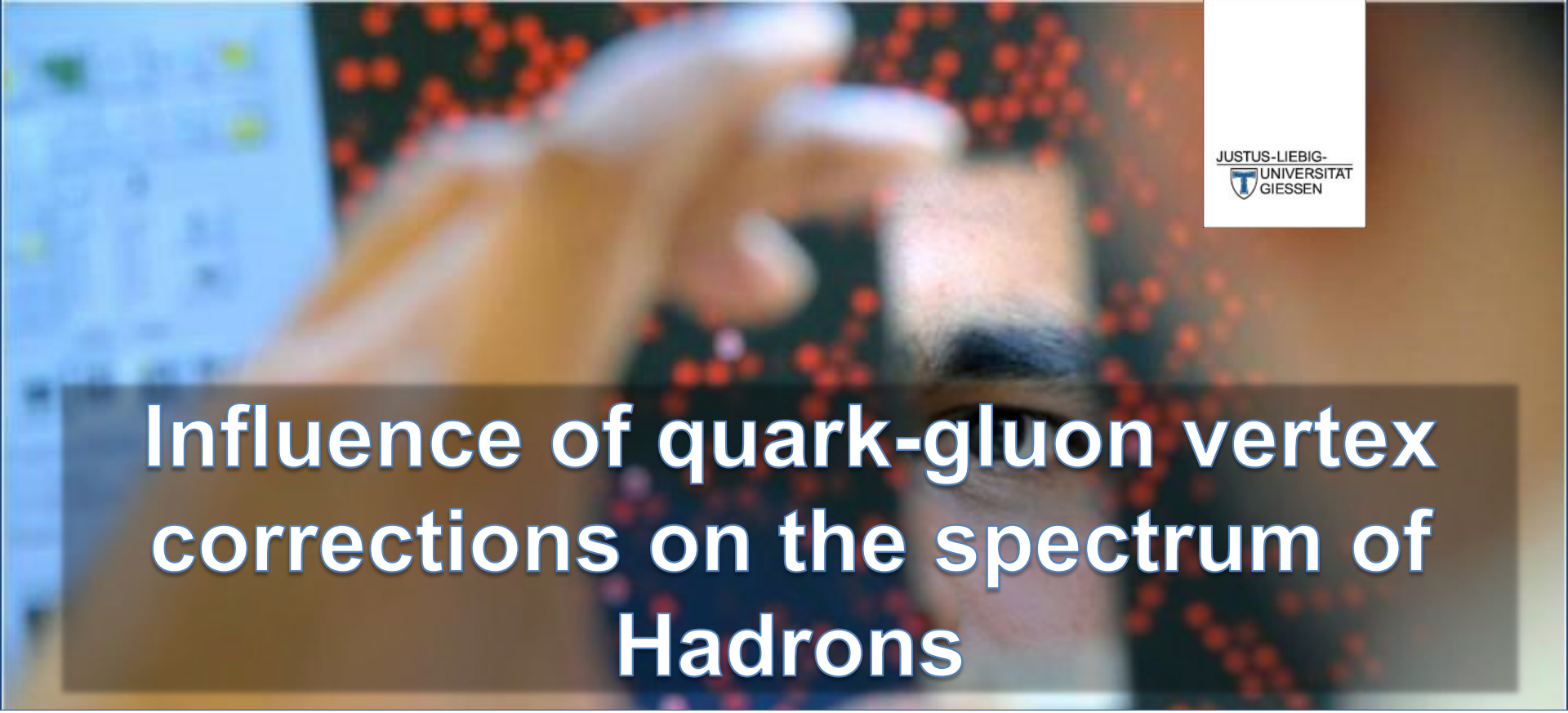


Influence of quark-gluon vertex corrections on the spectrum of Hadrons

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

JLU DAS LEBEN STUDIEREN DIE WELT ERFORSCHEN

FWF Der Wissenschaftsfonds.

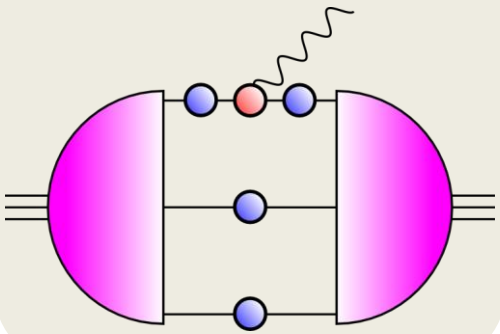
Richard Williams

Together with: ***Helios Sanchis-Alepuz***

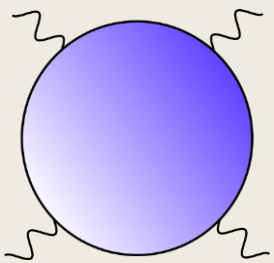
Motivation

Aim: Computation of **hadron properties** from the quarks and gluons of QCD

EM form-factors



Hadronic LBL



See talk by Eichmann

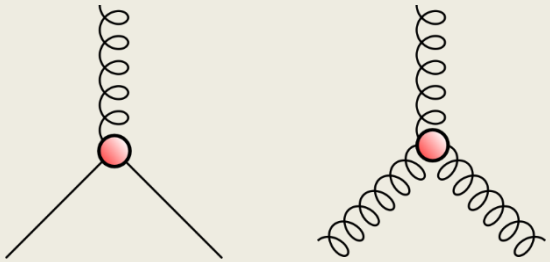
QCD Green's functions / Dyson-Schwinger Approach

Nonperturbative ▪ Covariant ▪ Multi scale ▪ Light + Heavy

- Meson/Baryon spectroscopy
- Form factors
- Tetraquarks

see next talk by Heupel

e.g.

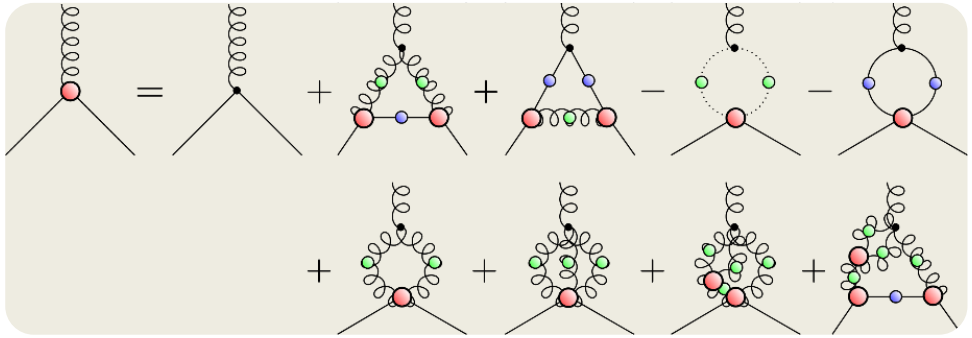


$$\Gamma^{\mu\nu\dots}_{ij\dots}(p_1,p_2,\dots)=\sum_a F_a(p_1^2,p_2^2,\dots)\tau^{\mu\nu\dots}_{a,ij\dots}(p_1,p_2,\dots)$$

Dyson-Schwinger and Bethe-Salpeter Equations

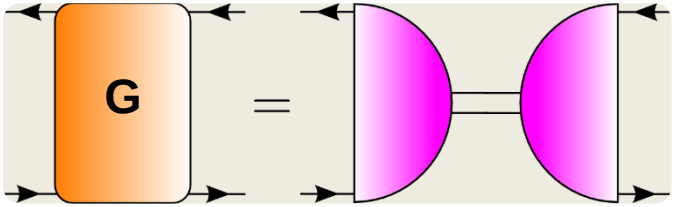
Quark propagator

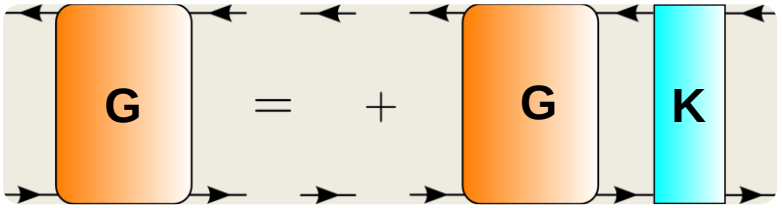
Quark-gluon vertex



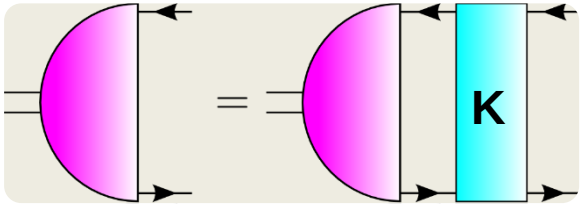
Alkofer *et al* Ann.Phys 324 (2009)
RW, 1404.2545

Poles in *n*-body functions





Homogeneous BSE



Symmetries: constrain the form of the interaction kernel.

When applied to hadron physics, (almost) always in combination with:

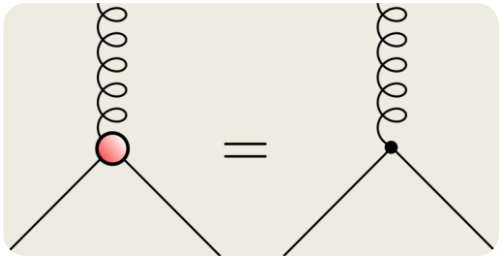
RAINBOW-LADDER

RAINBOW-LADDER

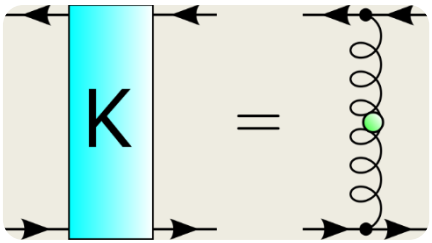
RAINBOW-LADDER

RAINBOW-LADDER

Rainbow-Ladder

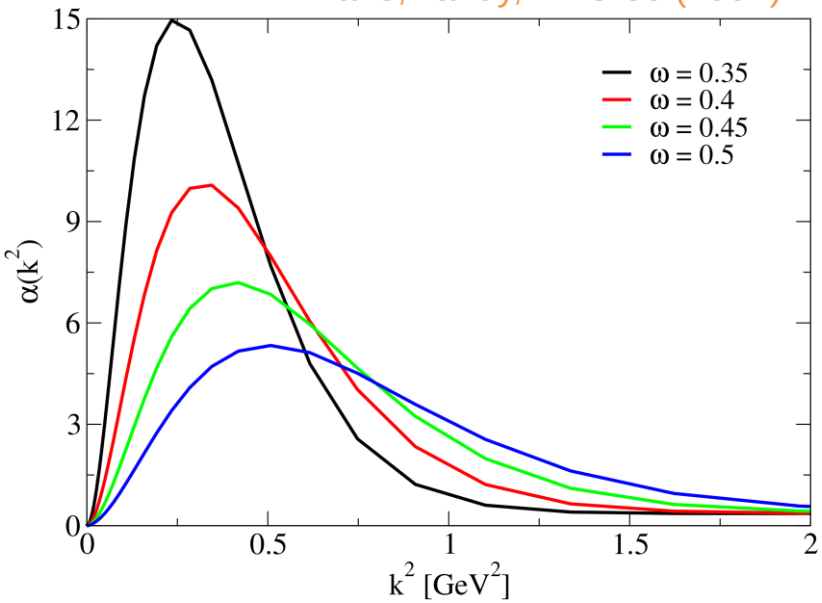


- Quark gluon vertex **bare**, γ^μ
- “Gluon” provided by effective interaction, $\alpha(k^2)$
- BS kernel: single gluon exchange



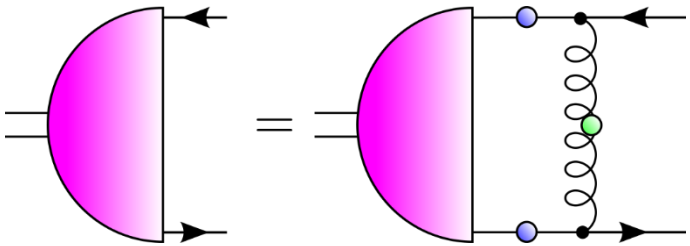
DCSB ▪ AX-WTI ▪ V-WTI

Maris, Tandy, PRC 60 (1997)



$$\alpha(k^2) = \alpha_{IR}(k^2, \omega) + \alpha_{UV}(k^2)$$

Rainbow-Ladder: Meson I



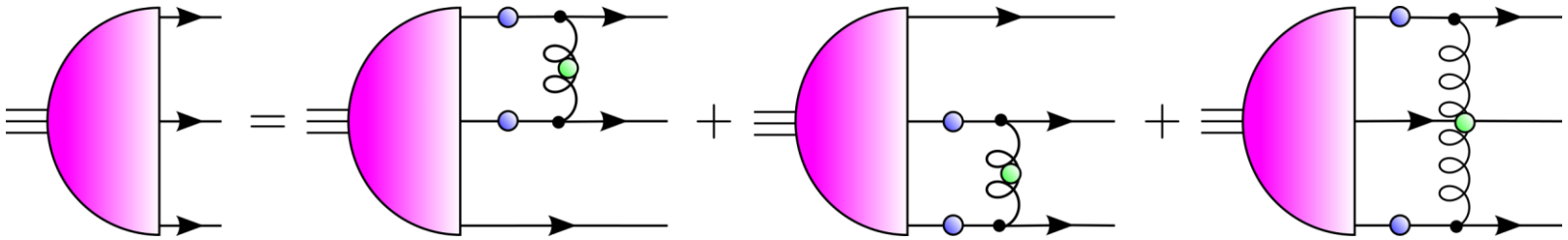
Neglecting quark flavour dependence

KERNEL:	**AMPLITUDE:**
Partial kinematic dependence	4 or 8 components

Qin *et al*, PRC 85 (2012)
Fischer, Kubrak and RW, EPJ A50 (2014)
Rojas *et al*, 1407.3598

Rainbow-Ladder: (1 x **1**) = 1 kernel component

Rainbow-Ladder: Baryon I



Permuted two body kernel

Neglecting irreducible three-body forces

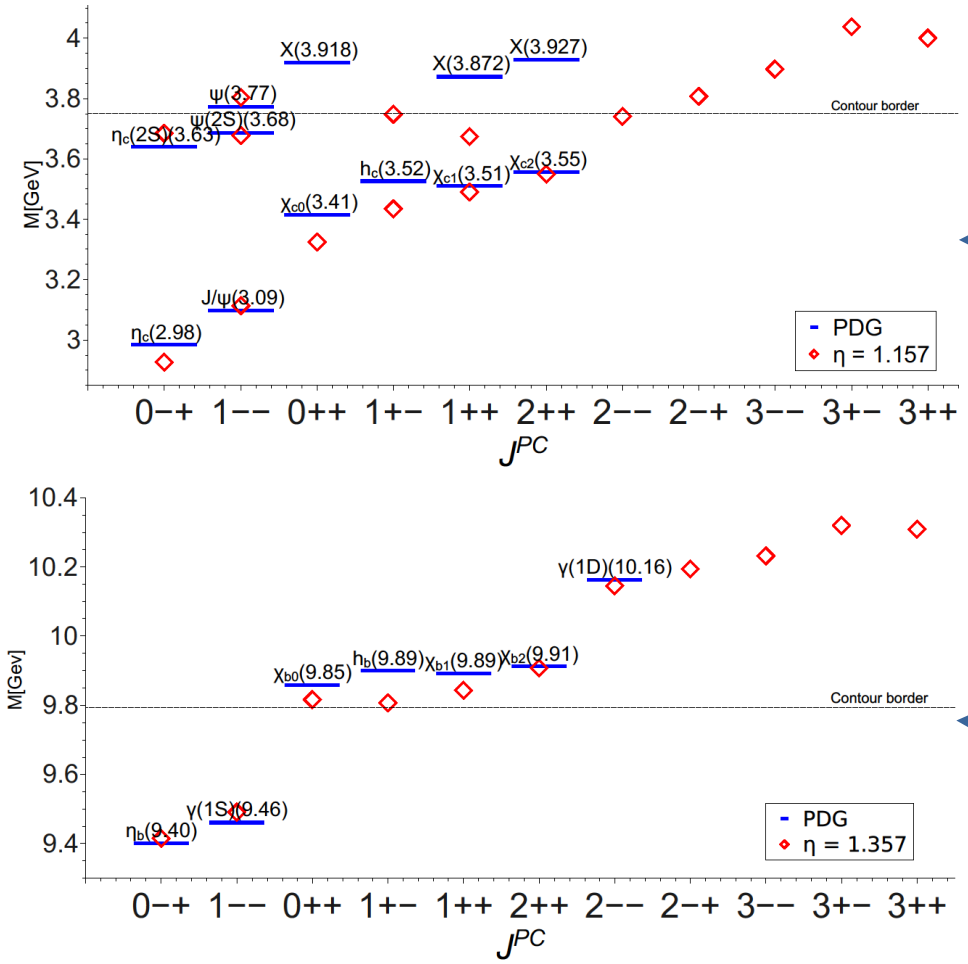
KERNEL:	**AMPLITUDE:**
Partial kinematic dependence	64 or 128 components

N,	Eichmann *et al,* PRL 104 (2010)
N/Δ,	Sanchis-Alepuz *et al*, PRD 84 (2011)
Octet/ Decuplet	Sanchis-Alepuz *et al, 1408.5577*

Rainbow-Ladder: (3 x **1**) = 3 kernel components

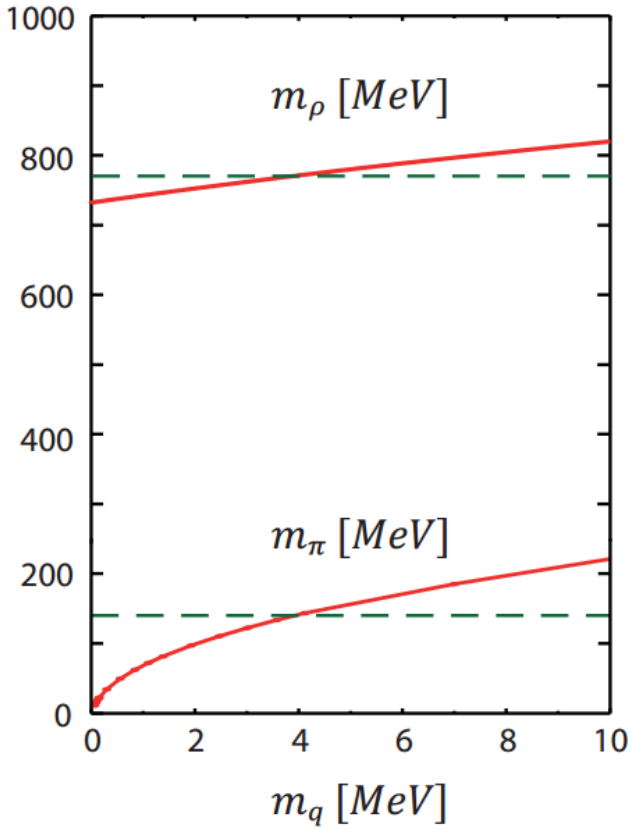
Rainbow-Ladder: Meson II

Heavy-heavy mesons



Fischer, Kubrak and RW, *in prep*

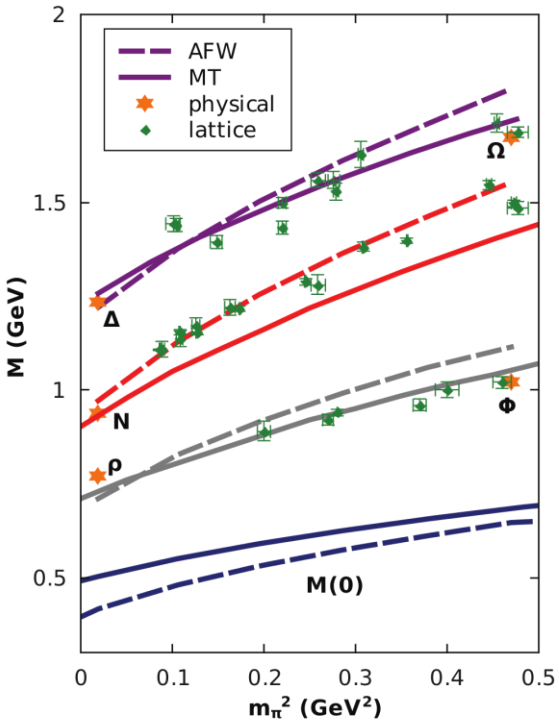
Light **pseudoscalar/vector** mesons

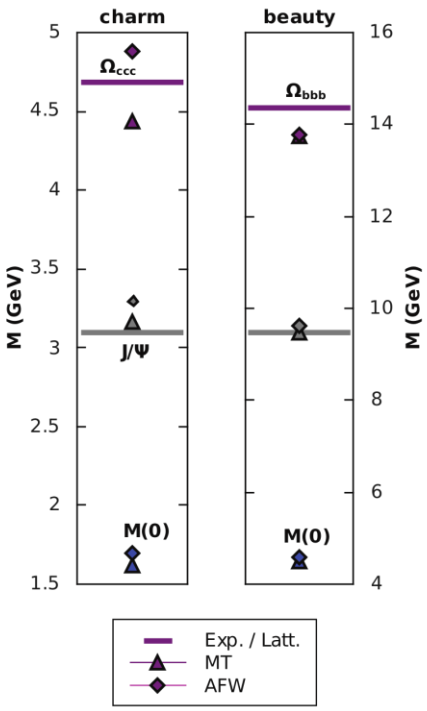


Excited states and **exotics?**

Rainbow-Ladder: Baryon II

Nucleon/Delta/Omega: Good masses/Form-Factors





Good agreement

- Masses insensitive to eff. int.
- Consistent meson/baryon kernel

Sigma terms:

$$\sigma_{\pi X} = m_q \frac{\partial M_X}{\partial m_q}$$

$\sigma_{\pi N} = 30(3)$MeV

$\sigma_{\pi \Delta} = 24(2)$MeV

Too low by 20 to 30%

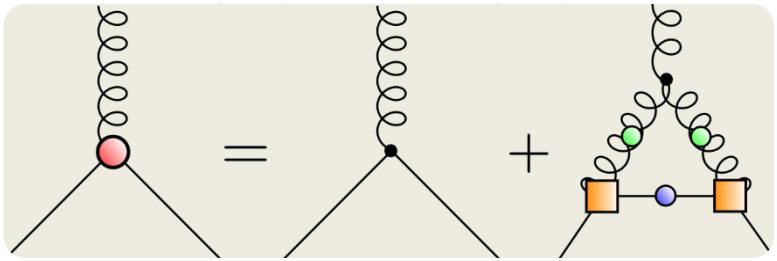
Sanchis-Alepuz *et al*, PLB 733 (2014)

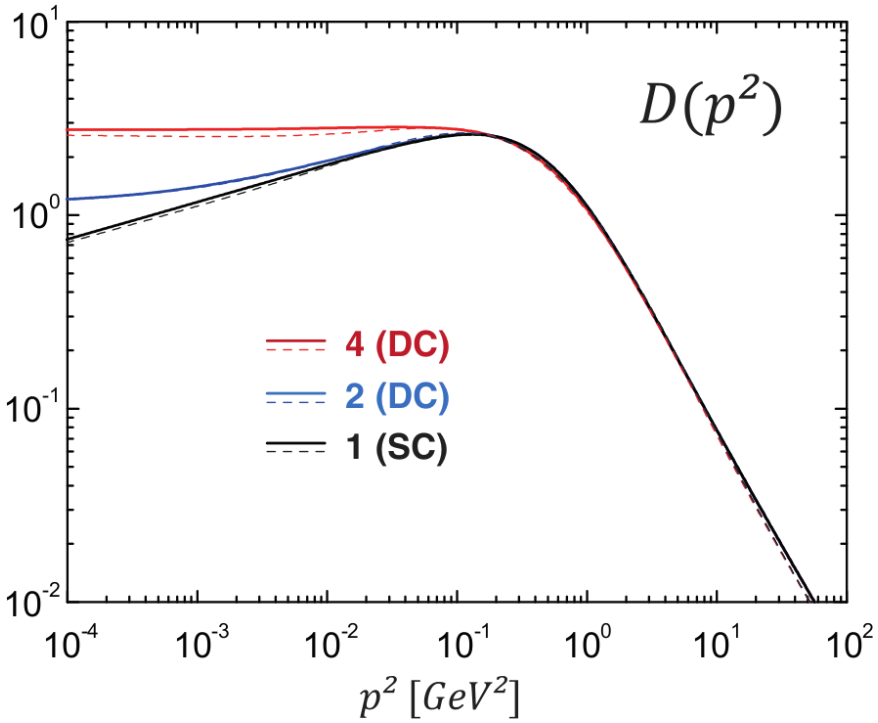
Suggestive:

- Pion cloud effects
- Irreducible three-body forces
- Gluon self-interaction

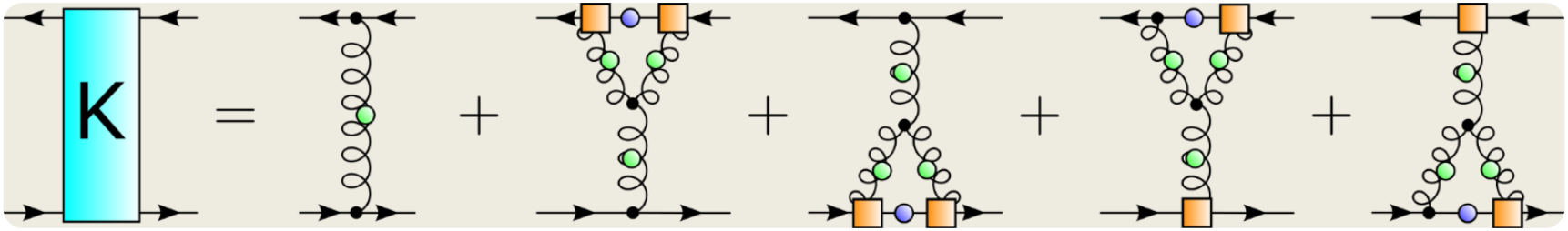
ALL BEYOND RAINBOW-LADDER

Beyond Rainbow-Ladder



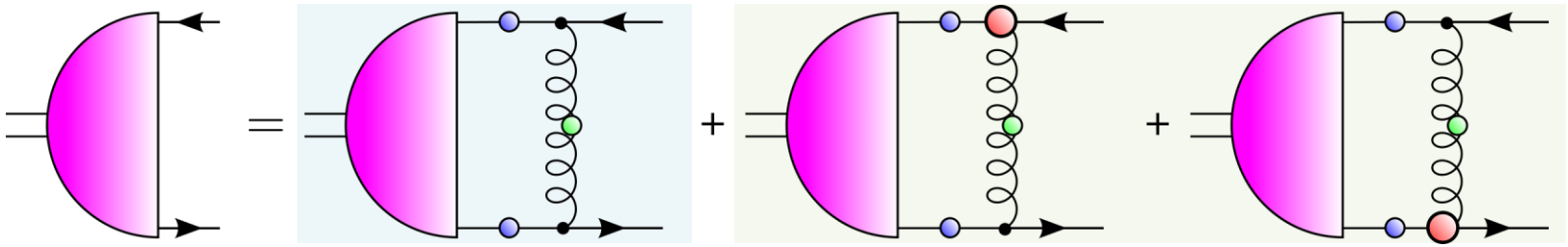


- Quark gluon vertex **dressed**, $\Lambda^{\mu}(k,p)$
- Gluon provided by DSE/FRG/Lattice
- Possibly dressed 3g-vertex
- BS kernel: “dressed” gluon exchange



DCSB ▪ AX-WTI ▪ V-WTI ▪ FLAVOUR

Beyond Rainbow-Ladder: Meson



KERNEL:

Full kinematic dependence

Diagrammatic

Watson *et al*, FBS 35 (2004)
Fischer and RW, PRD 78 (2008)
Fischer and RW, PRL 103 (2009)

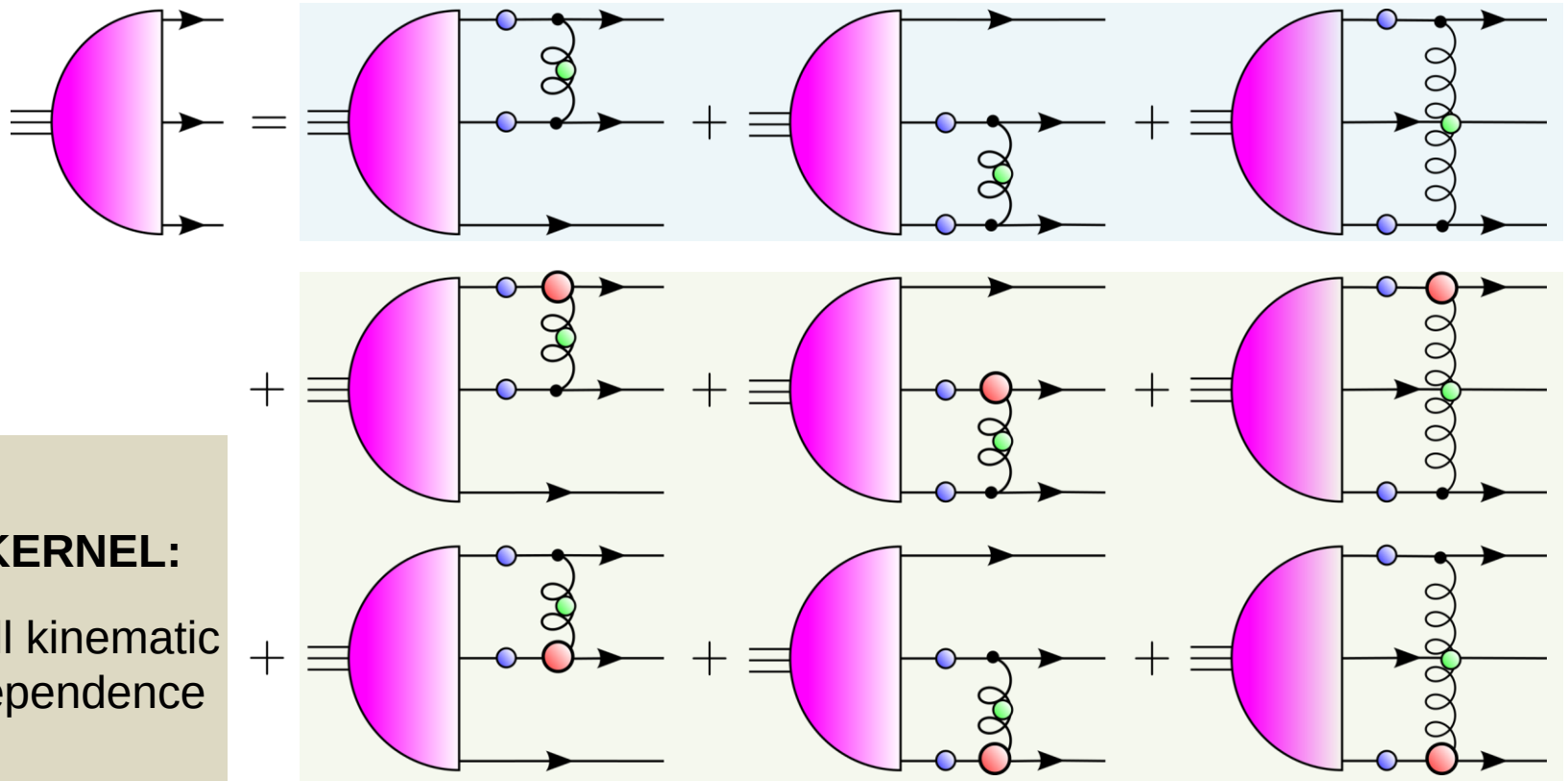
Non-Diagrammatic

Chang *et al*, PRL 103 (2009)
Heupel *et al*, EPJA 50 (2014)

Beyond Rainbow-Ladder: (1 x **1**) + (2 x **8**) = 17 kernel components

Beyond Rainbow-Ladder: Baryon

Example: Λ_{uds} with isospin breaking



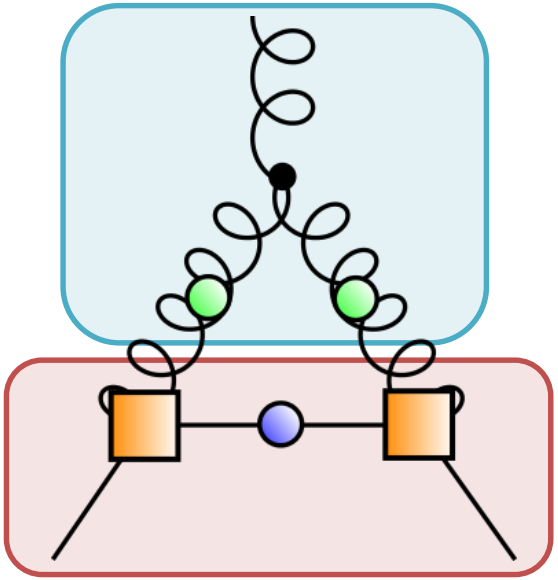
KERNEL:

Full kinematic dependence

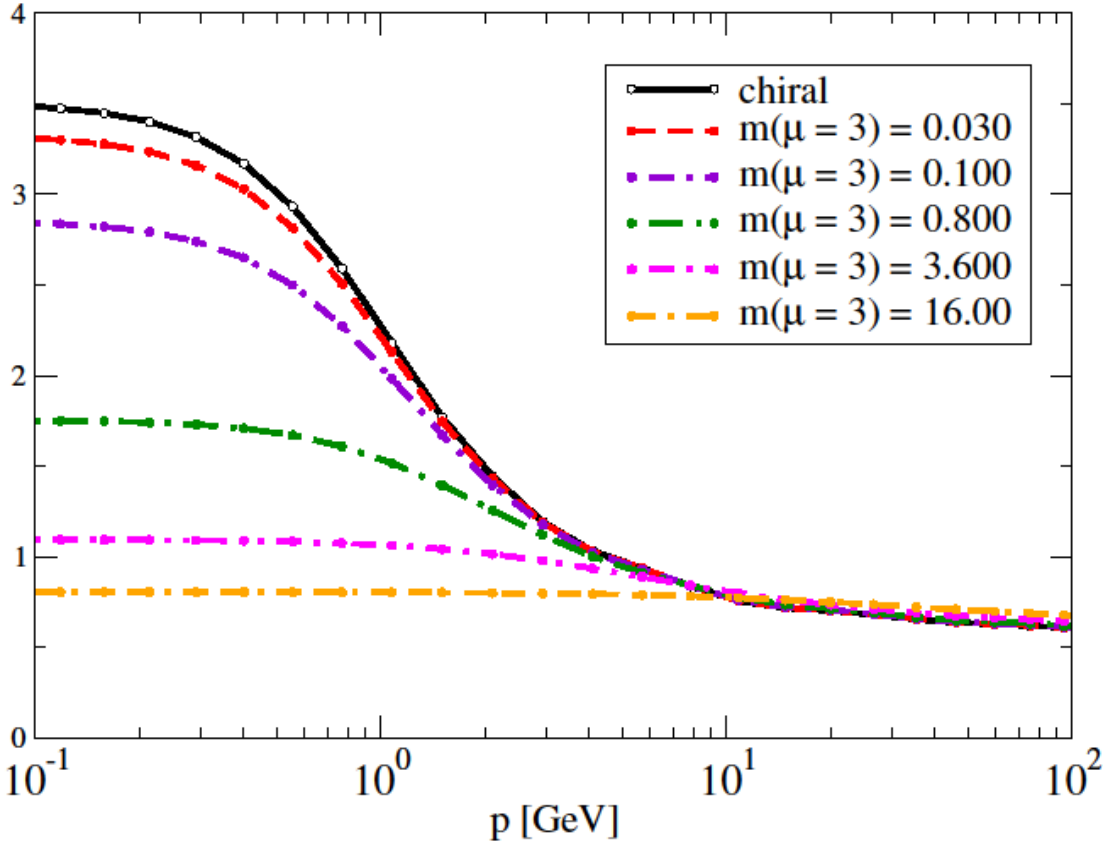
Beyond Rainbow-Ladder: (3 x **1**) + (6 x **8**) = 51 kernel components

Beyond Rainbow-Ladder: non-Abelian vertex contribution

Gluon self-interaction



Intrinsic flavour dependence

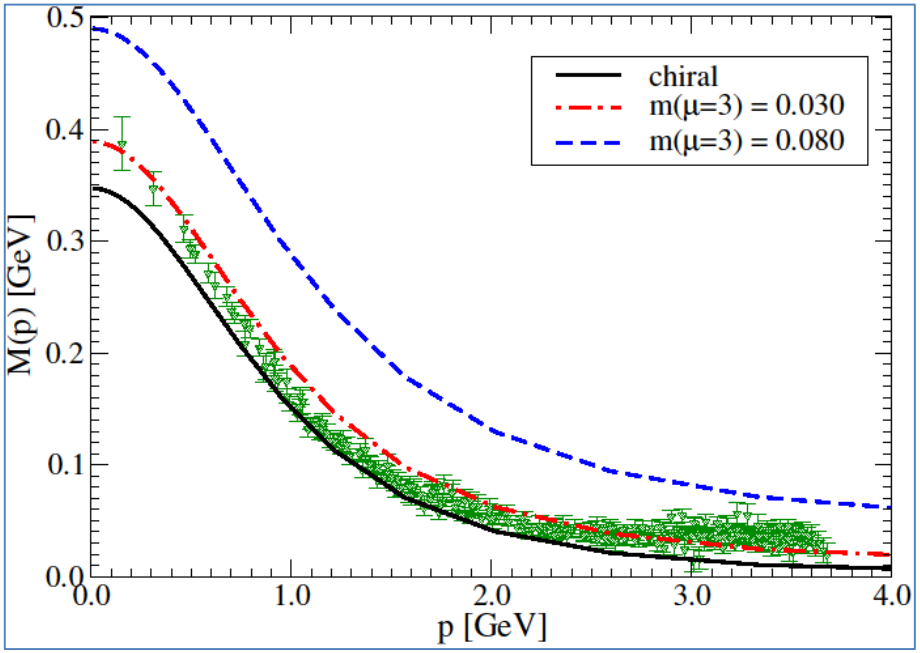


Basic decomposition: see Eichmann, APPS 7 (2014)

$$\Gamma_\mu^a(p_1,p_2,p_3) = t^a \sum_{i=1}^{8} h_i(p_1^2,p_2^2,p_3^2)\tau_\mu^i(p_1,p_2,p_3)$$

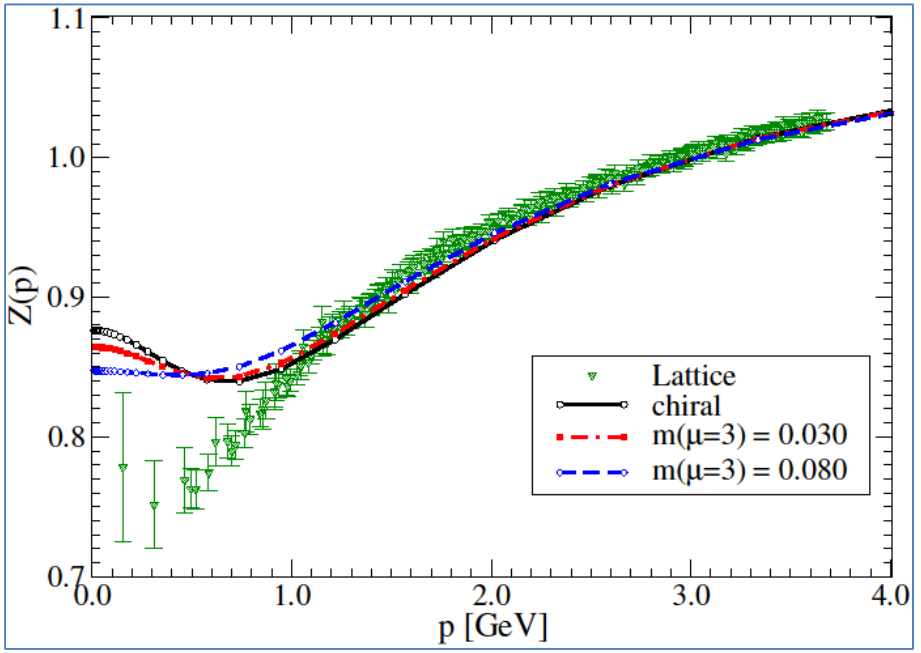
Results: Quark propagator

Modelling of Green's functions deferred to higher order in n, or higher order in "loops".

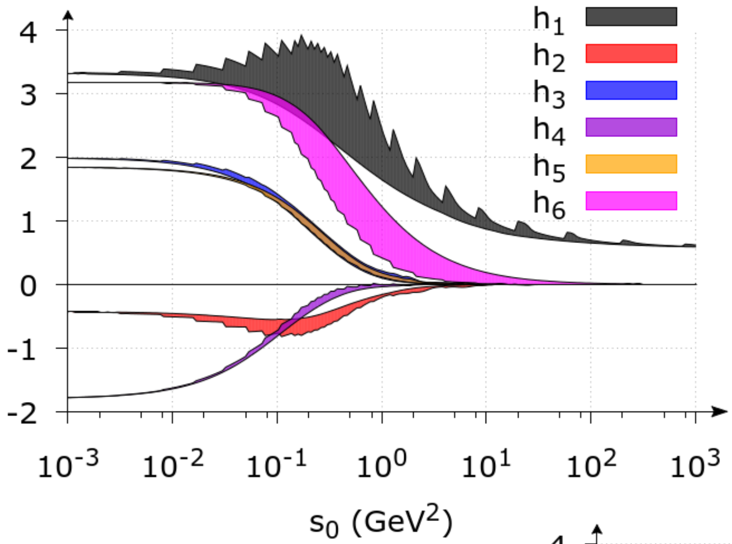


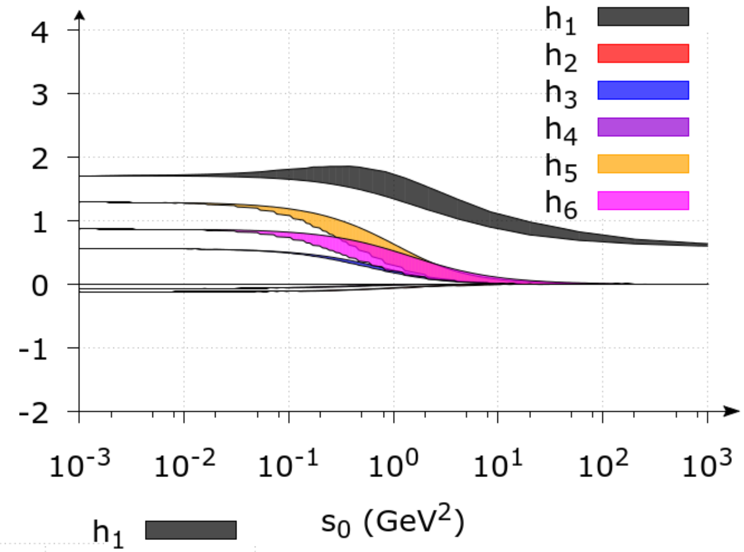
- **Quark mass function**

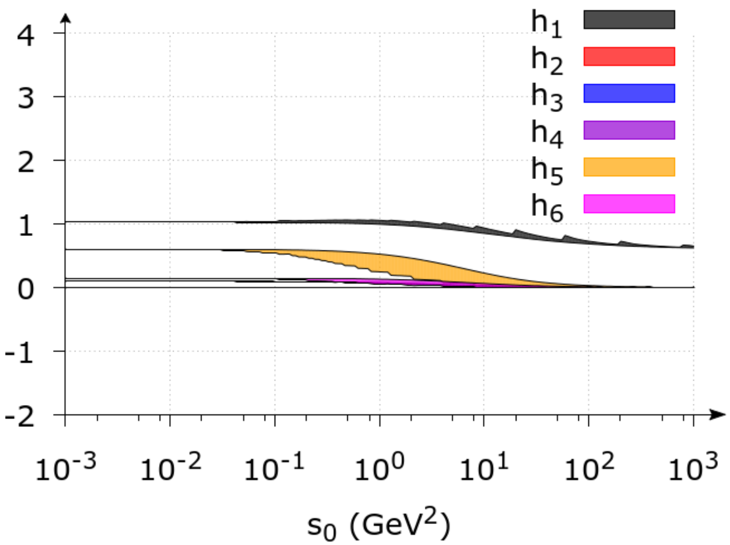
- **Quark wave function renormalisation**



Results: Resultant quark-gluon vertex



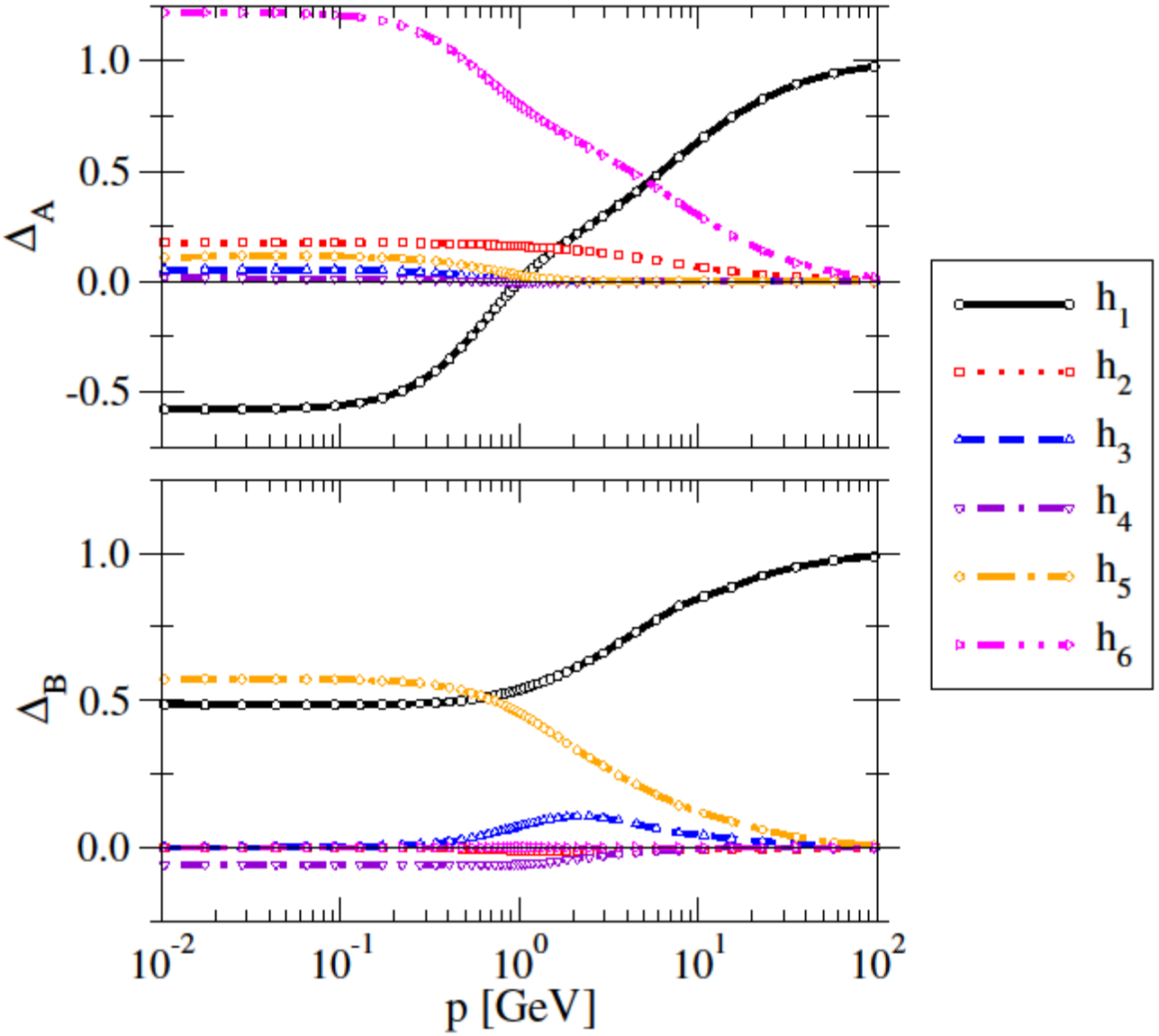




Tree-level (h1) dominant.
(h5) and (h6) important.

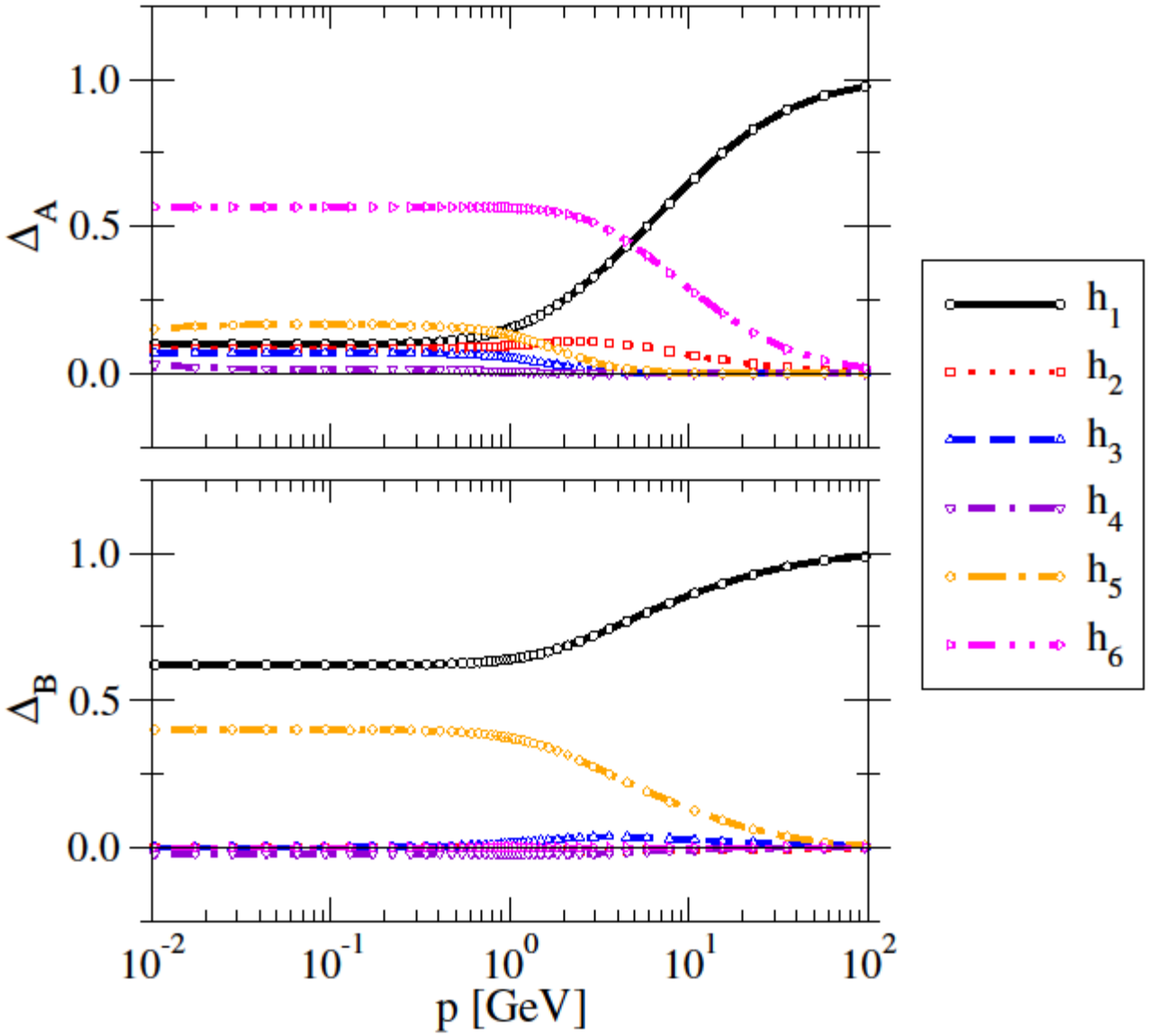
Results: projected vertex in quark DSE I

Light quarks

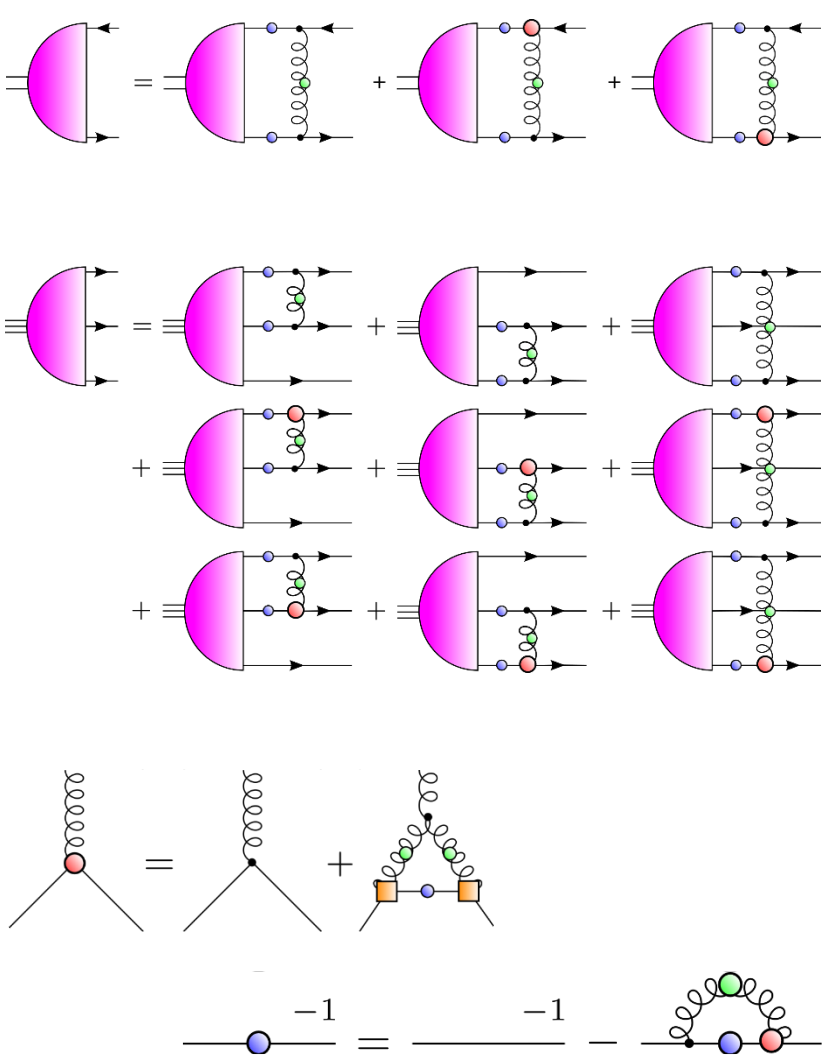


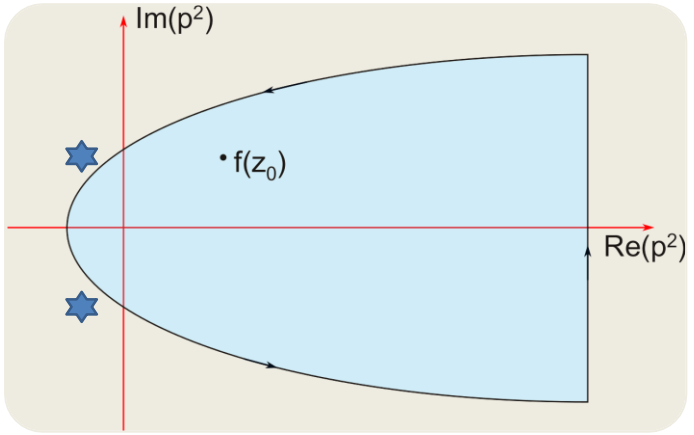
Results: projected vertex in quark DSE II

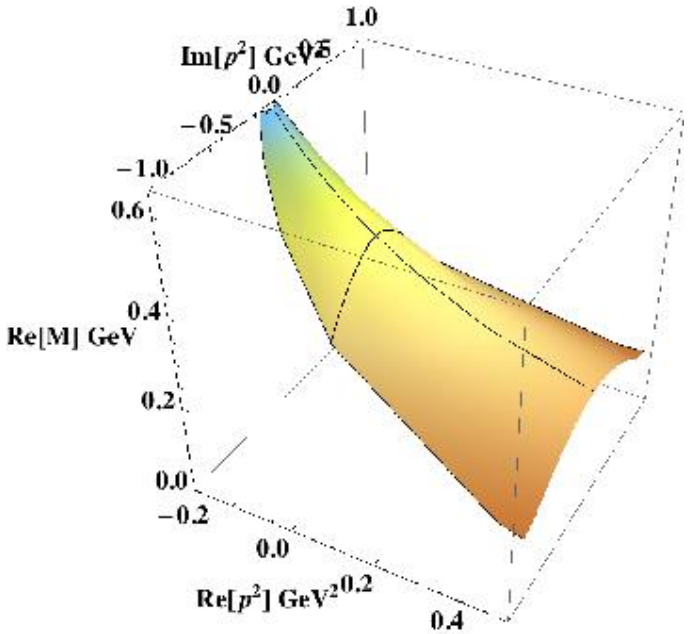
Heavy quarks



Results: Analytic Continuation







Results: Mesons and Baryons

Typical Rainbow-Ladder (Maris-Tandy)

	0^{-+}	0^{++}	1^{--}	1^{+-}
$n\bar{n}$	138	**644**	757.2	852
$s\bar{s}$	693	1080	1090	1205
$c\bar{c}$	2925	3323	3113	3433
$b\bar{b}$	9414	9815	9490	9806

$1/2^+$	$3/2^+$
940	1260
	1720

Beyond Rainbow-Ladder (preliminary: unfixed scales. S-wave Delta)

	0^{-+}	0^{++}	1^{--}	1^{+-}
chiral	0	**489**	762	946
$s\bar{s}$	729	1148	1238	1510
$c\bar{c}$	2960	3520	3253	3770
$b\bar{b}$	9195	9992	9352	10130

$1/2^+$	$3/2^+$
1010	1210
	2080

Light scalar Heupel *et al, EPJA 50 (2014)*

Heavy scalar Chang *et al, PRC 85 (2012)*

Anomalous chromomagnetic moments?

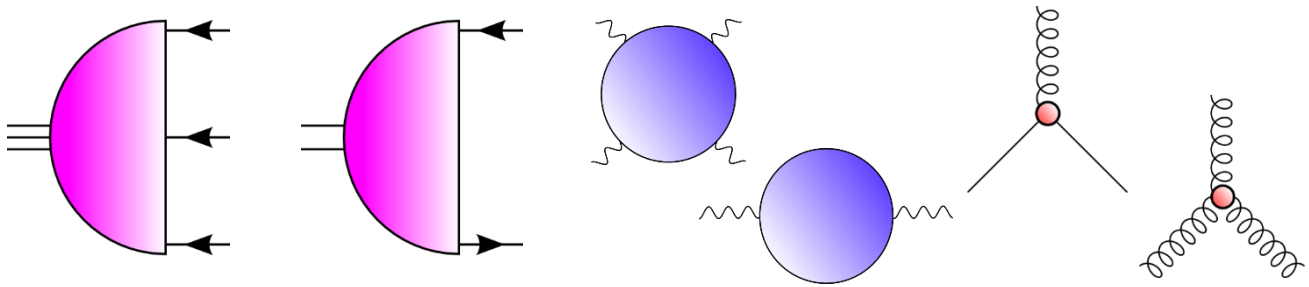
Summary and Outlook

- Higher Green's functions (vertices) **routinely** calculable
- Symmetries provide stringent **constraints**
- "Realistic" descriptions of the quark-gluon interaction available
- Now, **Mesons** and **Baryons** *beyond rainbow-ladder*

Investigate **thoroughly** impact of:
gluon self-interaction ▪ quark-gluon components ▪ pion cloud effects
Abelian + non-Abelian components ▪ flavor dependence / octet-decuplet

Apply to: LO HVP muon g-2 ▪ EM form factors ▪ Transition matrix elements

WIP ☺



Beyond Beyond Rainbow-Ladder!