

**FWF**

Der Wissenschaftsfonds.

KARL-FRANZENS-UNIVERSITÄT GRAZ  
UNIVERSITY OF GRAZ



The **DSBSE** approach to hadrons

(Dyson-Schwinger-Bethe-Salpeter-Equation)

Andreas Krassnigg

ACHT2015

7.10.2015



@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 - Just a Glimpse
- Hadron Decays
- Form Factors
- Outlook

# Hadron Theory

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

## BIG PROTON with MINI QUARKS AND GLUON



This 7" diameter (18 cm) **PROTON** pouch unzips to reveal 3 mini **QUARKS** (up, up, down) and one mini **GLUON** inside. Take the quarks and gluon out, put them back in—however you like to play! Not to scale, of course. If the quarks were to scale with respect to the 7" proton, they would be 1.77 microns wide.

*Felt/fleece. 100% handmade. Zipper and liner color will vary.*

**\$39.75** PLUS SHIPPING

*Also includes mini-pamphlet on particles' properties*

*Set contains 5 pieces.*



*Zipper on reverse side of proton.*



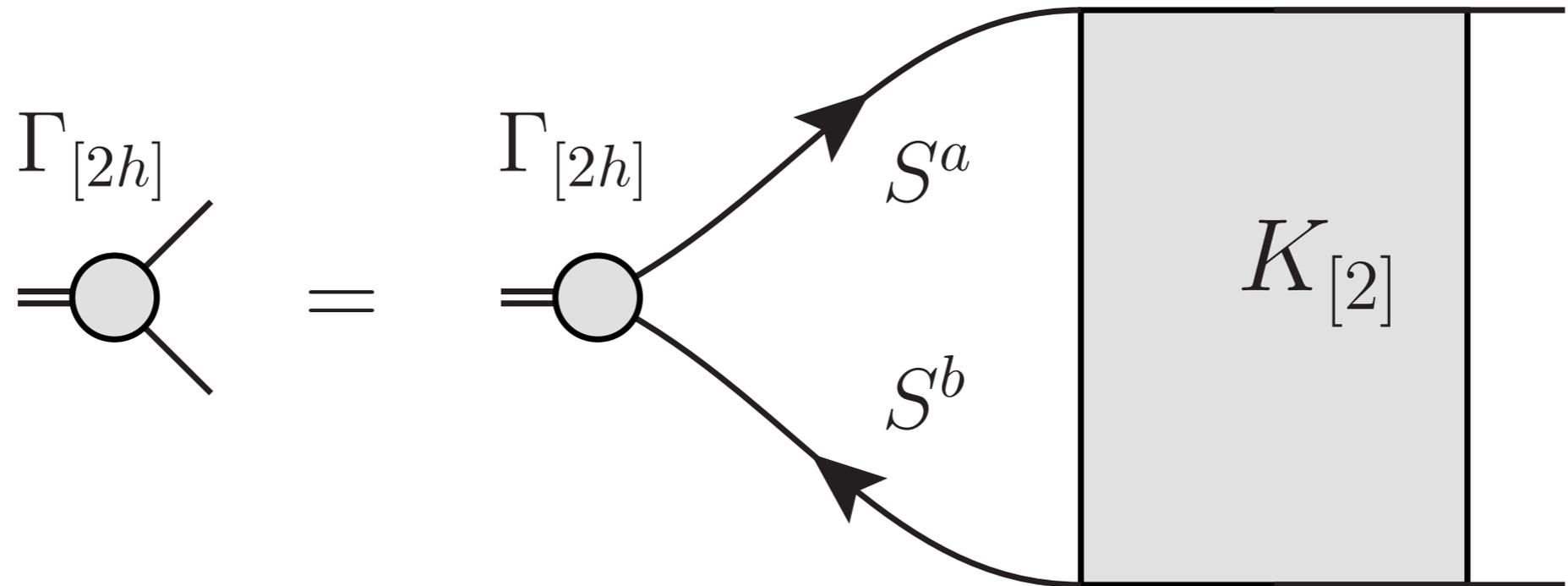
<http://www.particlezoo.net/>

# The Tool: DSBSE Formalism

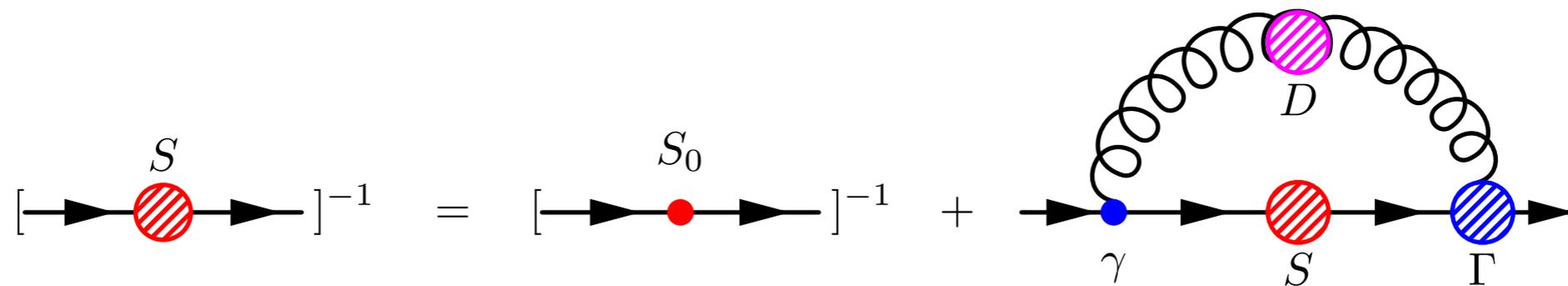
- **Dyson-Schwinger** equations can be used to **solve QCD**
- **Bethe-Salpeter** and **Faddeev**-type equations allow covariant and symmetry-preserving study of **bound-state problems**
- Infinite set of **coupled** (and nonlinear) **integral equations**
- Numerical studies: **Truncation**  $\leftrightarrow$  numerical effort  
 **see talk by M. Huber**
- 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

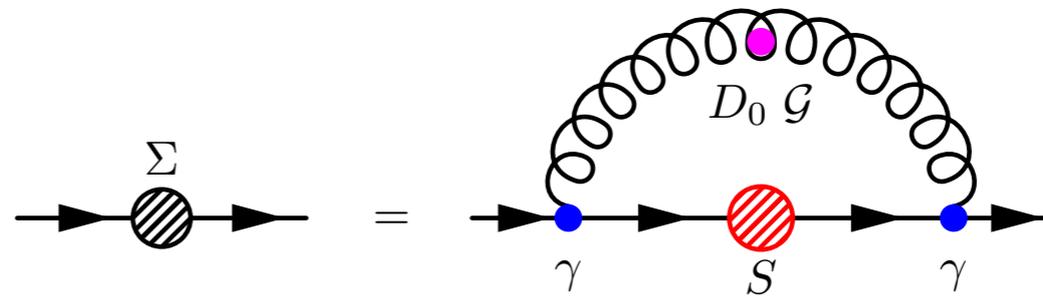


quark DSE

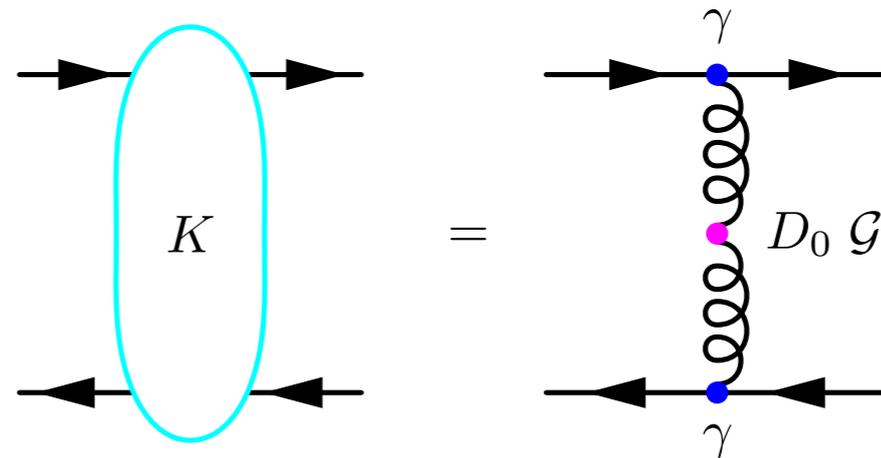


# Rainbow-Ladder Truncation

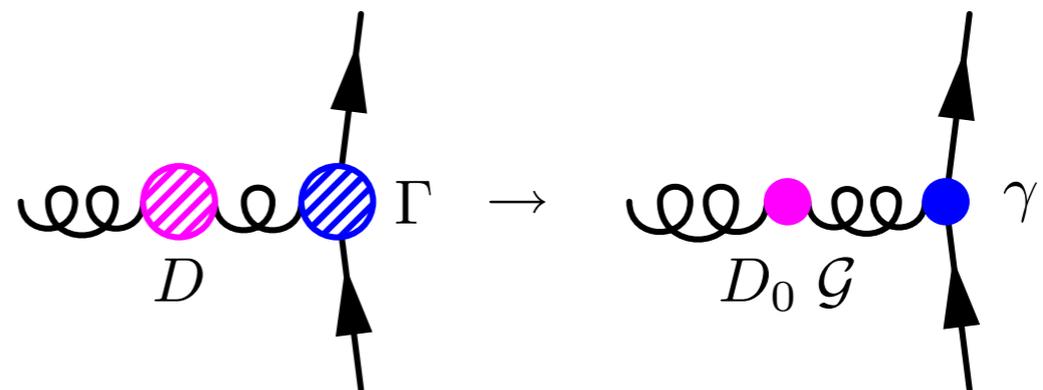
Gap equation / quark self-energy:



BSE:

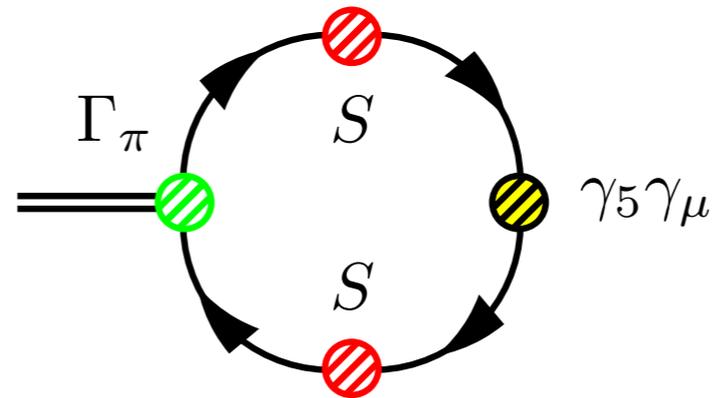


Interaction:

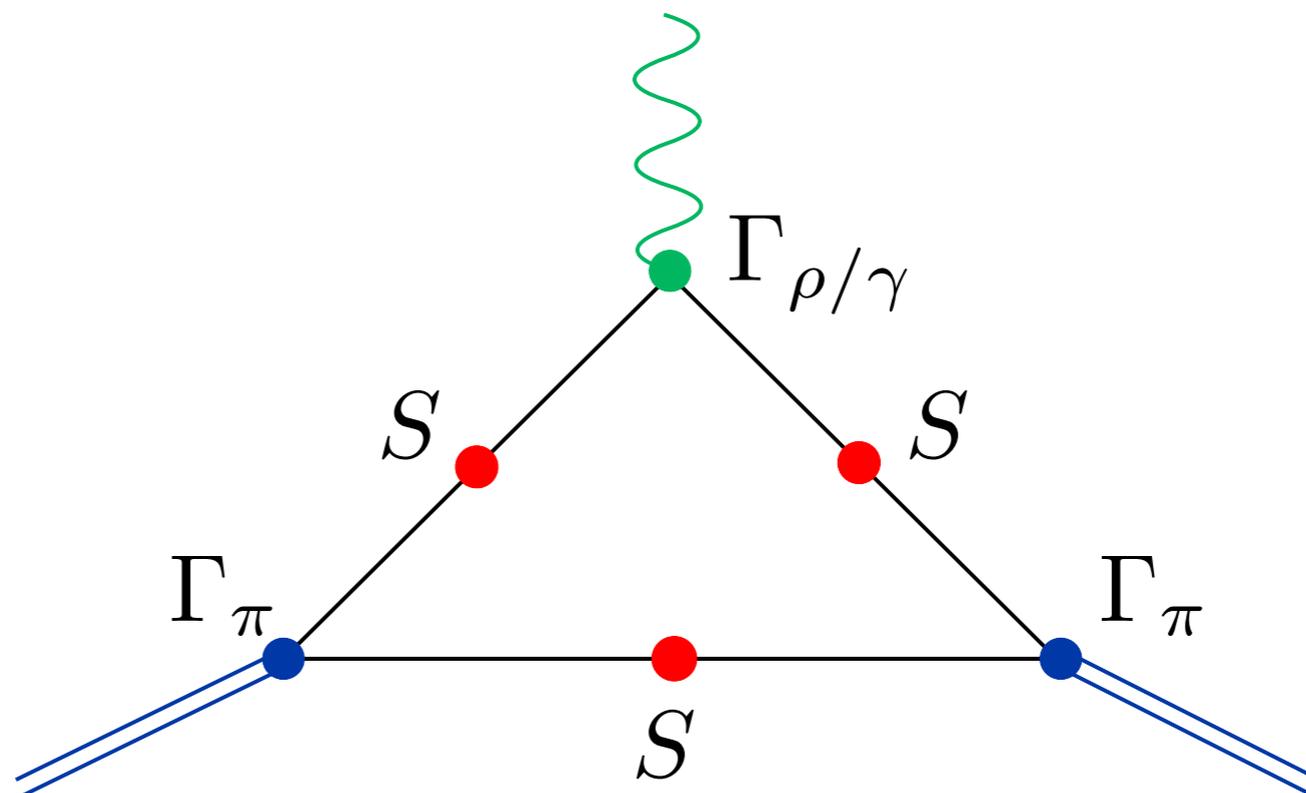


# Beyond Spectroscopy

Leptonic decay:

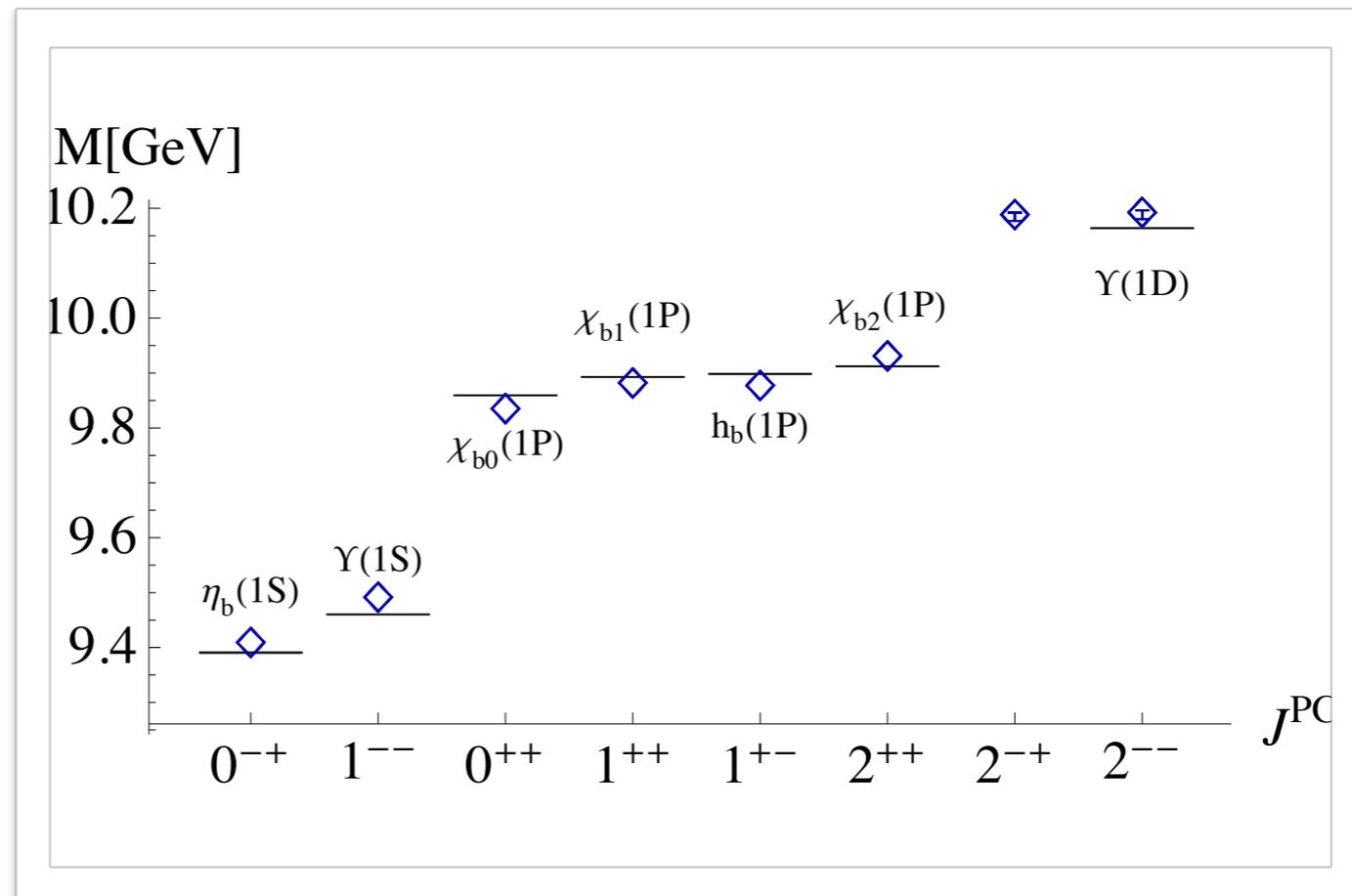


Hadronic decay  
& Form factor:



# Spectroscopy (short)

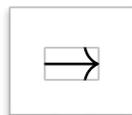
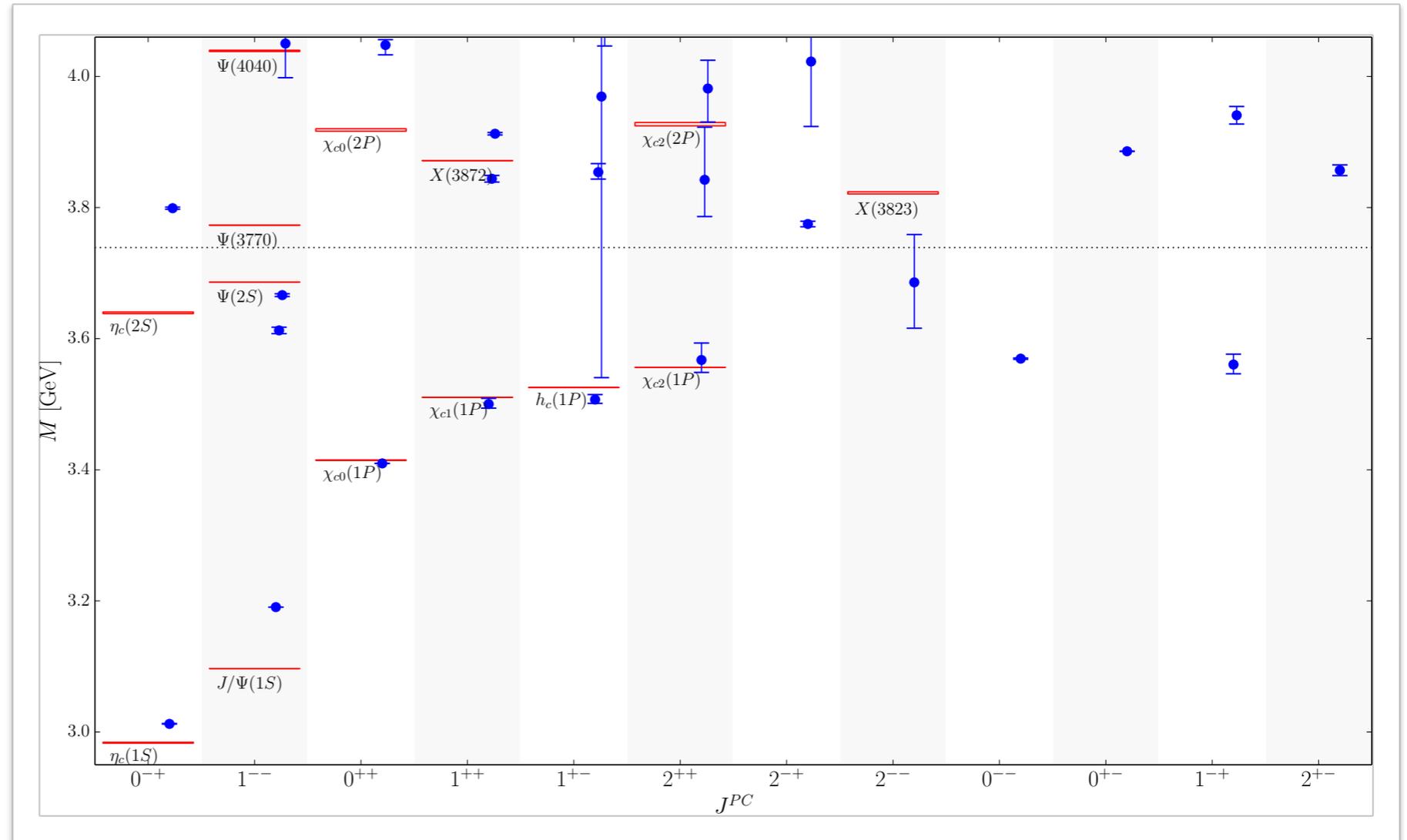
- Use RL truncation for simplicity on comprehensive scale
- apply it to systems where corrections beyond RL are expected least important
- First attempt: Bottomonium ground states:



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

# Spectroscopy (short)

- 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
- Next step: more freedom in effective interaction



see talk by  
T. Hilger

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

# Leptonic Decays

- Preliminary
- heavy quarkonia
- S vs. D wave in  $1^{--}$  channel
- state ID
- missing states?

## Ground states

State	$J^{PC}$	$f$ Calc.	$f$ Exp.
$\eta_c$	$0^{-+}$	401	339(14)
$J/\Psi$	$1^{--}$	450	416(5)
$\eta_b$	$0^{-+}$	773	—
$\Upsilon$	$1^{--}$	768	715(5)

## First radial excitations

$\eta_c(2S)$	$0^{-+}$	244(12)	189(50)
$\Psi(2S)$	$1^{--}$	30(3)	294(4)
$\eta_b(2S)$	$0^{-+}$	419(8)	—
$\Upsilon(2S)$	$1^{--}$	467(17)	497(4)

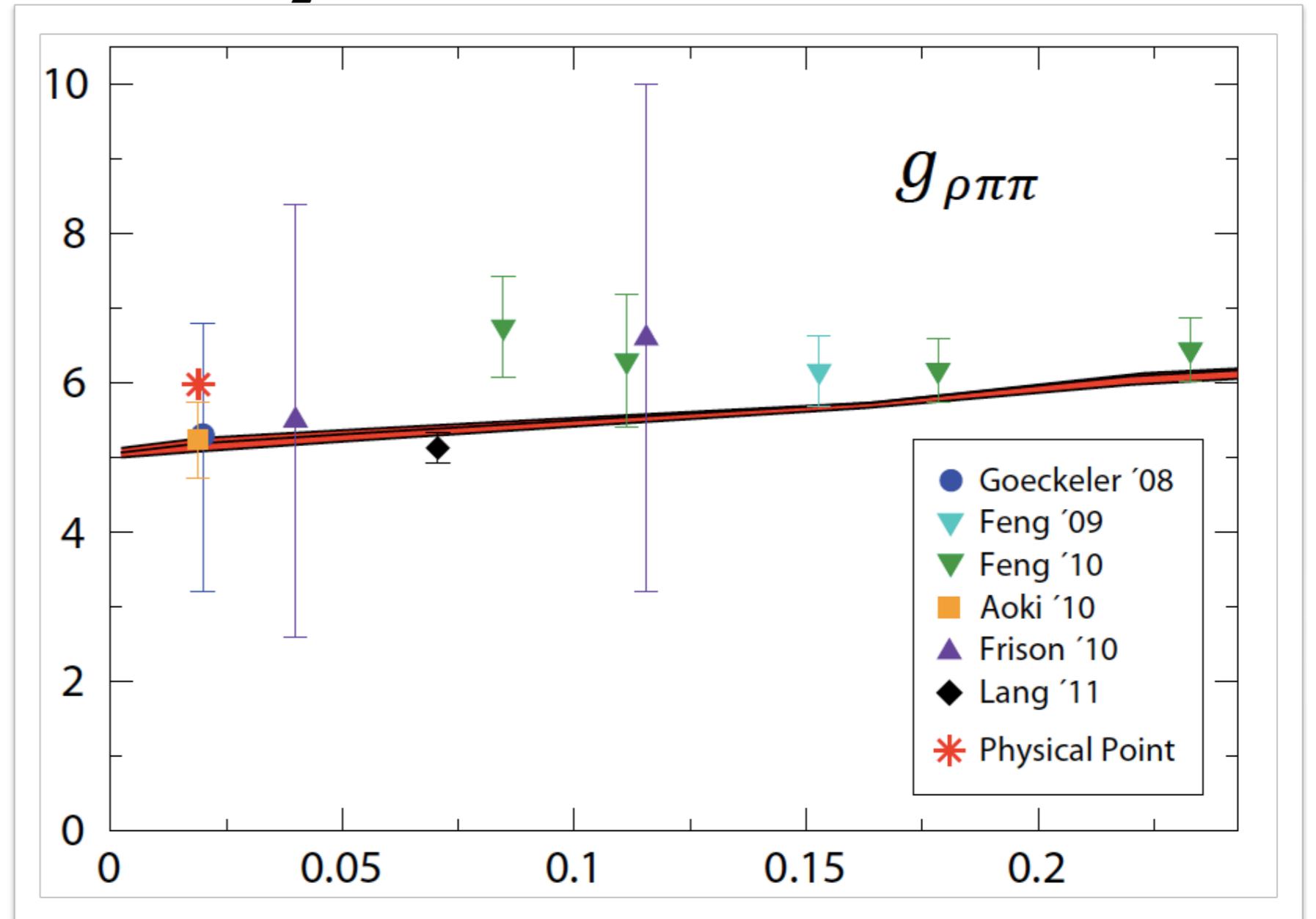
## Second radial excitations

$\eta_c(3S)$	$0^{-+}$	145(145)	—
$\Psi(3770)$	$1^{--}$	118(91)	99(3)
$\eta_b(3S)$	$0^{-+}$	534(57)	—
$\Upsilon(1D_1)$	$1^{--}$	41(7)	—

T. Hilger, A.K., in preparation

# Hadronic Decays

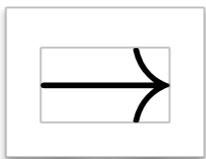
- Hadronic decay
- $\rho \rightarrow \pi\pi$
- **Compare:**
  - \* Experiment
  - \* Lattice QCD
- Analogously for **baryon** case  
 $\Delta \rightarrow N\pi$



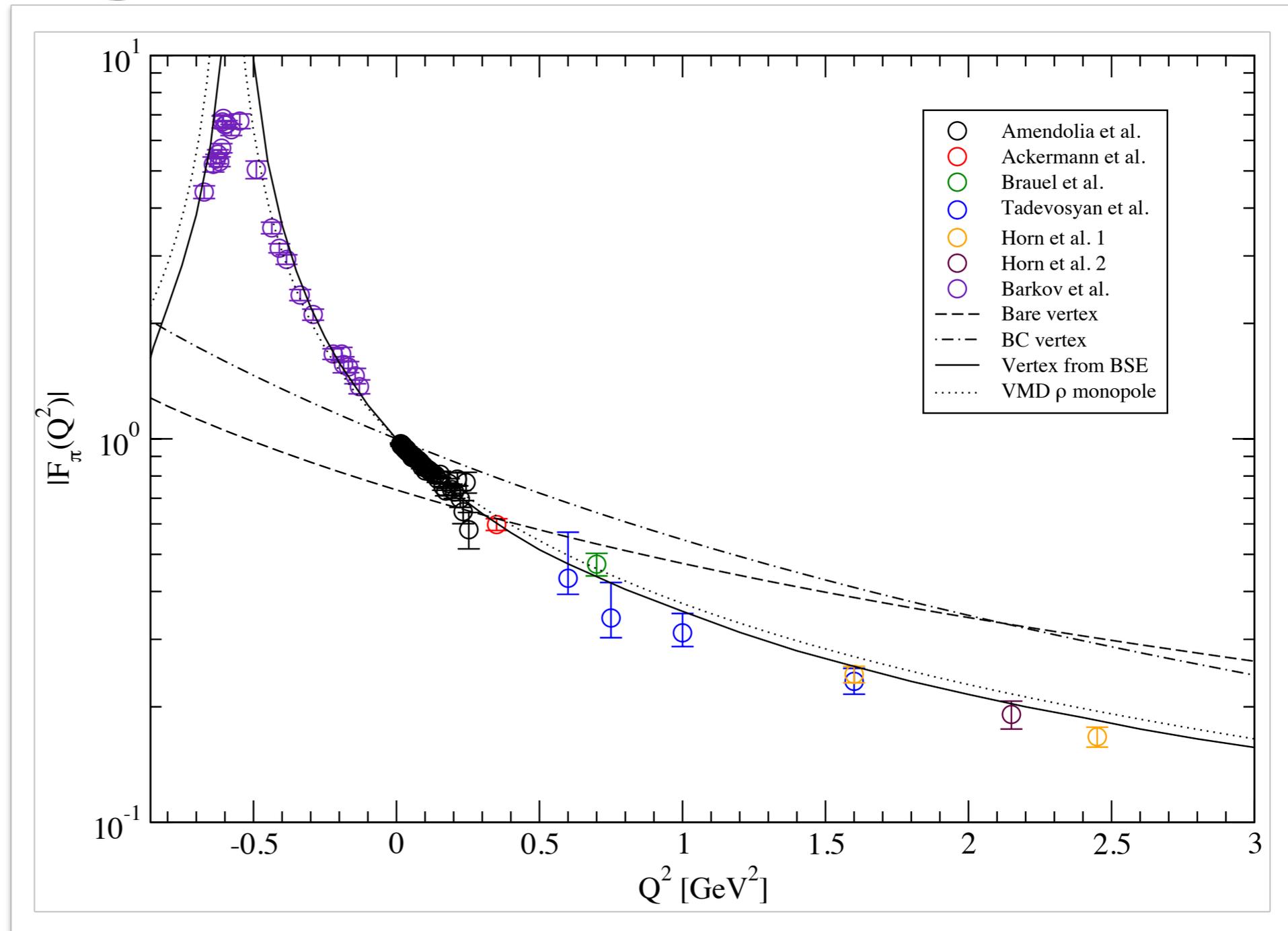
V. Mader, G. Eichmann, M. Blank, A.K., PRD 84 (2011) 034012

# Electromagnetic FF

- Pion em ff
  - \* spacelike
  - \* timelike
- Consistent construction
- Charge conserv.
- Charge radius
- Analogously for baryons



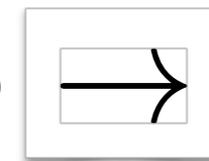
see also talk  
by V. Sauli



T. Hilger, G. Eichmann, A.K., in preparation

# 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  
see talk by H. Sanchis-Alepuz
  - your order goes here ...





Thank you very much for your attention!