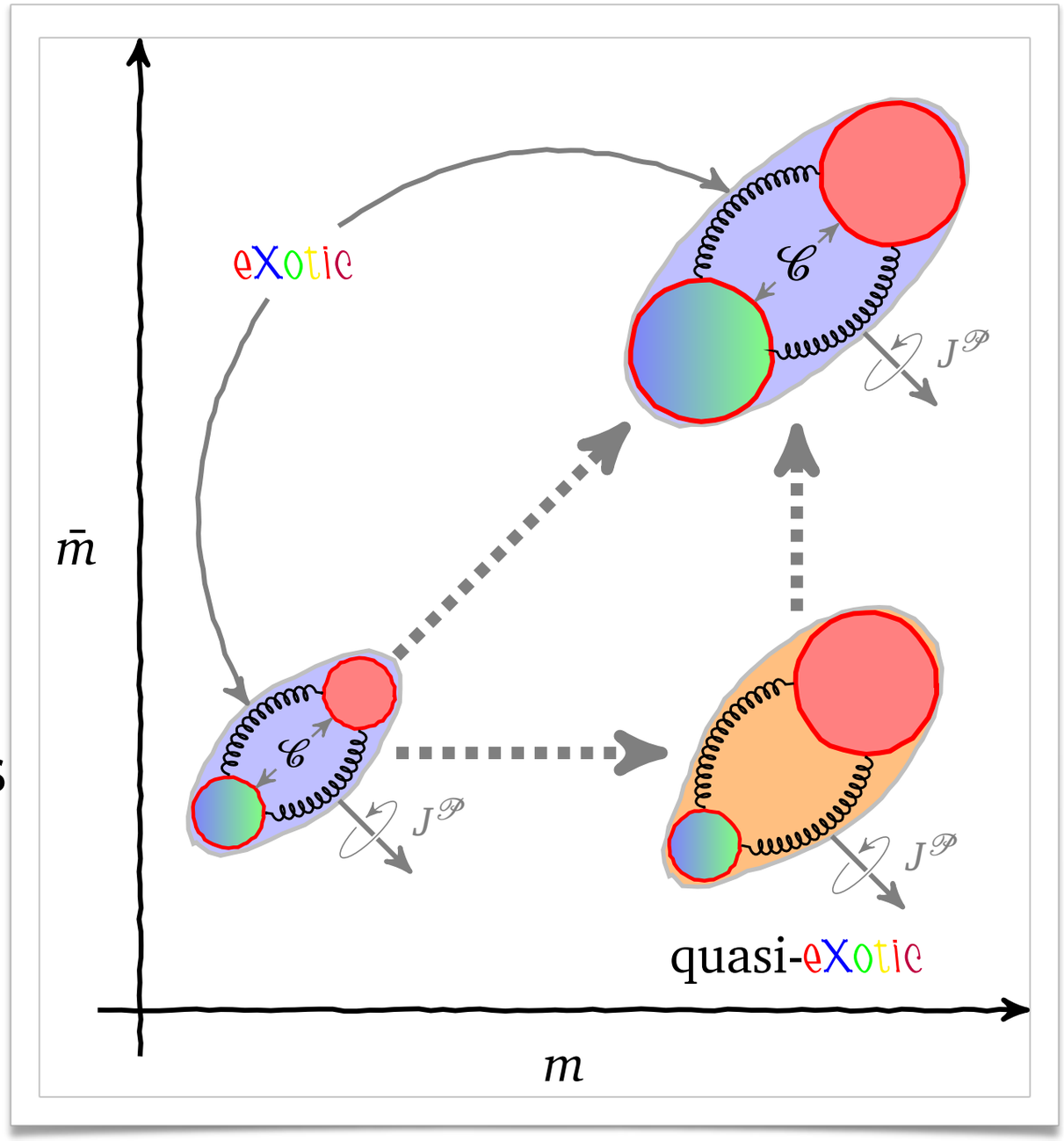
State	J^{PC}	Calc. I	II	Exp.
Pseudoscalar				
η_b	0^{-+}	773	756	–
$\eta_b(2S)$	0^{-+}	419(8)	285	–
$\eta_b(3S)$	0^{-+}	534(57)	333	–
$\eta_b(4S)$	0^{-+}	–	40(15)	–
Vector				
Υ	1^{--}	768	707	715(5)
$\Upsilon(2S)$	1^{--}	467(17)	393	497(4)
$\Upsilon(1^3D_1)$	1^{--}	41(7)	371(2)	–
$\Upsilon(3S)$	1^{--}	–	9(5)	430(4)
$\Upsilon(2^3D_1)$	1^{--}	–	165(50)	–
$\Upsilon(4S)$	1^{--}	–	20(15)	341(18)

FWF A.K., M. Gomez-Rocha, T. Hilger, arXiv:1603.07232, to appear in FBS

Quasi-Exotic Mesons

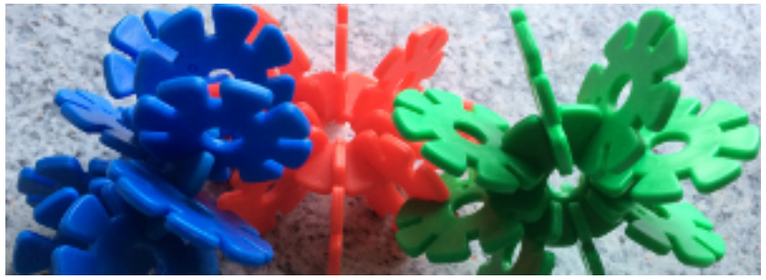


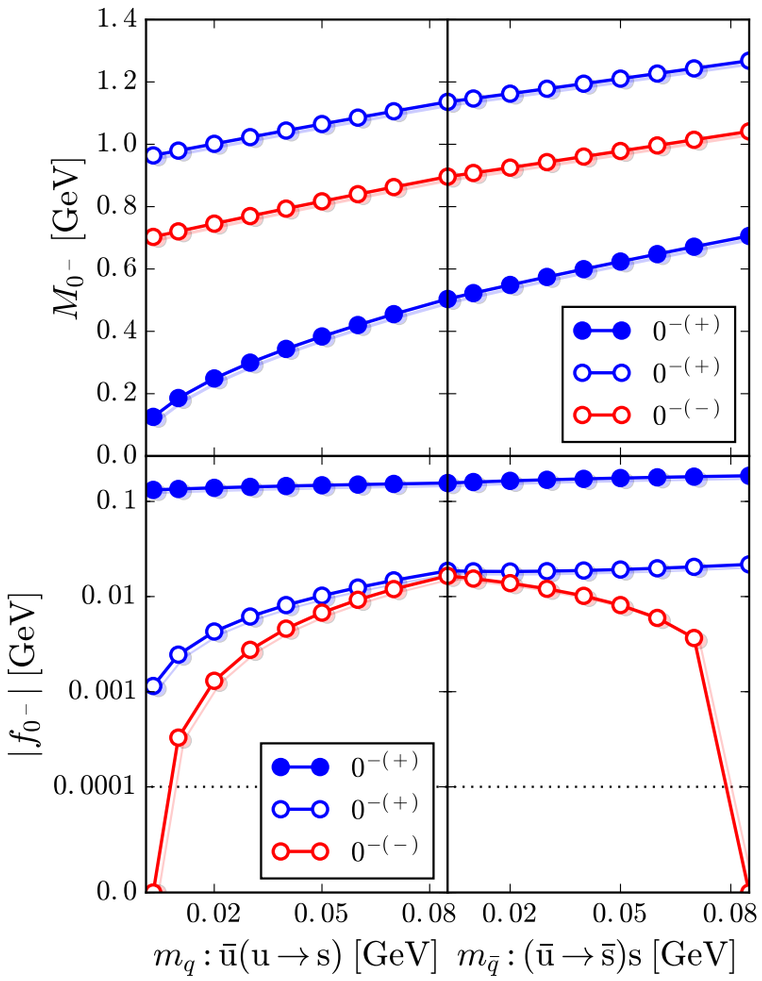
- Think about it:
- Exotic quantum numbers in quark model restrained by C
- What happens for open flavor?
- No C restriction
- Covariant quark-bilinear amplitude allows for exotics, thus
- Quasi-exotic open-flavor states exist as well
- One QX connected to two exotics
- Prime example: Charged Pion

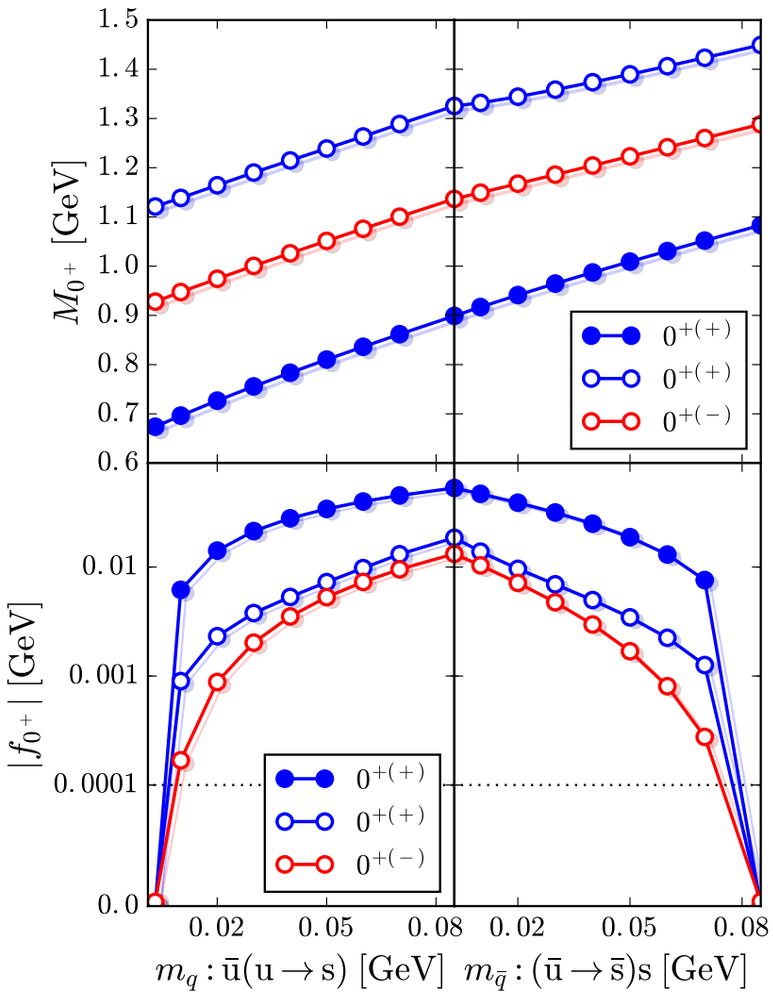


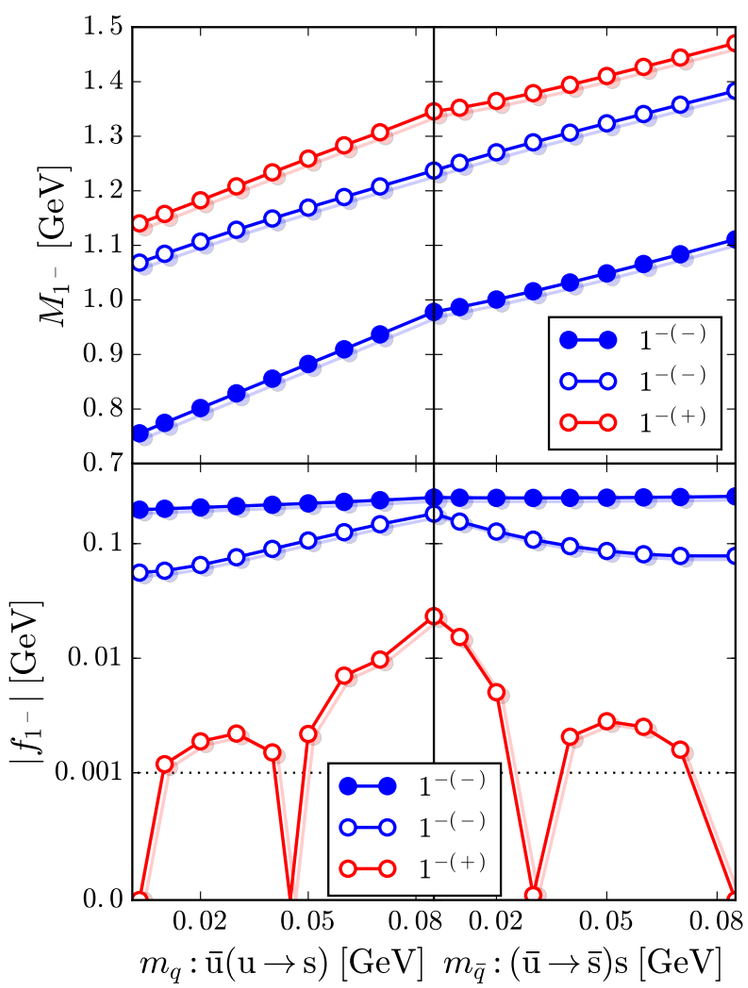
T. Hilger, A.K., arXiv:1605.03464

Quasi-Exotic Mesons



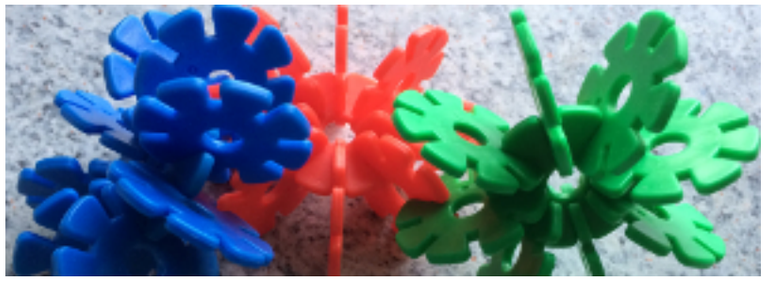




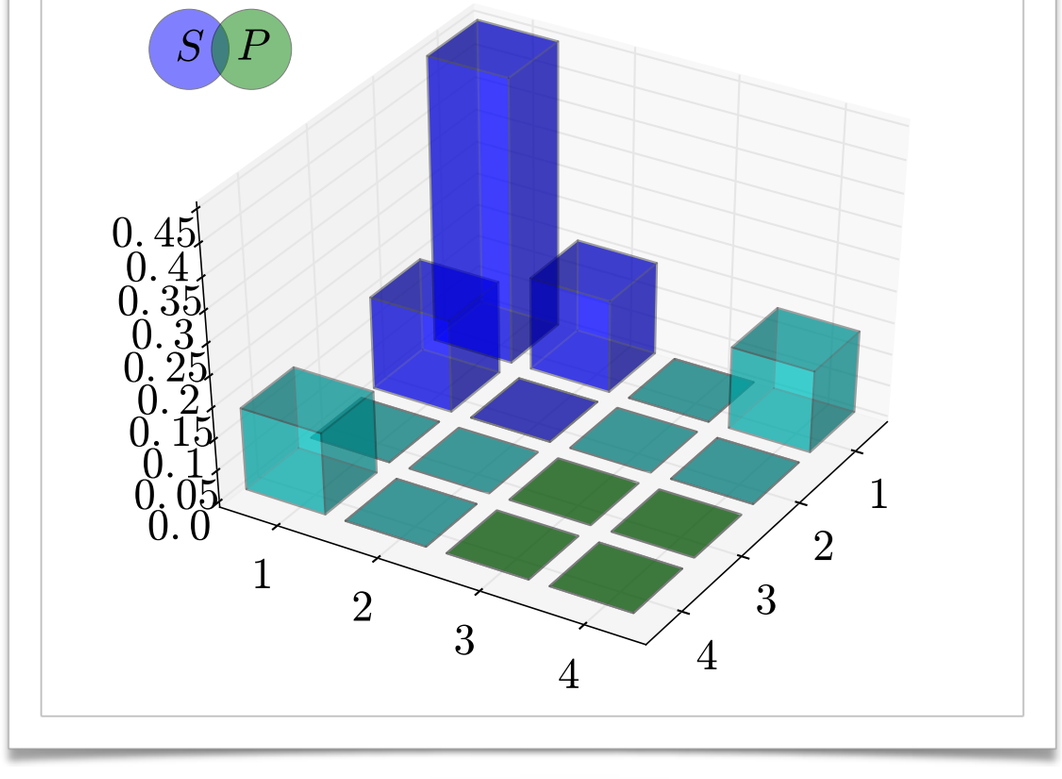


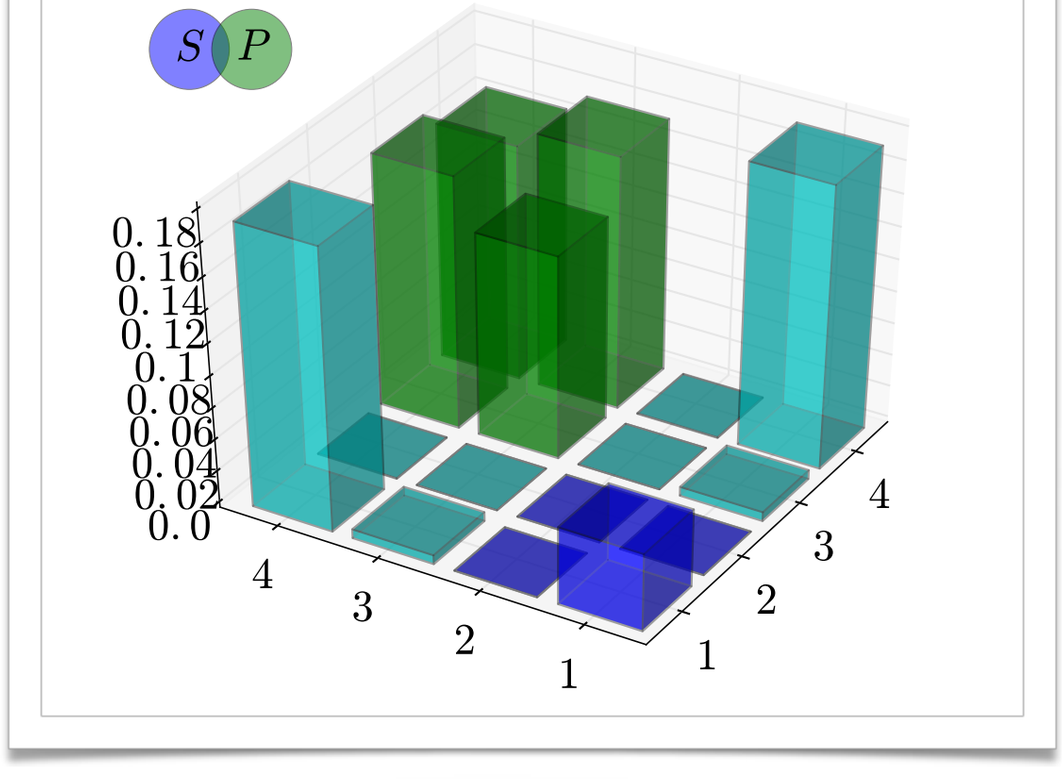
T. Hilger, A.K., arXiv:1605.03464

Orbital Angular Momentum



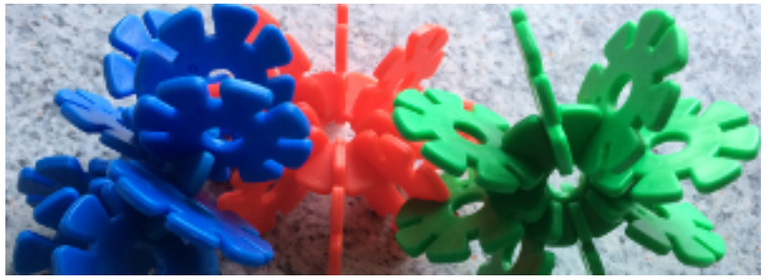
- Investigate covariant amplitude and its components w.r.t. orbital angular momentum corresponding to relative momentum
- Plot squared contribution to BSA's canonical norm per covariant
- Interpretation in analogy to quark-model S, P, D waves



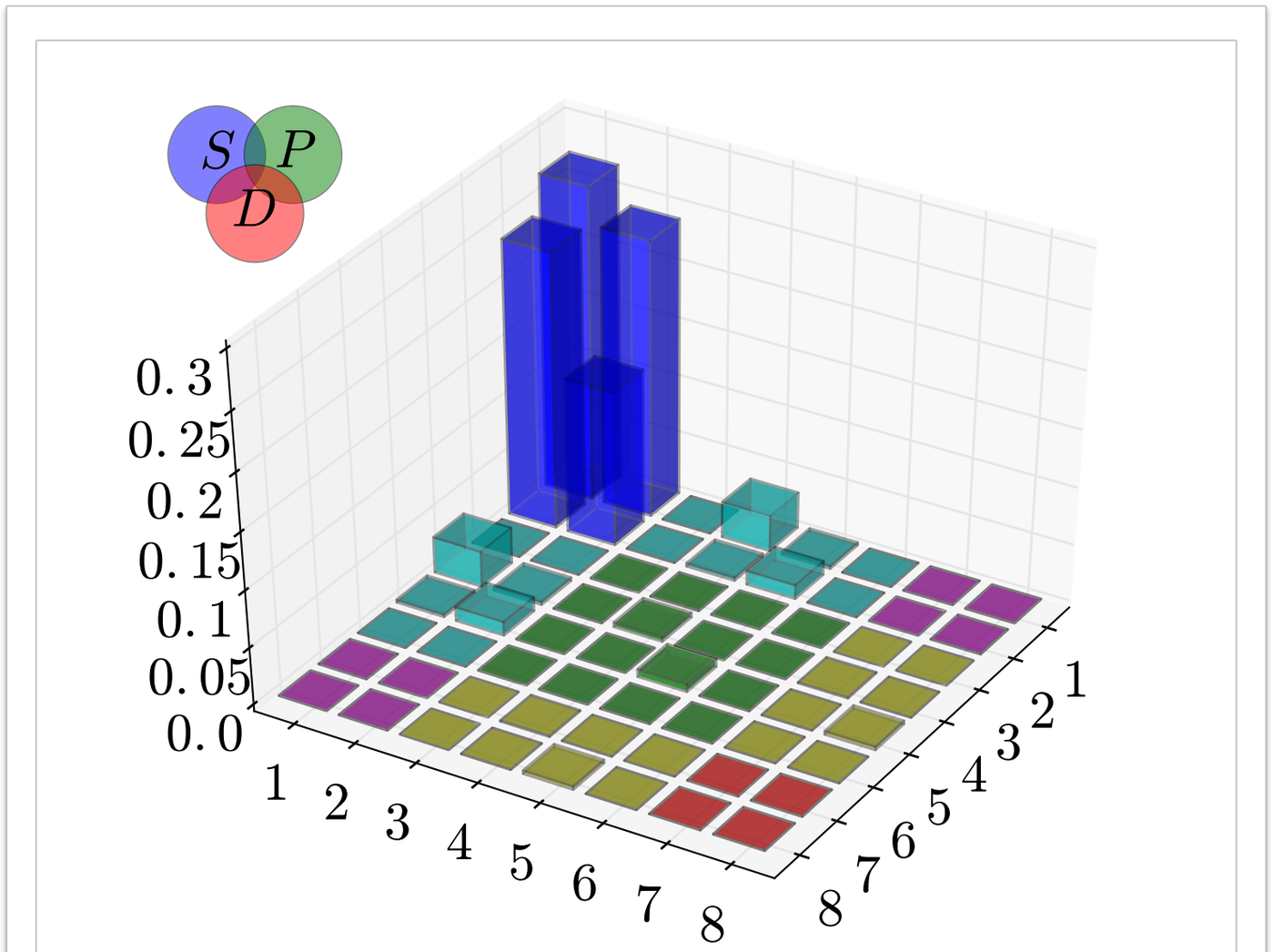


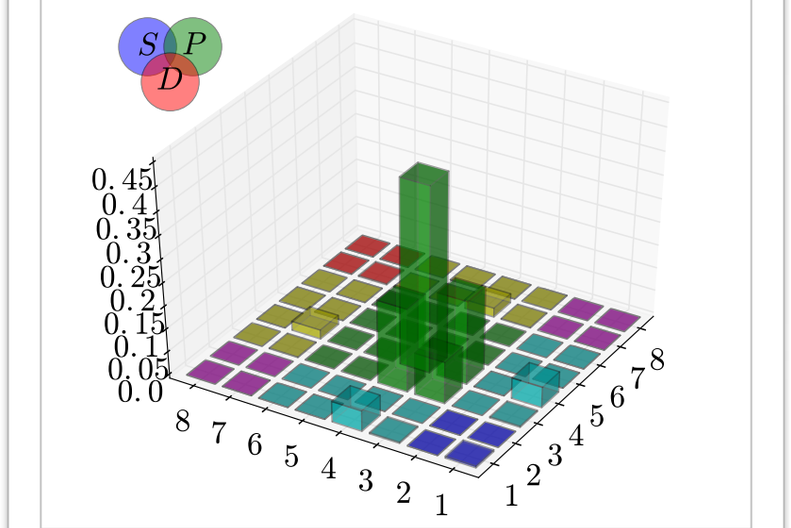
T. Hilger, M. Gomez-Rocha, A.K., arXiv:1508.07183

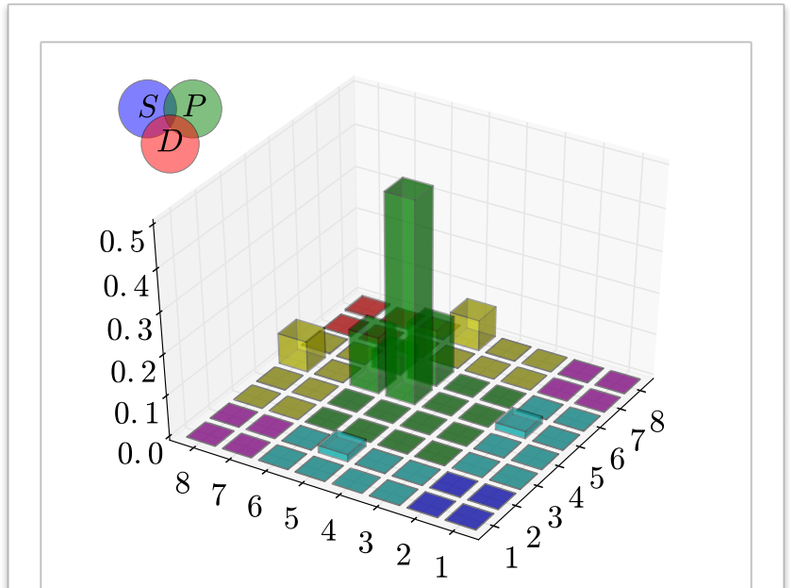
Orbital Angular Momentum



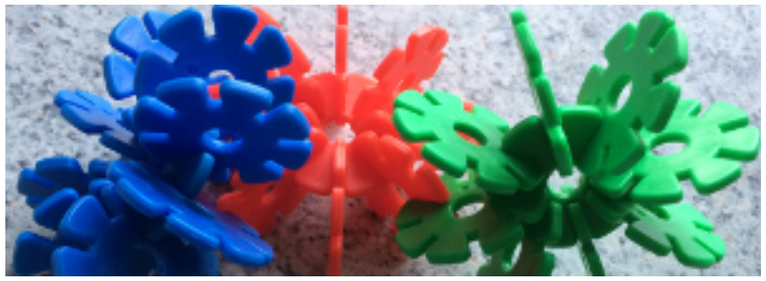
- Ground states as expected



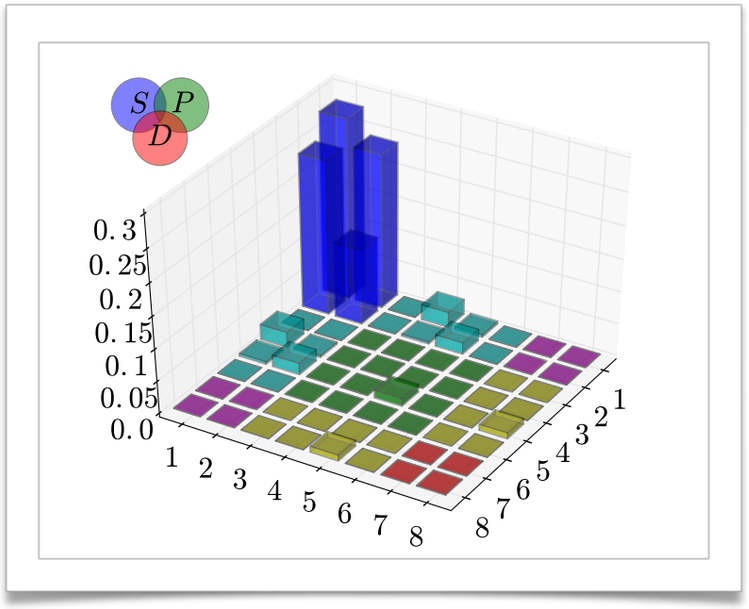


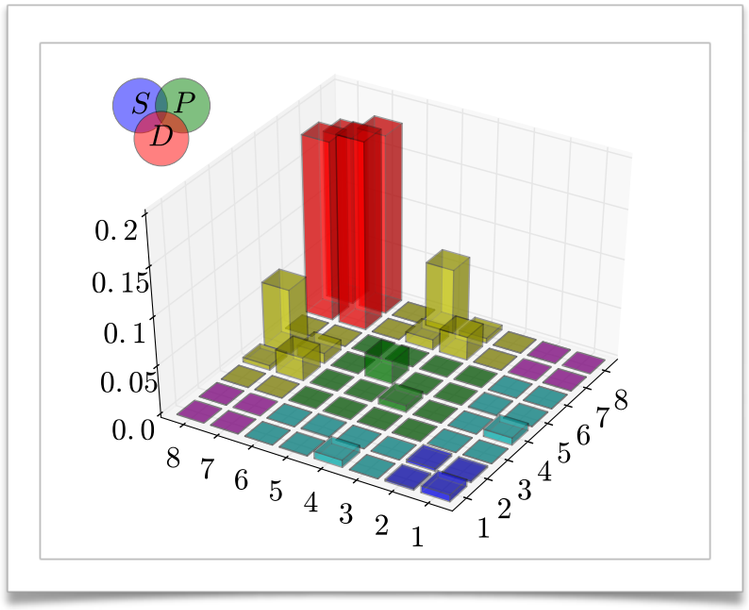


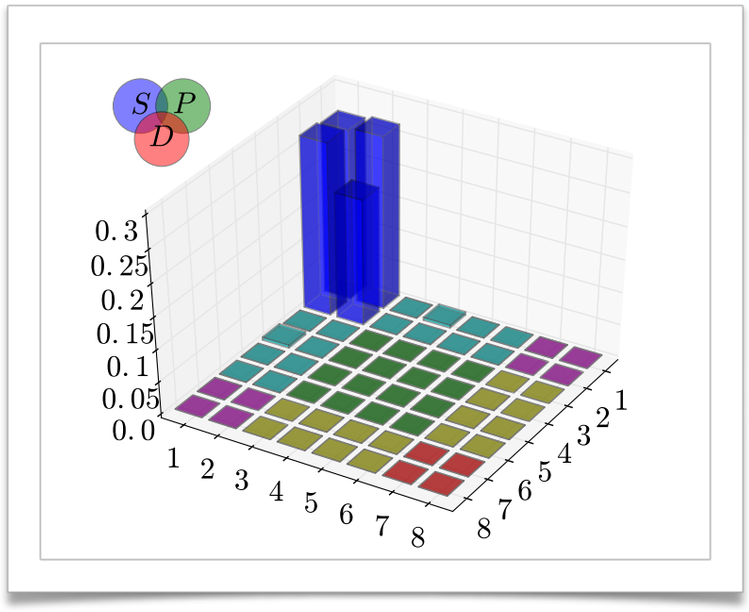
Orbital Angular Momentum



- Ground and excited states in vector channel

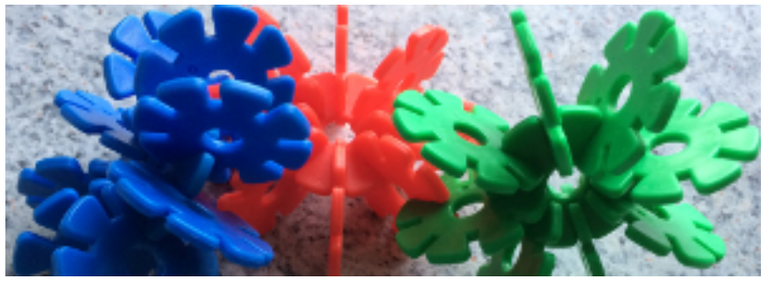




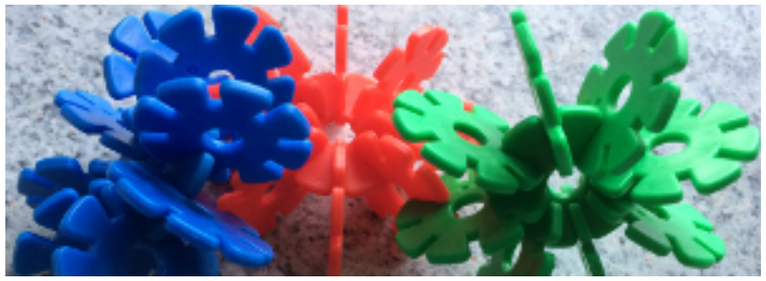


T. Hilger, M. Gomez-Rocha, A.K., arXiv:1508.07183

Where Can I Place My Order? - Outlook

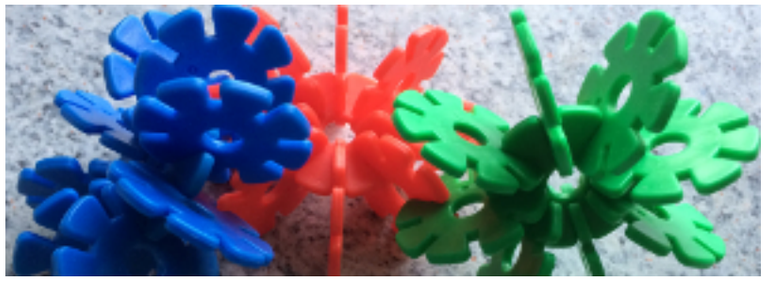


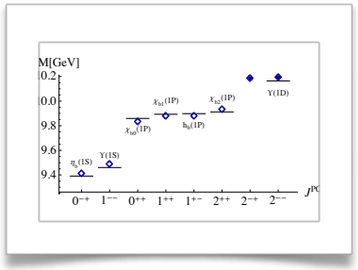
- We have:
  - connection to QCD
  - covariance
  - correct chiral-limit behavior
  - symmetries & constraints
- We can compute:
  - meson spectra (comprehensively)
  - meson leptonic decay constants
  - meson e.m. properties
  - meson hadronic transitions/decays
  - baryon properties in consistent 3-quark setup
  - your order goes here …



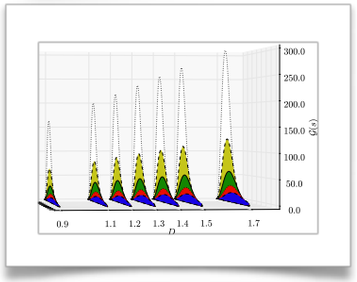
Thank you very much for your attention!

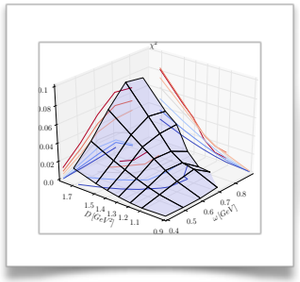
Reminder



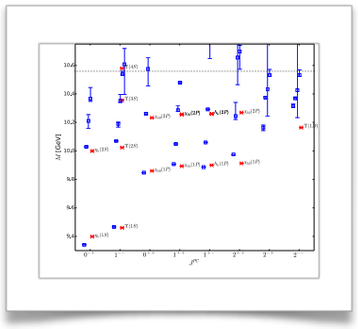


M. Blank, A.K., PRD 84 (2011) 096014

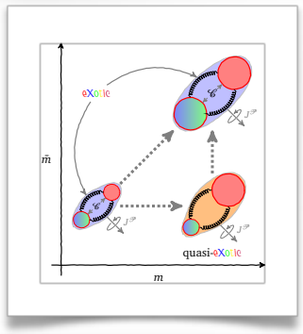




T. Hilger, M. Gomez-Rocha, A.K., arXiv:1508.07183

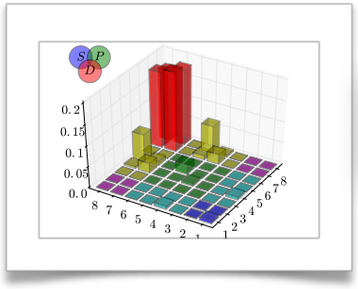


T. Hilger, C. Popovici, M. Gomez-Rocha, A.K., PRD 91 (2015) 034013

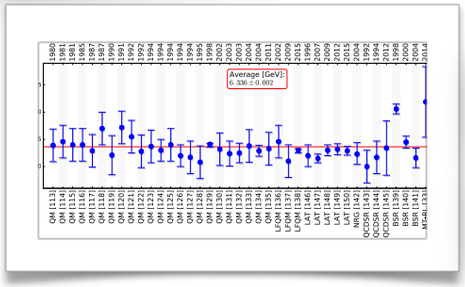


T. Hilger, M. Gomez-Rocha, A.K., PRD 91 (2015) 114004

T. Hilger, A.K., arXiv:1605.03464



T. Hilger, M. Gomez-Rocha, A.K., arXiv:1508.07183



M. Gomez-Rocha, T. Hilger, A.K., PRD 92 (2015) 054030

M. Gomez-Rocha, T. Hilger, A.K., PRD 93 (2016) 074010