Nucleon swelling and Compton scattering

M. Yosoi

Problem of ^{4}He point nucleon density distribution

Variable proton size in CMD calculation

Quasifree Compton scattering

Different effective masses for nucleon

non-relativistic $[\frac{1}{2m}p^2 + U_S(r,\varepsilon)]\psi_S = \varepsilon\psi_S$

$$U_S = V_S + iW_S$$

- $\frac{m_S^*(\varepsilon)}{m} = 1 - \frac{d}{d\varepsilon}V_S(\varepsilon)$ (conventional effective mass)
- $\frac{\tilde{m}(\varepsilon)}{m} = [1 + \frac{m}{k}\frac{\partial}{\partial k}V_S]^{-1}_{k=k(\varepsilon)}$ (effective k-mass)
- $\frac{\overline{m}(\varepsilon)}{m} = [1 - \frac{\partial}{\partial \varepsilon}V_S]_{k=k(\varepsilon)}$ (effective E-mass)

$$\frac{m_S^*(\varepsilon)}{m} = \frac{\tilde{m}(\varepsilon)}{m} \cdot \frac{\overline{m}(\varepsilon)}{m}$$

relativistic $[\vec{\alpha} \cdot \vec{p} + \gamma_0(m + U_\sigma + \gamma_0 U_0)]\phi = E\phi$

- $\frac{M^*}{m} = 1 + \frac{V_\sigma}{m}$ (Dirac mass)
- $\frac{m_e^*(\varepsilon)}{m} = 1 - \frac{d}{d\varepsilon}V_e(\varepsilon) = 1 - \frac{V_0}{m}$ (Lorentz mass)

(Schroedinger equivalent)

QCD base

- NJL

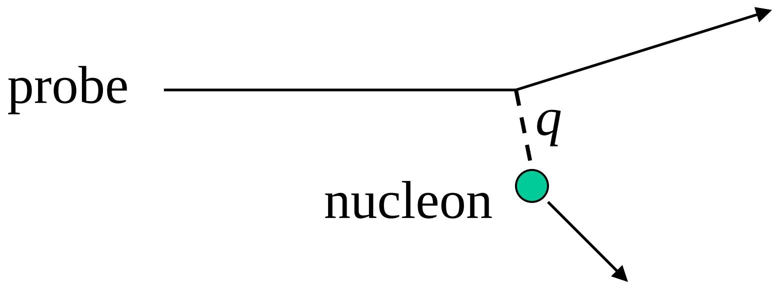
$$f_\pi^* / f_\pi \sim m_\sigma^* / m_\sigma$$
$$\sim m_V^* / m_V \sim m_N^* / m_N$$

- QCD sum rule

Nucleon form factor (or size) in nuclear medium

Is it changed from free nucleon?
(medium effect other than mass shift)

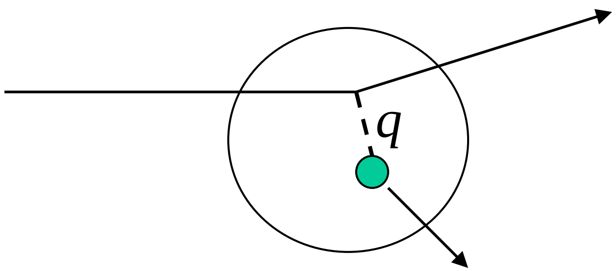
- elastic



[interaction ✕ form factor]

$$F(q^2) = 1 - \frac{1}{6} q^2 < r^2 > + \cdots\cdots$$

- quasi-elastic



If the exchange particle is a hadron
→ medium effect of itself
 photon → MEC
  gluon ?
FSI (final state interaction) effect

Quark substructure approach to ^{4}He charge distribution

L. Wilets and M. A. Alberg*
Department of Physics, Box 351560, University of Washington, Seattle, Washington 98195-1560

S. Pepin and Fl. Stancu
Université de Liège, Institut de Physique B.5, Sart Tilman, B-4000 Liège 1, Belgium

J. Carlson
Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545

W. Koepf
Department of Physics, The Ohio State University, Columbus Ohio 43210
(Received 19 December 1996)

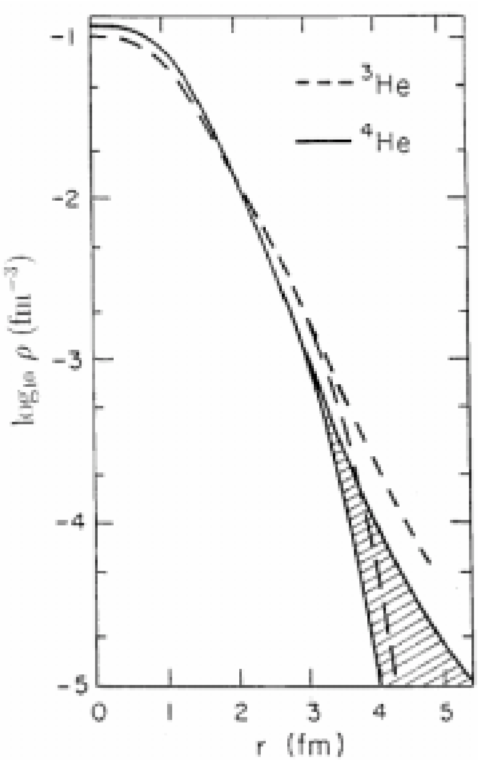


FIG. 1. Model-independent charge distributions for ^{3}He and ^{4}He extracted from experiment. Reproduced from McCarthy *et al.* [1], who state that "the extreme limits of $\rho(r)$ cover the statistical, systematical as well as the completeness error of the data."

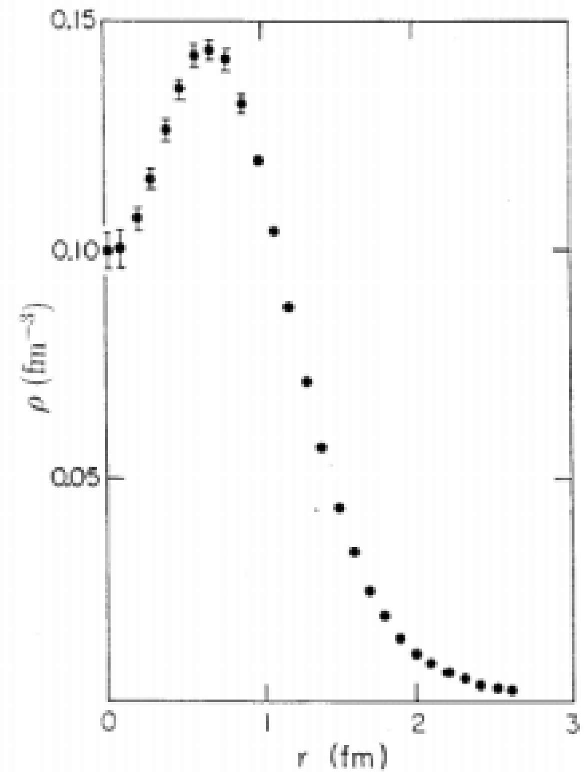


FIG. 2. Point-proton density distribution for ^{4}He obtained by unfolding the free proton form factor, allowing for meson exchange corrections and relativistic effects. Reproduced from Sick [2].

Nuclear density distribution

[Experiment] (e,e') or μ-atom

↓ ← model-independent analysis

charge density distribution

fold ρ_p + MEC ↑ ↓ ← unfold proton charge distribution ρ_p

point proton density distribution

↑

ground state wave function

↑ ← Green function MC, etc.

(many body) Schroedinger eq. (Dirac eq.)

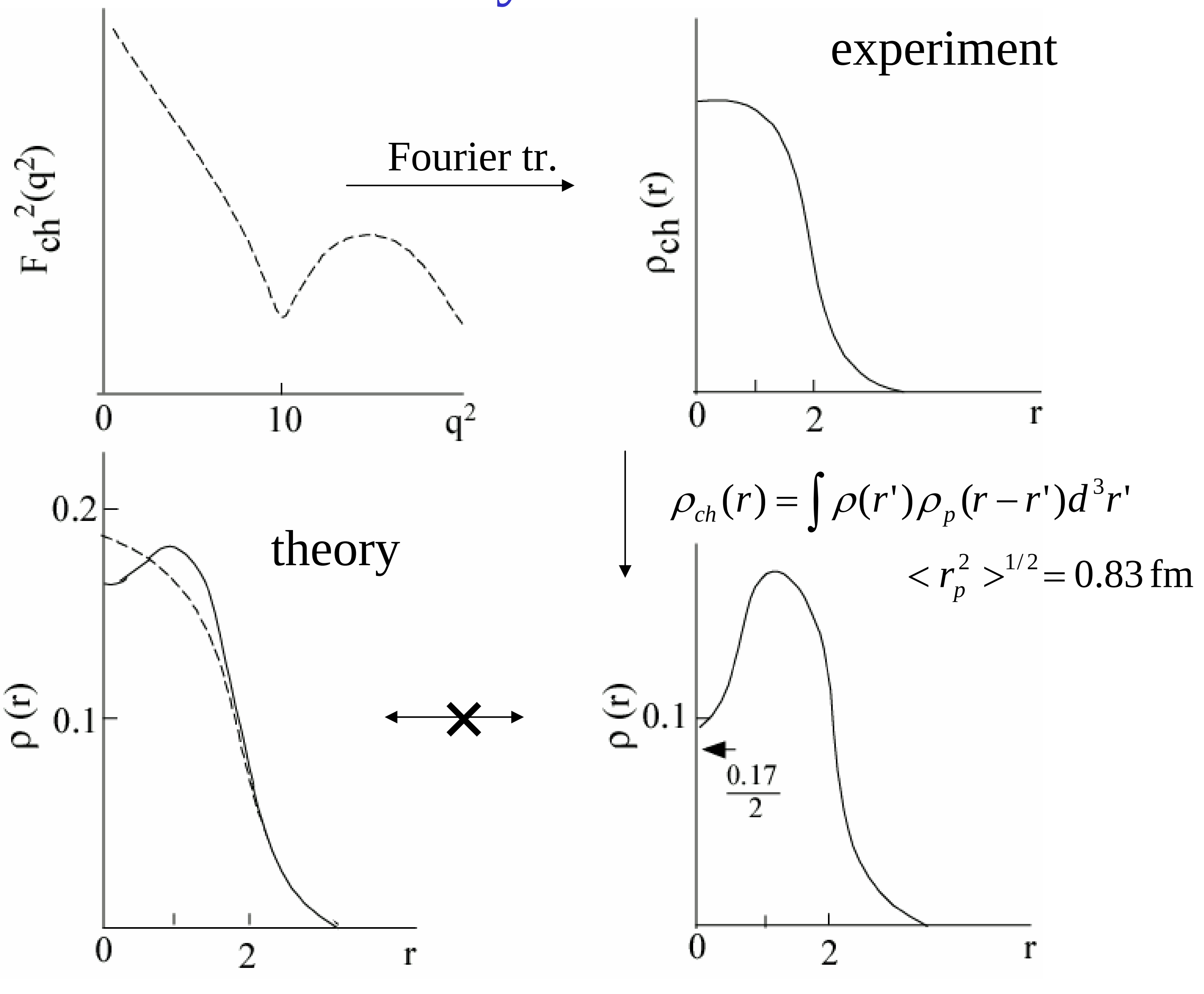
↑

[Theory] NN interaction (2-body, 3-body)

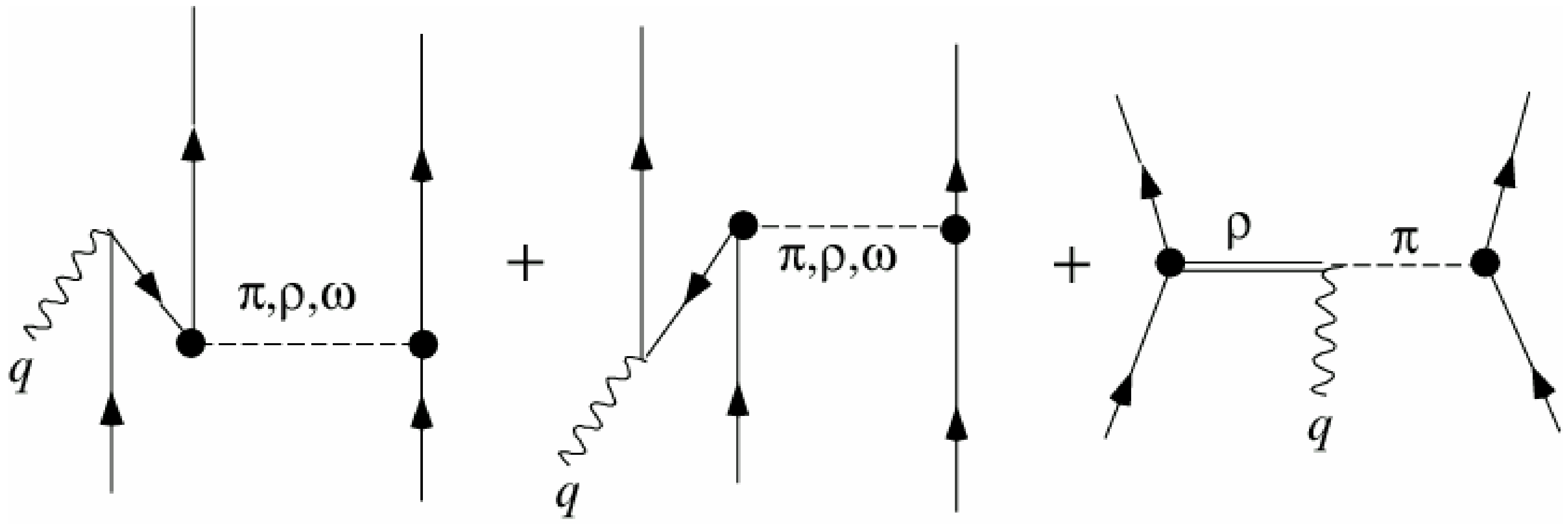
Usually unfold (fold) the charge distribution of free proton

→ If proton is **"swelling"** in the nucleus, ……?

Point nucleon density distribution in ^{4}He



Usually it is due to MEC (meson exchange current)



Chromodielectric Soliton Model

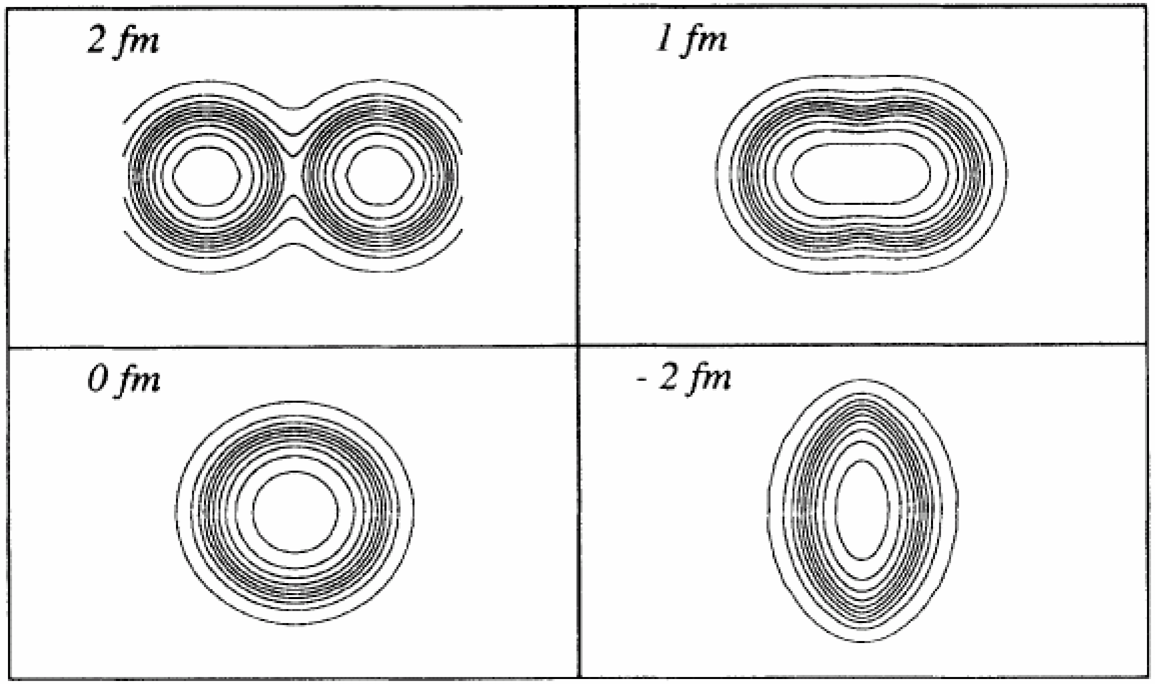


FIG. 1. The scalar field, $\sigma_\alpha(\mathbf{r})$ of Eq. (16), from which the single-quark wave functions are generated, for four different values of the deformation parameter α between 2 fm and -2 fm. The fields correspond to the parameter set with $f = 3$ and $c = 10\,000$, and are shown with equal increments between adjacent contours.

Variable rms proton charge radius

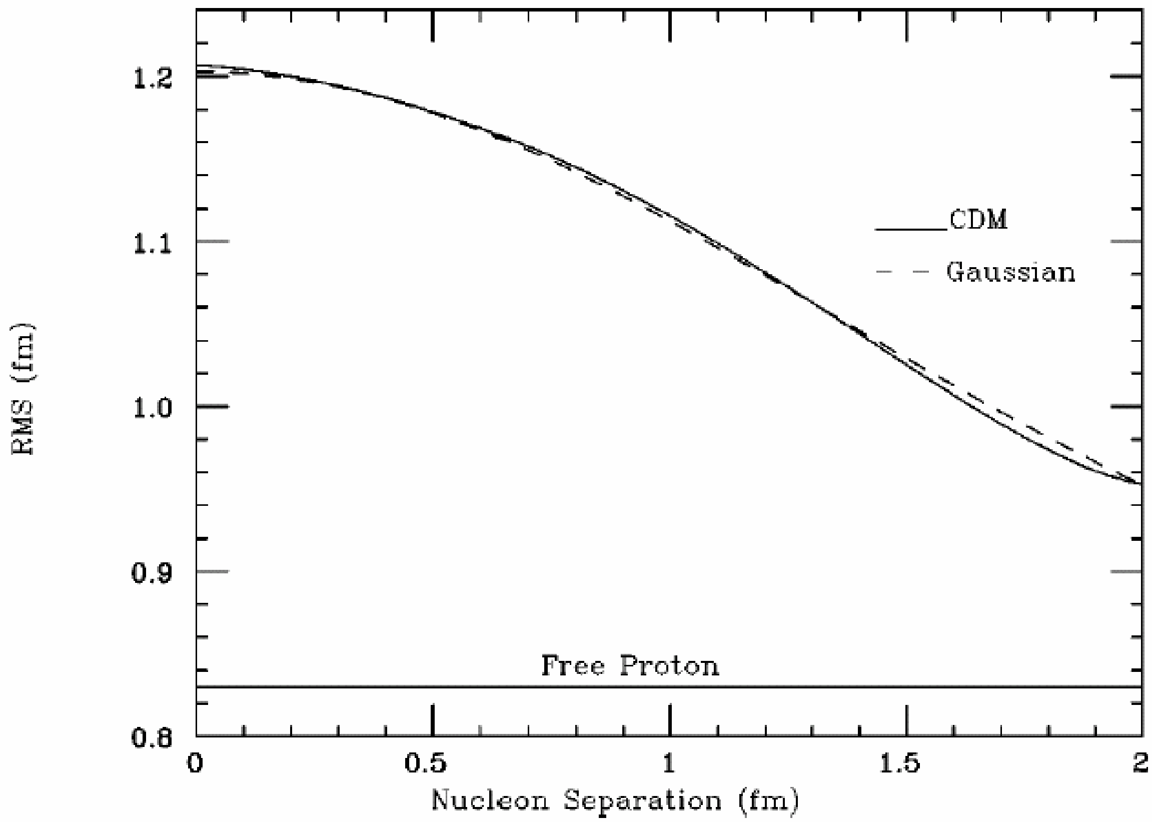


FIG. 3. Proton rms charge radius r_p of Eq. (1) as a function of internucleon separation. The line labeled CDM is the calculated chromodielectric model result. The dashed line is a Gaussian approximation, normalized to the free value, with a size parameter given by Eq. (3)

Folding variable proton size to the point proton density distribution

- assume Gaussian distribution $b(r') = \sqrt{2/3}\, r_p(r')$.

- 2-nucleon pair charge density

$$\rho_{\rm pair}(\boldsymbol{r_i},\boldsymbol{r_j};\boldsymbol{r}) = \{\delta_{ip}\exp[-|\boldsymbol{r}-\boldsymbol{r_i}|^2/b^2(r_{ij})] + \delta_{jp}\exp[-|\boldsymbol{r}-\boldsymbol{r_j}|^2/b^2(r_{ij})]\}/\pi^{3/2}b^3(r_{ij}),$$

- independent pair approzimation

$$\rho_{\rm ch}(r) = \frac{1}{3}\sum_{i<j}\int d^3r_i \int d^3r_j\ f_2(\boldsymbol{r_i},\boldsymbol{r_j})\rho_{\rm pair}(\boldsymbol{r_i},\boldsymbol{r_j};\boldsymbol{r}).$$

$$f_2(\boldsymbol{r_1},\boldsymbol{r_2}) = \int |\psi(\boldsymbol{r_1},\boldsymbol{r_2},\boldsymbol{r_3},\boldsymbol{r_4})|^2 d^3r_3 d^3r_4,$$

^{4}He density distribution

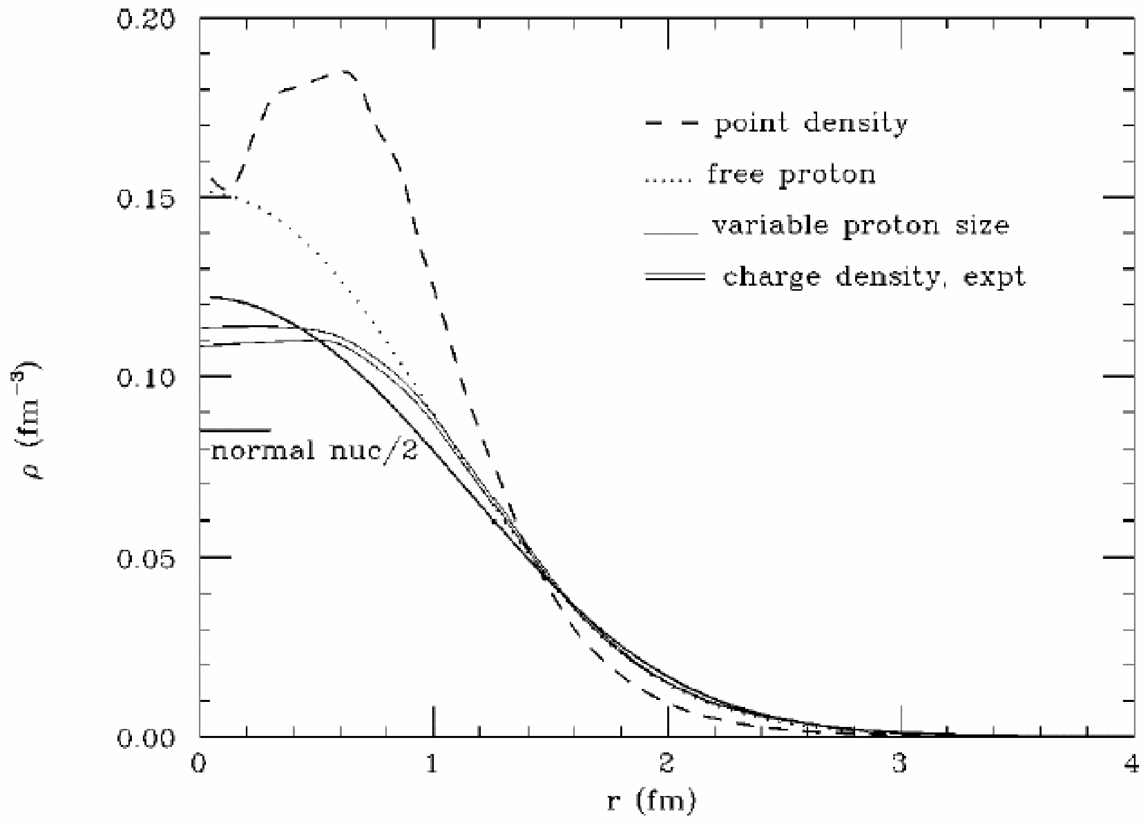
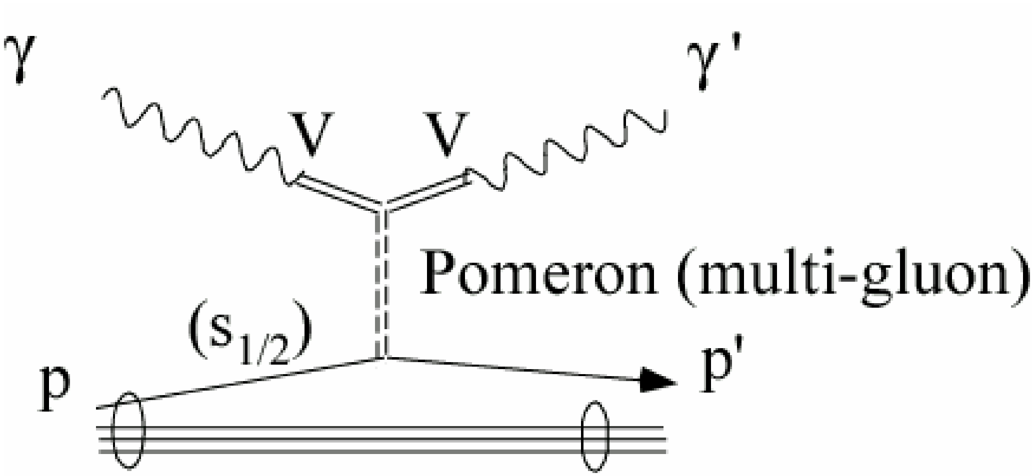
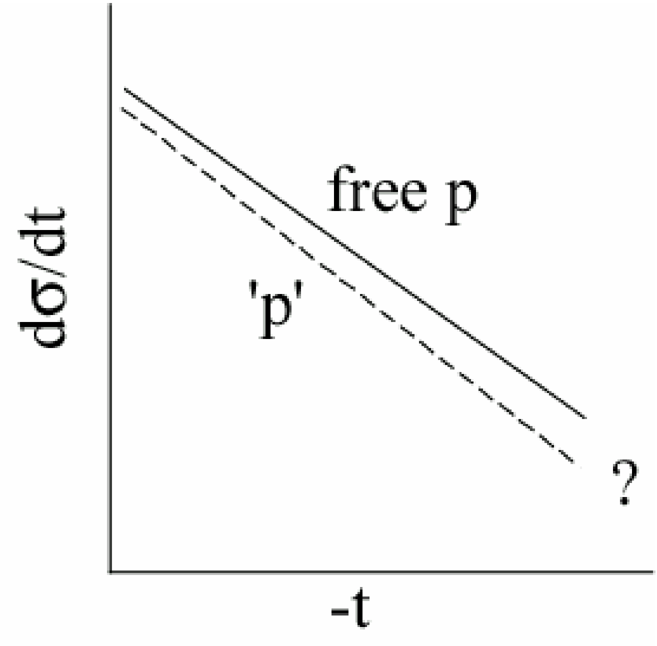


FIG. 4. ^{4}He density distributions: The dashed line is the point density from a parametrized Green's function Monte Carlo calculation. The curve labeled "free proton" is the charge distribution obtained from a Gaussian proton charge distribution with a fixed size parameter (as is usually done). The curve labeled "variable proton size" uses the Gaussian fit of Fig. 3. We also indicate half the normal nuclear density 0.17/2 fm^{-3}.

$^{4}He(\gamma,\gamma p)^{3}H$ in VD energy region

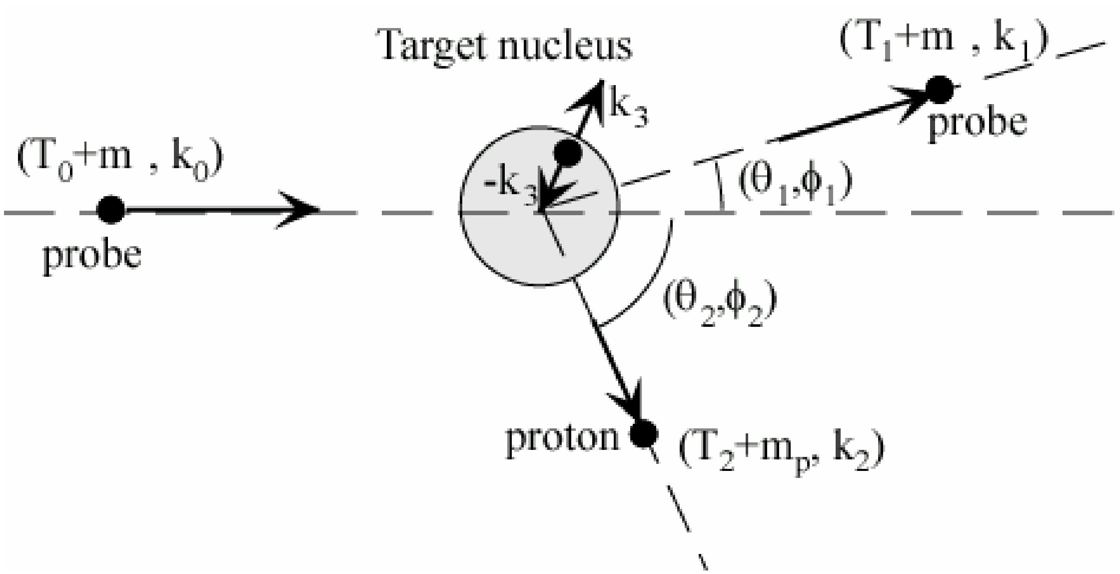




ISI, FSI: small
no MEC ?
$E_\gamma >> E_{sep}$

+
Polarization observables

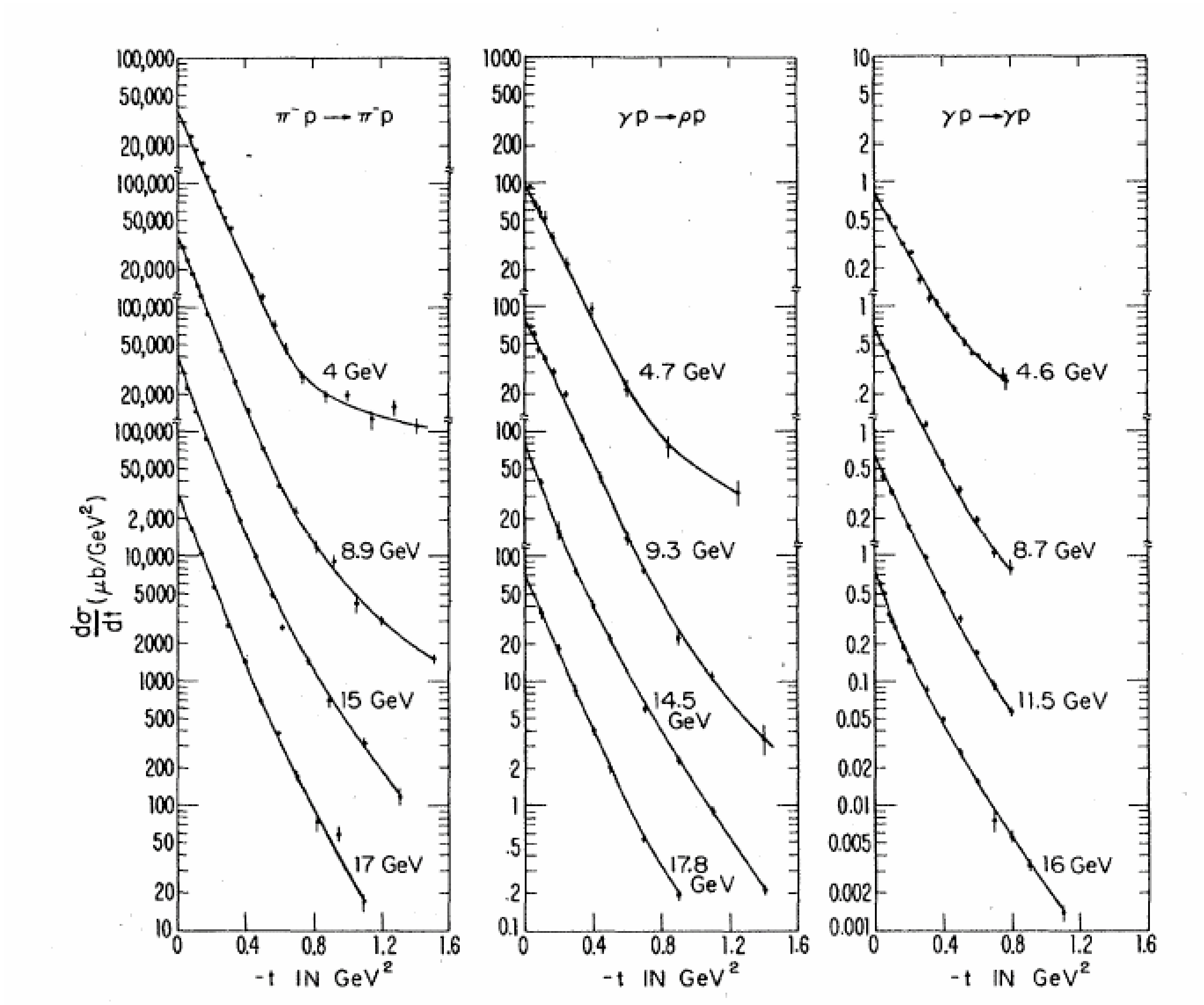
Quasifree kinematics



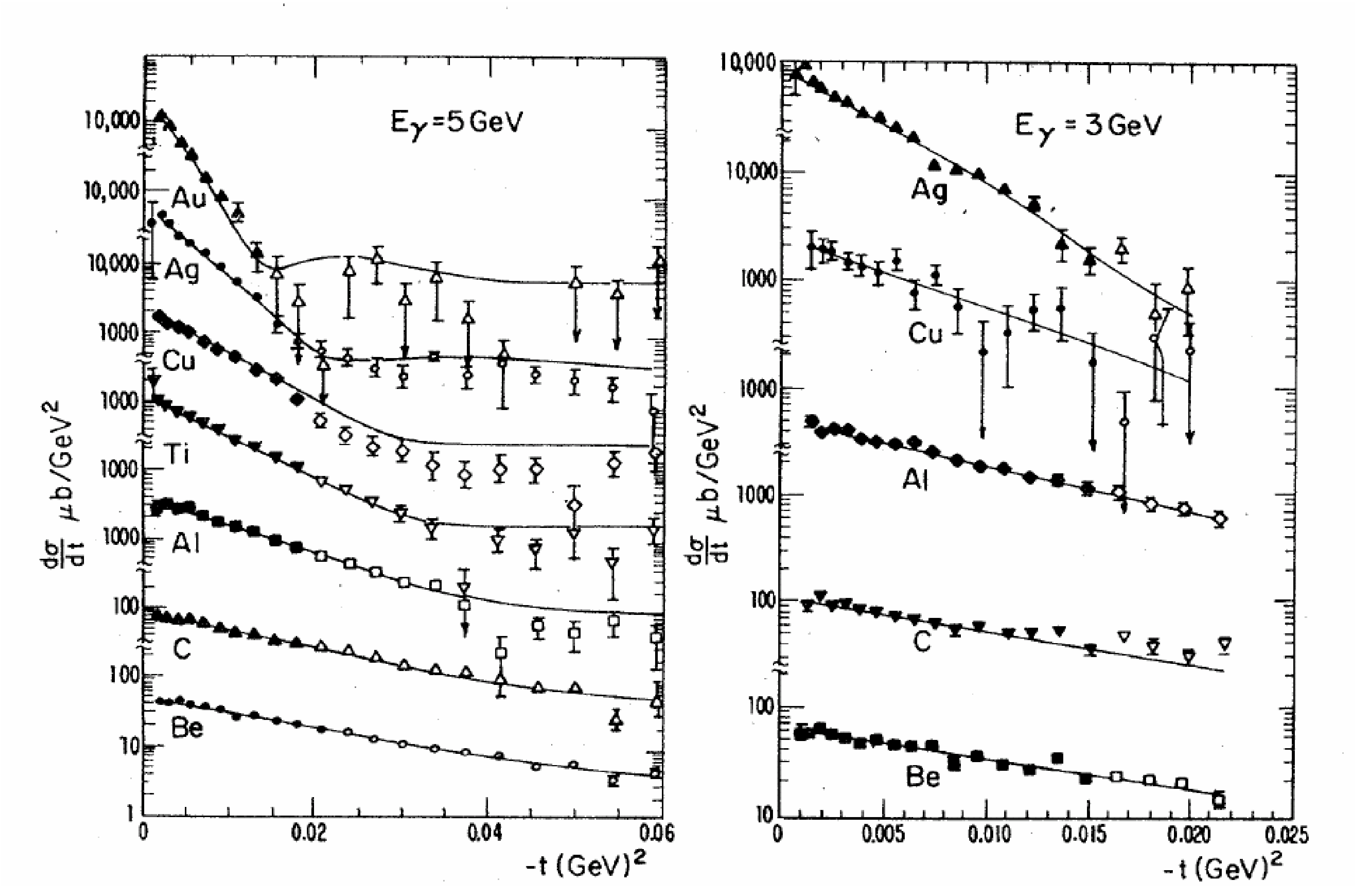
$$\vec{k}_3 = \vec{k}_0 - \vec{k}_1 - \vec{k}_2$$

$$E_{sep} = T_0 - (T_1 + T_2 + T_3)$$

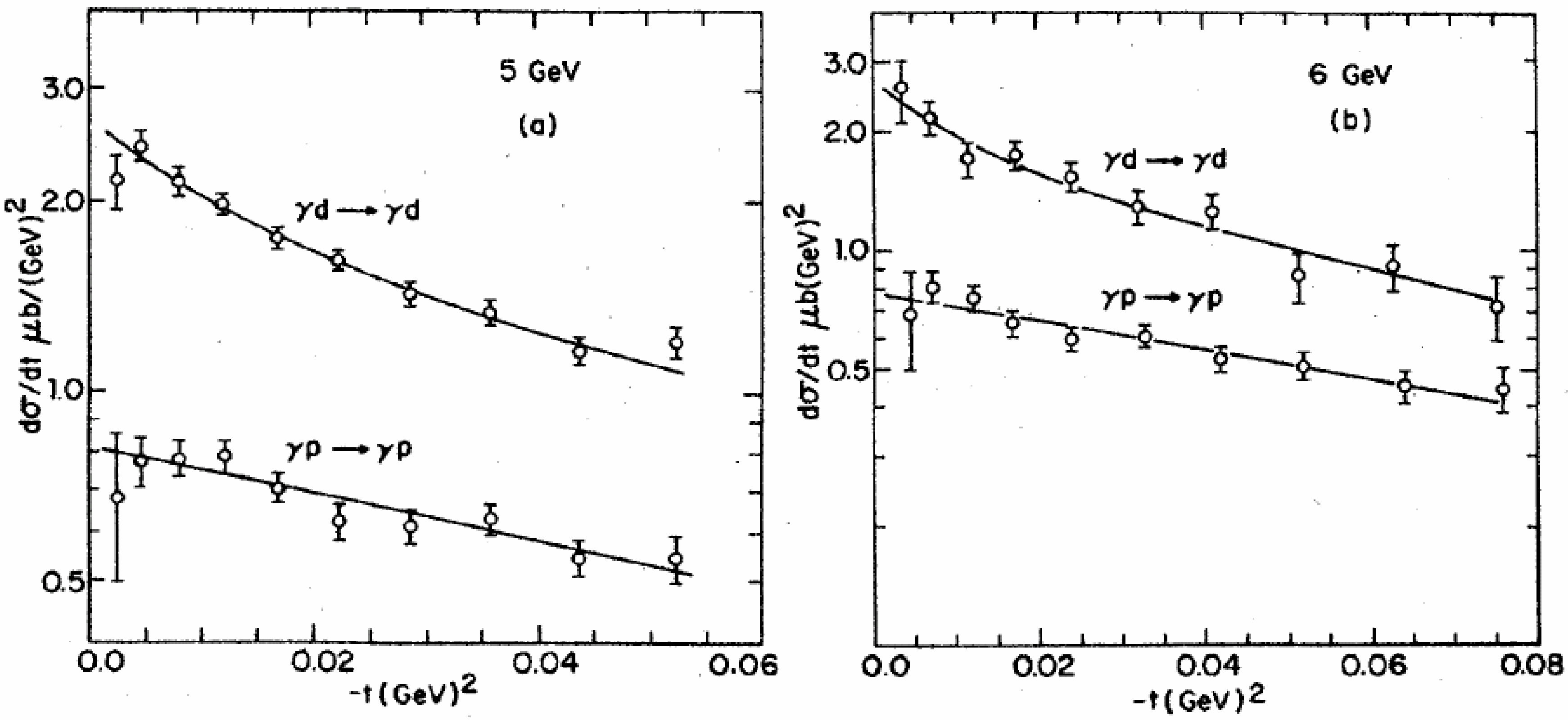
γp → γp data above GeV energy (1960's-1970's)



Compton scattering for nuclear target (coherent + incoherent)



$\gamma d \rightarrow \gamma d$ data



after 1990, many precise $\gamma p \rightarrow \gamma p$ below 1 GeV

→ Nucleon polarizability

レーザー電子光によるクォーク核物理専用施設実行計画書
(平成8年)

GeV領域偏極ガンマ線による陽子コンプトン散乱実験

1・実験提案者

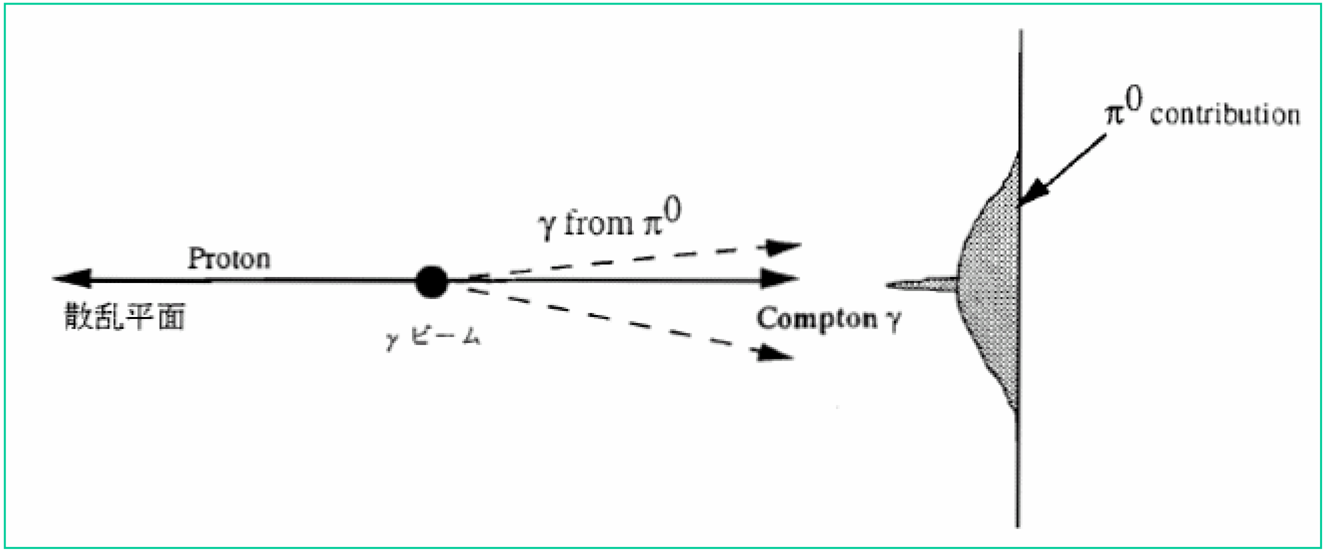
須田利美　（東北大学理学研究科・助手）　代表者
前田和茂　（東北大学理学研究科・助教授）
寺沢辰夫　（東北大学核理研・助教授）
今野収　（東北大学核理研・助手）
丸山浩一　（東京大学原子核研究所・助手）
和田義親　（明治薬科大学物理・教授）
藤原守　（大阪大学核物理センター・助教授）
堀田智明　（大阪大学核物理センター・教務補佐員）
Gerard Garino　（東京大学原子核研究所・学振特別研究員）
Rory Miskimen　(Univ. of Massachusette　・助教授)
Jeff Shaw　（Univ. of Massachusette・ポスドク）

2・目的：

ＧｅＶ領域の偏極γ線による陽子コンプトン散乱反応の断面積及び偏極分解能を測定し、核子構造を調べる。

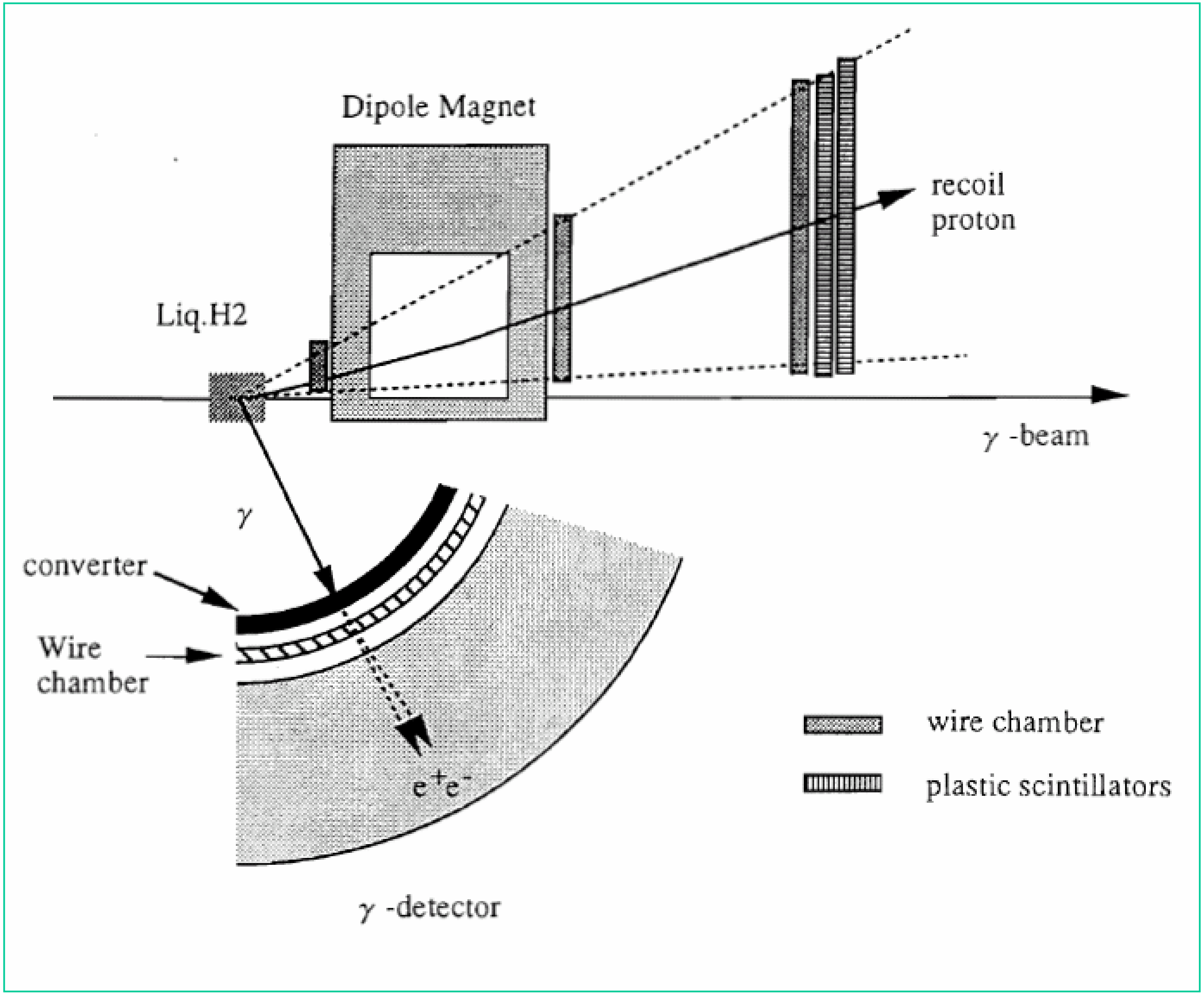
Identification of Compton events

coincidence measurements of scatted-γ and recoil-p



Co-planarity is important for Compton and π_0 separation

Detection system (by T.Suda)



Yield estimation

- $d\sigma/d\Omega$ ~ 1 nb/sr
- $N\gamma$ ~ 10^7 /sec
- Nt ~ 1 mol

→Y= 0.006 $\Delta\Omega$ ($\Delta\Omega$ ~ 1 sr)

need one order high intensity to divide $E\gamma$ into10 energy bins