Hadrons in the Quark Model[a]

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The Cork Model

Up Charm Top

Down Strange Bottom

- Introduction, Classification Scheme, Simple Predictions
- Meson Spectrum
- Baryons Spectrum
- Meson Transitions
- Baryons Transitions & Sundries

NORTH POLE
ALASKA
Fairbanks
Anchorage
GREENLAND
ICELAND
Reykjavik
YUKON
Whitehorse
NORTHWEST
TERRITORIES
Yellowknife
BRITISH
COLUMBIA
ALBERTA
Edmonton
Calgary
SASK.
Saskatoon
Regina
MANITOBA
Winnipeg
CANADA
VANCOUVER
Victoria
SEATTLE
HAWAIIAN ISLANDS
Honolulu
SAN FRANCISCO
Salt Lake City
Denver
LOS ANGELES
SAN DIEGO
Las Vegas
UNITED STATES
MINNEAPOLIS
MILWAUKEE
CHICAGO
DETROIT
ONTARIO
QUÉBEC
MONTREAL
Québec
LABRADOR
NEWFOUNDLAND
St. John's
P.E.I.
N.S.
Halifax
GUELPH
BOSTON
NEW YORK
PHILADELPHIA
WASHINGTON D.C.
ATLANTA
ST. LOUIS
El Paso
DALLAS
HOUSTON
NEW ORLEANS
Jacksonville
Bermuda
MIAMI
THE BAHAMAS
HAVANA
MEXICO CITY
Acapulco
MEXICO
GUATEMALA
BELIZE
HONDURAS
JAMAICA
Kingston
Guatemala
San Salvador
EL SALVADOR
NICARAGUA
Managua
COSTA RICA
San José
PANAMA
CARACAS
VENEZUELA
BOGOTA
COLOMBIA
Galápagos Islands
Quito
ECUADOR
PERU
LIMA
BRAZIL
Belém
RECIFE
MOSCOW
LENINGRAD
KIEV
FINLAND
Helsinki
SWEDEN
NORWAY
OSLO
COPENHAGEN
STOCKHOLM
POL.
BUCHAREST
ROM.
BUDAPEST
YUG.
VIENNA
ATHENS
GREECE
HAMBURG
AMSTERDAM
BRUSSELS
GERMANY
Bonn
SWITZ.
ITALY
ROME
PARIS
FRANCE
LONDON
IRELAND
Ankara
TURKEY
IRAQ
CYPRUS
ISTANBUL
Tunis
Tarabulus
TUNISIA
Algiers
ALGERIA
SPAIN
MADRID
LISBON
Rabat
CASABLANCA
MOROCCO
Azores
Madeira
Canary Islands
WESTERN SAHARA
MAURITANIA
Nouakchott
MALI
Bamako
SENEGAL
Dakar
Cape Verde Islands
GAMBIA
GUINEA-BISSAU
GUINEA
IVORY COAST
LIBERIA
Monrovia
Conakry
Freetown
SIERRA LEONE
SURINAM
GUYANA
Georgetown
Paramaribo
TRINIDAD
Port-of-Spain
Tobago
Barbados
Martinique
Dominica
Guadeloupe
Antigua
Virgin Islands
PUERTO RICO
Santo Domingo
San Juan
St. Lucia
Grenada
Aruba
Curaçao
Cuba
Nassau
Cayman Islands
HAITI
DOMINICAN REP.
8000 km
3000 miles
5000 miles

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Sketch of treatment of semileptonic decays (mesons), strong decays (baryons)

Semileptonic decay: decay of a hadron to a final state containing a hadron and a pair of leptons. Mediated by weak interaction: understanding these requires understanding the interplay between the dynamics of the weak interaction leading to the decay, and the strong interaction that provides the binding in the parent and daughter hadron

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Consider the decays $B^- \to D^0 \ell \bar{\nu}_\ell$, and $B^- \to D^{*0} \ell \bar{\nu}_\ell$. Decay mediated by the weak left-handed current $\bar{c}\gamma_\mu \left(1-\gamma_5\right) b$.

However, we do not have free quarks, so must evaluate the hadronic matrix elements of this current, $\langle D^0(p')|\bar{c}\gamma_\mu \left(1-\gamma_5\right) b|B^-(p)\rangle$ and $\langle D^{*0}(p',\varepsilon)|\bar{c}\gamma_\mu \left(1-\gamma_5\right) b|B^-(p)\rangle$

For the vector current, the matrix element between the B vand D states must be a vector:

$$\langle D^0(p')|\bar{c}\gamma^\mu b|B^-(p)\rangle = f_1(q^2)p^\mu + f_2(q^2)p'^\mu \equiv f_+(q^2)(p+p')^\mu + f_-(q^2)(p-p')^\mu$$

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Similarly

$$\langle D^0(p')|\bar{c}\gamma^\mu\gamma_5 b|B^-(p)\rangle = 0$$

$$\langle D^{*0}(p',\varepsilon)|\bar{c}\gamma^\mu b|B^-(p)\rangle = ig(q^2)\epsilon^{\mu\nu\alpha\beta}\varepsilon^*_\nu(p+p')_\alpha(p-p')_\beta$$

$$\langle D^{*0}(p',\varepsilon)|\bar{c}\gamma^\mu\gamma_5 b|B^-(p)\rangle = f(q^2)\varepsilon^{*\mu} + \varepsilon\cdot p\left[a_+(q^2)(p+p')^\mu + a_-(q^2)(p-p')^\mu\right]$$

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All our ignorance hides in the form factors ($f_+,\ f_-$, etc.). Use quark model wave functions that we have obtained to estimate these form factors, and hence decay rate. Calculations of this kind are very useful for aiding in the extraction of CKM matrix elements, for instance.

I: Construct a representation of the meson states. In the non-relativistic limit,

$$|X(\vec{p}_X, J\rangle = \sqrt{2m_X} \int d^3p \sum \langle L, m_L, S, m_s | J, M\rangle \Psi_X^{LM_L}(\vec{p}) \chi_{s\bar{s}}^{Sm_s}$$

$$\times \left| q\left[\frac{m_q}{m_X}\vec{p}_X + \vec{p}, s\right] \bar{q}\left[\frac{m_{\bar{q}}}{m_X}\vec{p}_X - \vec{p},\right]\right\rangle$$

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II: reduce the Dirac current to two-component (Pauli) form, as wave functions use Pauli spinors: $\bar{c}\gamma_\mu b \rightarrow$ structure in σ_i.

Eg, $V_0^{++} = \sqrt{4\pi}\left[\left(1 + \frac{p_\lambda^2}{6m_b m_c}\right)\mathcal{Y}_{00} - \frac{\sqrt{2}k}{12m_b m_c}\mathcal{Y}_{10}\right]$

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III: Choose components of currents, evaluate matrix elements of corresponding Pauli operators using the wave functions obtained from spectrum. Eg. For $B \rightarrow D$, first choose $\mu = 0$ (since both B and D are pseudoscalars, there's no choice of spin-projection to be made).

$$\mu = 0: \ (m_B + E_D) f_+(q^2) + (m_B - E_D) f_-(q^2) = \sqrt{m_B m_D} \int d^3p \psi_D^* \left[\vec{p} + \frac{m_u}{m_D} \vec{p}_D \right] \psi_B(\vec{p})$$

$$\mu = 3: \ (f_+ - f_-) p_D = \sqrt{m_B m_D} \int d^3p \psi_D^* \left[\vec{p} + \frac{m_u}{m_D} \vec{p}_D \right] \psi_B(\vec{p}) \left[\frac{p_3}{2m_b} + \frac{p_3 + p_D}{2mc} \right]$$

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$$f_+ = F \left[1 + \frac{m_b}{2\mu_-} - \frac{m_b m_c}{4\mu_+ \mu_-} \frac{m_u}{m_D} \frac{\beta_B^2}{\beta_{BD}^2} \right]$$

$$f_- = F \left\{ 1 - (m_B + m_D) \left[\frac{1}{2m_c} - \frac{1}{4\mu_+} \frac{m_u}{m_D} \frac{\beta_B^2}{\beta_{BD}^2} \right] \right\}$$

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$$F = \sqrt{\frac{m_D}{M_B}} \left[\frac{\beta_B \beta_D}{\beta_{BD}} \right]^{3/2} \exp \left[- \left(\frac{m_u^2}{4m_D^2} \frac{p_D^2}{\beta_{BD}^2} \right) \right]$$

$$\frac{1}{\mu_\pm} = \frac{1}{m_b} \pm \frac{1}{m_c}; \ \beta_{BD}^2 = \frac{\beta_B^2 + \beta_D^2}{2}$$

How do we treat strong (hadronic) decays (like $\Delta \to N\pi,\ \rho \to \pi\pi,\ \psi \to D\bar{D}$)?

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We want a pair creation operator that creates pairs out of the QCD vacuum $\Longrightarrow$ vacuum quantum numbers.

Vacuum has quantum numbers $J^{PC} = 0^{++}$ (scalar). We can get this by having the pair created with spin triplet, P-wave, $J = 0 \implies {}^3P_0$; model is often called the ${}^3P_0$ model.

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We make an *ansatz* for the operator:

$$T = -3C_{{}^3P_0} \sum_{ij} \int d^3p_i d^3p_j \delta^3\left(\vec{p}_i + \vec{p}_j\right) C_{ij} F_{ij}$$

$$\times \sum_m \langle 1, m, 1, -m | 0, 0 \rangle \chi_{ij}^m \mathcal{Y}_i^{-m}\left(\vec{p}_i - \vec{p}_j\right) b_i^\dagger\left(\vec{p}_i\right) d_j^\dagger\left(\vec{p}_j\right)$$

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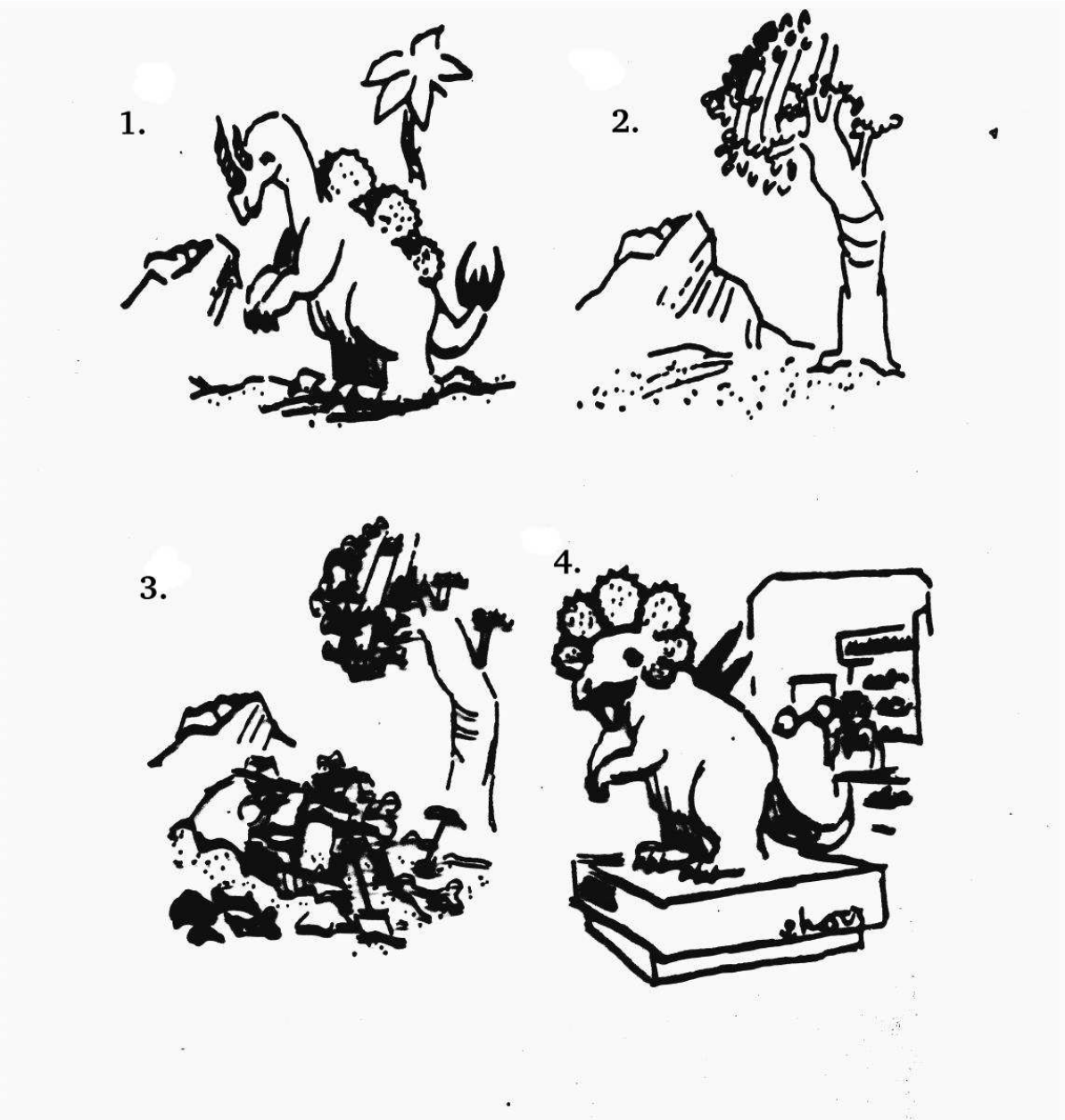
We'll need to think about 4 matrix elements: color, flavor, spin, space.

Skeleton of newly discovered dinosaur species reconstructed from two fossils

(Disputed by some experts)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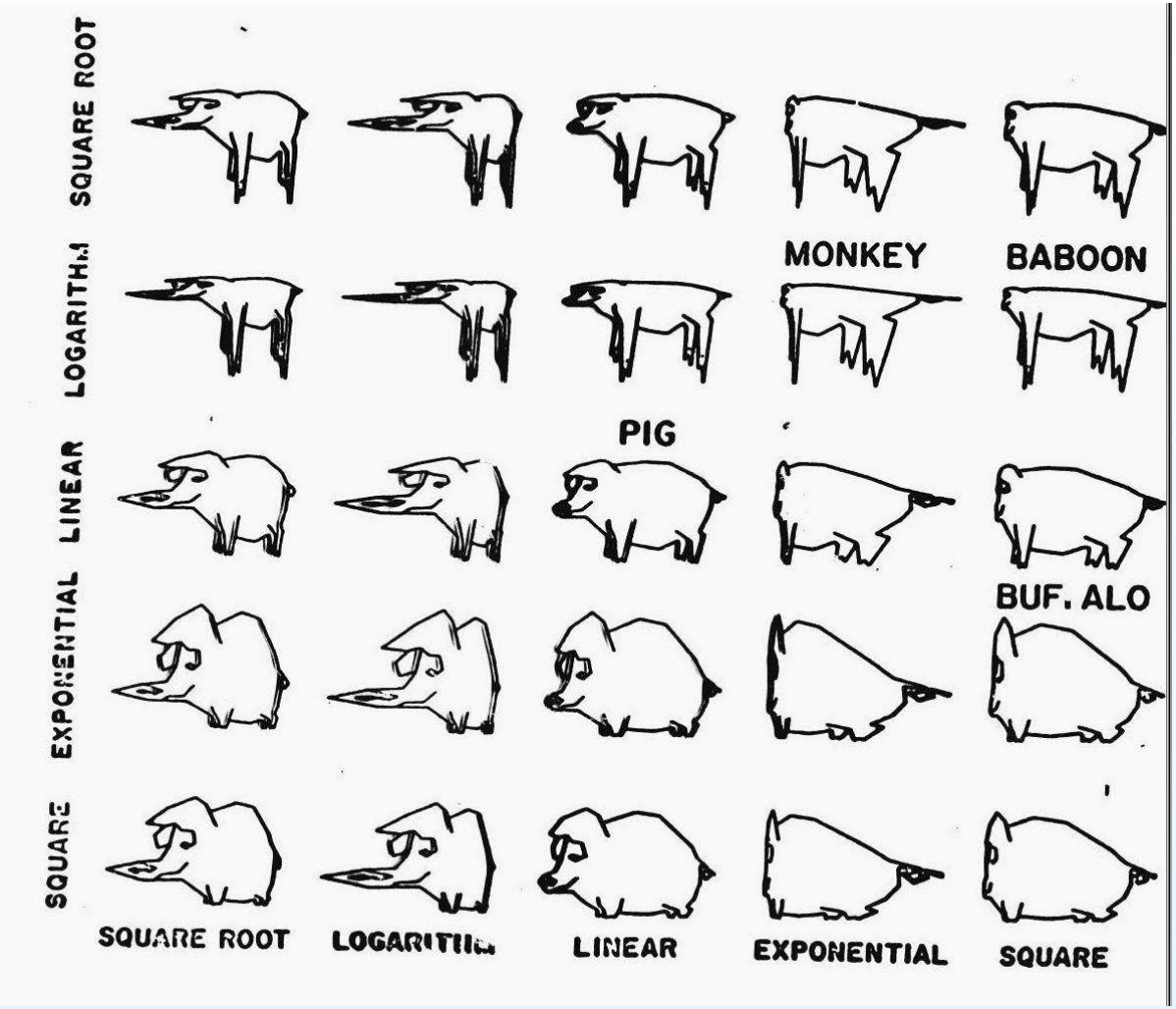
SQUARE ROOT
LOGARITHM
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EXPONENTIAL
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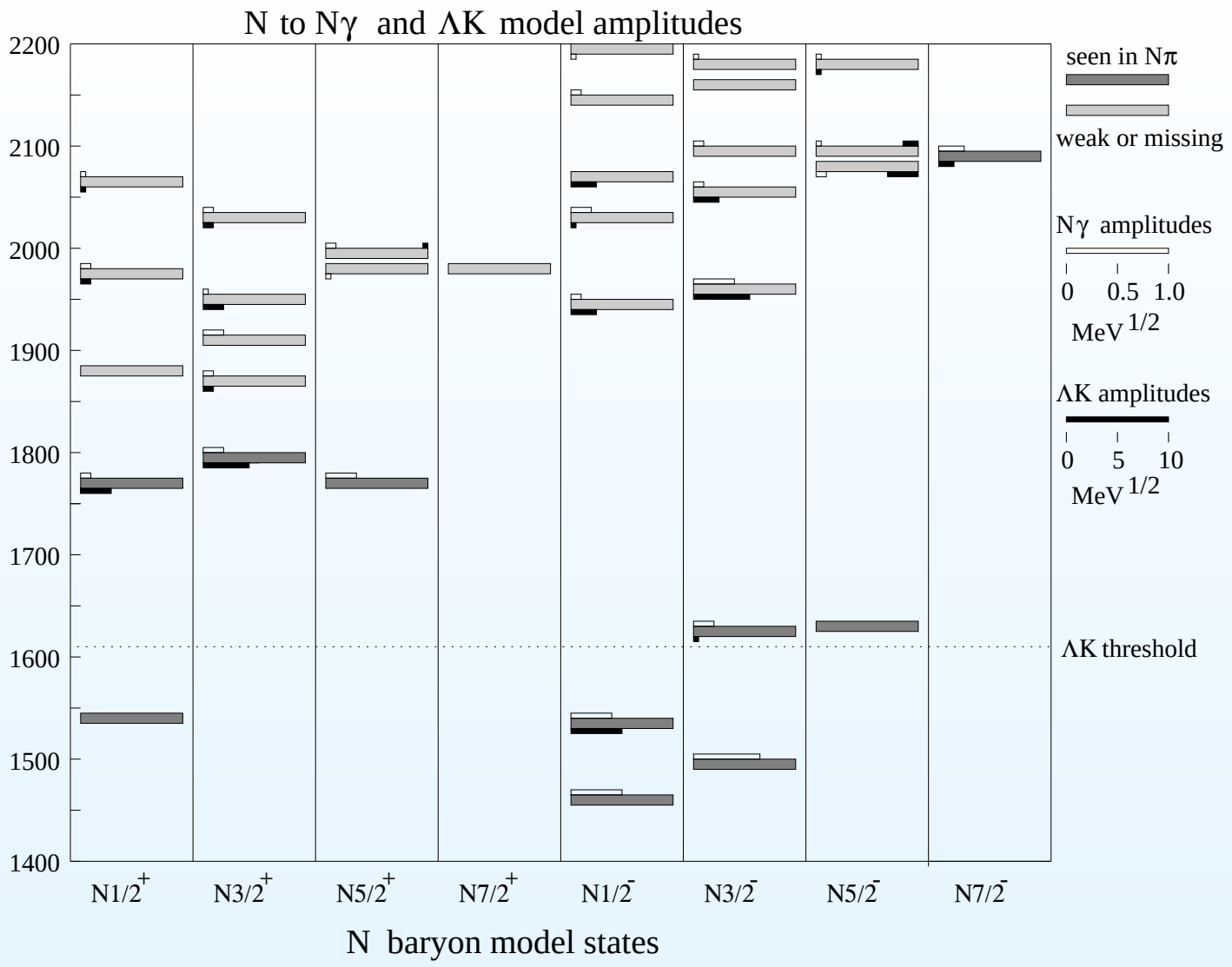
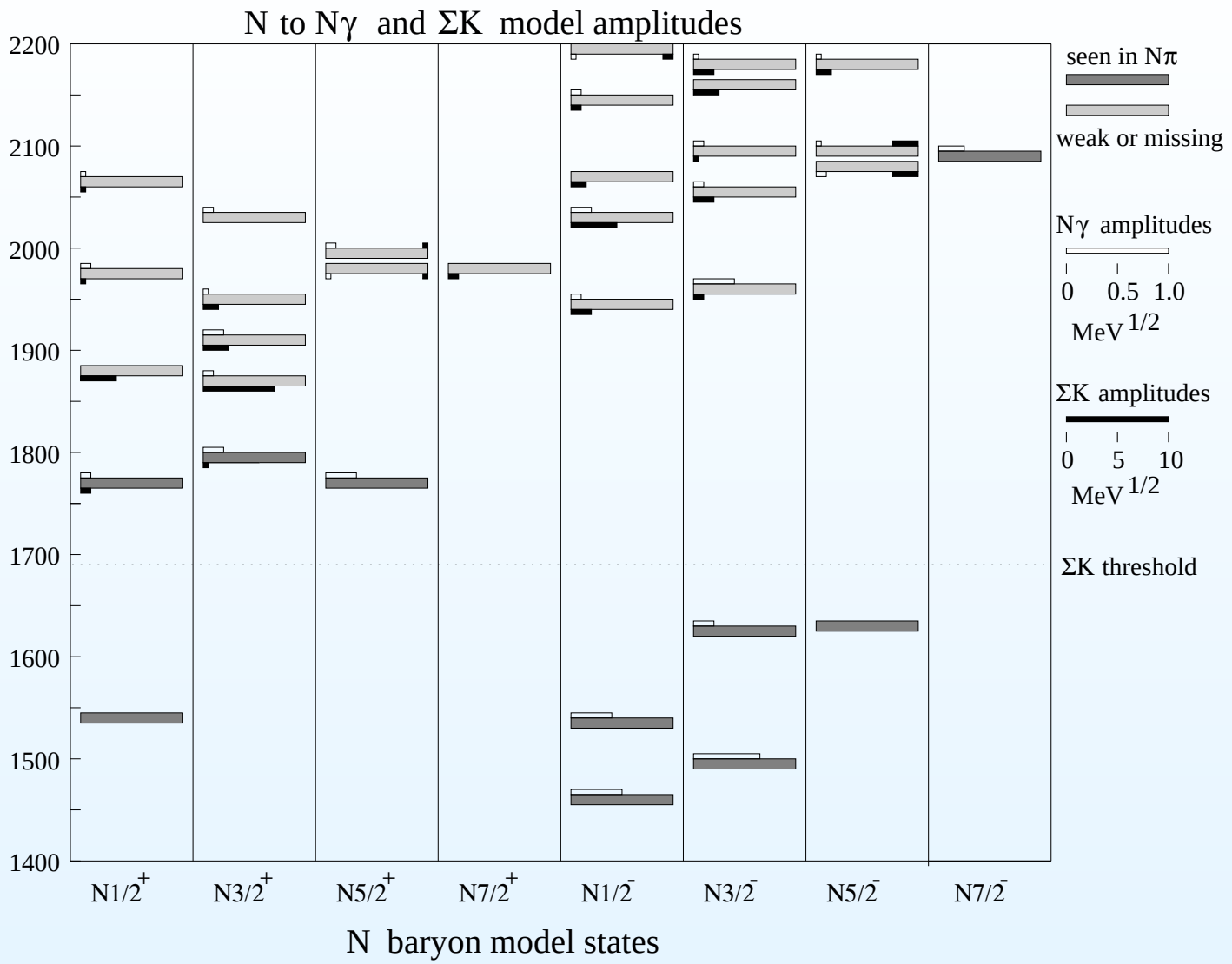
BABOON
PIG
BUF. ALO
SQUARE ROOT
LOGARITHM
LINEAR
EXPONENTIAL
SQUARE


N to Nγ and ΛK model amplitudes
2200
2100
2000
1900
1800
1700
1600
1500
1400
seen in Nπ
weak or missing
Nγ amplitudes
0 0.5 1.0
MeV 1/2
ΛK amplitudes
0 5 10
MeV 1/2
ΛK threshold
N1/2+
N3/2+
N5/2+
N7/2+
N1/2-
N3/2-
N5/2-
N7/2-
N baryon model states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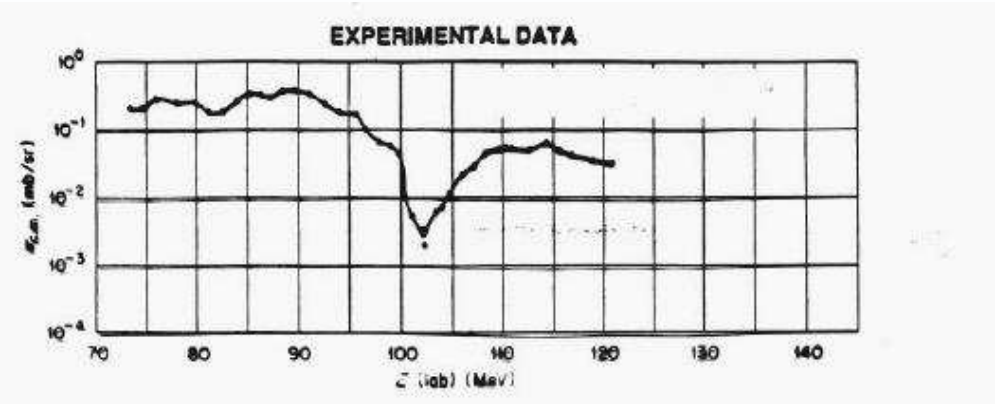
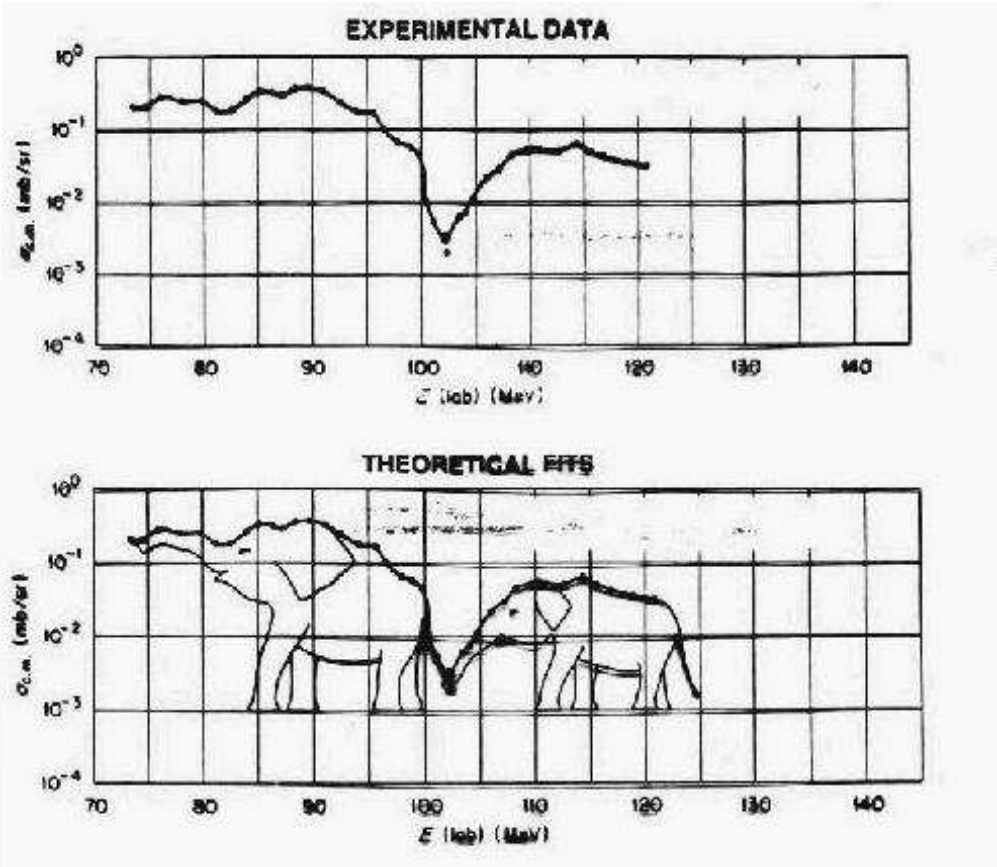
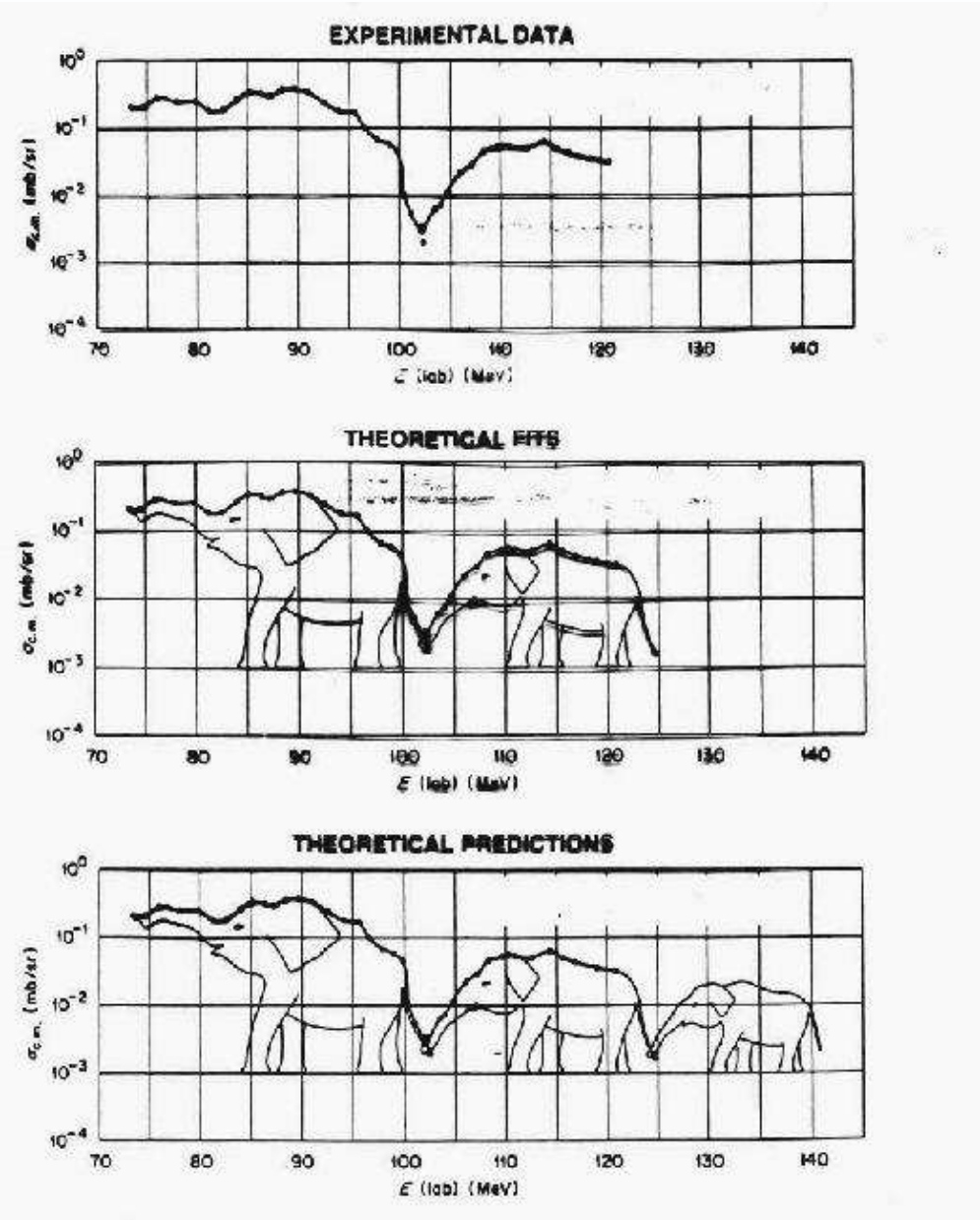

EXPERIMENTAL DATA
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$\sigma_{c.m.}$ (mb/sr)
70
80
90
100
110
120
130
140
Σ^- (lab) (Mev)


EXPERIMENTAL DATA
THEORETICAL FITS
70
80
90
100
110
120
130
140


EXPERIMENTAL DATA
THEORETICAL FITS
THEORETICAL PREDICTIONS
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$\sigma_{c.m.}$ (mb/sr)
70
80
90
100
110
120
130
140
E (lab) (MeV)

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Etc.

The Cork Model

Up Charm Top

Down Strange Bottom