Response to comments on laser induced pellet fusion with nano-spheres and flat target

Laszlo P. Csernai, Univ. of Bergen, NO
Norbert Kroó, Wigner FK, Budapest, HU. Dec. 10, 2019

Thick Coin like target - New Developments

L.P. Csernai, N. Kroo, I. Papp

Thickness of the target is: h

h depends on pulse energy, ignition energy, target mass, …

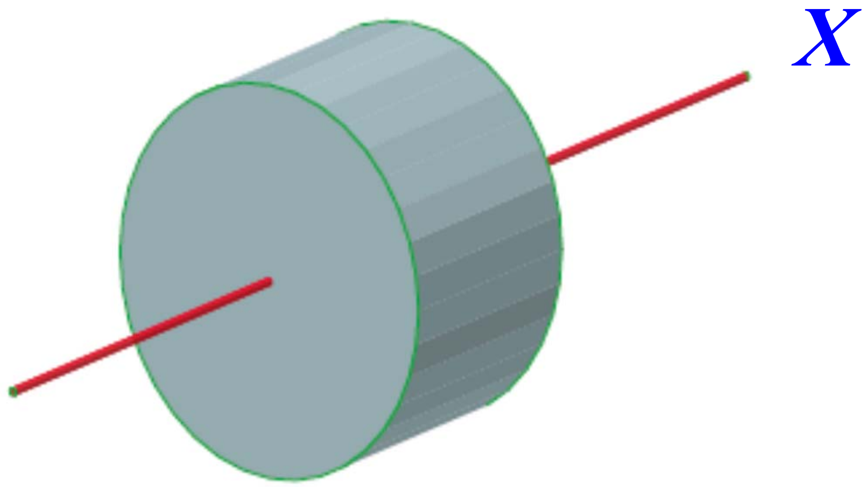


Figure 1: (color online) The target still should be compact to minimize the surface effects. The irradiation is performed along the $x-$axis from both sides towards the target. The laser beam should be uniform hitting the whole face of the coin shaped target.

Comment 1a:

Csernai relativisztikus lökéshullámmal *összenyomás nélkül* akar felfűteni egy fúziós kapszulát, mondván, hogy az majd -
hasonlóan a kvark-gluon plazmához -
time like módon egyszerre begyullad és elég. A kvark-gluon plazmához én nem értek, de a fúzióshoz valamennyire igen.
*Itt nincs **time-like** reakció*, a fúziós hatáskeresztmetszet kicsi.

Kiemelés, L.P. Cs.

What is a “time-like” detonation ?

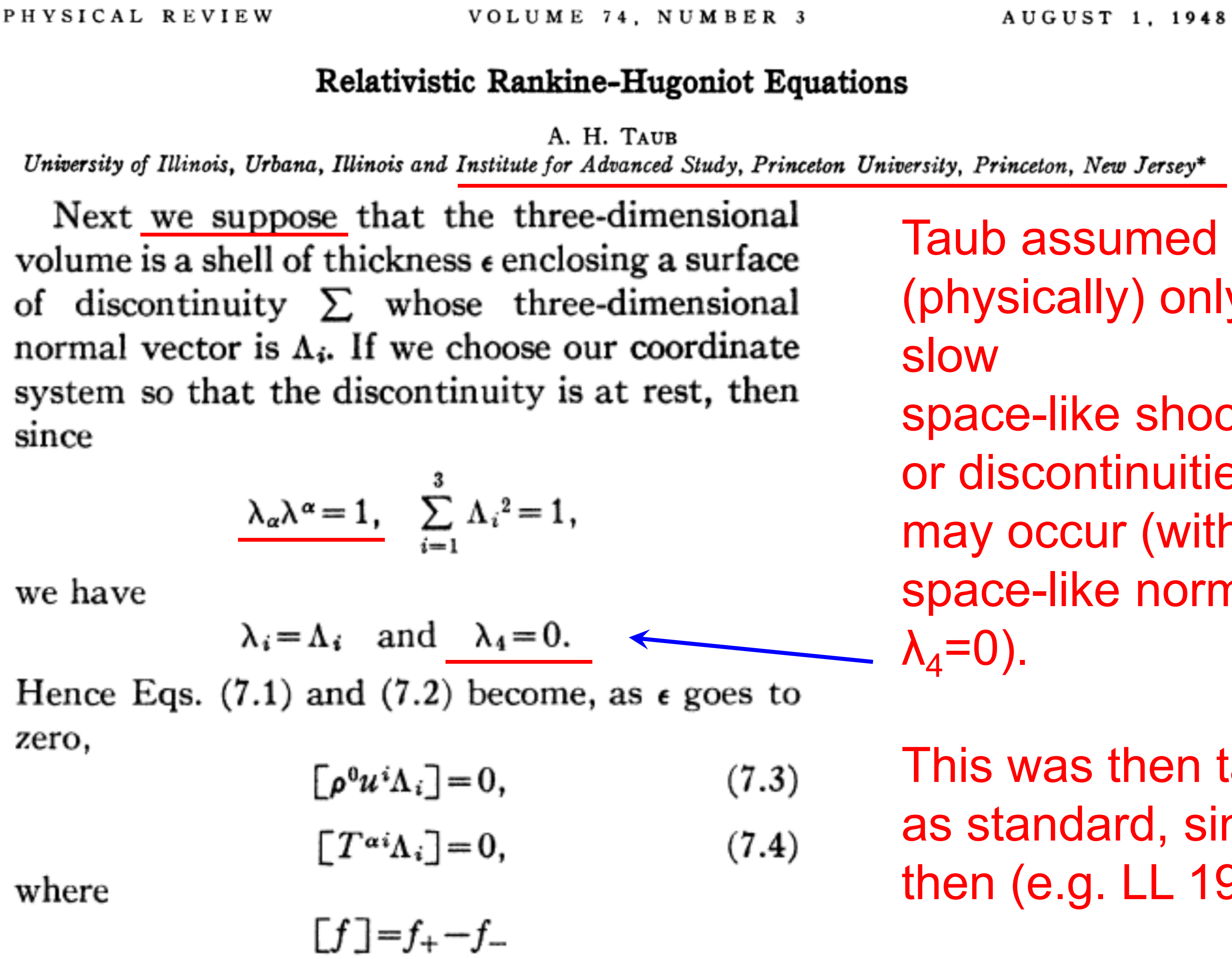
In Classical Fluid Dynamics (CFD) the detonations (rapid burning) are described by the Rankine-Hugoniot relations: The Rayleigh – line and the Rankine-Hugoniot adiabat.

These “space-like” fronts propagate “slowly” with a speed slightly above the speed of sound. All present fusion CFD models assume this mechanism.

The correct, covariant version of these relations was discovered in relativistic Heavy Ion physics.

However, also in everyday physics there are also “time-like” (=simultaneous) burning fronts, like in a diesel engine without glowing spark-plug. Such kind of *old engines* are giving a “knocking” sound and lead to the rapid wear off of the cylinders. Senior people might still remember this sound.

[A.H. Taub (1948)]



PHYSICAL REVIEW VOLUME 74, NUMBER 3 AUGUST 1, 1948

Relativistic Rankine-Hugoniot Equations

A. H. TAUB
*University of Illinois, Urbana, Illinois and Institute for Advanced Study, Princeton University, Princeton, New Jersey**

Next we suppose that the three-dimensional volume is a shell of thickness ϵ enclosing a surface of discontinuity Σ whose three-dimensional normal vector is Λ_i. If we choose our coordinate system so that the discontinuity is at rest, then since

$$\lambda_\alpha\lambda^\alpha=1, \quad \sum_{i=1}^{3}\Lambda_i{}^2=1,$$

we have

$$\lambda_i=\Lambda_i \quad \text{and} \quad \lambda_4=0.$$

Hence Eqs. (7.1) and (7.2) become, as ϵ goes to zero,

$$[\rho^0 u^i\Lambda_i]=0, \tag{7.3}$$

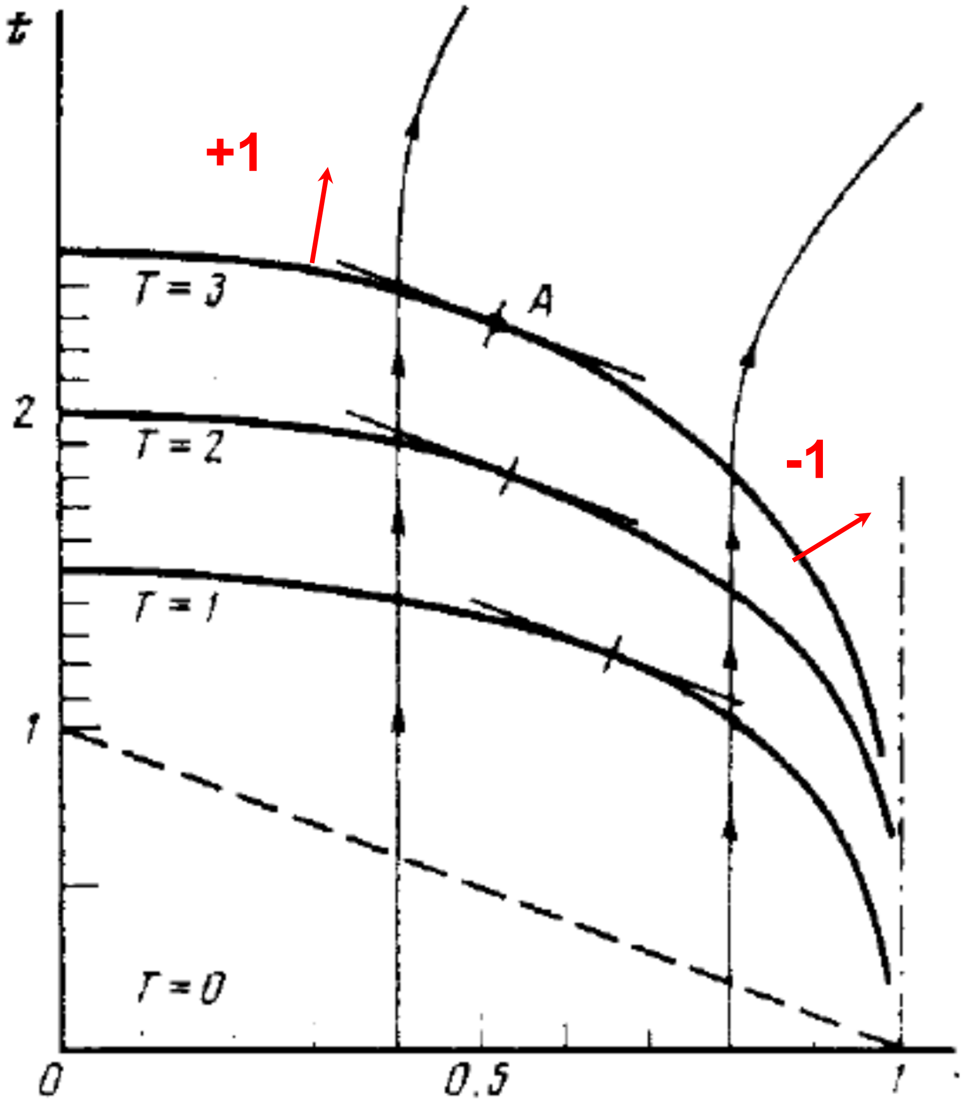
$$[T^{\alpha i}\Lambda_i]=0, \tag{7.4}$$

where

$$[f]=f_+-f_-$$

Taub assumed that (physically) only slow space-like shocks or discontinuities may occur (with space-like normal, λ_4=0).

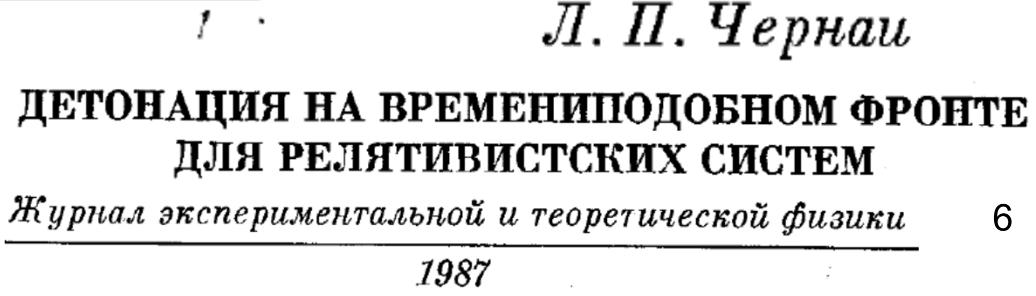
This was then taken as standard, since then (e.g. LL 1954-)



[L. P. Csernai, Zh. Eksp. Teor. Fiz. 92, 379-386 (**1987**) & Sov. Phys. JETP 65, 216-220 (1987)]

corrected the work of [**A. Taub**, Phys. Rev. 74, 328 (**1948**)]

$$\lambda_\alpha \lambda^\alpha = \pm 1$$


Л. П. Чернаи

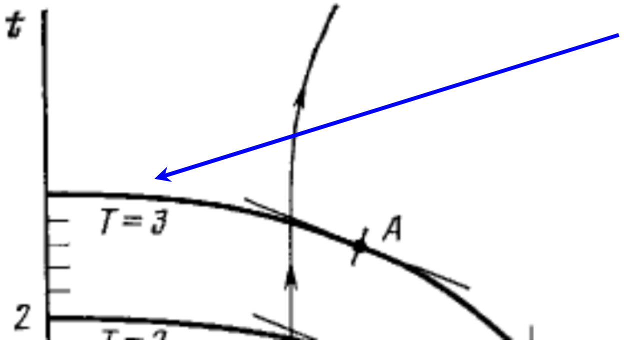
ДЕТОНАЦИЯ НА ВРЕМЕНИПОДОБНОМ ФРОНТЕ
ДЛЯ РЕЛЯТИВИСТСКИХ СИСТЕМ

Журнал экспериментальной и теоретической физики

1987

Do we need pre-compression? Is the Burning speed fast enough?

összenyomás nélkül



Even in our patent we describe that we may need **pre-compression**. Because the space-time contour line of the detonation front represents a thin or thick layer where the D+T reaction takes place.

In classical approximation the reaction rate is $n_D\, n_T < v\, \sigma >$, which depends on the densities quadraticly, and v is the relative speed of the two nuclei.

This reaction rate will be discussed later on in connection with other comemnts. This was not the direct subject of our patent an neither of our papers. However, we always mentioned the possible need of precompression.

Comment 1b:

Amennyiben sikerül a kvázi prompt felfűtés 10-20 keV-re, a target tágulni fog az ionhang sebességével, az égés hatásfoka arányos a sűrűség és a sugár szorzatával. Ahhoz, hogy gazdaságos fúzió legyen, mintegy 30% hatásfokra van szükség. A térfogat viszont köbös, ezért az adott hatásfokhoz szükséges tömeg a sűrűség négyzetével fordítva arányos. Ezért egy folyadék vagy szilárdtest sűrűségű gömb csak igen nagy méretben ad hatékony fúziót, ez a hidrogénbomba, amit nem lézerrel fűtenek. Ezért célszerű összenyomni. Egyszerűen úgy is lehet ezt megérteni, hogy ha felfűtöm, de nem nyomom össze, akkor a magok még angströmnyi távolságban vannak egymástól, amikor a Coulomb ütközések hatáskeresztmetszete sokkal nagyobb a fúzióénál, ráadásul tágul az egész, a hatásfok 1% alatt lesz. Neutronokat lehet így kelteni, de reaktor ebből nem lesz.

The ignition and burning process

The comment **assumes a space-like ignition front** and 3D spherical and thermally equilibrated, isotropic matter. The statement is that the expansion due to the transverse pressure will exceed the (spherical) compression shock.

This is already not true initially as the expansion due to the pressure is going with the **speed of sound** while the compression shock is **supersonic.** This is obvious in all LLNL NIF experiments already.

In our **initial, 3D, spherical model** calculations, we also assumed spherical geometry, and isotropic irradiation, which led to thermally equilibrated fuel. For equilibrated, radiation dominated matter the EoS is: $p = e/3$.

In our present **1D, flat target configuration** with two laser beams, we do not have thermal equilibrium, ➔ there is no, p, T, and μ. The momentum of the matter points in the $\pm x$ direction.

Thus, the reaction rate, $n_D\, n_T < v\, \sigma >$, is much higher because the relative speed, v, is much higher. I.e. the space-time burning hyper-surface is thinner.

This is also shown in the experiment:
[G. Zhang, et al., Phys. Lett. A 383 (2019) 2285-2289.]

Experimental test of similar configuration @ ShenGuang-II Up, Shanghai :

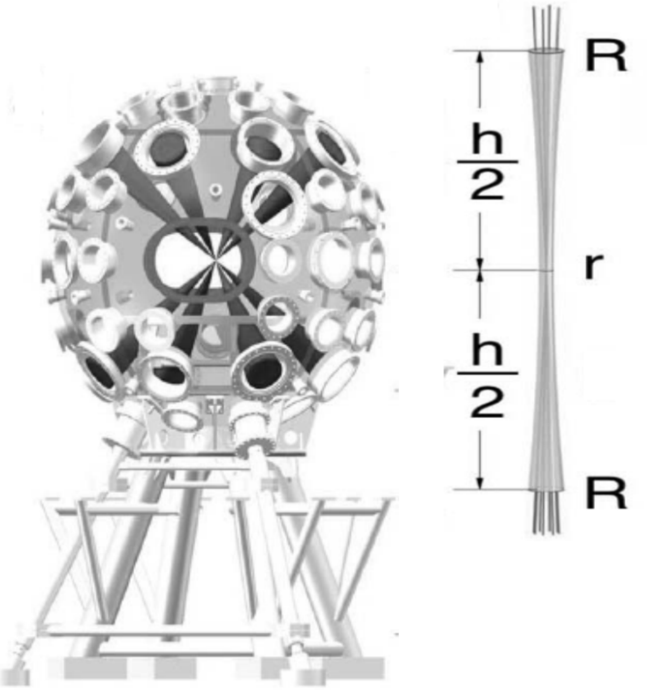
Nuclear probes of an out-of-equilibrium plasma at the highest compression **Phys. Lett. A 383 (2019) 2285-2289.**

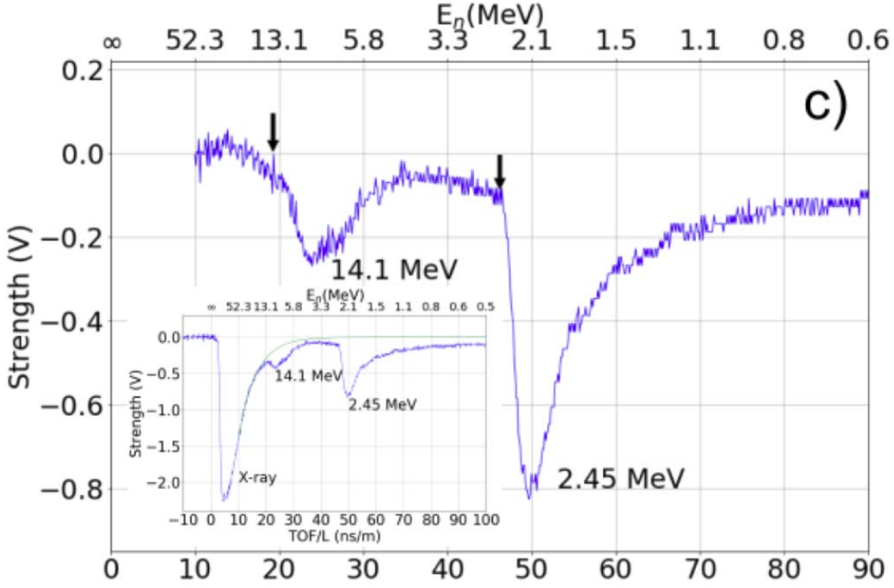
G. Zhang[a,b,*], M. Huang[c], A. Bonasera[d,e,*], Y.G. Ma[f,b,i,*], B.F. Shen[g,h,*], H.W. Wang[a,b], W.P. Wang[g], J.C. Xu[g], G.T. Fan[a,b], H.J. Fu[b], H. Xue[b], H. Zheng[j], L.X. Liu[a,b], S. Zhang[c], W.J. Li[b], X.G. Cao[a,b], X.G. Deng[b], X.Y. Li[b], Y.C. Liu[b], Y. Yu[g], Y. Zhang[b], C.B. Fu[k], X.P. Zhang[k]

4 (up) + 4(down) lasers
Target thickness, h (3.6μm-1mm) & radius, R, (150-400μm) were varied.

Total pulse energy 1.2kJ (2ns) for 8 beams.
Shortest (250ps) pulses -> 100s MeV ions > non-thermal distr. = directed ion acceleration

Typical fusion neutron energies were measured & used to extract the target density.





Experimental test of similar configuration @ ShenGuang-II Up, Shanghai :

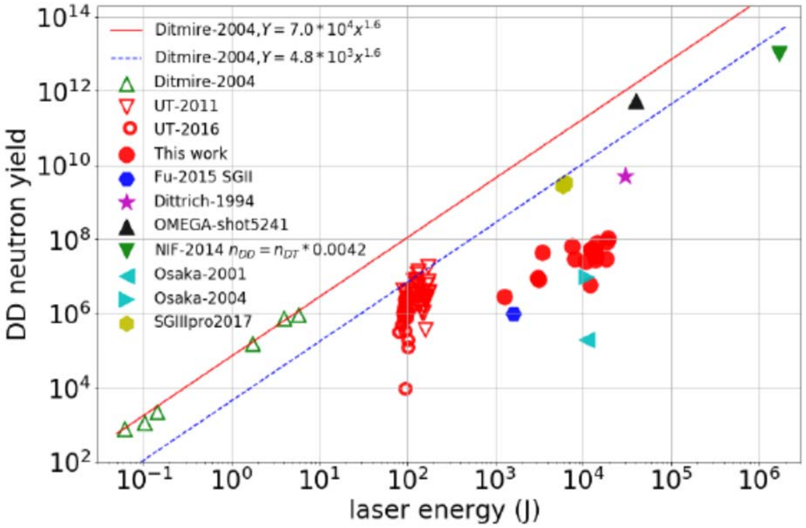


Figure 3: (color online) Fusion yield as function of laser energy. Different experimental results Ditmire-2004[40], UT-2011[20], UT-2016[19], Fu-2015 SGII[45], Dittrich-1994[49] , NIF-2014[48] , Osaka -2001[46], Osaka-2004[47], OMEGA-shot5241[41]and SGIIIpro2017[42] are indicated in the inset.

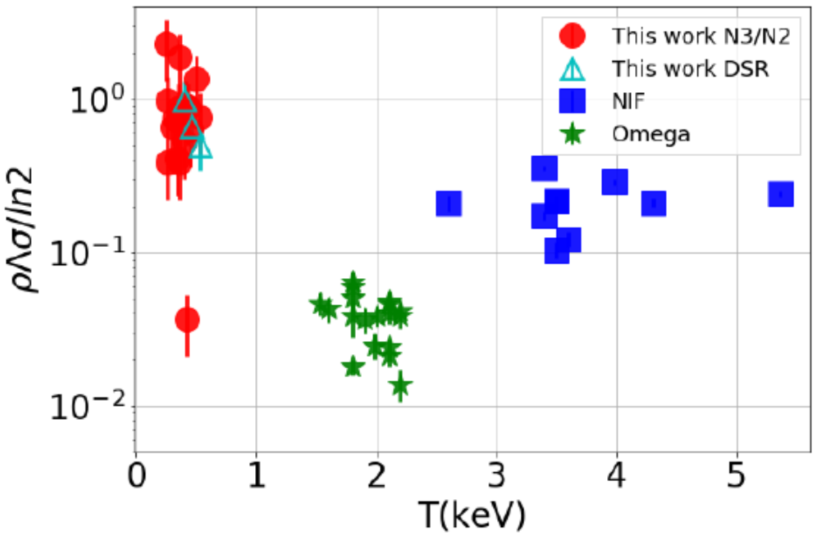


Figure 4: (color online) $\Lambda\rho\sigma/\ln 2$ obtained from eq.(4) vs T from eq.(1). Omega and NIF data are derived from the experiments[25], using the Down Scatter Ratio[23, 21]. Our results using the DSR method (N_4/N_3) are given by the open triangle symbols in good agreement with the N_3/N_2 ratios.

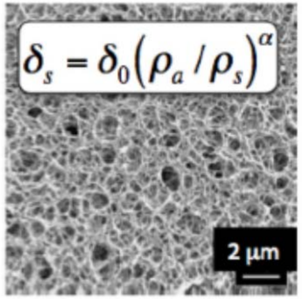
Stimulated by these considerations we decided not to fight non-equilibrium effects but rather enhance them, i.e. study plasmas highly compressed and completely out of equilibrium.

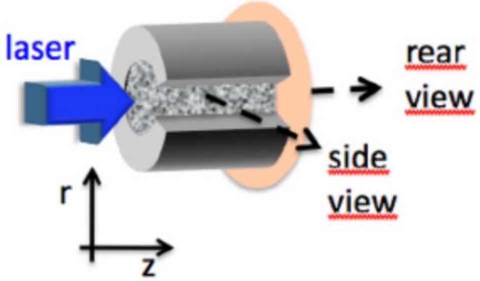
No time-like ignition, non nano-shells !

Pre-compression methods

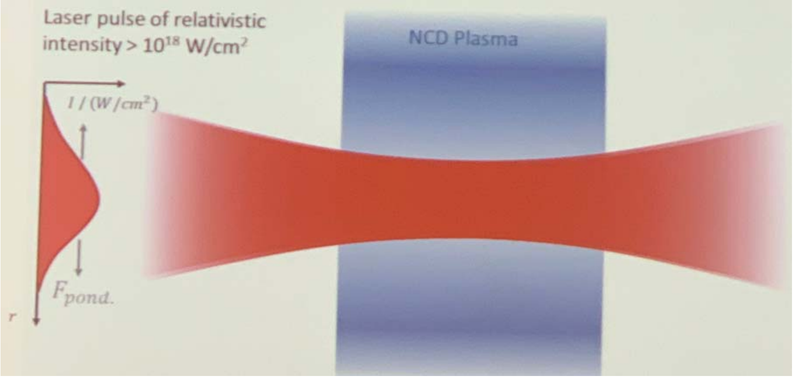
1. Linear beam compression [G. Zhang, et al., Phys. Lett. A **383** (2019) 2285.]
2. Transparent target recoil [M. Gyulassy, L.P. Csernai, Nucl. Phys. A (1986)]

3. Foam target / GSI PHELIX laser:
[Gus'kov et al., Phys. Plasmas **18**, (2011) 103114;
Nicolai Ph. et al., Phys. Plasmas **19**, (2012) 113105





4. Plasma self focusing
[A. Pukhov, et al., Phys. Plasmas **6(**7), (1999).



Comment 2a:

Kroó ötlete sokkal szerencsétlenebb. Ő a fúziós kapszula belsejében akar nanorészecskéket elhelyezni, hogy a megnövekvő térerősség következtében majd nagyobb legyen az abszorpció. Viszont a fúzióhoz szükséges lézerintenzitásokon a *felületen plazma keletkezik, és a lézerfény nem tud a térfogatba behatolni*, csak a kritikus sűrűségig, ahol részben visszaverődik, részben abszorbeálódik, így kölcsönhatni sem tud a térfogatban, belül levő nanorészecskékkel (még relativisztikus intenzitásokon sem). Kritikus sűrűség, ahol a plazmafrekvencia megegyezik a lézerfrekvenciával. Emiatt nem könnyű lézerfúziót csinálni immár 50 éve. *Nincs térfogati abszorpció!*

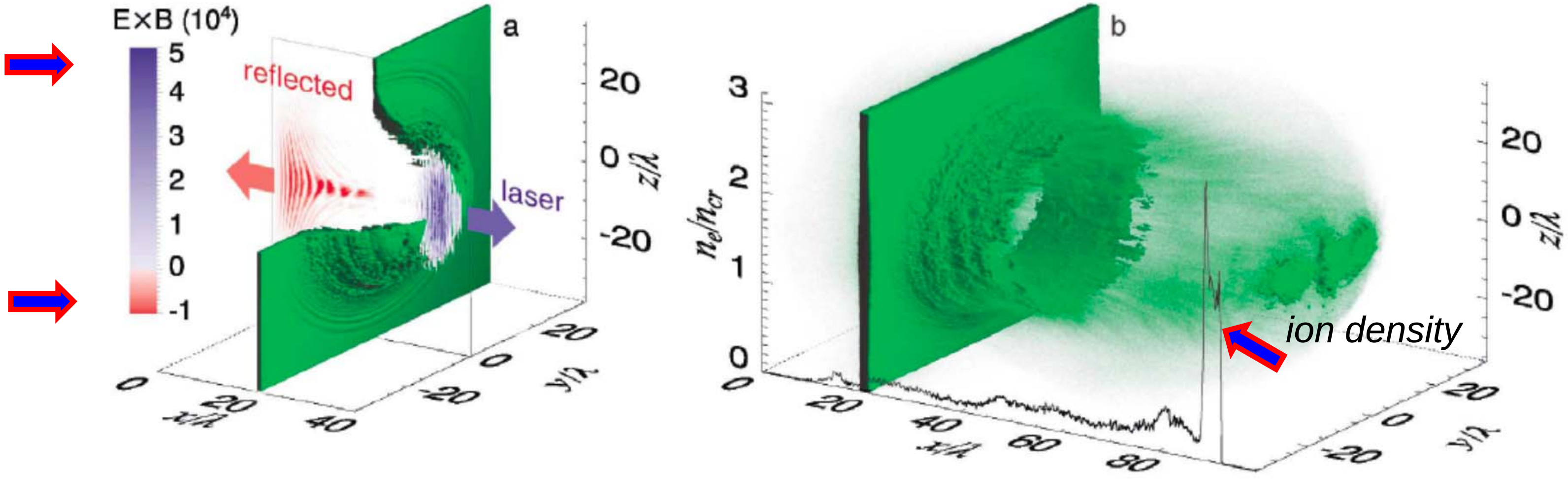
Surface Plasmon Reflection

The experiments # 2 and 3, on the previous page show the opposite. The reflection is negligible.

The method of nano-rods on the target surface prevent such a reflexing, see:[Kaymak, V., Pukhov, A., Shlyaptsev, V.N. and Rocca, J.J. (2016). Nanoscale ultra-dense Z-pinches formation from laser-irradiated nanowire arrays. Phys. Rev. Lett. 117, 035004.] This is mentioned in our publication.

Most importantly in energetic orthogonal laser irradiation leads to Laser Wake Field Acceleration (LWFA), the laser light penetrates into the plasma. This also **focuses** the electrons, positrons and ions in different phase-space locations, which not only opposes the comment, but also contributes strongly to the **pre-compression**

[**Laser-Piston**, T.Esirkepov, M.Borghesi, V.Bulanov, G.Mourou, T.Tajima, PRL 92 (2004) 175003]

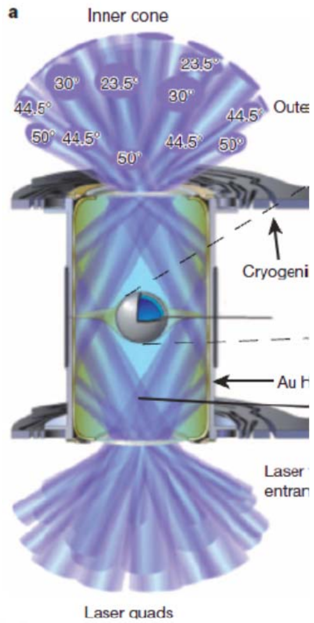


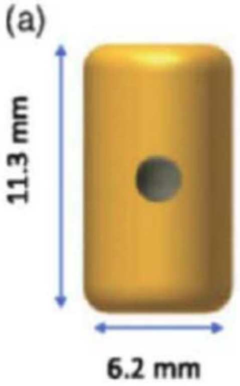
Classical Electrodynamics: Reflection

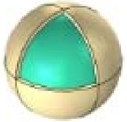
(I am also teaching)

Not everything is reflecting, Gold or depleted uranium does, COC does not.

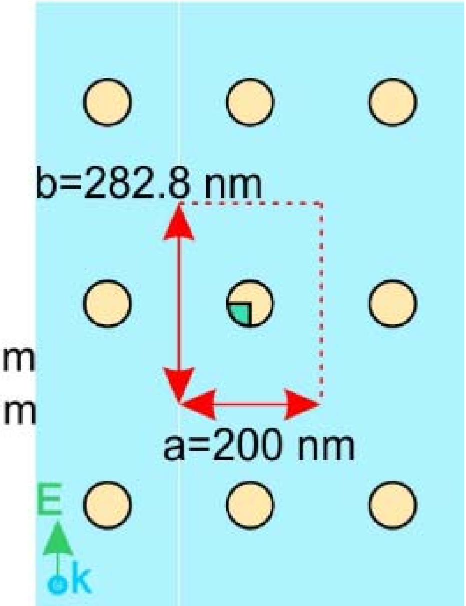
Not all body shapes are reflecting.







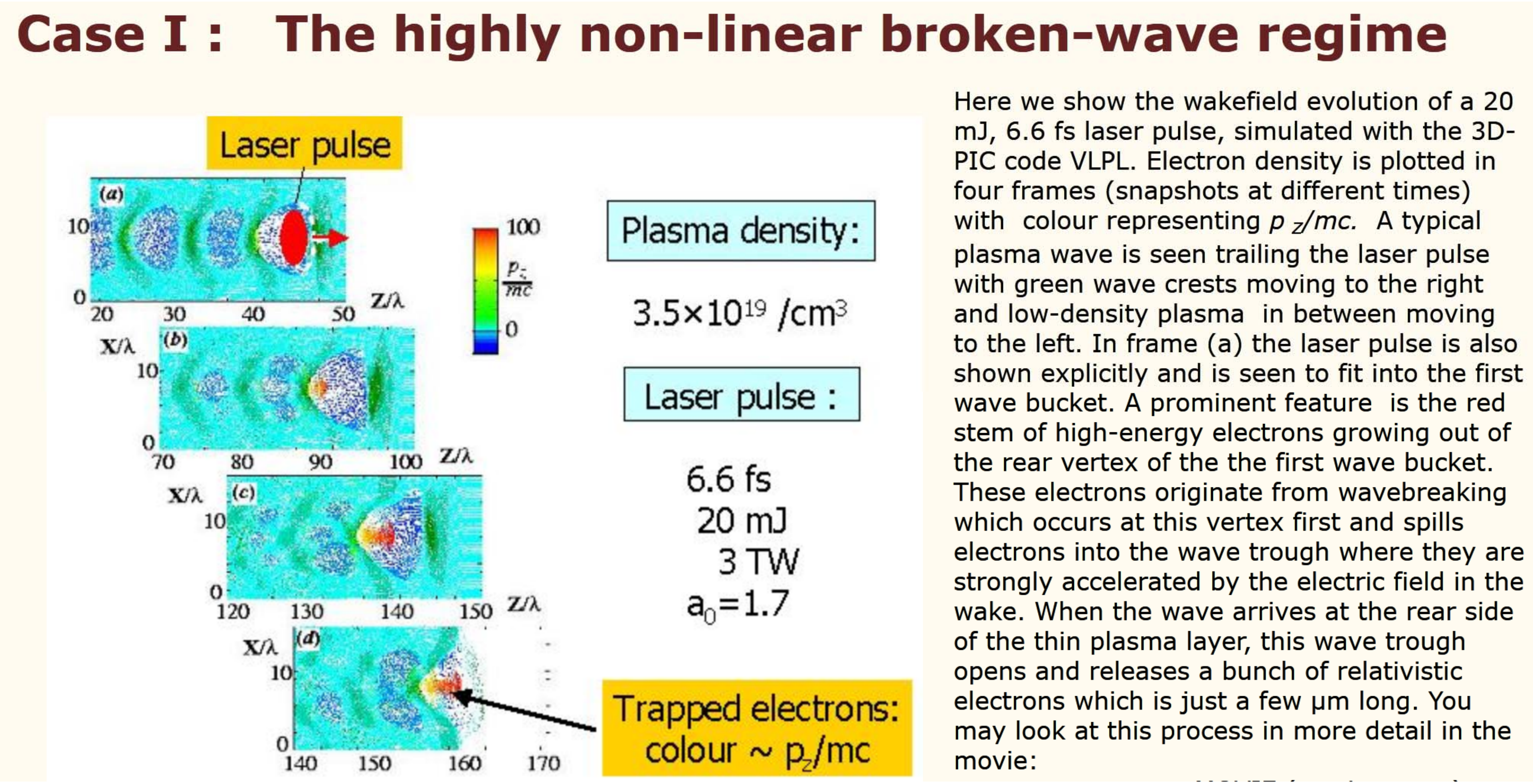
r_{inner} = 27.1 nm
r_{outer} = 30.0 nm
GAR = 0.9



M. Csete, et al., University of Szeged, HU]

Laser Wake Field Acceleration

http://www2.mpq.mpg.de/lpg/research/LWFA/LWFA.html



Case I : The highly non-linear broken-wave regime

Plasma density:

3.5×10^{19} /cm^3

Laser pulse :

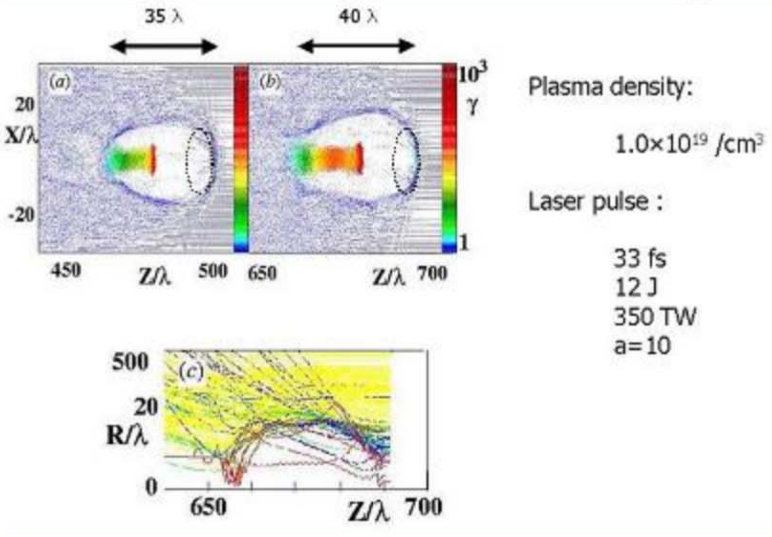
6.6 fs
20 mJ
3 TW
$a_0=1.7$

Trapped electrons:
colour ~ p_z/mc

Here we show the wakefield evolution of a 20 mJ, 6.6 fs laser pulse, simulated with the 3D-PIC code VLPL. Electron density is plotted in four frames (snapshots at different times) with colour representing p_z/mc. A typical plasma wave is seen trailing the laser pulse with green wave crests moving to the right and low-density plasma in between moving to the left. In frame (a) the laser pulse is also shown explicitly and is seen to fit into the first wave bucket. A prominent feature is the red stem of high-energy electrons growing out of the rear vertex of the the first wave bucket. These electrons originate from wavebreaking which occurs at this vertex first and spills electrons into the wave trough where they are strongly accelerated by the electric field in the wake. When the wave arrives at the rear side of the thin plasma layer, this wave trough opens and releases a bunch of relativistic electrons which is just a few µm long. You may look at this process in more detail in the movie:

A. Pukhov and J. Meyer-ter-Vehn, Appl. Phys. B74, 355 (2002)

Case II : The solitary bubble regime



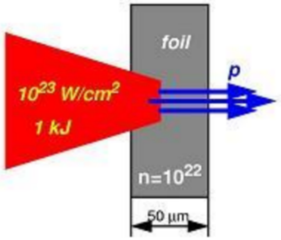
In this second case, a laser intensity significantly above the wave-breaking limit ($a=eA/mc^2=10$) has been chosen such that the wakefield breaks completely after the first oscillation and only a single wakefield bubble survives which is practically void of electrons. Part (c) of the figure below shows electron trajectories in a comoving frame. Yellow electrons are only slightly perturbed by the laser pulse, blue electrons are scattered away, while red electrons hit by the central part of the laser pulse form the mantle of the bubble and are predominantly trapped in the bubble. The trapping is so efficient that after a certain propagation distance there are more trapped electrons in the bubble than were initially in the same volume. At this point beam-loading effects set in and the bubble starts to stretch; after 500 laser cycles the extension is 35 λ and after 700 laser cycles 40 λ. This stretching has a significant effect on the energy spectrum.

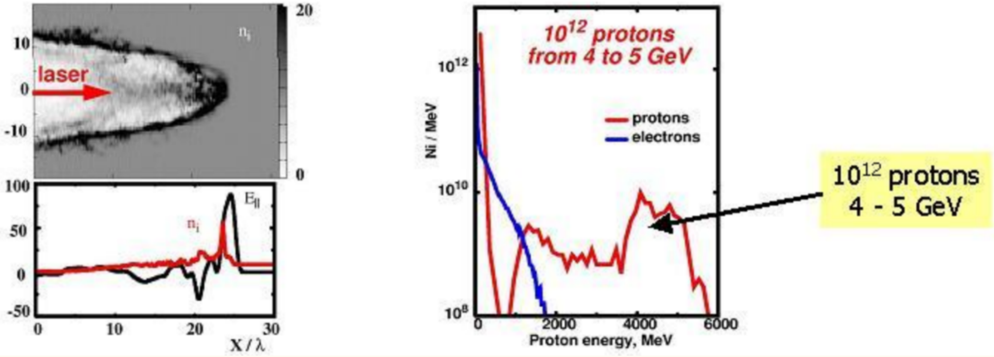
Generation of relativistic ions

D. Habs, G. Pretzler, A. Pukhov and J. Meyer-ter-Vehn, Progress in Particle and Nuclear Physics 46, 375 (2001).

1 kJ, 15 fs pulses incident on 30 μm plastic foil may result in 10^{14} , 4-5 GeV protons.

1 kJ , 15 fs laser pulse
focussed on 10 μm spot
of 10^{22}/cm^3 plasma

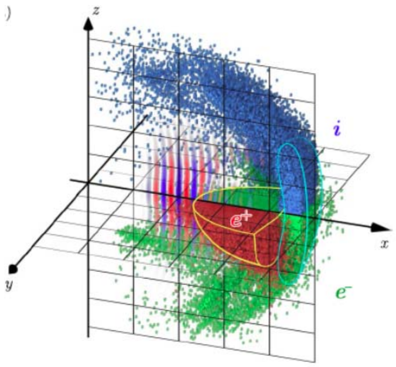


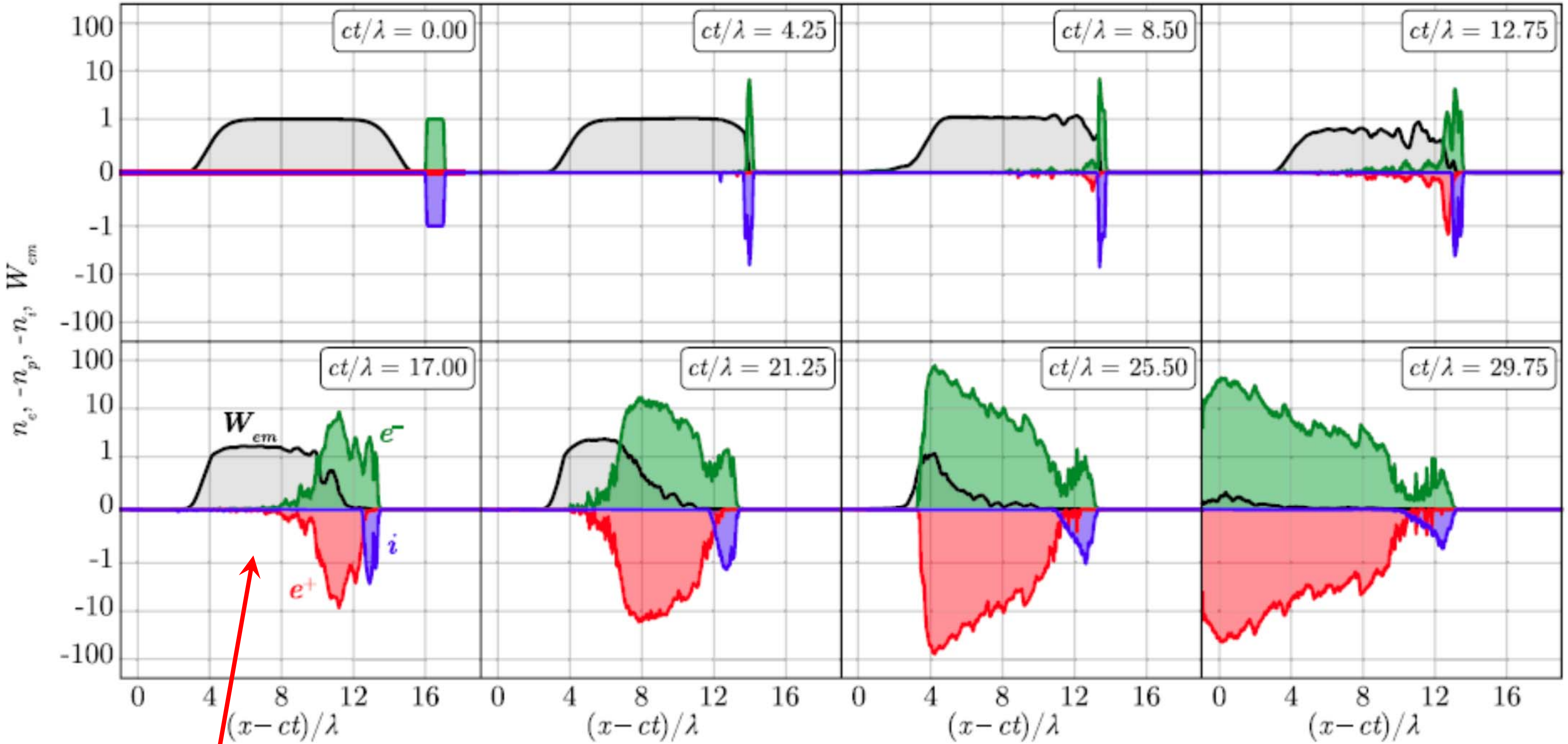


LWFA modeling – PIC (Non. Rel.!)

[A.S. Samsonov et al., Nature, Scientific Reports **9** (2019) 11133]

Ion density is strongly increased!





W_{em} , e^+ . e^- , i (ions)

Other comments:
Kedves ………..!
Mivel én kezdetektől fogva egy nyilvános szemináriumi előadásról beszéltem, nem egy projektre akarom rátukmálni magam, nincs értelme egy olyan zártkörű előadásnak, amit azon projekt számára tartanék, amiben nem kívánok részt venni. Majd megtartom nyilvános közönség számára úgy, hogy videon is be lehessen csatlakozni, és akkor Csernai is meghallgathatja.
Üdv: … … …

Ezekből az alapvető dolgokból minden diákom vizsgázik.
Szóval nekem a projekttel kapcsolatban ezek a kizárólag szakmai ellenvetéseim , így voltam kénytelen visszautasítani Kroó és Csernai valóban kedves invitálását a projektben való részvételre, és ezért sajnálom azokat, akik kénytelenek ezt tenni szakmai meggyőződésük ellenére.

Amennyiben véleményemet elfogultnak tartod, az EPS plazmafizikai szekció Beam Plasma and Inertial Fusion Board tagjaként tudok segíteni külső, külföldi, független szakmai bíráló felkérésében. Véleményem szerint egy fizikai projekt elbírálására nem egy, a minisztériumban ülő, jogi vagy gazdasági diplomával rendelkező ember az alkalmas.

No comment