Hadron Spectroscopy and the Structure of the Proton

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2nd Workshop on Detectors for Forward Physics at LHC
La Biodola, Elba, Italy
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Abstract

A mass analysis of the whole particle spectrum, combined with the hypothesis that hadrons are solid-phase and shell-structured, indicates that the proton and the neutron are made of three shells. Mesons states corresponding to shell 1 (pion) and 2 (kaon) are available, but no shells 1 and 2 baryons have been seen. This may be due to the fact that mesons and baryons are built on different lattice systems, the baryonic one being less cohesive.

One of the interpretations of the shape of the p-p elastic scattering d σ /dt also relies on a three-layered proton.

In atomic physics, the understanding of the spectral rules by Balmer and Rydberg led to Bohr's atomic model and then to quantum mechanics; from that, chemistry was elucidated in just 6 months;

in particle physics this is not the case: early mass rules such as Gell-Mann Okubo and the Chew-Frautchi plots are no longer mentioned by the RPP of the PDG;

the orthodox view is that there are no hadron mass rules, and if you think you found some then you are a crackpot, and you will not be allowed to publish your results; you better join the effort to try and compute the spectrum from QCD, promised already 30+ years ago;

in the meanwhile, CKM hadron chemistry remains mysterious, and structural information about (a few) particles is provided by scattering experiments.

Paolo Palazzi worked on several scattering experiments:

- pi-D elastic at PS
- p-p elastic at ISR
- e-p DIS at SLAC
- ν-Fe, ν-p, ν-d DIS at SPS
- ALEPH at LEP
- TOTEM at LHC

Forward cross section shows a variation in slope at –t =0.16: structure?

FURTHER RESULTS ON SMALL-ANGLE ELASTIC PROTON-PROTON SCATTERING AT VERY HIGH ENERGIES

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Received 22 July 1971

This work extends our previous investigations at the CERN Intersecting Storage Rings, with improved statistics at three different energies, wider angular range and a better control over systematic errors. Values for the (diffraction) shape parameter b are given.

1973, PP@SLAC group A, e-p DIS

- point-like spin ½ partons
- gluons, sea
- sum rules
- partons = quarks?   =((

  Zweig rule, SU(N) ~ permutations, neutrals, chemistry..

! PDG tables, decay analysis, for each particle count stable leptons after all decays, $\gamma = 2$: $\mu = 3$, $\pi = 4$, etc…

- count is linear with mass!
- shell structure? 3D stability: cuberoot of m

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
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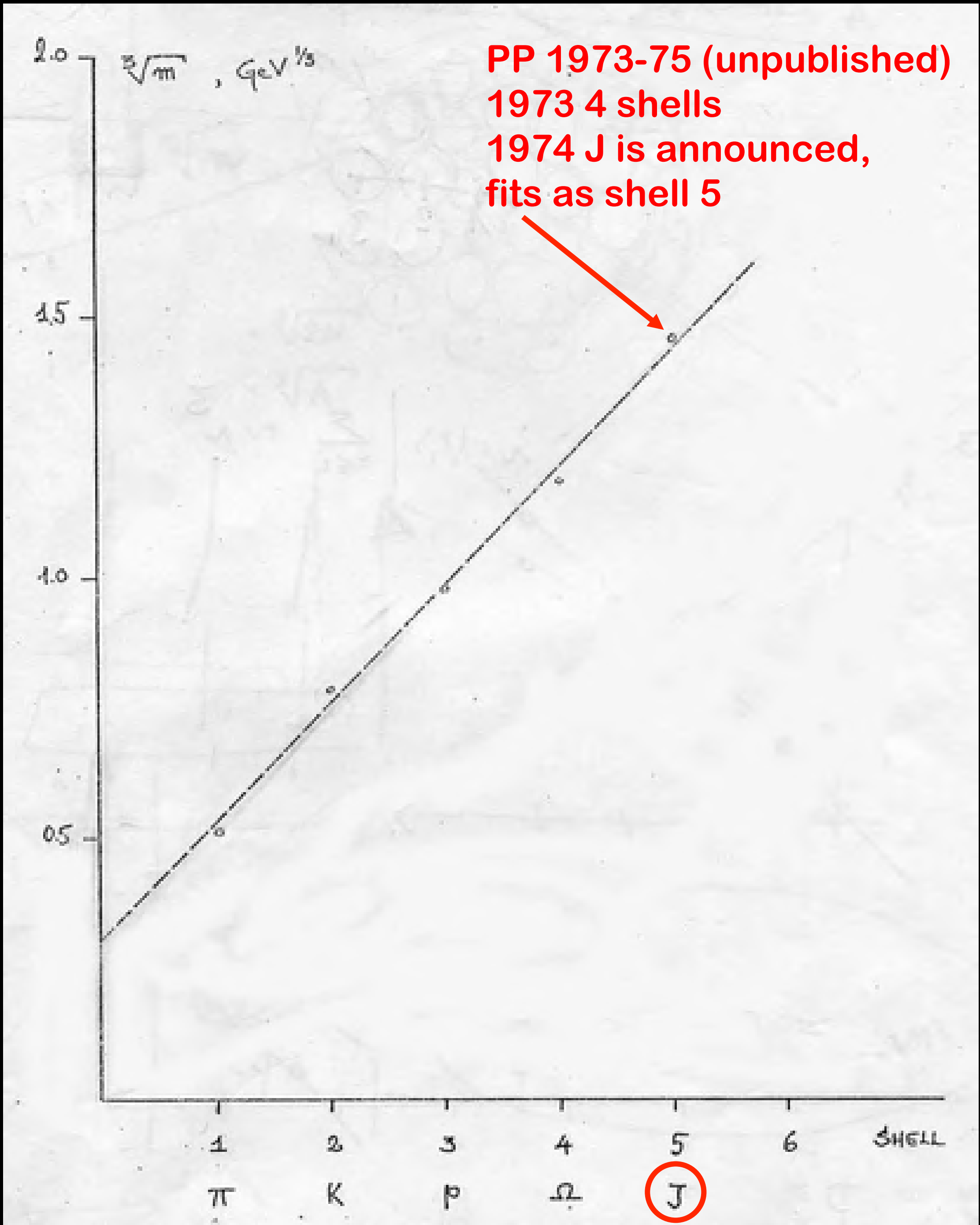
Received 4 January 1964

If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" [1-3], we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dynamical "bootstrap" model for all the strongly interacting particles within which one may try to derive isotopic spin and strangeness conservation and broken eightfold symmetry from self-consistency alone [4]. Of course, with only strong interactions, the orientation of the asymmetry in the unitary space cannot be specified; one hopes that in some way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hypercharge directions.

Even if we consider the scattering amplitudes of strongly interacting particles on the mass shell only and treat the matrix elements of the weak, electromagnetic, and gravitational interactions by means

ber $n_t - n_{\bar{t}}$ would be zero for all known baryons and mesons. The most interesting example of such a model is one in which the triplet has spin $\frac{1}{2}$ and $z = -1$, so that the four particles d^-, s^-, u^0 and b^0 exhibit a parallel with the leptons.

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" [6] q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(q\,q\,q)$, $(q\,q\,q\,q\,\bar{q})$, etc., while mesons are made out of $(q\,\bar{q})$, $(q\,q\,\bar{q}\,\bar{q})$, etc. It is assuming that the lowest baryon configuration $(q\,q\,q)$ gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q\,\bar{q})$ similarly gives just **1** and **8**.


PP 1973-75 (unpublished)
1973 4 shells
1974 J is announced,
fits as shell 5
2.0
1.5
1.0
0.5
GeV 1/3
1
2
3
4
5
6
SHELL
π
K
p
Ω
J

I was not alone:

- mass difference of 70 MeV/c^2 :
  - Nambu in 1952,
  - Mac Gregor in 1970, and a few more
- Stable leptons as constituents:
  - Barut in 1978

Malcolm Mac Gregor's number plate

STABLE PARTICLES AS BUILDING BLOCKS OF MATTER *

A.O. Barut **

International Centre for Theoretical Physics, Trieste, Italy.

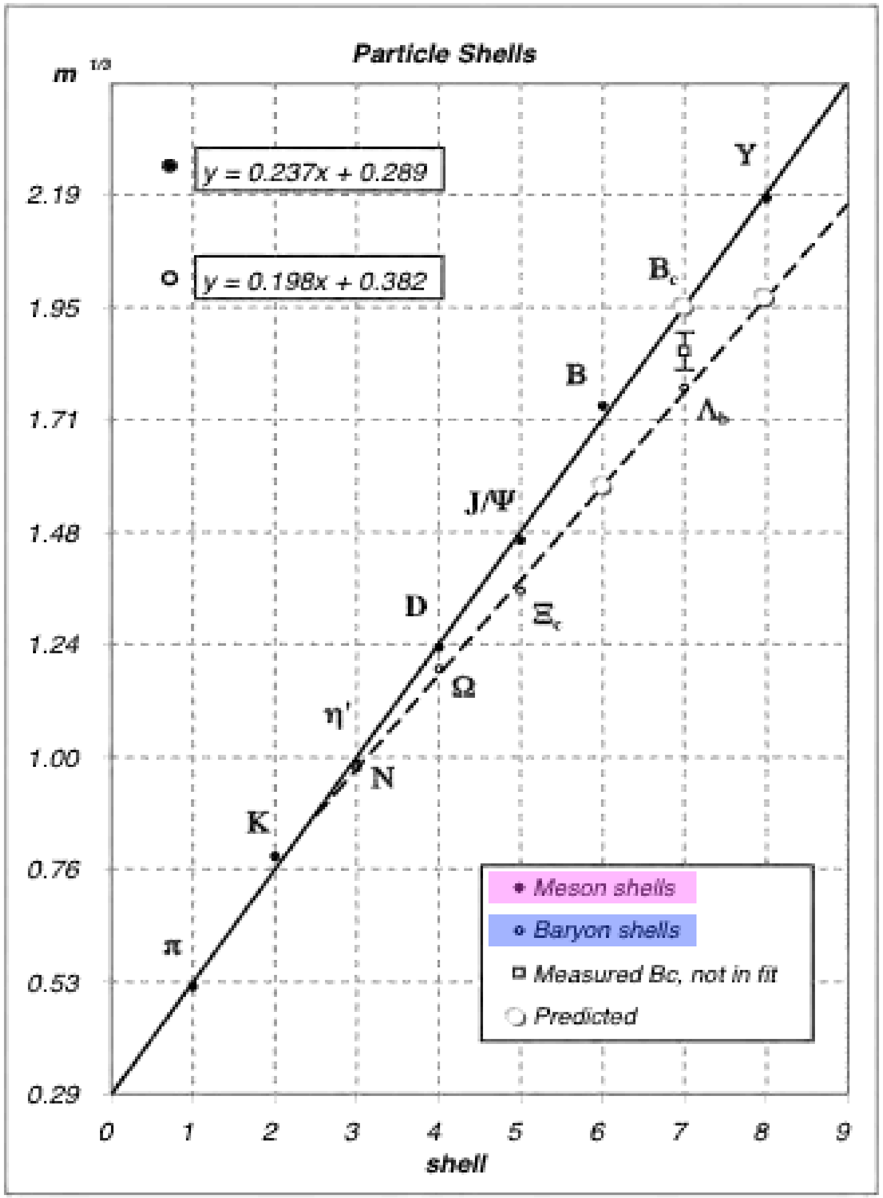
ABSTRACT

Only absolutely stable particles can be truly elementary. A simple theory of matter based on the three constituents, proton, electron and neutrino (and their antiparticles), bound together by the ordinary magnetic forces is presented, which allows us to give an intuitive picture of all processes of high-energy physics, including strong and weak interactions, and make quantitative predictions.

MIRAMARE - TRIESTE

April 1979

CERN-OPEN-2003-006
19 Mar 2004



CERN-OPEN-2003-006
24-JAN-2003
Revision 2, 19-MAR-2004

Particles and Shells

Paolo Palazzi, CERN

2003

Abstract

The current understanding of particle masses in terms of quarks and their binding energy is not satisfactory. Both in atoms and in nuclei the organizing principle of stability is the shell structure, while this does not seem to play any role for particles. In order to explore the possibility that shells might also be relevant at this inner level of aggregation, atomic and nuclear stability are expressed by "stablines", alignments of the 1/3 power of the total number of constituents of the most stable configurations. Could similar patterns be found in the particle spectrum? By analyzing the distribution of particle lifetimes as a function of mass, stability peaks are recognized for mesons and for baryons and indeed the cube roots of their masses follow two distinct stablines. Such alignments would be a strong indication that the particles themselves are shell structured assuming only that each constituent contributes a constant amount to the total mass. This is incompatible with the prevalent view that the partons —real physical constituents seen in deep-inelastic scattering experiments—are the quarks. The mass of the B_c predicted by interpolation with the meson stabline is 7.4 ±0.2 GeV. On the baryon stabline two missing states are predicted at 3.9 and 7.6 GeV.

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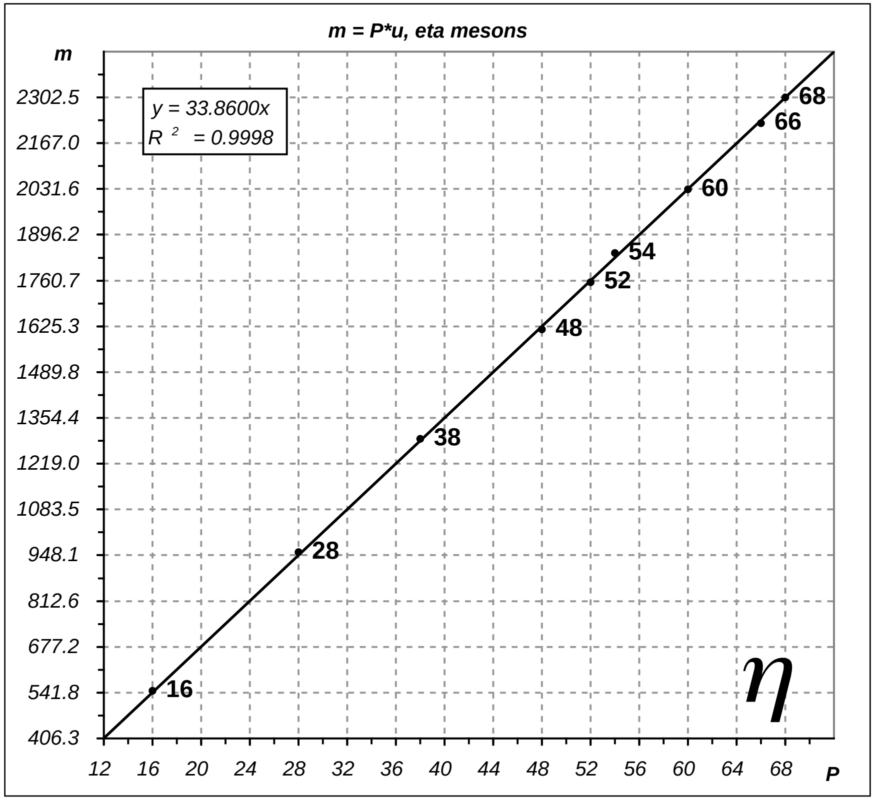
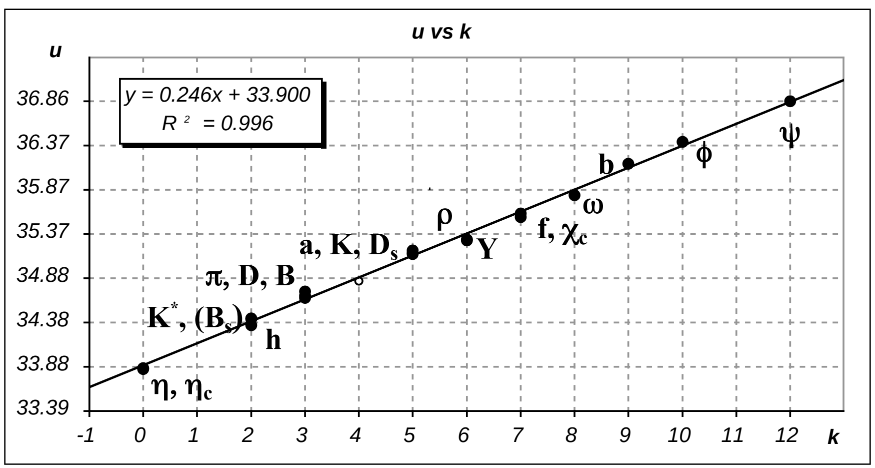
censorship, blacklisting on arXiv: 70 MeV/c2 mass quantum not statistically relevant!

really?

meson mass system





Preprint: p3a-2004-001
28-JUL-2004
Revision 1, 5-APR-2005

Patterns in the Meson Mass Spectrum

Paolo Palazzi

2004

Abstract

The conjecture that particle masses are multiples of a unit u of about 35 MeV has been proposed in various forms by several authors: mesons are even multiples of u, leptons and baryons odd multiples. Here this mass quantization is reassessed for all particles with mass below 1 GeV (stable leptons and $f_0(600)$ excluded), and found to be statistically significant. Subsequently all the mesons listed by the PDG are grouped in families defined by quark composition and J^{PC}, and analyzed for even mass multiplicity with a unit close to 35 MeV separately for each group. For all the the families that can be analyzed unambiguously this multiplicity hypothesis is found to be statistically significant. Most scalar and vector families show a dependence of u from the spin, while for pseudoscalars the effect is not present. Only 5 states out of 120 are rejected due to abnormally large fit residuals. The mass units of the various families are quantized on a grid of 12 intervals of about 0.25 MeV, ranging from 33.88 up to 36.86 MeV. The location of the values on the u-grid shows an intriguing pattern of correlation with the quantum numbers.

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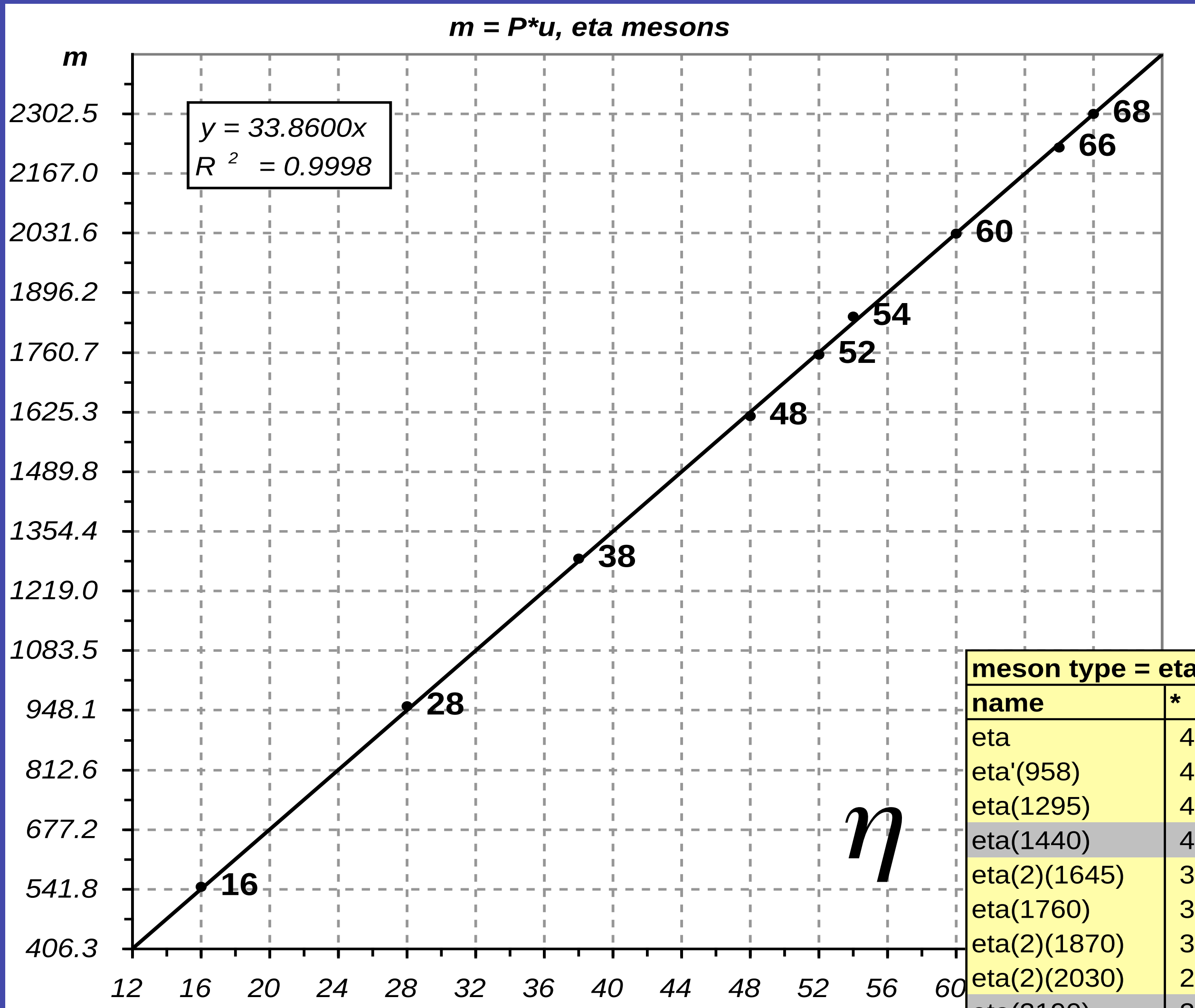
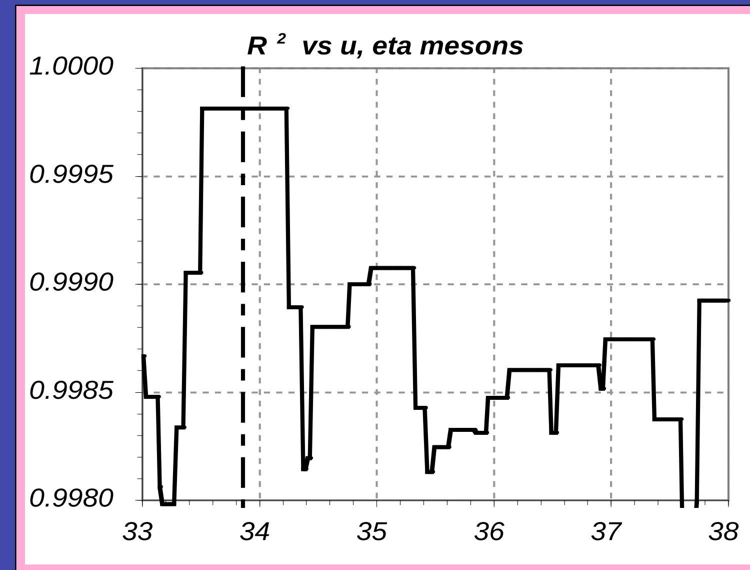


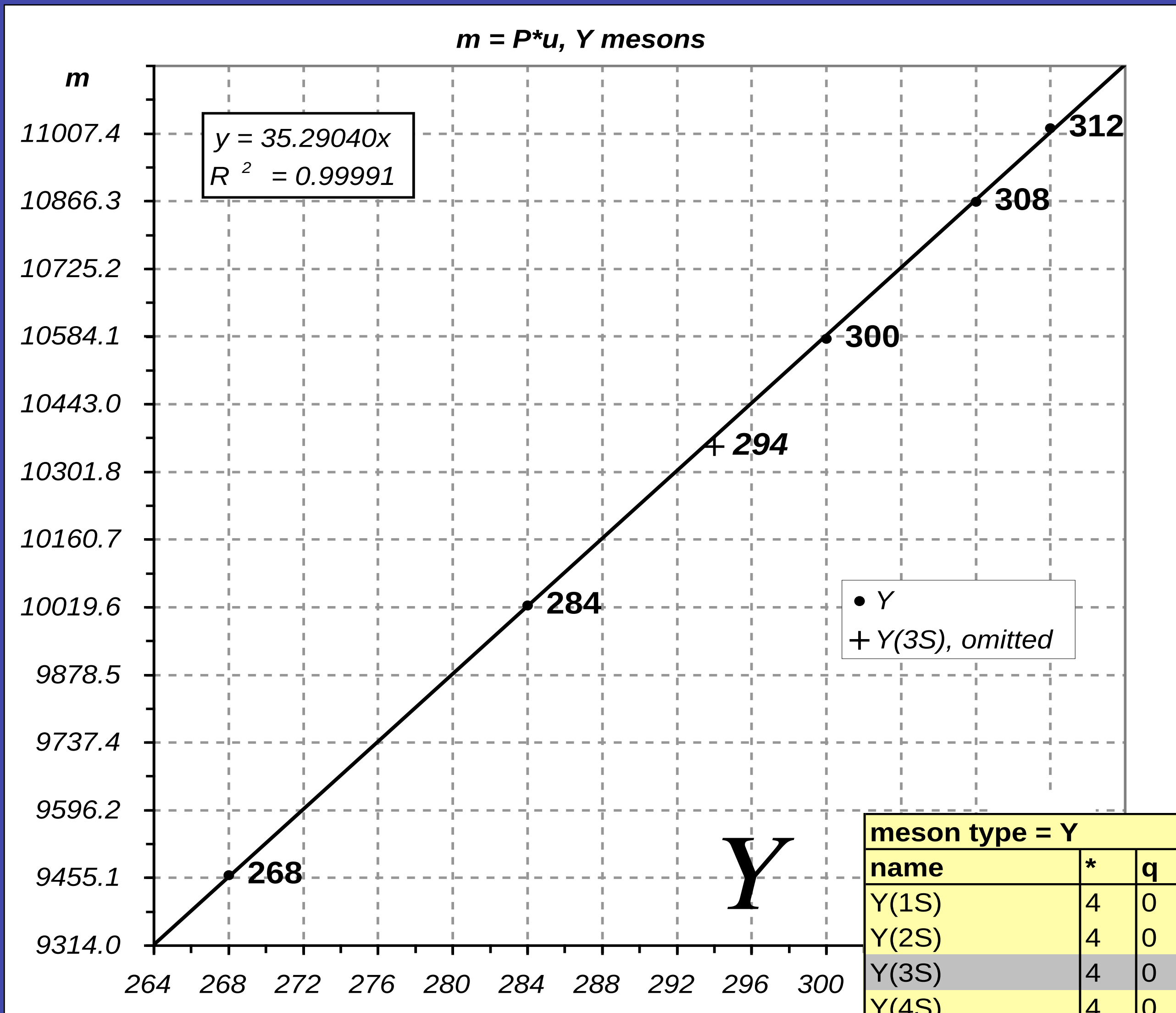


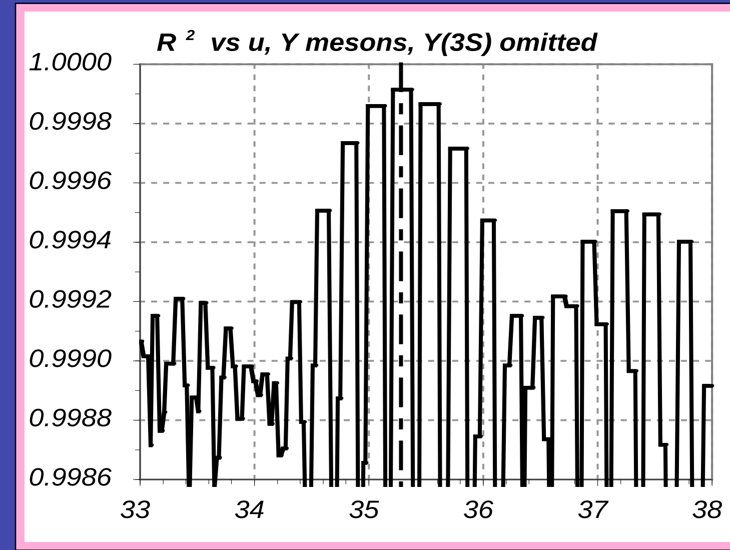
residuals

meson type = eta										
name	*	q	J	x	P	m	errm	u=m/P	dm	dm/m
eta	4	0	0		16	547.3	0.1	34.206	5.5	1.01%
eta'(958)	4	0	0		28	957.8	0.1	34.206	9.7	1.01%
eta(1295)	4	0	0		38	1293.0	5.0	34.026	6.3	0.49%
eta(1440)	4	0	0	1	42	1435.0	35.0	34.167	12.9	0.90%
eta(2)(1645)	3	0	2		48	1617.0	5.0	33.688	-8.3	-0.51%
eta(1760)	3	0	0		52	1756.0	11.0	33.769	-4.7	-0.27%
eta(2)(1870)	3	0	2		54	1842.0	8.0	34.111	13.6	0.74%
eta(2)(2030)	2	0	2		60	2030.0	20.0	33.833	-1.6	-0.08%
eta(2190)	2	0	0	1	64	2190.0	50.0	34.219	23.0	1.05%
eta(2)(2250)	2	0	2		66	2225.8	13.0	33.723	-9.0	-0.40%
eta(2225)	3	0	0	1	66	2227.0	35.0	33.742	-7.8	-0.35%
eta(2280)	3	0	0		68	2302.5	12.0	33.860	0.0	0.00%
eta(4)(2320)	2	0	4	1	68	2328.0	38.0	34.235	25.5	1.10%

summary eta mesons	
u	33.86 ± 0.053
p-value	0.999 **--> *p*(H_0) = 0.001**
spin dependence	no
omitted	4 large errm

low mass

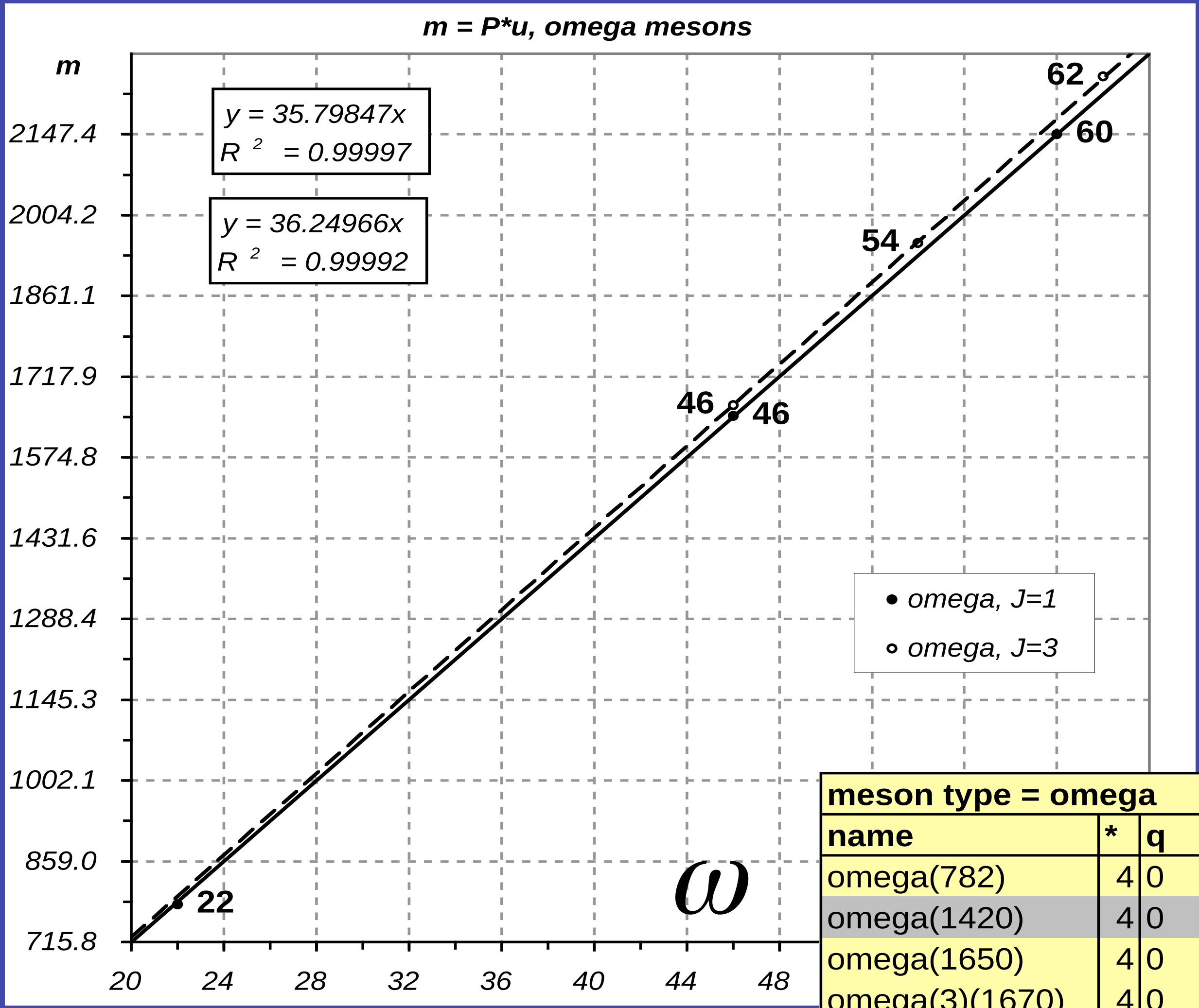




meson type = Y										
name	*	q	J	x	P	m	errm	u=m/P	dm	dm/m
Y(1S)	4	0	1		268	9460.3	0.26	35.300	5.5	0.06%
Y(2S)	4	0	1		284	10023.3	0.31	35.293	4.0	0.04%
Y(3S)	4	0	1	3	294	10355.2	0.50	35.222	-16.8	-0.16%
Y(4S)	4	0	1		300	10580.0	3.50	35.267	-3.7	-0.04%
Y(10860)	4	0	1		308	10865.0	8.00	35.276	-0.9	-0.01%
Y(11020)	4	0	1		312	11019.0	8.00	35.317	11.9	0.11%

summary Y mesons	
u	35.29 ± 0.009
p-value	0.985 --> $p(H_0)$ = 0.015
spin dependence	not assessed, all states are J=1
omitted	1 Chauvenet

high mass



meson type = omega										
name	*****	**q**	**J**	**x**	**P**	**m**	**errm**	**u=m/P**	**dm**	**dm/m**
omega(782)	4	0	1		22	782.6	0.1	35.571	-5.0	-0.64%
omega(1420)	4	0	1	1	40	1419.0	31.0	35.475	-12.9	-0.91%
omega(1650)	4	0	1		46	1649.0	24.0	35.848	2.3	0.14%
omega(3)(1670)	4	0	3		46	1667.0	4.0	36.239	-0.5	-0.03%
omega(3)(1995)	2	0	3		54	1955.0	30.0	36.204	-2.5	-0.13%
omega(2145)	2	0	1		60	2148.0	15.0	35.800	0.1	0.00%
omega(3)(2250)	2	0	3		62	2250.0	20.0	36.290	2.5	0.11%

spin dependence du/dJ

summary omega mesons	
omitted	1 large errm
spin dependence	yes, Z=13.9
u, J=1	35.80 ± 0.049
p-value	> 0.934 (all states), 0.942 for J=1, 0.947 for J=3

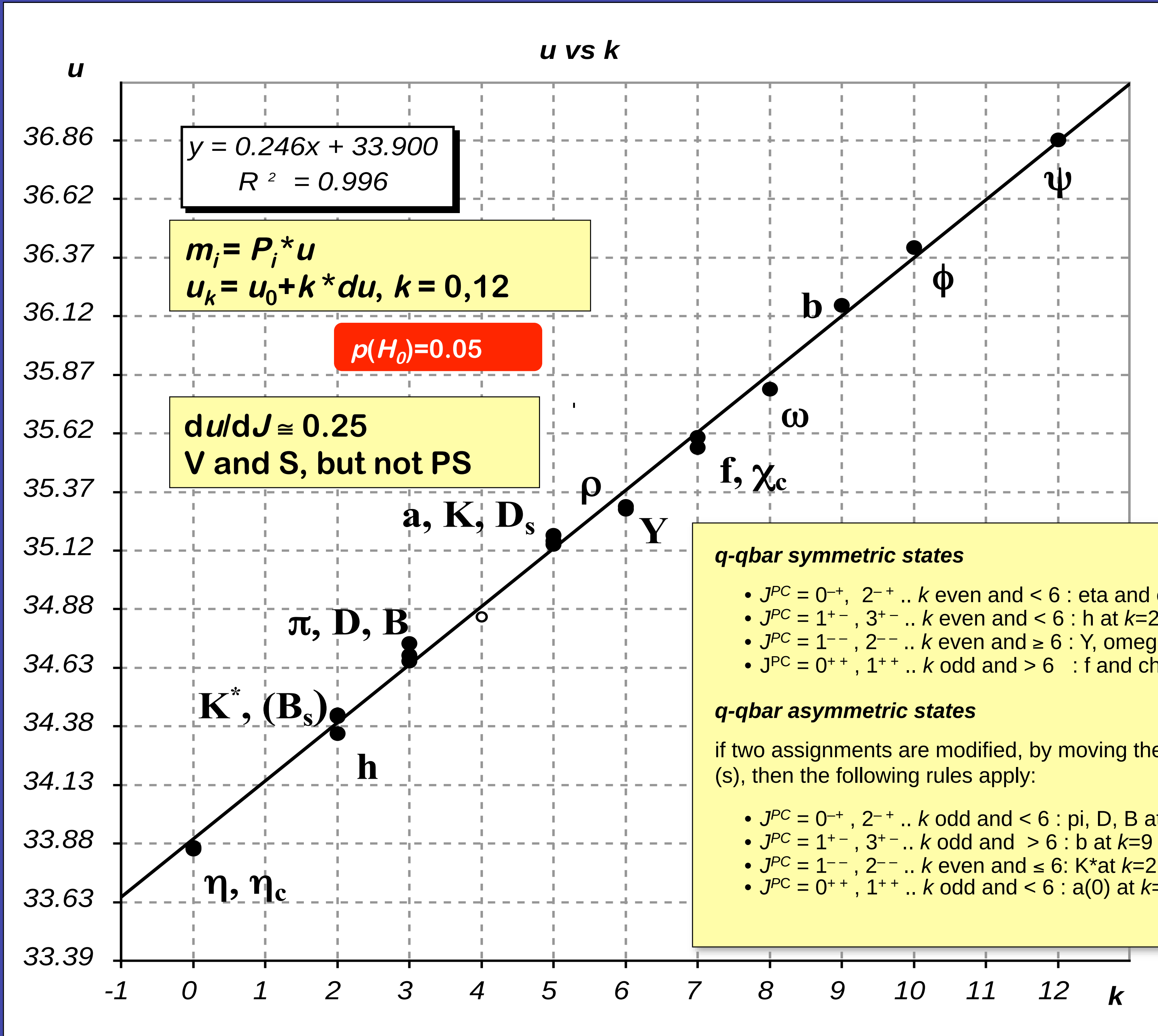
summary

Summary of mass unit analysis, mesons

							states	omitted					used	
type	k	u	erru	uw	p-value	du/dJ	PDG	(1)	(2)	(3)	(4)	tot		rating
pi	**3**	34.69	0.051	34.68	0.997	N	11	1		1	1	3	8	****
b	**9**	36.16	0.050	36.16	0.990	N	3						3	***
rho	**6**	35.19	0.071	**35.31**	0.973	N	11	2		1		3	8	***
a					0.995	Y	13	2				2	11	****
a(0)	**5**	35.00	0.073	**35.17**	0.941									
K	**6**	35.34	0.073	35.39	0.943	N	11				1	1	10	***
K*					0.882	Y	12	1		1	2	4	8	
K*(1)	**2**	34.35	0.016	34.35										****
eta	**0**	33.86	0.053	33.86	0.999	N	13	4				4	9	****
h	**2**	34.42	0.056	34.43	0.975	N	6	2				2	4	****
omega					0.934	Y	7	1				1	6	****
omega(1)	**8**	35.80	0.049	35.81	0.943									
phi					0.732	Y	3						3	**
phi(1)	**10**	36.51	0.050	**36.41**										
f	**7**	35.78	0.070	**35.60**	0.998	?	33	5	18			23	10	***
D^+	**3**	34.67	0.016	34.66	0.997	N	5						5	****
D^0		34.58	0.023	34.60	0.960	N	4						4	****
D(s)	**5**	35.16	0.021	35.15	0.997	N	6						6	****
eta(c)	**0**	33.89	0.022	33.87			2						2	**
psi	**12**	36.84	0.034	36.87	0.959		7			1		1	6	****
chi(c)	**7**	35.57	0.006	35.56		Y	3						3	**
B	**3**	34.74	0.005	34.73			3				1	1	2	*
B(s)	**2**	34.42	0.004	34.42			2						2	*
Y	**6**	35.29	0.009	35.30	0.985		6			1		1	5	****
		avg->	0.044		0.949		161	18	18	5	5	46	115	**<-tot**
leptons	**4**	34.84	0.022	34.84			2						2	**

u-quantum

du/dk



q-qbar symmetric states

- $J^{PC} = 0^{-+}$, 2^{-+} .. *k* even and < 6 : eta and eta_c at *k*=0
- $J^{PC} = 1^{+-}$, 3^{+-} .. *k* even and < 6 : h at *k*=2;
- $J^{PC} = 1^{--}$, 2^{--} .. *k* even and ≥ 6 : Y, omega, phi, psi at *k*=6, 8, 10, 12;
- $J^{PC} = 0^{++}$, 1^{++} .. *k* odd and > 6 : f and chi_c at *k*=7

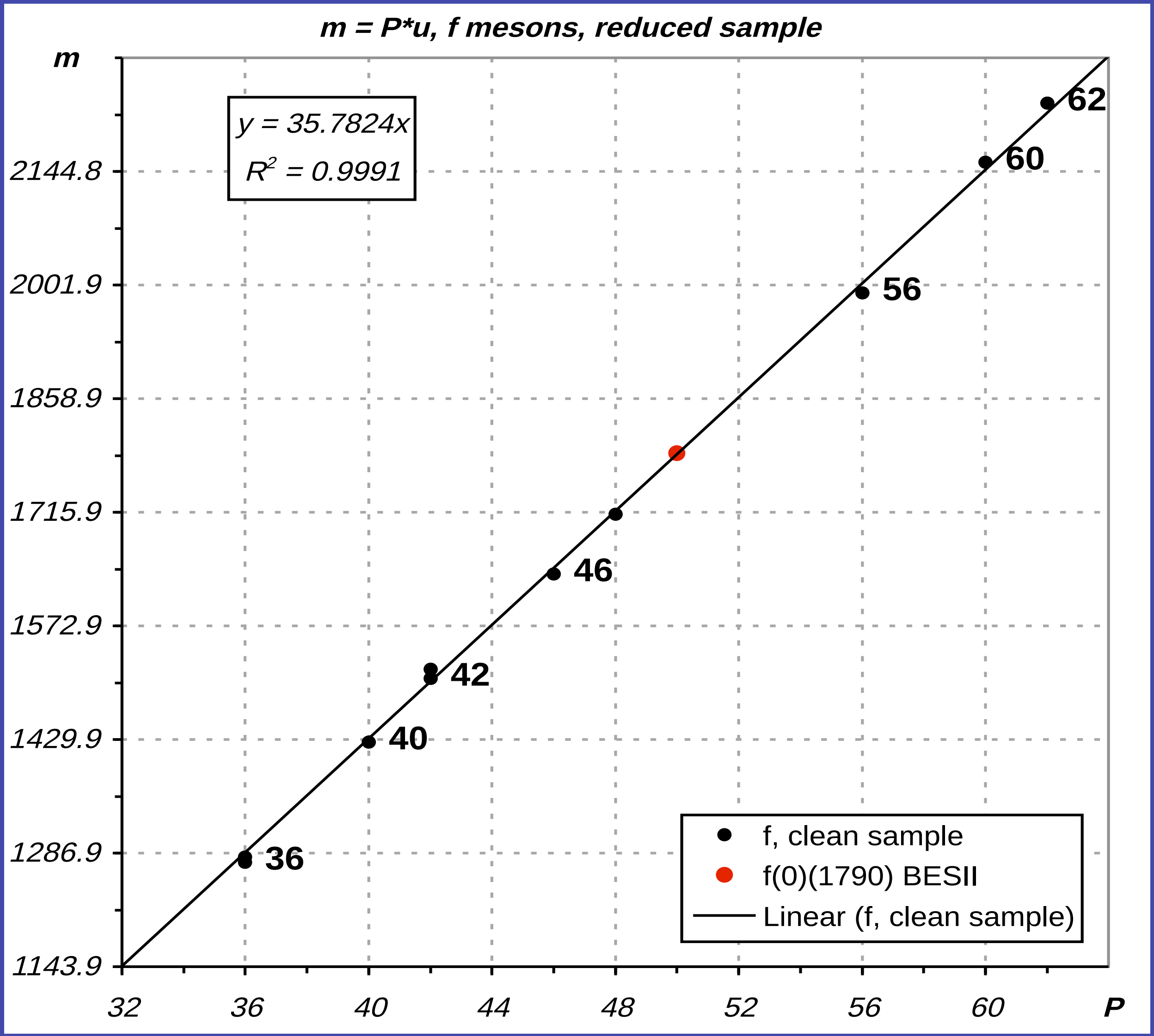
q-qbar asymmetric states

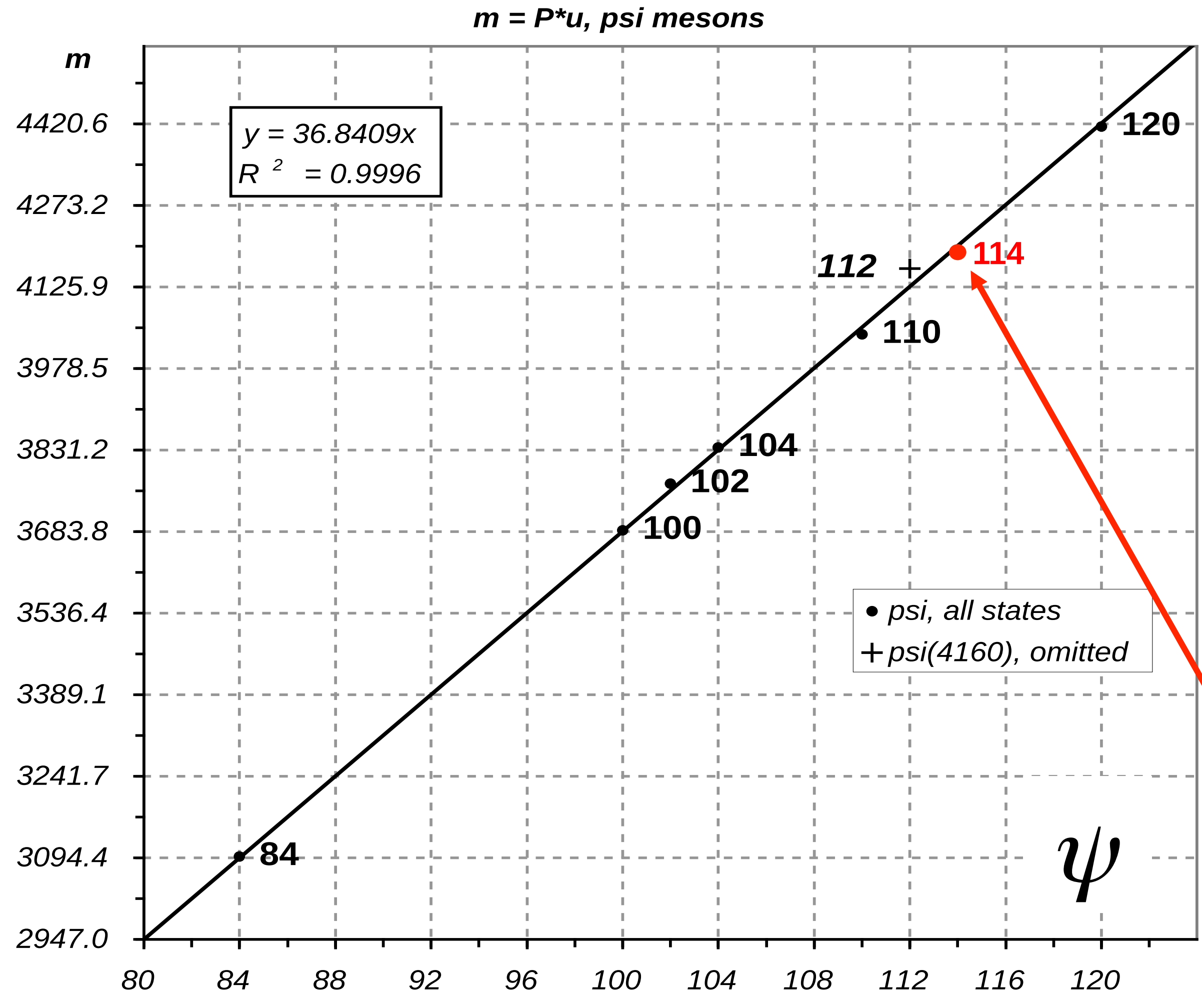
if two assignments are modified, by moving the K from 6 to 5 and neglecting the B (s), then the following rules apply:

- $J^{PC} = 0^{-+}$, 2^{-+} .. *k* odd and < 6 : pi, D, B at *k*=3
- $J^{PC} = 1^{+-}$, 3^{+-} .. *k* odd and > 6 : b at *k*=9
- $J^{PC} = 1^{--}$, 2^{--} .. *k* even and ≤ 6: K*at *k*=2, rho at *k*=6
- $J^{PC} = 0^{++}$, 1^{++} .. *k* odd and < 6 : a(0) at *k*=5;

$p(H_0)$= 0.000...

new states must agree (and they do)





Reject: psi(4160)

2004: psi(4160) rejected

The psi(4160) with a residual of 33, rejected by Chauvenet's criterion. Its mass quoted by the PDG is based on a single measurement by DASP, and in the DASP paper the result of their analysis is compared with MARK1 data showing a more complex peak structure.

Above the psi(4040) the MARK1 data show a peak at around 4110 and possibly more. The psi(4415) is seen unambiguously by both experiments. The DASP view of the discrepancy is: "..our data are in closer agreement with those of SLAC-LBL but show some differences in the finer details of the energy dependence. For instance the 4.16 structure is not resolved in the SLAC-LBL data".

For sure there are differences, but the DASP interpretation is questionable. Apparently some MARK1 peaks were never identified or never made it to the PDG. A possible interpretation of their spectrum around 4100 is: psi(4040), P=110; psi (4125), P=112; possibly a psi(4200) , P=114; no psi (4160).

2007: new BES value = 4191.6 ± 6.0

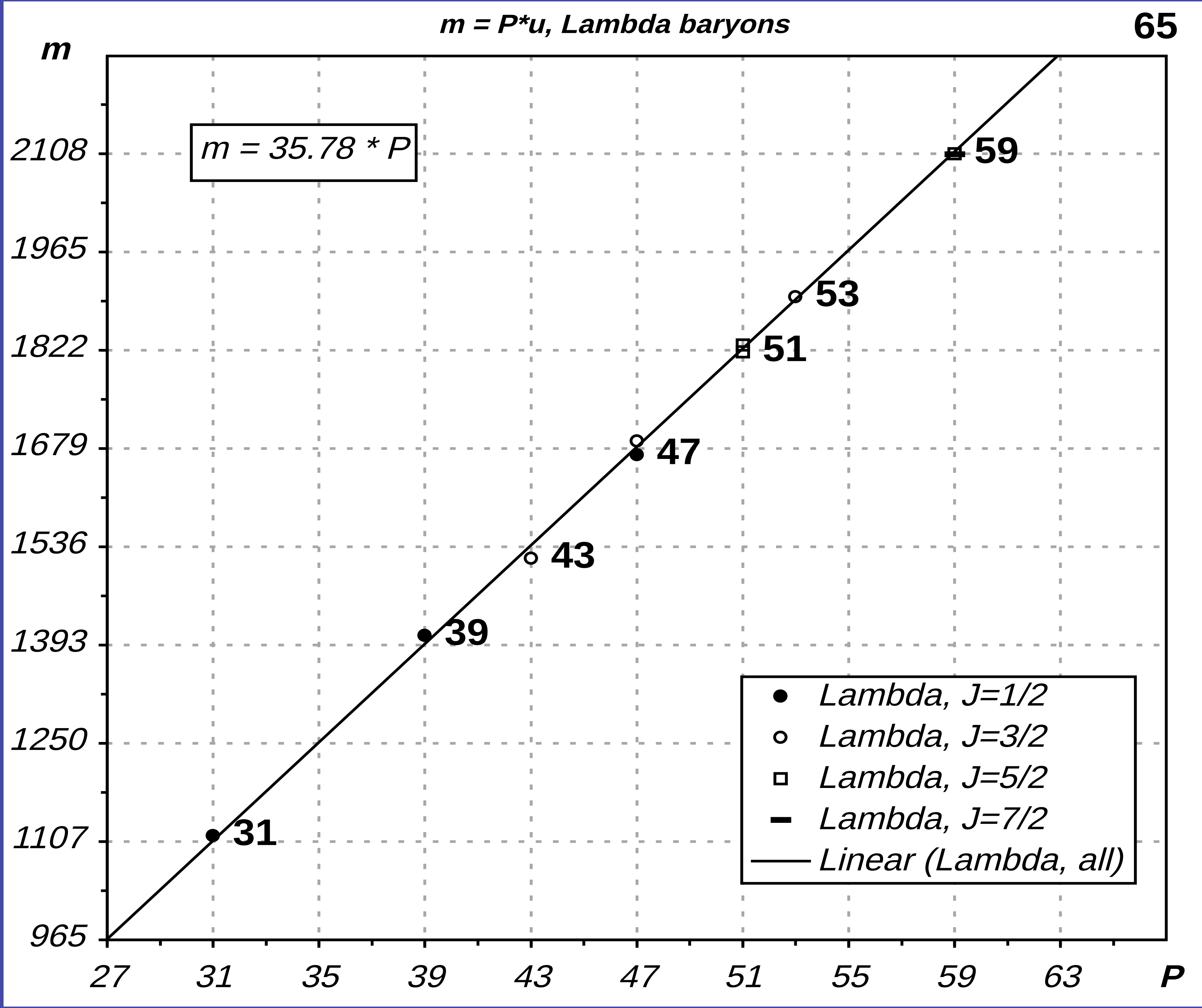
meson type = psi

name	*	q	J	x	P	m	errm	u	dm	dm/m
psi(1S)	4	0	1		84	3096.9	4.0E-02	36.868	2.2	0.07%
psi(2S)	4	0	1		100	3686.0	9.0E-02	36.860	1.9	0.05%
psi(3770)	4	0	1		102	3769.9	2.5	36.960	12.1	0.32%
psi(3836)	3	0	2?		104	3836.0	13.0	36.885	4.5	0.12%
psi(4040)	4	0	1		110	4040.0	10.0	36.727	-12.5	-0.31%
psi(4415)	4	0	1		120	4415.0	6.0	36.792	-5.9	-0.13%
psi(4160)	4?	0	1	3	112	4159.0	20.0	37.134	32.8	0.79%

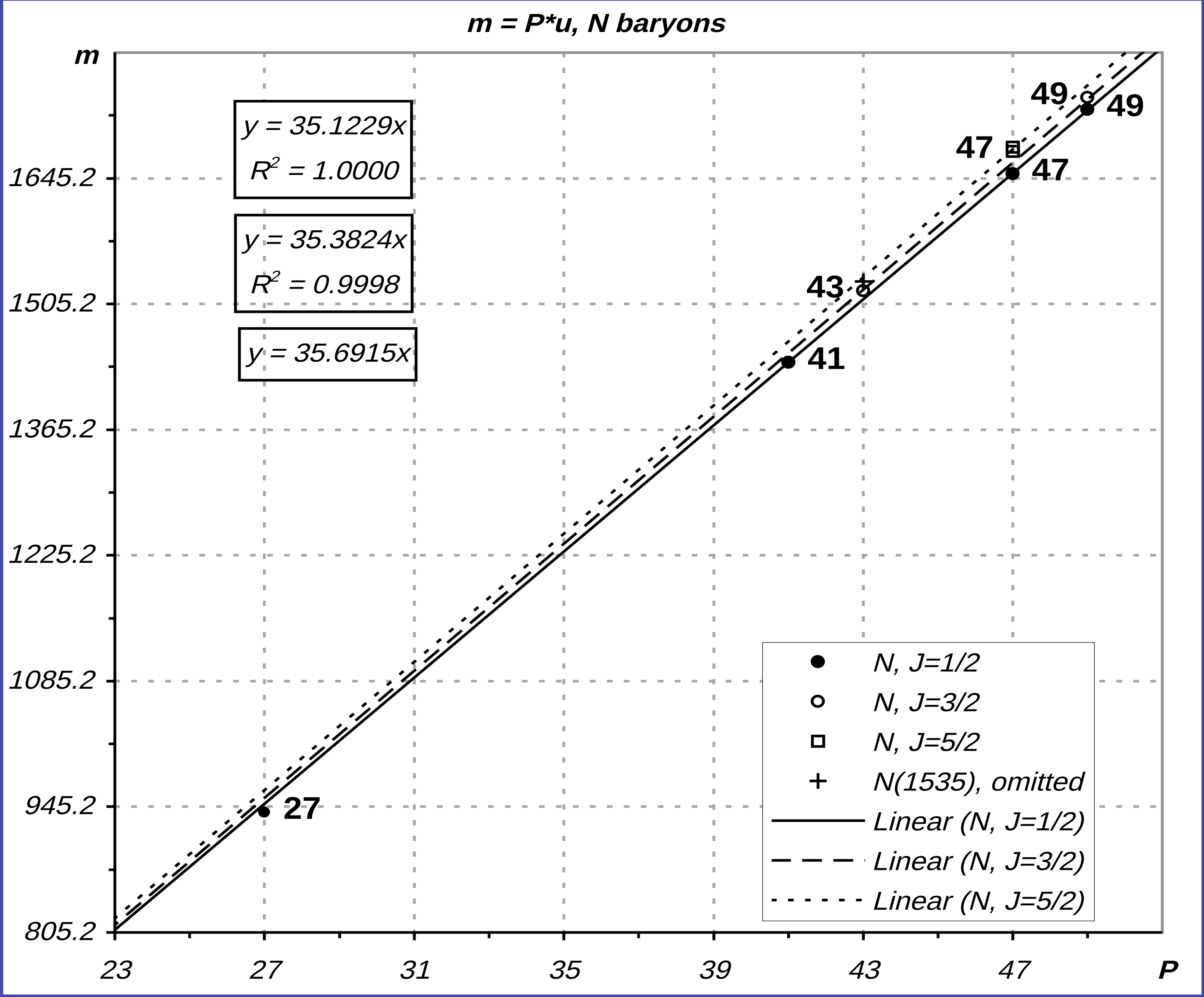
outliers

baryon mass system

regs

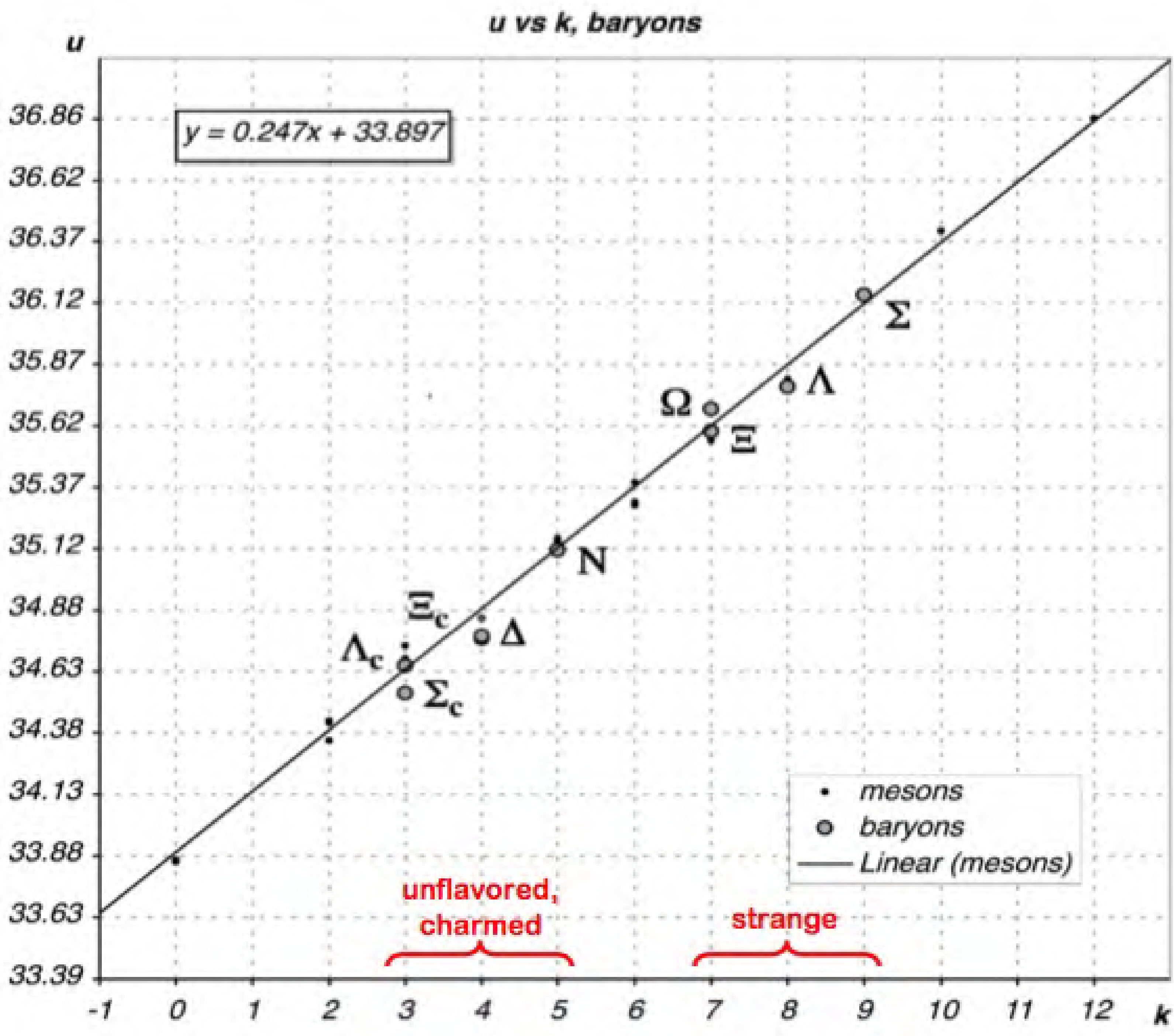

m = P*u, Lambda baryons
m
m = 35.78 * P
2108
1965
1822
1679
1536
1393
1250
1107
965
27
31
35
39
43
47
51
55
59
63
P
31
39
43
47
51
53
59
Lambda, J=1/2
Lambda, J=3/2
Lambda, J=5/2
Lambda, J=7/2
Linear (Lambda, all)

du/dJ



m = P*u, N baryons
m
1645.2
1505.2
1365.2
1225.2
1085.2
945.2
805.2
23
27
31
35
39
43
47
P
y = 35.1229x
R2 = 1.0000
y = 35.3824x
R2 = 0.9998
y = 35.6915x
49
49
47
47
43
41
27
N, J=1/2
N, J=3/2
N, J=5/2
N(1535), omitted
Linear (N, J=1/2)
Linear (N, J=3/2)
Linear (N, J=5/2)

u vs k

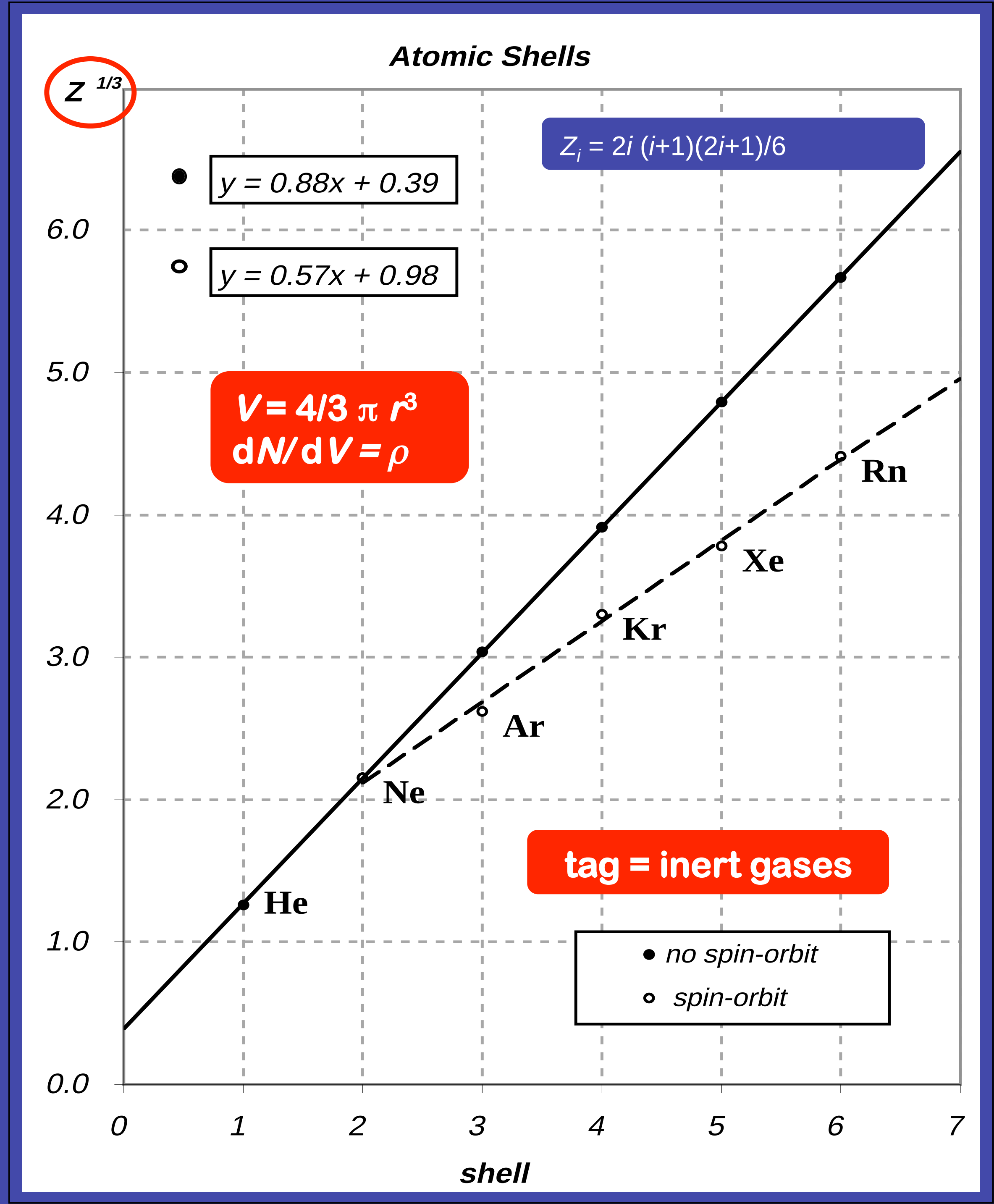


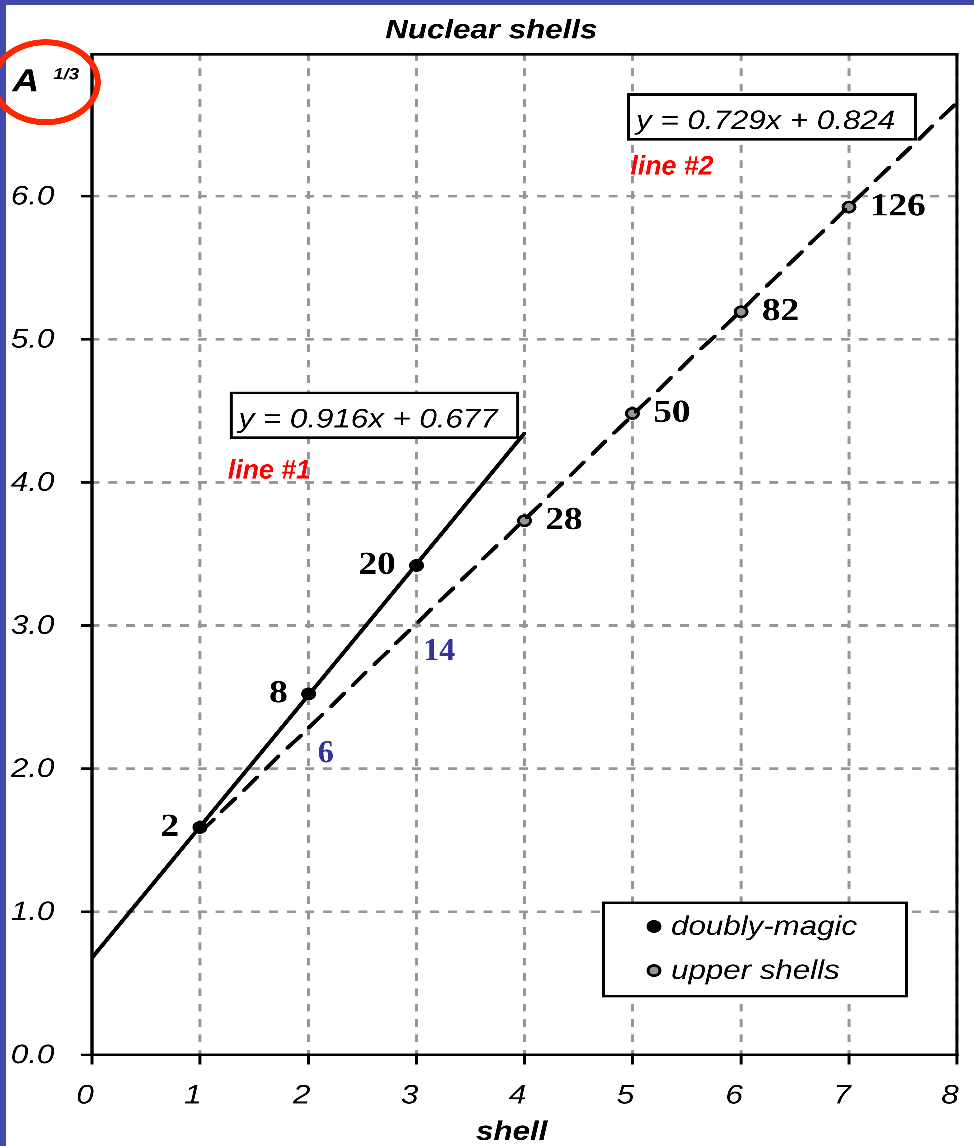
u vs k, baryons
u
y = 0.247x + 33.897
36.86
36.62
36.37
36.12
35.87
35.62
35.37
35.12
34.88
34.63
34.38
34.13
33.88
33.63
33.39
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
k
Σ
Λ
Ω
Ξ
N
Ξ_c
Δ
Λ_c
Σ_c
mesons
baryons
Linear (mesons)
unflavored,
charmed
strange

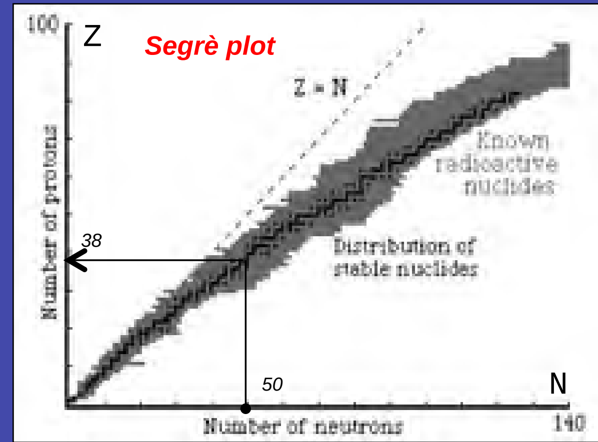
back to shells

atomic shells

$Z^{1/3}$







nuclear shells

$A^{1/3}$

2 shell lines with interesting properties:

- **cross at the first shell**, He-4 (δy<3%);
- in shells 2 and 3, line #2 corresponds to values of A of **12=6+6** and **28=14+14**; 14 recognized long ago as quasi-magic; the "magicity" of 6 is a more recent result;
- the **ratio of the cubes of the slopes of the two lines is 1.99**, very close to 2: the number of nucleons in series #2 grows from one shell to the next at a rate = 1/2 the one of series #1;
- in line #1 the **"packing fraction" is maximal**:

$$(0.916)^3 = \mathbf{0.768}$$

N_i = 2, 8, 20, 28, 50, 82, 126: magic
Z_i from Segrè plot, max. stability
$A_i = N_i + Z_i$
plot $A_i^{1/3}$ vs i, tag = N_i

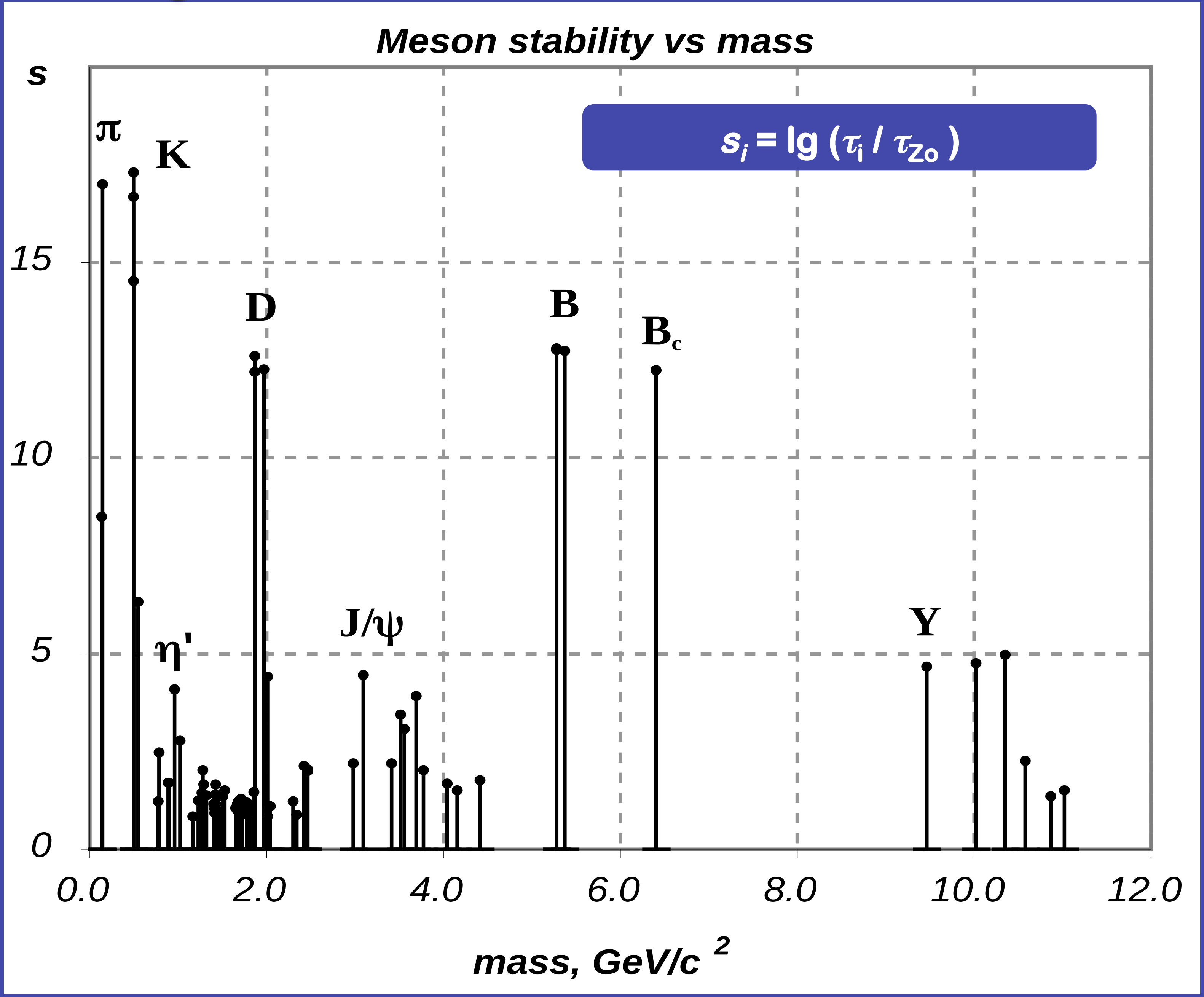
$A1(n) = 2*[\Sigma(i+1)*i,\ \ i=n,1,1] = 2*[(n+1)*n + n*(n-1) +..+2*1]$

$= 4, 16, 40, 80, ...$

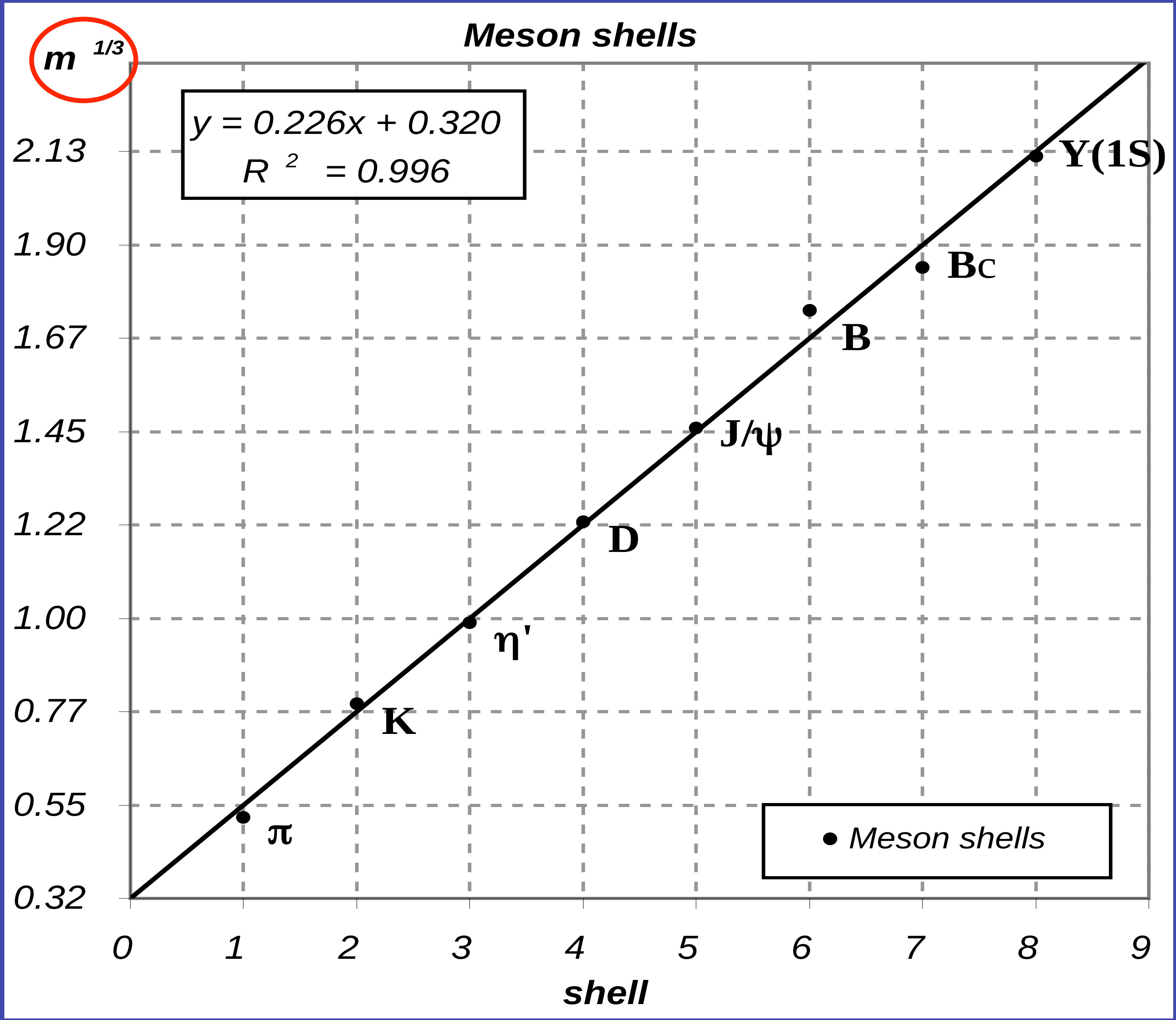
$A2(n) = 2*[\Sigma(i+1)*i,\ \ i=n,1,2] = 2*[(n+1)*n + (n-1)*(n-2)+..]$

$= 4, 12, 28, 52, 88, 136, 200, 280$

meson stability



meson shells



combine meson mass shell plot with mass units:

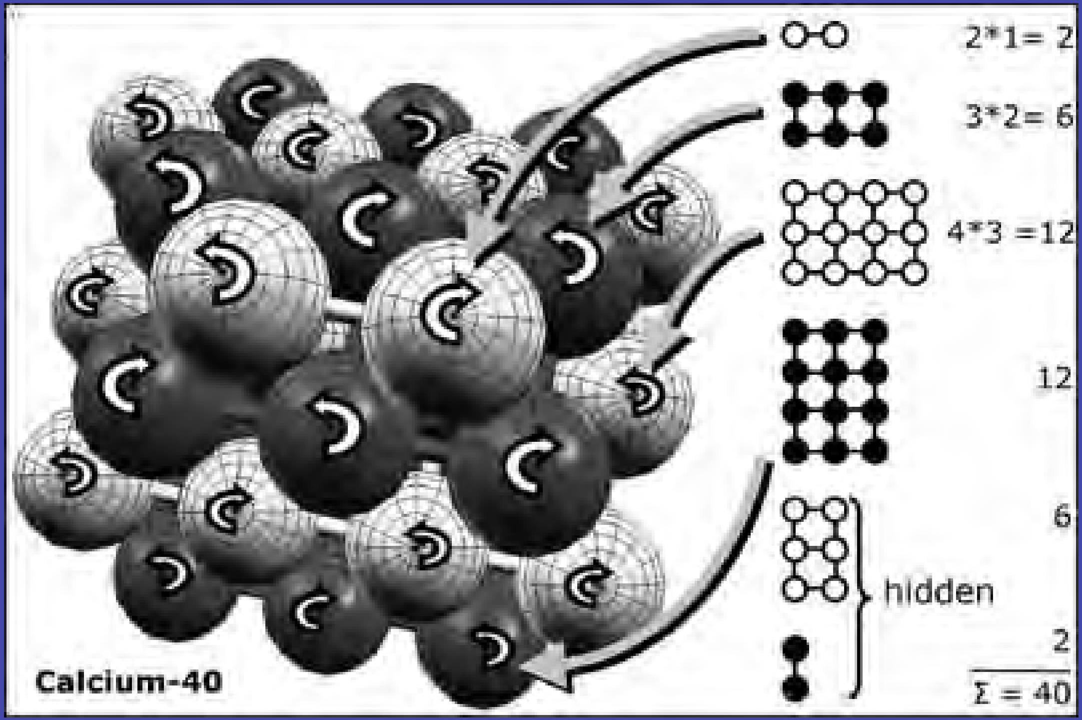
35 MeV/c^2 = 1 constituent

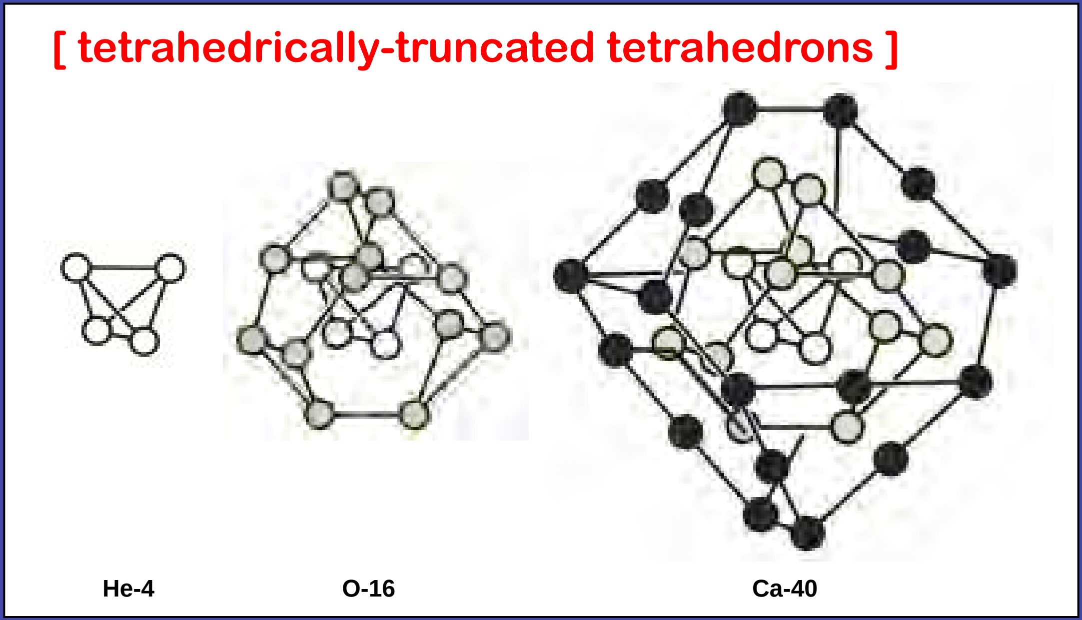
M(i): (**4, 14, 28, 54, 84**, 152, * , 294) [*i* =1,8], *y* = **0.712** * *x* + **0.894**, R^2 = 0.9981

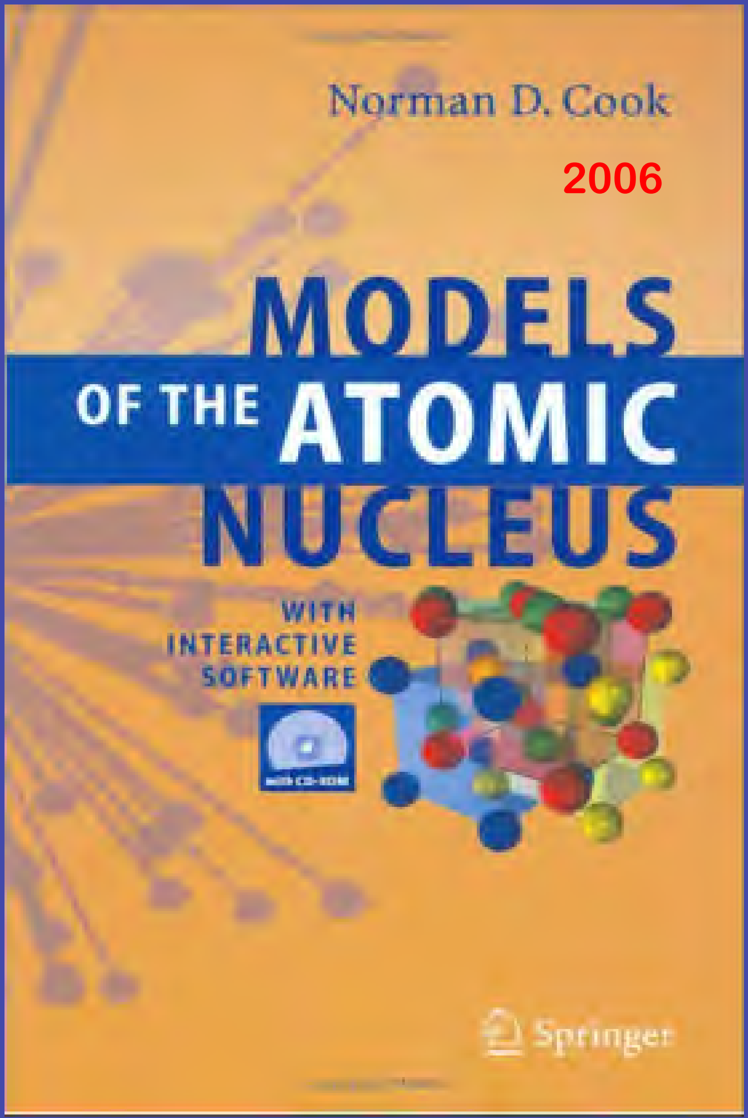
very similar to the corresponding values for the second nuclear line

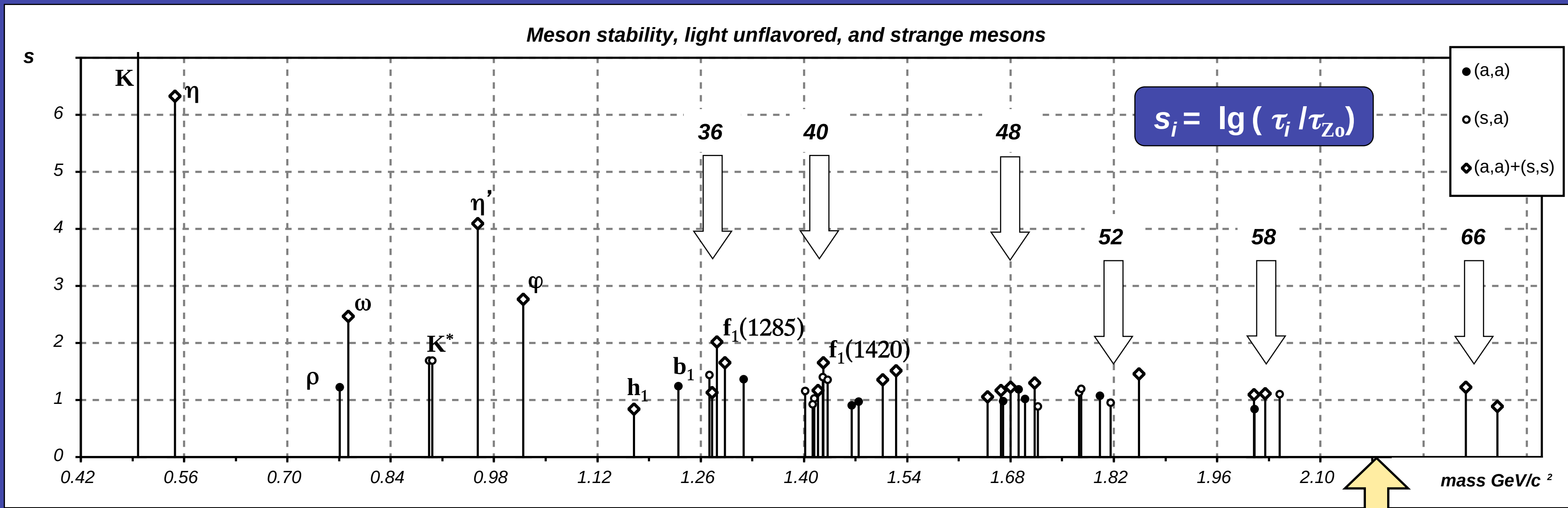
N(i): (**4, 12, 28, 52, 88**, 140, 208) [*i* =1,7], *y* = **0.729** * *x* + **0.824**, R^2 = 0.9999

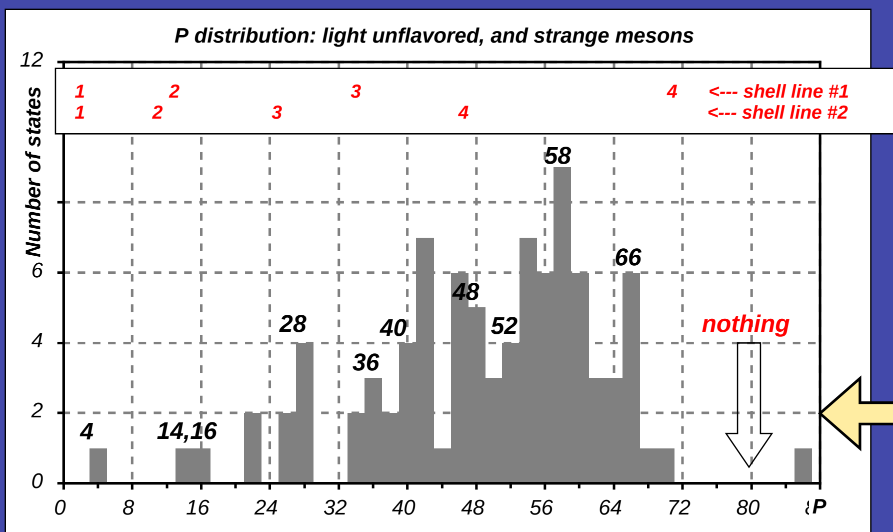
A1(n) = 2*[Σ(i+1)*i, i=n,1,1] = 2*[(n+1)*n + n*(n-1) +..+2*1]
A2(n) = 2*[Σ(i+1)*i, i=n,1,2] = 2*[(n+1)*n + (n-1)*(n-2)+..]











meson stability up to 2 GeV/c^2 with mass scale in steps of 70 MeV/c^2:

- the η **at *P*=16**, analogous of the **doubly-magic O-16**
- three clusters around 1260 MeV/c^2 (*P*=36), 1420 MeV/c^2 (*P*=40), and 1680 MeV/c^2 (*P*=48).
- three further clusters with fewer states, ~ 1820 MeV/c^2 (*P*=52), 2030 MeV/c^2 (*P*=58), and 2310 MeV/c^2 (*P*=66).

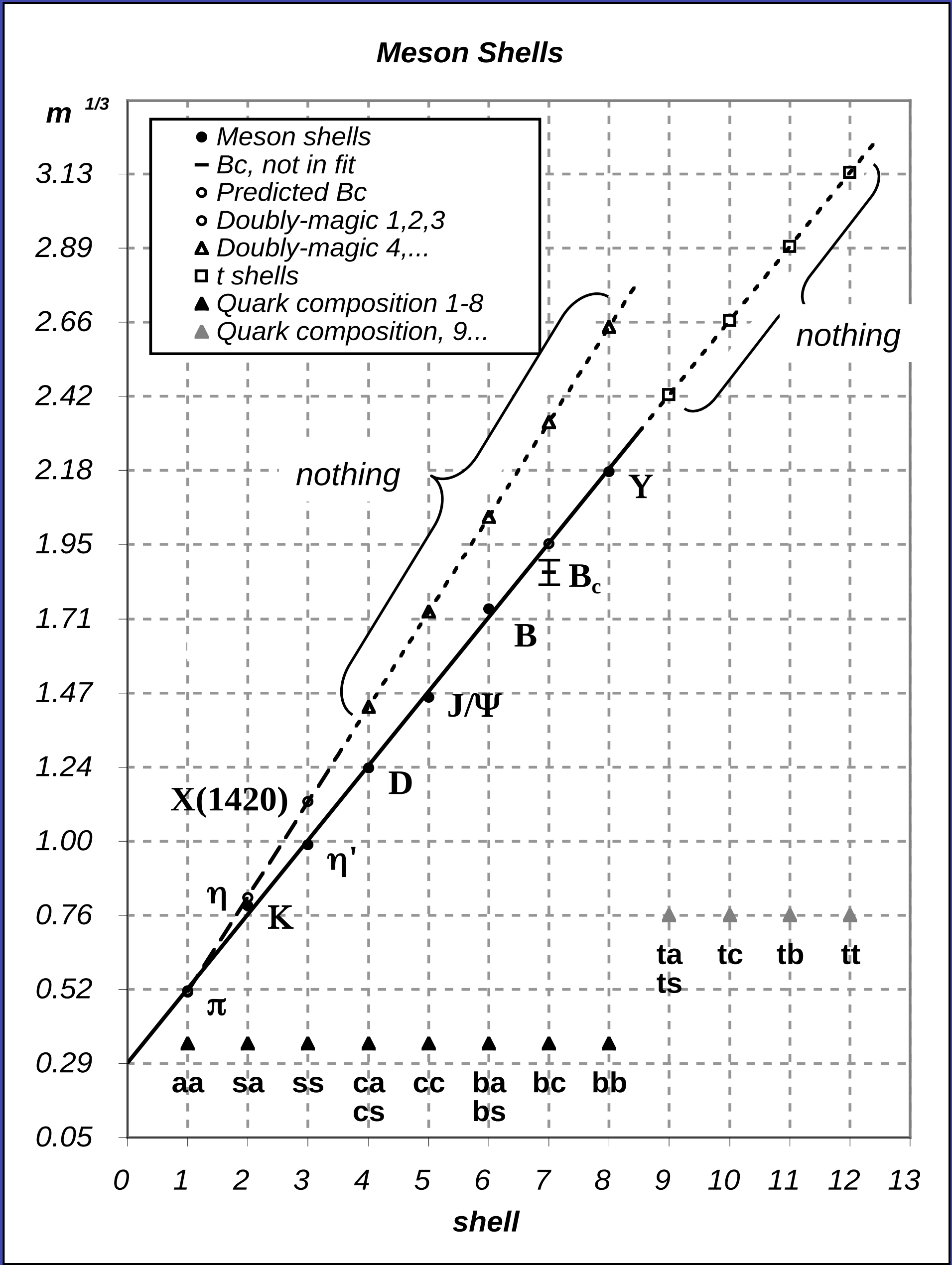
P=40 corresponds to shell 3 in the nuclear line #1, the **doubly-magic Ca-40**.

the *P* distribution for all (a,a), (s,a) and (s,s) states confirms the three clusters around **36, 40** and **48**, as well as at **52, 58** and **66**. In the shell interpretation the peaks at *P*=36, 48, 52, 58 and 56 would correspond to **sub-shells** (to be developed).

***P*=80** is the **doubly-magic shell 4** ~ 2800 MeV/c^2; the histogram is empty from *P*=72 to 84: as in nuclei, the **doubly-magic-equivalent shell series stops at 3.**

sub-shells

meson shells summary



- meson shells 1 to 8 corresponds to nuclear shell line #2, and also **doubly-magic** shells can be identified:
  1) π at *P* = 4 ~ He-4
  2) η at *P* =16 ~ O-16
  3) states at *P* = 40 ~ Ca-40

  but no states are known near the extrapolated mass values for the following shells in that series, P=80, ...;

- on the main meson shell line, the **quark composition progression** from shell 1 to 8 is:

  aa, sa, ss, ca+cs, cc, ba+bs, bc, bb ;

  – intriguing role of the s quark,

  – explanation of **the mysterious values of quark masses** (for whatever it is worth);

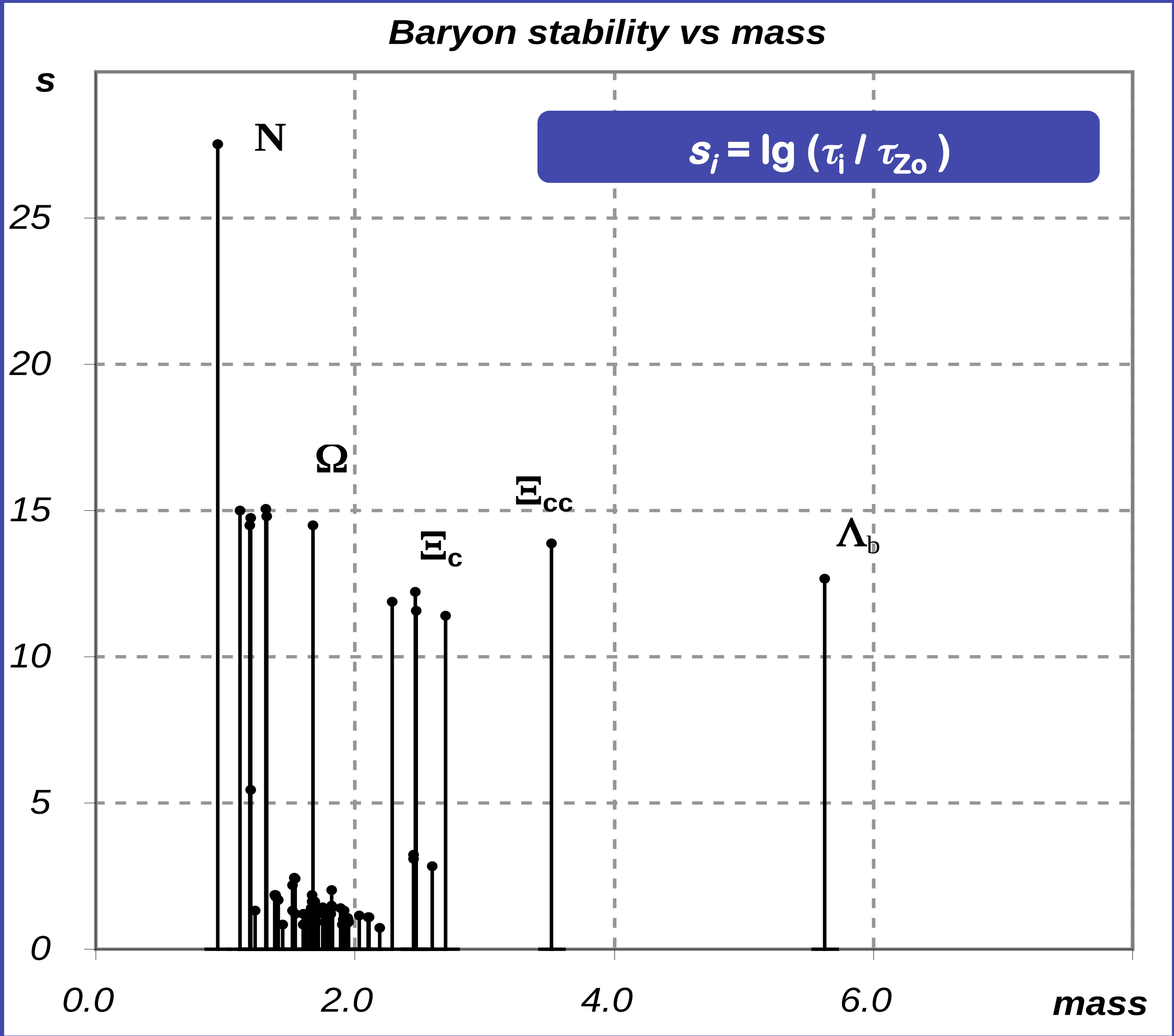
- **t quark:** expect 4 more shells at specific mass values in the range 14 - 31 GeV/c^2, none observed;

  – is shell **8** the **structural limit** for this kind of bound states, like 6 for atoms and 7 or 8 for nuclei?

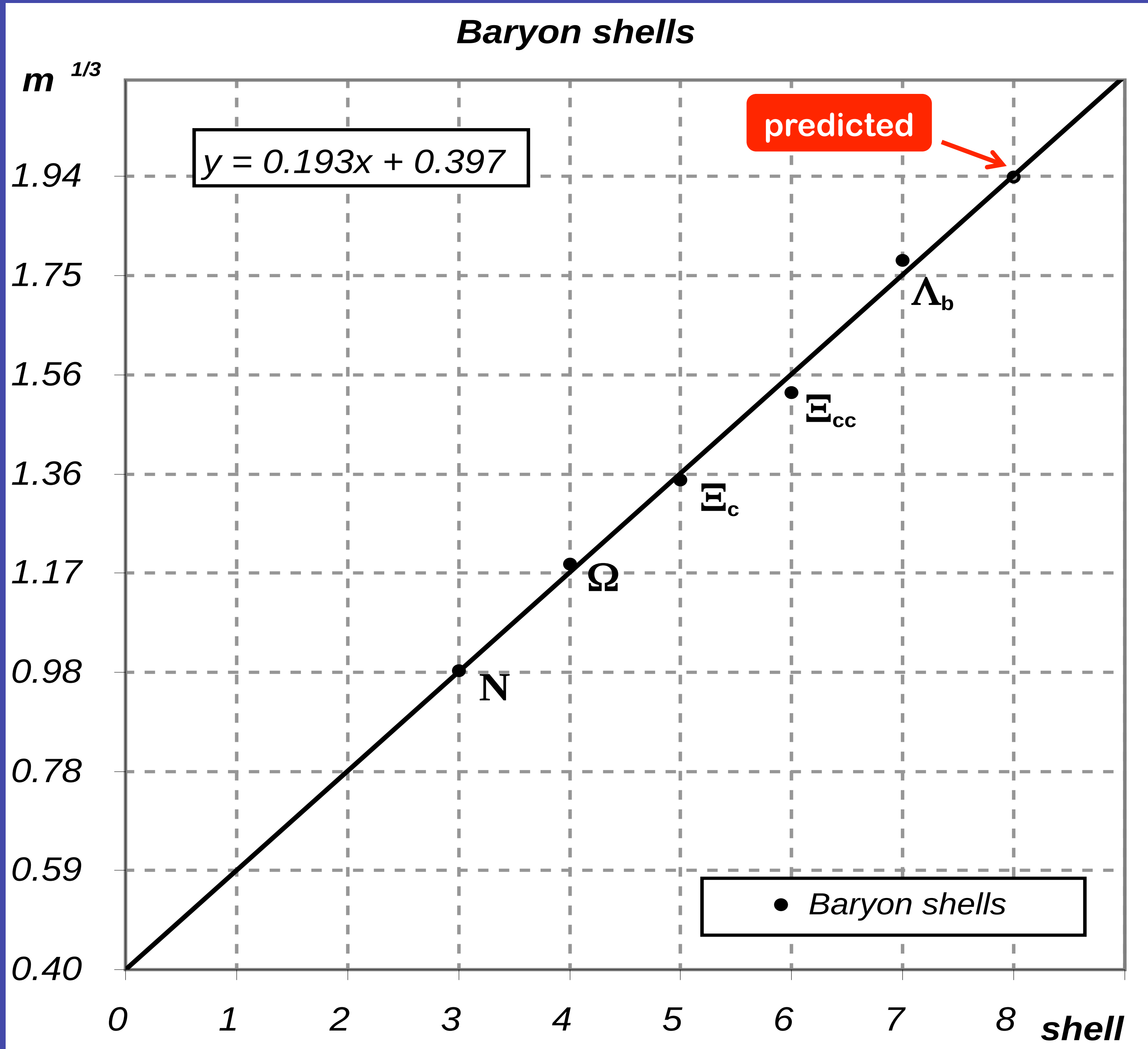
  – what are the **top events** from FNAL?

  $m(\mathrm{t}) = m(\mathrm{W}) + m(\mathrm{Z}^0)$

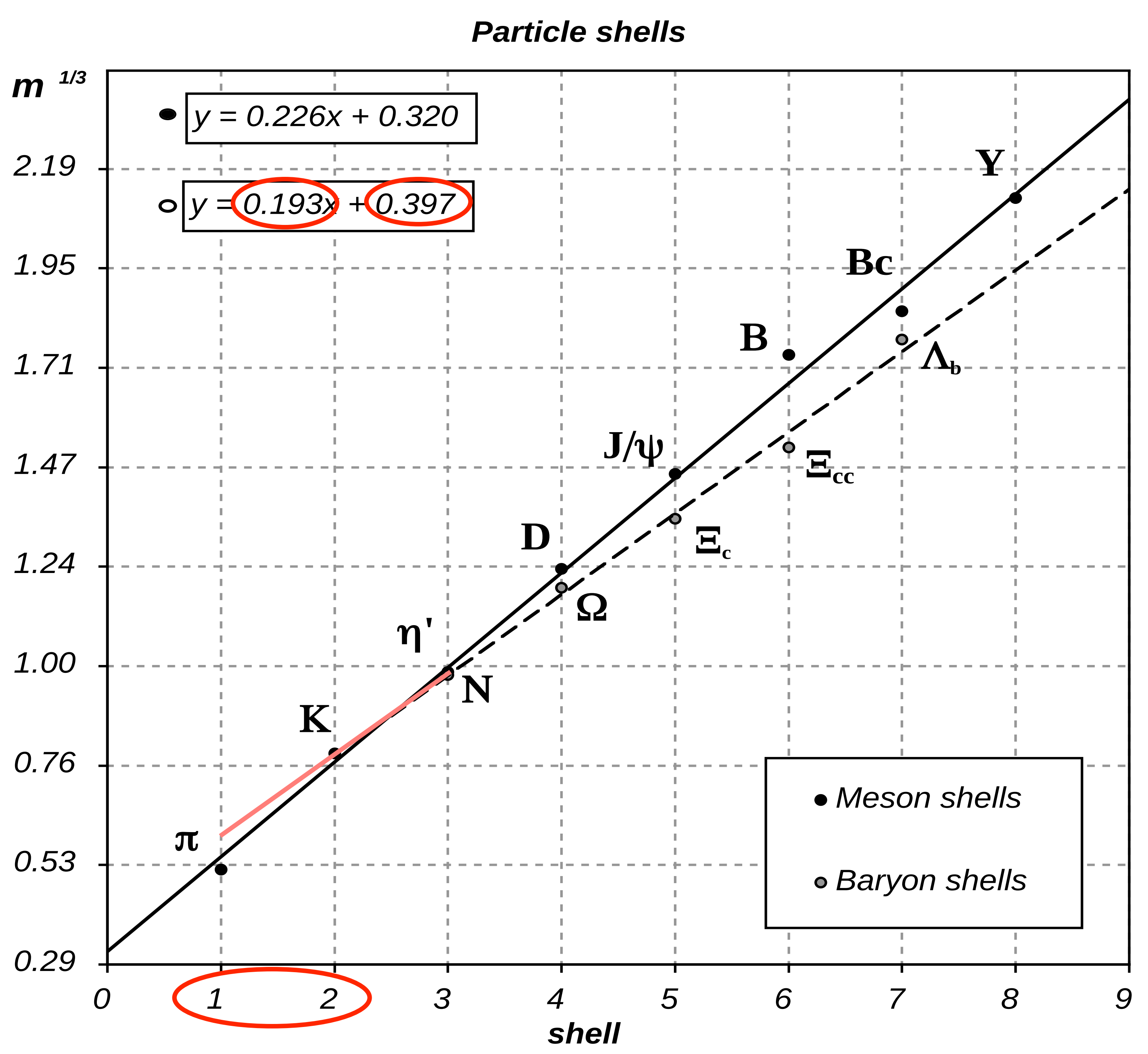
baryon stability



baryon shells



baryon vs meson shells



baryon shells organization, clues:

- shells 1 and 2 not cohesive
- density = 1/3 of the full FCC
- more than 4 nodes at shell 1
- restricted span of the u(k) grid:

  only 3,4,5 and 7,8,9, 6 out of 13 positions

diamond lattice? maybe..

proton structure

from scattering
and
from systematics

M. Islam: explain p-p dσ/dt with proton in 3 layers

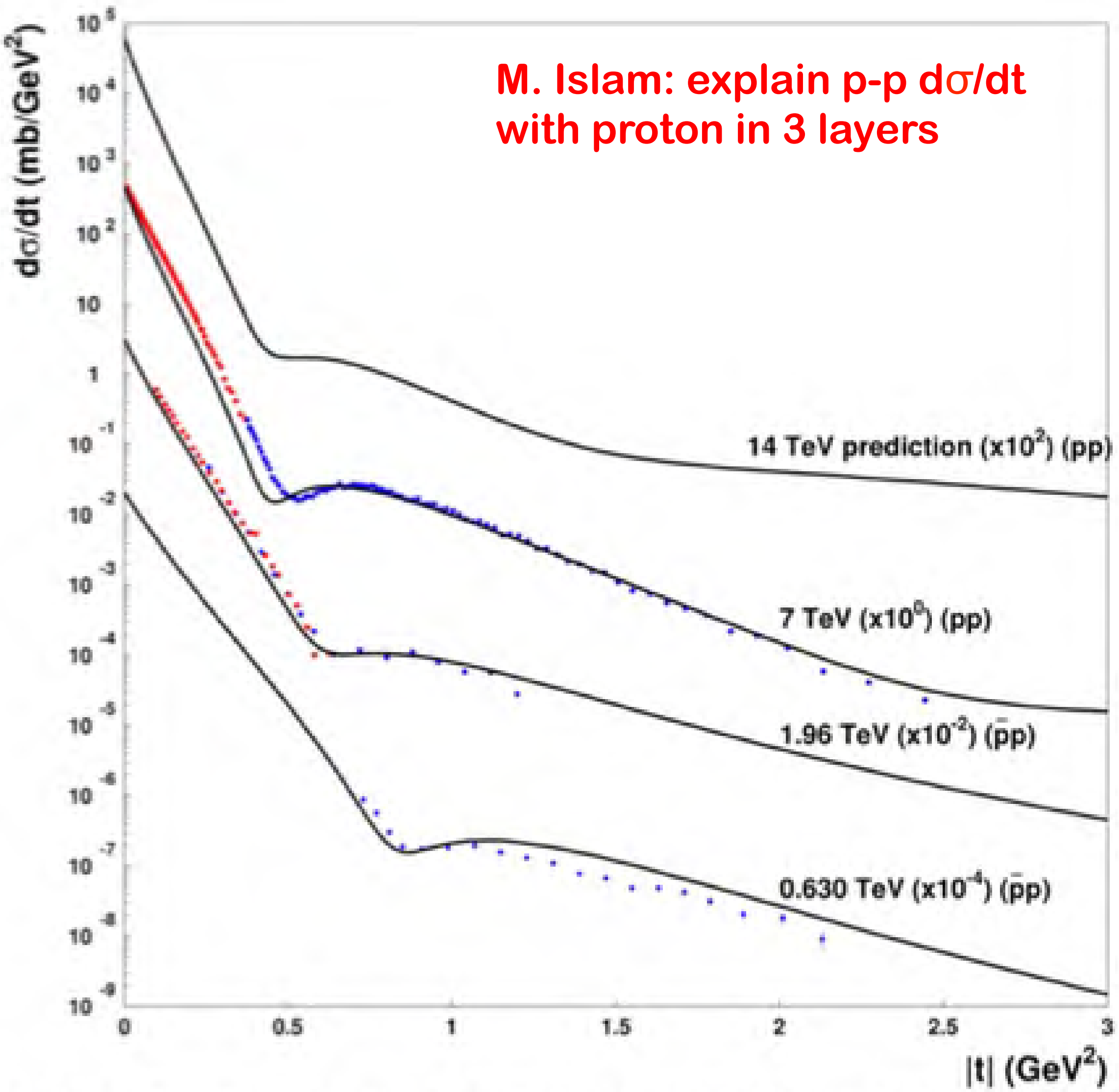


Fig. 5. Our calculated differential cross sections at 7.0 TeV (pp), 1.96 TeV (p̄p), and 0.630 TeV (p̄p) are shown (black curves). The experimental data are a) pp measurements at 7.0 TeV by TOTEM Collaboration (red and blue dots)[5, 6]; b) p̄p measurements at 1.96 TeV by D0 Collaboration (blue dots)[7] together with CDF and E710 measurements at 1.80 TeV (red dots); c) p̄p measurements at 0.630 TeV by UA4 Collaboration[8].
The black curve for 14 TeV $d\sigma/dt$ is our prediction for pp elastic scattering, which will be measured at LHC by the TOTEM Collaboration.

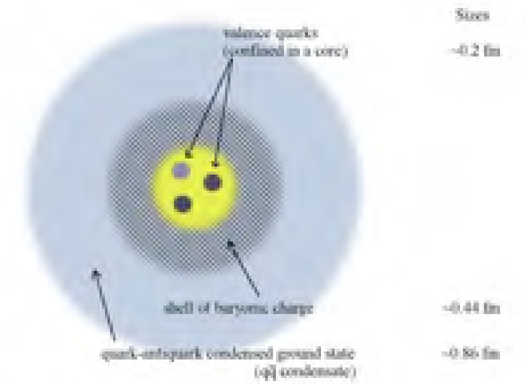


Fig. 1. Physical picture of the proton as a Condensate Enclosed Chiral Bag

proton structure

from scattering
and
from systematics

may converge

References:

research papers by Paolo Palazzi
on particle systematics and hadron models are at:

http://cdsweb.cern.ch/record/602200

http://particlez.org/p3a