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Nuclear Physics in the 1990's

Hadronic Probes*

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*transparencies for

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Goals for Nuclear Physics (NSAC Long Range Plan 1983)

"we must attempt to find experimental signatures for modes of excitation in which the quark degrees of freedom participate individually, not merely as the underlying structure of nucleons and mesons"

"the richness of QCD will give rise to a diversity of phenomena requiring study with a corresponding diversity of probes"

"effective exploration of the interface between nuclear physics and QCD necessarily involves, in addition to electromagnetic facilities, consideration of relativistic heavy ion collisions and of hadronic probes which address complementary fundamental aspects of this interface"

Amen

Scope of physics at a high intensity "kaon factory"

a very broad interdisciplinary program, comprising

a) Nuclear Physics (to be discussed)

b) Particle Physics (extensions of the standard model
rare decays to test symmetries
and constrain masses of new
particles, ...)

c) Condensed Matter Physics (μ spin resonance ....)

Message: interpret "nuclear physics" in the
broadest sense → expand its
intellectual content

Future Hadron Facilities (also leptons)

object: provide numerous intense particle beams of variable energy

Particle species:

a) Mesons ($\pi^{\pm}$, $K^{\pm}$, K_L)

b) Baryons (p, n, Λ, Ξ ....)

c) Antibaryons ($\bar{p}$, $\bar{n}$, $\bar{d}$ ....)

d) Leptons ($\mu^{\pm}$, ν ....)

FOCUS OF THIS TALK: strong interactions of strange and antibaryon probes

A Basic Question: understand the relevant <u>degrees of freedom</u> required to explain nuclear phenomena

↳ leads us to a study of the confinement mechanism of quarks within hadrons and nuclei

↳ branches of the problem:

a) hadron spectroscopy beyond $Q\bar{Q}$, Q^3 (hybrids, glueballs....)

b) modification of hadron structure in the nuclear medium (EMC-like effects with hadron probes) partial deconfinement

c) hadron breakdown to quark-gluon plasma at high (ρ, T) total deconfinement

We know quarks and gluons are in the nucleus, but to what extent need they be treated explicitly?

Some aspects of nuclear physics in the long term:

a) <u>new probes of old spectroscopies</u>

$\rightsquigarrow K^{\pm}, K_L, \bar{p} \ldots \longleftrightarrow e^-, p, n, \pi, \ldots$

exploit <u>unique features</u>: $K^+ \to$ long mean free path
$\bar{p} \to$ extreme surface localization

b) <u>new spectroscopies</u>

$Q^2\bar{Q}^2, Q\bar{Q}g$ hadrons
strange dibaryons
$S = -1, -2, -3 \ldots$ hypernuclei

c) study of nuclear response to <u>large</u> momentum transfer q or energy deposition ω

<u>Common themes</u>: hadronic vs. quark-gluon picture
understand successes of effective Lagrangians in the hadronic basis (vector mesons....;
develop a calculational scheme for non-perturbative QCD

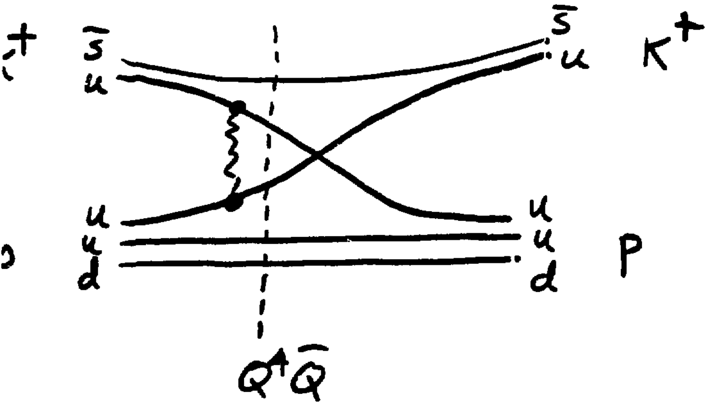
TWO BODY AMPLITUDES

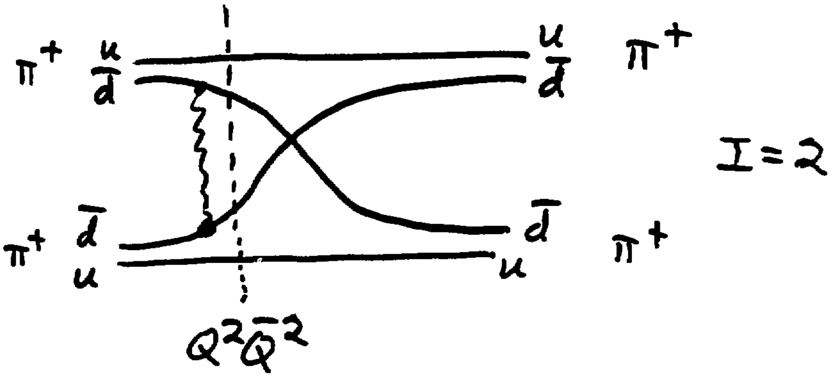
Two-Body Meson-Baryon Interactions:

Is perturbative one gluon exchange/quark exchang a useful approximation?

Perhaps, if intermediate state is "exotic" (not $Q\bar{Q}$ or Q^3)

Examples: (Pirner, Dosch ....)





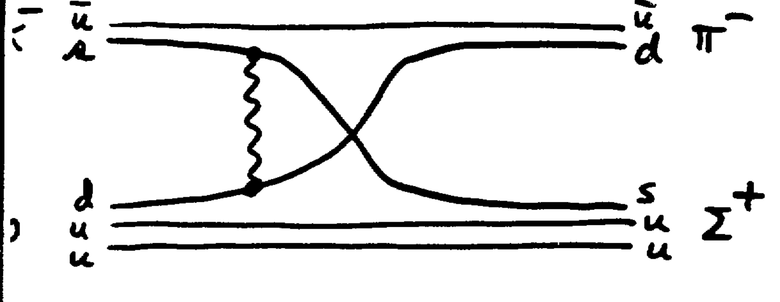
above are rearrangement (R) processes

→ no $Q\bar{Q}$ annihilation (A) graph occurs

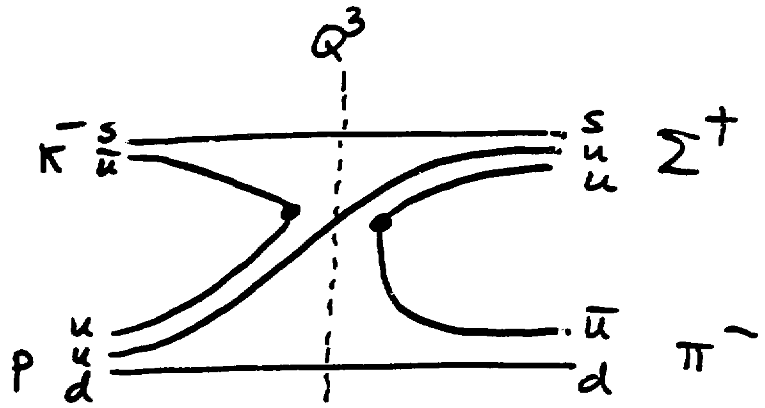
However, if both R and A graphs occur,

A will dominate

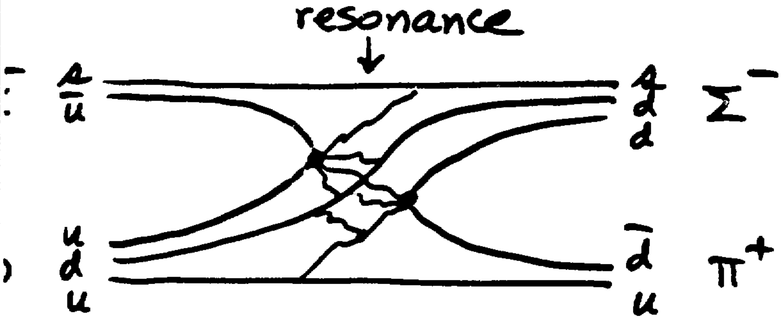
Example: $\bar{K}N \to \pi\Sigma$



R



A



A

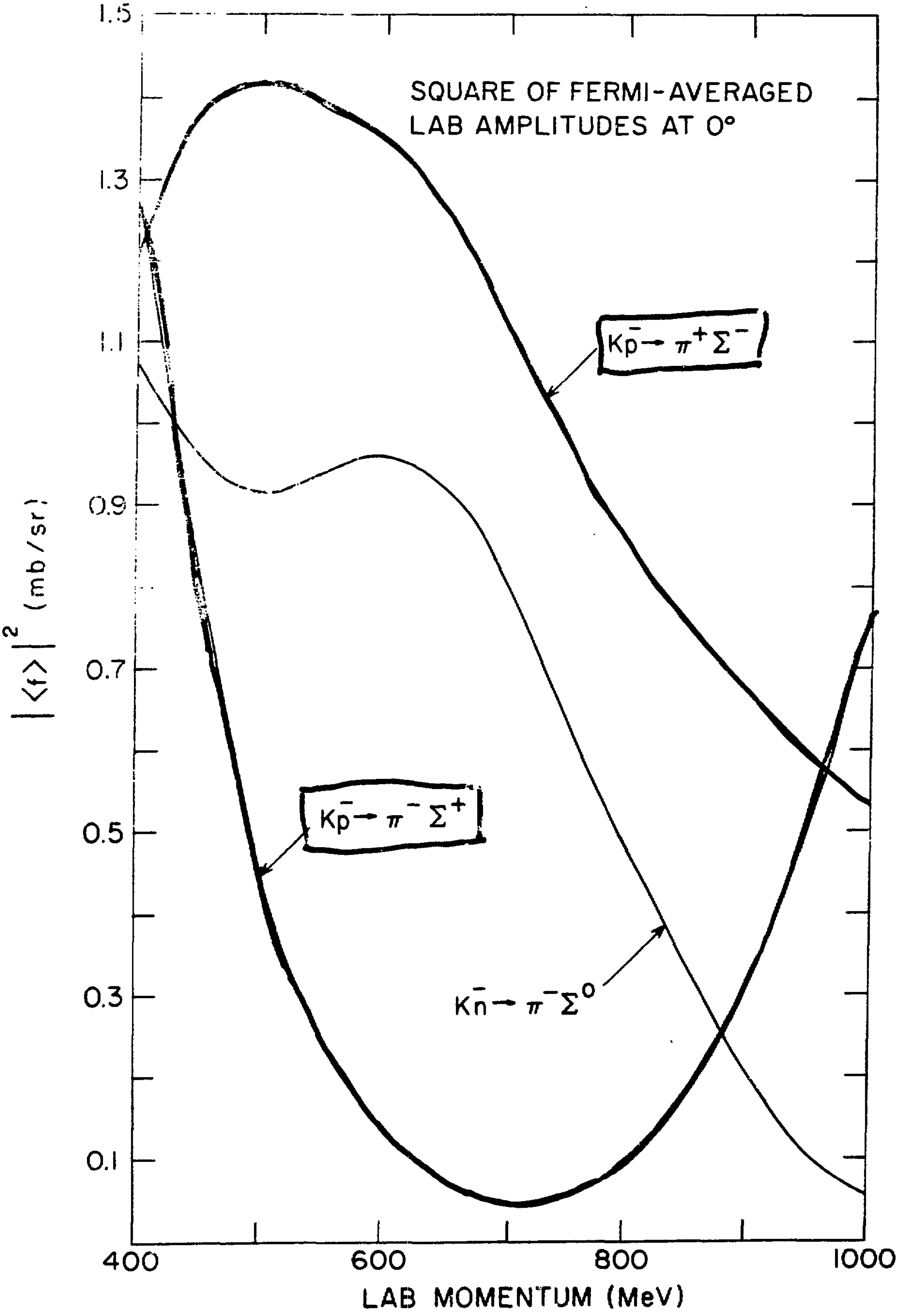
If R dominates → $\sigma_{K^-p \to \pi^+\Sigma^-} = 0$

Experimentally, $\boxed{\sigma_{K^-p \to \pi^+\Sigma^-} > \sigma_{K^-p \to \pi^-\Sigma^+}}$ from 0.4-0.9 GeV/c

⟹ A > R, with resonant intermediate states

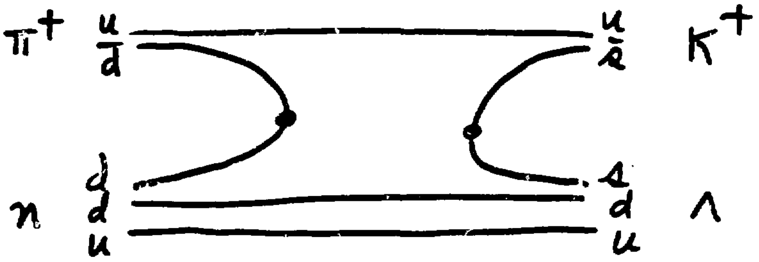
Lesson: $\boxed{\text{If } Q\bar{Q} \text{ annihilation is possible, it will dominate perturbative R process}}$

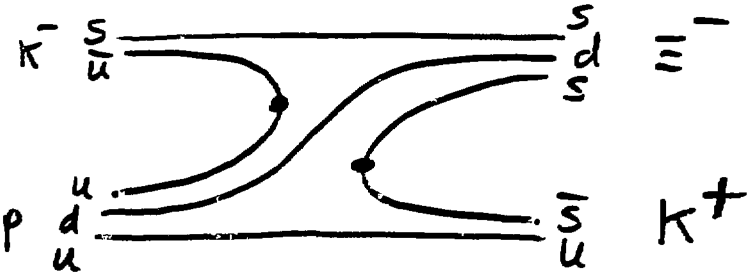
→ the problem of meson-baryon is non-perturbati

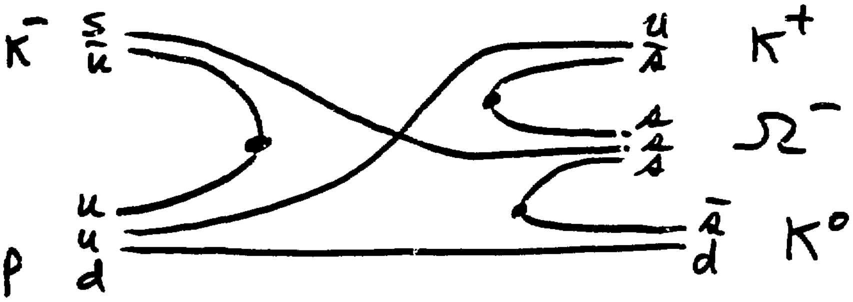

SQUARE OF FERMI-AVERAGED
LAB AMPLITUDES AT 0°
$K^-p \to \pi^+\Sigma^-$
$K^-p \to \pi^-\Sigma^+$
$K^-n \to \pi^-\Sigma^0$
$|\langle f \rangle|^2$ (mb/sr)
1.5
1.3
1.1
0.9
0.7
0.5
0.3
0.1
400
600
800
1000
LAB MOMENTUM (MeV)

Associated Production Reactions:

Here no R graph, only A







These processes tell us the strength of $s\bar{s}$ pair creation

$\rightarrow$ $\boxed{\text{reveal } SU(3)_{\text{flavor}} \text{ dependence of } Q\bar{Q} \text{ annihilation/creation}}$

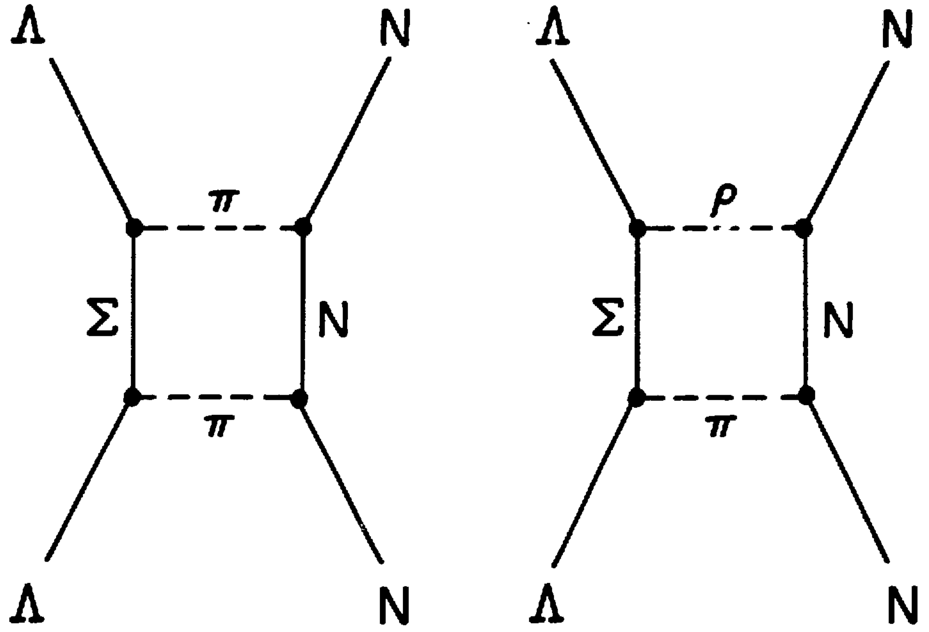
Message: Except possibly for K^+p, meson-baryon amplitudes are resonance dominated, and hence intrinsically non-perturbative

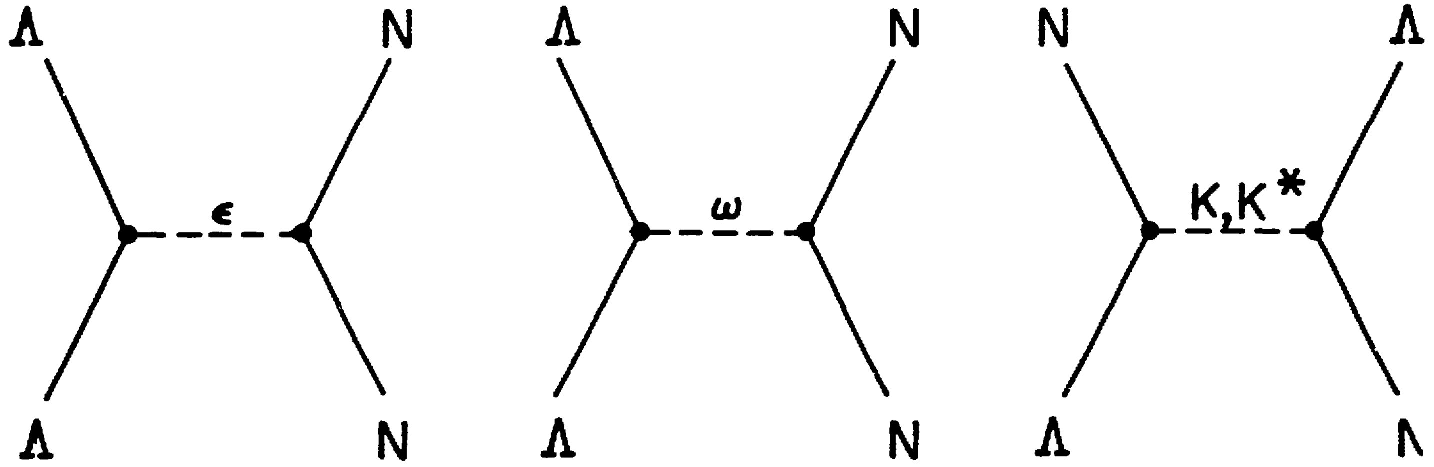
↳ if we want to calculate "medium corrections" in QCD, must understand $Q\bar{Q}$ annihilation as "doorway"

Quark/gluon vs. Meson Exchange Description of Strange Particle Interactions

emphasis on <u>spin-orbit</u> part

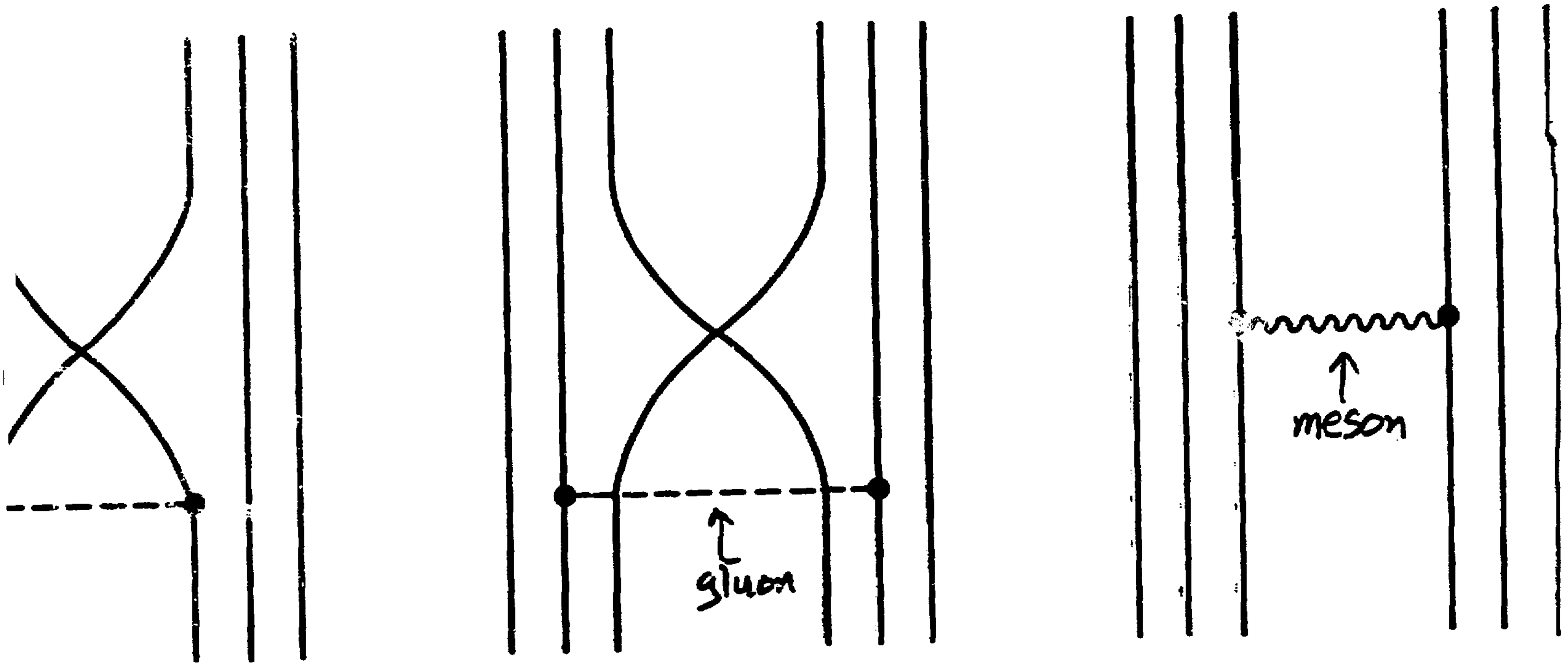
CONVENTIONAL MESON EXCHANGE MODELS





de Swart et al (non-relativistic, coordinate space)
Speth et al (relativistic, momentum space, à la Bonn)

T RANGE BARYON-BARYON INTERACTION IN QUARK MODEL



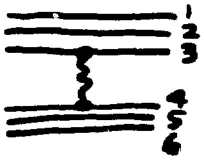
(a) (b)

perturbative quark-gluon exchange

(c)

meson exchan
between quar

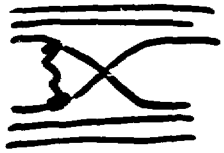
Technical details:

The ME graph  has spin-flavor factor

$$(\underset{\sim}{\sigma}_3 + \underset{\sim}{\sigma}_4)(V_0^\omega + V_0^\rho \, \underset{\sim}{\tau}_3 \cdot \underset{\sim}{\tau}_4)$$

or $\{\rho, \omega\}$ exchange. In SU(6), $V_0^\omega = V_0^\rho$, so we get

$$2V_0^\omega (\underset{\sim}{\sigma}_3 + \underset{\sim}{\sigma}_4) P_{34}^\sigma P_{34}^\tau$$

which is identical to the spin-flavor factor for 

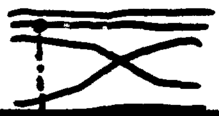
The same equivalence holds for strange quark and K^* exchange

Conclusion:

One gluon/quark (s,u,d) exchange
⟺ vector meson exchange [spin-flavor]

only distinction is radial/energy dependence

↳ hard to distinguish quark/gluon and meson exchange mechanisms from Σ spin-orbit splitting

Note:  smaller than 

STRANGE PARTICLE NUCLEAR PHYSICS

Why strange probes?

a) production of hypernuclei and study of their spectroscopy and decay

b) access to physics of strange dibaryons

c) Drell-Yan processes

K^+ offers prospect of studying effect of nuclear medium on the strange quark sea

($K^+ = \bar{s}u$ only gives annihilation with sea "s" quarks,
$K^- = s\bar{u}$ involves both valence + sea)

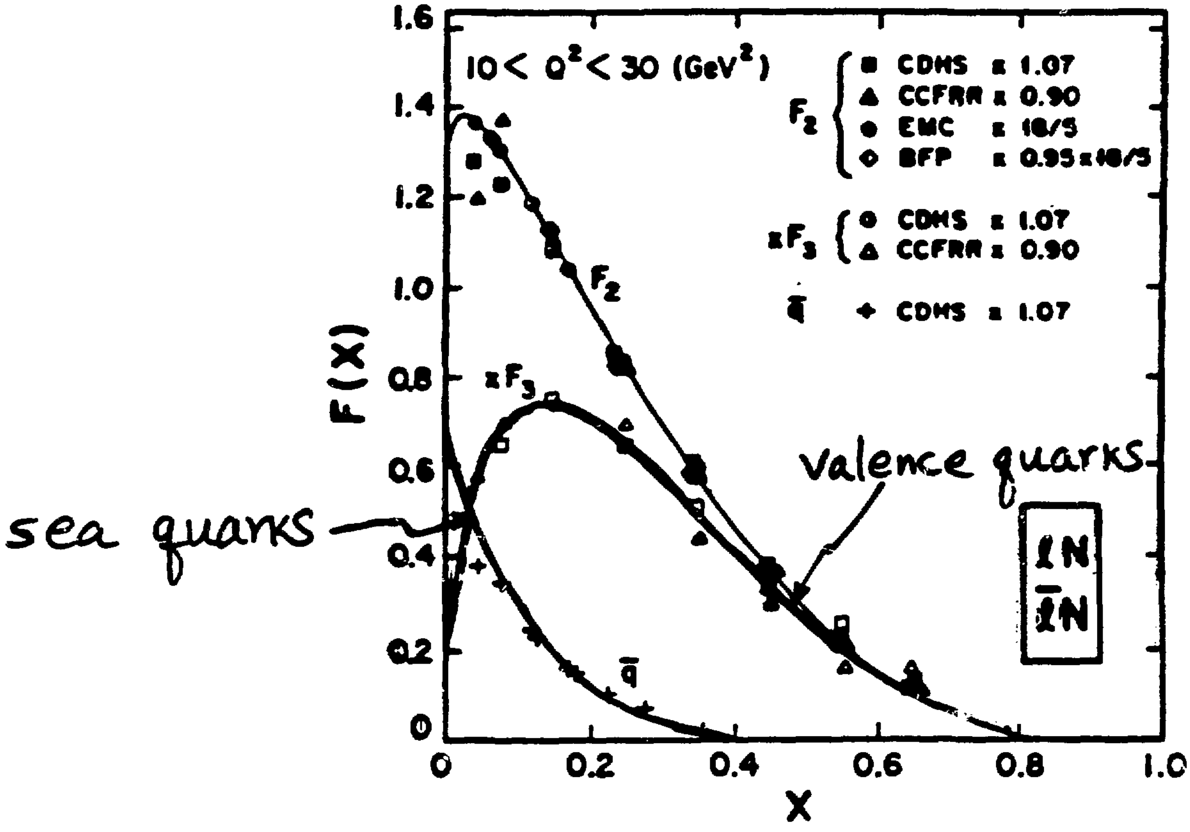
Note $\frac{2\bar{s}}{\bar{u}+\bar{d}} \approx \frac{1}{2}$ for nucleon

d) K^+-nucleus scattering and tests of partial deconfinement

⋮

DRELL-YAN PROCESSES AND THE $Q, \bar{Q}$ STRUCTURE FUNCTIONS IN THE NUCLEUS

STRUCTURE FUNCTIONS FOR THE NUCLEON



sea quarks

valence quarks

$$xF_3(x) = 3.6\,x^{0.55}(1-x)^{3.2}$$

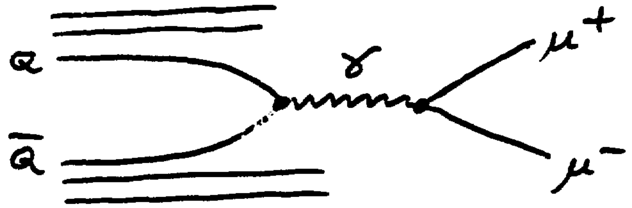
$$F_2(x) = 3.9\,x^{0.55}(1-x)^{3.2} + 1.1\,(1-x)^8$$

$$\bar{Q}(x) = 0.7\,(1-x)^8$$

Rev. Mod. Phys. 56, 561 (1984)

PRODUCTION OF LEPTON PAIRS IN HADRON-NUCLEUS

DRELL-YAN PROCESS:



$$\frac{d^2\sigma}{dM_{\mu\mu}\,dx_F} = \frac{8\pi\alpha^2}{9M_{\mu\mu}^3}\sum_i e_i^2\,\frac{x_1x_2}{x_1+x_2}\left[q_i(1)\,\bar{q}_i(2)+\bar{q}_i(1)\,q_i(2)\right]$$

where $x_F = \underset{\substack{\uparrow\\ \text{incident}\\ \text{hadron}}}{x_1} - \underset{\substack{\nwarrow\\ \text{target}}}{x_2}$; x = momentum fraction

a) proton-induced: $R_{\bar{q}} = \dfrac{\sigma^{pA}}{\sigma^{pN}} \sim \dfrac{\overset{\substack{\text{antiquarks}\\ \text{in the nucle}\\ \swarrow}}{\bar{u}^A(x_2)}}{\underset{\substack{\uparrow\\ \text{antiquarks in}\\ \text{the nucleon}}}{\bar{u}^N(x_2)}}$ $\quad x_1 >> x_2$

(J. Moss et al, P-772
at FERMILAB)

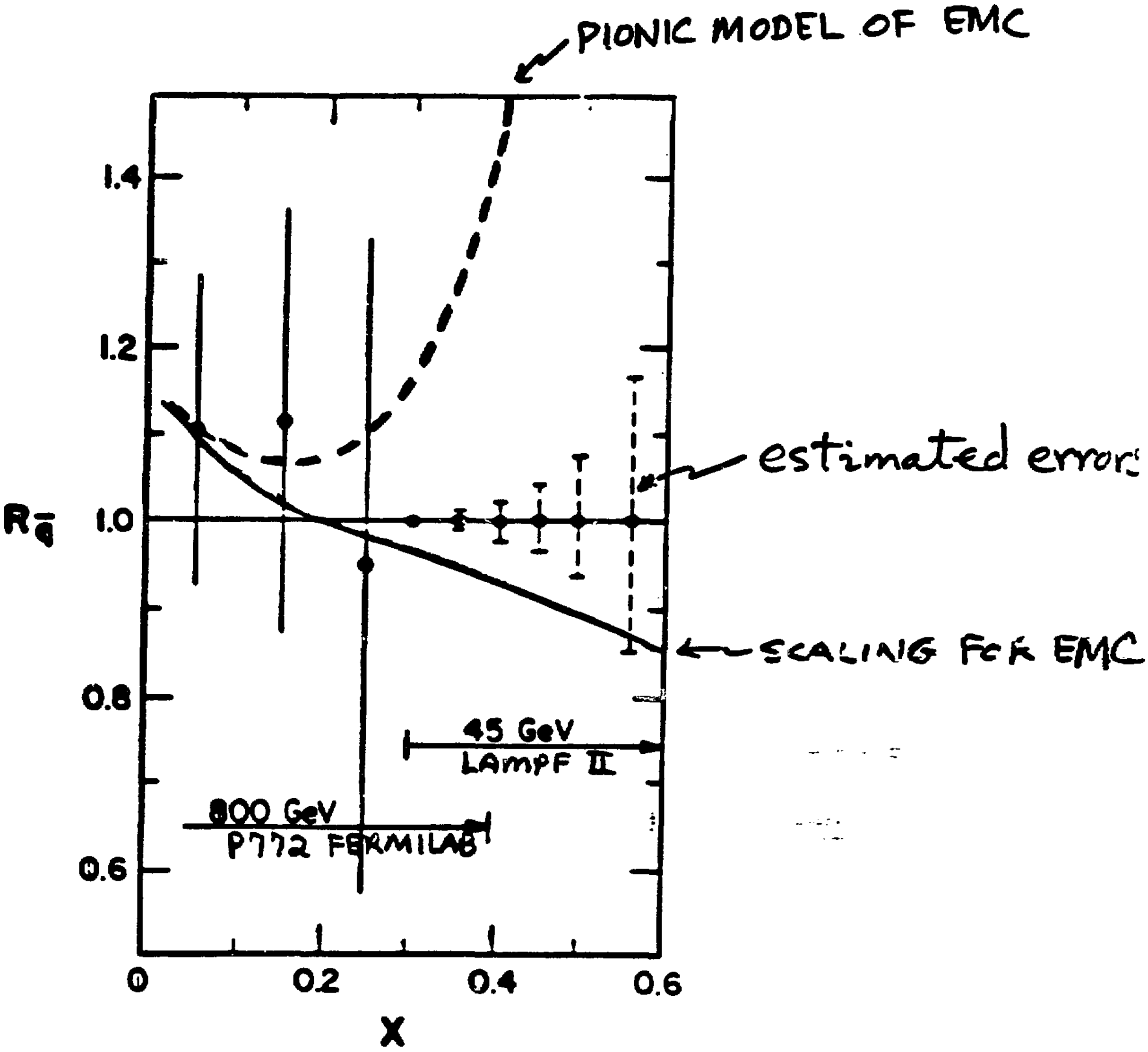
b) kaon-induced

$K^+ \longrightarrow$ effect of nuclear medium on strange quark sea [$\bar{s}$ in K^+ + s in nucl.]

$K^- \longrightarrow$ annihilation with both valence and sea

Note: $2\bar{s}/(\bar{u}+\bar{d}) \approx 1/2$ in the proton

RATIO OF ANTIQUARK DISTRIBUTIONS $R_{\bar{q}}$



$$R_{\bar{q}} = \bar{u}^{Fe}(x)/\bar{u}^{d}(x)$$

data from ν and $\bar{\nu}$ measurements of F_3

Why study hypernuclei?

a) a new many-body spectroscopy

- → look for dynamical symmetries which are forbidden for ordinary nuclei
- → rôle of "tagged" strange quark as impurity
- → remnants of SU(3) symmetry

Properties: $J^{\pi}(I)$, $\underbrace{\mu,\ B(E2),\ \beta,\gamma \text{ deformations}}_{\text{all unmeasured}}$

b) deduce effective hyperon-nucleon interaction

- → shed light on rôle of strange quarks in strong interactions

c) new information on four fermion weak interaction through $\Lambda N \rightarrow NN$ decay modes of hypernuclei

⋮

Possible Signatures for Quark Effects in Hypernuclei: Questions for discussion

a) Pauli blocking at the quark or hadron level?

effect on hypernuclear binding

↝ Pauli blocking of ud quarks in Λ produces repulsion; advocated by some as cure for $^{5}_{\Lambda}\mathrm{He}$ overbinding

Conventional cure: three body + tensor forces
suppression of $\Lambda N \leftrightarrow \Sigma N$ for $^{5}_{\Lambda}\mathrm{He}$

b) partial deconfinement of strange quarks

unlike a nucleon, we can dump a Λ into any shell model orbit → in principle study the density dependence of any deconfinement effect

↝ probe the persistency of $(sud)_{I=0}$ clustering deep inside the nucleus

signatures:
- decay widths of $s^{\Lambda}_{1/2}\, s^{-1}_{1/2}$ states
- isospin mixing in hypernuclei
- A dependence of shell spacing $\hbar\omega$
- weak decay rates of hypernuclei

Why we need a new hadron facility for hypernuclear studies?

The question of the existence and decay modes of narrow Σ and Ξ hypernuclear states is unlikely to be resolved with the current low intensity K^- beams at BNL + KEK

↳ fundamental questions of hyperon well depths, spin-orbit + isospin potentials remain

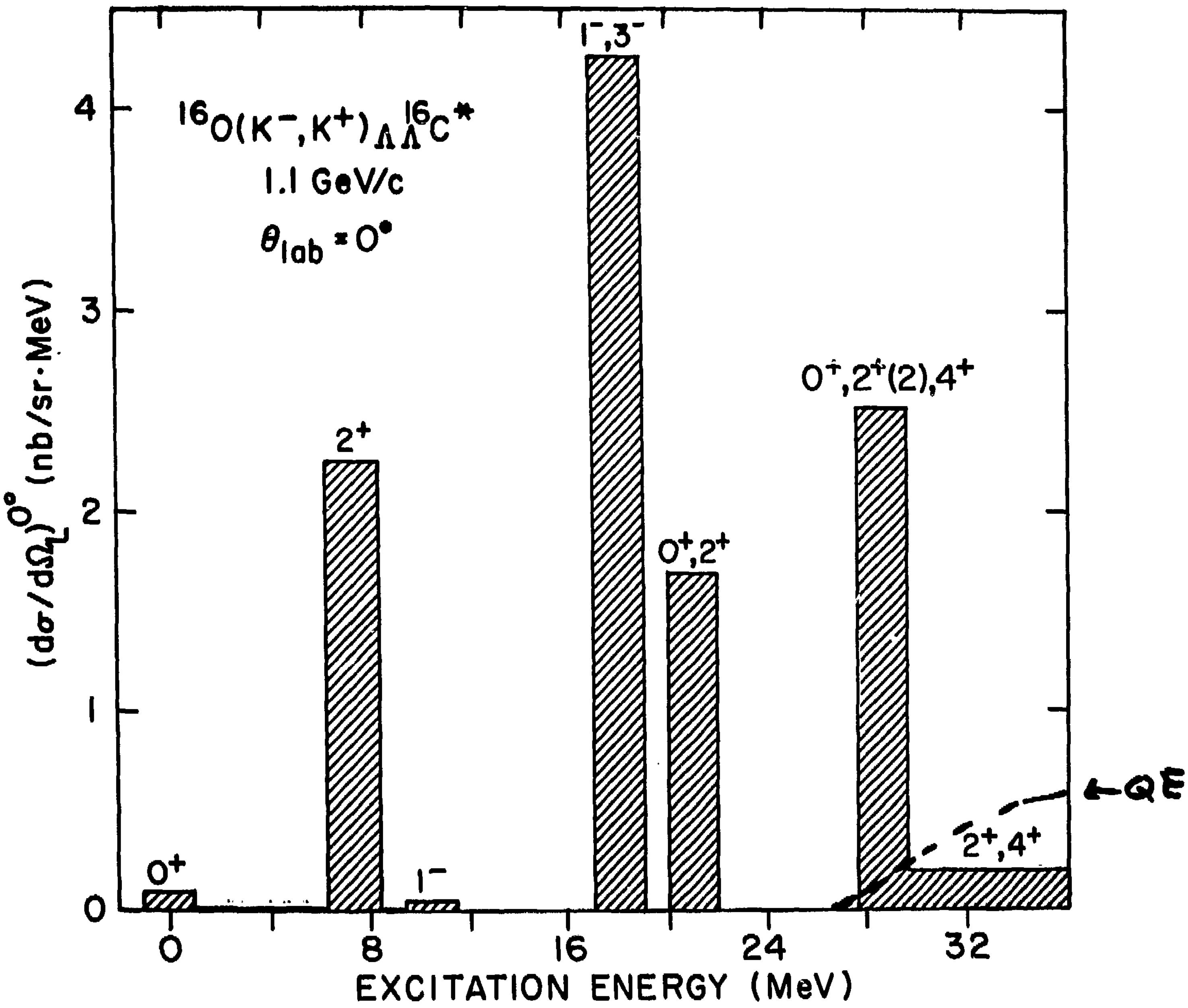
Λ spectroscopy unexplored for large A

↳ but here lie many interesting questions relating to deconfinement

Question of priorities: need a dedicated facility to address hadron/nuclear physics

↳ could enormously increase the pace of research with a factor of 100 in K^- intensity

a theoretical spectrum!



A. J. Baltz, CBD, D. J. Millener, Phys. Lett. 123B, 9 (1983)

K^+-nucleus elastic and total cross sections:

A test of partial deconfinement?

Arguments for utility of K^+ as a nuclear probe:

1) small two-body cross section $(\sigma_{K^+n}+\sigma_{K^+p})/2 \simeq 10$ mb for $k < 500$ MeV/c → unique among hadronic probes

→ long mean free path ($\gtrsim 5$ fm)

probe interior of the nucleus

sensitive to neutron densities

2) rapidly converging multiple scattering series

→ single scattering term dominates σ_T

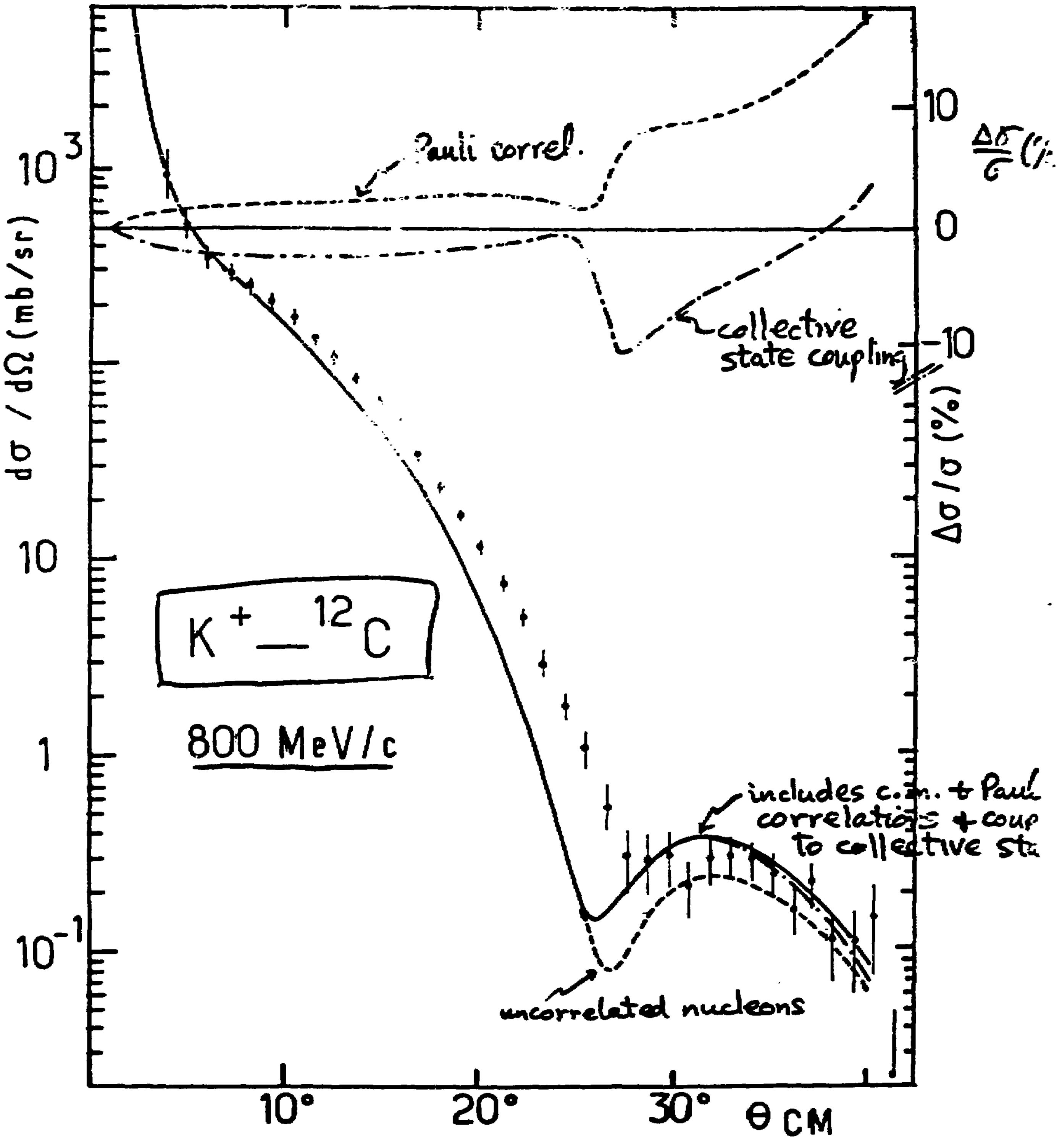
controllable reaction mechanism

$V_{opt}^{K^+} \sim \int \rho \tilde{t}$ is good approximation

Expect $\tilde{t} \approx t$ ↖ free space ampl.

↗ effective ampl. in nucleus

K^+–^{12}C ELASTIC SCATTERING ANGULAR DISTRIBUTION



[illegible] C25. 2619 (1982) data

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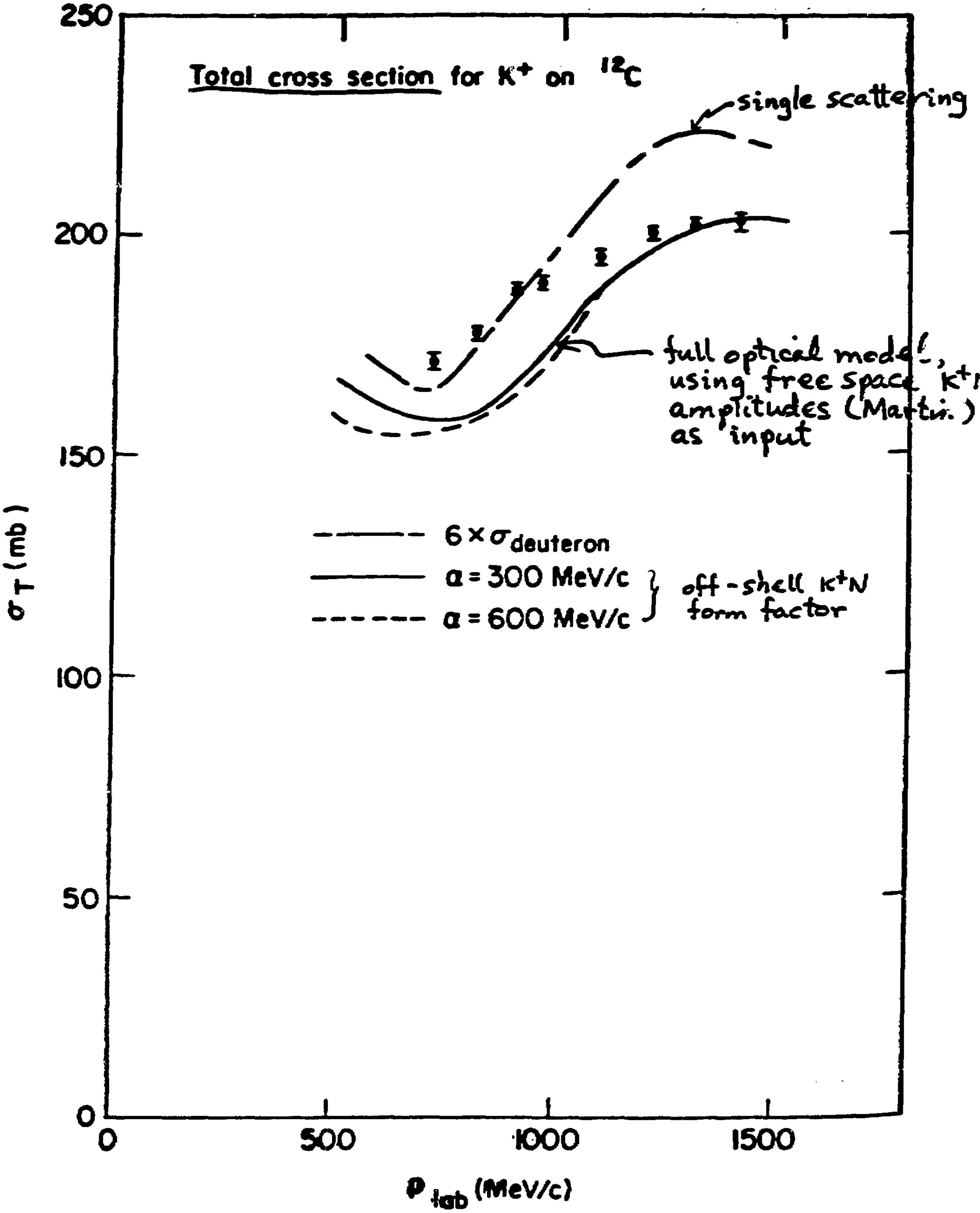


Bugg et al, Phys. Rev. 168, 1466 (1968) [data]
Siegel, Kaufmann + Gibbs, Phys. Rev. C30, 1256 (1984) [calc.]

Simple Interpretation:

In optical limit of Glauber approximation,

$$\boxed{\sigma^T = 4\pi\int_0^\infty b\,db\,\{1-e^{-2\,\mathrm{Im}\,\chi(b)}\cos(2\,\mathrm{Re}\,\chi(b))\}}$$

where

$$\chi(b) = \langle\sigma\rangle(i+\beta)T(b)/4$$

$$T(b) = \int_{-\infty}^{+\infty} dz\,\rho(r)$$

$$\beta = \mathrm{Re}\langle f_{K^+N}\rangle / \mathrm{Im}\langle f_{K^+N}\rangle \text{ at } 0^\circ$$

$$\langle\sigma\rangle = (\sigma^T_{K^+p} + \sigma^T_{K^+n})/2$$

To second order, for a Gaussian density $\rho(r) = \rho_0 e^{-r^2/R^2}$ and $\langle r^2\rangle_A^{1/2} = r_0 A^{1/3}$, we have

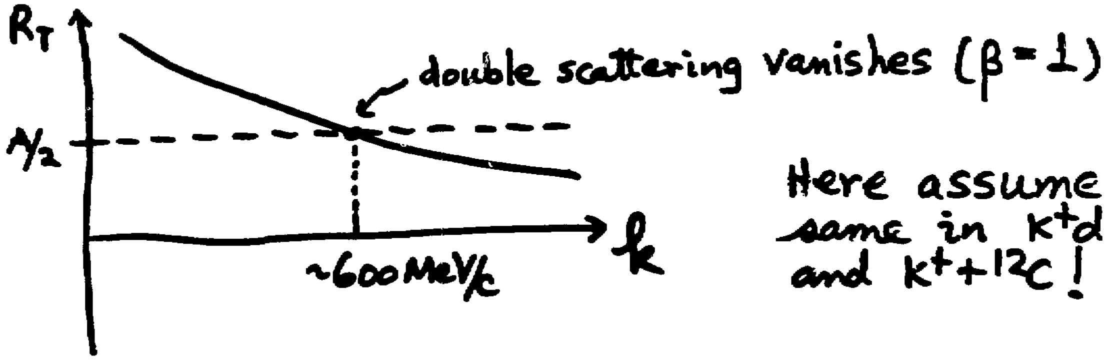
$$\sigma^T \approx A\langle\sigma\rangle + \frac{3}{8\pi}\left(\frac{\langle\sigma\rangle}{r_0}\right)^2 A^{4/3}(\beta^2-1)$$

and

$$\boxed{R_T = \frac{\sigma^T(K^++A)}{\sigma^T(K^++d)} \approx \frac{A}{2}\left[1 + \frac{3A^{1/3}}{8\pi}\frac{\langle\sigma\rangle}{r_0^2}(\beta^2-1)\right]}$$

so for $\beta < 1$ (large k), we get shadowing ($R_T < 1$) and for $\beta > 1$ (low k), anti-shadowing results ($R_T > 1$)

Thus



Here assume $\langle\sigma\rangle$ same in K^+d and $K^+ + {}^{12}C$!

Effect of partial deconfinement on K^+-nucleus scattering:

At low momentum ($k \le 400\,\mathrm{MeV/c}$), s-wave K^+N dominates, and

$$\delta_{S_{11}}^{K^+N} \approx -kR \quad \text{with } R \approx 0.32\,\mathrm{fm}$$

like hard sphere scattering

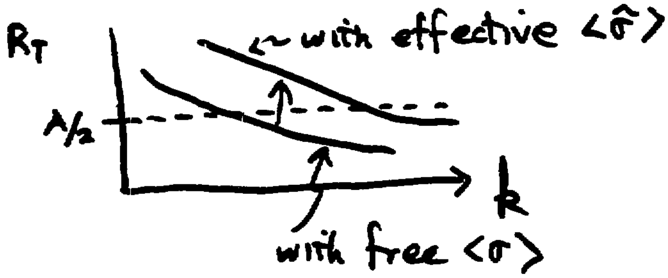
In the nuclear medium, we assume an effective phase shift

$$\tilde{\delta}_{S_{11}}^{K^+N} \approx -k\tilde{R} \quad \text{with } \tilde{R} > R \qquad [\text{"swollen" nucleon}]$$

Then

$$\boxed{R_T \approx \frac{A}{2}\frac{\langle\tilde{\sigma}\rangle}{\langle\sigma\rangle}\left[1 + \frac{3}{8\pi}A^{1/3}\frac{\langle\tilde{\sigma}\rangle}{r_0^2}(\tilde{\beta}^2 - 1)\right]}$$

with $$\frac{\langle\tilde{\sigma}\rangle}{\langle\sigma\rangle} \approx \frac{\sin^2(k\tilde{R})}{\sin^2(kR)} \approx \begin{cases} 1.15 & k = 0.5\,\mathrm{GeV/c} \\ 0.9 & k = 1\,\mathrm{GeV/c} \end{cases} \qquad \begin{matrix} R = 0.32\,\mathrm{fm} \\ \tilde{R} = 0.35\,\mathrm{fm} \end{matrix}$$



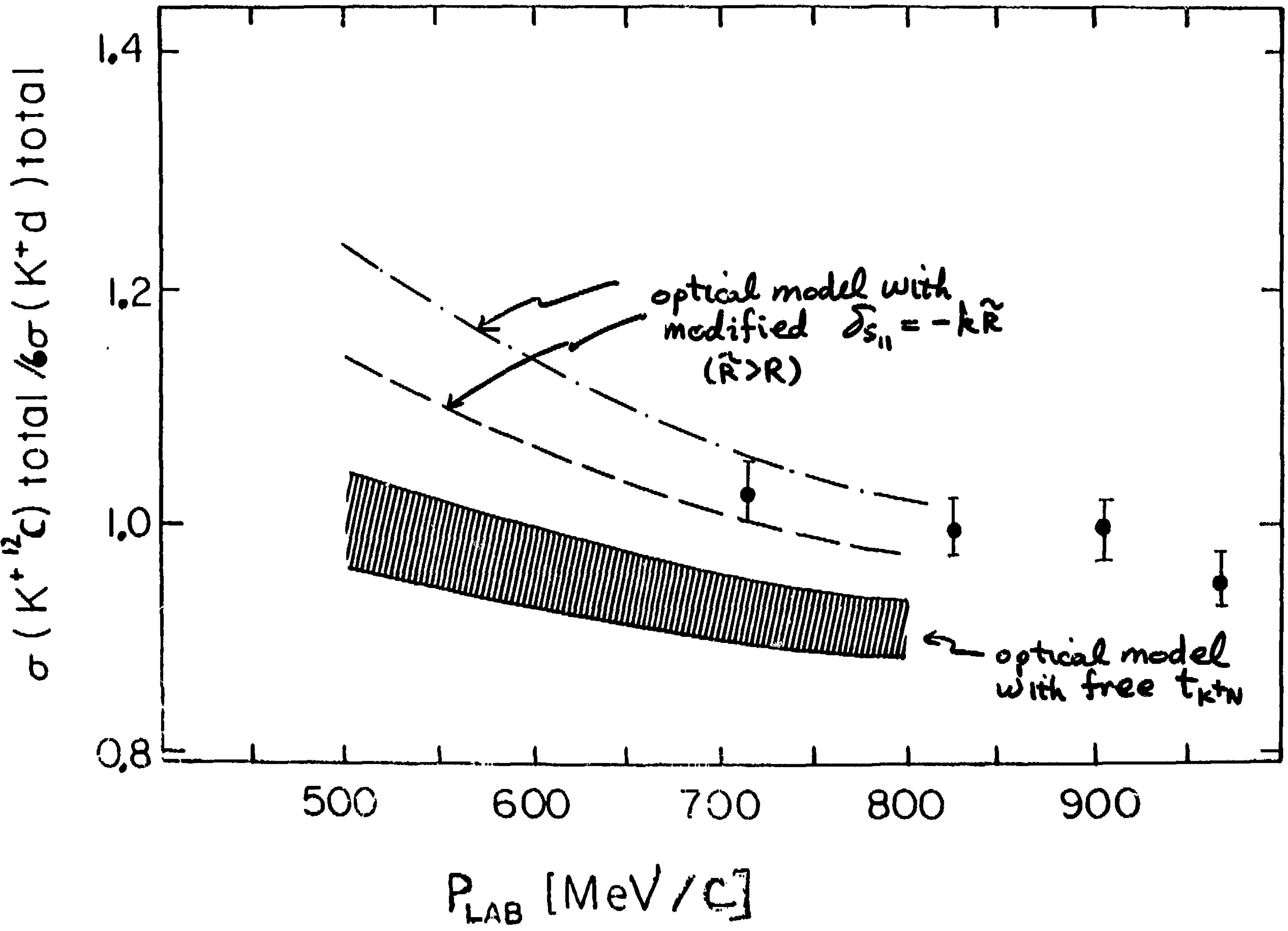
Suggestion : even better to measure ratio R_r of total reaction cross sections σ^R → independent of $\tilde{\beta}$

$$\sigma^R \approx A\langle\tilde{\sigma}\rangle - \frac{3A^{4/3}}{8\pi}\left(\frac{\langle\tilde{\sigma}\rangle}{r_0}\right)^2$$

$$\sigma^E \approx \frac{3A^{4/3}}{8\pi}\left(\frac{\langle\tilde{\sigma}\rangle\tilde{\beta}}{r_0}\right)^2$$

$$\longrightarrow \boxed{\frac{\sigma^E}{\sigma^R} \ll 1 \text{ for small } \langle\tilde{\sigma}\rangle}$$

RATIO OF TOTAL CROSS SECTION PER NUCLEON FOR $K^+ + d$ AND $K^+ + {}^{12}C$



Proposed experiment: J. Alster et al., AGS proposal 835 (1988)
Theoretical calcs.: P.B. Siegel et al, Phys. Rev. C31, 2184 (1985)

NUCLEAR PHYSICS WITH ANTINUCLEONS

Why antinucleon probes ?

a) nuclear structure studies

$(\bar{p}, \bar{p}')$
$(\bar{p}, \bar{n}) \rightarrow$ like (n, p)

Main features : very strong absorption
coherent tensor forces → spin effect

b) $\bar{N}$ annihilation on nucleons and nuclei

baryon exchange models () are unjustified at low energy and have little predictive power

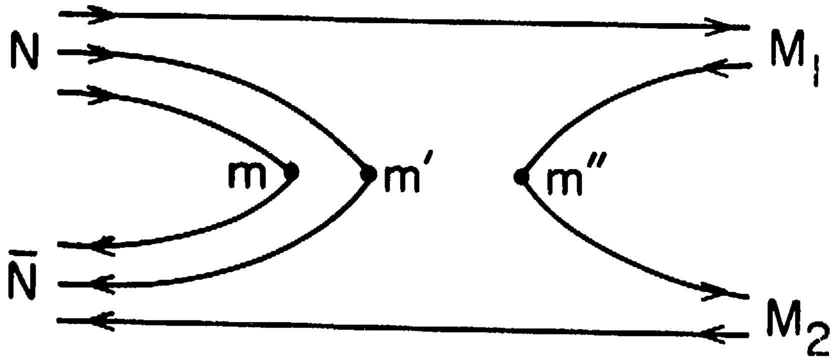
→ the short range annihilation phenomenon must necessarily be described at the quark level

$\bar{N}$ - nucleus studies useful for

→ nuclear equation of state

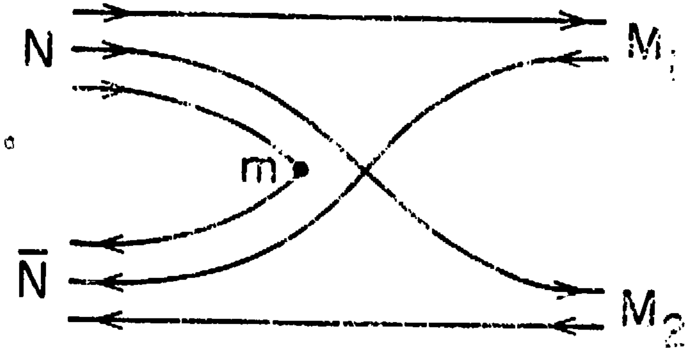
→ production of localized regions of quark-gluon plasma under favorable circumstances (important multinucleon proc.)

MECHANISMS FOR $N\bar{N}$ ANNIHILATION INTO TWO MESONS



A

"annihilation"



R

"rearrangement"

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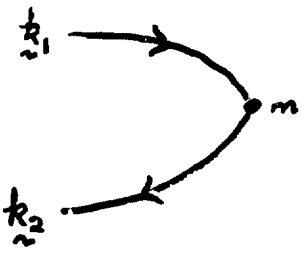
How to choose the $Q\bar{Q}$ annihilation vertex?

Possibilities:

1) ${}^3P_0$ model ($Q\bar{Q}$ pair has quantum nos. of vacuum $0^{++}(0^{+})$)



$$\mathcal{O}_{{}^3P_0} = \lambda_P \underset{\underset{\text{flavor}}{\uparrow}}{\chi_f}\, \underset{\underset{\text{color}}{\uparrow}}{\chi_c}\, \underset{\underset{\text{spin}}{\uparrow}}{\chi_m}\, \underset{\underset{\text{LS Clebsch}}{\uparrow}}{(1m\,1{-m}|00)}\, \underset{\underset{\text{P-wave}}{\uparrow}}{\mathcal{Y}_{1,-m}(\underset{\sim}{k})}$$

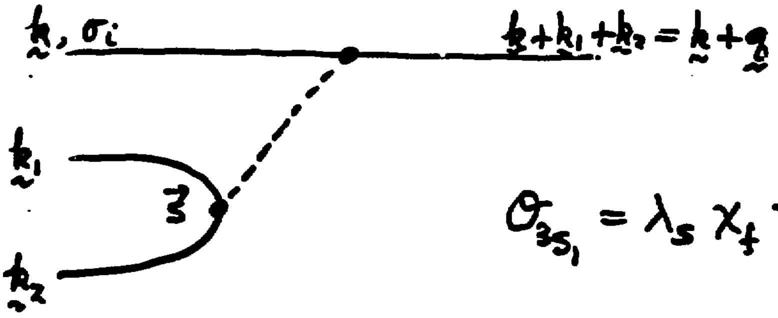
$\chi_f = (u\bar{u}+d\bar{d}+s\bar{s})/\sqrt{3}$

$\chi_c =$ color singlet 1_c

$$\chi_m = \begin{cases} \uparrow\uparrow & m=1 \\ (\uparrow\downarrow+\downarrow\uparrow)/\sqrt{2} & m=0 \\ \downarrow\downarrow & m=-1 \end{cases} \qquad S=1$$

APPROPRIATE FOR
STRONG COUPLING LIMIT
OF QCD
→ flux tube model (Isgur)

2) one gluon model (${}^3S_1$ vertex)



$$\mathcal{O}_{{}^3S_1} = \lambda_S\, \chi_f\, \chi_c\, \vec{\xi}\cdot(\vec{\sigma}_i \times \vec{q})$$

$\chi_c =$ color octet 8_c

WEAK COUPLING LIMIT
OF QCD

MESSAGE:

approximate selection rules in $N\bar{N}$ annihilation reveal the *quark-gluon dynamics* (or even baryonia!)

spin phenomena in annihilation (ex. polarization of vector mesons) very sensitive to reaction mechanism.

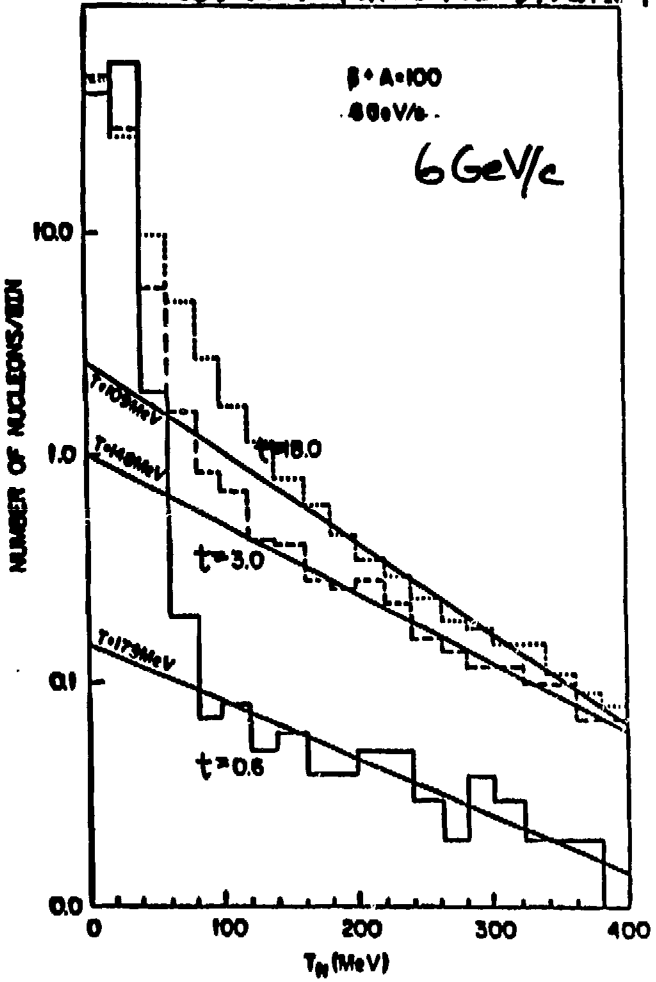
a *premium on $\bar{p}$ beams of the highest possible intensity* to give high precision data on *all* mesonic decay modes, including those with *≥ 1 neutral* and *rare modes* ($\ell\ell$ ....)

$\bar{p}$ INDUCED REACTIONS ON NUCLEI

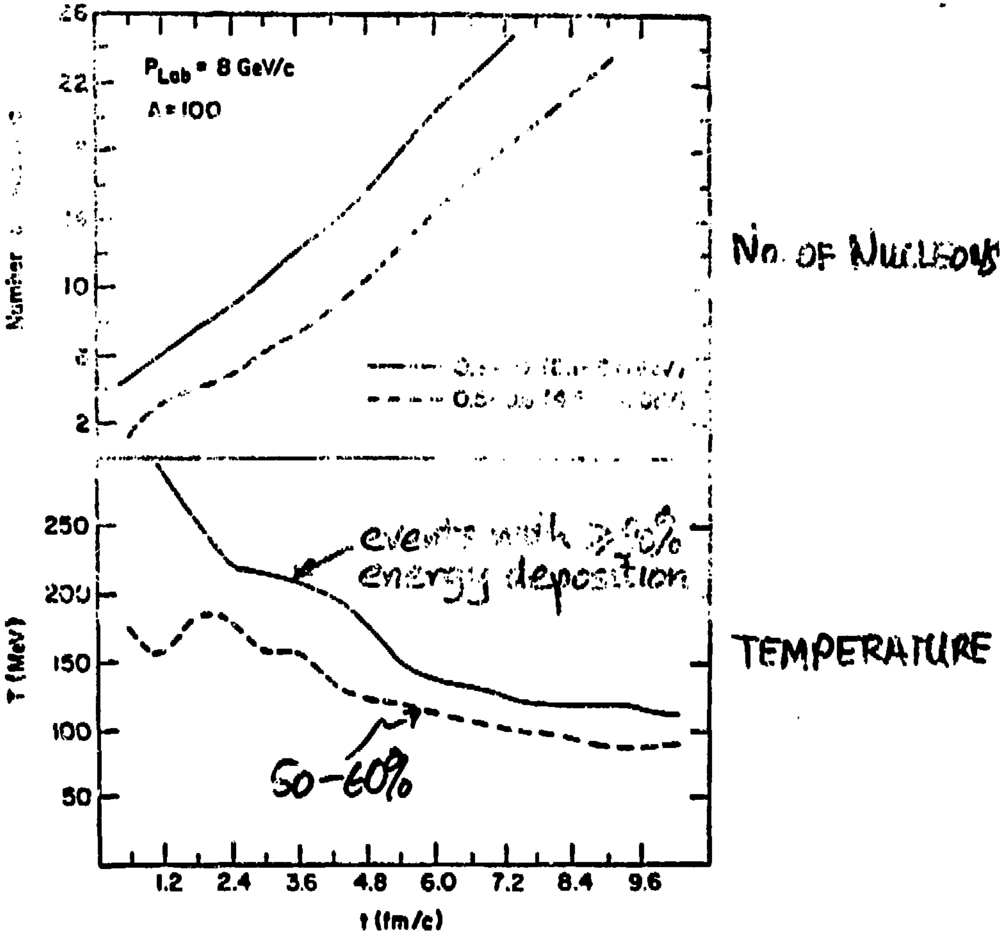
[emphasize large energy deposition or multinucleon aspect]

$\bar{p}$-NUCLEUS ANNIHILATION (cascade)

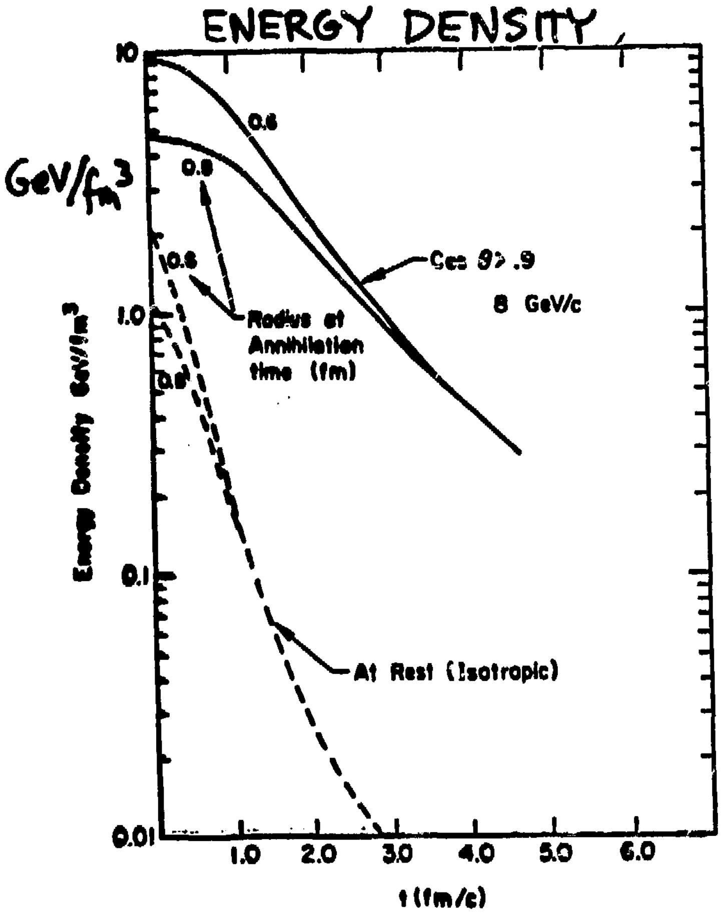
NUCLEON KINETIC ENERGY



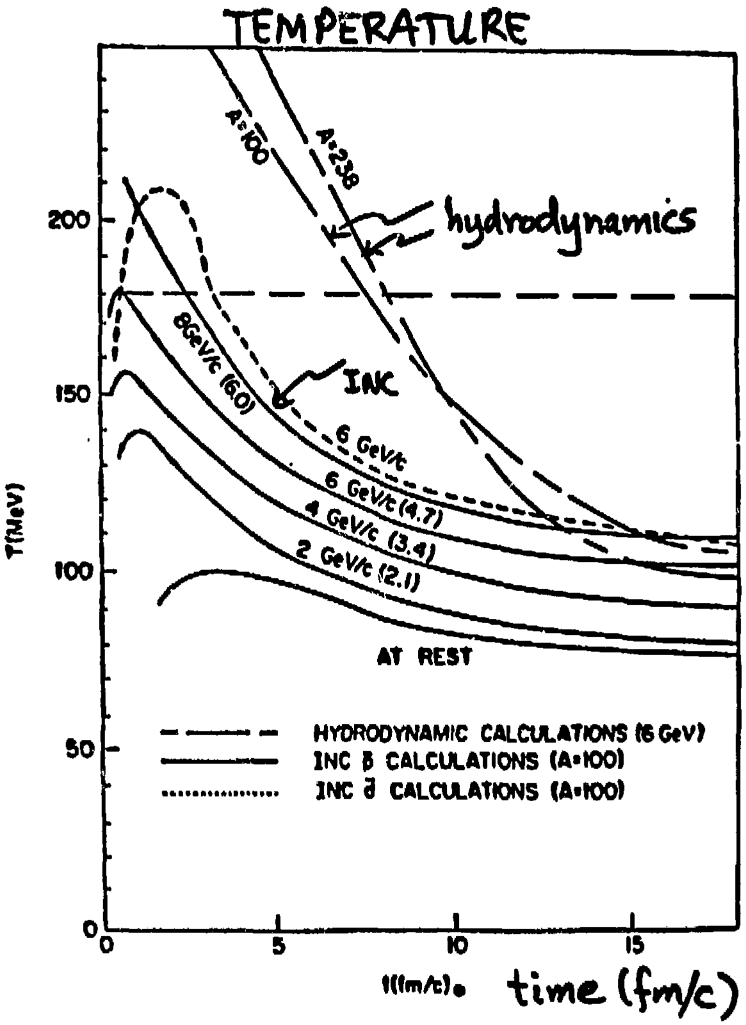
Example of the distribution of nucleon kinetic energies for times 0.6, 3.0 and 18.0 fm/c, illustrating the existence of a "cold" and a "hot" component.



Temperatures and number of nucleons involved in the "hot" distribution as a function of time for two different cuts on energy deposition. The solid curve shows results for > 90% energy conversion to nucleons and the dotted curve for 50-60% deposition.



Total energy density available in the annihilation process at rest and 8 GeV/c $\bar{p}$ momentum.

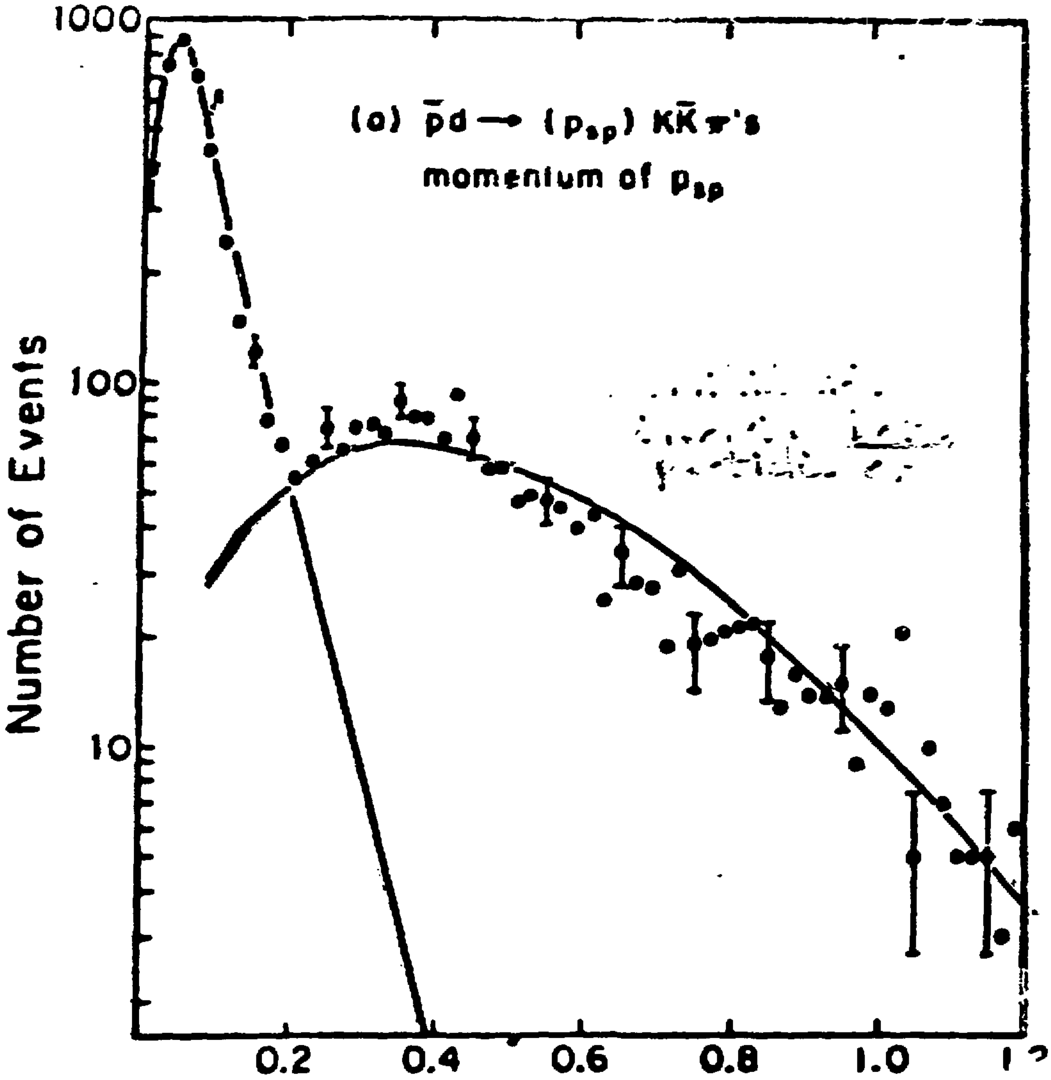


Temperatures achieved as a function of time for the INC and hydrodynamics calculations for various conditions.

STRANGENESS PRODUCTION IN $\bar{P}$-NUCLEUS ANNIHILATION

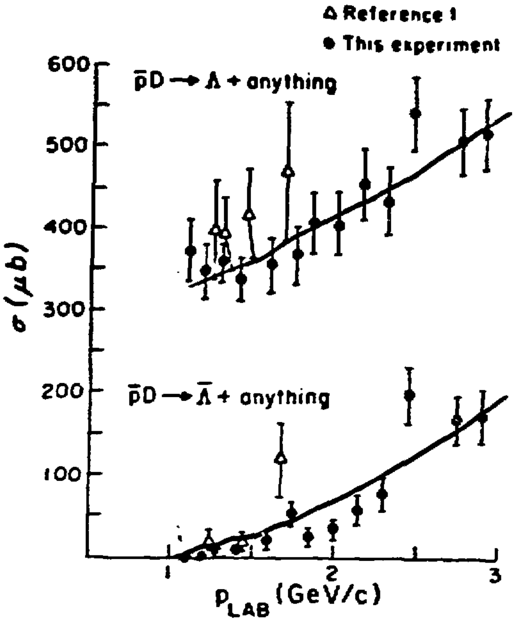
$\bar{p}d \rightarrow p + \bar{K}K + \pi's$

"spectator" events → see momentum distribution characteristic of deuteron wave function



h et al, NP B51,57(1973) Mom. of "Spectator" P (GeV/c)

CROSS SECTIONS FOR $\bar{p}d \to \Lambda + X$, $\bar{\Lambda} + X'$



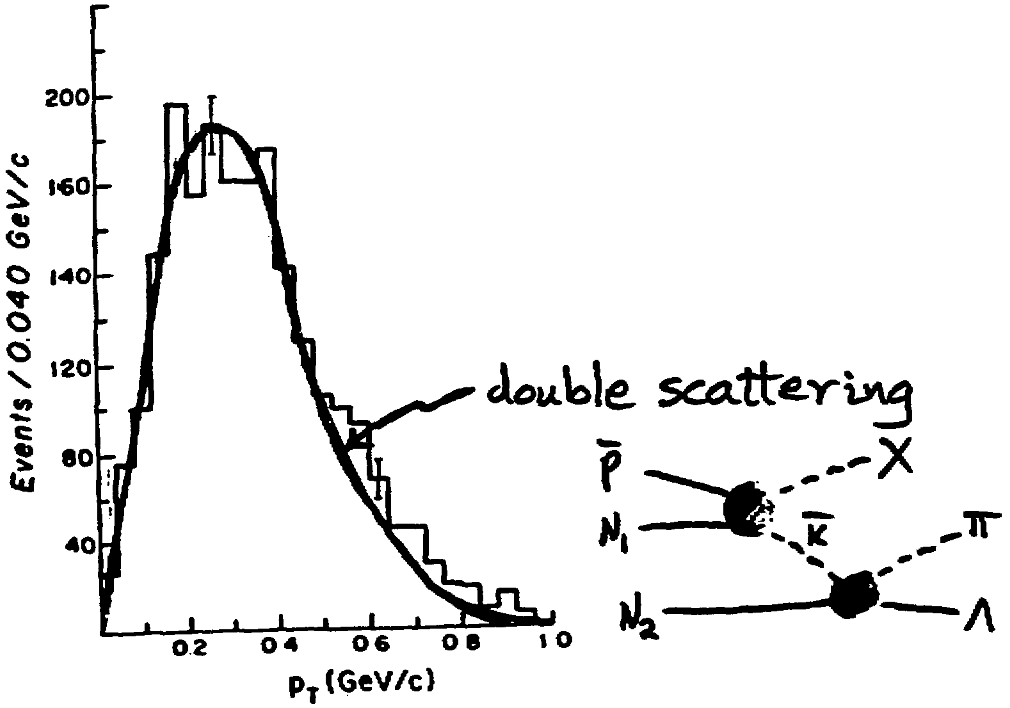
σ (μb)

$\bar{p}d \to \Lambda$

$\bar{p}d \to \bar{\Lambda}$

INCIDENT MOMENTUM

Λ transverse momentum spectrum

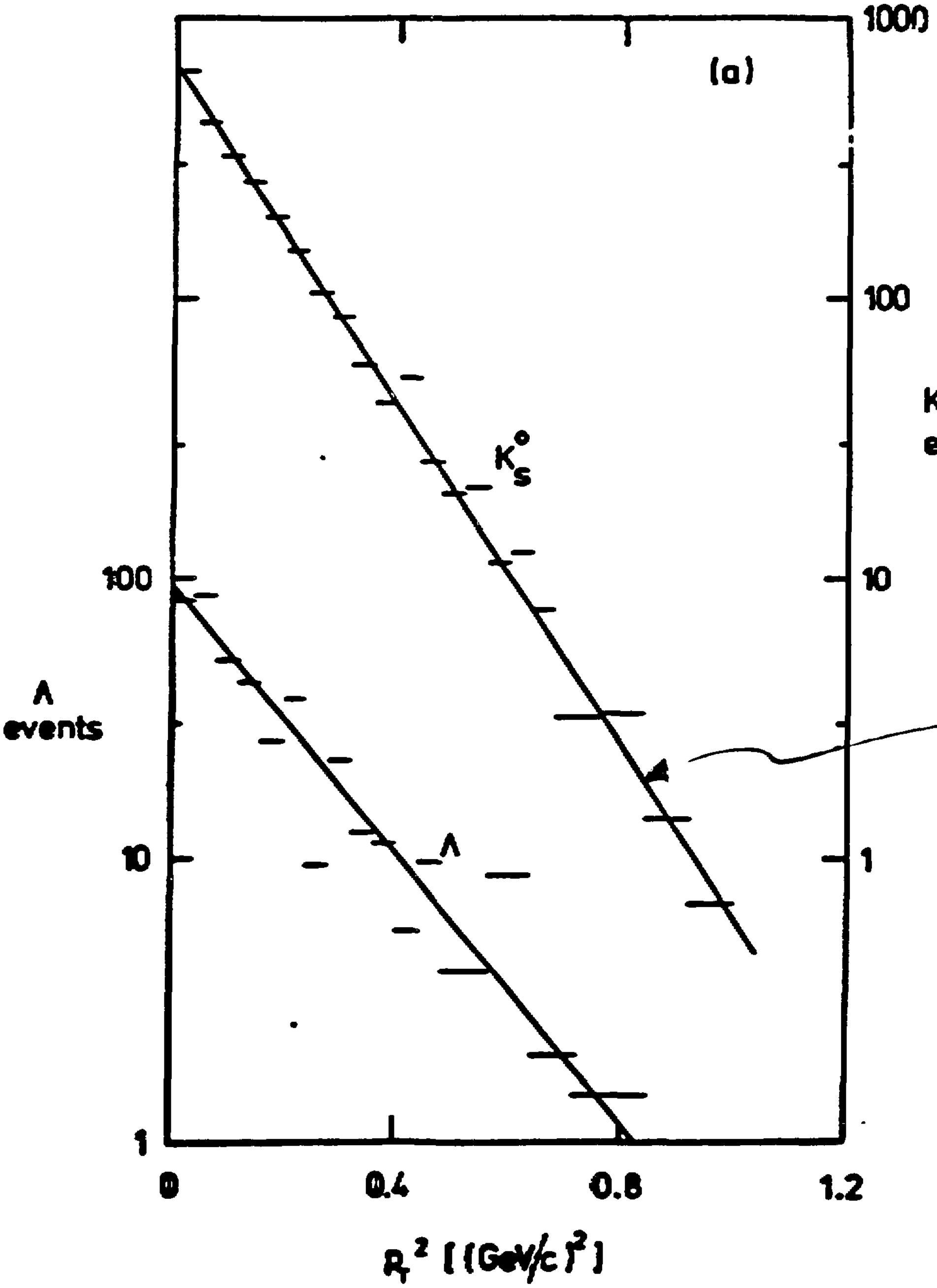


Oh + Smith, Nucl. Phys. B40, 151 (1972)

$\bar{p}d \to K_S$ or Λ INCLUSIVE

(0.4–0.9 GeV/c)

TRANSVERSE MOMENTUM p_T



$$\frac{dN}{dp_T} = N_0\left(\frac{2p_\perp}{p_0^2}\right)e^{-\frac{p_\perp}{p_0}}$$

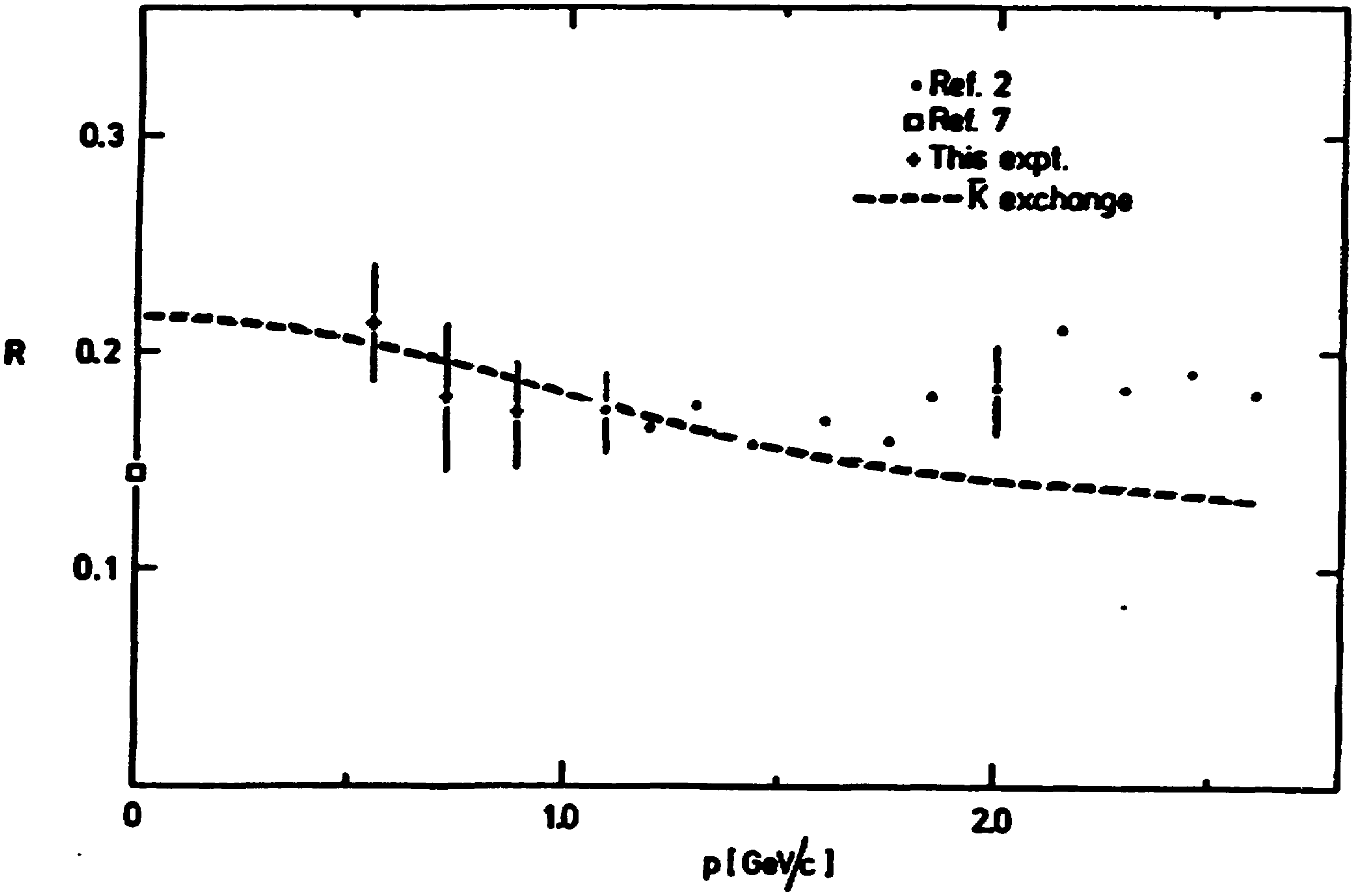
$$p_0^2 = \begin{cases} 0.18 & \Lambda \\ 0.14 & K_S \end{cases}$$

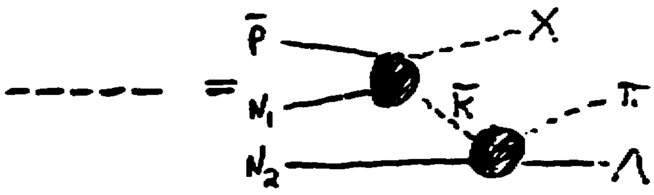
↑ (GeV/c)

p_T spectrum of Λ
does not change
over wide p_{lab} range

Parkin et al, Nucl. Phys. B

Λ/K_s RATIO R FOR $\bar{p}d \to \Lambda$ or K_s

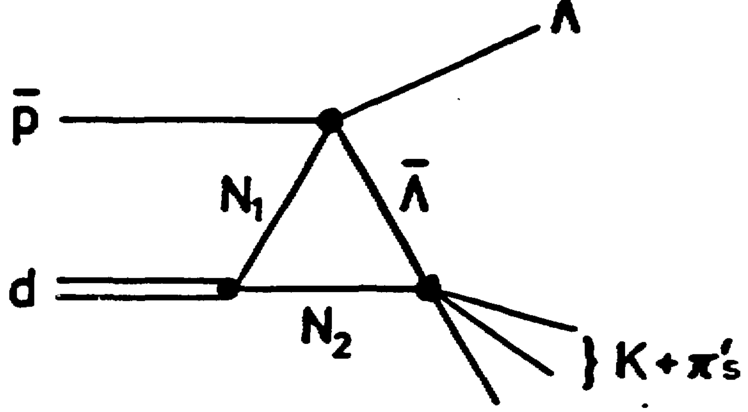


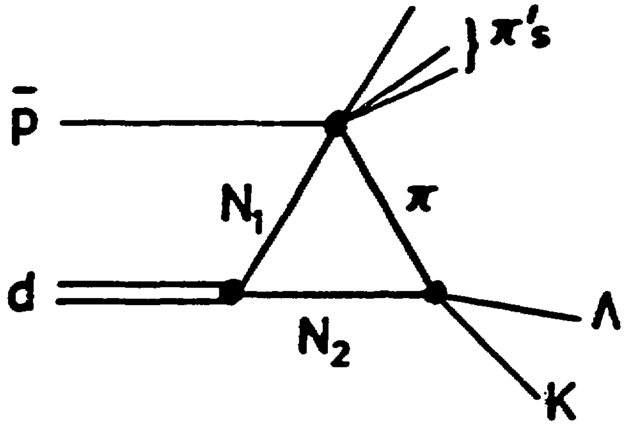


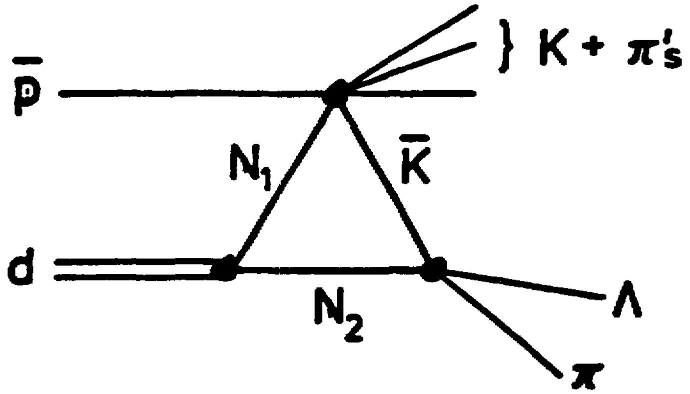
Parkin et al, Nucl. Phys. B (0.4–0.9 GeV/c) +

MECHANISMS FOR Λ PRODUCTION

(conventional)







← dominant for small p_{lab}

DATA ON STRANGENESS PRODUCTION IN $\bar{P}$-NUCLEUS

1) Conde et al, Phys. Rev. C29, 1531 (1984) $\bar{p}+A \to \Lambda$ at low p

Target	$\Lambda/\bar{p}$ Ratio
C	0.023 ± 0.006
Ti	0.021 ± 0.007
Ta	0.013 ± 0.004
Pb	0.027 ± 0.011

average 0.015 ± 0.009

→ compare to 0.0035 in $\bar{p}d$

2) Miyano et al, Phys. Rev. Lett. 53, 1725 (1984) $\bar{p}+Ta \to \Lambda, \bar{\Lambda}, K_s$ at 4 GeV/c

σ for $\bar{p}$+Ta	σ for $\bar{p}p$	
82 ± 6 mb	1.9 ± 0.07 mb	(K_s)
193 ± 12	0.53 ± 0.05	(Λ)
3.8 ± 2	0.48 ± 0.05	($\bar{\Lambda}$)

$$\boxed{\frac{\Lambda}{K_s} \approx \begin{cases} 1/4 & \text{for } \bar{p}p \\ 2.4 & \text{for } \bar{p}\,Ta \end{cases} \quad \text{at 4 GeV/c}}$$!

Question: Is the order of magnitude enhancement in Λ/K_s ratio a signal of new physics?

DATA ON STRANGENESS PRODUCTION IN $\bar{p}$-NUCLEUS

3) *Balestra et al*, Nucl. Phys. A452, 573 (1986)

$\bar{p}$+Ne at 0-600 MeV/c (LEAR)

p (MeV/c)	M<10	M≥10
0	93%	7%
100	88	12
200	75	25
500	73	27
1400	63	37
	↑ "surface"	↑ "internal"

M = multiplicity (charged)

for $\bar{p}$ Ne at 600 MeV/c :

$$\Lambda/\bar{p} \approx 0.019 \pm 0.004$$

$$K_s/\bar{p} \approx 0.008 \pm 0.002$$

$\rightarrow \dfrac{\Lambda}{K_s} \approx 2.4$, same as $\bar{p}$ Ta at 4 GeV/c

$$\boxed{(\Lambda/K_s)_{rest} \,/\, (\Lambda/K_s)_{600\,MeV/c} \le 1/10 \ !}$$

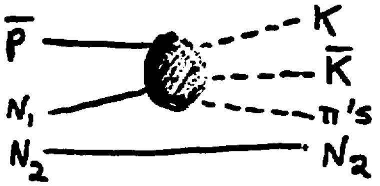
Rapidities: $\langle y \rangle = \begin{cases} 0.44 \pm 0.12 & \text{for } K_s \\ -0.044 \pm 0.09 & \text{for } \Lambda \end{cases}$ at 600 MeV/c

"surface" "internal"

∴ $\bar{p} + (1\text{-}2)N$ for K_s ; $\bar{p} + (4\text{-}11)N$ for Λ

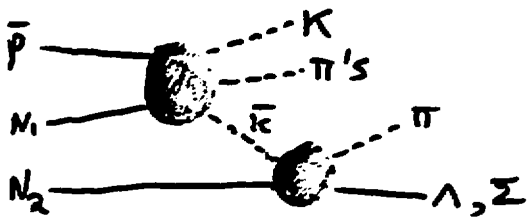
Rough theoretical interpretation of $\bar{p}d$ vs $\bar{p}$ Ta :

Consider



"spectator"

+



"rescattering"

Assume $K\bar{K}$ charge states equally produced, and let <u>w = probability of rescattering ($\bar{K}N \to \pi Y$)</u>

Then $$\boxed{N(K^+) : N(K^-) : N(K_s) : N(\Lambda+\Sigma) = 1 : 1-w : 1-\frac{w}{2} : 2w}$$

If $w \approx 1/10$, then $\frac{N(K_s)}{N(\Lambda+\Sigma)} \approx 4.8$ ⇝ <u>agrees with $\bar{p}d$</u>

<u>Conclusion</u>: for $\bar{p}d$, final state interactions modest ⇝ conventional picture OK

Now suppose $\boxed{w \approx cA^{2/3}/(1+cA^{2/3})}$; A = no. of spectato

∴ $c = 1/9$ fits $\bar{p}d$ → predict $w(\text{Ta}) \approx 0.78$

and hence $N(\Lambda+\Sigma)/N(K_s) \approx 2.5$, <u>in agreement with Ta</u>

<u>Note</u>: for large w , formulation in terms of "compound nucleus" is economical

General Observations on $\bar{p}$-nucleus annihilation

↝ probe equation of state of heated nuclear matter

↝ approach to chemical and thermodynamic equil.

Main search for quark ↔ hadron phase transition will take place in the arena of relativistic heavy ion collisions

↝ but $\bar{p}$ useful in studying mechanism of energy dissapation

↝ localized "hot spot" → emission of 10-20 nucl.

Advantages: can tag on multiplicity to emphasize internal $\bar{p}$ absorption

↝ enhance the hope for anomalous strangeness production

{ Λ production a multinucleon process
{ $K_s, K^\pm$ can be produced via 1st order proce

Caution: strangeness enhancement not necessarily signature of "quark-gluon soup"

↝ also occurs from conventional hadronic fireball once multinucleon processes incl.

Prospects

a) rich spectroscopy of strange systems

$S = -1, -2$ dibaryons

hypernuclei

↳ explore behavior of strange quarks in many body systems

b) $K^{\pm}, K^{0}$ induced reactions

↳ comparative nuclear structure studies (K vs p, π, e^{-} etc.) at medium energies

↳ lepton pair production (Drell-Yan) at high energies (sea quark distributions)

MESSAGE: Significant advances require kaon fluxes and energy range afforded by a kaon factory

other important aspects: mechanisms of strangeness production in relativistic heavy ion or $\bar{p}$-nucleus collisions → possible signatures for formation of QUARK-GLUON PLASMA