K^+ - Scattering from Nuclear Targets

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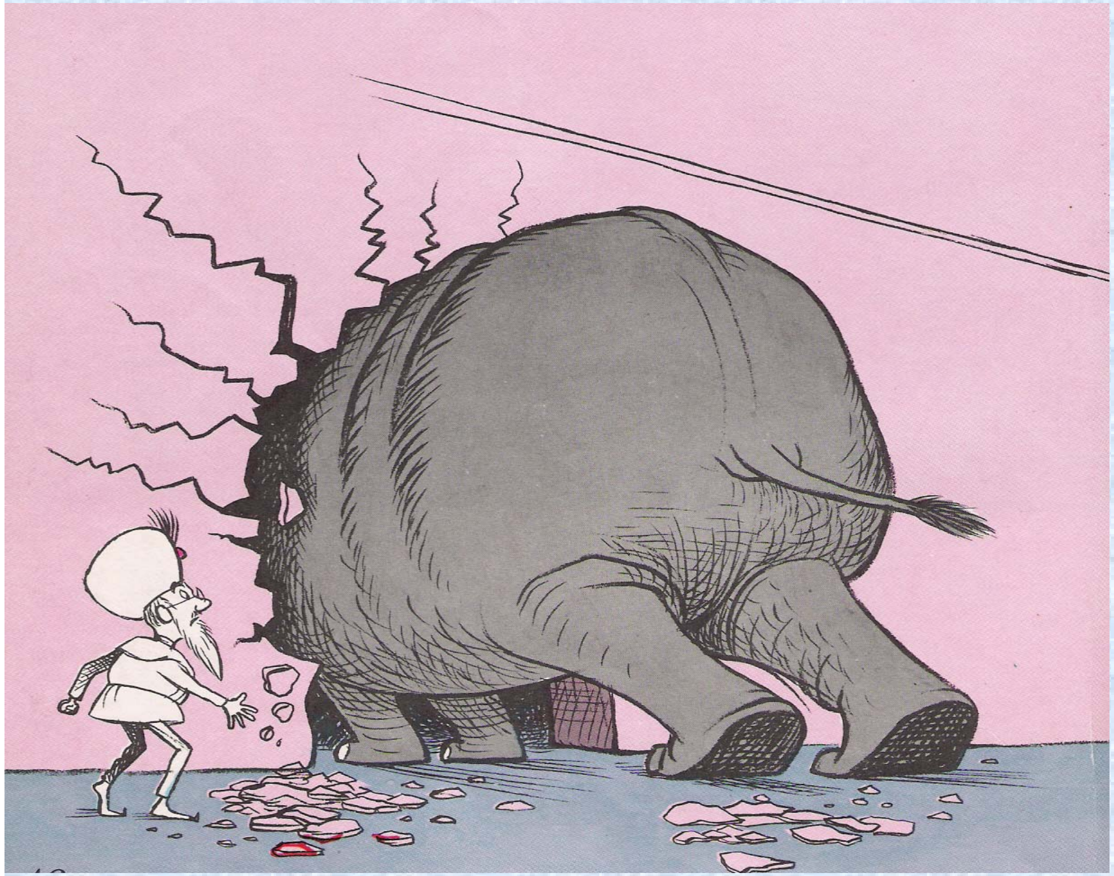
When is a Nucleon a Nucleon ? (Medium Effects)



The EMC effect shows that the nuclear medium modifies nucleon structure - measured at high values of momentum transfer ($Q^2 = 2M\upsilon$). An assumed consequence of nuclear density effects

Early measurements of K^+ total cross sections were enhanced, and also interpreted as a manifestation of the nuclear density.

The K^+ was proposed as a hadronic "replacement" for the electron.

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U H M E P

Initial K^+ -- e Comparison

^{40}Ca Target

Radius = 4 fm

K^+

550 MeV/c Incident Momentum

$\lambda_K = 0.39$ fm

Scattered at 80°

$Q^2 = (540 \text{ MeV/c})^2$

$\nu = 156$ MeV

$x = q^2/2M\nu = 0.91$

e

1500 MeV/c Incident Momentum

$\lambda_e = 0.20$ fm

Scattered at 20°

$Q^2 = (515 \text{ MeV/c})^2$

$\nu = 140$ MeV

$x = q^2/2M\nu = 0.93$

Obviously DIS can't be explored with these kinematics, but they are appropriate for QHD

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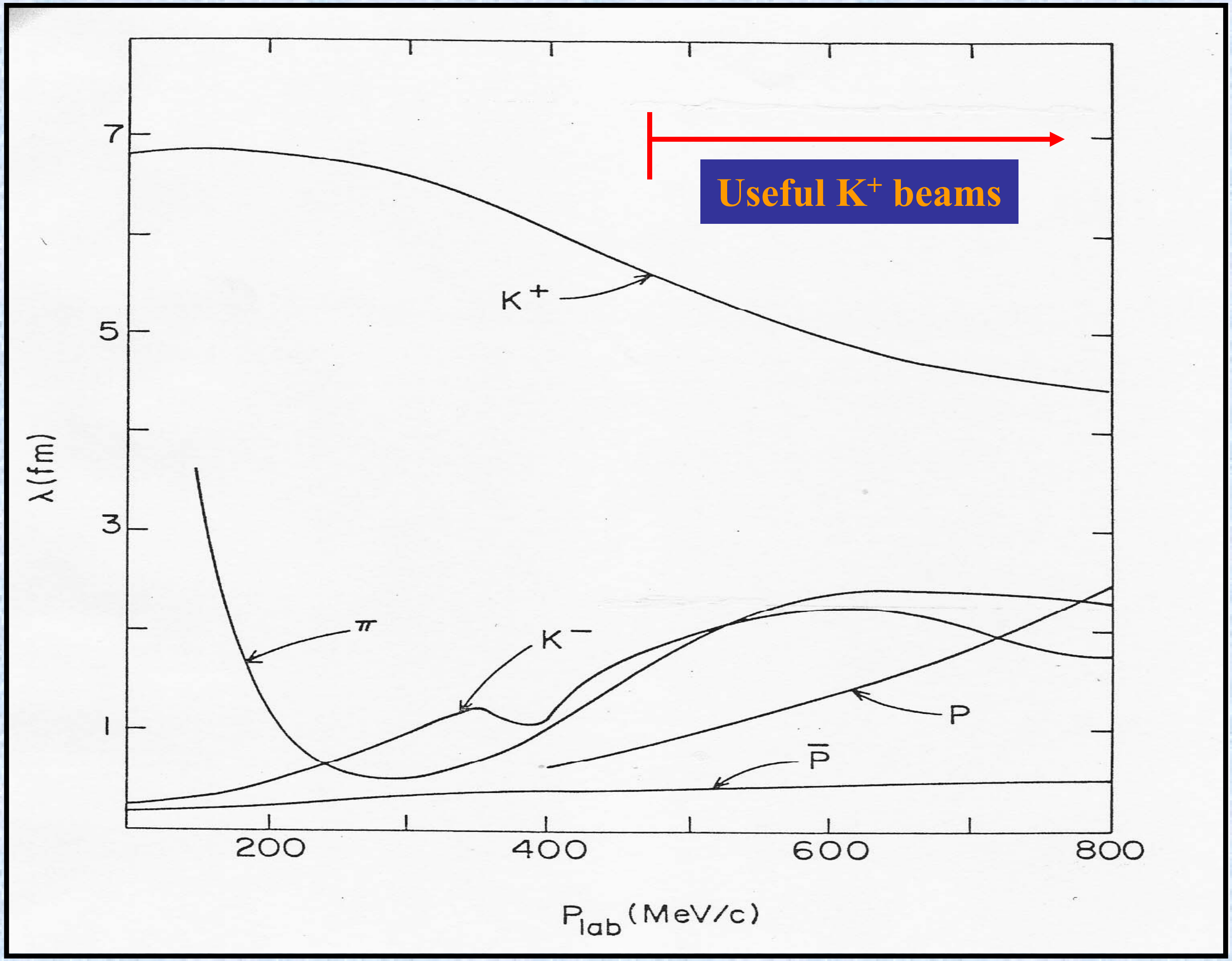
K^+ Mean Free path

Phy Rep 89(82)1



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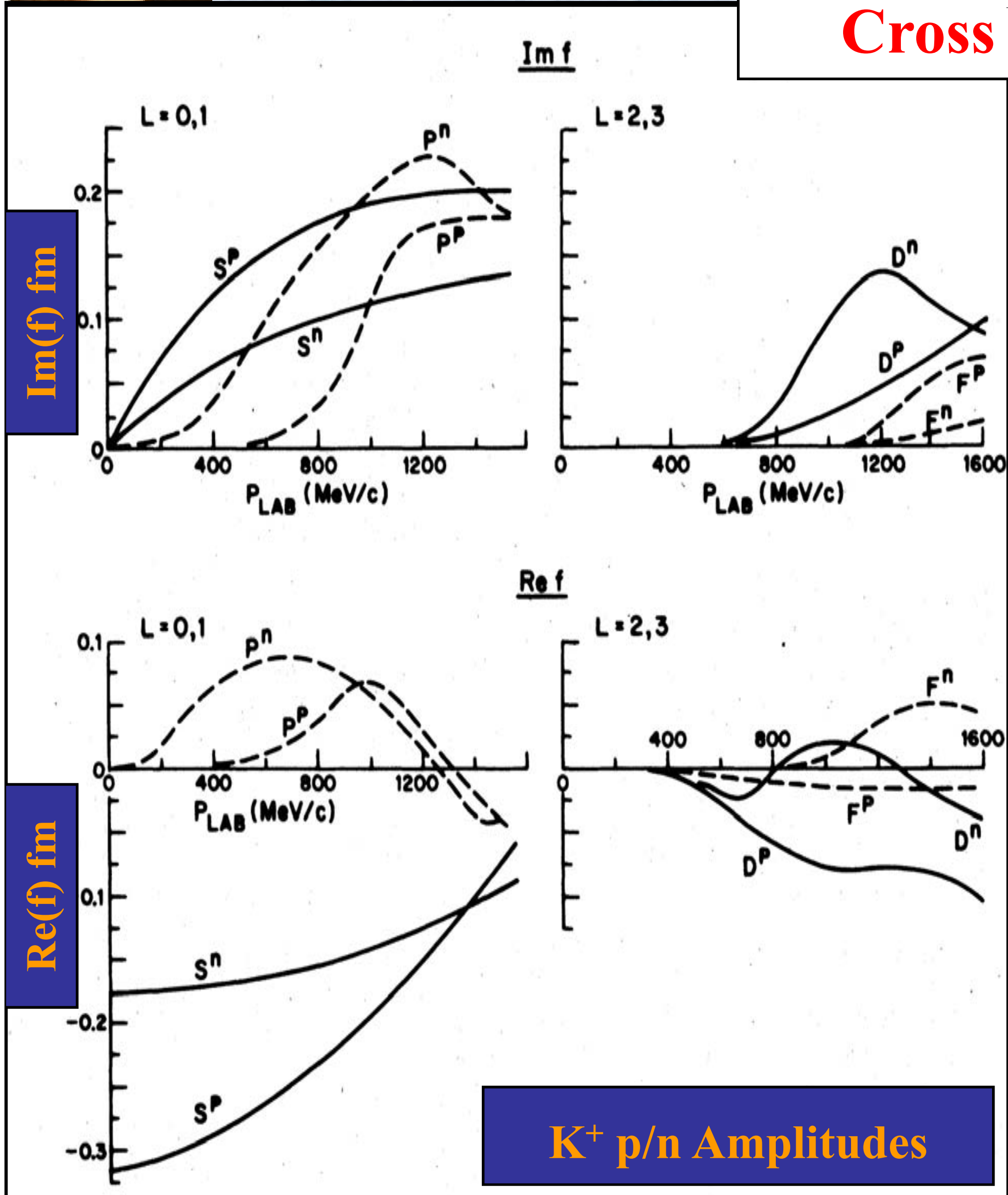
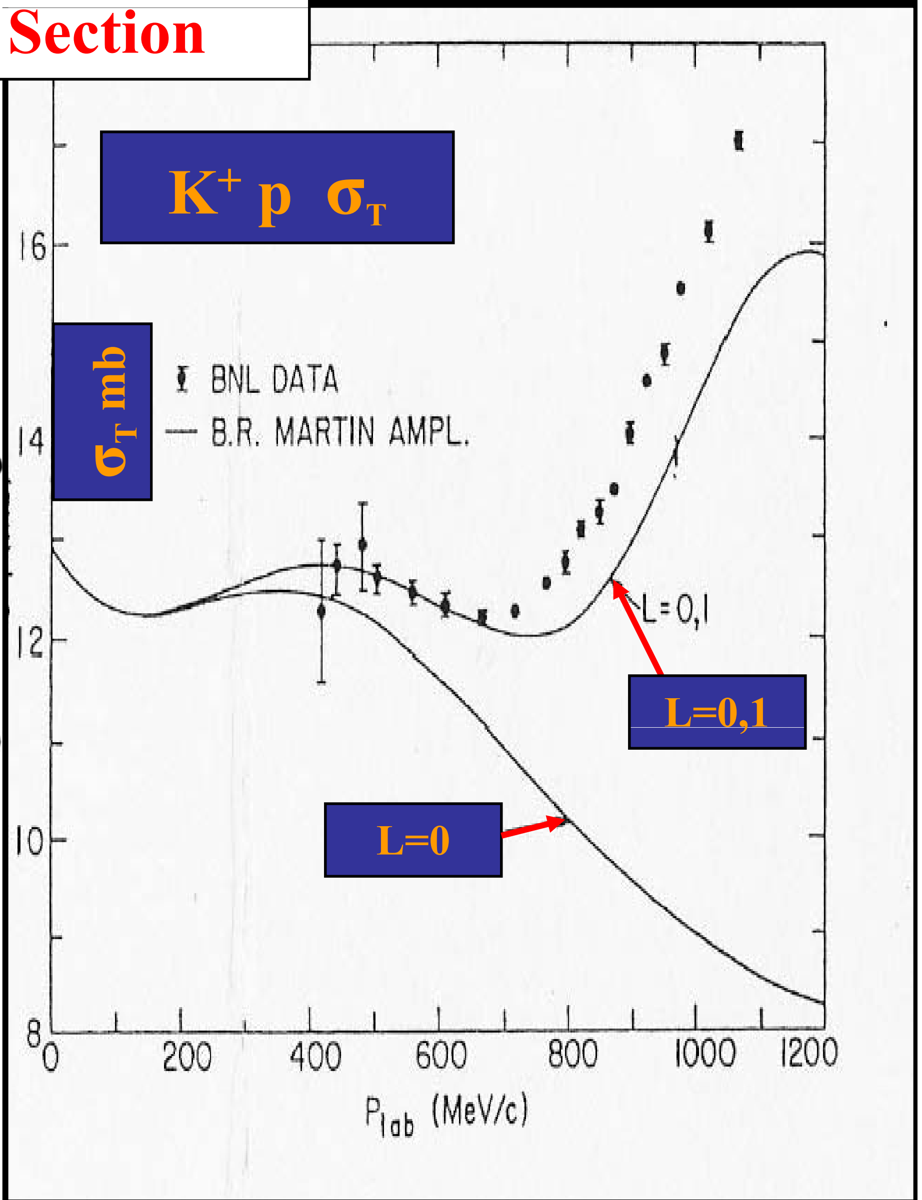
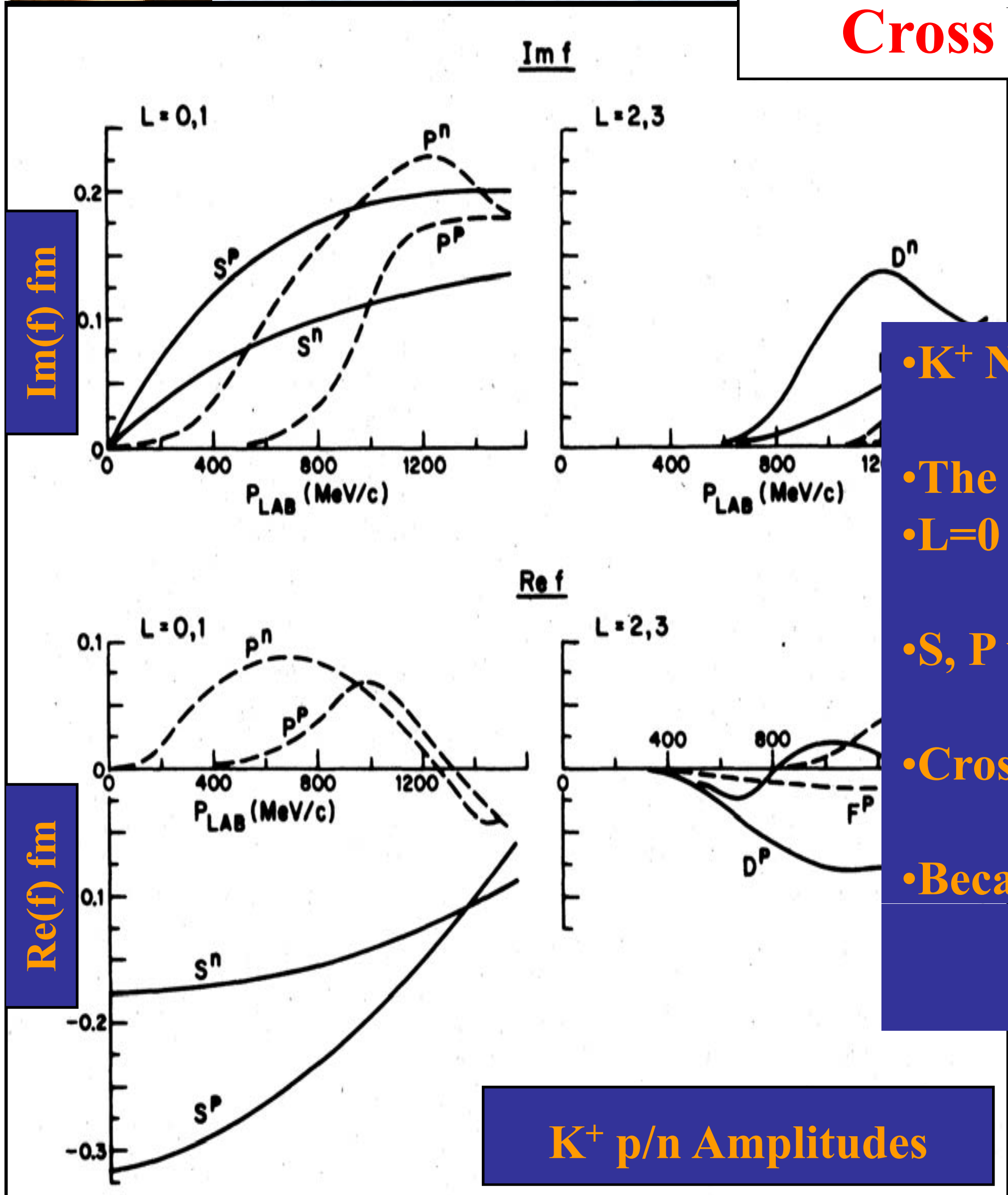
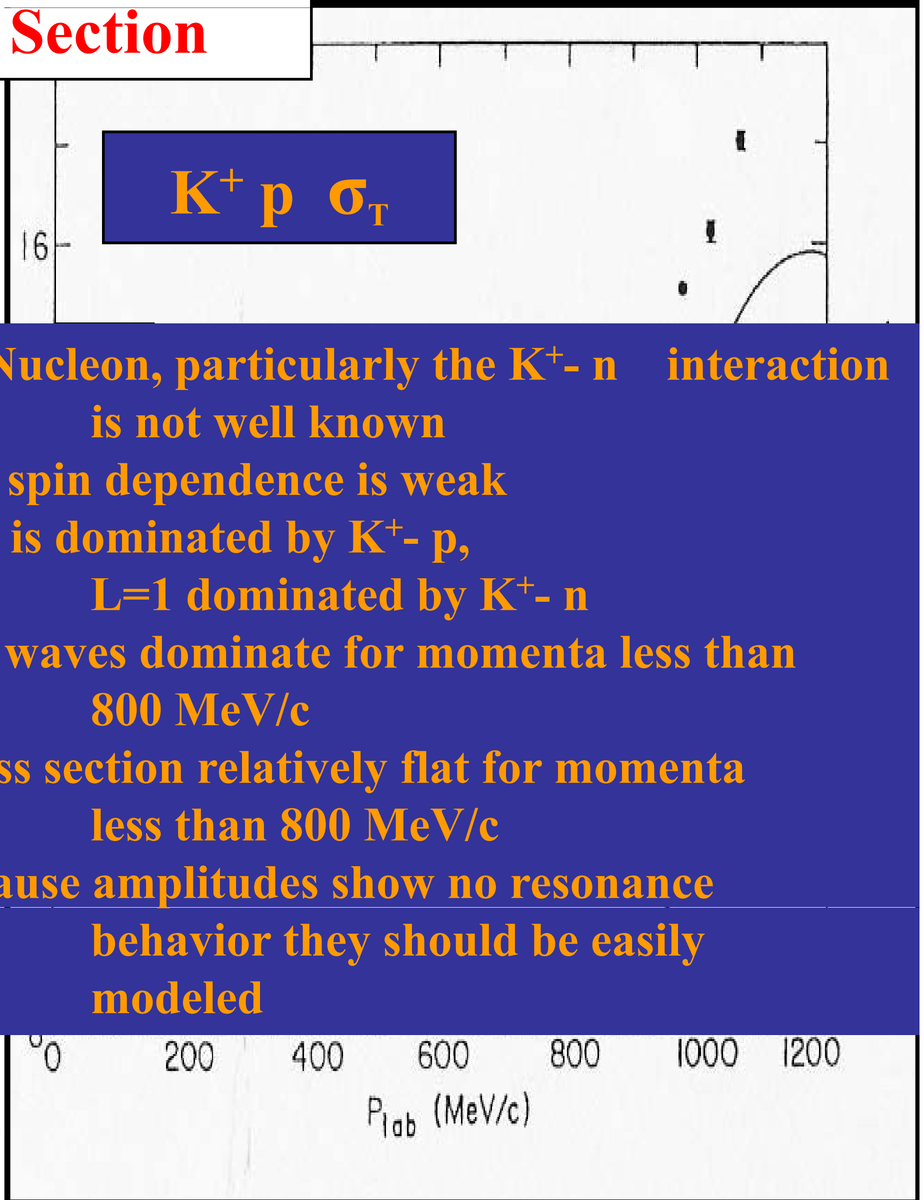
Elementary K⁺ Amplitude and Cross Section





Elementary K^+ Amplitude and Cross Section





- K^+ Nucleon, particularly the K^+- n interaction is not well known
- The spin dependence is weak
- L=0 is dominated by K^+- p, L=1 dominated by K^+- n
- S, P waves dominate for momenta less than 800 MeV/c
- Cross section relatively flat for momenta less than 800 MeV/c
- Because amplitudes show no resonance behavior they should be easily modeled

K^+-Nucleus Interaction

Because the Amplitudes are weak and essentially momentum independent one expects the tρ approximation for the optical potential to be valid ---

$$2\varepsilon V_{opt}(r) = -4\pi F_k b_0 \rho(r)$$

Implies

- **K^+ should be sensitive to the Nuclear Volume**
- **For example, K^- much more diffractive -- deeper minimum at lower Q^2**

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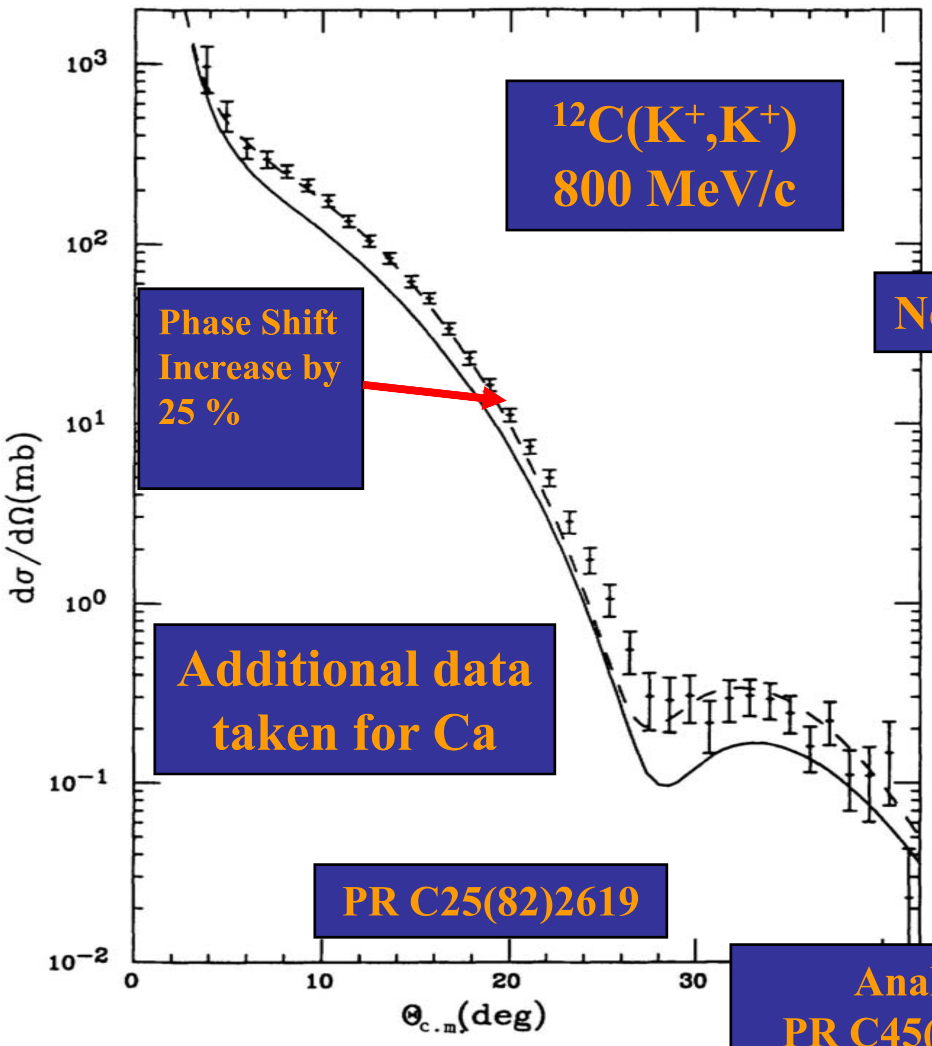
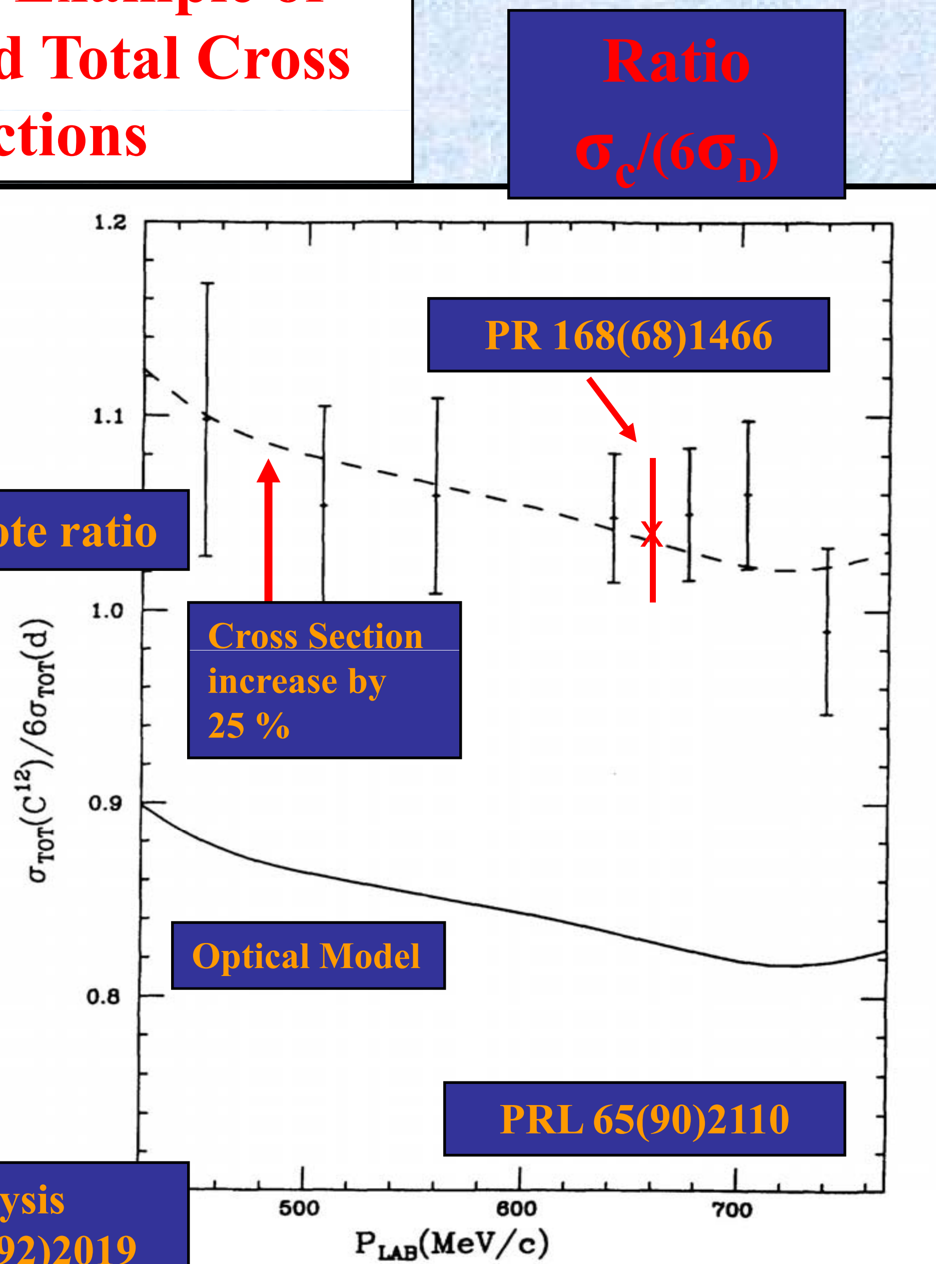
An Early Example of Elastic and Total Cross Sections





Analysis
PR C45(92)2019

K^+ Scattering Enhancements

K^+

- Scattering from C shows an increase of 36% in the 2-body amplitude – in Ca it is about 64%
- Can be explained by:

✓ Increasing the elementary phase shifts

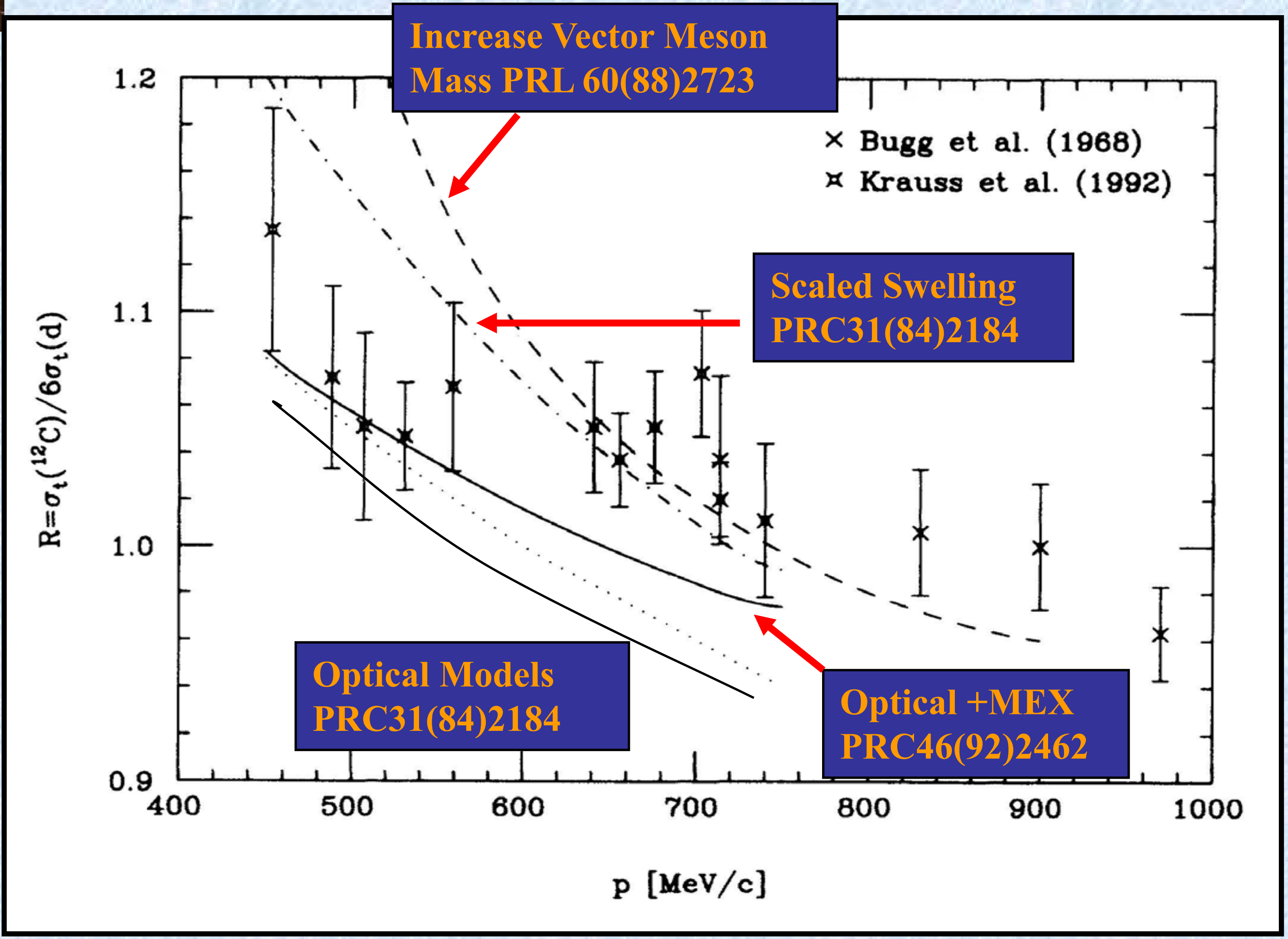
✓ Decrease the effective mass of the exchanged mesons (effective mass varies with density $[1 - \lambda\rho/\rho_0]$)

✓ Mesonic Currents

Calculations are not sensitive to common corrections (energy shifts, multiple scattering, etc)

Data is limited but there is a consistent discrepancy between data and theory.

K^+ C Total Cross Section Ratio Compared to Calculations



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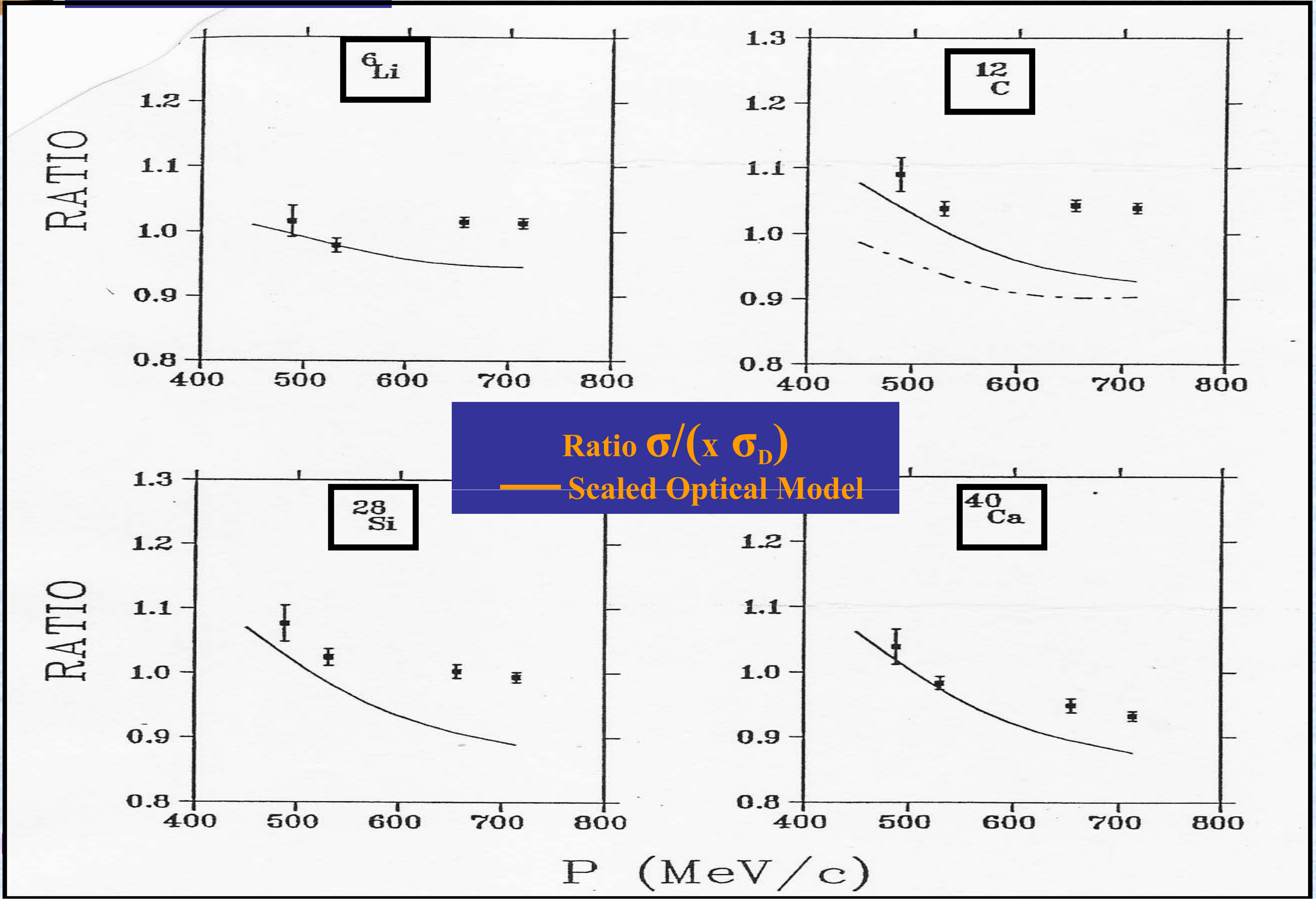
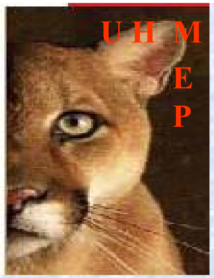
A Second Series of Experiments

PR C49(94)2569



Ratio $\sigma/(x\ \sigma_D)$

— Scaled Optical Model



Analysis

PR C(97)1304
PL B396(97)21

- σ_R less model dependent than σ_T
- An optical potential is required to extract σ_R from the transmission experimental data
- The results are not self-consistent
- Need elastic data to get the optical potential
- While a tρ approximation should be valid, it appears that potential is repulsive at low density but less so (or attractive) at high density
- Energy dependence of K^+-Li is similar to more complex nuclei
- Super ratio removes Energy dependence

$$[\sigma_{R(exp)} / \sigma_R(cal)]/[\sigma R(exp) / \sigma R(cal)]$$

- Meson Exchange is energy dependent

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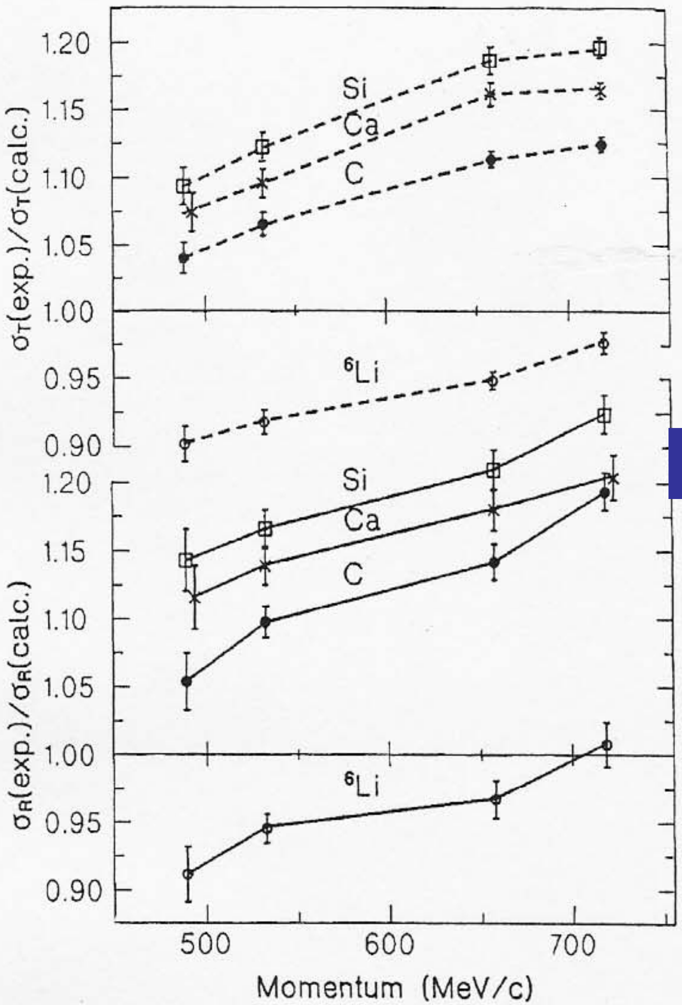
Analysis

Cross Section Ratios to [x D]

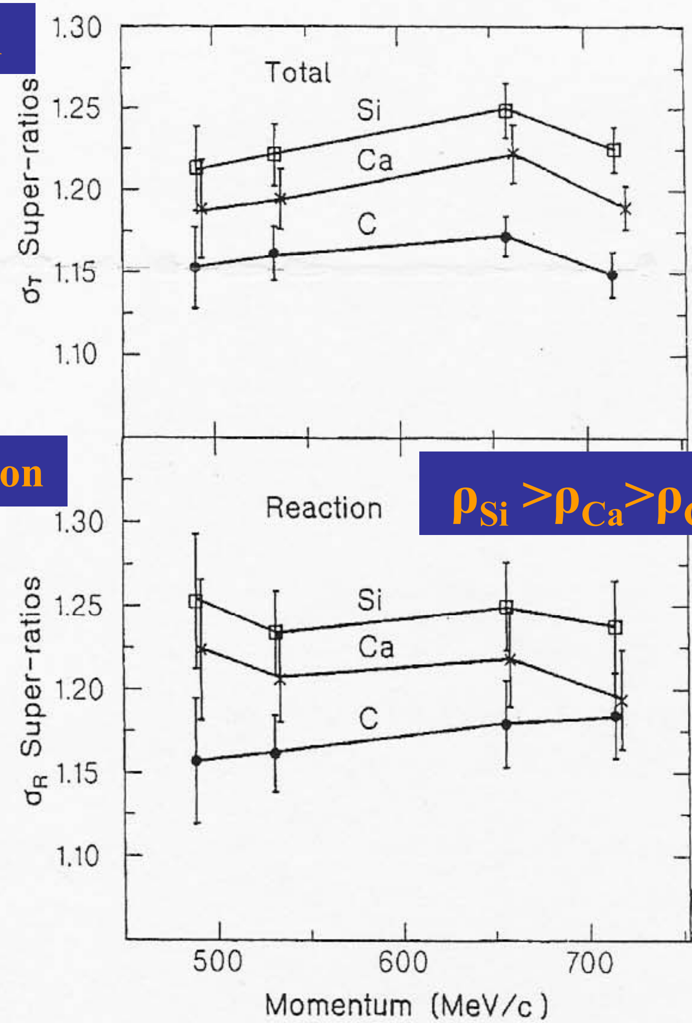
PR C(97)1304
PL B396(97)21

Super Ratio



Total

Reaction



$\rho_{Si} > \rho_{Ca} > \rho_C$

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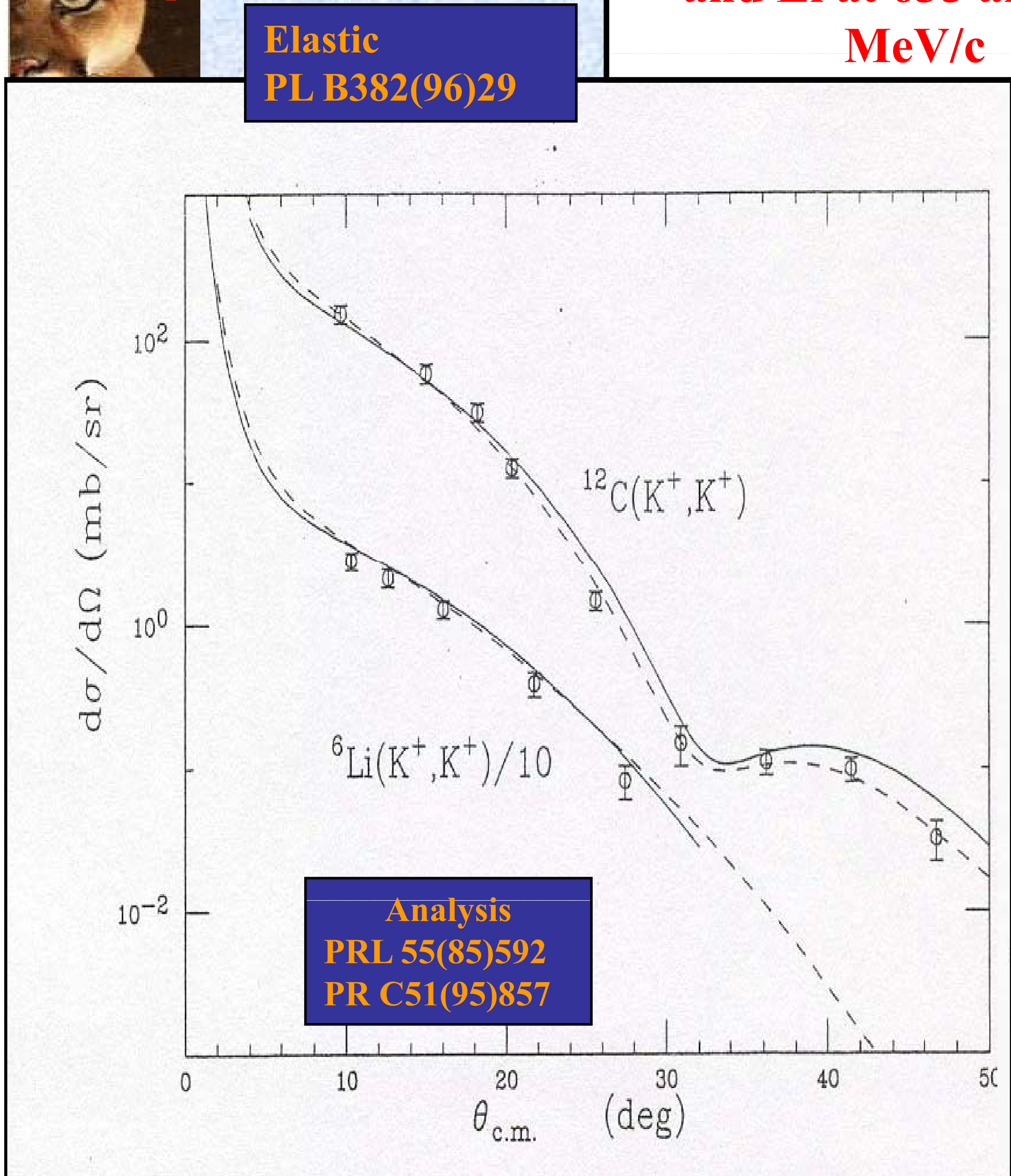
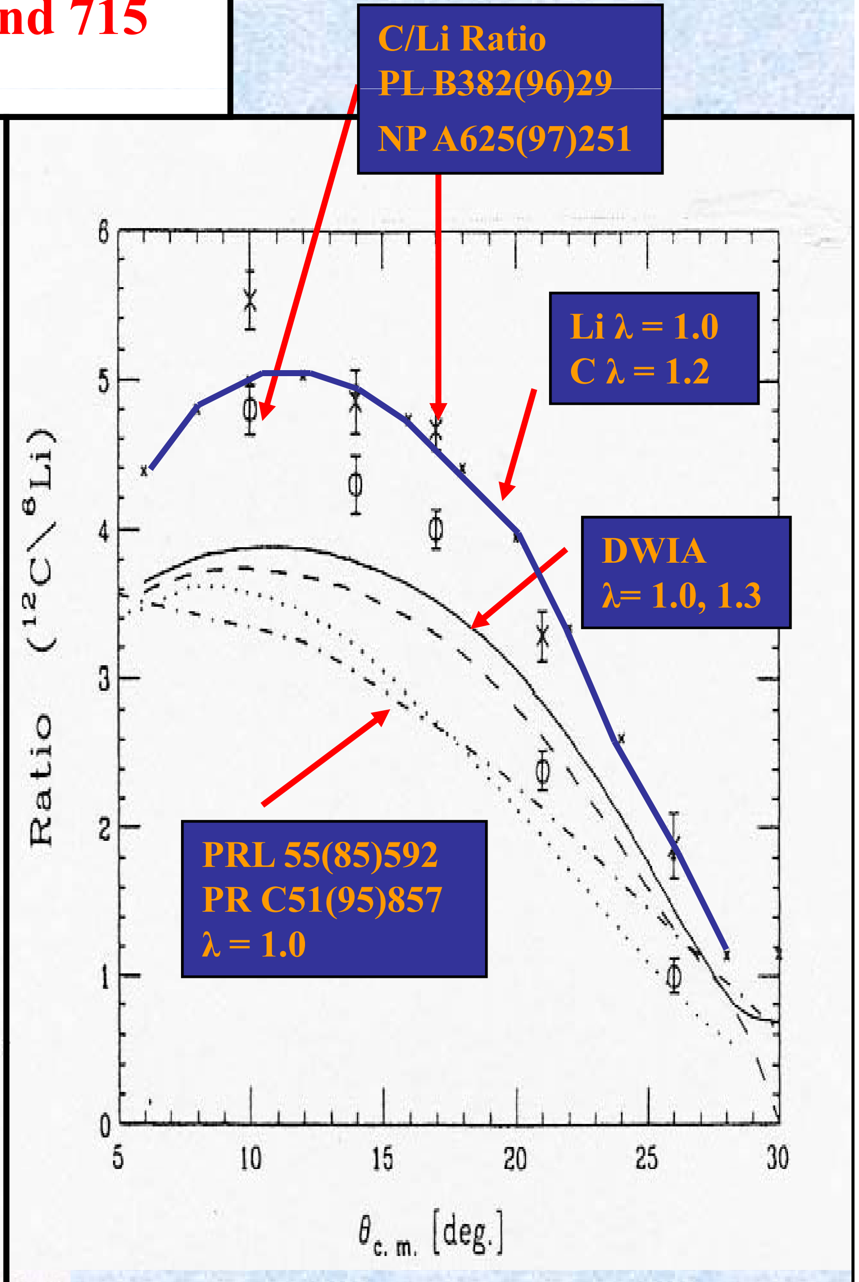
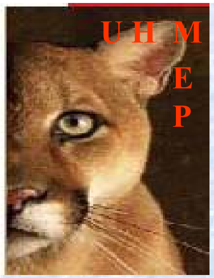
Elastic Scattering on C and Li at 635 and 715 MeV/c







Analysis

PR C(97)1304
PL B396(97)21

- Using a fit to σ_R and σ_T does not produce self consistent results, i.e. optical potentials constructed to fit σ_R and σ_T are not self consistent
- Need an increase of ~15% of Im V_{opt} for Li plus an additional 17-25 % of nuclear dependence
- A density threshold is added – use a linear density dependence for Im V_{opt} of the form

$$\alpha = 1 + \beta(\bar{\rho} - \rho_o)\Theta(\bar{\rho} - \rho_o)$$

$\rho_o = 0.088$; $\beta = 13.0$

$\bar{\rho}$ the average nuclear density

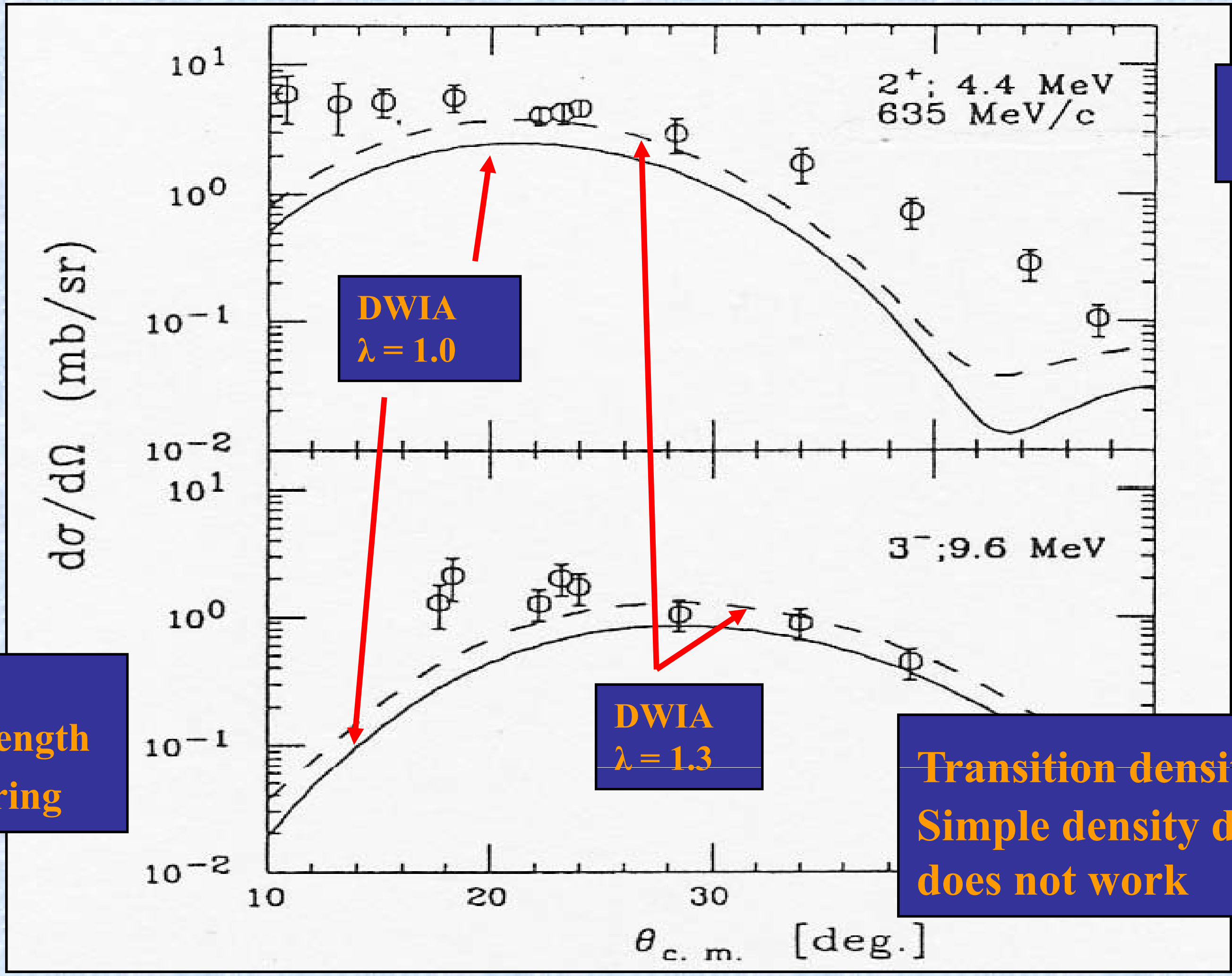
$$V_{opt} \rightarrow \mathrm{Re}\, V_{opt} + \mathrm{Im}\, V_{opt}\, [\,\alpha\,]$$

- $\rho_o > \bar{\rho}\,(\mathrm{Li}) = 0.049$

- **Self consistent fits for σ_R, σ_T, and V_{opt} are possible**

Inelastic Scattering

PL B382(96)29



ρ (C) = 0.104
ρ (T) = 0.063

DWIA uses Transition Strength from π Scattering

Transition density < ρo
Simple density dependence does not work

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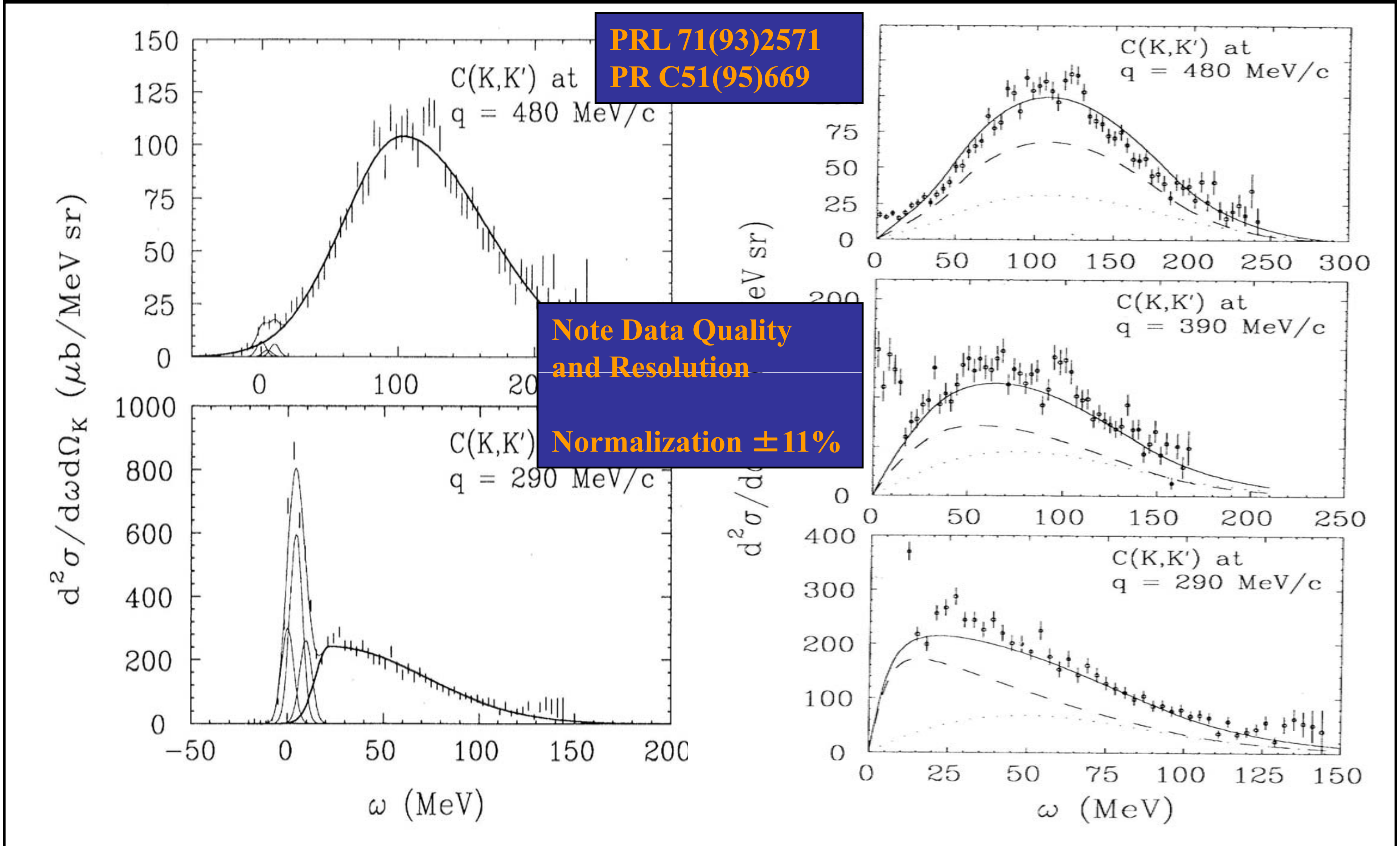
Quasi_free Scattering On D, C, Ca, and Pb



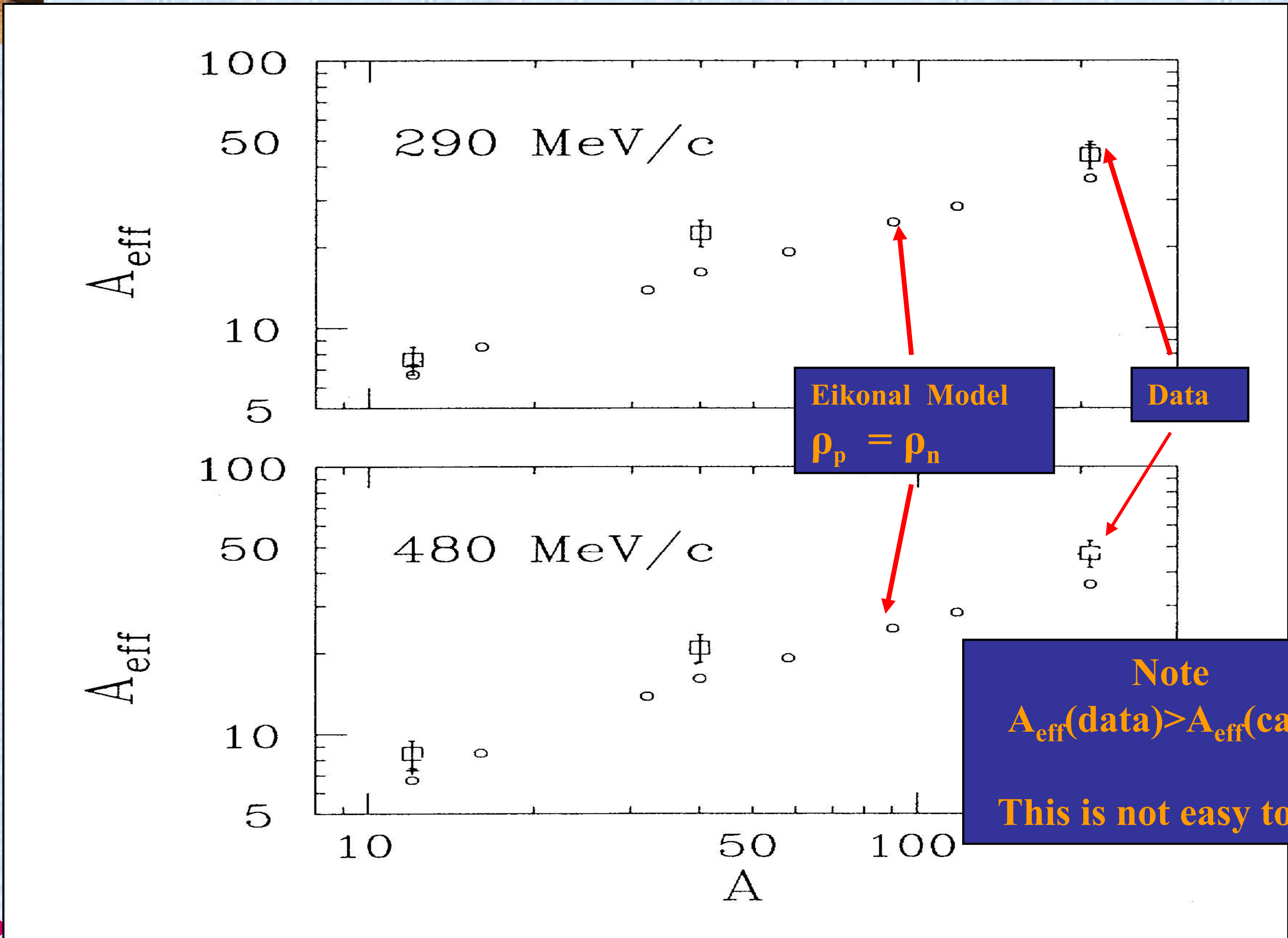
PRL 71(93)2571
PR C51(95)669

Note Data Quality and Resolution

Normalization ±11%

U H M
E
P

Number of Effective Nucleons



Note

A_{eff}(data)>A_{eff}(calc)

This is not easy to do

K^+ Ca Quasi Free in Analogy to EM Theory q = 500 MeV/c

PR C51(95)806

- Developed relativistic response in analogy to EM Scattering
- EM response (Dirac V-A) expressed in Coulomb/Transverse – Coulomb quenched
- 4-vector current-current formulation for K^+ and IA for nuclear response
- Nuclear current obtained from the Walecka model with ρ, ω, σ exchange
- Relativistic RPA applied to get the coherent nuclear response
- EM quenching due to the polarization of Nucleon sea – relativistic effect
- K^+ quenching is small and sensitive to cancellation of kinematics and Relativistic RPA
- Still need some renormalization so A_{eff}(exp) is used but shape is correct

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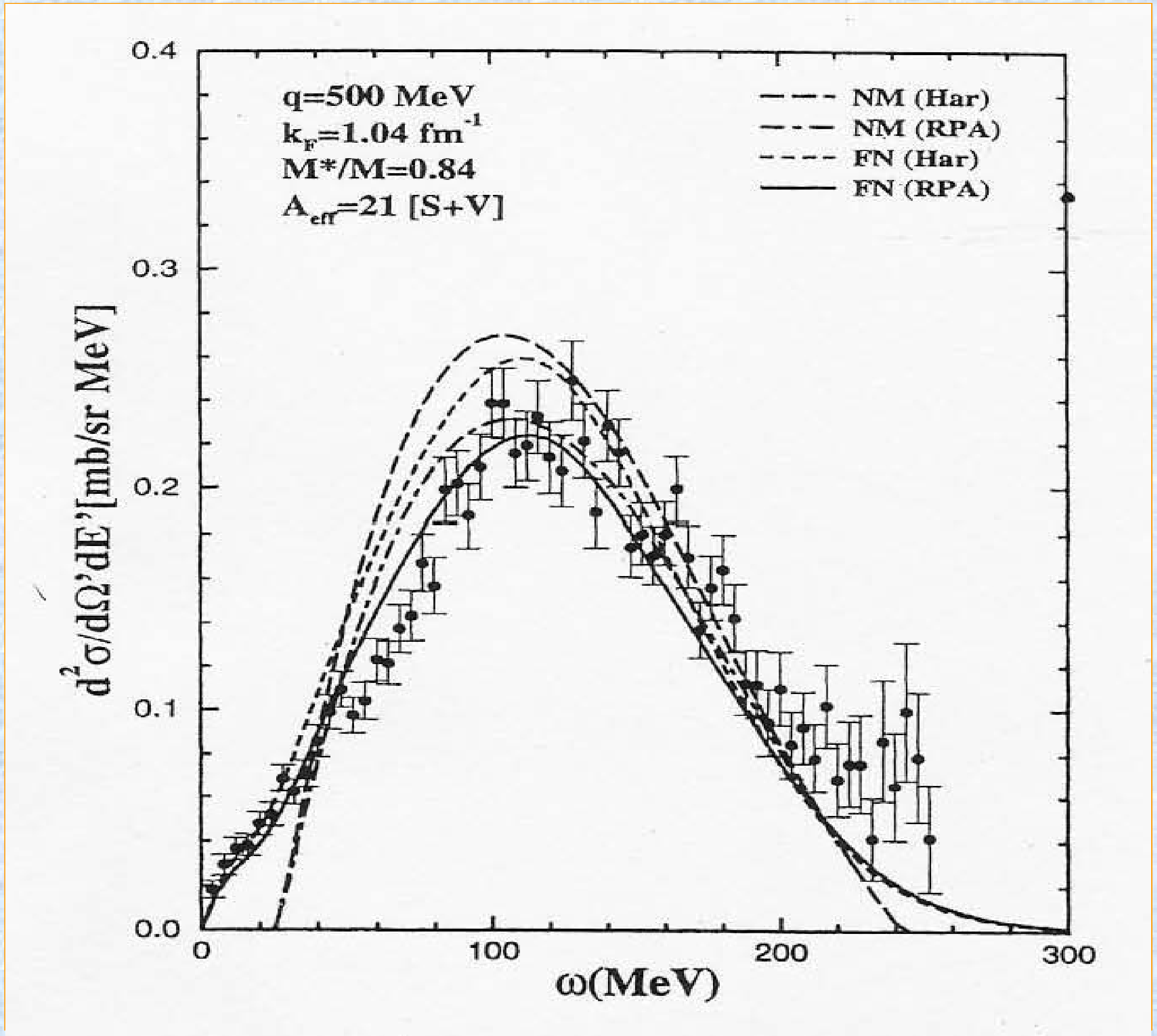
K^+ Ca Quasi Free in Analogy to EM Theory
q = 500 MeV/c

PR C51(95)806



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A Possible Round of New Experiments

Previous Experimental Parameters

- K^+ Momentum – 500 - 800 MeV/c
- K^+ flux -- 3 x 10^5 s^{-1} instantaneous; 0.5 x 10^5 s^{-1} avg
- π/K – 1
- At 500 Mev/c $\beta\gamma c\tau$ = 3.8m – Survival 0.12 at 8m
- Acceptance – 15%
- Beam Dimensions – 8 x 3 cm^2 - dispersed
- Targets – Mostly Natural 2-4 g/cm^2
- ΔE – 3 - 4 MeV (FWHM)
- $\Delta\theta$ – 2 - 4 Deg
- PID especially for pions and protons
- Attention to Normalizations
- Dominated by systematics – 15%

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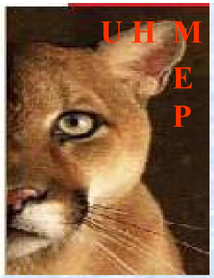

Conclusions

- Reaction, total, elastic, inelastic, quasi-free all seem to have the same problem(s)
- While it appears that the issue is related to nuclear density, a simple, direct dependence does not seem to work
- The data seem to indicate an increase in the Im V_{opt} with perhaps a more attractive real component
- Last review [NP A639(98)485c] suggests that there are possible "missing" medium effects in theory
- Final paper in response to a possible Θ^+ -- Nuclear density might enhance $K^+ nN \rightarrow \Theta N$?? [PRL 94(05)072301]

Have we asked the right questions ?

We need more data and more inspired theory

The End