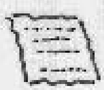
DEUTERON COMPTON SCATTERING IN EFFECTIVE FIELD THEORY

- INTRODUCTION / MOTIVATION

- EFT $\not{\pi}$ (M.J. SAVAGE, S.B., '00)
  (GRIEẞHAMMER, RUPAK, '00)



- EFT π

  (MALHEIRO, PHILIPS, van KOLCK, S.B., '99)

- CONCLUSION

Silas Beane (U of Washington) HALIFAX 8/01

Low γ

Why do we need an expansion parameter(s) for Nuclear Physics?

- Power-counting scheme to control errors

  IS WHAT IS LEFT OUT SMALL?

- Nuclear properties <=> Nucleon properties

  CAN WE RIGOROUSLY RELATE 2-BODY AND 3-BODY?

- Hierarchy of n-body forces

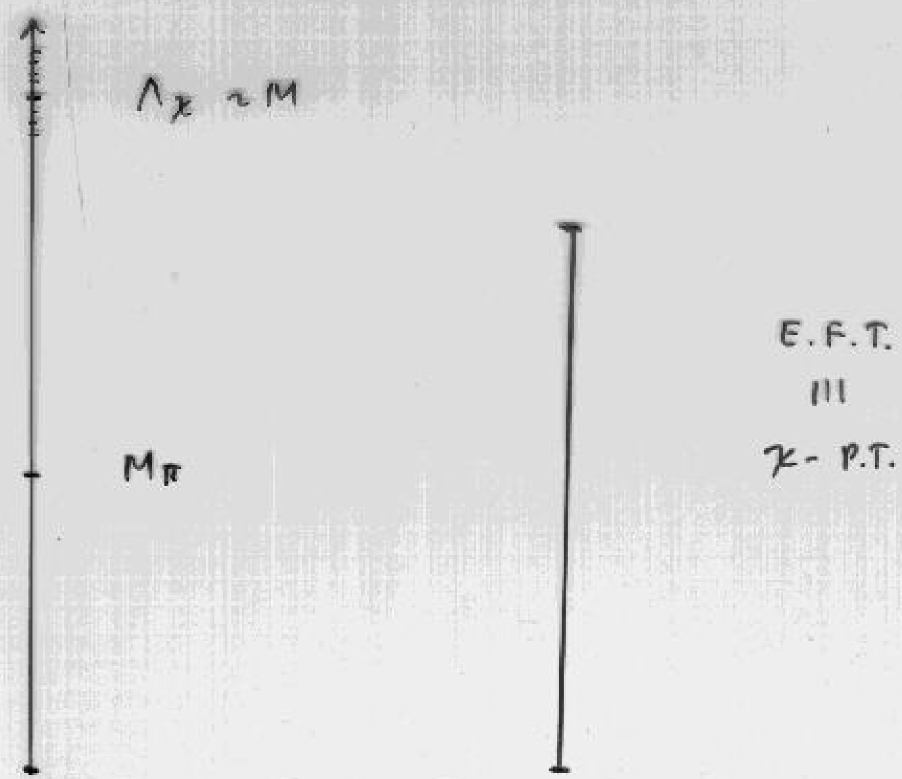
  $F_2 < F_3 < F_4 \ldots < F_n$?

- Nuclear physics <=> Lattice Q.C.D.

  M_q DEPENDENCE ?

How do small parameters arise?

$A = 1 \quad + \pi\text{'s} \quad + \gamma\text{'s}$

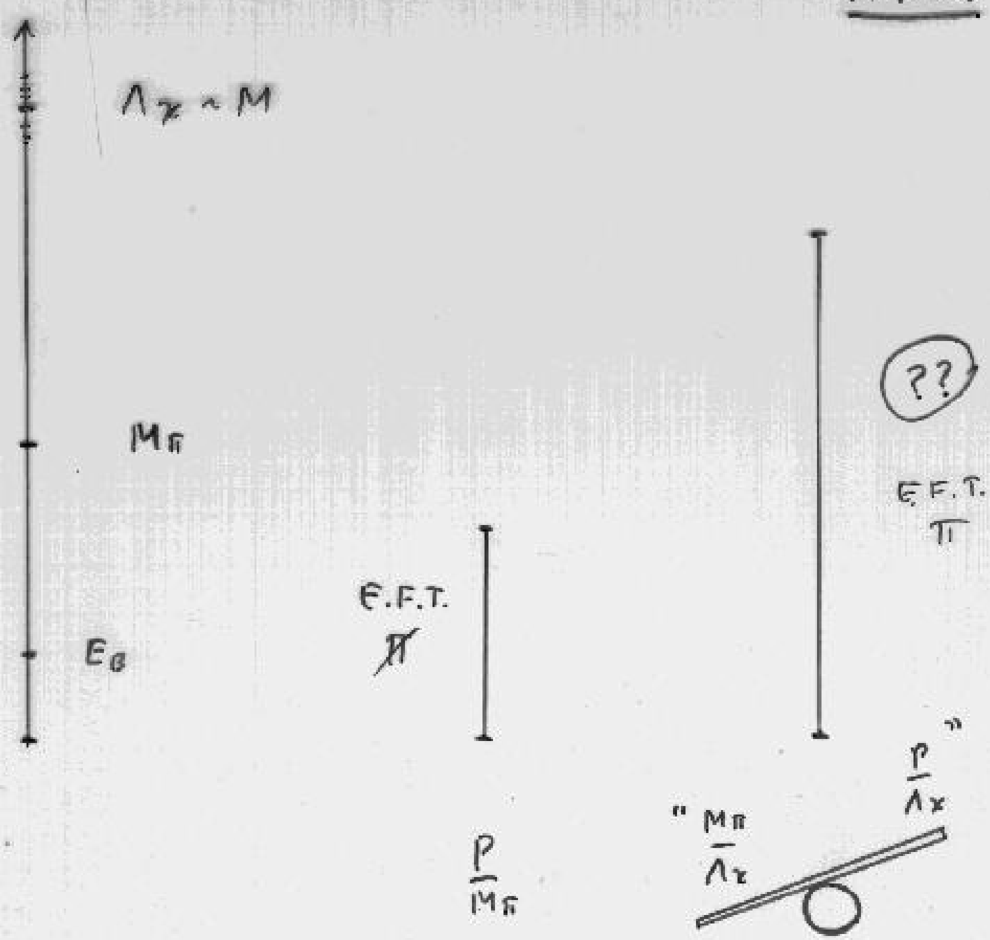


$$\frac{p}{\Lambda_\chi}, \quad \frac{M_\pi}{\Lambda_\chi}$$

Joint Perturbative expansion
in p and M_π.

THIS IS TRIVIAL !!

$\underline{A \geq 2 \quad + \pi\text{'s} \quad + \gamma\text{'s}}$ $\equiv$ **NUCLEAR PHYSICS**



At least **1** operator in the E.F.T must be treated nonperturbatively to generate E_B !!

OPERATORS ?

MOST GENERAL STRUCTURE CONSISTENT WITH

QCD

$$\mathcal{L}_{eff} = N^\dagger [i\partial_t + \frac{\vec{\nabla}^2}{2m}] N - \frac{1}{2}[C_0^S (N^\dagger N)^2 + C_0^T (N^\dagger \vec{\sigma} N)^2]$$

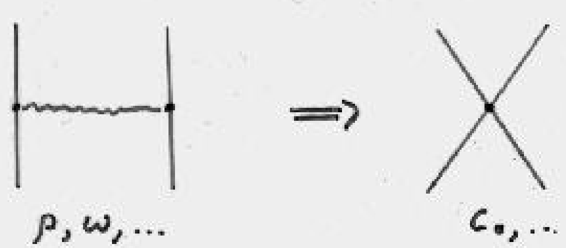
$$+ \frac{F_\pi^2}{4} \, tr(\partial_\mu \Sigma^\dagger \partial_\mu \Sigma) + \omega \frac{F_\pi^2}{2} \, tr(M_q (\Sigma^\dagger + \Sigma))$$

$$+ g_A N^\dagger \vec{A} \cdot \vec{\sigma} N + \ldots$$

INFINITE # OF OPERATORS.

DIFFICULT TO ORGANIZE !!

NOTE :



(EPELBAUM, '01)

NN SCATTERING

FERMI THEORY!

EFT π̸

dEFT π̸

EXAMPLE: **E.F.T. $\not\pi$**

$$\mathcal{L}_{EFF} = C_0 (N^+N)^2 + C_2 (N^+\overleftrightarrow{\nabla} N)^2 + C_4 (N^+\overleftrightarrow{\nabla}^2 N)^2 + \ldots$$

$$A(p) = -\frac{4\pi}{M}\left(\frac{1}{a} - \frac{1}{2} r p^2 - v p^4 + \ldots + ip\right)^{-1}$$

E.R.T.

no E_B

$a, r, \ldots \sim \frac{1}{\Lambda}$ $= -\frac{4\pi}{M} a \left(1 - iap + \left(\frac{ar}{2} - a^2\right) p^2 + \ldots\right)$

$a \gg \frac{1}{\Lambda}$ $= -\frac{4\pi}{M}\left(\frac{1}{a} + ip\right)^{-1}\left(1 + \frac{r/2\, p^2}{(1/a + ip)} + \ldots\right)$

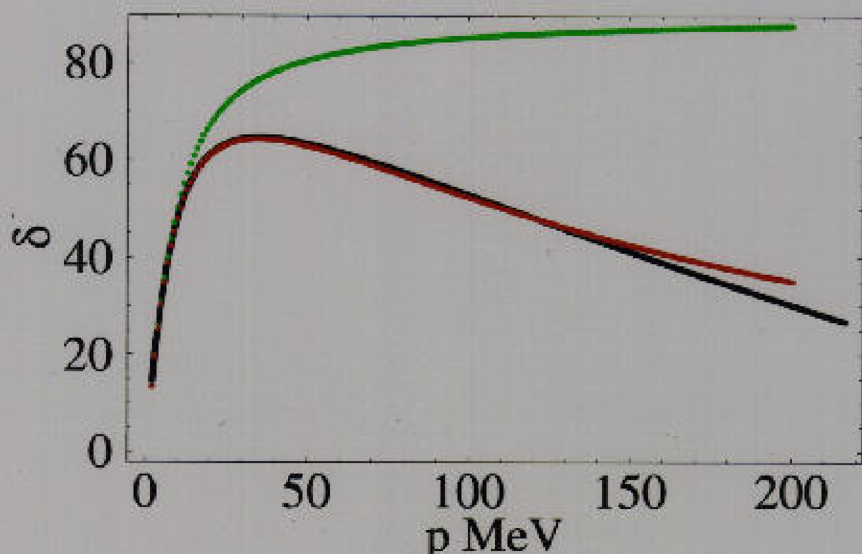
$a, r \gg \frac{1}{\Lambda}$ $= -\frac{4\pi}{M}\left(\frac{1}{a} - \frac{1}{2} r p^2 + ip\right)^{-1}\left(1 + \frac{v p^4}{(1/a - \frac{1}{2} r p^2 + ip)} + \ldots\right)$

$^1S_0$ CHANNEL

$$\frac{1}{\Lambda} \sim \frac{1}{M_\pi} = 1.4 \text{ fm}$$

$$a^{^1S_0} = -23.7 \text{ fm} \quad \gg \quad \frac{1}{\Lambda}$$

$$r^{^1S_0} = 2.73 \text{ fm} \quad > \quad \frac{1}{\Lambda}$$

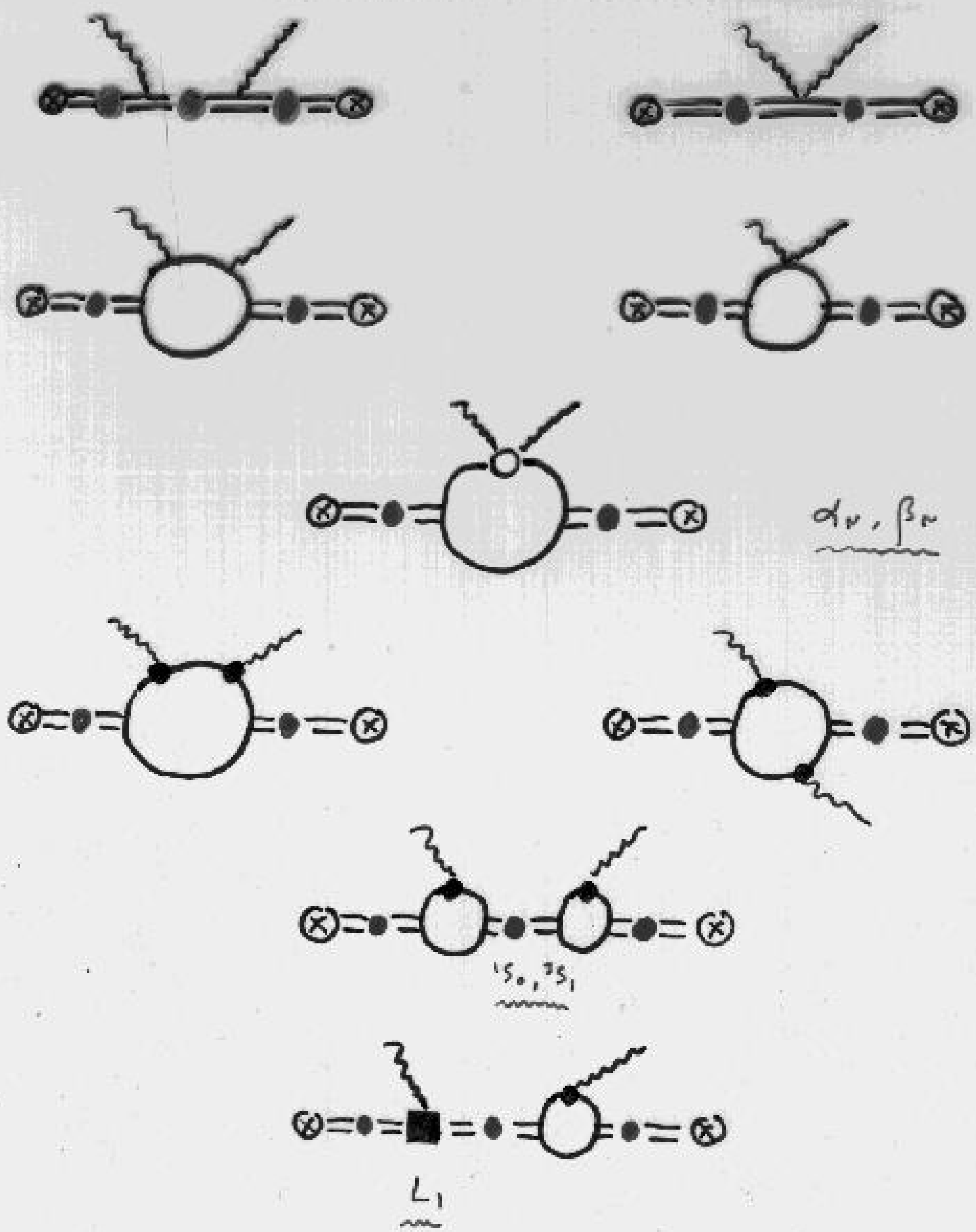


$a \gg 1/\Lambda$ (E.F.T $\not\pi$)

$a, r \gg 1/\Lambda$ (d E.F.T $\not\pi$)

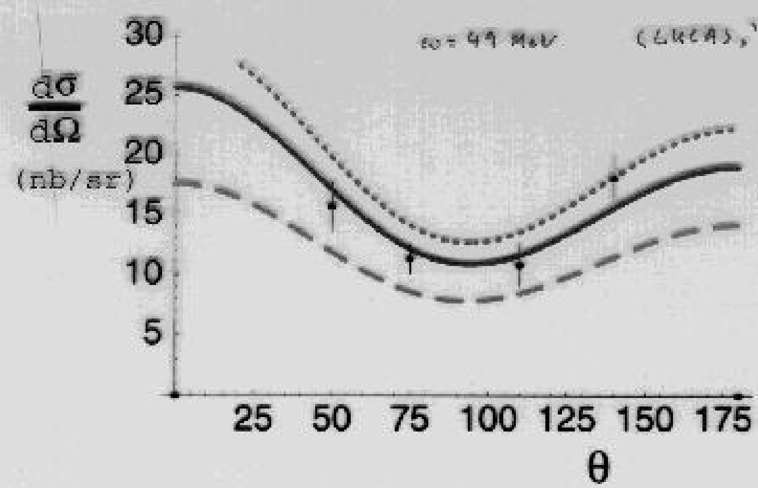
(SAVAGE, S.B., '00)

$\gamma d \to \gamma d$ dEFT$^{\not\pi}$



$+ \ldots$

$\gamma d \to \gamma d$ ($\not\pi$)



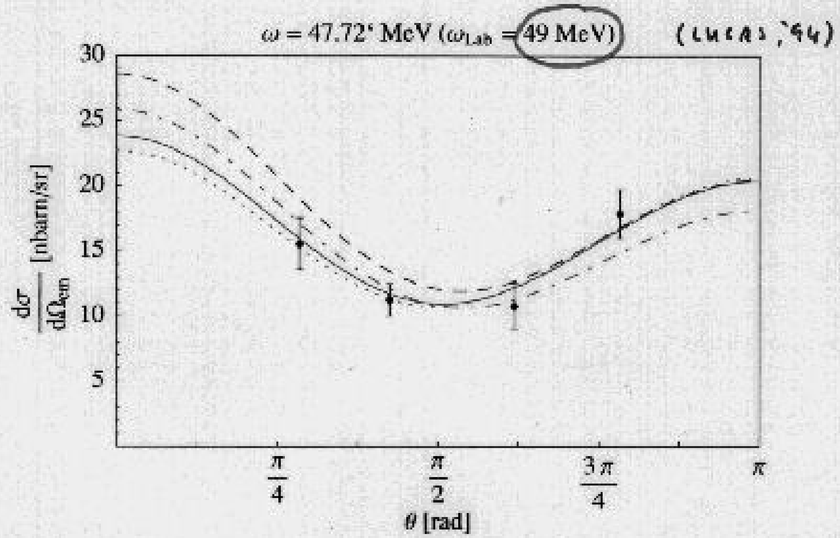
dEFT $\not\pi$

(S.R., SAVAGE '00)

······ $\alpha_N = \beta_N = 0$

—— α_N, β_N 1L LOOP χ-PT

– – – $r^{(^1S_0)} = r^{(^3S_1)} = 0$



EFT $\not\pi$

(Grießhammer, Rupak '00)

······ α_N, β_N FIT

– – – $\alpha_N = \beta_N = 0$

–·–· $\beta_N = 0$

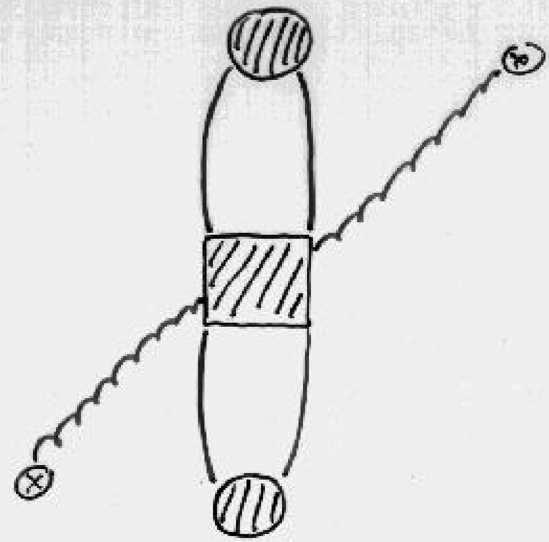
$\alpha_N \sim 5(2)$ $\beta_N \sim 16(12)$

THE PIONFUL THEORY ($\overset{\text{E.F.T.}}{\pi}$)

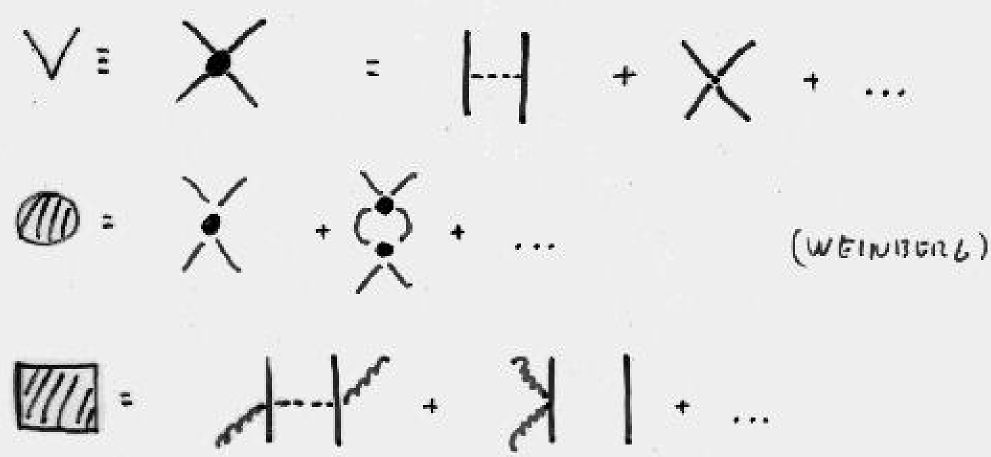
$p \ll \Lambda_\chi$

$Q \sim \frac{p}{\Lambda_\chi}, \frac{m_\pi}{\Lambda_\chi}$

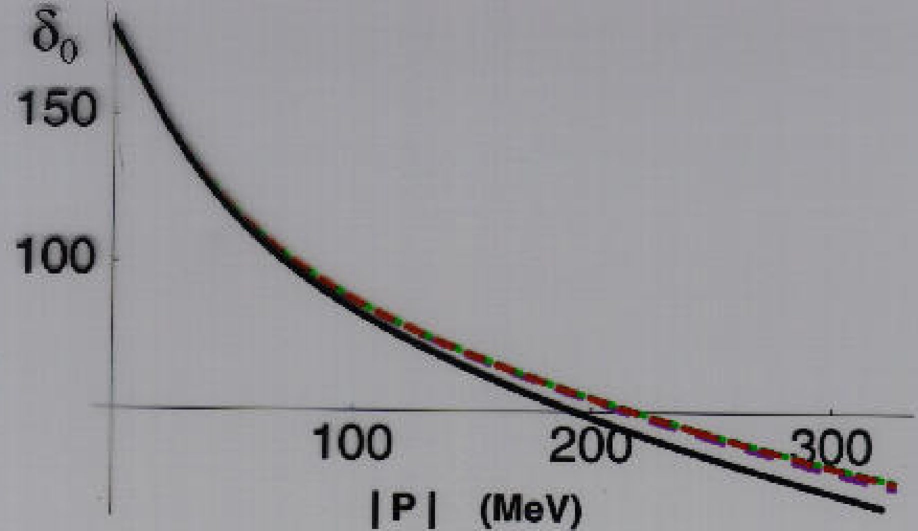
N's, π's and γ's



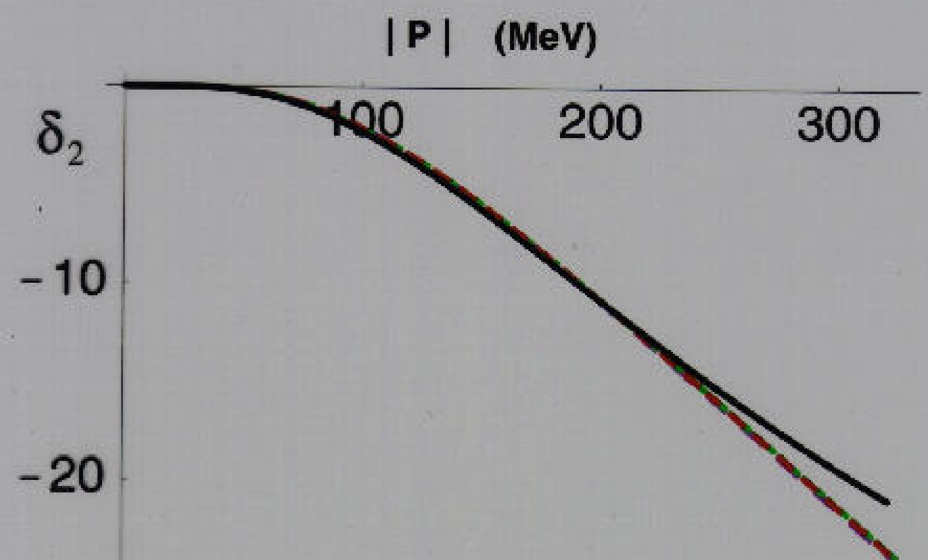
V and ▨ from χ-PT



np $^3S_1 - {}^3D_1$ PHASE SHIFTS LO EFT π

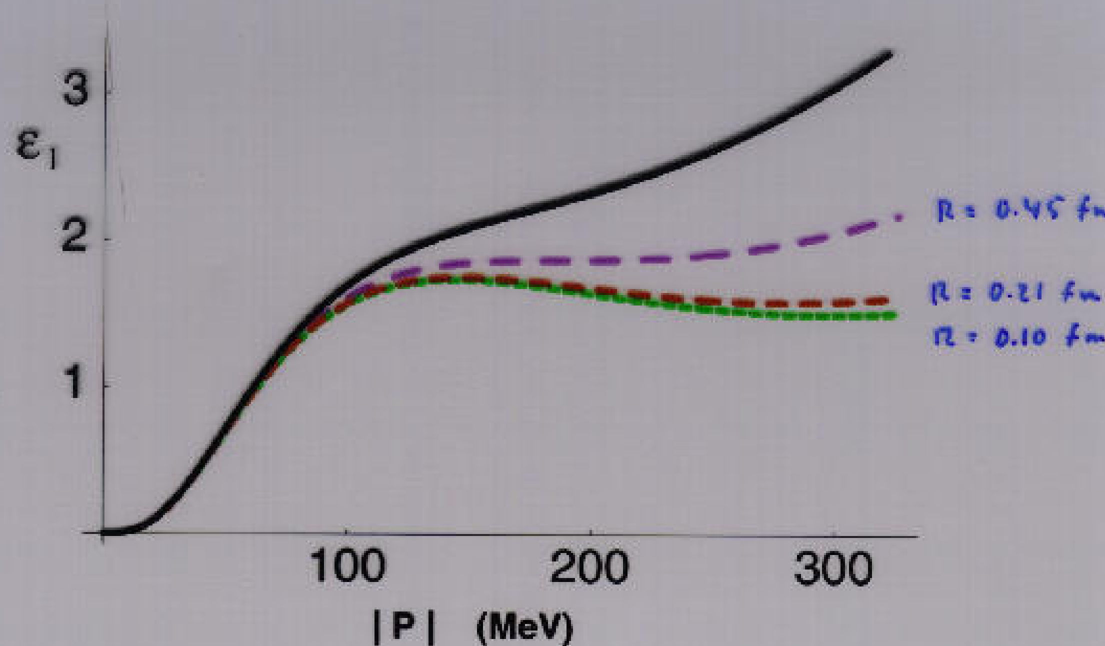


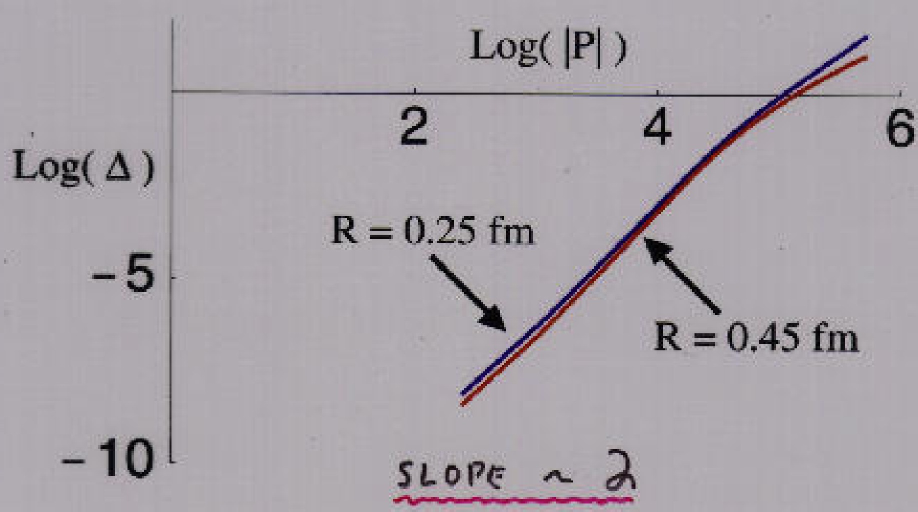
R = 0.45 fm
R = 0.21 fm
R = 0.10 fm



MANIFEST CUTOFF INDEPENDENCE !!

(BEDAQUE, SAVAGE, van KOLCK, S.B., '01)





SLOPE ~ 2

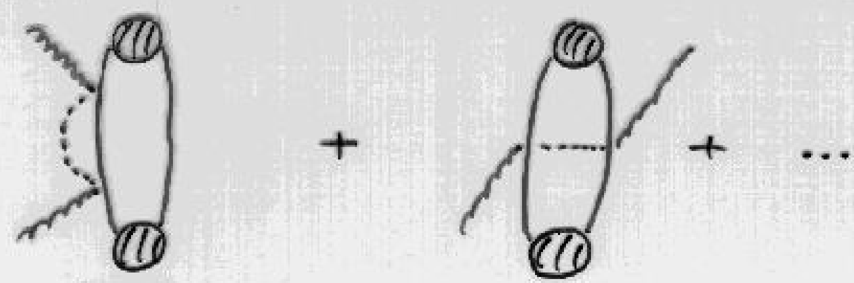
ERROR ~ $\mathcal{O}(p^2)$!!

$\Delta = \delta_R - \delta_{NIJMEGEN}$

$\gamma d \to \gamma d$

Q^2 : THOMPSON

Q^3 : NO FREE PARAMETERS !



$\Downarrow$

	TH.	EXP. (proton)
$\alpha_p = \alpha_n =$	$12.2 \times 10^{-4}\ fm^3$	$12.1 \pm 0.9 \pm 0.5$
$\beta_p = \beta_n =$	$1.2 \times 10^{-4}\ fm^3$	$2.1 \pm 0.8 \pm 0.5$

Q^4 : COUNTERTERMS !

$\Downarrow$

$\delta\alpha_{n,p}$
$\delta\beta_{n,p}$

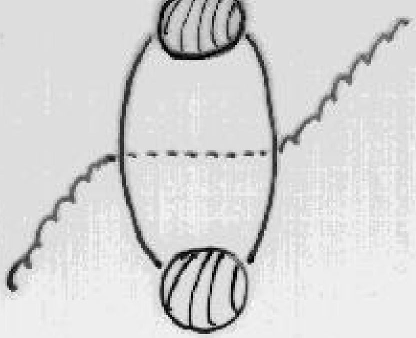
$\delta\alpha_p , \delta\beta_p$

CAN FIT $\delta\alpha_n , \delta\beta_n$ TO

$\gamma d \to \gamma d$

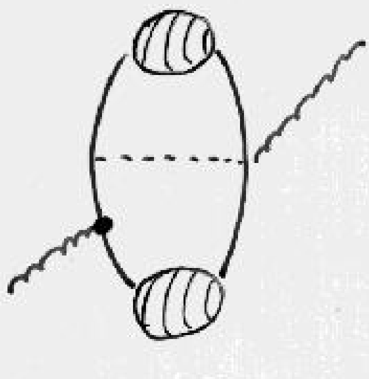
REGION OF VALIDITY ??

$\underline{Q}^3$



$\mathbb{1}$

$\underline{Q}^4$



$\frac{|\vec{p}|^2}{\omega M}$

χ PERTURBATION THEORY : $\omega \gg \frac{|\vec{p}|^2}{M}$

$$\underline{|\vec{p}| \sim M_\pi}$$

$$\underline{\frac{M_\pi^2}{M} \ll \omega \ll \Lambda_\chi}$$

THIS E.F.T. DOES NOT RECOVER

THOMPSON LIMIT.

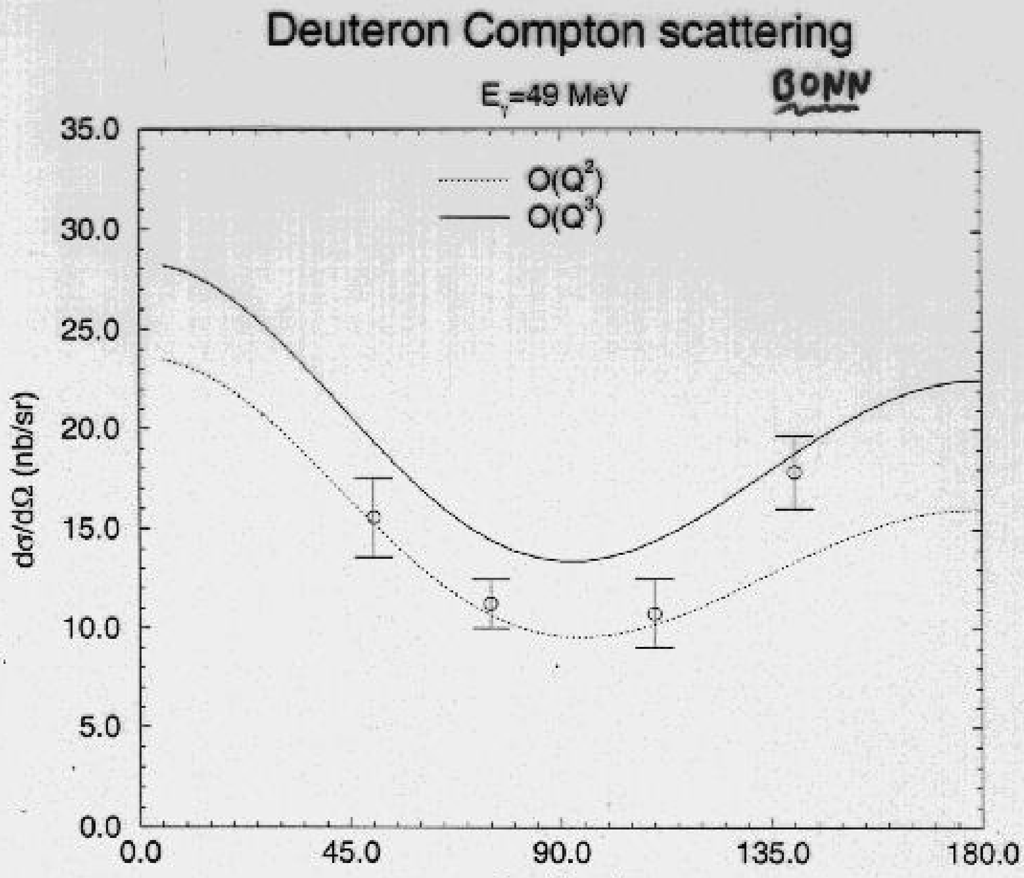
BEGINS TO FAIL AT $\omega \sim 40$ MeV

$$\frac{1}{\omega - B - \frac{\vec{p}^2}{M}} \xrightarrow[\omega \to M_\pi]{} \frac{1}{\omega} + \mathcal{O}\left(\frac{B}{\omega}, \frac{\vec{p}^2}{\omega M}\right)$$

$\Downarrow$

χ - PT propagator !

$E_\gamma = 49\,\mathrm{MeV}$ [Lucas. 94]

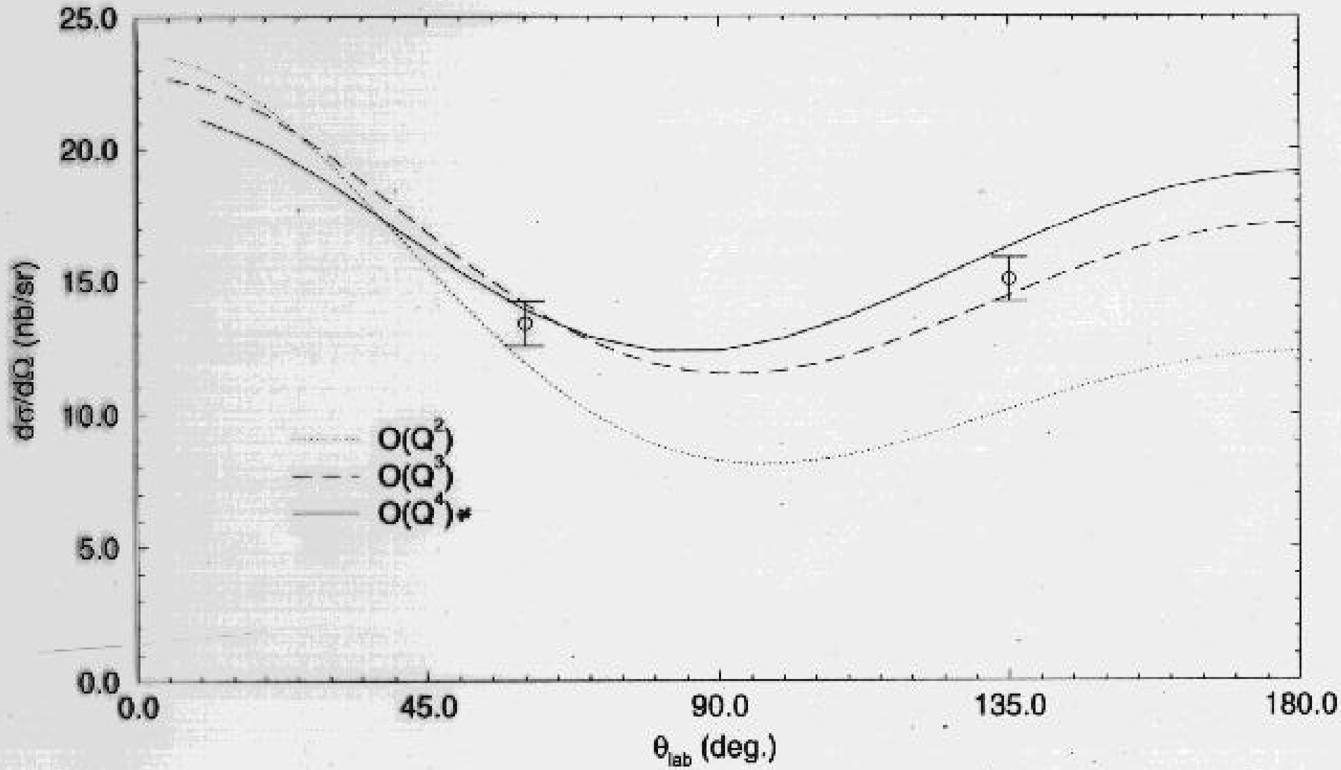


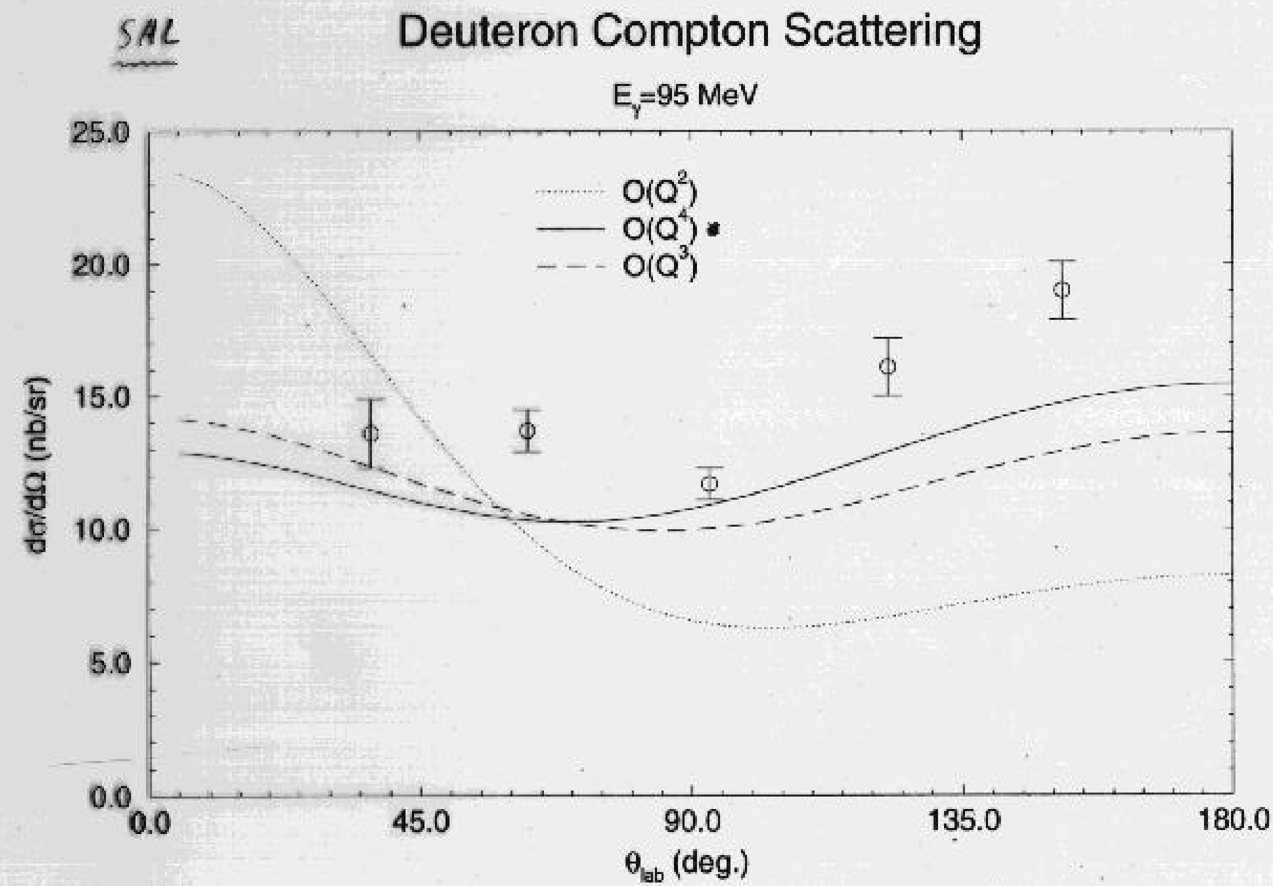
(MALHEIRO, PHILLIPS, van Kolck, S.B.)

(EPELBAUM, GLÖCKLE, MEIßNER)

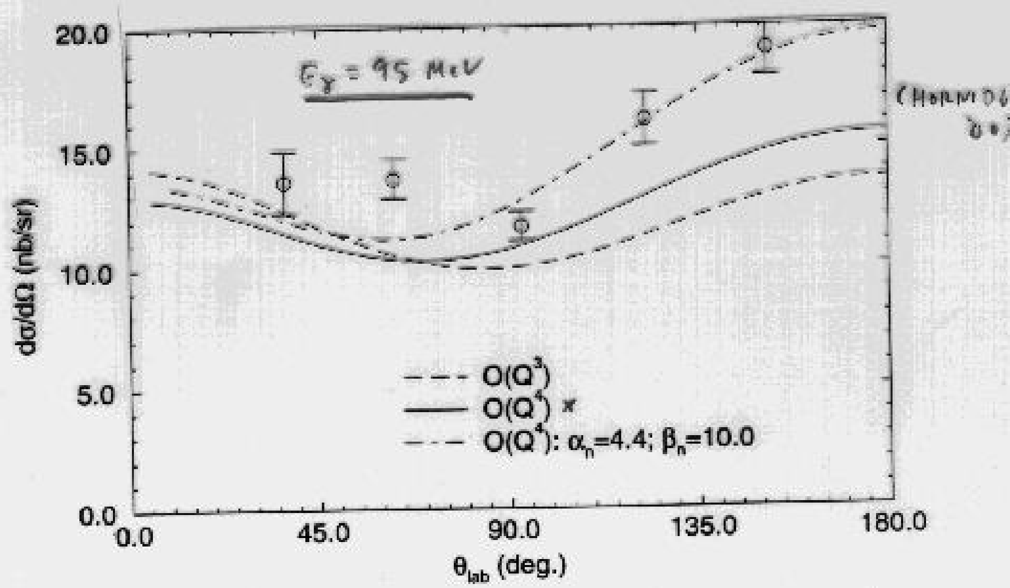
CHIRAL WAVEFUNCTIONS

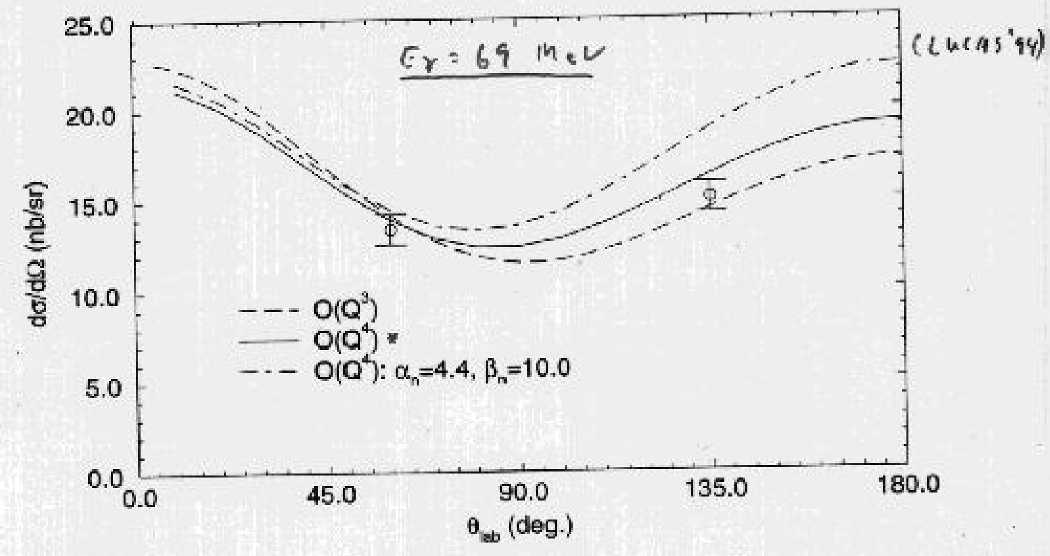
$E_\gamma = 69$ MeV




SAL
Deuteron Compton Scattering
E$_\gamma$=95 MeV
O(Q^2)
O(Q^4) *
O(Q^3)
dσ/dΩ (nb/sr)
25.0
20.0
15.0
10.0
5.0
0.0
0.0
45.0
90.0
135.0
180.0
θ$_{lab}$ (deg.)

$\gamma d \to \gamma d$ (WEINBERG)





RECALL: EFT $\not\pi$ $\alpha_n \sim 2$ $\beta_n \sim 12$!!

(S.B., MALHEIRO, PHILLIPS, van KOLCK '99)

CONCLUSION

- EFT PROVIDES A SYSTEMATIC CALCULATIONAL SCHEME TO STUDY PHOTONUCLEAR REACTIONS IN A UNIFIED MANNER.

- NEUTRON PROPERTIES CAN BE EXTRACTED FROM NUCLEAR EXPERIMENTS IN A CONTROLLED WAY.

EFT $\not\pi$: $\alpha_n \sim (5, 2)$ $\beta_n \sim (16, 12)$

MORE LOW-ENERGY DATA IS WELCOME !!

EFT π : EXTRACTION OF α_n, β_n FROM $\gamma d \to \gamma d$ MUST AWAIT FULL Q^4 AMPLITUDE.