Meson-baryon Scattering with Extended-on-mass-shell Scheme at $O(p^3)$

Junxu LU

29 May 2018, IPN-Orsay

Cooperator: XiuLei Ren, Lisheng Geng, Menglin Du, Ulf-G. Meissner

My research and its significant

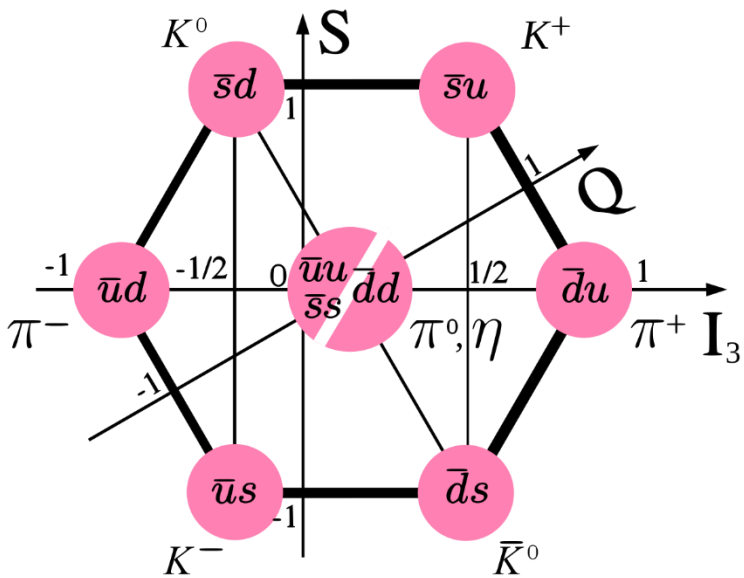
Framework

Results

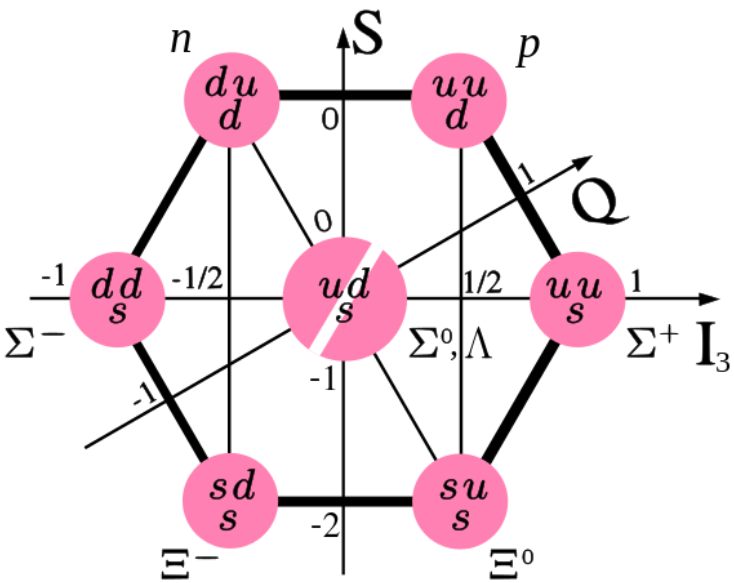
Meson-Baryon scattering

Characterized by

- Charge Q
- Strangeness S
- Third component of isospin I_3



Meson Octet



Baryon Octet

From wikipedia

Meson-Baryon scattering

Basic motivation: description of experimental data

- WI08 and SP92 solution for πN and KN scattering phase shifts

  R. L. Workman et al., Phys. Rev.C86, 035202 (2012).

  W. J. Briscoe et al., SAID on-line program, see http://gwdac.phys.gwu.edu.

- Cross section of $\overline{K}N$ channel

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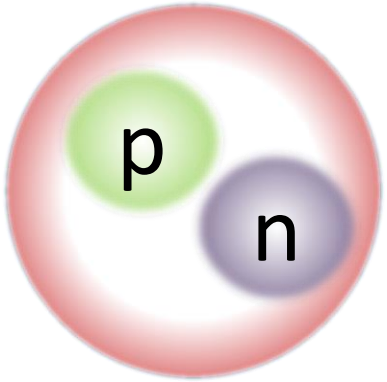
Phenomena related with Meson-baryon scattering

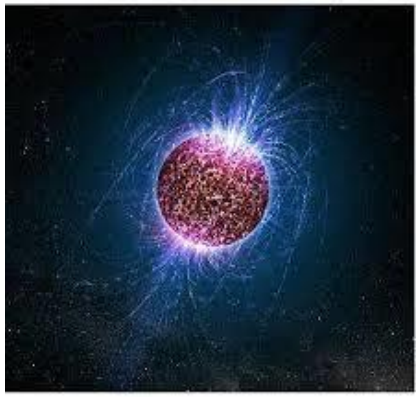
- Baryon-baryon interaction
  - Nuclear force or hyper-nuclear physics



Deuterium

A bound H-dibaryon?

Inoue PRL 106 (2011) 162002



Neutron star

Lonardoni PRL 114 (2015) 092301

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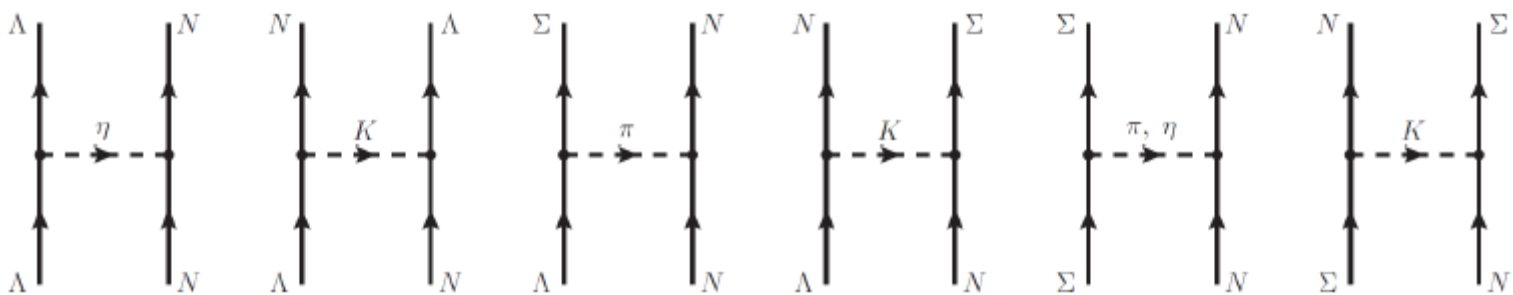

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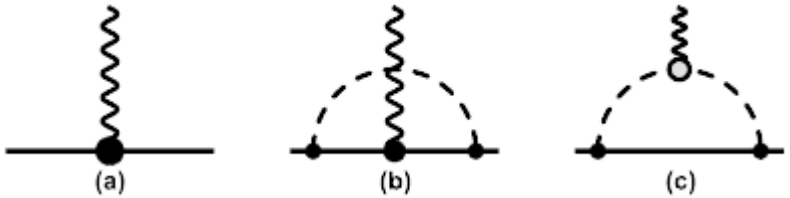
Phenomena related with Meson-baryon scattering

- Baryon-baryon interaction
  - Nuclear force or hyper-nuclear physics
- Intrinsic properties of baryons
  - Baryon magnetic moments

$$\mu_p = 2.793\mu_N$$

$$\mu_n = -1.913\mu_N$$

Anomalous magnetic moment of baryons



Related Feynman diagrams

Meson-Baryon scattering

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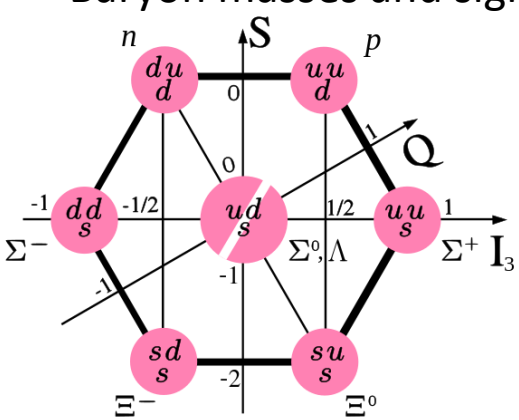
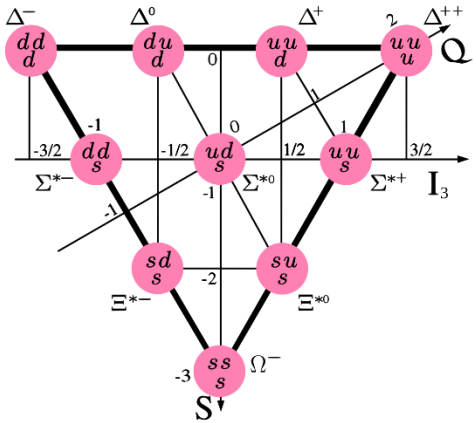
Phenomena related with Meson-baryon scattering

- Baryon-baryon interaction
  - Nuclear force or hyper-nuclear physics
- Intrinsic properties of baryons
  - Baryon magnetic moments
  - Baryon masses and sigma terms





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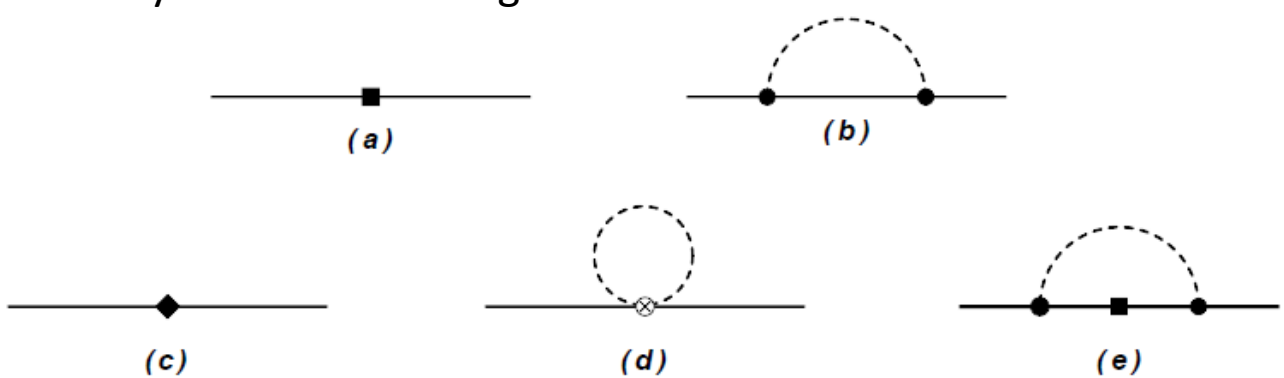

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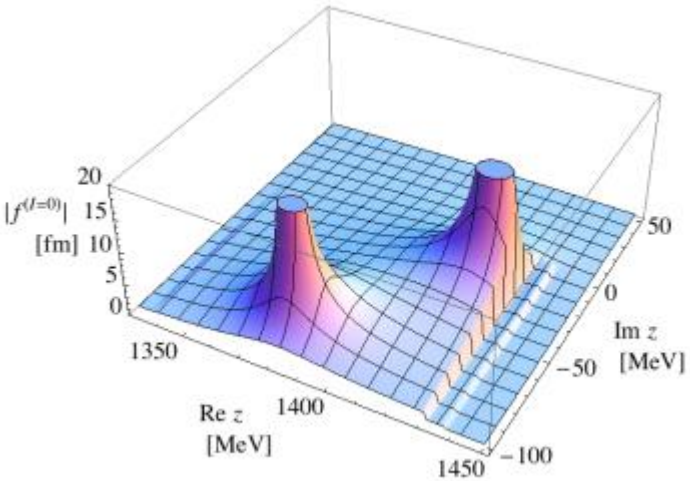
Phenomena related with Meson-baryon scattering

- Baryon-baryon interaction
  - Nuclear force or hyper-nuclear physics
- Intrinsic properties of baryons
  - Baryon magnetic moments
  - Baryon masses and sigma terms
- Meson-baryon molecules
  - The double-pole structure of $\Lambda(1405)$ in $\bar{K}N$ and its coupled channel



Meson-Baryon scattering

SCATTERING ----- INTERACTION

- Strong interaction ----- Quantum chromodynamics (QCD)

Asymptotic freedom of QCD:

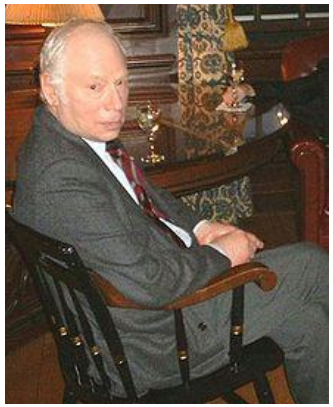
- The transfer momentum is too low to perform a perturbation solution
- Substitute -------- Effective field theory (EFT)

Weinberg's Chiral EFT

Advantages

- Systemically improve the description
- Estimate theoretical uncertainties
- Consistent with three or more body interaction

First proposed by Steven Weinberg



Chiral EFT

- Hadrons as degrees of freedom
  - Mesons or baryons instead of quarks and gluons
- Powering counting rules

$$D = 4L + \sum_n n\, V_n - 2N_M - N_B$$

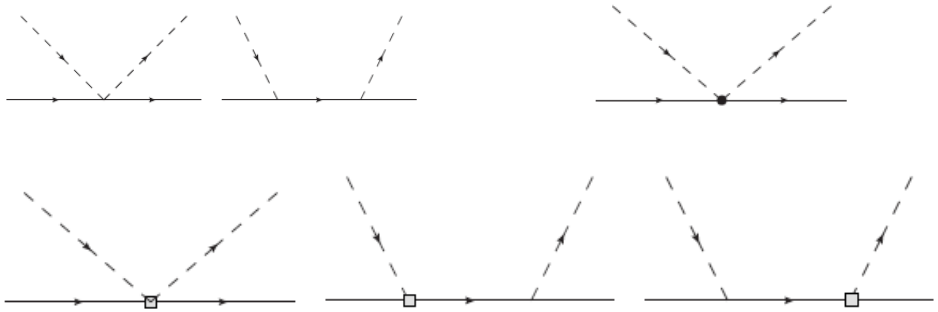
- D: chiral order of certain diagram
- L: number of loops
- V_n: number of n-th order vertices
- N_M: number of meson propagators
- N_B: number of baryon propagators

$$\mathcal{L}_{EFT} = \mathcal{L}_{MB}^{(1)} + \mathcal{L}_{MB}^{(2)} + \mathcal{L}_{MB}^{(3)} + \cdots + \mathcal{L}_{MM}^{(2)} + \cdots$$

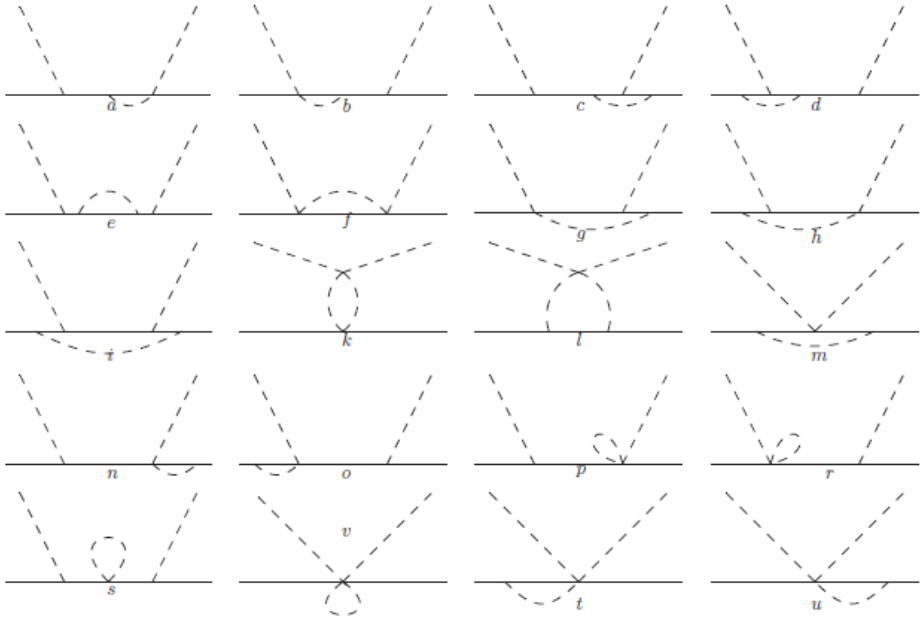
where the superscripts denote the chiral order

Diagrams

- Tree level



- Loop level



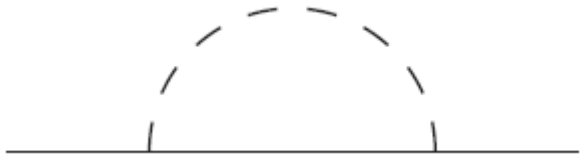
renormalization

Rewrite the bare values of C, m_B, f in lagrangians with their physical values

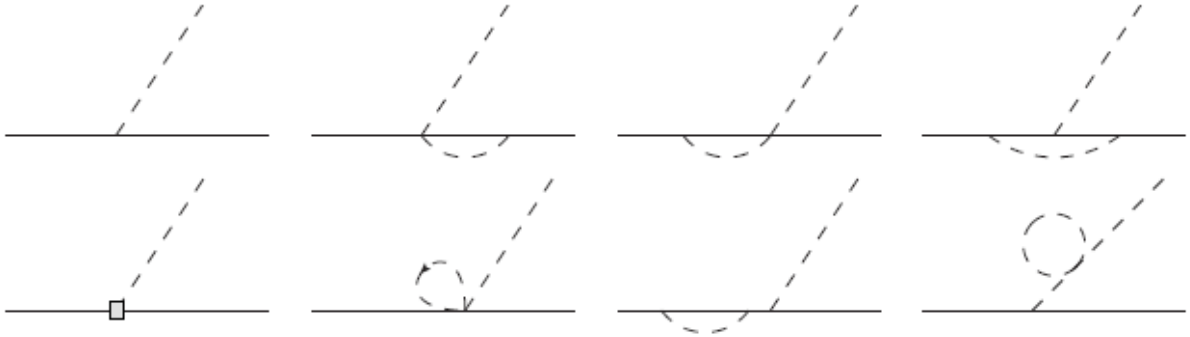
- C :coupling constants
- m_B:baryon masses
- f :decay constants

- m_B:baryon masses

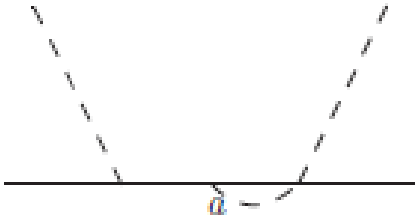
$$m_{ph} = m_{bare} + \Sigma_{O(p^2)} + \Sigma_{O(p^3)}$$



- C :coupling constants $C_{ph}\gamma^5 \not{q}_f = C_{bare}\gamma^5 \not{q}_f + C_{ph}\gamma^5 \not{q}_f Z + C_{ph}\gamma^5 \mathcal{A}_{loop}(s) + C_{ph}\gamma^5 \not{q}_f \Delta_F$



Power counting breaking(PCB) terms

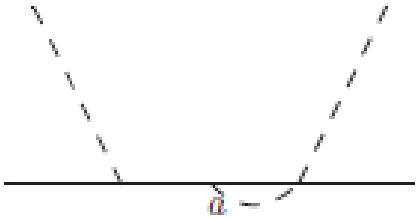


Power counting rules

$$D = 4L + \sum_n n\, V_n - 2N_M - N_B = 3$$

Expected: $A_{loop} = \mathcal{O}(p^3) + \mathcal{O}(p^4) + \cdots$

Power counting breaking(PCB) terms



Power counting rules

$$D = 4L + \sum_n n\, V_n - 2N_M - N_B = 3$$

Expected: $A_{loop} = \mathcal{O}(p^3) + \mathcal{O}(p^4) + \cdots$

Realistic: $A_{loop} = \mathcal{O}(p^0) + \mathcal{O}(p^3) + \cdots$

PCB

Extended-on-mass-shell scheme

Proposed by T. Fuchs et al. in Phys.Rev.D**68**,056005(2003)

- Absorb PCB terms with contact terms

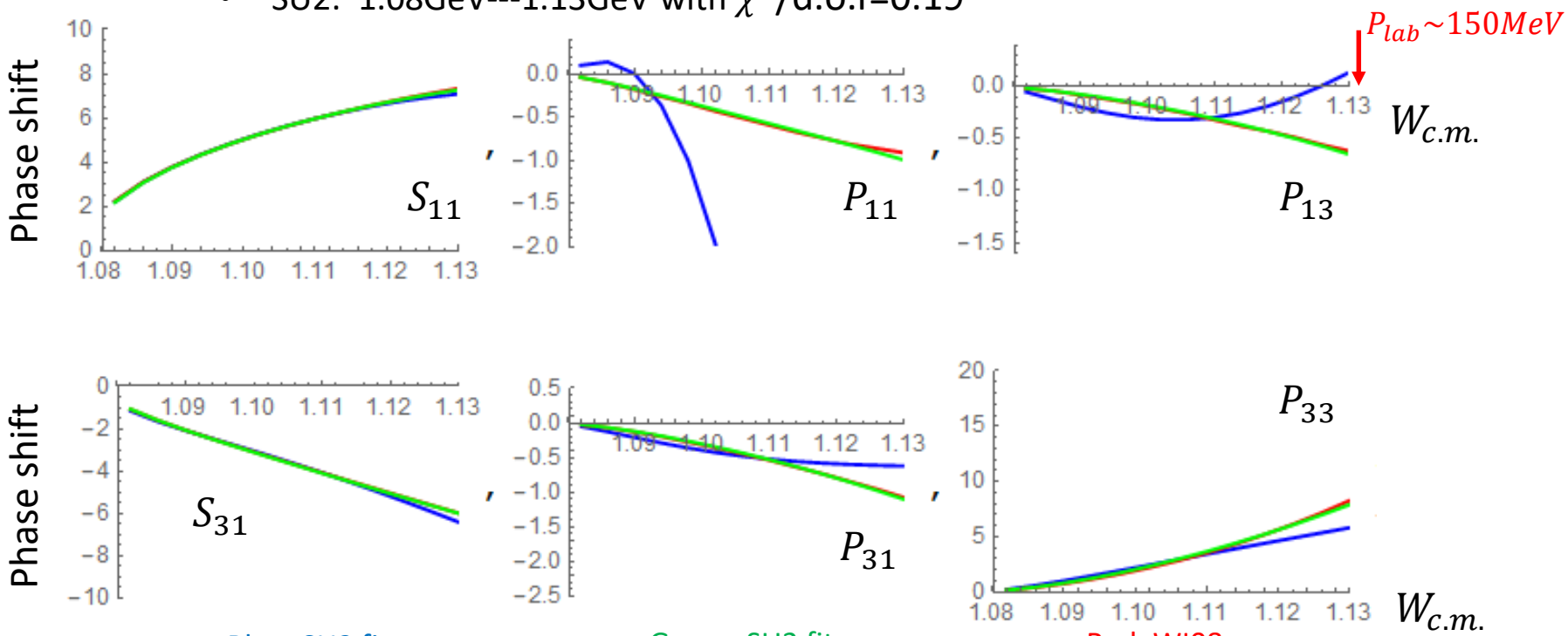
Perform the renormalization in two steps:

- Firstly, traditional $\overline{MS} - 1$ subtraction to cancel UV divergencies
- Second, EOMS subtraction to remove the PCB terms

Preliminary Results

πN phase shifts in S_{11}, P_{11}, P_{13}, S_{31}, P_{31}, P_{33} partial waves $\boxed{L_{2I,2J}}$

- Error bar: $err(\delta) = \sqrt{e_s^2 + e_r^2 \delta^2}$ e_s=0.1°:systematic error e_s=2%:relative error
- Fitting strategy
  - SU3: 1.08GeV---1.116GeV, except P_{11} 1.08GeV---1.096GeV with χ^2/d.o.f=1.9
  - SU2: 1.08GeV---1.13GeV with χ^2/d.o.f=0.19



- Blue: SU3 fit
- Green: SU2 fit
- Red: WI08

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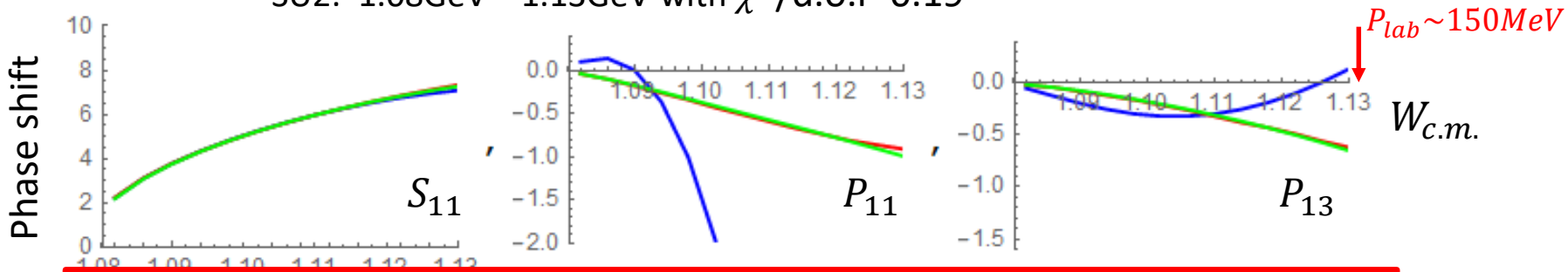
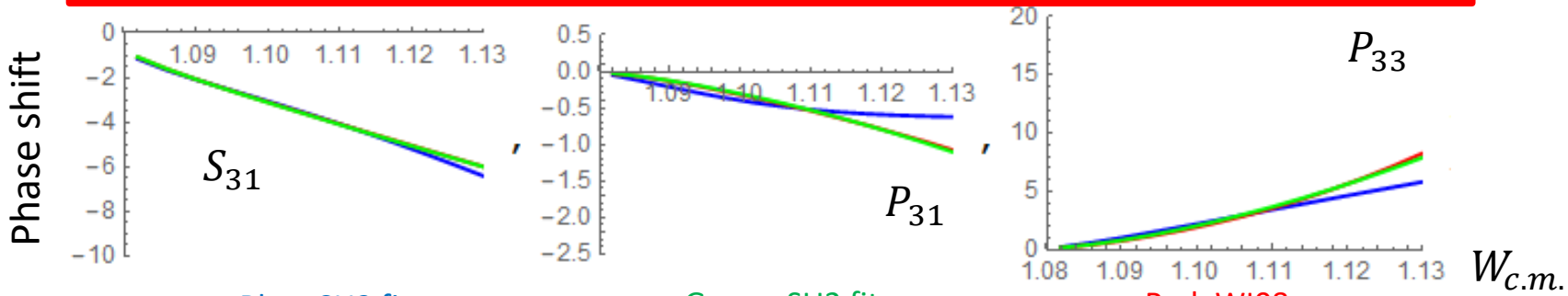


The fitting strategy needs improvement!!!



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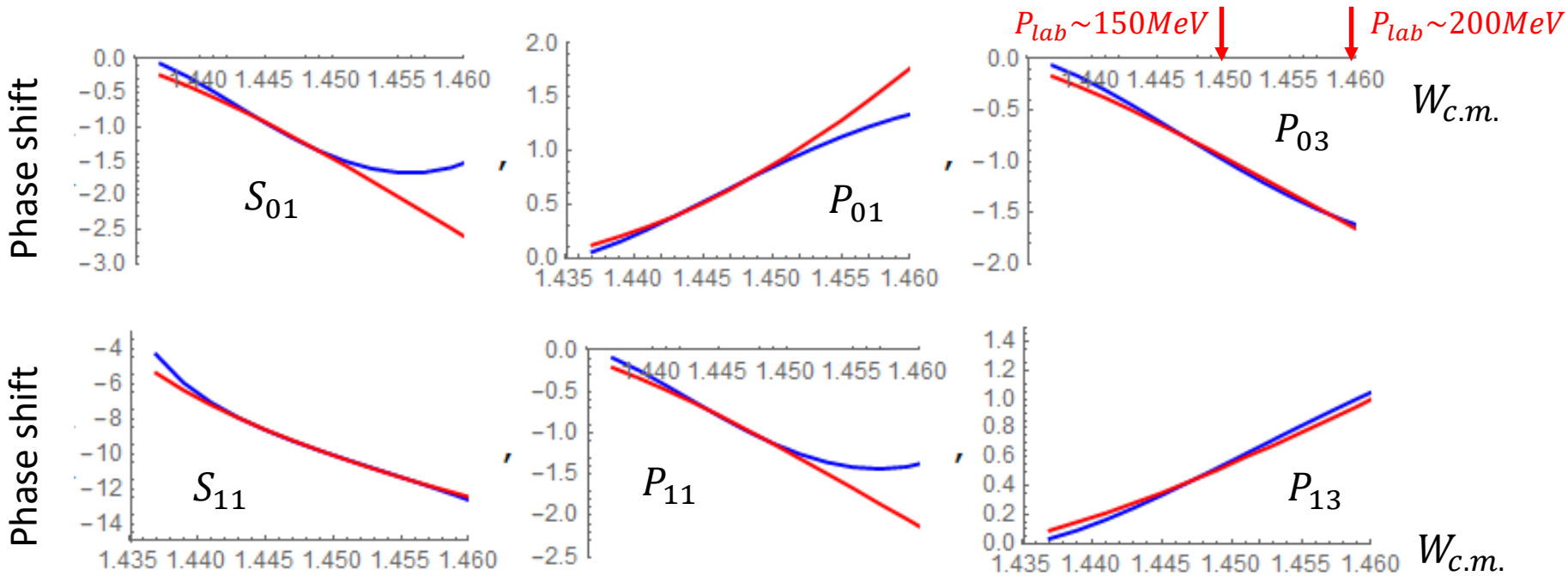
Preliminary Results

KN phase shifts in S_{01}, P_{01}, P_{03}, S_{11}, P_{11}, P_{13} partial waves $\boxed{L_{I,2J}}$

- Error bar: $err(\delta) = \sqrt{e_s^2 + e_r^2\delta^2}$ e_s=0.1°:systematic error e_s=2%:relative error
- Fitting strategy
  - SU3: 1.443GeV---1.450GeV with χ^2/d.o.f=0.45 for I=0,and with χ^2/d.o.f=0.23 for I=1



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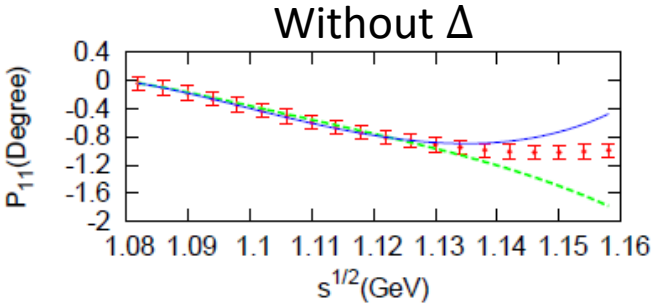
For now

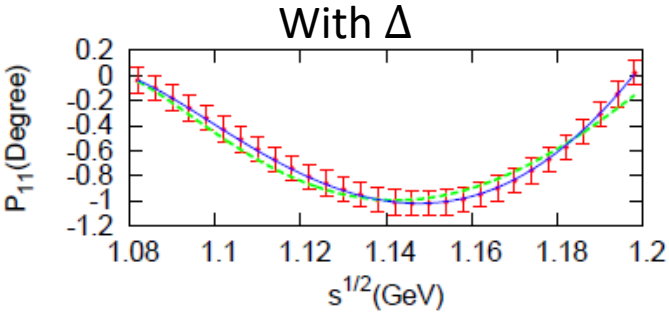
- We have performed the calculation of Meson-baryon scattering with Extended-on-mass-shell scheme
- We have obtained a group of LECs by fitting the partial wave phase shifts of πN and KN channels

Improvement

- Fitting strategies: enlarge the energy range
- Extra constraints from $\bar{K}N$ channel and the resonance of $\Lambda(1405)$
- Include the contribution from baryon decuplet $(\Delta, \Xi^*, \Sigma^*, \Omega)$

SU2 case



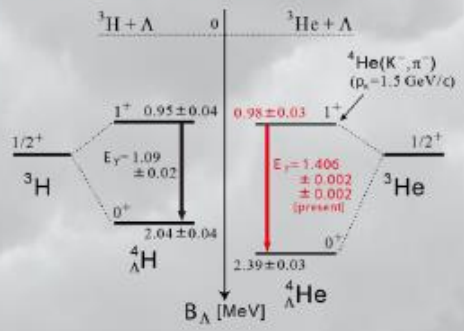


Thank you

Hypernuclear physics

- We do not know in the present…

1. **Large CSB in A=4 hypernuclei?**



Yamamoto PRL 115 (2015) 222501...

2. **A bound H-dibaryon?**

Inoue PRL 106 (2011) 162002...

3. **Hyperon puzzle**

Lonardoni PRL 114 (2015) 092301...

4. Why is the Λ-nuclear spin-orbit splitting so small?
5. What is the role of three-body ΛNN interactions in hypernuclei and at neutron-star densities?
6. The Σ-nuclear interaction is established as being repulsive, but how repulsive?
7. Where is the onset of ΛΛ binding?
8. Do Ξ hyperons bind in nuclei and how broad are the single-particle levels given the ΞN → ΛΛ strong decay channel?
9. Where is the onset of Ξ stability?

…

Gal RMP 88 (2016) 035004