2[nd] Conference on Nuclear and Particle Physics,
13 - 17 Nov. 1999, Cairo, Egypt

The C-N-cycle Additional Channels through the Combinative Resonances Phenomenon (CIRs).

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ABSTRACT
The Combinative Isobare Resonances are shown as new channels of the C-N-cycle.

In 1994 we had firstly used our new developed approach - the "Method of Spectra Superposition" providing measurement of $d\sigma(E)/d\Omega$ at every accelerator (including colliders !) with highest energy-resolution depending (for thin targets) only on energy-resolution of detectors [1-5].
Rarely one can read about this[6].

That time the Excitation Function (EF) of the $^{12}C(p,p_o)$ elastic scattering with energy-resolution ≈10keV for E_p=16 ÷ 19.5 MeV of cyclotron protons by using the multiangular magnetic spectrograph as detector was measured.

It was wonderful when after data processing so surprised curve with a saturated structure of overlapped resonances - **fluctuations of cross-section** (**Fig.1**) was obtained (in contrary to EF obtained by M.J. LeVine and P.D.Parker in 60'th at the tandem generator [7]).

The precise agreement between well known thresholds and nuclear levels with the brightest anomalies in our curve and "not disappearing" fine structures in full-events curve (stat.err. 3%) - all this, only, had satisfied me that these structures are not just a joke of statistics. Fig.1 shows a comparison of our obtained EF with thresholds and levels of well known product-nuclei.

But what are the other structures ? - **here's the main thing!**
For answering the question a computer program allowing to examine quite a number of different versions of resonances identification was writen. After a lot of runs a miracle result was obtained - the multiple coincidence of predicted lines (levels) with EF-anomalies (**Fig.2, 3**), - in suggestion that at the beginning stage of interaction (before the final nucleus and particles -products), any temporary **Intermediate Nuclear System** (IS) with a charge-forbidden nucleus + interior charge-compensator particle(s) is forming.
IS-evolution will be finished by collapsing of charge-compensator particle(s) (the interior capture) - which is the action of forming a final nucleus-product.
Let's consider formation of an Intermediate System with ^{13}**C** going to ^{13}N.

Version I and Version II

for real products lead to

Reading 0.

Reading 0.

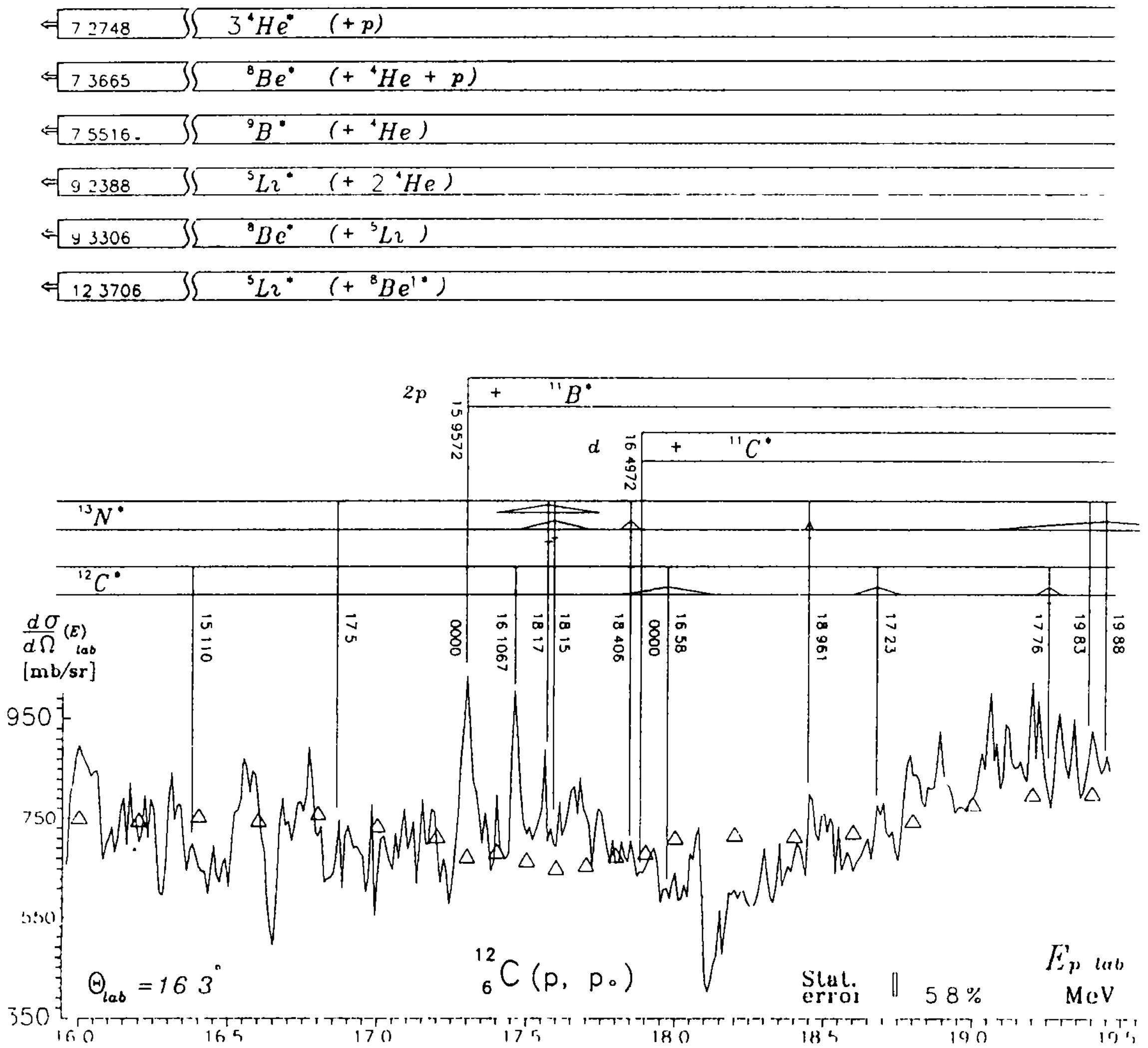
$$E_{pCM} = E^{*}_{LNP} + \Delta M_{OS} - \Delta M_{PS}$$

E_{pCM}	E^{*}_{LNP}	ΔM_{OS}	ΔM_{PS}
proton energy in CMS	level energy of nucleus -product	mass defect of output system	mass defect of primary system

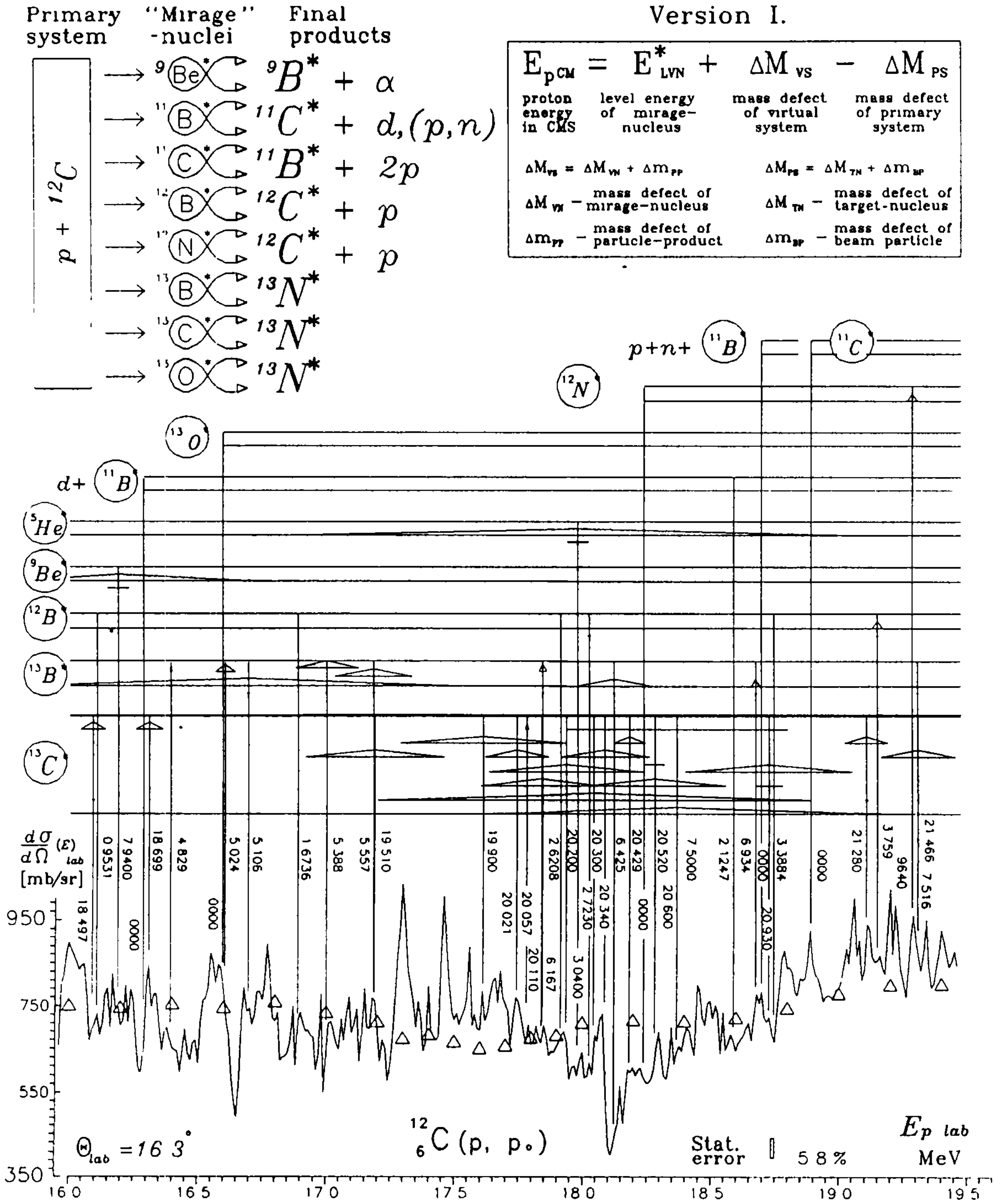
$\Delta M_{OS} = \Delta M_{NP} + \Delta m_{PP}$ $\Delta M_{PS} = \Delta M_{TN} + \Delta m_{BP}$

ΔM_{NP} – mass defect of nucleus-product ΔM_{TN} – mass defect of target-nucleus

Δm_{PP} – mass defect of particle-product Δm_{BP} – mass defect of beam particle

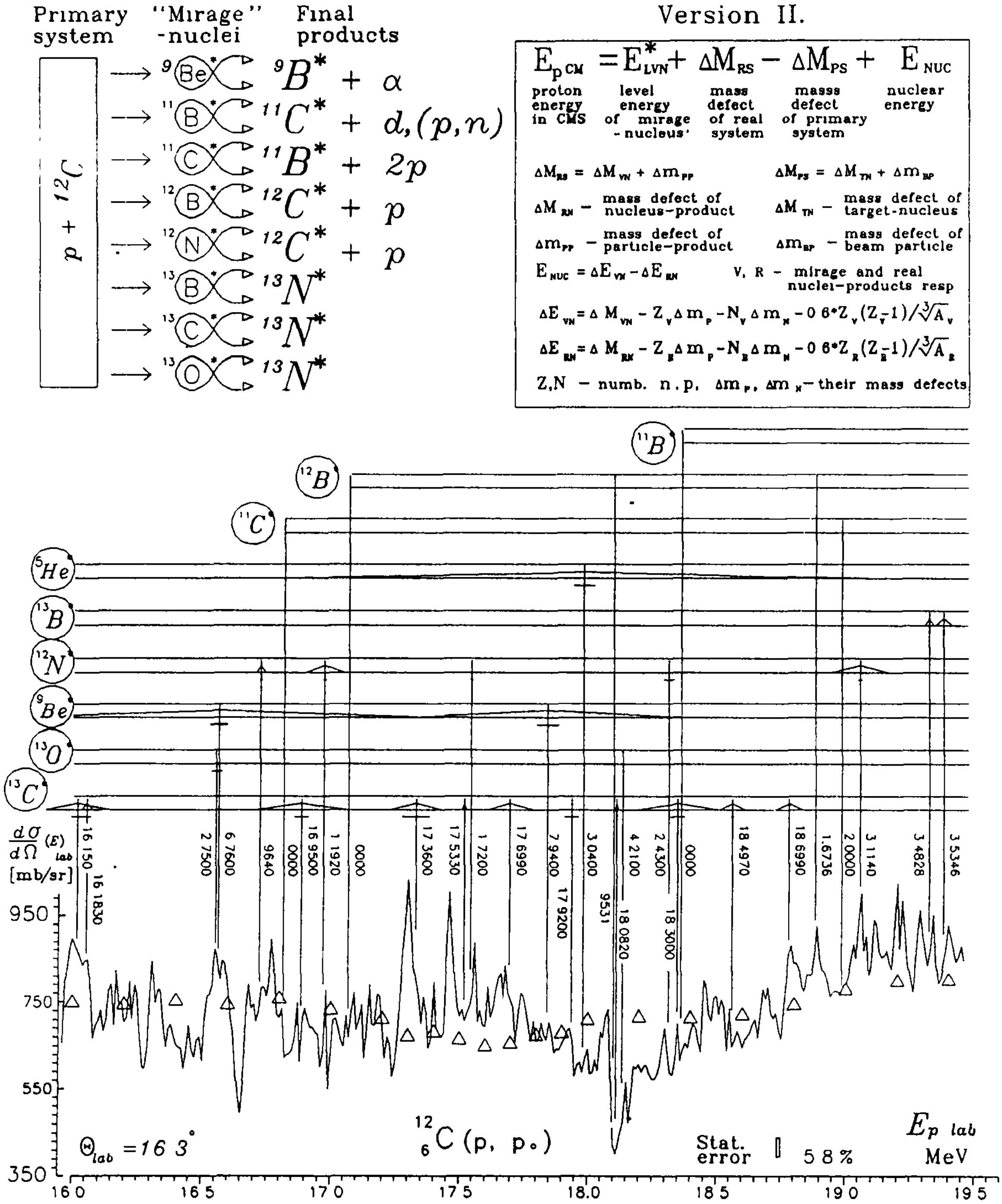


Pic. 1. Excitation Function from MSS in comparison with levels diagrams of the final nuclei and thresholds of their production on READING 0.
△ - from Physical Review -133. 4B (1964), p B934-B947



Pic. 2. Excitation Function from MSS in comparison with levels diagrams of the charge forbidden nuclei and thresholds of their production on VERSION I.

△ – from Physical Review –133. 4B (1964), p B934–B947.



Pic. 3. Excitation Function from MSS in comparison with levels diagrams of the charge forbidden nuclei and thresholds of their production on VERSION II.

△ - from Physical Review -133. 4B (1964), p.B934-B947.

Traces-resonances of the forbidden ^{13}**C** in EF of the elastic scattering $^{12}C(p,p_o)$ are quite normal if one remembers the **projectile-stimulated internuclear "soft"** $\pi^{\pm}$ [8-10] and its decay leptons (below).

Primary System (PS) — Intermediate Nuclear System (IS) — Final System (FS)

$$p + {}^{12}_{6}C \nearrow \Rightarrow \left({}^{13}_{6}C^* + {}_{\pi}\oplus\right)^{+} \Rightarrow {}^{13}_{7}N^{*+} \qquad (1)$$

$$p + {}^{12}_{6}C \searrow \Rightarrow \left({}^{13}_{6}C^*_{\pi\to} + {}_{\mu,}\oplus_{e,\,\nu}\right)^{+} \Rightarrow {}^{13}_{7}N^{*+} + \nu_{\mu}...\nu_{e} \qquad (2)$$

Here we can see two branches of the IS-evolution which lead to write for projectile energy in **c.m.**-system respectively two possible expressions (3) and (4) separately answering to such Resonances through the **strong** and **weak & electromagnetic** interactions.

$$E_{PCM} = E_{LVN}^{^{13}C^*} + [\Delta M^{^{13}C}] - [\Delta M^{^{12}C} + \Delta m_p], \qquad \text{(denotations in Pictures)} \qquad (3)$$

$$E_{PCM} = E_{LVN}^{^{12}C^*} + [\Delta M^{^{13}C} - \Delta m_n + \Delta m_p + \frac{3}{5}\frac{6(7-5)}{13^{1/3}}] - [\Delta M^{^{12}C} + \Delta m_p]. \qquad (4)$$

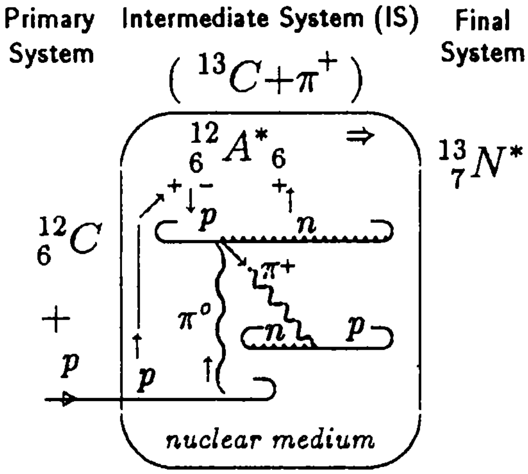
For general, these expressions in Readings I and II are presented on the Figures 2 and 3 respectively.

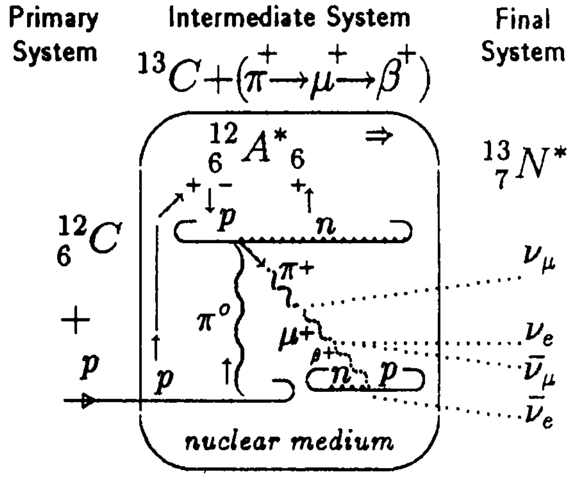
Thereby as the common interpretation of unrecognized anomalies the mechanism of the **Combinative** Excitations of **Isobar Resonances** (CIR) was proposed. It accounts the contribution into dynamics of the $[\mathbf{p} +^{12} \mathbf{C}]$ - system of all possible excitations as resonances of forming all of the projectile energy-accessible nuclei –isobars of well known final nuclei-products.
So it's very likely that **"soft" pions** (which are absolutely real inside the nucleus but virtual - for the exterior space) **indeed demonstrate proper behavior in the:**

- **nuclei-products spectrum and**
- **projectile energy losses** ([8], page 7) displaying additive CIR-resonances due to formation of the short-lived(displayed) isobaric charge-forbidden nuclei /with charge-compensator(s)/ by following transformation into already well known final nuclei-products.

Just doing justice for the participation of **weak & electromagnetic** interactions it should be said **the same** about the **soft** $\pi^{\pm}$ **decay products** inside the nucleus.(See. [8], p. 7, and also remember [11] Chapter 10. – "Spin-Isospin Excitations and Pion-like Modes in Nuclei").

Here below are shown two diagrams for two chains of the $^{13}C \rightarrow {}^{13}N$ proces accordingly. Collapsing follows by the time of interior capture of the charge-compensator particle (lower ends of the sloping wavy lines). Pointers show the **in** or **out** of the **n/p** into neutron/proton subsystems of nucleus.



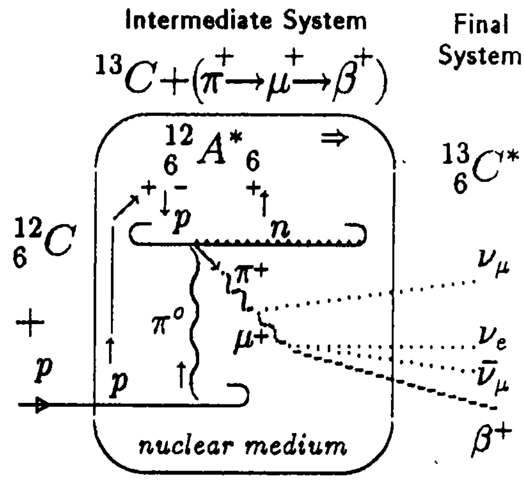


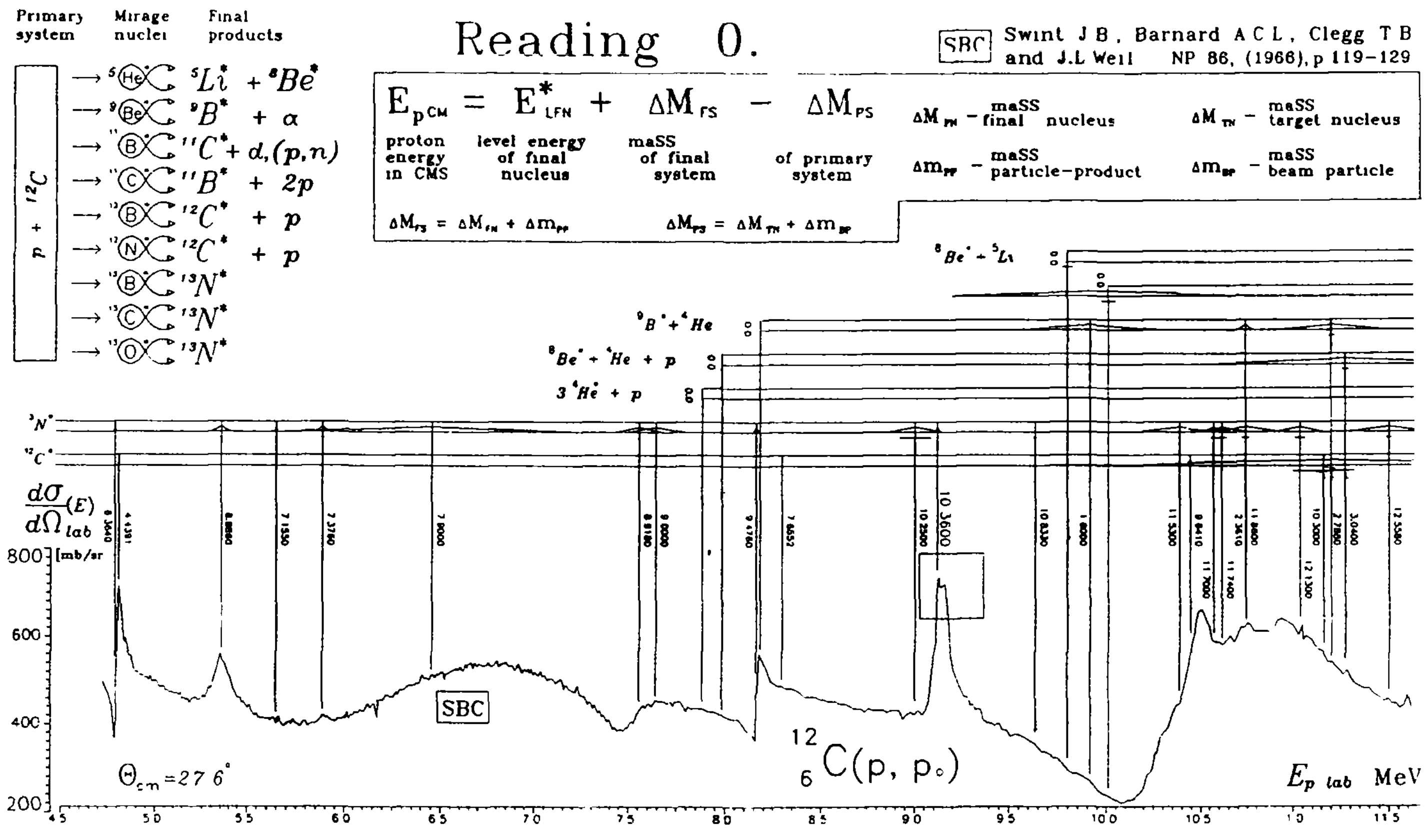
What are the more and newer proofs ?

Examining for validity the CIR-phenomenon the many years ago precisely measured [12] high statistics **EF** of $^{12}C(p,p_o)$ within $E_p = 5 \div 11.5$ MeV was analyzed (**Fig.4**) where also found many such displays [12, 13] also were found and among them – two brightest – at **9.159 MeV** (**Fig.5** - line 12.106 MeV) - for strong and at **10.502 MeV** (**Fig.6** - line 11.080 MeV) -for weak & electromagnetic interactions (see squares) with direct projectile-stimulated β^+-decay - see diagram below and expression (4) $+\mathbf{m_e c^2}$ at the right side.

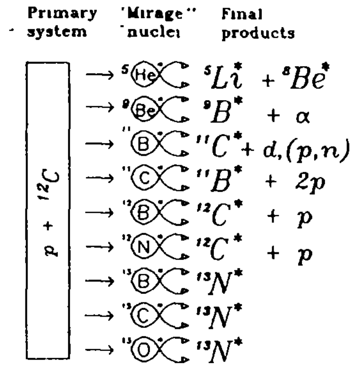
And we can see this high peak (Fig.6) right there, where it should be taken – at E_p=11.055 MeV (for 511 keV with 11.080 MeV -level). Really, it is not a neutrino-initiated process, but the hadron-nuclear – with higher (by more then fourteen orders !) cross-section. **So, already we have some news for the famous** CN **and** CNO **-cycles !** Besides the ordinary ^{13}C-production through the β^+-decay of ^{13}N (10 minutes) we should account quite real direct (fast) ^{13}C-production due to the projectile-stimulated β^+-decay. This can really moderate parameters of the interstellar fusion processes decreasing number of dynamically involved ^{13}N but increasing one of the ^{13}C (page 10).

Direct Production of $^{13}C^*$





Pic. 4. Excitation Function of $^{12}C(p,p_0)$ composed with well known resonances of Final Nuclei production



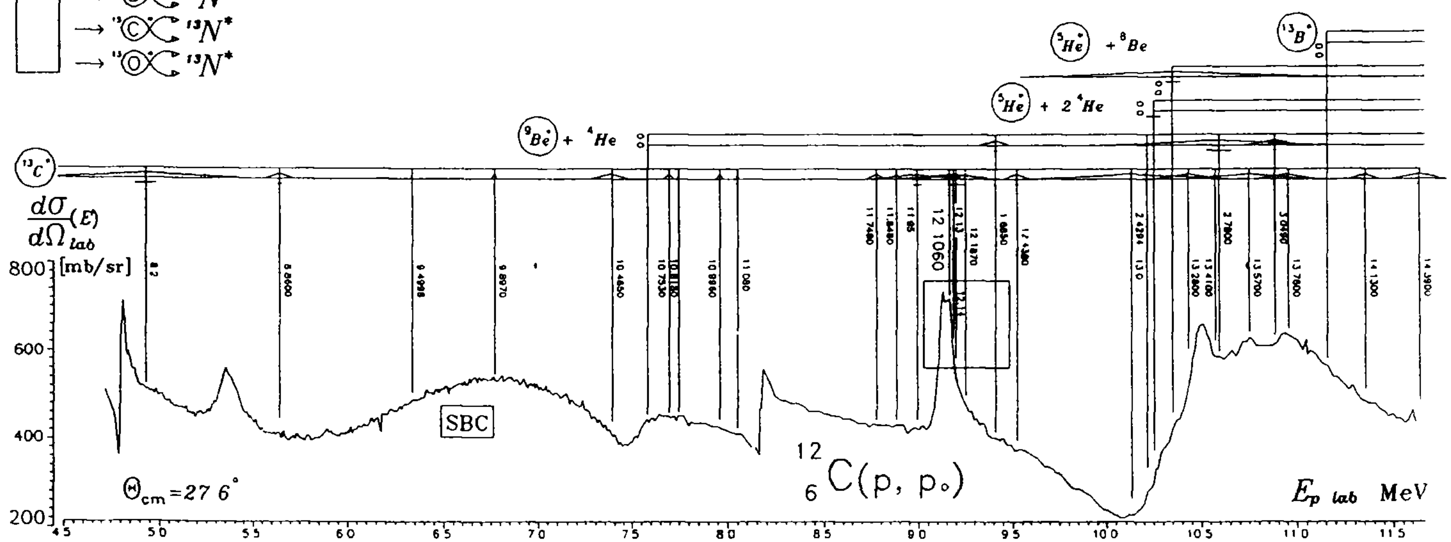
Reading I.

SBC Swint J.B., Barnard A.C.L., Clegg T.B and J L Weil NP 86, (1966), p 119–129

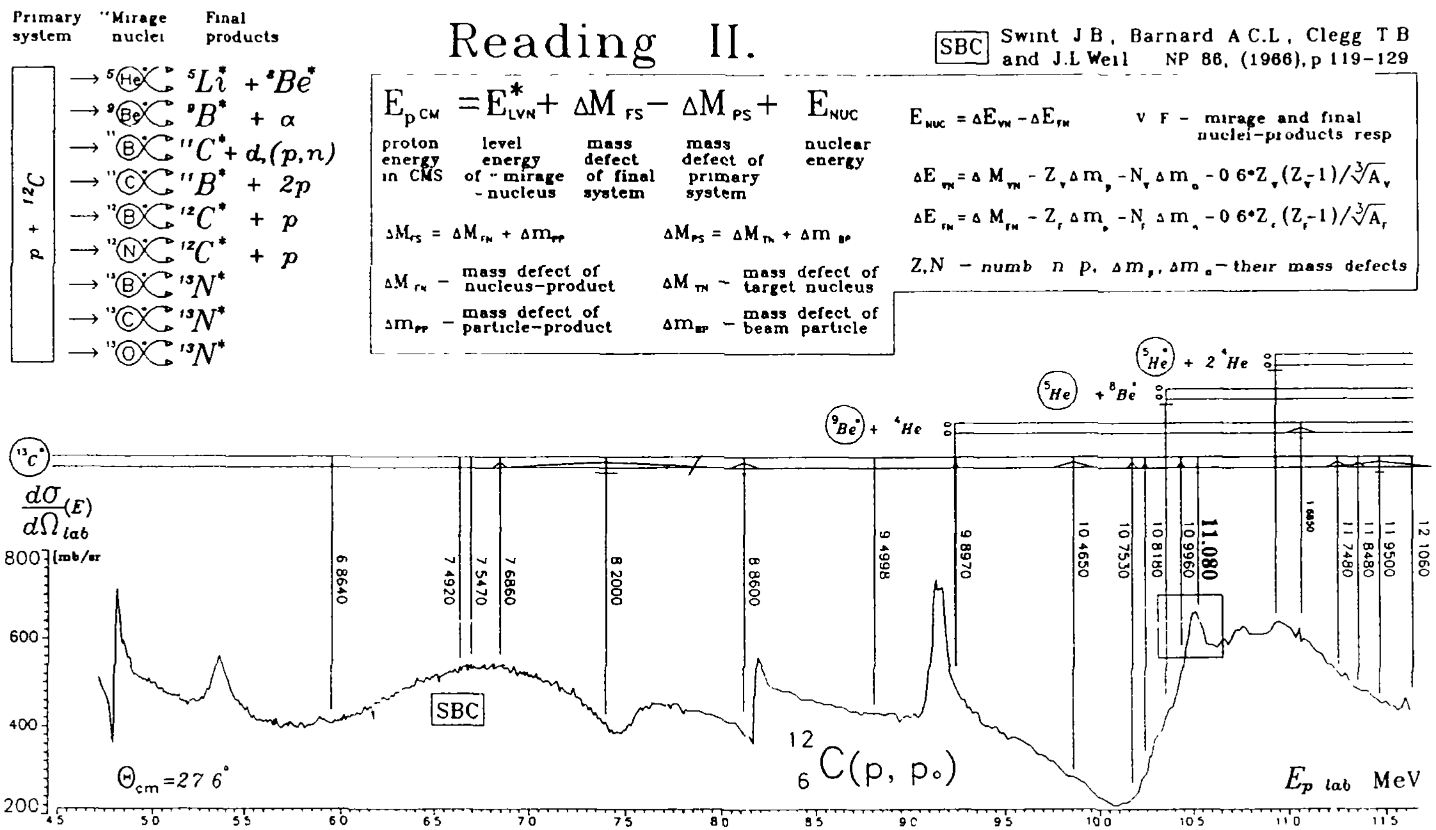
$$E_{pCM} = E^{*}_{LVN} + \Delta M_{VS} - \Delta M_{PS}$$

- E_{pCM} – proton energy in CMS
- E^{*}_{LVN} – level energy of mirage-nucleus
- ΔM_{VS} – mass defect of virtual system
- ΔM_{PS} – mass defect of primary system
- ΔM_{VN} – mass defect of mirage-nucleus
- ΔM_{TN} – mass defect of target-nucleus
- Δm_{PP} – mass defect of particle-product
- Δm_{BP} – mass defect of beam particle

$\Delta M_{VS} = \Delta M_{VN} + \Delta m_{PP}$ $\Delta M_{PS} = \Delta M_{TN} + \Delta m_{BP}$



Pic. 5. Excitation Function of $^{12}C(p,p_0)$ composed with CIR-resonances, produced through the **strong** interactions



Pic.6. Excitation Function of $^{12}C(p,p_0)$ composed with CIR-resonances, produced through the **em.& week** interactions.

CN-cycle

$$
\begin{aligned}
{}^{12}C + p &\Rightarrow {}^{13}N + \gamma && + 1.944\ MeV \\
{}^{13}N &\Rightarrow {}^{13}C + \beta^{+} + \nu && + 1.199\ MeV \\
{}^{13}C + p &\Rightarrow {}^{14}N + \gamma && + 7.550\ MeV \\
{}^{14}N + p &\Rightarrow {}^{15}O + \gamma && + 7.293\ MeV \\
{}^{15}O &\Rightarrow {}^{15}N + \beta^{+} + \nu && + 1.738\ MeV \\
{}^{15}N + p &\Rightarrow {}^{12}C + {}^{4}He && + 4.965\ MeV
\end{aligned}
$$

Modified CN-cycle

$$ {}^{13}N + \gamma \qquad + 1.944\ MeV $$

$$ \nearrow \quad \searrow $$

$$ \nearrow \qquad {}^{13}C + \beta^{+} + \nu \qquad + 1.199\ MeV $$

$$ {}^{12}C + p \ \searrow $$

$$ {}^{13}C + \underline{\text{stim}}\beta^{+} + \nu \qquad + 1.199\ MeV $$

$$
\begin{aligned}
{}^{13}C + p &\Rightarrow {}^{14}N + \gamma && + 7.550\ MeV \\
{}^{14}N + p &\Rightarrow {}^{15}O + \gamma && + 7.293\ MeV \\
{}^{15}O &\Rightarrow {}^{15}N + \beta^{+} + \nu && + 1.738\ MeV \\
{}^{15}N + p &\Rightarrow {}^{12}C + {}^{4}He && + 4.965\ MeV
\end{aligned}
$$

Some first news for *pp*-cycle ??

Another proof is obtained recently in examining for CIRs the precise *EF* [14] of the $^7Li(p,p_o)$ low energy scattering within $E_p = 1 \div 3.5\ MeV$ (**Fig.7**) where are found such displays and among them – the brightest – at point $E_p = 2\ MeV$ (level 0.4776) for the $^7Li(p,n)\textcircled{^7Li}\underset{\pi}{\rightarrow}{}^7Be$ Combinative Resonance (Fig.8) through the *strong* interactions.

$$\underset{\text{Primary System}}{(PS)} \qquad \underset{\text{Intermediate System}}{(IS)} \qquad \underset{\text{Final System}}{(FS)}$$

$$p + {}^7_3Li \Rightarrow n + \left({}^7_3Li^* + \underset{\pi}{\oplus}\right)^+ \Rightarrow {}^7_4Be^{*+} + n \qquad (5)$$

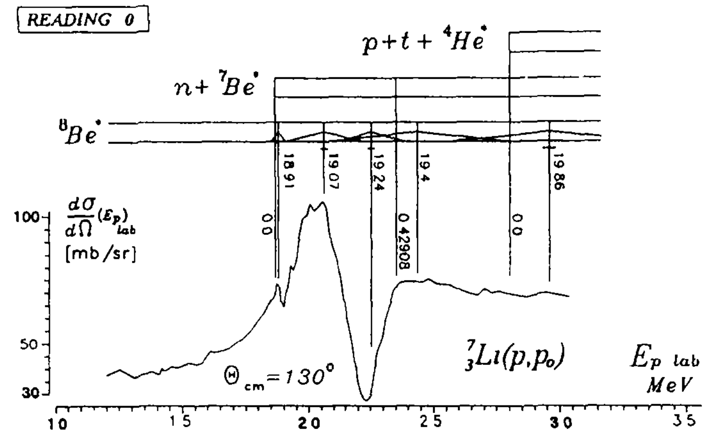
A fresh brightest prove of CIR-validity already found quite recently in EF of $^{12}C(d,d_o)$ near the $E_d \approx 2.7\ MeV$ (in stage of processing, unpublished).

Therefore, it seems that **the adduced experimental arguments tell us about the real validity of the CIR.** The figures (5) and (6) showing us that the CIRs, are some kind of scanning of all possible energy-accessible decay modes of the *IS* $[\mathbf{p} + {}^{12}\mathbf{C}]$, - including, in addition, the forbidden combinations containing charge-forbidden nuclei with only "interior decay" through capture of the interior charge-compensator particle(s) by a nucleon, transforming it into isopartner (charge exchange).

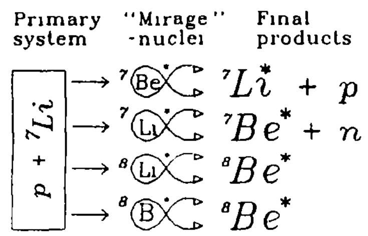
For **strong** process it is capture of the $\pi^\pm$ by nucleon at *IS* and for **weak & electromagnetic** process – interior $\mu^\pm$ or $e^\pm$ –capture.

It should be well noted that in the stellar plasma conditions we should "suspect" generation of the such forbidden nuclei through the CIRs, but their life-time will become essentially prolonged due to the permanent electron strike-jarring which don't allow to the wandering charge-compensator particle(s) be captured in short time by nucleon(s).

This means, it should be taken, that quite a lot of such forbidden nuclei (not expected yet ! for the known stellar cycles) can become in dynamic equilibrium at stars !.

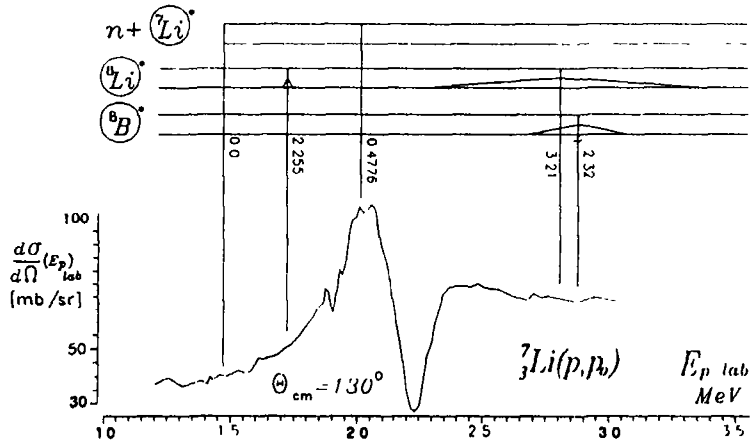


Pic 7. Excitation Function from Phys. Rev 101,116 (1956) in comparison with levels of the ***real*** nuclei-products and thresholds of their production on READING 0



The Combinativ Resonances

READING I



Pic. 8. Excitation Function from Phys. Rev. 101,116 (1956) in comparison with levels of the forbidden nuclei-products and thresholds of their production on READING I.

In other words, we are talking about the additional CIR-based still unknown channels in all stellar and energy cycles – as the background for their modern review. Very likely, that CIRs should be considered from this point of view - of the perfectly important and great moment task now [15,16].

Concluding all this let's stress the most important obvious properties of the CIRs and some due to them new opportunities.

1. It's evidently that for (1)-kind decay from a Combinative Resonance state any emitted products are absent - as follows any **recoil is absent too**! This is a perfect property of the CIRs(1) – they are energy unshifted on azimuthal angles so, that they can be used as precise unshifted energy-calibration standards for the nuclear cross-section measures with high energy-resolution !

2. The CIRs of (2)-kind are shifted due to ν_μ, ν_e -emission, it's the cause why they (probably) can be used for obtaining upper level of the ν_μ -mass (presently $m_\nu \leq 270\ keV$) in case of validity inside the nucleus the chain

$$\pi^{\pm} \longrightarrow \nu_\mu,\ \mu^{\pm} \longrightarrow e^{\pm},\ \nu_\mu,\ \nu_e,\ \nu_e. \qquad (6)$$

3. Existence of the CIR opens us large opportunities. Really, CIRs can become a new precise and wide applicable tool for investigations on the:

- search for **additional channels** in both stellar and energy **fusion cycles**,
- moderation of the IS properties for plasma medium and stellar conditions, (formation, life-time, decay modes),
- low-energy dynamics of the Intermediate Systems (IS) (structure, formation, life-time, decay),
- properties of the *IAR* $+\pi$- *dissociation* (for projectile energy up to free π),
- search for "stability island" using *EFs* of the heavy-ion collisions,
- studies of the cluster modes of the break-up of light nuclei scattered by a the heavy nucleus-target, where in the Excitation Function of elastic scattering will be directly observable all possible ordinary and forbidden cluster combination of output channels, presented as *IARs* and *CIRs*,
- proton "weak decay" in nuclear medium helping us in more advancing consideration of the fundamental problem of proton stability in universe,
- solar neutrino deficit and related astrophysics, *for inst. see (1), (peak 9.159 MeV - level 12.1060 of* $^{13}C^*$*), and (5) (peak 2 MeV - level 0.4776 of* $^{7}Li^*$*)*,
- fundamental properties of soft-π modes in nuclear matter and at stars.

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(to the question of reaction channels relations !!!)