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Forschungszentrum Jülich
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Chiral dynamics with (non) strange quarks

(status & outlook project B.3)

Ulf-G. Meißner, Univ. Bonn & FZ Jülich

Supported by DFG, SFB/TR-16 "Subnuclear Structure of Matter" and by EU, I3HP-N5 "Structure and Dynamics of Hadrons"

Personnel

Team leaders:	B. Kubis, UGM, [A. Rusetsky]
Students:	P. Bruns, R. Nißler, U. Raha (part-time)
Collaborators:	V. Bernard (Strasbourg), V. Baru (ITEP), A. Kudryatsev (ITEP), J. Haidenbauer (FZJ), C. Hanhart (FZJ), S. Krewald (FZJ), E. Epelbaum (FZJ & HISKP), A.W. Thomas (JLab), J. Gasser (Bern) B. Borasoy (HISKP), H. Krebs (HISKP), A. Sibirtsev (HISKP & JLab)

⋆ Note sizeable additional funding & man-power

⋆ Note partial overlap w/ project C.3

RESEARCH DIRECTIONS

- TWO-FLAVOR CHIRAL PERTURBATION THEORY
  - Neutral and charged pion production $\Rightarrow$ tests of CHPT and isospin violation
  - Construction of subthreshold amplitudes $\Rightarrow$ LECs, sum rules, convergence
  - SU(2) amplitudes serve as input for SU(3) calcs $\rightarrow$ *matching*

- SU(3) CHIRAL DYNAMICS w/ COUPLED CHANNELS
  - KN scattering, kaonic hydrogen and deuterium $\Rightarrow$ scattering lengths, threshold amplitudes, nature of the $\boldsymbol{\Lambda(1405)}$, ...
  - gauge invariant photo- and electroproduction $\Rightarrow$ threshold amplitudes, low resonances, ...
  - $\boldsymbol{\eta, \eta'}$ physics: em & hadronic decays, quark masses, ...

- CHIRAL EFFECTIVE NUCLEAR FIELD THEORY
  - 2N and 3N forces at N^{3}LO $\Rightarrow$ precision calculations of few-nucleon systems
  - construction electroweak current operators $\Rightarrow$ $\boldsymbol{d, t,^3 He,^4 He}$ form factors, (em) pion production, *neutron amplitudes*, ...

and that is not all...

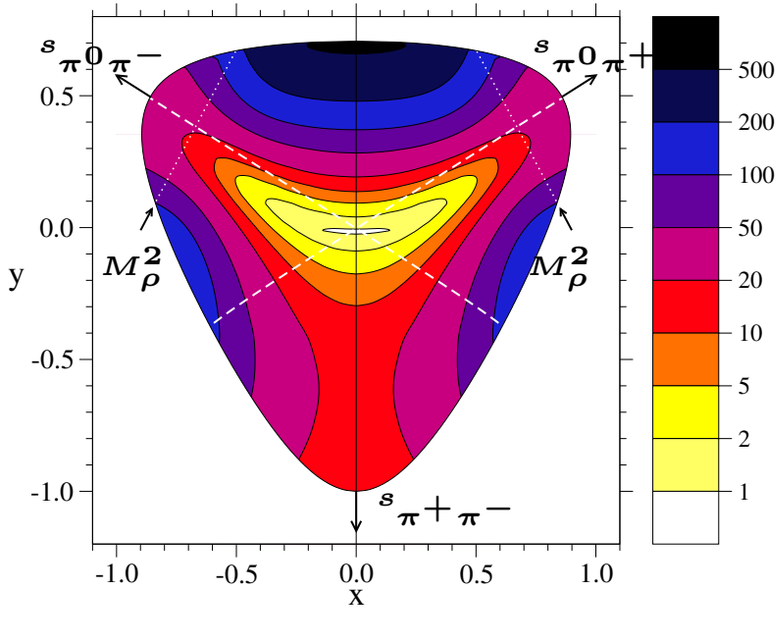
EX. 1: QUARK MASS RATIOS from η' DECAYS

Borasoy, Nißler, M., Phys. Lett. B **643** (2006) 41

– Gross-Treiman-Wilczek relation

$$r = \frac{\Gamma(\eta' \to \pi^0 \pi^+ \pi^-)}{\Gamma(\eta' \to \eta \pi^+ \pi^-)} \simeq (16.8) \frac{3}{16} \left(\frac{m_d - m_u}{m_s} \right)^2$$

Gross, Treiman, Wilczek, Phys. Rev. D **19** (1979) 2188



– Two assumptions:

(a) $\pi^0 - \eta$ mixing relates the two amps

(b) both amps are essentially constant over p.s.

– Investigate in chiral unitary approach

$\longrightarrow$ successfull description of MM scattering data & many decay modes

$\longrightarrow$ both approximations can be shown to be *inappropriate*

– predictions: $\Gamma(\eta' \to \pi^0\pi^-\pi^+) = 3120\,\text{eV}$ $[< 3800]$ $\qquad r = 3.9\%$ $[< 4.1]$

$\Gamma(\eta' \to 3\pi^0) = 330\,\text{eV}$ $[315 \pm 78]$

$\Rightarrow$ need more precision data to get at the quark mass ratio (WASA at COSY, ELSA, . . .)

EX. 2: $a(K^- p)$ from SCATTERING EXPERIMENTS

Borasoy, M., Nißler, Phys. Rev. C **74** (2006) 055201

– DEAR kaonic hydrogen results are *strange*

M., Raha, Rusetsky, Eur. Phys. J. C **35** (2004) 349

– How precisely can one determine the scattering length $a(K^- p)$ from scattering data alone?

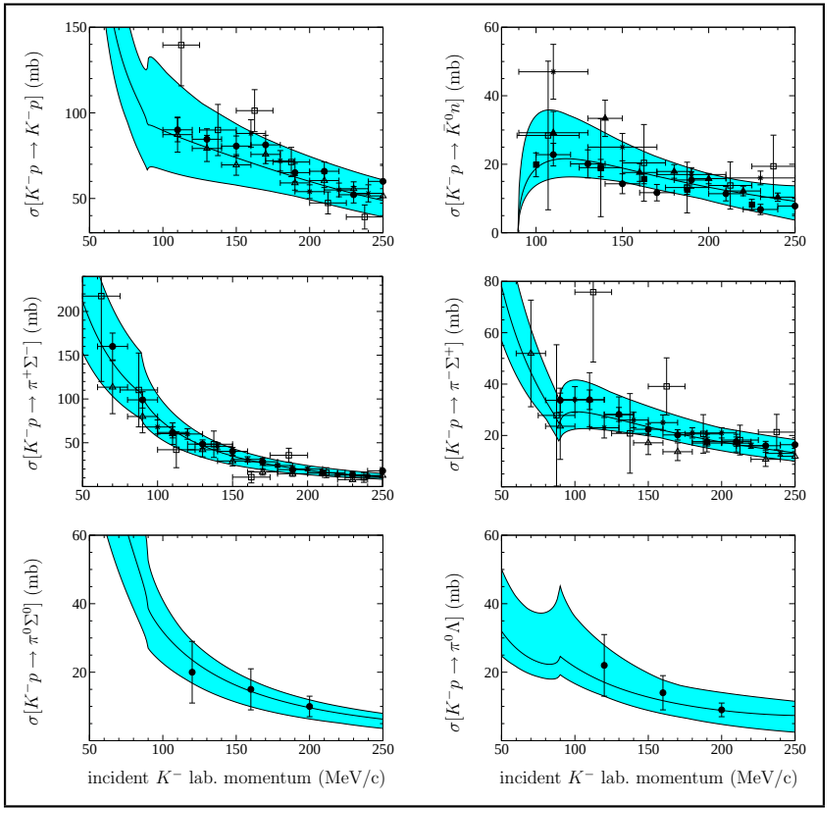
– Chiral unitary approach @ NLO: 14 LECs

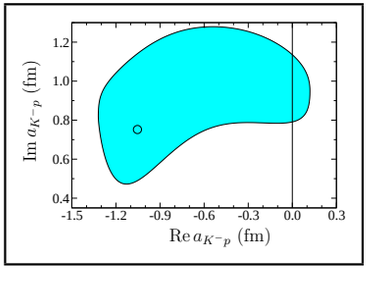
→ about 10000 MC fits in parameter space

→ 1σ bands

[method developed in project C.2]

$\Rightarrow a_{K^- p} = (-1.05 + i0.75)$ fm

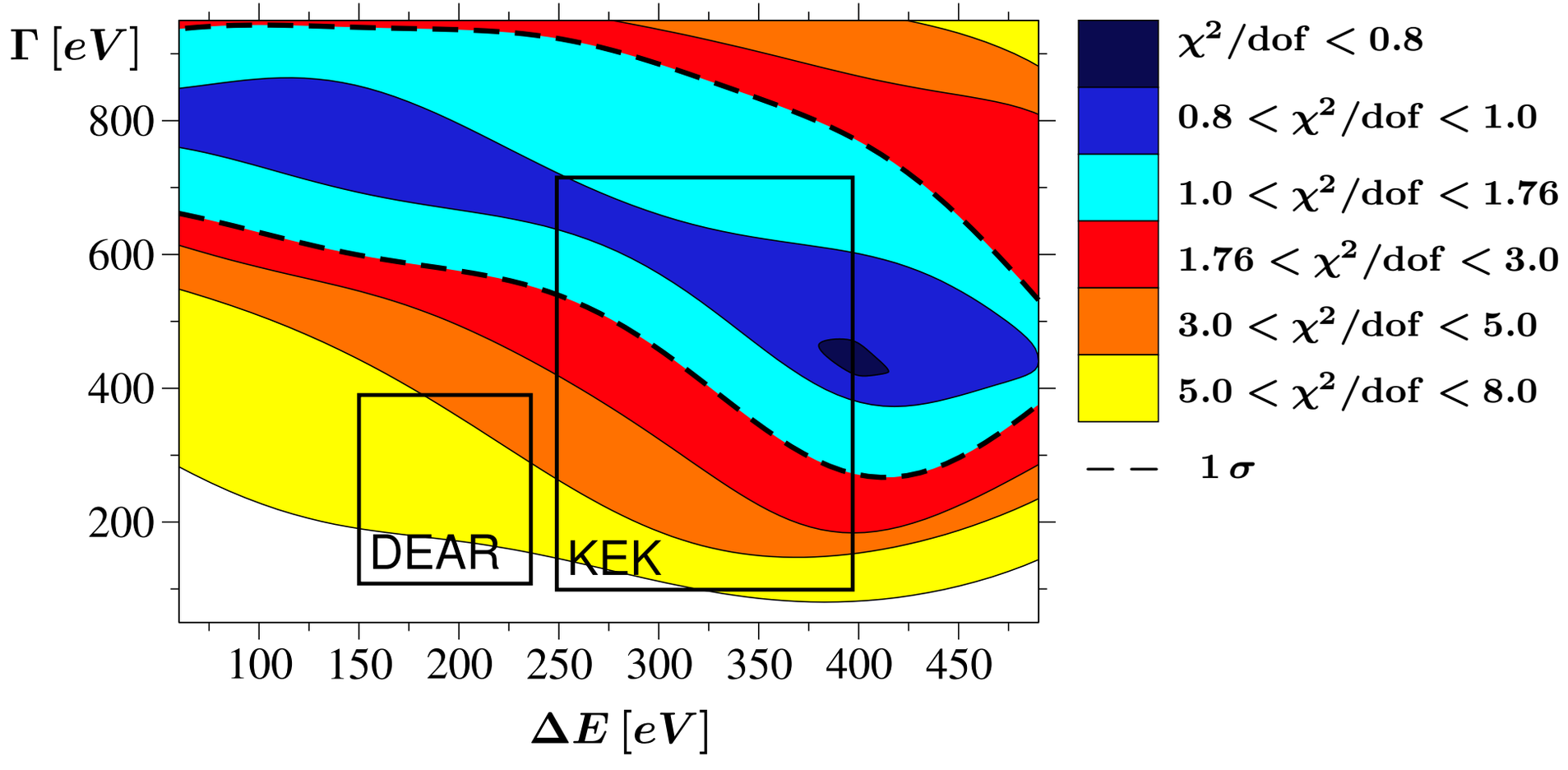




How does that compare w/ kaonic hydrogen?

RELATION TO KAONIC HYDROGEN EXPERIMENTS

- Discrepancy between scattering and bound state (DEAR) data very clear:



$\longrightarrow$ fundamental $\bar{K}N$ interaction not fully understood

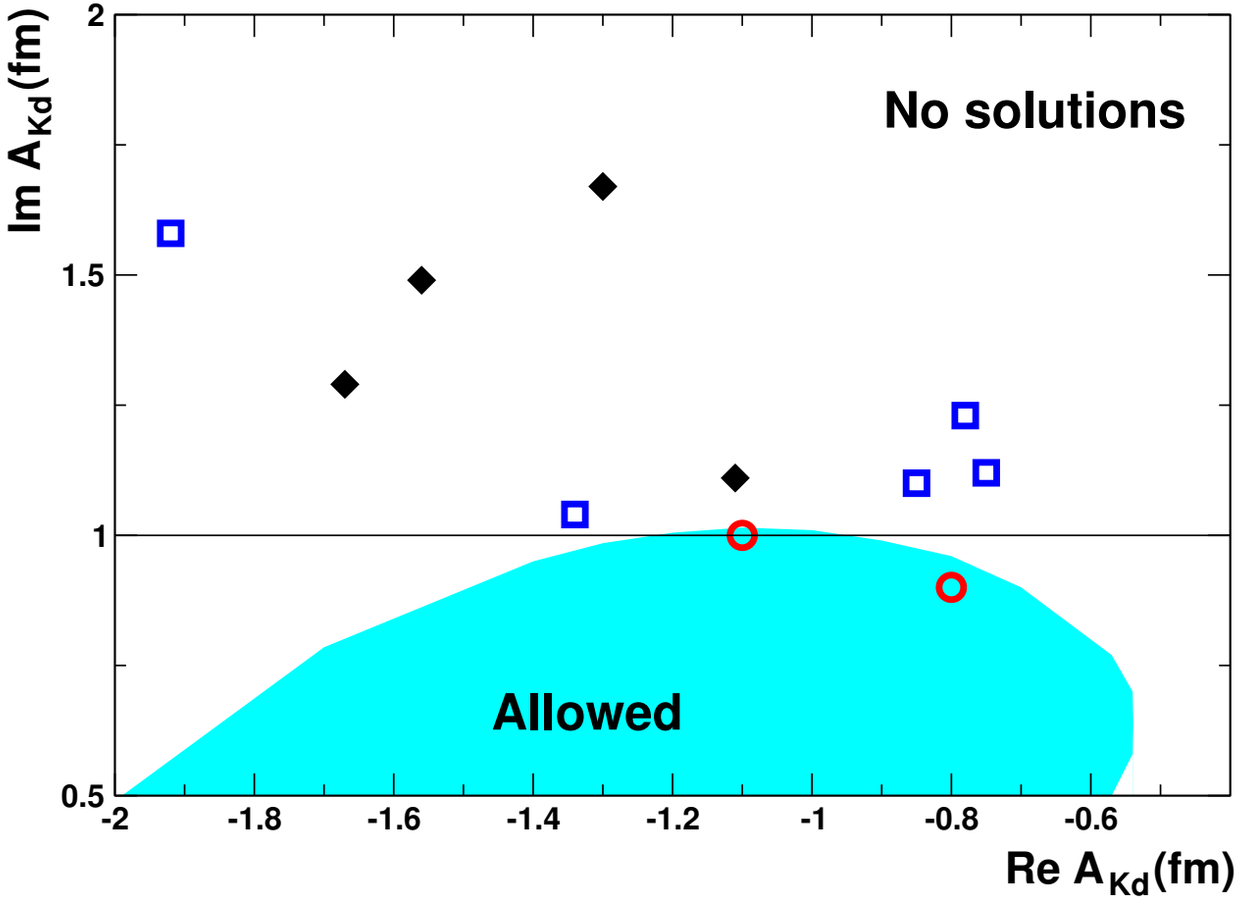
$\longrightarrow$ more info from kaonic deuterium

M., Raha, Rusetsky, Eur. Phys. J **C 47** (2006) 473

KAONIC DEUTERIUM: ALLOWED REGIONS

M., Raha, Rusetsky, Eur. Phys. J **C 47** (2006) 473

- Plane where solutions exist for a_0 and a_1 consistent with DEAR



$\longrightarrow$ very restrictive (much less if KpX input is used)

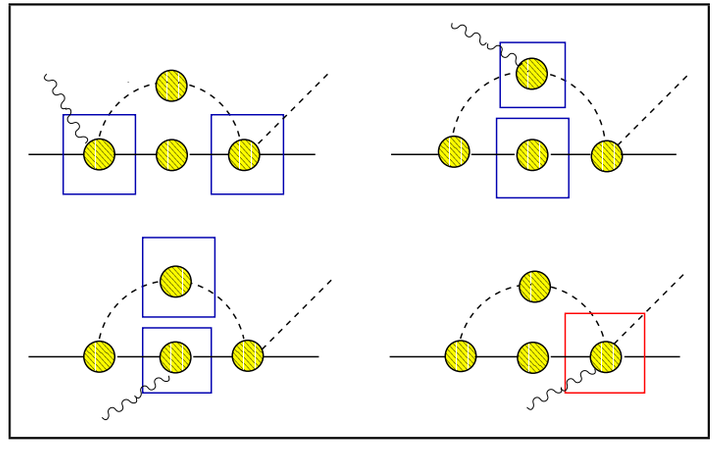
EX. 3: GAUGE INVARIANCE in EM MESON PRODUCTION

Borasoy, Bruns, M., Nißler, Phys. Rev. C **72** (2005) 065201; in prep.

- Problem: existing calculations for kaon/eta photo- and electroproduction in chiral coupled-channel analyses do not respect gauge invariance

- Solution: For a given resummation scheme, must attach the photon to **all** vertices and intermediate states

  Kvinikhidze, Blankleider, Phys. Rev. C **60** (1999) 04403, 04404



- considered so far: $\gamma\phi B \to \phi B$
- consider now: $\gamma B \to \phi B$

$\to$ most elementary blobs calculated except 5-pt fct

$\to$ on the way to a gauge and chiral invariant analysis of kaon, eta photo/electroproduction off the nucleon

$\to$ still lots of hurdles to take

EX. 4: ISOSPIN VIOLATION & STRANGE FFs

Kubis, Lewis, Phys. Rev. C **74** (2006) 015204

– Z-coupling to the proton

$$G_{E,M}^{p,Z} = (1 - 4\sin^2\theta_W)G_{E,M}^{p} - G_{E,M}^{n} - G_{E,M}^{s} - G_{E,M}^{u,d}$$

– Isospin violation can mock up strangeness

→ calculation of isopin violation in em ffs mandatory

– complete one-loop calculation using IR

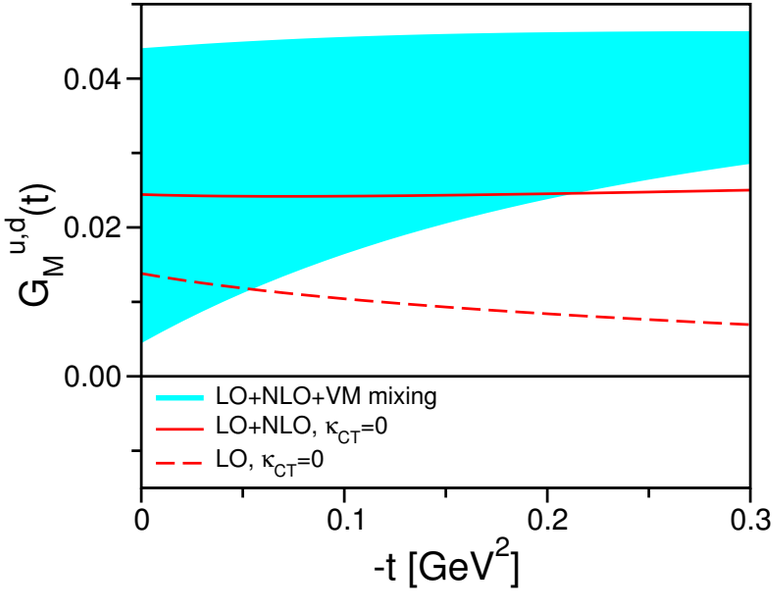
→ all isospin br. in loops $\sim m_n - m_p$

→ counter terms estimated using resonance exchange

a) $\rho - \omega$ mixing & b) ρ, ω tensor/vector couplings

a) Kucukarslan, M., Mod. Phys. Lett. A **21** (2006) 1423

b) Belushkin, Hammer, M., hep-ph/0608337 → project C.2



⇒ Effect on central values of SAMPLE, A4, HAPPEX: 5-14%, 5-14%, 13-30%

⇒ must be included in future high precision determinations of the strange ffs

EX. 5: ϕ-MESON PHOTOPRODUCTION from NUCLEI

Sibirtsev, Hammer, M., Thomas, Eur. Phys. J. A **29** (2006) 209

- SPRING-8 data on incoherent ϕ-meson photoproduction show anomalous A-dependence

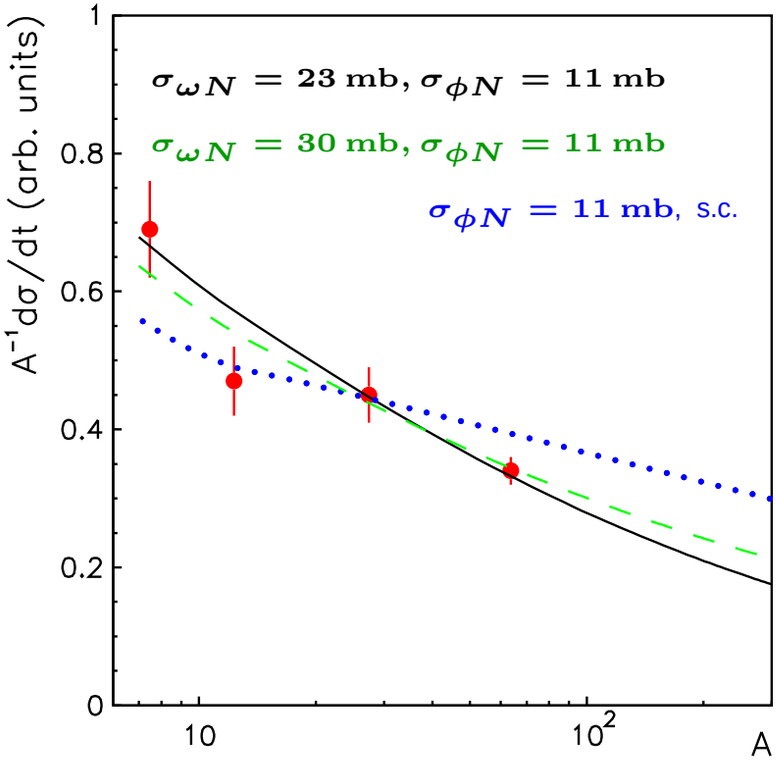
$$\sigma \sim A^{\alpha},\ \alpha = 0.72 \pm 0.07,\ \sigma_{\phi N} = 35^{+17}_{-11}\ \mathrm{mb}$$

Ishikawa et al., Phys. Lett. B **608** (2005) 215

- Analysis of coherent and incoherent production in single & coupled channel(s) VMD opt. pot. models

$\longrightarrow$ coherent photoproduction well described by s.c. model with $\sigma_{\phi N} \simeq 10\ \mathrm{mb}$

$\longrightarrow$ incoherent photoproduction best described by c.c. model with $\gamma N \to \omega N \to \phi N$ ($\omega - \phi$ mixing) and $\gamma N \to \pi N \to \phi N$ transitions using $\sigma_{\omega N} = 23\ \mathrm{mb}$ and $\sigma_{\phi N} = 11\ \mathrm{mb}$



$\Rightarrow$ more precise data on incoherent photoprod. (t-dep.) are called for

AND MUCH MORE ...

- Three-nucleon forces to N^{3}LO
  - five different topologies, very messy, but: *no new* parameters → fig.
  - two subclasses $\sim g_A^6$ completed, interesting structures Bernard, Epelbaum, M., in prep.
- Four-nucleon forces to N^{3}LO
  - completely worked out, *no* free parameters Epelbaum, Phys. Lett. B **639** (2006) 456
  - small attractive contribution to ^{4}He B.E. Rozpedzik et al., nucl-th/0606017
- Chiral EFT hyperon-nucleon potential at LO
  - good description of all data, bound hypertriton

  Polinder, M., Haidenbauer, Nucl. Phys. A **779** (2006) 244
- Study of the infrared renormalization group limit cycle in QCD

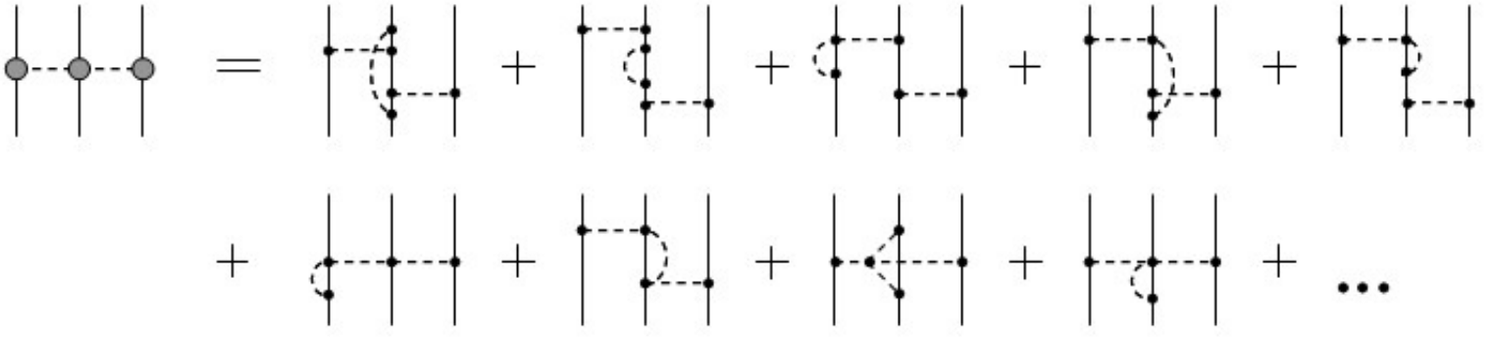
  Epelbaum, Hammer, M., Nogga, Eur. Phys. J. **C 48** (2006) 169
- Weinberg power counting rectified, LO studies Epelbaum, M., nucl-th/0609037

$\Rightarrow$ important developments for the theory of meson production off light nuclei

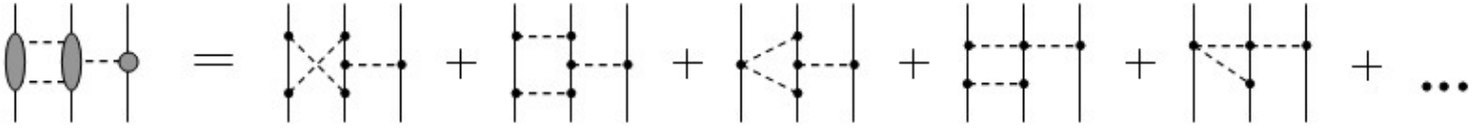
3N INTERACTION to N^{3}LO: STRUCTURE

Bernard, Epelbaum, M., work in progress

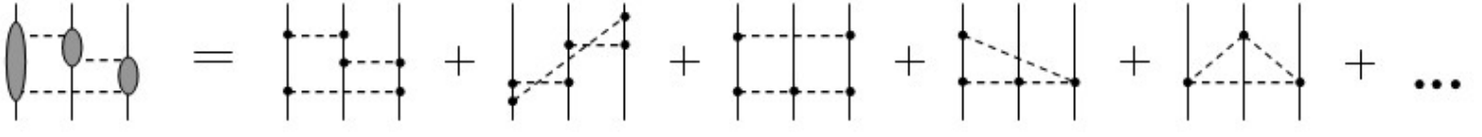
- 2π



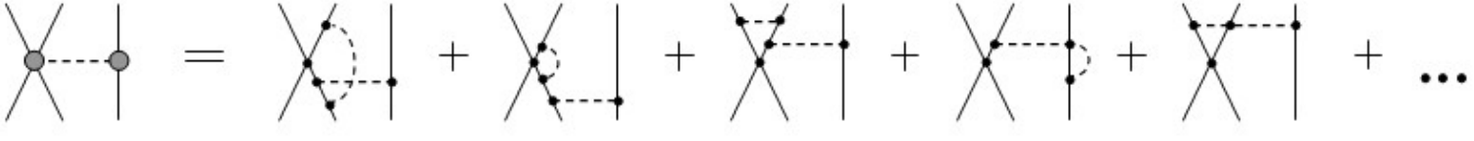
- 2π-1π



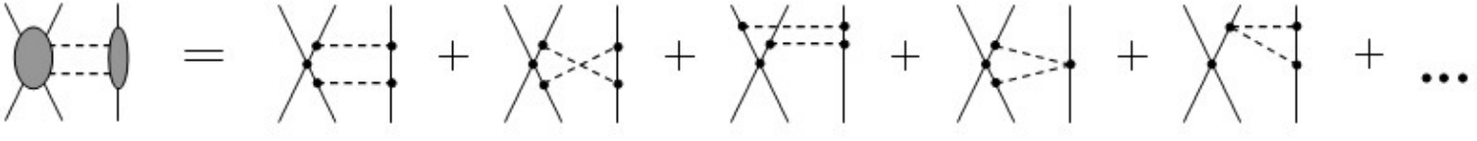
- 2π-$2N$



- 1π-contact



- 2π-contact



SUMMARY & OUTLOOK

- B3: Meson production off nucleons and light nuclei
  - precision calculations in SU(2) chiral dynamics (matching)
  - gauge invariant formulation of chiral coupled channel dynamcis
  - systematic investigation of em & hadronic processes w/ π, K, η, η'
  - systematic development of chiral nuclear effective field theory

$\Rightarrow$ **Progress in chiral dynamics with light quarks**

$\oplus$ **QCD and nuclear physics**

Outlook for the next funding period:

- Chiral dynamics w/ strange quarks remains a central topic of the th'y acivities
- Chiral nuclear EFT important for n properties $\rightarrow$ new project

(Epelbaum, Hammer)

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plus numerous plenary & invited talks, conference proceedings etc.